Development of the full simulation of the tracker concepts for the Future Circular Collider (FCC-ee) project.

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02/07/2024

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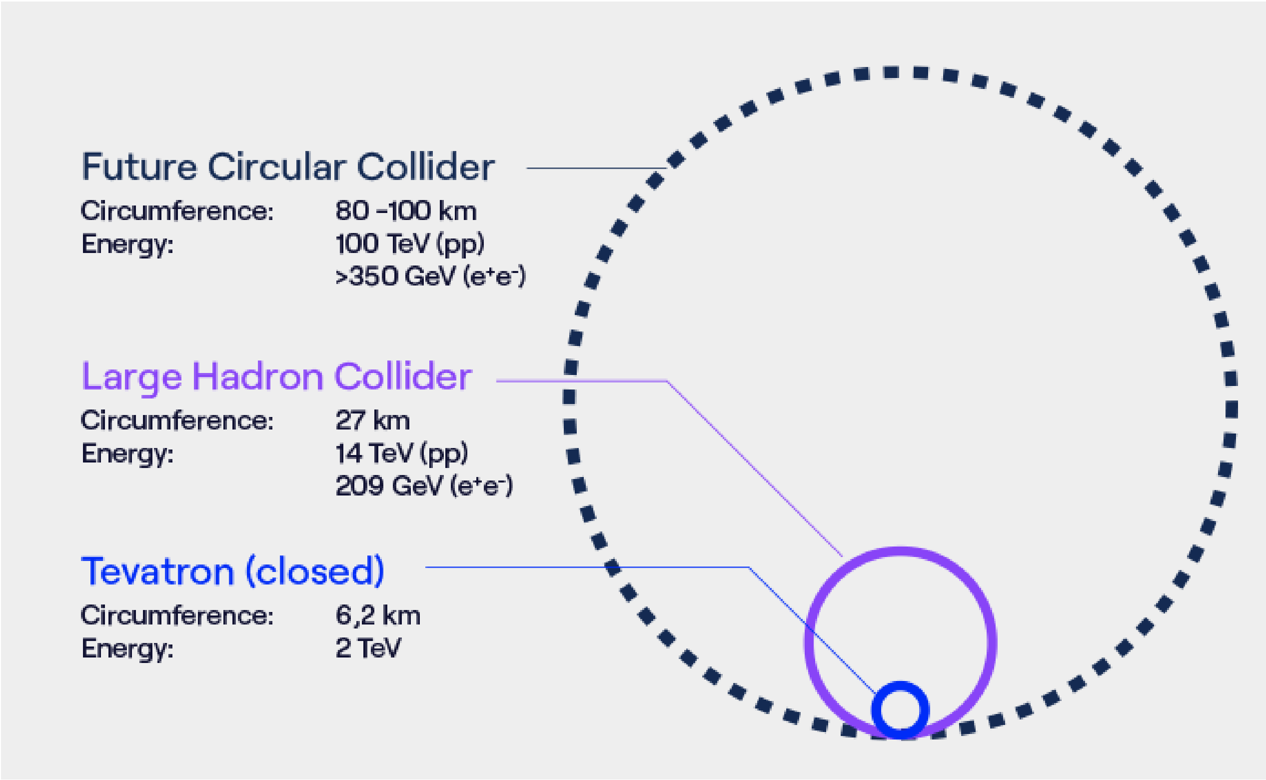
Introduction – FCC

FCC scheme [1].



DETECTOR CONCEPTS

- **CLD**
- **IDEA**
- **ALLEGRO**

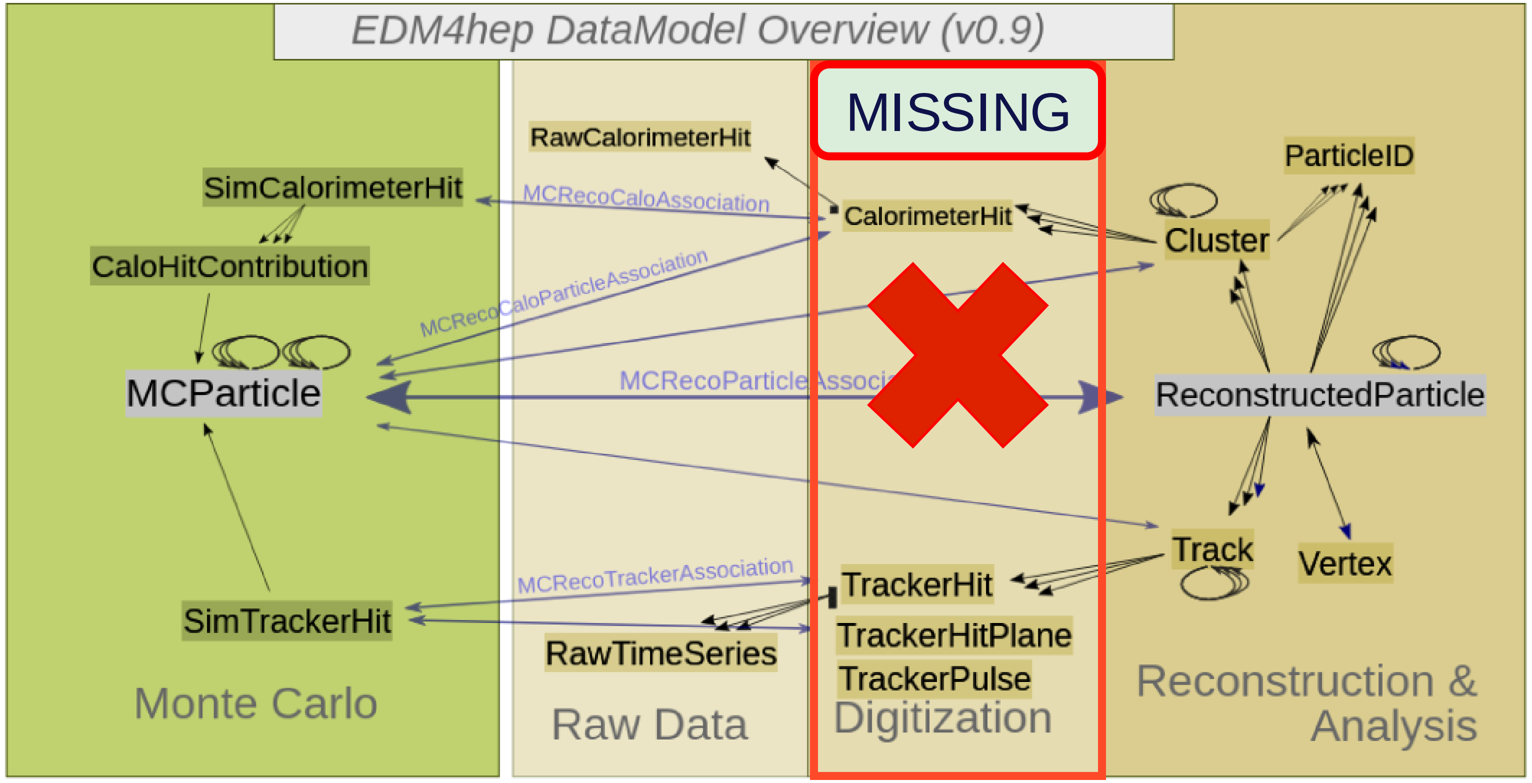
Key Physics Goals:

- Precise b, c, t tagging
- Higgs decay modes
- Higgs recoil mass reconstruction
- tt properties with Z boson sample

Enhanced Measurements:

- Electroweak observables
- b-quark electroweak parameters

Motivation



Digitization: Process of translating the simulated hits into the electronic readout response.

Current Problem:

- No digitizer for the tracking system
- Fixed resolution in reconstruction

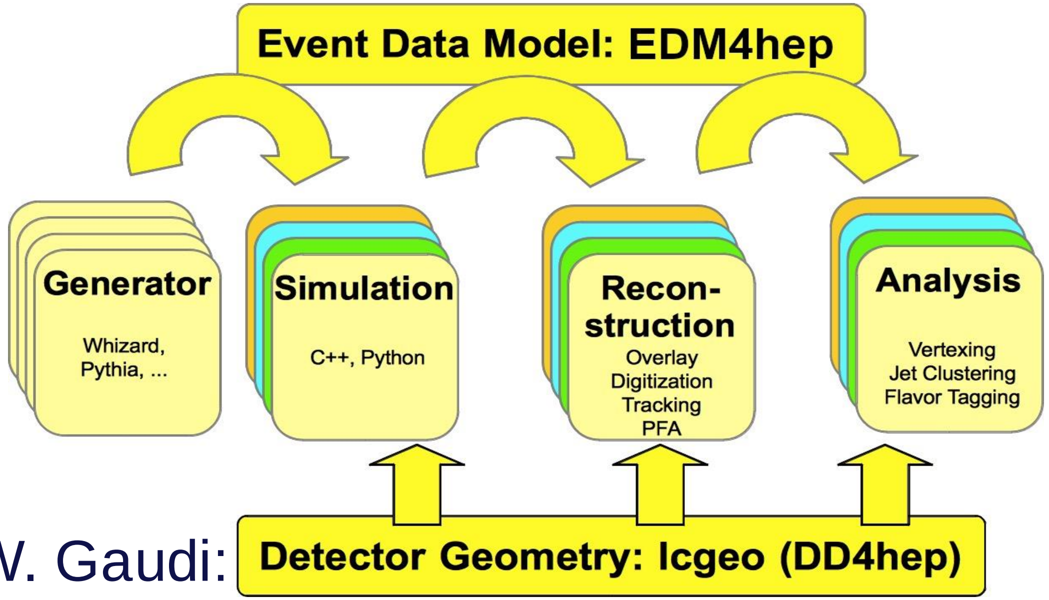
Implications:

- Limited precision.
- Inaccurate data analysis.
- Inefficiencies in measurements.
- Potential delays in scientific progress.

Digitization from Scratch:

- Pixel Vertex System
- Initial implementation in CLD
- Future use in CLD, IDEA, ALLEGRO

Full Simulation



FW. Gaudi:

DD4hep:
- Detector description software
- Integrates geometry, materials, reconstruction

Key4hep:
- Unified software framework
- Ensures interoperability and common tools

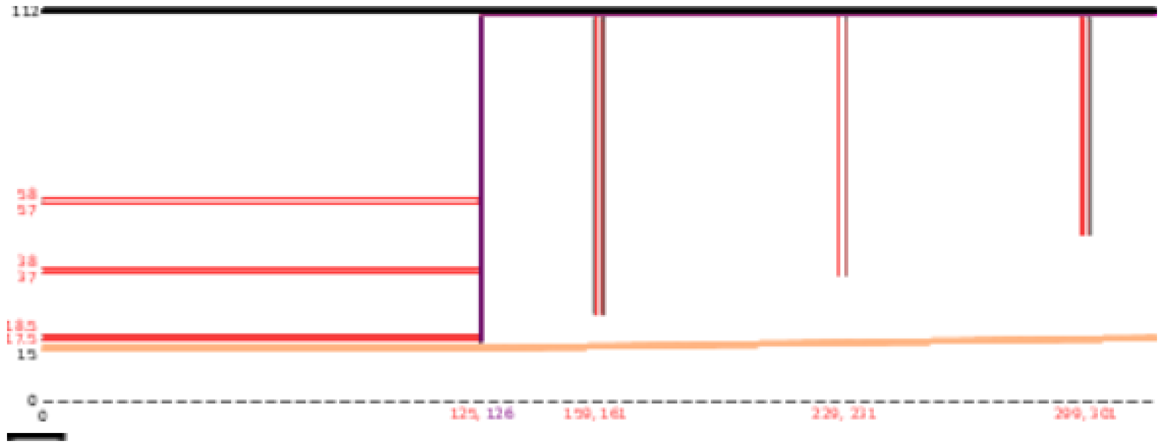
EDM4hep:
- Data model for high-energy physics
- Optimized for event data storage/access

Gaudi Algorithm:
- Flexible data processing framework
- Enables modular, reusable designs

