Tracking performance towards TDR and other public usages

Minjung Kim (UC Berkeley)

Berkeley EIC meeting

27 August 2024 (Tue)

Tracking status in EICrecon

✦ **Truth seeding as well as realistic seeding give reasonable tracks: confirmed by tracking QA (resolution and efficiency in local Berkeley people), vertaxing group and PWGs**

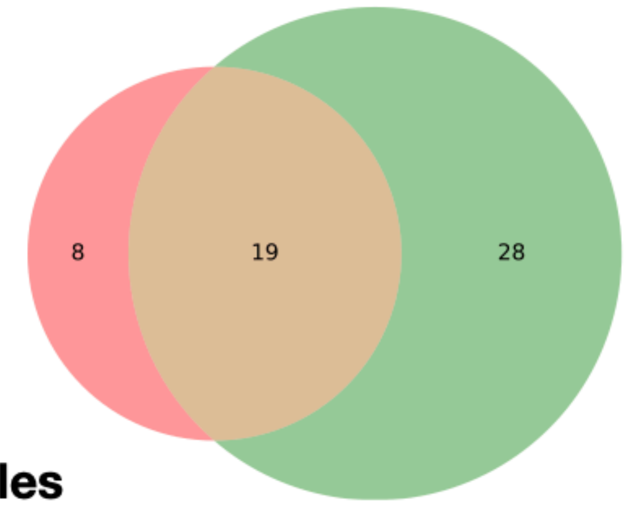
✦ **Room for improvement:**

- Matching between MC particle and reco. tracks: Matching based on angular distance is tricky in large multiplicity events with background tracks

  ➡**Hit based association is implemented (thanks Barak!); not default yet but as an additional output information**

- Discrepancy between truth seeding and realistic seeding
  - Truth seeding takes the all charged particles generated (physics level generator) particle with loose pT and eta cut
  - So, even the particles leaving less than 3 hits on tracker are in there, while secondary particles produced in material cannot be considered

  ➡ **Leave as caveat as we will, in the end, use realistic seeding as a default setting**



MC particles
(PYTHIA generated stable particles with min. 3 hits)
Truth seeding
(Some kinematic cuts but covers most of final stable particles created by PYTHIA)
Realistic seeding
(Possibly reconstructed secondary particles)

✦ **Detector implementation:**

- Geometry including service seems fairly reasonable, but actual silicon characteristics is missing

Reminder: Observables for tracking performance estimation

✦ **Momentum resolution:**

- Matching reco. track and generated particle and compare momentum
- Implemented in benchmark for "single particle gun"

✦ **Tracking efficiency:**

- Matching reco. tracks and generated particles and count how many particles are found as tracks in the detector
- Many local results in different physics environments

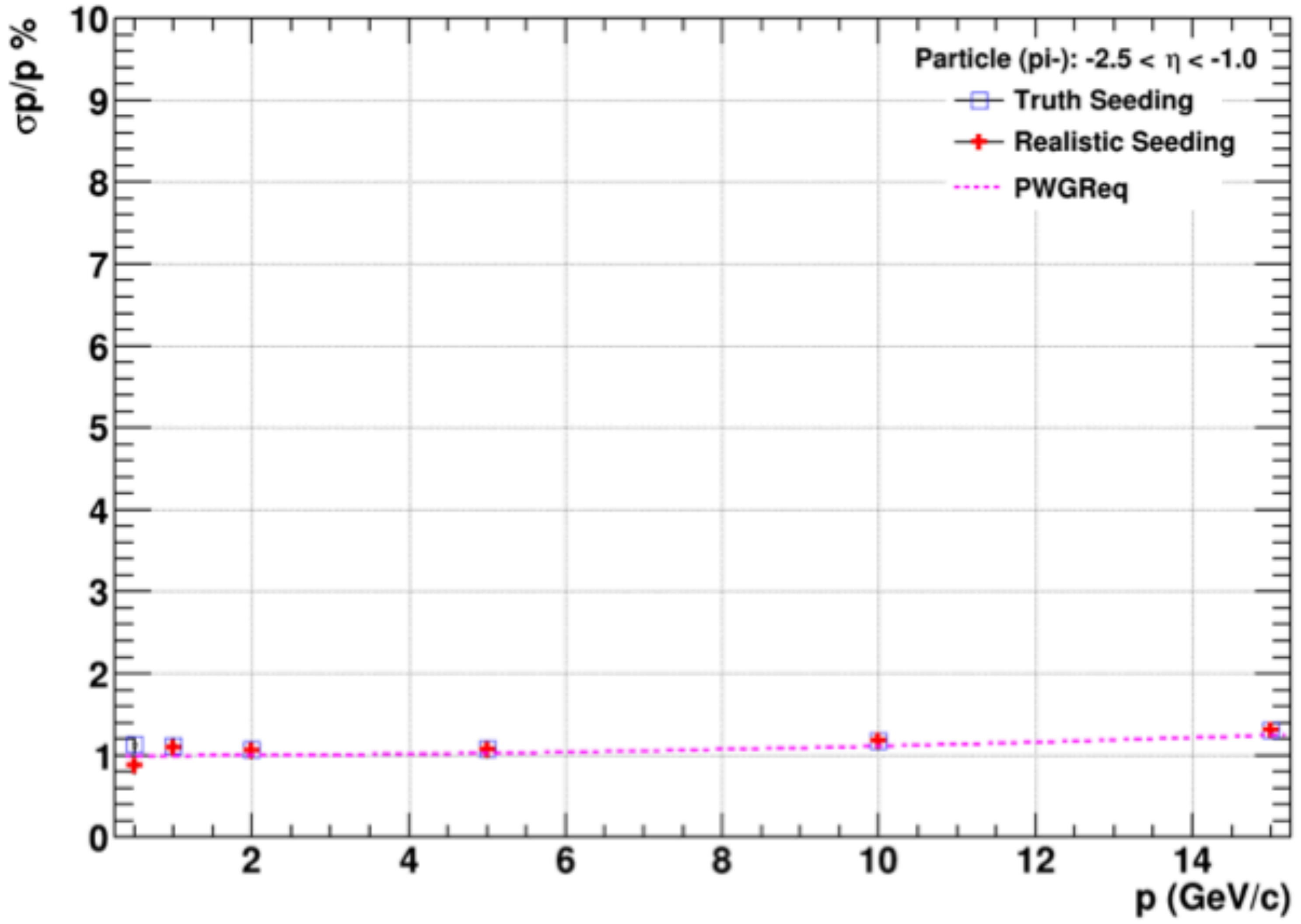
✦ **Track purity:**

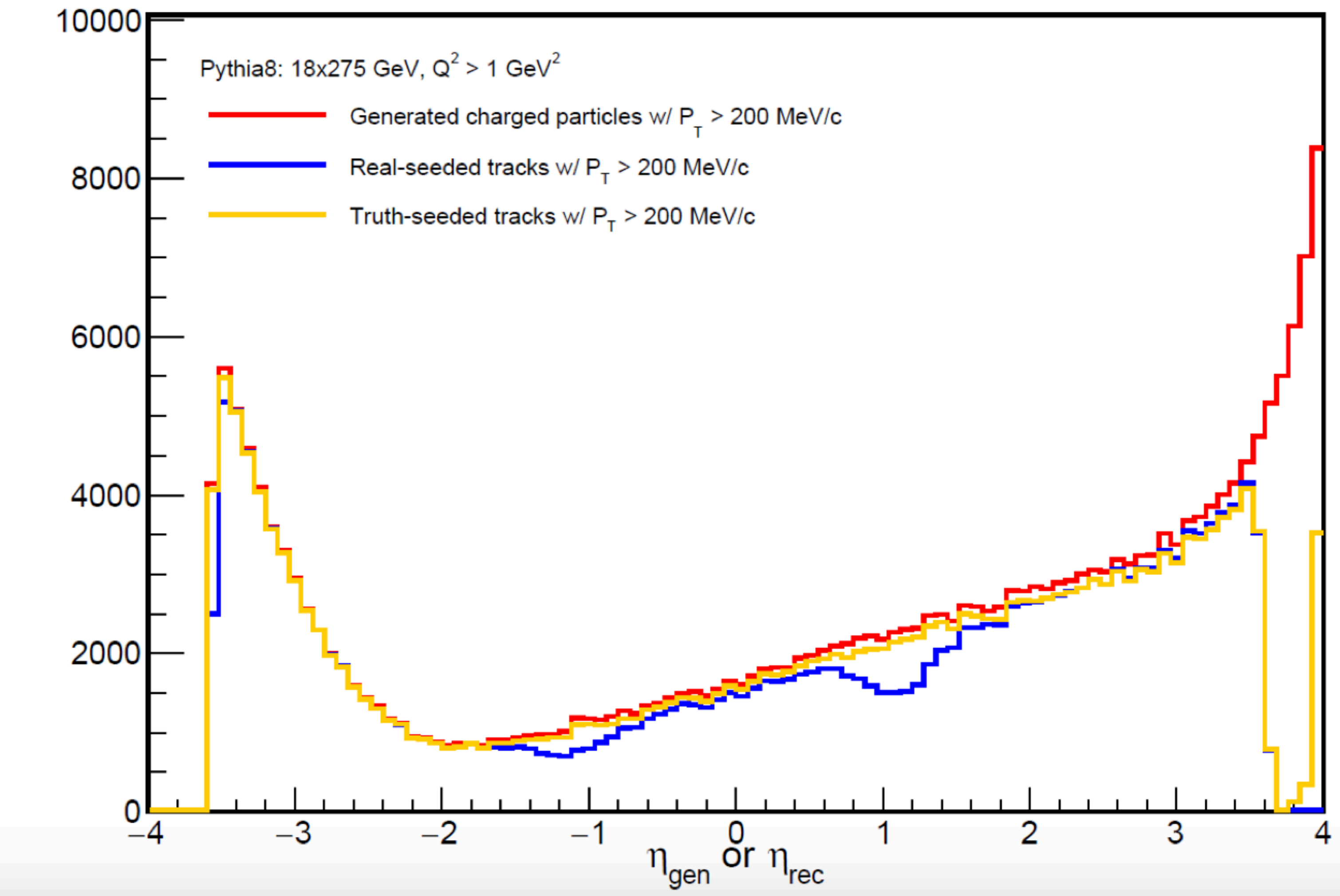
- Check how many reconstructed tracks are originated from input particles, not from random associations
- Huge effort from Ben studying "Beam-gas background" and noise study is ongoing by Mitac

✦ **Etc.:**

- Residual in each (active) tracking layer: studied by Beatrice
- Hit purity: per track, how many hits created from matching particle were associated with

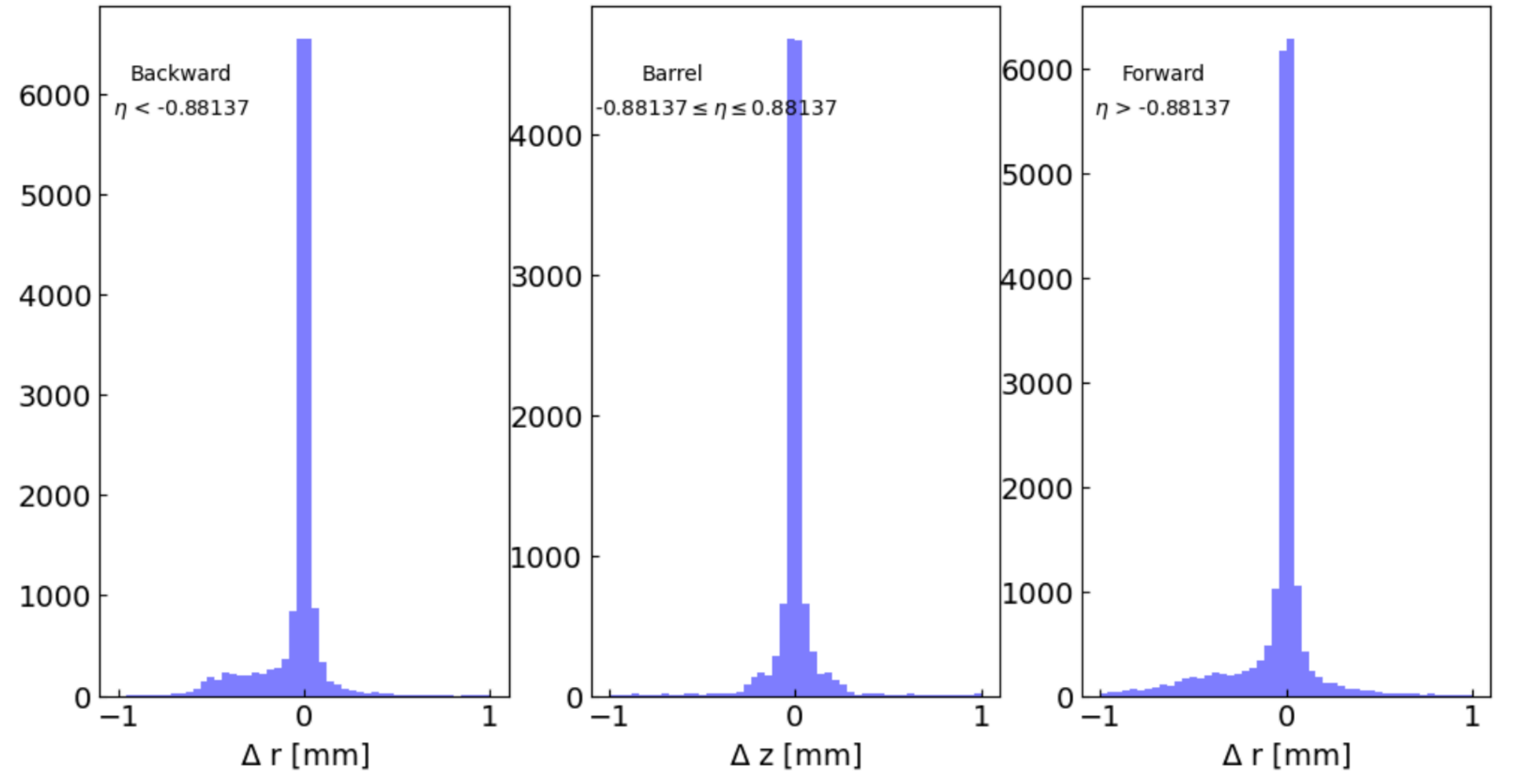
Work by Shyam Kumar





Reminder: Observables for tracking performance estimation

DCA and secondary vertexing: expected to be done by vertexing group



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- ✦ **Etc.:**
  - Residual in each (active) tracking layer: studied by Beatrice
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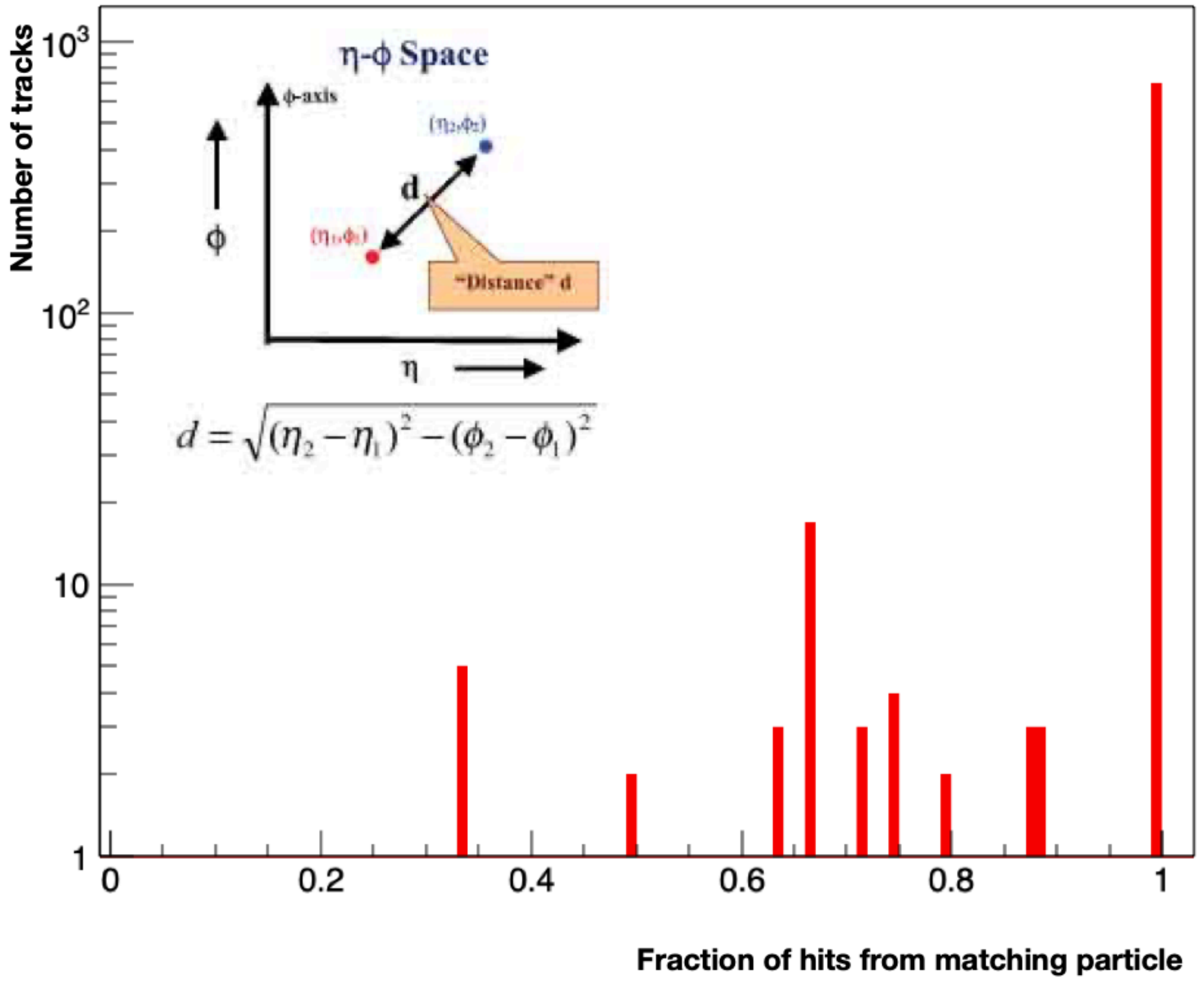


➡ **All observables should be studied differentially: pT, eta, phi, particle species**

Tracking performance: To realistic environments

- ✦ **Single particle event: good and clean validation environment**
  - Baseline: resolution is already part of benchmark - can be easily extended to additional observables
    - ➡ **@Shujie: any other contributions outside Berkeley? Otherwise, anyone who involved in tracking studies can easily collaborate with Shyam**
- ✦ **Track density: DIS events with different Q2 events**
  - All the machineries for single particle gun events can be directly adopted and integrated into benchmark by varying the input physics events
    - ➡ **Need some optimization depending on the physics system**
- ✦ **Take into account background:**
  - External physics source: background from beam-gas interactions and synchrotron radiation
    - ➡ **Finalization of Ben's work with observables defined in previous slides / SR contribution updated (last Nov.)**
    - ➡ **Barak volunteered**
  - Hardware source: noise, multiple scattering, conversion electrons, …
    - ➡ **Miao's work**
- ✦ **More realistic geometry and tracker spec into simulation**
    - ➡ **Any update from Joe's study realizing in near future?**

Tentative list of figures & questions to be answered

- ✦ **Baseline: Efficiency, purity and resolution as a function of pT, eta (phi), particle species and multiplicity with single particle gun to high Q^2 DIS events**
- ✦ **Impact of background: baseline defined above with presence of background sources**
  - External background; beam-gas, synchrotron radiation, ……..
  - Internal background; noise, material,….
- ✦ **Impact of other subsystems than silicon tracker: baseline defined above with varying subsystem usages**
  - Impact of TOF, MPGD layers
  - Constraint power of tracking to performance of other subsystems; DIRC incident angle, …..

➡ **Most of results were already accessed and discussed; around 2-3 months of full-time manpower on top of Mitao, Barak and Joe’s work.**

Backup

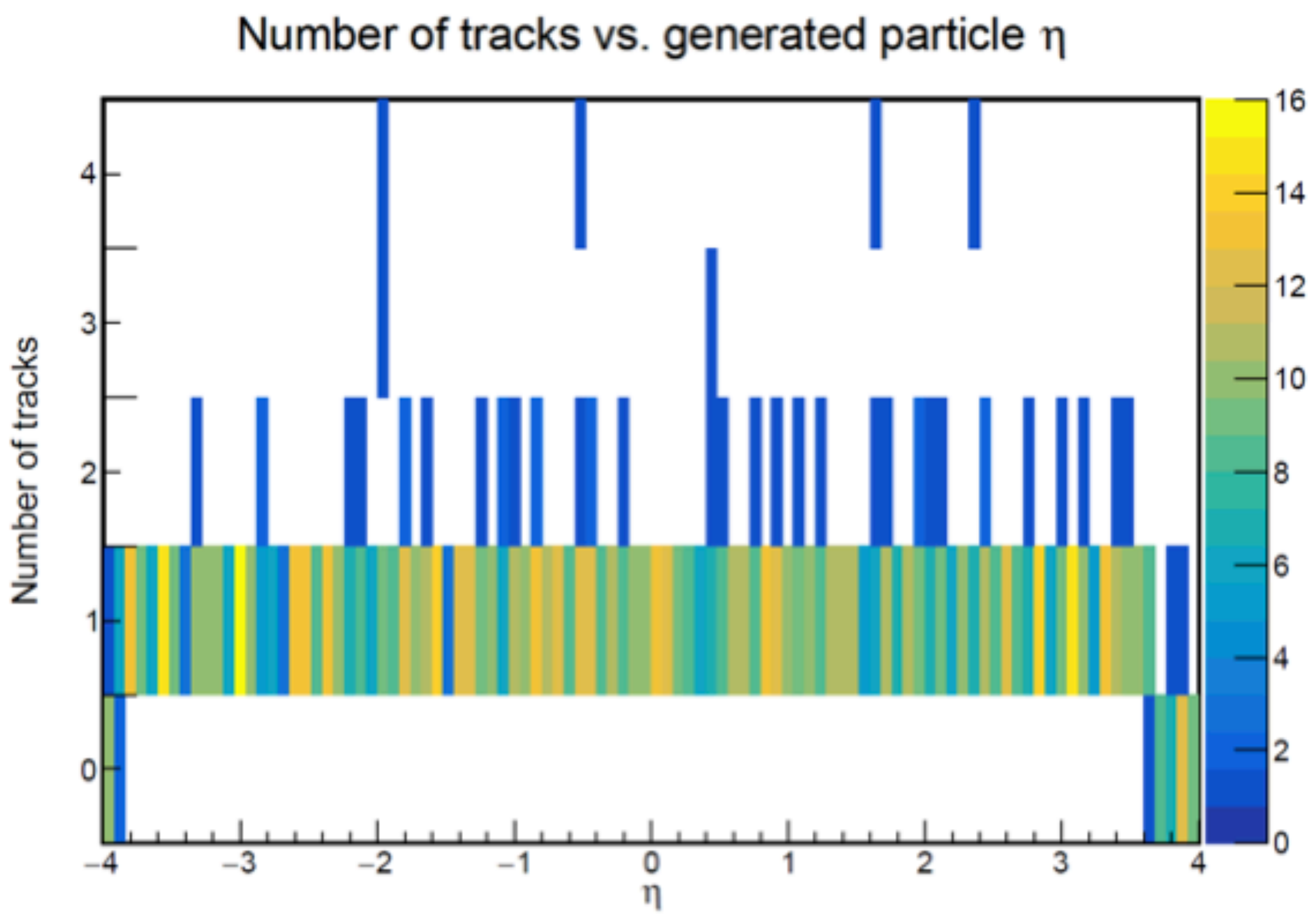
Impact of greedy ambiguity resolution solver in true-seeded tracking

