UC Berkeley Tracking Updates

EIC UC Consortium

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Residuals study

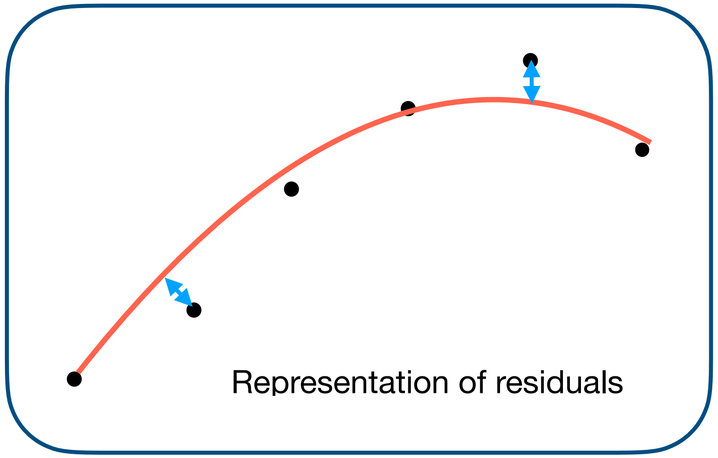
Issue + Motivation

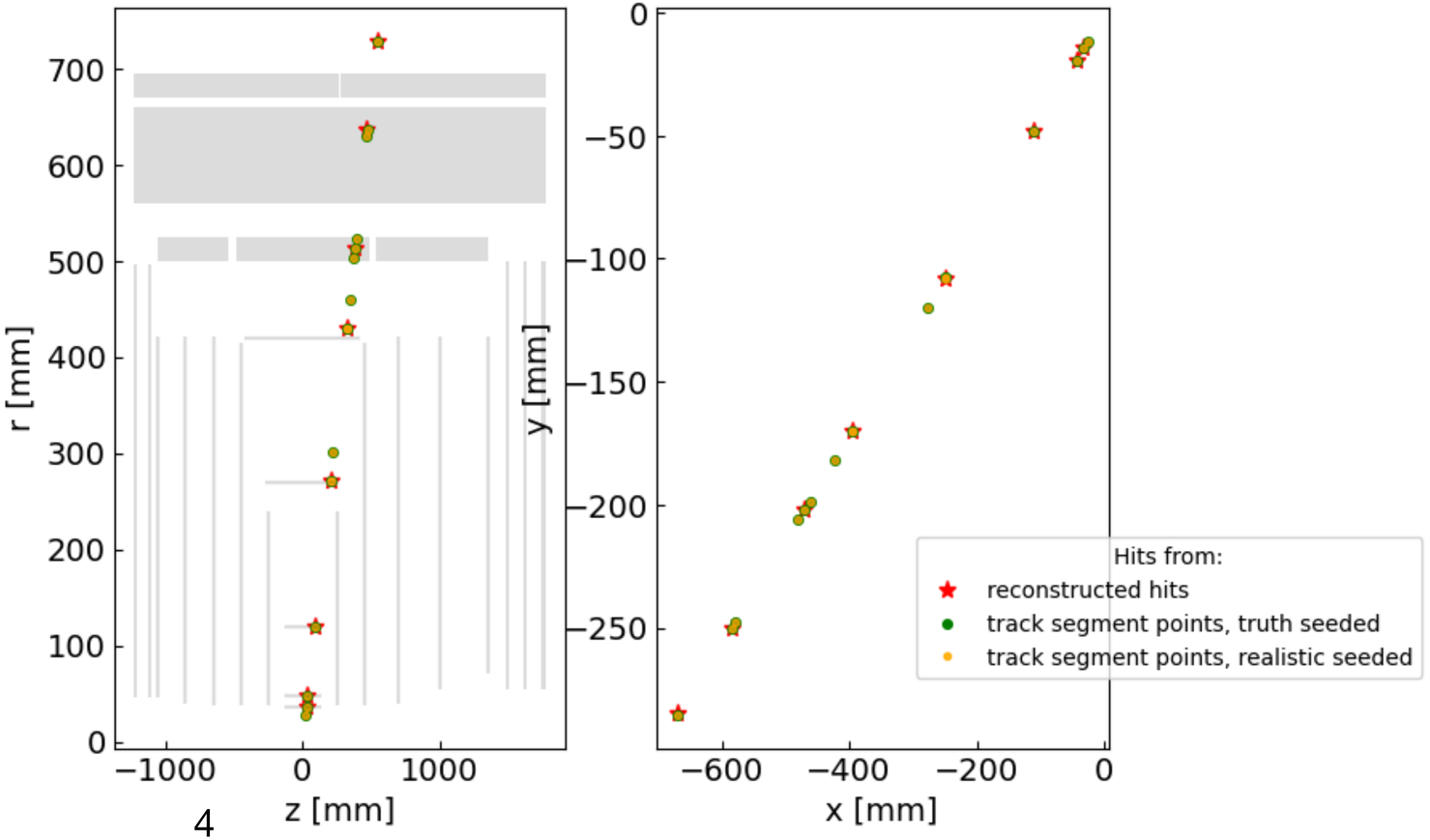
Residuals

- Study the track reconstruction performance at each layer of the central tracker geometry
- The χ^2 depends on tracking parameters and is not as straightforward as a residual
- There is also an arbitrary χ^2 cut of 15 that separates hits from becoming measurements or outliers

Defining a residual

- Compare the “RecHits” with the “CentralTrackSegment.points”
- Find the track point with the closest distance to the reconstructed hit in Δr(Δz) for the barrel(endcap)
- Barrel layer residual:
  - $\Delta z = z_{\text{hit}} - z_{\text{trackpoint}}$
- Endcap layer residual:
  - $\Delta r = r_{\text{hit}} - r_{\text{trackpoint}}$

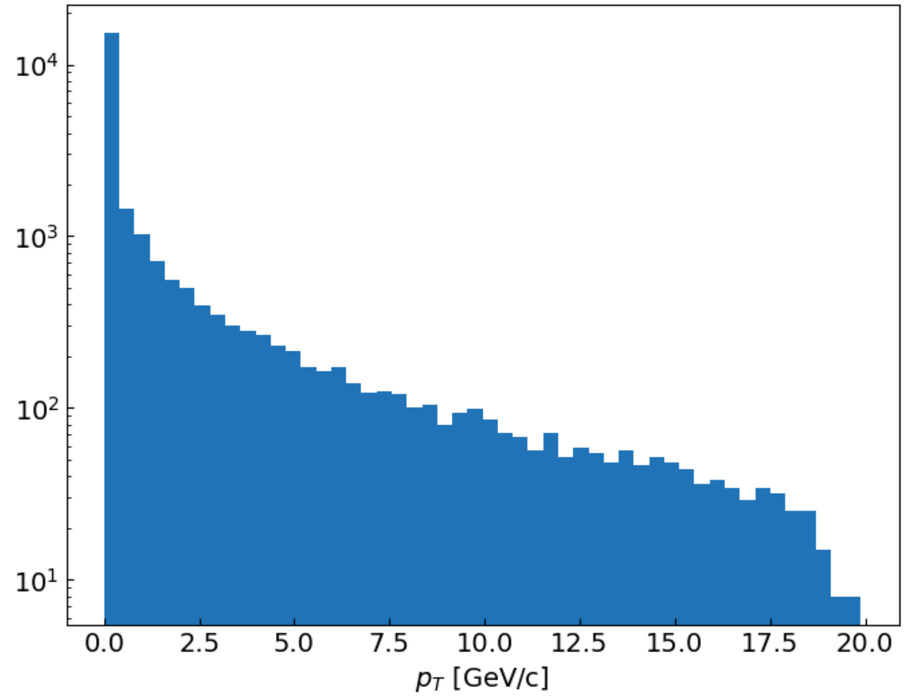


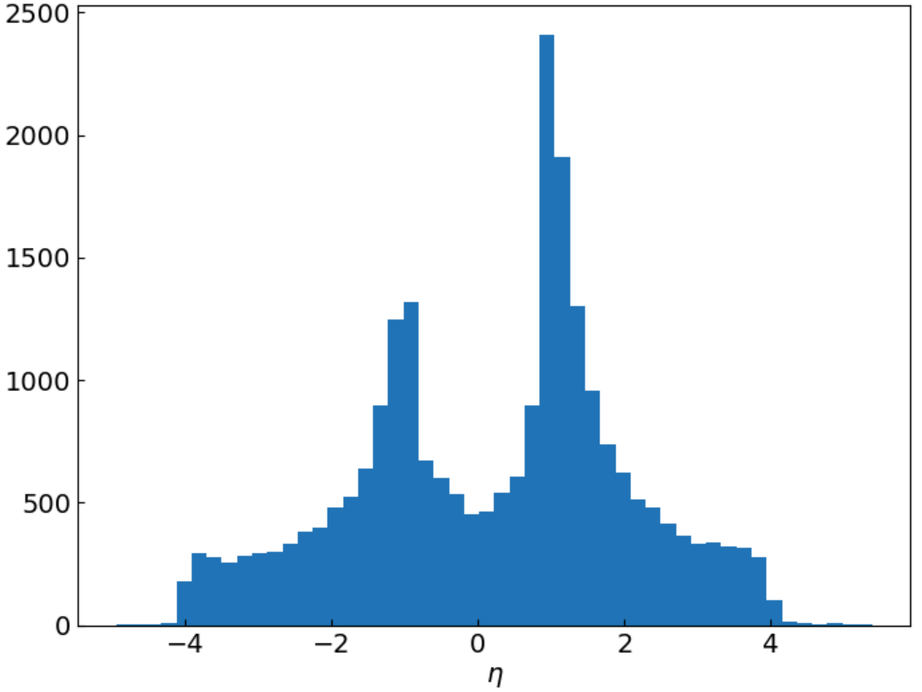


Sample of events

Events used:

- Single muon
- 10,000 events
- 0.5 < p < 20 GeV
- -4 $\leq \eta \leq$ 4
- Only looking at the central tracker

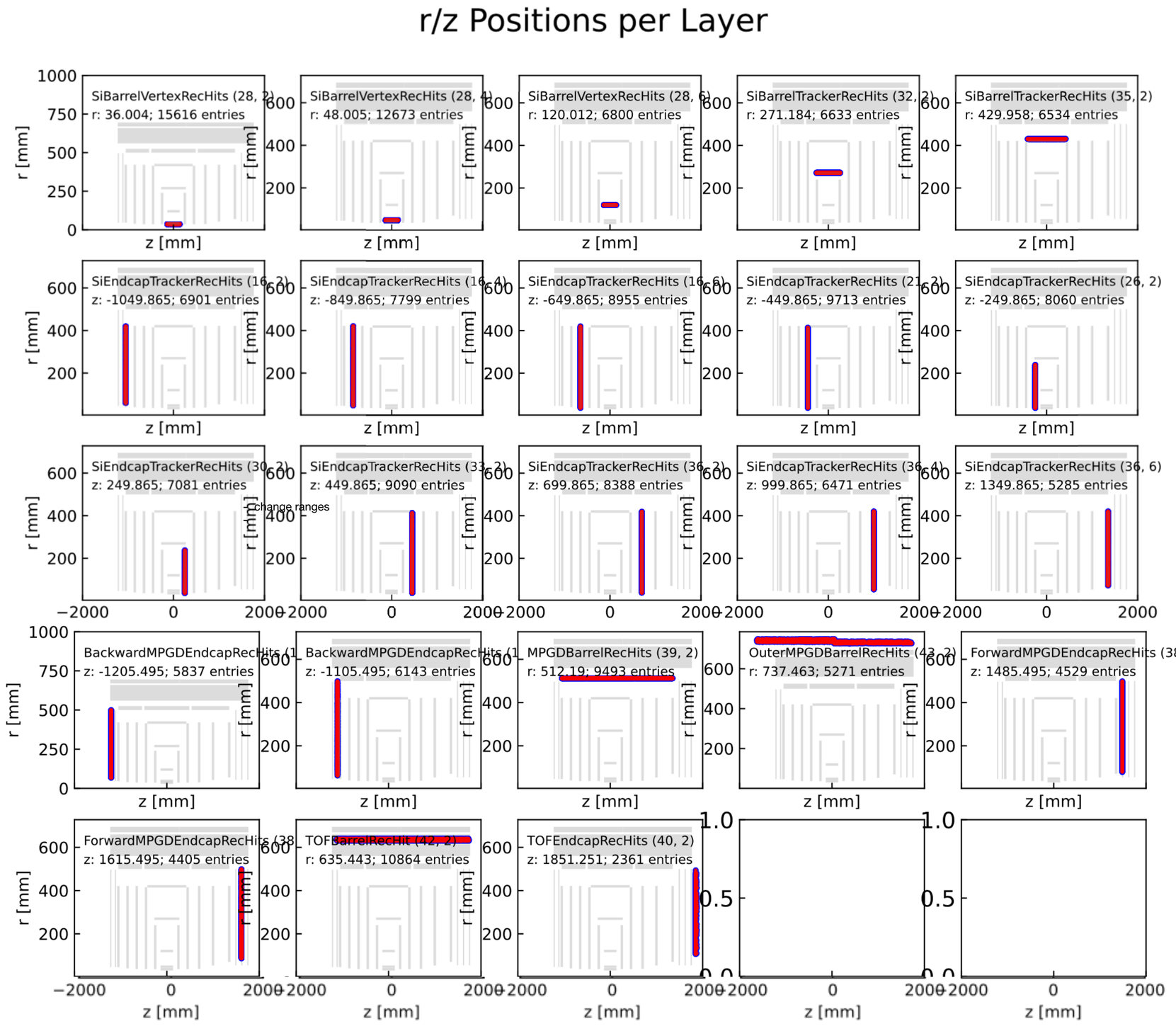




r/z positions per layer

Central Track Measurements
Track segment points matched to Central Track Measurements
Detector configuration