Podio:
- C++ data model
- Supports I/O and transient data

CLD Vertex Detector – Particle Reconstruction

Sub-detector	Sensor area [m^2]	Cell size [mm^2]	Number of channels [10^6]
VTX barrel	0.358	0.025×0.025	570
VTX petal discs	0.172	0.025×0.025	270



Vertex Detector Sketch:
- Barrel and forward region (ZR plane)
- Dimensions in mm

Colour Codes:
- **Red lines**: Sensors
- **Black lines**: Support structure
- **Magenta lines**: Cables
- **Orange**: Vacuum beam pipe

ddsim --steeringFile **cld_steer.py** --compactFile $K4GEO/FCCee/CLD/compact/CLD_o2_v05/**CLD_o2_v05.xml** --enableGun --gun.particle **mu-** --gun.energy **10*GeV** --gun.distribution uniform --outputFile mu_CLD_10xxxev_10Gev.slcio --numberOfEvents **1000**

k4run **CLDReconstruction.py** --inputFiles **mu_CLD_1000ev_10Gev.slcio** --outputBasename **mu_slcio_1000ev_CLD_RECO** --num-events -1

Difficulties and what needs to be done.

Difficulties:

- Undefined pixel arrangement.
- Fixed resolution smearing limits accuracy.
- Trajectory angle uses one point per layer, “ignoring” multiple scattering.
- Variable data formats complicate integration.
- Simplified energy deposition affects charge prediction.

Needs to be done:

- Pixel definition in each layer.
- Segment layers into pixels.
- Decode segmentation data.
- Compute entry and exit point.
- Determine trajectory angle considering multiple scattering.
- Conversion energy deposited (Edep) to charge.
- Evaluate detector’s spatial resolution.

Resolution and Smearing

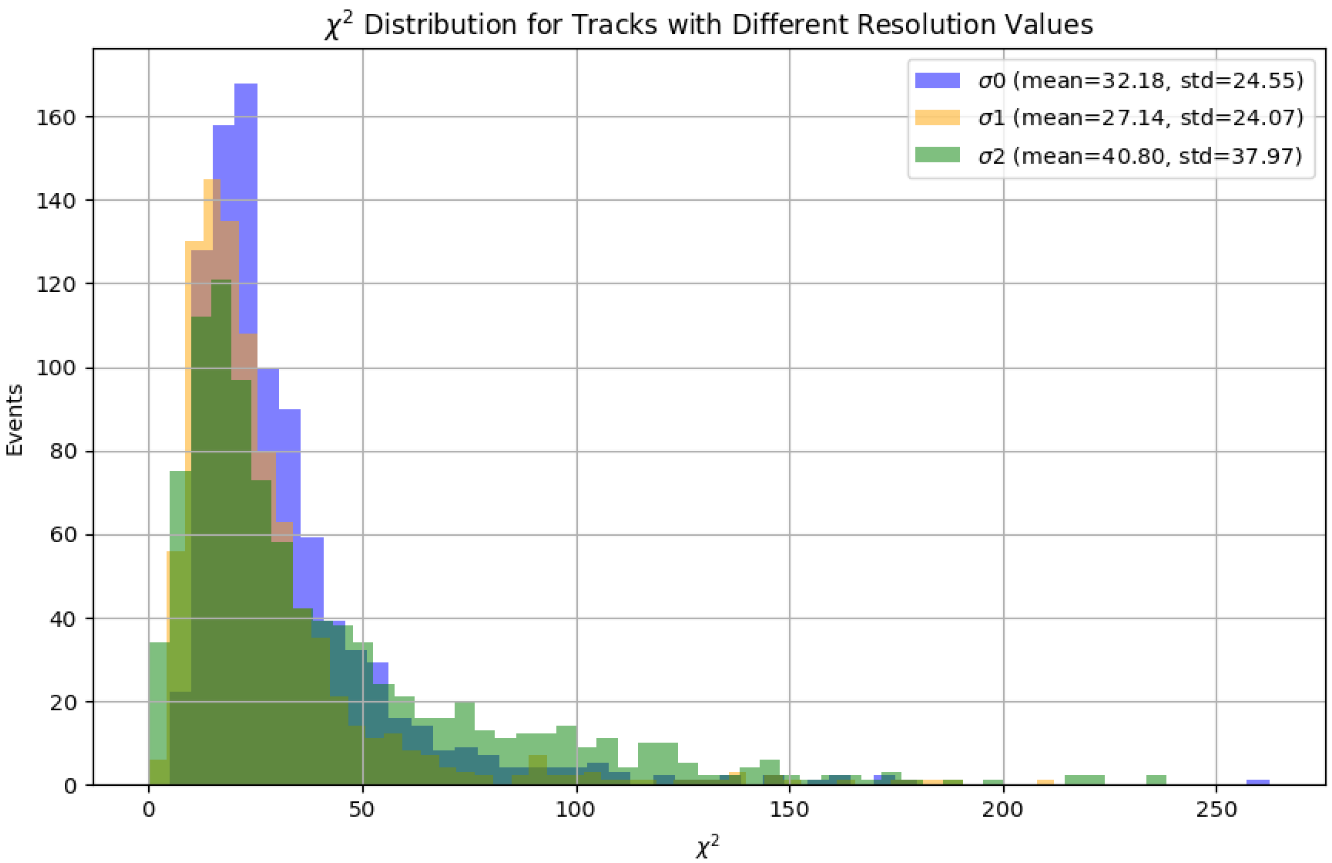
Smearing:
- Adds measurement errors
- Modifies ideal measurements

