UNIVERSITY OF HOUSTON

BERKELEY LAB
Bringing Science Solutions to the World

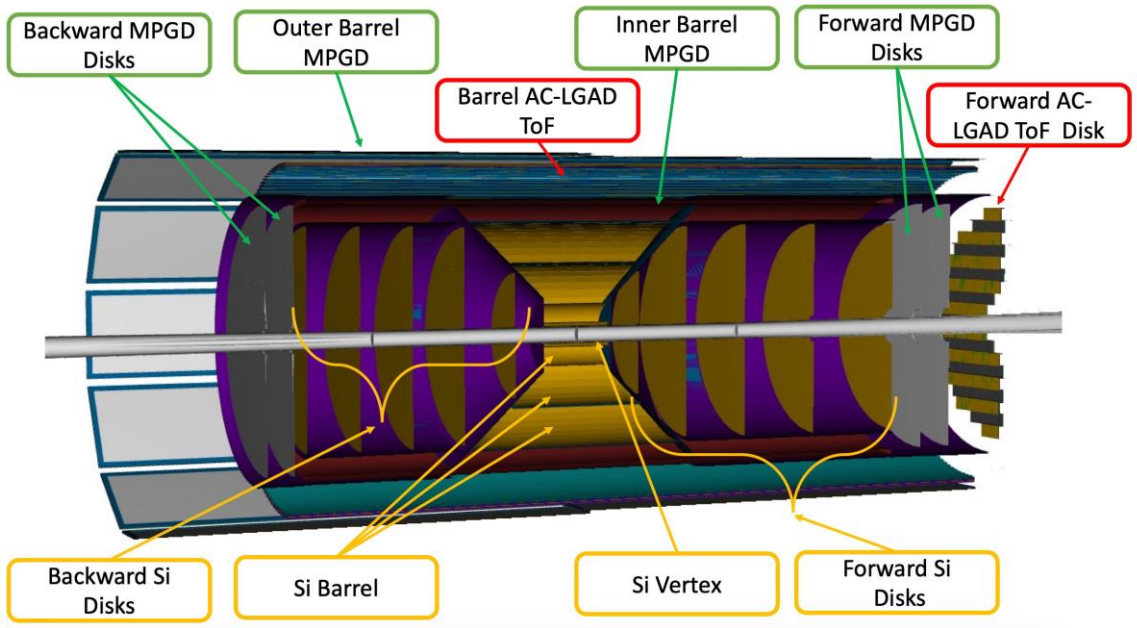
Track reconstruction and vertexing – status and ongoing work

Barak Schmookler, Shujie Li, Ernst Sichtermann

(on behalf of the Tracking CC WG)

Central Tracker

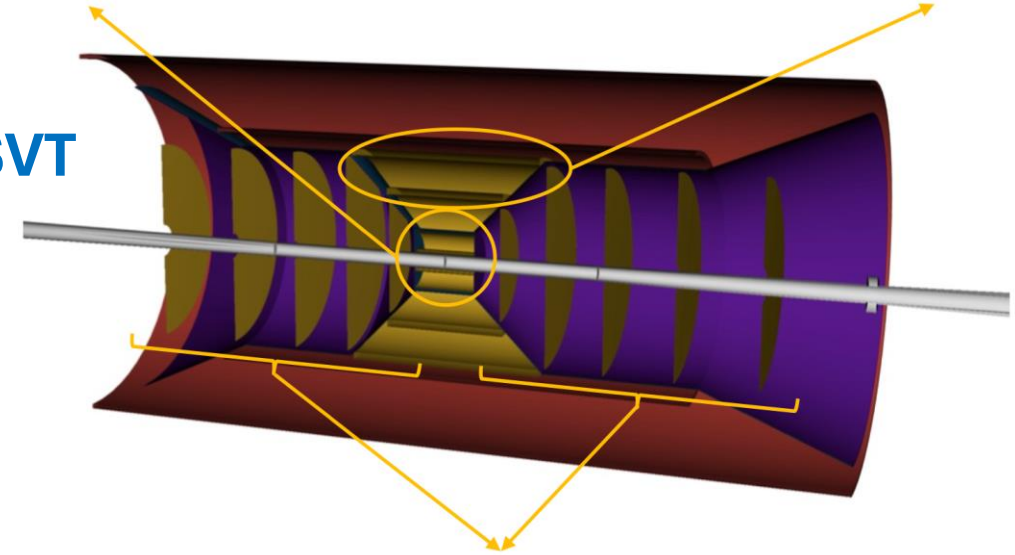
Full tracking system: Silicon Vertex Tracker (SVT) + MPGDs + AC-LGAD TOF detectors



Inner Barrel (IB)
- Two curved silicon vertex layers
- One curved dual-purpose layer
- 0.05% X/X0 per layer

Outer Barrel (OB)
- One stave-based sagitta layer
- One stave-based outer layer
- 0.25/0.55% X/X0 per layer

SVT



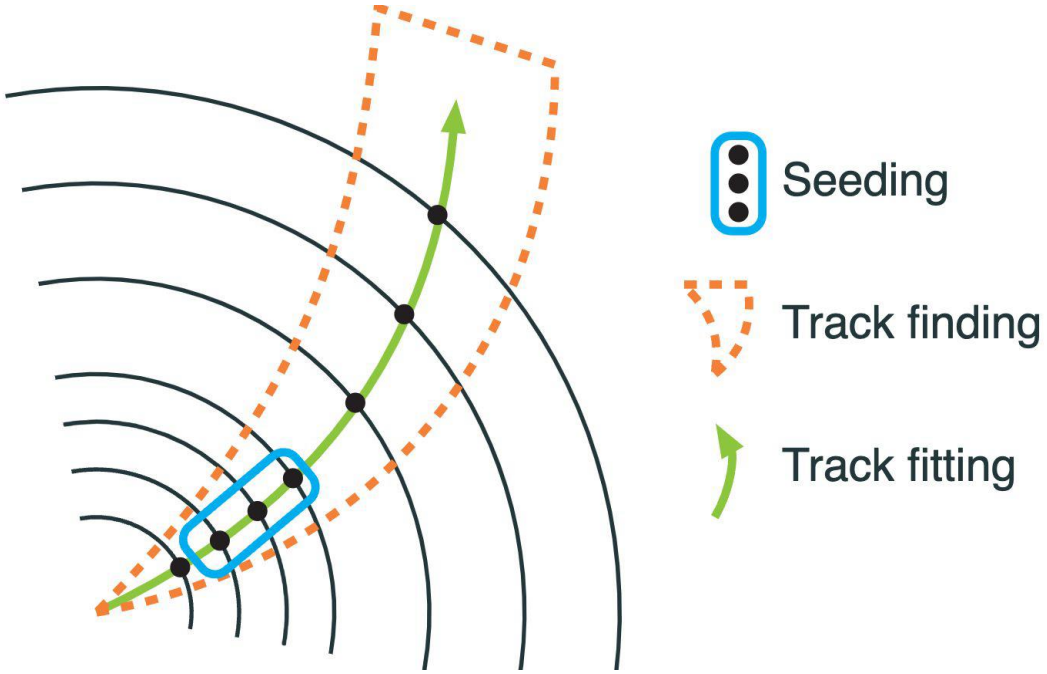
Electron/Hadron Endcaps (EE, HE)
- Five disks on either side of the Interaction Region
- 0.25% X/X0 per layer

MPGDs and **AC-LGADs** provide
- additional hit points for track reconstruction (**<150 μm**, **30 μm**)
- fast timing hits for background rejection (**10-20 ns**, **30 ps**)

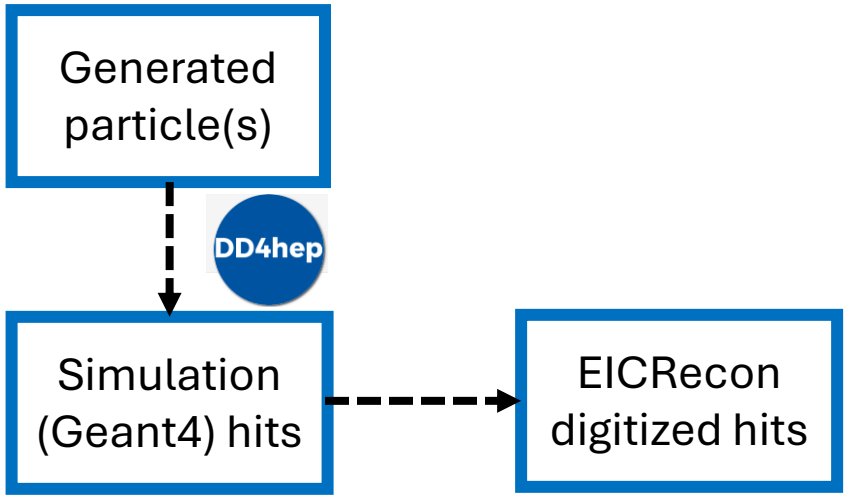
65 nm MAPS technology (ALICE ITS3)
O(20x20 μm^2) pixel size
Total active area of 8.5 m^2

