Single-pion momentum resolution and bias study in simulation(TPC SA)

Polytracking and Custom Kalman refitting compared with the upstream Polyseeding + ACTS chain

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Tracking Software Meeting

Momentum resolution studies help evaluate and improve tracking reconstruction

- Characterize tracking performance
- Cross-check the standard reconstruction
- Identify sources of bias
- Support physics measurements

This talk covers three parts

1

Simulation changes

2

Study method

3

Momentum results

Part 1 · How this simulation differs from the upstream defaults

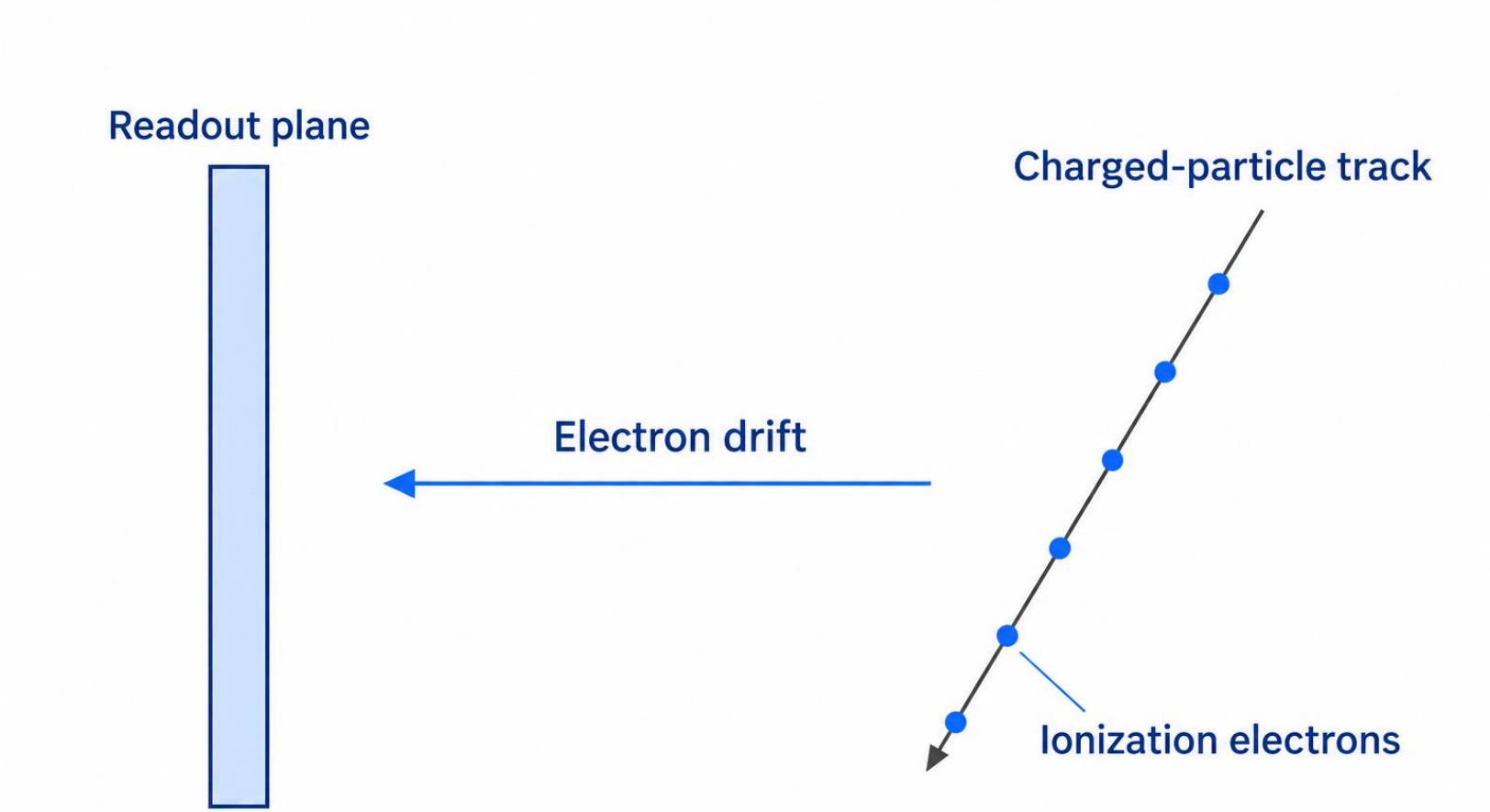
From ionization to charge on the readout pads

1 **Simulation changes**

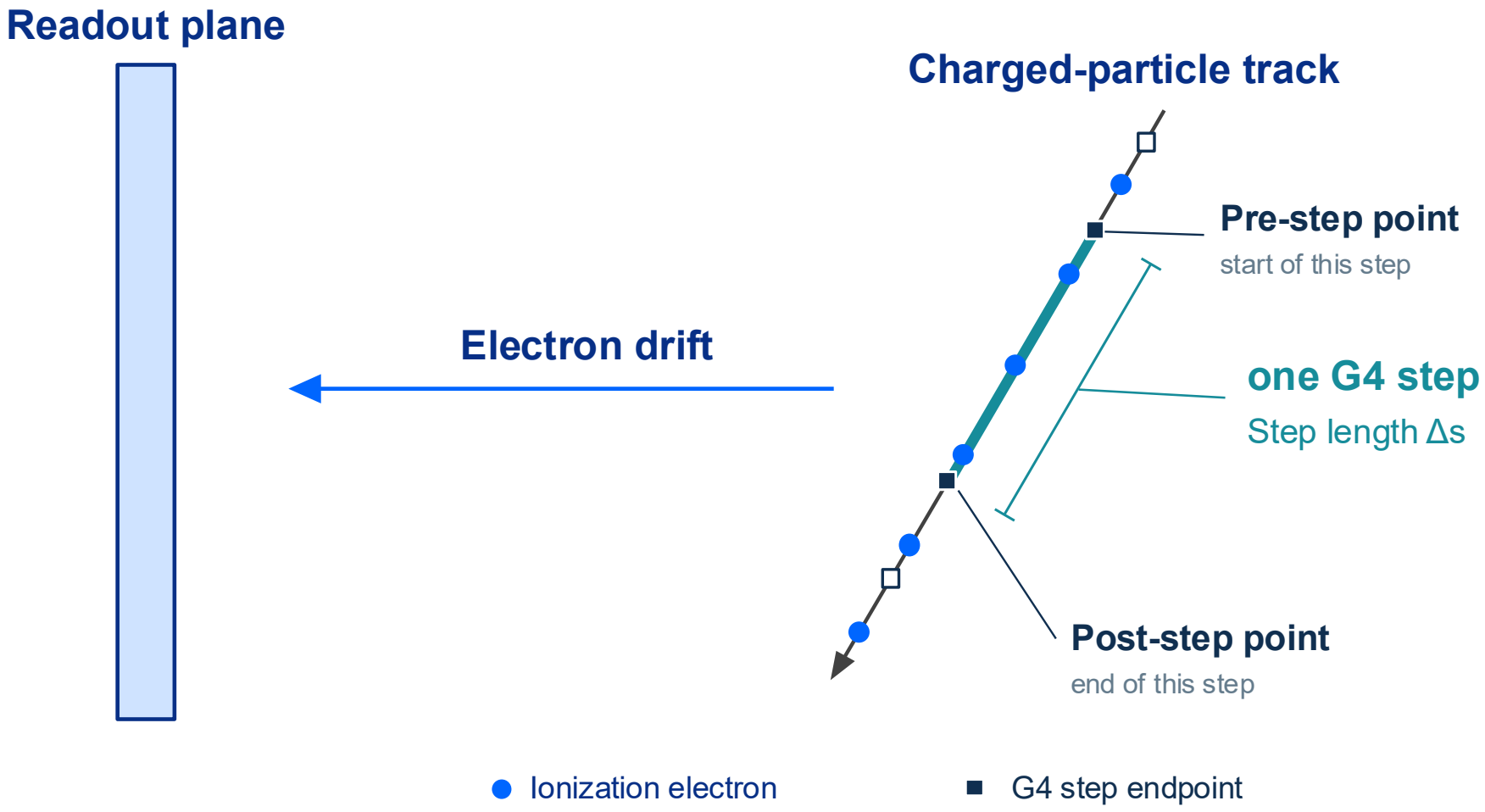
2 Study method

3 Momentum results

Ionization electrons drift from the track toward the readout



Geant4 advances each particle track through consecutive steps



How electrons are placed along a step

A Individual electron placement (upstream)

1 Begin with the total electron count

Given $N_e = 30$ electrons



Thirty electrons to place

2 Place each electron independently



30 electrons → 30 independent positions

B Cluster placement (the model used in this study)

1 Sample primary ionization sites

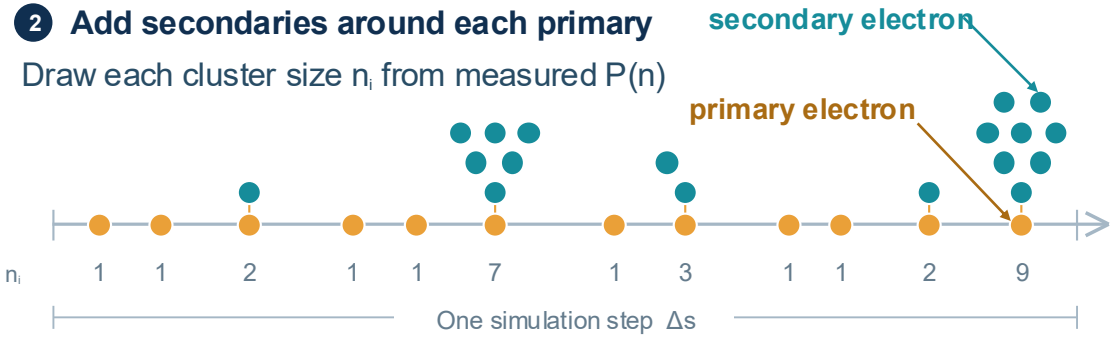
$N_p \sim \text{Poisson}(\rho_p \Delta s)$ Example: $N_p = 12$



