TIME RESOLVED SPECTROMETRY ON THE TEST BEAM LINE AT CTF3

M. Olvegård, A. Dabrowski, T. Lefèvre and S. Doebert, CERN, Geneva, Switzerland
E. Adli, University of Oslo, Norway

Abstract

The CTF3 provides a high current (28 A) high frequency (12 GHz) electron beam, which is used to generate high power radiofrequency pulses at 12 GHz by decelerating the electrons in resonant structures. A Test Beam Line (TBL) is currently being built in order to prove the efficiency and the reliability of the RF power production with the lowest level of particle losses. As the beam propagates along the line, its energy spread grows up to 60%. For instrumentation, this unusual characteristic implies the development of new and innovative techniques. One of the most important tasks is to measure the beam energy spread with a fast time resolution. The detector must be able to detect the energy transient due to beam loading in the decelerating structures (nanosecond) but should also be capable to measure bunch-to-bunch fluctuations (12 GHz). This paper presents the design of the spectrometer line detectors.

CTF3 TEST BEAM LINE

CLIC Test Facility 3 (CTF3) [1] is an electron accelerator test facility at CERN, built by an international collaboration, in order to test CLIC technology [2]. The first part of the machine generates a high current beam (almost 30 A for 140 ns pulse length and bunched at 12GHz), which is transported to the CLic EXperimental area (CLEX). One of the CLIC crucial issues is the reliability and efficiency of the RF power production. This is addressed in CLEX in the Test Beam Line (TBL) [3]. Built in stages, with a first Power Extraction and Transfer Structure (PETS) module installed in 2009, the TBL will experimentally characterize the stability of the drive beam during the deceleration.

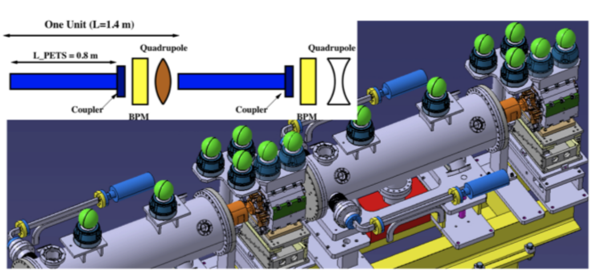

Figure 1: Schematic view of a typical TBL girder containing two PETS modules, 2 BPMs and 2 quadrupole magnets.

In its final form, the TBL will be composed of sixteen identical modules. Each module will consist of a 0.8 m PETS with a coupler, a beam position monitor (BPM) and a quadrupole on a precision movable support, see Fig. 1. The 28 A beam from CTF3 is decelerated by about 5 MeV in each PETS, producing about 150 MW of 12 GHz power. Due to transient effects during the filling time of the PETS, the first 3 ns of the bunch train will have a huge energy spread from the initial energy down to the final energy of the decelerated beam, see Fig. 2. Time-resolved spectrometry is therefore an essential beam diagnostics tool in order to measure the beam energy spectrum after deceleration.

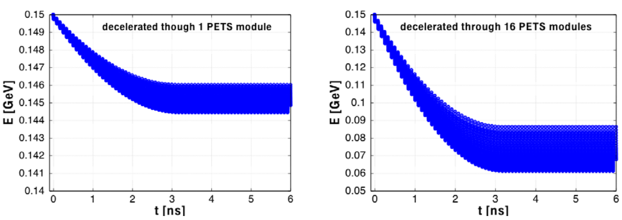

Figure 2: Time resolved energy distribution of decelerated beam after 1 PETS module (left) and 16 PETS modules (right), for the first 6 ns of the 140 ns pulse train.

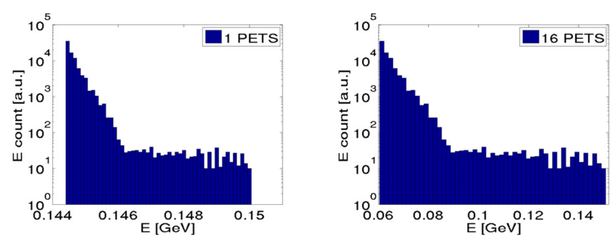

Figure 3: Histogram of the final energy distribution of a 140 ns pulse train after deceleration through 1 PETS module (left) and 16 PETS modules (right).

This paper presents the time resolved spectrometer design for the TBL.

TIME RESOLVED SPECTROMETRY

The spectrometer under design (see Fig. 4), will consist of a bending magnet, which provides an energy dependent horizontal deflection to the electrons, followed by an optical transition radiation (OTR) screen [4] observed by a CCD camera to provide a high spatial resolution profile measurement and then lastly a novel segmented beam dump for the time resolved energy measurement.

