Impact of Background on the Detector

Occupancies and Radiation Levels

André Sailer

CERN-PH-LCD, Humboldt-Universität zu Berlin

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Table of Contents

Beam Induced Backgrounds

- Beam pipe half-opening angle is 10 mrad
- **Coherent pairs** leave detector inside beam pipe
- **Trident pairs** are orders of magnitude below incoherent pairs
- Only **incoherent pairs** and $\gamma\gamma \to$ **hadron events** studied for occupancies

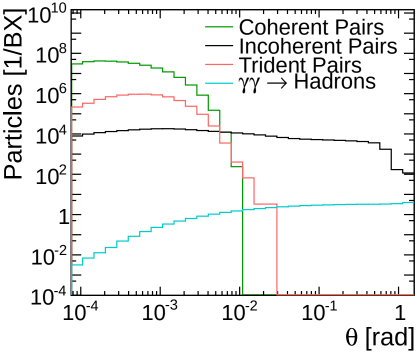
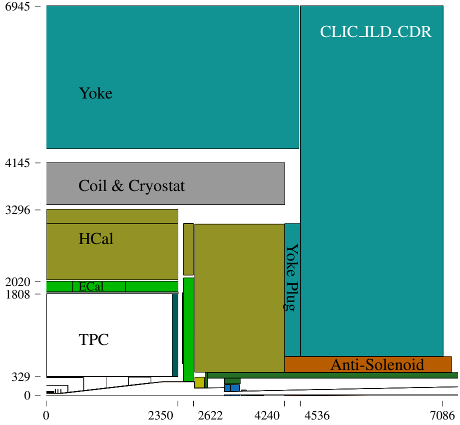


Fig. 2.2: Angular distribution of background particles

Simulation Parameter and Analysis

- Used CLIC_ILD_CDR detector model
- Fieldmap instead of uniform solenoid field ($B_Z = 4$ T)
- GEANT4 simulation with QGSP_BERT_HP physics list
- Recorded all particles
  - Passing through tracking detectors
  - Depositing energy in calorimeters
- LCD-Note-2011-021



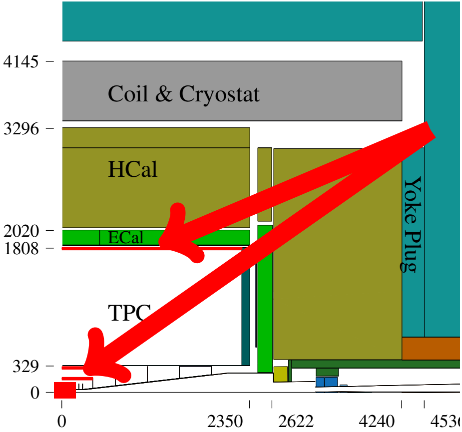
Quadrant of the CLIC_ILD_CDR detector

Hit Rates, Occupancies and Radiation Levels

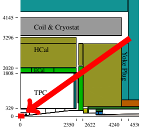
For tracking detectors

- Hit rates: Number of simulated hits divided by sensor surface
  - Applied 3.4 keV or 17 keV threshold for hit rates, depending on detector thickness
  - Plots not including safety factors
- Occupancies
  - Multiply hit rates with safety factors
    - Incoherent Pairs: 5
    - $\gamma\gamma \to$ Hadrons: 2
  - Multiply with cluster size per hit
    - Pixels: 5
    - Strips: 3
  - Pixel/Strip size depend on detector
- Total ionising dose (TID)
  - Sum up deposited energy and divide by mass of detector
- Non-ionising energy loss (NIEL)
  - Weight energies with damage factor relative to 1 MeV neutrons
  - Depend on particle kinetic energy and type
- Assuming 200 days with 50% running time

Barrel Like Silicon Detectors



Vertex Detector Occupancies



- Hit rate in the vertex detector, first layer: $6 \cdot 10^{-3}$ Hits/mm^2/BX
- Occupancy (including safety and cluster factor, $20 \times 20\ \mu$m^2 pixels): 2% per train

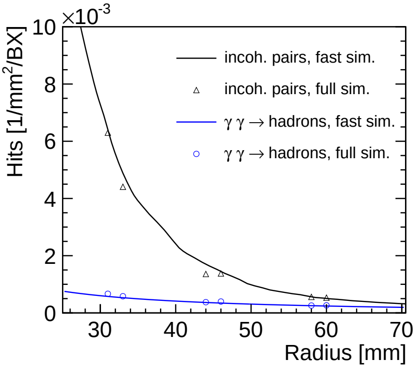
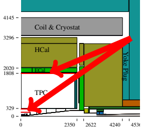


Fig. 4.9a: Hit rates in CLIC_ILD vertex barrel

Silicon Envelope: Occupancy



- Pairs/$\gamma\gamma \to$ hadron contributions similar
- Uniform along Z
- Resulting train occupancy in SIT1: 200%
  - Every strip with two hits per train
- SET: 13%
  - Back-scattering photons from BeamCal

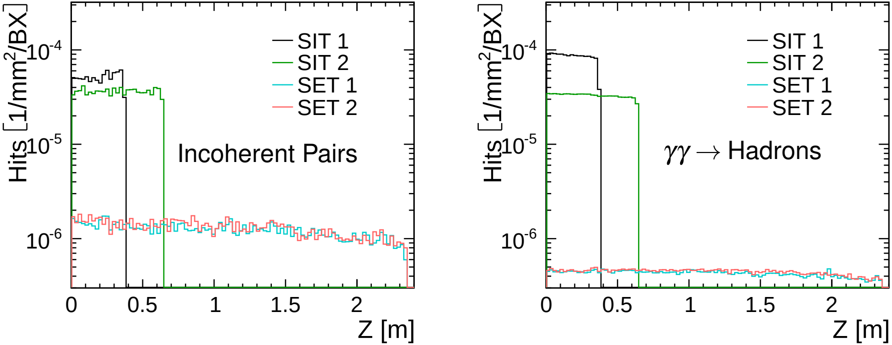
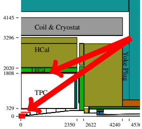
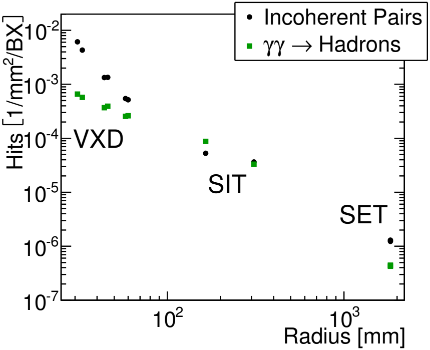


