CERN – EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CTF3 Note 042 (Tech.)
PS/RF/Note 2002-021
(CTF3 Review)

CTF3 PROJECT REVIEW
2nd – 4th October 2001
Copies of Transparencies

Collected by G. Geschonke

Abstract

A comprehensive project review of CTF3 was held from 2nd - 4th of October 2001 at CERN in the presence of an International Review Committee. In this note copies of the transparencies shown during the presentations are presented, as well as the recommendations given by the referees.

Geneva, Switzerland
1 February2001

Contents

CTF3 Review

Referees:

Dr. B. Aune CEA Saclay

Prof. Dr. Heino Henke, Technische Universität Berlin

Prof. Dr. Robert Siemann, SLAC

Mandate of the Review Committee:

The design of CTF3 has reached a stage, where technical solutions are being frozen and manpower and financial resources must be made available by CERN and collaborating institutes. The review committee is therefore asked to:

- Review the proposed machine scheme and the technical solutions proposed.
- Comment on proposed alternative technical solutions.
- Identify technical difficulties and propose areas where more development is required.
- Review the proposed construction phases, the planning and required resources.
- Produce a written statement about the feasibility of the proposed scheme and the major challenges in the design.

CTF3 Review

Programme

Tuesday 2.10.2001 40 – SS – C01

09:00 – 09:15 Welcome by C.Wyss, CERN Director for Accelerators
09:15 – 09:45 Introduction to CTF3 *G.Geschonke*
09:45 – 10:05 Injector *H.Braun*
10:05 – 10:25 Injector Optics, *A.Yeremian/SLAC*
10:25 - 10:45 Gun and Prebuncher design *T.Garvey / LAL*
10:45 – 11:10 Coffee Break
11:10 – 11:25 Photo-Injector Option *G.Suberlucq*
11:25 – 11:40 Laser for photo injector *I.Ross / RAL*
11:40 – 12:00 Drive Beam Accelerator Optics *D.Schulte*
12:00 - 12:30 Drive Beam Accelerator Structures *E.Jensen*

12:30 – 14:00 Lunch

14:00 – 14:30 Longitudinal Dynamics *R.Corsini*
14:30 – 15:00 Optics for Delay Loop and Combiner Ring, *C.Biscari / INFN Frascati*
15:00 – 15:15 Transfer Lines *C.Milardi / INFN Frascati*
15:15 – 15:30 Hardware Developments *A.Ghigo / INFN Frascati*
15:30 – 16:00 RF Deflectors *A.Gallo / INFN Frascati*
16:00 – 16:30 Coffee Break
16:30 – 16:50 RF power Generation *G.Mcmonagle*
16:50 – 17:10 RF Pulse Compression *I.Syratchev*
17:10 – 17:30 Mechanical design of BOC cavity /*R.Losito*
17:30 – 18:00 Low Power RF *R.Bossart / E.Peschardt*

Wednesday 3.10.2001 40 - SS-C01

09:00 – 09:20 30 GHz Power Production after Linac *R.Corsini*
09:20 – 09:40 Main Beam *H.Braun*
09:40 – 10:00 30 GHz Test Stand *W.Wünsch*
10:00 – 10:30 Coffee Break
Travelling wave buncher *L.Thorndahl*
10:30 – 11:00 Experiments done in LPI and planned in preliminary phase *L.Rinolfi*
11:00 – 11:30 Organisation / Collaborations / Planning / Status / Budget *G.Geschonke*
11:30 – 12:00 CTF3 in the context of CLIC and Discussion *J.P.Delahaye*

12:30 – 14:00 Lunch

afternoon detailed discussions as requested by referees, Salle A Main Building

Thursday 4.10.2001 40 – R-A10

10:00 – 12:00 Closed Session with DG, representatives of Collaborations and CSC

Introduction to CTF3

G.Geschonke
CERN / PS

Aim of review:

Review the technical solutions
are they realistic ?

Give us technical advice
Comment on alternatives

Guide our funding bodies:
- CERN
- Collaborations

CTF3 is only possible as International collaboration

INFN Frascati
LAL Orsay
Rutherford Appleton Laboratory
SLAC
Strathclyde University
Uppsala University

CTF3 is not a user facility

Experimental machine :

Demonstration of the RF power generation scheme for CLIC
- Novel drive beam scheme in the two-beam scenario
- This two-beam scheme is not limited to CLIC

long RF pulse at low frequency
==> short RF pulse at high frequency with high power
using an electron beam for energy storage

high efficiency

Demonstration of major CLIC Components

RF power source at 30 GHz with nominal CLIC parameters

Make use of already existing material:

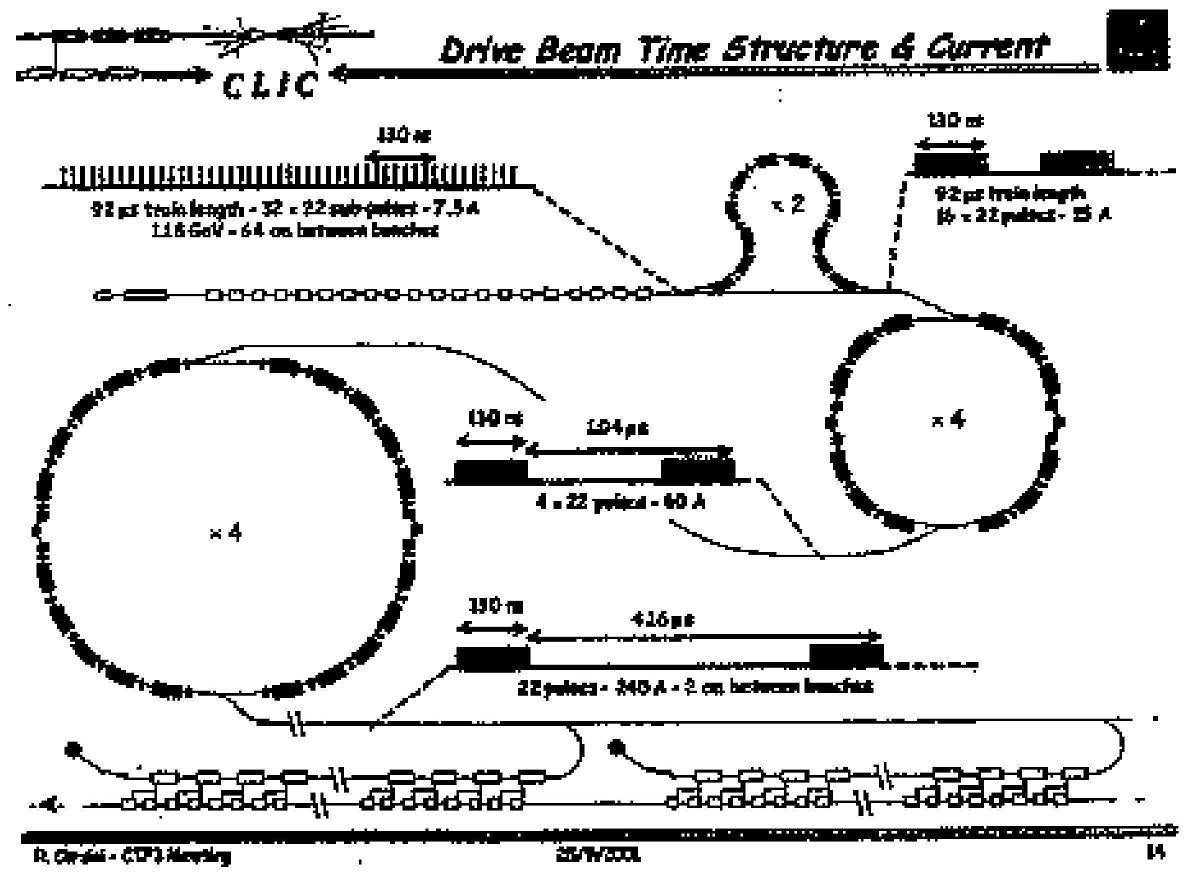
LPI complex available since LEP shut-down:
LEP injector Linac LIL and Electron-Positron Accumulator EPA

Building : Linac tunnel, space for rings, control room

Hardware:
3 GHz RF system: klystrons, modulators, accelerating sections
magnets, power supplies,
control system

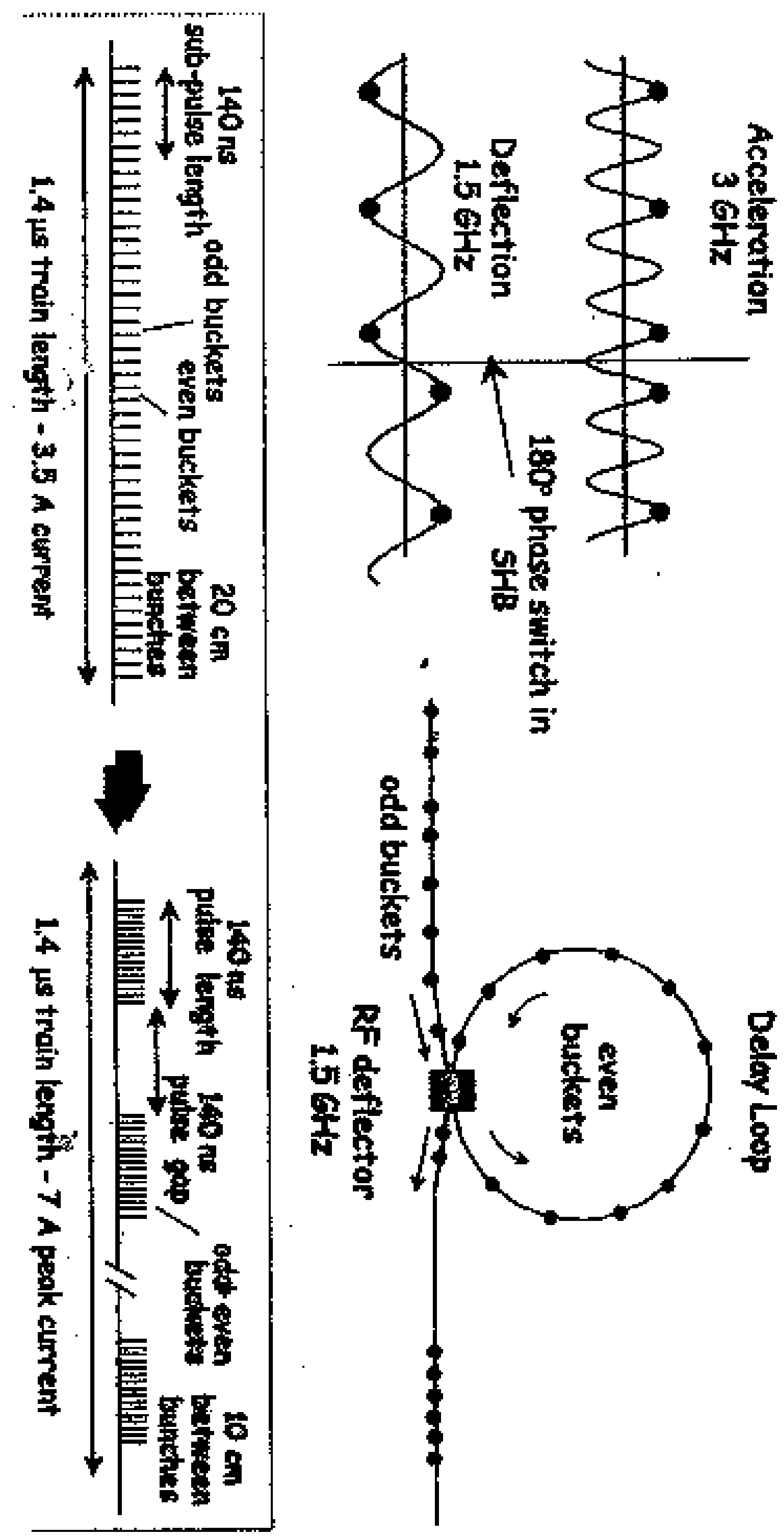
==> some technical choices are a consequence of existing equipment

CLIC - CTF3

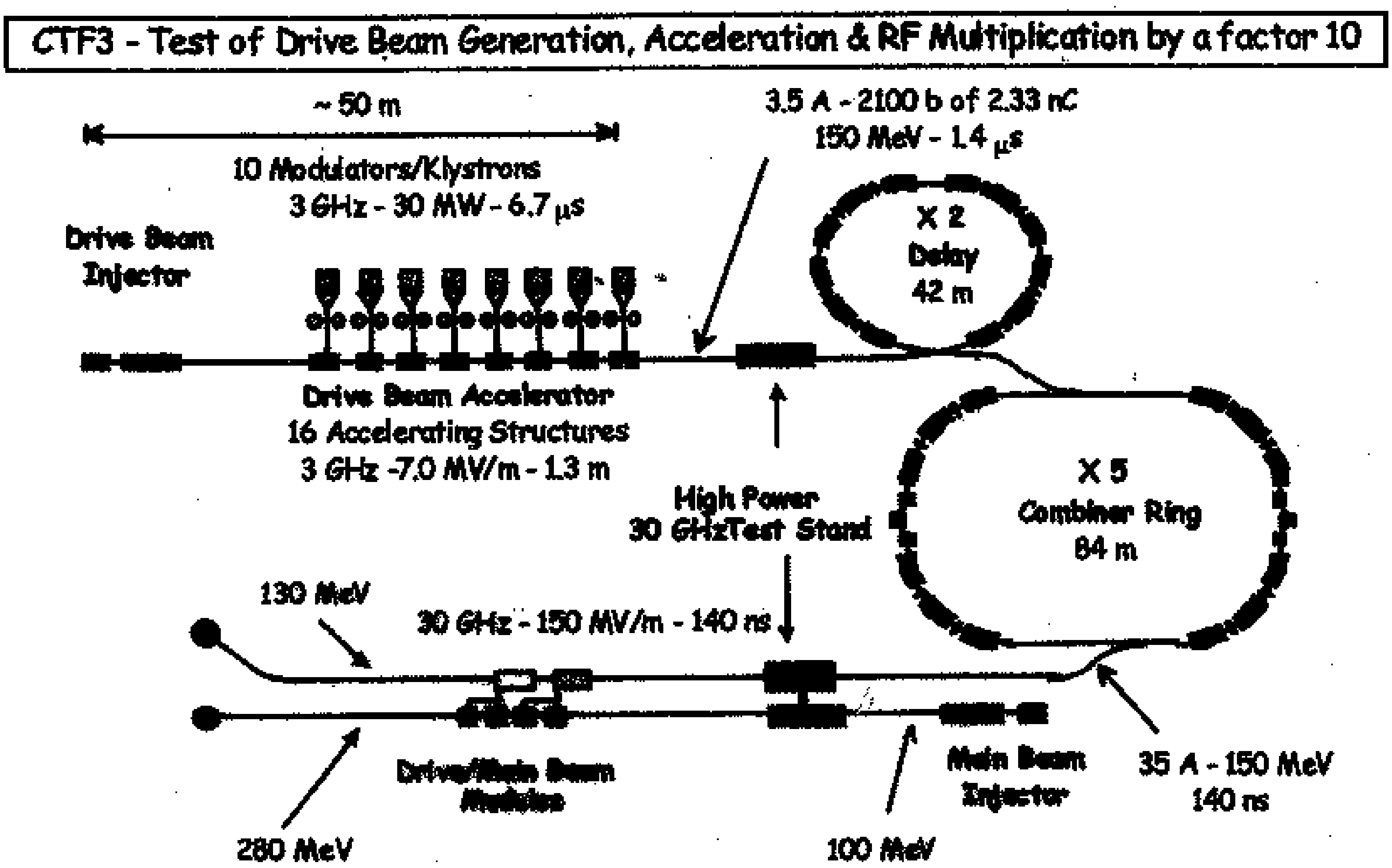


		CTF3	CLIC (3 TeV)
Drive beam			
Acceleration frequency	MHz	2 998.55	937
repetition rate	Hz	5	100
energy	MeV	150	1180
Number of accelerating structures		16 + 2	182
average current after linac	A	3.5	7.5
Number of klystrons		10	182 x 2
Number of RF pulse compressors		9	0
Beam pulse length	µs	1.4	92
Bunch spacing before compression	cm	20	64
Delay Loop length	m	42	39
Combiner Ring length	m	84	78
Average beam current after compression	A	35	240
Bunch spacing after compression	cm	2	2
Drive beam energy per pulse	kJ	0.8	814
average beam power	kW	4.1	81 000
Main beam			
Number of accelerating structures		max 8	22 x 976
RF Pulse length	ns	140	130
Acceleration Frequency	GHz	30	30
Acceleration Gradient	MV/m	150	150

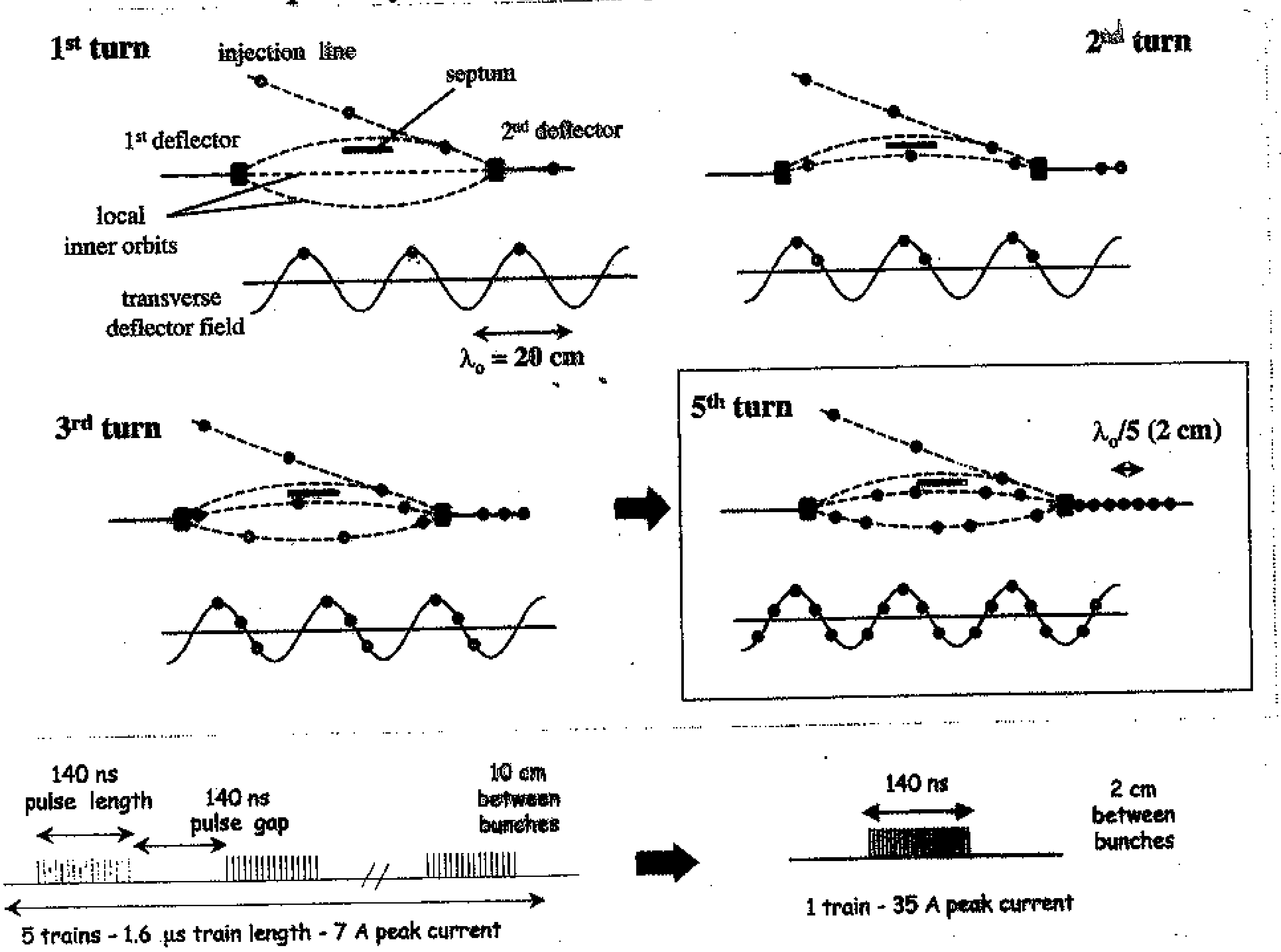
"Phase-coding" of bunches



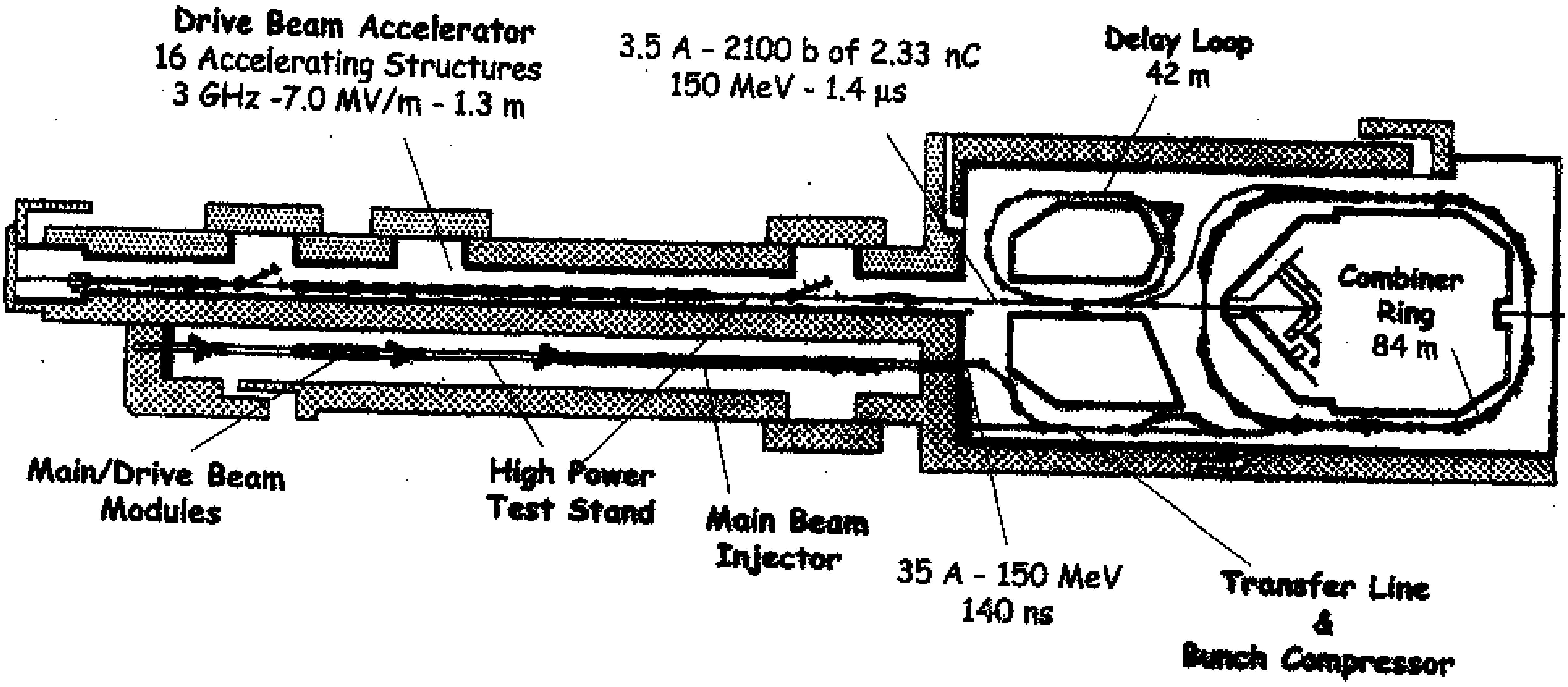
Generic layout of CTF3



Bunch frequency multiplication - Combiner Ring injection



CTF3 layout - Nominal phase

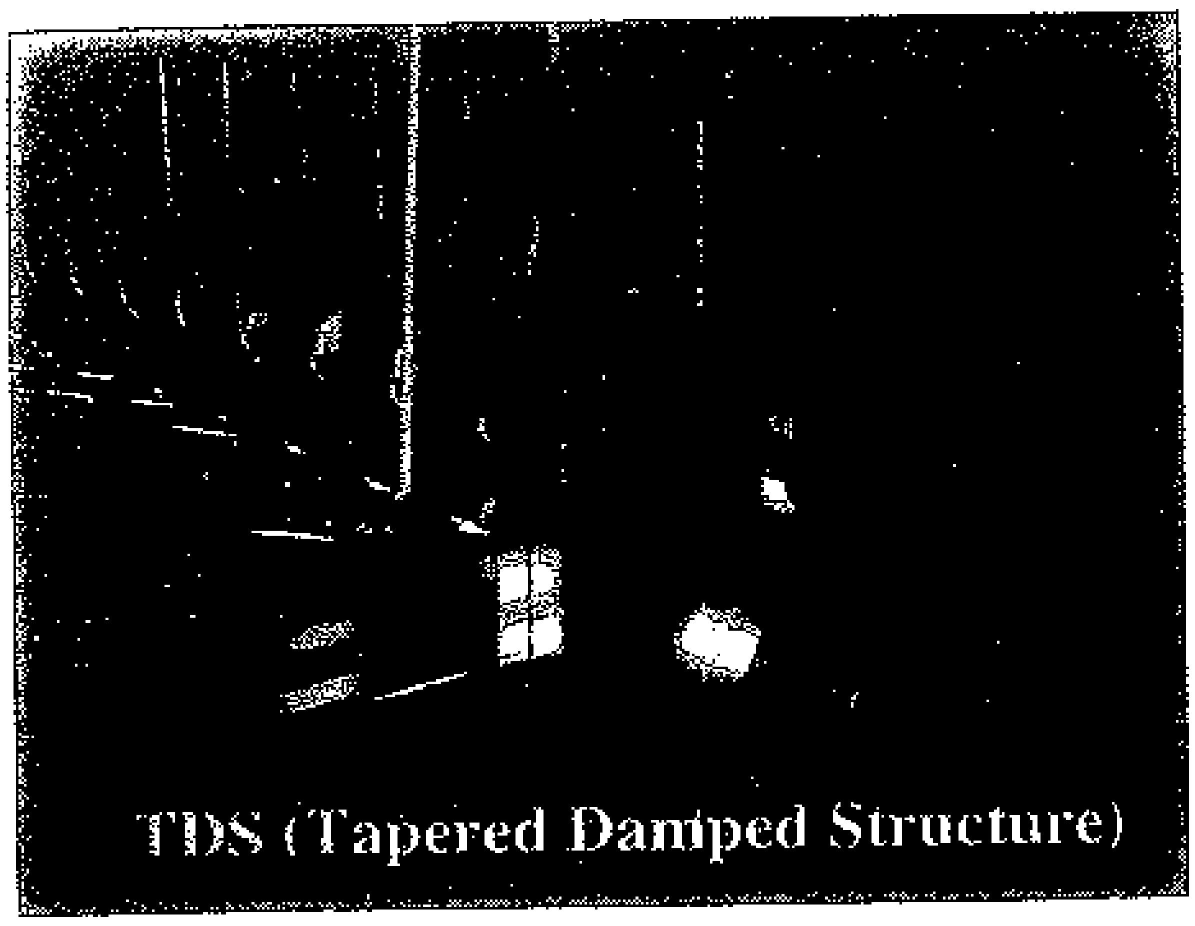


A possible housing of the CLIC Test Facility (CTF3) in the LEP Pre-injector building

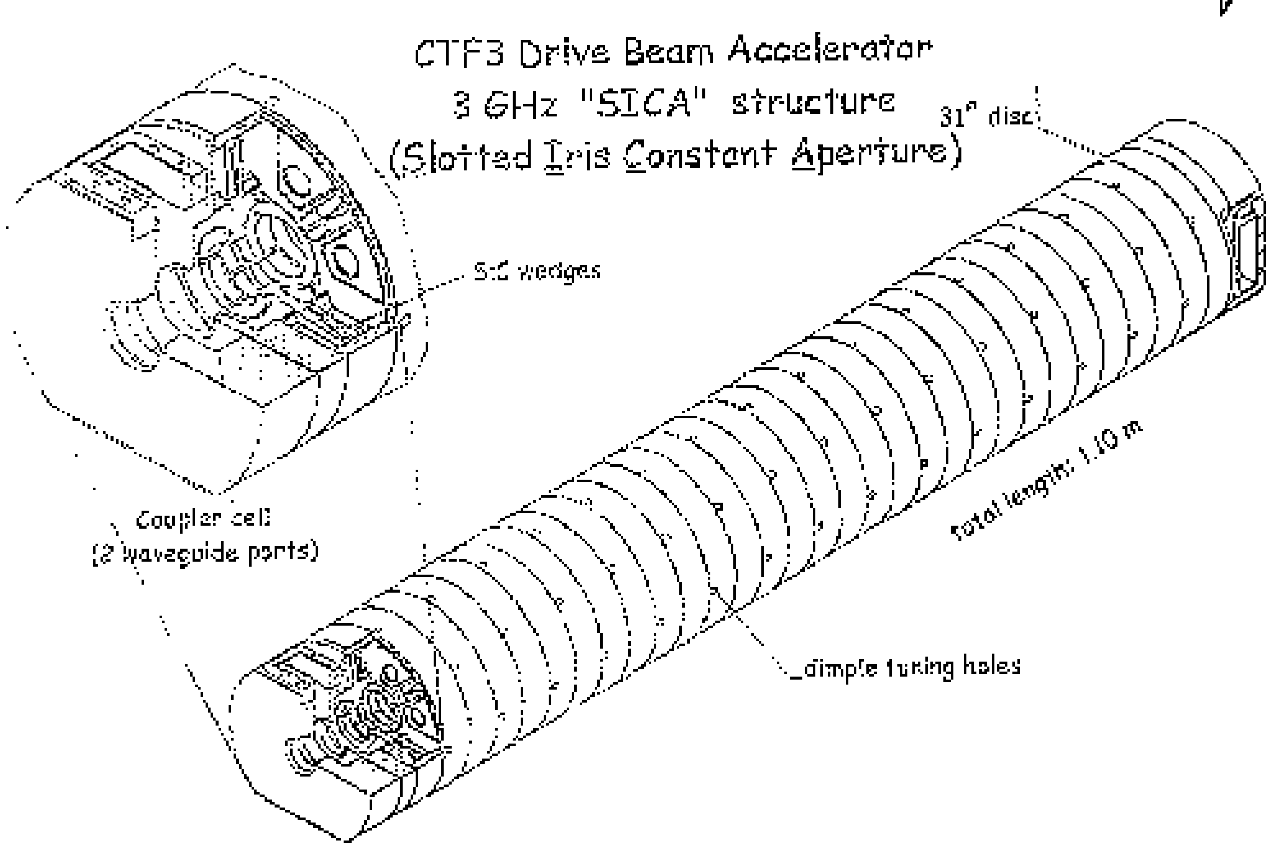
Main objectives and challenges

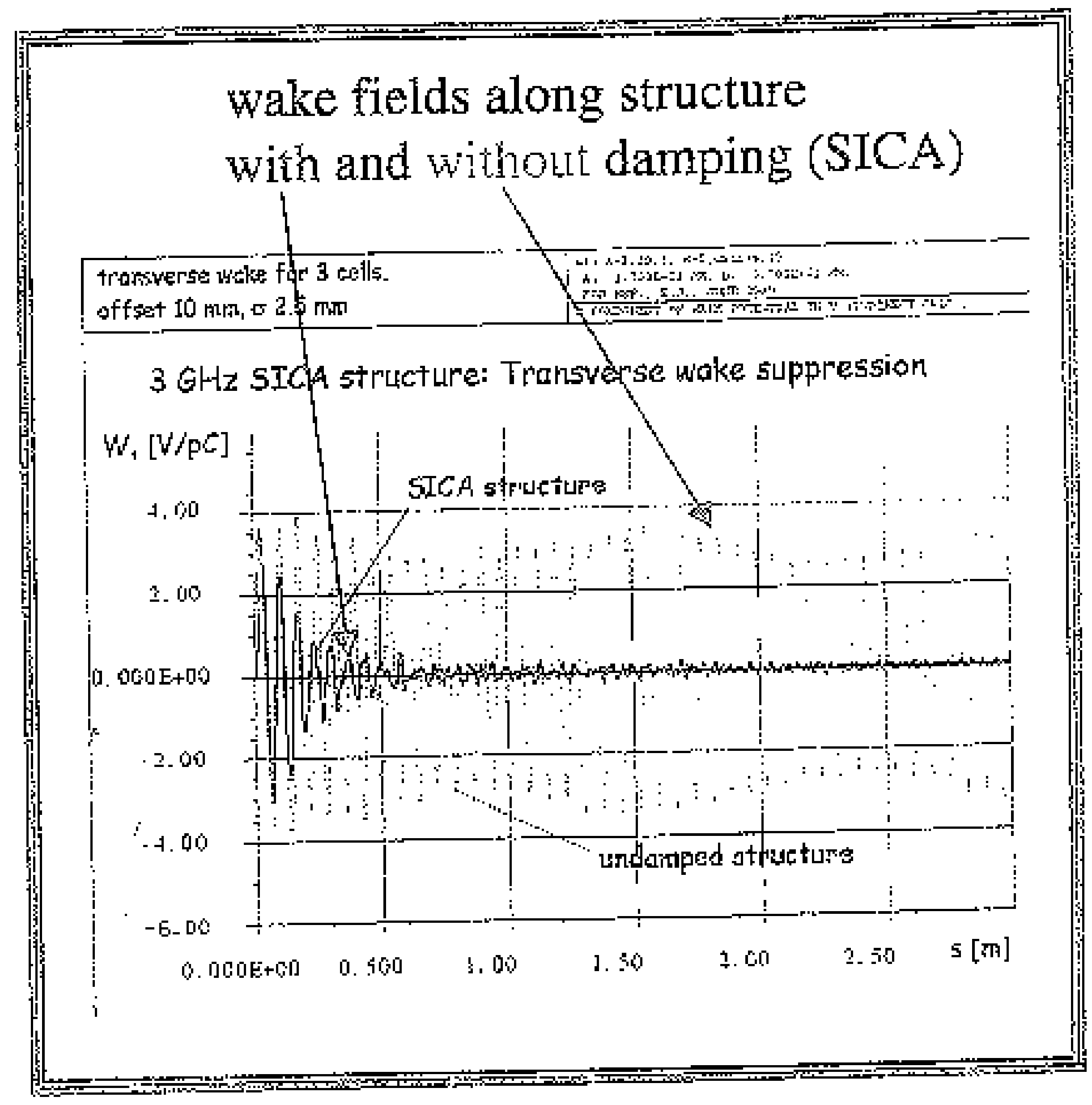
Drive beam production: 3.5 A, Estimation: Stability of Voltage and beam current of 10^{-3} ! satellite bunches bunch phase coding	Thermionic injector wide bw 1.5 GHz klystron Alternative: Laser gun
Drive beam accelerator: Near 100% beam loading high beam current in short bunches beam stability	strong damping of HOM, new RF structures
Delay loop, Combiner ring, bunch compressor injection with RF deflector isochronous lattice Impedance coherent synchrotron radiation handling of 35 A beam current	bunch length manipulation
3 GHz RF: pulse compression, long flat-top	longer RF pulse, phase ramping New BOC development

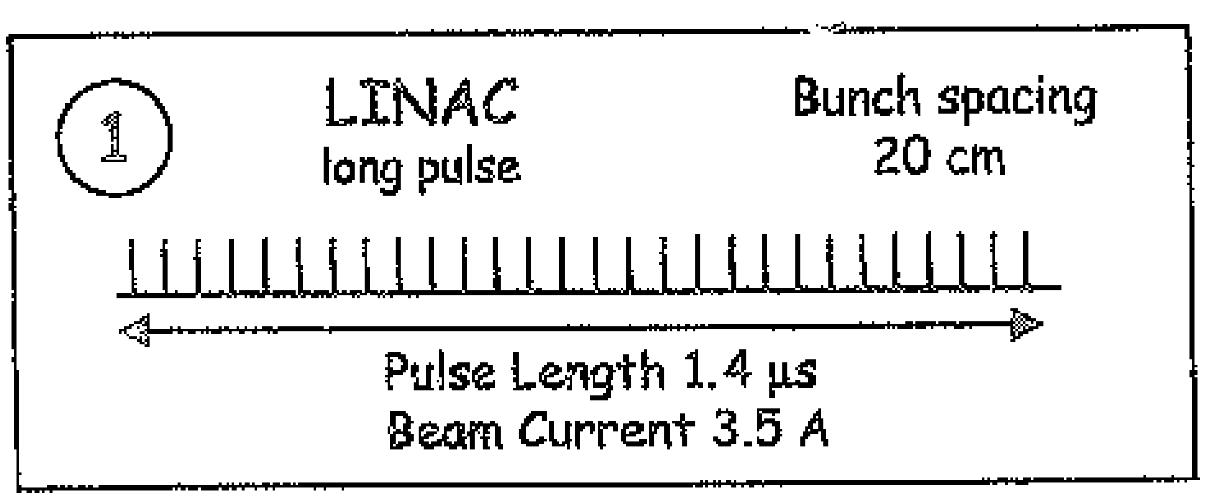
Drive beam accelerating structure

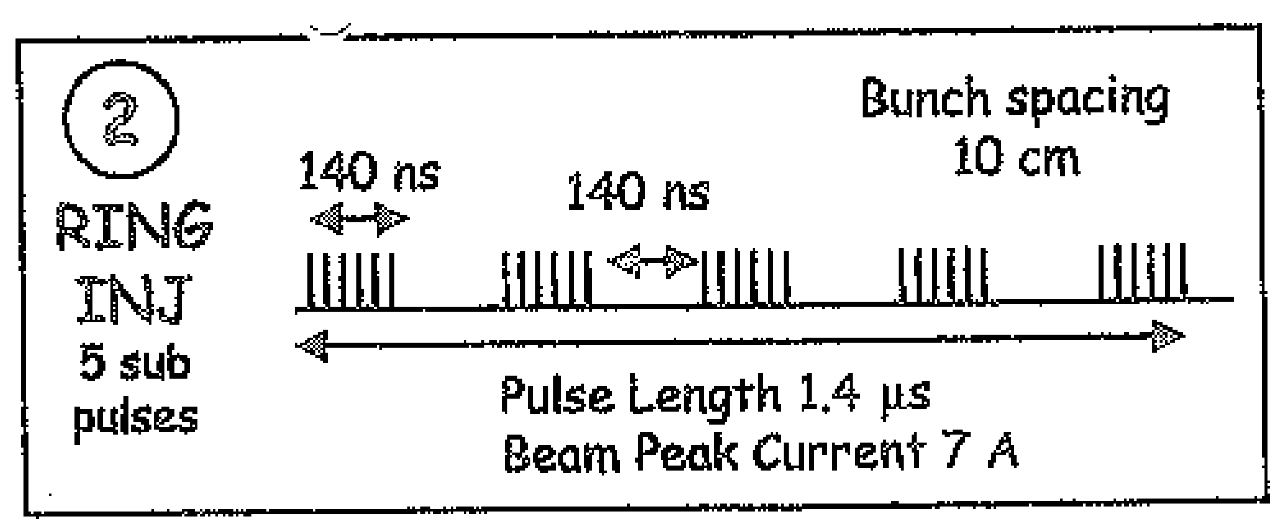


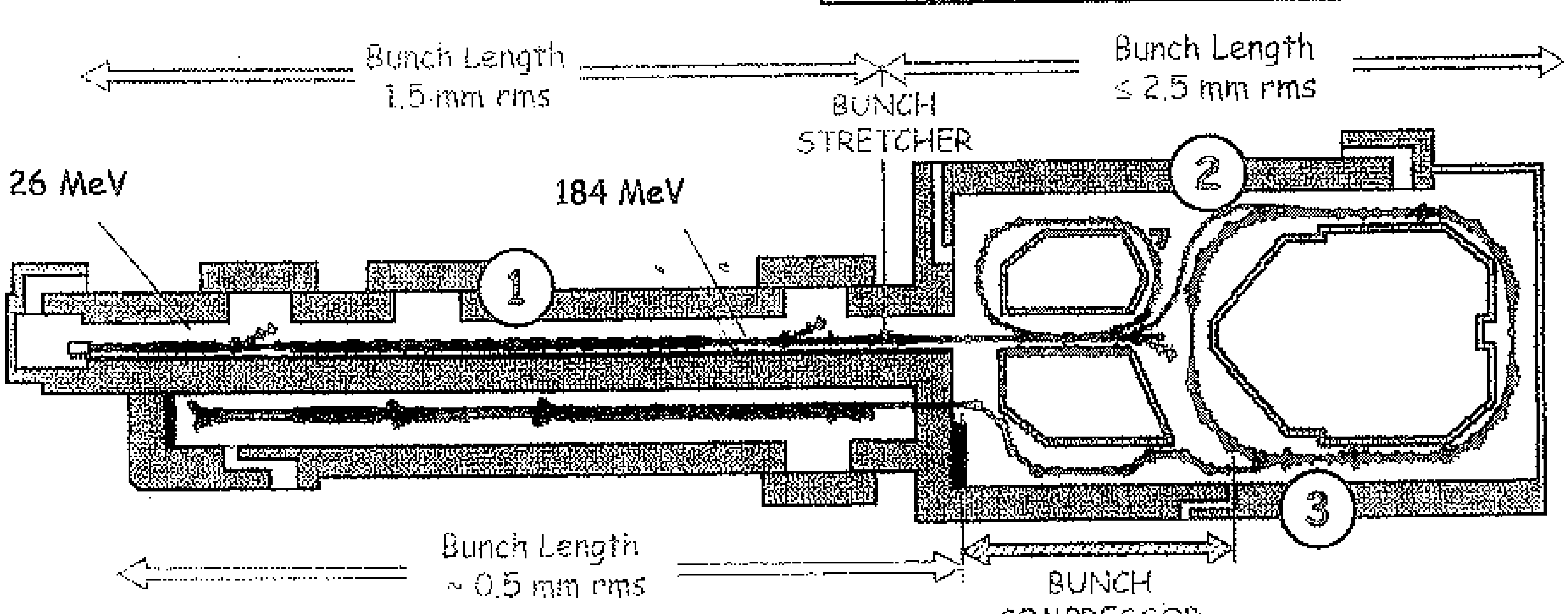
High beam current =>
Beam induced modes have to be damped
Prototype of TDS structure built, RF power tested
New structure type has been developed :
(SICA = Slotted Iris Constant Aperture)



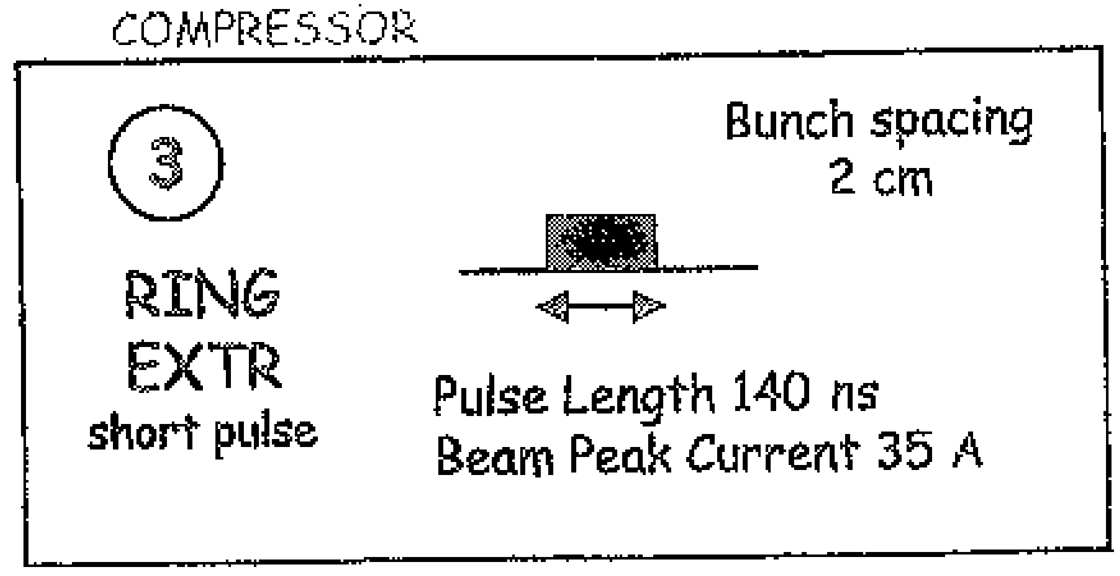








Bunch Length (rms)	0.5-2.5	mm
Bunch Charge	0.1-2.4	nC
Norm Emittance (rms)	100	π mm mrad
β-functions	0.5-15	m
Beam size	0.25-1.5	mm

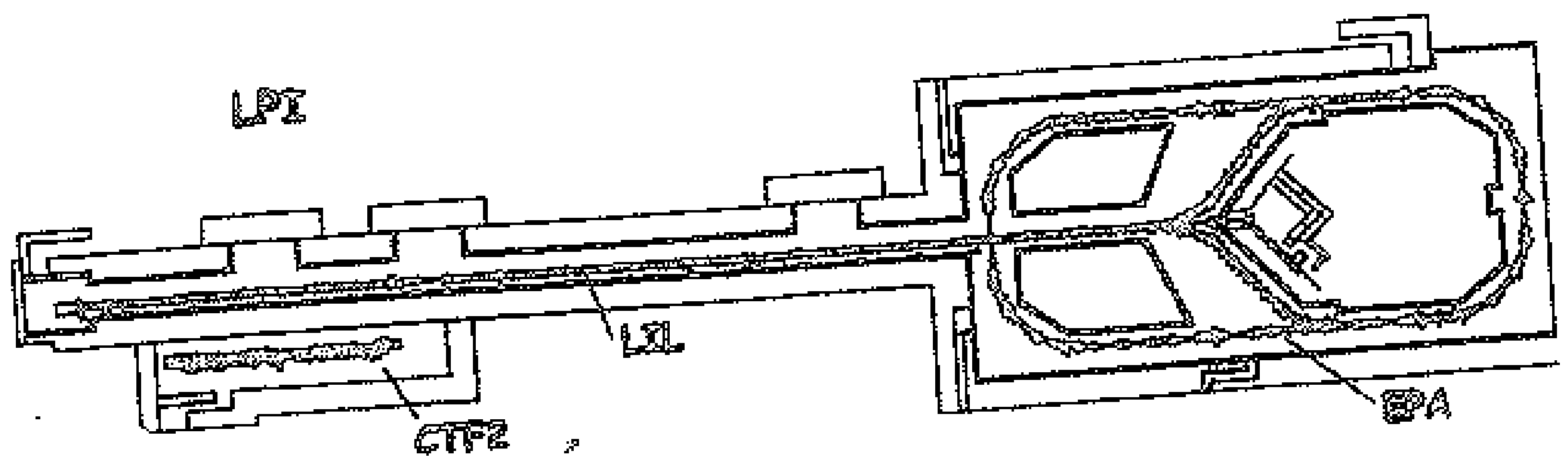


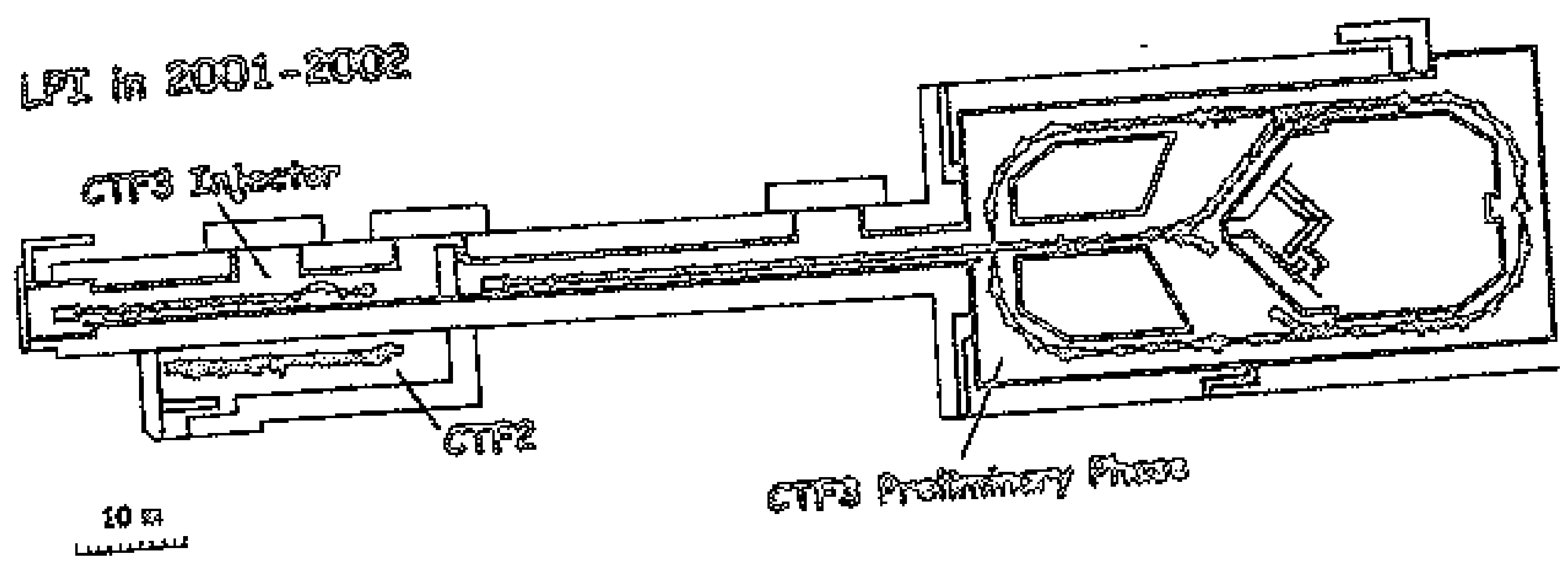
2005 - 2006

Construction in phases

Preliminary phase
2001 / 2002

LPI + modified EPA
new e-gun
only 8 accelerating sections
EPA ring 17 mm shorter
transfer lines and EPA isochronous





demonstrate bunch recombination by factor 3-5
using 2 RF deflectors

limited beam current

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Major building modifications

Radiation shielding

Beam power 5 kW !

shielding assumes :
permanent beam loss of only 5% (250 W)
beam loss monitors in interlock chain shut-off beam

additional shielding required:

some outside walls

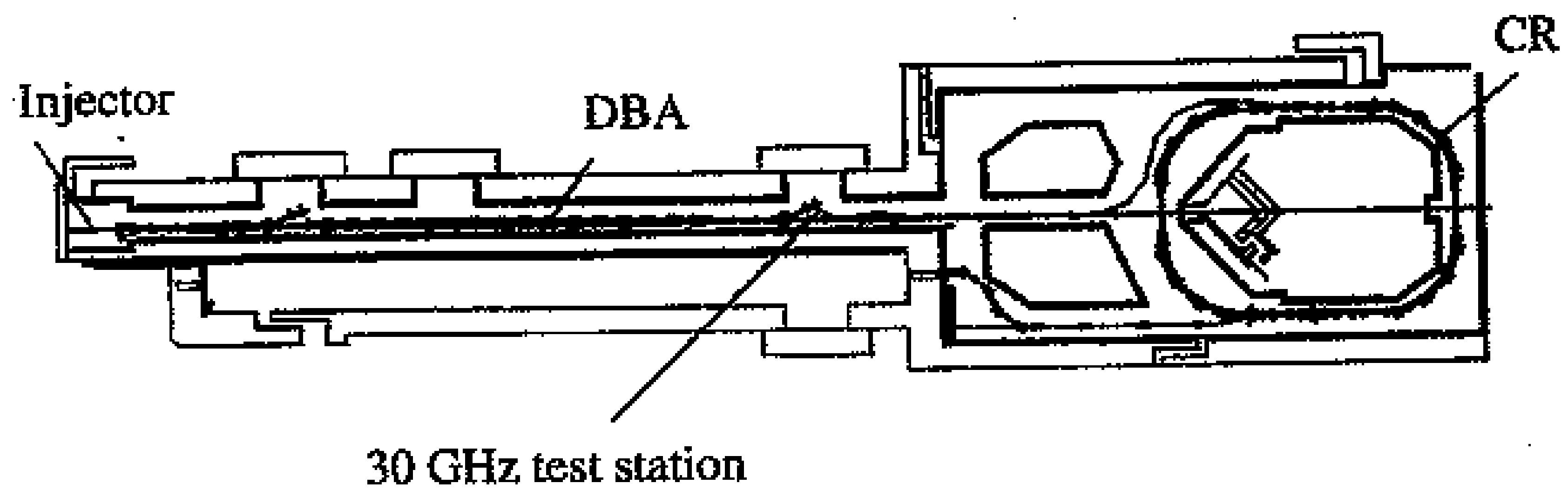
between accelerator tunnel and klystron gallery above
up to 20 cm of iron

above EPA:
additional 90 cm concrete

Other building modifications:

make room for DL
new CLEX building

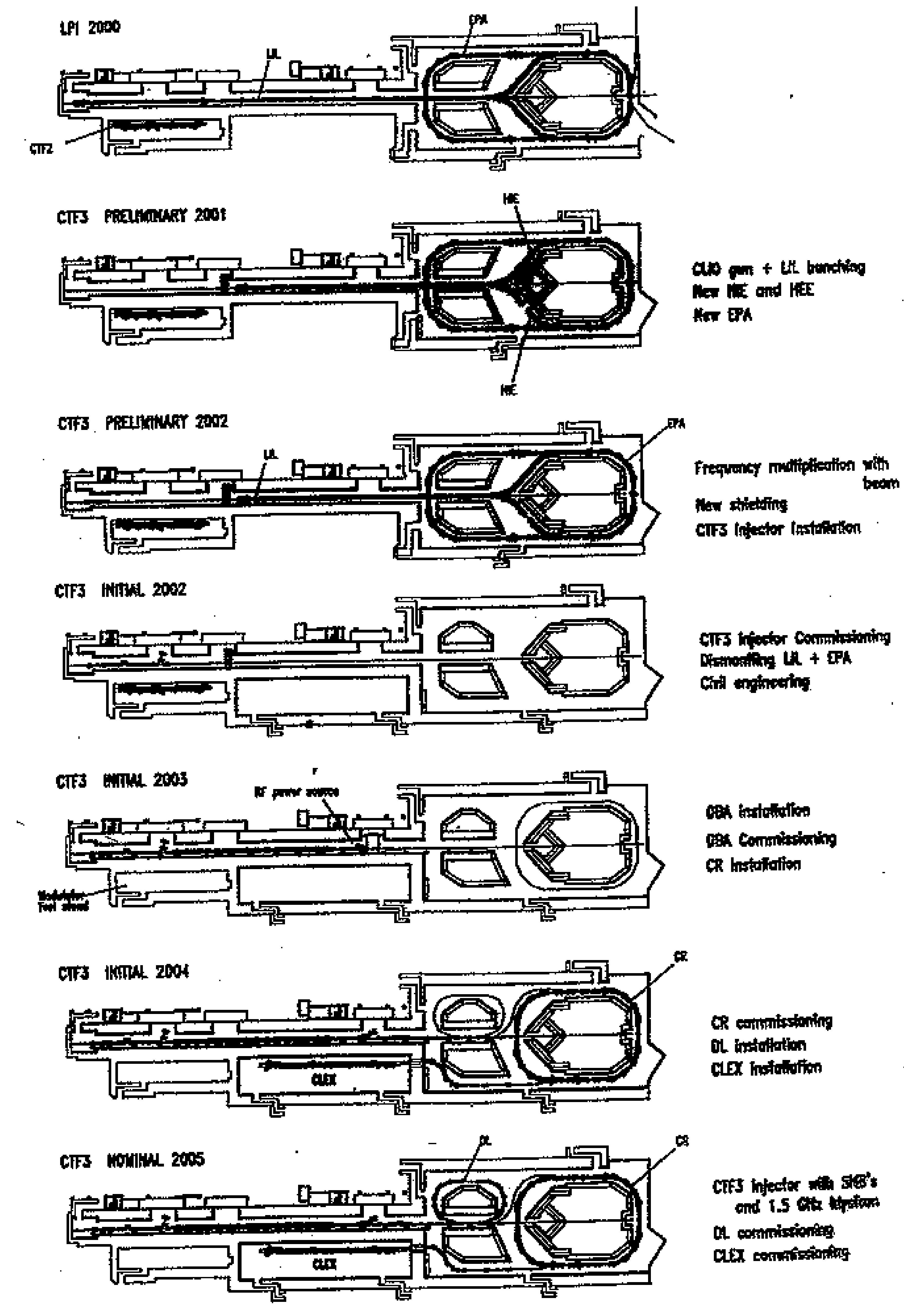
Initial phase
_2003 / 2004_



new injector (no Sub-harmonic bunchers ...)
new accelerating structure's for DBA
30 GHz test station after linac

transfer lines
combiner ring

combination tests can be done at reduced bunch charge



DBA = Drive Beam Accelerator
CR = Combiner Ring
DL = Delay Loop
SHB = Sub Harmonic Buncher
CLEX = Clic Experimental area (30GHz)

From LPI to CTF3

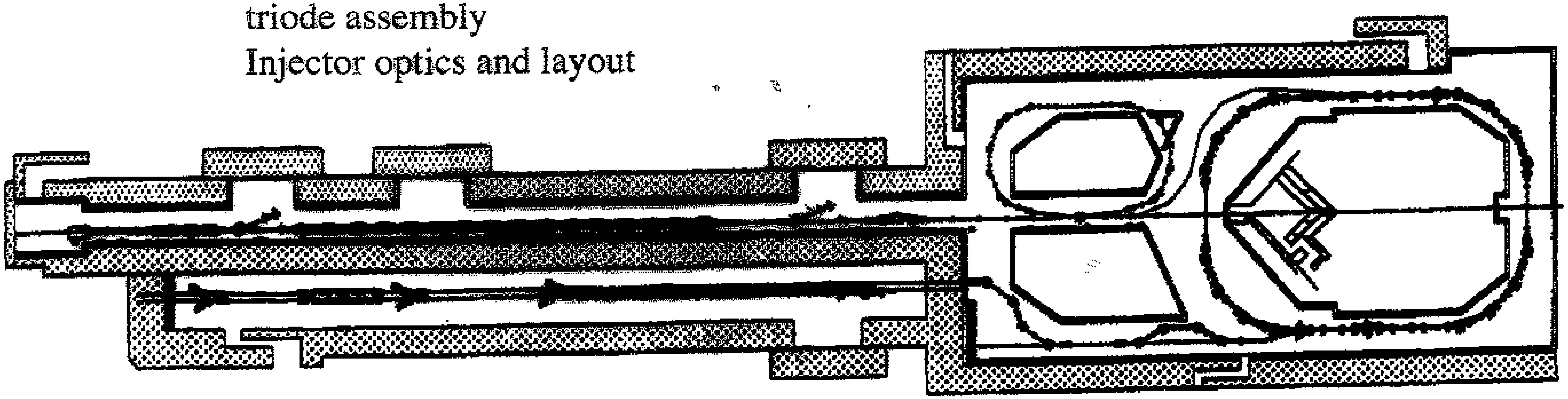
B.FAVRAT
13-06-2001

Collaborations

LAL:
gun, HV deck
pre-bunchers
CLIO-type gun for prel. phases already delivered

INFN Frascati:
transfer lines, bunch lengthening chicane
Delay Loop layout and hardware
Combiner Ring layout and hardware
RF deflectors
Fast kickers
Participate in commissioning and exploitation

SLAC:
triode assembly
Injector optics and layout



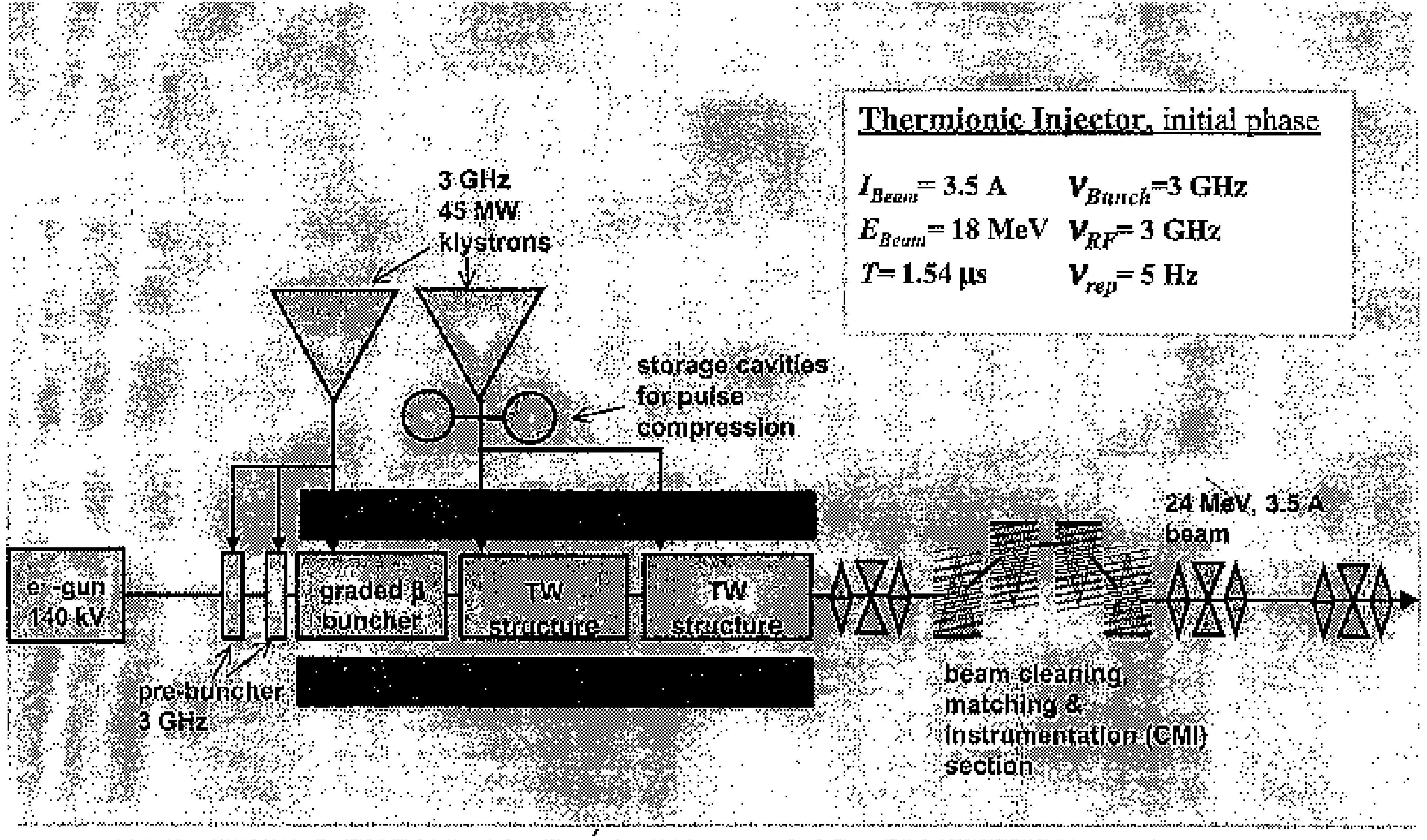
RAL and **Strathclyde University**:
Laser for Photo-Injector option

Uppsala University:
mm wave detector for beam diagnostics
participation in commissioning

CTF3 drive beam injector

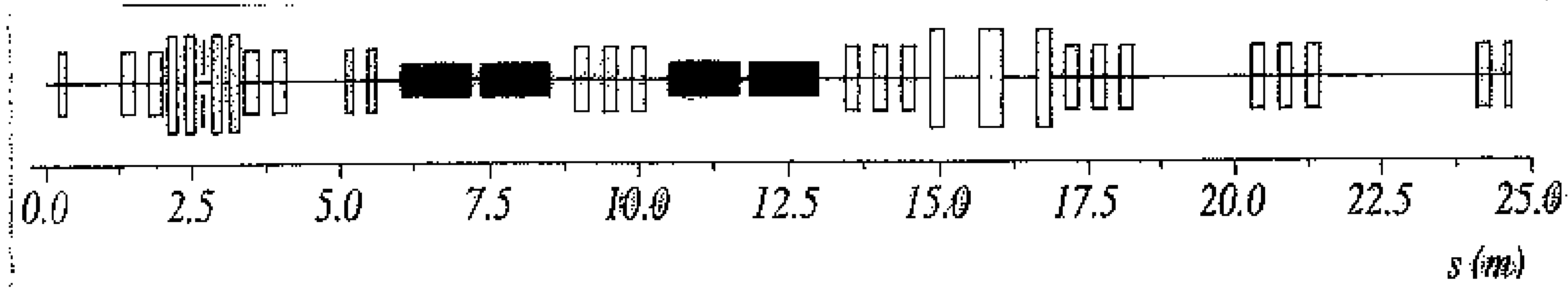
Hans Braun

- requirements
- initial phase
  concepts, problems and remedies
- nominal phase
  options
  bucket switching
- schedule
- contributions from collaborating institutes



chicanes

1. energy collimation (@18 MeV)
2. bunch compression and instrumentation (@ 50 MeV)



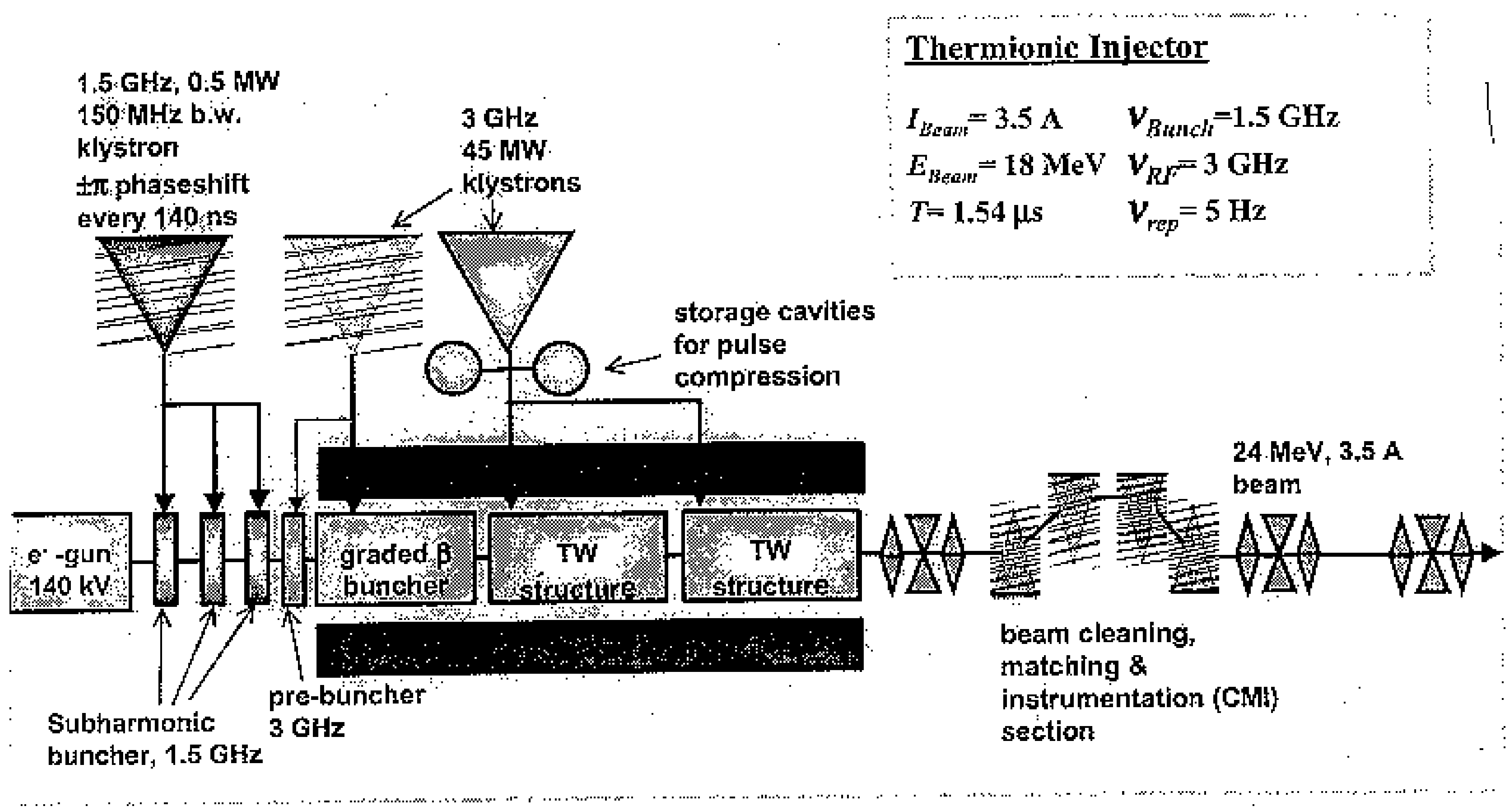
specific problems initial phase

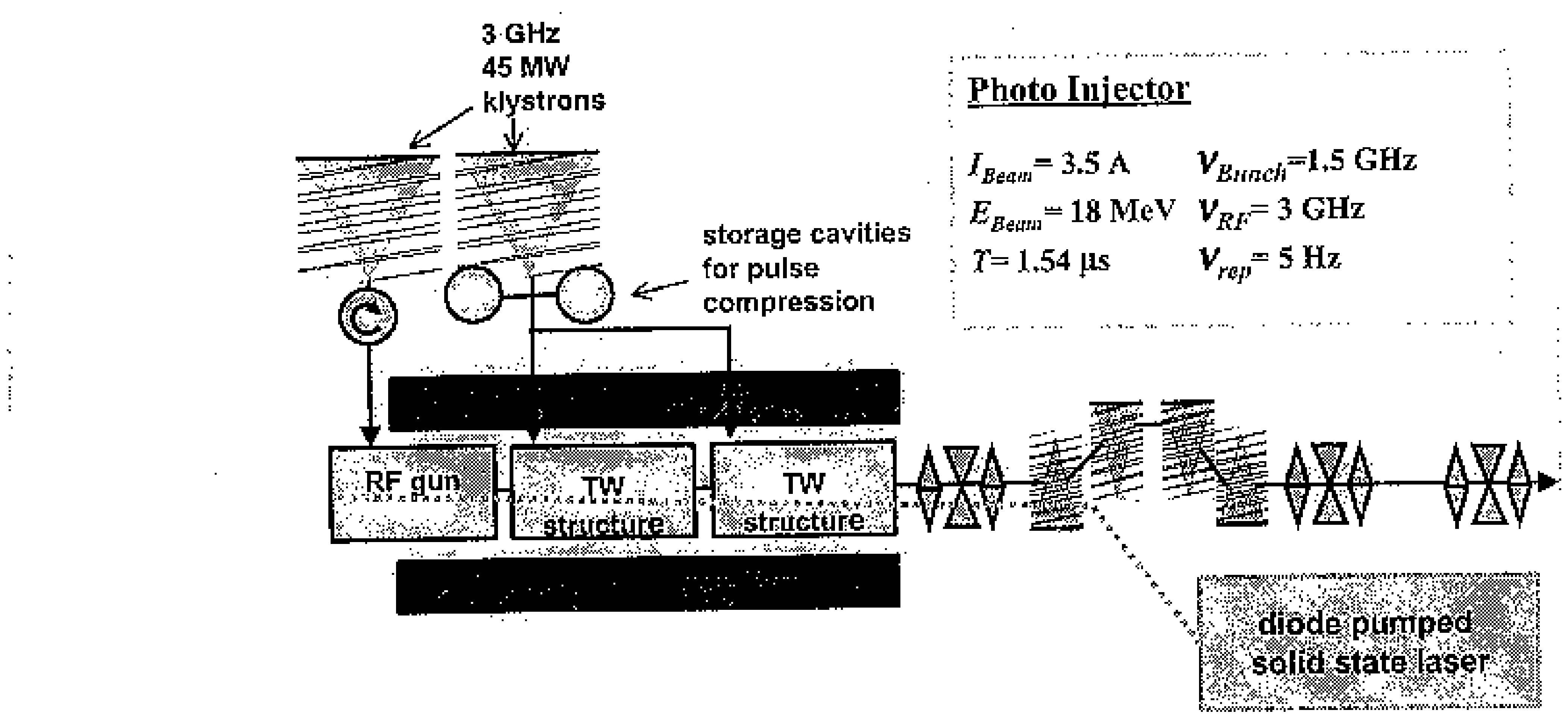
- **total charge per pulse**
- **charge stability**
- **bunch length**
- **energy spread**

Requirements

Parameter	Initial	Nominal	Unit
Pulse Length	1.54		µs
Beam Current	3.5		A
Charge per pulse	5390		nC
Bunches/pulse	4620	2310	
Charge per bunch	1.17	2.33	nC
Emittance, norm., r.m.s.	< 100	< 100	mm-mrad
Bucket switching	none	every 140ns	
Allowed charge in Satellite	-	<7	%
Bunch Spacing	0.33	0.67	ns
Bunch Length (rms)	< 5	< 5	ps
Energy spread (single bunch rms)	< 0.5	< 0.5	MeV
Energy spread (total on flat top incl. Beam loading)	< 1		MeV
Charge Variation bunch to bunch (<20 MHz)	< 2		%
Charge Flatness total on flat top (>20 MHz)	< 0.1		%
Beam Repetition Rate	5		Hz

CTF3 injector variants for nominal phase





requirement	potential problems	remedies
total charge per pulse	heavy beam loading	140 ns scavenger train for transients
		2nd prebuncher with external load
		buncher with large power overhead
	emittance deterioration & beam break-up	detuned & damped acc. structures
		strong focusing
		large apertures
	deterioration of vacuum	all systems can be baked at 150°C
		generous pumping
		large apertures
charge stability	beam loading induced energy spread	reduced bandwidth of grid pulser
		beam current feedback on grid pulser
longitudinal emittance	downstream longitudinal gymnastics / efficiency of 30 GHz power production	graded β buncher
		sophisticated prebunching
		energy collimation
		bunch compressor

RF Photo-Injector option for CTF3 drive beam

Advantages of such an solution:

+ absence of low charge parasite bunches
+ no phase/energy tails as produced in conventional bunching systems
+ easy 180^0 phase switching
+ design of RF gun for CTF3 parameters straight forward
+ RF gun and photo-cathode technology well established at CERN
+ smaller beam emittances in all three phase space planes
+ much less parameters (2 RF ampl. & phases compared with 6)
+ possibility of single bunch operation for beam monitor development, wakefield, CSR,...

But:

– laser requirements for producing the long drive beam train very demanding
– past experience with CTF II laser system not very encouraging
– Unprecedented average current requirement for photo-cathodes

⇒ High current tests of cathodes in PS photo-cathode lab. last winter demonstrated feasibility of cathodes

⇒ R&D program in collaboration with RAL and Strathclyde University for the development of an all diode pumped, solid state laser system

Additional problem nominal phase

◆ bucket switching every 140 ns with ≤ 5ns switching time

	Method	Problems
Thermionic solution	1.5 GHz sub harmonic bunchers with Q≈10 driven by 500kW, large b.w. (150 MHz) klystron	Parasite charge in 'empty buckets
		Current droop during switching
Photo injector	Switching of optical delay in laser beam line with pockel cells	Pockel cell driver
		Pockel cell lifetime

Contributions from collaborations

SLAC

- design of beam-line initial & nominal phase
- gun triode for initial & nominal phase

LAL

- design and construction of gun electronic (HV, grid pulser, controls electronic,…) and support structure (hot deck,…)
- design and construction of 3 GHz pre-bunchers

RAL

- development of diode pumped laser amplifier for generation of long bunch train with photo-injector

Inst.of Photonics / Strathclyde

- development of diode pumped, pulsed laser oscillator

year	Initial phase	Nominal phase	
		photo injector	thermionic injector
2001	Design of beamline and all components	Build laser configuration for PILOT	Design of SHB bunchers, RF networks and modulator
2002	Construction of components		
	Assembly of beamline	PILOT experiment long train photo-injector demo.	
	Move CTF II components to CTF3 injector	Decision which solution to take	
2003	Injector commissioning	Upgrade PILOT laser to CTF3 laser Build RF gun	Order and install 1.5 GHz klystron and network components Build SHB's
2004	Injector operation		
2005		Install laser and RF gun	Install SHB's
		Commissioning of nominal phase	

CTF3 Pre-Injector Beam Line

October 2, 2001

Anahid Dian Yermeian, SLAC

Beam line Configuration

Gun – optics and status

Beam line optics and expected beam parameters

Strengths for Bunchers, Accelerators and magnets

Diagnostics for tuning and beam quality verification

Conclusions

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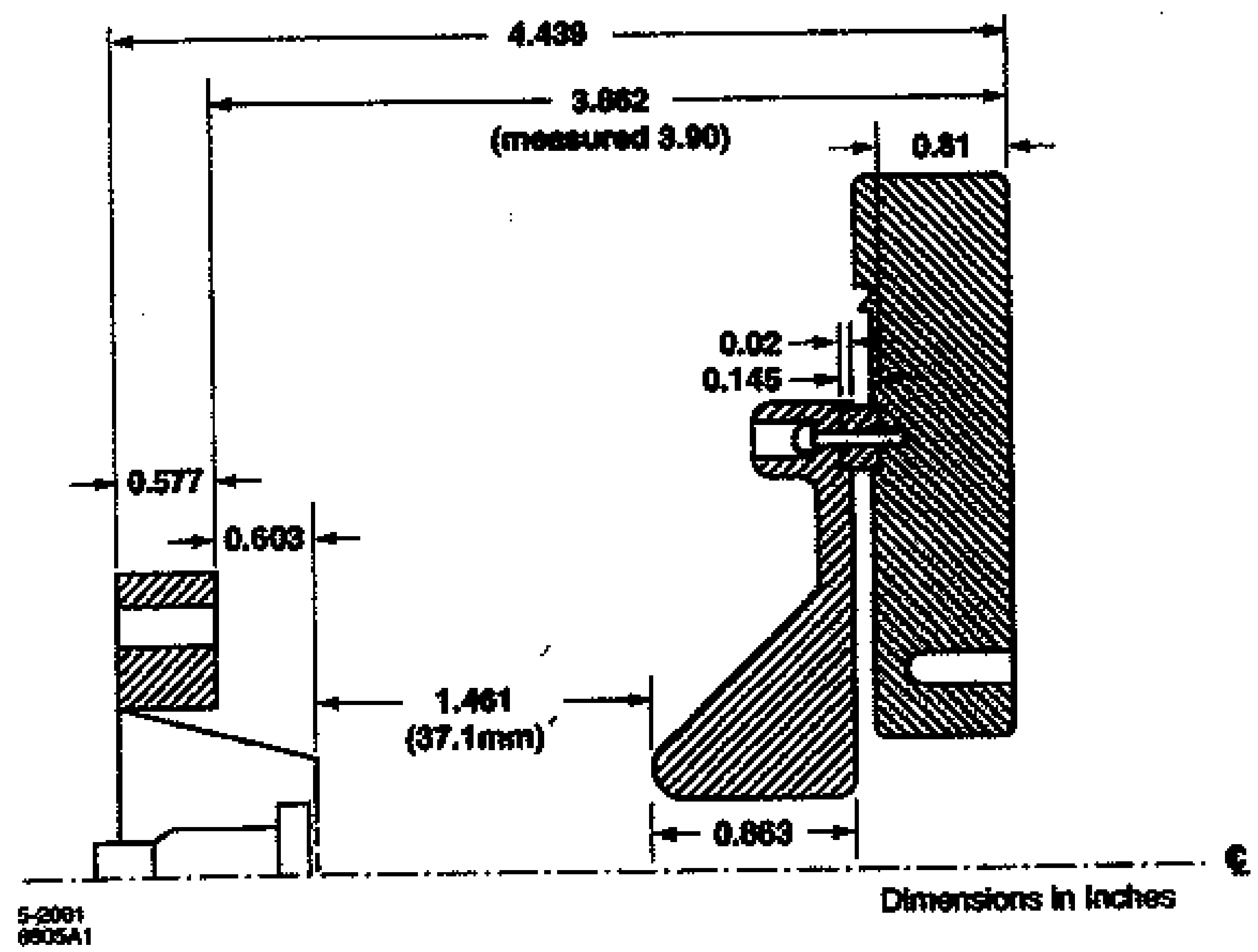
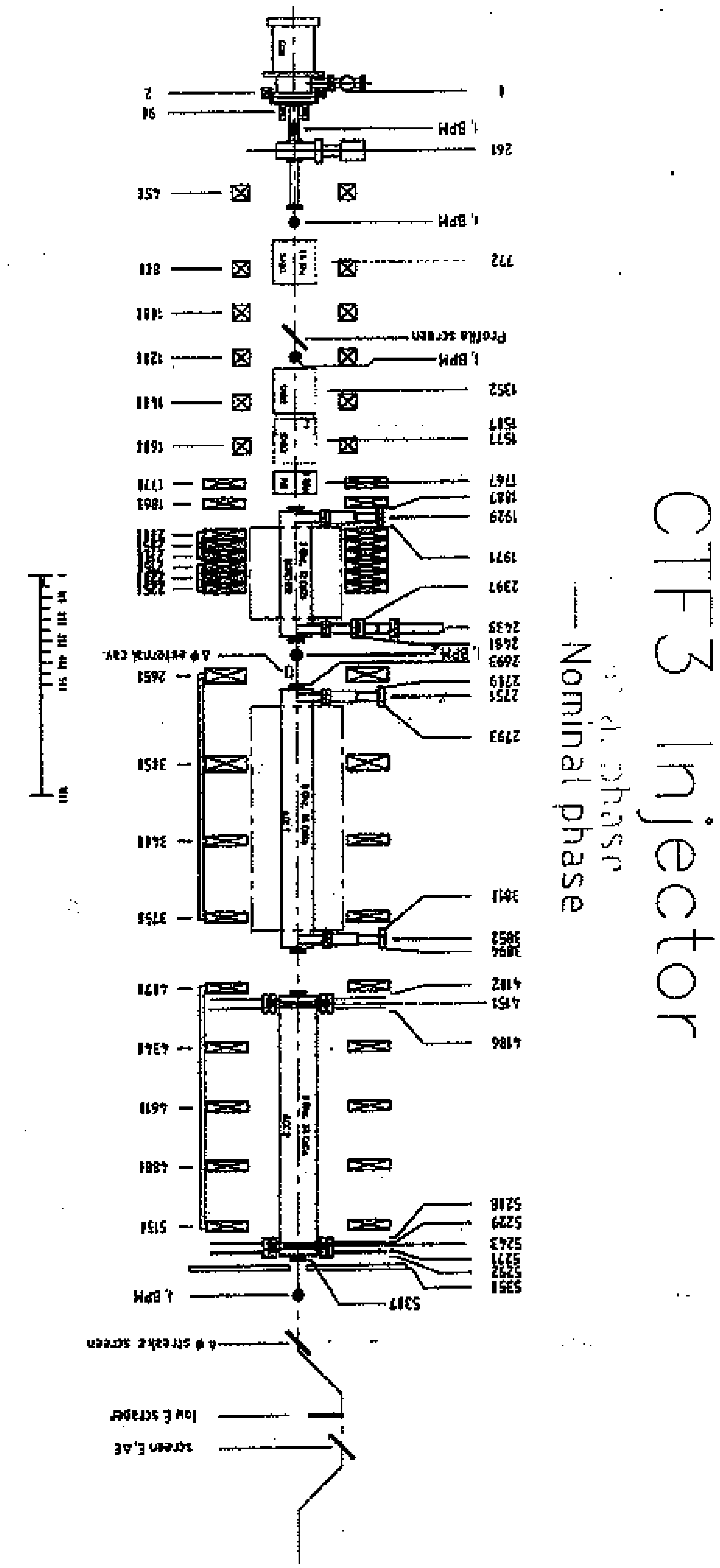
Gun Anode – Cathode Geometry



The gun is one of the spare Thermionic guns from SLAC originally built for Boeing by Ron Koonts, now on loan to CERN

The gun was modified at SLAC for the CTF3 Anode Cathode configuration and High Voltage processed up to 160 KV in January 2000, before shipping to CERN with a spare cathode already installed.



CTF3 Review. October 2, 2001, at CERN
Dian Yeremian, SLAC

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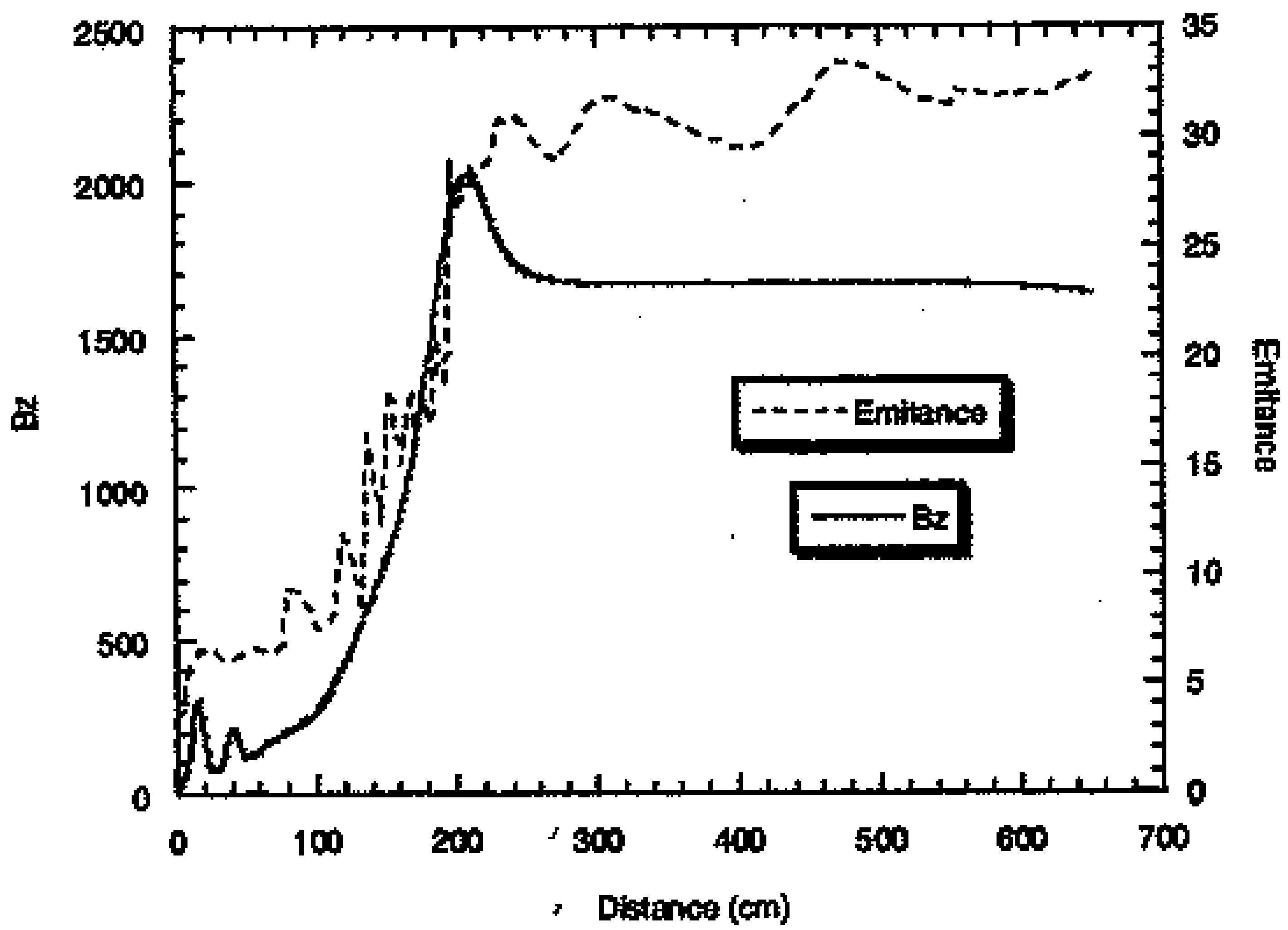
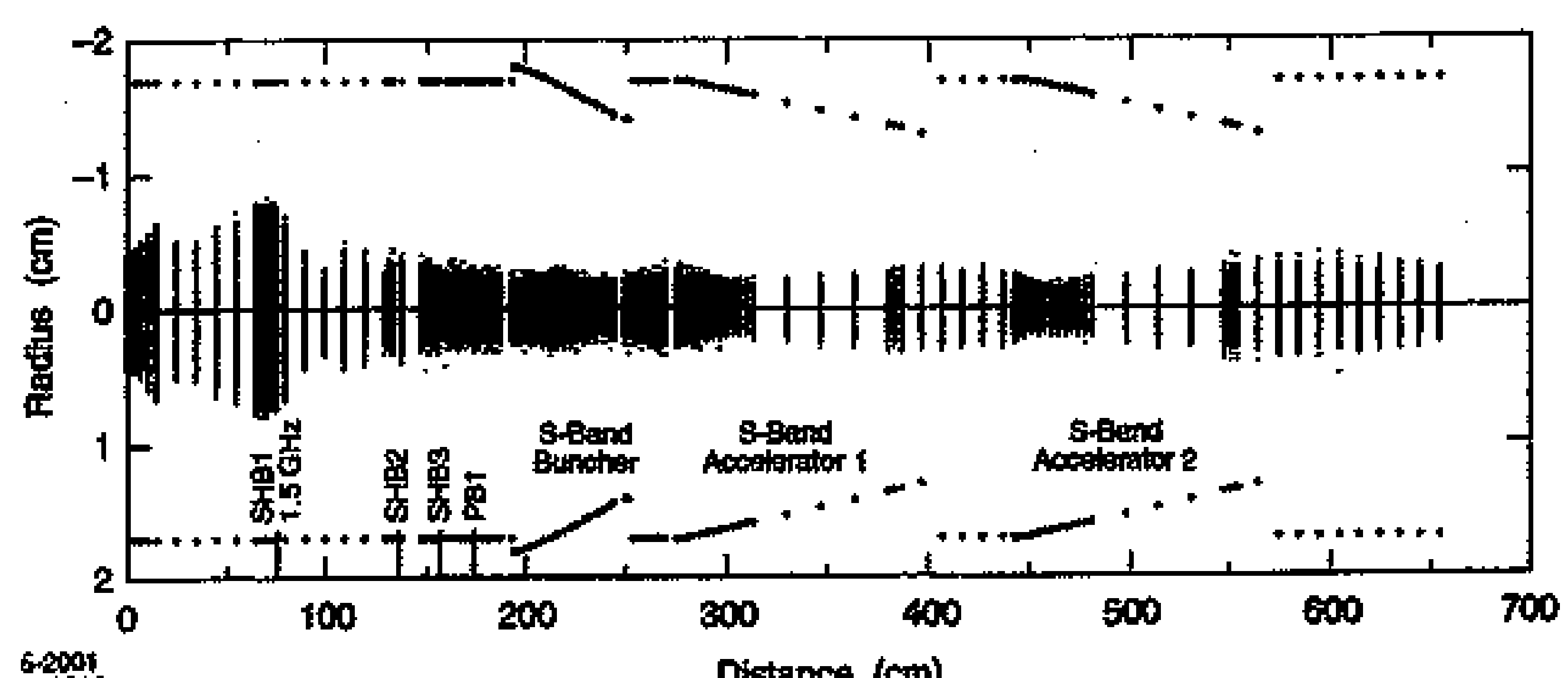
Electron Beam Characteristics as Simulated with PARMELA

Longitudinal Magnetic Field and Emittance, Nominal Phase



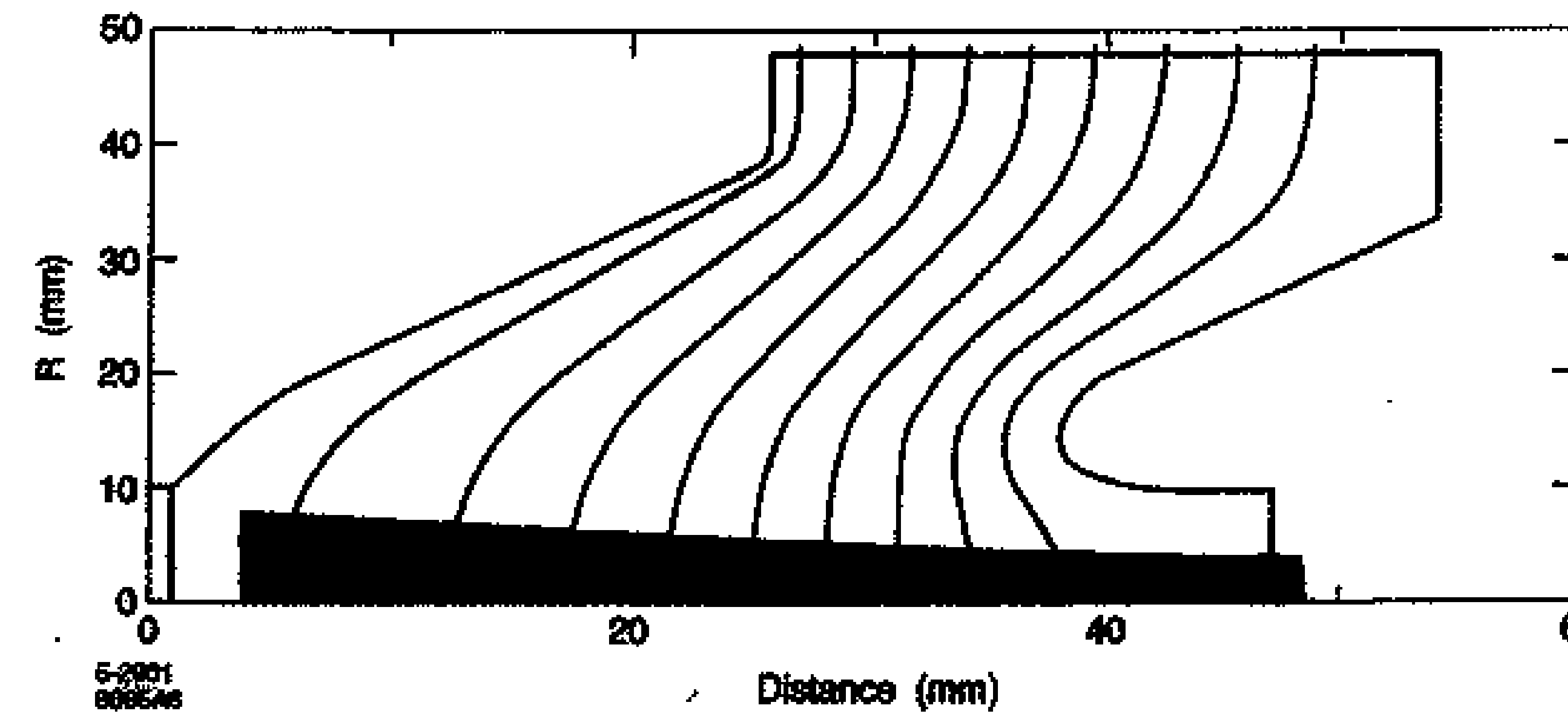
The Beam Envelope, Nominal Stage



Gun Characteristics

Beam simulations in anode cathode region conducted with E-GUN

CTF3 gun ray trace from EGUN. 5 A, 140 kV grid limited mode.



Electron Beam Parameters of the CTF 3 Gun.

Parameters CTF3 gun # 1					
I	5	7	9.3	10.4	Amp
V	140	140	140	150	keV
$\varepsilon_{edge,N}$: incl. thermal and grid effects	26	20	13	14	mm - mrad

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Simulated Electron Beam Characteristics and RF Parameters

Electron Beam Parameters at End of Accelerator 2.

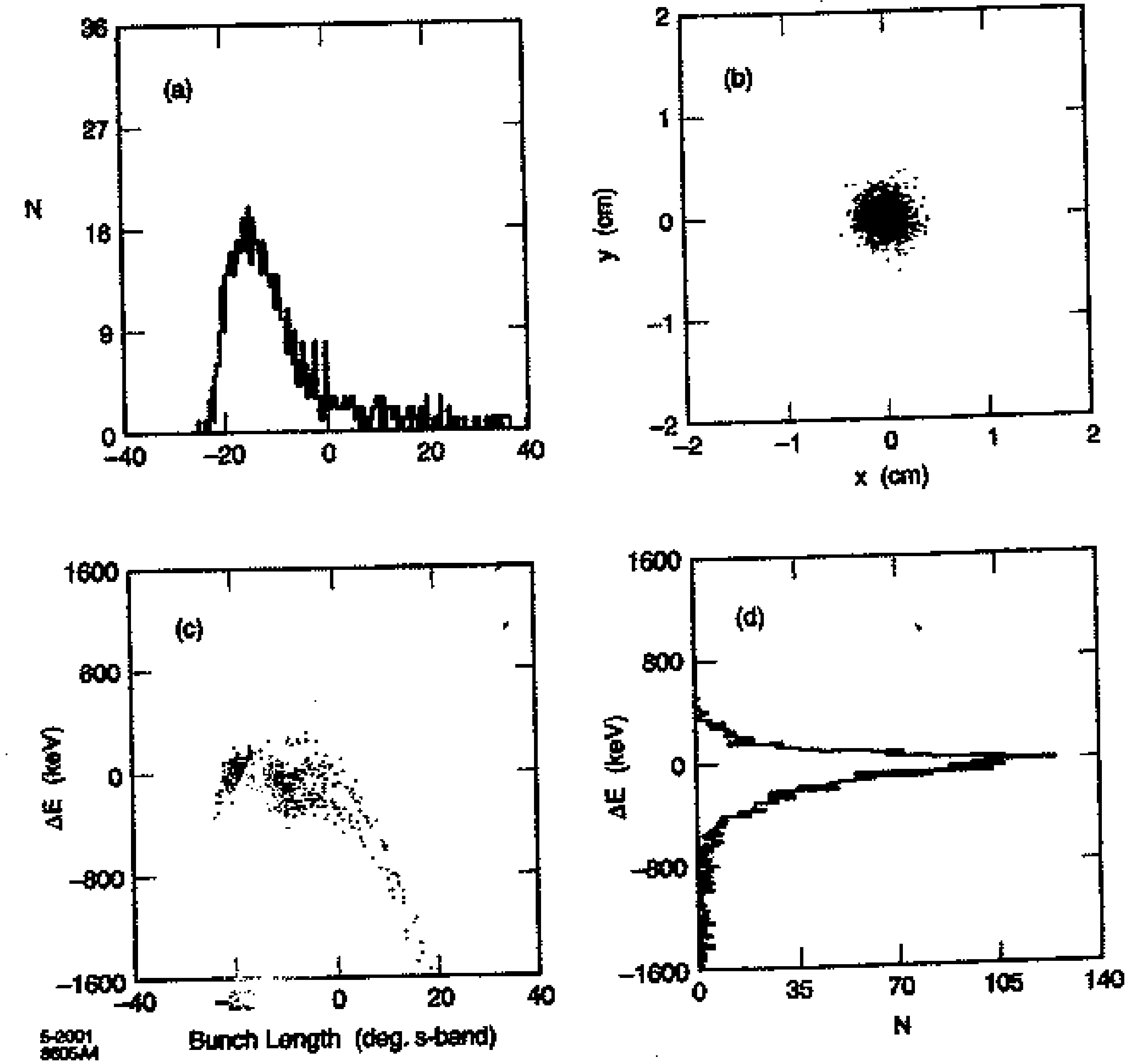
Parameters	Unit	Nominal / Initial Target	Simulation End Acc. 2
Beam Energy	MeV	~20	17.2 / 17.5
Beam Current in 20°	A	3.5	3.5
Charge per bunch in 20°	nC	2.33 / 1.2	2.33 / 1.2
Allowed charge in Satellite	%	<7 / -	8 / -
Bunch Length (FWHM)	ps	< 12	12
Emmittance, N, rms	mm-mrad	< 100	35 / 50
Energy spread (single bnch, fwhm)	MeV	< 0.5	0.5 / 0.3

Buncher s and Accelerator s Parameters

RF Structure Parameters	Unit	Nominal / Initial
RF Fundamental Frequency	GHz	2.99855
SHB Frequency (Nominal phase)	GHz	1.5
SHB Gap voltage no. 1, 2, 3 (Nominal phase)	KV	20, 20, 20
PB Gap voltage (Nominal phase)	KV	52
PB Gap voltage no. 1 and 2 (Initial phase)	KV	14, 30
17 Cell Buncher gradient (w/ Beam Loading)	MV/m	8.4 to 10.8
RF Peak Power into TPV Buncher	MW	35
Accelerator Gradient Cell 1, 27, 34 (w/ BL)	MV/m	11.4, 0.5, -6.8
RF Peak Power into accelerator	MW	35

Electron Beam Characteristics as Simulated with PARMELA

Single Bunch Parameters



Conclusion

The CTF3 preinjector beam line including from the gun to the end of the second accelerator section has been designed for both the Nominal and the Initial phase operation

All bunching and accelerating Gradients have been Defined.

All solenoid strengths and shapes have been defined.

All diagnostics for tuning and characterizing the beam have been defined

The gun is already transferred to CERN from SLAC. The HV and electronics system is being designed at LAL

The traveling wave buncher and accelerator sections exist or are in manufacturing stage.

The prebuncher and the subharmonic bunchers detailed design is under way at CERN and LAL

The solenoids are at the drawing stage at CERN and soon will go out for manufacturing bids.

The detailed design of the diagnostics is under way at CERN

It remains to define the vacuum pumping and monitoring points on the beam line

It remains To design the steering magnets once all the other details are sufficiently defined and drawn on the beam line drawing.

It remains to include the actual SHB and PB electric fields once these are designed. (Currently we use sign waves, and this is not a bad approximation so we expect no surprises

I want to thank the many people at CERN, LAL, and SLAC who have contributed to this work.

CTF3 Solenoid Strengths and Parameters per Power Supply Excluding Voltage loss in the power cables

Name	type	Nturn	R (mΩ)	I* (A)	Imax** (A)
Bucking coil	NLCTA	169	350	8	20
Gun Lens***	NLCTA	320	1360	9	10
S1	Tesla Eng.	64	39	95	200
S2	Tesla Eng.	64	39	70	200
S3	Tesla Eng.	64	39	70	200
S4	Tesla Eng.	64	39	70	200
S5	Tesla Eng.	64	39	187	200
S6	Tesla Eng.	64	39	187	200
S7	CERN	72	48.4	195	200
S8	CERN	72	48.4	195	200
S9-11	CERN	72	145.2	263	200
S12-14	CERN	72	145.2	173	200
S15-18	CERN	108/72	242.2	657	700
S15-18	CERN	72	242.0	611	700

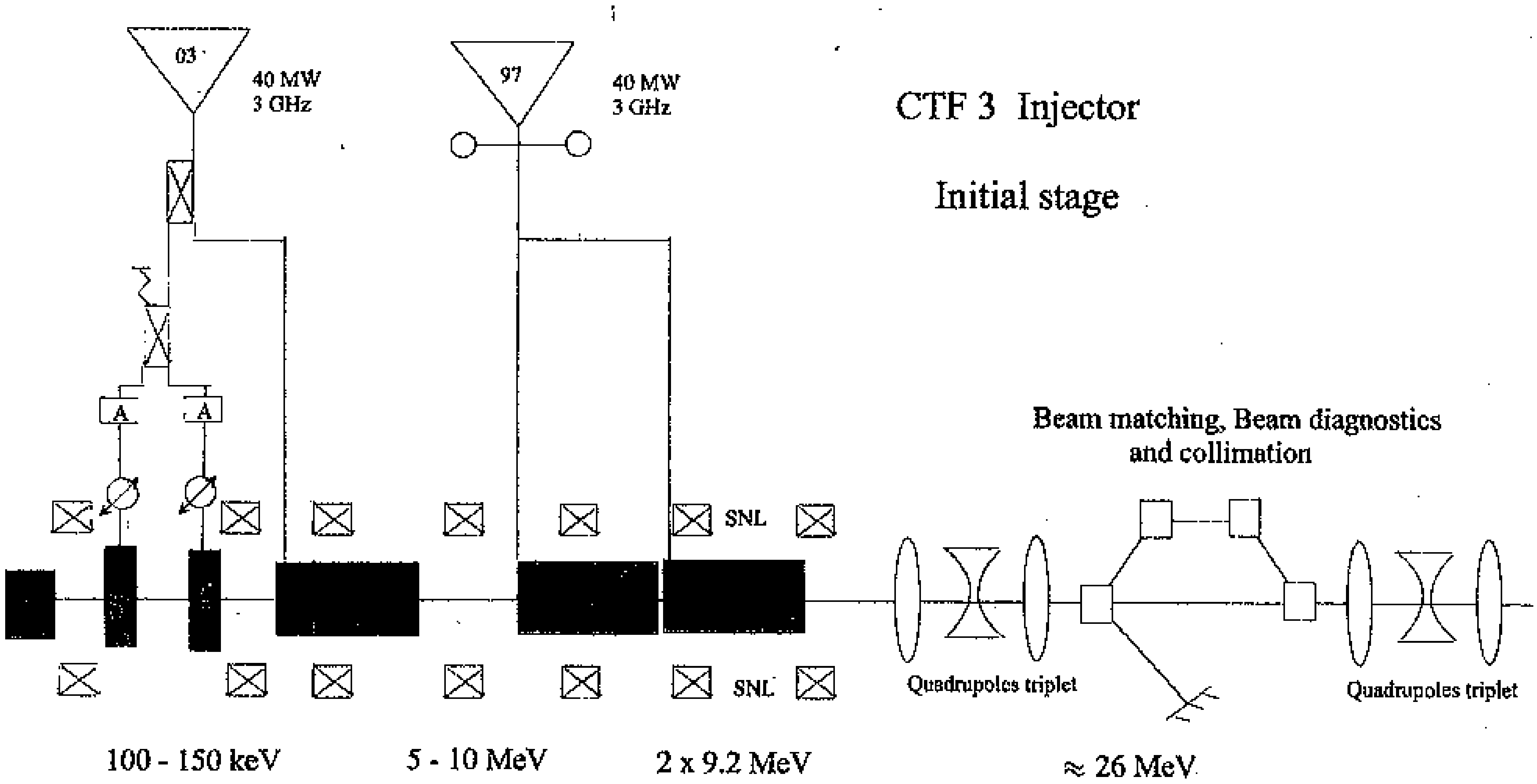
Note:
*** I is the expected current needed in the solenoid from the simulations**
**** Imax is current I would like to have available for added margin taking into account coil limit (as in lens) or power supply limit as in S7 and S8**
***** the data is for NLCTA lens. If possible I would like to add 30% more turns to this lens by adding 3 more layers in the vertical direction.**
****** Power lost in the cable s from PS to coil are not included. Power should be kept to a minimum length specially for the high current case.**

- Gun Electronics
- High Voltage System
- Pre-bunching Cavities

M. Bernard, G. Bienvenu, B. Jacquemard, B. Mouton,
M. Omeich, R. Roux,

CTF3 GUN specification

	UNIT	OLD	NEW
Voltage stability	%	0.1	1
Current	A	9	6
Current flat-top	%	0.1	1 -> 0.1
HV	kV	140	140
HV (processing)	kV	160	160



f_{RF} = 2.99855 GHz for all RF structures

PB1, PB2 = Pre-bunchers

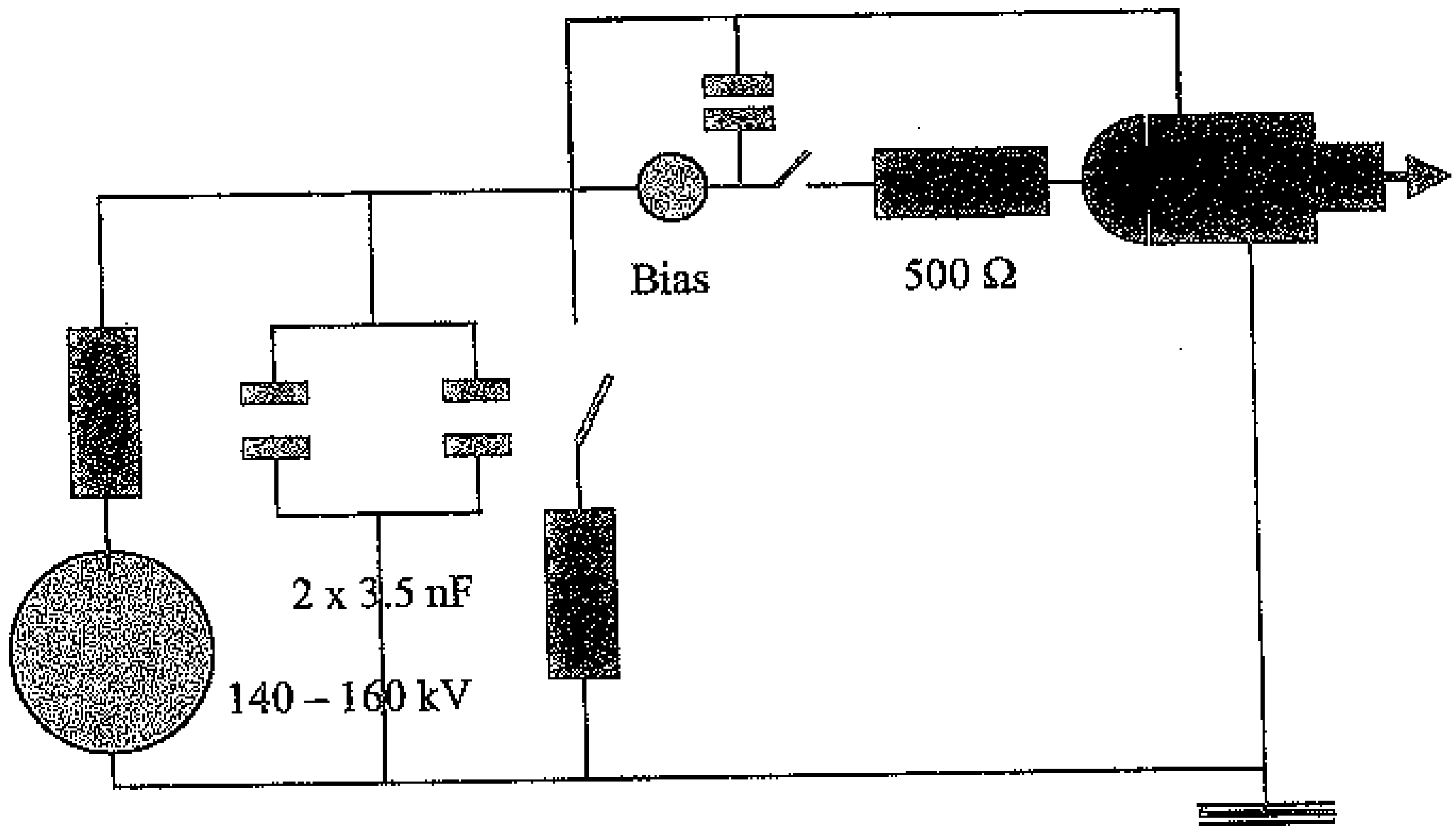
B1 = Bunching system (TW structure)

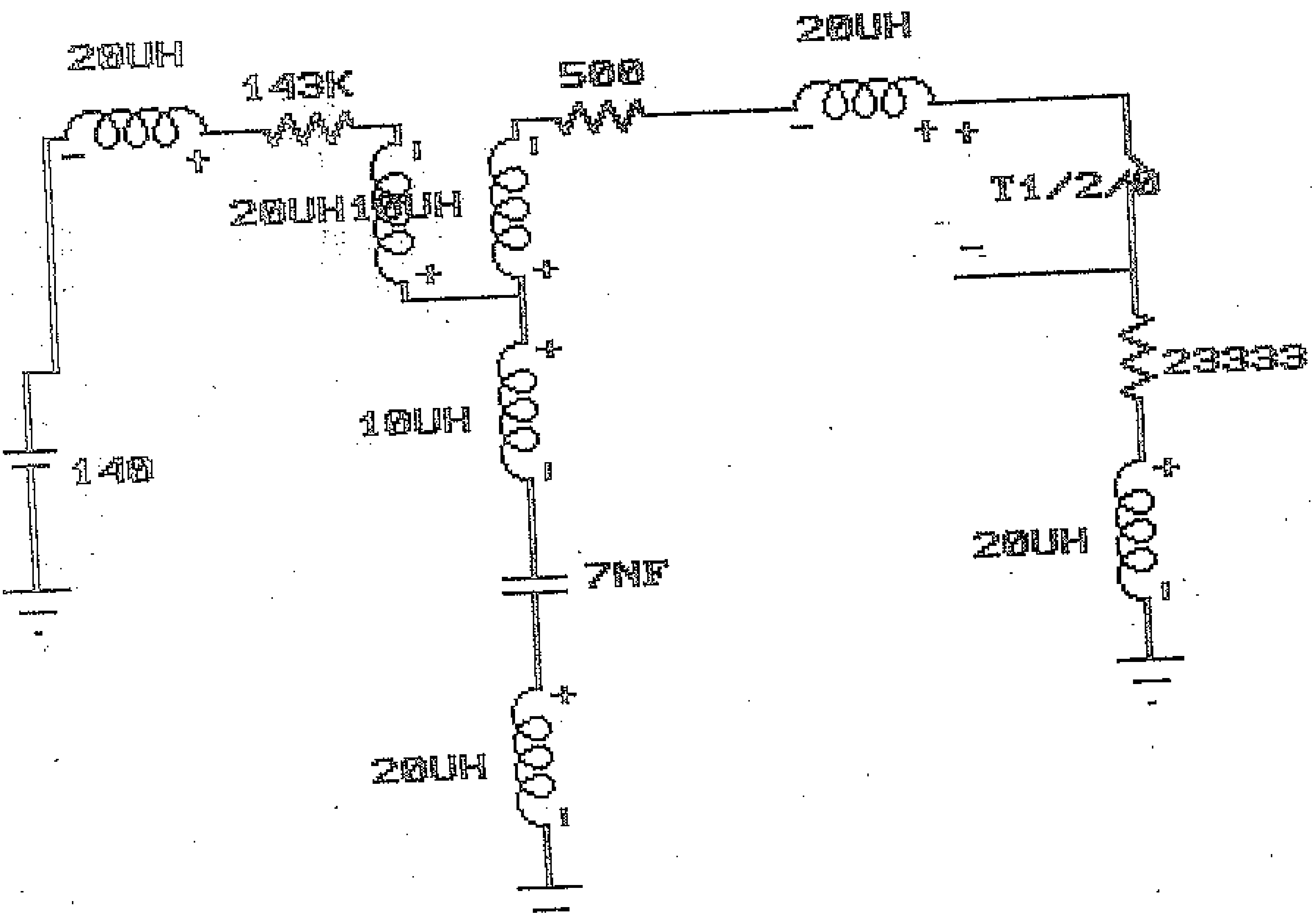
S1, S2 = Accelerating system (TW, 1.3 m , 9.2 MV/m)

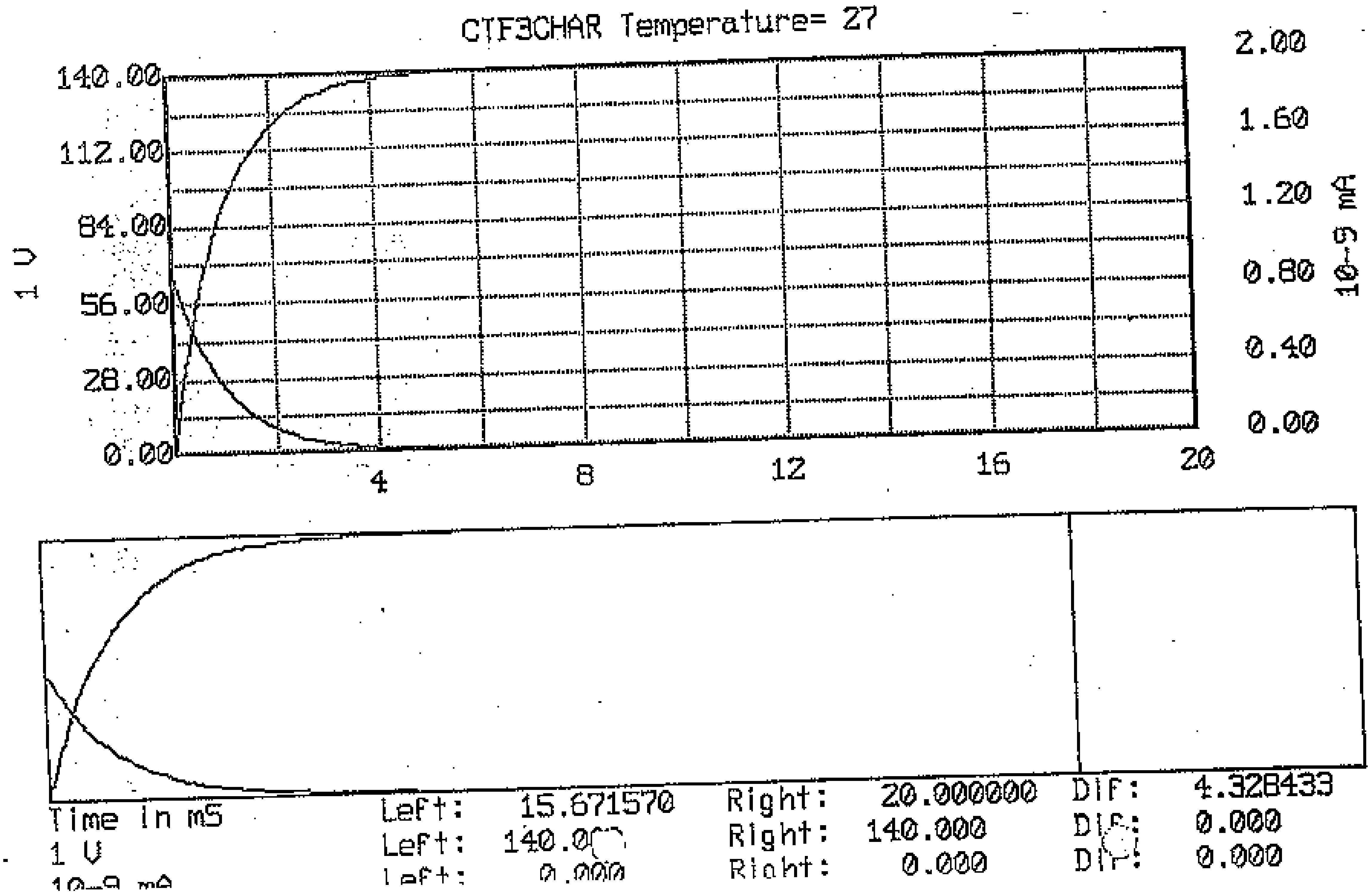
SNL = Solenoids

March 2000

Schematic layout of CTF3 gun







Short-circuit protection

With the new parameters:

I = 6 A => Q ~ 10 μC   ΔV/V = 1% => C = Q/ΔV = 7nF

Stored energy = 70 J

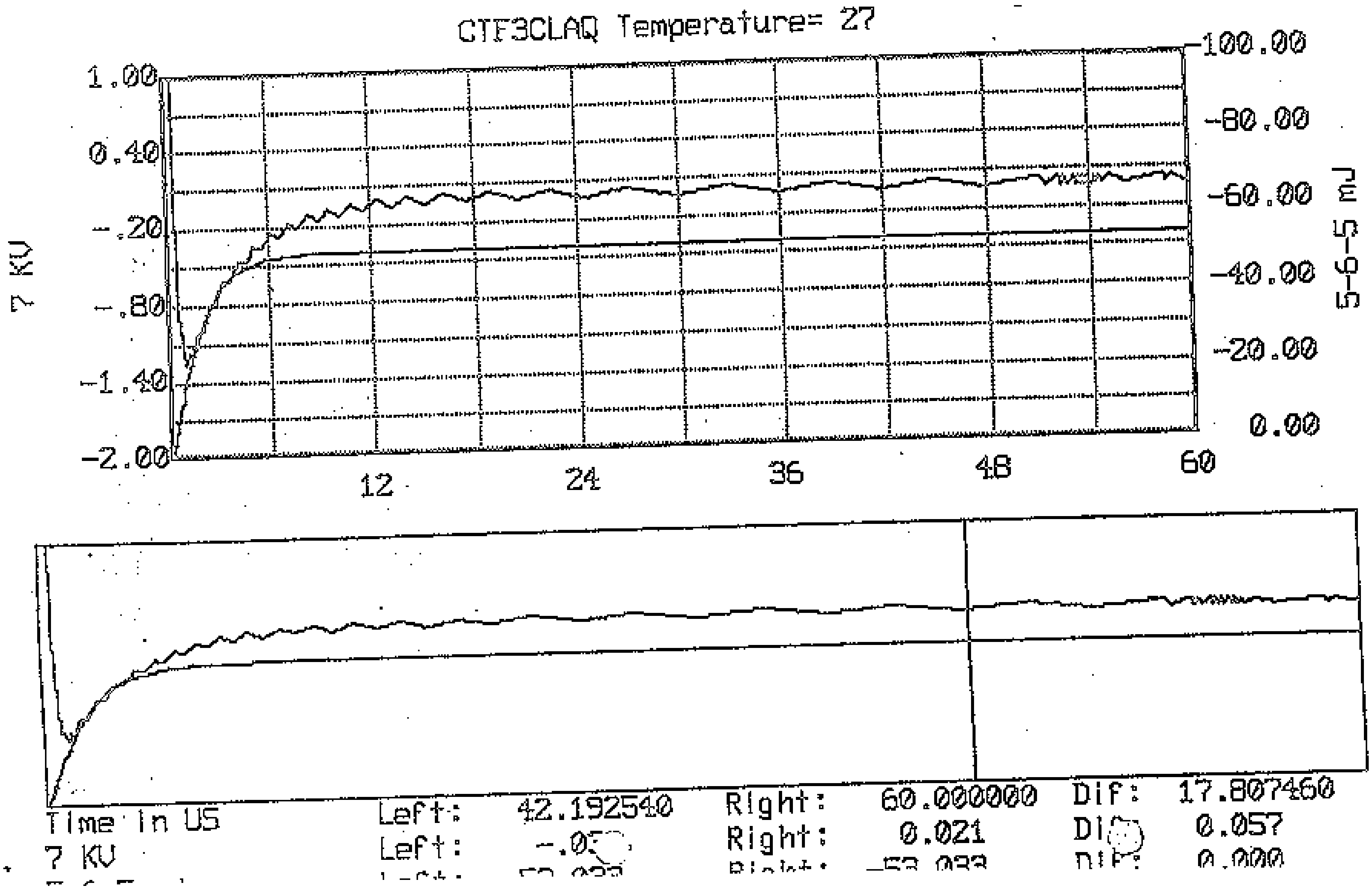
Hypothesis:

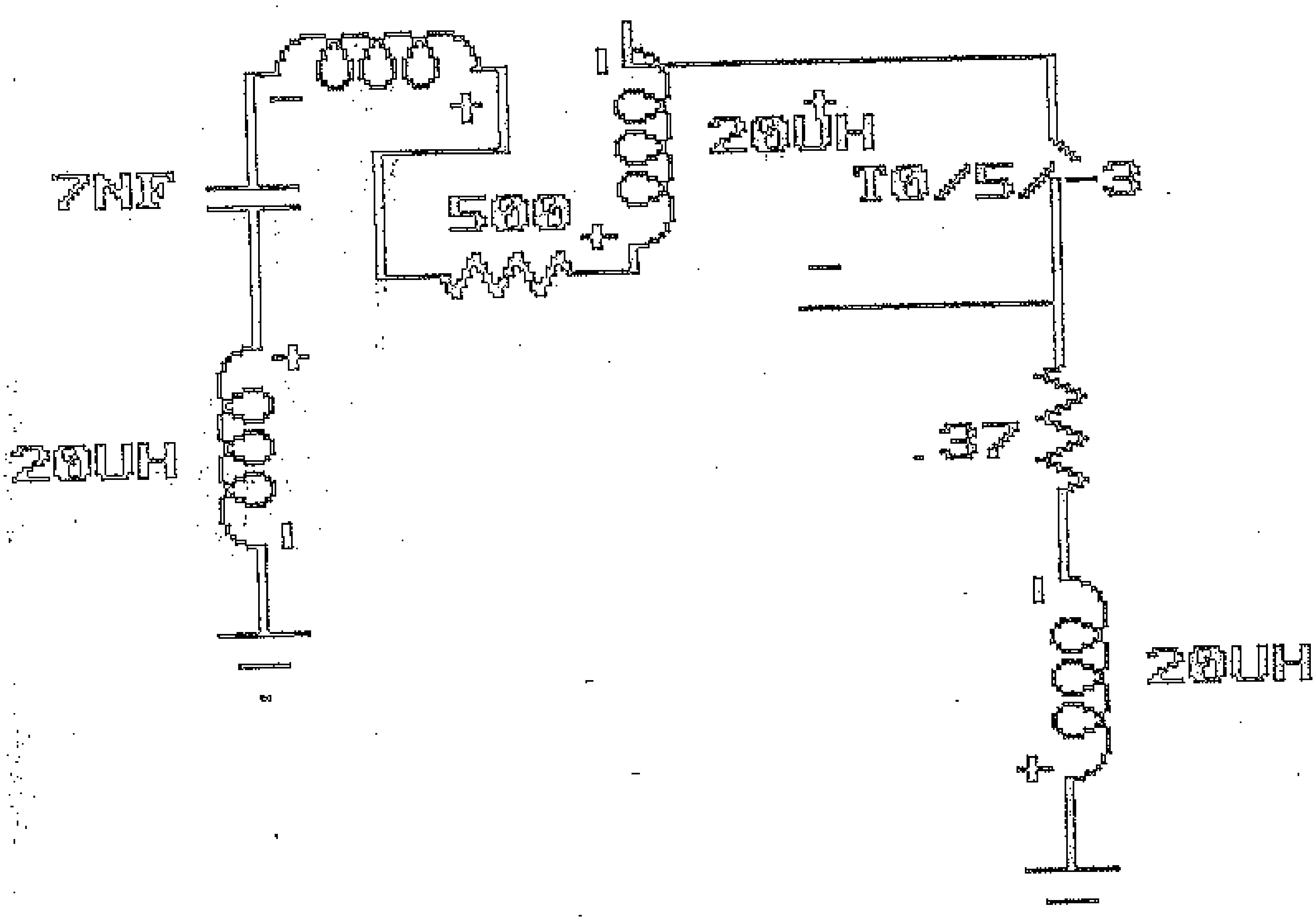
Vacuum 1×10^{-9} Torr, Arc potential 50-100 V

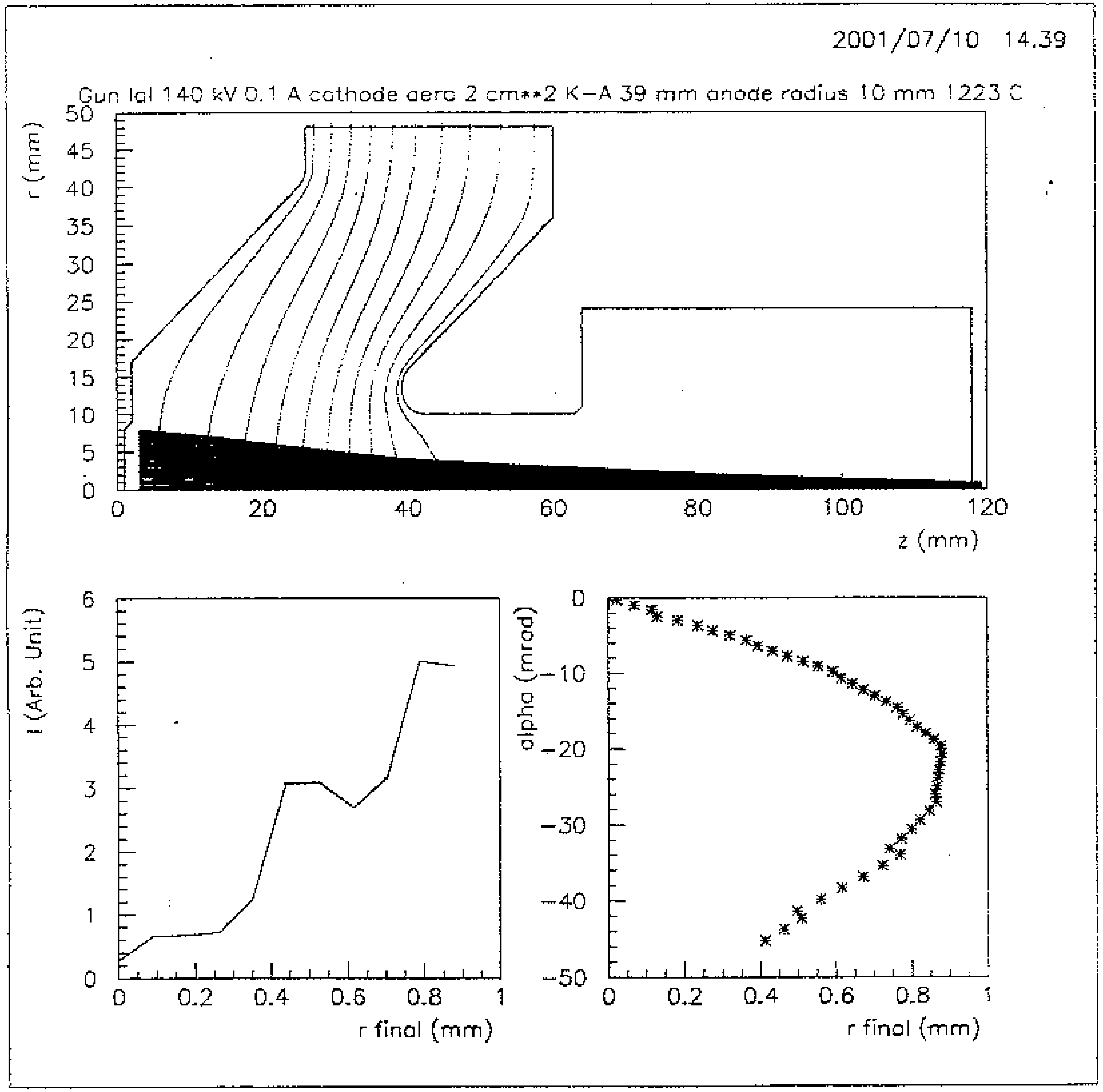
With a 500 Ω resistor

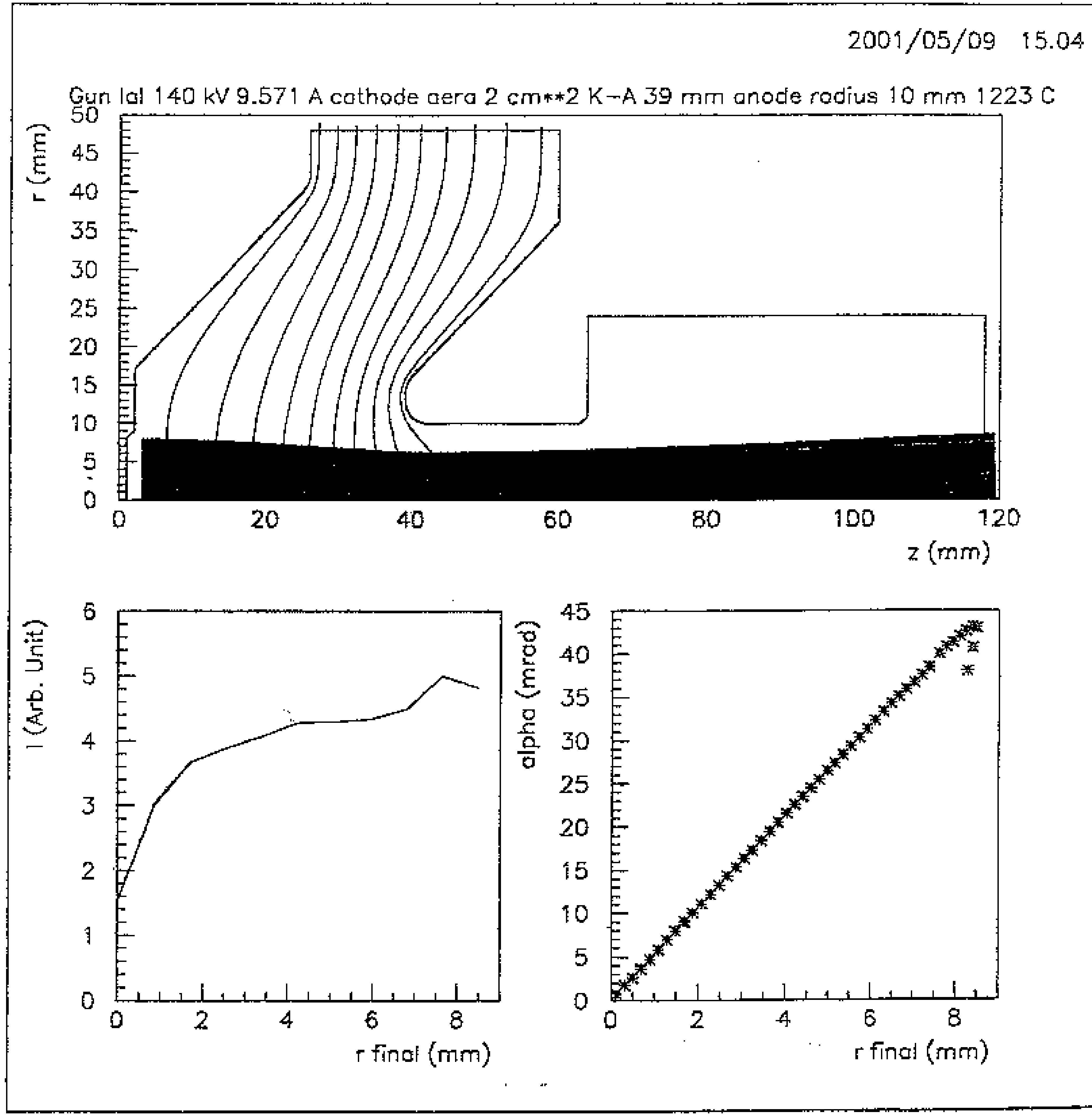
I peak = 280 A   (100 A for CLIO)

$W_{Gun} < 0.1$ J


CTF3CLAQ Temperature= 27
7 KV
5-6-5 mJ
1.00
0.40
-.20
-.80
-1.40
-2.00
-100.00
-80.00
-60.00
-40.00
-20.00
0.00
12
24
36
48
60
Time in US
Left: 42.192540
Right: 60.000000
Dif: 17.807460
7 KV
Right: 0.021
0.057

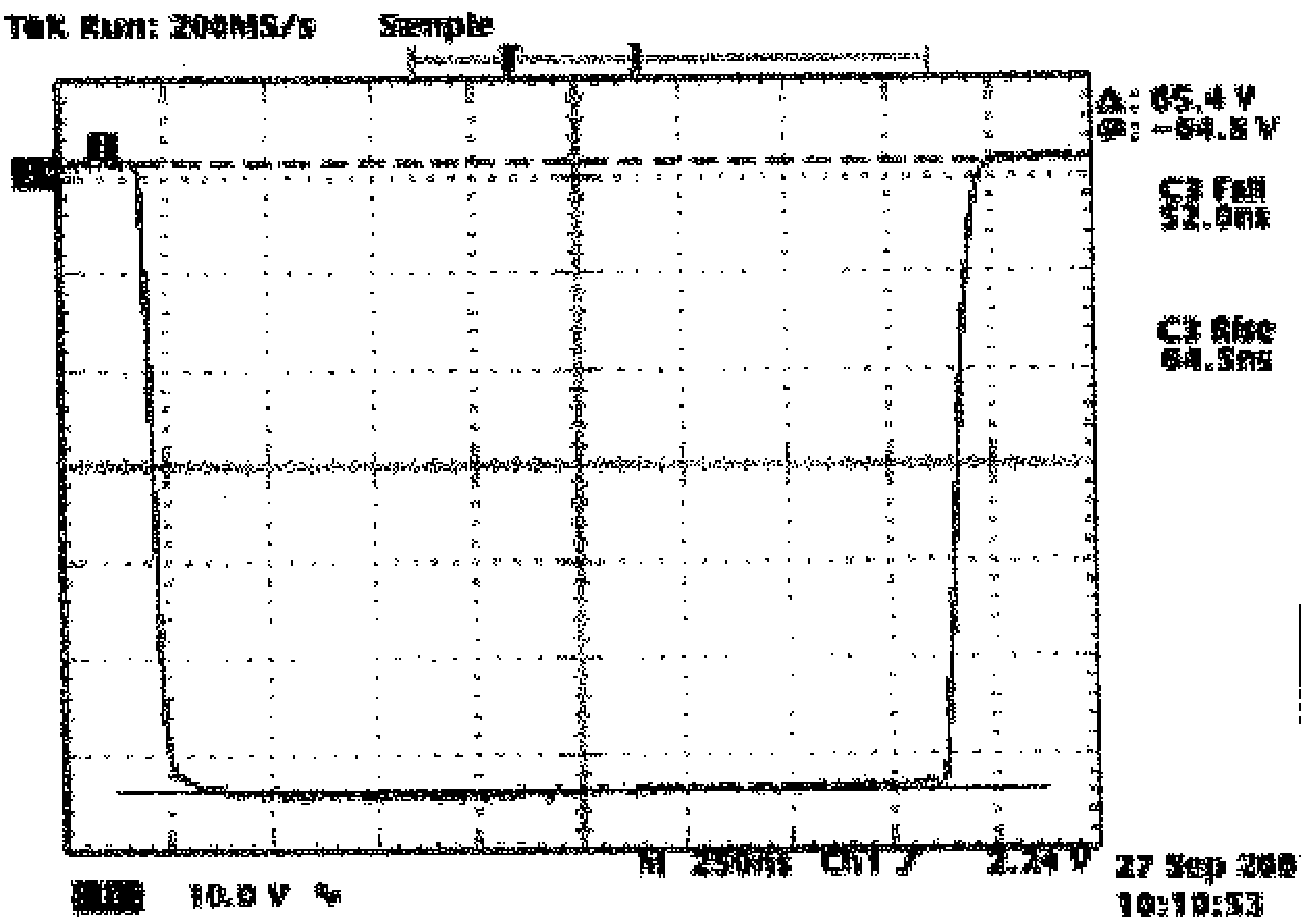

7NF
20UH
500
20UH
T6/5
3
.37
20UH

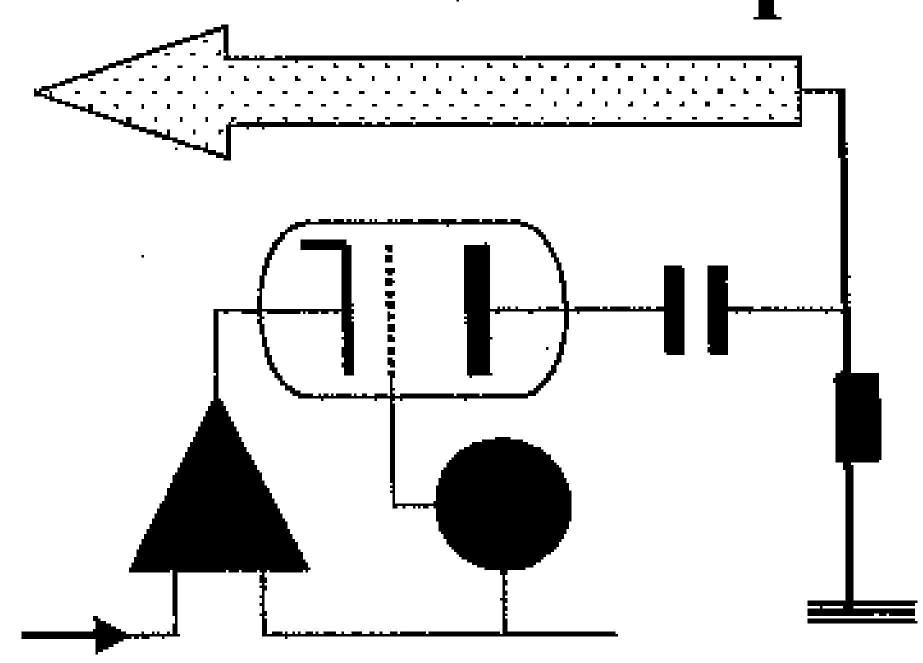

2001/07/10 14.39
Gun lal 140 kV 0.1 A cathode aera 2 cm**2 K-A 39 mm anode radius 10 mm 1223 C
r (mm)
z (mm)
I (Arb. Unit)
r final (mm)
alpha (mrad)
r final (mm)


2001/05/09 15.04
Gun lal 140 kV 9.571 A cathode aera 2 cm**2 K-A 39 mm anode radius 10 mm 1223 C
r (mm)
z (mm)
I (Arb. Unit)
r final (mm)
alpha (mrad)
r final (mm)

Preliminary tests

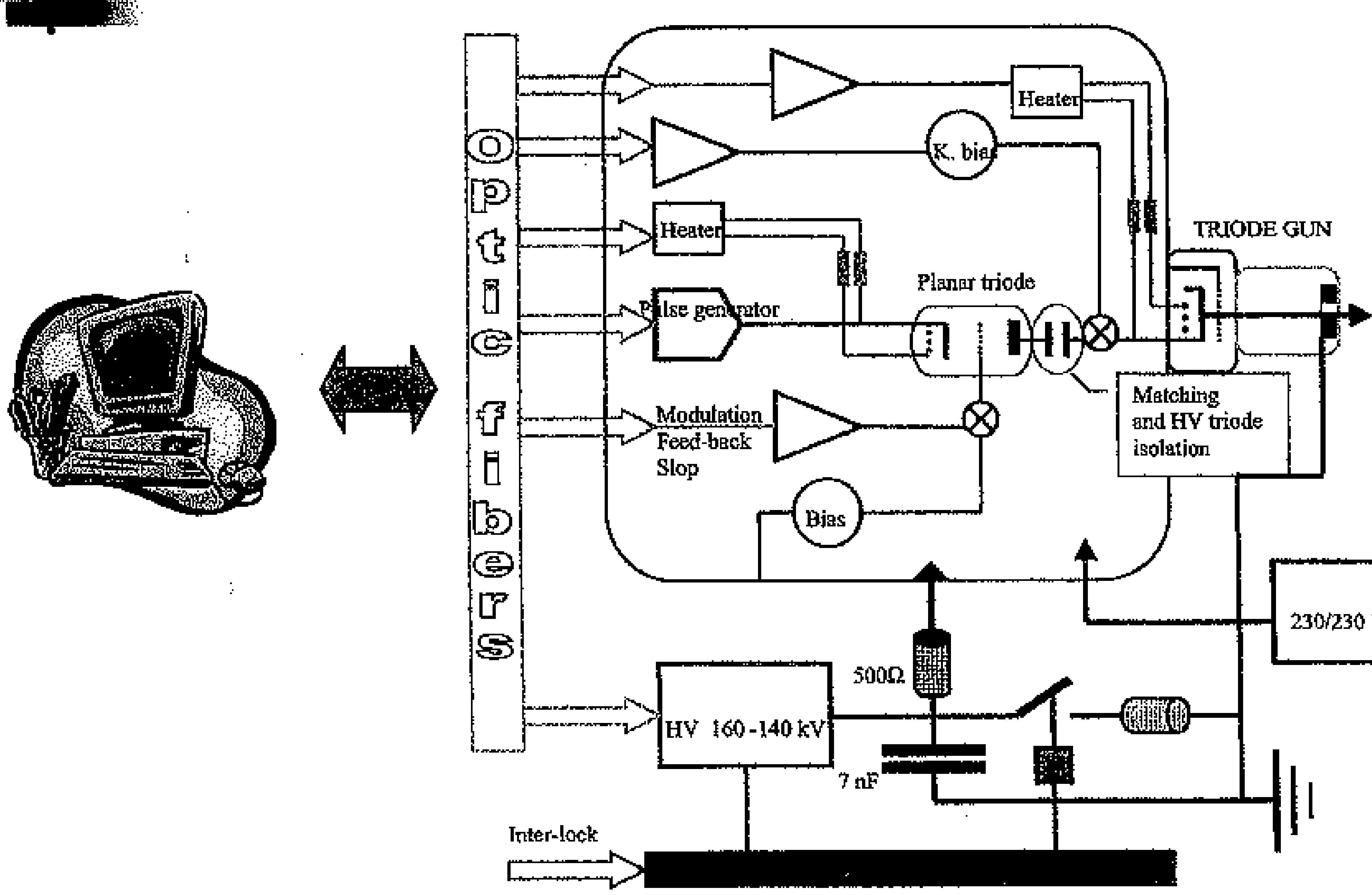
Triode output





R = 70 Ω BW < 20 MHz
C = 2.2μF Probe 1/11
I = 10.3 A

Electronic synoptic



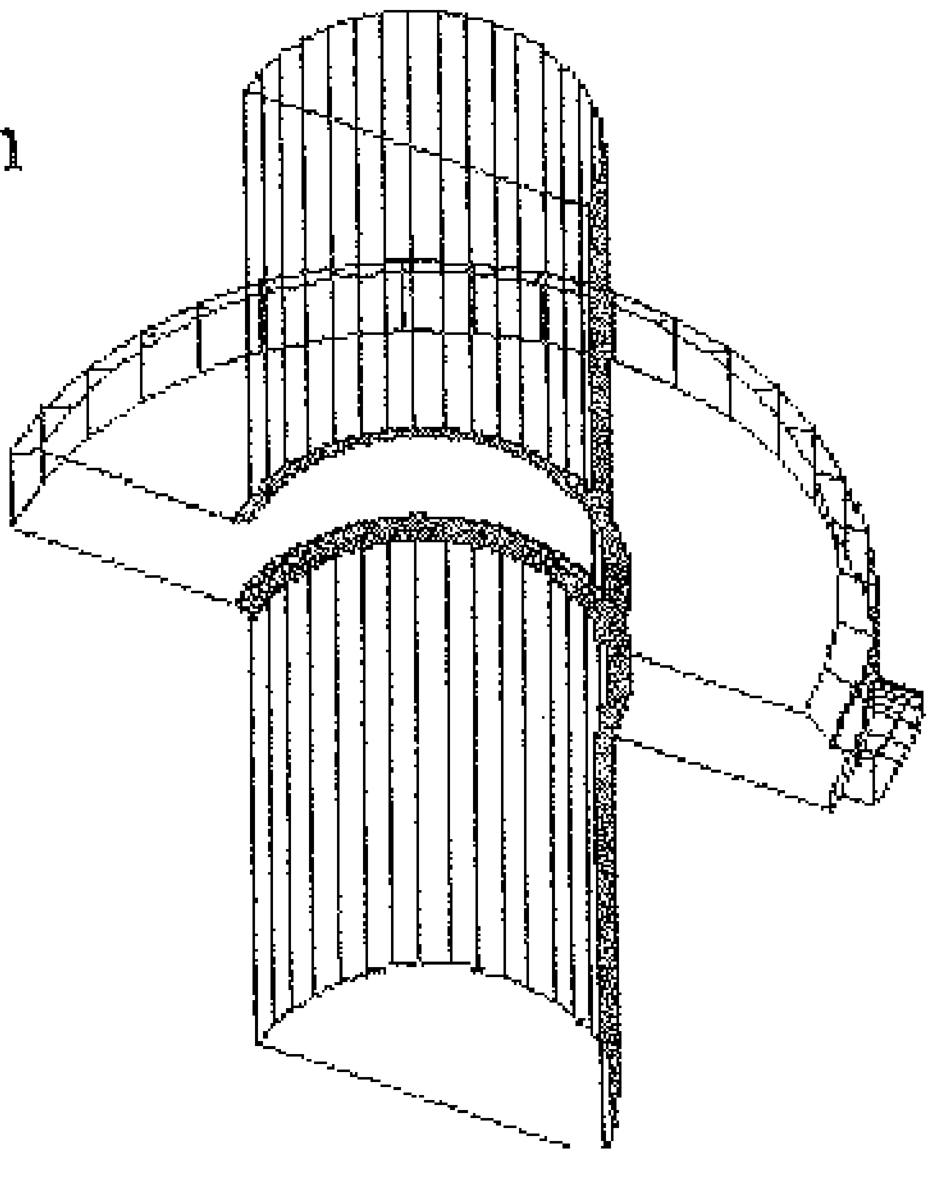
Prebunchers for the CTF3 injector

- First prebuncher : normal simple design

- Second prebuncher : beamloading compensation

First prebuncher

In copper, coupled with a waveguide,
modelised with superfish and HFSS



Cut-off with a large diameter = 34 mm

↓

Long range electric field

↓

Longer cut-off = 90 mm
Transit Time Factor = 0.4 (140 keV)

Q = 10 670 $R_s = 1.02\ M\Omega$

Cavity dimensions : $R_c = 41.6$ mm
$h_c = 18$ mm

For a better magnetic field symmetry, cut-off axis shifted by 0.7 mm

Second prebuncher

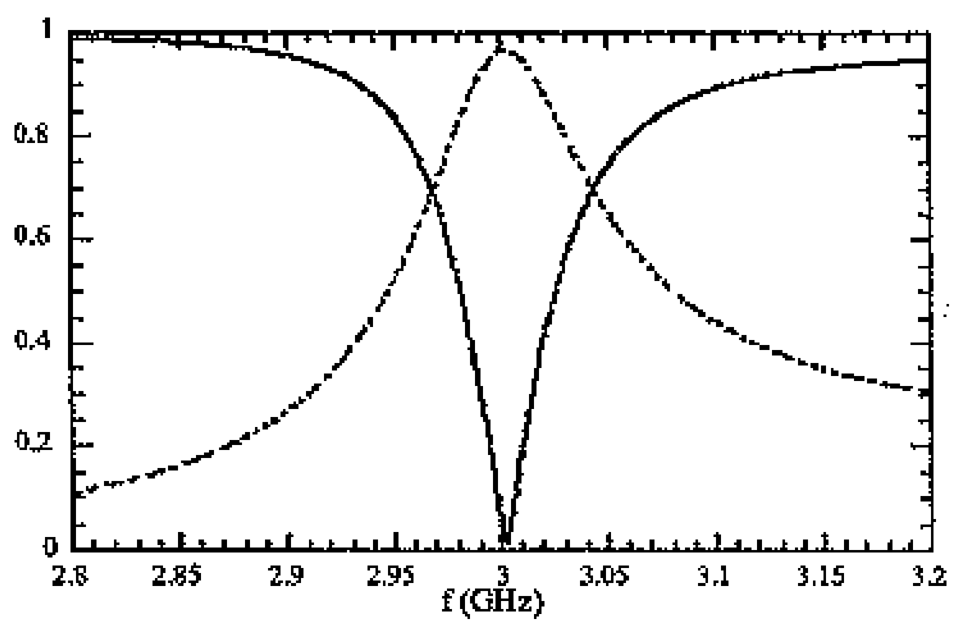
Beamloading $$V_{ind} = \frac{R_s T^2 I_{harm}}{(1+\beta)}$$

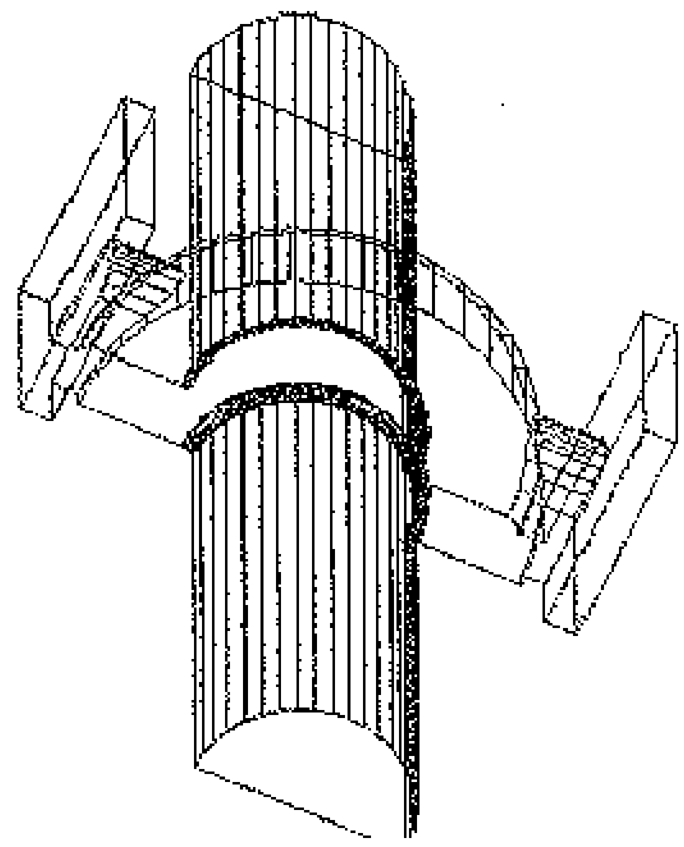
Two cases :

If bunch length is long , FWHM ≈ 8.33 mm

Same as the first but in **stainless steel** ⇒ $V_{ind} = 7.4$ kV

If bunch length shorter ⇒ one needs an external load and overcoupling





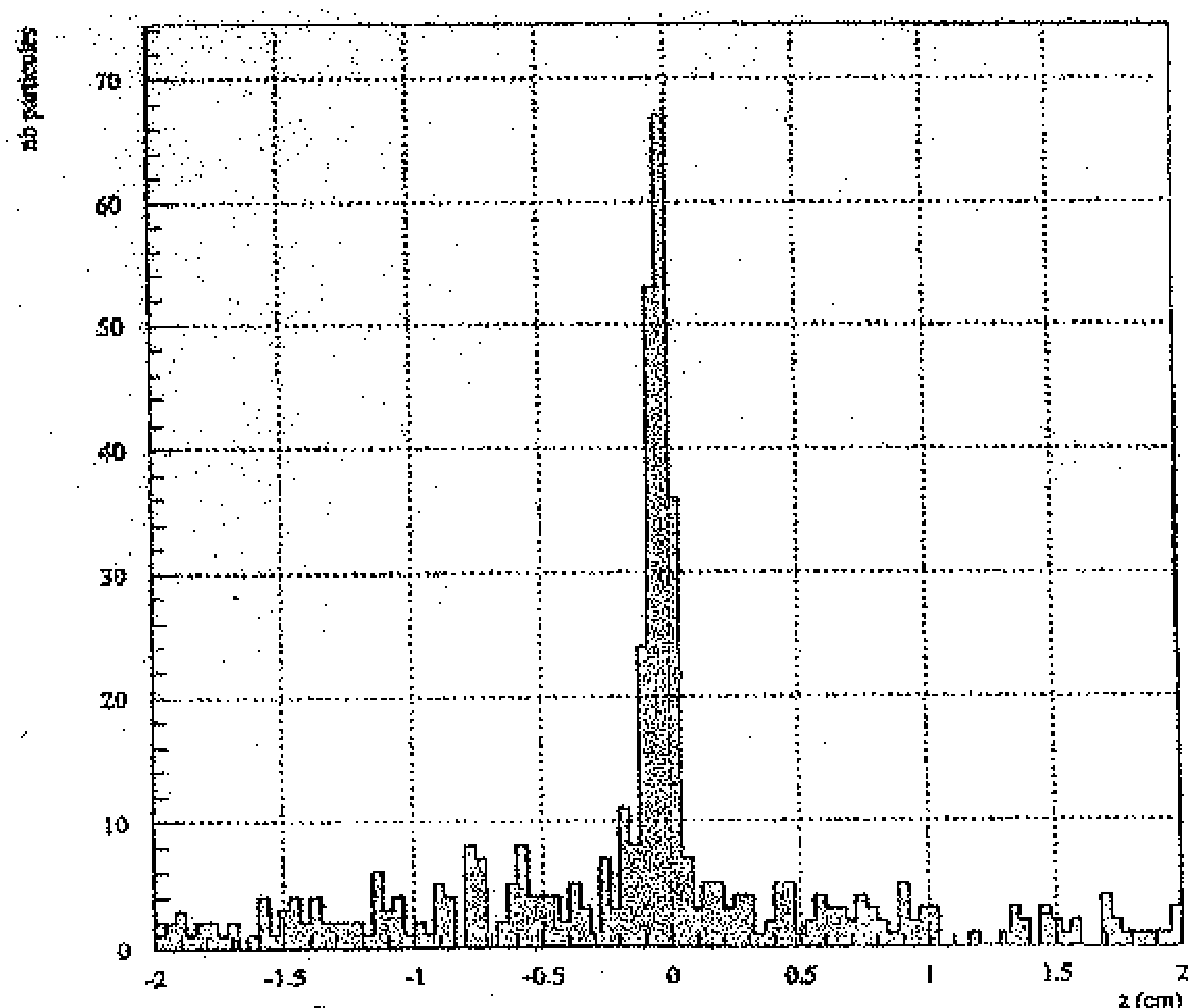
Few simulations with PARMELA

- Very simple calculations, just to see the bunching
- Assuming PB1 is situated where SHB1 will be

V = 60 kV
Using field given by Superfish

E=140 keV

1000 part.
No space charge



Z = 92.3 cm, FWHM = 1.3 mm

Drive Beam Photo-injector Option

for the CTF3 Nominal Phase

G. Suberlucq

- Motivation
- CTF3 Drive Beam Requirements
- CTF3 RF gun design
- The Laser ⇒ (I. Ross / RAL)
- The Photocathode
- Cost estimate
- Possible schedule

Motivation

Expected advantages of the photo-injector option compared to the thermionic source :

- The laser time structure can be easily manipulated to produce the best shape ⇒ flexibility for studies and for minimizing transient beam-loading in the CLIC main beam
- "Empty" buckets really empty ⇒ reduce losses and the radiation level
- Smaller emittances (transversal and longitudinal) ⇒ easier beam transport and bunch length manipulation.
- No low-energy tails at the end of the injector.
- Compactness of injector
- Less expensive

CTF3 Drive Beam Photo-injector Requirements (1)

	Unit	CTF-3
Pulse charge	nC	2.33
Pulse width (FWHH)	ps	10
Peak current	A	240
Number of pulses	-	2310
Distance between pulses	ns	0.667
Charge stability	%	± 0.1
Train duration	μs	1.54
Train charge	μC	5.4
Repetition rate	Hz	5
Mean current	mA	0.026
Minimum QE at λ_{laser}	%	1.5
Minimum lifetime at QE_{min}	h	100
Shots during lifetime	$x\ 10^9$	3.9
Photo cathode produced charge	C	10
Mean Laser power at the cathode	W	0.008
Photo-injector Reliability	%	≥ 95

CTF3 Drive Beam Photo-injector Requirements (2)

BUT

To be taken into account the photo-injector MUST also demonstrate the feasibility for CLIC

- On paper for the laser and with the today technology
  ⇒ This has been done : see CLIC Note 462

- As close as possible of the CLIC working point for the photocathode
  ⇒ This has been done : see CTF3 Note 020

⇓

The photo-injector should be an option for CTF3 and CLIC

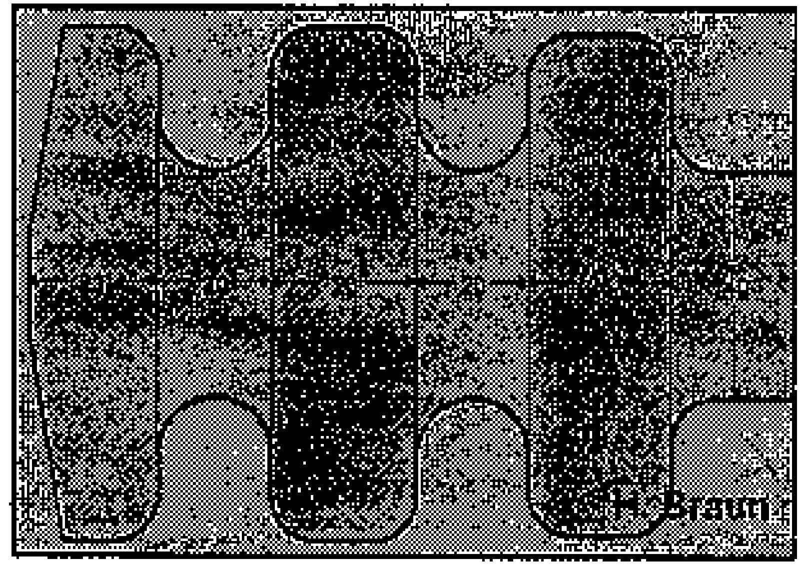
⇓

see CLIC Note 487

CTF3 RF gun design

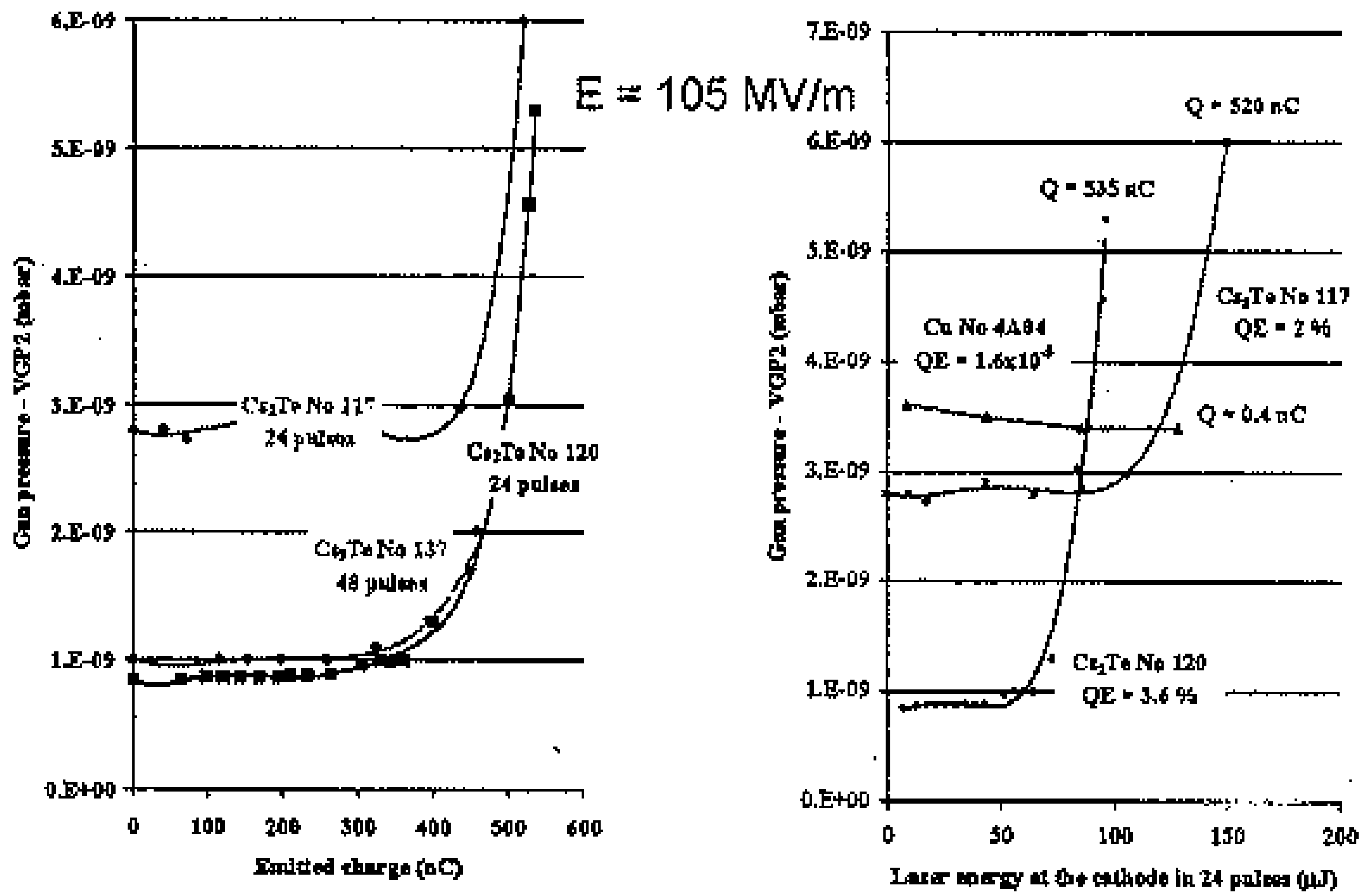
The design for the RF gun is based on the existing CTF 2 drive beam gun

RF frequency	2.99855 GHz
RF power	30 MW
Beam energy	5.6 MeV
Beam current	3.5 A
Peak field on cathode	85 MV/m
Unloaded Q	13000
Coupling factor β	2.9
Delay beam /RF	400 ns



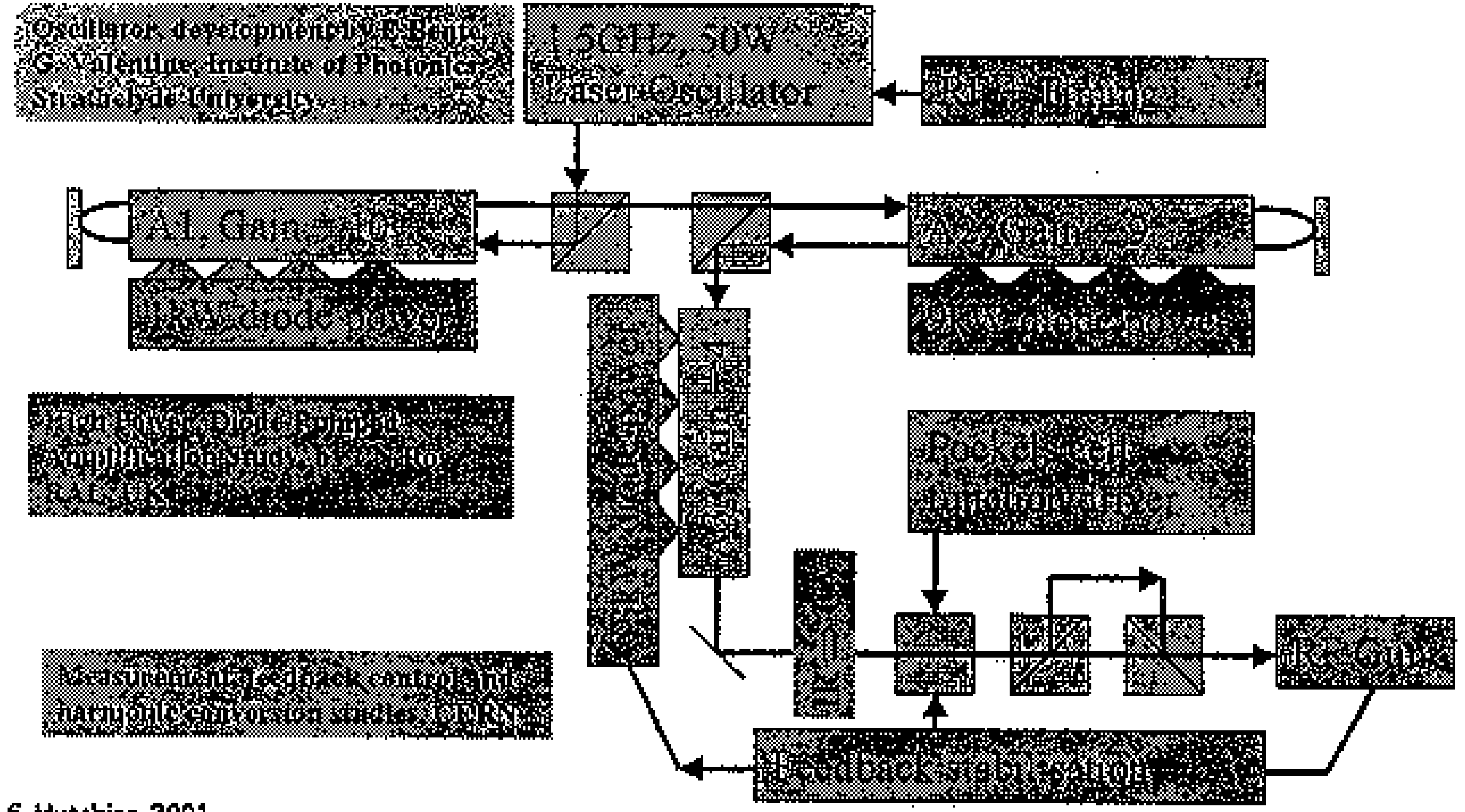
Special attention should be paid to the vacuum pumping speed

CTF-2 Drive Beam : RF Gun Desorption ?



