p_T Resolution Issues for High Momenta Tracks (3 TeV detector)

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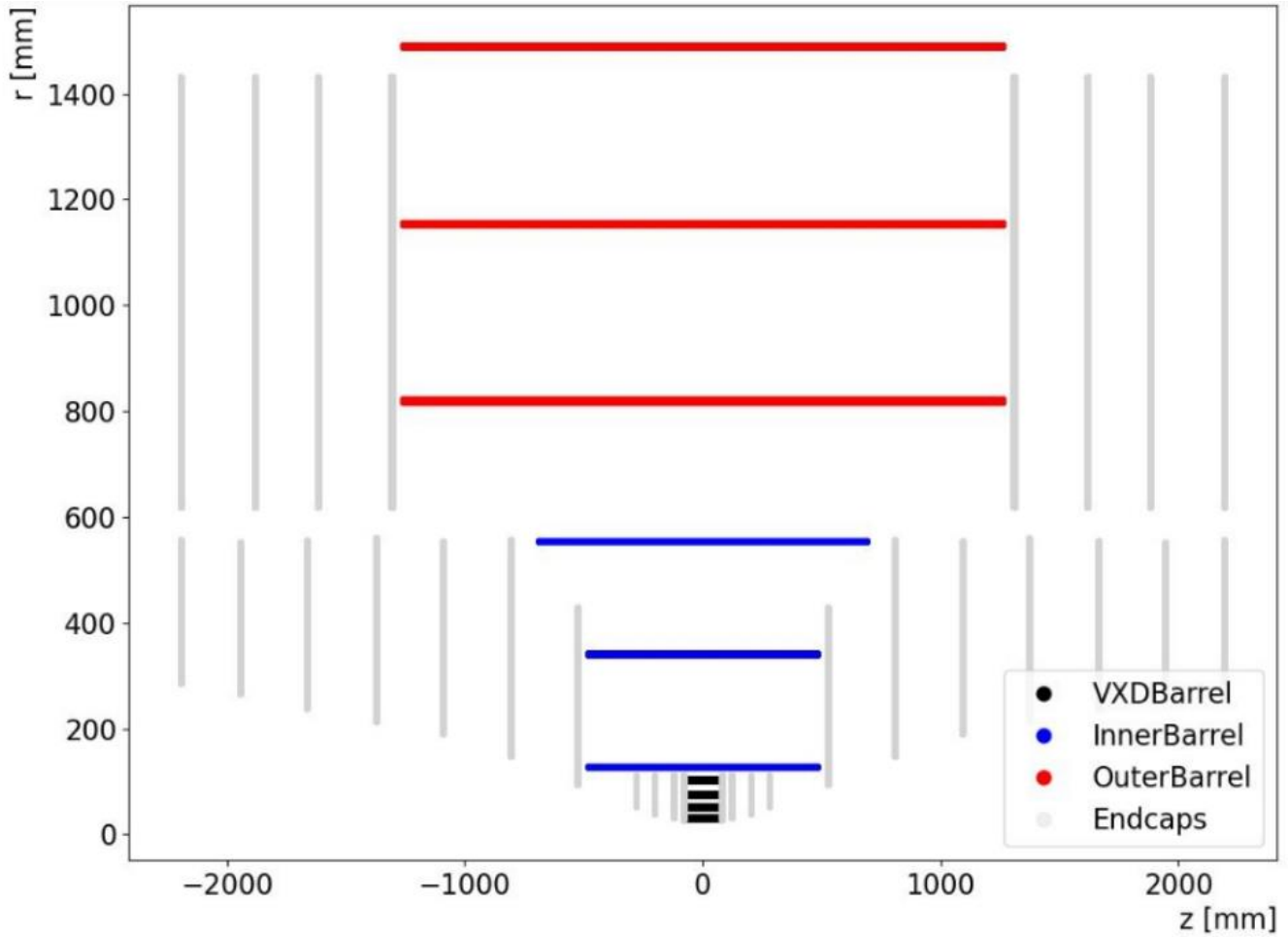
Background

- First noticed poor p_T resolution in our long-lived particle study for both prompt & displaced tracks w/o BIB overlay
  - Particles have high p_T & tracks often reconstructed with low # of hits
  - Hurts ability to reconstruct LLP mass & use track p_T as BIB discriminator
- Use 3 TeV detector design, 2-pass tracking configuration to reconstruct displaced tracks
  - Later verified similar p_T resolution for baseline tracking setup in mucoll-benchmarks using particle gun samples
- Today will present results of this investigation in hopes of feedback/discussion

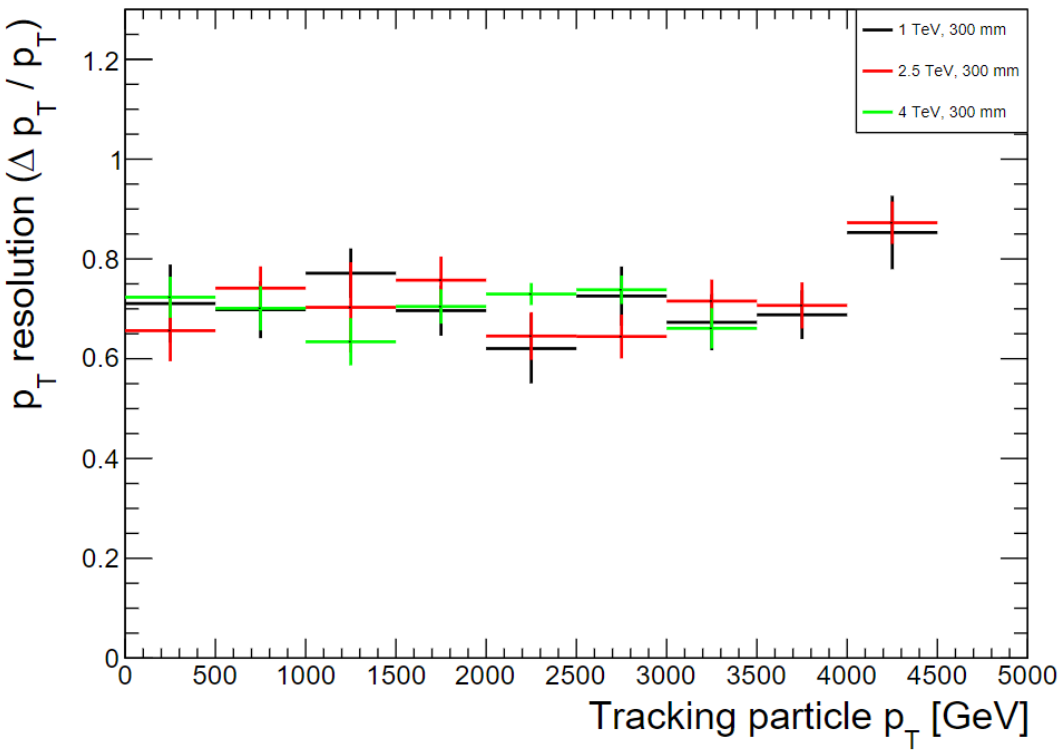
Reminder: 3 TeV tracker geometry

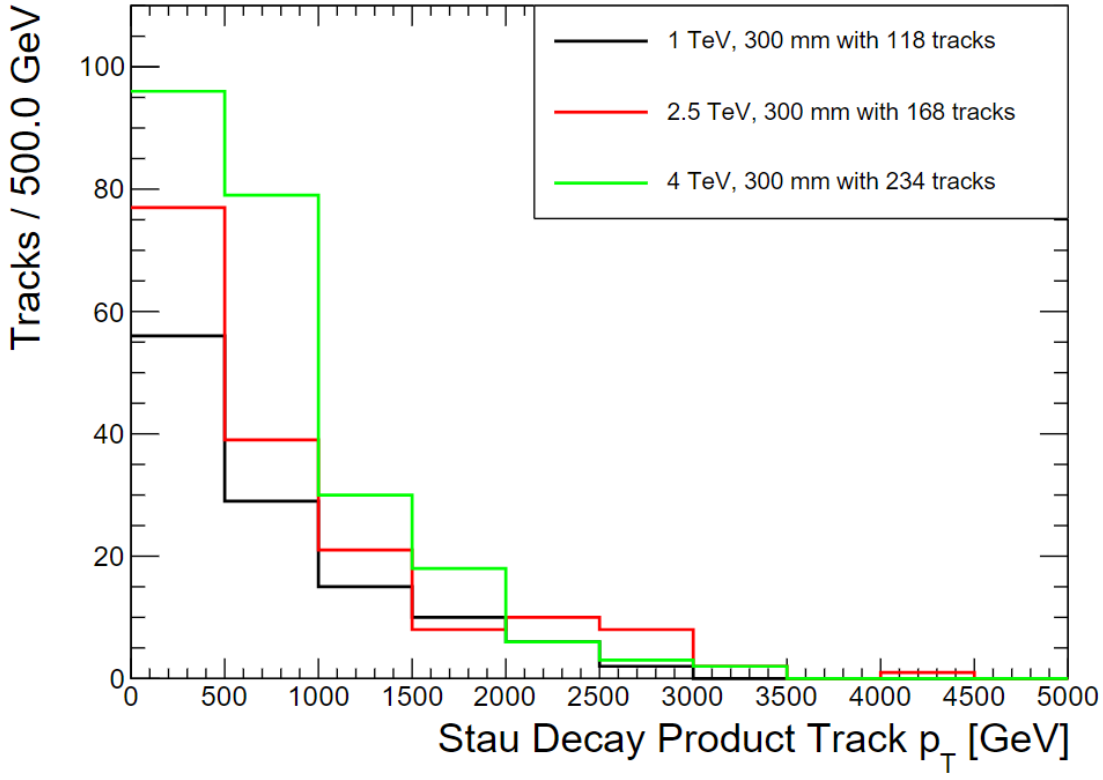
- Similar to MAIA tracker, but VXD Barrel has 4 doublet layers
  - Ideally expect track passing through all barrel layers to have 14 hits



Displaced Tracks p_T, p_T res.

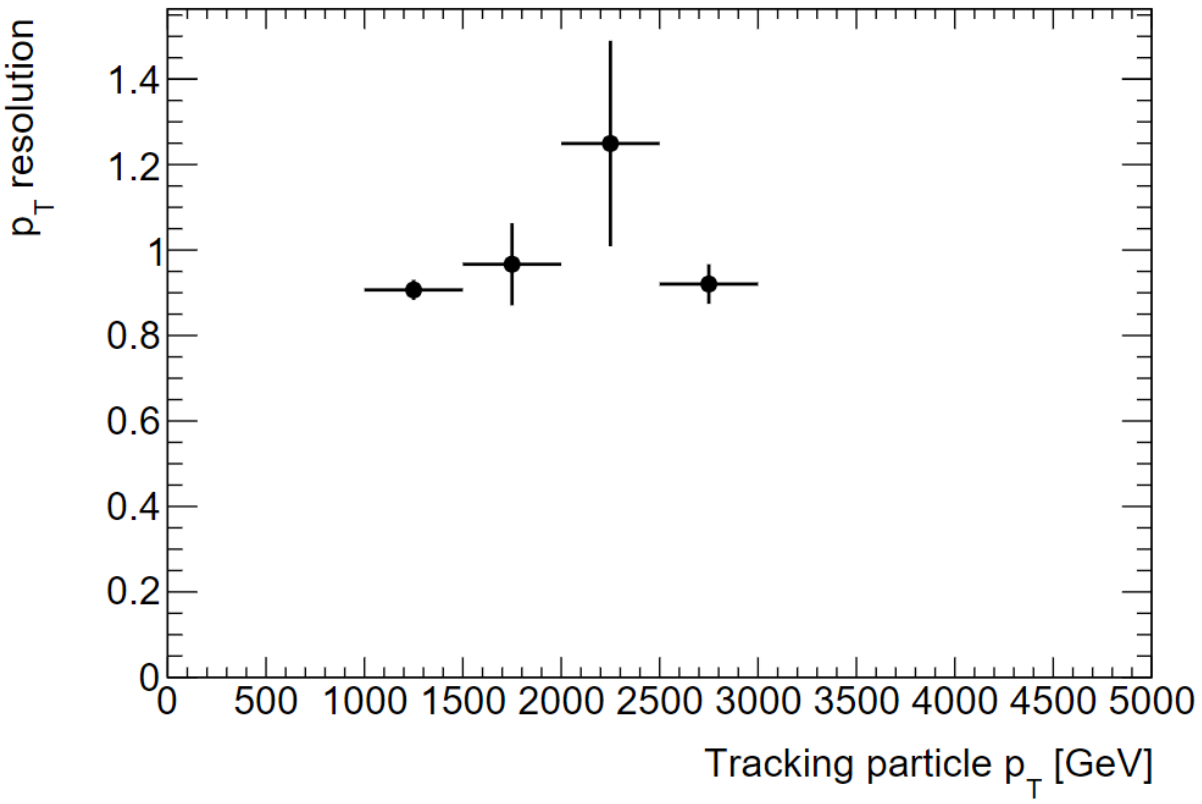
Displaced tracks: tracks associated to τ decay products ($\tilde{\tau}$ decays to τ)

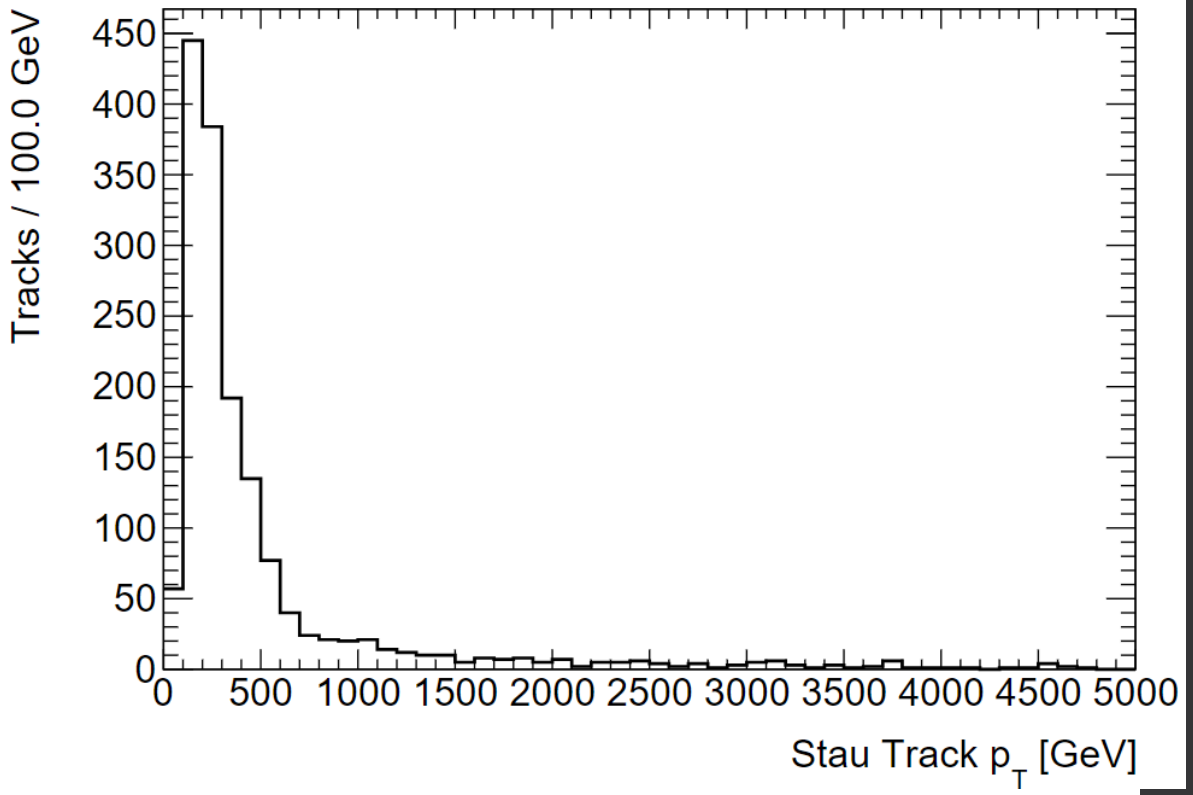




Track p_T is generally reconstructed lower than truth p_T

Prompt $\tilde{\tau}$ Tracks (4 TeV 10 ns)





Track p_T is reconstructed significantly lower than truth p_T
Note: extending timing windows does mitigate this

Particle Gun Samples

- Generated 50, 500, 3000 GeV momentum 1000 event samples of muons & pions evenly distributed in $|\eta| < 1.5$
  - Will present results with baseline tracking configuration + track truth

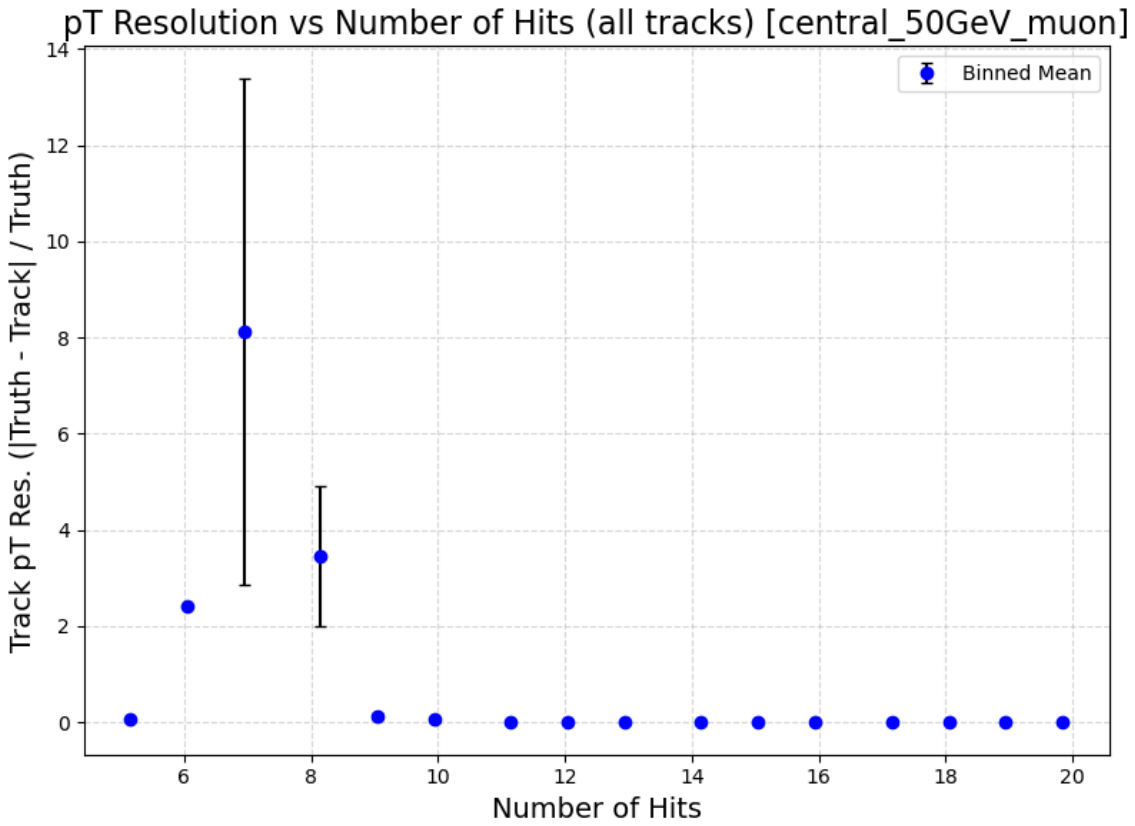
Momentum	Particle	Avg. $\Delta p_T / p_T$
50 GeV	μ^-	5.5%
	π^+	4.4%
500 GeV	μ^-	21.1%
	π^+	21.1%
3000 GeV	μ^-	41.4%
	π^+	43.3%

