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Spectrometry in the Test Beam Line at CTF3

E. Bravin; F. Carra; N. Chritin; A. Dabrowski; A. Dallocchio; S. Doebert; T. Lefèvre; *M. Olvegaard.

CERN – Geneva/CH
* University of Oslo-NO

Abstract

The CLIC study is based on the so-called two-beam acceleration concept and one of the main goals of the CLIC Test Facility 3 is to demonstrate the efficiency of the CLIC RF power production scheme. As part of this facility a Test Beam Line (TBL), presently under commissioning, is a small-scale version of a CLIC decelerator. To perform as expected the beam line must show efficient and stable RF power production over 16 consecutive decelerating structures. As the high intensity electron beam is decelerated its energy spread grows by up to 60 %. A novel segmented beam dump for time resolved energy measurements has been designed to match the requirements of the TBL. As a complement, a diffusive OTR screen is also installed in the same spectrometer line. The combination of these two devices will provide both a high spatial resolution measurement of both the energy and energy spread and a measurement with a few nanoseconds time response. This paper describes the design of the new segmented dump and presents the results from the first commissioning of the TBL spectrometer line.

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SPECTROMETRY IN THE TEST BEAM LINE AT CTF3

M. Olvegård*, E. Bravin, F. Carra, N. Chritin, A. Dabrowski, A. Dallocchio,
S. Doebert, and T. Lefèvre, CERN, Geneva, Switzerland, E. Adli, University of Oslo, Norway

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INTRODUCTION

The CLIC study (Compact Linear Collider) aims at a 3 TeV e^+e^- collider [1], based on a two-beam acceleration concept: A high intensity drive beam, decelerated in Power Extraction and Transfer Structures (PETS) generates the 12 GHz RF power needed to accelerate the main beam. The feasibility of this scheme is being addressed at the CLIC Text Facility (CTF3) [2] at CERN. CTF3 is approaching its final stage, which will include the commissioning of the Test Beam Line (TBL), a small-scale CLIC decelerator with 16 conseutive PETS. The study will focus on having a constant power production while maintaining the drive beam stable, with a minimum of particle losses [3, 4], and that requires dedicated diagnostics.

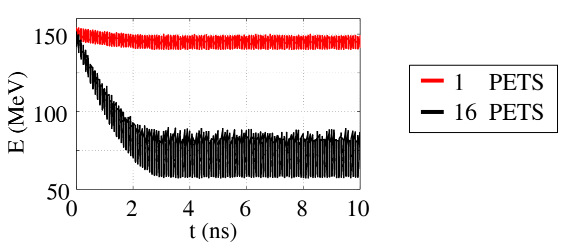

Figure 1: Energy as a function of time for the decelerated beam. The nominal pulse length is 140 ns. [3]

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Beam Parameters

CTF3 provides TBL with a high intensity (28 A during 140 ns) electron beam. Simulations with PLACET [5] predict that, as the beam propagates through the PETS and looses energy, its single-bunch energy spread grows significantly, as can be seen in Fig. 1 and Table 1. A first goal of the diagnostics in TBL is to study the consistency between RF power measurements and the energy lost by the beam. As a complement to a standard integrated energy measurement, a single-shot time resolved measurement is desirable, for a confirmation of the beam parameters along each beam pulse. At an early stage, the high risk of breakdowns in the decelerating structures is another fact that pushes for a single-shot device. The high energy transient, visible in Fig. 1, due to the full beam loading of the decelerating cavities, needs also to be detected through spectrometry.

Table 1: The Expected Beam Parameters in TBL[3, 4]

N^o of PETS #	**mean energy** $<E>$	**steady state** $\sigma_E/<E>$
1	144.9 MeV	1.04 %
4	129.7 MeV	1.4 %
8	109.5 MeV	2.2 %
16	68.8 MeV	5.8 %

SPECTROMETRY IN THE TBL

Fig. 2 shows a sketch of a diagnostics section in TBL. Just before the spectrometer magnet there is an OTR screen for the transverse beam profile and emittance measurement. It is used to varify the optics of the beam line and to set up an optimized measurement in the spectrometer line. A second OTR screen is located behind the magnet and provides a high spatial resolution ($\sim$100 μm) measurement of the integrated beam energy and energy spread. As a complement to that there is a device for time resolved energy measurement in the spectrometer line, namely the “segmented beam dump”. This paper introduces the spectrometry elements in TBL, with an emphasis on the final design of a new segmented dump for time resolved spectrometry in TBL.

