Update on backgrounds and occupancies in CLICdet

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Acknowledgements:
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CLICdp detector optimisation and validation meeting

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Overview

Motivation:

1. Motivation

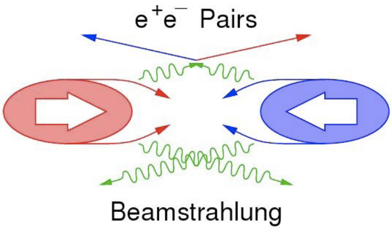
Study goals

- Obtain the beam-induced background yields and their distributions at all energy stages as good knowledge of unwanted particles creation is required for a quality detector design and precise physics studies
- Estimate the arising occupancies in tracking detectors and calorimeters, if they are found to be too high it may trigger a change in the detector design
- Provide information about luminosity spectra and their quality for different Beam Delivery System (BDS) designs required by physics studies, e.g. top quark mass measurement via threshold scan

Introduction:

2. Introduction
   - Backgrounds creation
   - Analysis workflow

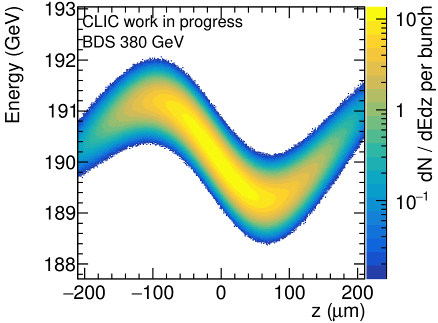
Background creation



- 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 workflow

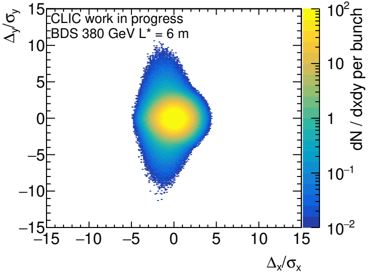


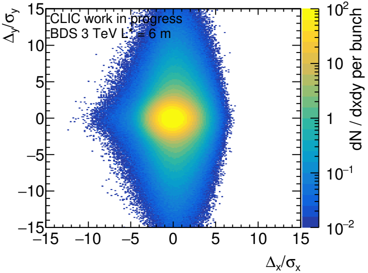
- Beams are created at the beginning of the Beam Delivery System with energy spread coming from the Main Linac
- Then they are transported through the BDS using PLACET; the emitted synchrotron radiation photons are stored in text files for further analysis

- Finally the electron and positron beams are used to create the backgrounds in Guinea-Pig
- The background text files can be translated to .slcio files and embedded in CLICdet model using DD4hep/lcgeo
- Additional step is necessary for $\gamma\gamma \to$ hadrons, where Pythia6.4 is used to fragment strings coming from Guinea-Pig

Beam parameters and luminosity:

Beam distributions at IP



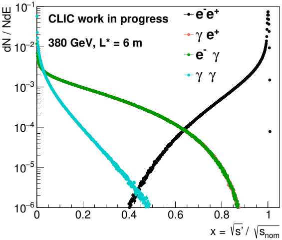


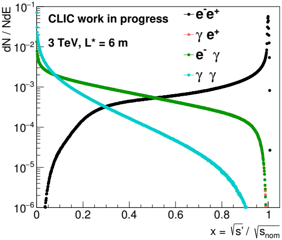
design	σ_x (nm)	σ_y (nm)
baseline 380 GeV	149	2.9
PLACET 380 GeV L*=6 m (core)	151.8	3.0
PLACET 350 GeV L*=6 m (core)	157.4	3.2
baseline 3 TeV	40	1.0
PLACET 3 TeV L*=6 m (core)	48.6	1.2

- Beam size in the 350 GeV design is slightly larger, and at 3 TeV is significantly (20%) larger than expected

- The core is well contained in $3\sigma_x \times 3\sigma_y$ surface for 380 GeV and 350 GeV designs with 99.99% of particles inside, while at 3 TeV it is only 96.4%