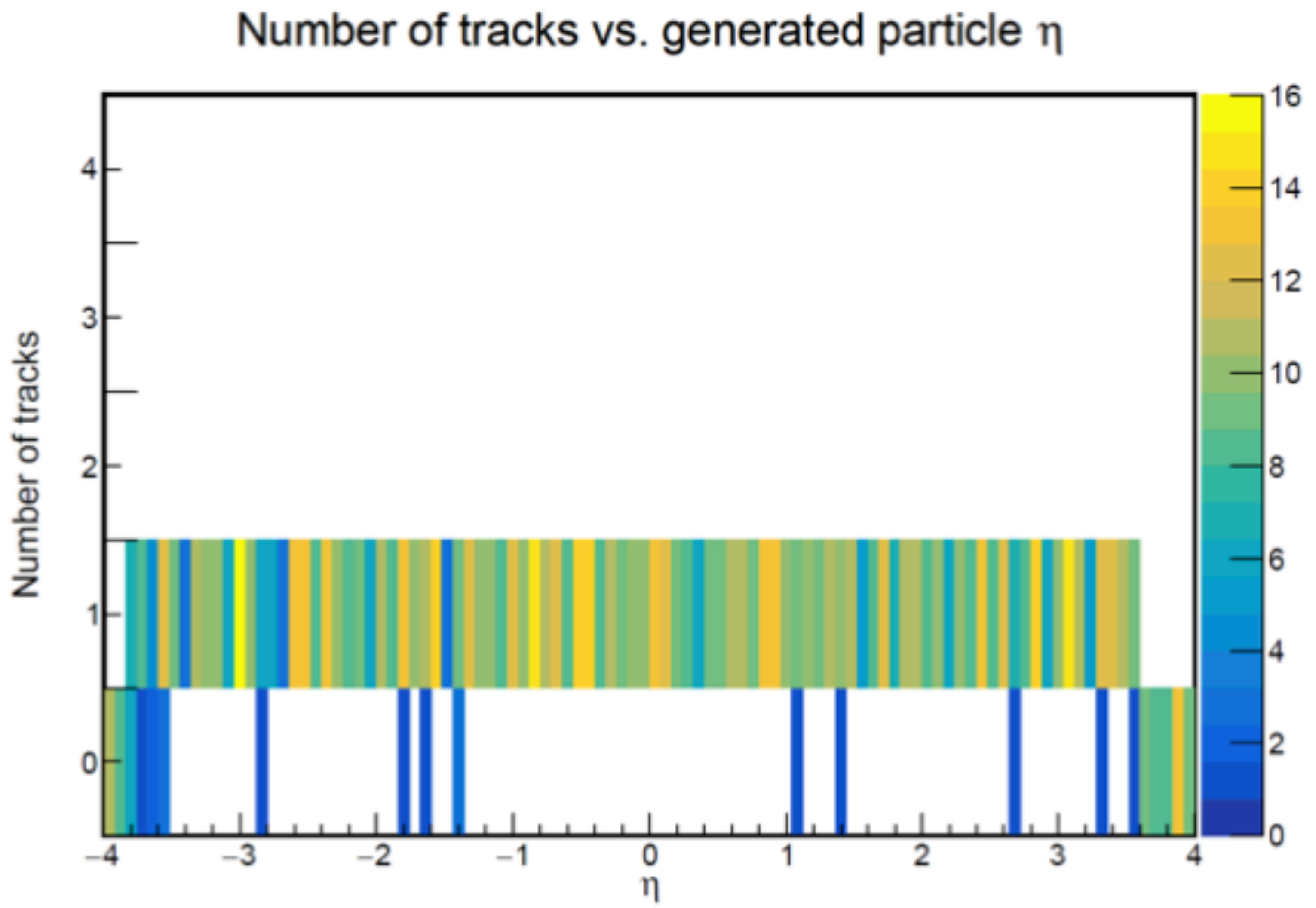
Single μ^- generated:

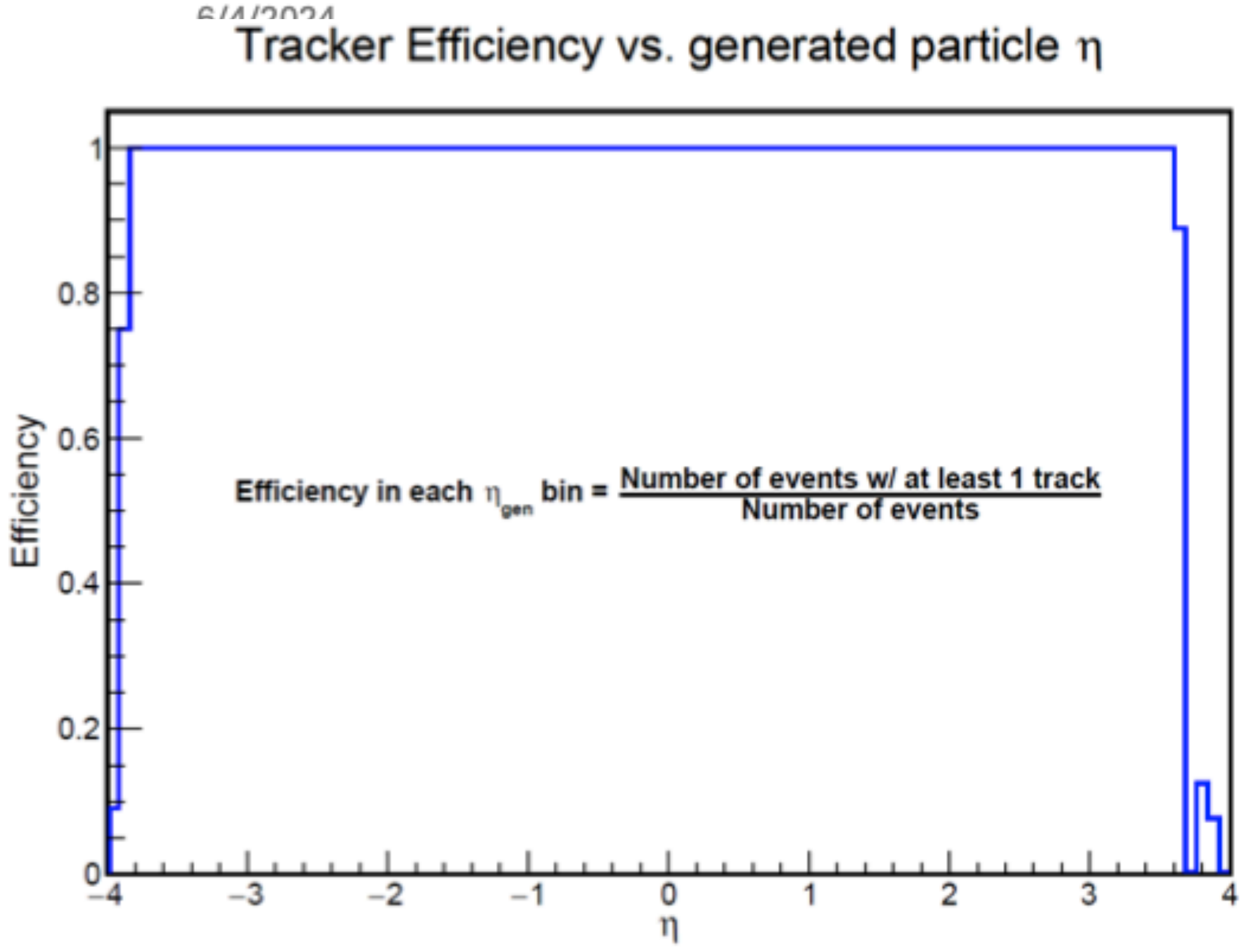
0.5 GeV/c < P < 20 GeV/c

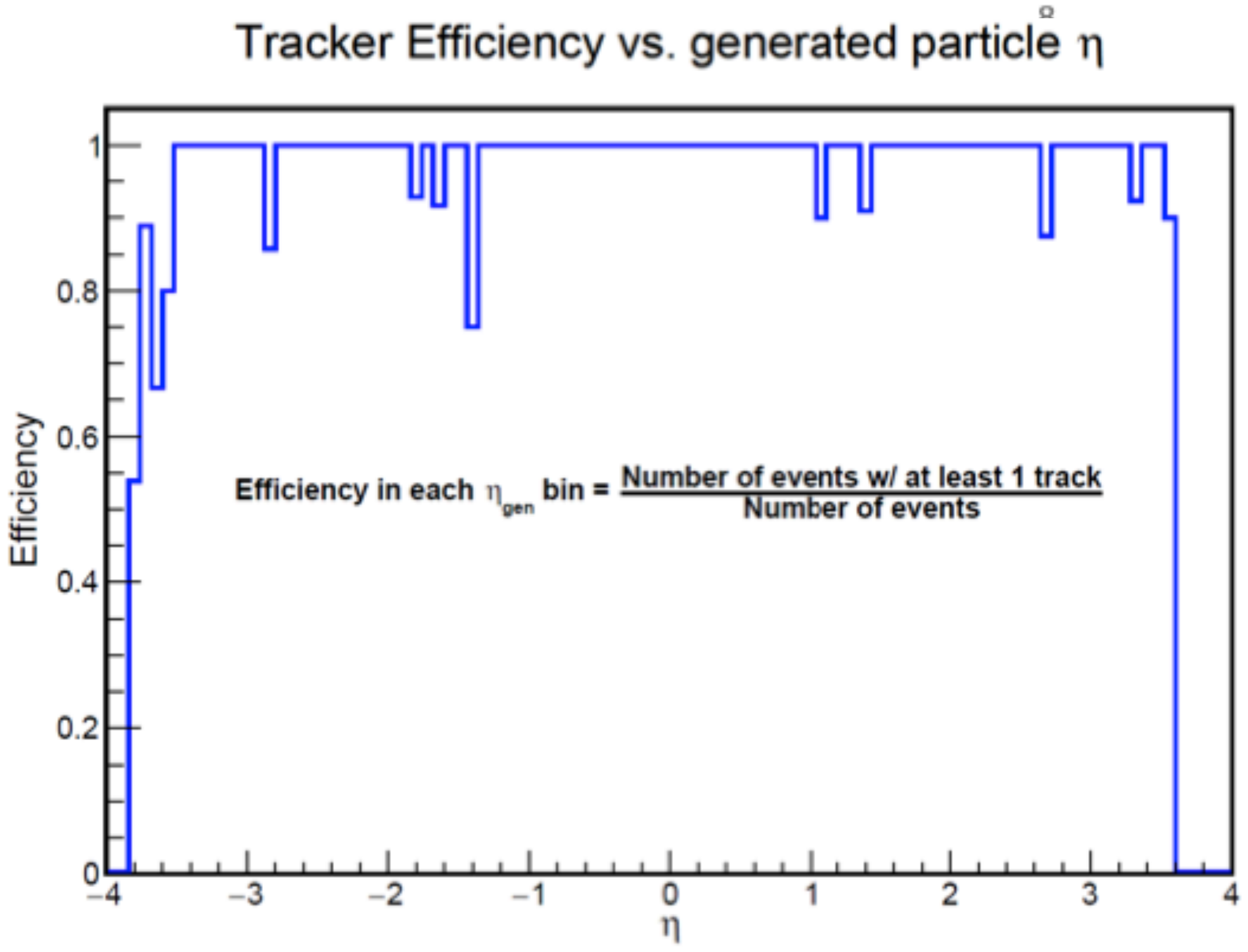
$-4 < \eta < 4$

Generated vertex: (0,0,0) mm









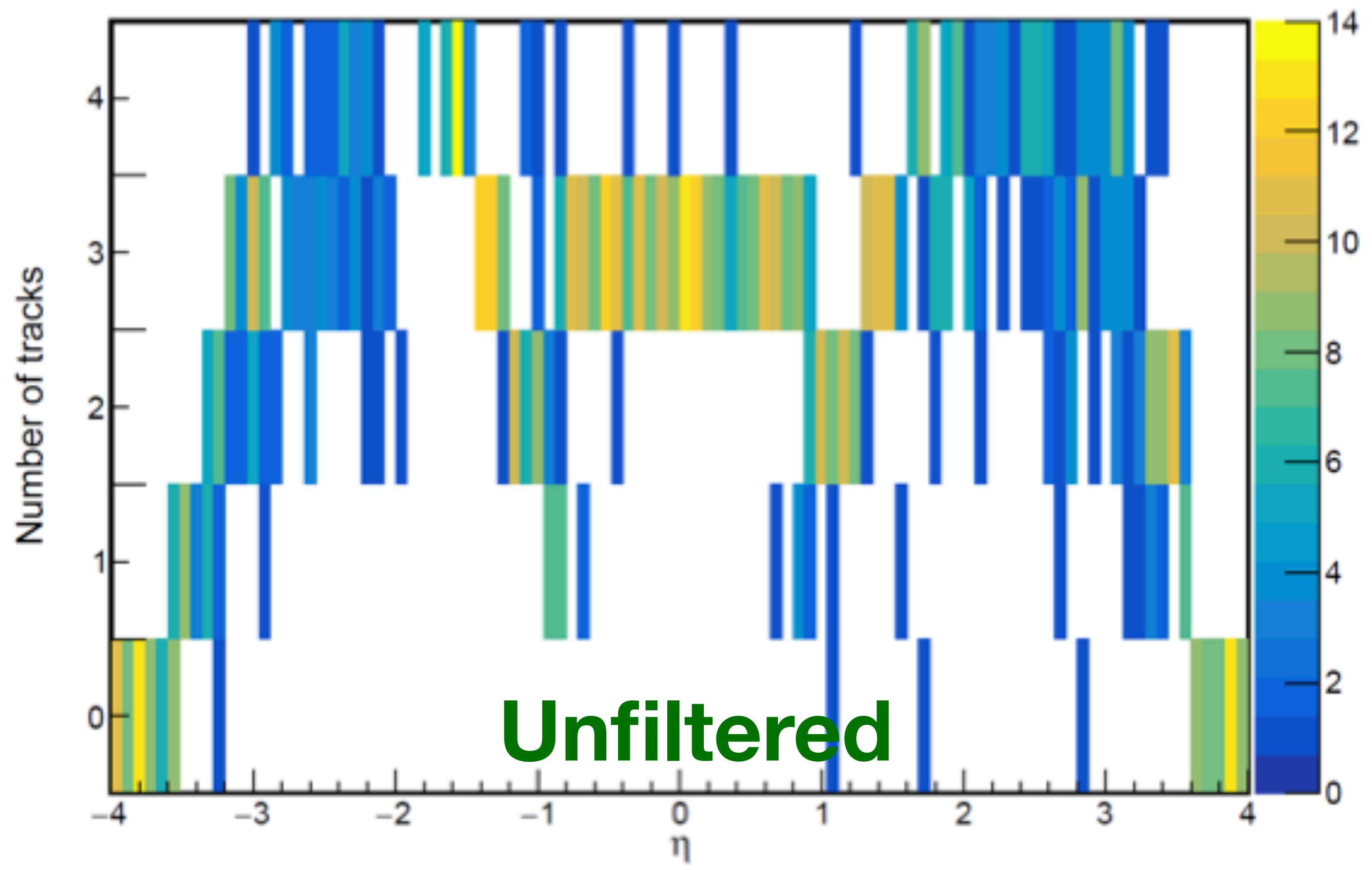
Impact of greedy ambiguity resolution solver in real-seeded tracking

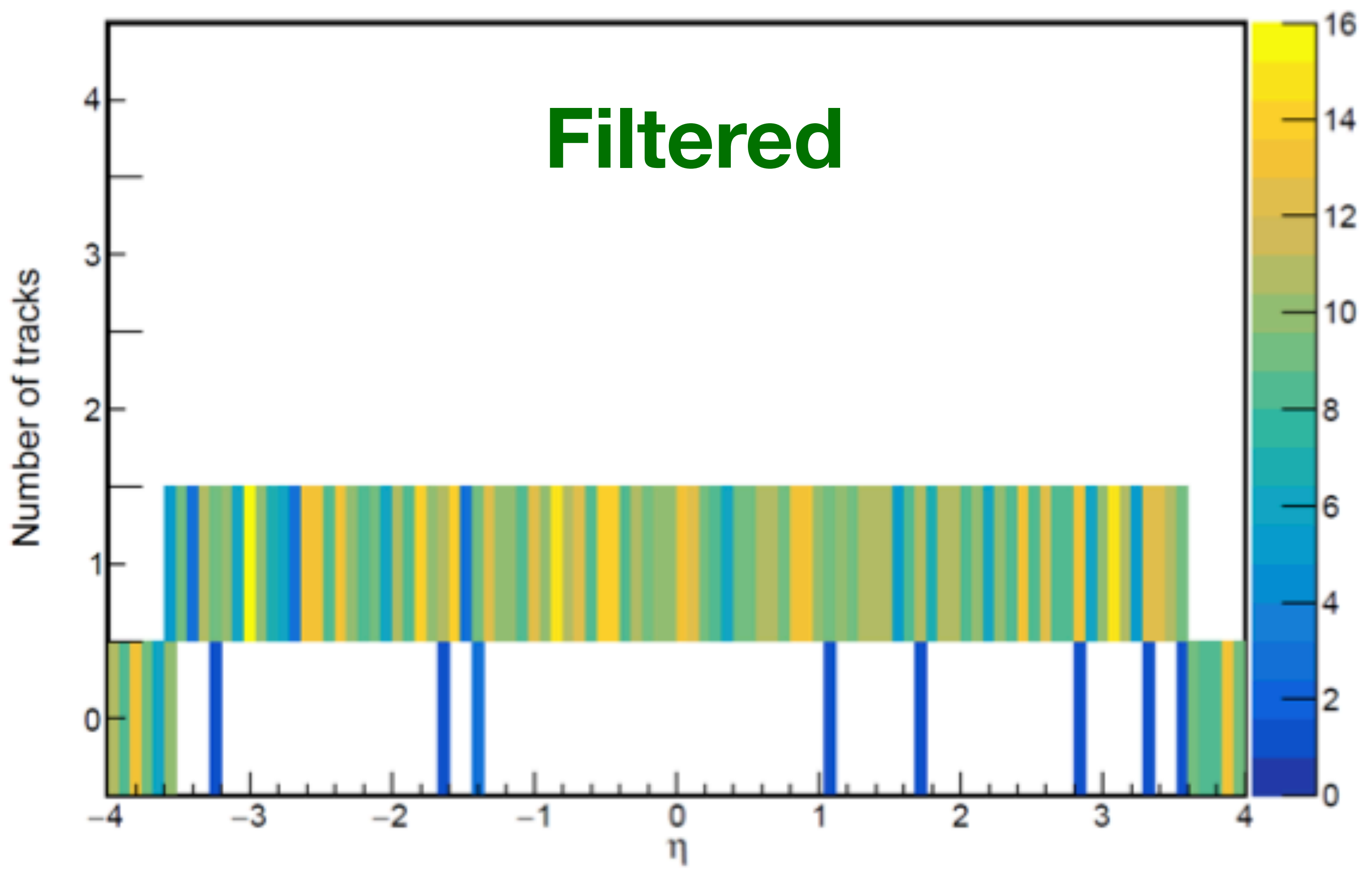
Single μ^- generated:

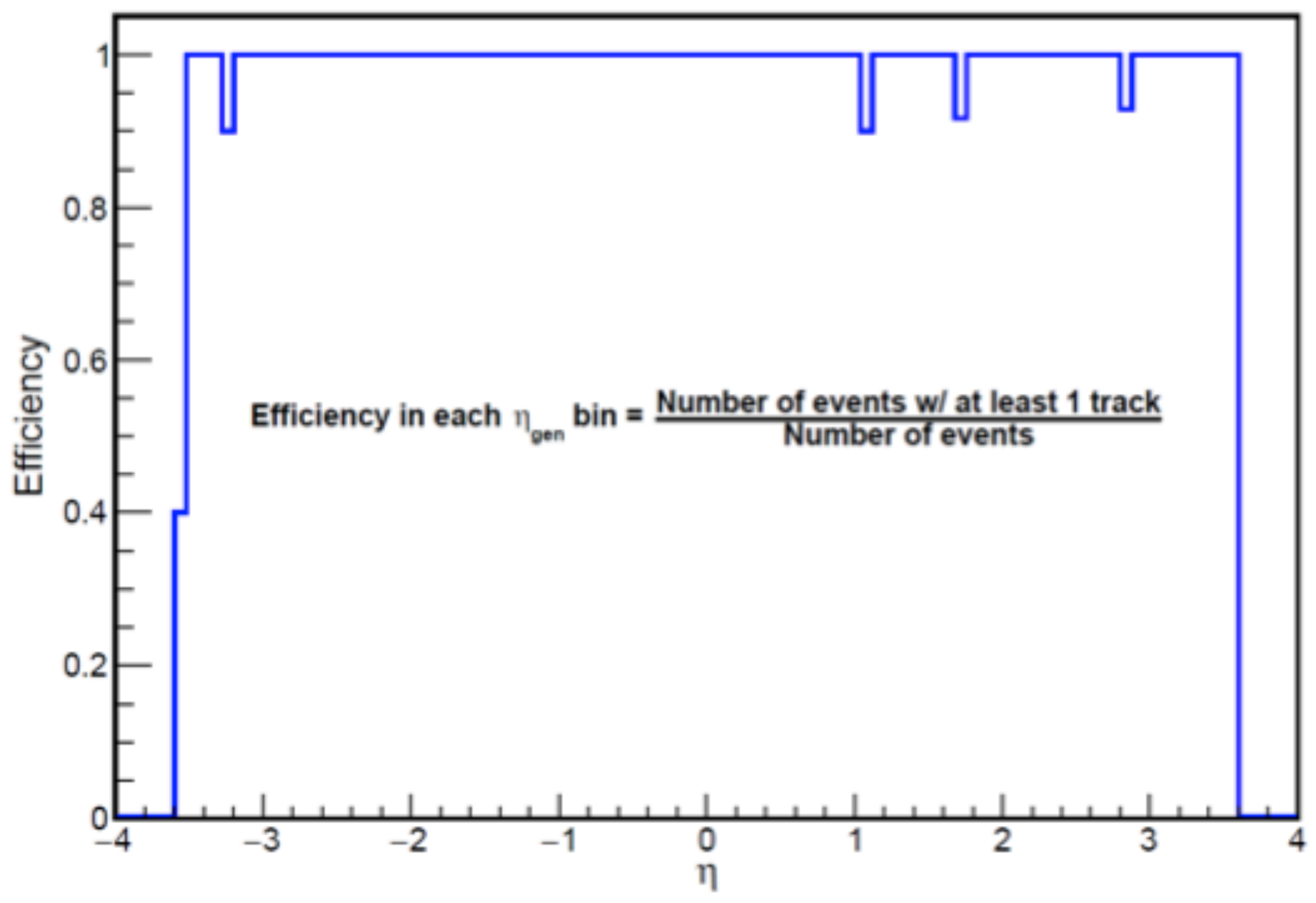
0.5 GeV/c < P < 20 GeV/c

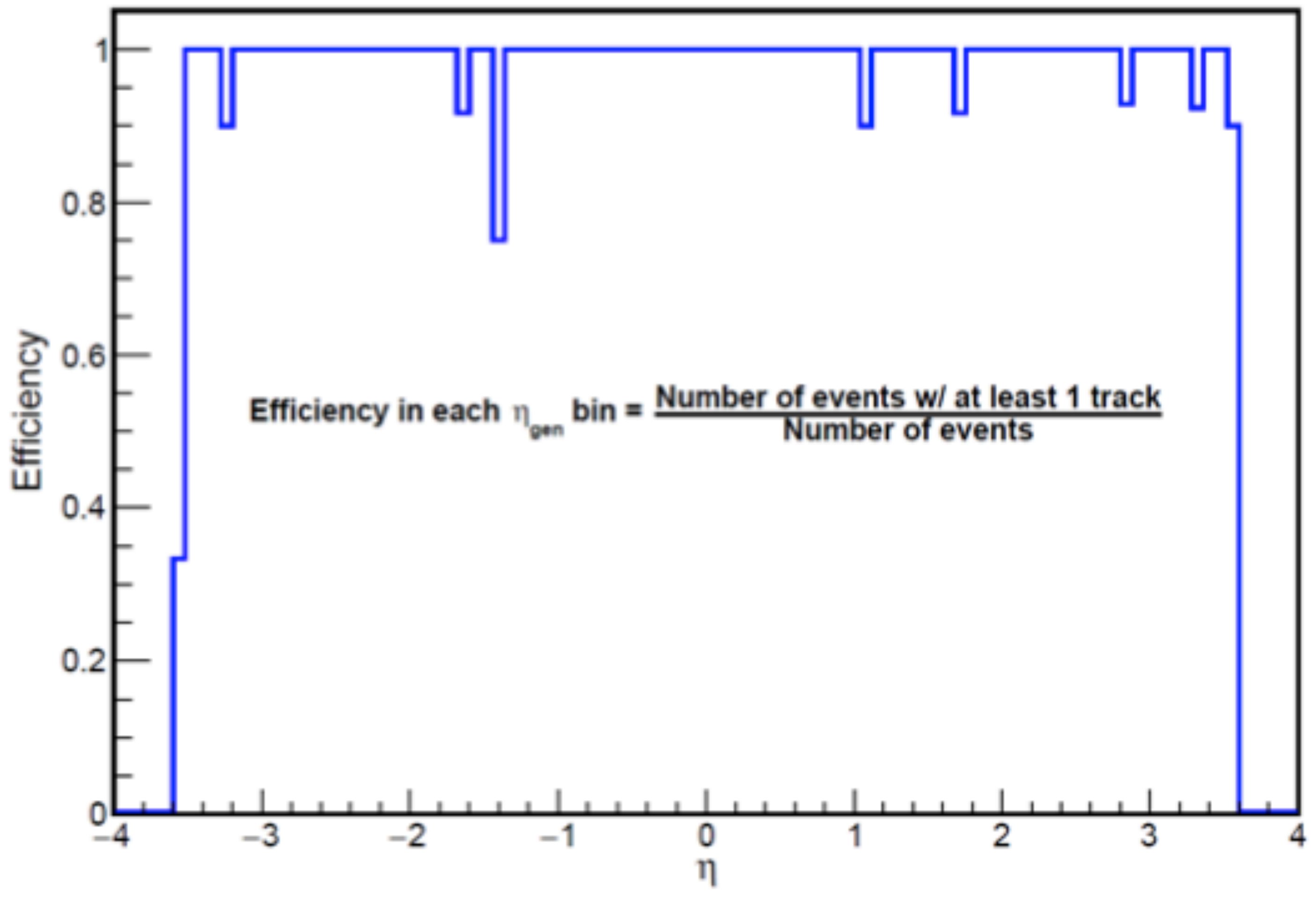
-4 < η < 4

Generated vertex: (0,0,0) mm



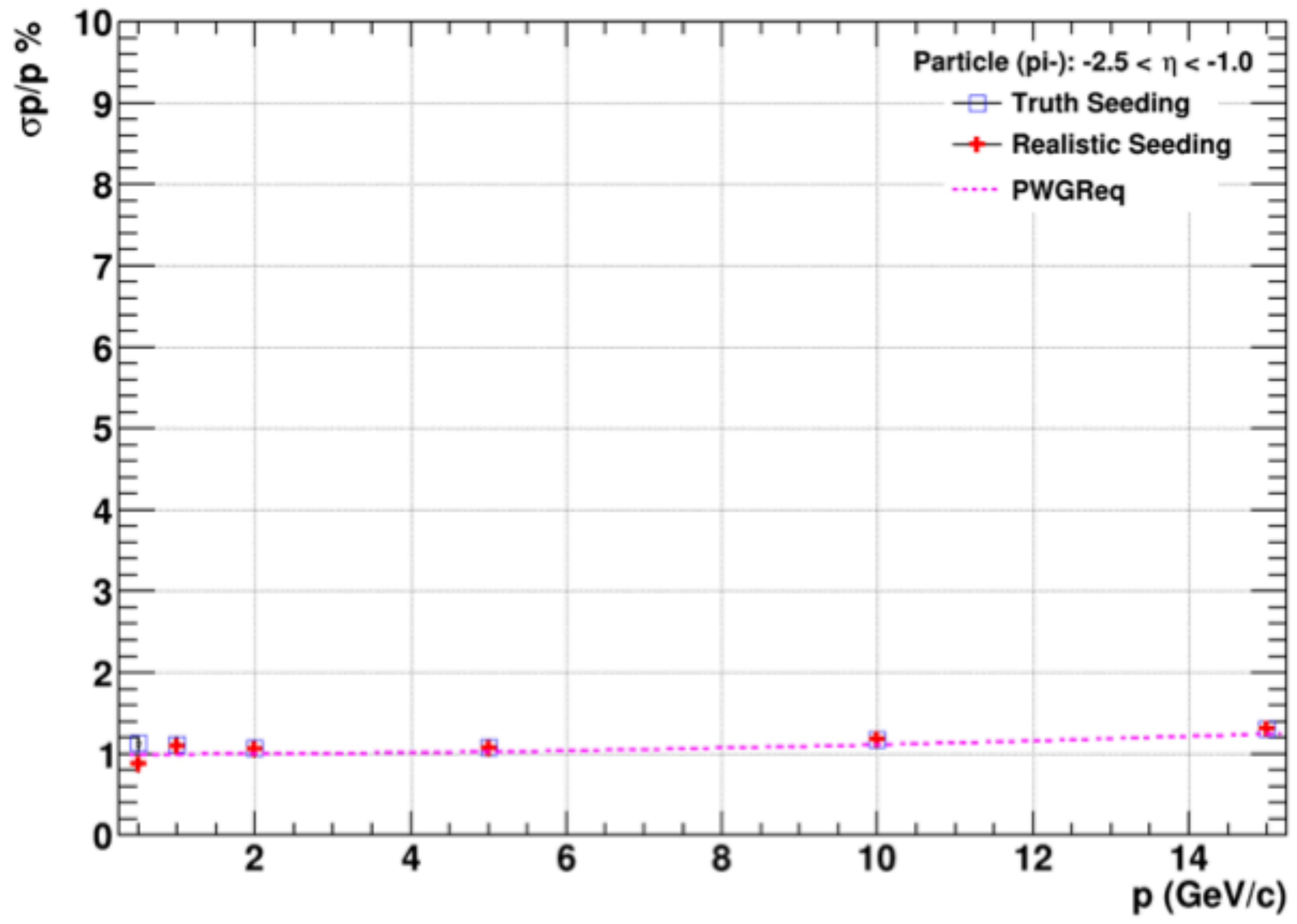


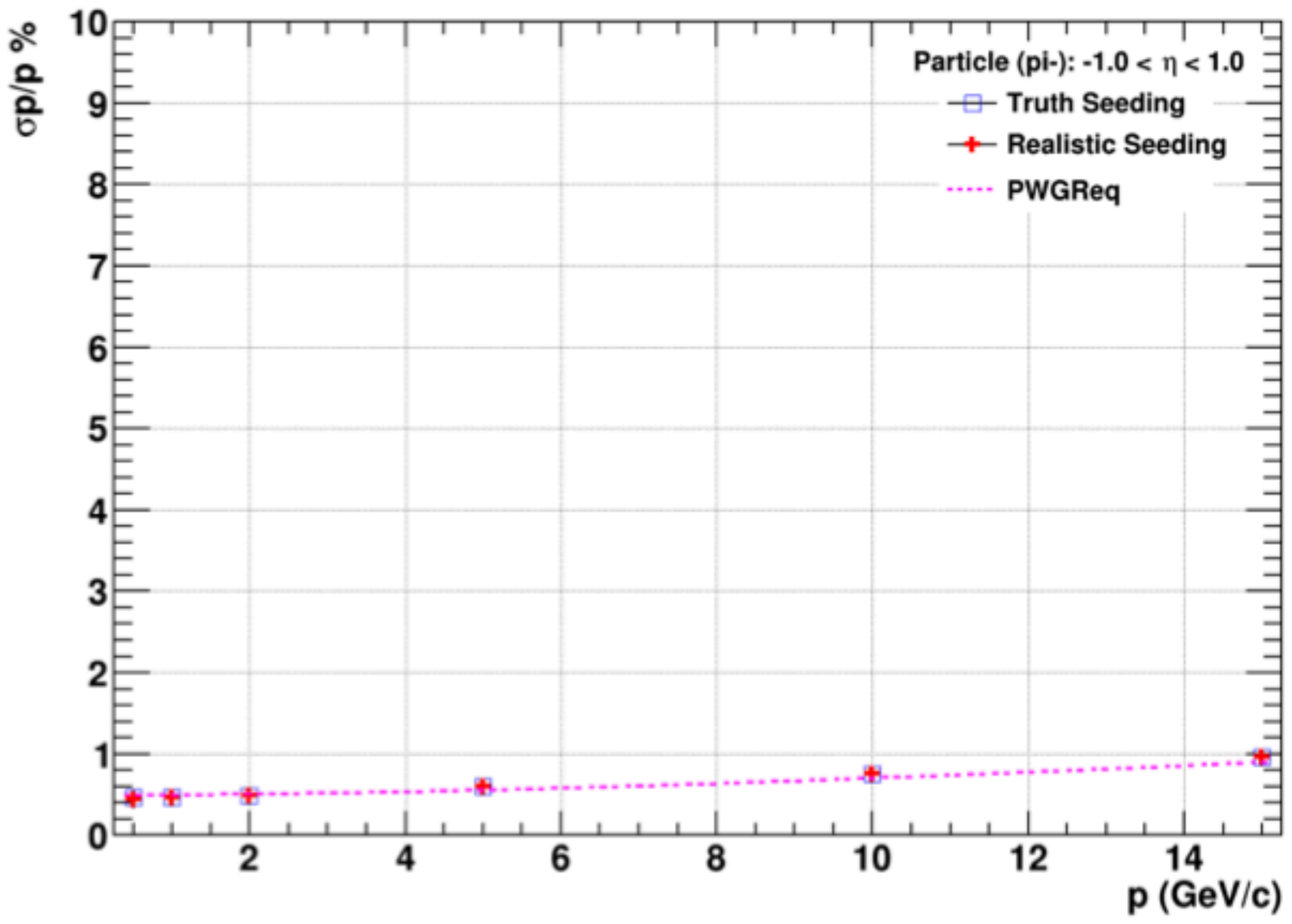


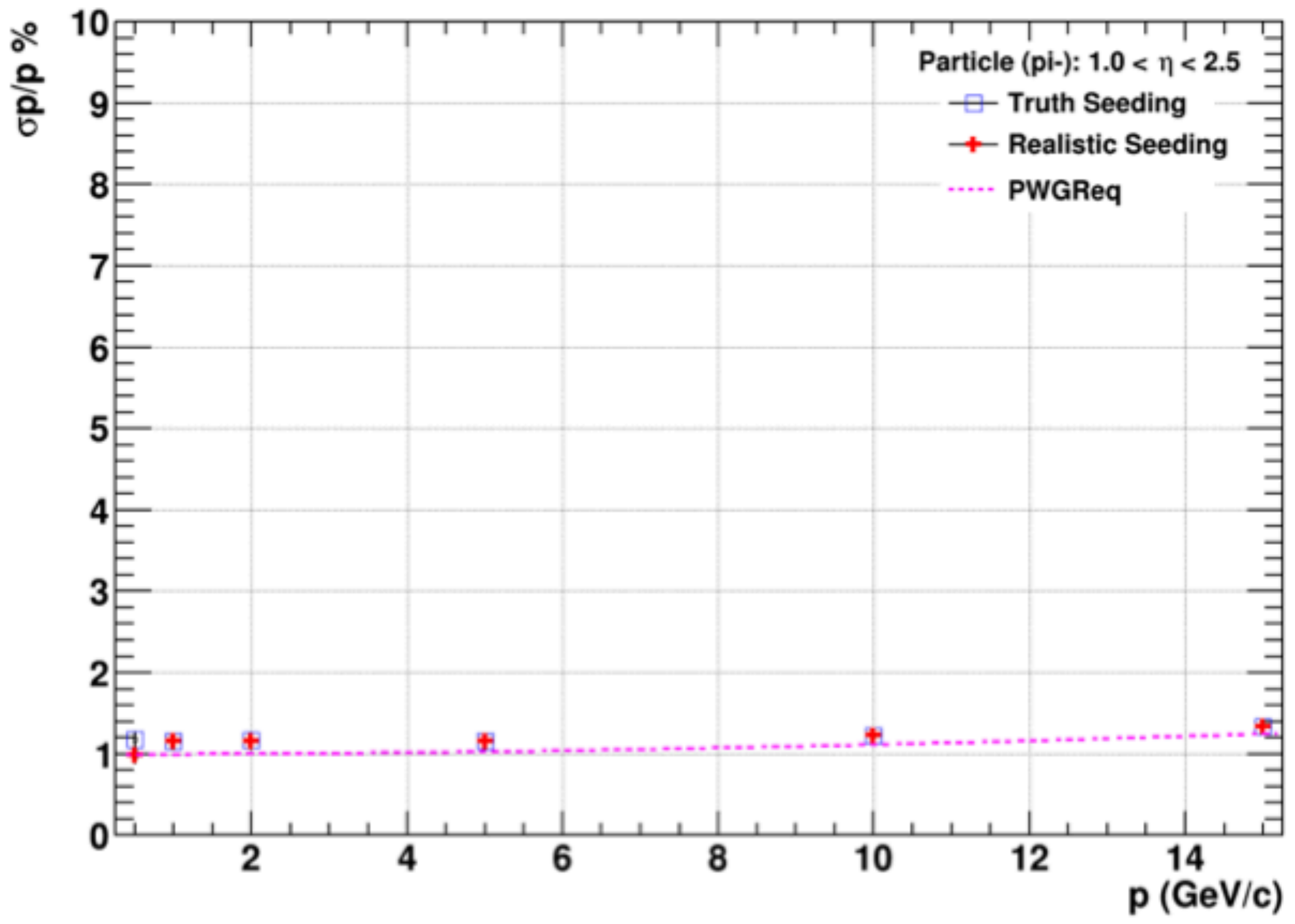


Updated track momentum resolution

Work by Shyam Kumar





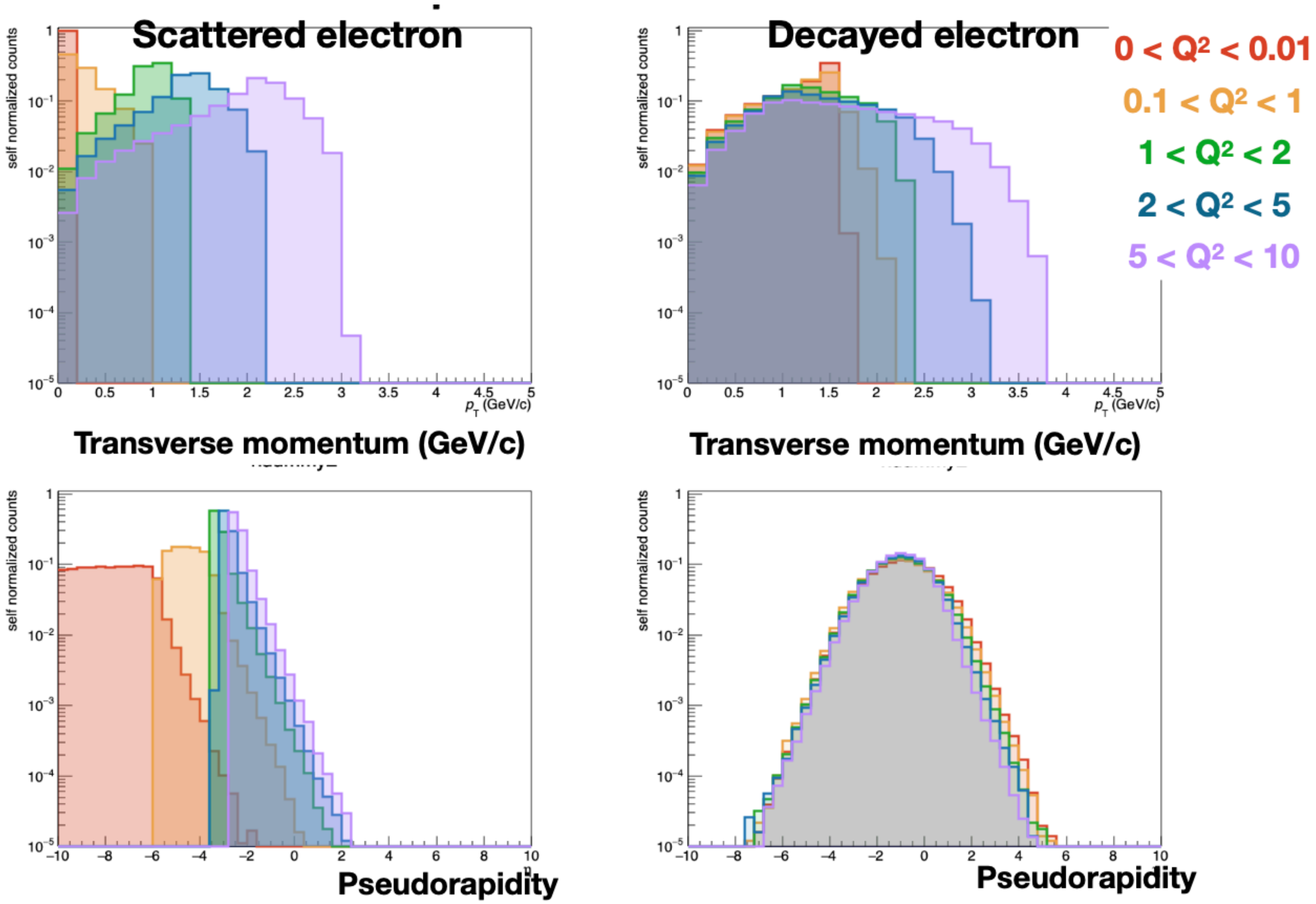


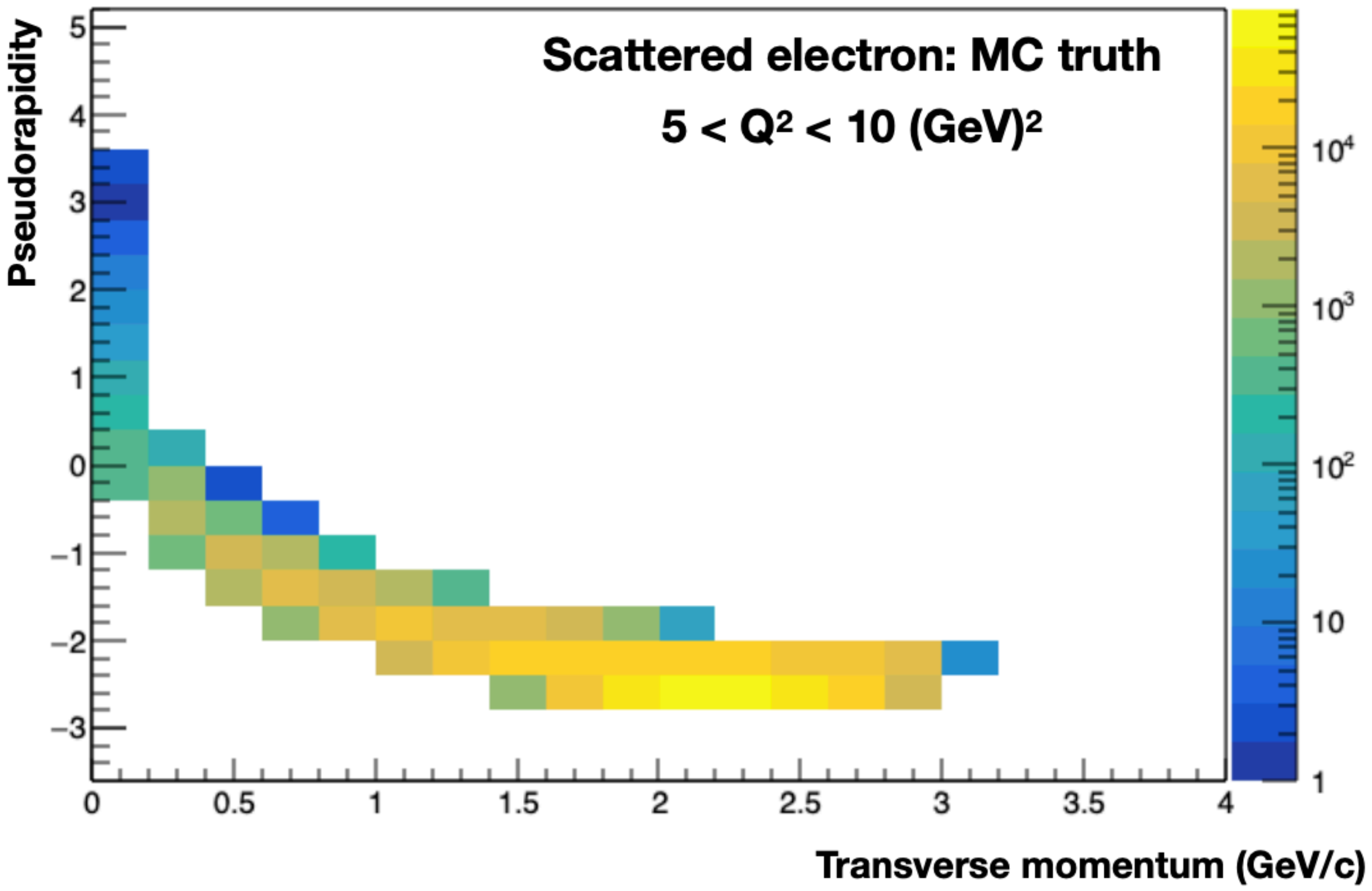
- ✦ **Momentum resolution plots are now part of monthly benchmark campaign**
- ✦ **Additional performance plots (efficiency and purity…) will be added, running automatically for quality checks - accessible in online web browser**

