CLIC POST-COLLISION LINE LUMINOSITY MONITORING

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Abstract

The CLIC post collision line is designed to transport the un-collided beams and the products of the collided beams with a total power of 14 MW to the main beam dump. Full Monte Carlo simulation has been done for the description of the CLIC luminosity monitoring in the post collision line. One method of the luminosity diagnostic is based on the detection of high energy muons produced by beamstrahlung photons in the main beam dump. The disrupted beam and the beamstrahlung photons produce at the order of 10^6 muons per bunch crossing per cm^2, with energies higher than 10 GeV. Threshold Cherenkov counters are considered after the beam dump for the detection of these high energy muons. Another method for luminosity monitoring is presented using the direct detection of the beamstrahlung photons.

INTRODUCTION

The 1.5 TeV electron/positron CLIC beams, with a total power of 14 MW per beam, must be focused to nanometer spot sizes in the interaction point (IP) to reach the required luminosity. The resulting strong beam-beam effects lead to a strong emittance growth for the outgoing beam as well as to the production of beamstrahlung photons and e+e- pairs. The post- collision lines (PCL) are designed to transport, from the interaction point to the main beam dump, both the un-collided beams as well as the collided beams (disrupted beam, coherent e+e- pairs and beamstrahlung photons) with its increased momentum spread and angular divergence [1, 2]. The conceptual design of the CLIC post-collision line considers luminosity monitoring for a fast feedback to the beam steering.

Each colliding beam feels a strong electromagnetic field of the other beam which results in beam blow-up, disruption, beamstrahlung, deflection and other effects. The beam deflection angle depends on the offset between the bunches [3] and can be used for luminosity monitoring at the CLIC post-collision line. The characteristic angle of beamstrahlung radiation at the CLIC beams energy of 1.5 TeV is $\gamma^{-1} \approx 0.34\,\mu rad$ with respect to its emitting electron trajectory. Since the CLIC e+e- beam angular divergence at the interaction point is $\approx 11.5\,\mu rad$ the distribution of the beamstrahlung photons is well included in the angular distribution of the e+e-beams.

In this paper we propose luminosity monitoring based on the detection of beam-beam products in the post-collision line and on the sensitivity to any beam-beam offsets in the interaction point. With a suitable feedback mechanism this offset can be minimised and therefore the luminosity optimised. Other beam diagnostics will be included in the post-collision line, for example beam loss monitors and BPMs, but those will be considered in future work.

POST-COLLISION LINE LUMINOSITY MONITORS

We consider here two independent diagnostic tools, although their signals can be combined for a complete luminosity optimisation.

The beam dump luminosity monitors are located in the main beam dump area and detect high-energy muons resulting from beamstrahlung photon conversion into muon pairs. A similar technique was proposed for the SLC [4]. The monitors will be positioned after the main beam dump plus a few meters of concrete shielding. The main dump is 315 m away from the interaction point. Beamstrahlung photons impinging the water dump will predominantly produce electron-positron pairs. However, a substantial fraction of these high energy photons will produce muons. While the electromagnetic shower is fully absorbed in the dump the high energy muons will escape the main dump nearly unaffected, except for some energy losses due to ionization. In addition some high energy muons will also be produced in the water dump by the intense disrupted beam and e+e- coherent pairs. The design for the CLIC post collision line considers a vertical separation by a magnetic chicane of the beamstrahlung photons from the disrupted beam and e+e- coherent pairs of about 12 cm. This distance is enough to distinguish the muon contributions from the disrupted beam and the beamstrahlung photons.

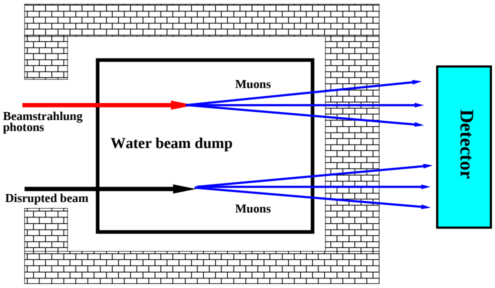

Figure 1: Sketch of the main dump area. The luminosity monitors detect high-energy muons resulting from the conversion of beamstrahlung photons and the disrupted beam, which is vertically separated by 12 cm.

