Beam induced backgrounds at 380 GeV and 3 TeV simulated using Guinea-Pig and DD4hep – work in progress

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Overview

Motivation

- Beam parameters impact the backgrounds distributions thus their choice must be a good compromise between the luminosity and background yields
- Good knowledge of backgrounds created in collisions is required for a quality detector design and precise physics study
- Studying direct background sources may trigger a change in the design of the forward detector region if occupancies are found to be too high

Backgrounds creation overview

- Beamstrahlung is a type of synchrotron radiation caused by charged particles' interactions with the electromagnetic field of the incoming beam, it is strongly linked with the pinching effect
- It is the main cause of the lower energy tail in e^-e^+ luminosity spectrum
- Beamstrahlung interactions with e^-, e^+ or other photons lead to production of unwanted particles: coherent and incoherent pairs, hadrons
- Schuler and Sjorstrand parametrisation for $\gamma\gamma \rightarrow$ hadrons production total cross-section was used: $\sigma_{\gamma\gamma}(E_{cm}^2) = 211\ nb(E_{cm}^2\ \mathrm{GeV}^{-2})^{0.0808} + 215\ nb(E_{cm}^2\ \mathrm{GeV}^{-2})^{-0.4525}$
- E_{cm} of a photon system allowed to produce hadrons was chosen to be above 2 GeV

Beam parameters choice

Geometrically luminosity can be aproximated by following expression:

$$\mathcal{L} \propto \frac{N}{\sigma_x \sigma_y}, \quad (1)$$

where: $\mathcal{L}$ - luminosity, N - number of particles, σ_x, σ_y - horizontal/vertical beam size

While the number of produced beamstrahlung photons is proportional to:

$$n_\gamma \propto \frac{N}{\sigma_x + \sigma_y} \quad (2)$$

- Having σ_x or σ_y much bigger than the other allows us to minimize the beamstrahlung while leaving luminosity at the desired level
- Thus the choice for CLIC horizontal-to-vertical ratio of 50:1 at 380 GeV and 40:1 at 3 TeV

Analysis environment

- Most recent versions of PLACET, GUINEA-PIG both C and C++ versions and ILCSoftware were used, though with custom modifications
- PLACET was modified to enable extraction of synchrotron radiation photons produced in magnets
- GUINEA-PIG software was modified to implement extraction of beamstrahlung at the end of tracking instead of at the creation
- DD4hep was modified to set initial vertex at the initial position of the first particle in the collection
- Detector model contains a sensitive beampipe extended up to the last sector bend magnet on the upstream side - in line with 3 TeV design, apertures may be different at 380 GeV

Analysis workflow

- Generate initial particles' distribution and transport the beams through Beam Delivery System using PLACET
- Collide electron and positron beams in GuineaPig
- Analyze background particles' spectra in ROOT enviroment
- Embed GuineaPig's output in DDhep simulation with CLIC_o3_v08 modified model with one particle per event unless the hadron events are analyzed
- Additional step when $\gamma\gamma \rightarrow$ hadrons is analyzed: colliding photons and fragmenting strings in Pythia6.4 using HADES
- Study the hits' distributions and energy depositions

PLACET – overview

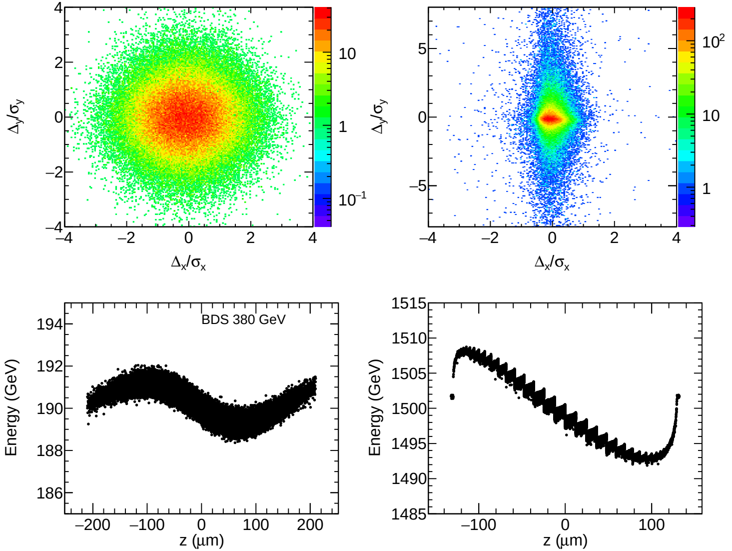
- Program to simulate the dynamics of a beam in the presence of wakefields
- Allows one to investigate single and multibunch effects in bending, quadrupole and multipole magnets and accelerating (decelerating) cavities
- Beam can be represented as slices with only tranverse motion or macroparticles with longitudinal motion included
- PLACET1 (C and C++, originally D. Schulte) was designed for linear lattices, PLACET2 developed by Dario Pellegrini allows one to transport beams through recirculating machines
  - This study uses PLACET-OCTAVE interface
  - 10^5 macroparticles/beam usually used in this study

