Status and Plans for PID Reconstruction: ToF

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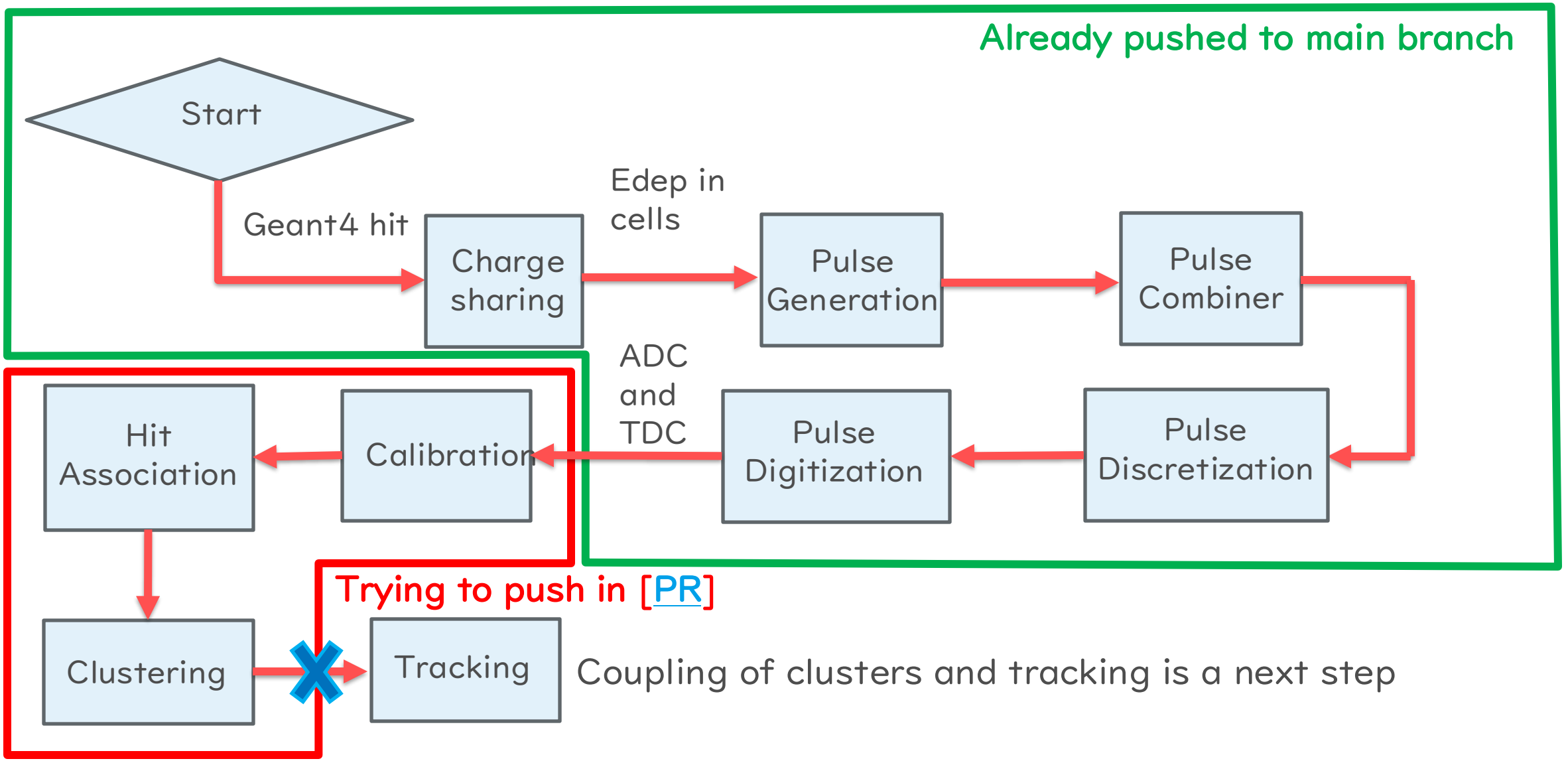
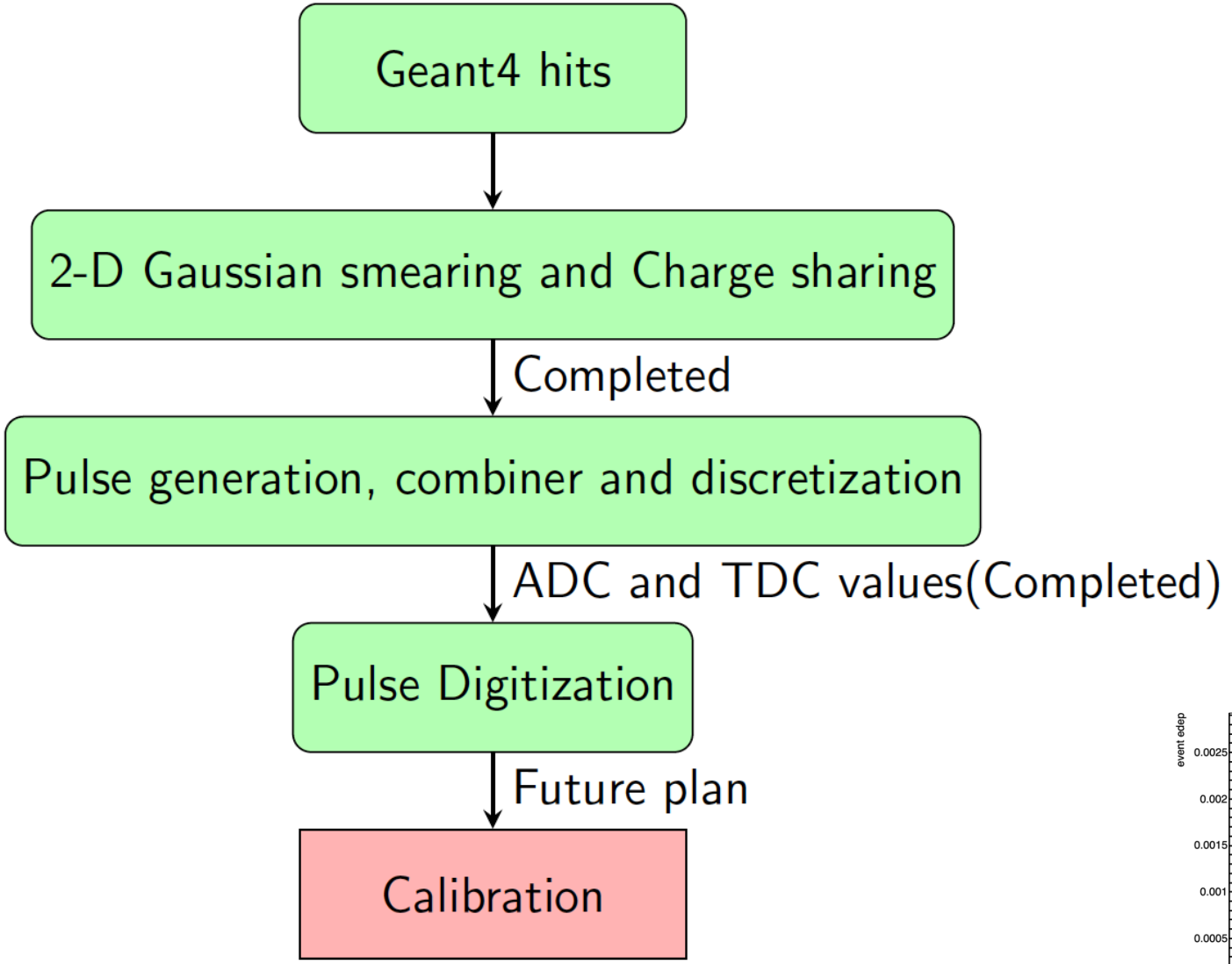
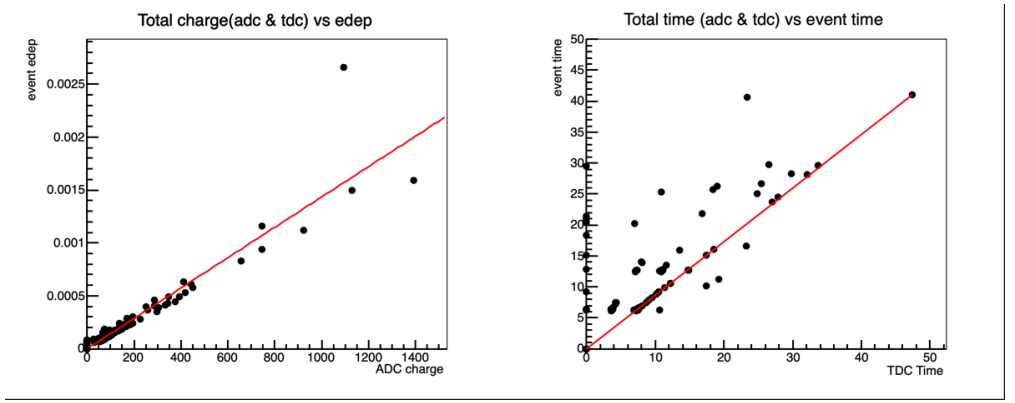
Digitization work-flow

