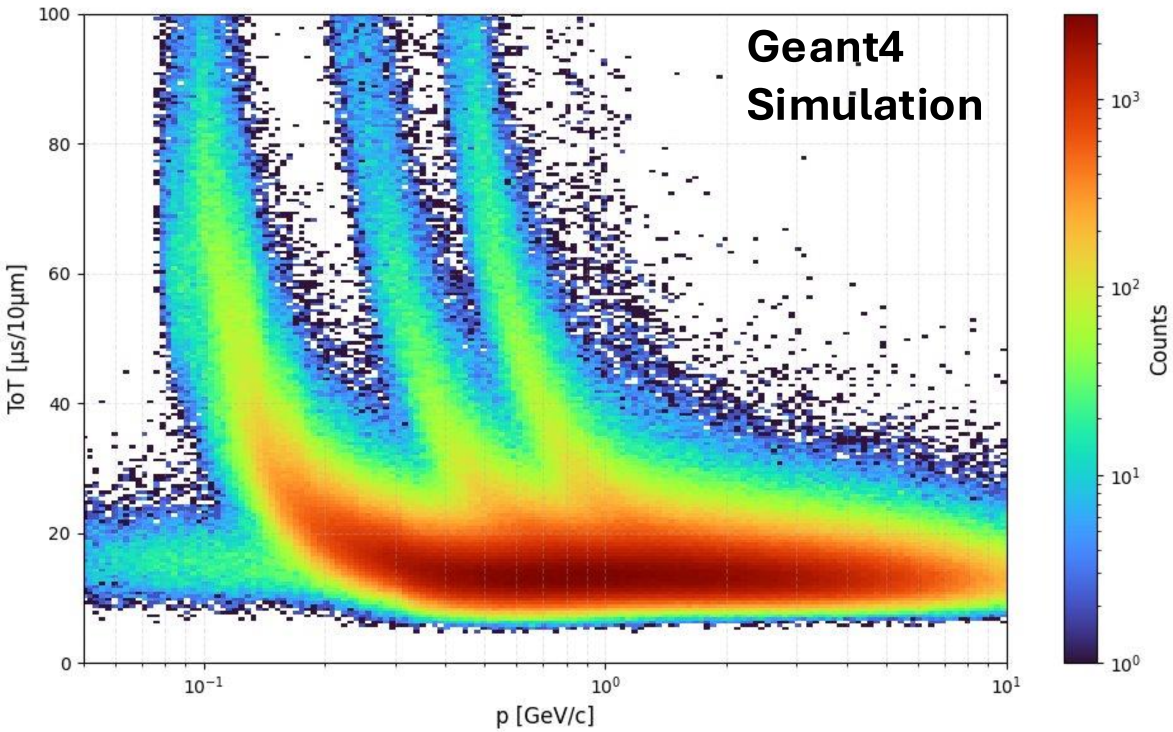
PID with ALICE 3 trackers using Time-over-Threshold

ELMA Workshop on "Energy loss measurements with MAPS"
10th-11th September 2025

Henrik Fribert on behalf of the ALICE collaboration



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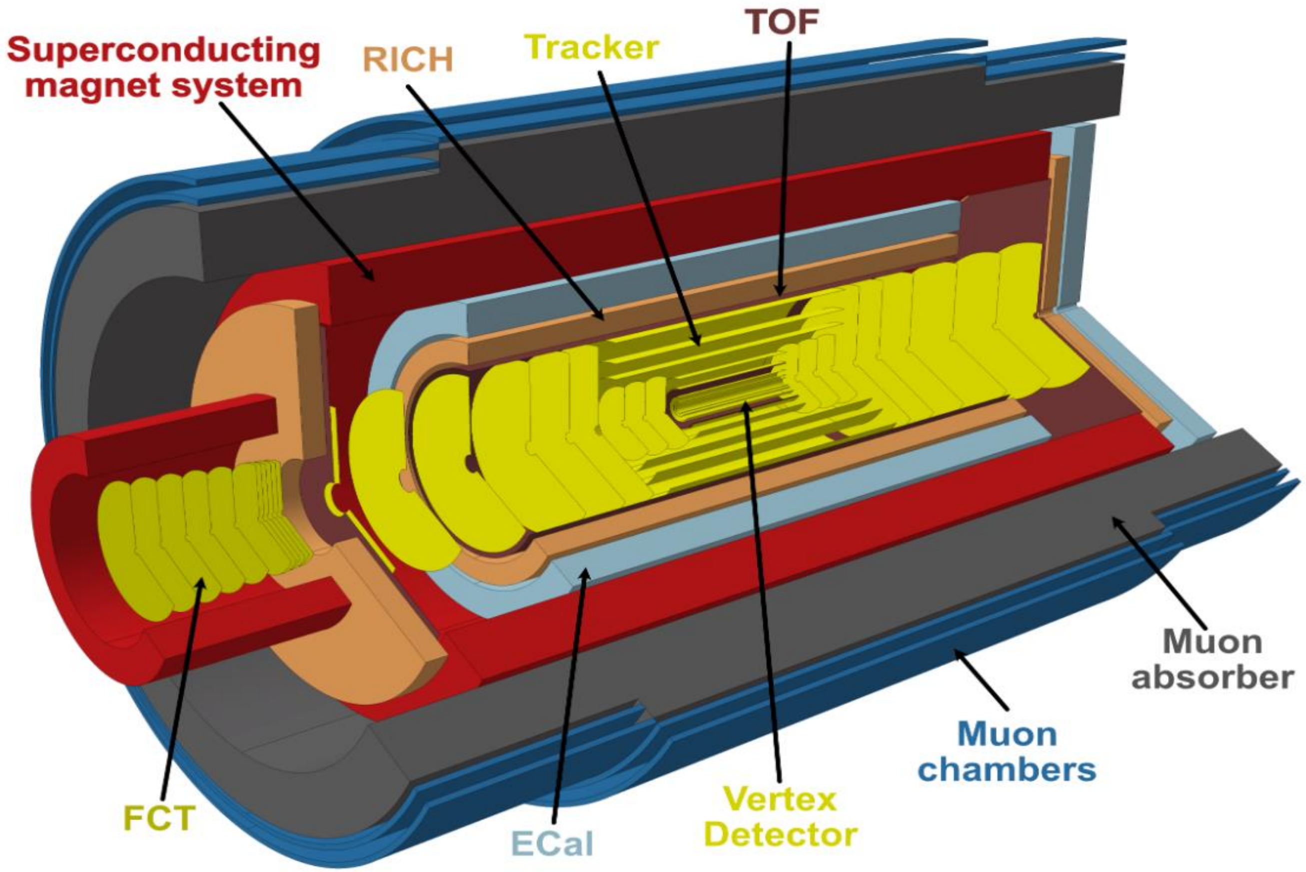
ALICE 3

- ALICE 3 is a planned new detector system based on large-area silicon detectors starting data-taking in 2036

- Based fully on silicon technology (**60 m^2** of MAPS tracker)
  - Current pp-rate: 500 kHz / 1 MHz
  - ALICE 3 pp-rate: 24 MHz

- *Can we exploit the full potential of MAPS trackers?*
  → **Amplitude measurement**



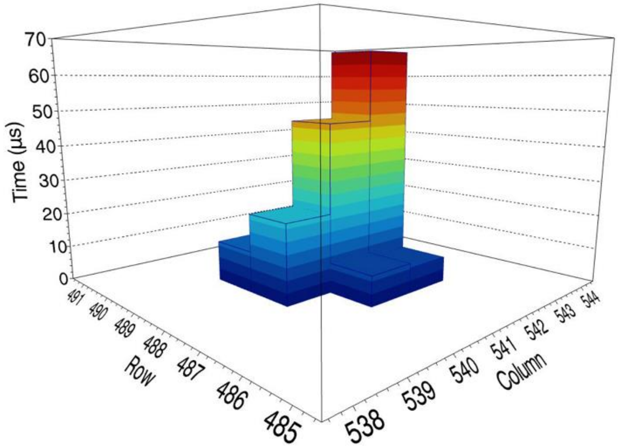
ALICE3 LOI

Amplitude measurement for ALICE 3 trackers

This talk

Improved spatial resolution

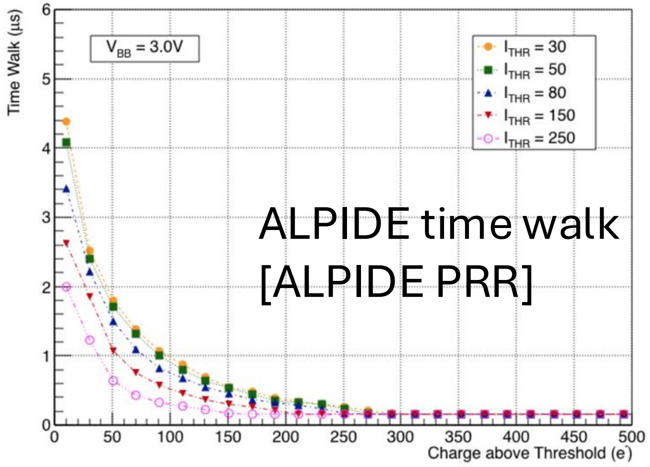
- for hits with multiple pixels firing (cluster size > 1)
- Using weighted mean for cluster position calculation



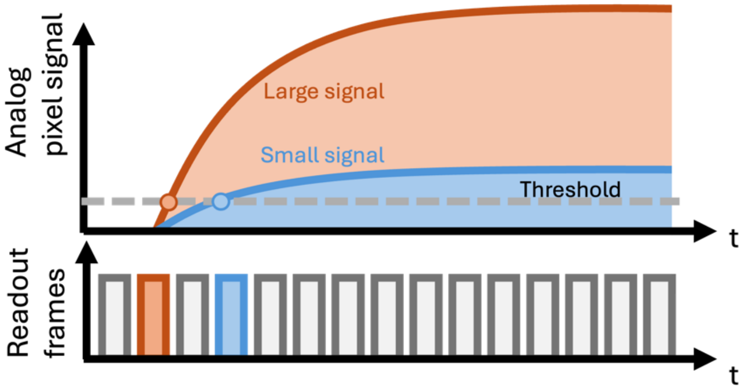
ITS2 color run, signals measured on pixels in an example cluster [A.Triolo]