Simple physics case: Exclusive J/ψ photoproduction

- ✦ Coherent production of eA→eA'J/ψ→e(e+e-)A' with eSTARLight

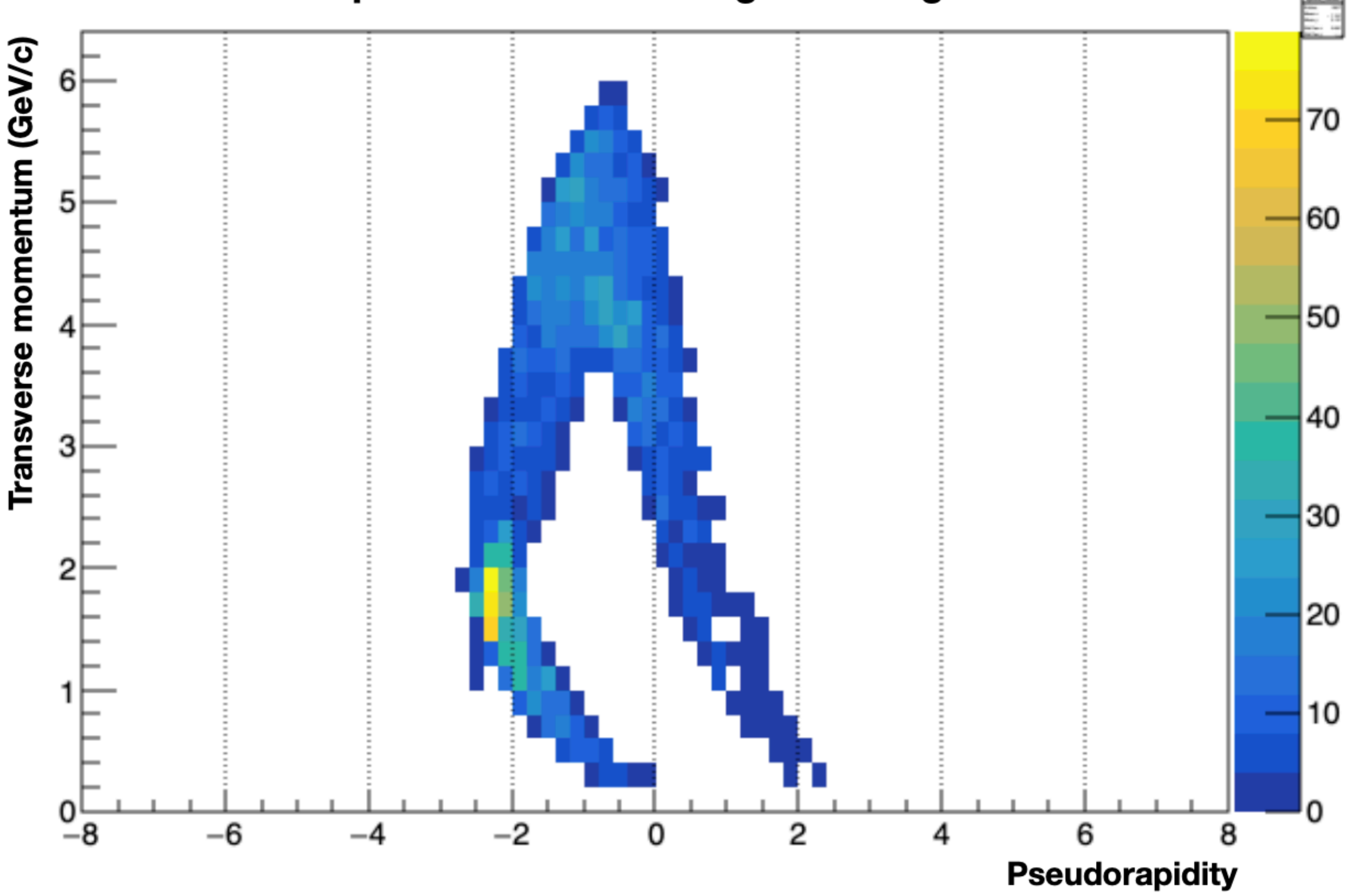
- ✦ Final state particle kinematics are well constrained; most of cases 3 electrons



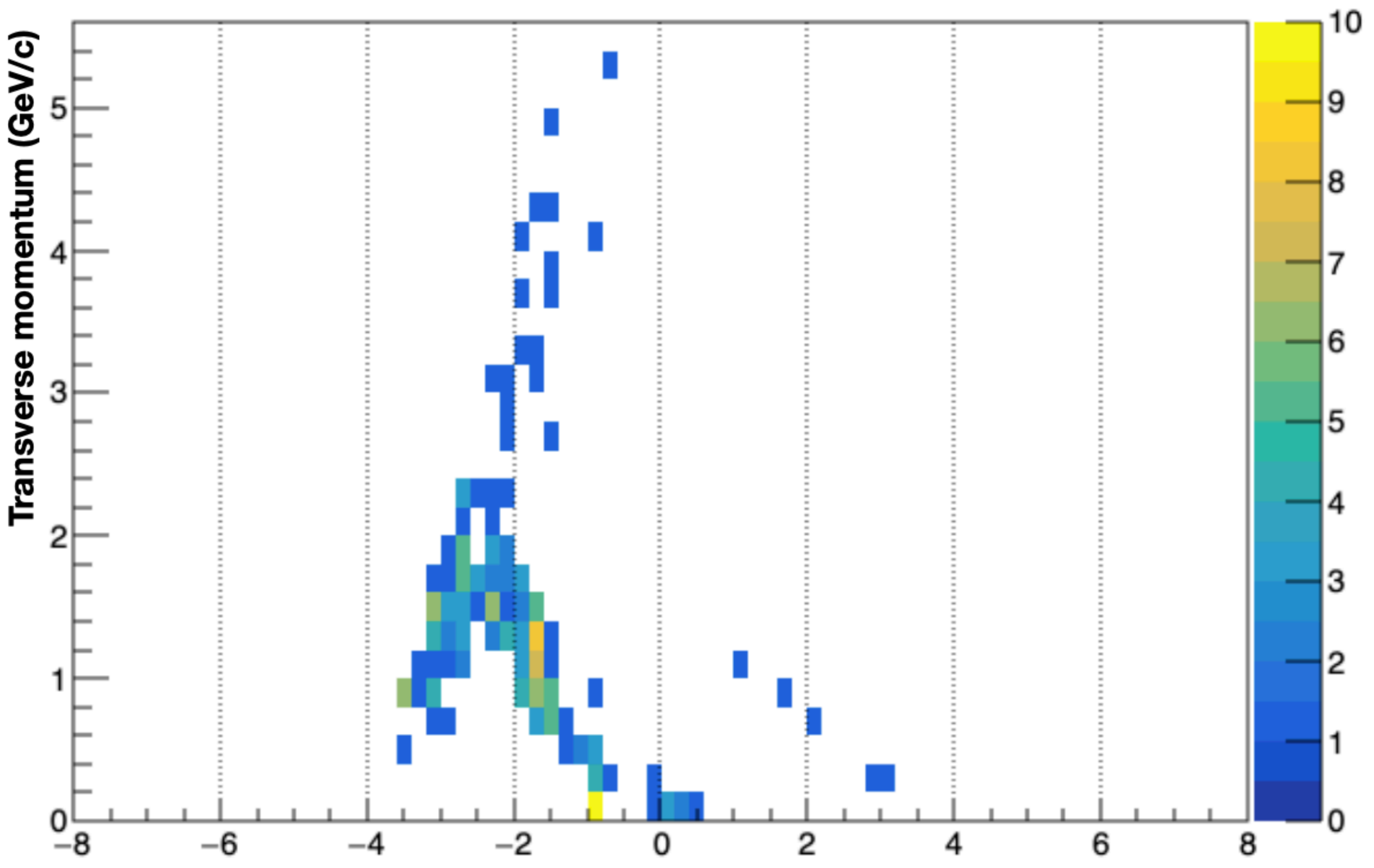


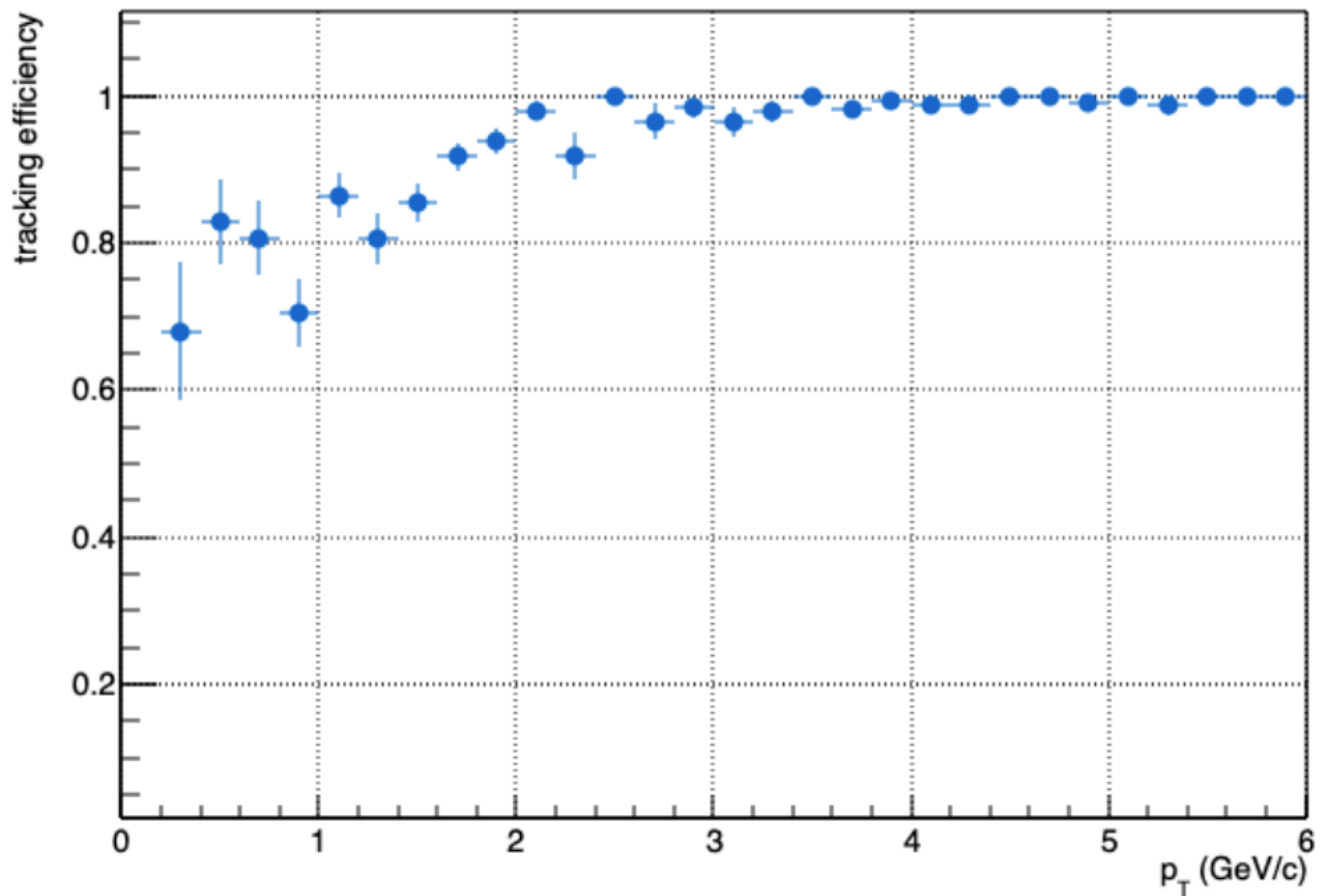
Simple physics case: Exclusive J/ψ photoproduction

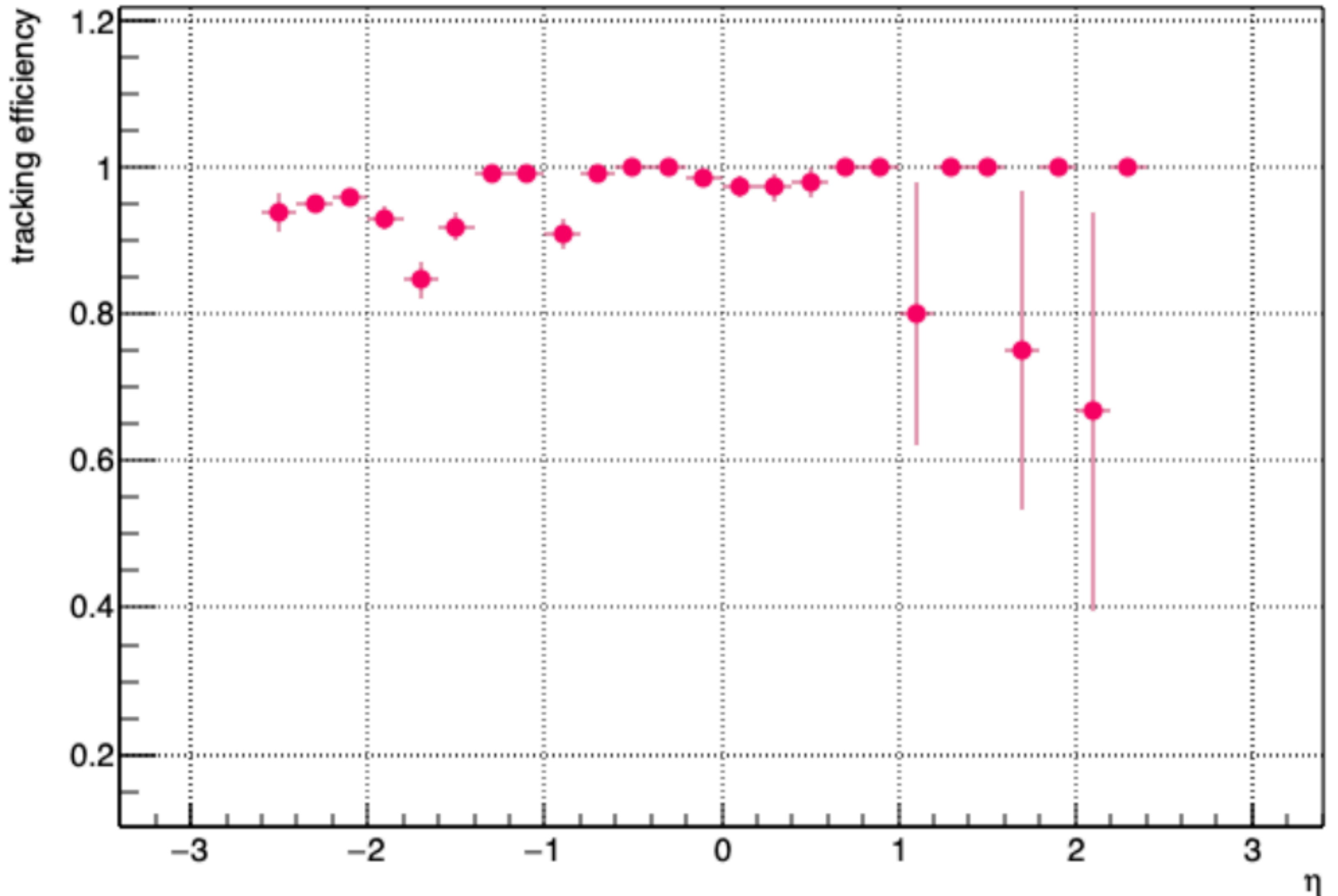
MC eta-pT distribution having matching tracks



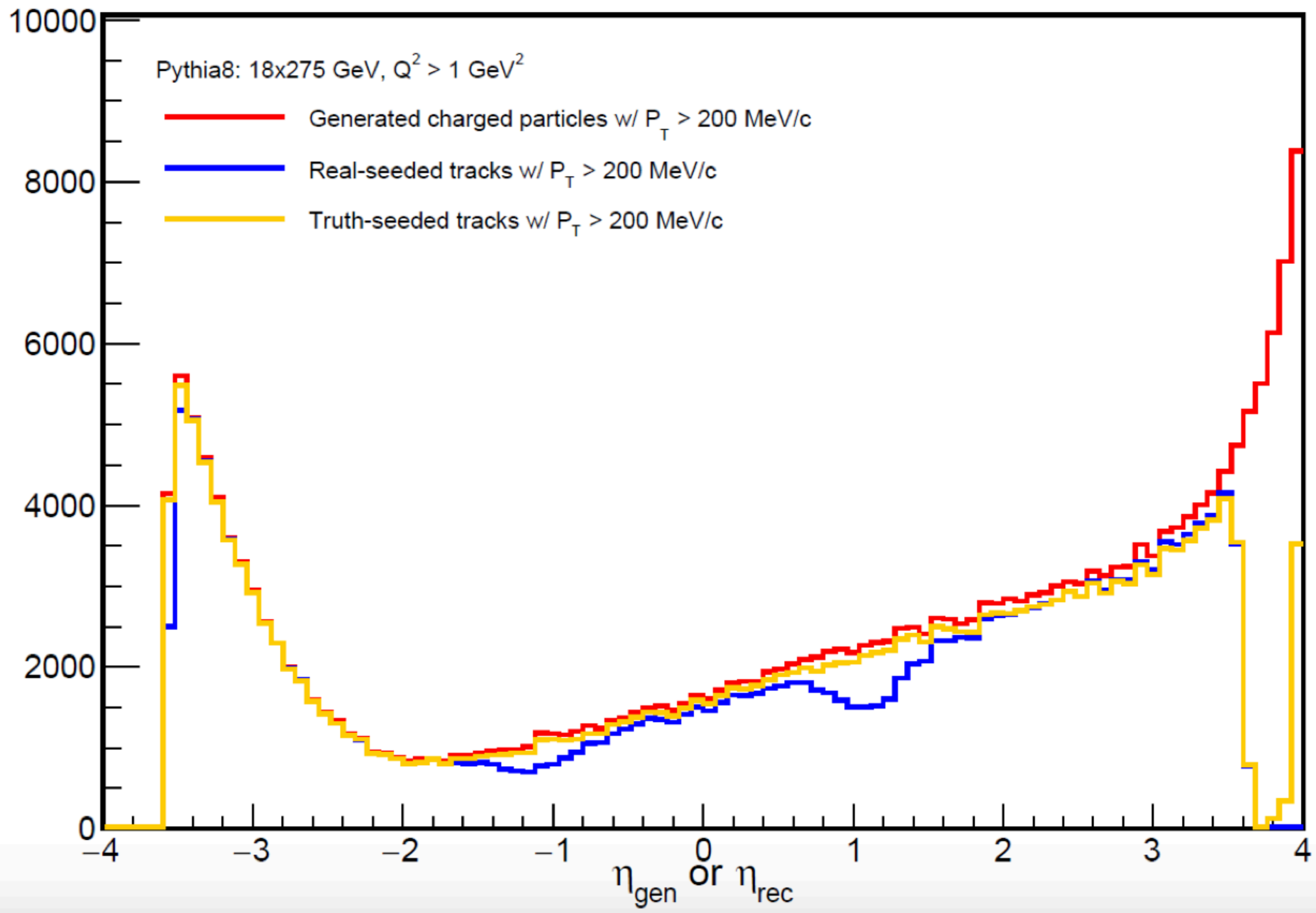
MC eta-pT distribution not having matching tracks