ToF digitization work-flow design; BToF



ToF digitization work-flow design; EToF

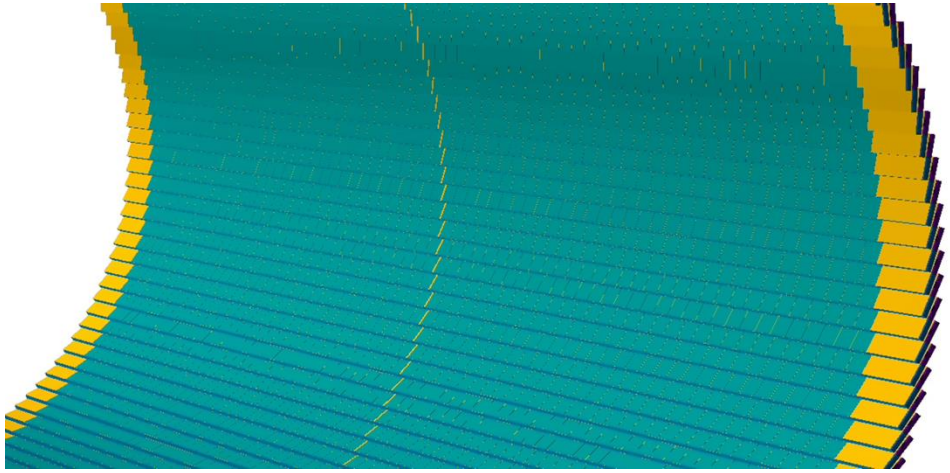


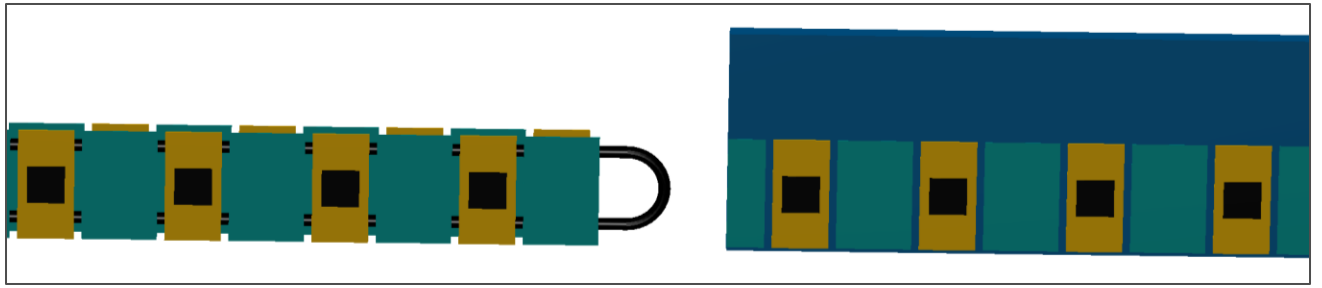


Geometry updates in EPIC simulation

update: BTOF geometry

- Before: Sensor on one side → New: Sensors on both sides

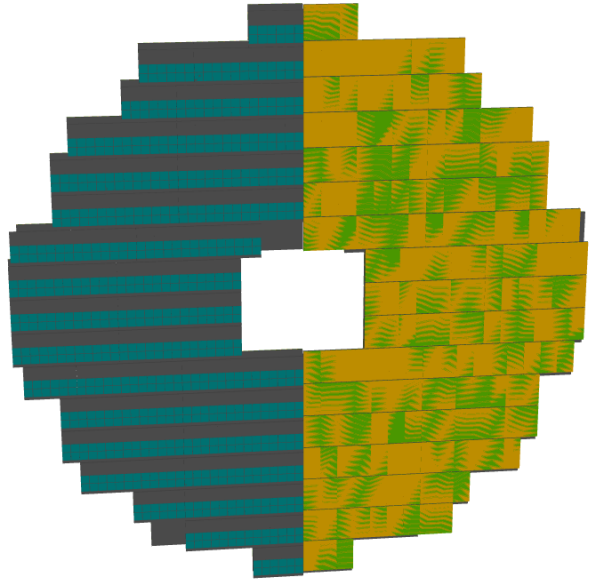




- Cooling tubes in carbon form
- Updated to match proposed drawing [Link]
- Updated on May 2025

