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BEAM LOSS LOCALISATION WITH A OPTICAL BEAM LOSS MONITOR IN THE CLEAR FACILITY AT CERN

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Abstract

A prototype of a Beam Loss Monitor based on the detection of Cherenkov light in optical fibres is being developed to measure beam losses in the CERN Super Proton Synchrotron. Several testing campaigns have been planned to benchmark the simulations of the system and test the electronics in the CLEAR facility at CERN. During the first campaigns, the emission of Cherenkov light inside optical fibres and the photodetector characterisation were studied. Fibre-based Beam Loss monitors continuously monitor beam losses over long distances. The localisation of the beam loss could be calculated from the timing of the signals generated by the photosensors coupled at both ends of the optical fibre. The experimental results of an optical fibre Beam Loss Monitor installed in the CLEAR facility are reported in this paper.

INTRODUCTION

An optical fibre Beam Loss Monitor (BLM) [1] is composed of a several tens of meters long quartz optical fibre equipped with a photodetector on each end. They could be installed alongside the beamline to increase the detection distance. When particles are lost, the shower of secondary particles reaching the fibre produces Cherenkov photons. Part of the emitted light is captured and transported through the fibre in both directions. The photons are collected by the photosensors at the extremities of the fibre. Hence, optical fibre BLMs are suitable and cost-effective for measuring beam losses across long distances.

A first serie of beam tests [2], were performed at the CLEAR facility with the aim to characterise the Cherenkov light produced in silica fibres. The light attenuation and the Cherenkov capture angles in optical fibres were studied in detail, as well as the saturation effect of the Silicon Photo-Multiplier (SiPM) detectors. These initial results have been used to benchmark simulation models developed for the design of an optical fibre Cherenkov monitor in the CERN accelerator complex. In this contribution, new experiments were performed to study the precision of such a monitor to localise beam losses, produced in this case intentionally. The position of the loss is calculated by measuring the arrival time of the signals measured at both ends of the fibre. Different setups were investigated varying the distance between the fibre and the beamline and also measuring with amplified and non amplified SiPMs.

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METHOD

In the CLEAR experimental setup, the fibre is installed parallel alongside the beamline. Because the Cherenkov photons travel in both directions inside the fibre, signals at both ends, downstream and upstream[1], can be used to calculate the loss location. However, the upstream signal gives a better longitudinal resolution than the downstream one [3]. Therefore the loss location calculation from the upstream signal is preferable.

Figure 1 illustrates the arrival times at the upstream end of two different beam losses at A and B locations.

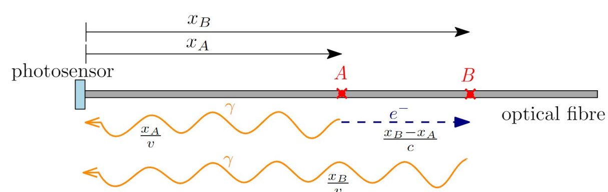

Figure 1: Arrival time between two signals at the upstream fibre end [4].

Particle A reaches the fibre at the moment $t = 0$, right before particle B. The time difference between the two particles is $(x_B - x_A)/c$. Each particle produces photons that arrive at the photosensor at $t_A = x_A/v$ and $t_B = x_B/v$ times, respectively. The photon velocity can be calculated by $v = c/n$, where $c = 0.3$ m/ns is the speed of light in a vacuum and $n = 1.46$ the average refractive index of silica in the visible spectrum. Therefore, in our system, the velocity of the photons is $v = 0.2055$ m/ns.

The arrival time difference between the two photons is given by:

$$\Delta t = t_B - t_A = \frac{x_B - x_A}{c} + \frac{x_B}{v} - \frac{x_A}{v} \quad (1)$$

From Eq. 1, the upstream arrival time difference can be expressed as:

$$\Delta t_{up} = \frac{\Delta x}{c} \cdot (1 + n) \quad (2)$$

Similarly, the expression for the downstream arrival time difference is:

[1] Downstream corresponds to the beam direction, and Upstream is the opposite direction.

