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CTF3 INJECTOR PROFILE MONITOR

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The electron gun of the CLIC Test Facility 3 (CTF3) produces 15.6 μ s long pulses with an energy of 140keV and a current that can be as high as 9A. For the nominal beam operation a 5.4A beam current is generated and sent downstream into the bunching system and the rest of the accelerator. The corresponding beam charge will induce a thermal load that most of the materials, considered as radiators, would not withstand. With this problem in mind, we have built a beam imaging system, installed just after the gun and equipped with two screens. The first one is a phosphorescent screen which yields a high signal and can be for low beam currents. The second screen, a thin graphite foil, is used as a forward OTR radiator and can stand the full beam intensity. Moreover, the time resolution of OTR is very good, in the femtosecond range. This allows the observation of the evolution in time of the beam size during the pulse by using a gated camera. We present in this paper the first results obtained using this system.

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Abstract. The electron gun of the CLIC Test Facility 3 (CTF3) produces 15.6 μ s long pulses with an energy of 140keV and a current that can be as high as 9A. For the nominal beam operation a 5.4A beam current is generated and sent downstream into the bunching system and the rest of the accelerator. The corresponding beam charge will induce a thermal load that most of the materials, considered as radiators, would not withstand. With this problem in mind, we have built a beam imaging system, installed just after the gun and equipped with two screens. The first one is a phosphorescent screen which yields a high signal and can be for low beam currents. The second screen, a thin graphite foil, is used as a forward OTR radiator and can stand the full beam intensity. Moreover, the time resolution of OTR is very good, in the femtosecond range. This allows the observation of the evolution in time of the beam size during the pulse by using a gated camera. We present in this paper the first results obtained using this system.

INTRODUCTION

The injector of the CTF3 facility in the nominal phase will produce intense beams [1], which impose severe constraints on the design of beam profile monitors. Very few materials can be used to produce screens capable of standing the full beam induced thermal load [2]. For this reason the use of a thermal resistant material like graphite has been considered as an Optical Transition Radiator (OTR). Even if they are not commonly used for non relativistic particles, enough photons will be emitted to be measured using an intensified camera. A preliminary test [3] was already made in 2002 on an 80keV electron beam produced at the CERN photocathode R&D laboratory. The characteristic of backward OTR generated from an aluminium screen was measured and found to be in good agreement with our expectations. However an additional difficulty arises when using materials like graphite which have a low reflectivity coefficient. The backward OTR is then strongly suppressed. To overcome this limitation, the screen is tilted in order to observe the forward OTR light emitted at 90° which, according to our calculations will produce even more photons than in the backward direction.

Even if the system is designed to measure the full beam charge, it is always helpful during the commissioning period to have the possibility to image lower intensity beams. For this purpose, scintillating screens, which yield a considerable amount of photons, are classically used [4]. However, one must be careful because phosphorescent screens are subject to saturation, limiting the accuracy of the measurement. Moreover their use must be limited to the observation of small charges, since above a given charge density the risk of damaging the screen is high.

The beam imaging system we designed for the CTF3 injector is described below, presenting both the mechanical assembly with the two screens and the details of the optical system. The performance and limitations obtained with the phosphorescent screen are reported. Measurements obtained with the OTR screen are shown as well, emphasizing on the linearity of the light emission which provides precise quantitative measurements. OTR light has a very fast time response and measurements relative to the temporal evolution of the beam size are presented.

OVERVIEW OF THE SYSTEM

The installation of the new CLIC Test Facility 3 started in January 2003. By the end of the year, the injector and the first part of the accelerator had already been installed and commissioned [5]. The layout of the CTF3 injector is presented in Figure 1.

