HGCAL DPG Related Topics

Longitudinal Shower Profile, Event Reconstruction, and 2024 HGCAL Beam Test Events

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TIDC Workshop @ Yilan Toucheng (宜蘭頭城)

22. November. 2024

Photo source: https://www.businesstoday.com.tw/article/category/80732/post/201306060034/

High Granularity Calorimeter

5D imaging sampling calorimeter

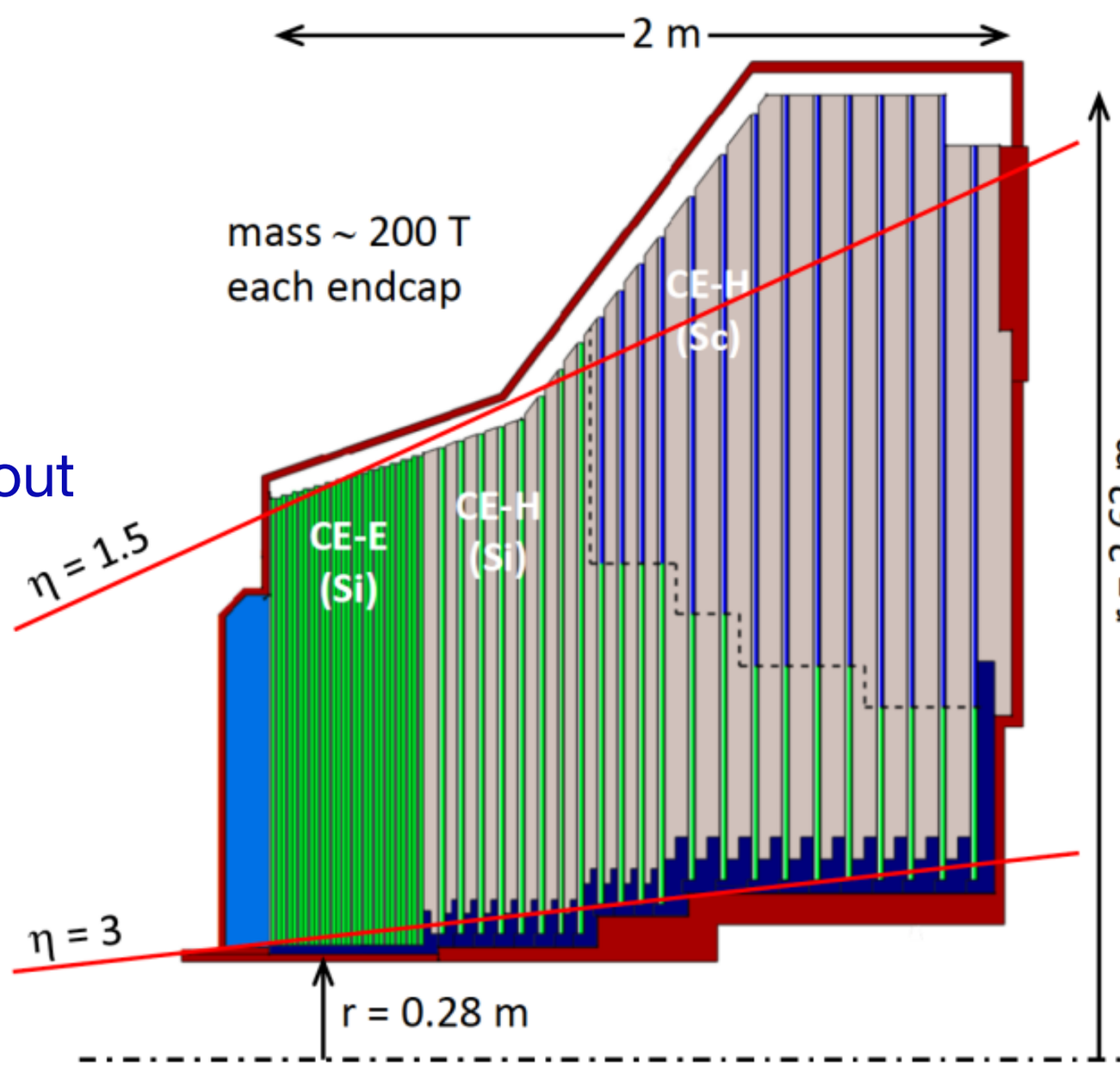
- Covering $1.5 < |\eta| < 3$
- Electromagnetic (CE-E): 26 layers
- Hadronic (CE-H): 21 layers

Active materials

- Silicon sensors
- Plastic scintillator with SiPM readout

Passive materials

- Lead absorber plates
- Copper cooling plates
- CuW baseplates
- Compact and dense (~225 tons)



Agenda

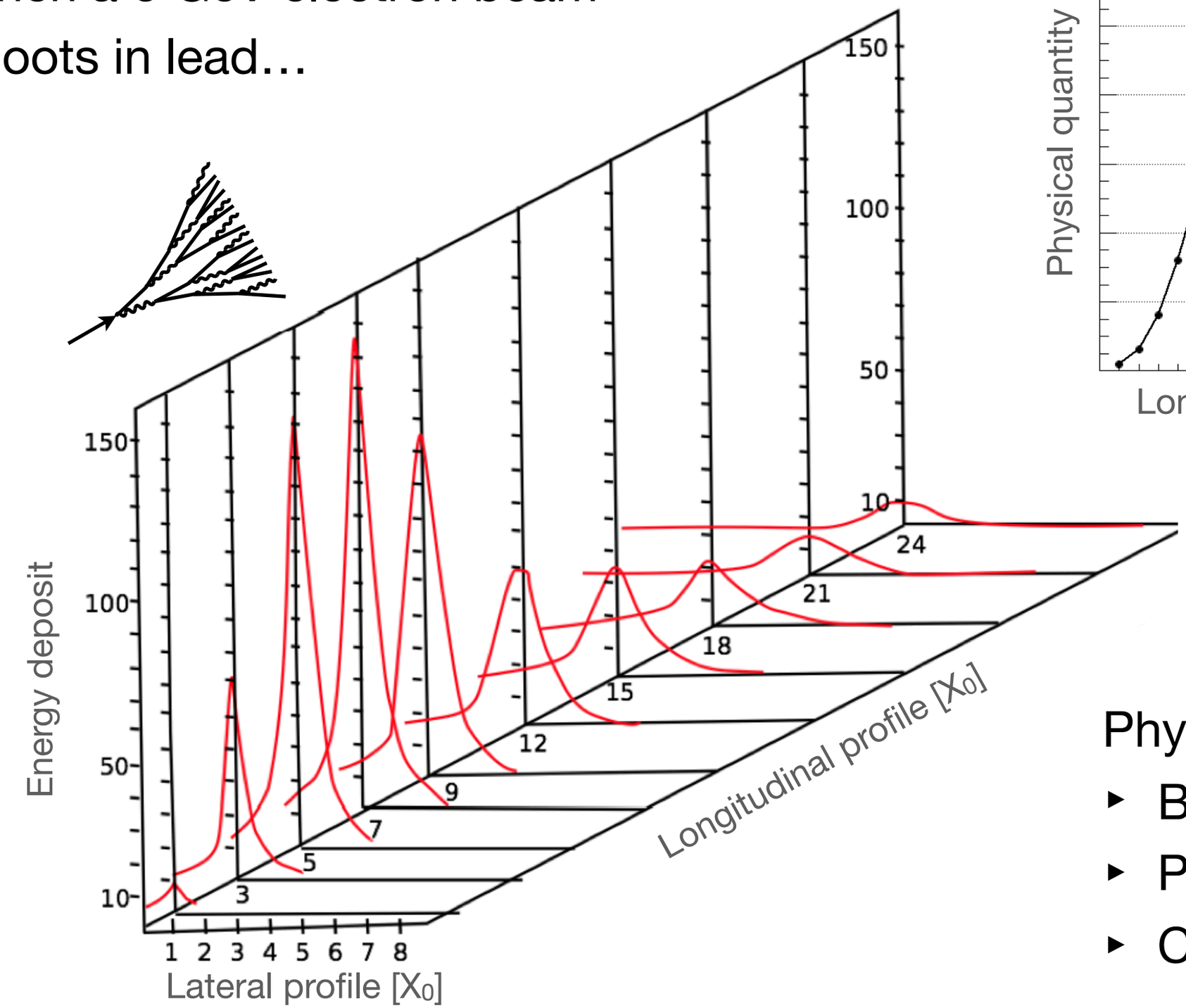
- Study of longitudinal shower profile in HGCAL
- HGCAL event reconstruction using TICL framework
- Raw data handling & 2024 beam test events
- Summary

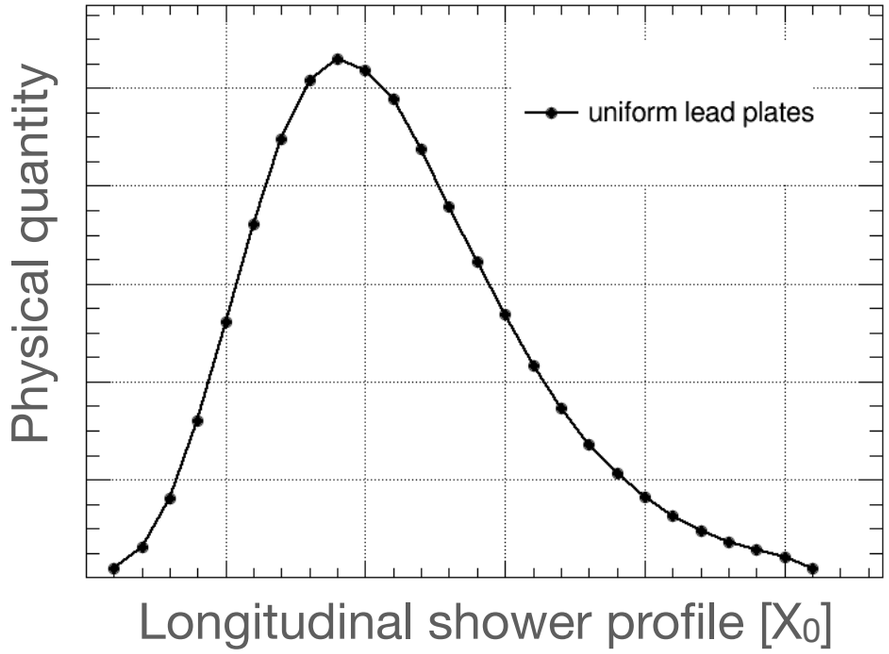
Longitudinal Shower Profile

Photo source: https://www.businesstoday.com.tw/article/category/80732/post/201306060034/

Typical EM Shower Profile

When a 6 GeV electron beam shoots in lead…





Physics in EM shower

- Bremsstrahlung
- Pair production
- Compton Scattering

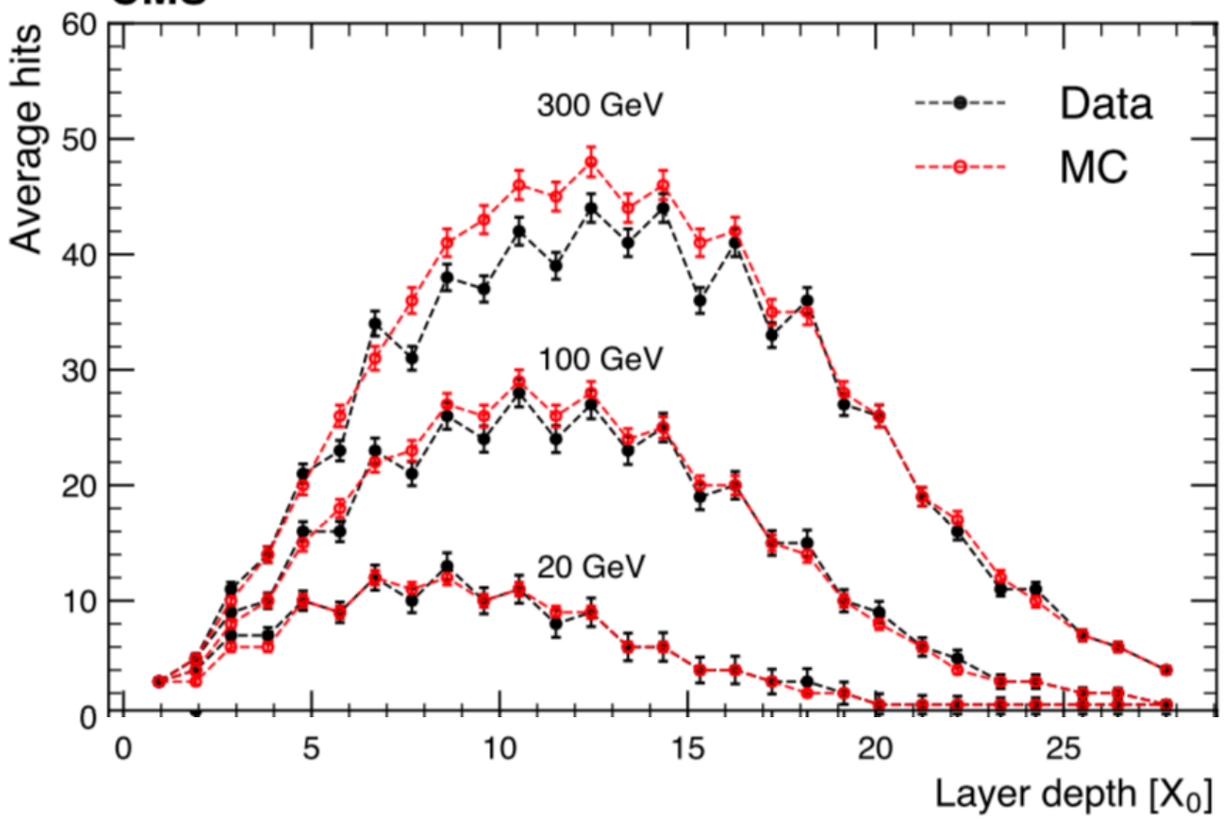
https://www.physi.uni-heidelberg.de/~sma/teaching/ParticleDetectors2/sma_ElectromagneticCalorimeters.pdf

Longitudinal Shower Profile in 2018 beam test

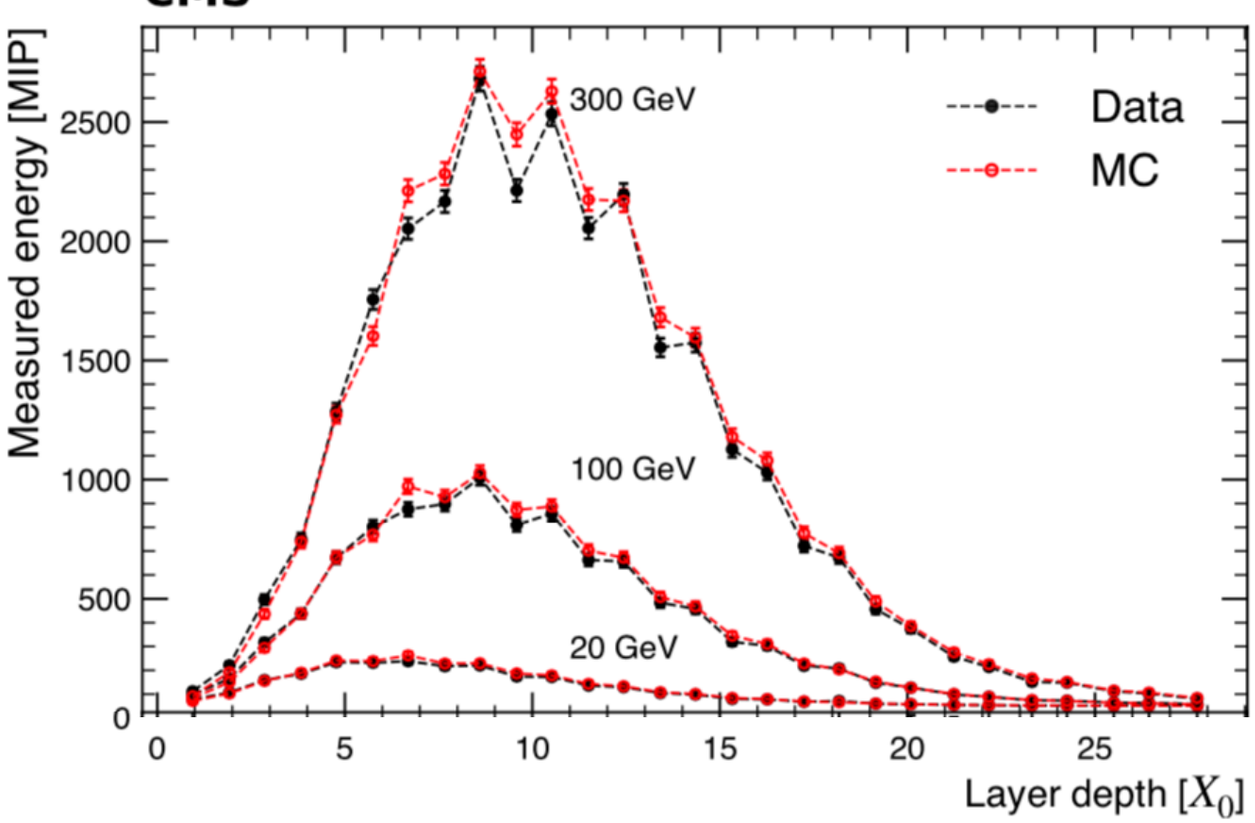
CMS HGCAL collaboration et al 2022 JINST 17 P05022