Luminosity distributions at 380 GeV and 3 TeV





design	$\mathcal{L}_{total}$ $(x10^{34} \frac{1}{\mathrm{s\ cm^2}})$	$\mathcal{L}_{0.01}$ $(x10^{34} \frac{1}{\mathrm{s\ cm^2}})$
baseline 380 GeV	1.5	0.9
PLACET 380 GeV L*=6 m	1.51	0.88
PLACET 350 GeV L*=6 m 'standard'[1] option	1.39	0.83
PLACET 350 GeV L*=6 m 'alternative'[2] option	1.08	0.68
baseline 3 TeV	5.9	2.0
PLACET 3 TeV L*=6 m	6.25	2.24

- The luminosity in 380 GeV design is in agreement with the baseline values, while at 3 TeV there is a 5-12% safety margin for static and dynamic imperfections

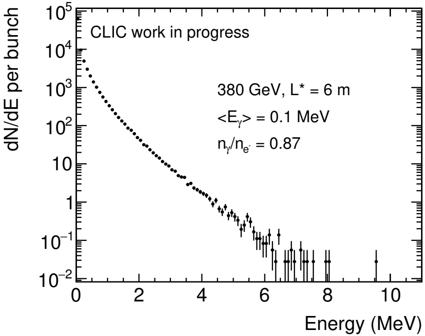
[1] 380 GeV nominal parameters running at 350 GeV

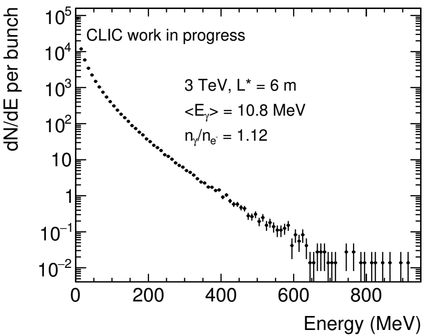
[2] Beam with 90% of the charge and 110% of length, lowered energy spread

Backgrounds distributions:

4. Backgrounds distributions
   - Synchrotron radiation
   - Beamstrahlung photons
   - $\gamma\gamma \rightarrow$ hadrons
   - Incoherent pairs
   - Coherent pairs and trident cascades