The CTF3 Photo-injector Laser System   I. Ross, RAL

Collaboration RAL, Strathclyde University and CERN



S.Hutchins 2001

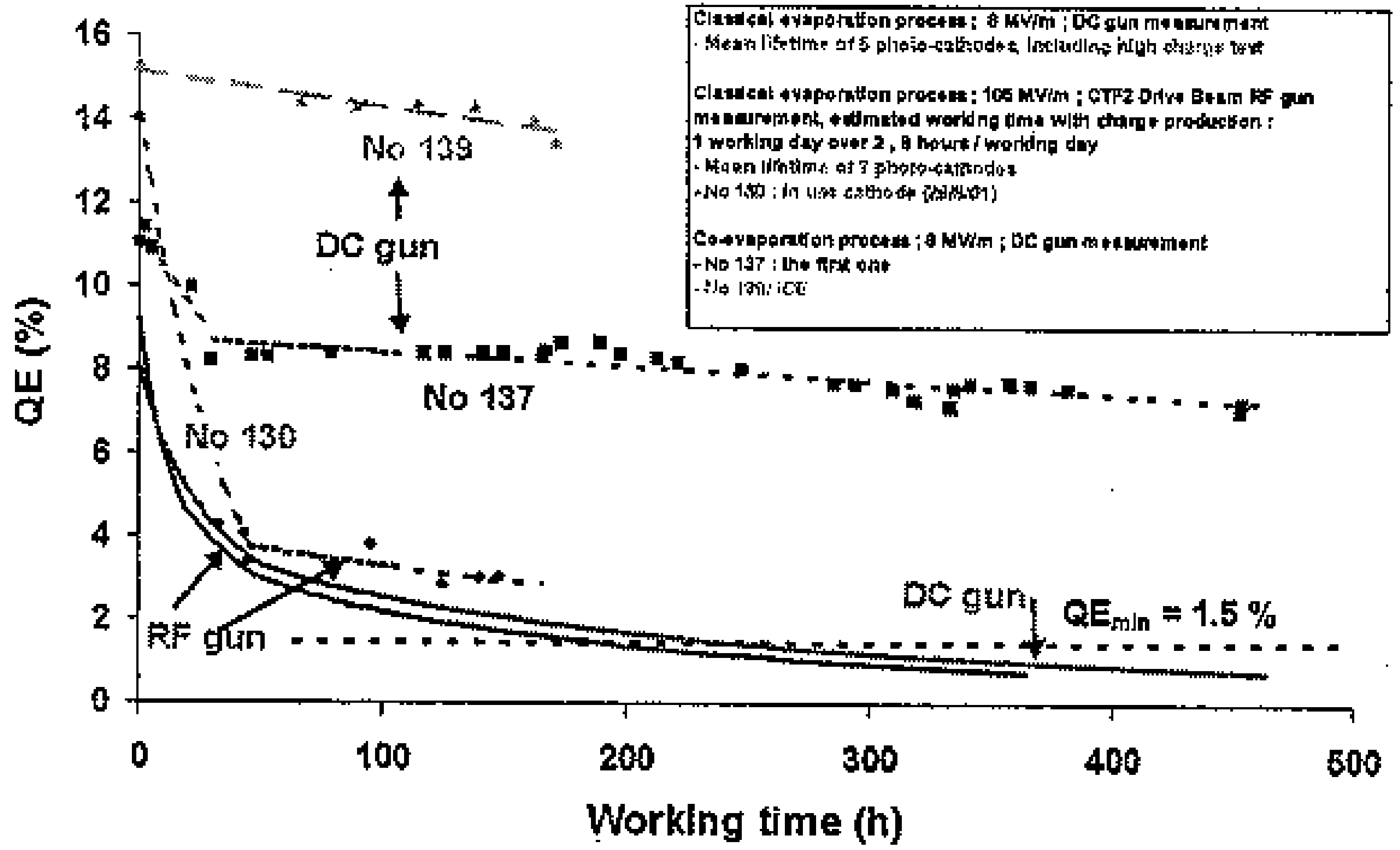
Cs_2Te Photocathode properties

Performances obtained at CTF or during the High Q test :

- Working wavelength < 270 nm
- Maximum electric field : at least 125 MV/m
- Fast response time : < few ps (measurement limited by instrumentation)
- Low dark current : similar to copper
- High peak current : up to 10 kA
- Macro-pulse charge : 750 nC in 48 pulses, spacing 333 ps
- High mean current : at least 1 mA - 1μC at 1 kHz - (limited by laser power and HV power supply)
- Mean current density : 21 mA/cm²
- Resistance to laser damage: at least 6 W/cm² @ 262 nm

- Lifetime : QE > 1.5 % during 460 h @ 750 μA, 1.4×10^{-9} mbar at 8 MV/m in the DC gun

Cs_2Te Photocathode lifetime



Laser Parameter List (preliminary)

MO + PA	Wavelength	1047 nm (Nd :YLF)	
	Pulse width (FWHH)	≤ 10 ps	
	Pulse train duration	> 100 μs	
	Repetition rate	5 Hz (100 Hz)	
	Timing jitter	± 1 ps	
MO	Frequency	375 – 750 – 1500 MHz	
	Output energy / pulse	133 – 66 – 33 nJ	
	Output power in the pulse train	50 W	
Power Amplifier	Distance between pulses	0.667 ns	
	Amplitude stability	± 0.1 % (with feedback)	
	Wavelength on the photocathode	262 nm	
	Total efficiency from IR_{out} to $UV_{cathode}$	3.6 %	
	Included safe margin trans. (operation + material)	50 %	
	Charge / bunch	2.33 nC	
	Photocathode QE	1.5 %	4.5 %
	UV energy at the cathode / pulse	0.75 μJ	0.25 μJ
	Output IR energy / pulse	21 μJ	7 μJ
	Output IR energy / train	3.15 J	1.05 J
	Pulse train mean power	31.5 kW	10.5 kW
	Extracted output power / optical pumping power	0.66	
	Optical pumping power	47.7 kW	16 kW

Cost estimate

Preliminary cost estimate :

- Material (without infrastructures and spares) : 0.5 - 1 MCHF
  - Laser : 500 kCHF with QE ~ 4.5 %
  - Photocathodes : 20 kCHF
  - RF gun : 100 kCHF
- Exploitation :
  - material (with spares) : 70 kCHF / year
  - manpower : 1 man-year / year

Possible schedule

- **Till the end of 2002 : More tests**
  - Experiments to demonstrate the reliability of the laser as close as possible of the CTF3 conditions (PILOT)
  - Photocathode lifetime at high QE in the CTF2 and RF gun desorption study
- **End of 2002 : final decision on the CTF3 source**

If the photo-injector is selected

- **Spring 2003 :** Main parts will be ordered
- **18 months** will be necessary to build all parts of the photo-injector
- **Mid 2004 :** Laser-room and infrastructures should be ready to start the laser assembly
- **Autumn 2004 :** Laser starting-up - the RF gun will be ready
- **Winter 2004-2005 :** RF gun installation with the RF network - starting-up and commissioning of the photo-injector
- **Spring 2005 : Operational production of electron beam in CTF3**

A LASER SYSTEM FOR THE PHOTO-INJECTOR OPTION FOR CLIC/CTF3

I. Ross

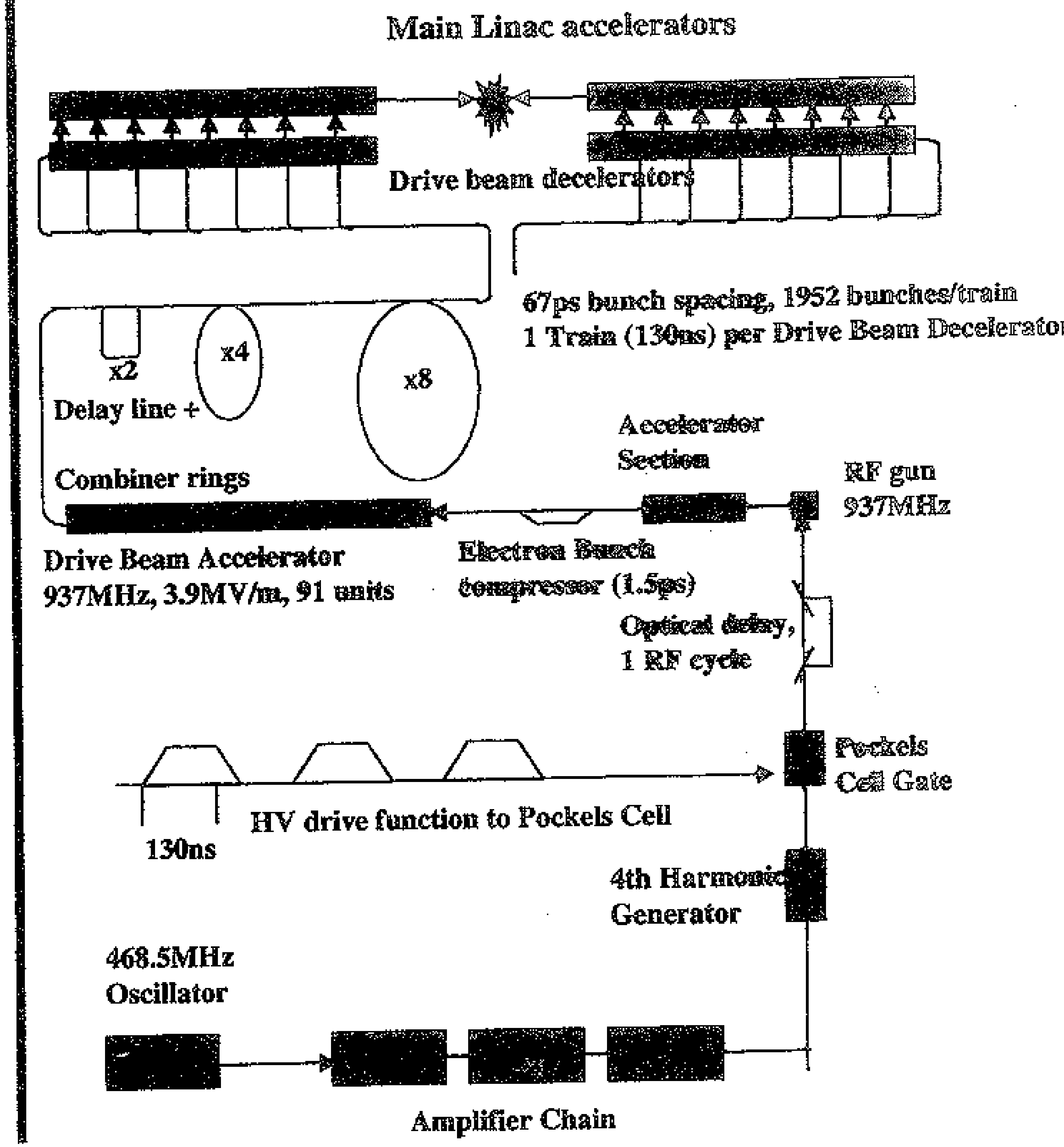
*BACKGROUND

*LASER DESIGN AND DEVELOPMENT PROGRAMME

*RECENT R&D PROGRAMME RESULTS

*'PILOT' TESTS ON CTF2

CLIC DRIVE BEAM PHOTO-INJECTOR



QUESTIONS TO ANSWER

- Is it feasible?
- Is it affordable?
- Where are the uncertainties in the physics/technology?
- What programme will establish confidence and lead to an optimised design?

PHOTO-CATHODE SPECIFICATIONS

	CLIC	CTF3
Quantum efficiency assumed	1.5%	4.5%
UV energy per micropulse	5μJ	0.25μJ
Pulse duration	<10ps	<10ps
Wavelength	<270nm	<270nm
Time between pulses	2.13ns	0.67ns
Pulse train duration	91.6μs	1.5μs
Repetition Rate	100Hz	5Hz
Energy stability (rms)	0.1%	0.1%
Laser/RF synchronisation	<1ps	<1ps
Reliability	10^9 shots between servicing 4 months at 100Hz	

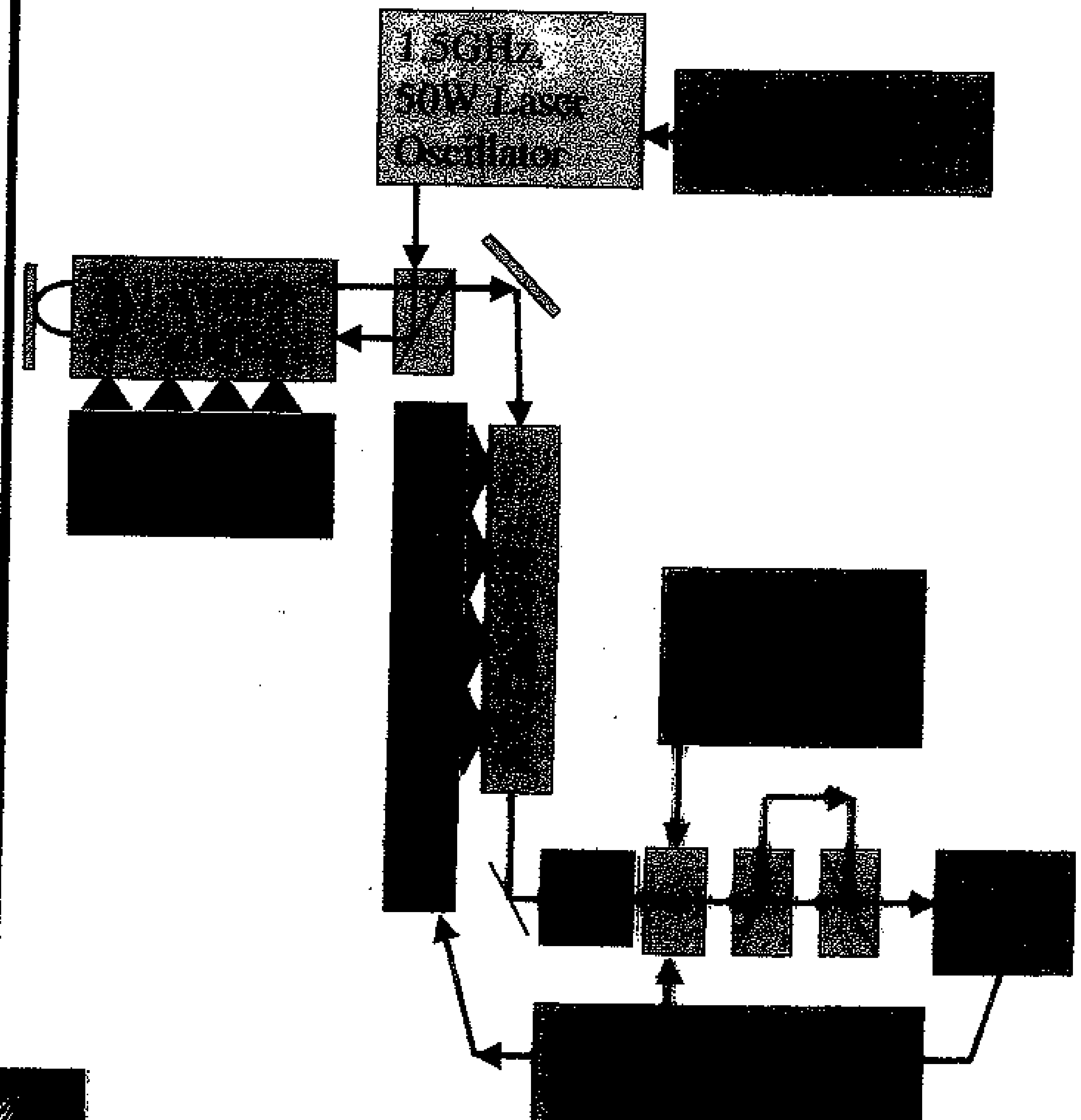
DESIGN STUDY ISSUES

*PHOTO-CATHODE	robust, QE, stable
*DP OSCILLATOR	power, repetition rate
*DP AMPLIFIER	power, efficiency, stability
*HARMONIC GENERATION	efficiency
*FEEDBACK	0.1%?
*SYNCHRONISATION	1ps

CLRC

THE CTF3 PHOTO-INJECTOR LASER SYSTEM

RAL, IOP and CERN



CLRC

LASER SPECIFICATIONS

	CLIC	CTF3
Energy per micropulse	100μJ	7μJ
Total pulse train energy	4.3J	16mJ
Pulse train mean power	47kW	10.5kW
Laser average power	430W	80mW
Stability and controllability	0.1%	0.1%
Efficiency of IR to UV	5%	5%

STATE OF THE ART

COMMERCIAL SYSTEMS

10W cw TEM_{00}	Nd:Vanadate	- for pumping Ti:S (eg Millenia)
1kW cw	Nd:YAG	- for engineering applications
1J / 100Hz	Nd:YAG	- for engineering applications

DEMONSTRATED SYSTEMS

Oscillators - 5kW cw multimode
200W cw TEM_{00}
50W cw modelocked TEM_{00}

MOPA - 10J / 100Hz
10mJ / 15fs / 1kHz

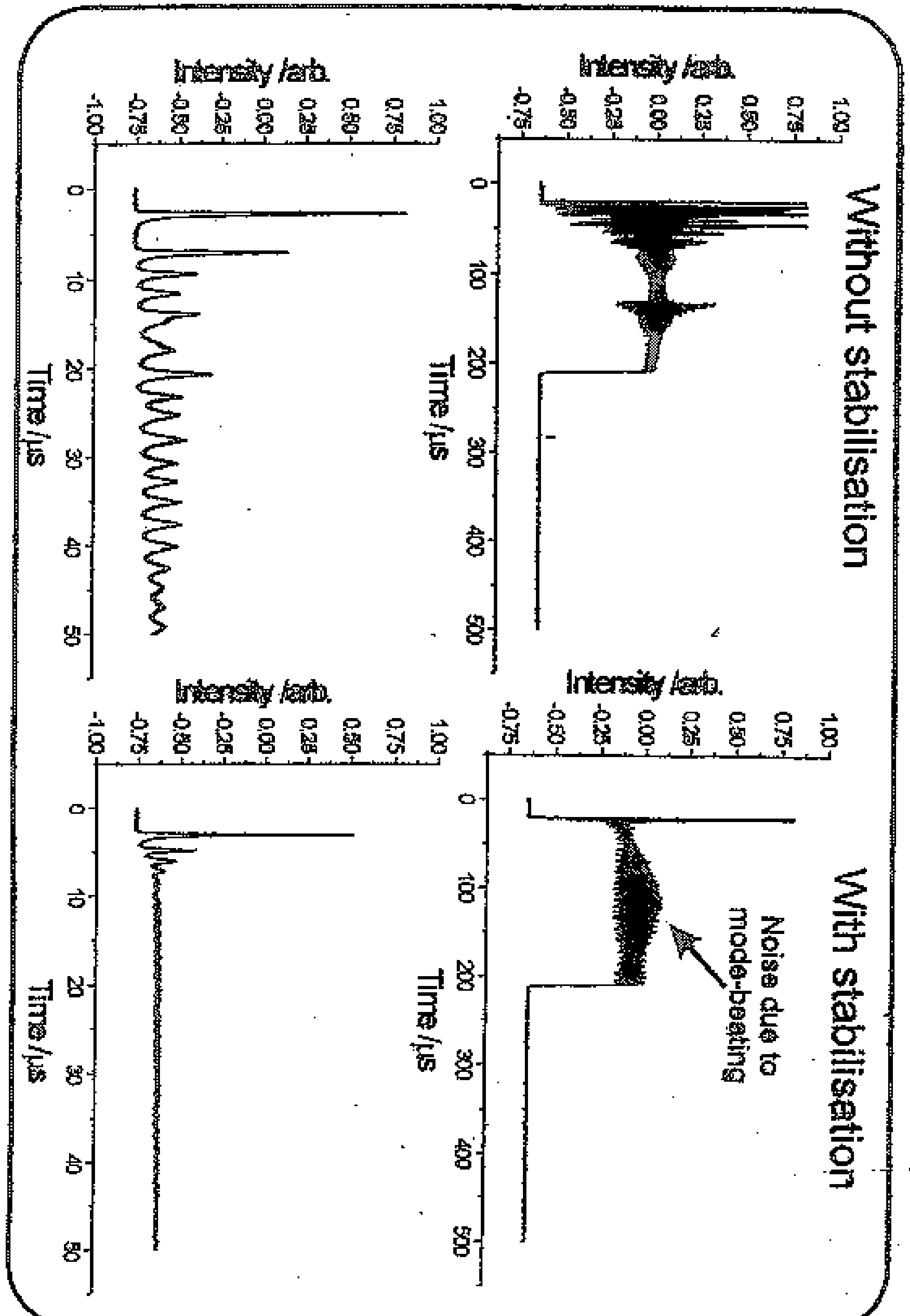
DESIGNED SYSTEMS

Oscillators - >10kW

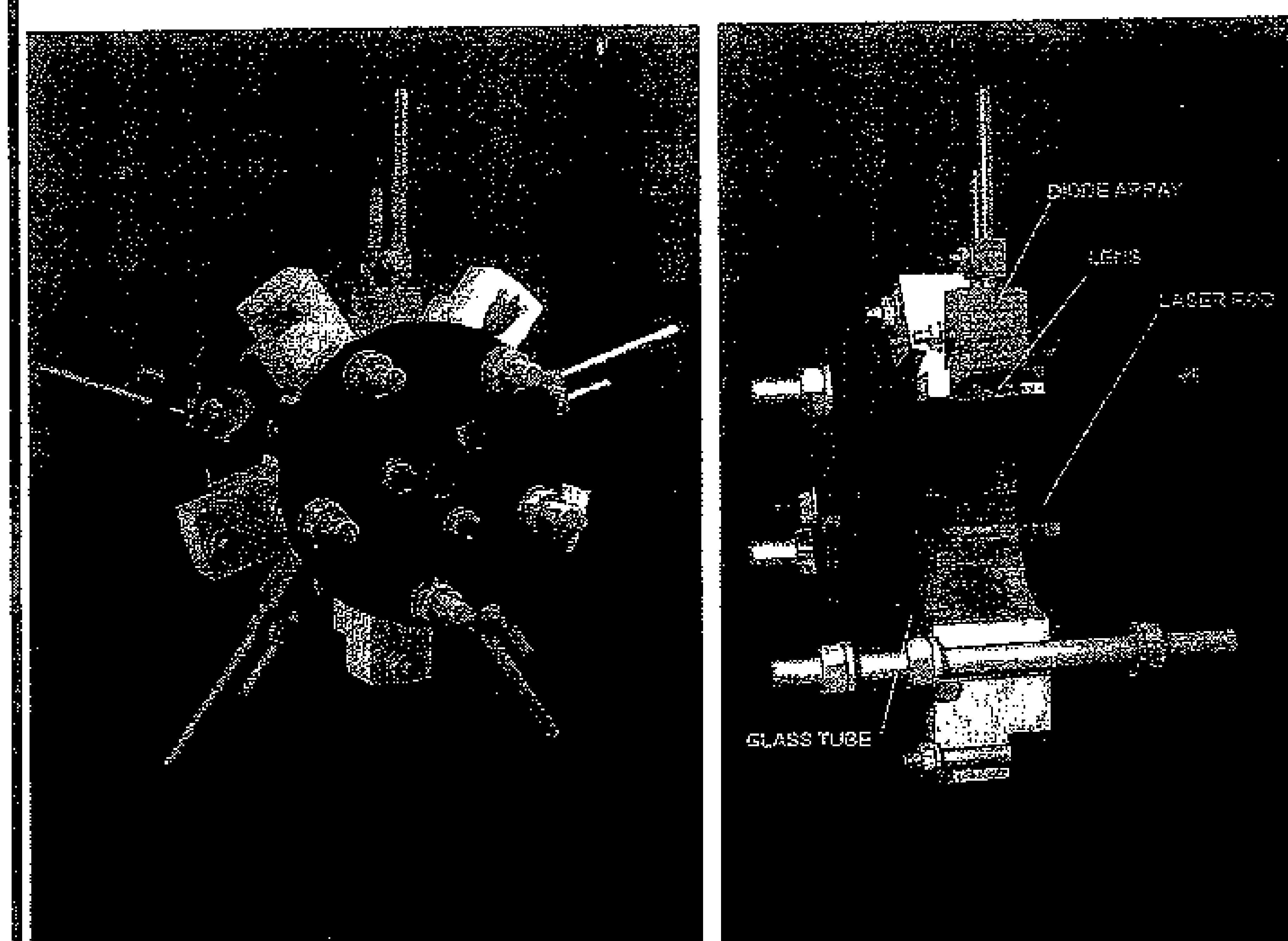
MOPA >100kW

Combined differential+proportional stabilisation of quasi-cw Nd:YLF laser

- Peak power after stabilisation(in 200μs) = 60W (300W pump)

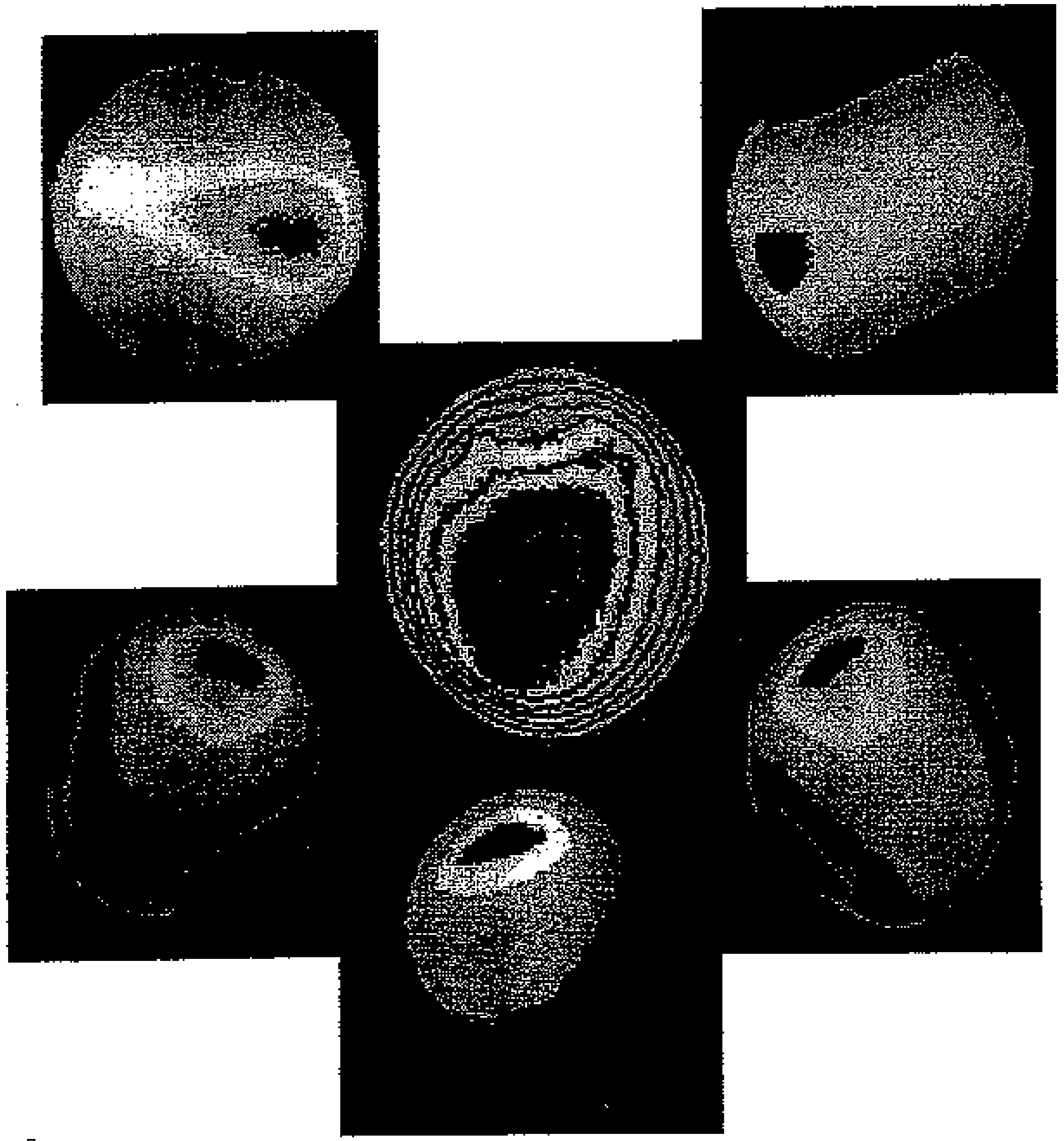


5kW DIODE-PUMPED TEST AMPLIFIER



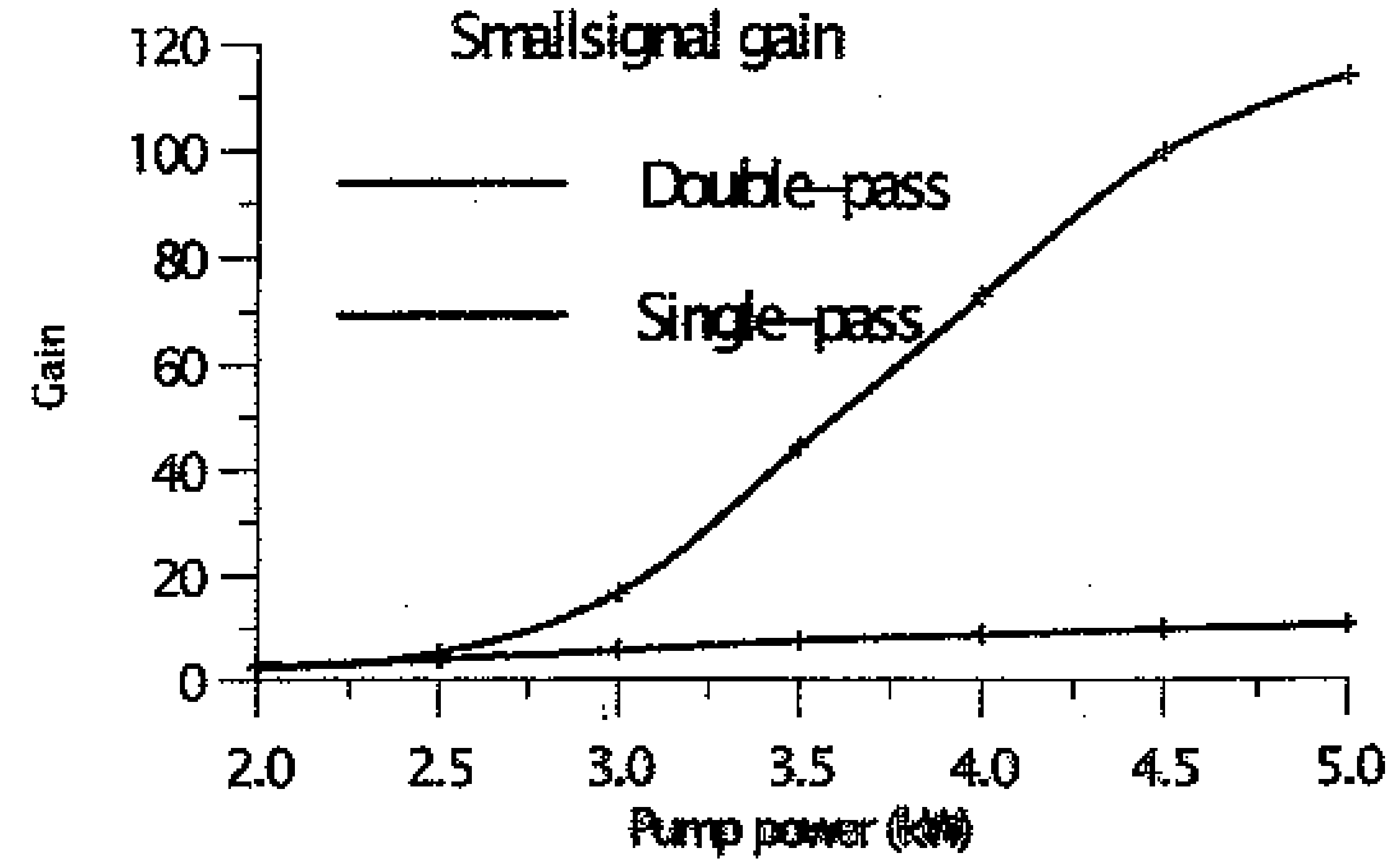
Pump-distribution

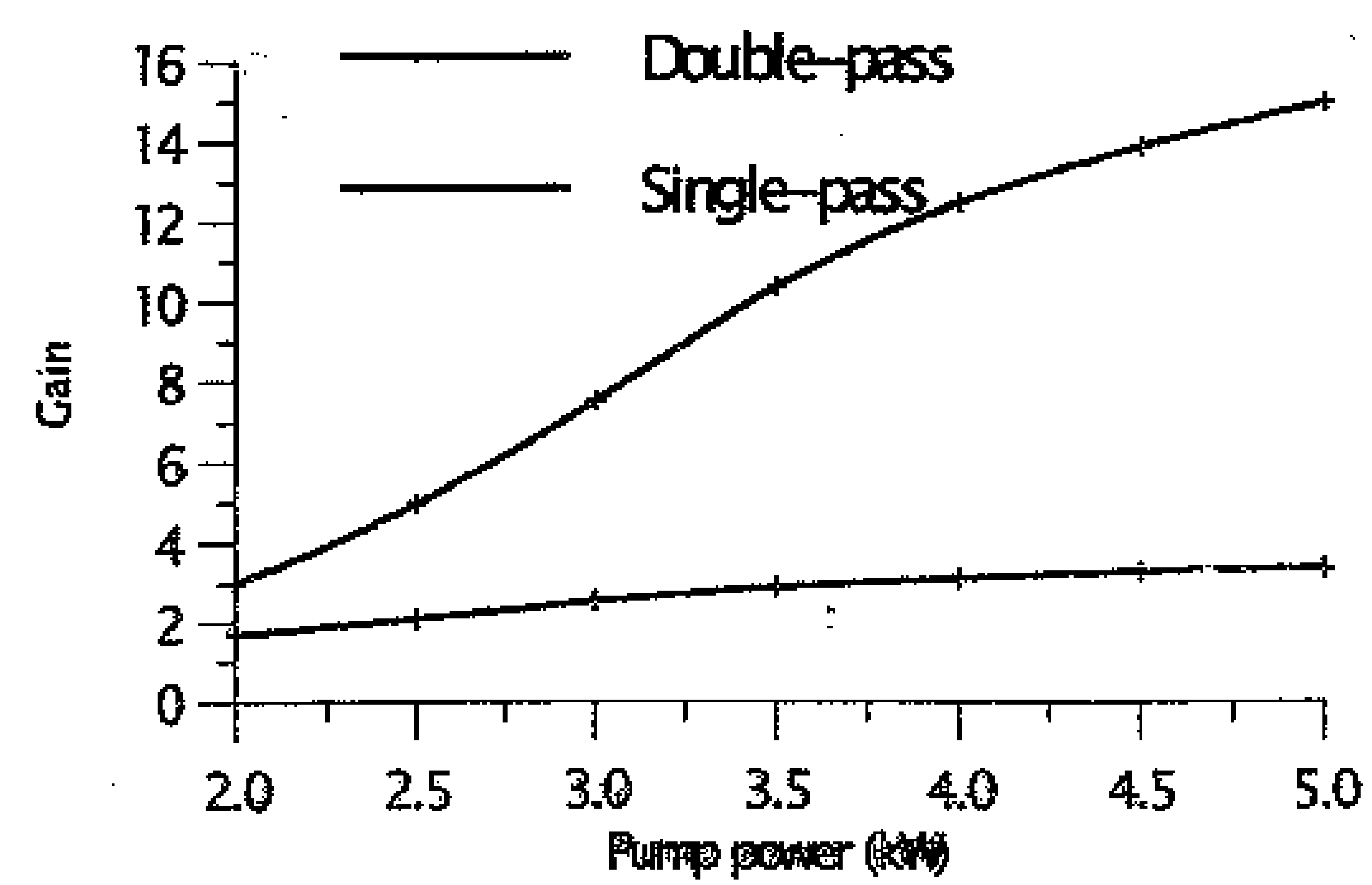
(fluorescence intensity)



Gain versus pump power

Pumping: 100V, 400µs, 5Hz





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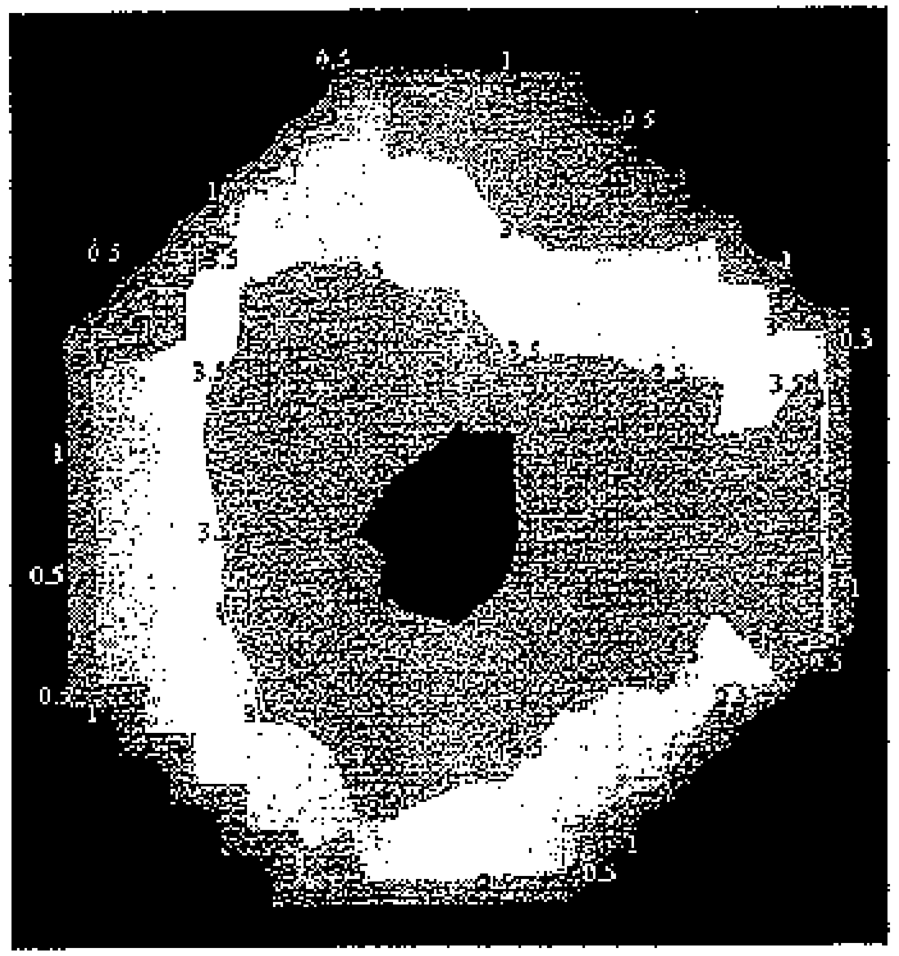
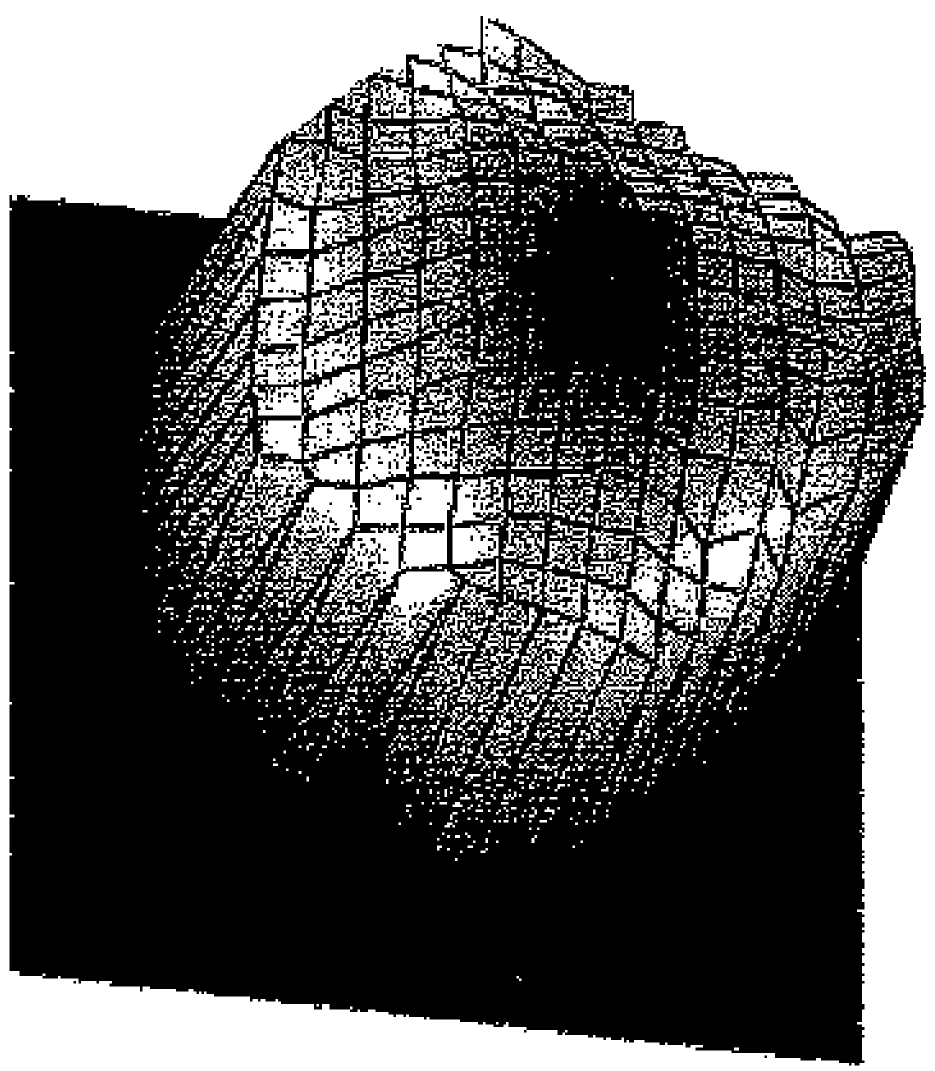
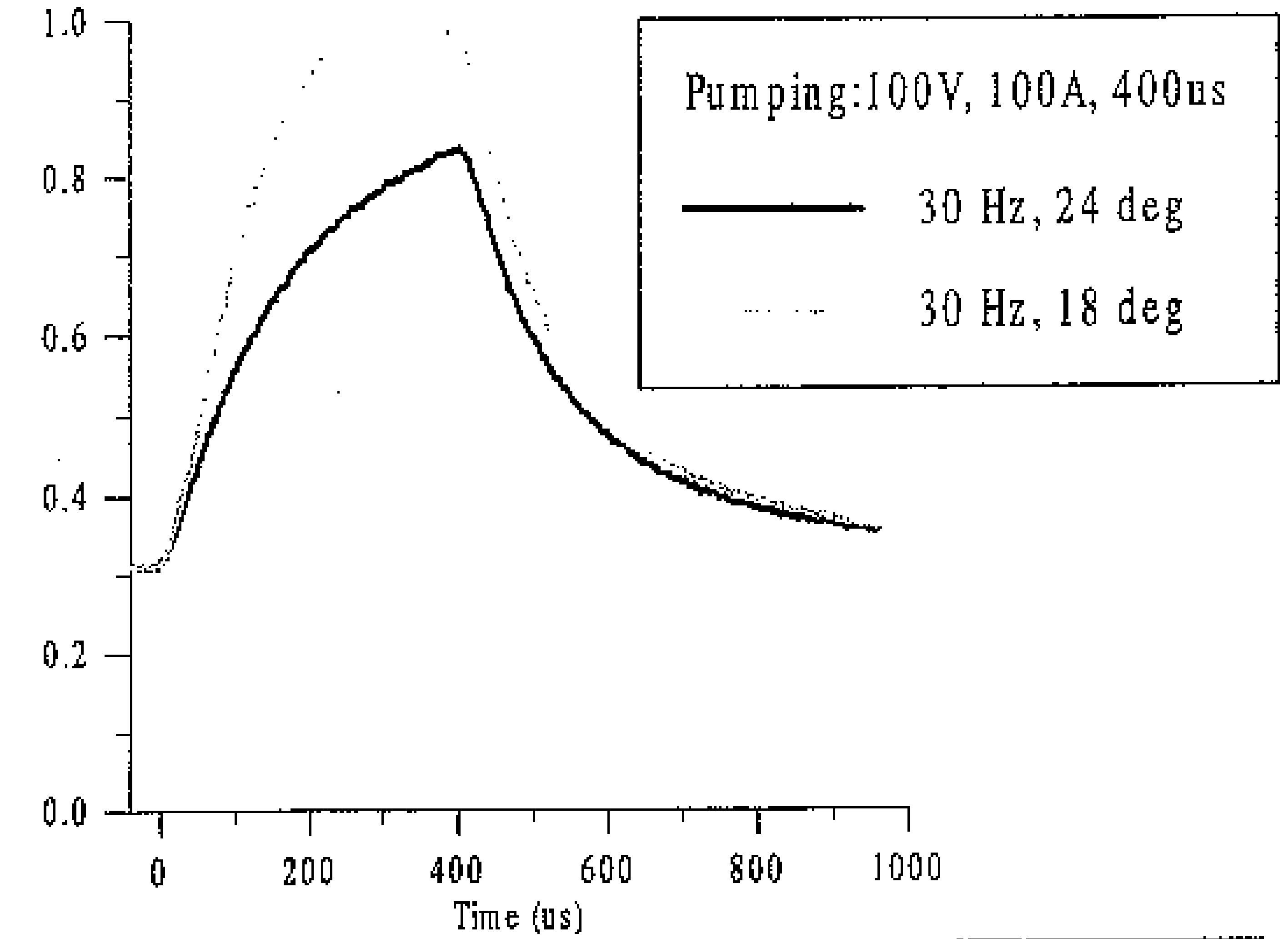
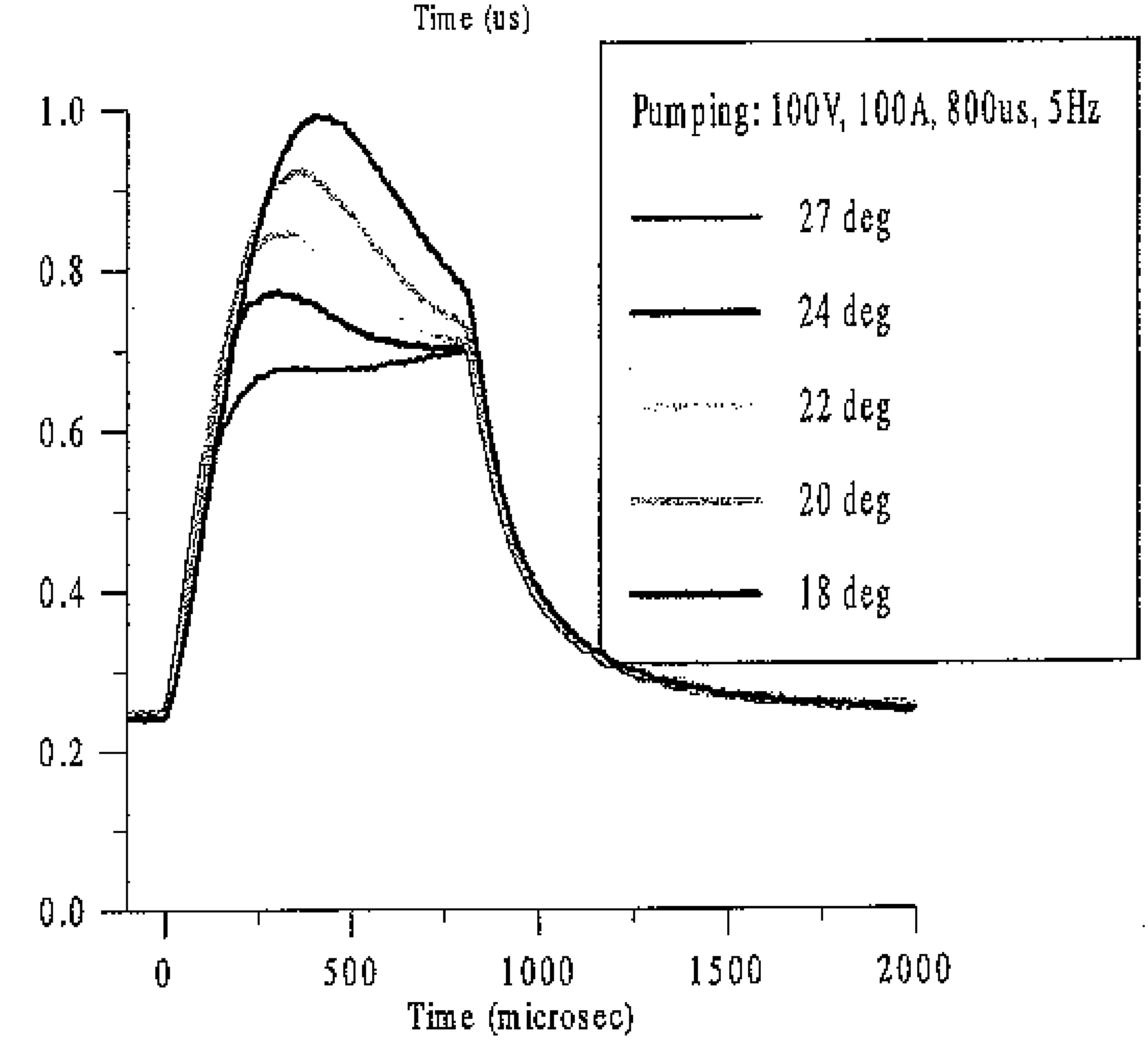
Saturated gain-distribution at single pass amplification



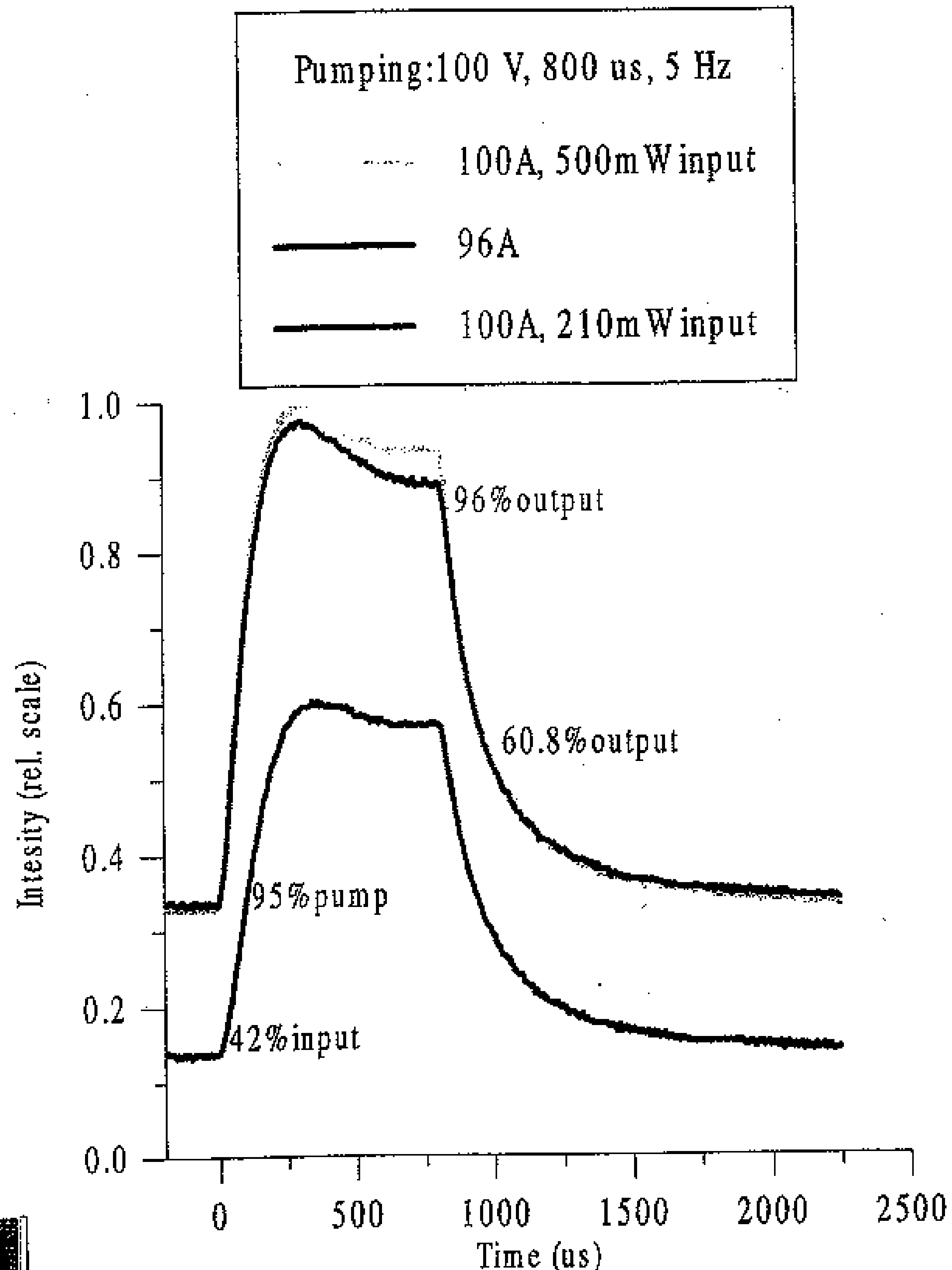


Effect of cooling temperature on amplifier gain

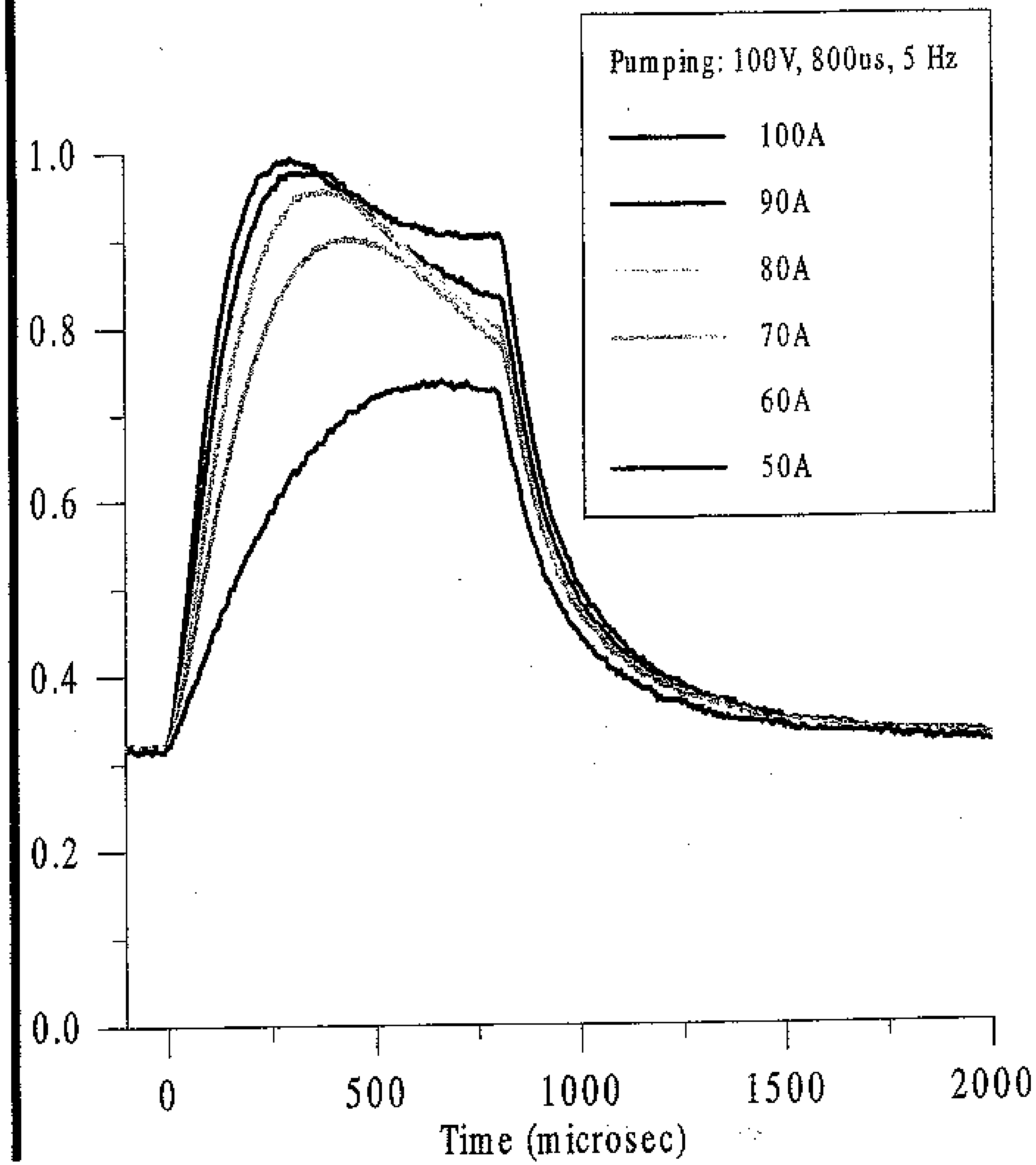




Effect of changing of the input-power and pump-power

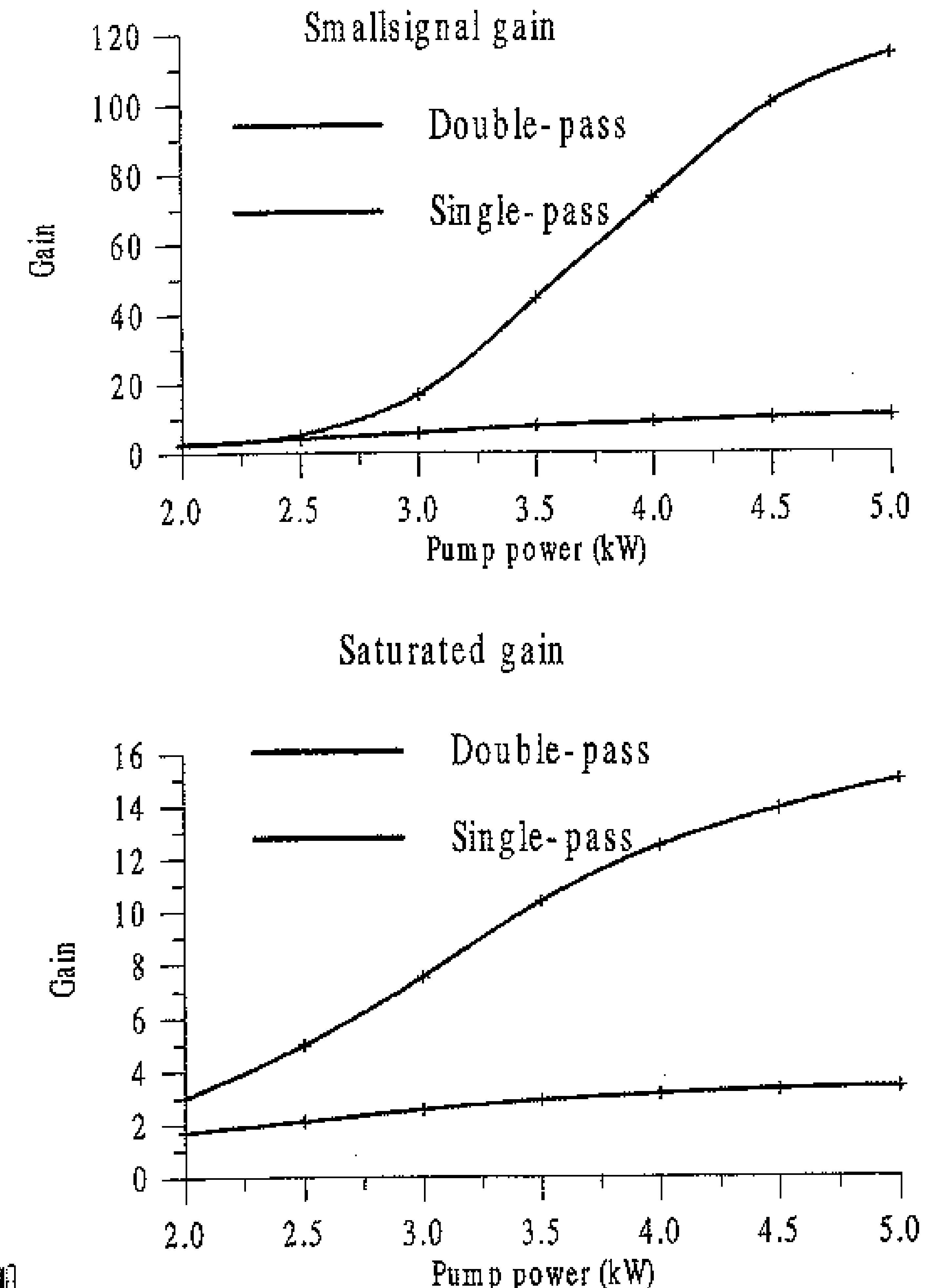


Dependence of amplifier gain on the pumprate



Gain versus pump power

Pumping: 100V, 400μs, 5Hz



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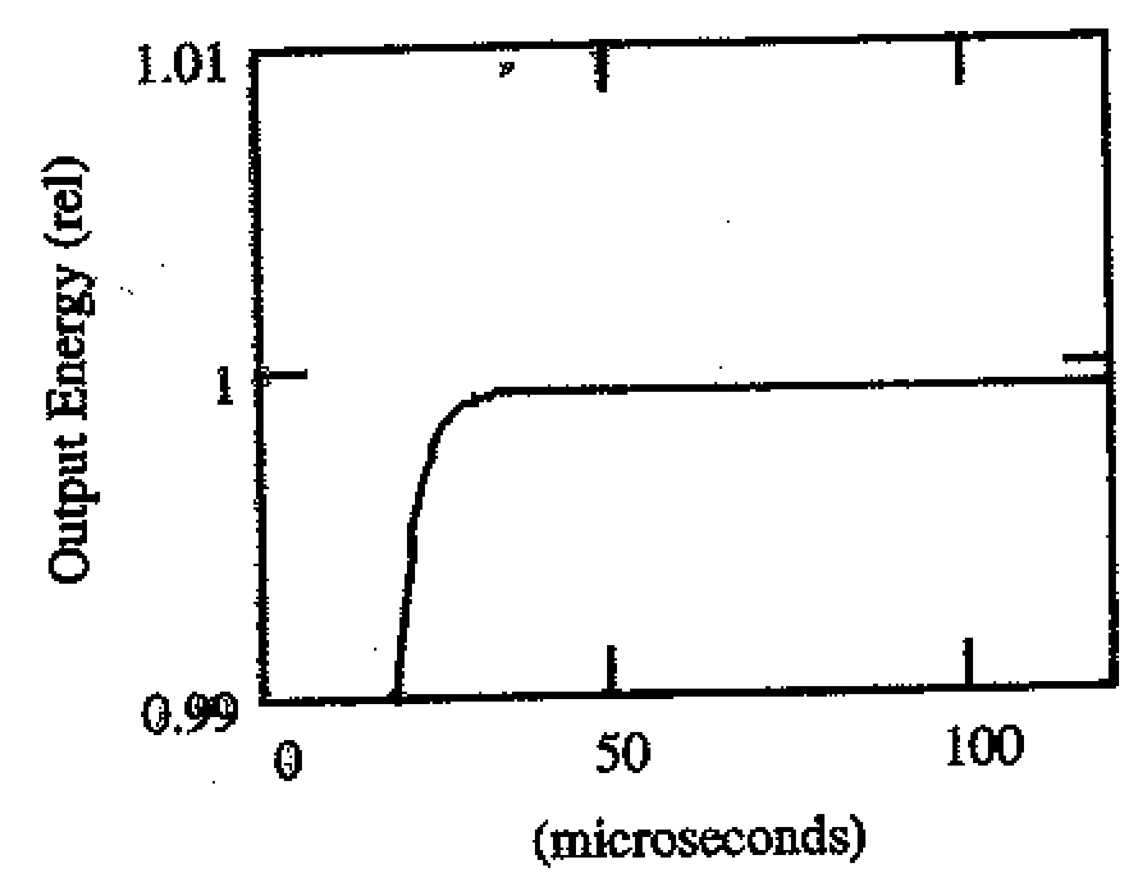
FINAL AMPLIFIER DESIGN - PHYSICS

For maximum stability the trick is to operate in quasi-steady-state mode with continuous pulse train input.



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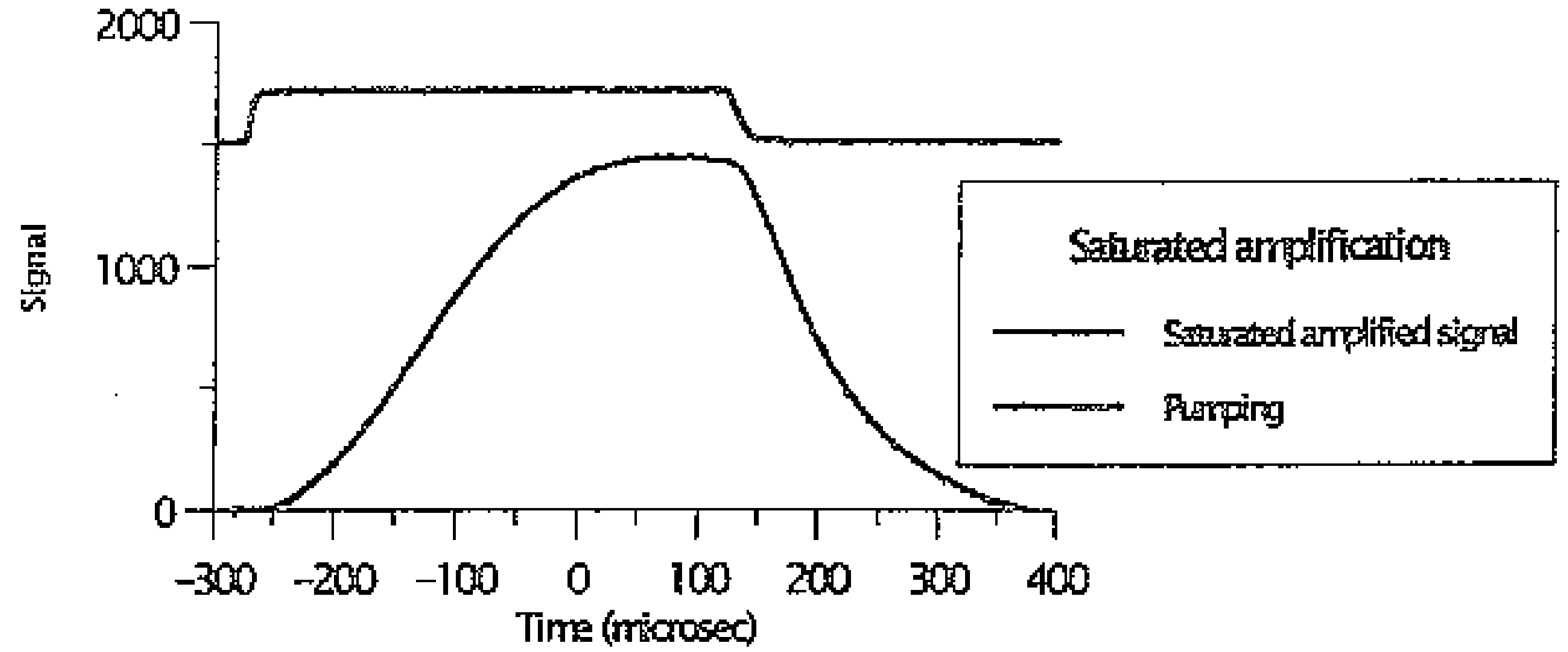
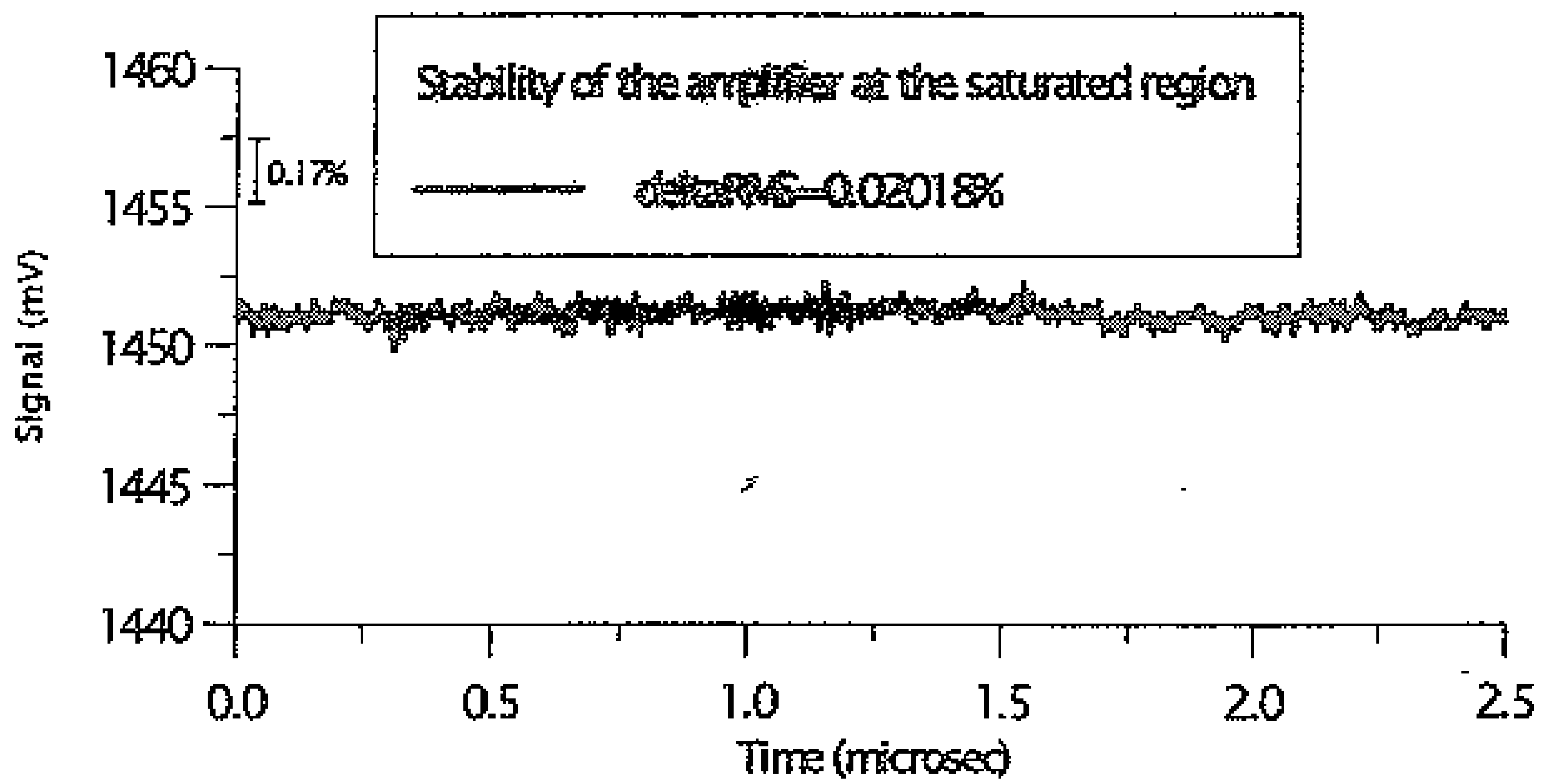
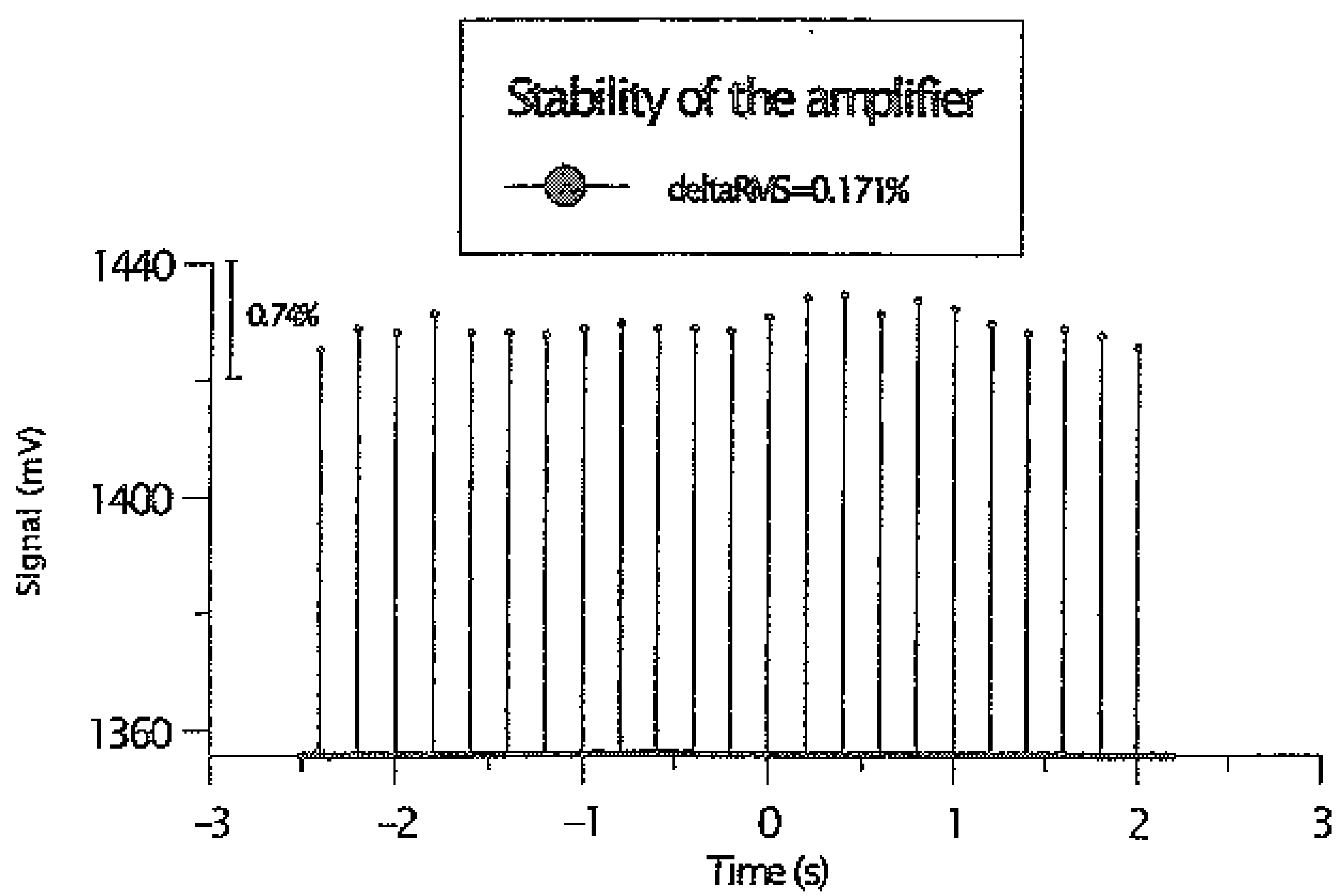
- 45 -

Stability of the amplifier system

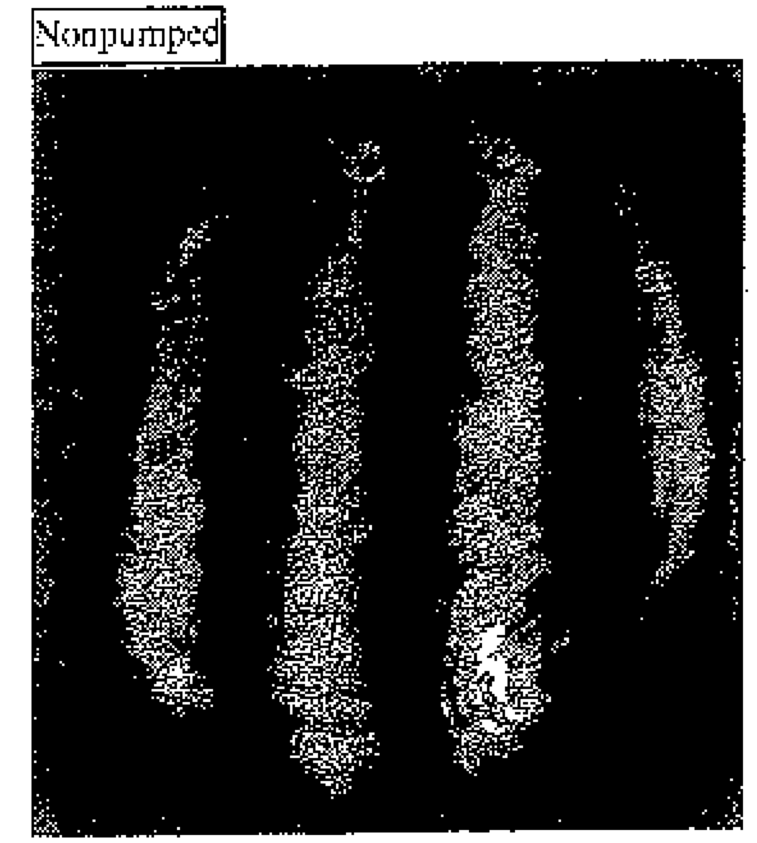


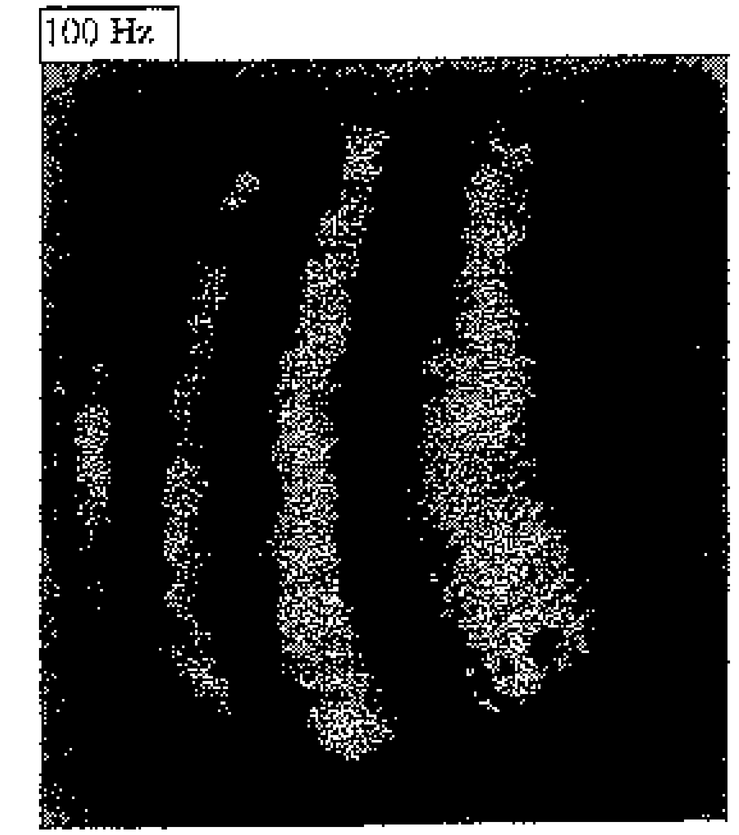




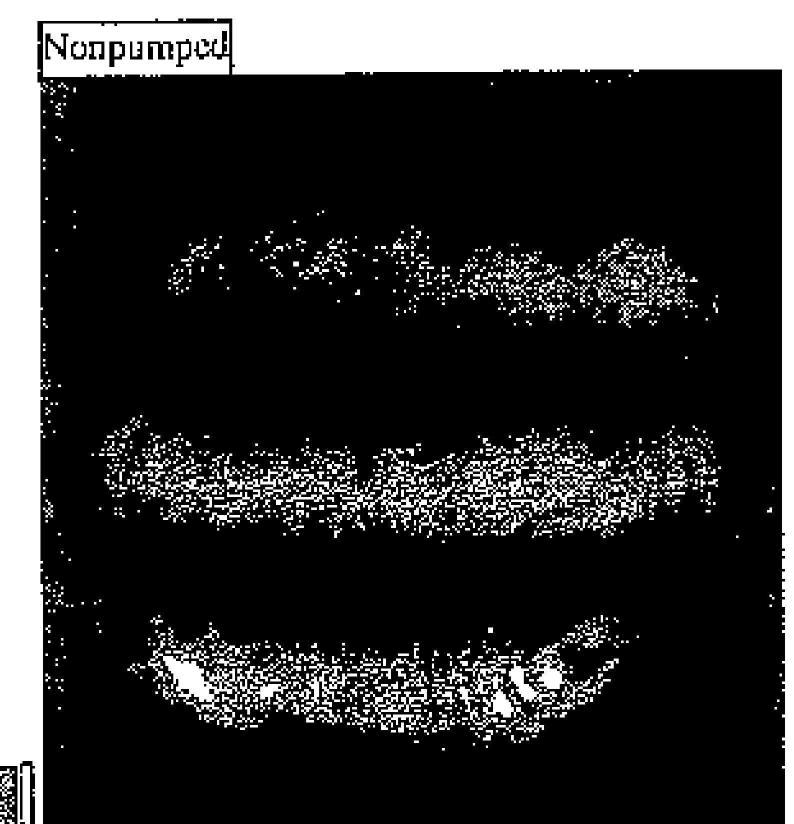
Thermal-lensing effect in the Nd:YLF rod

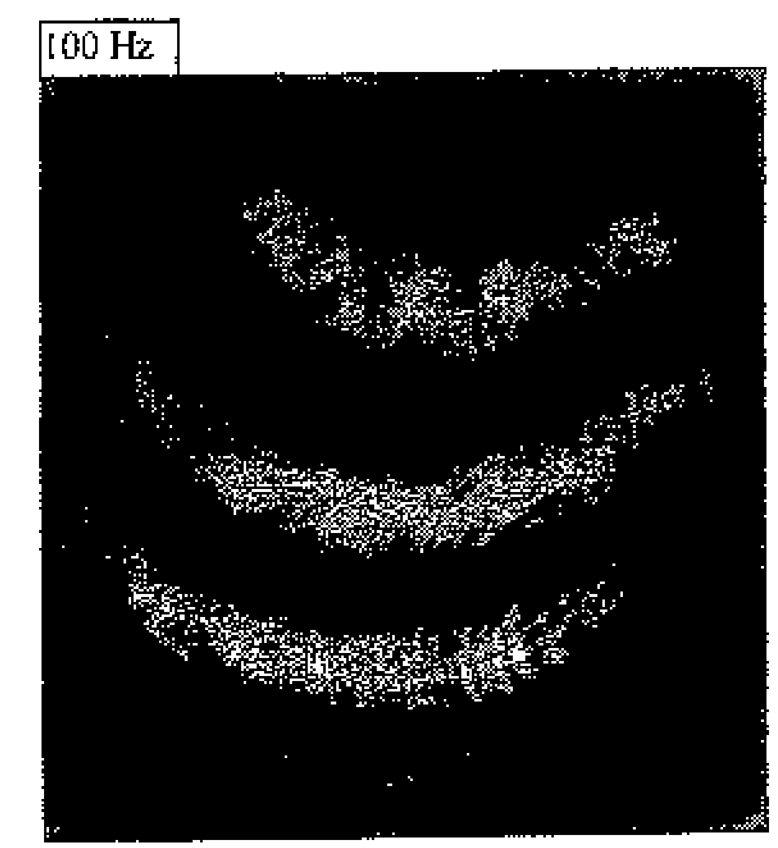
Vertical fringes:





Horizontal fringes:





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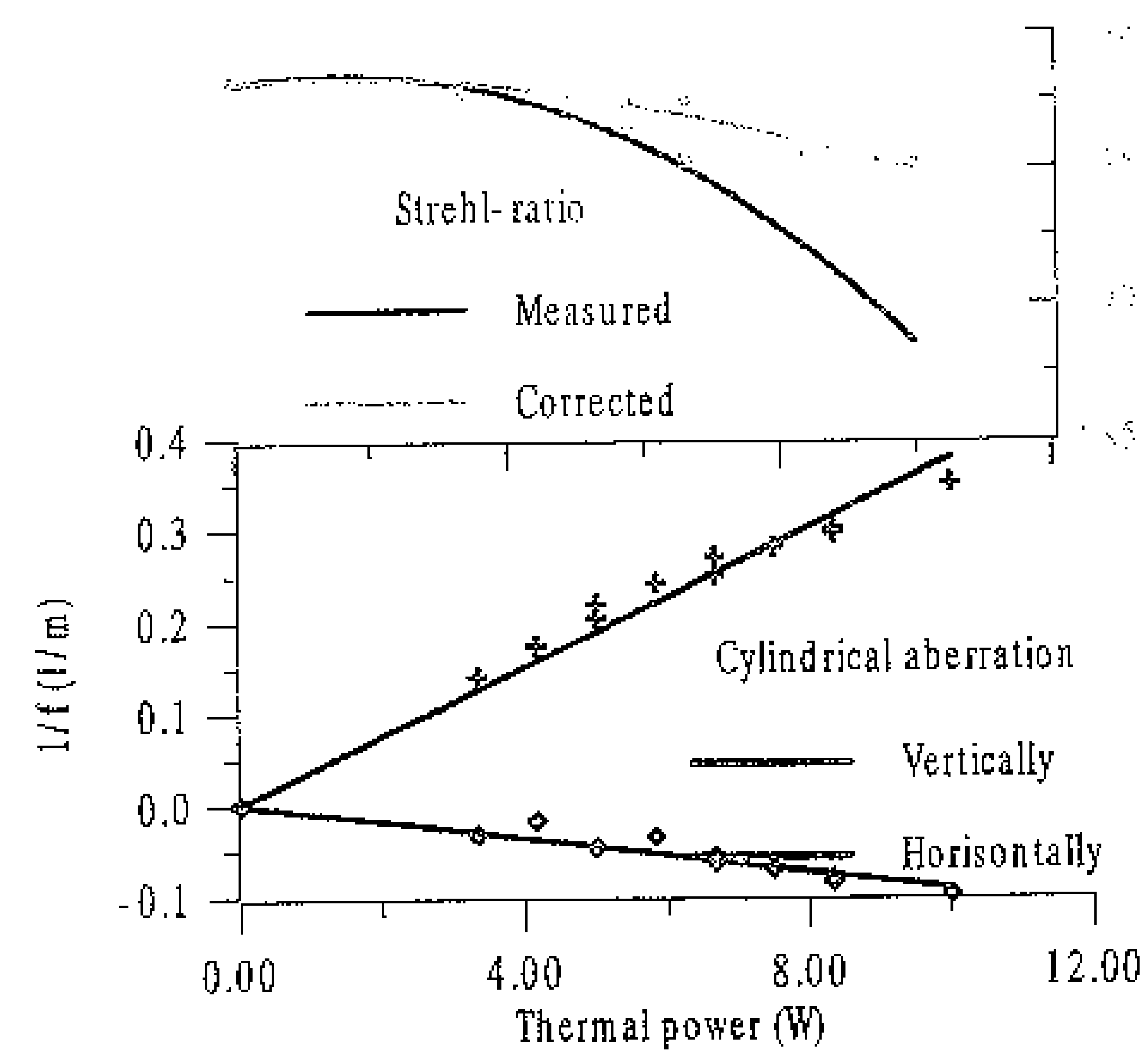
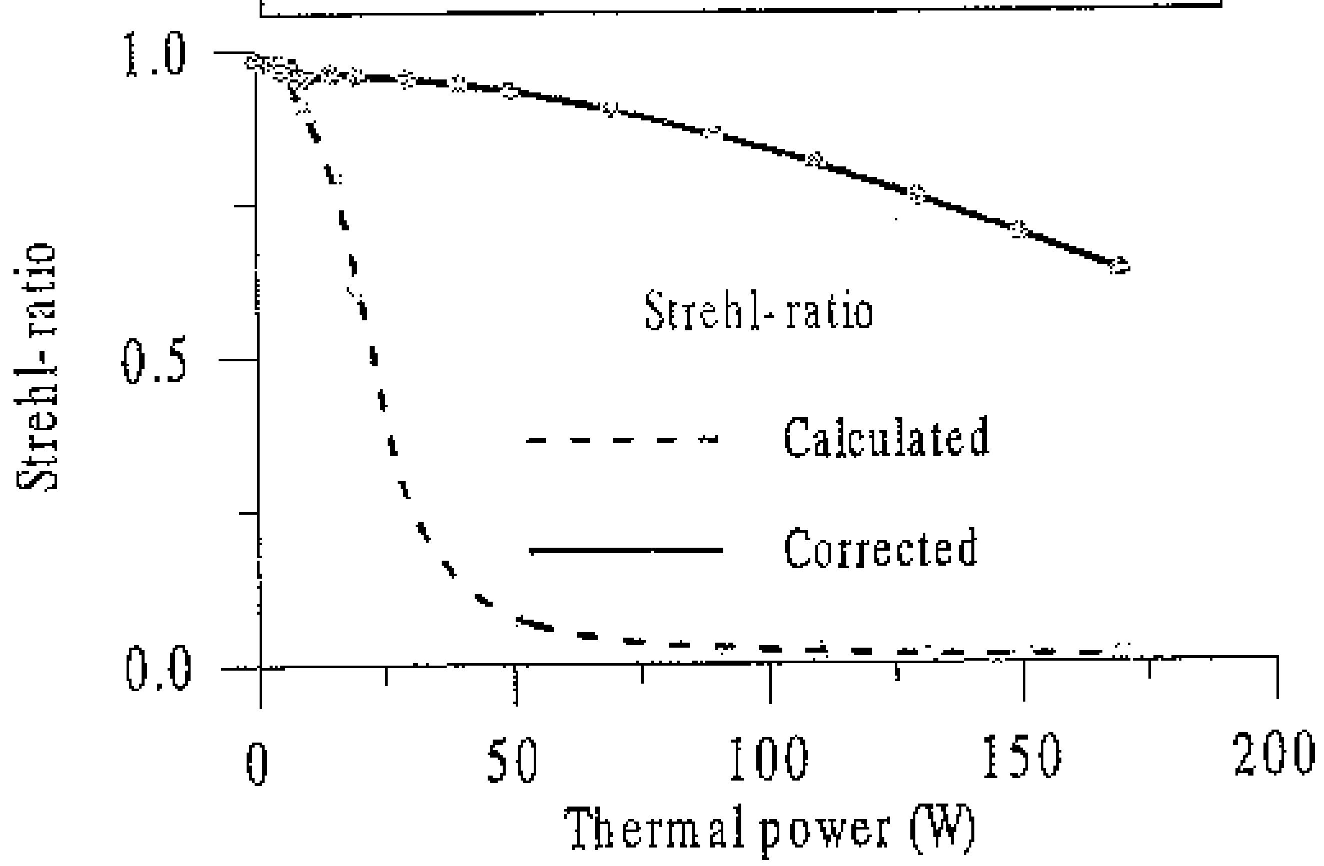
Thermal lensing measurements



Final design: Thermal power 170 W
Vertical aberration f= 15 cm
Horisontal aberration f= -60 cm
Strehl ratio 0.012



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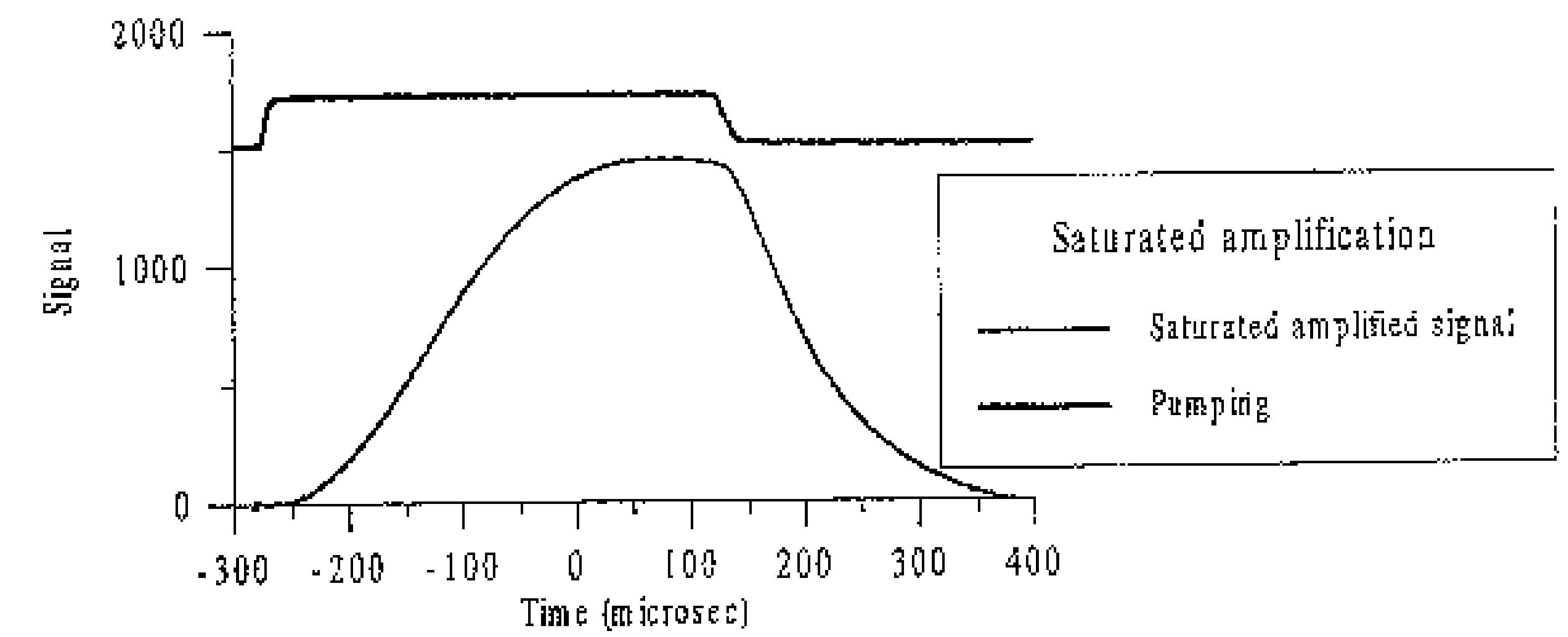
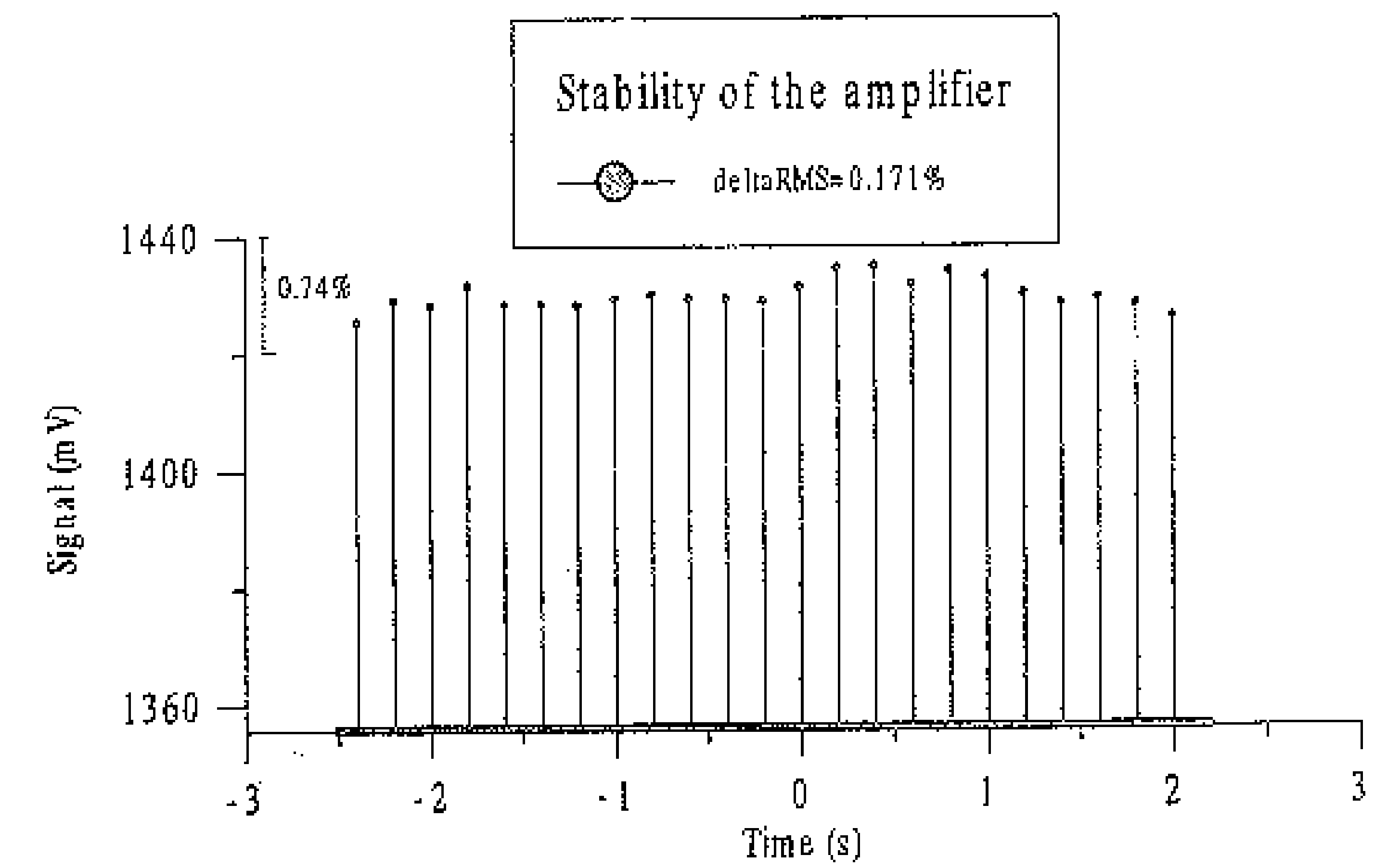
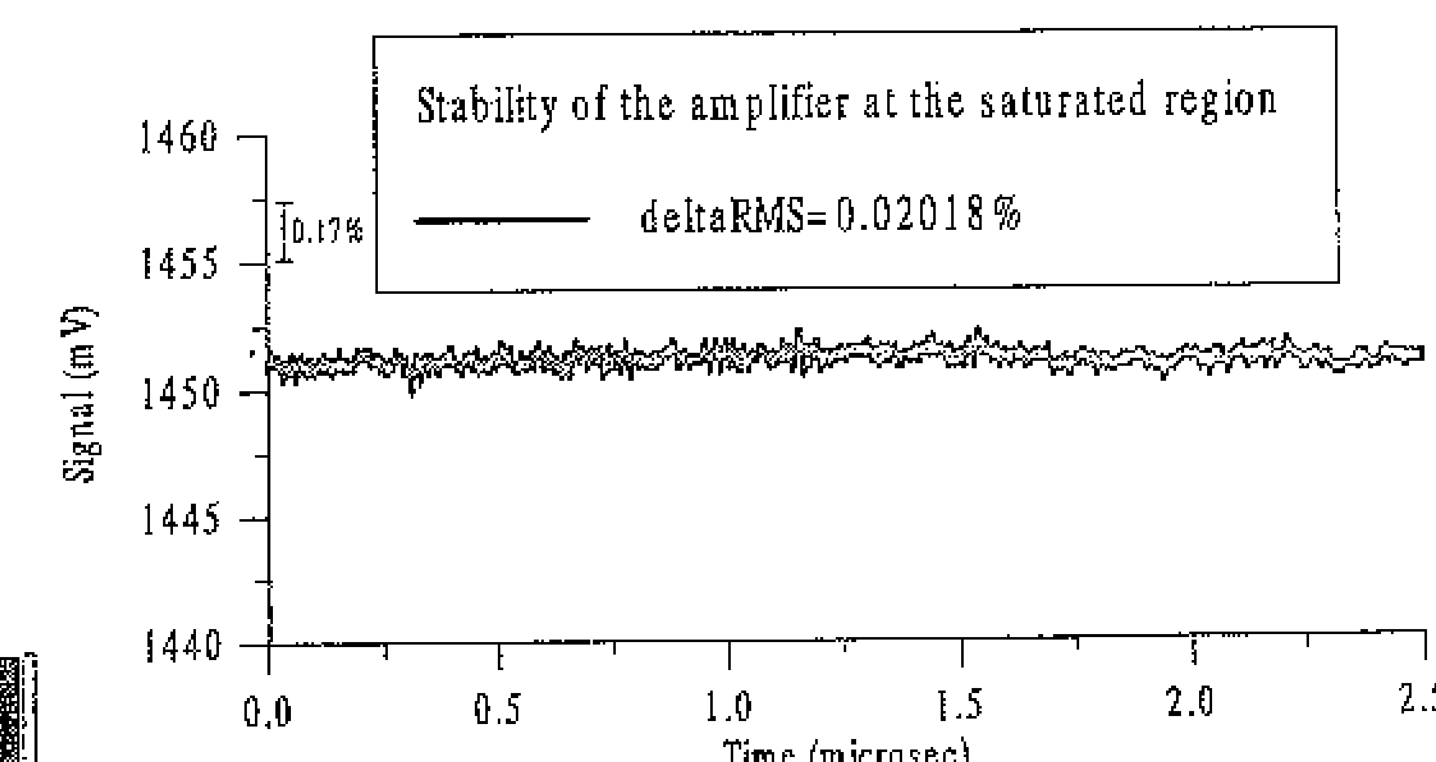
Stability of the amplifier at saturation







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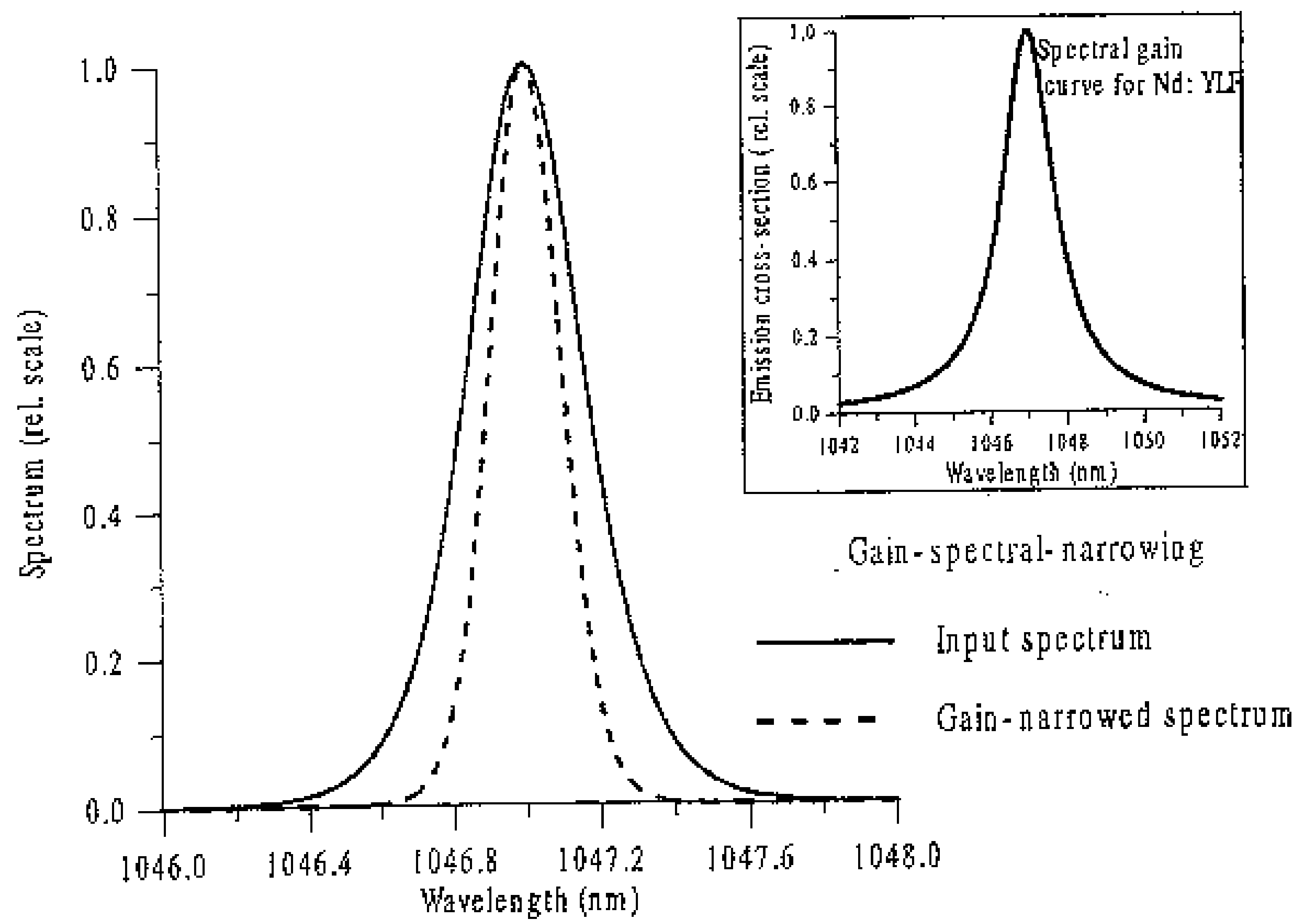
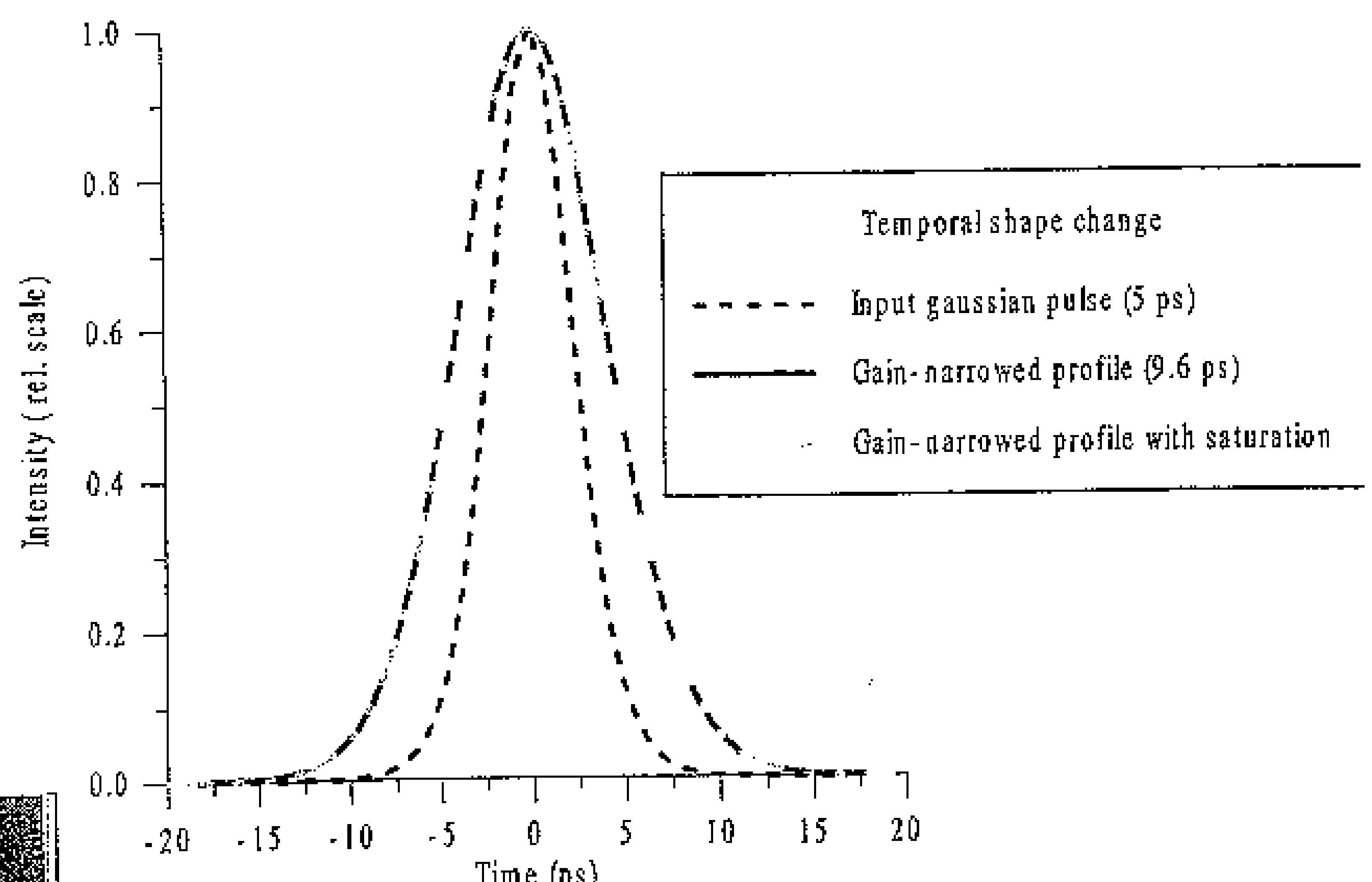
Calculated effect of amplification and saturation on pulse shape for Nd: YLF





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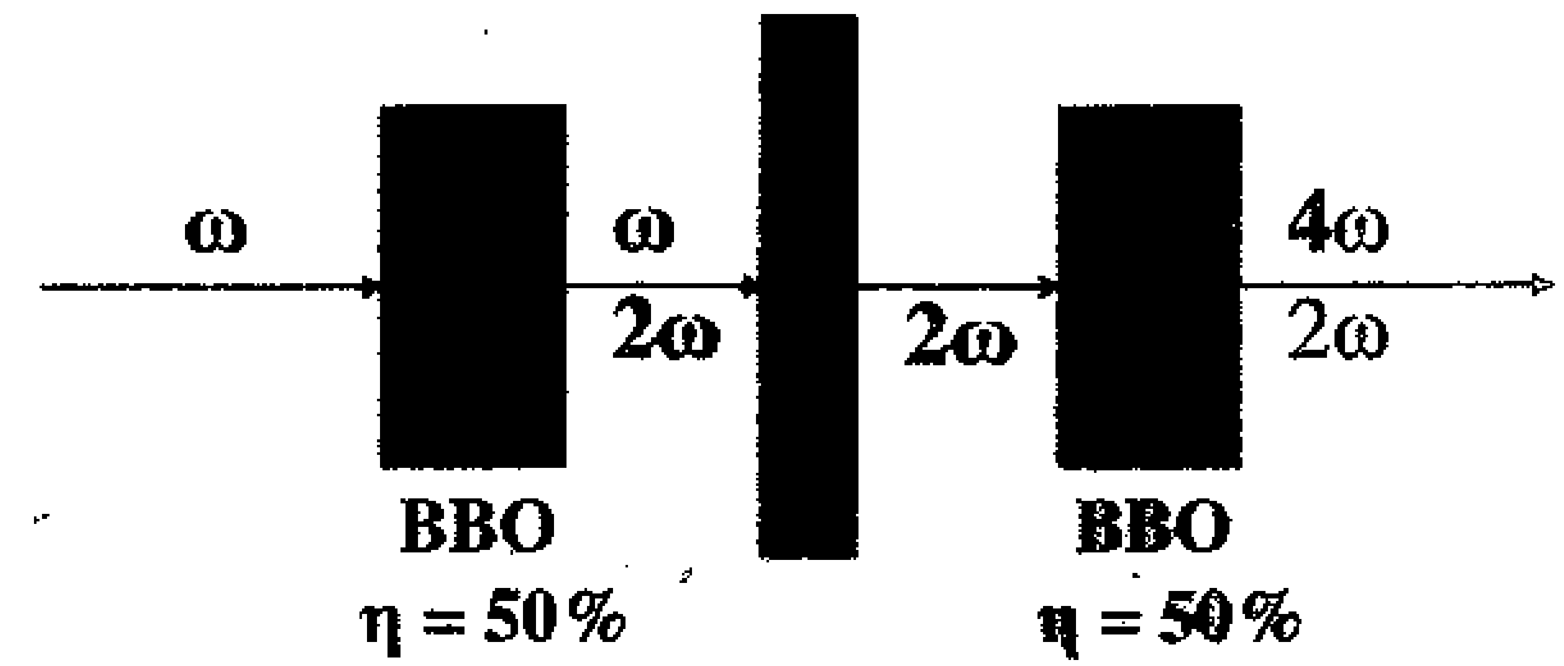
FOURTH HARMONIC GENERATION



- Predicts 25% efficiency overall
- Literature reports 25% efficiency
- Design assumes 14% - achievement of say 20% would substantially cut the cost of the laser.

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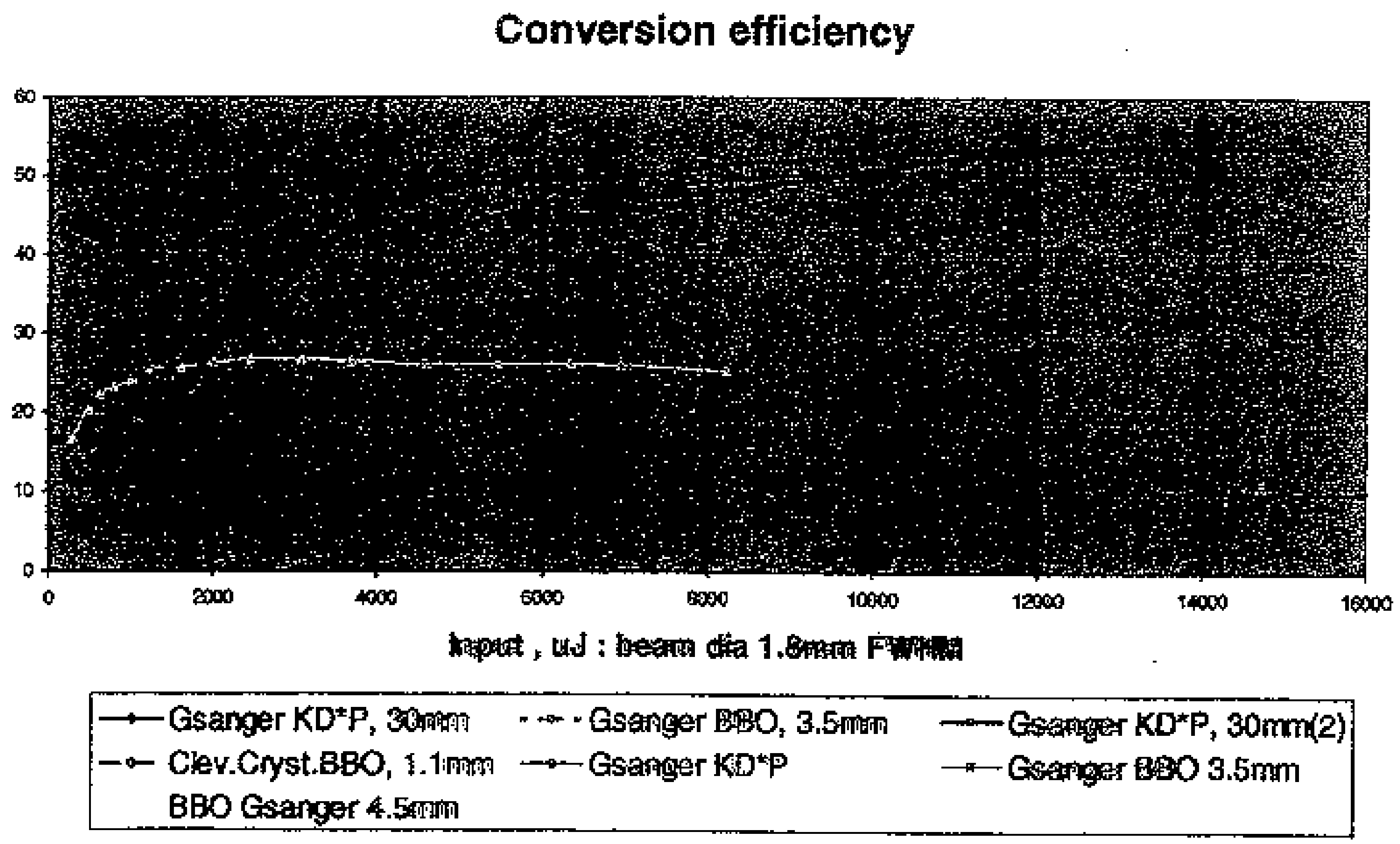
SECOND AND FOURTH HARMONIC CONVERSION EFFICIENCY MEASUREMENTS



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SUMMARY

- Gain - OK, suggest high pump efficiency
- Efficient extraction - OK, but more accurate data required
- Self-stabilisation - Yes, to a few % but not well matched to analysis
  - improvement anticipated
  - needs slow feedback system
- 30% amplified beam uniformity
  - better with fatter rod
- Thermal lensing and astigmatism measured
  - predict good correction for CLIC power
- Polished rod fractured at predicted power/cm
  - etched rod believed better

CLRC

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REMAINING CHALLENGES FOR CLIC?

*STABILITY - Requires slow feedback system
- Fast feedback system??

*SYNCHRONISATION - To be determined

*UNIFORMITY - OK improvements expected
- options possible

*AMPLIFIED PULSE TRAIN - Low risk

*ENERGY EXTRACTION OVER LARGE AREA
- Low risk

OUTSTANDING ISSUES

*1.5GHz(CTF3)/0.5GHz(CLIC) oscillator

*Electron charge measurement and stabilisation to 0.1%

*Synchronisation

*Photo-cathode reliability

‘PILOT’ CTF2 TESTS

AIMS

Demonstrate stable pulse train operation yielding 0.2nC per electron bunch from the photo-cathode at a frequency of 250MHz and for a train length of 1.5ì s.

Demonstrate optical feedback stabilisation of the optical pulse train to 1%.

Demonstrate beams on the photo-cathode spatially uniform to 30%.

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‘PILOT’ CTF2 TESTS

AIMS

Demonstrate stable pulse train operation yielding 0.1nC per electron bunch from the photo-cathode at a frequency of 500MHz and for a train length of 1.5μs.

Demonstrate optical feedback stabilisation of the optical pulse train to <1%.

Demonstrate beams on the photo-cathode spatially uniform to 30%.

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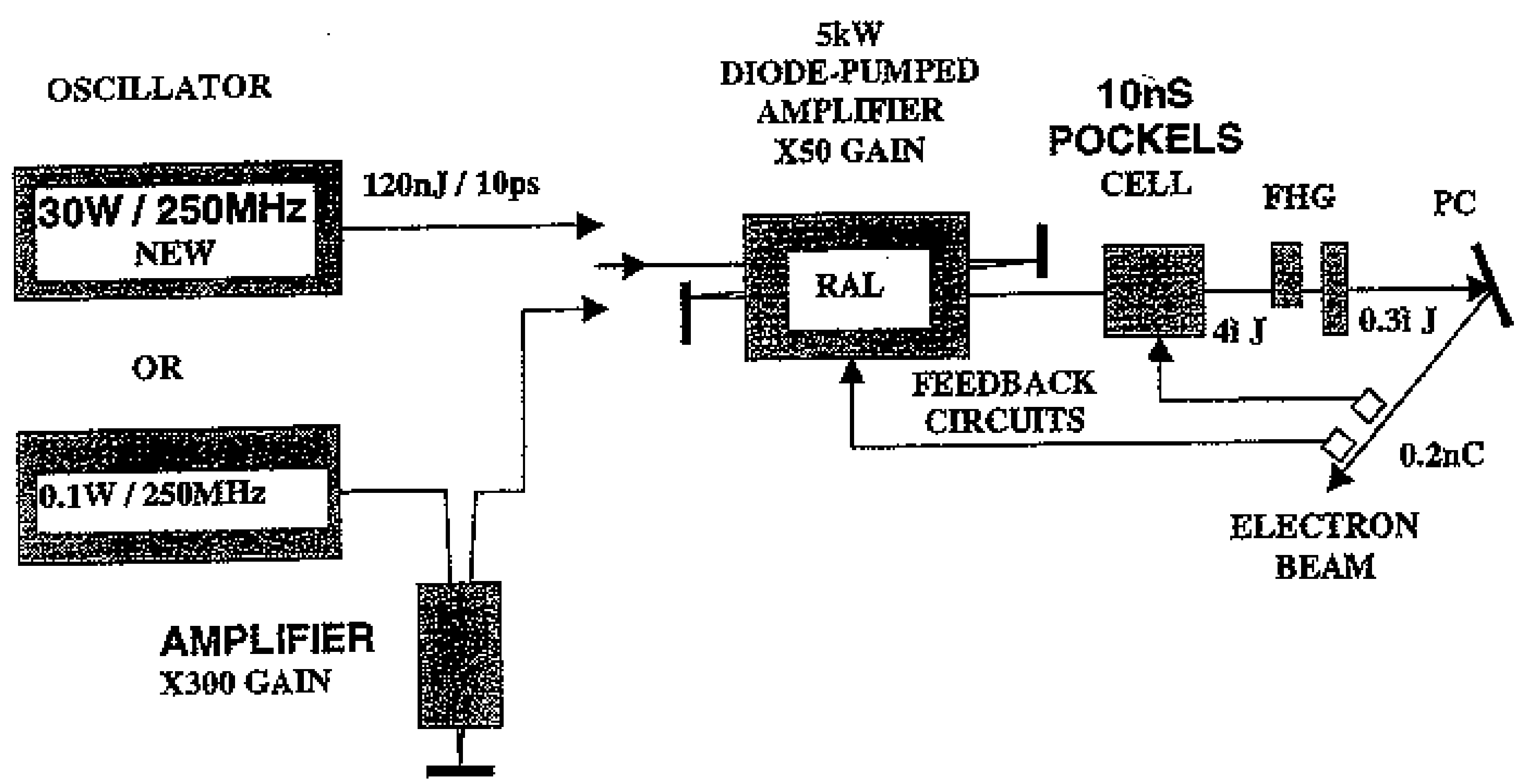
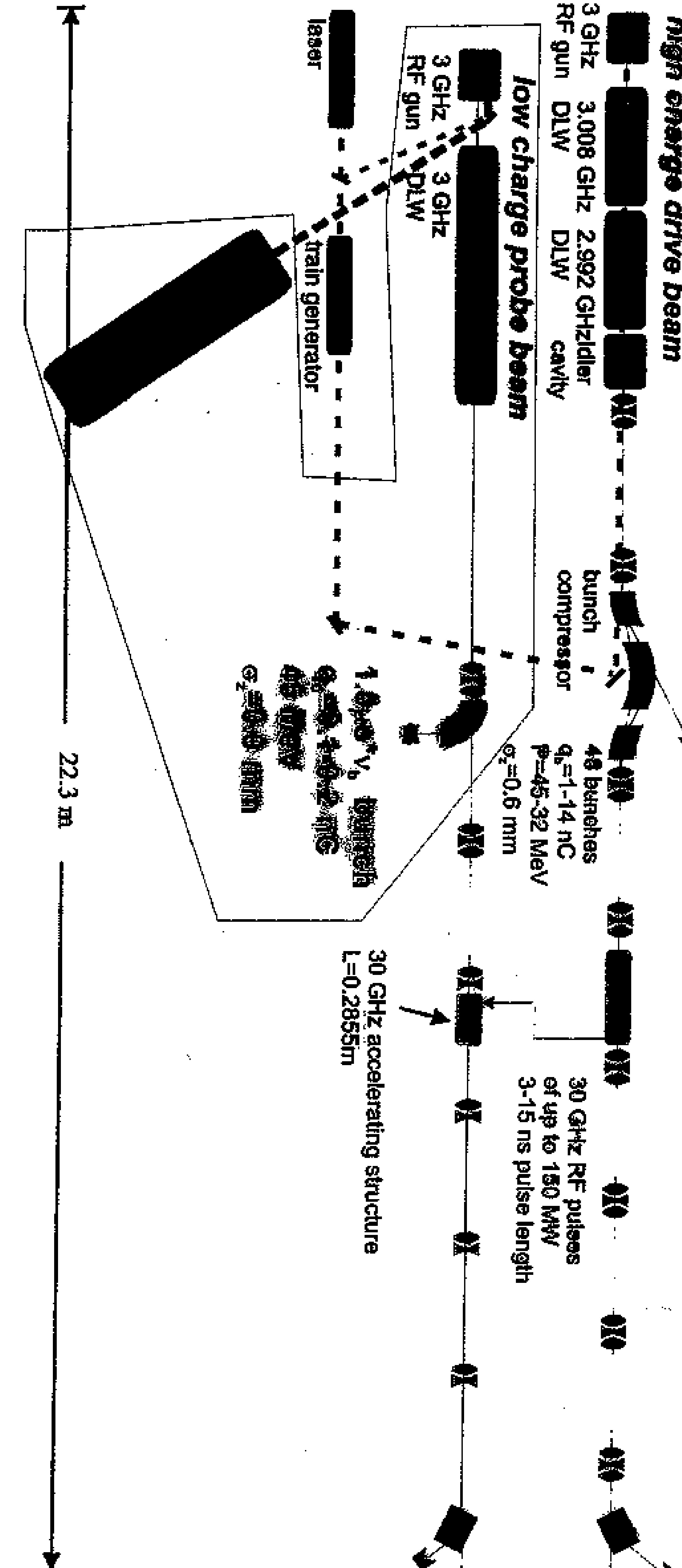
PHOTO-INJECTOR LASER FOR 'PILOT' TESTS





Optics Design and Simulations for the CTF3 Drive Beam Accelerator

D. Schulte

The Beam

Bunch charge	q	nC	2.33
Bunch length	σ_z	mm	1.5
Norm. emittances	$\epsilon_{x,y}$	μm	100
Initial energy	E_0	MeV	24
Distance betw. bunches	Δs	m	0.2
No of bunches			≈ 2100
Final beam energy spread	$\Delta E/E$	%	5

The Structure

Length	L	m	1.2
Load. Gradient	G	MV/m	6.5
No of cells			34

Two different designs: TDS and SICA

both use damping and detuning

$\Rightarrow$ the SICA has lower transverse wakefields

the wakefields have been calculated by

A. Millich, L. Thorndahl, E. Jensen, I. Syratchev

Simulations

Simulations have been performed using PLACET

20 structures were simulated

- space is available
- slightly conservative estimate

longrange transverse wakefields

- individual cells are simulated
  - with uncoupled modes (4-5)
- dipole loss factors 50% higher
  - uncertainty of the calculation, simplifications made
- Q-values 50% higher
  - imperfect loads
- $Q = 1000$ in end cells (no damping)

RF phase will be adjusted for compression

- $\Phi_{RF} = -6°$ is assumed

General Considerations

In each lattice, the quadrupole strengths can be varied

weak focusing

$\Rightarrow$ sensitiv to wakefields

strong focusing

$\Rightarrow$ sensitive to energy errors

$\Rightarrow$ compromise is necessary

the energy must be well controlled because of the ring

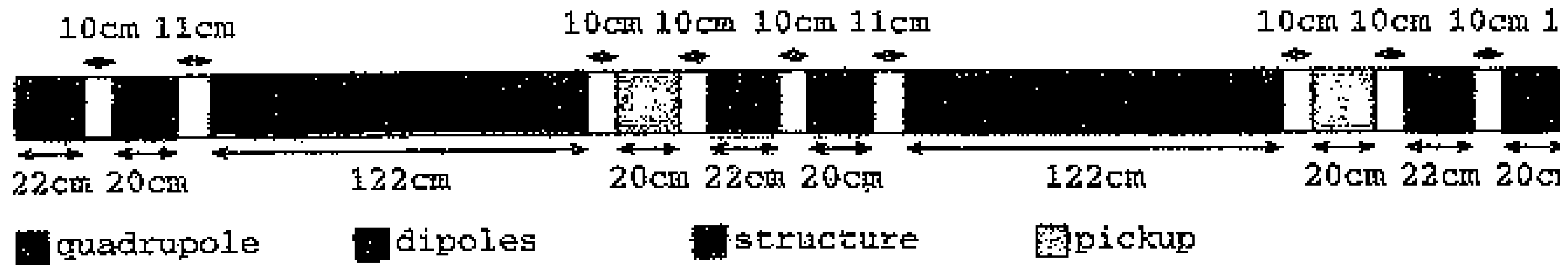
$\Rightarrow$ stronger focusing

more difficult to start (low intensities are not simpler)

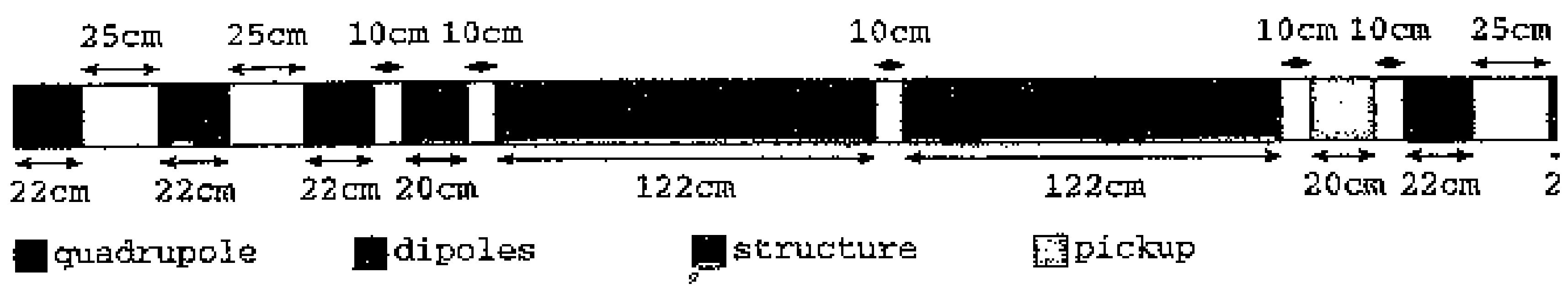
once the linac runs, injecting into the ring should be simpler

Investigated Options

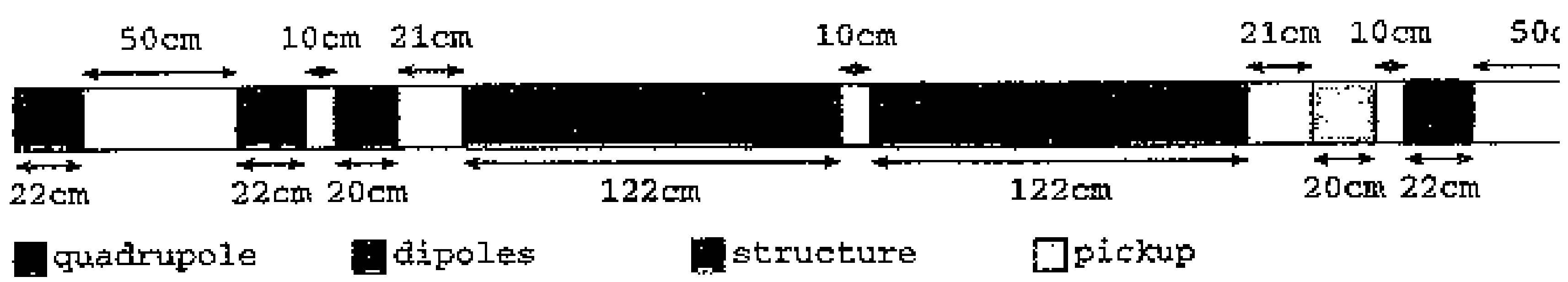
FODO lattice with one structure per half-cell



triplet lattice with two structures per cell



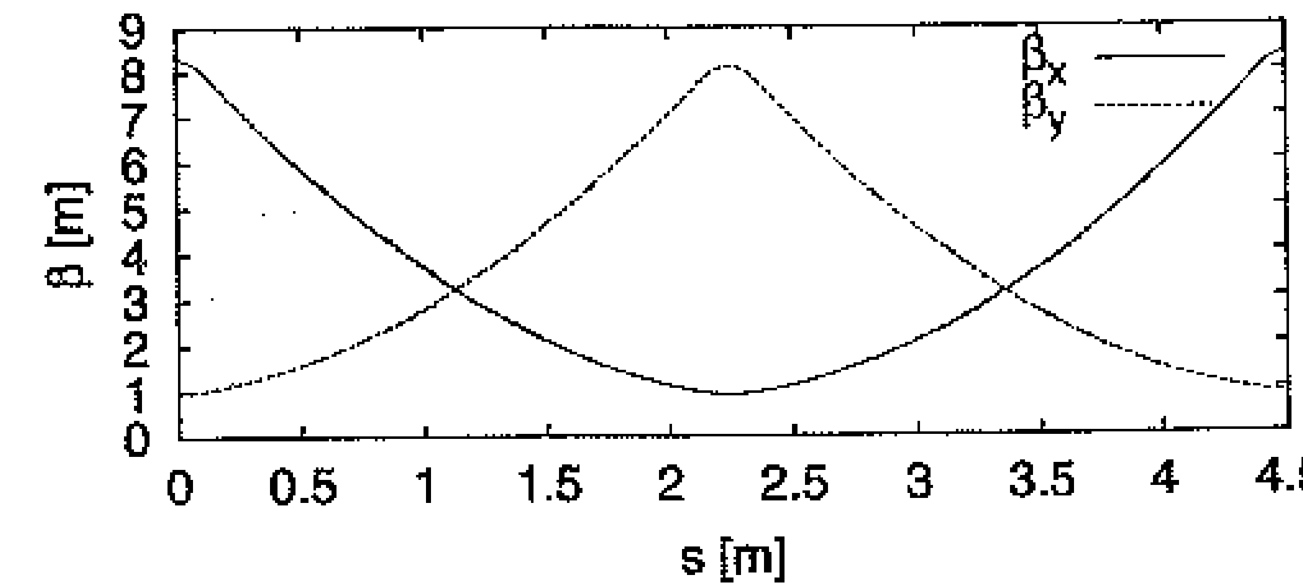
doublet lattice with two structures per cell



⇒ space requirement and cost is very comparable

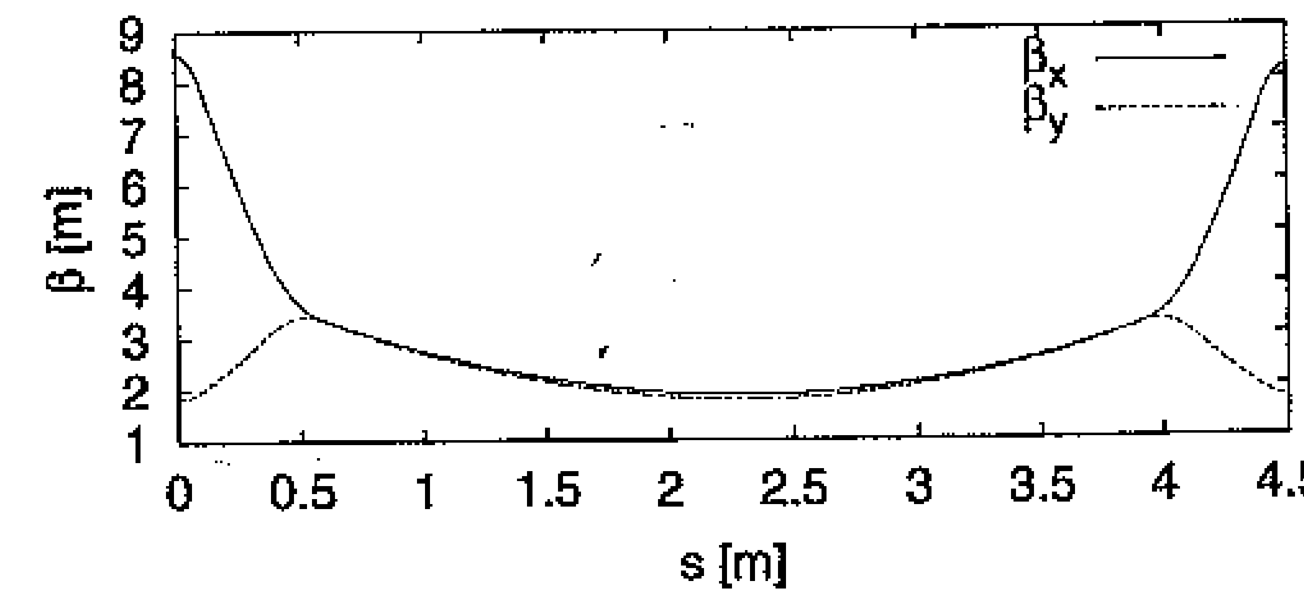
Beta-Functions

FODO-Lattice



$\mu_{x,y} \approx 105°$

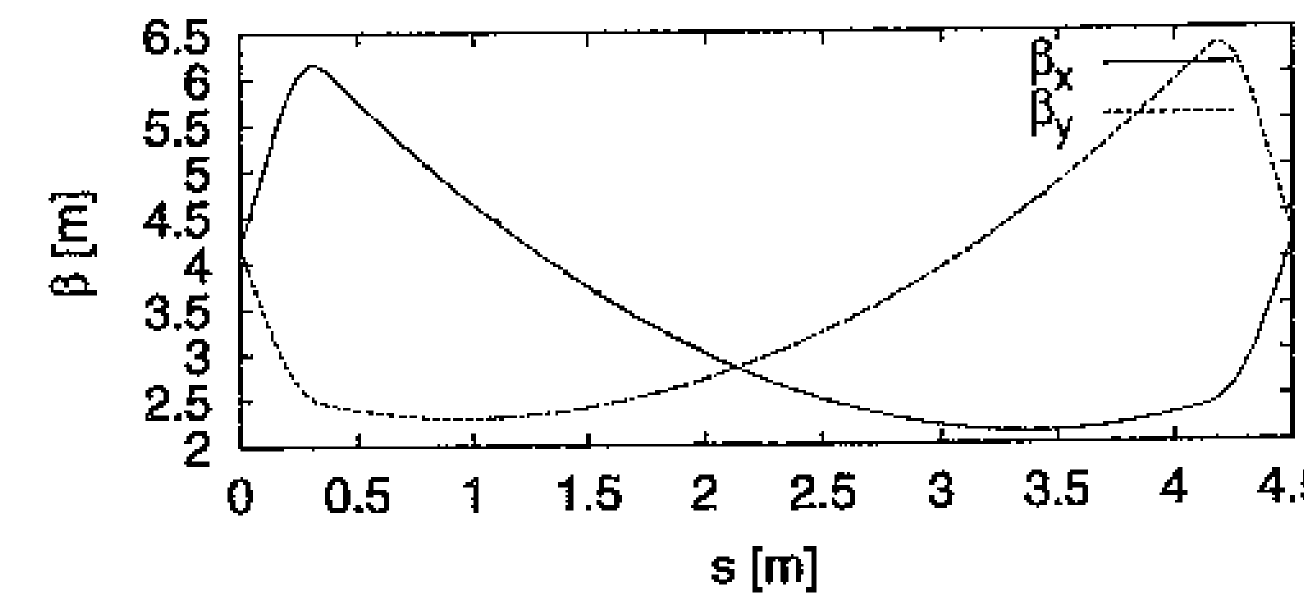
Triplet-Lattice



$\mu_x \approx 95°$

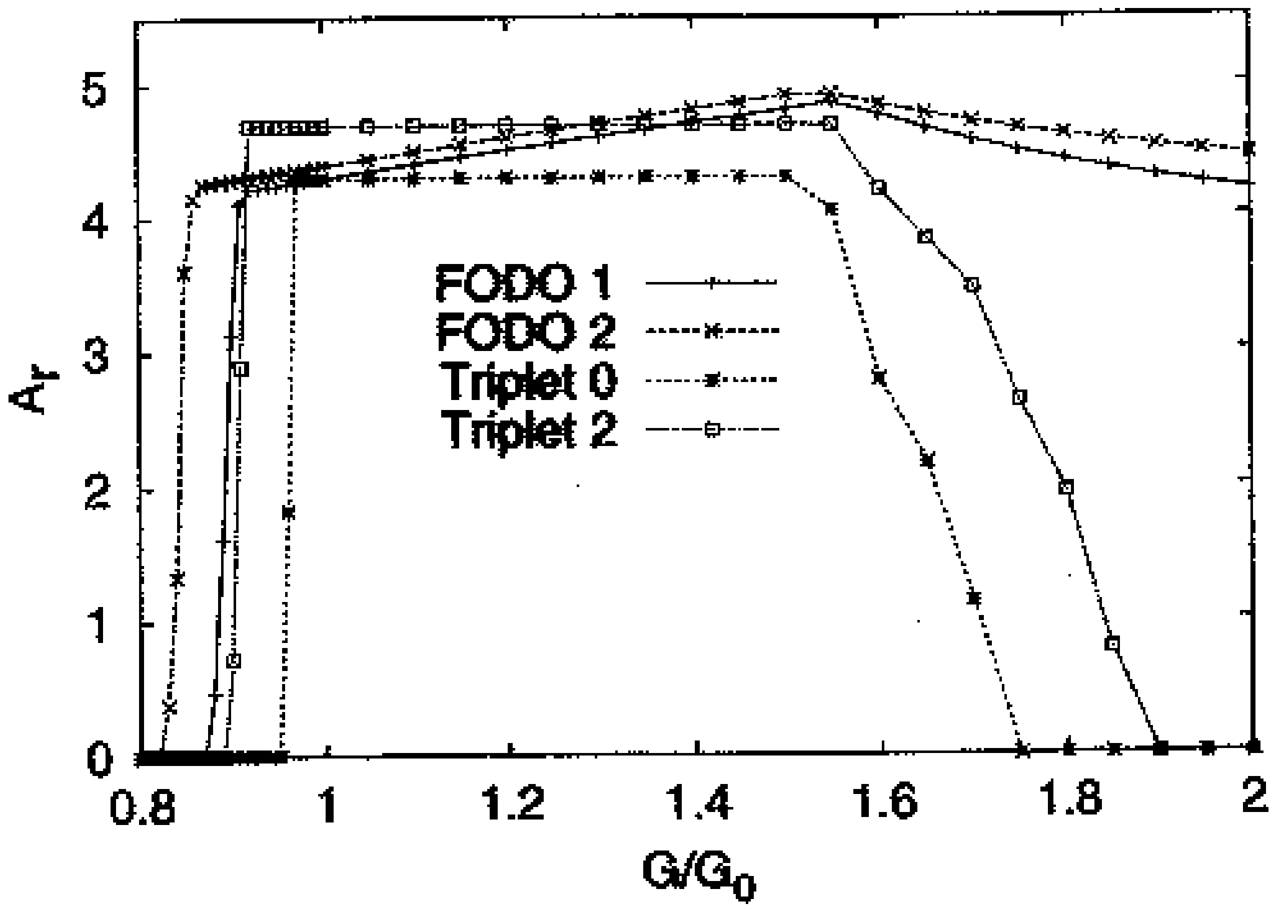
$\mu_y \approx 110°$

Doublet-Lattice



$\mu_{x,y} \approx 80°$

Gradient Error



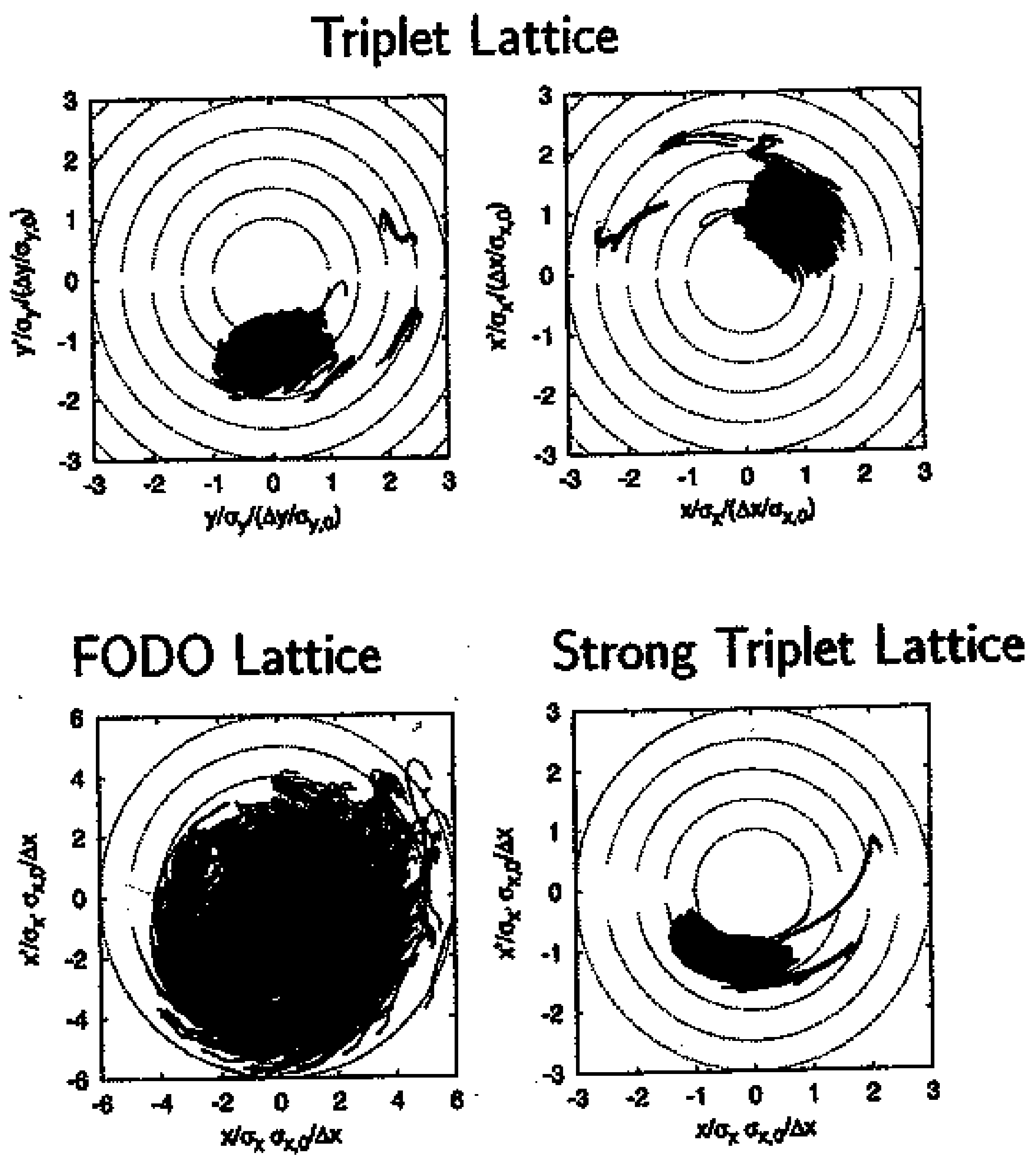
The acceptance A_r is defined such that any particle with initial positions x_0, x'_0, y_0 and y'_0 that fulfils

$$\sqrt{\left(\frac{x_0}{\sigma_{x,0}}\right)^2 + \left(\frac{x'_0}{\sigma_{x',0}}\right)^2 + \left(\frac{y_0}{\sigma_{y,0}}\right)^2 + \left(\frac{y'_0}{\sigma_{y',0}}\right)^2} \leq A_r$$

will pass through the accelerator.

⇒ a gradient that is too high is less of a problem than a gradient that is too low

Jitter Amplification

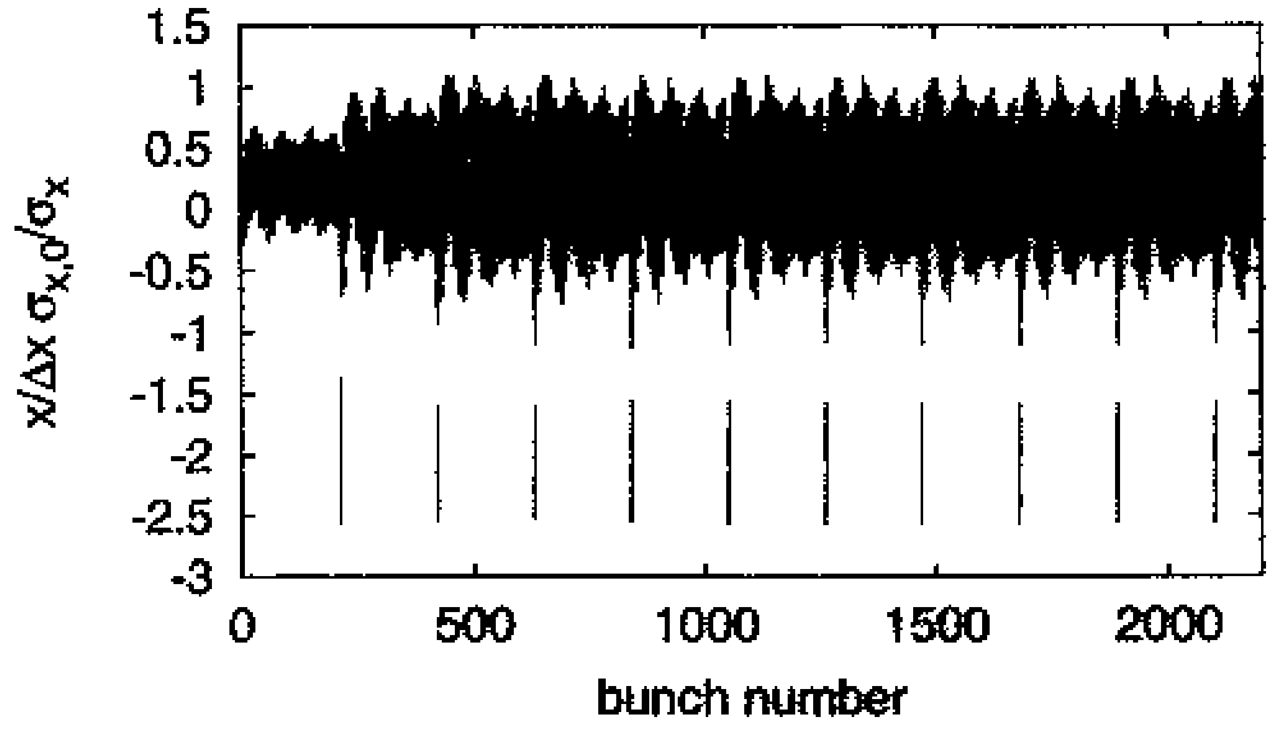


Single bunches are kicked hard

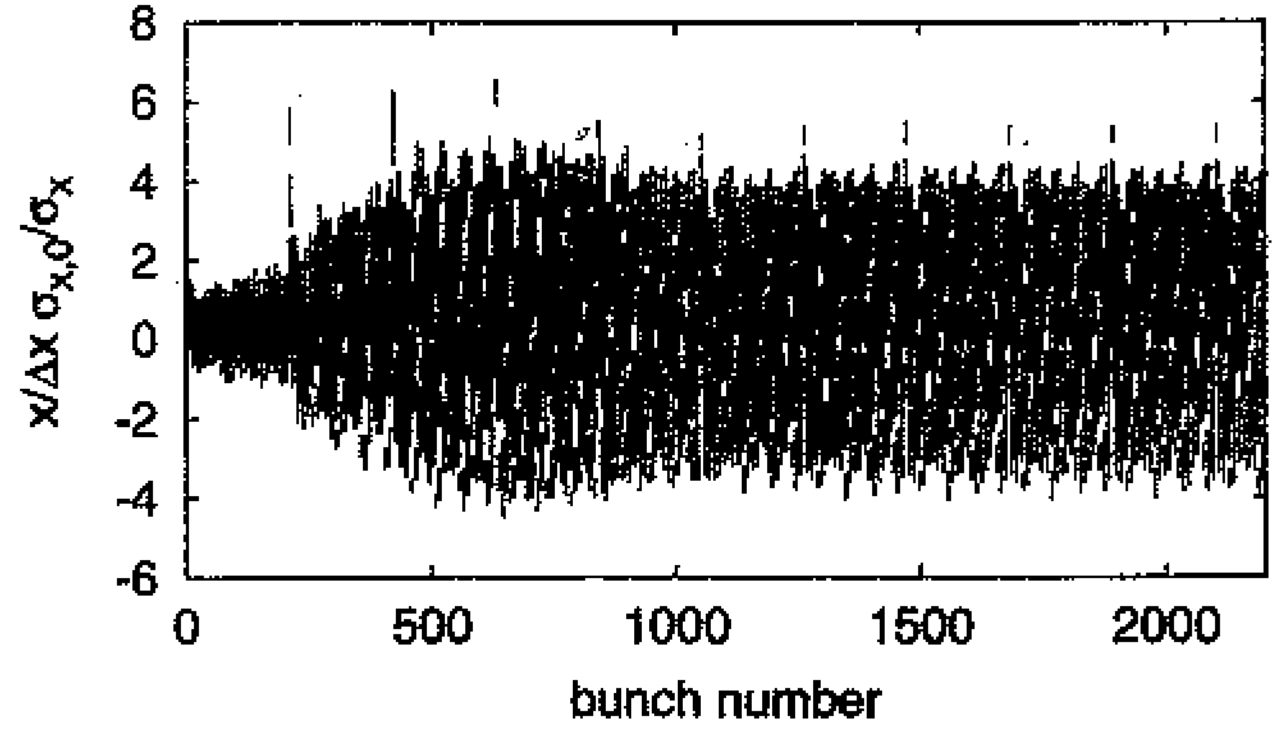
⇒ triplet lattice better than FODO lattice

Jitter Amplification

Triplet Lattice

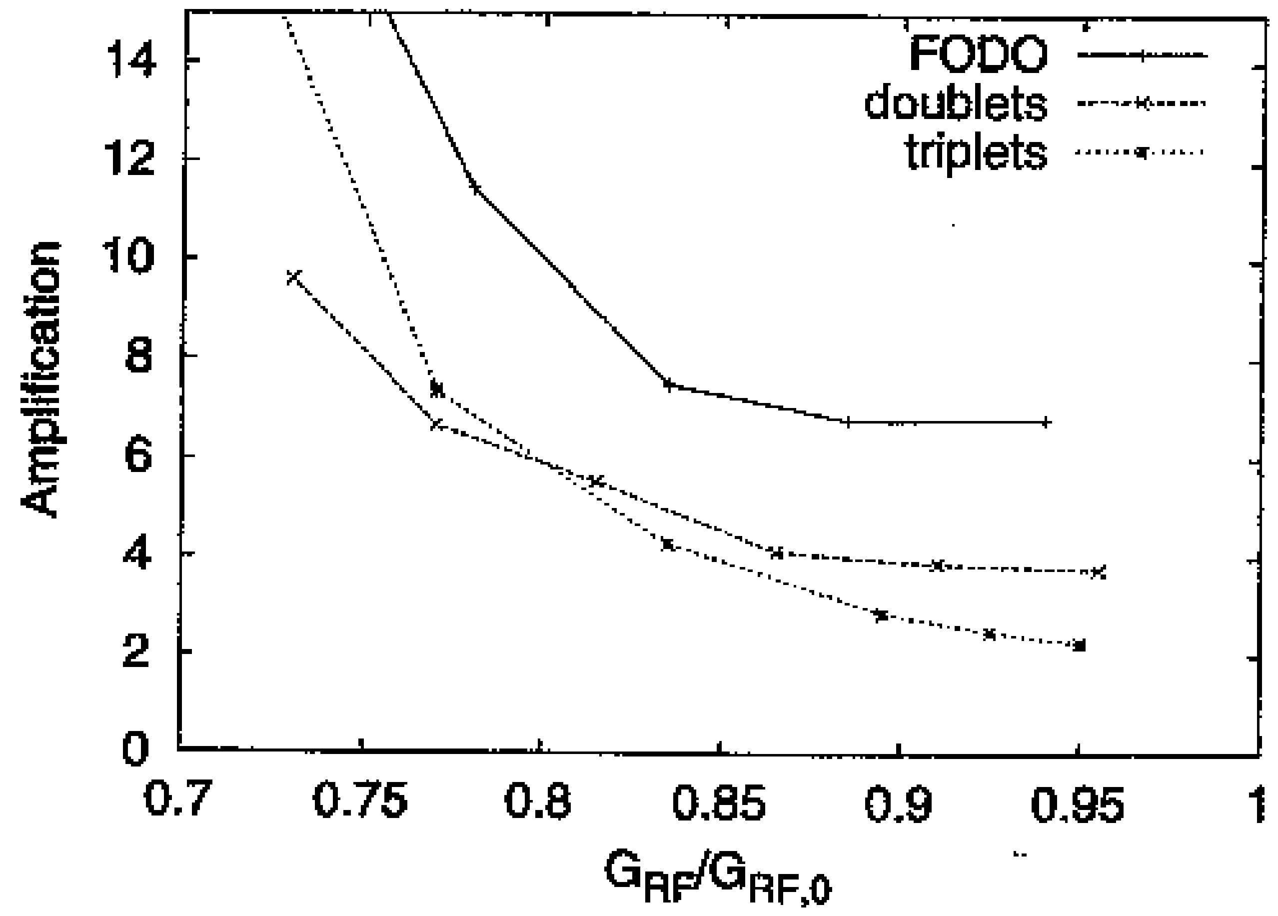


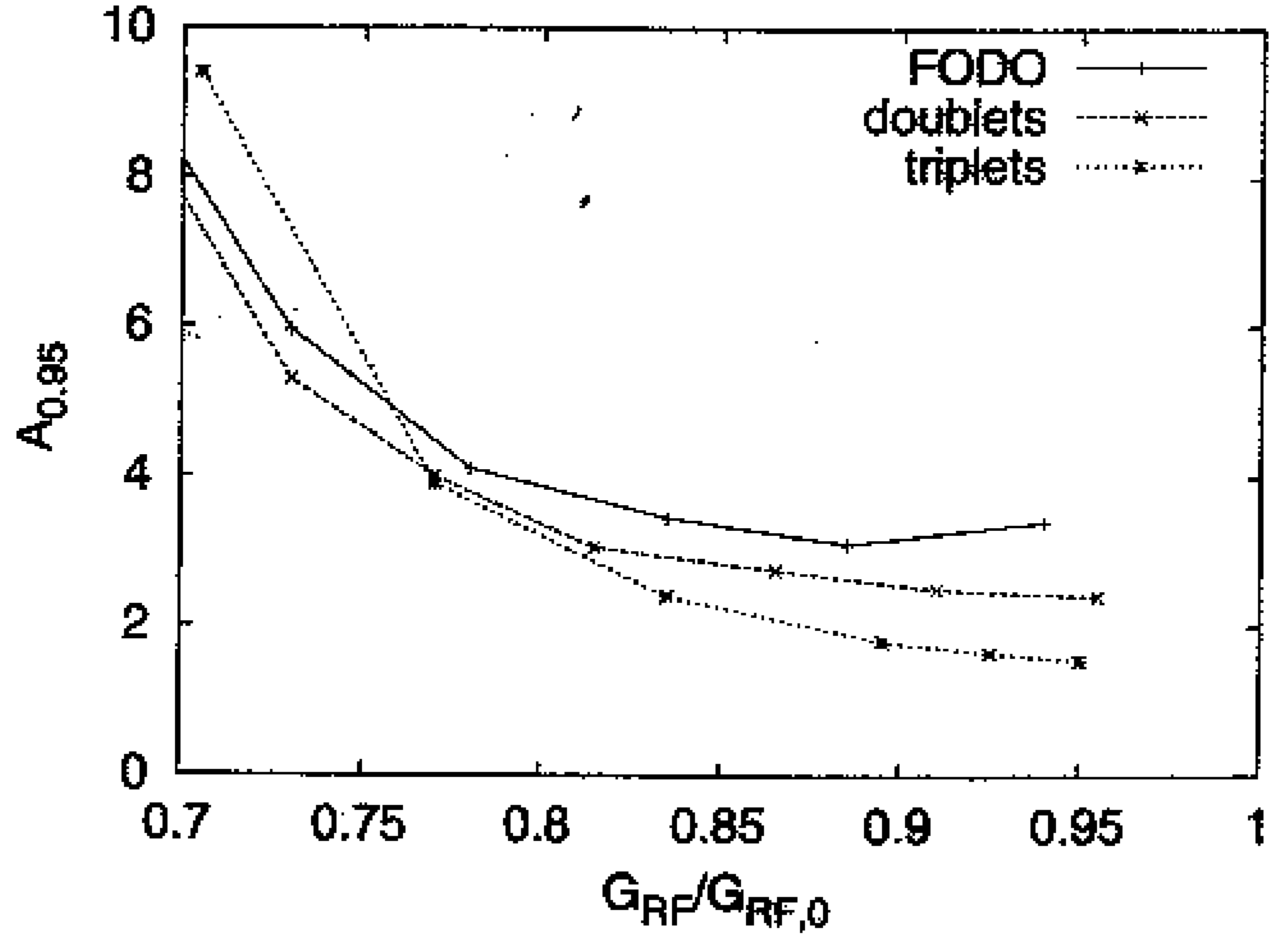
FODO Lattice



bunches at intersections of trains are kicked hard

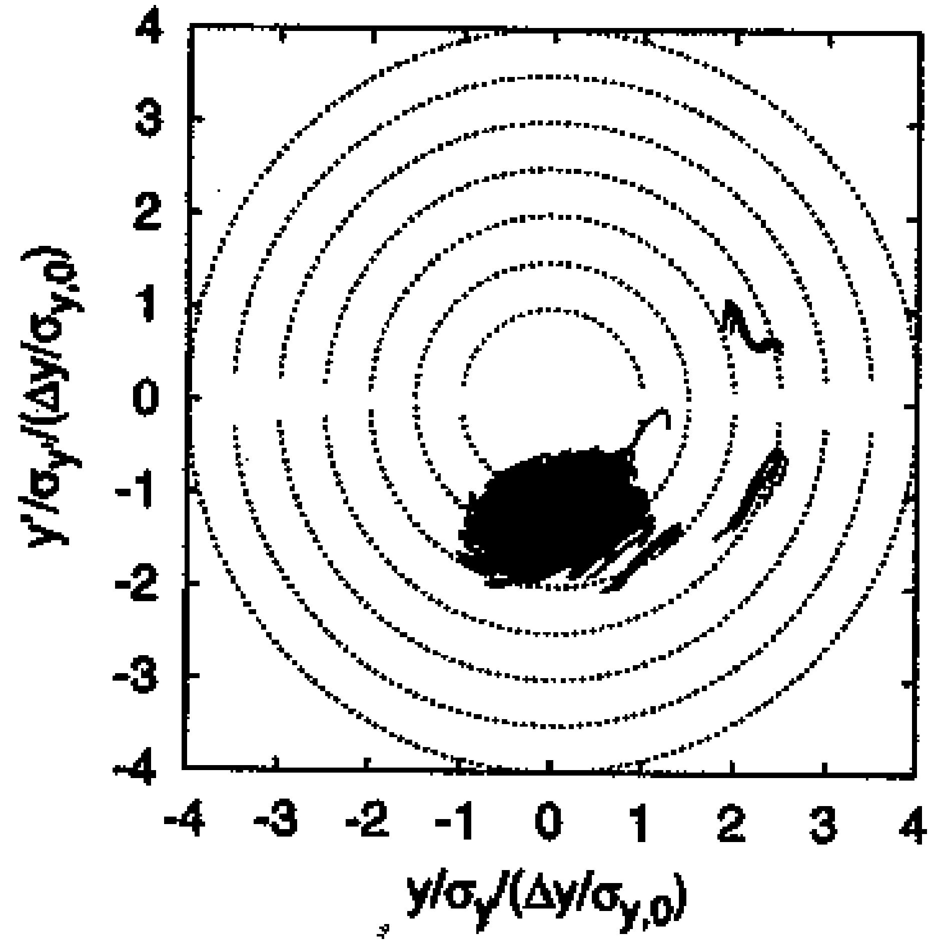
Amplification vs. Energy Acceptance



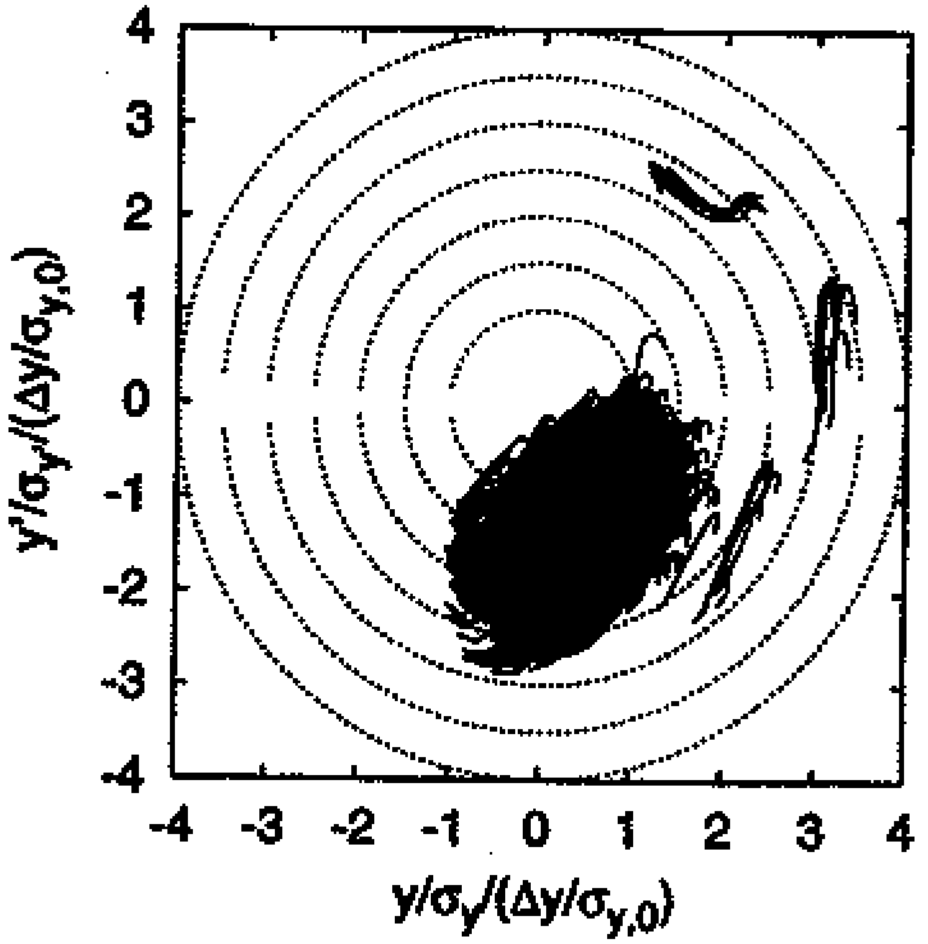


Initial Energy

$E_0 = 24\,\mathrm{MeV}$



$E_0 = 16\,\mathrm{MeV}$



Bunch-to-Bunch Transverse Jitter

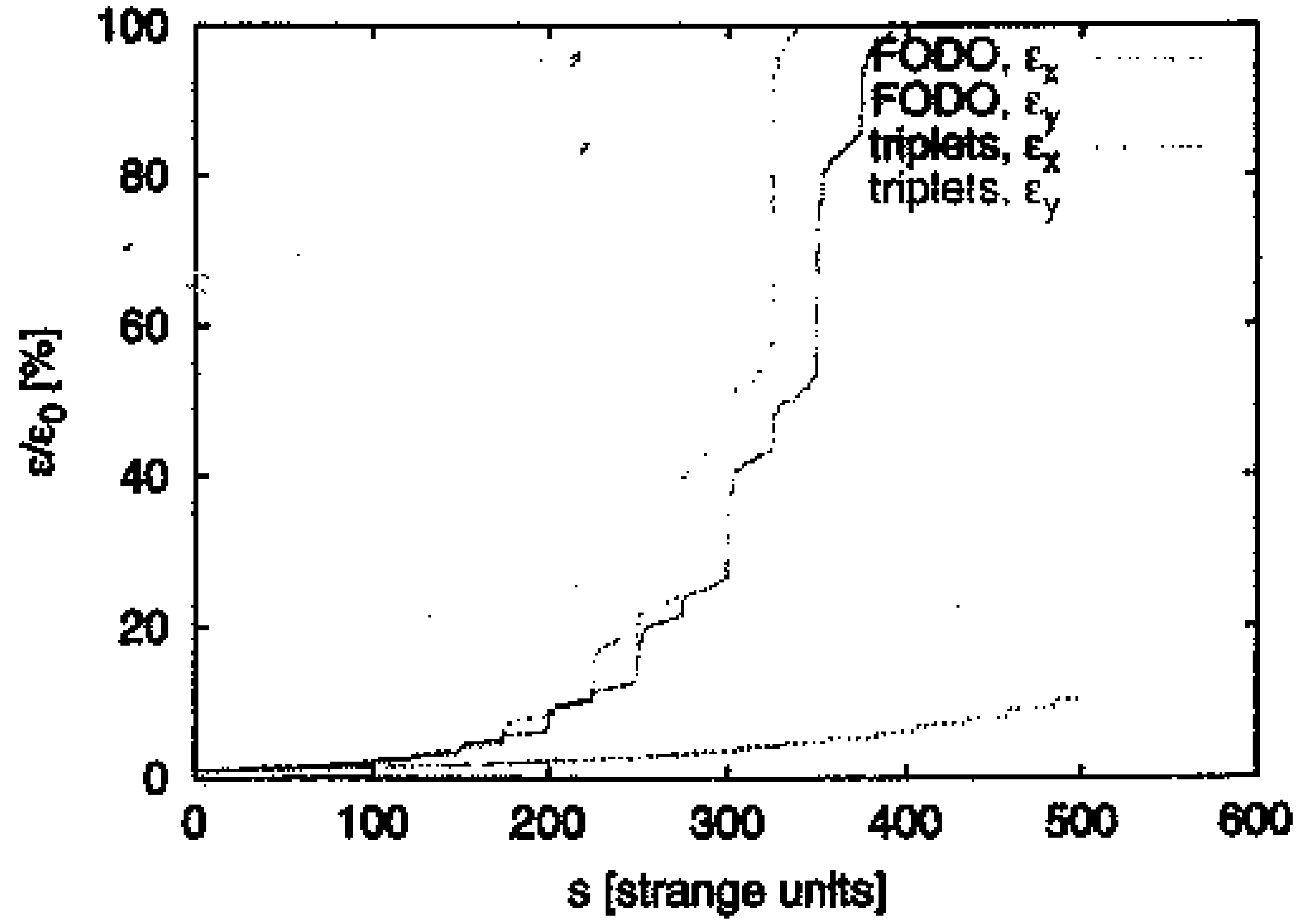
Hard to measure

should be absent in slow devices

but sub-harmonic bunches is fast

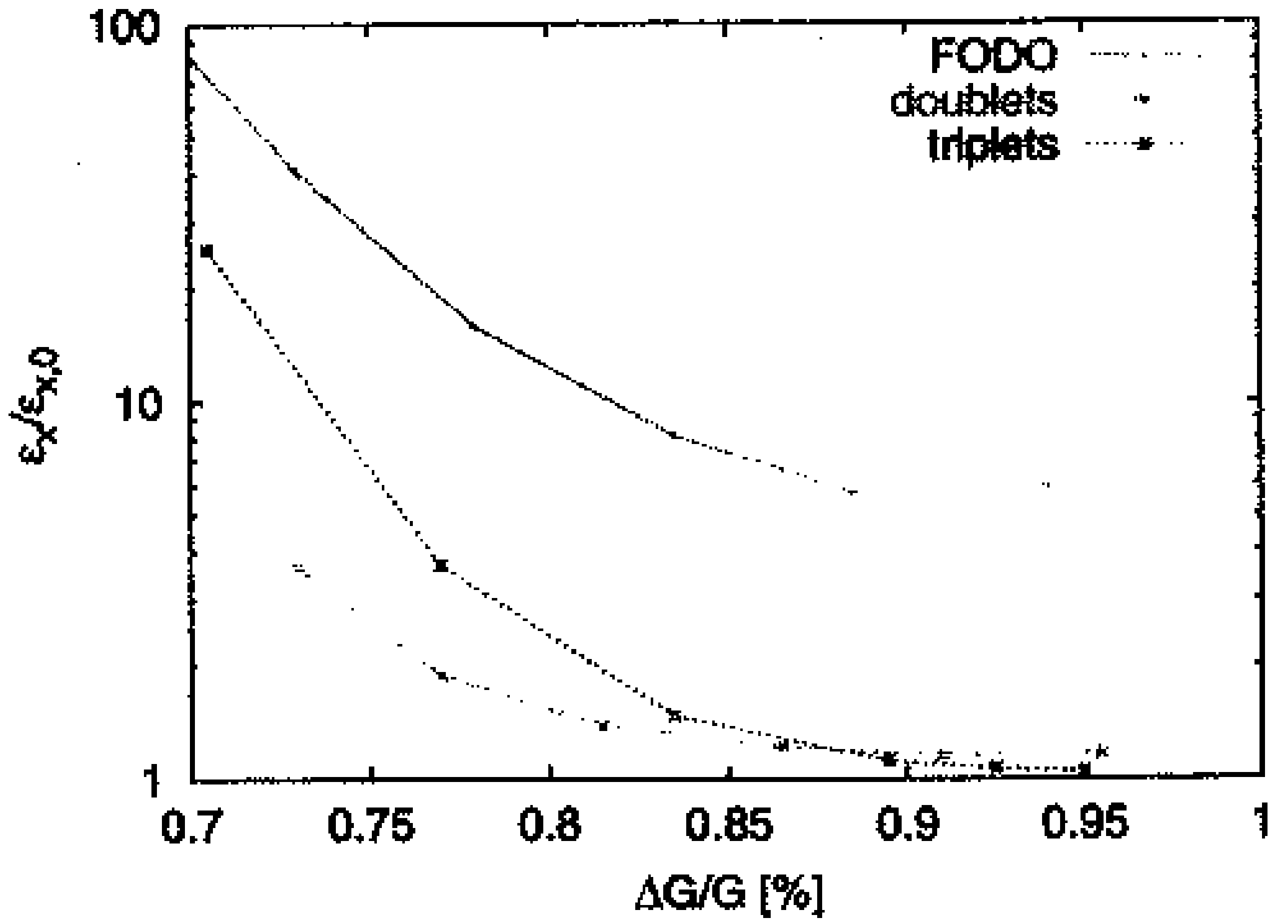
an angle and position jitter of $\delta = 0.1\sigma$ increases emittance by only 1%

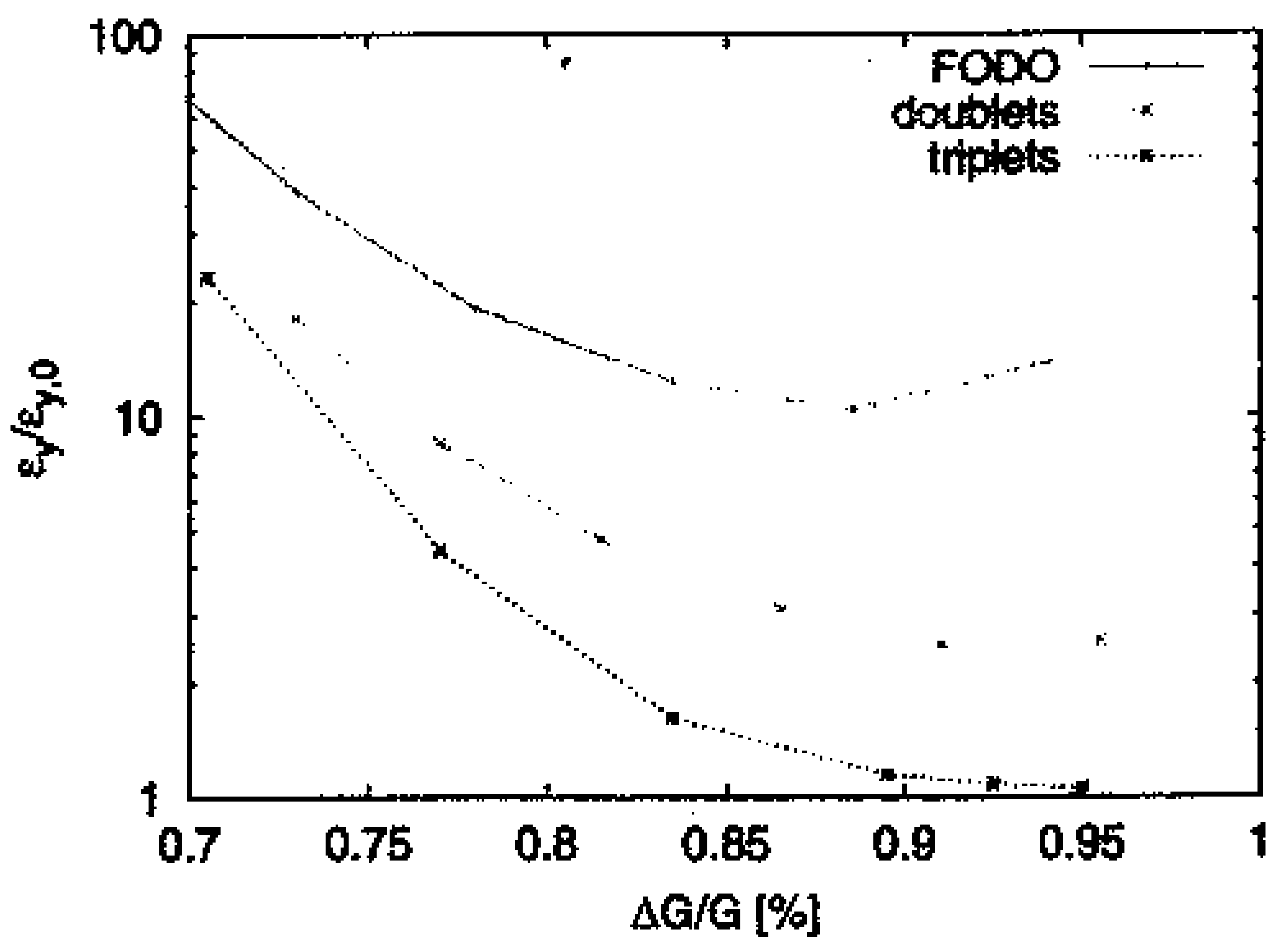
should not lead to a large emittance due to wakefields



⇒ use triplet lattice

Bunch-to-Bunch Transverse Jitter, Cont.





