BEAM-BEAM BACKGROUND IN CLIC IN PRESENCE OF IMPERFECTIONS

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Abstract

Beam-beam background is one of the main issues of the CLIC MDI at 3 TeV CM. The background level has a significant impact on the interaction region design. This paper presents a study of the background expected rates and luminosity according to different beam parameters and considering different machine conditions, using an integrated simulation of the Main LINAC and BDS sub-systems.

INTRODUCTION

Because of the high energy and high luminosity foreseen at CLIC the beam-beam background rates are expected to be high. These backgrounds need to be carefully investigated in order to verify that the experimental conditions are acceptable. In order to use realistic bunch shapes at the interaction point we simulate the full transport through the Main Linac (ML) and the Beam Delivery System (BDS) using the tracking code PLACET [1]. The beam are brought into collision using the GUINEA-PIG code [2] to calculate luminosity and background rates. The relevant processes are: the emission of beamstrahlung photons, the coherent pair production, the incoherent pair production and $\gamma\gamma \rightarrow$ hadrons events. A detailed description of these processes as well as the cross sections implemented in GUINEA-PIG can be found in Reference [3]. Here we remind that incoherent pair and hadrons can be produce with a considerable momentum in the transverse plane, thus they can reach the detector forward as well as central region. In Table 1 the CLIC nominal main parameters at 3 TeV and the calculated background rates per bunch crossing are reported. The emittance values include the budgets for imperfections. The actual values depend on the single machine and change during operation.

Table 1: Nominal main parameters of CLIC at E_{cm} = 3 TeV. All background are per bunch crossing.

Luminosity L	[10^{34}cm^{-2}s^{-1}]	5.9
repetition frequency fr	[Hz]	50
bunches per train N_b		312
distance between bunches Δ_y	[ns]	0.5
particles per bunch N	[10^{10}]	0.372
bunch length σ_z	[μm]	44
emittances $\gamma\epsilon_x/\gamma\epsilon_y$	[nm]/[nm]	660/20
beam sizes σ_x^*/σ_y^*	[nm]/[nm]	45/1
beamstr. phot./particle n_γ		2.1
incoherent pairs N_{pairs}	[10^3]	330
coherent pairs N_{coh}	[10^7]	33
hadronic events N_H		2.8

In this paper we investigate the luminosity and background rates correlation and fluctuations according to different beam parameters and in presence of machine imperfections.

BEAM-BEAM JITTER

Most of the imperfections, like ground motion or misalignments of the magnets, lead to an offset of two beams at the interactions point. In order to estimate the effect of beam-beam offsets on luminosity and background we have calculated the last two using the bunch shapes after tracking trough perfect ML and BDS and scanning the relative offsets of the two beams in the vertical and horizontal plane. A perfect head on collision in the plane that is not scanned is considered.

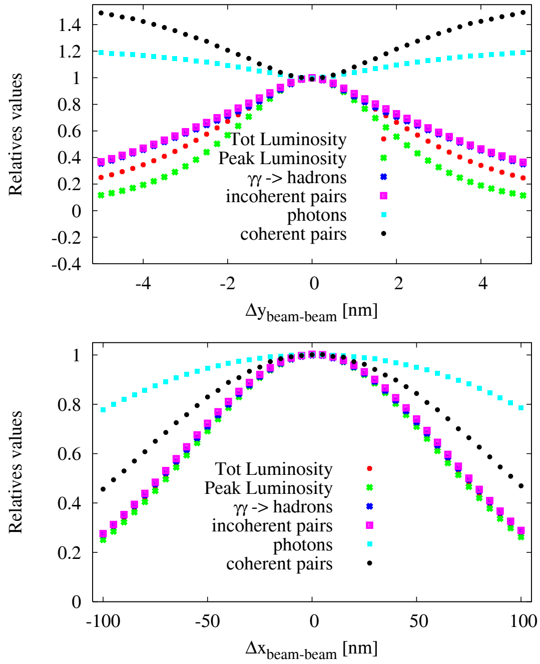

Figure 1: Luminosity and backgrounds relative rates as a function of the vertical(top) and horizontal(bottom) relative beam-beam offset.

The results are shown in Fig. 1 for the vertical offset and for the horizontal one. Each point is the average of 20 bunches with different initial random distributions. The incoherent pairs and hadronic event rates follow the luminosity curves fairly well in the case of a horizontal offset, while more background with respect to luminosity is produced when the relative beam-beam offset reaches 2 σ of the vertical beam distribution.