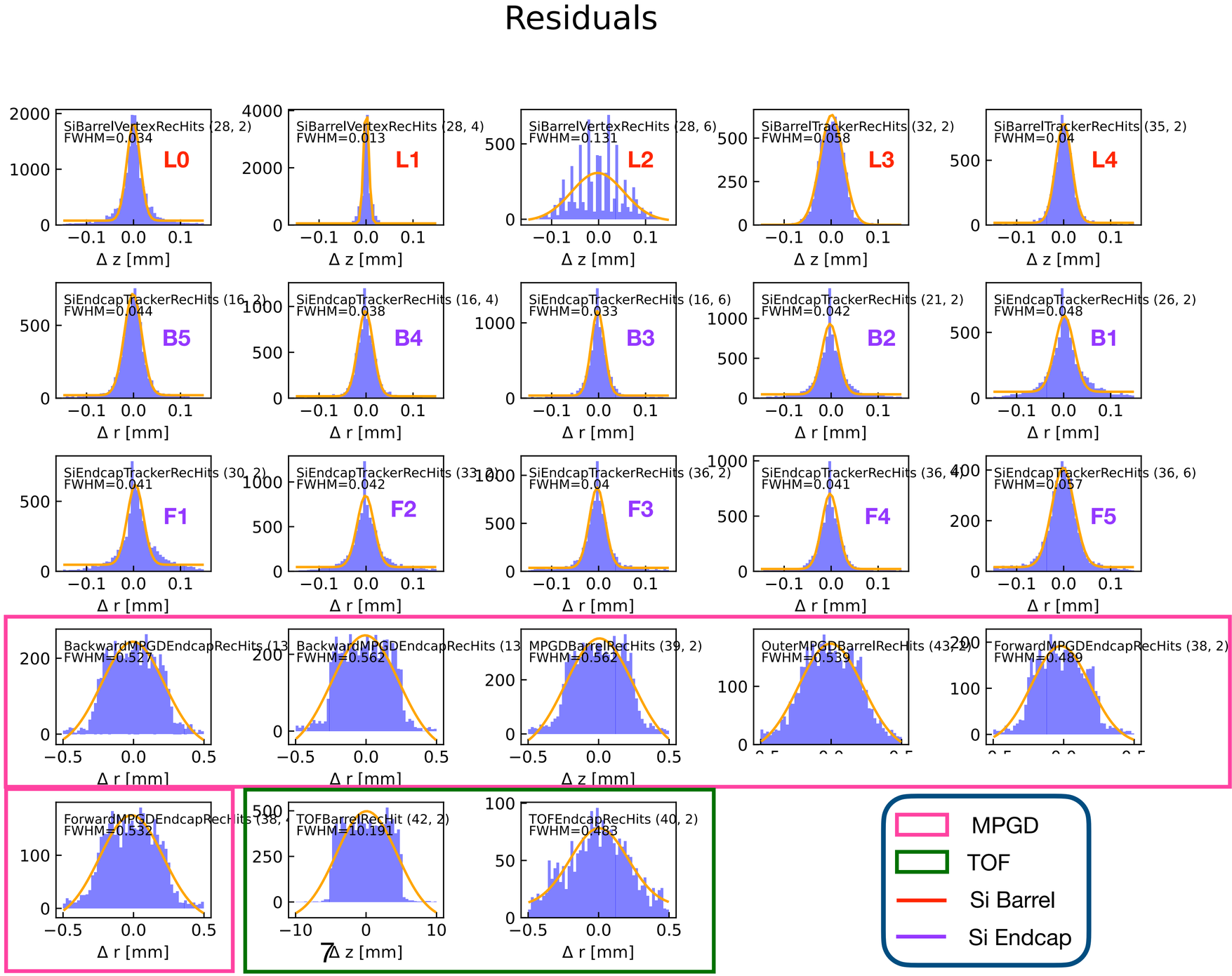
- Track segment points matched with measurement hits
- Visually, it looks like the measurements line up nicely with the track points



Residuals

per layer

- Realistic seeded, μ-
- Silicon peaks range from a FWHM of 13 - 131 μm
- Predicted track segments



FWHM at different layers

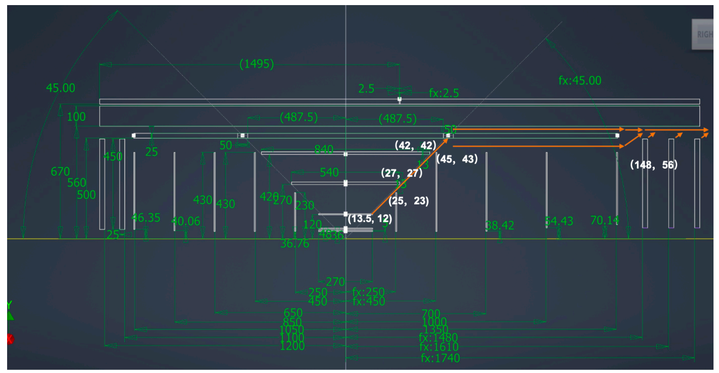
*See different TOF endcap coordinates at: https://eic.jlab.org/Geometry/Detector/Detector-20231031150001.html

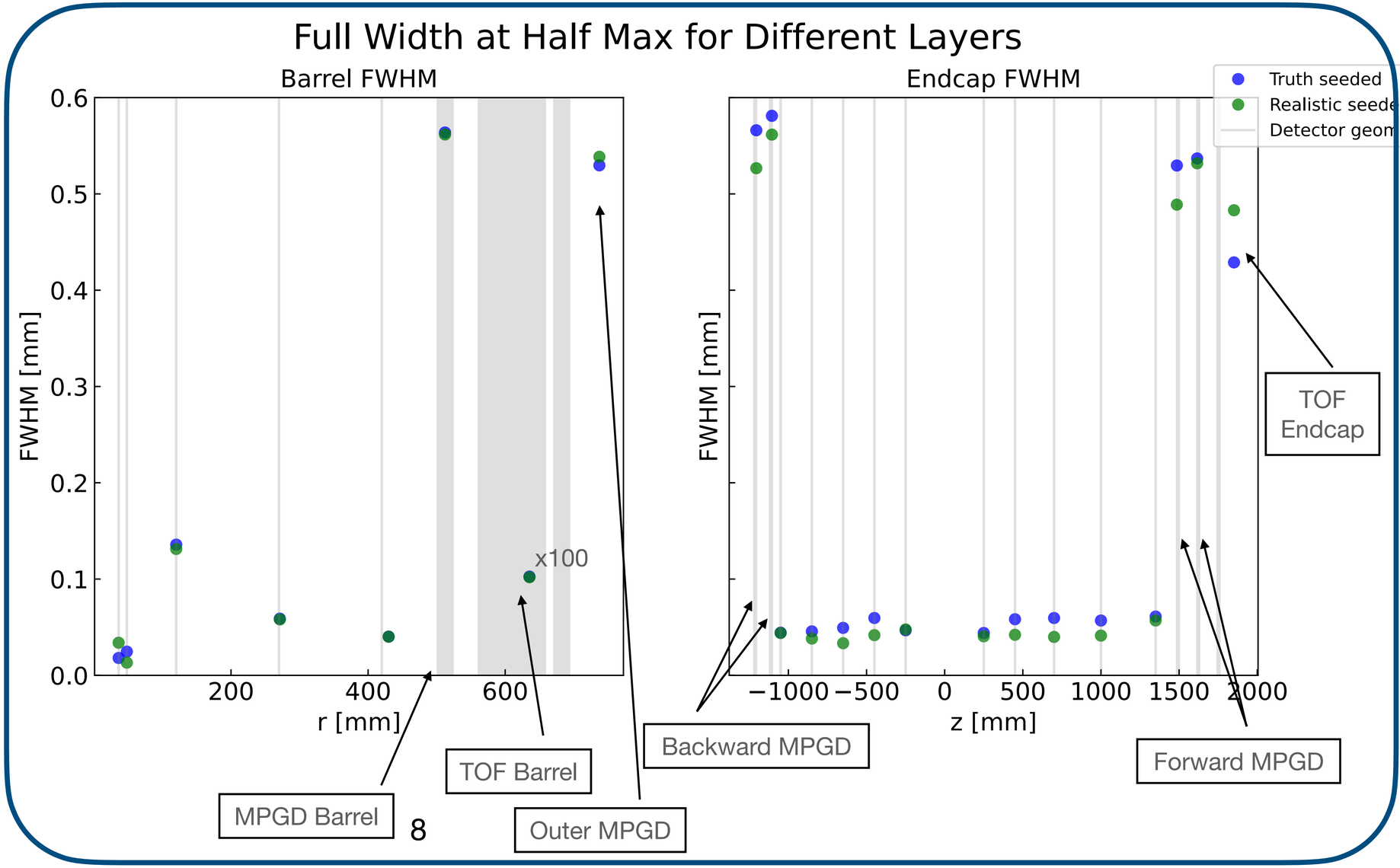
Region	Layer	radius [mm]	length [mm]	X/X0
IB	L0	36	270	0.05 %
	L1	48	270	0.05 %
	L2	120	270	0.05 %
OB	L3	270	540	0.25 %
	L4	420	840	0.55 %

Region	Disk	z [mm]	inner radius* [mm]	outer radius [mm]	X/X0
EE	ED0	-250	36.76	240	0.24 %
	ED1	-450	36.76	415	0.24 %
	ED2	-650	36.76	421.4	0.24 %
	ED3	-850	40	421.4	0.24 %
	ED4	-1050	46.35	421.4	0.24 %

Region	Disk	z [mm]	inner radius* [mm]	outer radius [mm]	X/X0
HE	HD0	250	36.76	240	0.24 %
	HD1	450	36.76	415	0.24 %
	HD2	700	38.46	421.4	0.24 %
	HD3	1000	53.43	421.4	0.24 %
	HD4	1350	70.14	421.4	0.24 %

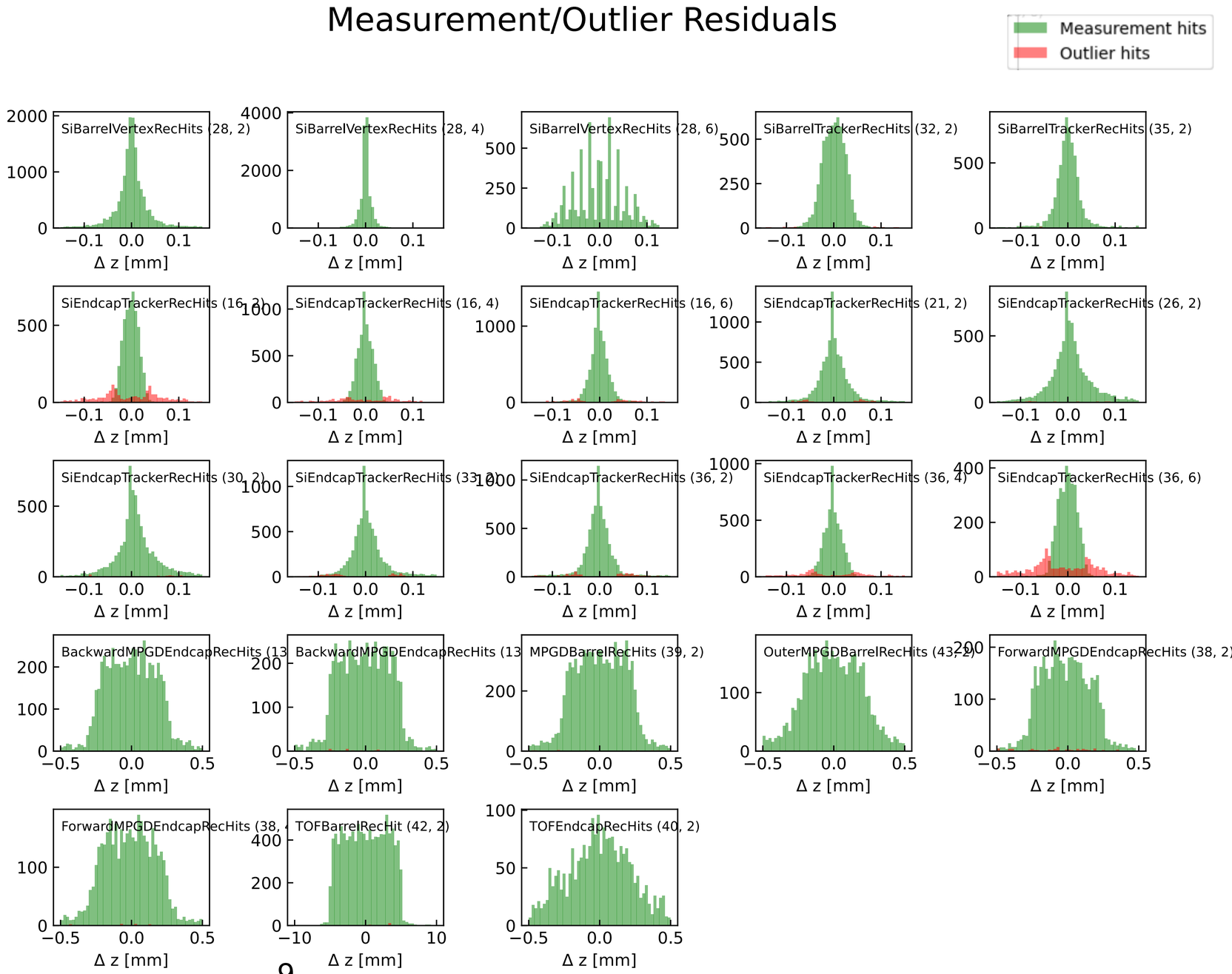
https://wiki.bnl.gov/EPIC/index.php?title=Si_Vertex_Tracker





Measurement vs outlier hits

- Predicted track states
- Realistic seeded
- See which hits were used in the final track fit
- Higher percentage of outliers visible in the outer silicon endcaps