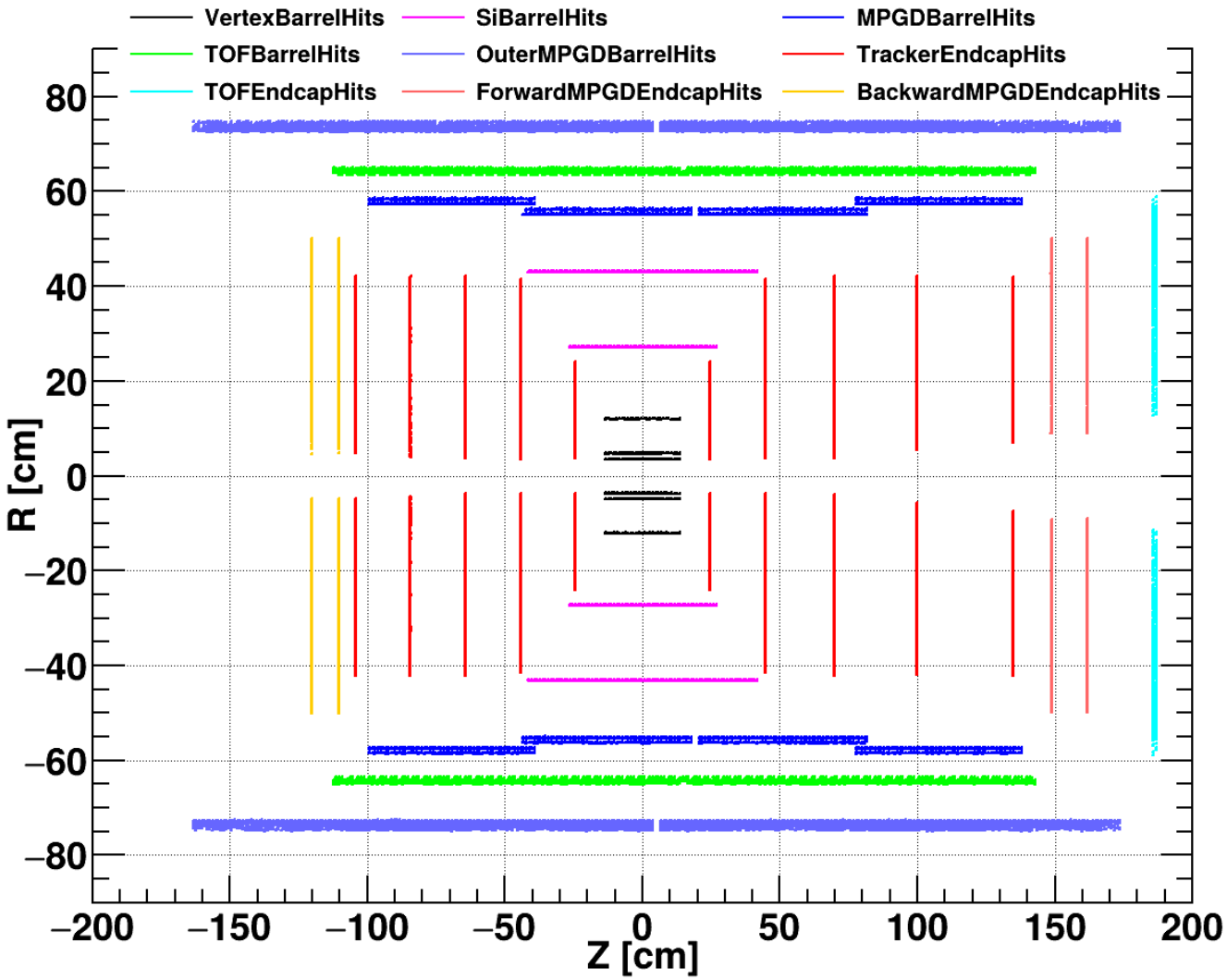
Tracking workflow

- The current track reconstruction scheme first builds seeds (tracklets) in the SVT using a loose set of cuts.
- The track seeds are then projected to the other tracking layers and additional SVT, MPGD, TOF hits are attached.
- The final track parameters are saved at the reconstructed track's point-of-closest approach to the beamline (z-axis) following track smoothing.



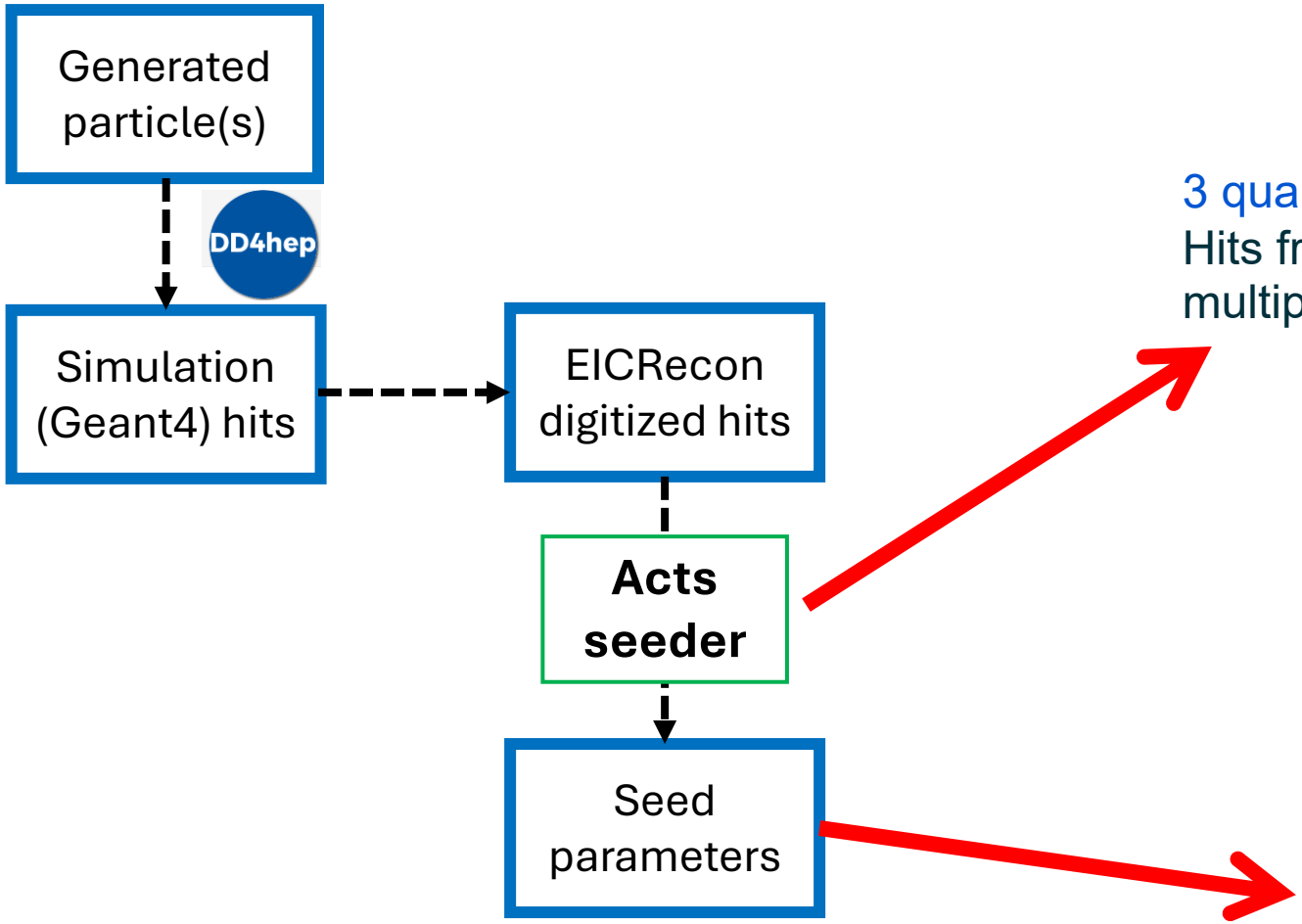
Tracking workflow





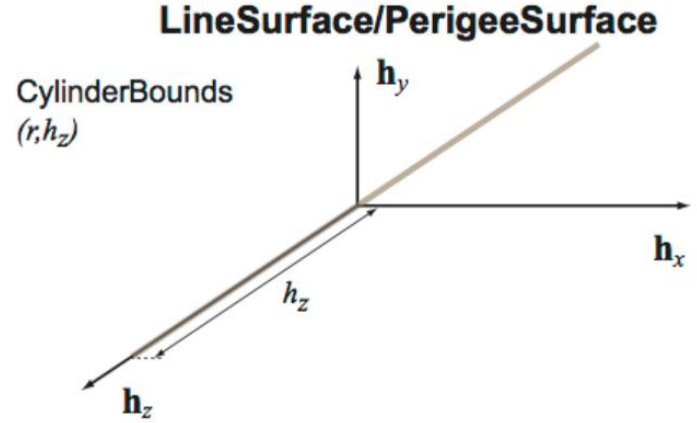
Shyam Kumar

Tracking workflow

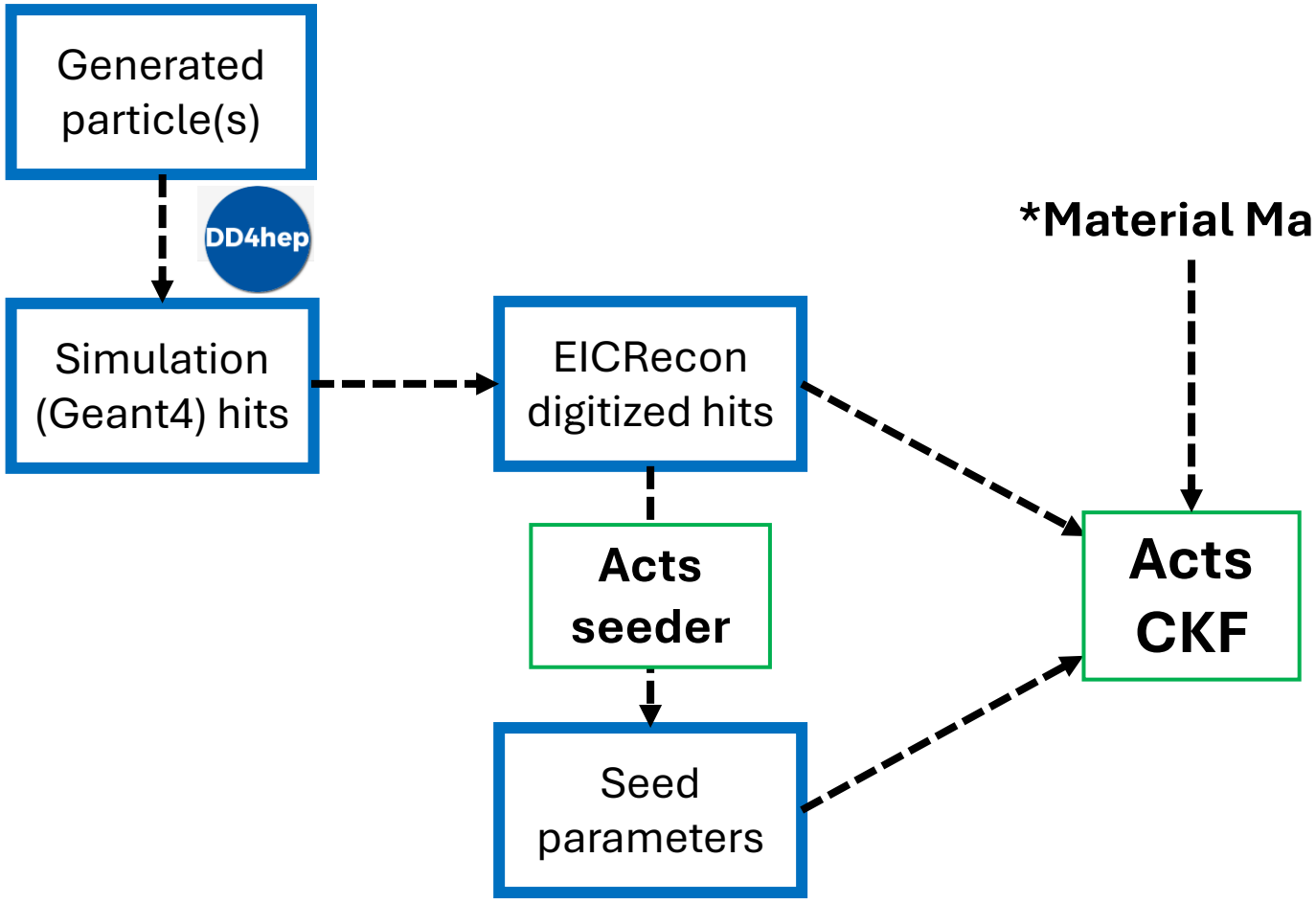


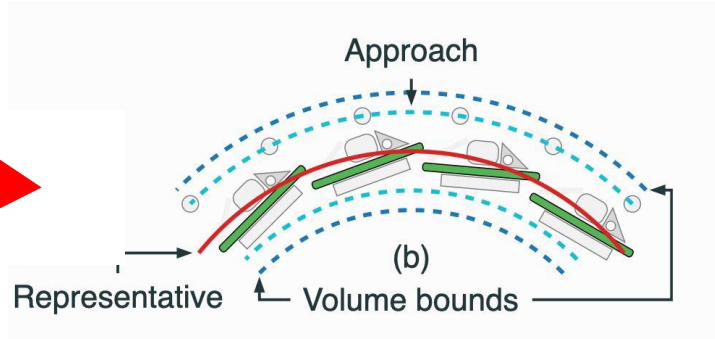
3 qualified hits → 1 track seed → 1 set of initial params
Hits from one particle can construct multiple seeds → multiple identified tracks → need to resolve duplicates.