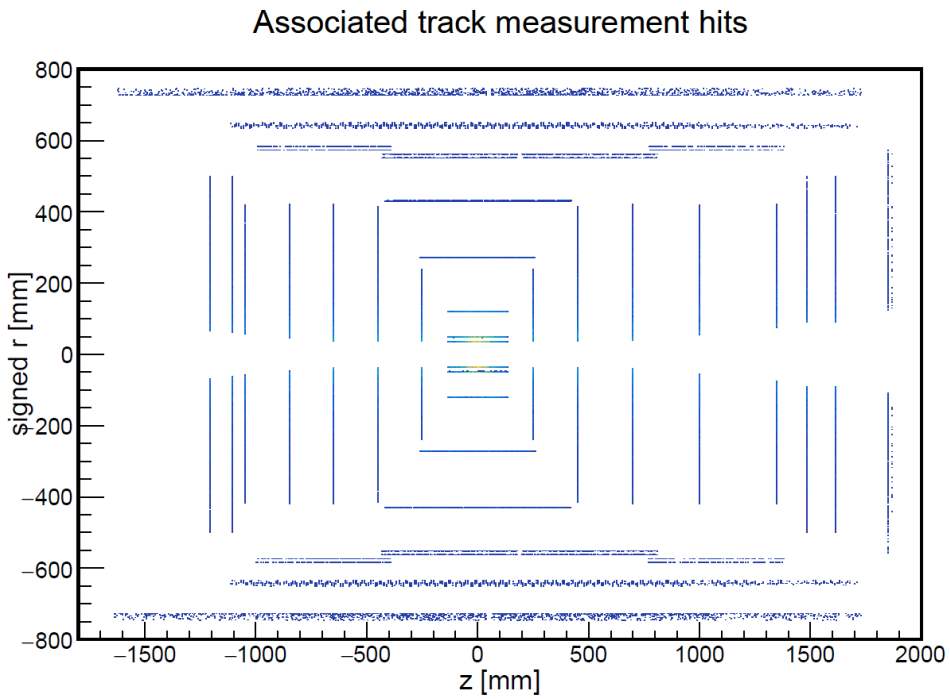
update: ETOF geometry

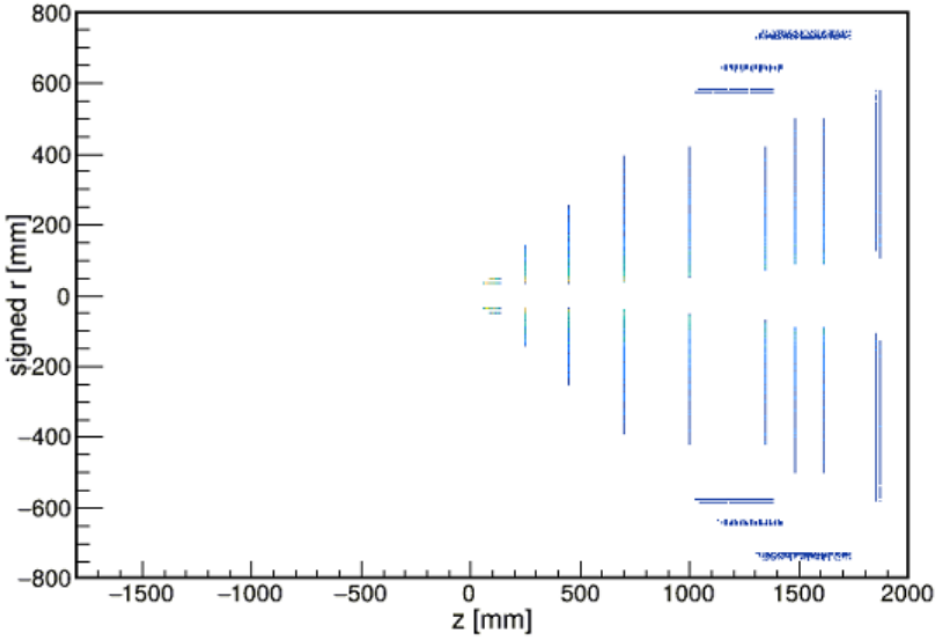
- Issue: ACTS is unable to use tracking information on the back side of ETOF [Report]
  - Error with ETOF geometry implementation



Cover on the left removed to show sensors

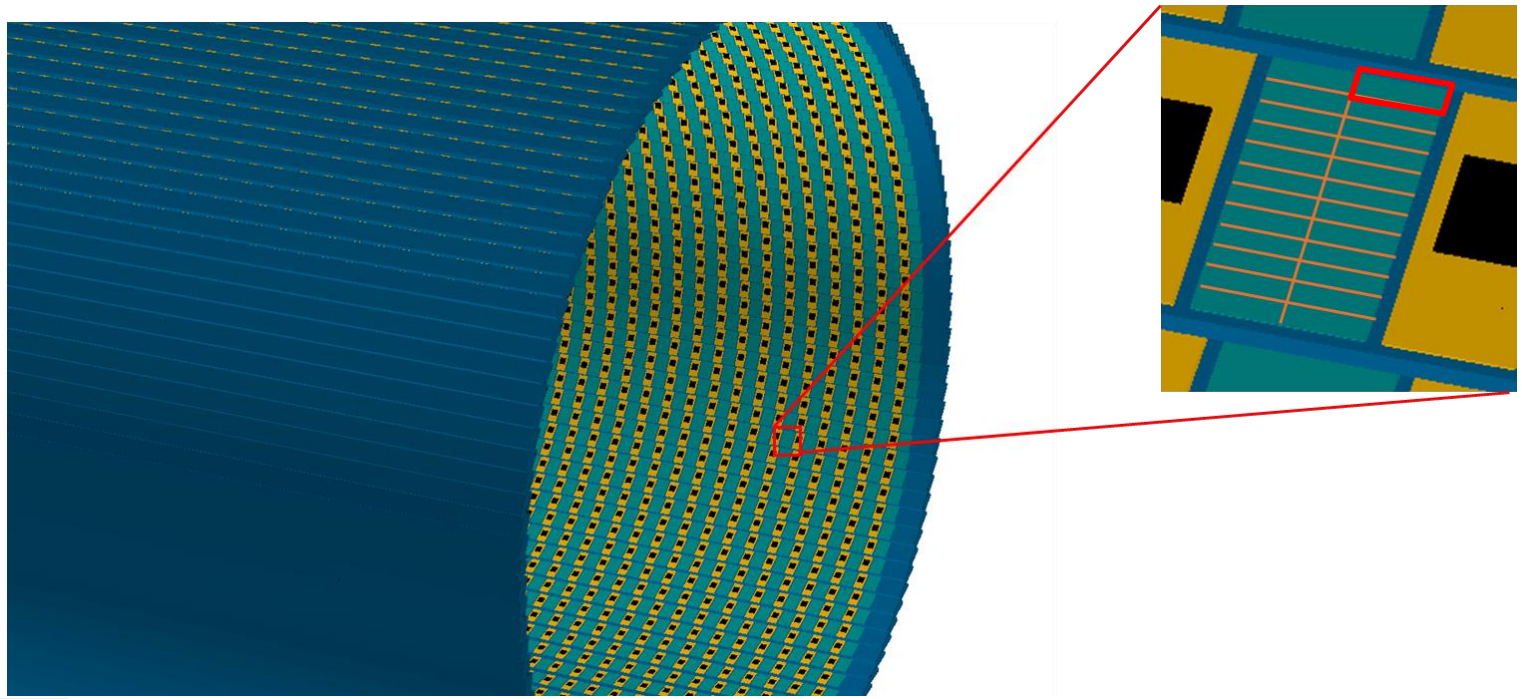
- Fixed in [PR]





update: strip size

- Realistic BTOF grid size: 0.5 cm * 0.5 mm
- Realistic ETOF grid size: 0.5 mm * 0.5 mm
- However, position better than 0.5 mm because of charge sharing (not yet implemented).
- Reduced BTOF grid size to 0.5 cm * 0.1 mm
- Reduced ETOF grid size to 0.1 mm * 0.1 mm