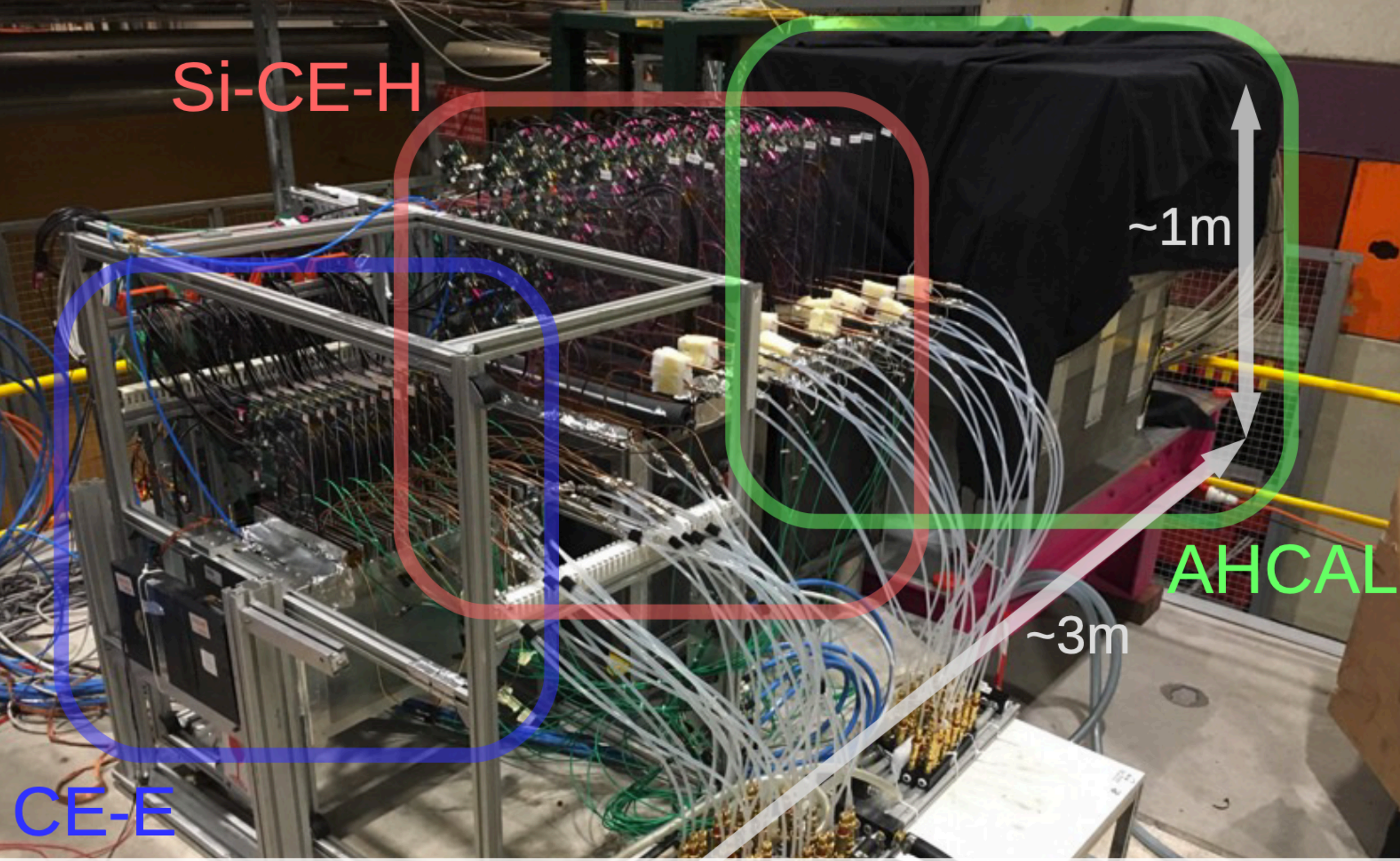
- Zigzag patterns appear in HGCAL longitudinal shower profile
- Understand its physical mechanism can
  - Improve Data/MC agreement
  - More accurate reconstruction of the energy of EM particles
  - Optimize HGCAL trigger design