Beam parameters at IP

design	σ_x (nm)	σ_y (nm)	σ_z (μm)
nominal 380 GeV	149	2.90	70
PLACET 380 GeV 'realistic'	148.7	3.03	69.2
nominal 3 TeV	40	1	44
PLACET 3 TeV 'realistic'	48.7	6.7	43.4

- Realistic beams are transported with synchrotron radiation effects ON and with correlated energy spread ($\sigma_E = 0.35\%$) taken from the end of main linac
- The design at 380 GeV is not as sensitive to the correlated energy spread as the 3 TeV one

Beam distributions at IP

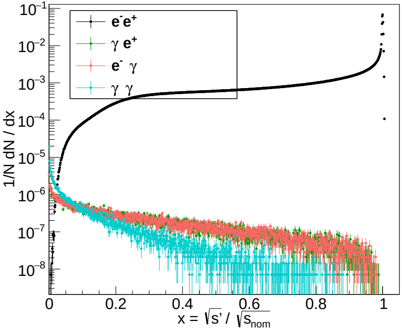


GUINEA-PIG – overview

- Generator of Unwanted Interactions for Numerical Experiment Analysis – Programme Interfaced to GEANT
- Simulates the interactions in relativistic beam collisions of electrons, positrons and photons
- Two parallel versions available: original developed by Daniel Schulte and written in C, C++ version done by a team from LAL, Orsay
- Outputs luminosity information, background particles: incoherent pairs (electrons and muons), coherent pairs, trident cascades (only C++), $\gamma\gamma \rightarrow$ hadrons, beamstrahlung, bremsstrahlung, Bhabha electrons, minijets (deprecated)

You can find more on GUINEA-PIG code in Daniel's last presentation: https://indico.cern.ch/event/632420

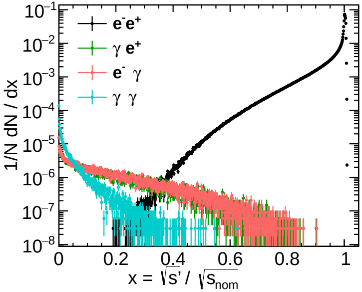
Luminosity spectra at 3 TeV



type	$\mathcal{L}\ (x10^{34} \frac{1}{\text{s cm}^2})$
nominal e^-e^+	5.90
e^-e^+	6.99
γe^+	6.13
$e^-\gamma$	6.12
$\gamma\gamma$	6.28

- Total integrated luminosities of unwanted collisions are of the same order as e^-e^+
- The obtained e^-e^+ luminosity value is comparable to the nominal one

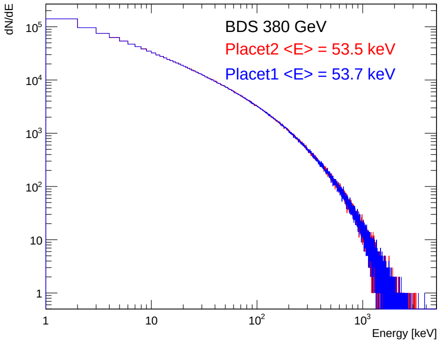
Luminosity spectra at 380 GeV

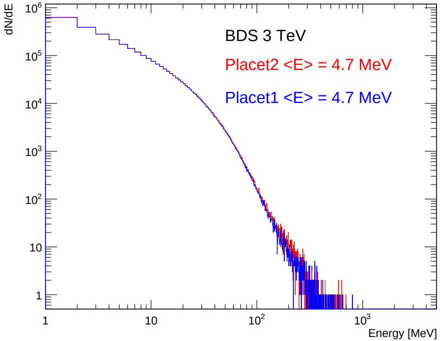


type	$\mathcal{L}$ ($x10^{34} \frac{1}{\text{s cm}^2}$)
nominal e^-e^+	1.50
e^-e^+	1.50
e^-e^+ 1%	0.91
γe^+	0.82
$e^-\gamma$	0.82
$\gamma\gamma$	0.53