Grid size

Plans for Geometry and digitization

- Time walk/edge correction
- Use CFD instead of EICROC for BTOF
  - EICROC uses constant threshold, not constant fraction
- Add noise to pulses

- Add support structure cooling tubes to ETOF
- Add acceptance gap into BToF

Ongoing studies

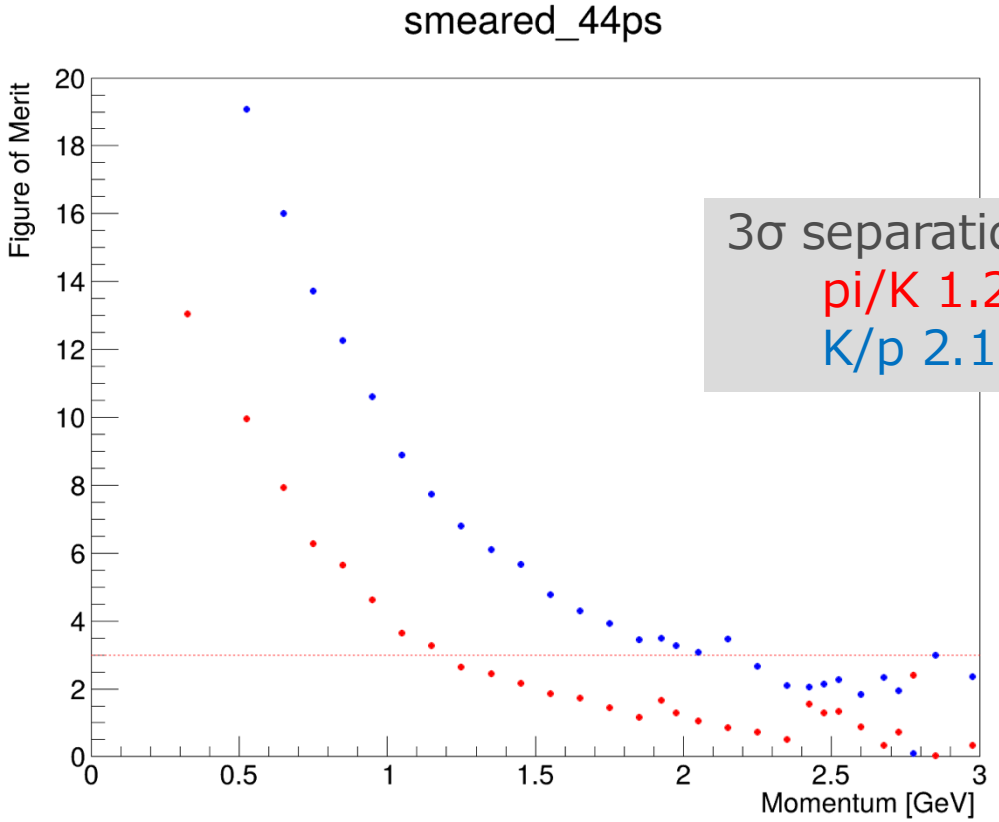
Timing resolution vs PID performance

BToF

- Total timing resolution of 44 ps satisfies the PID requirement by a narrow margin
  - Note: Adding timing smearing by hand
  - This 44 ps includes:
    - the sensor timing resolution, electrical jitters, and the finite T0 resolution
  - $$\mathrm{FoM} = \frac{|\mu_1 - \mu_2|}{\sqrt{\sigma_1^2 + \sigma_2^2}}$$
  - **Need to update this study with full digitization**

ETOF

- We started a same study for the fToF

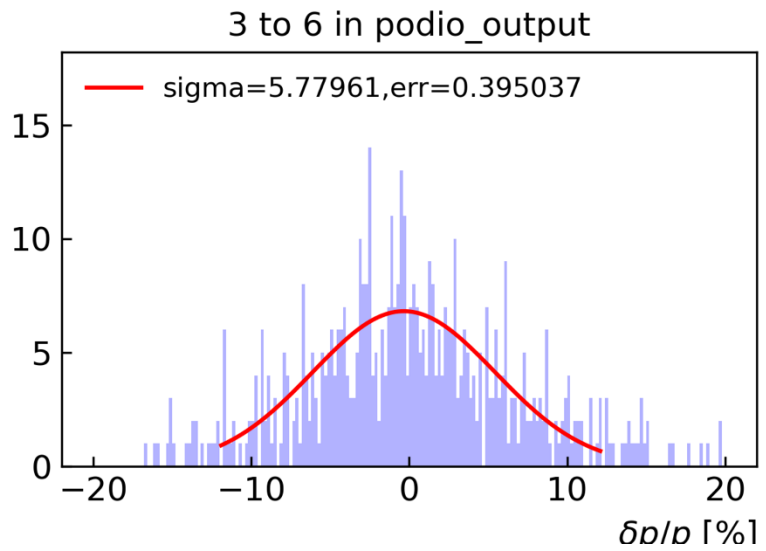


3σ separation
pi/K 1.2 GeV
K/p 2.1 GeV

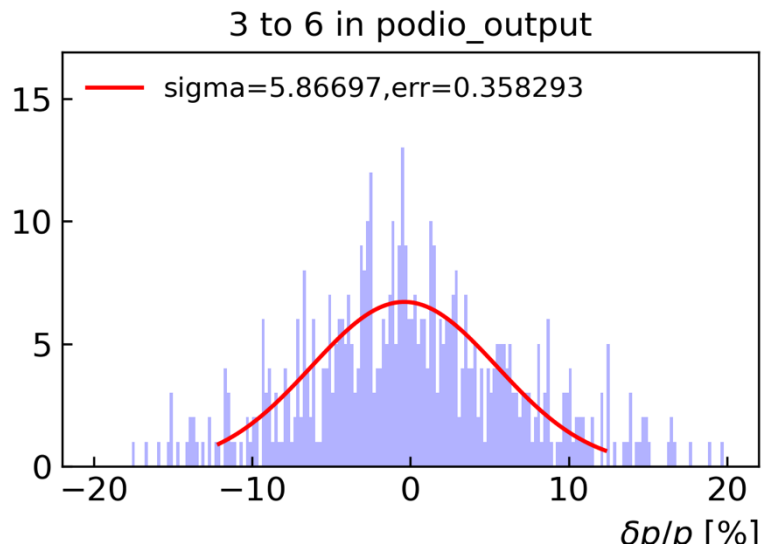
EToF contribute to the tracking?