Improved timing resolution

- Correcting for time walk

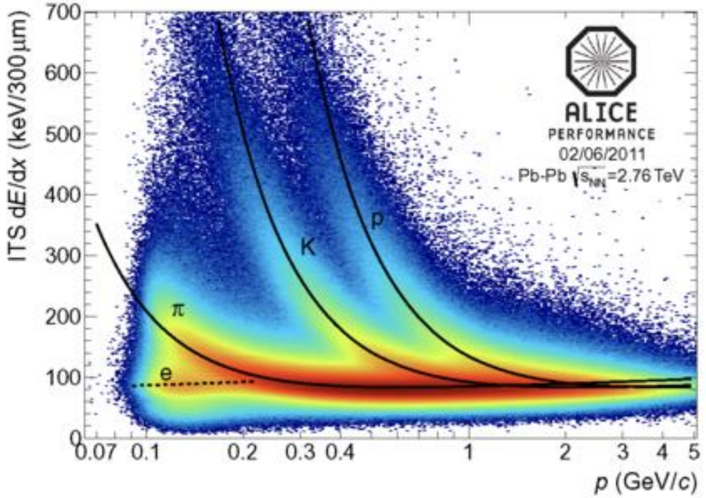


ALPIDE time walk [ALPIDE PRR]



Particle identification

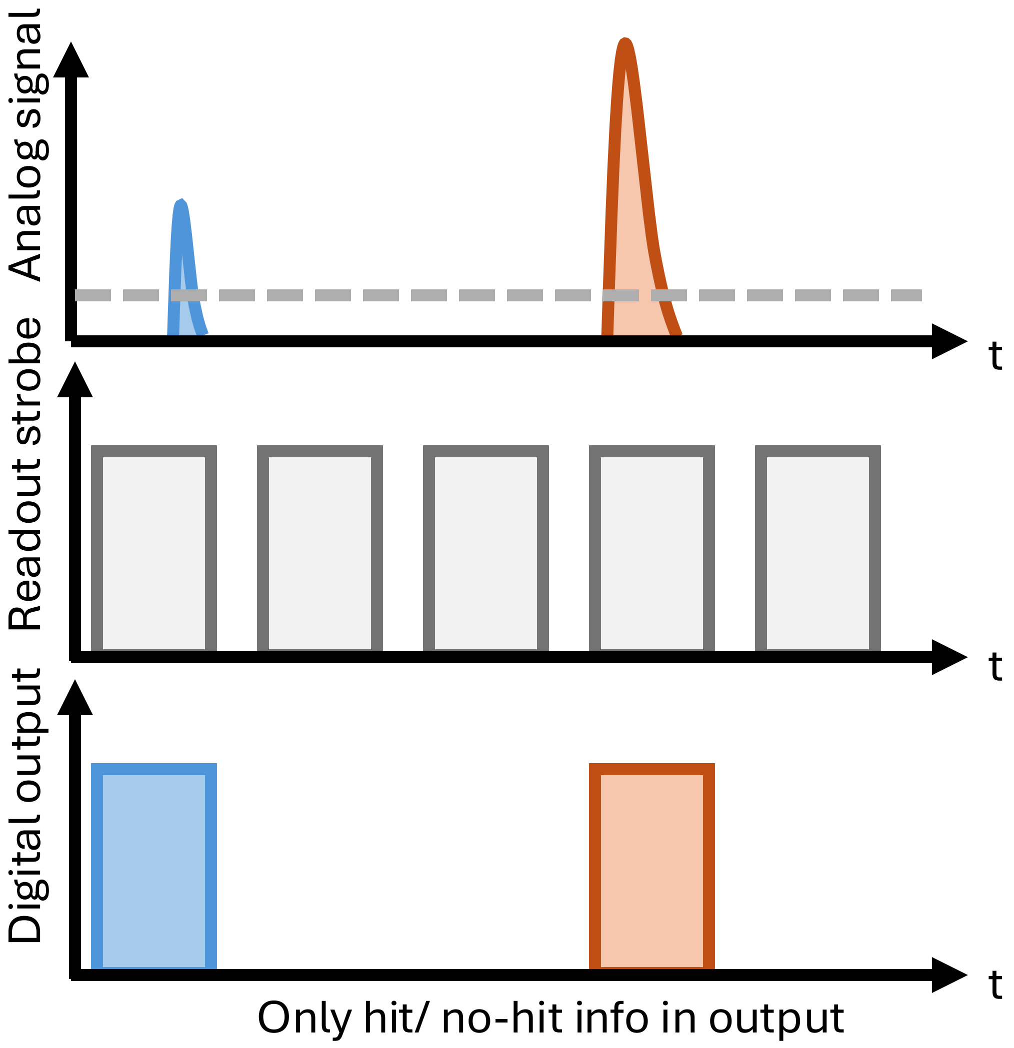
- Measuring energy loss
- Performance limited by active layer thickness and number of layers



PID performance of ITS1

Time-over-Threshold

- Similar to color runs in ITS2 (see Calibration and performance of the upgraded ALICE Inner Tracking System, A. Triolo et al.)
- Running the readout as quickly as possible
- Over sampling the signal → measure multiple times before it can go away
- Signal decay time (ToT) depends on signal amplitude (deposited charge)



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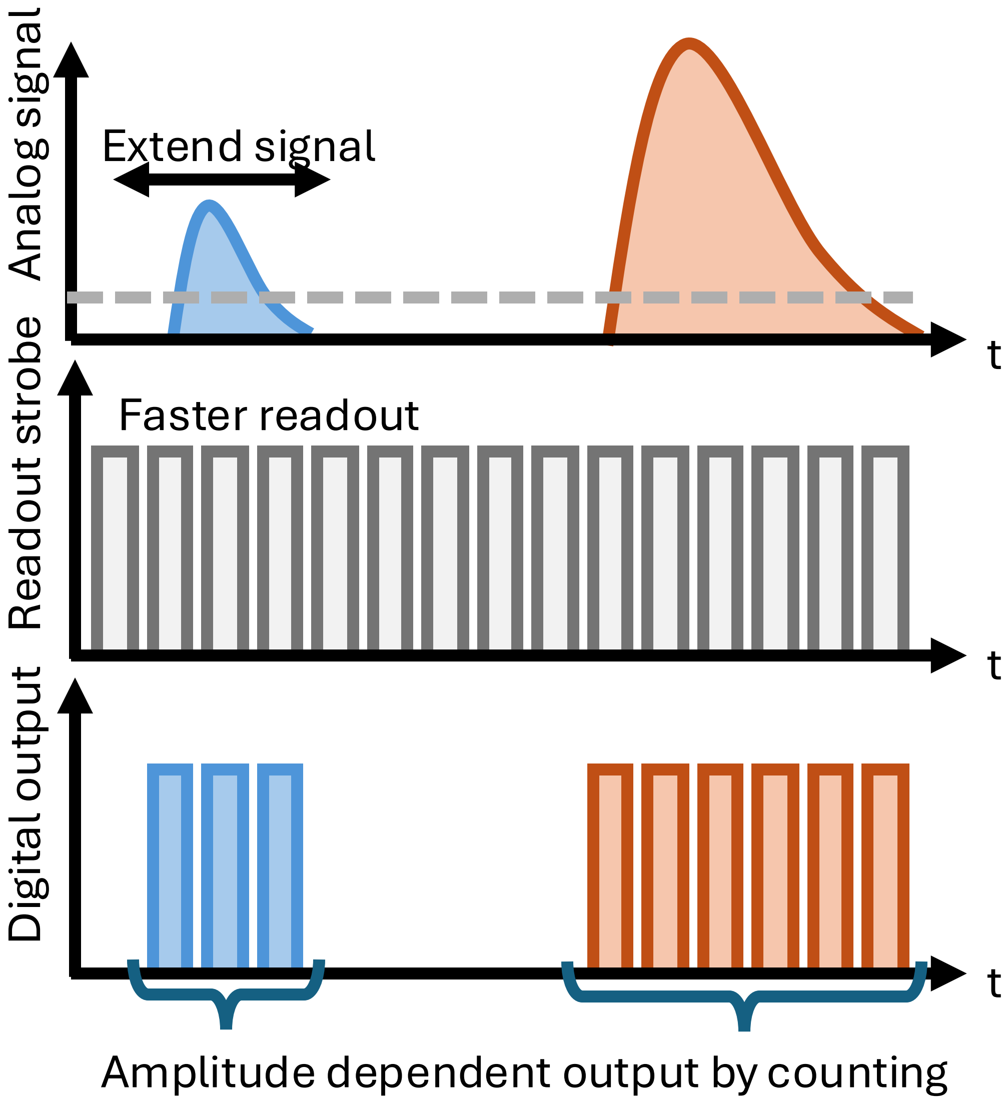
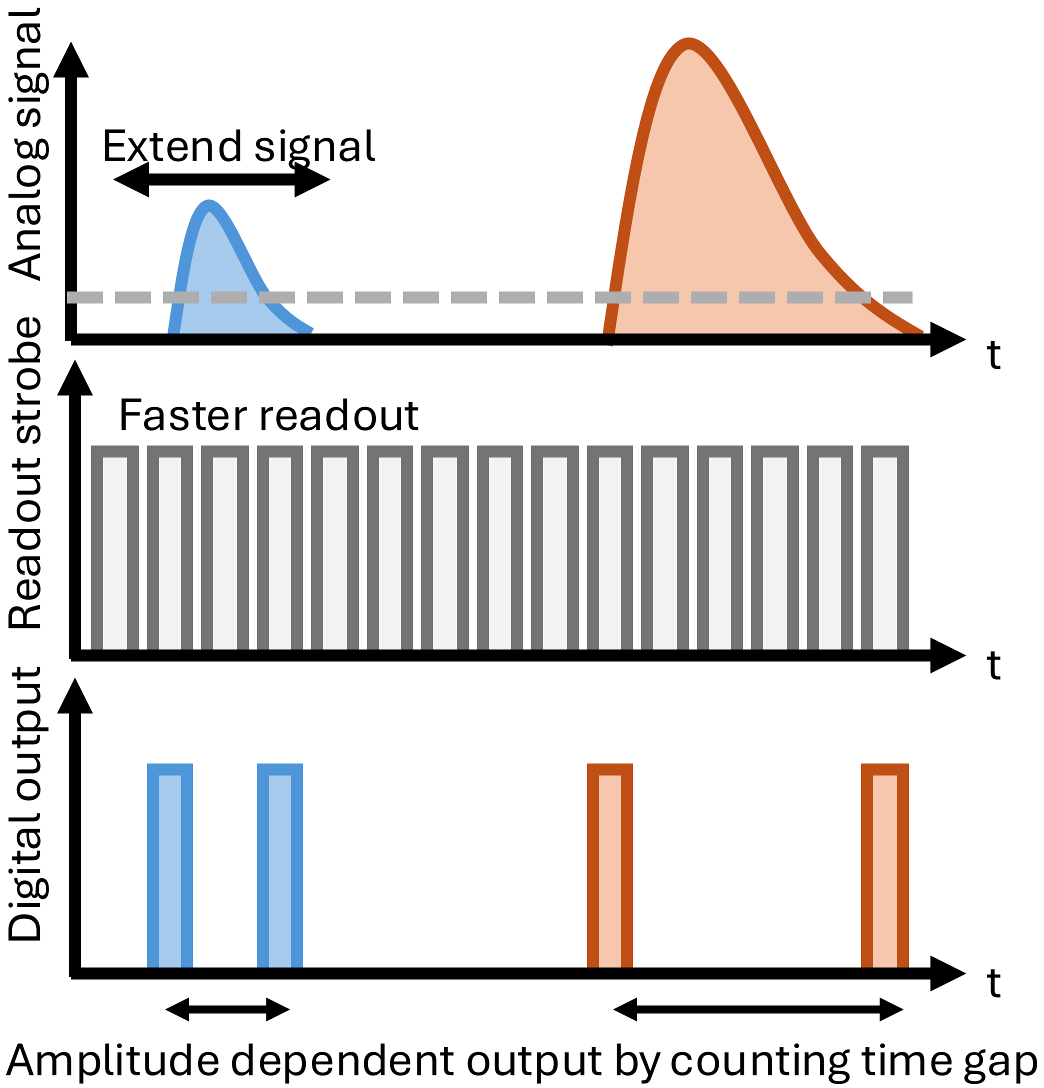


