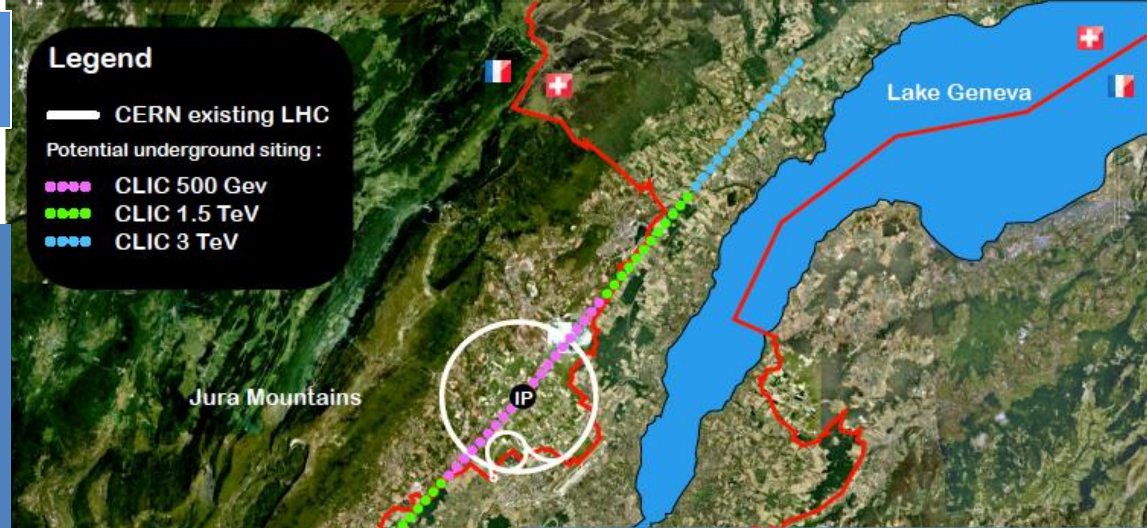
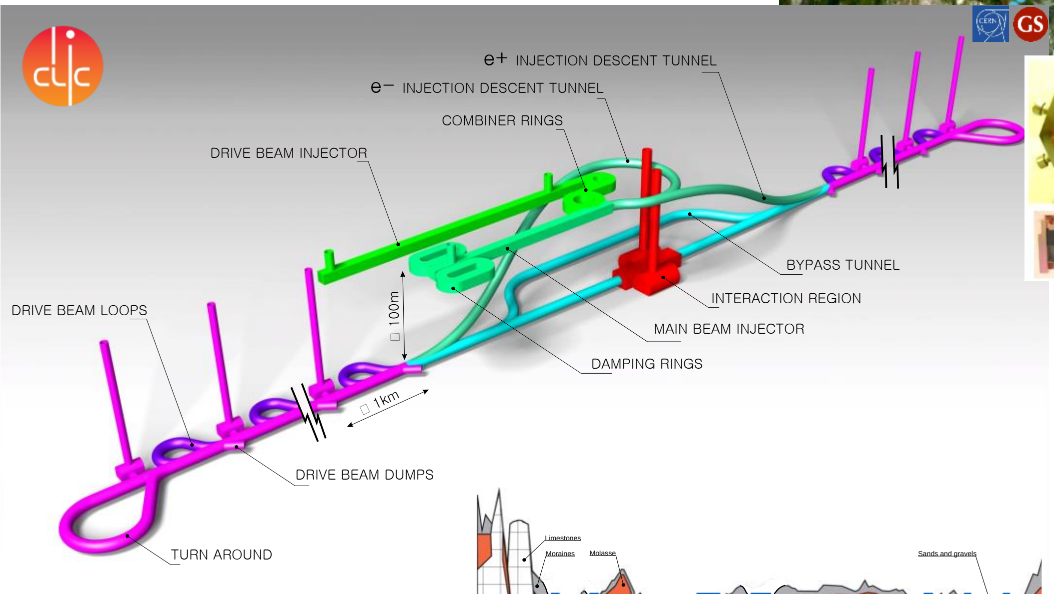
The CLIC project

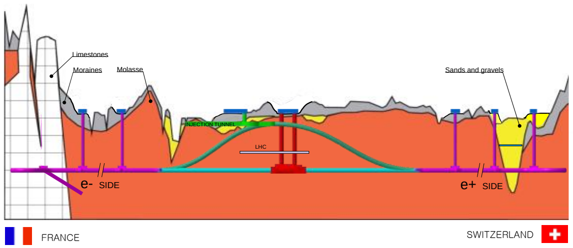
Outline:
- Brief introduction and overview
- Across the main activities
- Brief summary

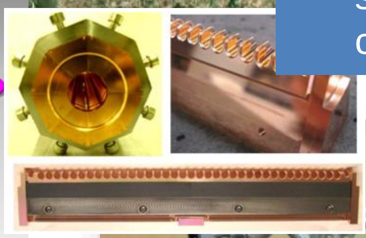


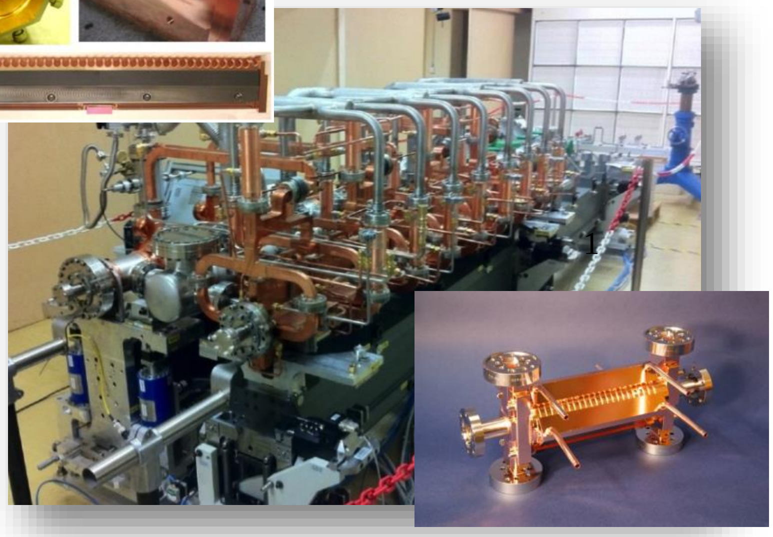
Key features:
- High gradient (energy/length)
- Small beams (luminosity)
- Repetition rates and bunch spacing (experimental conditions)



CLIC SCHEMATIC
(not to scale)





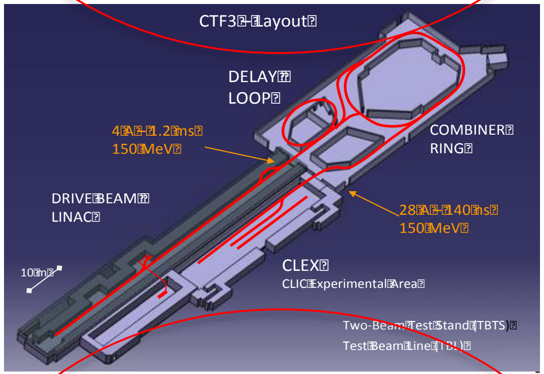


Accelerator collaboration with ~50 institutes
New institutes are joining:
In 2014 SINAP Shanghai and IPM Tehran

Detector collaboration operative with ~25 institutes

2013-18 Development Phase

Develop a Project Plan for a staged implementation in agreement with LHC findings; further technical developments with industry, performance studies for accelerator parts and



2018-19 Decisions

On the basis of LHC data and Project Plans (for CLIC and other potential projects as FCC), take decisions about next project(s) at the Energy Frontier.

- Common work with ILC related to several acc. systems as part of the LC coll., also related to initial stage physics and detector developments
- Common physics benchmarking with FCC pp and common detect. challenges (ex: timing, granularity), as well as project implementation studies (costs, power, infrastructures …)

CLIC Workshop 2015

26-30 January 2015
CERN
Europe/Zurich timezone

- Overview
- Timetable
- Registration
  - Modify my Registration
- Speaker index
- List of registrants
- Accommodations
- Insurance and Visa information
- How to come to CERN
- Visitors' Portable Computers Registration
- CERN Shuttle service
- CERN Bike sharing service
- CLIC Study Website
- Physics and Detector Study Website
- Video Services
- Bank Transfer

The **CLIC workshop 2015** will cover Accelerator as well as the Detector and Physics studies, with its present status and programme for the coming years.

For the Accelerator studies, the workshop spans over 5 days: 26th-30th of January.
For CLICdp, the workshop is scheduled from Tuesday afternoon January 27th to lunchtime on Friday 30th.

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sessions will be organised subject-wise by their conveners.
2- The CLICdp Institute Board meeting will take place over lunch on Thursday.

We are looking for the widest possible participation and in particular we will encourage presentations and involvement of younger colleagues.

~260 registered (and ~200 talks)

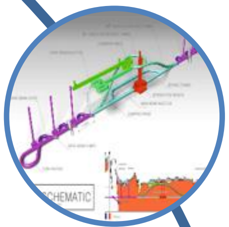
Main elements:

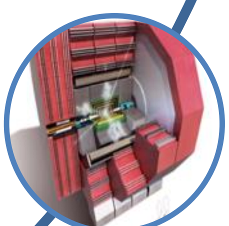
- Open high energy frontier session session
- Accelerator sessions focusing on collaboration efforts and plans 2015-2019, parallel sessions and plenary
- High Gradient Applications for FELs, industry, medical
- Physics and detector sessions on current and future activities
- Collaboration and Institute Boards

LINEAR COLLIDER COLLABORATION

Main activities

http://clic-study.web.cern.ch/content/clic-accelerator-activities





Parameters, Design and Implementation

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- Integrated Modeling and Performance Studies
- Feedback Design, Background, Polarization
- Machine Protection & Operational Scenarios
- Electron and positron sources
- Damping Rings
- Ring-To-Main-Linac
- Main Linac - Two-Beam Accelerati
- Beam Delivery System
- Machine-Detector Interface (MDI
- Drive Beam Complex
- Cost, power, schedule, stages

X-band Technologies

- X-band Rf structure Design
- X-band Rf structure Production
- X-band Rf structure High Power Testing
- Novel RF unit developments (high efficiency)
- Installation and Operation of High power Testing Facilities
- Basic High Gradient R&D

Experimental verificatio

- CTF3 Consollidation & Upgrades
- Drive Beam phase feed-forward and feedbacks
- Two-Beam module string, test with beam
- Drive-beam front end including modulator development and injector
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- Low emittance ring tests
- Accelerator Beam System

Technical Developments

- Damping Rings Superconducting Wiggler
- Survey & Alignment
- Quadrupole Stability
- Warm Magnet Prototypes
- Beam Instrumentation and Control
- Two-Beam module development
- Beam Intercepting Devices
- Controls
- Vacuum Systems

Detector and Physics

- Physics studies and benchmarking
- Detector optimisation
- Technical developments

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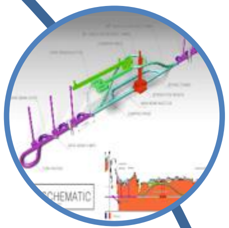

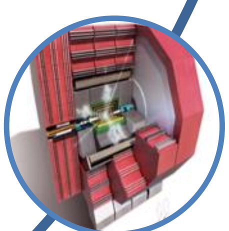

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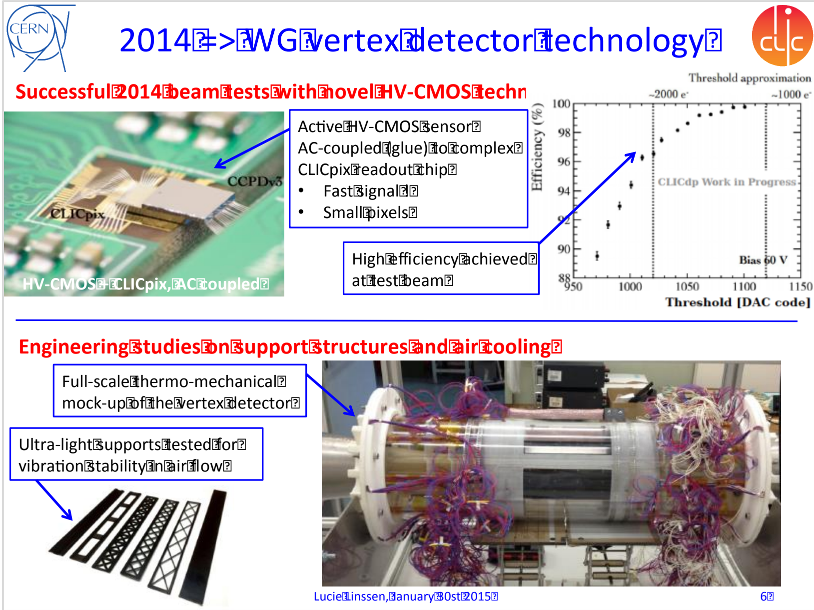
Detector and Physics

- Physics studies and benchmarking
- Detector optimisation
- Technical developments

CLIC det & phys activities 2014-15

Good technical progress in 2014, in many domains:

- Higgs benchmarking studies (paper underway)
- Detector optimisation towards a new CLIC detector concept
- Development towards improved software tools
- Vertex technology R&D
- Fine-grained calorimeter R&D (CALICE, FCAL)



Possible thanks to many contributors!