- Implement EToF structure into simulation
- Checking tracking performance with or without EToF hits
  - Momentum resolution WITH EToF: 5.78%
  - Momentum resolution WITHOUT EToF: 5.87%

W/ EToF



W/O EToF



Material budget impact on downstream system

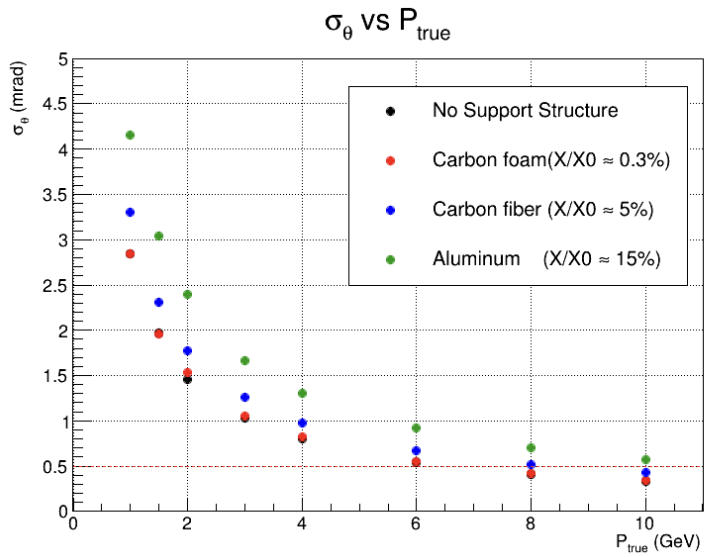
- Material budget is crucial for ToF system design
- Need to check the effect to the downstream detectors

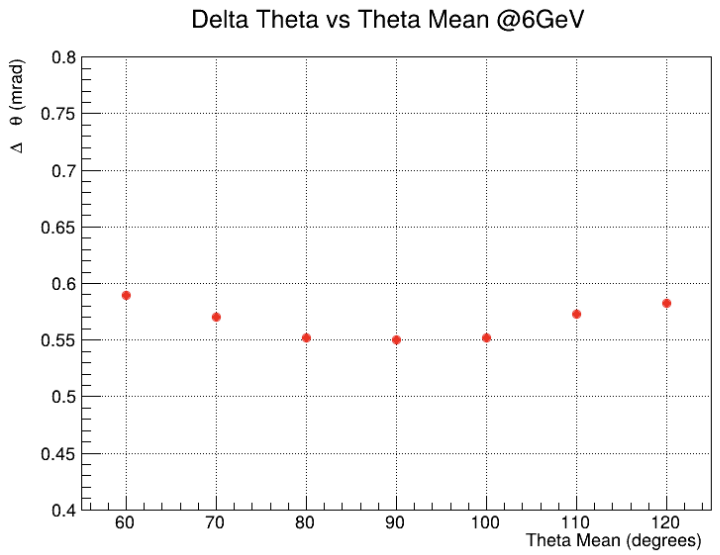
BToF

- Checked the tracking performance at the hpDIRC surface
  - Slightly worse than 0.5 mrad requirement
  - While dense BToF material does not degrade significantly → Discussion is ongoing
  - Need to improve tracking → Fast tracking?

EToF

- We started similar study for EToF as well



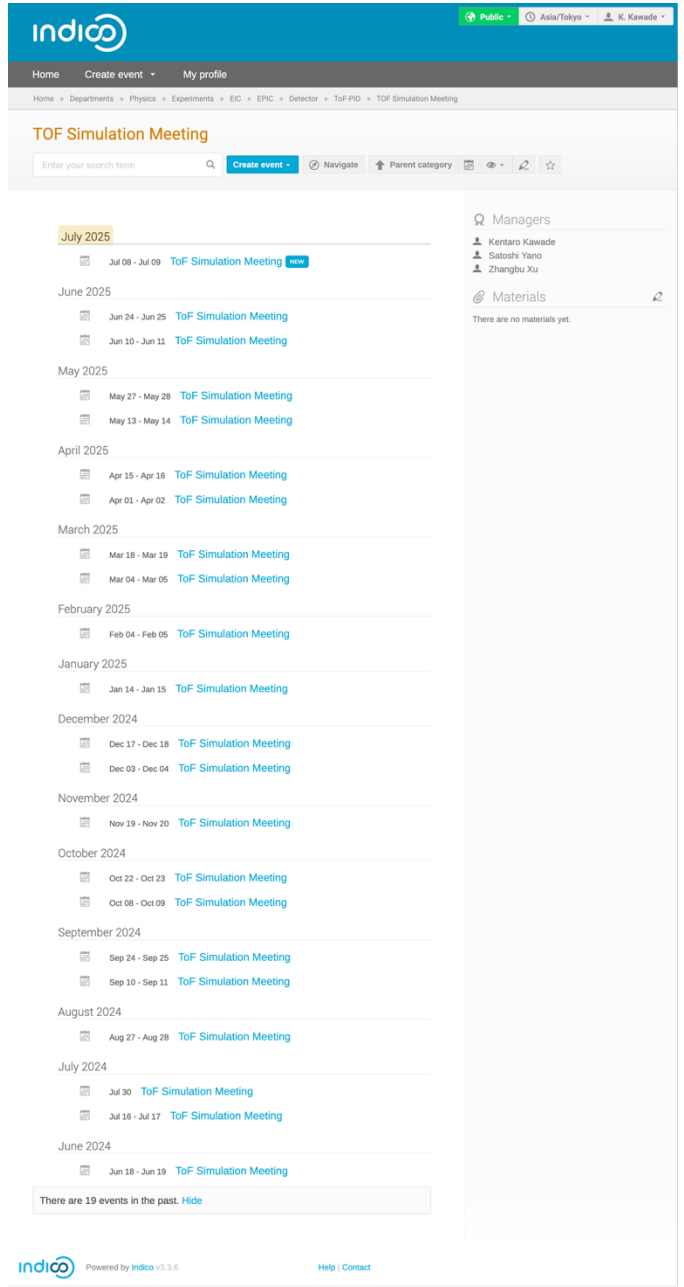


BACKUP

ToF Simulation Working Group

- Coordinators
  - Kentaro Kawade, Tommy Tsang Chun Yuen
- Holding biweekly meeting
- Current Activities
  - Tommy (KSU)
    - Digitization for BToF
    - Implement new ToF geometry/design
  - Honey Khindri (IIT Madras)
    - Digitization for EToF
  - Kyohei Ono
    - Impact of ToF material budgets on hpDIRC resolution
  - Kentaro Kawade
    - Evaluate PID performance
  - New Comer: Abdelghani El Ouardi ()

