Beam-induced backgrounds in 380 GeV CLIC

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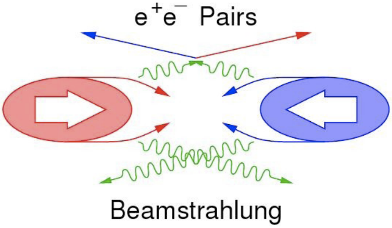
Overview

Motivation

- Due to constraints coming from beam tuning and detector construction a decision has been made to study the impact of moving the last quadrupole of the Final Focus System outside of the detector
- The L* value change influence on the beam-induced backgrounds and luminosity spectra has to be assesed
- Synchrotron radiation emitted in Final Focus System may cause direct hits and its distribution in the IP region has to be known
- Good knowledge of unwanted particles creation is required for a quality detector design and future precise physics studies

Beam-induced backgrounds overview



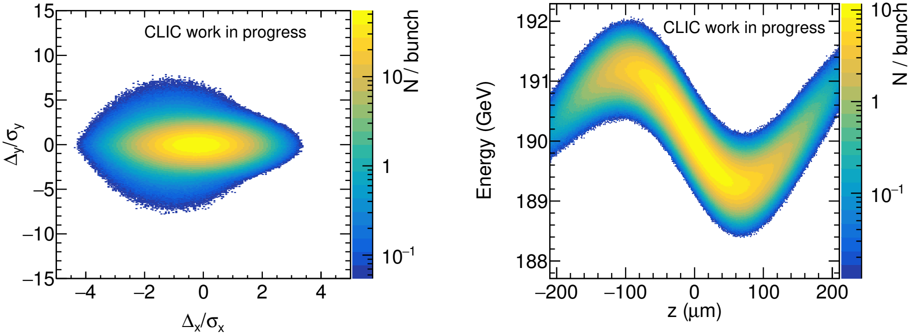
- Synchrotron radiation is created in strong focusing magnets of the Final Focus System
- Beamstrahlung photons, another type of synchrotron radiation caused by charged particles' interactions with the electromagnetic field of the incoming beam, are produced in large quantities and with high energies

- This emission 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: incoherent pairs, hadrons, coherent pairs and trident cascades (for $\sqrt{s} > 1$ TeV)

Analysis environment

- Most recent versions of PLACET, GUINEA-PIG, and DD4hep/lcgeo were used, although with custom modifications
- PLACET, a beam tracking code, was modified to enable extraction of synchrotron radiation photons produced in magnets
- GUINEA-PIG, software that brings the beams into collisions and simulates background creation, was modified to implement extraction of beamstrahlung photons at the end of tracking instead of at the creation point
- DD4hep provided tools to transport background particles through the CLIC detector model on the Grid and which was managed by iLCDirac

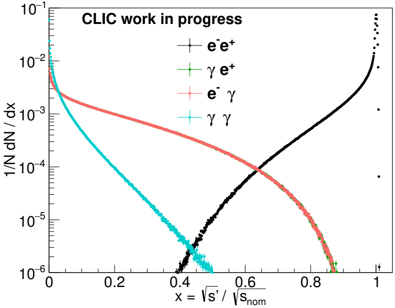
Beam distributions at 380 GeV with L* = 6 m



design	σ_x (nm)	σ_y (nm)
baseline 380 GeV	149.0	2.9
PLACET 380 GeV L*=4.3 m (core)	147.8	2.96
PLACET 380 GeV L*=6.0 m (core)	150.0	3.35

- Beam transported through the BDS with larger L* is 13% larger in vertical direction
- Energy spread shape from the Main Linac has been used throughout the entire study

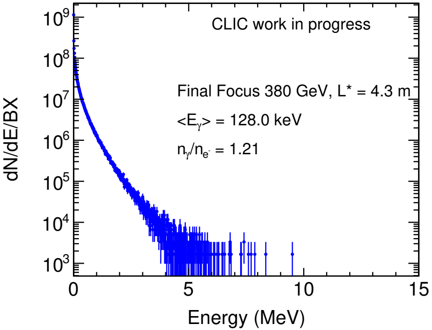
Luminosity spectra at 380 GeV with L* = 6 m