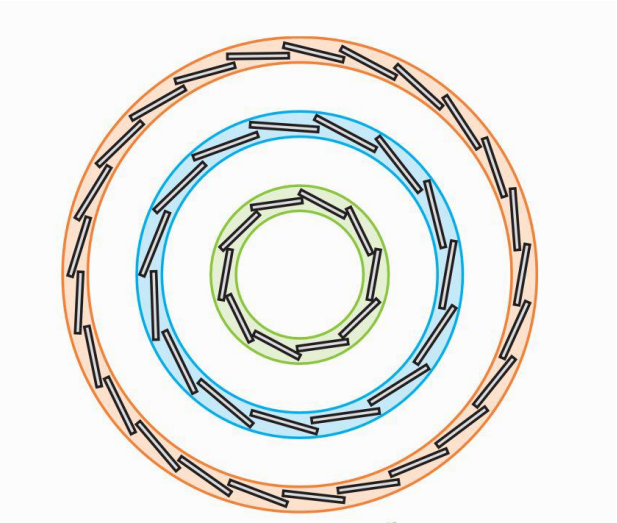
$$\vec{x} = (l_0, l_1, \phi, \theta, q/p, t)^T$$



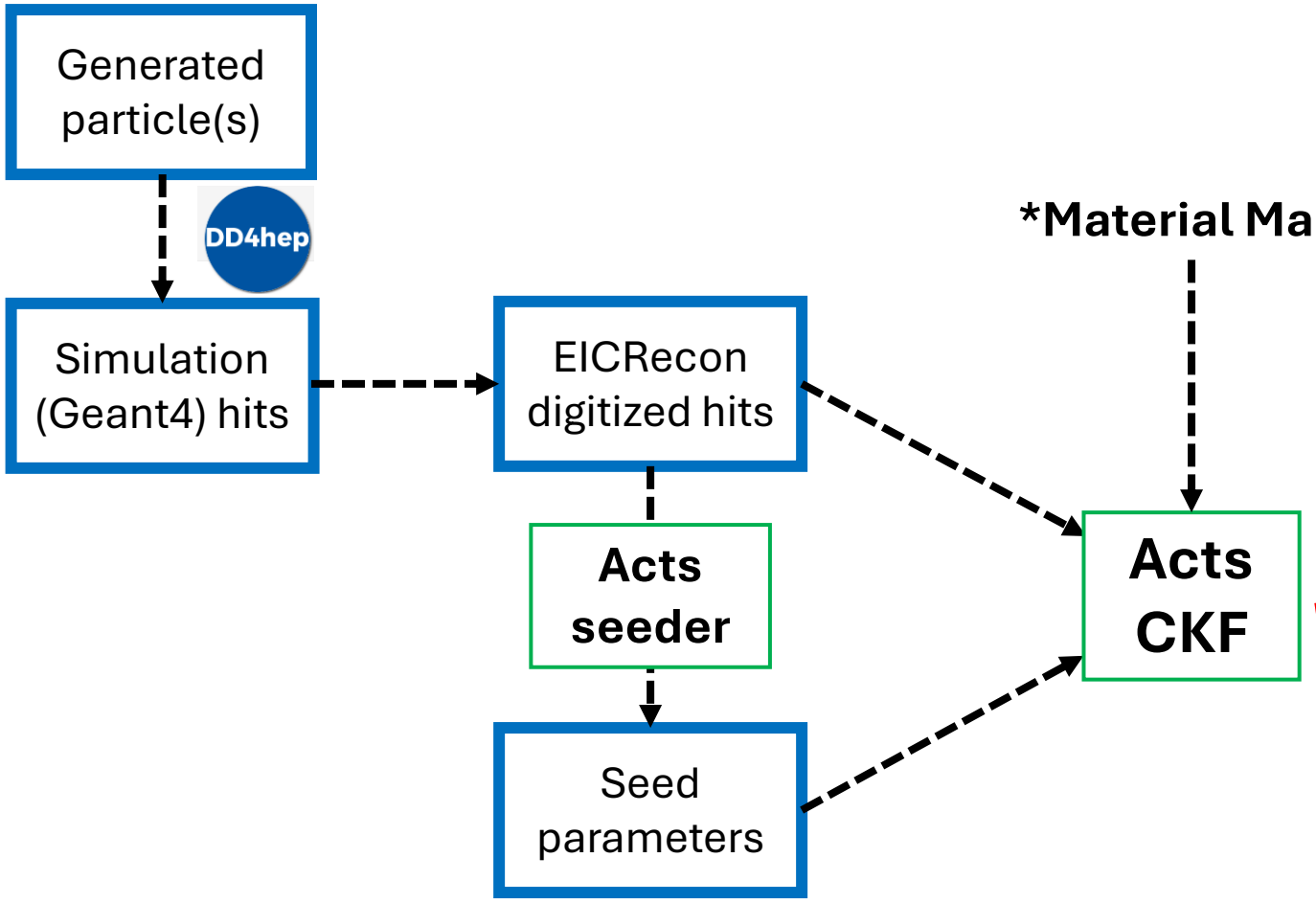
Tracking workflow





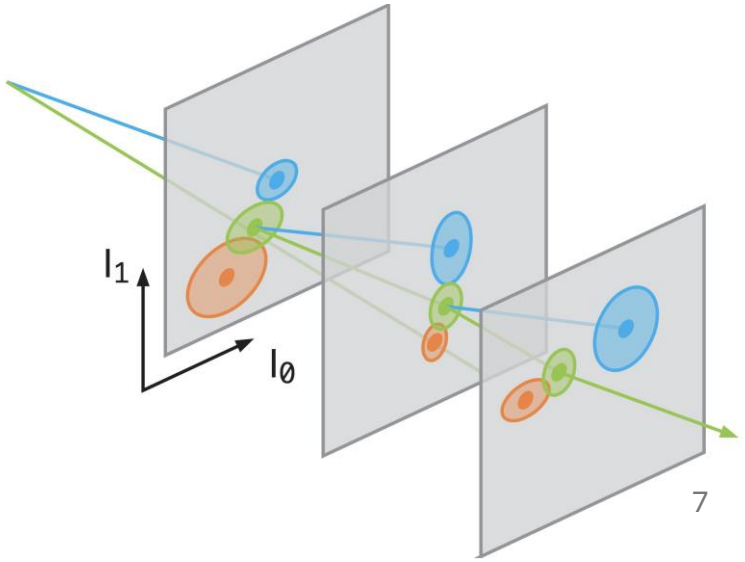


Tracking workflow



Combinatorial Kalman Filter (CKF)

- Initial guess from orthogonal seed finder
- Core tracking algorithm for combined track finding and fitting
- Hits which deviate from projected track will be rejected by chi2 (residual weighted by resolution and material effects) cut
- Demonstrated to handle high multiplicity tracking
- Expect to have 5-8 hits per particle with the current tracker design



Tracking workflow

Generated particle(s)

DD4hep

Simulation (Geant4) hits

EICRecon digitized hits

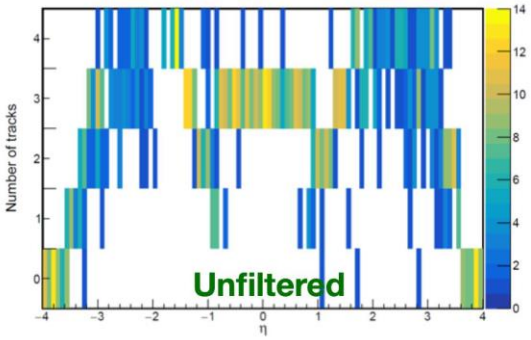
Acts seeder

Seed parameters

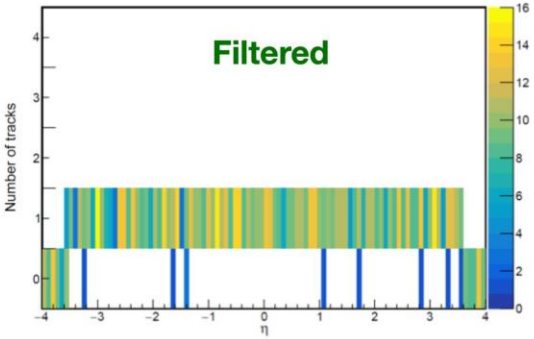
*Material Map

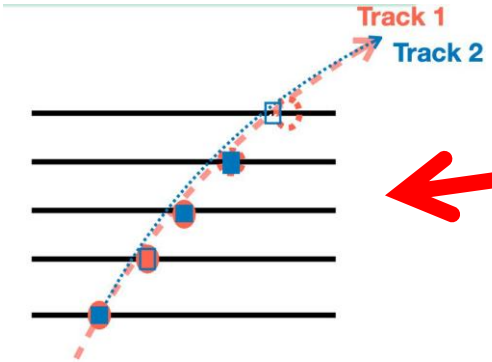
Acts CKF

‘Unfiltered’ reconstructed tracks



# of tracks per particle before/after





Acts ambiguity resolver

Final reconstructed tracks

Tracking performance – single particle events

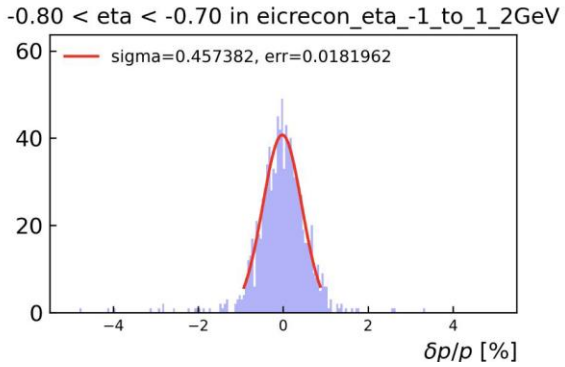
Source events

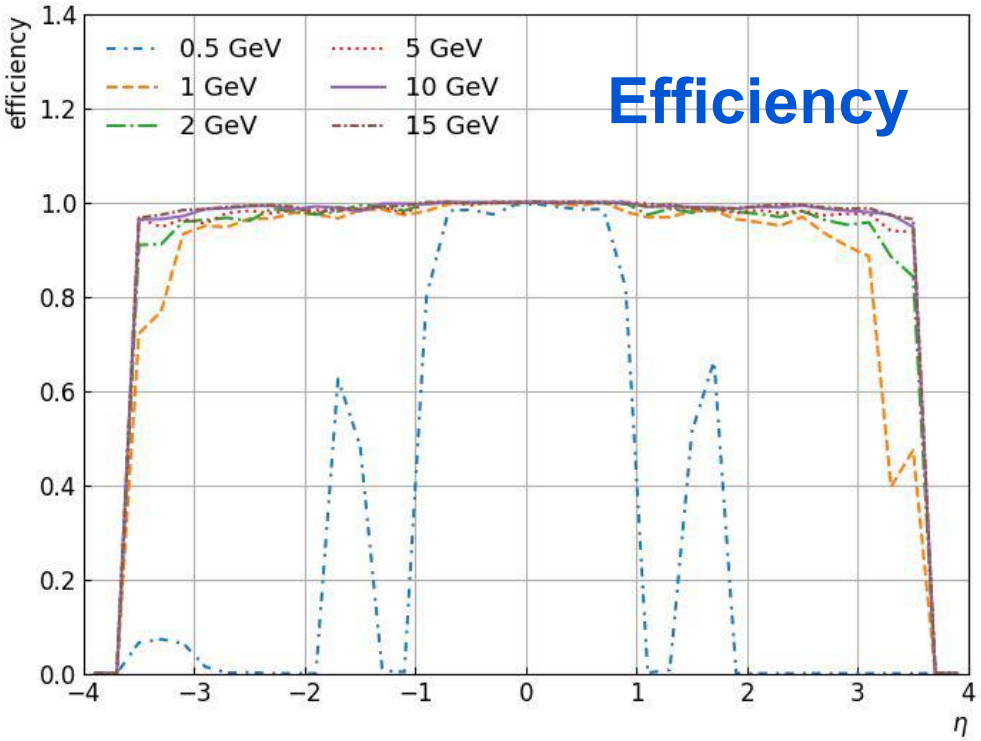
- Single pion+ event at fixed momentum uniformly distributed in polar angle

