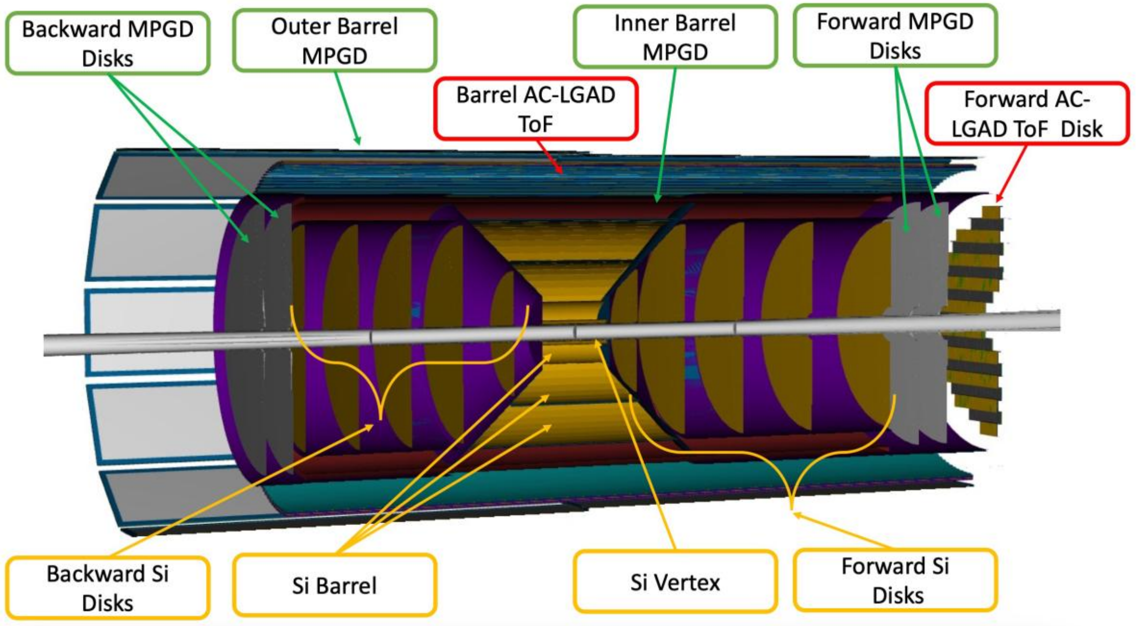
ePIC Tracking and Vertexing

Barak Schmookler

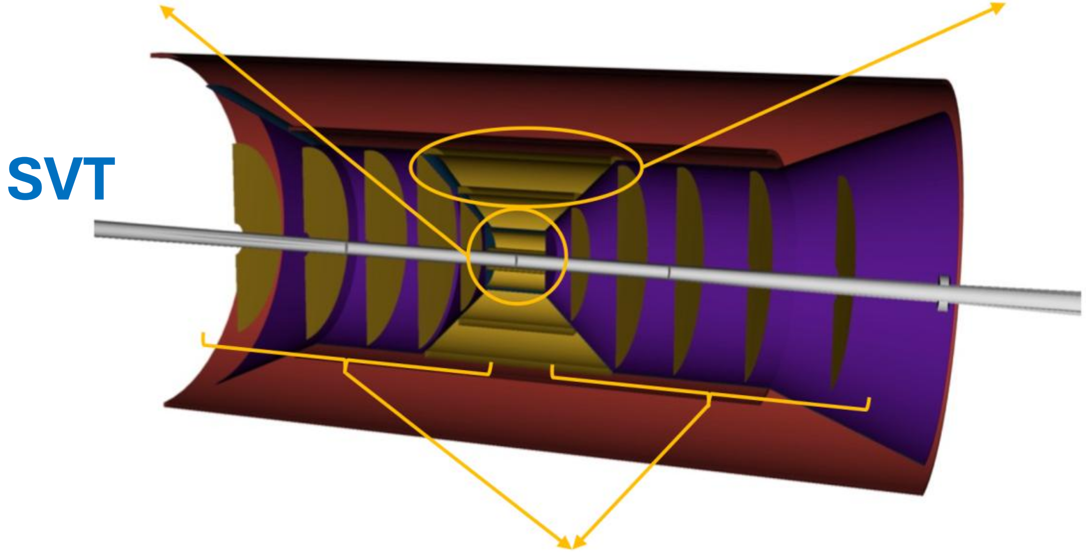
Central Tracker

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



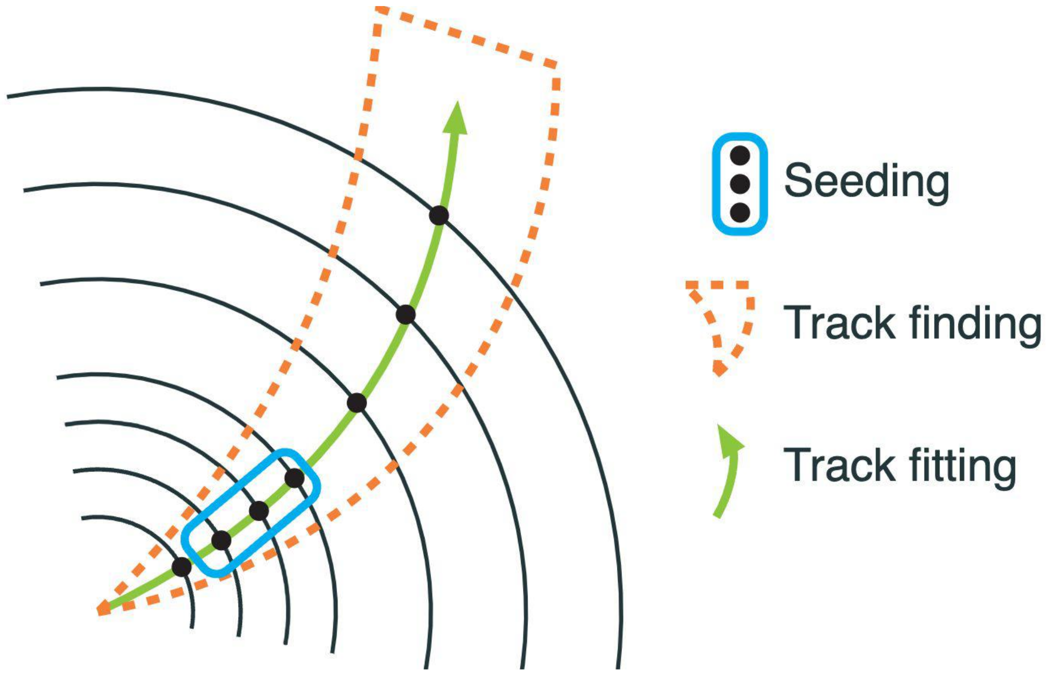
Electron/Hadron Endcaps (EE, HE)
- Five disks on either side of the Interaction Region
- 0.25% X/X0 per layer

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

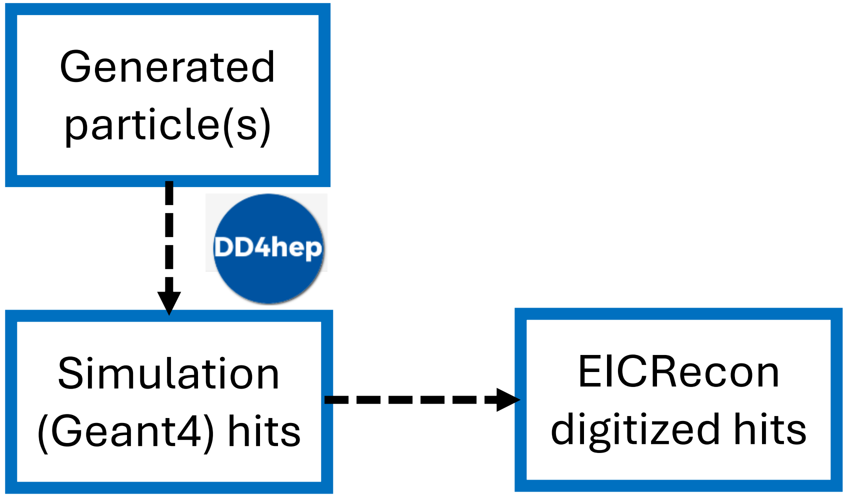
MPGDs and AC-LGADs provide
- additional hit points for track reconstruction (<150 μm, 30 μm)
- fast timing hits for background rejection (10-20 ns, 30 ps)