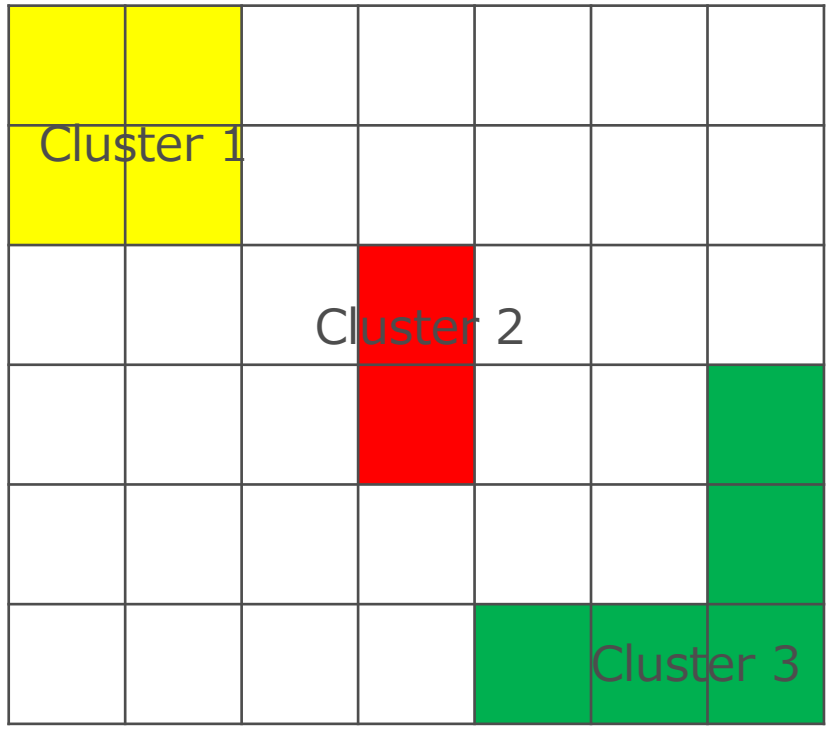
https://indico.bnl.gov/category/569



Calibration, clustering and Hit association

- Calibration of TDC to time is just a linear transformation
  - Same for ADC
  - **No time walk (slewing) correction**
- Clustering is just weighted average of neighbors
  - Group connected neighbors together
    - Hits are neighbors if $\Delta t < 1$ ns
  - Weighted by E_{dep}
  - Time of a cluster = time of the earliest hit
  - **No Edge correction**
- Association of reconstructed hit with true hits
  1. They come from the same sensor
  2. Time difference between the two hits < 1 ns
  3. If there are multiple hits within 1 ns
     → choose the one with the smallest t difference

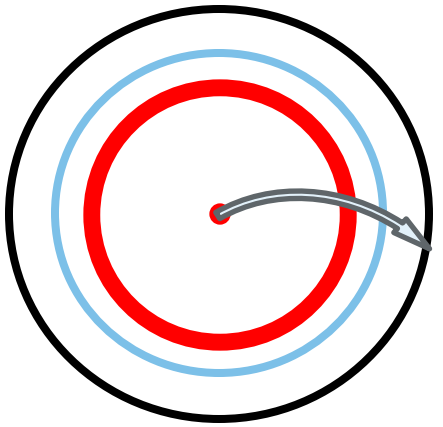
Time axis not shown



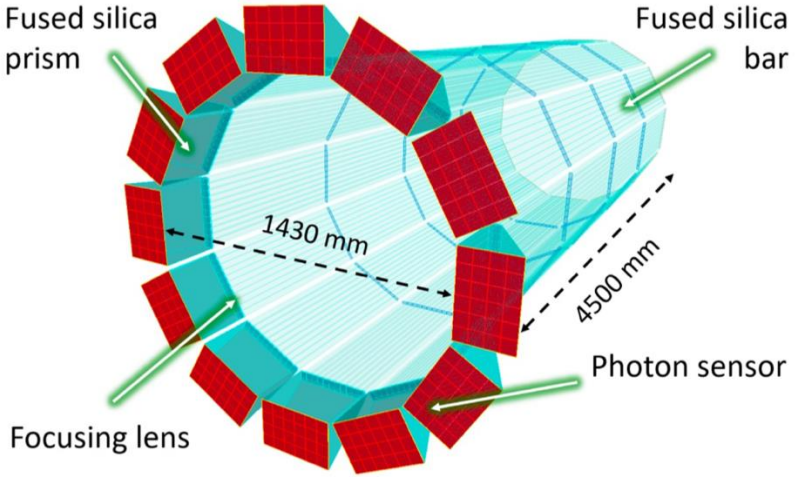
Motivation: Material budget

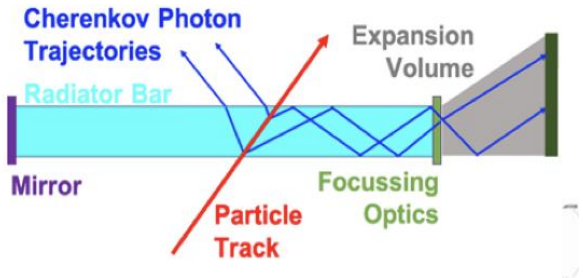
- Estimate the impact of BTOF material budgets on the outer hpDIRC angular resolution
  - To optimize the BTOF design and performance
  - Crucial inputs for sensors, structures and readout PCBs
    to relax the tight requirement (1% X_0)

- hpDIRC is a **Cherenkov** particle identification detector
  → Angular resolution at the surface is important
    - Target@6 GeV/c: $\Delta\theta = 0.5$ [mrad]
  - Material budget of BTOF
    → Affects on angular resolution due to multiple scattering effects
    Determine the upper limit of the BToF material budget



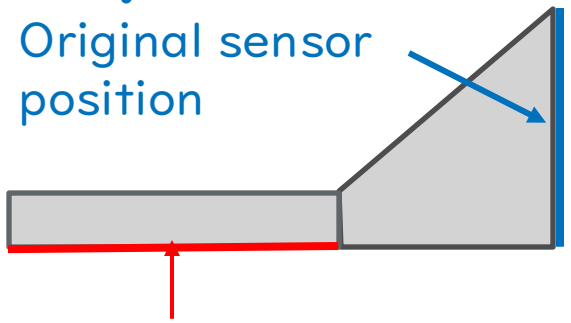
hpDIRC:
high performance Detection of Internally Reflected Cherenkov light