Objectives for 2015 will focus on:

- A new CLIC detector concept !
- Consolidation of the new software tools
- Physics => focus more on Beyond Standard Model capabilities
- Continuation of vertex technology R&D
- Continuation of fine-grained calorimeter R&D (CALICE, FCAL
- Start of main silicon tracker R&D

[More information and details for each point]

Possible CLIC stages studied in the CDR

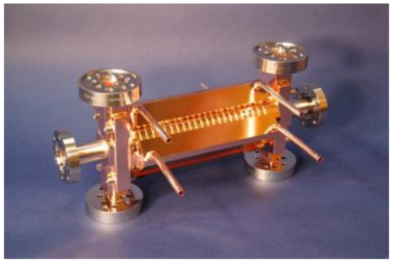


Table 1: Parameters for the CLIC energy stages of scenario A.

Parameter	Symbol	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	$\sqrt{s}$	GeV	500	1400	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		354	312	312
Bunch separation	Δt	ns	0.5	0.5	0.5
Accelerating gradient	G	MV/m	80	80/100	100
Total luminosity	$\mathscr{L}$	10^{34} cm^{-2}s^{-1}	2.3	3.2	5.9
Luminosity above 99% of $\sqrt{s}$	$\mathscr{L}_{0.01}$	10^{34} cm^{-2}s^{-1}	1.4	1.3	2
Main tunnel length		km	13.2	27.2	48.3
Charge per bunch	N	10^9	6.8	3.7	3.7
Bunch length	σ_z	μm	72	44	44
IP beam size	σ_x/σ_y	nm	200/2.6	∼ 60/1.5	∼ 40/1
Normalised emittance (end of linac)	$\varepsilon_x/\varepsilon_y$	nm	2350/20	660/20	660/20
Normalised emittance (IP)	$\varepsilon_x/\varepsilon_y$	nm	2400/25	—	—
Estimated power consumption	P_{wall}	MW	272	364	589

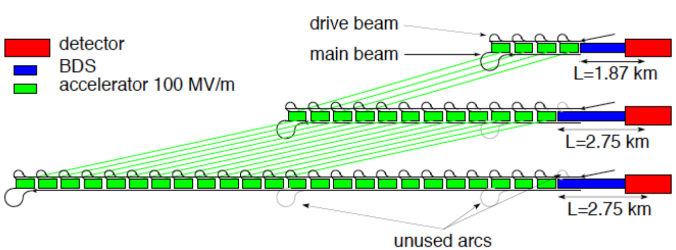


Fig. 3.6: Simplified upgrade scheme for CLIC staging scenario B.

Table 2: Parameters for the CLIC energy stages of scenario B.

Parameter	Symbol	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	$\sqrt{s}$	GeV	500	1500	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		312	312	312
Bunch separation	Δt	ns	0.5	0.5	0.5
Accelerating gradient	G	MV/m	100	100	100
Total luminosity	$\mathscr{L}$	10^{34} cm^{-2}s^{-1}	1.3	3.7	5.9
Luminosity above 99% of $\sqrt{s}$	$\mathscr{L}_{0.01}$	10^{34} cm^{-2}s^{-1}	0.7	1.4	2
Main tunnel length		km	11.4	27.2	48.3
Charge per bunch	N	10^9	3.7	3.7	3.7
Bunch length	σ_z	μm	44	44	44
IP beam size	σ_x/σ_y	nm	100/2.6	∼ 60/1.5	∼ 40/1
Normalised emittance (end of linac)	$\varepsilon_x/\varepsilon_y$	nm	—	660/20	660/20
Normalised emittance	$\varepsilon_x/\varepsilon_y$	nm	660/25	—	—
Estimated power consumption	P_{wall}	MW	235	364	589

Key features:

- High gradient (energy/length)
- Small beams (luminosity)
- Repetition rates and bunch spacing (experimental conditions)

Cost/power: Design/parameters & Technical developments

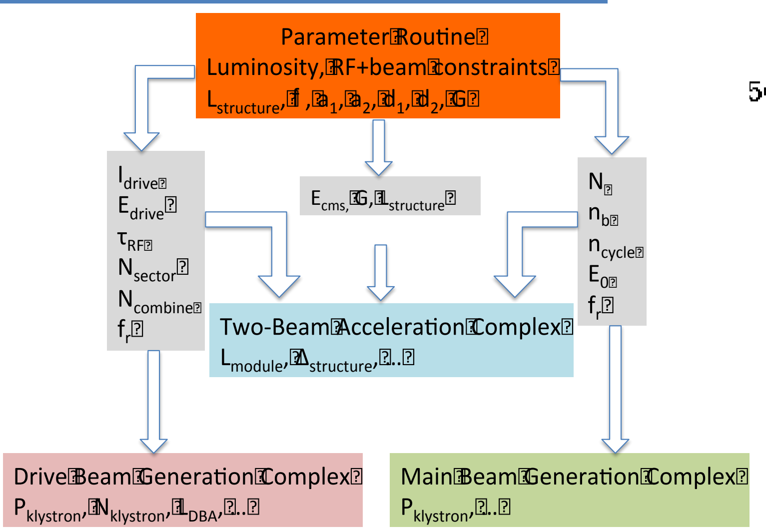
Automatic procedure scanning over many structures (parameter sets)

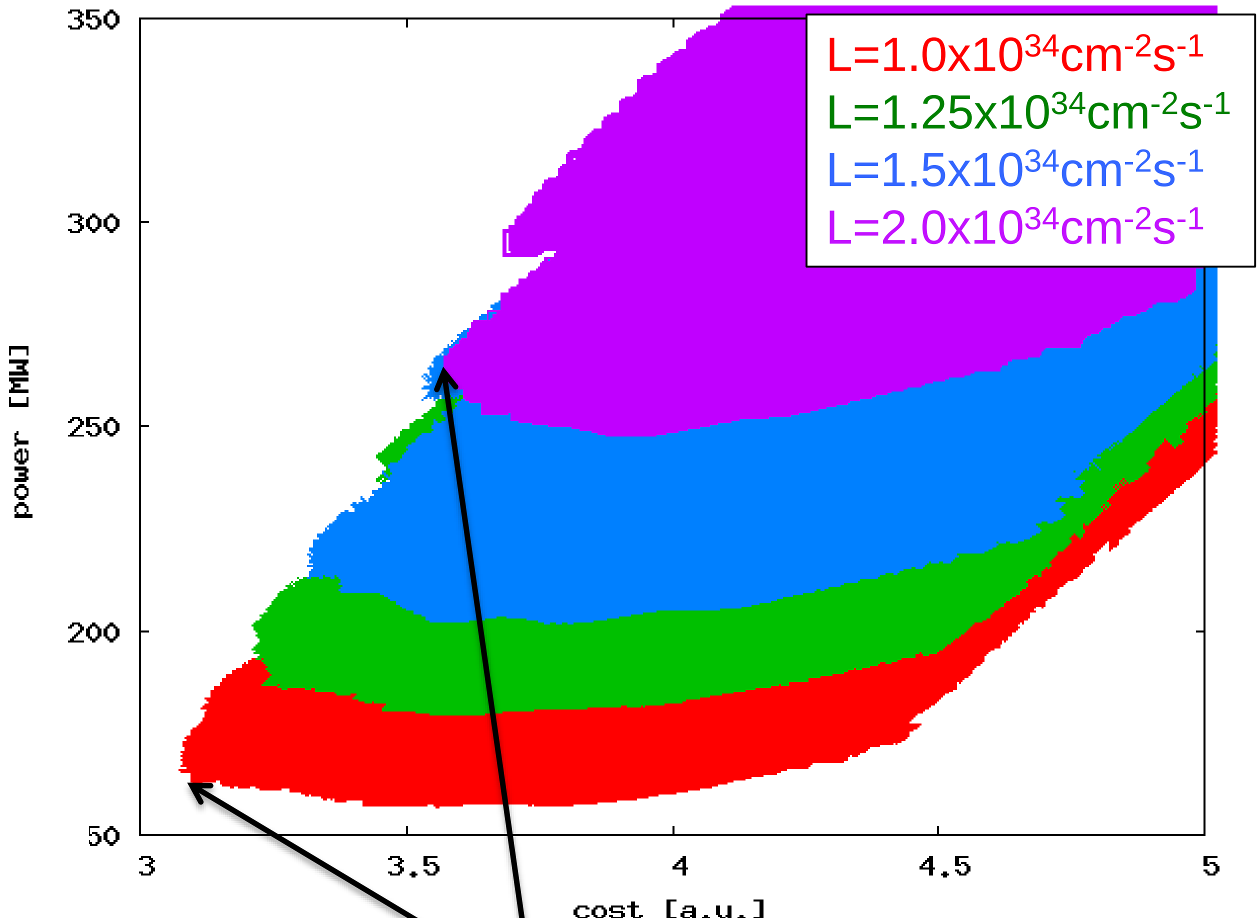
Structure design fixed by few parameters

$a_1, a_2, d_1, d_2, N_c, f, G$

Beam parameters derived automatically

Cost calculated – and power



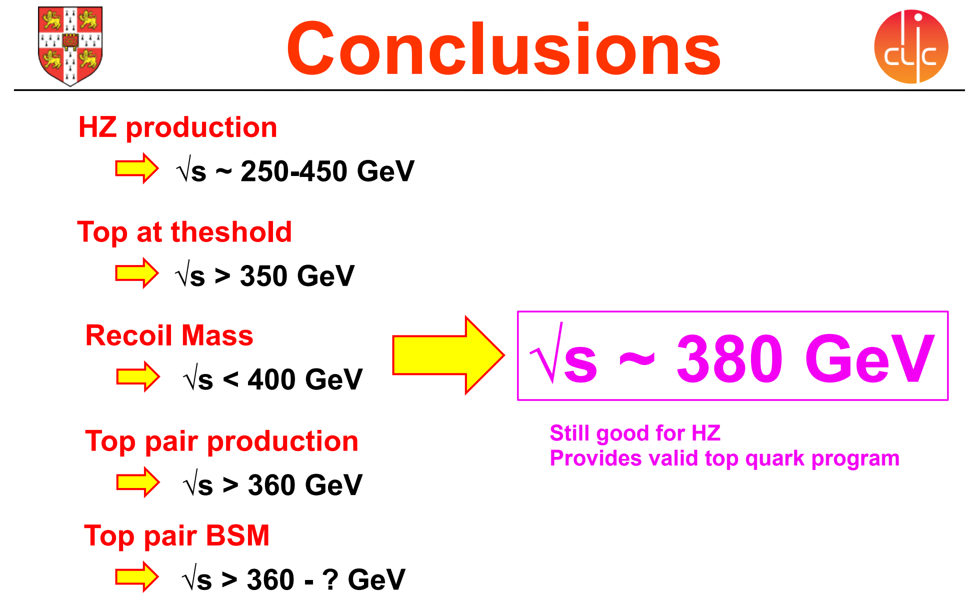


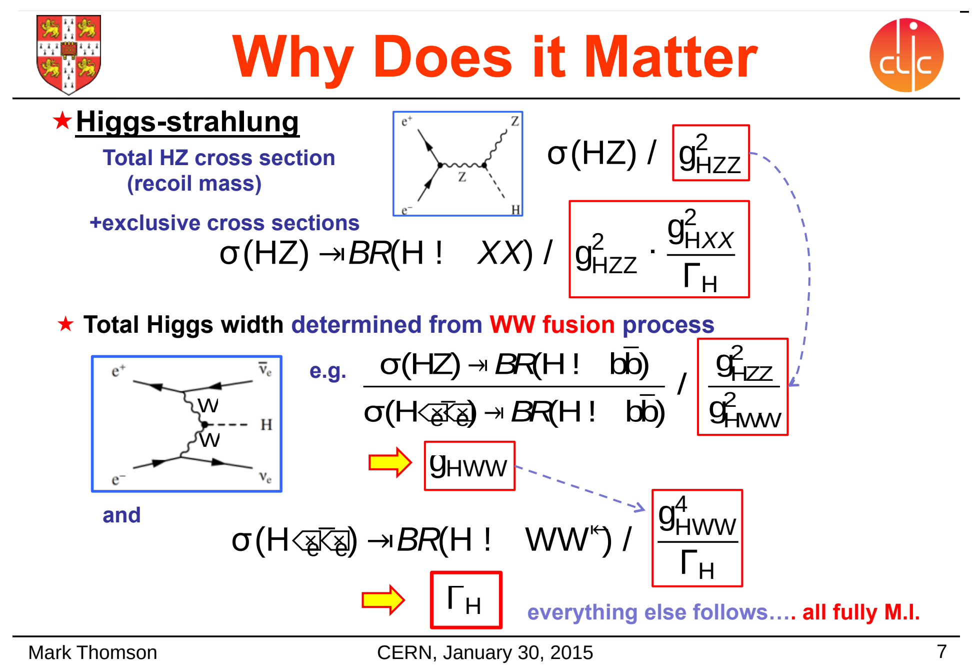
Luminosity goal significantly impact minimum cost
For $L=1\times10^{34}cm^{-2}s^{-1}$ to $L=2\times10^{34}cm^{-2}s^{-1}$:
Costs 0.5 a.u. and O(100MW)