- See worsened resolution as momentum increases

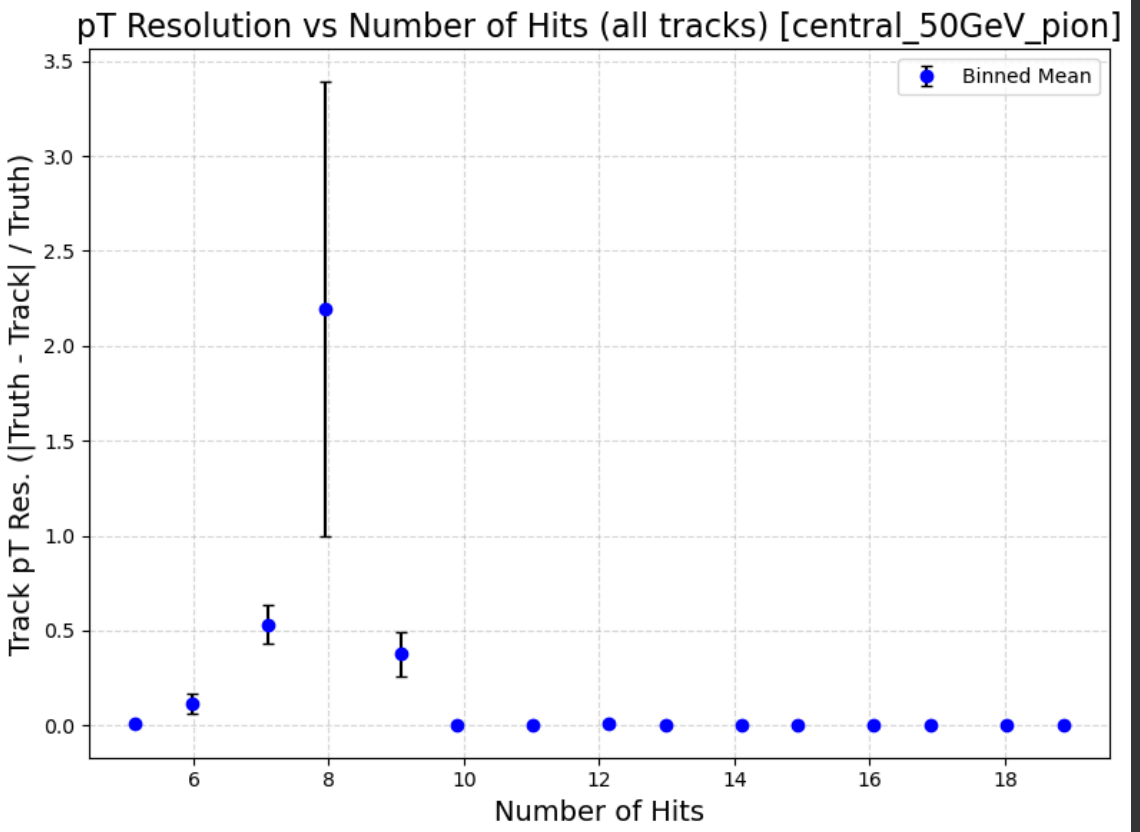
50 GeV Particle Gun Plots

Note: only cleaning is $N_{Hits} > 3.5$, particles in uniform $|\eta| < 1.5$ distribution, use mucoll benchmarks reconstruction + hit-based matching