Average hits



Measured energy



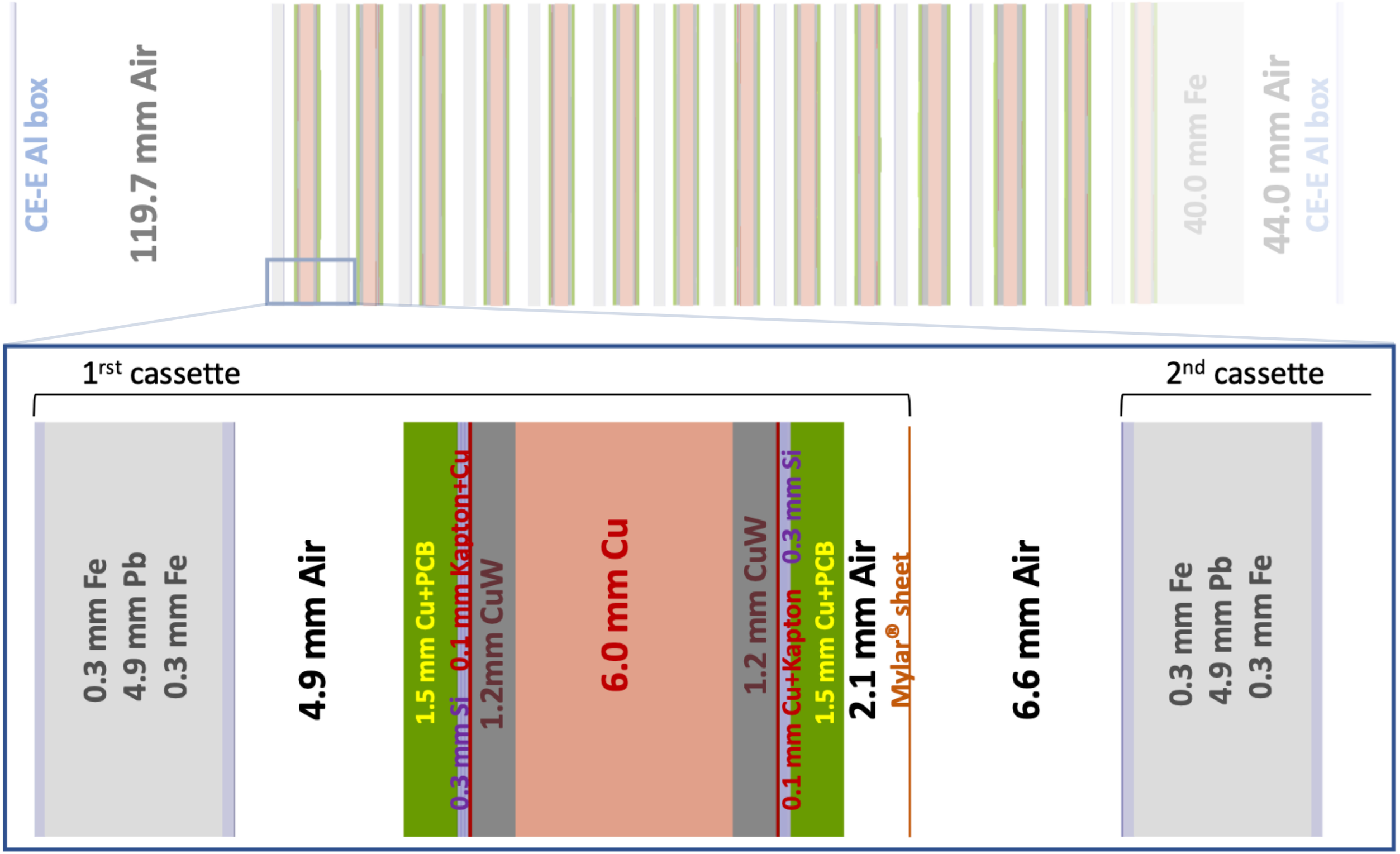


Prototype in the 2018 HGCAL beam test activity

2021 *JINST* **16** T04002

“Sandwich” Placement of Silicon Modules

2021 *JINST* **16** T04002



Toy Detectors in Geant4 Simulation

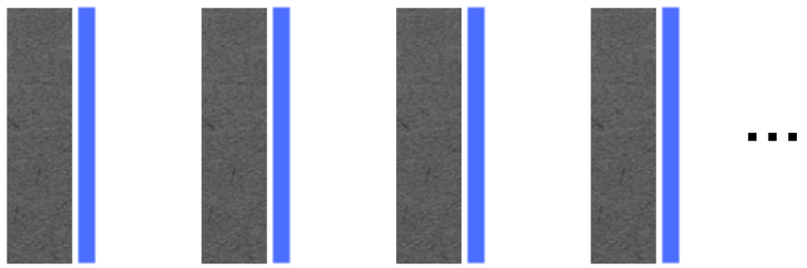
Geometry of toy detectors

Lead

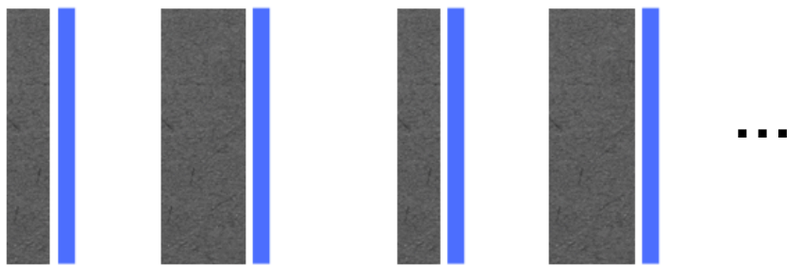
Si sensor

PCB

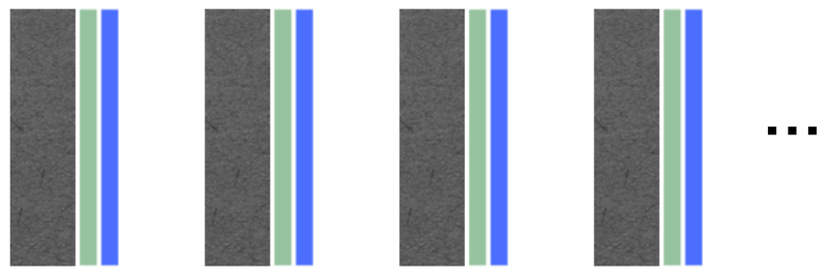
Scheme (a) Equal thickness



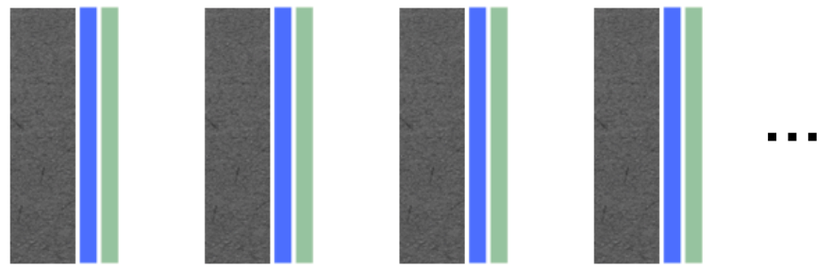
Scheme (b) Alternating thickness



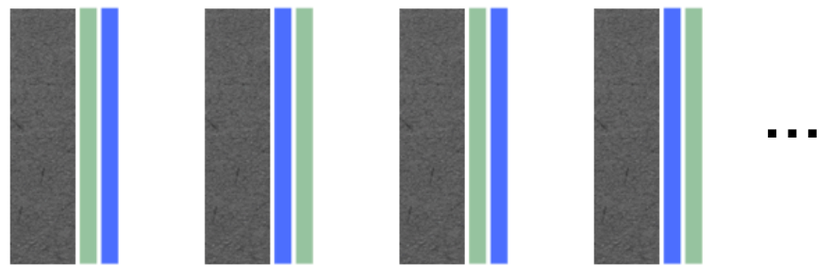
Scheme (c) All PCB before Si



Scheme (d) All PCB after Si



Scheme (e) Alternating manner

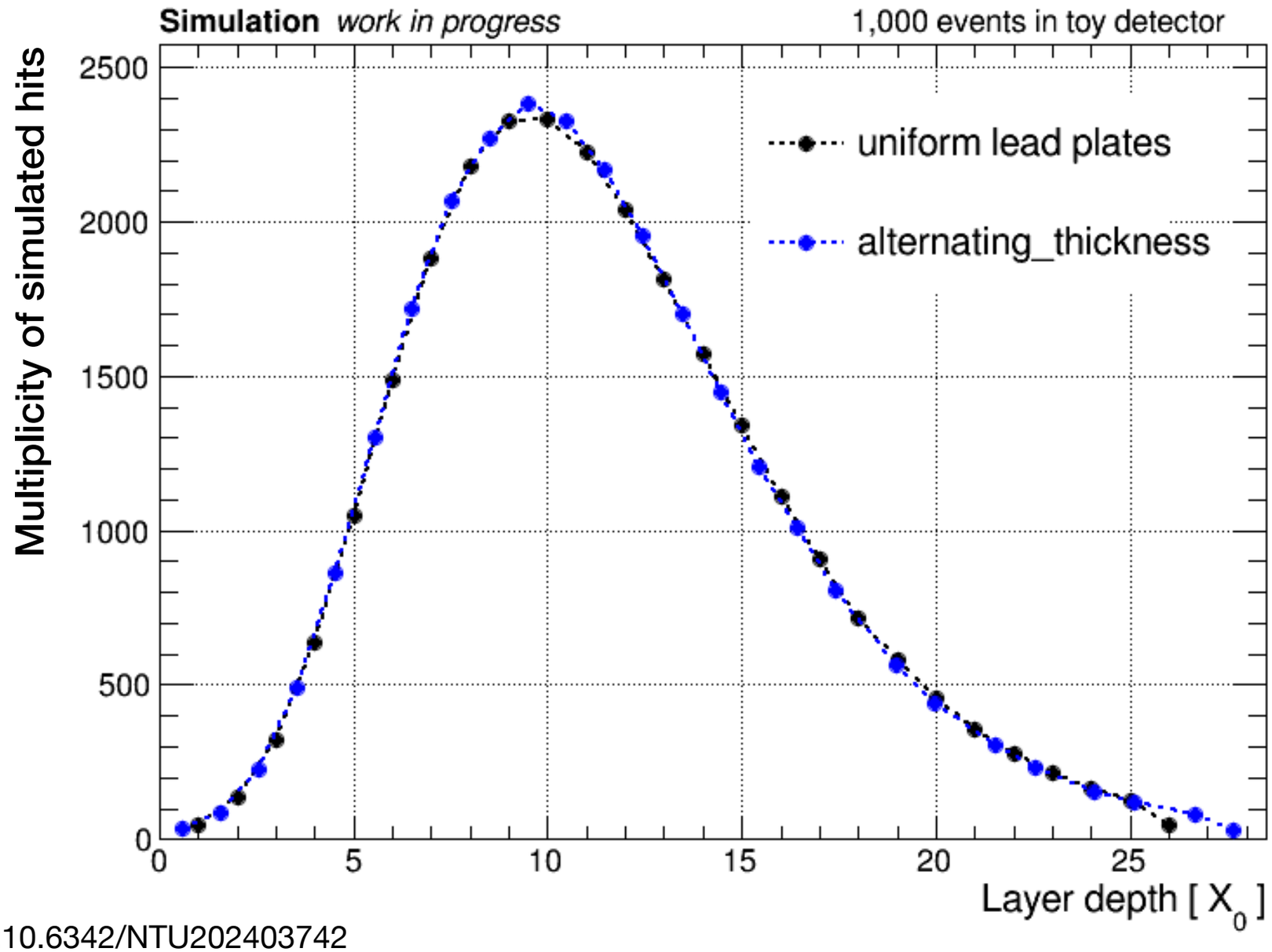


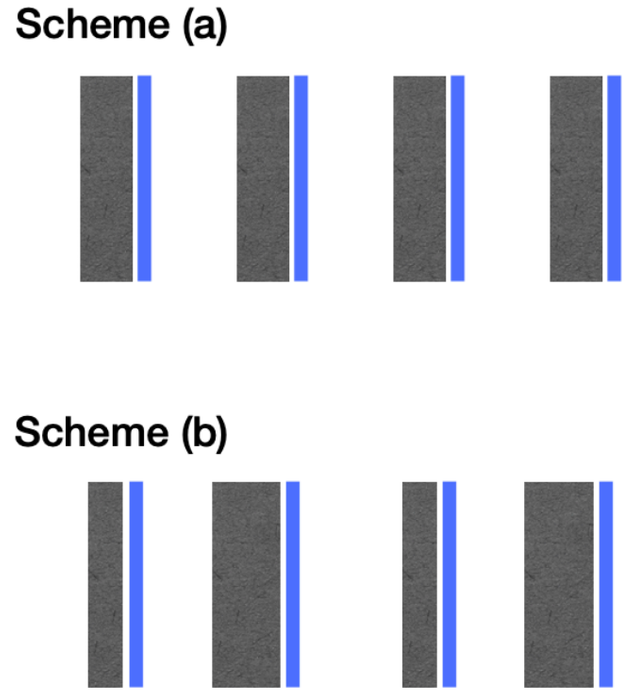
before after before after

doi:10.6342/NTU202403742

Effect of Adding PCB Layers

- No zig-zag is found in the geometry with alternating thickness

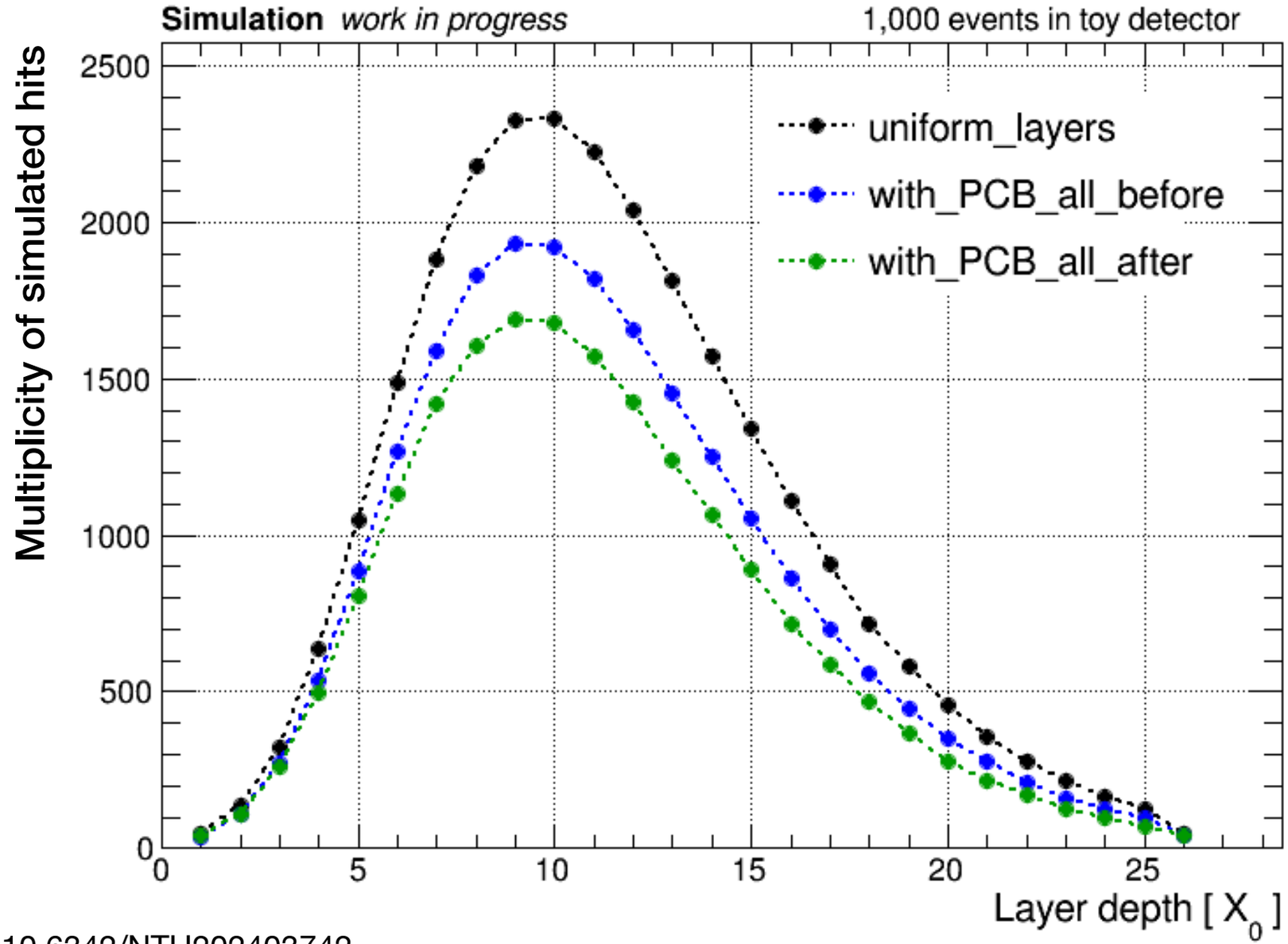




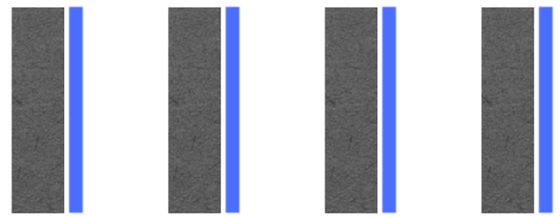
doi:10.6342/NTU202403742

Effect of Adding PCB Layers

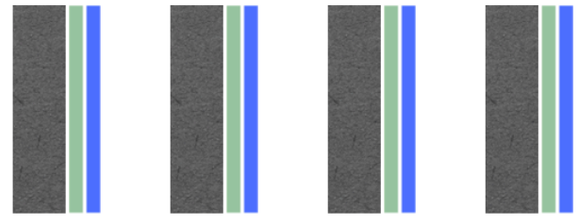
- PCB layers have shielding effects



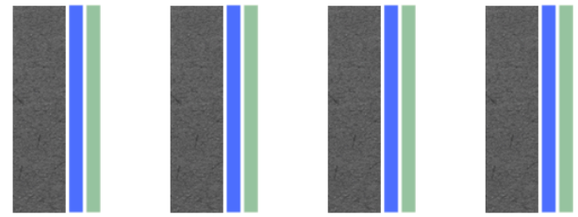
No PCB layers



All PCB before Si



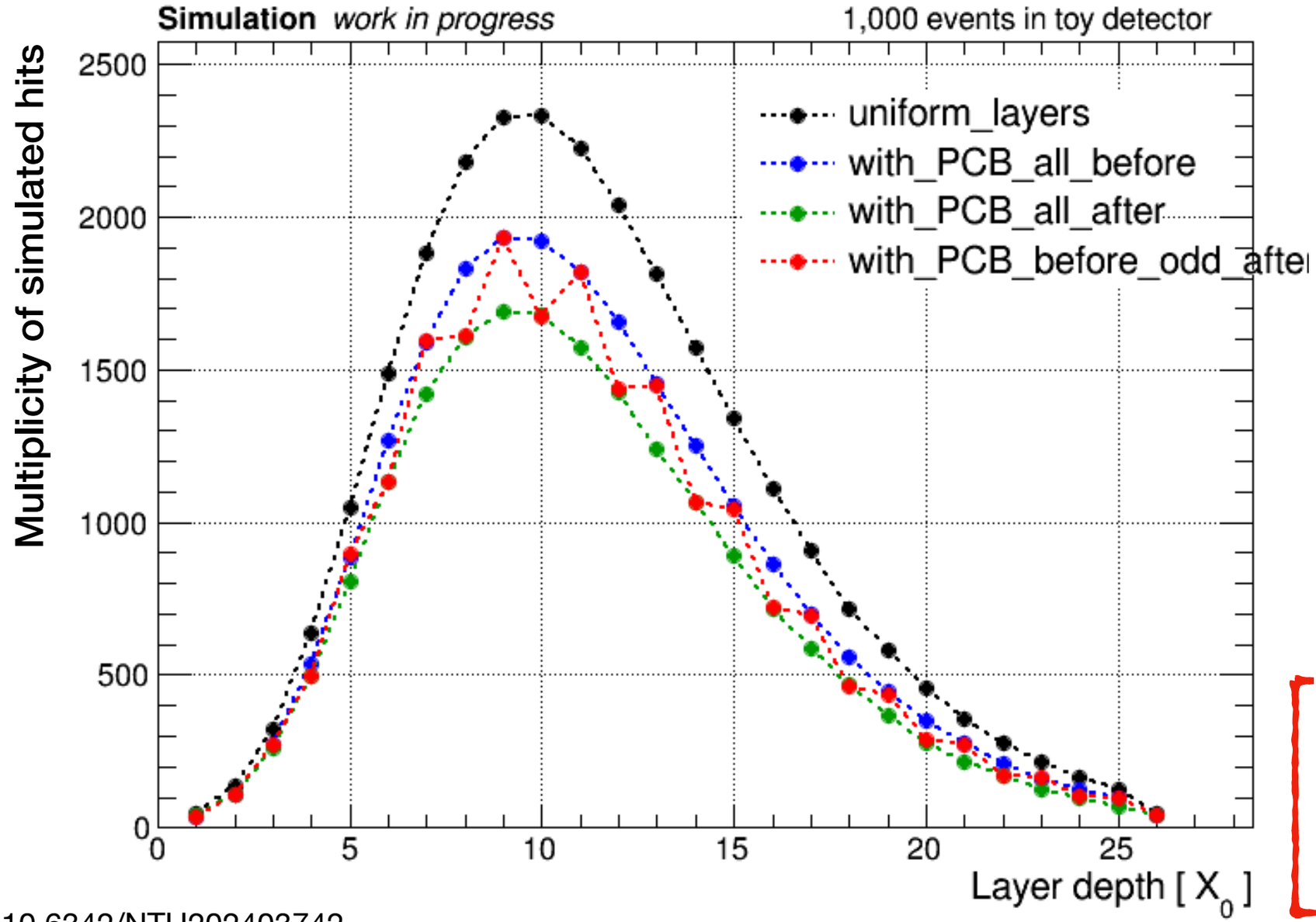
All PCB after Si



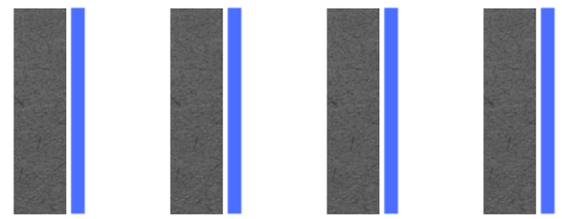
doi:10.6342/NTU202403742

Effect of Adding PCB Layers

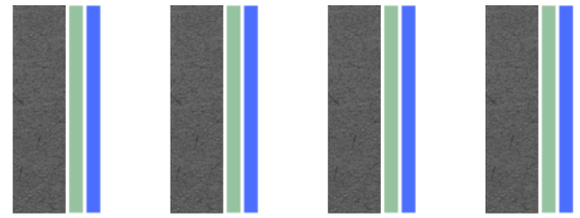
- PCB layers have shielding effects
- Zigzag pattern appears in alternating PCB placement!



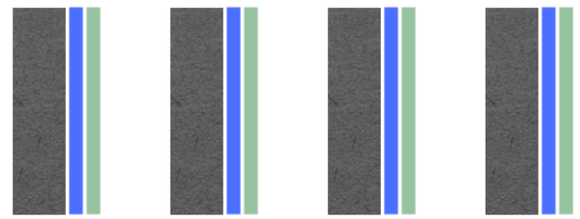
No PCB layers



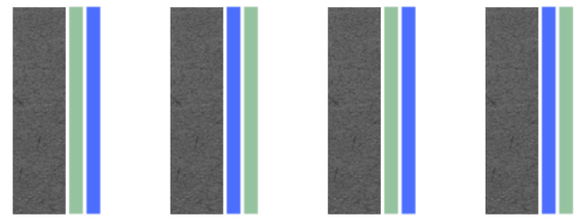
All PCB before Si



All PCB after Si



Alternating manner

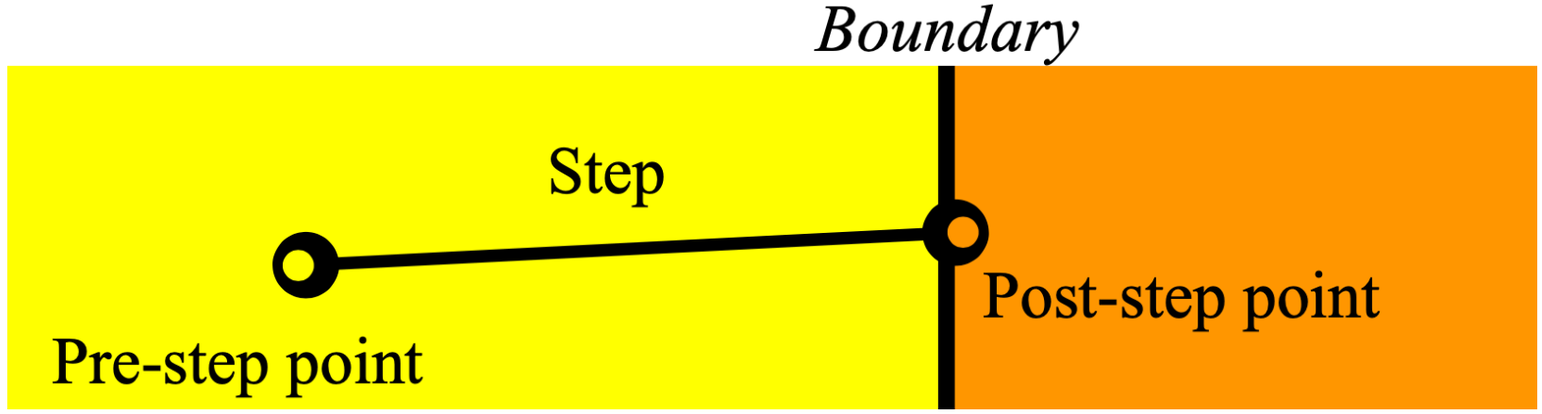


doi:10.6342/NTU202403742

Flag Backward Hits in Geant4 Simulation

GEometry **AN**d **T**racking 4

- A platform for the simulation of the particle passage through matter using Monte Carlo method.
- Based on C++ with a modern object-oriented design.
- Geant4 includes facilities
  - geometry
  - tracking
  - detector response
  - run management
  - visualization and user interface

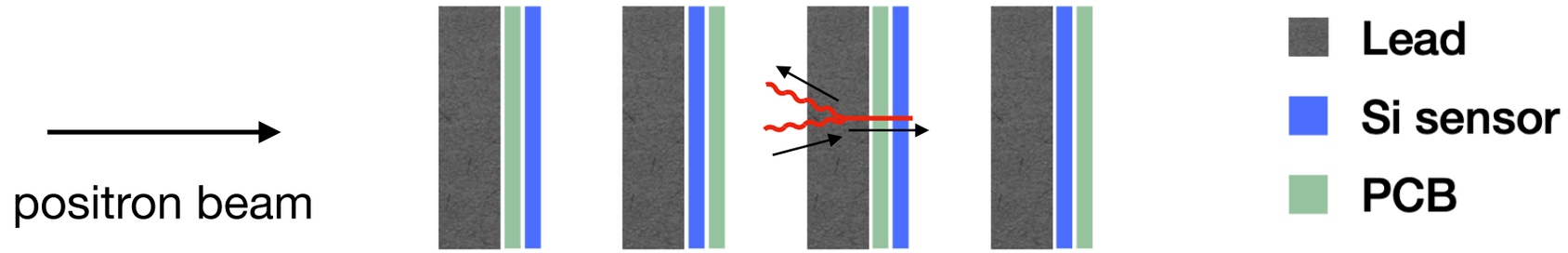


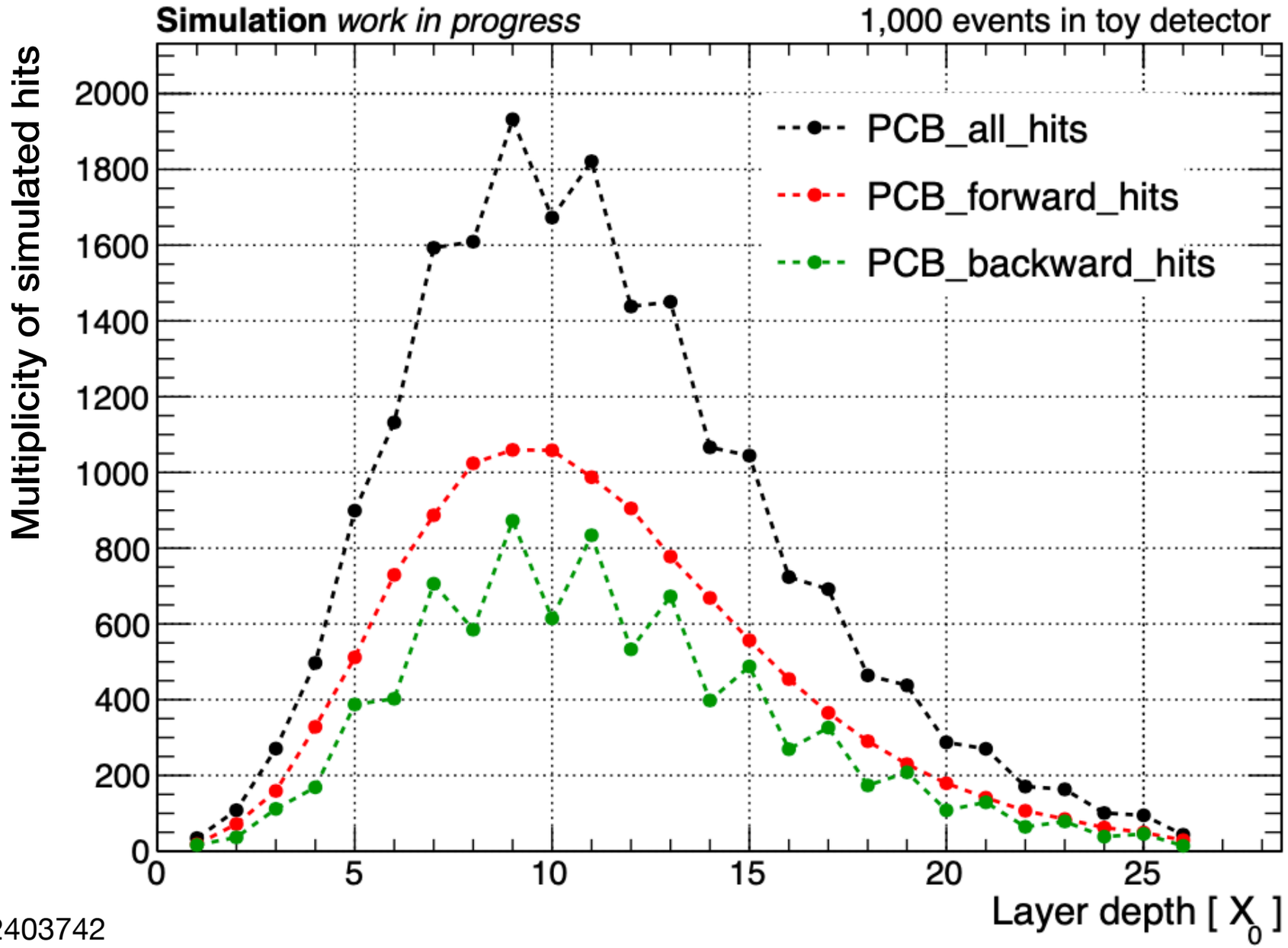
→ **Add a new variable indicating hits from backward tracks!**

“Backward hits”

https://en.wikipedia.org/wiki/Geant4
https://indico.cern.ch/event/781244/contributions/3251881/attachments/1782480/2900505/Introduction-and-Kernel-Course-Jan2019.pdf