⇒ triplet lattice

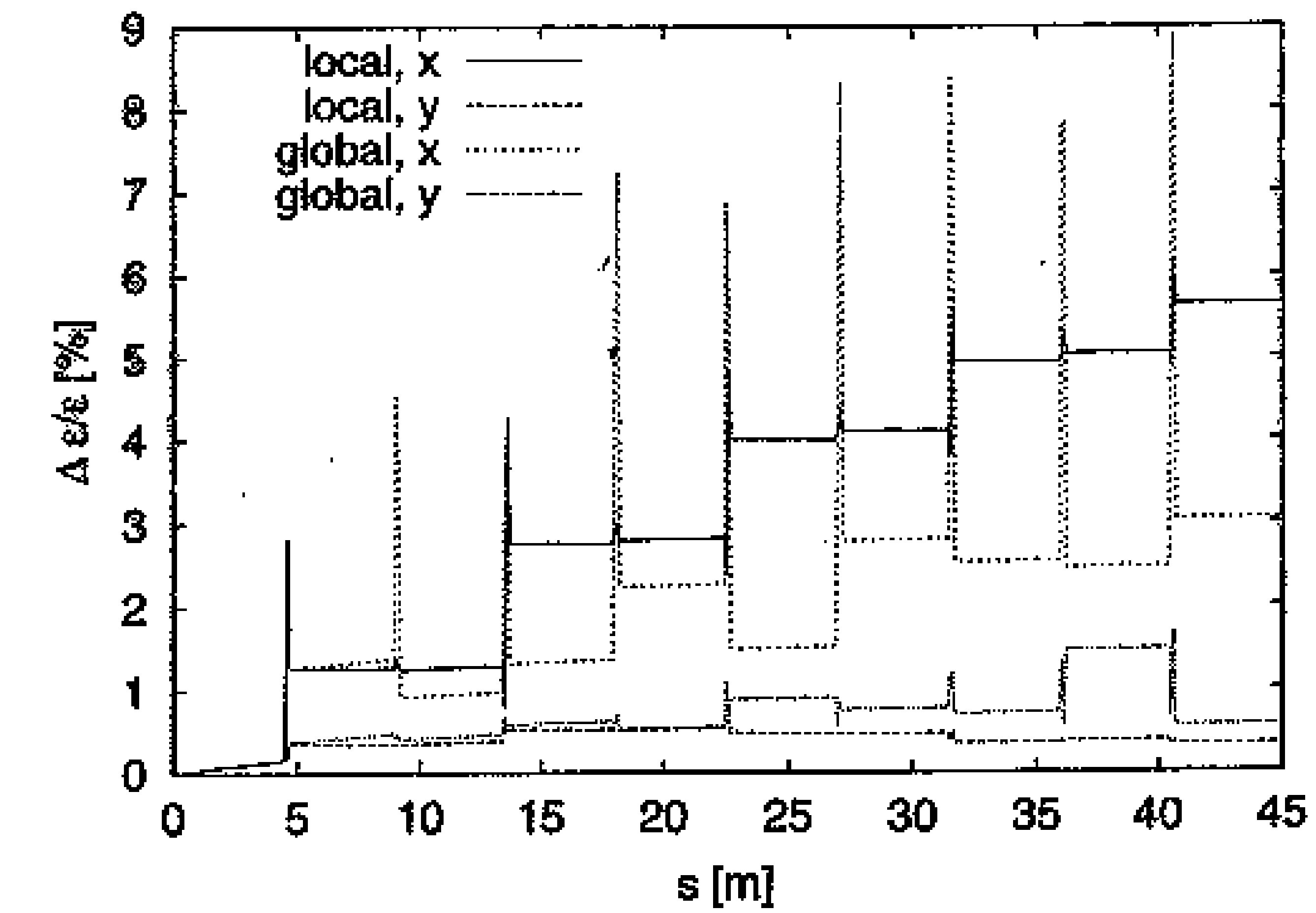
Chromatic Emittance Growth

Gradient is assummed to vary slowly

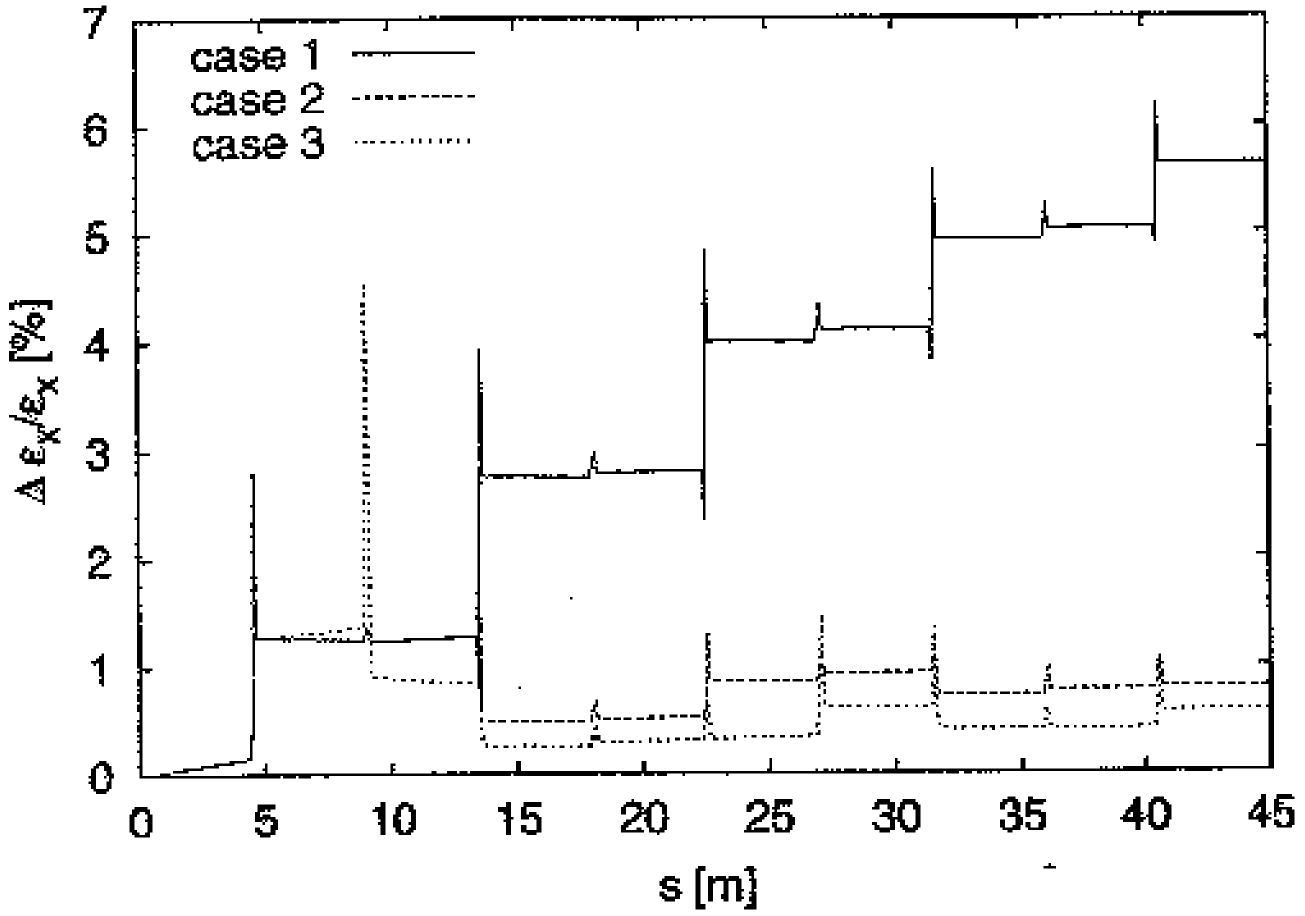
amplitude $\delta = 5\,\%$

next pair of structures has opposite variation

$$
\begin{aligned}
G_1(s) &= G_0(1+\delta\sin(2\pi s/L_{train})) \\
G_2(s) &= G_0(1\pm\delta\sin(2\pi s/L_{train}))
\end{aligned}
$$



Local Gradient Variation



Vertical emittance growth is smaller

three cases considered

1)

2)

3)

Beam-Based Alignment

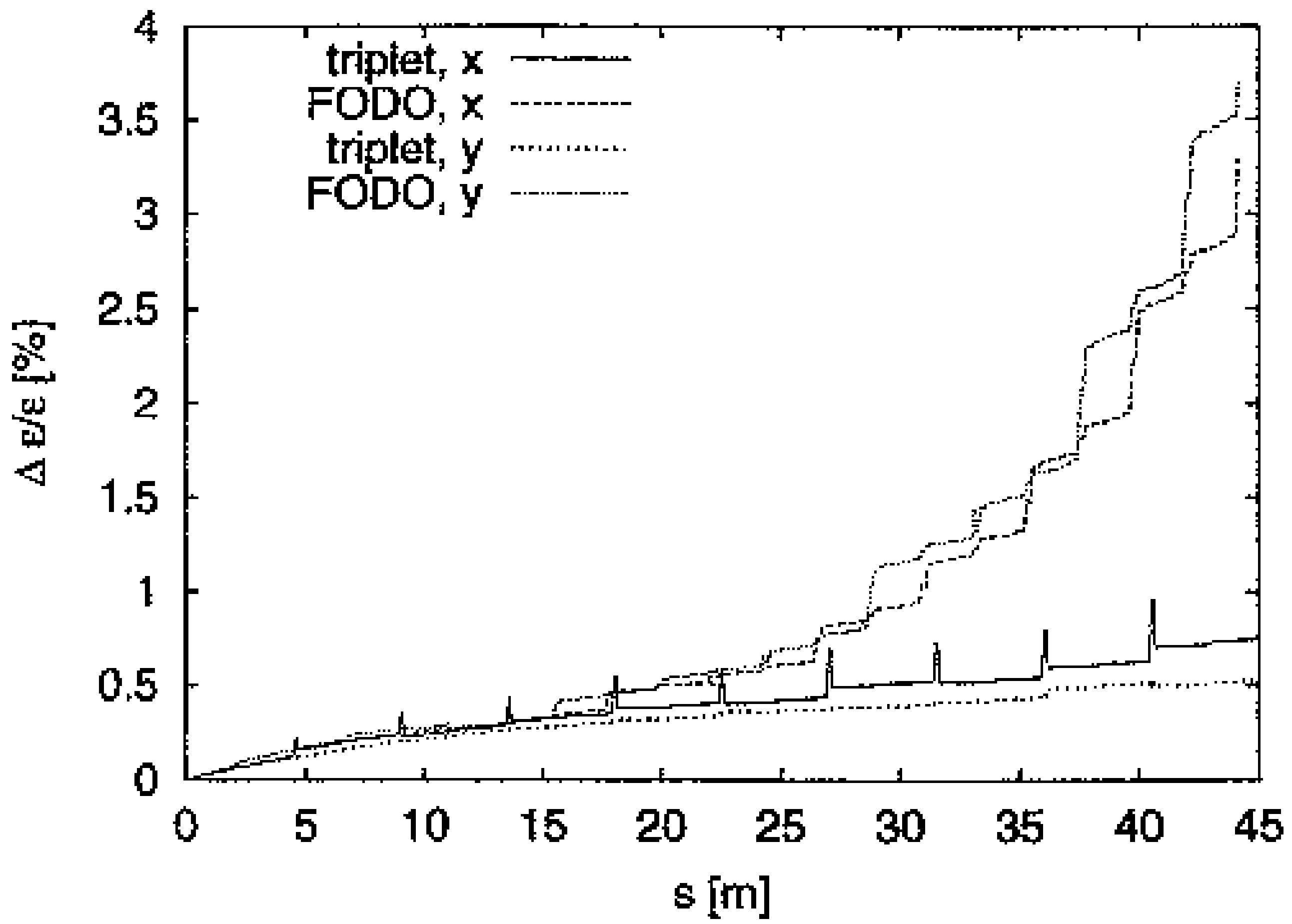
All elements are initially misaligned with an RMS of $200\,\mu\mathrm{m}$

one-to-one correction used as beam-based alignment

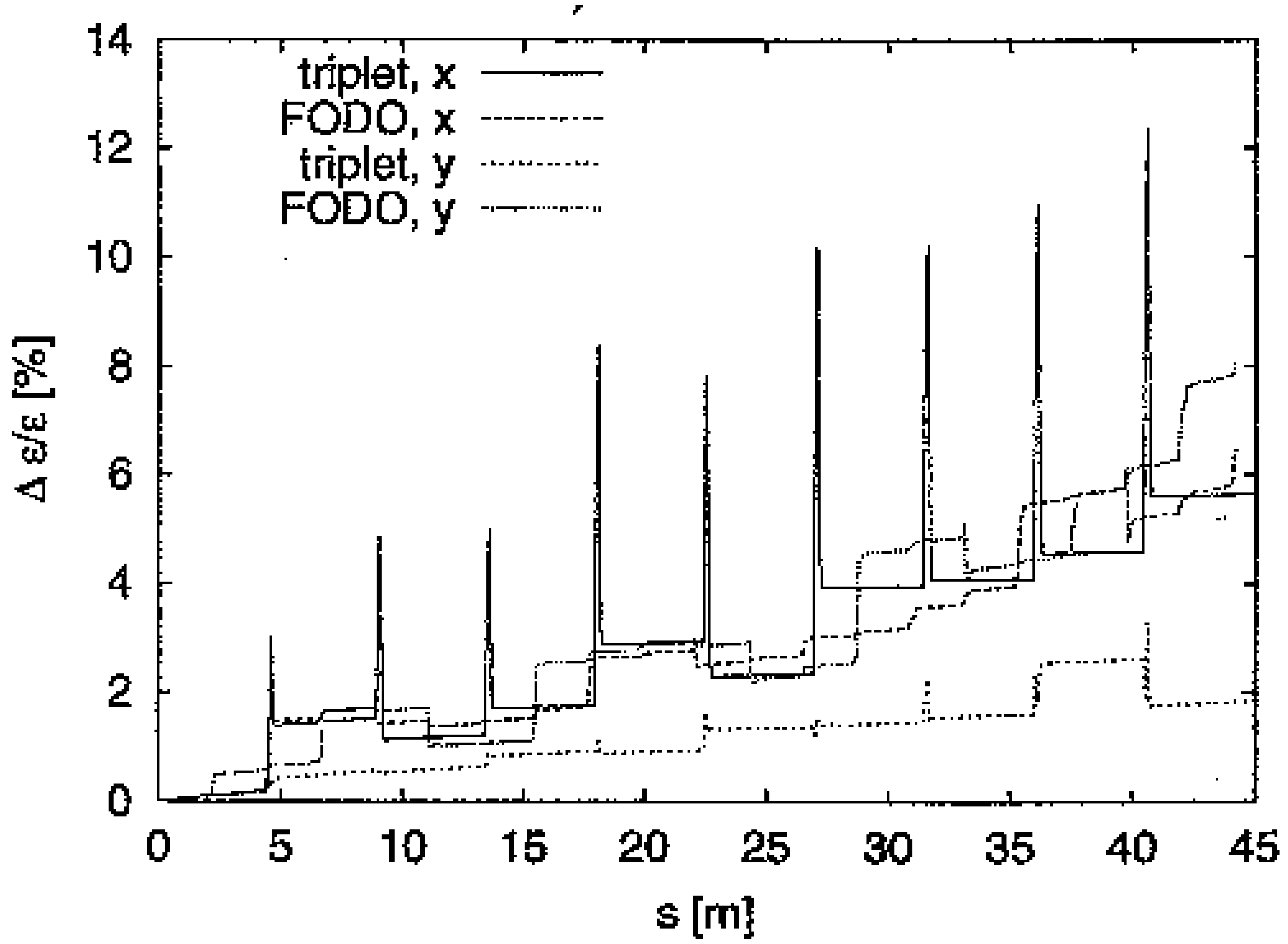
each dipole corrector is set to minimise offset in the next BPM

FODO-Lattice vs. Triplet-Lattice

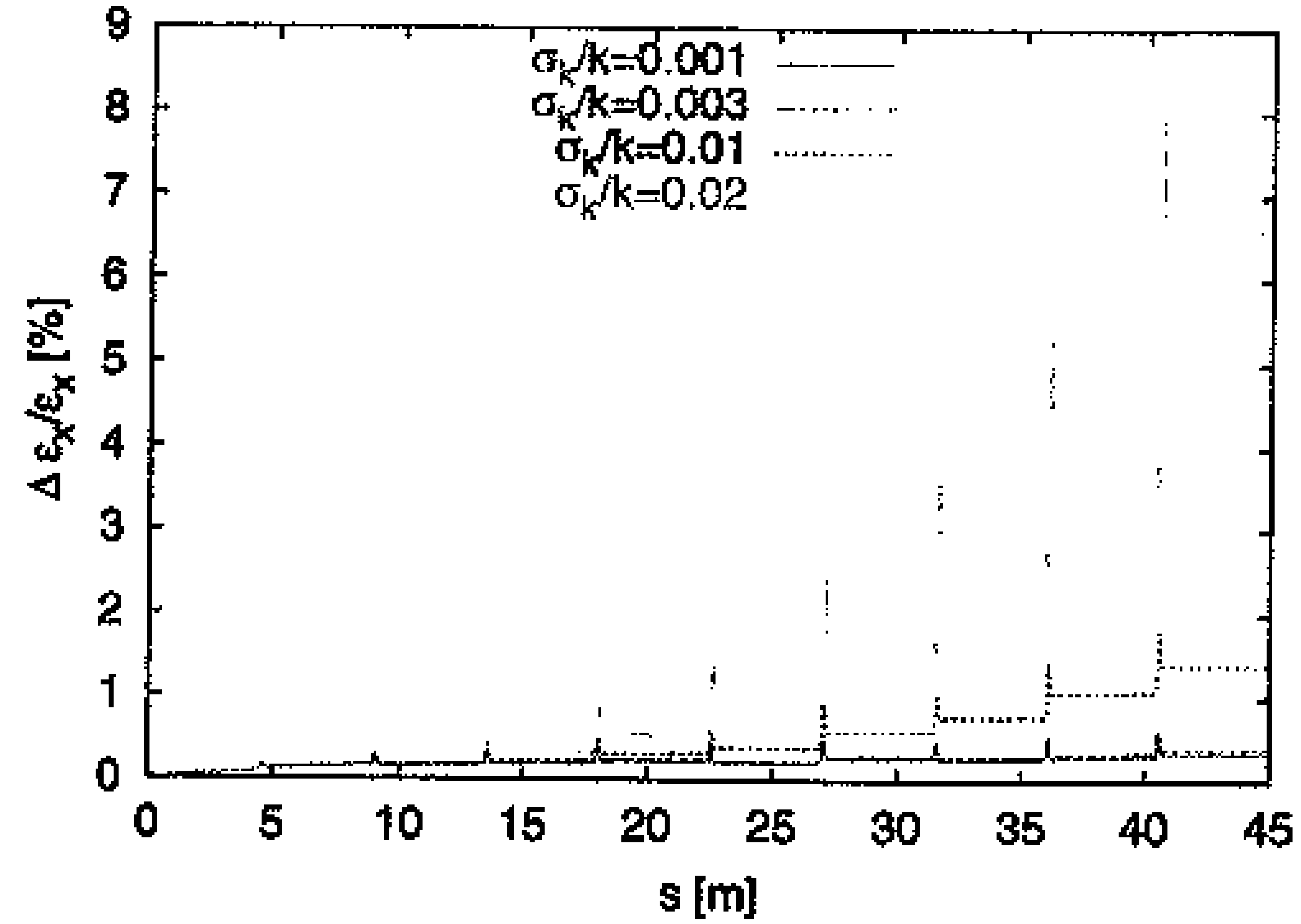
Local gradient error with $\delta = 0\%$



Local gradient error with $\delta = 5\%$



Quadrupole Strength Error



A Gaussian error has been added to quadrupole strengths

the average over 100 machines is shown

the vertical plane is much better

$\Rightarrow$ an error of $\sigma_k/k \leq 0.01$ seems acceptable

average betatron function enlarged by quadrupole error

maximum $A_{0.95}$ for beam jitter for 100 simulated machines is 2.35 for $\sigma_k/k \leq 0.01$ (1.85 without betatron mismatch)

Conclusion

Triplet lattice with two structures per triplet gives better compromise between wakefield and dispersive effects than FODO lattice

$\Rightarrow$ use triplet lattice

beam and bunch-to-bunch jitter amplification is large in FODO lattice

$\Rightarrow$ but triplet lattice is OK

local gradient variation is of some concern

$\Rightarrow$ break resonance

static emittance growth is small

corrector would be better placed in the centre of triplet

$\Rightarrow$ but not too much improvement

Drive Beam Accelerator Structures
E. Jensen

CLIC

History

- Feb-00: successful TDS high power tests,
- May-00: re-considering slotted iris structure,
- Jul-00: SICA – combining slotted iris with constant aperture
- 22-Nov-00: Market Survey started (SICA & TDS)
  30 European firms contacted, 6 interested and qualified to bid.
- 30-May-01: Invitation to Tender (SICA & TDS)
  6 firms contacted, 4 positive answers
- 20-Aug-01: successful SICA high power tests
- 23-Aug-01: Tender opening, structure type decided (SICA)
- 19-Sep-01: Proposal through FC, letter of intent dispatched

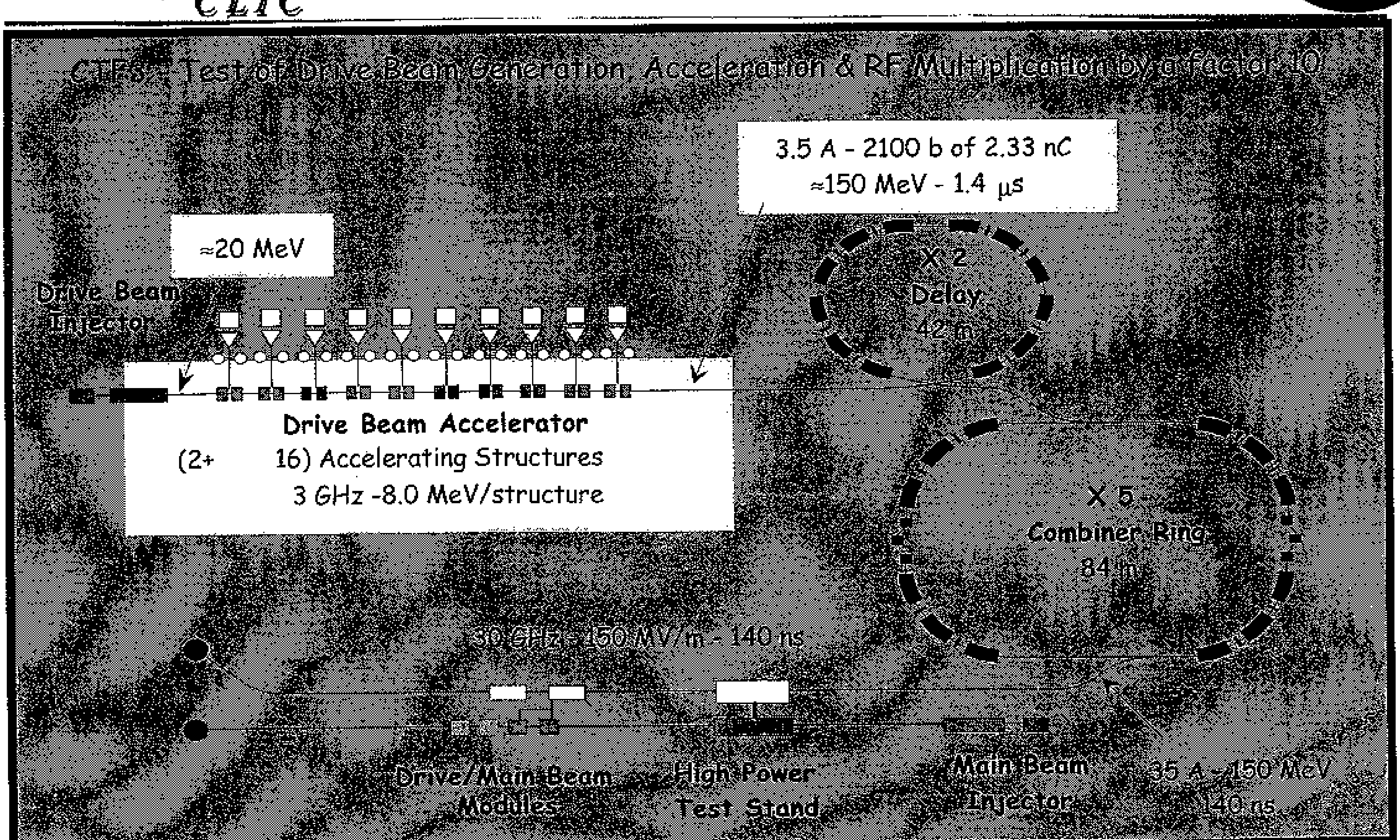
.... *now*

- Apr-02: 1st full size prototype ready
- Apr-03: delivery of 18 SICA structures

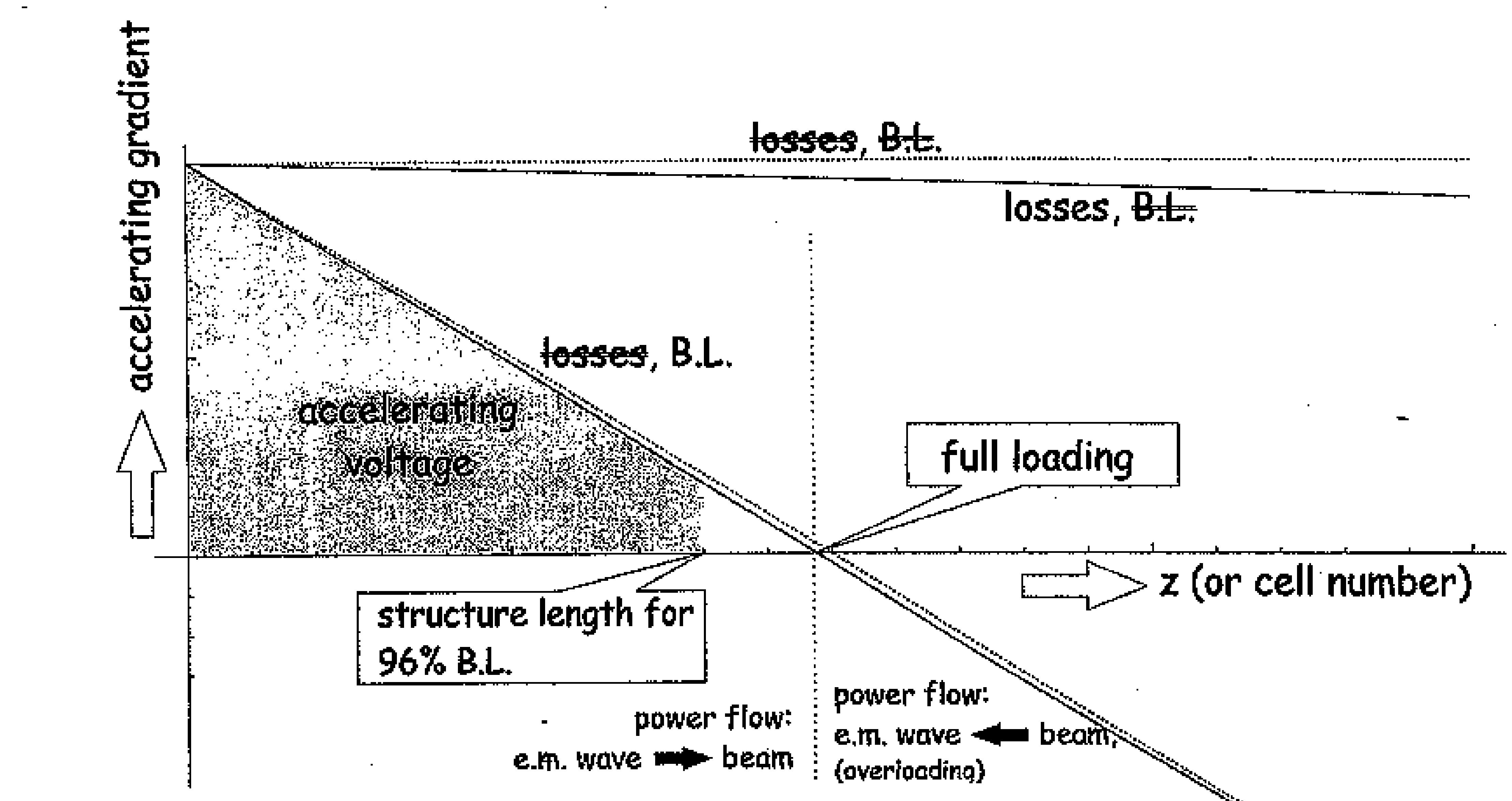
Challenges

1. Full beam loading
   allows for very high efficieny!
2. Transverse wakefields
   serious issue: beam current 3.5 A, 1.5 μs!

CTF3 DBA



Full beam loading



This illustration simplified for constant impedance

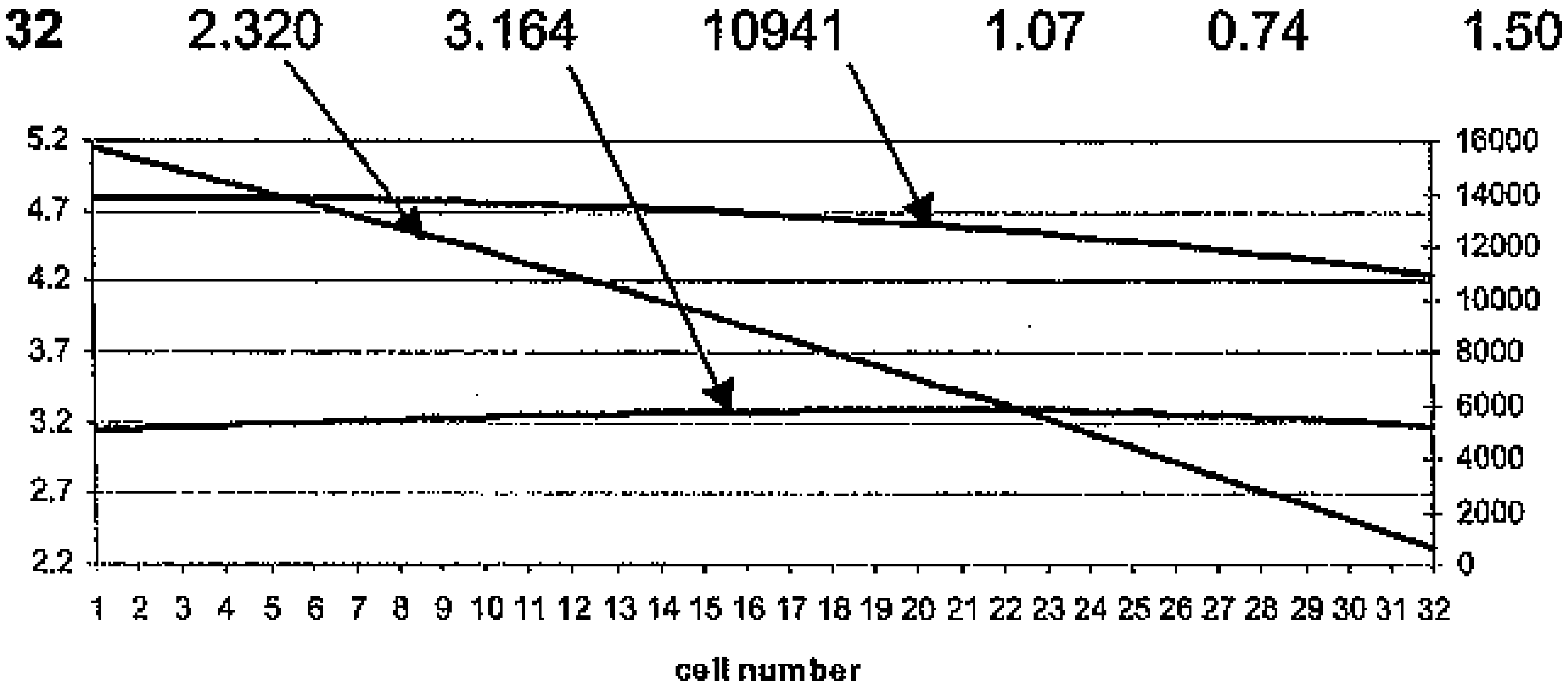
- initial gradient $\propto \sqrt{P_{in}}$
- overloading if
  - current too high, or
  - input power too small, or
  - structure too long.

"smooth" approximation:

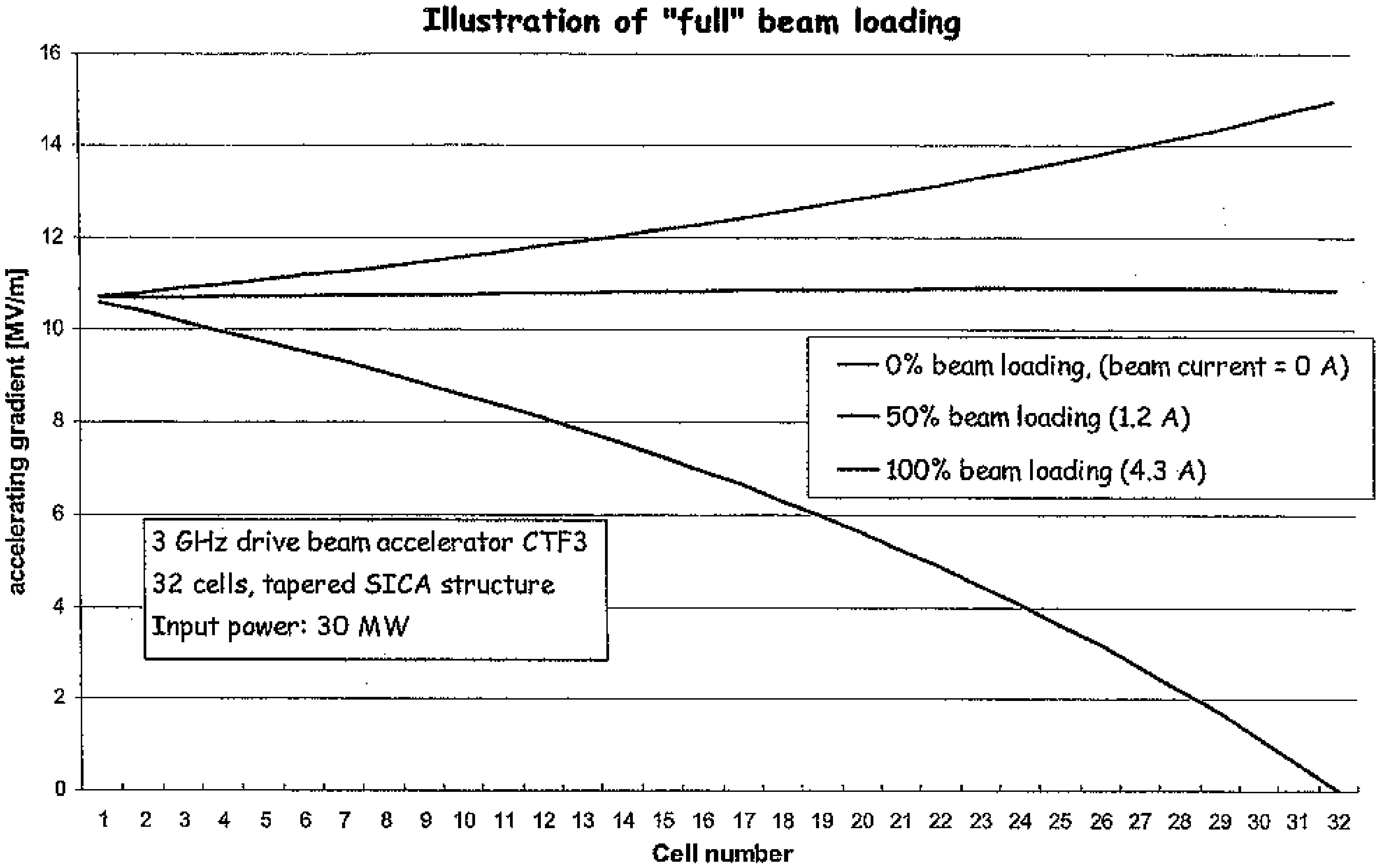
$$\frac{d}{dz}E_{acc} = -\frac{\omega}{2v_g}\frac{r}{Q}I_B - \frac{\omega}{2v_g}\frac{1}{Q}E_{acc}$$

"nominal" case - 32 cells

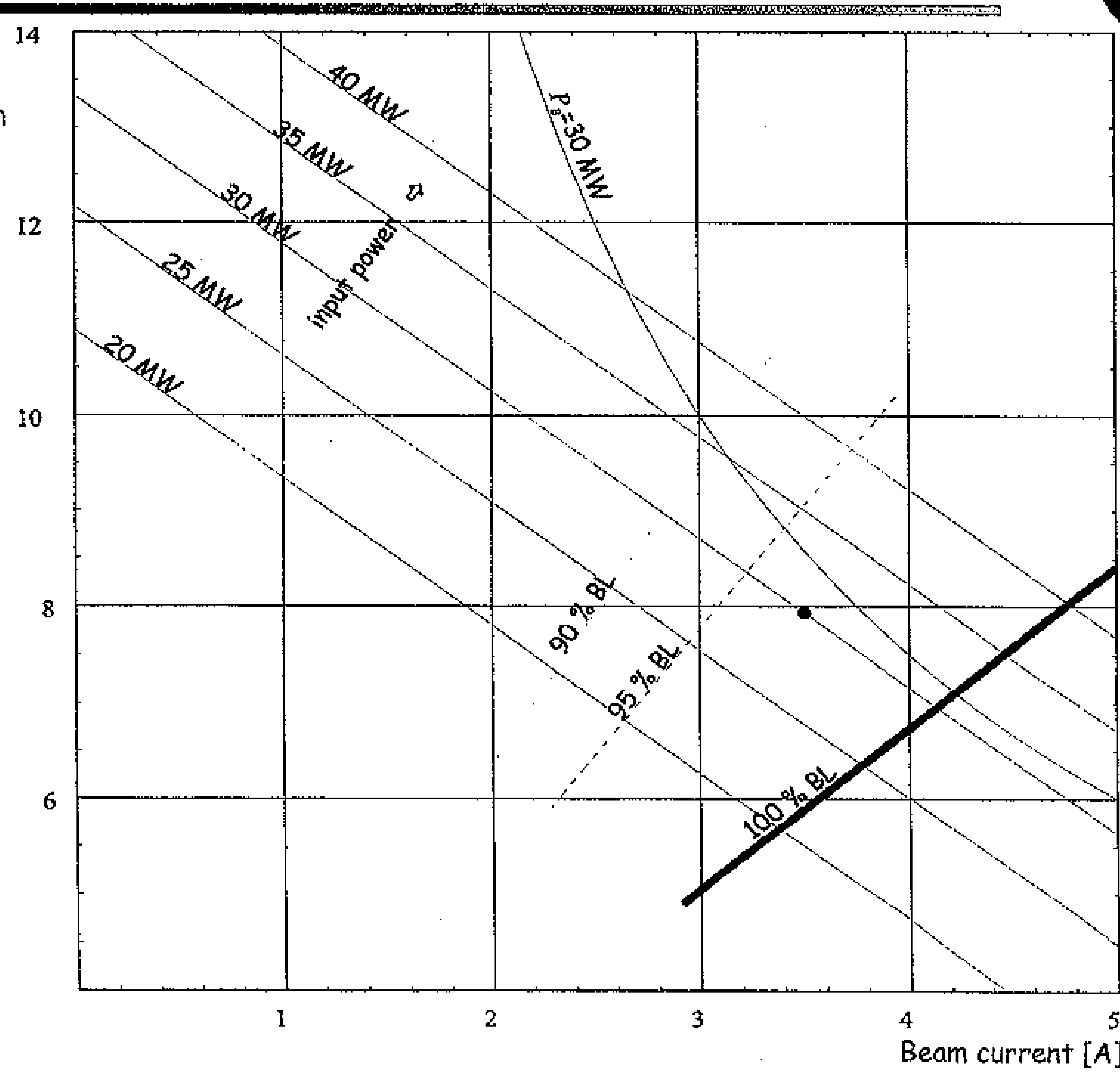
cell#	vg[% c]	R'/Q[kΩ/m] (Linac def.)	Q	P_{in}[MW]	P_{out}[MW]	P_{loss}[MW] accum.	P_B[MW] accum.	W[mJ]	V[kV]	V[MV] accum.
1	5.155	3.145	13868	30.00	28.68	0.09	1.24	63	353.39	0.353
4	4.918	3.176	13871	26.09	24.83	0.33	4.85	58	338.69	1.384
7	4.674	3.206	13874	22.36	21.16	0.55	8.29	52	322.72	2.369
10	4.421	3.235	13645	18.83	17.70	0.74	11.56	46	305.35	3.303
13	4.160	3.260	13488	15.51	14.45	0.92	14.63	40	286.16	4.181
16	3.891	3.279	13273	12.41	11.44	1.07	17.49	34	264.80	4.997
19	3.614	3.289	12994	9.58	8.69	1.20	20.10	28	240.85	5.744
22	3.328	3.288	12644	7.03	6.24	1.31	22.45	22	213.86	6.413
25	3.035	3.273	12220	4.79	4.13	1.39	24.48	16	183.19	6.995
29	2.632	3.225	11539	2.39	1.90	1.47	26.64	9	135.29	7.610
32	2.320	3.164	10941	1.07	0.74	1.50	27.76	4	92.81	7.933



acc. gradient dependance on beam current



"nominal" case - 32 cells



nominal w/o coupler cells:
7.93 MeV,
η = 92.5 %,
κ= 97.4 %,
τ = 98.6 ns

with coupler cells:
7.97 MeV
η = 93 %,
κ= 97.9 %
τ = 100.4 ns

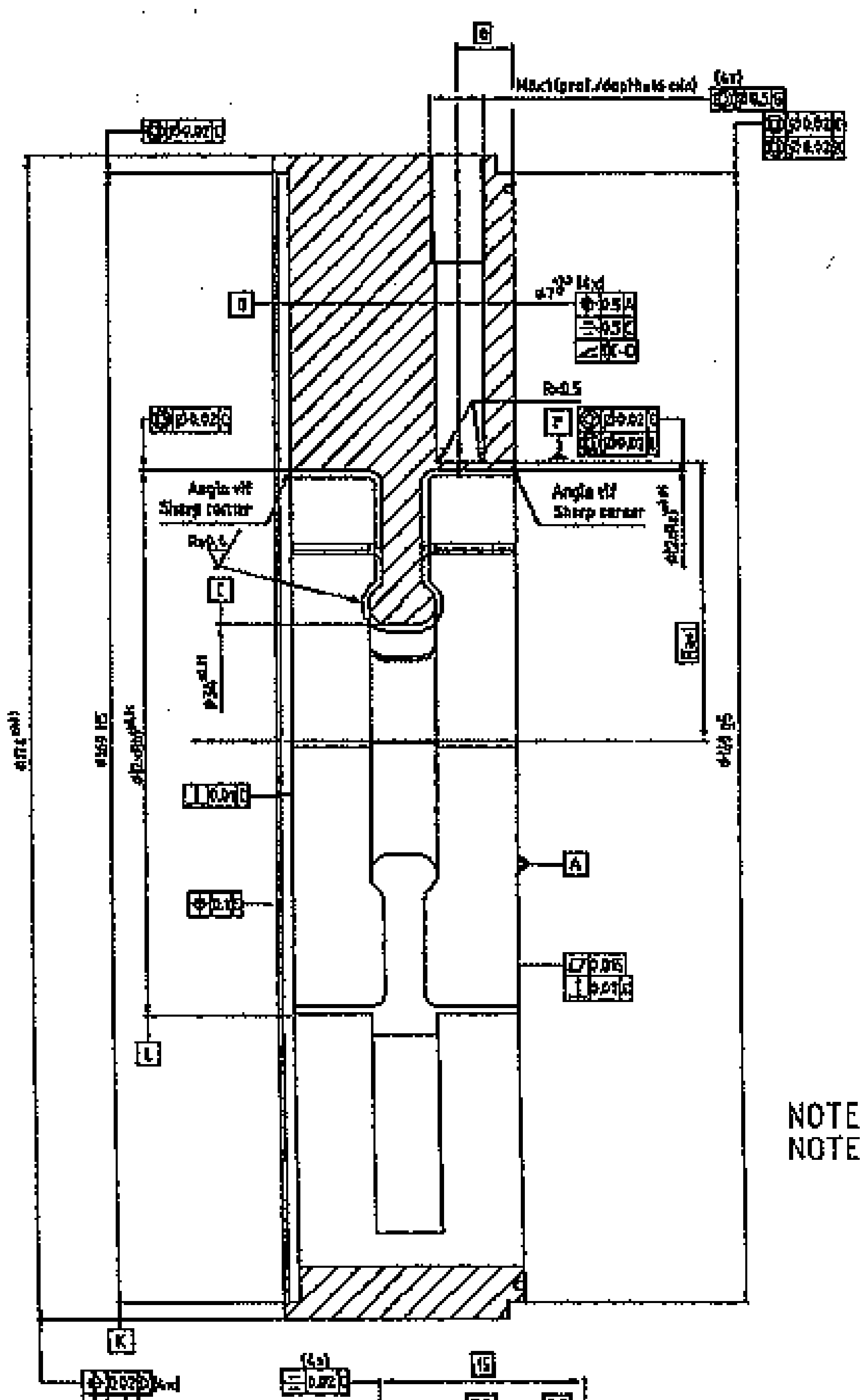
Transverse wakefields- two solutions

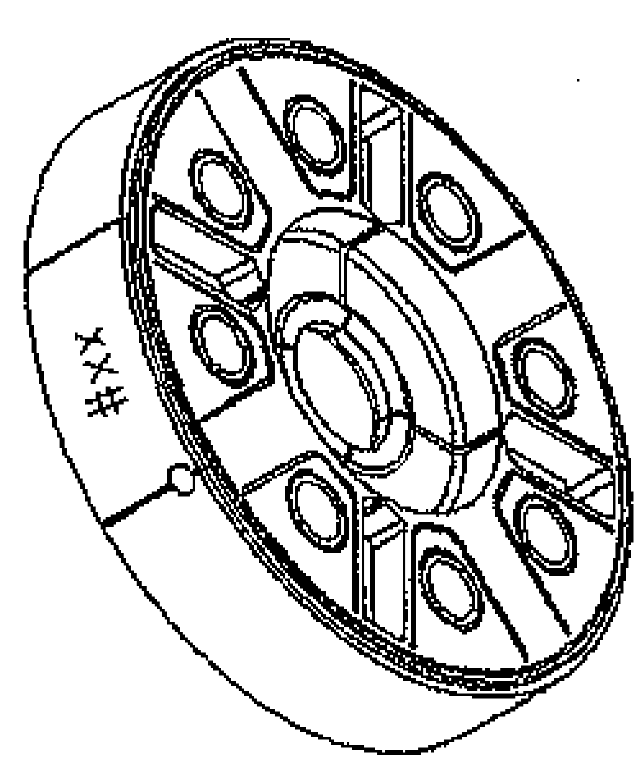
CLIC

SICA (slotted iris - constant aperture)	**TDS** (tapered damped structure)
Detuning method:	
varying nose cones (a = 17 mm, nose = 0 ... 4.66 mm), constant (large) aperture ⇒ low short range wake	iris variation (a = 17 ... 13.3 mm), wide detuning
Mode selection (selectively damp HOM's, but not the fundamental !):	
geometric type (uses field symmetry)	filter type
radial iris slots couple dipole modes to SiC loads placed in currugated waveguides.	waveguides with cutoff > 3 GHz to couple HOM's to SiC loads.
Calculated damping of 1st dipole:	
$Q \approx 5$	$Q \approx 18$
Construction:	
external diameter 174 mm, compact, round.	larger external diameter 460 mm, possibility to access SiC after brazing
Status (Octobre 2001):	
4 cell prototype tested (35 MW), full size prototype being built	prototype ready, high power tested up to 40 MW.
Potential issues:	
field enhancement (1.3) near slot	fabrication(?), handling(?)

SICA excerpt tech. drawing

CLIC

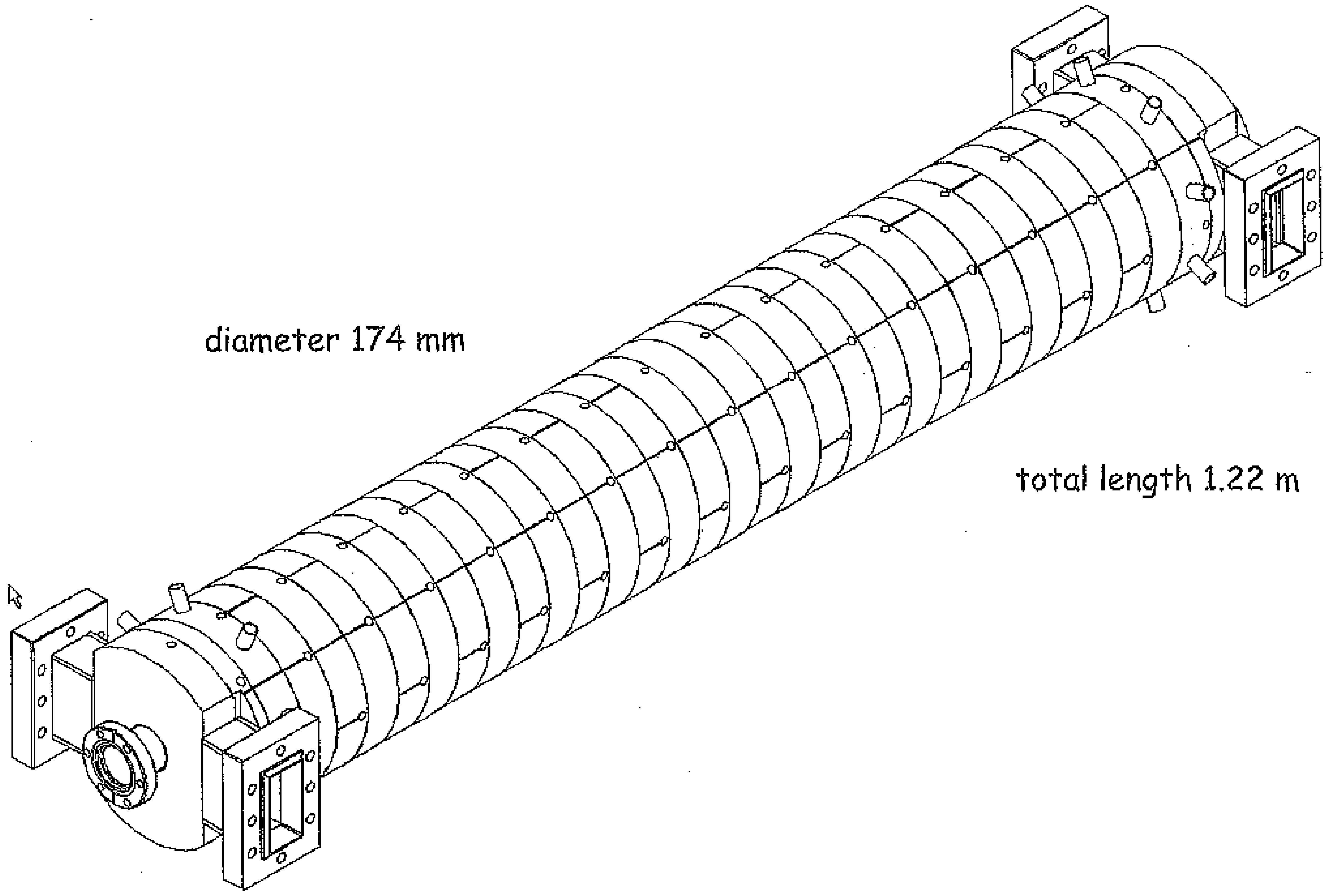




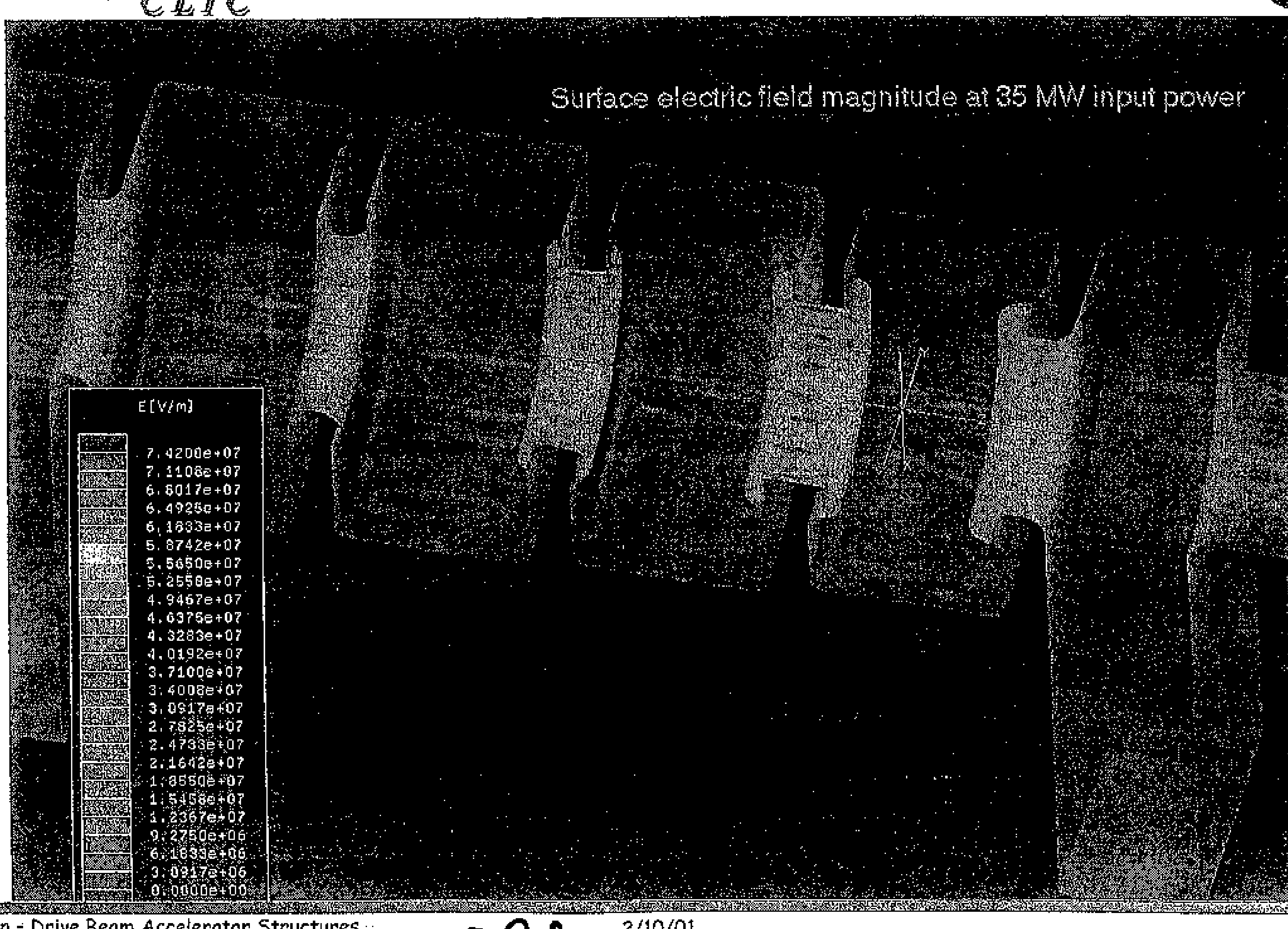
disc	Ra (mm)	La (mm)	Rb (mm)	Lb (mm)
#4	41.450	0.067	41.409	0.141
#5	41.409	0.141	41.362	0.222
#6	41.362	0.222	41.307	0.310
#7	41.307	0.310	41.246	0.406
#8	41.246	0.406	41.178	0.508
#9	41.178	0.508	41.105	0.616
#10	41.105	0.616	41.024	0.731
#11	41.024	0.731	40.936	0.852
#12	40.936	0.852	40.841	0.979
#13	40.841	0.979	40.740	1.112
#14	40.740	1.112	40.632	1.250
#15	40.632	1.250	40.517	1.393
#16	40.517	1.393	40.395	1.542
#17	40.395	1.542	40.267	1.695
////	////	////	////	////
#19	40.129	1.854	39.988	2.016
#20	39.988	2.016	39.836	2.184
#21	39.836	2.184	39.679	2.355
#22	39.679	2.355	39.515	2.530
#23	39.515	2.530	39.347	2.709
#24	39.347	2.709	39.162	2.891
#25	39.162	2.891	38.980	3.077
#26	38.980	3.077	38.787	3.266
#27	38.787	3.266	38.587	3.458
#28	38.587	3.458	38.381	3.653
#29	38.381	3.653	38.166	3.850
#30	38.166	3.850	37.949	4.049
#31	37.949	4.049	37.723	4.251
#32	37.723	4.251	37.489	4.455

NOTE : on the outside diameter of the disc (see #xx on the isometric view), engraved its number !
NOTE : sur le côté diamètre extérieur (voir #xx sur la vue isométrique), graver son numéro (xx)

SICA - assembly

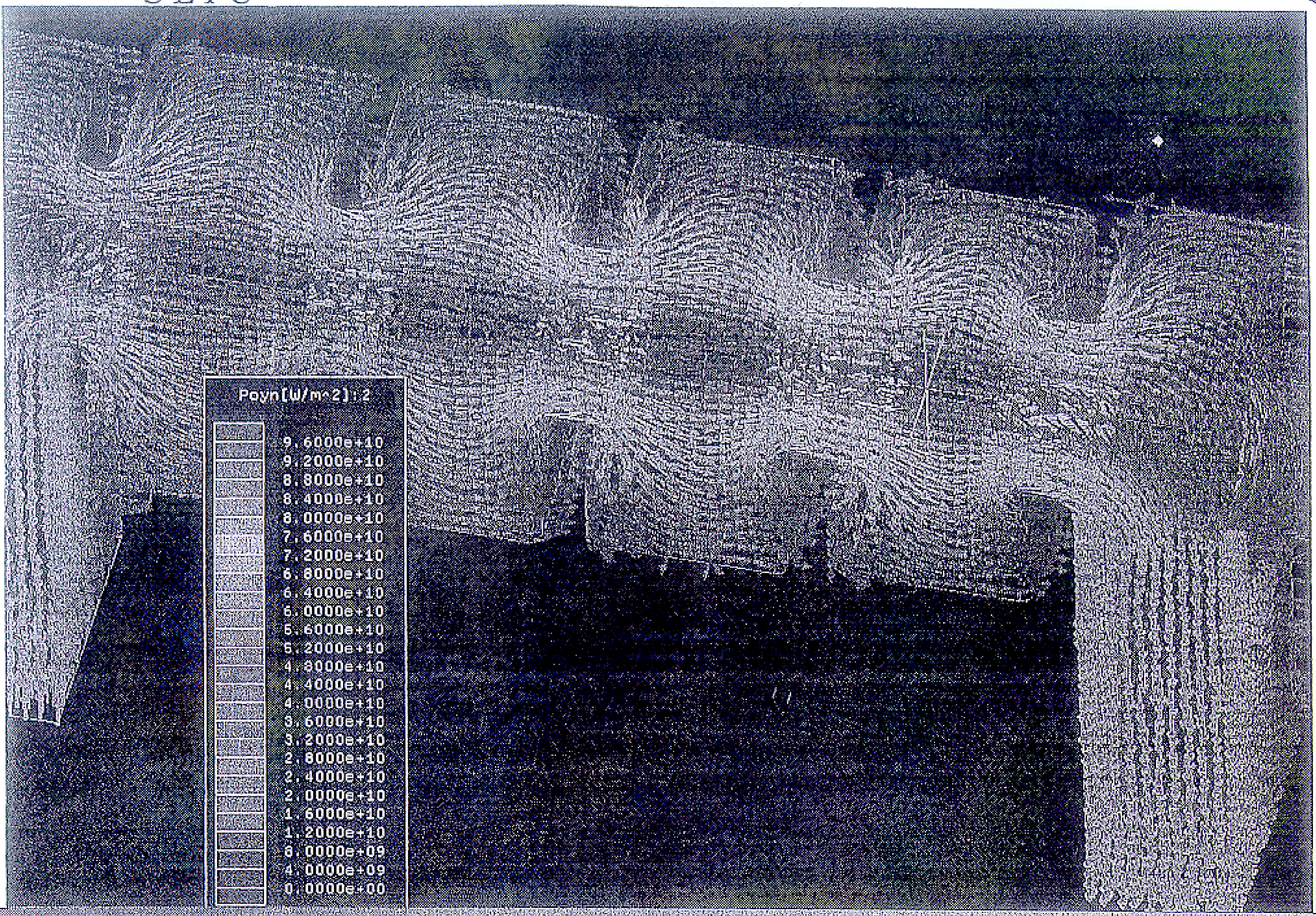


SICA - geometry and field distribution



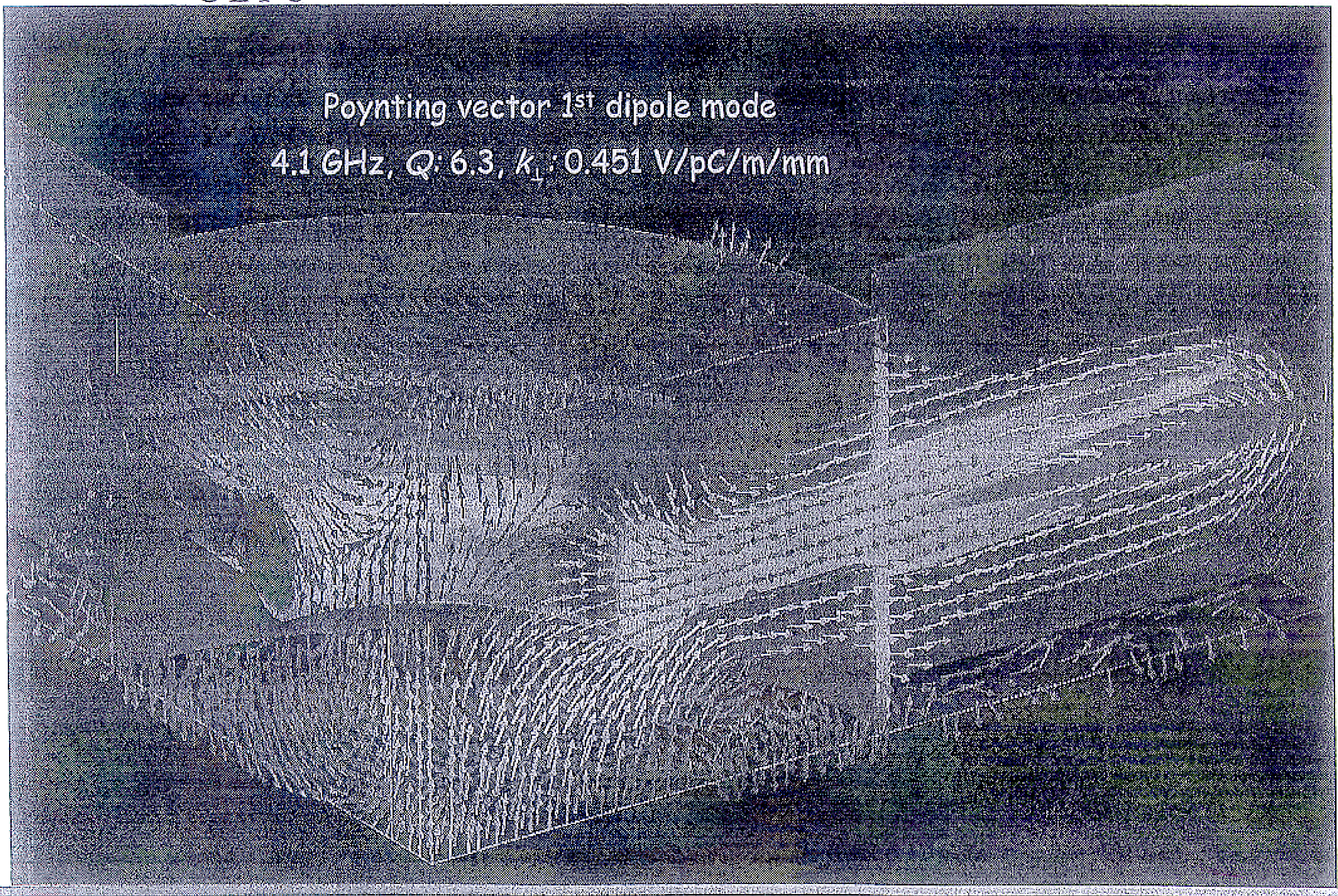
CLIC

SICA - Poynting vector

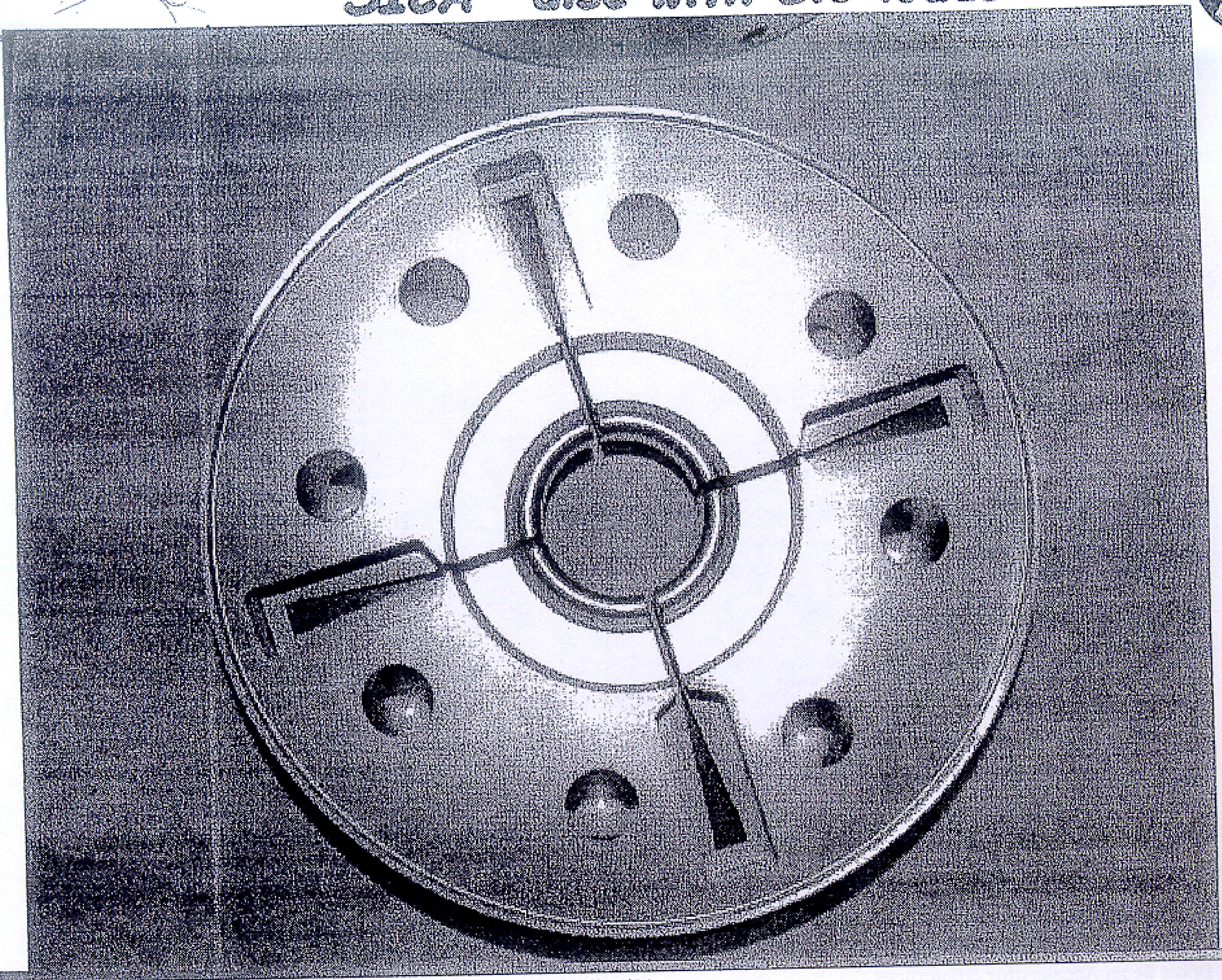


CLIC

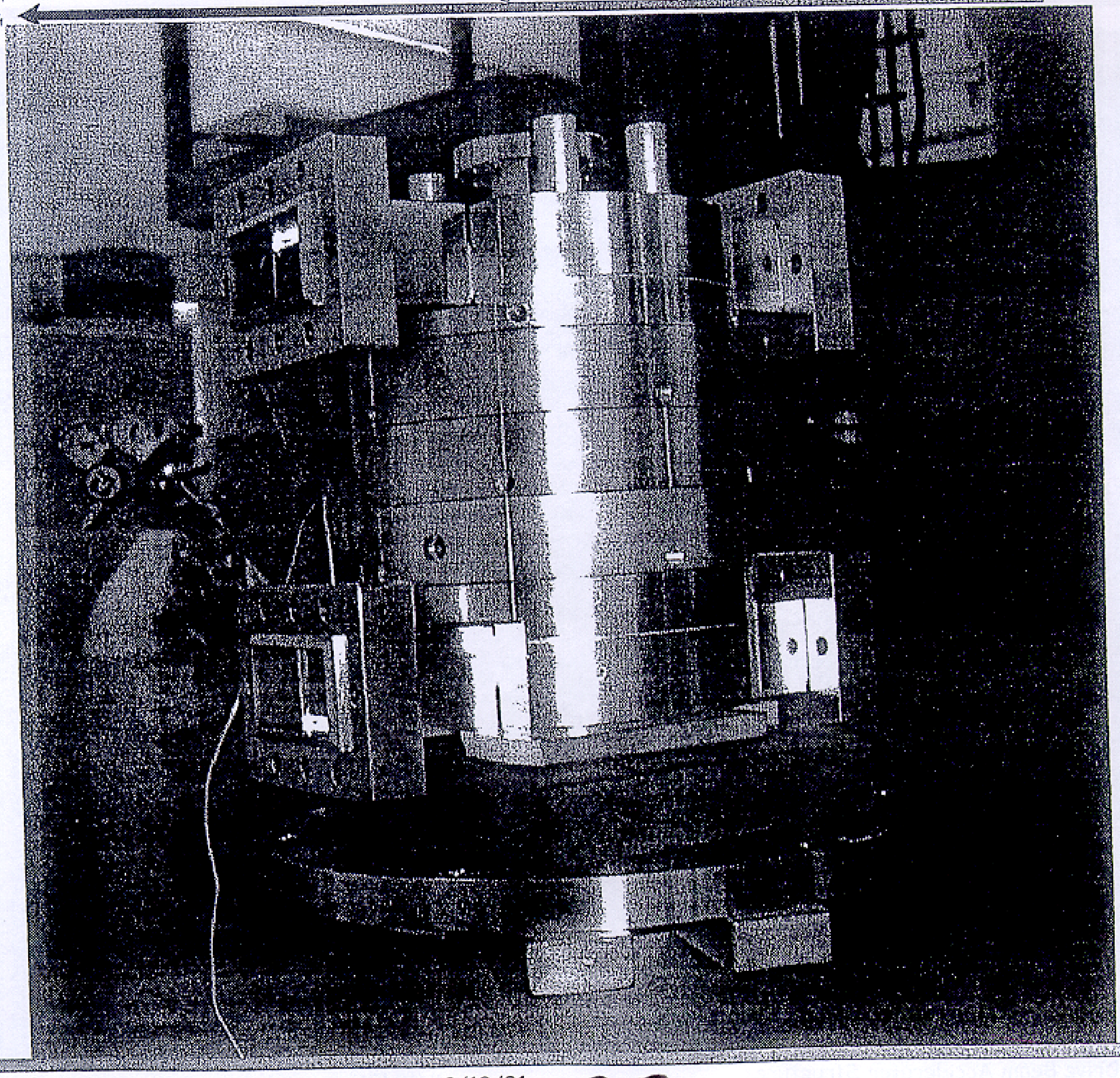
SICA - 1st dipole mode damping



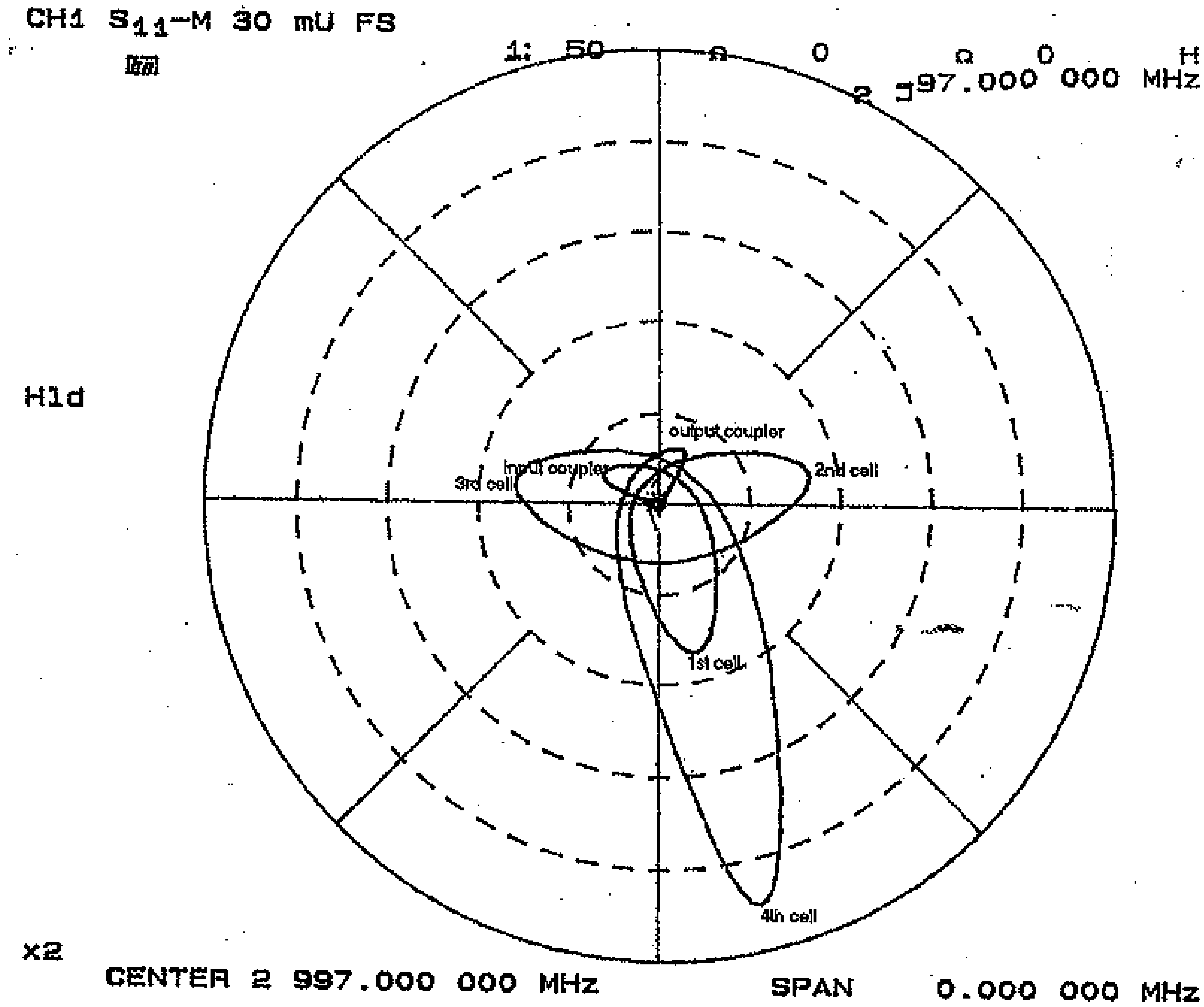
SICA - disc with SiC loads



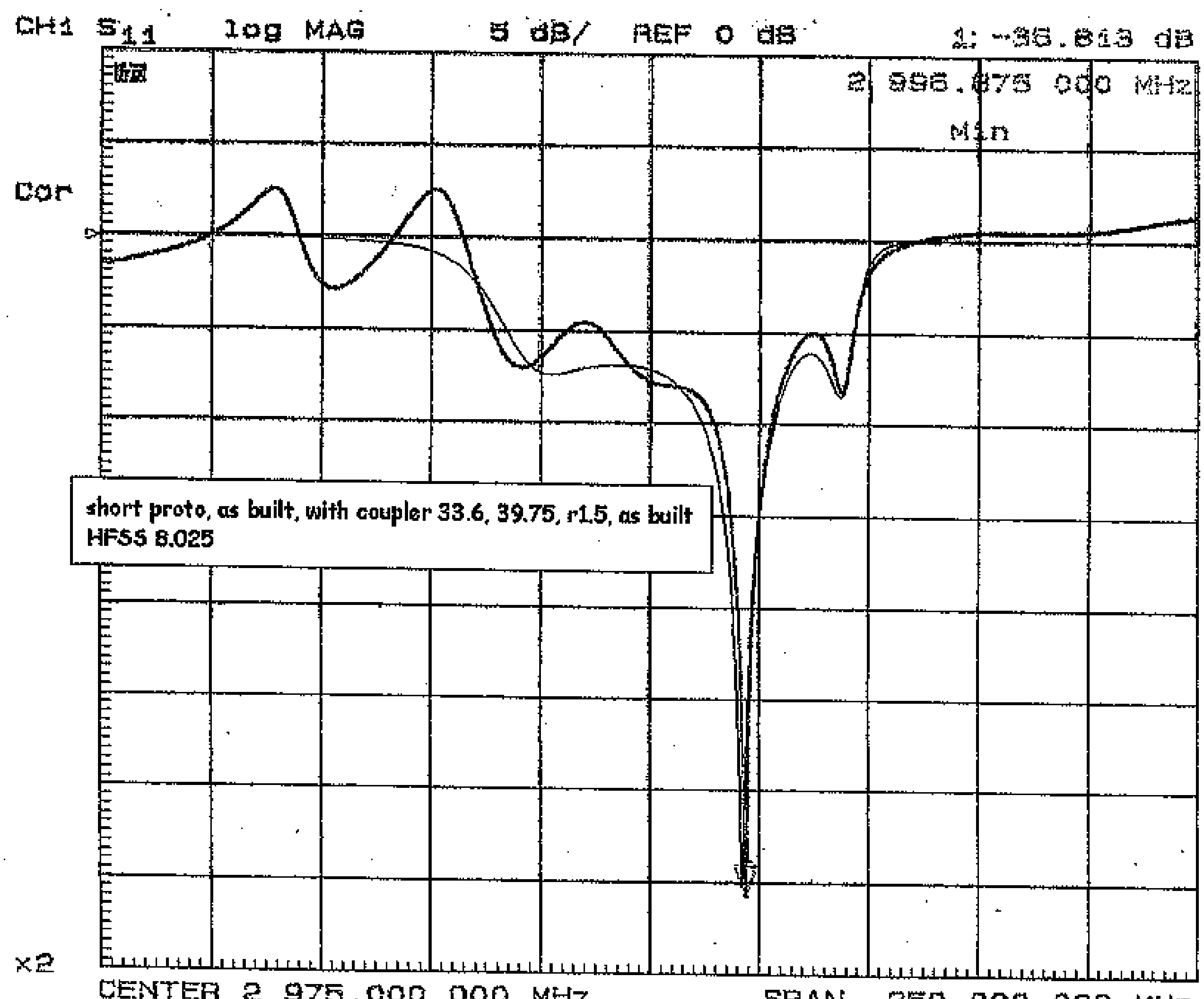
SICA - 4 cell prototype, brazing



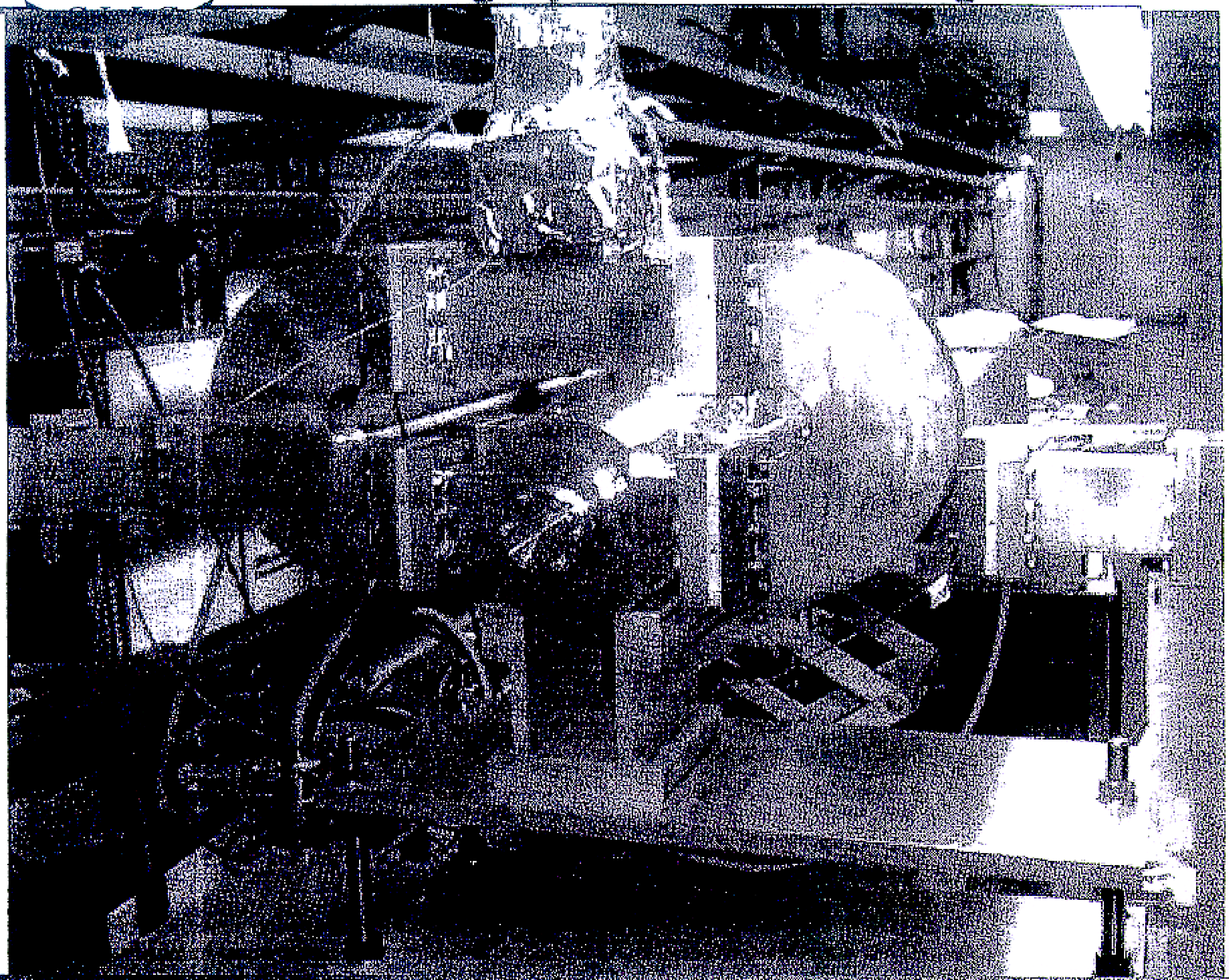
Bead-pull SICA



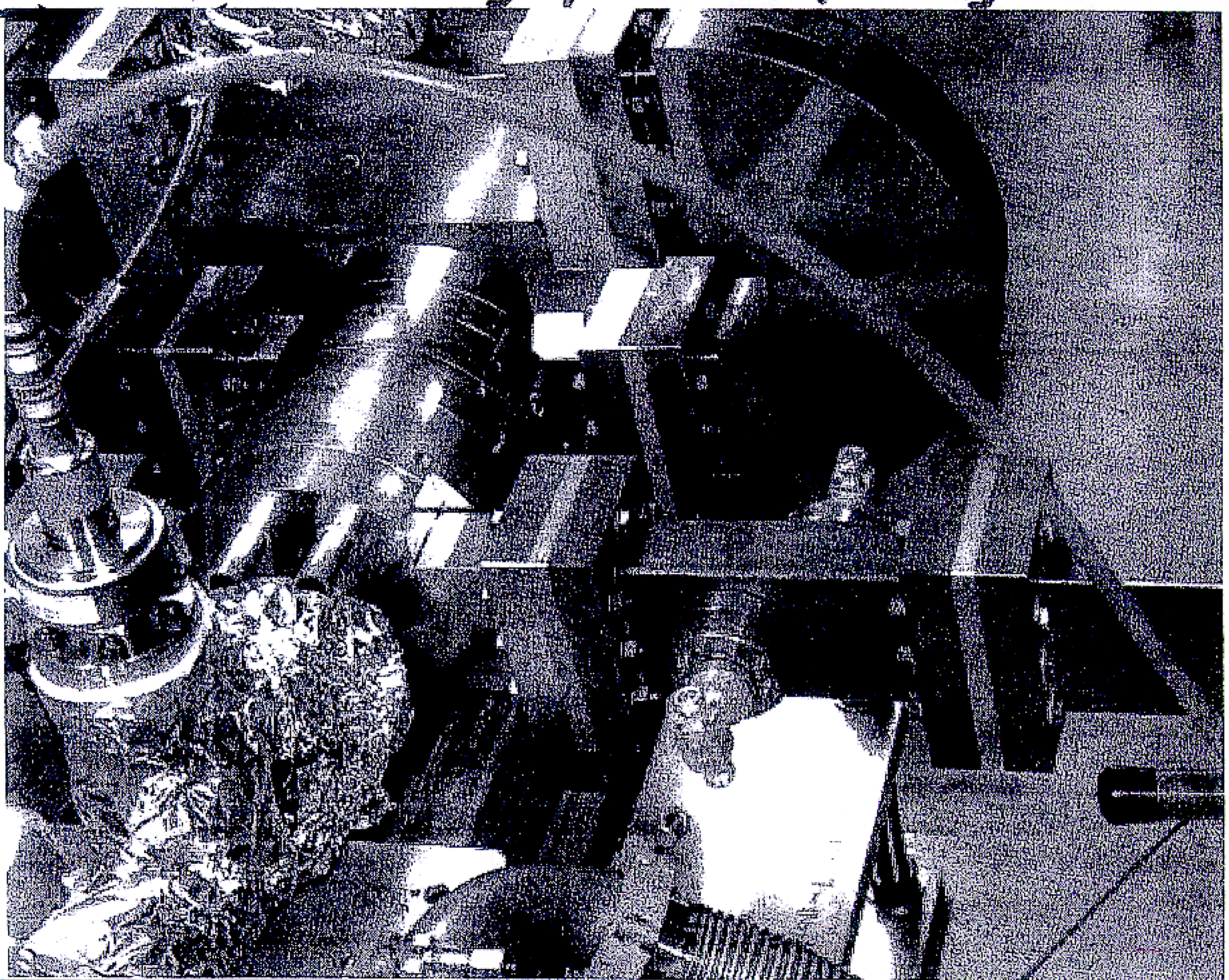
SICA: Input matching



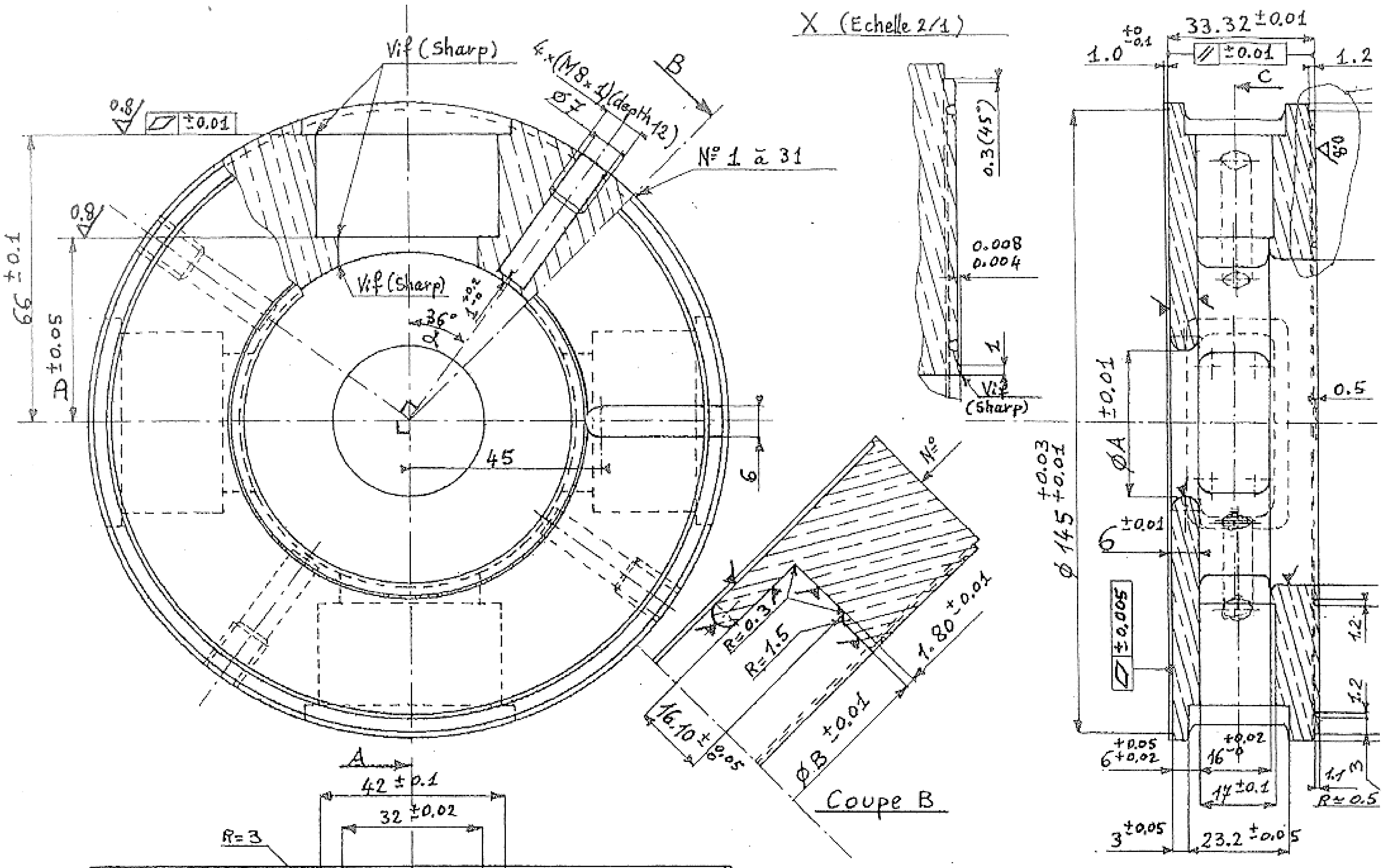
SICA high power test, 17Aug-01



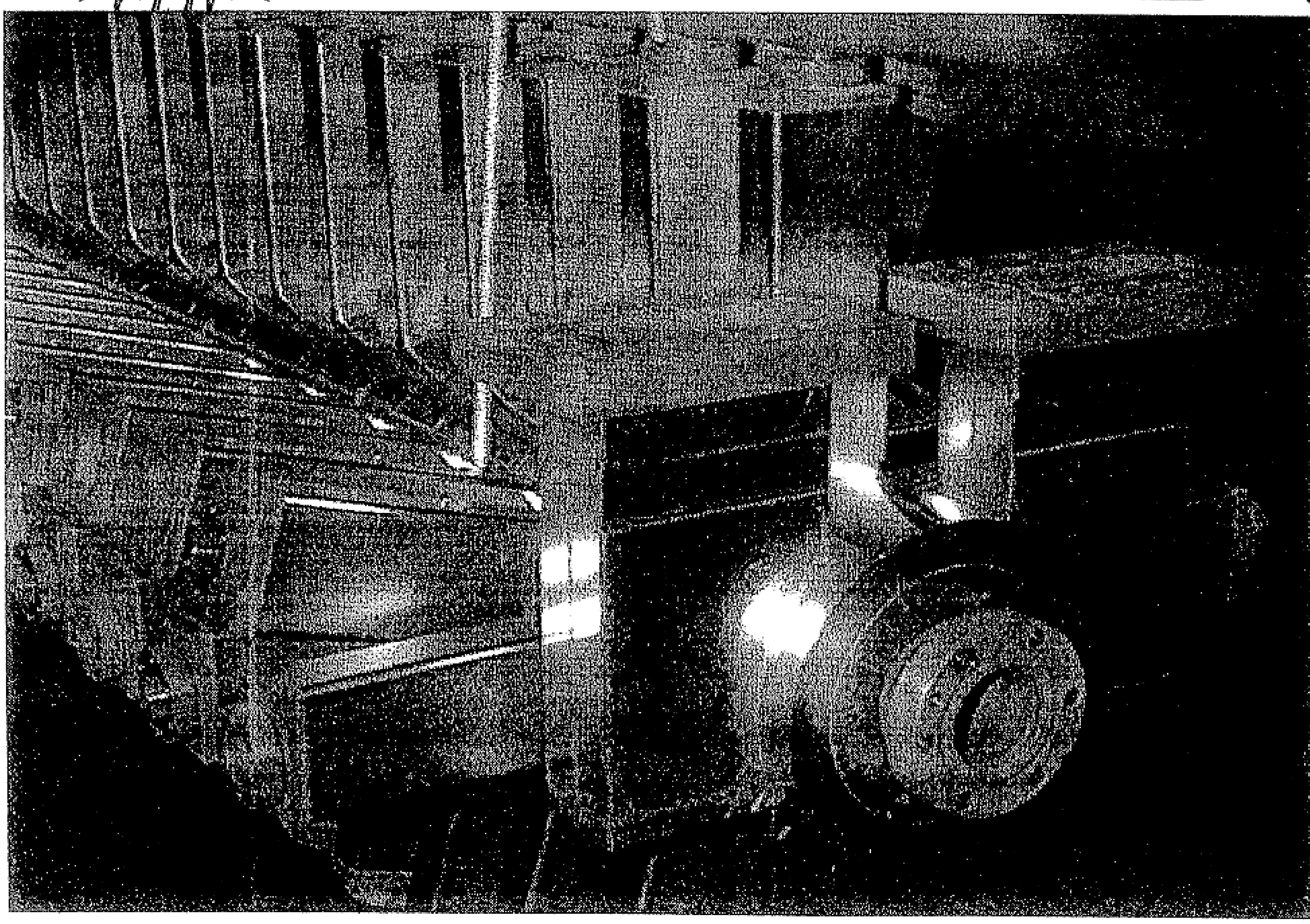
SICA high power test, 17Aug-01



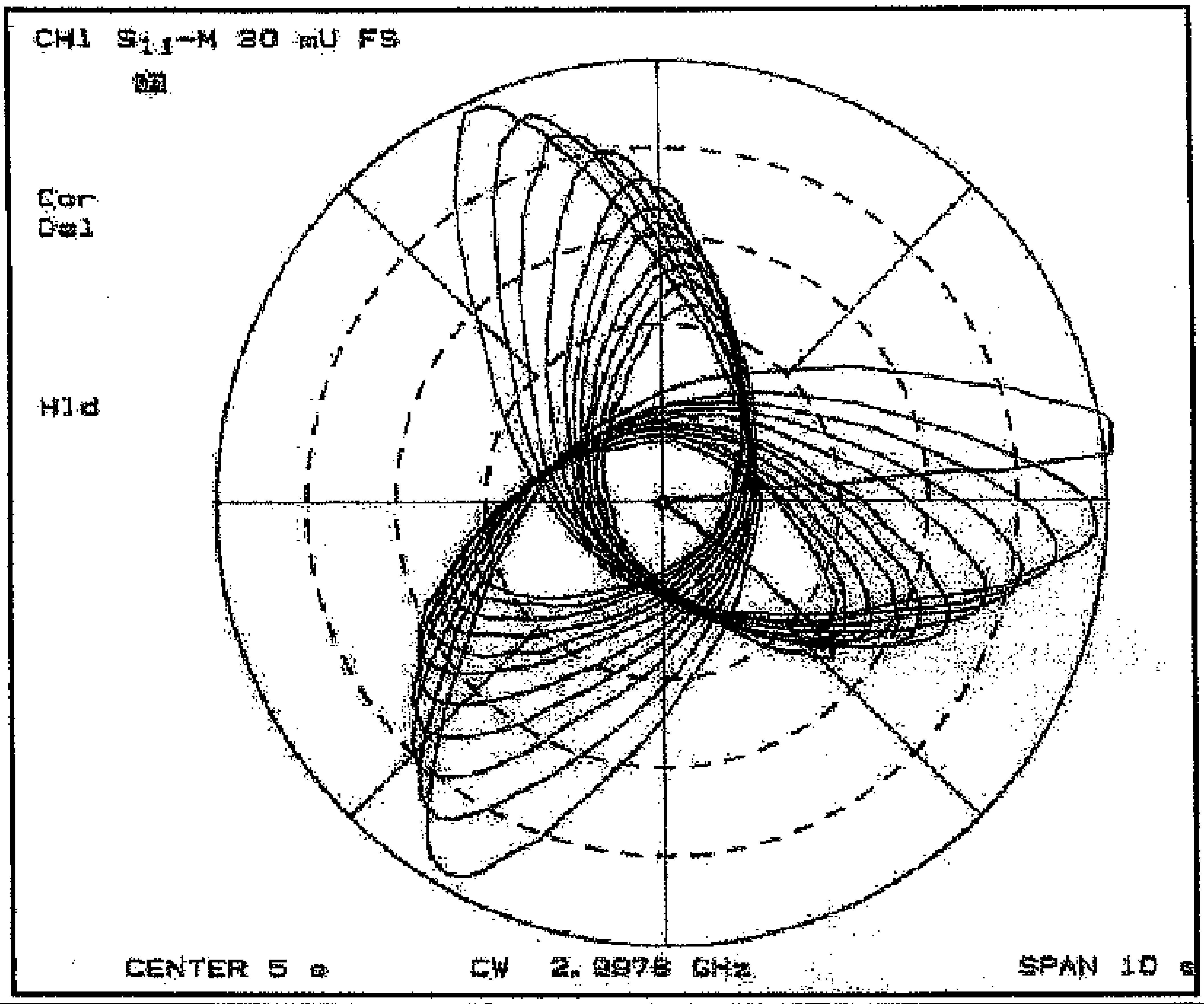
TDS, excerpt tech. drawing



TDS prototype

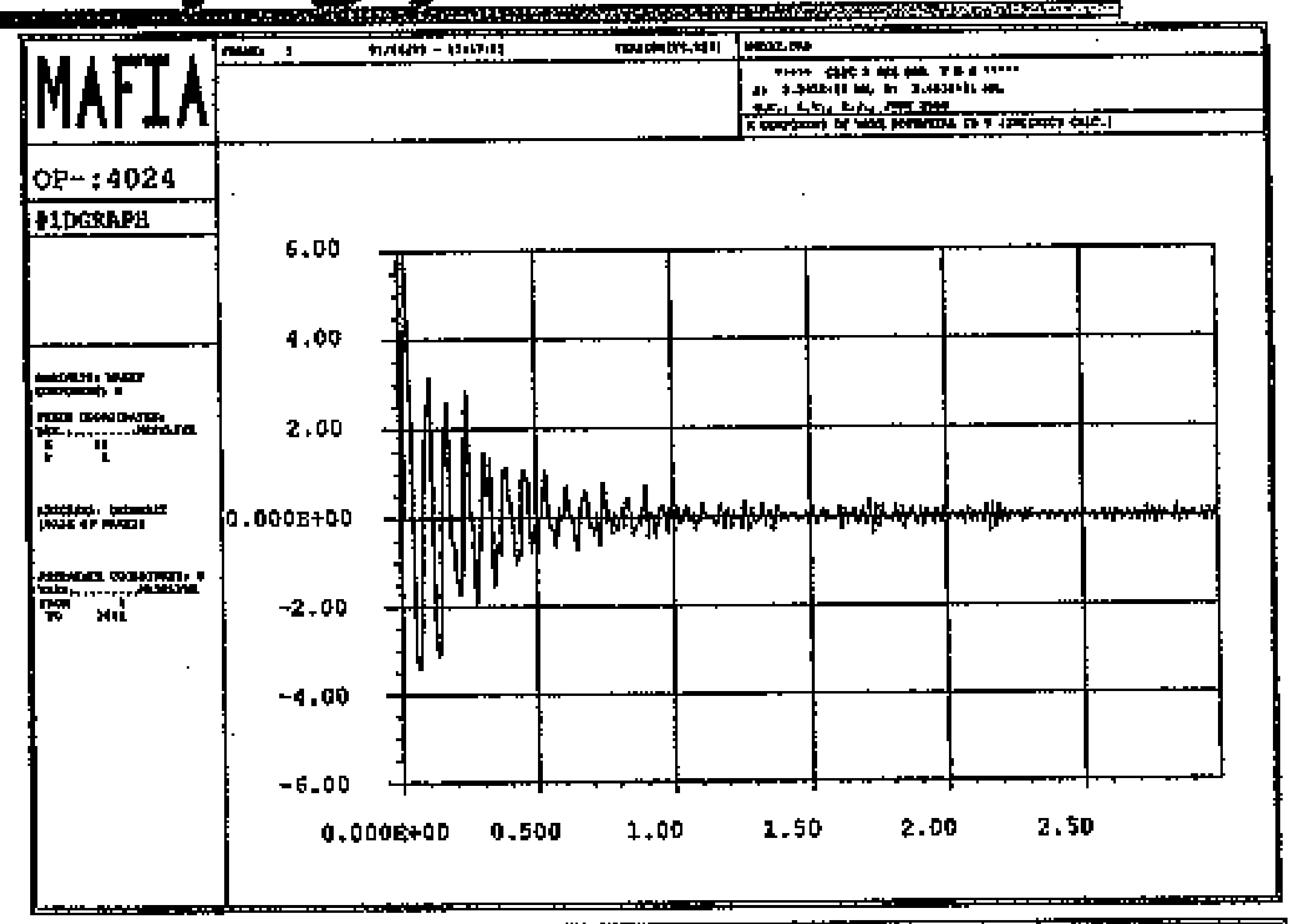


Bead-pull measurement TDS

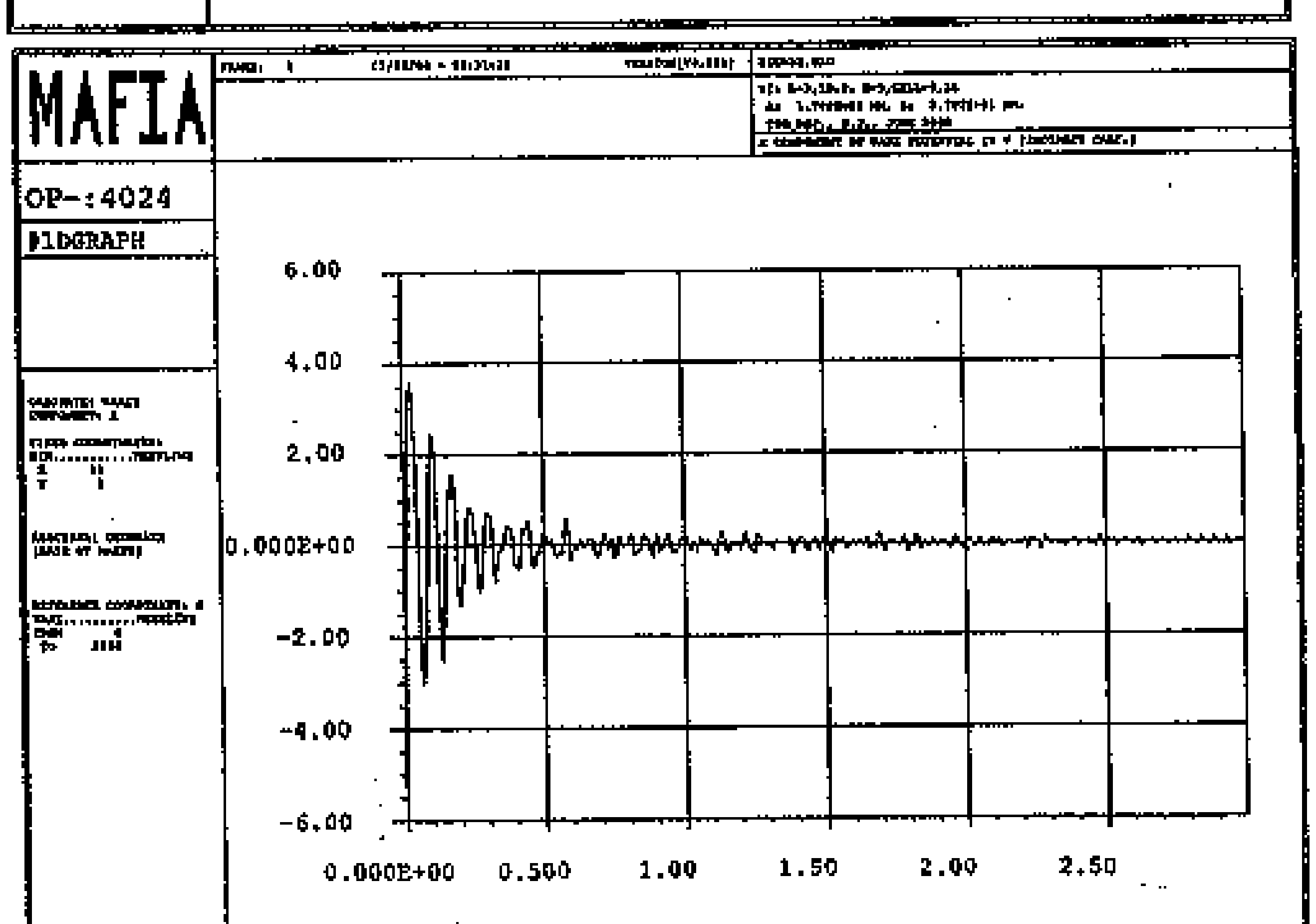


HOM damping performance:

TDS, cell 32
⊥ wake, σ: 2.5 mm



SICA, cell 32
⊥ wake, σ: 2.5 mm



CTF3 Longitudinal Beam Dynamics Issues

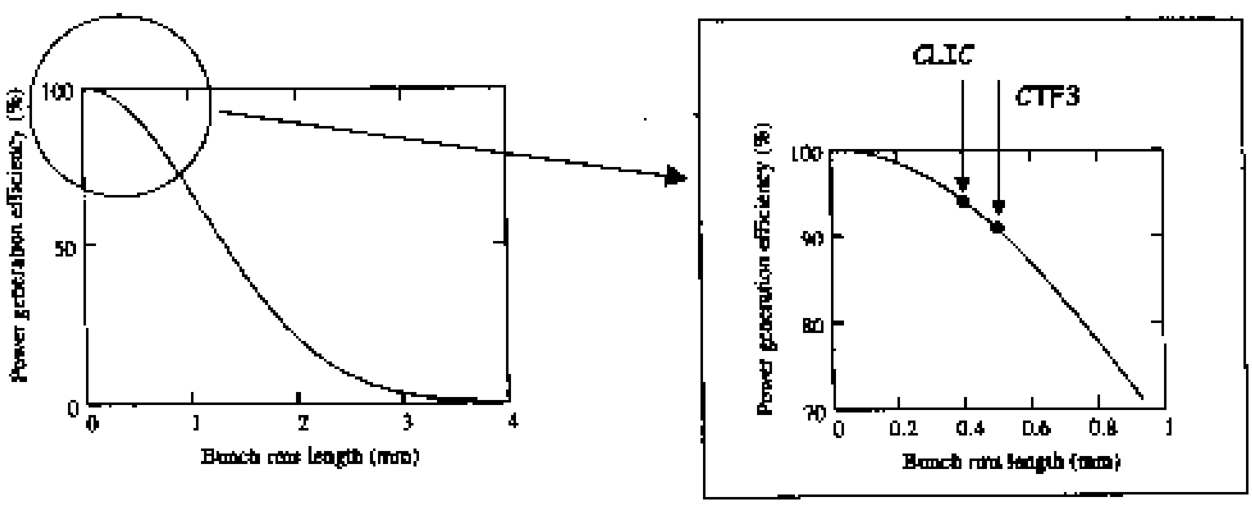
Roberto Corsini

- Bunch length & phase requirements
- Bunch length gymnastics in CTF3 - effects & constraints
  - Coherent Synchrotron Radiation (CSR)
  - Ring longitudinal impedance
  - Isochronicity - momentum compaction
  - Bunch length limitations at ring injection
- Longitudinal phase space evolution - simulations
- Idle cavity option

Final bunch length requirements

$P_{PETS} \propto F^2 q_B^2$ where $F = \int e^{-2i\pi\nu t}\rho(t)\,dt \Rightarrow F = e^{-\frac{(2\pi\sigma\nu)^2}{2}}$ for gaussian bunches

In order to efficiently produce 30 GHz power in the PETS, the bunches must be short.
In CLIC the nominal bunch length is $\sigma \sim 0.4$ mm rms
In CTF3, for efficiencies around 90% ⇒ $\sigma \sim 0.5$ mm rms

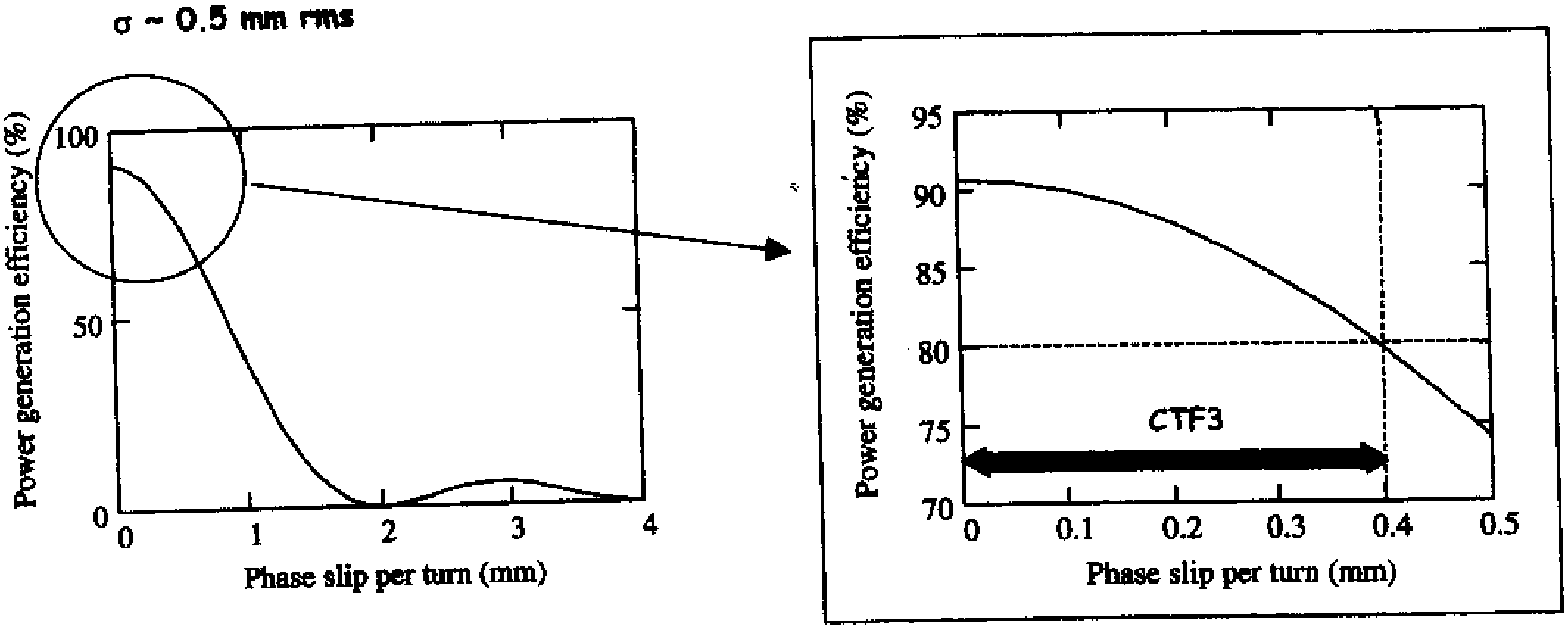


Requirements on bunch phase

The distance between bunches after combination is 2 cm (15 GHz). Any variation in bunch-to-bunch distance corresponds to a loss of efficiency.

Below - reduction in 30 GHz power generation efficiency, for a linear phase slip of the center of the injected bunches.

For instance, in order to stay above 80% ⇒ Δs < 0.4 mm / turn



Considerations on bunch length in CTF3

- A very short bunch length is required after combination for efficient 30 GHz power production
- In order to avoid excessive bunch lengthening, the momentum compaction of the transfer lines, the delay loop and the combiner ring must be kept very small
- However, for short bunches, the longitudinal impedance as well as coherent synchrotron radiation emission become important issues:
  Energy spread & energy loss ⇒ bunch lengthening & phase errors

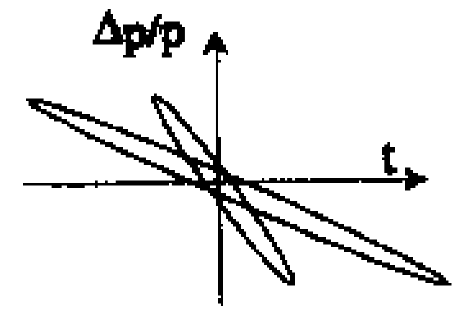
Strategy:

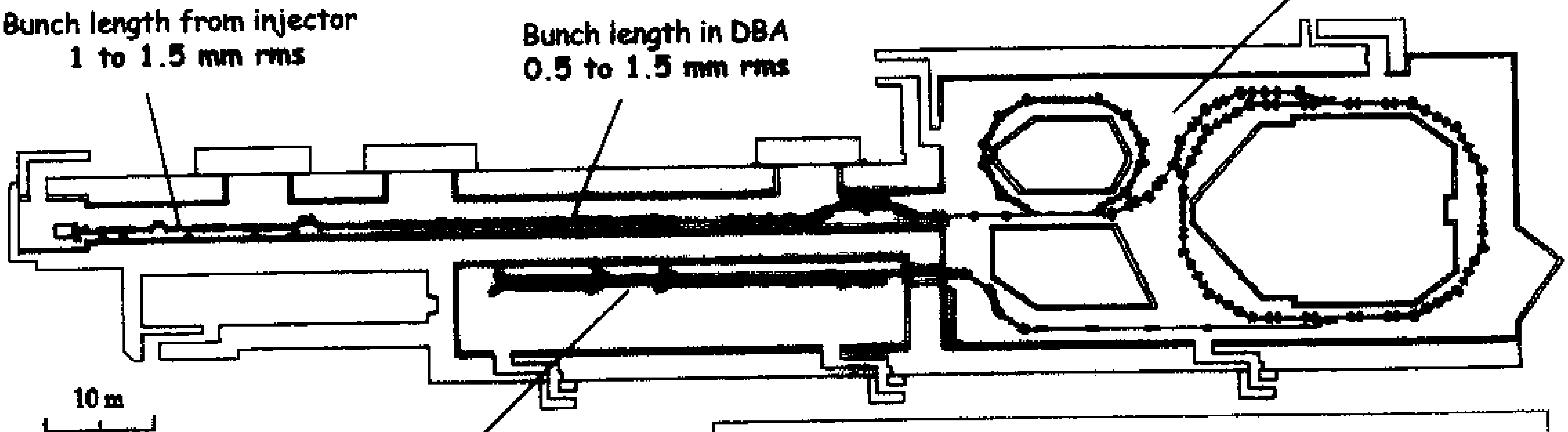
- Compress the bunches to the final value only after the combiner ring
- Optimize the bunch length in the different systems composing the CTF3

Optimizing the bunch length in CTF3

DBA

short bunches are good for transverse stability
& larger correlation for the same total energy spread





DL and CR

long bunches are good to avoid CSR and impedance effects
max bunch length limited by injection with RF deflectors
energy spread limited by the momentum compaction of the ring and the transfer lines

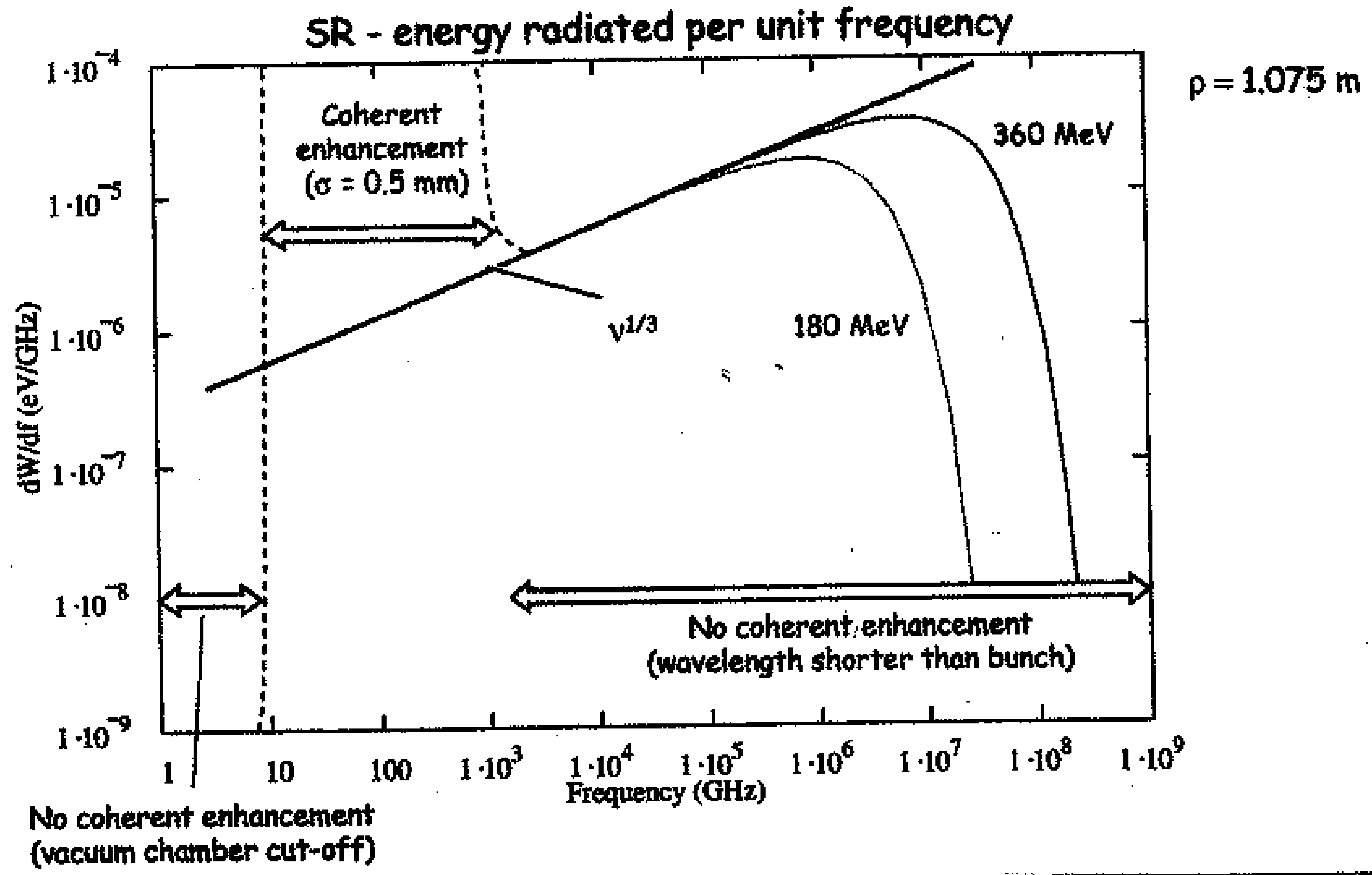
Magnetic bunch compression (stretching)

$$c\,\Delta t = R_{56}\,\Delta p/p \qquad R_{56} = \int \frac{D}{\rho}\, ds$$

$R_{56} > 0$ $\qquad$ $R_{56} < 0$

Coherent Synchrotron Radiation (CSR) emission

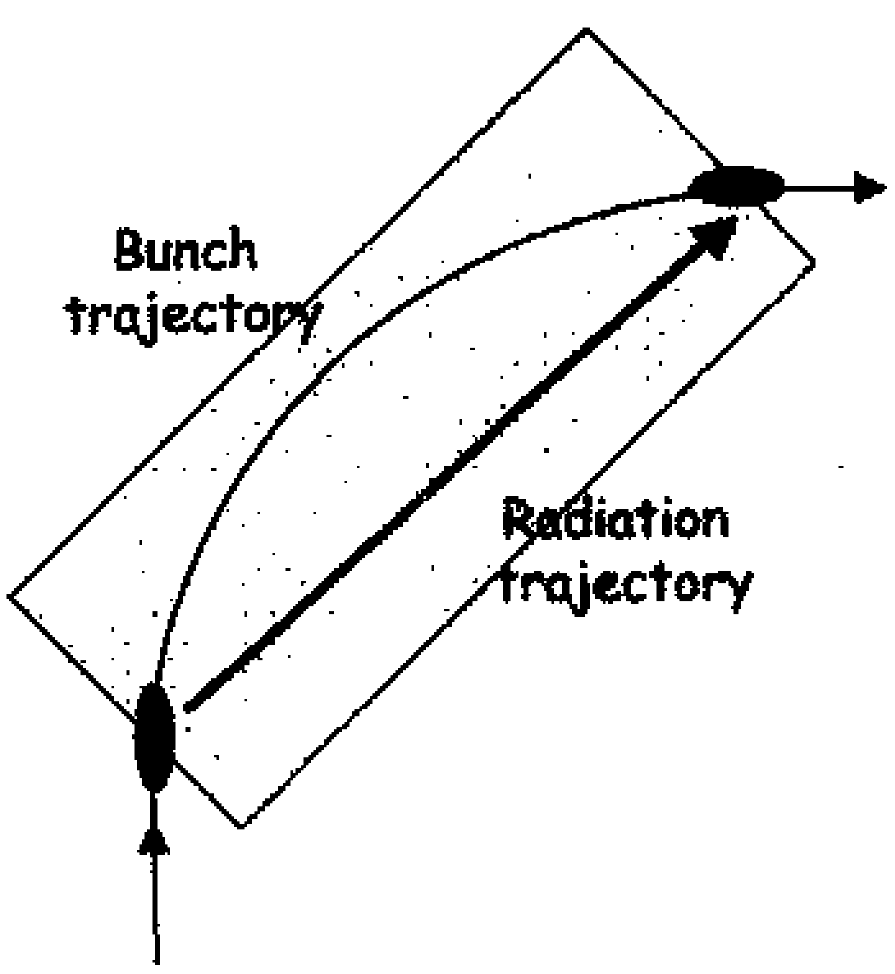
Short, high-charge electron bunches in magnetic bends radiate coherently at wavelengths larger than the bunch length. The effect is an average energy loss and an energy spread. When the vacuum chamber is small compared to the wavelength emitted, the emission is reduced (shielding)



The CSR wake-field

The CSR is similar to a longitudinal wake-field, causing an average energy loss and an energy spread whose amplitude does not depend on the beam energy.

When the beam-pipe dimensions is small compared to the wavelength emitted, the wake is reduced (shielding)

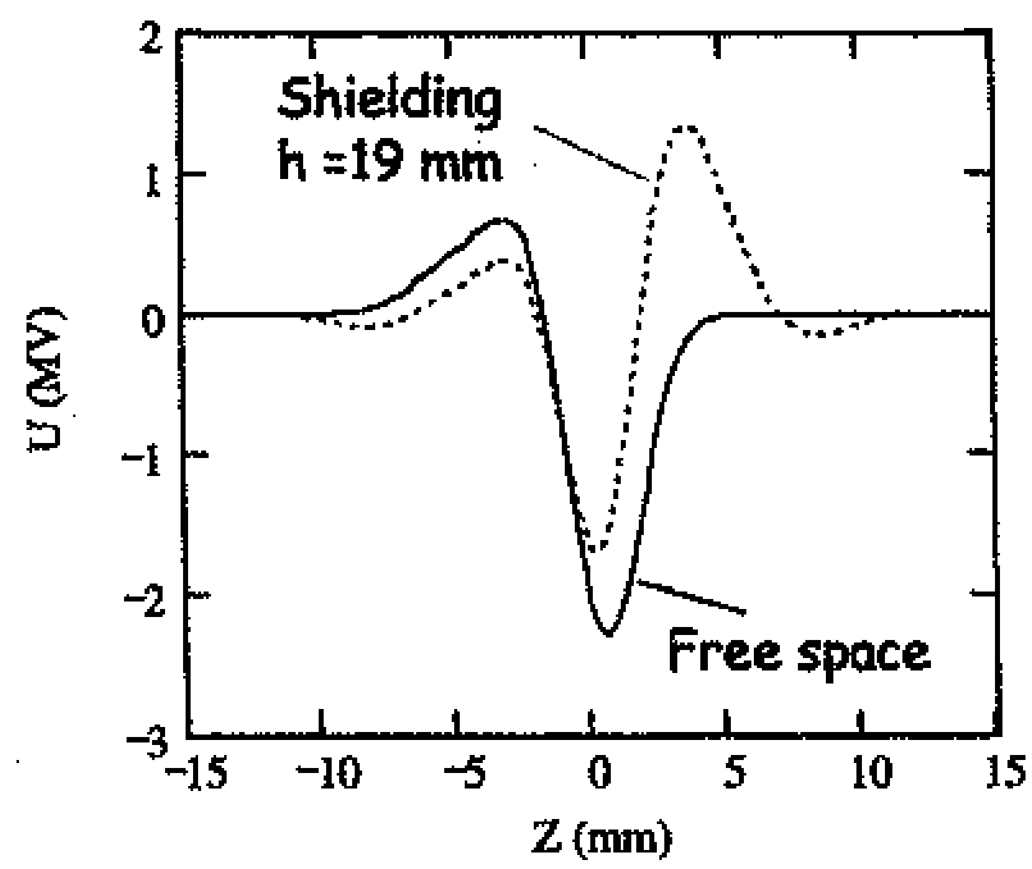


The emitted radiation can overcome the bunch along its curved path. Therefore, unlike a classical wake, the bunch head can be accelerated.

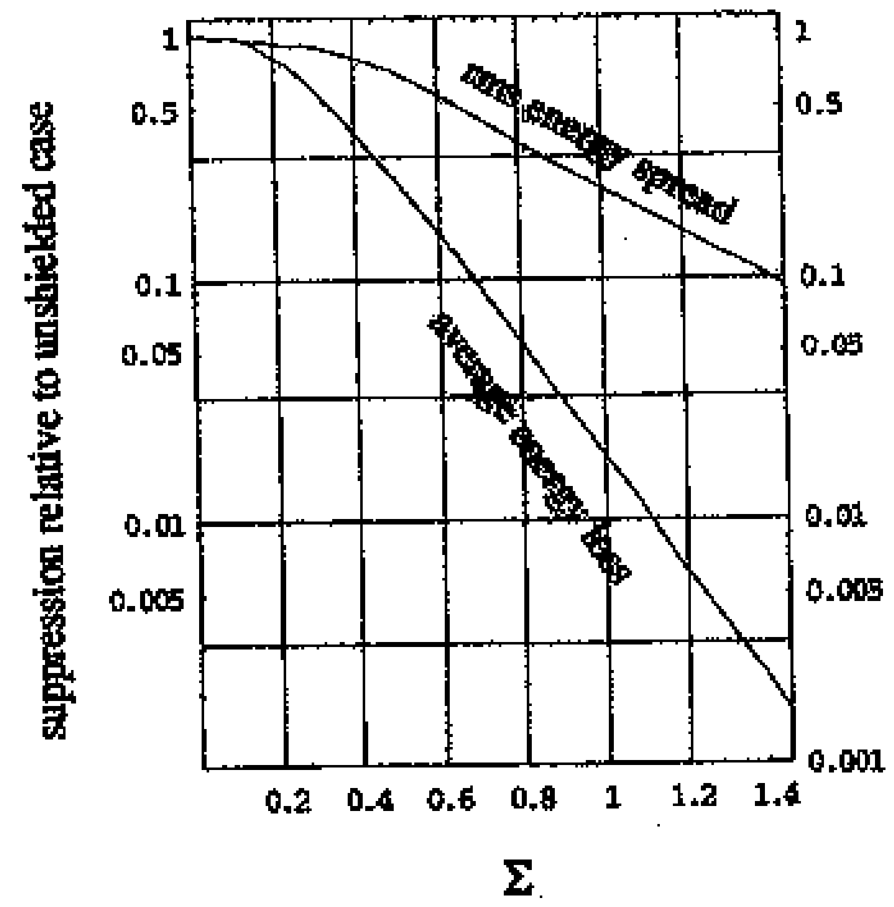
CSR Wake

σ_Z = 1.5 mm - Q_B = 2.33 nC

9/2 turns in CR

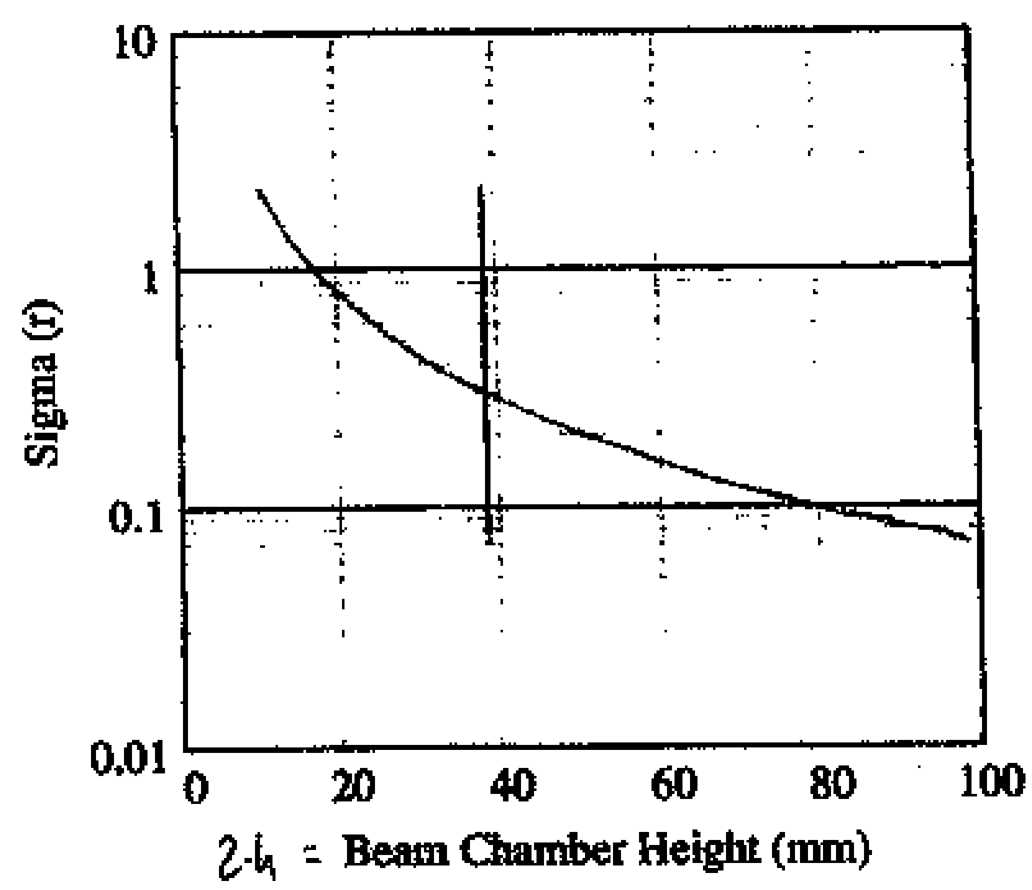


Shielding effect for CSR



Effect of shielding for CSR induced energy loss and spread, as a function of the scaling parameter Σ, defined as:

$$\Sigma(h) = \frac{\sqrt{2\rho}\,\sigma_z}{h^{3/2}}$$



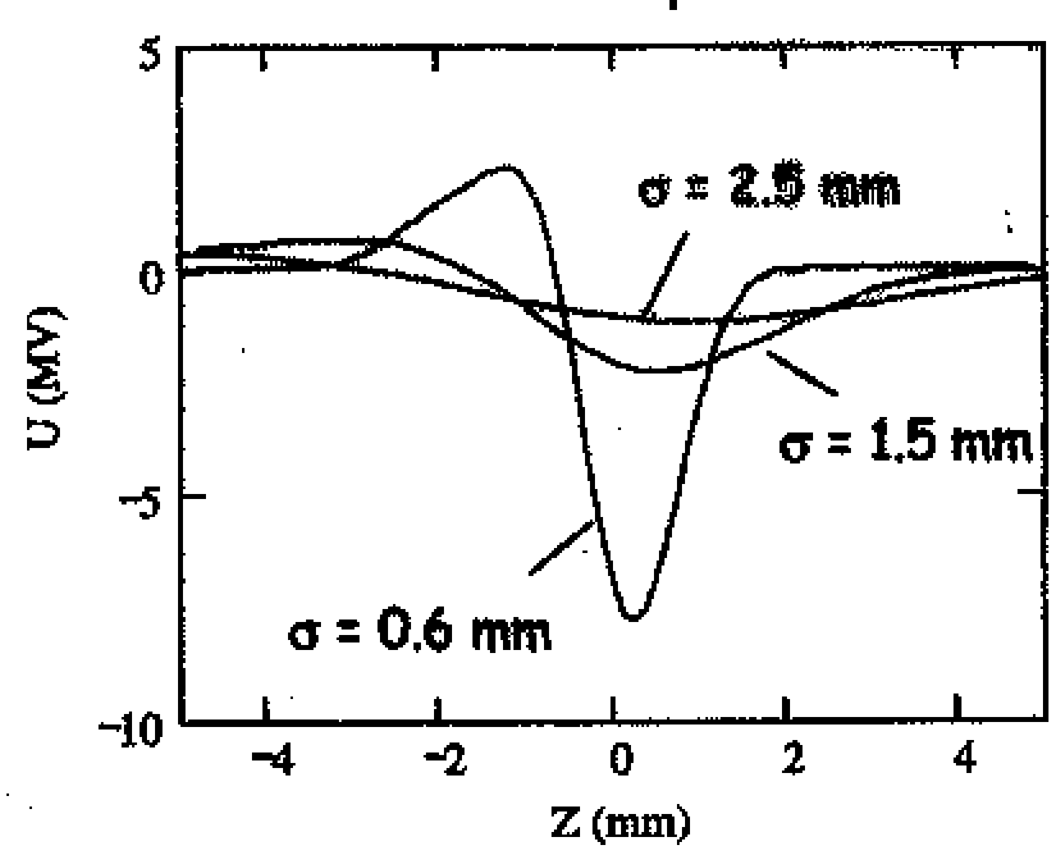
Σ parameter as a function of beam chamber height, for a bunch with σ_z = 1.5 mm

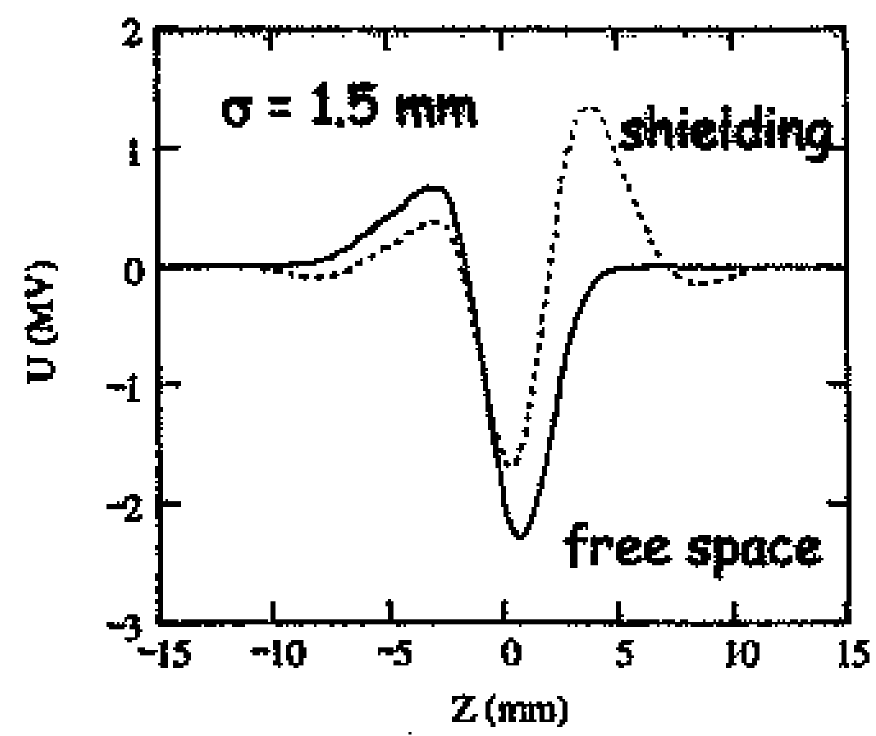
For 2h = 38 mm ➡ Σ = 0.3

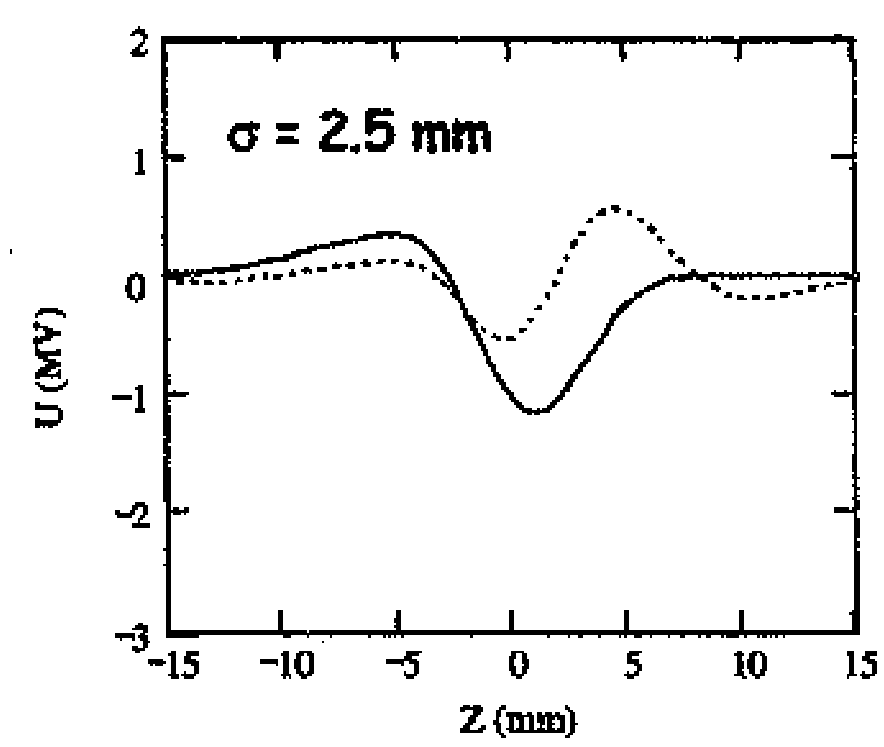
The CSR wake-field - II

CSR wake for 9/2 turns in the ring, for different bunch lengths, in free space (left) and including shielding in a h = 19 mm vacuum chamber (left)

Q_B = 2.33 nC







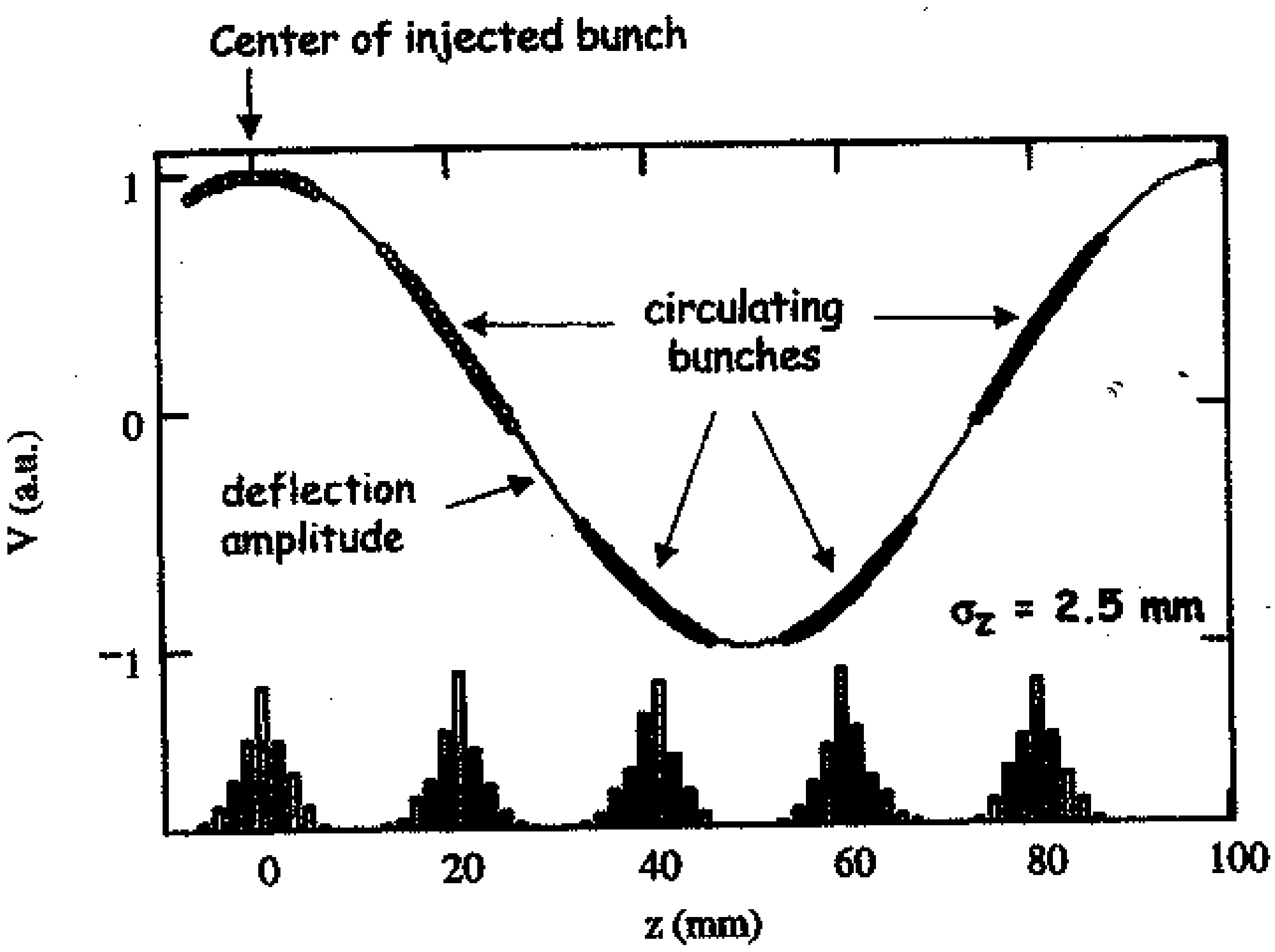
If the bunches are compressed to the final length before injection in the ring, the CSR wake would be too strong

Stretching the bunches before injection reduces the CSR wake

Bunch length limitation at injection I

The bunch length is increased before the delay combiner and the ring, to minimize CSR and longitudinal wake-field effects.

The main limitation to the maximum bunch length acceptable in the ring comes from the injection by RF deflectors



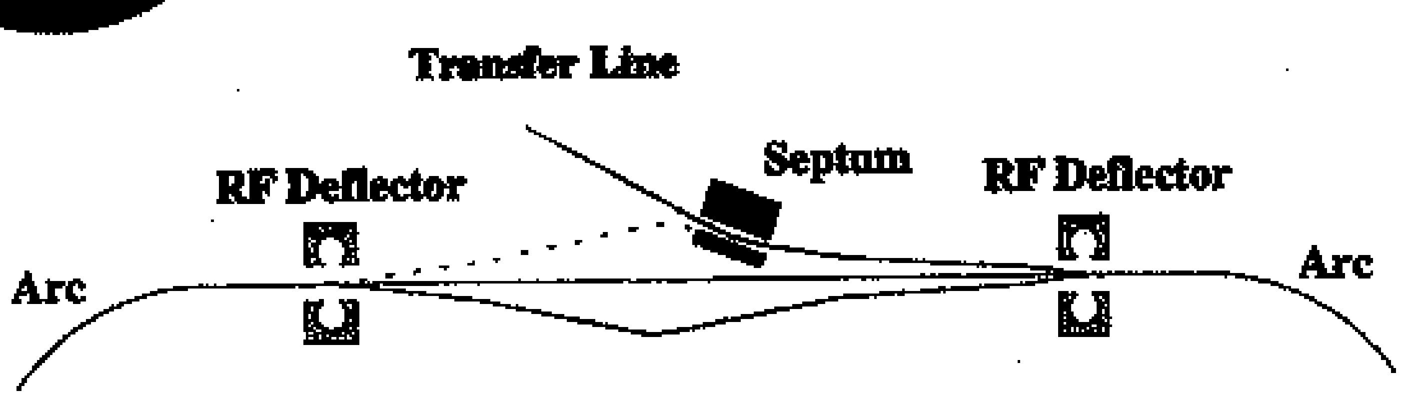
A long bunch has a large phase extension in the 3 GHz deflector, so the kick experienced by the bunch tails is different from the one experienced by the bunch center:

- Reduction of "useful" kick to avoid septum
- Effective emittance growth (only at injection)

⬇

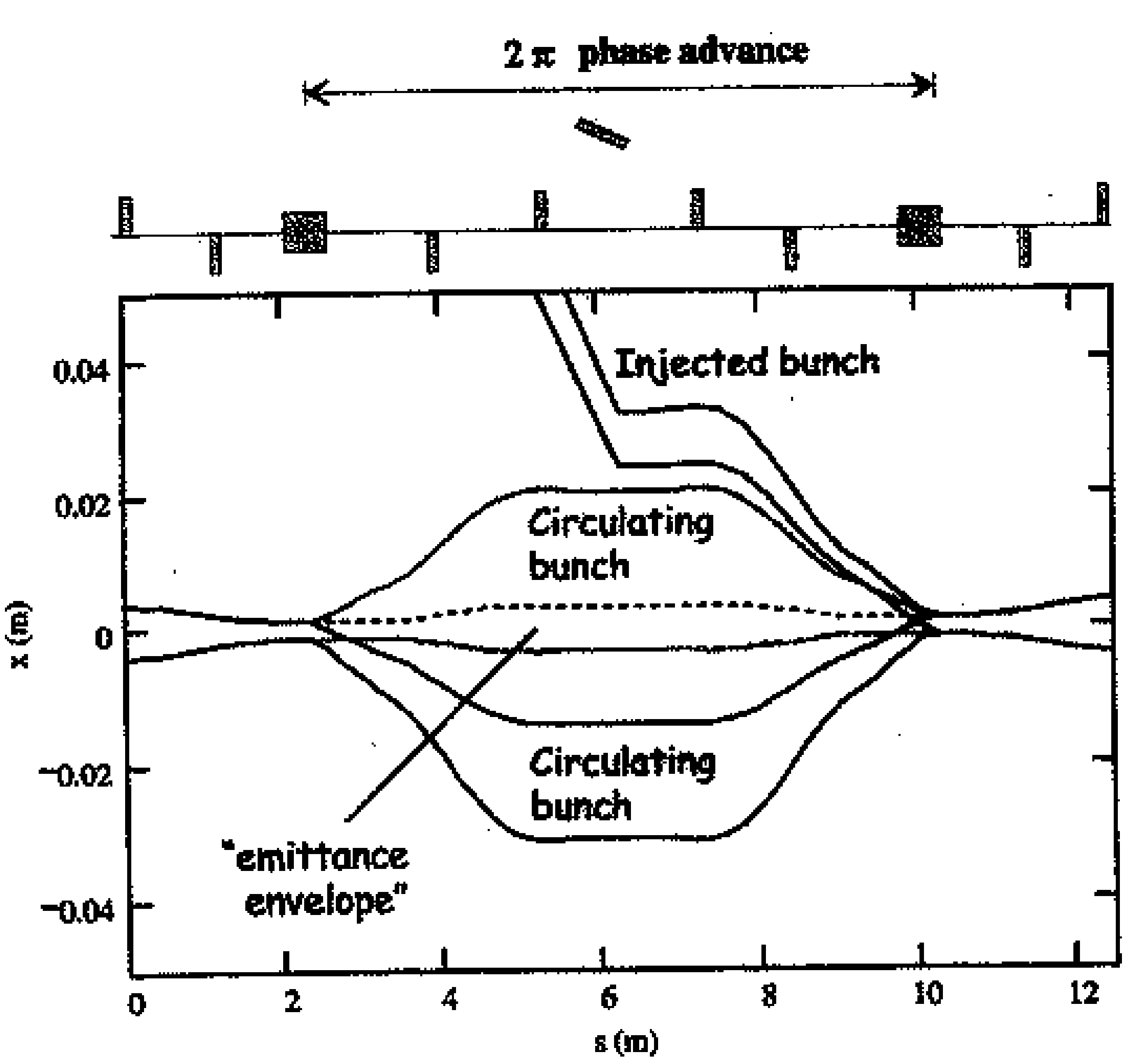
- Max bunch length ~ 2.5 mm rms

Bunch length limitation at injection II



- Layout of injection region

C. Biscari, CTF3 Note 24

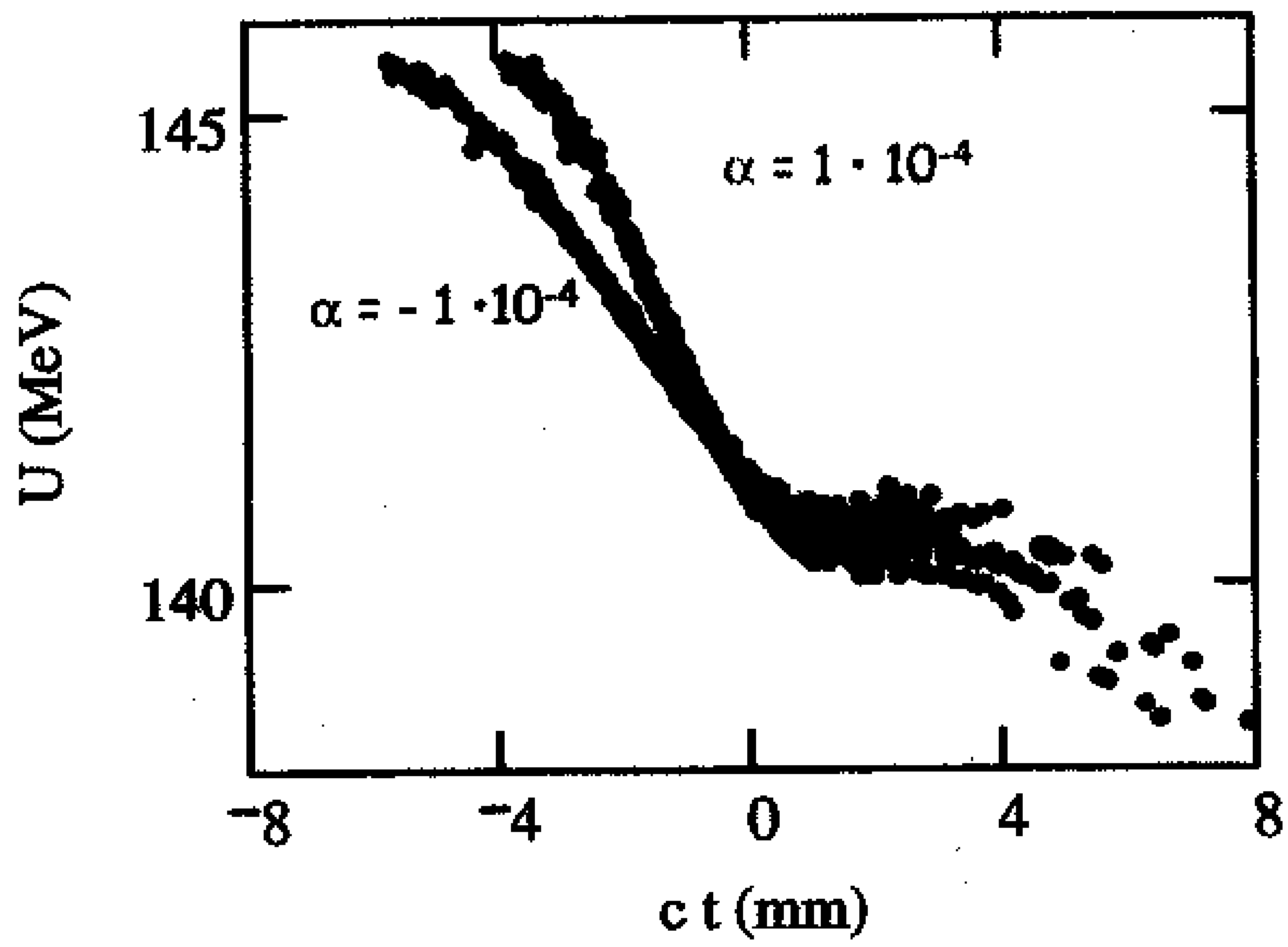


Beam envelopes (2 σ longitudinal and horizontal) for injected and circulationg bunches, σ_z = 2.5 mm.

The space available for the septum is ~7 mm, the kick from the RF deflector is 10 mrad (6 MW at 150 MeV)

Isochronicity - momentum compaction

The ring momentum compaction α causes a distortion in the longitudinal phase space

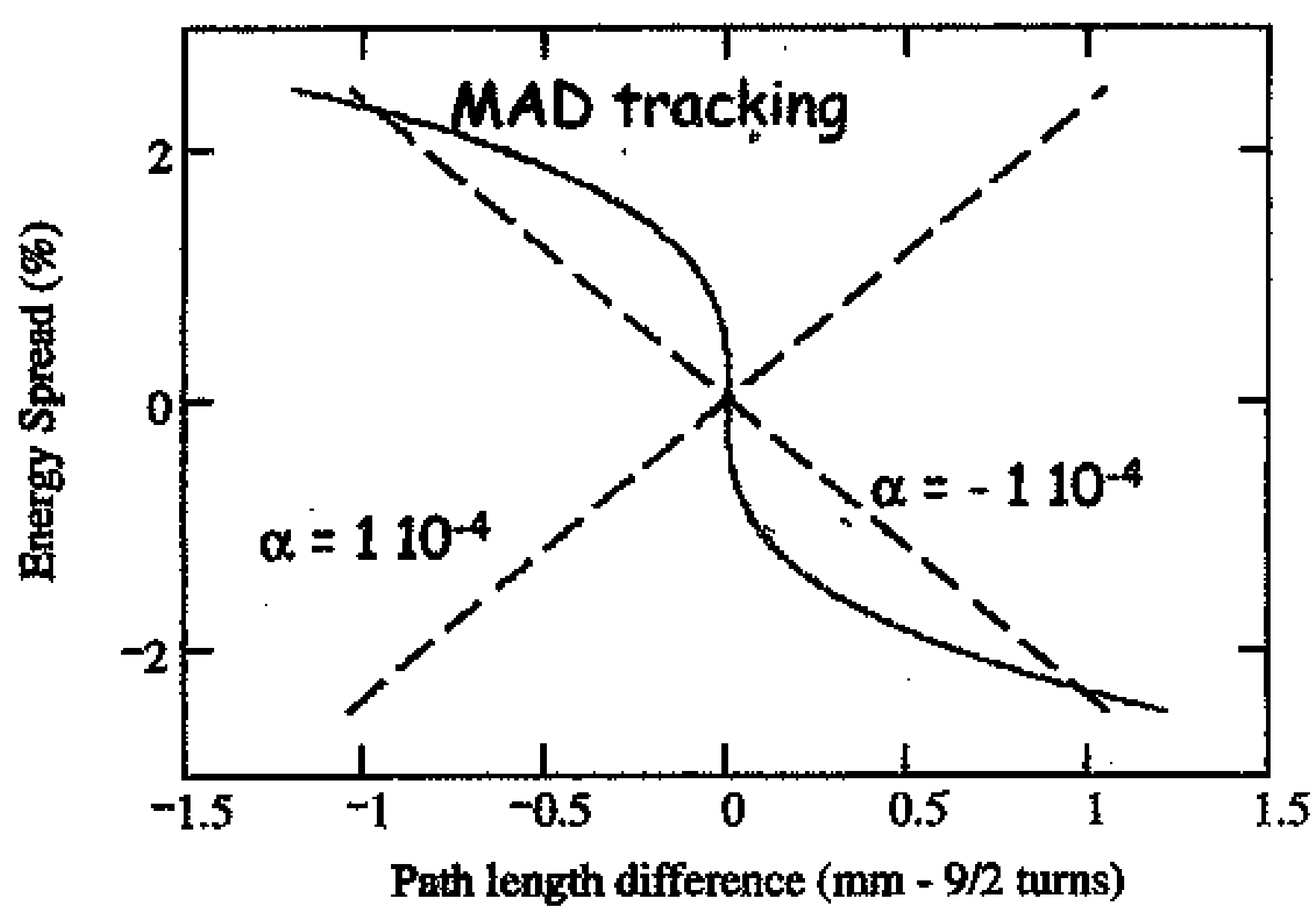


Requirement: $\alpha < 1\ 10^{-4}$

Longitudinal phase space distribution, after 9/2 turns, for two different values of the ring momentum compaction

Momentum compaction α in the combiner ring

Isochronicity curve in the combiner ring - comparison between requirements and MAD tracking



C. Biscari, CTF3 Note 24

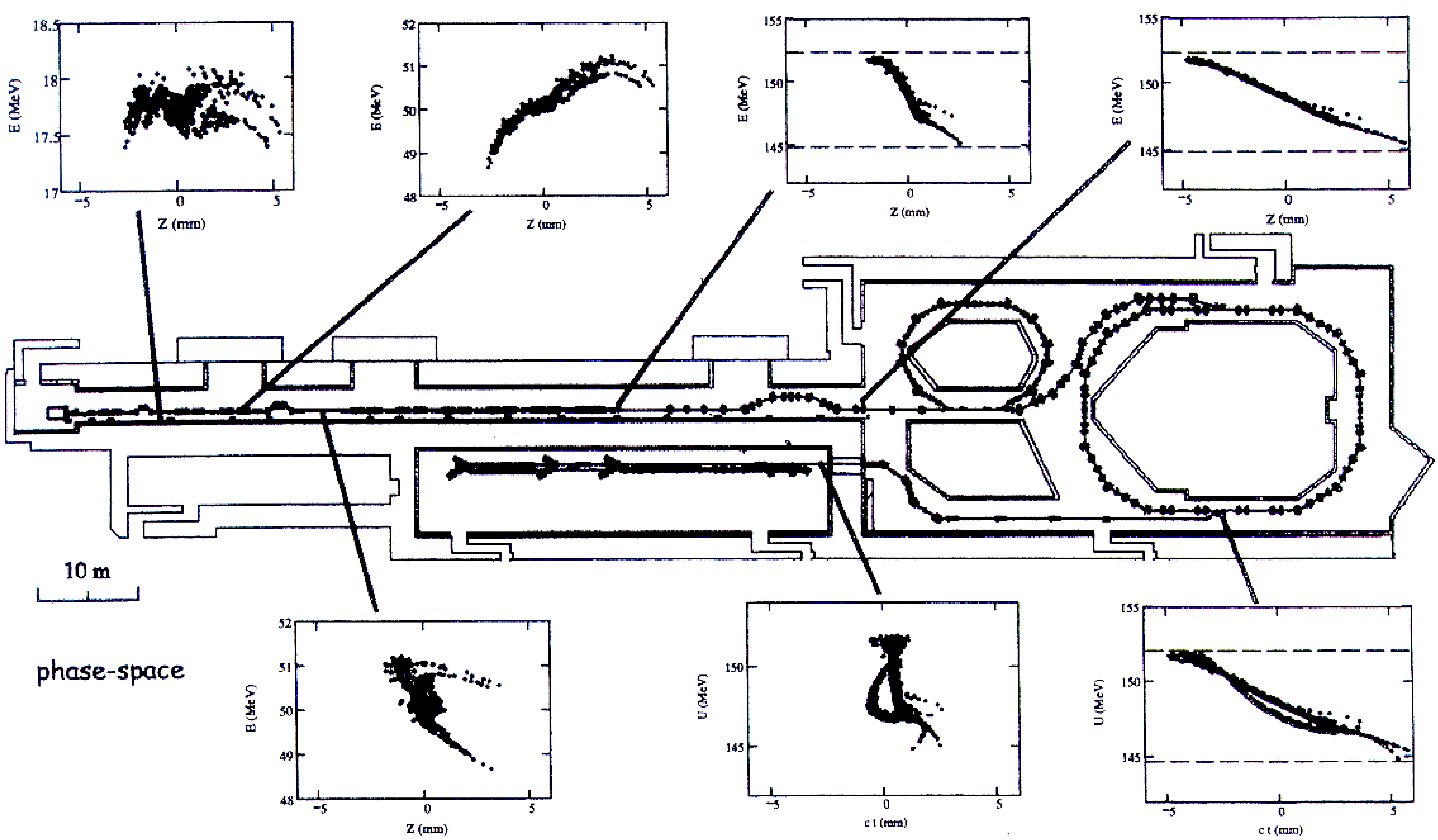
Longitudinal phase space evolution - simulations

- A model of the single-bunch longitudinal phase space evolution in the complex, based on the use of macroparticles, has been used.
- The starting point is a longitudinal phase space distribution at the exit of the injector obtained from PARMELA.
- The evolution in the drive beam accelerator is calculated taking into account the RF field in the accelerating structures and the longitudinal short-range wake-fields.
- The short-range wake-fields are modeled applying to the macro-particle distribution delta wake-fields of the form:

$$W_z = w_1 \exp\left(w_2 \sqrt{z/\mathrm{mm}}\right)$$

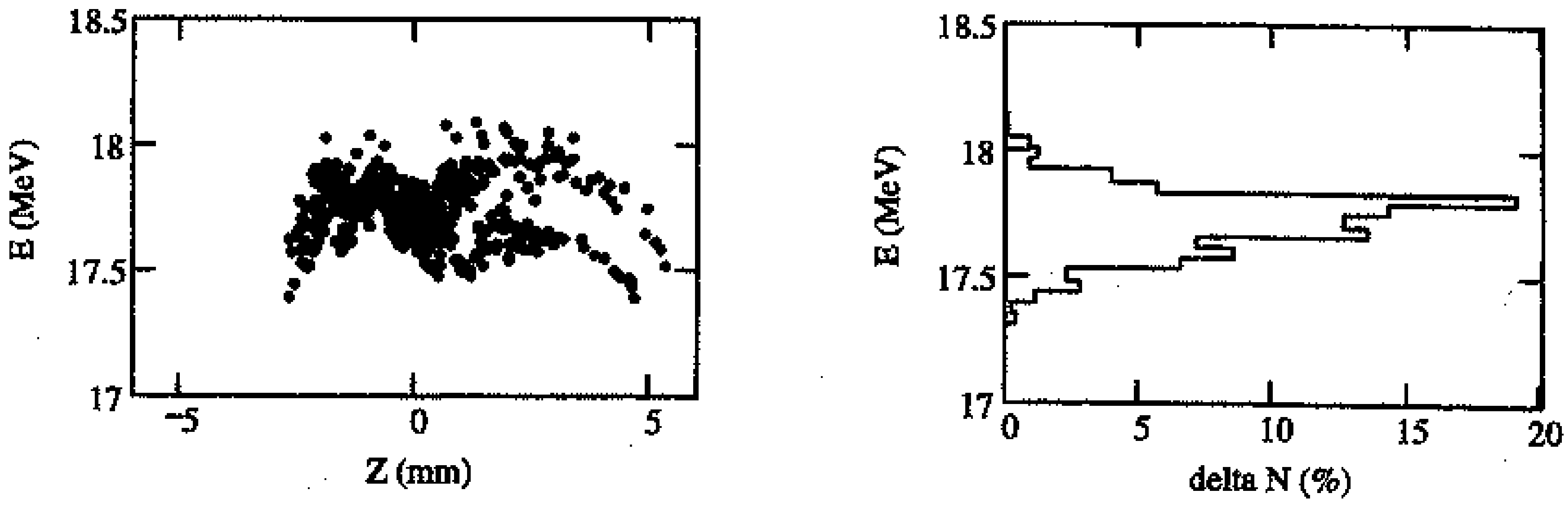
- The evolution in the ring has been calculated taking into account CSR, conventional wakes and momentum compaction. An analytical model has been used for CSR, with the approximation of considering a Gaussian longitudinal distribution for the bunches.
- The conventional wake-fields have been treated using a delta wake model similar to the one used in the linac.

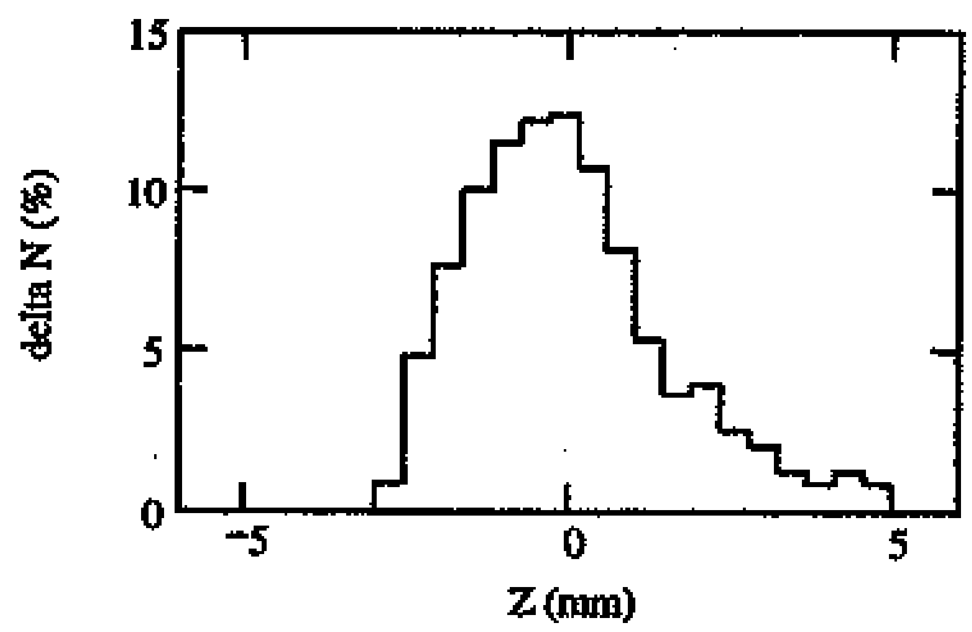
Bunch length evolution in CTF3 - II



Longitudinal phase space at the injector exit

①





Particle distribution in longitudinal phase-space, bunch shape and momentum spectrum after the cleaning chicane

σ_z = 1.5 mm

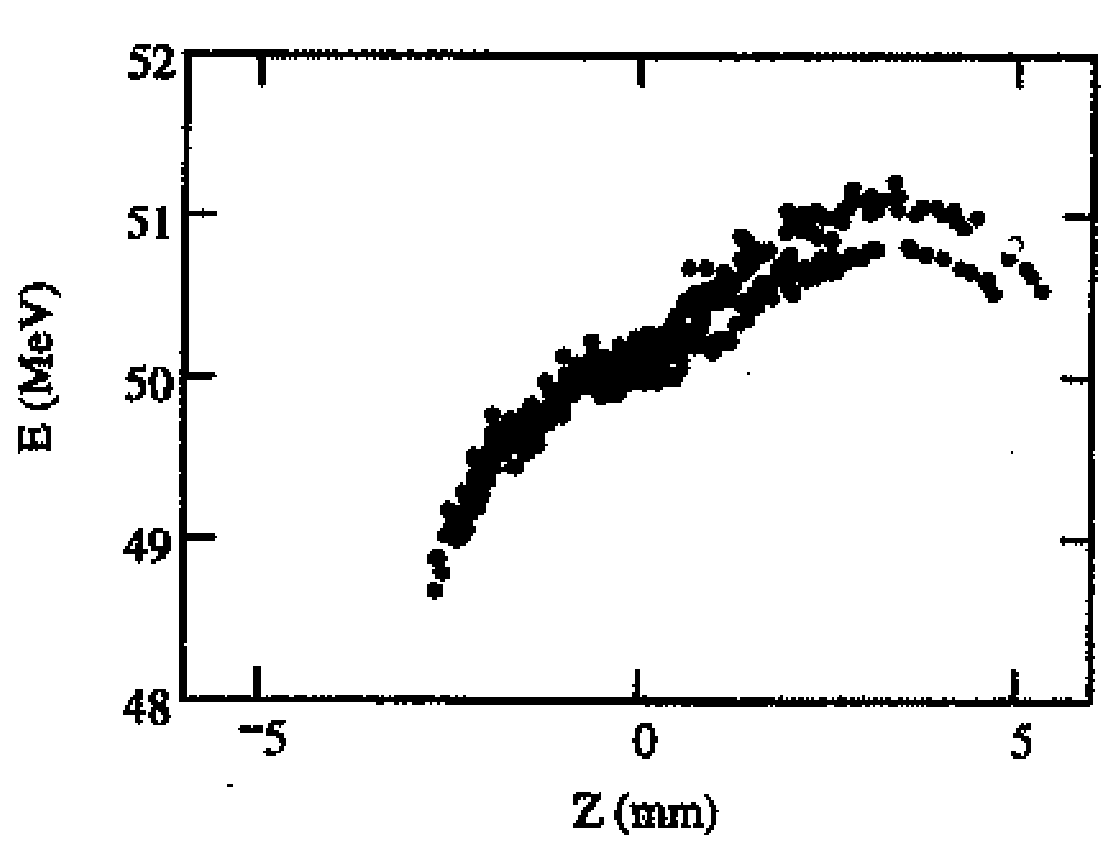
σ_p = 0.12 MeV

D. Yeremian

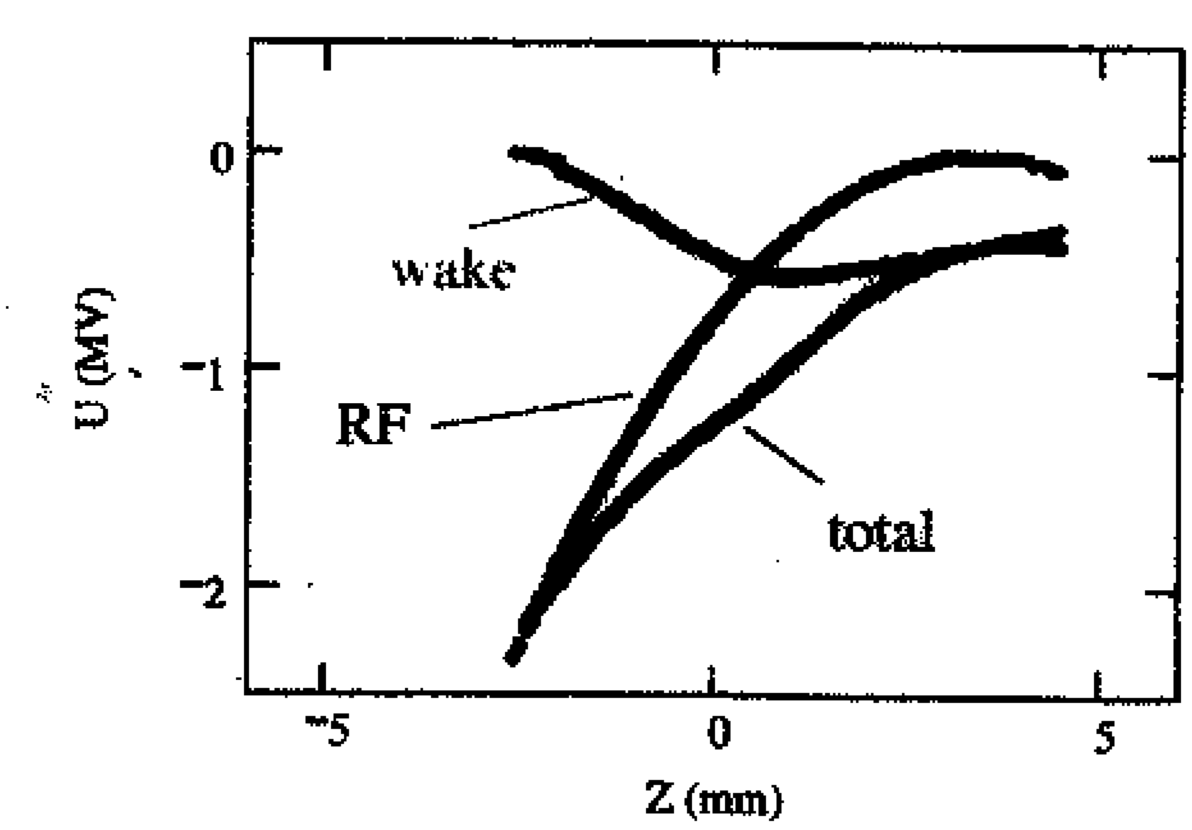
Phase space before the compression chicane

②

The beam is accelerated in a first linac section. A correlated energy spread is introduced by the combination of off-crest acceleration and short-range wake-field.