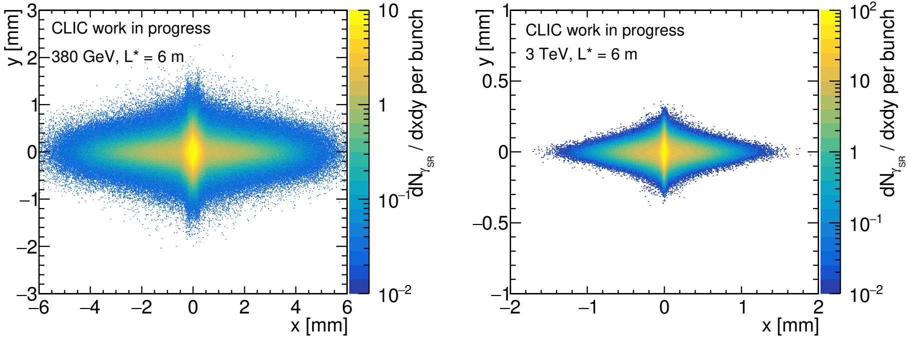
Synchrotron radiation energy spectra





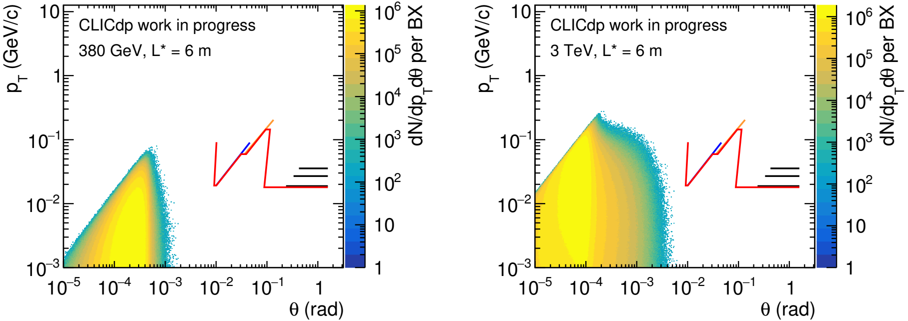
- Only photons coming from the last straight part of the Final Focus System have been included
- The energy has been recorded at the emission point
- The average energy of emitted synchrotron radiation increases by a factor of 100 at the higher energy stage

Synchrotron radiation distributions in IP region



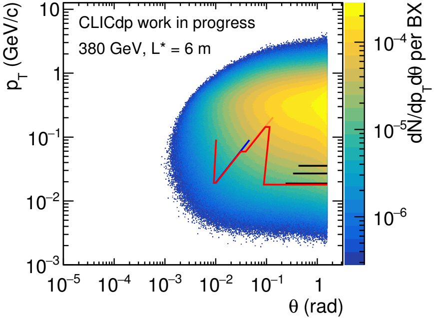
- Only photons coming from the Final Focus System have been included and extrapolated to the IP region
- There are no direct hits coming from synchrotron radiation produced in the FFS
- The results do not take into account any photon interactions with matter, e.g. reflections from the beampipe

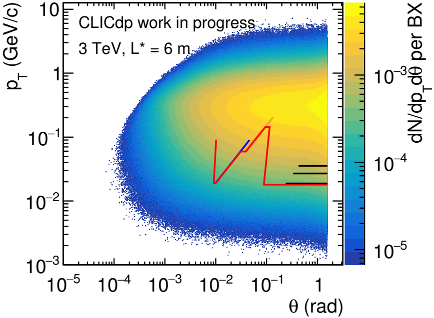
Beamstrahlung energy spectrum



- Beamstrahlung, as required by design, is not a source of direct background in the detector
- There are 1.4 beamstrahlung photons per electron at 380 GeV, 1.35 (1.2 in the 'alternative' option) at 350 GeV, and 2.1 at 3 TeV

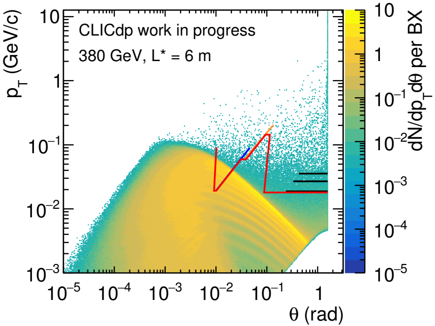
$\gamma\gamma \to$ hadrons overview





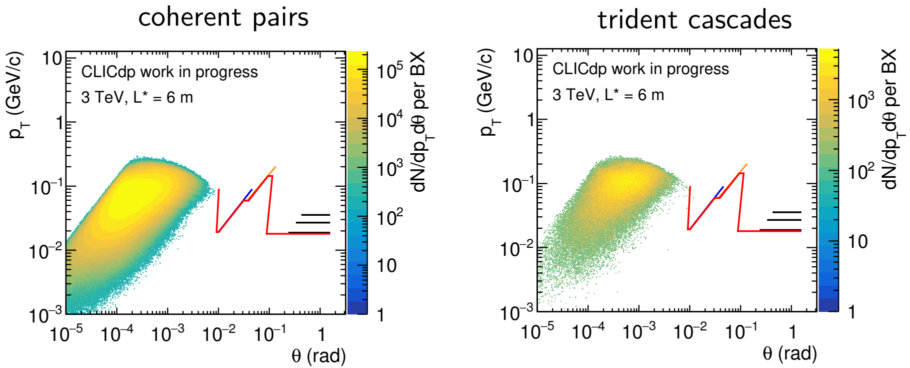
- Over 90% of produced hadrons have transverse momentum high enough to reach the barrel region and thus they are one of the major sources of direct background and occupancies
- There are 0.17 $\gamma\gamma \to$ hadron events per BX at 380 GeV, 0.15 (0.11) at 350 GeV and 3.1 at 3 TeV

