Simulation studies for the main tracker

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Outline

- Occupancy due to beam induced background
  - Detector simulation in mokka
  - Analysis of hit density from incoherent pairs and $\gamma\gamma \rightarrow$hadron events

$\rightarrow$ limits on strip/pixel size in the main tracker

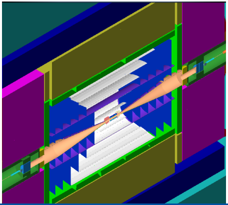
- Detector response
  - T-CAD finite element simulation
  - Charge sharing and cluster size
  - Spacial resolution

$\rightarrow$ do we benefit from analog readout?

Beam induced background, occupancy

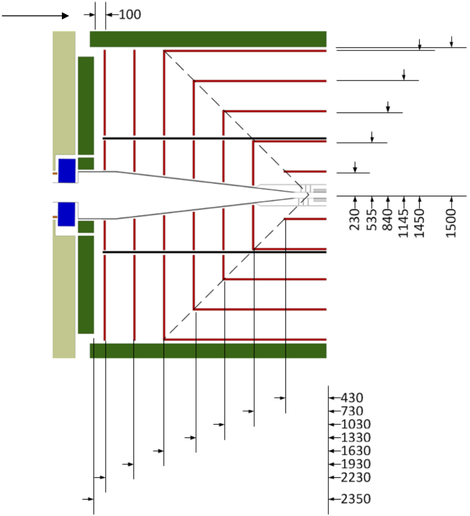
Beam induced background, detector model

- Detector simulation using mokka
- CLIC_ILD_CDR detector model as starting point (4 T field)
- Removal of TPC and silicon tracking layers
- Insert all-silicon tracker, tracker support tube and modified beampipe
- Incoherent pairs and $\gamma\gamma \rightarrow$ hadron background samples at 3 TeV
- Study hit rates in the silicon tracker
- New analysis code, validated against results published in CDR



Tracker geometry

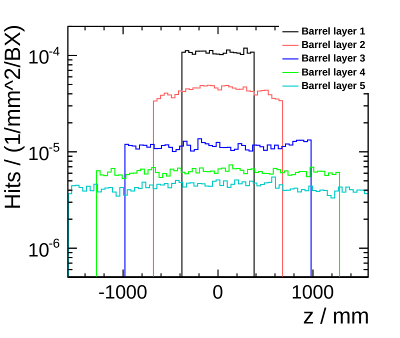
- Current tracker layout and beampipe geometry
- CF support tube implemented (5 mm wall)
- Endcap discs split in inner and outer part
- CLIC_ILD_CDR vertex detector (3 double layers)
- CLIC_ILD_CDR forward region



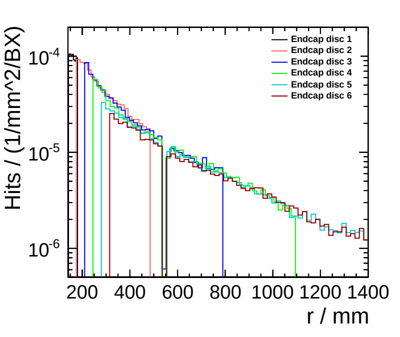
Hitrate in main tracker

- Hitrate from incoherent pairs and $\gamma\gamma \rightarrow$ hadrons in the main tracker
- No digitization, no clustering, no safety factors

Barrel



Endcap discs



Occupancy in the main tracker

- Calculate occupancy, assuming 100 mm × 50 μm strips, avg. cluster size 2.6, apply safety factors 5 (pairs) and 2 (gghad)
- Large cell size leads to high occupancy, up to ≥ 100 %

