BEAM LOSS MONITORING AT THE CLIC TEST FACILITY 3

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Abstract

With its 4kW average beam power, the CLIC test facility 3 (CTF3) is a machine where the control of beam losses is an important issue. Beam losses must be monitored all along the linac in order to keep the radiation level and the activation as low as possible. The Beam Loss Monitor (BLM) system currently under development is described. The goal of our effort is to provide quantitative beam loss measurements. An intensive simulation work has been carried out in order to estimate the e^+ - e^- showers in a realistic accelerator environment. Based on these results, we investigate two scenarios to measure beam losses using a set of 48 detectors distributed along the machine.

INTRODUCTION

With the development of high intensity accelerator, the control of beam losses becomes a crucial issue. The beam loss monitoring system is a key component of the machine protection system, where a high level of reliability is required to ensure the safe operation of the facility [1]. At CERN, the Compact Linear Collider (CLIC) [2] study enters a new phase with the construction of the third test facility, named CTF3 [3]. As a prototype of the CLIC Drive Beam, CTF3 is built with the aim of demonstrating the feasibility of the project.

Northwestern University, as a member of the CTF3 collaboration [4], develops the beam loss monitoring system for the linac. The linac, providing a 3.5A, 1.5µs electron beam pulse of 150MeV, is scheduled for completion by the end of 2004. The BLM system must be able to detect losses corresponding to the ‰ of the nominal beam current, which can not be measured accurately by other means. As a first step of the study, a set of simulations using Geant3.21 were initiated in July 2003. The results of this analysis were summarised in a note [5] and provides a useful base for the definition of the requirements for the detector technology to be adopted. In parallel to the simulations a preliminary test of beam loss monitoring was performed in November 2003 [6] on the already existing part of the accelerator. Due to the heavy beam loading in the accelerating structures, any beam current variations along the pulse lead to transient effects which create energy dispersion. During the test, important transient effects in the first 50 nanoseconds of the beam pulse were observed, indicating that the detector need to have a fast time response in order to correlate beam losses during the pulse.

An overview of the system to be installed in 2004 is presented in this paper, particularly the detector and the acquisition system. A more sophisticated study has also been performed, based on Geant3.21 simulations. Since the number of detectors and the detector size are already known, we assume two different scenarios where the detectors are positioned in a different manner around the machine. The performances of these two cases are compared with the aim of delivering both the intensity and the position of the beam loss along the machine.

OVERVIEW OF THE BLM SYSTEM

The CTF3 linac is based on accelerating modules which are composed of a beam position and intensity monitor followed by a set of three quadrupoles and two 3 GHz accelerating cavities. Each module is 4m long and there are a total of 9 consecutives modules along the linac. It was decided based on initial simulations and cost considerations to build a system with 4 detectors per module. The layout of a linac module equipped with beam loss monitors is shown in Figure 1.

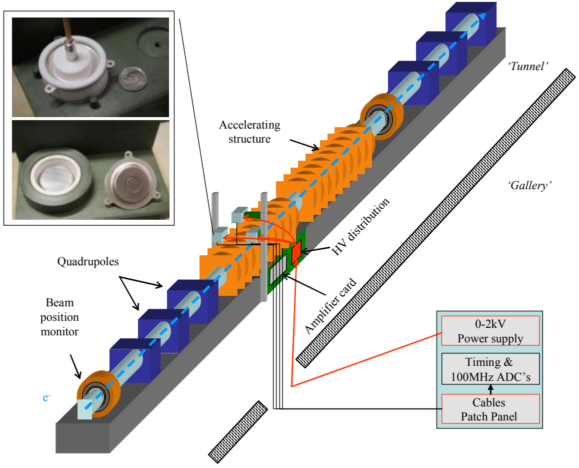

Figure 1: Layout of the beam loss system in a CTF3 linac module

The detector is a small chamber sensitive to charged particles and developed by Northwestern University, Fermilab and Richardson Electronics. It offer both a very good resistance to radiation and a high dynamic range (>10^5). Next tests aim at comparing the different types of chambers; either filled with helium and used as an ionization chamber, or just under vacuum and used as a Secondary Electron Monitor chamber (SEM). The choice would be based on the compromise between the time resolution, which is faster for the SEM mode, and the sensitivity, which is 1000 higher for the ionization mode. The output signal is amplified near the detector itself. Data acquisition, based on 50MHz ADC's is performed in a gallery, located just above the accelerator tunnel. In total 48 signals are sampled in order to provide a mapping of the beam losses along the accelerator. The mechanical support for the detectors allows an easy modifications of their longitudinal (z) and transverse (ϕ) positions depending on the experimental needs.