The segmented dump is a device composed of parallel metallic plates designed to stop the incident particles. By measuring the deposited charge in each segment, the beam profile can be reconstructed. The material and the dimension of the segments must be optimized depending on the beam parameters, in particular the energy and the expected energy spread. The segments need to be long enough to stop the primary particles. On the other hand the segment thickness must be chosen to optimize the

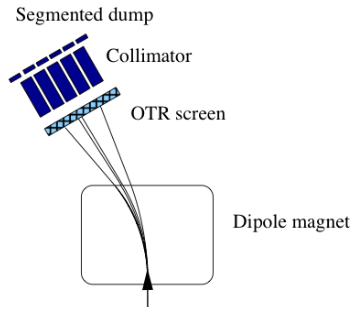

Figure 4: Schematic of the layout of the spectrometer.

spatial resolution, which will suffer from a smearing due to multiple scattering. Moreover, because of the high power carried by the beam, thermal changes must be considered as a crucial issue, as well as radiation effects that will influence the long-term response of the detector.

DESIGN OF SEGMENTED DUMP FOR THE TEST BEAM LINE

The detector design presented here is based on a design of an installed and operational segmented dump at CTF3 [5], but adapted to the unique beam conditions at the TBL. Simulations using the monte-carlo code FLUKA [6] was used in order to optimise the design parameters, based on beam energy with a range of 50 MeV to 150 MeV and on the thermal constraints linked to the high charge beam. Given the thermal constraints the design of the detector will consist of two parts, the first being the design of the active segments, and the second being the design of the upstream collimator, designed to absorb 90% of the full beam power. Since the effects of multiple scattering and the thermal effects of energy deposition are most significant for the higher beam energy, an initial FLUKA study was performed using a 150 MeV electron beam, incident on tungsten. Simulations were performed here assuming an infinitely small beam size.

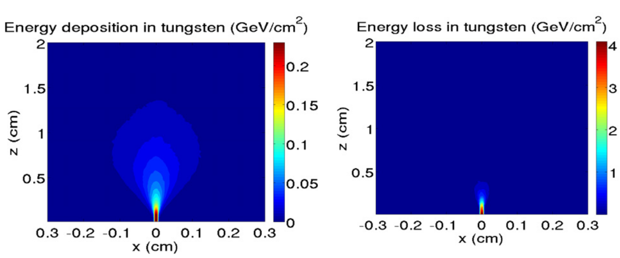

Figure 5: Total energy deposition (left) and energy loss by primary electrons (right) in a tungsten block.

As shown in Fig. 5, the total energy deposited in the material, by both the primary electrons and the secondary particles and photons, was calculated as a function of the longitudinal coordinate z and the transverse coordinate x. In addition, the energy loss by the primary electrons was also scored, as shown on the neighbouring plot. Tungsten was chosen because of its relatively high melting point, and high Z number, thus able to stop the electron beam within a relatively short distance, in order to make the detector as compact as possible. The distributions in Fig. 5 are projected in the longitudinal direction in order to estimate respectively the longitudinal distance needed to stop the primary electrons and also the corresponding EM shower. As shown in Fig. 6 and Table 1, after 1.48 cm, 99.9% of the primary 150 MeV electrons have been stopped in tungsten. The absorption of the full electromagnetic shower takes more material, due to the combination of photons and electrons/positrons in the secondary shower. From Table 2, a 10 cm of tungsten will absorb more than 99.9% of the beam power, and hence is chosen as the dimension of the tungsten segments.

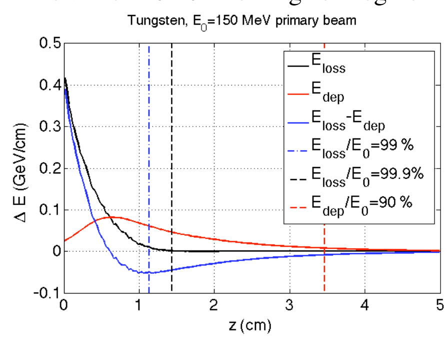

Figure 6: Longitudinal distribution of the energy loss of primary electrons (black) and the energy deposition (red) due to both primary electrons and the secondary shower.

Table 1: Longitudinal depth in cm corresponding to a particular fraction of energy loss by the primary electrons.

Material	Energy (MeV)	Distance fractional energy loss (cm)		
		70%	99%	99.9%
Tungsten	150	0.40	1.14	1.48
Tungsten	100	0.38	1.02	1.30
Tungsten	50	0.31	0.75	0.93
Graphite	150	14.09	30.72	35.79
Iridium	150	1.73	4.68	5.88
Iron	150	0.34	0.96	1.26

Table 2: Longitudinal depth to absorb a certain fraction of the total beam energy.

Material	Energy (MeV)	Distance of fractional total energy deposition (cm)		
		70%	99%	99.9%
Tungsten	150	1.73	5.88	8.78
Tungsten	100	1.53	5.68	8.58
Tungsten	50	1.13	5.23	8.13

The width of the dump segments is optimized based on multiple scattering of the primary electrons, and the transverse resolution needs of the measurement. As shown in Fig. 7, multiple scattering will contribute to a widening of the transverse distribution of the other of tens of microns. Table 3, 90% of the shower is contained within 1.6 mm of tungsten for 150 MeV electrons.