Cheapest machine is close to lowest power consumption

Stages to be studied

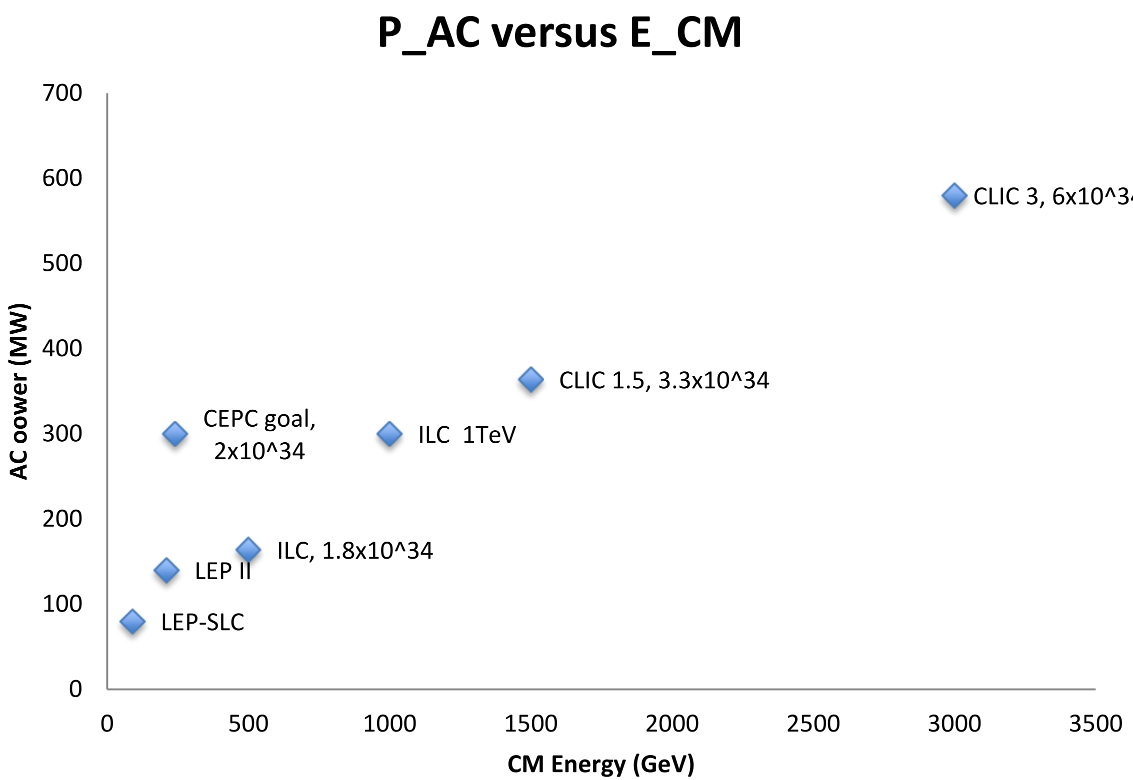
- First stage: E_{cms}=380Gev, $L=1.5\times10^{34}cm^{-2}s^{-1}$, $L_{0.01}/L>0.6$
  - Luminosity based on physics and machine studies in 2014
  - 420 GeV and 360GeV have also been studied
- Second stage: E_{cms}=O(1.5TeV)
- Final stage: E_{cms}=3TeV, $L=5.9\times10^{34}cm^{-2}s^{-1}$, $L_{0.01}/L>0.3$





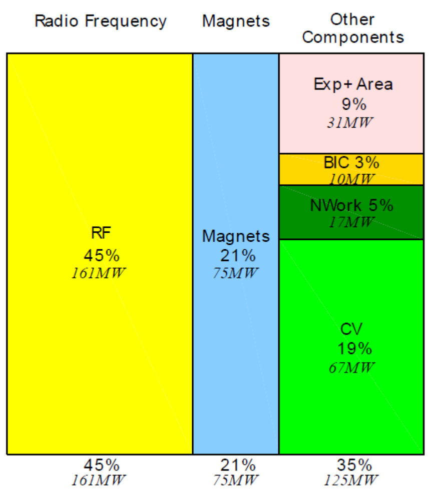
- Next natural steps: Optimised cost and power for given luminosity
- Hopefully needed to redo with new LHC results at some point

e+/e- Colliders: P_{AC} vs E_{CM}

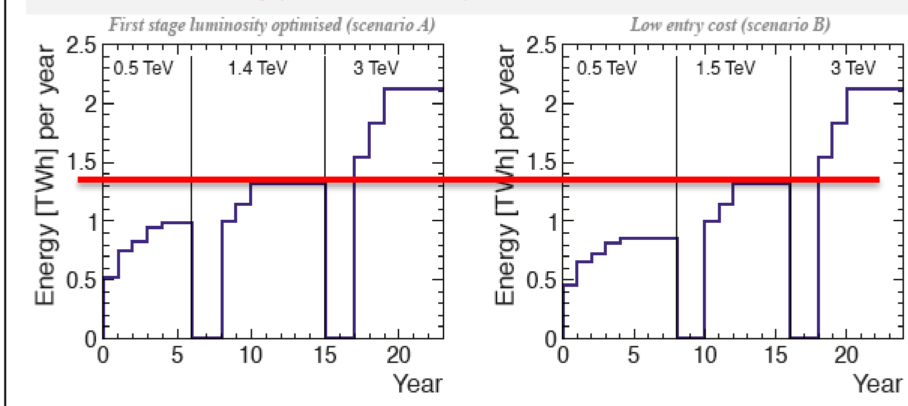


Power reductions are being looked at:

- Machine parameters and technical developments
- Consider where the power is dissipated (distributed or central)
- Look at daily and yearly fluctuation – can one run in "low general demand" periods
- Understand and minimize the energy (consider also standby, MD, down periods, running scenarios



CERN energy consumption 2012: 1.35 TWh



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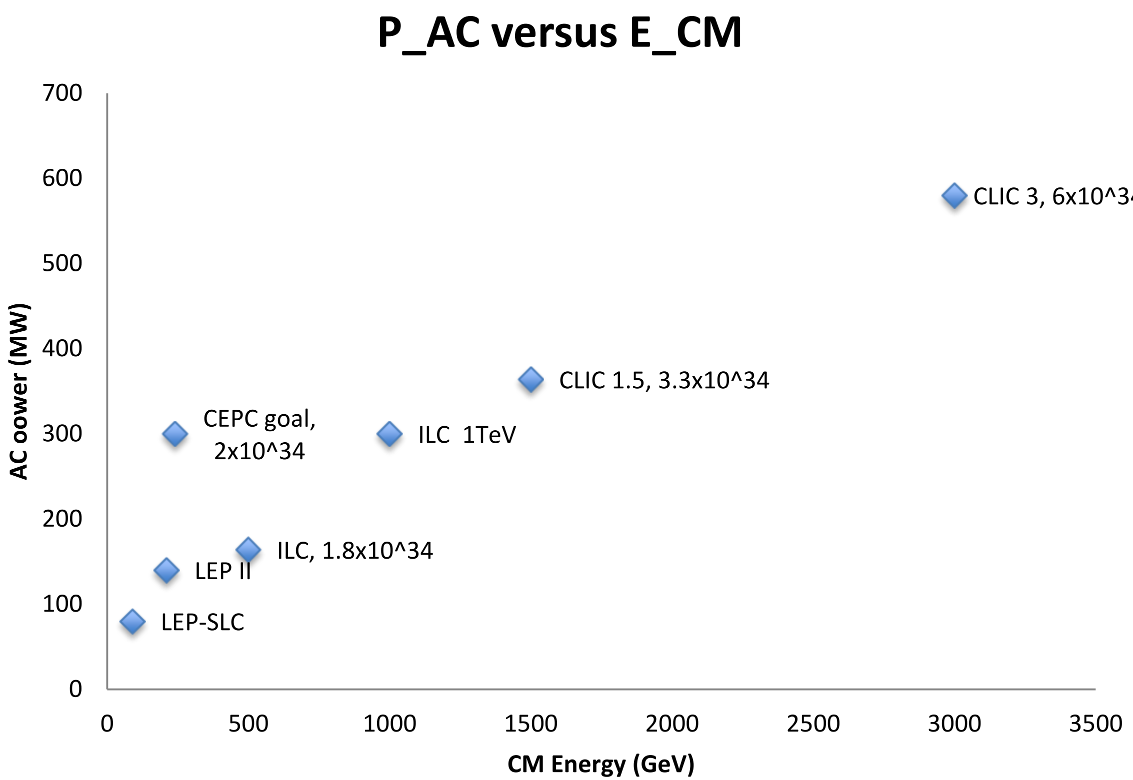
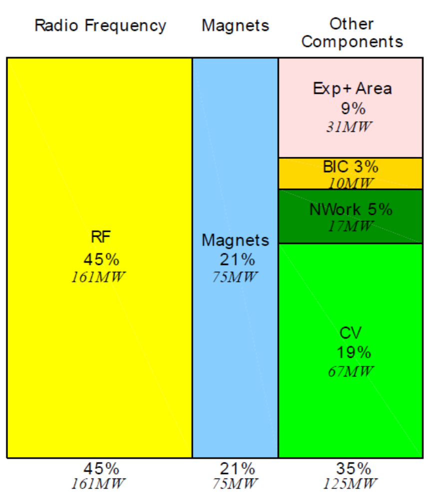


Beyond the parameter optimization there are other on-going developments (design/technical developments):

- Use of permanent or hybrid magnets for the drive beam (order of 50’000 magnets)
- Optimize drive beam accelerator klystron system
- Electron pre-damping ring can be removed with good electron injector
- Dimension drive beam accelerator building and infrastructure are for 3 TeV, dimension to 1.5 TeV results in large saving
- Systematic optimization of injector complex linacs in preparation
- Optimize and reduce overhead estimates



