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REQUIREMENTS OF CLIC BEAM LOSS MONITORING SYSTEM

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Abstract

The Compact Linear Collider (CLIC) [1] is a proposed multi-TeV linear electron-positron collider being designed by a world-wide collaboration. It is based on a novel two-beam acceleration scheme in which two beams (drive and main beam) are placed in parallel to each other and energy is transferred from the drive beam to the main one. Beam losses on either of them can have catastrophic consequences for the machine, because of high intensity (drive beam) or high energy and small emittance (main beam). In the framework of machine protection, a Beam Loss Monitoring (BLM) system has to be put in place. This paper discusses the requirements for the beam loss system in terms of detector sensitivity, resolution, dynamic range and ability to distinguish losses originating from various sources. The two-beam module where the protection from beam losses is particularly challenging and important, is studied.

INTRODUCTION

The BLM system is a key element of the CLIC machine protection scheme [2]. The primary role of the system is to detect potentially dangerous beam instabilities and prevent subsequent injection into the Main Beam linac (MB) and the Drive Beam decelerators (DB). Its secondary role, as an important part of beam diagnostics, is to localize and characterize the beam loss distribution. This includes the ability to measure the time structure of the losses, which would indicate the origin of beam perturbations. In principle, these two roles could be decoupled and represented by two different systems. In practice it is usually the same system which provides both: safety and diagnostics.

The DB and MB are not the only elements which have to be protected from beam losses. Other CLIC elements which could suffer from losses are: predamping rings, damping rings (with superconducting undulators which should be protected from quenching), bunch compressors, transfer lines (especially turnarounds), combiner rings, the drive beam accelerator, the beam delivery system (the BLM system may be used in beam-based collimator alignment).

The considerations presented are based on simulations of beam losses in the CLIC tunnel using the Monte Carlo Transport code, FLUKA [3, 4]. The FLUKA model includes the concrete tunnel, floor, beamline components and silicon carbide girders. The MB and DB components include the quadrupoles, Power Extraction and Transport Structures (PETS) and Accelerating Structures (AS), as shown in Figure 1. The layout of the modules were represented in accordance to their energy dependent position in the MB.

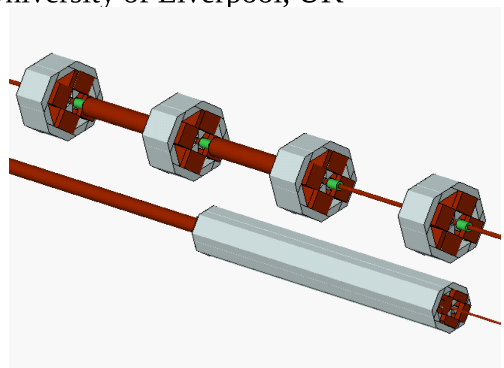

Figure 1: Illustration of FLUKA geometry.

The losses, which are expected to have a very small impact angle, are represented by a electrons travelling in the direction of the beam, generated in a circular distribution just inside of the copper beam pipe. The absorbed doses were scored in a fine scoring mesh of cubic bins of $8\ \mathrm{cm}^3$.

SYSTEM SENSITIVITY

Ideally, the system sensitivity should allow for detection of standard losses expected during normal operation. In CLIC, the largest part of operational losses is expected to originate from beam-gas interactions. In [5] it is estimated that $2 \cdot 10^{-4}$ of the total MB intensity will hit the spoilers at the end of the linac. An estimation of the losses along the aperture of the MB is not available yet, but it is expected to be smaller than the fraction intercepted by the spoilers. This would impose a very low limit on the sensitivity.

On the other hand, in order to avoid luminosity losses due to beam loading variations, the losses should be controlled to the 0.1% level in nominal operation [6]. This is a situation in which the diagnostic aspect of the BLM system becomes crucial in understanding the failure. Therefore, a continuous loss of 10^{-3} of the beam is used here as a criterion to derive the sensitivity of the BLM protecting the MB and DB elements. The continuous loss is an approximation as the aperture restrictions are located at the end of every accelerating structure which is repeated 8 times per module. In case of the DB, four loss points per module, corresponding to the aperture restriction at the end of every PET structure are simulated.