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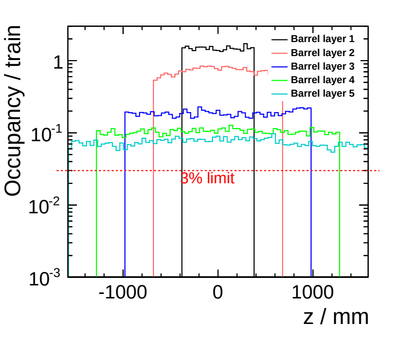
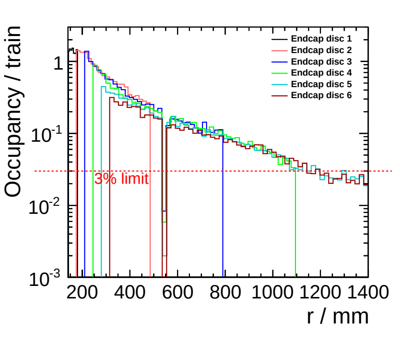


Endcap discs



Max. strip length in the main tracker

- Maximal strip length to keep occupancy per bunch train at 3 %, assuming 50 μm strip pitch, avg. cluster size 2.6, safety factors 5 (pairs) and 2 (gghad)

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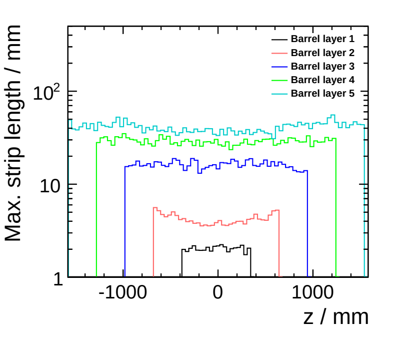
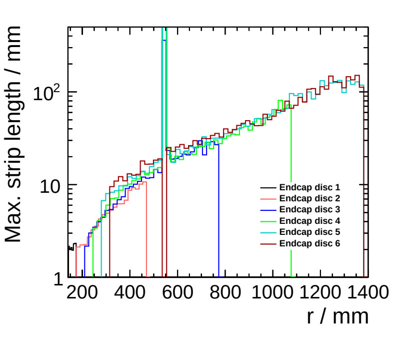


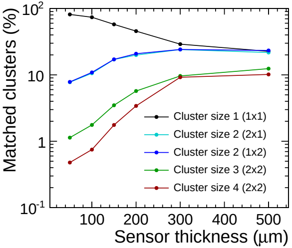
Endcap discs



Sensor simulation

Motivation

- For overall detector performance, 7 µm single point resolution in main tracker required. How to achieve?
- Spatial resolution can be improved over the binary limit of $\frac{p}{\sqrt{12}}$, if charge is shared among two cells. Can we benefit from that?

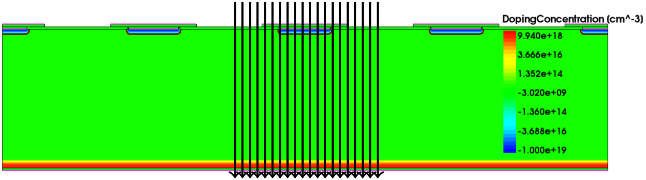


From: Analysis of Timepix test beam data, Sophie Redford, CLIC workshop, Jan. 2015

- Aims of this study:
  1. Understand the variation of the cluster size with thickness
  2. Evaluate possible ways to modify the sensor design in order to increase spatial resolution, especially in thin sensors
  3. Support decision on possible readout scheme (digital or binary) for tracker frontend

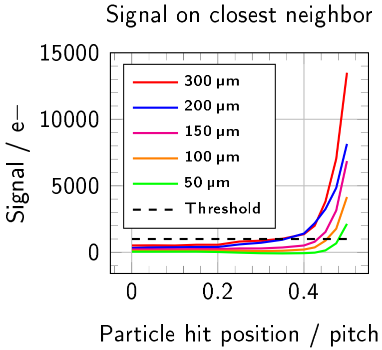
Sensor

- T-CAD finite element simulation of silicon sensor
- As starting point: AC-coupled p-in-n silicon strip sensor, best guess of process details, 2 dimensional cut, no B-field (yet)
- Simulate particle hit at several positions in the strip unit cell, fixed incidence angle
- Readout of current signal → integration over time → charge signal per strip