https://cds.cern.ch/record/2798674/files/Publication.pdf

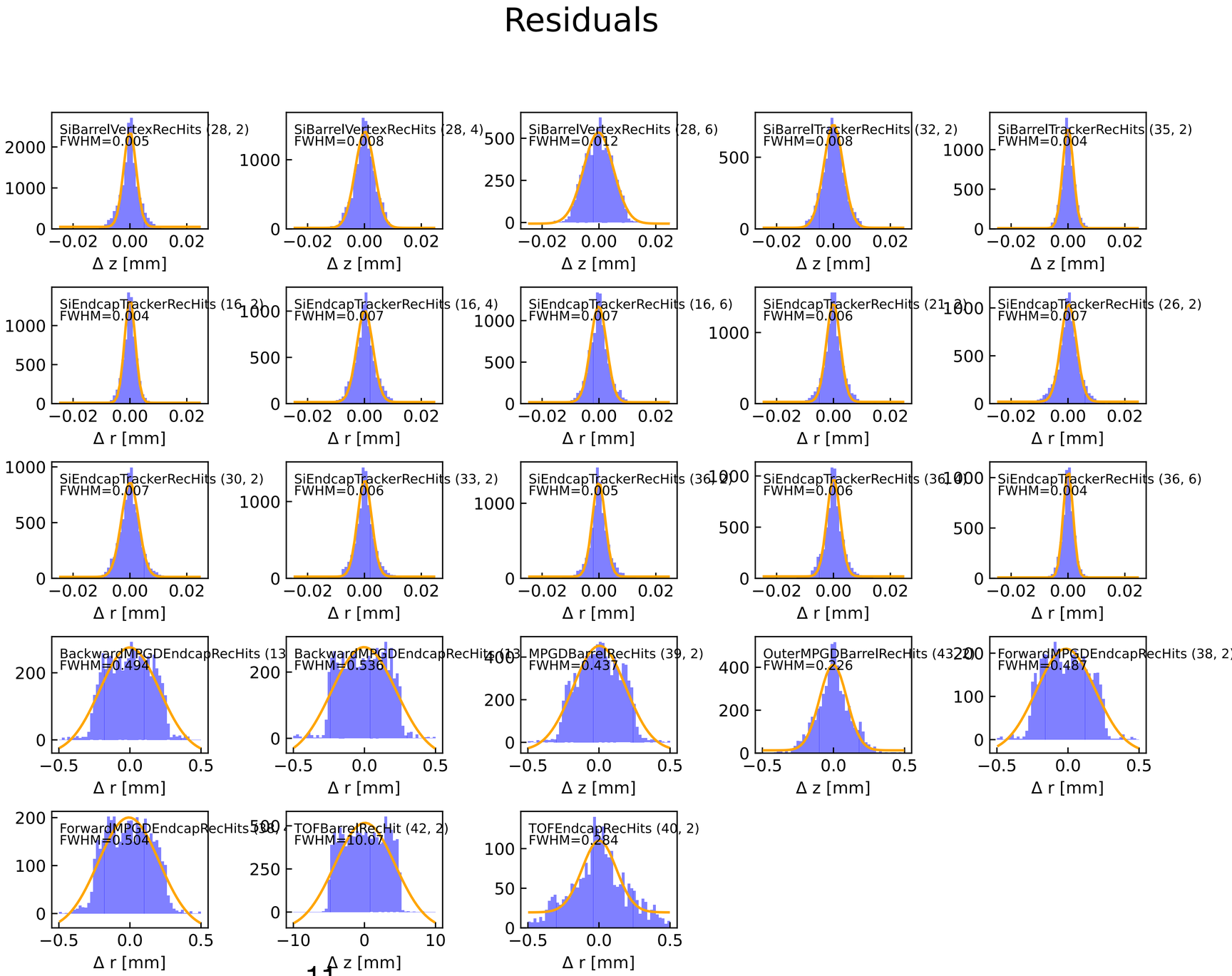
ACTS Track States

Predicted, filtered, and smoothed track states

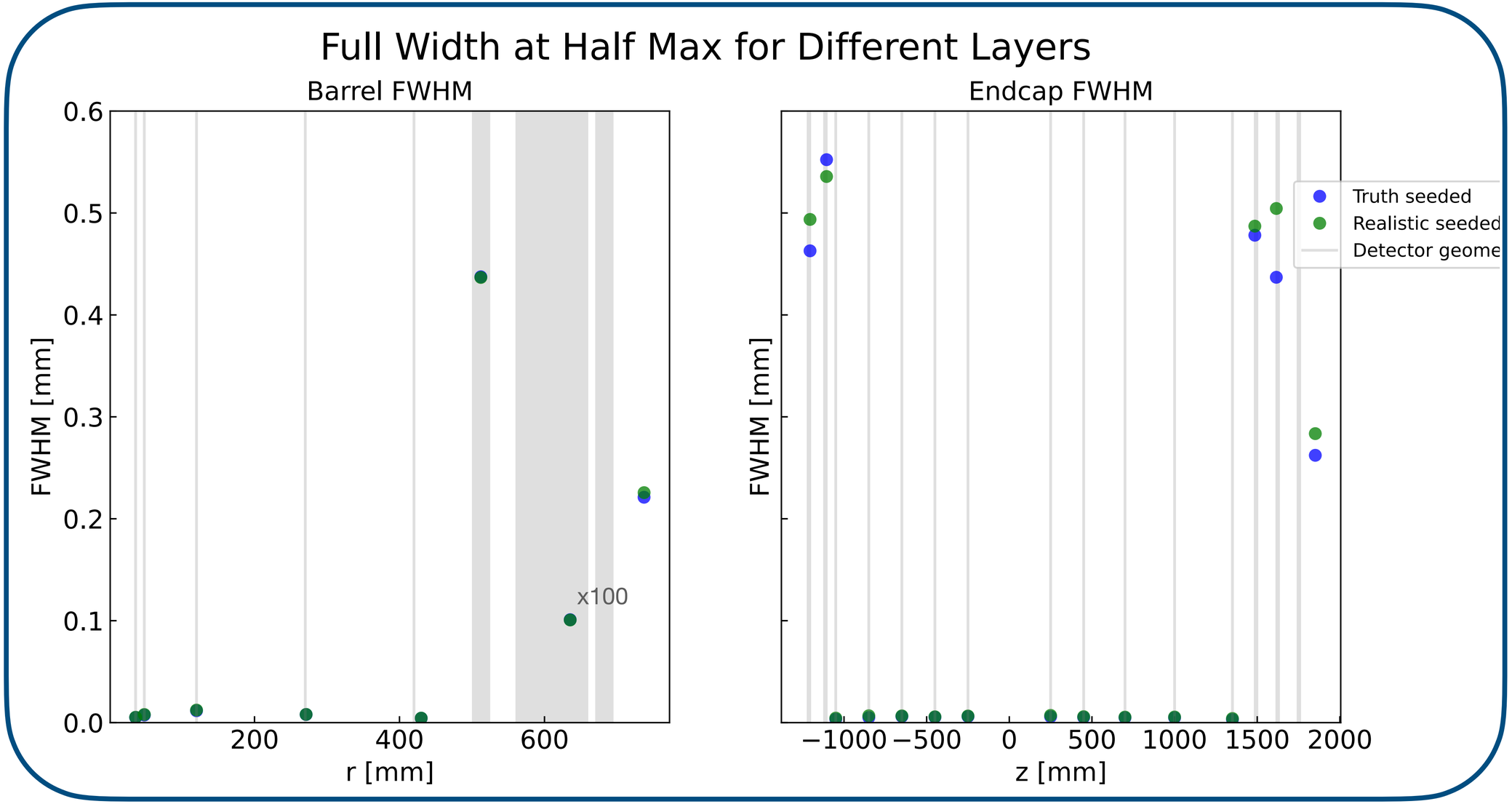
- 3 optional sets of track parameters from track fitting process
- *Predicting*: determines track state at state k based on previous k – 1 measurements
- *Filtering*: adjusts the predicted track state at state k taking into account the measurement at state k
- *Smoothing*: adjusts the filtered track state with all measurements taken into account
  - Rauch–Tung–Striebel (RTS) smoother
    - Ensures that information from all measurements is included in the track parameter estimate at each measurement

Residuals: smoothed track states

- realistic seeded
- FWHM:
  - silicon: ~4-20 μ
  - MPGD: ~200-500 μ
  - TOF barrel: ~10 mm in z
    - should be ~30 μ in $r\phi$
  - TOF endcap: ~280 μ

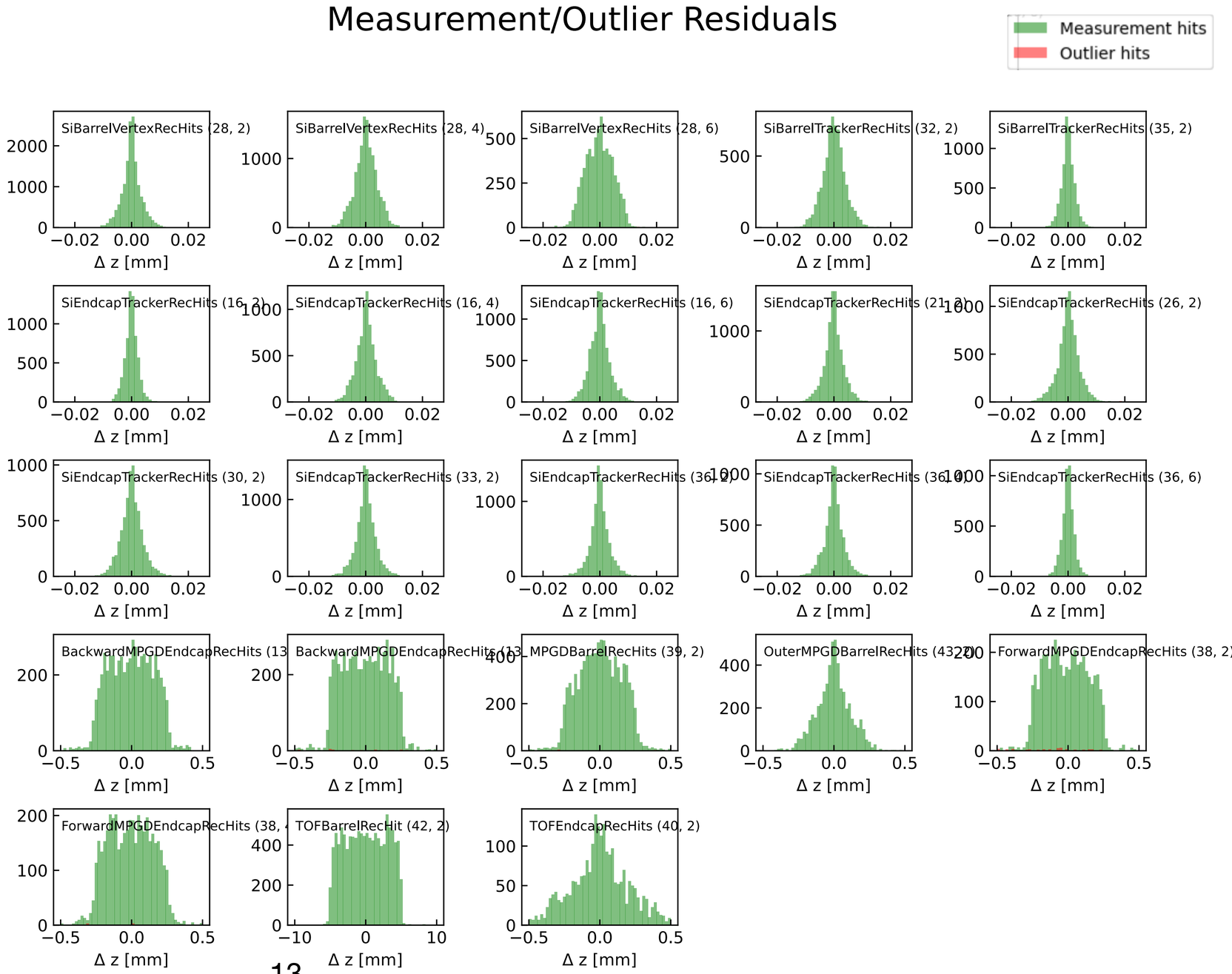


FWHM, smoothed track states



Measurement vs outlier hits

- Smoothed track states
- Realistic seeded
- See which hits were used in the final track fit
- Not a high percentage of outliers seen compared to the measurement hits



Duplicate tracks study

Issue + Motivation

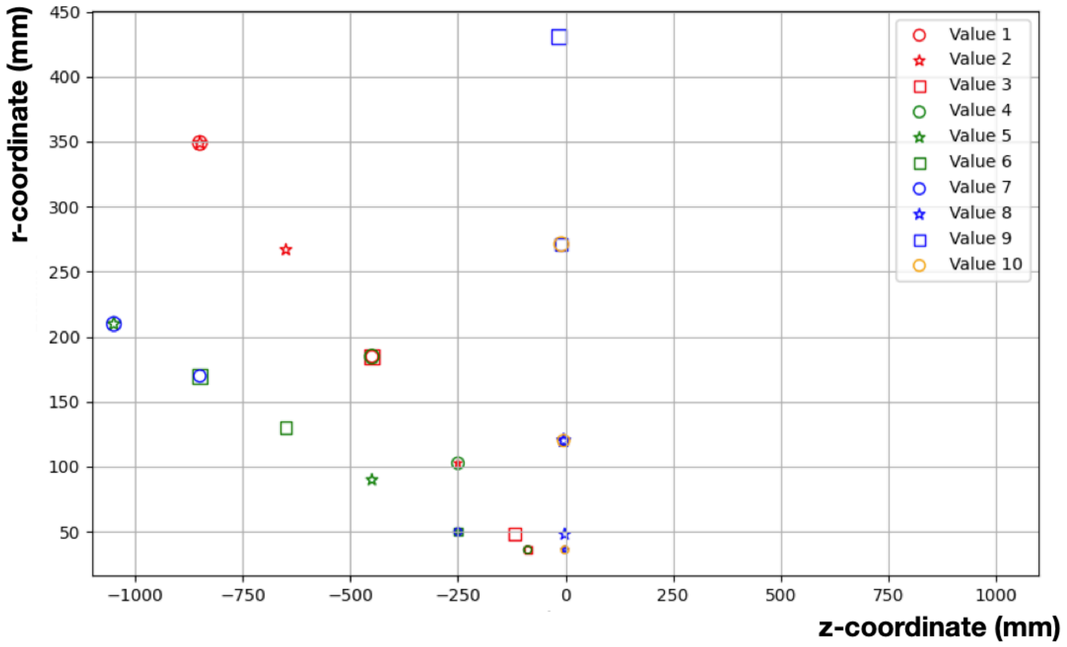
Duplicate Tracks

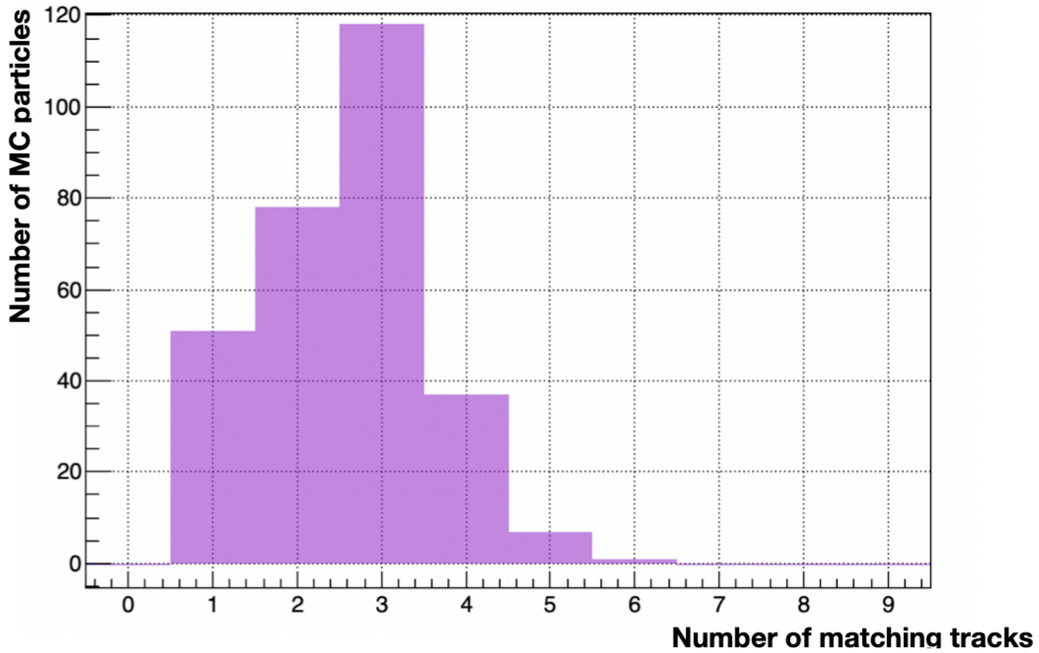
See Minjung Kim's presentation here for more information!

