BLM CROSSTALK STUDIES ON THE CLIC TWO-BEAM MODULE

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Abstract

The Compact Linear Collider (CLIC) is a proposal for a future linear e^+-e^- collider that can reach 3 TeV center of mass energy. It is based on a two-beam acceleration scheme, with two accelerators operating in parallel. One of the main elements of CLIC is a 2 m long two-beam module where power from a high intensity, low energy drive beam is extracted through Power Extraction and Transfer Structures (PETS) and transferred as RF power for the acceleration of the low intensity, high energy main beam. One of the potential limitations for a Beam Loss Monitoring (BLM) system in a two-beam accelerator is so-called "crosstalk", i.e signals generated by losses in one beam, but detected by a monitor protecting the other beam. This contribution presents results from comprehensive studies into crosstalk that have been performed on a two-beam module in the CLIC Test Facility (CTF3) at CERN.

INTRODUCTION

The CLIC [1] is a proposal for an electron/positron collider where particles will be boosted to energies up to 1.5 TeV. The required accelerating gradient (100 MV/m) can be achieved via a novel two beam acceleration scheme. RF power from a high intensity (~100 A), low energy (2.37 GeV) Drive Beam (DB) is extracted via Power Extraction and Transfer Structures (PETS), and transferred through a waveguide system to supply the high gradient RF cavities of the high energy, low current (~1 A) Main Beam (MB). The principal constituent of the CLIC linacs is a 2 m long module (the Two Beam Module, TBM), which is a combination of accelerating structures, quadrupoles and PETS. Five different types of TBMs are sufficient for the manufacture of the main CLIC accelerating complex. The simultaneous operation of two parallel accelerators can be challenging for the design of a Beam Loss Monitoring (BLM) system. Losses from one beam line can be detected by the BLMs protecting the other one, reducing the capability of estimating the origin of the losses. This phenomenon is known as crosstalk. In the CLIC Conceptual Design Report the proposed beam loss monitoring system for machine protection is based on ionisation chambers, since they satisfy the requirements in terms of sensitivity and dynamic range. Distributed detectors, such as optical fibres, are also under investigation for their ability to cover the full beam line, preventing potentially dangerous beam losses from going undetected. The present work summarises BLM crosstalk measurements for two different detectors, Little Ionisation Chambers (LICs) and optical fibre BLMs (OBLMs), performed at the prototype TBM hosted at CTF3.

TWO BEAM MODULE LAYOUT AT CTF3

The CTF3 complex at CERN was constructed with the aim of studying the feasibility of the CLIC two-beam technology. CALIFES (Concept d'Accélérateur Linéaire pour Faisceau d'Electron Sonde) is a 26 m electron linac with a Cs_2Te photoinjector pulsed by a UV laser. It provides a flexible electron beam with a bunch charge in the range of 0.05 - 0.6 nC and energy up to 200 MeV with a 1.5 GHz bunching frequency. CALIFES aims to mimic the CLIC main beam [2]. To examine the feasibility of the high current beam production and transport, a scaled version of the CLIC Drive Beam providing an electron beam of up to 28 A with a maximum energy of 120 MeV has been built [3].

The first CLIC Two Beam Module prototype was installed in CTF3 in May 2015. It comprises two PETS and two quadrupoles on the Drive Beam side, four accelerating structures (ACS) on the Main Beam, and instrumentation including one Beam Position Monitor (BPM) for each beam and two wakefield monitors on the main beam.

To study the crosstalk of the BLMs at the CTF3 TBM, four LICs and two optical fibres were installed on both sides of the TBM.

THE BLM EXPERIMENTAL SETUP

The LICs installed at the TBM are cylindrical ionisation chambers, with a diameter of 9 cm and a length of 18 cm. They consist of three circular, parallel plate, Al electrodes separated by 0.5 cm and are filled with N_2 at a pressure of 0.4 bar. Four detectors were used to cover the module. Two of them where installed on the main beam, approximately 5 cm downstream of the TBM accelerating structures, and two on the drive beam, around 10 cm downstream of the quadrupoles.

The OBLM systems consist of an optical fibre coupled to a photosensor. High energy particles generated by beam losses produce Cherenkov light in the optical fibre. These photons propagate in the fibre and are detected by the photosensor, giving information on the intensity of the loss and, if the timing is taken into consideration, also its original location [4]. Two high-OH, pure silica optical fibres from Thorlabs [5] were installed, approximately 15 cm above each beam line. On the Main Beam side, the fibre covers both the TBM and a 4 m upstream segment, while on the Drive Beam side the optical fibre extends over the TBM but only

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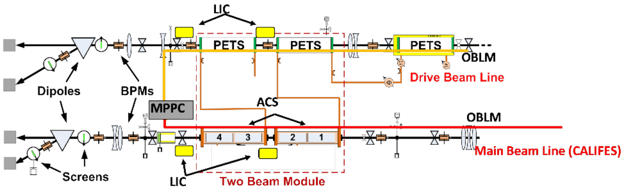

Figure 1: Layout of the BLM installation on the TBM in CTF3 (modified from [2]).