- Luminosities of unwanted collisions are of around half the value of e^-e^+
- The obtained e^-e^+ luminosity value is comparable to the nominal one

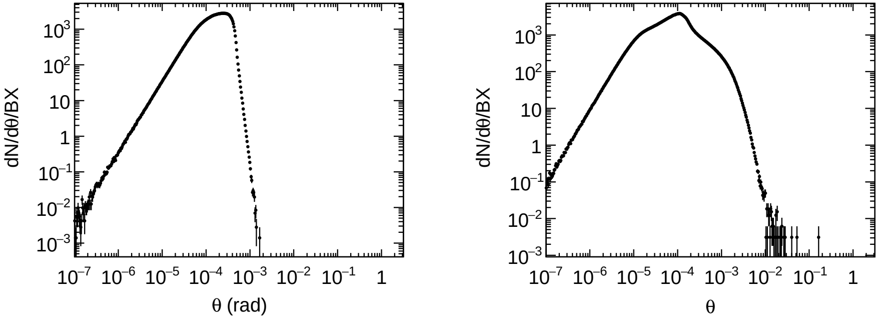
Synchrotron radiation energy spectra at 380 GeV and 3 TeV





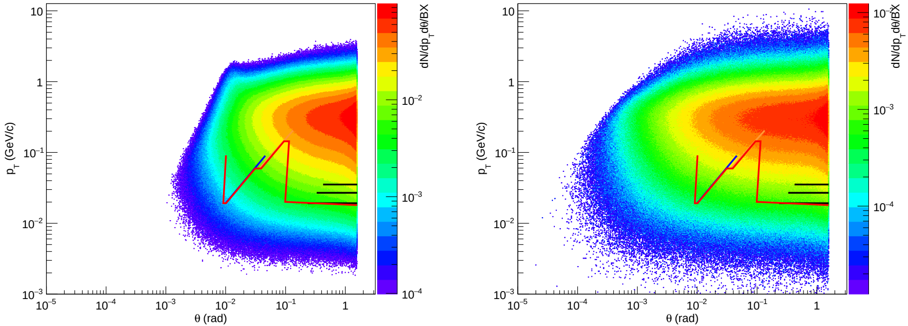
- At 380 GeV there are 23.5 SR photons per macroparticle, with 22.6 from sbends and 0.8 from quadrupoles
- At 3 TeV there are 59.1 photons, with 57.1 from sbends and 2.0 from quadrupoles

Beamstrahlung overview



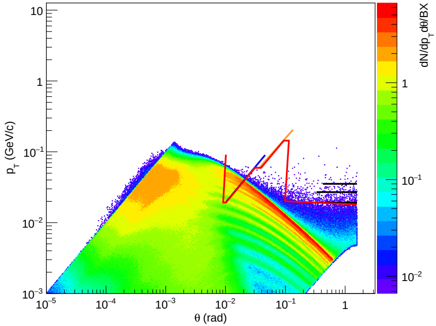
- Beamstrahlung photons are a source of direct background, as expected (design requirement)
- There are on average 1.5 photons per BX at 380 GeV and 2.4 at 3 TeV

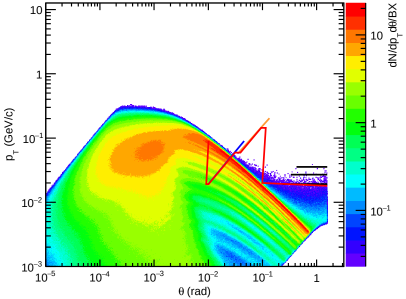
$\gamma\gamma \to$ hadrons overview



- There are 0.17 $\gamma\gamma \to$ hadron events per BX at 380 GeV and 3.5 at 3 TeV
- Most (90%) of produced hadrons are with high polar angles and are one of the major sources of direct background and occupancies in the detector