- Seed is made with 3 hits → several seeds can be found along one trajectory, leading duplicate tracks
- Correlation between a number of generated hits (N_{hit}) and a number of duplicate tracks (N_{trk}):

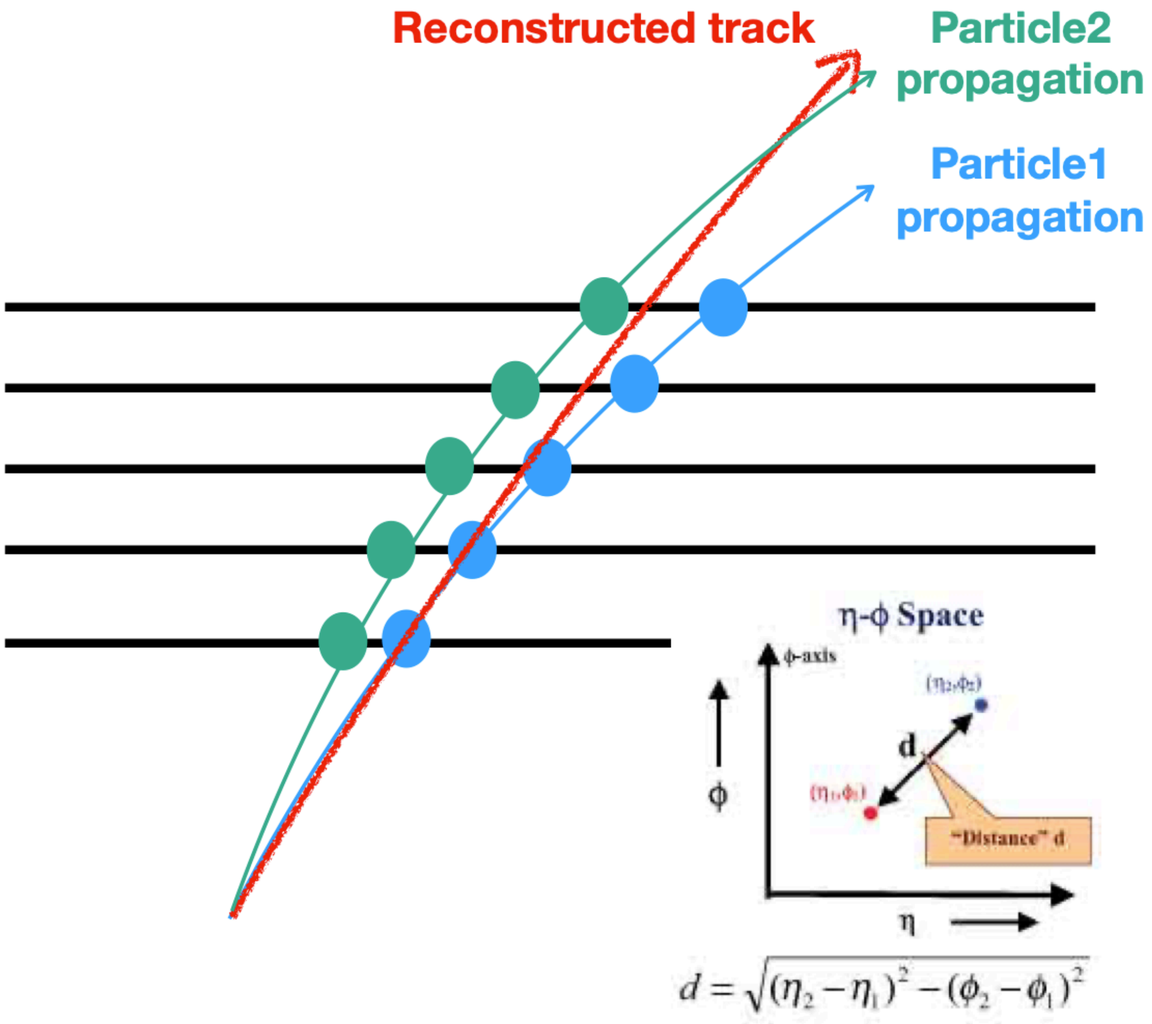
$$N_{trk} \propto {}_{N_{hits}}C_3$$

- Reduction by requiring using middle space point only once (as a middle space point), but still there





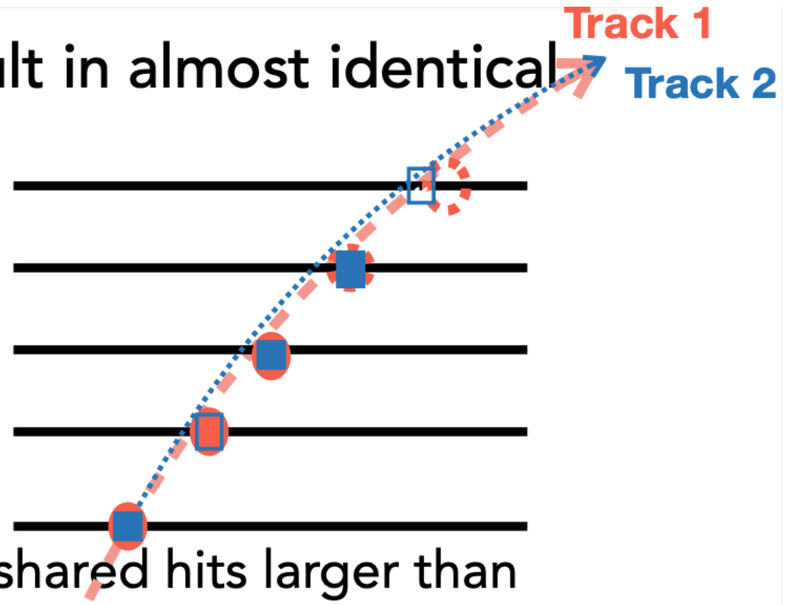
Matching process



- Two different matching methods were considered:
  - Hit level matching: check the source of hits in the track and matching to the particle giving maximum contribution
  - Angular distance matching: matching reconstructed track with the particle having the closest value of the distance (similar to EICrecon way)
- Angular distance based matching gives similar result with hit level matching, but not always
  →Can we introduce hit level matching used at the LHC exp. in EICrecon? MC source of generated hits not written in TrackerHit object

Greedy ambiguity resolution solver

- After tracking, seeds originated from same particle result in almost identical reconstructed tracks
  - More or less similar reconstructed kinematic variables
  - Almost same sets of associated hits
- **Greedy ambiguity resolution solver**:
  1. Iterate trajectories and find the trajectory having number of shared hits larger than certain threshold
  2. Find the competetors and keep better quality trajectory only
  3. Repeat till you have trajectories having shared hits below certain threshold: number of shared hits required!

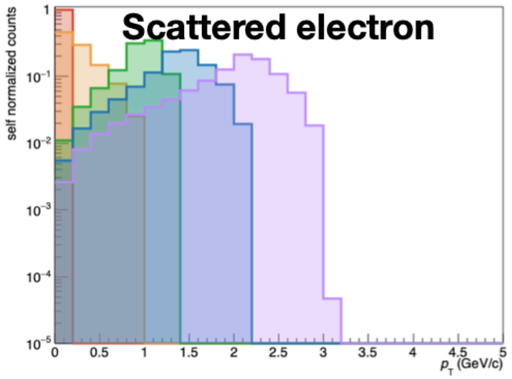


➡ **Native support in ACTS,** not implemented in official EICrecon yet

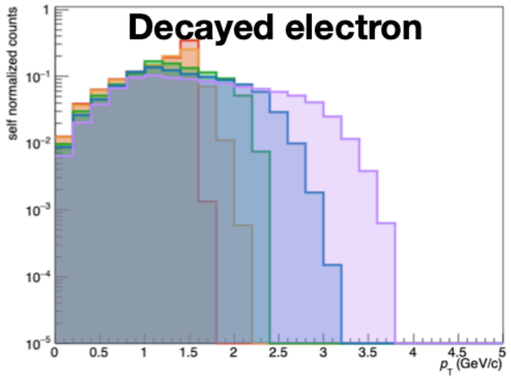
★ ML based methods under development

J/ψ photoproduction at EIC

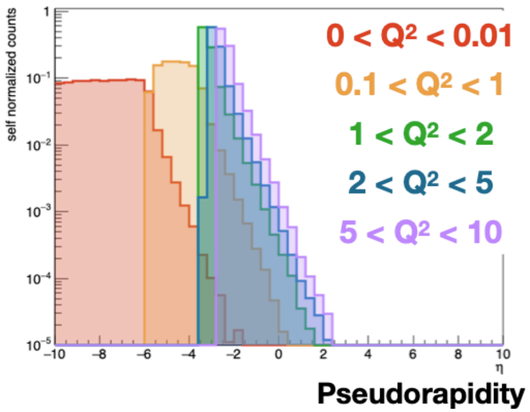
- Coherent production of eA→eA′J/ψ→e(e+e-)A′ with eSTARLight
- Final state particle kinematics are well constrained; most of cases 3 electrons



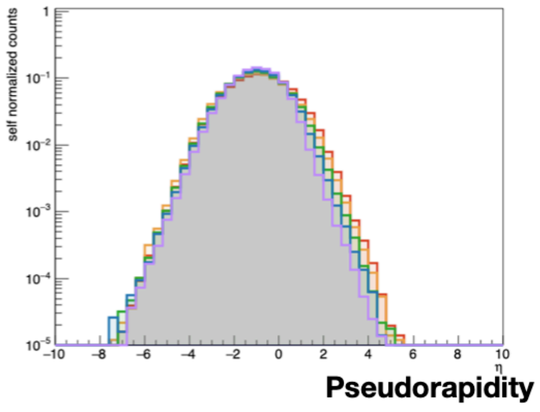
Transverse momentum (GeV/c)



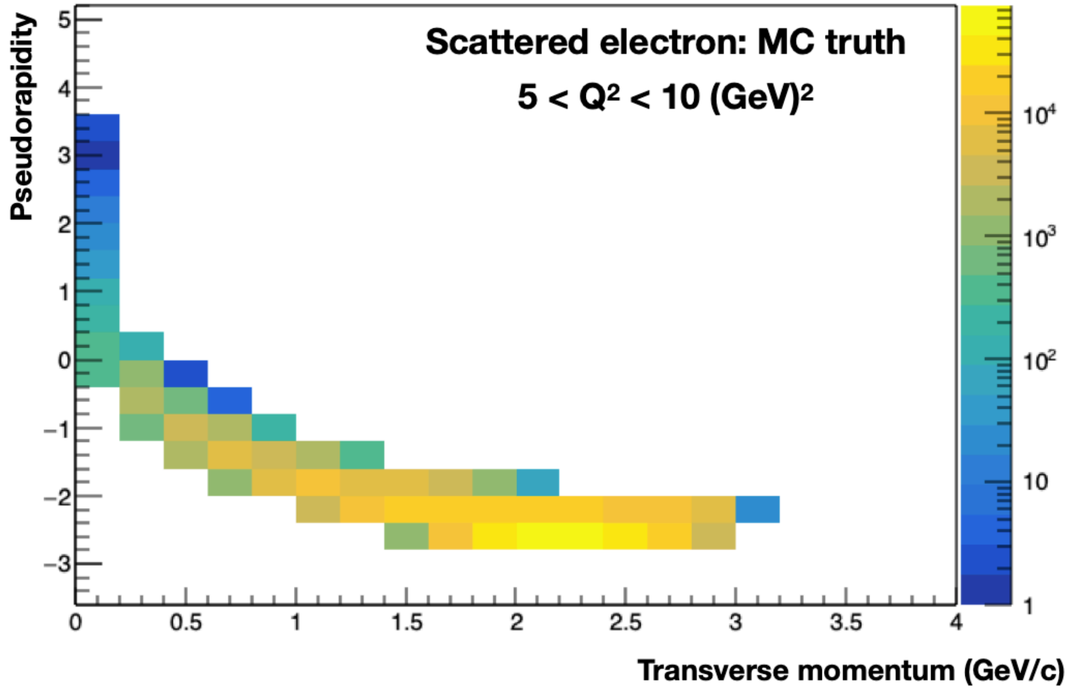
Transverse momentum (GeV/c)



Pseudorapidity

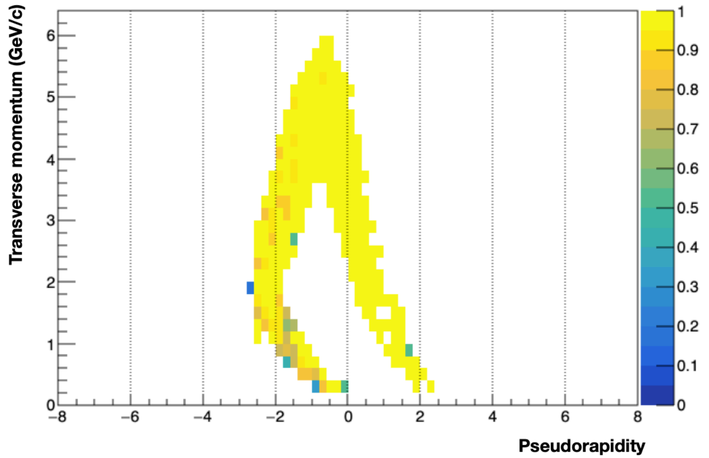


Pseudorapidity



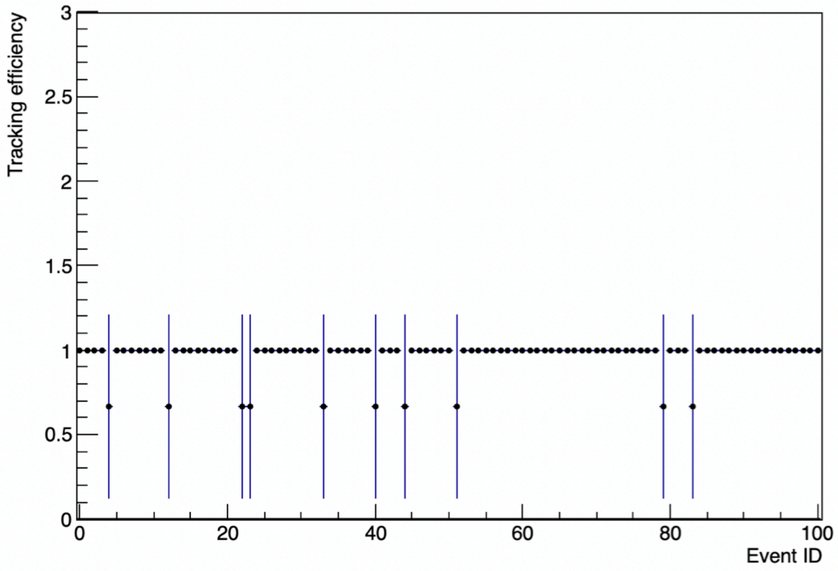
Physics Performance

J/ψ photoproduction ($5 < Q^2 < 10$)

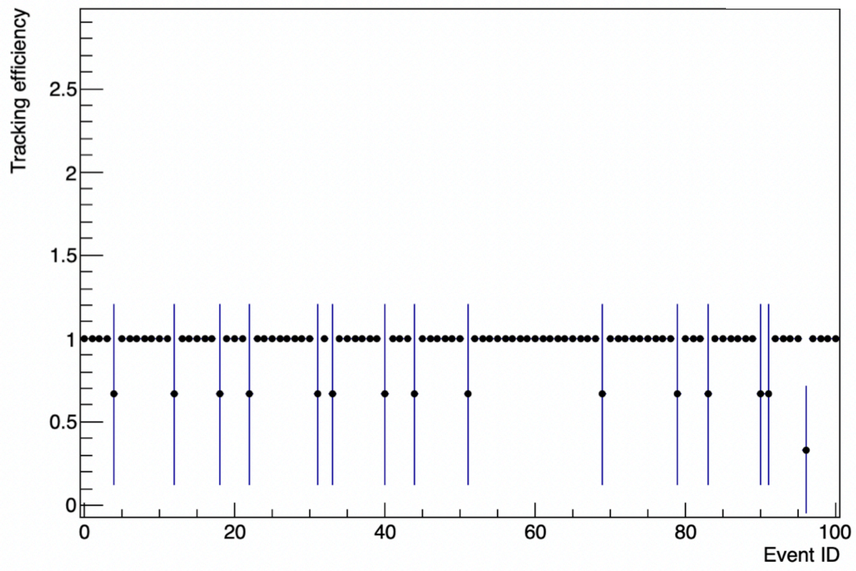


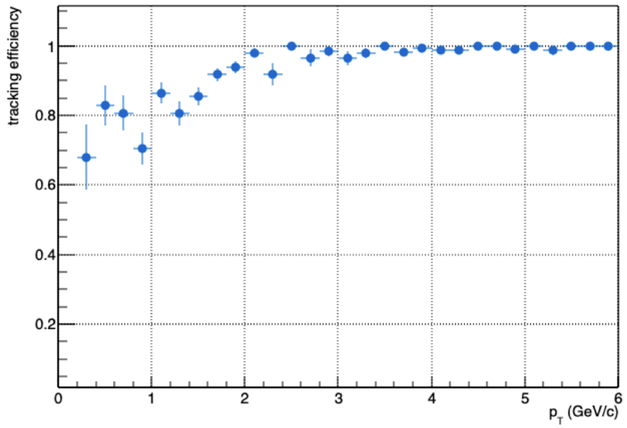
- Greedy ambiguity resolution solver works well!! (No events with duplicate tracks!)