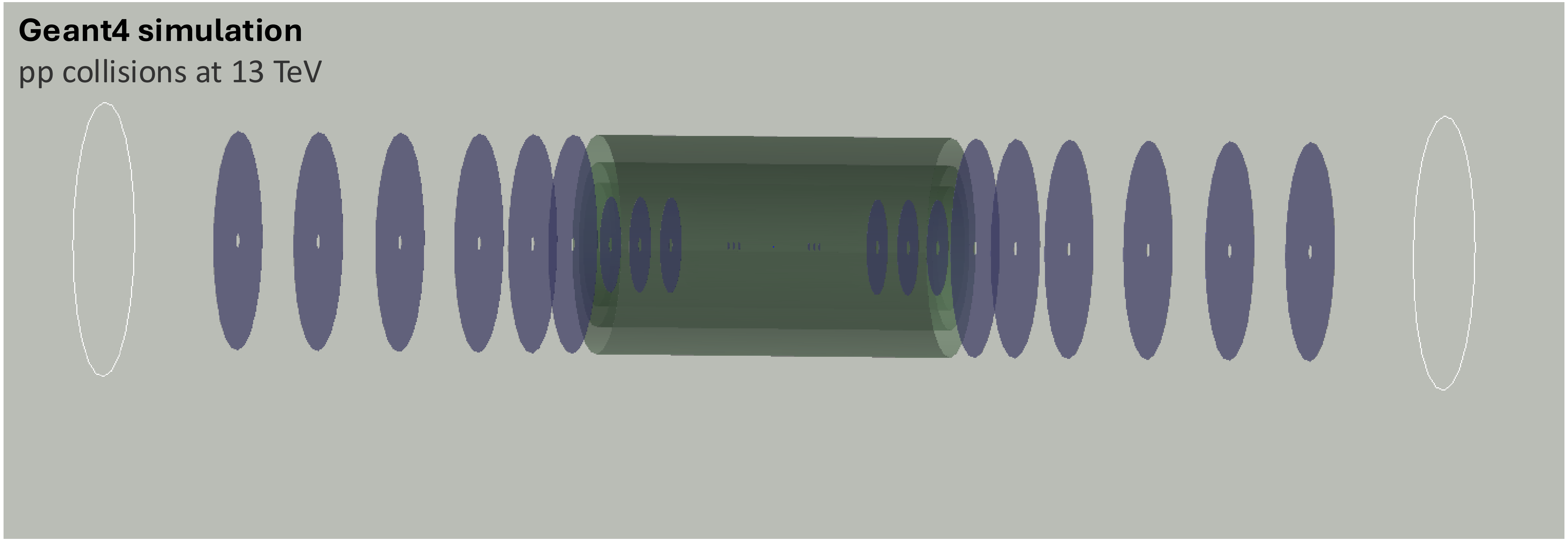
Time-over-Threshold

- Over-sampling increases the data rate substantially, factor O(30)
- Power consumption constraints of the sensor to be considered
- Proposed implementation idea:
  - Send signal only at the edges using digital front-end sensitive to rising and falling edge
- Similar approach utilized in DPTS and MOST sensors already
- Additional bit can be added to differentiate the two types of hits
  - Robustness in reconstruction



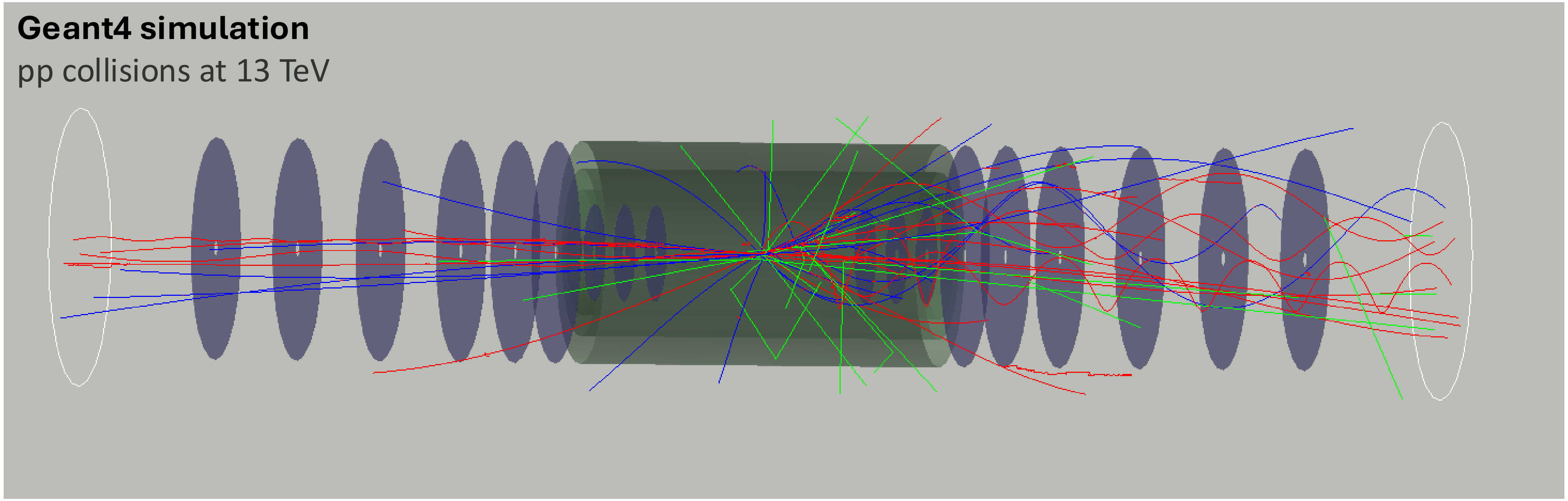
Geant4 simulation

- Implement simplified ALICE 3 tracker geometry (LOI version) in Geant4 with magnetic field of 2T
- Carbon is added behind each layer to replicate the material budget



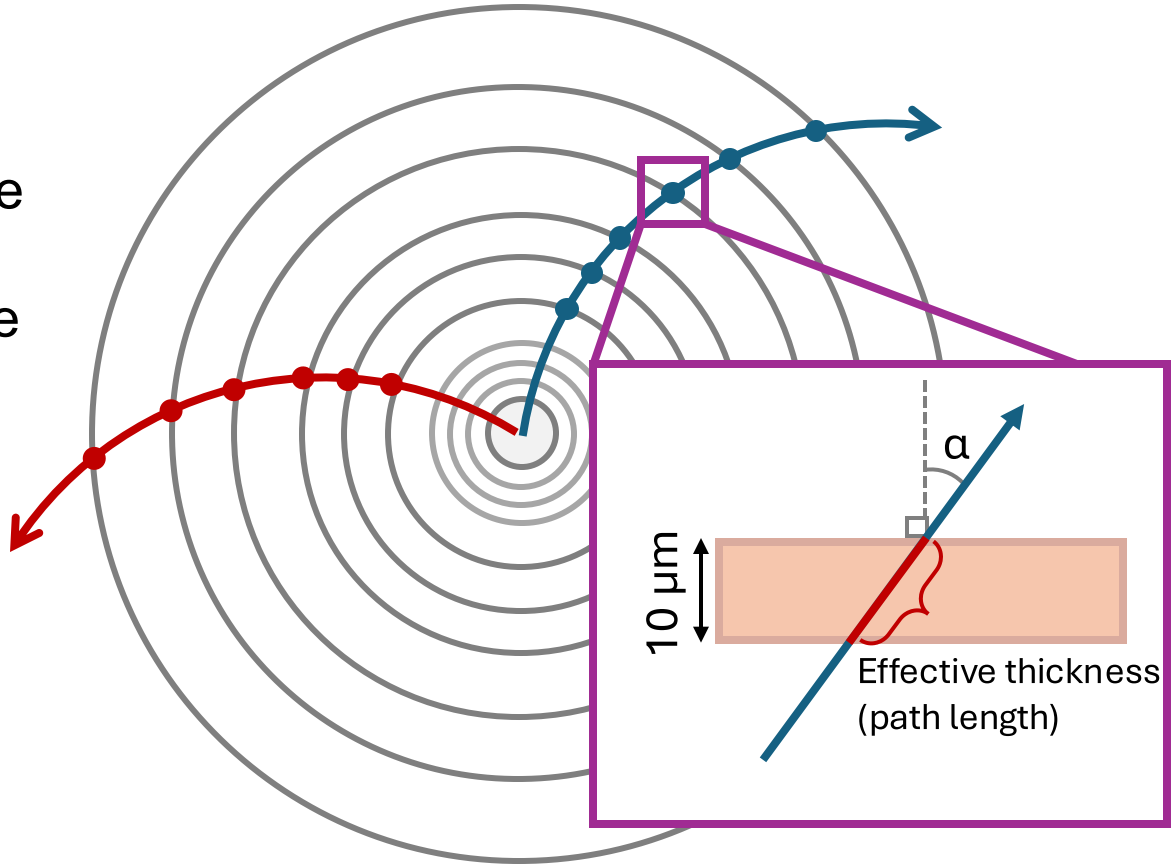
Geant4 simulation

- Events were generated with Pythia (pp collisions at 13 TeV) and used as input for the PrimaryGenerator in Geant4
- ThermalFIST event generator was used to add light nuclei (d, t, He3) to the input