1.5 m upstream. The fibres are located towards the upstream of the TBM to include important elements of the two beam lines (a PETS at the drive beam and an optical transition radiation screen at the main beam). The characteristics of the two optical fibres are summarised in Table 1. In order to achieve higher sensitivity at the low current CALIFES beam line, a fibre of larger diameter (365 nm) than the one of the drive beam was selected. The optical readout consists of a Hamamatsu 14400-pixel Multi-Pixel Photon Counter (MPPC) S12572-25C [6], connected to an AC coupled circuit based on a 50 Ohm resistor and a 100 nF capacitor. In Fig. 1 the schematic layout of the TBM and the BLMs installed is illustrated. Fig. 2 shows the installation of the fibres and the LICs on the main beam. To shield the electronics from RF noise, custom made modules that contain the MPPC readout and a low-pass filter for high frequency noise filtering at the high voltage input have been designed. The modules are mounted in an RF shielded crate with a dedicated back plane for the voltage and ground distribution. The crate is located downstream of the TBM on the main beam side, and only the downstream signal of the optical fibers was acquired. The data acquisition of all BLMs is performed via a 12-bit 100 MS/s SIS-330x ADC card controlled via a VME crate. The schematic layout of the OBLM acquisition electronics is presented in Fig. 3.

Table 1: Optical Fibre BLM

	Main Beam	Drive Beam
Length (m)	7	5
core diameter (μm)	365	200
clad diameter (μm)	400	240
NA(numerical aperture)	0.22	0.22

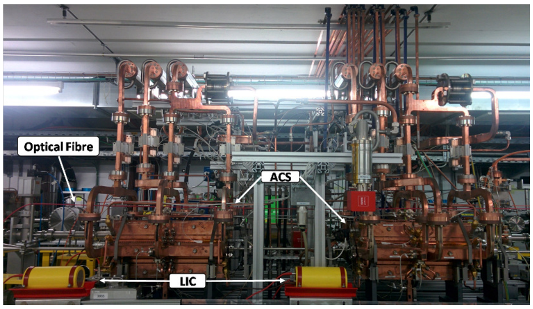

Figure 2: Installation of BLMs at the TBM Main Beam.

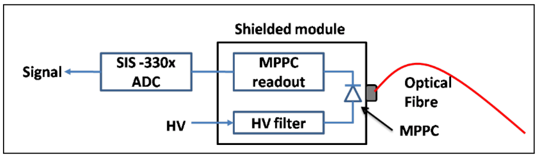

Figure 3: Schematic layout of the OBLM acquisition electronics.

CROSSTALK MEASUREMENTS WITH CALIFES

Beam loss measurements were performed while increasing the beam charge at CALIFES from 0.7 nC (10 bunches) to 11.4 nC (200 bunches), as measured by the beam charge monitor after the electron gun. A set of 100 shots were acquired for each setting. The sum signal from the BPM positioned just upstream of the TBM was used for measuring the relative beam charge on a shot to shot basis.

Califes Normal Operation

For the beam charges observed during this experiment the ionisation chambers did not monitor any losses. The sensitivity limitation is a consequence of the 12-bit resolution of the ADC cards, since these chambers have demonstrated charge measurements down to a few pA. Both drive beam and main beam optical fibre BLMs were sensitive to the losses from the CALIFES beam. The mean signal of the Main Beam optical fibre BLM in the case of a 160 bunch train is presented in Figure 4. The first, low peak can be explained as the contribution of the dark current from the CALIFES electron gun whereas the large peak is induced from beam losses. The detected charge Q was calculated via

$$Q = \frac{1}{R_L} \int_{t_0}^{t_1} V(t)dt \qquad (1)$$

where $R_L = 50\,\Omega$ is the measuring load, V(t) the BLM signal and $(t_0, t_1) = (1588.5, 1718.8)$ the integration limits that include only the beam loss signal. Fig. 5 summarizes the BLM detected charge versus CALIFES beam charge, for the two fibres over the TBM. In Fig. 6 the crosstalk of main to

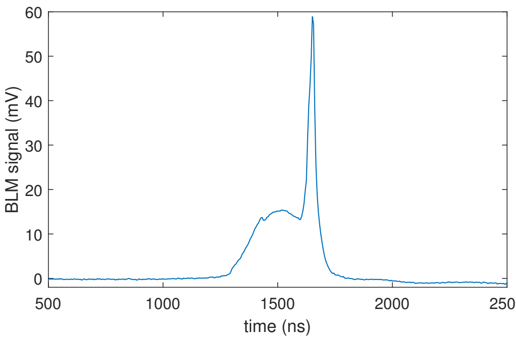

Figure 4: Signal of CALIFES beam losses from the Main Beam optical fire BLM.