Figure 2 shows the absorbed doses resulting from distributed losses of 10^{-3} of a single DB train intensity at

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2.4 GeV and the MB intensity at 9 GeV. The registered dose per pulse in a position close to the beam pipe, where the BLM detectors could be installed, is in the range of $10^{-7} - 10^{-5}$ Gy. This number is used as an estimation of the system sensitivity. However it should be kept in mind that a smaller value is recommended.

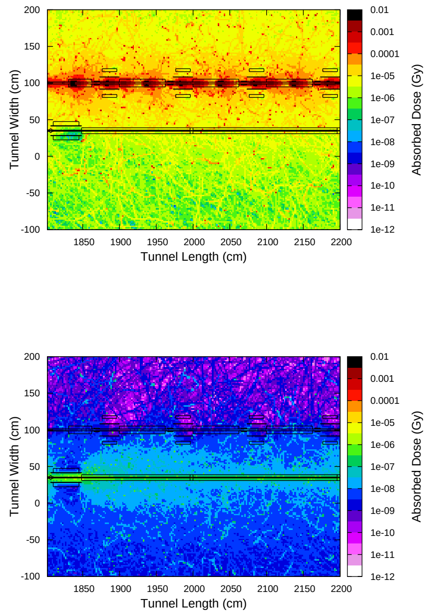

Figure 2: Dose per pulse due to maximal operational losses of the DB at 2.4 GeV (above) and the MB at 9 GeV (below).

DYNAMIC RANGE

The dynamic range of the system should allow the detection of the signal corresponding to an onset of dangerous beam losses. Here, the dangerous losses are defined as the ones which can cause damage to accelerator elements.

Beam losses become destructive at the level where 1% of the DB or 0.01% of the MB hits a single aperture restriction [2]. The aperture restrictions are located at the far end of the accelerating and PET structures. The results from FLUKA simulations of such a situation are presented in Figure 3, where the loss electrons were simulated at single points representing the locations of aperture restrictions.

The dose is presented for a loss within a single pulse. The values read from these figures are about $0.01 - 0.1$ Gy. It can therefore be concluded that the dynamic range of the system should be in the range $10^4 - 10^5$ (Table 1).

SIGNAL RESOLUTION

It is assumed that every false trigger of injection inhibit will lead to about 10 seconds dead-time for the validation

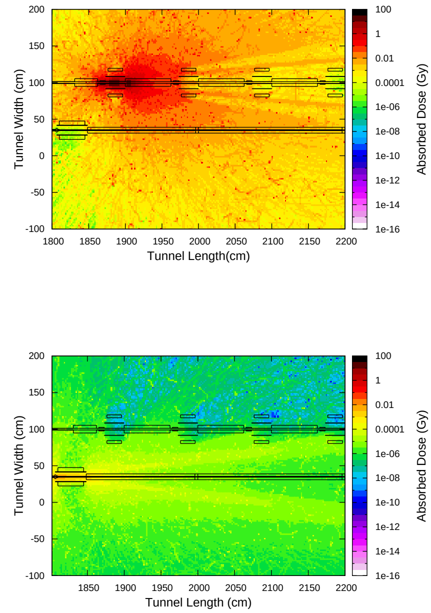

Figure 3: Dose due to damaging loss of the DB at 2.4 GeV (above) and the MB at 9 GeV (below).

of intensity-ramp procedure of the beam protection system. The dead time due to false triggers should be limited to 0.1% in order not to affect the operational availability. Hence false triggers should occur less than once per 10^4 seconds (8.6 times per day). At 50 Hz this corresponds to a false trigger probability of $2 \cdot 10^{-6}$ per cycle. To achieve such level of system performance, the individual BLM false triggers rate should be about 10^4 (number of individual BLM channels) times lower i.e. $2 \cdot 10^{-10}$, corresponding to statistical fluctuation of about 7 sigma [1]

The injection inhibit threshold should be at about 10% of the signal at damage (safety factor). For DB at 2.4 GeV it corresponds to 0.05 Gy. In this case, assuming no dependence of the resolution from the signal amplitude, the resolution should be better than 10 mGy.