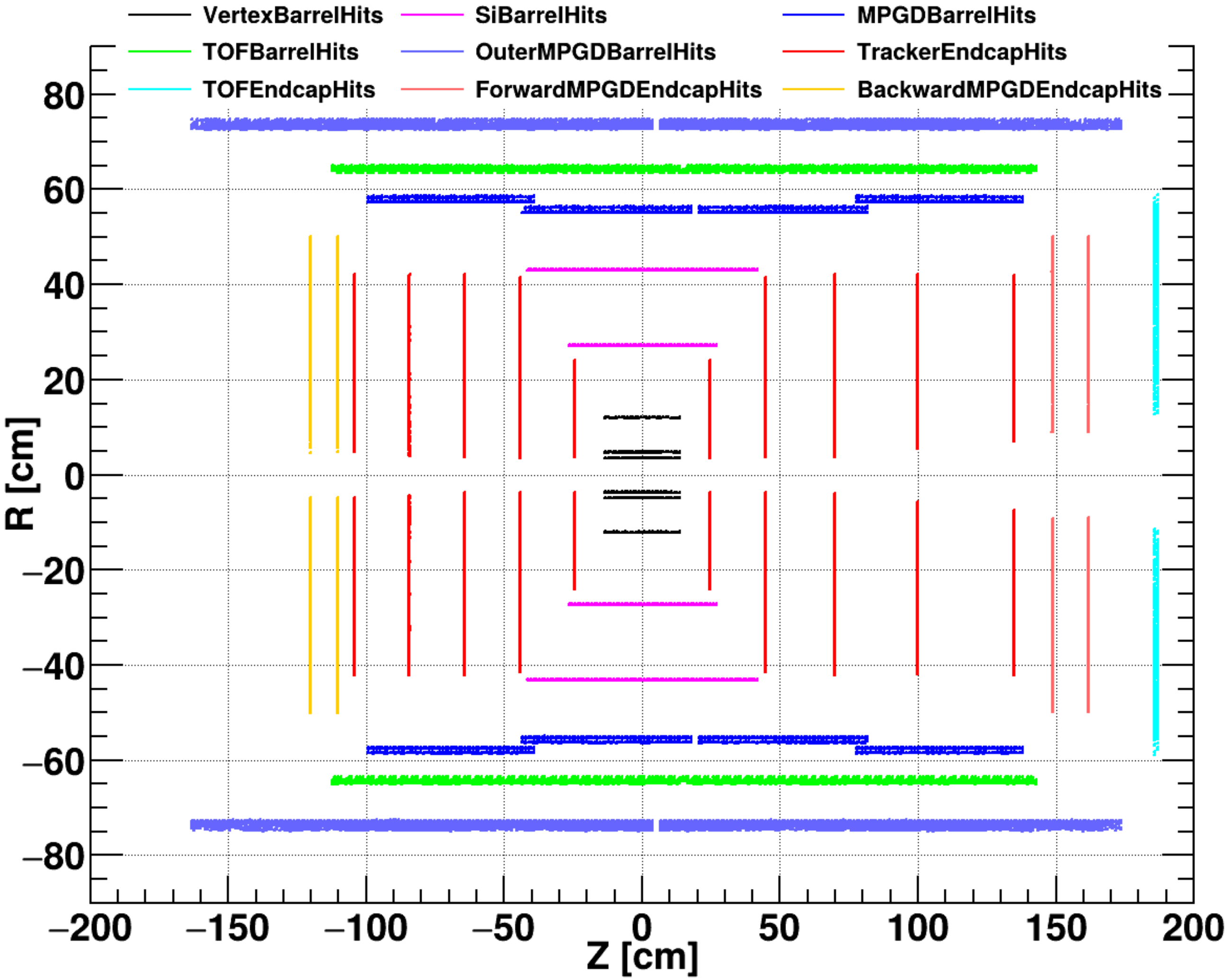
Tracking workflow

- 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.

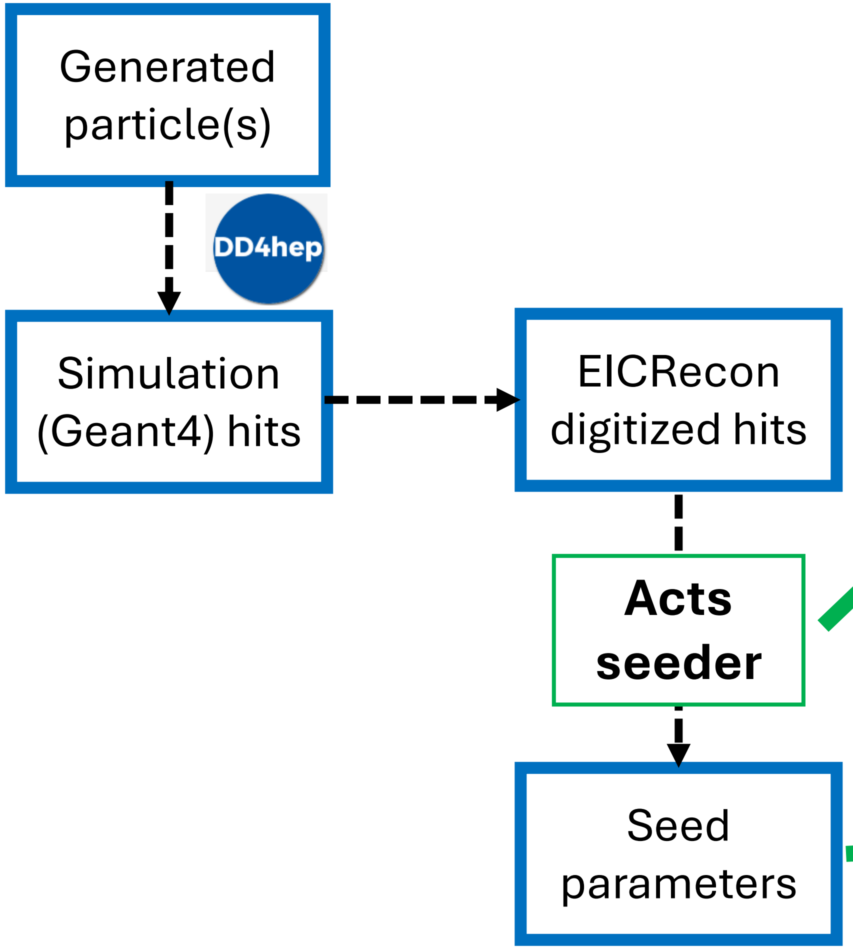


Tracking workflow



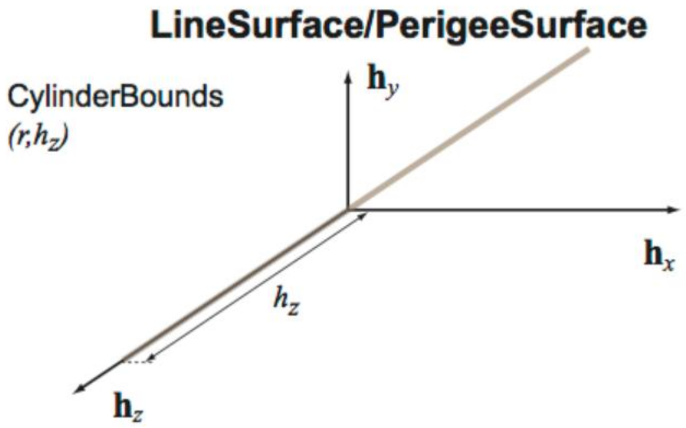


Tracking workflow



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

Generated particle(s)

DD4hep

Simulation (Geant4) hits

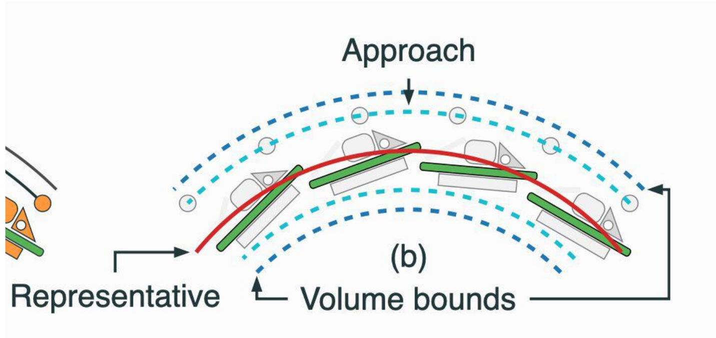
EICRecon digitized hits

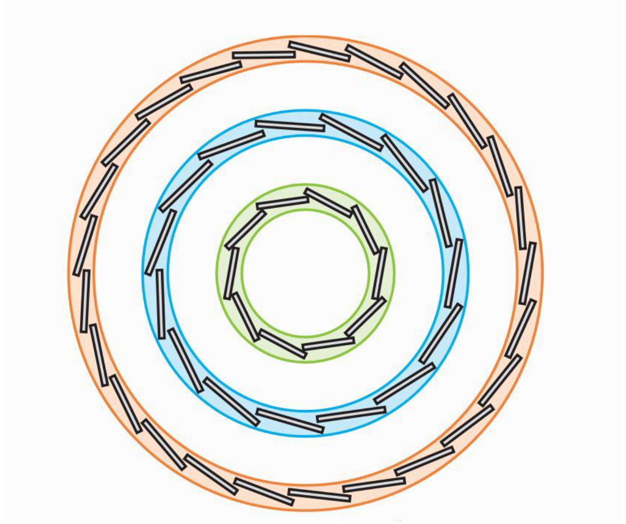
Acts seeder

Seed parameters

***Material Map**

Acts CKF





Tracking workflow

Generated particle(s)