Random sites along the step; constant ionization rate

2 Add secondaries around each primary

Draw each cluster size n_i from measured P(n)

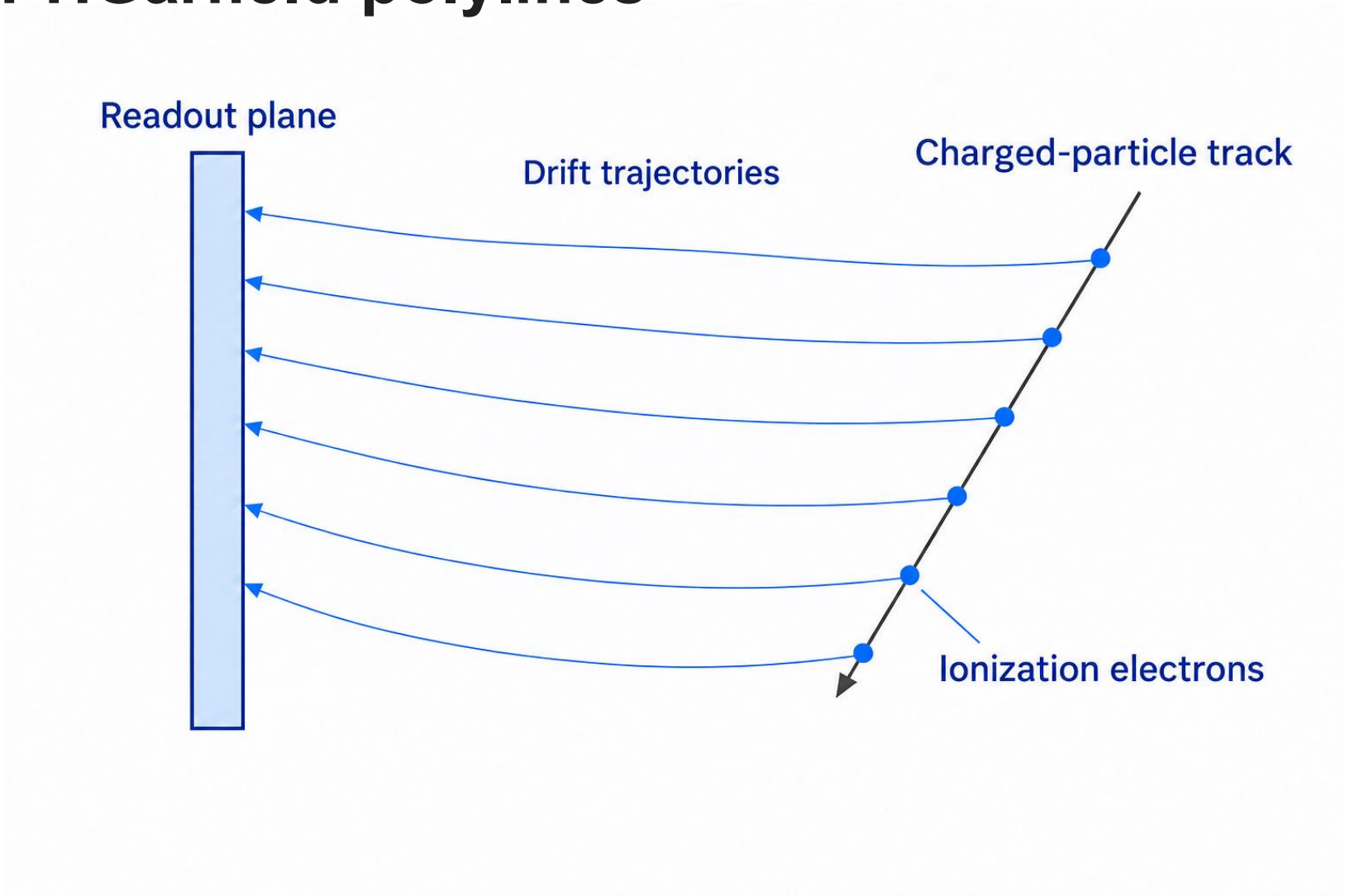


12 primary + 18 secondary = 30 electrons

Illustrative counts and cluster sizes; equal totals are chosen for comparison.

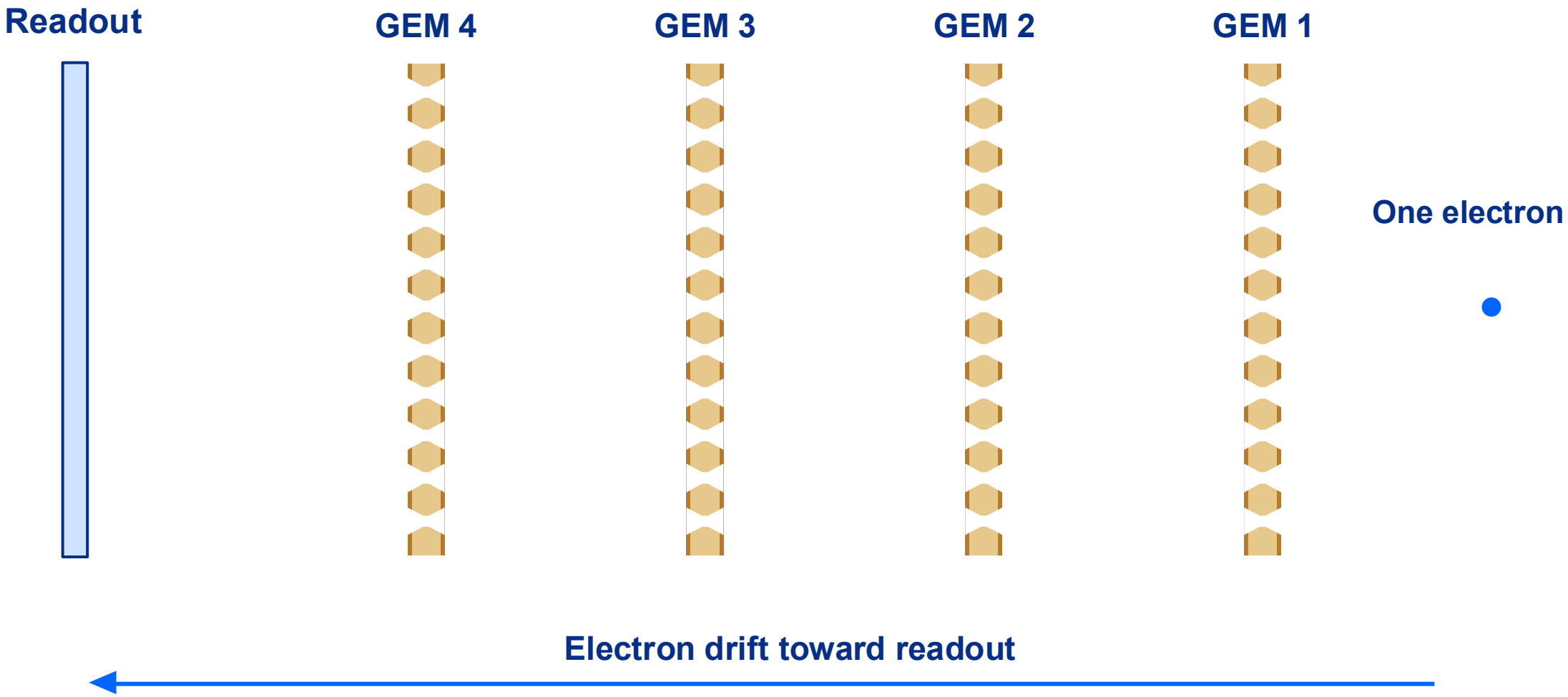
Reference: Fischle et al., NIM A 301 (1991) 202–214.

Electrons drifting distortions were simulated in this study through PHGarfield polylines



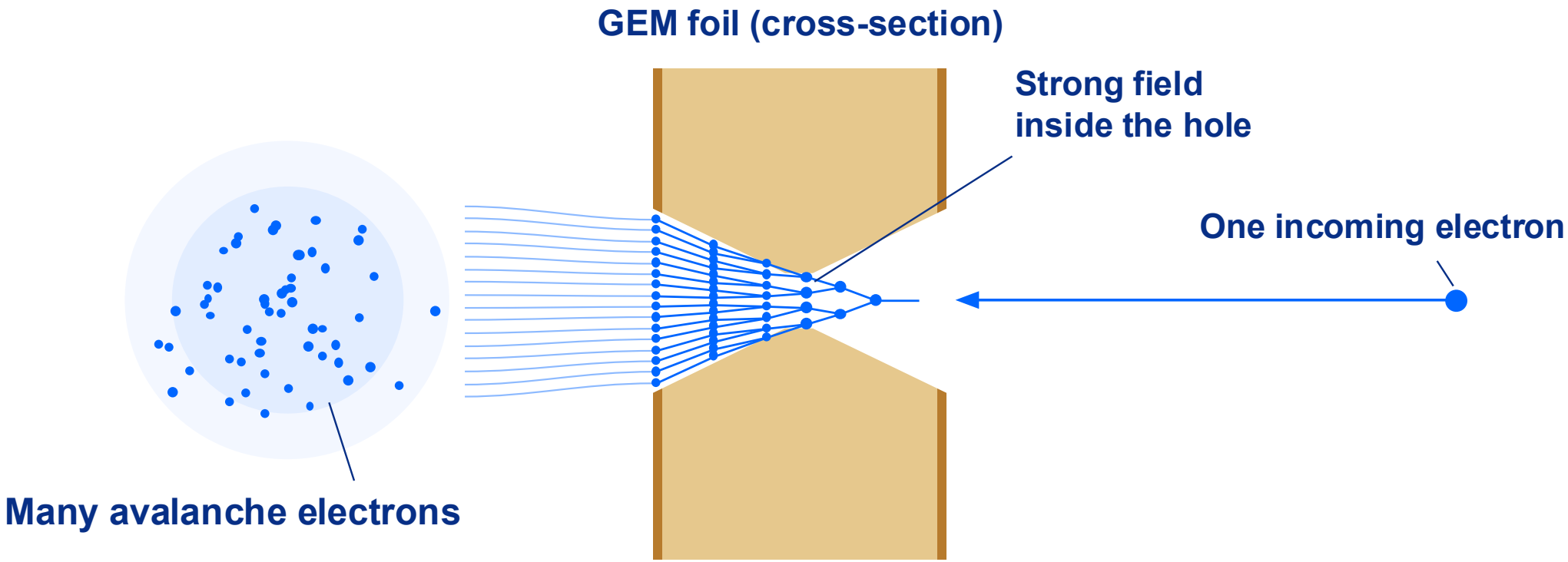
An electron arrives at the GEM stack

Side view of the readout and four GEM foils, before amplification.