Observables

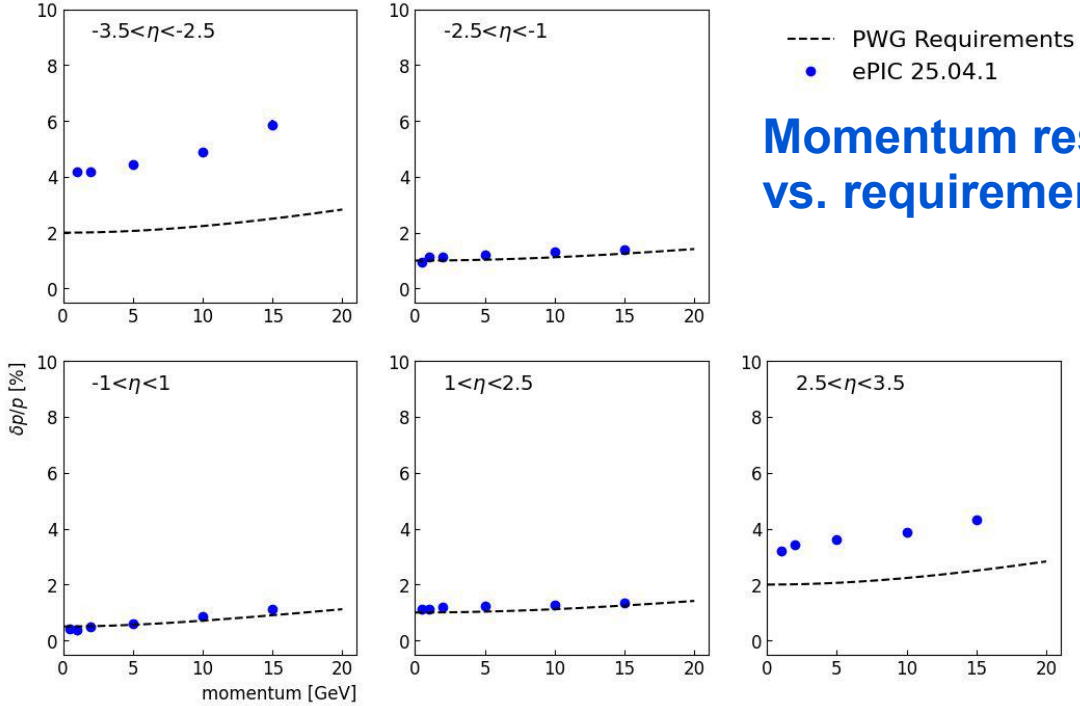
- **Efficiency**: fraction of generated particles with a reconstructed track
- **Resolution**: dp/p, theta, phi, DCAr
- **Pull distributions**: reconstructed resolution compared to reconstructed covariance matrix

dp/p Resolution fit
(recon - initial)/initial





Efficiency



Momentum resolution vs. requirements

Tracking performance – single particle events

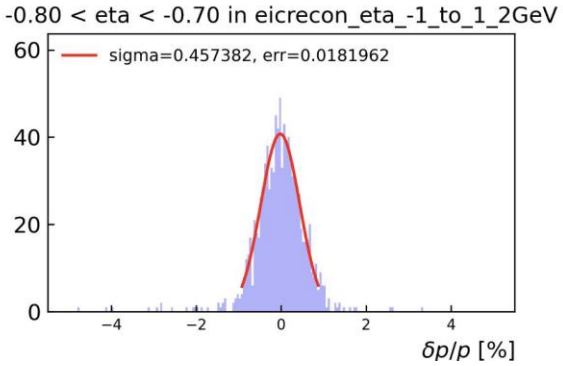
Source events

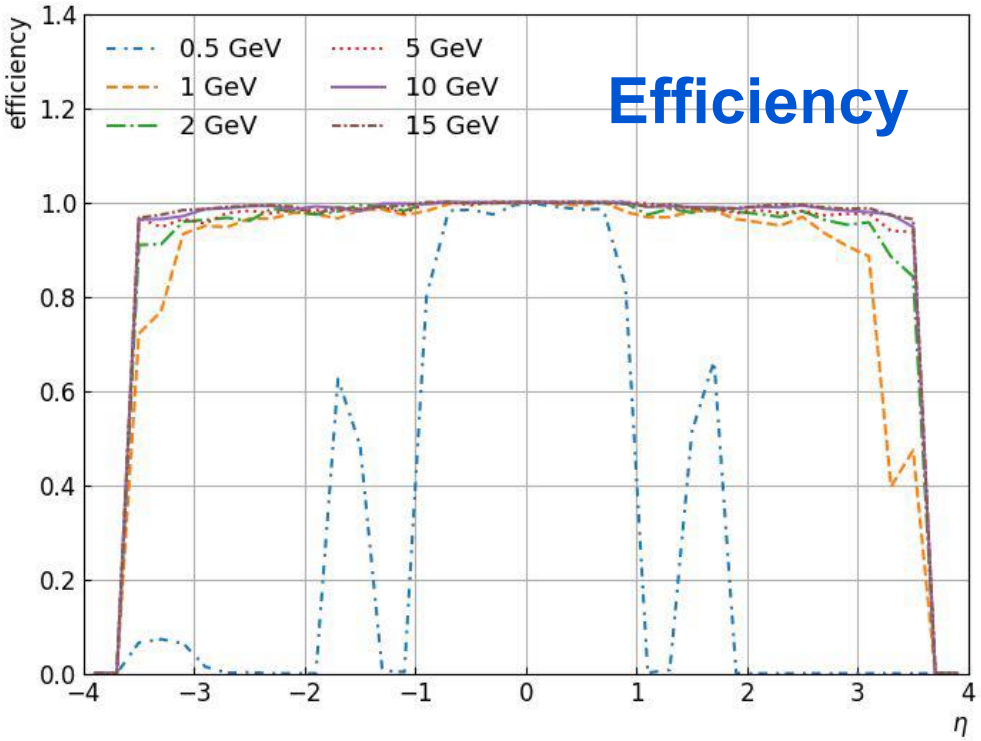
- Single pion+ event at fixed momentum uniformly distributed in polar angle

Observables

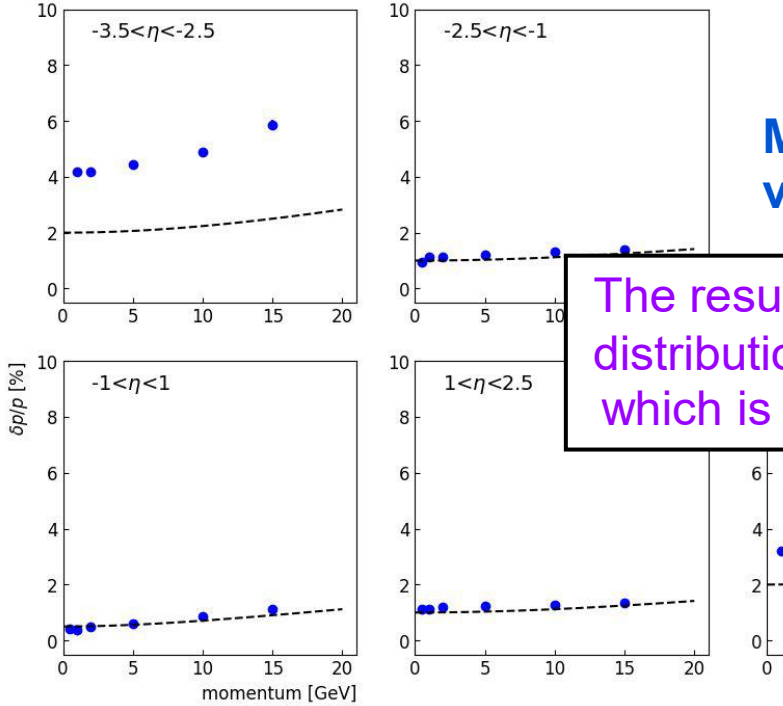
- **Efficiency**: fraction of generated particles with a reconstructed track
- **Resolution**: dp/p, theta, phi, DCAr
- **Pull distributions**: reconstructed resolution compared to reconstructed covariance matrix

dp/p Resolution fit
(recon - initial)/initial





Efficiency



PWG Requirements
ePIC 25.04.1

Momentum resolution vs. requirements

The results depend on the input distribution within the wide bins, which is flat in polar angle here

