Beam induced backgrounds and occupancies in CLICdet

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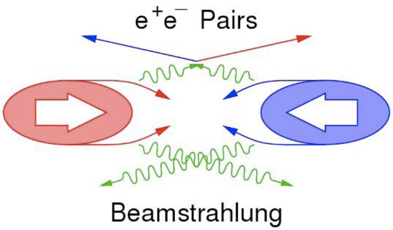
Overview

Motivation

- Obtain the beam-induced background yields and their distributions at all energy stages relevant to CLIC, 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

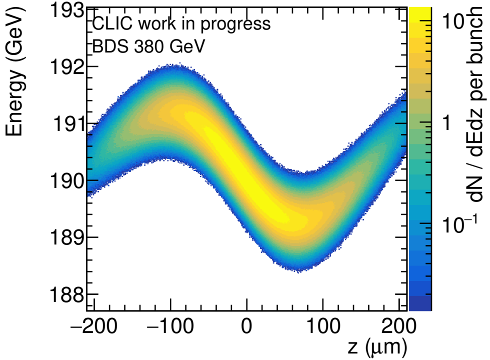
Background creation



- Synchrotron radiation is created in strong focusing magnets of the Final Focus System and can travel downstream along the beam
- 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)

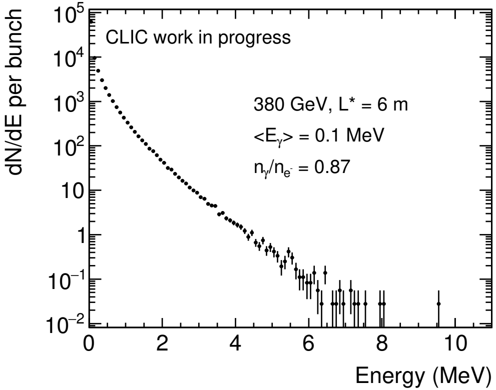
Analysis workflow - assumptions and software

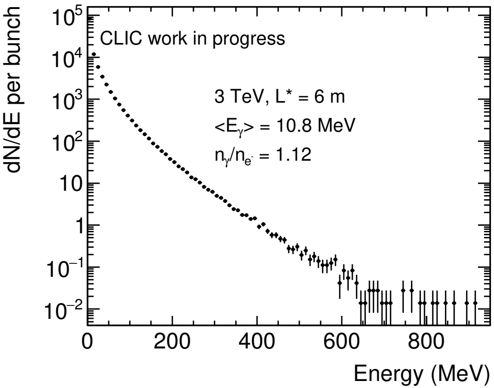


- Beams are created at the beginning of the Beam Delivery System with energy spread coming from the Main Linac
- The most recent designs of BDS with $L^* = 6$ m are used, more on BDS in Fabien Plassard's talk: CLIC BDS with long L*
- Then beams are transported through the BDS using PLACET; the emitted synchrotron radiation photons are stored in text files for further analysis

- Finally the electron and positron beams are brought to collision using Guinea-Pig
- The background output files can be translated to .slcio files and embedded in CLICdet model
- Energy depositons and linked occupancies are simulated in DD4hep/lcgeo
- Additional step is necessary for $\gamma\gamma \rightarrow$ hadrons, where Pythia6.4 is used to fragment strings coming from Guinea-Pig