DIS event: Pythia with $Q^2 > 1$ GeV at the 18x275 GeV



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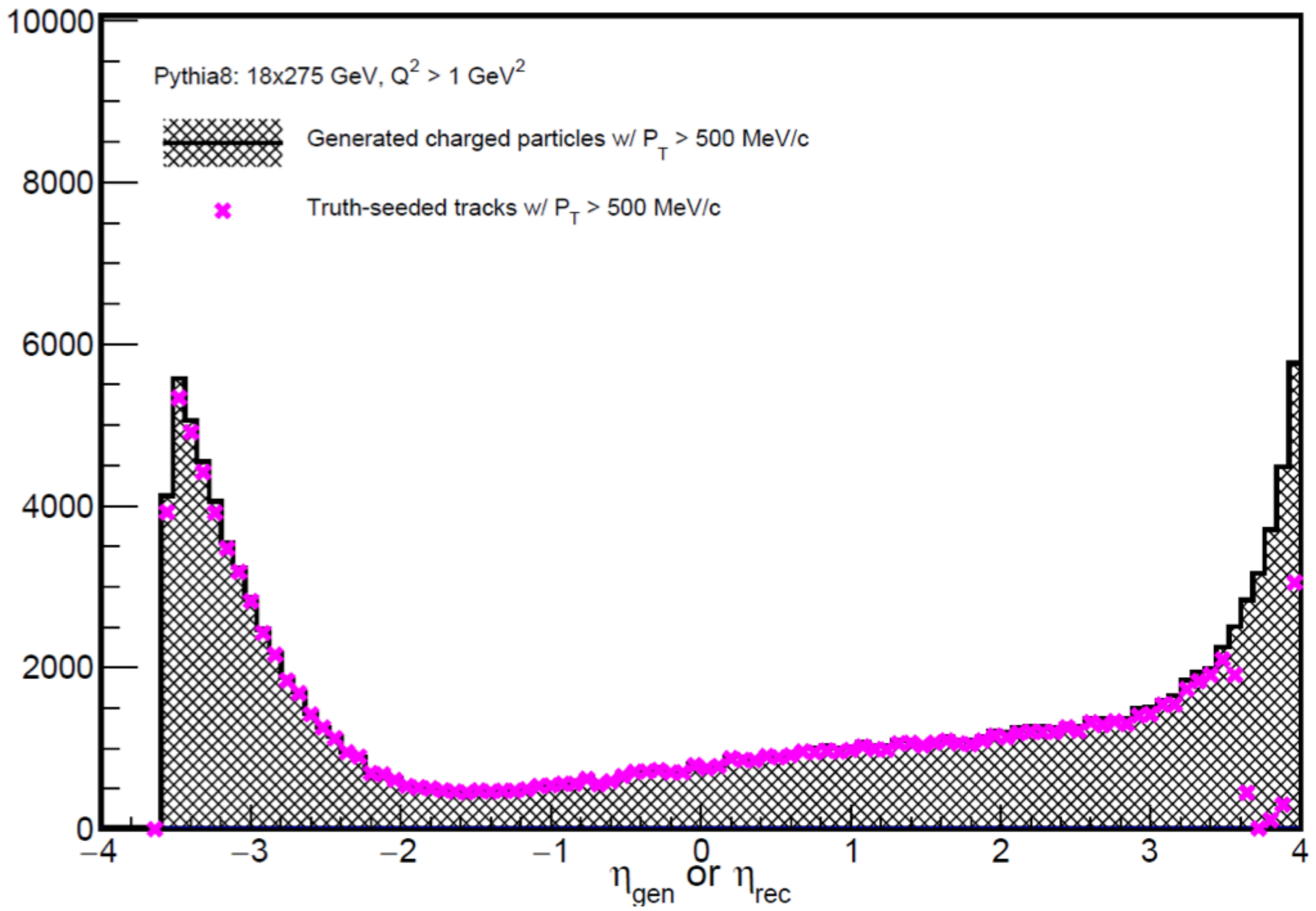
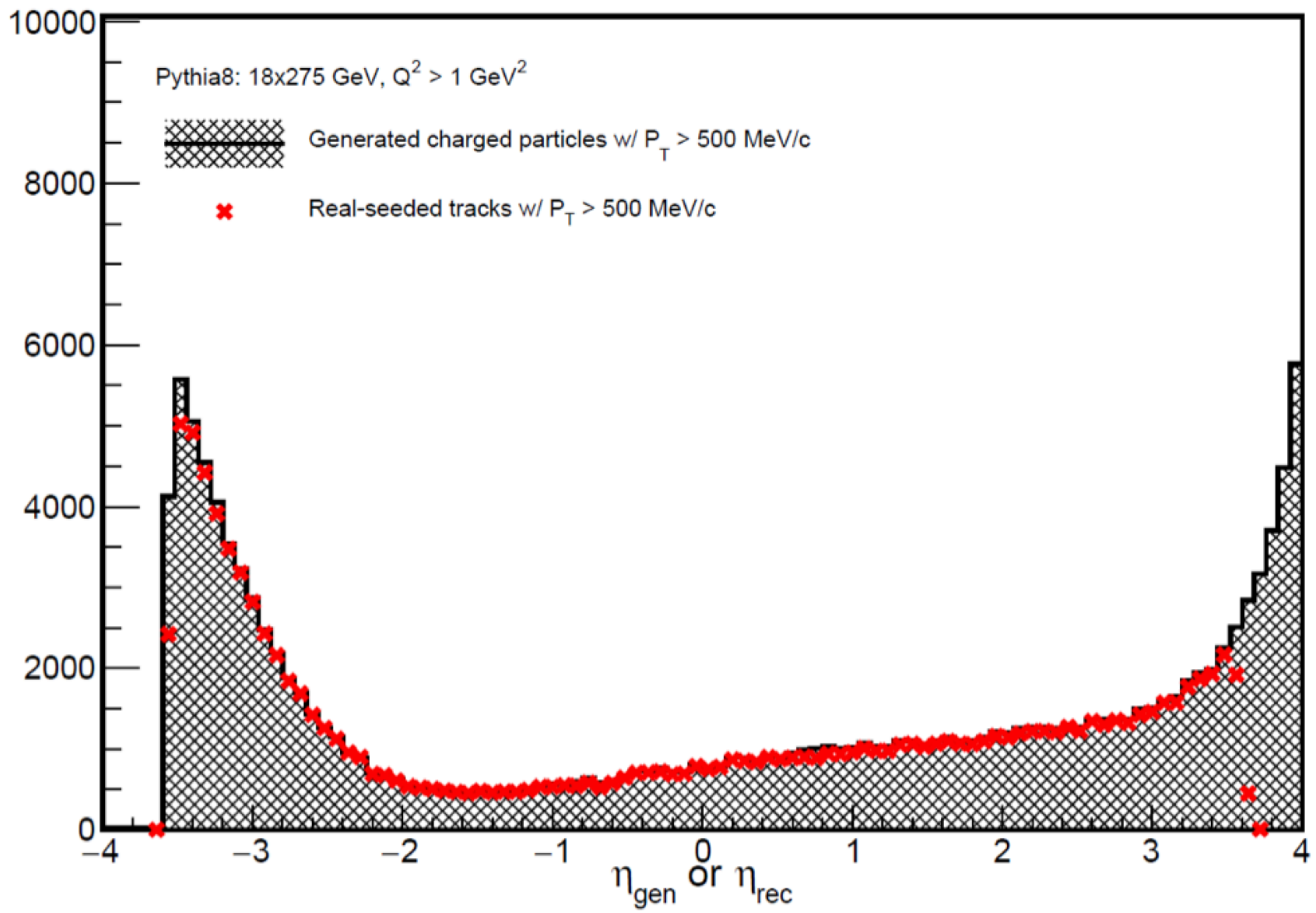
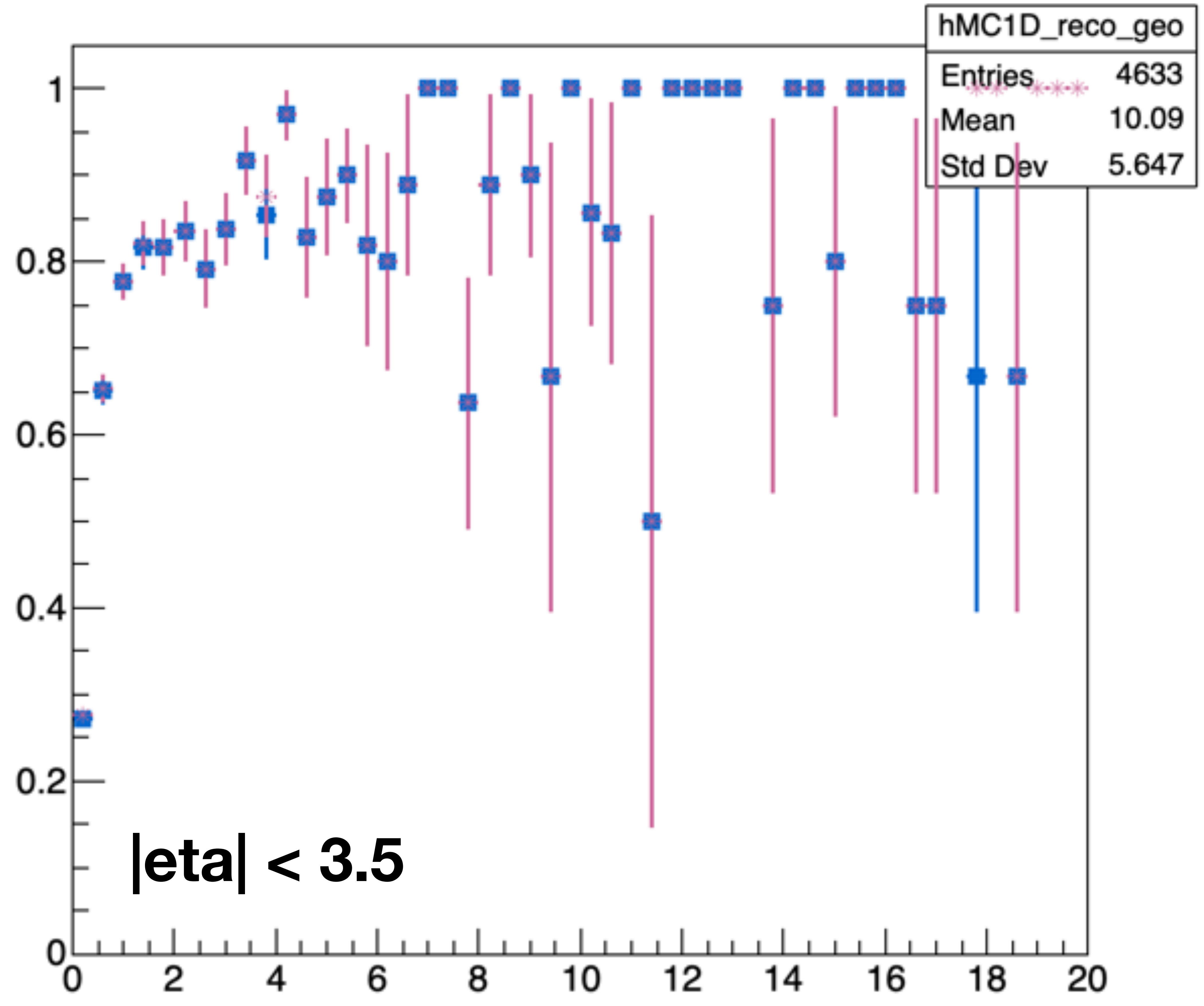


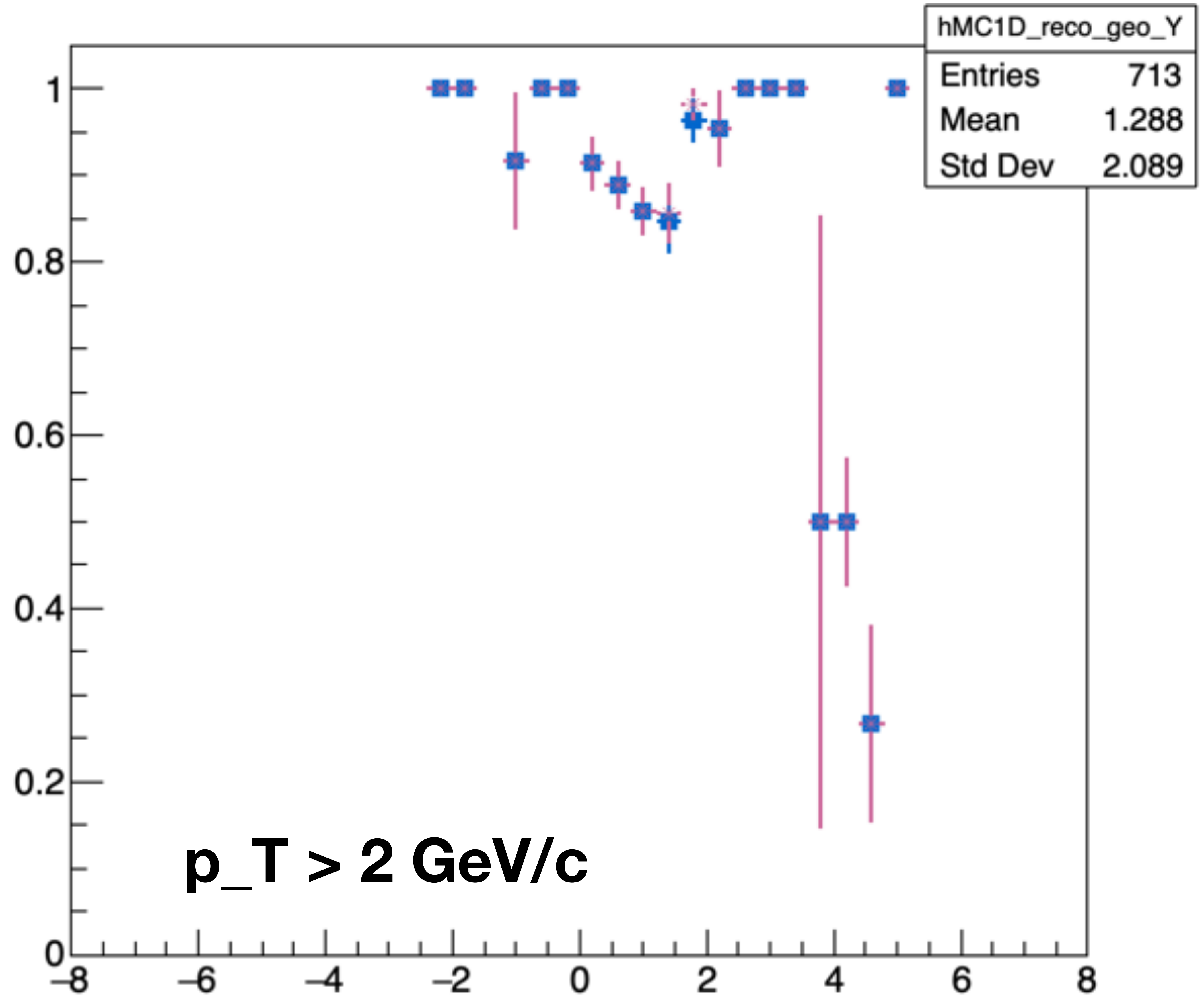


- ✦ Tracking efficiency above pT > 500 MeV shows no strong eta dependence and reach up to ~ 100%

DIS event: Pythia with Q² > 1000 GeV at the 18x275 GeV

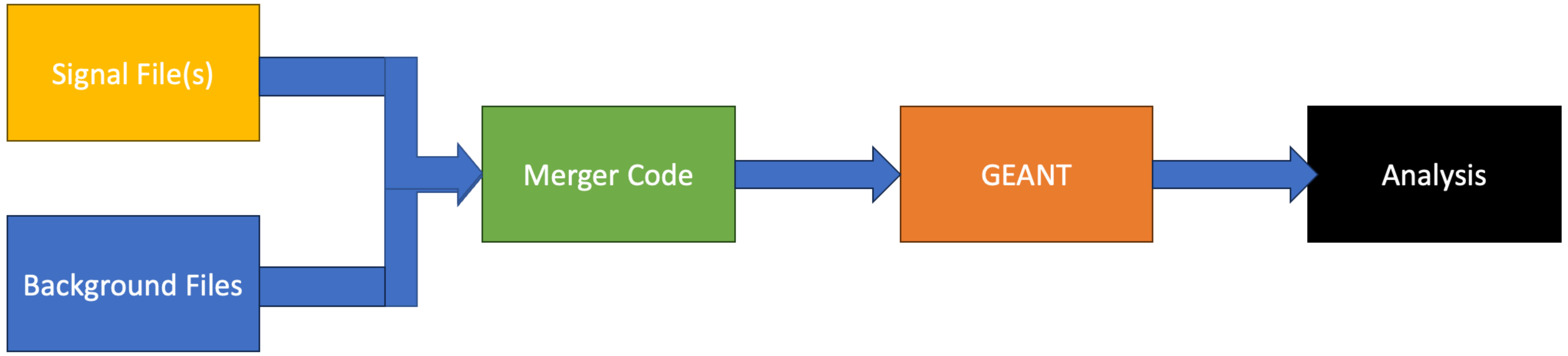
Work-in-progress!!





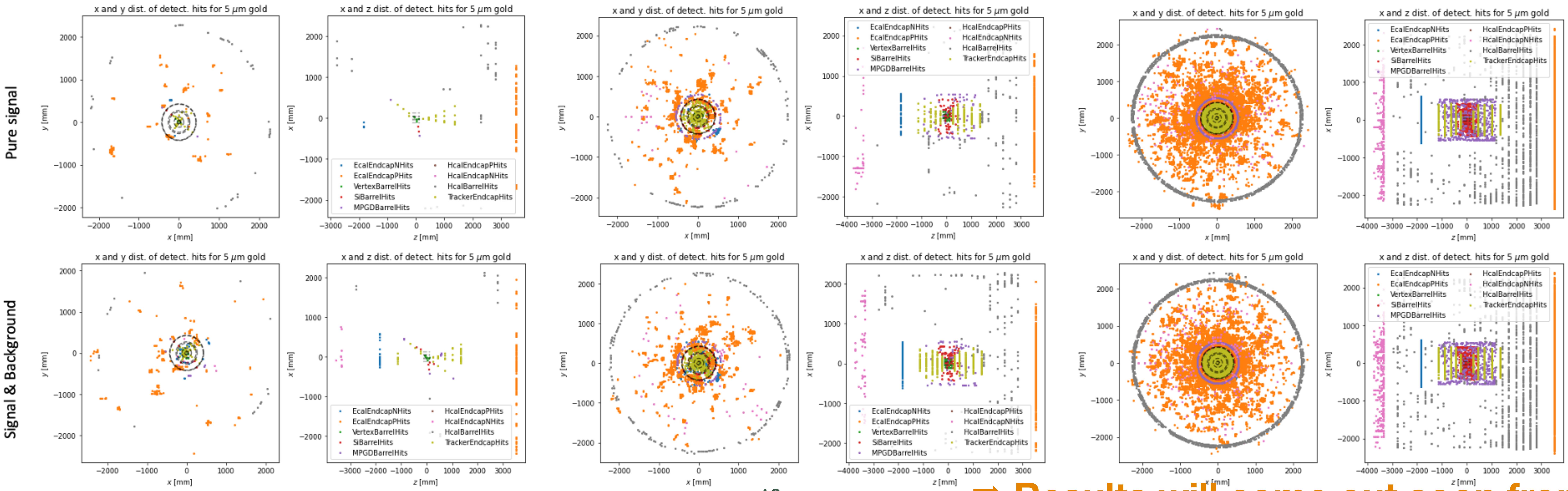
✦ Eta dependent inefficiency stays in high pT: further investigation is needed

DIS with physics background



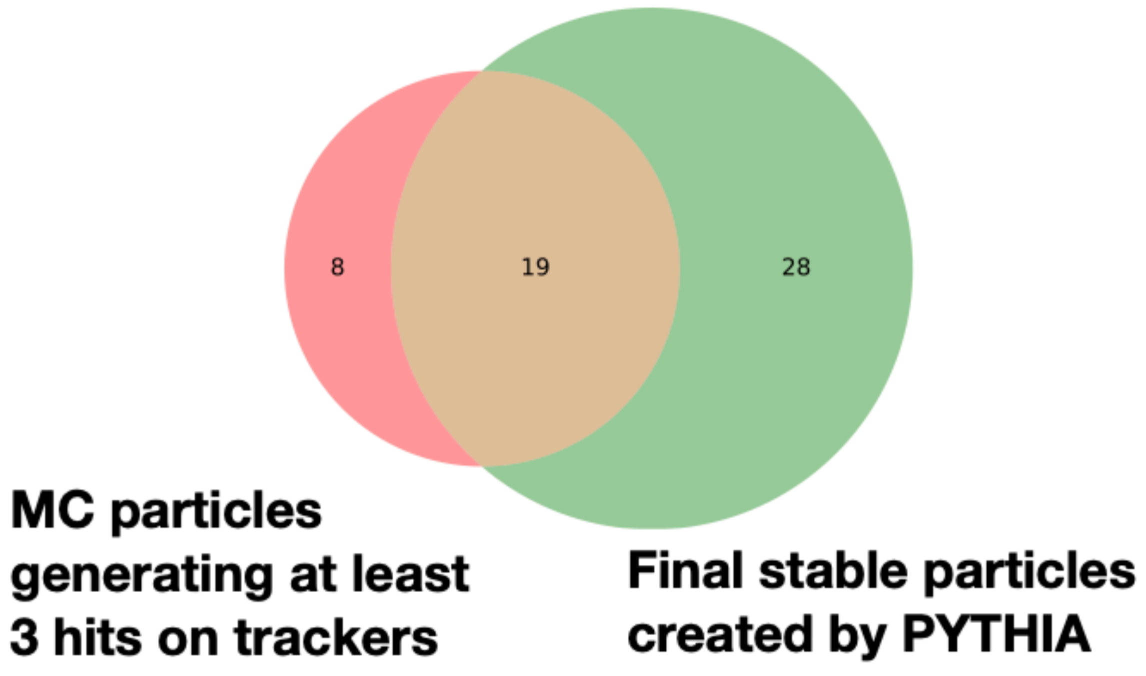
- ✦ **Signal: DIS Q2 > 1 GeV, 10x100 GeV**
- ✦ **Background:**
  - Synchrotron Radiation
  - Hadron Gas: 31347 Frequency in Nanoseconds
  - Electron Gas: 333 Frequency in Nanoseconds

1 Event | 10 Events | 100 Events



➡ **Results will come out soon from Ben**

Tracking algorithm: room for improvements!



MC particles
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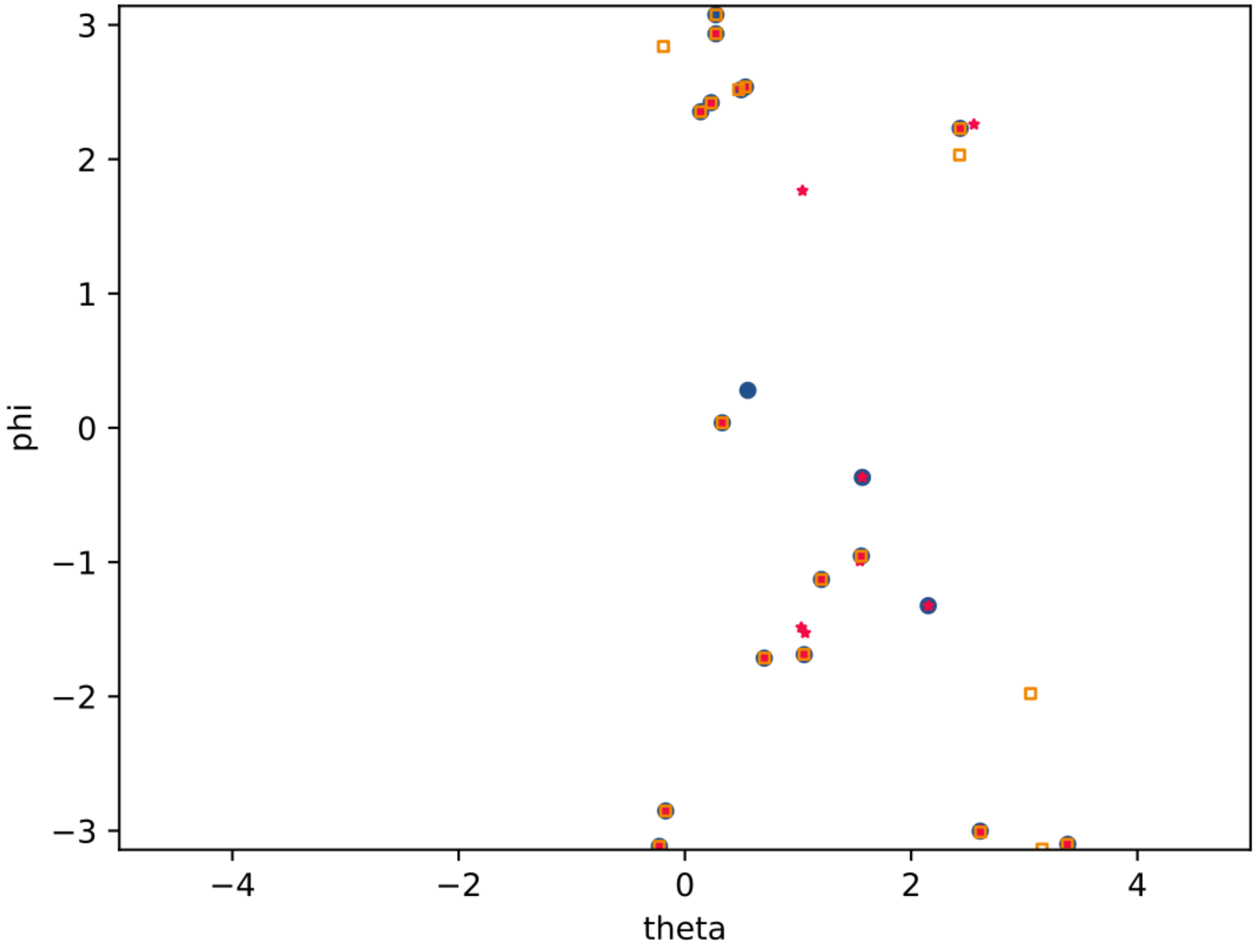
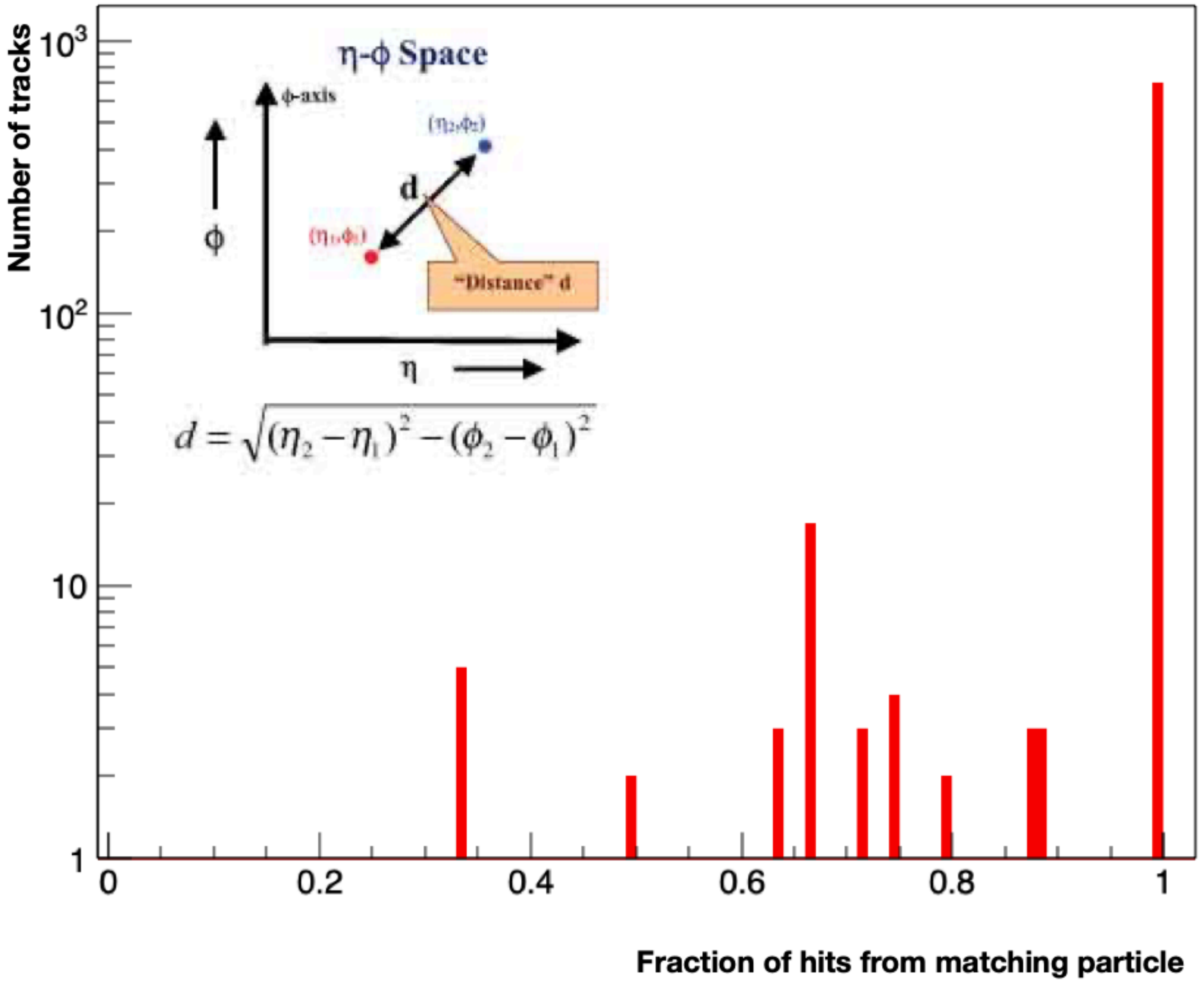
Truth seeding
(Some kinematic cuts but covers most of final stable particles created by PYTHIA)
Realistic seeding
(Possibly reconstructed secondary particles)