Longitudinal phase space distribution before the compression chicane

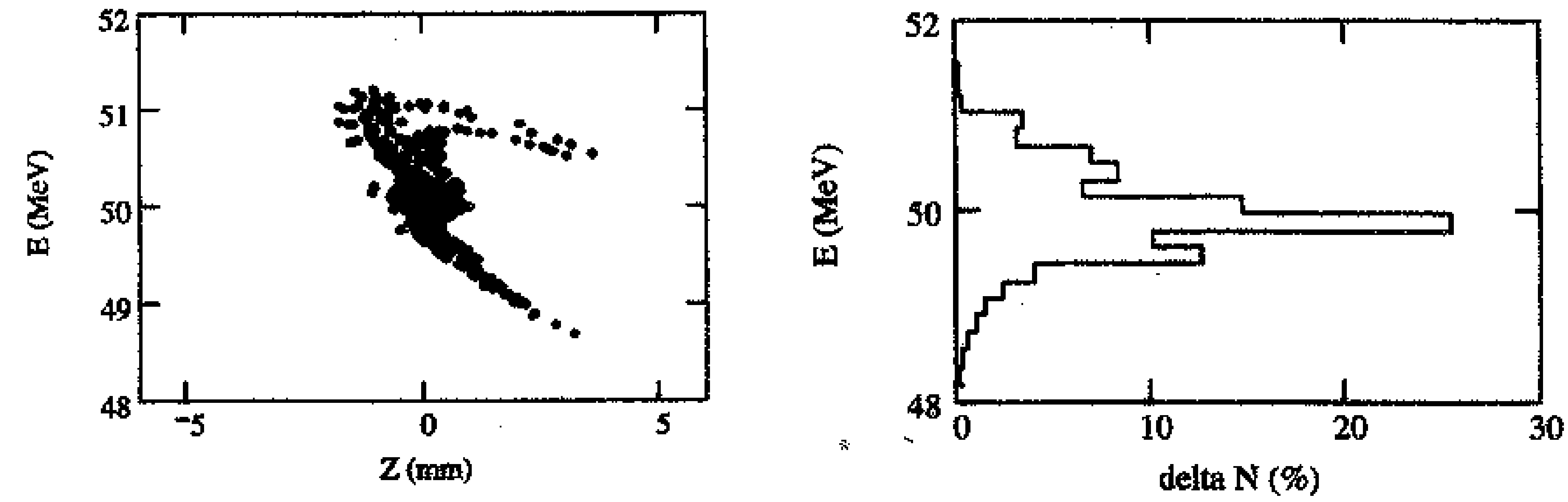


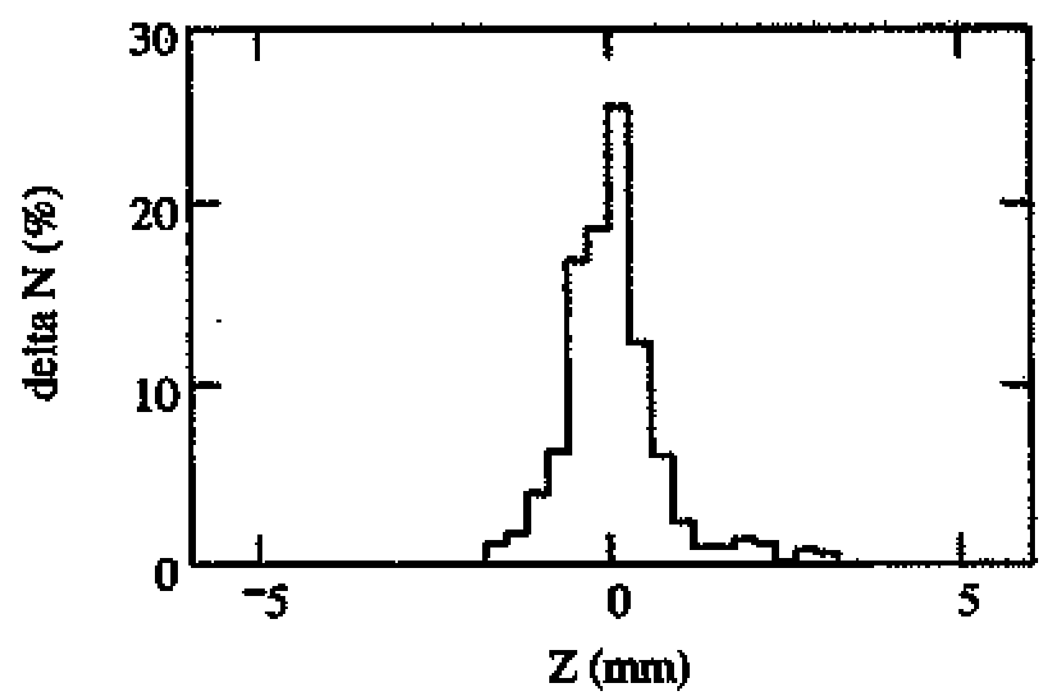
Longitudinal short-range wake-field in the linac and RF field

(-11° off-crest)

Phase space after the compression chicane

③ The bunches are compressed in the compression chicane.





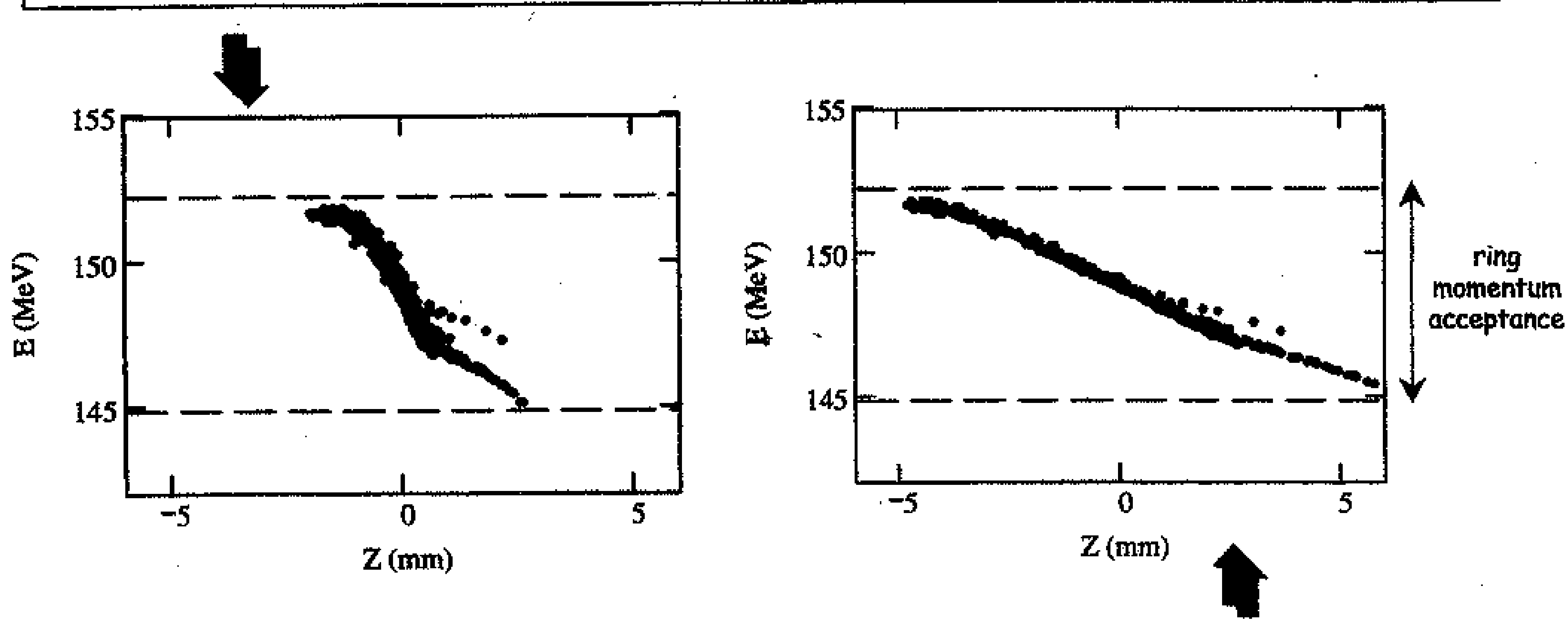
Particle distribution in longitudinal phase-space, bunch shape and momentum spectrum after the compression chicane

σ_z = 0.7 mm

σ_p = 0.45 MeV

Phase space after the DBA

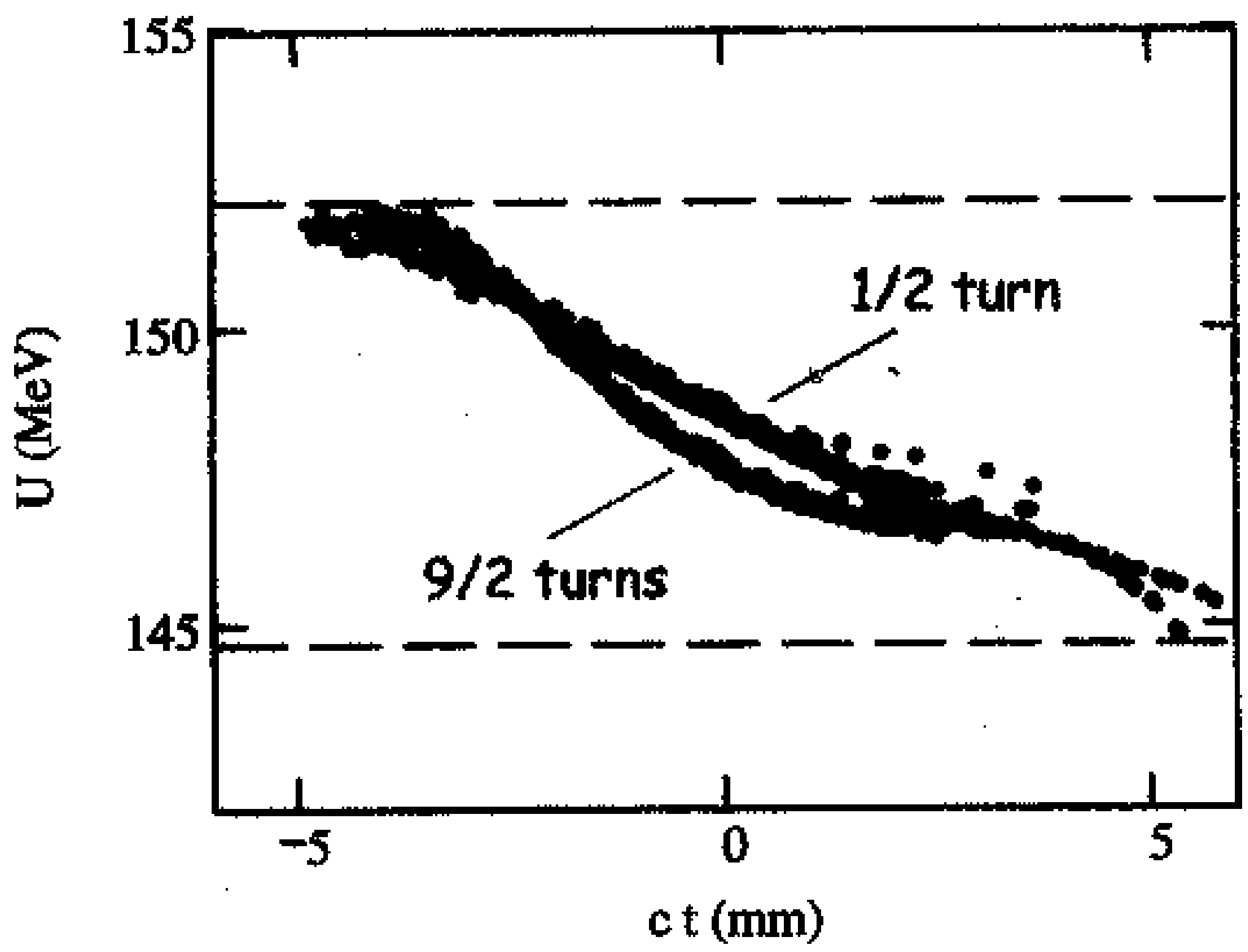
④ The beam is further accelerated in the second part of DBA. A correlated energy spread (opposite sign) is introduced. The total energy spread must be within the ring acceptance



⑤ The bunches are stretched in a 4 bends achromat to σ_z ~ 2 mm

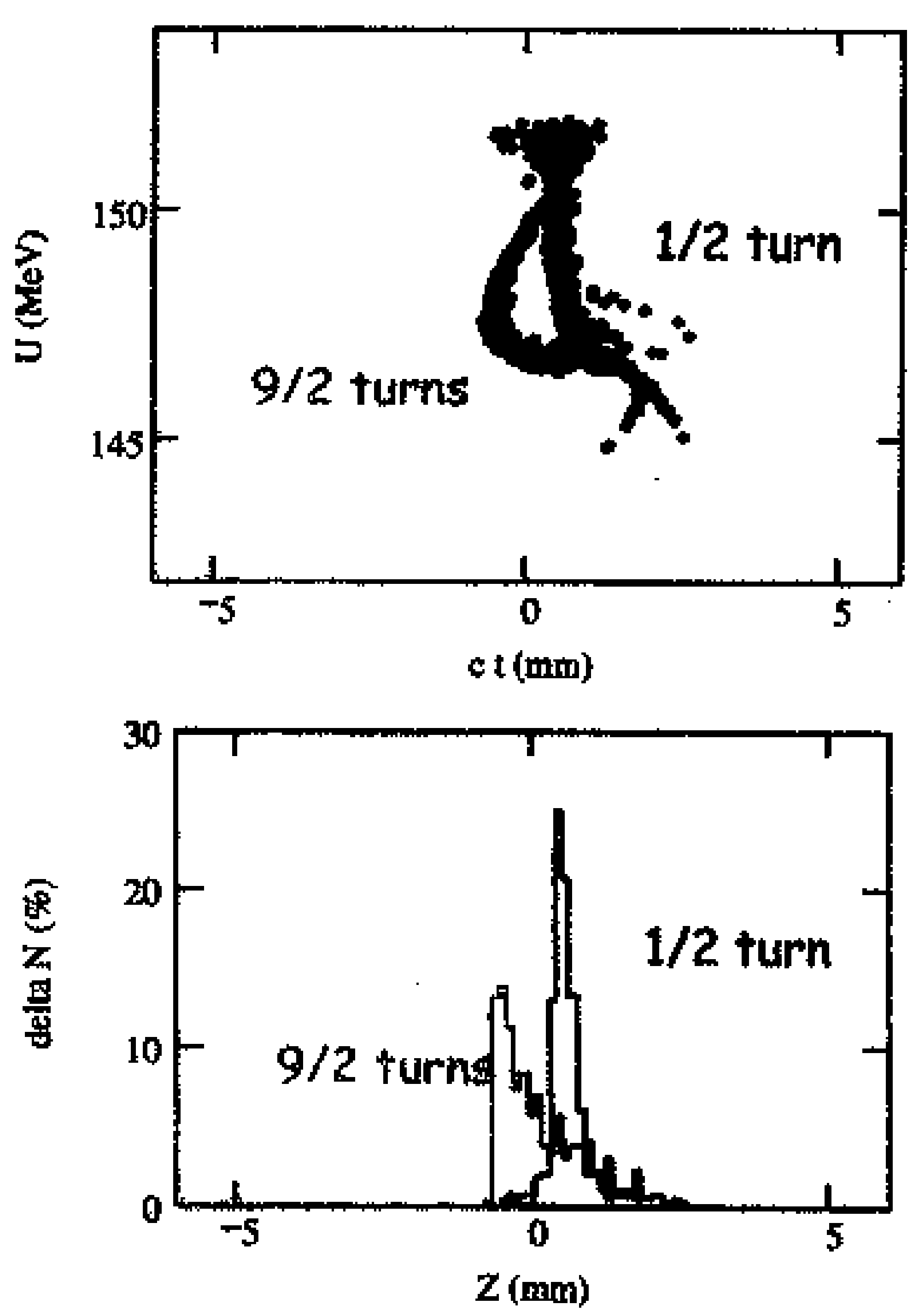
Phase space after the Combiner Ring

⑥ The particle distribution is distorted by CSR, wake-fields and residual momentum compaction. Bunches belonging to different pulses make different numbers of turns (from 1/2 to 9/2) in the Combiner Ring, and will have different phase-space distributions.



Final bunch compression

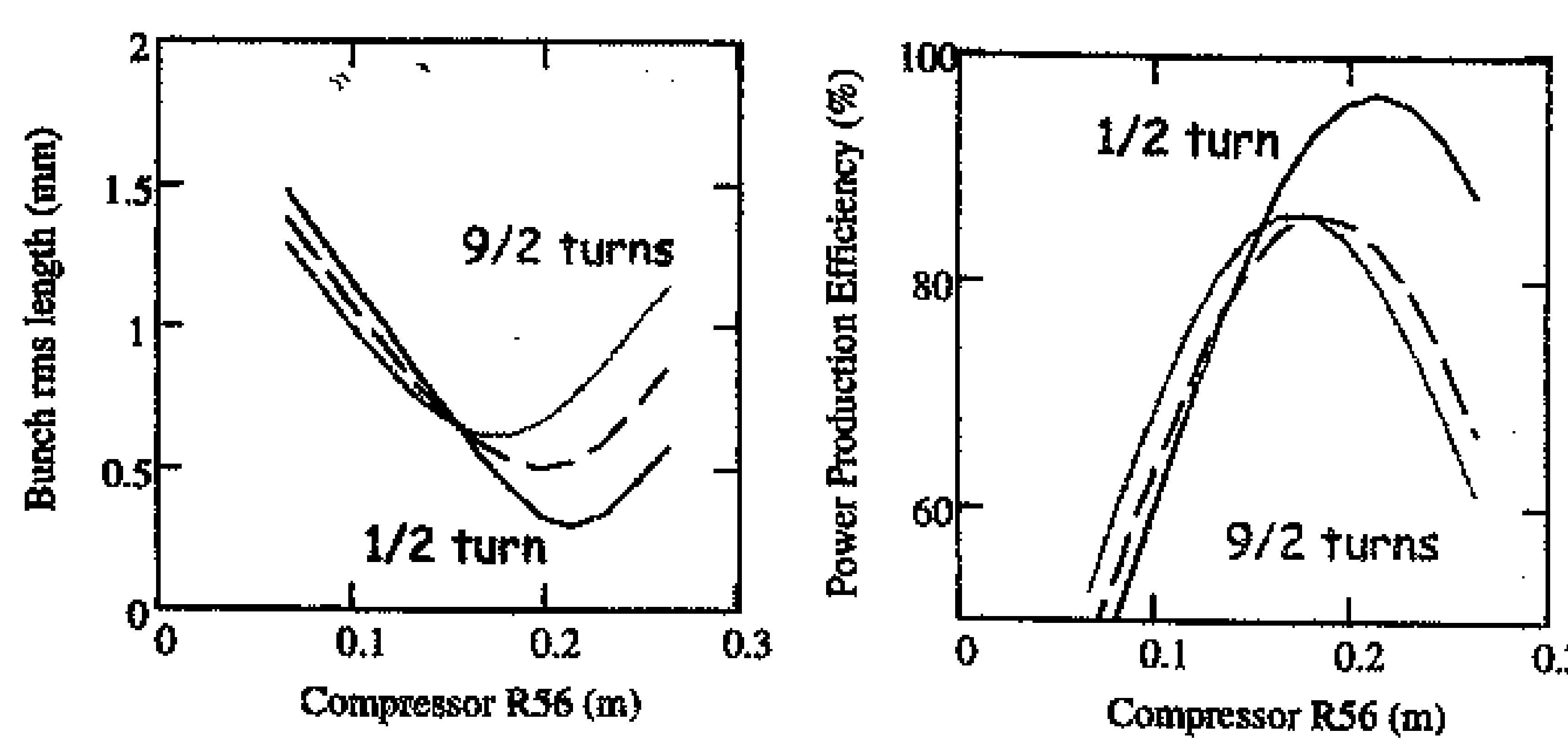
⑥ During the final compression, bunch-to-bunch energy differences are converted in phase errors, and differences in phase space distribution prevent optimum compression



$420\ \mu m < \sigma_Z < 620\ \mu m$

$\eta_{RF} \geq 86\ \%$

Bunch length and corresponding power production efficiency as a function of the compression strength



H. Braun

Idle 15 GHz for improved 30 GHz power production efficiency in CTF3

problems

- contradictory requirements for optimum bunch-length from combiner ring and 30 GHz power production.
- combiner ring increases effective longitudinal phase space area due to CSR and vacuum chamber impedance

however

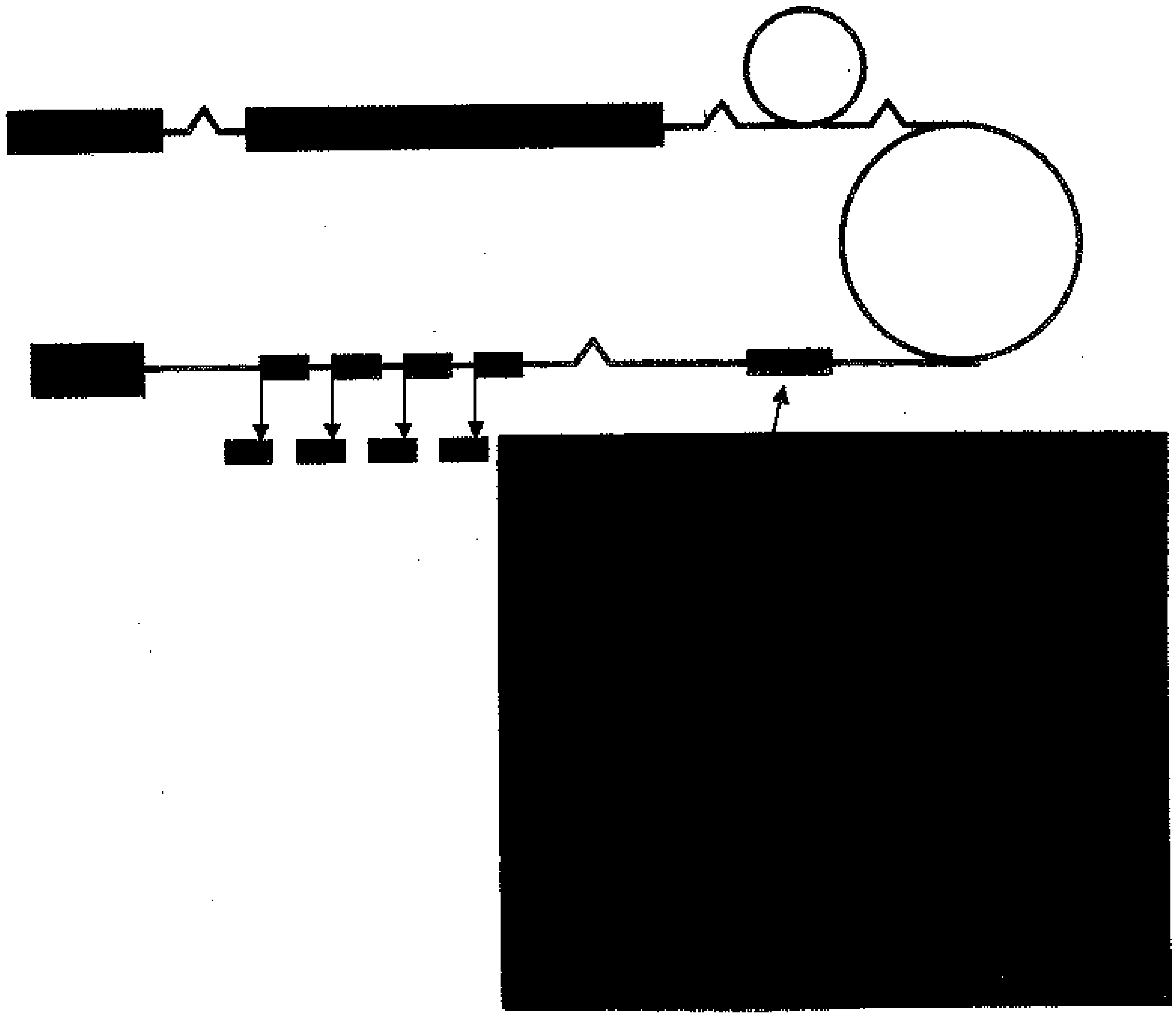
- effective longitudinal phase space after compressor is still small enough for sufficient bunch compression but it needs an energy spread R_{65} x σ_z larger than what is acceptable for the combiner ring

solutions

- increase drive beam energy to decrease ΔT/T

  and/or

- introduce R_{65} downstream of combiner ring. This requires a cavity running at 15 GHz. We want to introduce a correlation in the bunches but we don't need to add energy to the beam, thus an idle cavity acting as a reactance on the beam seems to be attractive !



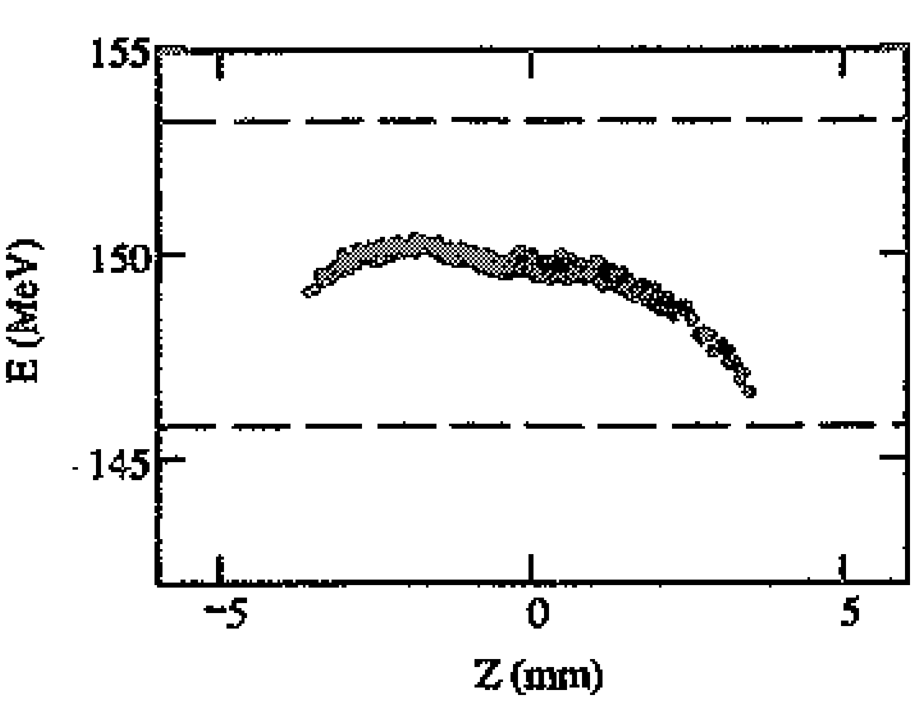
Idler Cavity Design

To get the fast risetime a travelling wave structure terminated with a matched load, very similar to a PETS, seems to be practical. We give four examples for possible configurations. This is a first try on the design, probably better solutions exists.

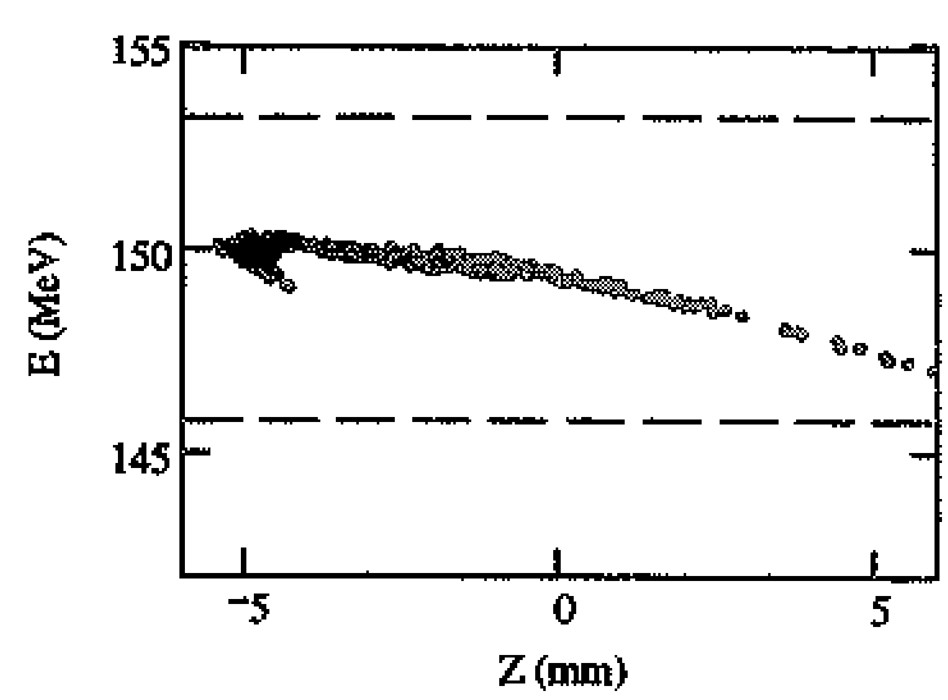
The solutions with two structures offer faster risetimes and more flexibility due to the possibility to remove or add structures. However, they require more structure length. The magnitude of transverse wakefields is probably small compared to the downstream 30 GHz PETS's.

Idle cavity option - I

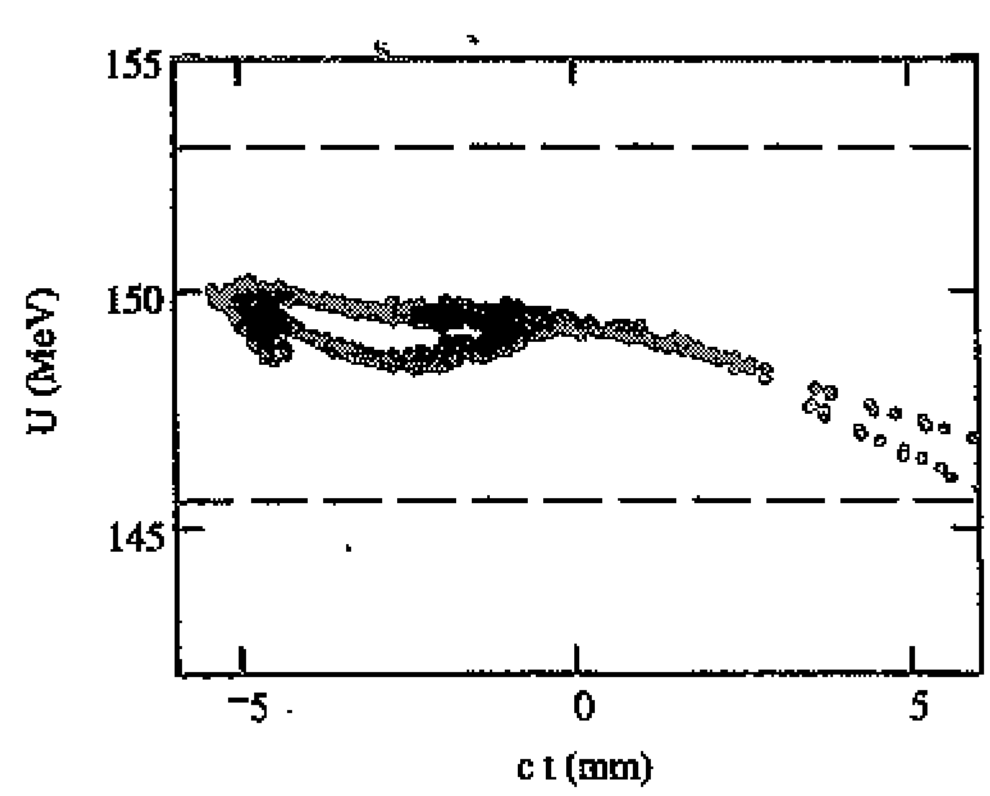
Longitudinal phase space distribution at the end of DBA



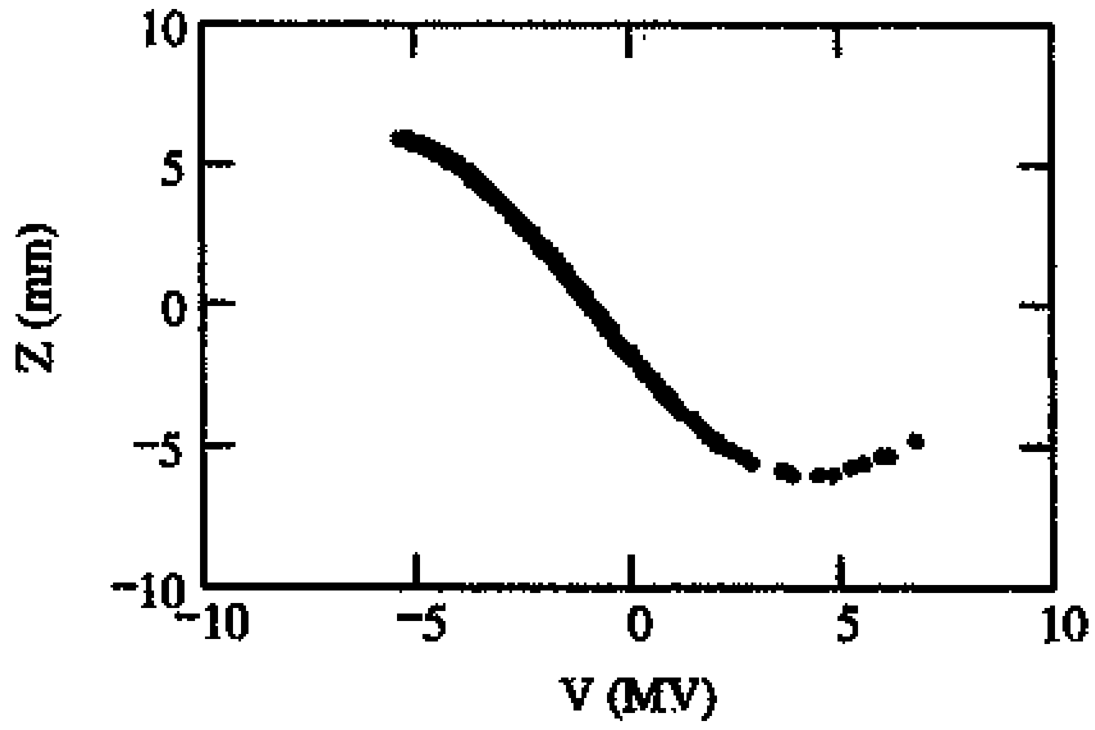
Bunch stretching to ~ 2 mm rms



Longitudinal phase space distribution after the combiner ring



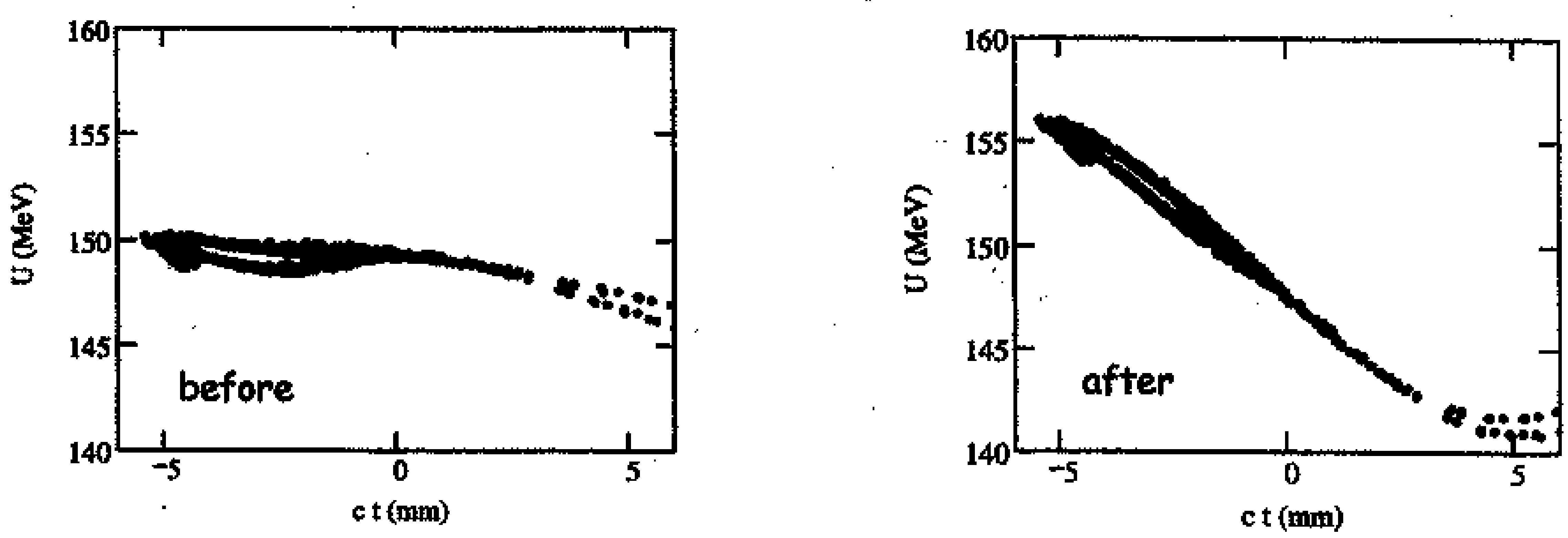
Idle cavity option - II



Steady state longitudinal field in idle cavity, over the bunch extension

peak integrated voltage	6 MV
de-phasing	60 degrees

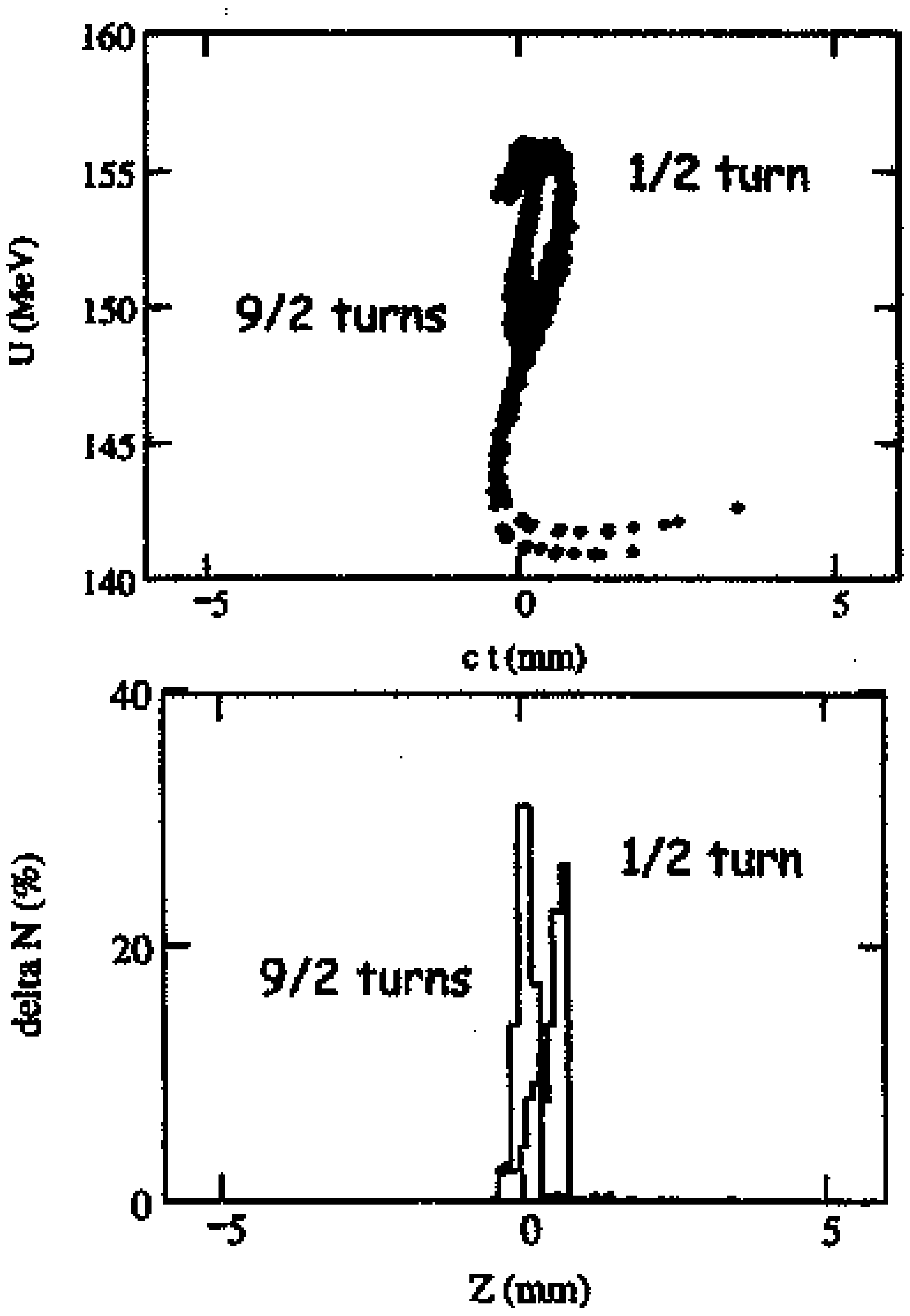
Longitudinal phase space distributions, before and after the idle cavity



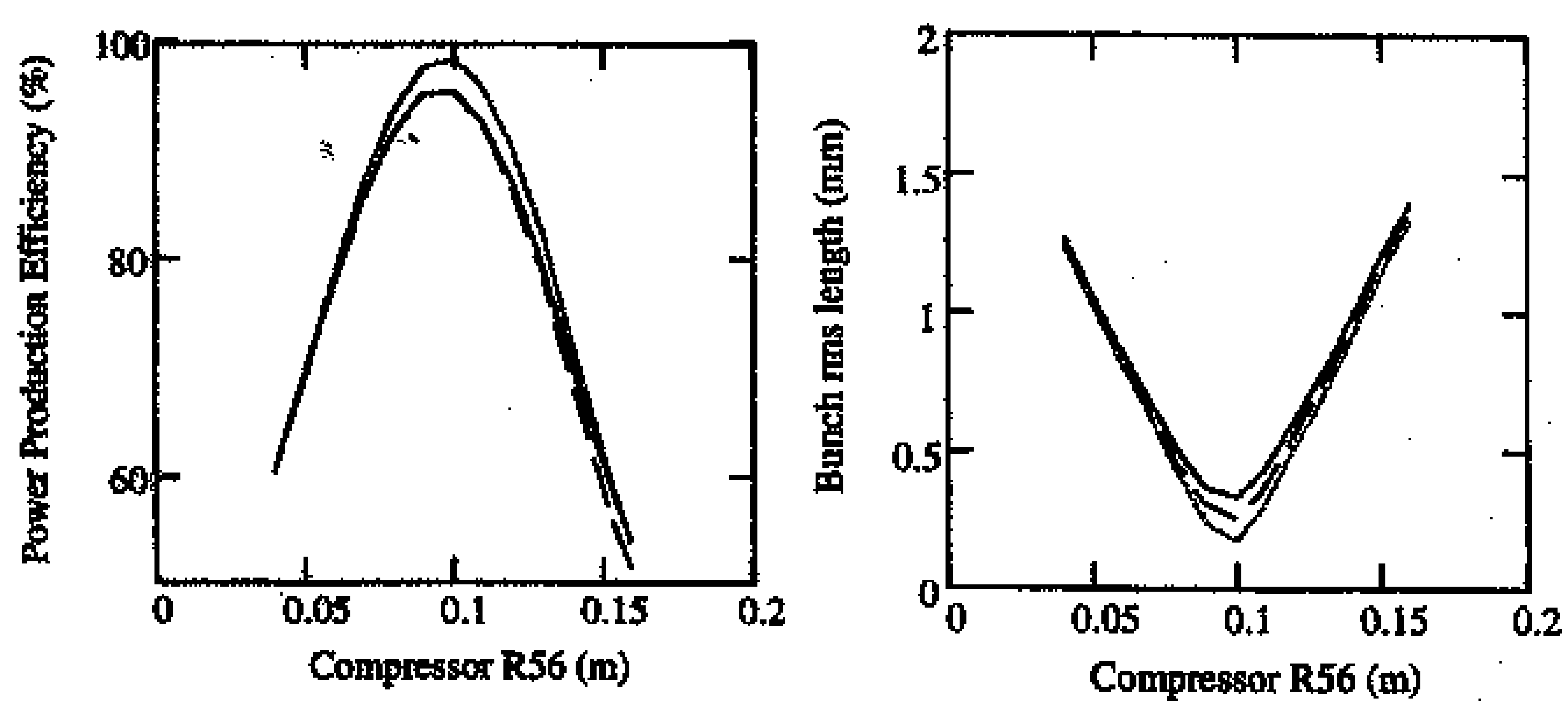
Idle cavity option - final compression

$200\ \mu m < \sigma_Z < 330\ \mu m$

$\eta_{RF} \gtrsim 95\ \%$



Bunch length and corresponding power production efficiency as a function of the compression strength



SUMMARY

- A very short bunch length is required in CTF3 after recombination for efficient 30 GHz power production
- The rms bunch length is changed along the complex in order to minimize distortions to the phase space distribution.
- In particular, the rms bunch length is maximized to ~ 2 mm in the Delay Loop and the Combiner Ring.
- By a careful design of the components it is possible to keep the conventional wake-fields contribution within the design limits.
- The Delay Loop and the Combiner Ring are isochronous to 2nd order.
- The bunches are finally compressed to ~ 500 μm.
- A simplified model, based on macro-particle distribution and analytical calculations has been developed to evaluate the evolution of the longitudinal phase space in the CTF3 complex, taking into account CSR and conventional wake-fields.
- The results show that the desired bunch length and 30 GHz power production efficiency can be obtained after final compression with the assumptions made above.

Ring Impedance

Besides the CSR effect, the electromagnetic interaction with the vacuum chamber can produce energy spread and energy loss.

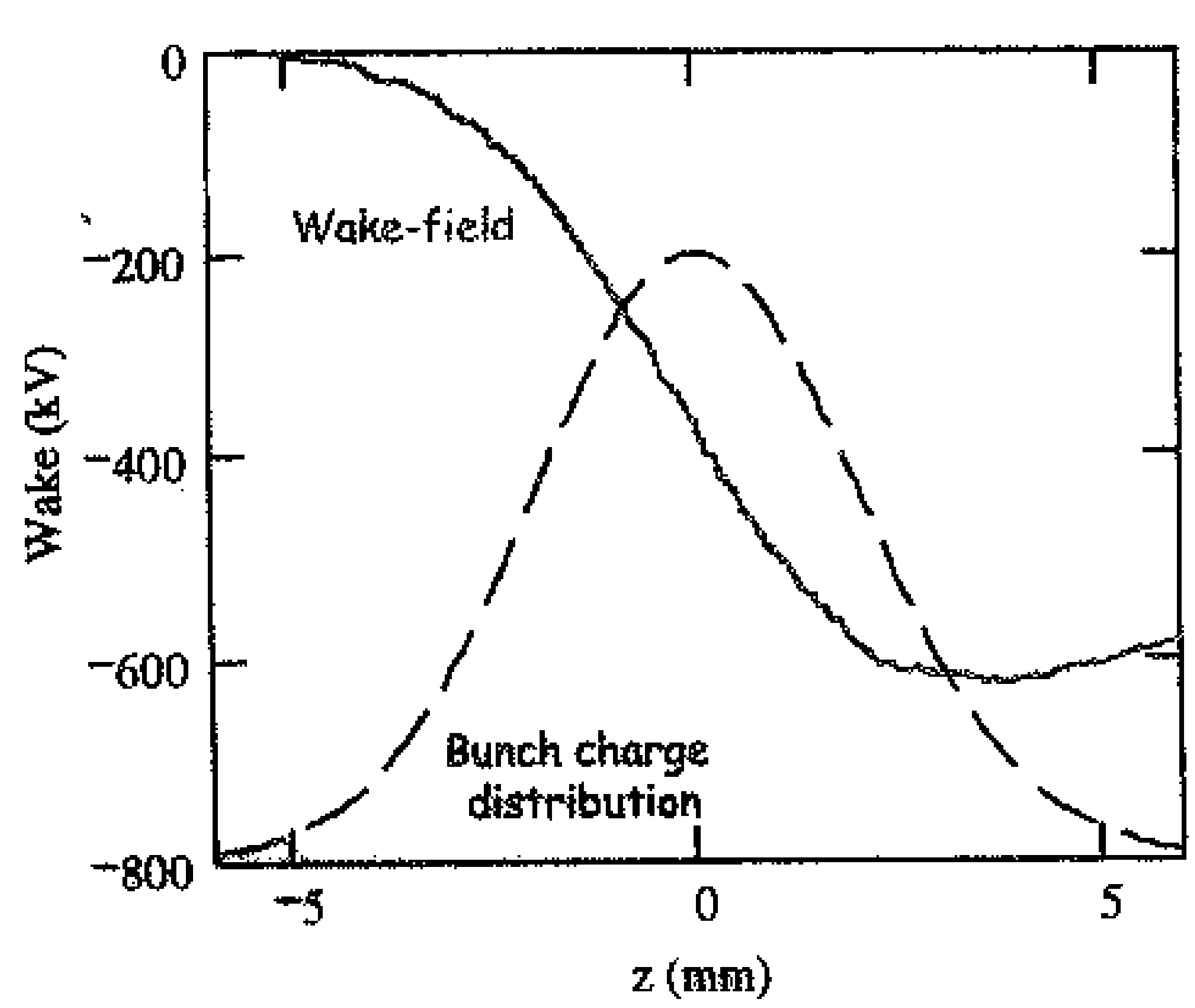
A rough evaluation of an acceptable impedance can be made by assuming a purely inductive impedance. The limit of the normalized impedance is found to be $Z/n < 0.4\ \Omega$. The estimated value compared to the impedance of other accelerator rings (for example, $Z/n \sim 21\ \Omega$ in EPA and 0.6 Ω in DAFNE) shows that a very careful design of the CTF3 combiner ring vacuum chamber is necessary.

A more precise evaluation can be obtained by a time-domain calculation of the contributions of the different elements in the ring

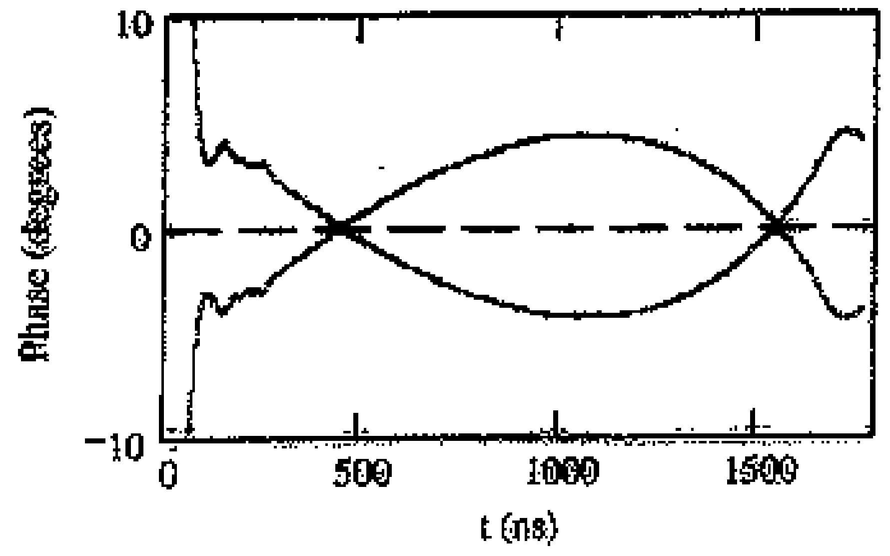
Here it is shown the cumulative wake-field obtained by summing up the different contributions, for a bunch with σ_z = 2 mm

The main effects are coming from the BPMs and the RF deflectors

A. Ghigo, M. Zobov, CTF3 Note 26



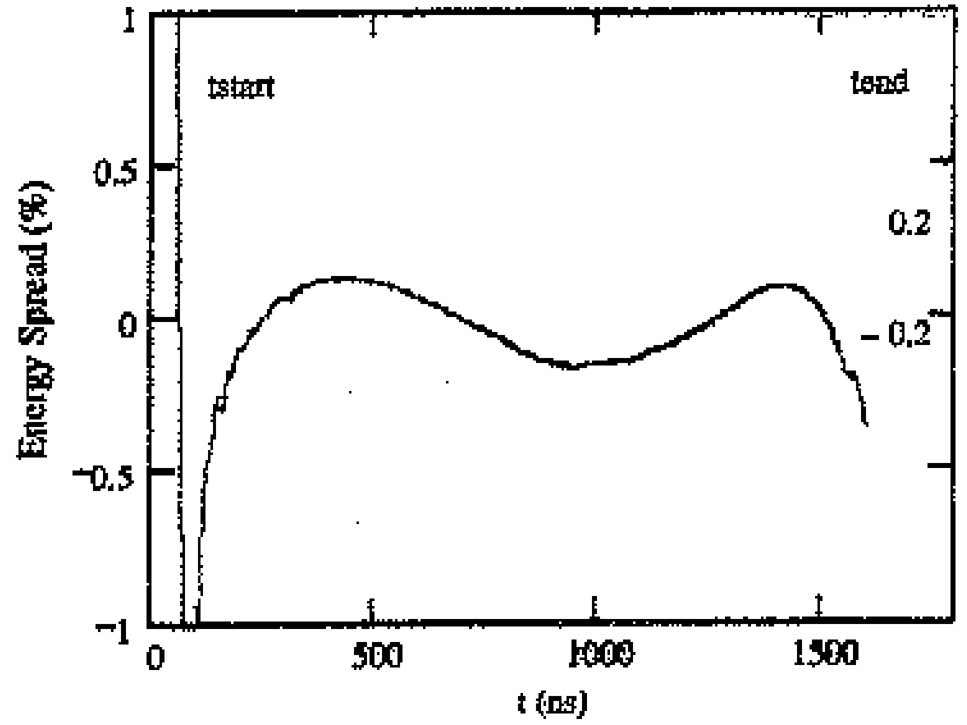
Effect of energy variations along pulse

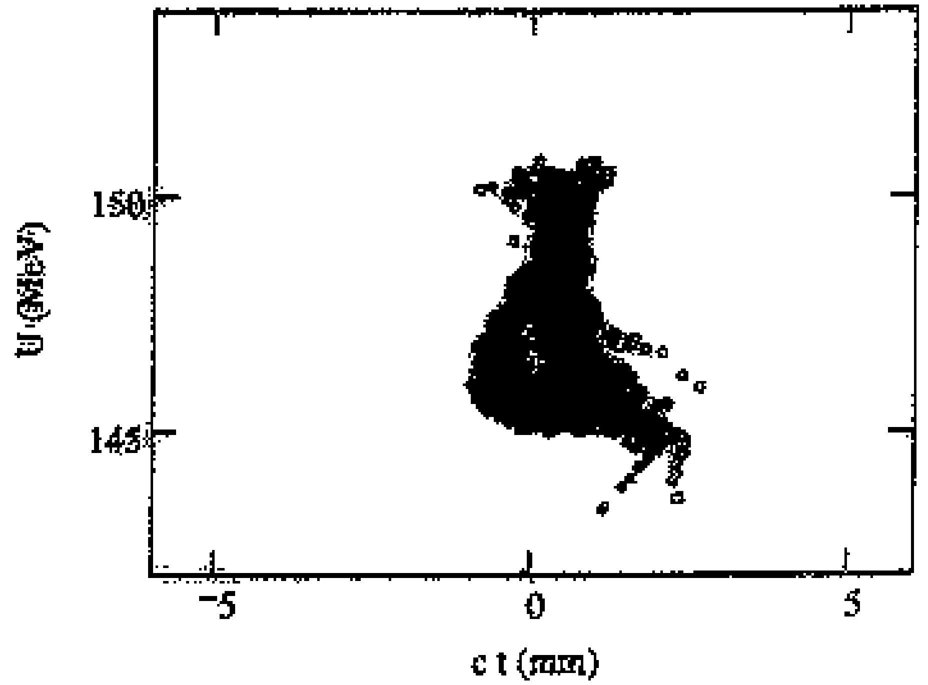


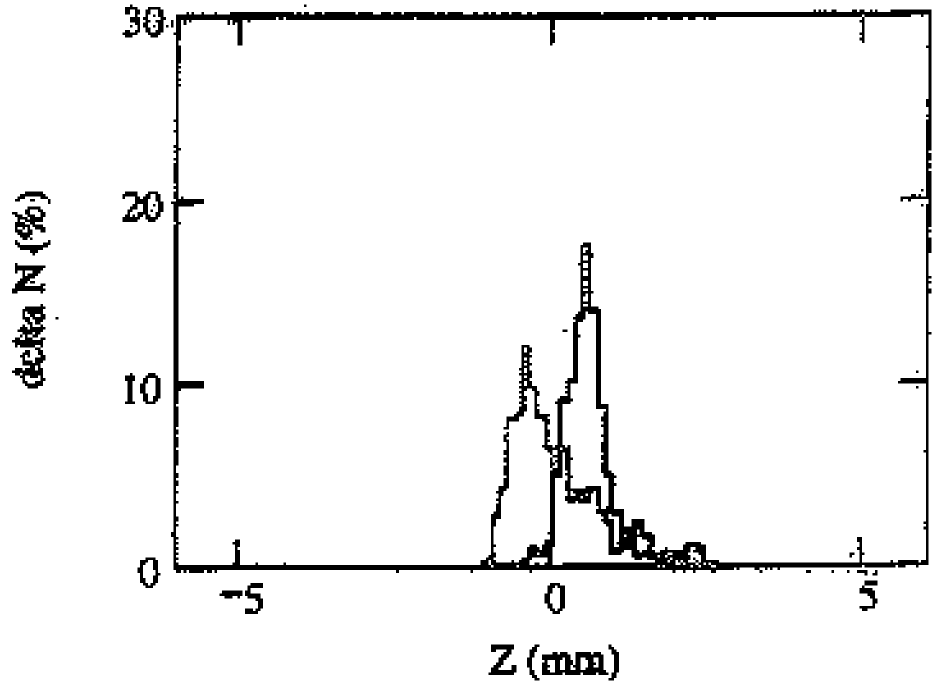
Phases from klystrons

T. Syratchev

Energy spread over 1.4 μsec







$470\ \mu m < \sigma_Z < 640\ \mu m$

$\eta_{RF} \gtrsim 85\ \%$

DELAY LOOP

and

COMBINER RING DESIGN

C. Biscari

C. Biscari, A. Clozza, A. Gallo, A. Ghigo, M. Preger, C. Sanelli,

F. Sannibale, M. Serio, F. Sgamma, M. Zobov

LNF, INFN, Frascati, Italy

CTF3 REVIEW – 2-3 October 2001, CERN

OUTLOOK

- **General considerations**
- **Combiner ring**

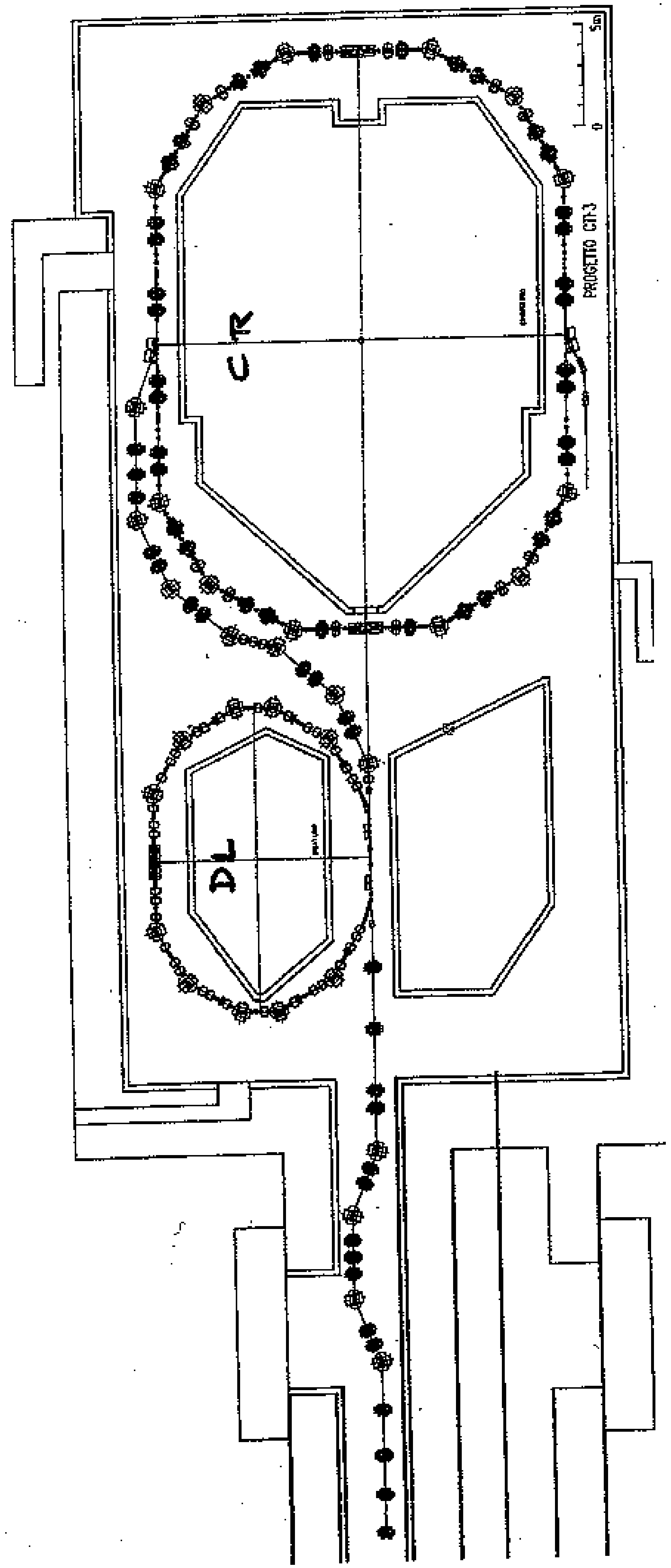
  Parameters
  Optics design
  Path length tuning
  Isochronicity
  Orbit/trajectory correction

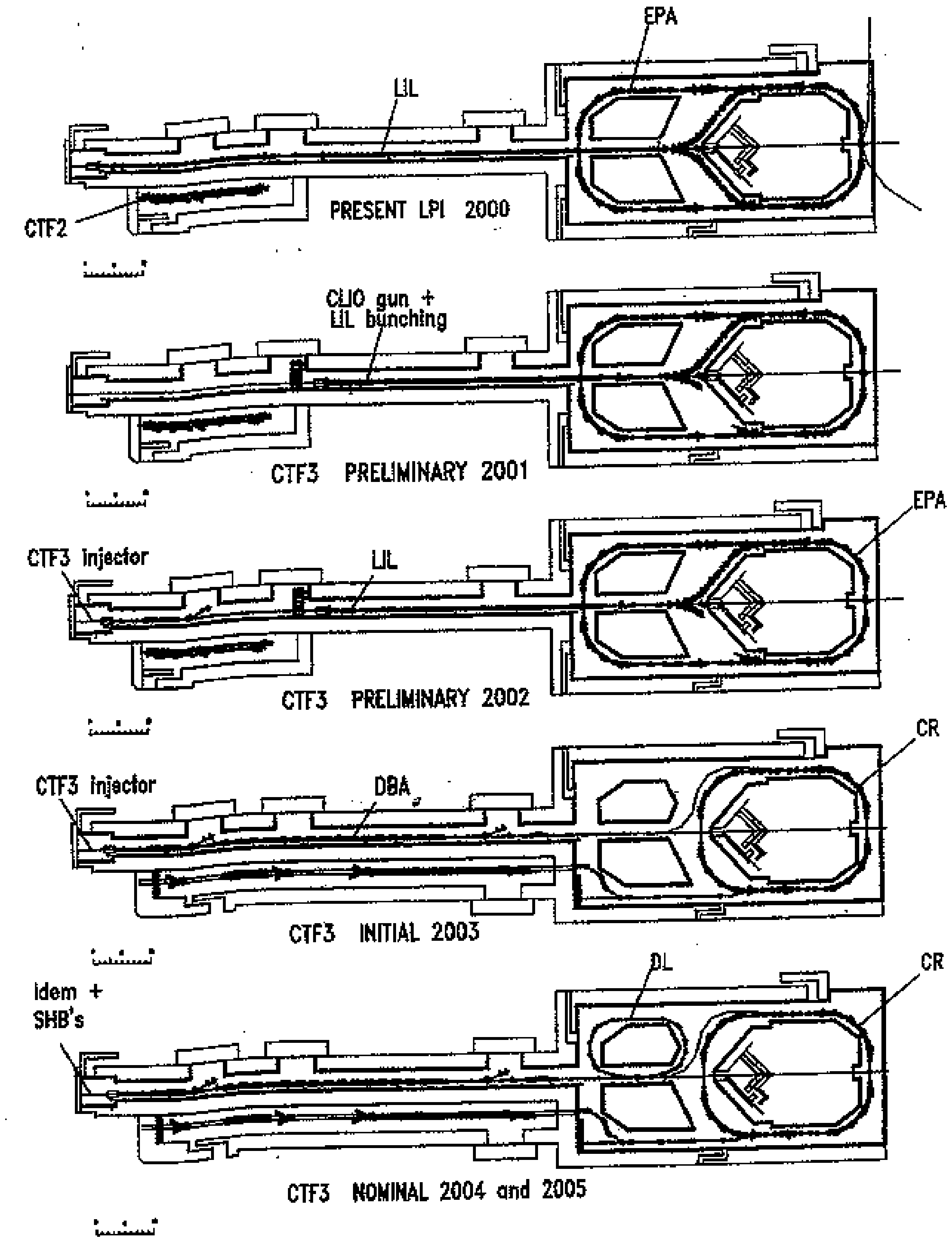
- **Delay loop**

  Parameters
  Optics design (A and B)
  TL Matching
  Isochronicity

- **Work in progress**

  CR as storage ring





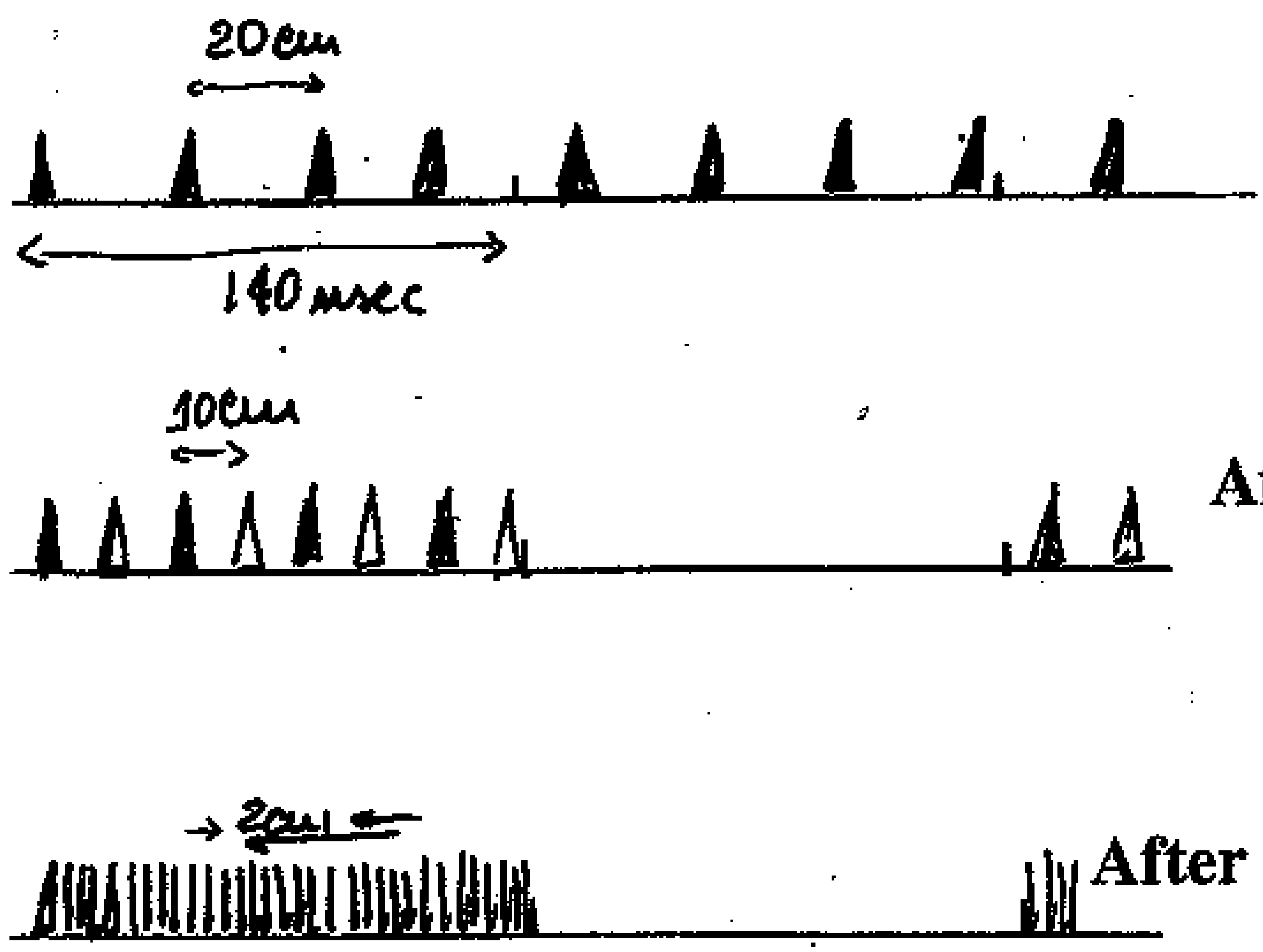
From LPI to CTF3

DBA = Drive Beam Accelerator
CR = Combiner Ring
DL = Delay Loop
SHB = Sub Harmonic Buncher

Drive Beam

High current in short bunches, low energy

Energy (MeV)	180 – 350
Emittance (mm mrad)	1 – 0.5
Bunch length (mm)	1
Bunch charge (nC)	2.3 – 1.0



After Linac

After Delay Loop

After Combiner Ring

Frequency multiplication must keep the bunch structure (longitudinal and transverse)

Control of bunch length + possibility of modifying it (to deal with CSR)

Isochronicity

Tunable R_{56}

Stretcher and compressors

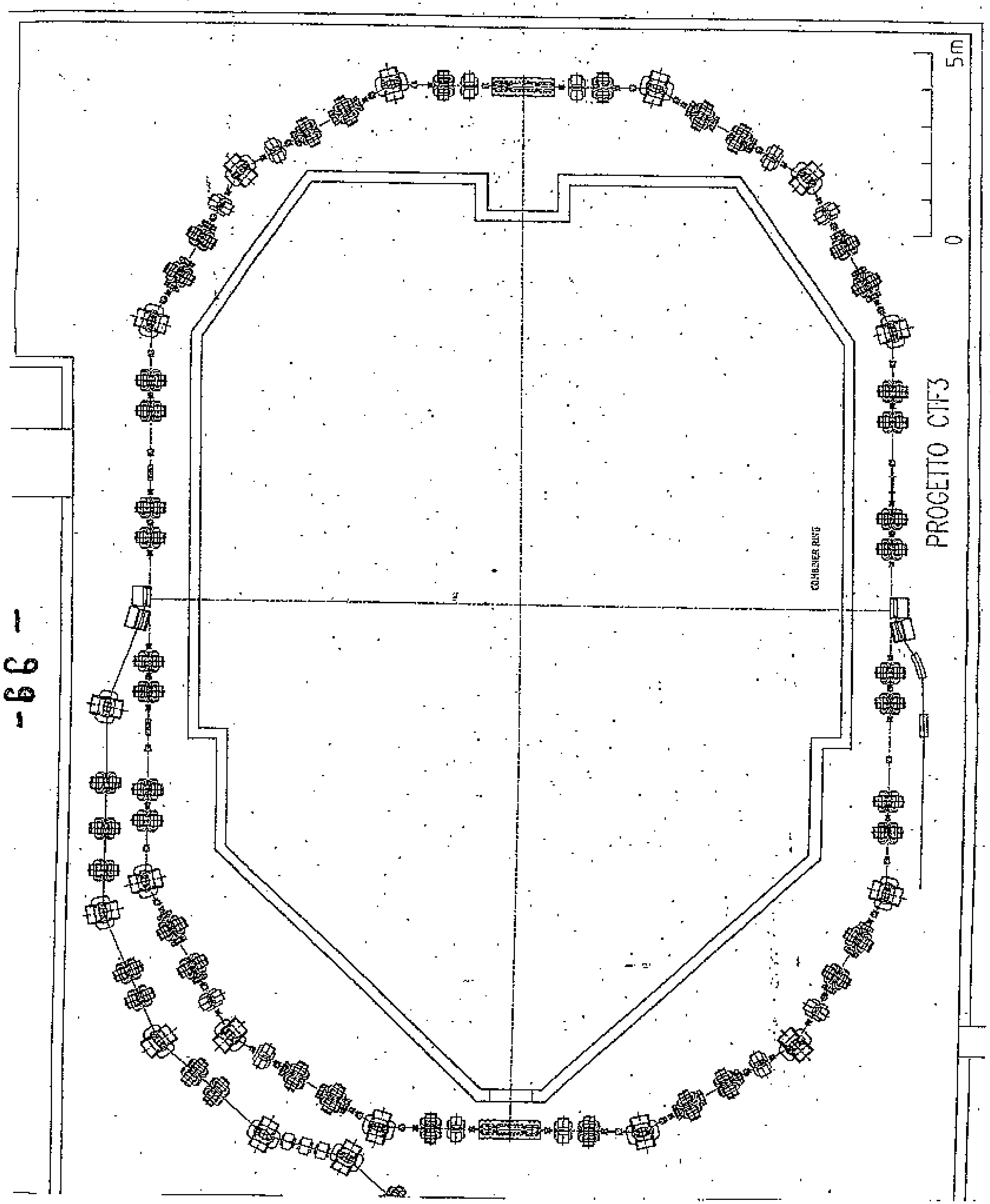
Path length tuning

Linac frequency

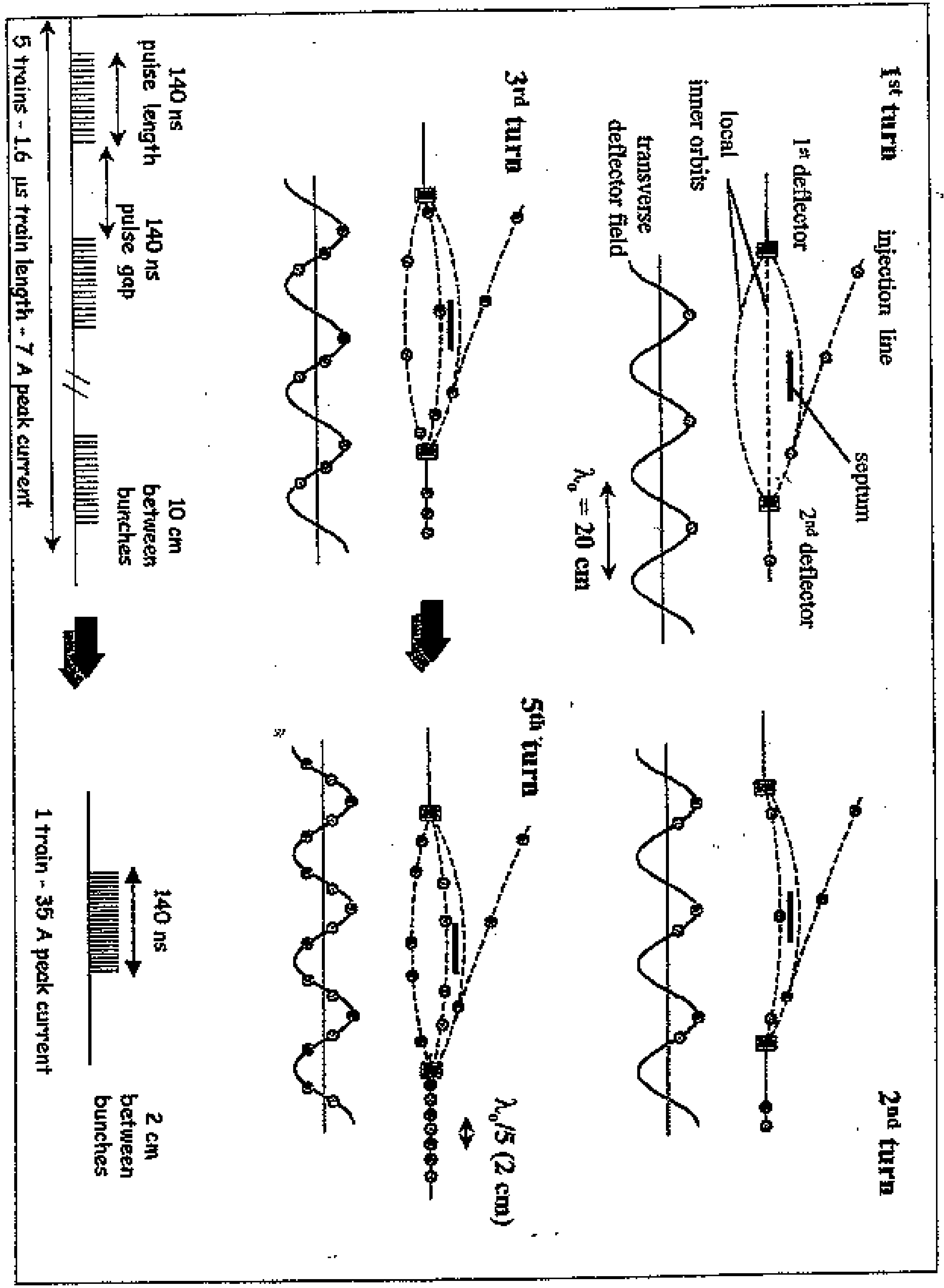
Wigglers

Space constraints +

reusing when possible existing hardware, design material and documentation



COMBINER RING



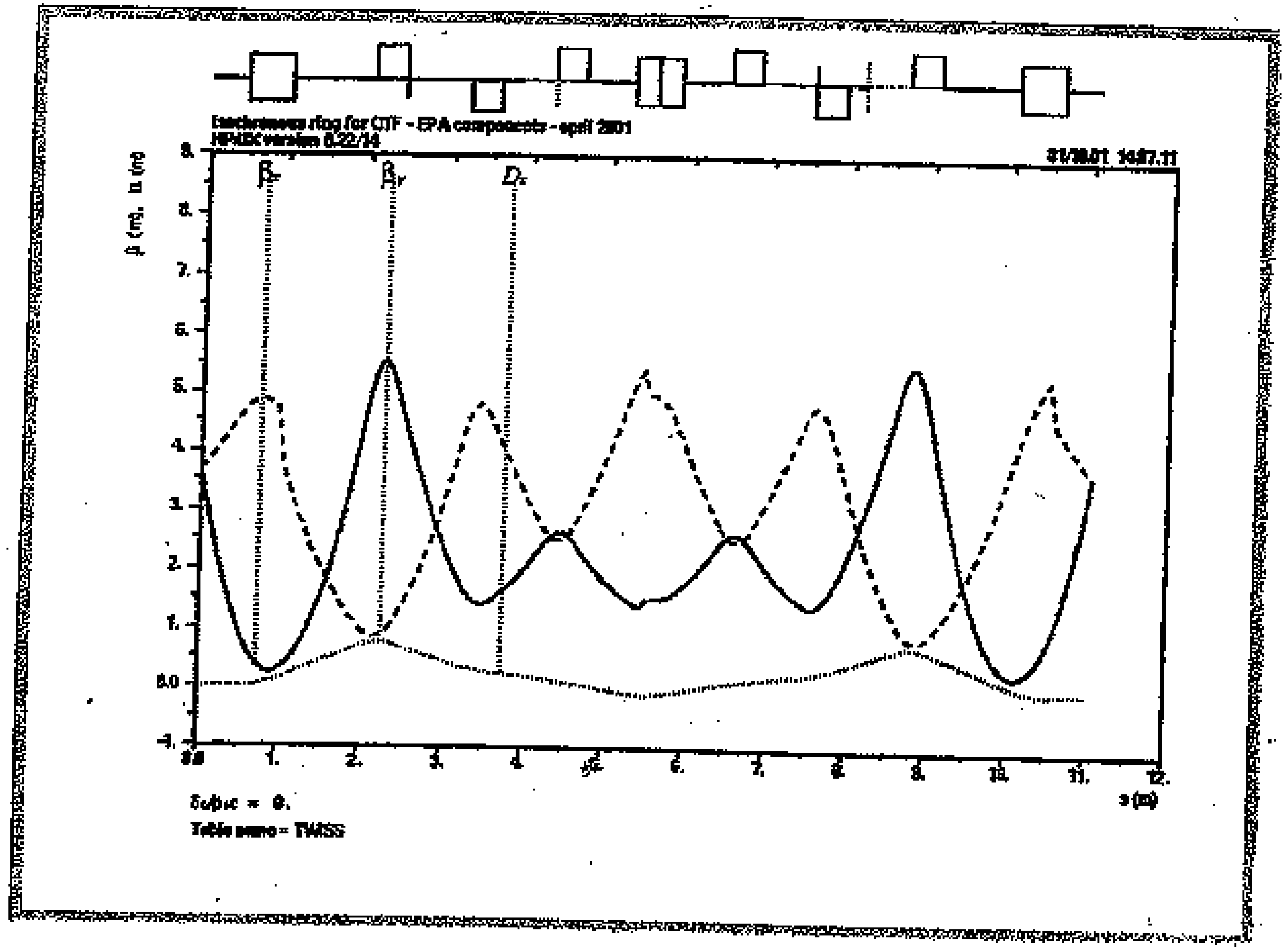
Principle of x5 bunch frequency multiplication in the CR

COMBINER RING PARAMETERS

Energy (MeV)	180/350
Bρ (T m)	0.60/1.17
Circumference (m)	84.0
No. Cells	4
Max. beta (m) (H/V)	11.1/11.1
Max. Dispersion (m)	0.72
Betatron Tune (H/V)	7.23/4.14
Chromaticity (H/V)	-12.0/ -8.8
Momentum compaction	$<10^{-4}$
Horizontal emittance (mm mrad)	1.0/0.5
Vertical emittance (mm mrad)	1.0/0.5
Energy spread (%)	±1
Energy acceptance (%)	±2.5

Isochronous arc

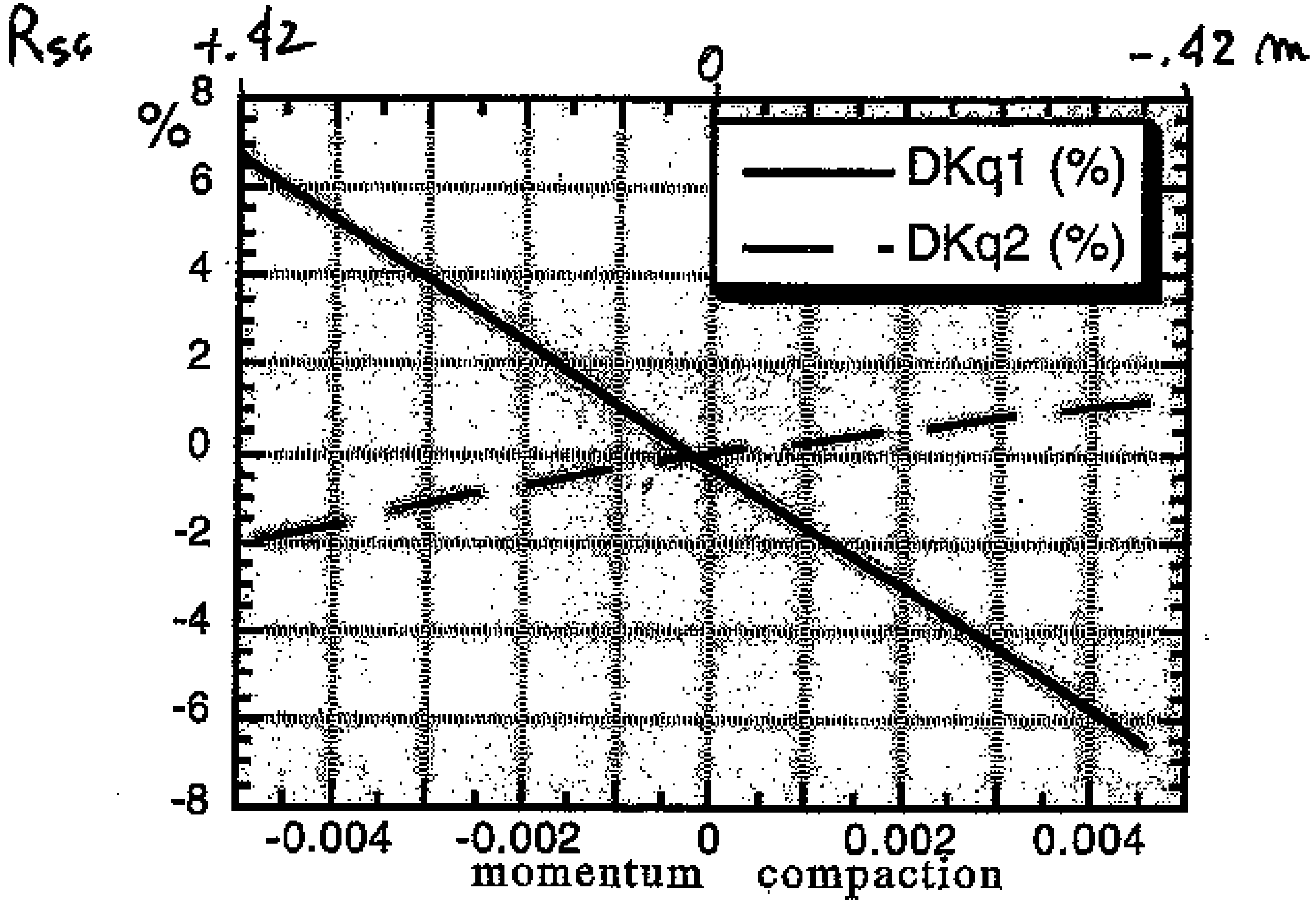
(three-bends achromat)

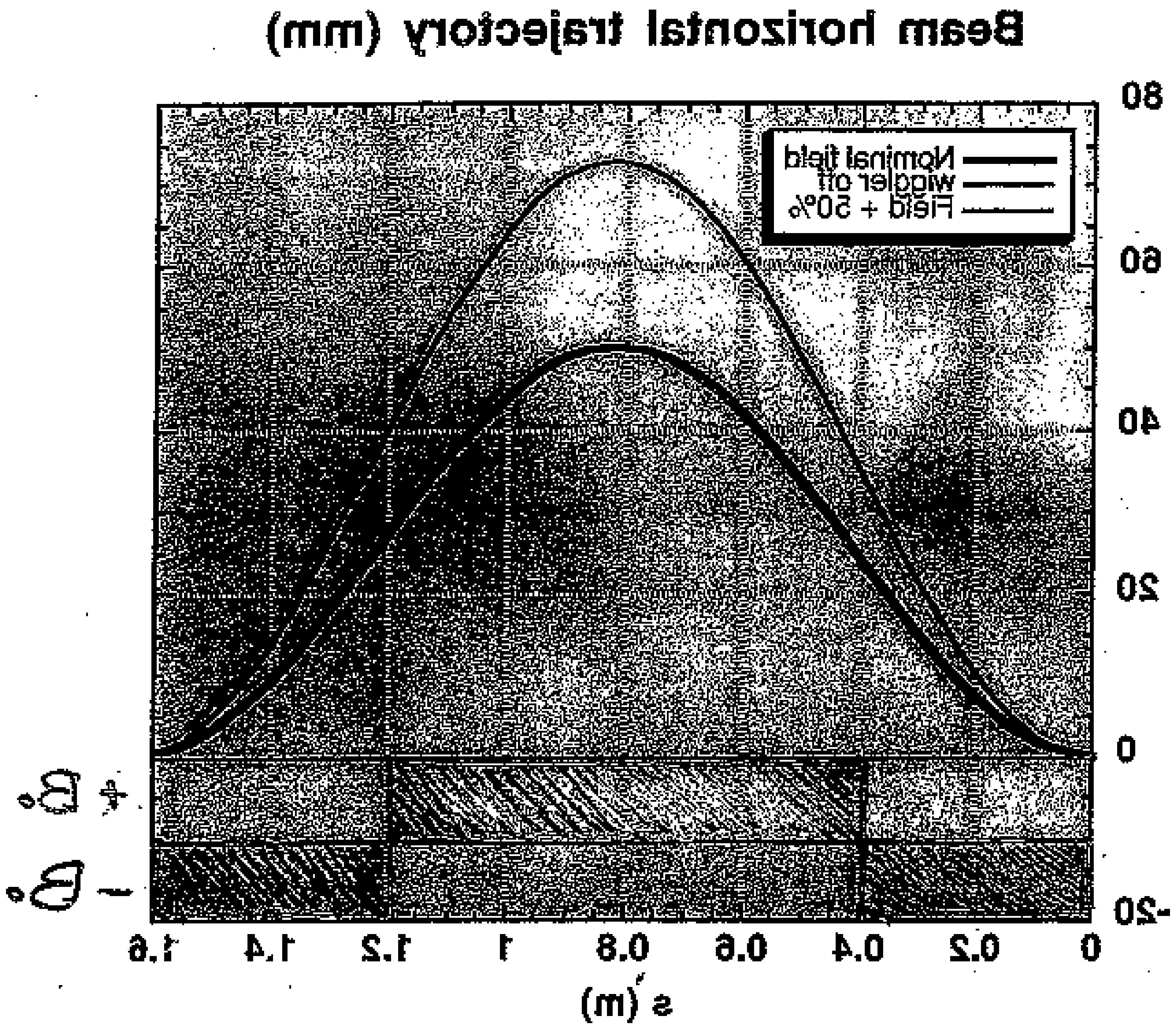


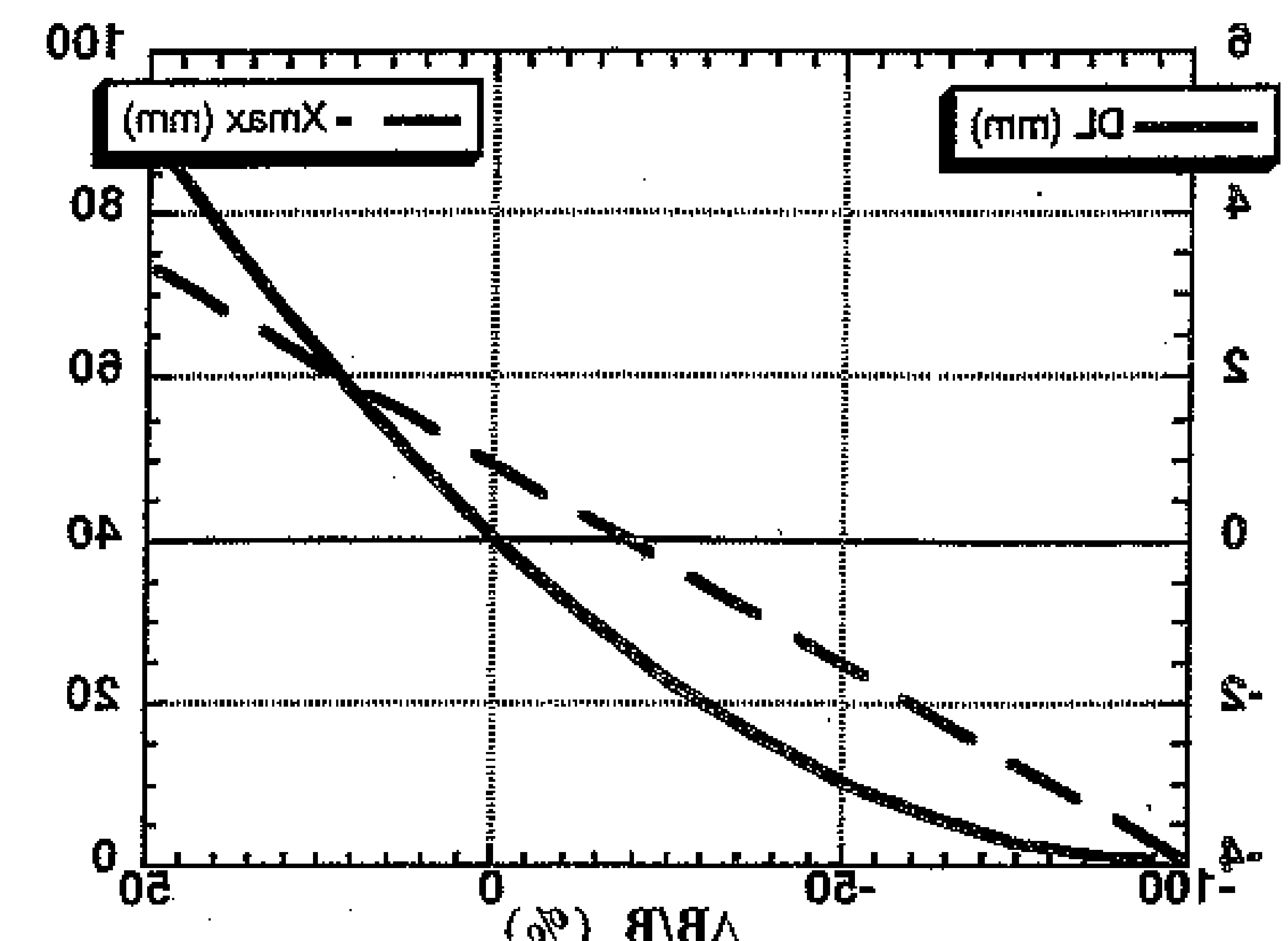
$$R_{56} = \int \frac{D}{\rho}\, ds = 0$$

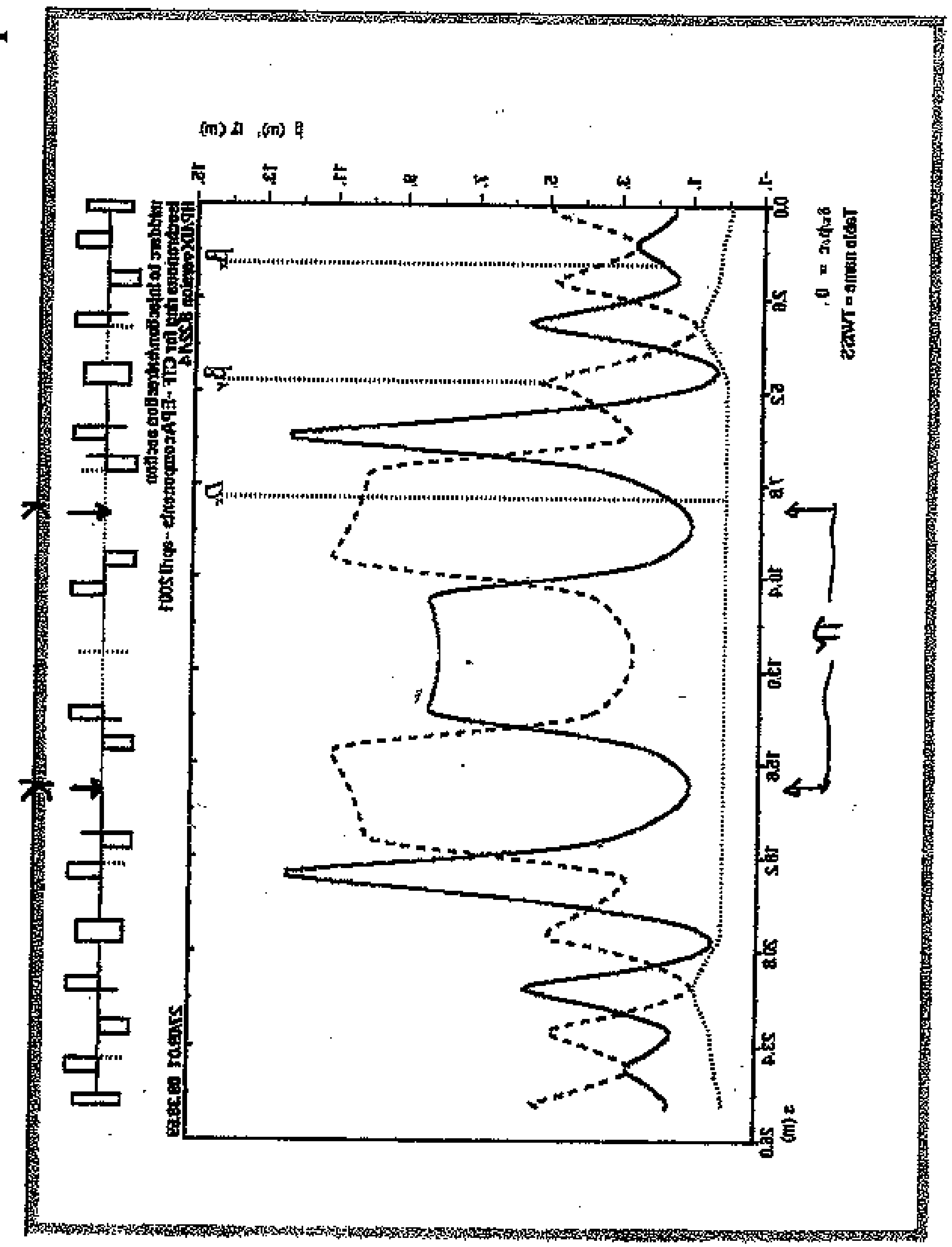
R_{56} tunability

$$D_o\,(\text{m}) = 40.218\ \alpha_c - 0.10278$$



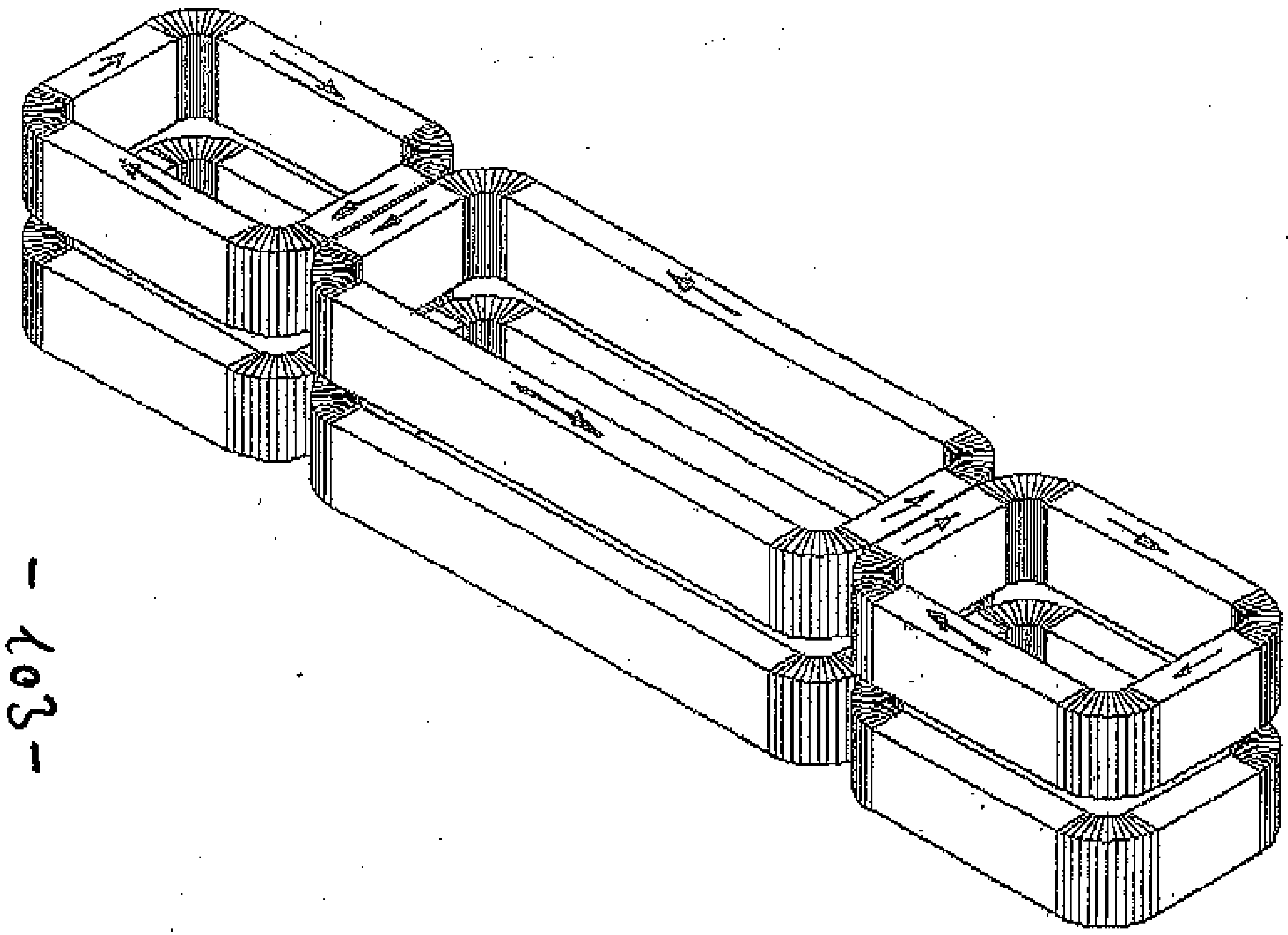






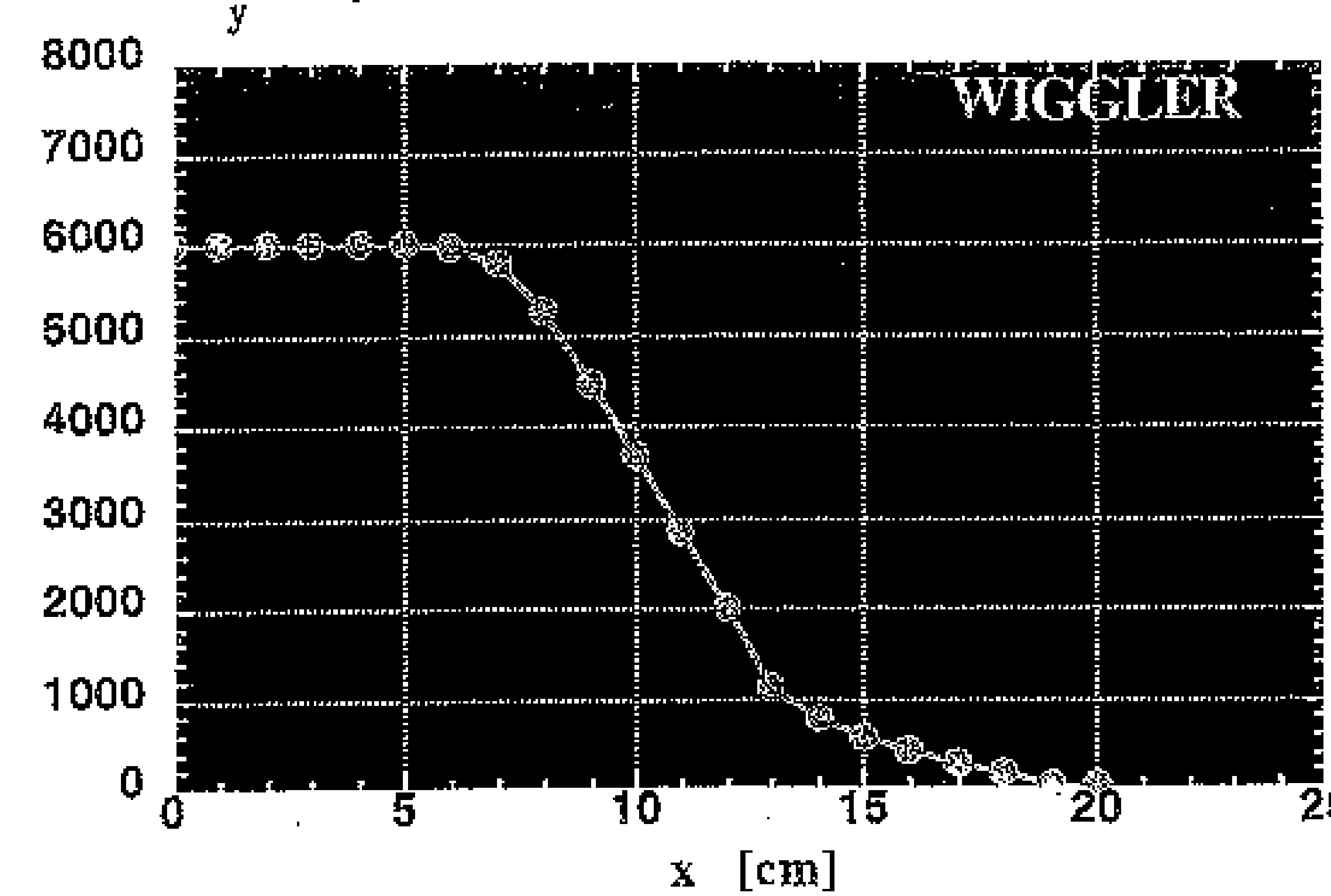
Optical functions of injection/extraction from midpoints of adjacent arcs

Path – length tuning wiggler field

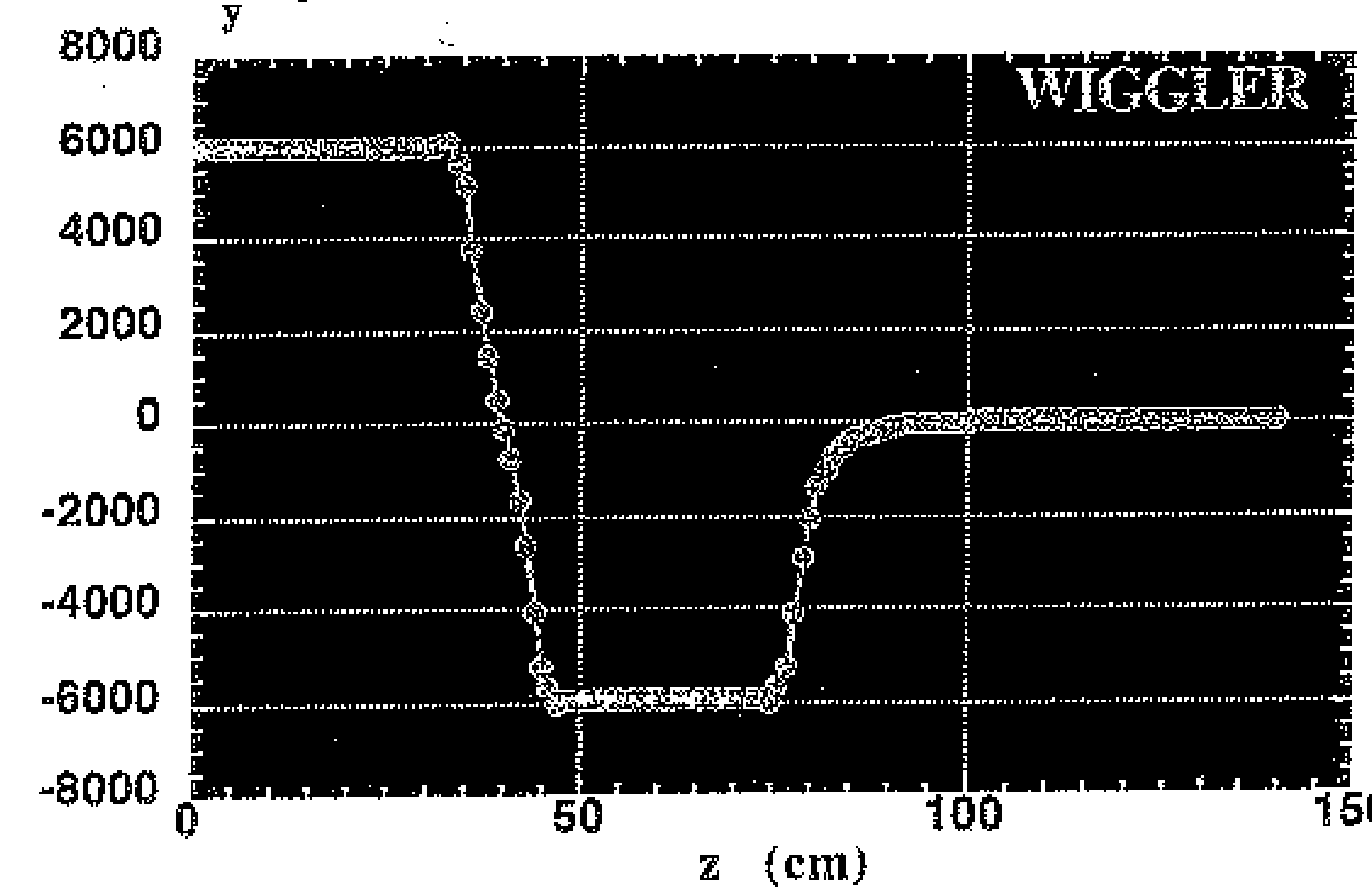


WIGGLER COILS

B_y (gauss) - transverse behaviour

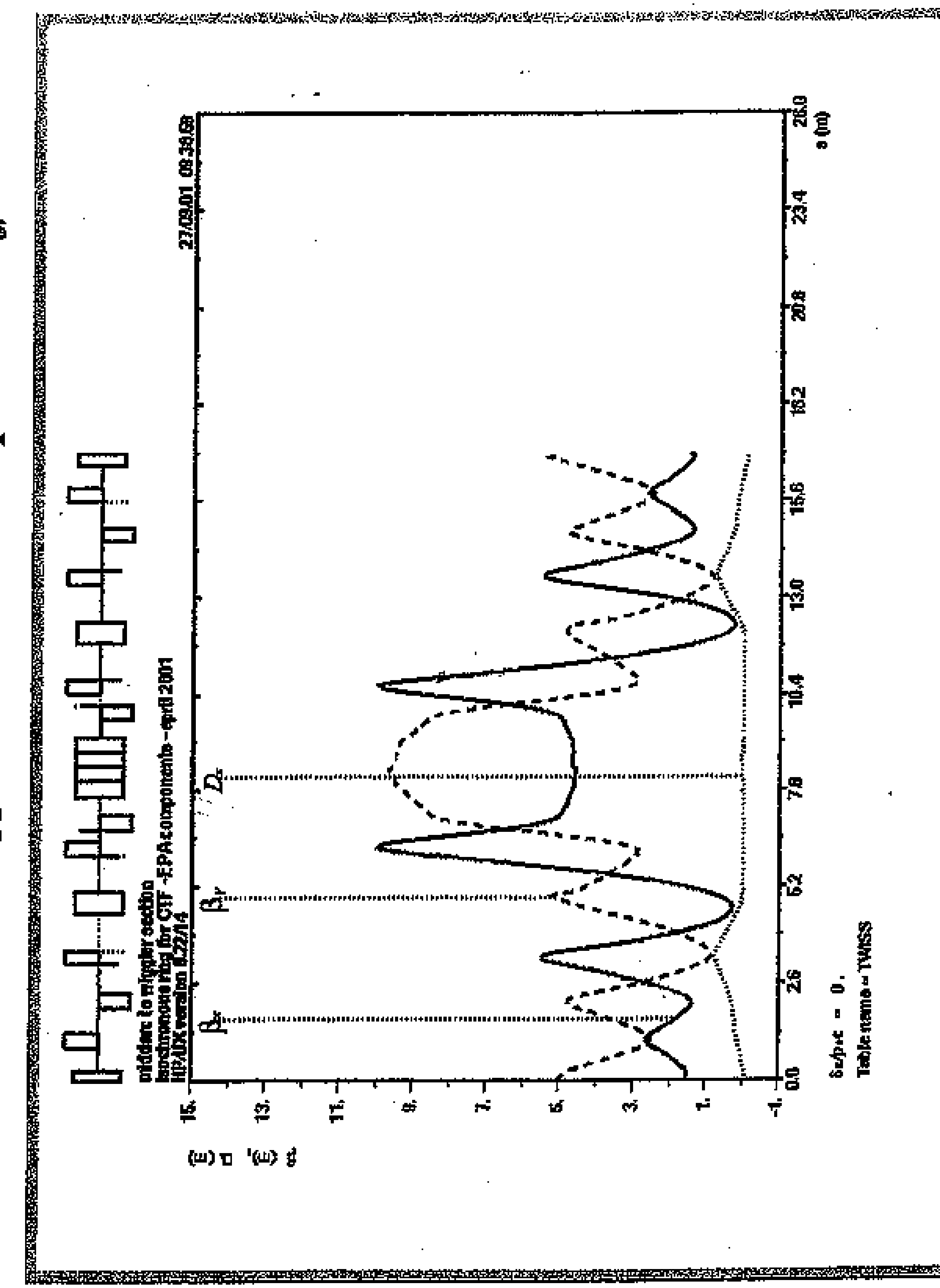


B_y (gauss) - longitudinal behaviour

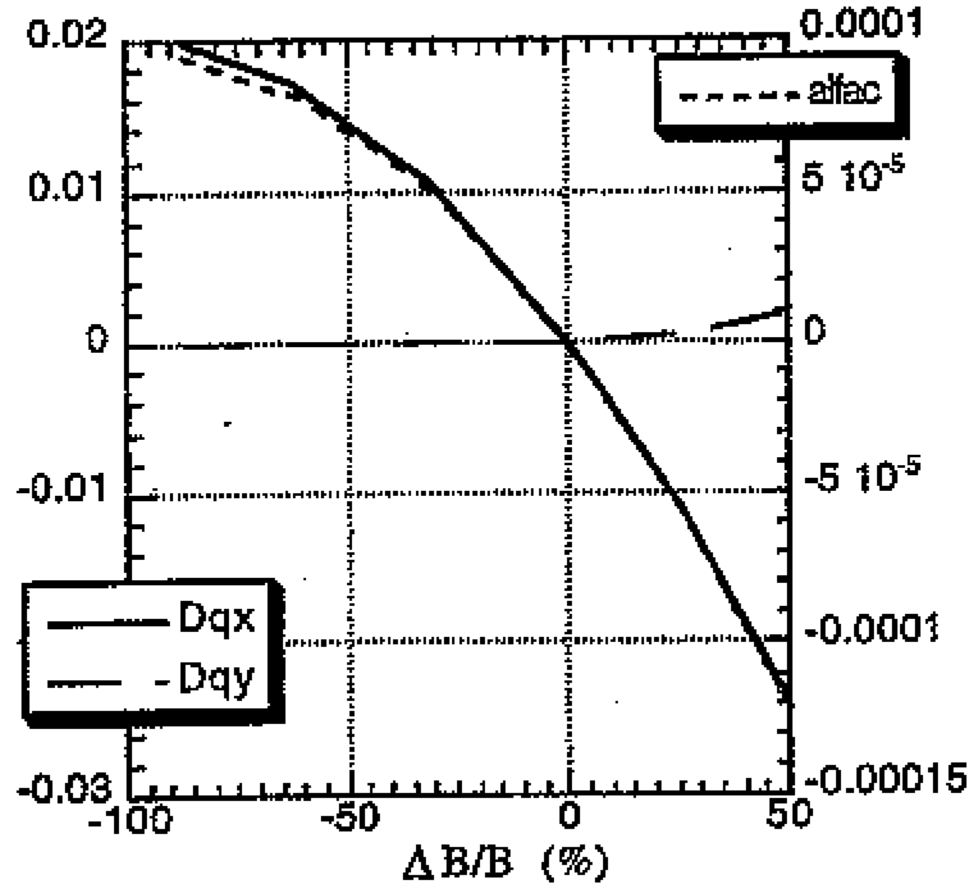


WIGGLER PARAMETER LIST
(3D calculations)

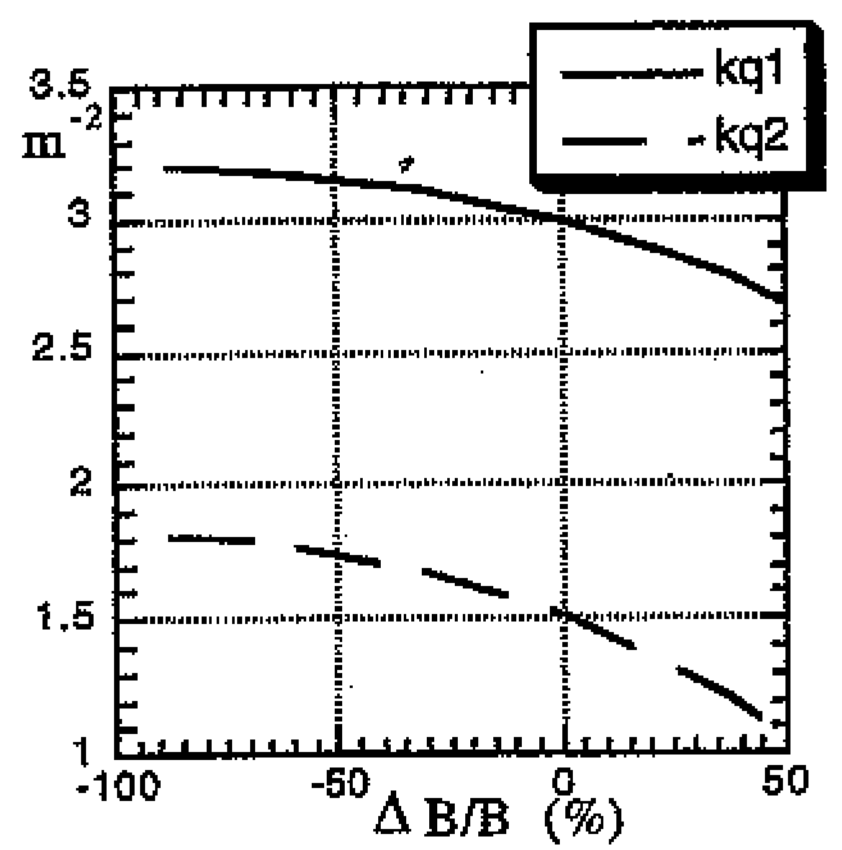
Nom. Magnetic Field	T	0.6
Nom. Magnet Gap	mm	40
Wiggler Period Length	m	1.6
Number of Periods		1
Number of Full Poles		1
Number of Half Poles		2
Wiggler Length	m	1.638
Ampere-turns per pole (full)	A	12330
Ampere-turns per pole (half)	A	9420
Turns per pole		40
Nom. Excitation Current (full pole)	A	308.25
Current Density (full pole)	A/ mm^2	4.36
Nom. Excitation Current (half pole)	A	235.5
Current Density (half pole)	A/ mm^2	3.33
Nom. Total Power Consumption	W	6410
Water Flow per magnet	l/min	9.3
Water Temperature Rise	°C	10
Iron weight	kg	1925
Copper conductor weight	kg	242



Optical functions of wiggler section from midpoints of adjacent arcs



Momentum compaction and change in betatron tunes as a function of wiggler field.

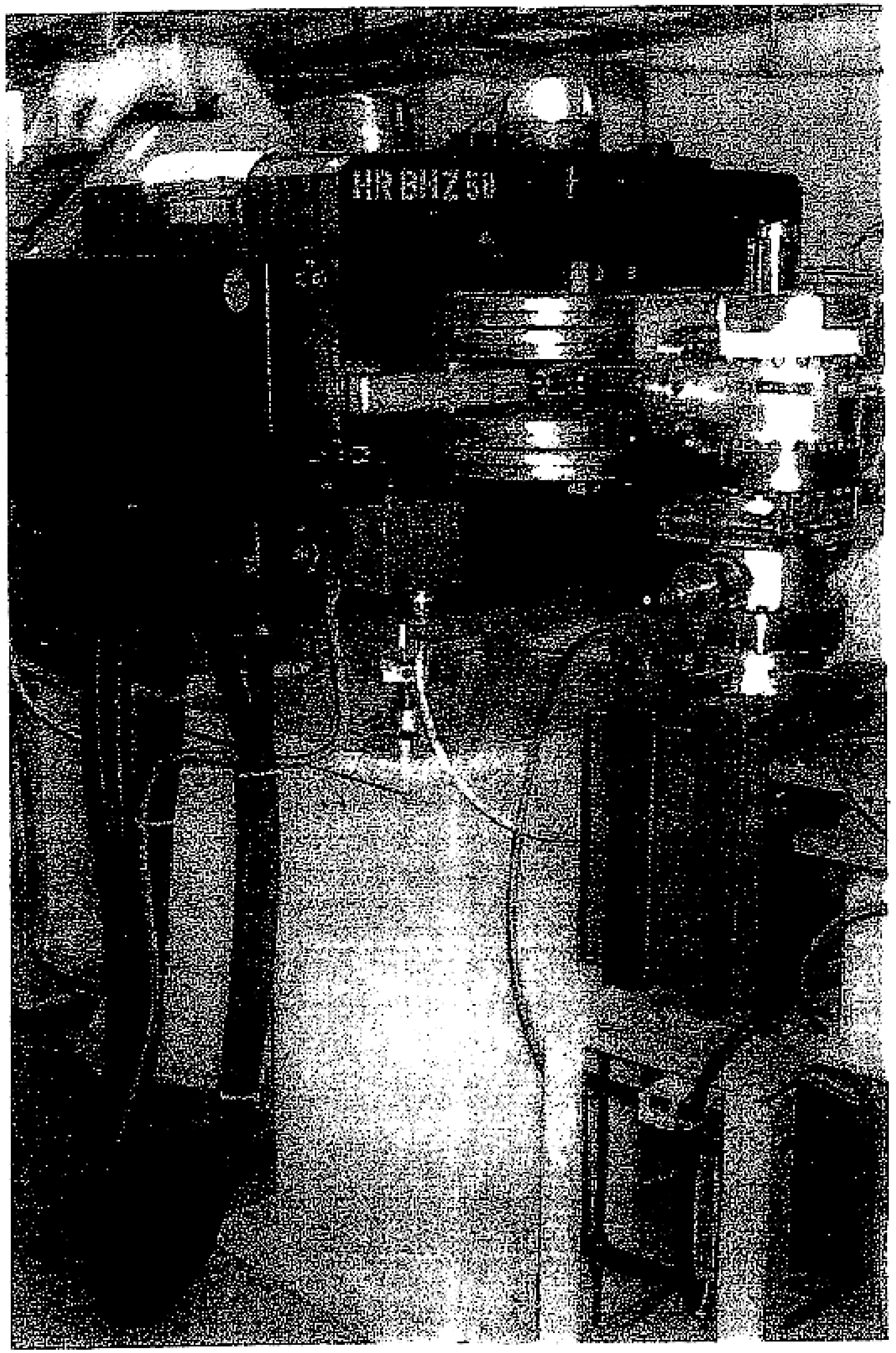


Strength of the wiggler section quadrupoles which match transverse betatron waists at the wiggler center as a function of wiggler field

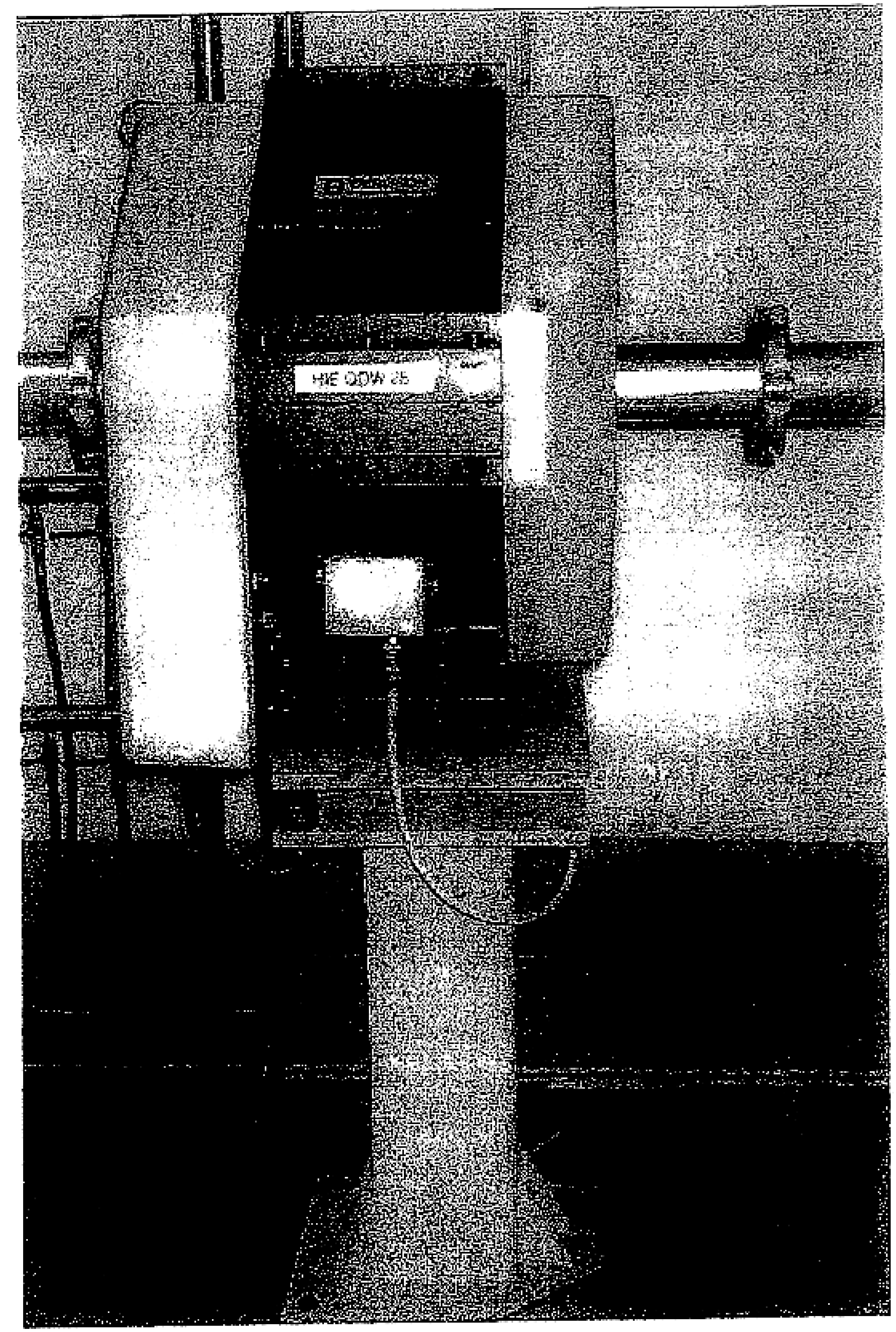
COMBINER RING MAGNETS

A)	N. of Dipoles (type 4.7)	12
	Dipole Field (T)	0.55/1.07
	Dipole Bending Radius [m]	1.09
	Pole width [mm]	230
	Gap height [mm]	45
B)	N. of Quadrupoles	48
	N. of Quadrupoles type 4.8.2	12
	Magnetic length [m]	0.38
	Maximum K_1 [m^{-2}]	2.24
	Maximum gradient [T/m]	0.51/0.99
	Quadrupole families (minimum/preferred)	2/3
	Pole width [mm]	140
	Available aperture [mm]	200
	N. of Quadrupoles type 5.3	36
	Magnetic length [m]	0.38
	Maximum K_1 [m^{-2}]	3.54
	Maximum Integrated Gradient [T]	0.81/1.57
	Quadrupole families (minimum/preferred)	7/12
	Pole width [mm]	134
	Available aperture [mm]	184
C)	N. of sextupoles	24
	Magnetic length [m]	0.10
	Maximum K_2 [m^{-3}]	100
	Max Integrated Gradient [T/m]	6/11.7
	Sextupole families	3
	Available aperture [mm]	108
D)	N. of Path Length Tuning Wigglers	2
	Pole width [mm]	150
	Gap height [mm]	40

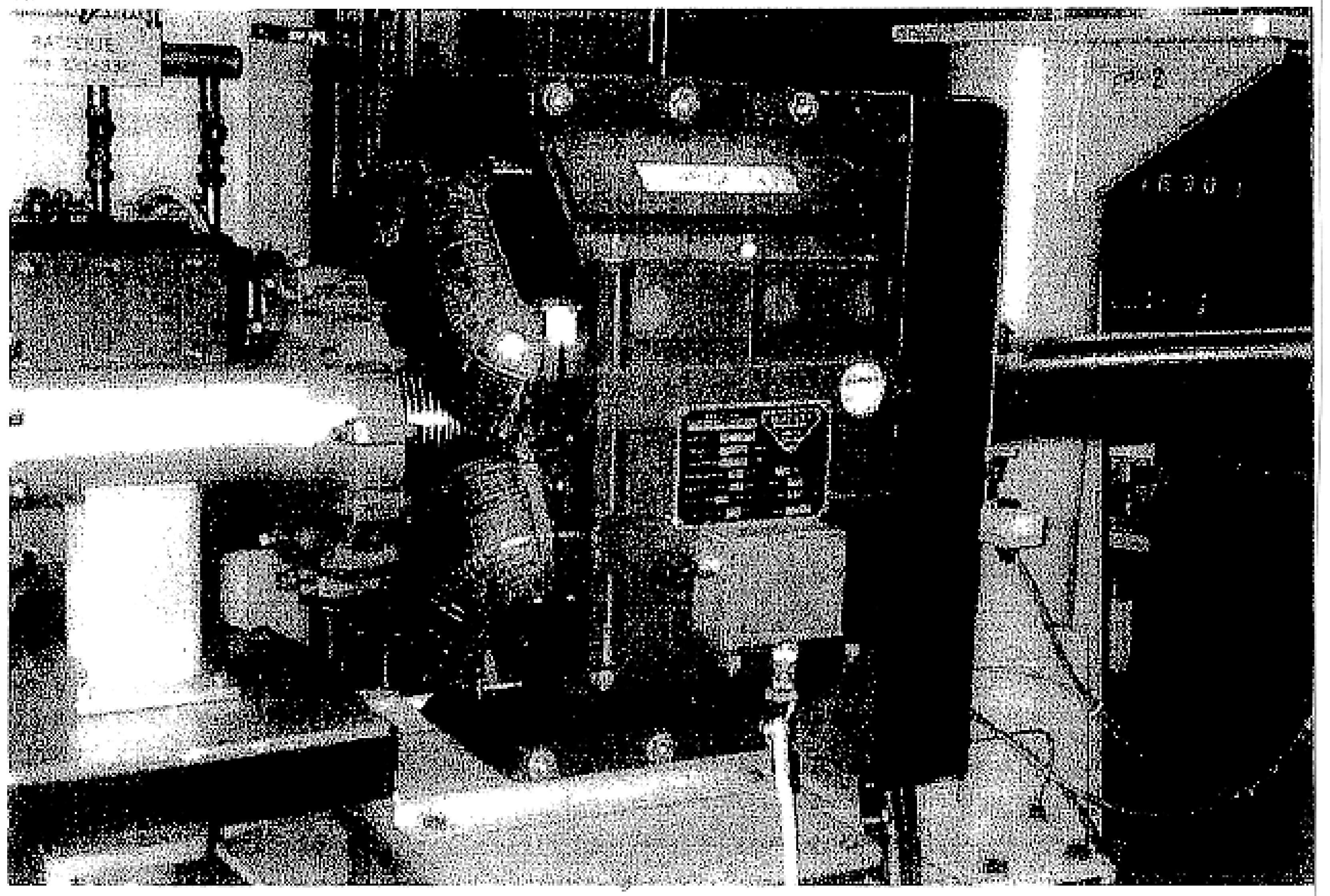
EPA DIPOLE



EPA QUADRUPOLES



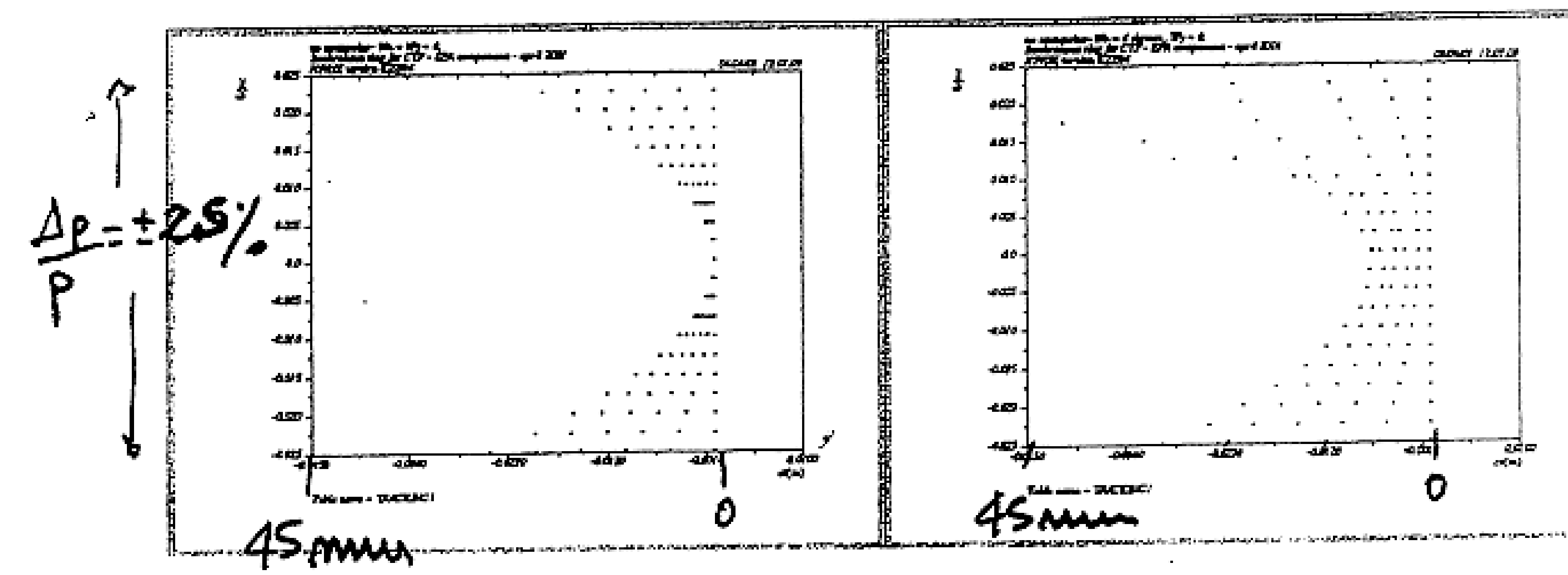
EPA QUADRUPOLES



Isochronicity

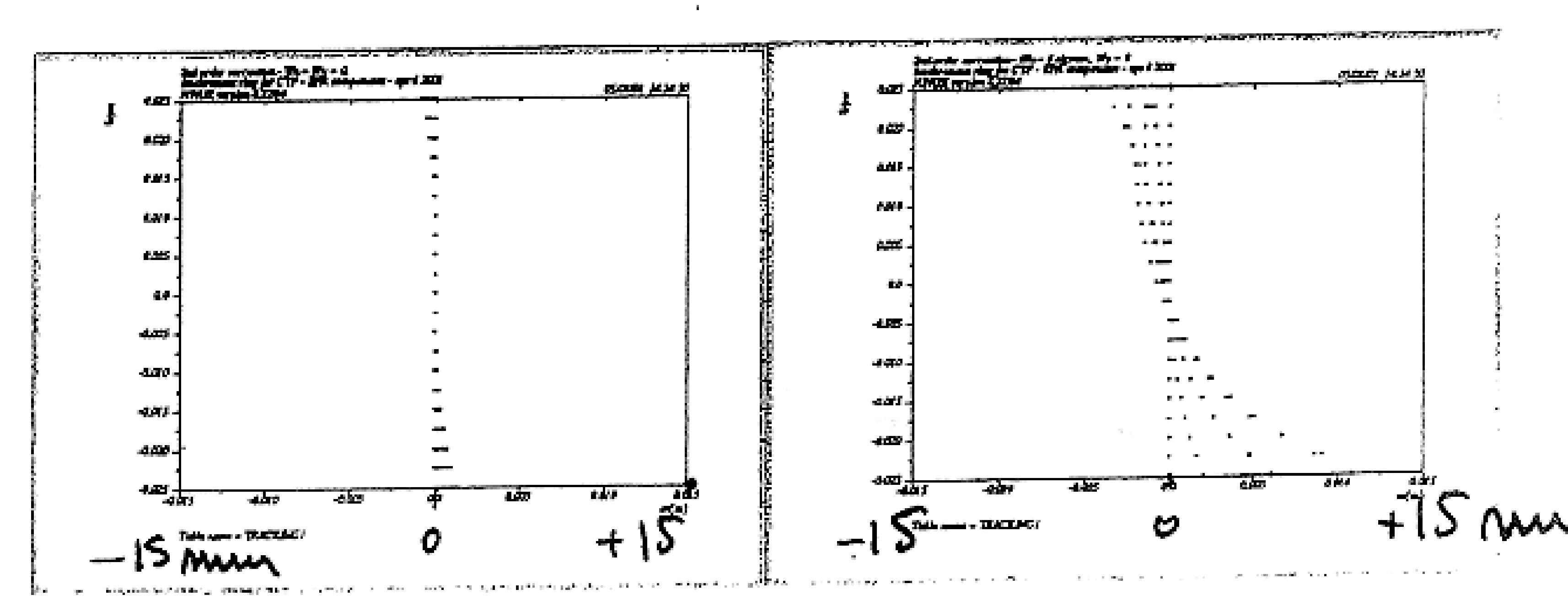
$$c\Delta t = R_{56}\frac{\Delta p}{p} + T_{566}\left(\frac{\Delta p}{p}\right)^2 + \dots$$

[redacted]



x = y = 0 x = 3 σ_x ; y = 0

[redacted]



x = y = 0 x = 3 σ_x ; y = 0

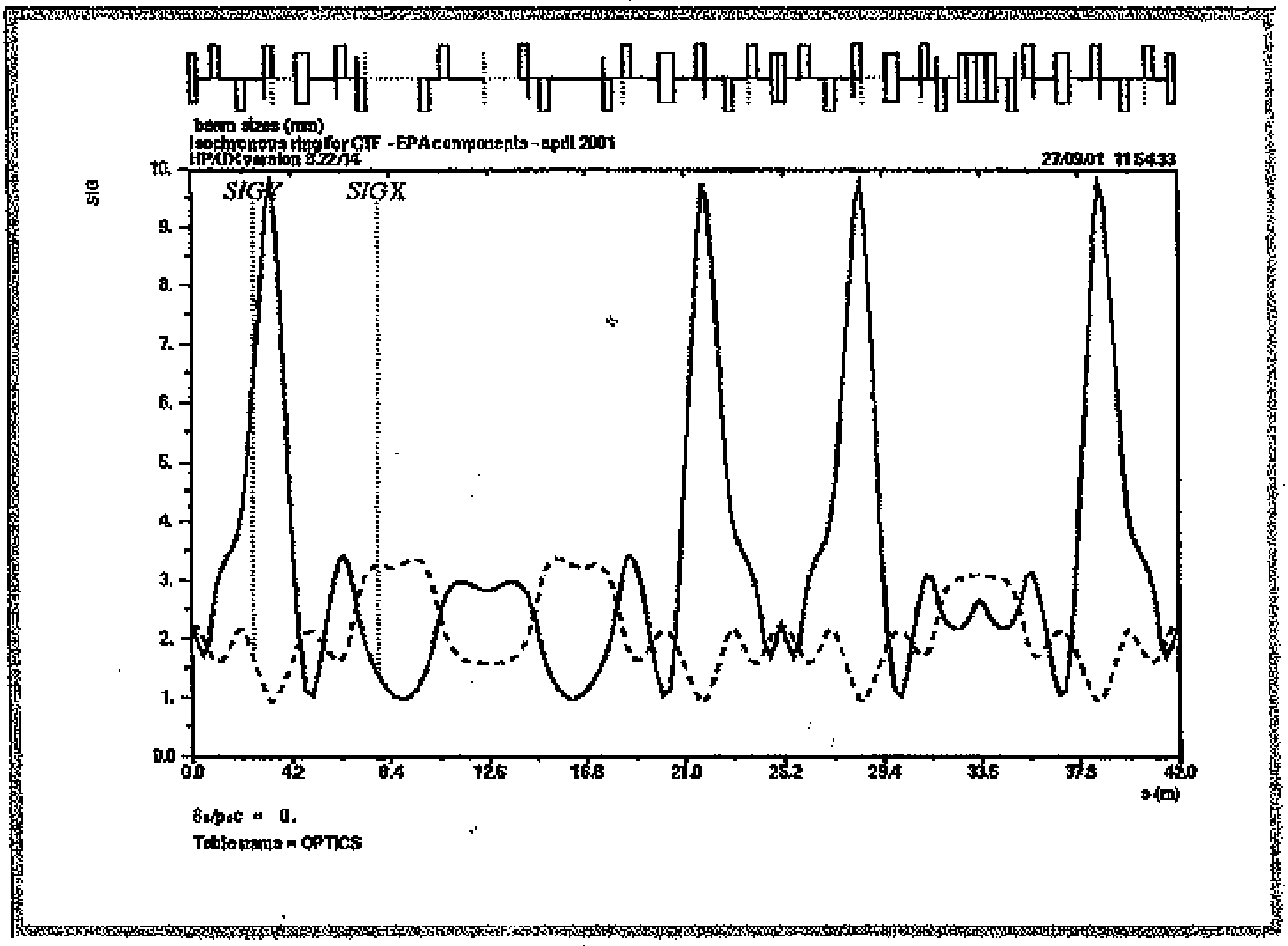
$\frac{\Delta p}{p} = \pm 1\% \rightarrow 3\sigma_x < 1$ mm

$3\sigma_y < 2$ mm

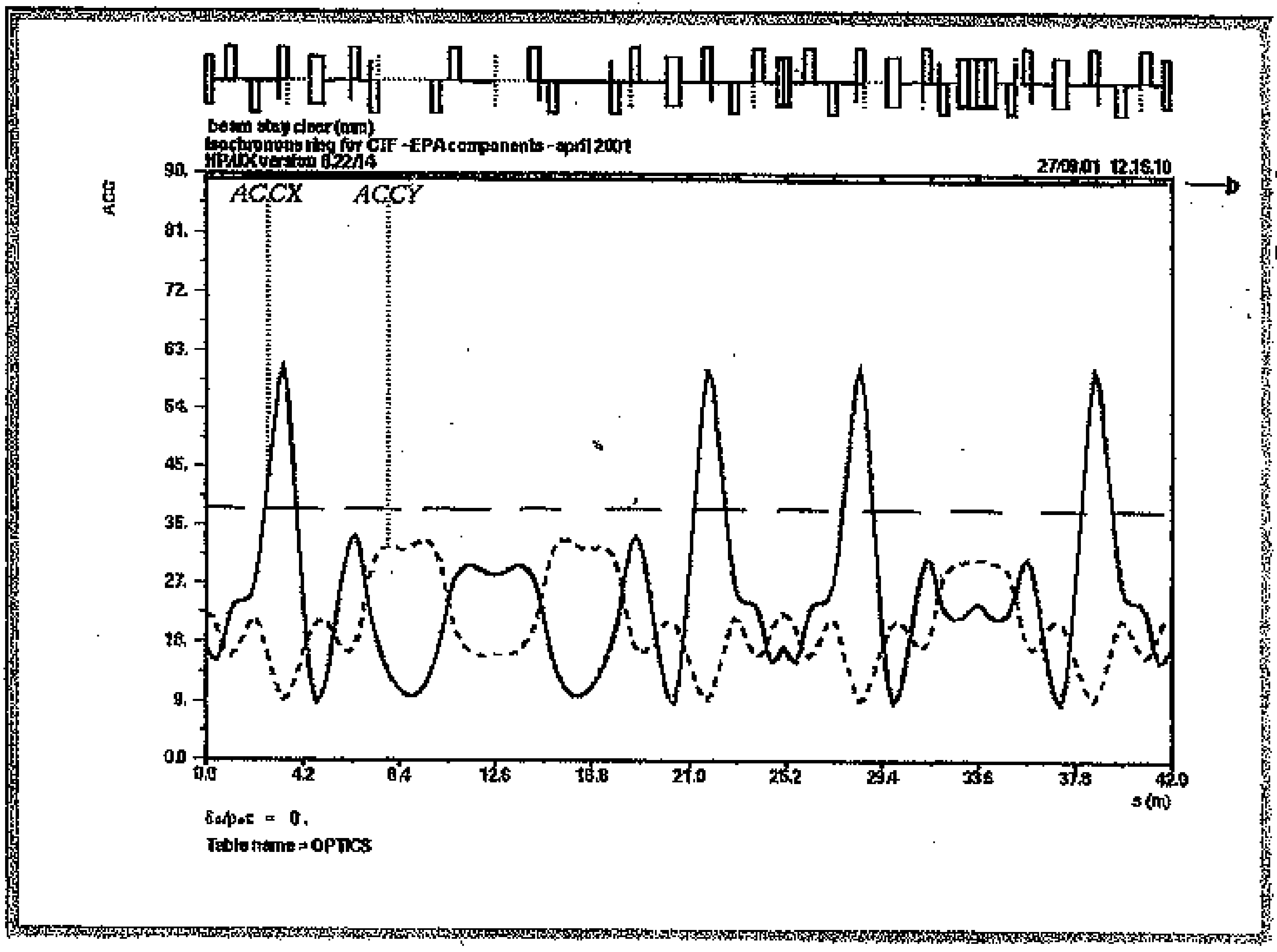
CR – Beam sizes $\sigma_x = \sqrt{\varepsilon_x \beta_x} + \frac{\Delta p}{p} D_x \quad \sigma_y = \sqrt{\varepsilon_y \beta_y}$

$\varepsilon_x = \varepsilon_y = 1$ mm mrad

$\Delta p/p = 0.01$



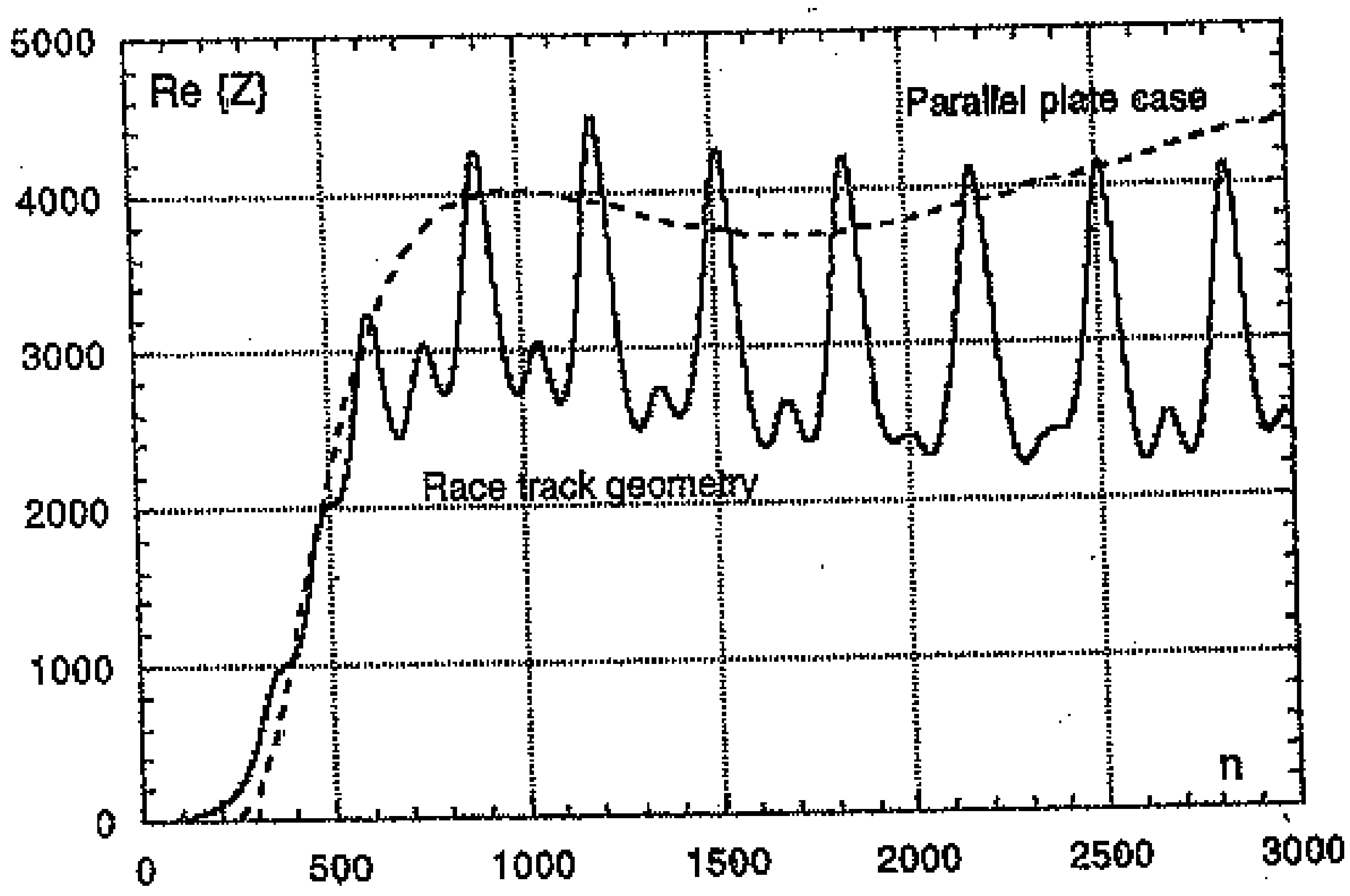
Beam Stay Clear $A_x = 10\sigma_x + 0.05 D_x \qquad A_y = 10\sigma_y$



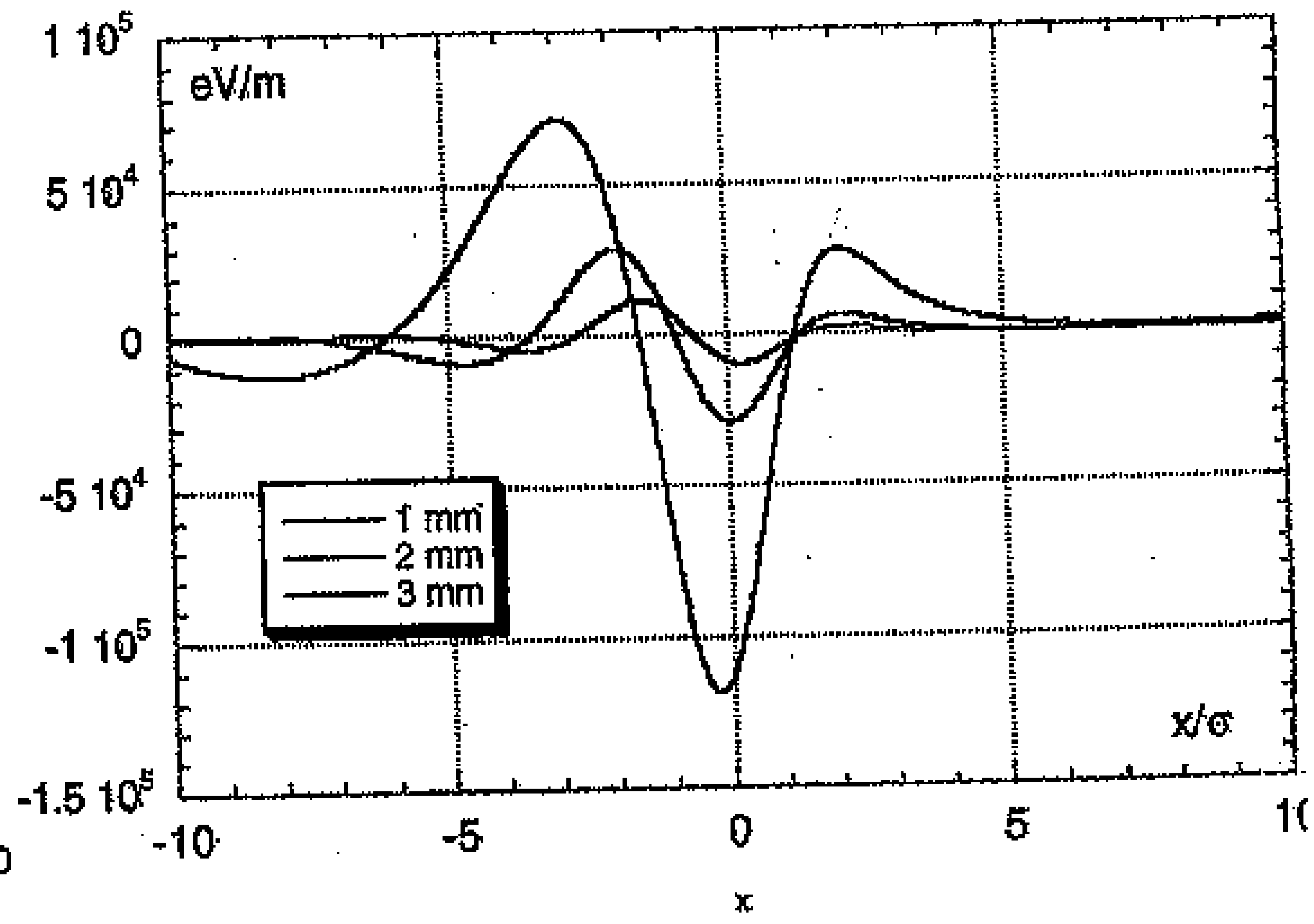
→ Vacuum chamber apertures

CSR in CTF3 COMPRESSOR RING MAGNETS

CSR IMPEDANCE (real part)

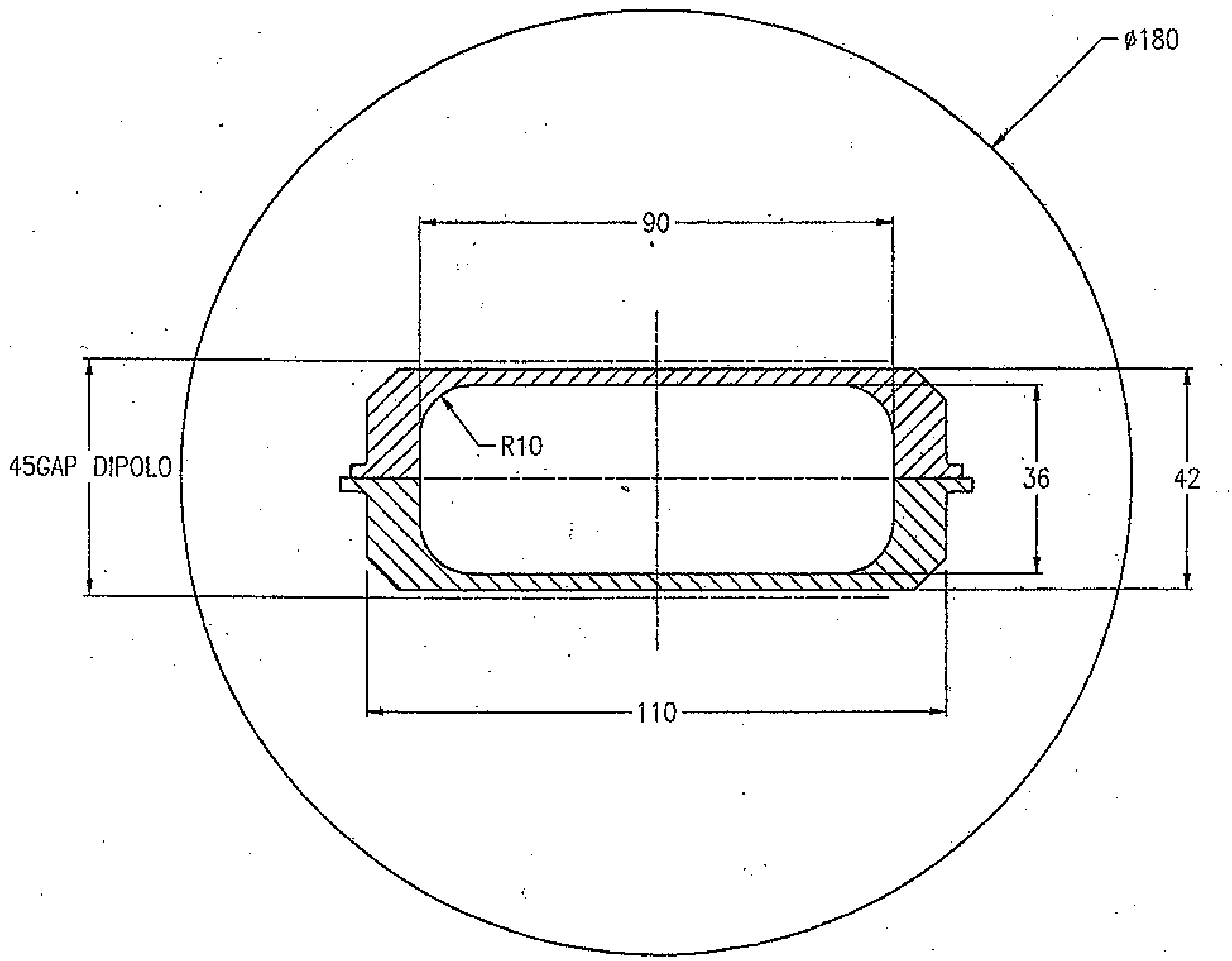


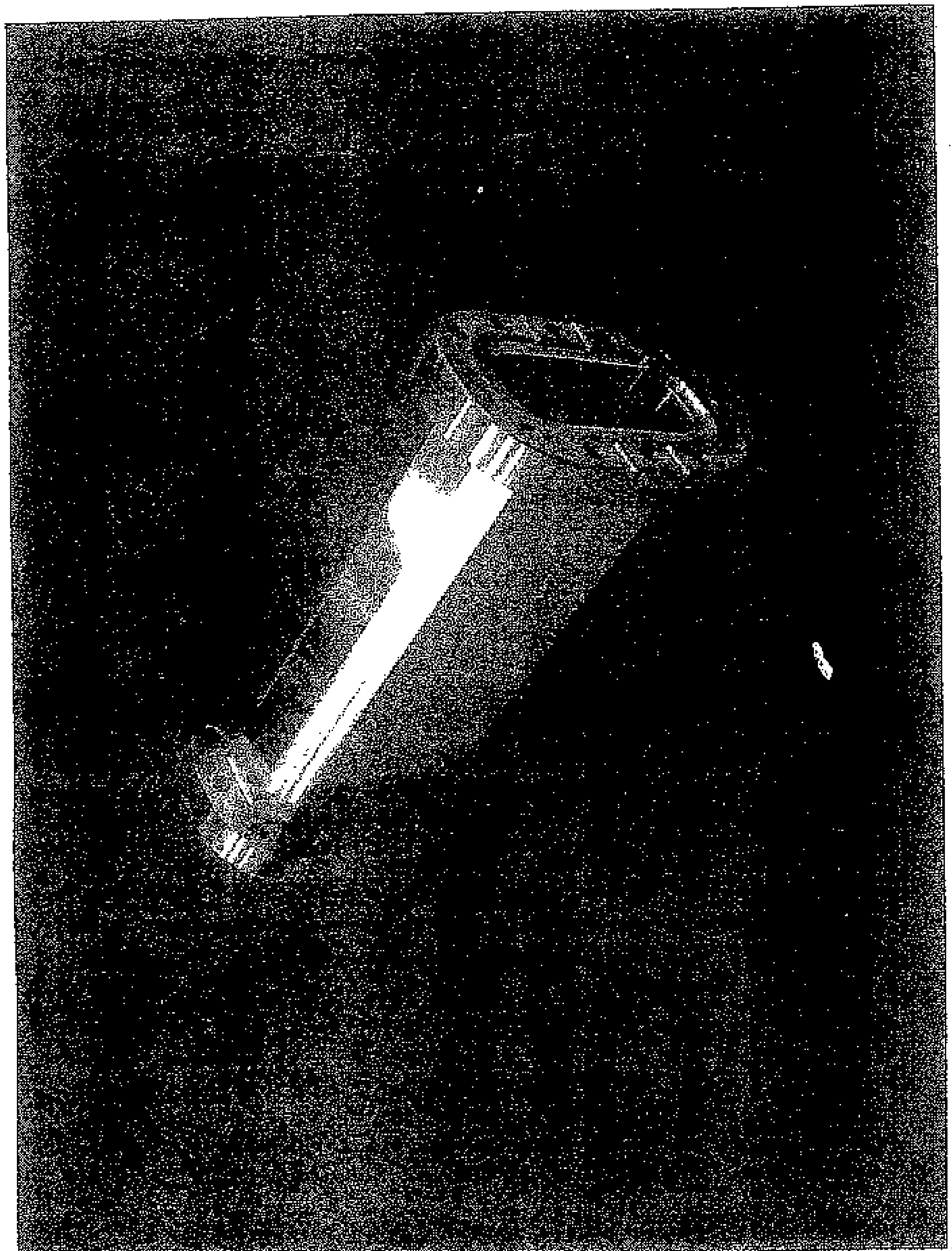
CSR WAKE FORCE (for different bunch length)



For EPA magnets incorporated in CTF3 compressor ring design and the vacuum chamber of 90x36 mm^2 the parallel plate approximation can be applied to estimate the energy loss and energy spread

For a bunch of 2 mm long with a charge 2.33 nC the energy spread due to CSR after 5 turns is contained within ±0.5% of the nominal ring energy





Orbit and trajectory correction

The correction procedure of the closed orbit and/or the trajectory in the combiner ring has been discussed only preliminarily.

Correcting the closed corrects also the trajectory when the combiner ring is used for the recombination. The trajectory in the first five turns oscillates around the corrected closed orbit with amplitudes determined by the injection offset.