Incoherent pairs overview



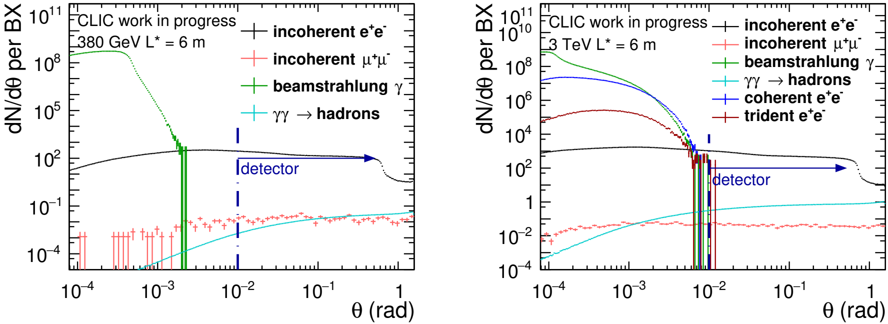
- There are on average 46k incoherent pairs per bunch crossing at 380 GeV, 42k (31k) at 350 GeV, and 280k at 3 TeV
- In all cases only around 10% of the incoherent pairs are a source of direct background, mostly in the forward detector region, irradiating BeamCal and LumiCal subdetectors

Coherent pairs and trident cascades at 3 TeV



- There are on average $1.6 \cdot 10^9$ coherent pairs per bunch crossing at 3 TeV, $L^* = 6$ m in comparison with $6.8 \cdot 10^8$ value from the CDR
- In addition, there are $2 \cdot 10^7$ trident cascades per bunch crossing
- The coherent pairs do not introduce direct background in the detector although some trident cascades may cause limited depositions in the BeamCal

Backgrounds' angular distributions



- Incoherent pairs and $\gamma\gamma \rightarrow$ hadron events are the only significant source of direct background at this energy stage
- Trident cascades and coherent pairs are boosted in the forward direction and do not cause any direct hit in the detector at 3 TeV

Occupancy estimation:

5 Occupancy estimation

Tracking detector occupancies

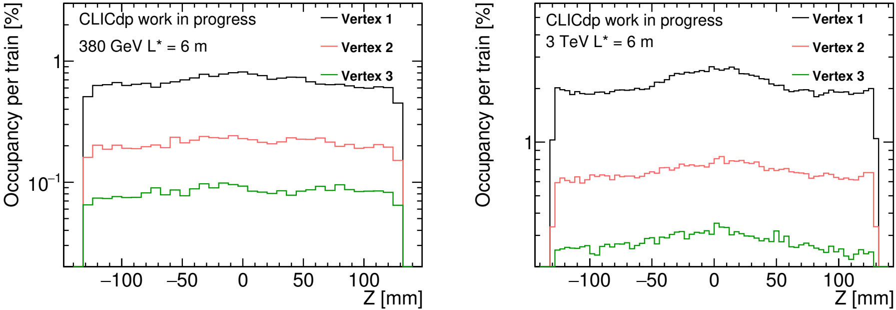
Tracking detectors read-out occupancy definition used in this analysis:

$$Occupancy/train = \sum_{proc} Hits_{proc}/(mm^2 \cdot n_{BX}) \cdot n_{bunches/train} \cdot p \cdot l \cdot cs \cdot sf_{proc} \,, \quad (1)$$

where:

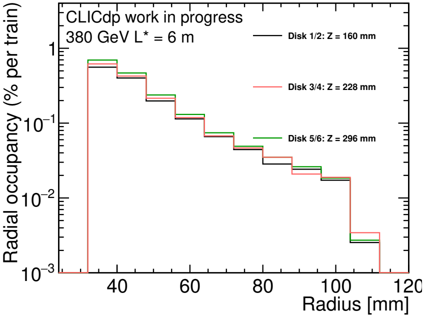
- p is granularity in the transverse direction (pitch)
- l is sensitive element's length (pixel's or strixel's)
- cs is the average number of readout cells responding to each hit (cluster size), used 5 for vertex and 3 for tracker
- sf are safety factors for uncertainty of simulation results: 5 for incoherent pairs, 2 for $\gamma\gamma \rightarrow$ hadrons events
- Cut-off energy deposition are 6.4 keV for tracker's sensors and 3.2 keV for vertex pixels

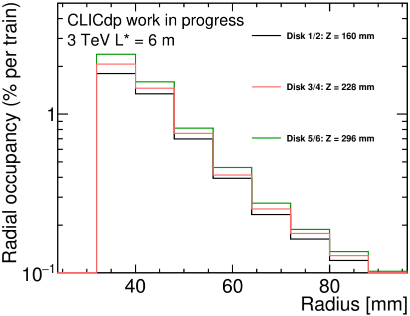
Vertex detector occupancies - barrel region



- The highest occupancies are present in the first layer of Vertex detector
- All detector layers are well below the maximum readout occupancy of 3%

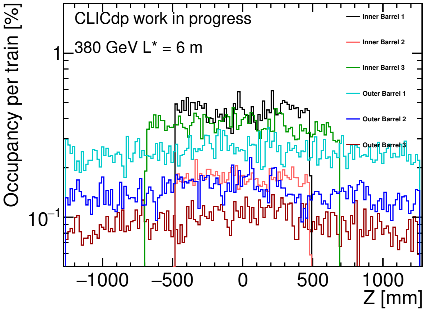
Vertex detector occupancies - endcaps region

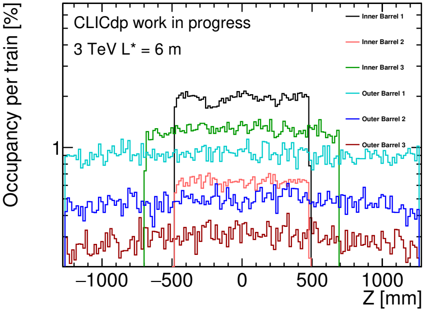




- The highest occupancies are present in the first layer of Vertex detector
- The endcaps see less occupancy than the barrel region
- All detector layers are well below the maximum readout occupancy of 3%

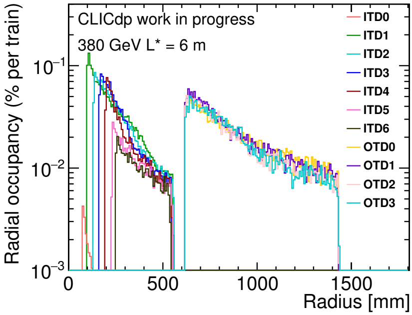
Tracking detector occupancies - barrel region

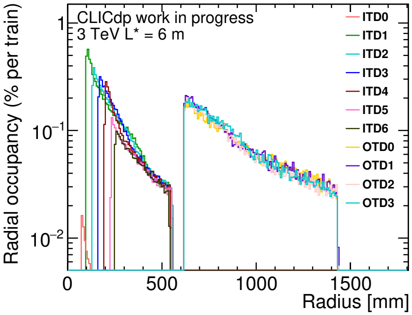




- The highest occupancies are present in the first layer of Vertex detector
- All detector layers are well below the maximum readout occupancy of 3%