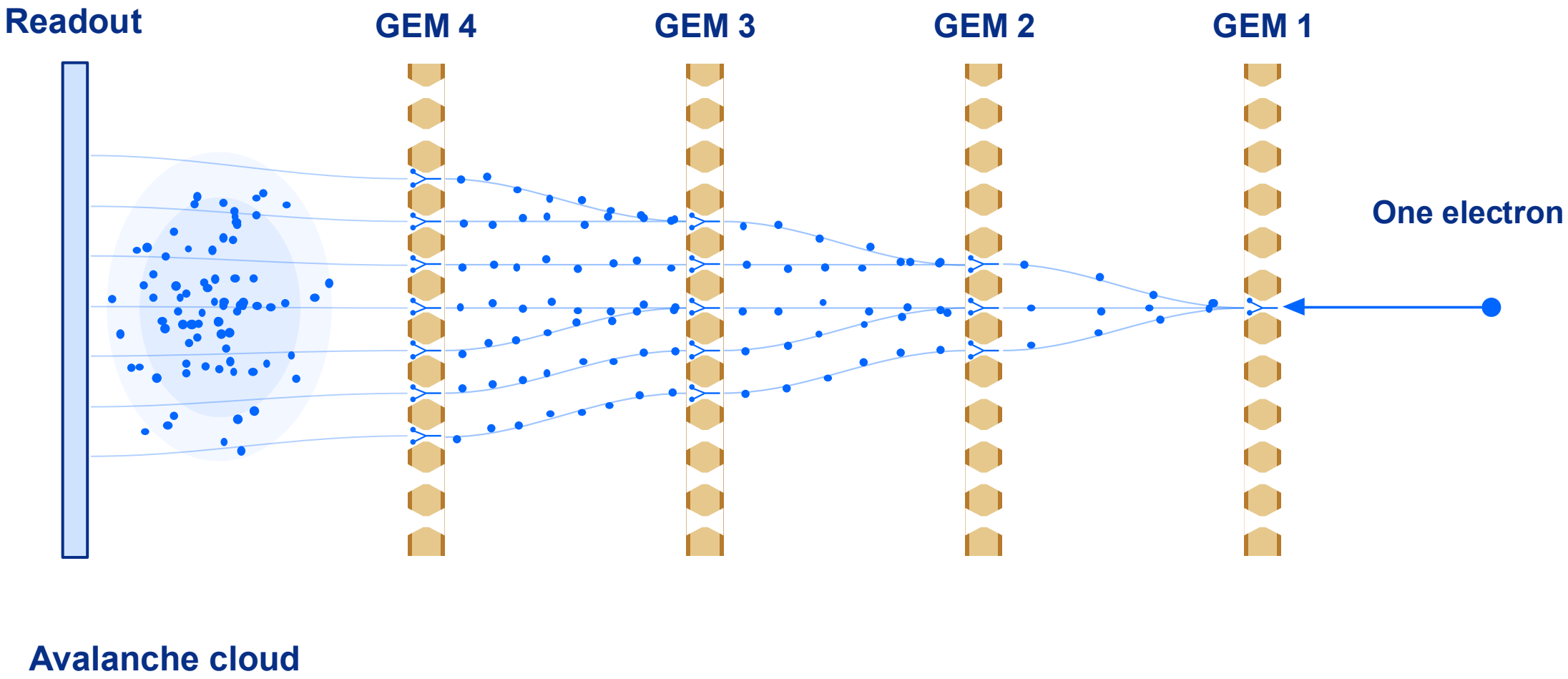
Schematic, not to scale.

Avalanche multiplication begins inside a GEM hole



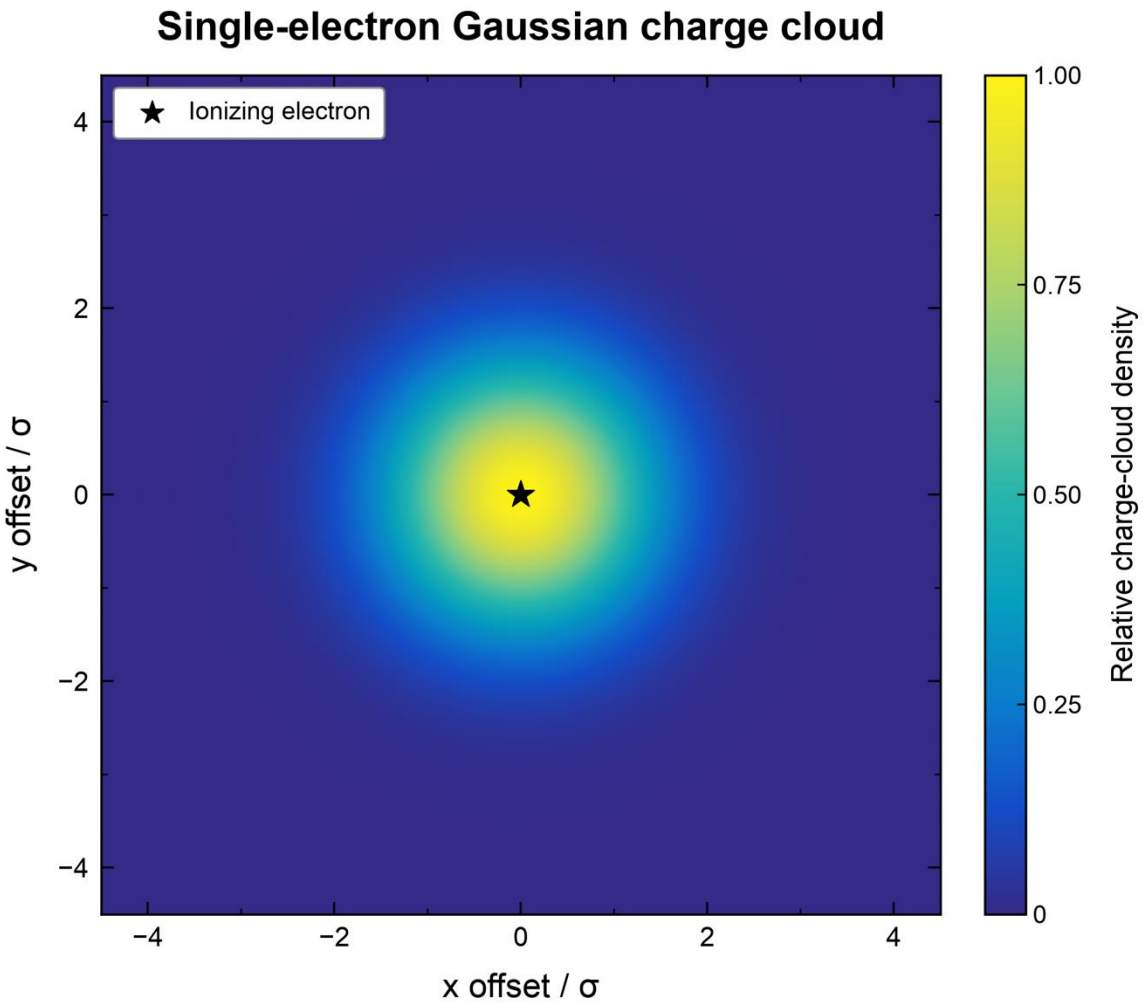
Schematic, not to scale.

Successive GEMs amplify and spread the electron cloud



Four-GEM schematic matching the sPHENIX context. Electron counts, foil spacing and cloud widths are illustrative.