Tracking performance – single particle events

Source events

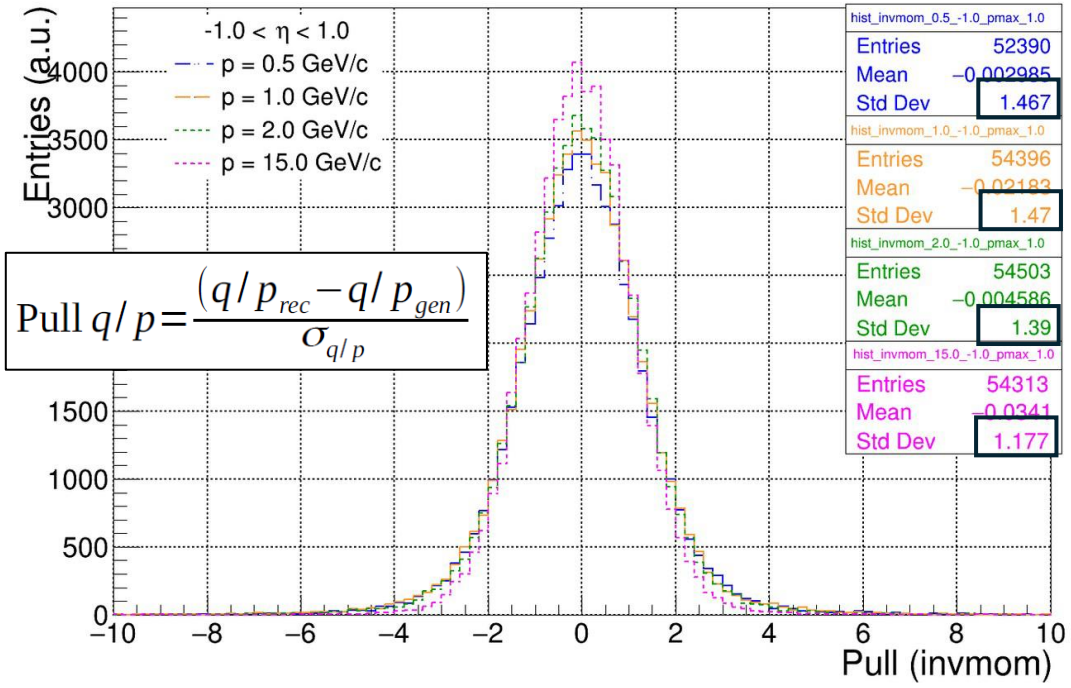
- Single pion+ event at fixed momentum uniformly distributed in polar angle

Observables

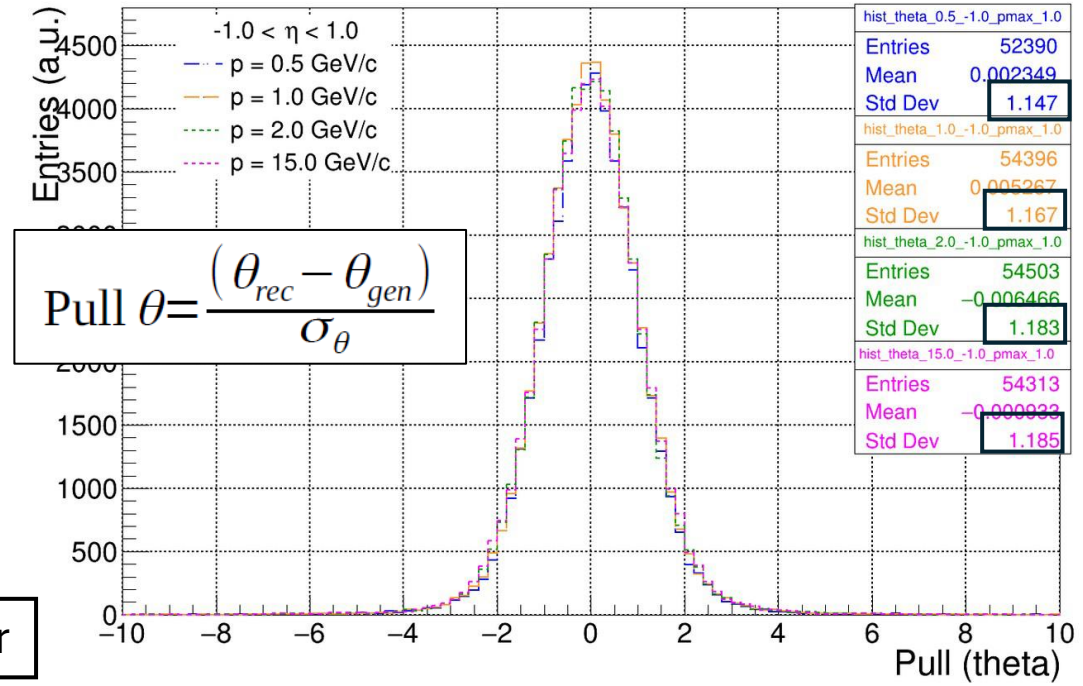
- **Efficiency**: fraction of generated particles with a reconstructed track
- **Resolution**: dp/p, theta, phi, DCAr
- **Pull distributions**: reconstructed resolution compared to reconstructed covariance matrix

Pull distributions vary between 1.1 and 1.5

Pull distributions



Shyam Kumar



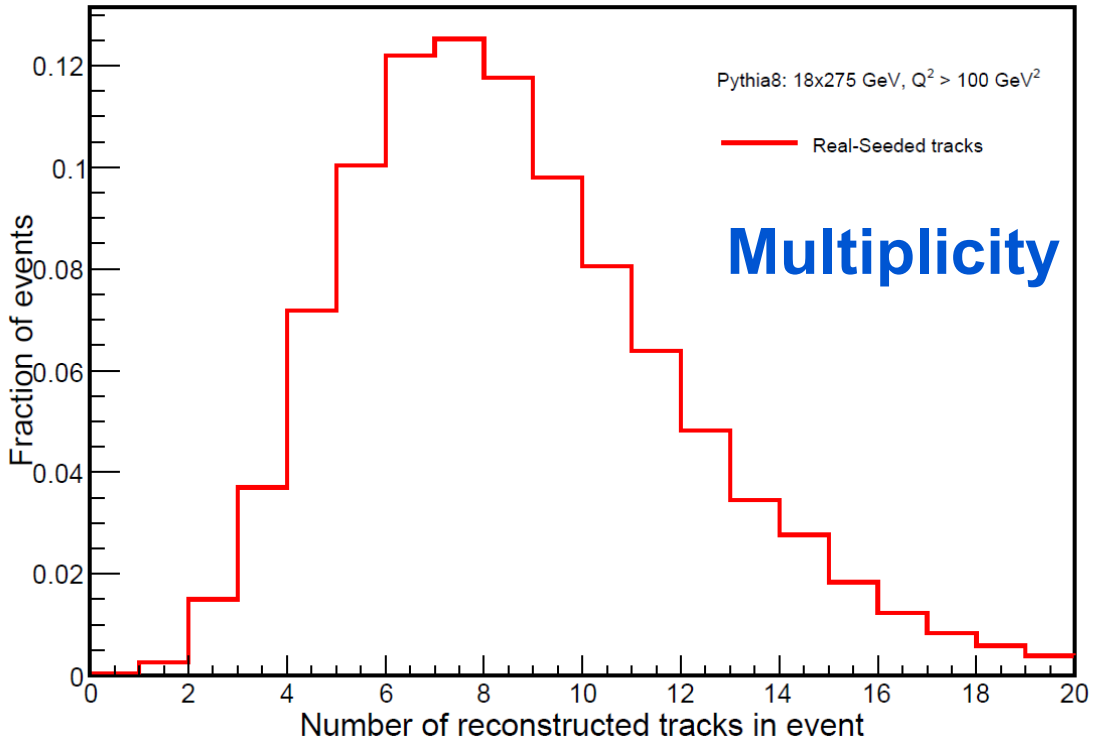
Tracking performance – DIS signal events

Source events

- DIS events simulated with a minimum Q^2 threshold and beam-smearing effects applied

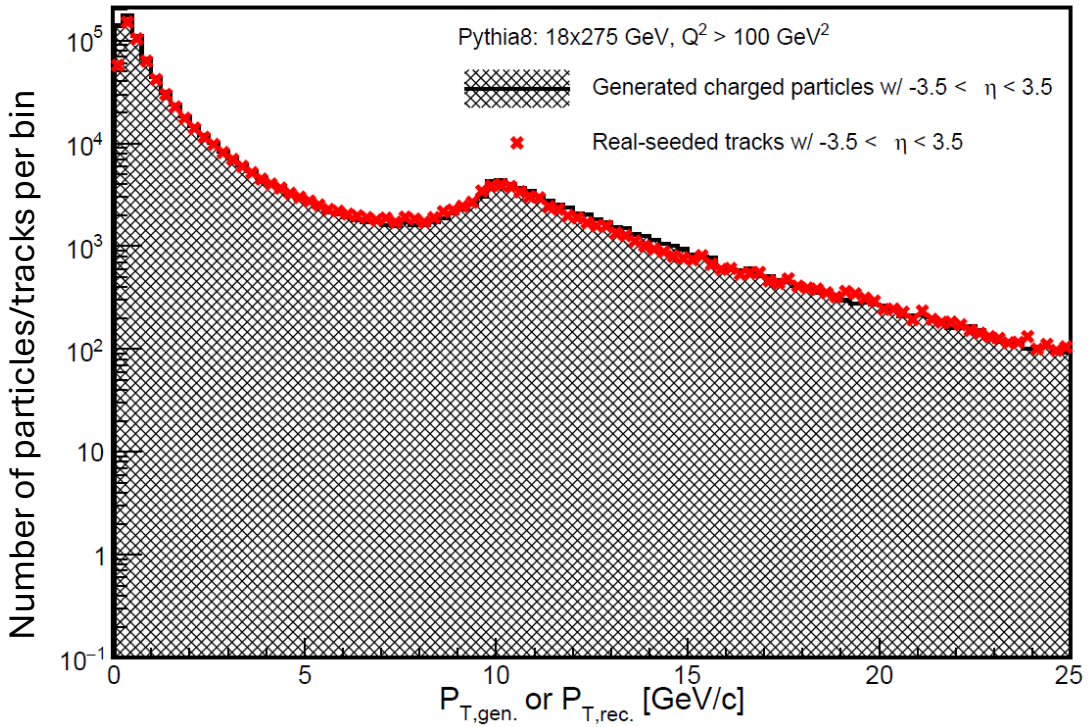
Observables

- **Track multiplicity**: number of reconstructed tracks per event
- **Track spectra**: reconstructed eta distribution for tracks
- **Efficiency**: fraction of generated particles with a reconstructed matched track
- **Purity**: fraction of hits used in a track fit associated with a given generated particle



ePIC 25.05.0

Reconstructed P_t distribution



Tracking performance – DIS signal events

Source events

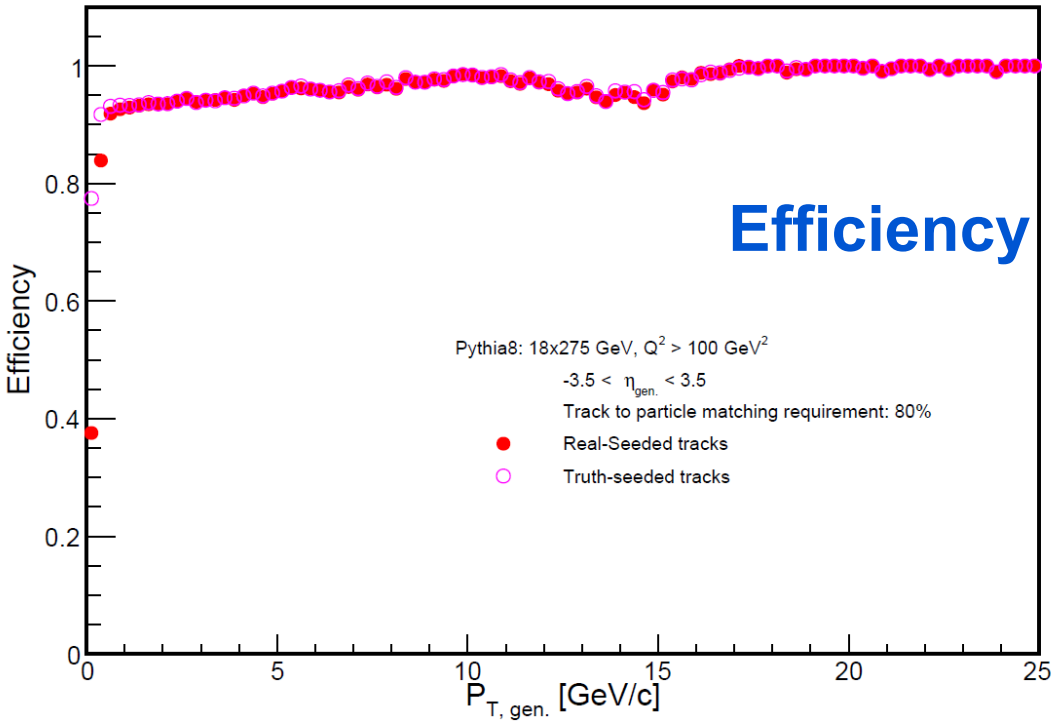
- DIS events simulated with a minimum Q^2 threshold and beam-smearing effects applied