SEGMENTED BEAM DUMP

A segmented dump works principally as a Faraday cup: incoming particles are stopped in a block of metal and the absorbed charge is measured. Through the horizontal segmentation the particle distribution can be reconstructed and

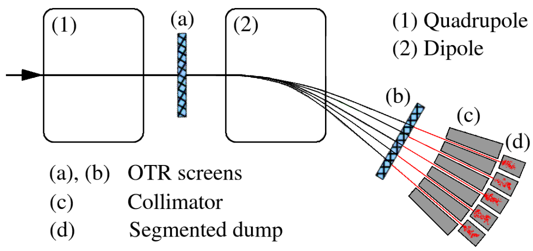

Figure 2: Sketch of a diagnostics section at TBL.

the energy spread of the beam determined within a single pulse. The sampling of the signal can be fast and hence be used as a time resolved spectrum.

There are already two operational segmented dumps at CTF3 [6], for a 3.5 A, 1.5 or 3 GHz beam of 20 MeV and 60 MeV beam, and the experience with these has been the starting point for the new design. The initial beam energy in TBL, the current and the bunch frequency is higher (150 MeV, 28 A, and up to 12 GHz [3]), and both dimensions and materials have been adapted to the new beam conditions, based on extensive simulations using the Monte Carlo code FLUKA [7]. A 150 MeV electron will generate a shower of secondary particles when interacting with matter. The size and the shape of this electromagnetic shower, which can be studied in detailed with FLUKA, depends on the medium and will set the limit for the amount of material needed to stop the particle. A first basic design, motivating the choice of material and dimensions, has been described in detail in [8].

Spatial Resolution

The spatial resolution of the new segmented dump has been optimized by the choice of tungsten as the segment material. In high Z materials as tungsten the cross talk between segments is reduced and the segments can be kept thin (3 mm) in the transverse direction. A collimator upstream from the segments (see Fig. 2) reduces the cross talk further by only allowing one beamlet to reach each of the in total 32 segments, through 400 μm slits.

By linking a beam distribution from PLACET, to a basic detector geometry in FLUKA, the performance of the detector has been studied. The signal, i.e. the net charge stopped in each individual segment, has been computed with FLUKA, and the reconstructed distribution has been compared with a reference PLACET distribution. Fig. 3 shows the result of such a simulation for the 16 PETS case. The particle distribution reconstructed from the segmented dump follows well the corresponding PLACET distribution, and the standard deviation is 1.97 cm and 1.89 cm respectively, an agreement within 5 %.

Thermal Considerations

The multi-slit collimator, made of tungsten, also serves the purpose of a thermal buffer, by absorbing a large fraction of the high intensity beam. The segments are thus protected from an excessive thermal load, but with the effect that the collimator will absorb up to 500 J/pulse, the spatial distribution of which is visible in Fig. 4 (a). Without cooling the resulting instantaneous temperature increase per pulse is up to 75 C° and therefore a water-cooling system has been designed. A Finite Element Method thermomechanical analysis was performed to study the temporal evolution of the thermal effects in the collimator, for 1 Hz and 5 Hz pulse repetition rate. As can be seen in Fig. 4 (b), the cooling system keeps the collimator safely below the melting temperature of tungsten, which is 3422 C°. With the cooling system it will be possible to avoid an unacceptable deformation of the collimator slits. The maximum horizontal displacement of a collimator "tooth" is estimated to $\sim$ 30 μm and the thermal expansion is in the same order of magnitude, for the worst case scenario. [9]

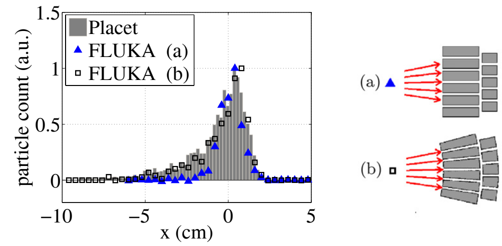

Figure 3: Simulations show clearly the advantage of a concentric geometry to the former parallel geometry. Note: angles strongly emphasized in the sketch.