Purpose:
- Reflect real uncertainties
- Use statistical distributions

Fixed Resolution: Quick Solution, Gaussian Smearing in actual implementation.

```
<processor name="VXDBarrelDigitiser" type="DDPlanarDigiProcessor">
  <parameter name="SubDetectorName" type="string">Vertex </parameter>
  <!--PlanarDigiProcessor creates TrackerHits from SimTrackerHits, smearing them according to the input parameters.-->
  <!--whether hits are 1D strip hits-->
  <!--resolution in direction of u-->
  <parameter name="ResolutionU" type="float"> 0.003 0.003 0.003 0.003 0.003 0.003 </parameter>
  <!--resolution in direction of v-->
  <parameter name="ResolutionV" type="float"> 0.003 0.003 0.003 0.003 0.003 0.003  </parameter>
  <parameter name="SimTrackHitCollectionName" type="string" lcioInType="SimTrackerHit">VertexBarrelCollection </parameter>
  <!--Name of TrackerHit SimTrackHit relation collection-->
  <parameter name="SimTrkHitRelCollection" type="string" lcioOutType="LCRelation">VXDTrackerHitRelations </parameter>
  <!--Name of the TrackerHit output collection-->
  <parameter name="TrackerHitCollectionName" type="string" lcioOutType="TrackerHitPlane">VXDTrackerHits </parameter>
  <!--verbosity level of this processor ("DEBUG0-4,MESSAGE0-4,WARNING0-4,ERROR0-4,SILENT")-->
  <parameter name="Verbosity" type="string">WARNING </parameter>
</processor>
```

Control Plots - Fixed Resolution

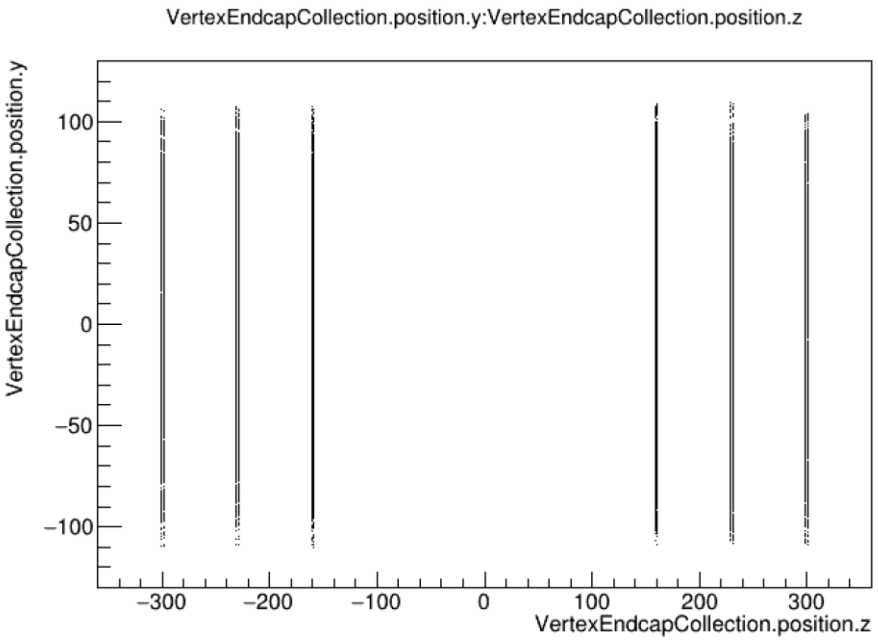


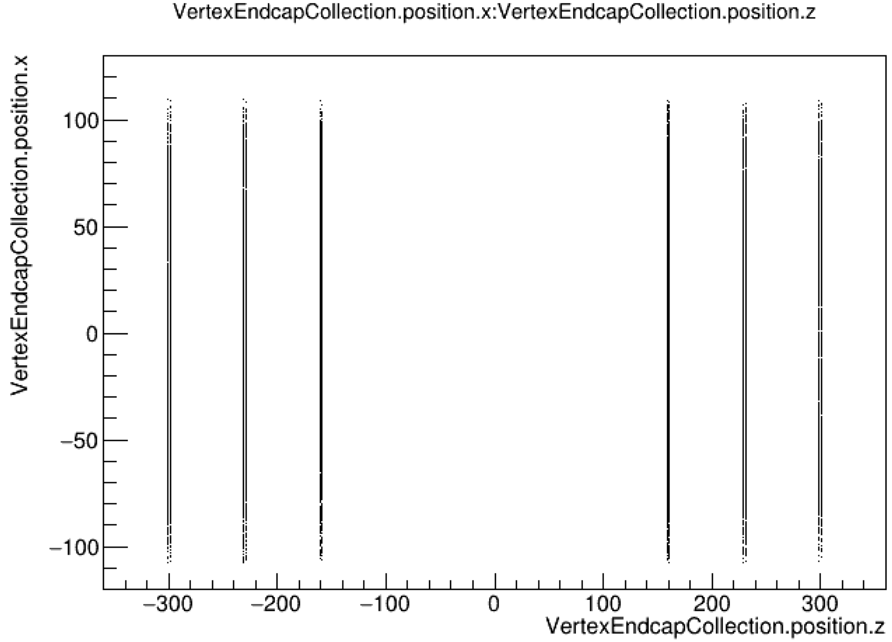
x^2 of the reconstructed tracks using the fixed resolutions given in the table