Observables

- **Track multiplicity**: number of reconstructed tracks per event
- **Track spectra**: reconstructed eta distribution for tracks
- **Efficiency**: fraction of generated particles with a reconstructed matched track
- **Purity**: fraction of hits used in a track fit associated with a given generated particle

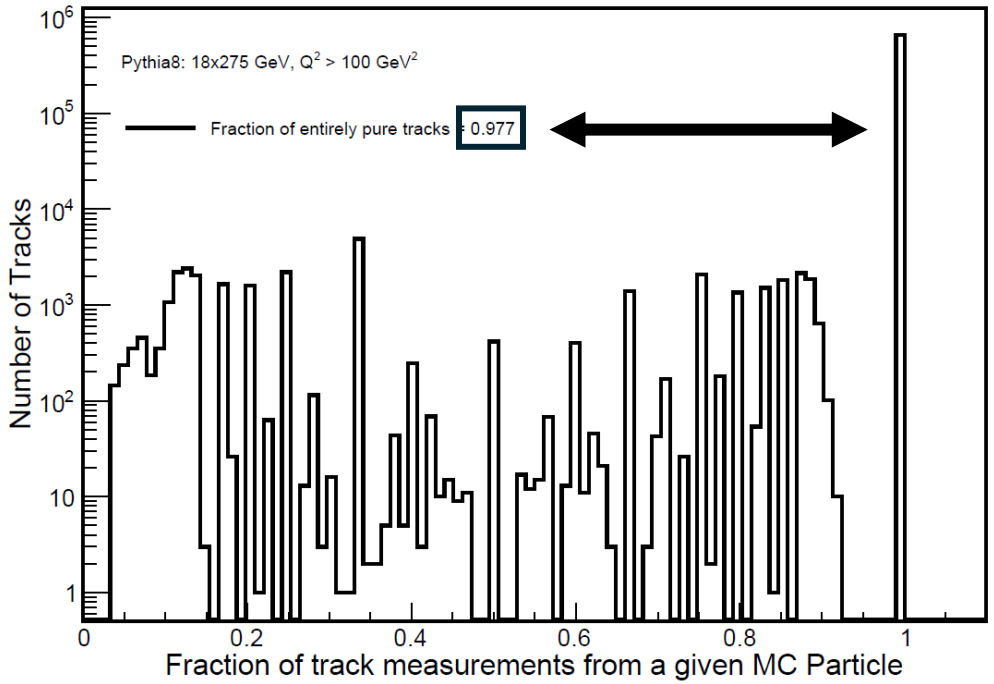
Tracks w/ 100% purity should have resolution performance as found in single-particle studies

Efficiency



Purity

Real-seeded tracks



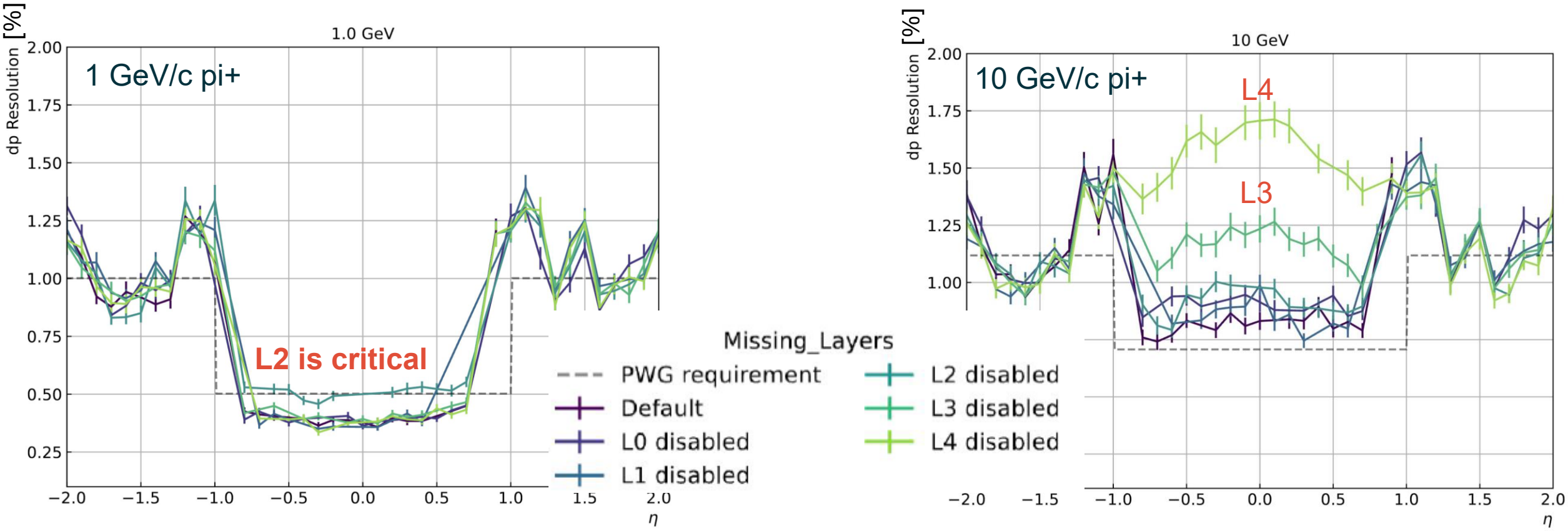
ePIC 25.05.0

Ongoing and future efforts

- Necessity and sufficiency of tracking layout
  - As has been shown, every SVT layer has a clear purpose
  - Need to demonstrate the optimal configuration of the outer tracker of MGPDs and TOF
- Tracking performance in the presence of beam-induced backgrounds and noise
  - Initial studies have been done on the impacts of beam-induced backgrounds
  - Ongoing effort to embed noise hits into the simulation
  - Plan to revisit seeding volume and CKF parameters when realistic background and noise are fully incorporated into the simulations

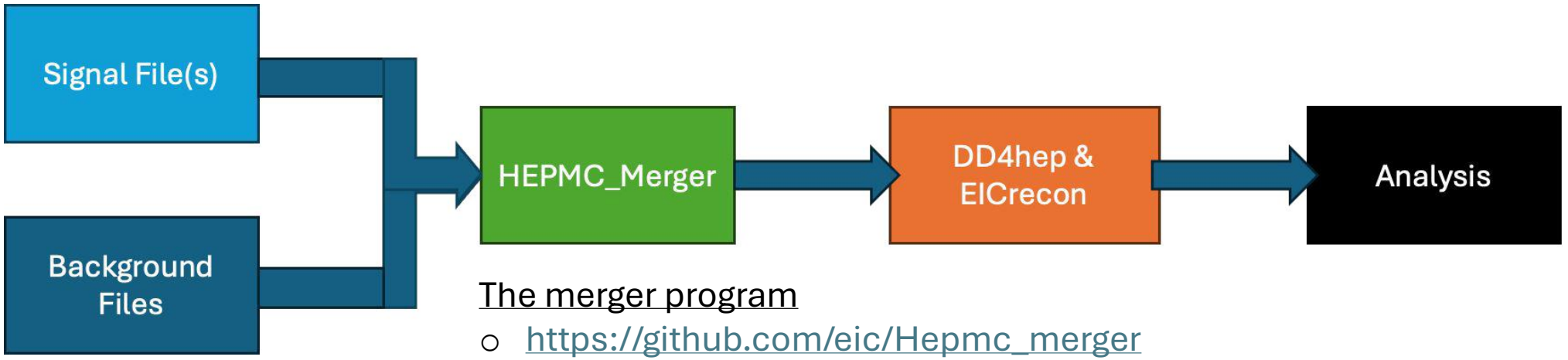
Tracking layer impact study

Motivation: study impact of a given tracking layer
Simulation setting: exclude hits from a given layer when doing track reconstruction while keeping the geometry and materials in the DD4hep simulation
Example study: momentum resolution with a disabled **SVT Barrel layer** (L0 to L4)



Track reconstruction with realistic beam-induced backgrounds

Motivation: study how well our device and track finding and fitting perform in the presence of backgrounds
Simulation setting: DIS (forced) + background merged events



The merger program
- https://github.com/eic/Hepmc_merger
- sample each source file according to their frequency
- within a fixed-length (2us) time window label each source particle with custom generator code

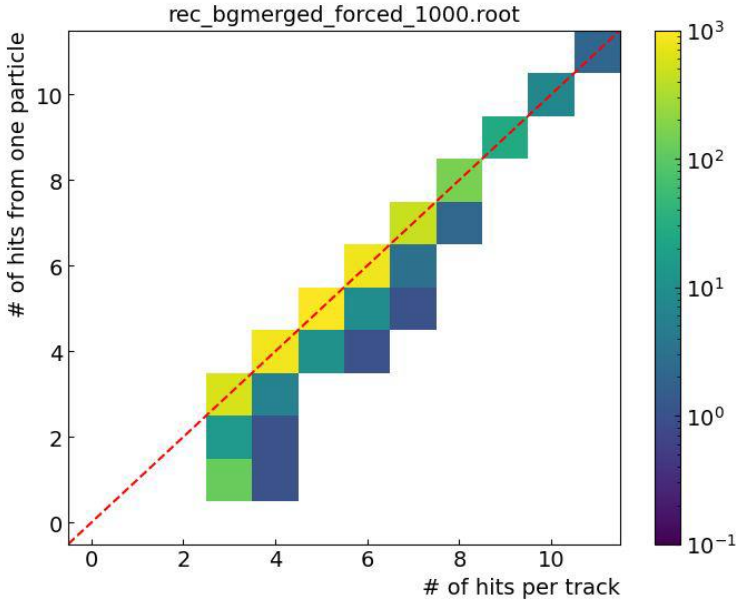
One event = one collision **merged** → one 2us time slice contains (in simulation setting shown here)

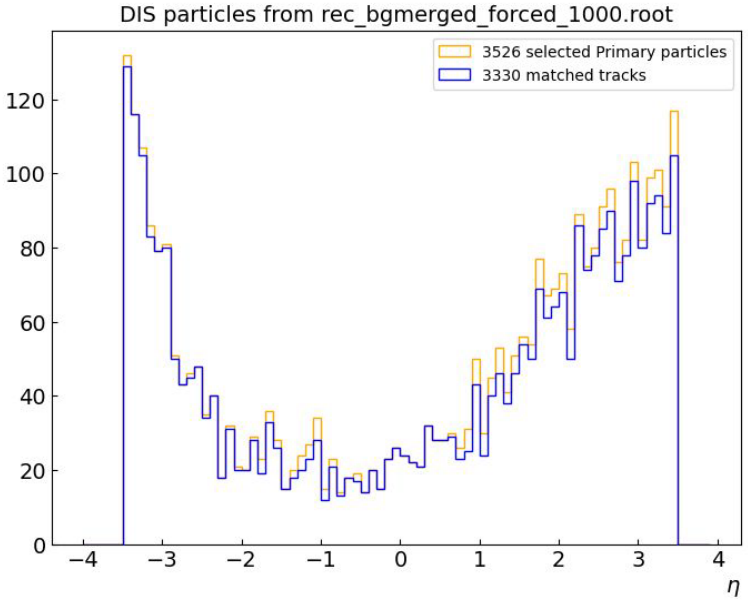
- One 18x275 NC DIS event with $Q^2 > 1$ GeV$^2/c^2$. (This is NOT the highest lumi configuration)
- Beam background at calculated frequency – SR, electron Bremsstrahlung, Coulomb, Touschek, proton beam gas.