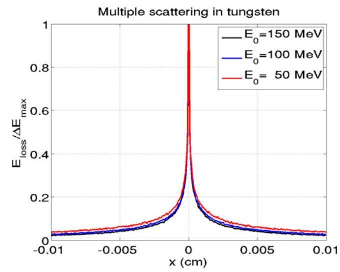

Figure 7: The effect of multiple scattering on the transverse position of the stopped primary electrons.

Table 3: Effect of multiple scattering on the transverse distribution of stopped primary electrons for different materials and beam energies.

Material	Energy (MeV)	Transverse width shower (cm)	
		90% e- stopped	99% e- stopped
Tungsten	150	0.16	0.57
Tungsten	100	0.21	0.64
Tungsten	50	0.27	0.68

Table 4: Summary of detector dimensions.

Parameter	Dimension
Tungsten collimator depth	10 cm
Tungsten collimator slit width	400 μm
Tungsten segment depth	2.0 cm
Tungsten segment width	3 mm

DESIGN OF THE TBL SPECTROMETER

From the energy distribution of the decelerated beam, as shown in Fig. 3, the resulting transverse distribution, down stream from the dipole magnet is calculated. The resulting distribution depends on the choice of the magnetic field in the dipole and the spectrometer drift length. An optimal layout is still to be finalised, but typical transverse distributions are given in Fig. 8.

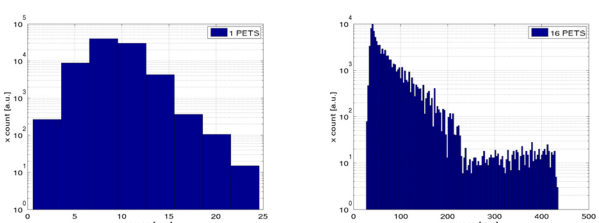

Figure 8: Typical transverse beam distributions downstream of the spectrometer dipole magnet for a beam of 1 PETS and 16 PETS, and the same dipole field.

The total energy deposition, in the realistic system has been studied as depicted in Fig. 9. The increase in temperature and the cumulative radioactive dose can be calculated from these values.

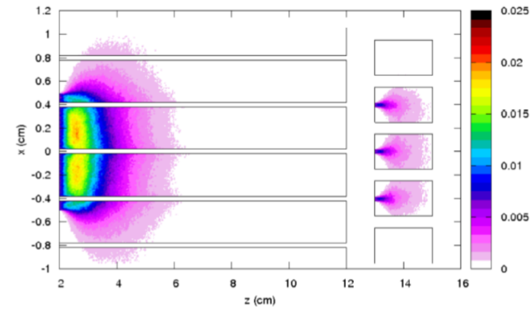

Figure 9: Energy deposition in the detector of a 150 MeV e- beam, given the final geometry of the collimator and active segments with dimensions as listed in Table 4.

CONCLUSIONS AND PERSPECTIVES

The main segmented dump design parameters have been identified for the time resolved energy measurement for the CTF3 TBL spectrometer. The design is based on an upstream collimator absorbing 90% of the beam power and a downstream active segmented dump with 3 mm wide segmentation. The mechanical design of the Dump will start soon and will be based on the temperature and radiation dose constraints estimated here. More simulations will be done in the future in order to quantify the impact of secondary particles on the measured charge.

ACKNOWLEDGEMENTS

Supported by the EU under contract PITN-GA-2008-215080.

REFERENCES

[1] G. Geschonke and A. Ghigo Eds, “CTF3 Design Report”, CERN/PS 2002-008 (RF).
[2] G. Guignard (Ed.), “A 3 TeV e+e- linear collider based on CLIC technology”, CERN 2000-008, 2000.
[3] S. Döbert, G. Rumolo, D. Schulte, I. Syratchev, D. Carrillo, “Progress on the CTF3 Test Beam”, LinProc. EPAC’06 and CLIC note 690, 2006.
[4] C. Welsh *et al.*, “Optimization of OTR screen surface” Review Advanced Material Science. 16 (2007) 73-79.
[5] T. Lefèvre *et al.*, “Segmented Beam Dump for Time resolved Spectrometry on a High Current Electron Beam”, DIPAC’07, Italy.
[6] "The FLUKA code: Description and benchmarking" G. Battistoni, S. Muraro, P.R. Sala, F. Cerutti, A. Ferrari, S. Roesler, A. Fasso`, J. Ranft, Proceedings of the Hadronic Shower Simulation Workshop 2006, Fermilab 6--8 September 2006, M. Albrow, R. Raja eds., AIP Conference Proceeding 896, 31-49, (2007).