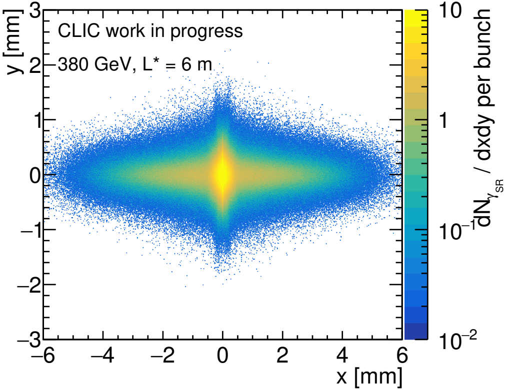
Synchrotron radiation energy spectra

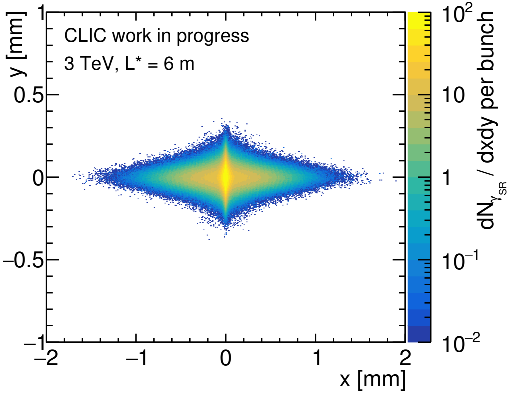




- Only photons coming from the last straight part of the Final Focus System have been included
- The energy has been recorded at the emission point
- The average energy of emitted synchrotron radiation increases by a factor of 100 at the higher energy stage

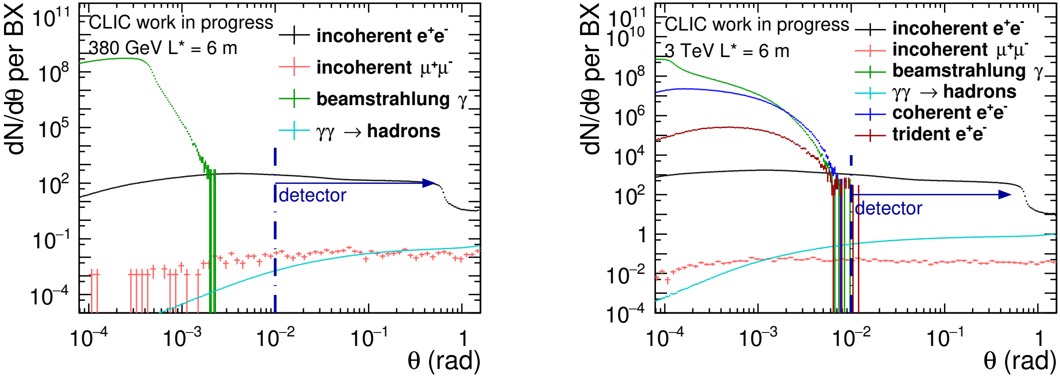
Synchrotron radiation distributions in IP region





- 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

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

Tracking detector occupancies

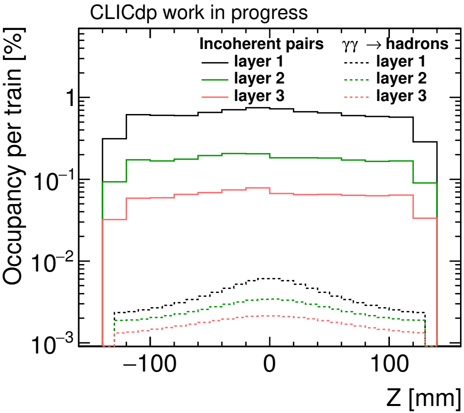
Tracking detectors read-out occupancy definition used in this analysis:

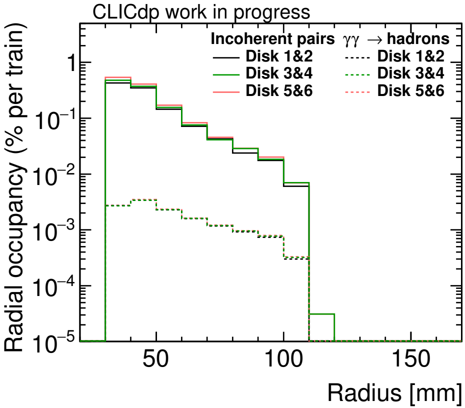
$$Occupancy/train = \sum_{proc} Hits_{proc}/(mm^2 \cdot n_{BX}) \cdot n_{bunches/train} \cdot p \cdot l \cdot cs \cdot sf_{proc} \;, \qquad (1)$$