✦ **Number of tracks are different in truth/realistic seeding:**

- Truth seeding takes the all charged particles generated (physics level generator) particle with loose pT and eta cut
- Truth seeding: even the particles leaving less than 3 hits on tracker are in there/secondary particles produced in material cannot be considered

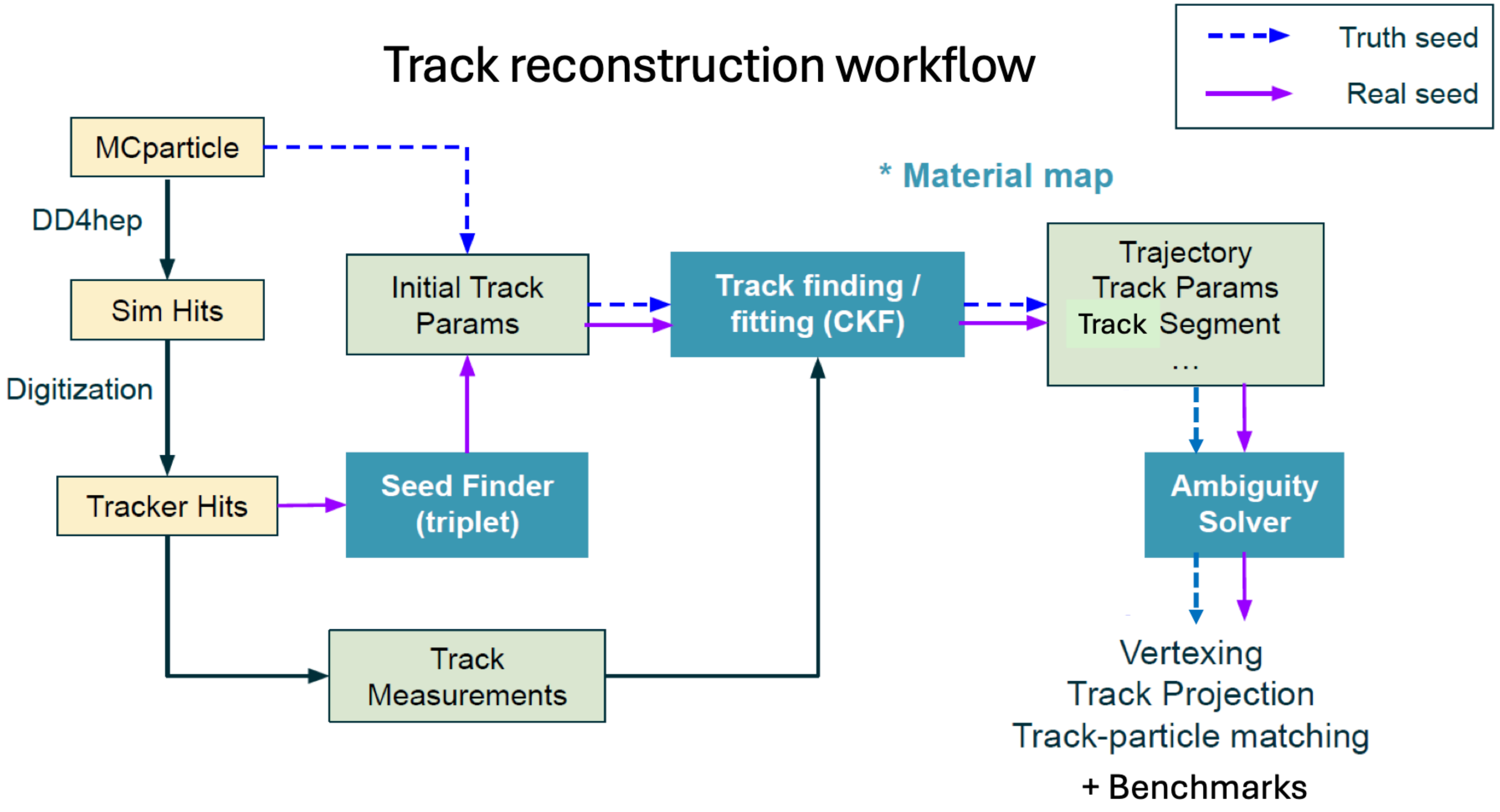
✦ **Matching between MC particle and reco. tracks:**

- Matching based on angular distance/Tricky in large multiplicity events with background tracks

Summary and outlook

- ✦ Greedy Ambiguity Resolution Solver (from ACTS) is now part of EICrecon
- ✦ Further reco. algorithms (Vertexing, PID matching,..) as well as Physics performance studies can realize without additional modification in their code showing good performance!
- ✦ QA on DIS sample looks reasonable; several features should be double-checked!
- ✦ Extending towards detailed tracking performance studies
- ✦ As well as improvement on the machineries

Track reconstruction workflow



Plots from EIC Yellow Report

Only relevant for us at this moment!

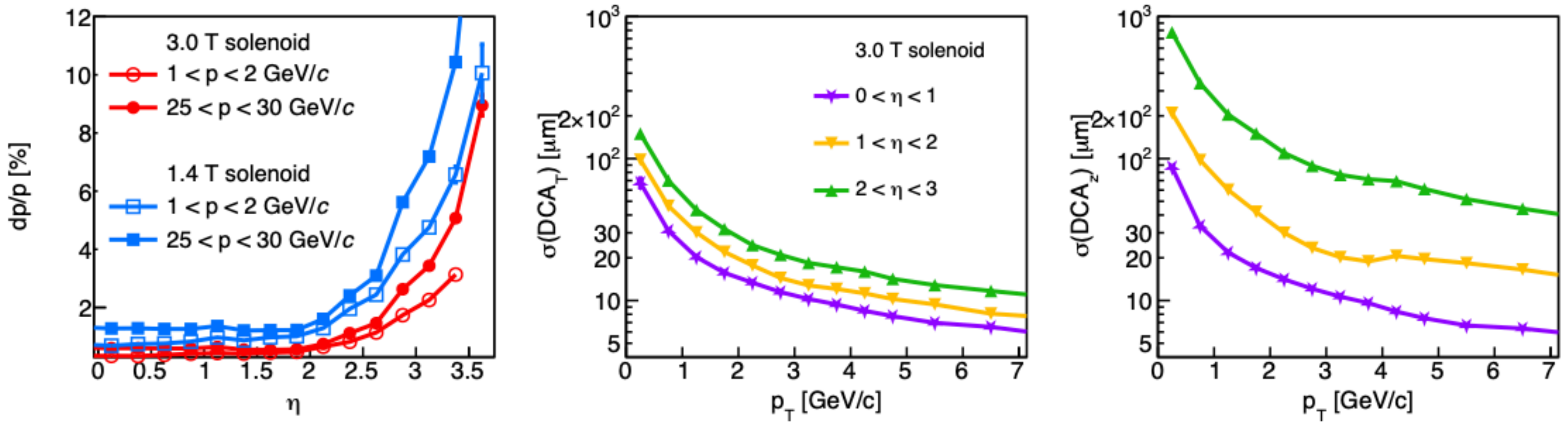
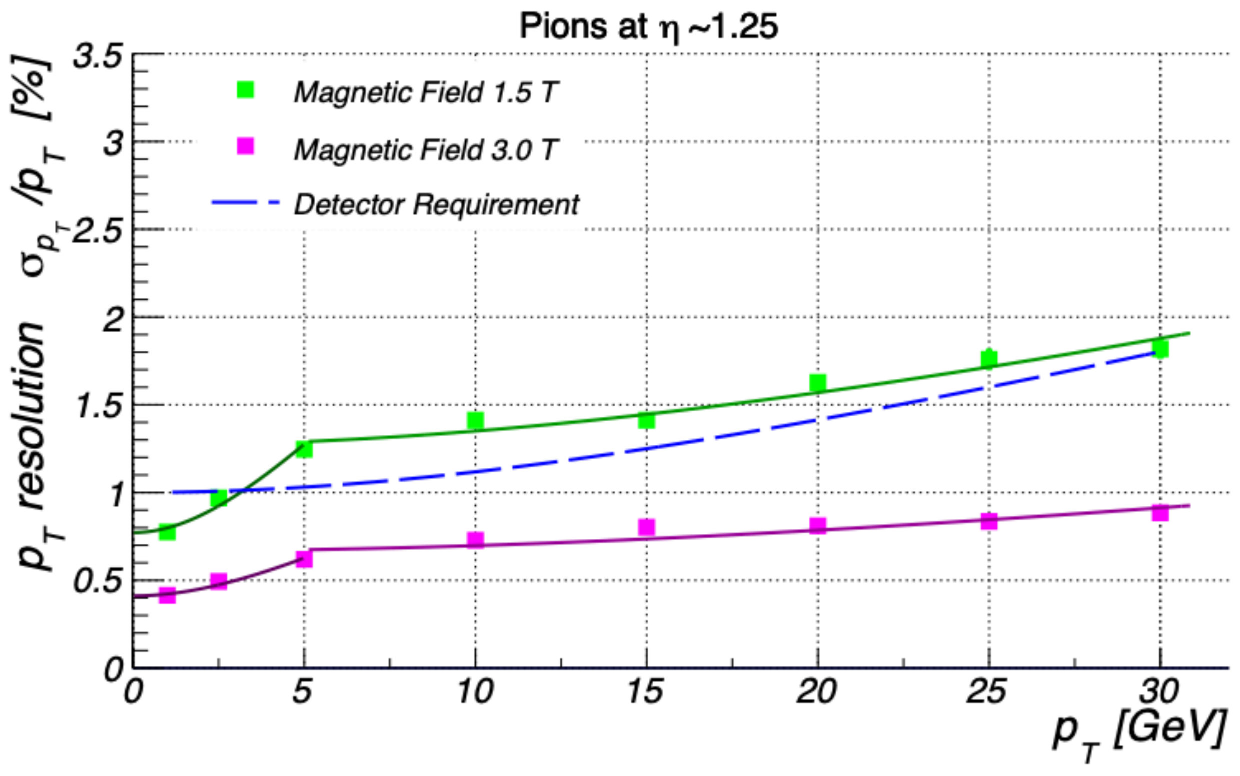


Figure 11.18: Detector resolutions. Left: Momentum resolution as a function of pseudorapidity for pions for two magnetic-field configurations for representative momentum bins. Center: Transverse Distance-of-Closest-Approach (DCA_T) resolution as a function of transverse momentum for several pseudorapidity bins. Right: Longitudinal Distance-of-Closest-Approach (DCA_z) resolution as a function of transverse momentum for several pseudorapidity bins.

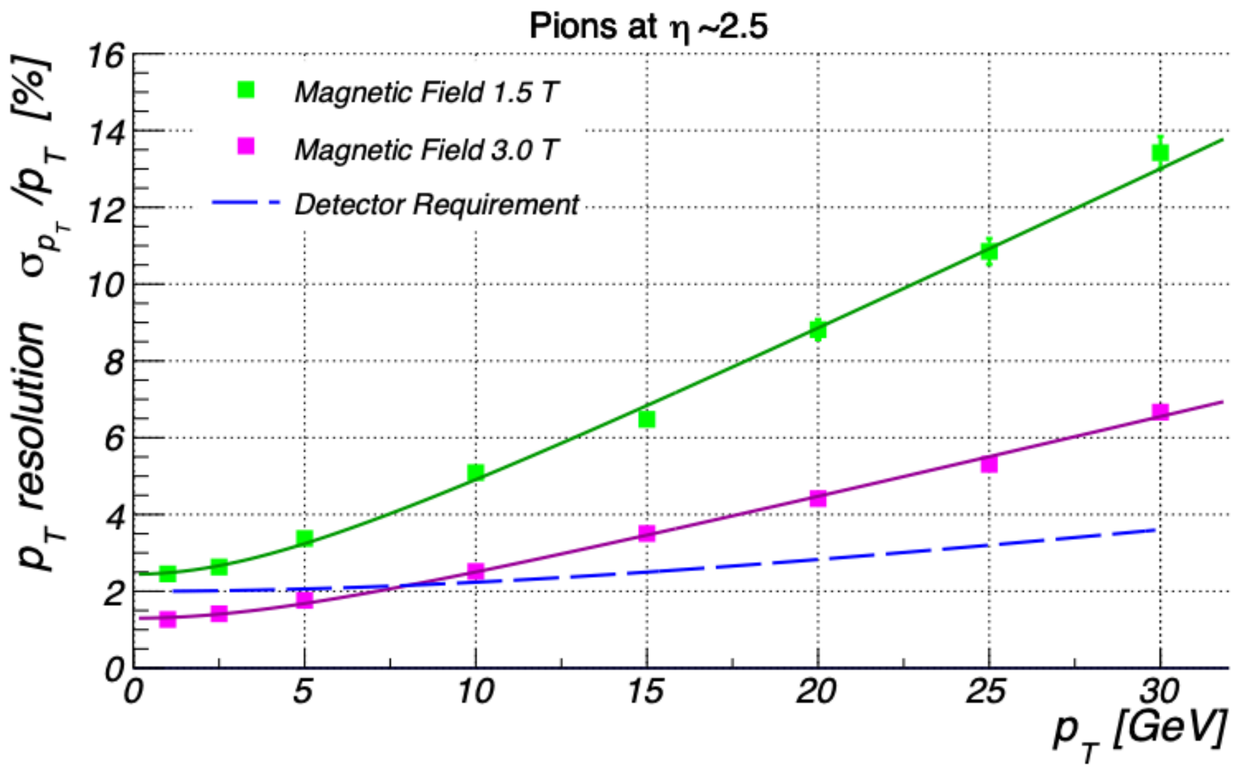
normal function fitted to the $\Delta p/p \equiv (p_{truth} - p_{reco})/p_{truth}$ distribution. Here, the labels 'truth' and 'reco' represent generated and reconstructed variables, respectively. Momentum-resolution results for pions are shown as a function of pseudorapidity in Fig. 11.18 (left). As expected from the leading-order $\sim 1/B$ dependence of the momentum resolution, doubling the magnetic field improves the momentum resolution by a factor of $\approx$2. The resulting distributions were characterized using fits with the functional form

$$dp/p = Ap \oplus B, \quad (11.1)$$

where $\oplus$ is shorthand notation for sum in quadrature. The A and B fit parameters are presented in Table 11.8.

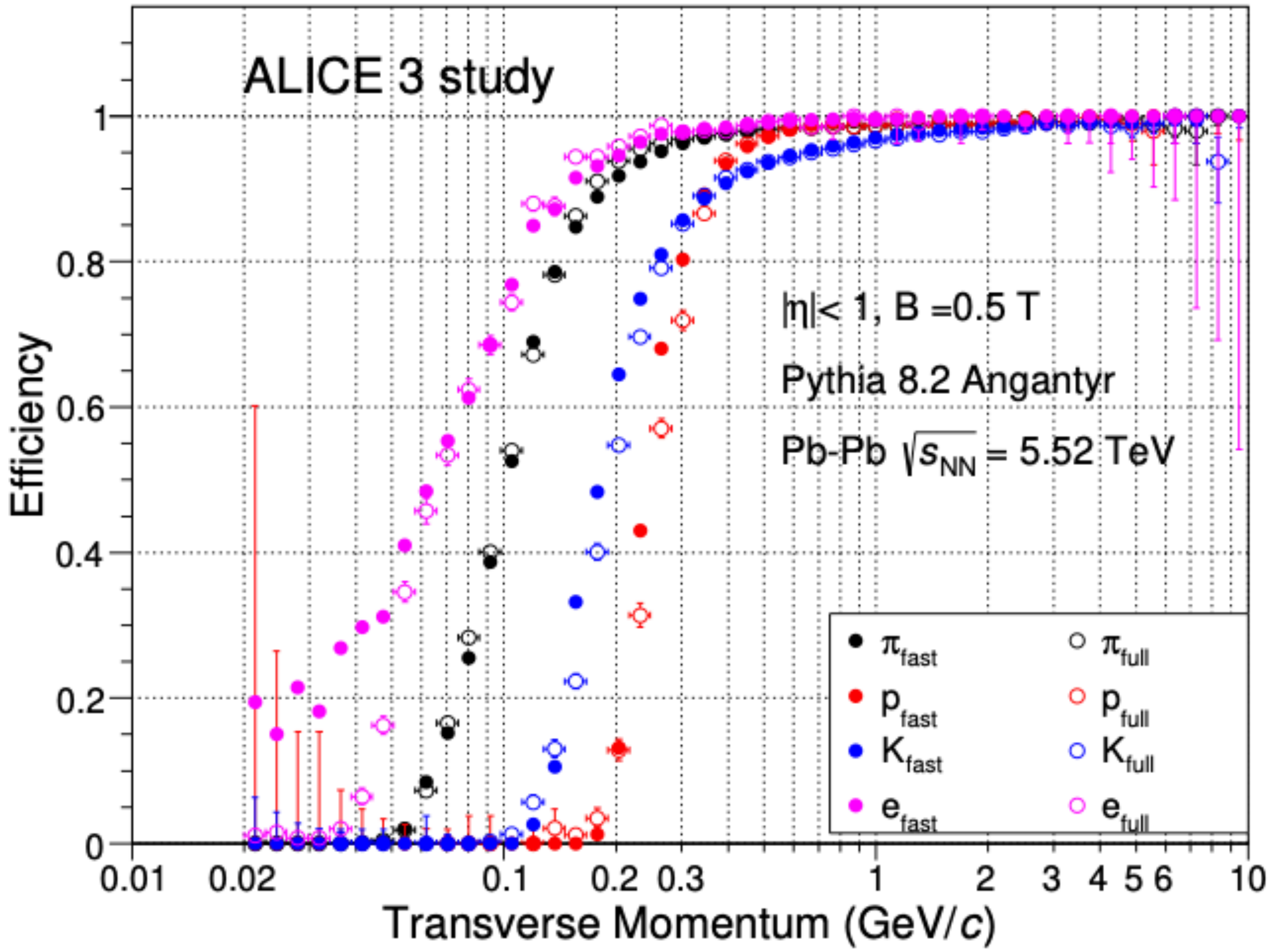


(a) $\eta = 1.25$



(b) $\eta = 2.5$

Plots from ALICE 3 LoI



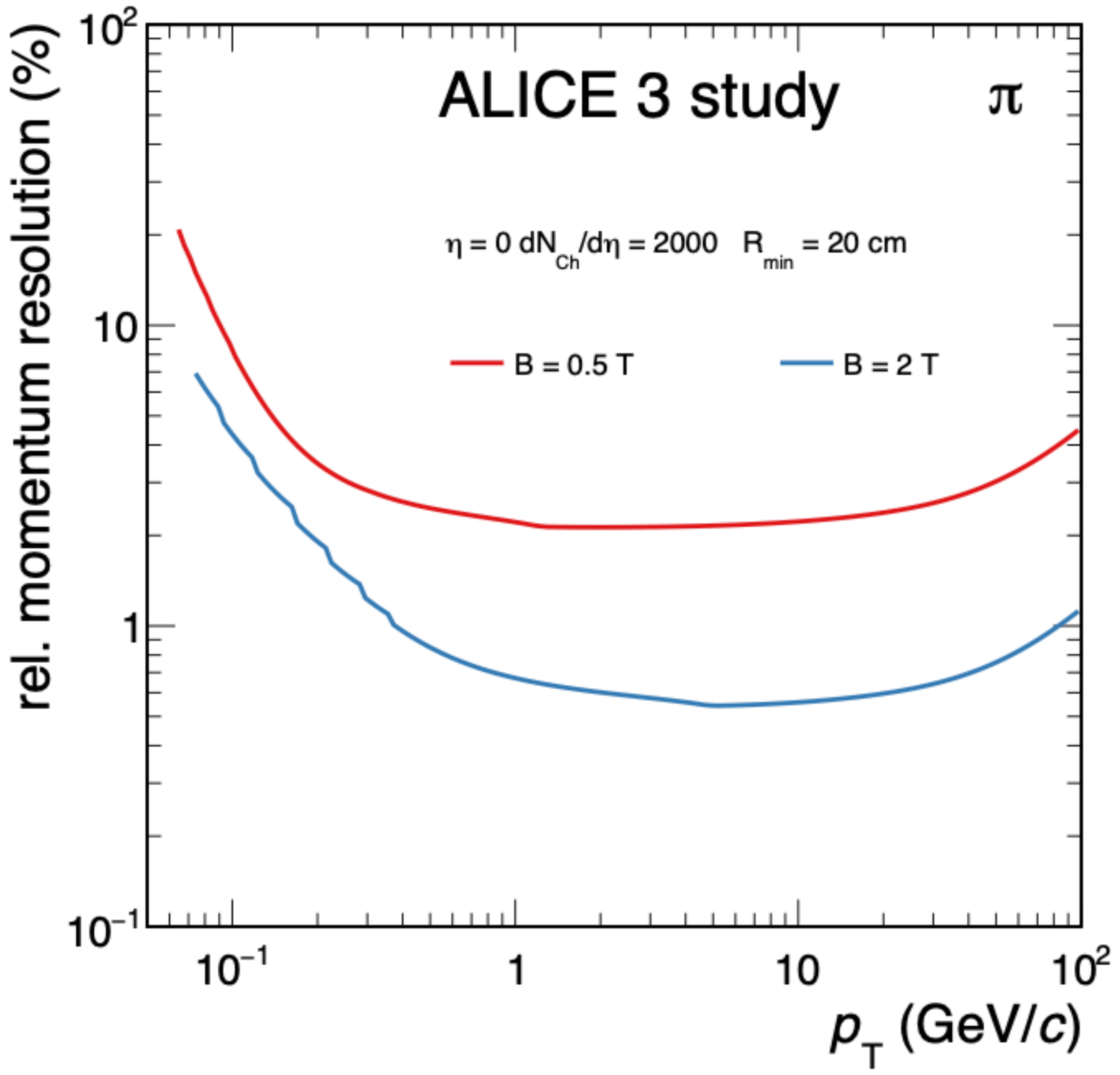


Figure 11: Comparison of the relative transverse momentum resolution for pions as a function of the p_T obtained with the fast analytical tool for $B = 0.5\,T$ (red) and $B = 2\,T$ (blue).