Preliminary results: Purity and Efficiency for DIS (forced) + background sample

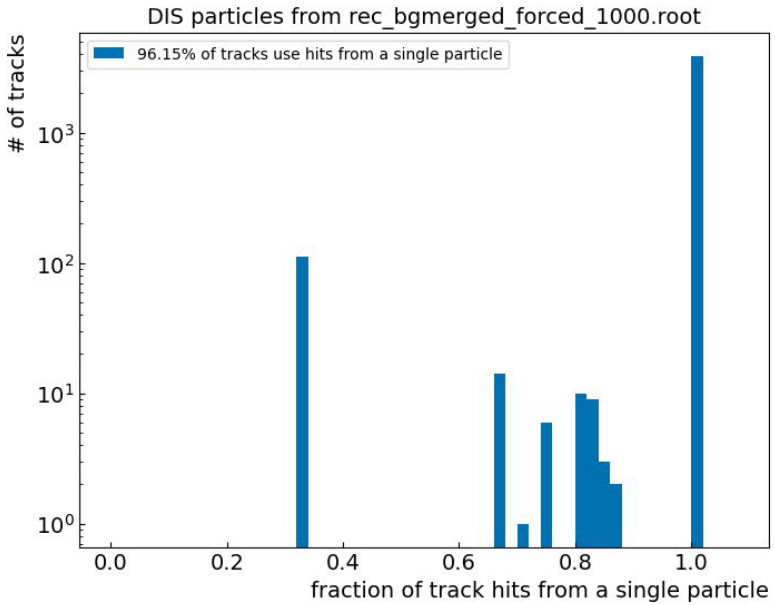
18x275

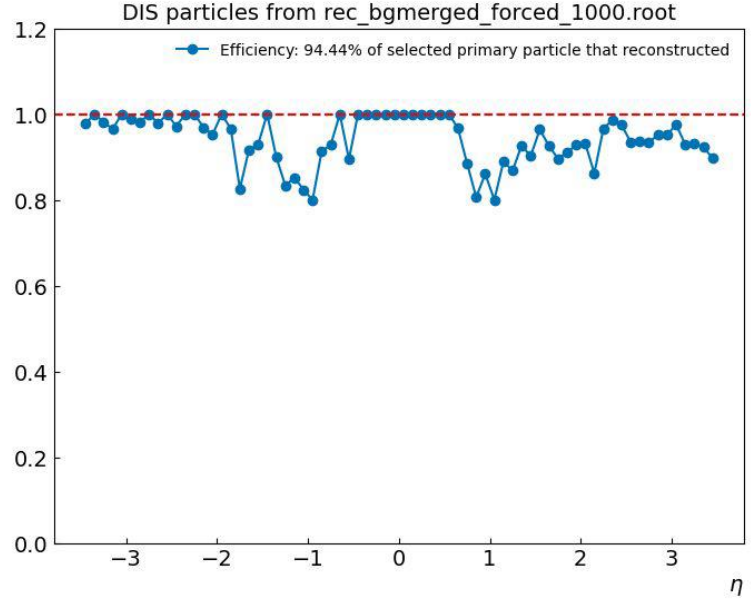
No detector noise included yet





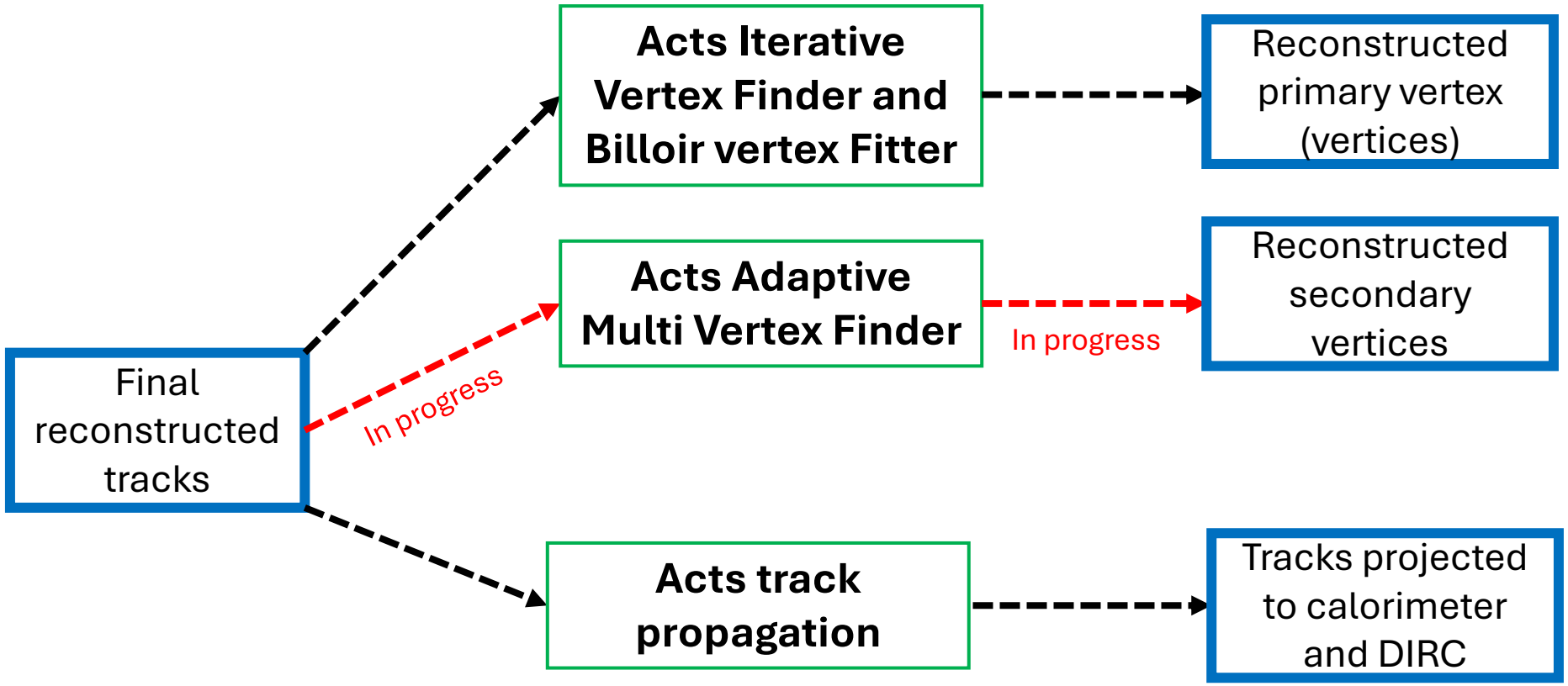
Very good purity except for tracks with less than 5 hits





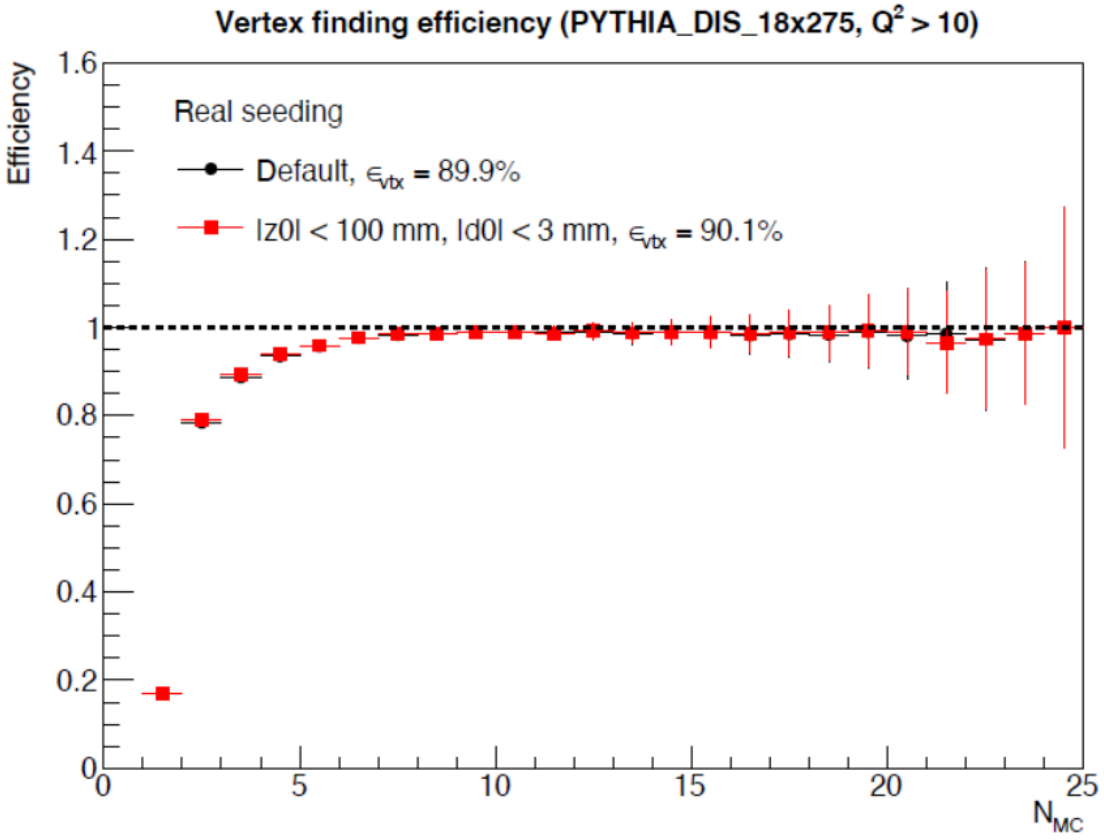
Excellent efficiency for electrons. Inefficiency dominated by low-momentum pions.