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

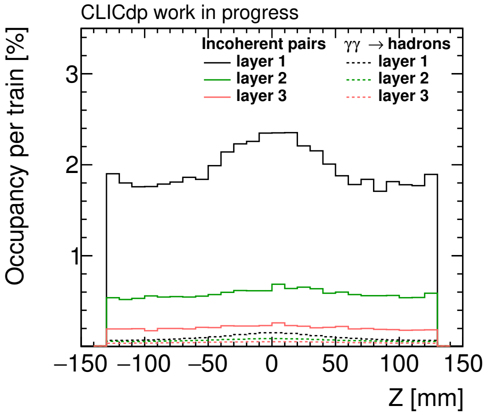
Vertex detector occupancies - 380 GeV

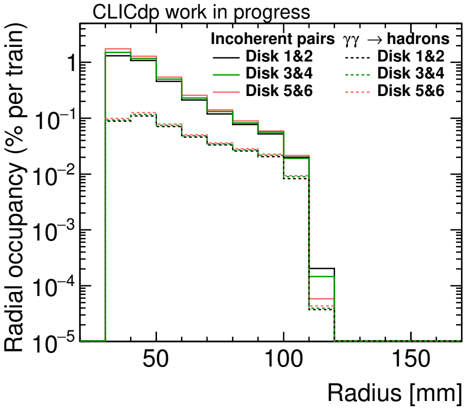




- The highest occupancies are present in the first layer of Vertex detector
- Half of the irradiation in the Vertex endcaps comes from backscattered particles from BeamCal and LumiCal

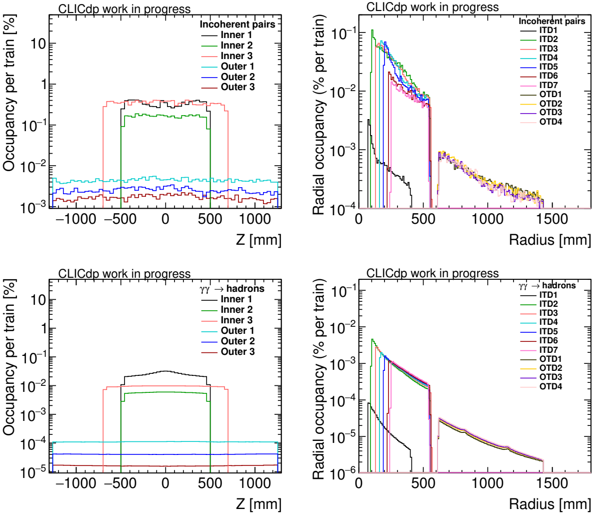
Vertex detector occupancies - 3 TeV





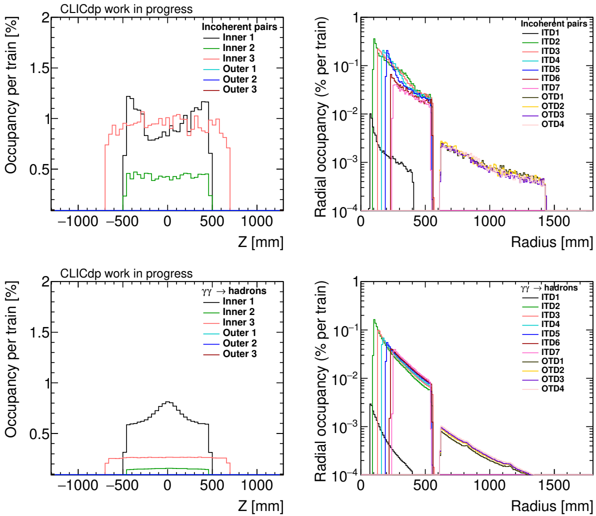
- The highest occupancies are present in the first layer of Vertex detector
- Combined effect of incoherent pairs and $\gamma\gamma \rightarrow$ hadrons give rise to high occupancies, close to the read out limit of 3%

Tracking detector occupancies - 380 GeV



- All detector layers are well below the maximum readout occupancy of 3%
- At this energy stage incoherent pairs dominate the observed occupancies
- Occupancies and irradiation of outer tracker layers are negligible
- First tracker disk sees much lower occupancies thanks to its high granularity 25x25 μm^2