DD4hep

Simulation (Geant4) hits

EICRecon digitized hits

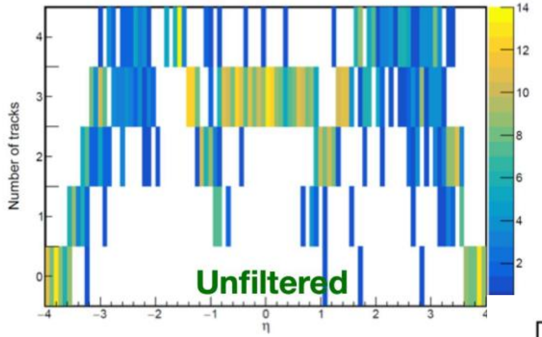
Acts seeder

Seed parameters

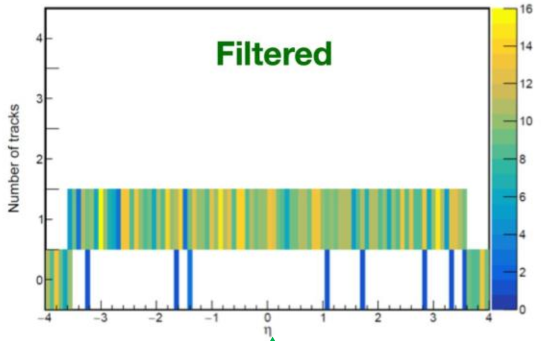
*Material Map

Acts CKF

'Unfiltered' reconstructed tracks



# of tracks per particle before/after



Acts ambiguity resolver

Final reconstructed tracks

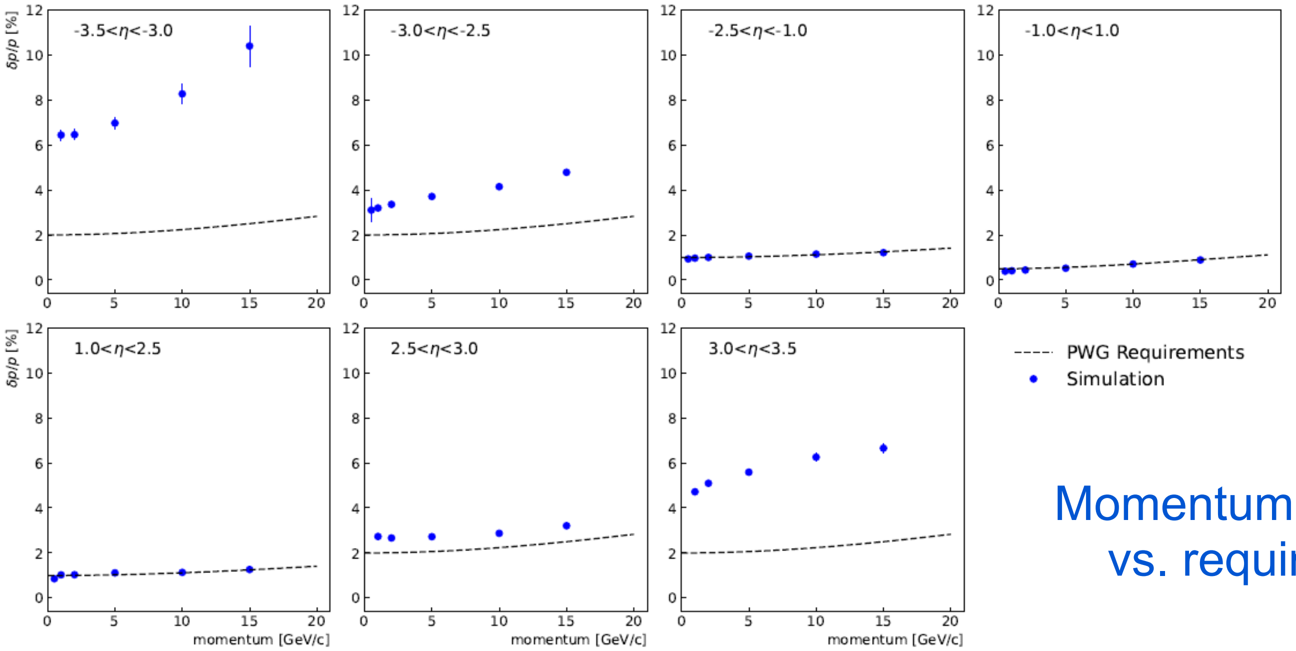
Tracking performance – single particle events

Source events

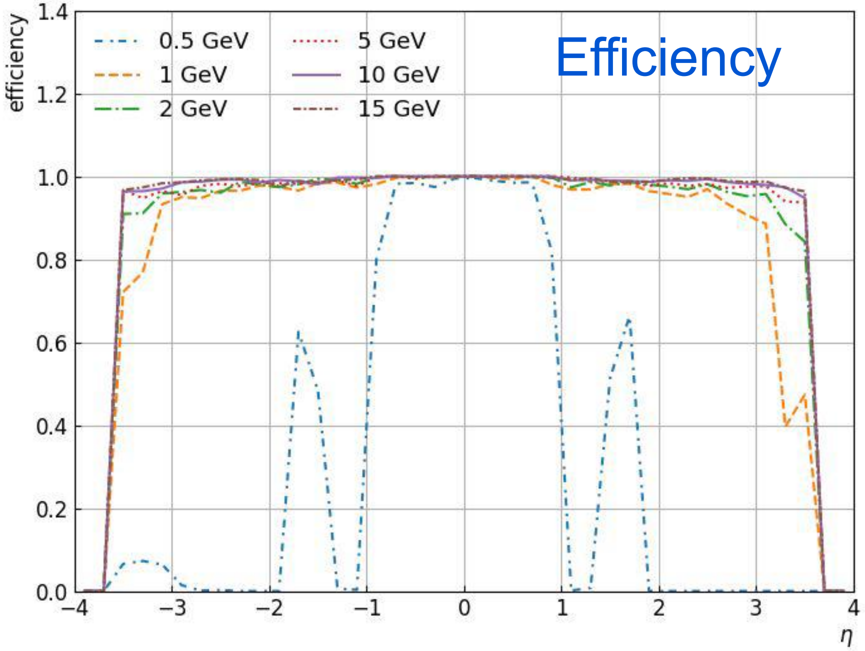
- Single charged pion events at fixed momentum uniformly distributed in angle

Observables

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



Momentum resolution vs. requirements



The momentum resolution requirements in the larger |η| bins represent a combined detector requirement on the tracking and calorimeter detectors.