Simulations : misalignments in the quadrupoles

$\Delta x = 200\ \mu$

$\Delta y = 100\ \mu$

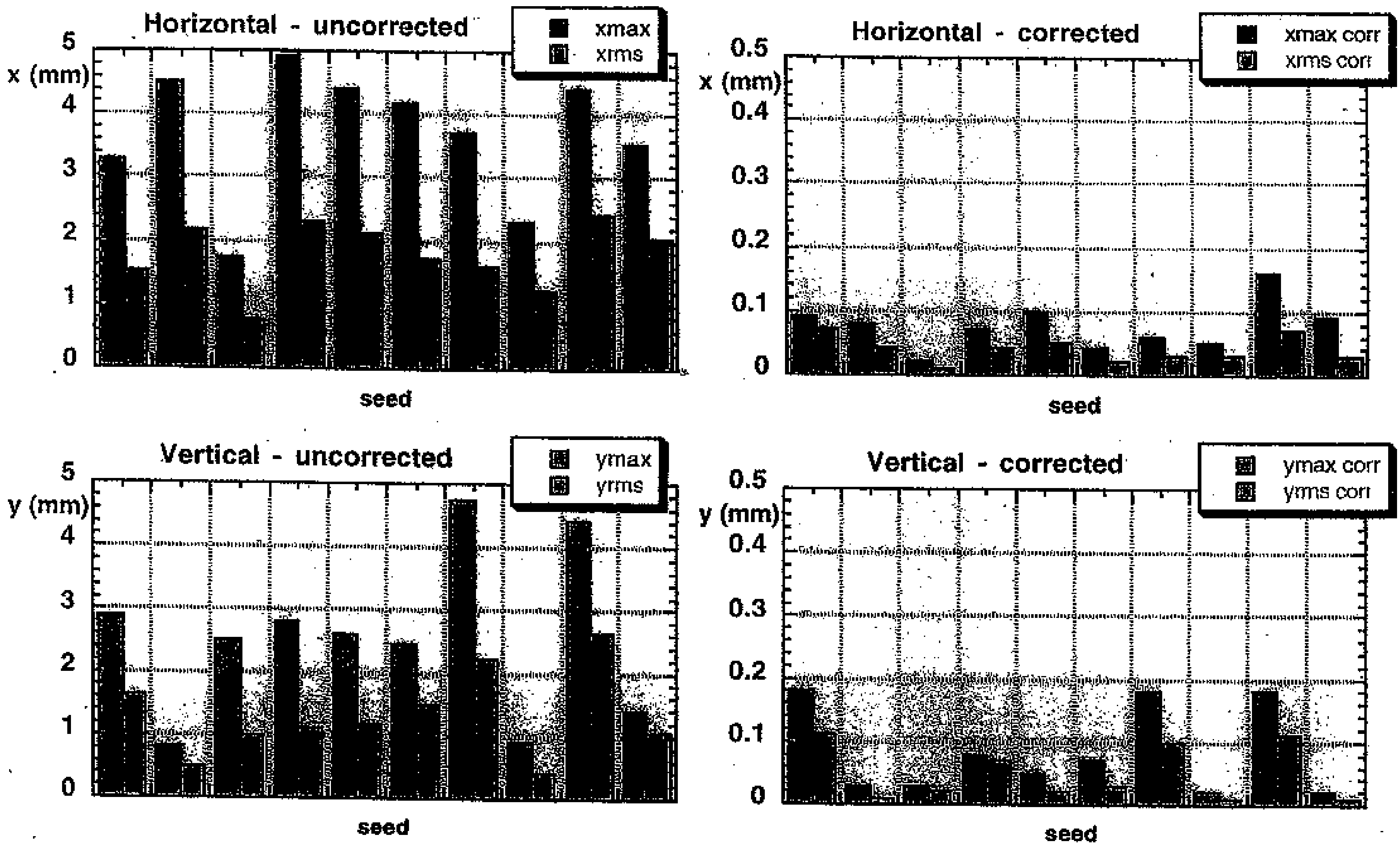
$\Delta\theta = 0.02$ mrad

20 correctors and 20 monitors per plane

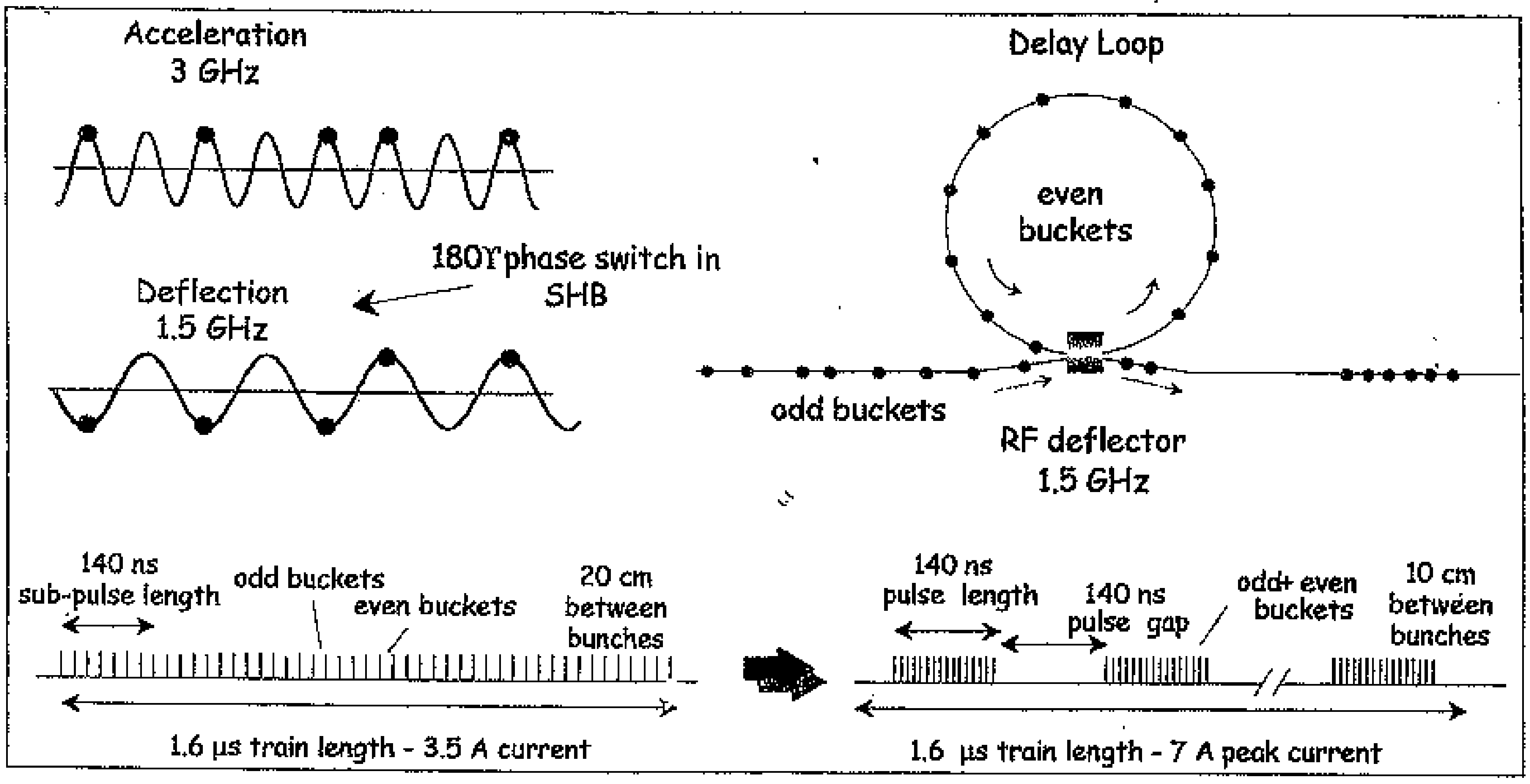
maximum corrector kick less than 1mrad

	before correction	after correction
x_{max} (mm)	3.8 ± 1.0	0.08 ± 0.04
x_{rms} (mm)	1.9 ± 0.5	0.04 ± 0.02
y_{max} (mm)	2.8 ± 1.3	0.11 ± 0.07
y_{rms} (mm)	1.5 ± 0.7	0.06 ± 0.04

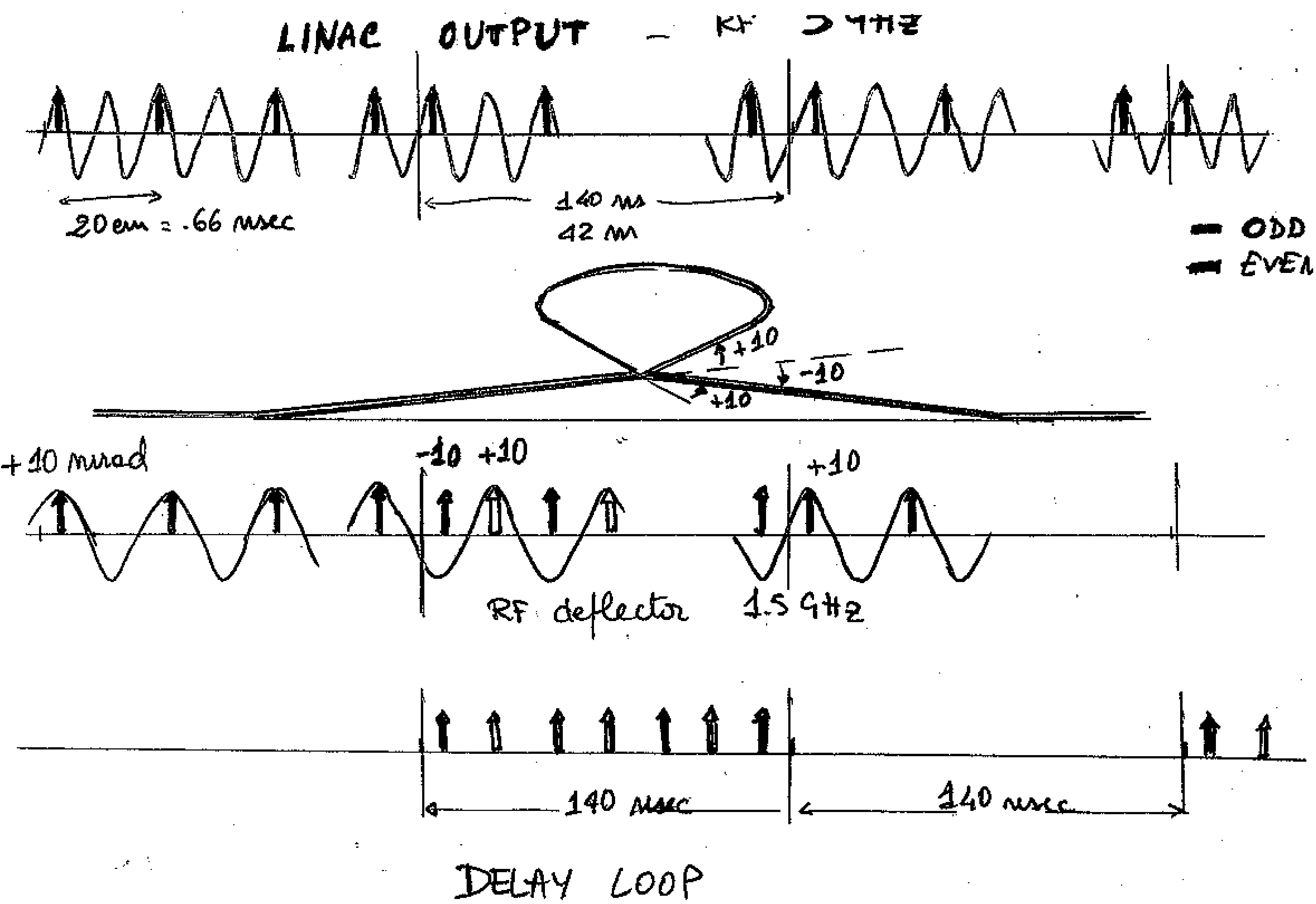
SIMULATION OF ORBIT/TRAJECTORY CORRECTION

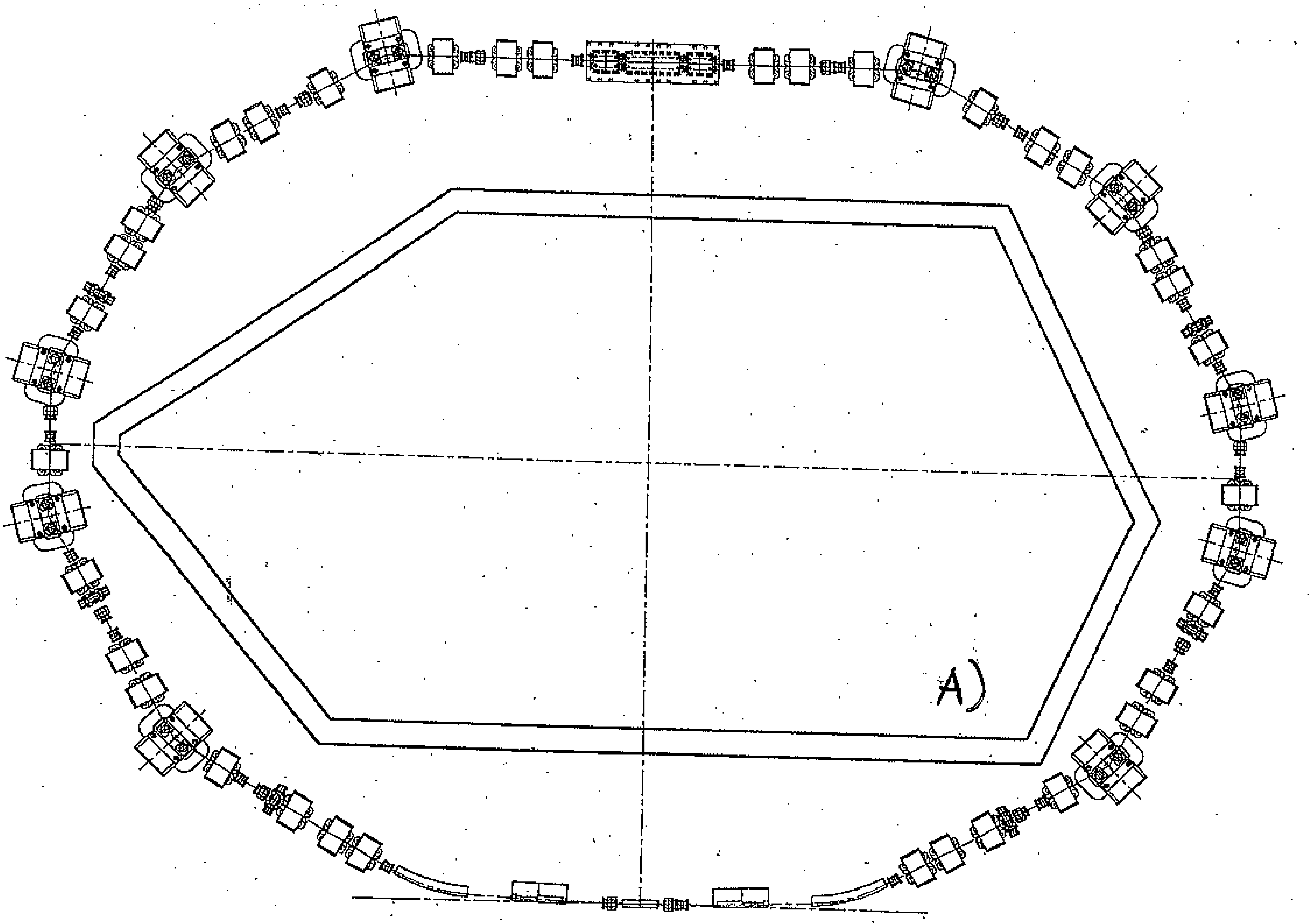


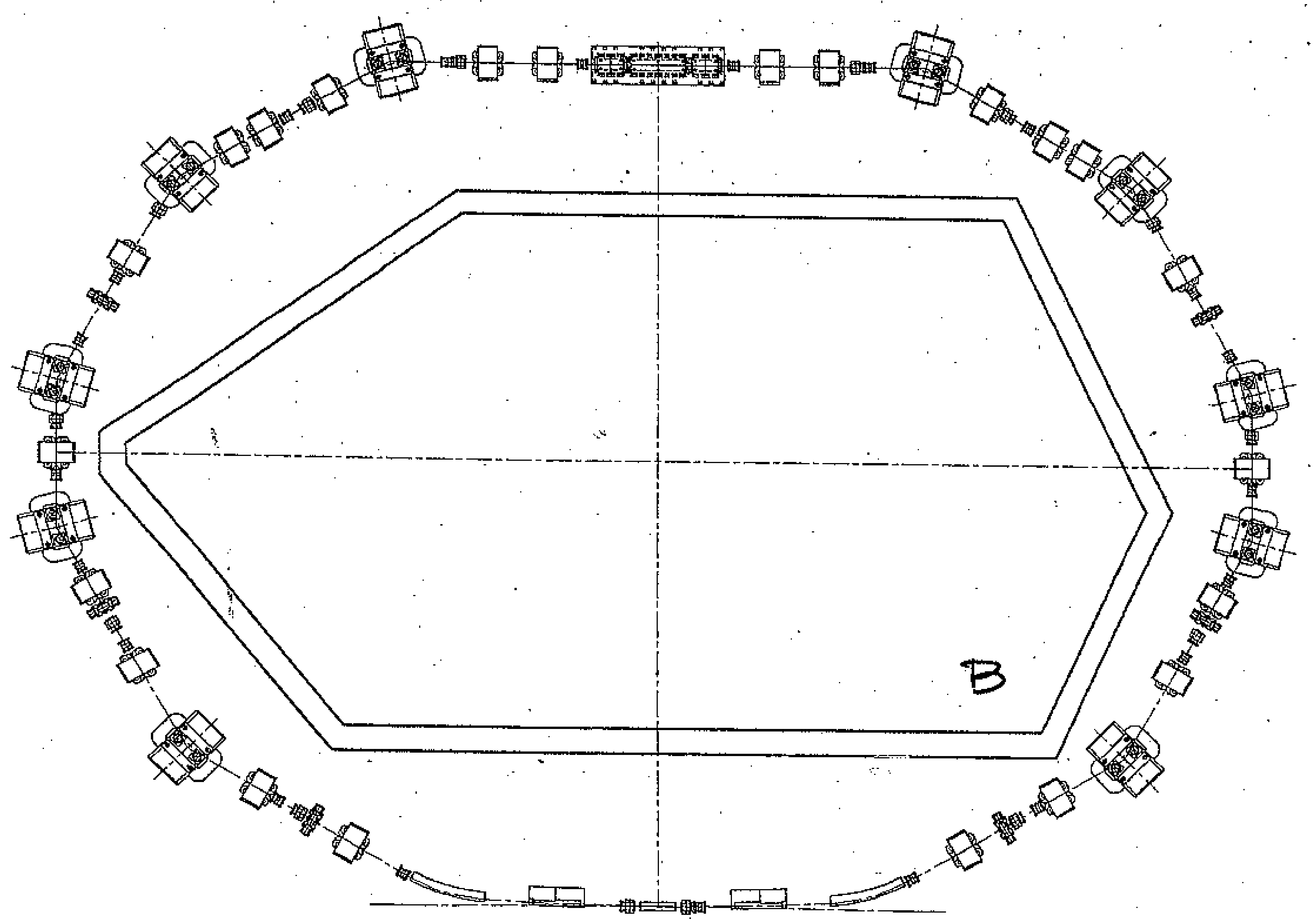
DELAY LOOP



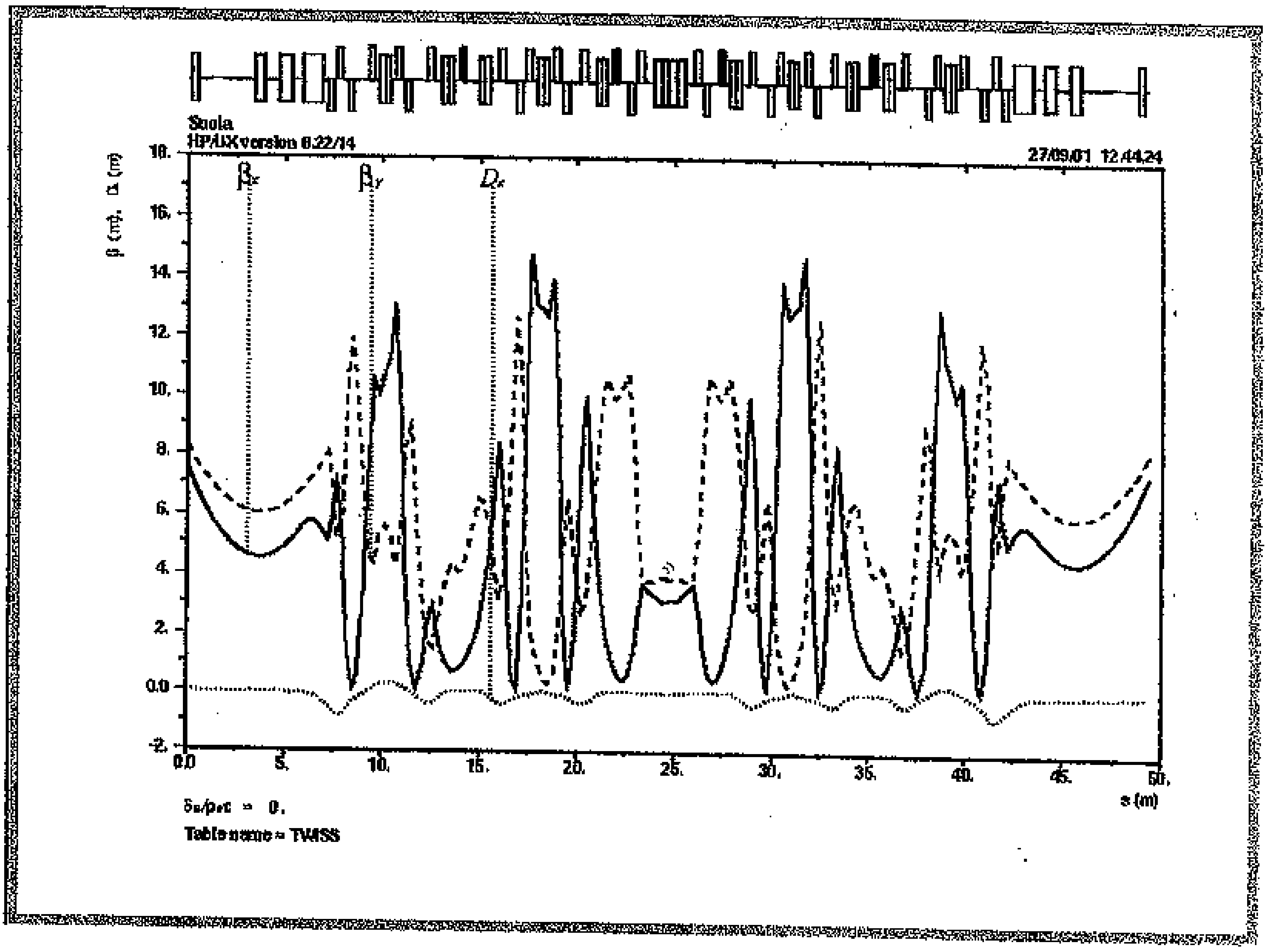
Principle of x2 bunch frequency multiplication in the DL



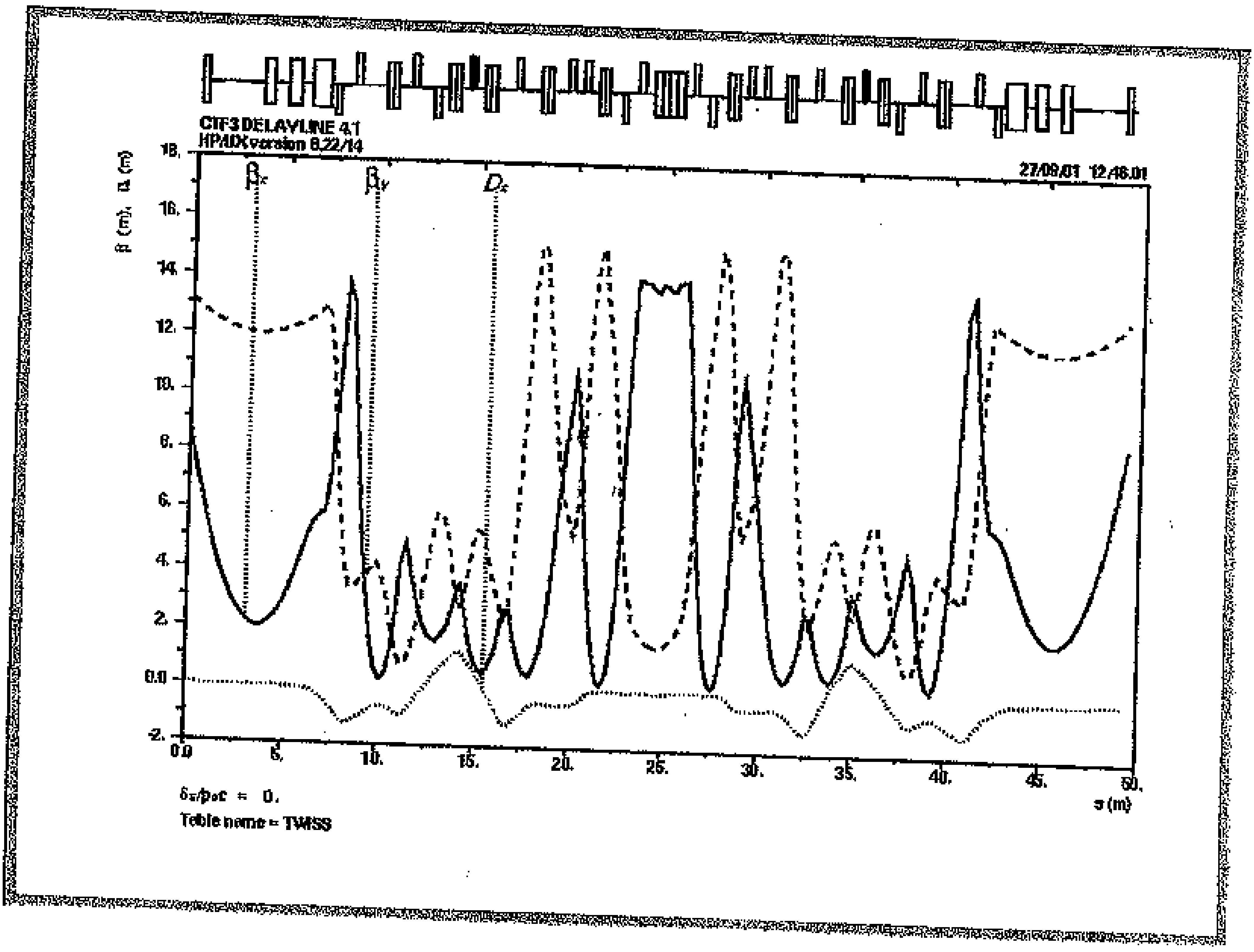

A)


B

Delay Loop Optical Functions – Solution A



Delay Loop Optical Functions – Solution B



Delay Loop Linear Lattice

$$ct = (ct)_0 + R_{56}\frac{\Delta p}{p}$$

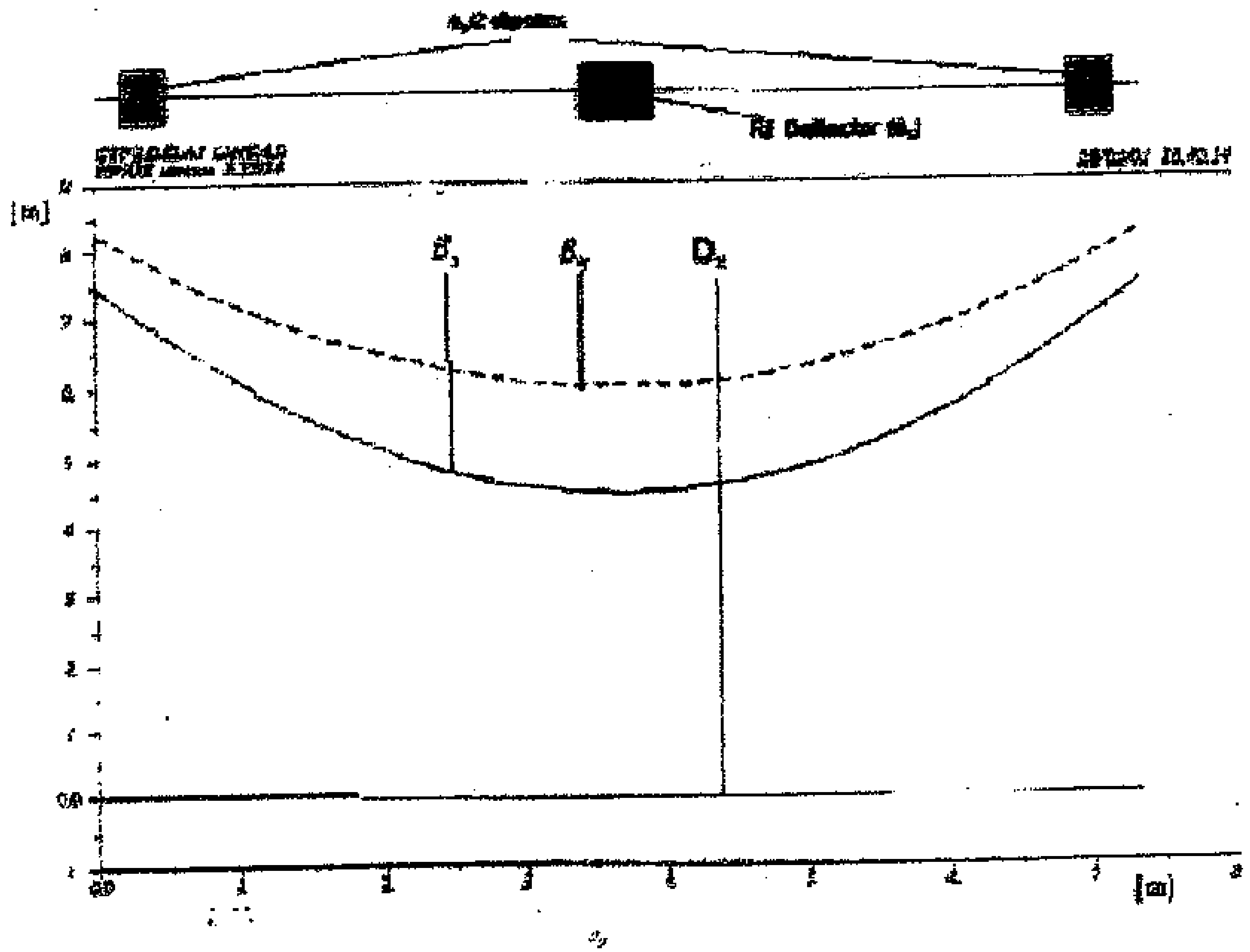
$$R_{56} = \int \frac{D_x}{\rho} ds = 0$$

$$|\alpha_p| \le 5 \cdot 10^{-4} \qquad |R_{56}| \le 2.1 \cdot 10^{-2}\ m$$

Main Parameters

	A)	B)
Max. Horizontal Beta [m]	14.8	11.5
Max. Vertical Beta [m]	12.7	14.5
Max. Dispersion [m]	0.85	1.3
Horizontal Betatron Tune	5.90	4.0
Vertical Betatron Tune	2.19	1.4
Horizontal chromaticity	-18.9	-6.4
Vertical chromaticity	-10.2	-8.6

Even Bunches Line Matching



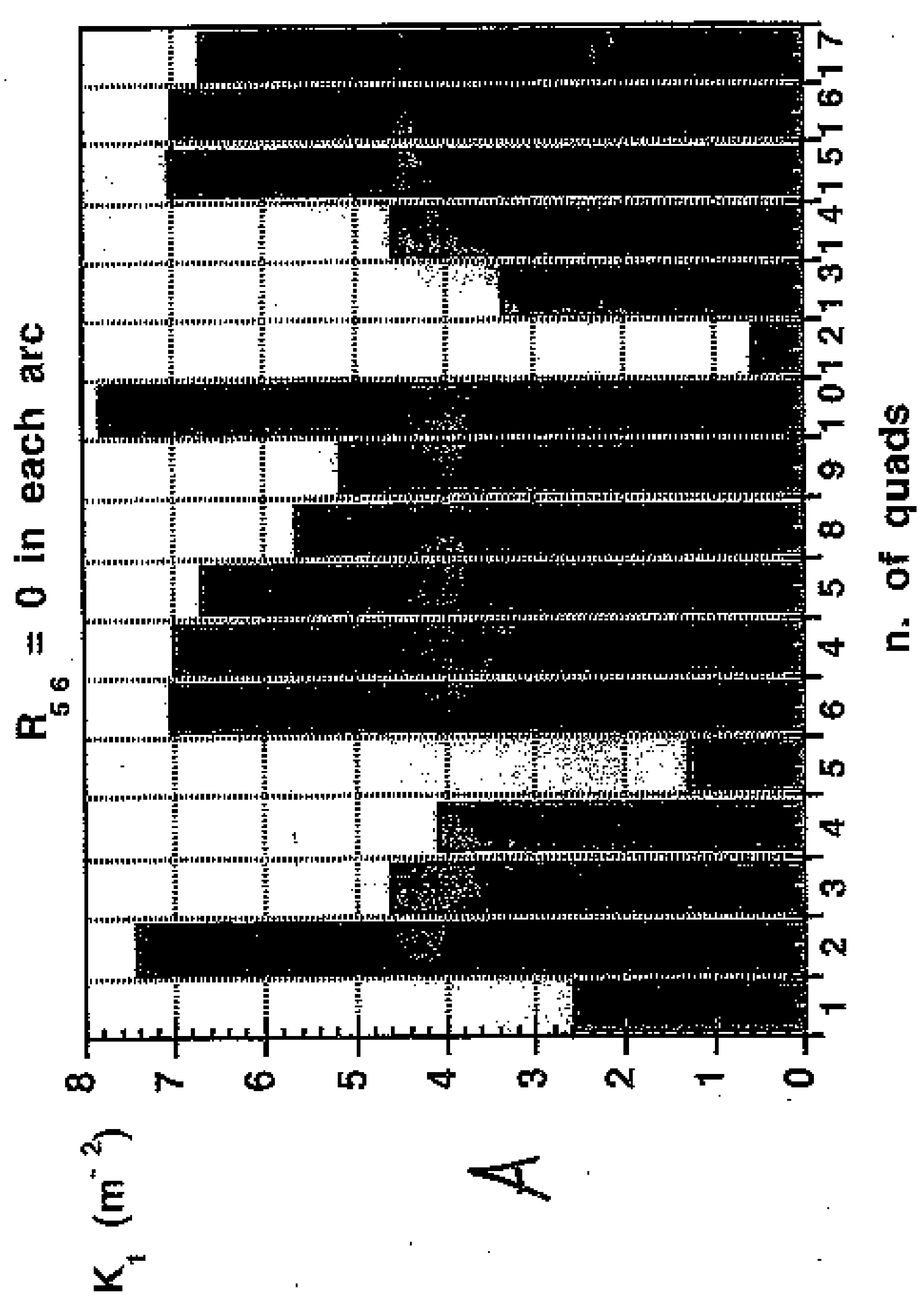
Even Bunches Line Optical Functions

Dispersion is self-matched and beta functions and derivatives present the same values of the ones see by the odd bunches at the end of the DL

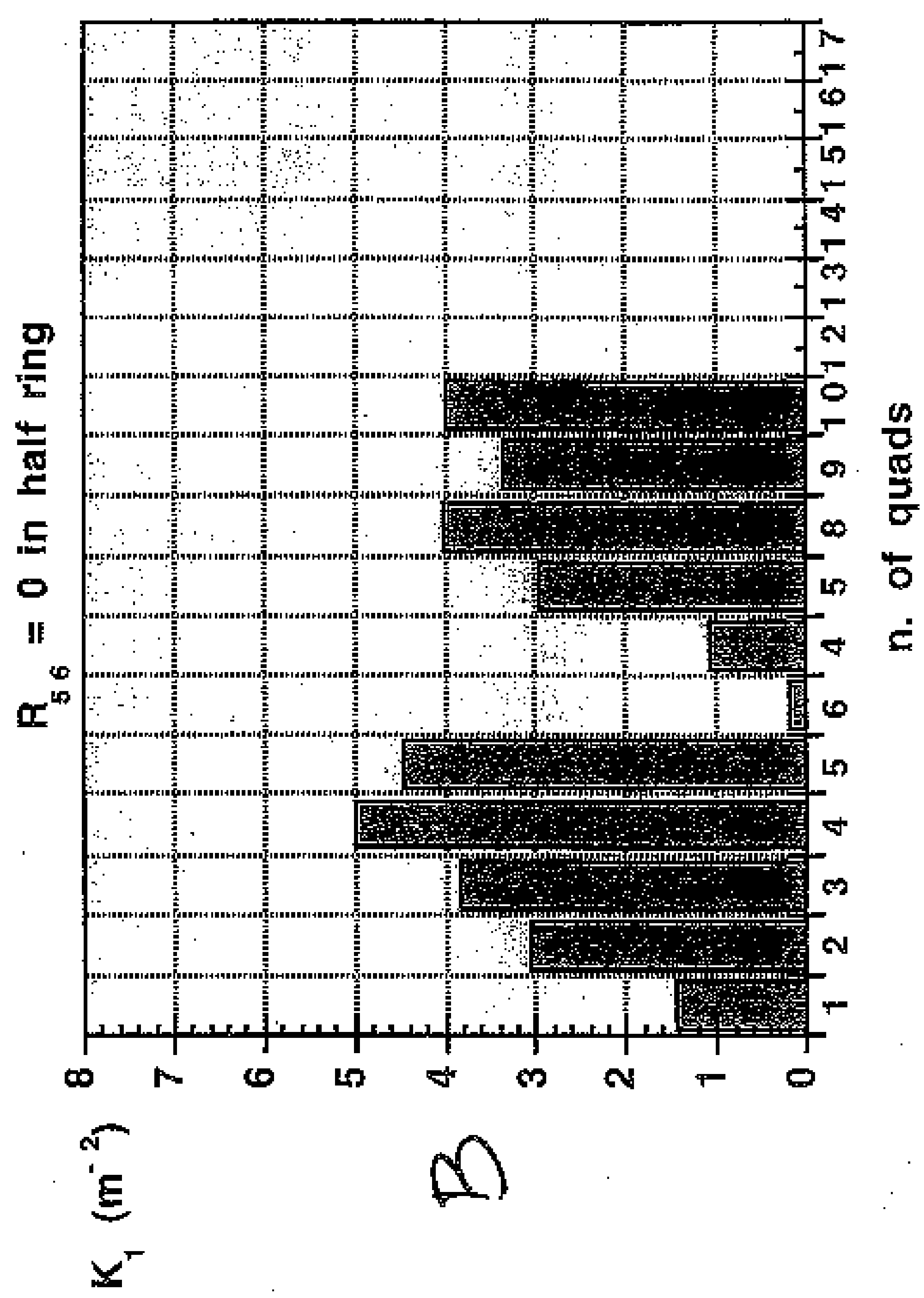
The Isochronicity condition is not completely fulfilled but the very small value of R_{56} at the line output (0.2 mm) does not require any particular care

Delay Loop Magnetic Elements

	A)	B)
A) Number of Dipoles (EPA-like)	10	10
Dipole Bending Radius [m]	1.079	1.079
Dipole Bending Angle [deg]	30	30
Dipole Field [T] (180/350 MeV)	0.60/1.1	0.60/1.1
Integrated Quadrupole Coeff. in Dipoles [T] (180/350 MeV)	0.2/0.4	0.2/0.4
B) Number of Quadrupoles (DAΦNE Accumulator-like)	34	22
Max. Integrated Gradient [T] (180/350 MeV)	1.4/2.7	0.9/1.3
Quadrupole Families (minimum/preferred)	14/18	11
C) Number of Sextupoles (DAΦNE Accumulator-like)	10	?
Max Integrated Gradient [T/m] (180/350 MeV)	11/22	?
Sextupole Families	5	?
D) Number of Path Length Tuning Wiggler	1	1
E) Number of 2° Septa (DAΦNE Accumulator-like)	2	2
F) Number of 27°.14 Septa (DAΦNE Accumulator-like)	2	2
G) Injection Dipoles Number	2	2
Injection Dipoles Bending Angle [mrad]	5	5



A



B

Second Order Isochronicity

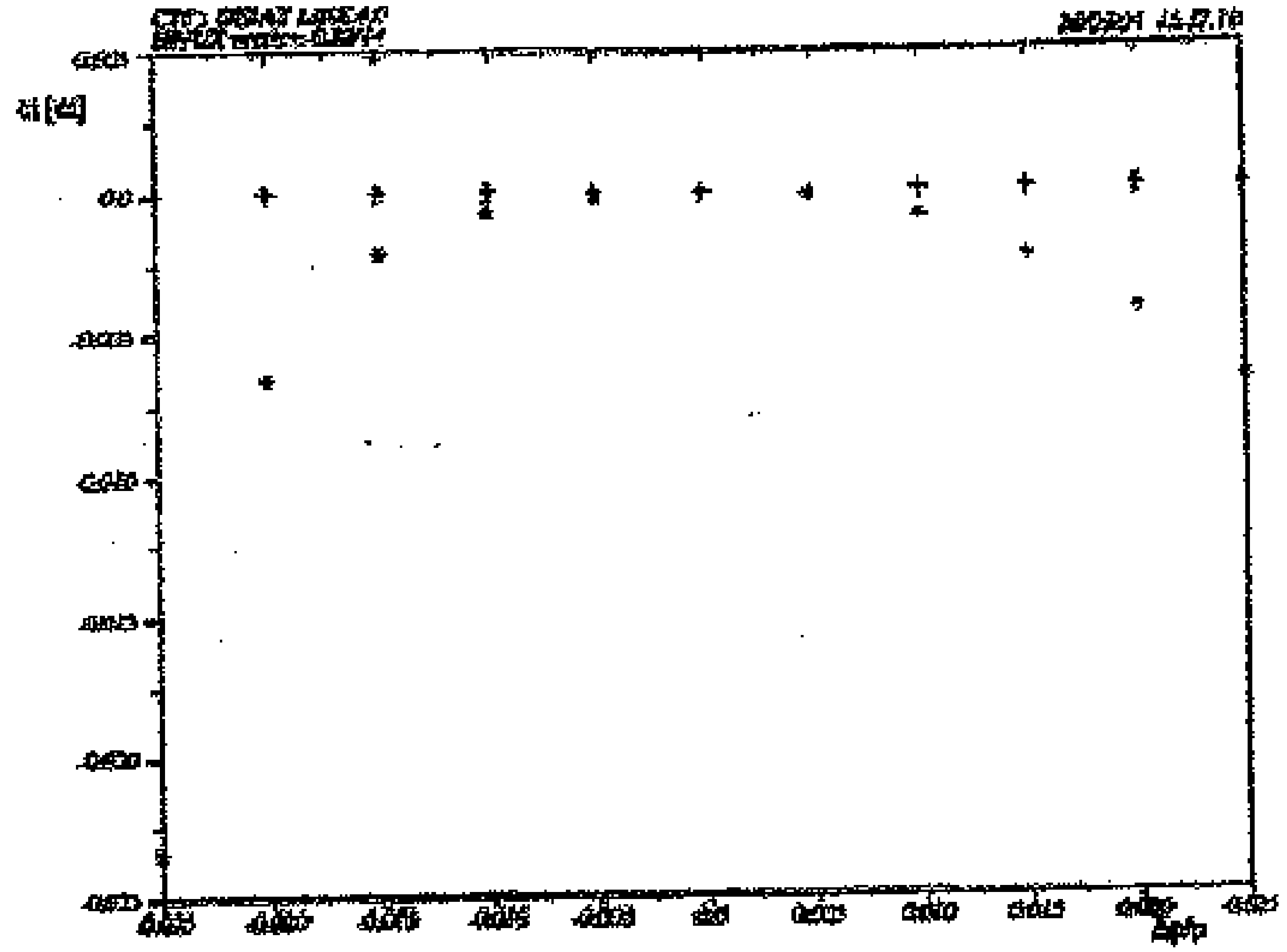
$$ct = (ct)_{0+} R_{56}\frac{\Delta p}{p} + T_{516}\ x_0\frac{\Delta p}{p} + T_{526}\ x'_0\frac{\Delta p}{p} + T_{536}\ y_0\frac{\Delta p}{p} + T_{546}\ y'_0\frac{\Delta p}{p} + T_{556}\ (ct)_0\frac{\Delta p}{p} + T_{566}\left(\frac{\Delta p}{p}\right)^2$$

T_{ijk} elements of the second order transfer matrix

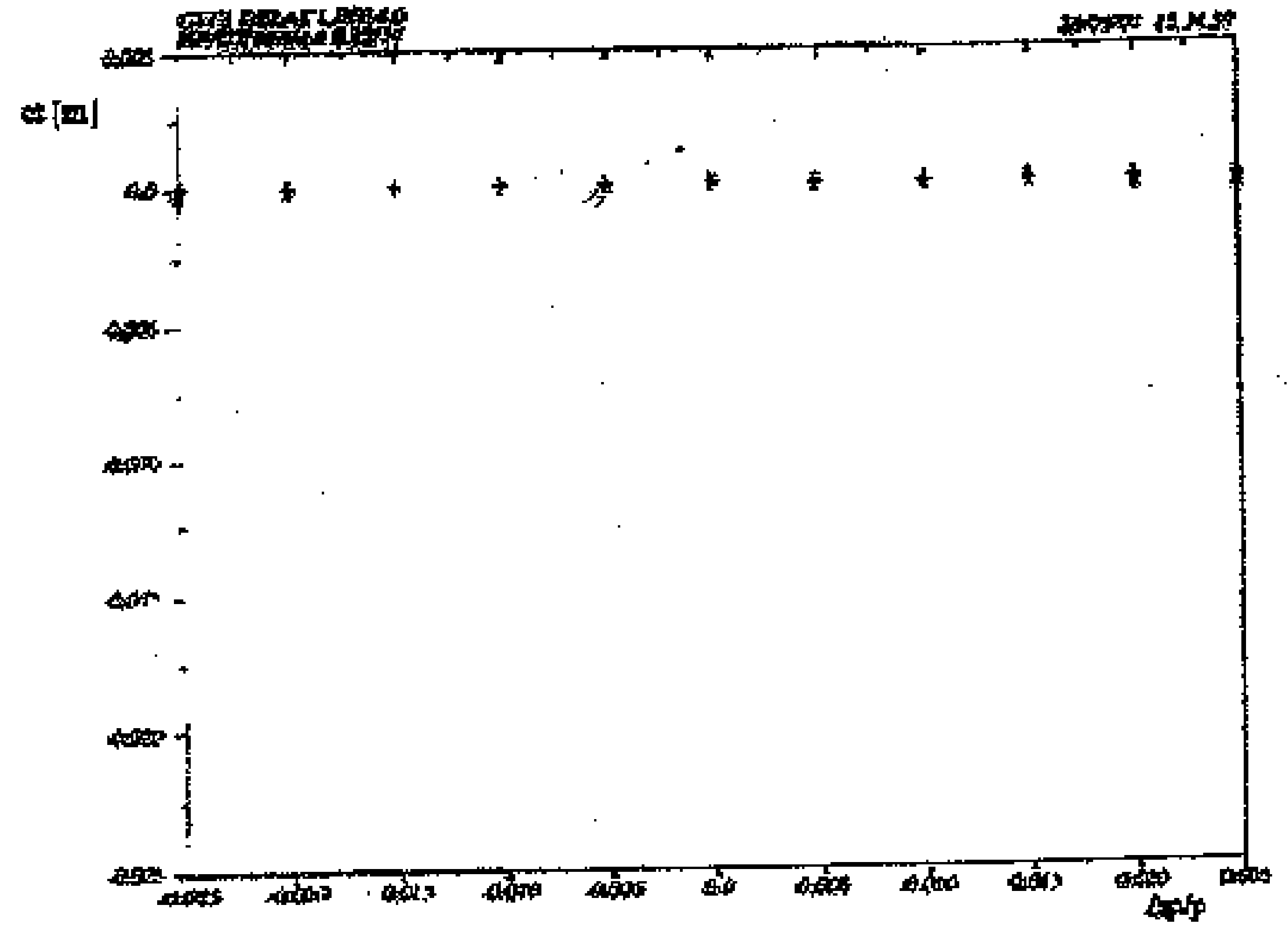
Isochronicity is achieved when:

$$T_{5i6} = 0 \qquad \forall\ i$$

⇨ Need of strong focusing sextupoles

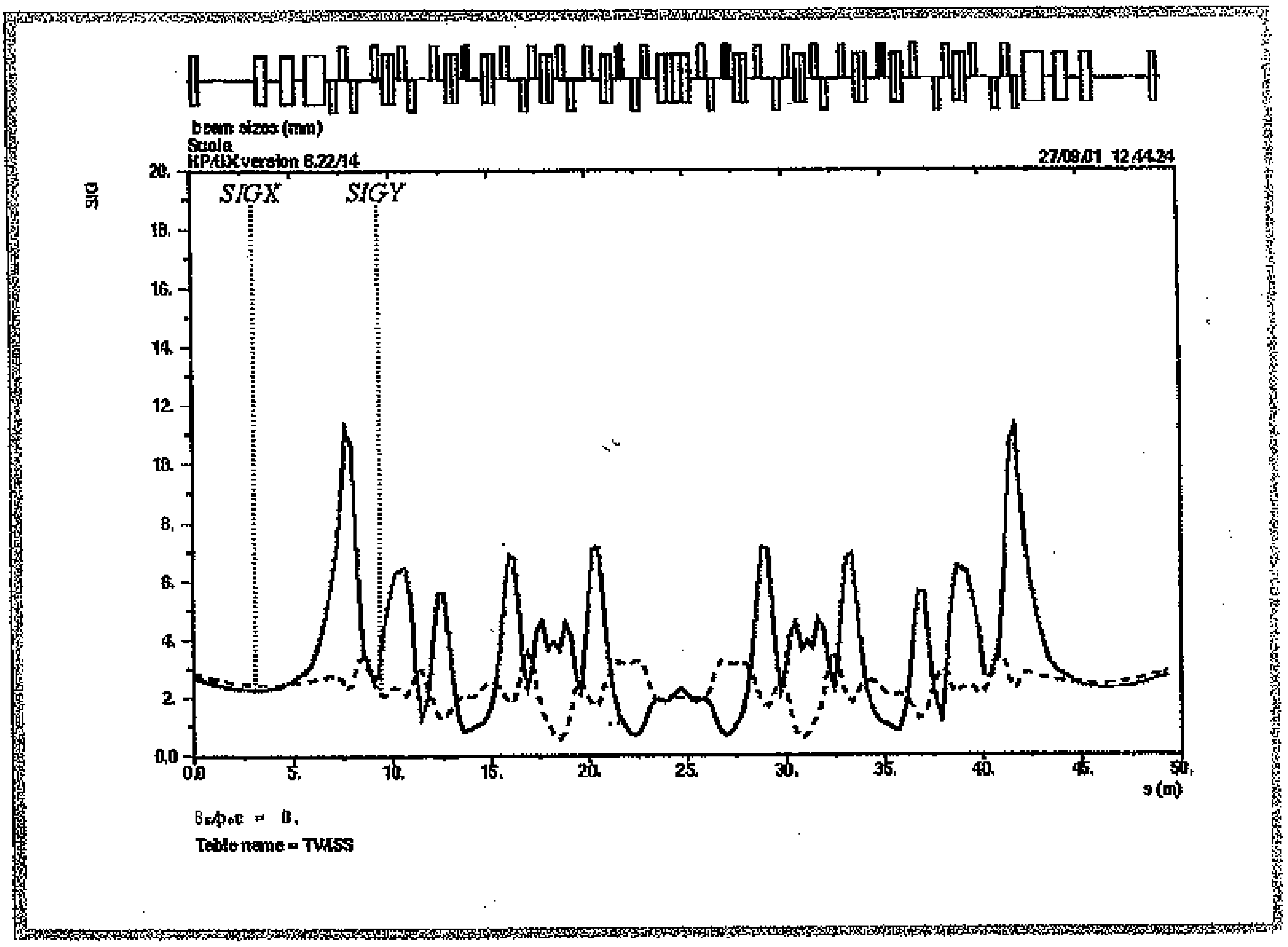


Off-energy Particles Longitudinal Position at DL Input (Crosses) and Output (Dots)
First Order Correction

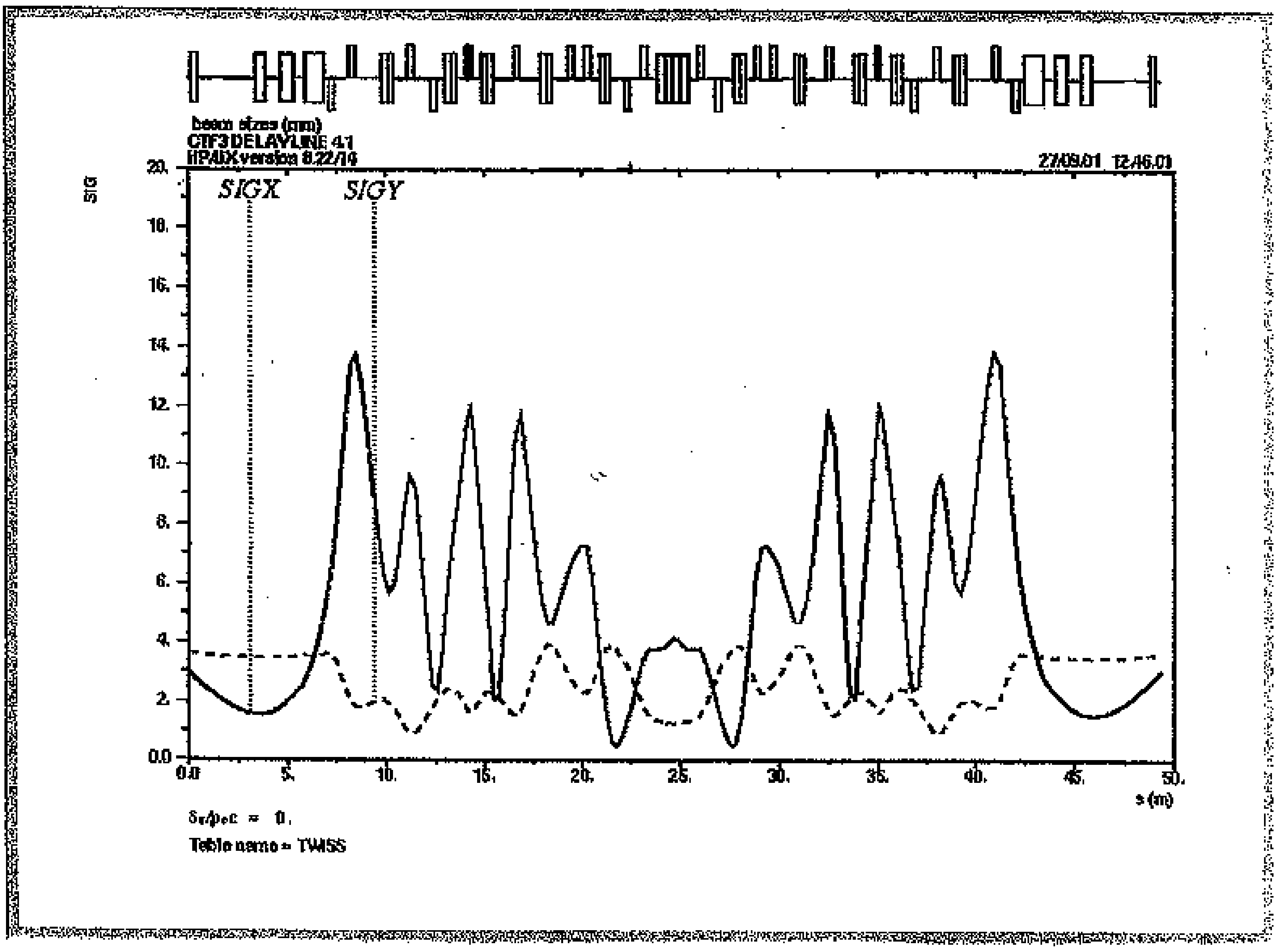


Second Order Correction

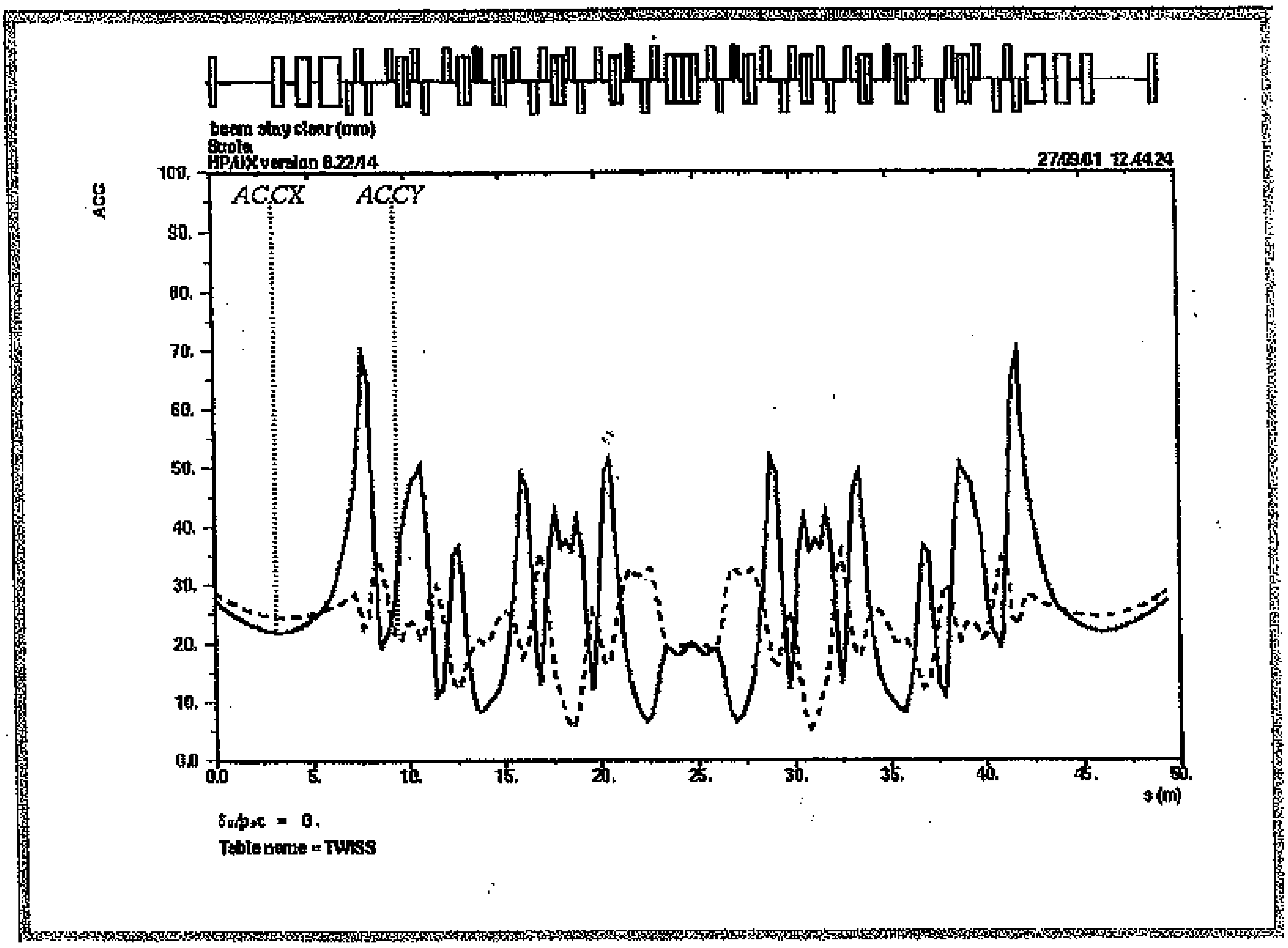
Delay Loop Beam sizes – Solution A



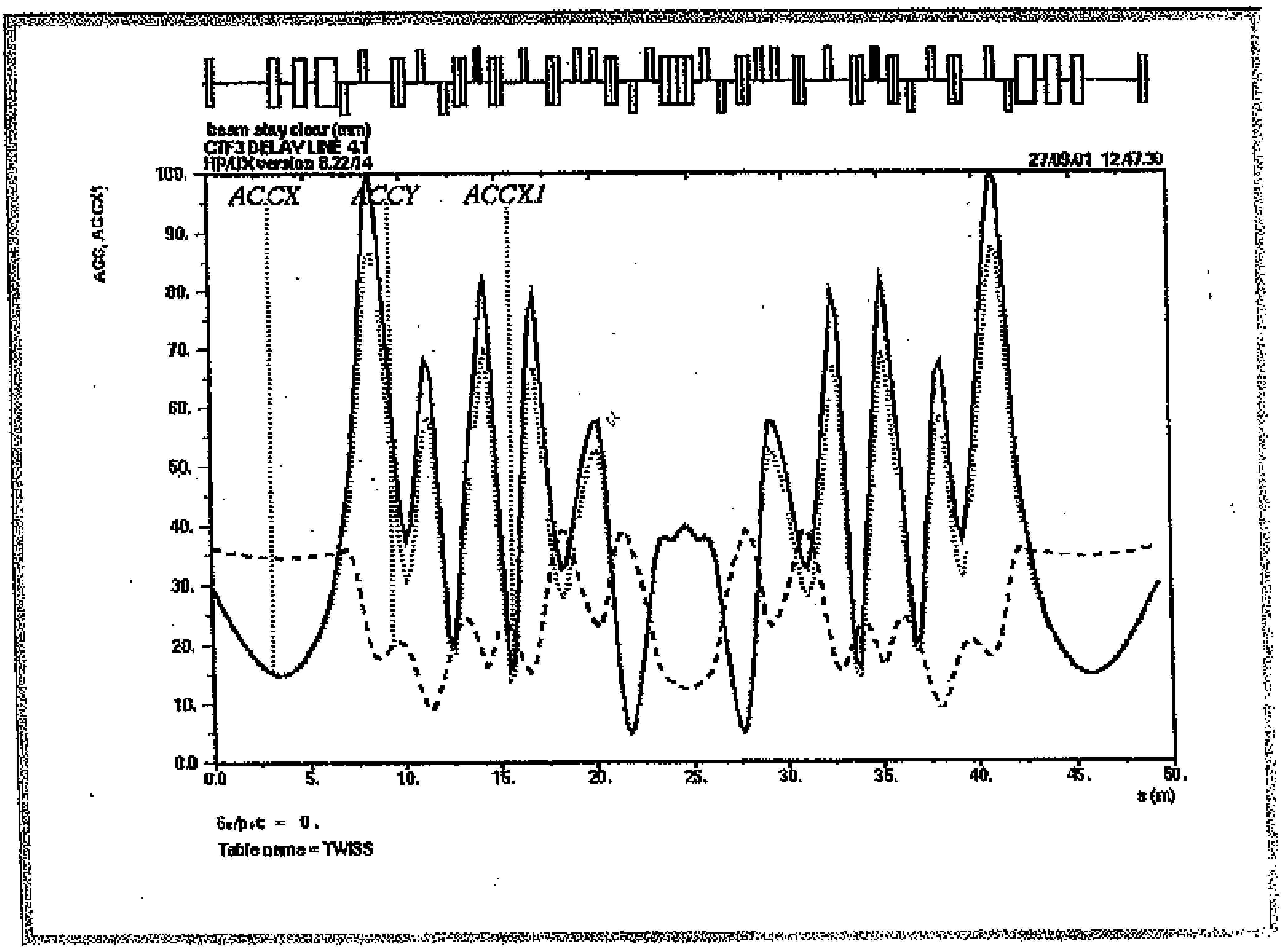
Delay Loop Beam sizes – Solution B



Delay Loop Beam Stay Clear – Solution A



Delay Loop Beam Stay Clear – Solution B



Work in progress

- Six-dimension particle tracking
- Definition of corrector dimensions + positioning of the monitors + analysis of other kind of errors (dipole misalignments, dipole and quadrupole field errors, monitor errors,...) + trajectory correction in the combiner ring without the option of storing the beam
- Solution B for the Delay Loop
- Storage ring option for the Combiner Ring

Combiner ring => Storage ring

Storing a beam would allow **DC measurements of orbit and betatron functions (machine modelling)**, although the lattice for beam storing has to be modified with respect to the nominal one since it cannot be isochronous.

The RF system design is based on a **single-cell cavity** already available at LNF. In order to contain cost and complexity of the system, a moderate gradient is foreseen, obtainable with a simple (and cheap) RF power source (such as solid state amplifier).

It can be installed in the extraction region, symmetric to the extraction kicker.

RF System

Parameter	Symbol	Value
Frequency	f_0	**356.8 MHz**
Harmonic number	h	**100**
Voltage	V_{RF}	**≈ 70 kV**
Shunt impedance	R_S	**≈ 2.5 MΩ**
RF power	P_{RF}	**≈ 1 kW**
Beam current (s.b.)	I_b	**≈ 3.5 mA**

MainRingFunctions.vi
/u1/dafne/offLineTools/MainRingFunctions.vi
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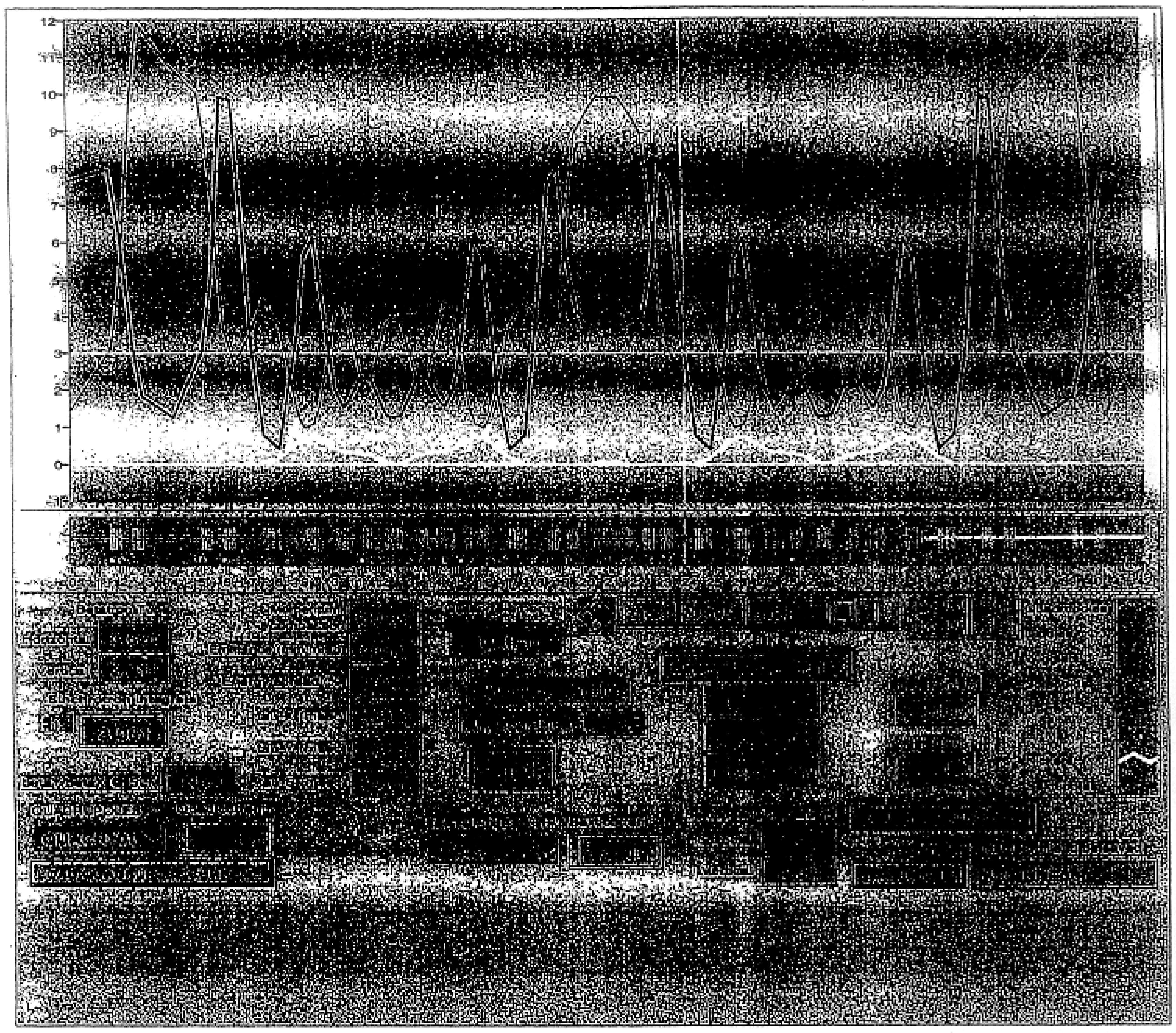
Printed on 10/01/2001 at 02:50 PM



$E = 350$ MeV

$\alpha_c = 0.0025$

$\frac{\Delta E}{E} = 2.9\ 10^{-4}$

$\varepsilon = 5.3\ 10^{-9}$ m·rad

$\sigma_L = 4$ mm

$V_{Loss} < 40$ keV

$\tau_T \approx 100$ sec

(10% coupling)

~1 mC (3.5 mA

Page 1

MainRingFunctions.vi
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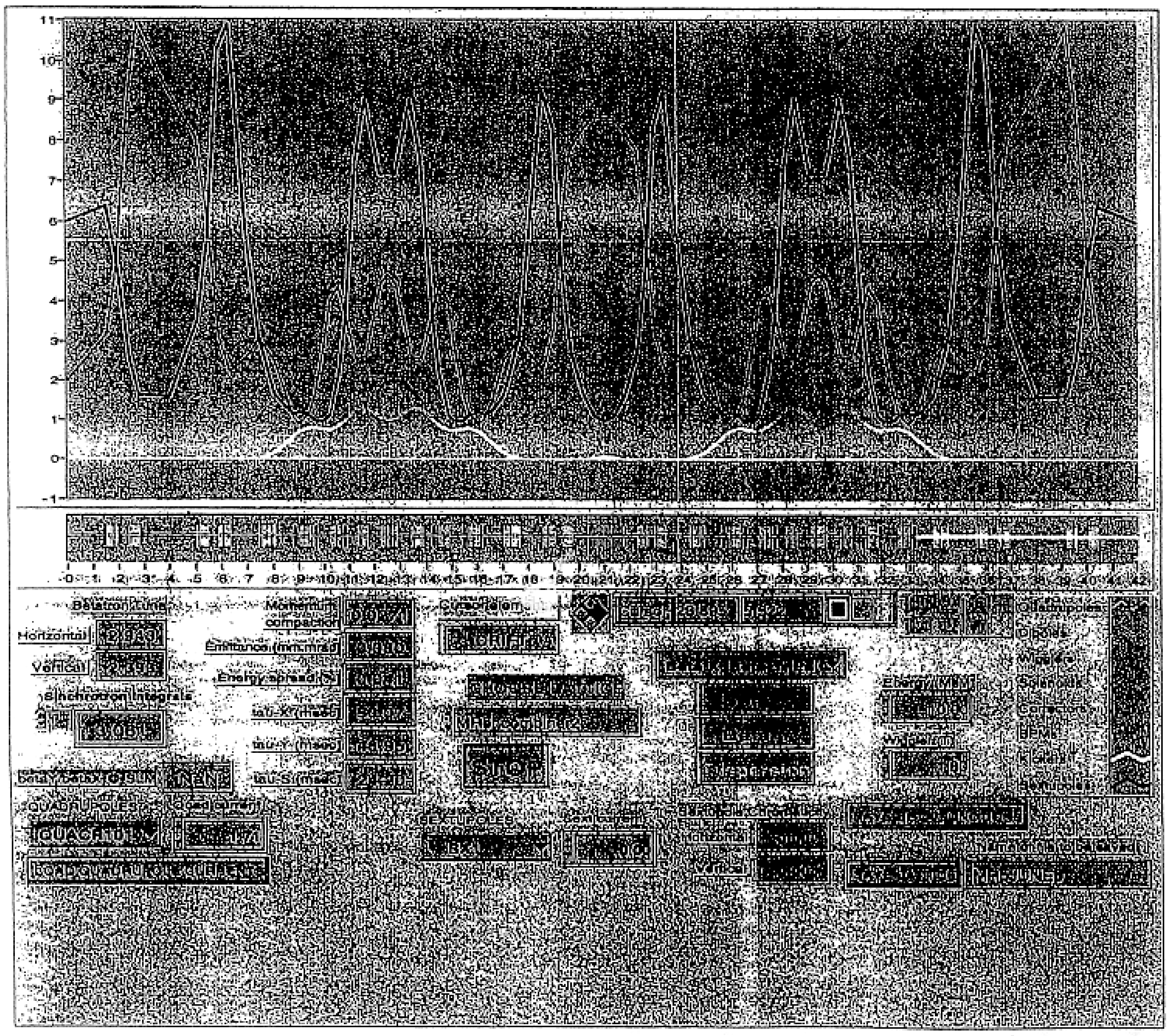


$E = 350$ MeV

$\alpha_c = 0.027$

$\frac{\Delta E}{E} = 2.9\ 10^{-4}$

$\varepsilon = 3.8\ 10^{-8}$ m·rad

$\sigma_L = 12$ mm

$V_{Loss} < 17$ keV

$\tau_T \approx 1000$ sec

(10% coupling)

High momentum compaction lattice

Parameter	Symbol	Value
Energy	E	350 MeV
Momentum compaction	α_c	$2.7\ 10^{-2}$
Energy spread	σ_E/E	$2.9\ 10^{-4}$
Emittance	ε	$3.8\ 10^{-8}$ m rad
Bunch length	σ_z	12 mm
Beam losses (@$q_b \approx 1$ nC)	V_{loss}	< 17 keV
Touschek lifetime	τ_T	≈ 1000 s

Low momentum compaction lattice

Parameter	Symbol	Value
Energy	E	350 MeV
Momentum compaction	α_c	$2.5\ 10^{-3}$
Energy spread	σ_E/E	$2.9\ 10^{-4}$
Emittance	ε	$5.3\ 10^{-9}$ m rad
Bunch length	σ_z	4 mm
Beam losses (@$q_b \approx 1$ nC)	V_{loss}	< 40 keV
Touschek lifetime	τ_T	≈ 100 s

Beam Parameters

E = 180 - 350 MeV

$\varepsilon_x = \varepsilon_y = 10^{-6}$ [m rad]

$\Delta p/p = 1\%$

l_b bunch length from the Linac

$l_b = 1.5$ mm

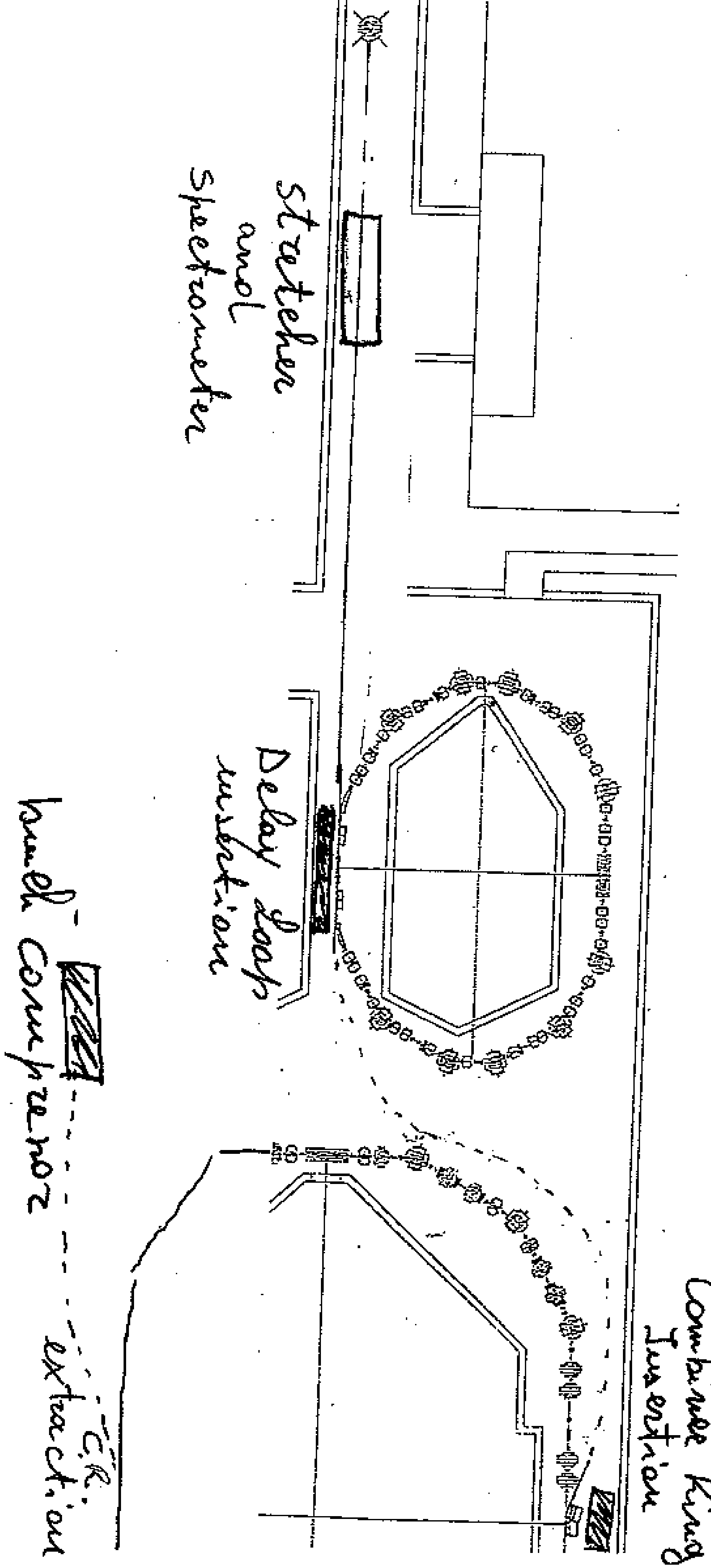
Δl_b bunch length tunability

$\Delta l_b = \pm 1.6$ mm

CTF3 Transfer Line

Catia Milardi

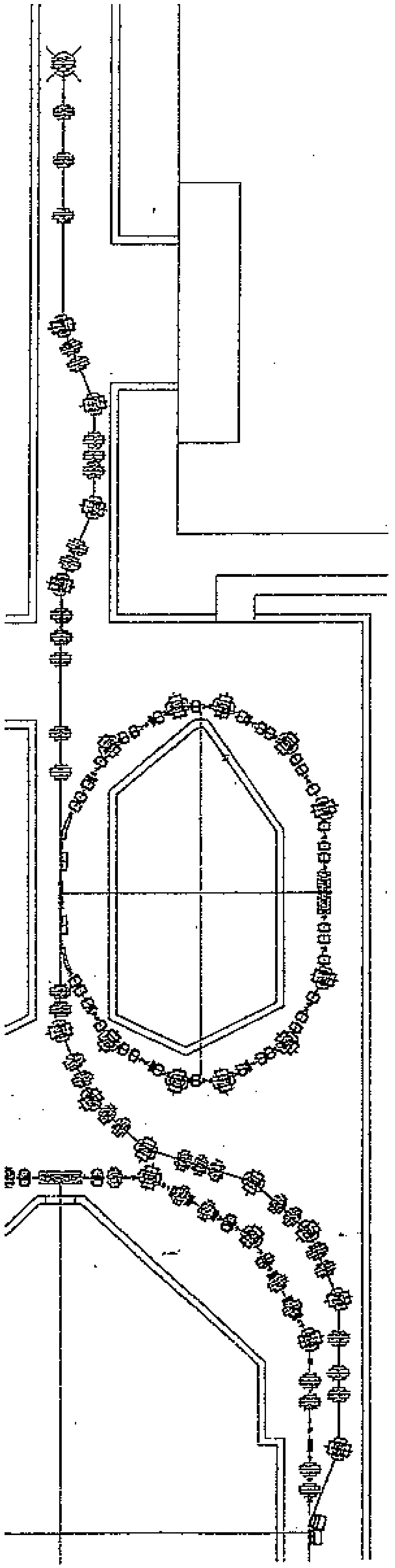
October 2-3 2001



General Requirements

The CTF3 Transfer Line main issues:

- **isochronicity**
- **bunch length match tuning**
- **low $\beta_{x,y}$ to minimize chromatic effects**
- **low η_x to have small contribution to second order isochronicity as well as to transverse emittance.**
- **match the Delay Loop and Combiner Ring insertions**
- **reuse as much as possible EPA magnets and power supplies**



Isochronicity

The path length variation with energy is:

$$c\Delta t = R_{51}x + R_{52}x' + R_{56}\Delta p/p + T_{566}(\Delta p/p)^2 + \ldots$$

the first order approximation neglects contribution from T matrix

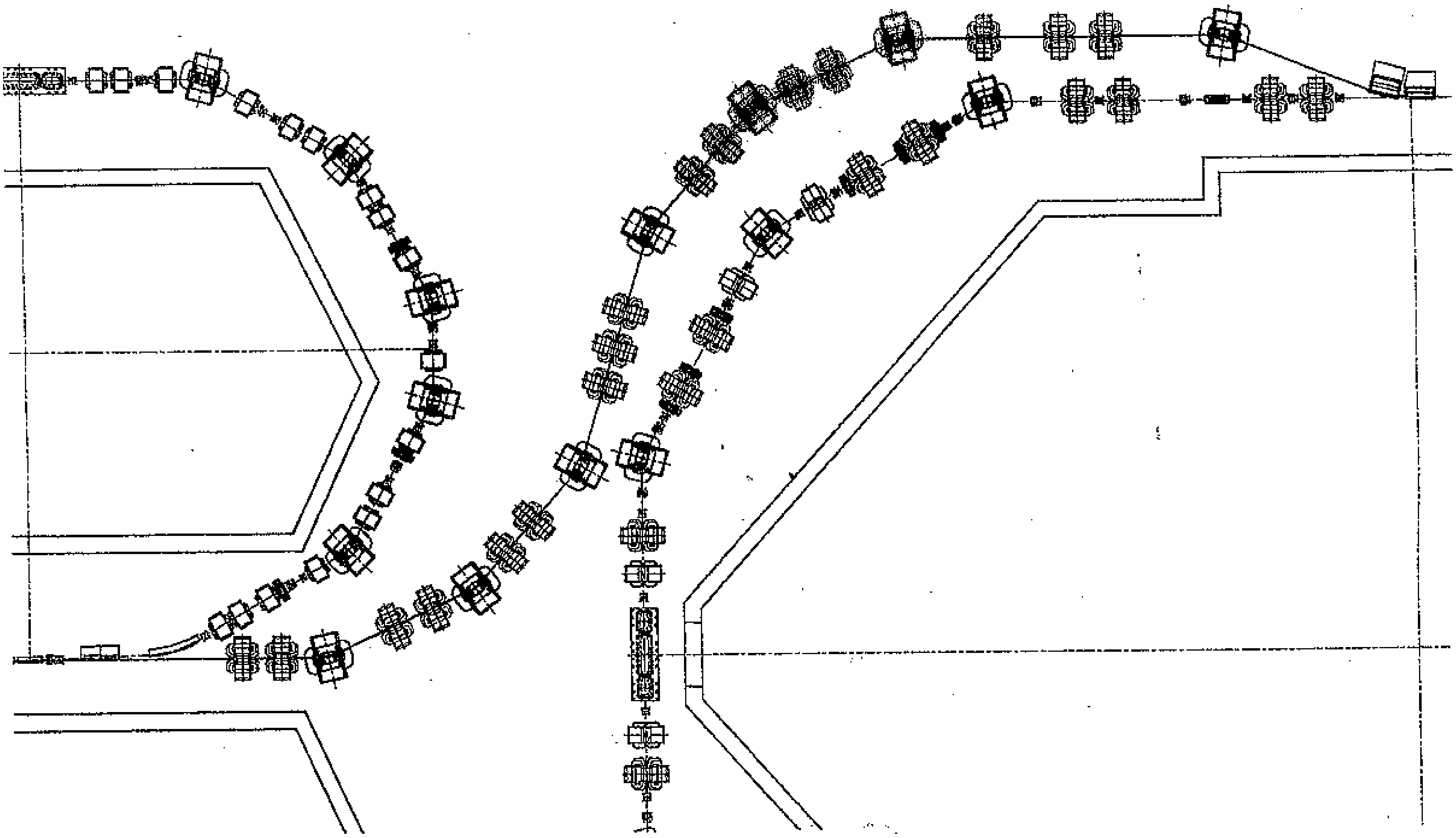
the achromatic condition implies

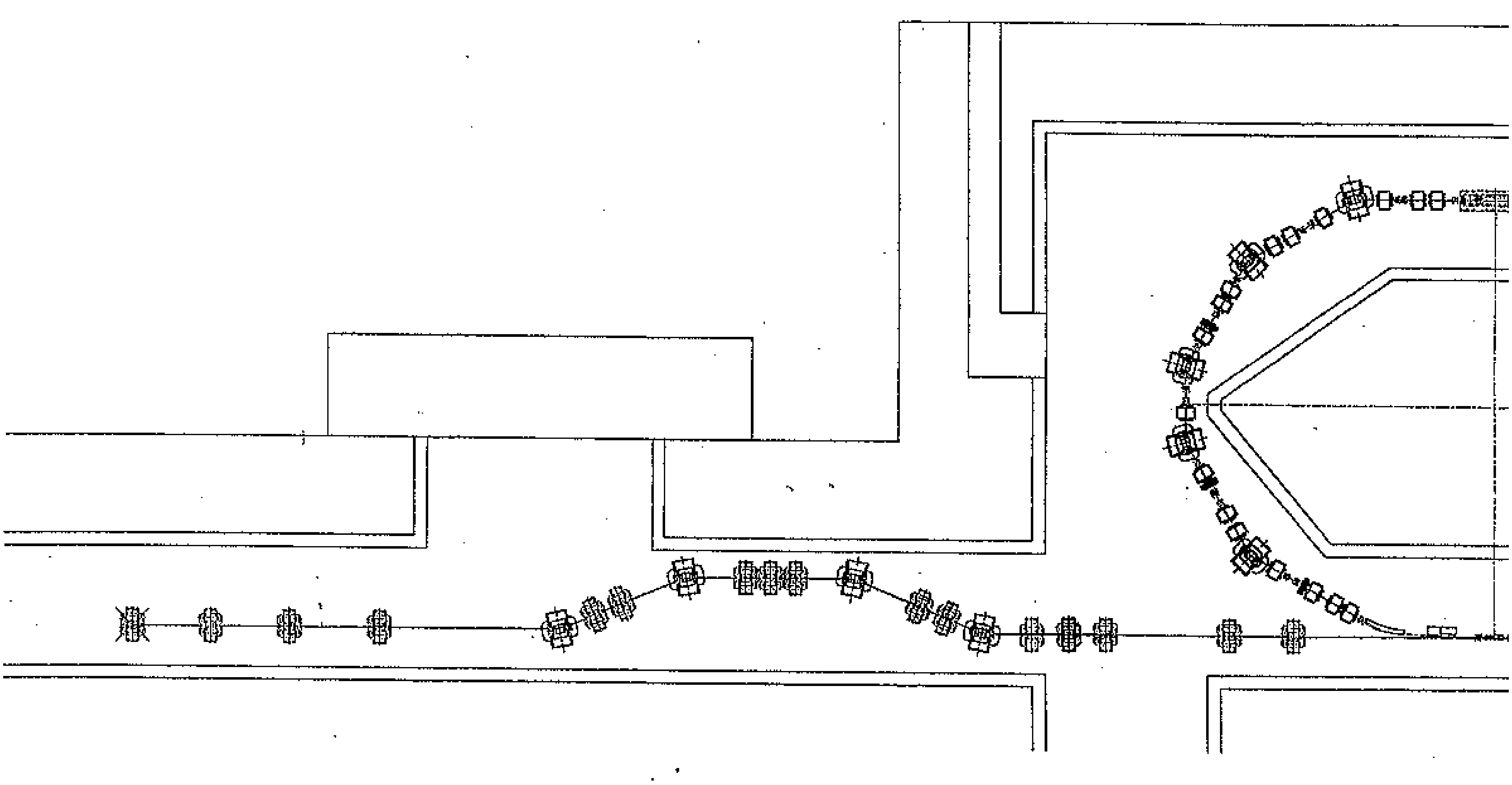
$$R_{51} = R_{52} = 0$$

$$c\Delta t = R_{56}\Delta p/p$$

the isochronicity condition becomes

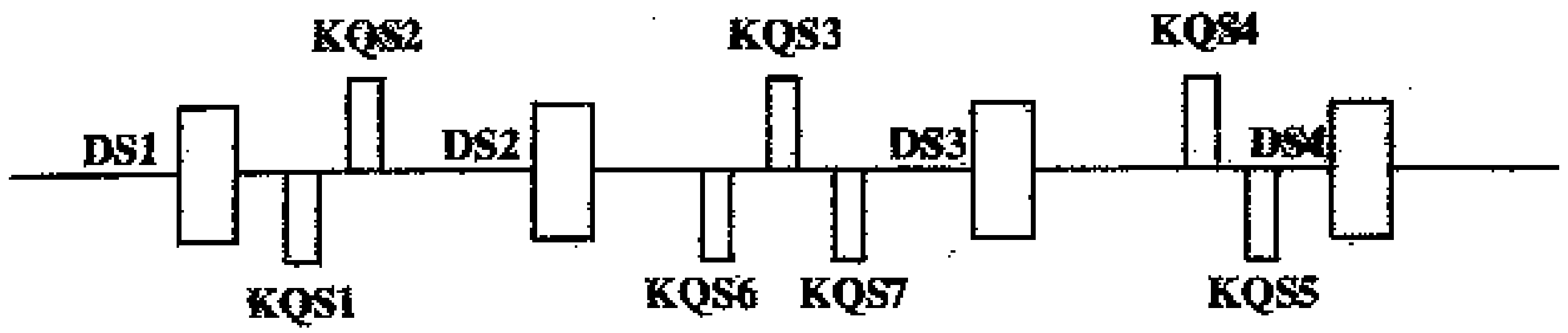
$$R_{56} = 0$$





Four-Bends Achromat

$$-.16\ [m] \le R_{56} \le .16\ [m]$$

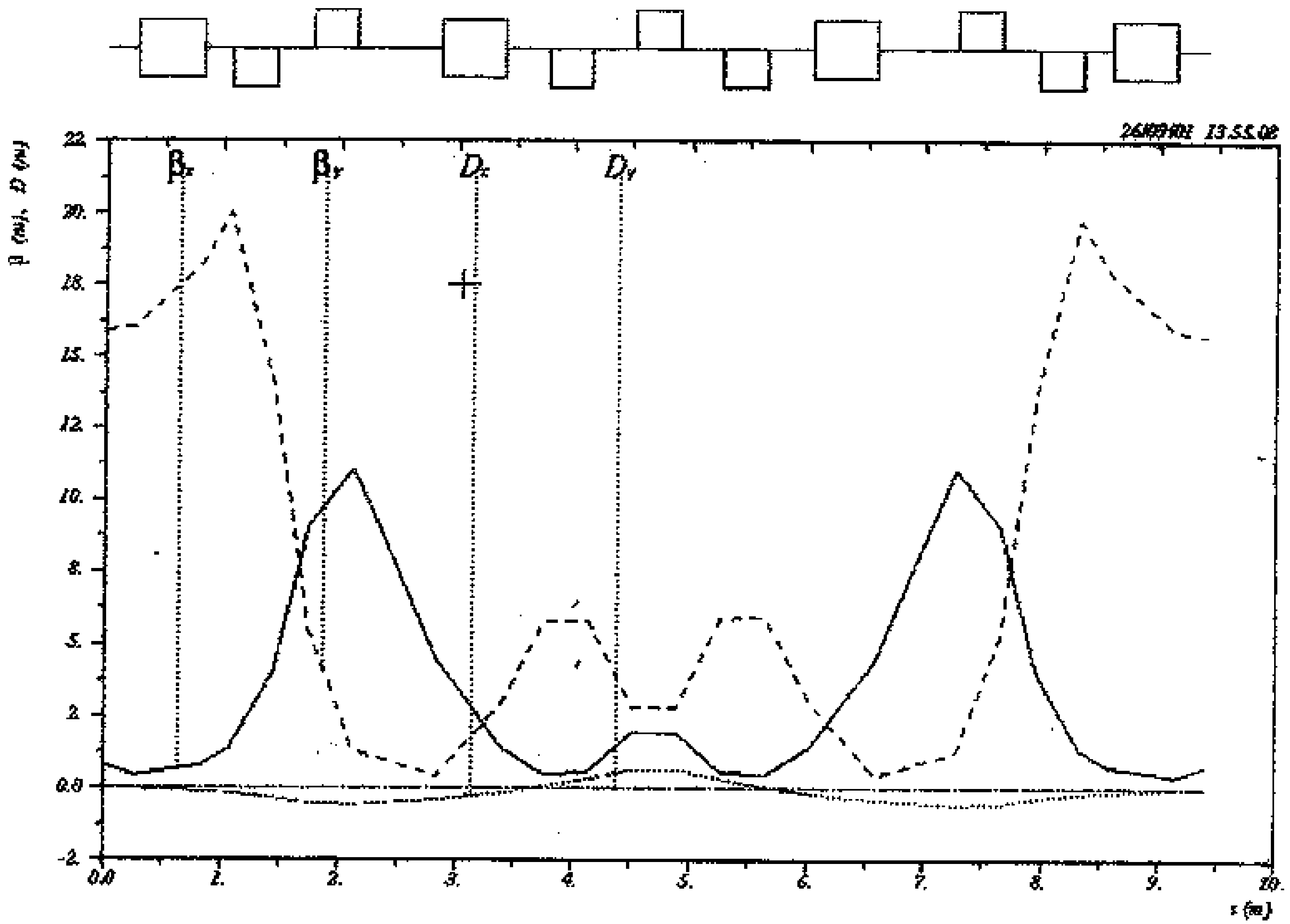


	R_{56} = -.16 [m]	R_{56} = 0 [m]	R_{56} = .16 [m]
KQS1 K (m^{-1})	-1.04	- .99	-1.28
KQS2	2.18	1.89	1.53
KQS3	1.73	1.84	2.4
KQS4	1.82	1.89	1.53
KQS5	1.50	- .99	-1.28
KQS6	- .86	- .79	-1.55
KQS7	- .91	- .79	-1.55

DS1
DS2 $\alpha = 18^0$
DS3 $\rho = 1.79$ m
DS4

DS1, ..,DS4 are the EPA TL magnets

Four-bends achromat twiss functions



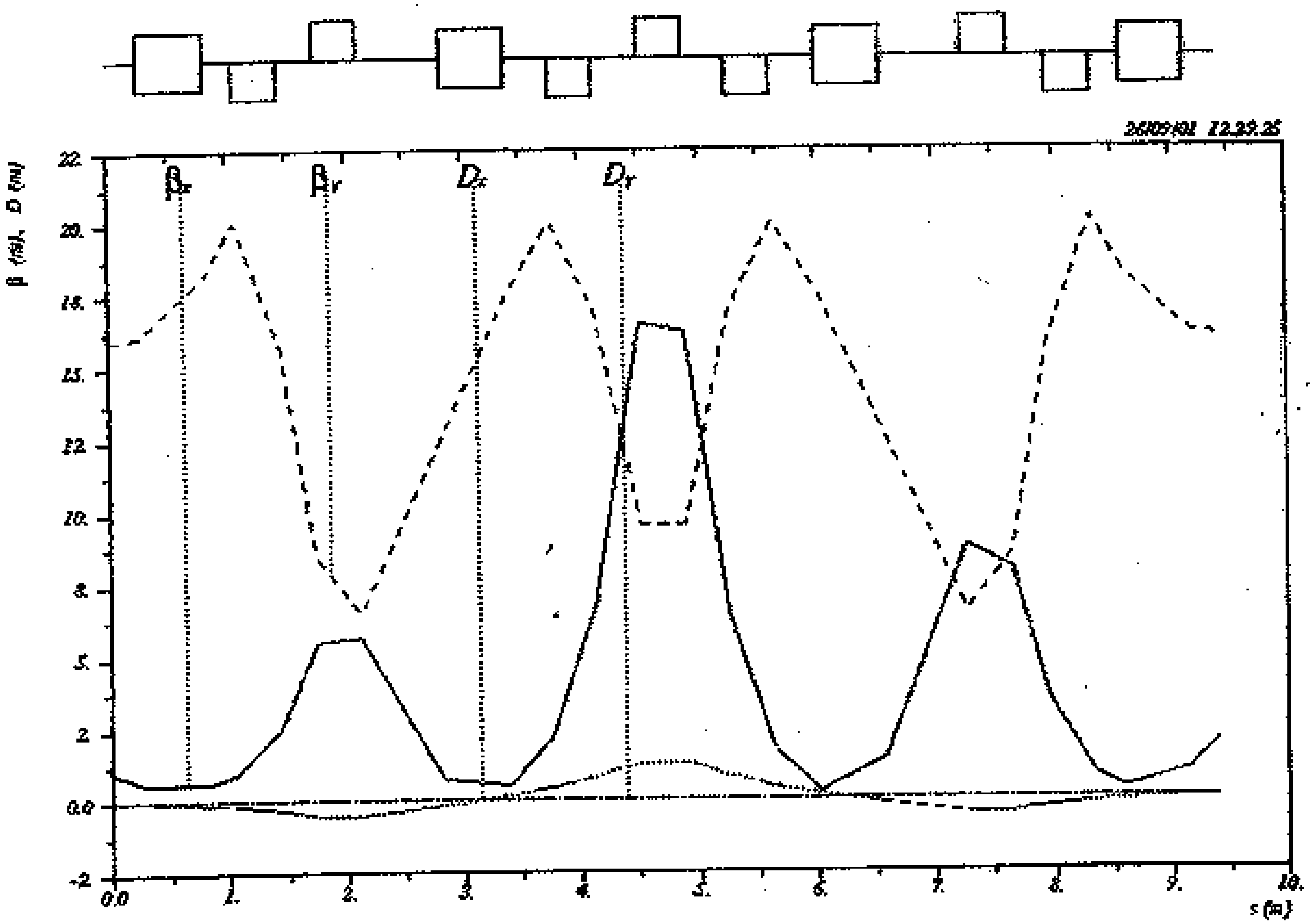
R_{56} ~ .16

assuming no E, z correlation the rsm bunch lenght σ_l is

$$\sigma^2_l = \sigma^2_{l0} + R_{56}\sigma^2_e$$

the achromat can be used to stretch the bunch

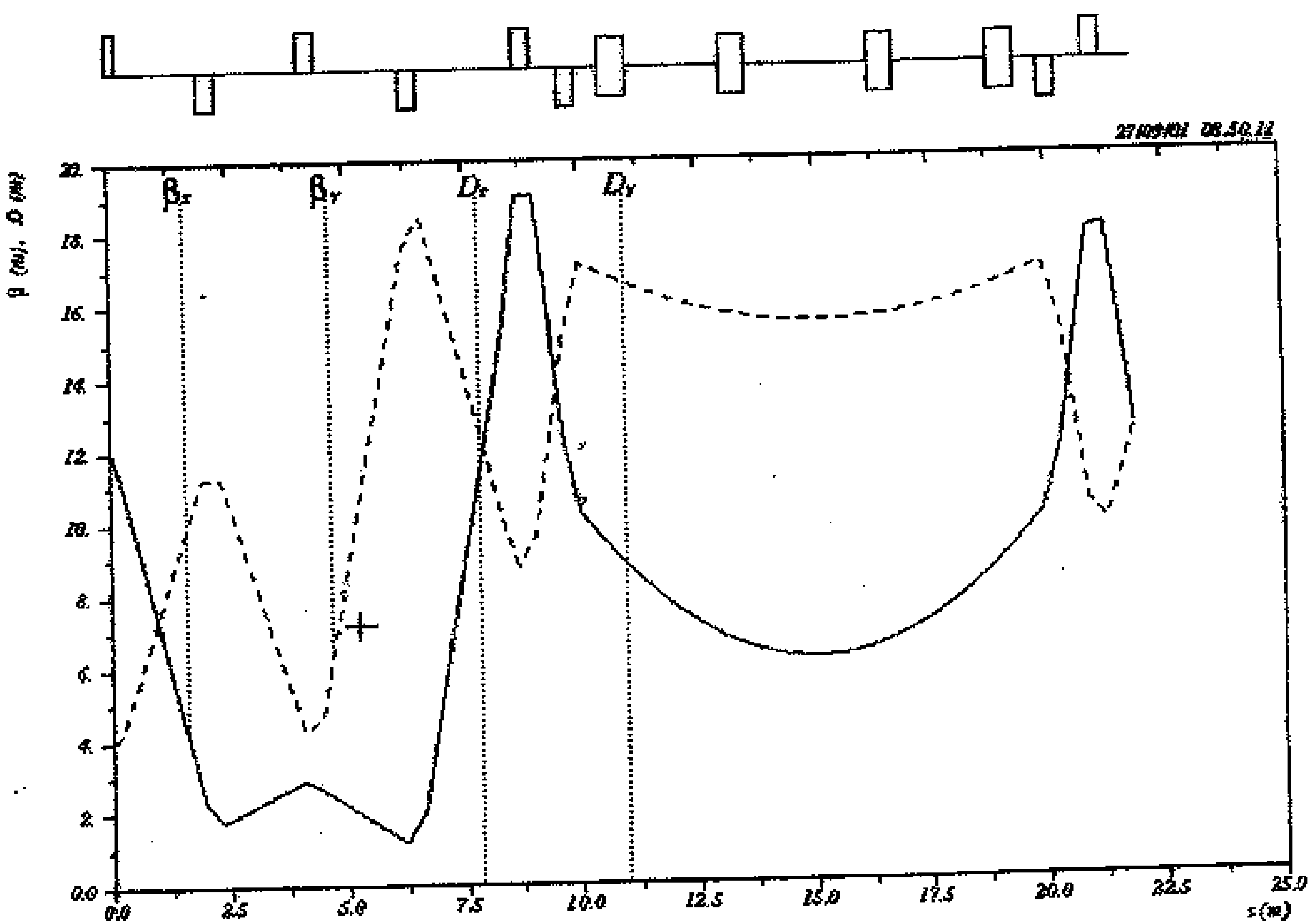
Four-bends achromat twiss functions



$R_{56} \sim 0$

the achromat is isochronous

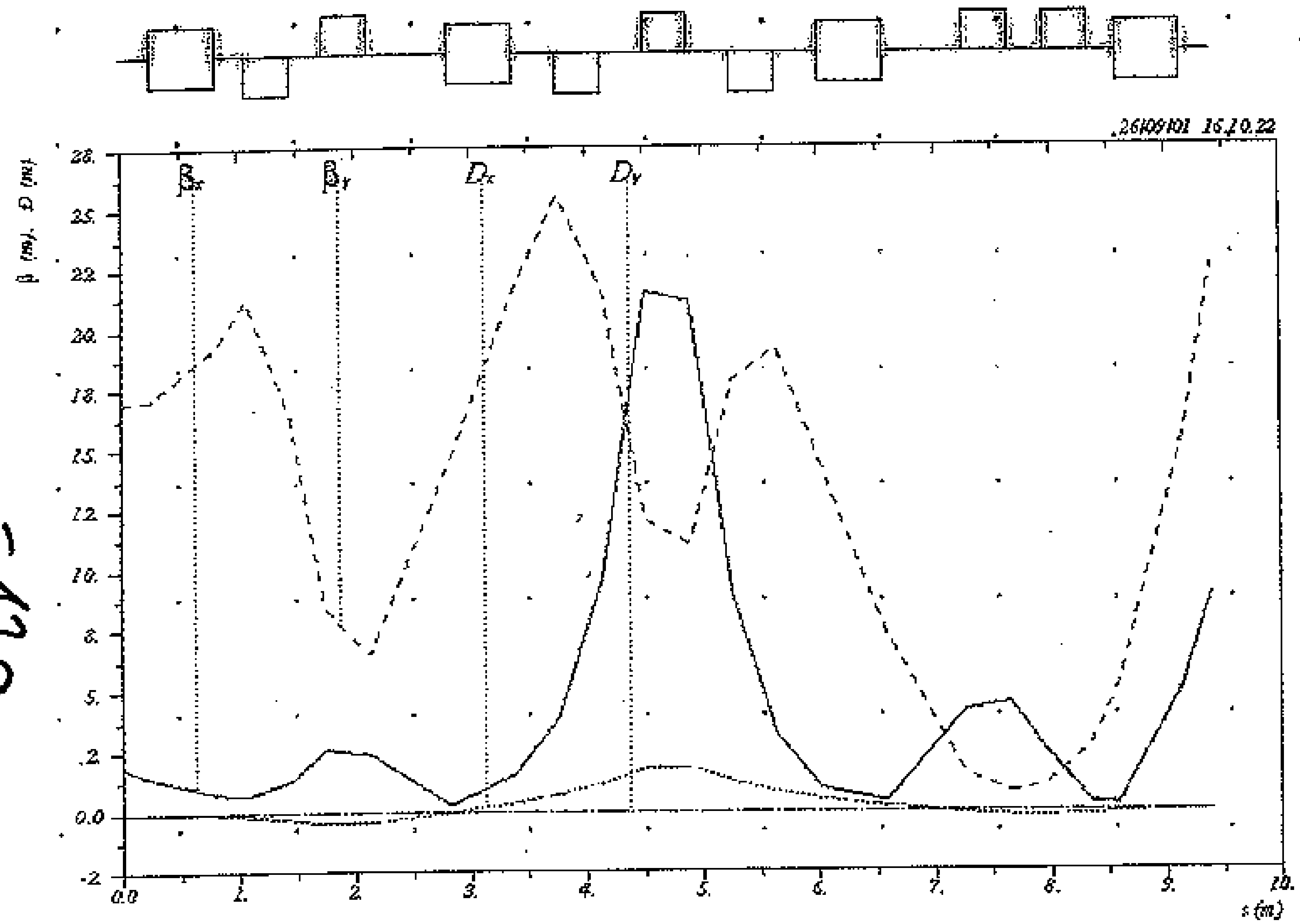
Four-bends achromat off twiss functions



$R_{56} = 0.$!!

Four-bends achromat

twiss functions



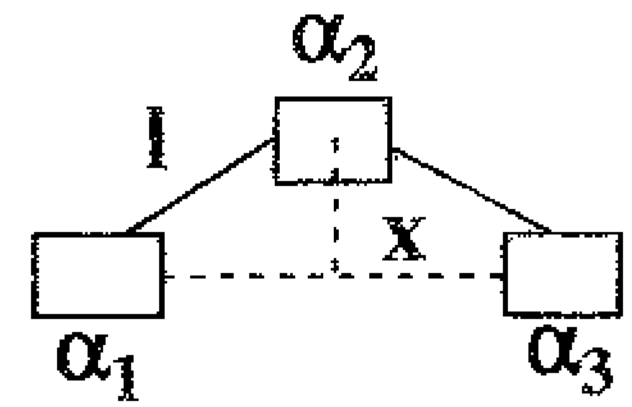
$R_{56} \sim -.16$

Three-bends achromat

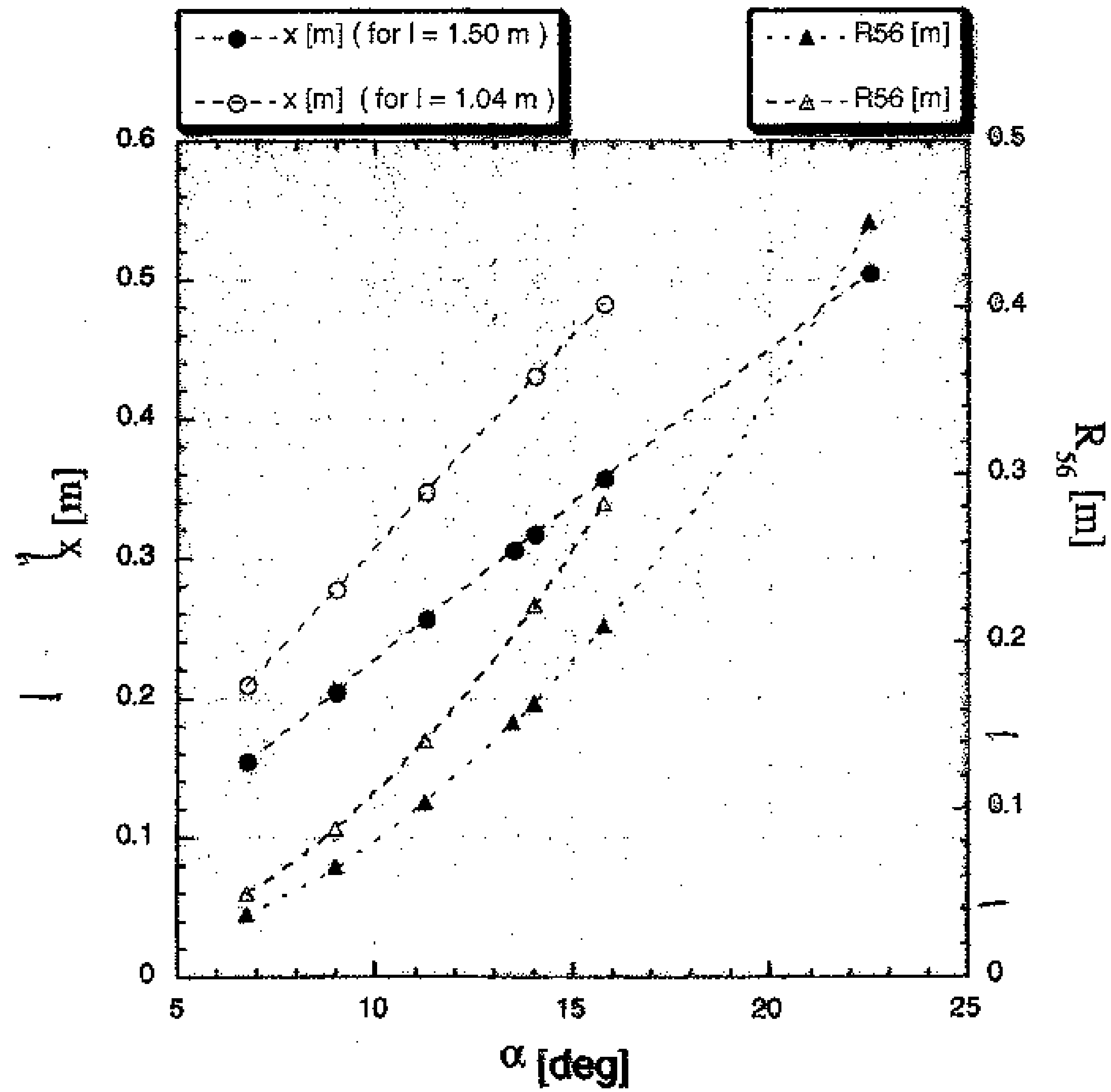
$\alpha_1 = \alpha_3$

$\alpha_2 = 2\,\alpha_1$

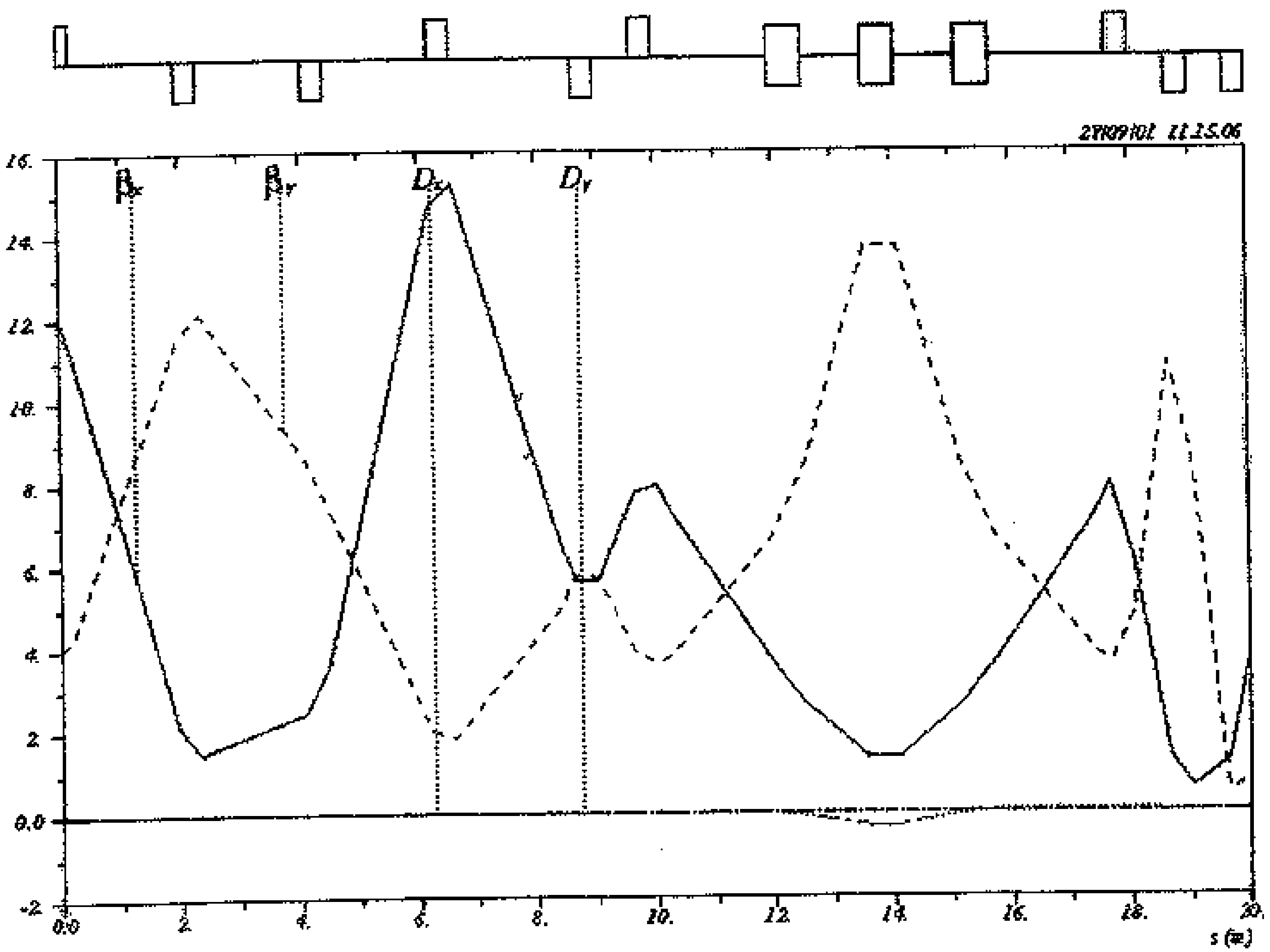
$.06\,[m] \leq R_{56} \leq .16\,[m]$



$\alpha_1 = \alpha_2 = \alpha_3 = 0 \qquad R_{56} = 0.$

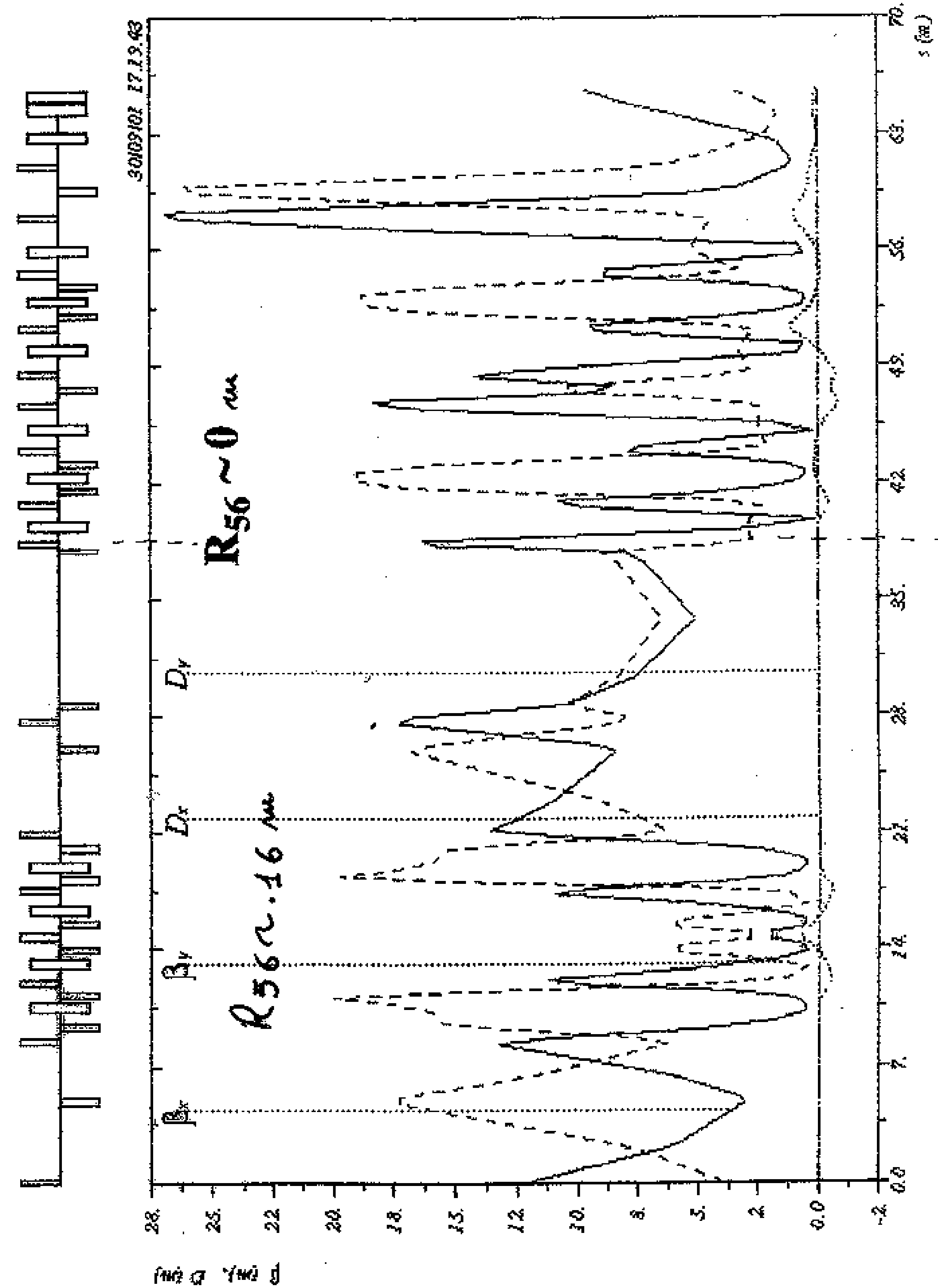


Three-bends achromat twiss functions



R_{56} ~ .16

CTF3 Transfer Line twiss functions



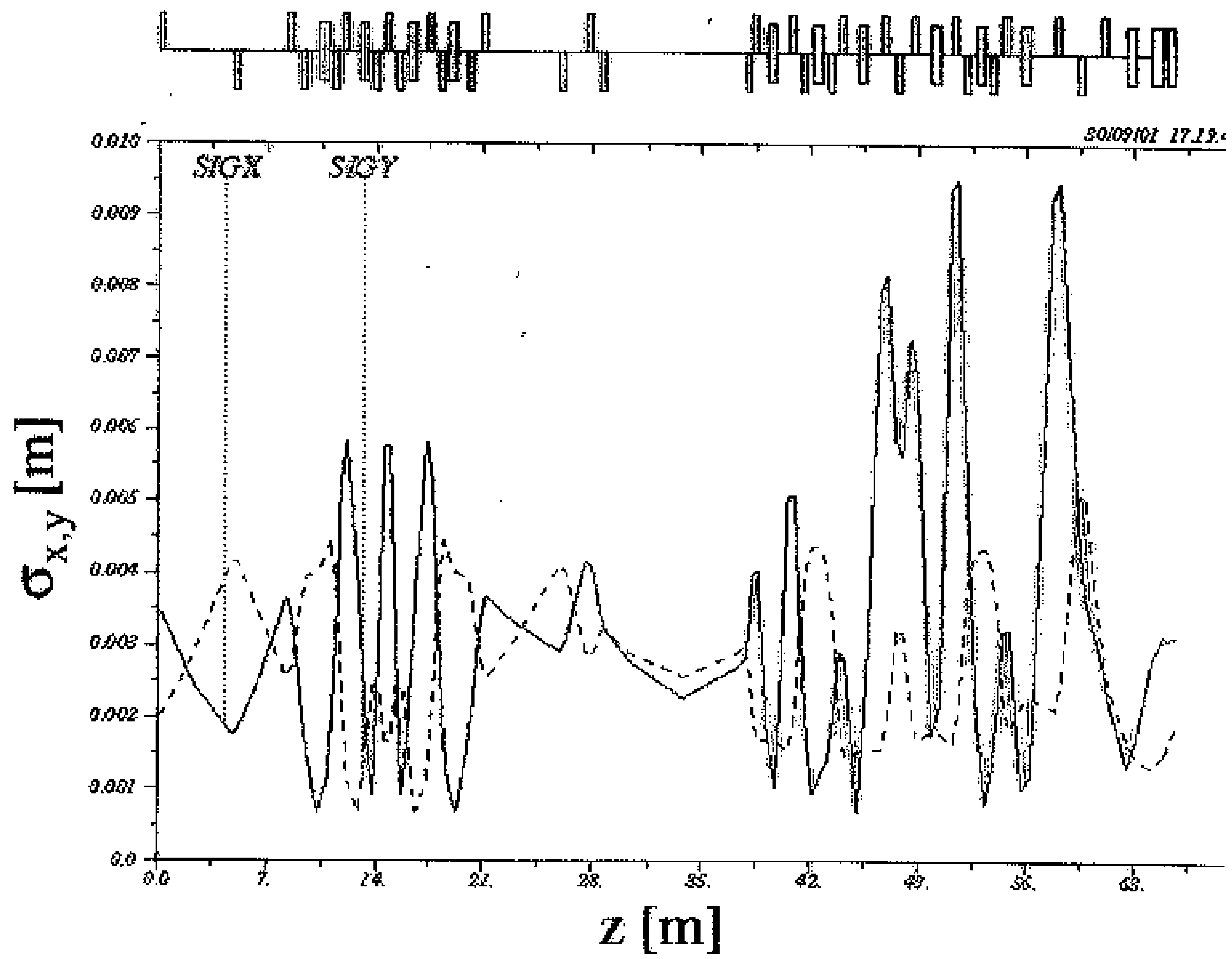
Beam Envelope

$$\varepsilon_x = \varepsilon_y = 10^{-6}\ [\text{m rad}]$$

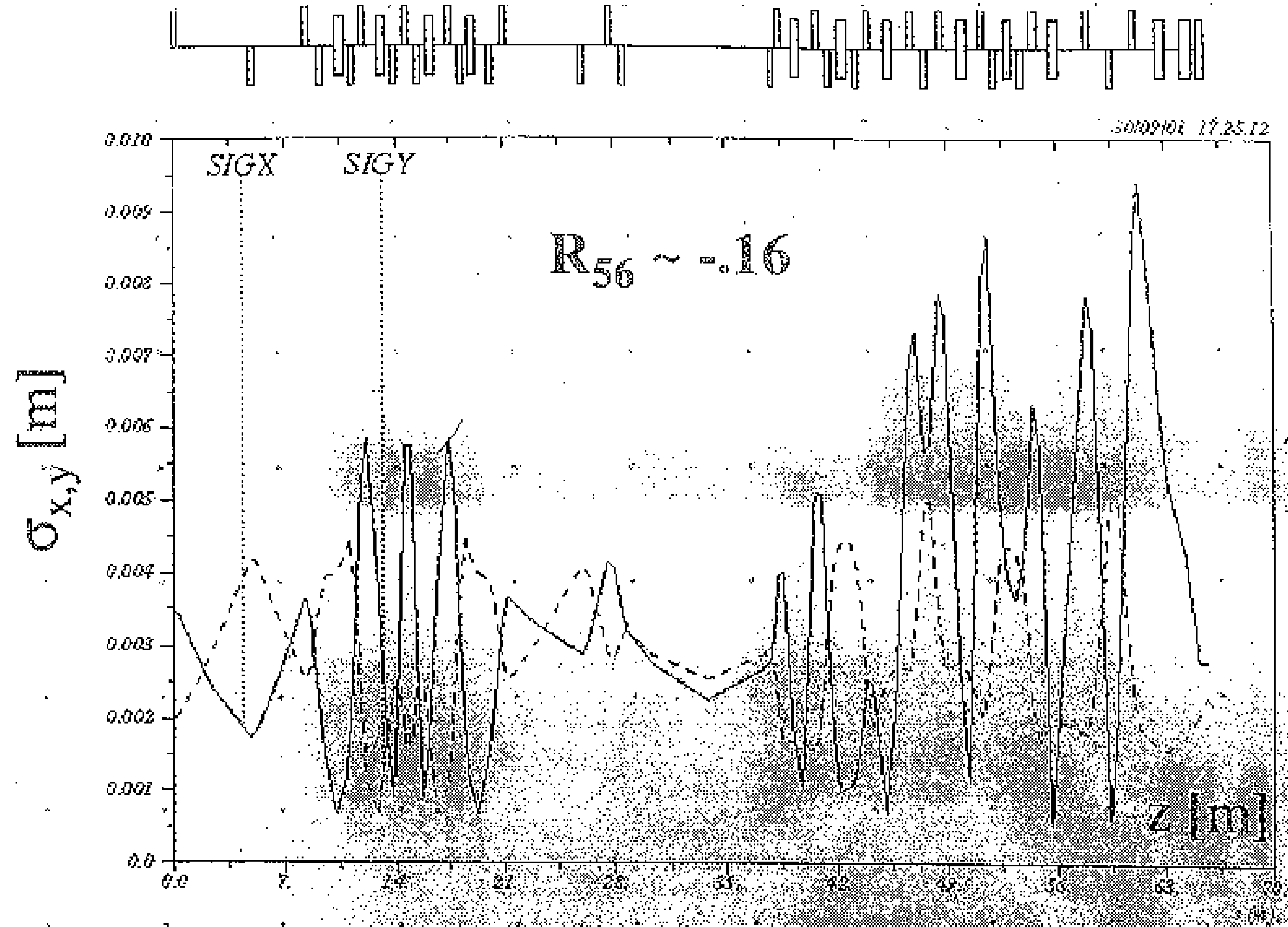
$$\sigma_e = .8\%$$

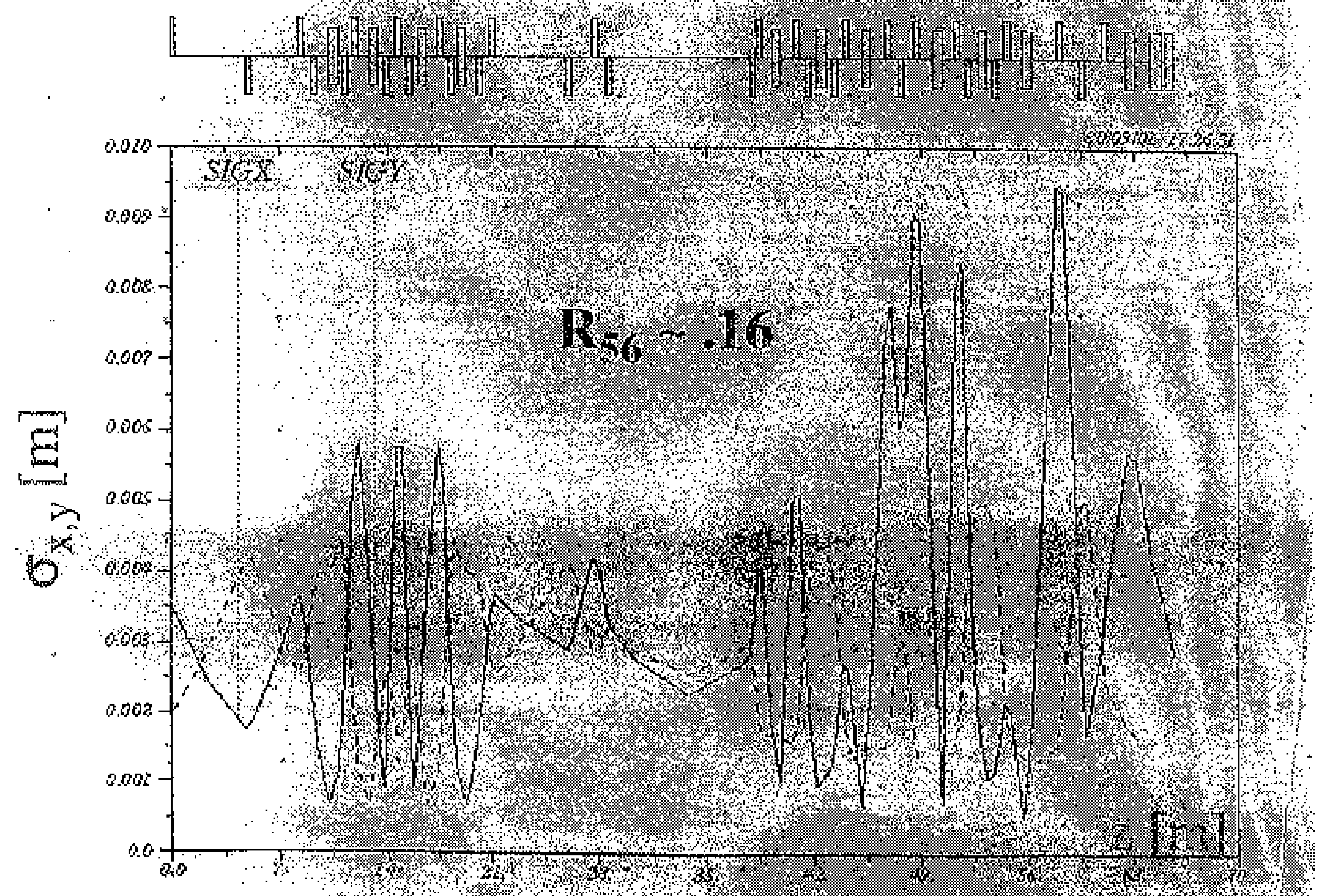
$$\sigma_x = [\varepsilon_x\beta_x + \sigma_e\eta^2_x]^{1/2}$$

$$\sigma_y = [\varepsilon_y\beta_y]^{1/2}$$



$R_{56} \sim 0$





Magnets Used

32 Quadrupoles
11 Bending magnets
2 Septa

Quadrupoles:

$l_m = .38$ m (overall .592 m)

K_{MAX} = 9.21 m^{-2} @.18 GeV

K_{MAX} = 4 73 m^{-2} @.35 GeV

Bendings:

$l_m = .561$ m (overall .87 m)

$\alpha = .392$ rd

Bend & Septum List

	L_m [m]	Angle [rad]	Zone
DS1	.561	-.3927	4 Bends Achromat
DS2	.561	.3927	
DS3	.561	.3927	
DS4	.561	-.3927	
ID1	.561	-.4248	I Isochronous Arc
ID2	.561	-.4248	
ID3	.561	-.4248	
ID4	.561	.4248	II Isochronous Arc
ID5	.561	.4248	
ID6	.561	.4248	
SPT1	.6197	-.0349	Combiner Ring Injection
SPT2	.7122	-.3428	
DSP	.561	.3777	

Quadrupole List

	L_m [m]	$K L_m$ [m^{-1}]	Zone
Q1	.38	.29	From Linac
Q2	.38	.26	
Q3	.38	.82	
Q4	.38	.43	
KQS1	.38	- .99	4 Bends Achromat
KQS2	.38	1.89	
KQS3	.38	1.84	
KQS4	.38	1.89	
KQS5	.38	- .99	
KQS6	.38	- .79	
KQS7	.38	- .79	
KQDL	.38	-.36	
KQDL1	.38	.70	
KQDL2	.38	-.31	Delay Loop Insertion
KQDL3	.38	1.49	
KQDL4	.38	-.33	
KQDL5	.38	-1.55	
KQDL6	.38	2.28	
KQF(1)	.38	1.85	I isochronous arc
KQD(1)	.38	-.67	
KDDQ1	.38	1.18	
KDDQ2	.38	-1.31	
KDDQ3	.38	1.15	
KQF(2)	.38	1.668	II isochronous arc
KQD(2)	.38	-.60	
KSPQ1	.38	.95	Combiner Ring Injection
KSPQ2	.38	-.79	
KSPQ3	.38	.48	

Conclusions

* **The CTF3 Transfer Line has been completely designed up to the Combiner Ring, and some of its parts can be used for the line joining the RF power source.**
* **satisfies the CTF3 spatial general layout**
* **reuse the EPA magnets**
* **match the ring insertions**
* **satisfies the first order isochronicity**
* **keeps low the value of the Twiss functions**
* **Two schemes have been studied for an achromat insertion able to tune R_{56} in the ± .16 [m] range.**
* **The S-shape section is also tunable in terms of R_{56} always in the ± .16 [m] range.**

Next

* further optics optimization
* complete the Combiner Ring extraction line
* fix the bunch diagnostic tools and their position
* vacuum chamber definition and project
* study the impact of the higher order terms on the beam dynamics

CTF3 Combiner Ring Impedance Contributing Elements (Very preliminary)

1. Phenomena' (not discontinuities)

a) Coherent Synchrotron Radiation;
b) Space Charge;
c) Resistive Walls

2. Big Vacuum Chamber Objects

a) RF Deflectors
b) Extraction Kicker
c) BPMs or Striplines
d) Synchrotron Radiation Port
e) Injection Port
f) Extraction Port
g) Cavity if necessary

3. Small Discontinuities

a) Tapers
b) Pumping Slots
c) Valves
d) Flanges
e) Shielded Bellows
f) Surface Roughness

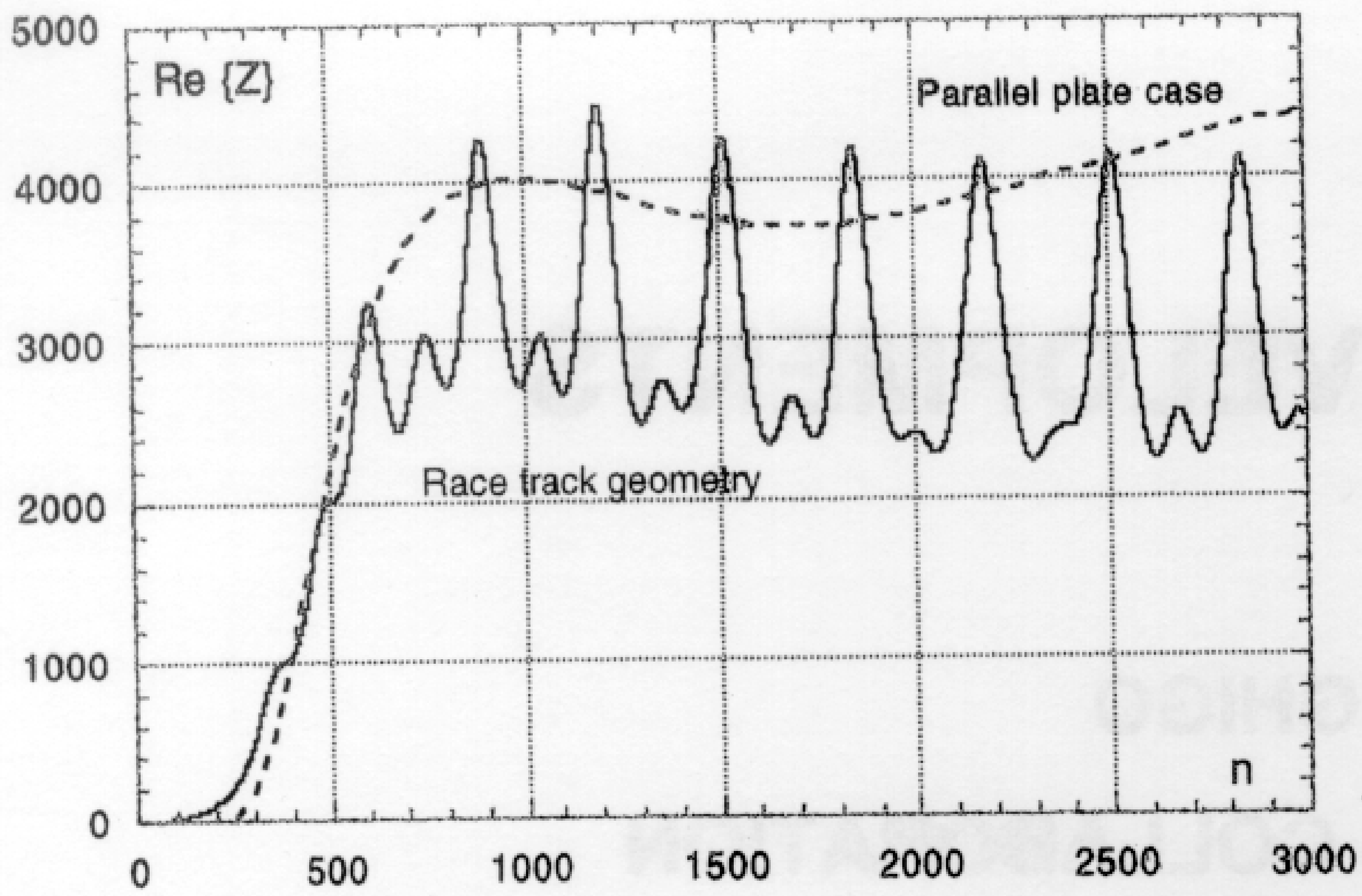
HARDWARE DEVELOPMENTS

ANDREA GHIGO
ON BEHALF OF CTF3 COLLABORATION

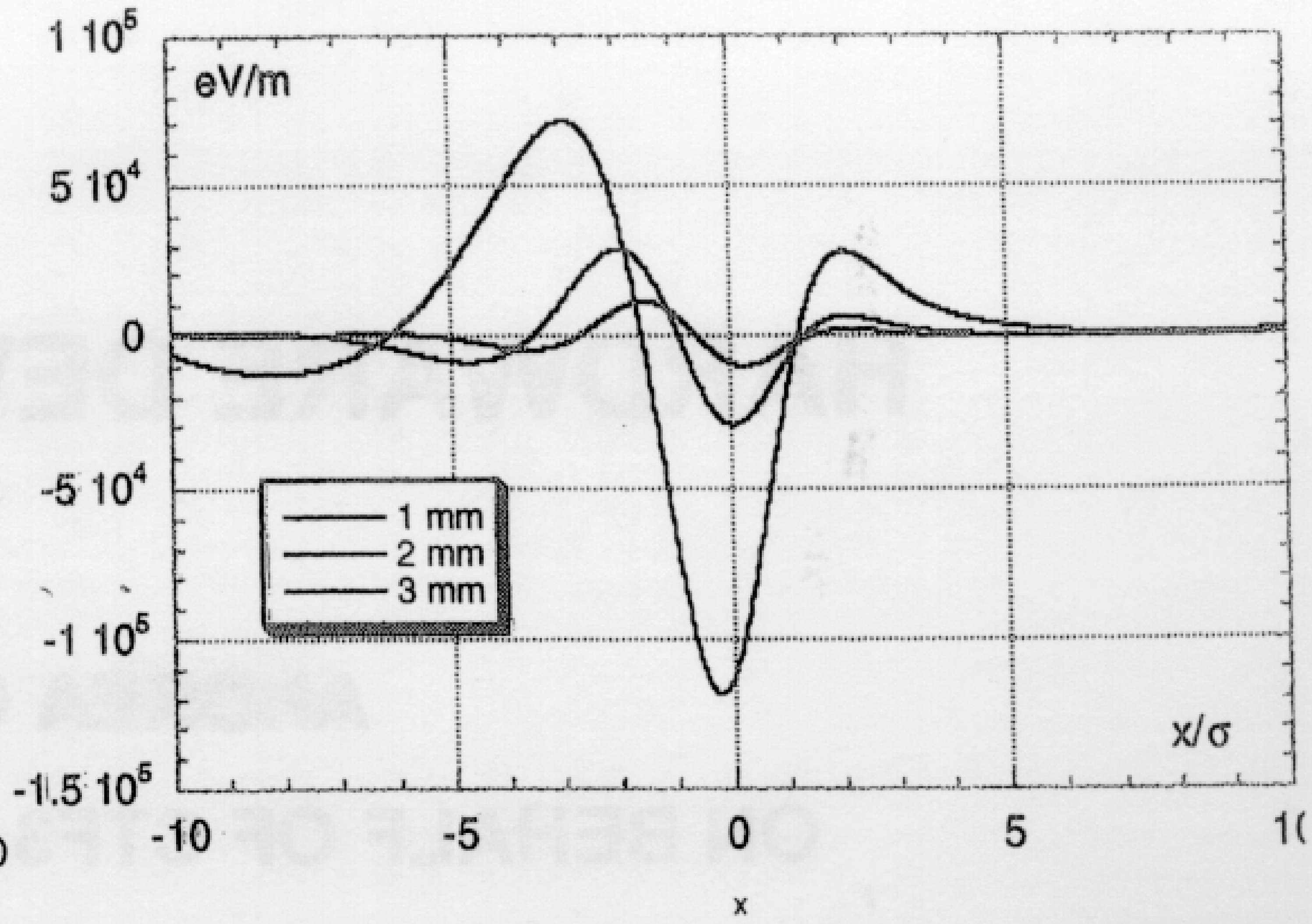
CTF3 REVIEW 2 OTTOBRE 2001

CSR in CTF3 COMPRESSOR RING MAGNETS

CSR IMPEDANCE (real part)

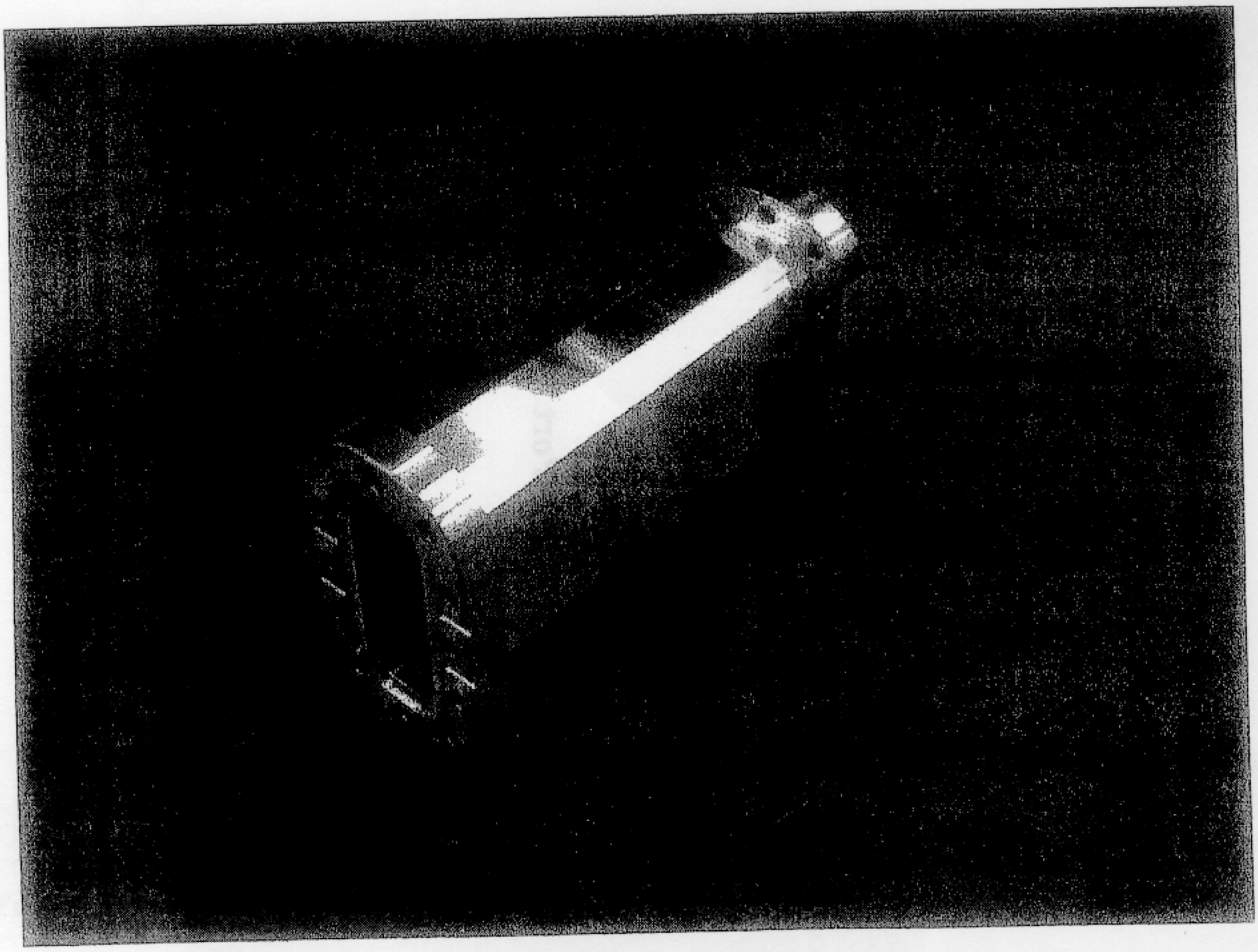


CSR WAKE FORCE (for different bunch length)



For EPA magnets incorporated in CTF3 compressor ring design and the vacuum chamber of 90x36 mm^2 the parallel plate approximation can be applied to estimate the energy loss and energy spread

For a bunch of 2 mm long with a charge 2.33 nC the energy spread due to CSR after 5 turns is contained within ±0.5% of the nominal ring energy



Resistive Wall Impedance and Wake

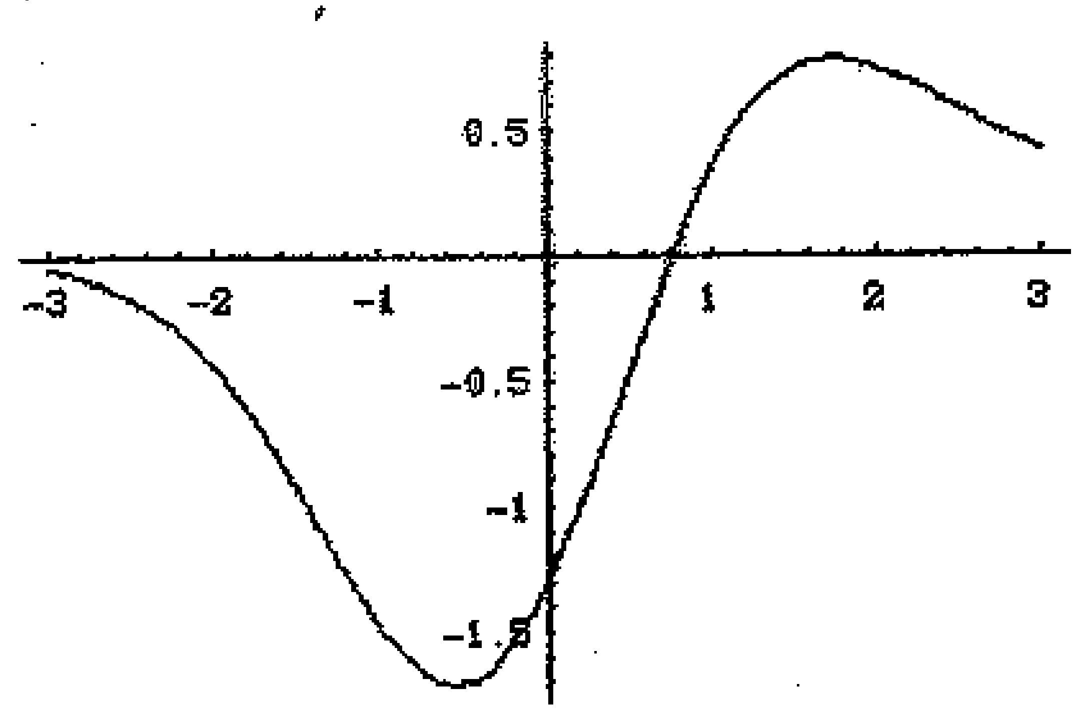
$$\frac{Z}{L}(\omega)=(1+j)\frac{\omega}{c}\frac{Z_0\delta}{4\pi b}F_0\left(\frac{b}{a}\right)$$

$$\frac{dk}{dL}=\frac{c}{4\pi^2 b\sigma_z^{3/2}}\sqrt{\frac{Z_0\rho}{2}}\Gamma\left(\frac{3}{4}\right)F_0\left(\frac{b}{a}\right)$$

$$W(s)=\frac{Bc^{3/2}}{4\sigma_z^{3/2}}\left(\frac{|s|}{\sigma_z}\right)^{3/2}\exp\left\{-\frac{s^2}{4\sigma_z^2}\right\}\times$$
$$\left\{I_{-3/4}\left(\frac{s^2}{4\sigma_z^2}\right)-I_{1/4}\left(\frac{s^2}{4\sigma_z^2}\right)\mp I_{-1/4}\left(\frac{s^2}{4\sigma_z^2}\right)\pm I_{3/4}\left(\frac{s^2}{4\sigma_z^2}\right)\right\}$$

where

$$B=\frac{1}{4\pi b}\sqrt{\frac{2\rho Z_0}{c}}$$

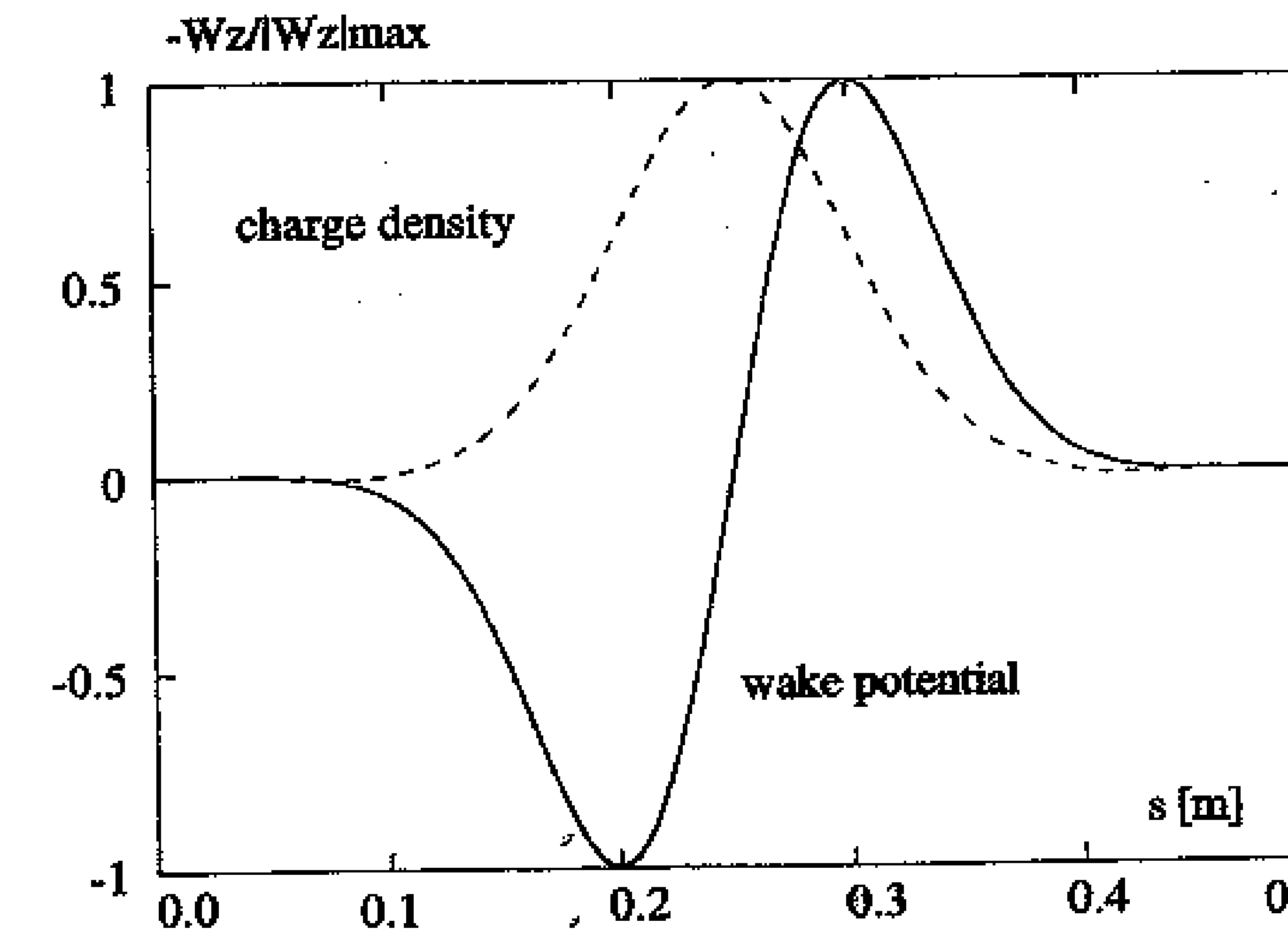


For CTF3 Combiner Ring after 5 turns:

E lost = 13.35 keV
ΔE = 35.25 keV

Low Frequency Impedance Limit

Assume purely inductive machine impedance jωL. Then, the wake potential and the maximum energy spread ΔE are:

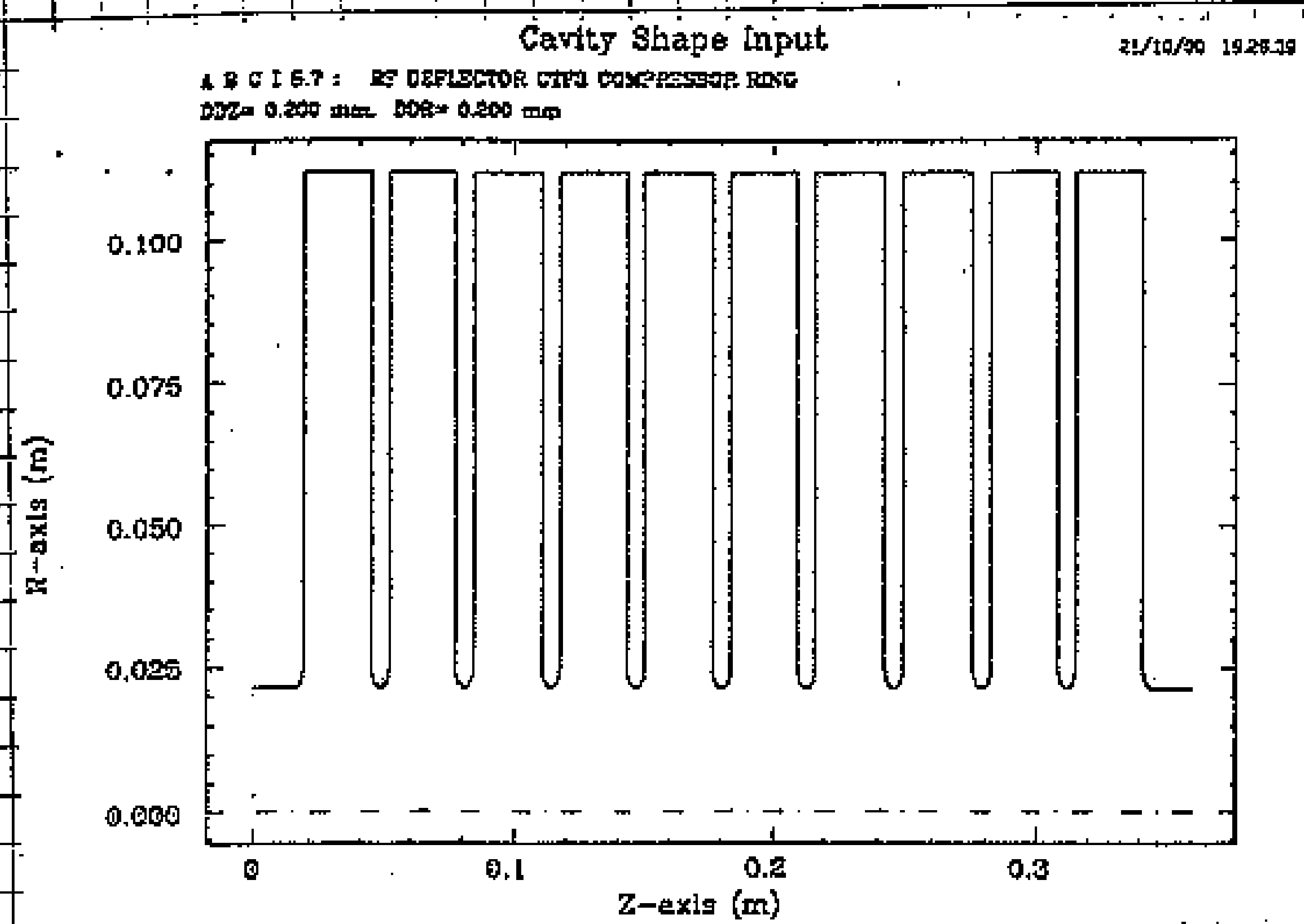


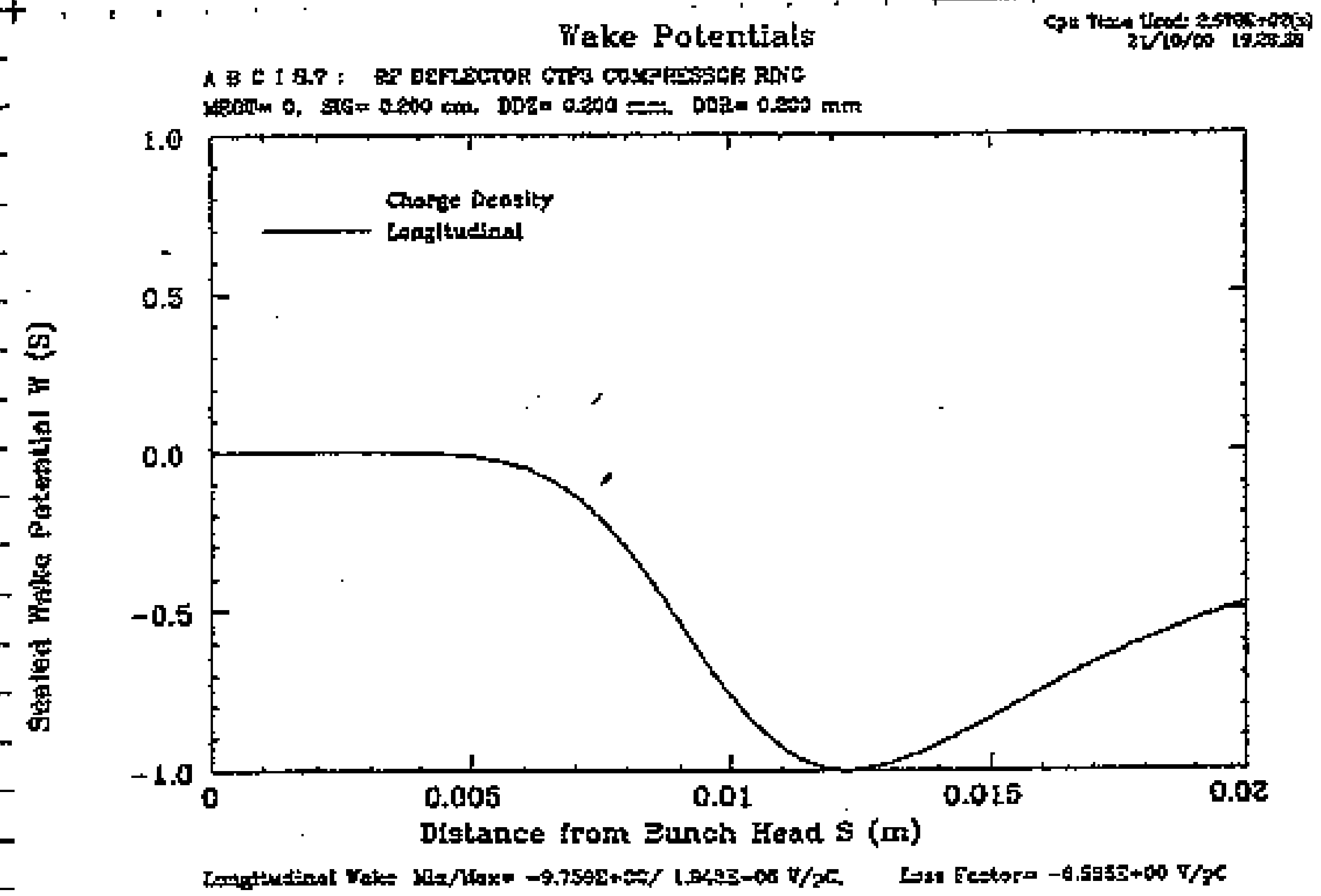
$$\Delta E=Q\left(W_z^{\max}-W_z^{\min}\right)=\frac{2QLc^2}{\sqrt{2\pi}e\sigma^2}=\frac{2Qc^2|Z/n|}{\omega_0\sqrt{2\pi}e\sigma^2}$$

For the bunch with rms length σ = 2 mm and the charge Q = 2.33 nC and assuming that the energy spread is equal to 1% the low frequency impedance limit is:

$$\left|\frac{Z}{n}\right|\cong 0.32\Omega$$

CTF3 RF deflector



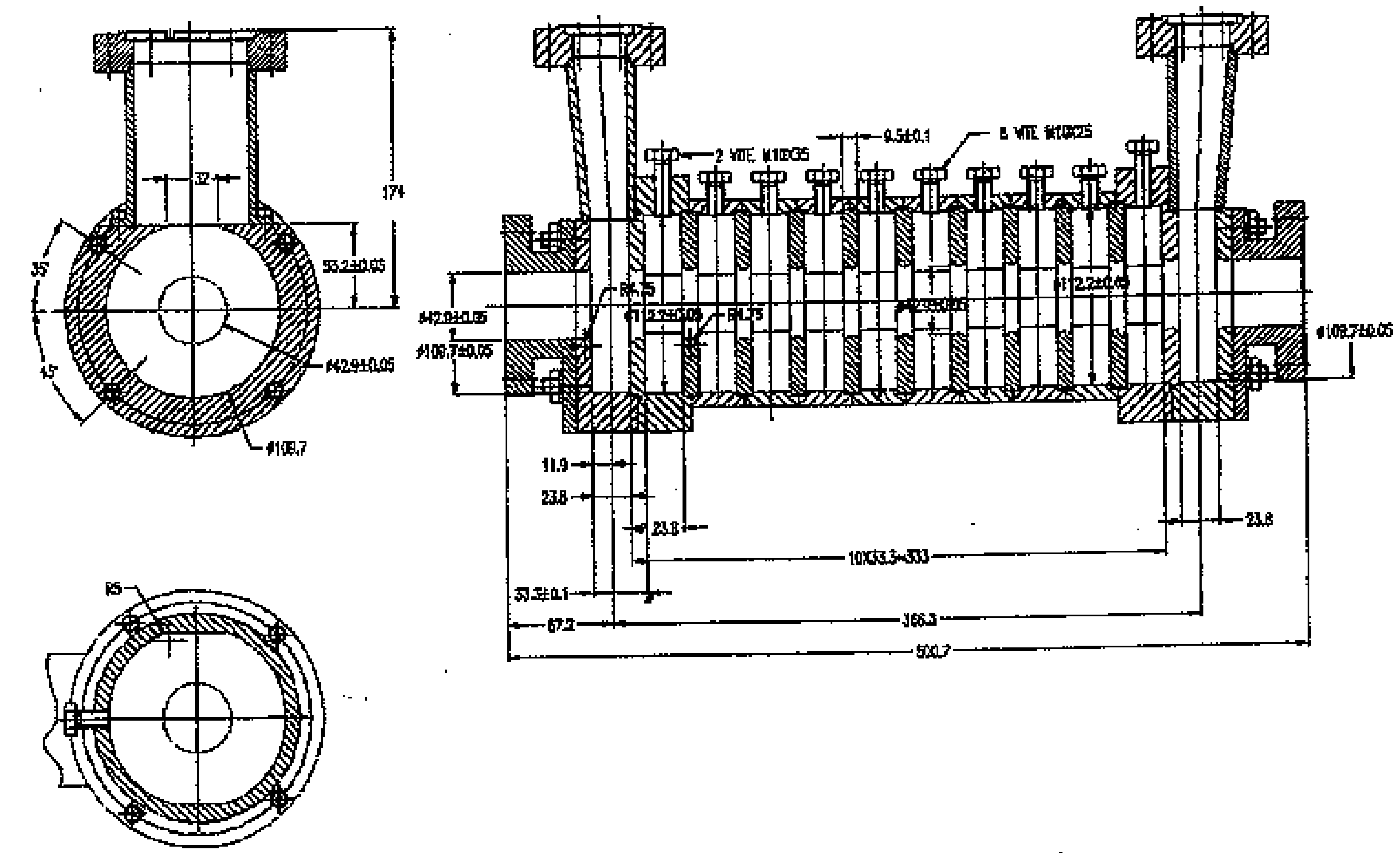


σ_z, MM	k_e, $\frac{V}{C}$	$\lvert W_{MAX} \rvert$, $\frac{V}{C}$
0.5	$1.866 \cdot 10^{13}$	$1.567 \cdot 10^{13}$
1	$8.532 \cdot 10^{12}$	$1.170 \cdot 10^{13}$
2	$6.585 \cdot 10^{12}$	$8.759 \cdot 10^{12}$
3	$5.665 \cdot 10^{12}$	$8.449 \cdot 10^{12}$

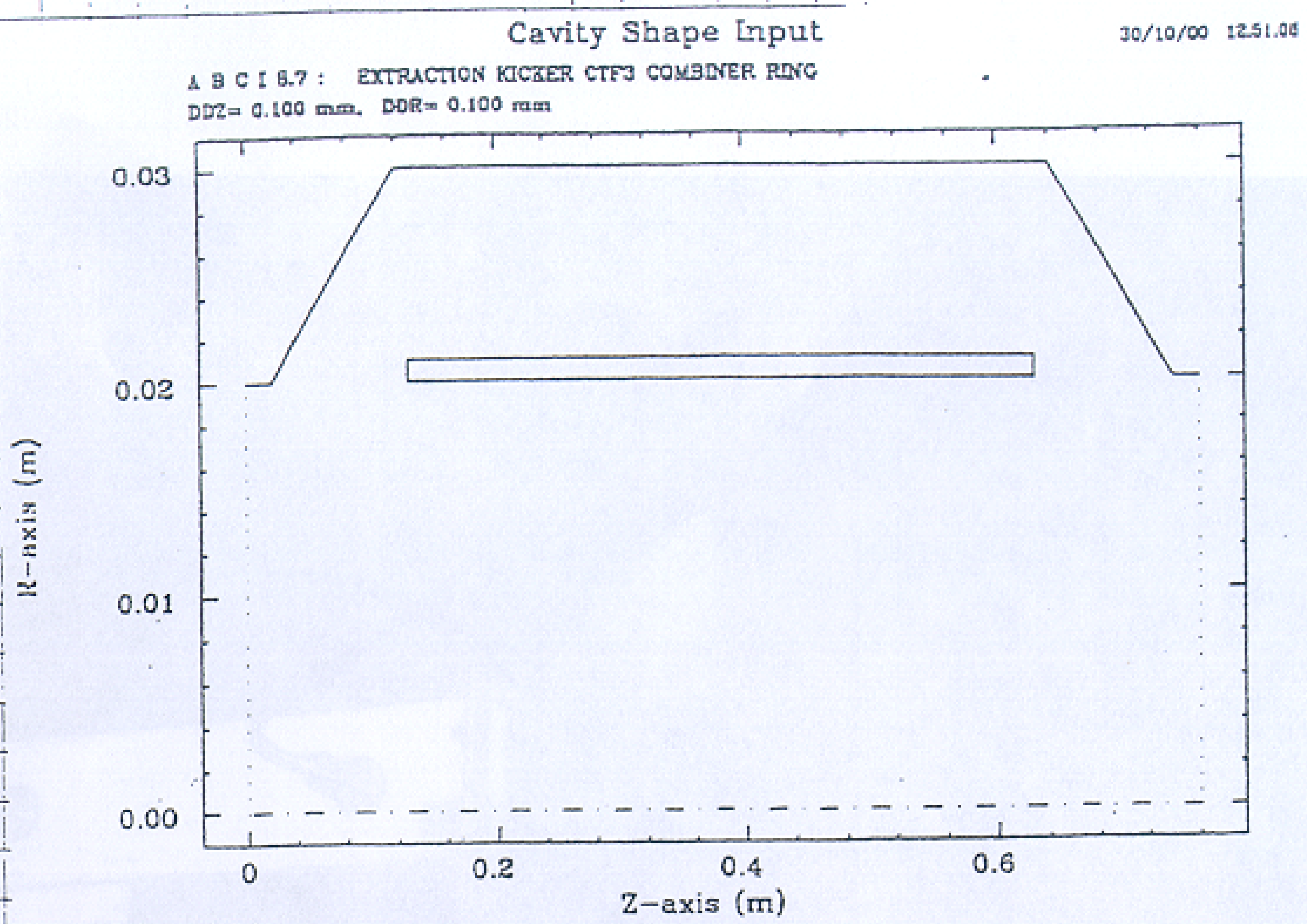
at $\sigma_z = 2$ MM for 2 deflectors after Stage and 2.75 nC:

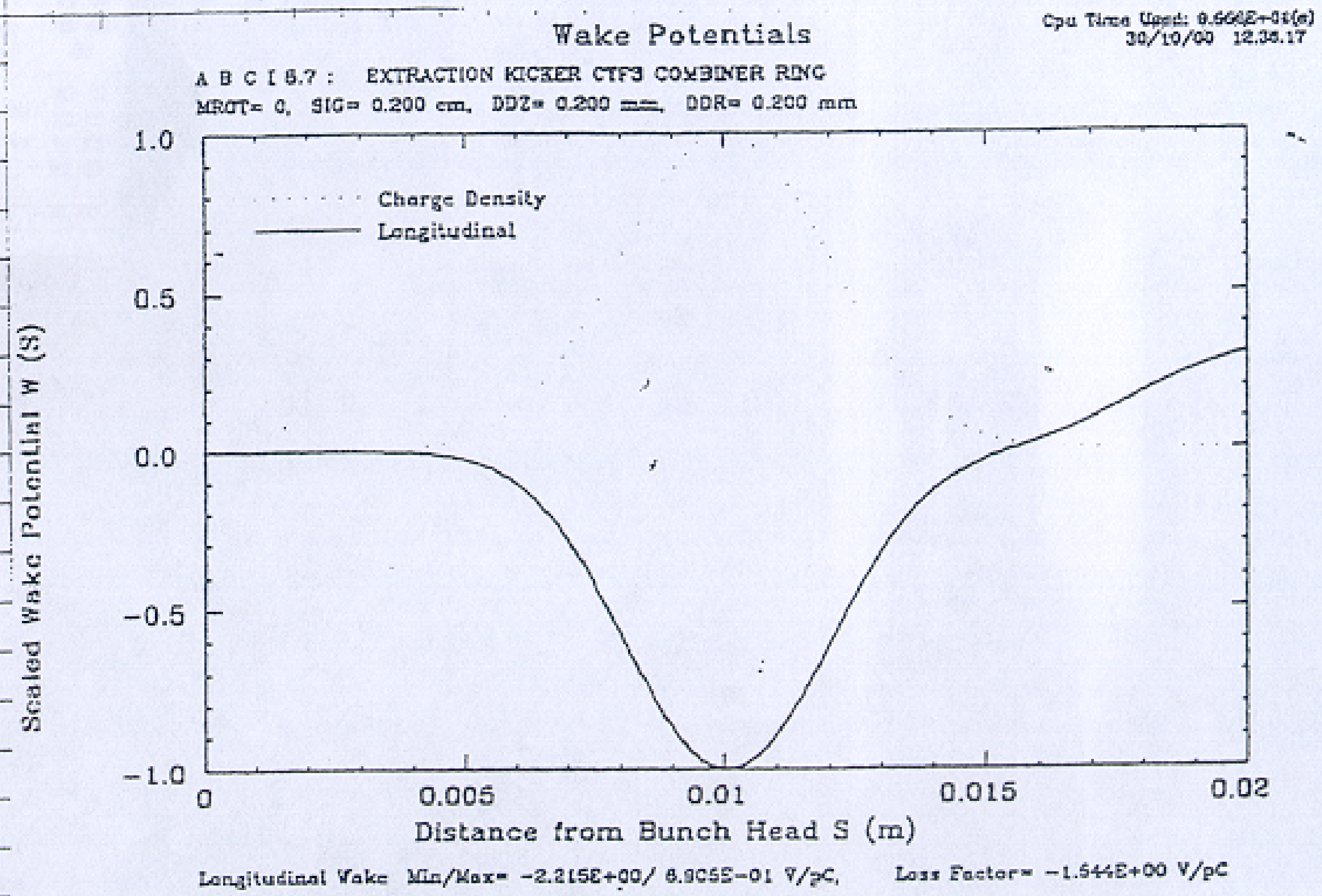
$e \Delta V = 268$ keV (spread)

$eV = 181$ keV



CTF3 Extraction Kicker



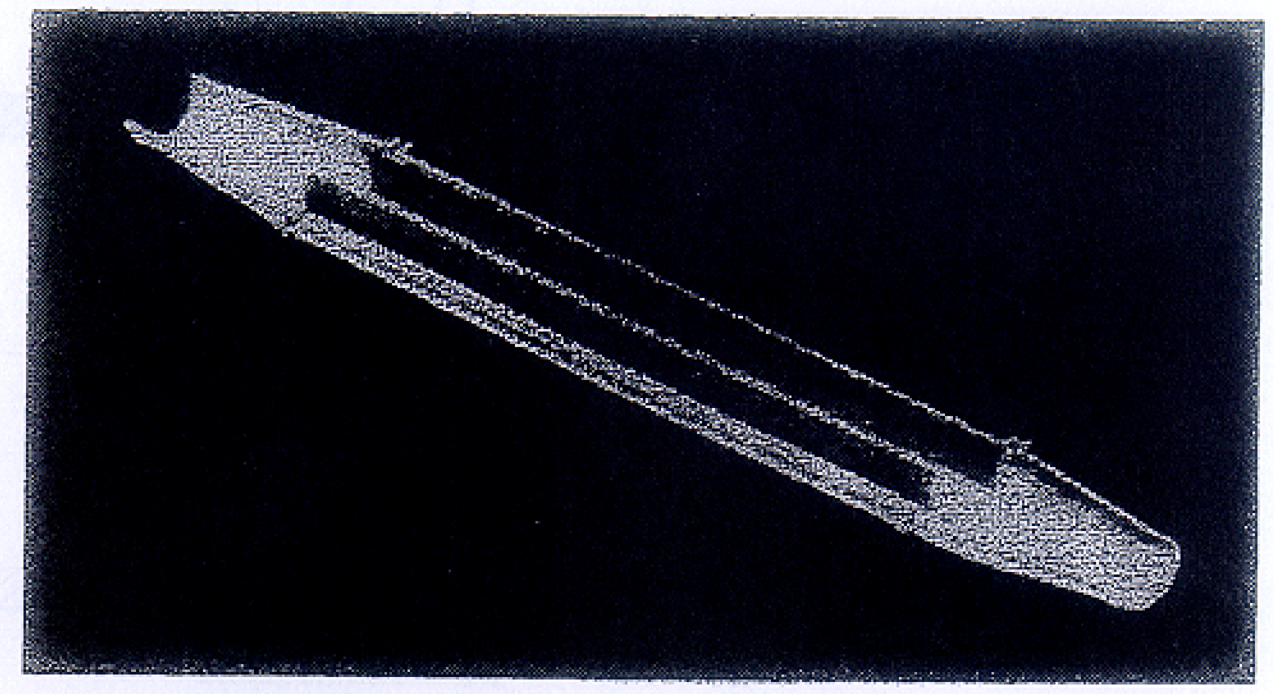


σ_z, MM	K_e, $\frac{V}{C}$	W_{MAX}	W_{min}, $\frac{V}{C}$
0.5	$5.914 \cdot 10^{12}$	$5.667 \cdot 10^{11}$	$-9.667 \cdot 10^{12}$
1	$3.008 \cdot 10^{12}$	$9.420 \cdot 10^{10}$	$-4.205 \cdot 10^{12}$
2	$1.544 \cdot 10^{12}$	$6.905 \cdot 10^{11}$	$-2.215 \cdot 10^{12}$
3	$9.897 \cdot 10^{11}$	$7.935 \cdot 10^{11}$	$-1.429 \cdot 10^{12}$

After 5 turns with $Q = 2.33\,nC$:

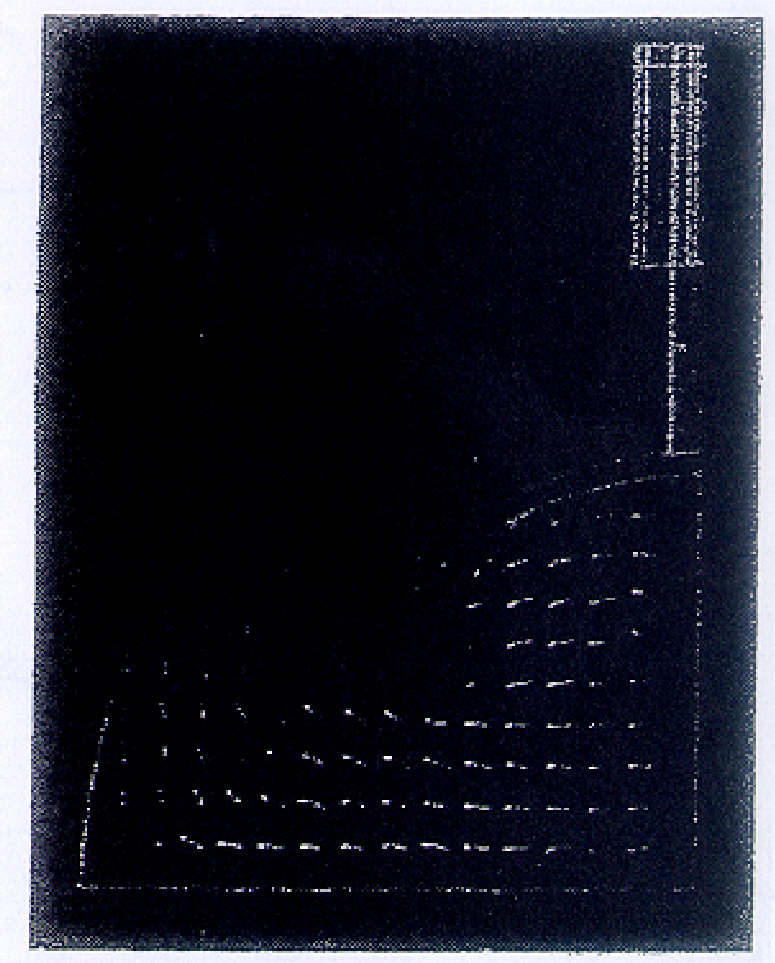
$E_{lost} = 18\ keV$, $\Delta E_{MAX} = 34\ keV$ } for $\sigma_z = 2$ MM

CTF3 Extraction Kicker

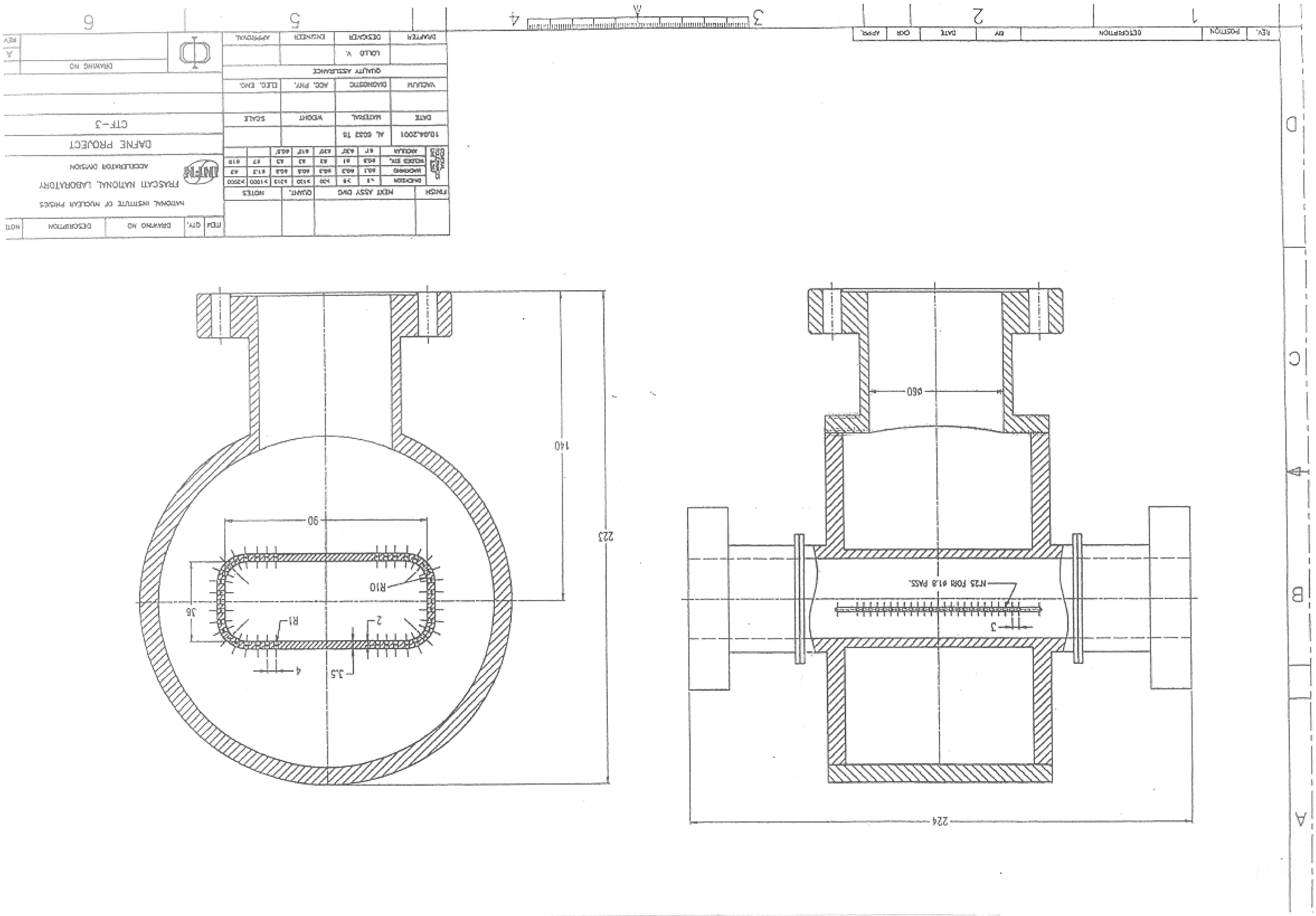


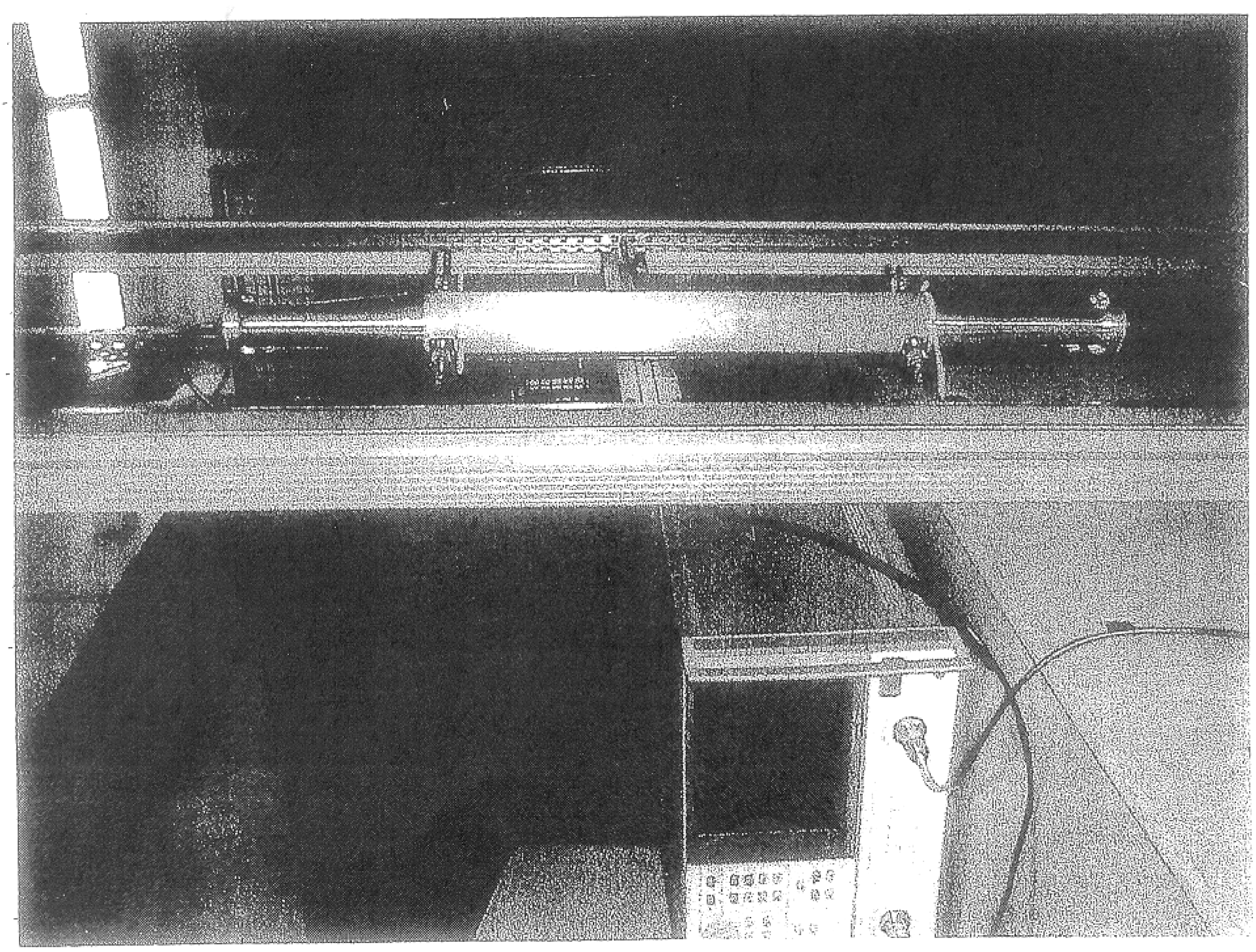
Transverse E–field

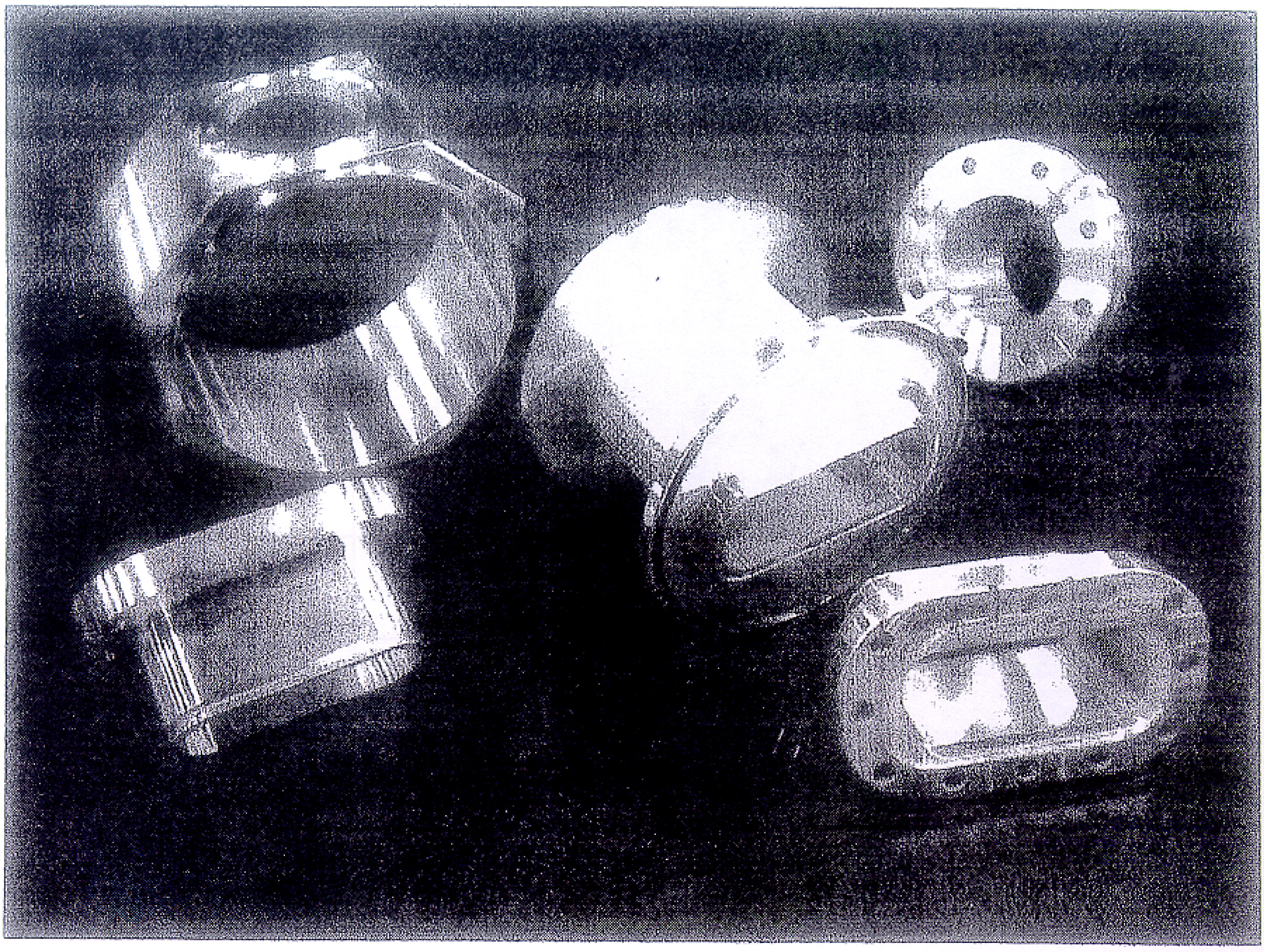
Transverse H–field

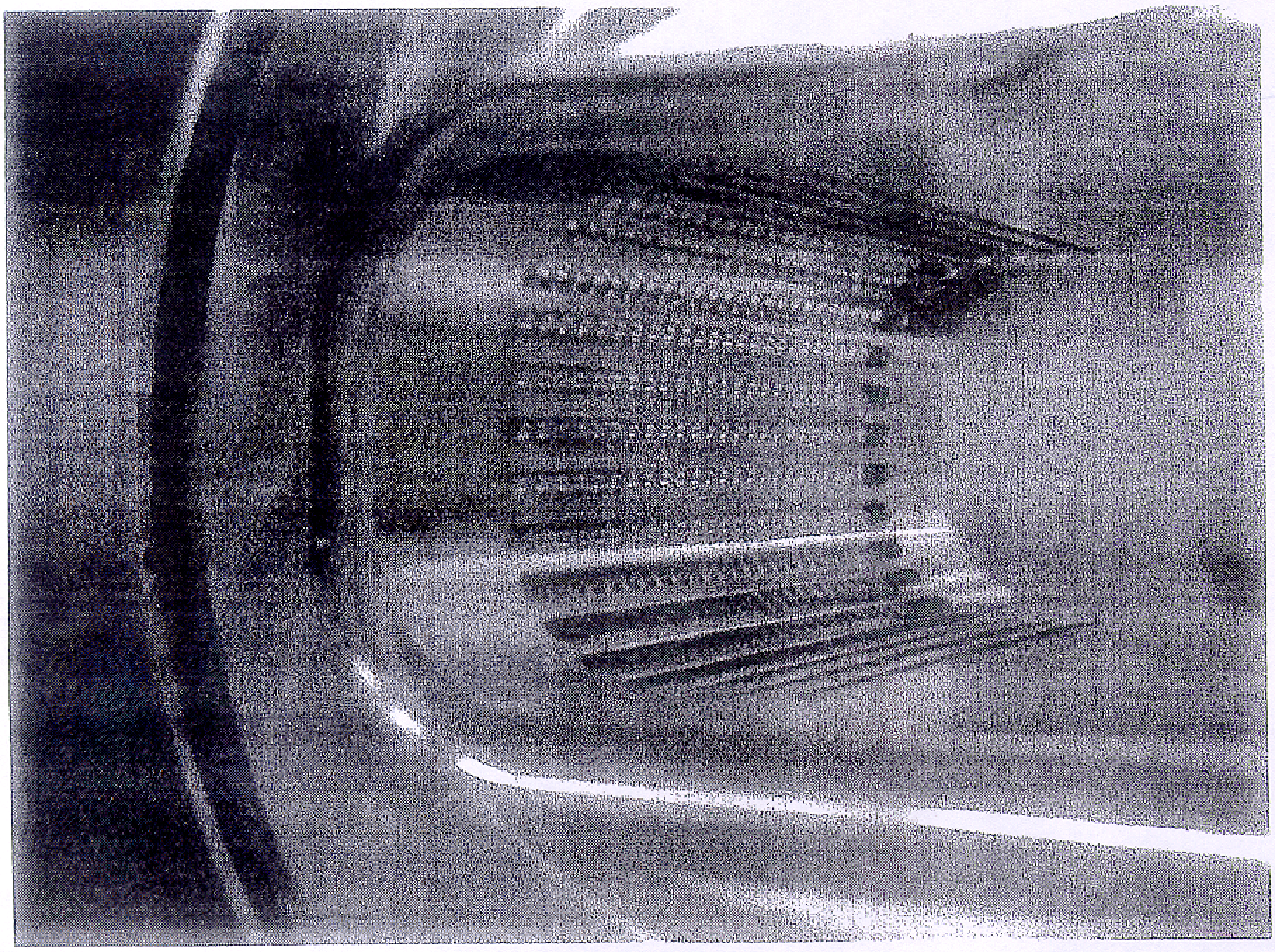


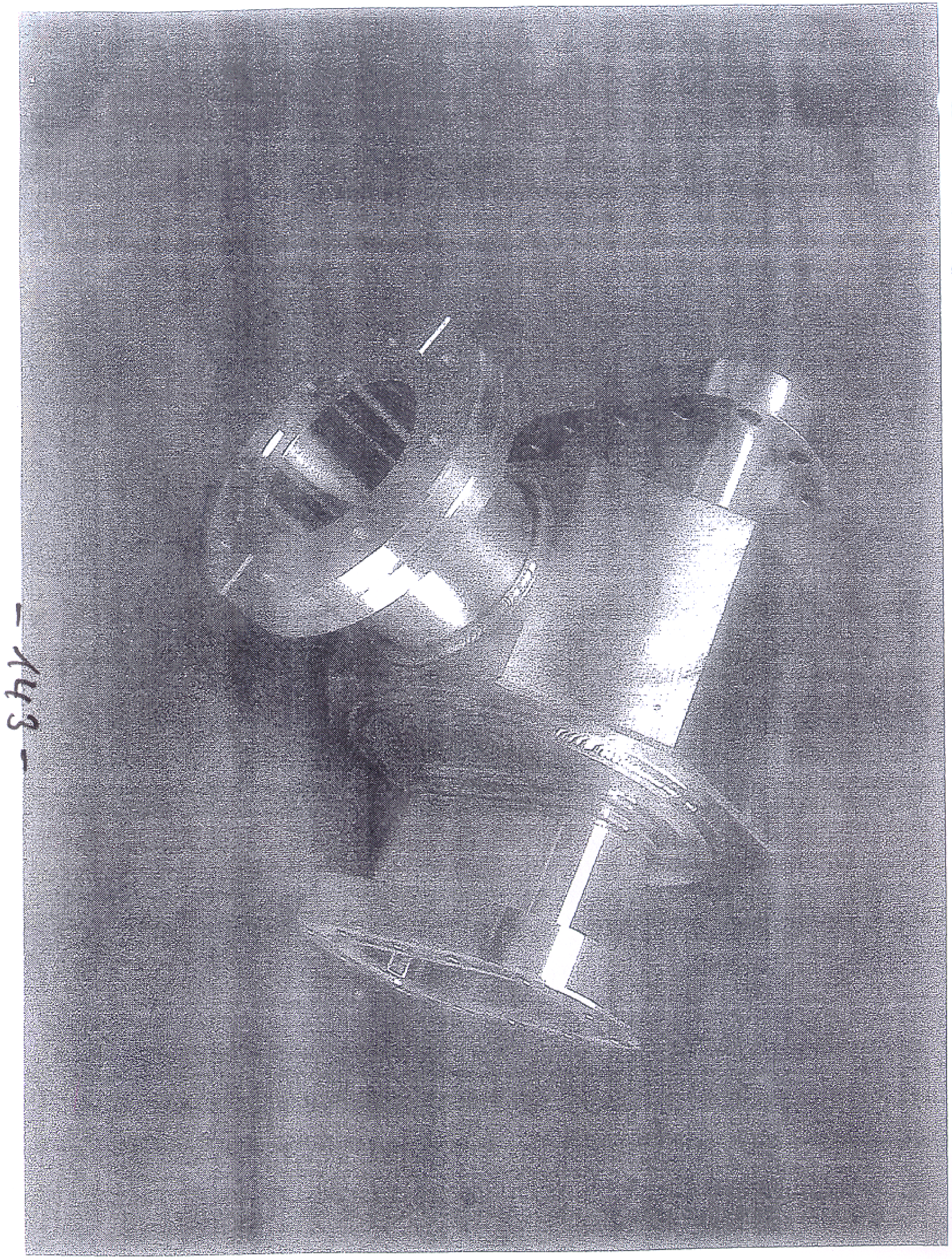
Shunt impedance of the deflecting mode: higher than 60 KΩ.