$\frac{\Delta p_T}{\text{Truth } p_T}$ vs. Number of Hits

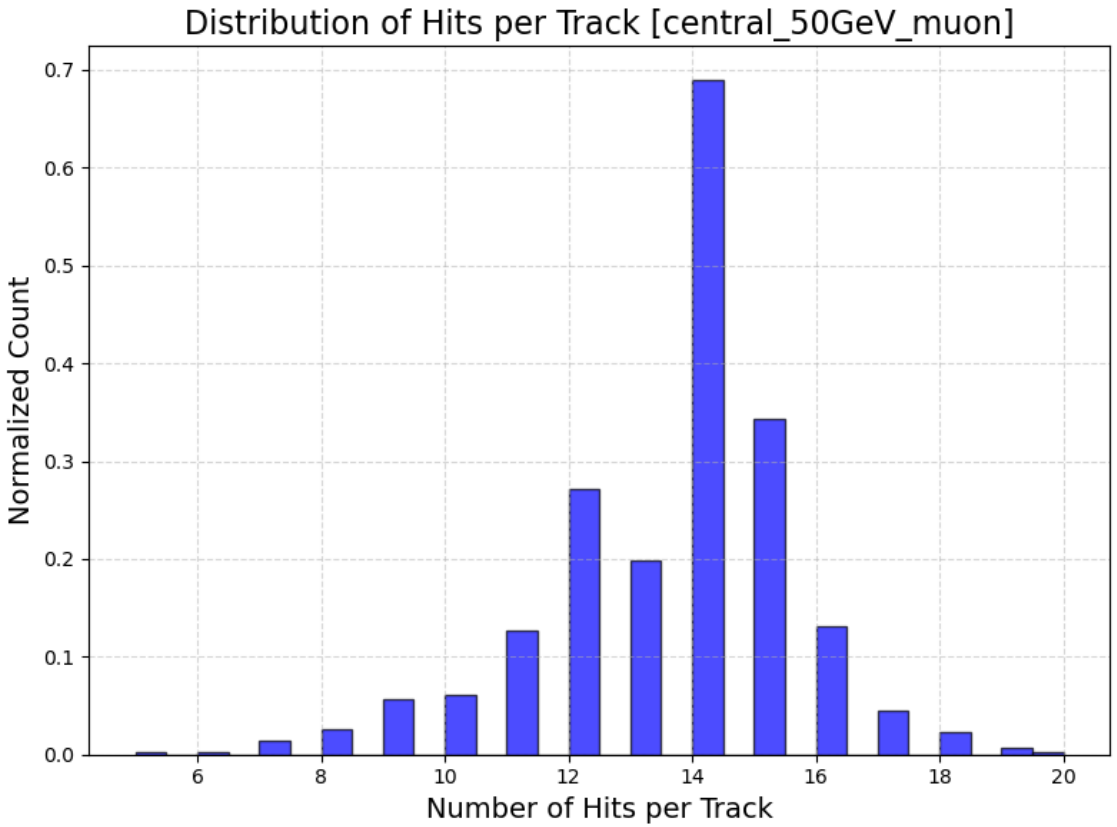


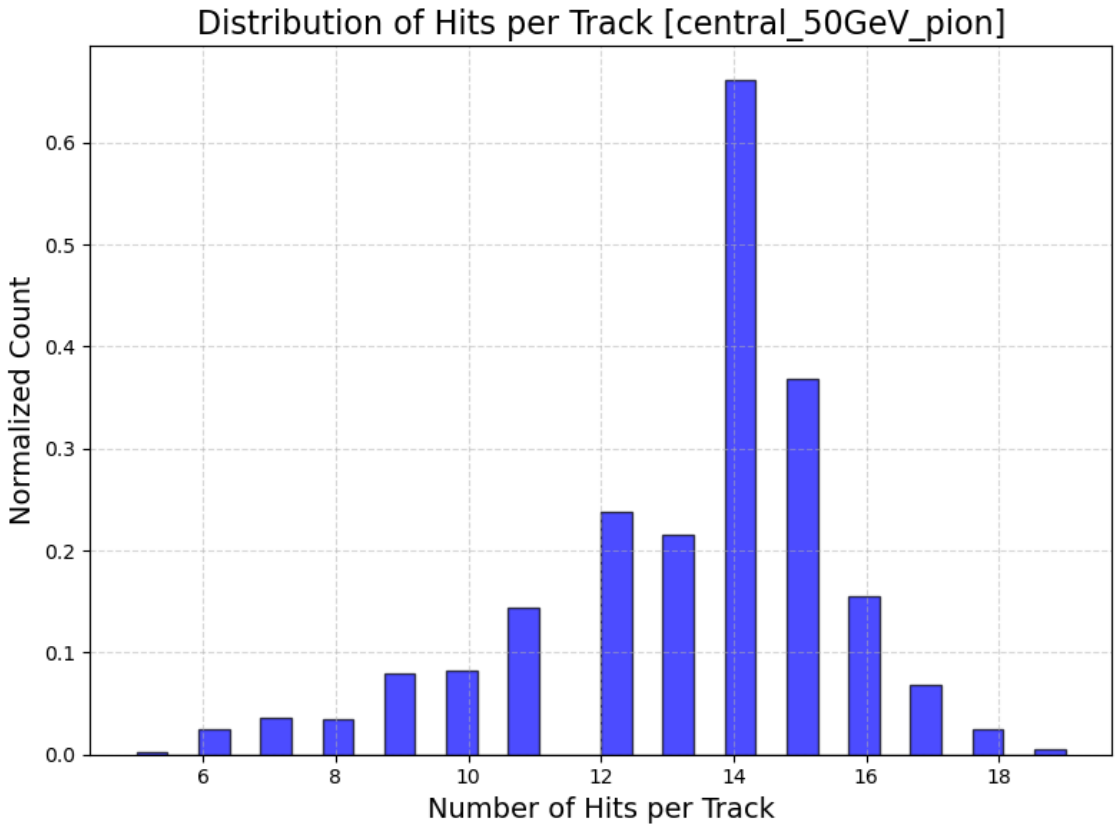
Avg: 5.5%



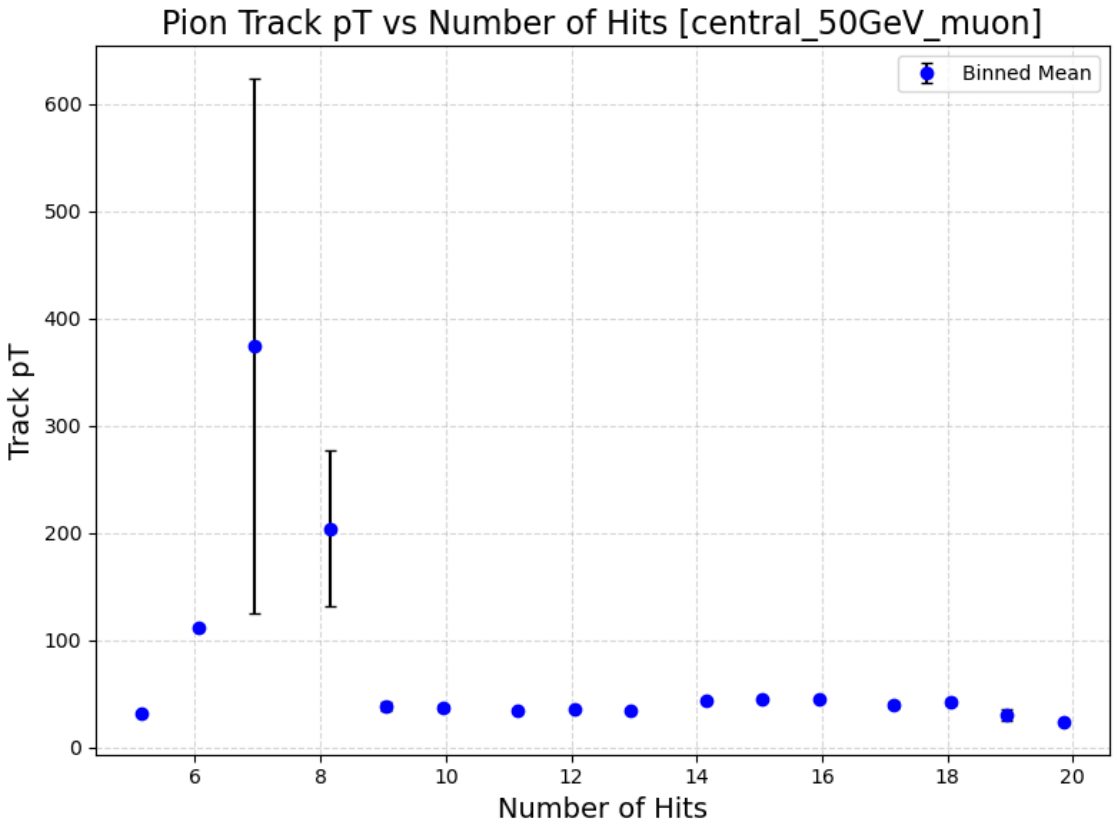
Avg: 4.4%

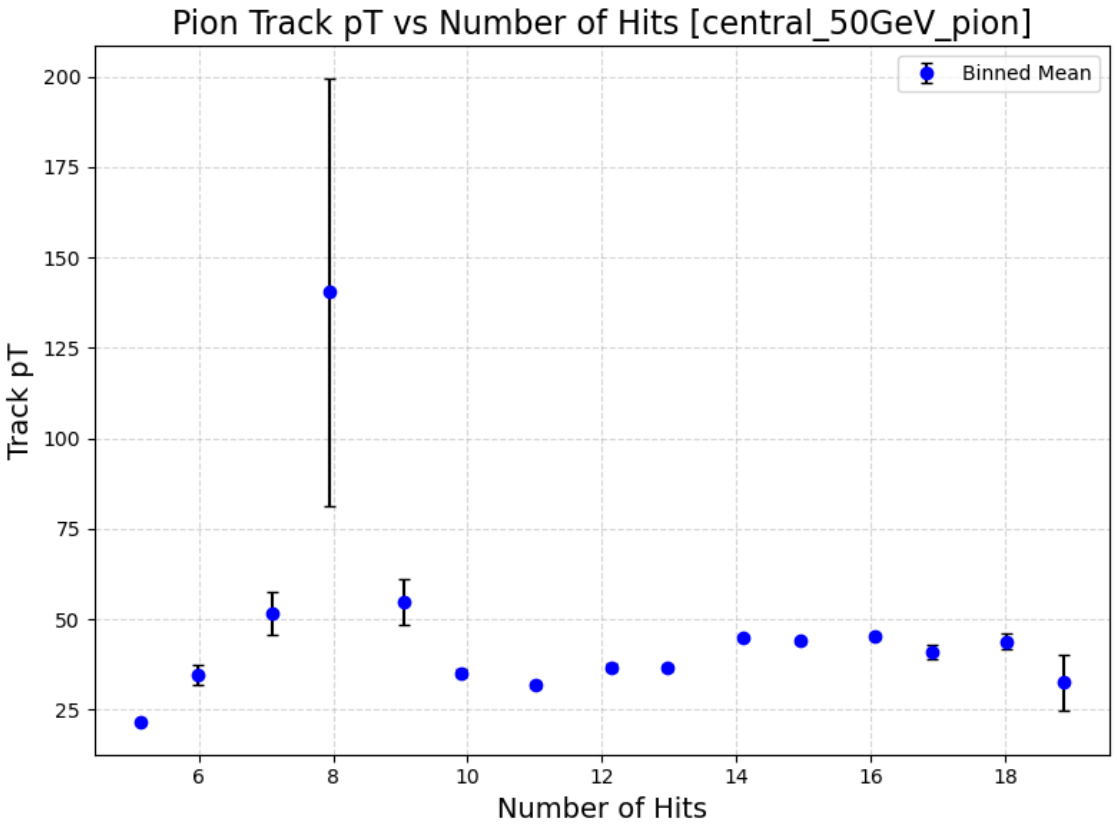
Number of Hits



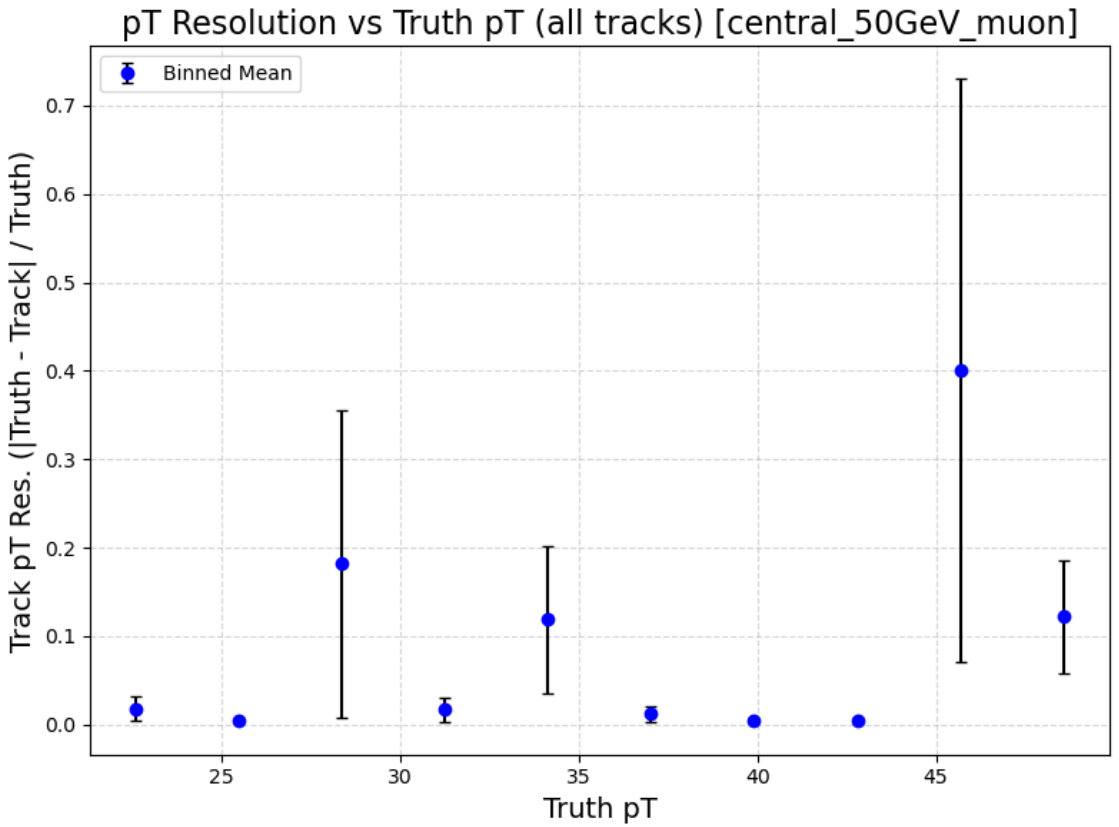


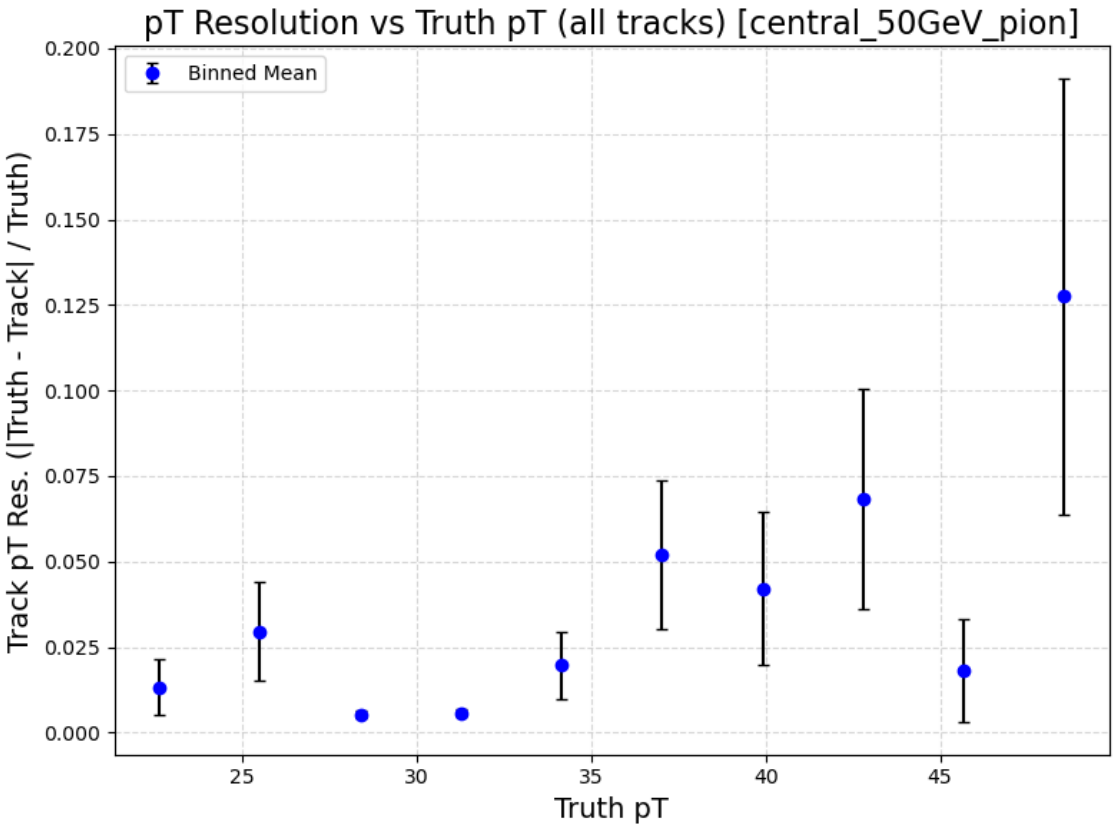
Track p_T vs. Number of Hits



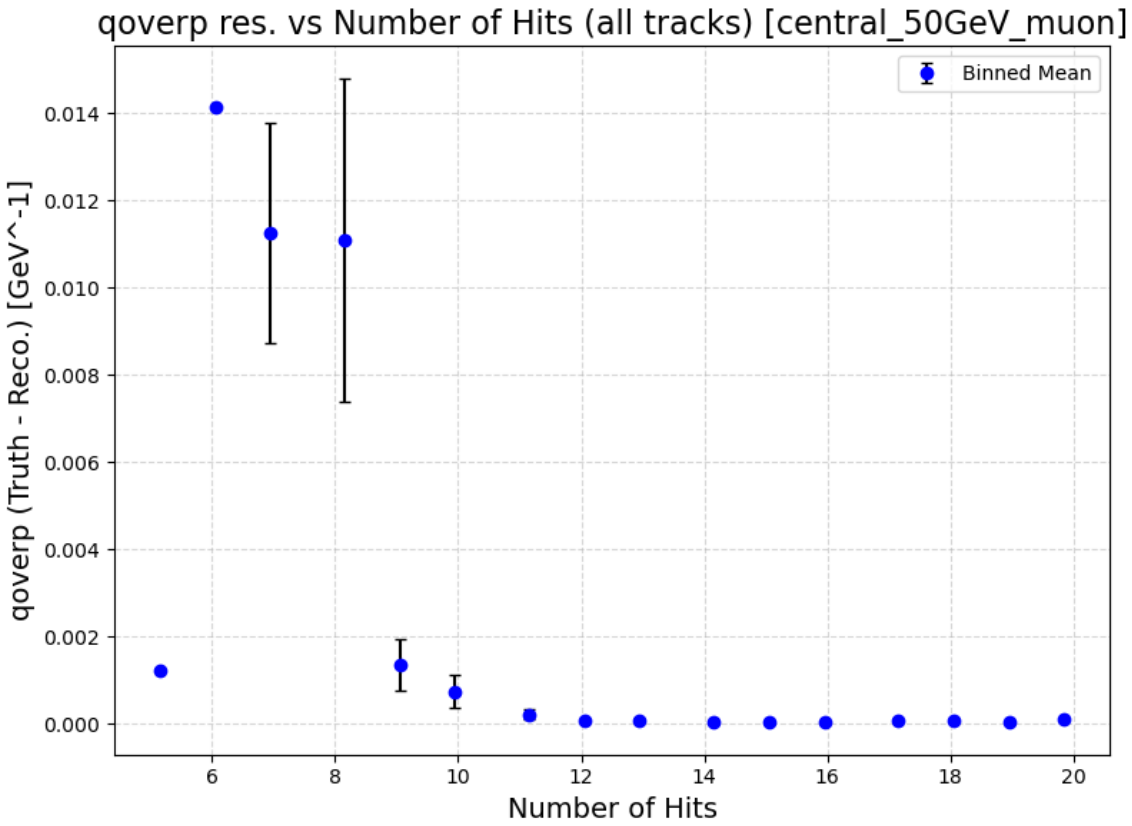


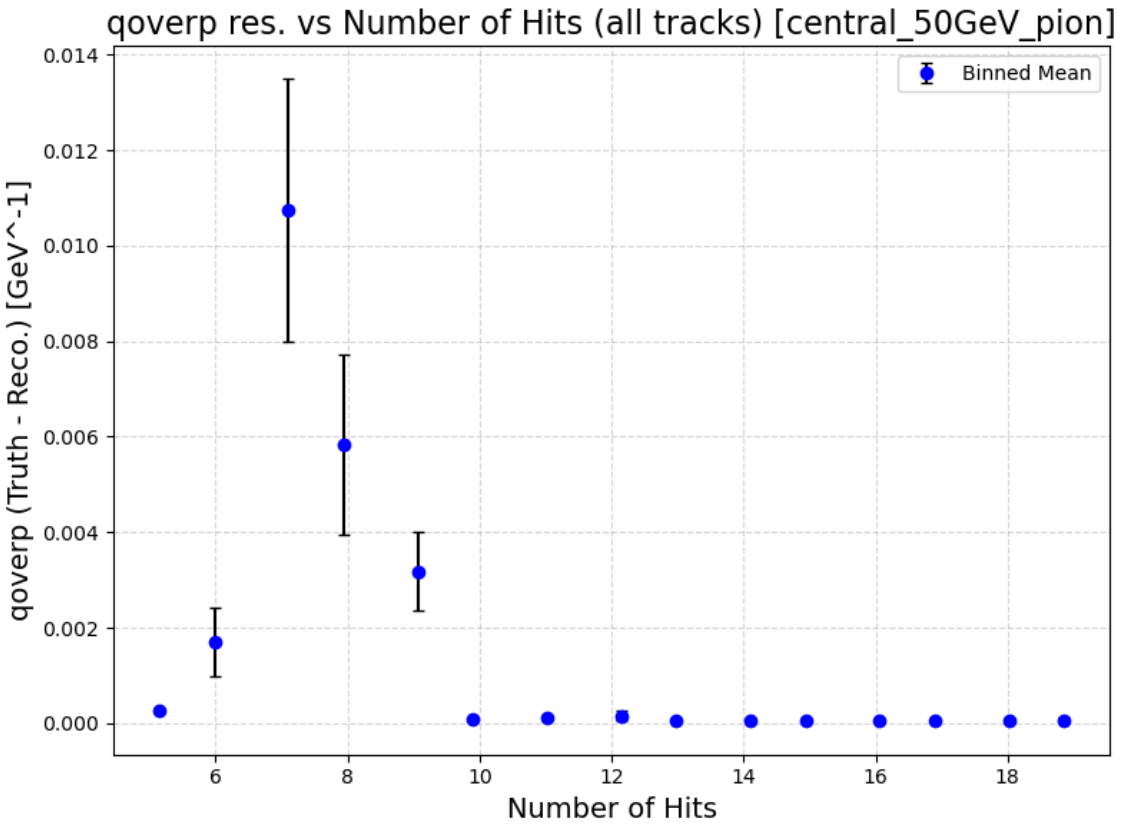
$\frac{\Delta p_T}{\text{Truth } p_T}$ vs. Truth p_T





$\Delta\left(\frac{q}{p}\right)$ vs. N_{hits}



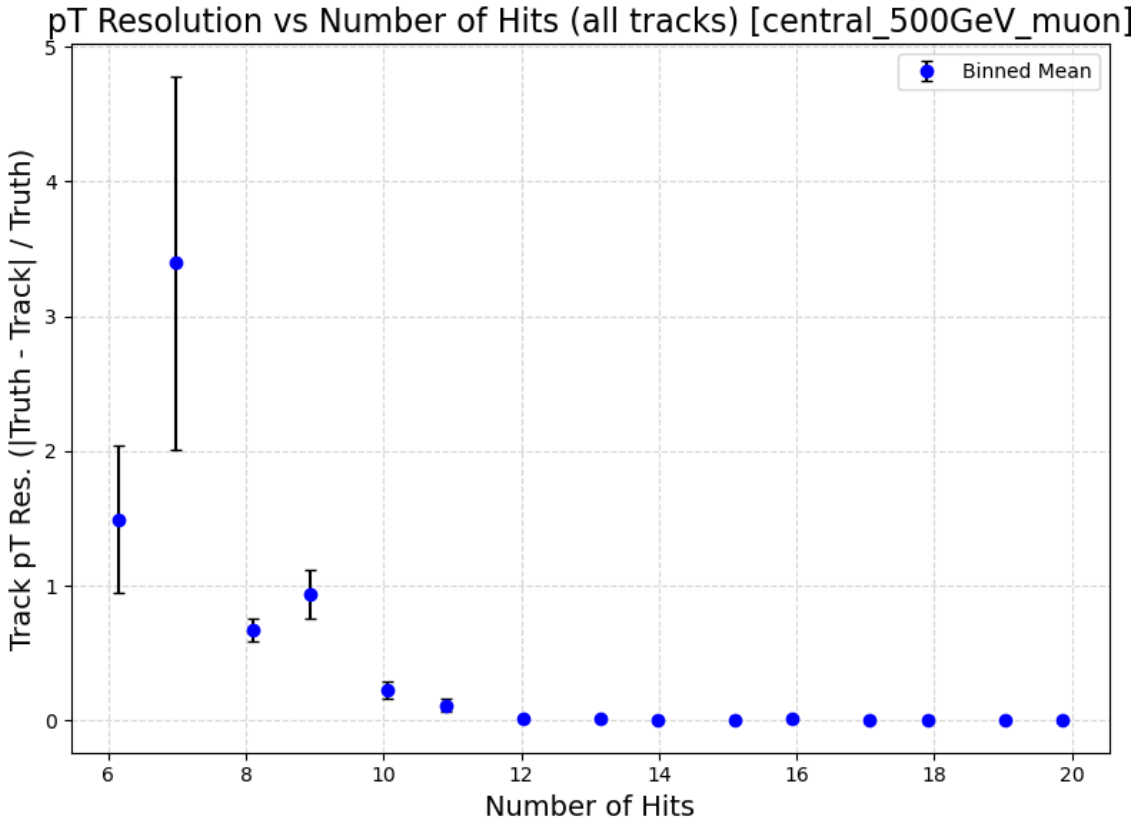


Note: $\frac{q}{p}$ is parameter actually used by ACTS

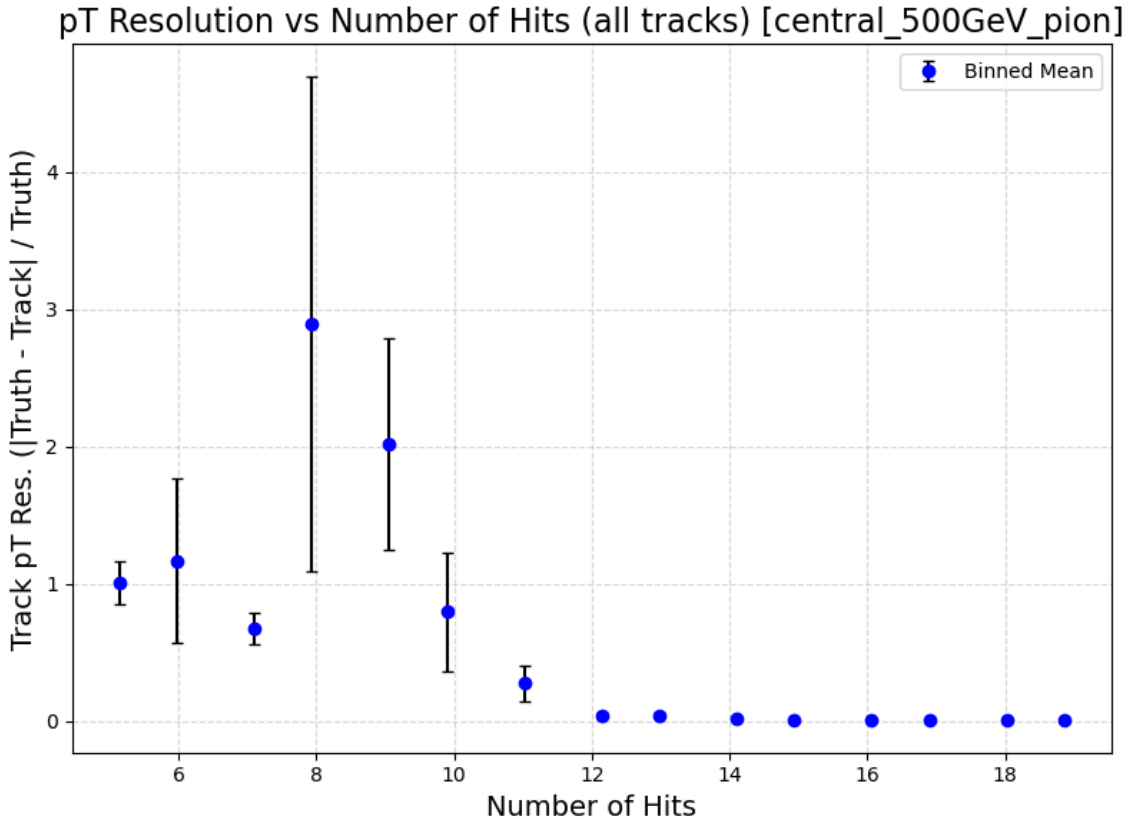
500 GeV Particle Gun Plots

Note: only cleaning is $N_{Hits} > 3.5$, uniform $|\eta| < 1.5$ distribution, particles in uniform $|\eta| < 1.5$ distribution, use mucoll benchmarks reconstruction