SIMULATIONS USING GEANT3.21

The Geant simulations of the CTF3 Drive Beam accelerator used an idealized geometry that describes the general shape and composition of the accelerator components but does not represent structural details. Due to multiple scattering and the nature of the measurement, a more detailed geometrical representation is not required for this study.

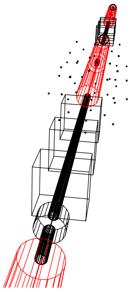

Figure 2: Geometry simulated by Geant3.21

The simulations are carried out in order to investigate the performances of our system in localizing a loss within a single module. The beam loss is on its longitudinal position along the accelerator and its azimuthal position. A beam loss occurring at ϕ=90° is simulated every 10cm in z along the entire length of one of the accelerator modules. The beam energy was chosen to be 50MeV which is an intermediate energy for the CTF3 beam (24 - 150MeV).

Two possible layouts for the detectors are considered in these simulations. Each design employs 4 detectors per module. In the first design all the detectors are placed at a single z position and different ϕ positions, while in the second, the detectors are placed at the same ϕ position but different z positions along the module. Both cases placed the detectors at a radial distance of 30cm from the beam line. The detection method is not specified here. The only assumption made is that the detectors are circular with a sensitive surface of 1cm^2. These are the same characteristics as the detectors proposed for this system.

Case 1: 4 detectors at different ϕ positions

The fluxes of charged particles passing through each detector are shown in Figure 3. One can see that it is difficult to determine the z position even if the intensity is known. The drop in observed flux after 50cm is caused by the absorption of the beam loss shower by the first accelerating structure. The signal produced in the first accelerating structure is nearly indistinguishable from the signal produced before the second quadrupole. The ϕ position (90°) may be discernible in this arrangement but both the beam loss intensity and position are correlated and thus very difficult to determine. However this layout can provide useful information for beam tuning in a configuration where the position of the beam loss is easily predictable. On the CTF3 linac, the beam optics are set in such a way that beam losses would happen more likely near the central quadrupole. One option could be to install a set of detectors in this region.

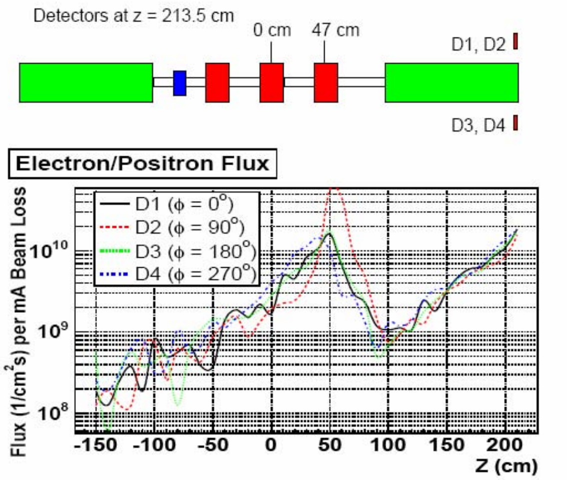

Figure 3: Electrons/Positrons flux versus the longitudinal position of the beam loss. Each curve corresponds to the output signal amplitude of each of the 4 detectors located at different ϕ positions.

Case 2: 4 detector at different Z positions

The results for the second design are shown in Figure 4. In this case, there is no possibility to discern the ϕ position of the loss. But this detector arrangement is superior in determining the z position by looking at the relative amplitude difference between the four signals. Knowing the position, the beam loss intensity can be then estimated by looking at the signal amplitudes.

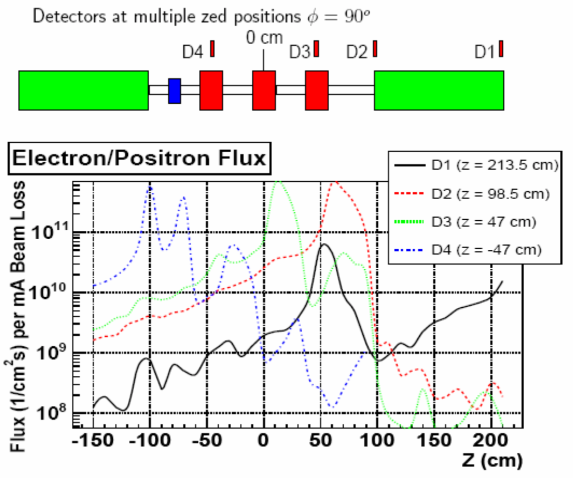

Figure 4: Electrons/Positrons flux versus the longitudinal position of the beam loss. Each curve corresponds to the output signal amplitude of each of the 4 detectors located at different z positions

Evolution along the Linac

Given the small size of the detectors used in the system, it is important to consider the effect of the transverse flux distribution on the accuracy of the measurements. To illustrate this point, Figure 5 shows the flux distribution in the X/Y plane at 100cm from a point of a beam loss.