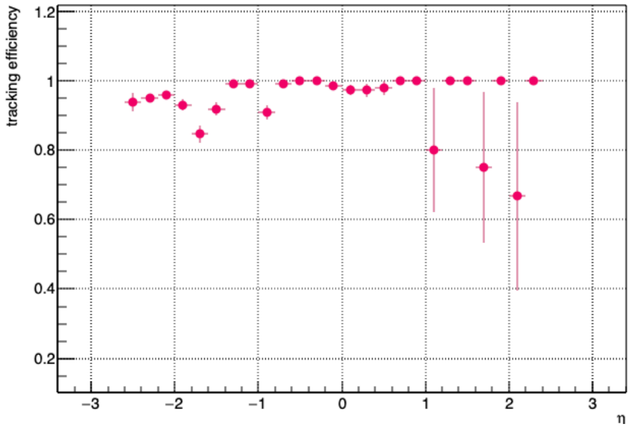
True seeding



Realistic seeding



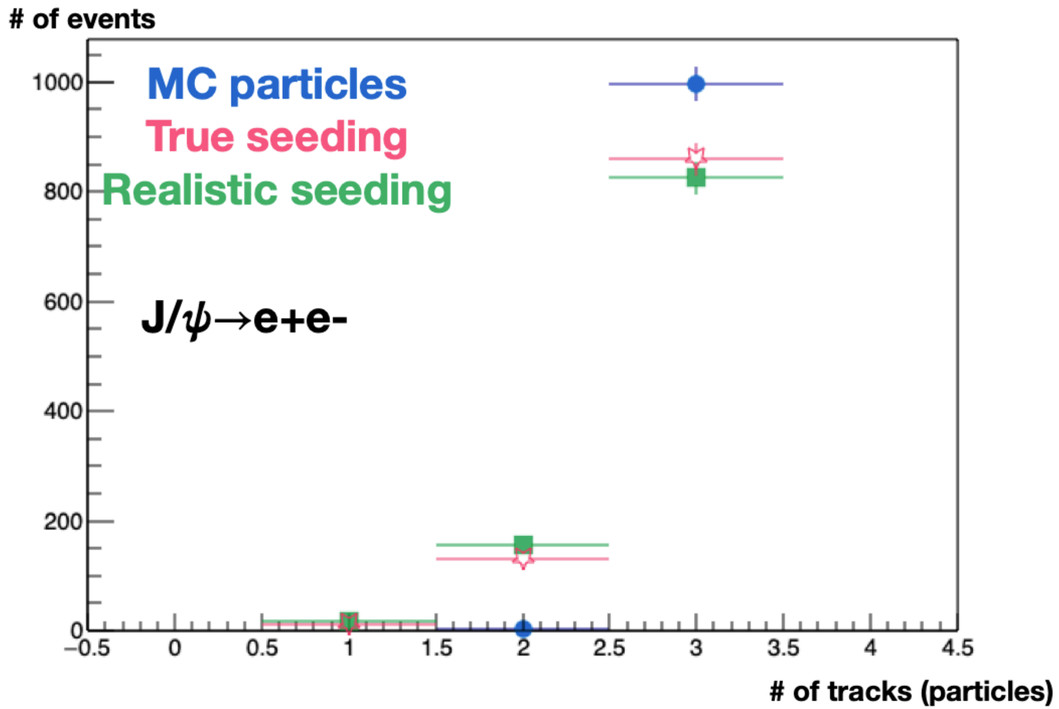


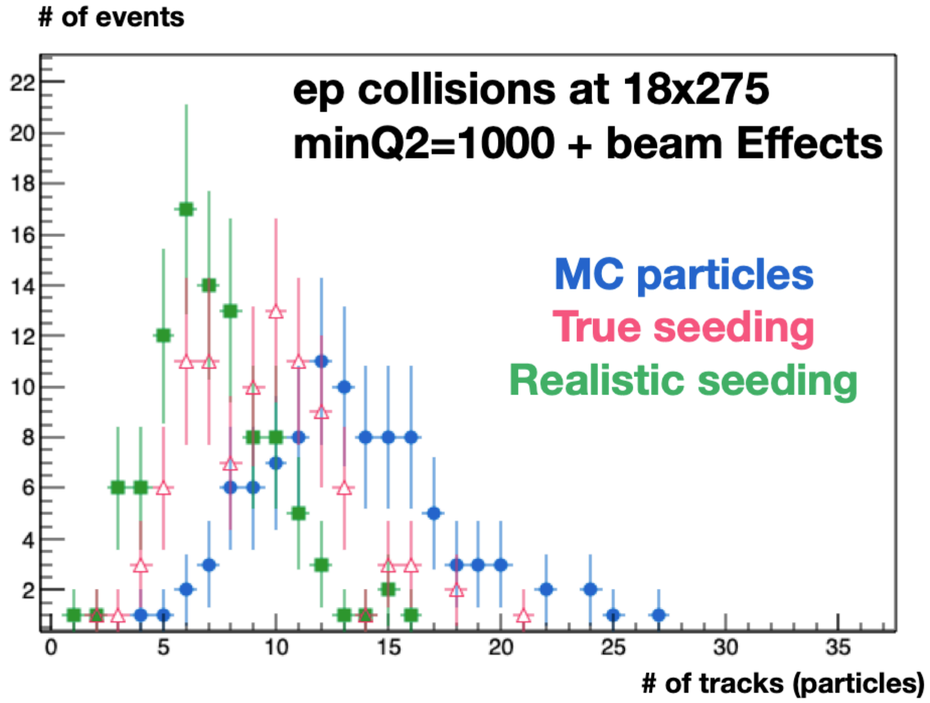


- Fully efficiency above 2 GeV/c
- No eta dependence found within -2.5 < eta < 2.5
- Tracking efficiency: $\frac{\textbf{number of reconstructed, matched tracks}}{\textbf{number of generated final state particles}}$

Physics Performance

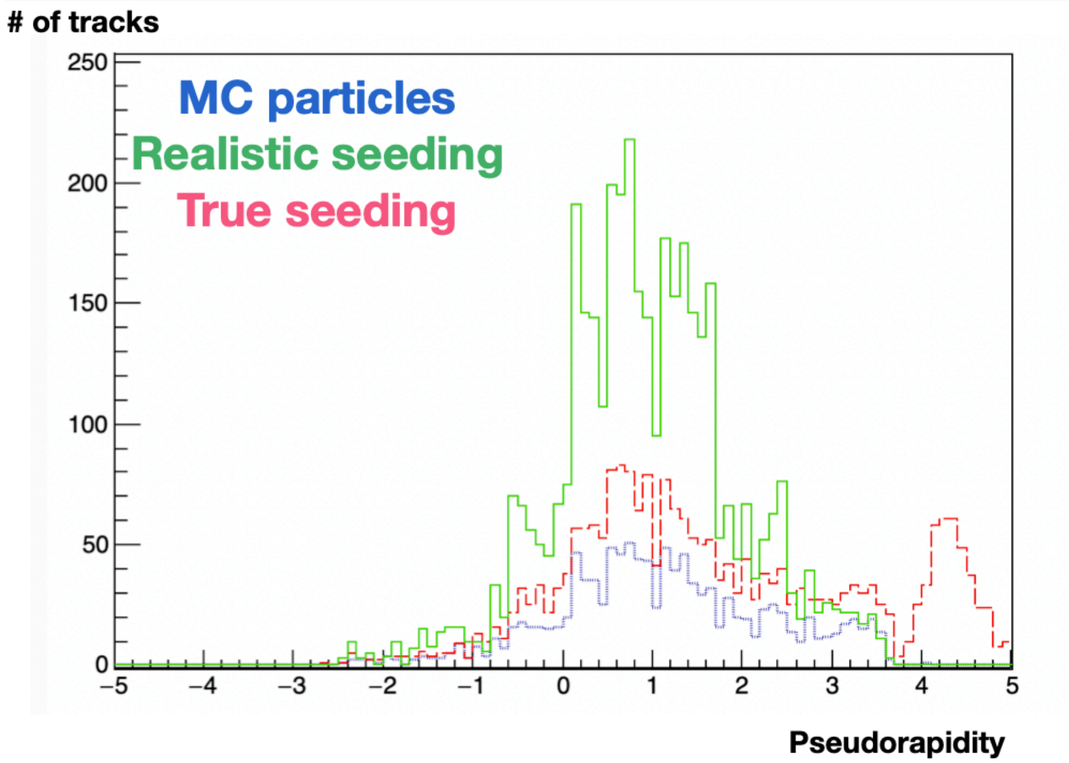
DIS events

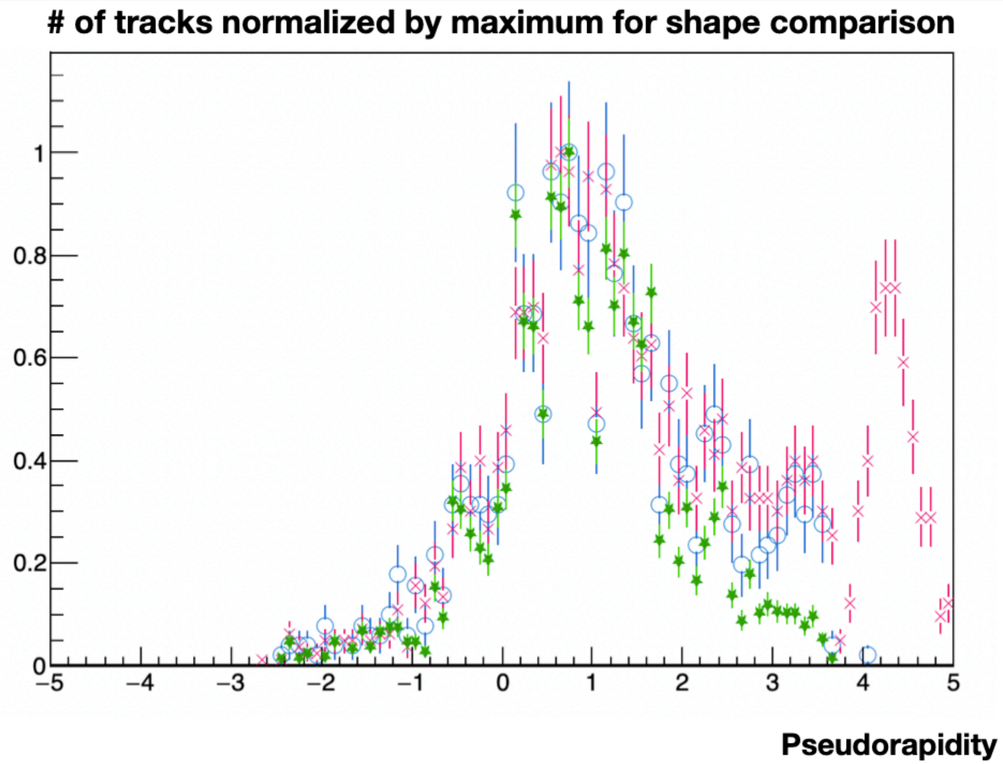




- Efficiency loss in true seeding/realistic seeding: No kinematic cuts on MC particles yet
- Slightly worse performance in realistic seeding: over-suppressed by duplicates rejection?
- More complicated in DIS

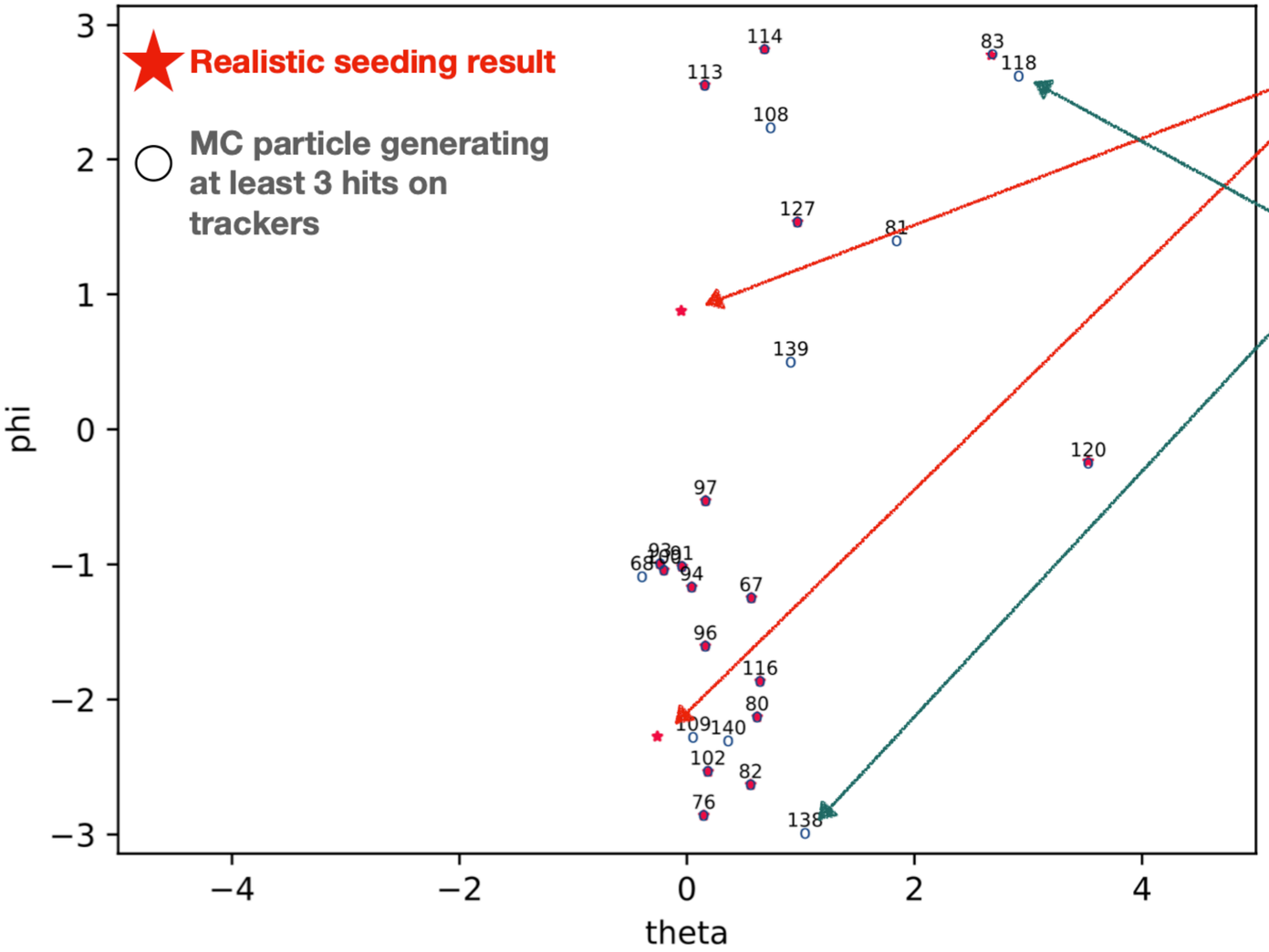
High Q^2 DIS events, seed-level





- MC particles: stable particles generating at 3 hits on silicon trackers
- Much larger entries w.r.t. MC particles in realistic seeding: duplicate seeds visible as expected
- Larger entries in true seeding w.r.t. MC particles in true seeding, with seeds in B0 acceptance

Realistic seeding: fake seeds & missed particles



- Seeds without matching trackable MC particles
- Particles without matching seeds
- More quantitive analysis required! tracker hits associated with seed

Current wishlist + status

- **MC source and quality of tracker hit**: already there in dd4HEP output but not in podio data structure
- **Number of shared hits for trajectory**: already there in podio data structure but not updated properly → should be updated after CKFtracking and before filling trajectory information (some examples available in ACTS repo.)
- **List of tracker hits associated with seed**

- **Native support of greedy ambiguity resolution solver**

* Current status: pull request coming soon!