DAFNE PROJECT
CTF-3
FRASCATI NATIONAL LABORATORY
ACCELERATOR DIVISION
NATIONAL INSTITUTE OF NUCLEAR PHYSICS
10.04.2001
AL 6082 T6
LOLLO V.



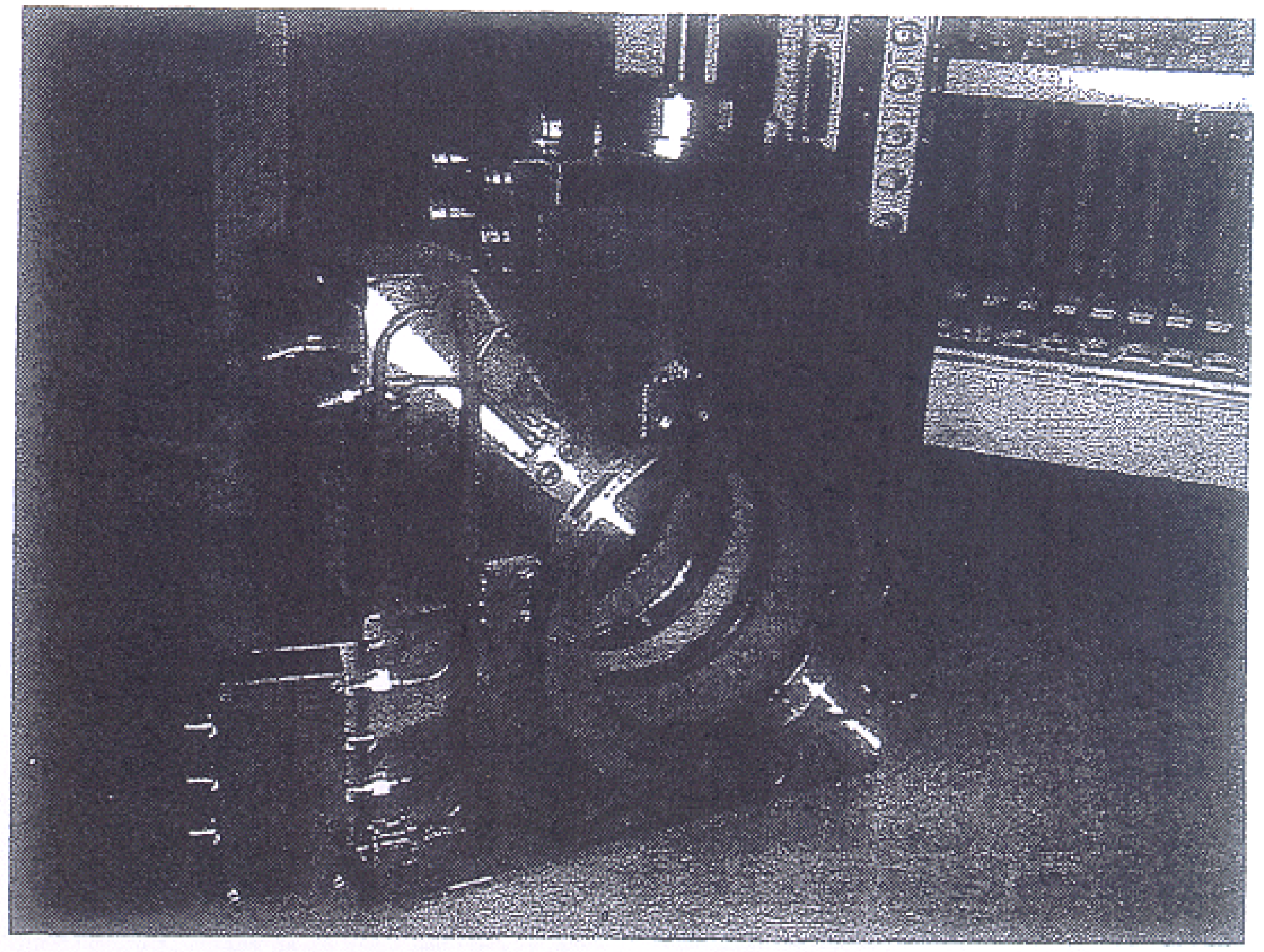


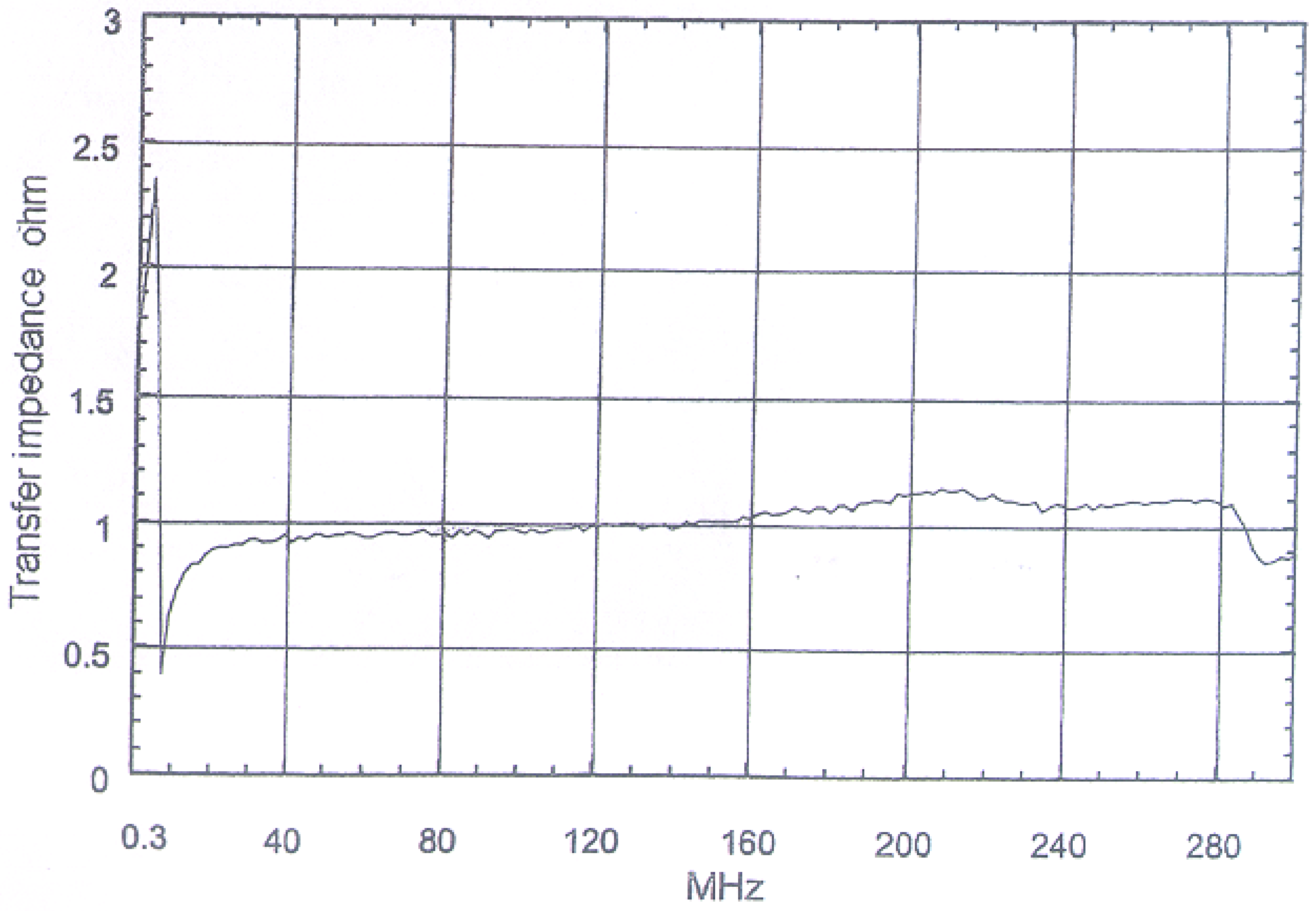


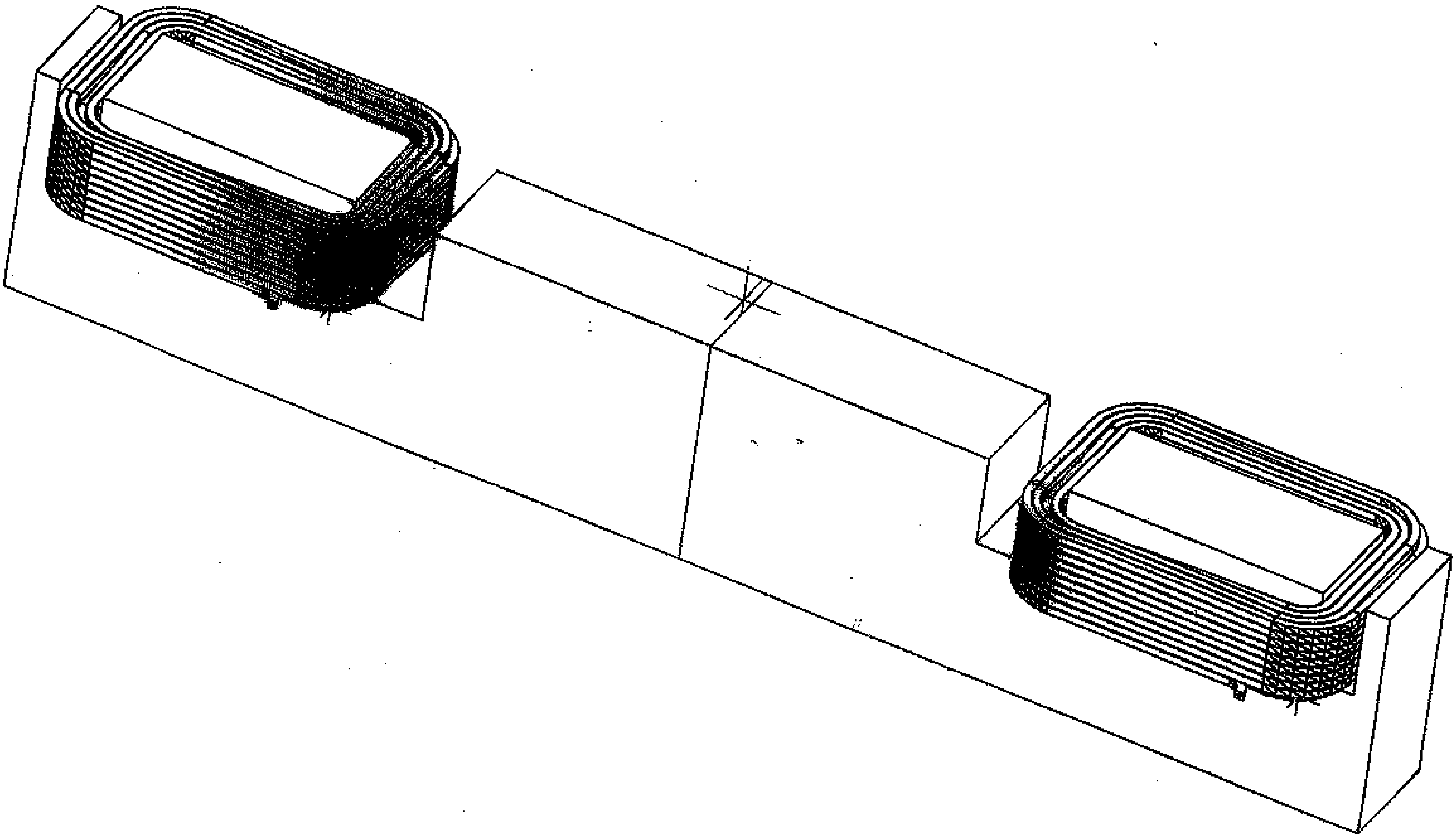


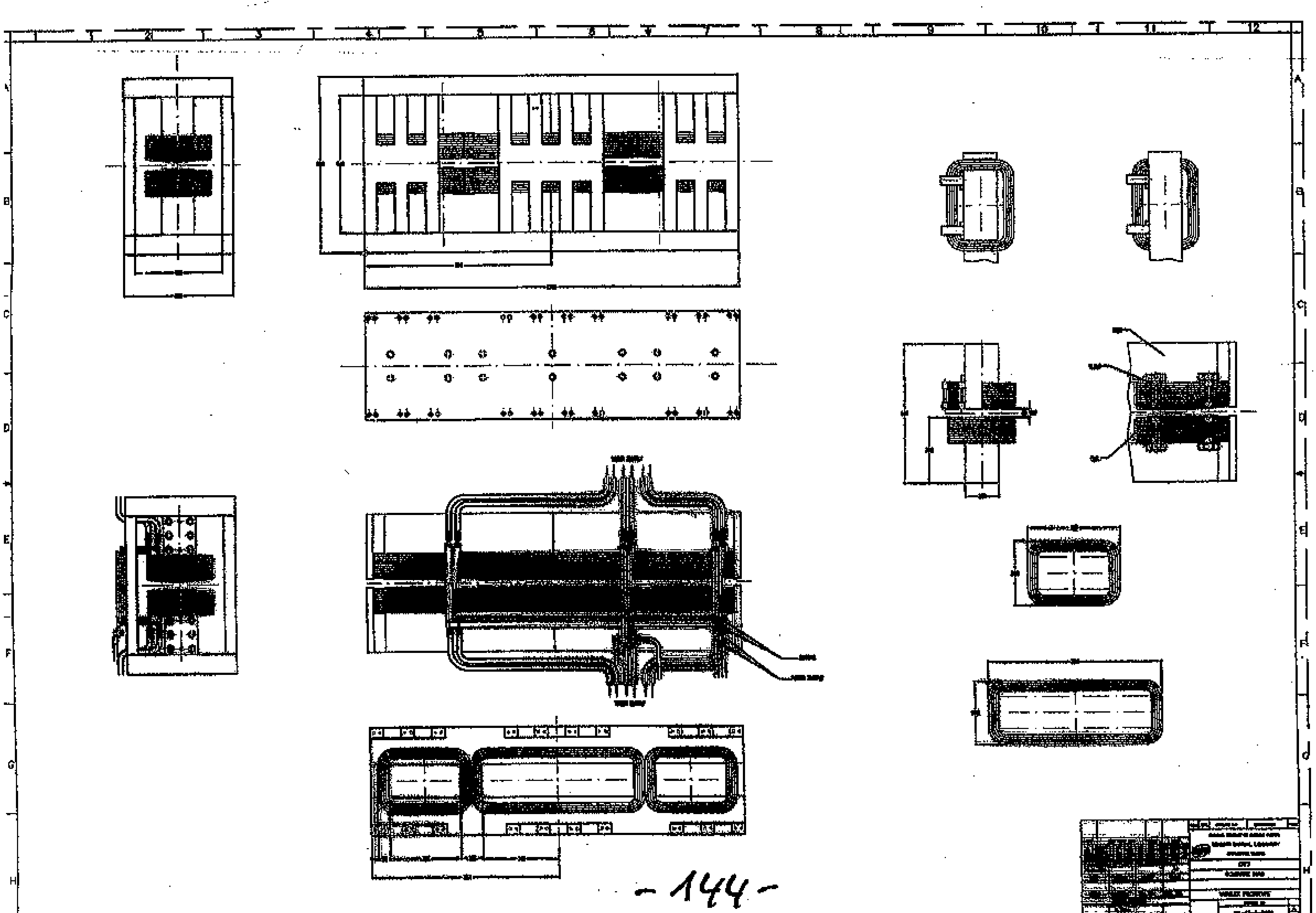
UMA Beam Position Monitor

Transfer Impedance Measurements









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CTF3 RF DEFLECTORS
(D. Alesini)

SUMMARY

INTRODUCTION

- CTF3 RF Deflectors Parameters
- Choice of the Lengeler-like structures for the Combiner Ring:

MULTIBUNCH DYNAMICS

- Single passage out-of-phase wake and multibunch regime
- Multi-passage tracking

  1) ***Tracking code scheme***
  2) ***Results***
  3) ***Conclusions***
  4) ***Further analysis***

DEFLECTOR DESIGN

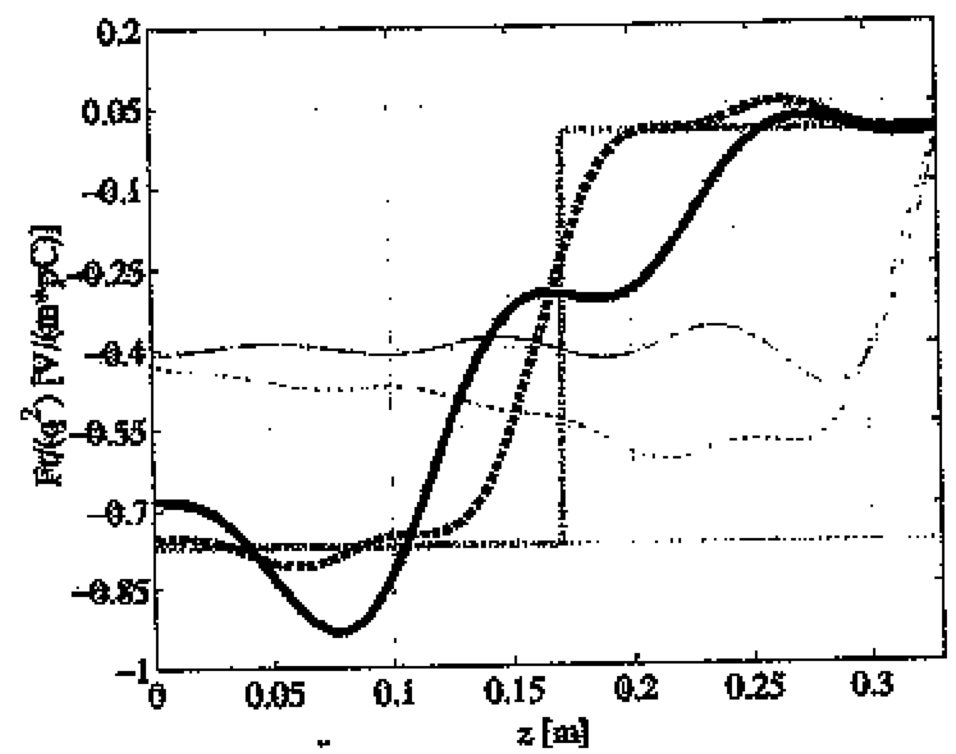
- 2D cell simulations
- HFSS 3D Cell simulations
- HFSS 3D simulations of the RF coupler
- HFSS 3D simulations of the single cell tuning
- Simulations of a SW cavity for the delay line

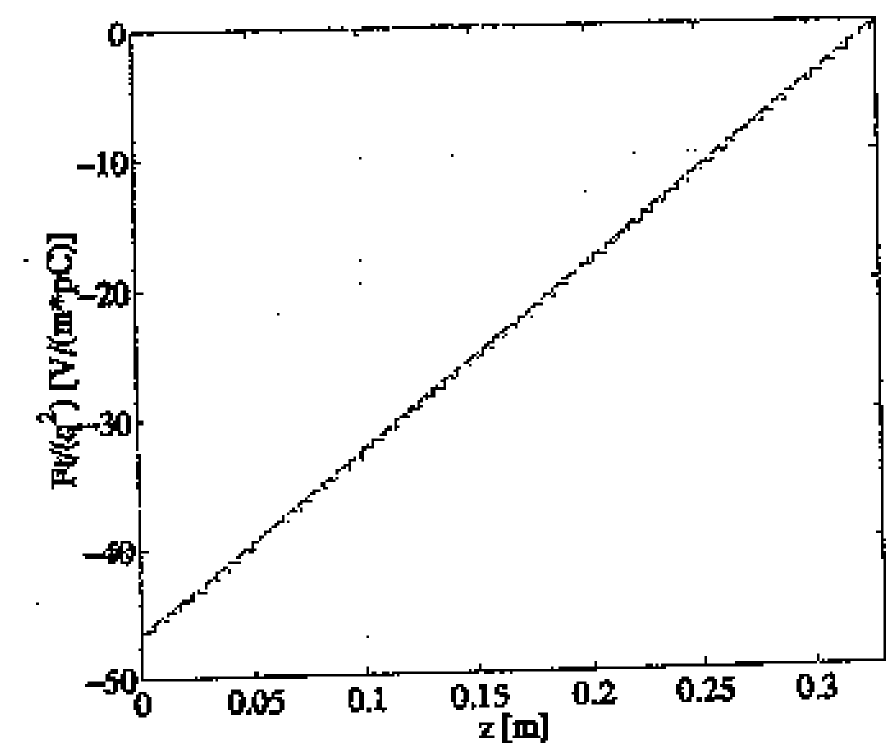
DEVICES UNDER CONSTRUCTION

- Alluminium prototype
- Vacuum-tight copper device

MULTIBUNCH DYNAMICS

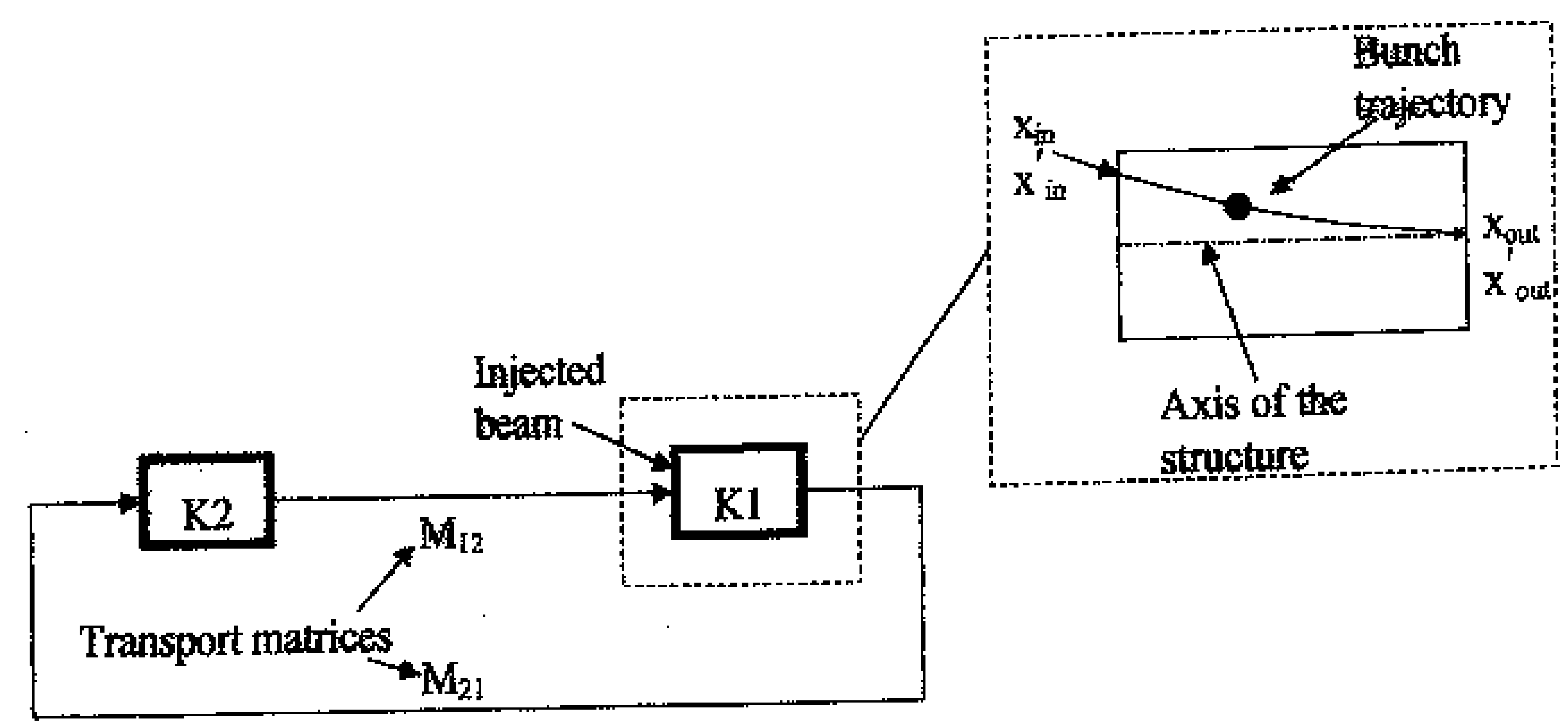
- Single passage out-of-phase wake and multibunch regime





- Multi-passage tracking

1) ***Tracking code scheme*** → the bunches are modeled as macroparticles
→ rigid profile model of the wake

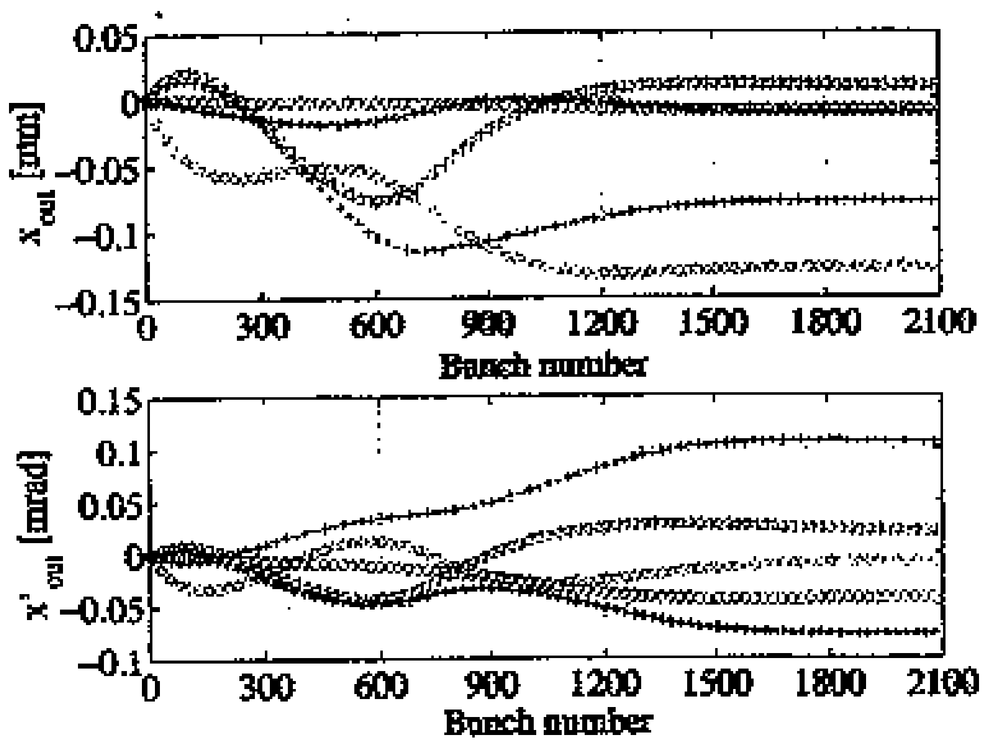


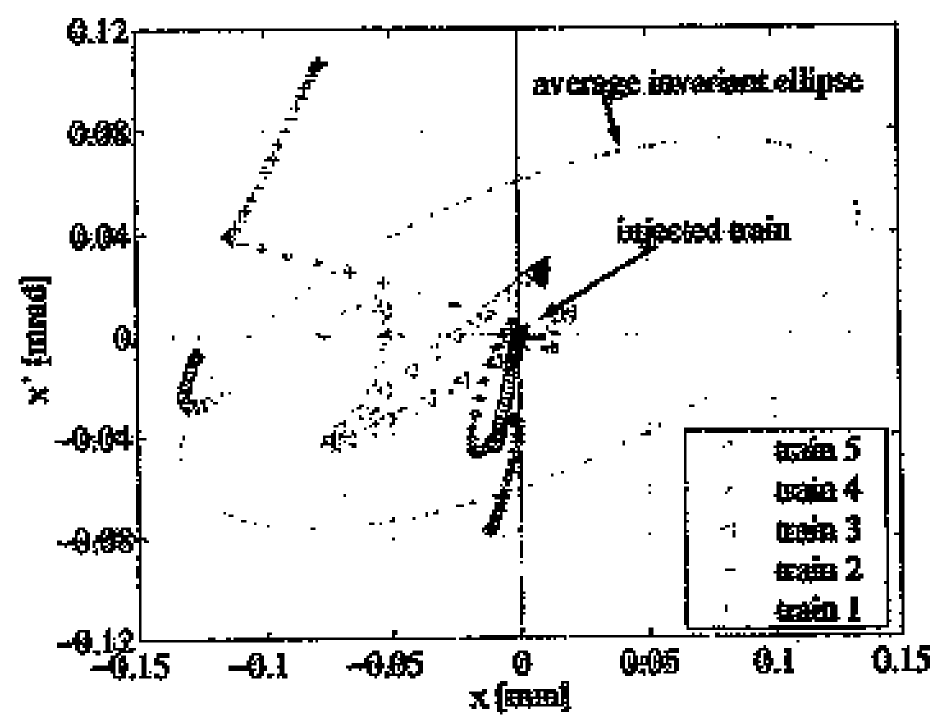
2) ***Results***

a) **Perfect injection** of the 5 trains ($x_{in}=0$, $x'_{in}=0$):

→ $I_{o\text{-}av}=8\cdot10^{-3}$ mm mrad $I_{o\text{-}max}=4.2\cdot10^{-2}$ mm mrad

→ bunch design emittance $\varepsilon\approx0.5$ mm mrad @ 180 MeV

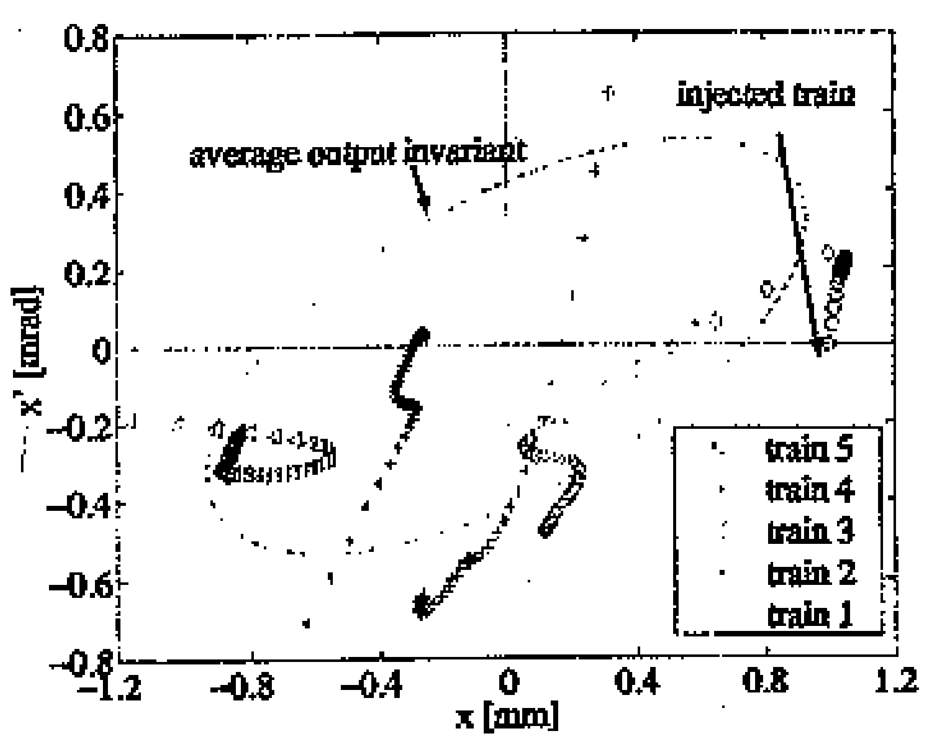


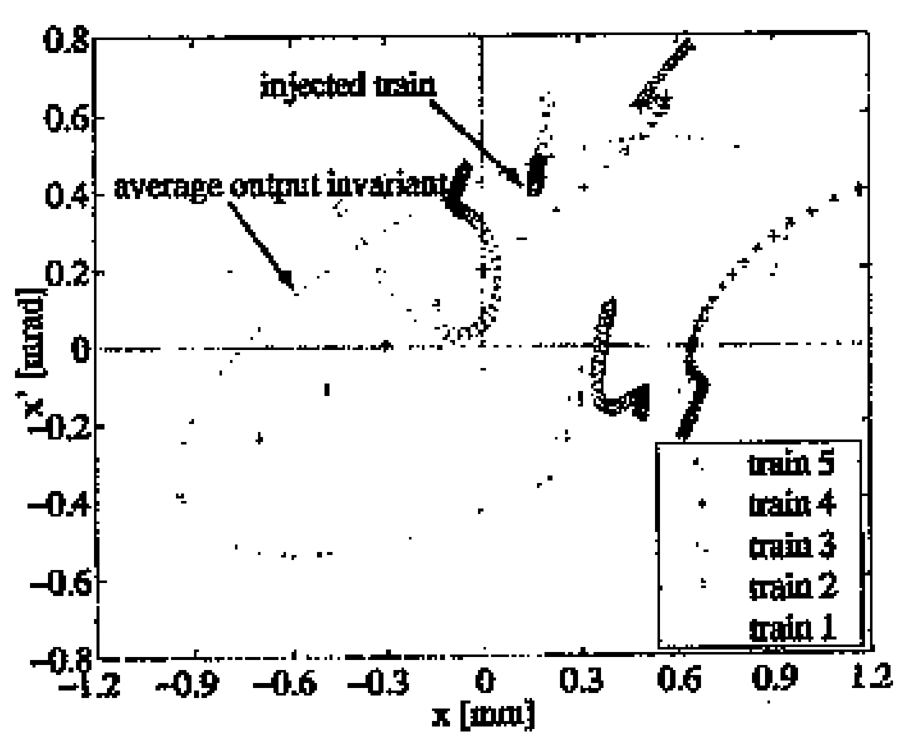


b) **Injection errors:**

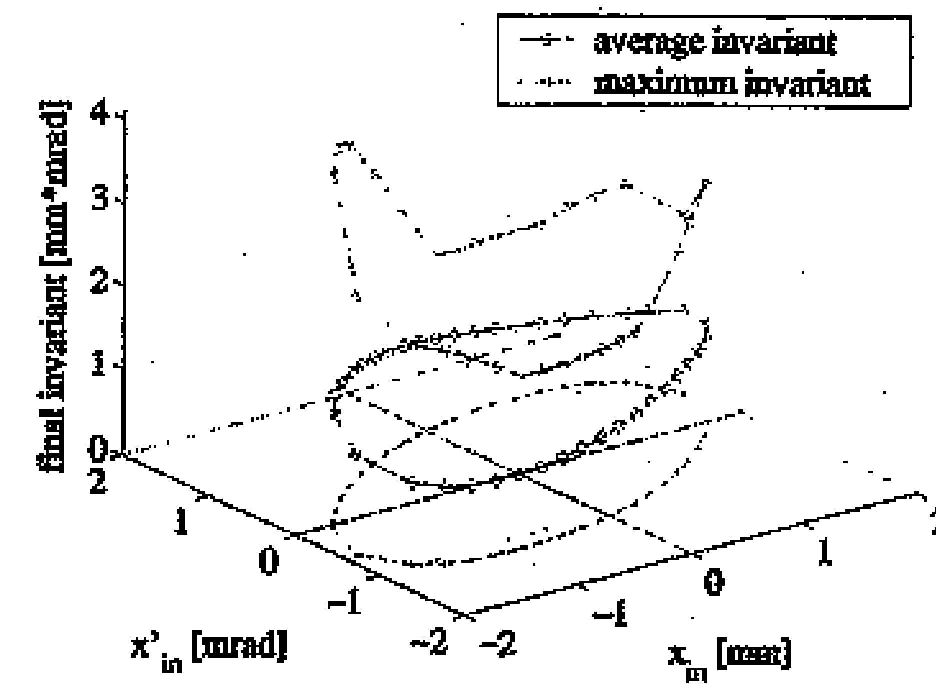
Same Invariant I_{in} → $x_{in}=1$mm, $x'_{in}=0$ → $I_{o\text{-}av}=0.392$ mm mrad → $I_{o\text{-}max}=0.814$ mm mrad

Same Invariant I_{in} → $x_{in}=0$, $x'_{in}=0.633$ mrad → $I_{o\text{-}av}=0.405$ mm mrad → $I_{o\text{-}max}=0.850$ mm mrad

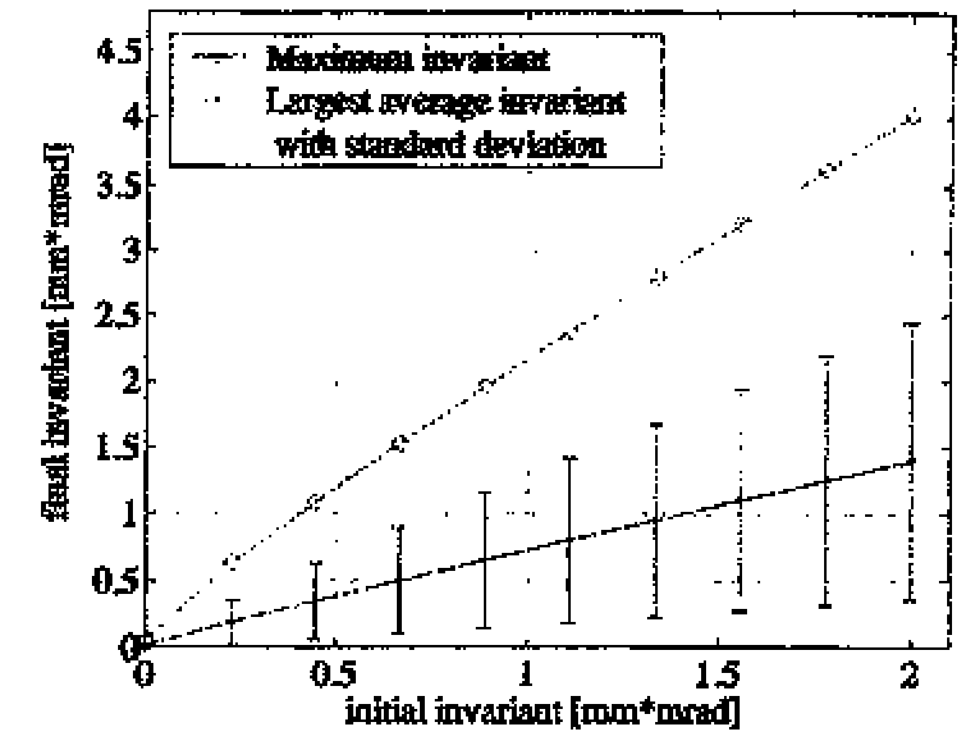




c) **Injection errors scan**

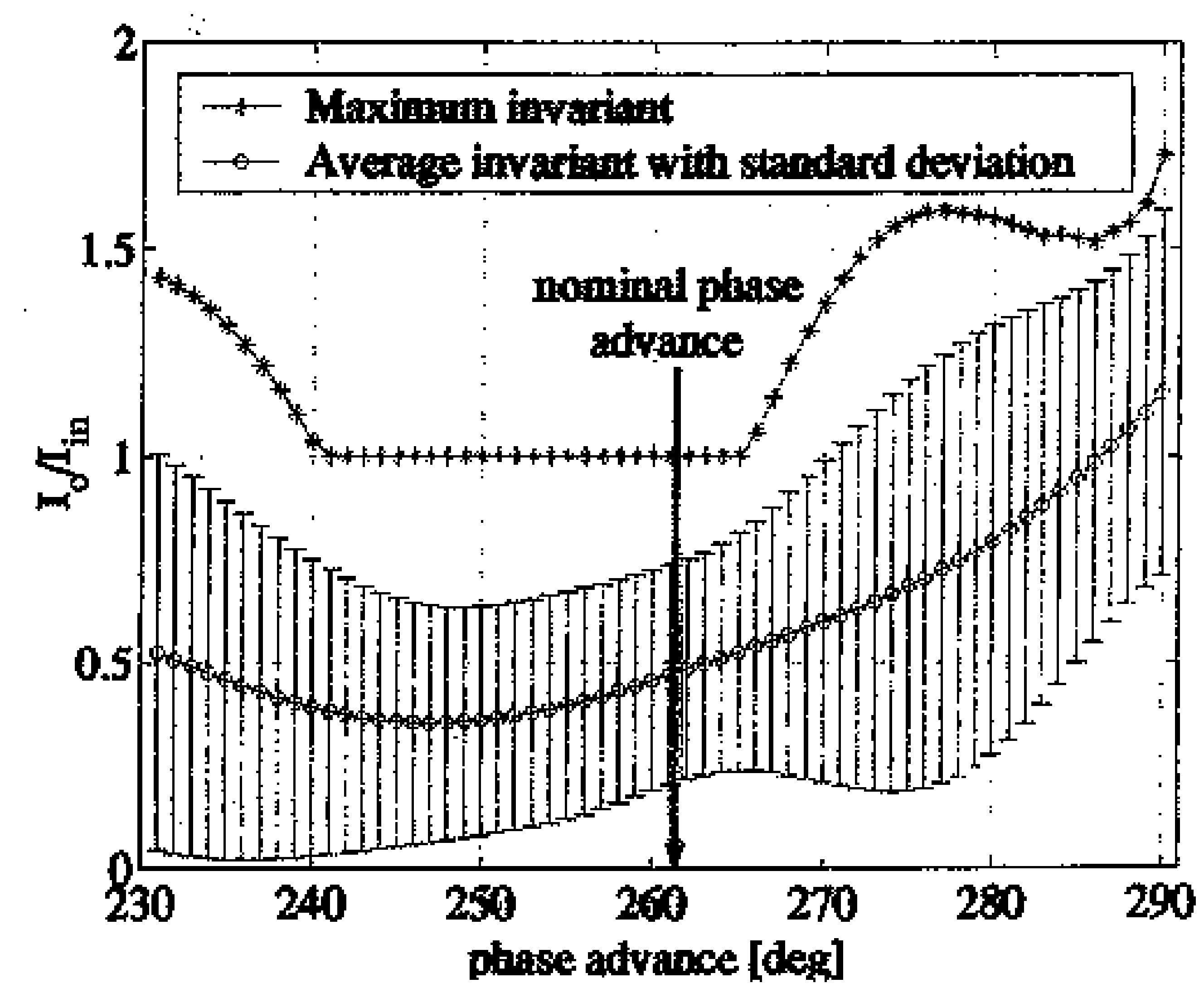


$I_{o\text{-}max}$ and $I_{o\text{-}av}$ for a given I_{in} and various betatron phases



I_{po_max} and $I_{po\text{-}av}$ as a function of the injection Courant-Snyder Invariant

d) **Tune dependence** of the Courant-Snyder invariant magnification I_o/I_{in} ($x_{in}=1$mm, $x'_{in}=0$)



3) *Conclusions*

→ The spread of the macroparticle Courant-Snyder invariant values caused by the **systematic effect** (x_{in}=0, x'_{in}=0) is a **small fraction** of the CTF3 bunch design emittance;

→ The $\mathbf{I_{o\text{-}max}}$ **and the** $\mathbf{I_{o\text{-}av}}$ of the final distribution are **not constant** for a given I_{in} but **depend on the betatron phase** of the bunch **train at the injection** and on the **horizontal tune**;

→ For our **nominal phase advance** the scenario is good: the $I_{po\text{-}av}<I_{in}$ ("cooling"), $I_{po\text{-}max}/I_{in}\leq 2.6$;

→ **Modifications of the phase advance** of the order of ±10° ($\Delta Q_x \approx \pm 0.03$) does not significantly change the scenario;

→ Anyway, some tune values may give magnification factors larger than 10;

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4) ***Further analysis***

→ Effects of the **other modes of the** structure on the beam **dynamics**;

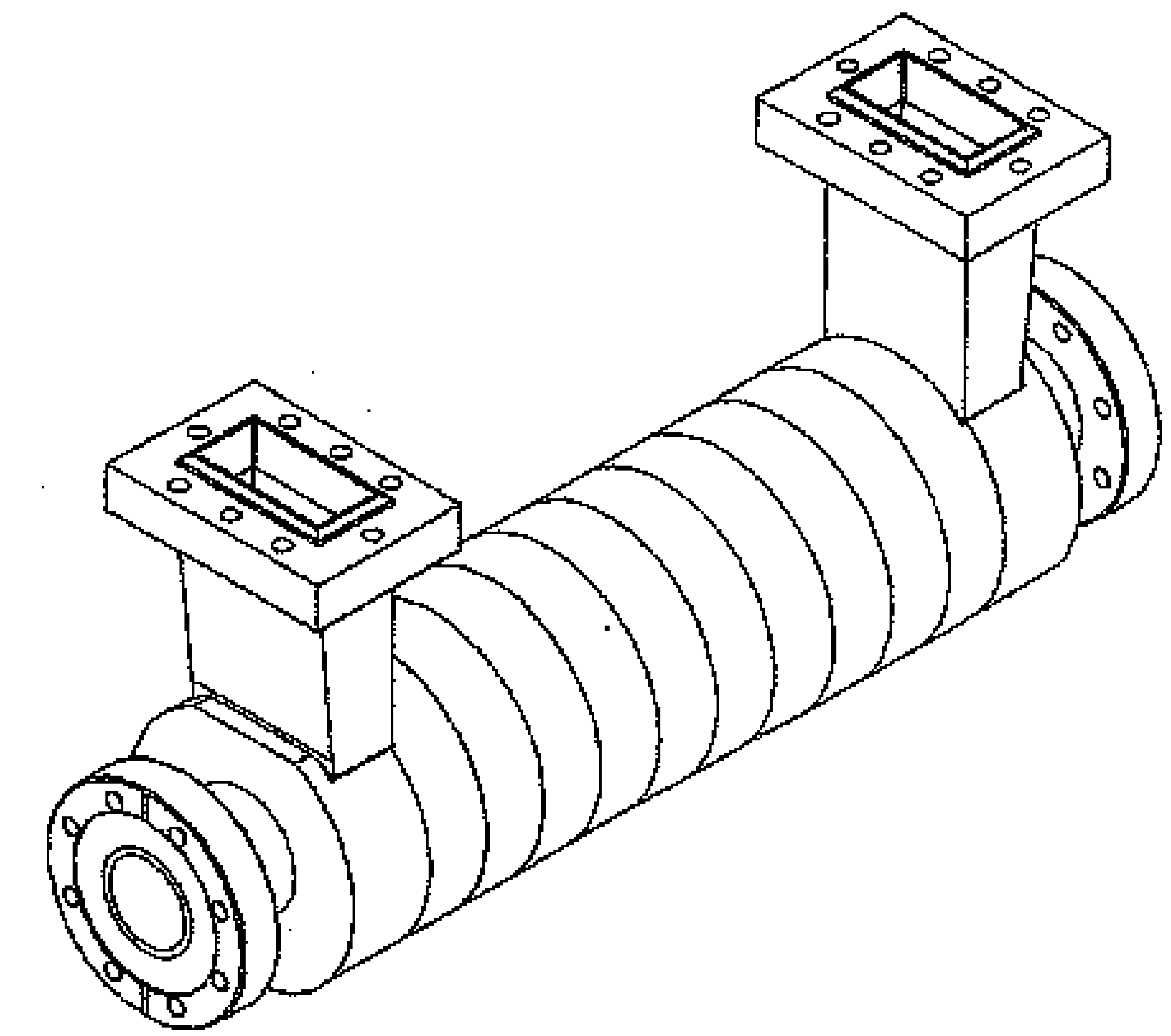
→ Beam loading effects due to **off-time injection** and finite **bunch length**;

→ Effects of **different injection conditions** for "odd" and "even" bunches in each incoming train due to the "memory" of the different paths in the delay loop;

→ ....

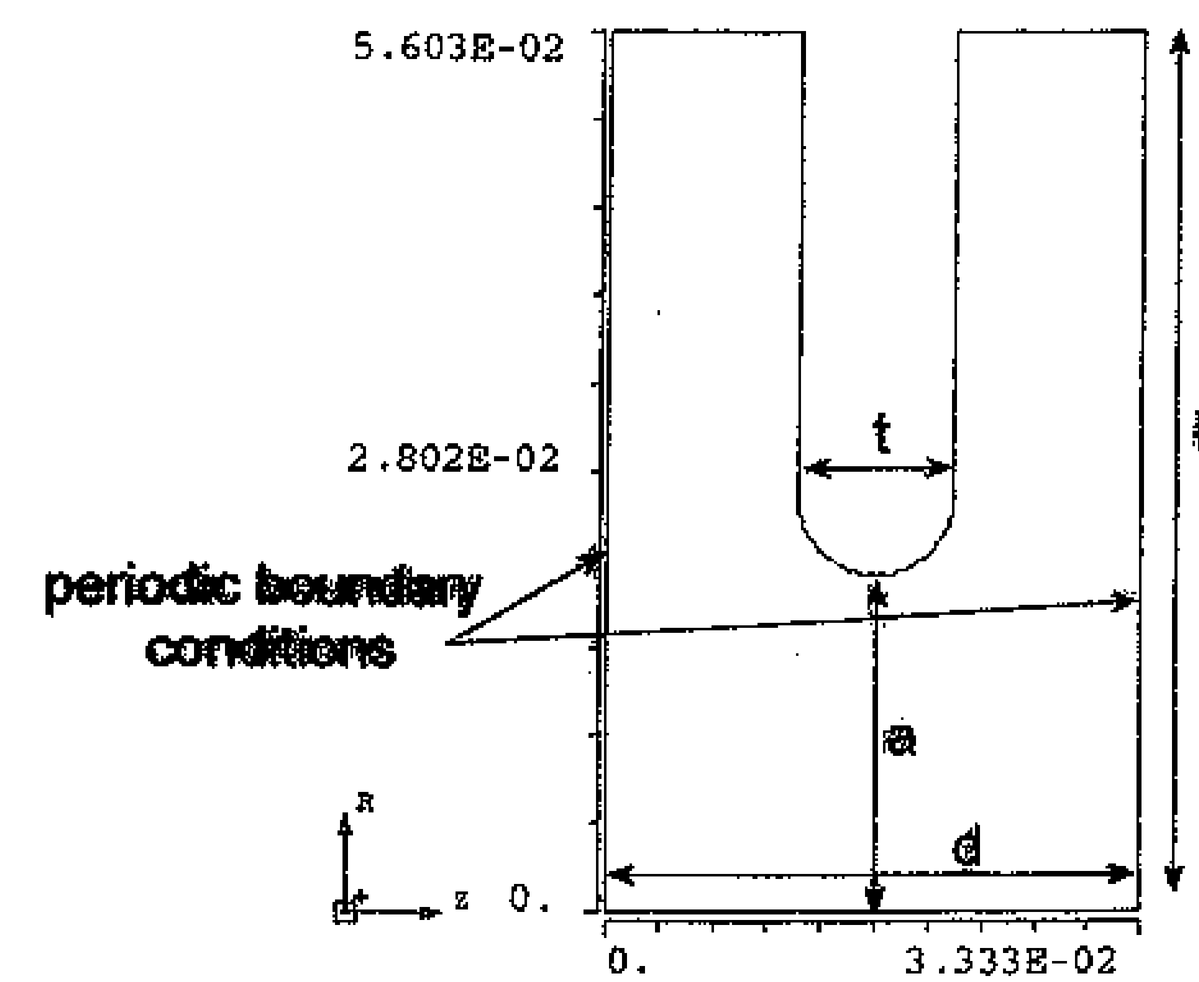
DEFLECTOR DESIGN

- Sketch of the 10 cell deflector



- 2D cell simulations

→ **MAFIA simulated structure**



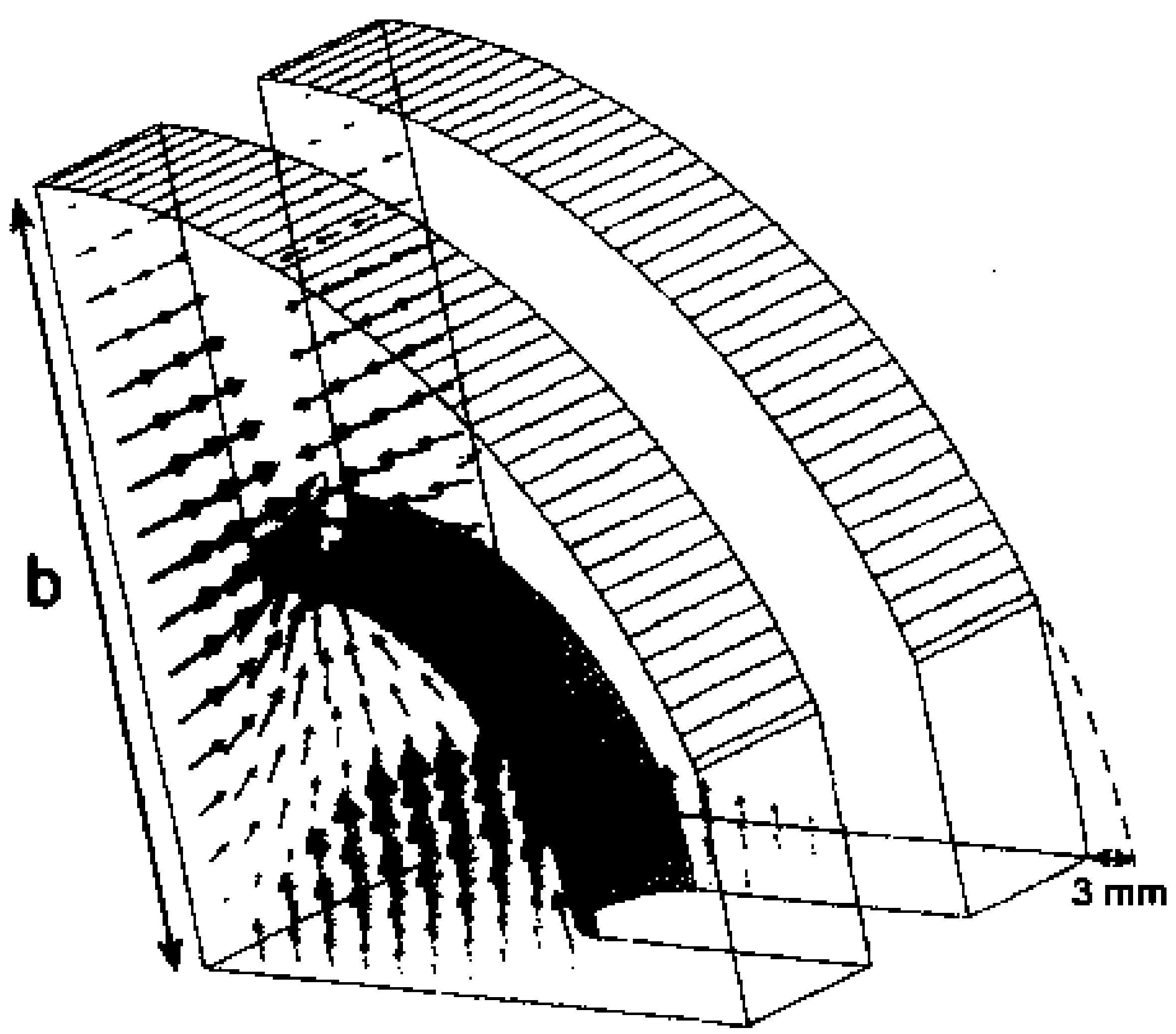
→ **Check of the resonant frequency of the scaled structure**

→ **Parameters sensitivity:**

$\Delta f/\Delta a$=-13.2 MHz/mm
$\Delta f/\Delta b$=-49.7 MHz/mm
$\Delta f/\Delta t$= 2.9 MHz/mm
$\Delta f/\Delta d$=1.2 MHz/mm

- <u>HFSS 3D Cell simulations</u>

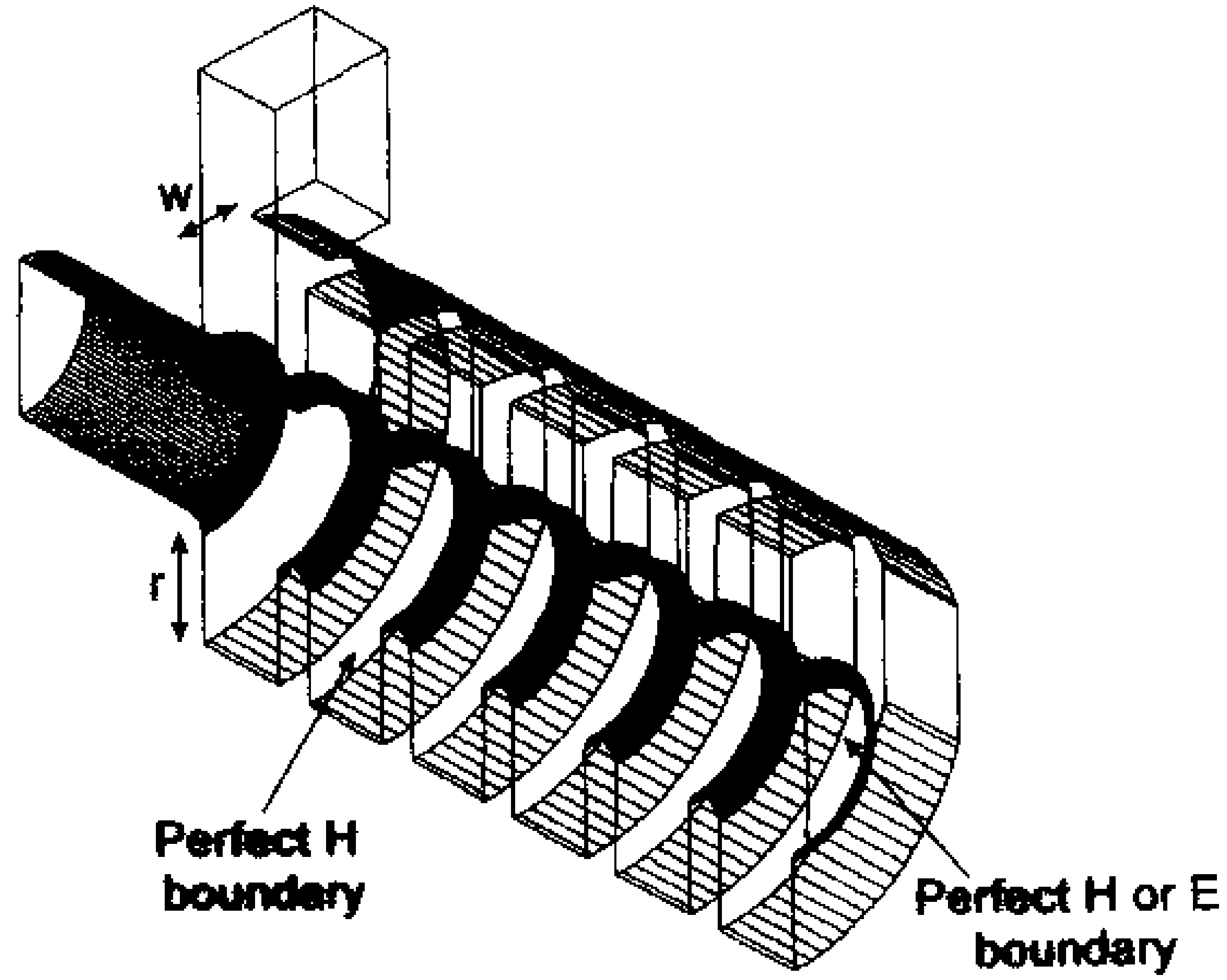
→ **Azimuthal asymmetry for vertical and horizontal deflecting mode splitting**



→ **re-tuning of the fundamental mode by the sensitivities obtained by MAFIA (modified b radius)**

Dimensions	Simulation results
a = 21.43 mm b = 56.03 mm d = 33.33 mm t = 9.53 mm	$f_{2\pi/3}$ = 2998.7 ± 0.3 MHz (code uncert.) $\Delta f = f_{vert} - f_{hor} \approx 48$ MHz

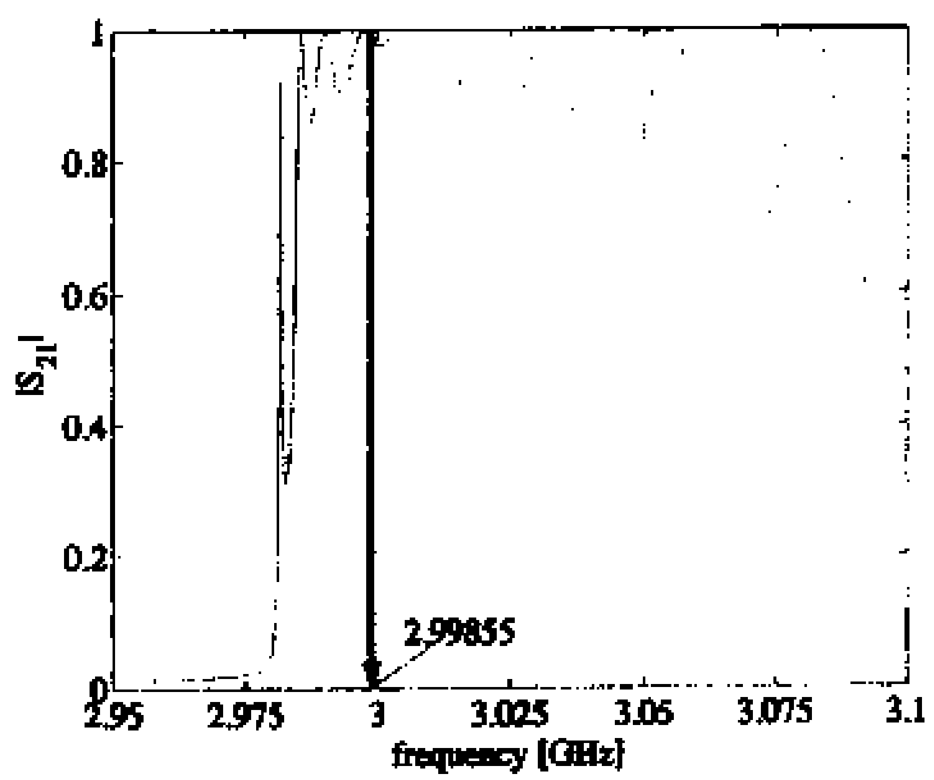
- <u>HFSS 3D simulations of the RF coupler</u>

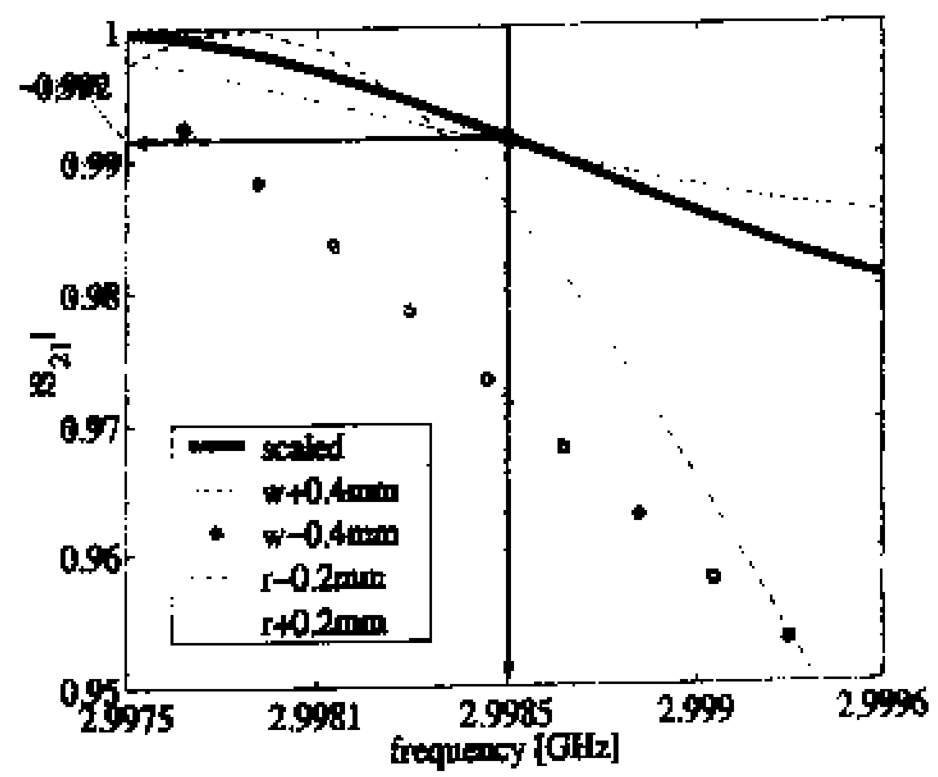


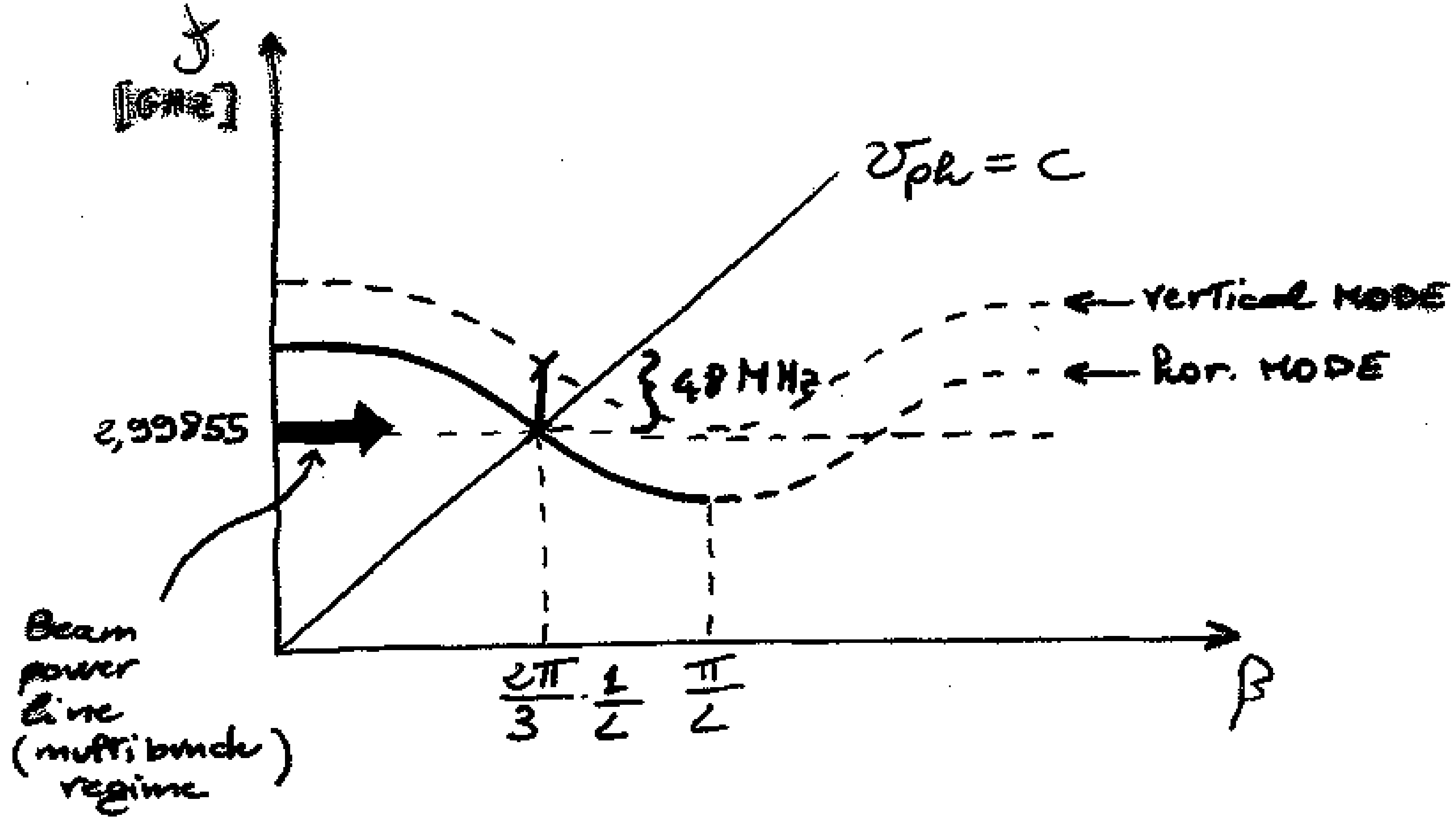
→ **scaled coupler**

→ **azimuthal and longitudinal symmetries of the structure: tetrahedral mesh reduction**

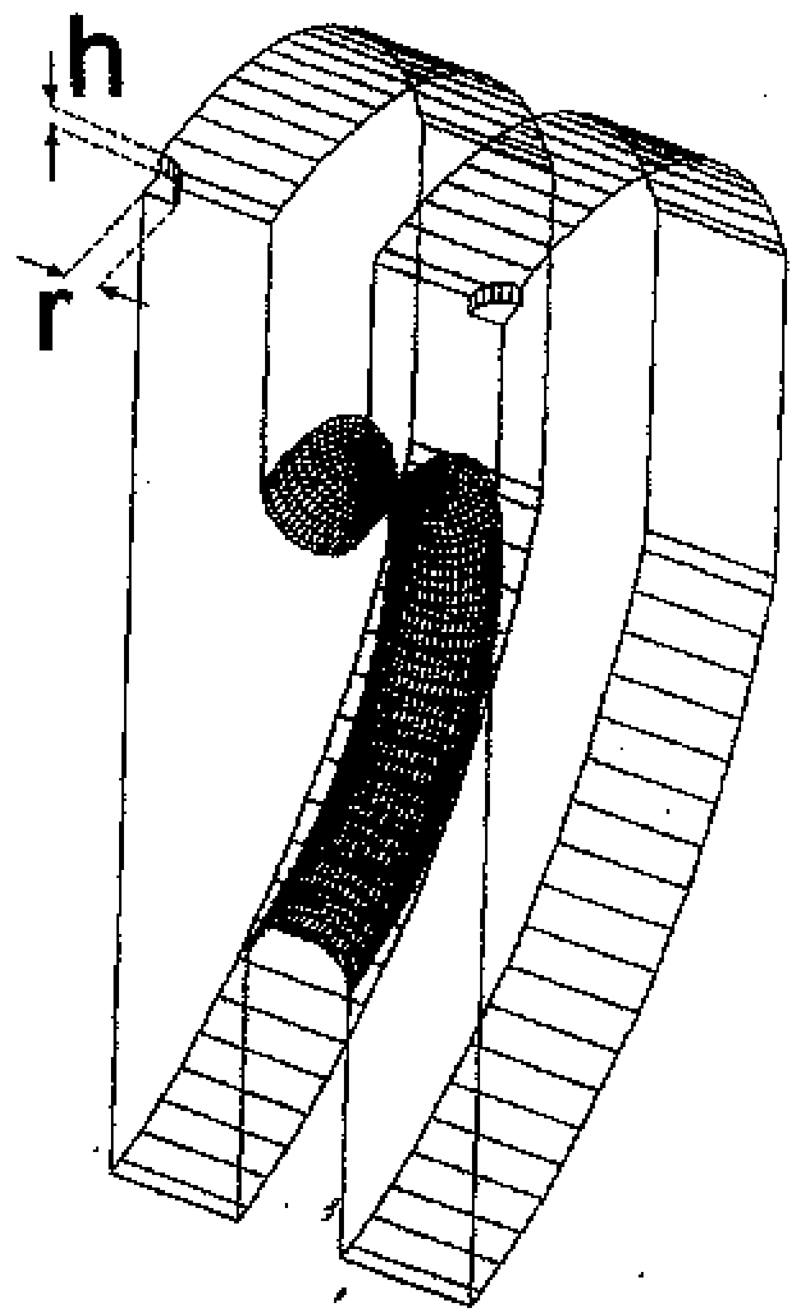
→ **coupling cell parameters variation (w, r)**







HFSS 3D simulations of the single cell tuning



→ **tuning of the single cell resonant frequency (r=3mm)**

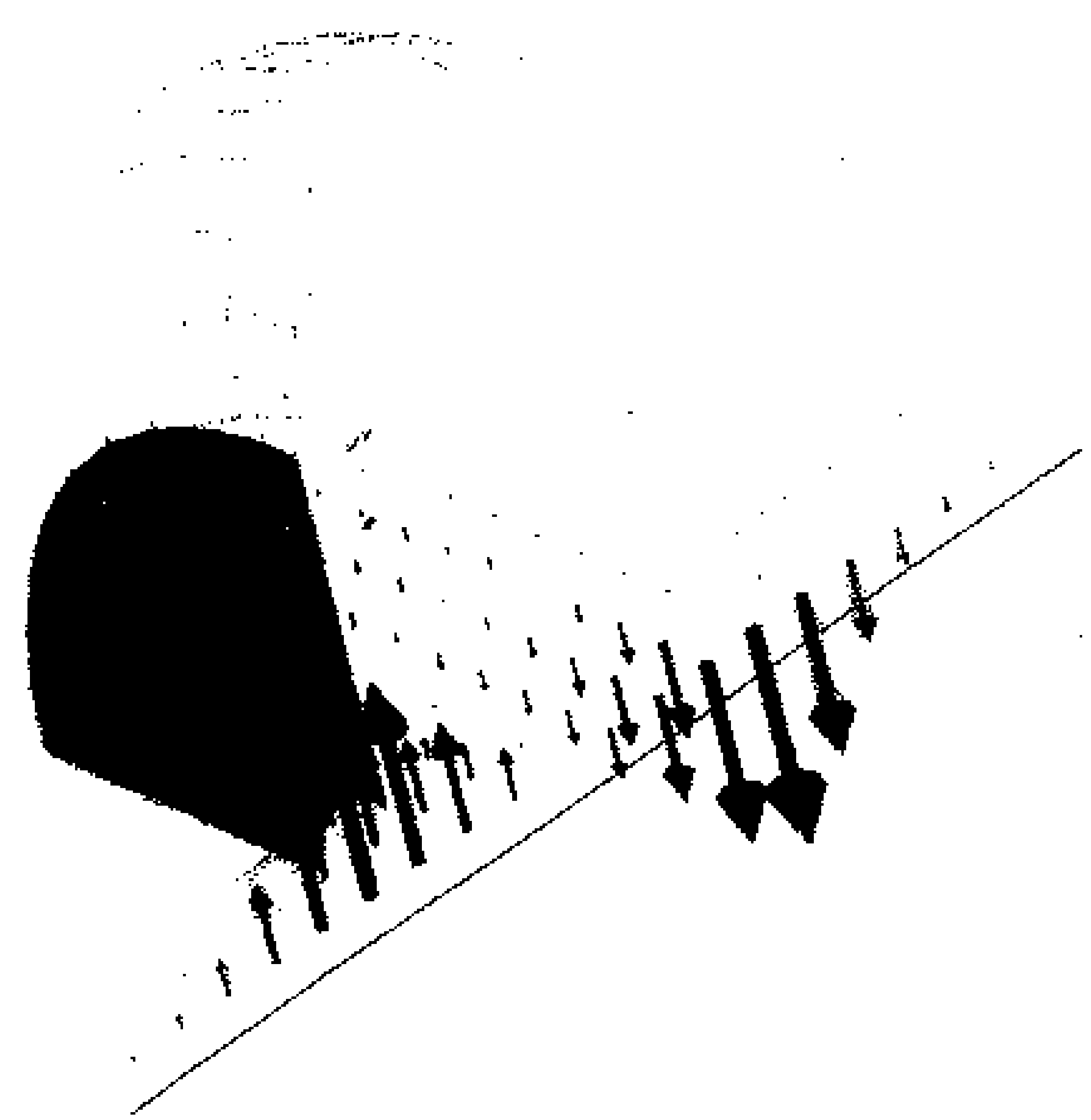
tuner position (h)	Δf
1mm	≈ 0.5 MHz
2mm	≈ 1 MHz

- Simulations of a SW cavity for the delay line

→ **Reasonable dimensions @ 1.49928 GHz compared with a scaled Lengeler structure**

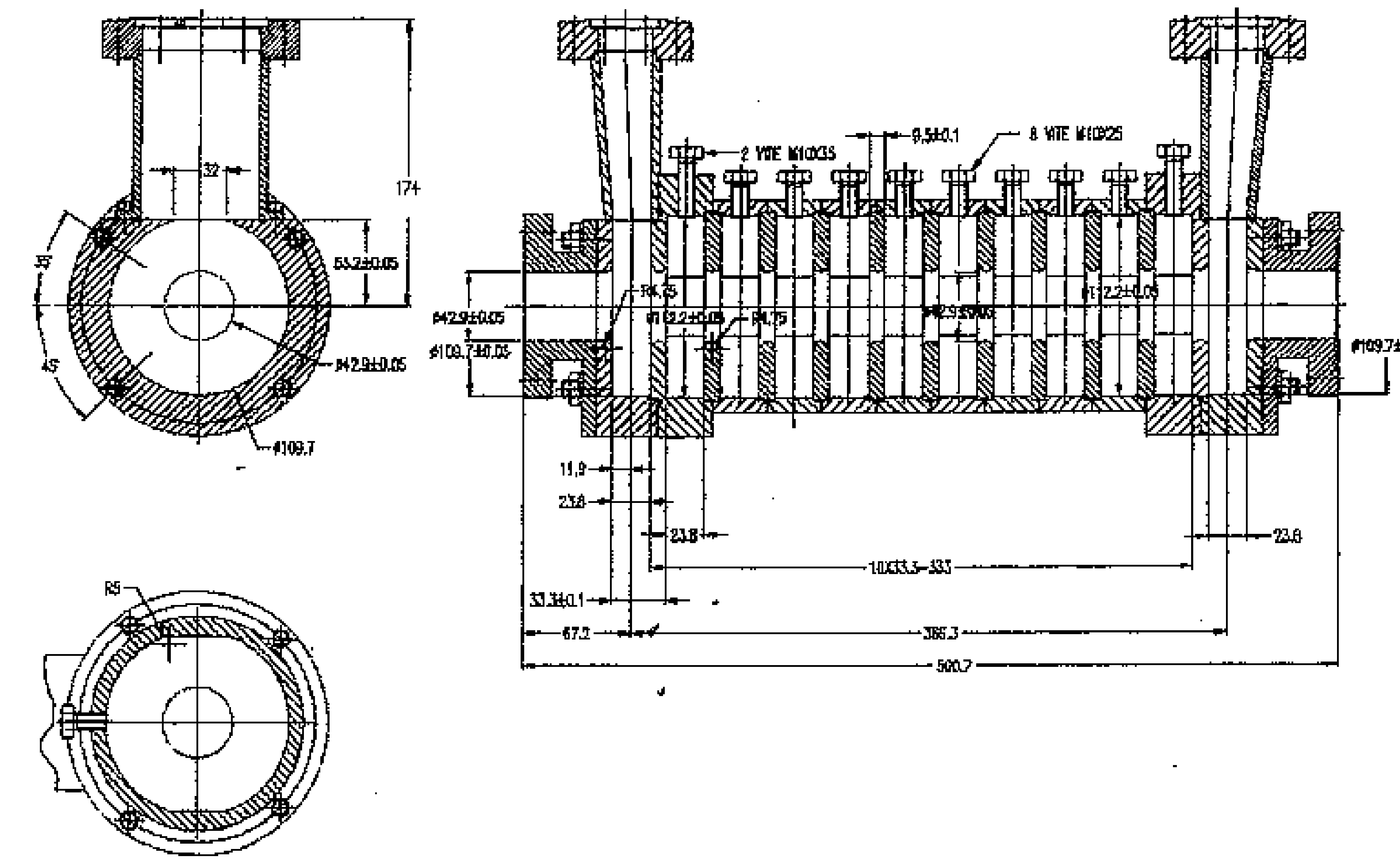
→ **Efficiency**

→ **No bunches probing the out-of-phase wake**



DEVICES UNDER CONSTRUCTION

- Alluminium prototype

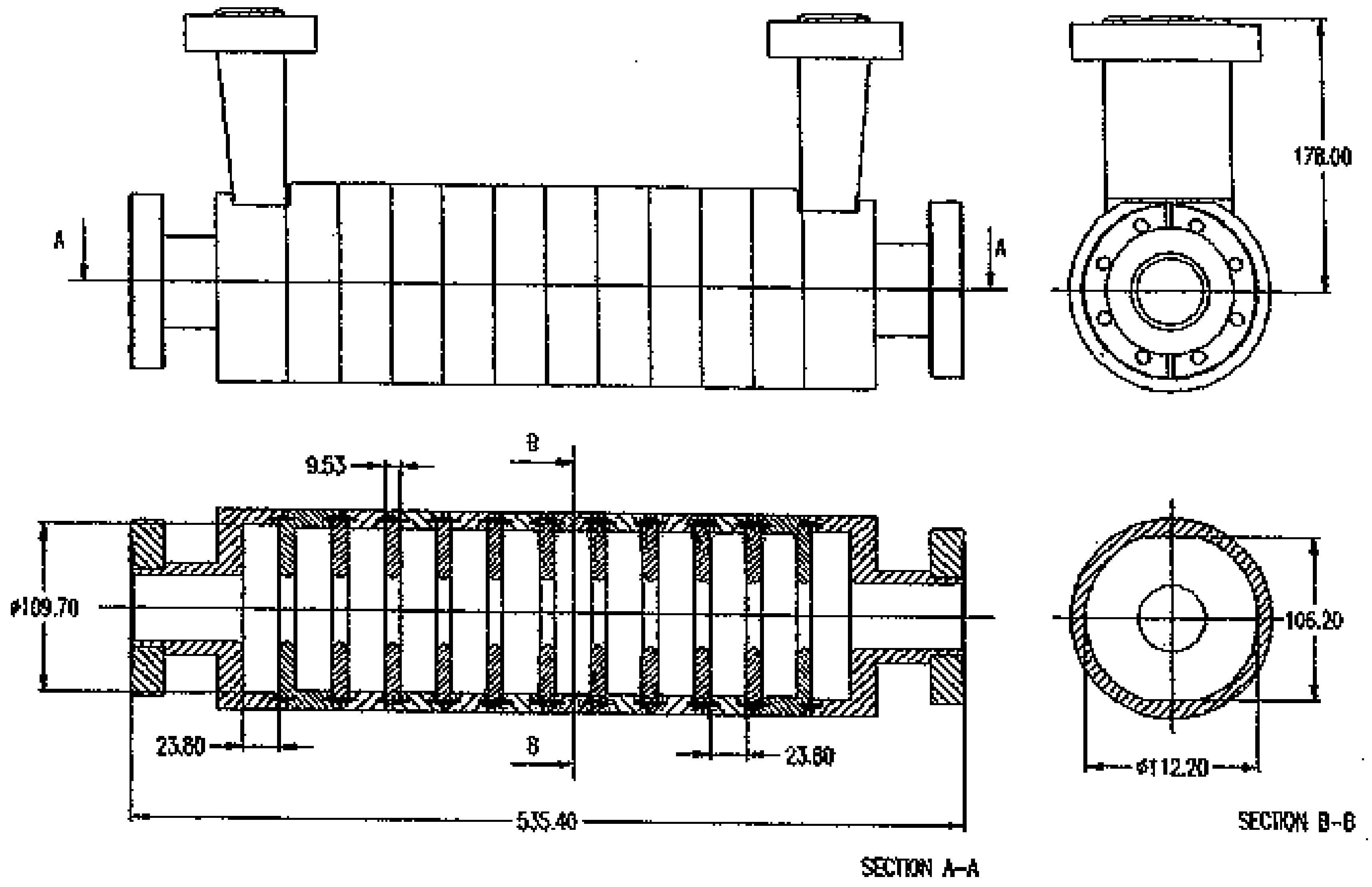


→ **Dispersion curve measurements**

→ **Coupler efficiency measurements**

→ **Field flatness and cells tuning**

• <u>Vacuum-tight copper device</u>



→

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THE OFFER AND QUOTATION NR IPJ/ P-X/ F-3/2001

FOR: **CONSTRUCTION AND TESTING OF TWO TRAVELLING WAVE SECTIONS OPERATING IN DEFLECTOR MODE**

Date of issue: 1 October 2001

PRESENTED TO:

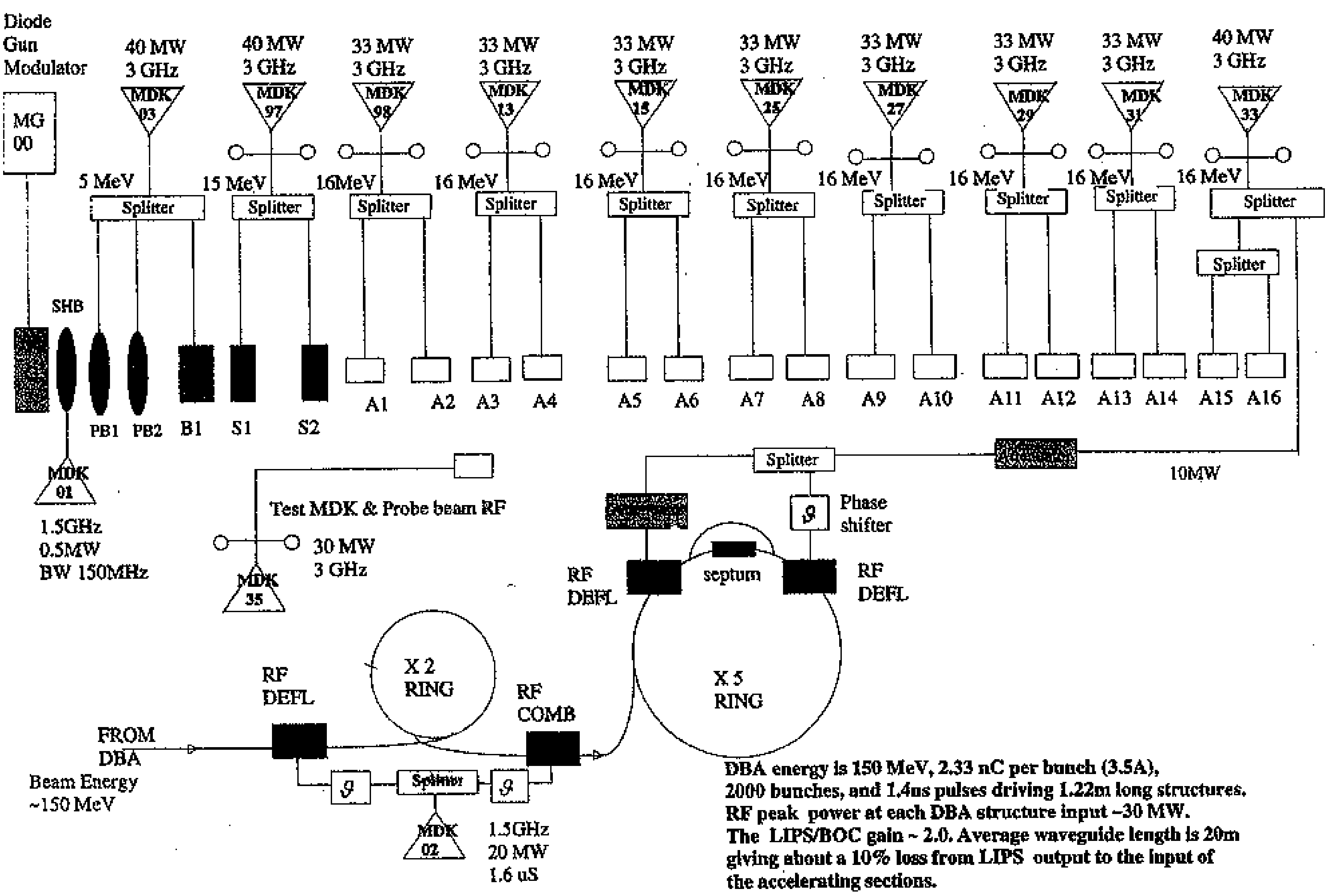
LABORATORI NAZIONALI DI FRASCATI OF INFN
ACCELERATOR DIVISION
P.O. BOX 13
00044 FRASCATI - (Italy)

CTF3 Nominal Phase

Klystron-Modulators and other RF components

G.McMonagle

CTF3 Review 2nd October 2001



DBA energy is 150 MeV, 2.33 nC per bunch (3.5A), 2000 bunches, and 1.4us pulses driving 1.22m long structures. RF peak power at each DBA structure input ~30 MW. The LIPS/BOC gain ~ 2.0. Average waveguide length is 20m giving about a 10% loss from LIPS output to the input of the accelerating sections.

LIPS Peak Power versus Klystron Pulse Length

Limitations of Klystron Pulse Length

- Saturation of HV Pulse Transformer, $\Phi = \int U \cdot dt < \Phi_{sat}$
  Φ<1.68Vs for trafo of TH2094, can be changed by other trafo Φ<2.25Vs of TH2132.

- Cathode High Voltage Breakdowns
  It is very difficult to condition the gun of an old klystron for longer pulses (TTE).

- RF Losses of RF Windows
  Klystron TH2094 (LIL): 35MW x 4.5µs or 31MW x 5.0µs.
  Klystron TH2100 (CTF3): 38MW x 5.0µs, to be tested.

LIPS Compression Gain G versus Klystron Pulse Length T

Flat top of LIPS pulse: T2=1.4µs, $\Delta P/P<\pm 1\%$, $\Delta\varphi<\pm 6$deg.
Duration of pulse compression: T3=1.6µs, $t_r = t_f = 0.1$µs.

T =	4.5µs	5.0µs	5.5µs	6.0µs	
G(T)=	1.90	2.04	2.12	2.16	
η(T)=	59%	57%	54%	50%	$\eta = G \cdot T2 / T$

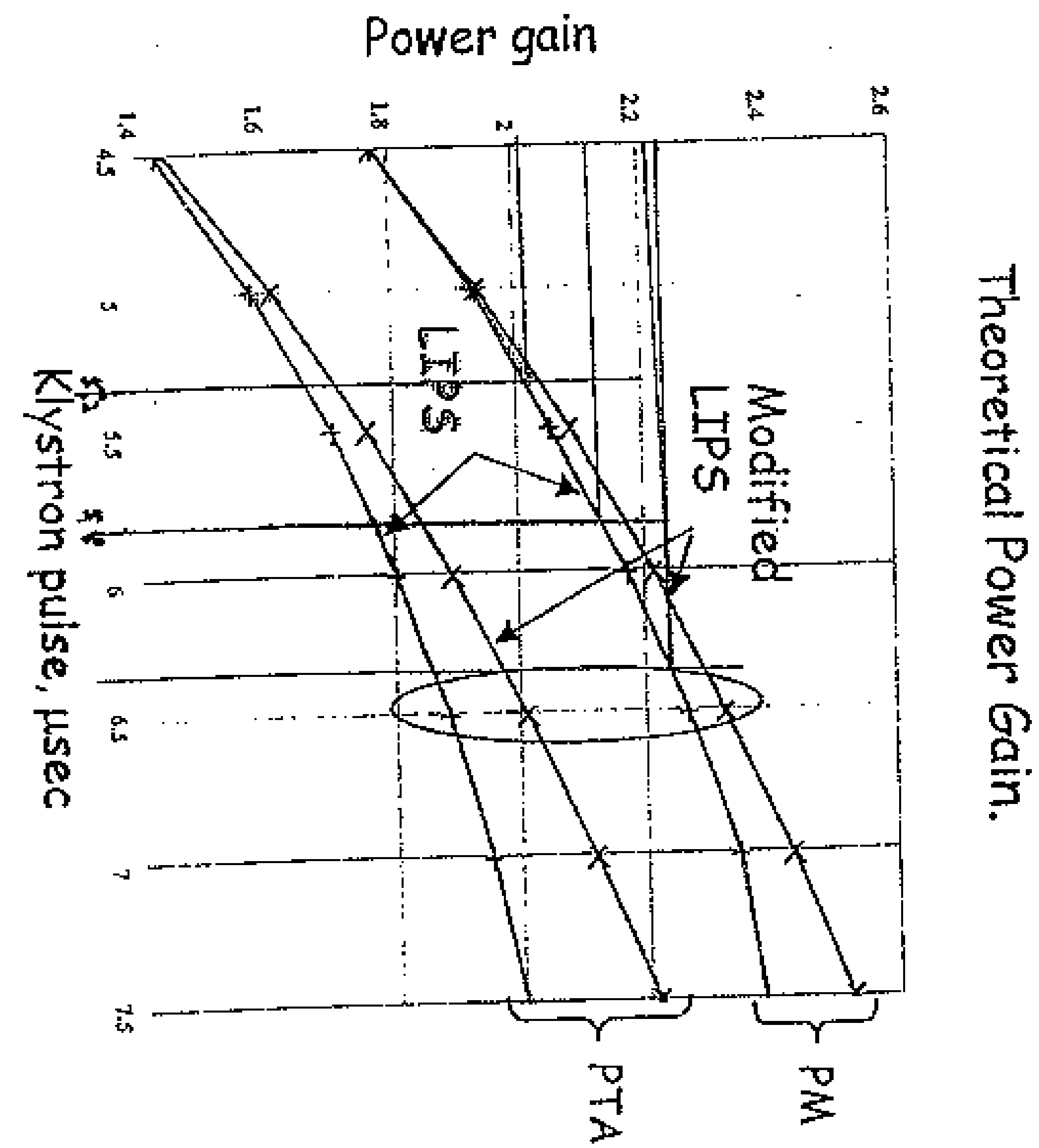
LIPS Peak Power P_L for TH2094, $P_L = G \cdot P_K$

- T = 4.5µs ; P_K = 35MW, G = 1.90, P_L = 66MW
- T = 5.0µs : P_K = 31MW, G = 2.04, P_L = 63MW

For constant dielectric losses of the RF windows, $P_K \cdot T$=const, a short pulse length 4.5µs provides a higher LIPS peak power P_L, since the RF losses in the LIPS cavities are less.

Conclusion

If the klystron RF power is limited by the dielectric losses of the RF window, it is recommended to use the klystron at the highest nominal power which the klystron is built for, because it provides the best pulse response and the best LIPS pulse compression gain at this working point.



LIPS modification is mainly the adjusting of the cavity coupling.

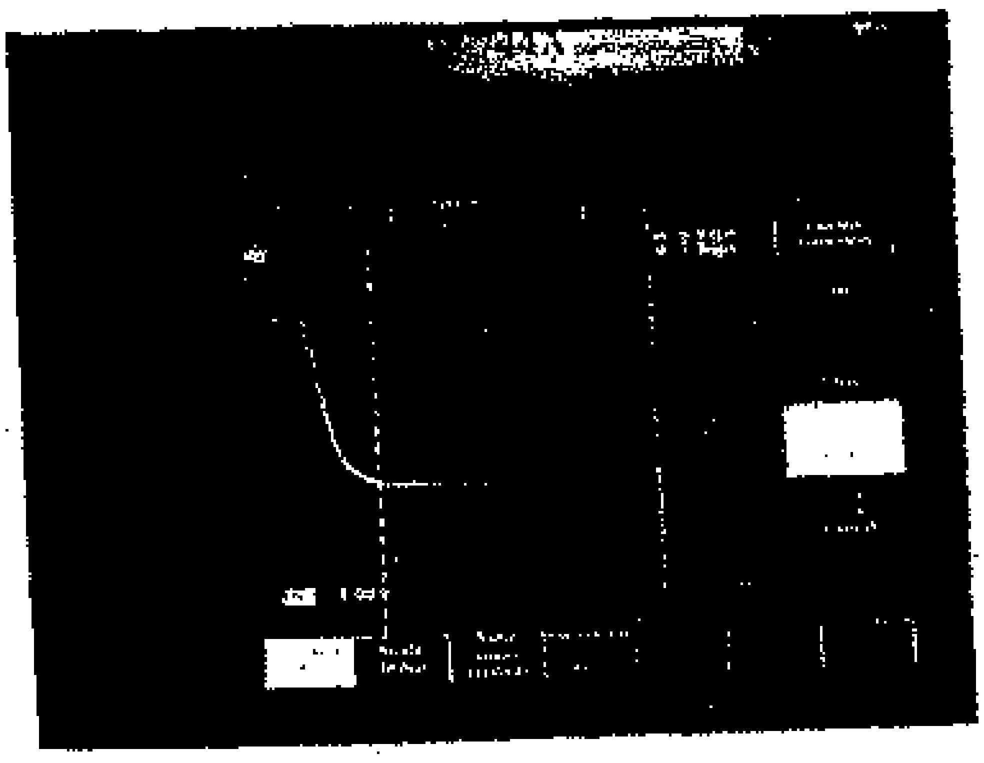
Klystron-Modulator peak operating parameters

Parameters	35 MW klystron-modulator	45 MW klystron-modulator	Units
RF Frequency	2998.55	2998.55	MHz
RF Peak output	35 (37)	45	MW
RF average power	17.5 (18.5)	20	kW
RF power gain	53	54	dB
Klystron efficiency	45	44	%
Rf pulse length	4.5	4.5	µs
Klystron voltage	273	305	kV
Klystron current	285	335	A
PFN impedance	5.5	4.4	Ω
Pulse transformer ratio	1:13	1:14.85	
Pulse voltage ripple	±0.15	±0.15	%
Pulse stability	±0.1	±0.1	%

Rise time 10 – 90% ≈ 740 nS 2/9/99
Fall time 90 – 10% ≈ 1.5µS
Flat top ≈ 5.5µS
Pulse width at 75% = 7µS
Pulse width (Rise time + flat top) ≈ 6.3µS

Measured with PFN impedance ~ 4.4 ohms
and pulse transformer ratio 1:14.8 and klystron TH2132

Measured on MDK97



	MDK	Nominal Peak Power Output MW			Maximum peak power available from klystron with security margin MW			Peak power available available at each of the two accelerating sections, two per klystron (1) (2) MW			Peak power available at accelerating section using 800nS rise time of klystron voltage, two per klystron (2) (4) MW		
Klystron voltage flat top legnth		4.5µS	5.0µS	5.5µS	4.5µS	5.0µS	5.5µS	4.5µS	5.0µS	5.5µS	4.5µS	5µS	5.5µS
	03	45	43	41*	43	41	39						
	13	35	35	35	33	33	33	27	28.6	30	30	31.6	33.8
	15	35	35	35	33	33	33	27	28.6	30	30	31.6	33.8
	25	35	35	35	33	33	33	27	28.6	30	30	31.6	33.8
	27	45	43	41*	43	41	39	35.3	35.5	35.6	39.2	39.2	40
	29	35	35	35	33	33	33	27	28.6	30	30	31.6	33.8
	31	45	43	41*	43	41	39	35.3	35.5	35.6	39.2	39.2	40
	33 (3)	45	43	41*	43	41	39	30.2	30.5	30.5	33.6	34.3	37.6
	35	35	35	35	33	33	33						
	97	37	37	37	35	35	35	28.7	30.3	31.9	31.9	33.5	35.9
	98	37	37	37	35	35	35	28.7	30.3	31.9	31.9	33.5	35.9
Total peak power available to accelerating sections with a pulse width of 1.6µS (MW) (Nominal 540 MW)								532	553	571	591	612	649

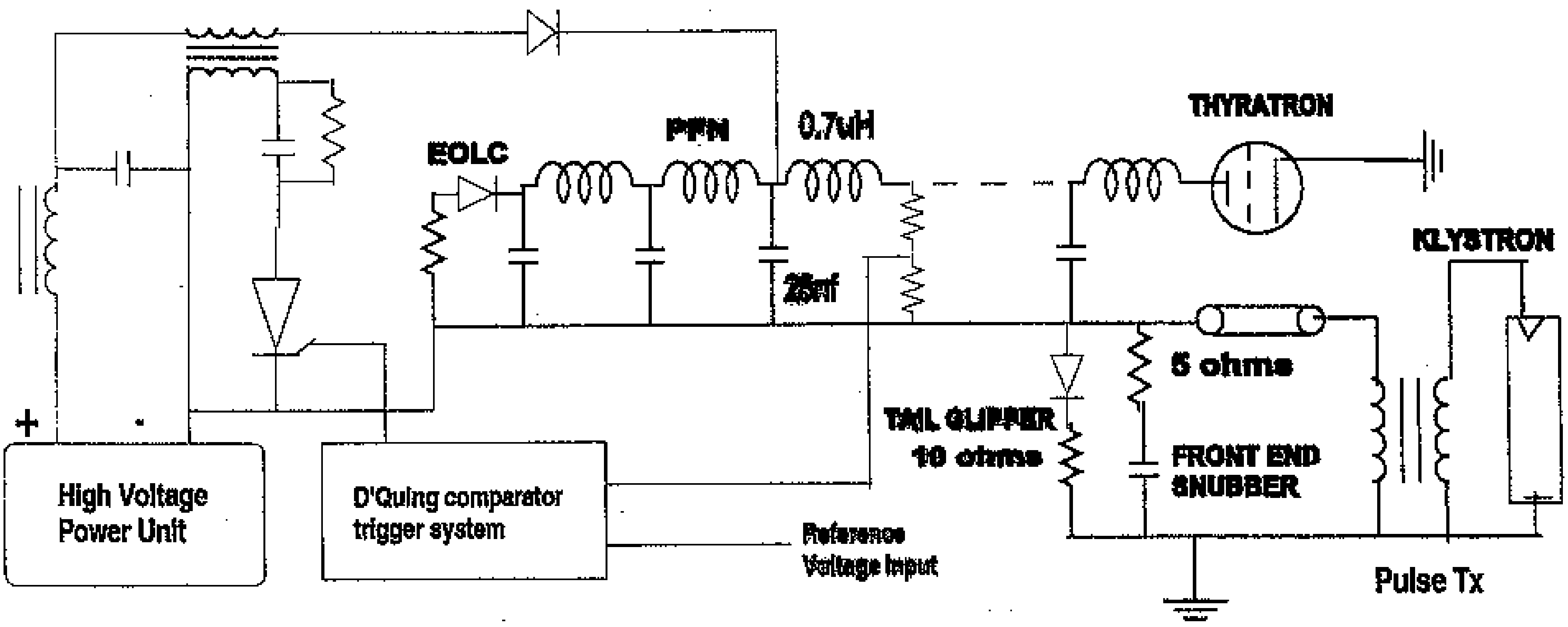
(1) Communication of LIPS gain from R. Bossart (LIPS Gain 1.8 at 4.5µS, 1.9 at 5µS, 2 at 5.5µS)
(2) 0.4dB power loss in waveguides
(3) Three way split of RF power after LIPS, first split 6:1
(4) Communication I.Syratchev
* increase in pulse width → lower maximum voltage applied to klystron → lower peak power out (THALES)

3 GHz Klystron Modulator Status

- The klystrons and modulators can be used as they exist to produce the required power to the accelerating structures for the 150 MeV nominal phase
- Reserve klystrons can replace some lower power klystrons to increase available power
- There is the capability to increase the pulse width of the 35/37 MW systems for energy upgrade by modifying the pulse forming networks and pulse transformers if necessary

- **Reserve klystrons**
- 2 TH2100 37 MW
- 1 TH2100 45 MW (November 2001)
- 1 TH2132 45 MW (March 2002)
- 4 YK1600 35 MW (2 already mounted in HT tanks)

Modulator Schematic Diagram



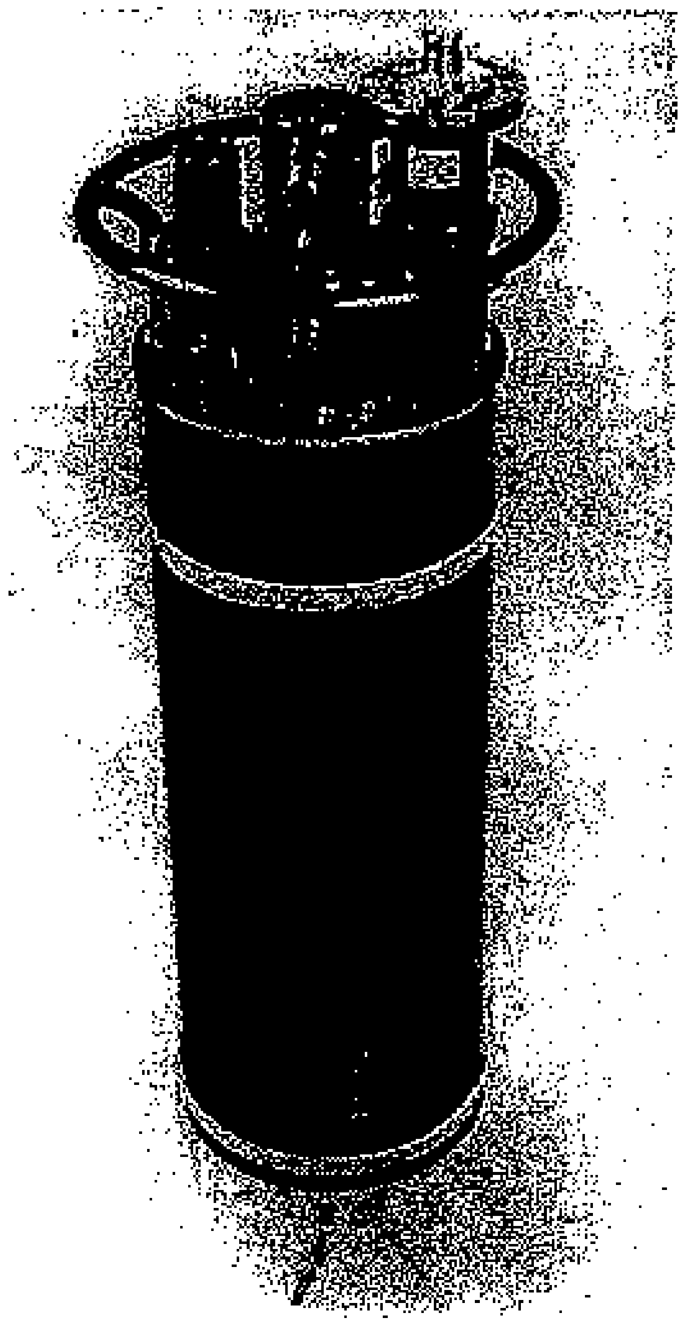
3 GHz Klystrons

	Valvo YK1600 35 MW	Thales TH2094 35 MW	Thales TH2100 37 MW	Thales TH2100 45 MW	Thales TH2132 45 MW
Klystron Voltage (kV)	270	270	280	305	305
Modulator PFN voltage (kV)	40	40	41	41	41
Pulse Transformer ratio (1: x)	1 : 13	1 : 13	1 : 13	1 : 14.8	1 : 14.8
PFN Impedance (ohms)	~ 5.0	~ 5.0	~ 5.0	~ 4.4	~ 4.4

G.McMonagle CTF3 Review 2nd October 2001

PT6006
Pulsed Klystron Amplifier

The PT6006 is an 8 cavity, L-band tunable pulsed high power klystron which features an output section of the extended interaction type to optimise instantaneous bandwidth.



QUICK REFERENCE

Centre frequency
1.3 GHz
Instantaneous bandwidth
90 MHz
Peak output power (Nominal)
100 kW
Gain
25 dB

Cathode modulated
Solenoid focused
Liquid cooled

Input RF connector
TYPE N
Output RF connector
3 1/8"standard coaxial

TYPICAL OPERATION

Heater voltage
7 volts
Heater current
18 amps
Beam voltage (peak)
33 kV
Beam current (peak)
12.6 amps
Beam duty factor
0.05
Efficiency
25%

TYPICAL PERFORMANCE

Frequency range
1.25 -1.34 GHz
Peak output power
90 kW minimum
Bandwidth*
90 MHz
Saturated gain
25 dB
Beam pulse length
8.5 μs
Beam duty factor
0.05
Spurious output power level
-85 dB

* for peak power output of 90 kW minimum

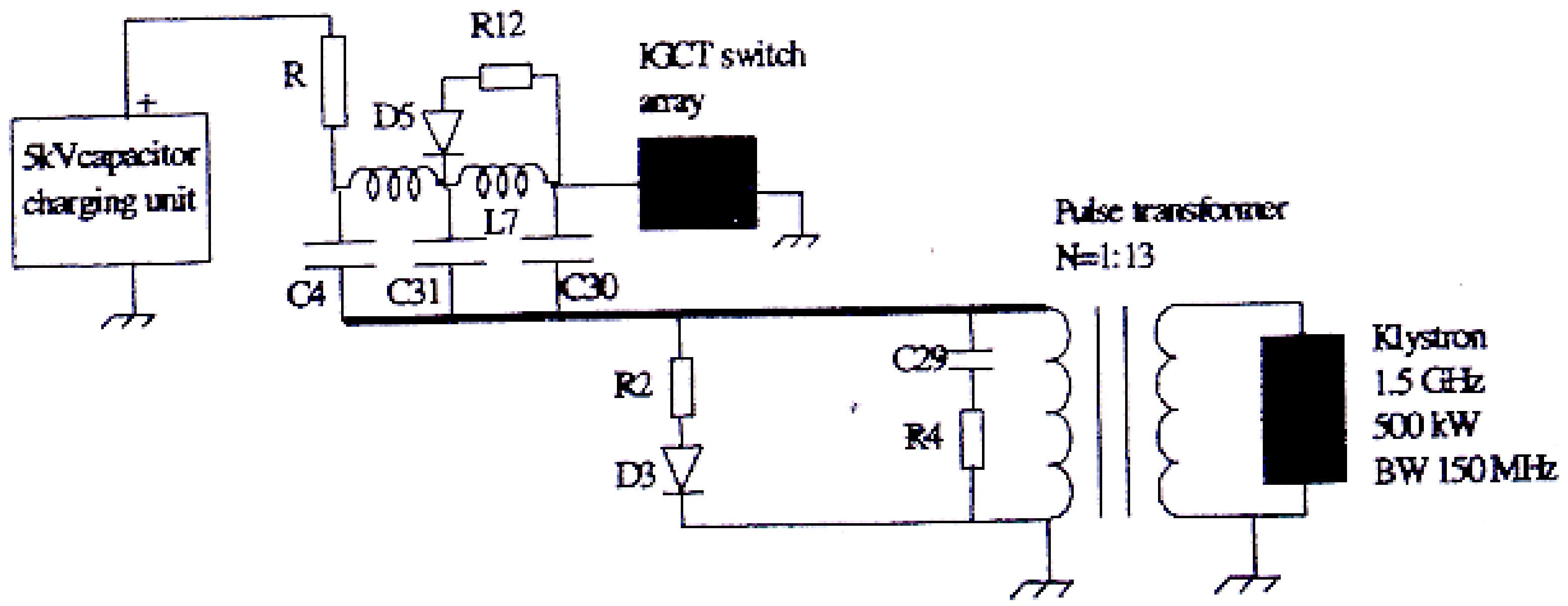
TMD

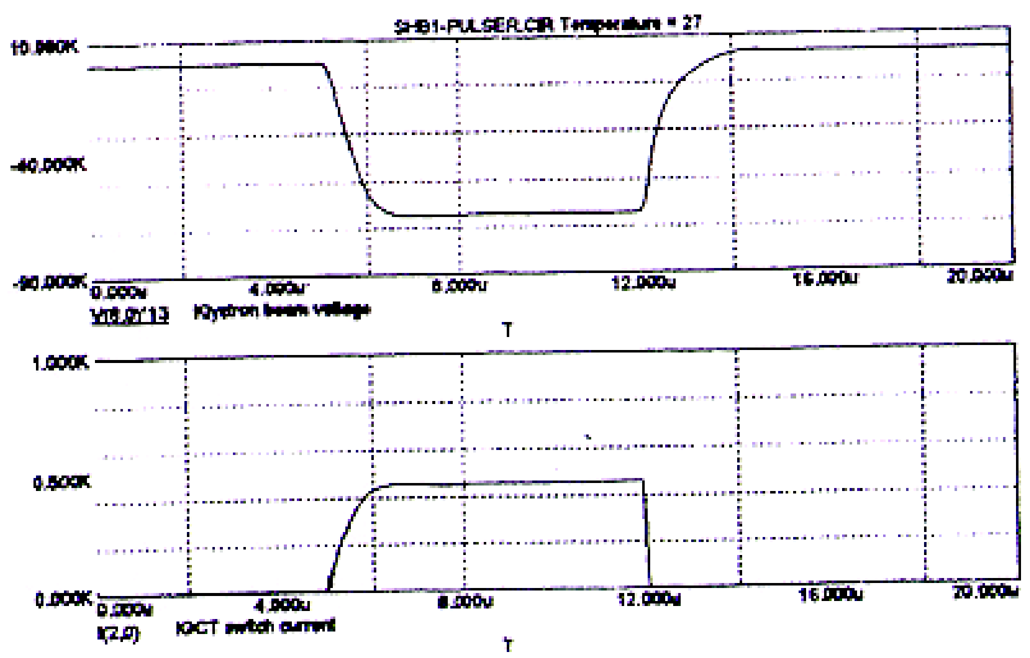
1.5 GHz klystrons and modulators

- 0.5 MW Broadband 150 MHz klystron feasibility study completed, call for tender to manufacture being processed
- Modulator for broadband klystron being manufactured and developed in CERN using existing equipment apart from the solid state switch (delivery December 2001)
- narrow band 20 MW 1.6μS klystron on order from Thales
- modulator based on existing 3 GHz systems to be constructed in 2002/2003
- specifications for 1.5 GHz waveguides, phasors attenuators, splitters, couplers etc. in preparation for price enquiry next year

SHB modulator main parameters

Parameter	Value	Units
Primary capacitor voltage	5	kV
Peak IGCT pulse current	450	A
Pulse voltage rise time(10-90%)	800	ns
Flat top voltage deviation over 2 µs pulse width	0.3	%
IGCT DC voltage for 100 FIT failure rate	2800	V





It is also possible to mount the tube horizontally but in that case it would be difficult to use transformer oil because of the problems in sealing the gun region of the tube when the tube is removed from the socket.

A self-connecting plug has been fitted to the end of the gun which will work immersed in transformer oil. The action of lowering the tube into the solenoid will automatically make the cathode, heater and grid connections.

A cut-away drawing of the tube with overall dimensions is shown in Figure 14.

5. CONCLUSIONS AND RECOMMENDATIONS OF THE STUDY

The main conclusions of the feasibility programme are:-

i) The calculations show that the PT6006 klystron can be scaled to give the required output power over the correct bandwidth at the higher frequency required.

ii) The same number of buncher cavities will be needed as in the standard design but a longer body stack will be required because of the higher power operation. The latter means operating at a higher EHT voltage which increases the interaction length.

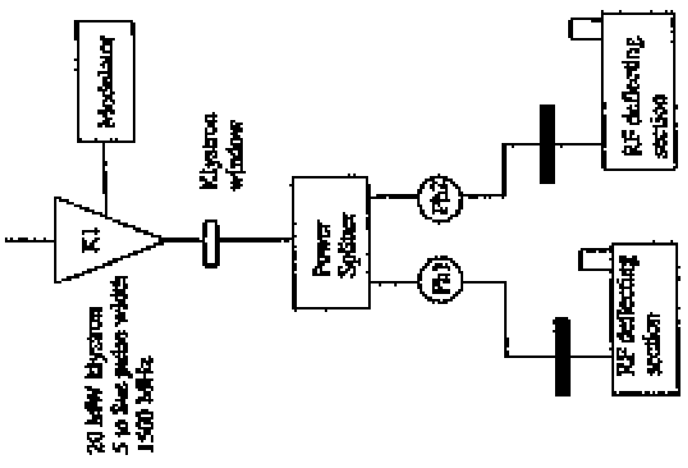
iii) The existing coaxial RF window used on the PT6006 will be adequate for use in the new design although it may need pressurised air or insulating gas to ensure arc-free operation.

iv) A larger 'pillbox' waveguide window can be provided if necessary.

v) It is recommended that a gridded gun is used on the tube as described in this report. This will give better RF pulse shaping and more flexibility with pulse length and timing. However a non-gridded version of the gun design can be produced if the equipment available makes it inconvenient to use the gridded technology.

vi) The mounting position of the tube can be vertical, with the gun downwards, or horizontal. In the former case, transformer oil insulation can be used around the gun for cooling and insulation. With horizontal mounting, the gun is best insulated with a gas such as SF6. The gun will operate in either of these environments.

vii) An insulated collector has been provided to allow for the possibility of collector depression to improve the overall efficiency of the tube.



General L-band klystron parameters

Parameters	Value	Units
Centre frequency	1500	MHz
Bandwidth (1 dB)	8.5 (min)	MHz
Peak Output Power	20 (min), 25 (max)	MW
Pulse width	5 max at 25 MW, 8 max at 20 MW	μs
Repetition frequency	100 (max)	Hz
Electronic efficiency	42	%
Klystron beam voltage	260 (max)	kV
Klystron beam current	250 (max)	A
Microperveance	1.9 (min) to 2.0 (max)	$\mu A/V^{3/2}$
Heater voltage	28 (max)	V
Heater current	28 (max)	A
Large signal gain	49.5	dB
SF6 pressure on RF window	1.5 (max)	bar
Focal coil voltage	180	V
Focal coil current	70	A
RF window flange	CPR 650F	-

RF deflector klystron-modulator parameters

Parameters	TW deflector MDK	SW deflector MDK	Units
Peak output power	25 (max)	20 (max)	MW
RF pulse width	5 (max)	8 (max)	μs
Repetition frequency (max)	100	50	Hz
Klystron perveance	1.9 [2.0]	1.9 [2.0]	$A/V^{3/2}$
Voltage pulse width	6	9	μs
Klystron beam voltage	250 [245]	230 [225]	kV
Klystron beam current	238 (243)	210 [213]	A
PFN impedance	4.5	4.75	Ω
Klystron to PFN mismatch	+5	+5	%
Number of PFN cells	25	25	-
Cell capacitance	32	42.5	nF
Cell inductance	0.7 [0.65]	1.0 [0.87]	μH
PFN operating voltage	34 [33]	31 [30.5]	kV
Pulse transformer ratio	1:14.85	1:14.85	-
Pulse transformer volt-seconds	1.76 [1.73]	2.3 [2.15]	VS
Thyratron peak current	3.67 [3.7]	3.29 [3.4]	kA
Thyratron average current	1.3	1.65	A
PFN charging power	30	30	kW
PFN charging time	15	18	ms

Conclusions

The existing 3GHz modulators and klystrons can all be used in the CTF3 Nominal phase.
They can eventually be upgraded to higher power operation with no technical difficulties if needed
The 1.5 GHz klystrons have positive feasibility reports, one is on order, a price enquiry for manufacture for the other is being prepared.
The associated modulators for the 1.5 GHz klystrons are being manufactured.
Specifications for 1.5 GHz passive components are being prepared for price enquiry next year

RF Pulse Compression.

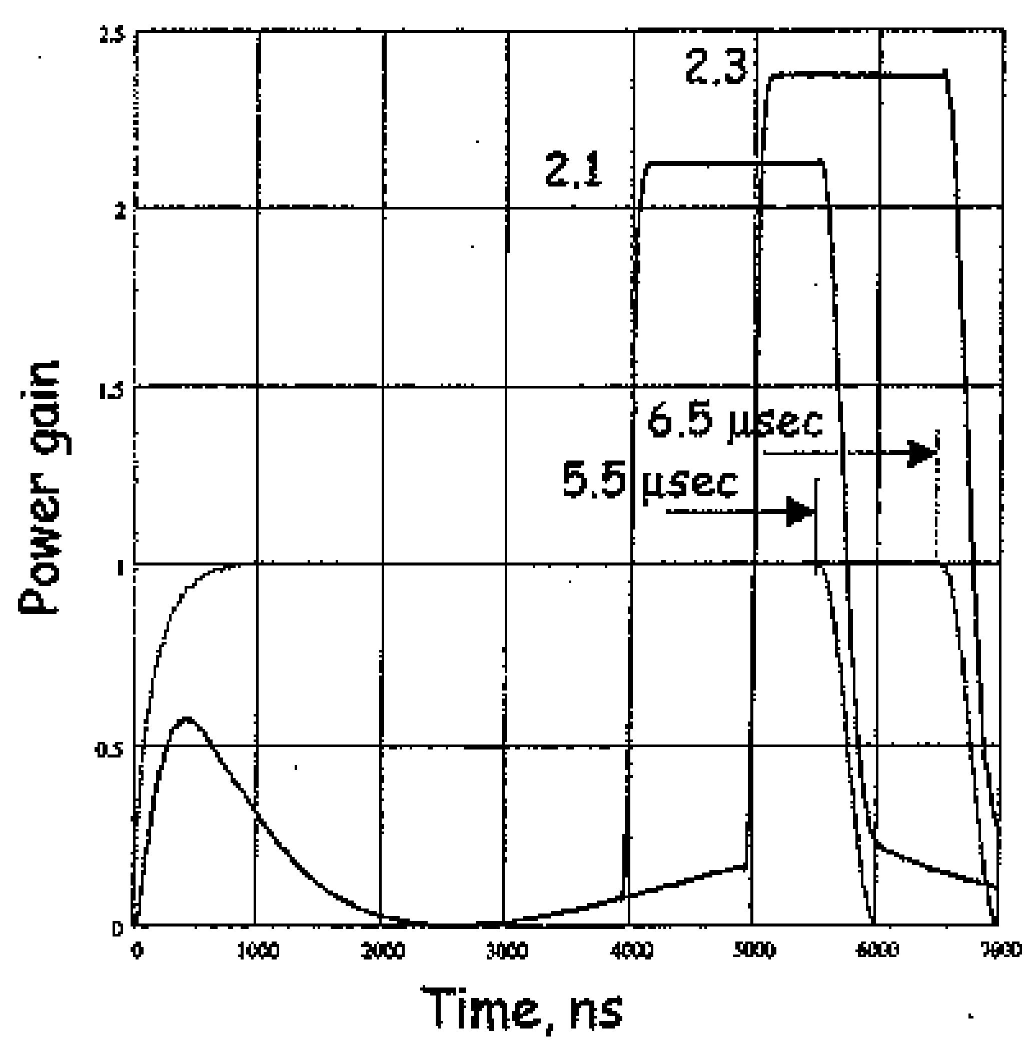
I.Syratchev

- **RF Pulse Compression is the only way to increase RF power level from the number of klystrons available for CTF#3.**

- **RF phase/amplitude modulation is the tool to control the RF pulse shape in a system - klystron plus "SLED"-like RF pulse compressor.**

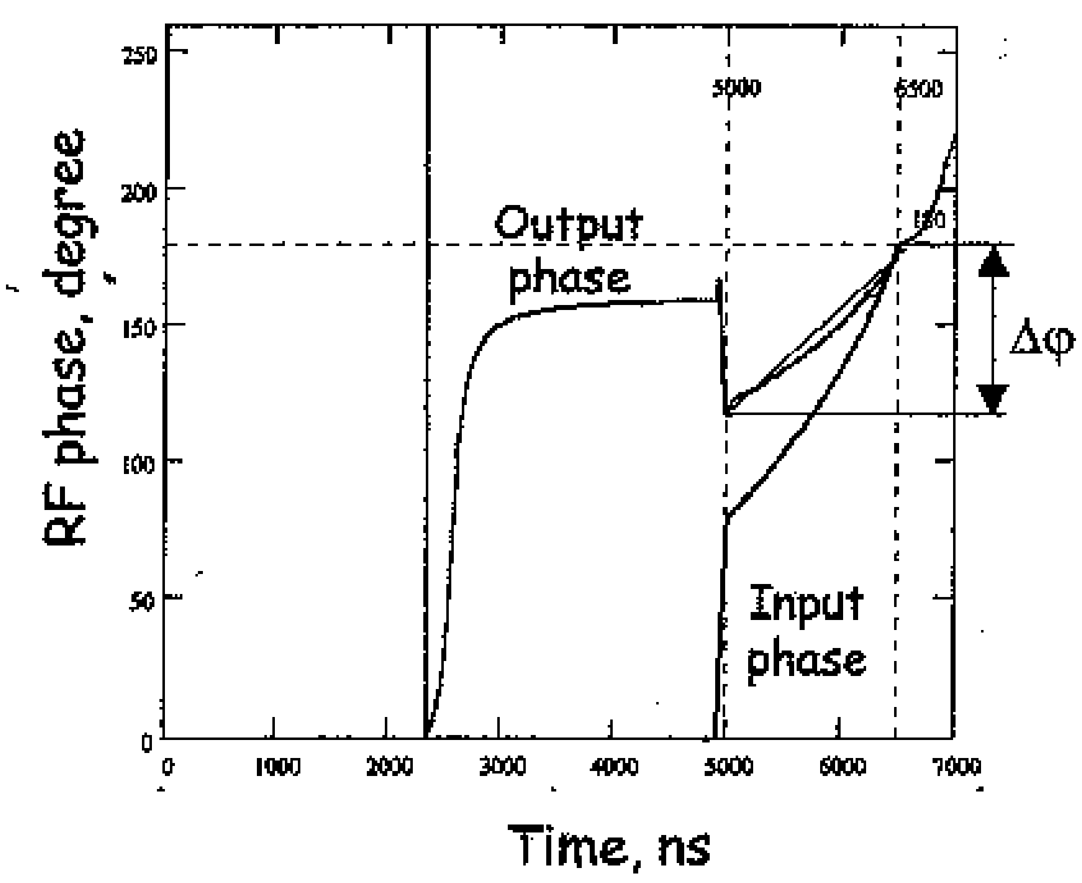
The flat pulse after the cavity based pulse compressor (LIPS), with modulation of the input RF phase (PM).

LIPS cavity $Q_0 = 1.8\times10^5$, $\beta=8$



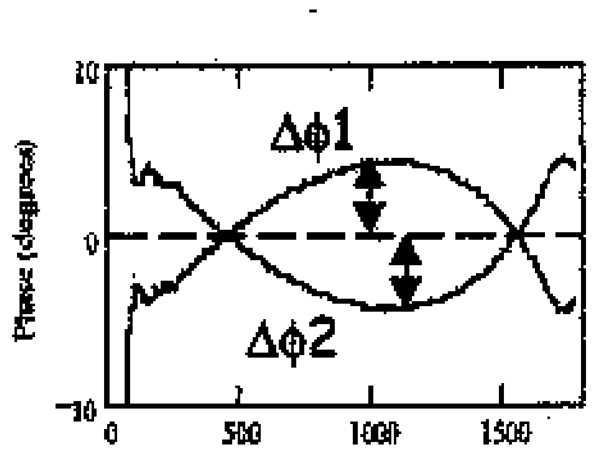
The linear part of the phase slop will be compensated with the frequency shift:

$\pm\Delta\omega T_{out} = \pm\Delta\varphi$

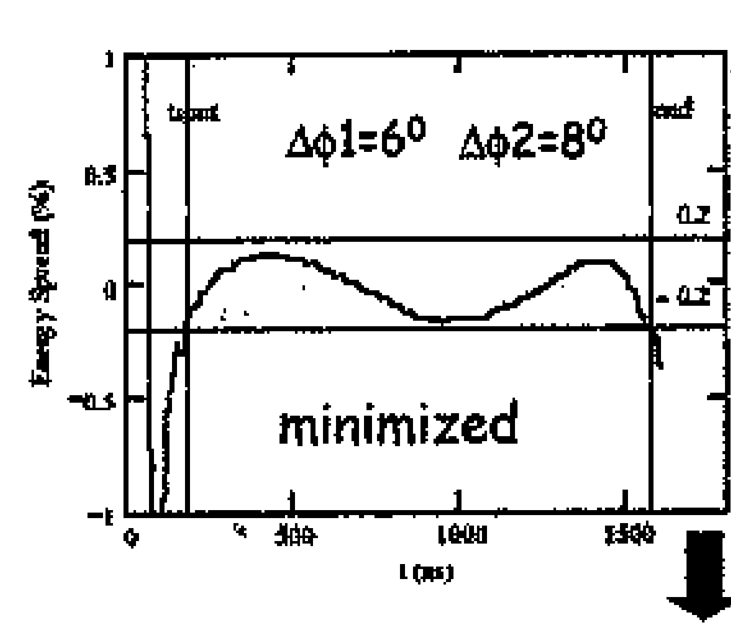


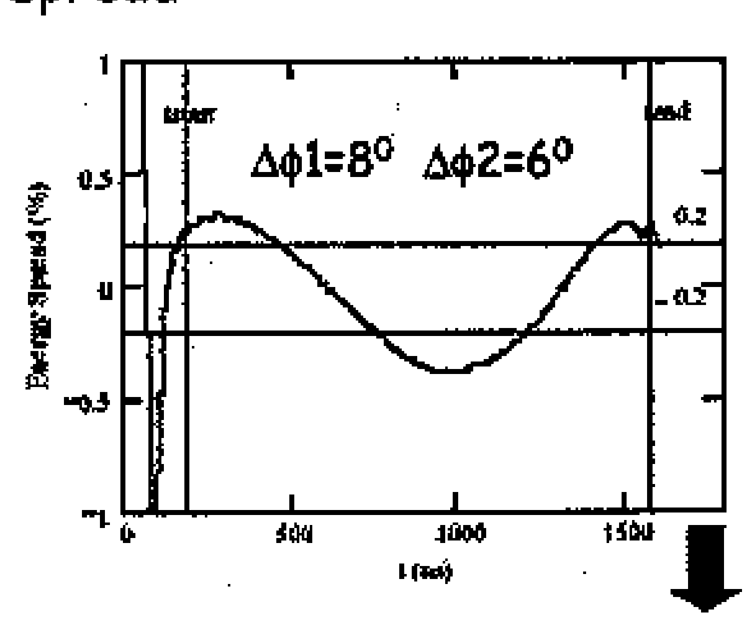
The effect of residual RF phase sage and energy spread. R. Corsini

The residual phase envelops after two RF stations

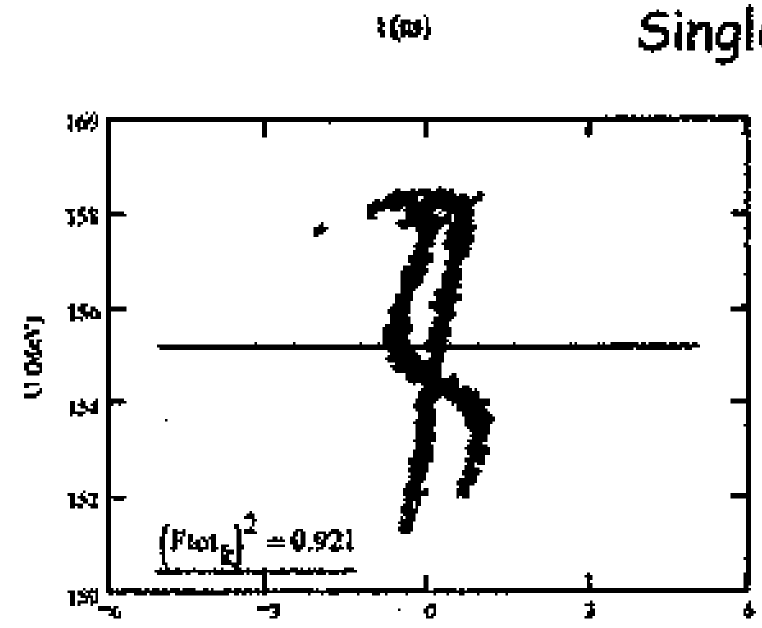


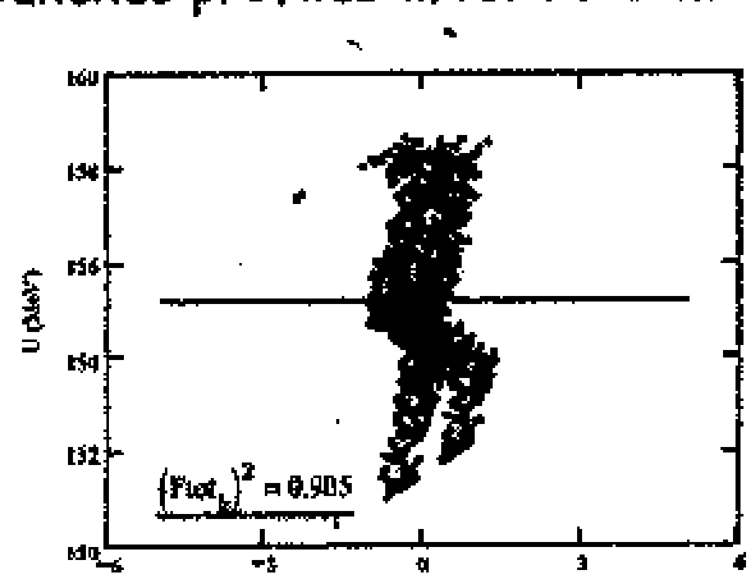
Energy spread

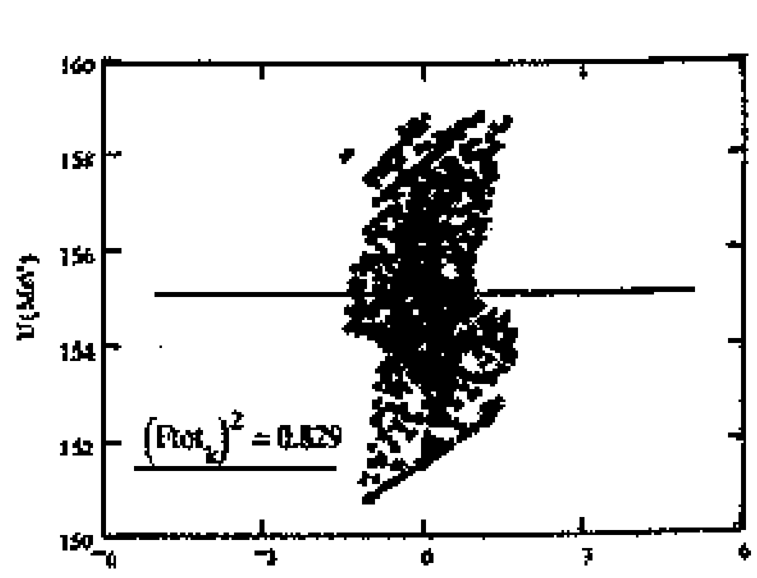




Single bunches profiles after re-combination.

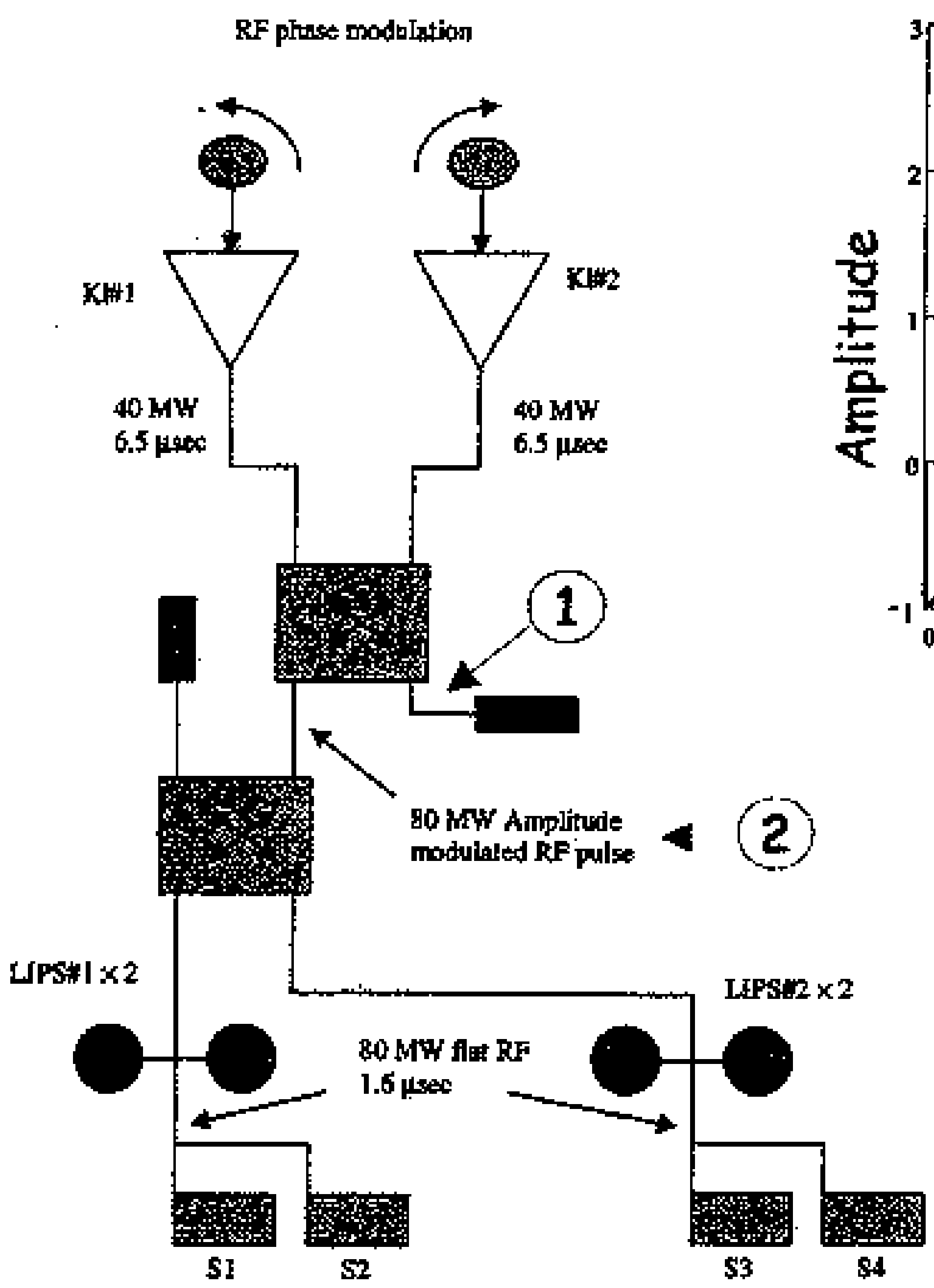


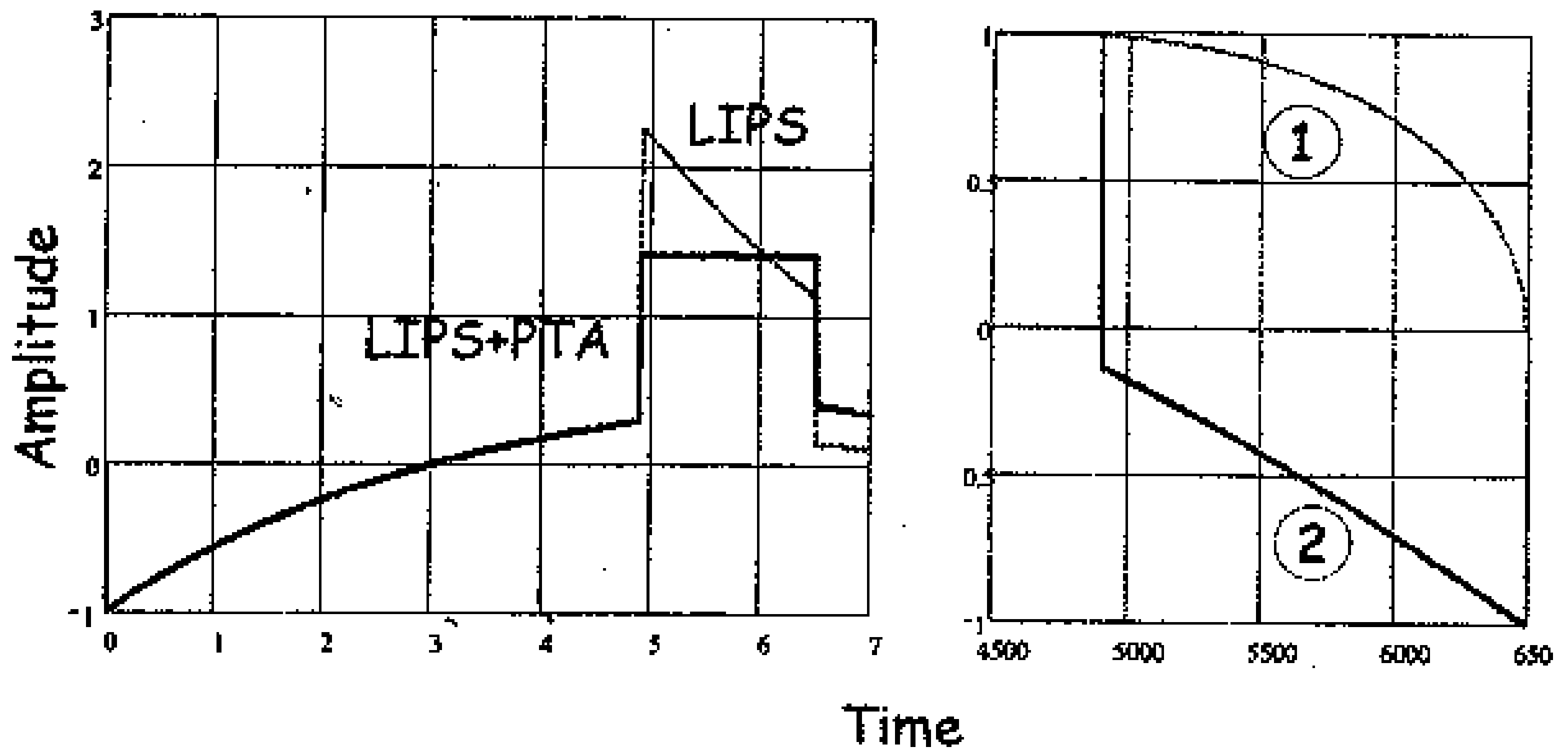




No energy spread

The flat pulse after the cavity based pulse compressor (LIPS), with modulation of the input RF phase-to-amplitude (PTA).





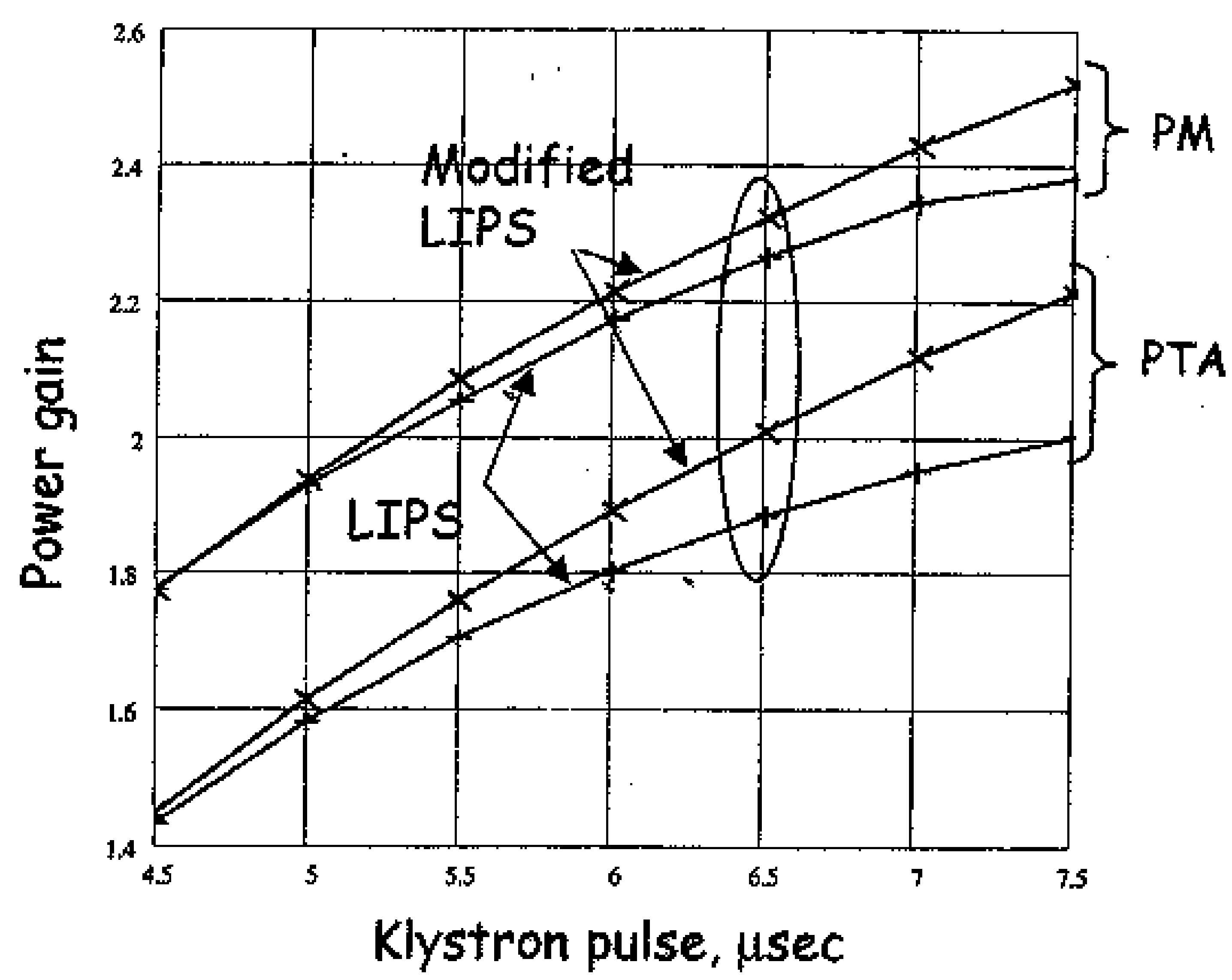
Comparison between PTA and PM

Pros:
- Output pulse flat both in RF amplitude and phase.
- Easy RF power level control.
- Better stability of operation.

Cons:
- Less efficient (~10%).
- Two klystrons needed.

RF Pulse Compression system for CTF3.

Power gain.



LIPS modification is mainly the adjusting of the cavity coupling.

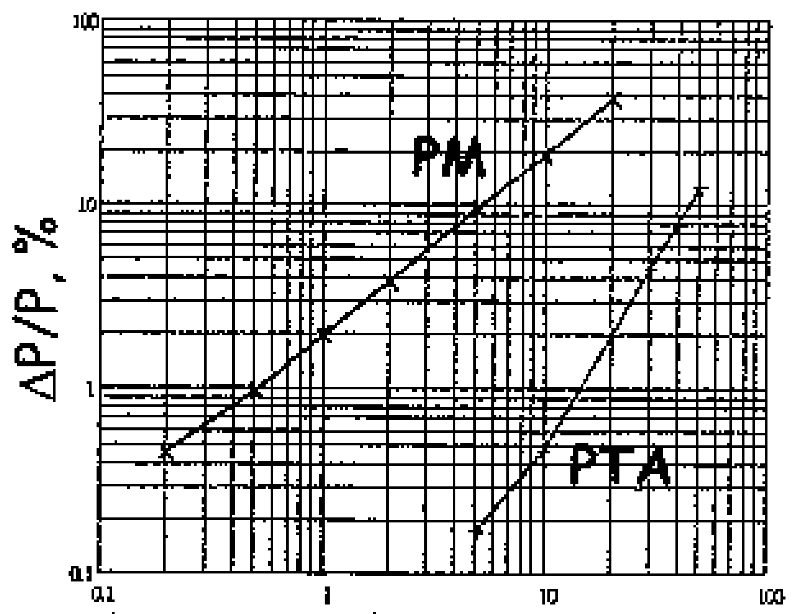
System operation stability.

Because of the energy spread, the demand on the compressed pulse flatness is:

$\Delta P/P < 2\%$

The main sources of instability:

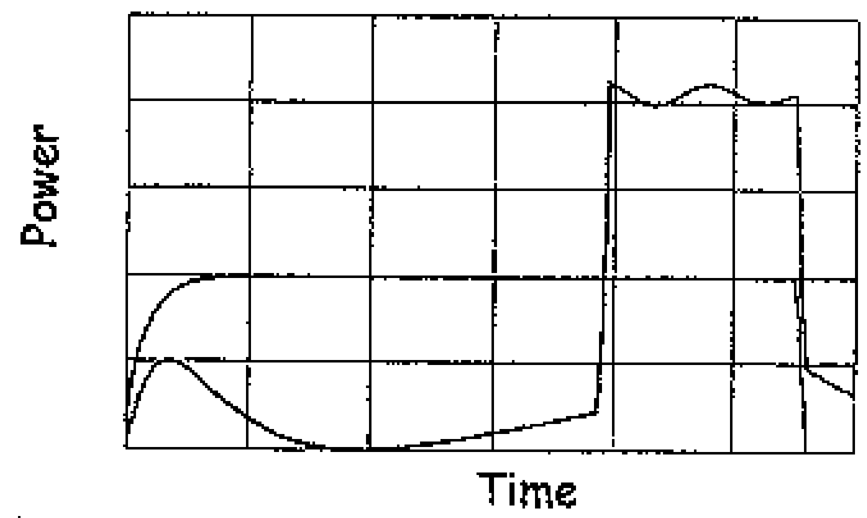
① Klystron RF phase and amplitude jitter as result of HV supply instability.



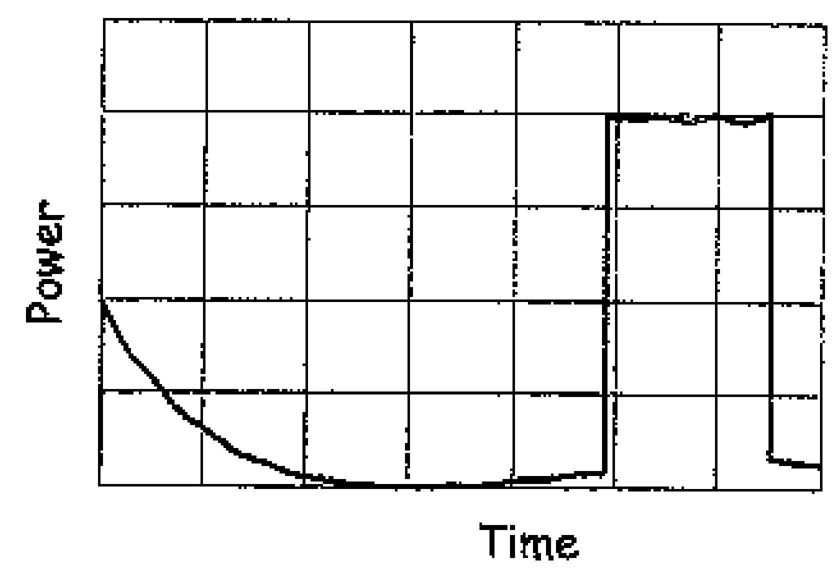
Klystron's RF phase amplitude of ripples, degree.

The examples of the compressed RF pulse distortion due to the klystron RF phase ripples.

a) RF Phase modulation. Klystron RF phase ripples 3^0 peak-to-peak.



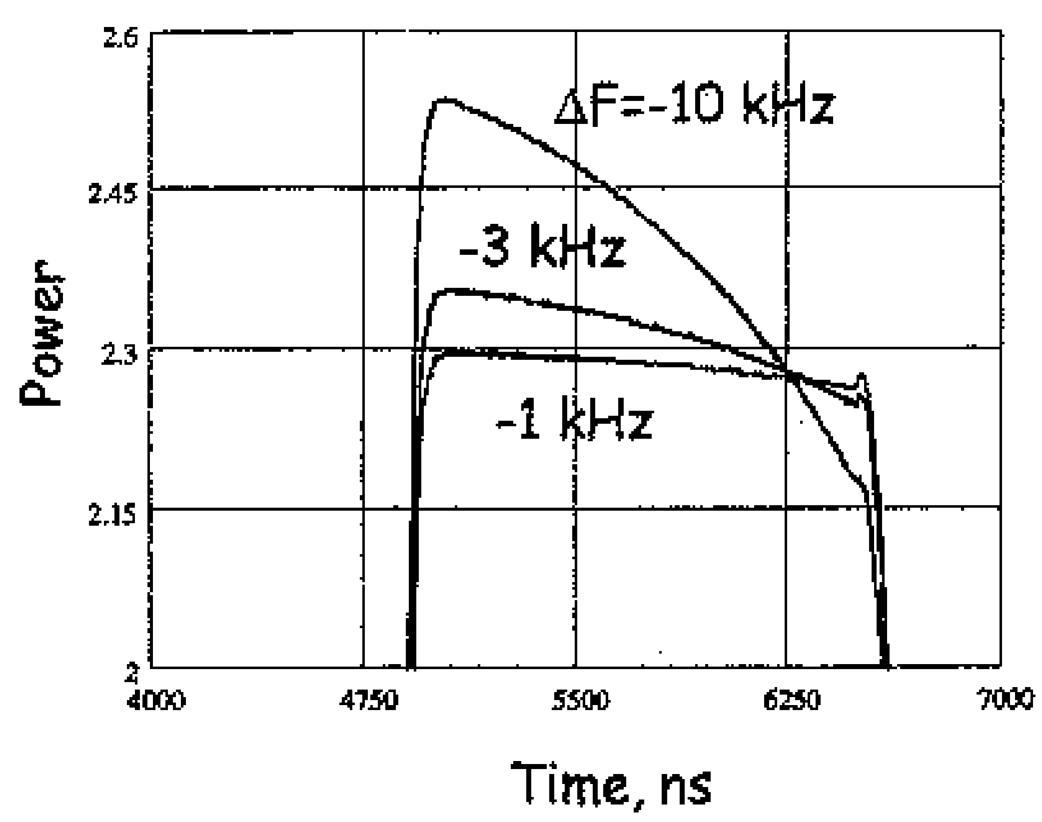
b) RF Phase-to-amplitude modulation. Klystron RF phase ripples 10^0 peak-to-peak.



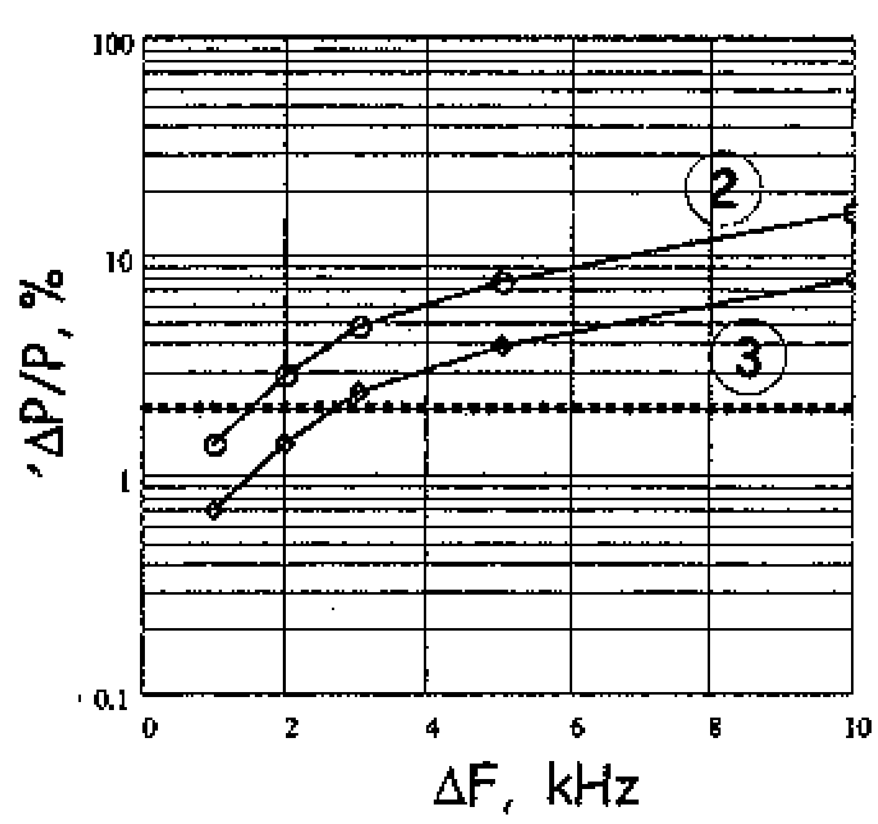
RF Pulse Compression system for CTF3.

System operation stability.

② The frequency deviation of the storage cavity, mainly because of the temperature variation.