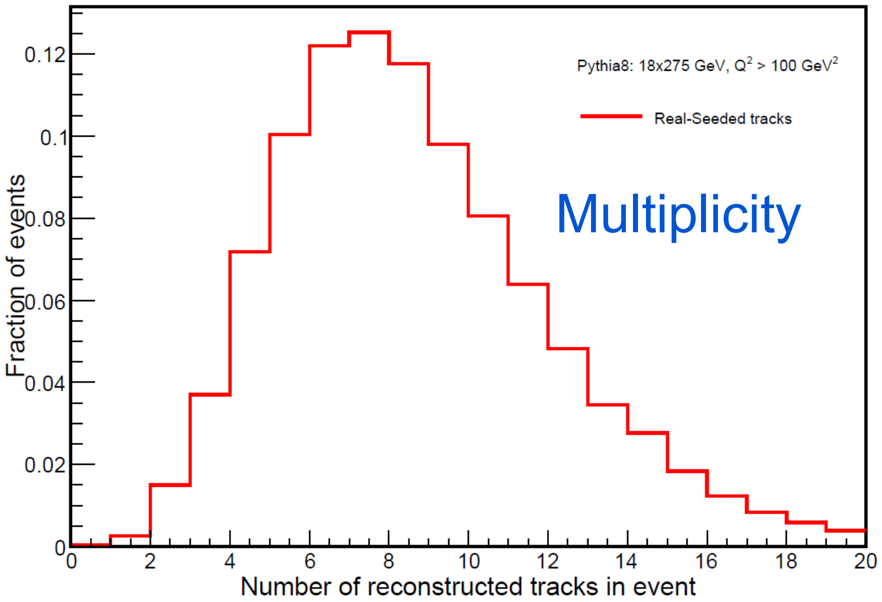
Tracking performance – DIS signal events

<u>Source events</u>

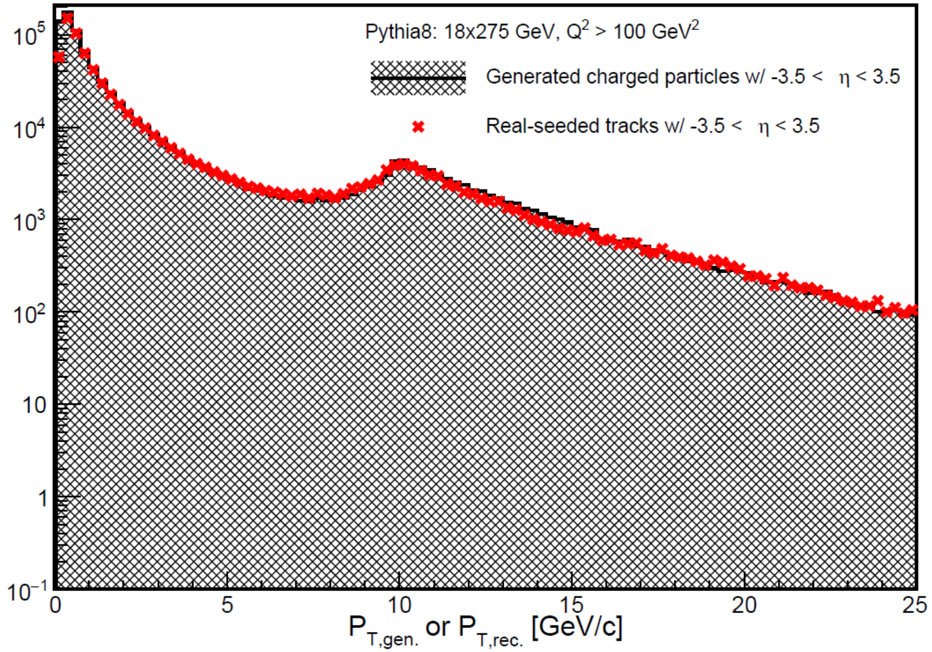
- DIS events simulated with a minimum Q^2 threshold and beam-smearing effects applied

<u>Observables</u>

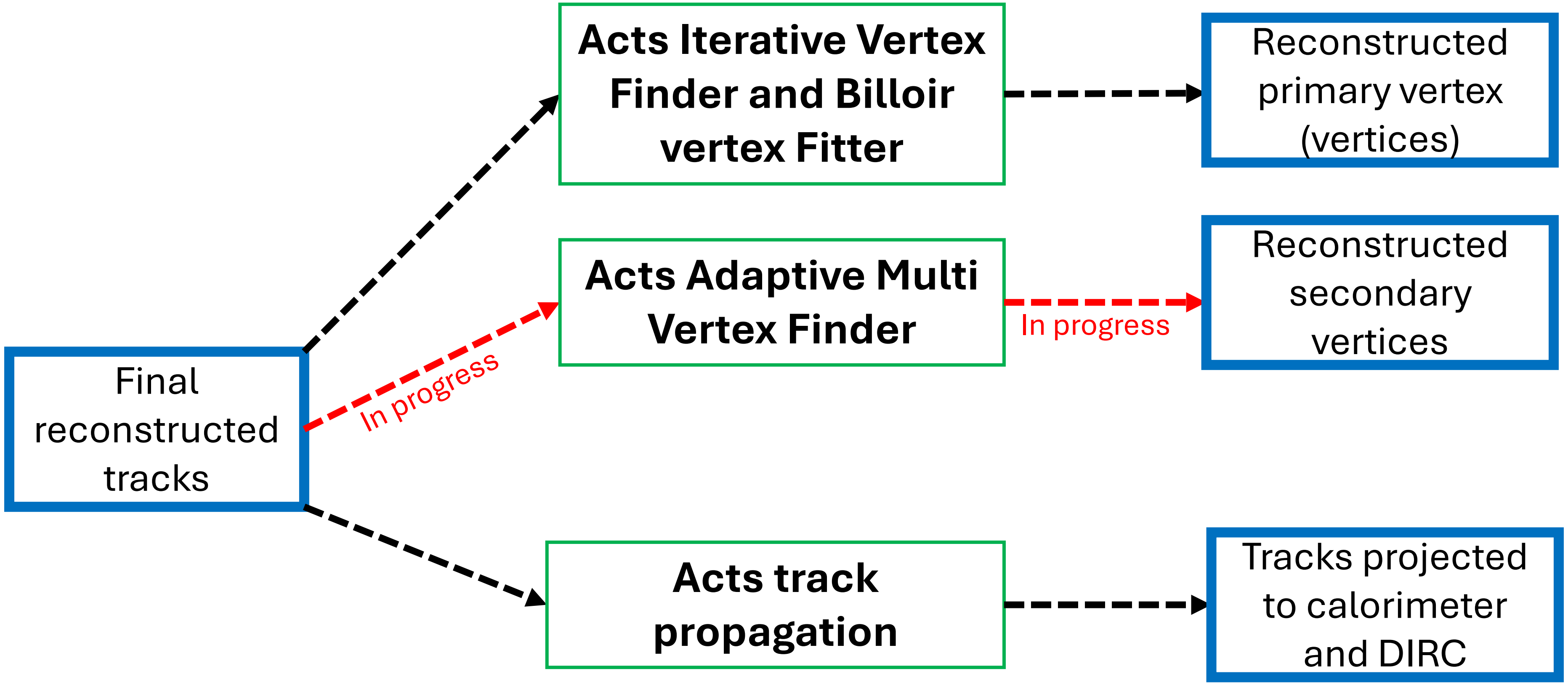
- **Track multiplicity:** number of reconstructed tracks per event
- **Track spectra**: reconstructed eta or P_t distribution for tracks
- **Efficiency**: fraction of generated particles with a reconstructed matched track
- **Hit Purity**: fraction of hits used in a track fit associated with a given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