Fig. 5.7: Hit rates in SIT/SET along the length of the detector

VXD/SIT/SET Occupancy

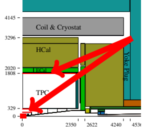


- Hit rates combination of p_T, magnetic field, and geometric effects
  - Slope between $R^{-2.4}$ to R^{-1}
- In SIT pairs and hadrons contribute similarly
- In SET back-scatters significant contribution to hit rates



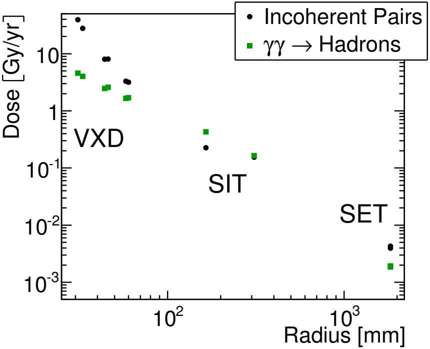
Hit densities in barrel silicon tracking detectors

Total Ionising Dose



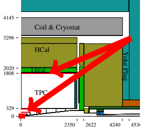
Total amount of energy deposited divided by mass of sensors

- Scaling with hit rate
- About 50 Gy/yr in VXD
- Down to few mGy/yr in SET



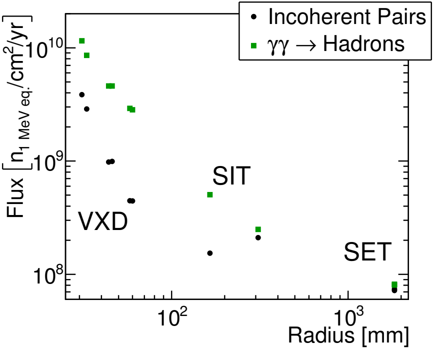
Total ionising dose in silicon tracking detectors

Non-Ionising Energy Loss



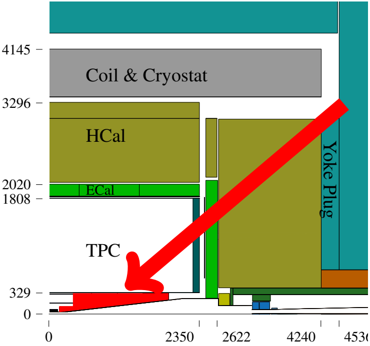
Displacement damage in silicon structure

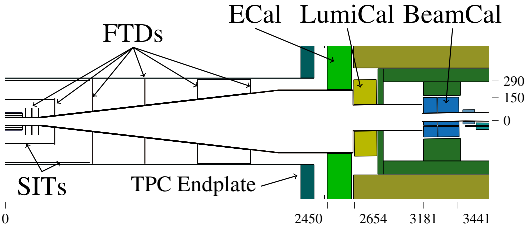
- Given in 1 MeV-equivalent-neutron flux
- Passing particles weighted depending on momentum and type
- Hadrons with larger damage factor
- Few 10^{10} n/cm^2/yr (LHC: 10^{14})
- At larger radius neutrons produced in BeamCal become more important



Non-ionising energy loss in silicon tracking detectors

Forward Tracking Disks





Pixel Vertex Disks: Occupancy

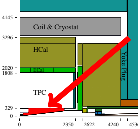
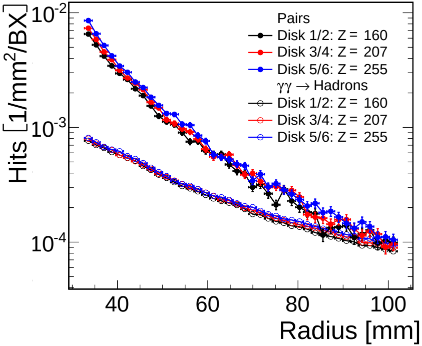
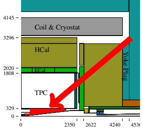


Fig. 4.9b: Hit rate in pixel vertex disks



- Hit rate or occupancy similar to vertex detector barrels (few percent)
- Outer disks see higher rate, because of smaller acceptance
- Maximum occupancy (including safety and cluster factor, $20 \times 20\ \mu m^2$ pixels): 3%

Forward Strip-Disks: Occupancy



- Similar contributions from pairs and hadrons
- Occupancy in the first FTD too large (1000%), decided to change to pixels (1% occupancy)
- Other disks require temporal segmentation to keep occupancy at acceptable level

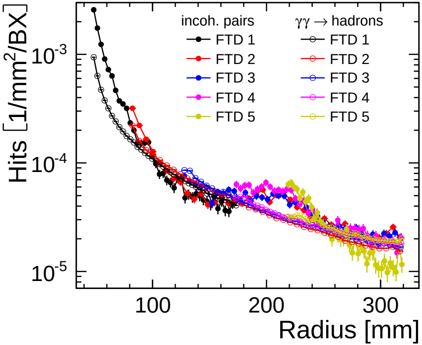
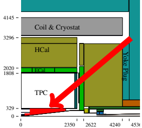
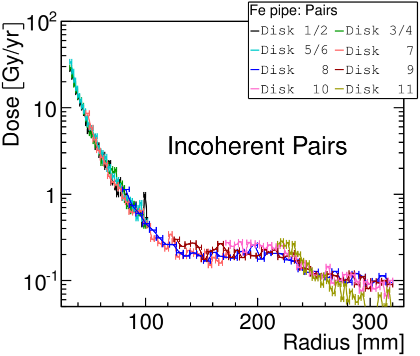