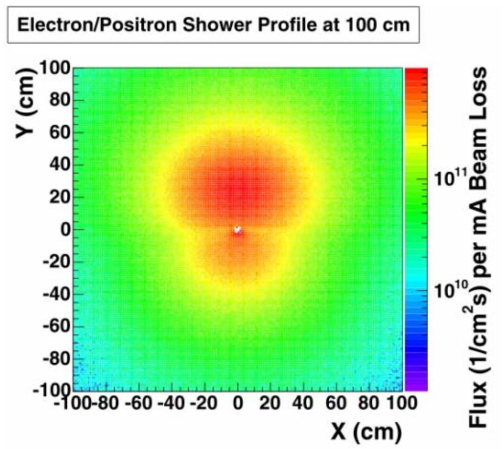

Figure 5: Electrons / Positrons flux distribution at 100cm from the point of the beam loss in the X/Y plane transverse to the beam line.

This simulation was run with only the accelerator beam pipe to demonstrate the effect more clearly. The secondary fluxes are not symmetrically distributed around the beam pipe but rather concentrated along the axis of the beam loss. The effect of the shower asymmetry becomes more pronounced at higher beam energies as can be seen in Figure 6. At 25MeV, the effect is only 25% but at 1GeV the effect produces almost an order of magnitude difference between the fluxes measured on either side of the beam pipe.

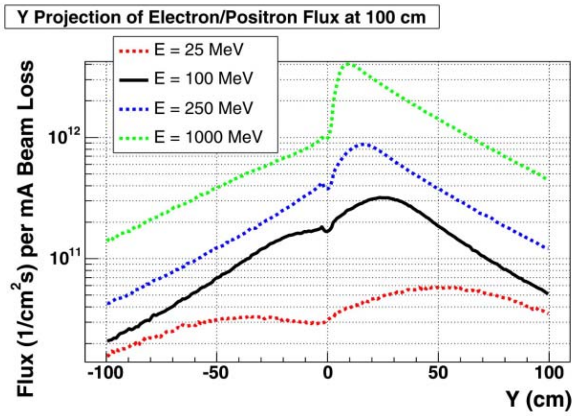

Figure 6: Y projection of the e$^+$-e$^-$ flux at 100cm from the point of the beam loss. Each curve corresponds to various beam energies from 25MeV to 1GeV.

The accuracy of a system that relies on detectors at a single ϕ position (Case 2) may thus be inherently limited by this azimuthal asymmetry. This effect can also have a non negligible impact for a system based on Case 1, especially for high energy particles if the shower transverse size becomes small compared to the detector size and the distance between detectors.

CONCLUSION AND PERSPECTIVES

A beam loss monitoring system is under development on the CLIC Test Facility 3 linac. It relies on fast detectors and a 50MHz acquisition system to study the time evolution of the beam losses during the 1.5μs of the pulse duration. The sensitive surface of the detector is 1cm^2. A total of 48 BLM's, 4 detectors per linac module, will be installed in the CTF3 linac by the end of the year.

Beam loss simulations in a linac module (4m long) have been carried out using Geant3.21. Two layouts with a different positioning of the 4 detectors have been considered and compared with the aim of determining the intensity and the position of the beam loss. The first one considers 4 detectors at the same longitudinal position (z) but different transverse positions while the second system has 4 detectors at different z positions but same transverse position.

The relative amplitudes of the detector output signals in case 2 are very sensitive to the z position of the beam loss and should provide a much better method of beam loss measurement overall. On the other hand the transverse flux distribution of the e$^+$/e$^-$ shower cannot be ignored. Especially in the case of higher energy beams, the azimuthal asymmetry can lead to large inaccuracies in the beam loss intensity measurements.

An obvious solution would be to have the full azimuthally coverage at different z positions. In our design, the cost of the system is dominated by the price of the cables and the ADC's. A cost efficient improvement could be to install more chambers and add the signals from all the detectors at a single z. The cabling, the amplifier electronic and the acquisition system are kept the same.

ACKNOWLEDGMENT

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