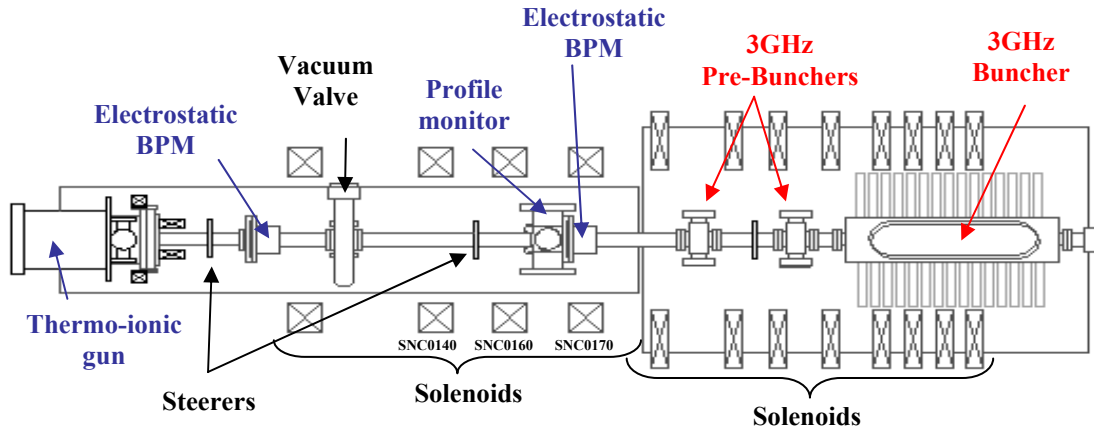


Figure 1. The CTF 3 injector beam layout

A 140keV electron beam is produced by a thermo-ionic gun. The beam current and the pulse length can be adjusted from 100mA to 9A and from 300ns to 1.6 μ s by changing the voltage and the duration of the gun pulser. Using a set of solenoids and two steering magnets, the beam is transported to the 3GHz bunching system, itself composed of two standing wave cavities (prebunchers) and a travelling wave structure (buncher). The beam current and positions are monitored using two electrostatic pickups [6].

Due to very strong space constraints the beam imaging system is attached to the second beam position monitor. The details of the beam profile monitor are given in Figure 2. This device is composed of a long cylinder which provides 3 positions for two screens and one to allow the beam to pass through. The vacuum chamber has an extension tube in order to keep the pneumatic insertion mechanism out of the solenoid magnetic field. The first screen is a 5 μ m thick P47 phosphor ($Y_2SiO_5 : CeTb$) deposit on a 10 μ m thick aluminum foil. It emits visible photons in the wavelength range from 370nm to 480nm with a decay time of 100ns. The total number of photons emitted per electron in a 2 π solid angle is high, of the order of 400. This light yield makes the P47

phosphor screen a perfect choice for the observation of small beam charge. The second screen is a $5\mu\text{m}$ thick carbon screen used as an OTR target, dedicated to the imaging of the full beam charge. The normal of the screen is tilted with respect to the beam trajectory by 30° so that the forward radiation emitted at the back plane of the screen is observed. Only 10^{-4} photons per electron are emitted in the visible range from 400 to 600nm [3] and an intensified camera must be foreseen to allow its detection. The optical system is composed of a set of achromat lenses. A first lens, placed very close to the vacuum tank view port is used to optimize the light collection. A semi transparent mirror splits the optical line in two distinct paths sending 50% of the light onto a normal CCD camera dedicated to the observation of the phosphor screen, and the remaining 50% onto a gated and intensified camera bought from Proxitronic [7]. In the right side of Figure 2, one can see two images representing the screens as seen by the corresponding camera. These pictures are used for calibration using references on the screen support. The active area of the screen has a diameter of 40mm and the optical calibration gives a spatial resolution of $200\mu\text{m}$ per pixel.

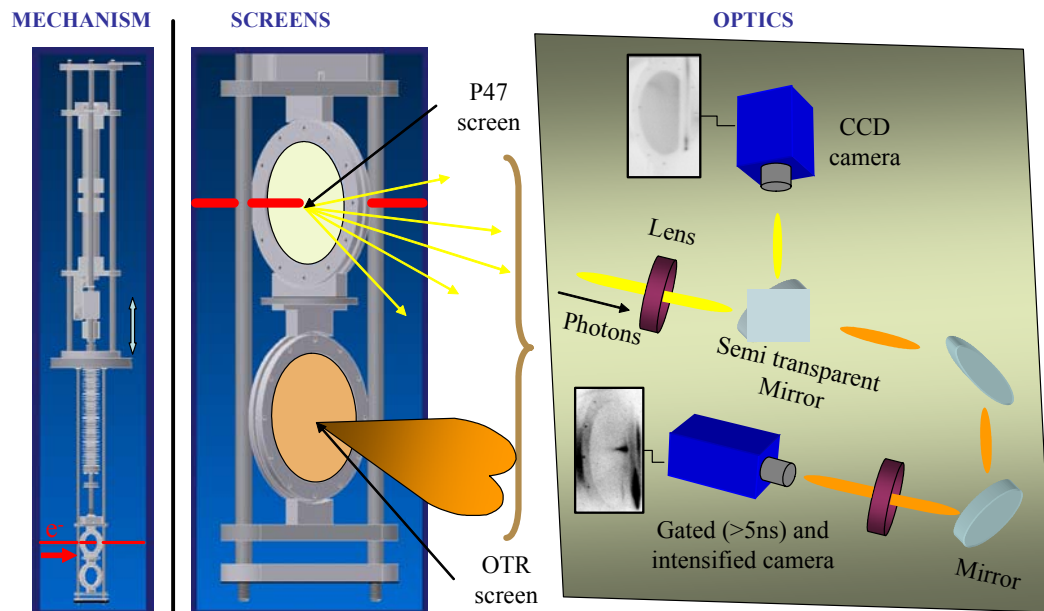


Figure 2. The CTF 3 injector beam profile monitor

Several tests have been performed using the two screens. The most representative results are reported in the following paragraphs.