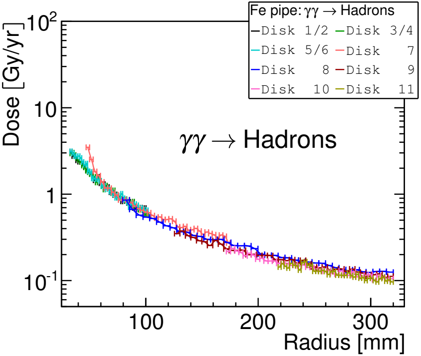
Fig. 5.8a: Hit rate in forward tracking disks

Forward Tracking Disks: TID

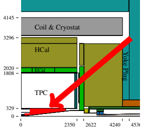


- Similar to VXD
- Few tens of Gray per year maximum

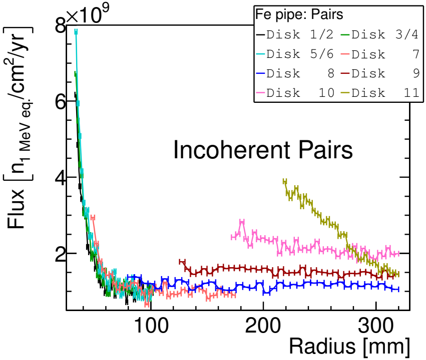


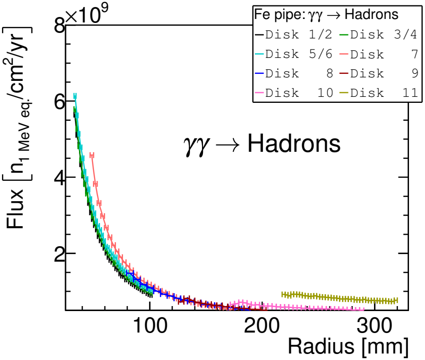


Forward Tracking Disks: NIEL

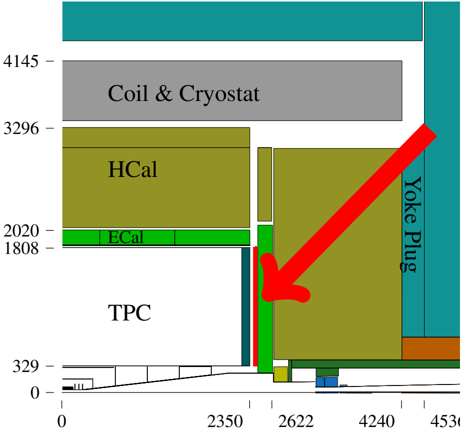


- In Pixel disks: $10^{10}\ \mathrm{n/cm^2/yr}$
- For outer forward tracking disks back-scattering neutrons important
  - Isotropically produced in e.m. showers in the BeamCal
  - Flux falls with distance to the BeamCal
- From $\gamma\gamma \to$ Hadrons: last disks also see slight rise

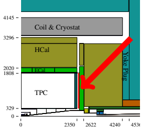




Endcap Tracking Disks



Endcap Tracking Disks: Occupancy



- Small hit rate: 10^{-6}Hits/mm^2/BX
- Occupancy (30 cm strips): 40–80%

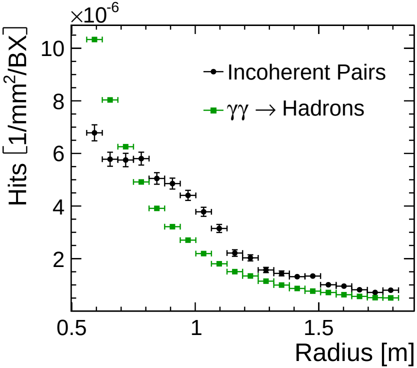
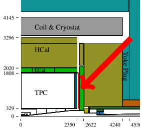
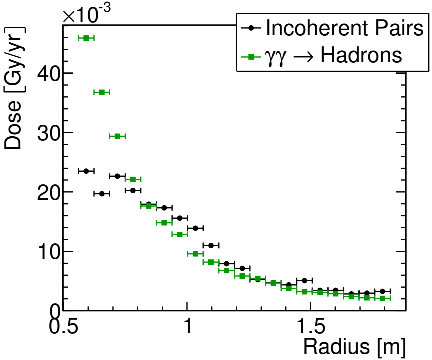


Fig. 5.8b: Hit rate in ETD

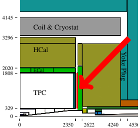
Endcap Tracking Disks: TID



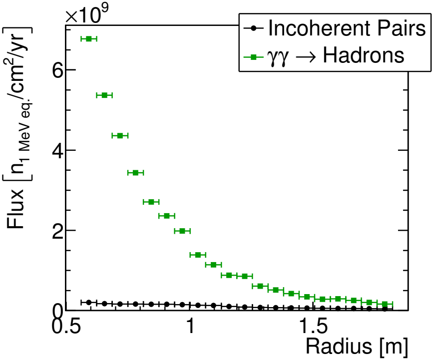
- Tens of mGy/yr



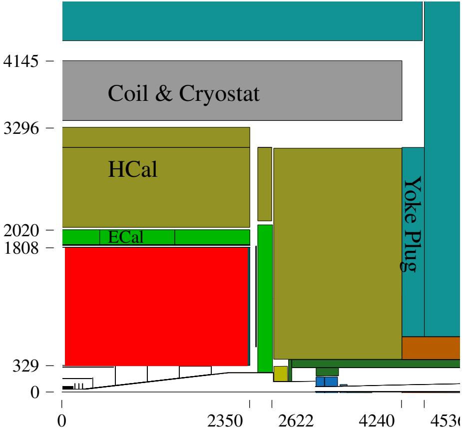
Endcap Tracking Disks: NIEL



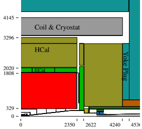
- Flux from hadrons in ETD higher than in last FTD
  - ETD closer to calorimeter
- Flux below $10^{10}\ \mathrm{n/cm^2/yr}$