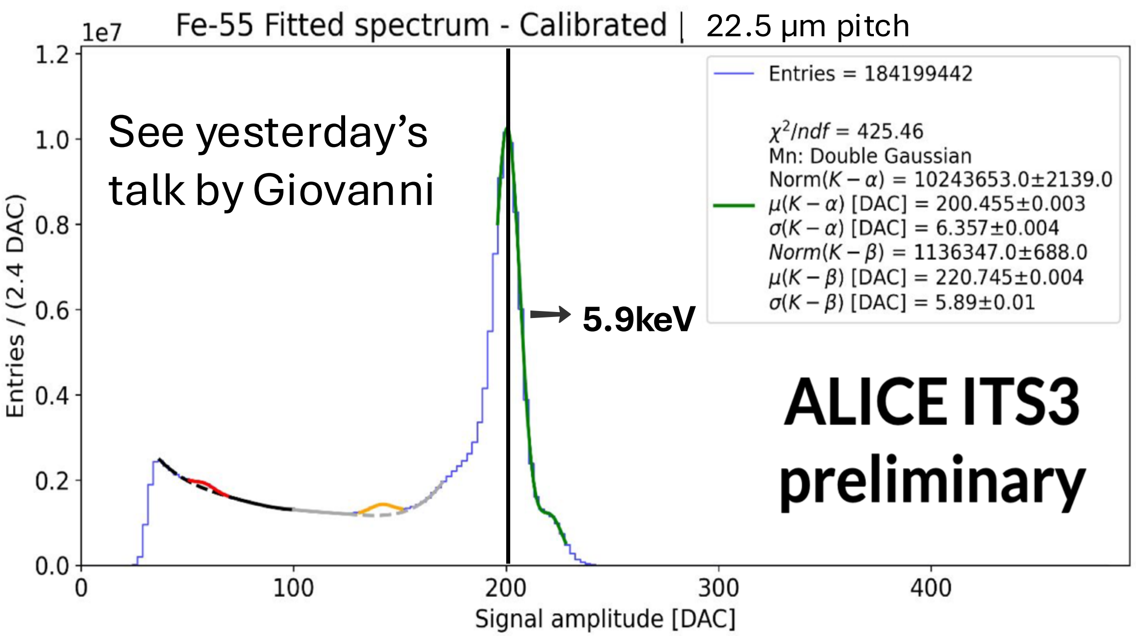
PID with middle and outer layers

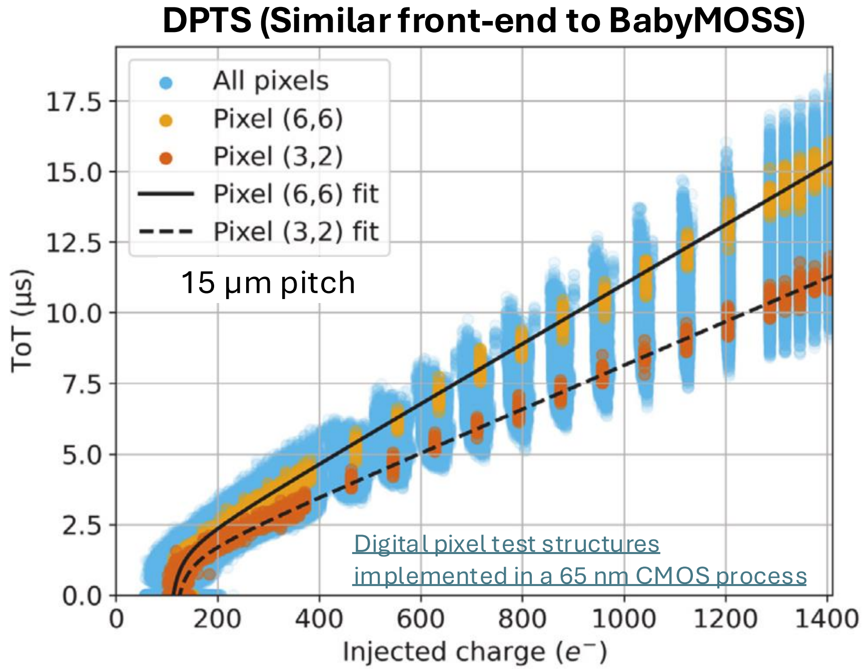
- Currently not considering vertex detector due to overall tighter requirements
- In Geant4 simulation
  - Generated particles pass through the different layers
  - Energy deposition (depending on the effective thickness, incidence angle) is simulated
- In Python
  - Apply a threshold of 100 e^- on deposited charge for each hit
  - Convert charge above threshold to ToT according to lab measurements (see next slides)



E_{Loss} to ToT conversion

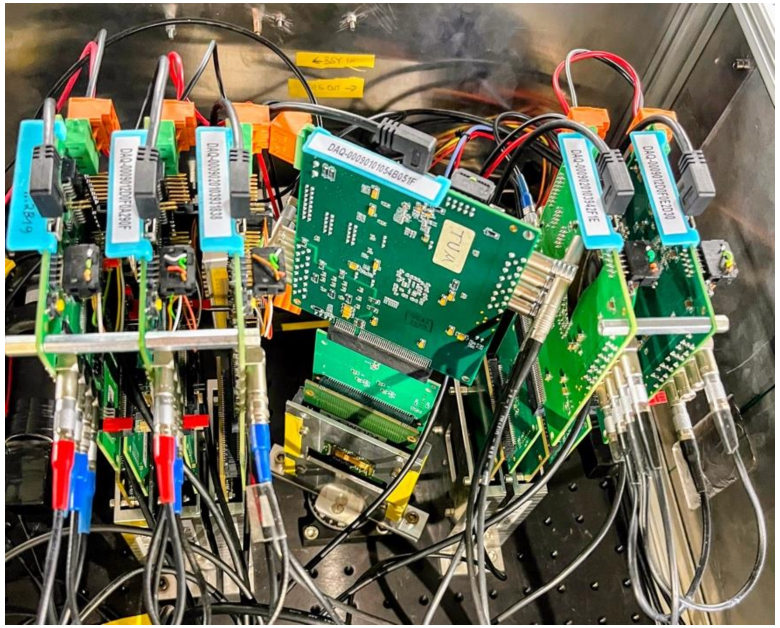
- Using ITS3 state-of-the-art MAPS prototypes (BabyMOSS & DPTS)
- For the charge to ToT conversion, we do the conversion according to measurements with a ^{55}Fe source
  - K_α peak X-rays with an energy of 5.9 keV
  - Sampling period of 4 μs
  - Linear conversion between energy and ToT
- For example: roughly 60 μs for main peak at 14 bins
  - → 5.9 keV / 14 = 420 eV bin size equivalence
  - → 105 eV / μs

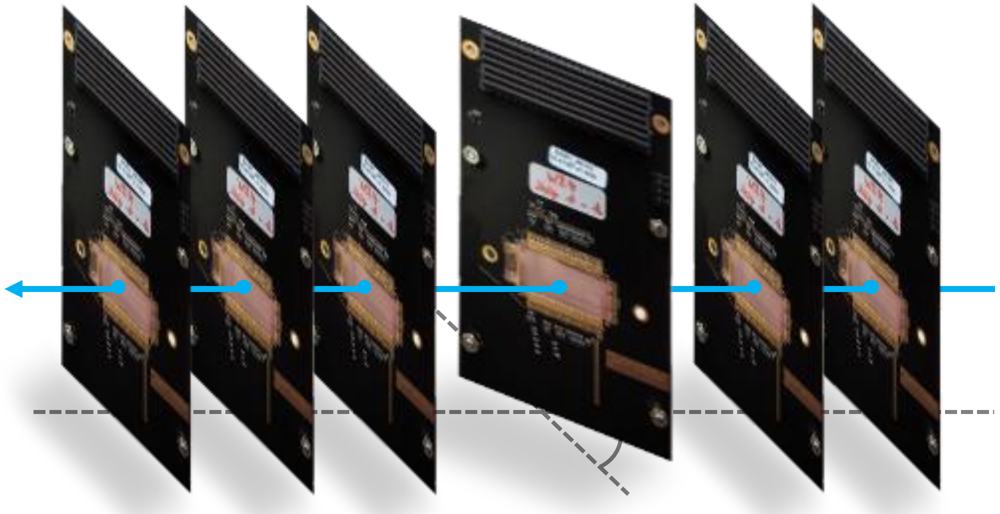




Effects of track angle on E_{Loss}

- Electron beam of 2.4 GeV/*c*
- Study ToT measurement using oversampling method with ITS3 (BabyMOSS) prototype sensor
- Varied angles of DUT (Device Under Test) of 0°, 30°, 45°, and 60° to investigate the change of energy deposition