MEASUREMENTS WITH THE P47 PHOSPHOR SCREEN

High Sensitivity Measurement of the Gun Dark Current

If the gun pulser is off, only the dark current emitted from the gun triode grid can hit the screen. Two pictures of this dark current are presented in Figure 3. The shape

of the intermediate grid electrode is imaged on the screen and the magnification of this image can be adjusted by varying the current in one of the solenoids. By measuring the total light intensity on each image and taking into account the screen light yield, the solid angle of our optical line (1/4000 of the total number of photons emitted) and the camera sensitivity, the dark current is estimated to be in the range 10-100 μ A.

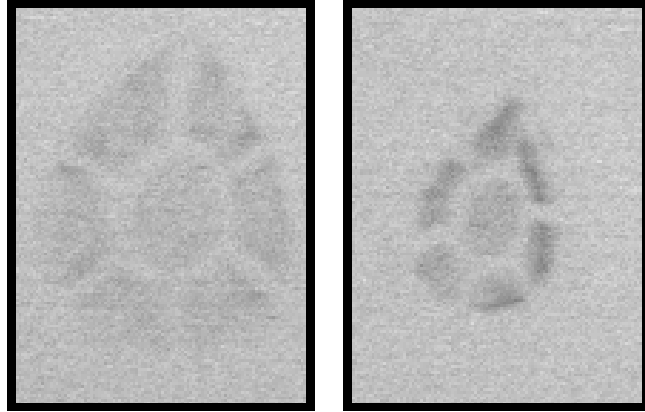


Figure 3. Images of the dark current flowing from the gun triode grid for two different focusing conditions

Sign of Damage on the Screen

After some running time, a clear sign of damage is observed on the screen, as depicted in Figure 4. The P47 deposit has been removed at least partially over a zone exposed to the beam. The supplier [7] indicates that after a beam irradiation corresponding to a total charge of 5C/cm², the sensitivity of the screen would decrease by a factor 2.



Figure 4. Images of the Phosphor screen after high beam current irradiation

Taken with a reduced beam current of 0.5A and a 400ns pulse length, two different beam images are shown in Figure 5. The beam position is moved in and out of the damaged zone of the screen using a steering magnet so that the light yield can be

checked. A reduction of the screen efficiency, equivalent to 27% of the nominal light yield of the screen is measured. According to our estimations the total charge seen by the screen should have been lower than $0.1\text{C}/\text{cm}^2$. This would indicate that this damage is the consequence of a bad manipulation sending onto the screen a beam with a much too high charge, which basically heats up and removes the phosphor deposit.

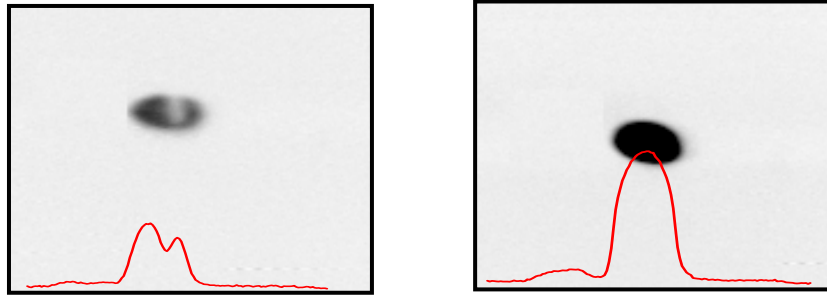


Figure 4. The two images are acquired with the same beam current and under identical focusing conditions. The beam has just been displaced in the down direction by few millimeters using a steerer.

MEASUREMENT WITH THE GRAPHITE OTR SCREEN

Precise Beam Size Measurements

For nominal operating conditions an electron beam of 5.4A current and $1.6\mu\text{s}$ pulse duration is observed using the graphite OTR screen. Beam images obtained using the intensified camera and a 500ns time gate are shown in Figure 5. The pictures are taken under different focusing conditions by adjusting the current in a solenoid.