Tracking detector occupancies - endcaps region



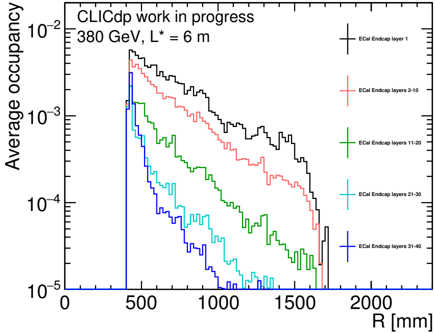


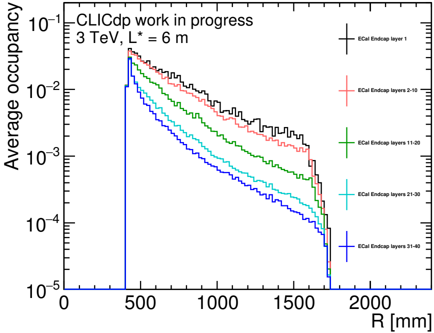
- The highest occupancies are present in the first layer of Vertex detector
- Tracker's endcaps see have lower occupancies than the barrel region
- All detector layers are well below the maximum readout occupancy of 3%

Calorimeteres occupancies

- Calorimeter readout time per bunch train is separated into 12 windows, each 25 ns long
- Occupancy of a cell is defined as a number of time windows with energy deposition above threshold
- Threshold energy is 40 keV for ECal and 300 keV for HCal

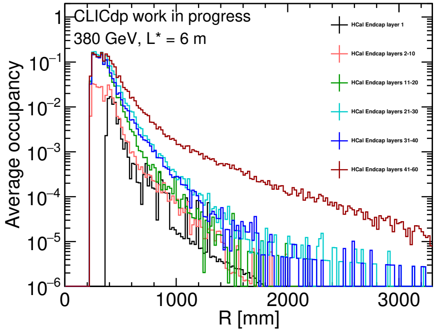
ECal endcap occupancies

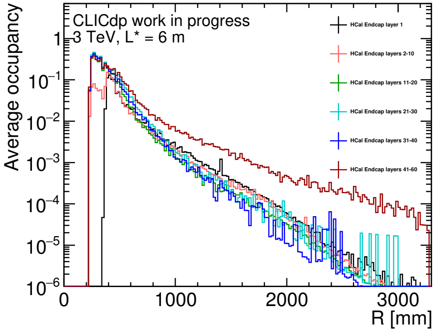




- Radial distribution shows the average occupancy among cells contained in certain radius
- The incoherent pairs and $\gamma\gamma \rightarrow$ hadrons events are plotted together
- The biggest source of occupancy are the incoherent pairs
- Occupancies at 380 GeV are an order of magnitude below the 3 TeV level

HCal endcap occupancies





- HCal suffers from higher occupancies than ECal
- Layers 41-60 have the highest background yield, coming from scattering in the BeamCal region

Summary and outlook:

6 Summary and outlook

Summary and outlook

- All major types of beam-induced backgrounds along with the occupancy distributions have been presented for two main energy stages of CLIC, they can be also found at CLIC Beam-beam webpage
- The main sources of direct background are incoherent pairs and $\gamma\gamma \rightarrow$ hadrons events
- The longer L* designs at 380 GeV and 3 TeV reach the nominal luminosity, unclear about the 350 GeV as the quality is more important
- The direct synchrotron radiation, without taking into account photon reflections, is not causing hits in the detector region
- In all tracking detectors the read-out occupancies are below the required 3% mark per bunch train; at 380 GeV there is room for changes in beampipe design if necessary

Outlook

Future works:

- Analyze the synchrotron radiation production in Final Focus System at 380 GeV including the possible reflection against the beampipe and its impact on the detector design
- Create a Synrad+ model of CLIC Final Focus
- Obtain apertures of the vacuum system in the FFS for input to the synchrotron radiation study
- Look into using or developing other software (BDSim, MDISim) for benchmarking

Thank you!