Time Projection Chamber (TPC)



TPC: Voxel Occupancy



- Dedicated study for TPC Occupancies: LCD-Note-2011-029
- Including 1 Beam halo muon per BX
- Large occupancy (30%, no safety factor) in inner pad rows of TPC, dominated by hadrons
- Also large impact from back-scattering pairs
- Impact of beam pipe has to be studied further
- Layout (TPC/beam pipe/BeamCal) has to be optimised

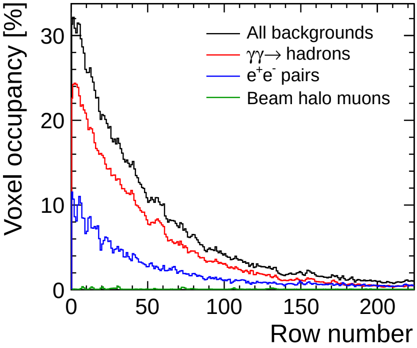
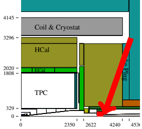


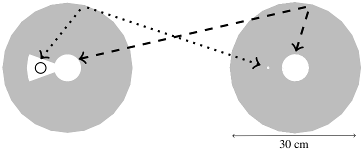
Fig. 5.9: Voxel Occupancy per train.
Voxel size: $6 \times 1 \times 2$ mm^3

Geometry Optimisation

BeamCal Layout



- Reduced hole for the incoming beam pipe inherited from the ILC model to fit snugly around CLIC incoming beam pipe ($R \approx 4$ mm)
- Closed absorber structure as much as possible, including graphite
- Background in the VXD from back-scattering particles reduced by 30% (25% total)



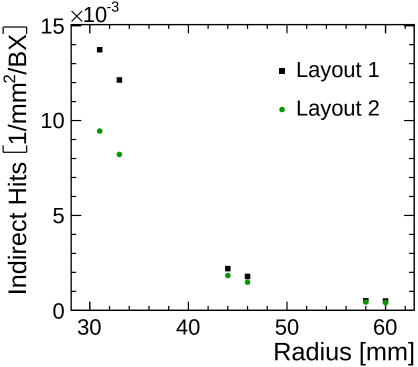
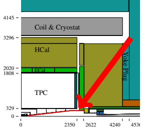
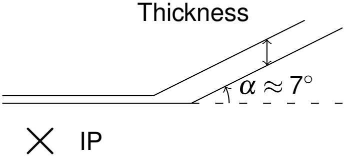


Fig. 9.2b: Hit rate in the VXD for the different BeamCal implementations

Beam Pipe Thickness



- Beam pipe moved outside tracking acceptance
- Beam pipe can be used as mask



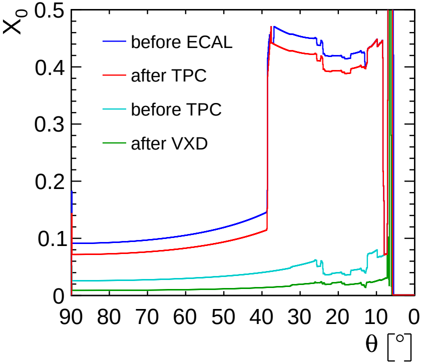
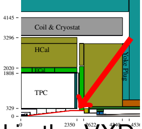
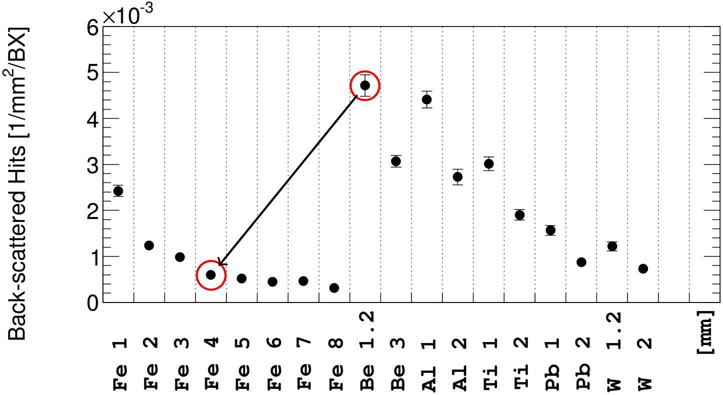


Fig. 5.4b: Material budget in CLIC_ILD_CDR

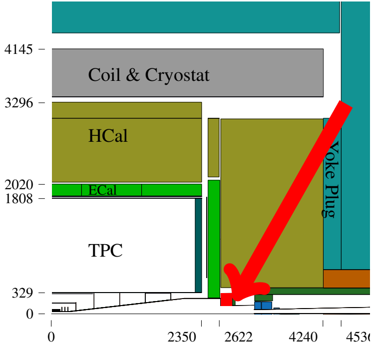
Beam Pipe Thickness: Result



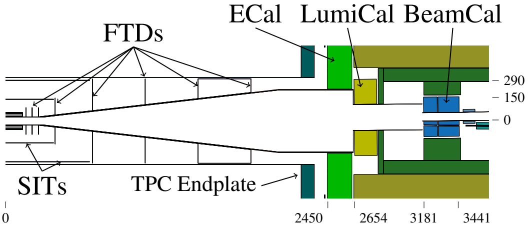
- Thickness and material investigated for minimal background in the VXD
- Using 4 mm thick iron, reduced background from back-scatters by 90% compared to 1.2 mm beryllium



LumiCal

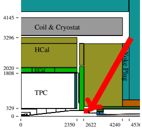


4145
Coil & Cryostat
3296
HCal
2020
ECal
1808
TPC
329
0
0
2350
2622
4240
Yoke Plug



ECal
LumiCal
BeamCal
FTDs
SITs
TPC Endplate
290
150
0
0
2450
2654
3181
3441

LumiCal



- Electrons in LumiCal clearly visible
- Background affects precise energy measurement, systematic error
- Occupancy above 10% at the downstream, inner edge