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$$\Delta t_{\text{down}} = \frac{\Delta x}{c} \cdot (1 - n) \tag{3}$$

The number of particles lost is proportional to the signal measured at each photosensor and can be compared to the intensity loss calculated using two fast beam current transformers installed on the CLEAR beam line at the beginning of the line (Q_{GUN}) and at the end of the line (Q_{THz}). The charge lost during the scans is determined by:

$$Q_{\text{lost}} = Q_{\text{GUN}} - Q_{\text{THz}} \tag{4}$$

TEST-BENCH SETUP

The CLEAR facility at CERN [5] features a 220 MeV, 40 m long linear electron accelerator. Distributed along the beamline are a number of screens (that we will refer to as BTVs) that can be remotely inserted to measure the transverse beam size and position through the emission of scintillation or transition radiation. The impact of the electron beam on the screen will also generate controlled beam losses at a well defined location along the accelerator. In this work, the test results for the Cherenkov BLM installed parallel and 10 cm away from the beam pipe are reported. The fibre covered the last 21.75 m, where the BTV390, BTV620, BTV730 and BTV810 are installed. Figure 2 presents the BTV locations and the distances between them along the CLEAR beamline.

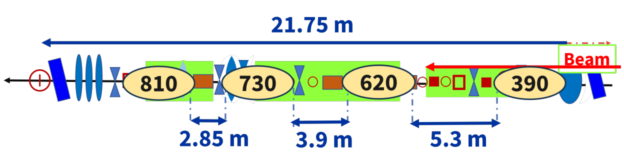

Figure 2: Screen locations in the CLEAR beamline.

Using steering magnets (namely K320, K540, K590, K710 and K780) installed in the last half of CLEAR beam line, the beam was displaced both in the horizontal and vertical planes. Figure 3 shows the locations of those magnets and the distances between them along the CLEAR beam line.

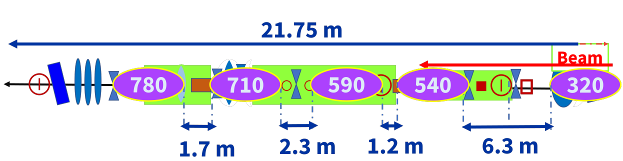

Figure 3: Magnet locations in the CLEAR beamline.

The electronic detection system, including Downstream and Upstream photosensors, power supplies and oscilloscope, was installed in a safe technical gallery, located above the accelerator hall. The extremities of the fibre were passed through two holes in the ceiling. This configuration entails valuable benefits during the experiments, allowing easy access to the electronics during beam operation.

A silica fibre of 100 m length was selected as Cherenkov sensor. The core diameter of the fibre is 200 µm.

The SiPM S14160-3015PS from Hamamatsu was used as photosensor. Its main characteristics can be found in Table 1.

Table 1: Hamamatsu Silicon Photo-multiplier [6]

Code	Pixels	Op. Voltage	Average PDE(λ)
S14160-3015PS	40000	42 V	20%

In the tests, screens and steering magnets were used one by one such that the beam charge is kept constant while generating losses. Each measurement point consists of the average of 10 consecutive beam pulses and was executed with single bunch and trains of 5 and 10 bunches. The distance between two consecutive bunches is 666 ps.

RESULTS

Figure 4 shows the photodetector signals obtained for the measurements of the losses generated in the fibre installed at 10 cm from the beamline. Beam losses were generated by inserting BTV390, BTV620, BTV730 and BTV810 screens separately during the single bunched beam shots. The blue line corresponds to background noise measurement with no screen inserted.

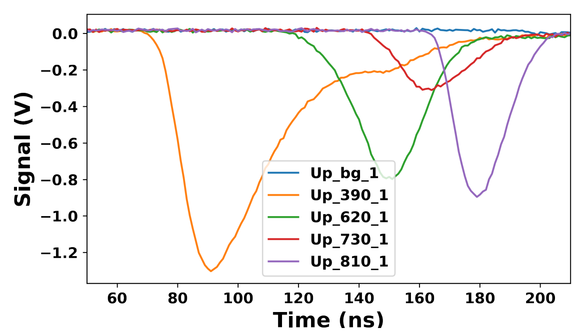

Figure 4: Upstream signals for beam losses generated by the screens during single bunch operation. The fibre is installed at 10 cm away from the beamline.

The photon arrival time at the SiPM is established on the start of the dropping edge of the signals, considering a threshold voltage value of −0.015 V to avoid the noise. This is the value used to evaluate the beam loss position. For the four peaks observed the arrival time for impacts at each screen is: $t_{390} = 67 \pm 4$ ns, $t_{620} = 112 \pm 4$ ns, $t_{730} = 142 \pm 3$ ns, and $t_{810} = 161 \pm 2$ ns.

The calculation of the time intervals between the screens is then used to estimate the distance between screens. Table 2 summarises the time intervals for the screen pairs: 620−390, 730 − 620 and 810 − 730. The distance interval values between the screens are calculated using Eq.2.