$\frac{\Delta p_T}{\text{Truth } p_T}$ vs. Number of Hits

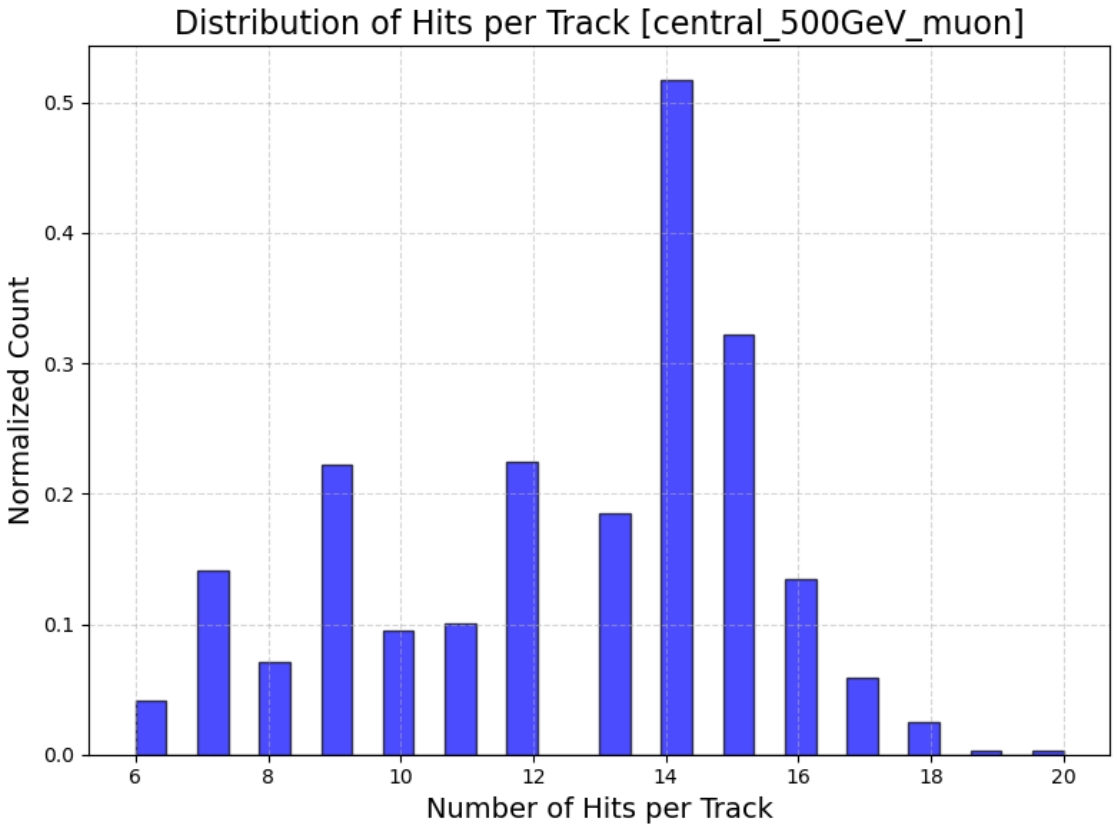


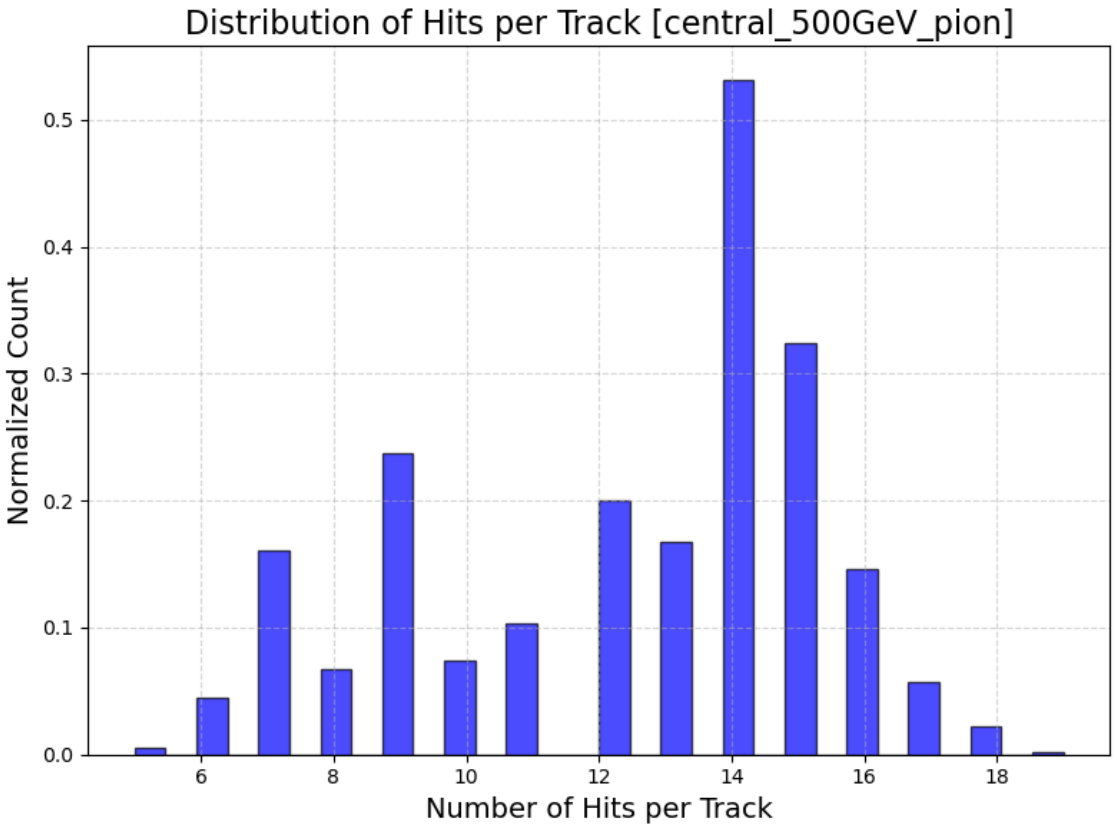
Avg: 21.1%



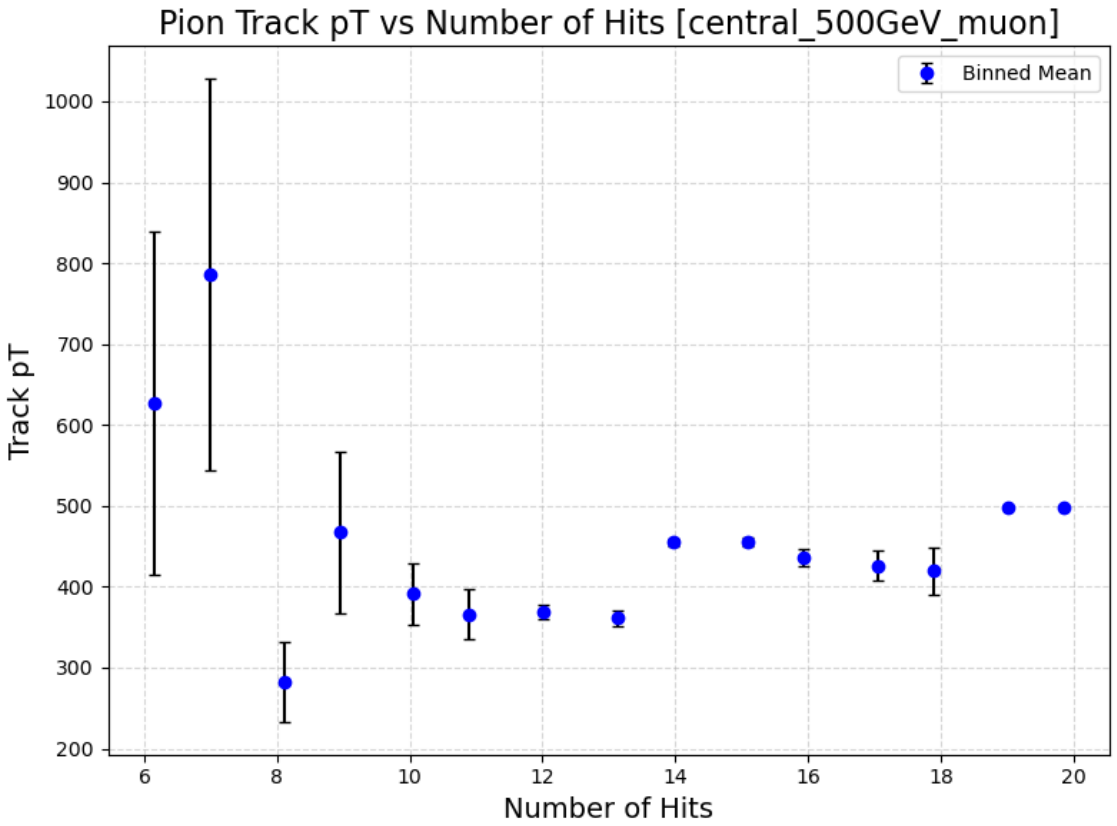
Avg: 21.1%

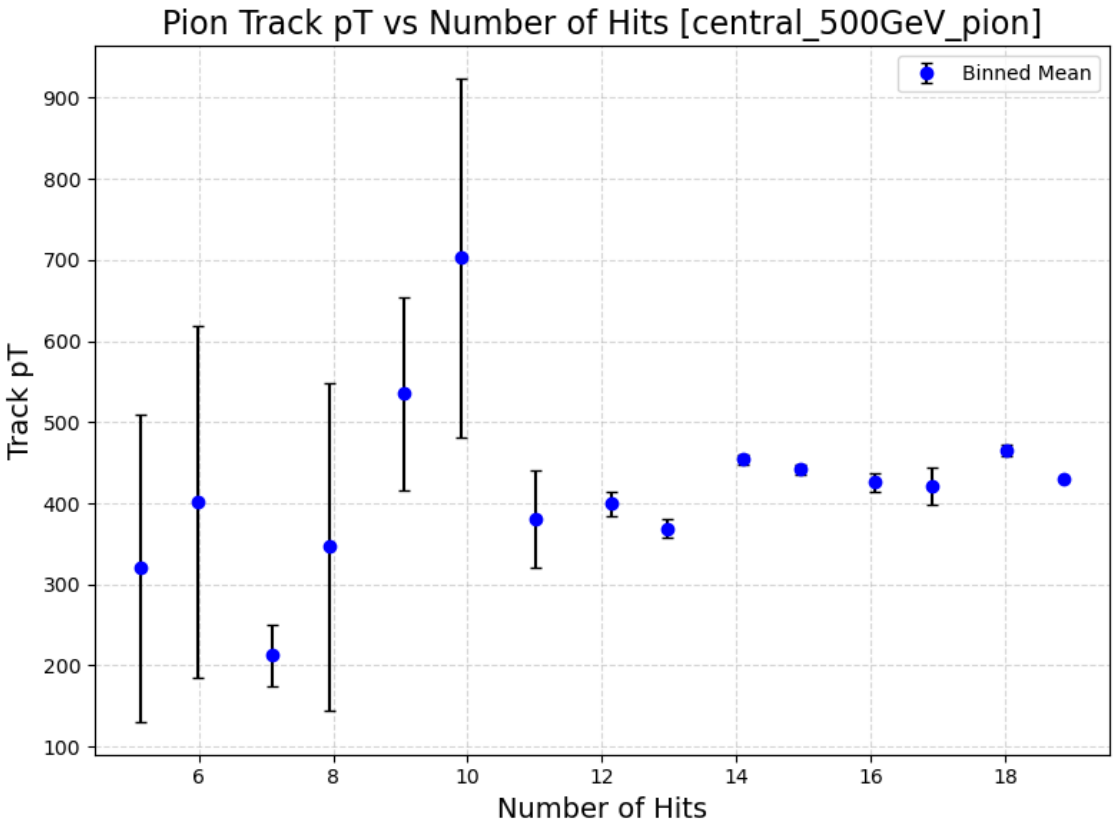
Number of Hits



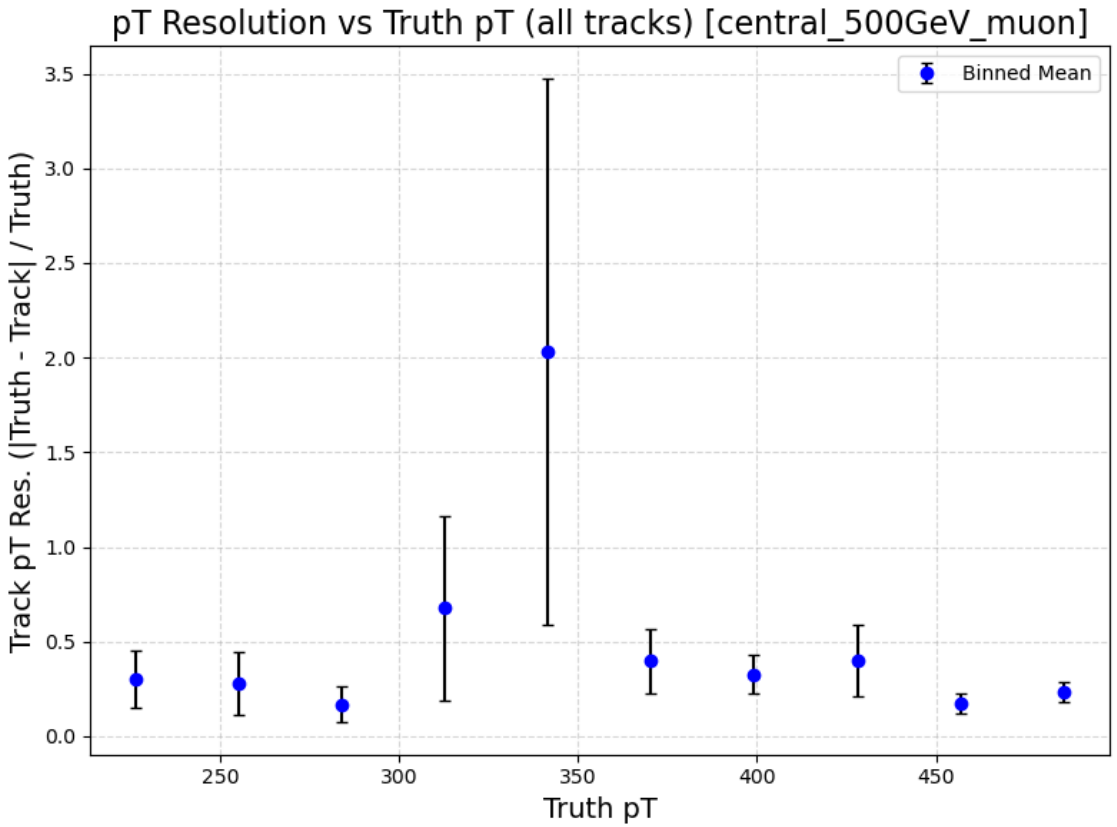


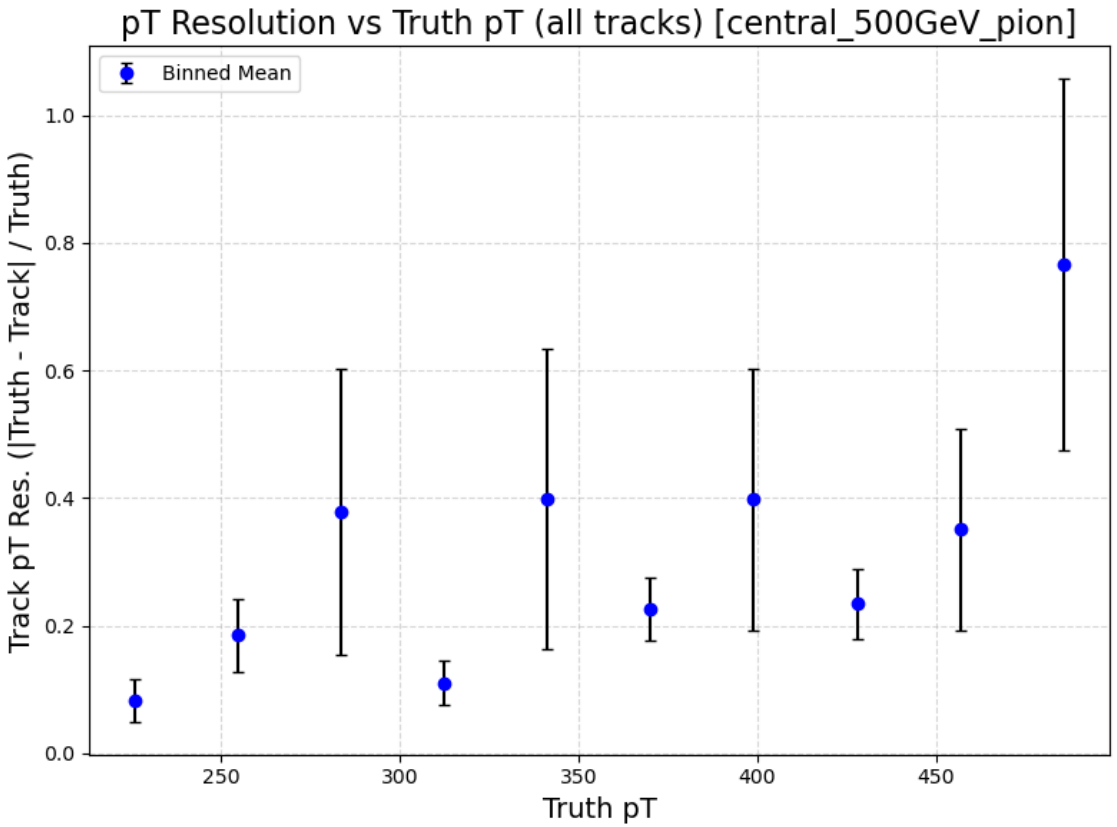
Track p_T vs. Number of Hits



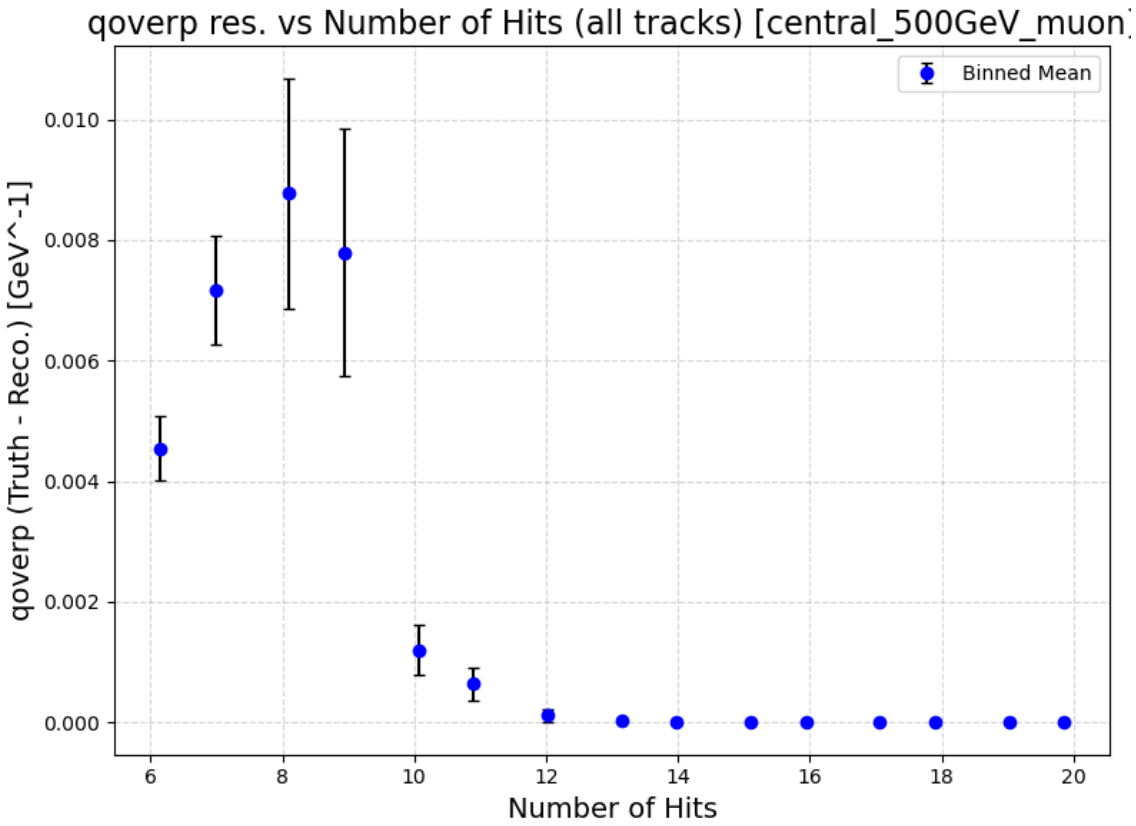


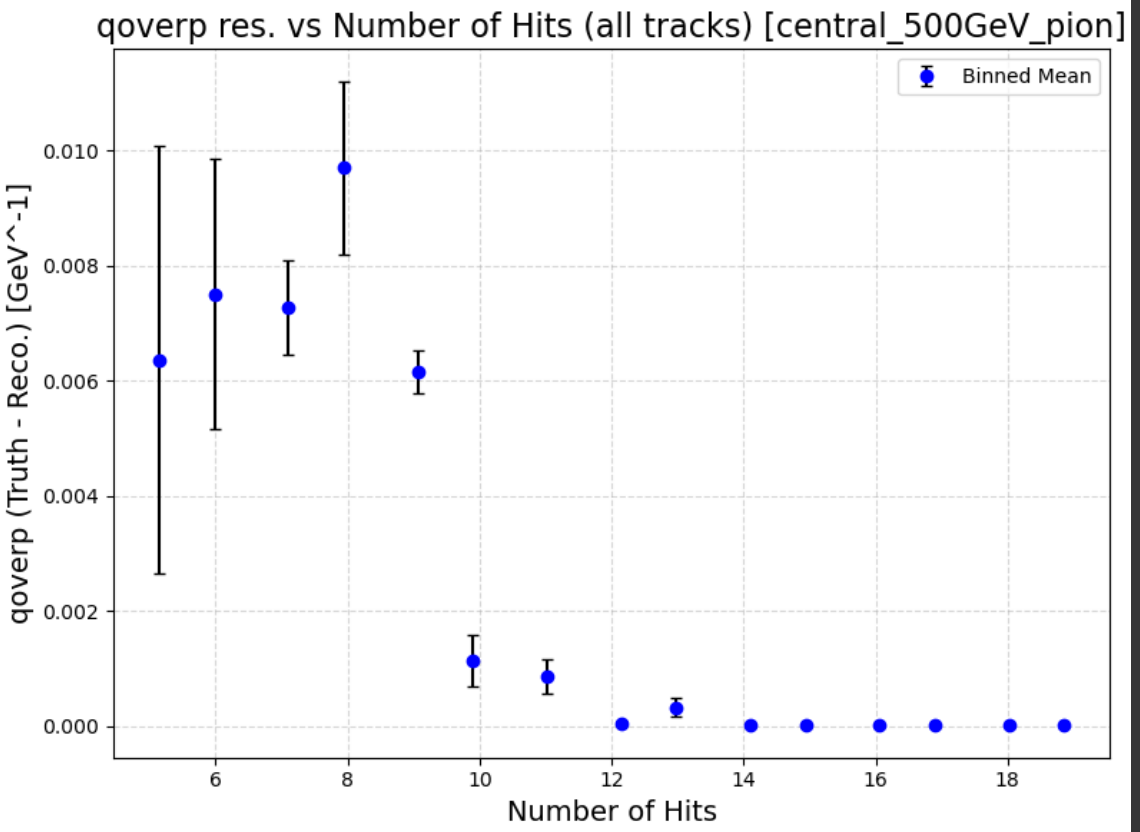
$\frac{\Delta p_T}{\text{Truth } p_T}$ vs. Truth p_T





$\Delta\left(\frac{q}{p}\right)$ vs. N_{hits}

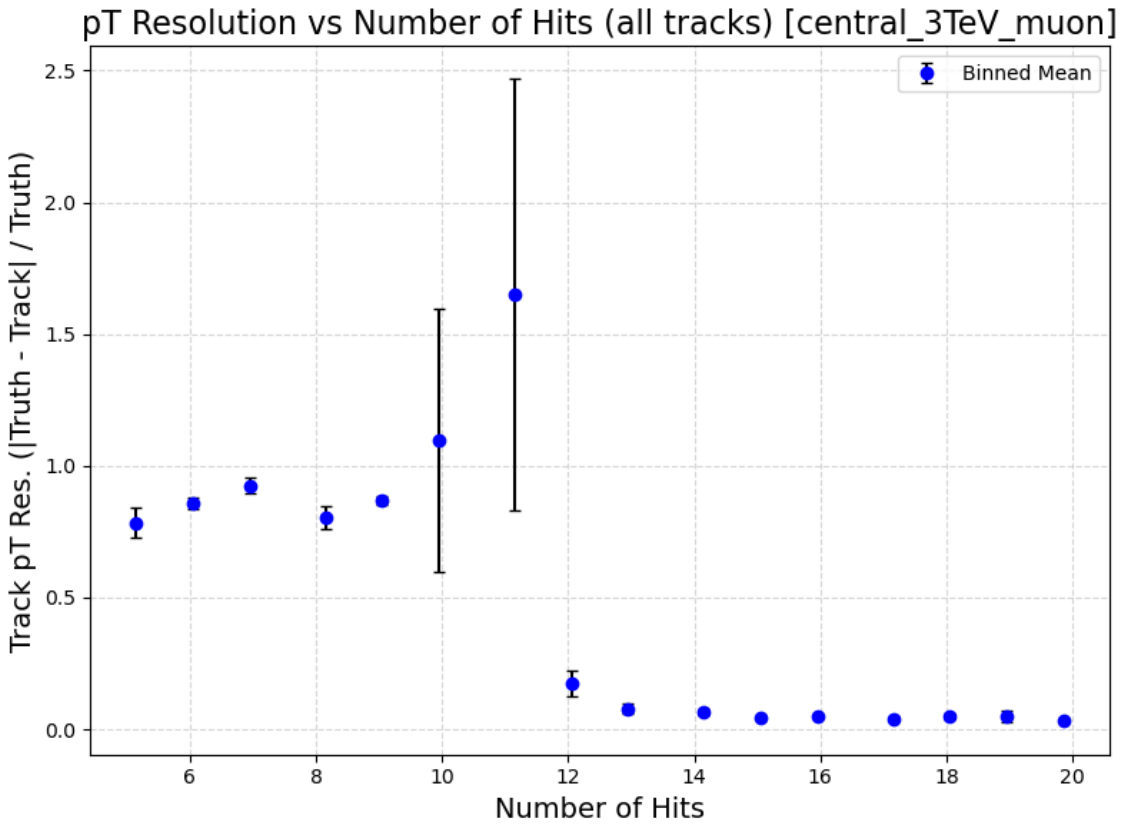




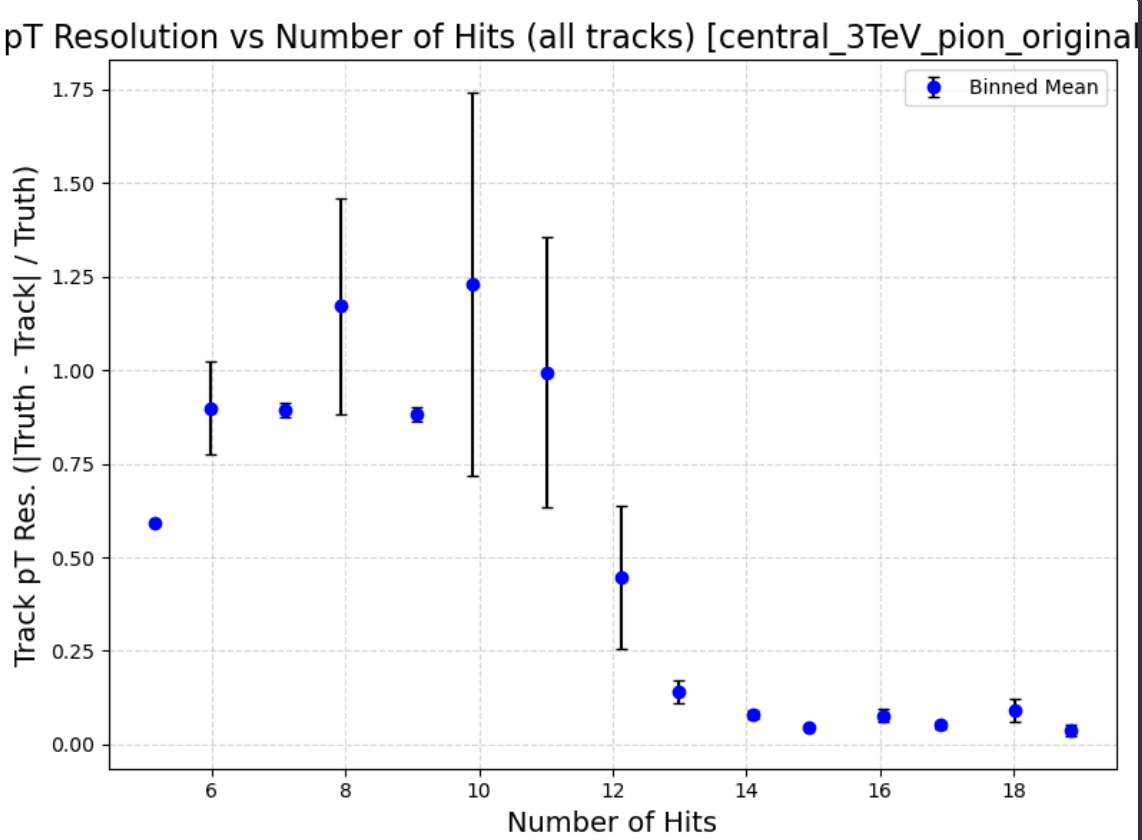
3 TeV Particle Gun Plots

Note: only cleaning is $N_{Hits} > 3.5$, particles in uniform $|\eta| < 1.5$ distribution, use mucoll benchmarks reconstruction