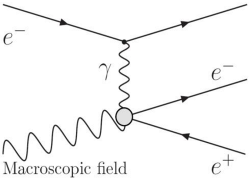
Incoherent pairs as background

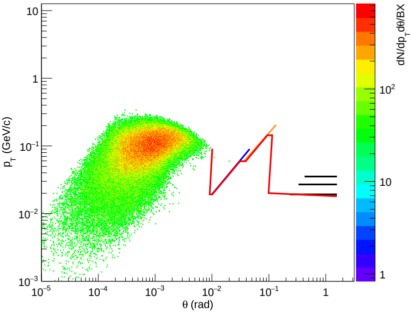




- Incoherent pairs are one of the main sources of direct background at both energy stages: 380 GeV (left) and 3 TeV (right)
- There are 56k incoherent pairs per bunch crossing at 380 GeV and 380k at 3 TeV

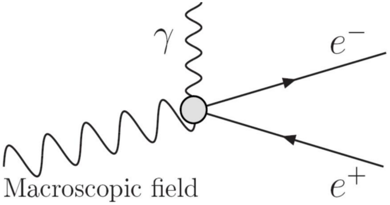
Trident cascades overview

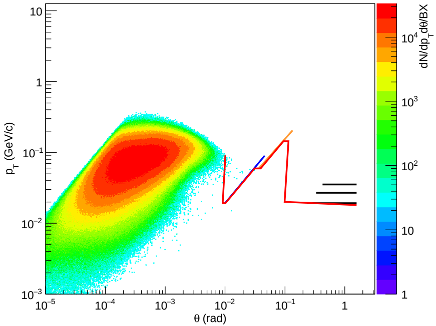




- There are 3kk trident cascades at 3 TeV
- Trident pairs production is strongly suppressed at lower energy stage and no trident pairs have been observed

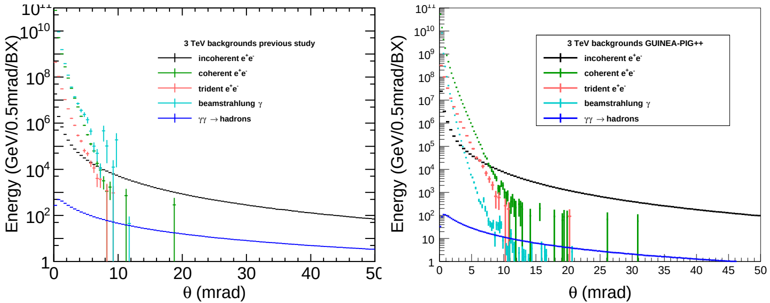
Coherent pairs overview





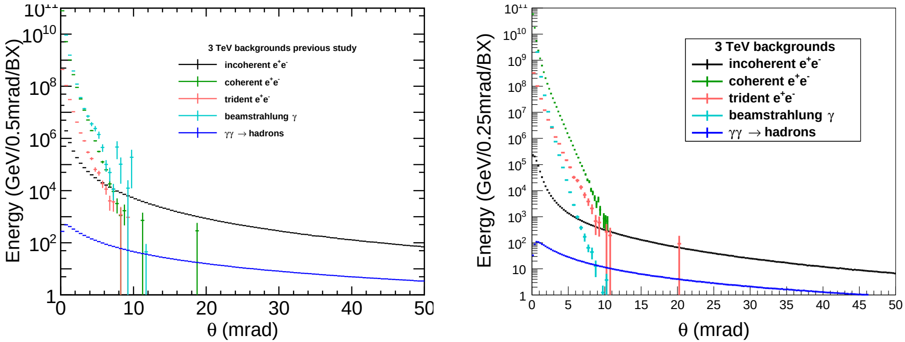
- There are 300kk coherent pairs at 3 TeV, with the distribution described above the energy deposition would be 175 GeV/BX
- Coherent pairs production is strongly suppressed at lower energy stage and no coherent pairs have been observed