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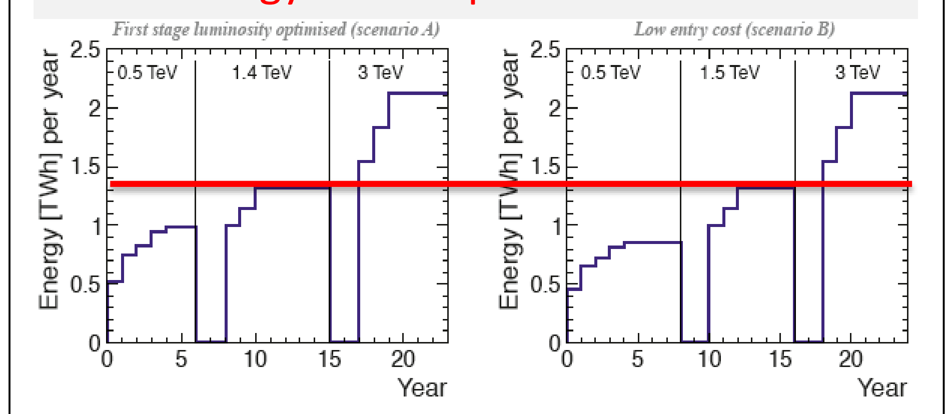
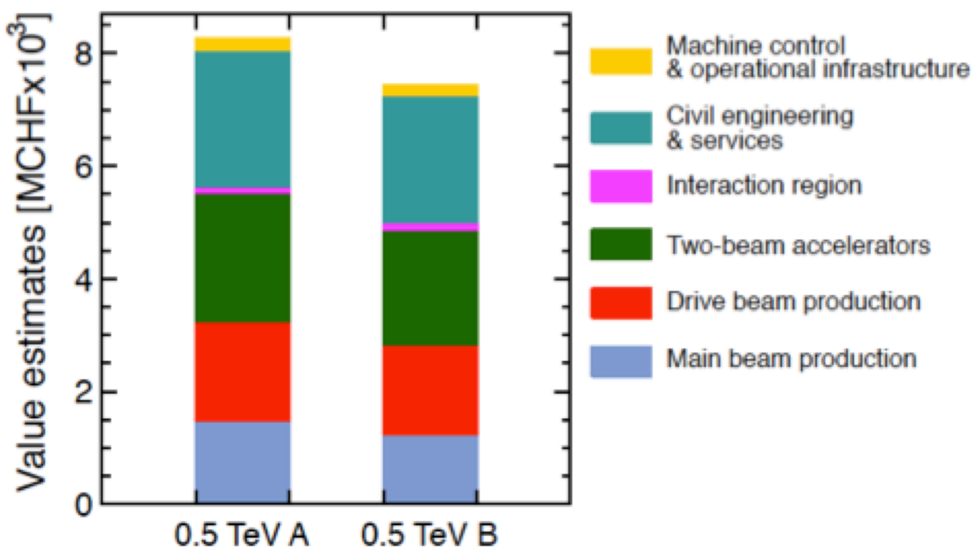


Developments for costs



First to second stage: 4 MCHF/GeV (i.e. initial costs are very significant)

Caveats:

- Uncertainties 20-25%
- Possible savings around 10%
- However – first stage not optimised (work for next phase), parameters largely defined for 3 TeV final stage

CDR costs can now be updated

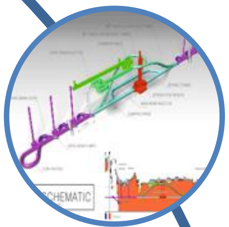
- New parameters optimizing costs, affect mostly initial stages
- Technical developments, affects all stages
- Too early for updated industrial quotes in some areas (other areas can be updated)

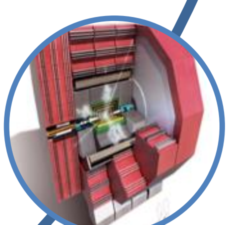
2012 CHF versus 2015 CHF ?

LINEAR COLLIDER COLLABORATION

http://clic-study.web.cern.ch/content/clic-accelerator-activities

Main activities





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- Detector optimisation
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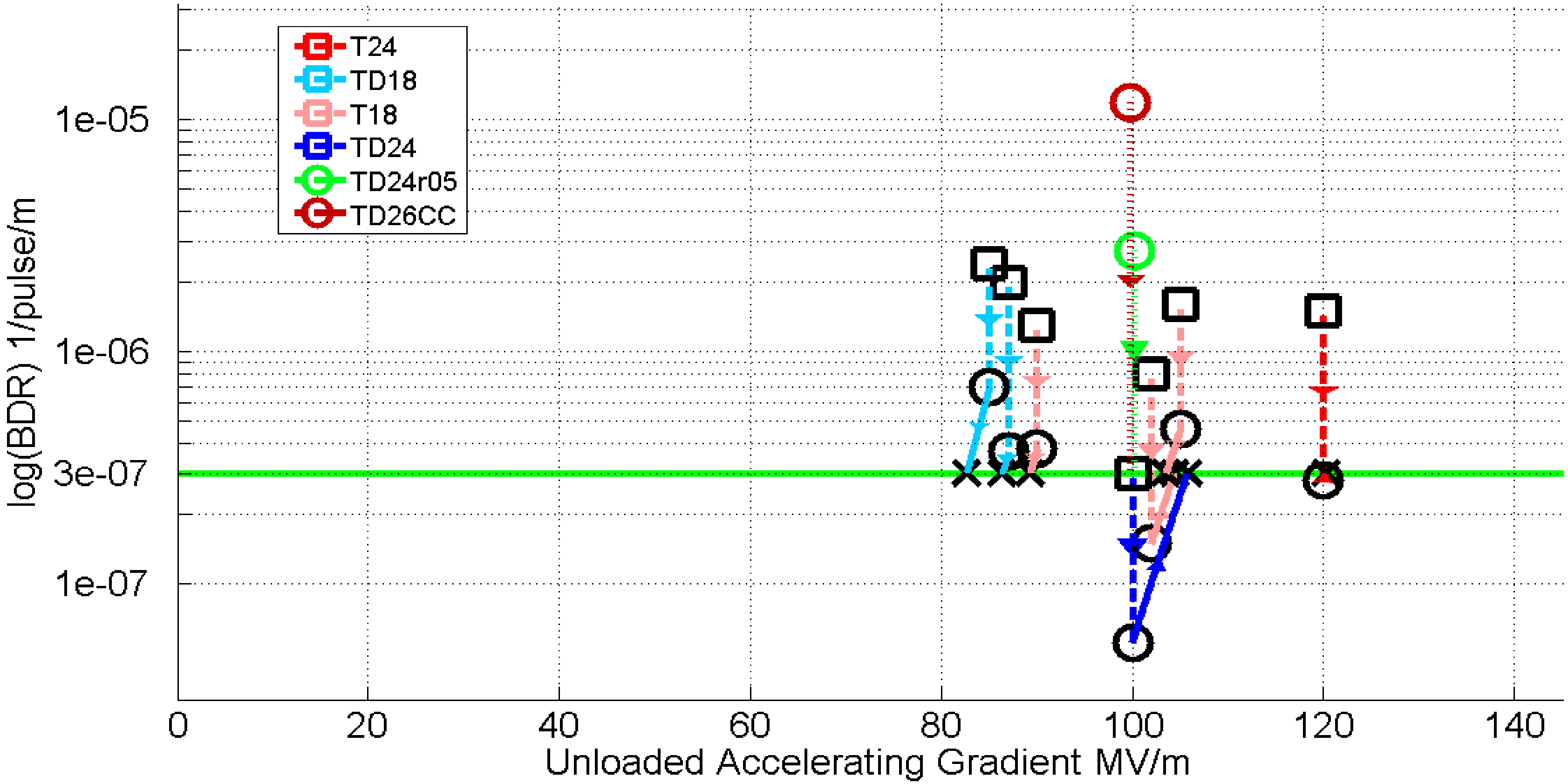
High-gradient accel. structure test status



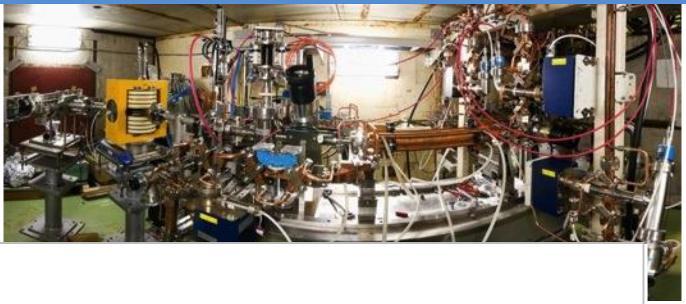
Results very good, design/performance more and more understood – but:

- numbers limited, industrial productions also limited
- basic understanding of BD mechanics improving
- condition time/acceptance tests need more work
- use for other applications (e.g. FELs) needs verification in coming years

In all cases test-capacity is crucial

X-band test-stands

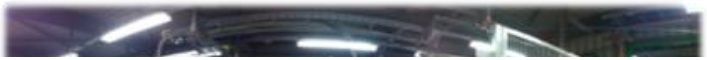
Previous:
Scaled 11.4 GHz
tests at SLAC and KEK.

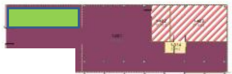


NEXTEF at KEK

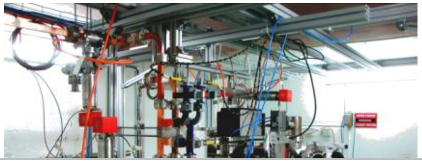
ASTA at SLAC

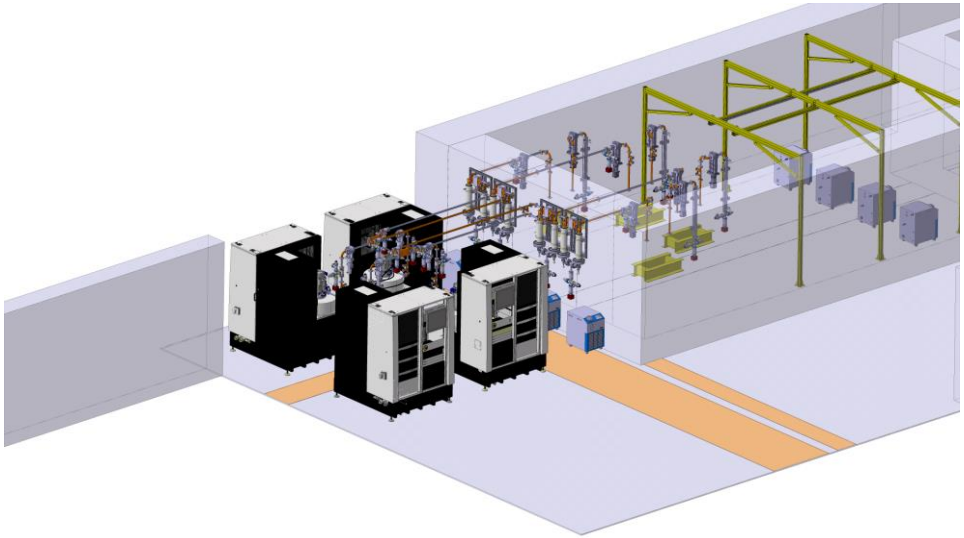
… remain important, also linked to testing of X-band structures from Tsinghua and SINAP





- **XBox-1** – T24, beam loading experiment ongoing and will continue.
- **XBox-2** – Finish crab cavity, TD26CC next.
- **XBox-3** – Under preparation.
- **NEXTEF** – Finish Tsinghua-built T24. KEK-built TD24R05 next.
- **ASTA** – Commissioning clone of our NI-based control system. KEK/SLAC-built TD24R05 installed and ready to go.