Tracking detector occupancies - 3 TeV

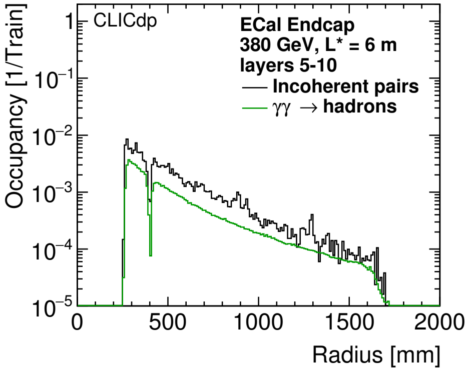


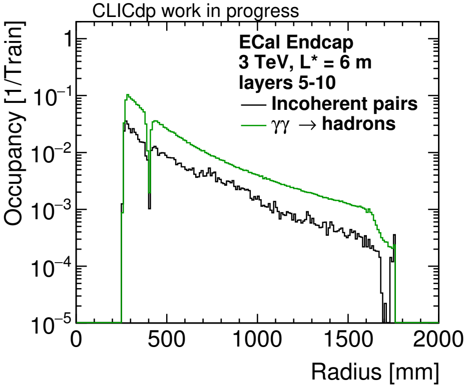
- All detector layers are below the maximum readout occupancy of 3%, although the inner tracker approaches the required limit
- $\gamma\gamma \rightarrow$ hadrons events have much higher impact at this energy stage
- Occupancies and irradiation of outer tracker layers are very low and are not going to impact the detector's performance significantly

Calorimeteres occupancies

- Initial assumption: calorimeter readout time per bunch train is separated into 8 windows, each 25 ns long, totaling 200 ns from the beggining of a train
- Occupancy of a cell is defined as a number of time windows with energy deposition above threshold
- Threshold energy is 0.5 MIP (40 keV) for ECal and 0.3 MIP (300 keV) for HCal
- ECal cell size is 5x5 mm^2 and HCal is 30x30 mm^2
- Occupancy of a detector is defined as an average number of saturated cells over full integration time
- Radial distribution will present the average occupancy among cells at given radius

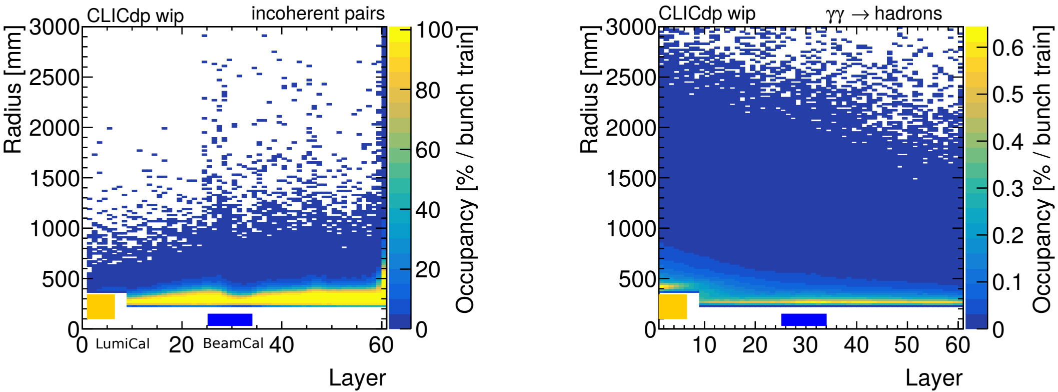
ECal endcap occupancies





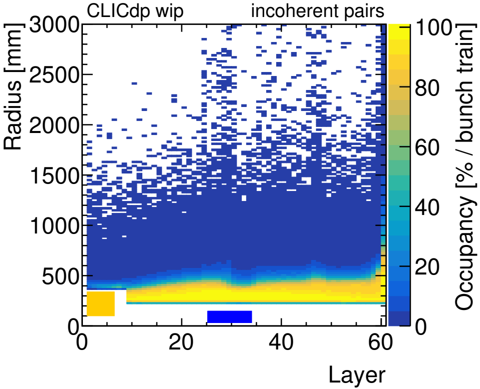
- Occupancies at 380 GeV are an order of magnitude below the 3 TeV level
- $\gamma\gamma \rightarrow$ hadrons events are more prominent at the higher energy stage
- No final requirements for occupancies in ECal prepared but they are generally low due to high granularity – not a show-stopper