$\frac{\Delta p_T}{\text{Truth } p_T}$ vs. Number of Hits

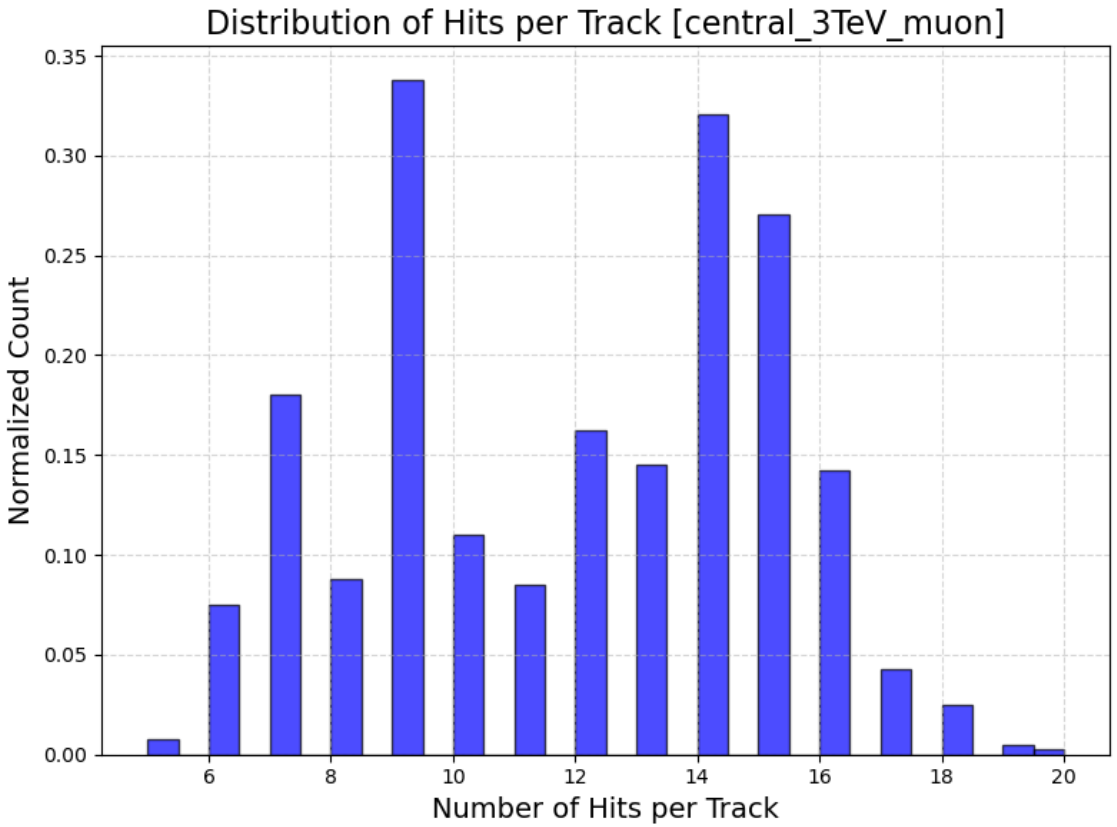


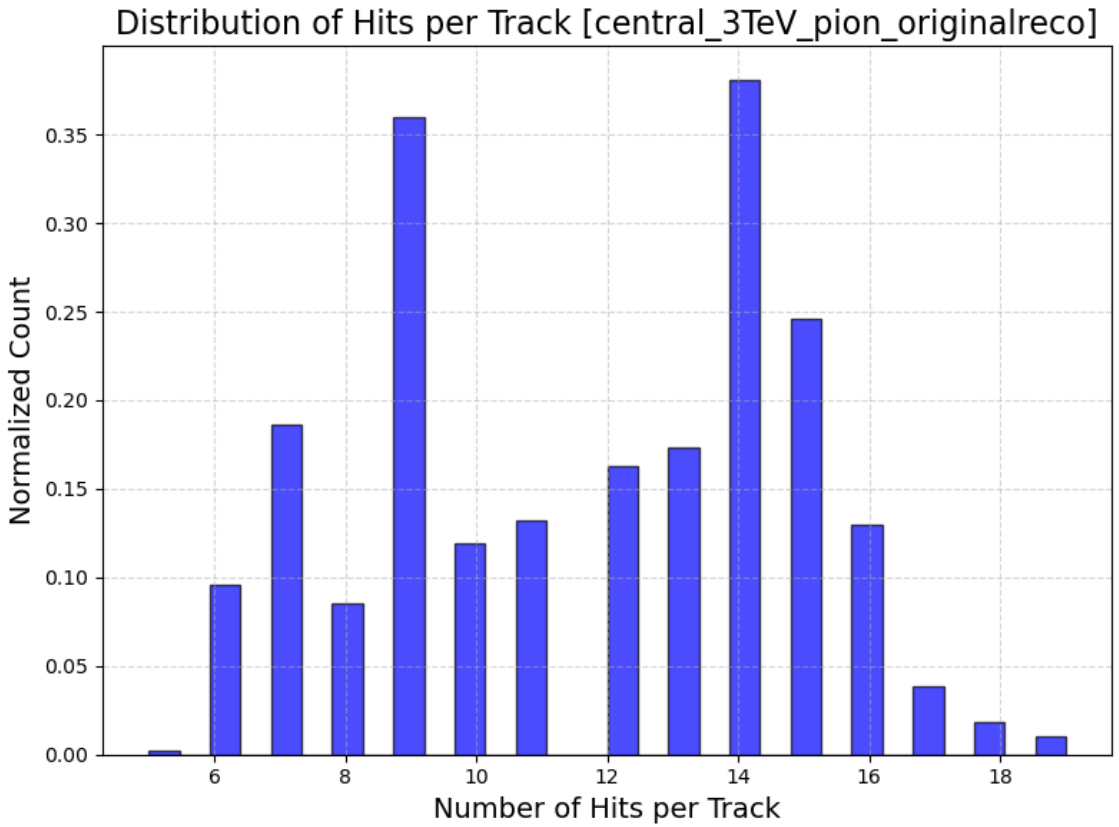
Avg: 41.4%



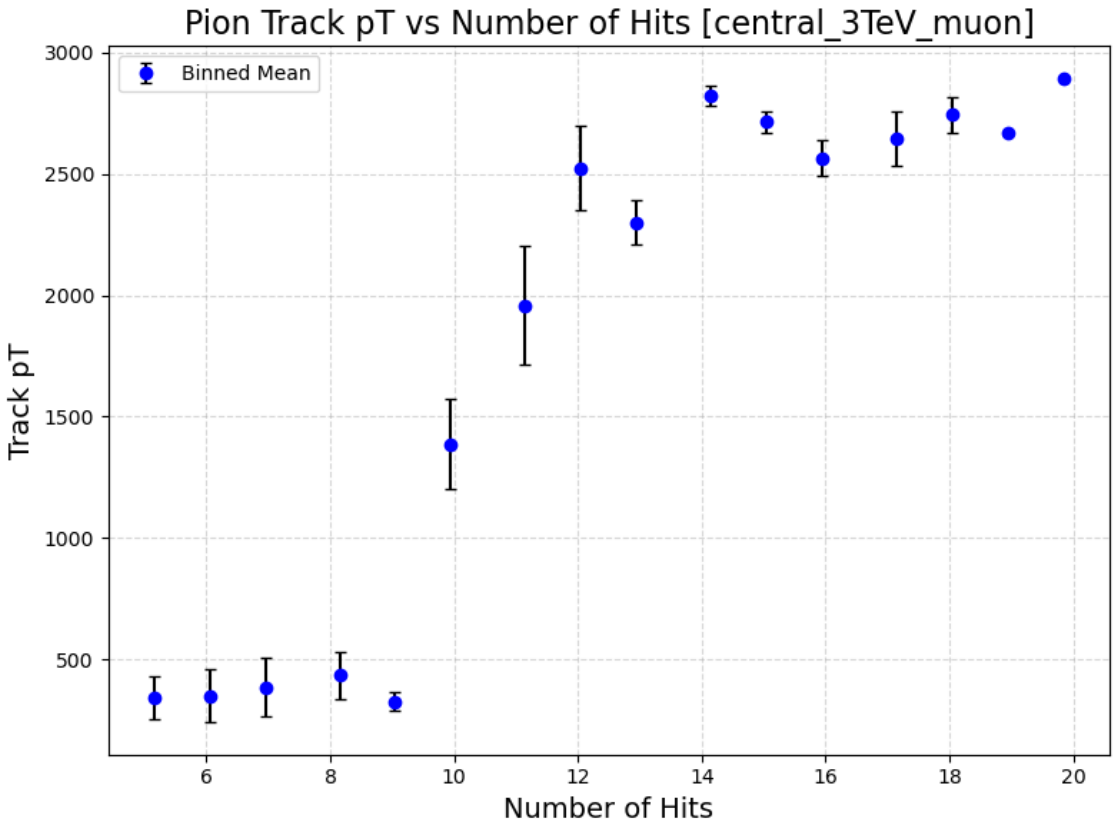
Avg: 43.3%

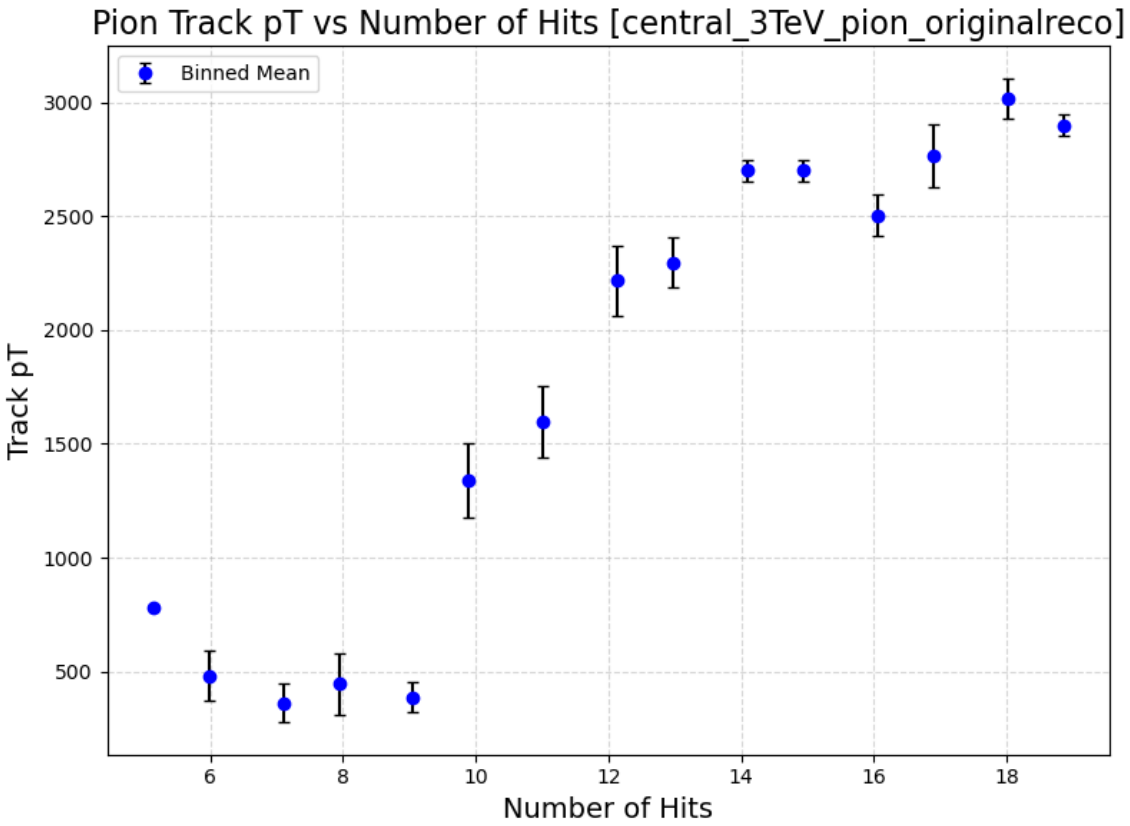
Number of Hits



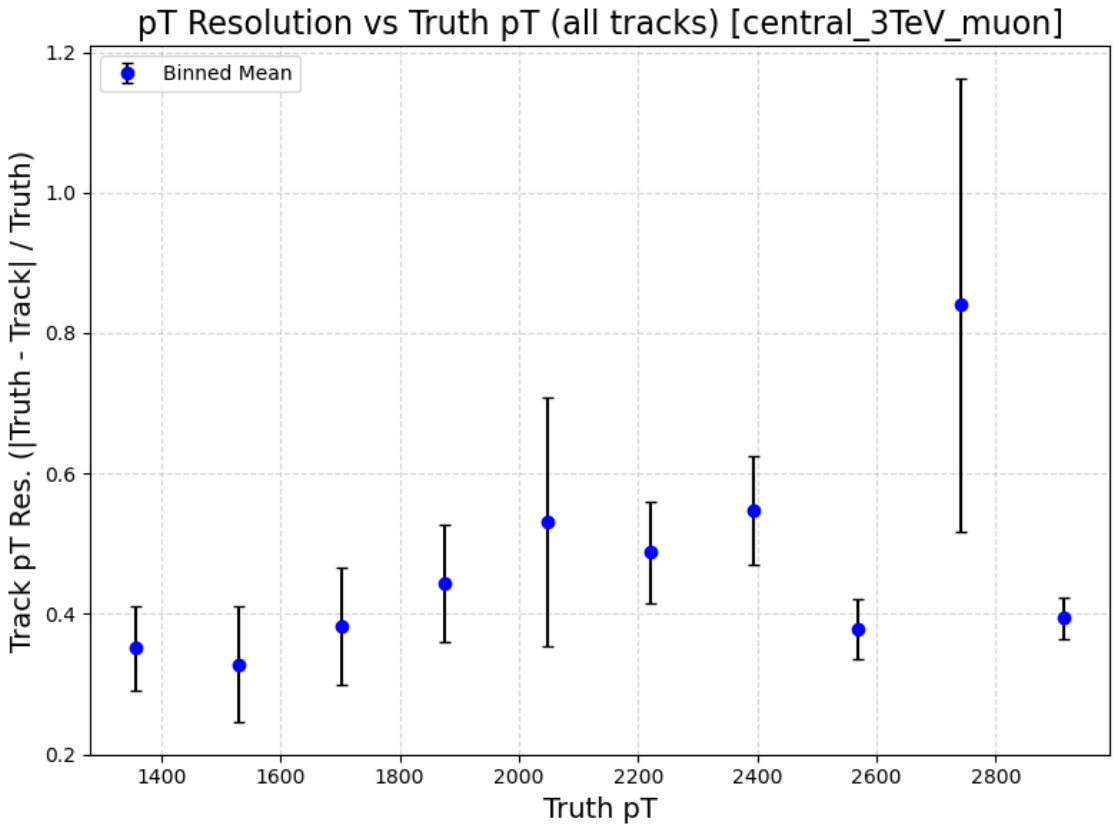


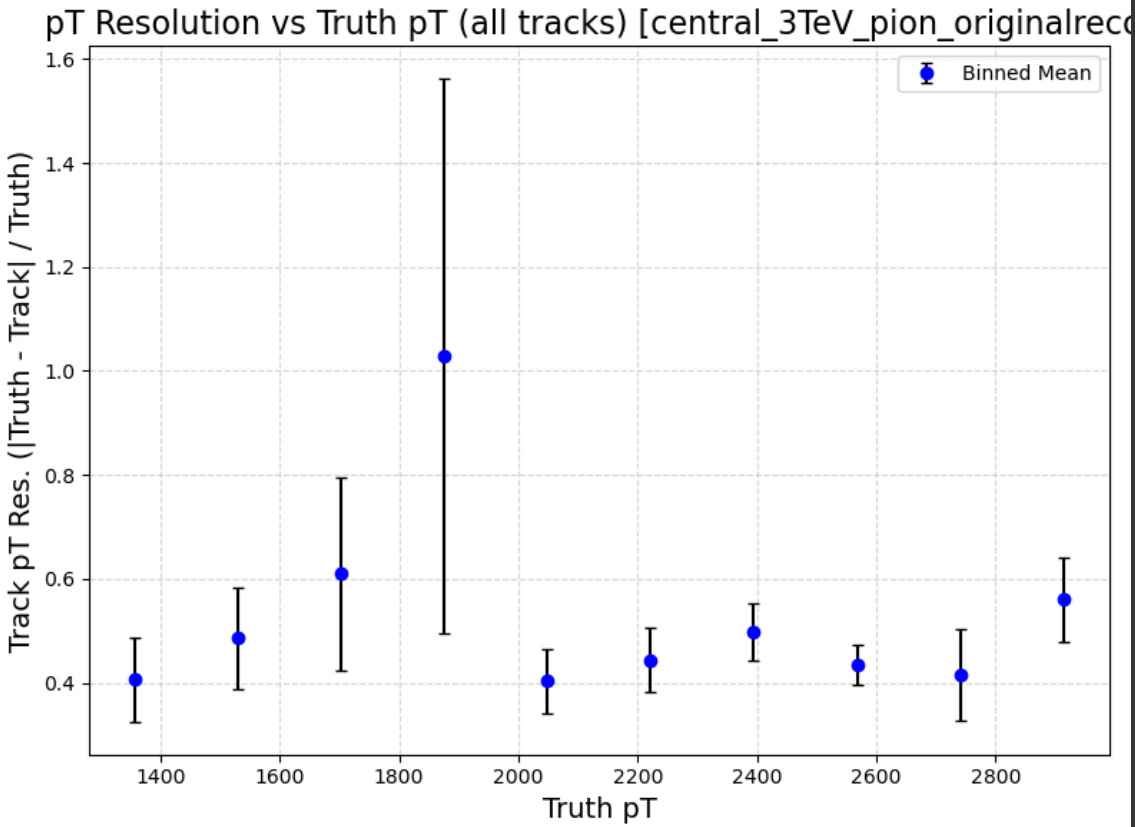
Track p_T vs. Number of Hits



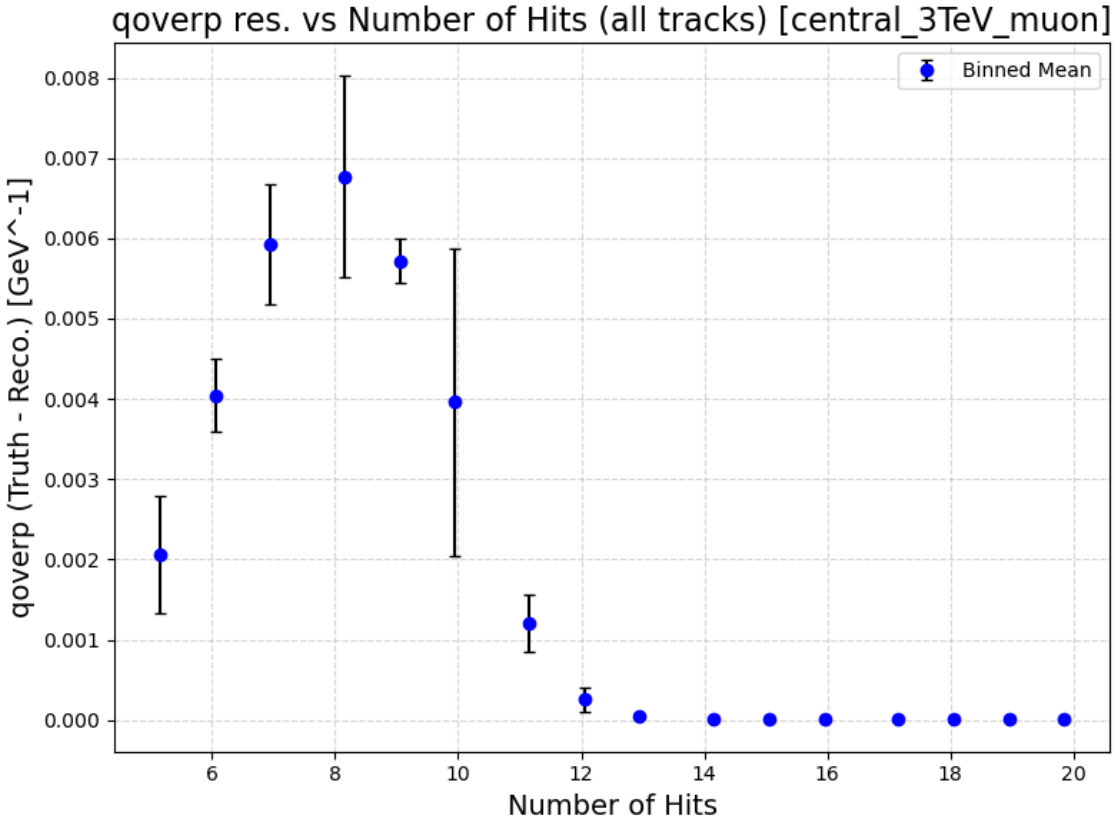