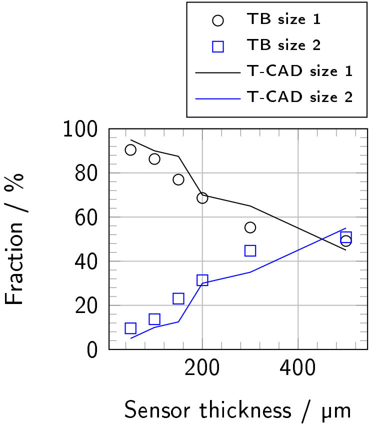


T-CAD results - Cluster size

- Compare signals to threshold level
- Estimate fraction of multi-hit clusters

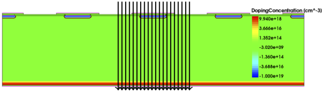


- Good agreement to testbeam results

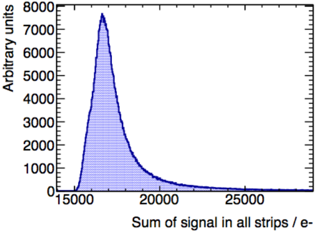


Toy monte carlo

Random position for incident particle



Landau distribution of charge



Toy monte carlo

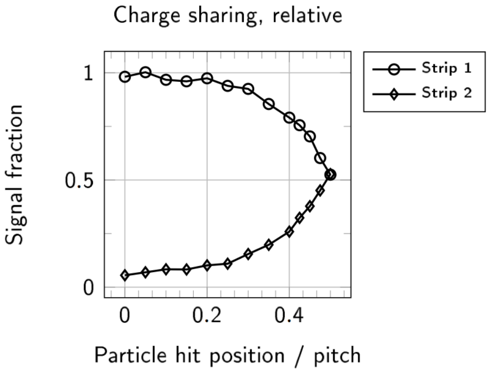
Random position for incident particle

↓

Distribute charge to individual strips according to T-CAD

↑

Landau distribution of charge



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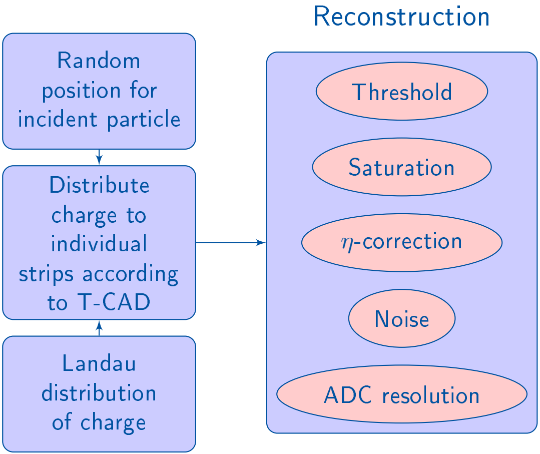

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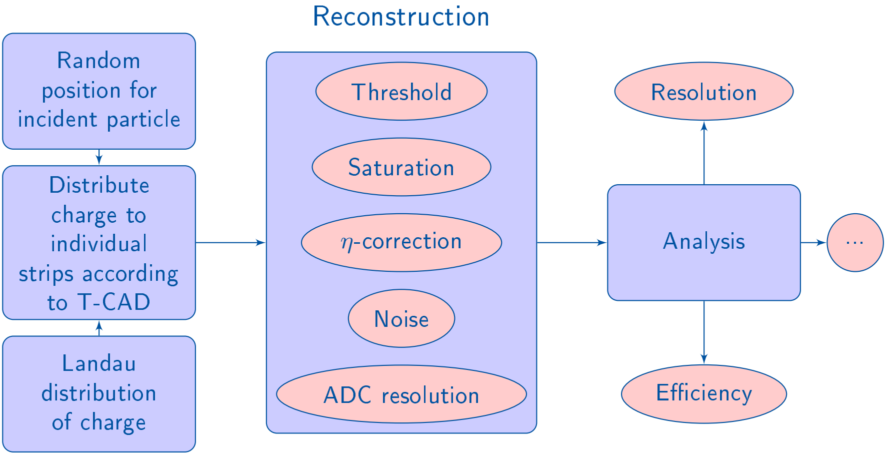
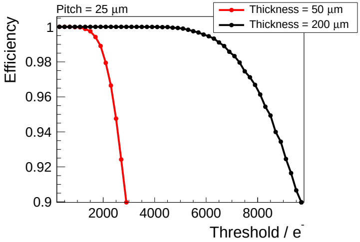
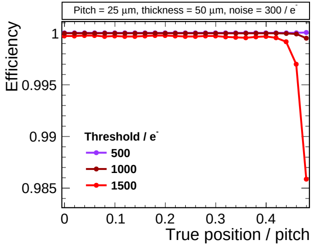