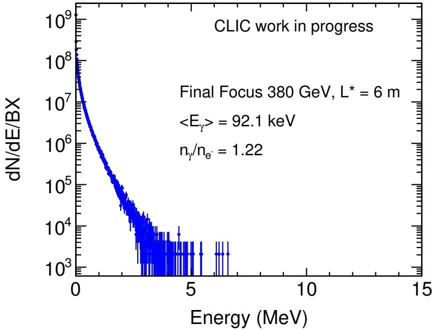


- The total luminosity is lower by 8% and the peak one is lower by 10%
- In both cases the peak luminosity is close to 60% of the total value

design	$\mathcal{L}_{total}$ $(x10^{34}\text{cm}^{-2}\text{s}^{-1})$	$\mathcal{L}_{0.01}$ $(x10^{33}\text{cm}^{-2}\text{s}^{-1})$
baseline 380 GeV	1.5	9.0
PLACET 380 GeV L*=4.3 m (core)	1.55	9.1
PLACET 380 GeV L*=6.0 m (core)	1.42	8.2

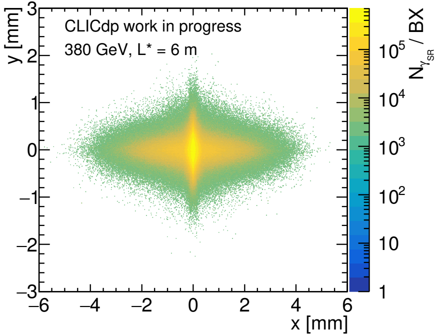
Synchrotron radiation energy spectra

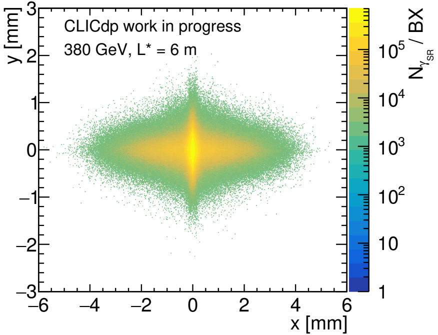




- Only the photons coming from the Final Focus System had been taken into account, and energies were recorded at the emission point
- The longer Beam Delivery System does not results in a different number of synchrotron radiation photons produced in Final Focus System
- The photons produced in shorter BDS tend to have 40% higher

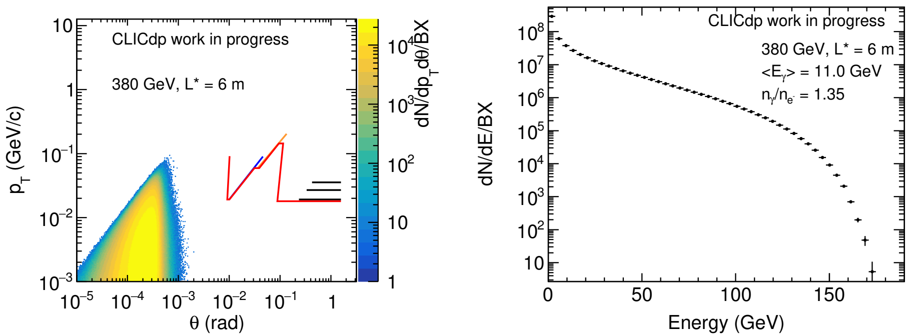
Synchrotron radiation distributions in IP region





- Only the photons coming from the FFS have been included and extrapolated to the IP region
- The SR spot size in the IP region is larger in the extended L* design
- SR photons do not cause any direct hits in the detector region

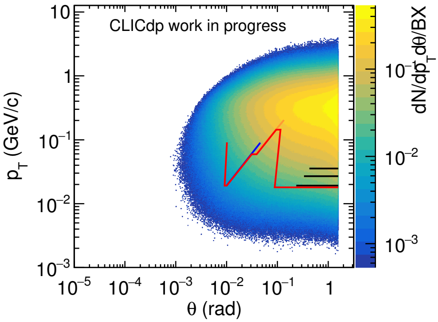
Beamstrahlung photons overview



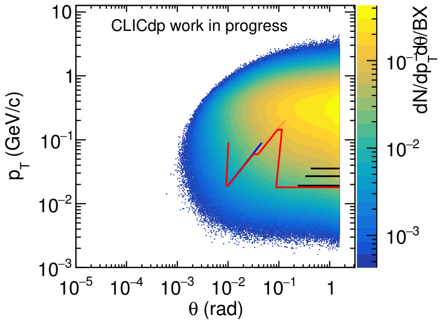
- The amount of produced beamstrahlung photons and their average energies are almost identical between the two designs
- Beamstrahlung photons are not a source of direct background