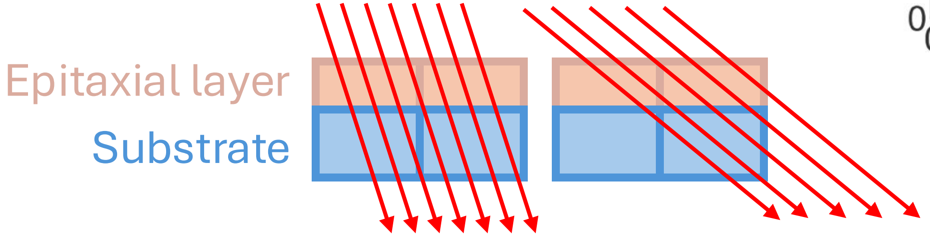




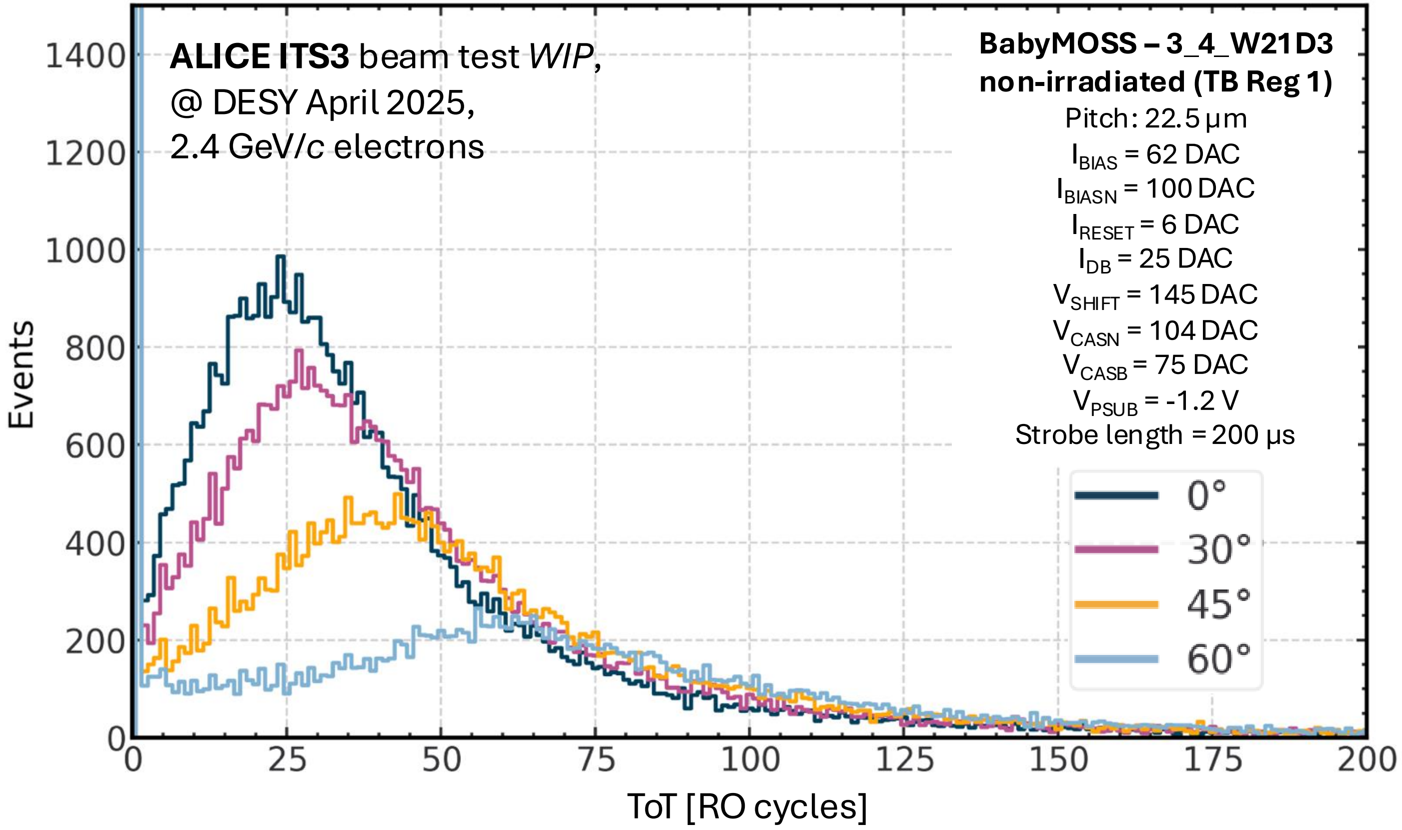
BabyMOSS telescope with inclined BabyMOSS as DUT

Angle measurements

- Cluster size = 1 spectra
- For shallow tracks pixel border effects become more important
- More details on methodology will be presented by M. Menzel at the TWEPP 2025 (contribution will be available soon)

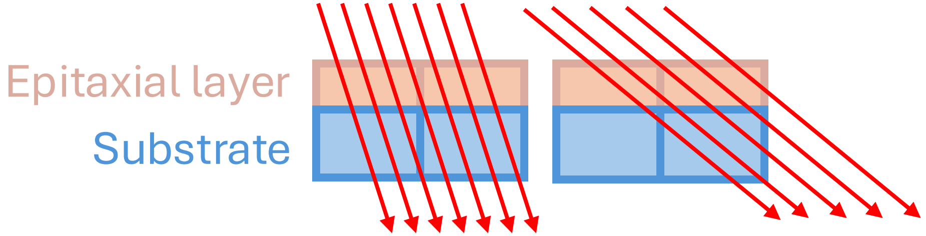


Test beam data using BabyMOSS

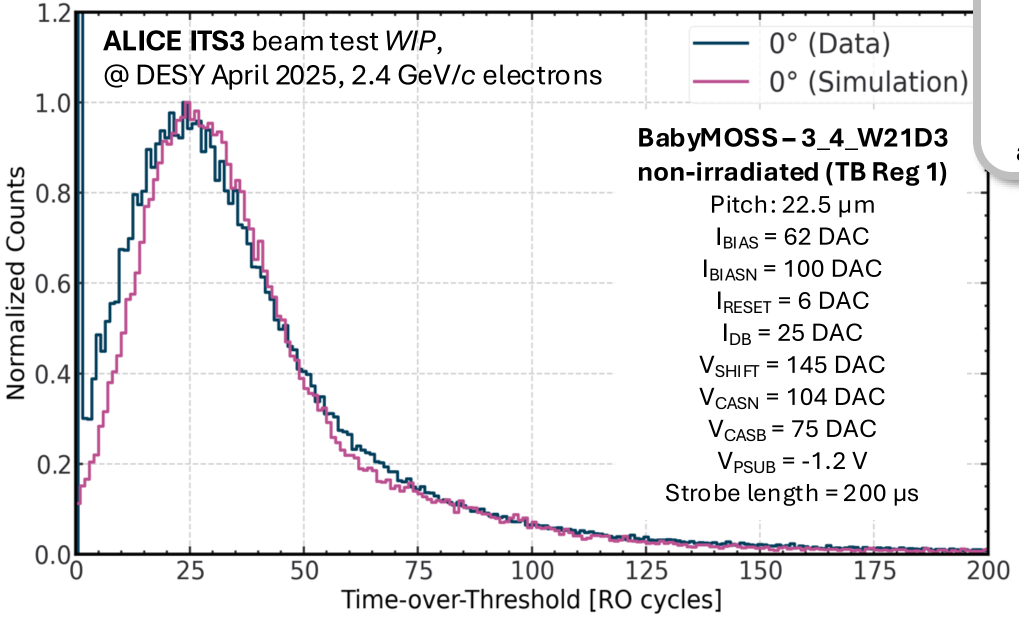


Angle measurements

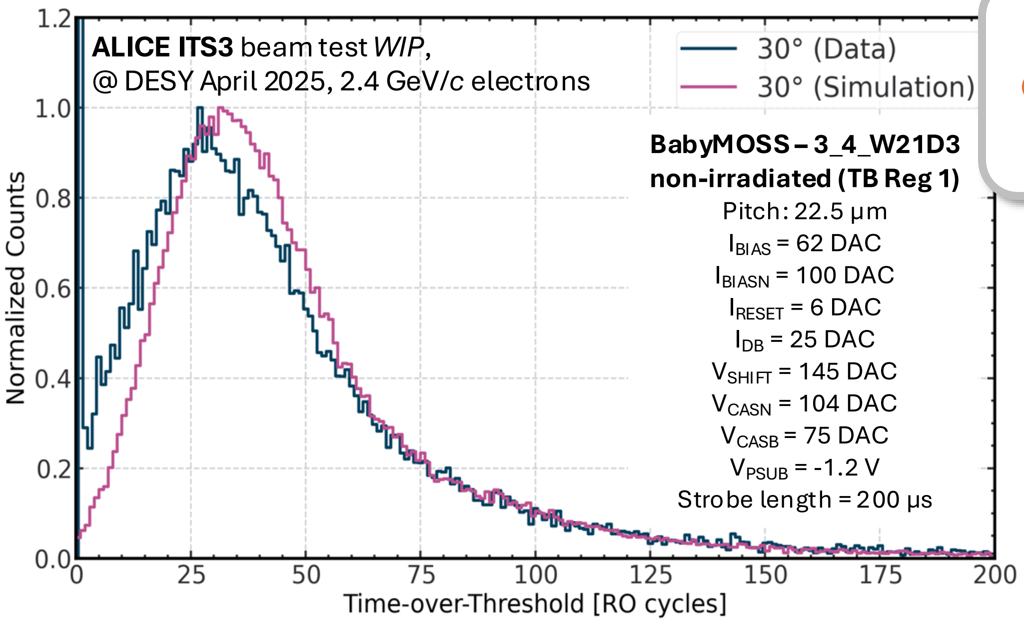
- Cluster size = 1 spectra
- Simulated energy response in 10 µm silicon (+ corrected track length) with Geant4
- For shallow tracks pixel border effects become more important
- More detailed digitization needed to simulate exact charge collection and deposition within pixels



Comparison: Test beam from April – Geant4



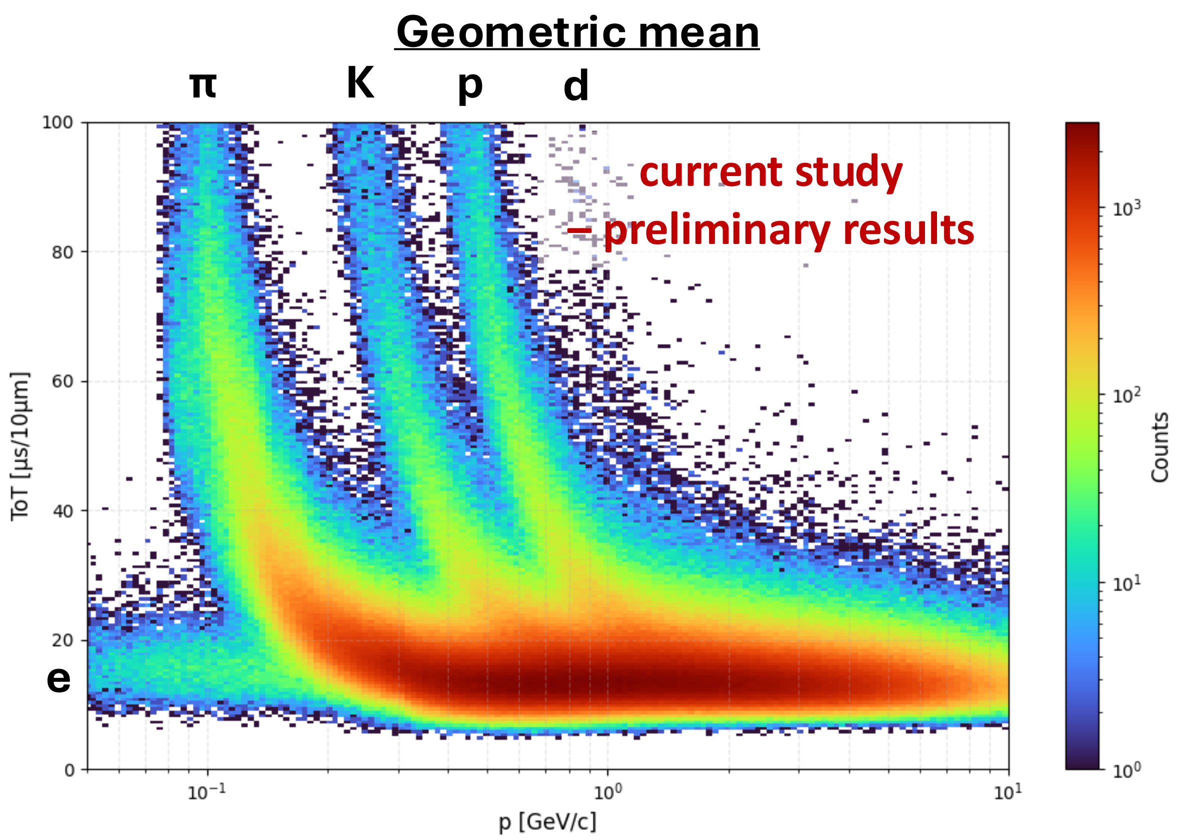
Good agreement



To be improved

PID with middle and outer layers

- Implementing these steps, we get an estimate of the performance that could be achieved by using amplitude information
- Geometric (or truncated) mean used to mitigate effects of the Landau tail in the charge distribution
- No momentum smearing, tracking efficiency, …