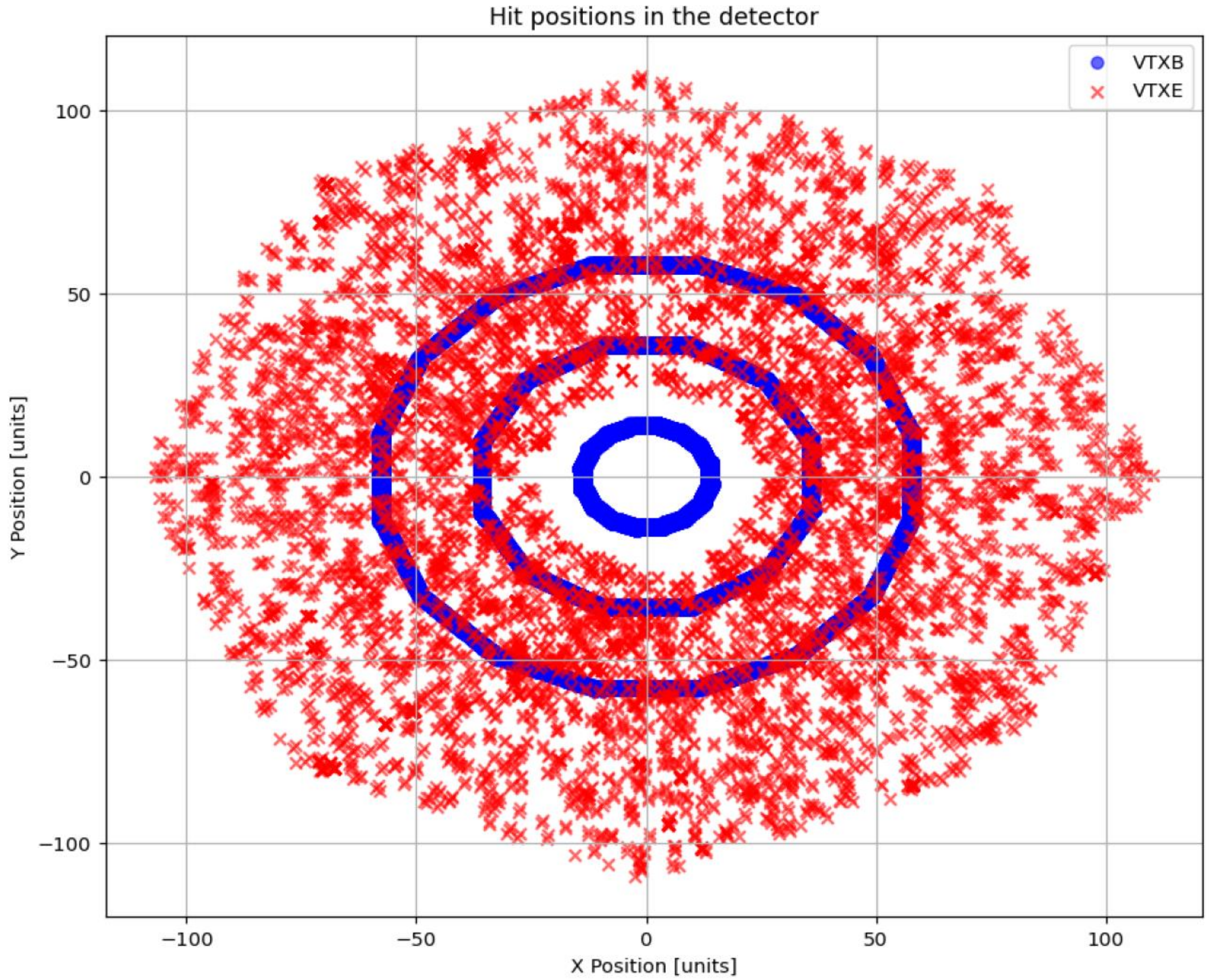
Name	σ1 (mm)	σ0 (mm)	σ2 (mm)
VXDBarrelDigitiser **Resolution U**	0.010	0.003	0.0001
VXDBarrelDigitiser **Resolution V**	0.010	0.003	0.0001
VXDEndcapDigitiser **Resolution U**	0.010	0.003	0.0001
VXDEndcapDigitiser **Reslution V**	0.010	0.003	0.0001