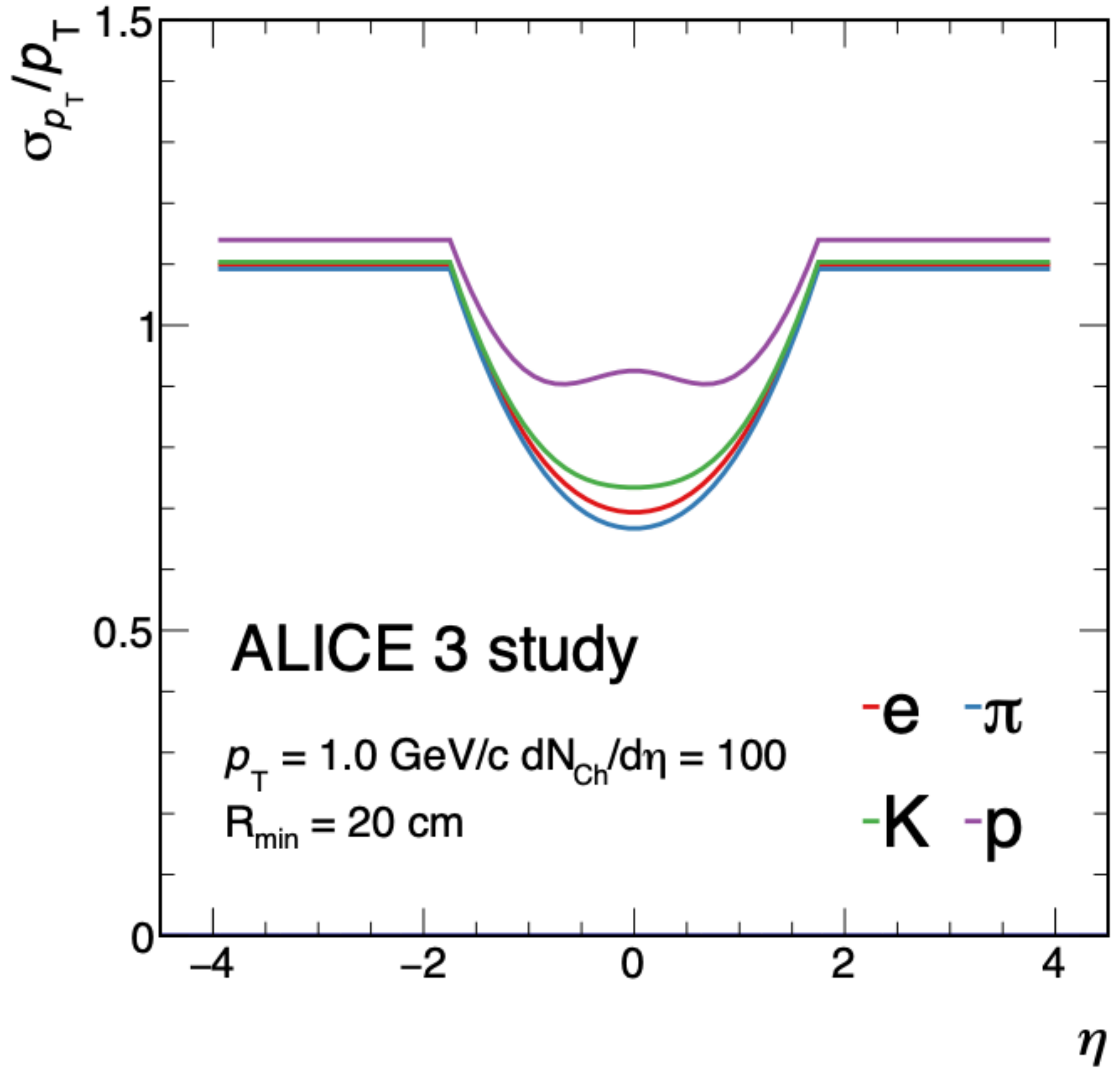


Figure 12: Relative transverse momentum resolution (in %) as a function of the pseudorapidity obtained with FAT for electrons, pions and protons with $p_T = 1\,\text{GeV}/c$ and minimum radius of the tracks R = 20 cm in a magnetic field B = 2 T. The continuation from $|\eta| = 2$ out to $|\eta| = 4$ is set to be constant as achievable with forward dipoles.

Plots from ITS 3 TDR

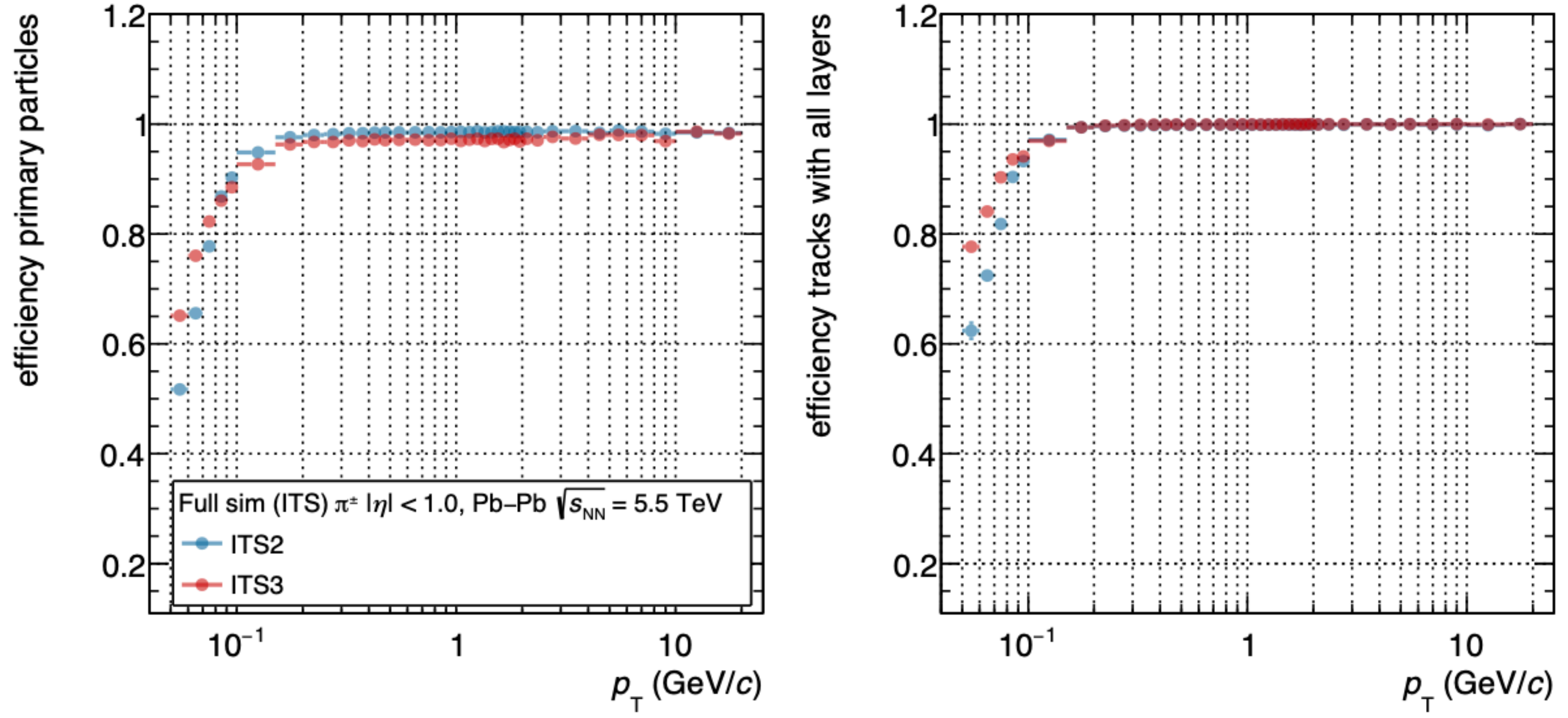


Figure 7.6: Track-reconstruction efficiency for charged pions with $|\eta| < 1$ as a function of the track p_T for the ITS2 and ITS3 detectors. The left panel shows the performance for the reconstruction of all primary charged pions, while the right one for tracks with a hit on each ITS layer.

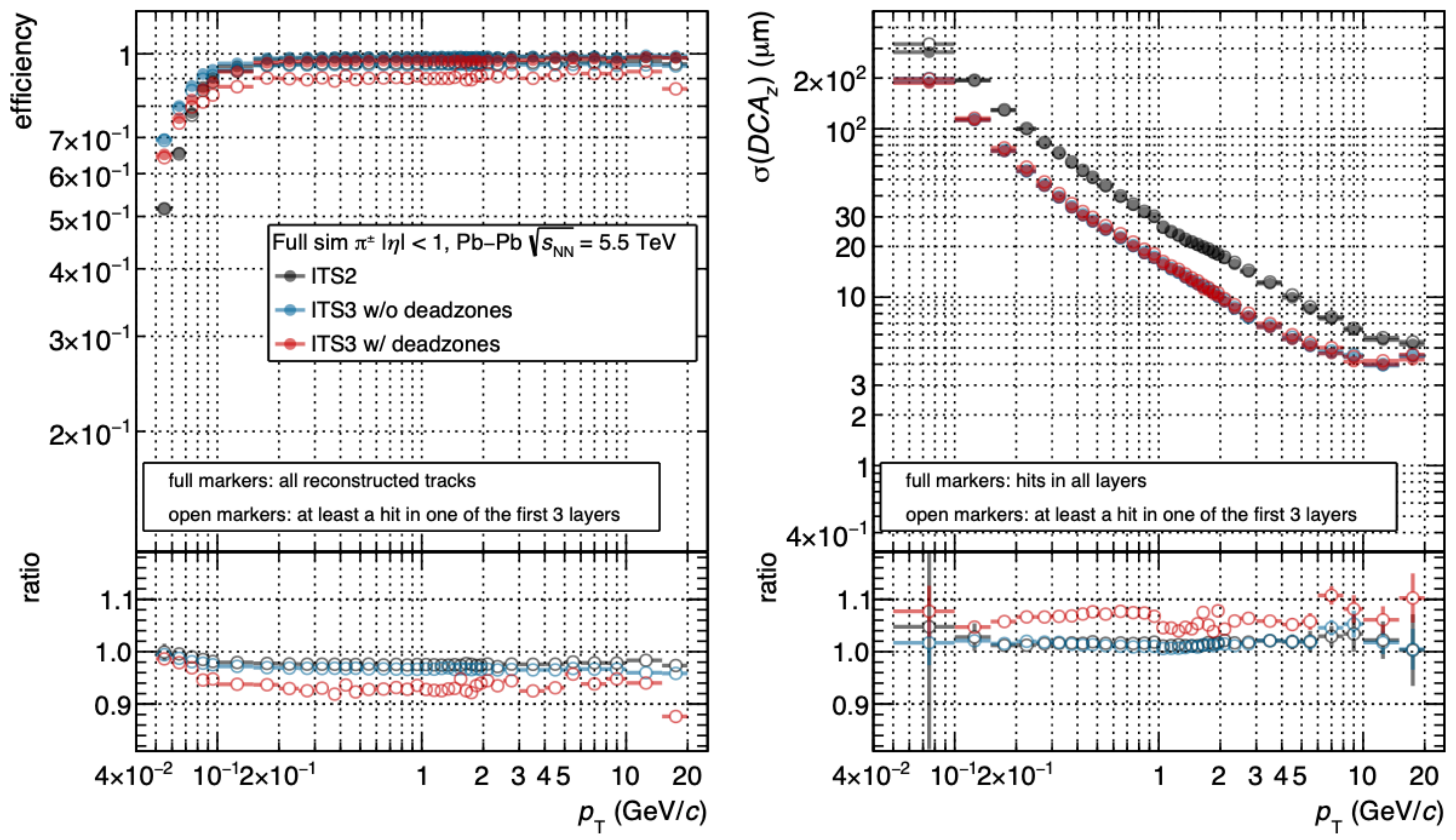


Figure 7.12: Comparison of track-reconstruction efficiency (left panel) and impact-parameter resolution in the longitudinal direction (right panel) as a function of the track p_T with the ITS2 and the ITS3, with and without dead zones. The efficiency is reported for all tracks and tracks having at least one hit in one of the first three layers. The impact-parameter resolution is reported for tracks with a hit on each layer and for tracks having at least one hit in one of the first three layers.

Plots from ITS 3 TDR

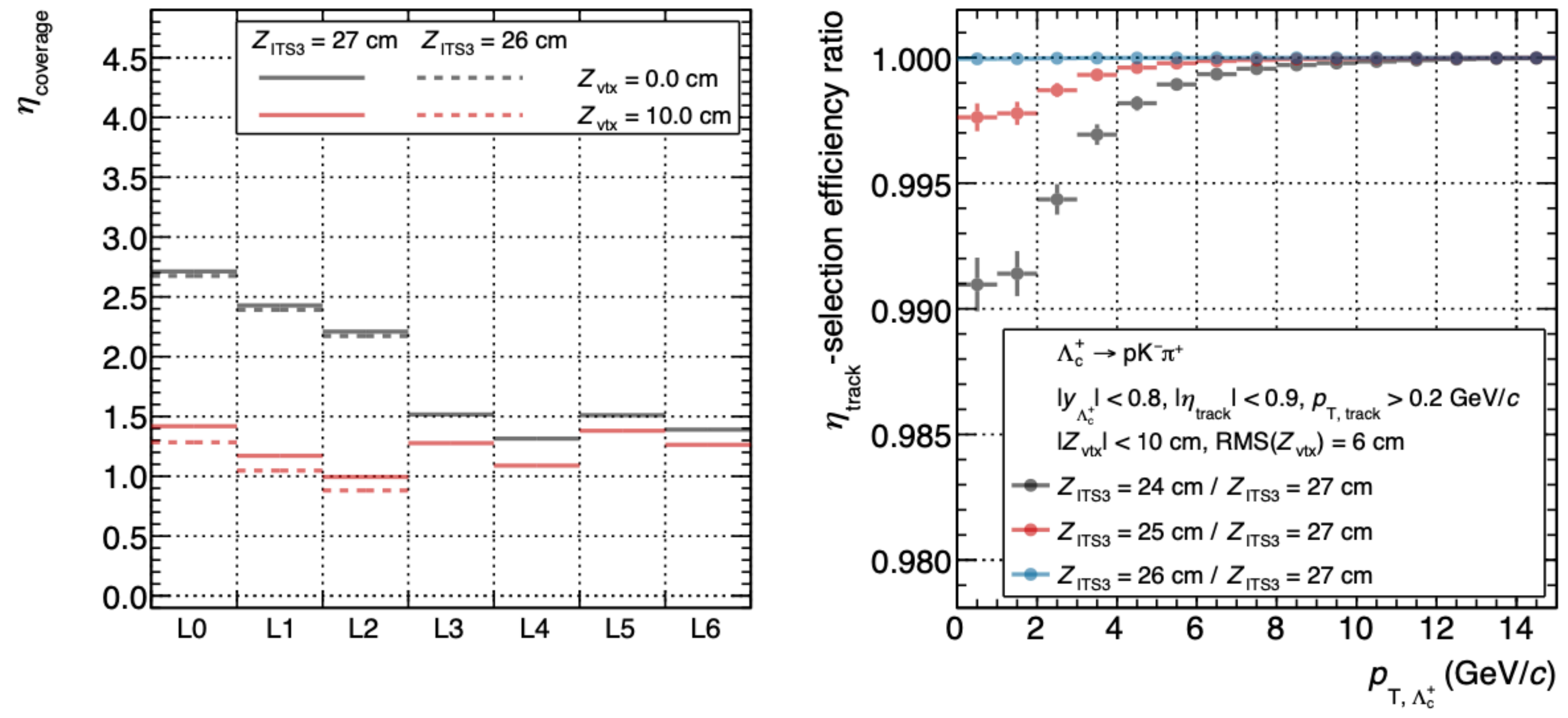


Figure 7.11: Left: pseudorapidity coverage of the seven ITS layers calculated with respect to different positions in z of the collision point. Two alternatives are considered for the ITS3 layers (see text for details). Right: ratio of the η_{track}-selection efficiency for the $\Lambda_c^+ \rightarrow pK^-\pi^+$ reconstruction for ITS3 outer layer lengths with respect to the 27 cm case. The gray dashed line at $y = 1$ is shown as a reference.

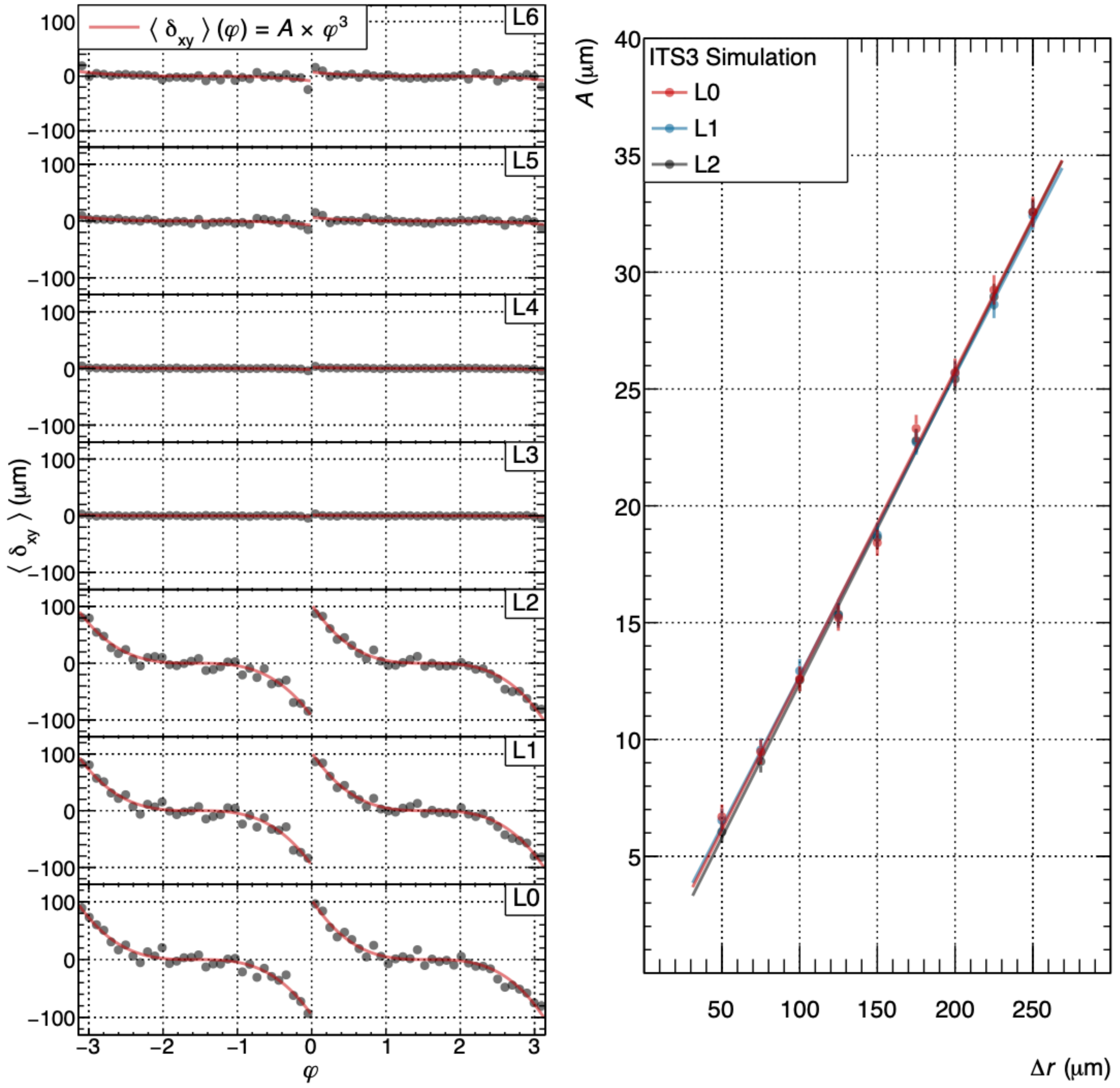


Figure 7.16: Left: mean value of the track-to-cluster residuals in the transverse plane as a function of the azimuthal angle φ for each ITS layer for an elliptical distortion of the ITS3 layers characterised by an eccentricity parameter (ϵ) times the radius (r) of 200 μm. Right: amplitude of the $\langle \delta_{xy} \rangle$ modulation obtained by fitting the distributions shown in the left panel as a function of Δr for the three ITS3 layers.

Tracking performance estimation

without vertexing / PID

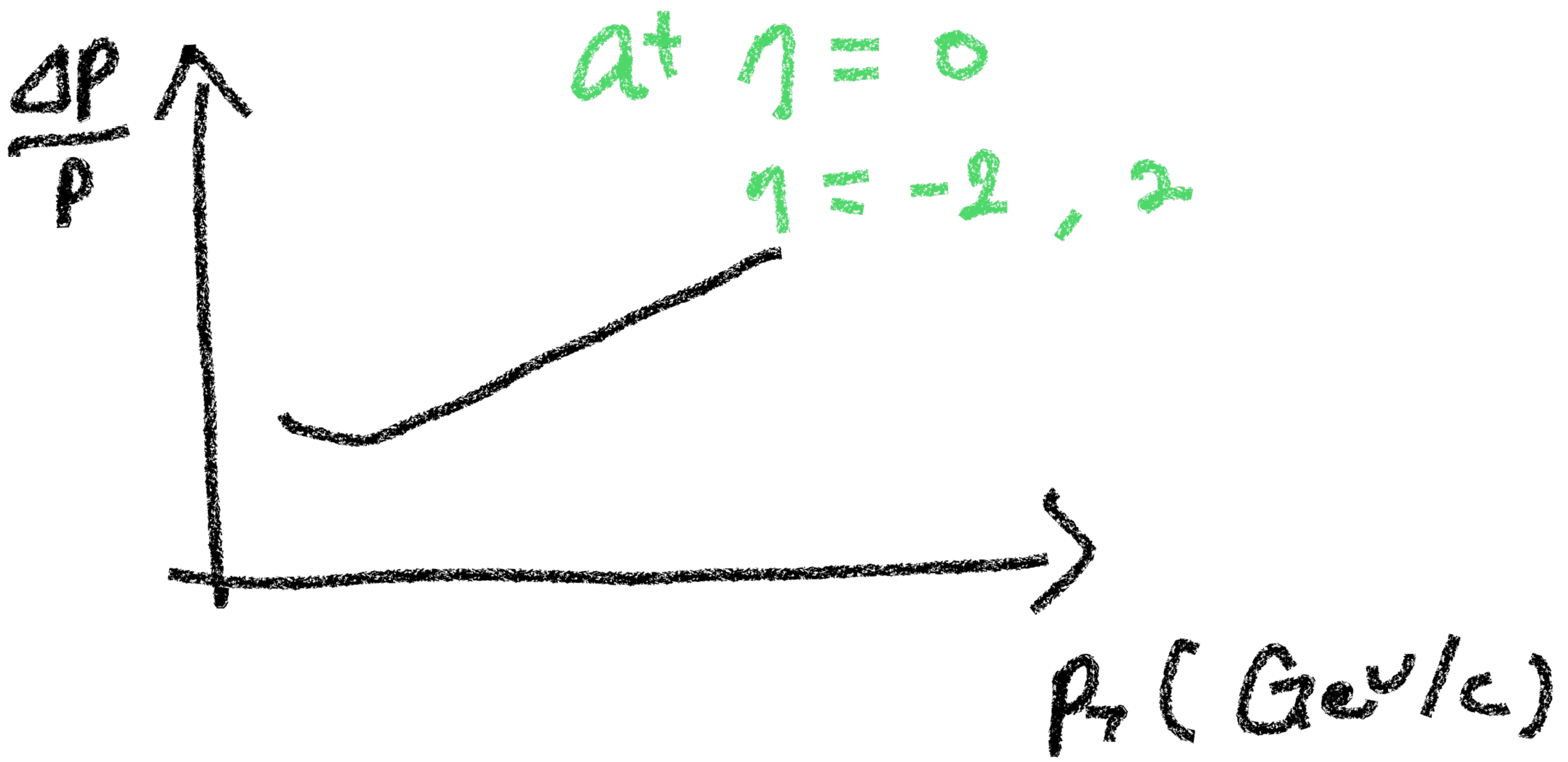
What should be on y-axis?