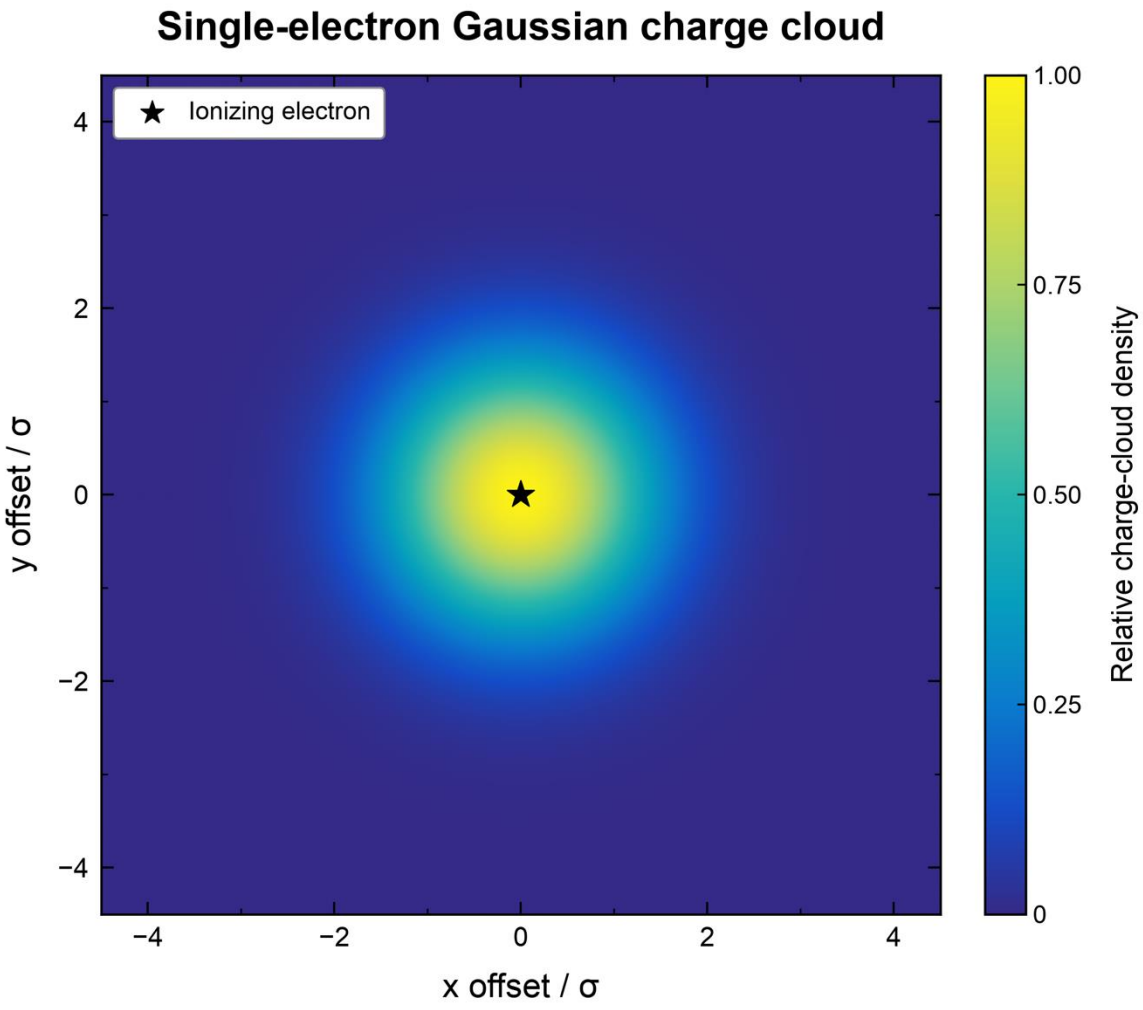
An avalanche cloud is modeled as a 2D Gaussian in this simulation



Illustrative width. The black star is exactly at the Gaussian center.

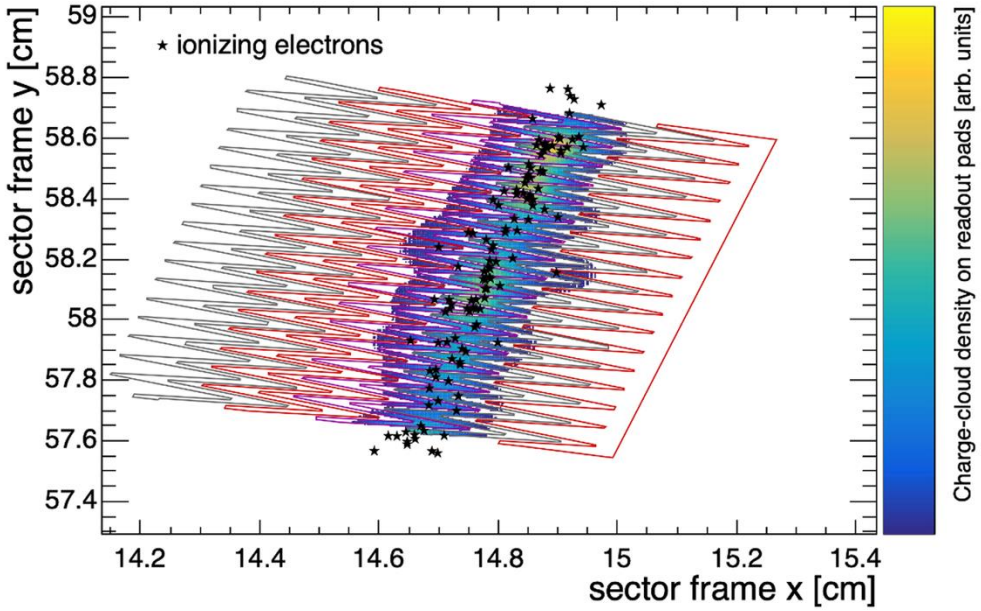
Initially developed by Mariia in a TPC Toy Model, then we worked together on this.

Each avalanche cloud intersects the zigzag polygons



Illustrative width. The black star is exactly at the Gaussian center.

Initially developed by Mariia in a TPC Toy Model, then we worked together on this.



The integration of the 2d Gaussian circle(avalanche cloud) in each zigzag polygon is collected as charge amount

Part 2 · Study method

1 Simulation changes
2 **Study method**
3 Momentum results

Study design

TPC only tracks

Simulated sample

Single π^+ and π^-
pT = 0.2–10 GeV/c
Uniform $\eta \in [-1.1, 1.1]$
10,000 per charge per pT stratum

Reconstruction procedule

Polyseeding + ACTS

Compared with Polytracking +
Custom Kalman refit (link to Github)
(initially developed by me, with subsequent improvements by Yuri)