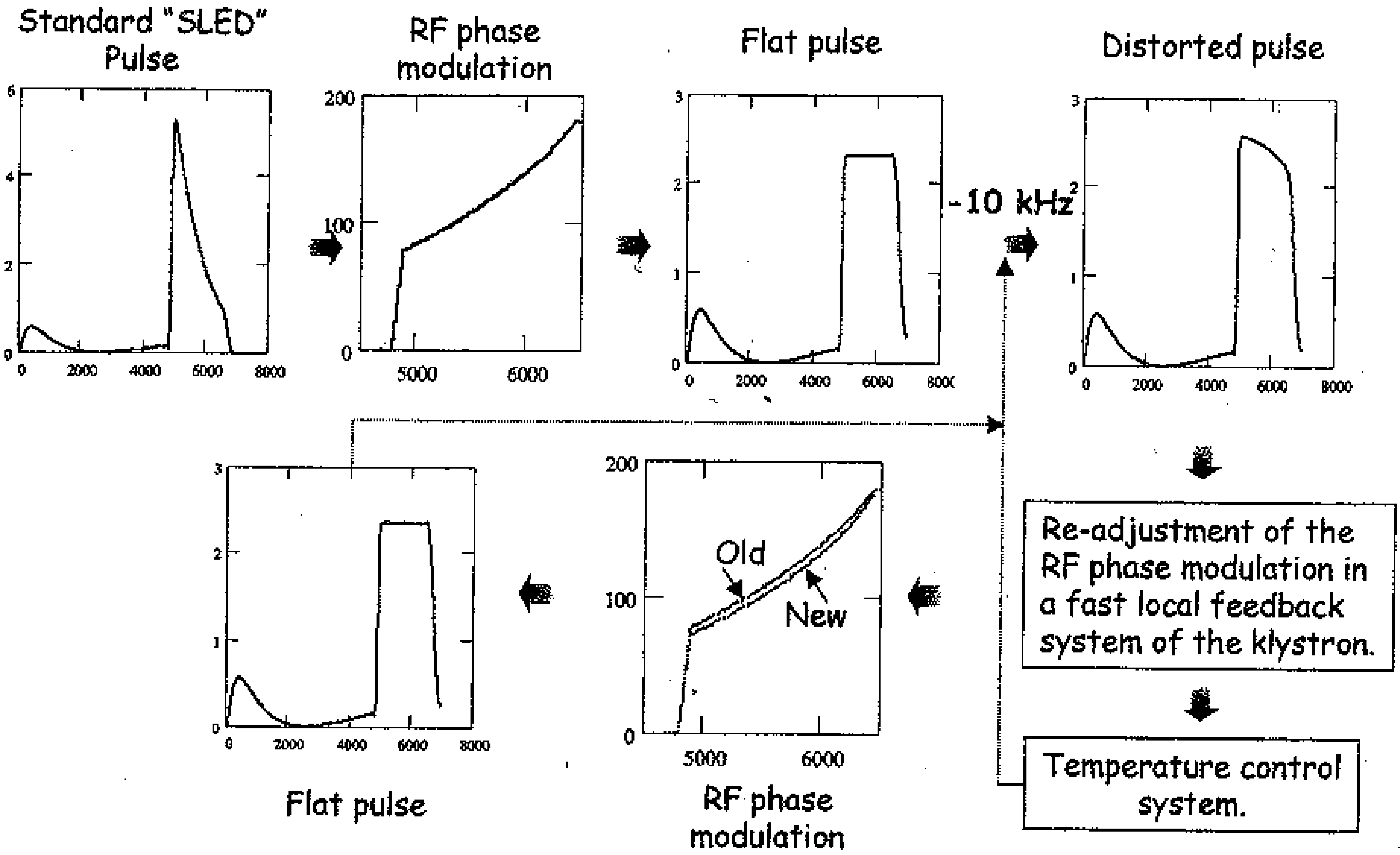
③ The identity of the LIPS cavities resonant frequencies.



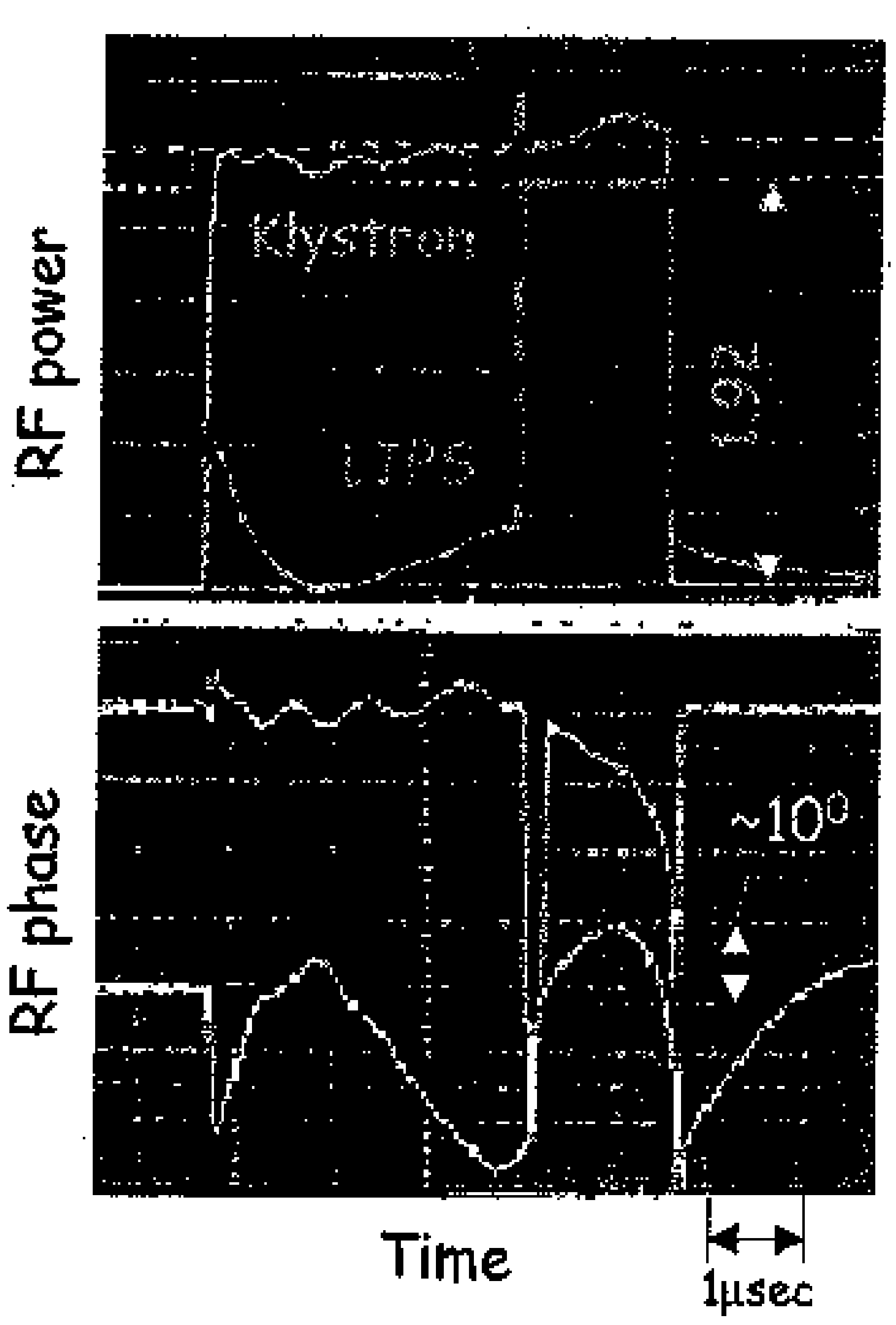
To keep the flatness of the compressed pulse within specified $\Delta P/P$, the temperature stabilization of the cavity must be < $\pm 0.04\ ^0C$.

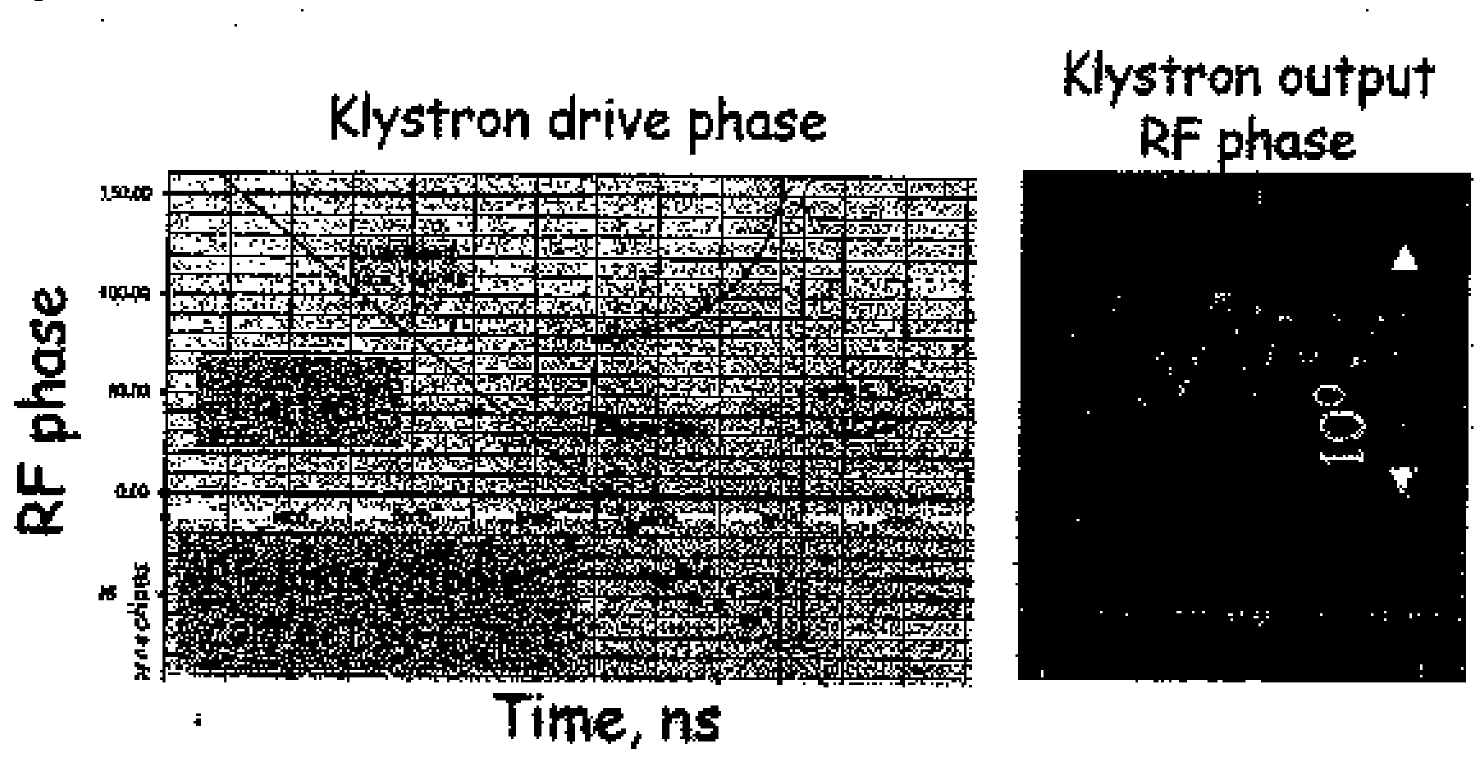
System operation stability.

Algorithm of the fast correction of the cavity frequency shift.



Experiments at a high RF power level. R. Bossart, December 2000.

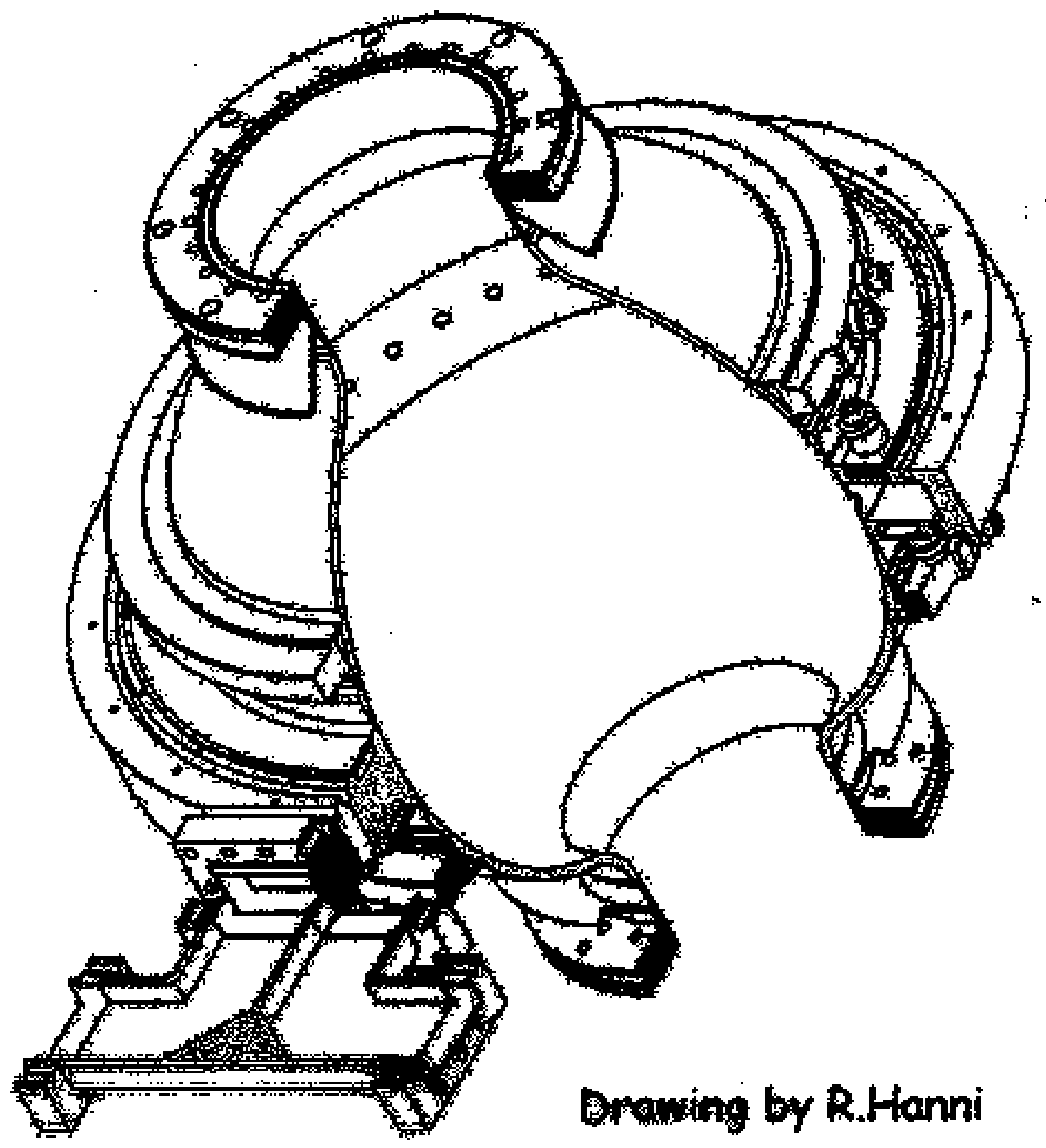




Parameters:

Q unloaded	1.6×10^5
Coupling	8.0
Tin	5 μsec
Tout	1.4 μsec
P out/in	34.7/18 MW
P gain/teor.	1.92/2.04
$\Delta P/P$	< 1%

3 GHz Barrel Open Cavity pulse compressor.



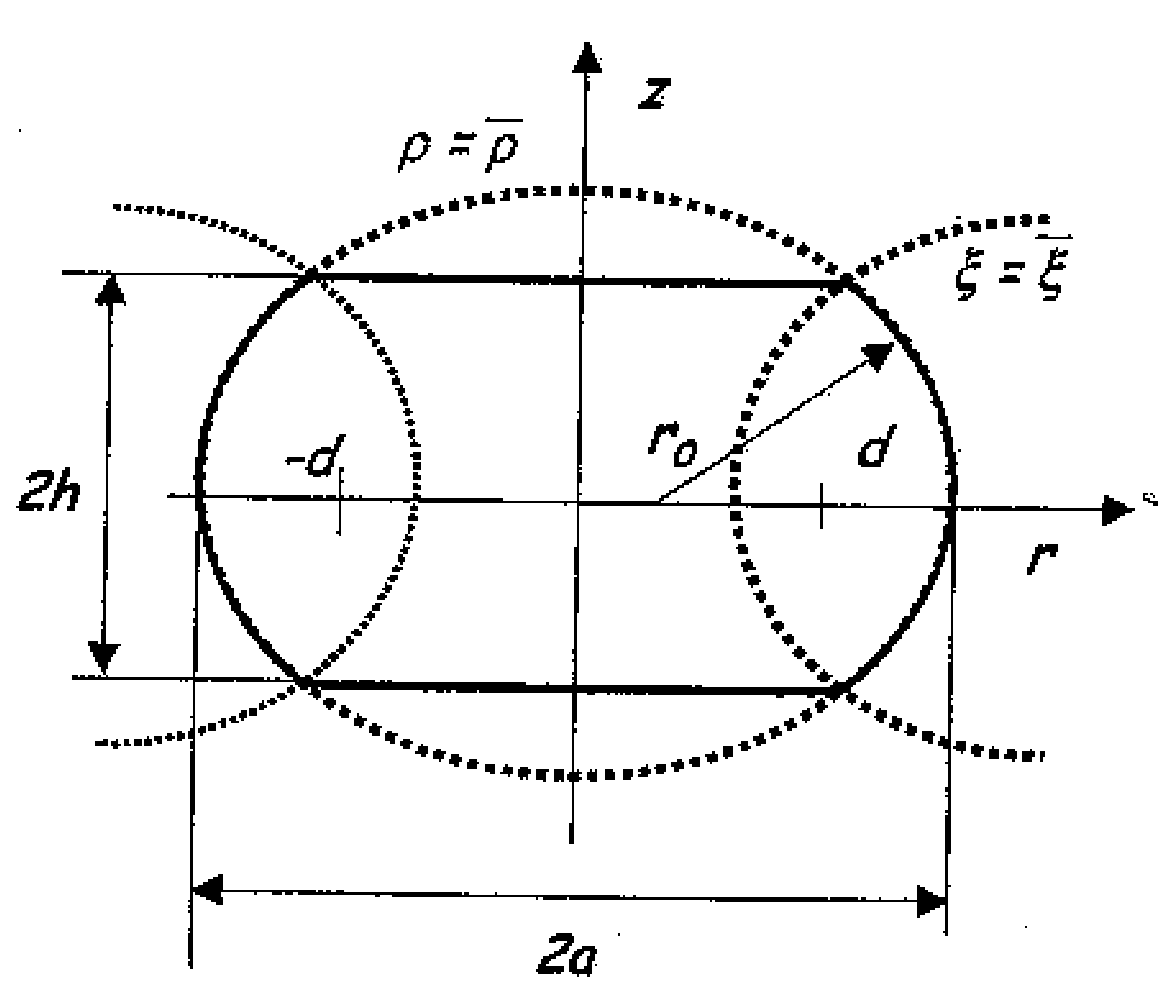
Drawing by R.Hanni

#1. We need at least four more RF Pulse Compressors.

#2. BOC Compressor operates in a TW regime utilizing single cavity:

- no needs for additional 3 db couplers and doubling the cavities,
- the system is more stable in operation.

The Barrel-cavity brief theory.



Cavity profile

$$z = \sqrt{a r_0 \left\{ 1 - \left(\frac{r}{a} \right)^2 \right\}}$$

The eigen-frequency of the Barrel cavity with E_{mnq} oscillation is the solution of the next equation:

$$ka = \nu_{mn} + \frac{(q - 1/2)\alpha}{\sin\theta}$$

ν_{mn} is a root of the Bessel function that for the big m can be approximated as:

$$\nu^0_{mn} = m - \mu t^0_n \qquad (n = 1, 2, \ldots),$$

$$-t^0_n = [(n - 0.25) 1.5\pi]^{2/3}, \qquad \mu = \left(\frac{m}{2} \right)^{1/3}.$$

The optimal radius r_0, when the external caustic has the smallest height comes from: $r_0 = 2a \sin^2\theta$ where α and θ are derived from:

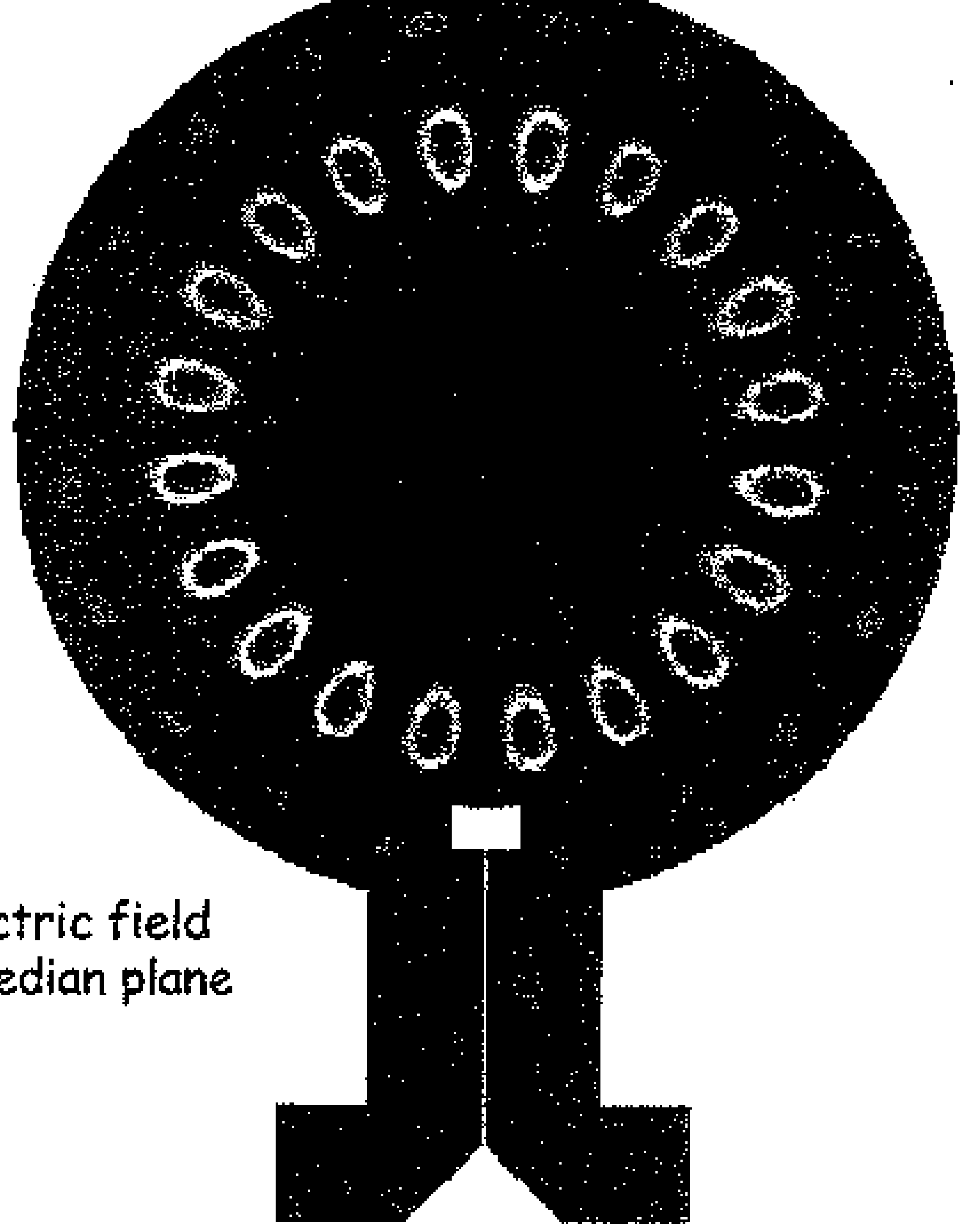
$$\sin\alpha = \sqrt{\frac{a}{r_0}} \sin\theta \qquad \cos\theta = \frac{m}{\nu_{mn}}$$

Finally the height of the external caustic and Q-factor of the cavity are:

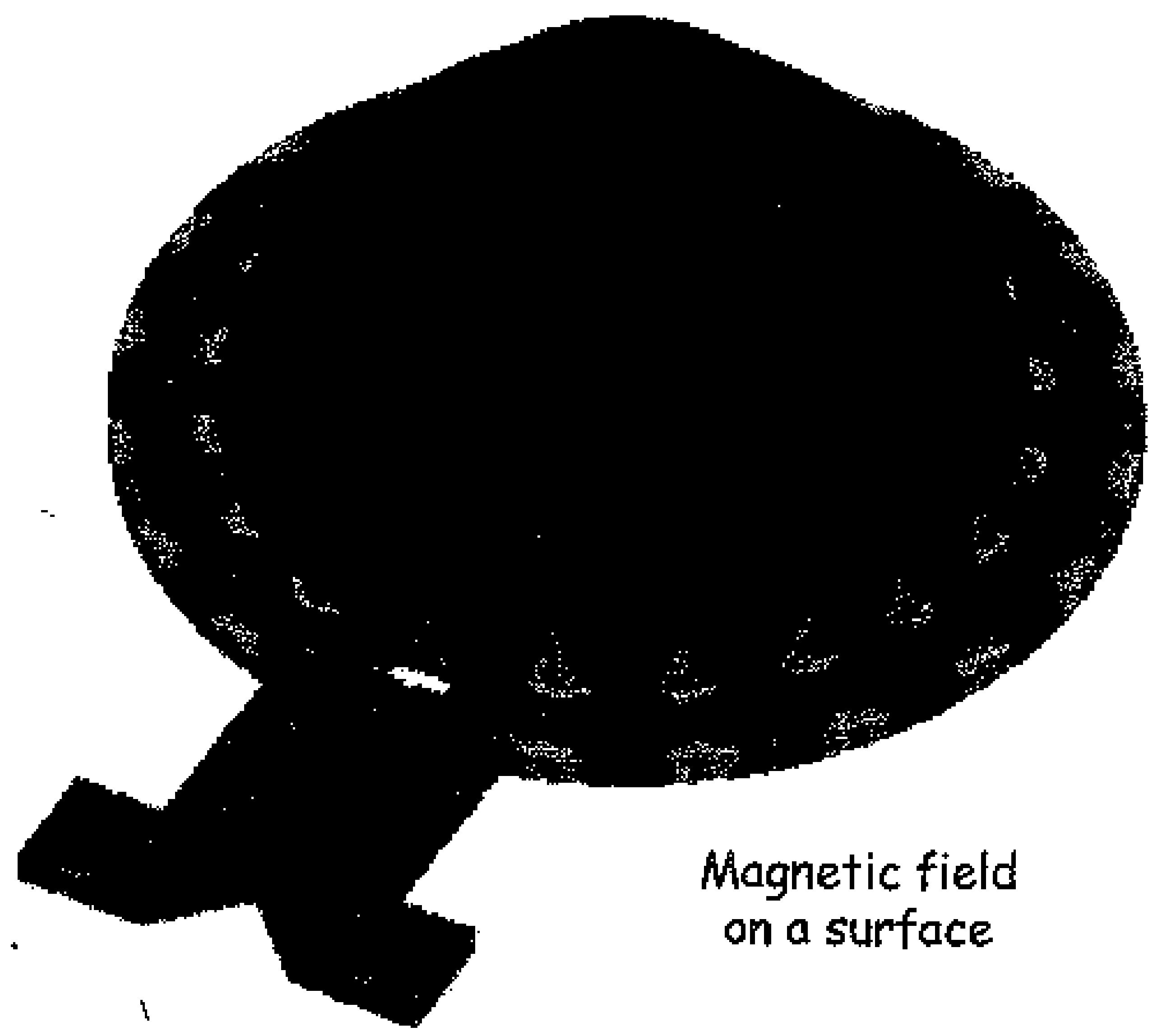
$$z_{q-1} = 2\sqrt{(q - 1/2) \frac{a \sin\theta}{k \sin 2\alpha}}$$

[redacted]

RF fields plots with BOC operating in a traveling wave regime (rotating $TM_{10,1,1}$ mode)



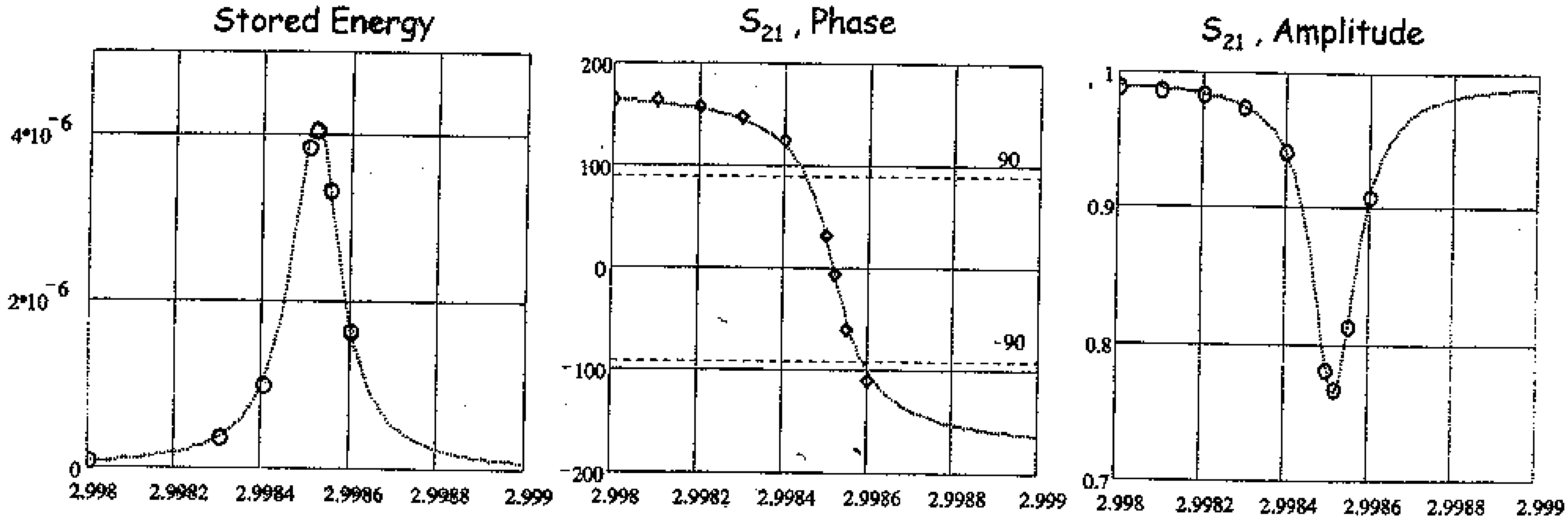
Electric field at median plane



Magnetic field on a surface

Analytical (dash) and HFSS (circles) calculation of the loaded Q-factor for the BOC with 15 mm diameter coupling holes,

Stored Energy S_{21}, Phase S_{21}, Amplitude



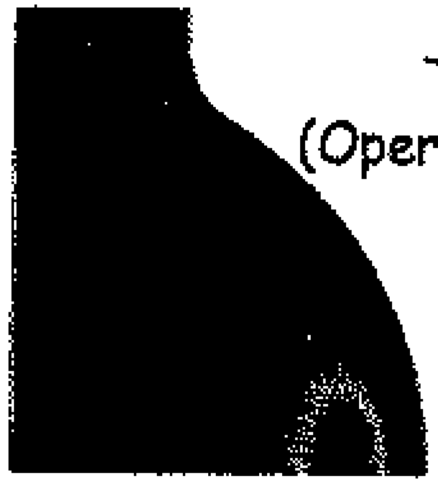
Frequency, GHz

$$W(f)=\frac{W_\infty}{1+(Q_L\Omega(f))^2} \qquad \Psi(f)=\frac{Q_L\Omega(f)}{1+(Q_L\Omega(f))^2} \qquad \Gamma(f)=\sqrt{1-\frac{\alpha^2(\beta)/\beta}{1+(Q_L\Omega(f))^2}}$$

$$W_\infty=\tau(\beta)\times\alpha(\beta)\times P_{RF} \quad \Omega(f)=\frac{f}{f_0}-\frac{f_0}{f} \quad \tau(\beta)=\frac{2Q_0}{\omega(\beta+1)} \quad \alpha(\beta)=\frac{2\beta}{\beta+1} \quad Q_L=\frac{Q_0}{\beta+1}$$

$Q_0 = 1.95\times10^5$, $F_0 = 2.99852$ GHz, $\beta = 7.8$

Modes separation.



$TM_{10,1,1}$ (Operation mode)

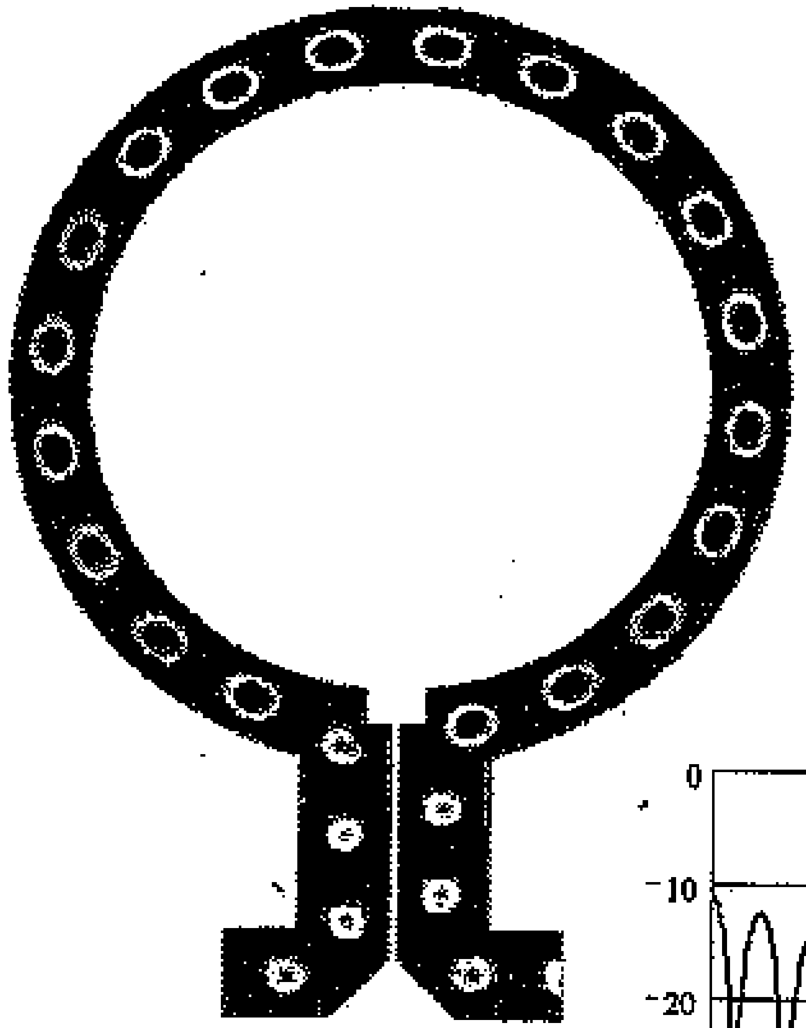
2.998 GHz

$TM_{8,1,3}$

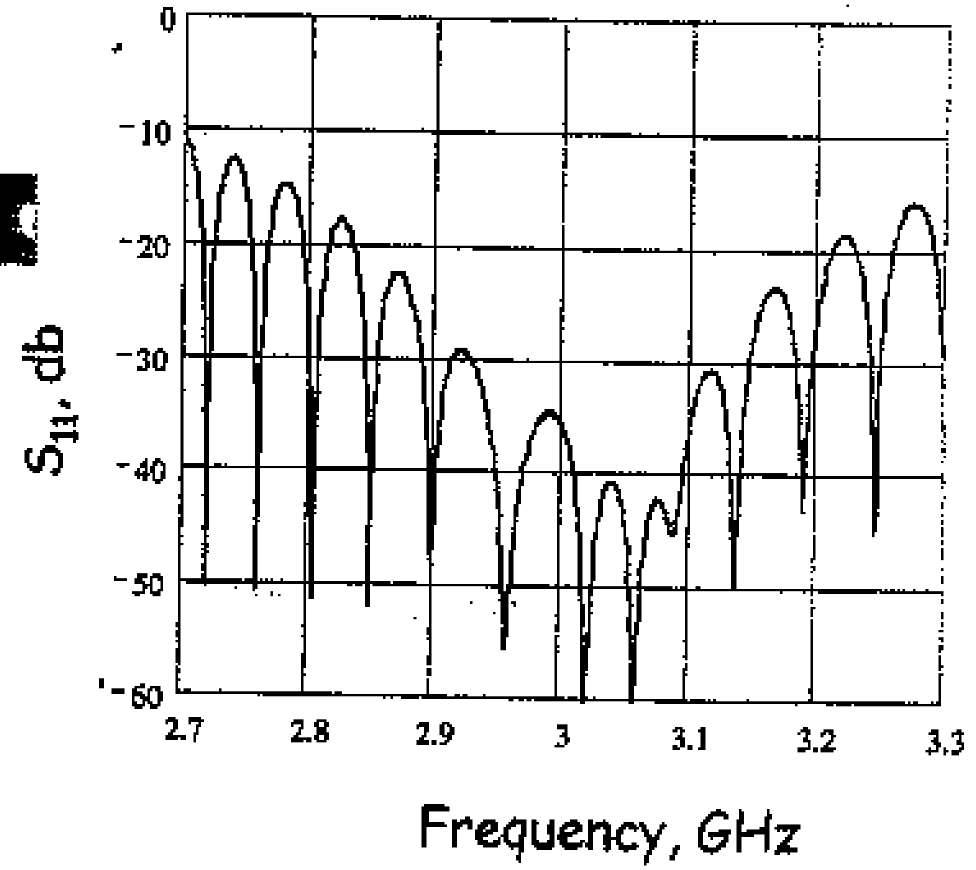
3.0134 GHz

$TM_{6,1,5}$

3.0215 GHz



Waveguides matching.



Mechanical Design of BOC cavity

R. Losito
CERN-SL/CT

The Team (SL/CT Group)

- **Raymond Hanni**
  - Responsible for the definition of the fabrication procedures and follow-up
- **Sebastien Marque**
  - Numerical simulations, cooling design
- **Sylvain Gyrod**
  - draughtsman
- **Myself**
  - RF stuff....

Table of contents

- Specs
  - (Igor, Igor…)
- Design, Simulations & Solutions
- Conclusions

Specs

- Frequency: 2998.550 MHz
- Pulse shape:
  - 4.5÷6 μs, 5÷25 Hz rep. rate
- Power:
  - 40 MW from source
  - 1750 W average loss on walls (6 μs, 25 Hz)

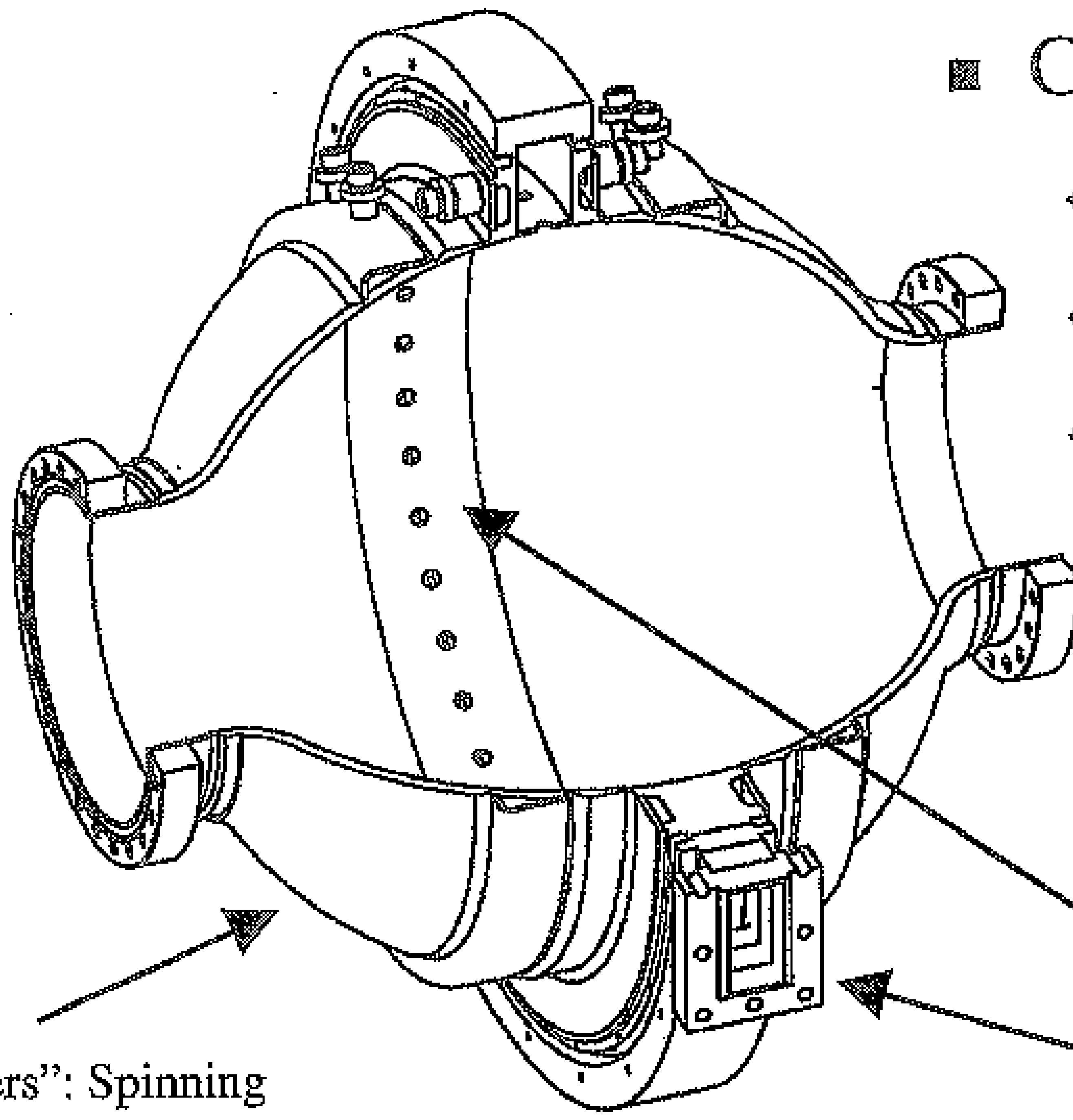
Specs

- Tuning Strategy: by water cooling.
  - Range: ± 250 kHz (± 0.0085% !!!)
- Consequences:
  - must be insensible to pressure variations ⇒
  - cavity must be very stiff ⇒
  - good precision for manufacturing.

Specs

- How to get the ideal frequency???
  - Cut & try: sensitivity is few MHz/mm at the equator.
- Proposed final fine tuning is through electrolytic etching
  - (but we would like to avoid it).

Design



- Cavity Material : OFE Copper
  - Thermal Conductivity: 400 W/m/K
  - Specific Heat: 385 J/Kg/K
  - Yield stress: 200 MPa

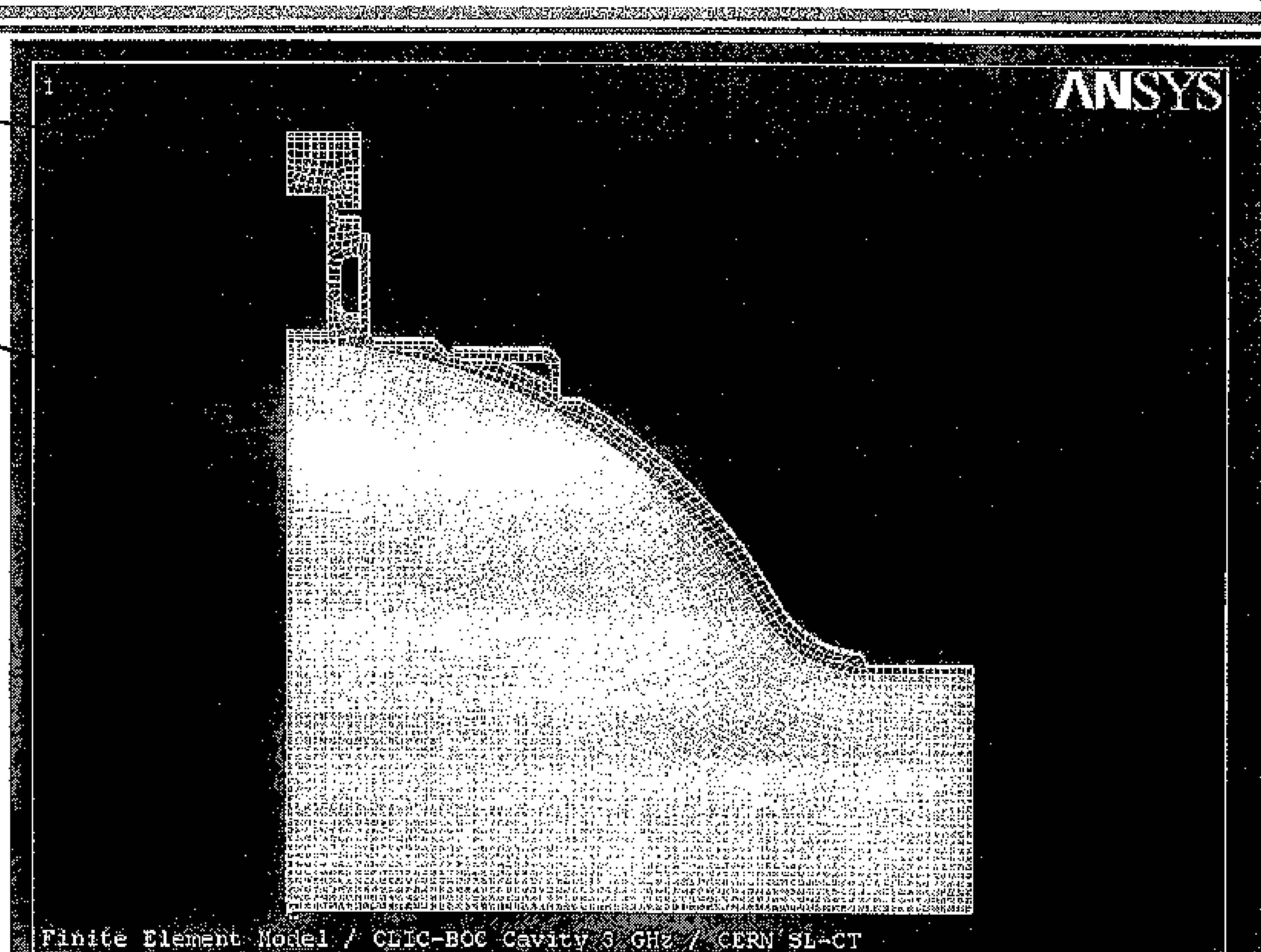
"Shoulders": Spinning

Equator + Waveguide:
Machined then EB welded

Simulations

Mechanical/Thermal elements

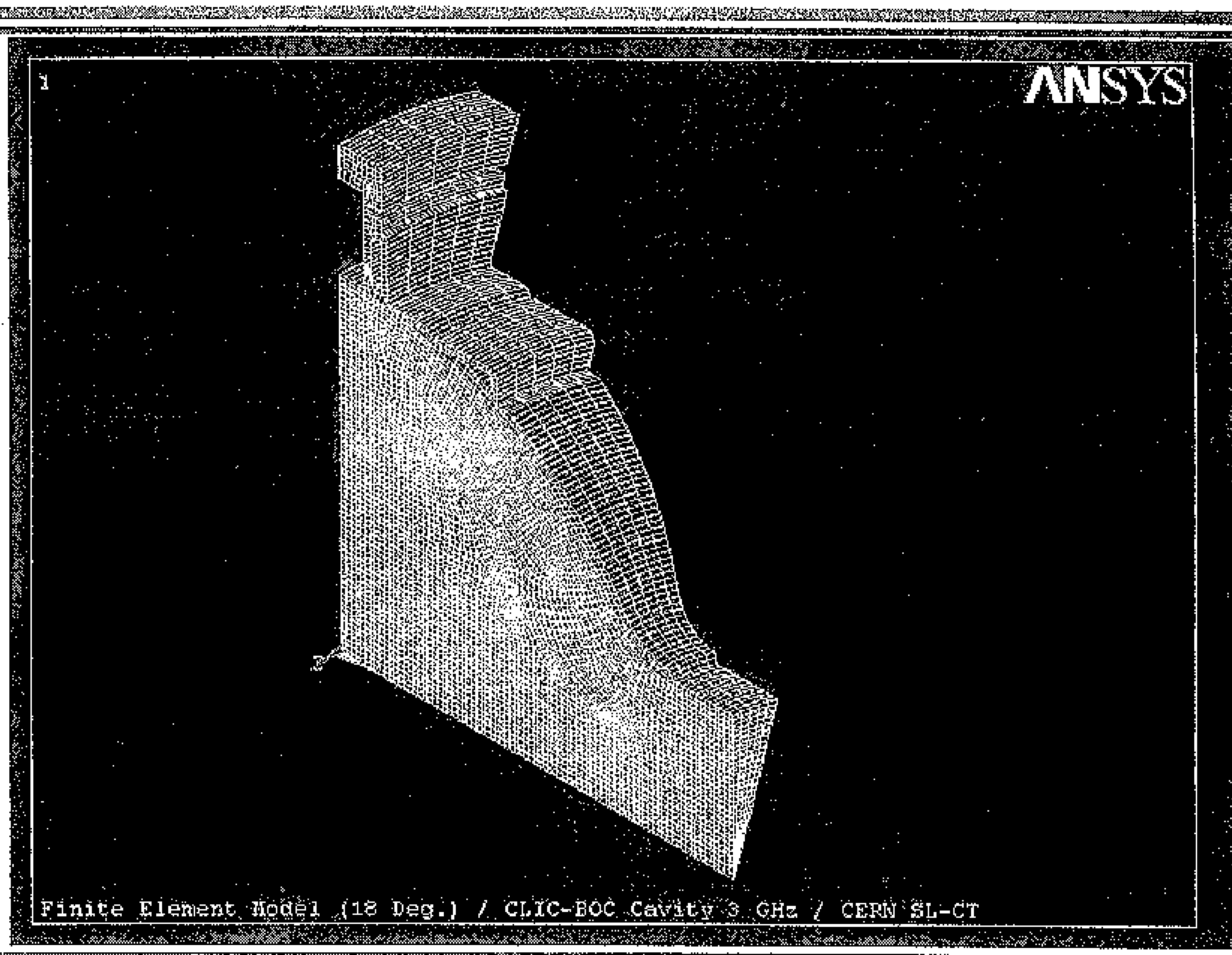
RF elements



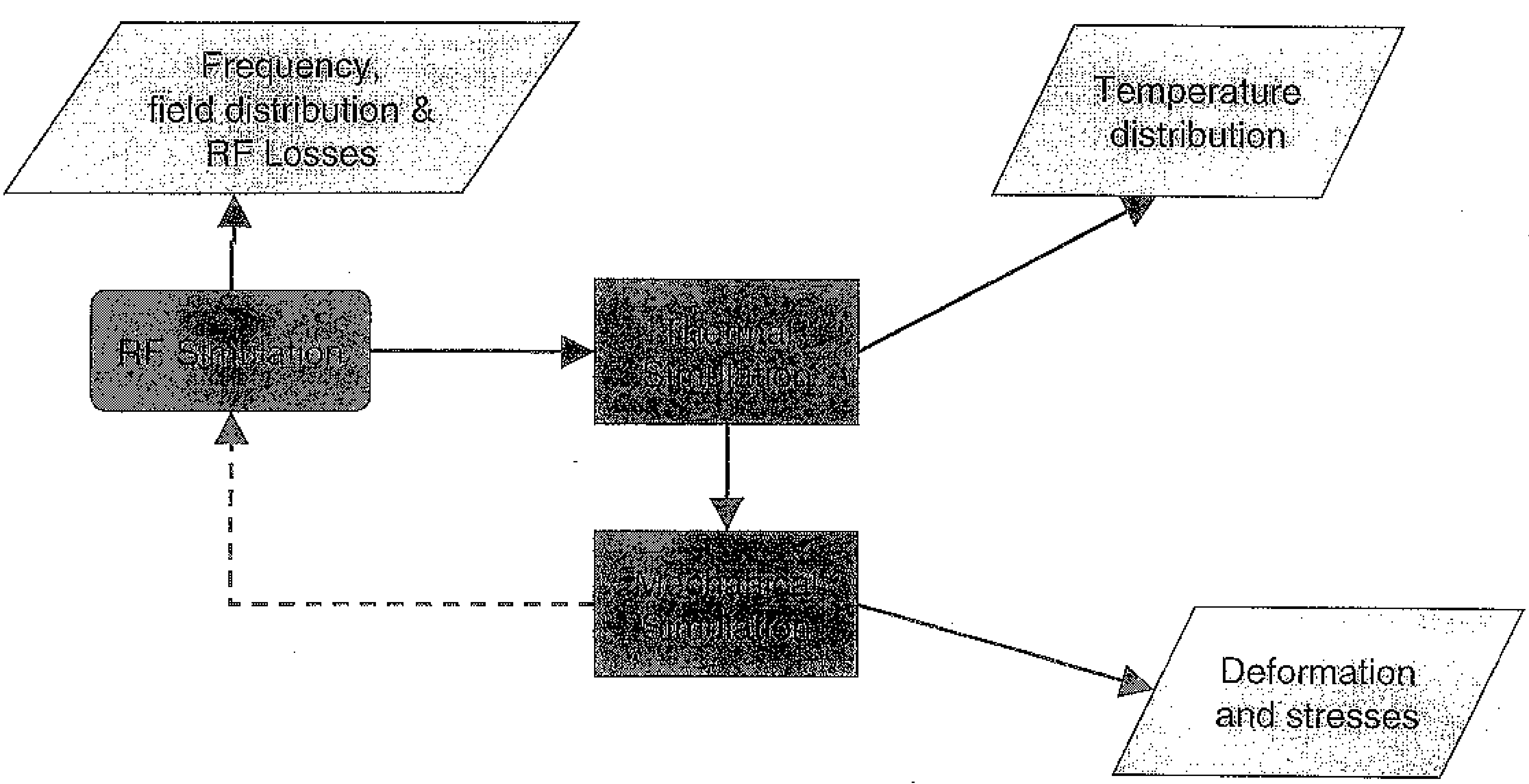
- Coupled Rf and Mechanical simulations made with ANSYS™

Simulations

- Drawback: only 3D elements are available for RF

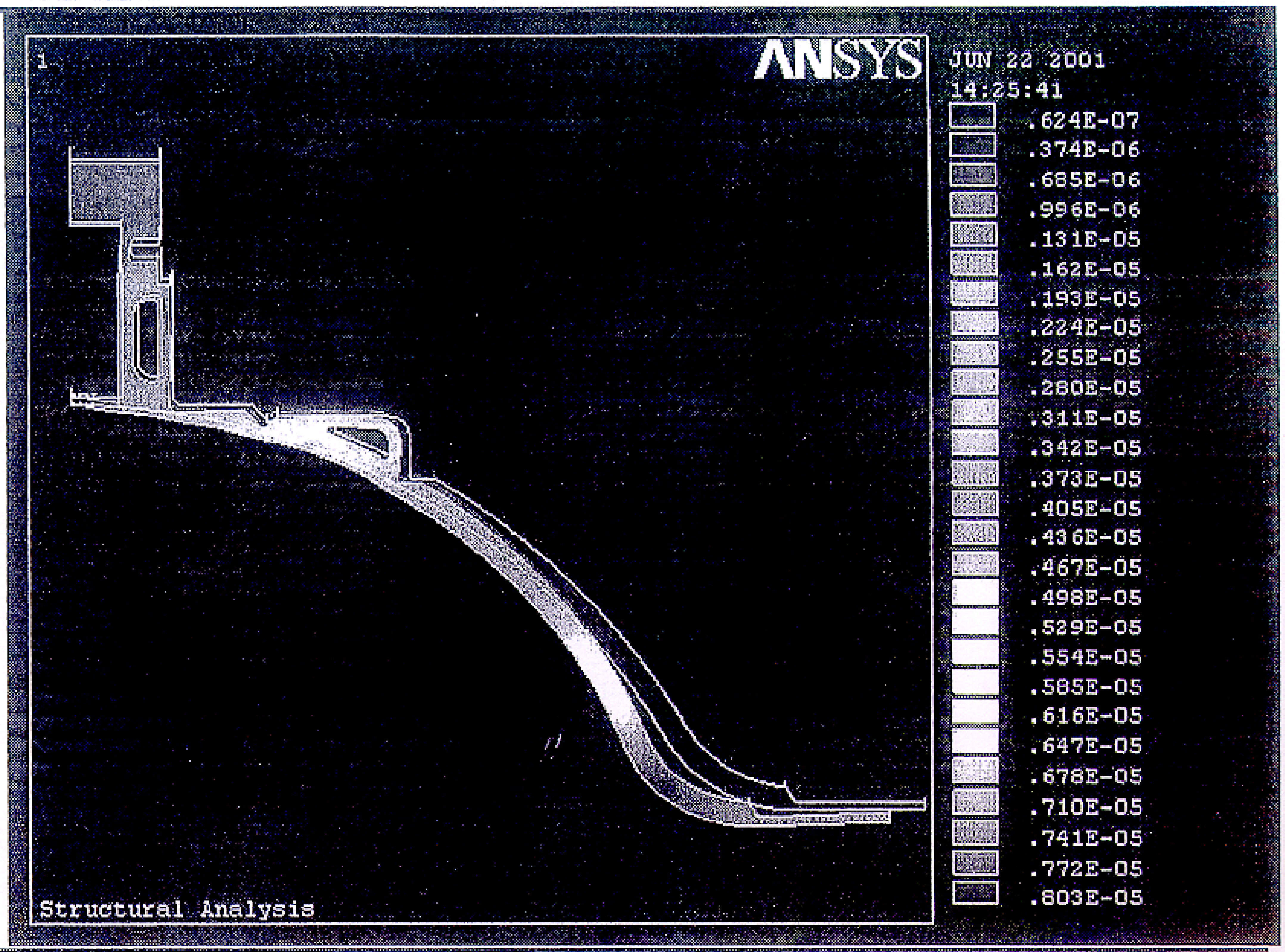


Simulations



Simulations

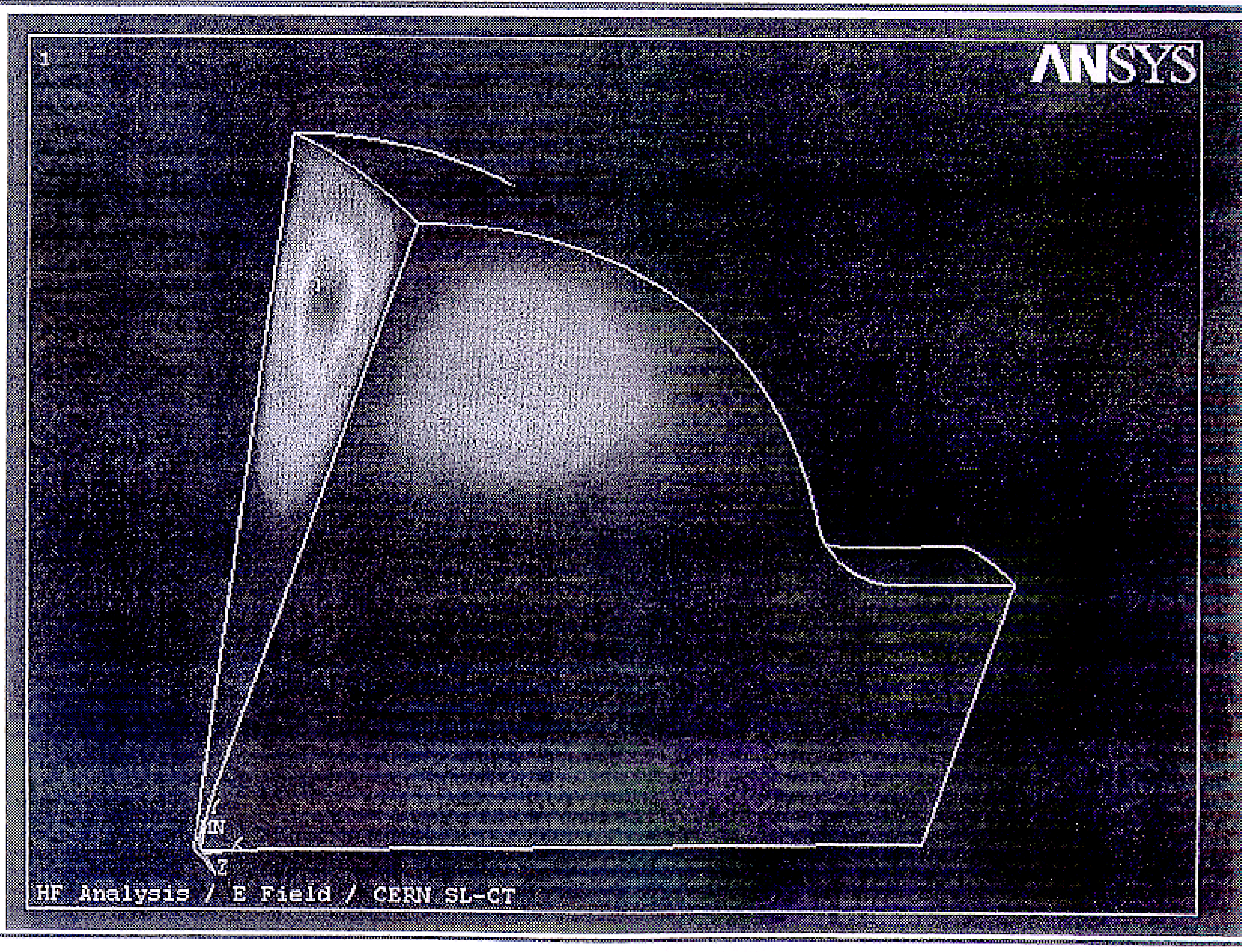
- Deformation due to Δp=1 Bar
- Max $|\Delta x|$=8μm
- Δf=8 KHz



Simulations

- Mode $E_{10,1,1}$:

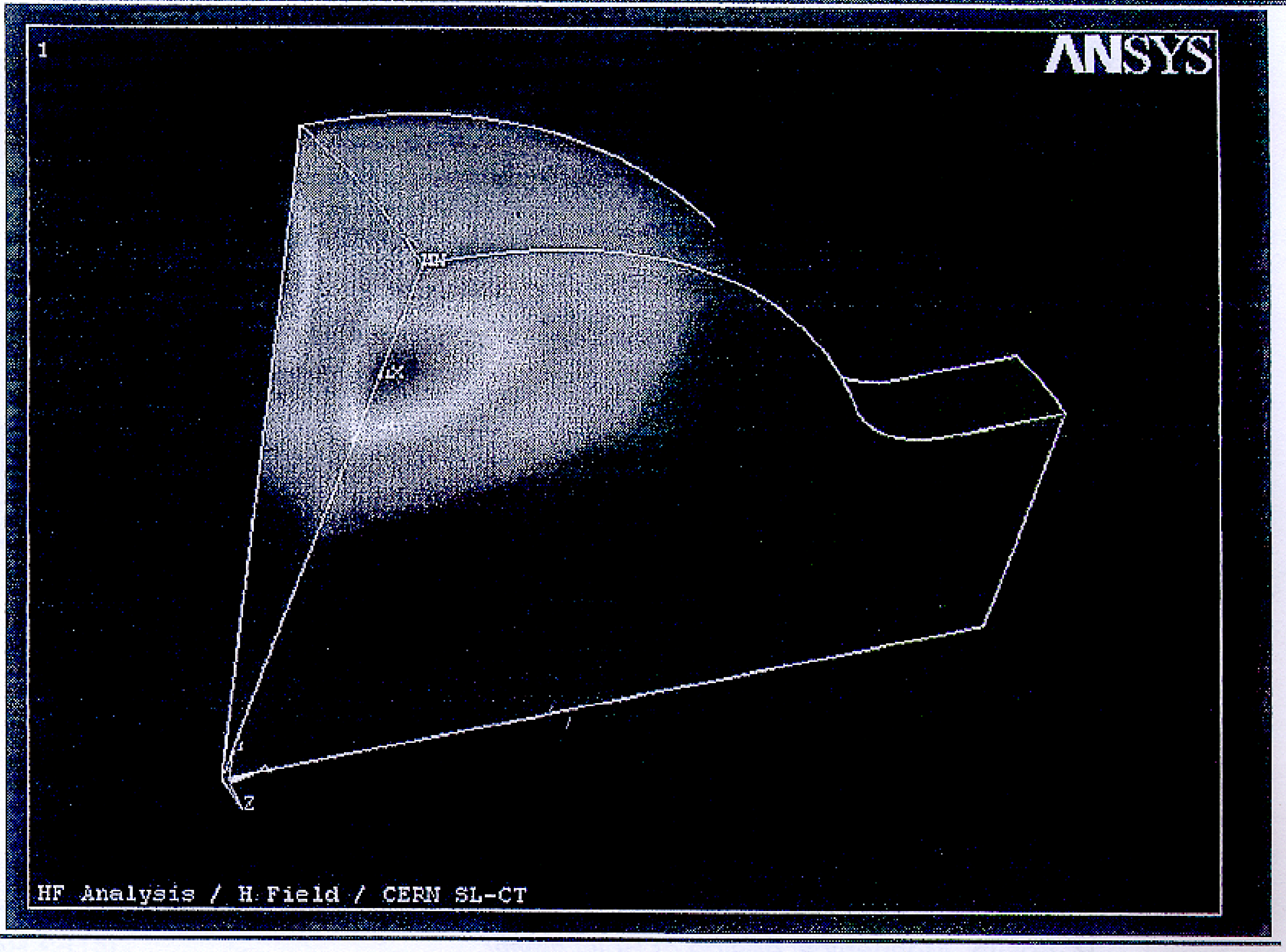
  E-Field



Simulations

- Mode $E_{10,1,1}$:

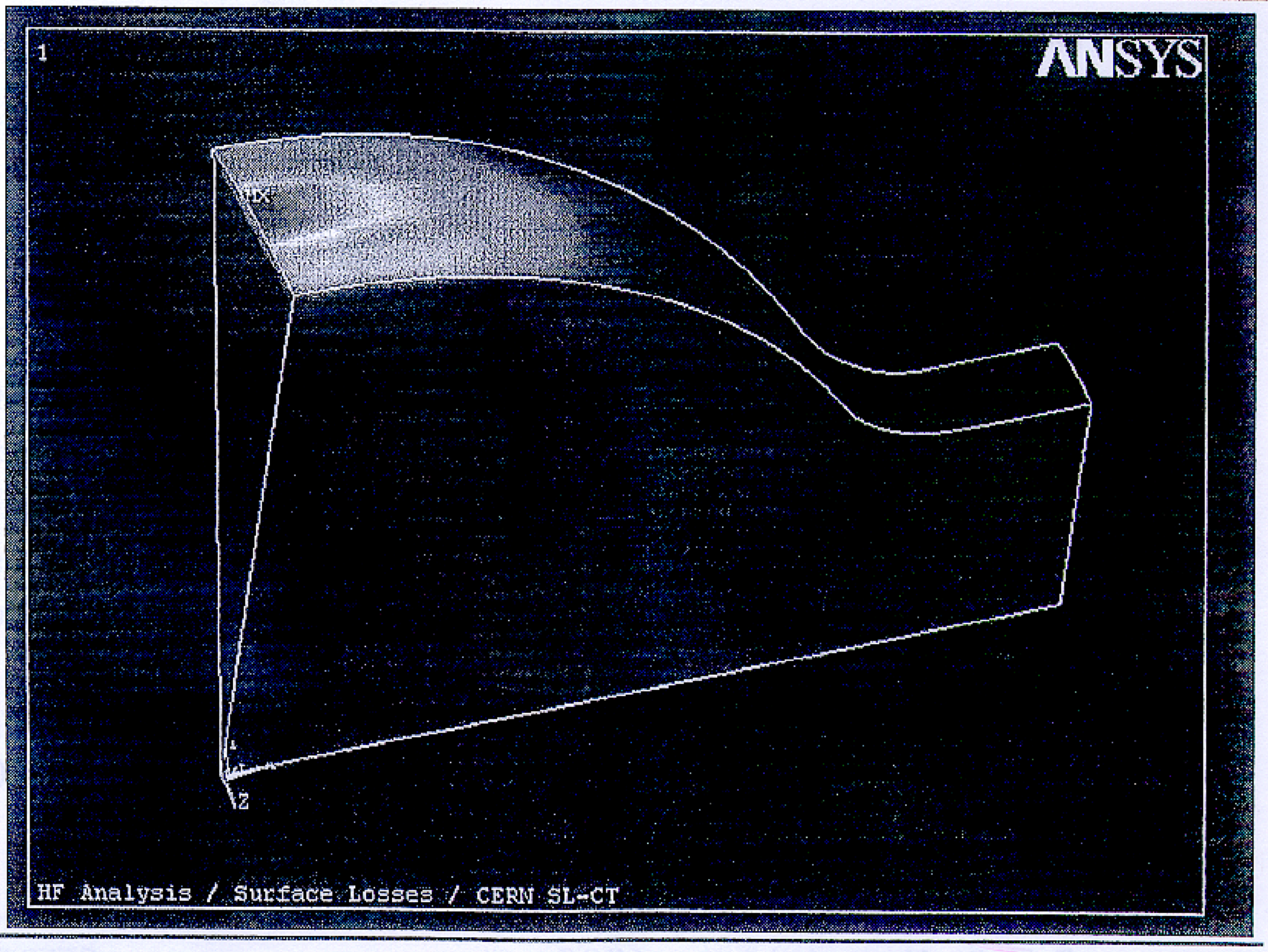
  H-Field



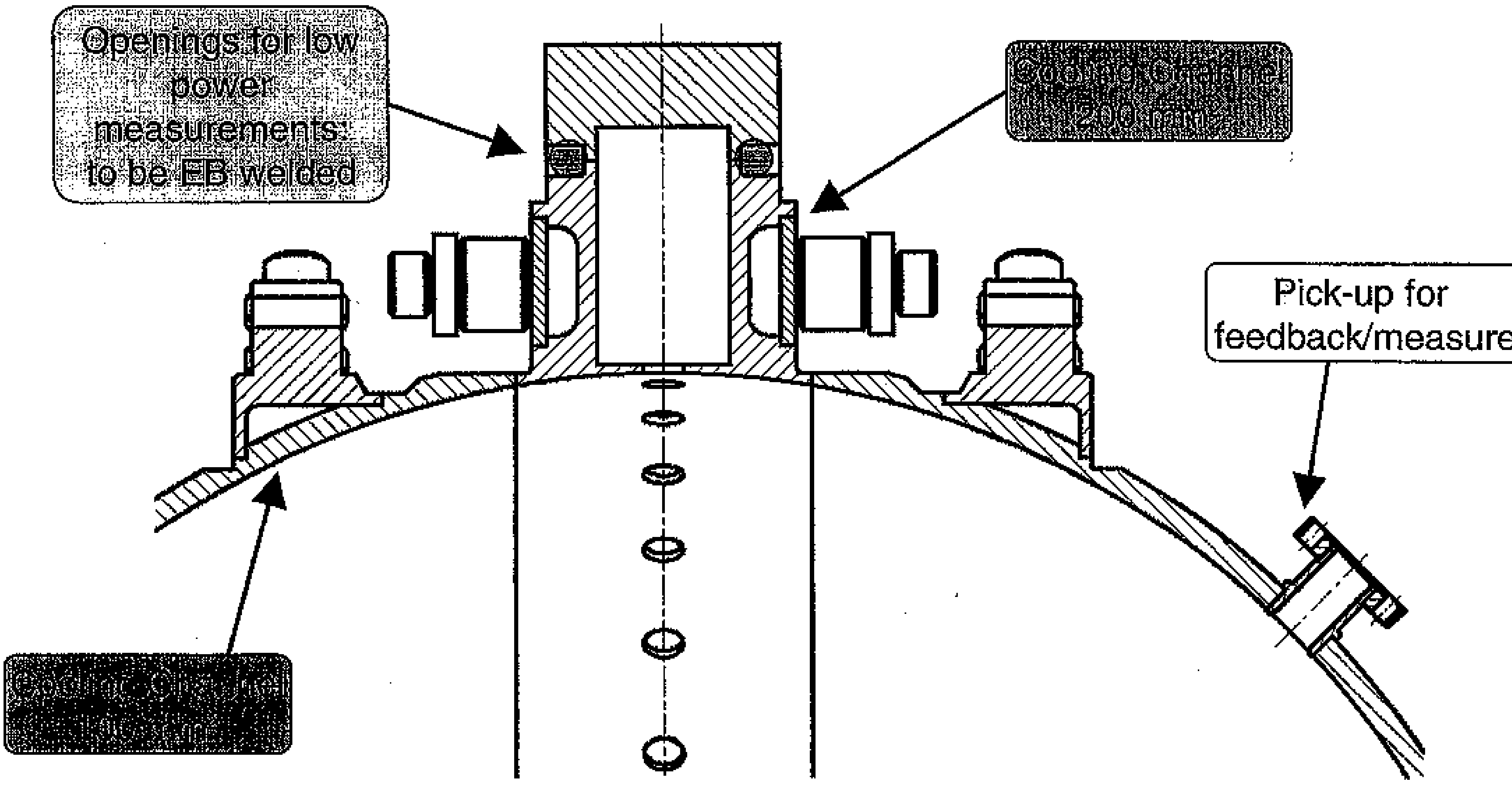
Simulations

- Mode $E_{10,1,1}$:

  Losses



Solutions



Design

- Demineralised Water
- Power to be dissipated : 1750 Watts
- Temperature rise for water: 1 K
- Coolant velocity < 2.5 m/s
- Turbulent regime

Water cooling Specs

- Water Flow:
  - 1 m^3/h for the waveguide cooling channels
  - 0.5 m^3/h for the shoulders' cooling channels
- Global Exchange coefficient :
  - 4700 $W/m^2/K$ for the waveguide cooling channels;
  - 7800 $W/m^2/K$ for the shoulders' cooling channels;
- Total Pressure Drop : 0.2 Bar
- Coolant Velocity : 1.3 m/s;
  Reynolds Number : 18000;

Simulations

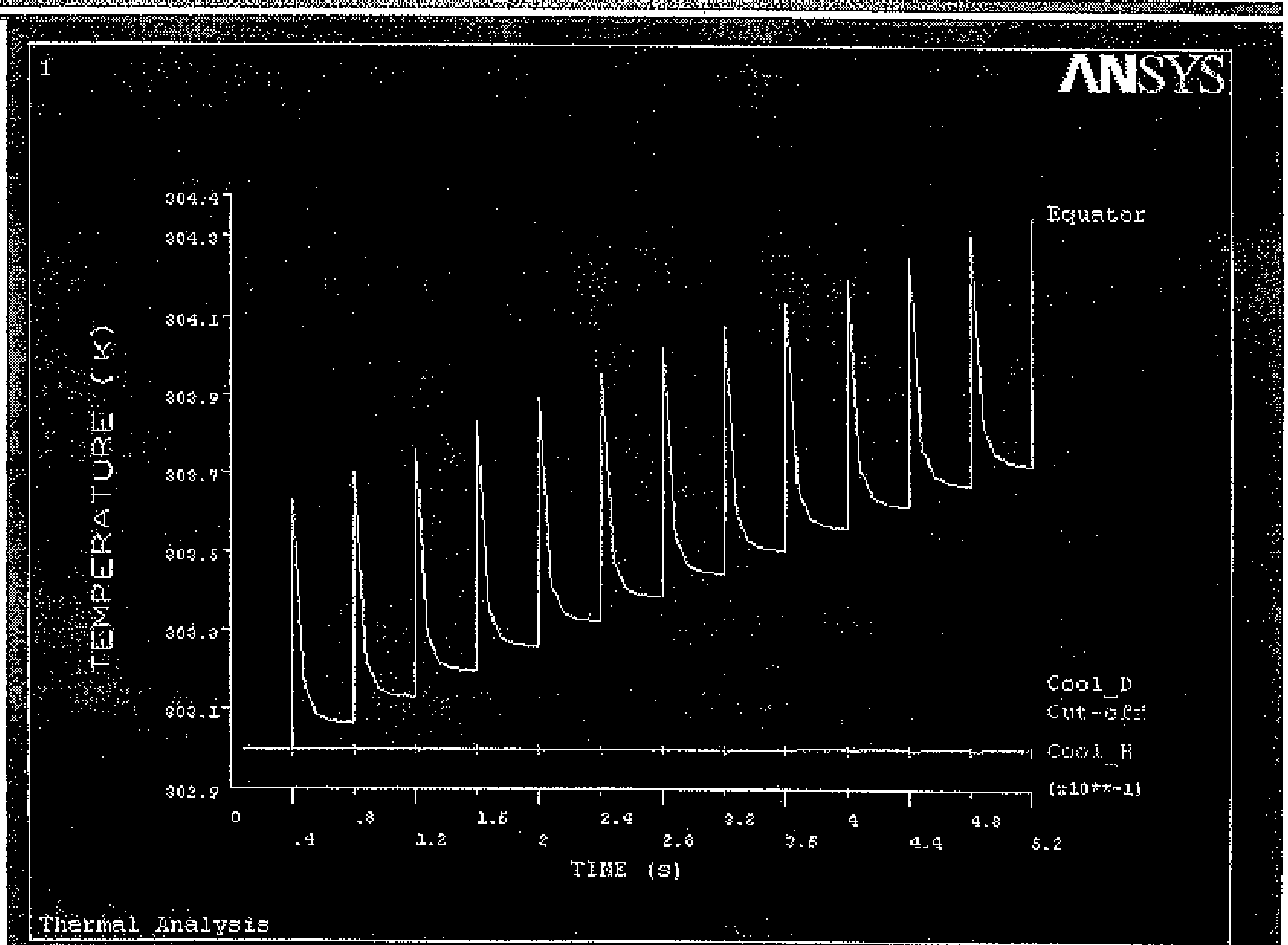
$$f = 2998.550 \quad MHz; \qquad Q = 180000; \qquad P_f = 40\ MW;$$

$$\beta = 6; \qquad \alpha = \frac{2\beta}{\beta + 1}; \qquad \tau = \frac{2Q}{\omega(\beta + 1)};$$

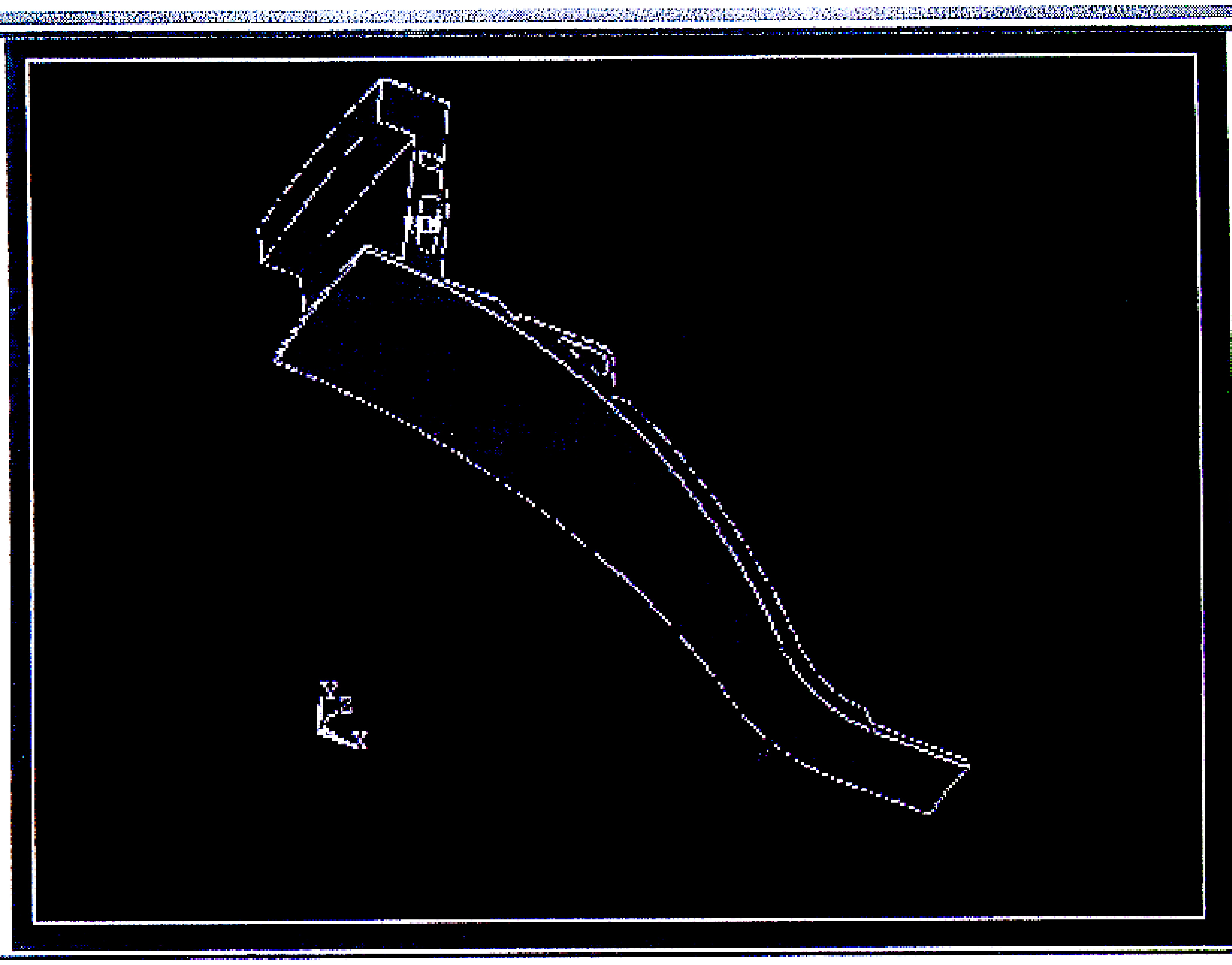
$$W = \tau\,\alpha\left(1 - e^{-\frac{t}{\tau}}\right)P_f; \qquad P_{diss} = \frac{\omega W}{Q}$$

Simulations

- 12 cycles, 25 Hz (0.52 sec)
- Max stored Energy: 148 J
- Coolant temperature: 303K

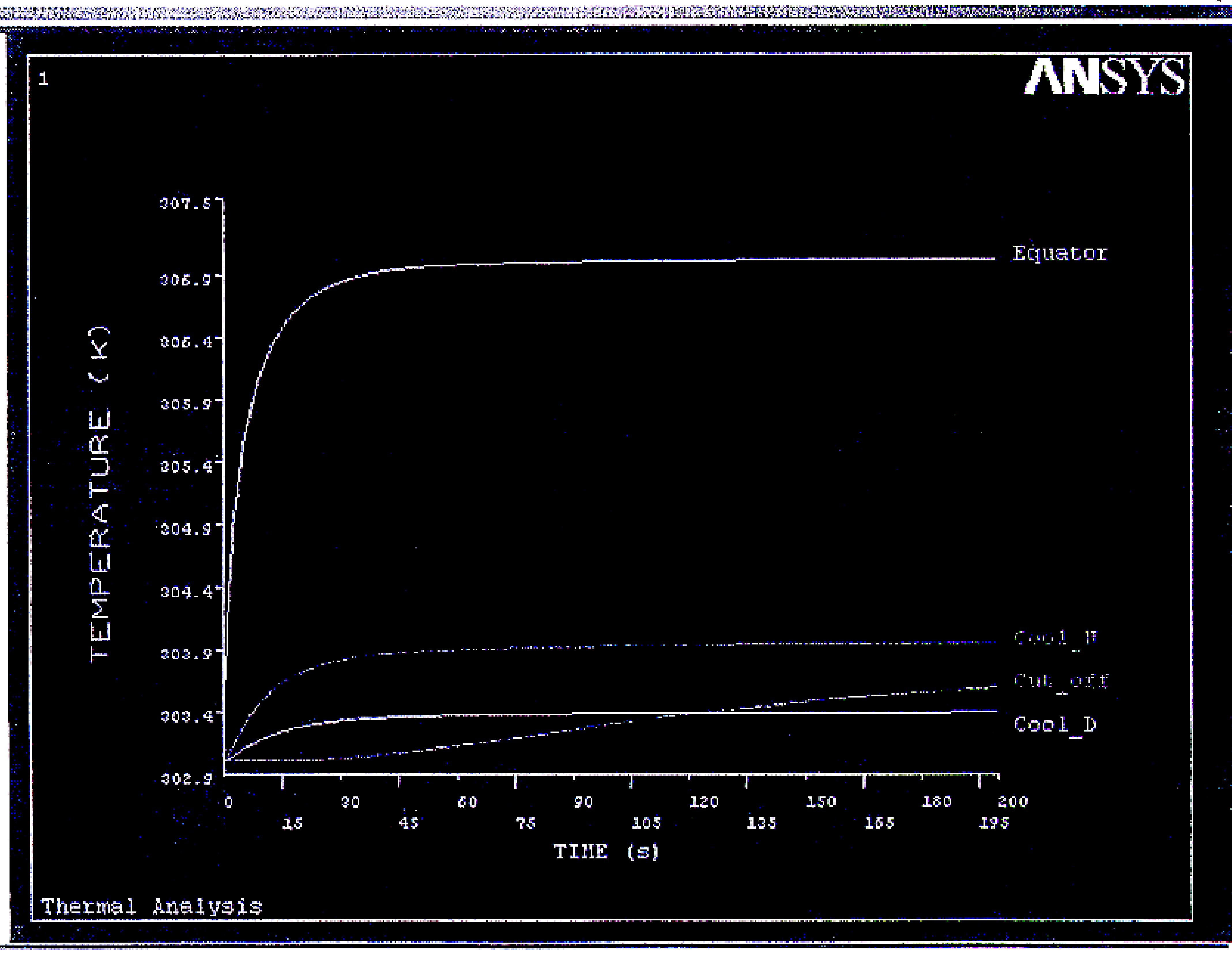


Simulations

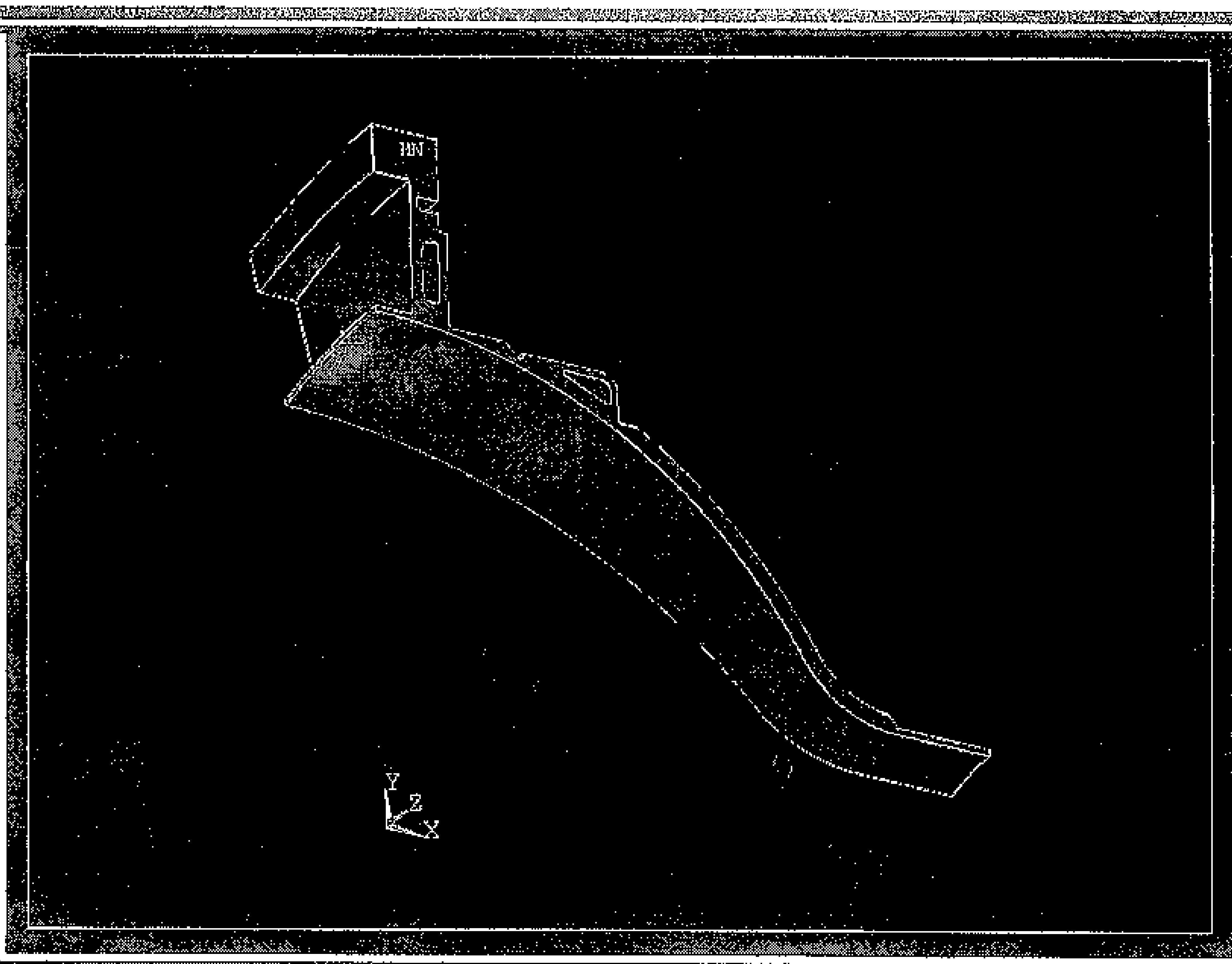


Simulations

- Response to step with average power: 1750 W
- Max Δt=4K
- Max |Δx|=6μm

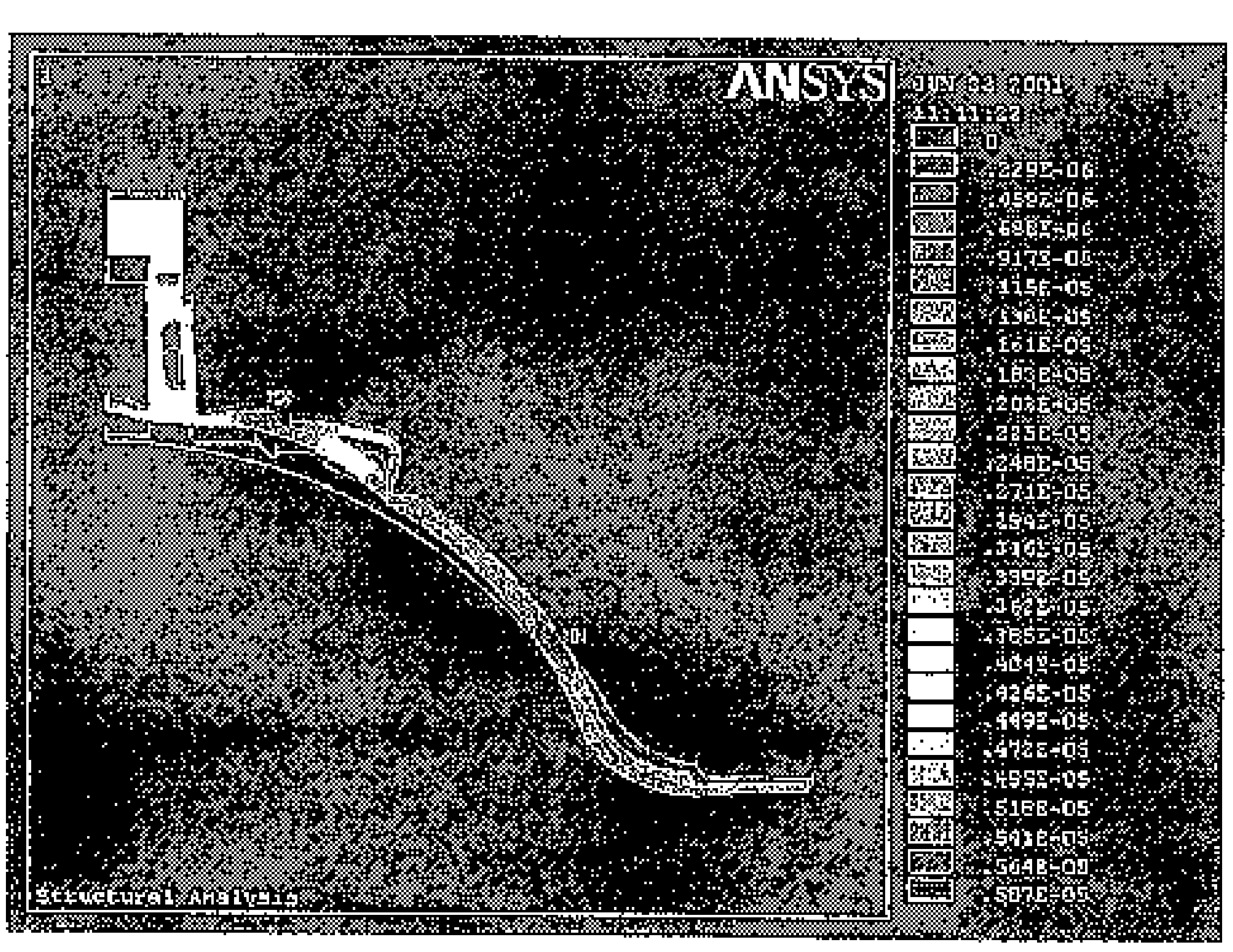


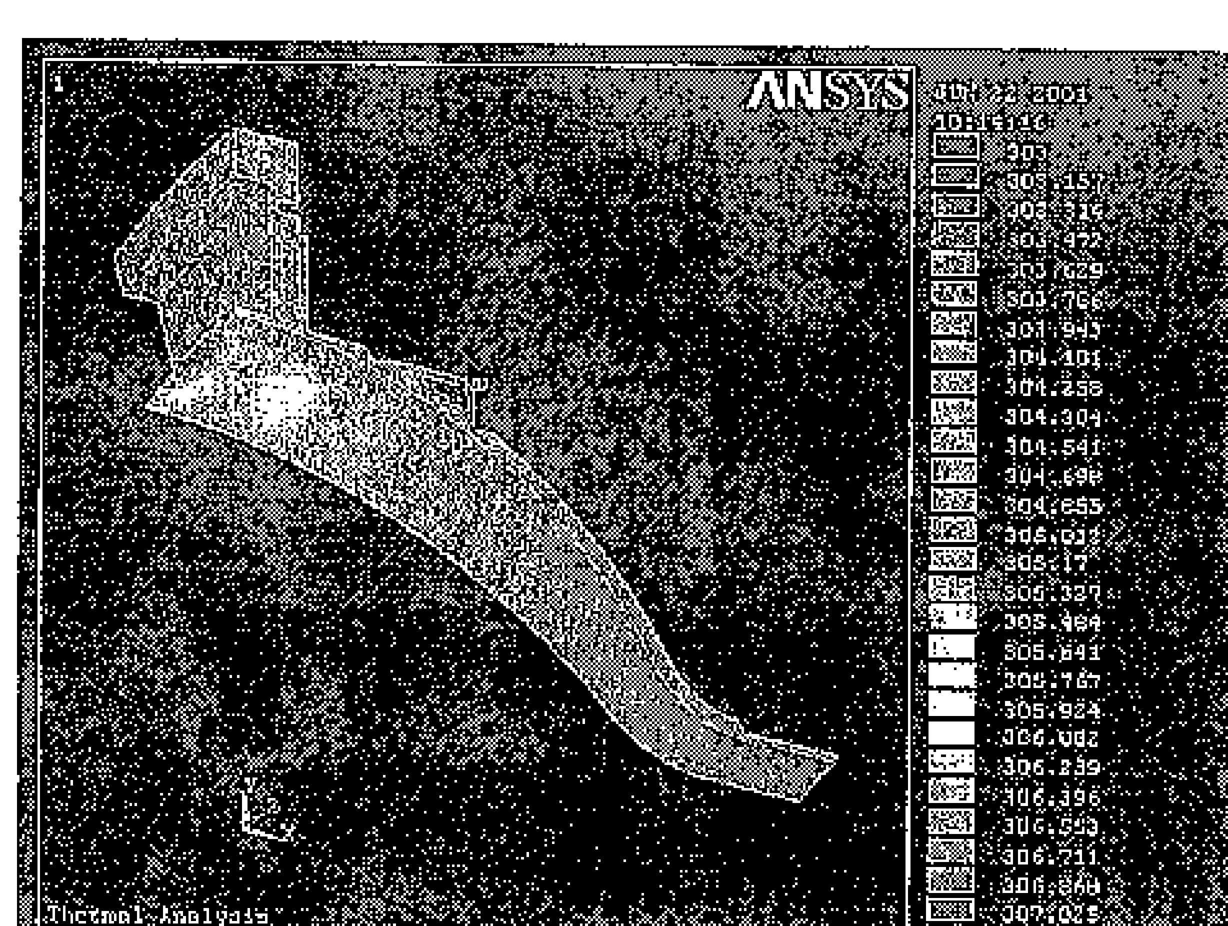
Simulations



Simulations

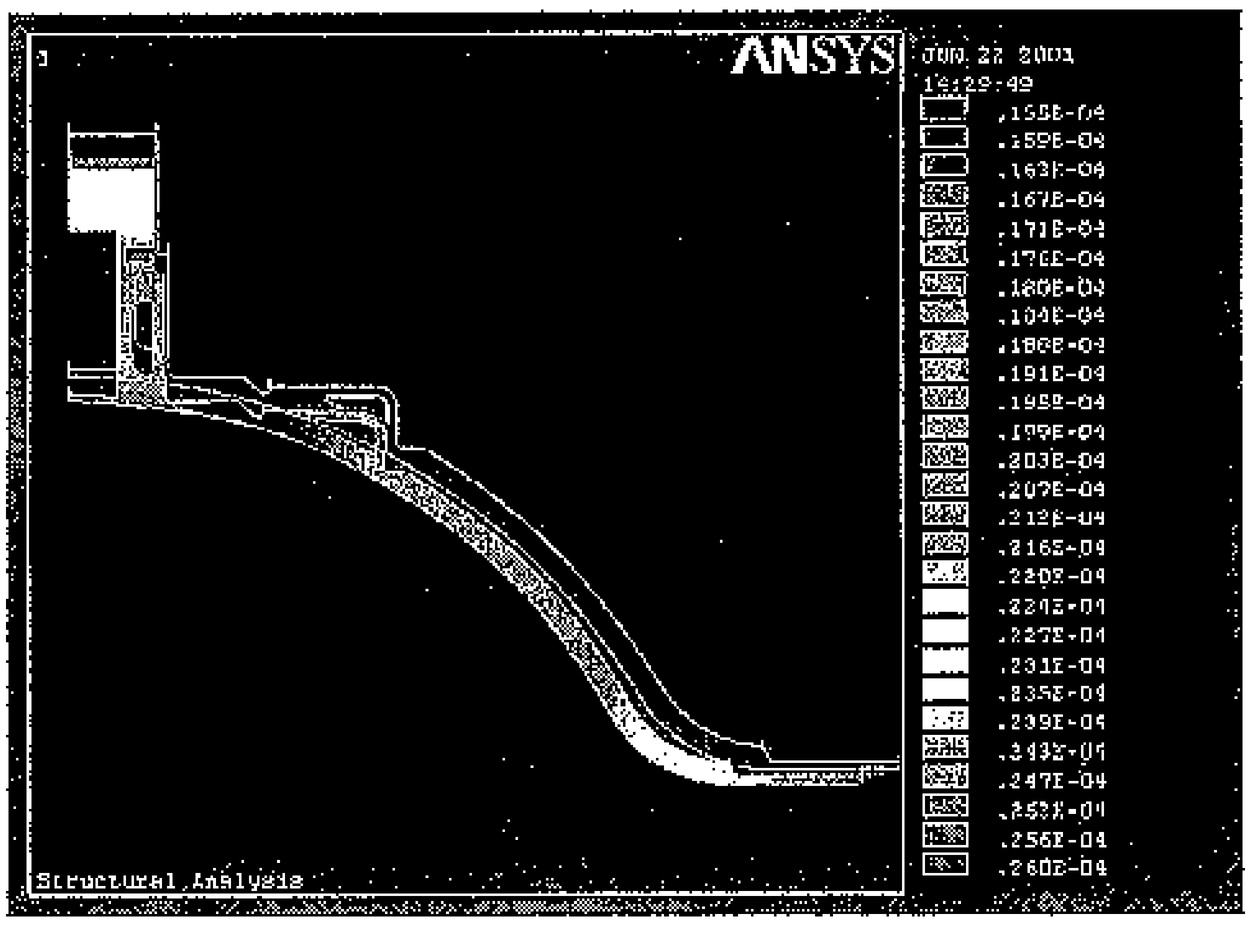
- f_0= 2998.550 MHz @ (<P $_{RF}$ >=1750 W + Water@303 K)
  - Max ΔT= 4.02 K
  - Max $|\Delta x|$= 6 μm, Δf_{RFOFF}= -110 KHz
  - Max Von Mises eq. Stress: 11 MPa

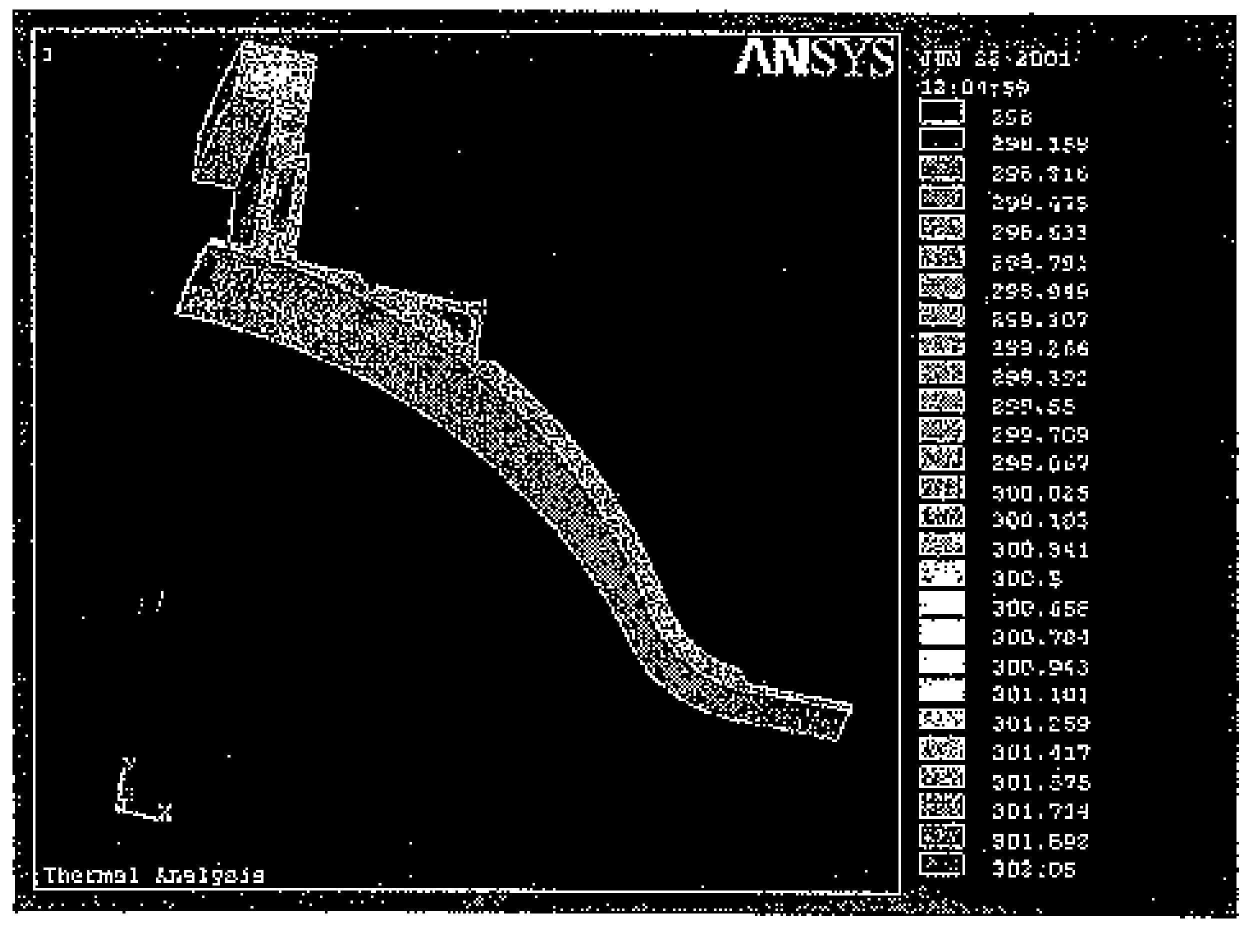




Simulations

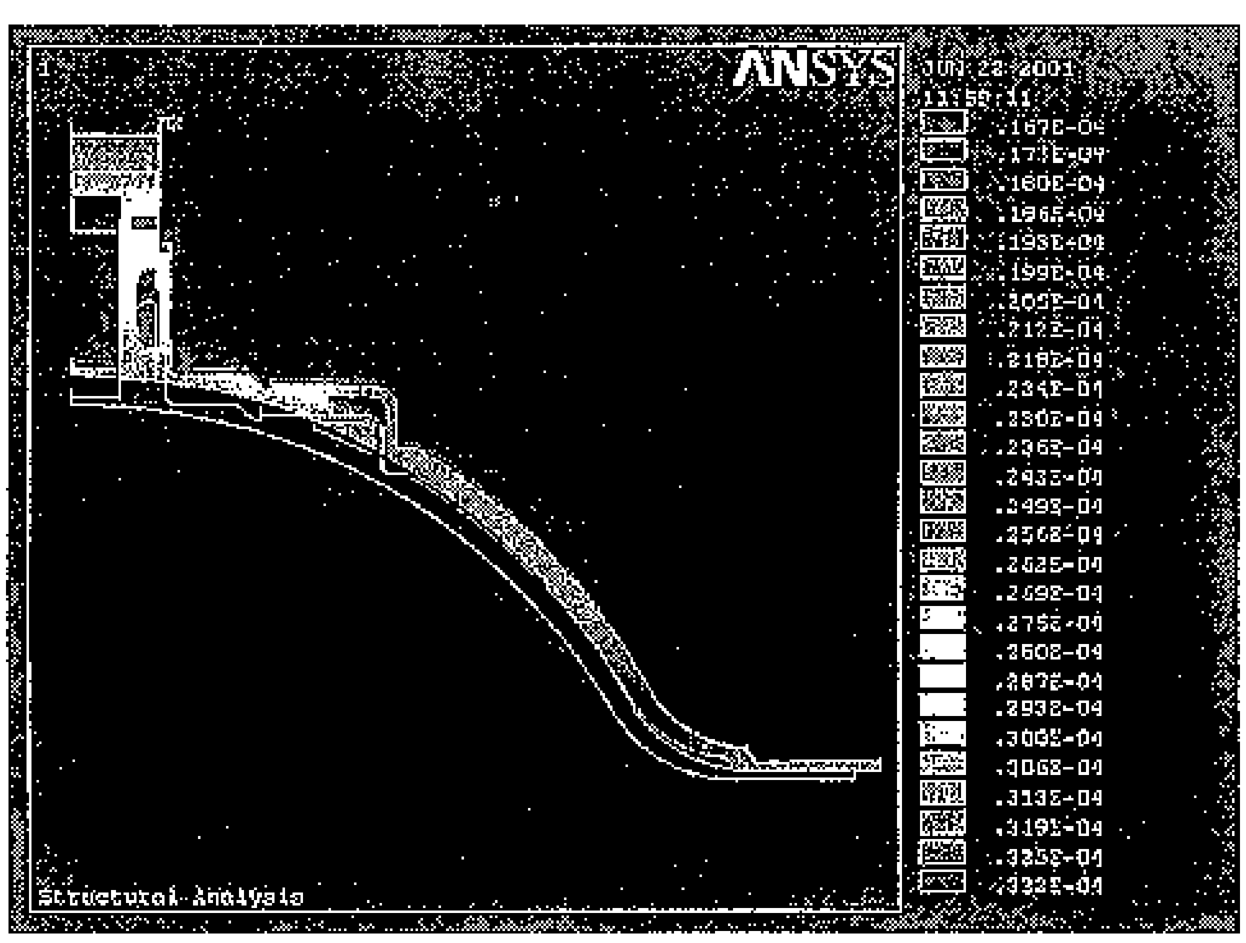
- Δf (<P_{RF}>=1750 W + Water@298 K)= +210 KHz
  - Max ΔT= 4.05 K
  - Max $|\Delta x|$= 26 µm,
  - Max Von Mises eq. Stress: 11 MPa

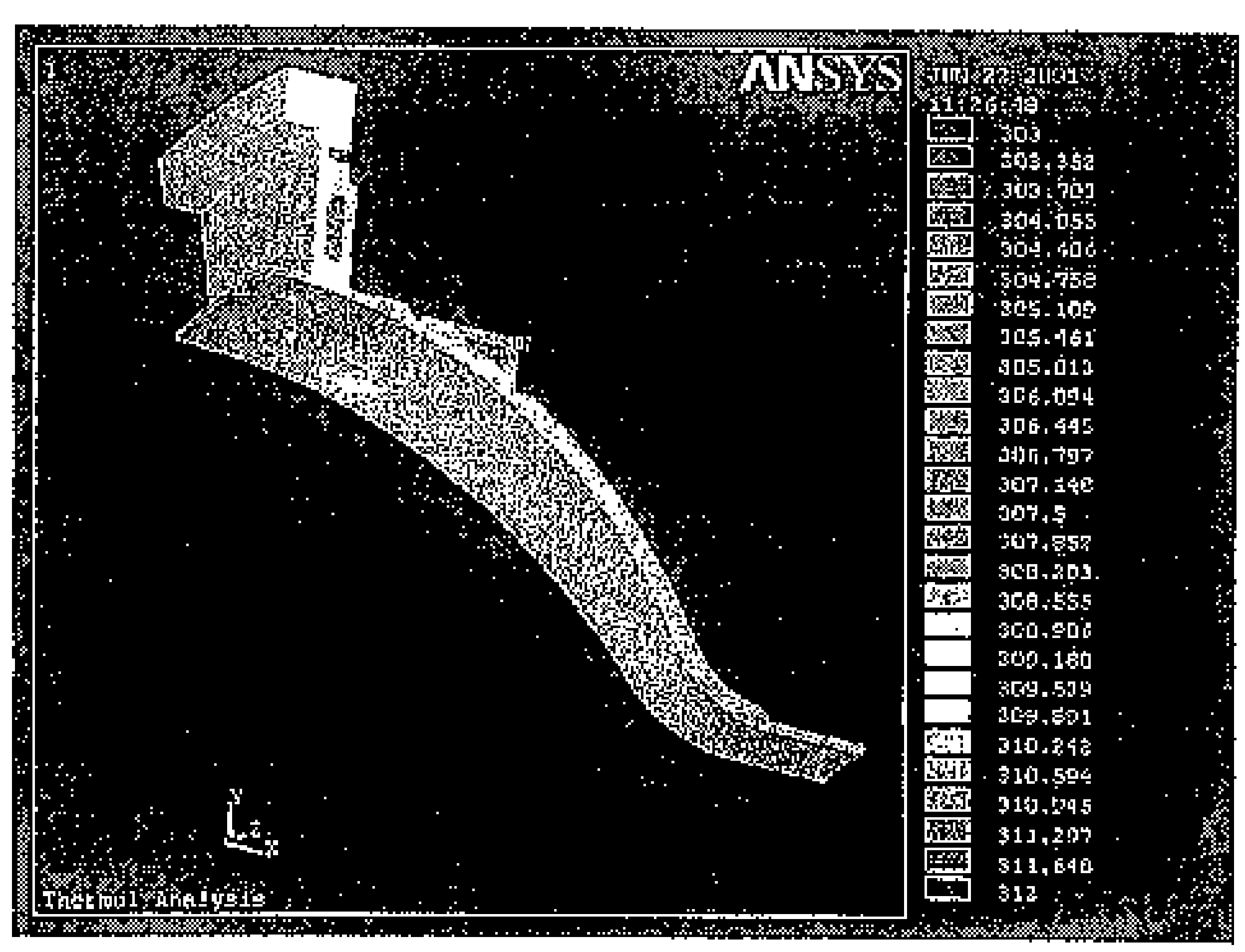




Simulations

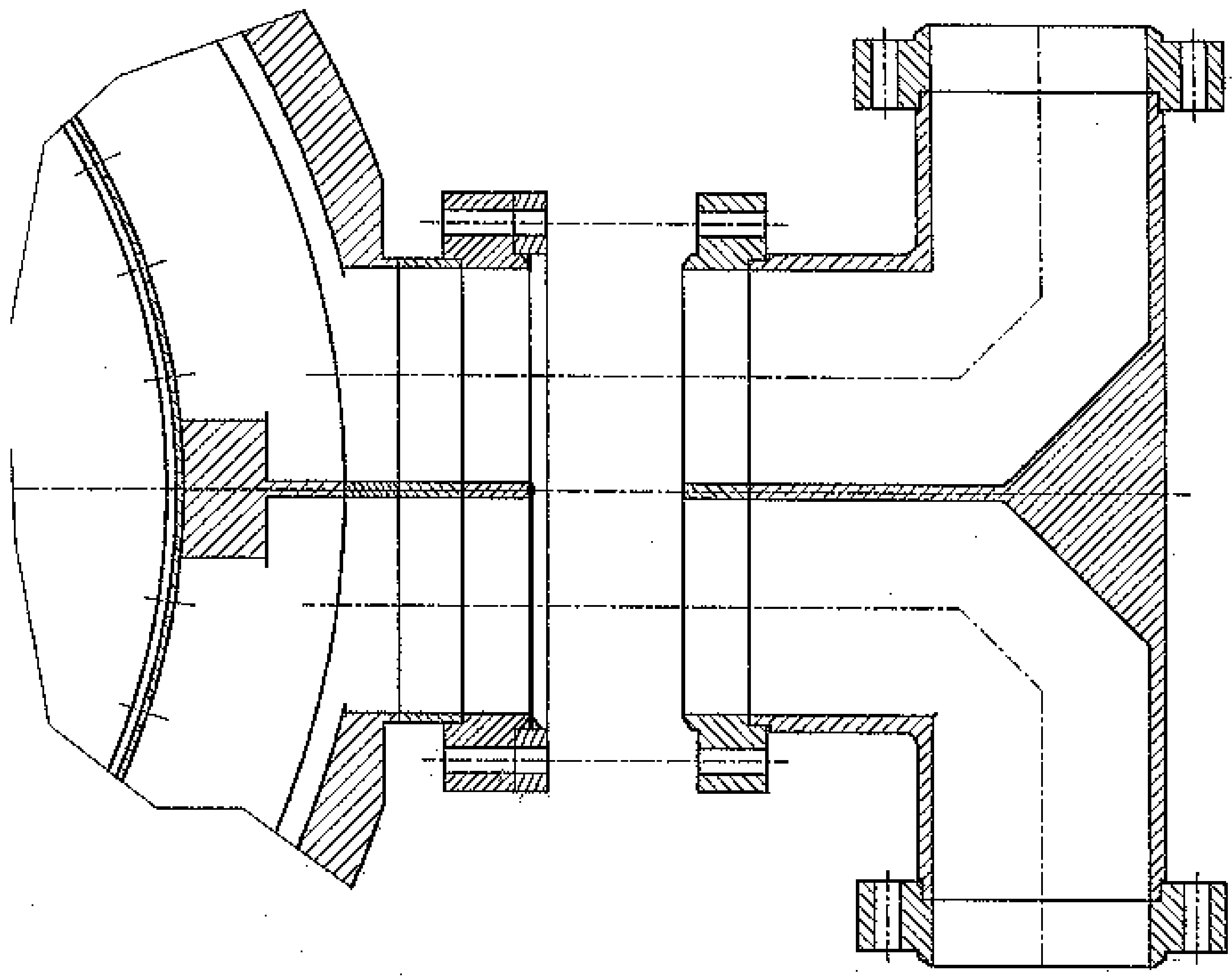
- Δf (<P_{RF}>=1750 W + Water@308 K)= -210 KHz
  - Max ΔT= 4.0 K
  - Max $|\Delta x|$= 33 µm,
  - Max Von Mises eq. Stress: 11 MPa



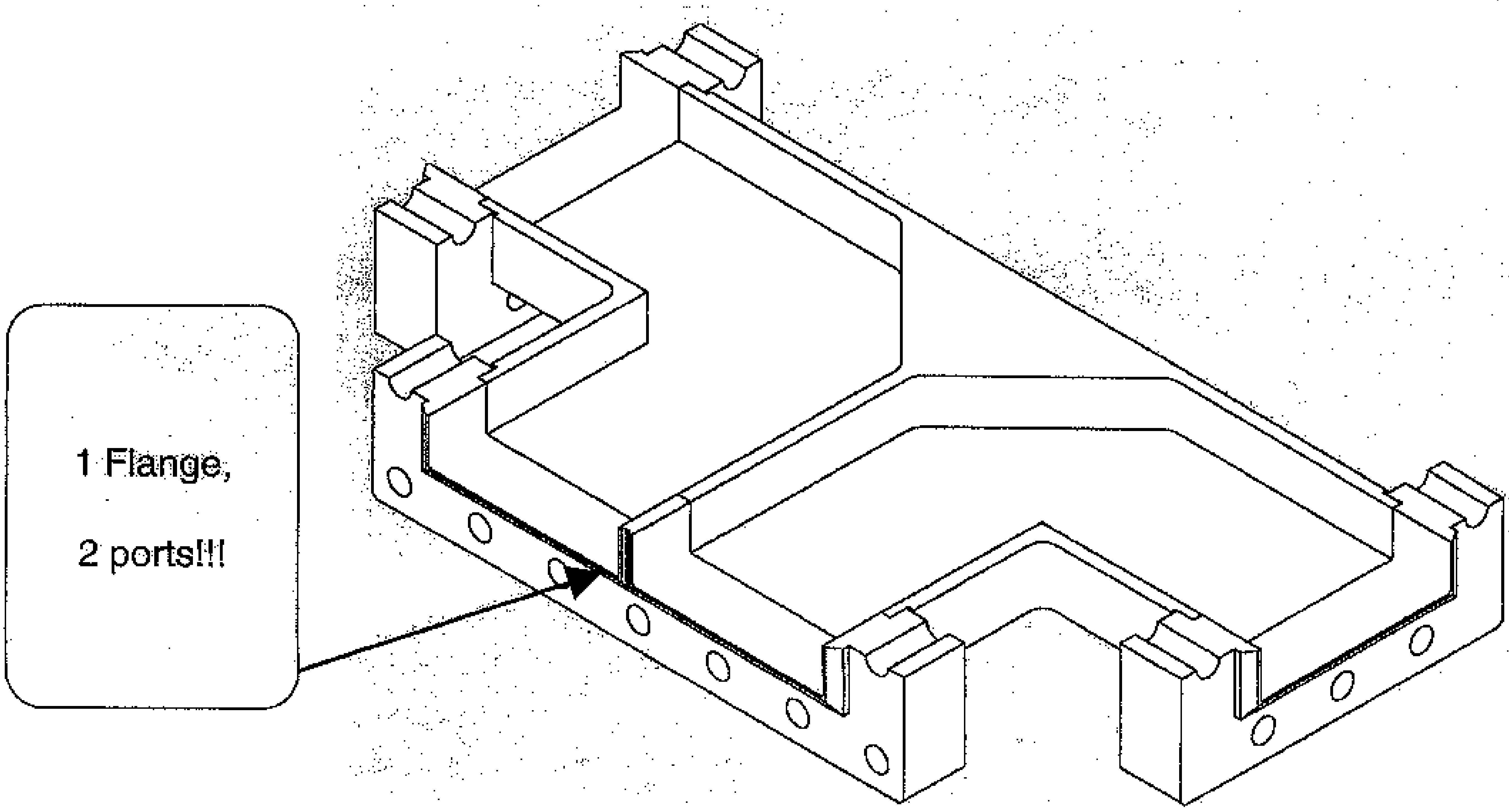


Solutions

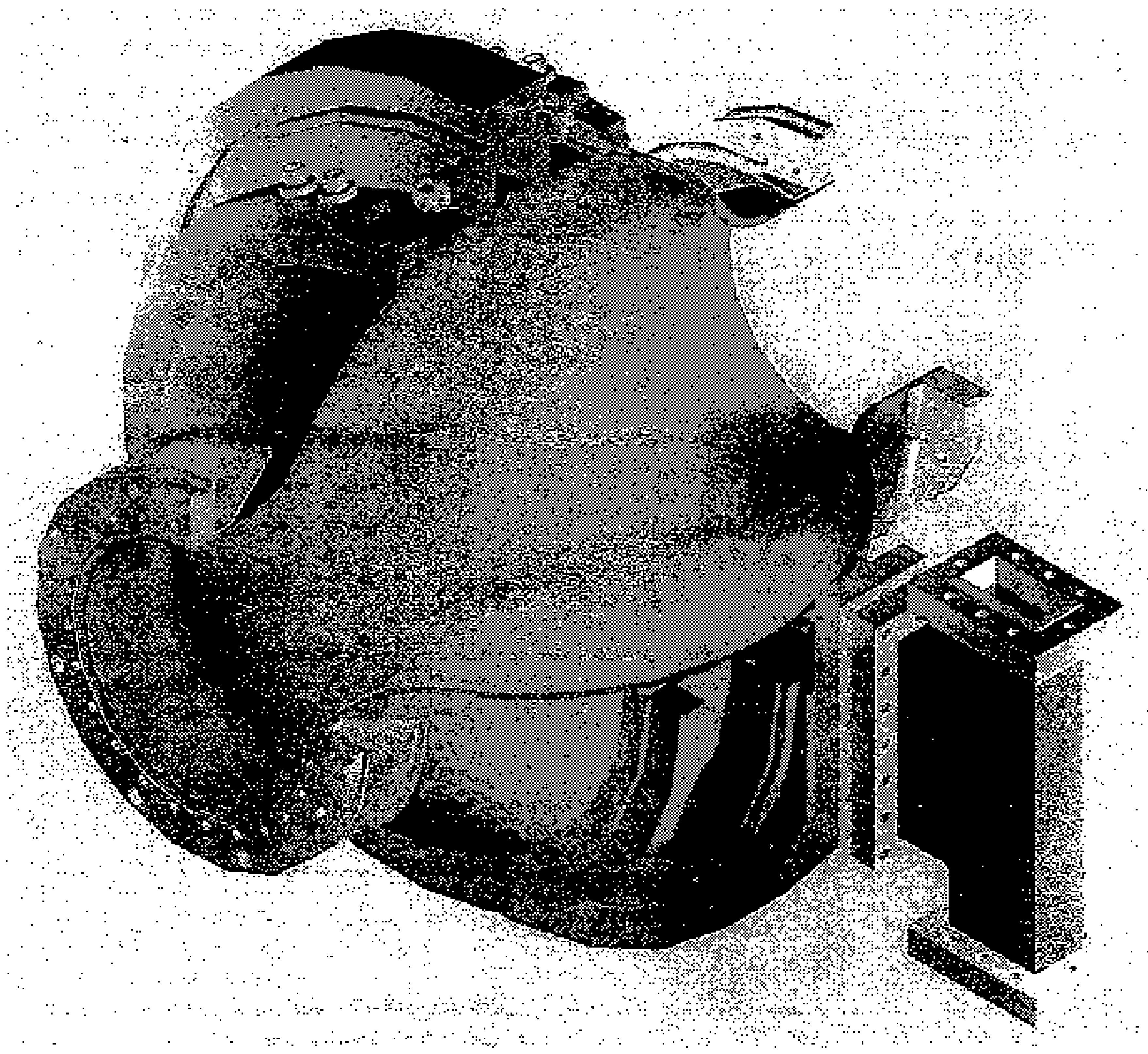
- Input/Output coupler has been divided in two parts, to ease machining and brazing
- The cavity will not see a brazing



Solutions



Solutions



Conclusions

- Simulations confirm that the specs are fulfilled
  - (and all parameters are consistent with Igor's experience)

- Production has already started, cavity available by February 2002.

The followings points will be treated:

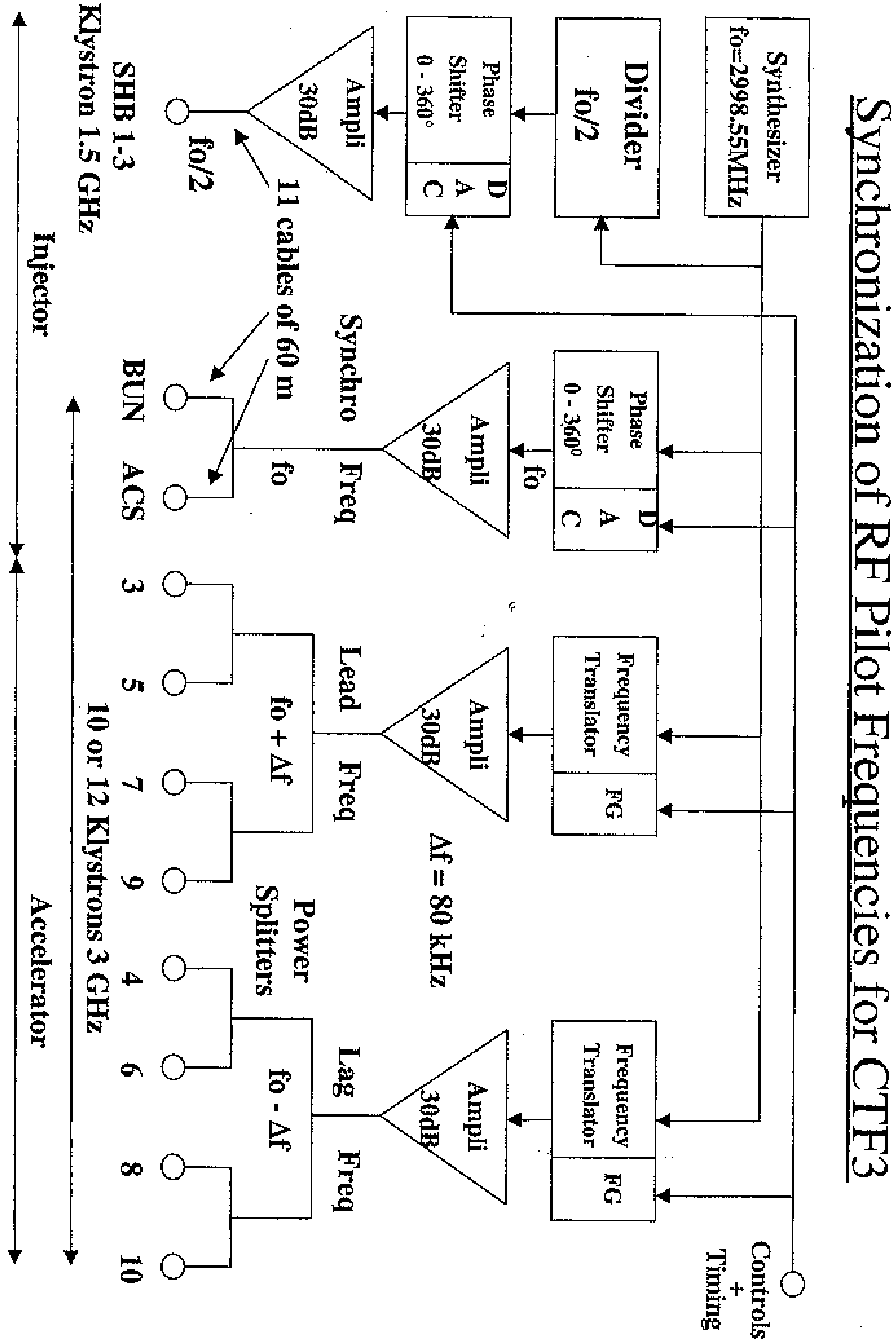
- Synchronization
- The RF Distribution System
- Phase Control
- The Data Acquisition System
- Voltage Control
- Energy Control

The CTF3 Low Power RF System

Ernst Peschardt
2/10/2001

Synchronization

- The RF master generator will be a synthesizer working at 2998.55 MHz.
- With a divider the frequency for the subharmonic buncher is derived.
- With other dividers the timing signals are generated.



Synchronization

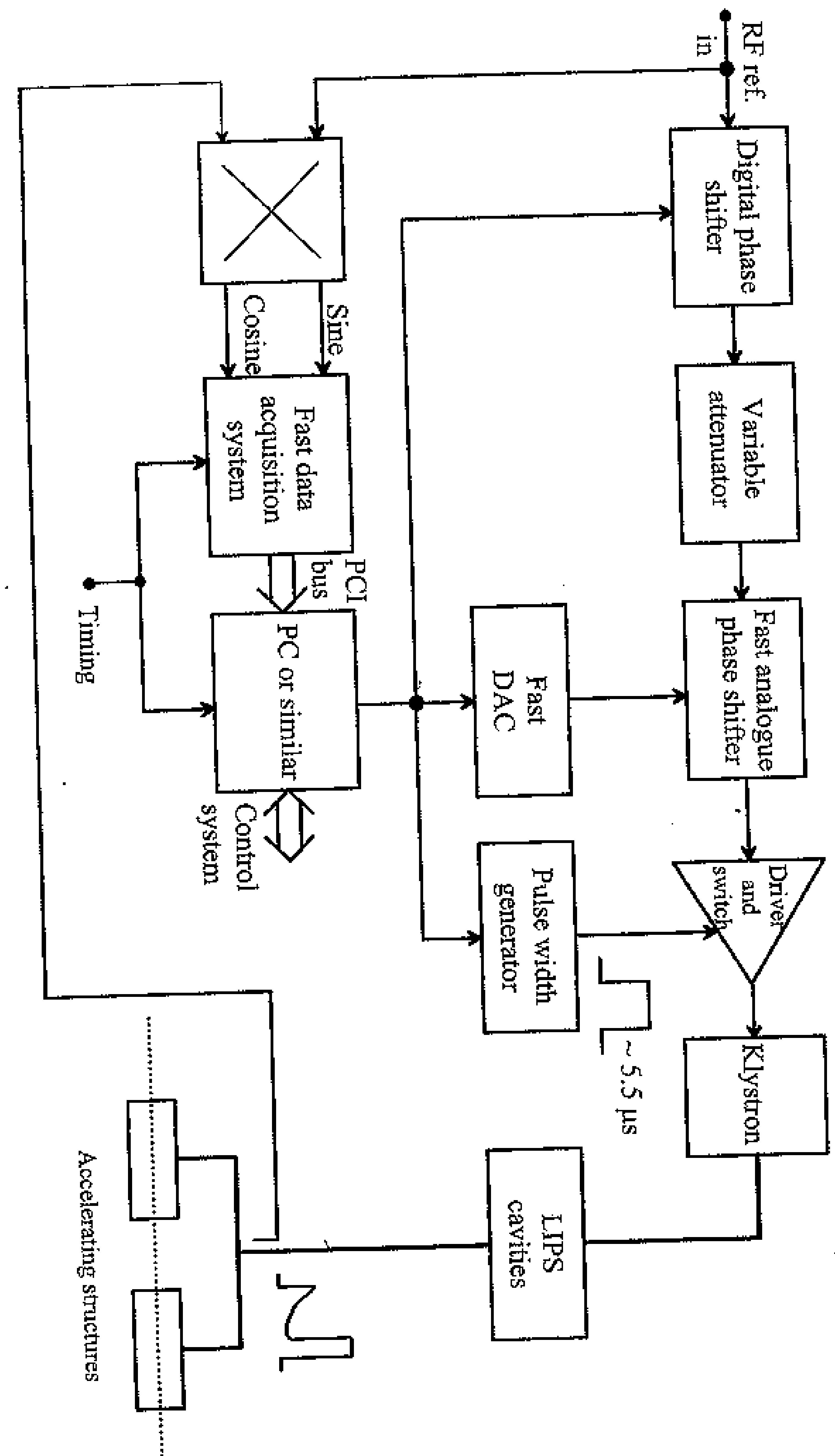
- Two more frequencies are generated centrally:
- A leading for the odd numbered klystrons with pulse compression.
- A lagging for the even numbered klystrons.

The Distribution system

- The signals to the 11 klystron are sent through equal length coaxial cables.
- Phase stabilized coaxial cables will be used (3 to 6 ppm/deg.)
- Over 60 m the phase drift will be less than 1.4 deg. RF at 3 GHz if the temperature varies 1 deg. between the cables.

Phase Control

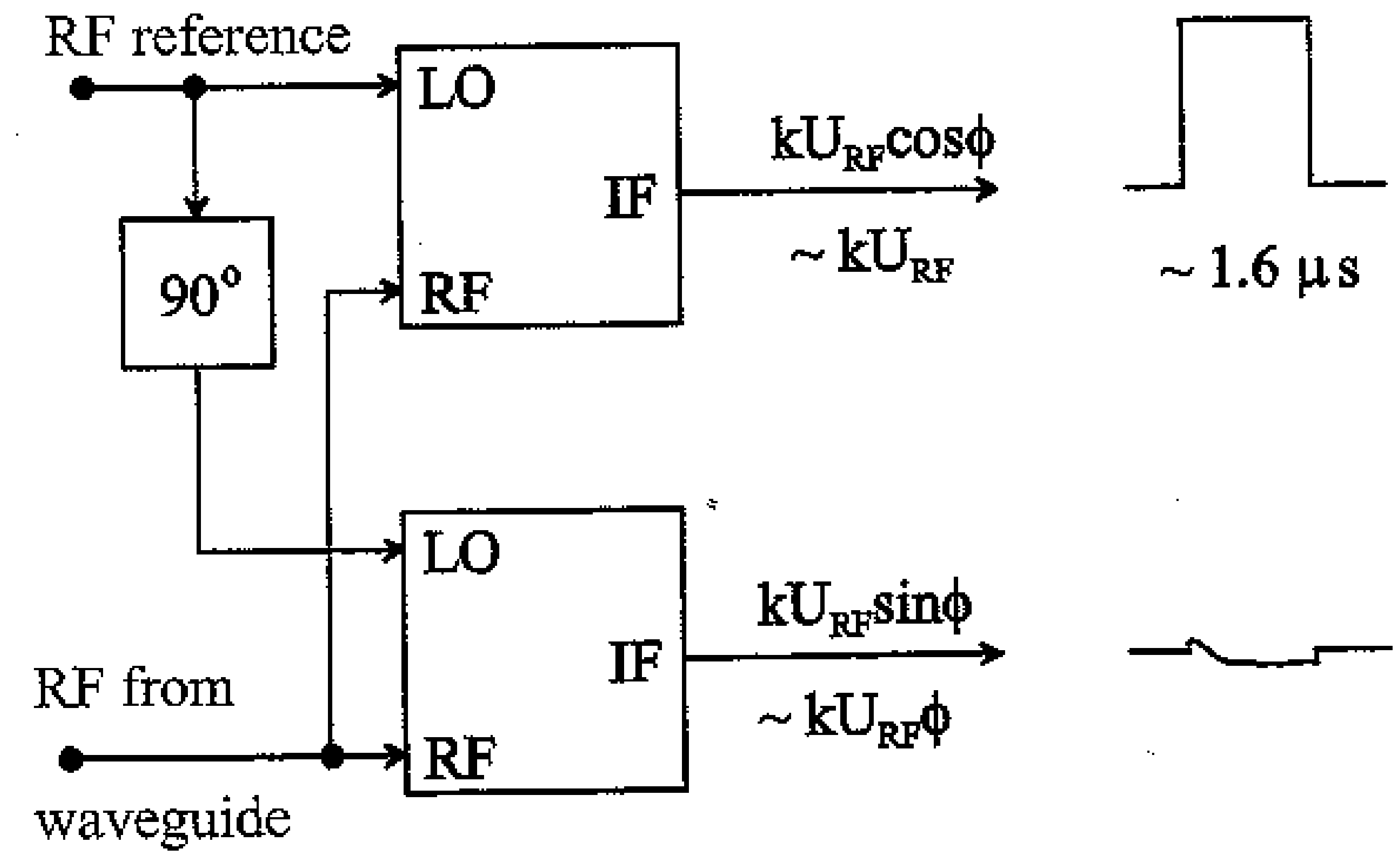
- At the input of each amplifier chain a 10 bit 360 degree phase shifter is used to set the phase with respect to the beam and the other accelerating sections.
- The fast analogue phase shifter is used for the phase programme for the pulse compression.



Block diagram of the phase control for one klystron with pulse compression

Phase Control

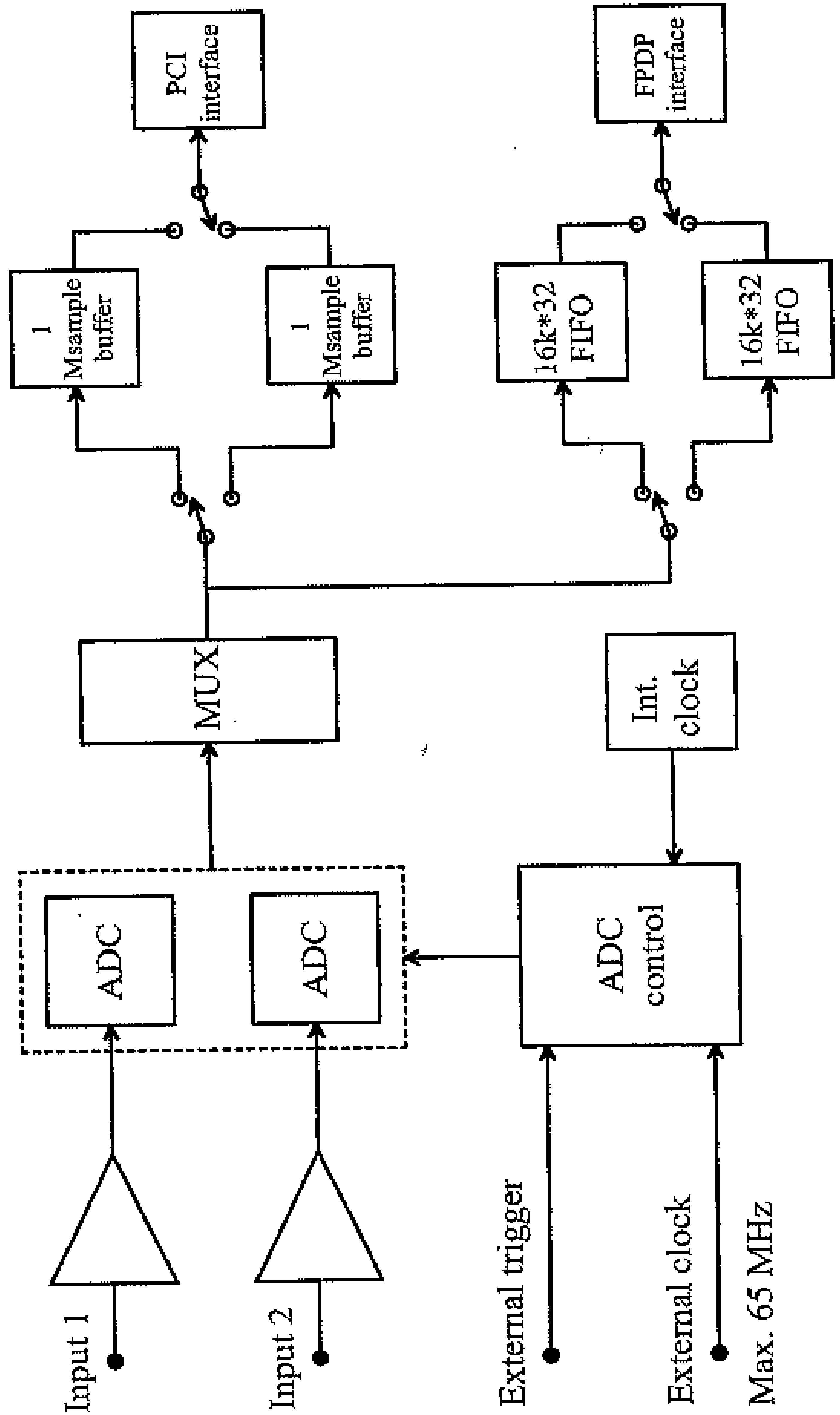
- Uncontrollable phase variations are compensated with a feed forward loop. The phase between the reference and a directional coupler in the waveguide is measured with a quadrature coupler.
- The average phase during the beam pulse is calculated and a correction applied to the digital phase shifter before the next pulse.



Quadrature mixer

Data Acquisition System.

- About 20 measurements are required during the duration of the beam pulse (1.4 ms).
- A fast system is therefore needed.
- ADC boards with sample rates up to 65 MHz and 12 bits and a PCI bus exist.
- The acquisition can be completely synchronized to the beam pulse.



Fast data acquisition system

Beam Energy Control

- The power gain of the compressor can be adjusted with high resolution by changing the duration of the RF power production.
- Eventually by measuring the beam position at the end of the linac a feed forward loop could be implemented.
- Was successfully used in LIL.

Voltage Control

- At nominal beam current the accelerating cavities are fully loaded.
- With the same klystron power at low current the average field would then be twice as high.
- The klystron output power can be varied between17 and 35 MW by changing the modulator voltage.
- Another factor two by changing the gain of the pulse compression.

RF Power Production in CTF3 using the DBA

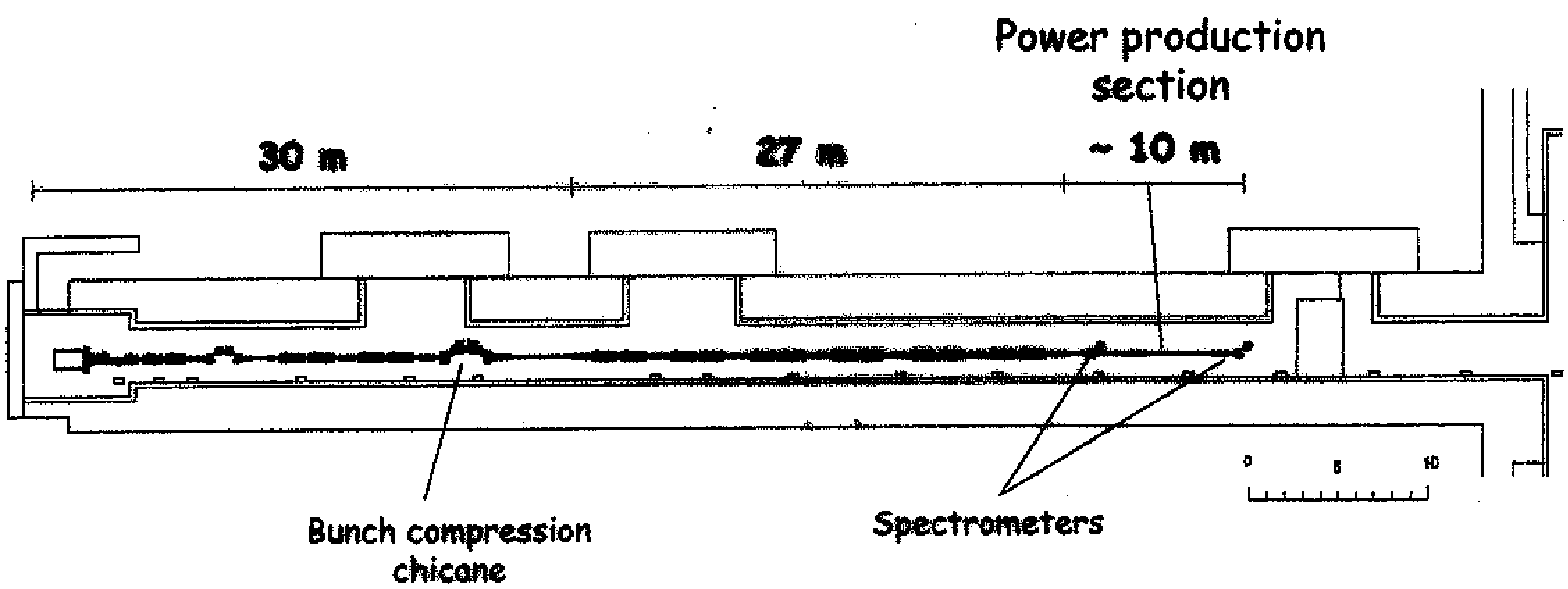
R. Corsini

MOTIVATIONS:

- Following recent evidence of high-gradient limitations and damage in 11.4 GHz NLC prototype structures as well as in 30 GHz CLIC prototype structures, the CLIC study group started an intense R&D program, centered on high-power test of components.
- These test are at present carried out in CTF II, which will be shut down at the end of 2002.
- The CLIC study needs a 30 GHz high power source (in the 100 MW range) at an early stage in CTF3 after CTF II shut down and before CTF3 Nominal Phase operations in 2005.

The DBA should be commissioned towards the end of 2003, and be in operation in 2004.
Can the DBA beam be used to produce 30 GHz power with the required characteristics ?

Drive Beam Accelerator Layout

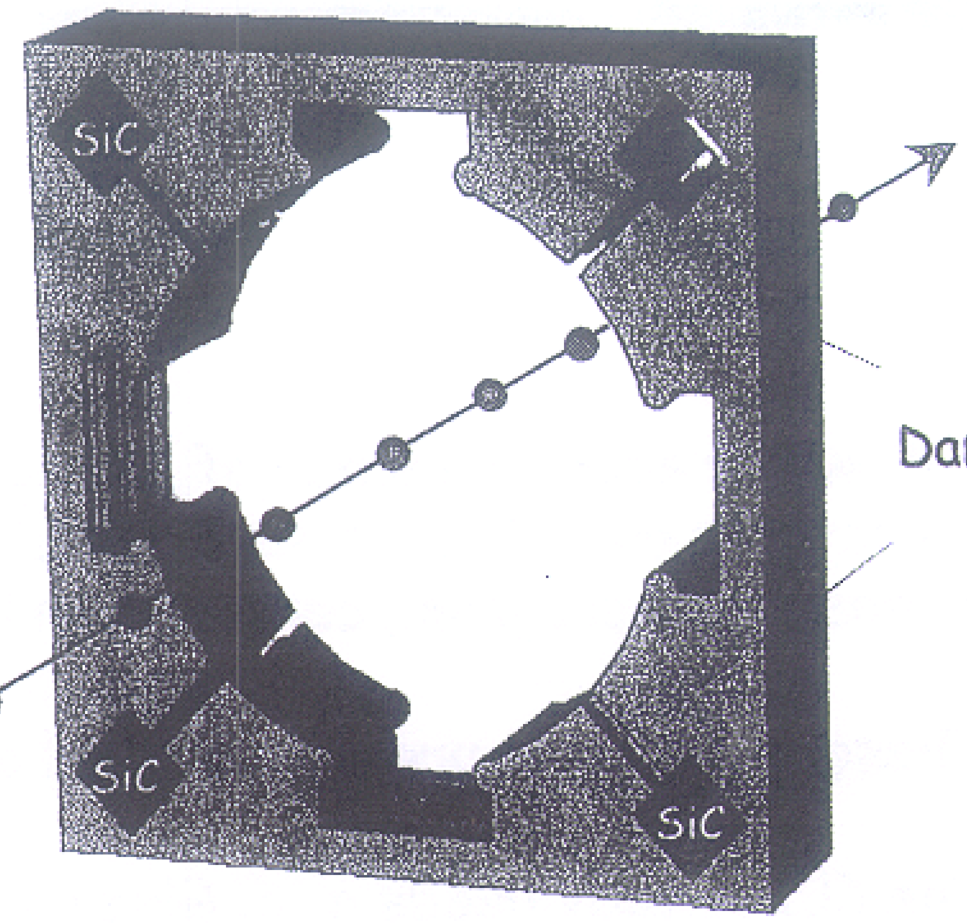


The DBA zone can be separated from the rest of the CTF3 building. High power tests can thus proceed while doing civil engineering and installation work in the rest of the complex.

Power Extraction and Transfer Structures

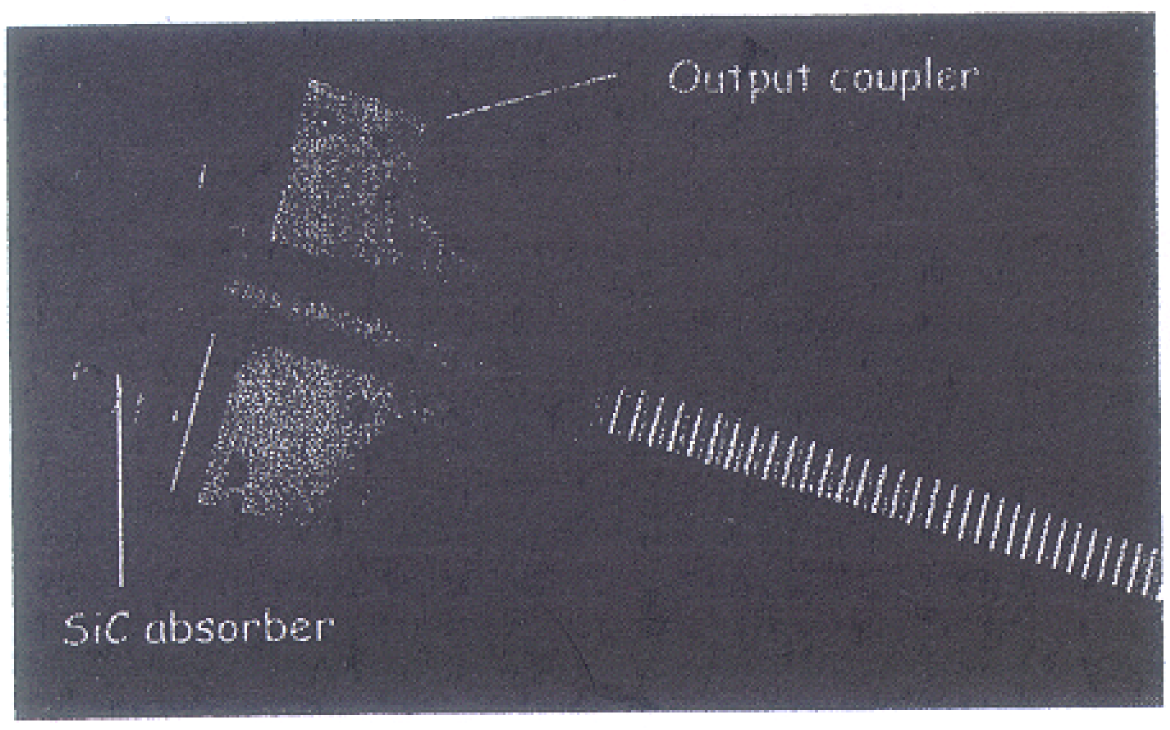
A.Millich - L.Thorndahl - G.Carron

Transverse slice (3-cells) of the CLIC Power Extraction and Transfer Structure



Damping slits

Drive Beam with 30 GHz time structure



Extremity of open PETS used in CTF II showing output couplers and channels. Also visible is a piece of SiC damping material.

RF Power Production in CTF3 using the DBA

QUESTIONS:

- What kind of structure is most adapted to such a task ?
- What would be the requirements on the electron beam ?

The basic formula for RF power production in Power Extraction and Transfer Structures (PETS) is (~~steady-state~~ regime, linac Ω):

$$P = \frac{\omega}{4c} I^2 \left(\frac{R'}{Q}\right) \frac{1}{\beta_g} l_s^2 F^2 \qquad (1)$$

- I^2: Limited by gun & linac performances
- l_s^2: Limited by transport and RF losses
- F^2: Maximum of about 1 for short bunches, no phase errors
- $\left(\frac{R'}{Q}\right) \frac{1}{\beta_g}$: Structure design, linked to aperture and transverse wakes, finally limited by transport

REQUIRED POWER

- At present, about 40 MW, 15 ns pulses used for structure testing in CTF II, limited by breakdowns - such power level in the CTF3 linac would already be an extension of the present tests, since longer pulses (≥ 100 ns) would be possible. The repetition rate is also potentially higher (5 Hz ⇒ 25 Hz).

- A new CLIC accelerating structure is at present under development. 58 MW at the structure input are needed to reach 150 MV/m accelerating field for the new structure design. The surface to accelerating field ratio in this structure is 2.18 - peak surface field ≈ 300 MV/m (I. Syratchev).

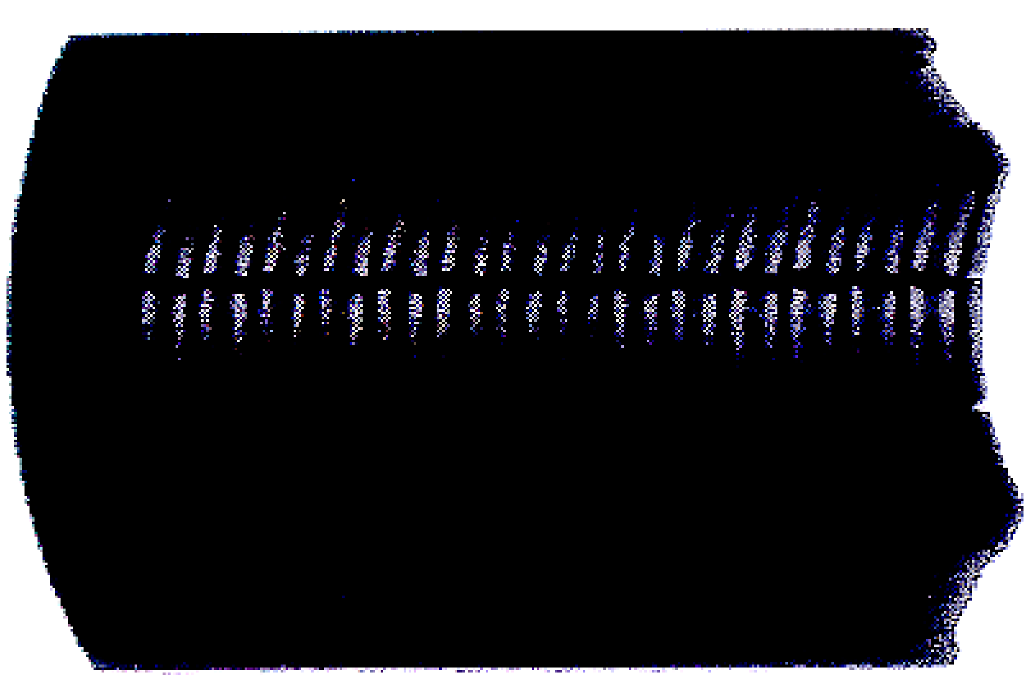
- Operational experience with CTF II has shown that in practice, only 2/3 of the theoretical RF power is obtained.

Required power ≈ 100 MW

(including form factor, PETS imperfections, coupler & waveguide losses, but NOT including PETS Q-value, that must be treated in the calculation)

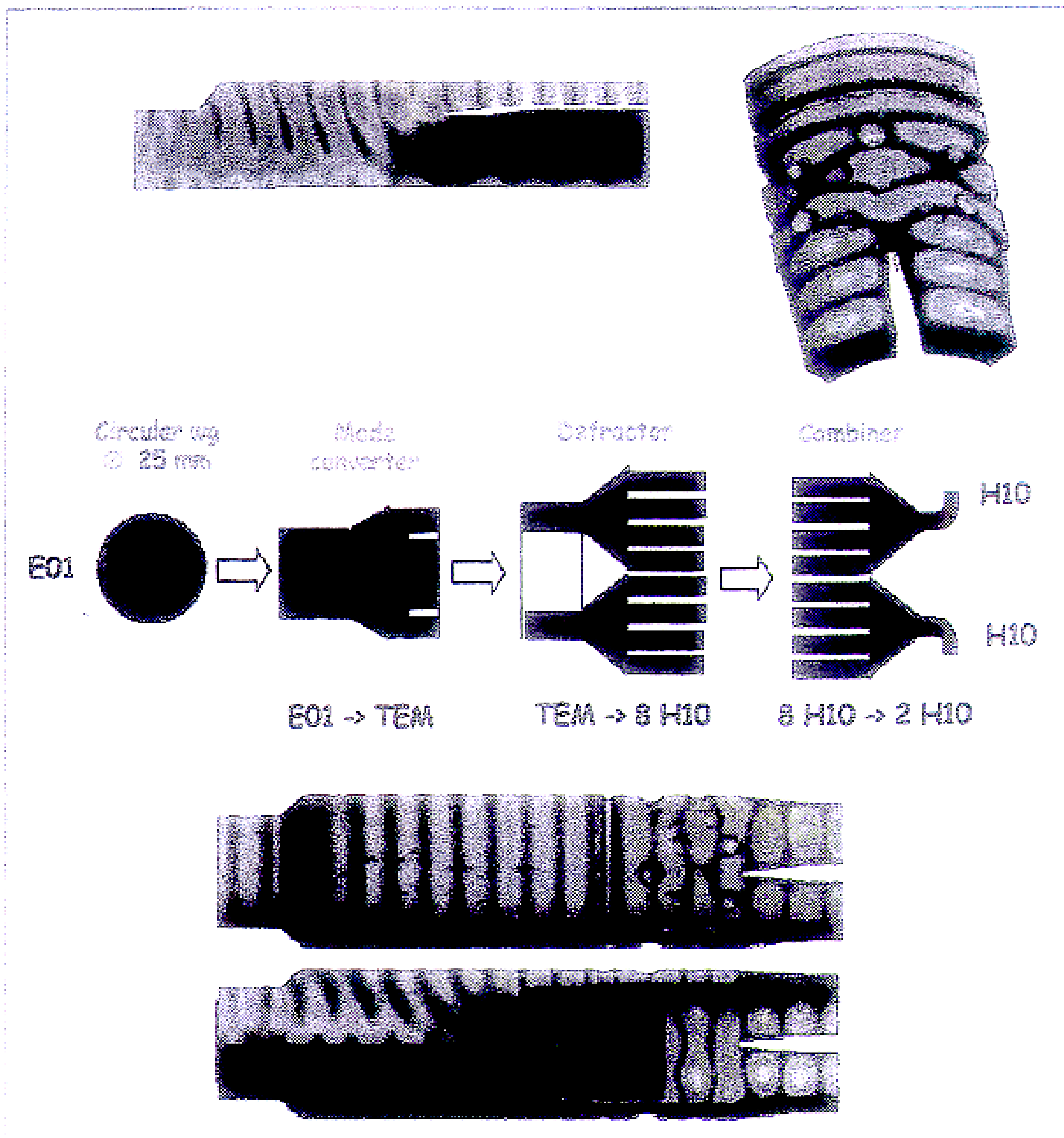
Circularly symmetric PETS

I. Syratchev



Quarter C-PETS geometry with 12 SiC loads.

Coupler Design for C-PETS



3/10/2001

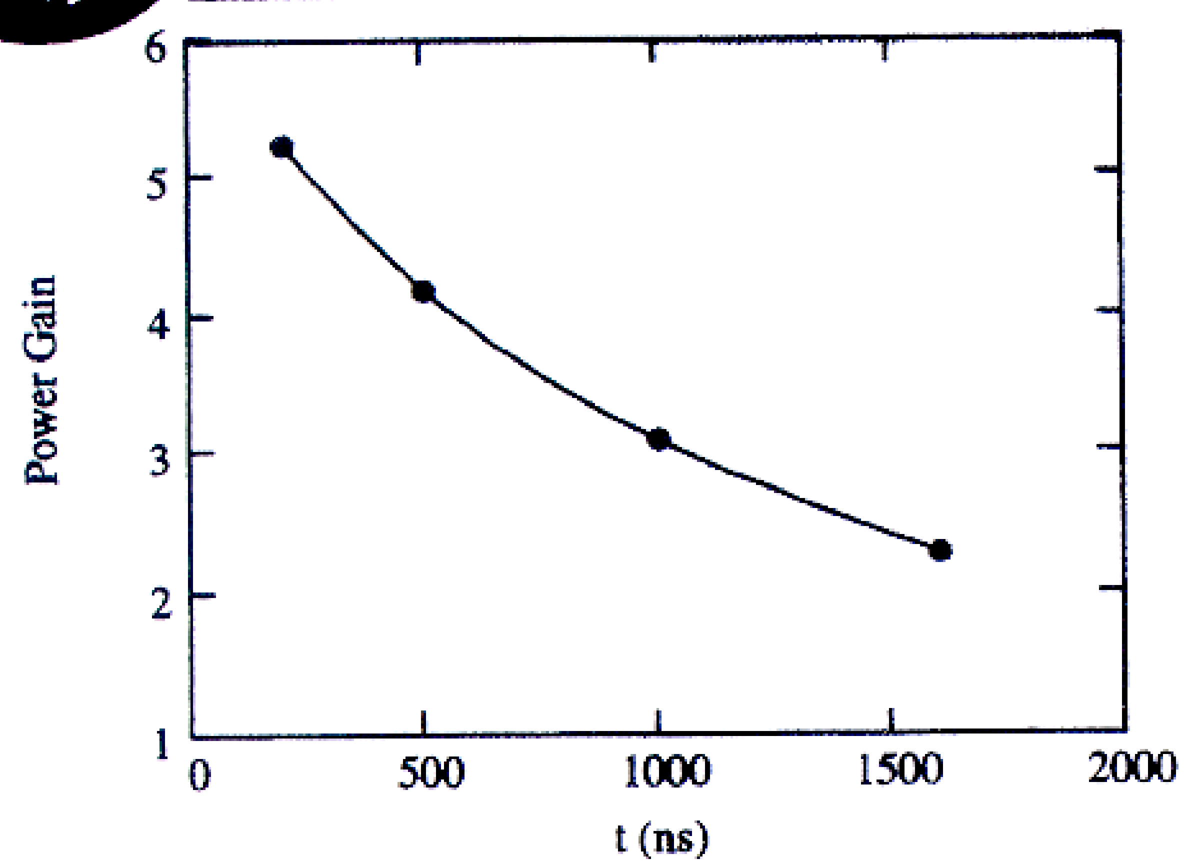
MAXIMUM FIELD IN PETS

Maximum surface field in PETS:

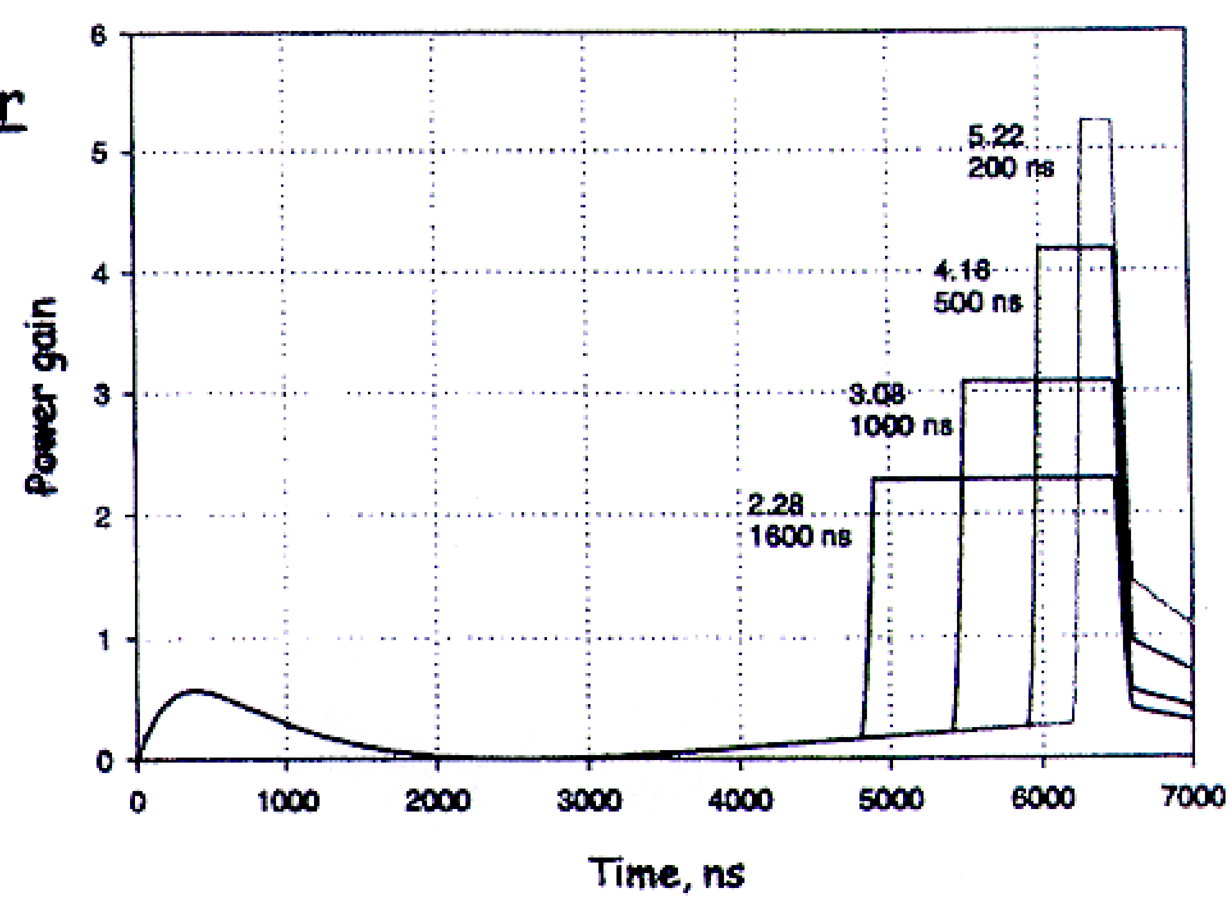
- As mentioned, the max surface field in the accelerating structures to be tested is of the order of 300 MV/m
- It looks reasonable to limit the maximum surface field anywhere in the PETS to a significant lower value (e.g. a factor 2). The PETS themselves should not be part of the breakdown studies !

Required max surface field in PETS ≤ 150 MV/m

ELECTRON BEAM CURRENT



Data from Igor



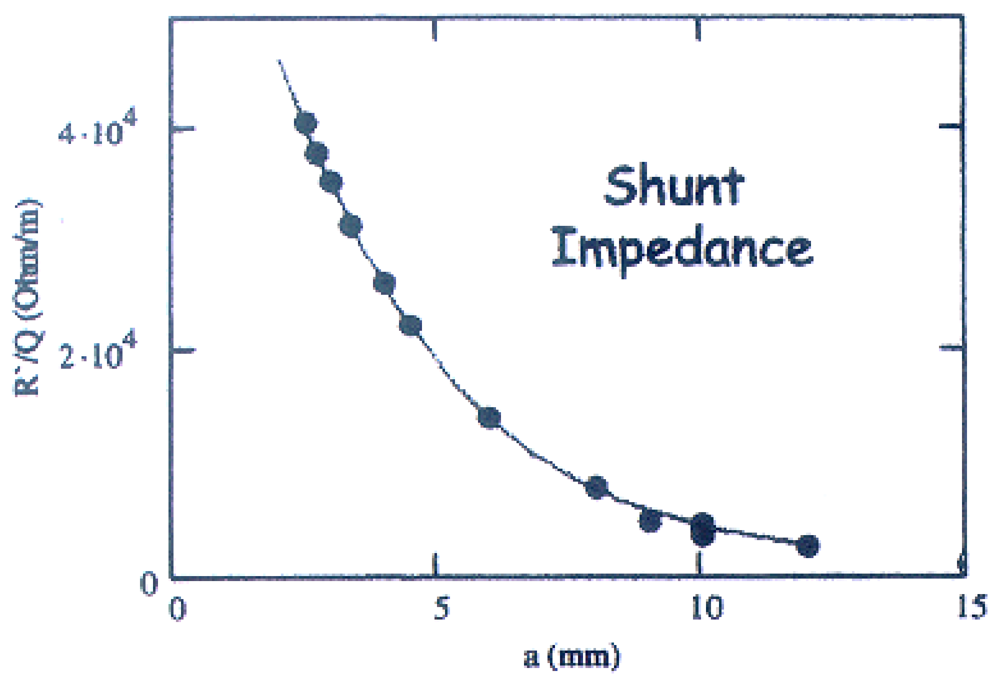
- For a reduced electron pulse length (≈ 200 ns) the current can be increased from 3.5 A to 5 A, for the same beam loading - the beam energy will also increase by the same factor from 150 MeV to 210 MeV

Electron beam current = 5 A

- the power at the DBA structure input would be 60 MW (possible?)
- The RF pulse compression system should manage also twice the nominal power
- the total beam peak power will be 1 GW

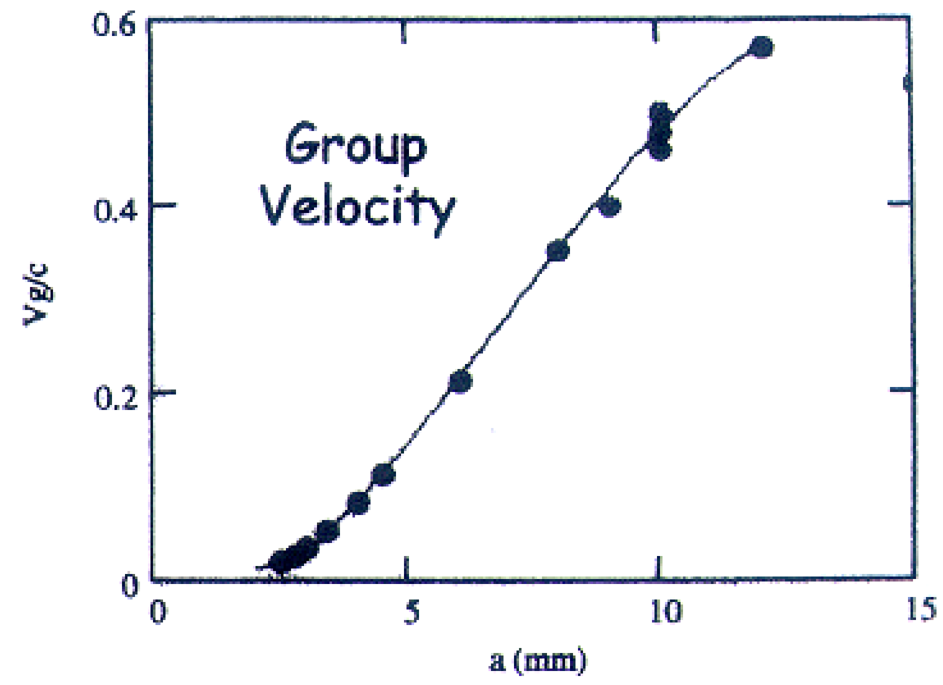
PETS scaling

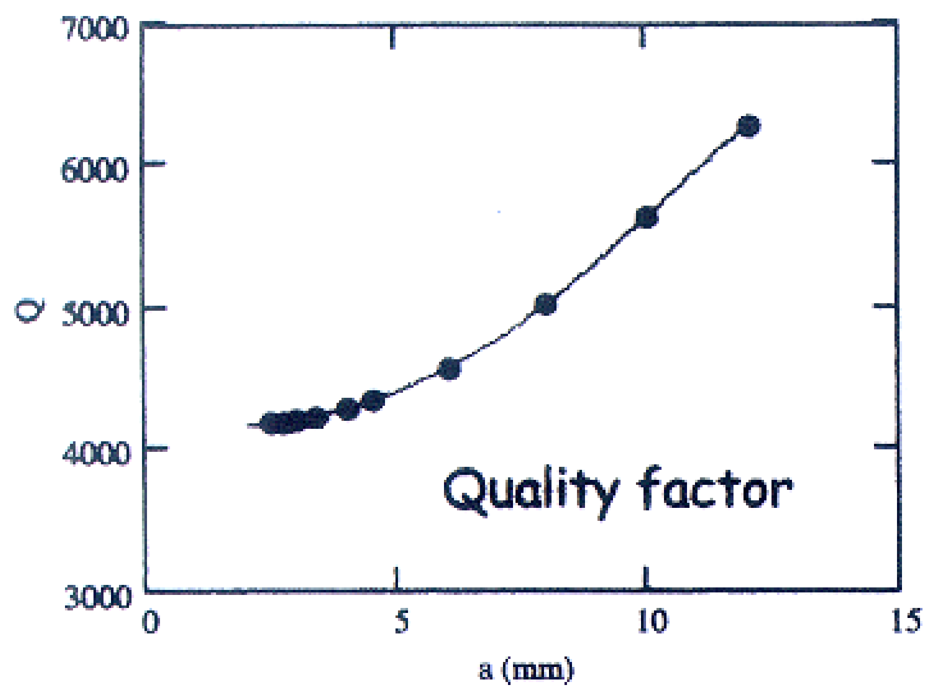
- Simple PETS design: cylindrically symmetric, iris loaded waveguide $2\pi/3$ phase advance, constant aperture.