“Backward” Compton Scattering





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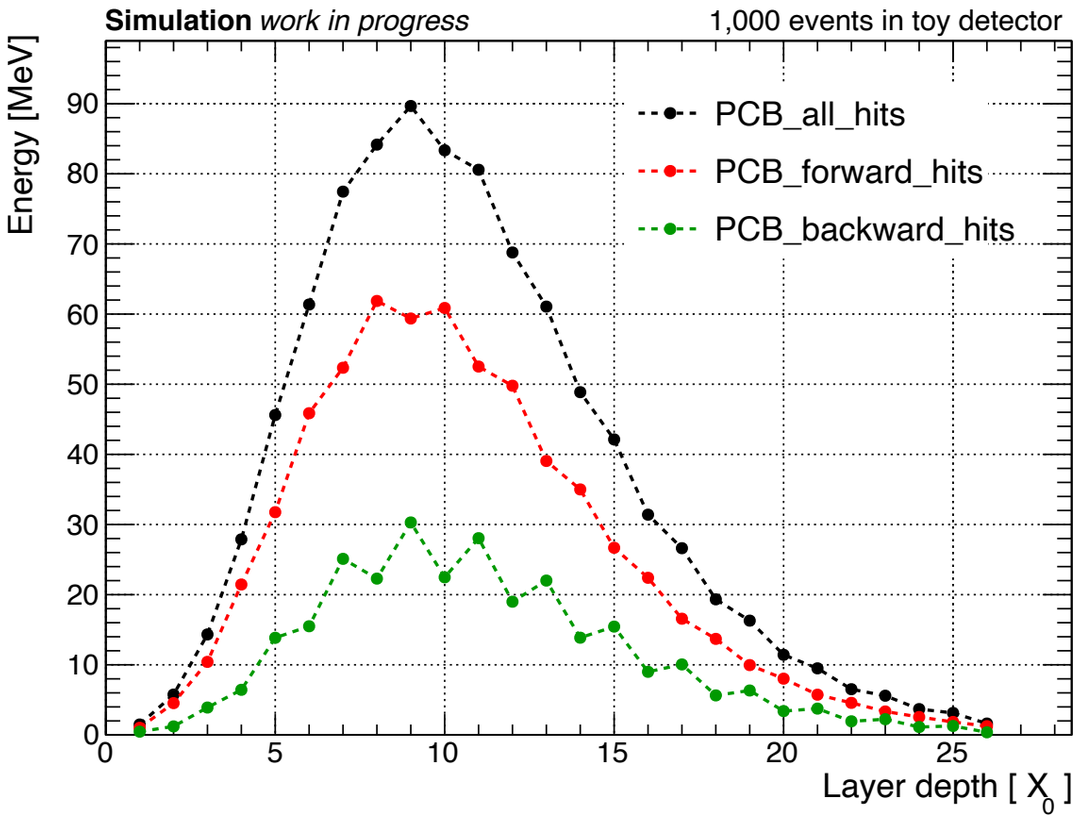
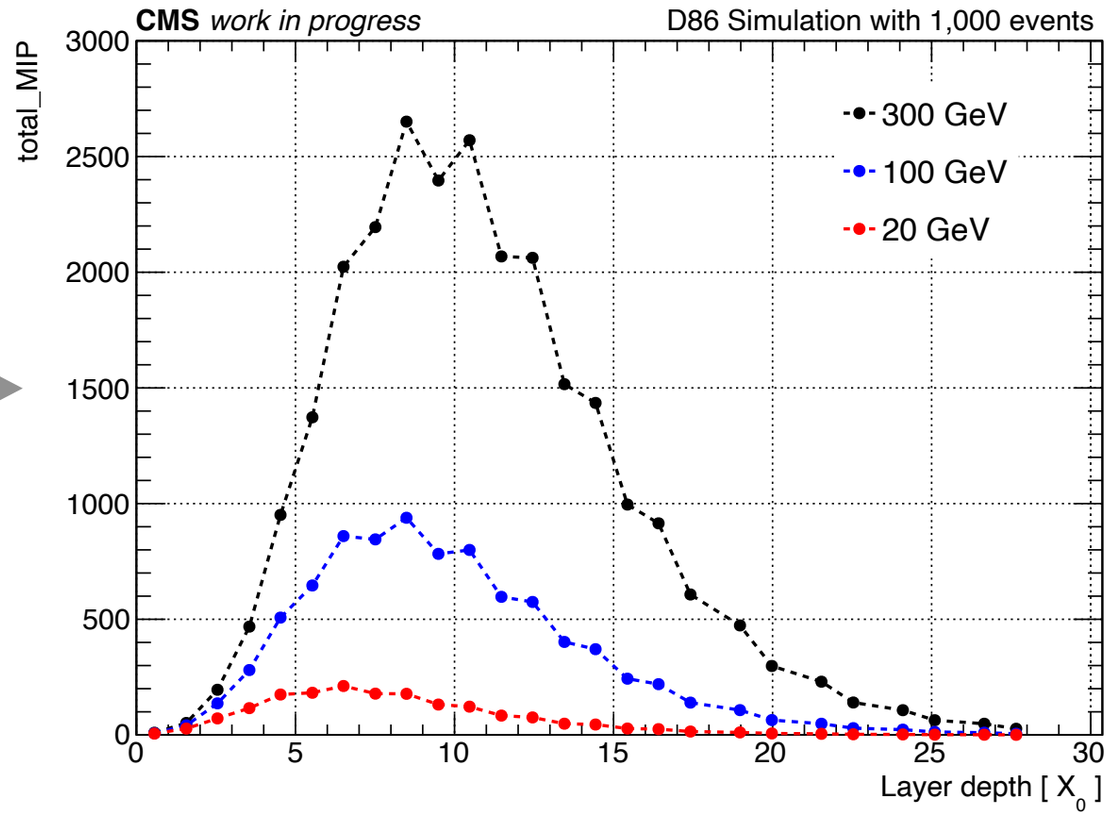
Longitudinal Profile for Deposited Energy

Toy Detectors



D86 in CMSSW



Putting more realistic passive layers

should evolve in the observed zigzag pattern

doi:10.6342/NTU202403742

HGCAL Event Reconstruction

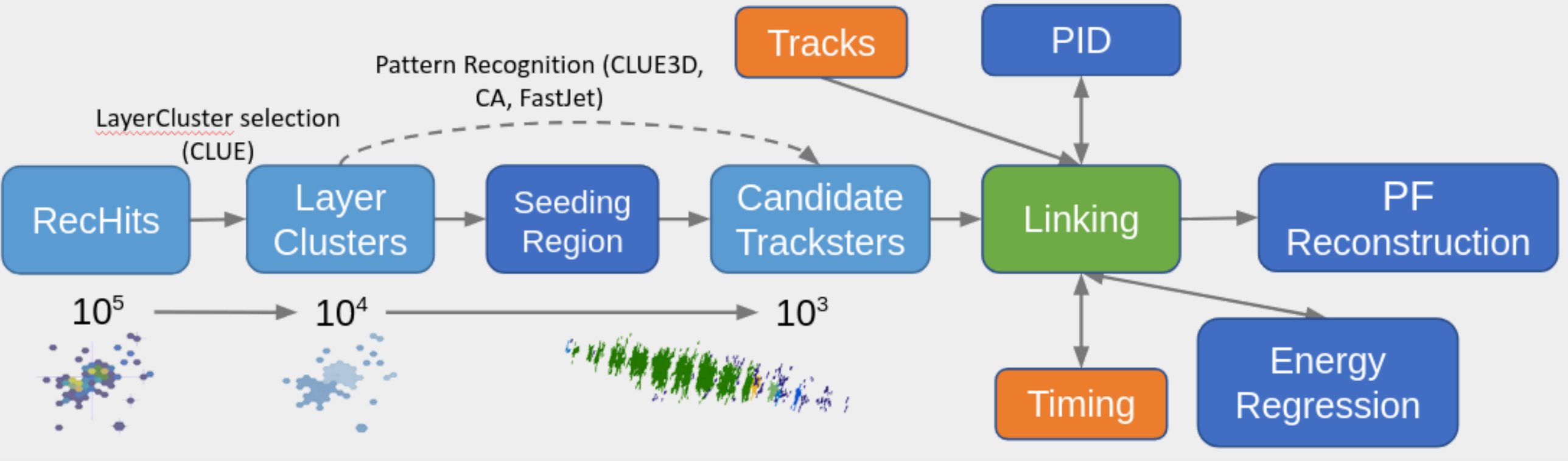
Materials from 2024 LHCC poster (link)

Photo source: https://www.businesstoday.com.tw/article/category/80732/post/201306060034/

TICL Framework

- The Iterative CLustering framework
  - Flexible and modular framework
  - Core algorithms are friendly to heterogeneous computing
- Initially designed for the HGCAL reconstruction, and currently being extended to potentially become the particle flow framework for phase-2

Felice Pantaleo *et al* 2023 *J. Phys.: Conf. Ser.* **2438** 012096

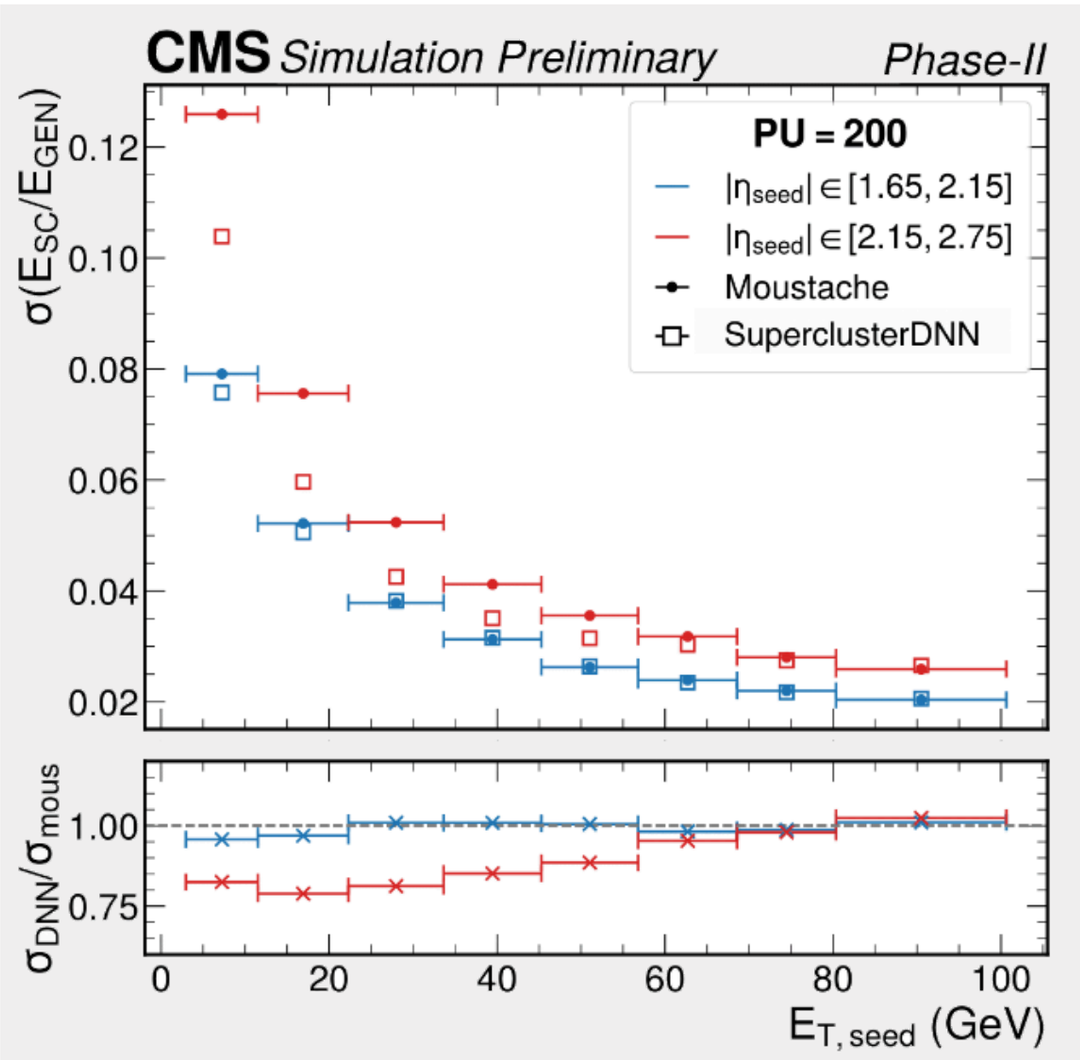


Source: Wahid Redjeb et al, https://indico.cern.ch/event/1474681/?view=standard_numbered#22-the-cms-phase-2-high-granul

Improved Linking Algorithms in TICL v5a

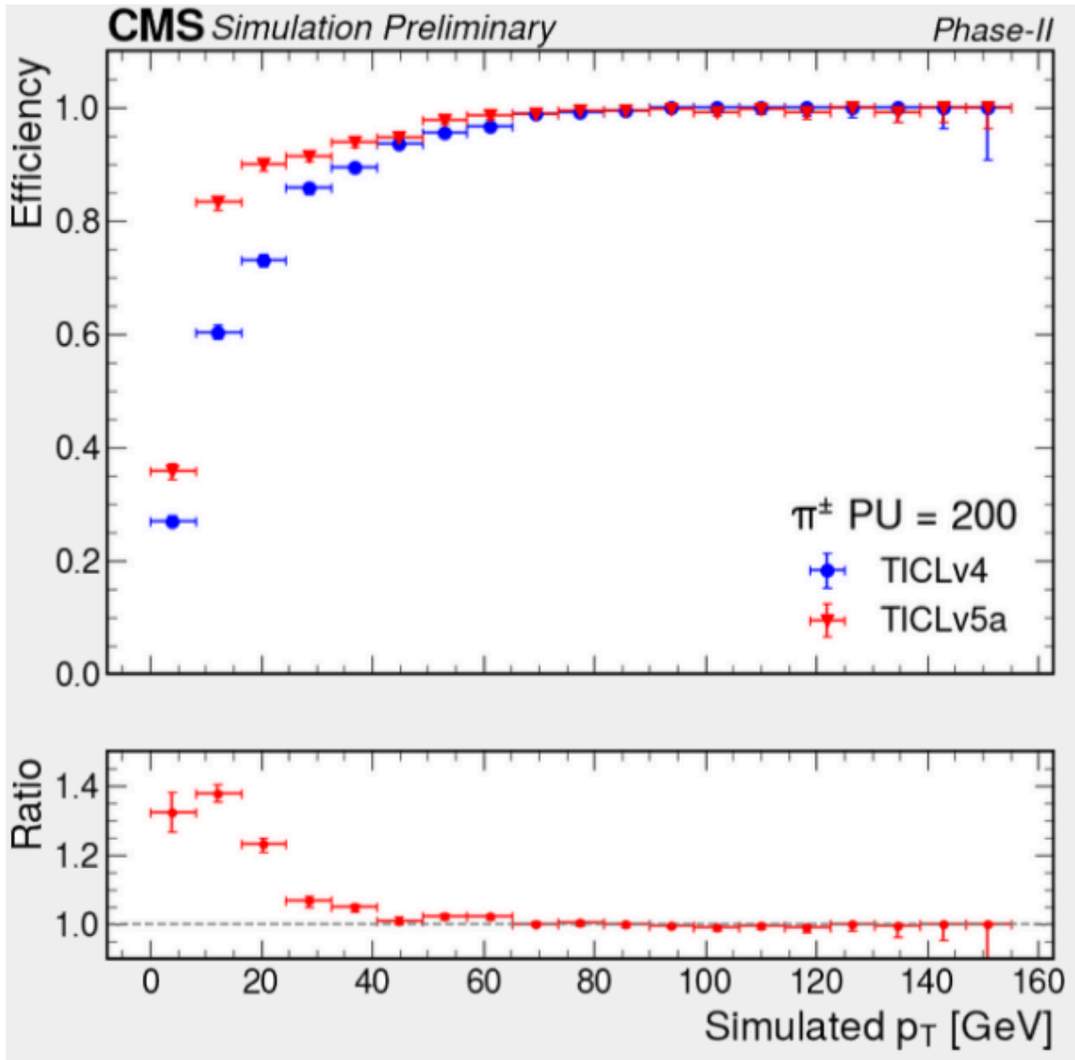
E/Gamma Super Clustering

- DNN-based algorithm
- To retain/reject tracksters within the seed window



Hadronic Shower Fragmentation

- Geometrical alignment compatibility
- Maximize energy collection by taking “un-tracksterized” layer clusters



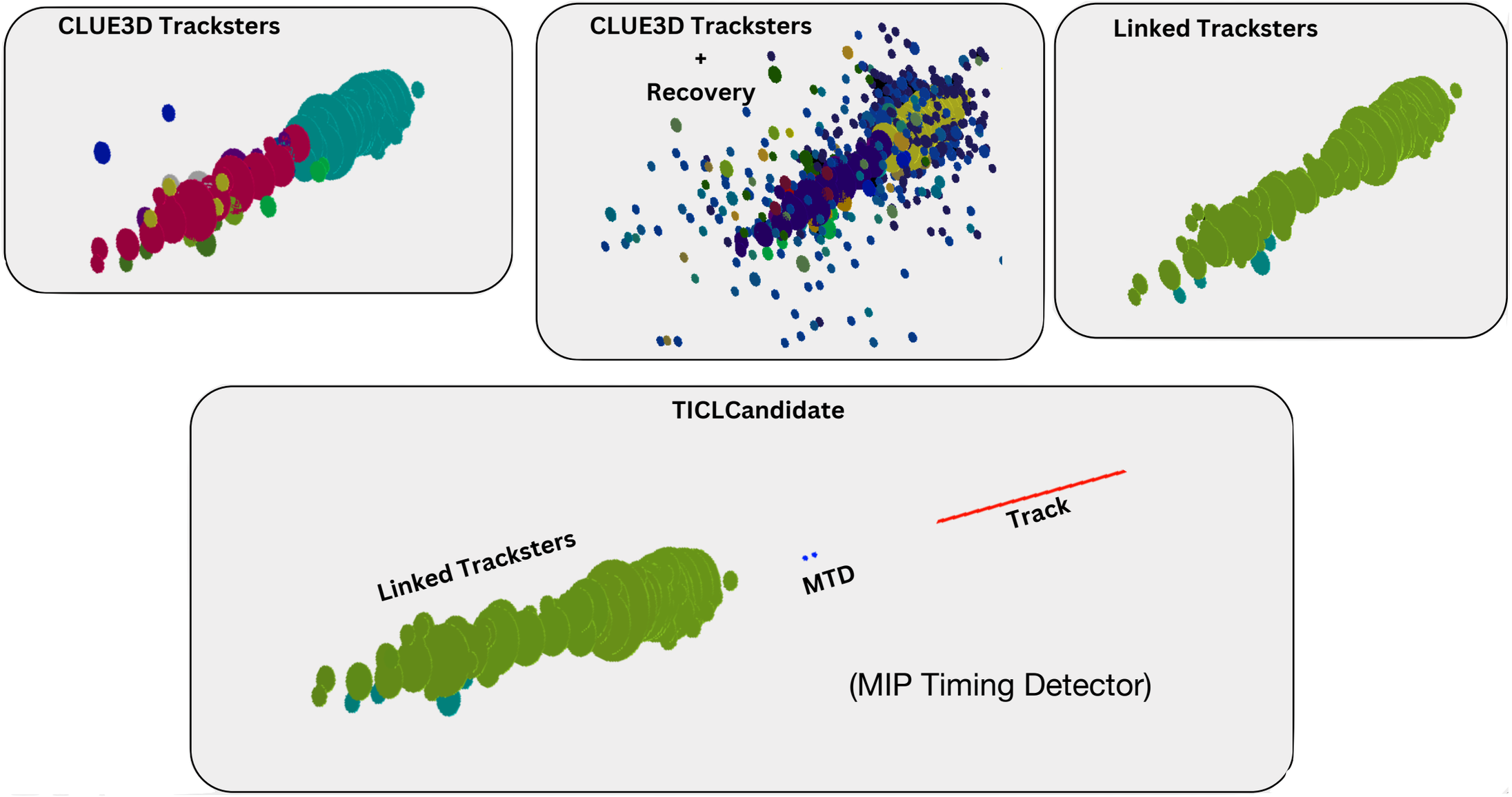
Source: Wahid Redjeb et al, https://indico.cern.ch/event/1474681/?view=standard_numbered#22-the-cms-phase-2-high-granul