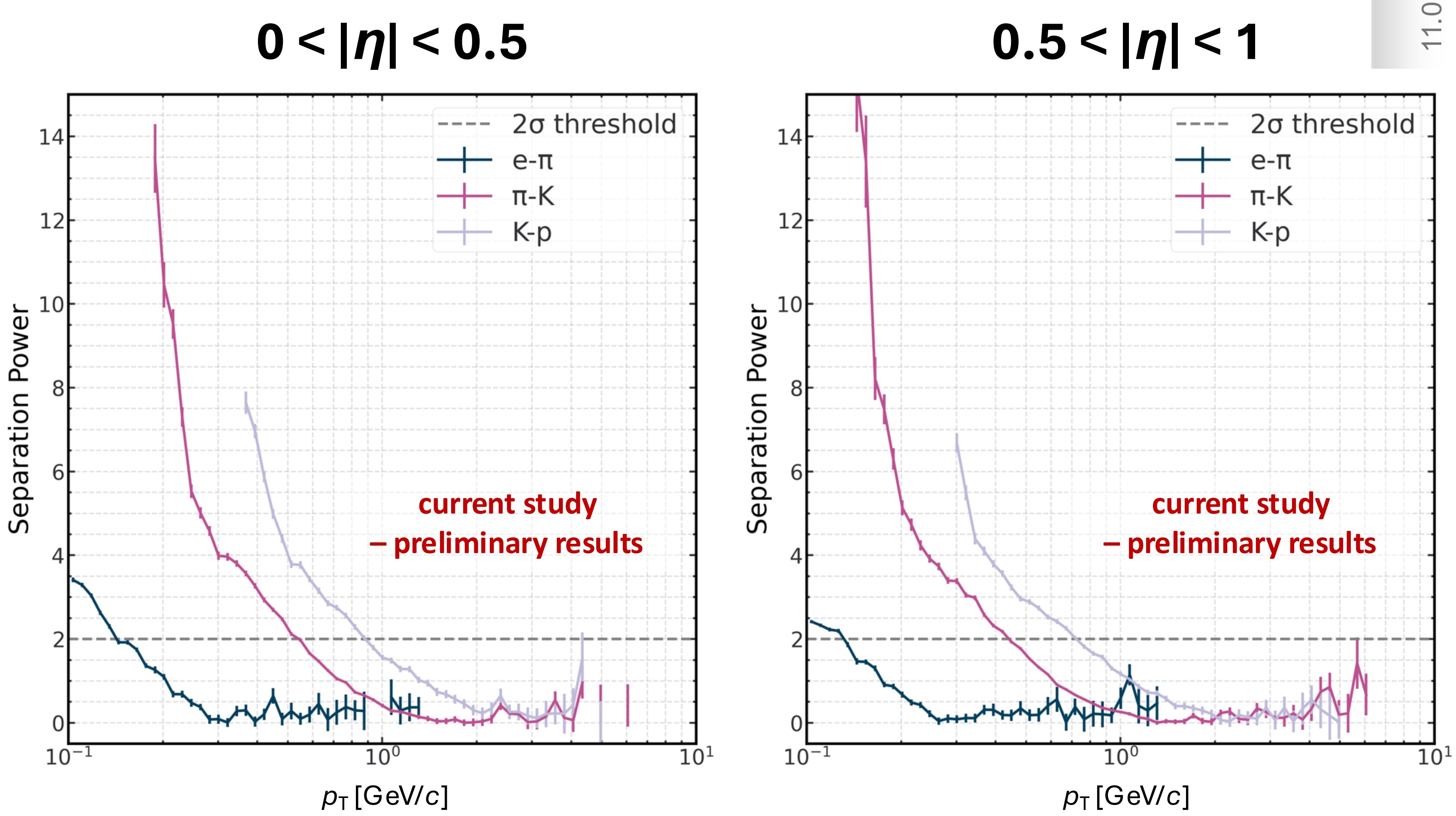


Separation power

- Separation power calculated as a function of p_T for different eta

$$SP = \frac{|\mu_A - \mu_B|}{\sqrt{\frac{\sigma_A^2 + \sigma_B^2}{2}}}$$

- Up to $p_T \sim 0.9$ GeV/c for kaon-proton pair
- Up to $p_T \sim 0.5$ GeV/c for pion-kaon pair
- Up to $p_T \sim 0.15$ GeV/c for electron-pion pair



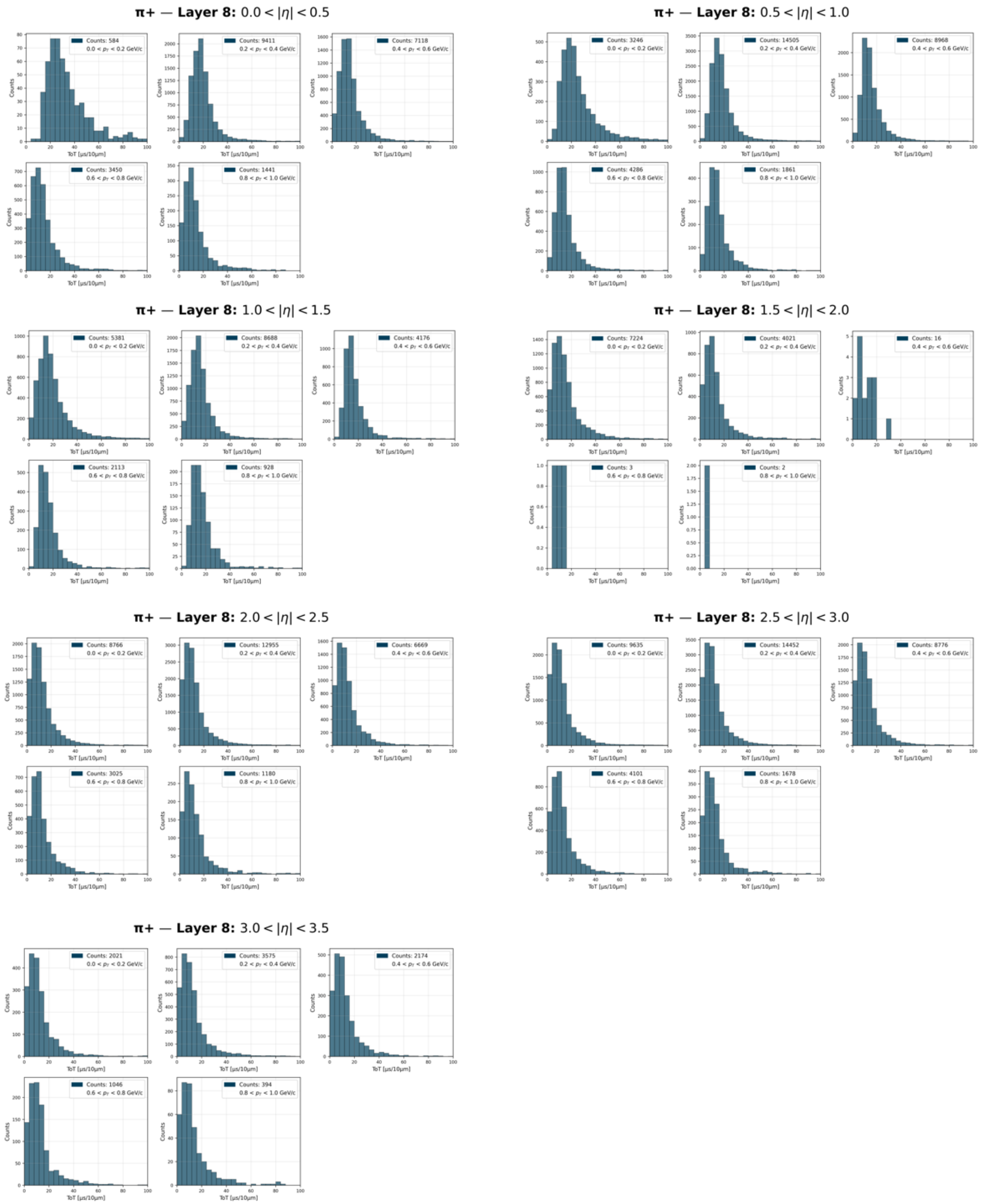
Adding ToT to Simulation

- How can adding dE/dx (ToT) information from OT improve ALICE 3 PID capabilities?