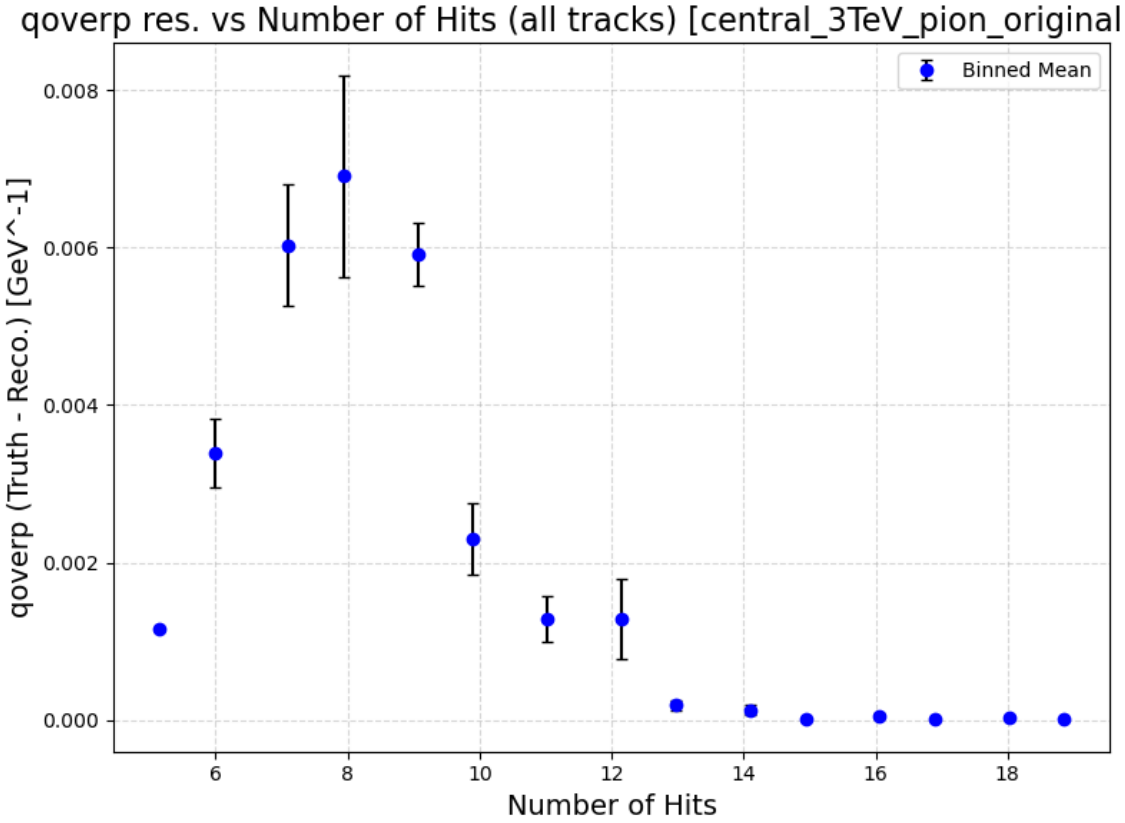
$\frac{\Delta p_T}{\text{Truth } p_T}$ vs. Truth p_T





$\Delta\left(\frac{q}{p}\right)$ vs. N_{hits}



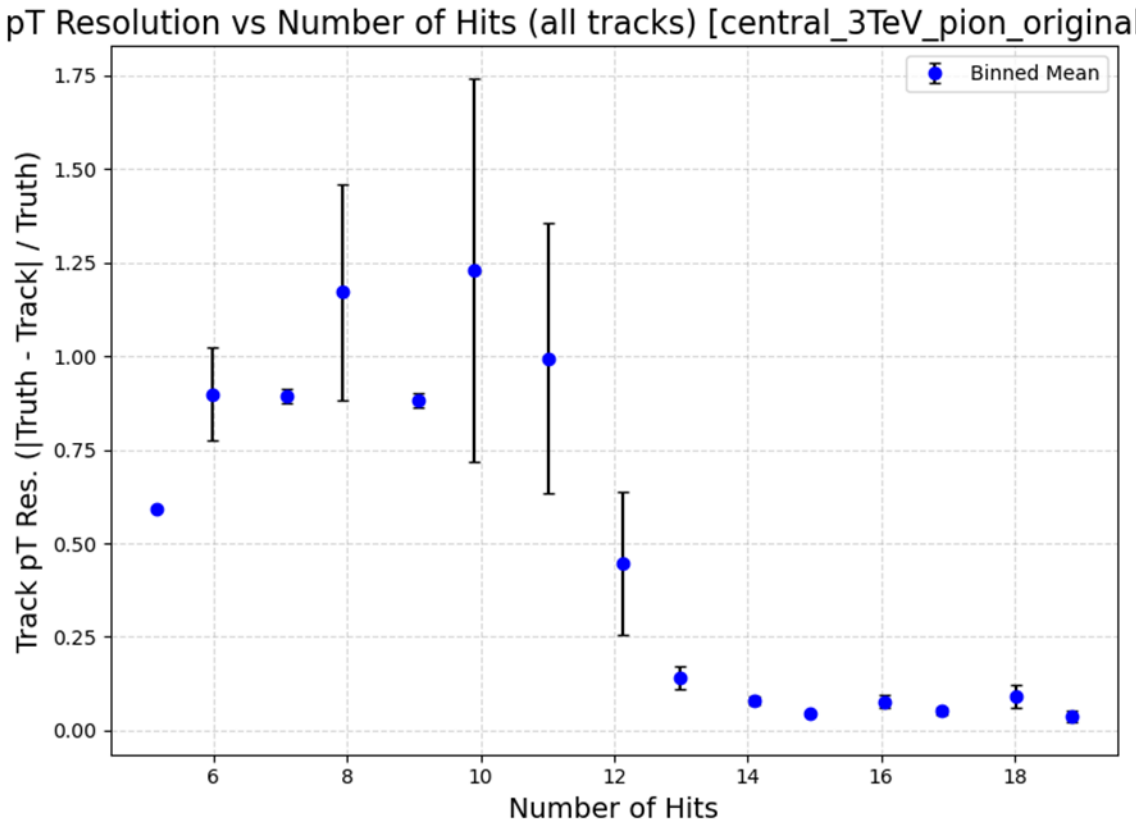


3 TeV Pion Gun Plots

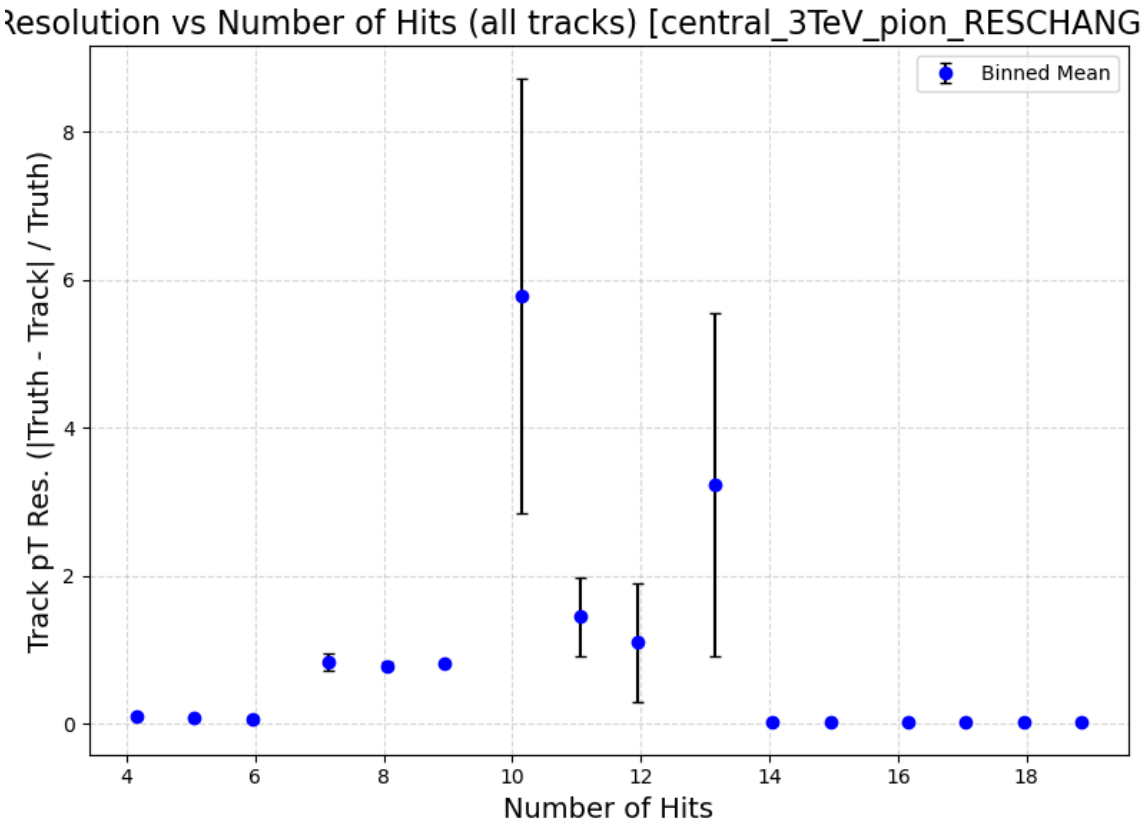
(nominal & improved spatial resolution)

Note: only cleaning is $N_{Hits} > 3.5$, uniform $|\eta| < 1.5$ distribution
Improved spatial resolution by 2x (worsening by 2x made p_T res. worse)