Particle Flow Interpretation

TICL candidate building

- Link track and linked-tricksters
- Apply energy regression and PID on final Trackster collection

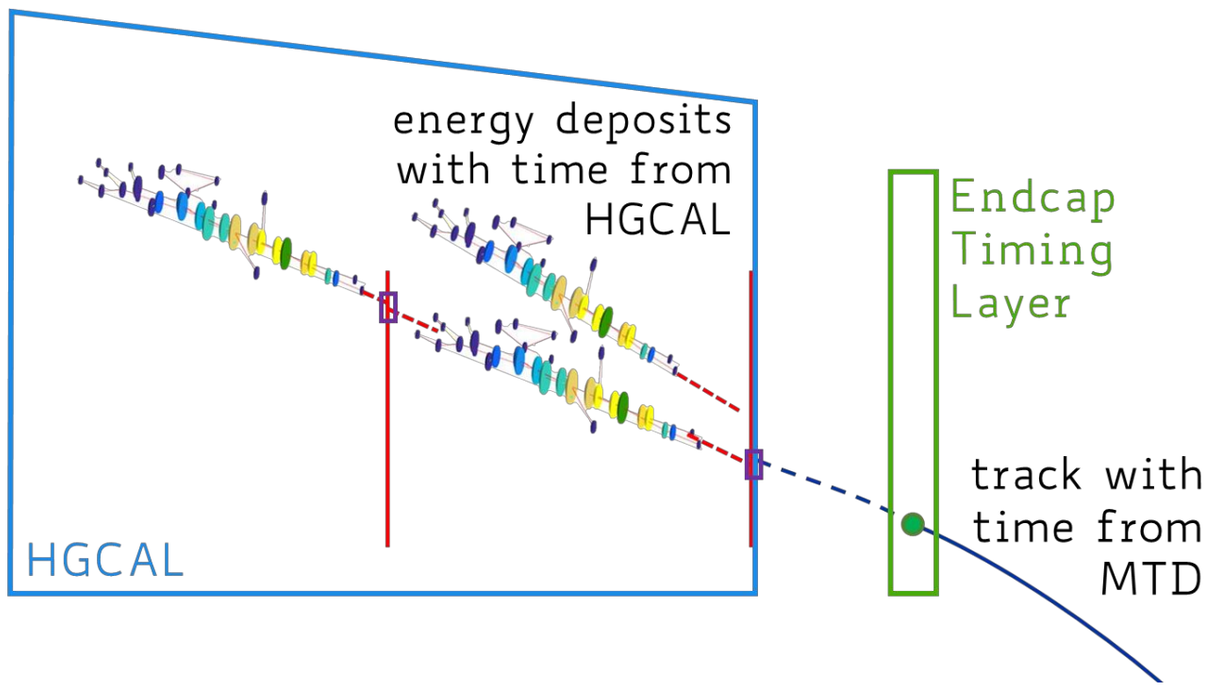
1. HGCAL and ETL time compatibility
2. Additional trackster merging

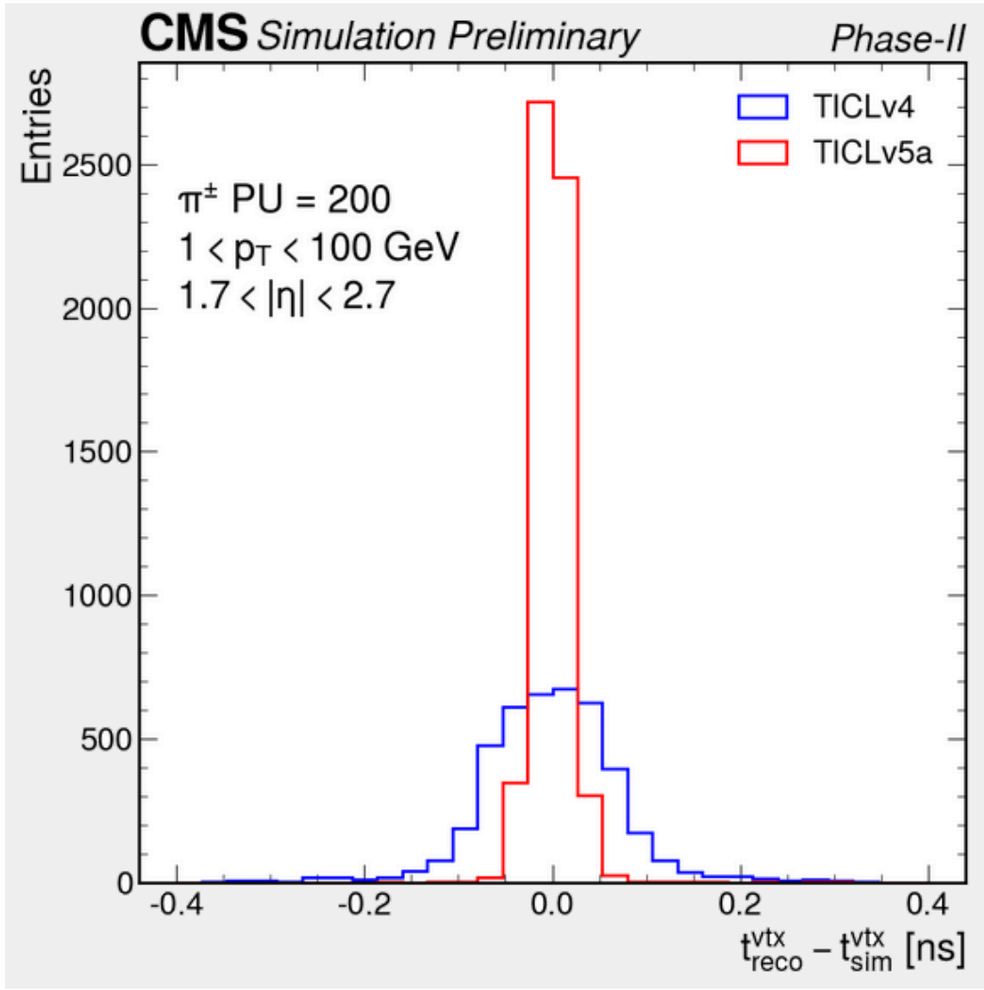


Source: Wahid Redjeb et al, https://indico.cern.ch/event/1474681/?view=standard_numbered#22-the-cms-phase-2-high-granul

Timing Information

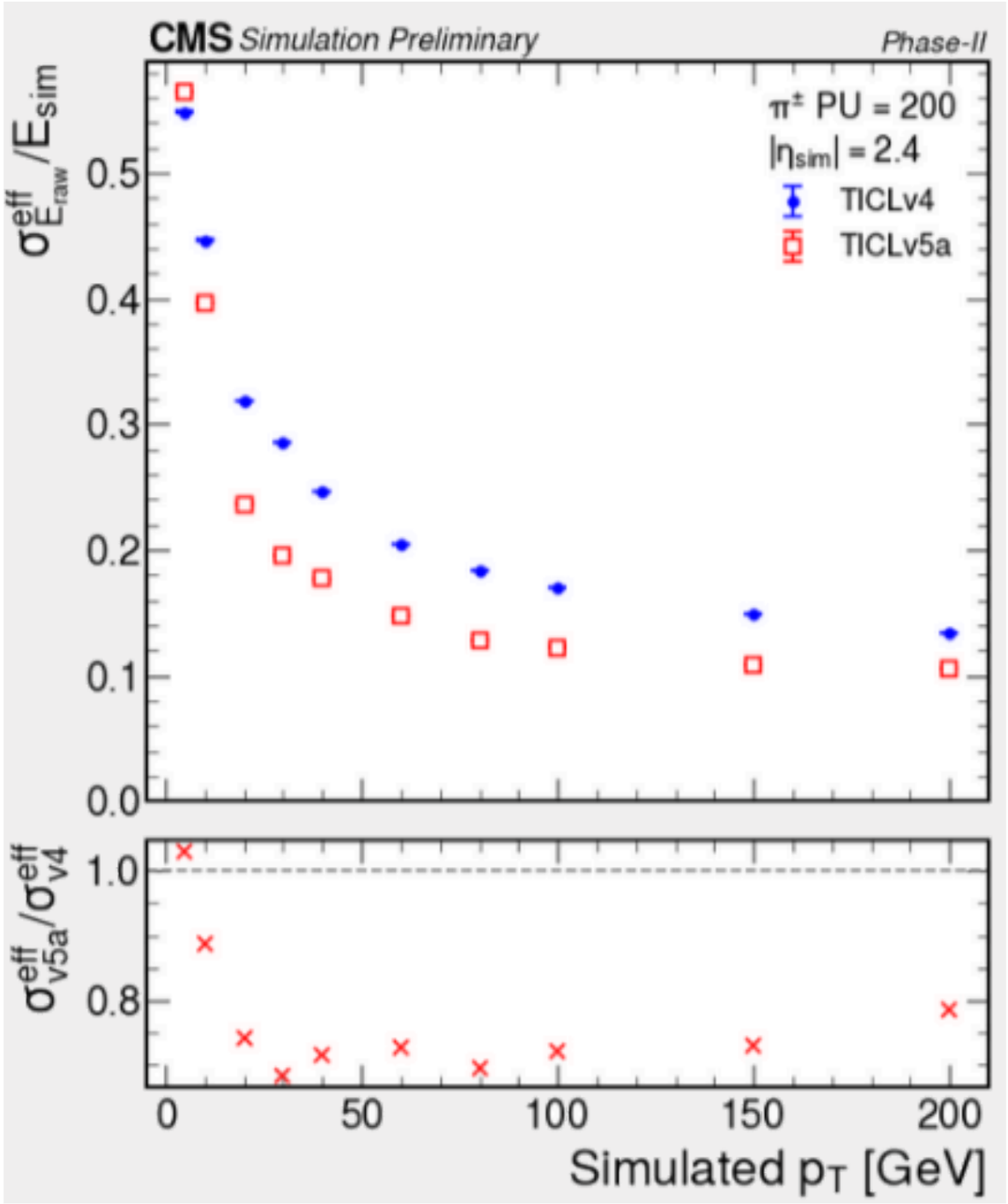
- Hits: Time of arrival (ToA) measured with a time-to-digital converter
- Layer cluster: average of the hits time weighted with time resolution
- Trackster: project layer clusters onto trackster barycenter plane
- TICL candidates
  - Trackster time propagated back to **the point closest to the beam spot**
  - Improvement from usage of HGCAL local time and propagation along the trajectory of track





Source: Aurora Perego et al, https://indico.cern.ch/event/1474681/?view=standard_numbered#23-use-of-time-information-in

Improved Energy Resolution



- Latest TICL development brought improvement in every step of the chain
  - Better EGamma performance with the improved SuperClustering
  - Better Hadronic Reconstruction
  - Improved final Particle Flow Interpretation

Source: Wahid Redjeb et al, https://indico.cern.ch/event/1474681/?view=standard_numbered#22-the-cms-phase-2-high-granul

2024 Raw Data Handling & Test Beam

Partial Selected Materials

Photo source: https://www.businesstoday.com.tw/article/category/80732/post/201306060034/

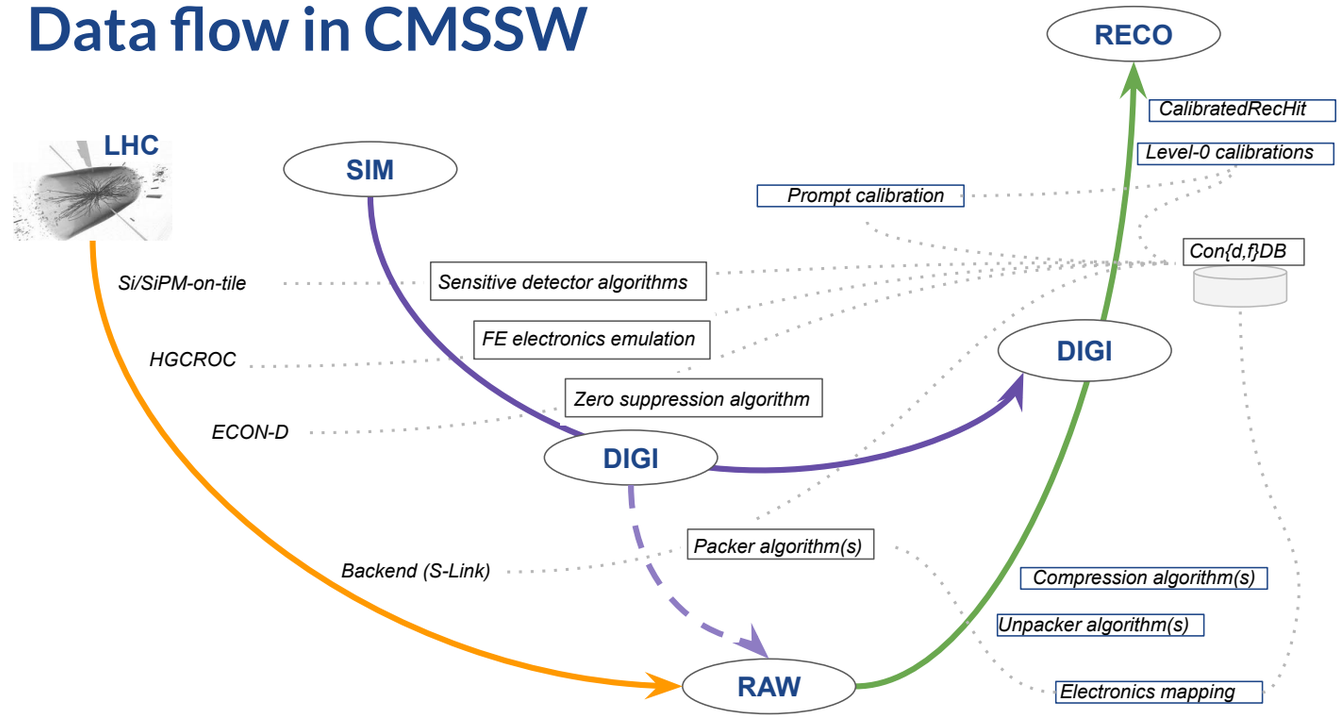
HGCAL Raw Data Handling

Phase-2 upgrade of new end-cap calorimeter

- 6 million channels → $\mathcal{O}$(700k) hits per event
- Heterogeneous computing
- Highly parallelization algorithms

HGCAL Raw Data Handling

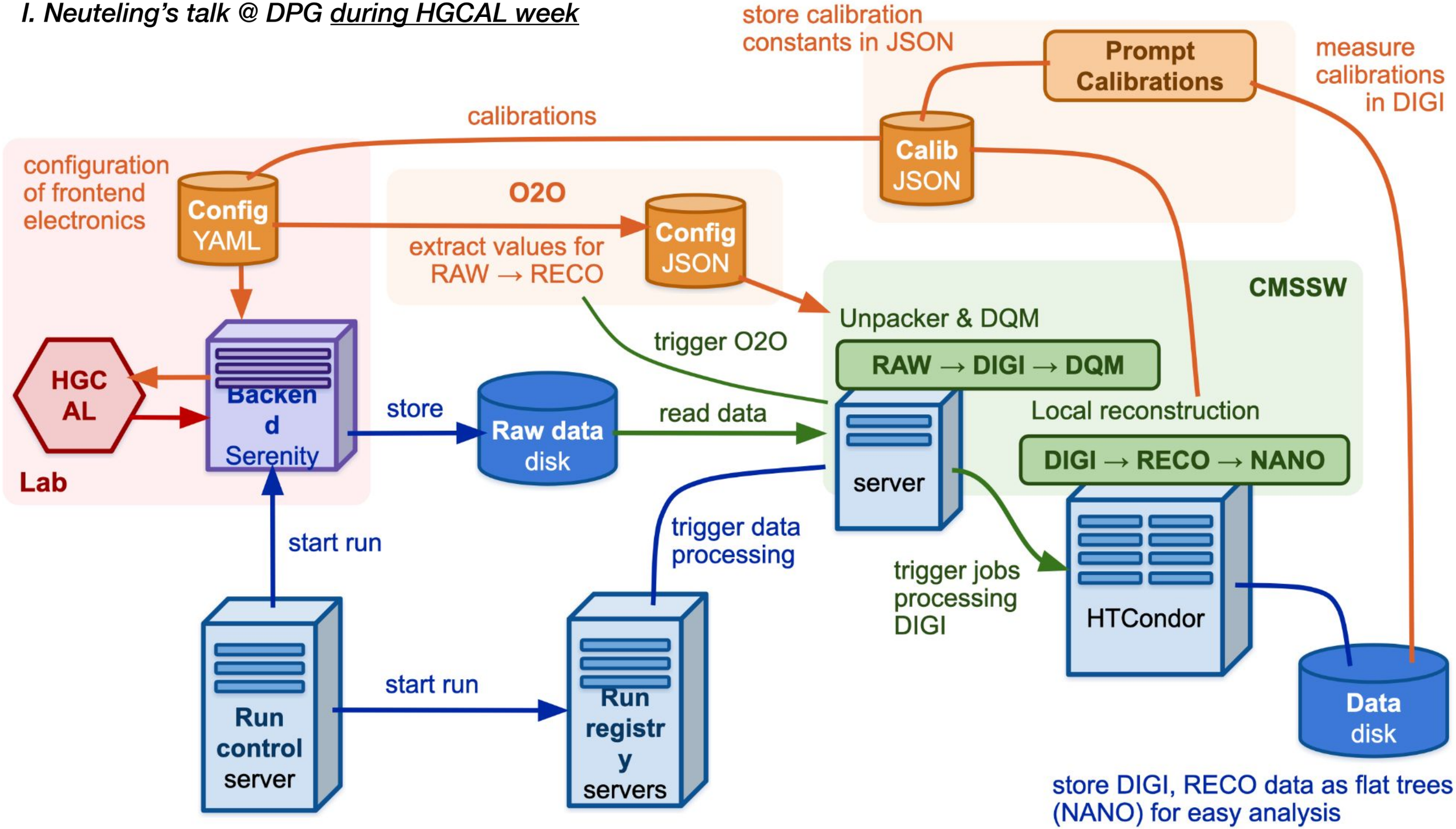
- 2022 October working group built
- 2023 Aug/Sep test-beam events
- Goal: RAW → **DIGI → RECO → DQM** / Nano
  - Level-0 calibration algorithms are developed
  - Algorithms are ported to Alpaka EDProducer for heterogeneous computing
  - HGCAL DQM service is established from scratch for the test beam activities