Beamline beamstrahlung monitors are based on either the direct counting of beamstrahlung photons in the post-

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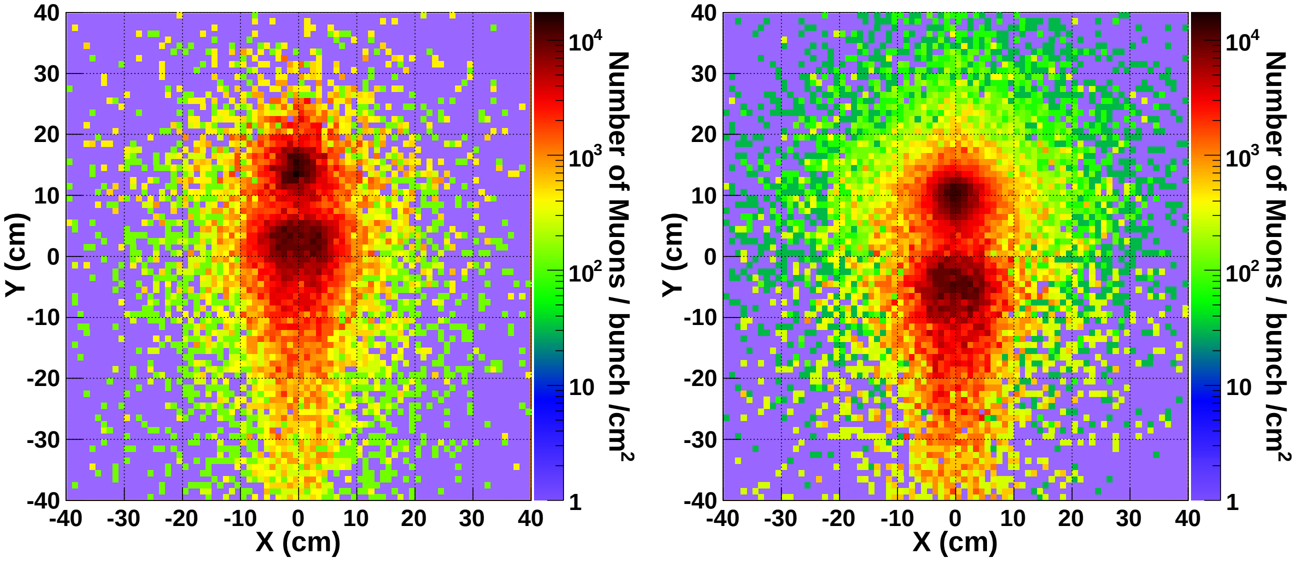

Figure 2: Spatial distribution of muons downstream of the main beam dump at various vertical offsets of the colliding beams. The muon distribution originating from the beamstrahlung photons are vertically separated upwards by 12 cm from the muons caused by the disrupted beam. Left plot: -9 nm vertical offset in the interaction point. Right plot: +9 nm vertical offset.

collision line, or indirect measurement where the photons could be converted into e+e- pairs in a thinfoil; the e+e- pairs could be observed via astandard Optical Transition Radiation screen (OTR) andphotomultiplier. Both methods have the aim of feeding back on the interaction point beam separation.

Monte Carlo Simulations of the beam dump luminosity monitors

For the simulations, the GEANT4 [5] Monte Carlo code was used with collision data [6] generated using the GUINEA-PIG [7] beam-beam simulation program. The data contains the energy, the spatial and the angular distribution of the particles after collision at the interaction point. The data were transported through the post-collision line to the main beam dump with a 12 cm separation between the spent beam and the beamstrahlung photons.

The simulation geometry in the vicinity of the beam dump is shown in Fig. 1. The water beam absorber is a cylindrical vessel made of 20 mm thick stainless steel. The length and the diameter of the beam dump are 10 m and 1.8 m, respectively. The volume of the water inside the dump is 25 m^3. 2.4 m thick concrete walls are surrounding the beam dump. The energy cuts in the simulations were set to 210 MeV for all particles.

Full Monte Carlo simulations were performed for transporting all the components of the post collision particles through the water based beam dump. Grid computing and CERN LXPLUS batch systems were used for obtaining sufficient statistical results. Several scenarios of beams offsets, waists and dispersions in horizontal and vertical directions were simulated, which could cause a decrease in luminosity.