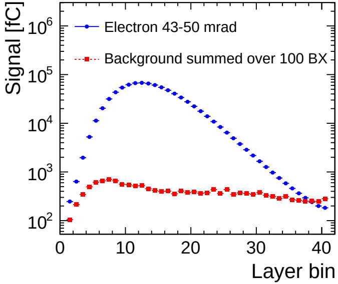


Fig. 9.5: 1.5 TeV electron above 100BX background

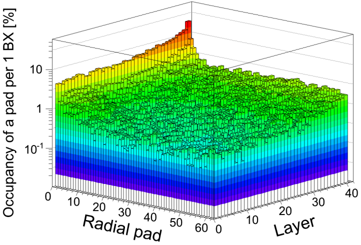
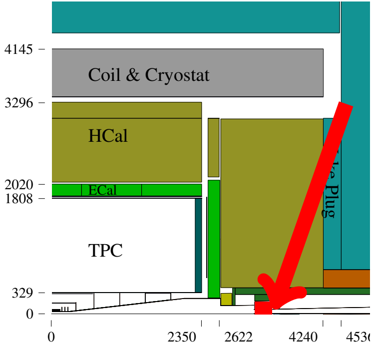
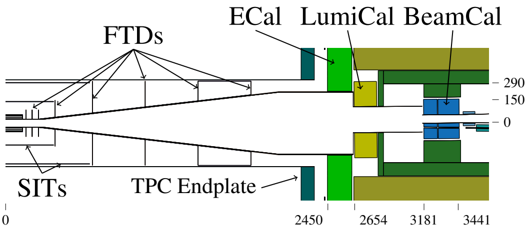


Fig. 9.5: Azimuthal average of occupancy per pad and BX

BeamCal

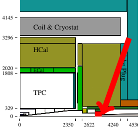


4145
3296
2020
1808
329
0
Coil & Cryostat
HCal
ECal
TPC
0
2350
2622
4240

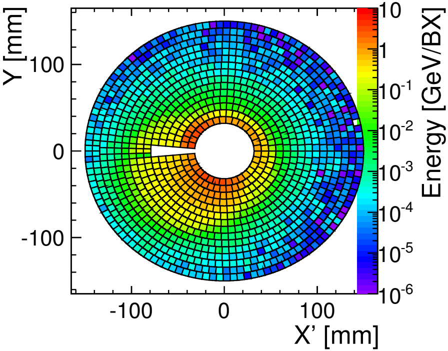


ECal
LumiCal
BeamCal
FTDs
SITs
TPC Endplate
290
150
0
0
2450
2654
3181
3441

BeamCal Energy Deposits

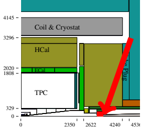


- 30 TeV energy deposited every BX
- Every cell sees energy deposit in every BX



Energy deposit from incoherent pairs in layer 5

BeamCal



- Large radiation levels in BeamCal
- 1 MGy/yr and 10^{14} neutrons/cm^2/yr
- Radiation hard sensors, also foreseen at ILC

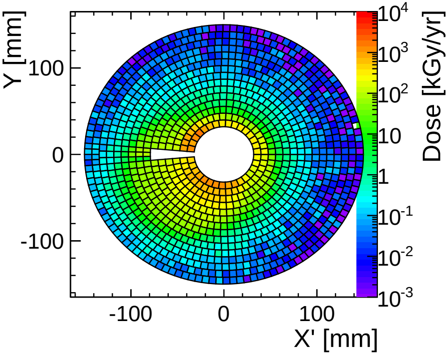


Fig. 9.7a: Total ionising dose in layer 5

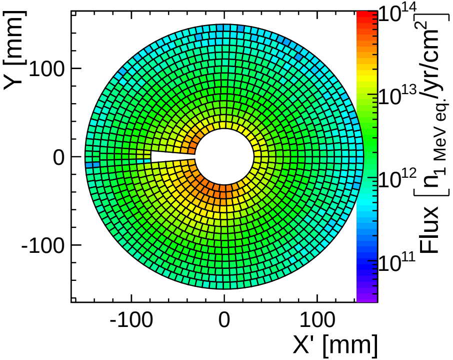
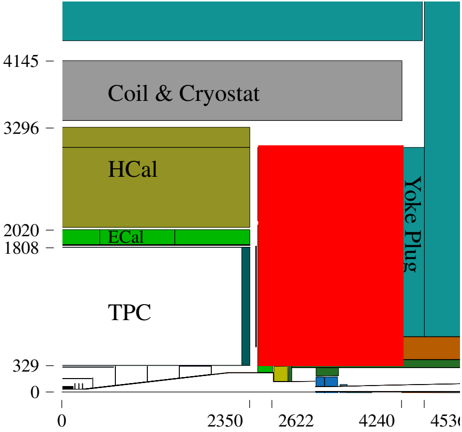
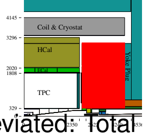


Fig. 9.7b: Equivalent neutron flux

Calorimeter Endcaps



Reconstructed Energy vs. Radius



- Large energy deposit in calorimeters: Total 37 TeV/Train
- Large deposit from secondaries from pairs in HCAL

Table 2.3, abbreviated: Total reconstructed Energy [TeV]