Reported observables

Momentum: width and median of δ

Pt_reco definition

For the ACTS result

Pt was taken from Svtxtrack object

Momentum residual

$$\delta = (p_{T,reco} - p_{T,true}) / p_{T,true}$$

Width: central 68% half-width of δ

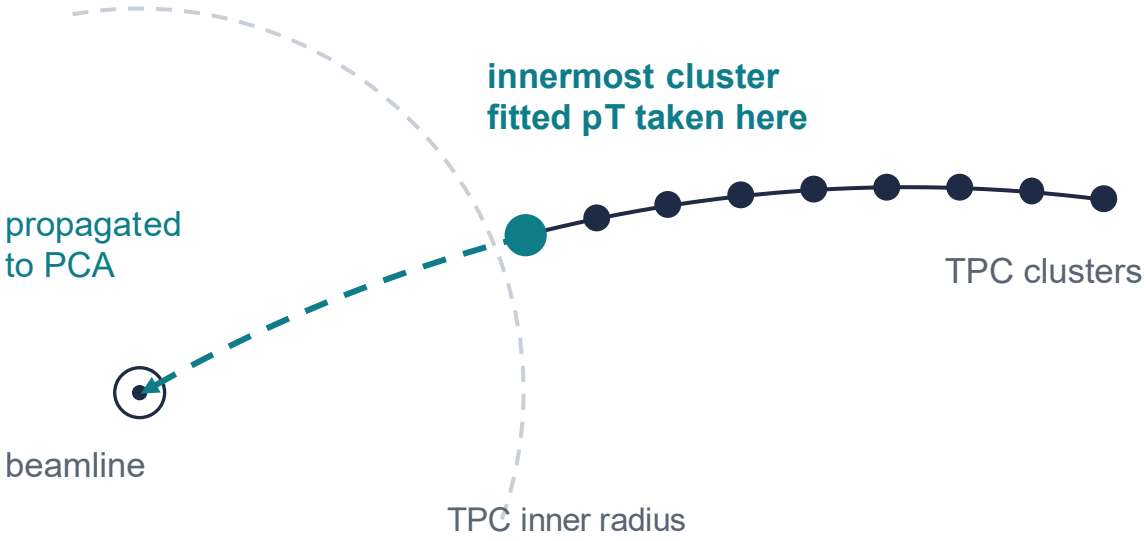
Bias: median of δ

Selection: Nclusters ≥ 33, generated $|\eta| < 1$

Pt_reco definition

For the Custom Kalman refitted result

Momentum of the innermost tpc cluster is propagated to the beamline PCA



Momentum residual

$$\delta = (p_{T,reco} - p_{T,true}) / p_{T,true}$$

Width: central 68% half-width of δ

Bias: median of δ

Selection: Nclusters ≥ 33, generated $|\eta| < 1$

Part 3 · Momentum results

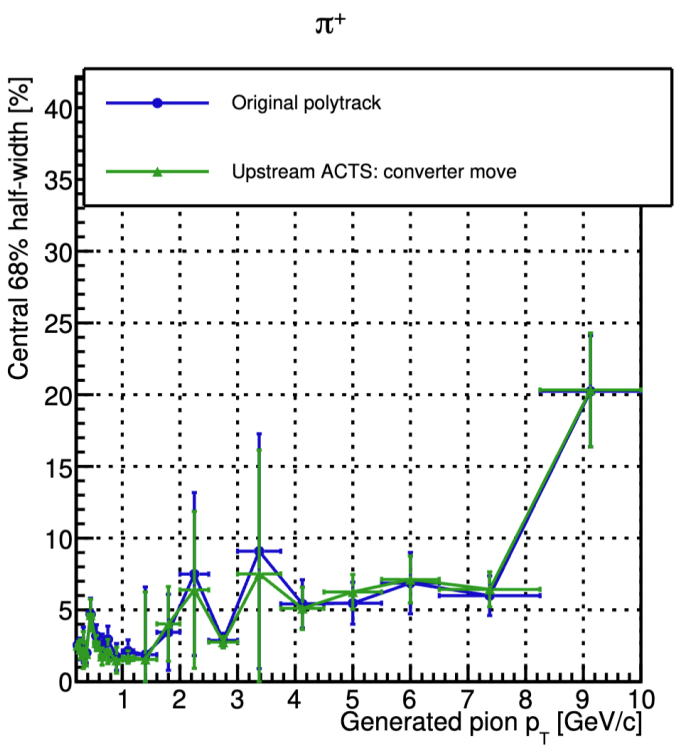