The muons spatial distributions are presented in Fig. 2 for the case of ±9 nm vertical offset in the interaction point. The left plot represents the muon distribution with energies $\geq$13 GeV when the observed beam has -9 nm vertical offset. The beam receives positive deflection after colliding with the second beam with opposite charge. The muon distribution originating from the beamstrahlung photons are vertically separated upwards by 12 cm from the muons caused by the disrupted beam. These separate distributions can be clearly seen in Fig. 2. In case of negative offset the muons from both the spent beam and the beamstrahlung photons move to positive direction while in case of positive offset the muons move to the negative direction. The displacement of the muon distributions is directly connected to different offsets in the interaction point and consequently to the quality of the luminosity. Therefore measuring the muon flux at different locations behind the beam dump allows determining the collision characteristics and giving feedback to the beam steering.

Details on the detector choice and locations are part of future studies; currently Cherenkov detectors are considered due to their capability of setting high energy-thresholds and therefore omitting low-energy background signals.

Monte Carlo Simulations of beamline beamstrahlung monitor locations

Possible beamline beamstrahlung monitor locations were simulated using the collision data from [6] for the beamstrahlung photon phase space information. The post-collision line was modeled in FLUKA [8], including the mass distribution of the beamline elements, the intermediate dump, magnets and all magnetic fields. The element main beam power losses were benchmarked against the results in [2].

For the study of direct photon counting, three candidate locations were chosen for photon detectors; The longitudinal locations along the post-collision line are 67 m, 75 m and 110 m, with the surface areas of each detector defined as 10 cm by 10 cm. The detectors are located in the tail of the photon cone, beginning 5 cm above the centre of the beamstrahlung cone. Possible detectors on the lower side of the beam are under study. The third longitudinal location is located after the intermediate dump and the C-shape magnets [1], where the separation of the beam-beam products is maximised, and is expected to give the optimum signal-to-background ratio. The first (second) upstream locations are just before (after) the intermediate dump and are chosen for a comparative study, as they are expected to have significant background from other beam-beam products and the disrupted main beam.

The Monte Carlo simulation is performed with the beamstrahlung photons as the source, with particles in the resulting EM showers tracked down to 1 MeV. The beams at the interaction point have no horizontal or vertical offset between them, and so the simulations give the approximate photon count and energy for the case of optimal luminosity. The simulations indicate that the dominating contribution to the photon signal comes from direct beamstrahlung detection, with a small contribution from EM showers from the intermediate dump in the post-collision line. Focusing on the detector located at 110 m, behind the intermediate dump, the photon rate per bunch crossing is 1.1×10^{7}, with a mean energy of 11 GeV. This signal is dominated by direct detection of beamstrahlung photons, with a smaller contribution from showers initiated by upstream loss of beamstrahlung photons. The resulting power load from the photons on the detector is less than 1 kW. A preliminary simulation has shown sensitivity to beam-beam offsets at the interaction point, although a full study is required, along with a full study of backgrounds arising from the IP and from the main beam dump.

The energy spectrum of the photons in the upper detector at 110 m is shown in Fig. 3. Studies of the indirect photon detection with e.g. the OTR detector are on-going.

CONCLUSION

Fast luminosity monitoring is an essential ingredient for optimizing the collision quality at the CLIC interaction point. In the CLIC post-collision line luminosity monitoring is considered for a fast feedback to the beam steering. Two independent diagnostic tools have been studied: luminosity monitoring behind the main beam dump by measuring the muons, which result from the conversion in the beam dump of beamstrahlung photons and the disrupted beam into muon pairs. The simulation results show that the location and flux of the muon distributions are directly connected to different beam offsets in the interaction point and consequently to the luminosity quality. The choice and detailed location of the muon detectors will be the next steps to study. In the second approach the direct measurement of beamstrahlung photons could be used for luminosity monitoring. A possible detector location has been studied and found to be at 110 m downstream the interaction point.

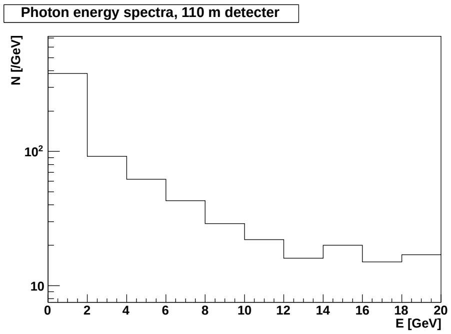

Figure 3: The direct energy spectrum of photons in the upper vertical detector at 110 m from the interaction point.

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