$\frac{\Delta p_T}{\text{Truth } p_T}$ vs. Number of Hits

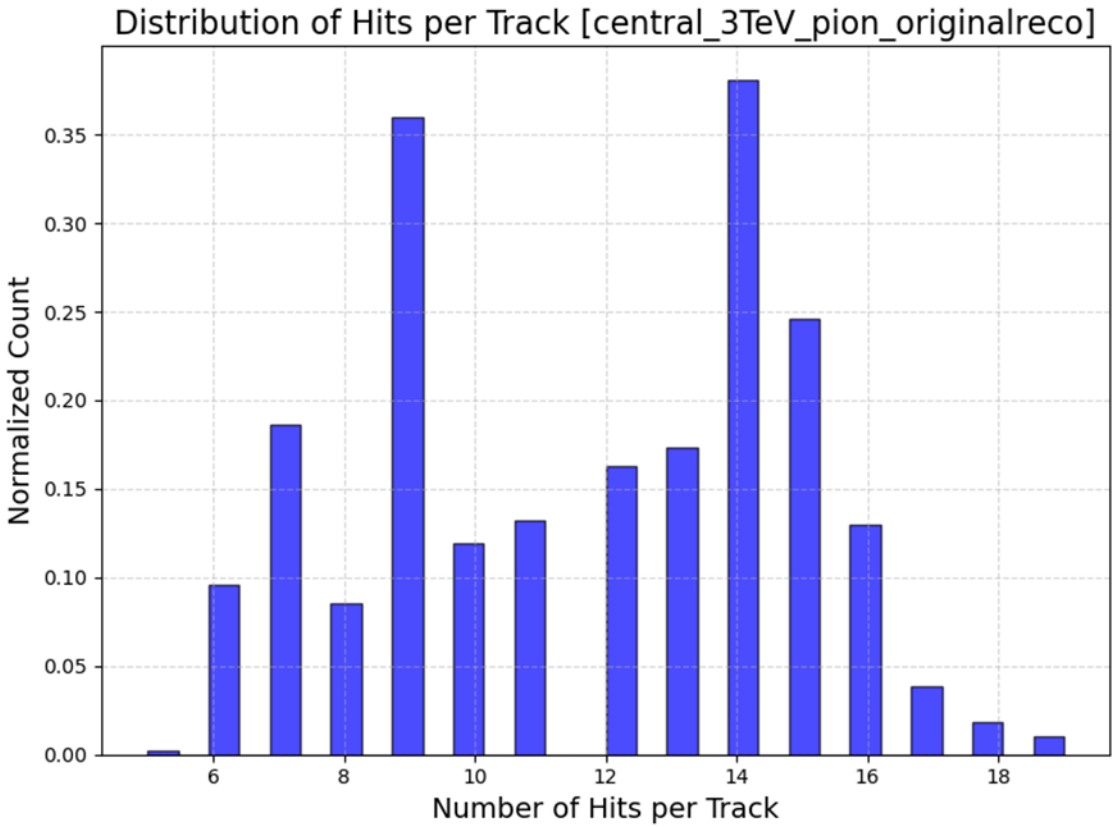


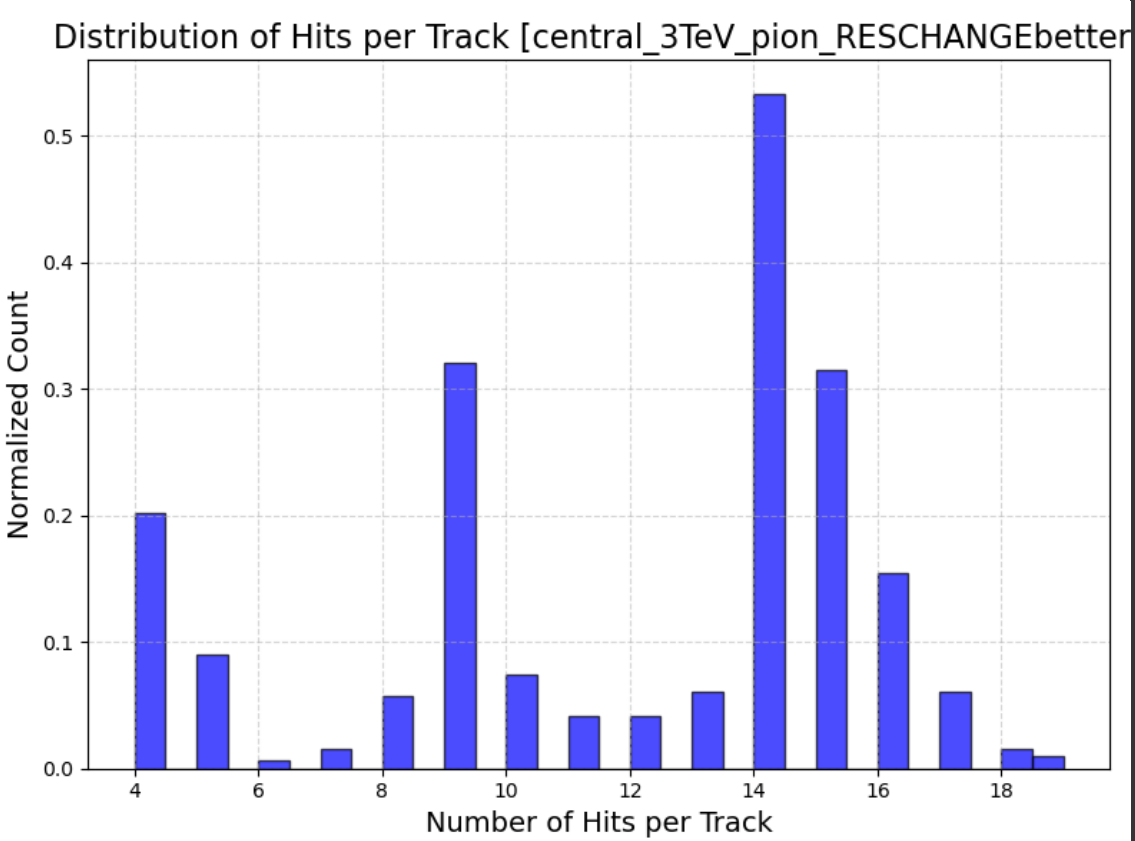
Avg: 43.3%
Tracking Eff.: 84.6%



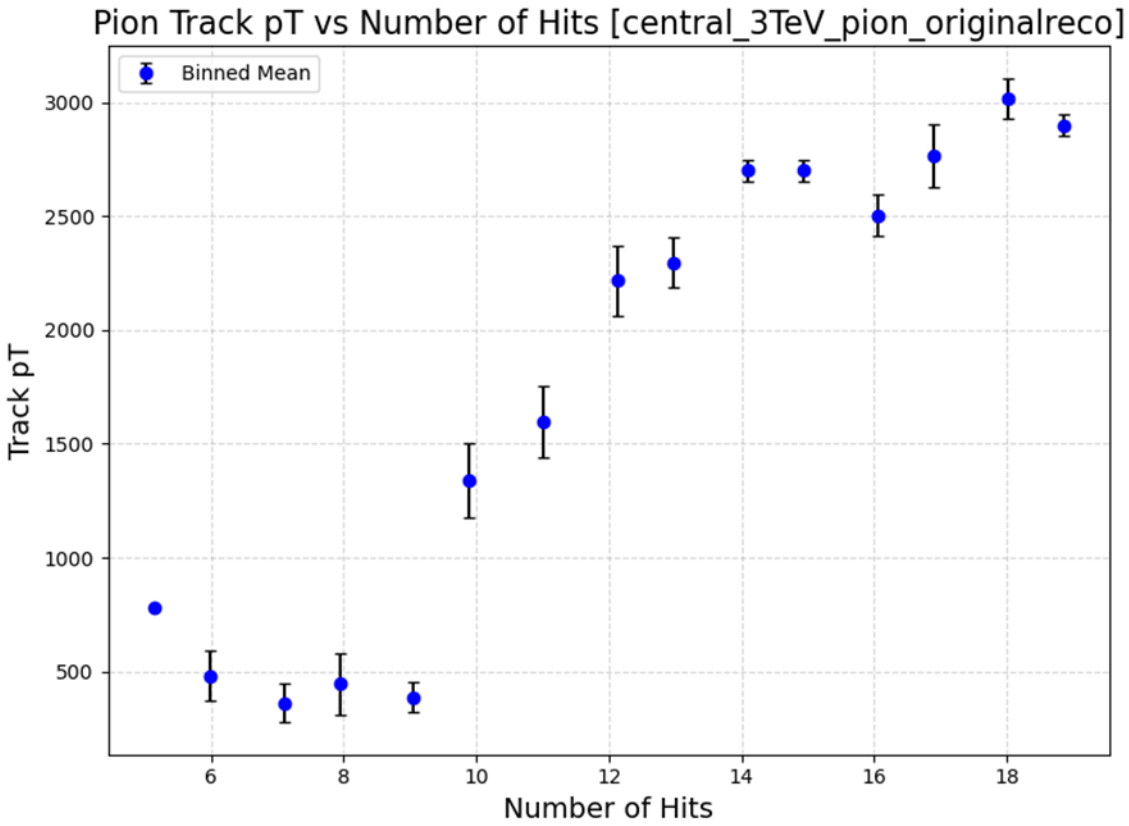
Avg: 30.0%
Tracking Eff.: 64.8%

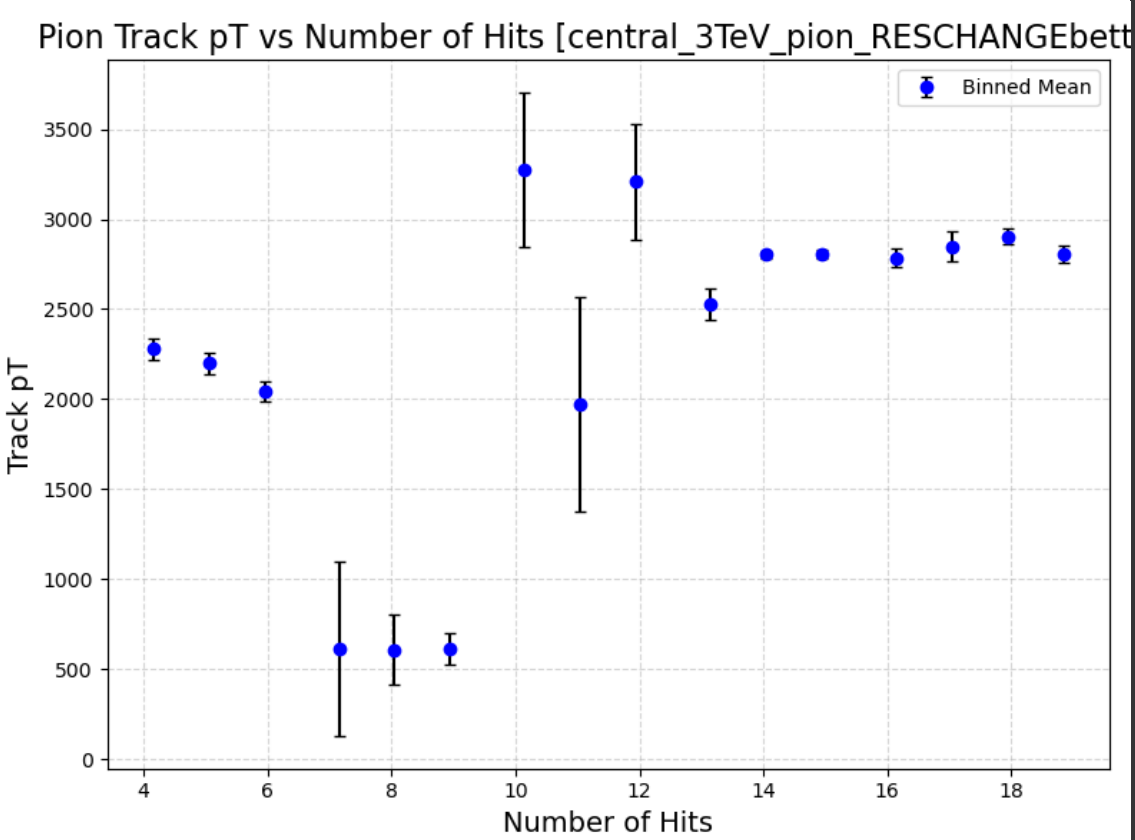
Number of Hits



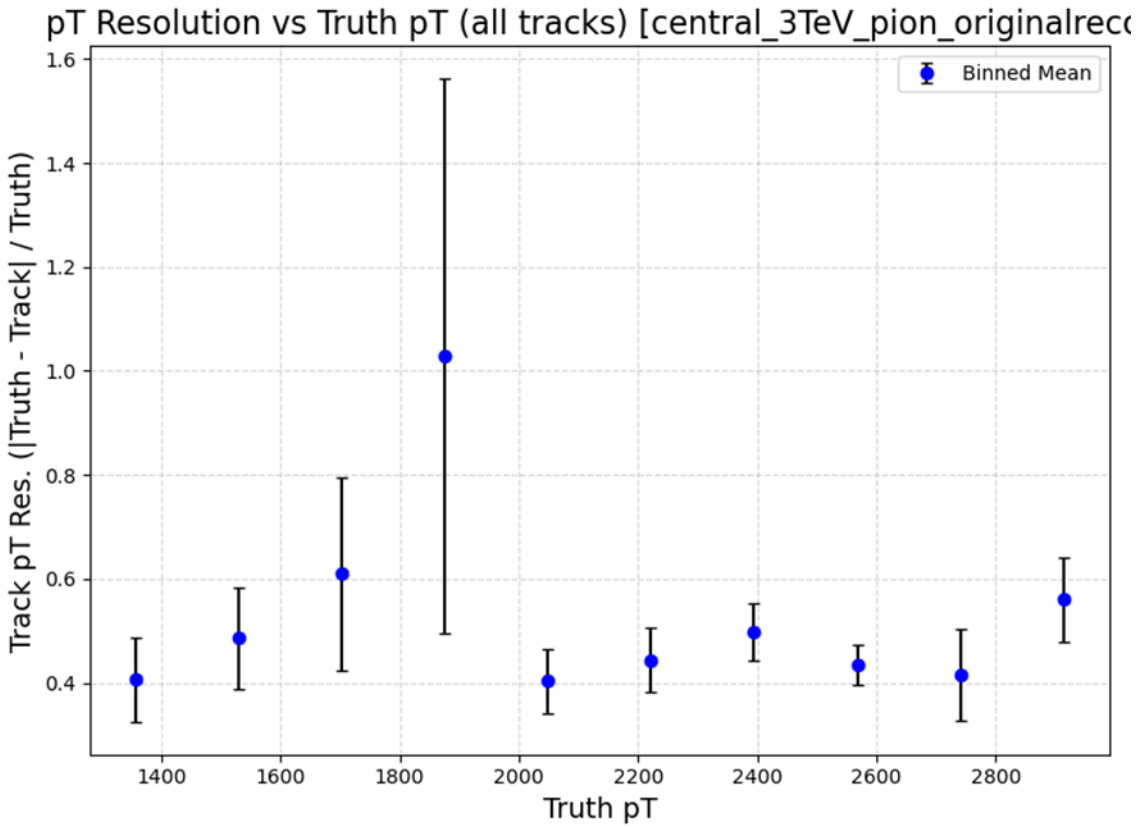


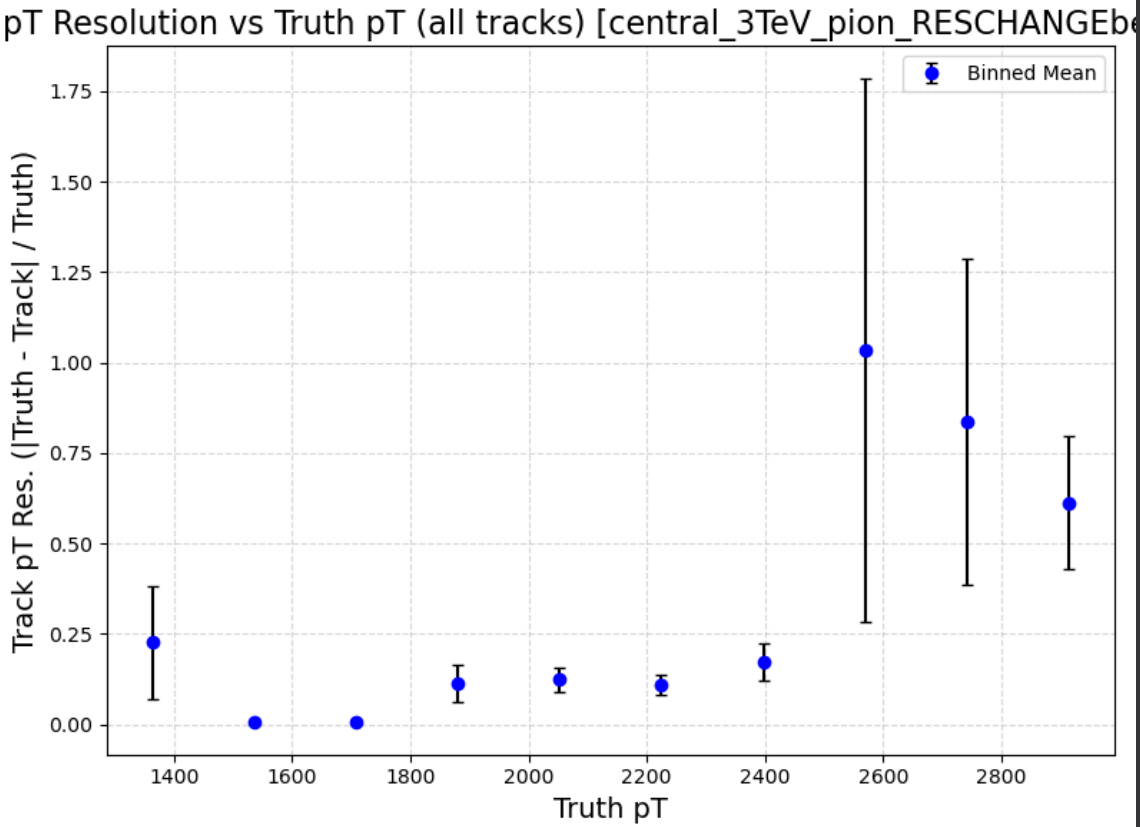
Track p_T vs. Number of Hits



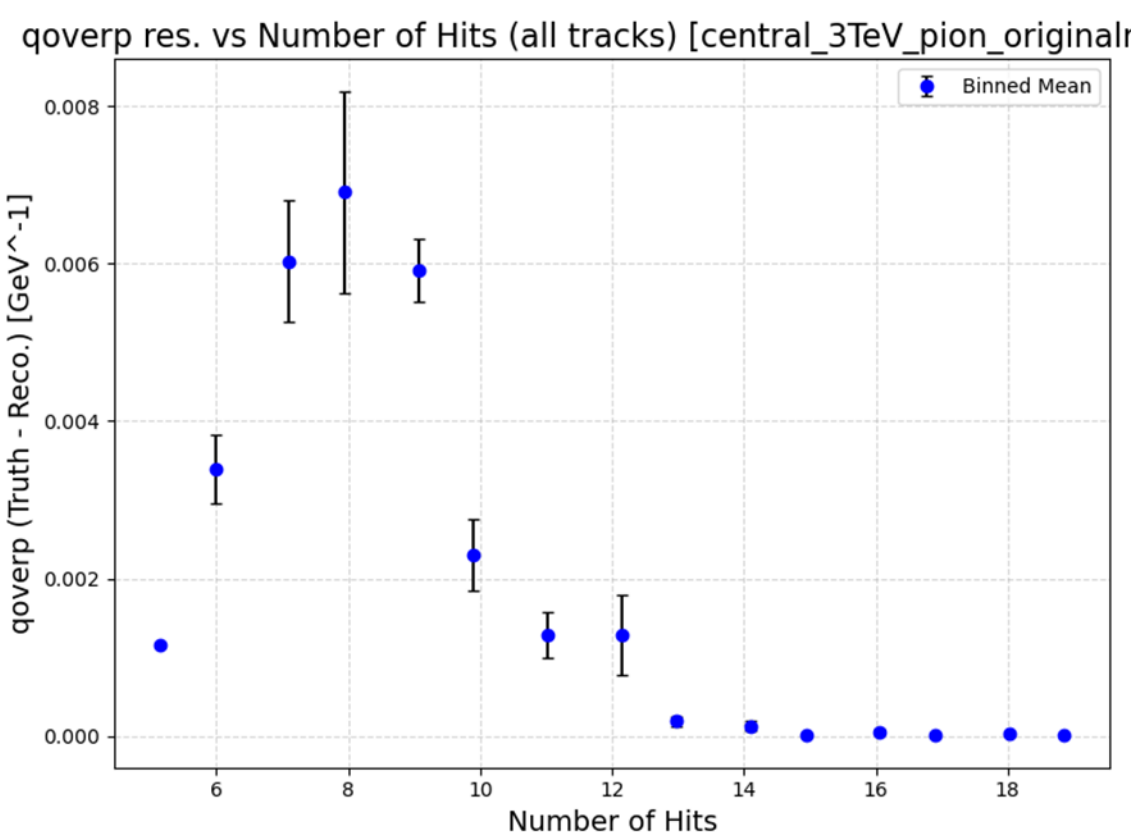


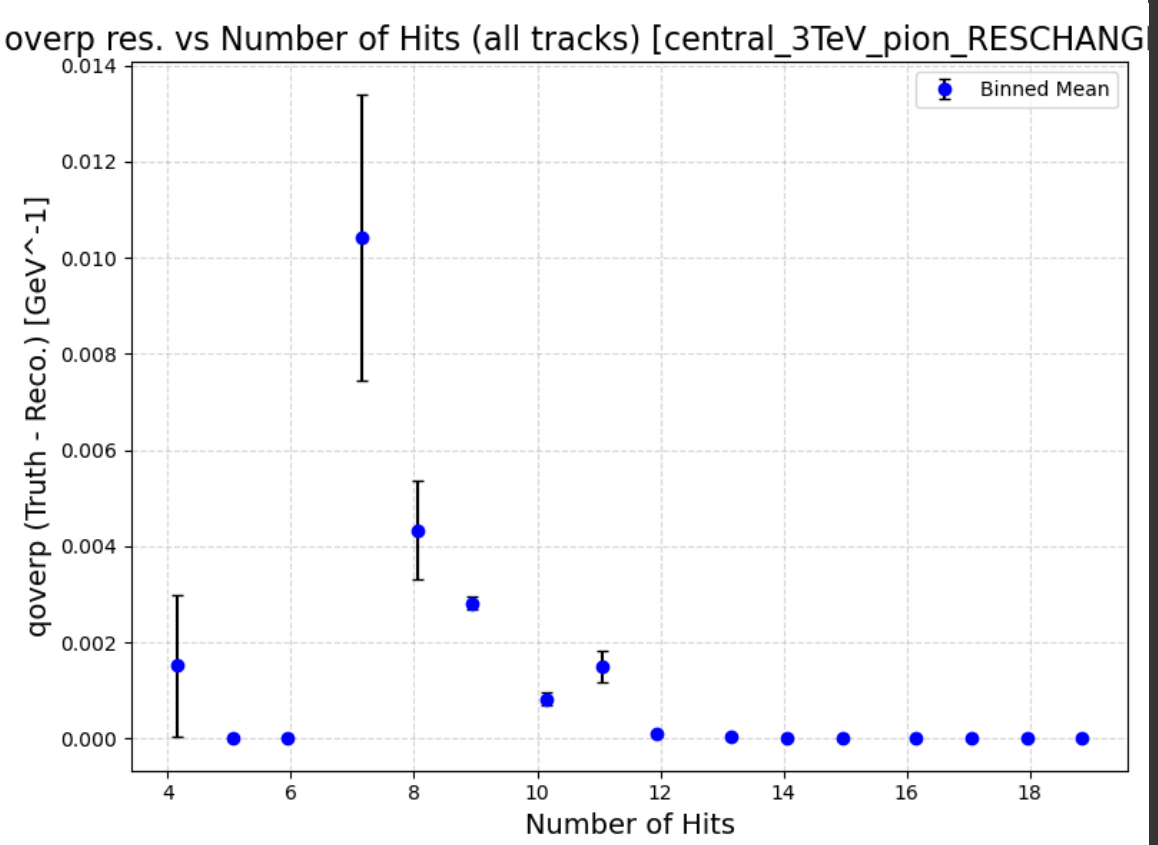
$\frac{\Delta p_T}{\text{Truth } p_T}$ vs. Truth p_T





$\Delta\left(\frac{q}{p}\right)$ vs. N_{hits}





Potential Causes

- Original theory was that radiation causing significant change in particle momentum mid-flight explained low # of hits associated to tracks
  - Observed this phenomenon for $\tilde{\tau}'s$
  - Does not seem to be the case for particle gun samples – only additional Monte Carlo particles likely produced from interaction w/ detector material
- Spatial uncertainties in digitization could be causing tracks to miss hits

Conclusions

- Poor track p_T resolution correlated with low number of hits associated to tracks, which is in turn correlated with momentum of tracking particle
- Improving spatial resolution of track hits improved p_T resolution, but worsened tracking efficiency
  - Improved resolution likely allows reconstruction of higher quality tracks
  - ~15% of events had unassociated tracks, ΔR-matching could match these
- Especially worse resolution for tracks reconstructed w/ low number of hits likely explains why $\tilde{\tau}$ tracks & displaced tracks have poor resolution

Future Investigation

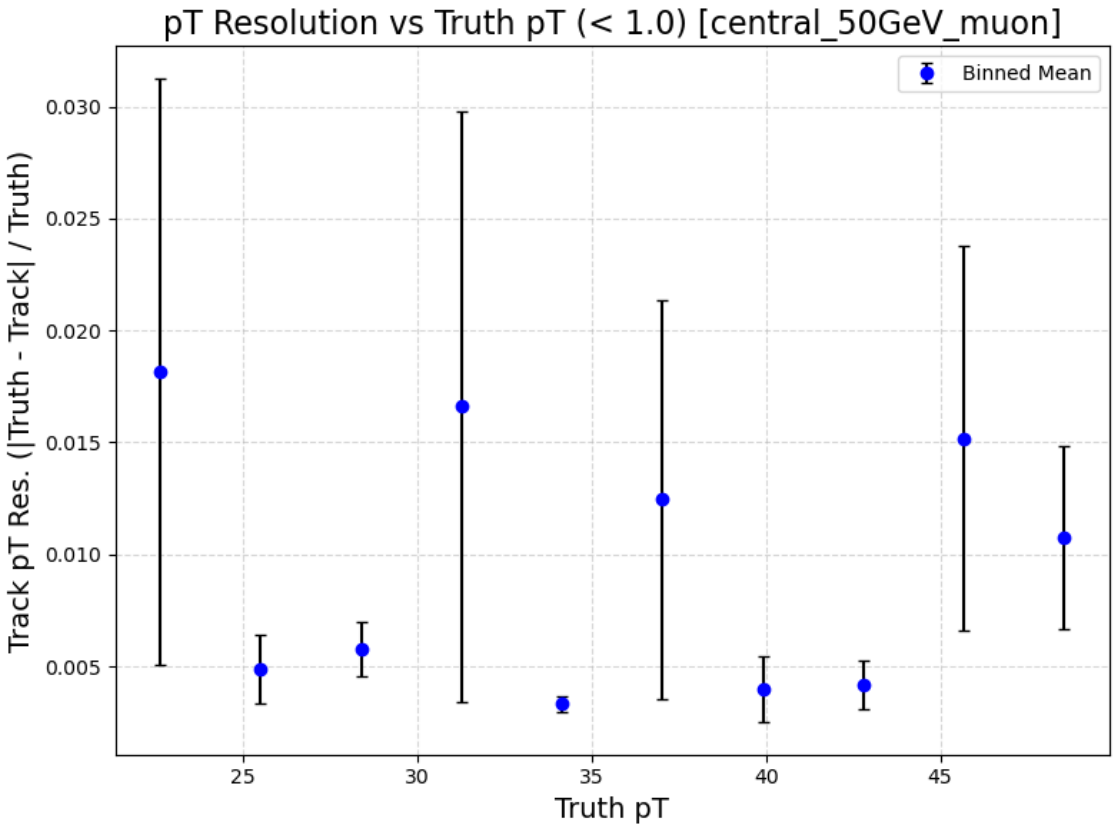
- If useful:
  - Repeat particle gun studies with significantly more events
  - Continue optimizing assumed spatial uncertainties to maximize p_T resolution & tracking efficiency
    - Try ΔR-matching to potentially mitigate loss in tracking efficiency
  - Investigate w/ BIB overlay
- Validate similar relationship w/ p_T res., N_{Hits} in our study
- For reconstruction of $\tilde{\tau}$ mass, can select high N_{Hits} tracks