1 Simulation changes

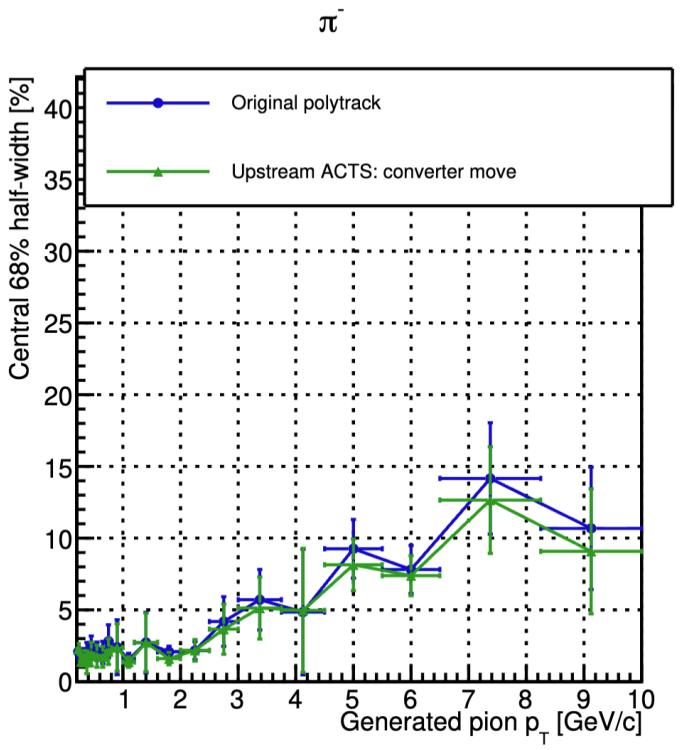
2 Study method

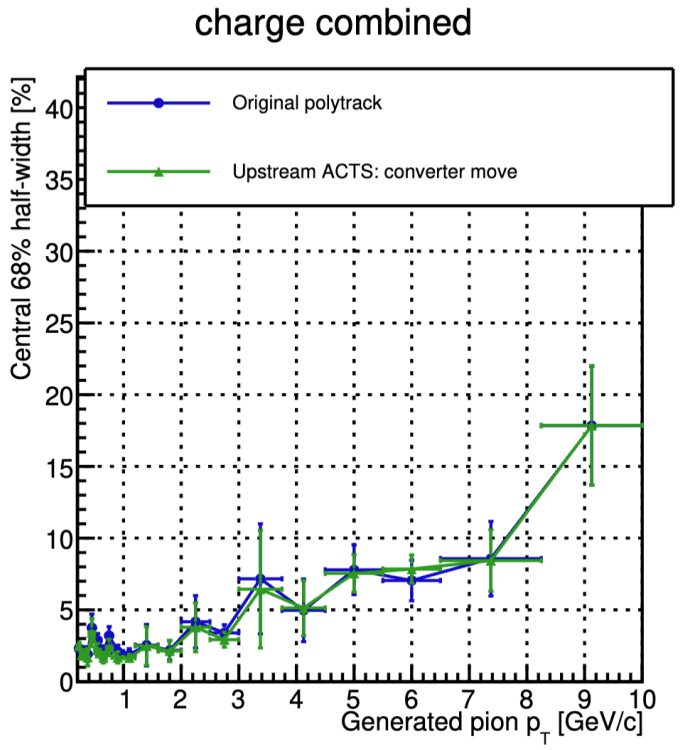
3 **Momentum results**

Pt residual width

Upstream coresoftware commit bfce189
Build/runtime environment: ana.576

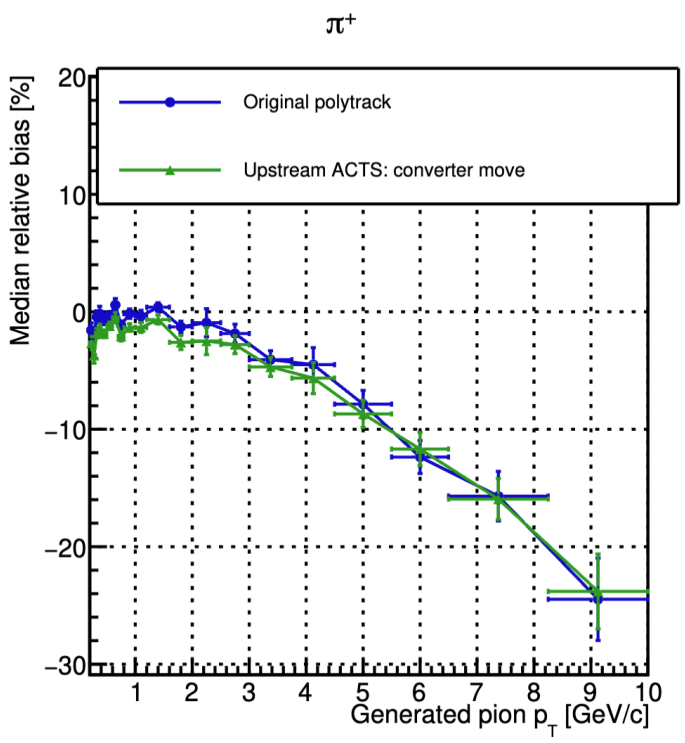


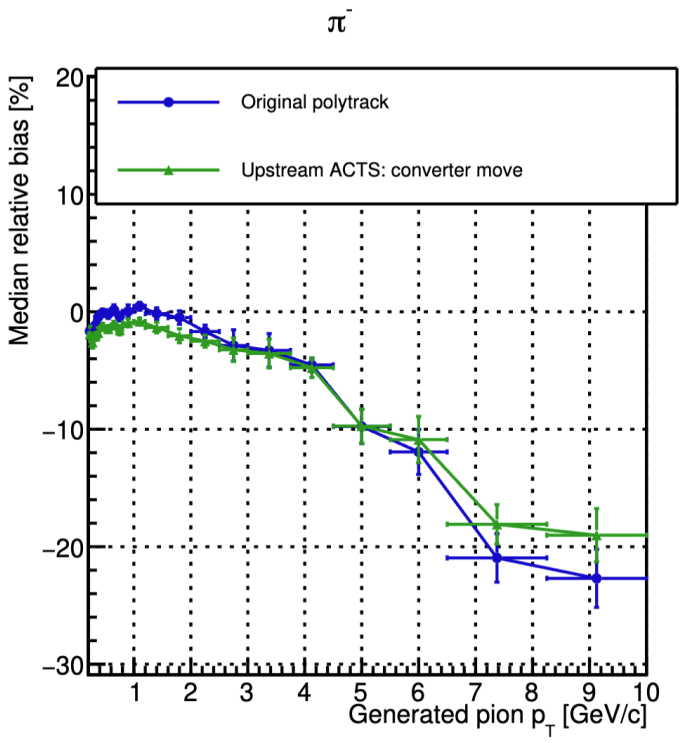


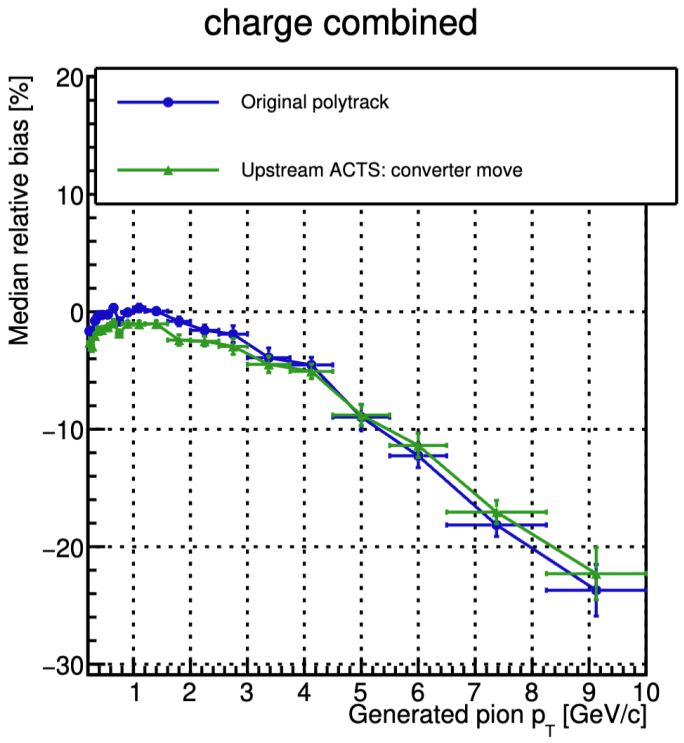


Median bias is large in high pt

Upstream coresoftware commit bfce189
Build/runtime environment: ana.576

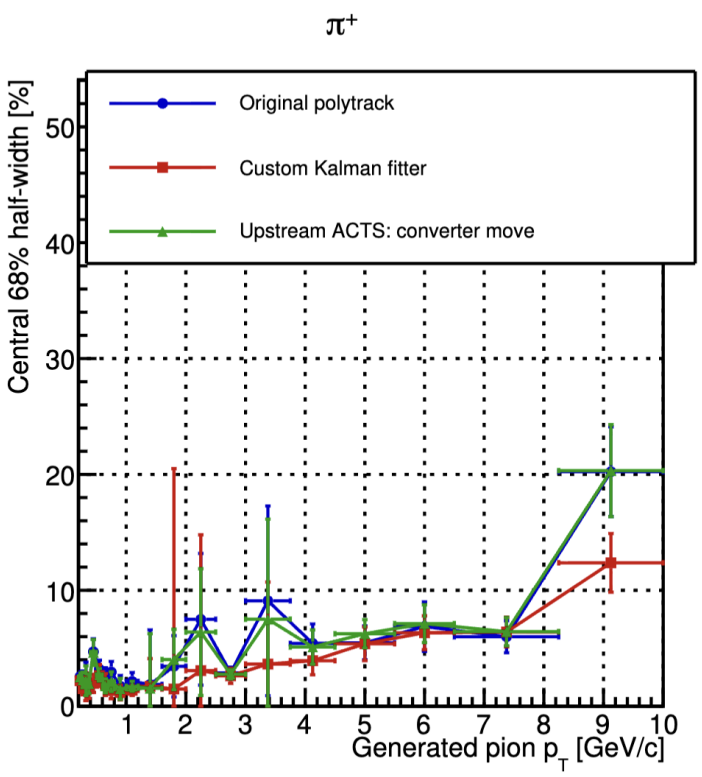


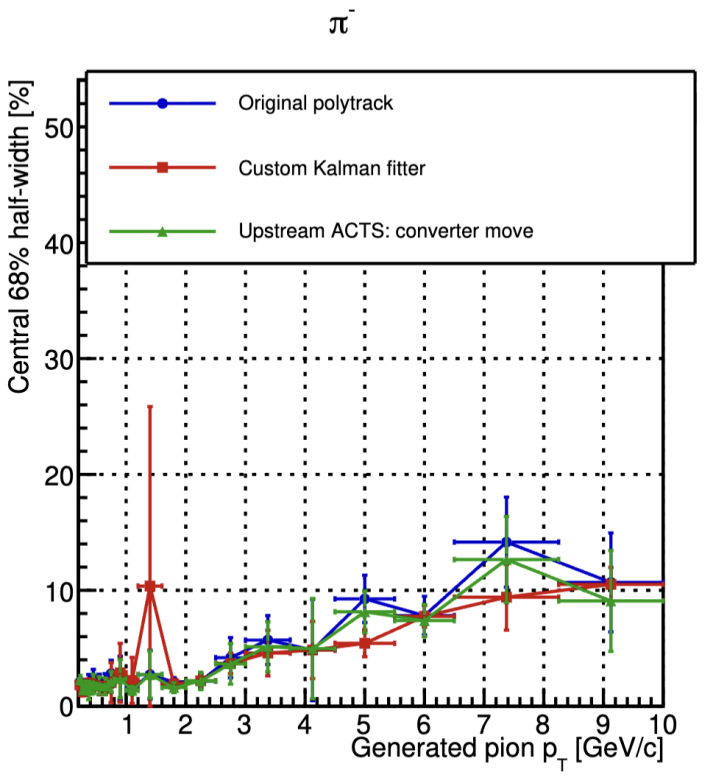


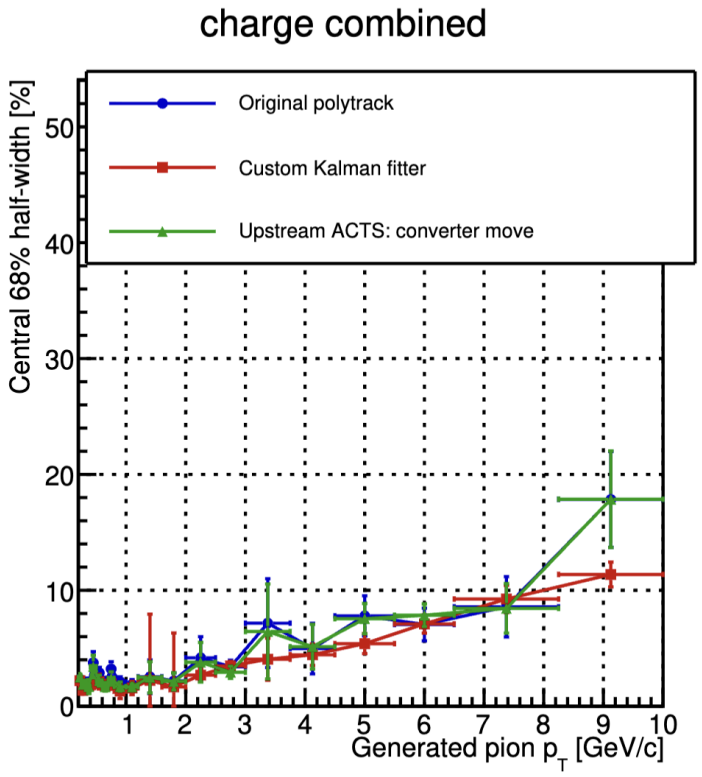


Pt residual width comparison with Custom Kalman Fitter

Upstream coresoftware commit bfce189