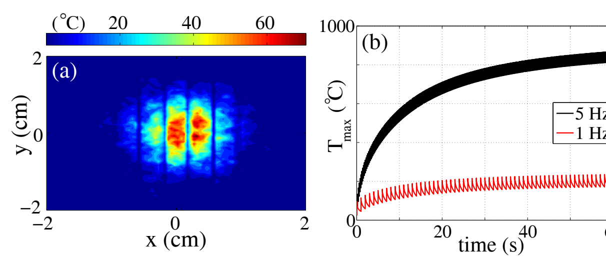

Figure 4: The tungsten collimator: (a) Transverse distribution of the maximum temperature increase per beam pulse; (b) the time evolution of the maximum temperature in the collimator, with cooling [9].

Geometry

The segmented dumps in the CTF3 linac have both collimators with parallel slits, which results in an uneven collimation due to the difference in angle of the incoming particles. Such a system underestimates the energy spread and requires a calibration procedure described in [10]. The new segmented dump overcomes this problem by using collimation through concentric slits, adapted to the divergence of the beam created in the dipole magnet.

Fig. 3 shows the two geometries, and the corresponding

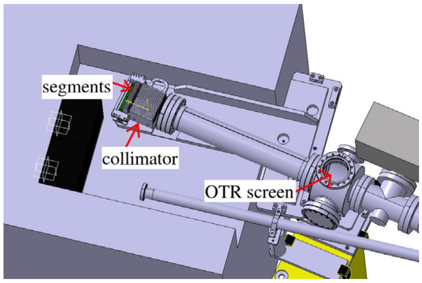

Figure 5: The TBL spectrometer line with the segmented dump as it will be installed inside the beam dump.

reconstructed distributions. The agreement with the reference beam from PLACET is much improved through the new geometry: a standard deviation of 1.97 cm (b), compared to 0.82 cm for the parallel geometry (a), and 1.89 cm for the reference beam.

Experimental Setup

Figure 5 shows the mechanical implementation of the segmented dump system inside the beam dump. Engineering drawings are under work and the manufacturing and installation is expected before the end of 2010. Visible in the same figure is also the tank of the spectrometer screen which contains: 1) a 50 μm thin carbon foil to stop synchrotron light generated in the magnet; 2) a 100 μm thick diffusive aluminum screen, with a parabolic shape to increase resolution [11]. The light emitted by the screen is imaged by a CCD camera, via an optical line. The spatial resolution of the screen is roughly 100 μm, mainly limited by the optics and the digitization of the camera image.

STATUS AND RESULTS

At present there is one PETS installed in the beam line and more are expected before the end of 2010. On the instrumentation side, there is a new system for monitoring the transverse profile. It consists of two OTR screens, for high and low intensity beams respectively, imaged by a CCD camera, and it is installed and ready for data taking. The OTR screen in the spectrometer line is already operational and behind it is a single-slit dump to perform time resolved spectrometry until the new segmented dump has been installed. The slit dump will then be transferred to the beginning of the beam line. In this way, there will be a comparable time resolved energy measurement before and after the deceleration of the beam.

Fig. 6 (a) shows the first beam spectrum acquired with the slit dump and the screen during the first days of TBL commissioning with a 12 GHz beam. The mean momentum 118.6 MeV/c from the screen agrees within 0.5 % with integrated momentum measurement from the slit dump at 119.1 MeV/c. However, the discrepancy between the momentum spread measurements (screen: 2.38 MeV/c; slit dump: 1.76 MeV/c) can only partially be explained by a difference in intrinsic beam size and divergence at the two locations. More detailed measurements and systematic studies of the OTR and slit dump resolution are therefore expected soon.

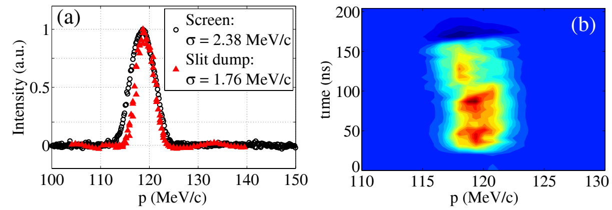

Figure 6: First beam spectrum in TBL. The average momentum spread along the pulse (a) and time resolved momentum measurement with a slit dump (b).

CONCLUSION

A new segmented dump has been designed particularly for the decelerated drive beam in TBL. This device, for which installation has been foreseen before the end of 2010, will be able to provide time resolved energy and energy spread measurement from pulse to pulse, with an up to 5 % accuracy.

Preliminary measurements, using an OTR screen and a slit dump, have already been made. Systematic measurements will be made in order to fully characterize all the spectrometer systems, as well as to study the beam optics.

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