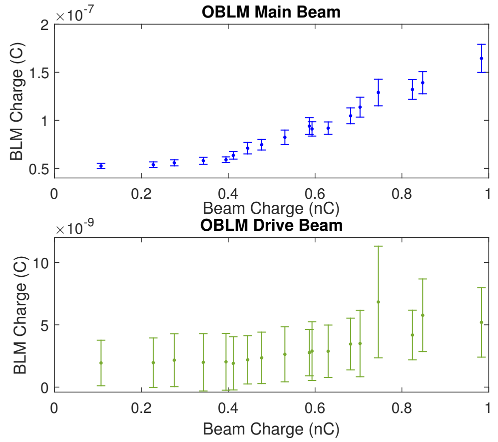

Figure 5: Charge generated in the Main (top) and Drive (bottom) Beam BLMs during CALIFES operation.

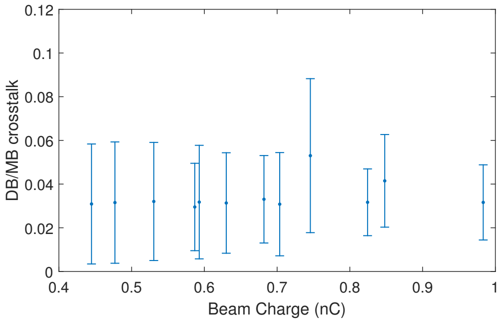

Figure 6: Crosstalk of Main to Drive Beam as measured by the oBLM system.

drive beam has been defined as

$$c_{MB} = \frac{Q_{DB}}{Q_{MB}} \tag{2}$$

where Q_{DB} and Q_{MB} are the total charges detected by the drive and the main beam optical fibres respectively. For the given beam and optics settings, the crosstalk signal on the drive beam OBLM was found to be independent of the beam current and ranges from 3 % to 5.5 % of the main beam OBLM signal, with a mean value of 3.4 %.

Loss scenario with Califes

The measurements were repeated for the case in which an optical transition radiation (OTR) screen [7], located approximately 3 m upstream the TBM, was intercepting the beam. In this case losses were detected by all BLMs. The signals of the main beam optical fibre BLM indicate saturation of the photodetector. As a result, in this case the crosstalk was only computed using the LIC detectors. The calculation was performed via Eq. 3 where Q_{DB} and Q_{MB} were the charges collected from the detectors with the largest signal on the drive and main beam respectively, namely the upstream LICs. Fig. 7 shows the signals of the two fibres and the two upstream LICs for several beam intensities. The signals of the upstream main beam ionisation chamber, presented on the right side of Fig. 7, show a very large peak exceeding 200 mV for high beam current (200 bunches). This indicates the generation of significant losses. On the drive beam side, the peak LIC signals are lower than 1 mV and barely exceed the noise level. For the estimation of the

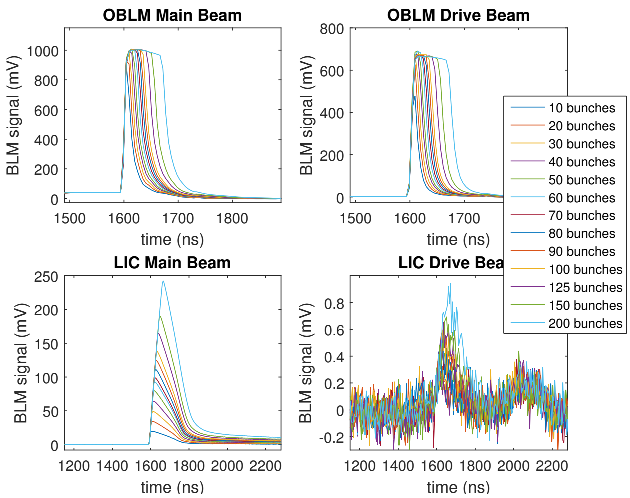

Figure 7: BLM signal after OTR screen insertion to CALIFES.

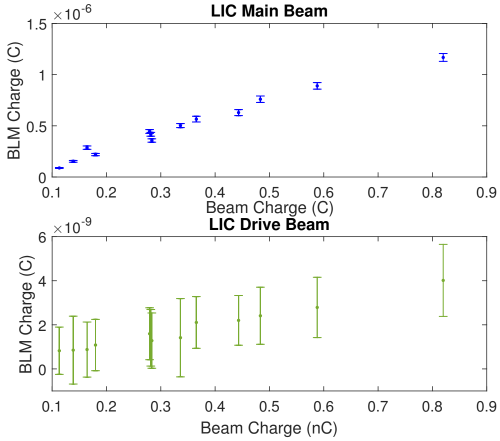

Figure 8: Signal of Main Beam and Drive Beam LIC after OTR screen insertion to CALIFES.