sketch from P. Ferreira da Silva with the help of A. David

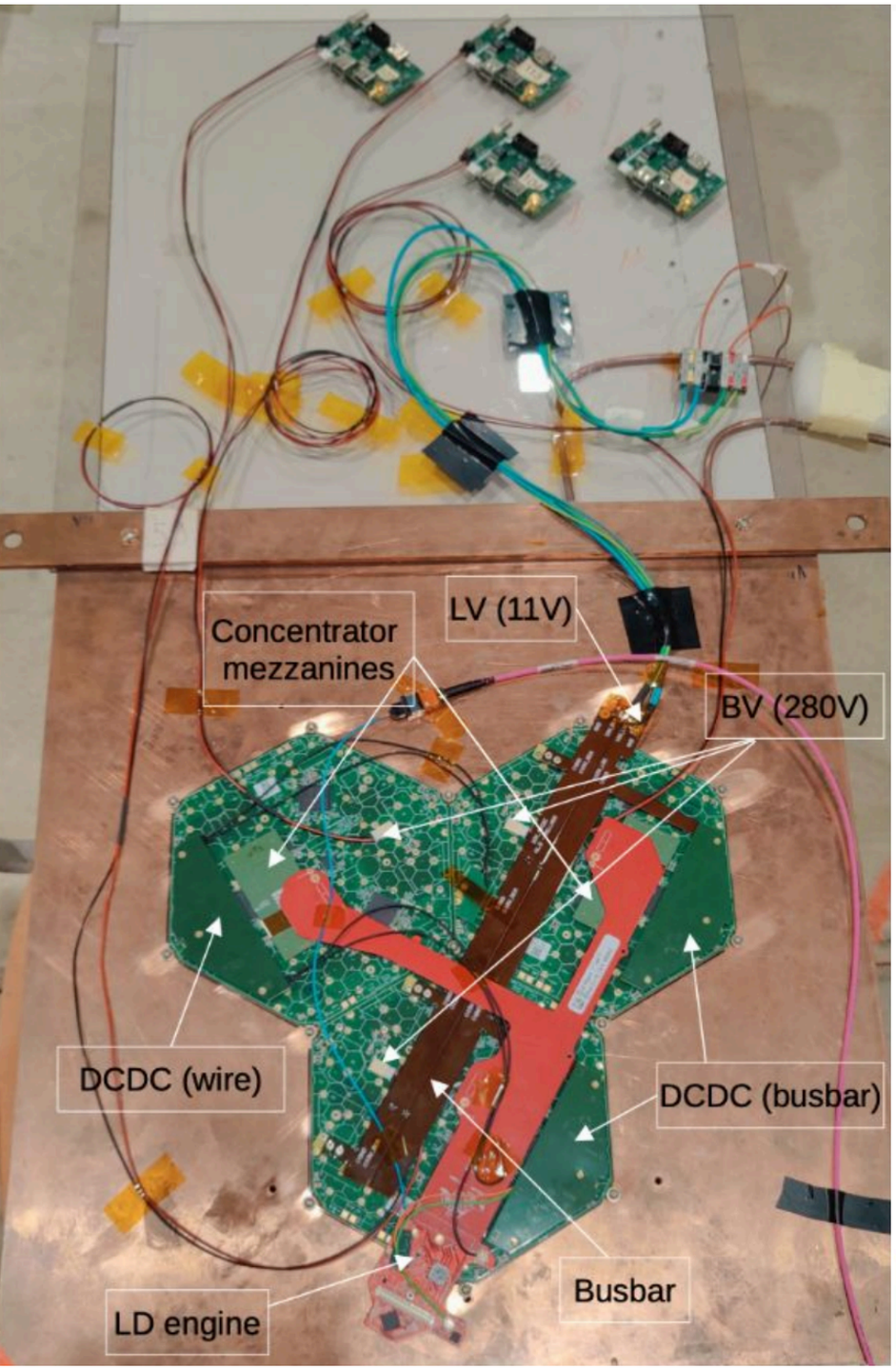
2024 Data Flow in Offline Software

I. Neuteling's talk @ DPG during HGCAL week



2024 Test Beam System

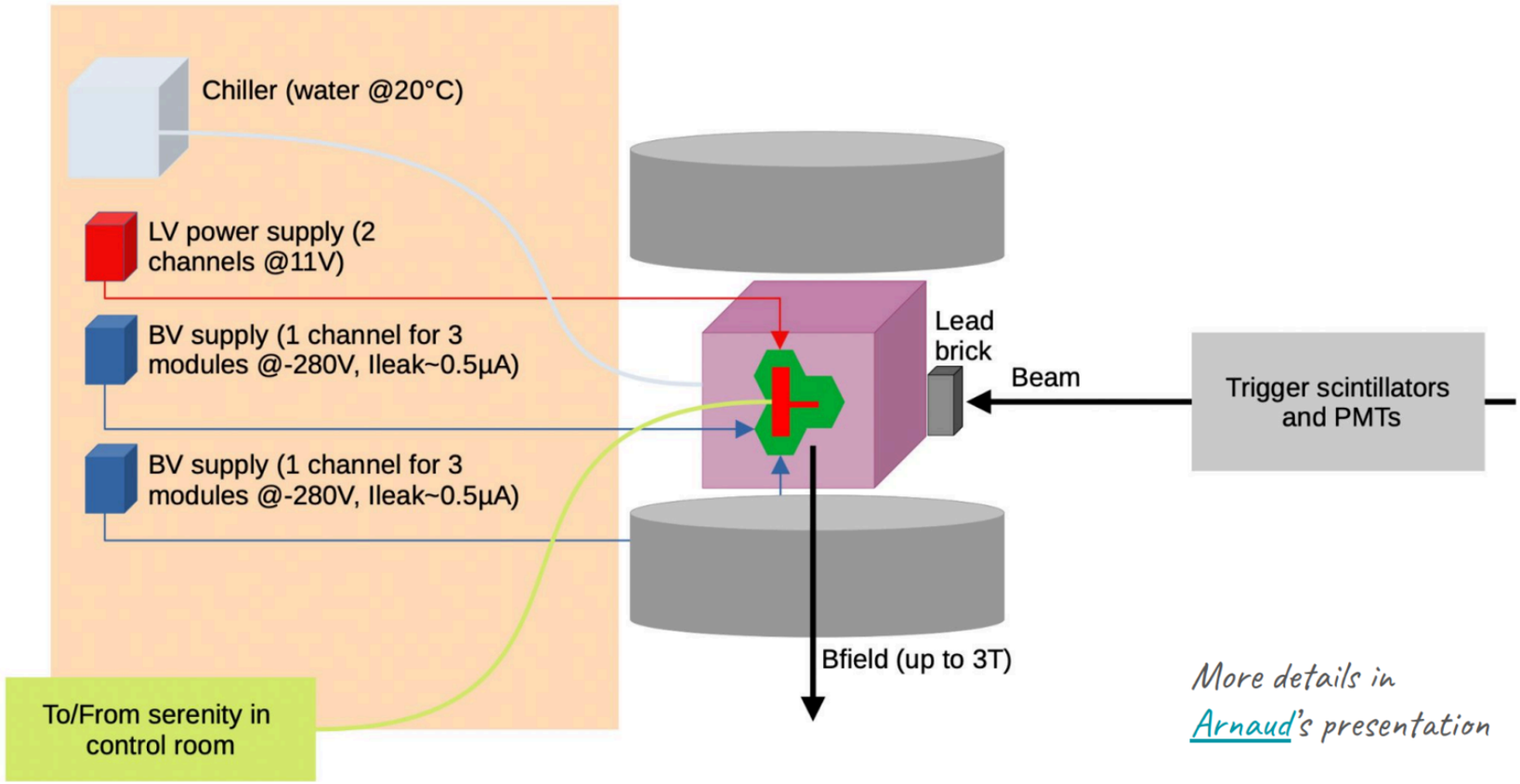
Source: HGCAL DPG Presentation



Description of the set up

Silicon V3 system

The setup consists of two identical layers, each assembled with three silicon modules (300 µm thick sensors) featuring a T-shape wagon and LD engine. A third layer, referred to as the "Partial train," includes one full module (ROCv3B) and one Semi-Right hexaboard. The LD full modules are equipped with HGCROC3B, and the concentrator mezzanine is equipped with ECONT-Prod1 and ECOND-Prod1. Additionally, a partial concentrator mezzanine for the Semi-Right also utilizes production ECONs.

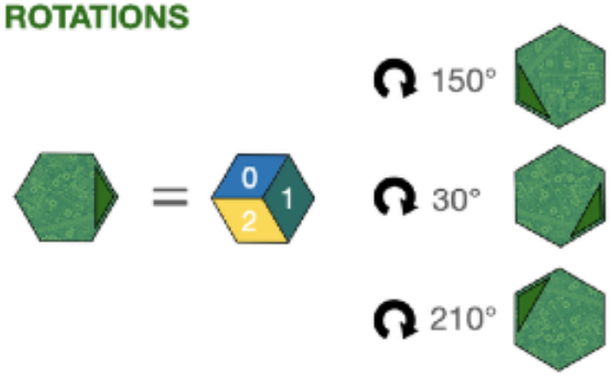


More details in Arnaud's presentation

Geometrical Layout

Drawing from C. Amendola

ROTATIONS



NUMBERING

Modules typecodes: 320MLF3WXIH00**NN**
ECON SN: 01.000**NN**
Engine number: 000**NN**

Front train

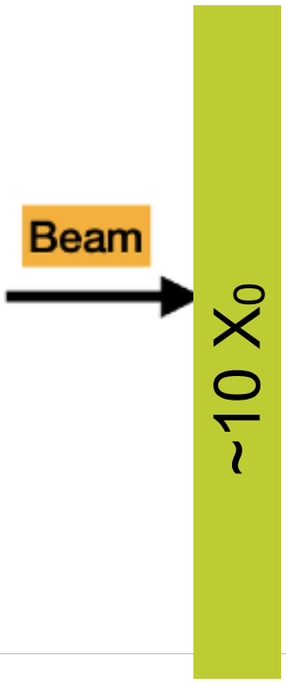
MPO12 fiber ID: B9
EMP channel (DAQ): 51
EMP channel (TPG): 59

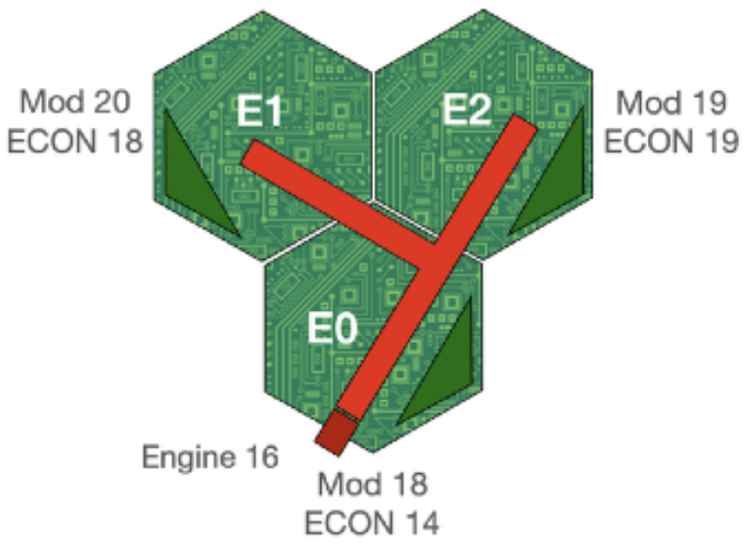
Back train

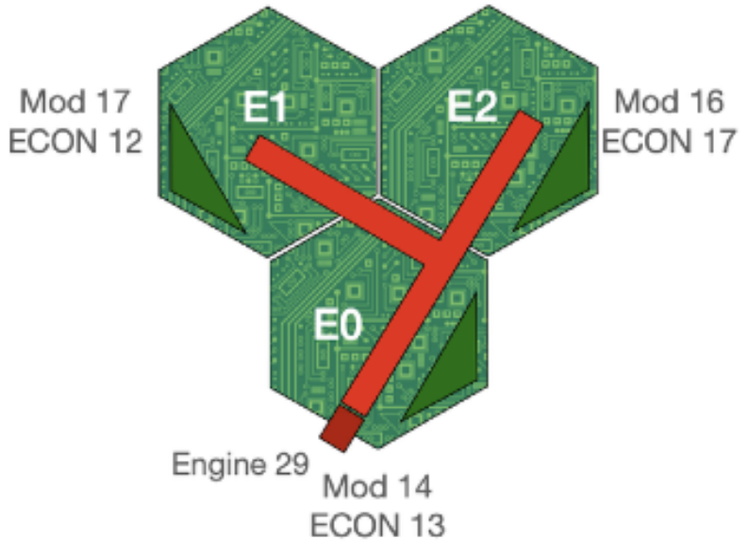
MPO12 fiber ID: B8
EMP channel (DAQ): 50
EMP channel (TPG): 58

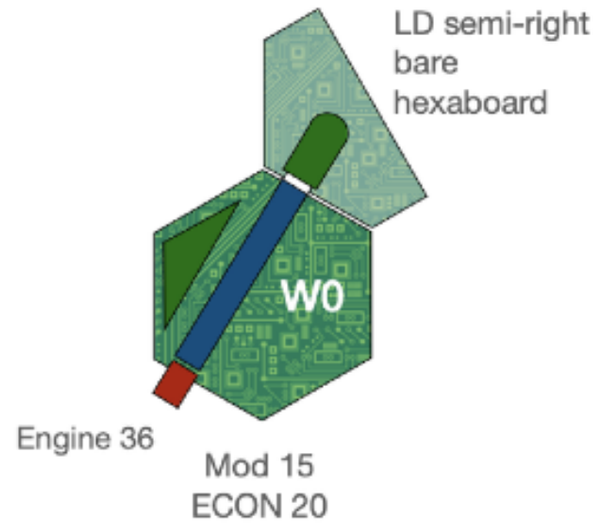
Additional train

MPO12 fiber ID: B7
EMP channel (DAQ): 49
EMP channel (TPG): 57









Setup in Magnetic Field

Source: HGCAL DPG Presentation

Description of the set up

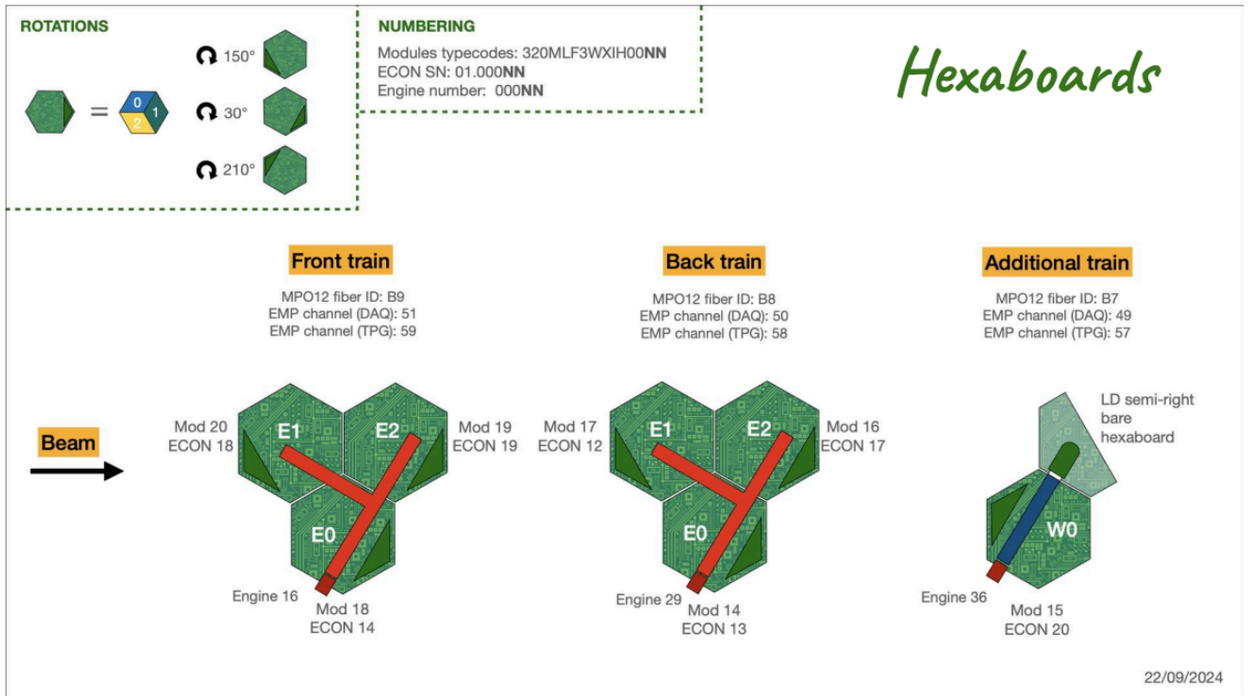
HGCAL beam test in magnetic field

Schedule at SPS-H2 Beam Line

1/09–25/09: Magnet during 5 days and beam with modules using ROCv3B and production ECONs.