SPATIAL RESOLUTION

The spatial resolution of the loss location has two aspects: resolution along the linac and a potential to distinguish between losses of the DB and the MB.

For diagnostic purposes, the longitudinal resolution should allow to distinguish between loss locations in two neighbouring quadrupoles. This corresponds to a longitudinal resolution of about 1 meter.

Because of the specific design of CLIC, with two parallel beamlines, it is important to be able to distinguish between the DB and the MB losses. Therefore, in horizontal

[1] Assuming that the tails of the reconstructed signal are gaussian, what, as learned from LHC experience, can be pessimistic.

Table 1: Estimation of sensitivity and dynamic range needed at the beginning and end of the MB and DB.

	Sensitivity [Gy]	**Dynamic range**
DB 0.24 GeV	$5 \cdot 10^{-6}$	$2 \cdot 10^{4}$
DB 2.4 GeV	10^{-5}	$5 \cdot 10^{4}$
MB 9 GeV	10^{-7}	10^{5}
MB 1.5 TeV	10^{-6}	10^{4}

transverse direction the necessary spatial resolution is better than 0.75 meter. The signal from the DB losses seen in monitors protecting the MB and vice versa is called "cross talk".

The highest "cross-talk" between the MB and the DB is observed at the beginning of the linac, where the MB energy is 9 GeV. The loss of 0.01% of the MB in this location would provoke, in the region close to the MB quadrupole (possible location of BLM), a signal of about $5 \cdot 10^{-4}$ Gy. In the same location, a loss of 1% of the DB train generates a similar signal. A single monitor installed in this location would not have ability to distinguish which beam suffers from abnormal losses.

TEMPORAL RESOLUTION

For the main part of the BLM system (protecting the main linacs), the temporal resolution requirement is easily achievable: the decision about the next pulse inhibit must be taken in less than 10 ms. Therefore, to fulfill the first mission of the system, a time resolution of this order is necessary.

For diagnostic purposes, a nanosecond scale resolution allows to resolve the time structure of the losses within a pulse. Due to the difference in time structure of the MB and the DB, such high resolution may further help to discriminate between losses of these two beams.

LOCATION DEPENDENCE

It is apparent from above that the system has to fulfill different specifications along the CLIC tunnel. In Table 1 there are examples of parameters estimated for the beginning and the end of the DB and the MB linacs. The sensitivity varies by 2 orders of magnitude while the dynamic range changes by one. In this situation, the use of different detectors for various parts of CLIC is maybe necessary.

TECHNOLOGIES

The main detector technologies currently studied for CLIC beam loss monitoring purposes are: ionisation chambers, diamond detectors and Cerenkov fibers.

Ionisation chambers were successfully used in many beam loss monitoring systems, for instance in LHC [7] and in SLAC [8], where a long gas-filled coaxial cable has been used. Their main advantages are radiation hardness and large dynamic range.

Diamond detectors become increasingly popular for BLM purposes. They are used at Fermilab and in LHC experiments. Their advantage is low dark current.

Cerenkov fibers are an emerging technology [9]. They are inexpensive, cover large areas and provide very good position and time resolution.

CONCLUSIONS

An initial study of the specification of the CLIC Beam Loss Monitoring system is presented. The expected sensitivity and dynamic range are estimated from FLUKA simulations. The sensitivity of the system should be better than 10^{-7} Gy. The dynamic range needed to measure beam losses is about 10^{5}.

An important challenge of the system is the need to distinguish between losses from the two different beam lines. It is especially difficult at the beginning of the Main Beam linac. Initial calculations show that the signal at the damage of the main beam cannot be distinguished from the one at drive beam damage.

This work will be extended with a goal to choose a working principle and a technology for the future CLIC BLM system.

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