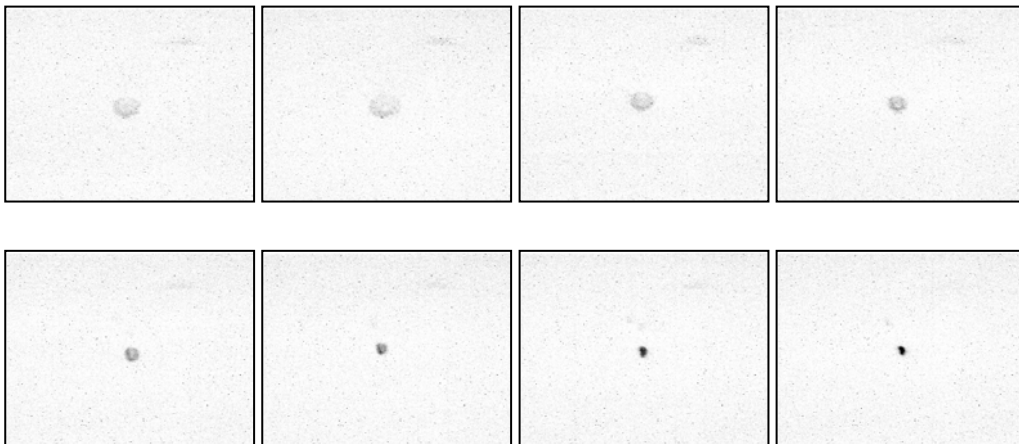


Figure 5. Set of beam images obtained for different focusing conditions

The corresponding vertical and horizontal R.M.S beam sizes are calculated and shown in Figure 6. The error bars correspond to the fluctuations observed on 10 consecutive measurements. Beam sizes from 3mm to 0.5mm are measured here with a

good accuracy. The precision is nevertheless not very good when the beam size is big. The number of photons is limited and the signal to noise ratio is in this case reduced.

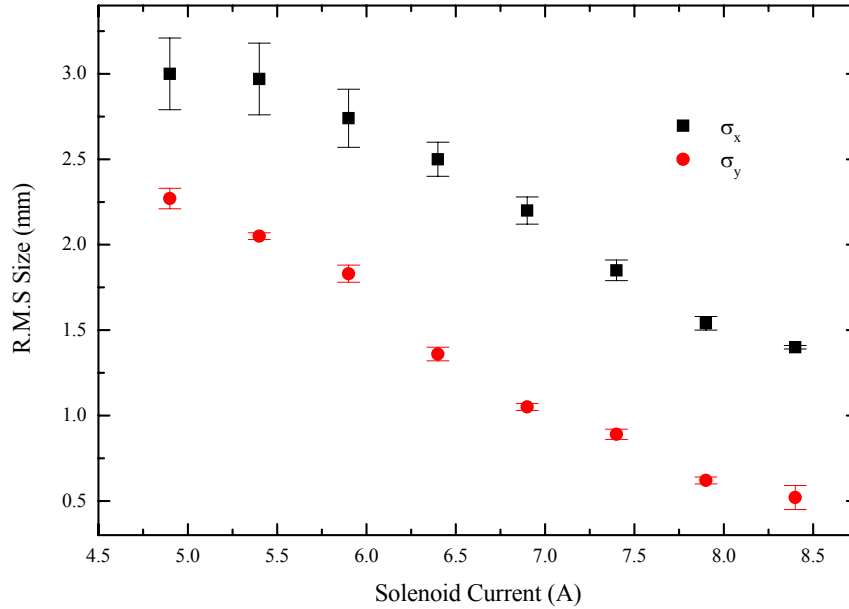


Figure 6. Evolution of the R.M.S. transverse beam size under different focusing conditions.

Temporal Evolution of the Beam Size within the Pulse Duration

A second set of measurements was taken using a different camera setting with a shorter gate duration. By adjusting the camera trigger, we can check the temporal evolution of the transverse beam size within the overall pulse duration. The results are given in Figure 7 where 8 images of the beam acquired at different timings are presented.