Very significant increase of test-capacity:

- First commercial 12 GHz klystron systems available
- Confidence that one can design for good (and possibly better) gradient performance
- As a result: now possible to use Xband technology in accelerator systems – at smaller scale

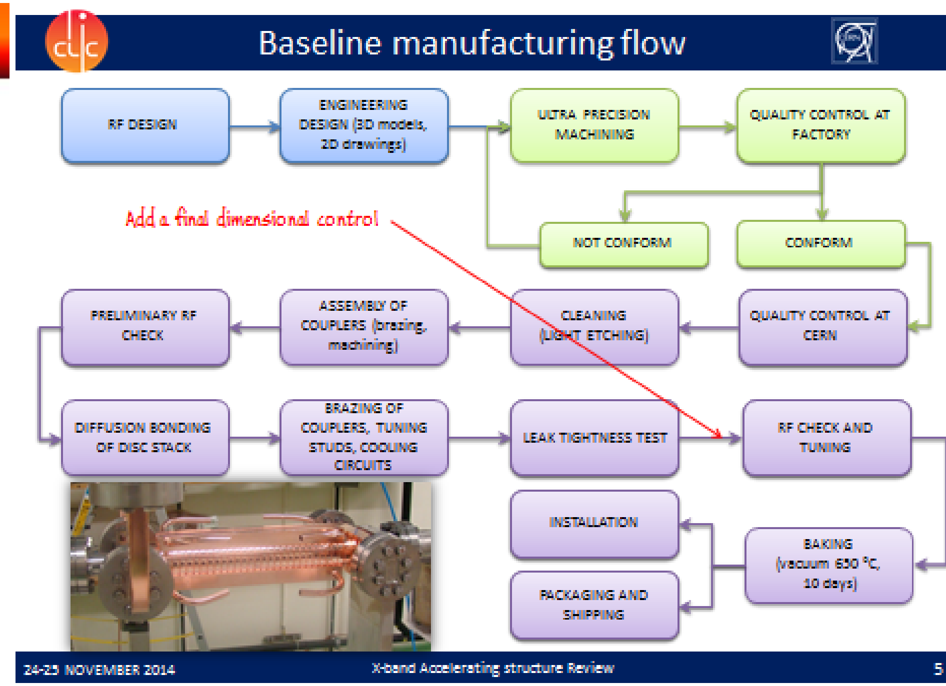
Accelerating structures in the pipeline

CLIC structures:

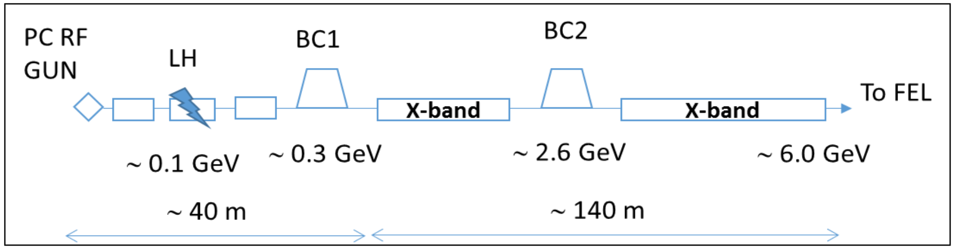
- Two TD26CC built and tested by KEK. *Still superb production*
- One TD26CC built by CIEMAT. *Next step after PETS.*
- Two T24s built by PSI in their production run. *Vacuum brazing alternative, benchmark for their production line.*
- One T24 built by SINAP. *Potentially leads to large X-band installation.*
- Whole structure in industry – Technical specifications are under preparation. *Industrialization, cost estimate.*

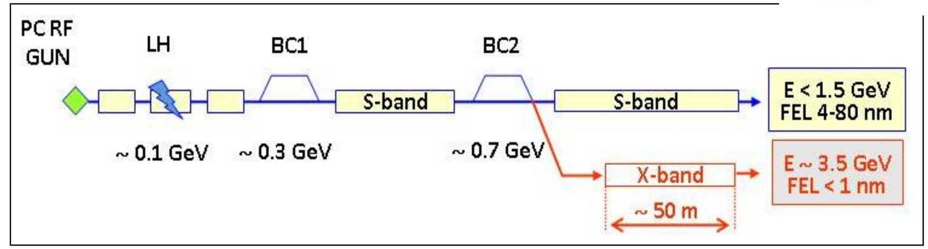
Other related structures:

- Structure in halves by SLAC. *Potentially cheaper, hard materials, preconditioned surfaces possible.*
- Choke-mode damping by Tsinghua. *Potentially cheaper*
- Four XFEL structures by SINAP. *New application with large potential.*
- High-gradient proton funded by KT (CERN technology transfer). *New application.*



Xband facilities - FELs





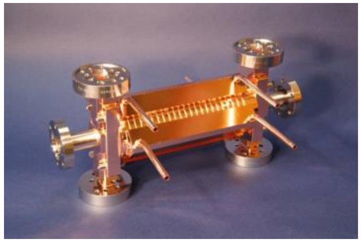
- X-band technology appears interesting for compact, relatively low cost FELs – new or extensions
  - Logical step after S-band and C-band
  - Example similar to SwissFEL: E=6 GeV, Ne=0.25 nC, σ_z=8μm
- Use of X-band in other projects will support industrialisation
  - They will be klystron-based, additional synergy with klystron-based first energy stage
- Started to collaborate on use of X-band in FELs
  - Australian Light Source, Turkish Accelerator Centre, Elettra, SINAP, Cockcroft Institute, TU Athens, U. Oslo, Uppsala University, CERN
- Share common work between partners
  - Cost model and optimisation
  - Beam dynamics, e.g. beam-based alignment
  - Accelerator systems, e.g. alignment, instrumentation…
- Define common standard solutions
  - Common RF component design, -> industry standard
  - High repetition rate klystrons (200->400 Hz now into test-stands)

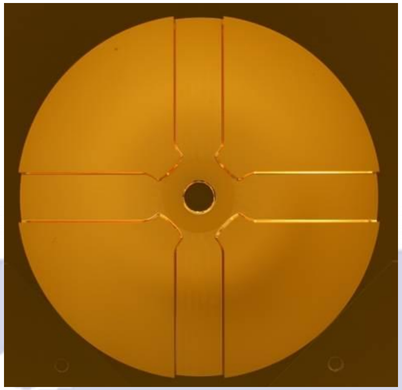
Important collaboration for X-band technology

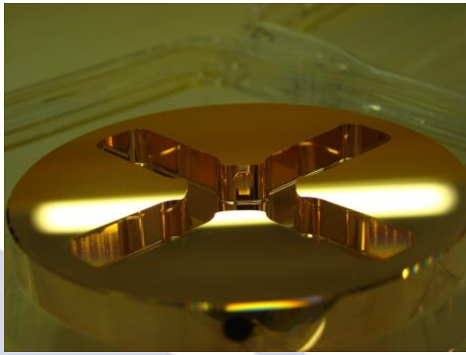
X-band structures and testing

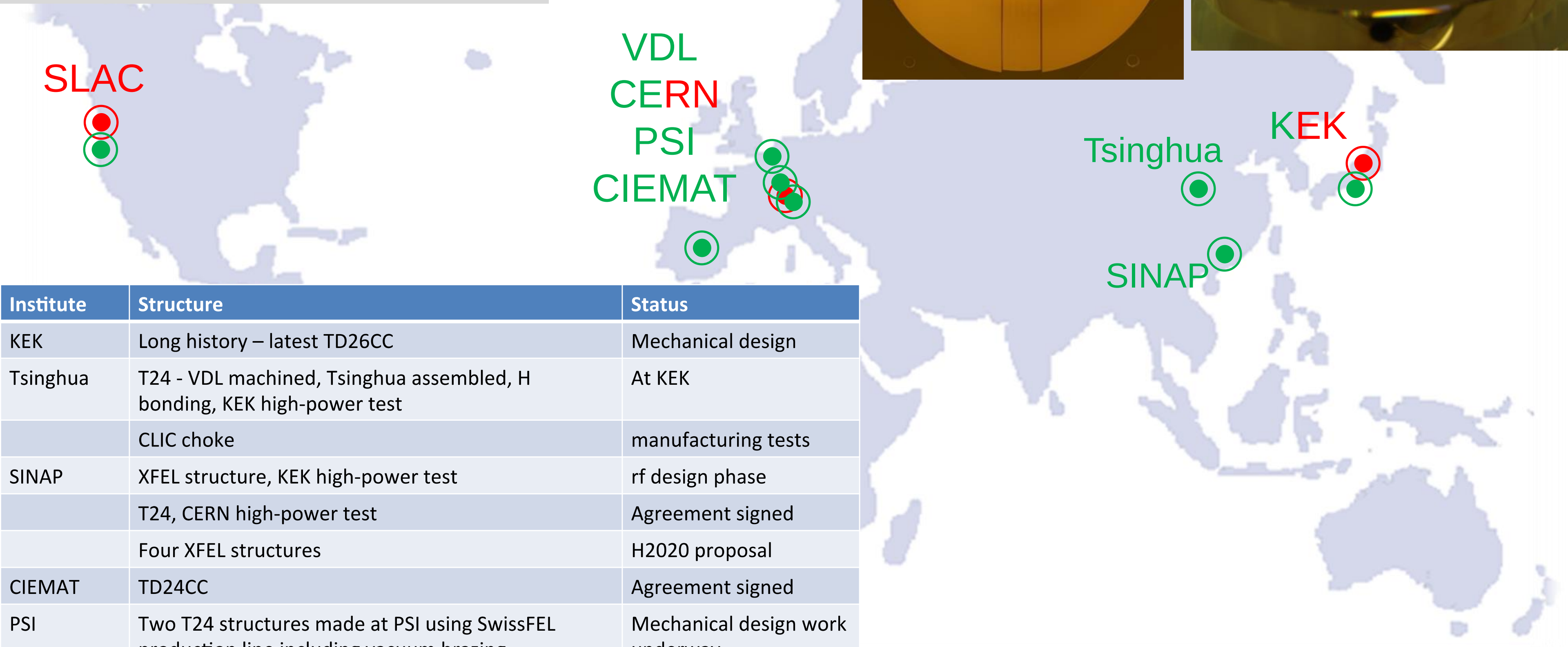
X-band Technologies:

- High gradient structures and high efficiency RF (structure prod. in green)
- X-band High power Testing Facilities (x3 increase) (in red)
- Use of X-band technologies for FELs



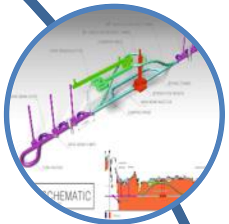


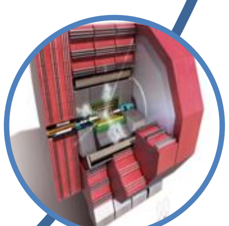




Institute	Structure	Status
KEK	Long history – latest TD26CC	Mechanical design
Tsinghua	T24 - VDL machined, Tsinghua assembled, H bonding, KEK high-power test	At KEK
	CLIC choke	manufacturing tests
SINAP	XFEL structure, KEK high-power test	rf design phase
	T24, CERN high-power test	Agreement signed
	Four XFEL structures	H2020 proposal
CIEMAT	TD24CC	Agreement signed
PSI	Two T24 structures made at PSI using SwissFEL production line including vacuum brazing	Mechanical design work underway
VDL	XFEL structure	H2020 proposal
SLAC	T24 in milled halves	machining
CERN	Structures and Test-stands	
	KT (Knowledge Transfer) funded medical linac	machining

Main activities





Parameters, Design and Implementation

- Integrated Baseline Design and Parameters
- Feedback Design, Background, Polarization
- Machine Protection & Operational Scenarios
- Electron and positron sources
- Damping Rings
- Ring-To-Main-Linac
- Main Linac - Two-Beam Acceleration
- Beam Delivery System
- Machine-Detector Interface (MDI
- Drive Beam Complex
- Cost, power, schedule, stages

X-band Technologies

- X-band Rf structure Design
- X-band Rf structure Production
- X-band Rf structure High Power Testing
- Novel RF unit developments (high efficiency)
- Creation and Operation of x-band High power Testing Facilities
- Basic High Gradient R&D

Experimental verification

- Drive Beam phase feed-forward and feedbacks
- Two-Beam module string, test with beam
- Drive-beam front end including modulator development and injector
- Modulator development, magnet converters
- Drive Beam Photo Injector
- Low emittance ring tests
- Accelerator Beam System Tests (ATF and FACET, others)

Technical Developments

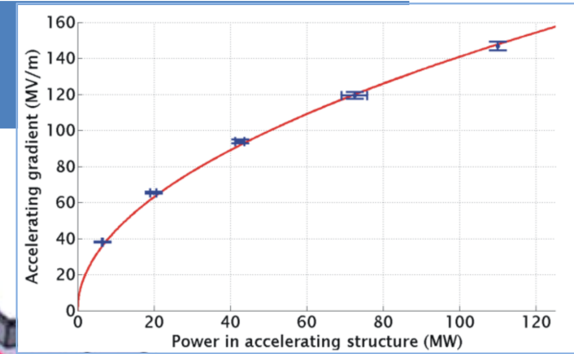
- Damping Rings Superconducting Wiggler
- Survey & Alignment
- Quadrupole Stability
- Warm Magnet Prototypes
- Beam Instrumentation and Control
- Two-Beam module development
- Beam Intercepting Devices
- Controls
- Vacuum Systems