$\gamma\gamma \rightarrow$ hadrons overview

380 GeV L* = 4.3 m

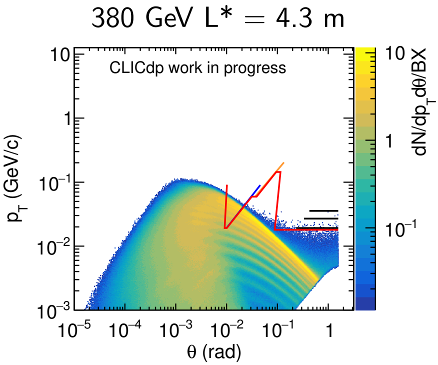


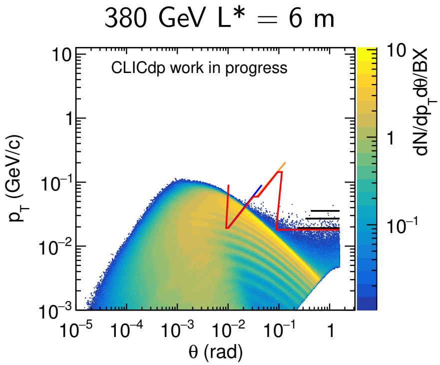
380 GeV L* = 6 m



- There are 0.18 $\gamma\gamma \rightarrow$ hadron events per BX at 380 GeV in L* = 4.3 m design, and 0.17 for the longer one
- Over 90% of produced hadrons have transverse momentum high enough to reach the subdetectors and are one of the major sources of direct background and occupancies

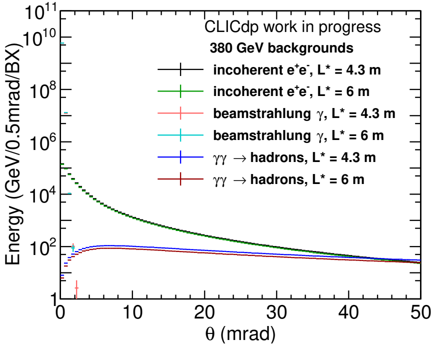
Incoherent pairs overview





- There are on average 90k incoherent pairs per bunch crossing at 380 GeV in L* = 4.3 case, and 84k for the longer design
- In both cases only around 9% of the incoherent pairs can be a source of direct background in the forward detector region, especially BeamCal

Backgrounds' angular energy distributions



- Incoherent pairs and $\gamma\gamma \to$ hadron events are the only significant source of direct background at this energy stage

- Angular distributions of backgrounds are almost identical in both designs
- The L* $= 6$ m one offers a minimally lower yield of $\gamma\gamma \to$ hadrons events

Backgrounds hits distribution

detector element	L* = 4.3 m (N_{hits}/BX)		L* = 6 m (N_{hits}/BX)	
	$\gamma\gamma \rightarrow$ hadrons	e^+e^- pairs	$\gamma\gamma \rightarrow$ hadrons	e^+e^- pairs
BeamCal	20.3	$5.33 \cdot 10^5$	20.8	$4.74 \cdot 10^5$
ECal barrel	13.1	57.2	12.1	51.7
ECal endcap	35.6	77.8	33.1	71.7
HCal barrel	2.32	2.03	2.15	1.84
HCal endcap	39.5	$1.53 \cdot 10^4$	38.0	$1.35 \cdot 10^4$
LumiCal	24.1	$1.36 \cdot 10^3$	22.9	$1.21 \cdot 10^3$
Inner Tracker barrel	4.14	40.2	3.76	35.9
Inner Tracker endcap	7.54	88.5	6.95	78.3
Outer Tracker barrel	1.45	34.2	1.33	30.1
Outer Tracker endcap	1.99	30.8	1.83	27.7
Vertex barrel	5.57	$2.11 \cdot 10^2$	5.07	$1.97 \cdot 10^2$
Vertex endcap	2.87	87.3	2.65	77.9

- The background particles are boosted in the beam direction and mostly influence the forward detector part, irradiating BeamCal, LumiCal and calorimeters' endcaps
- the longer L* design offers lower number of hits from both sources in all subdetectors

Summary and outlook

- When the design transition is made from L* = 4.3 m to L* = 6 m, CLIC loses 8% in total, and 10% in peak luminosities
- Beamstrahlung distribution does not change in any significant way and is not a source of direct background
- In the new nominal design there are less incoherent pairs produced and slightly fewer $\gamma\gamma \rightarrow$ events
- The biggest source of direct background is the incoherent pairs, irradiating mostly BeamCal with 500k hits/BX

Future works:

- Estimate the occupancies for all detector's sensitive elements
- Analyze the synchrotron radiation production in FFS at 380 GeV including the possible reflection against the beampipe and its impact on the detector design

Thank you!

Backup

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 $\gamma\gamma \to$ 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

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 presentation: https://indico.cern.ch/event/632420