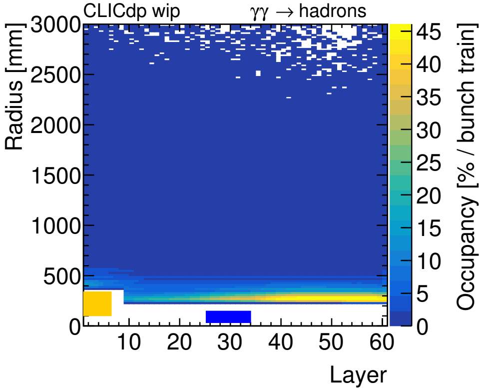
HCal endcap occupancies – 380 GeV



- HCal suffers from higher occupancies than ECal and is fully saturated in the lowest radius region
- Visible gap between ECal Endcap and ECal Plug in $\gamma\gamma \to$ hadrons occupancies
- Layers 20-25 and 35-60 at lowest radii have the highest background yield, especially coming from incoherent pairs' interactions with BeamCal material

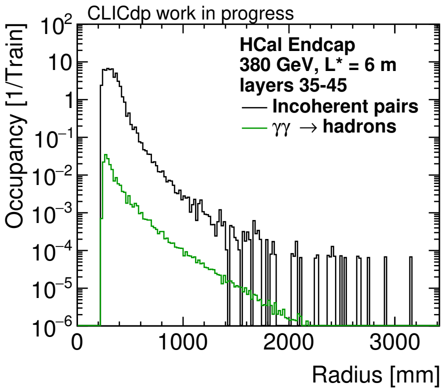
HCal endcap occupancies - 3 TeV

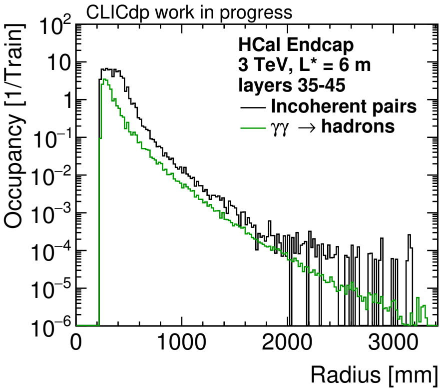




- HCal suffers from almost full saturation in radii below 400 mm
- Layers 41-60 see the highest background yield, coming from scattering in the BeamCal region
- $\gamma\gamma \rightarrow$ hadrons irradiation significant at this stage, has to be mitigated along with incoherent pairs

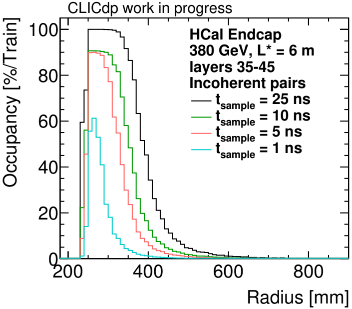
HCal endcap radial occupancies

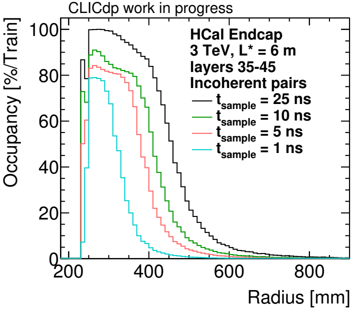


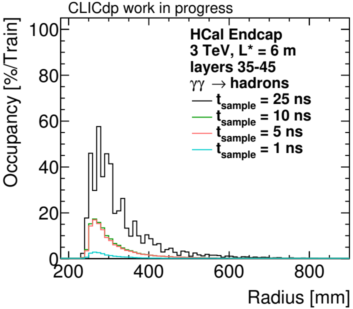


- The most irradiated regions are fully saturated with background particles, especially as a result of incoherent pairs interactions
- At 3 TeV $\gamma\gamma \rightarrow$ hadrons events saturate calorimeter almost at the same level as the incoherent pairs