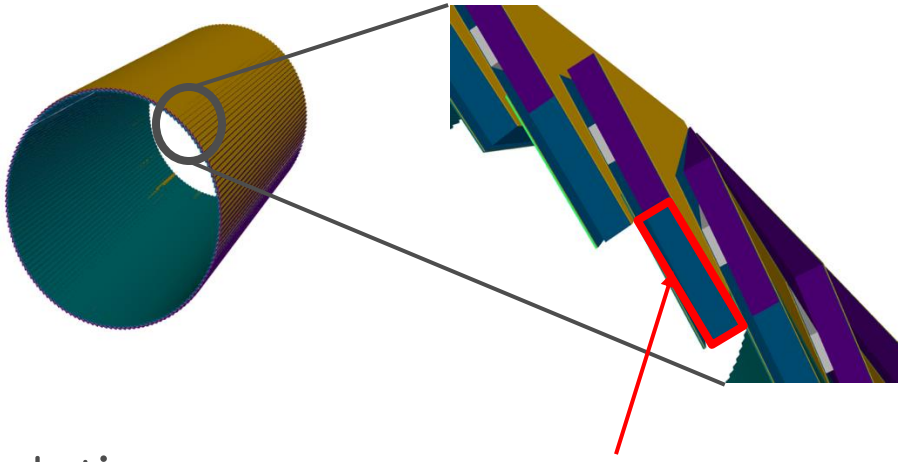




Simulation setup: Angle & Material Study

1. Added sensitive layer at the hpDIRC surface
   - To take truth hit position at the surface
2. Different BToF Support structure materials
   - Carbon foam (default) : 0.09 g/cm^3 (0.12% X/X$_0$)
   - Carbon fiber : * g/cm^3 (2.64% X/X$_0$)
   - Aluminum : 2.65 g/cm^3 (6.52% X/X$_0$)
3. Single particle full Detector simulation in DD4hep
   - Particle: π^-
   - Fixed Momentum: $1,\ 1.5,\ 2,\ 4,\ 6,\ 8,\ 10\ \mathrm{GeV}$
   - Direction
     - $\phi : 0^\circ \leq \phi \leq 360^\circ$
     - $\theta : 58^\circ - 62^\circ,\ 68^\circ - 72^\circ$ ...
4. EICrecon to perform tracking and calculate angular resolution
   - Take angular resolution using the **"Residual method"**

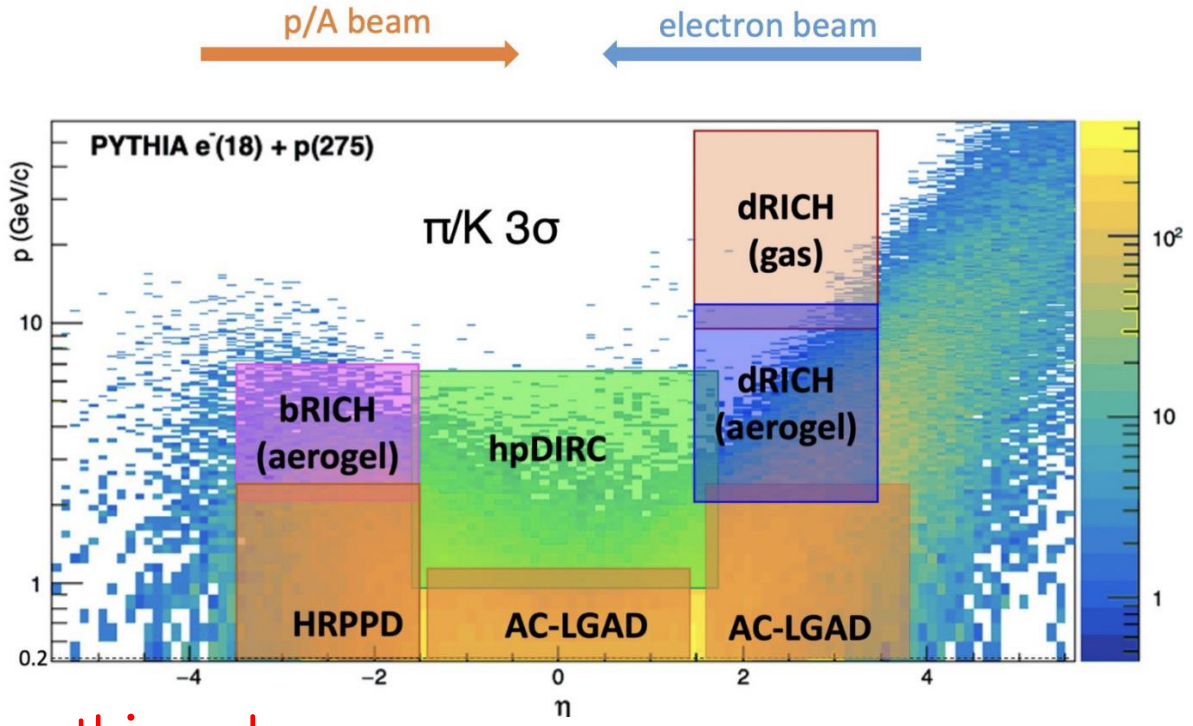




Note

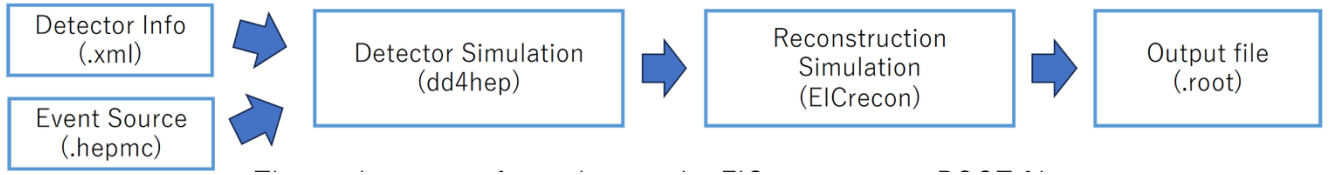
- Generators
  - Pythia NCDIS
    - N_{events}: 200k
    - Energy: 18x275 GeV
  - **Particle Gun: pi/K/proton**
    - N_{events}: 100k for each
    - $0.1 \leq p \leq 5.0$ GeV
    - Eta&Phi: Flat
  - epic ver 25.04.1