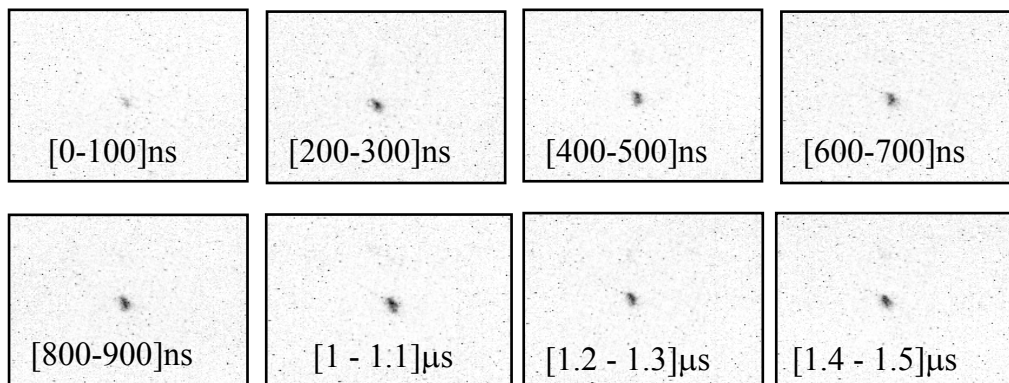


Figure 7. Set of 100ns gate time images taken at different timing position in the 1.56 μ s of the pulse duration.

The R.M.S. beam transverse sizes, σ_x and σ_y , are computed and reported in Figure 8.

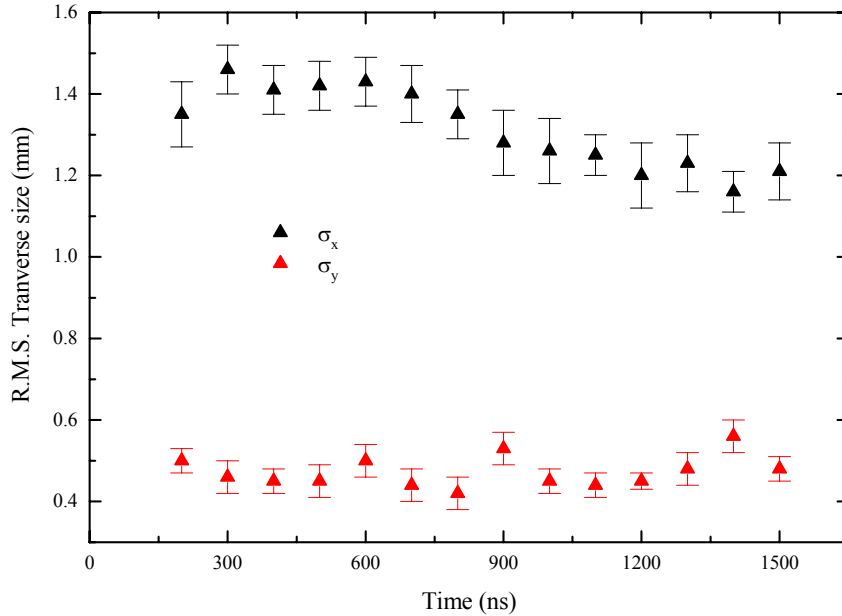


Figure 8. Temporal evolution of the transverse R.M.S. beam size within the pulse duration.

A reduction of the transverse size, σ_x , from 1.4mm to 1.2mm is measured between the beam head and the beam tail. The position of the beam centroid is also moving by some few hundred microns. Due to the lack of beam time, very few tests have been done in order to investigate the reasons of this observation. However two possible explanations can be mentioned. The first one would be due to a small reduction of the beam energy at the end of the pulse due to a capacitive drop of the gun high voltage platform. This would be correlated to a smaller beam size onto the screen when the beam is focused by the solenoid magnetic field. A second explanation of this focusing would come from the presence of positive ions released by the graphite screen when heated up by the beam. This effect is well known when using high charge density beams and has already been observed several times [8]. In our case, some simulations of this effect have already been performed and have indicated that a 10 to 20% beam size reduction can be expected. This result is within the range of what has been observed experimentally.

CONCLUSION

A beam imaging system has been developed and commissioned for the 140keV high charge beam produced in the CTF3 injector.

The P47 phosphor screen has shown its good efficiency to measure the 10-100 μ A from the triode dark current. However a sign of damage is already observed and illustrate the risk of using this type of screen on a high charge beam.

To our knowledge it is the first time that a beam imaging system for non relativistic particles is designed to operate using the forward OTR emission from a graphite foil. The results obtained so far with this screen are very encouraging, giving the possibility to obtain precise beam size measurements, which deliver helpful information to characterize the injector performance. Moreover, giving access to the time evolution of the transverse beam sizes, these OTR measurements provide a powerful way of studying the beam stability all along the pulse duration. However, few tests have been performed so far and to have conclusive results, more measurements will be done in the future.

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