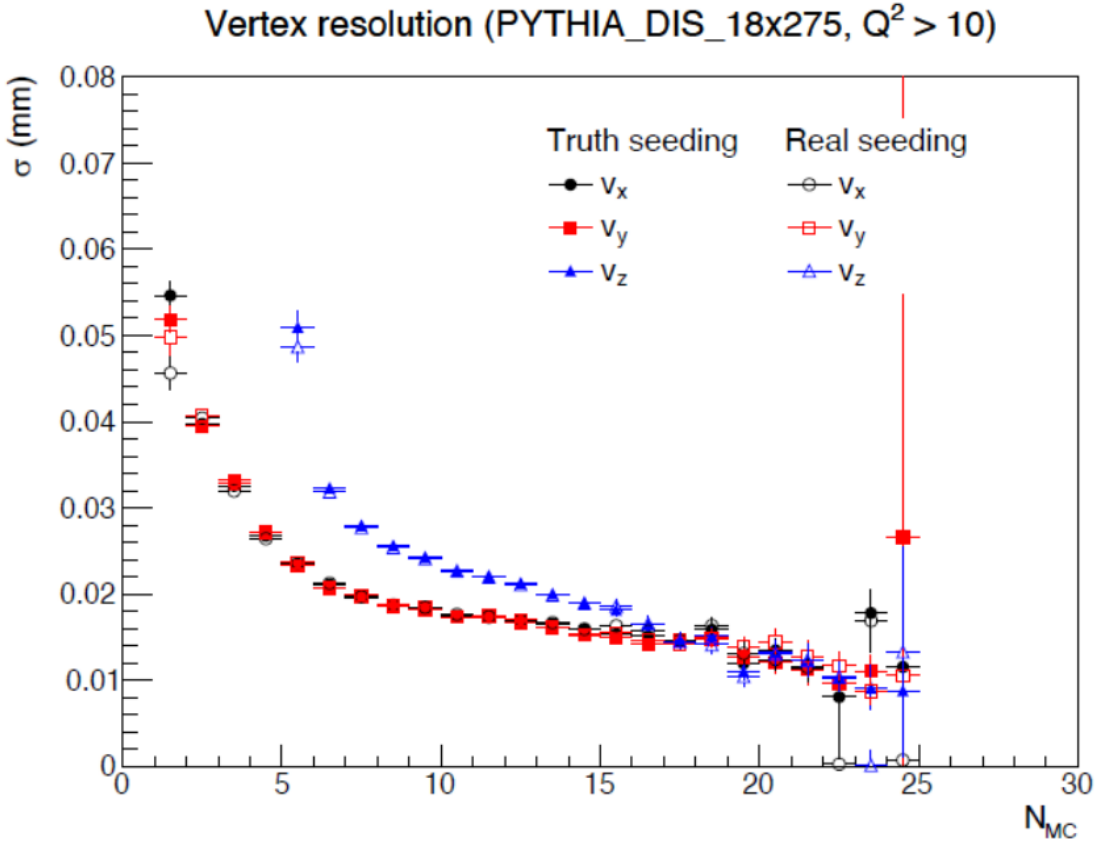
Vertexing and track projections workflow



Primary vertex reconstruction performance

Xin Dong
Rongrong Ma
Khushi Singla





N_{MC}: number of MC charged particles originating from collision vertex within |eta| < 3.5
Efficiency: fraction of event with at least one reconstructed vertex

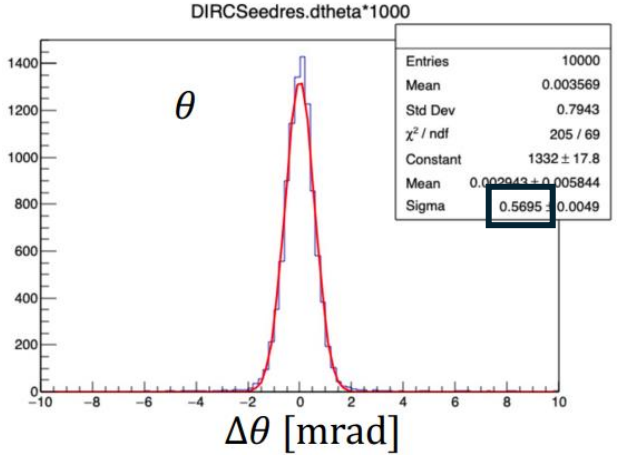
Track projections to the DIRC

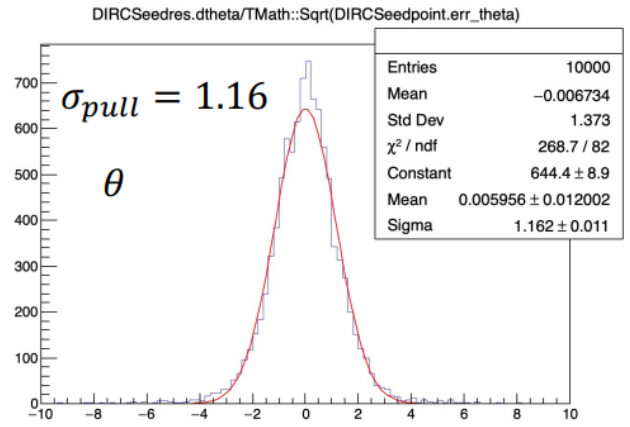
Roman Dzhygadlo
Matt Posik

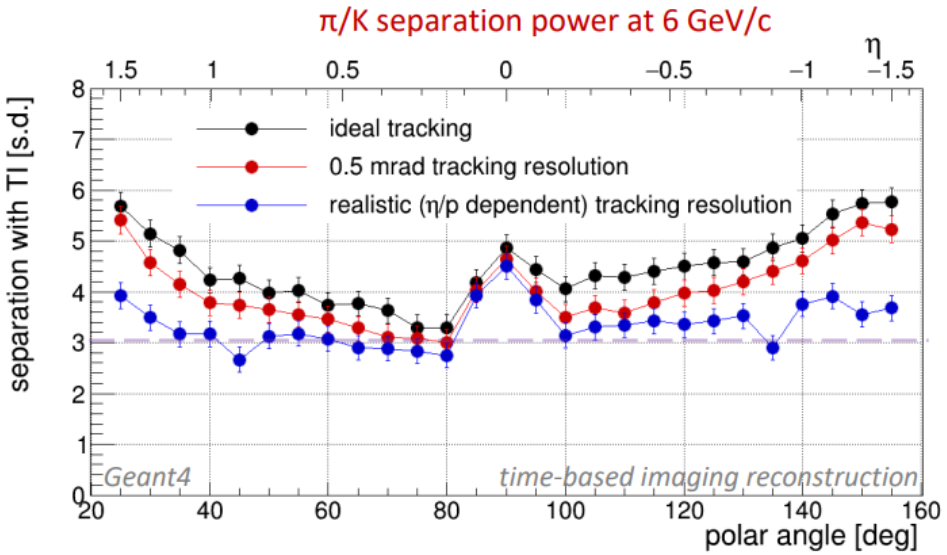
Several ongoing efforts

- Studying the effect of adjusting the material budgets near the BTOF and outer barrel MPGD layer on the track projection resolution at the DIRC
- Quantifying the impact of using BIC measurements on the track projection resolution at the DIRC
- Understanding better how material effects are incorporated into the track projection uncertainty estimation

6 GeV/c pi-

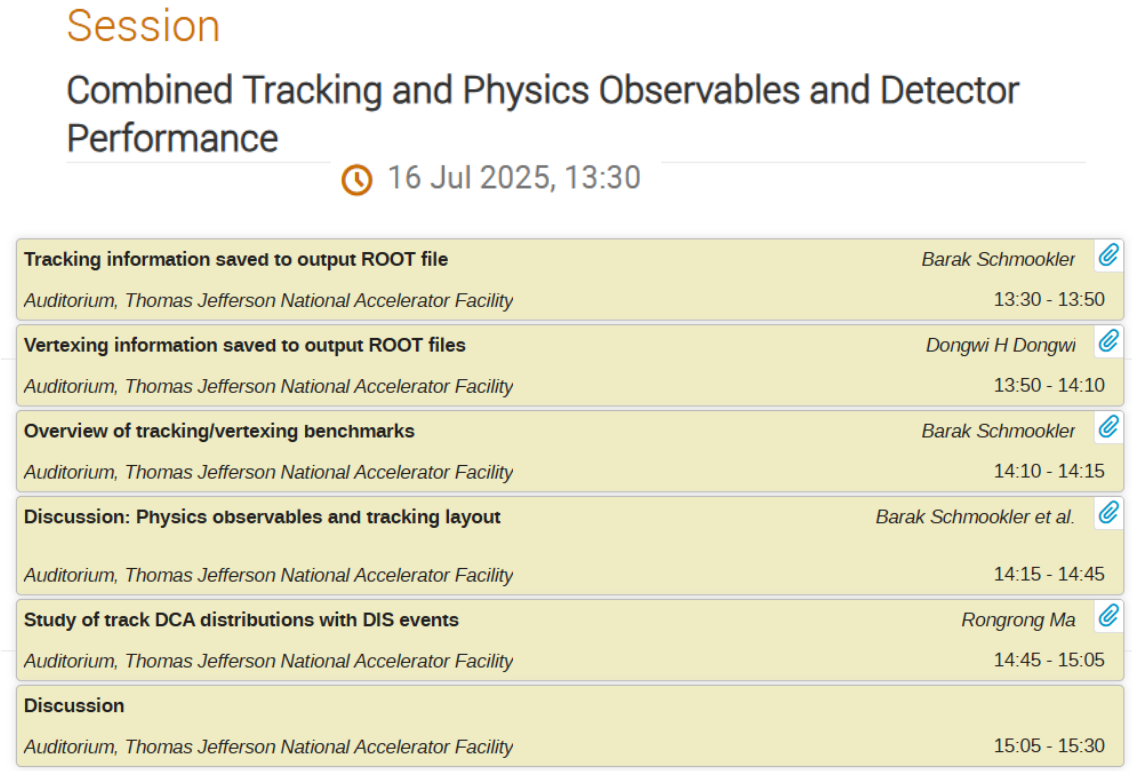






Communication with Physics Working Groups (PWGs)

- Productive joint session between the Tracking WG and the PWGs on Wednesday afternoon.
- We determined a few action items:
  - PWGs will put tracking requirements in wide bins in QCD science context; this requires, for example, the combination with e.m. calorimetry in the case of the scattered electron in small-x collisions.
  - Tracking WG will develop baseline track-quality selections.
  - The PWGs and the Tracking WG will work together to determine the best set of physics observables to demonstrate the capabilities and sufficiency of the tracking layout



Summary

- We have developed a mature framework for track reconstruction and primary vertexing.
- The Tracking WG has demonstrated the performance of the current tracking layout for single-particle and DIS signal events.
  - We plan to revise the tracking section of the pTDR by the end of the month to reflect the current status.
- Our ongoing efforts are focused on
  1. Demonstrating the sufficiency and necessity of the current tracking layout
  2. Studying the tracking performance under realistic running conditions
  3. Performing a systematic study of track projection resolutions
- Following the joint session, the Tracking WG and the PWGs will coordinate on completing several tasks.