Subdetector	Pairs	$\gamma\gamma$
ECAL Endcaps	2	11
HCAL Endcaps	16	6

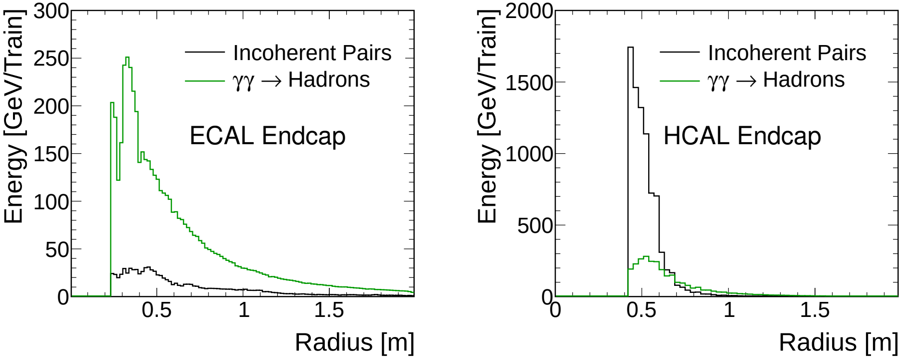
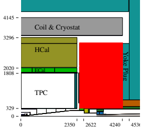
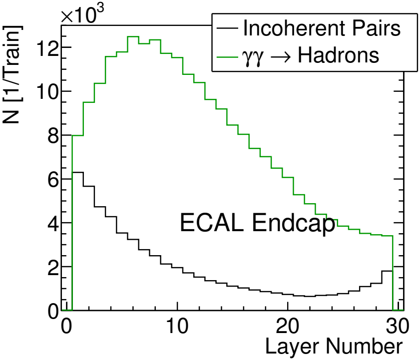
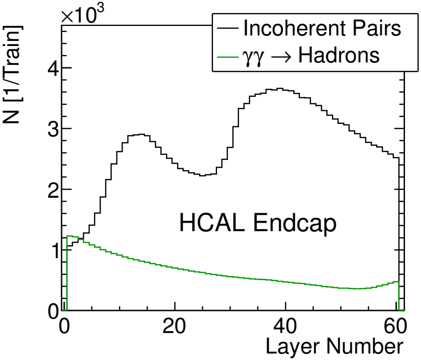


Fig. 2.8: Radial distribution of reconstructed energy in calo endcaps

Energy Deposits: Layers

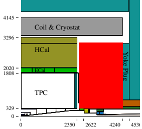


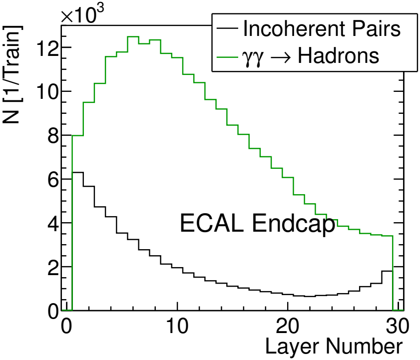


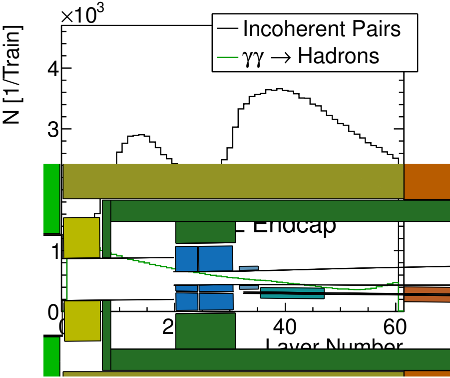


- Large number of hits from pairs in HCAL
- Dip in HCAL hits from pairs caused by “BeamCal Support” inside support tube

Energy Deposits: Layers

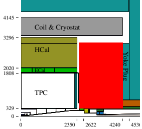




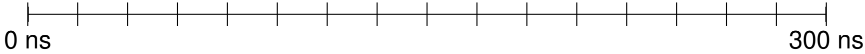


- Large number of hits from pairs in HCAL
- Dip in HCAL hits from pairs caused by “BeamCal Support” inside support tube

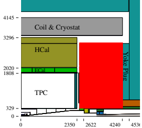
Occupancy Calculations



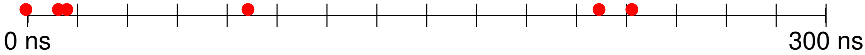
- Divided 300 ns starting with first bunch crossing into 12 $\times$ 25 ns time windows
  - Could use shorter total time (but hadronic showers take time to develop)
  - See next Talk by M. Thomson



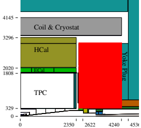
Occupancy Calculations



- Divided 300 ns starting with first bunch crossing into 12 × 25 ns time windows
  - Could use shorter total time (but hadronic showers take time to develop)
  - See next Talk by M. Thomson
- Distribute hits in window (with BX offset)
- Sum deposited energy in these time windows
- Apply threshold (0.3 MIP)
- Occupancy given as: Number of time windows with energy deposit above threshold
- Not including safety factors



Calorimeter Endcap Occupancy



- 50% of pads in ECAL at small radii
- Very high occupancy in HCAL: 10 out of 12 time windows see energy deposit

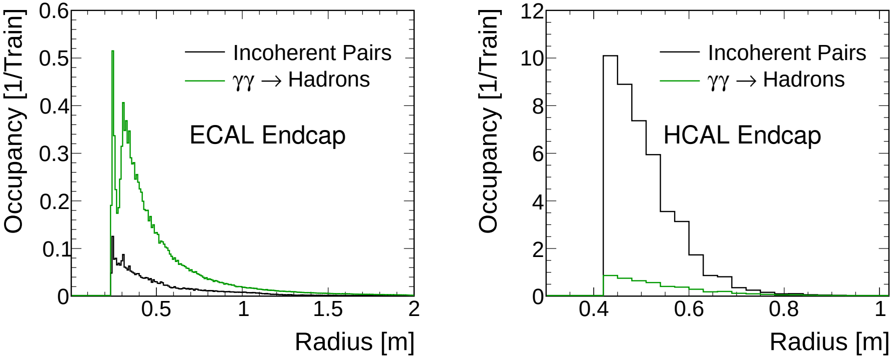


Fig. 2.9: Radial distribution of occupancy in calorimeter endcaps

HCAL Barrel $\approx R_{\text{Endcap}} = 2$ m

- At larger radii very small occupancy
- Much lower energy deposit in barrel
- Expect small occupancy in calorimeter barrel