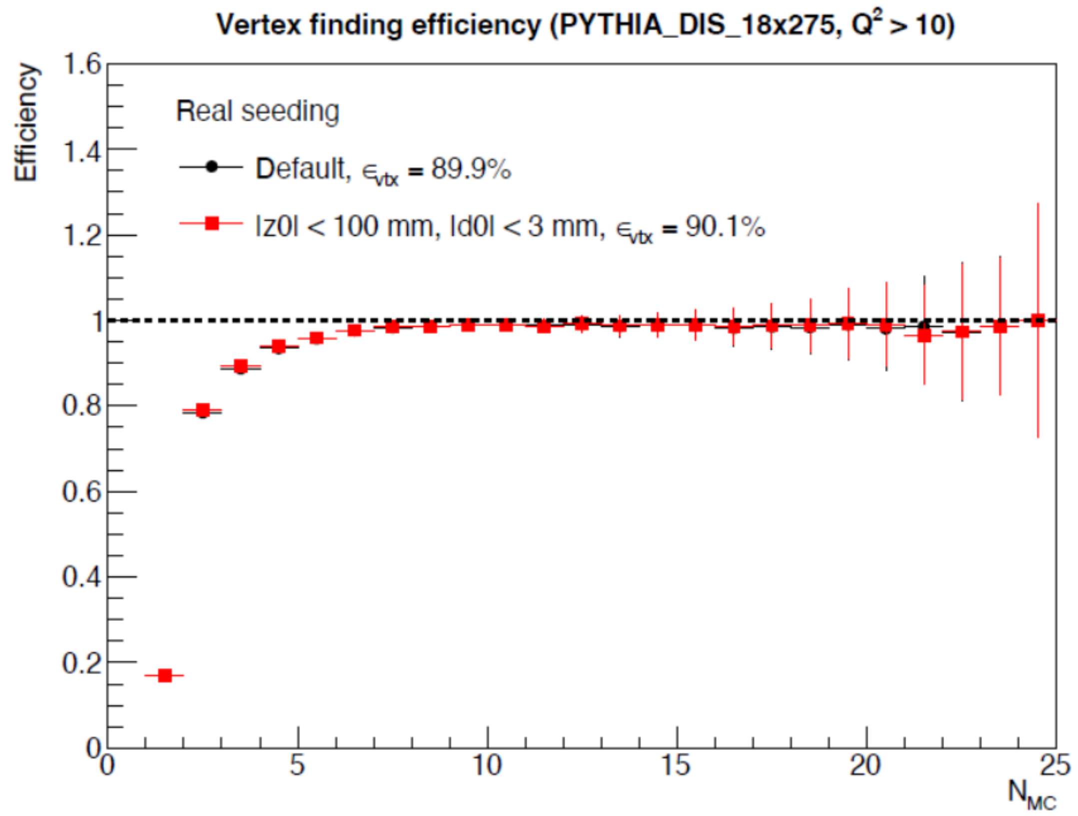
Reconstructed P_t distribution

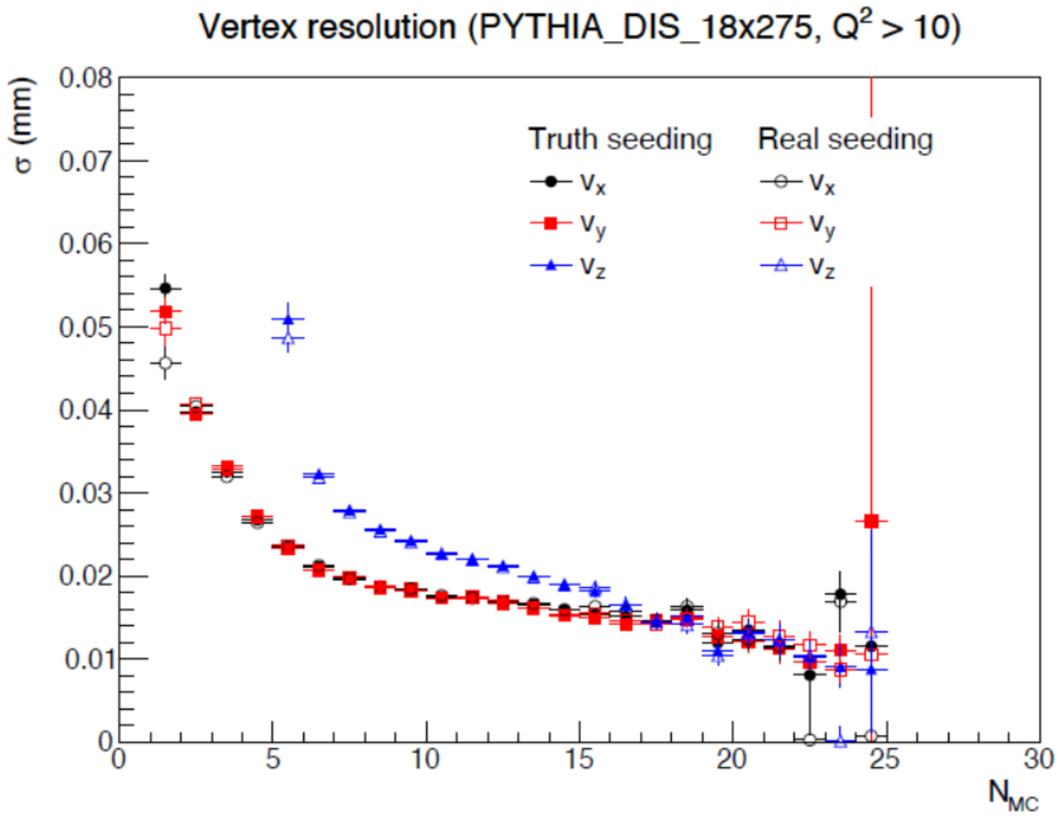


Vertexing and track projections workflow



Primary vertex reconstruction performance

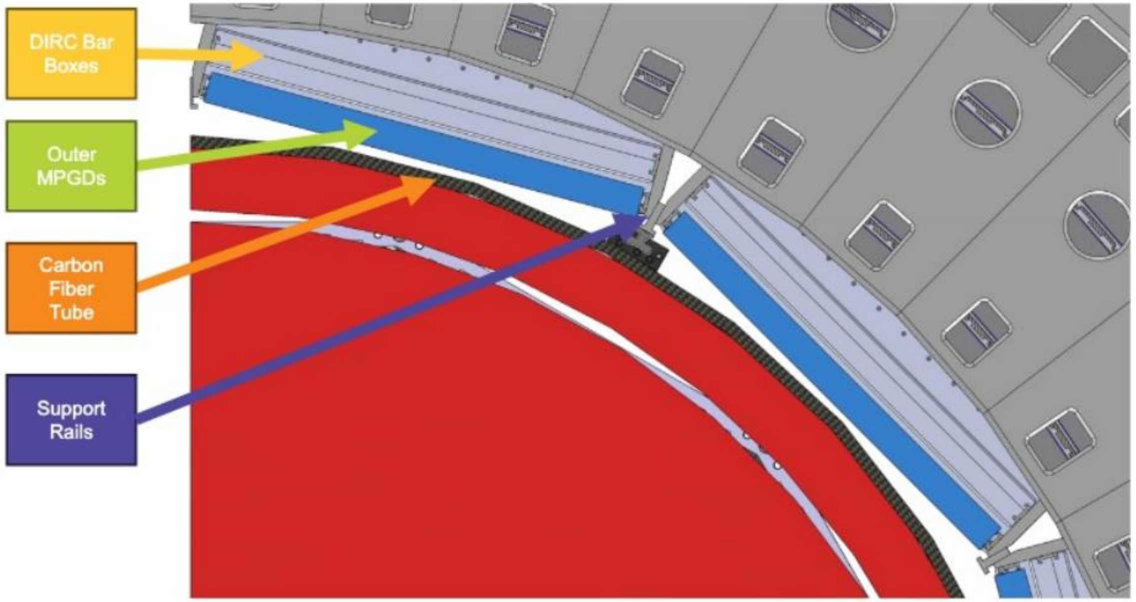




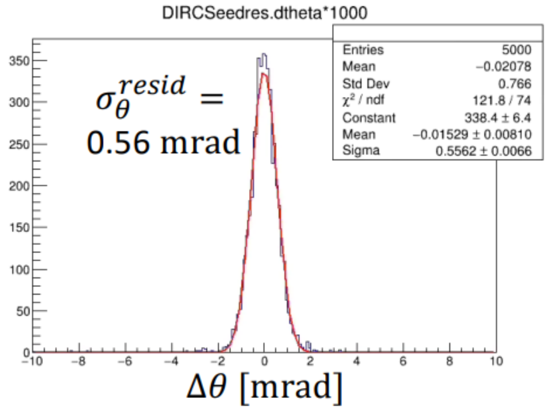
N_{MC}: number of MC charged particles originating from collision vertex within |eta| < 3.5
Efficiency: fraction of events with at least one reconstructed vertex

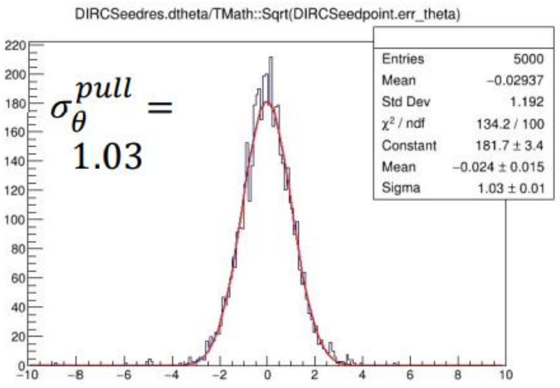
Track projections to the DIRC

- PID performance of the DIRC depends on the quality of the track projection at the DIRC surface.
- Implementation of material between the vertex and the DIRC in the simulation has been essential for an accurate determination of the track projection resolutions.