Similarly to the screens test, losses in the line were also created by steering a single bunch with magnets at the lo-

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Table 2: Signal Arrival Time Difference between Screens and Equivalent Distance

Screens	Real distance	Signal time interval	Estimated distance
620 - 390	5.3 m	45 ± 8 ns	5.5 ± 0.9 m
730 - 620	3.9 m	30 ± 7 ns	3.7 ± 0.8 m
810 - 730	2.85 m	19 ± 5 ns	2.3 ± 0.6 m

cations presented in Fig. 3. Figure 5 illustrates the signals obtained by the photosensors during this second part of the tests by the K320, K540, K590, K710 and K780 magnets in the horizontal plane. Again, the blue line shows the background noise without kicking the beam.

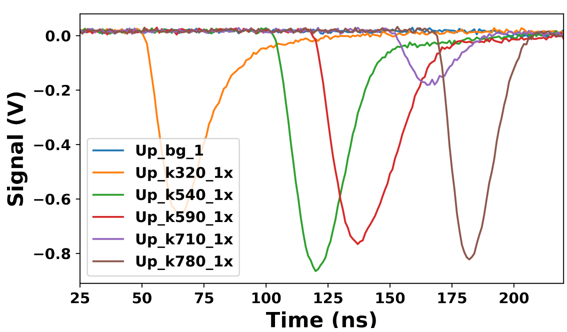

Figure 5: Upstream signals for the losses created in a fibre installed at 10 cm from the beamline by kicking the single bunch beam.

The starting points for the five signals correspond to: t_{320} = 43 ± 3 ns, t_{540} = 102 ± 4 ns, t_{590} = 118 ± 10 ns, t_{710} = 152 ± 6 ns, and t_{780} = 169 ± 3 ns.

As in the previous case, Table 3 summarises the time intervals between signal for different magnet kicks.

Table 3: Data Analysis of the Steering Magnet Loss Locations

Magnets	Real distance	Signal time interval	Estimated distance
540 - 320	6.3 m	53 ± 7 ns	6.7 ± 0.9 m
590 - 540	1.2 m	16 ± 14 ns	2.0 ± 2.0 m
710 - 590	2.3 m	34 ± 16 ns	4.0 ± 2.0 m
780 - 710	1.7 m	17 ± 9 ns	2.0 ± 1.0 m

Figure 6 presents the relation between the integrated signal from the photosensor and the beam intensity lost during the screen scans, for downstream and upstream photodetectors. In the lines, each point is calculated for 1, 5, and 10 bunches sequentially.

DISCUSSION AND FUTURE WORK

The results of the beam loss localisation presented in Tables 2 and 3 are consistent, taking into account the measure-

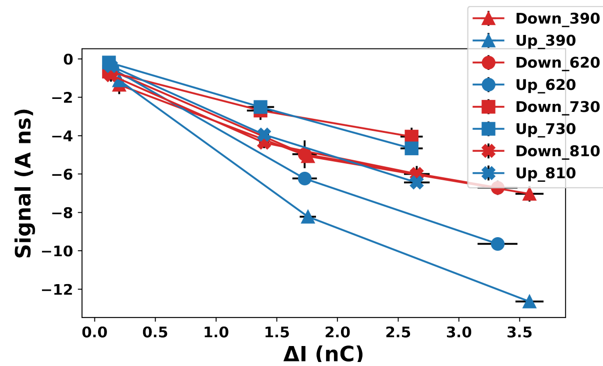

Figure 6: Intensity detection linearity of the Cherenkov BLM.

ment error, with the distances measured between the screens and steering magnets in each case (see Fig. 4 and 5). Larger errors were however observed in the magnet scans, which could be due to the different lost distribution compared to the loss distribution from the screen insertion. Possible ways to improve the error in the measurements are being investigated. However, a good correlation between arrival time of the signal and position of the loss is still observed. By the methodology of the upstream arrival time calculation, for the setup reported, a location resolution of approximately 1 m is achieved. A second methodology calculating the time difference between the downstream and upstream signals is under study.

In addition, the coefficients for the calibration of the system are being analysed. Figure 6 shows the preliminary results of the intensity loss analysis. The system detection behaviour is not guaranteed to be linear, and this can be a direct consequence of the saturation in the photosensor signals at the 5 and 10 bunches measurements.

Further steps include continuing the read-out development, particularly the effect of the amplifier that shapes and, in some cases, saturates the signal and the impact on the timing information. Additional tests are also being developed, such as the study of the distance between the fibre and the beamline and the localisation of a multi-bunched beam.

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