Table 2.3: Total reconstructed Energy [TeV]

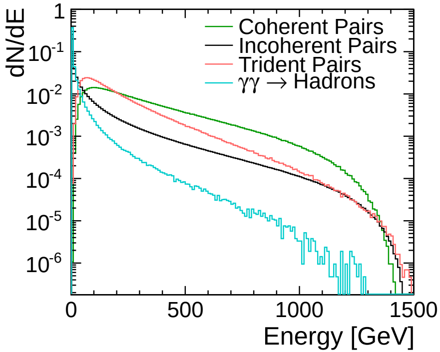
Subdetector	Pairs	$\gamma\gamma$
ECAL Endcaps	2	11
ECAL Barrel		1.5
HCAL Endcaps	16	6
HCAL Barrel		0.3
Total Calorimeter	18	19
Central Tracker		7

Summary, Conclusion, and Outlook

- Studied deposits from incoherent pairs and $\gamma\gamma \to$ Hadrons in all subdetectors (except muon system)
- Background rates impose constraints on spatial and temporal granularity of some detectors
- More improvements are possible
  - Optimise detector layout for background in all sub-detectors, e.g., TPC, Calorimeter
- Radiation levels not critical (except in the BeamCal)
- LCD-Note-2011-021: Beam-Induced Backgrounds in the CLIC Detectors
- LCD-Note-2011-029: Occupancy in the CLIC_ILD Time Projection Chamber

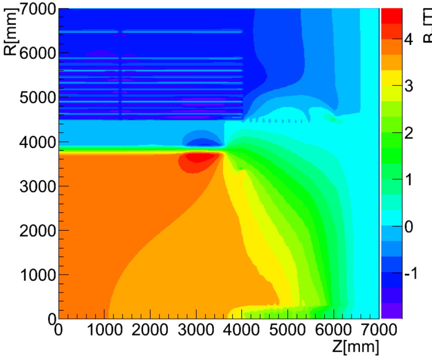
Backup Slides

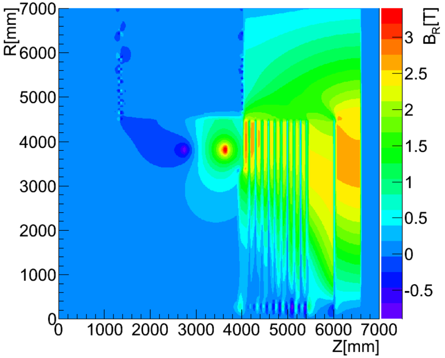
Background Energy Distribution



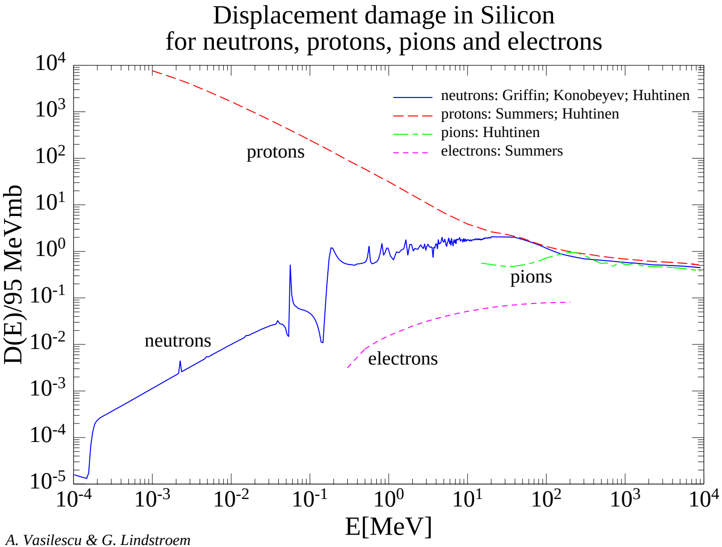
Field Map for Simulation

2D field map used for background studies





Equivalent Neutron Flux

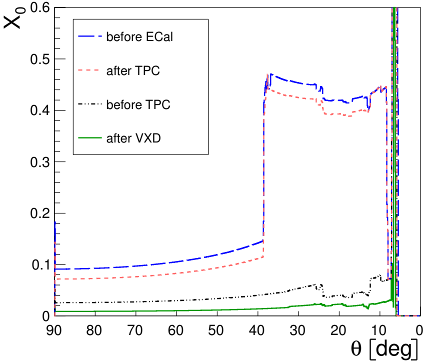


A. Vasilescu & G. Lindstroem

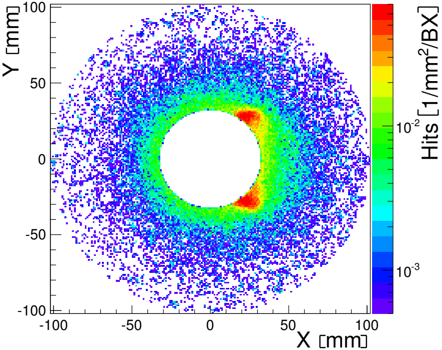
`http://sesam.desy.de/members/gunnar/Si-dfuncs.html`

CLIC_ILD_CDR Material Budget

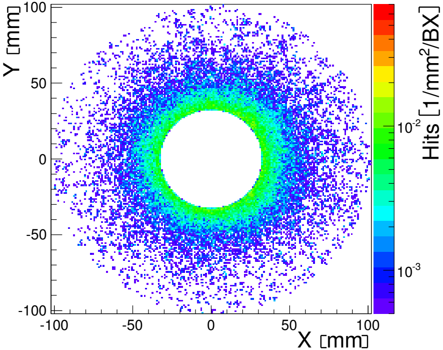
- Material Budget before the VXD, TPC and ECAL
- TPC Endcap from 40° to 10°
- Peak at 7° from beam pipe