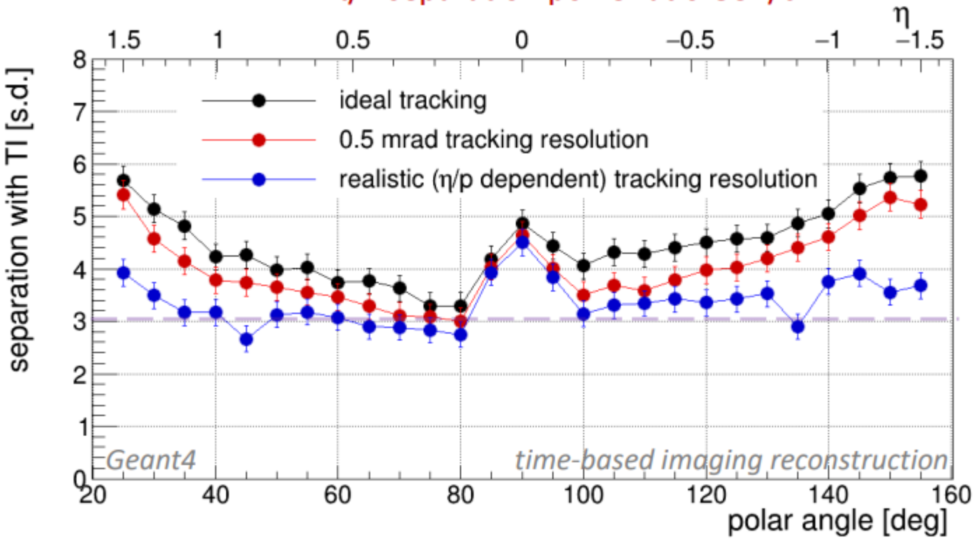


6 GeV/c pi-



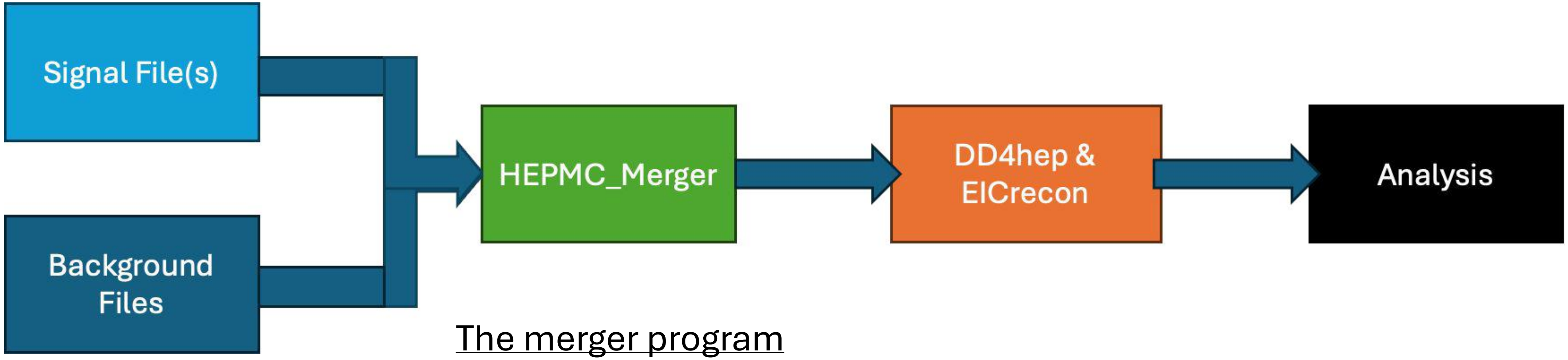


π/K separation power at 6 GeV/c



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



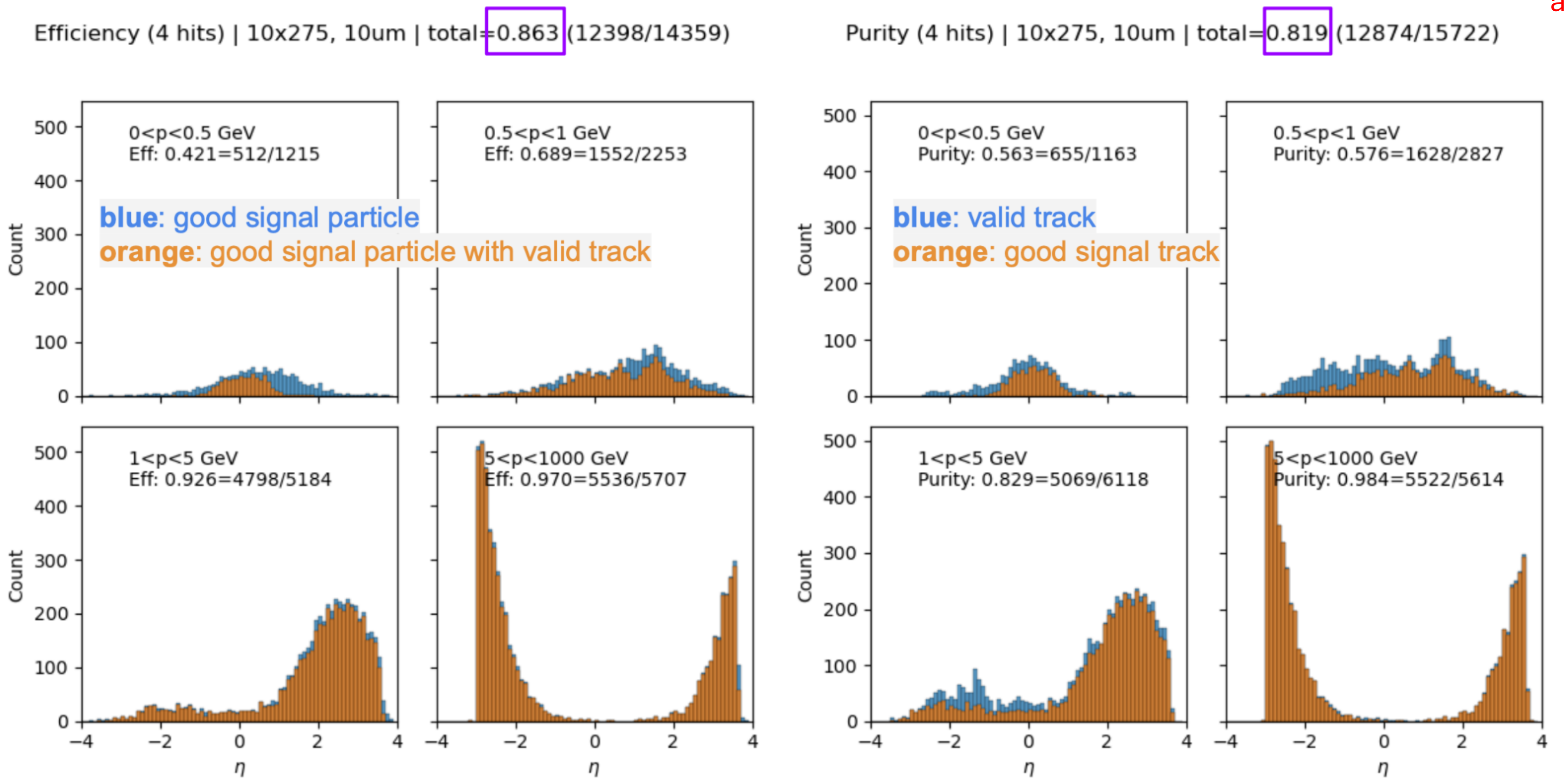
<u>The merger program</u>

- Sample each background source – SR, electron Bremsstrahlung, Coulomb, Touschek, proton beam gas – according to its frequency within a fixed-length (2us) time window
- Label each source particle with a custom generator code
- Example configuration: One 18x275 NC DIS collision with $Q^2 > 1$ GeV^2/c^2 per time slice with all backgrounds included at their respective rates