Toy monte carlo - Efficiency

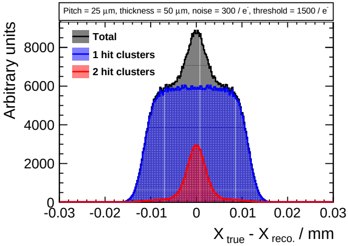


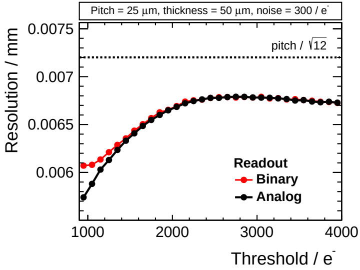


- Efficiency as function of applied threshold
- Efficiency fall-off defines upper threshold limit, lower limit is set by noise occupancy

- Efficiency as function of track hit position relative to strip (perpendicular incident)
- Due to charge sharing, inefficiency most pronounced for tracks hitting directly between the two strips

Toy monte carlo - Resolution

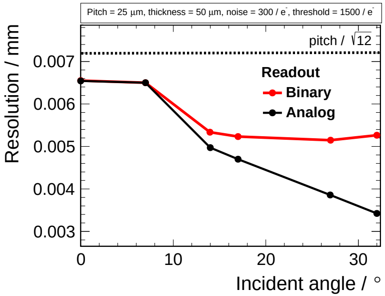




- Reconstruct particle hit position
- Center of gravity or η-method
- Residual by comparison to MC-truth particle hit position

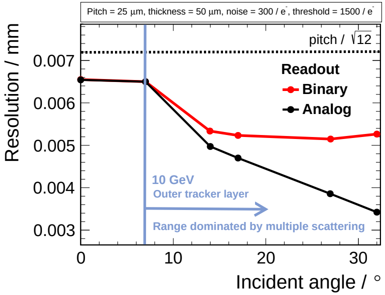
- Resolution as function of applied threshold
- No significant benefit from analog readout compared to binary readout
- $\sigma \approx 7\,\mu\text{m} \approx \frac{p}{\sqrt{12}}$

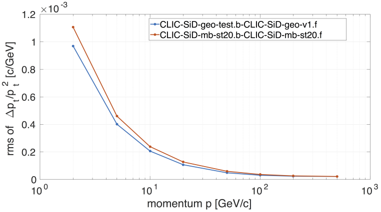
Toy monte carlo - Inclined incident



- No significant benefit from analog readout over binary readout for small incident angle
- At large angle (low-p_T tracks), analog readout benefits from increased charge sharing

Toy monte carlo - Inclined incident





- No significant benefit from analog readout over binary readout for small incident angle
- At large angle (low-p_T tracks), analog readout benefits from increased charge sharing
- However, for low-p_T tracks, the overall detector performance is dominated by multiple scattering and not by the single point resolution

Summary

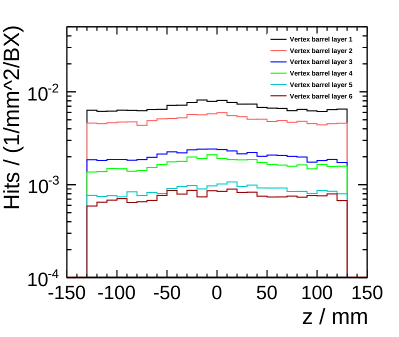
- Occupancy due to beam induced background restricts the maximal possible strip length in the main tracker
  - Few millimeters in the inner layers
  - Few centimeters in the outer layers
- Simulation study on charge sharing
  - T-CAD simulation reproduces the trend of increased charge sharing in thick sensors as seen in timepix testbeam
  - Simple toy model allows estimation of efficieny and resolution as function of operation parameters (threshold, noise, frontend adc resolution,...)
  - No real benefit in resolution from charge sharing and analog readout in thin planar sensors $\Rightarrow$ binary readout, $\sigma = \frac{p}{\sqrt{12}}$
  - However, planar sensor might (most certainly) not be the final answer for the main tracker
  - $\Rightarrow$ Possibility to look at other technologies by replacing T-CAD simulation part only