- **Improved selection criteria for true seeding input MC particles**?

Conclusions and Outlook

- “Biased” residuals can be calculated at a per layer level
  - Smoothed track states are needed to properly evaluate track performance
  - Unbiased residuals on the way!
- Current EICrecon implementation includes many duplicate tracks
  - Greedy ambiguity resolution solver fixes this —> currently being added to the official repository
    - Tested on J/psi events -> successful
    - Tested on DIS events -> still needs some work, currently seeing fake hits

Thank you!

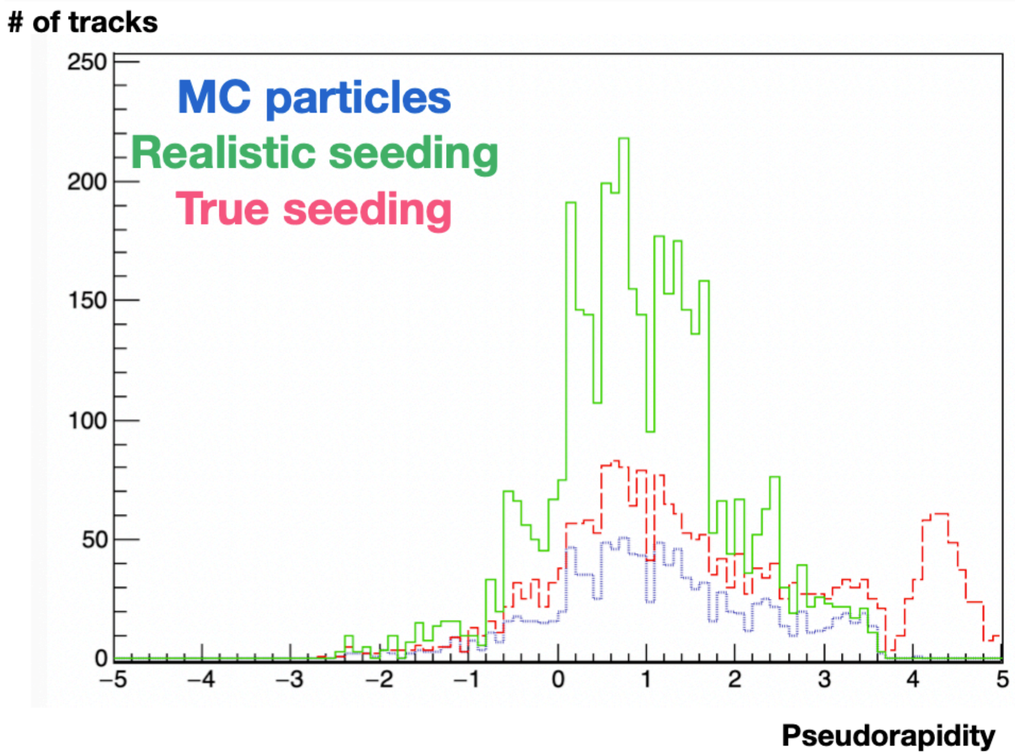
Backup

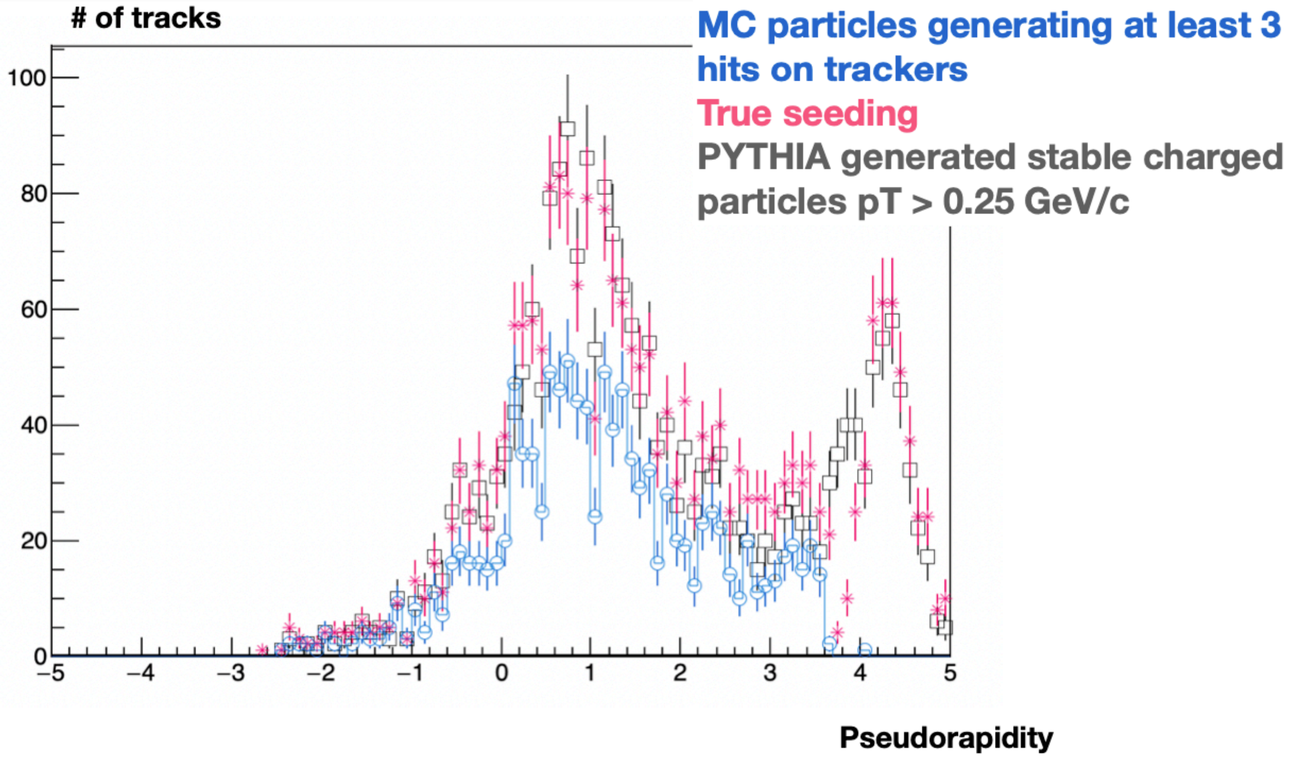
ePIC Tracking Performance

- Observables for tracking performance:
  - Tracking efficiency and purity
  - Position and momentum resolution
  - And so on…

  ➡ Compare reconstructed tracks with simulated particles
- Tracking performance for ePIC
  - Now: evaluate the tracking algorithms of realistic seeding and CKF tracking based on ACTS
  - Estimate the expected tracking performance upon change of detector geometry and experiment conditions and the feasibility of physics measurements

A caveat to truth seeding

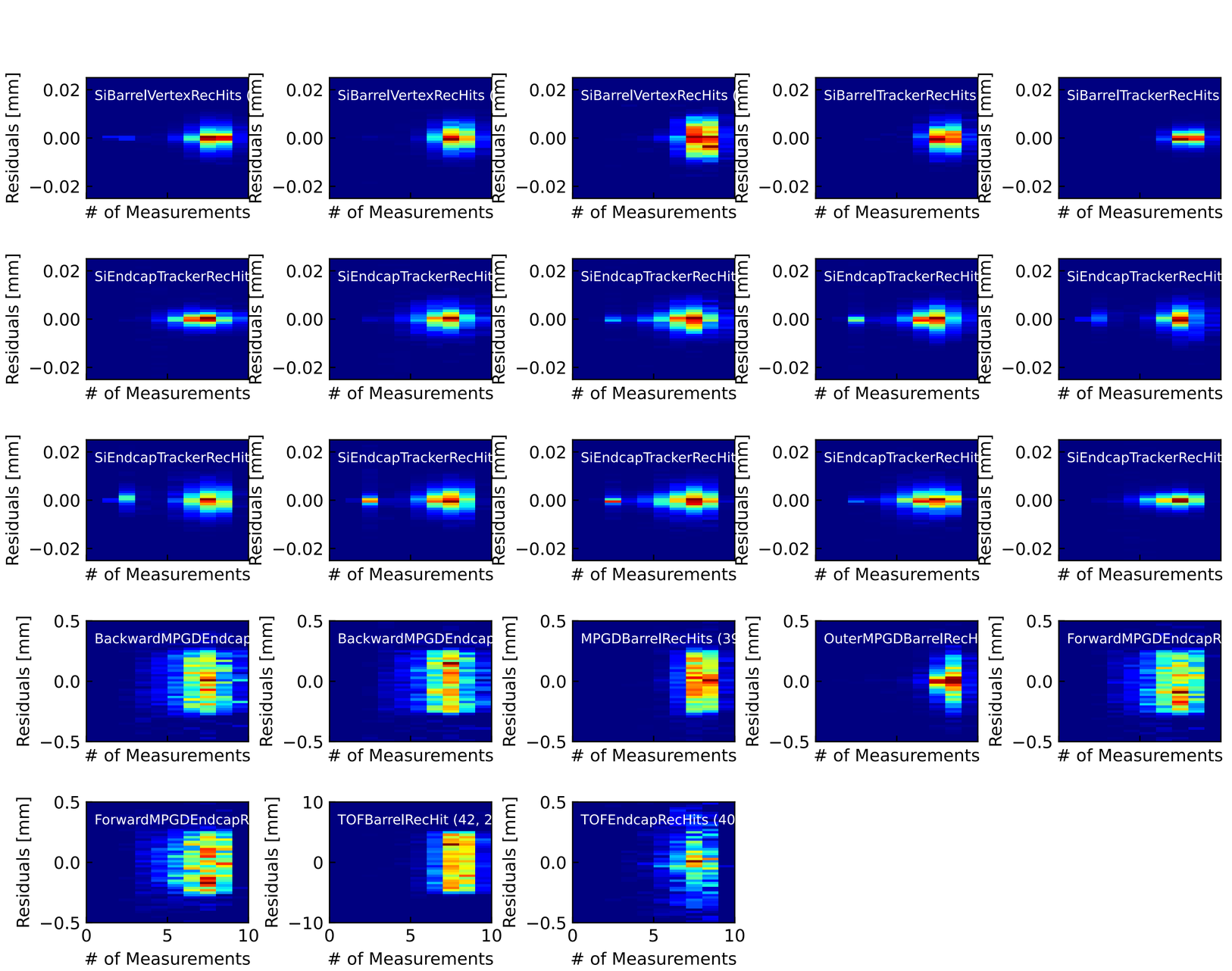




- Larger entries in true seeding w.r.t. MC particles in true seeding, with seeds in B0 acceptance
- True seeding takes PYTHIA generated charged particle with min. pT: doesn't guarantee whether they are really trackable in the detector! min. # of generated hits for input MC particles?

Looking at the # of measurements

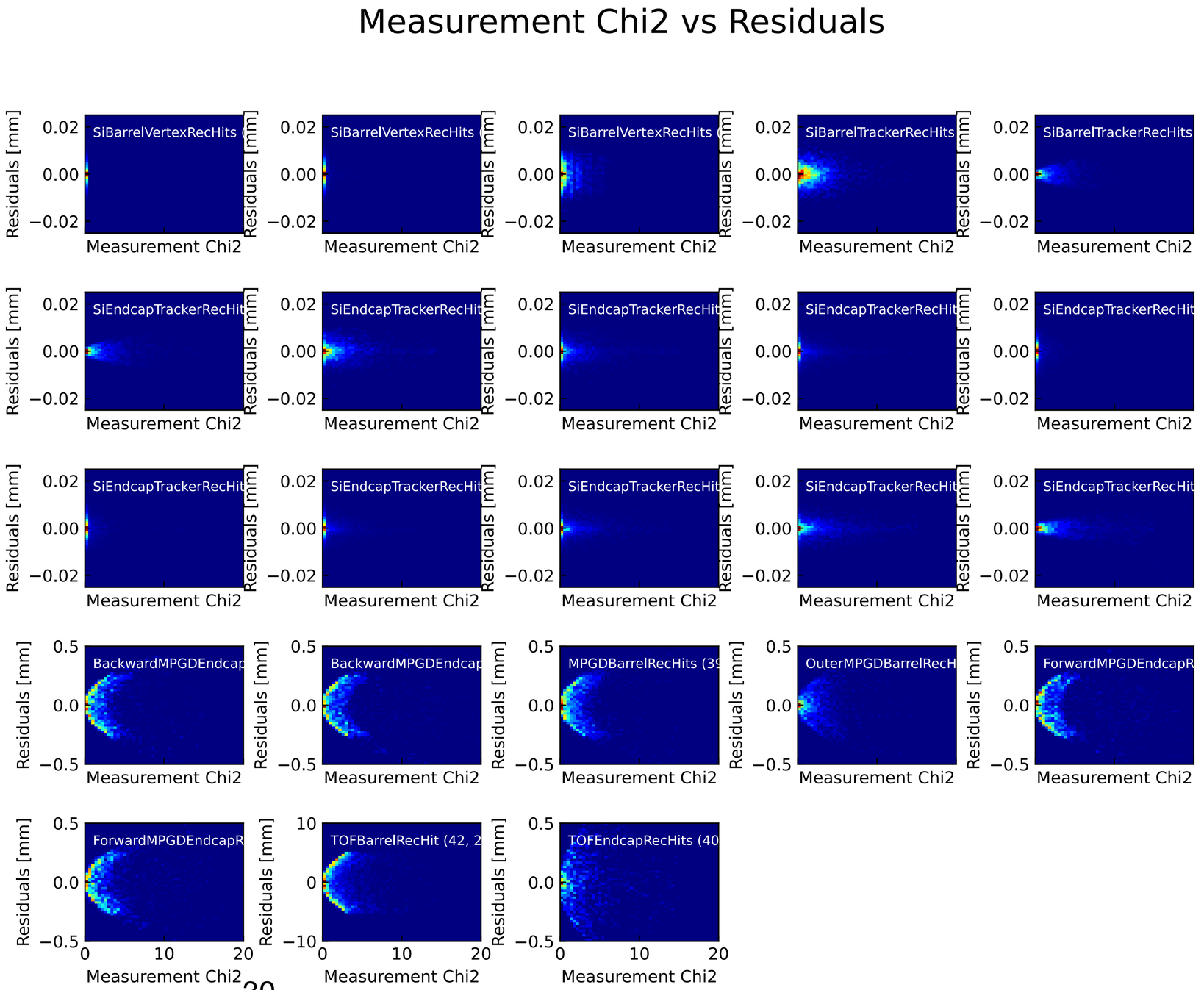
- Smoothed track states
- # of measurements vs residuals
- residuals is a hit quantity, # of meas is a track quantity
- mostly 6-8 hits per track



jet

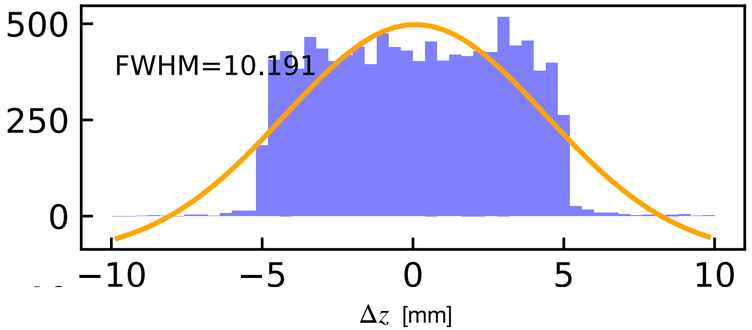
Measurement Chi^2

- Smoothed track states
- See more prominent correlation between measurement chi^2 and the residual in silicon L2