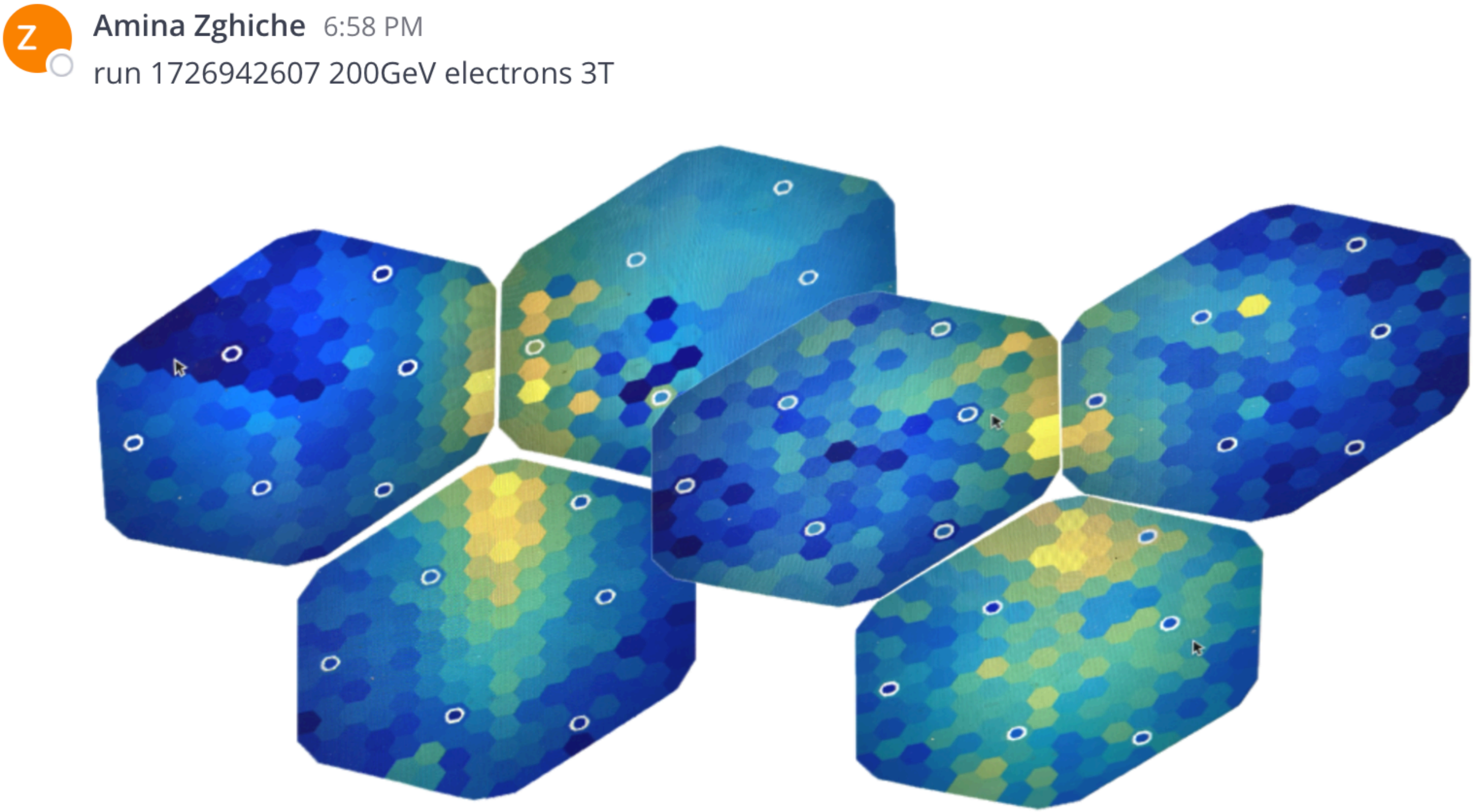
Back-end tests:

- Serenity system with VU7P.
- DTH board.
- Software based on HERD and XDAQ.



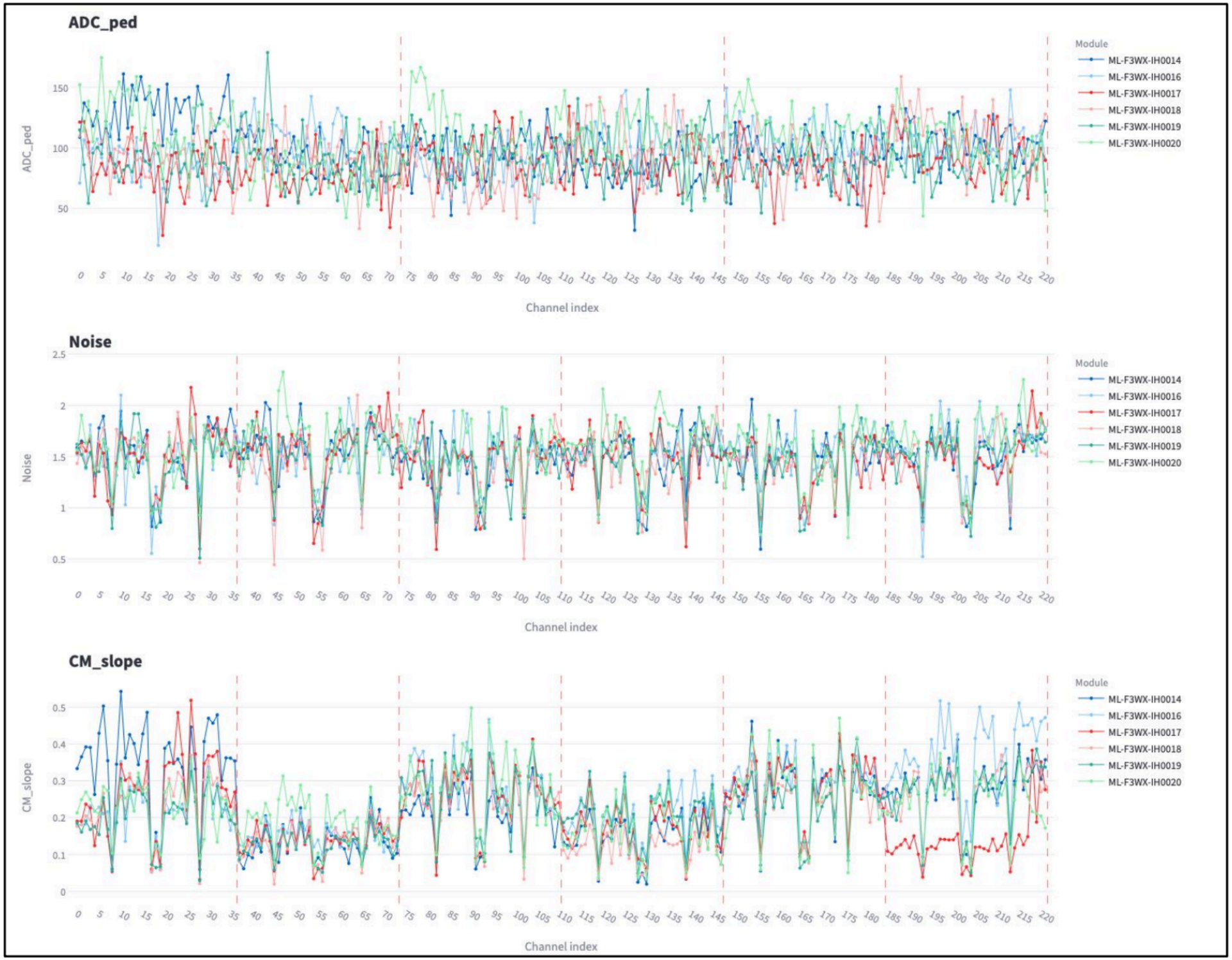
3

Beam Position with Magnetic Field



Evaluation of Pedestal and Noise

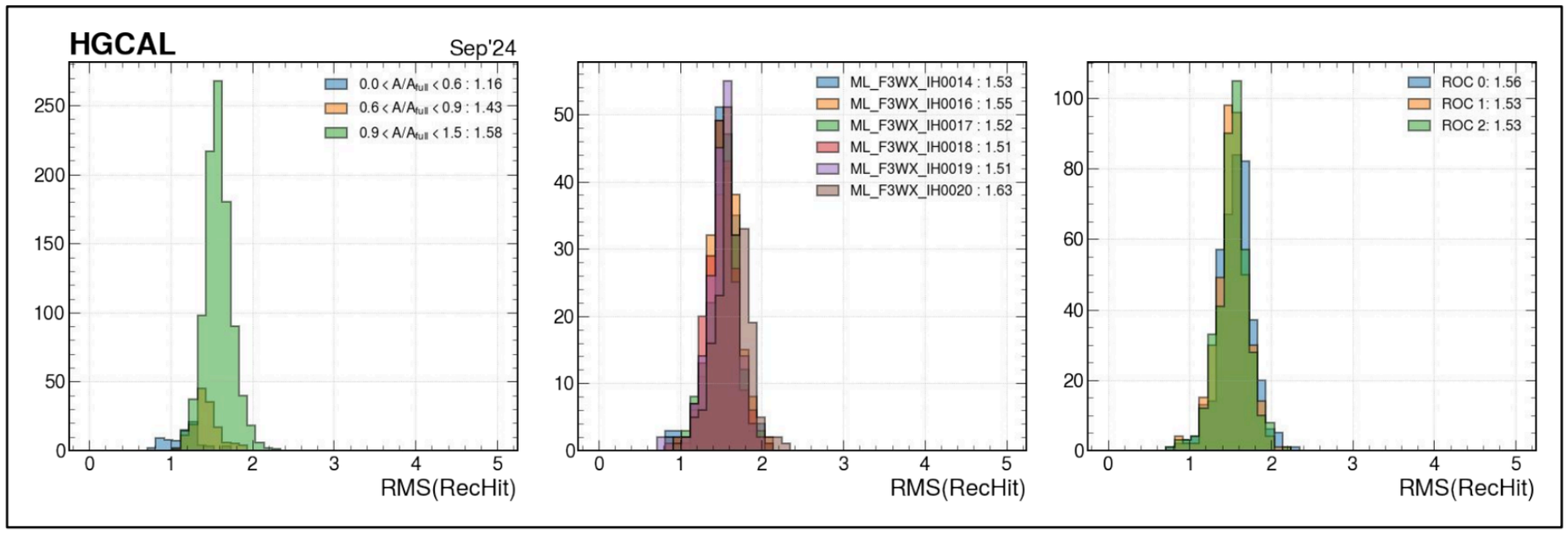
Source: HGCAL DPG Presentation



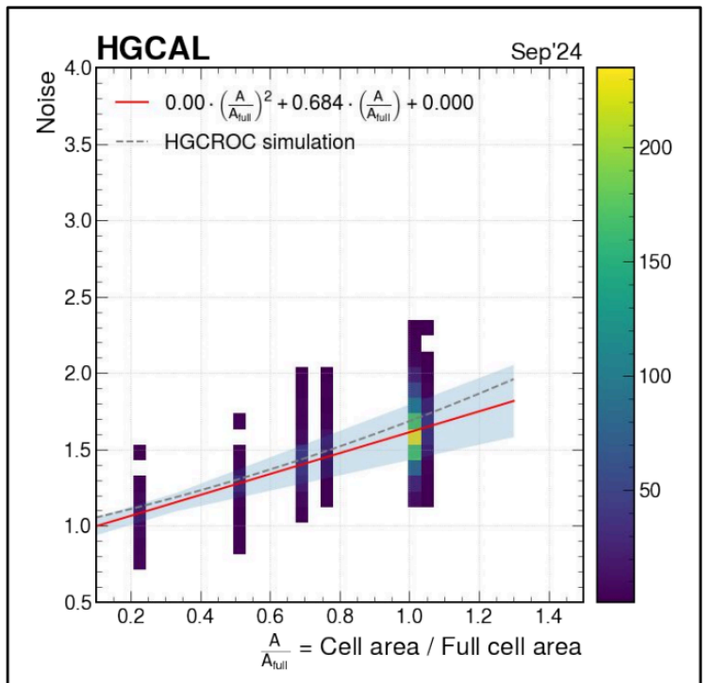
Some Highlights: Noise Study

Source: HGCAL DPG Presentation

Estimations



Caption: Distributions of the RMS of calibrated RecHits (in ADC units) after applying pedestal and common mode corrections. From left to right, the plots represent different Si cell areas, different modules, and different readout chips. These distributions correspond to the same run shown on slides 6 and 7.



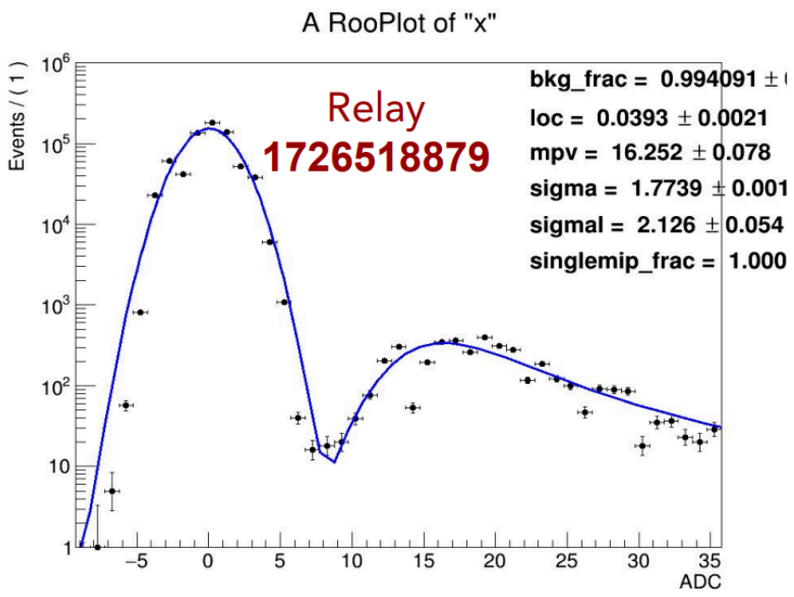
Caption: Noise distribution as a function of cell area, normalized to the area of a full cell. A red curve shows the result of an unbinned fit to the data using a polynomial function, alongside the expected values based on HGCROC simulations.

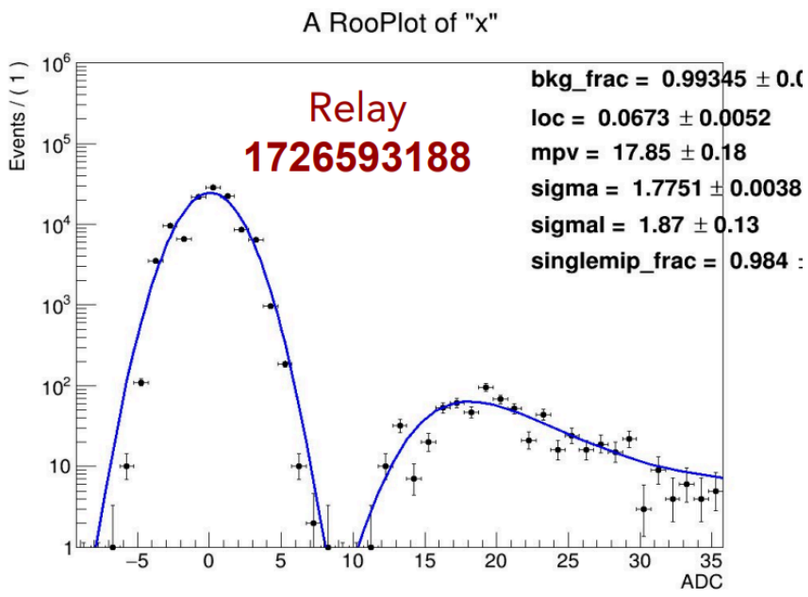
Some Highlights: MIP Scale Study

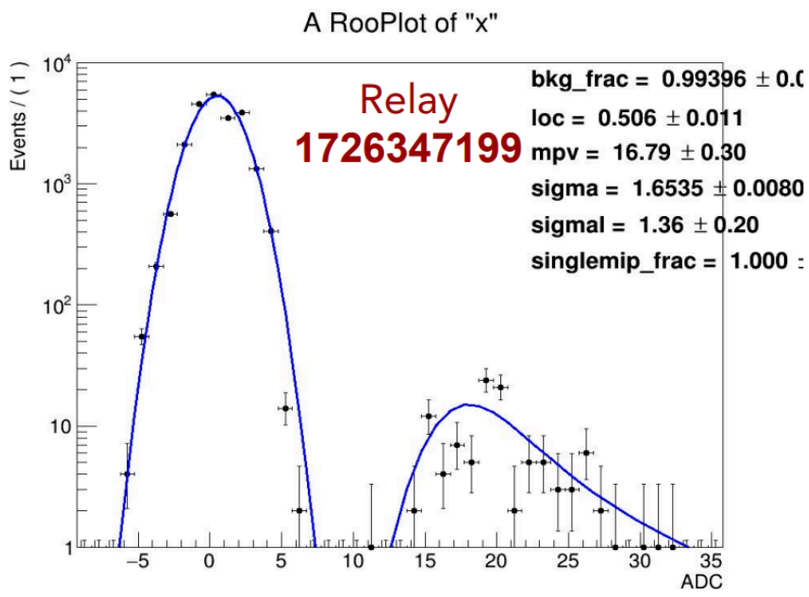
Source: HGCAL DPG Presentation

Comparison of Channel 219 from ML-F3WX-IH0016 in different Relays

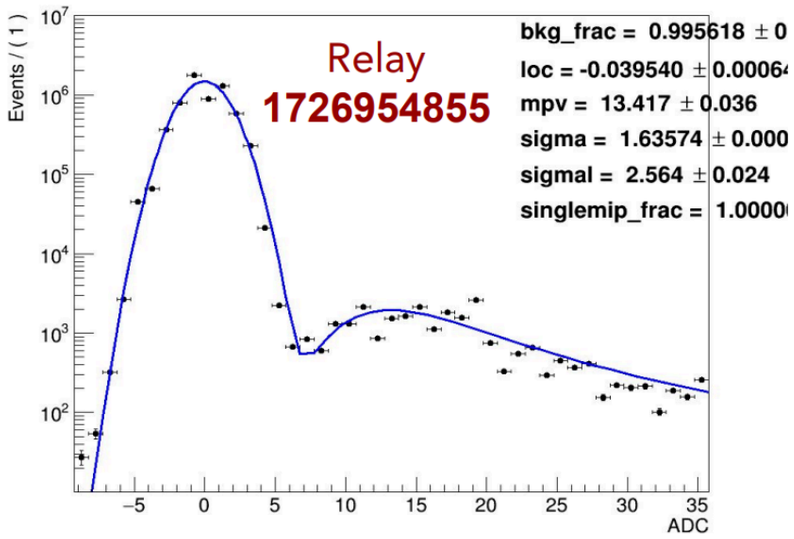
B=0 T and 150 GeV muons

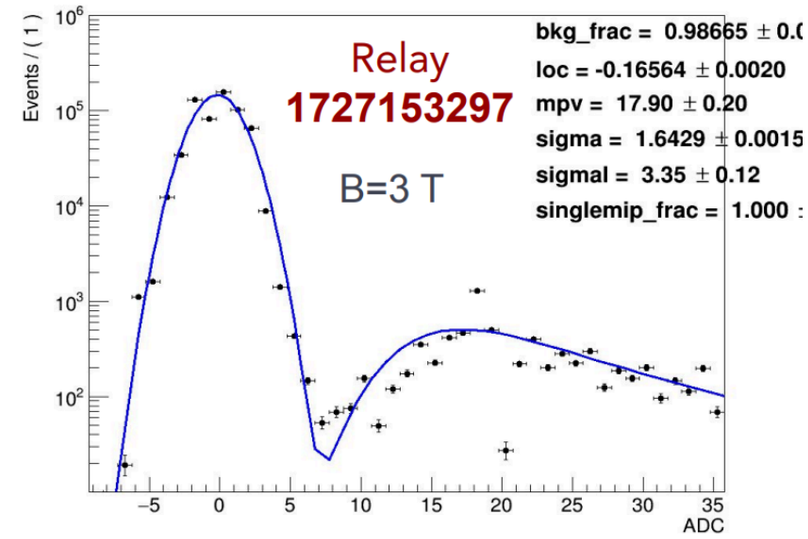


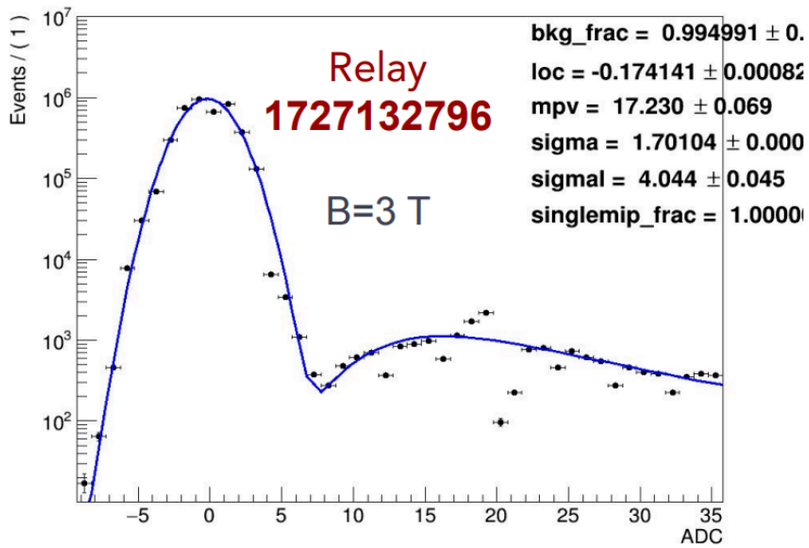




B=0 T and 250 GeV muons







Summary

Photo source: https://www.businesstoday.com.tw/article/category/80732/post/201306060034/