BEAM CHARGE AND EMITTANCE

During the tune-up of the machine bunches with reduced intensity are used. Figure 2 shows the relative luminosity and relative background rates according to different number of particles in the bunch. All the background rates fall to zero faster than luminosity, except for the number of photons that show a linear decrease with the number of particles in the bunch. One of the most important effect that machine imperfections induce on the beams is the beam size increase. In order to have an indication of this effect we have tracked beams with different horizontal and vertical emittance values through perfect ML and BDS systems. Figure 3 shows the dependence of background on the horizontal and vertical emittance. The curve of emitted beamstrahlung photons per particle describe very well the peak luminosity curve according to the horizontal emittance change, while it is insensitive to the vertical emittance variation. More relative luminosity than incoherent pair and hadronic events are expected for very low vertical emittances and for bigger horizontal emittances. The opposite behavior is expected for bigger vertical emittances and very low horizontal emittances. These studies indicate that the measurement of beamstrahlung photons is useful during machine set-up to tune the intensity of the beam and the horizontal beam size. At the same time the incoherent pair and hadronic events are the only two processes useful for the fine tuning of the vertical beam size and the relative beam-beam offsets. So far beamstrahlung photons and incoherent and coherent pairs have been considered as potential signal for luminosity tuning [4]. From this study it follows that hadronic events should be considered as well, even if further studies are needed. In the following we study the correlation between luminosity and hadronic event rates inducing imperfections in the ML and considering perfect BDS, which nevertheless include the non-linearities and emission of incoherent synchrotron radiation in all the magnets. The main beam parameters and the imperfections used in the simulation of the ML are reported in Table 2.

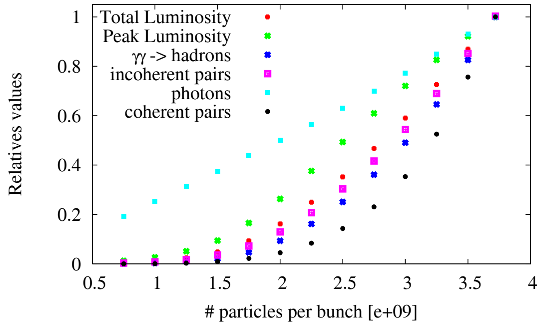

Figure 2: Luminosity and background relative rates for the nominal CLIC parameters as a function of the charge in the bunch.

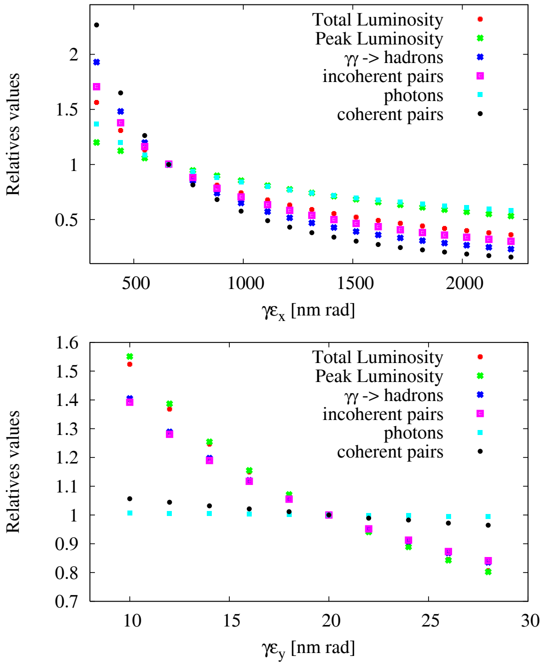

Figure 3: Luminosity and background relative rates for the nominal CLIC parameters as a function of the horizontal (top) and vertical (bottom) emittances.

Table 2: Values of the imperfections and beam parameters used in the main LINAC simulations.

imperfections	dim.	value
BPM vert. offset	μm	14
BPM resolution	μm	0.1
accelerating structure vert. offset	μm	7
accelerating structure vert. tilt	μrad	142
quadrupole vert. offset	μm	17
quadrupole vert. roll	μrad	100
beam parameters	dim.	value
Bunch charge N	particles	3.72e+09
Bunch length σ_z	μm	44
hor. emittance $\gamma\epsilon_x$	nm	660
vert. emittance $\gamma\epsilon_y$	nm	10

MACHINE IMPERFECTIONS

The listed imperfections are enough to bring the vertical emittance of the nominal beams to growth up to several order of magnitude if no correction scheme is applied to the machine. When the Beam-Based-Alignment (BBA), described in [5], is applied to the machine the resulting average emittance growth at the end of the ML stays well below 5 nm. We have steered the beams coming from the corrected ML into the BDS and tracked them to the interaction point in a perfectly aligned BDS. The resulting bunch shapes are used to compute luminosity and background rates again.