Tracking performance with background

10x275, 10um gold coating, at least 4 hits per track: OK efficiency, OK purity

All backgrounds included. Highest background rates at 10 GeV

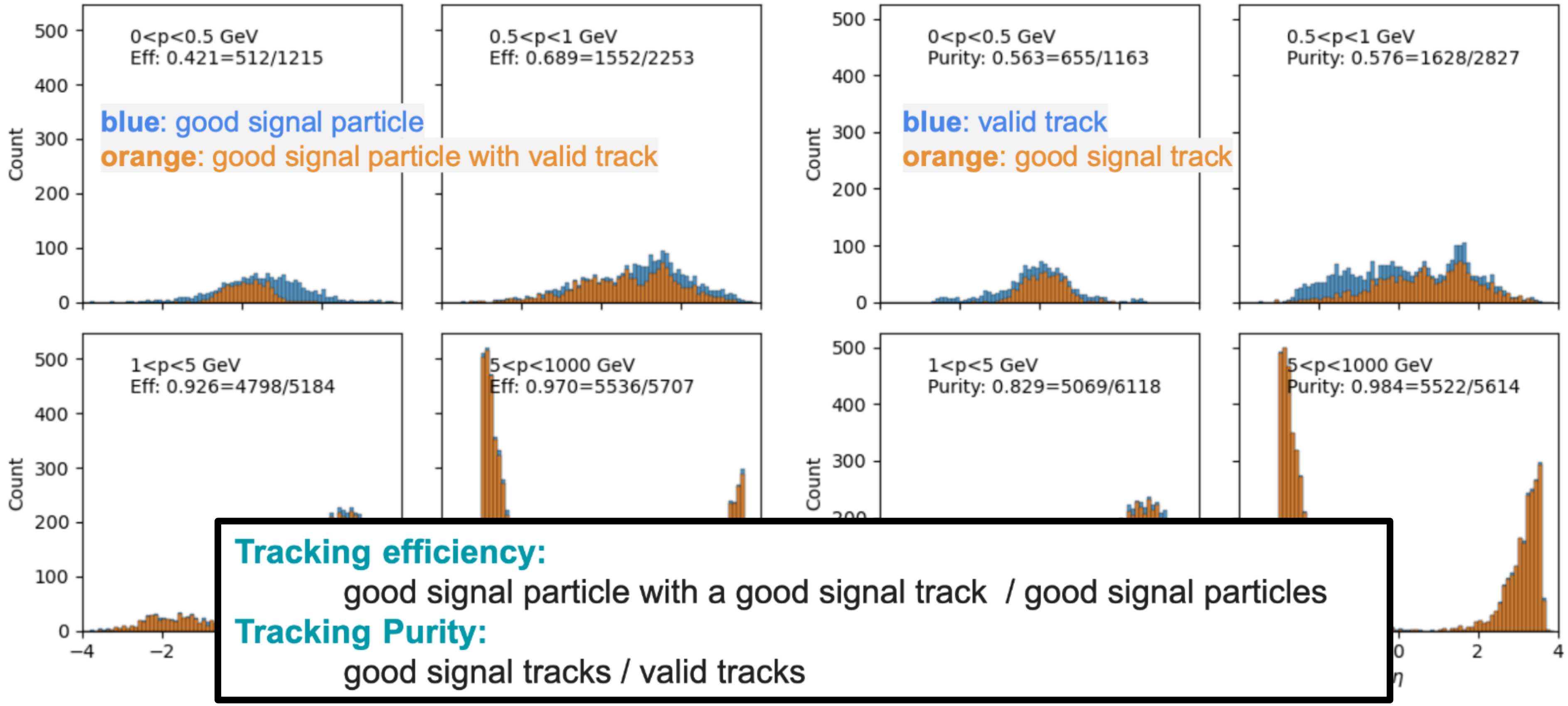


Tracking performance with background

10x275, 10um gold coating, at least 4 hits per track: OK efficiency, OK purity

All backgrounds included. Highest background rates at 10 GeV

Efficiency (4 hits) | 10x275, 10um | total=$\boxed{0.863}$ (12398/14359)   Purity (4 hits) | 10x275, 10um | total=$\boxed{0.819}$ (12874/15722)



Tracking efficiency:

good signal particle with a good signal track / good signal particles

Tracking Purity:

good signal tracks / valid tracks

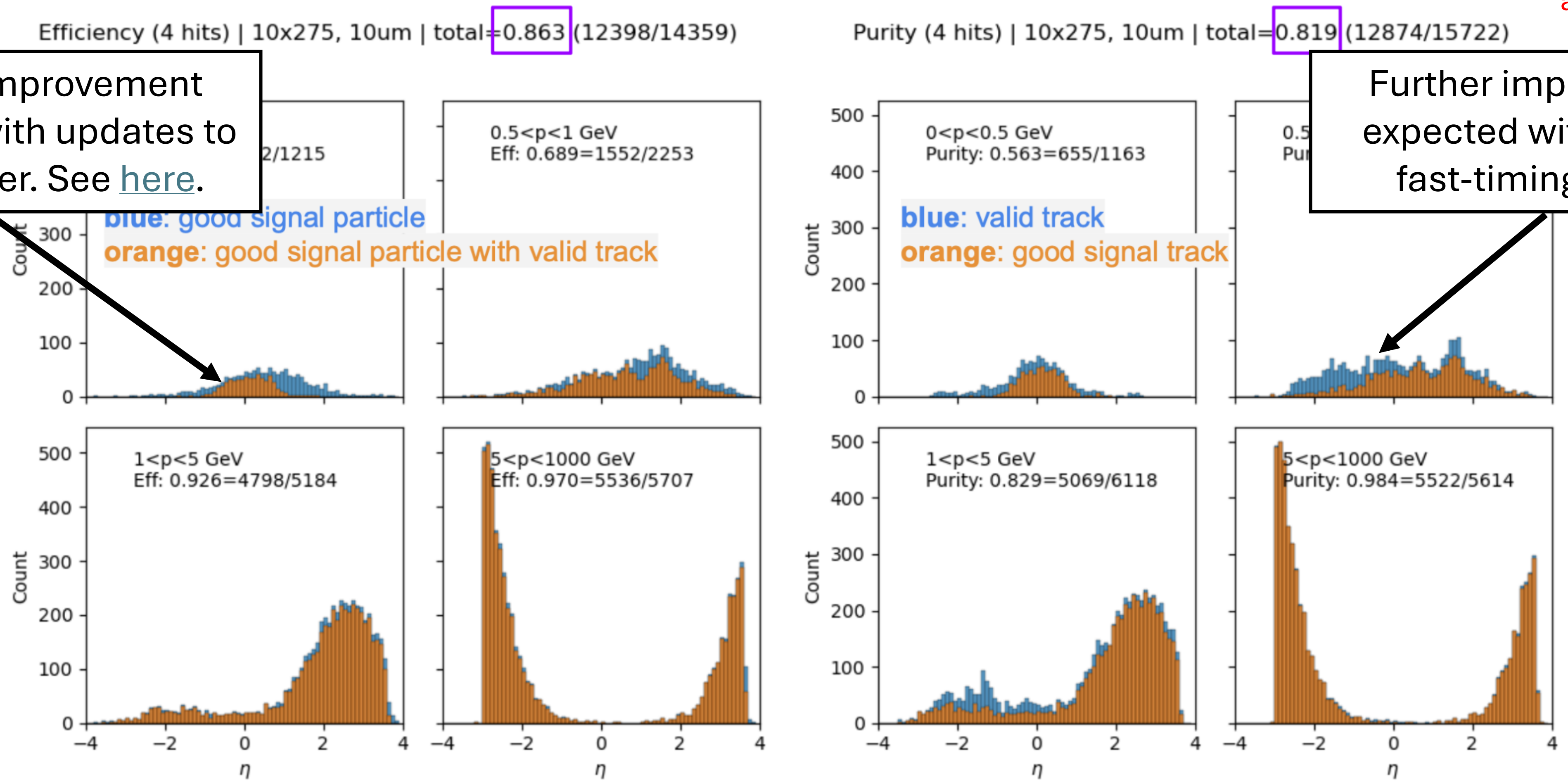
Tracking performance with background

10x275, 10um gold coating, at least 4 hits per track: OK efficiency, OK purity

All backgrounds included.
Highest background rates
at 10 GeV

Further improvement expected with updates to seed finder. See here.

Further improvement expected with cuts on fast-timing layers.