XY Distribution of Hits in FTD

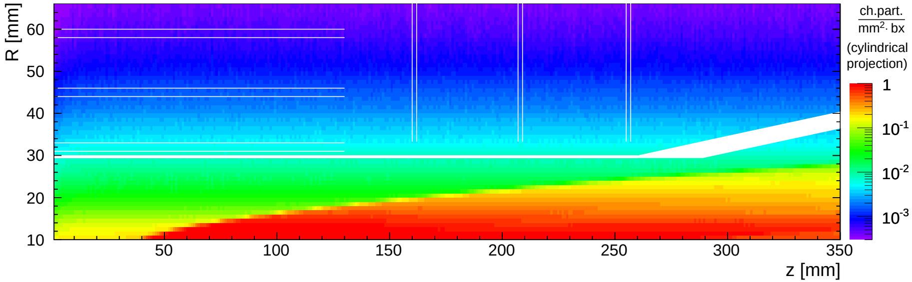


1.2 mm beryllium beam pipe

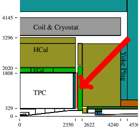


4 mm iron beam pipe

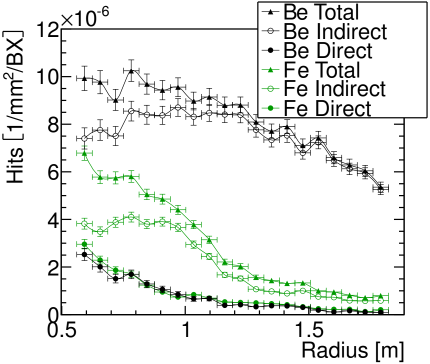
Incoherent Pair Envelope: 3 TeV



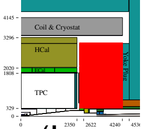
ETD Hit Rate Contributions



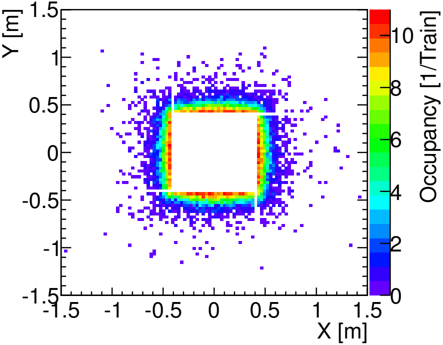
- Hit rates for beryllium and iron beam pipe
- Largest contribution from back-scatters
- Greatly reduced with iron beam pipe



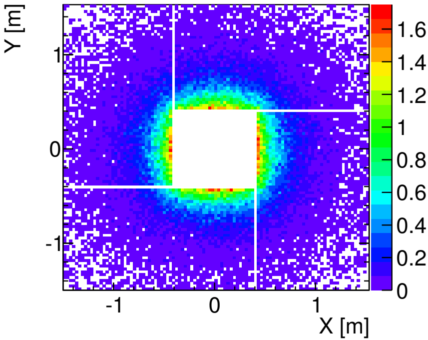
HCAL Endcap: *XY* Distributions



Pairs (Layer 40)

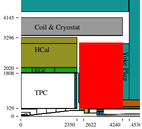


$\gamma\gamma \rightarrow$ Hadrons (Layer 1)

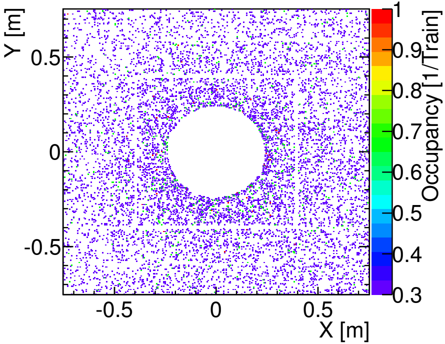


- Very large occupancy for pairs for the innermost cells
  - Could improve support tube/absorber, BeamCal position
- Occupancy for $\gamma\gamma \rightarrow$ Hadrons below 2.

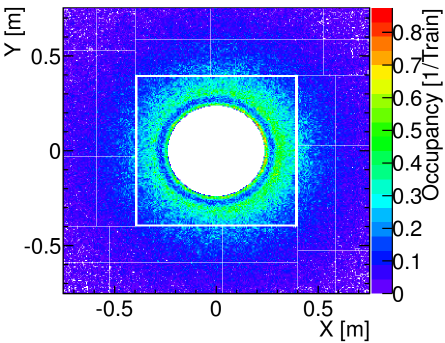
ECAL Endcap: *XY* Distributions



Pairs (Layer 1)

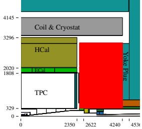


$\gamma\gamma \rightarrow$ Hadrons (Layer 6)



- Low statistics visible for pair sample
- Dip in radial distribution caused by thick conical beam pipe

Energy Deposits



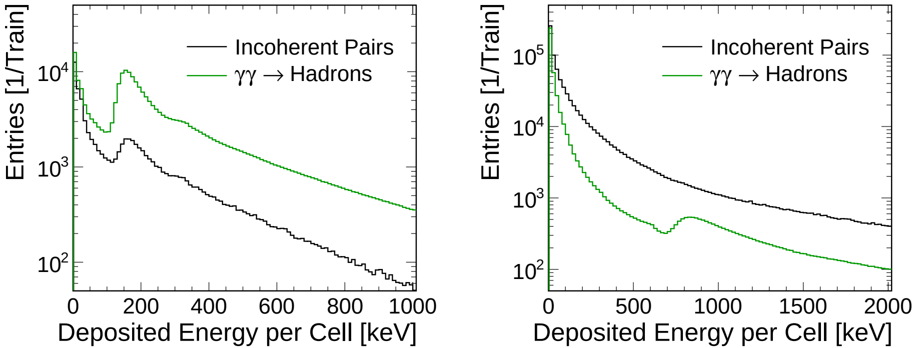


Fig. 2.7: Distribution of the hit energy, left ECAL, right HCAL