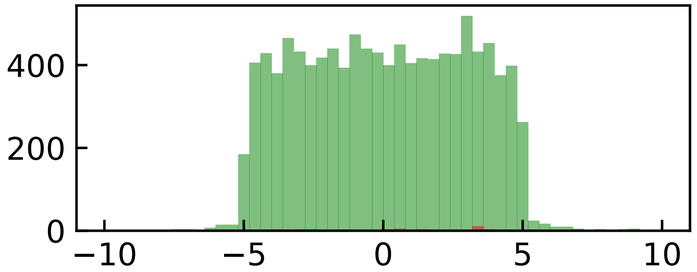


TOF Barrel layer

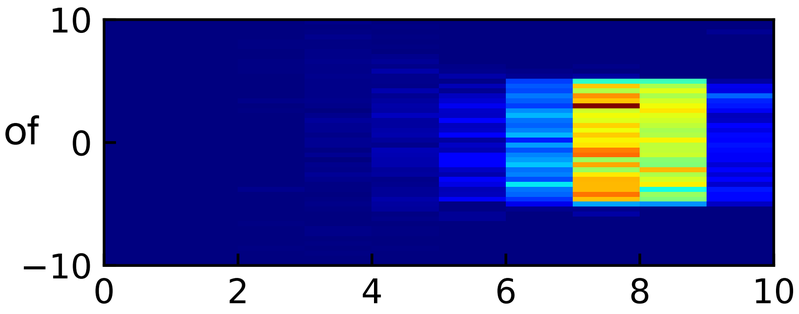
Residuals [mm]:



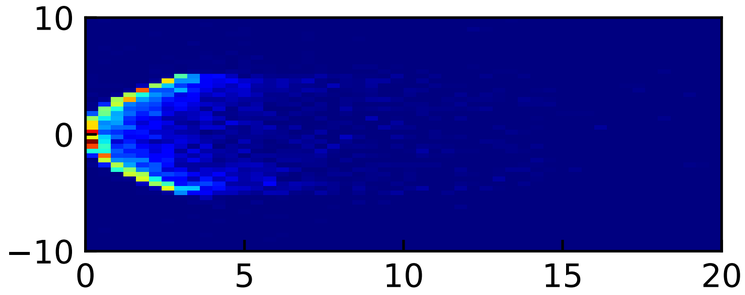
Residuals [mm] for measurements vs outliers:



Residuals [mm] vs # of measurements:

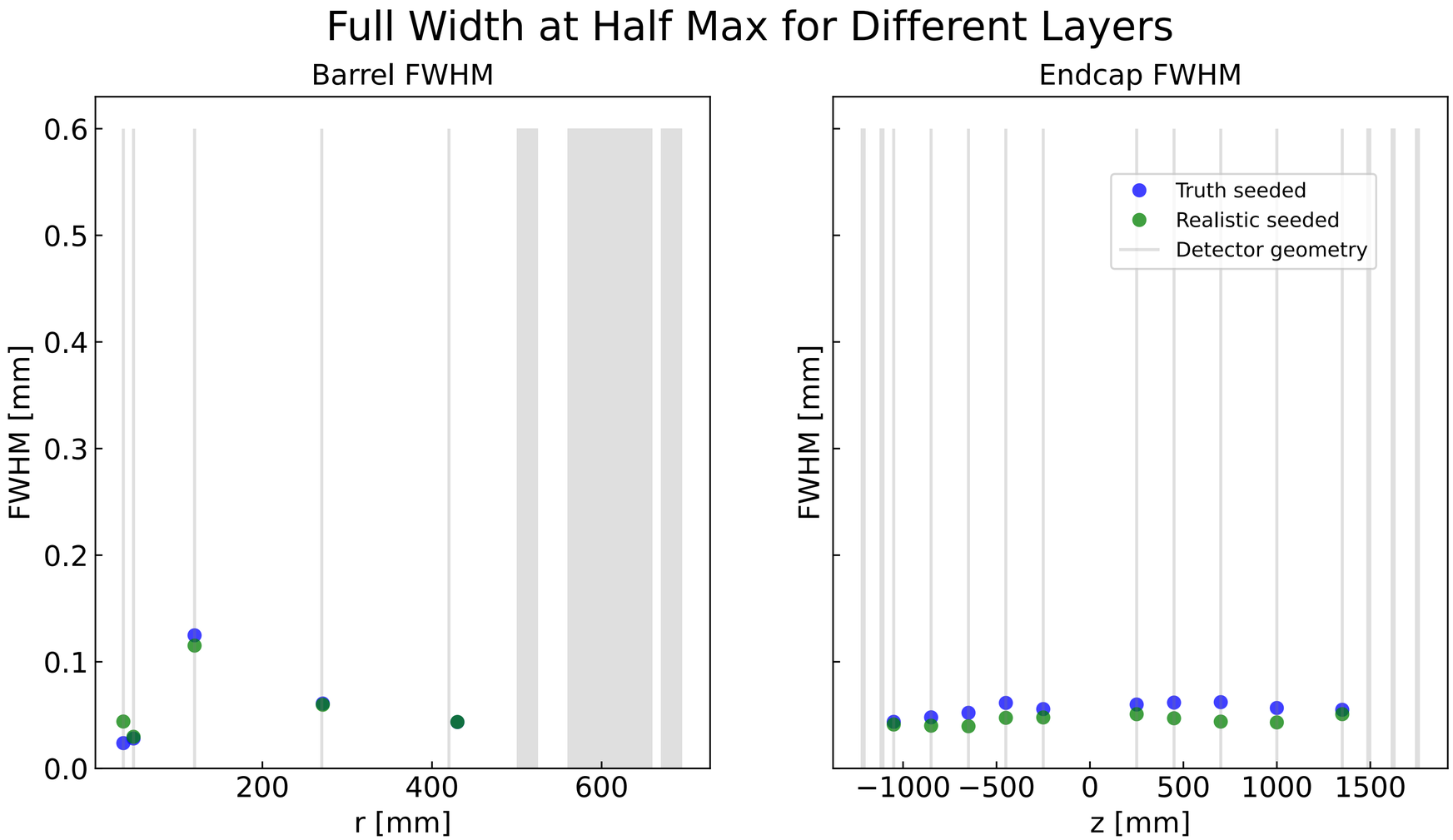


Residuals [mm] vs measurements chi2:



*azimuthal residuals in progress

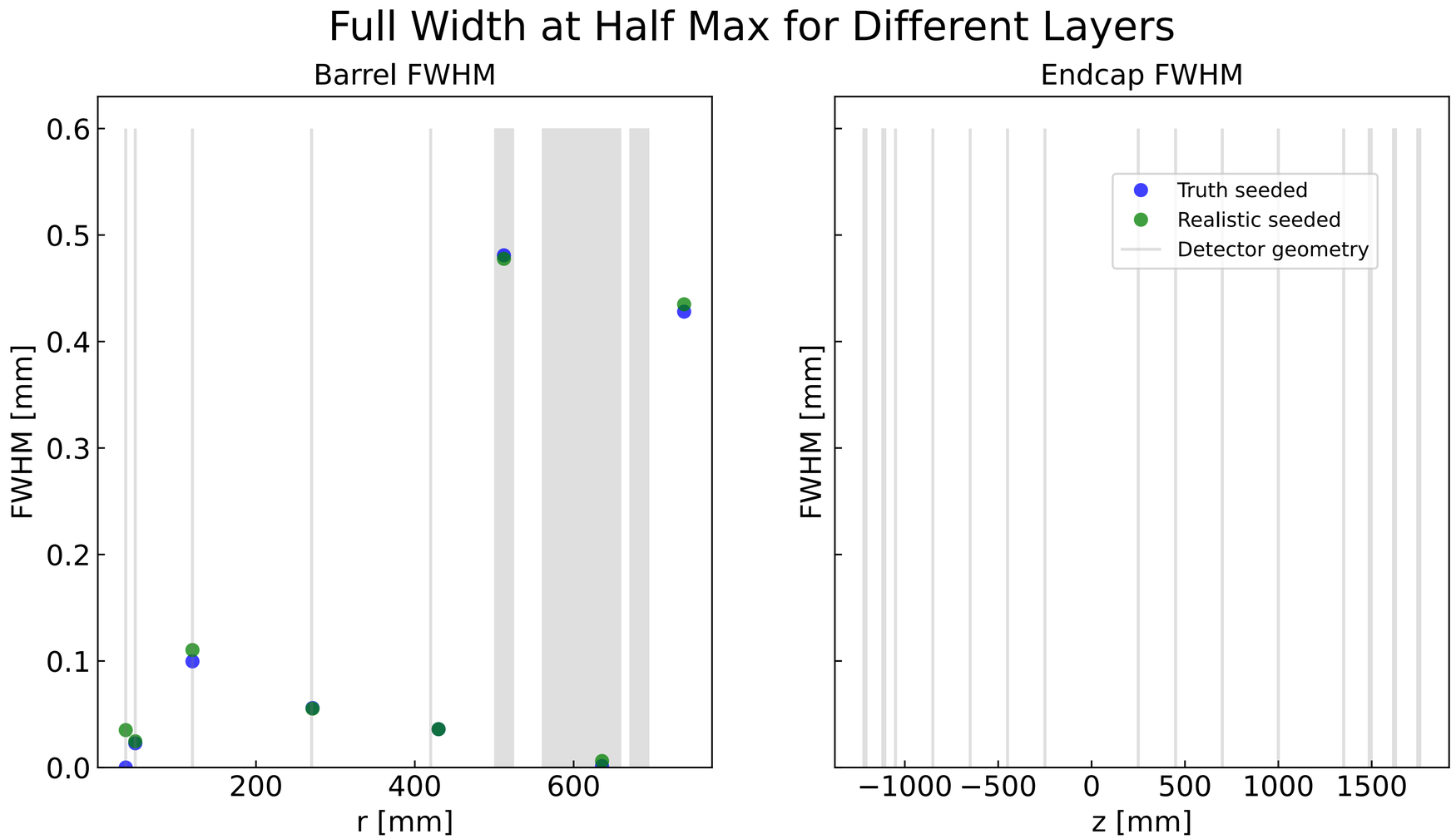
FWHM at different layers



- Not much changed

Single μ-, silicon only reconstruction

FWHM at different layers

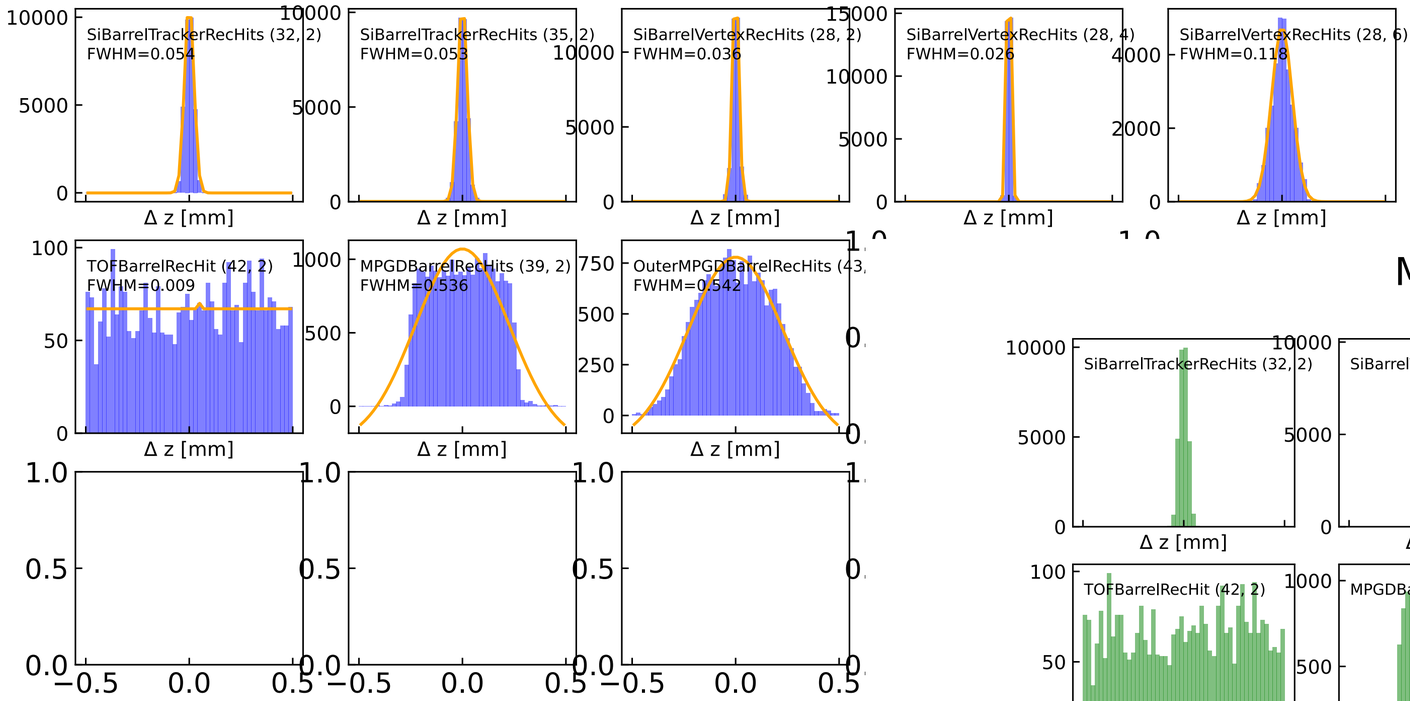


- Only looked at muons that were in the range of 85°<θ<95°

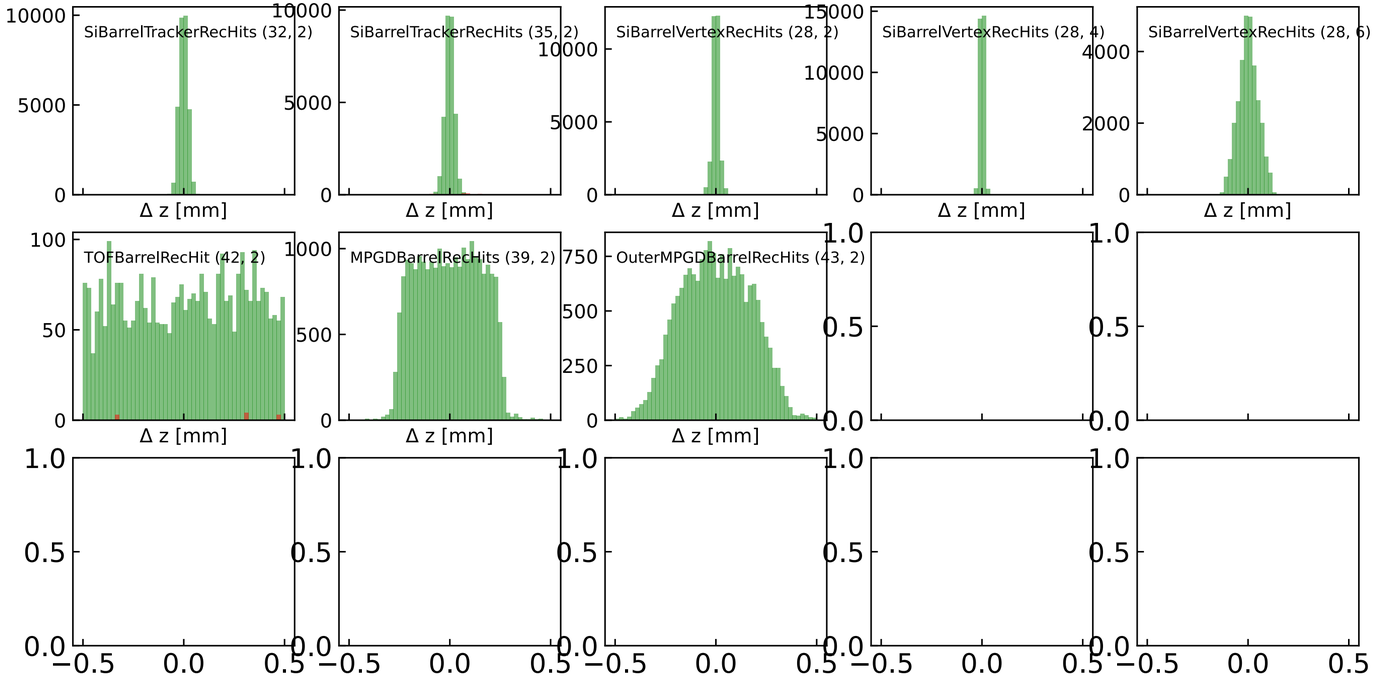
Single μ-, full reconstruction

90 degree muons

Residuals



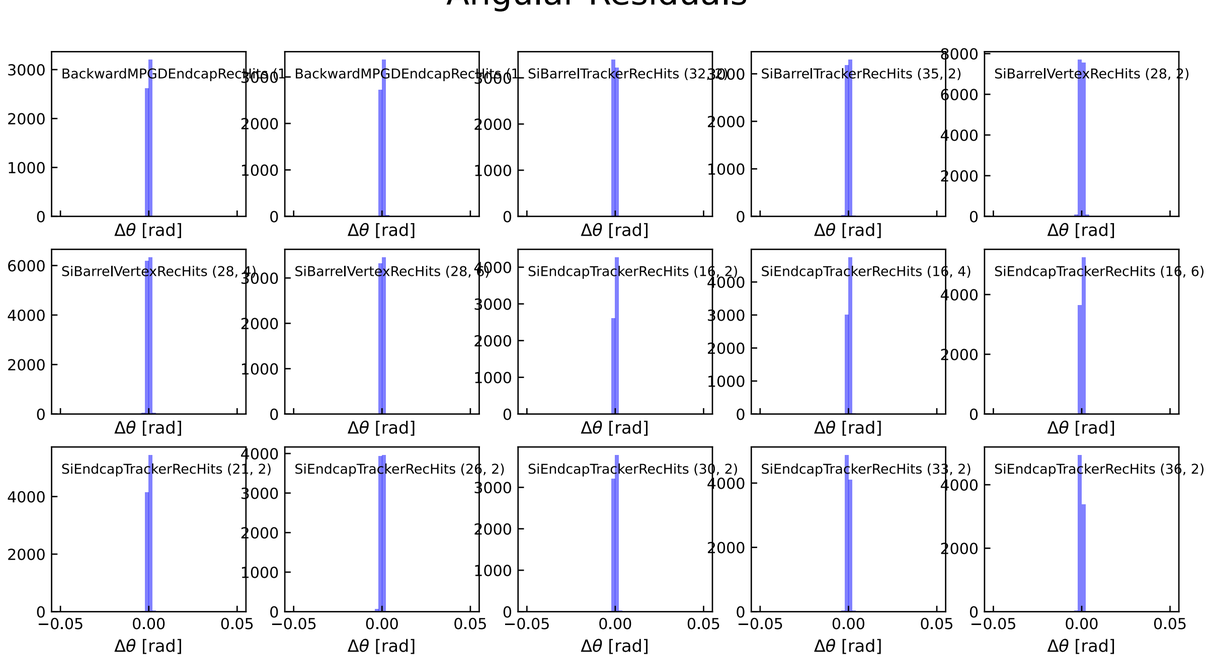
Measurement/Outlier Residuals

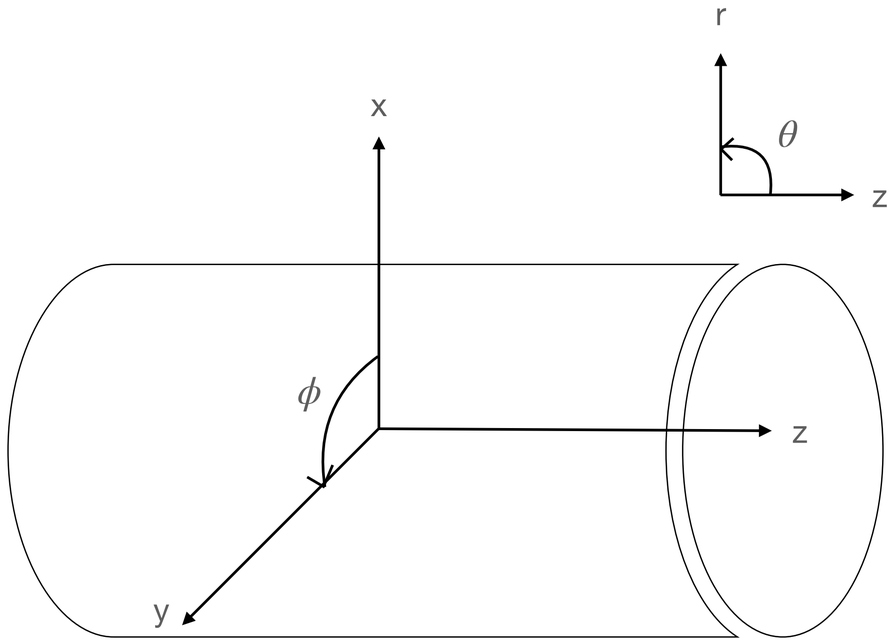


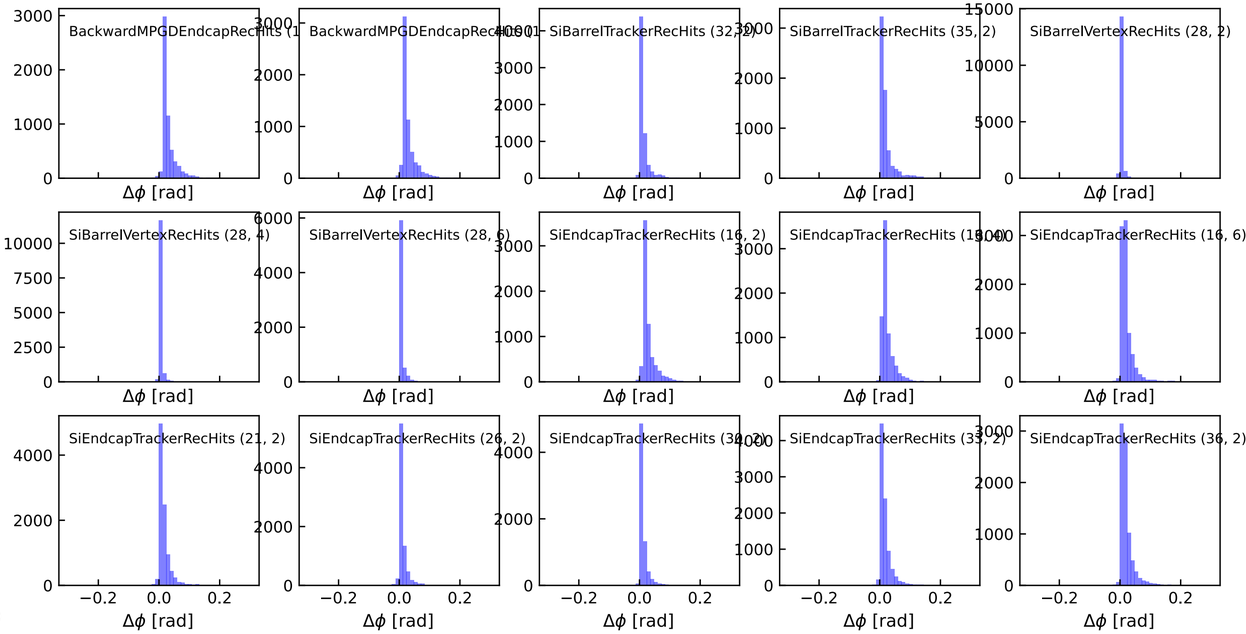
5 GeV muons

Angular residuals

per layer



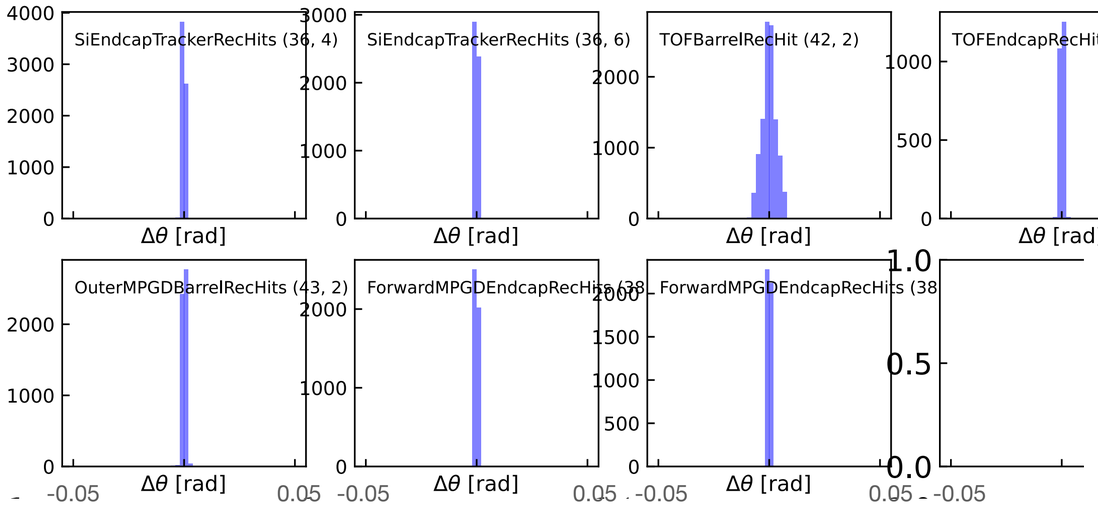


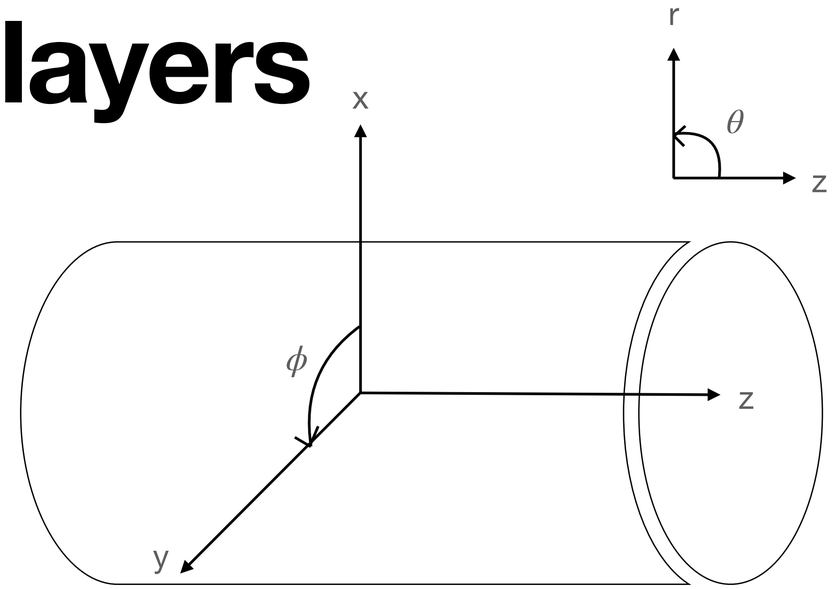


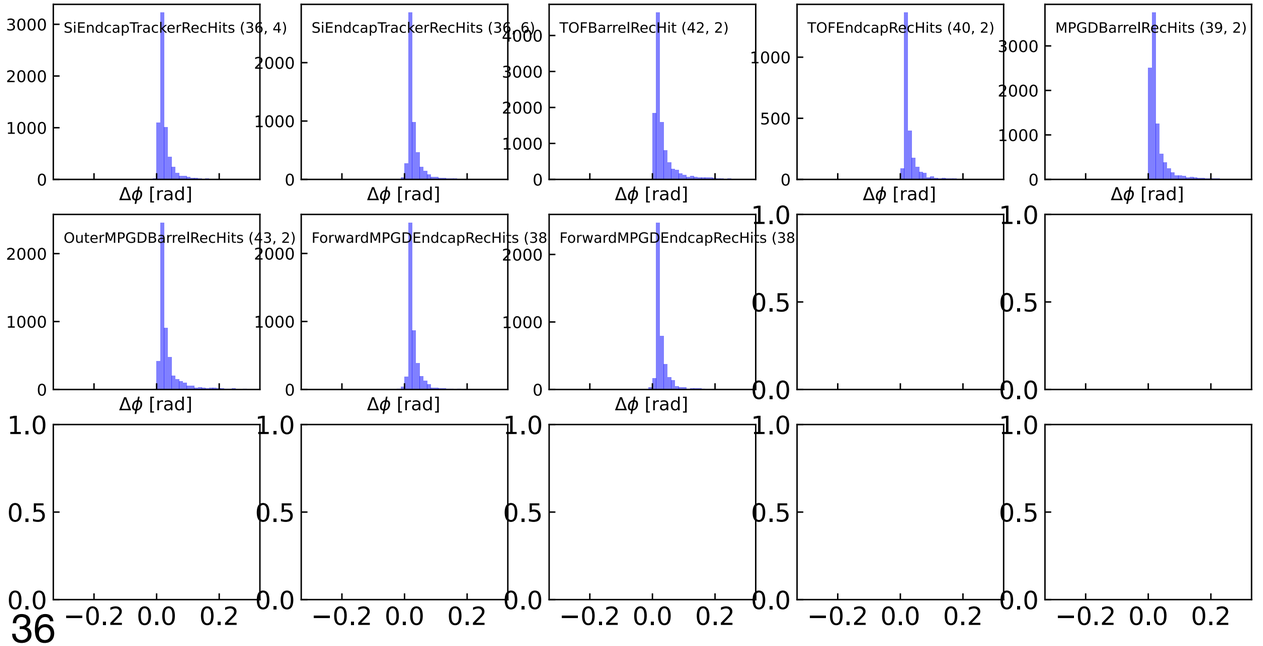
- Quick look at finding the difference in θ and ϕ

Angular residuals, remaining layers

per layer







- Quick look at finding the difference in θ and ϕ