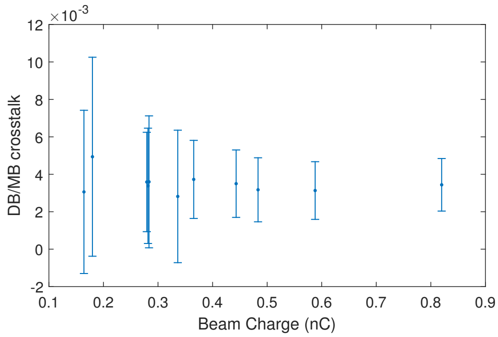

Figure 9: Crosstalk of the Main Beam to Drive Beam LIC after OTR screen insertion into the CALIFES.

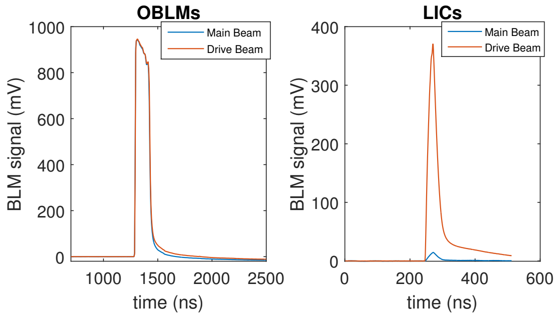

Figure 10: BLM signal induced by drive beam.

charge collected in the LIC, Eq. 1 was used with integration limits (t_0, t_1) = (1588.5, 1822.9) for both detectors.

The BLM signals for losses induced with different beam intensities are summarised in Fig. 8, increasing as expected with higher beam charge. The main beam crosstalk to the drive beam, calculated from Equation 3, is presented in Fig. 9 and is in all cases lower than 0.6 %.

CROSSTALK MEASUREMENTS WITH THE DRIVE BEAM

For the study of the drive beam crosstalk signal to the main beam BLMs a set of 100 shots was acquired with the drive beam on and CALIFES off. The mean beam current, as measured using the BPM located before the TBM, was 1.12 A. During the data-taking, the beam transmission was not ideal and the losses measured by the BLMs were significant. Fig. 10 shows the mean BLM signals for the examined detectors. In both OBLMs the photosensors are clearly saturated, hence no conclusion on the crosstalk for OBLMs can be drawn. The upstream LICs showed the highest signals and were used for the crosstalk estimation. The charge collected by the detector was estimated via Eq. 1, using integration limits that contain only the main peak, in particular (t_0, t_1) = (1276, 1568) for the drive and (t_0, t_1) = (1276, 1536) for the main beam.The crosstalk of the drive beam to main beam ionisation chambers can be calculated from

$$c_{DB} = \frac{Q_{MB}}{Q_{DB}} \tag{3}$$

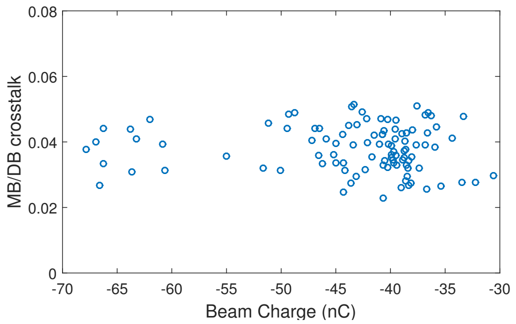

Figure 11: Crosstalk of the Drive Beam to Main Beam.

and the results are illustrated in Fig 11. For the given drive beam settings the crosstalk to the main beam detectors ranges from 2 to 5 % with a mean value of 3.68 %.

CONCLUSIONS

The observations of crosstalk in the CTF3 TBM may be one of the main limitations of a future CLIC BLM system. In this contribution we have presented the first set of measurements performed at the first prototype TBM. The main beam to drive beam crosstalk and vice-versa have been studied independently and estimated at 1 - 5 %. Previous simulations presented at the CLIC Conceptual Design Report have shown that a destructive loss (1 % of the beam) at the beginning of the drive beam (i.e. at 2.4 GeV) would generate a signal similar to those produced by a destructive loss (0.01 %) at the end of the main beam (1.5 TeV). However, note that the measurements presented here correspond to significantly different beam conditions in terms of energy and current with respect to the nominal CLIC values. Hence dedicated simulation would need to be performed to draw conclusions. The final crosstalk achieved in a future CLIC will be a combination of loss location, geometry and bunch structure. Nevertheless it is not expected to be significantly lower than the 1 % level.

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