Build/runtime environment: ana.576

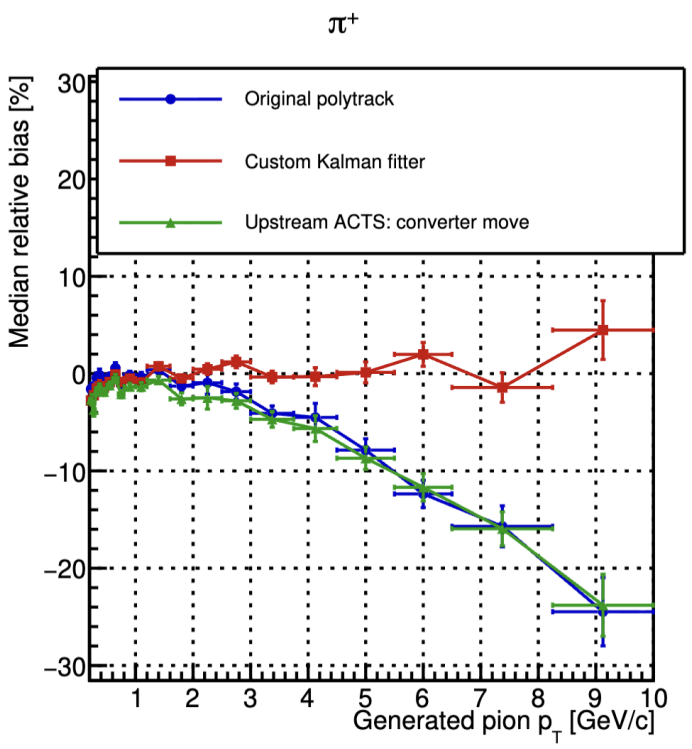


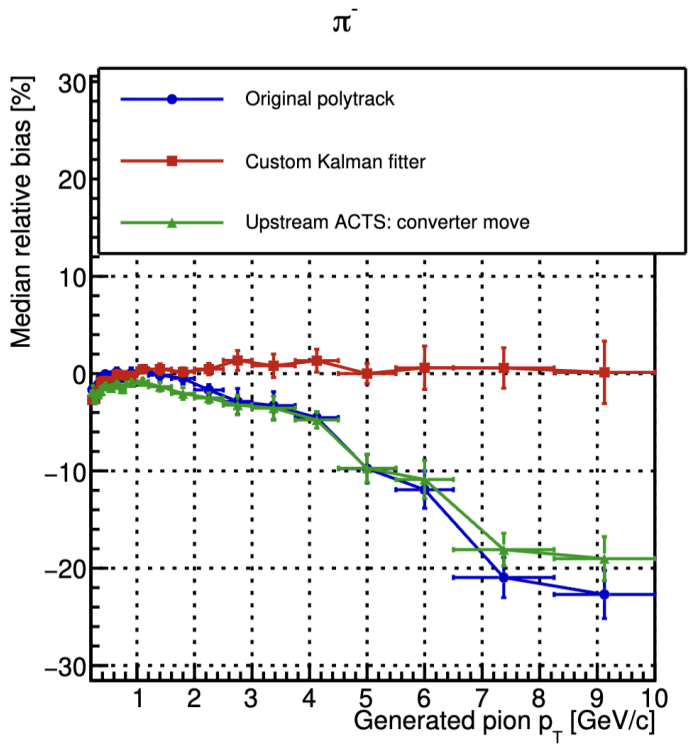


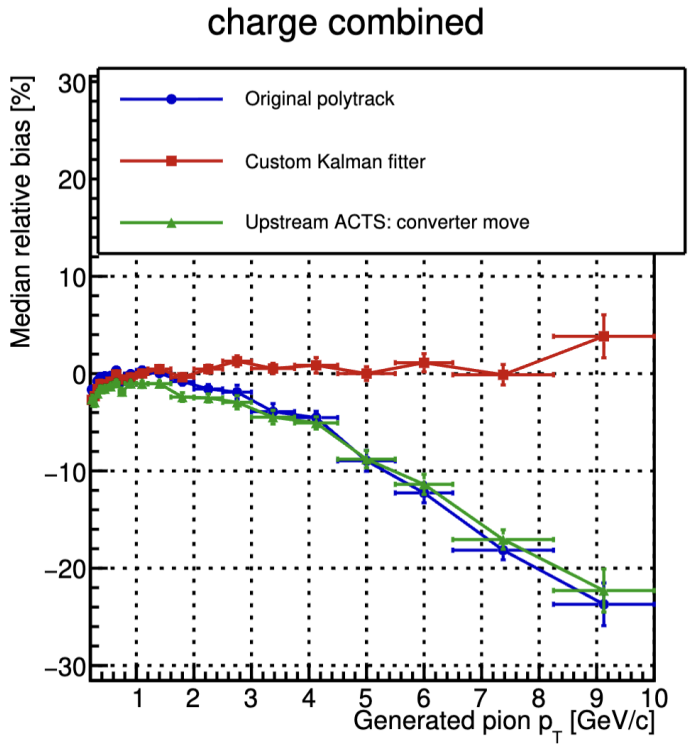


Median bias shows large difference

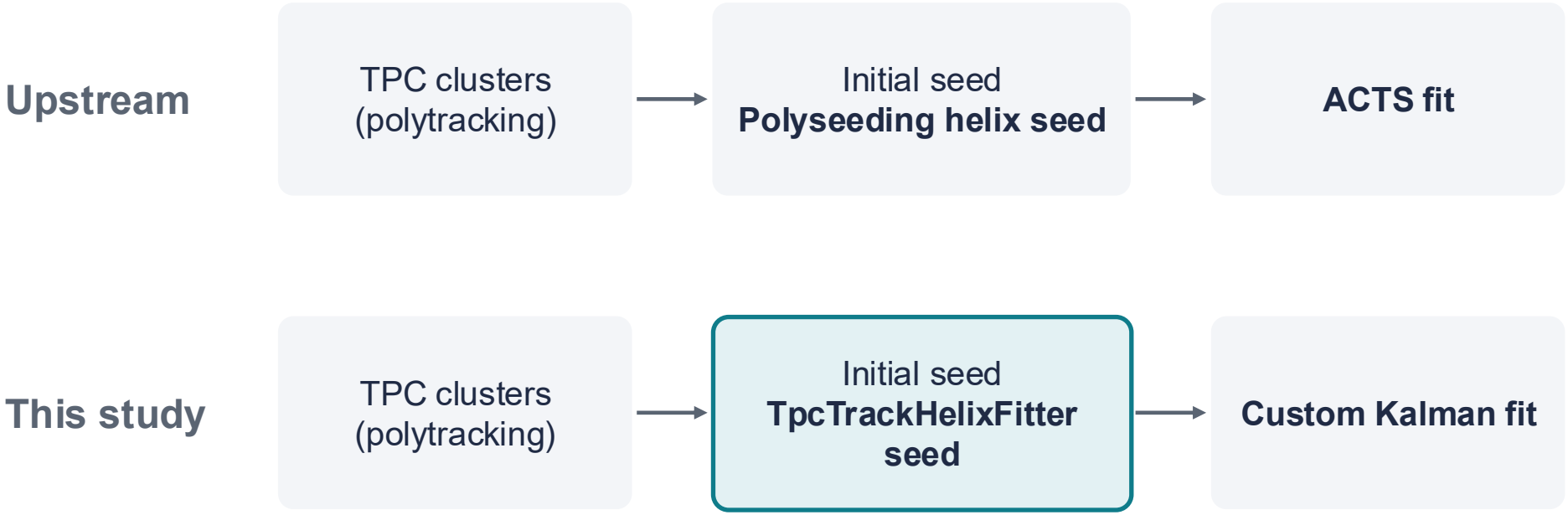
Upstream coresoftware commit bfce189
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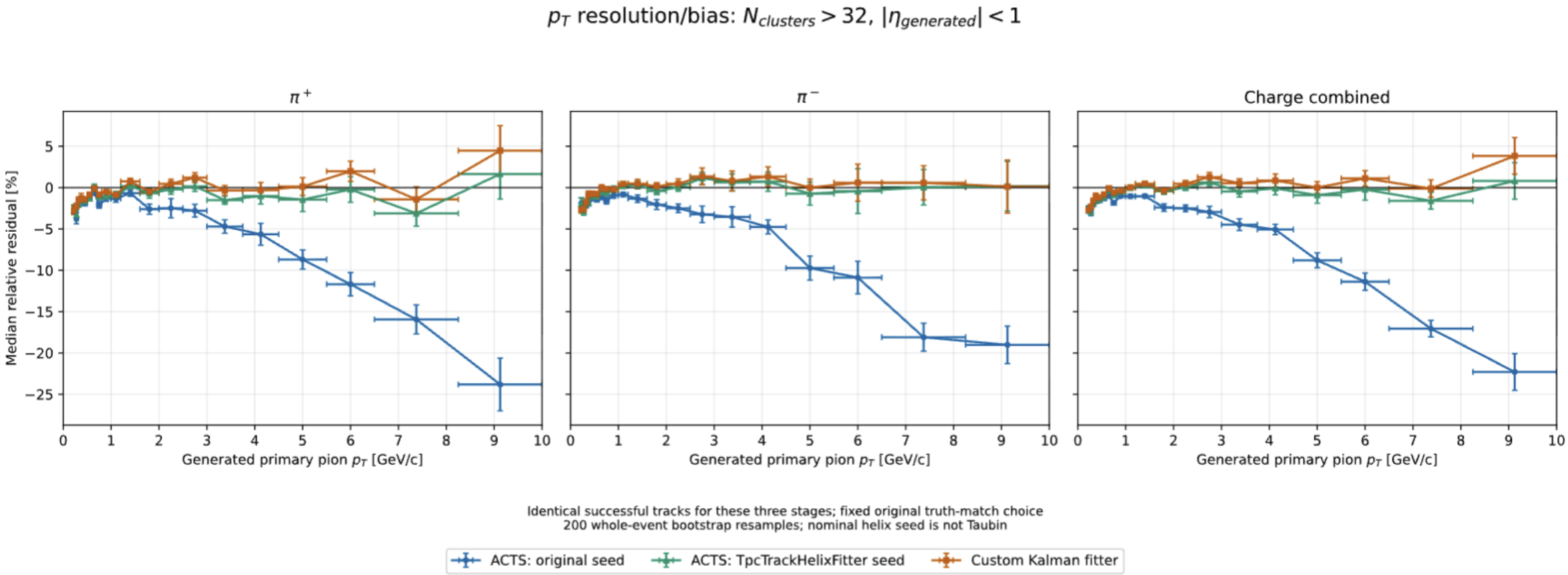
Seed construction contributes strongly to the high-pT bias in this TPC-only benchmark



Upstream coresoftware commit bfce189
Build/runtime environment: ana.576

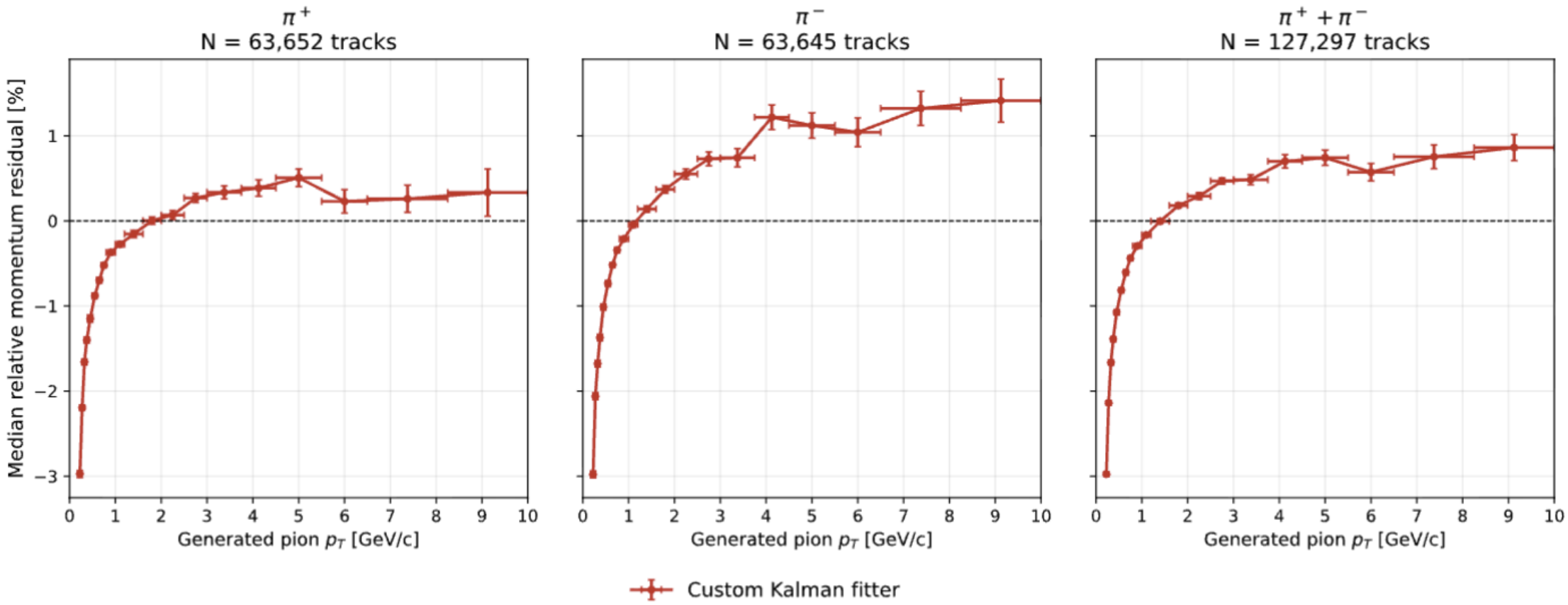
TpcTrackHelixFitter(Github)

Replacing the seed reduces the bias



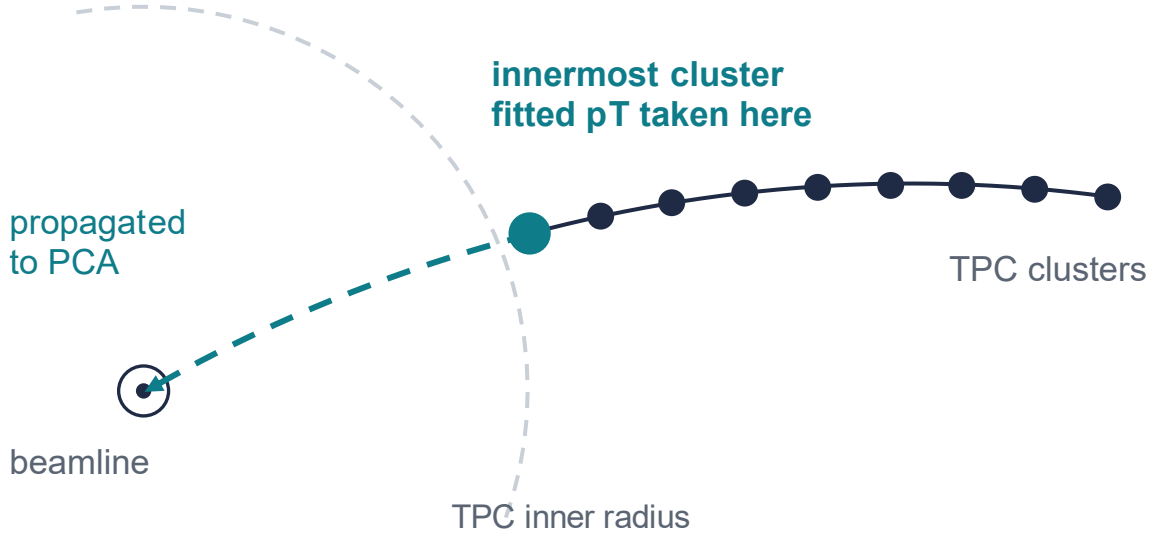
What about reco-pt bias in low pt region?