https://github.com/key4hep/CLDConfig/blob/main/CLDConfig/CLDReconstruction.py

Mapping in Vertex System

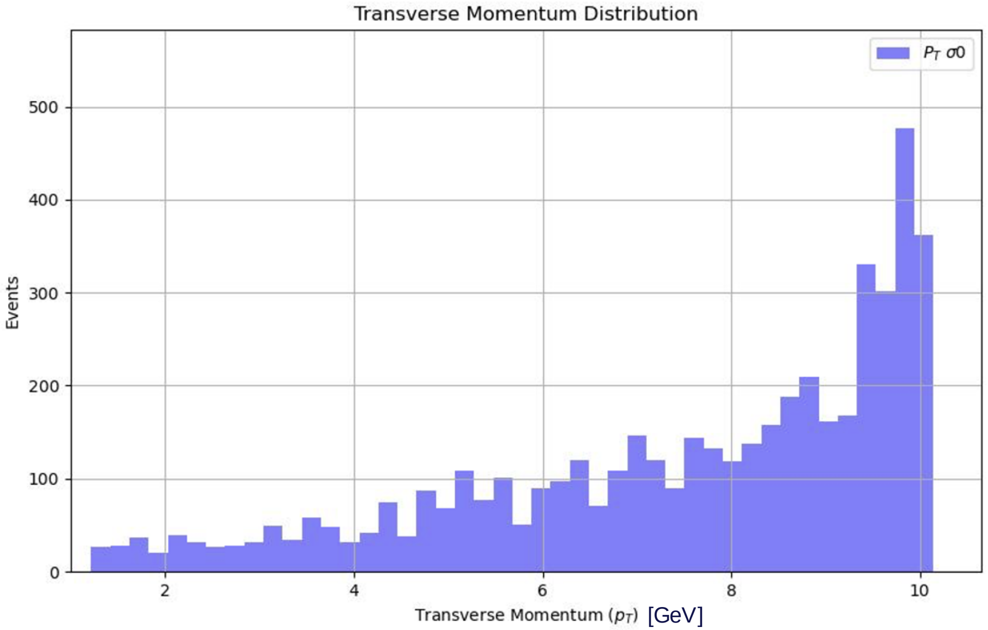


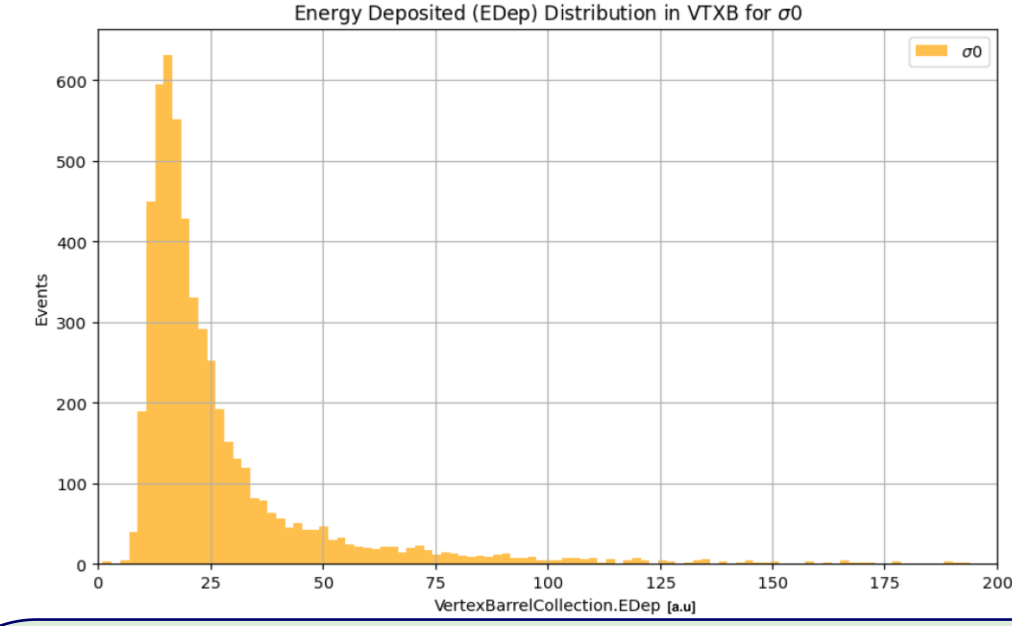


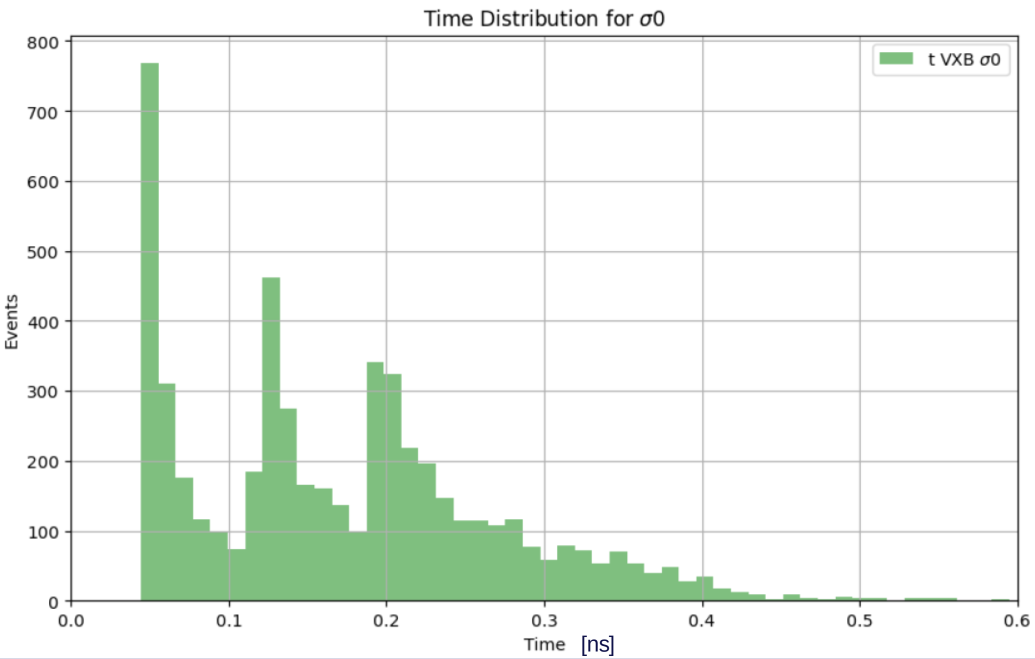


Mapping of the simulated hit for single muon with total energy of 10GeV for Vertex Barrel and Vertex Endcap.

Control Plots







Transverse Momentum Distribution (P_T):

- Peak near 10 GeV.
- Consistent with high-energy single muon events.

Time Distribution:

- Multiple peaks with the third decaying smoothly.
- Indicates complex interactions and muon decay within the detector.

Energy Deposition (E_{Dep}):

- Follow a landau shape

Digitization

Simulation Environment:

- Set up simulation with DD4hep.
- Integrate CLD detector model.
- Validate with initial test runs.

Read in SimHit:

- CellID (ID for detector), Edep (Deposited Energy), Time (Detection time)

Charge and Signal Response:

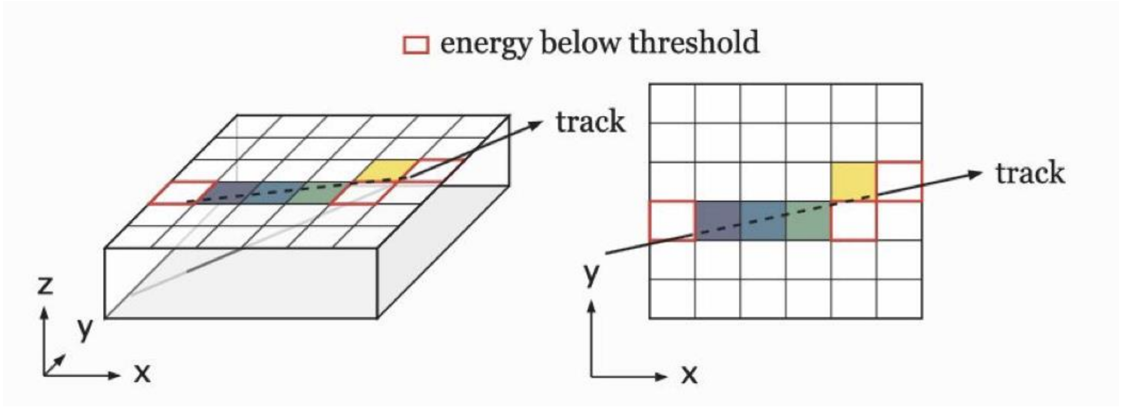
- Response by layer, apply threshold
- Segment and centre hits in each cell

Cluster Formation:

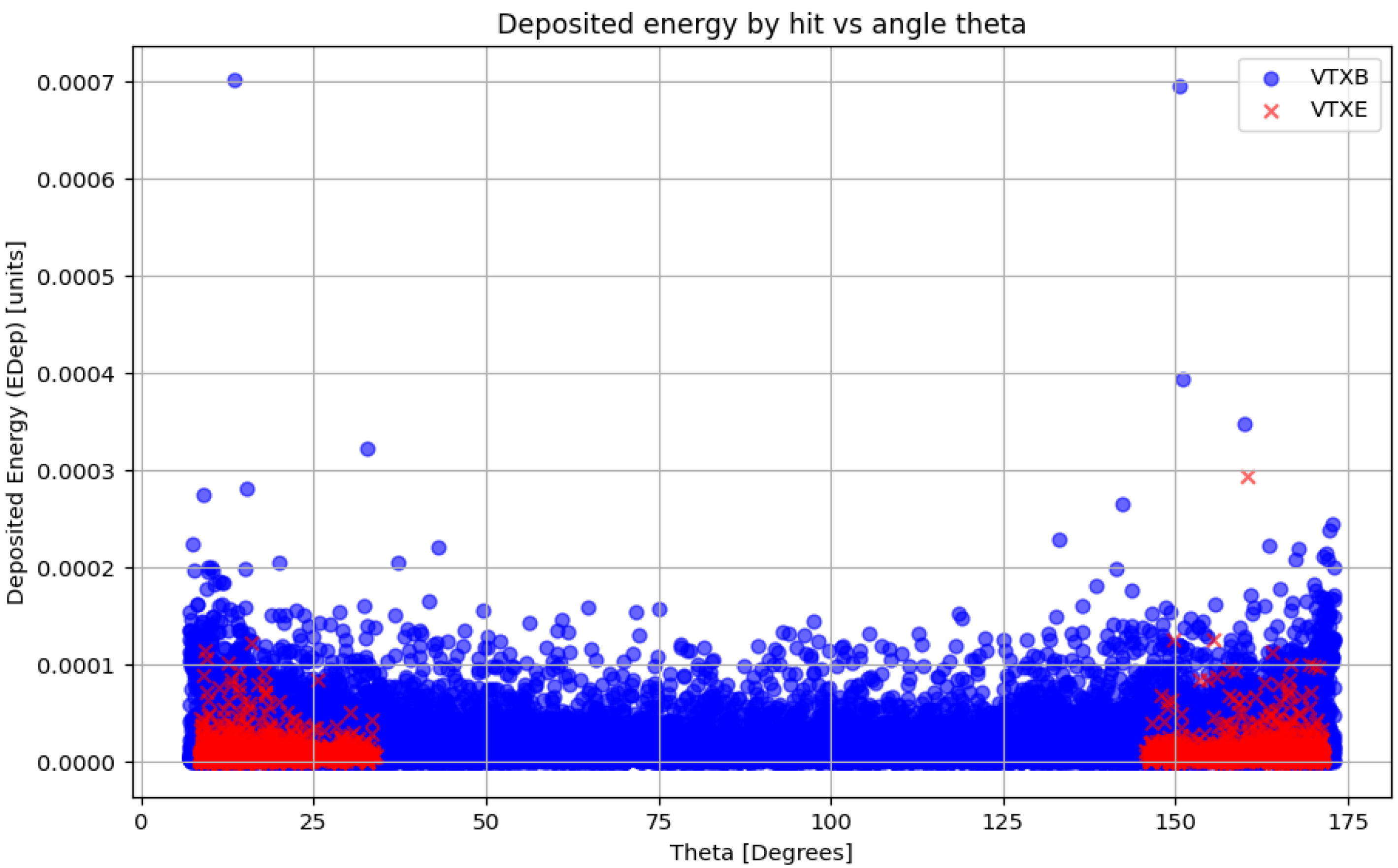
- Create clusters, evaluate efficiency and resolution

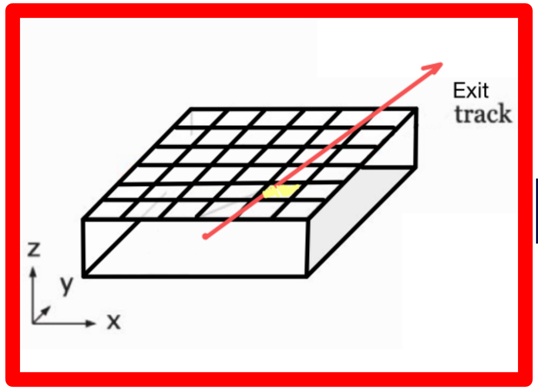
Integration and Testing:

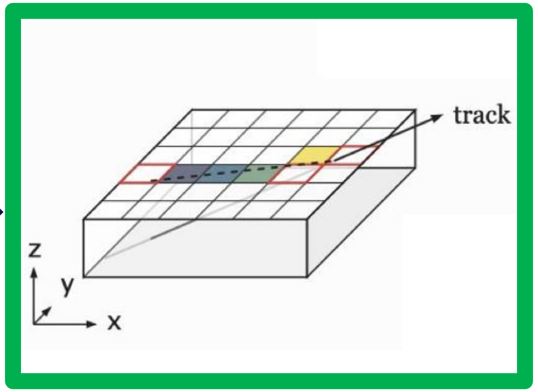
- Integrate into Key4hep framework.
- Test and extend to other FCC-ee concepts (IDEA, ALLEGRO).



Trajectory Angle in VTXB and VTXE







Single Detection Position:

- No entry/exit points
- Angle calculation based on one position.

Importance of Entry/Exit Points:

- Precise angle reconstruction
- Accuracy particle trajectory reconstruction
- Essential for improving vertex system precision
- Direct impact on digitization.

Conclusions

Achievements:

- Established a fully functional full simulation workflow from generation to reconstruction.
- Created a set of control plots (low-level reconstruction, tracking) to validate changes for subsequent development.
- Identified the weaknesses and locations of current functionalities (fixed resolution)
- Tested various configurations to properly document the current situation.
- Prepared a function to transform deposited energy into charge (available in the backup).

Conclusions

Next Steps:

1. **Definition of Segmentation (Pixels):**

   - Properly define the segmentation into pixels.

2. **Analysis of Entry and Exit Points:**

   - Obtain the information of the entry and exit points to access the trajectories within the sensor (available in Geant4).

3. **Projection of Charge:**

   - Project the charge from the trajectories to the pixelated surface.