Backup

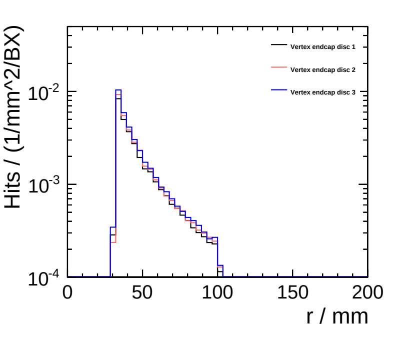
Hitrate in VXD

- Incoherent pairs and $\gamma\gamma \rightarrow$ hadrons in the vertex detector

Barrel



Endcap discs

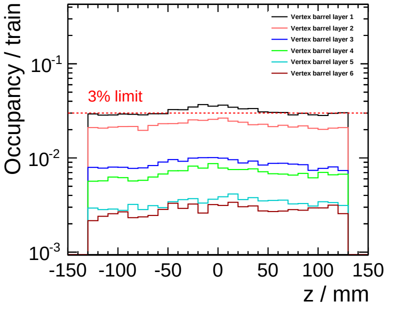


- No z-dependence, steep fall-off in r

Occupancy in VXD

- Incoherent pairs and $\gamma\gamma \rightarrow$ hadrons in the vertex detector (assuming 25 µm × 25 µm pixels, cluster size 5, safety 5 and 2)

Barrel



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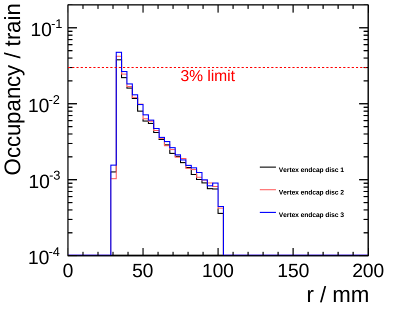
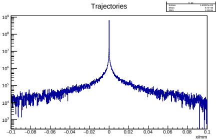
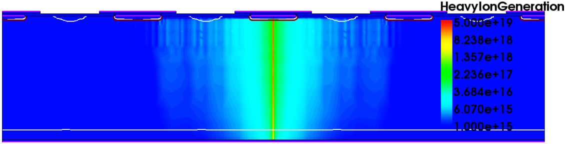


- With this parameters, occupancy $\leq 3\,\%$

Delta electrons in T-CAD

- No direct way to include delta electons in T-CAD
- Simple geant simulation to record energy deposit after particle incident with fine granularity, O(nm)
- Average over many events
  - Sharp core
  - Significant tails (delta electrons, scattering) over several 100 μm
- Take recorded energy deposits from geant4 as averaged input for charge carrier generation to T-CAD

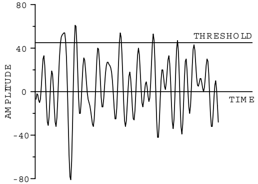




Noise rate - Rice formula

Noise hit rate: $f_t = \frac{f_0}{2} \exp\left(-\frac{v_{th}^2}{2\sigma^2}\right)$ with $f_0 = \frac{1}{2\sqrt{3}\tau}$

- Frequency at which a given threshold level v_{th} is passed
- Shaping time τ limits bandwidth
- Take CLIC active cycle of 156 ns into account
- With 100 ns shaping time, $V_{th}/\sigma = 3$ results in a noise occupancy of 2.5×10^{-3} per bunch train



From: Helmut Spieler, Semiconductor Detector Systems