Used Polytracking + custom Kalman fitter

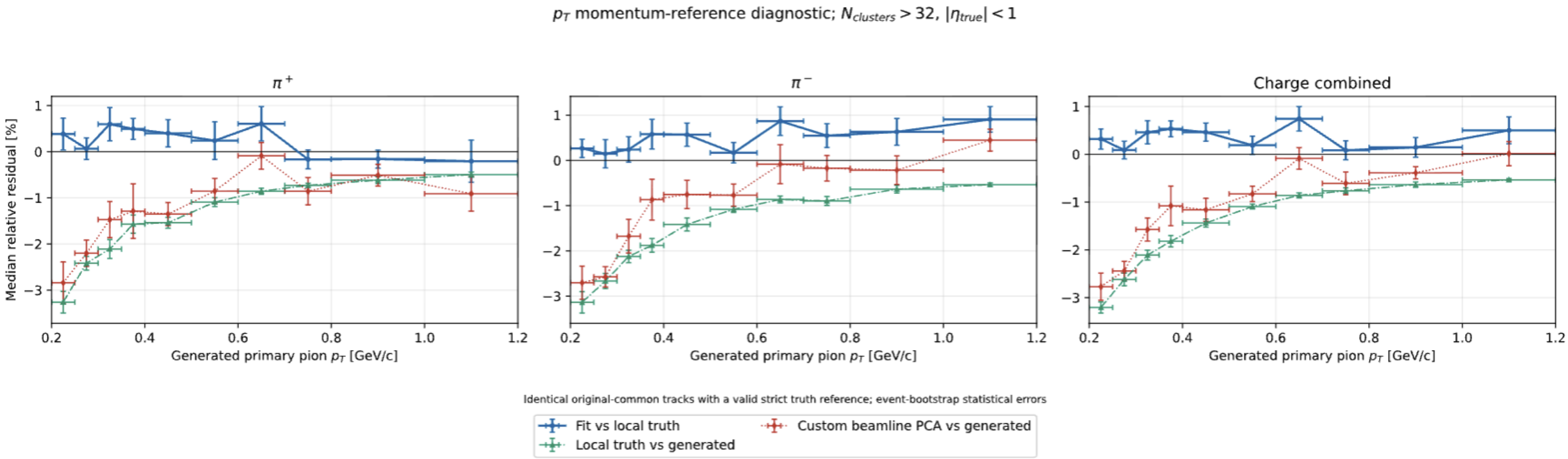


Charge combined. Values are median relative pT residual.

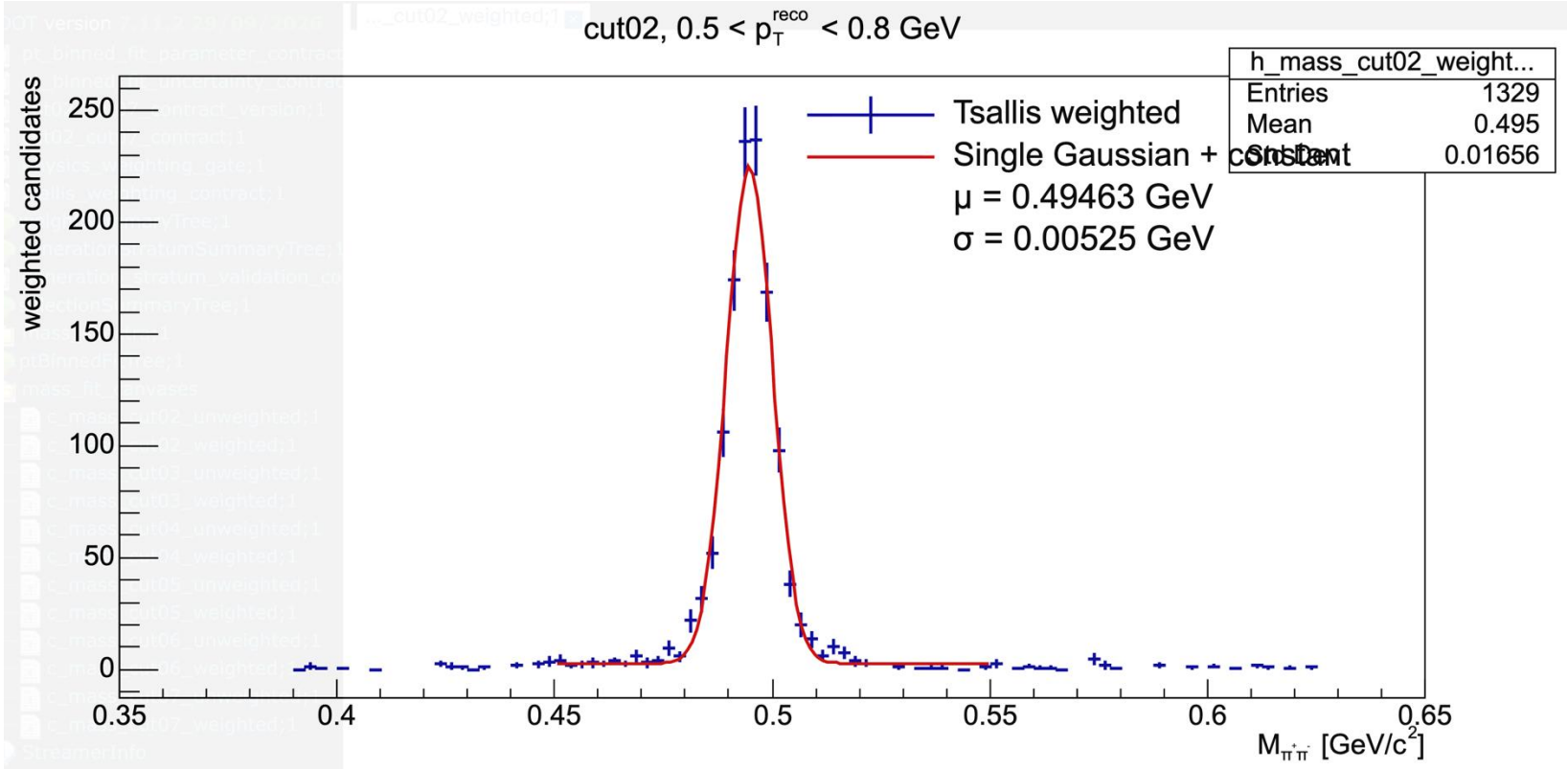
Energy loss before the TPC (affect low momentum tracks more)



Comparing at the TPC largely reduces the low-p_T median bias



The energy loss could explain why I saw lower kshort mass in simulation earlier



Summary

- Pt resolution and bias was studied
- An issue which could cause reconstructed pt bias was identified
- Low pt reconstruction bias due to energy loss before entering TPC could explain the kshort mass was lower in low pt region

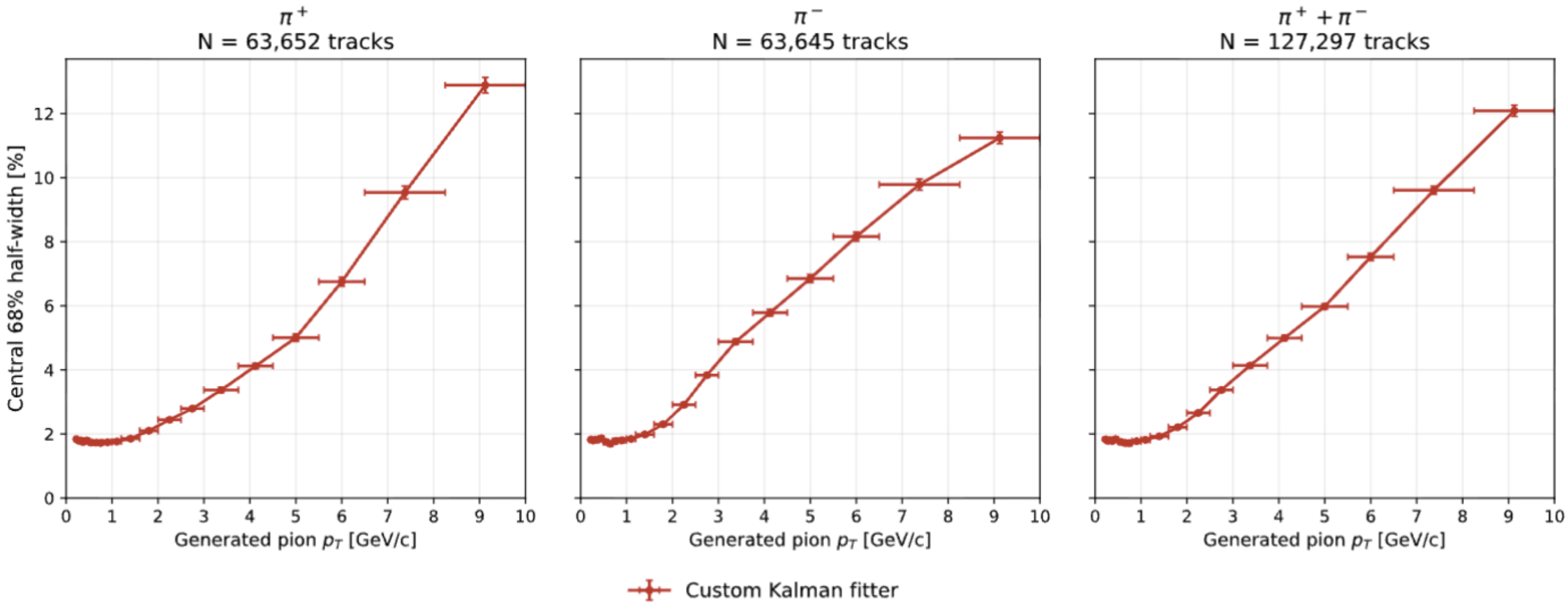
A question to ACTS expert

- Could the ACTS be tuned so that it is less sensitive to initial seed?
- Possible solutions:
  - Set a larger covariance for the seed so Kalman fitter will trust the seed less and later measurements more
  - Fit only few TPC clusters and then propagate the covariance of helix parameters to the initial seed properly

Backup

Momentum resolution

Used Polytracking + custom Kalman fitter



Charge combined. Width is the central 68% half-width of the relative pT residual.