Backup

Analysis environment

- Recent versions of PLACET, GUINEA-PIG (C++ 1.2.1), and iLCSoftware (Nov 15) 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 provide more information about produced beamstrahlung photons at the end of tracking
- DD4hep/lcgeo provided the tools to transport background particles through the DD4hep CLIC_o3_13 detector model on the Grid and which was managed by ILCDirac

PLACET – overview

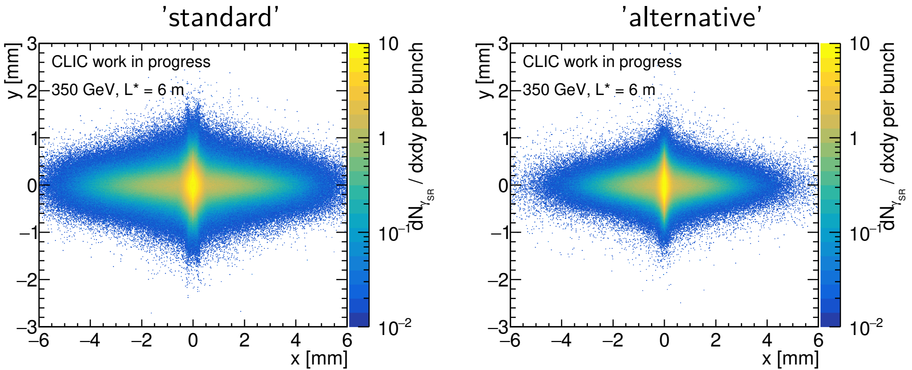
- Program to simulate the dynamics of a beam in the presence of wakefields
- Allows one to investigate single and multibunch effects in bending, quadrupole and multipole magnets and accelerating (decelerating) cavities
- Beam can be represented as slices with only tranverse motion or macroparticles with 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 recent presentation: https://indico.cern.ch/event/632420

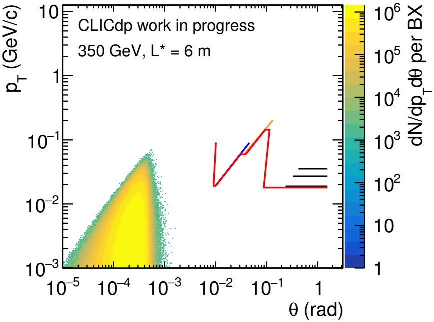
Synchrotron radiation distributions in IP region



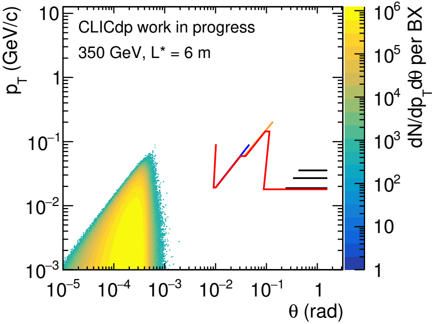
- SR beam spot size at IP is larger when the machine runs with nominal 380 GeV parameters
- There are no direct hits coming from synchrotron radiation produced in the FFS
- The results do not take into account any photon interactions with matter, e.g. reflections from the beampipe

Beamstrahlung energy spectrum at 350 GeV

'standard'



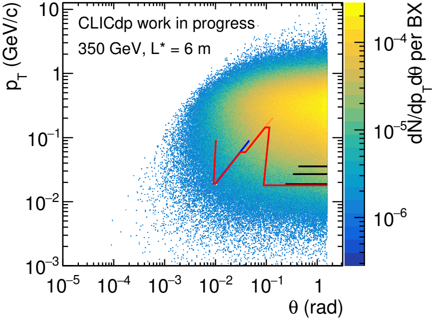
'alternative'