Figure 4 shows the correlation between total and peak luminosity vs the number of hadronic events. The cases of perfect machines and scaled beam emittances, as in Fig. 3 are compared with the cases of corrected machines and ini-

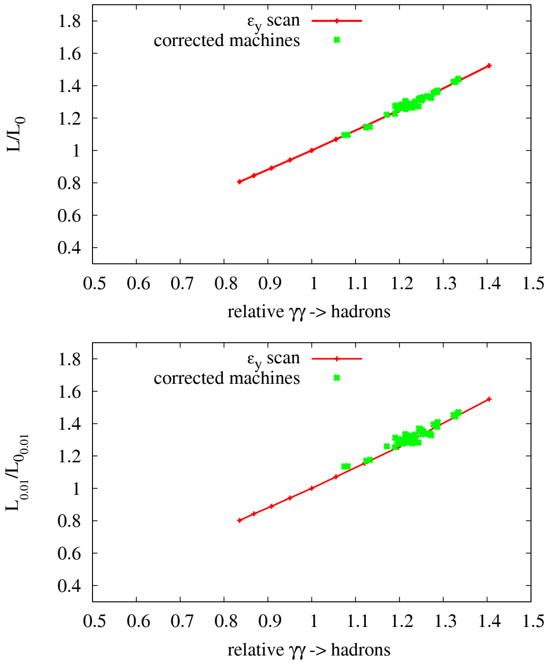

Figure 4: Total L(top) and Peak $L_{0.01}$(bottom) Luminosity vs number of $\gamma\gamma \to$ hadrons events, normalized to the nominal values, for perfect machines with different vertical emittance values and for corrected machines.

tial nominal beam parameters. The correlation in any case is linear but the fluctuations of luminosity and expected hadronic events are bigger for the corrected machines (on the average $\sim$5% instead of $<$1%), indicating that different emittance values are reached by the different machines after the linac BBA correction. The mean luminosity value is about 30% higher than the nominal case, and 25% more background with respect to the nominal value is expected. Finally we have studied the stability of the corrected machines with time, since the BBA described before cannot be applied train by train. We apply different time values of ground motion, modeled according to the ATL low [6] with a value of $A = 0.5 \times 10^{-6}$ $(\mu\mathrm{m})^2$/(ms), to the corrected ML machines and then we steer the beams trough ML and track them trough perfect BDS.

Figure 5 shows the correlation of the luminosity and hadronic event rates resulting from these simulations. The corrected machines after 10^5s of ground motion still present a linear correlation between luminosity and hadronic events rate and they show a very small spread around the values obtained with perfect machine and increased beam emittance values. When 10^6s of ground motion is applied to the machine the luminosity and background rates start to fluctuate more around the linear behavior (the fluctuations of the hadronic event rates are $>$ 15%). The majority of the machines have a relative low luminosity while still a significant number of hadronic events are produced.

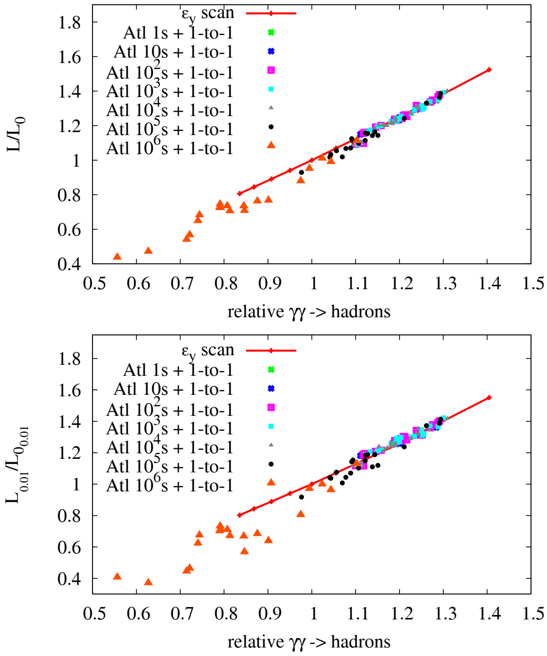

Figure 5: Total L(top) and Peak $L_{0.01}$(bottom) Luminosity vs number of $\gamma\gamma \to$ hadrons events, normalized to the nominal values, for perfect machines with different vertical emittance values and for corrected machines, after several time values of ground motion followed by simple steering trough the magnets are applied to the linac.

CONCLUSION

We have compared the hadronic background for nominal collisions with realistic conditions. During operation the luminosity may be larger than nominal if emittance is smaller than the budget. In this case, background levels can be up to 40% larger than nominal. Detectors should thus be able to handle this level not to have to artificially reduce the luminosity in order to reduce background.

Imperfections will lead to a reduction of the luminosity compared to this increased level. They also result in reduced background levels, even if the ratio of background to luminosity may increase somewhat.

The behavior of luminosity and the relevant beam-beam background processes shows that, besides beamstrahlung photons, coherent and incoherent pairs, the hadronic events may provide a signal for luminosity tuning.

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