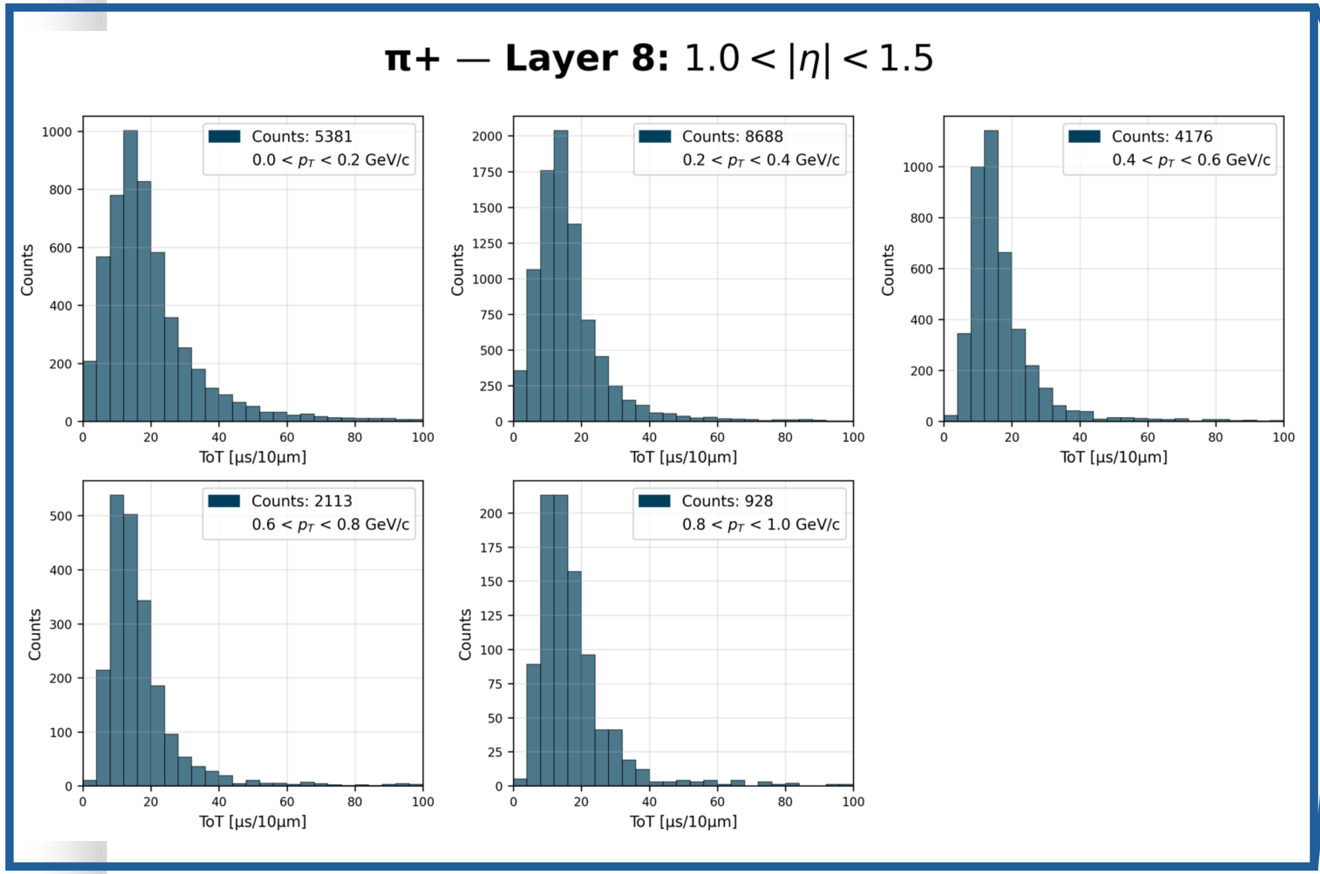
- Adding ToT information to fast simulation
  - Compare to RICH, TOF, Combined, …

- Prepared the look-up table inputs needed for simulation
  - ToT distribution according to parameters such as particle, layer, η, p_T

Example for pions at layer 8



Adding ToT to Simulation



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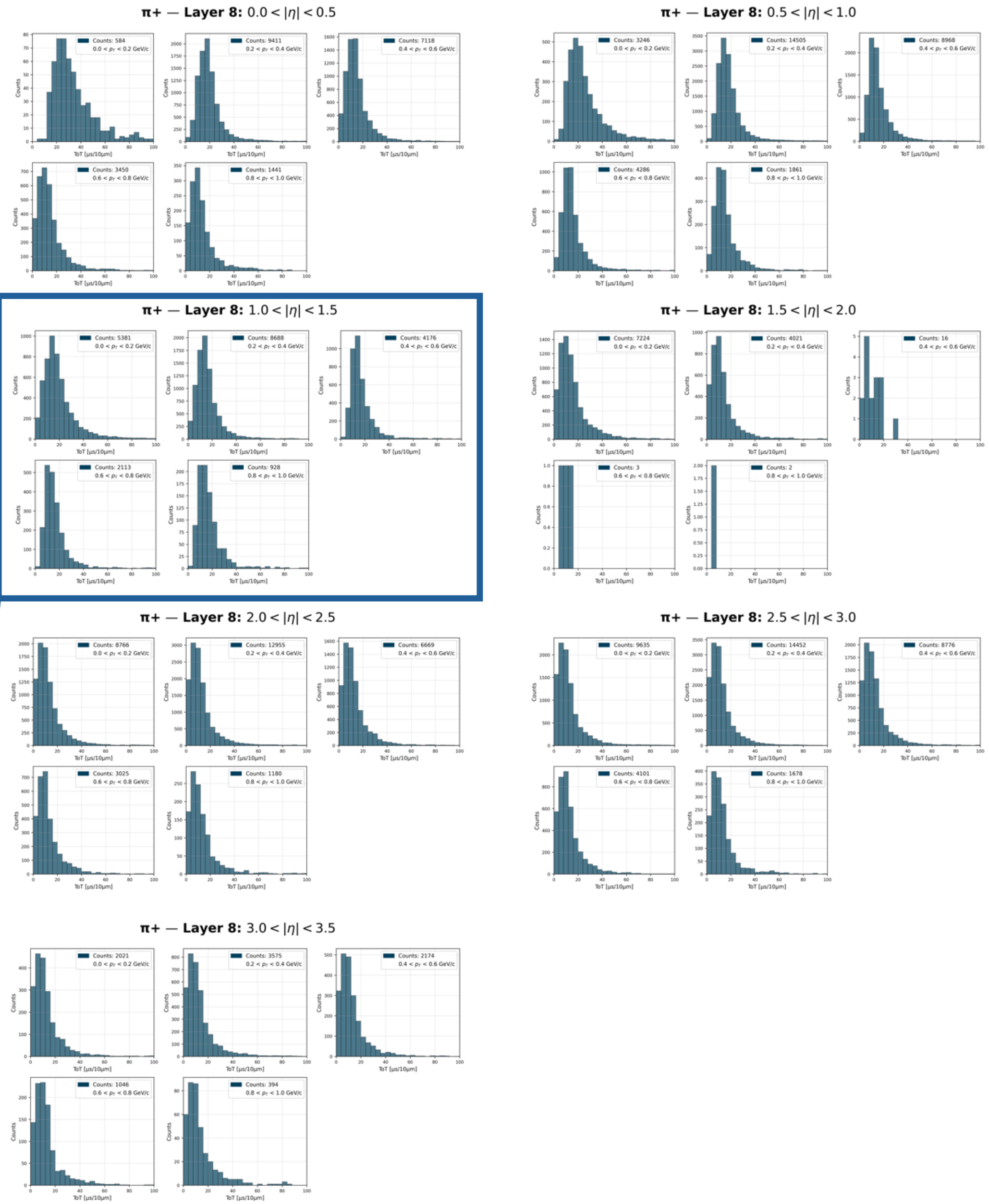
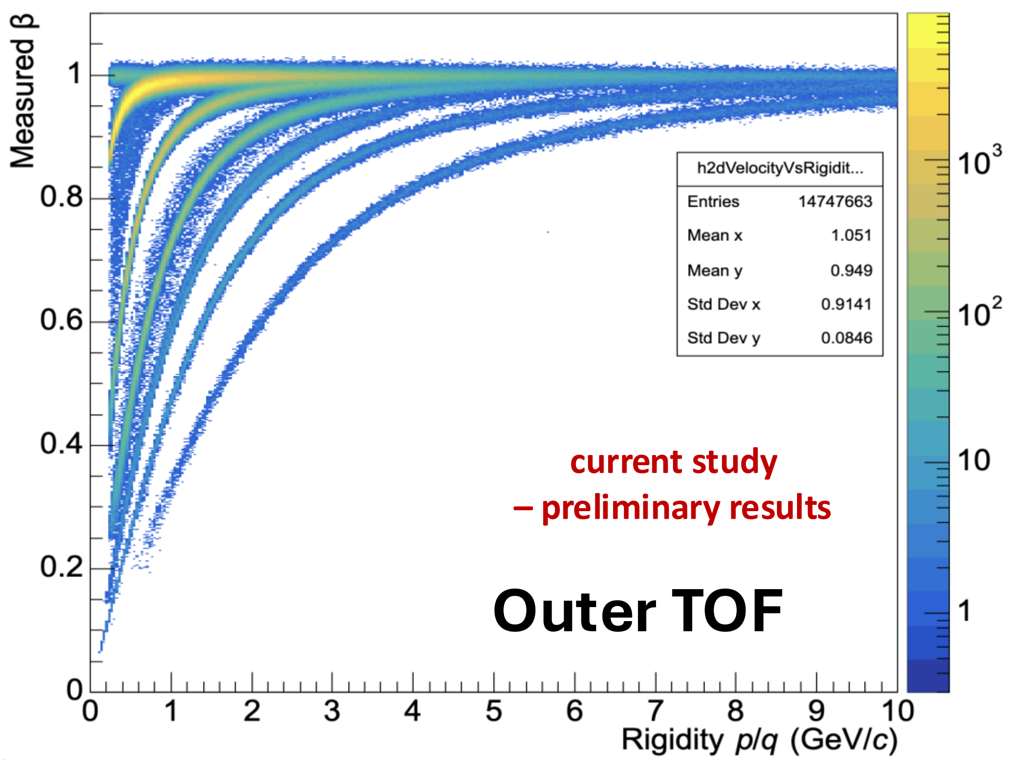
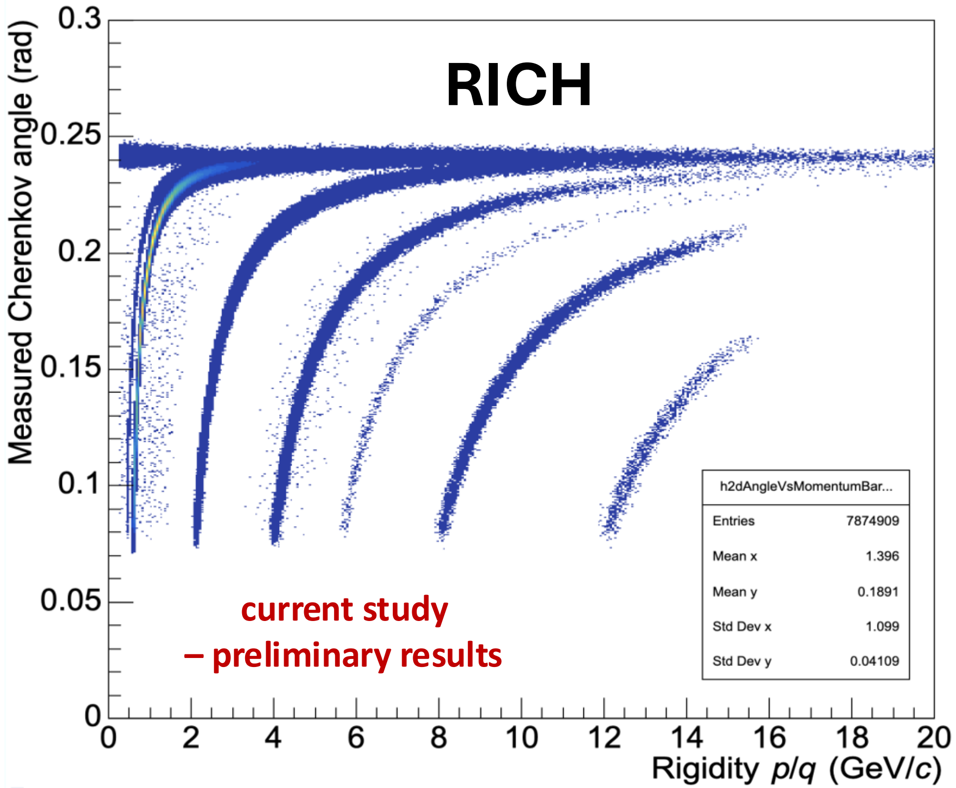