Backgrounds' angular energy distribution at 3 TeV



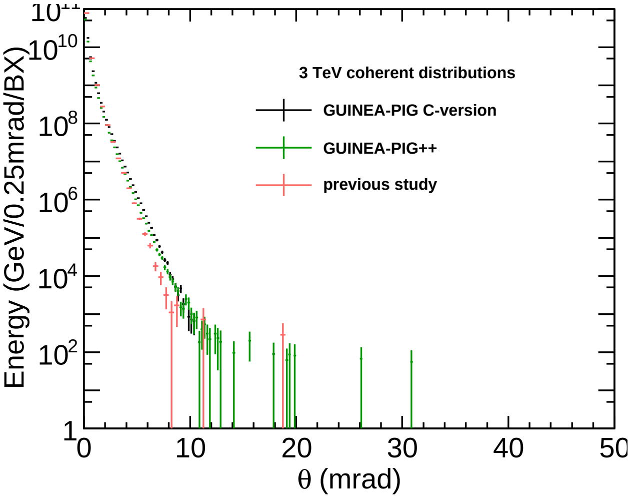
- It was found that some of the data used in the previous study was coming from both GUINEA-PIG C and C++ versions while new results are strictly C++ -only
- The previous results can be reproduced by turning off the energy loss of coherent particles and excluding bremsstrahlung photons from the photon beams

Backgrounds' angular energy distribution at 3 TeV



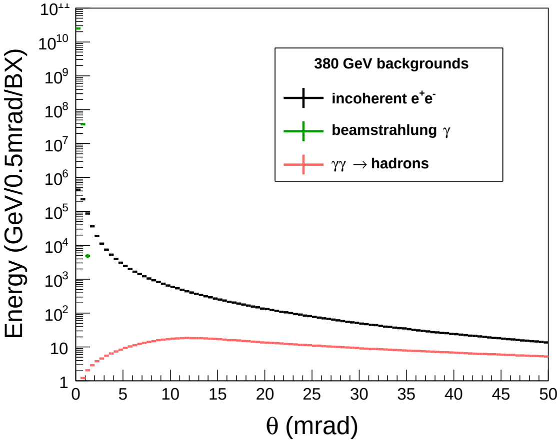
- When C version is used to obtain beamstrahlung and coherent pairs distributions the results are more comparable
- In addition, no energy loss was imposed on coherent pairs and no bremsstrahlung photon were produced
- Distributions are suddenly cut at around 10 mrad in comparison to more smooth descent in GUINEA-PIG++

Coherent pairs' angular energy distribution at 3 TeV



- All versions predict comparable yields of coherent pairs, the only difference laying in single particles with higher polar angles

Backgrounds' angular energy distribution at 380 GeV



- The only significant source of direct background at this energy are incoherent e^+e^- pairs

Summary

- All major types of backgrounds' distributions have been presented for both 380 GeV and 3 TeV stages of CLIC
- Significant differences in angular distributions of coherent pairs and beamstrahlung photons have been found between C and C++ versions of GUINEA-PIG
- If GUINEA-PIG C++ results are correct the occupancies in BeamCal and LumiCal may be too high and a change in the design proposed

Outlook

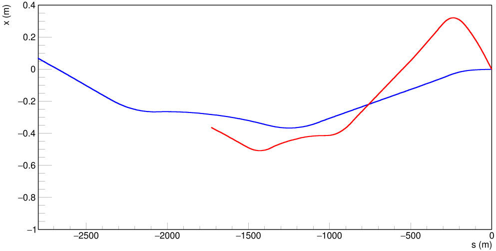
Future works:

- Study energy depositions and occupancies in further detail
- Analyze the beam halo effects at 380 GeV and its impacts on the detector design

Thank you!

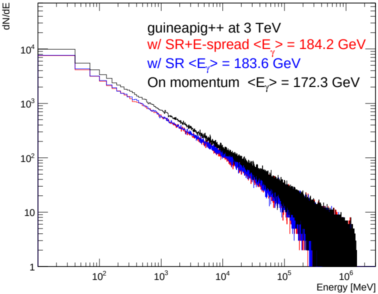
Backup

Beam delivery system design



- How much of the beamline is needed for a reliable study of synchrotron radiation impact on the detector or the IP? Prelimary assumption: simulate the straight part from the last sbend on.
- 380 GeV, $L^* = 4.3$ m design: 15.65 m, containing: QD0, OCTD0, SD0, DEC0, QF1, OCT1 and SF1
- 3 TeV, $L^* = 3.5$ m design: 14.21 m, containing: QD0, DD0, SD0, QF1, OCTF1 and SF1

SR and energy spreads impact on beamstrahlung's spectra at 3 TeV



- On momentum beam creates more photons in medium- and low-energy region, leading to an average energy lower by 6%
- Synchrotron radiation's presence has the biggest impact on beamstrahlung photons' average energy
- The addition of the energy spread leads to no significant change in beamstrahlung's spectra