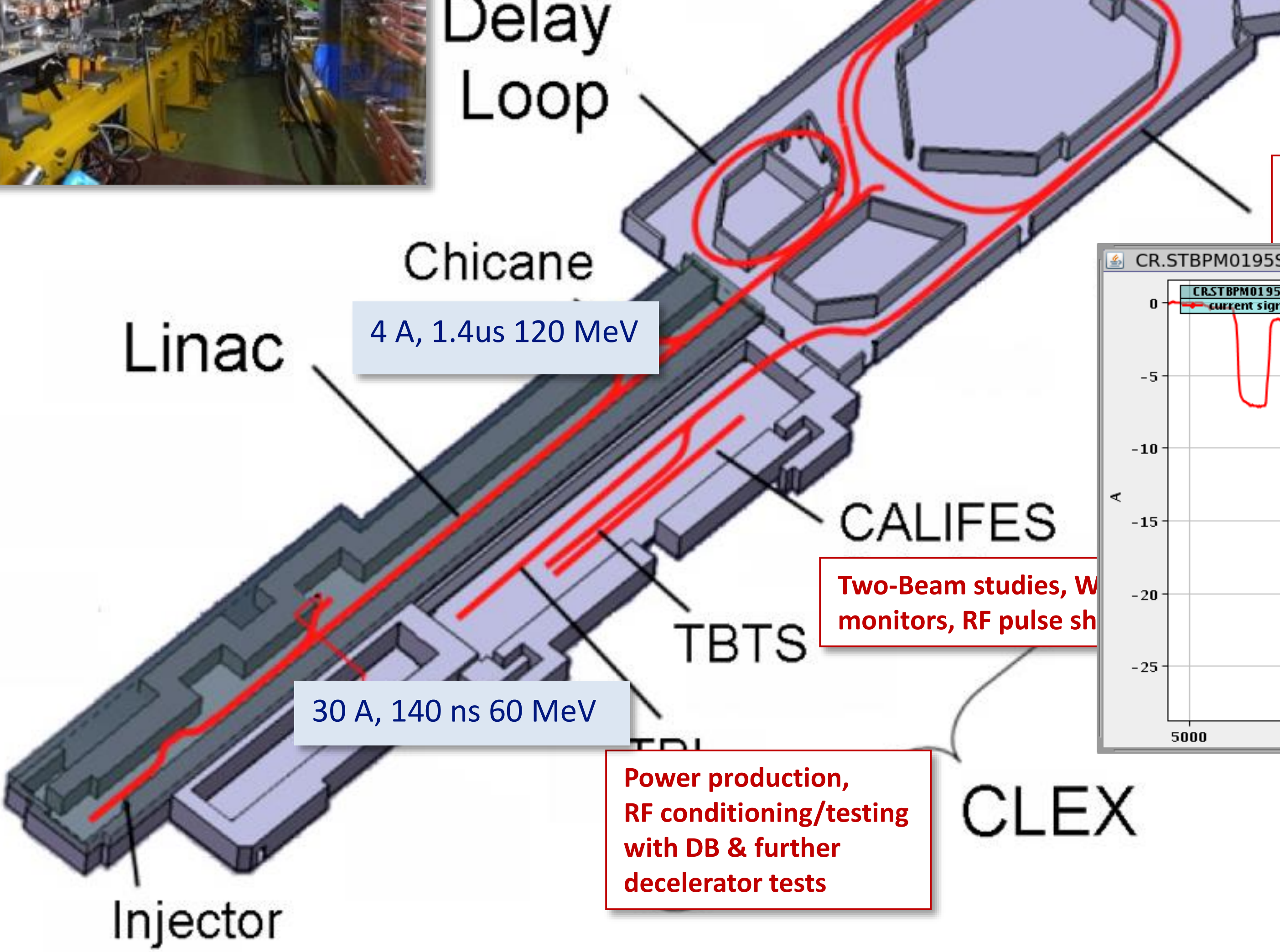
Detector and Physics

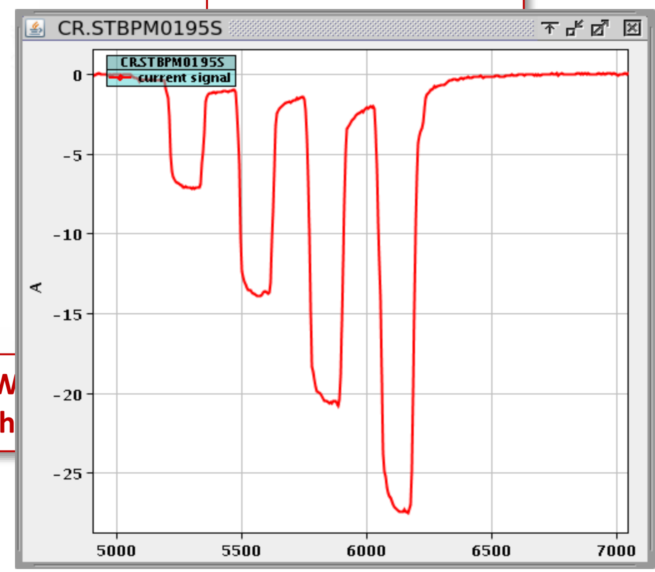
- Physics studies and benchmarking
- Detector optimisation
- Technical developments

CLIC Test Facility (CTF3)

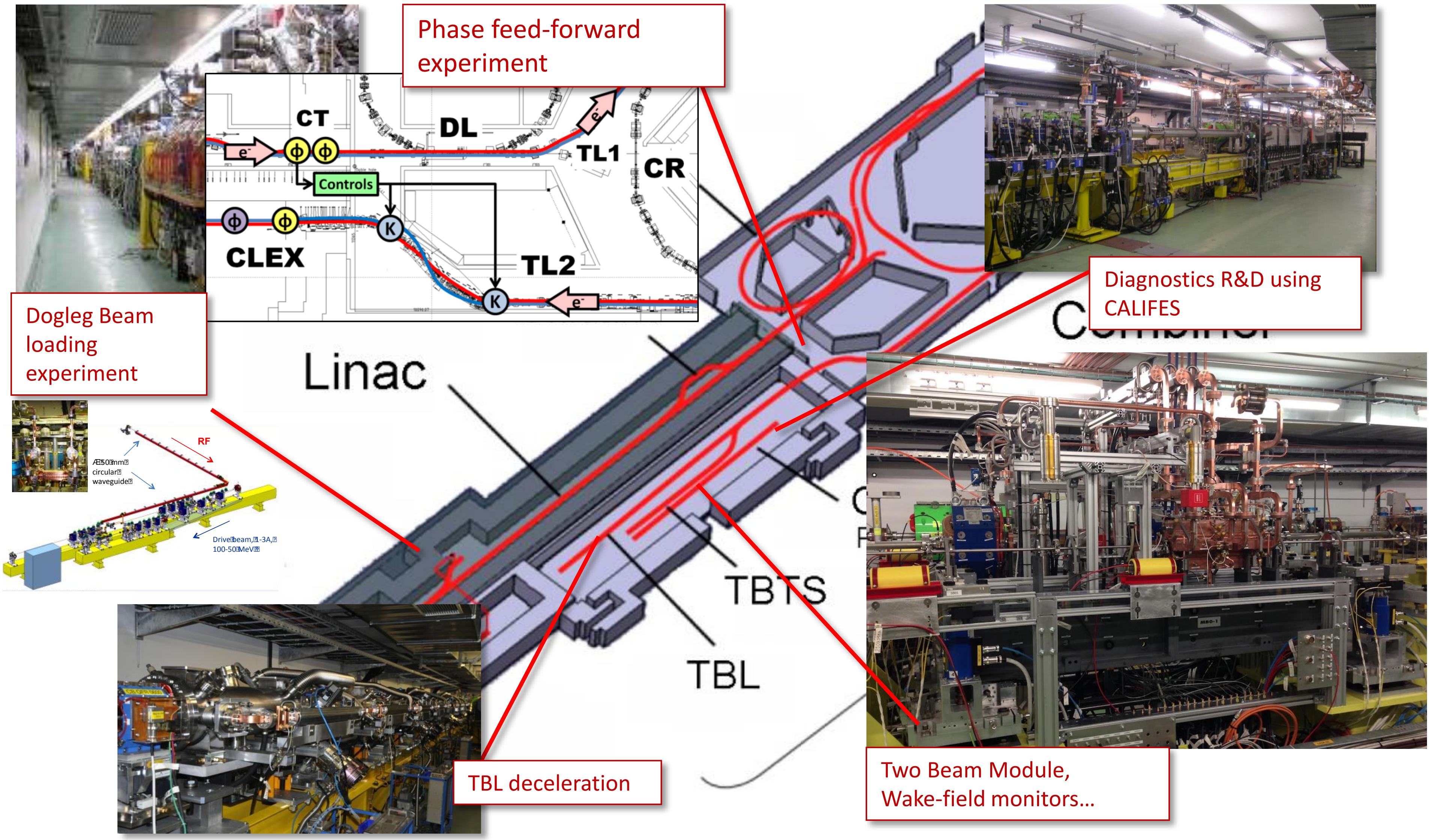
CLIC test facility - CTF3





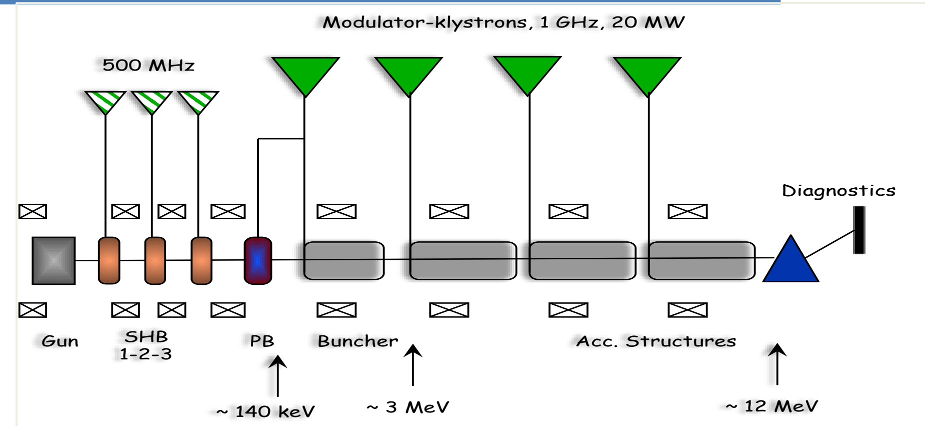


The next two years (2015-16)



CLIC system tests beyond CTF3

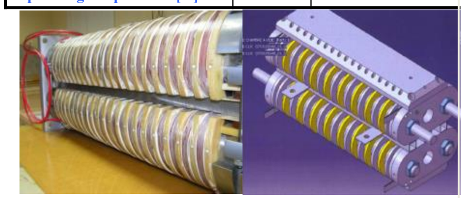
- Drive beam development beyond CTF3
  - RF unit prototype with industry using CLIC frequency and parameters
  - Drive beam front-end (injector), to allow development into larger drivebeam facility beyond 2018



- Damping rings
  - Tests at existing damping rings, critical component development (e.g. wigglers) ... large common interests with light source laboratories

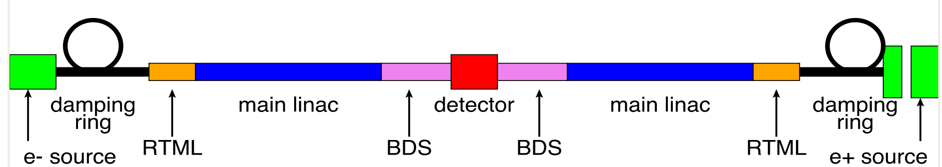
- Super-conducting wigglers
  - Demanding magnet technology combined with cryogenics and high heat load from synchrotron radiation (absorption)
- High frequency RF system
  - 1 GHz RF system respecting power and transient beam
- Coatings, chamber design and ultra-low vacuum
  - Electron cloud mitigation, low-impedance, fast-ion instability
- Kicker technology
  - Extracted beam stability
- Diagnostics for low emittance

Parameters	BINP	CERN/Karlsruhe
B_{peak} [T]	2.5	2.8
λ_W [mm]	50	40
Beam aperture full gap [mm]	13	13
Conductor type	NbTi	$NbSn_3$
Operating temperature [K]	4.2	4.2



Experimental program set-up for measurements in storage rings and test facilities:
ALBA (Spain), ANKA (Germany),
ATF (Japan), CESRTA (USA),
ALS (Australia)...