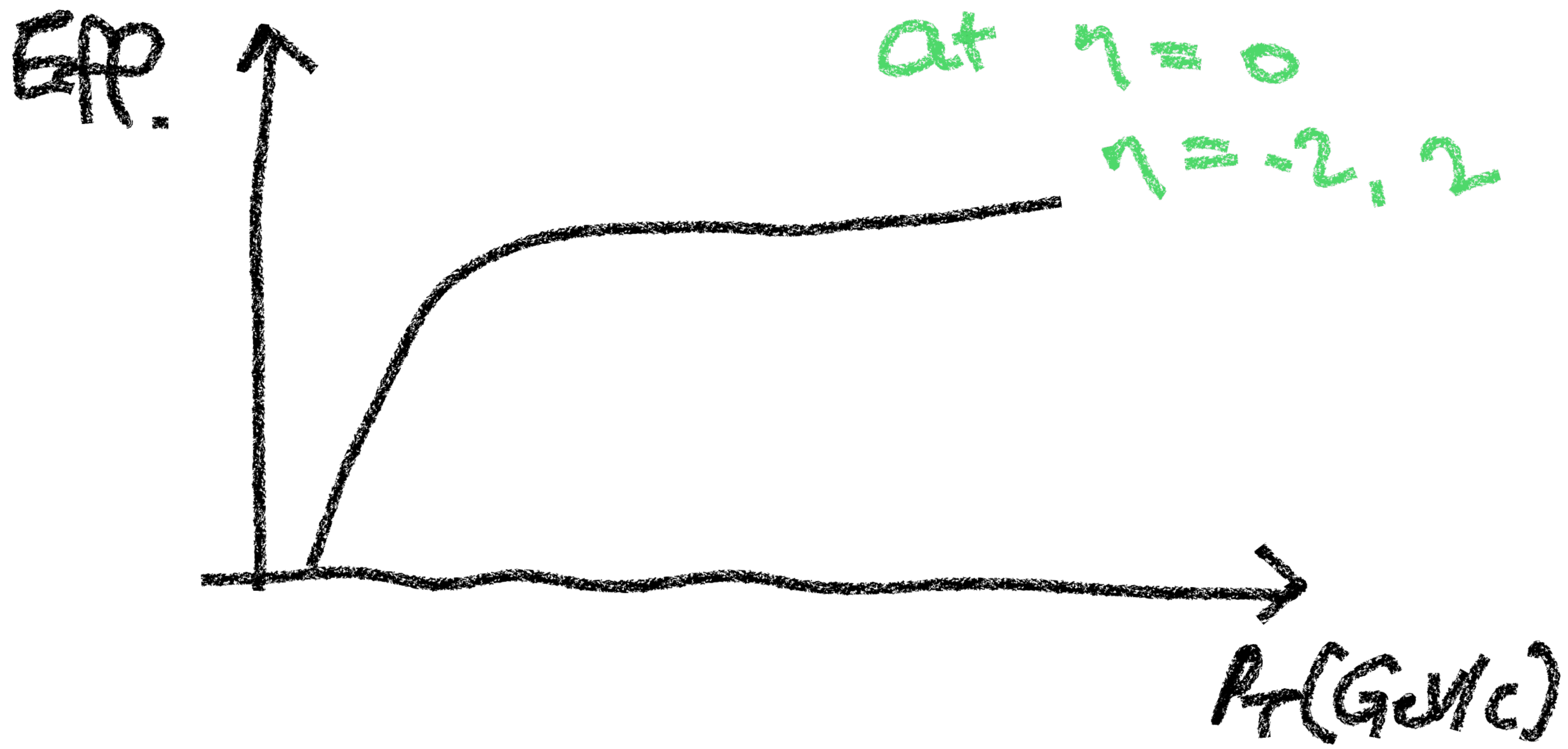
- Momentum resolution
- DCA resolution
- Efficiency
- Mean residuals
- Hit purity for beam-gas bkg.
- ……….

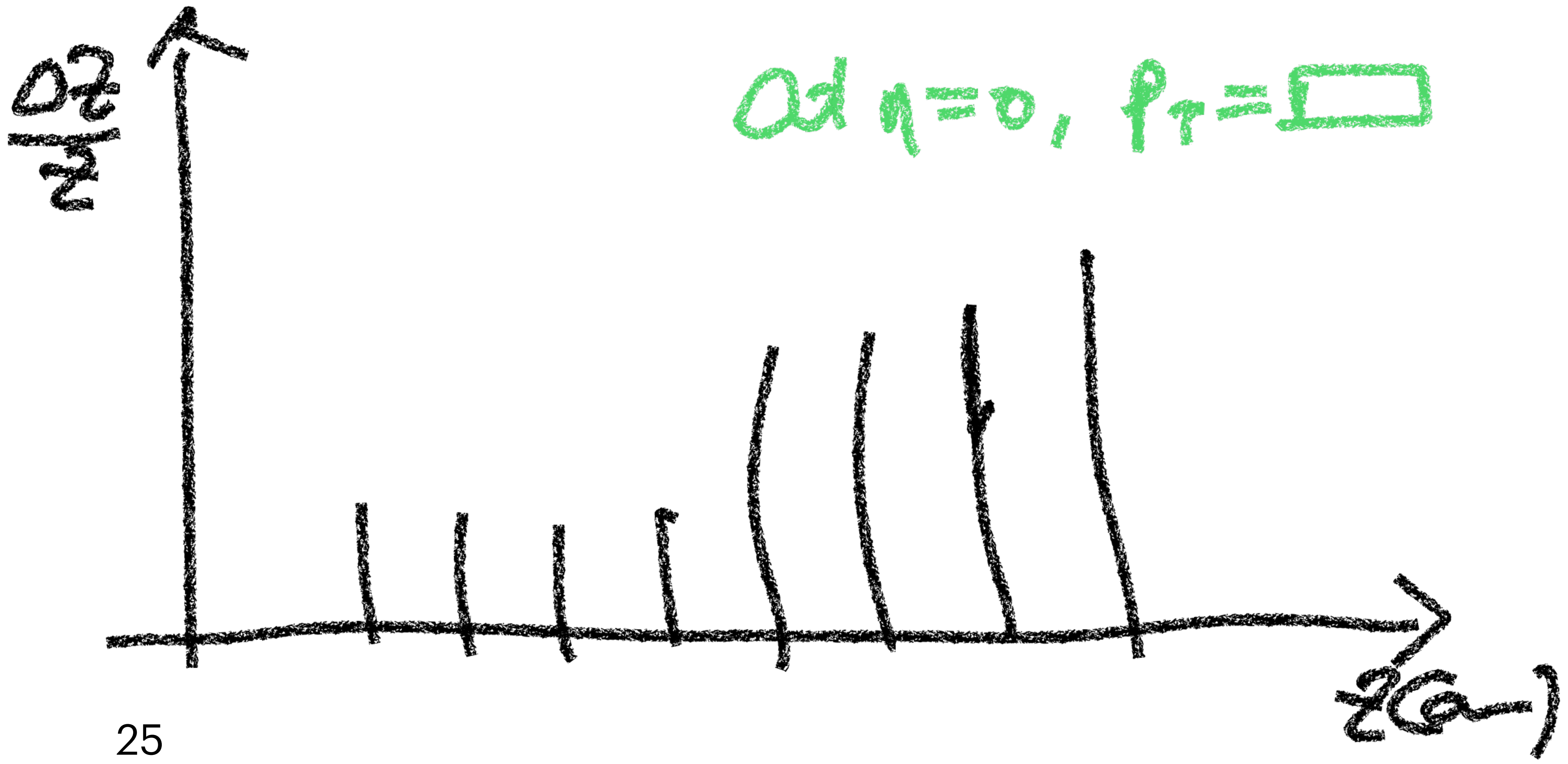
As a function of what? (Not necessarily x-axis!)

- Momentum (or pT)
- Eta
- Particle species
- Event characteristics (i.e. multiplicity)
- Different operating scenarios:
  - with and without RICH
  - Min. requirement of hits and/or min. Track radius?
    (*implicitly required to be 3 due to the seeding)
  - ……..

- Particle gun with electron/muon/pion/kaon/proton -> for particle species dependence
- Similar plots as a function of eta for edge effect?

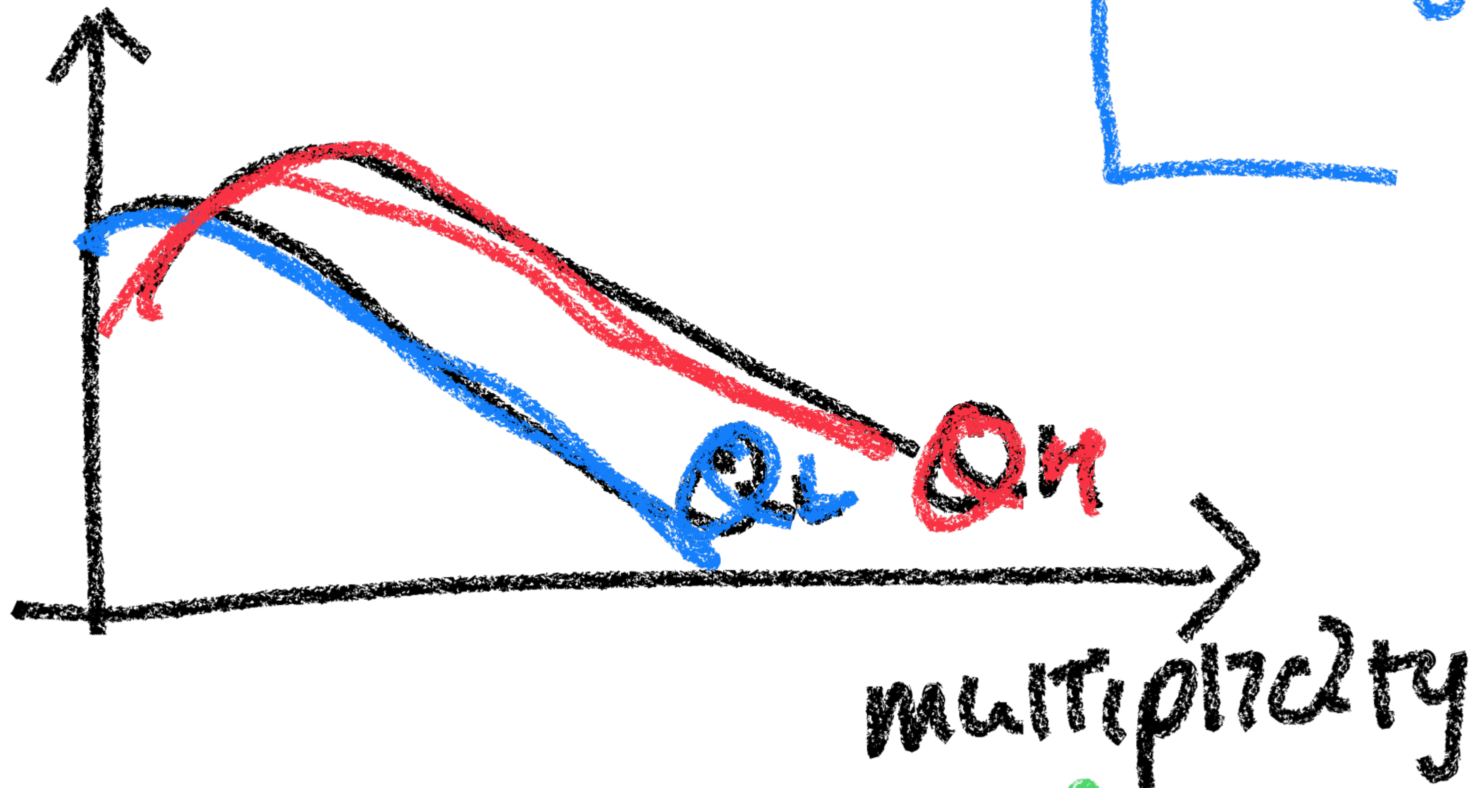




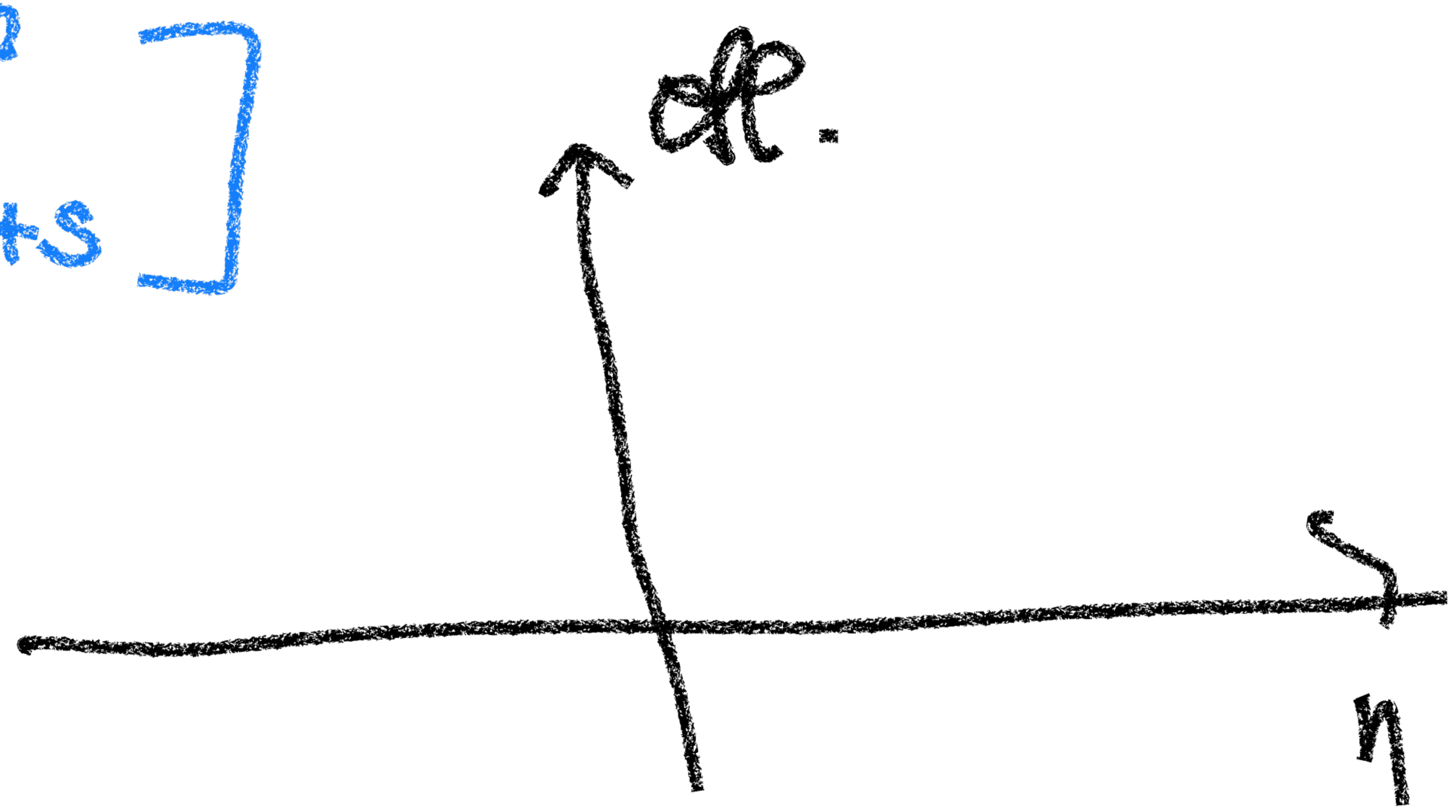


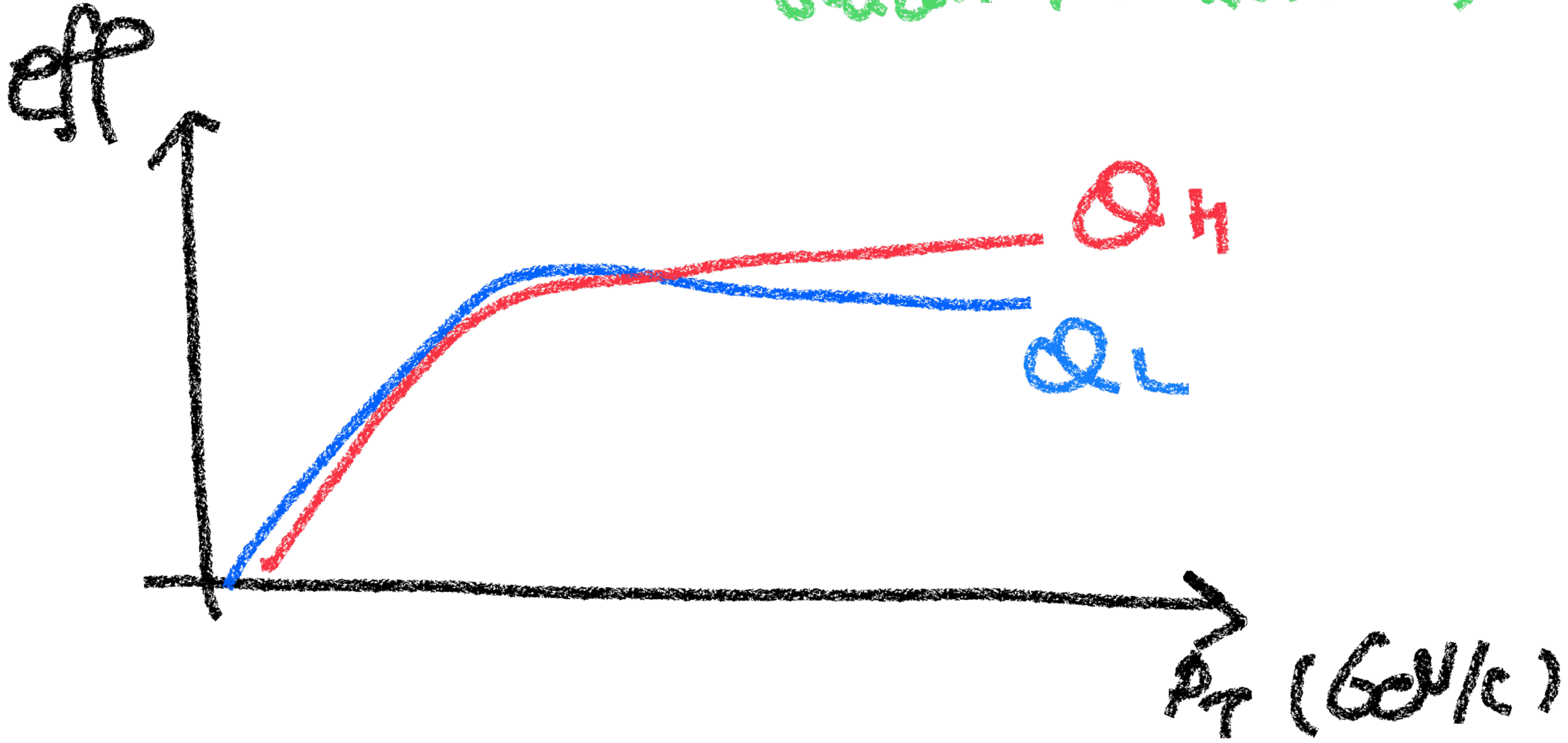
➡ For different Q^2 events showing distinct multiplicity distributions?

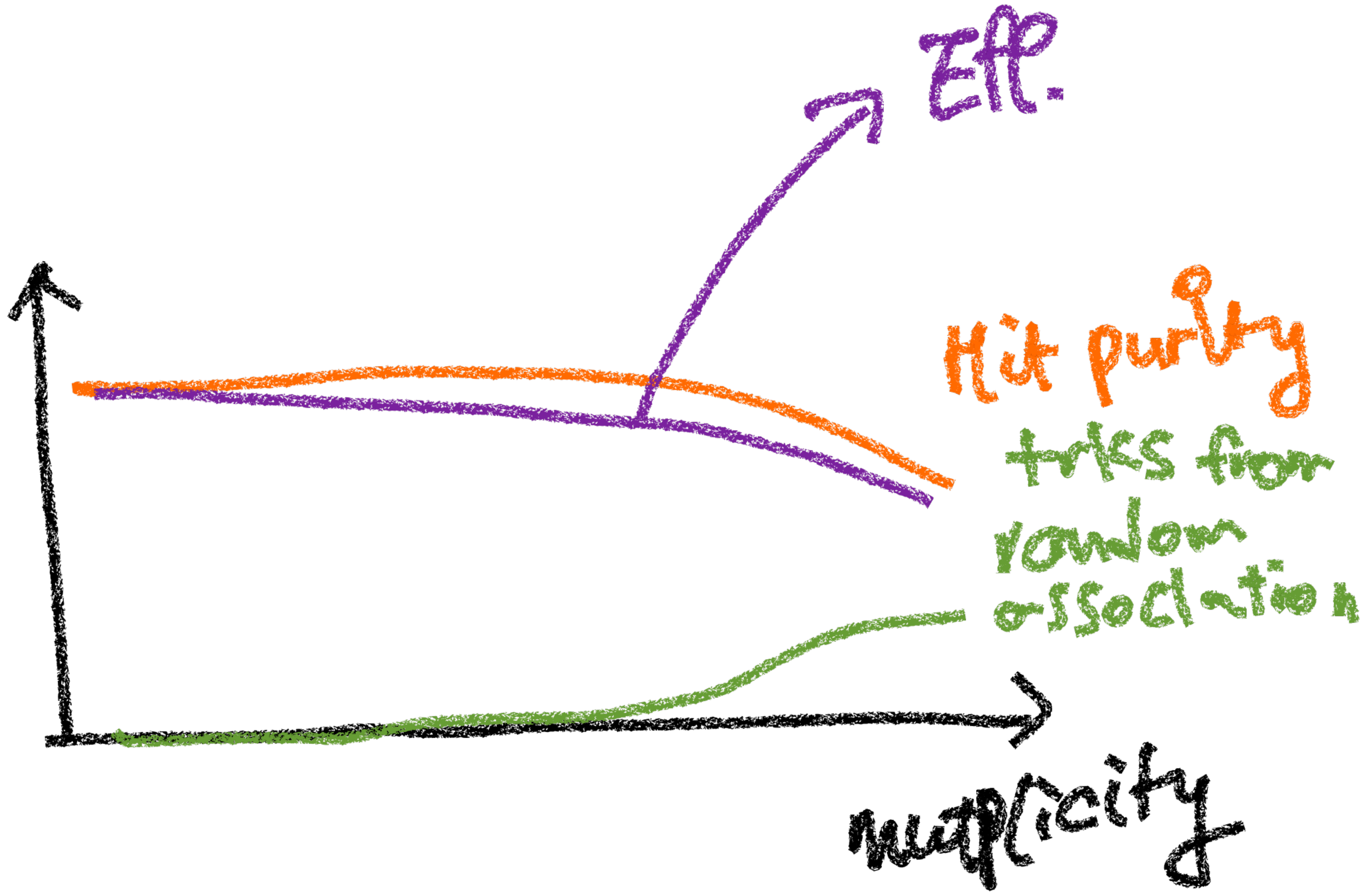
[High Q^2 / Low Q^2 DIS events]



(# of charged particle above ☐ MeV/c in Silicon trackers??)







- Background in full acceptance/ partially in acceptance / outside acceptance
- Efficiency should be only for those findables
- For tracking efficiency and contamination , use realistic signal to background ratio