Simulation

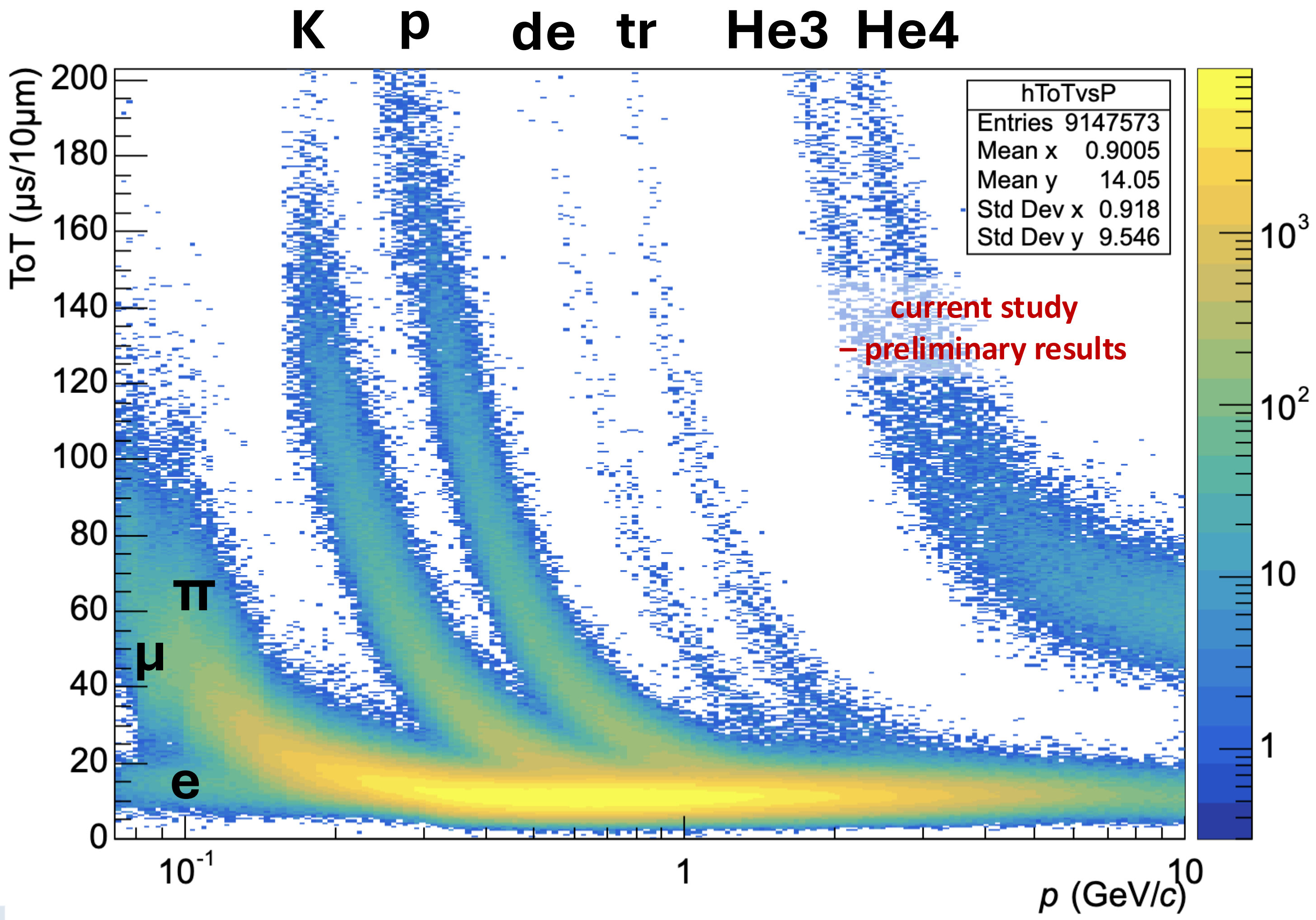
- ALICE 3 will perform PID using two TOF layers (19 cm & 85 cm radii) and a RICH (90 cm radius) to cover a large momentum range
- Investigate how the silicon tracker (ToT) could complement the PID
- Light nuclei as golden channels?
    - TOF cannot distinguish between particles with the same mass-to-charge ratio





Simulation

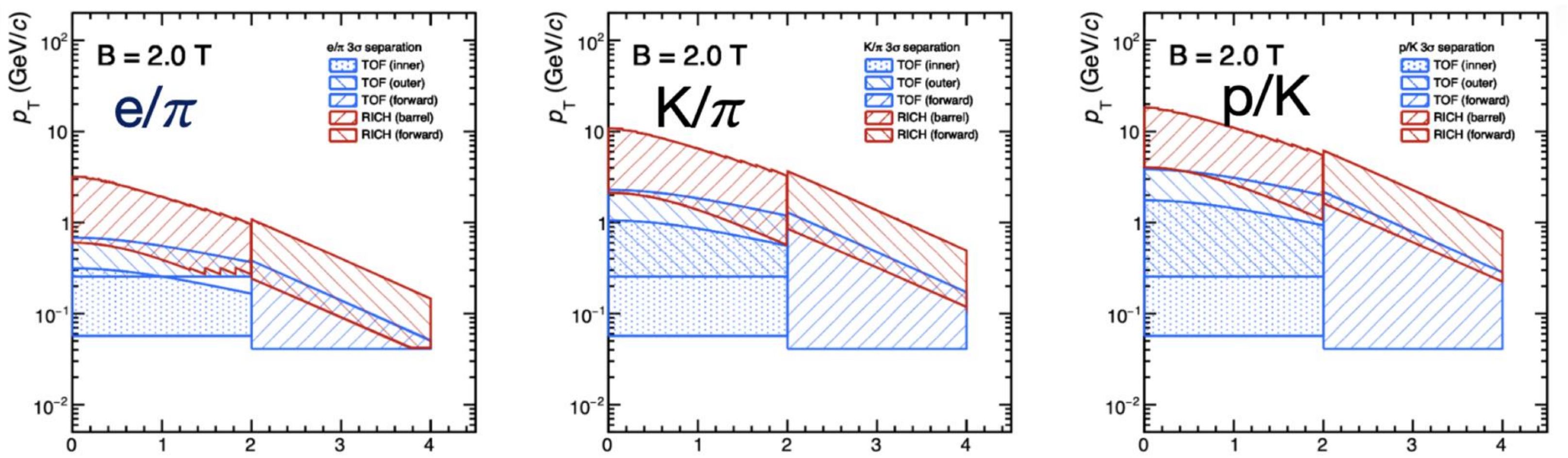
- Tracker PID implemented in the simulation
- Light nuclei added through the event generator
    - Nuclei enhanced production
- Light nuclei as golden channels?
    - Significant separation between for example deuteron and helium-4



Outlook

- ToT-based approach to PID will be implemented in the ACTS simulation setup, and performance to be estimated

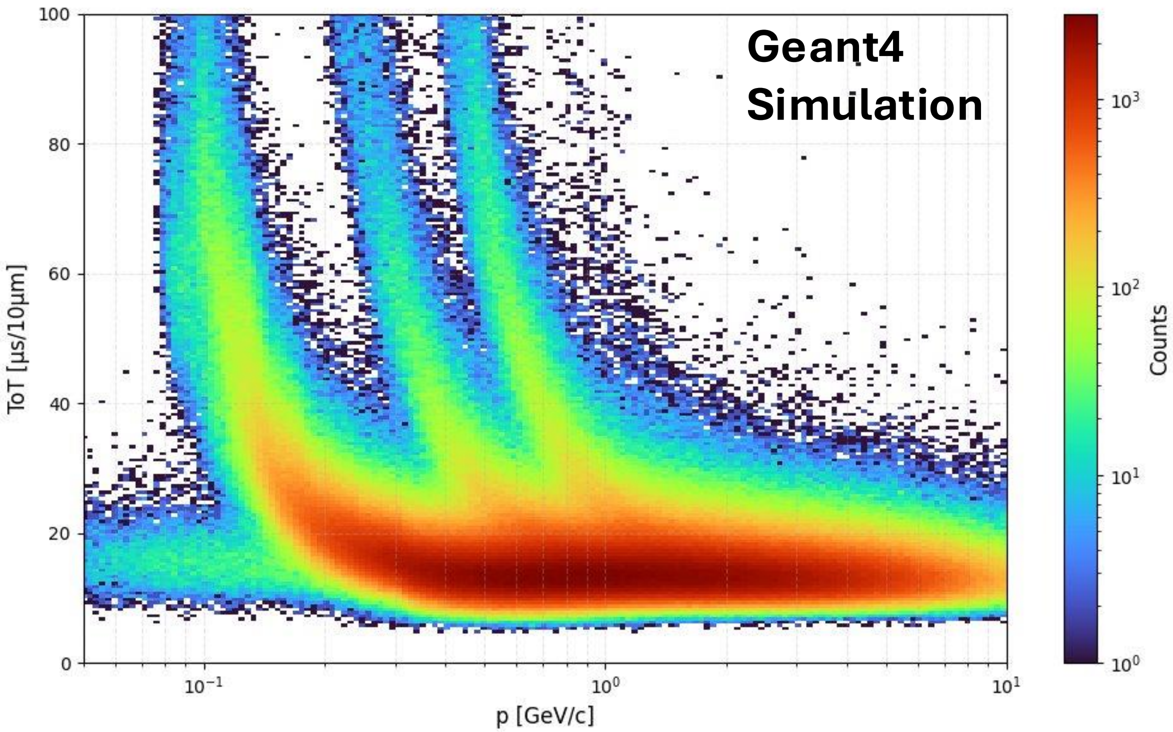
- Quantify using fast simulation how useful the energy loss information is for PID, considering TOF & RICH
    - Example of separation power for different detectors from the ALICE 3 scoping document



Scoping document for ALICE 3

Thanks!

Any questions?



Backup