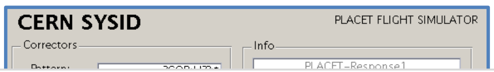
- Main beam (see slide later)
  - Steering tests at FACET, FERMI, …
- Beam Delivery System (see slide later)
  - ATF/ATF2



Performance verifications – CLIC

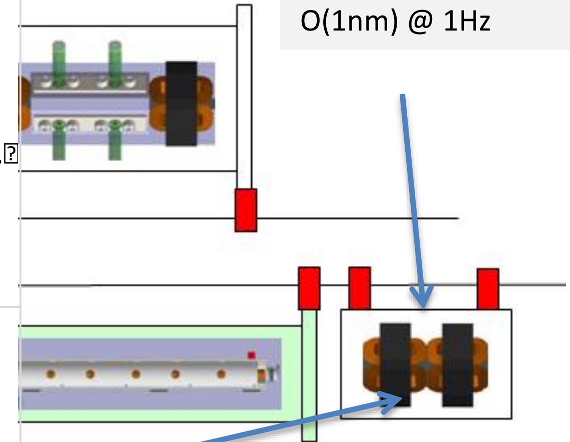
Our goal: an (almost) automatic correction

We want to make our BBA algorithms as automatic as possible. Two tools have been developed. SYSID and BBA tools



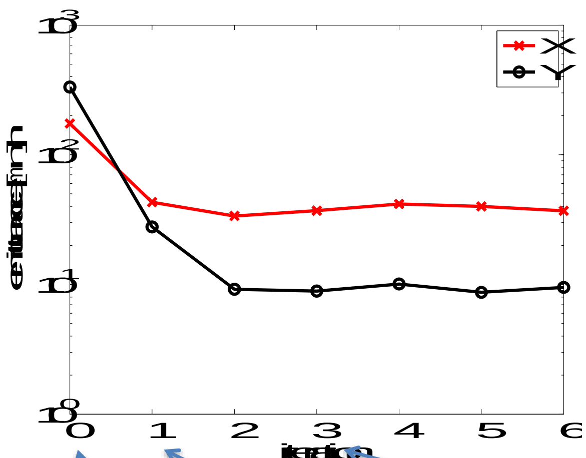
SYSID:
- Measures the machine optics

Stabilise quadrupole O(1nm) @ 1Hz



s+quads
) over about 200m

DFS at the SLAC Linac

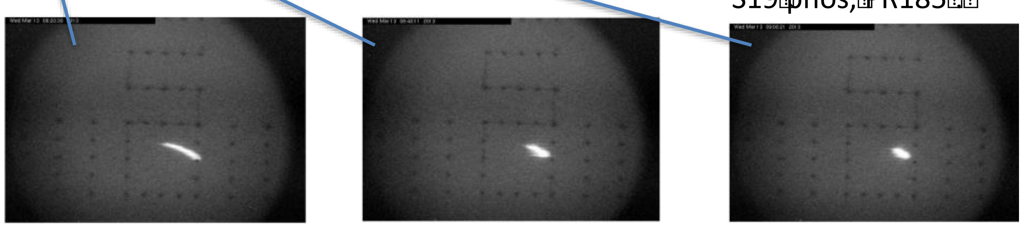


LI04-LI10:
Incoming oscillation/dispersion is taken out and flattened; emittance in LI11 and **emittance growth signific ntly reduced.**

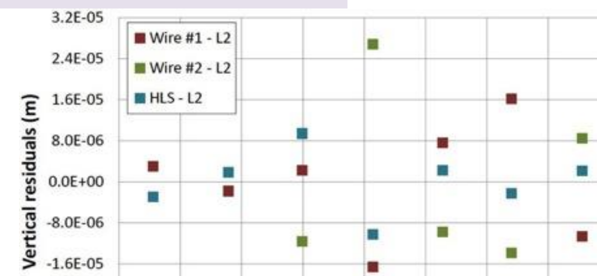
Emittance at LI11 (iteraton 1)
X: 43.2 x 10^{-5} m
Y: 27.82 x 10^{-5} m

Emittance at LI11 (iteration 4)
X: 3.71 x 10^{-5} m
Y: 0.87 x 10^{-5} m

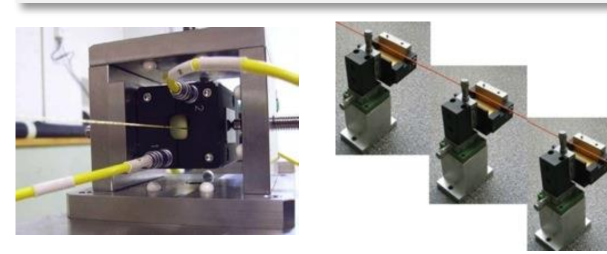
S19 phos, PR185



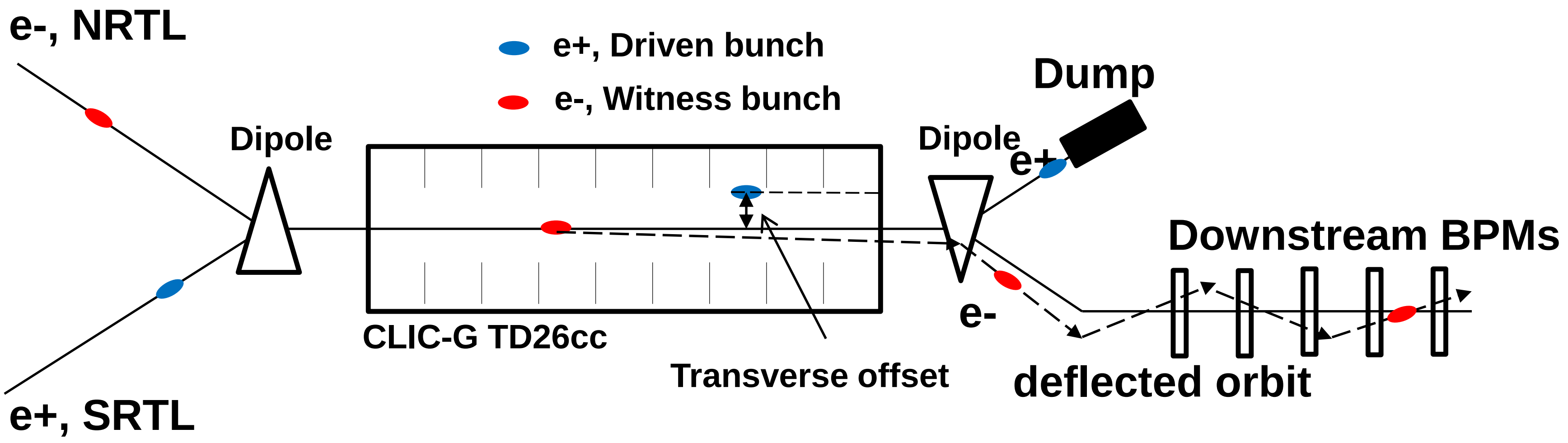
Before correction *After 1 iteration* *After 3 iterations*

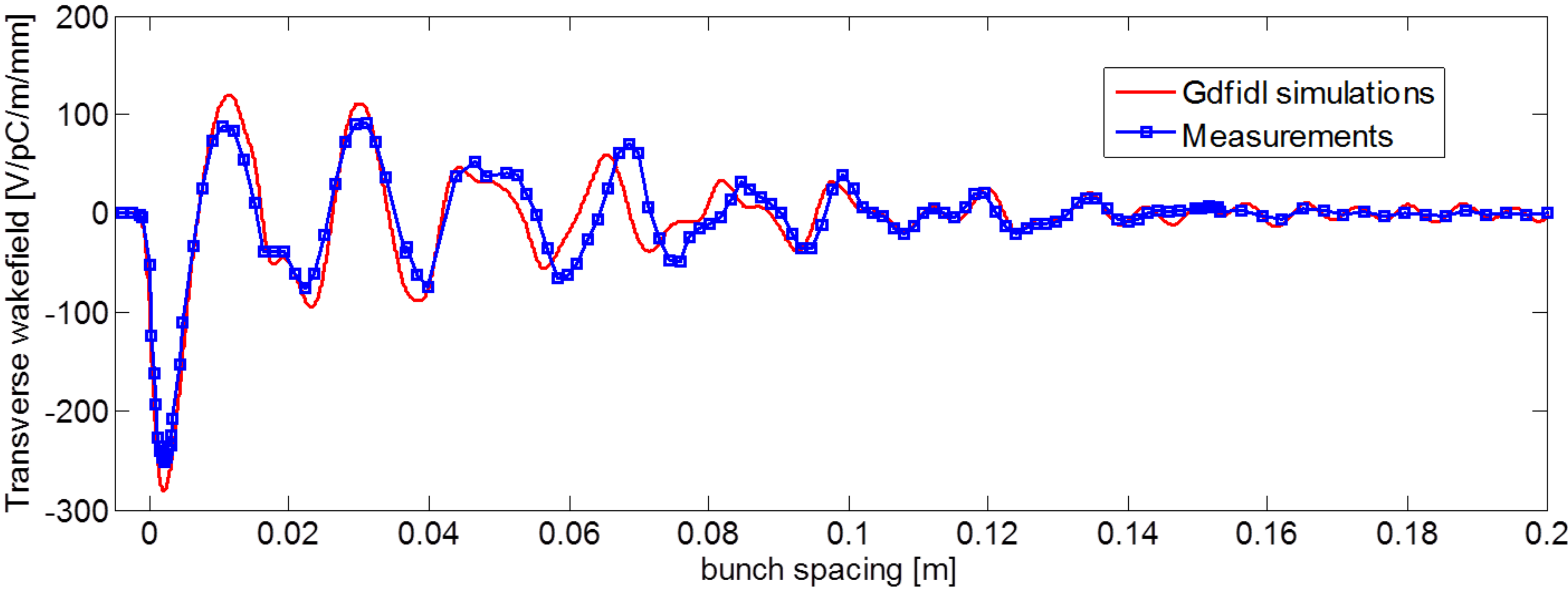


- Test of prototype shows
  - vertical RMS error of 11μm
  - i.e. accuracy is approx. 13.5μm