4. **Definition of Clusters:**

   -Define clusters and establish thresholds.

The full simulation is a crucial tool to derive physics performance and needs to be accurate . This development should be part of the standard FCCSW software.

Bibliography

[1] Abada, A., Abbrescia, M., Abdussalam, S., Abdyukhanov, I., Fernandez, J. A., Abramov, A., Aburaia, M., Acar, A., Adzic, P., Agrawal, P., Aguilar-Saavedra, J., Aguilera-Verdugo, J., Aiba, M., Aichinger, I., Aielli, G., Akay, A., Akhundov, A., Aksakal, H., Albacete, J., . . . Zurita, J. (2019). FCC-EE: The Lepton Collider. *The European Physical Journal. Special Topics*, *228*(2), 261–623. https://doi.org/10.1140/epjst/e2019-900045-4.

[2] *Detector requirements for FCC-ee*. Available at: https://indico.ific.uv.es/event/5365/contributions/13415/attachments/8156/9912/2020_10_07_Spanish_workshop_detector_requirements.pdf (Accessed: 27 June 2024).

[3] *EDM4hep*. Available at: https://edm4hep.web.cern.ch/ (Accessed: 27 June 2024).

[4] *Silicon vertex tracker geometry and simulation*. Available at: https://indico.bnl.gov/event/20473/contributions/84956/attachments/51902/88761/tracking_svt_ePIC_Jan2024-3.pdf (Accessed: 27 June 2024).

[5] *FCC-ee detector designs*. Available at: https://indico.cern.ch/event/789349/contributions/3298691/attachments/1805339/2946724/FCCCDR4March-MD.pdf (Accessed: 27 June 2024).

[6] *The future circular collider CERN*. Available at: https://home.cern/science/accelerators/future-circular-collider (Accessed: 27 June 2024).

FCC

Thank you
for your attention.

Questions?

Electric Charge per Event

Number of pairs electron – hole:

$$N = \frac{E_{dep}}{E_{ionization}}$$

Total Charge:

$$Q = N * e$$

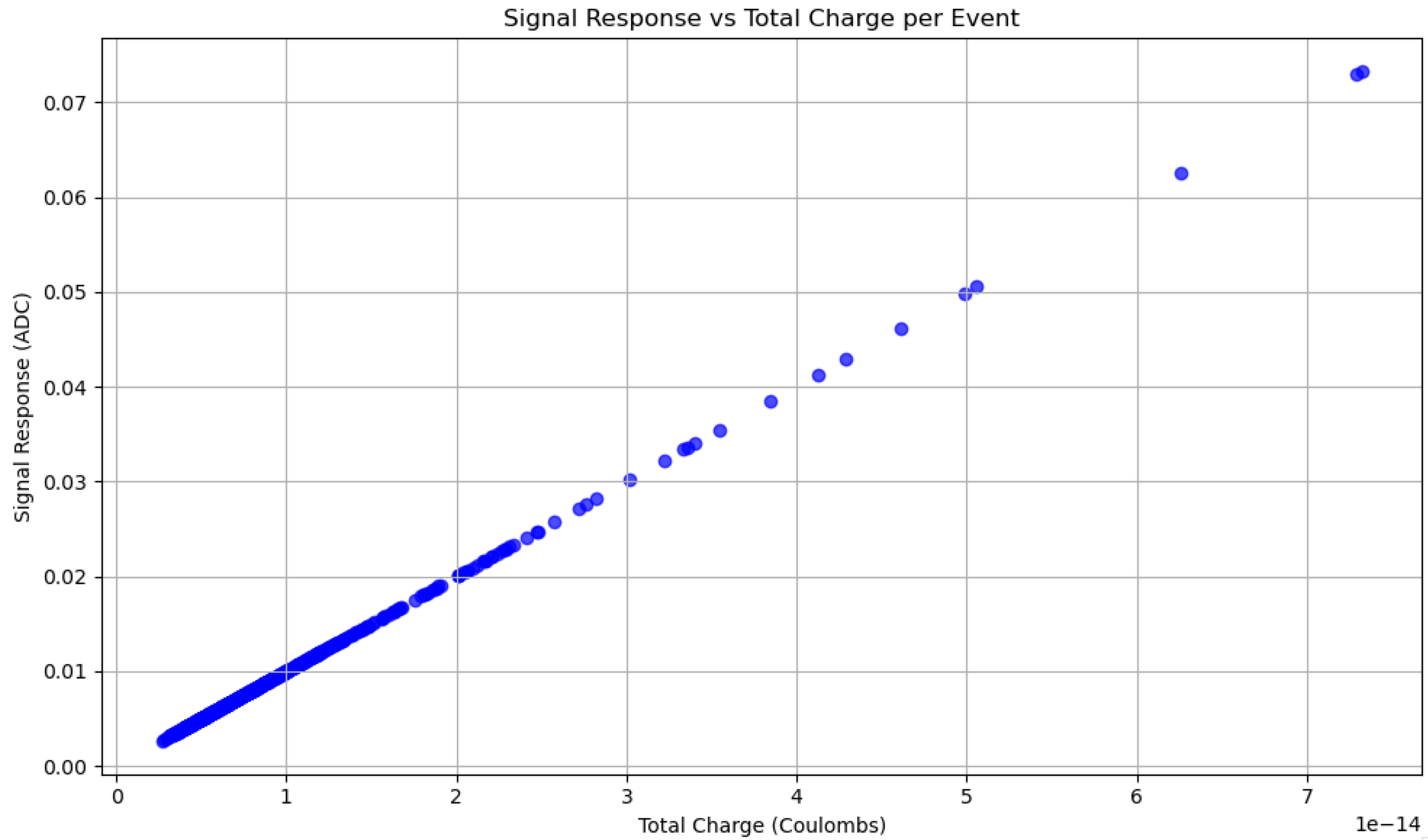
$E_{dep} \rightarrow [GeV]$

$Q \rightarrow [C]$

$e = 1.602e-19\ C$

$E_{ionization} = 3.66\ eV$

Linear generic function ADC(Q) for functionality test



Charge deposited by event in function of the signal response ADC (using a linear function).