Summary

- Our Geant4 simulations reveal that the observed zigzag pattern stems from detector geometry and shielding of backward-scattered secondary particles. Understanding this energy deposition pattern will enable more efficient trigger criteria for the HGCAL detector in Phase-2 operation.
- Various steps in the TICL framework have been improved, including better linking algorithms, PF interpretation, treatment in timing information, resulting in an enhancement in both time and energy resolution.
- The 2024 beam test campaign enabled us to test a full chain of sensors, DAQ and offline software. More analysis of test beam data is ongoing, quantifying the performance of pre-series HGCAL components.

01. October. 2024

HGCAL Beam Test Campaign

Thank you for your attention

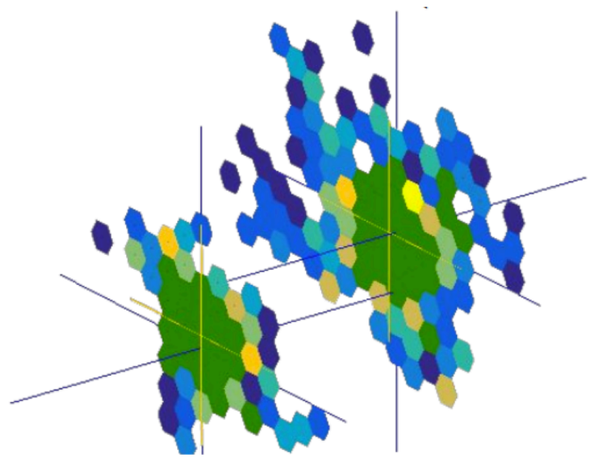
Backup

HGCAL reconstruction

CLUstering of Energy (CLUE) algorithm

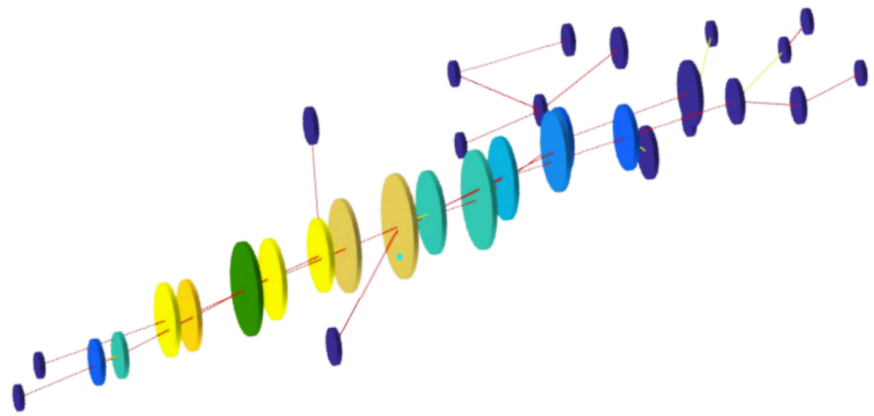
- Developed based on Imaging Algorithm
- Input **hits** and output **2D layer clusters**
- Energy density based
- Reduce dimensionality of the problem

  (10^5 hits to 10^4 layer clusters)



“The Iterative CLustering” (TICL) Framework

- Input **2D layer clusters** and output **3D objects / showers (TICL candidates)**
- Iterative algorithm
- Electromagnetic showers are easier to reconstruct
- Hadronic showers are reconstructed after EM showers

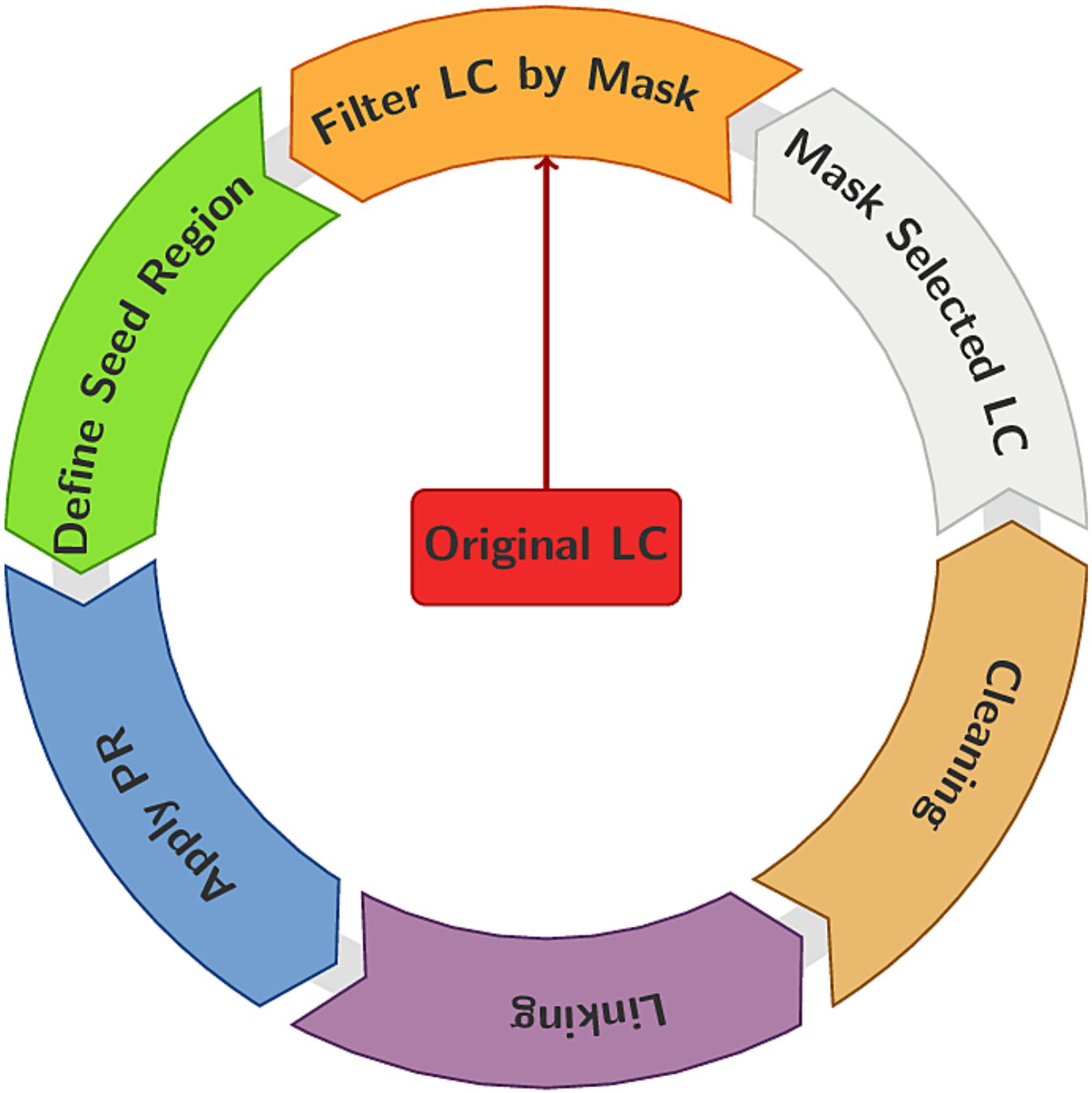


Reference: The HGCAL website and Marco Rovere’s slides

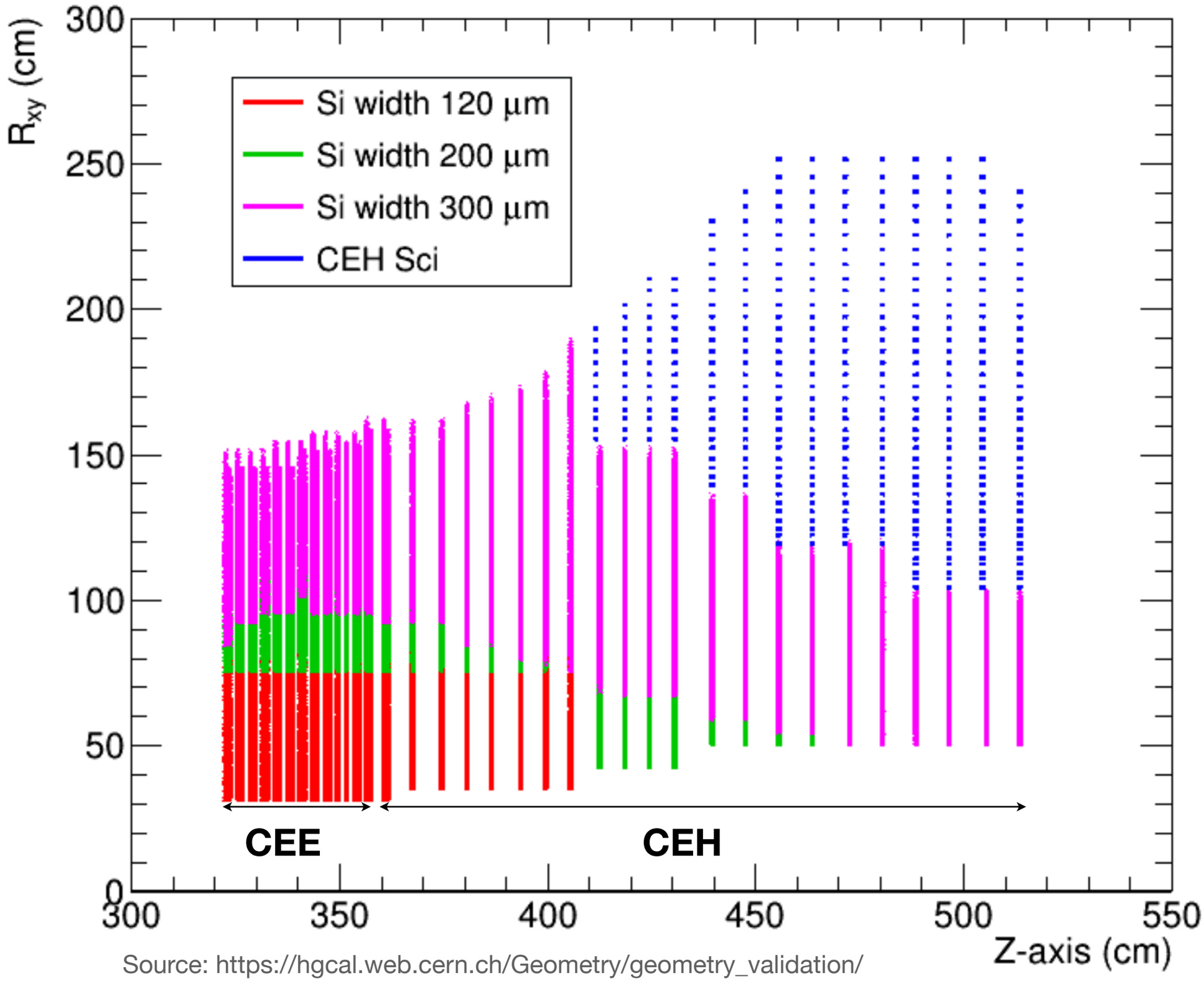
Skeleton of iteration

Five-step procedure of an iteration

- Filter and mask layer clusters
- Define seeding region
- Pattern recognition
- Link the recognized patterns
- Cleaning and classification



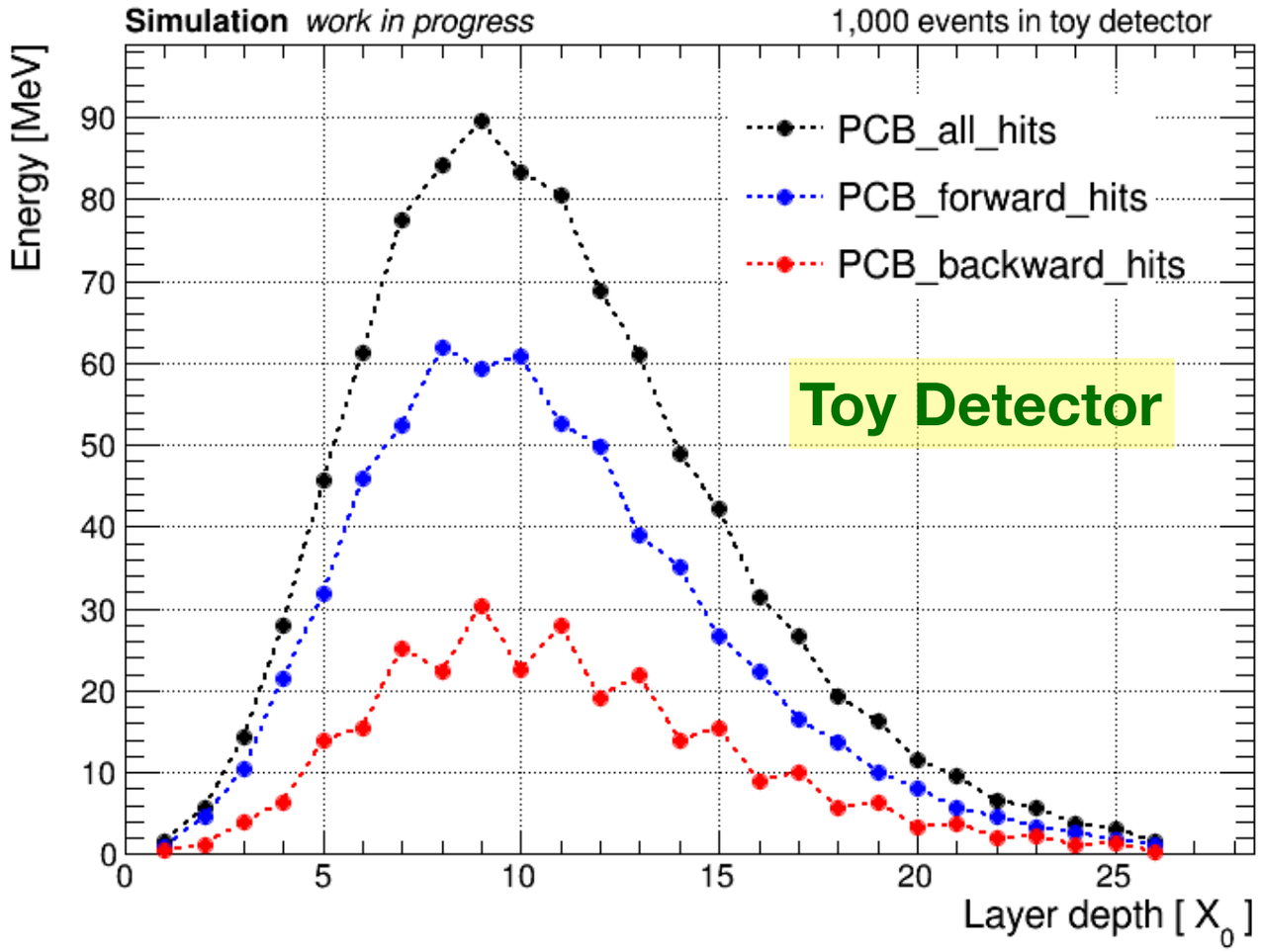
HGCAL Muon Tomography



Source: https://hgcal.web.cern.ch/Geometry/geometry_validation/

Geant4 Study Summary

- Our Geant4 simulations reveal that the observed zigzag pattern stems from detector geometry and shielding of backward-scattered secondary particles.
- Future studies with realistic detector geometry will clarify the origin of this zigzag energy deposition pattern.
- Understanding this energy deposition pattern will enable more efficient trigger criteria for the HGCAL detector in Phase-2 operation.



doi:10.6342/NTU202403742

TICL Summary

Latest development

- Better EGamma performance with the improved SuperClustering
- Better Hadronic Reconstruction
- Improved final Particle Flow Interpretation

Future development

- Fine tune Hadronic Linking algorithm
- Improve combination of energy between Tracks and Tracksters
- Improve PF Interpretation combining Egamma workflow with Hadronic reconstruction
- Redesign Particle Flow Barrel reconstruction and integrate it in TICL

Thank you for your attention

11. July. 2024

16th Patatrack Hackathon Event

Italian Pizza event @ CERN Prevessin