FACET measurements of wakefields

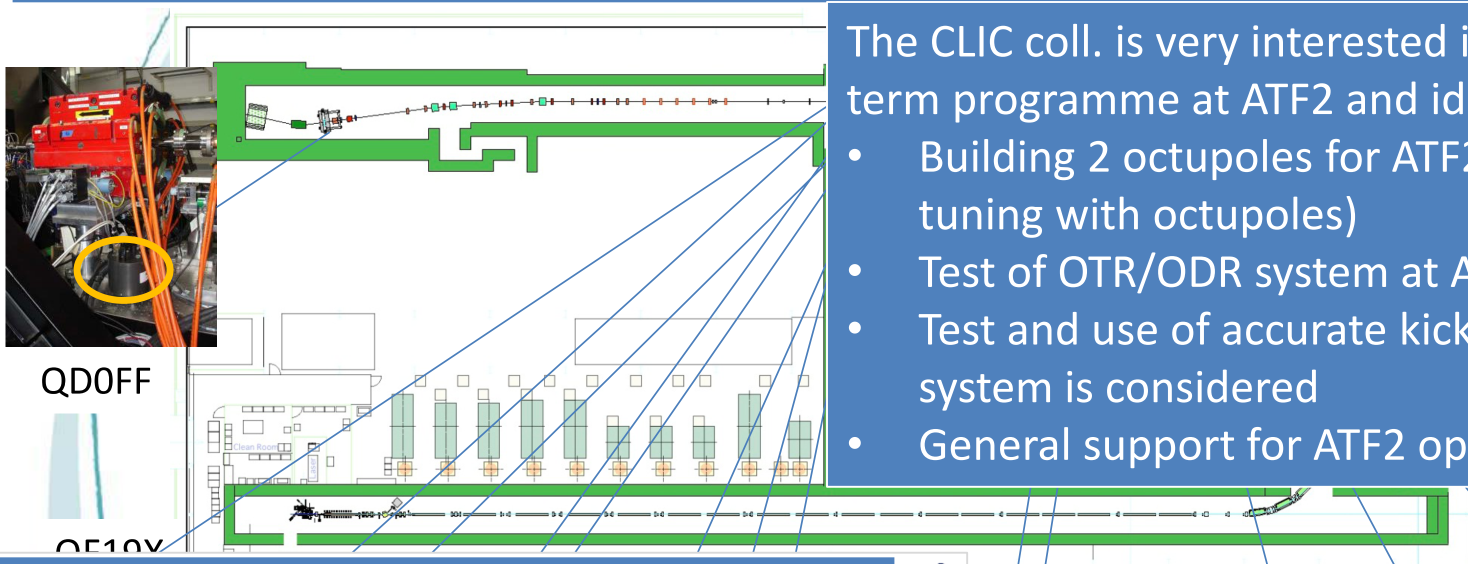


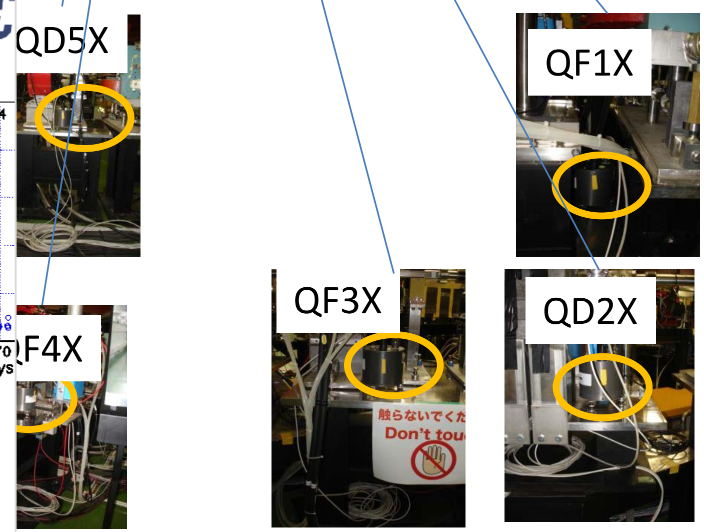


ATF2: Stabilisation Experiment

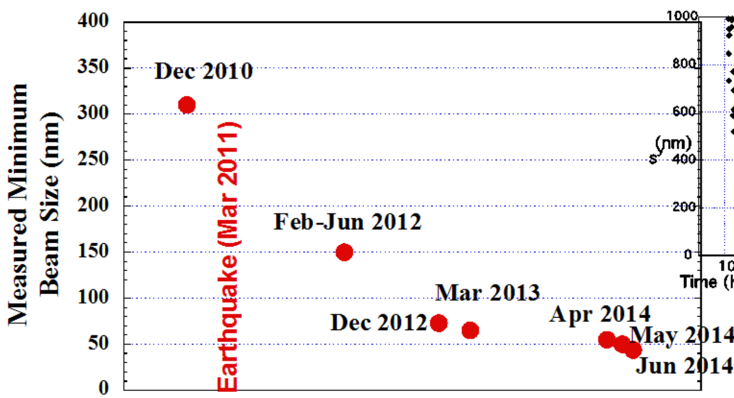
The CLIC coll. is very interested in a longer term programme at ATF2 and ideas exist for:

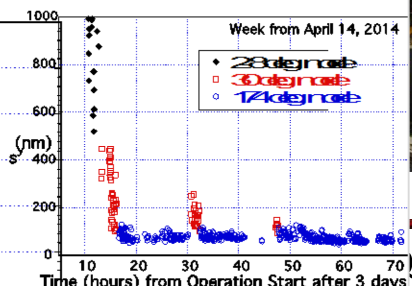
- Building 2 octupoles for ATF2 (to study FFS tuning with octupoles)
- Test of OTR/ODR system at ATF2
- Test and use of accurate kicker/amplifier system is considered
- General support for ATF2 operation

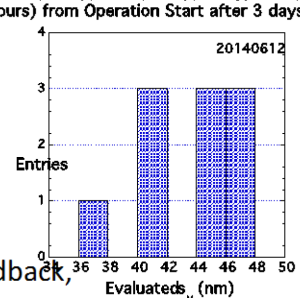




ATF-2 beam size development







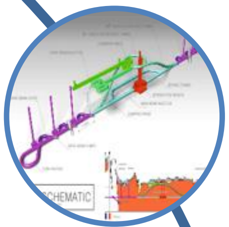
June: reaching 44 nm, very close to ILC goal (37 nm corr. to 6nm at ILC)

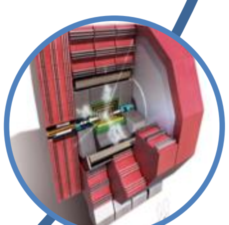
Field quality improvements, orbit stabilisation through feedback, shorted turn in 6-pole magnet, beam size monitor improvements

Main activities

LINEAR COLLIDER COLLABORATION

http://clic-study.web.cern.ch/content/clic-accelerator-activities





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- Beam Intercepting Devices
- Controls
- Vacuum Systems

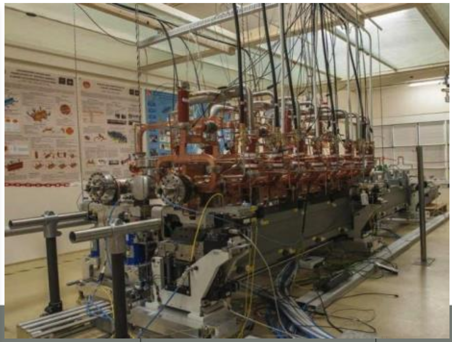
Detector and Physics

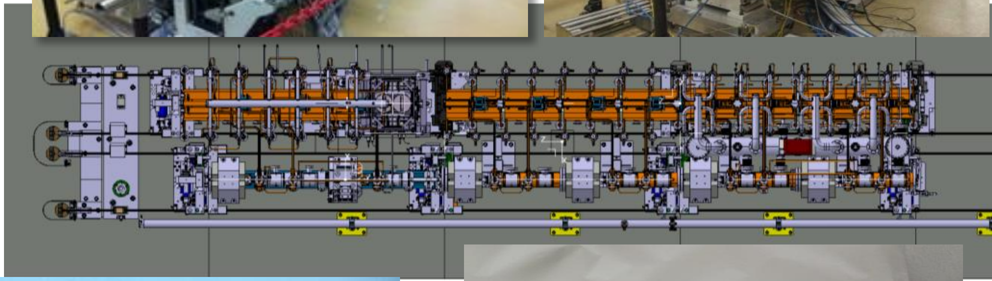
- Physics studies and benchmarking
- Detector optimisation
- Technical developments

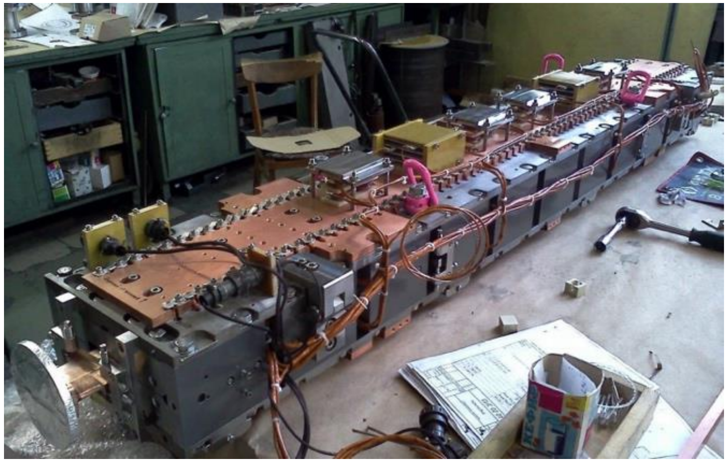
Technical activities – examples

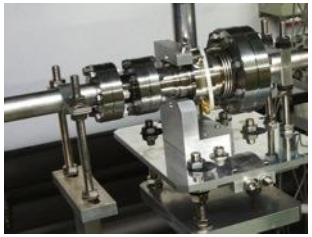
Technical Developments are motivated by several possible reasons:

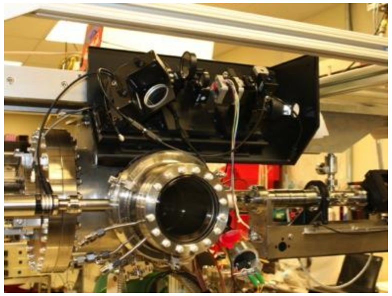
- Key components for systemtests
- Critical for machine performance
- Aimed at cost or power reduction

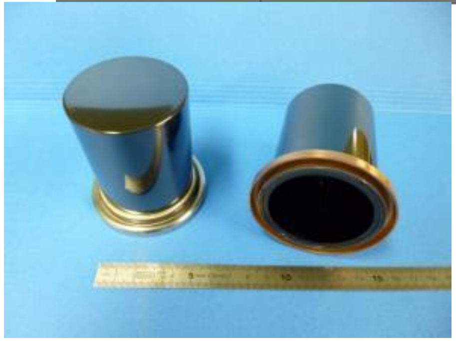




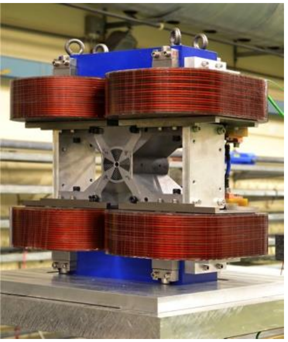


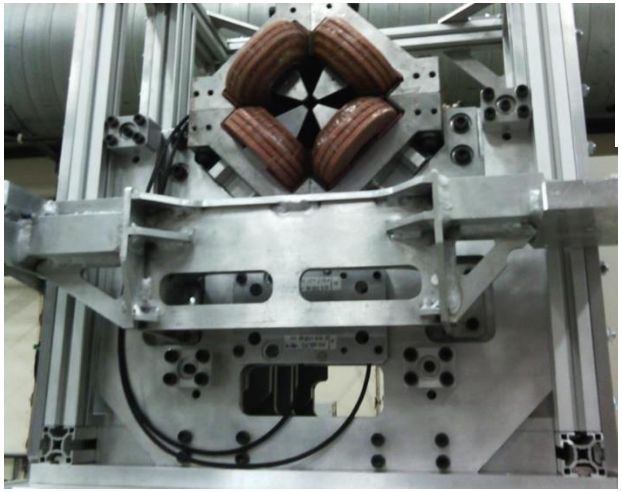






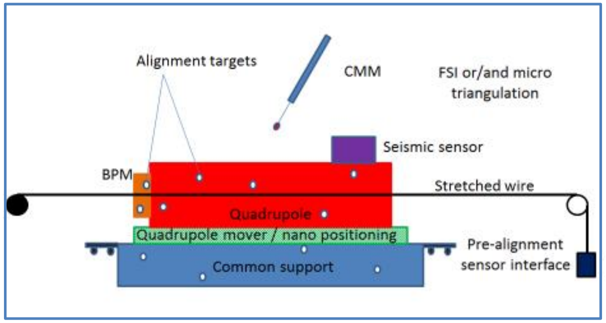
LINEAR COLLIDER COLLABORATION





Short term: some key issues

- Integration, ultra-high precision engineering and manufacturing
- Magnetic measurements with a vibrating stretched wire (and alternative based on printed circuit boards rotating search coils)
- Determination of the electromagnetic centre of BPM and RF structure using a stretched wire
- Absolute methods of measurements: new measuring head for CMM, combination of FSI and micro-triangulation measurements as an alternative
- Improve seismic sensors and study ground motion
- Nano-positioning system to position the quadrupole and BPM



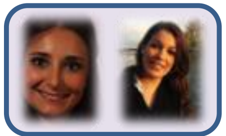
Long term

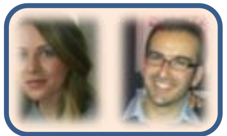
- Preparation of industrialization
- Optimization of performances and precision in all domains
- Extrapolation to other components

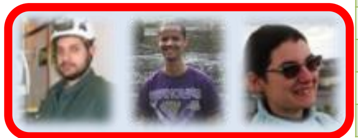
DMP	ES
ELTOS	IT
ETALON	DE
METROLAB	CH
SIGMAPHI	FR

Hexagon Metrology	DE
National Instruments	HU
TNO	NL

Cranfield University	GB
ETH Zürich	CH
LAPP	FR
SYMME	FR
University of Sannio	IT
IFIC	ES
University of Pisa	IT
Delft University of Technology	NL







Summary

The goals and plans for 2015-19 are well defined for CLIC, focusing on the high energy frontier capabilities – well aligned with current strategies – also preparing to align with LHC physics as it progresses in the coming years:

- Aim provide optimized stages approach up to 3 TeV with costs and power not too excessive compared to LHC
- Very positive progress on X-band technology, due to availability of power sources and increased understanding of structure design parameters
  - Applications in smaller systems; FEL linacs key example – with considerable interesting in the CLIC collaboration
- Also recent good progress on performance verifications, drivebeam, main beam emittance conservation and final focus studies
  - BBA discussions, BDS/ATF important
  - CTF3 running and plan until end 2016, strategy for systemtests beyond
- Technical developments of key parts well underway – with increasing involvement of industry – largely limited by funding
- Collaborations for CLIC accelerator and detector&physics studies are growing

Thanks

- Slides/figures/advice from CLIC collaboration members. Knowingly from L. Linssen, M.Thomson, A. Latina, K.Kubo and ATF colleagues, D.Schulte, R.Corsini, W.Fang, W.Wuensch and X-band team, , F.Tecker, T.Lefevre, M.Modena, N.Catalan, C.Garion, I.Syratchev, H.Mainaud Durant and PACMAN team, R.Tomas, Y.Papaphilippou, G.D'Auria, … and several more unknowingly or indirectly