Upcoming studies with backgrounds and noise

- We will repeat our tracking and vertexing performance studies with the following updates:
  1. Fixes to the background merger code (https://github.com/eic/HEPMC_Merger/issues/24)
  2. Inclusion of detector noise in the SVT
  3. Updated SVT sensor structure (https://github.com/eic/epic/pull/1137)
  4. Updated MPGD and TOF digitization and geometry
  5. Updated track seeding infrastructure
  6. Impact of fast-timing layers on performance
  7. Studies of tracking performance with changes to tracking layout

ACTS Orthogonal Triplet Seed Finder

How triplets are built, and how they're scored

1. **Build KD-tree** — index all space points in (ϕ, r, z)
2. **Middle SP cuts** — r / z / ϕ region of interest
3. **Box search** — Δϕ, Δr, Δz windows → candidate bottoms & tops
4. **Doublet + helix fit** — cotTheta, impact, scattering cuts
5. **Seed filter** — weight, rank, cap per middle SP

Seed weight (computed per top candidate, for a fixed bottom–middle doublet)

$$w = c_1 \cdot N_t - c_2 \cdot d_0 \quad (- c_3 \cdot |z_0| \quad \textit{only if seedConfirmation = true})$$

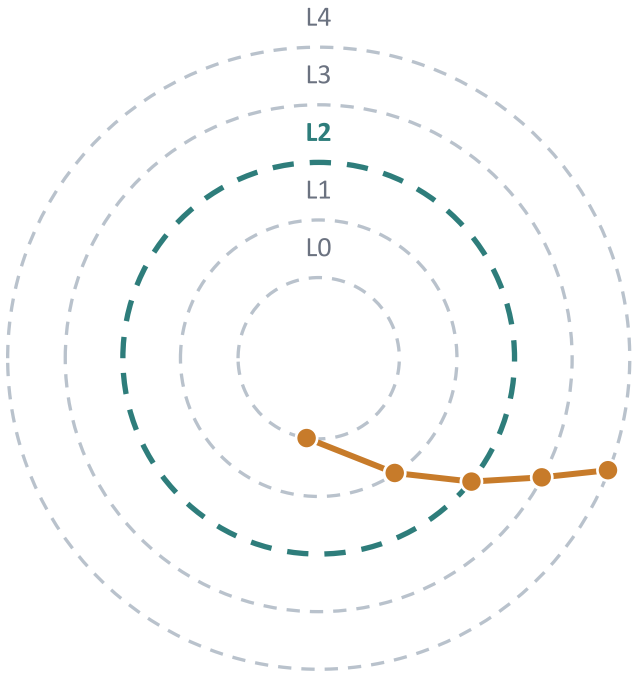
N_t = number of *other* top candidates (same bottom–middle pair) that are curvature-consistent and ≥ Δr_{min} apart, capped at compatSeedLimit. d_0, z_0 = impact parameter, vertex z of the fitted helix.

maxSeedsPerSpM keeps only the top-(maxSeedsPerSpM + 1) weighted seeds *per middle space point* — the cap is applied independently for every middle SP

Only φ, r, z drive candidate finding — no timing information is used at any stage of this algorithm.

ACTS Orthogonal Triplet Seed Finder

Worked example with our current configuration — 5-layer barrel seeding, one track



5 barrel layers, single track → 10 possible (bottom, middle, top) triplets.
Only L1 / L2 / L3 can ever be the middle point.

Middle SP	Candidate tops (same doublet)	N_t	# triplets before cap
L1	L2, L3, L4	3	3
L2	L3, L4	2	4
L3	(none)	1	3

N_t is larger for inner middle SPs — more outer layers remain as candidate corroborating tops.

Our current configuration

maxSeedsPerSpM = 0 → keep exactly 1 seed per middle SP → 3 seeds survive for this track (one from each of L1, L2, L3).

Tie-breaking: for middle = L2, all 4 triplets share N_t = 2 — the survivor is decided by which combination happens to give the smallest reconstructed d_0 (detector resolution / scattering), not by any real physics difference.

seedConfirmation = false → weight uses only d_0 and N_t (no z_0 term, no min-N_t threshold, no quality tiering).

ACTS Orthogonal Triplet Seed Finder

NEXT STEP: Evaluating the impact of enabling seedConfirmation

seedConfirmation = false (current)	seedConfirmation = true
Weight = $-c_2 \cdot d_0 + c_1 \cdot N_t$ only	Weight gains a $-c_3 \cdot \lvert z_0 \rvert$ term — seeds with larger vertex offset are penalized
No minimum-N_t requirement — every middle SP with ≥ 1 valid triplet is kept	sufficientTopDoublets() requires ≥ nTopSeedConf tops before a middle SP is even considered
No high/normal quality tiering; all seeds compete on weight alone	Seeds are tagged high-quality vs. normal; a normal seed is dropped if a high-quality one exists for the same middle SP
L3-middle seeds (N_t = 1) are never structurally disadvantaged vs. L1/L2	L3-middle seeds (N_t = 1) are the most exposed — may fail the nTopSeedConf threshold entirely

What we want to measure before switching it on:

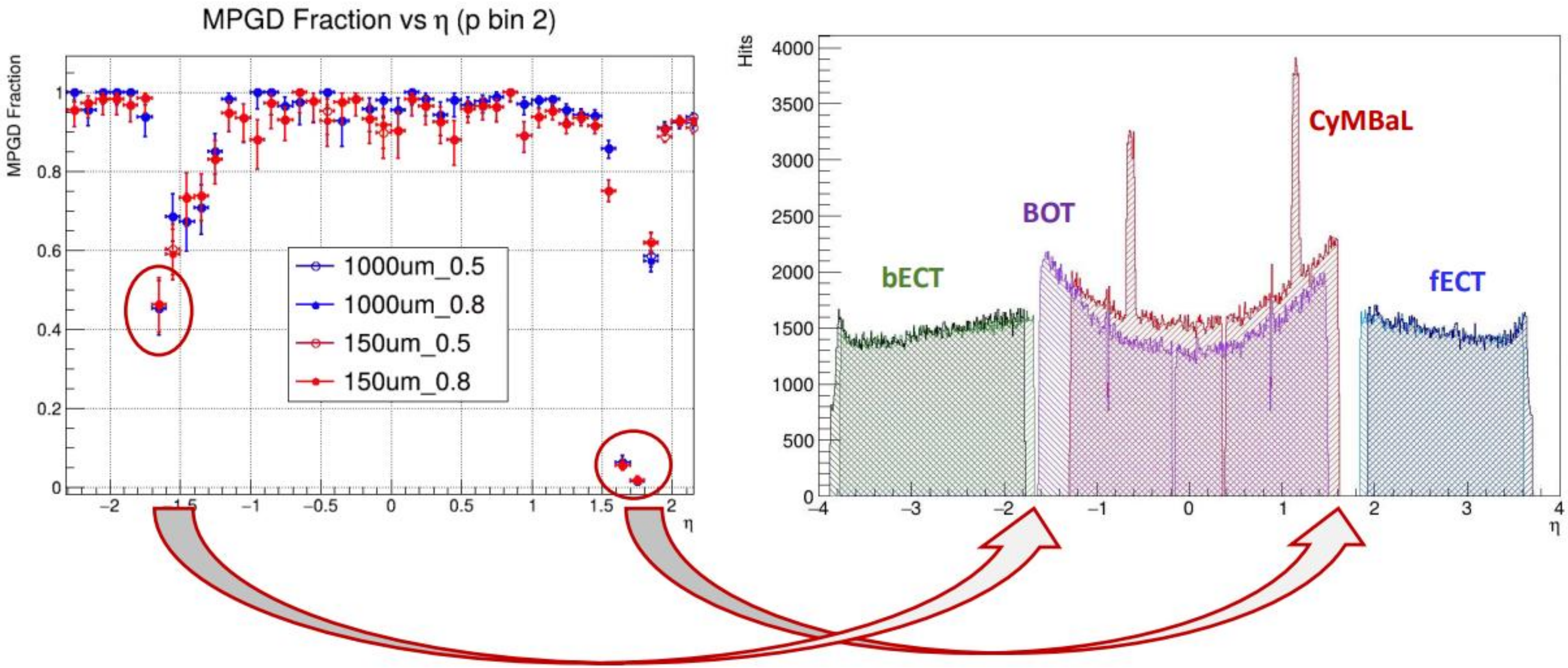
Efficiency: does the nTopSeedConf threshold cost us real seeds from thinner regions (e.g. our L3-equivalent middle layer)?
Purity: does quality tiering + the z_0 penalty meaningfully suppress fakes?

Impact of fast-timing layers on tracking

- We plan to incorporate the timing information from the fast-tracking layers into the reconstruction:
    1. We can use the fast-tracking layers assign a ‘timestamp’ to each track. This will allow us to build ‘physics’ events tied to specific bunch crossings, as well as check the impact of timing information on background rejection.
    2. In parallel, we will work to incorporate the timing information into the track chi-square calculation.
- First, we checked how often we see hits in the fast-timing layers for tracks passing our 4 or 5 hit requirement.

Impact of fast-timing layers on tracking: MPGD example

MPGD Fraction = #Good reconstructed tracks with MPGD hit / #Good reconstructed tracks



Summary

- In ePIC, we have developed a lot of infrastructure to perform track and vertex reconstruction, as well as study tracking and (primary) vertexing performance.
- Ongoing studies are focused on track seeding, implementation of more accurate detector response, and impact of fast-timing layers. In addition, we are studying the impact of any changes to the default tracking layout.
- Our studies so far have used event-based reconstruction. We should check that any streaming-based studies give consistent results to our event-based ones.