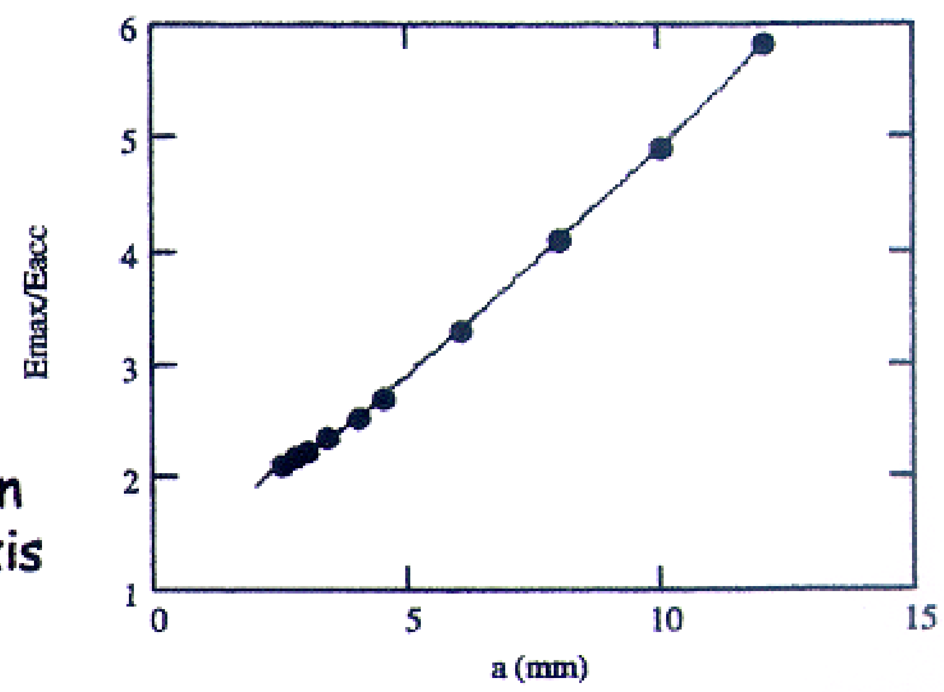
- Data from A. Millich (4 wg)
- Data from I. Syratchev (iris loaded)

Fit used for power calculation





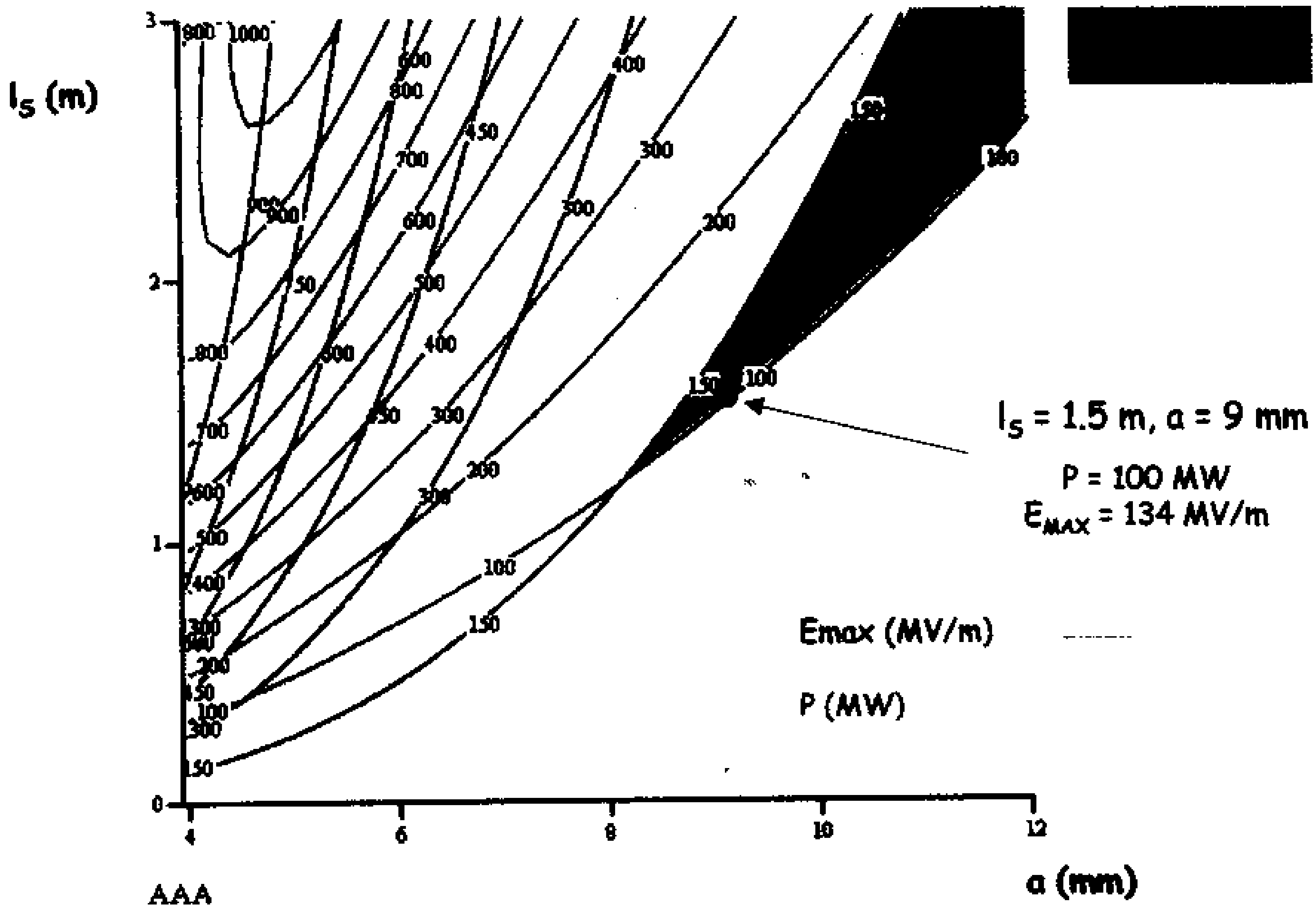
Ratio between max and on-axis field



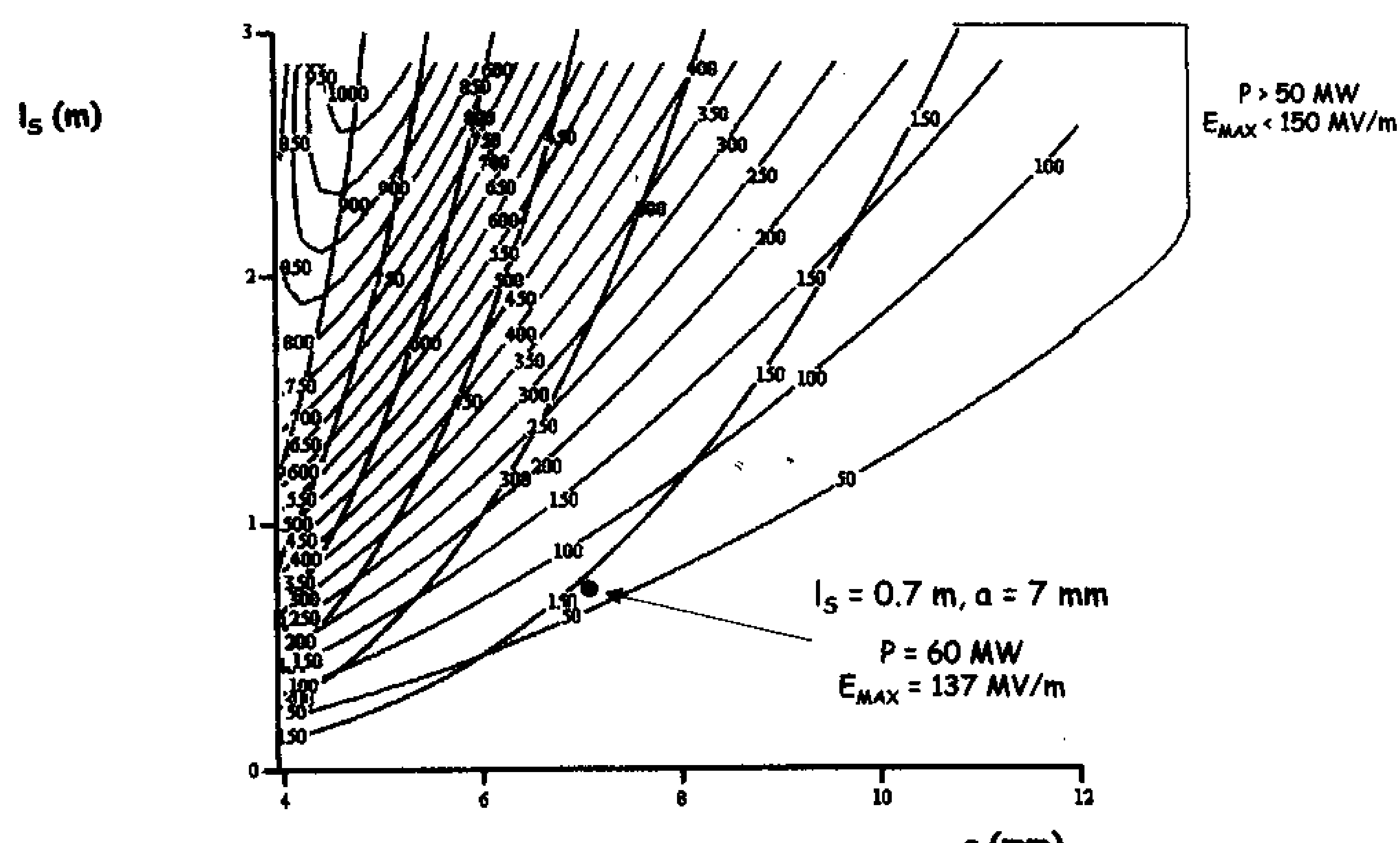
Pulse length - Repetition rate

- The filling time of the DBA structure is 100 ns (transient beam loading). The PETS filling time is typically much smaller (< 10 ns ?). For a 200 ns electron pulse length the RF pulse length should be > 100 ns. A longer electron pulse should be possible, with a somewhat reduced current.
- Shorter RF pulses are in principle possible. They will be useful to study the breakdown limit dependence on pulse length, in the region from 15 ns (tested in CTF II) up to the nominal CLIC pulse length.
- A high rep rate would be important to reduce the conditioning time and to perform life-time tests.
- The average beam power in the DBA for the nominal phase is 4 kW (5 Hz, 3.5 A, 150 MeV, 1.5 μs). The averge beam power for DBA RF power production would be 5 kW at 25 Hz. (5 A, 210 MeV, 200 ns).
- The CTF3 shielding is designed for an average beam power of 6 kW.

SIMPLE PETS



TWO "SIMPLE" PETS

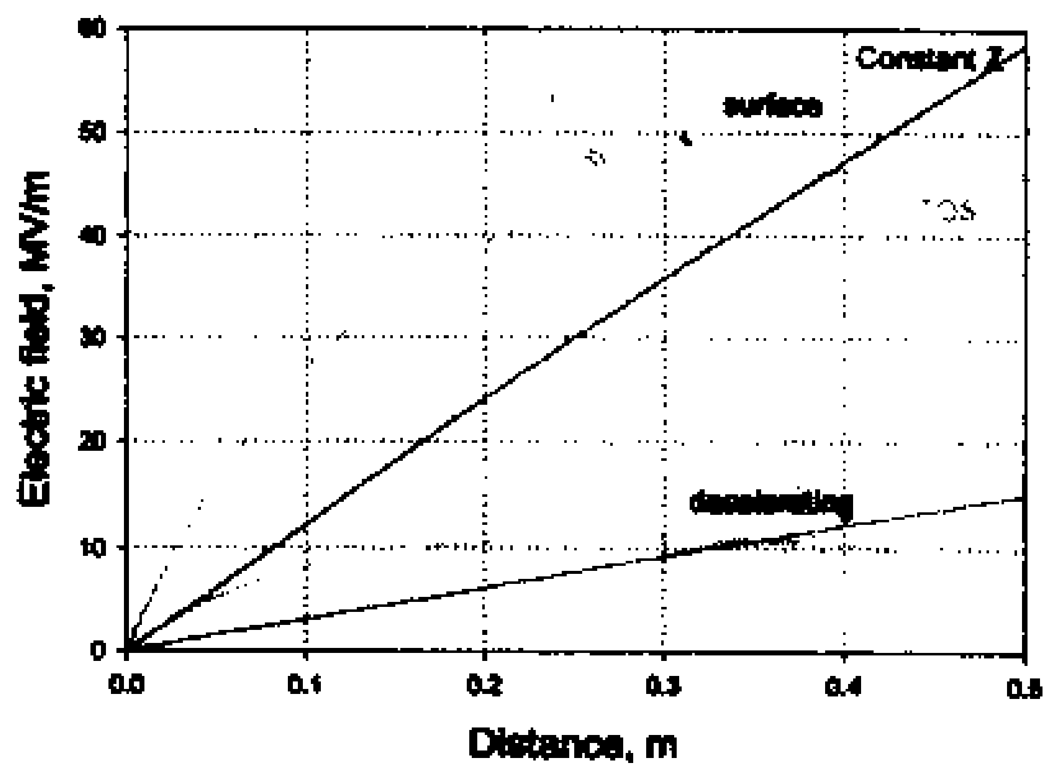


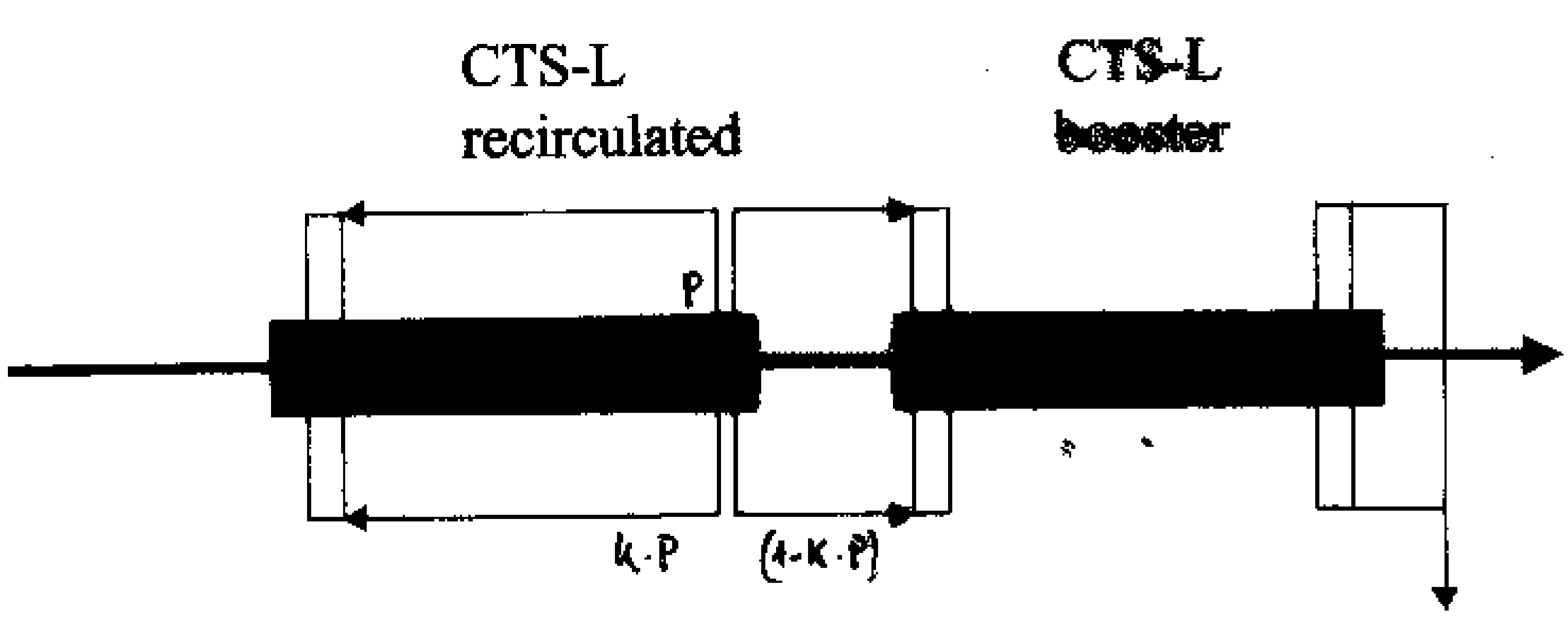
The tapered-out structure.

While the generation of the RF power with the beam, the highest surface field will take place at the end of the structure. The situation can be improved with the tapering the structure starting from the lower group velocity at the beginning towards higher group velocity at the end (Tapered-Out Structure).

Comparison for the 0.5 m structure and 3.5 A current

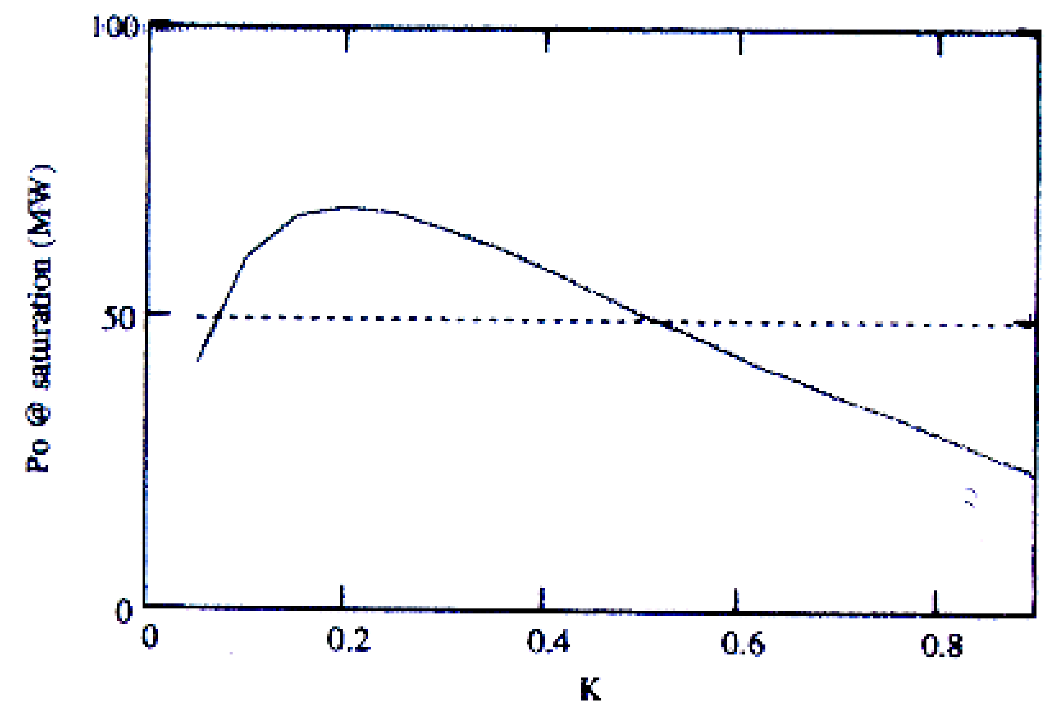
	Aperture, mm(bg,%)	Max. S. Field, MV/m	Power, MW
Constant z	7.5 (31.5)	58.5	12.54
TOS	5->10 (15-48)	46.0	14.87

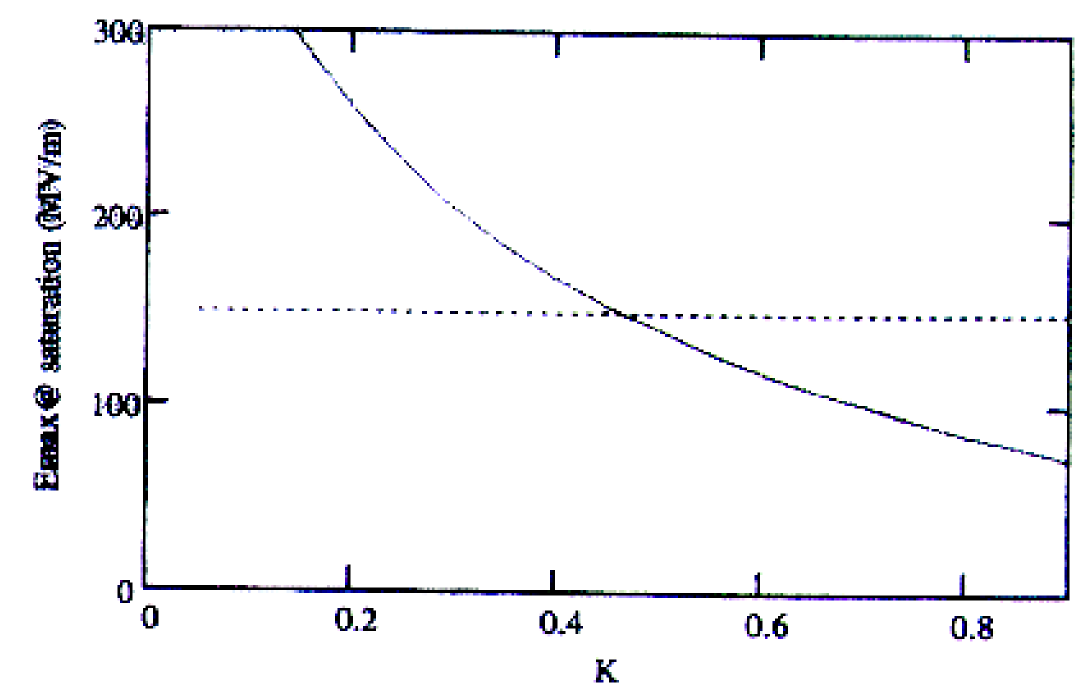




RECIRCULATION

- Not useful for single structure, P > 100 MW , due to limitation in peak surface field
- Can be used for two-structure operation (P> 50 MW), or for "booster" mode
- Example:





l_s = 0.5 m, a = 8.6 mm

P = 51 MW
E_{MAX} = 140 MV/m

Plus second structure in "booster" mode, will give:

P = 120 MW
E_{MAX} = 154 MV/m

SUMMARY - OUTLOOK

- Production of 30 GHz power in the 100 MW range using the DBA looks possible.
- Pulse lengths ranging up to the nominal CLIC value (150 ns) and a repetition rate of 25 Hz should be accessible.
- The optimum PETS design and parameters are still to be identified - some investigation in beam transport & stability must be made to assess that.
- Recirculation + booster operation can possibly be used with some advantage. A proof-of -principle test of recirculation in CTF II would be useful.

CTF3 probe beam / Hans Braun

- **applications**
- **options**

Warning:

Virtually nothing has been done so far for the probe beam, therefore all the considerations presented are very preliminary!

Probe beam applications

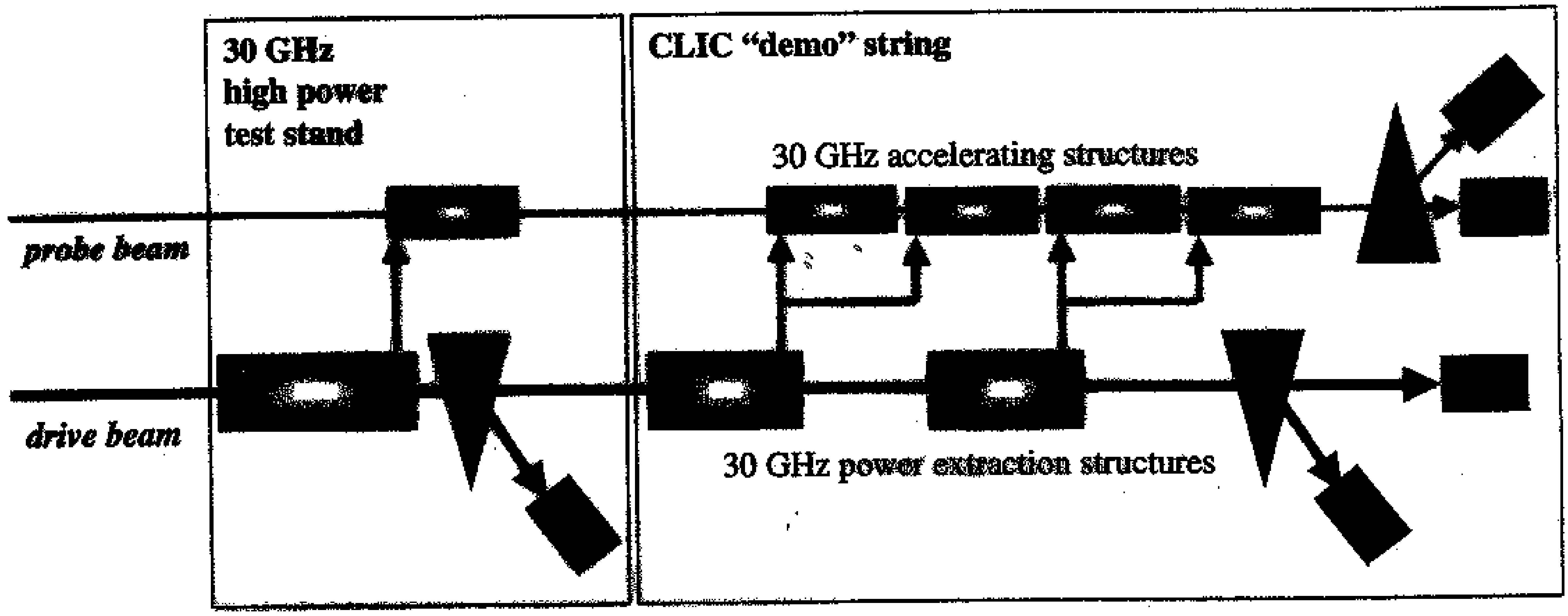
Single bunch probe beam

- test acceleration
- cross check of 30 GHz RF power calibration
- measure synchronous frequency of accelerating structures prototypes
- measure higher order modes frequencies of accelerating structures prototypes
- test-bed for CLIC main beam instrumentation
- engineering test-bed for CLIC accelerator module

Multi bunch probe beam

- test CLIC beam loading compensation scheme
- test damping of HOM's in accelerating structure prototypes
- test-bed for CLIC main beam instrumentation

CLEX - CLIC experimental area



Parameter space for probe beam injector

Injection energy in 30 GHz Module:

Assuming a 30 GHz module length of 1.4m, an aperture of Ø3.5 mm, a norm. injector emittance of 50 mm mrad and a 4σ beam clearance with

$$\gamma = \frac{64L}{d^2}\varepsilon$$

⇒ E>186 MeV

Bunch length:

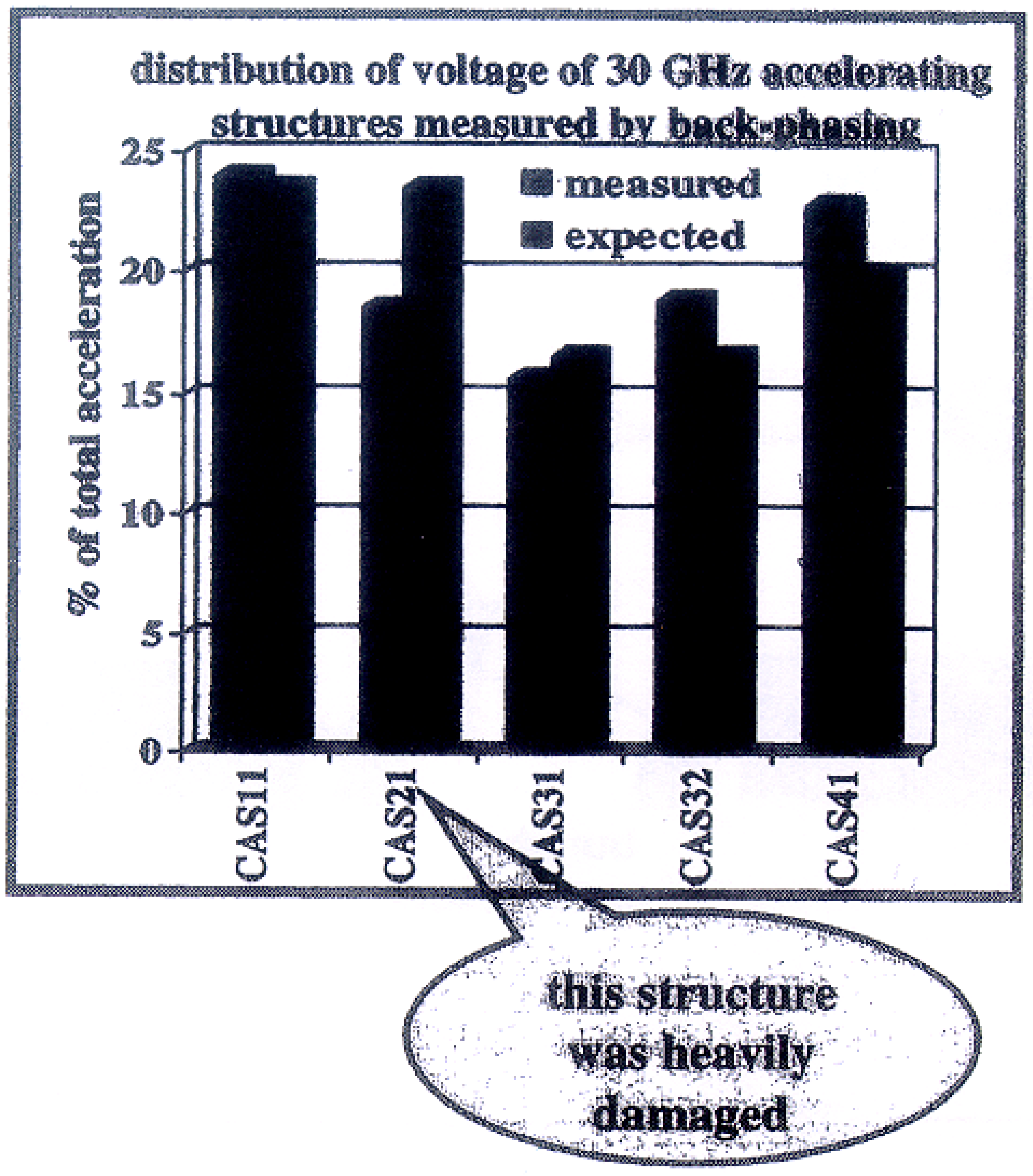
Energy spread due to b.l. $\Delta T/T \approx 1-\cos\omega\sigma_t$

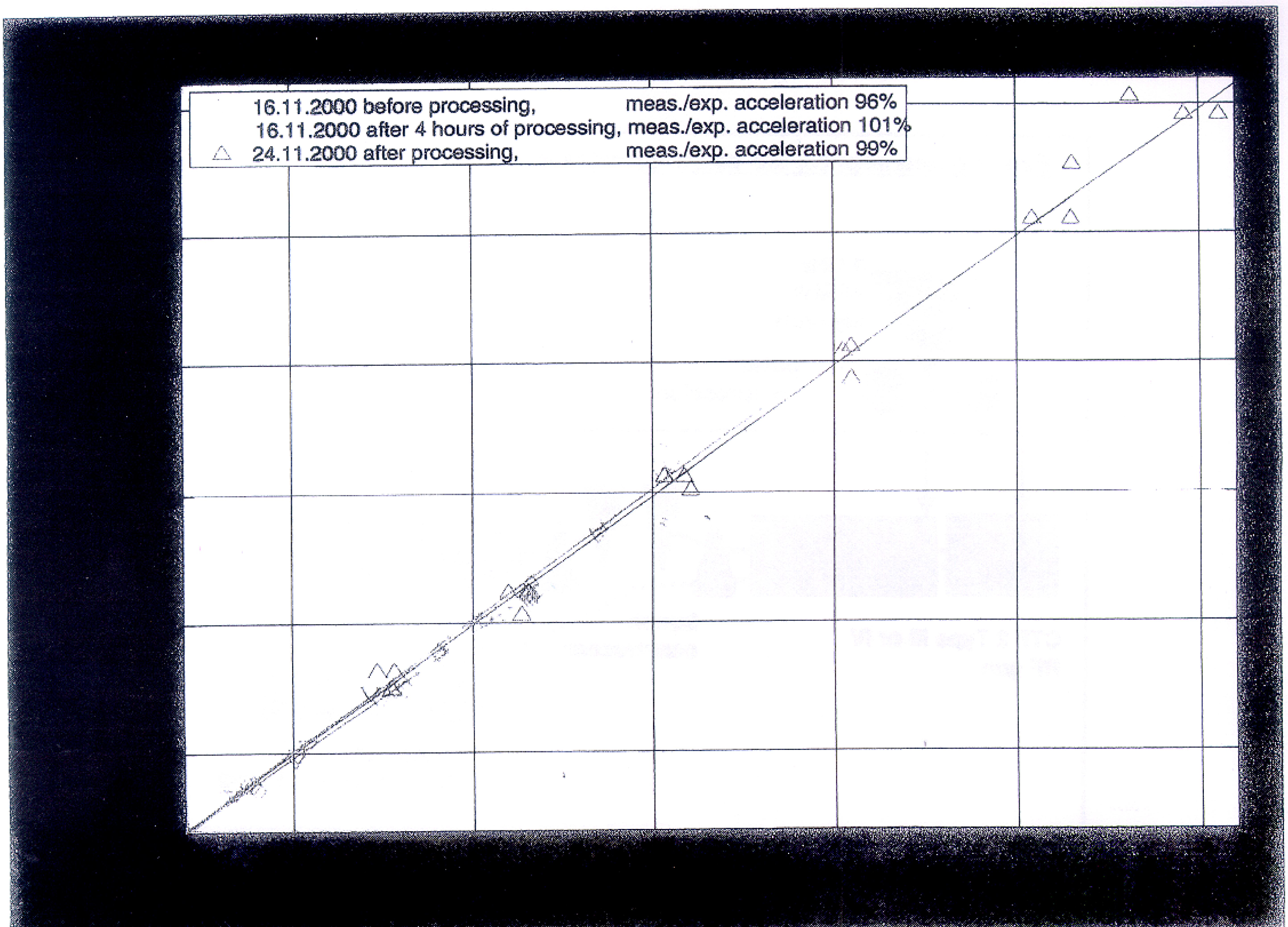
For $\Delta T/T \leq 1\% \Rightarrow \sigma_t \leq 0.75$ ps

Potential energy gain in a 30 GHz accelerator

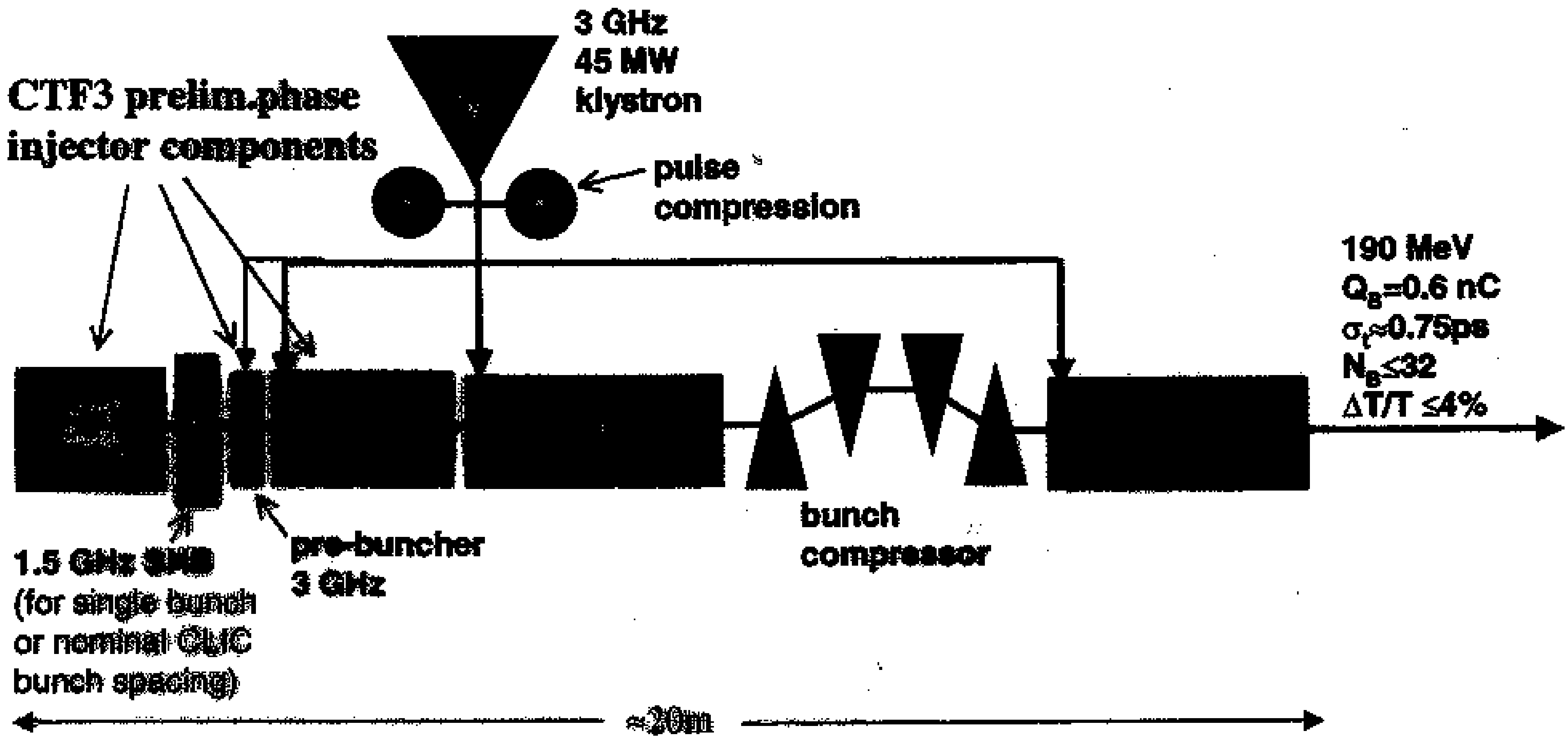
Assume 30 GHz structure parameters, E=150 MV/m, L=0.286m, $\Delta T = 3.51\ P^{1/2}$

If we decelerate the drive beam by 100 MeV we have 3.5 GW of 30 GHz power available. This is sufficient to power 24 accelerating structures, giving a total acceleration of 1.03GeV in an active length of only 6.9m !

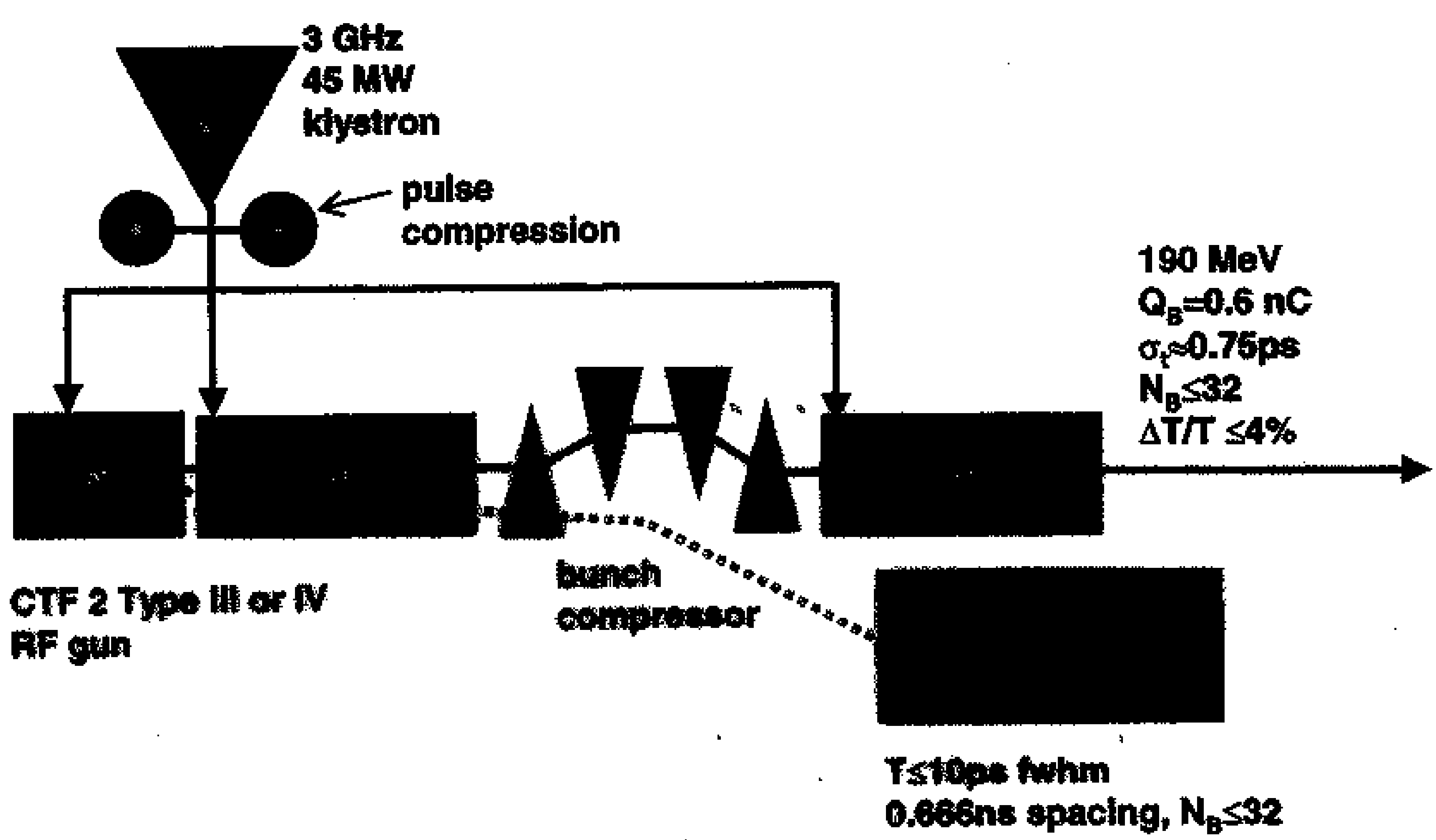

distribution of voltage of 30 GHz accelerating structures measured by back-phasing
% of total acceleration
25
20
15
10
5
0
measured
expected
CAS11
CAS21
CAS31
CAS32
CAS41
this structure was heavily damaged


16.11.2000 before processing, meas./exp. acceleration 96%
16.11.2000 after 4 hours of processing, meas./exp. acceleration 101%
24.11.2000 after processing, meas./exp. acceleration 99%

Probe beam source, thermionic gun scenario



Probe beam source, RF photo injector scenario



Summary

- The probe beam injector will be needed from 2005 on
- As for the drive beam we have two gun options, thermionic and a photo-injector.
- The choice will probably follow the choice for the drive beam
- Both options will make extensive use of existing equipment
- Both options need one 45 MW klystron with pulse compression as 3 GHz power source
- Both options will be about 20-25 m long
- Both options will need a bunch compressor
- No detailed design has been worked out yet
- Before making a more detailed design we need discussions and decisions what we want to measure with the probe beam

High-frequency high-power in CTF3

W. Wünsch

The nominal CLIC RF pulse is 30 GHz, 240 MW, 130 ns, 100 Hz giving an accelerating gradient of 150 MV/m.

The nominal CLIC drive beam is 240 A, 37 kJ.

In order to develop the CLIC RF system we need a such a beam and such a power…

We can probe these parameters with the CTF3 test stands.

The CTF3 test stands are foreseen to be the main experimental facilities for CLIC RF system development.

A test stand is a highly flexible single unit of two beam accelerator driven by the CTF3 beam and instrumented for high power, gradient and current tests.

For high power testing, the CTF3 test stands are direct descendents of CTF1 and CTFII.

We expect to start with the end-of-linac test stand (Roberto's talk) to get going as early as possible. We continue with the end-of-everything test stand for ultimate performance.

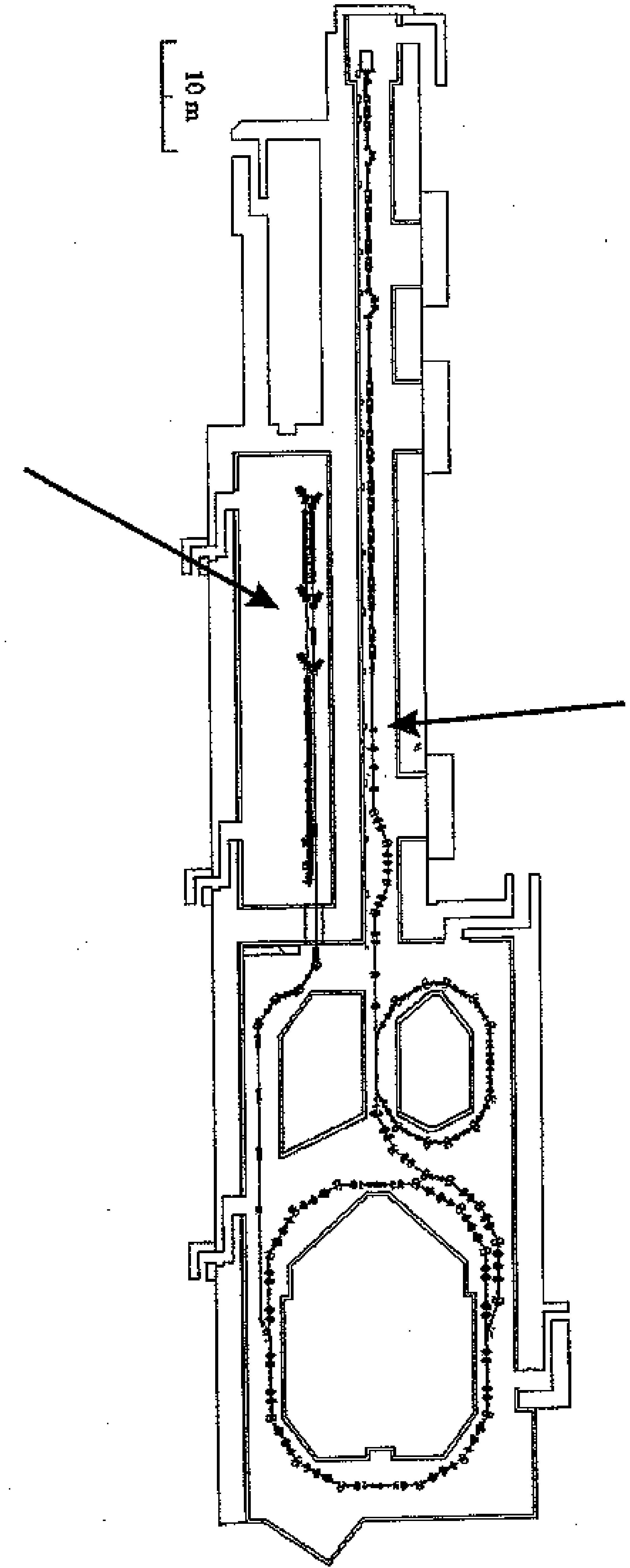
In order to be clear,

I will **NOT** present a detailed design and supporting calculations for the test stand - the work has not yet been done.

Nonetheless, 10 years of CTF1 and CTFII is direct evidence that the test stand is feasible and the accumulated experience make us very well prepared to design, build and operate it.

I will **NOT** present a detailed experimental program.

High powers and gradients are hot topics for which our understanding and achievements are evolving rapidly. We cannot say where we will be three or more years from now.



Materials: materials for arc resistance, materials for ultimate gradient.

Preparation and RF Processing: Machining, cleaning, pre-processing (glow discharge, laser melting etc.), 'soft' conditioning.

Pulsed surface heating: Physics, mechanics, materials, machining.

Lifetime testing.................................

Beam/structure interaction: Verification of RF parameters, field asymmetry, beam loading compensation, longitudinal and transverse wakefields, beam position signals.

Physics and Development

Structures:

Power generating structures

Accelerating structures

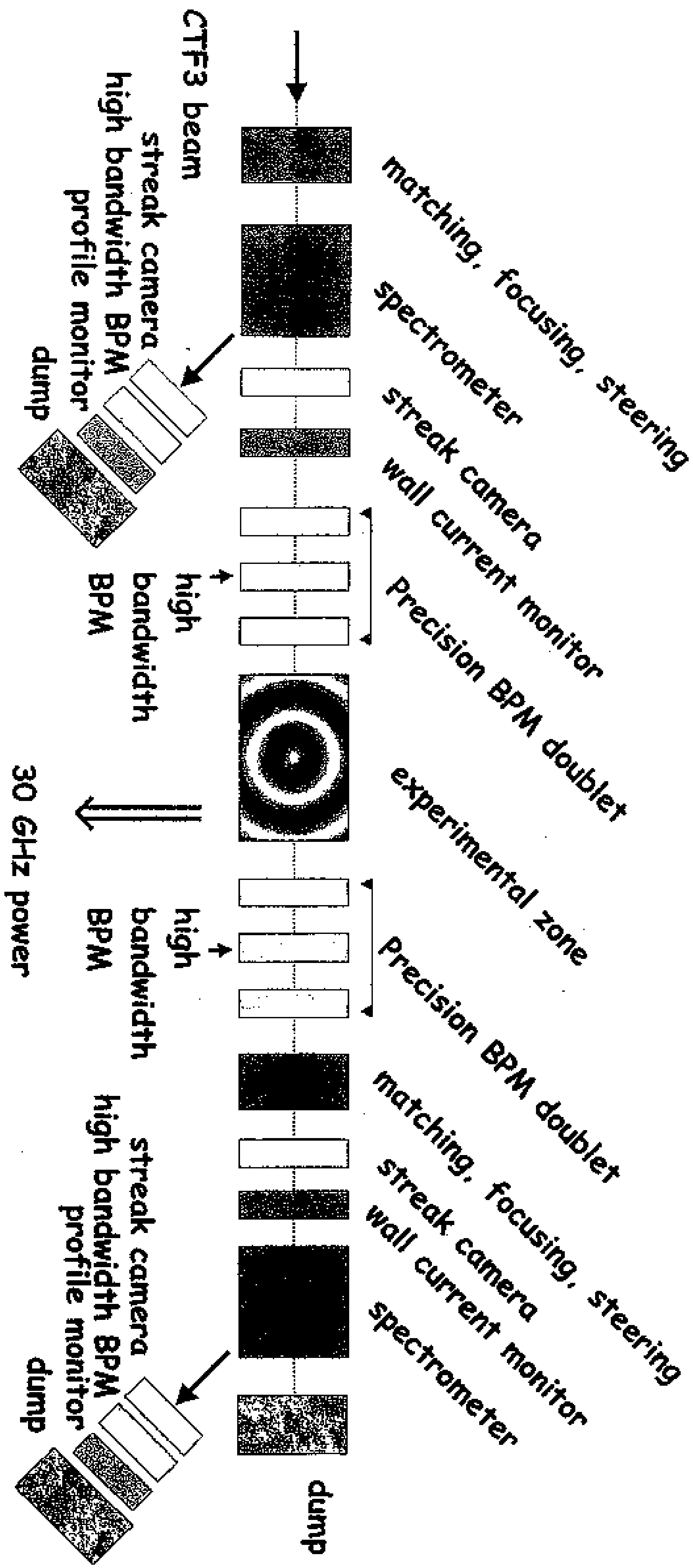
Waveguide components

Special test structures

Subjects:

Physics of breakdown: Trigger process, evolution of arc, absorption of RF energy, ultimate gradient, frequency scaling*, pulse length scaling, effect of RF design, effect of beam loss*, instrumentation.

Layout of test stand, power generating side



Power generation

CTFI - 24 A, 90 MeV, 8 ns, 80 MW
CTFII - 37 A, 60 MeV, 16 ns, 300 MW

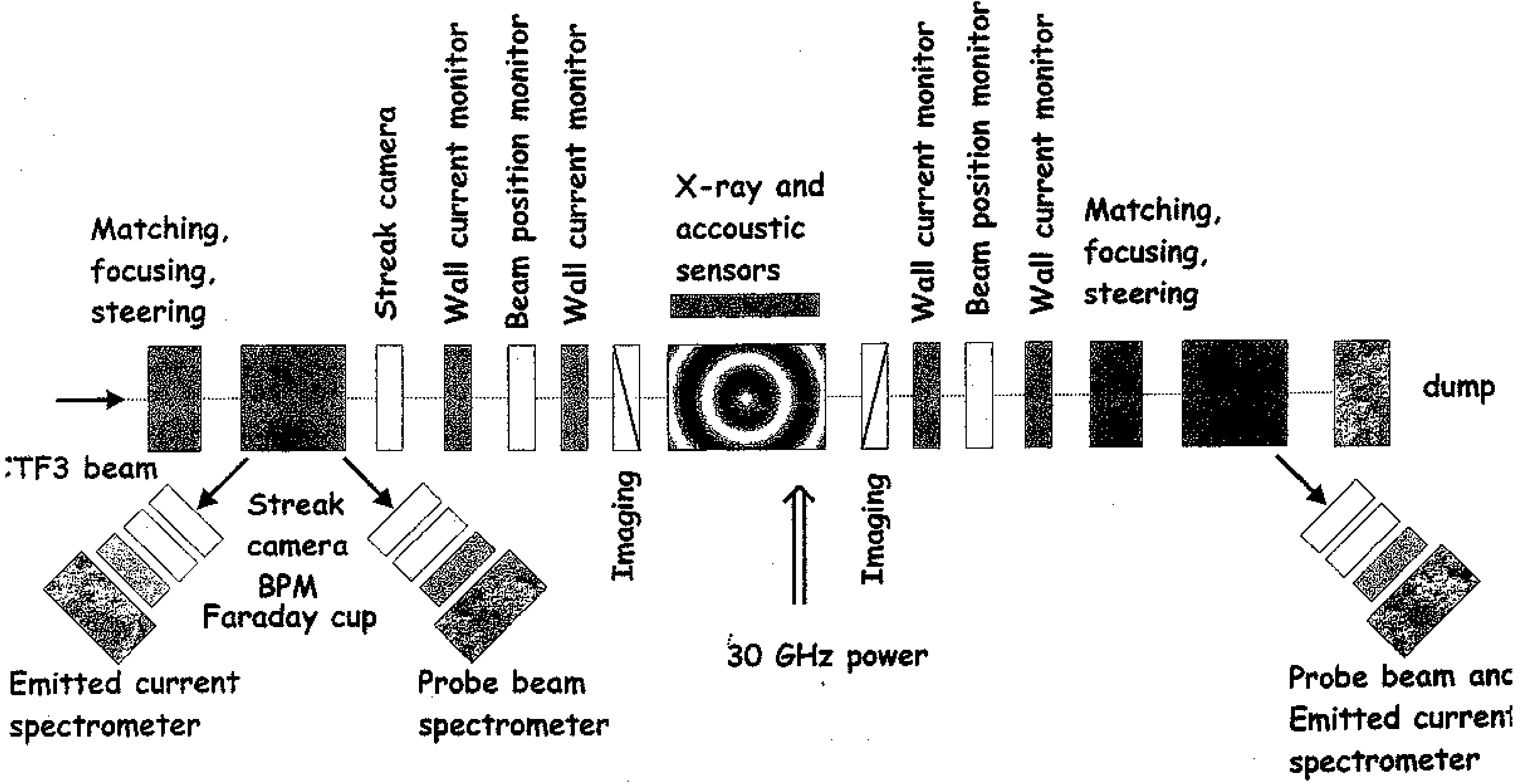
CTF3 - 35 A, 160 MeV, 130 ns
(End-of-linac- 3.5 A)

One of the most central design issues of the test stand is that of the power generating structures which must be matched to the current and energy of the driving beam.

CTF3 current* allows the use of existing CTFII style power generating structures. We may choose to re-optimize because,

Higher beam energy makes transmission through power generating structures easier.

Increased pulse length will be more difficult - but pulse length is an objective!



Optic and instrumentation layout of test stand, driven side

Gradient in the CTF3 3 GHz traveling wave buncher taking into account 5 A beam loading and 35 MW available input power

Cavity #	Phase Velocity β (C)	Gradient (MV/m)
1	0.71	8.37
2	0.76	9.34
3	0.82	10.06
4	0.88	10.60
5	0.94	11.00
6	1.0	11.25
7	1.0	11.36
8	1.0	11.36
9	1.0	11.30
10	1.0	11.21
11	1.0	11.11
12	1.0	11.01
13	1.0	10.94
14	1.0	10.88
15	1.0	10.84
16	1.0	10.80
17	1.0	10.73

Travelling-wave buncher for the CTF3 injector

H. Braun, G. Carron, R. Miller, A. Millich, L. Thorndahl, A. Yeremian

Specification:

- Seventeen 2π/3 S-band cells

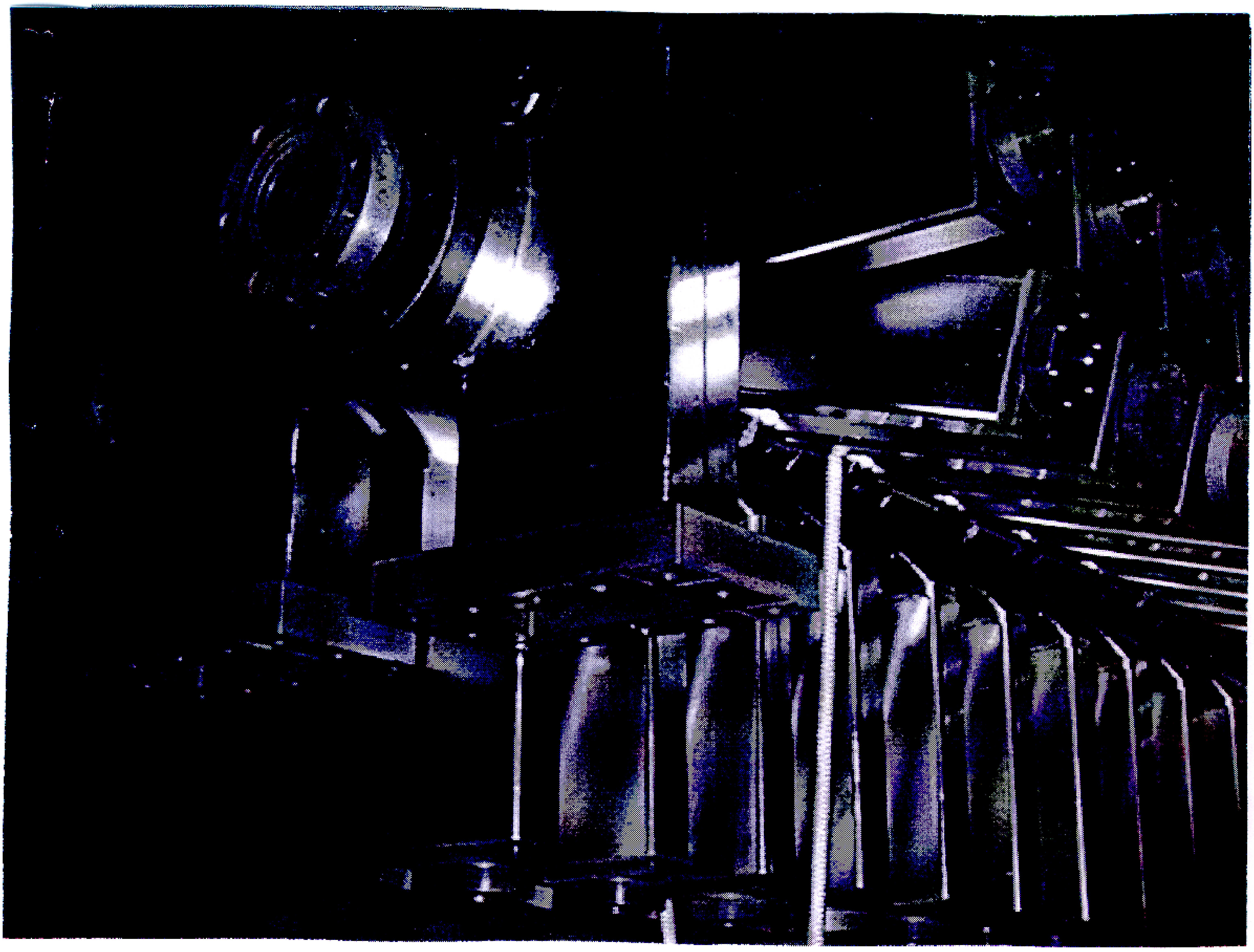
- The first 5 cells have linearly increasing phase velocity from 0.71c to c

140 keV: β=0.62

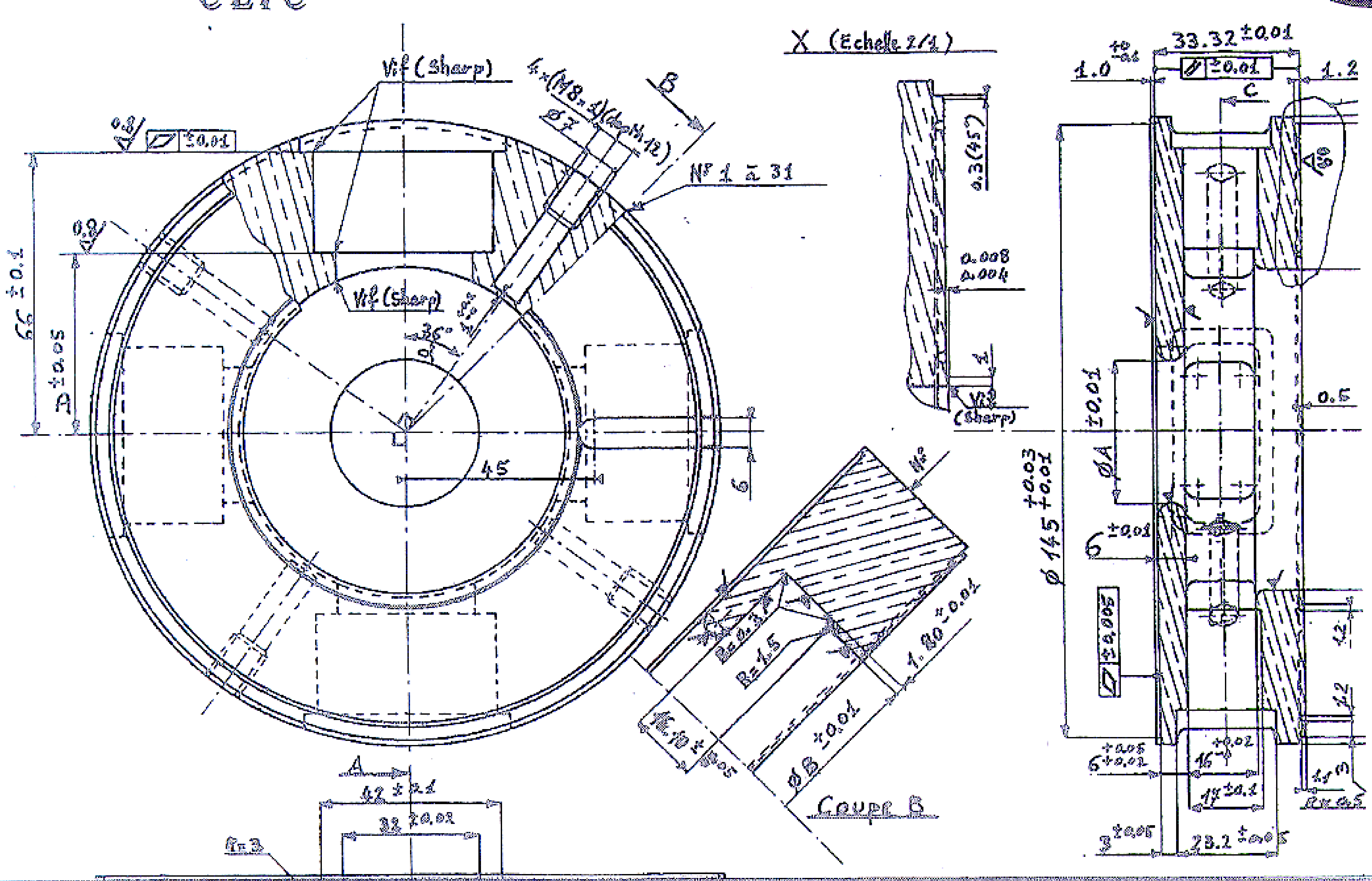
- With 35 MW input power the loaded starting gradient should be about 8 MV/m rising to 10 after 6 cells and then decreasing to about 8 for 5 A beam current

The TDS type design, with damping waveguides for HOMs, was chosen for convenience, since the hardware people involved had just built and tested a TDS structure.

Present status: The 17 cells are being measured and tuned.

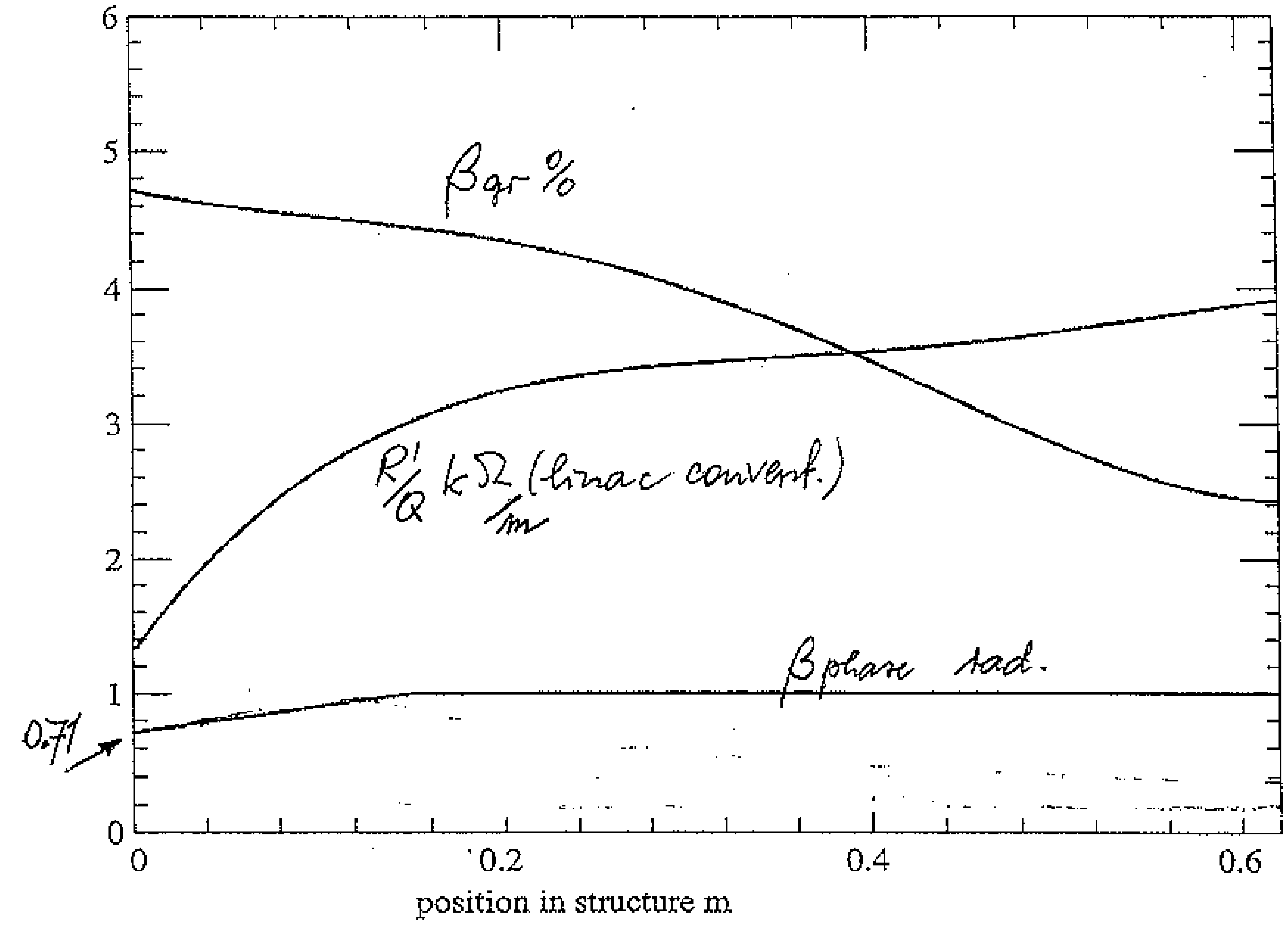


TDS, excerpt tech. drawing



Structure parameters

5A, 35 MW



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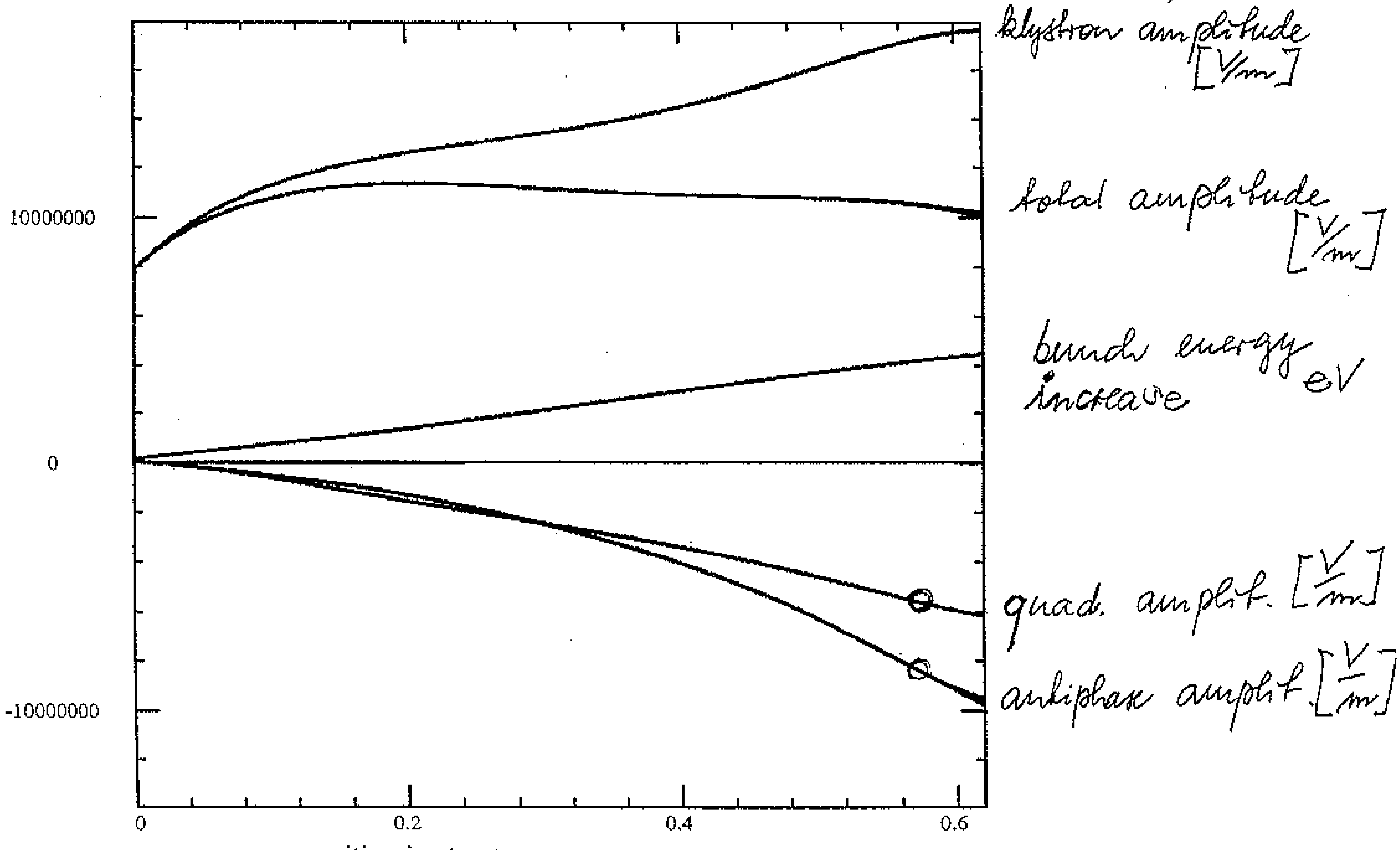
5A, 35 MW



Beamloading waves

a) wave in antiphase with klystron wave:

$$\frac{dE_1}{dz} = \frac{\omega}{2v_g}\frac{R'}{Q}\, i_b \underline{\cos\phi(z)} - \frac{\omega}{2v_g}\frac{1}{Q}E_1$$

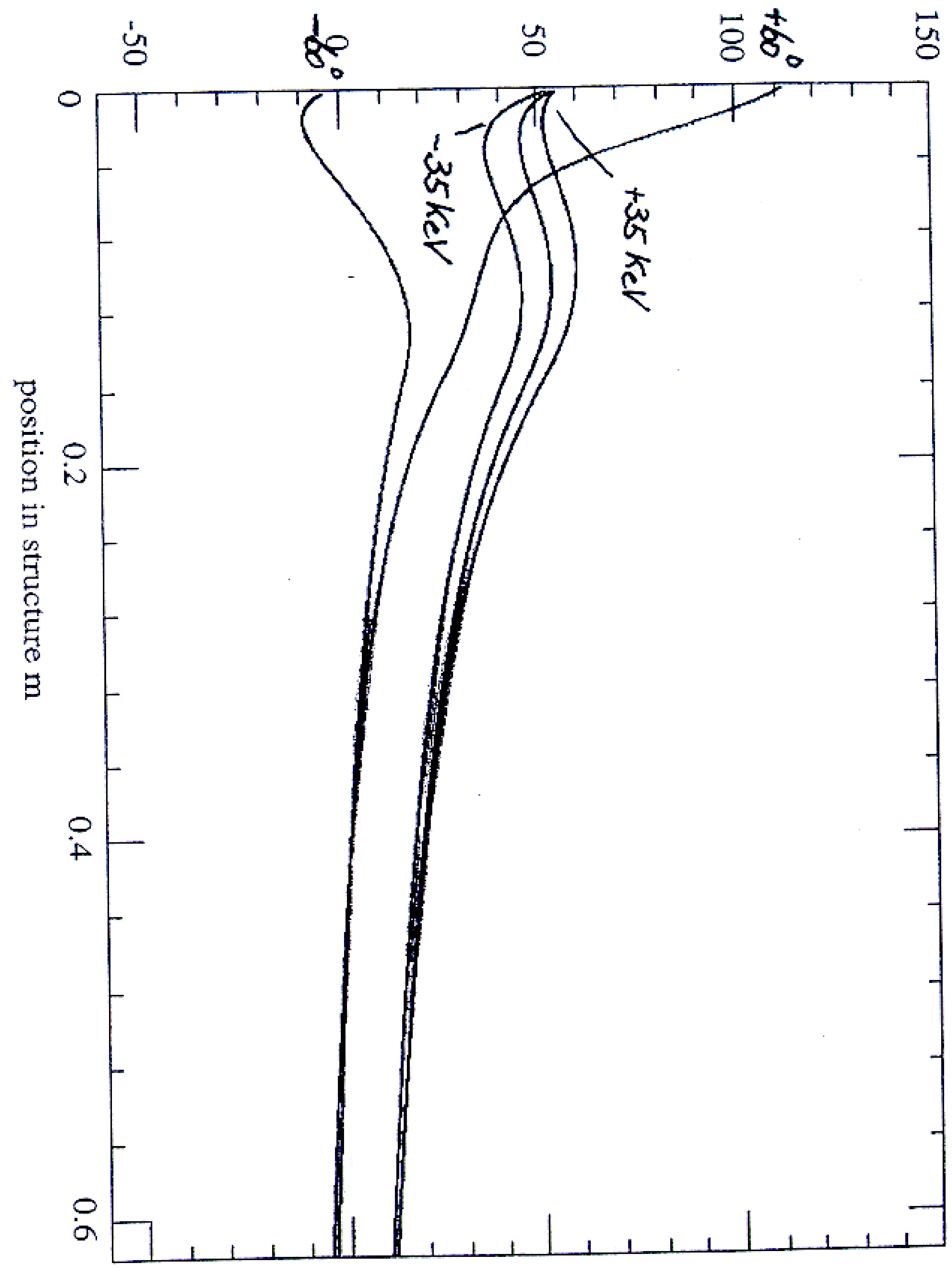
b) wave in quadrature with klystron wave

$$\frac{dE_2}{dz} = \frac{\omega}{2v_g}\frac{R'}{Q}\, i_b \underline{\sin\phi(z)} - \frac{\omega}{2v_g}\frac{1}{Q}E_2$$

$\phi(z)$: phase between bunch and klystron wave

NB: above expressions remain to be checked!

+55°: best choice found for center



Phase walk of extreme electrons

Conclusion: good agreement with Diaus results, comparison from ± 60 deg. to ± 8 deg.

To: A. Yeremian for Parmela calculations

1000E+01	.8400E+07	-.3242E+05	-.3973E+05	.8367E+07	-.2720E+00
2000E+01	.9486E+07	-.1477E+06	-.1598E+06	.9340E+07	-.9803E+00
3000E+01	.1035E+08	-.2964E+06	-.3236E+06	.1006E+08	-.1844E+01
4000E+01	.1106E+08	-.4705E+06	-.5441E+06	.1060E+08	-.2943E+01
5000E+01	.1165E+08	-.6761E+06	-.8274E+06	.1100E+08	-.4313E+01
6000E+01	.1211E+08	-.9152E+06	-.1140E+07	.1125E+08	-.5816E+01
7000E+01	.1247E+08	-.1207E+07	-.1458E+07	.1136E+08	-.7375E+01
8000E+01	.1277E+08	-.1553E+07	-.1774E+07	.1136E+08	-.8982E+01
9000E+01	.1303E+08	-.1926E+07	-.2071E+07	.1130E+08	-.1056E+02
1000E+02	.1329E+08	-.2336E+07	-.2365E+07	.1121E+08	-.1218E+02
1100E+02	.1358E+08	-.2799E+07	-.2671E+07	.1111E+08	-.1392E+02
1200E+02	.1390E+08	-.3296E+07	-.2979E+07	.1101E+08	-.1569E+02
1300E+02	.1427E+08	-.3848E+07	-.3305E+07	.1094E+08	-.1759E+02
1400E+02	.1473E+08	-.4488E+07	-.3668E+07	.1088E+08	-.1970E+02
1500E+02	.1524E+08	-.5188E+07	-.4051E+07	.1084E+08	-.2195E+02
1600E+02	.1580E+08	-.5975E+07	-.4467E+07	.1080E+08	-.2444E+02
1700E+02	.1641E+08	-.6874E+07	-.4923E+07	.1073E+08	-.2731E+02
1800E+02	.1697E+08	-.7810E+07	-.5385E+07	.1062E+08	-.3046E+02
1900E+02	.1740E+08	-.8785E+07	-.5801E+07	.1039E+08	-.3395E+02
2000E+02	.1760E+08	-.9881E+07	-.6241E+07	.9923E+07	-.3897E+02
	amplitude	amplitude	amplitude	amplitude	degrees with respect to klystron wave φ_1

	Grad. on bunch (amplitude x cos ($\varphi_2-\varphi_1$))	energy [eV]	φ_2 bunch deg. (w. resp. to klystron)	β bunch
1000E+01	.5554E+07	.1916E+06	.4814E+02	.6798E+00
2000E+01	.6386E+07	.3446E+06	.4588E+02	.7984E+00
3000E+01	.6211E+07	.5095E+06	.5001E+02	.8635E+00
4000E+01	.5792E+07	.6771E+06	.5393E+02	.9015E+00
5000E+01	.5687E+07	.8535E+06	.5456E+02	.9264E+00
6000E+01	.6282E+07	.1043E+07	.5023E+02	.9438E+00
7000E+01	.7079E+07	.1265E+07	.4406E+02	.9573E+00
8000E+01	.7562E+07	.1515E+07	.3928E+02	.9673E+00
9000E+01	.7809E+07	.1769E+07	.3572E+02	.9743E+00
1000E+02	.7912E+07	.2029E+07	.3291E+02	.9794E+00
1100E+02	.7921E+07	.2298E+07	.3058E+02	.9832E+00
1200E+02	.7867E+07	.2559E+07	.2872E+02	.9859E+00
1300E+02	.7768E+07	.2817E+07	.2716E+02	.9880E+00
1400E+02	.7627E+07	.3079E+07	.2578E+02	.9897E+00
1500E+02	.7449E+07	.3328E+07	.2463E+02	.9910E+00
1600E+02	.7216E+07	.3570E+07	.2362E+02	.9921E+00
1700E+02	.6899E+07	.3810E+07	.2269E+02	.9929E+00
1800E+02	.6488E+07	.4031E+07	.2189E+02	.9936E+00
1900E+02	.5943E+07	.4236E+07	.2116E+02	.9942E+00
2000E+02	.5046E+07	.4427E+07	.2047E+02	.9946E+00

5 A (through buncher) 35MW

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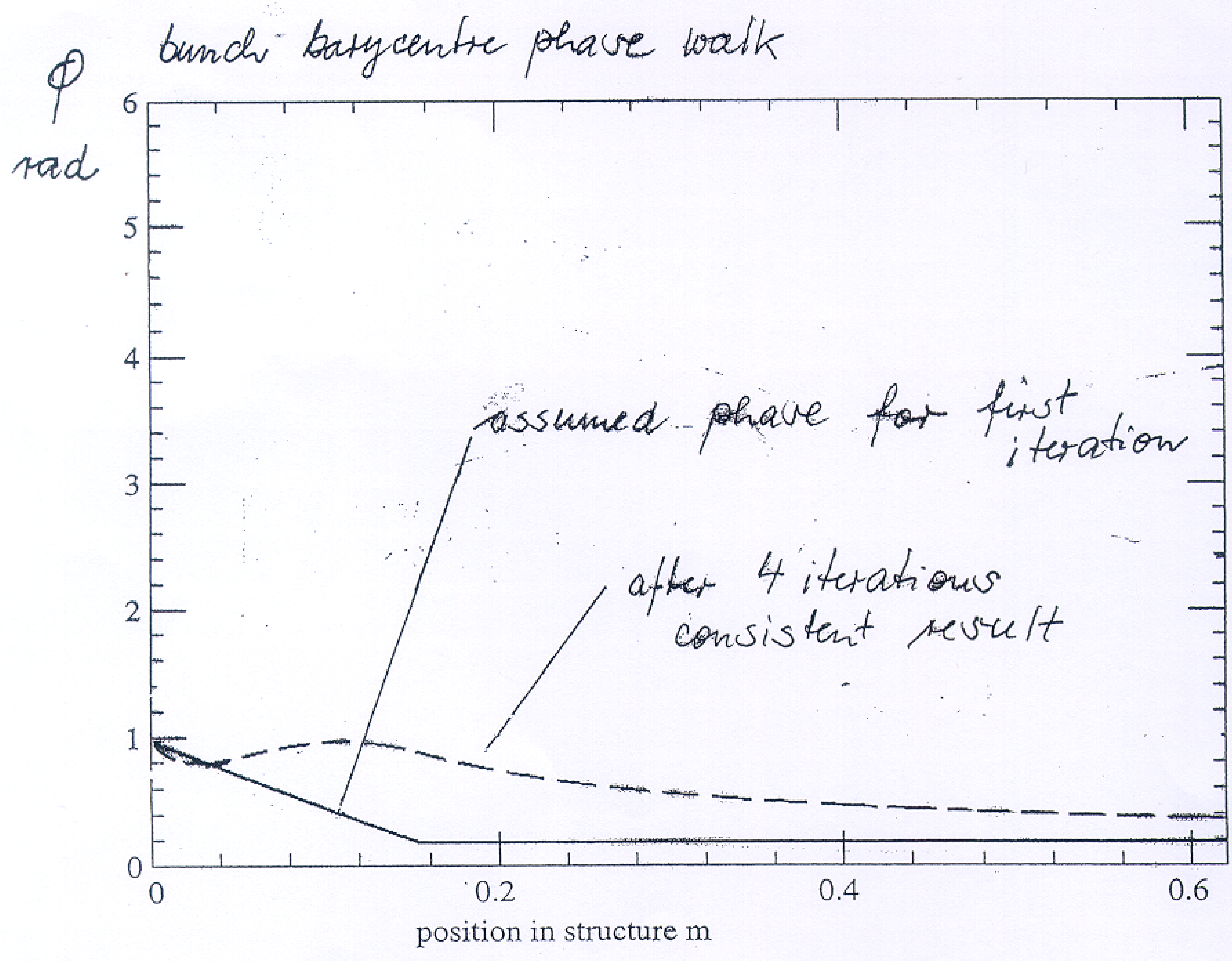
5A, 35MW



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CTF3 Preliminary phase

Experiments done in LPI and planned in CTF3

L. Rinolfi

Motivations

The CLIC Test Facility (CTF3) has been proposed to demonstrate the technical feasibility of the key concepts of the CLIC RF power source:

1) generation of a high-current, high-frequency drive-beam by combination of electron bunch trains in an isochronous ring using transverse RF deflectors.
2) operation with a fully-loaded drive-beam accelerator.
3) CTF3 will also provide the 30 GHz RF power needed to test the CLIC accelerating structures and components at the nominal gradient and pulse length (150 MV/m for 130 ns).

These issues will be fully covered in the CTF3 Nominal phase (2004-2005)

- The Preliminary Phase of CTF3 (2001-2002) is a demonstration of the first point, but at low-charge and short pulse.
  - * Also acquire experience in combiner ring operation and develop tools for next phases.

This demonstration is possible using the existing hardware - However, it needs a large number of modifications of the former LPI (LEP Pre-Injector) complex.

CERN - European Laboratory for Particle Physics

CLIC Note 470

Beam dynamics for the CTF3 preliminary phase

R. Corsini, A. Ferrari, L. Rinolfi, T. Risselada, P. Royer, F. Tecker

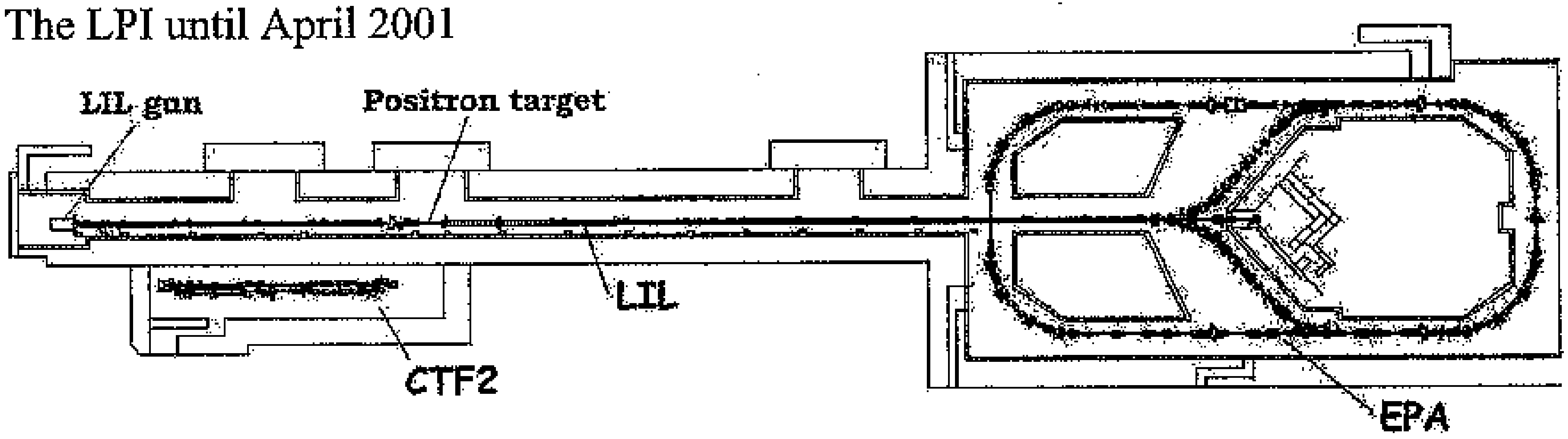
Abstract

In the framework of the CLIC RF power source studies, the new scheme of electron pulse compression and bunch frequency multiplication, using injection by RF deflectors into an isochronous ring, will be tested at CERN during the CTF3 preliminary phase. The present LPI complex will be modified in order to allow a test of this scheme at low charge. The design of the new front-end, of the modified linac, of the matched transfer line, and of the isochronous ring lattice is presented here. The results of the related beam dynamics studies are also discussed.

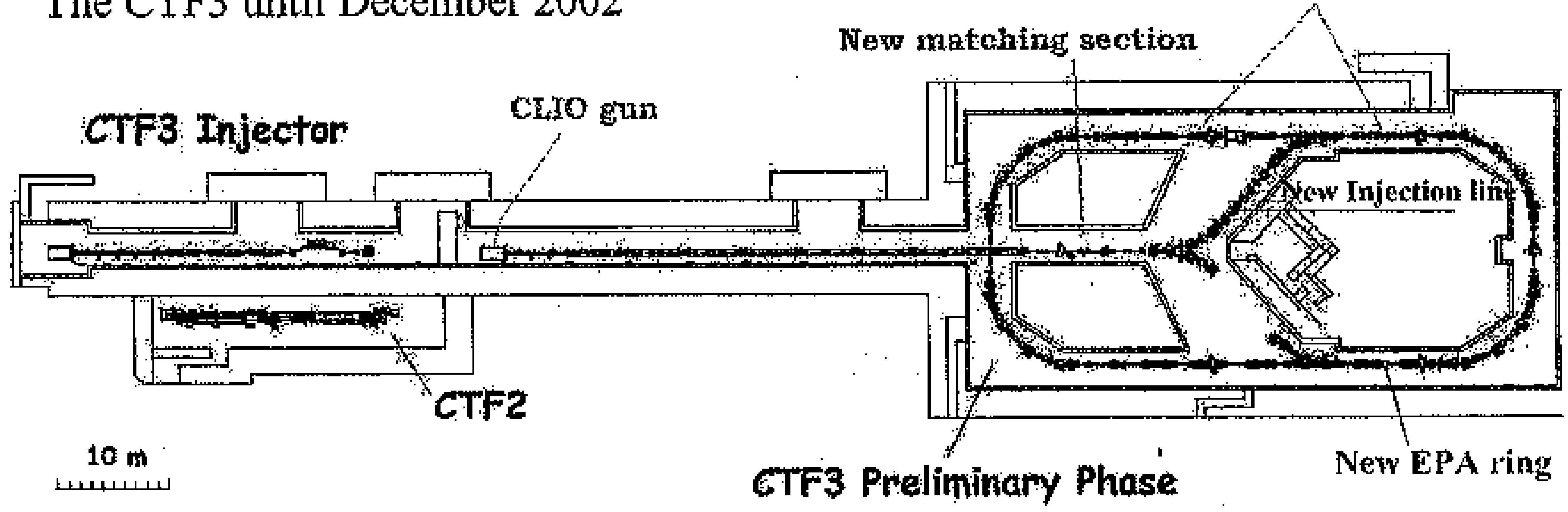
Geneva, Switzerland
January 30, 2001

Layout of CTF3 Preliminary phase

The LPI until April 2001



The CTF3 until December 2002



Isochronous machine

$$\eta = \frac{1}{\gamma^2} - \alpha$$

where γ = Relativistic factor E/E_0 α = Momentum compaction

For leptons storage rings:

γ is very large, then $\eta \sim |\alpha|$

Momentum compaction

$$\alpha = \frac{1}{C}\int_0^C \frac{D(s)}{\rho} ds$$

Modification of dispersion using N quadrupoles [1]

$$C\Delta\alpha = -\sum_{i=1}^{N} \Delta K_i L_i D_i D_i^*$$

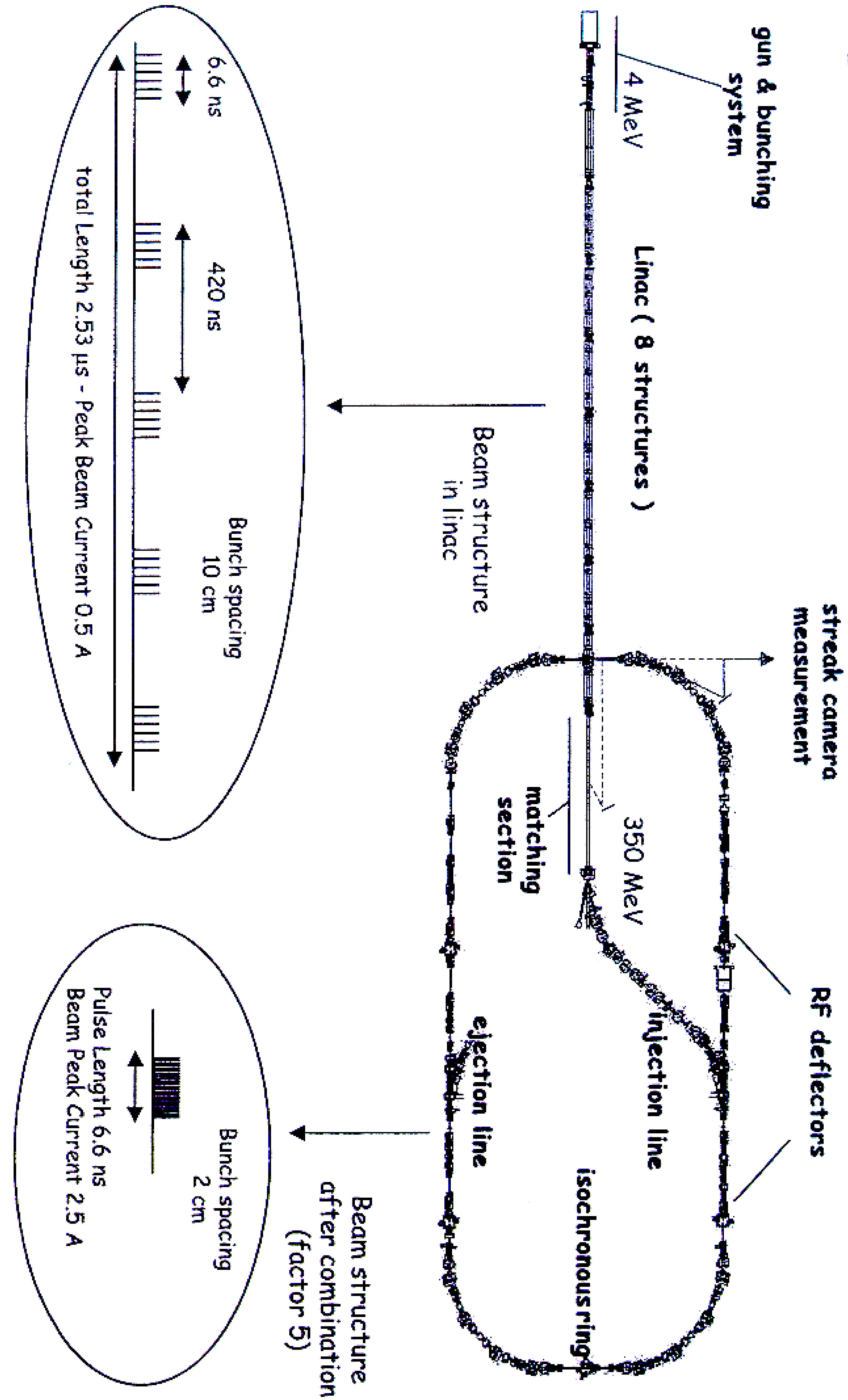
C = Ring circumference
ΔK = normalised gradient increment
L = quadrupole length
D = unperturbed dispersion at quadrupole
D* = modified dispersion at quadrupole

Small gradient change:

$$C\Delta\alpha \approx -\sum_{i=1}^{N} \Delta K_i L_i D_i^2$$

[1] T. Risselada, "Proceedings of the Fifth General Accelerator Physics Course", CERN 94-01, 1994.

General description of CTF3 preliminary phase



Bunch to bunch distance

Momentum compaction

$$\alpha = \frac{\frac{dC}{C}}{\frac{dp}{p}}$$

Time variation

$$dC = c\,dt = \alpha C \frac{dp}{p}$$

After N turns

$$N\,dt = \alpha \frac{C}{c}\frac{dp}{p} N$$

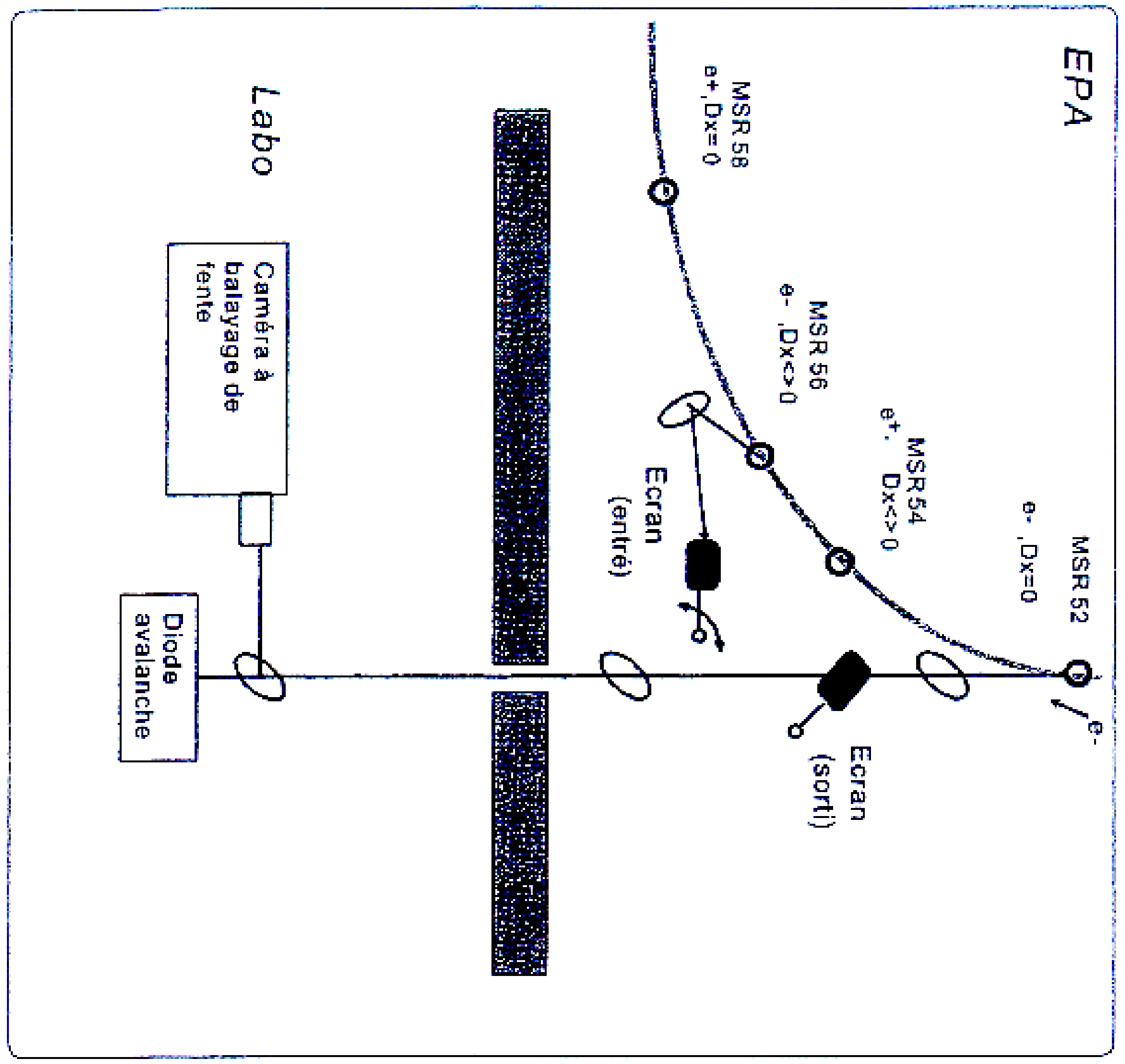
Bunch to bunch distance

$$\Delta t(N) = \Delta t(0) + N\,dt$$

Bunch to bunch distance versus α

$$\Delta t(N) = \Delta t(0) + \alpha \frac{C}{c}\frac{dp}{p} N$$

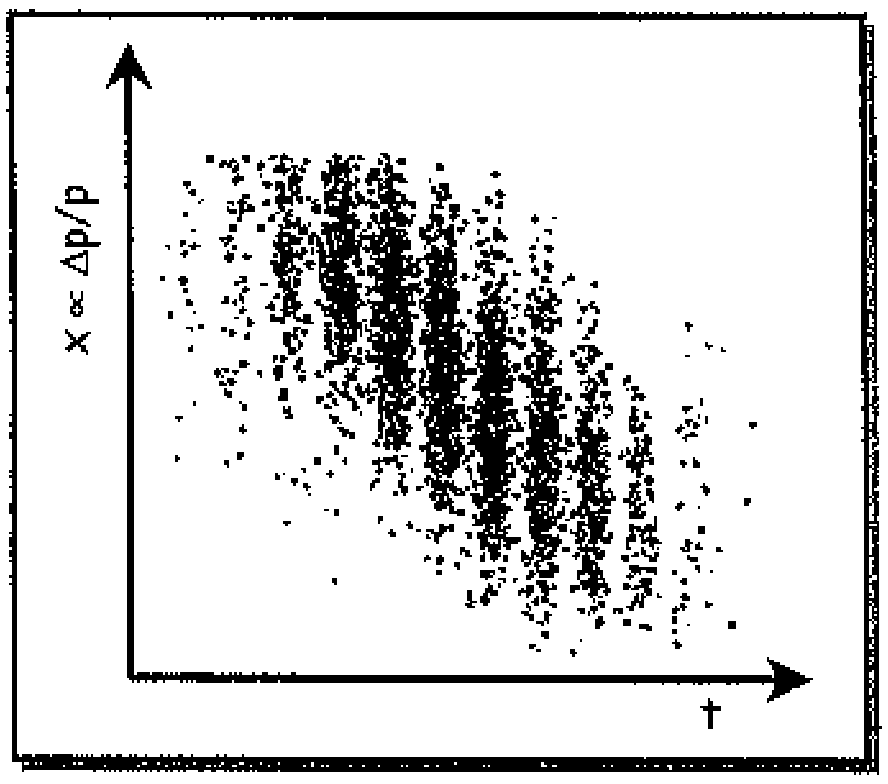
Streak Camera Layout



Layout for the micro-bunch measurements. A streak camera uses the synchrotron light coming from the EPA ring.

Two screens allow measurements in a dispersive region (MSR56) and in a non-dispersive region (MSR52).

Measurements with streak camera in EPA ring - 1

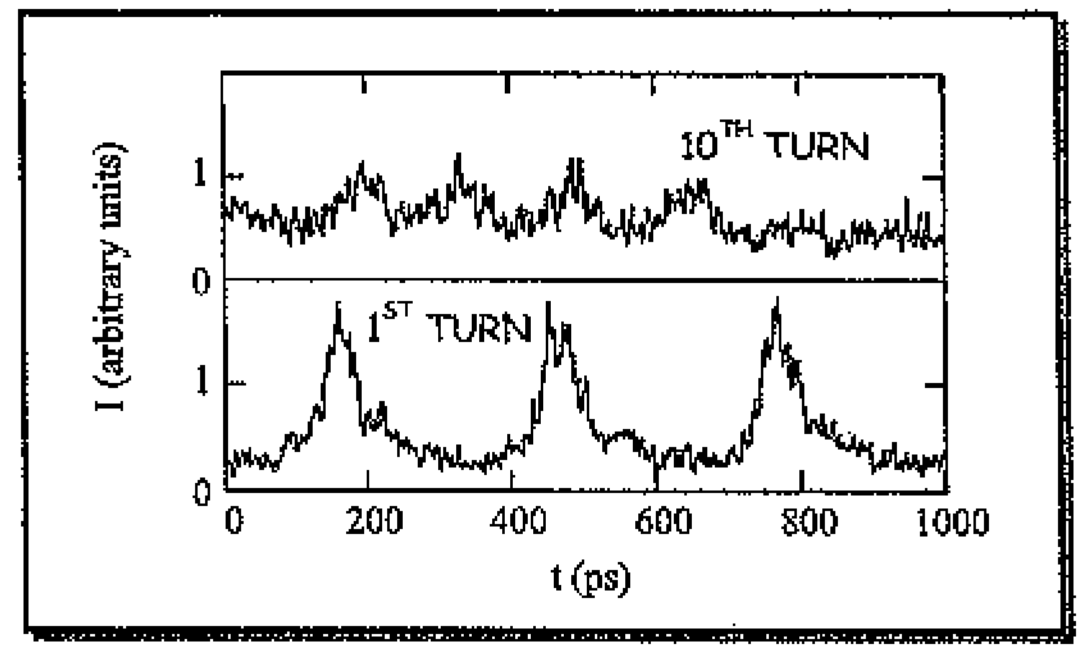


Streak camera image of the electron pulse
(April 1999)

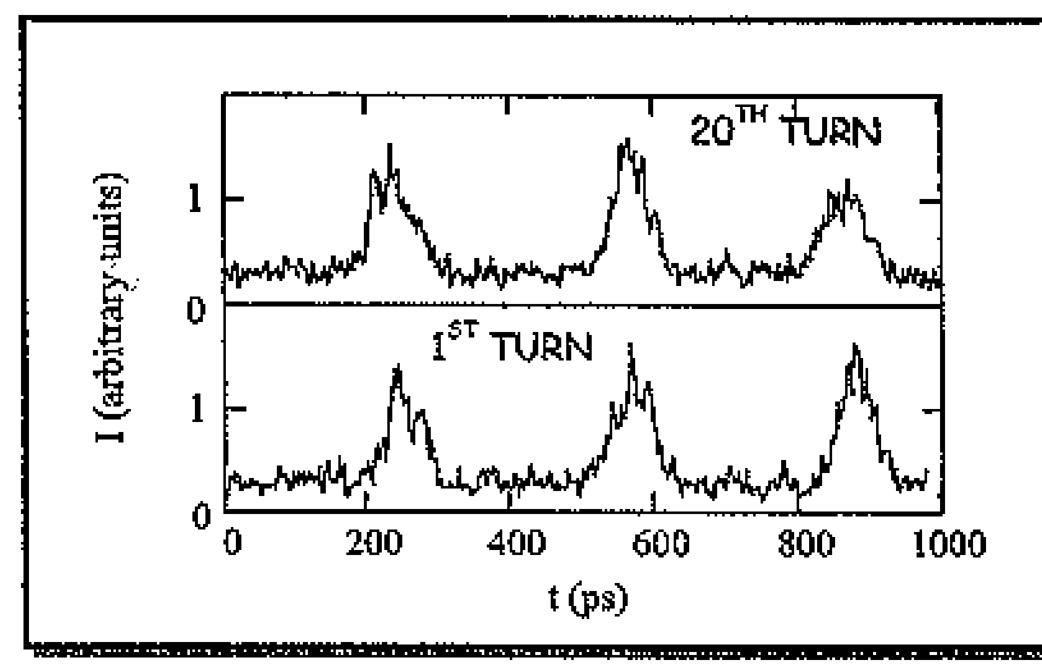
Streak camera image of the total pulse and corresponding time profile

Pulse profiles in time

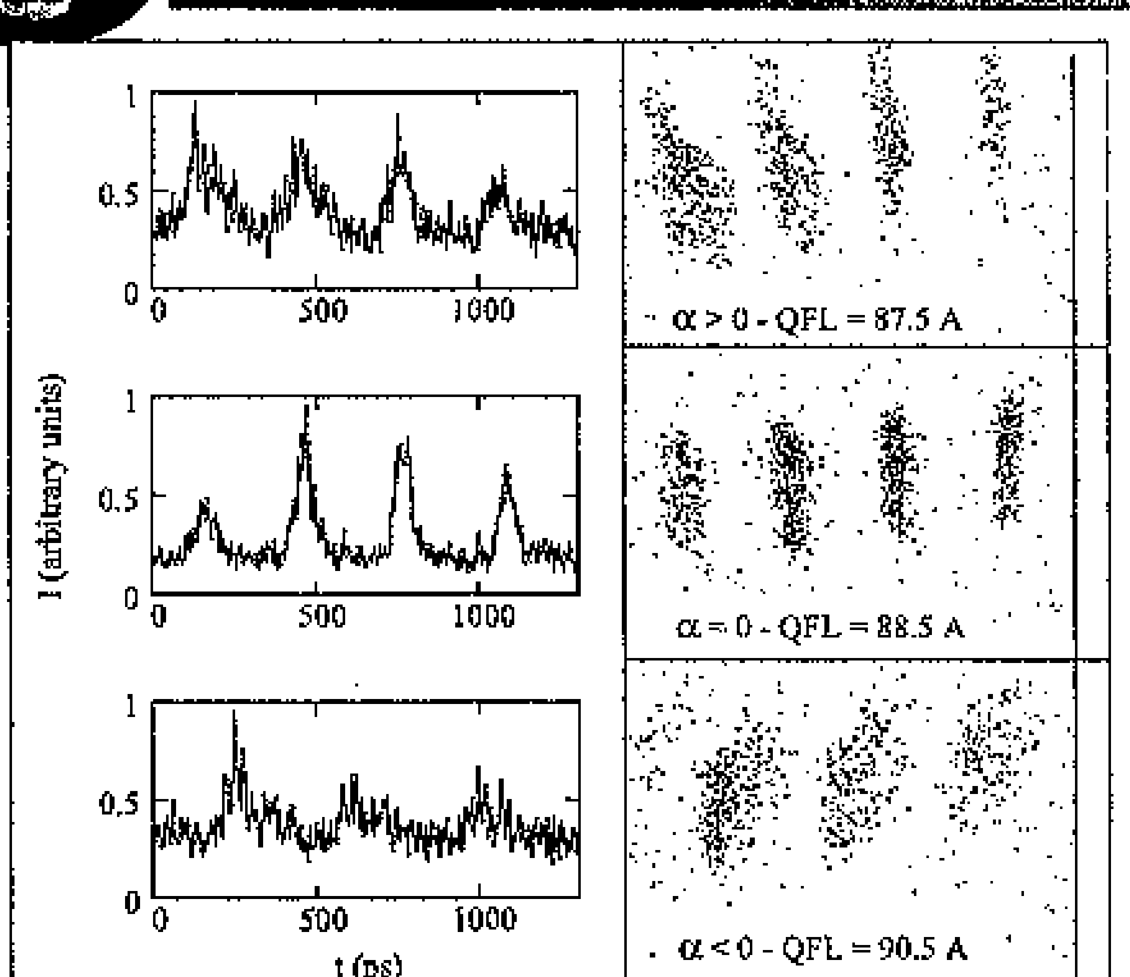
Nominal EPA optics



Isochronous EPA optics



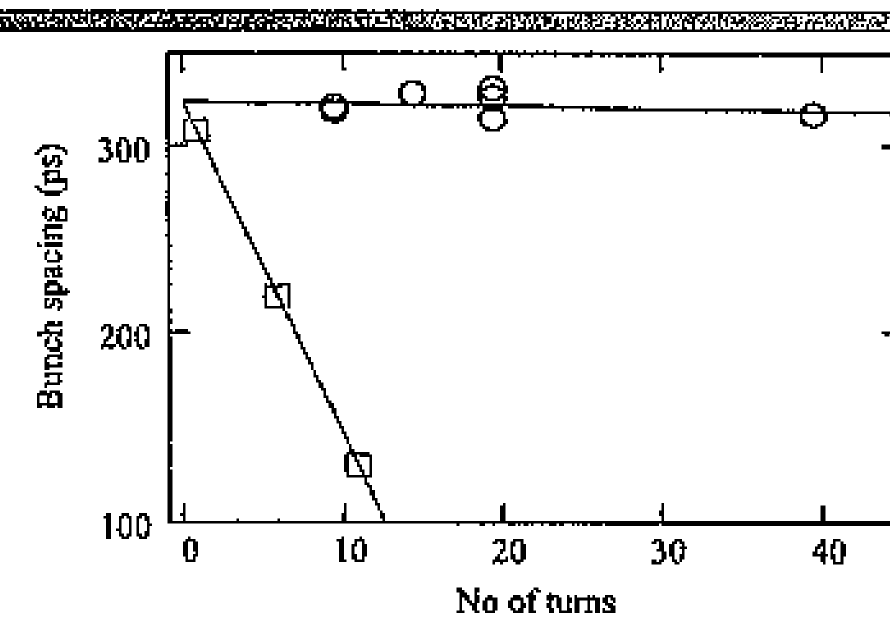
Measurements with streak camera in EPA ring - 2



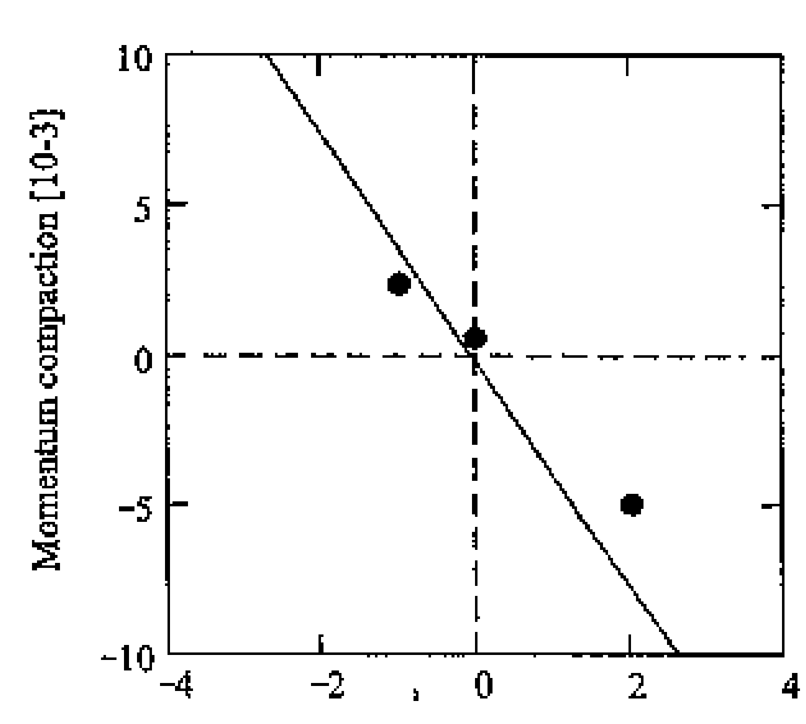
Streak camera images and time profiles for different settings of the QFL quadrupole family, around $\alpha = 0$ (20 turns)

nominal optics ($\alpha = 3.4 \times 10^{-2}$)
isochronous optics ($\alpha = 2.3 \times 10^{-4}$)

CTF3 & CLIC requirement $|\alpha| \leq \pm 1 \times 10^{-4}$

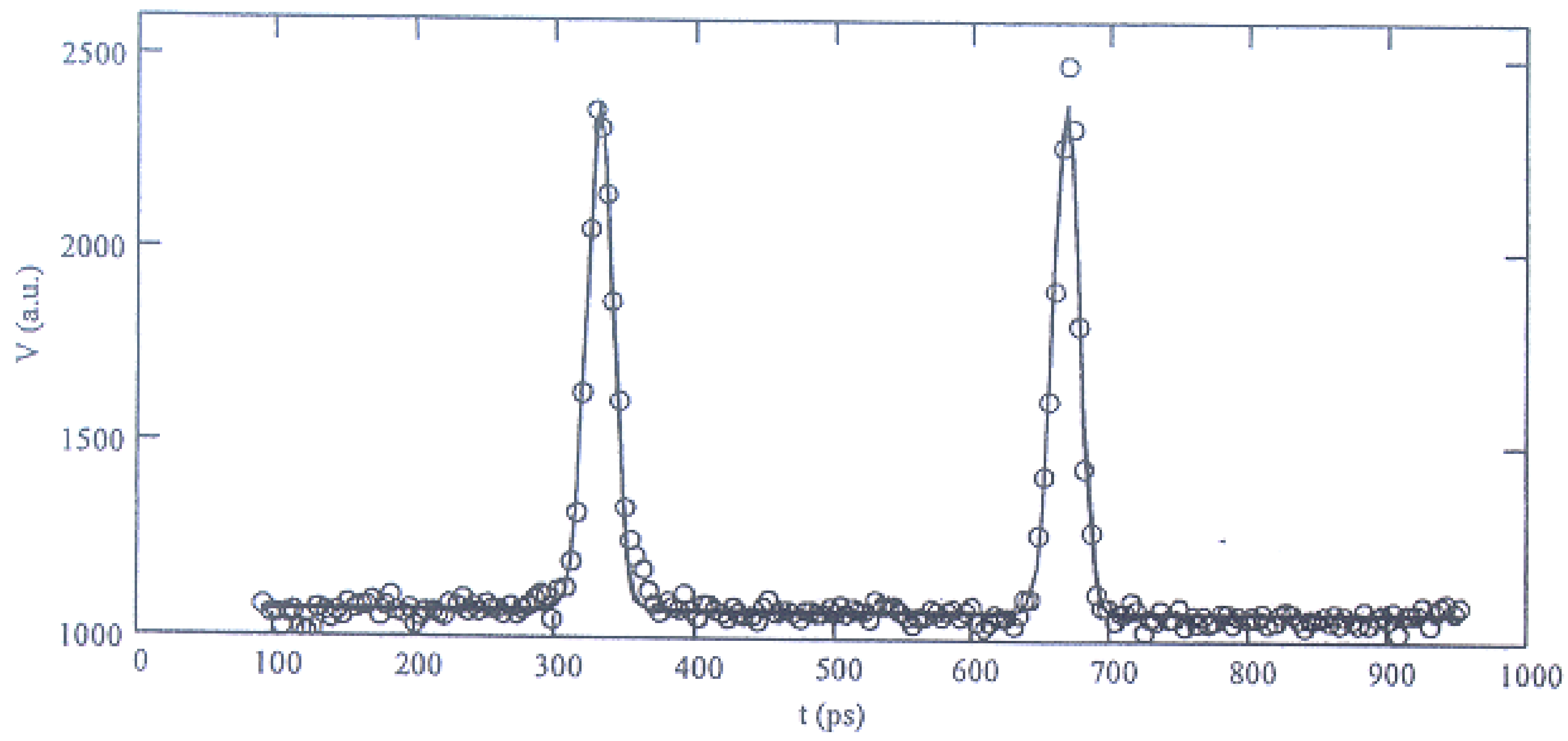


Bunch-to-bunch spacing as a function of the number of turns for the normal (squares) and the isochronous optics (circles).



Comparison between the momentum compaction evaluated with MAD (solid line) and the estimation based on the measured bunch distance (circles) as a function of QFL current variation

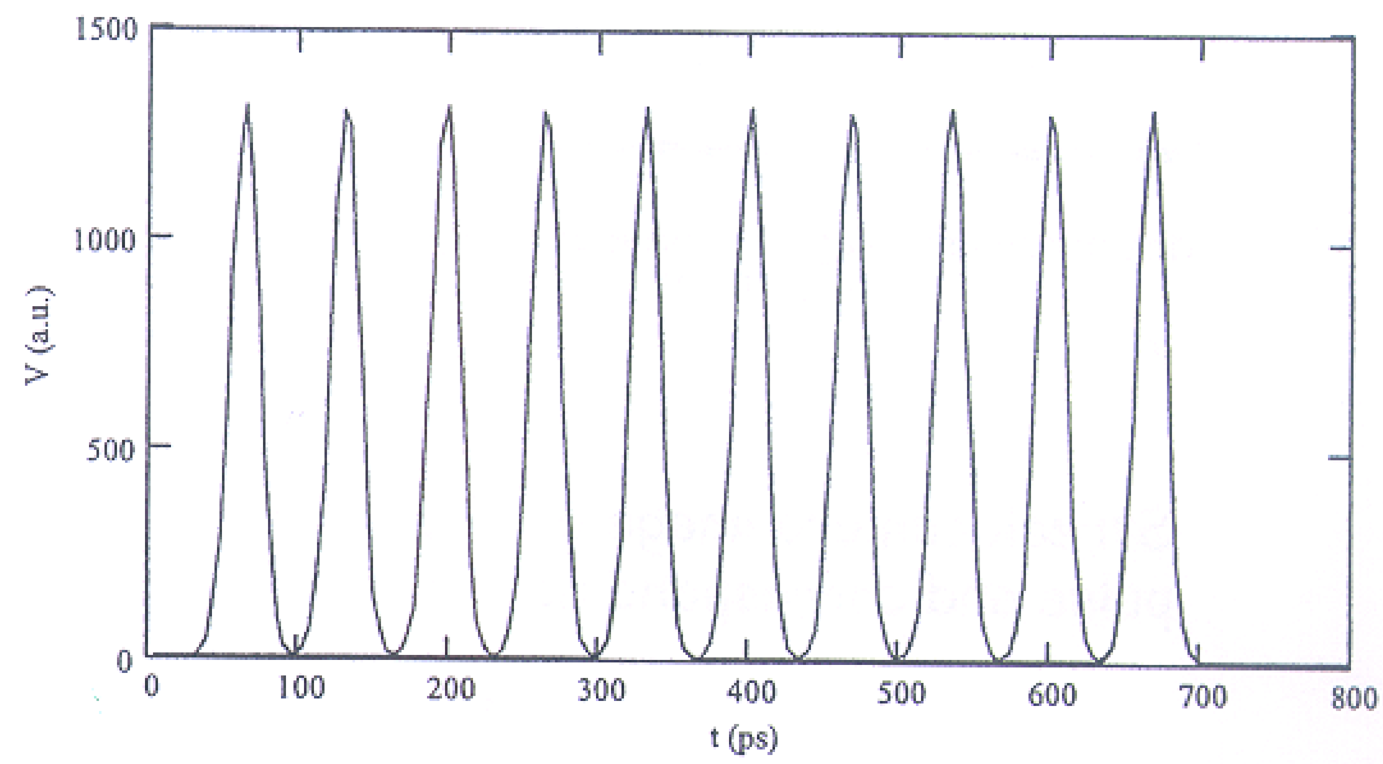
Measurements with streak camera in EPA ring - 3



Bunch length measurements
(December 2000)

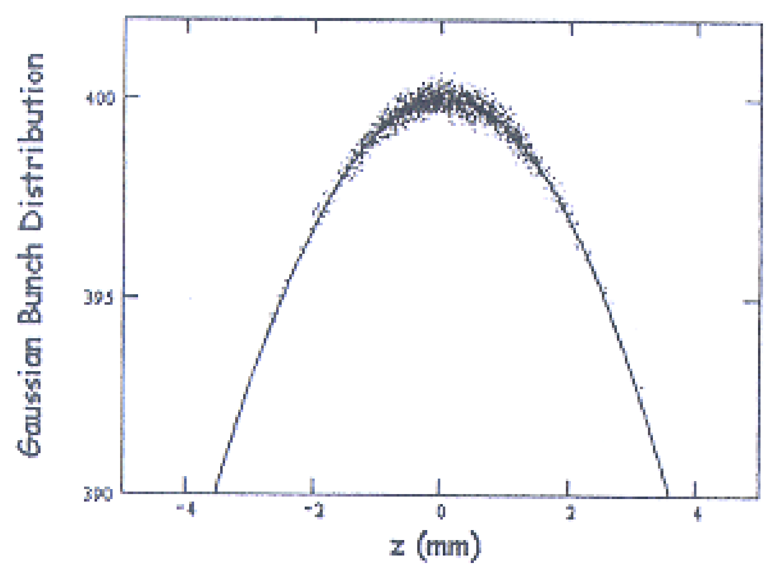
The Gaussian fit gives a bunch length of about 20 ps FWHM

Simulations of bunch combination by a factor 5 assuming 20 ps FWHM bunches

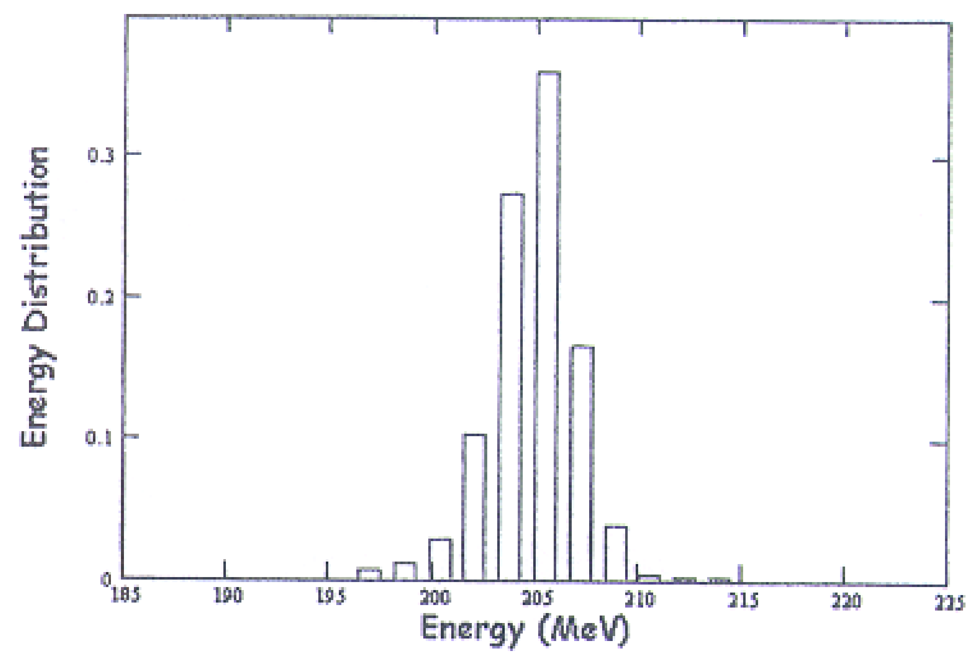


Bunch Length Measurements - 1

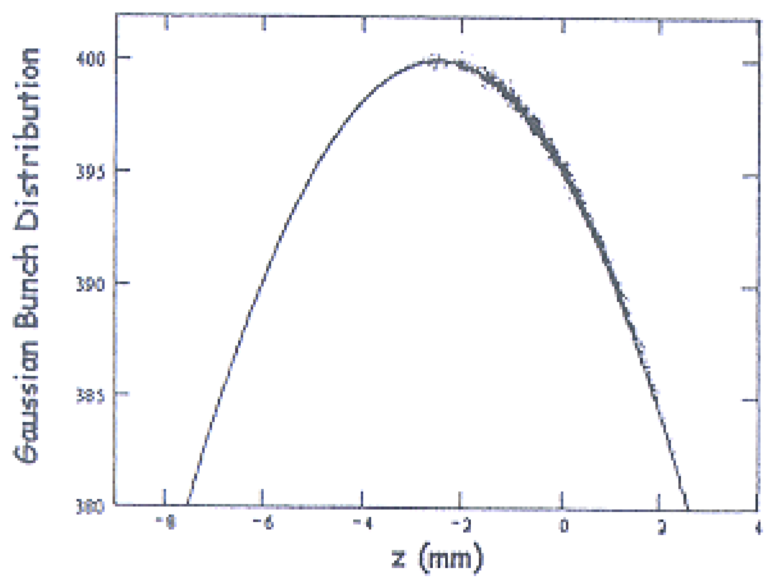
For a given bunch length, the energy spread depends on the phase of the bunch with respect to the rf wave in the linac.
The contribution of beamloading to the energy spread is made negligible by reducing the pulse charge.



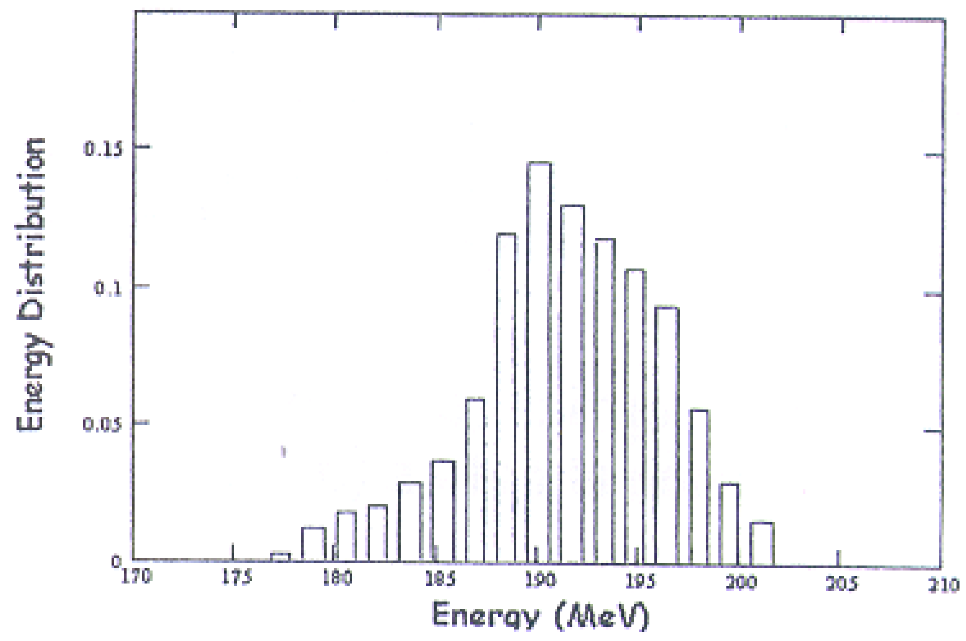
$\phi = 0$



SEM-Grid



$\phi \neq 0$



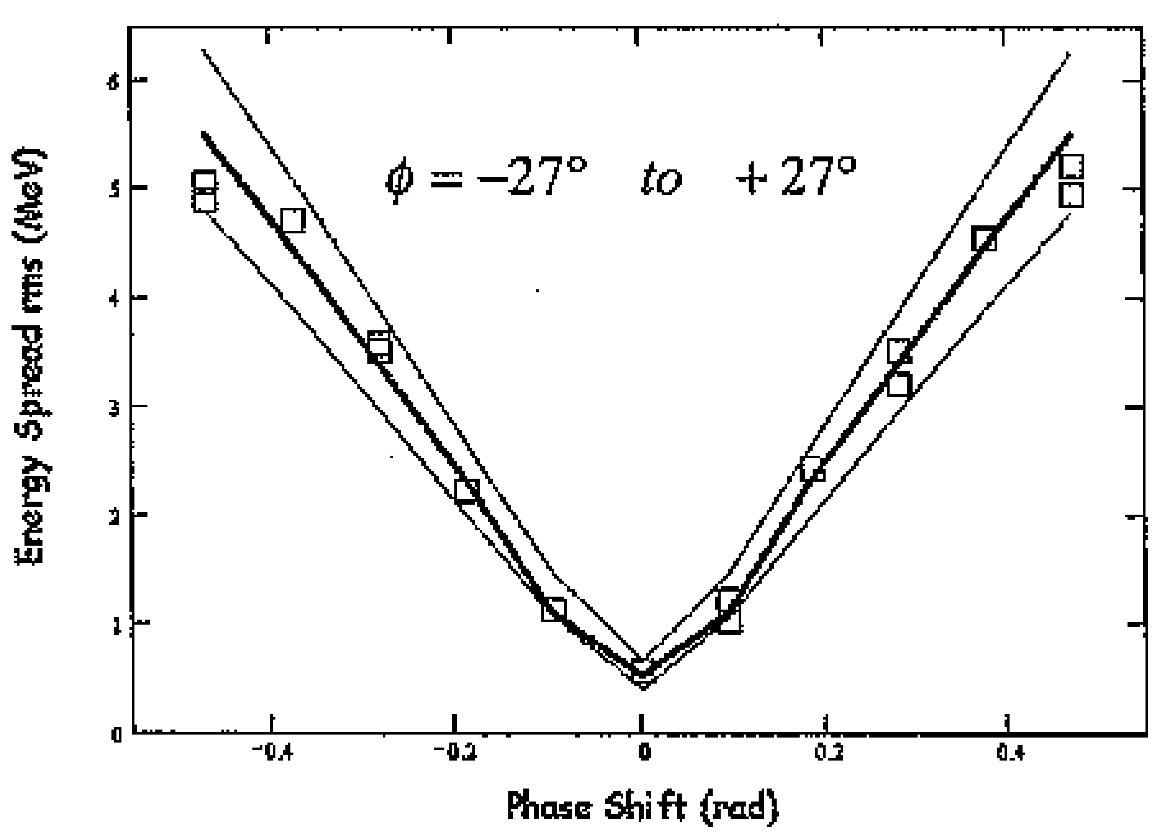
Bunch Length Measurements - 2

The phase between the bunch and the rf wave is changed and the energy spread is recorded using a SEM-grid at 2 different energies in the linac (LIL).

From the energy spread, the bunch length is deduced in the linac.

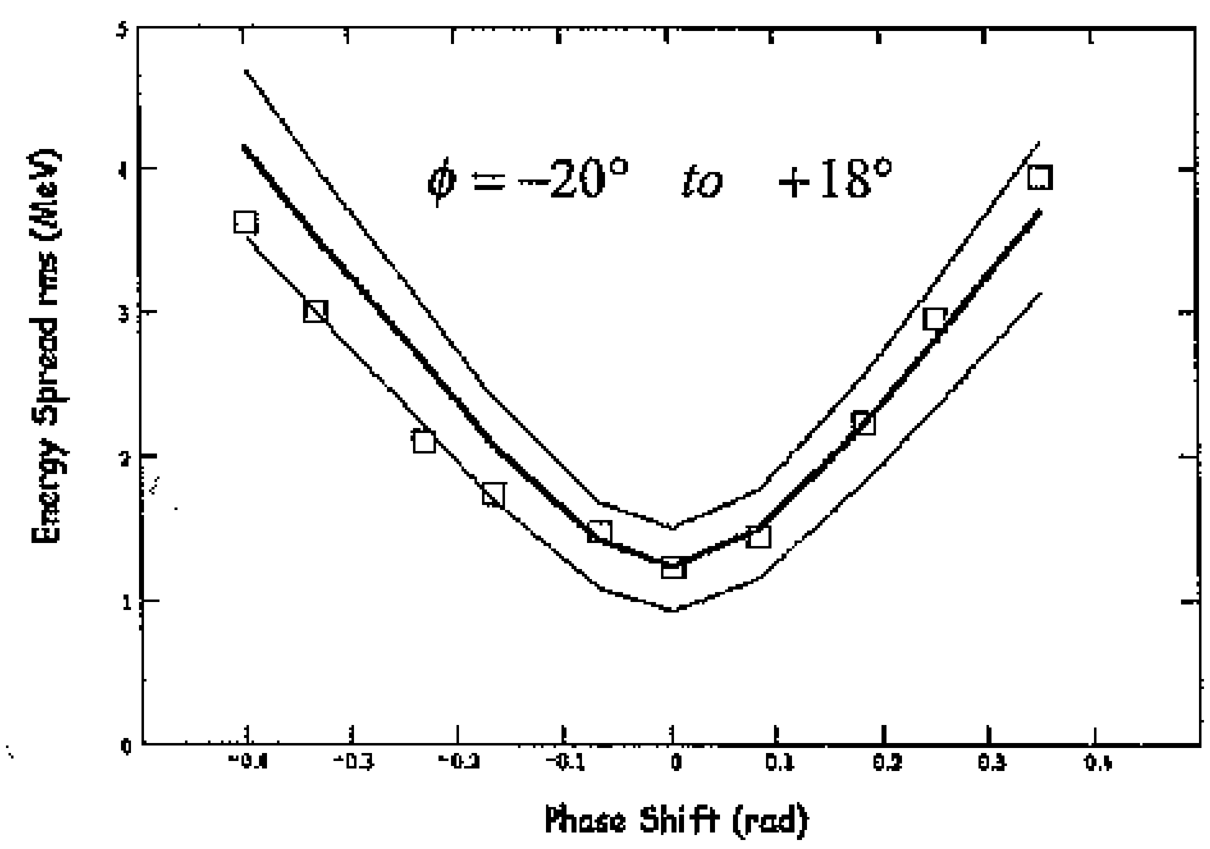
At 200 MeV

$\sigma_L = 7 \pm 1$ ps FWHM



At 500 MeV

$\sigma_L = 7.5 \pm 1$ ps FWHM



RF Frequency variation - measurements

$$C = n\lambda_o \pm \lambda_o / N$$

(ring circumference; RF wave length; Combination factor)

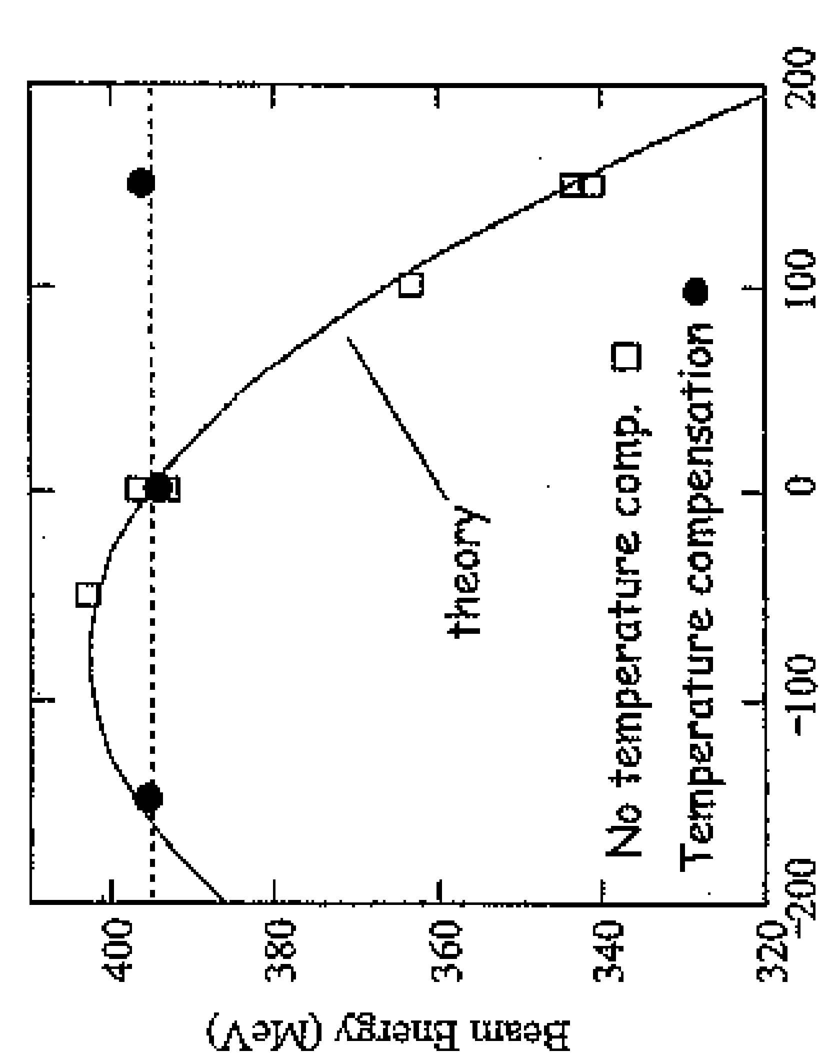
- In order to cover combination factors from 3 to 5, a frequency variation of ± 150 kHz is needed
- The frequency change must be followed by a corresponding change of ± 3° C in the operating temperature of the bunching system, the accelerating structures and the RF deflectors
- The behavior of the bunching system and of the accelerating structures has been tested experimentally in December 2000

No temperature compensation

- The bunching system OK for a frequency range of -50 / +100 kHz
- The accelerating gradient is reduced, as expected

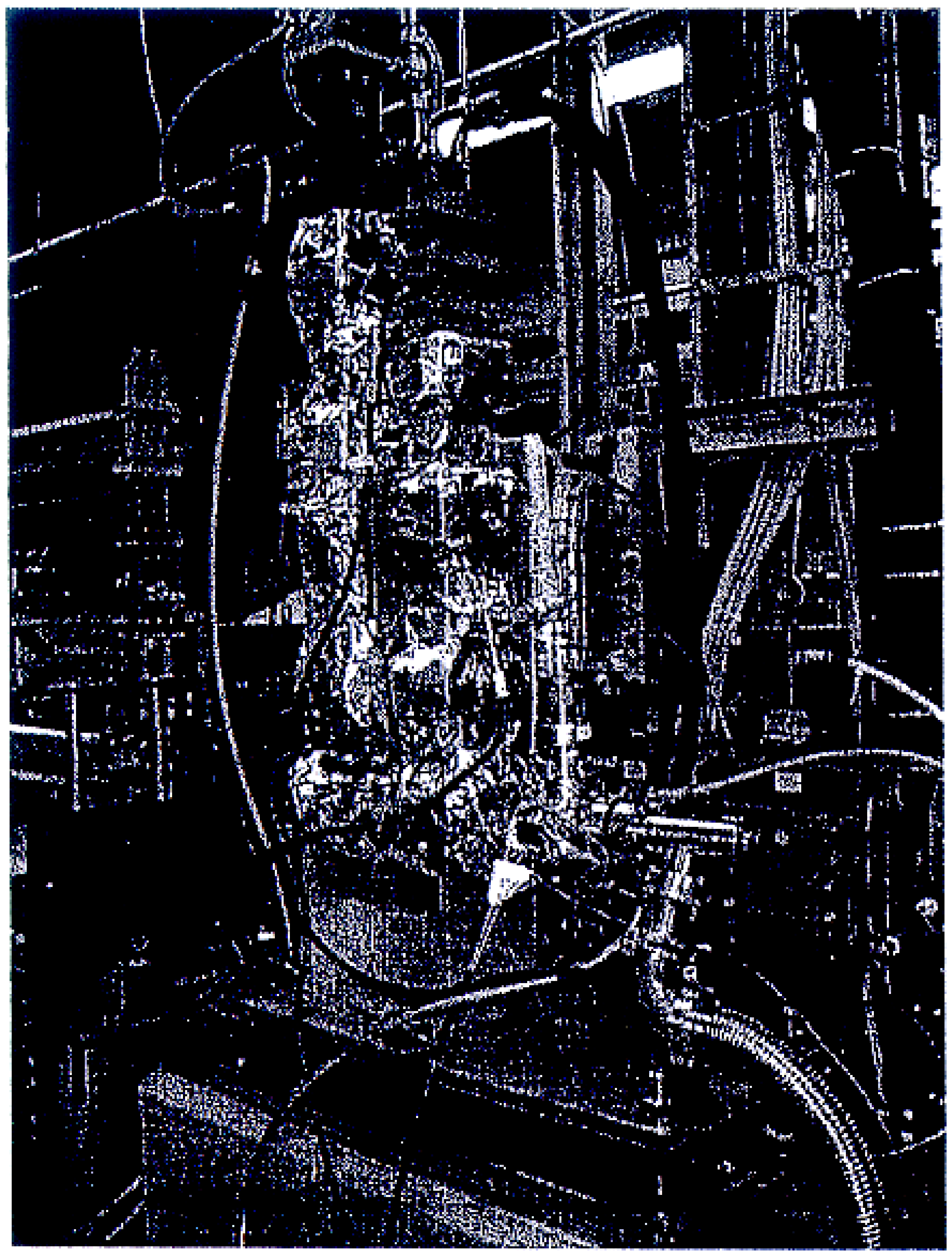
Temperature compensation

- No measurable effect on beam performance (bunch length, beam energy and momentum spread) over the full frequency range



Beam energy at the end of the Linac versus RF frequency change

Power Tests of the RF deflectors

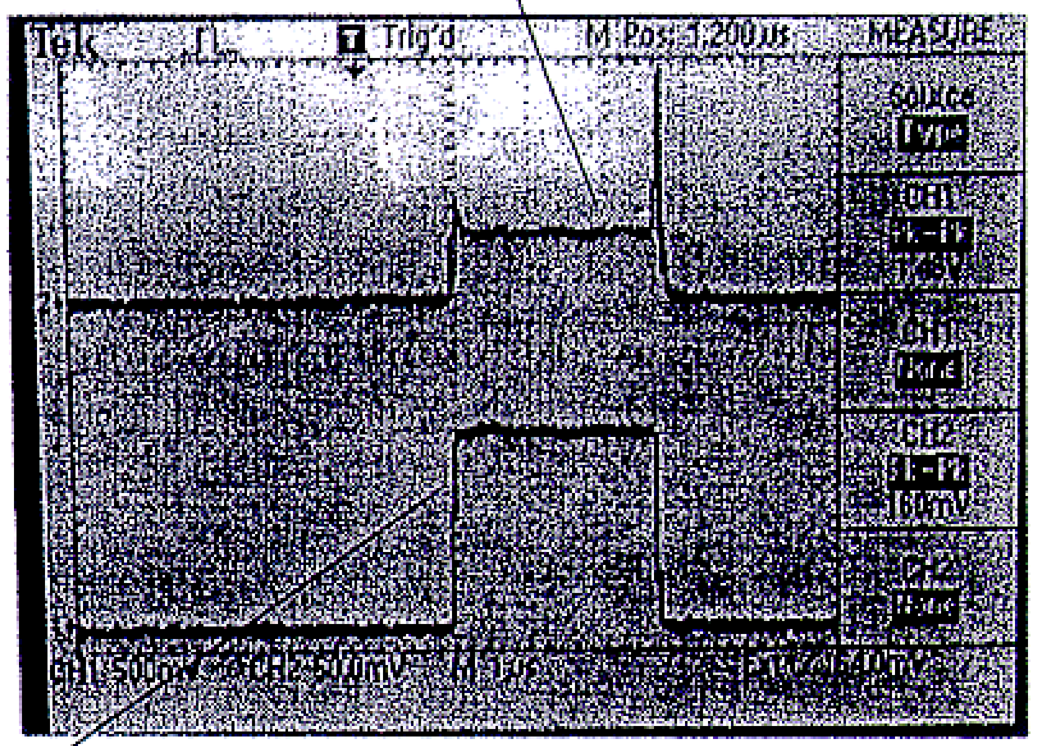


$$\text{mrad} \text{ — } \phi \approx 585 \frac{\sqrt{P}}{E} \quad (P \text{ — MW},\ E \text{ — MeV})$$

Nominal deflection angle ϕ = 4.5 mrad
Nominal beam energy E = 350 MeV
Nominal input power P = 7 MW

Both RF deflectors conditioned up to 13 MW

Reflected power signal



Forward power signal (2.5 µs, 7 MW, 3 GHz)

Other Beam Studies done and planned

The linac: Twiss parameters and emittances, Energy gains in the RF structures, Trajectory measurements, ...

The ring: Circumference measurements, Synchrotron frequency, ...

Experimental program for 2001 and 2002

Tests of injection with RF deflectors in the isochronous ring (single pulse)

Demonstration of bunch train combination for combination factors 3, 4, 5

Possible further tests:

- Bunch length and phase HF monitor (Uppsala University)
- Test of new deflector prototypes (INFN-Frascati)
- RF deflector stability studies
- Coherent Synchrotron Radiations studies,
- ....

Contributions to the CTF3 Preliminary phase

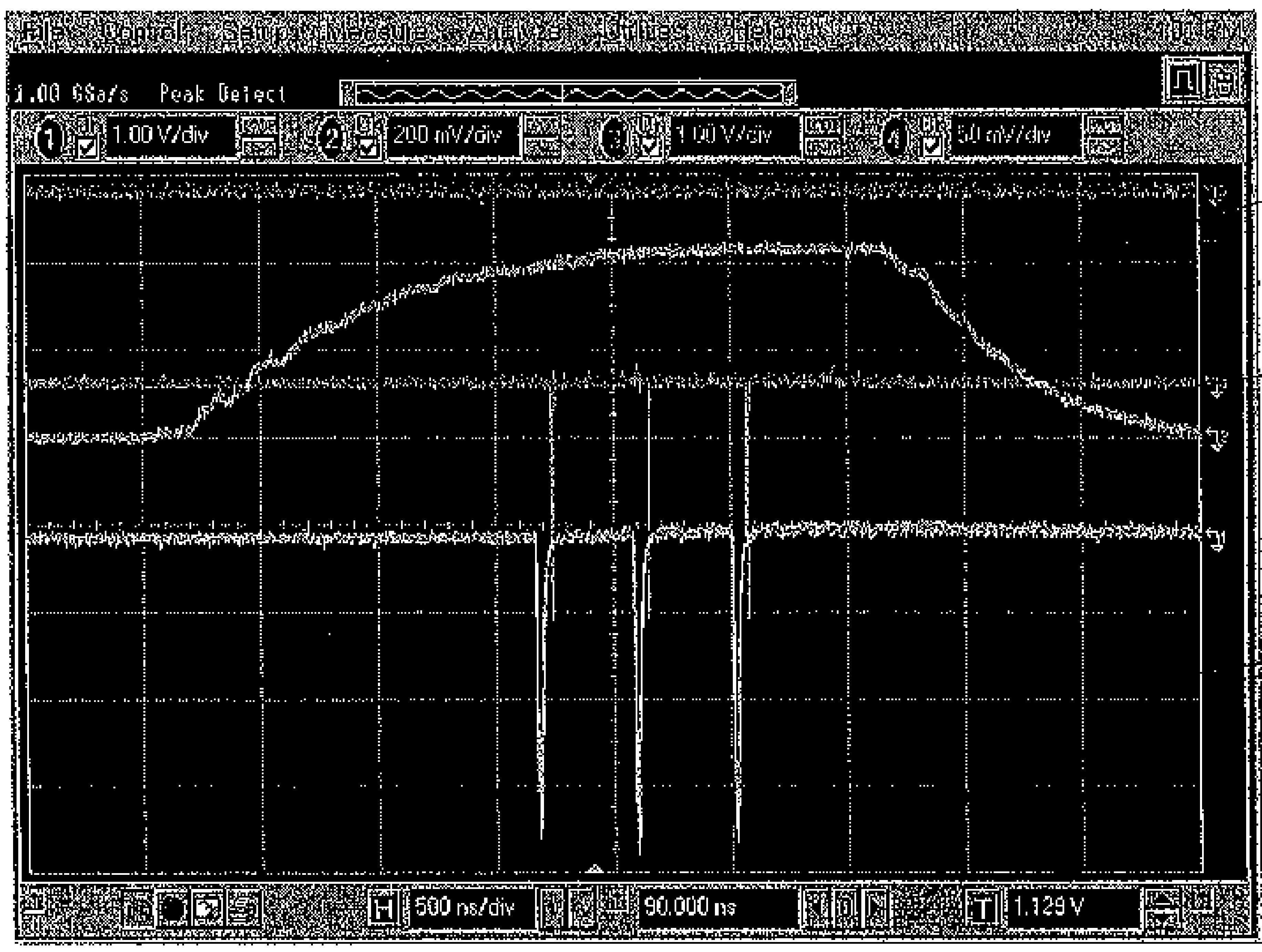
- Collaboration with other Institutes
  - LAL (CLIO gun)
  - Frascati (RF deflectors)
  - Uppsala University (Optics design)
  - IPN Orsay (RF wave guides installation)

- Technical Installation Committee (TIC)
  - All groups of the PS Division
  - EST, LHC, ST, TIS Divisions

- People participating in the 2001 commissioning with beam
  - CERN: 5 accelerator physicists
  - Uppsala University: 1 accelerator physicist (part-time)
  - Frascati: 3 accelerator physicists per week with beam (part-time)
  - Possible other contributions from CERN and external Institutes (under discussions)

First beam in CTF3 (3 pulses)

Friday 21st September 2001



Buncher loop

Wall current monitor after the bunching system

Capacitive electrode before bunching system (exit of gun)

R. Corsini, B. Dupuy, L. Rinolfi, P. Royer, F. Tecker

CTF3 Review

Organization / Collaborations / Planning / Status / Budget

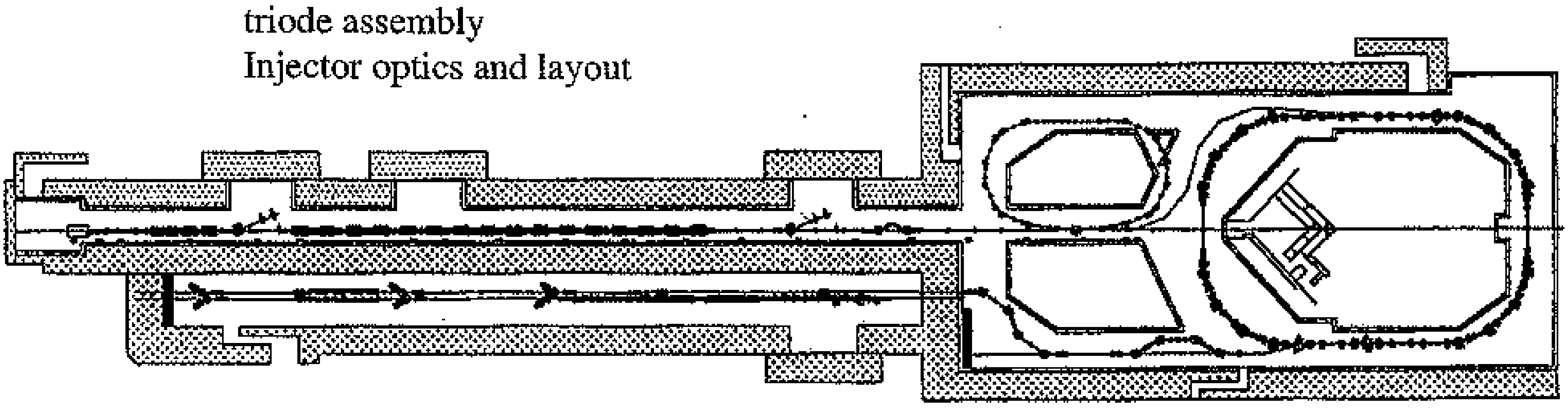
G.Geschonke
CERN / PS

Collaborations

LAL:
gun, HV deck
pre-bunchers
CLIO-type gun for prel. phases already delivered

INFN Frascati:
transfer lines, bunch lengthening chicane
Delay Loop layout and hardware
Combiner Ring layout and hardware
RF deflectors
Fast kickers
Participate in commissioning and exploitation

SLAC:
triode assembly
Injector optics and layout



RAL and **Strathclyde University**:
Laser for Photo-Injector option

Uppsala University:
mm wave detector for beam diagnostics
participation in commissioning

Nominal (and initial) phase

Thermionic Injector

Triode assembly delivered by SLAC

Work on Gun started at LAL

Design of Pre-bunchers under way at LAL

Beam dynamics of injector nearly complete (SLAC)
detailed layout started

Travelling wave buncher (CERN)
fabrication well advanced at CERN

Solenoids (CERN)
design well advanced

Sub-harmonic buncher (CERN)
design started

Photo Injector Option

high current tests of photo cathodes successful

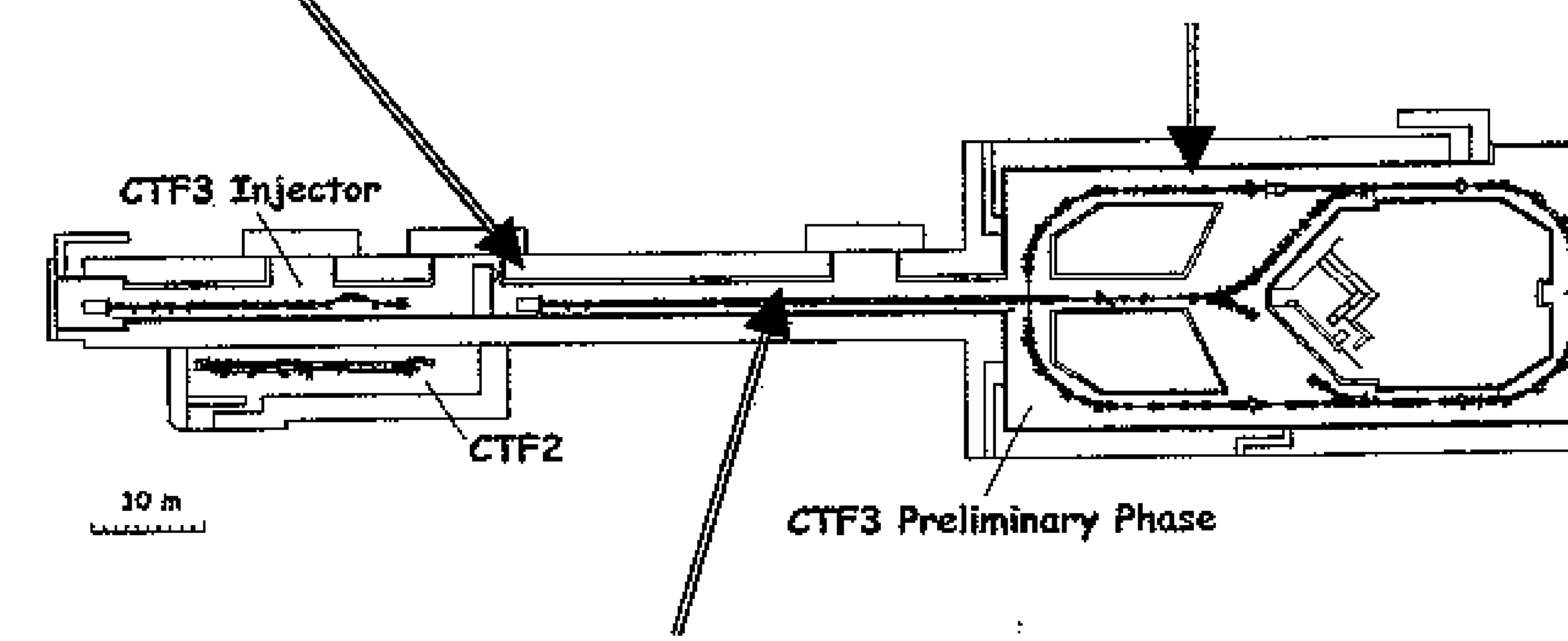
test of diode pumped high power laser amplifier
well advanced

Status

Preliminary Phase

New e-gun (CLIO type) delivered by LAL,
installed and commissioned

EPA ring modified,
circumference changed,
transfer lines modified



LIL linac modified

- Machine closed as planned on 17. September 2001
- Beam up to end of linac in first week of commissioning.
- Presently missing components being installed,
- Commissioning will continue
- Part of the operation schedule of the PS complex

RF power sources

3 GHz

45 MW klystron ordered, add. modulator built

RF Pulse compression:
long pulse power tests with promising result (LIPS):
up to 60 MW, limited by RF load

BOC cavity built, low power tested,
new design finished, prototype under construction

1.5 GHz

narrow band klystron ordered,
design study in October

wide band klystron:
design study received,
call for tender for klystron under preparation.

Drive Beam Accelerator (DBA)

Accelerating structures

TDS
prototype built, tested with RF power

SICA
Short section built and tested with High RF power
Full size structure being built at CERN

CERN FC has authorized to place a contract with industry for
18 SICA structures

DBA optics

Layout finished, detailed mechanical design to be done.

Beam Instrumentation well advanced

Transfer Lines

Design well advanced,
all existing magnets

Chicane designed

Delay Loop

optics design well advanced, nearly frozen

1.5 GHz deflector study is progressing

Combiner Ring

optics finished

vacuum components being designed, impedance !!

prototyping of HV kicker and pulser progressing

BPM under development, choice fixed

3 GHz RF deflector being designed,
cold model in fabrication,
offers for "real"structures", fabrication in 5 / 7 months,
installation in prel. phase possible during 2002.

11/07/01 SNOWMASS J.P. Delahaye

CERN policy

① LHC = unique CERN project
Commissioning : 2006 Payment → 2008
Time is contingency

② Project at CERN after LHC prepared now
- proton intensity upgrade : CNGS, Fixed Target, LHC, ISOLDE
- LHC upgrade : Luminosity, energy
- Multi-TeV e± Linear Collider : CLIC
- Neutrinos upgrade : Superbeam - ν Factory

③ Decision (2008?) depends on World-wide panorama
- Physics results from Tevatron / LHC
- Existence (or not) of Sub-TeV Linear Coll

④ CLIC technology = only realistic candidate for Multi-TeV Linear Collider
- Strong R & D still needed } → 2008
- Convincing validation in Test Facilities }
- Technology possibly available in 2008
- Progress limited by resources available
- Collaborations mandatory
  CTF3 : LAL - LNF - SLAC
  RAL - Strathclyde - Uppsala Uni
- Any body / Laboratory Welcome

3.2 Multi-TeV Electron-Positron Colliders

Most of the arguments and motivations for a sub-TeV e^+e^- collider also apply to multi-TeV accelerators of that type. The mass range accessible to search for Higgs bosons or other new particles will be much larger, according to the energy of the accelerator. The potential for discoveries and precision studies at very high energies, comprising novel aspects such as the production of new gauge bosons, of new quarks and leptons and composite Higgs bosons, is therefore much enhanced and extends in many cases beyond that of the LHC.

While a multi-TeV e^+e^- collider offers a greater physics potential, many years of intense R&D are still needed for such a machine. The CLIC design [8], developed and studied at CERN for more than 10 years, offers a promising way to build such a machine in the 3 to 5 TeV range. It is based on a two-beam scheme where intense low-energy electron beams provide the rf power to accelerate the high energy electron and positron beams. It is designed to reach very high accelerating gradients, allowing a much shorter total linac length than other schemes. A test facility (CTF3), currently planned at CERN, is intended to demonstrate the conceptual feasibility of this technique within the next five years.

3.3 Assessments and Comments of the Working Group

The Working Group sees a strong physics motivation for the construction of an e^+e^- linear collider, reaching at least 400 GeV collision energy and exceeding luminosities of 10^{34} cm^{-2} s^{-1}. Flexibility to increase the energy range to significantly higher energies will enhance its capability to study new processes and physics beyond the Standard Model. Justification of an extended energy range will greatly benefit from results obtained at the LHC.

The Working Group recommends the realisation of an e^+e^- linear collider in the collision energy range from 90 up to at least 400 GeV, with possible extension to higher energies. It is convinced that the decision to construct such a machine should be taken soon,

Promising techniques for a multi-TeV e^+e^- linear collider like CLIC are being developed at CERN but still need significant R&D work before the technical feasibility can be demonstrated. The Working Group recommends the continuation of R&D to show the feasibility of an e^+e^- linear collider in the multi-TeV collision energy range, such as CLIC.

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ECFA/01/213
21 September 2001

ECFA EUROPEAN COMMITTEE FOR FUTURE ACCELERATORS

REPORT OF THE WORKING GROUP ON THE FUTURE OF ACCELERATOR-BASED PARTICLE PHYSICS IN EUROPE[1]

EXECUTIVE SUMMARY

The ECFA Working Group on the future of accelerator-based particle physics in Europe has considered the possible options and time-scales for the next major accelerator project, the implications for the current particle physics programme and the strategy that ought to be pursued in the long-term future. Although charged with considering the future for Europe, it has also considered the international context since particle physics is intrinsically international. The Working Group makes the following recommendations:

In the immediate future:

1) the allocation of all necessary resources to fully exploit the unique and pioneering LHC facility;

2) continued support for ongoing experiments, since they promise significant scientific results, provide an optimal physics return on previous investment, and are vital for the education of young physicists;

3) the realisation, in as timely a fashion as possible, of a world-wide collaboration to construct a high-luminosity e^+e^- linear collider with an energy range up to at least 400 GeV as the next accelerator project in particle physics; decisions concerning the chosen technology and the construction site for such a machine should be made soon;

4) an improved educational programme in the field of accelerator physics and increased support for accelerator R&D activity in European universities, national facilities and CERN.

For the long-term:

5) a co-ordinated collaborative R&D effort to determine the feasibility and practical design of a neutrino factory based on a high-intensity muon storage ring;

6) a co-ordinated world-wide R&D effort to assess the feasibility and estimate the cost of a 3-5 TeV e^+e^- linear collider (CLIC), a very large hadron collider (VLHC) and a muon collider; in particular, R&D for CLIC is well advanced and should be vigorously pursued.

The central role of CERN in Europe must continue and will be essential as the fulcrum of the long-term future of particle physics. The Working Group considers it essential that, through CERN, Europe should be able to play a key role in the exploration of the multi-TeV horizon that will open in the post-LHC era.

The implementation of these recommendations would ensure a vibrant and exciting programme of investigations into the fundamental structure of matter and maintain Europe's leading role in this pioneering adventure in science.

[1] Address http://web.cern.ch/Committees/ECFA/ (Working Group)

3.4 R&D Accelerator

Although the main objective of CERN is obviously the LHC and its possible upgrading, in parallel a small but significant effort is made to explore options for the post-LHC era. The latter comprises a multi-TeV linear collider and advanced neutrino beams.

CERN's know-how in accelerator physics and technology has also been used for a feasibility study of a synchrotron, associated extraction lines and gantries for a cancer-therapy facility which has been concluded with a detailed conceptual design report in 2000.

Limited resources will severely restrict the amplitude and breadth of the R&D studies for future accelerators. They will not allow much more than an exploration of the possible options and the opportunity to remain in touch with leading-edge accelerator developments around the world.

Collaboration with other European laboratories interested in these topics is being established and contacts have been made with the interested communities in the US and Japan. These collaborations are imperative and provide invaluable help in a number of issues, which otherwise could be studied only superficially.

CERN/SPC/793
CERN/FC/4424
Original: English
28 May 2001

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE

CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Action to be taken		*Voting Procedure*
For recommendation to Council	**SCIENTIFIC POLICY COMMITTEE** 218th Meeting **11 and 12 June 2001**	-
For recommendation to Council	**FINANCE COMMITTEE** 285th Meeting **13 June 2001**	Simple Majority + 70 % of Member States' Contributions Present and Voting
For recommendation to Council	**COMMITTEE OF COUNCIL** 247th Meeting **14 June 2001**	Simple Majority
For Approval	**COUNCIL** 118th Session **15 June 2001**	Simple Majority

THE SCIENTIFIC ACTIVITIES OF CERN AND BUDGET ESTIMATES FOR THE YEARS 2002–2005

Over the years under consideration, the main goal is to finalise the construction of the LHC, while running a restricted scientific programme of high quality.

Council is invited to:

i) approve the overall figures proposed for 2002 to allow for the preparation of the 2002 Draft budget, and

ii) take note of the proposed budget estimates for 2003, 2004 and 2005.

7. SUMMARY OF THE MEDIUM-TERM PLAN

7.1 Scientific Programme

After more than 11 years of successful and efficient operation LEP is being dismantled and will be fully removed before the end of 2001. The analysis of LEP experimental data is expected to continue until 2003. The period 2002-2005 will be characterised by intense construction work towards the commissioning of the LHC by 2005/2006. Despite difficulties encountered by the civil-engineering contractors, the excavation of the caverns is proceeding and every effort is being made to make up for the accumulated delay. The LHC magnet system is now entering its production phase. Construction of the LHC detectors is proceeding according to the revised schedule. The installation of ATLAS is scheduled to start in 2003, CMS and ALICE in early 2004 and LHCb in mid-2004.

The non-LHC scientific programme essentially consists of already approved experiments. Several, such as the NOMAD and CHORUS neutrino experiments, and most of the SPS heavy-ions programme, have reached the end of their data-taking phase. However, two heavy-ions experiments with very specific goals optimized for the SPS are being kept on until 2003. The successful NA48 experiment will further study CP violating K-decay properties in 2002-2003. The CERN scientific programme has been considerably enriched by the introduction of a highly competitive neutrino activity, built around the CNGS facility, and the inception of the very promising TOF neutron facility.

Accelerator R&D is focused on the design and construction of a new test facility CTF3 (CLIC Test Facility 3) in preparation for the post-LHC generation of accelerators.

Full support from { PS division / CERN services / CERN management }

Very motivated and expert team

- Strong recommendation from CTF3 review Co[...]
- International collaborations (with resources)

LAL - LNF - RAL - SLAC - Strathclyde - Uppsala

October 4, 2001

CTF3 Review

B. Aune (Saclay), H. Henke (T. U. Berlin), R. Siemann (SLAC)

Introduction

CLIC is a multi-TeV linear collider that is a possible future CERN project. Distinctive CLIC features include

- A two-beam configuration to generate the RF power,
- High RF frequency, $f_{RF} = 30$ GHz,
- High accelerating gradient, $G = 150$ MeV/m.

CTF3 is a test facility that is part of the CLIC development and is a collaboration between CERN, INFN Frascati, LAL Orsay, RAL Didcot, SLAC, Strathclyde UK, and Uppsala University. CTF3 would test the underlying concepts of the RF power generation by experimentally demonstrating several critical aspects including high efficiency energy transfer from low frequency RF to the Drive Beam and frequency multiplication using a delay loop and a combiner ring. Thirty GHz RF would be produced at the end of the Drive Beam linac in the Initial Phase and with the beam from the combiner ring in the Nominal Phase. This power can be used to test accelerating structures and RF components to establish the feasibility of the CLIC accelerating gradient.

Specific CTF3 goals are

- Fully beam-loaded operation of the Drive Beam Accelerator
- Phase coding of bunches and bunch interleaving
- Control of bunch length and energy spread
- Production of 30GHz RF power at nominal CLIC requirements
- Provide a test facility for CLIC RF components

Principal Findings and Recommendations

CTF3 or an equivalent facility is imperative for the development of CLIC. The actual technical choice of CTF3 is based on existing buildings and components. Under the given boundary conditions collaborations are vital for the project. INFN (Frascati) is taking responsibility for the transfer lines, delay loop and combiner ring, which are major, essential parts of CTF3.

The CTF3 concept is sound, and it takes advantage of existing buildings and hardware to realize substantial savings. The project is staged intelligently with three stages that explore the various CTF3 goals with increasing demands on performance.

The project is technically demanding, but there are no insurmountable problems. Resources and schedule look possible but tight. We believe that, because of the technical demands, several years of commissioning and operation will be required after the completion of the installation.

CLIC is critically dependent on developing the processes, materials, techniques, etc. that firmly establish the feasibility of the high acceleration gradient. The RF power from CTF3 will be available for testing major CLIC components, but high power RF experiments need at least one fully dedicated and continuously available test stand. Either a dedicated power source or new collaborations devoted to understanding gradient limits are necessary soon for a timely and systematic exploration of the many issues that must be resolved.

Comments on Technical Solutions

Injector: A thermionic gun and bunchers have been designed with requirements on current magnitude and stability that are at the upper limit of what is possible. If the stability is not achievable right away, a feedback solution is foreseen. In parallel an RF gun is under design. It would allow for a better bunch structure and lower emittance. The main challenge is the drive laser. There is encouraging progress on that, and planned experiments should allow a choice between these two injector options.

Linac: A slotted iris structure with higher order mode damping and detuning (SICA) was chosen, and the first high power tests were positive. The 3 GHz power generation relies on existing klystrons, modulators, and modified LIPS pulse compression. The RF system will require sophisticated temperature and phase control. The linac would be operated fully beam-loaded to demonstrate high efficiency, but full beam-loading is not necessary for high power RF generation. Comparison between FODO, doublet and triplet optics showed best emittance preservation and smallest jitter amplification in the case of triplets.

Transfer lines, delay loop and combiner ring: All of these devices are isochronous, and parameters have been chosen but they are not final. They make use of existing magnets and are being designed to fit within the footprint of the available building. Work on the RF deflectors is in progress, and no major problems have been encountered. A novelty is the use of wigglers in the rings for path length control. The requirement on the low frequency impedance in the combiner ring, $Z/n = 0.4\Omega$, is low but possible with a smooth vacuum chamber and a minimum number of vacuum chamber transitions.

Longitudinal phase space manipulations: Very short bunches will create coherent synchrotron radiation in the rings and degrade the emittance. Bunches, which are compressed in the linac to reduce energy spread, must be lengthened before they are injected into the delay loop and compressed again after the combiner ring. This will be demanding and requires sophisticated diagnostics.

Staging of the project: A Prelimary Phase, which has already started, makes use of the existing linac, a new gun, and EPA ring with a modified lattice. It will allow the first demonstration of beam combining with factors of 3, 4 and 5 at low current. It will also allow first experiments on deflectors, on coherent synchrotron radiation effects, and bunch length and phase monitors. In a second stage, the Initial Stage, the new linac will be installed and will have a test stand for high power RF experiments. High power RF test stands will be invaluable for CLIC, and this test stand should remain operational during installation, commissioning and operation of the full CTF3 facility. The combiner ring, delay loop, CLEX experimental area and a probe beam will be added in the Nominal Phase, which is the third and final stage.

Probe beam and CLEX experimental area: CLIC needs 240 MW/m for 130 nsec at a repetition rate of 100 Hz. This would give 150 MeV/m accelerating gradient in the main linac. The CLEX test stand is intended for power generation, testing of waveguide components and accelerating structures at nominal parameters, study of breakdown phenomena at 30 GHz and other RF frequencies, and determining the ultimate possible gradient. A 200 MeV probe beam will serve for verification of RF parameters, measuring of wake effects, and the CLIC beam-loading compensation scheme.