HCal endcap occupancies - mitigation





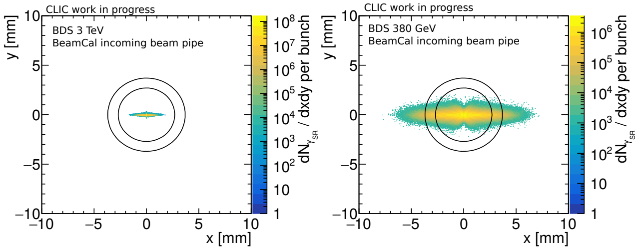


- High occupancy levels in the low radii region can be addressed through varying calorimeter's granularity, integration time of clusters, and shielding
- Varying cluster integration time lowers the occupancy while there is still a fully saturated region; the same technique used in ECal lowers occupancy $\propto N_{time\ windows}$
- Shielding with tungsten and polyethylene may strongly reduce the observed occupancy levels, at the cost of reduced acceptancy, more about shielding in: CLICdp-Note-2014-004

Beam pipe aperture estimation - requirements

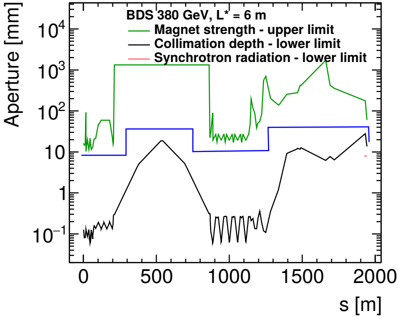
- Beam pipe apertures are needed for precise synchrotron radiation reflections study
- Aperture is limited by the use of warm magnets (max field at pole $\sim$ 1.5 T), collimation depth, beam stability and machine safety
- Collimation depth for 380 GeV machine assumed for now to be the same as for 500 GeV and 3 TeV CLIC: 15 σ_x and 55 σ_y from proceedings on Optimization of CLIC Baseline Collimation System

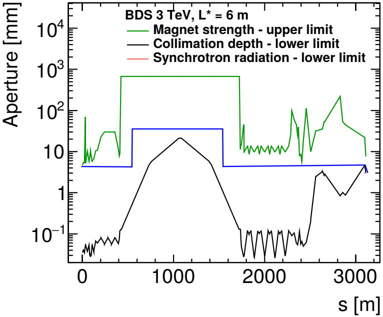
- Machine safety requires that no SR photon emitted from QF1 hits QD0 magnet of the final doublet; all direct SR photons should safely leave the detector without interacting with its material
- Beam pipe apertures should incur minimal impact on the bunch trains from resistive wall wakefields - still under study using PyHEADTAIL



Beam pipe aperture estimation - limits

- Using requirements decribed before and basing on previous studies first estimates at 380 GeV and 3 TeV can be given (blue line)
- Beam pipe aperture at 380 GeV should have approximately 10 mm radius and around 5-6 mm at 3 TeV, unless the magnet strengh requirements can be relaxed, e.g. towards maximum pole field of 1.8 T instead of 1.5 T
- Final results will requre knowledge about the impact of multibunch resistive wall wakefields





Summary

- The main sources of direct background are incoherent pairs at lower energy stage and also $\gamma\gamma \rightarrow$ hadrons events at 3 TeV
- The direct synchrotron radiation, without taking into account photon reflections, is not causing hits in the detector region
- Occupancies in tracker are below the required 3% mark per bunch train and do not pose a limiting factor on detector's performance
- Occupancies in the vertex are close to the maximal allowable occupancy
- ECal occupancies are generally low thanks to high granularity and limited secondary irradiation
- HCal occupancies are high in the region close to beam pipe; they are coming mostlyfrom incoherent pairs scattering in BeamCal
- More about backgrounds and their distributions in CLIC can be found on CLIC Beam-beam webpage

Outlook

Future works:

- Mitigate high occupancies in HCal
- Finalize the aperture estimation in the FFS for input to the synchrotron radiation study
- 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 Synrad+ and MDISim models of CLIC Final Focus
- Study CLICdet muon identification system and summarize the beam induced backgrounds study as a CLIC Note later this year