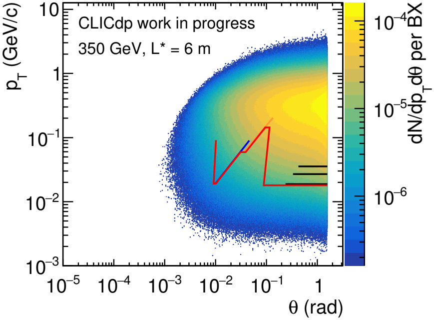
- Beamstrahlung photons distributions are in agreement between the two options
- The 'standard' one has a slightly higher number of photons per particle: 1.35 vs. 1.23 (10% increase)

$\gamma\gamma \rightarrow$ hadrons overview at 350 GeV

'standard'

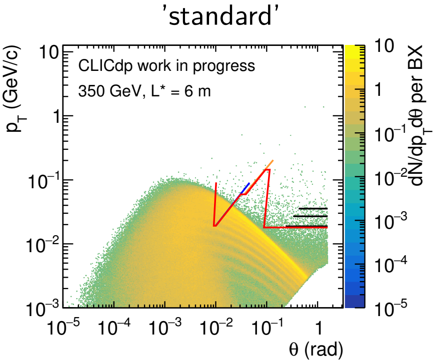


'alternative'



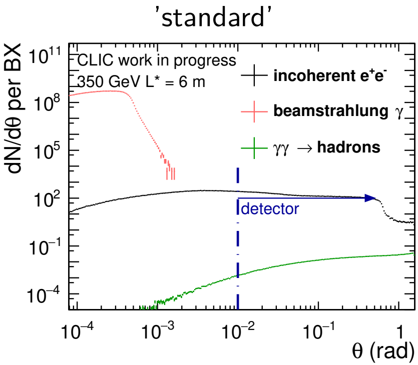
- $\gamma\gamma \rightarrow$ hadrons distributions are in agreement between the two options
- The 'standard' one has a higher number of events per bunch crossing: 0.15 vs. 0.11 (36% increase)

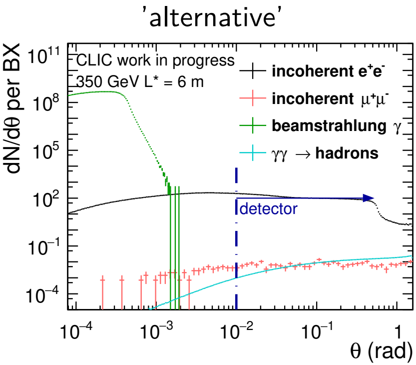
Incoherent pairs overview at 350 GeV



- Incoherent pairs distributions are in agreement between the two options
- The 'standard' one has a higher number of photons per particle: 42k vs. 31k (35% increase)

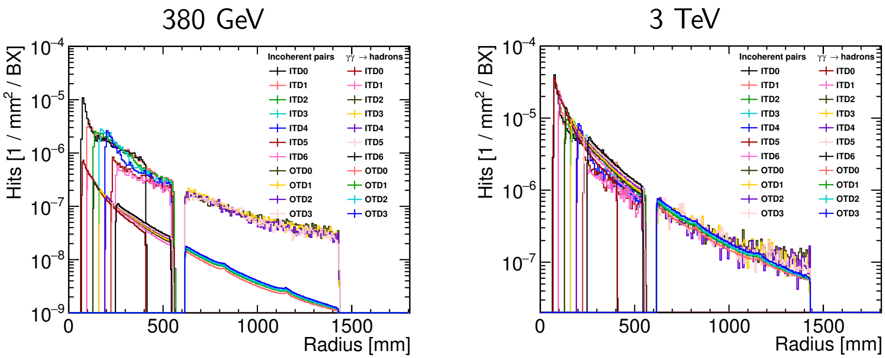
Backgrounds' angular distributions at 350 GeV





- Incoherent pairs and $\gamma\gamma \rightarrow$ hadron events are the only significant source of direct background at this energy stage
- Both designs provide comparable background yield in the detector region
- Muons have not been included due to low statistics available

Tracking detector hit densities - endcaps region



Tracking detector hit densities - endcaps region