This report focus on this only



ePIC PID requirement

- Reconstruction framework
  - **EIC Recon Version 1.24.2**

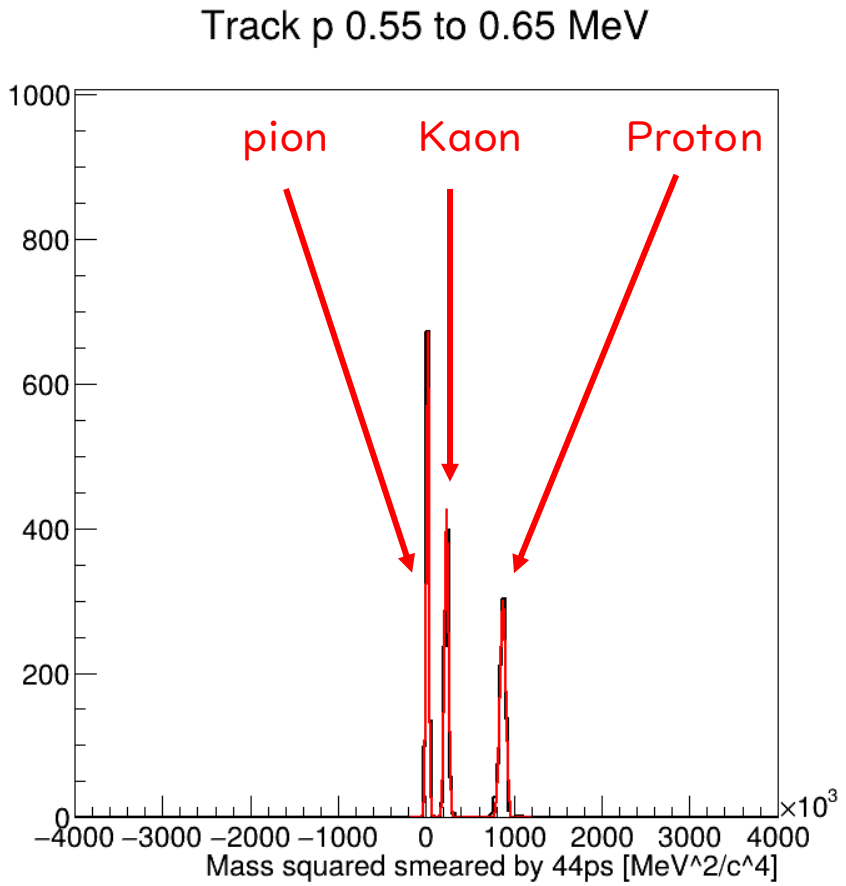


- Own developed offline analysis code

- PID performance when considering finite timing resolution will be shown

PID performance evaluation: Gaussian fit

- Obtain each mass peak and its width
  - inclusive 3 gaussian fitting



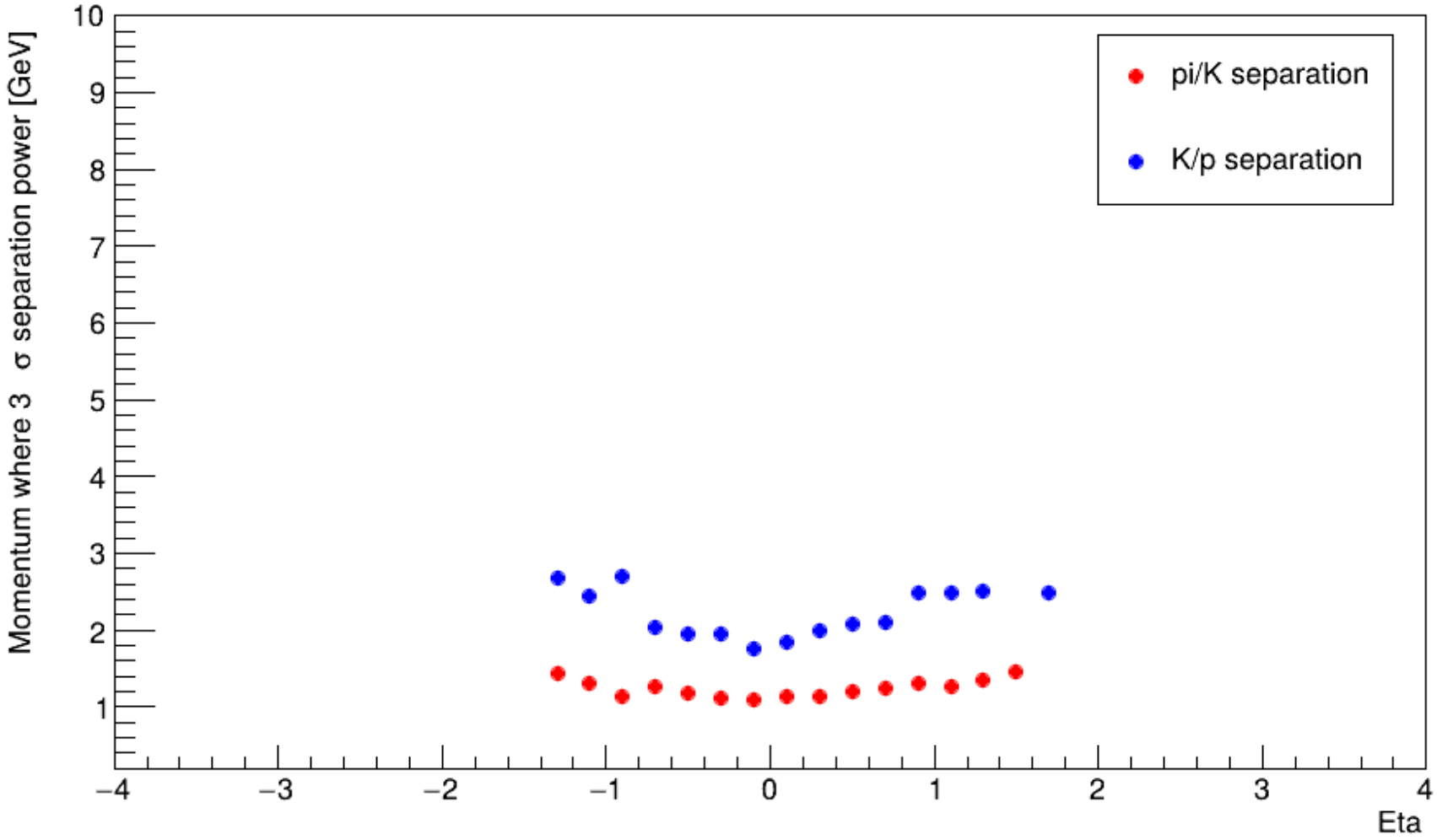
- Introduce Figure of Merit (FoM), to assess the PID performance quantitatively

$$\mathrm{FoM} = \frac{|\mu_1 - \mu_2|}{\sqrt{\sigma_1^2 + \sigma_2^2}}$$

  - μ : mass^2 peak position
  - σ : gaussian width

3 σ separation vs eta

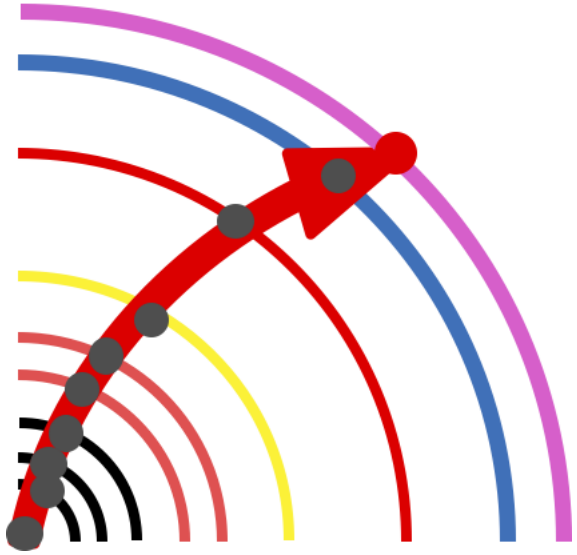
- Perform same analysis differentially



Tracking detail

Full reconstruction

Kalman filter
+ **all** Tracking det.



Fast reconstruction

Kalman filter
+ Tracker except Si