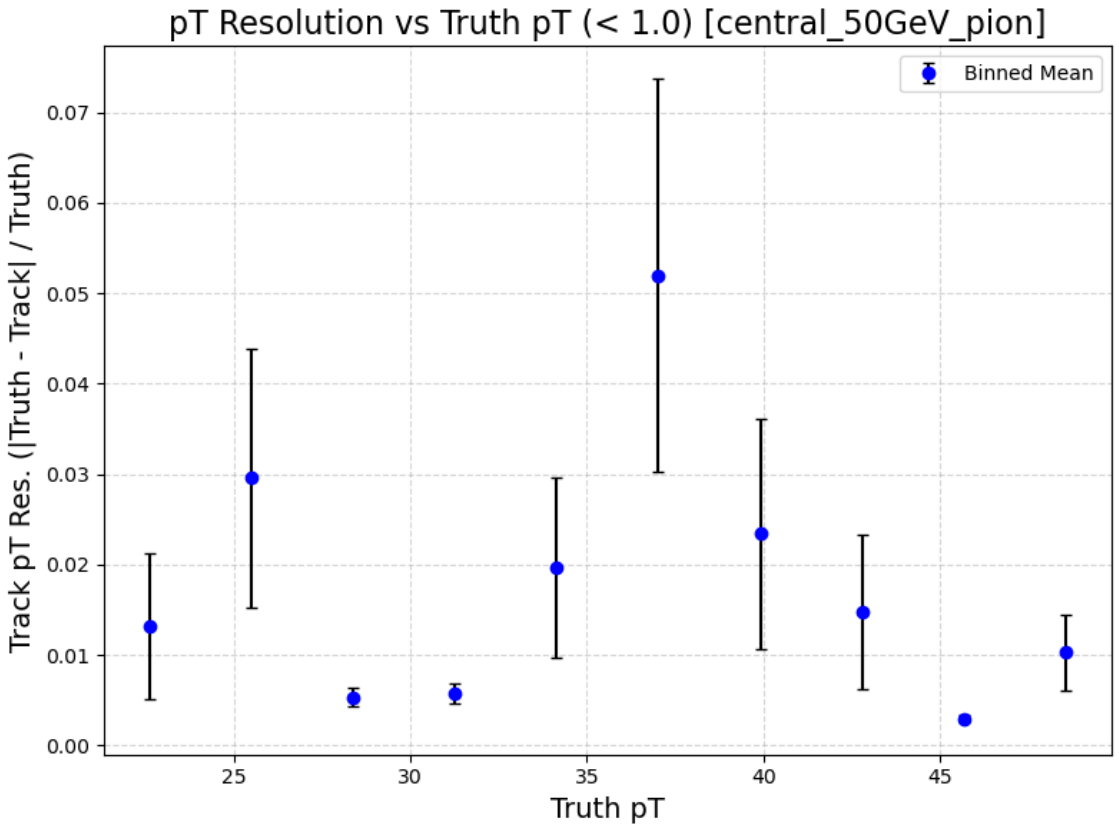
Memory Usage

- Observe very high memory usage for reconstruction just running ACTS tracking with 10% BIB overlay
  - Large portion of jobs failing when requesting 32 GB of RAM, processing 5 events / job
  - Memory usage seems to increase as continue processing events
- Also observe very large file size (~100 MB / event) for 10% BIB overlay, ~1 GB / event for 100% BIB overlay
  - This is after removing all calo hits & particle flow
- Is this what others are observing too? Any ideas for reducing memory usage?

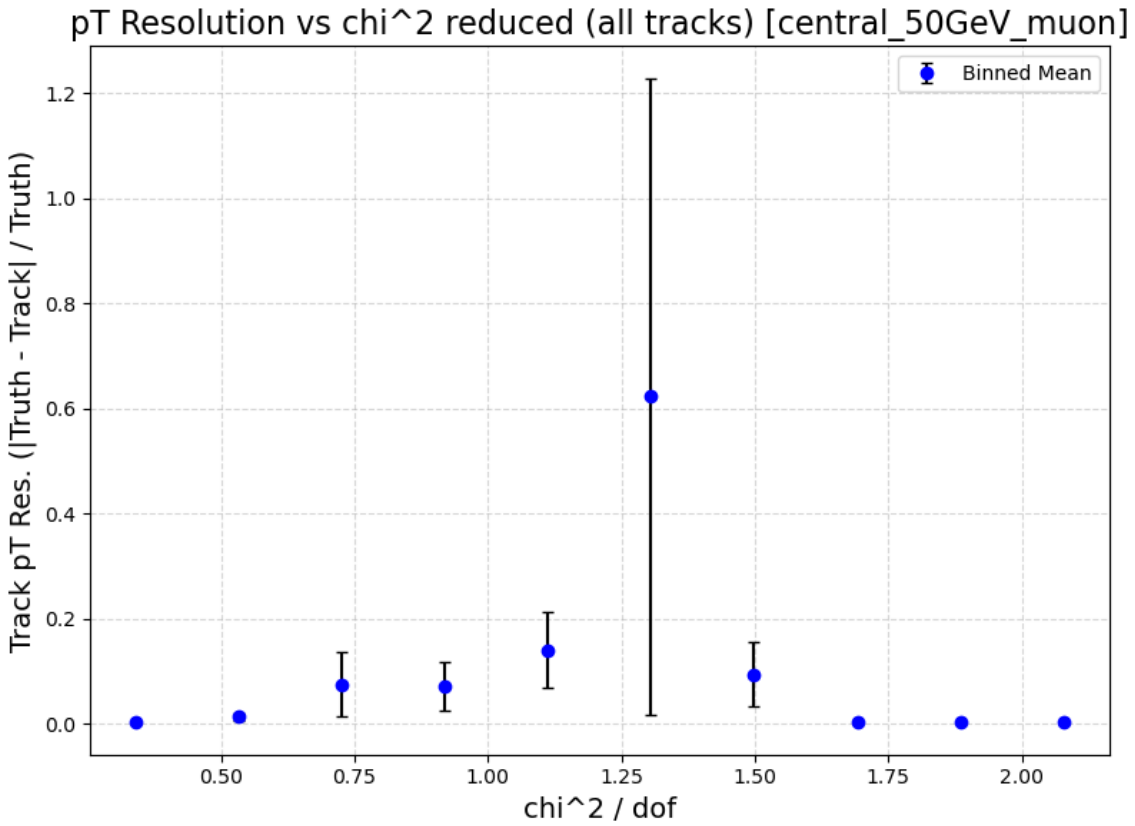
Backup

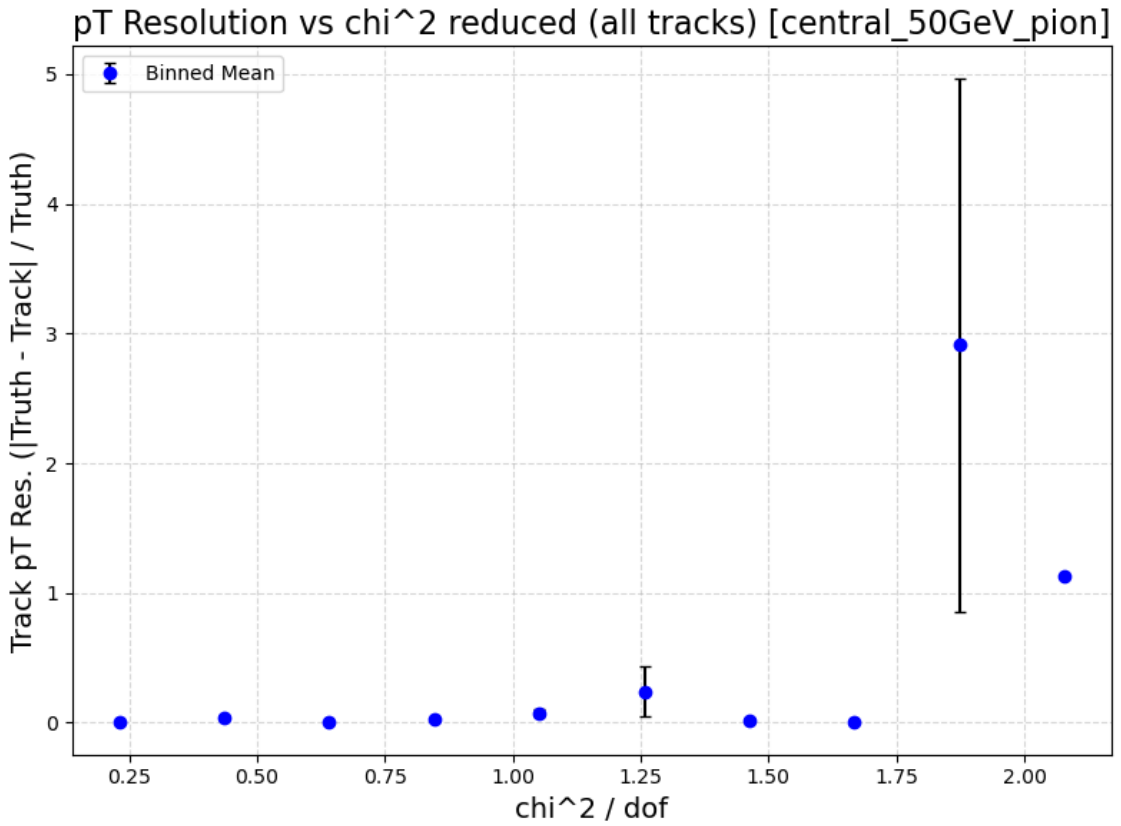
$\frac{\Delta p_T}{\text{Truth } p_T}$ vs. Truth p_T ($\frac{\Delta p_T}{\text{Truth } p_T} < 1.0$)



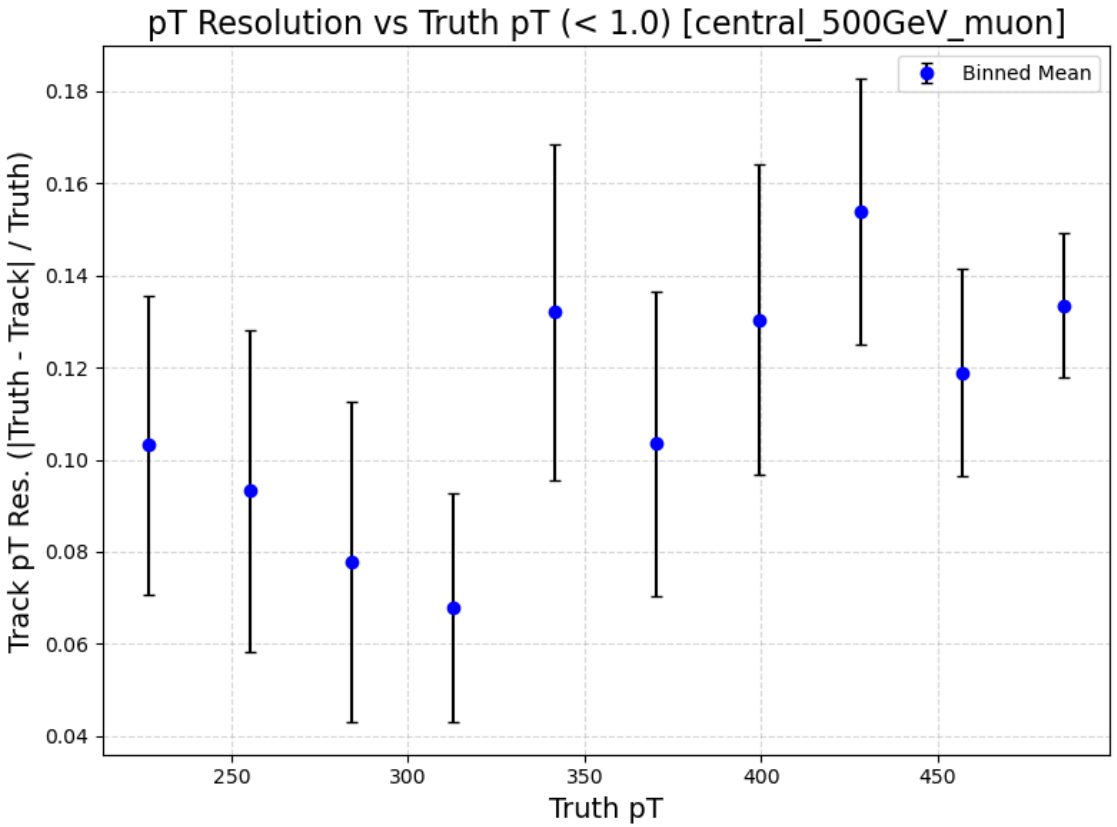


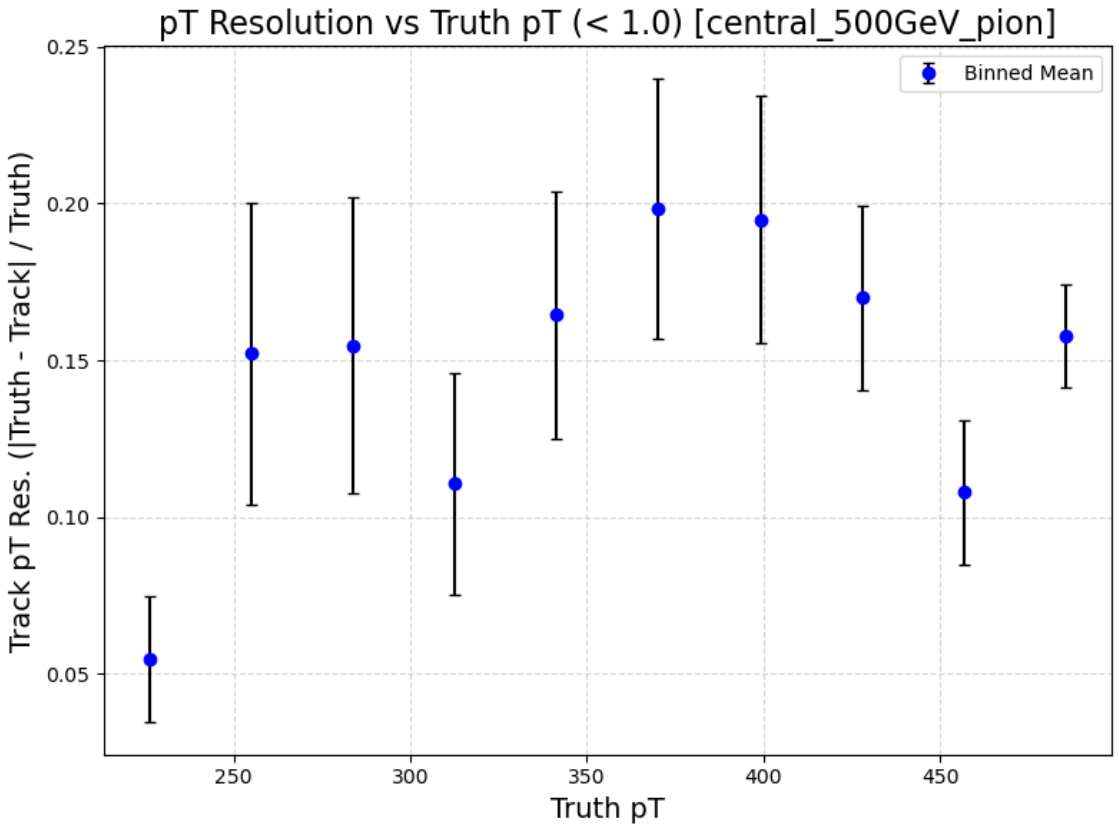
$\frac{\Delta p_T}{\text{Truth } p_T}$ vs. χ^2_{red}



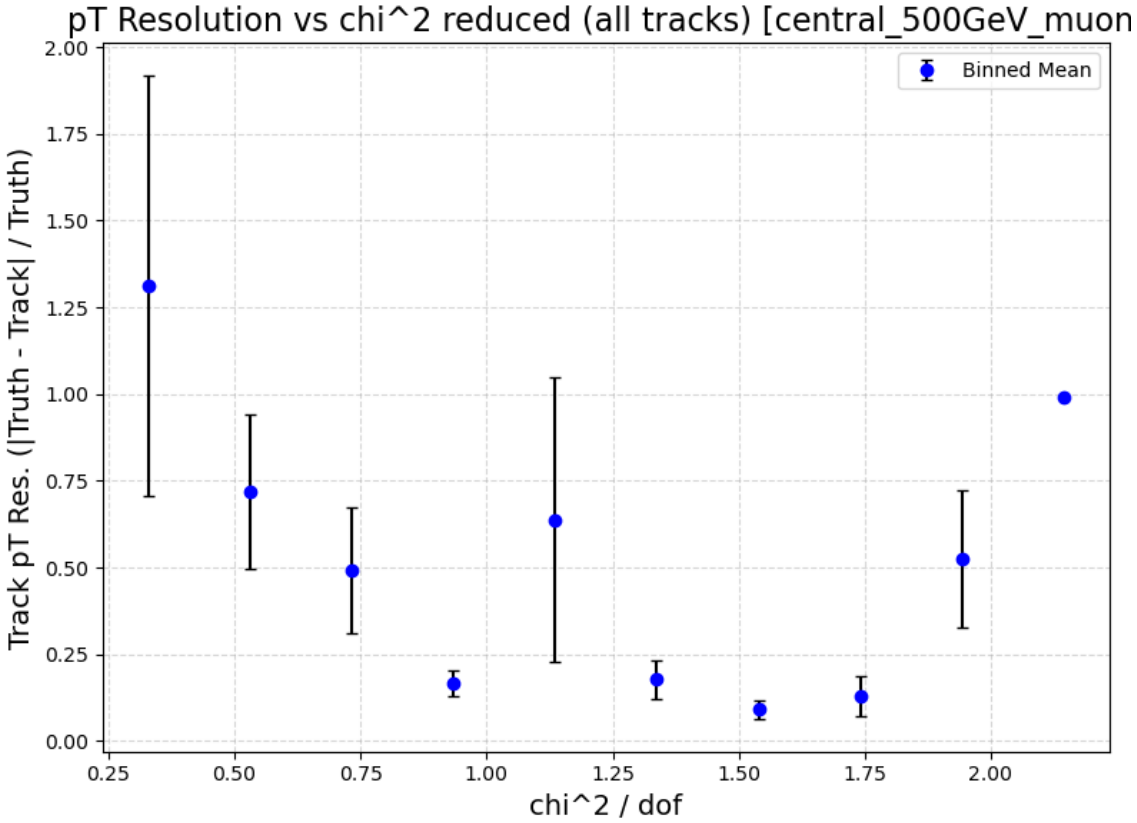


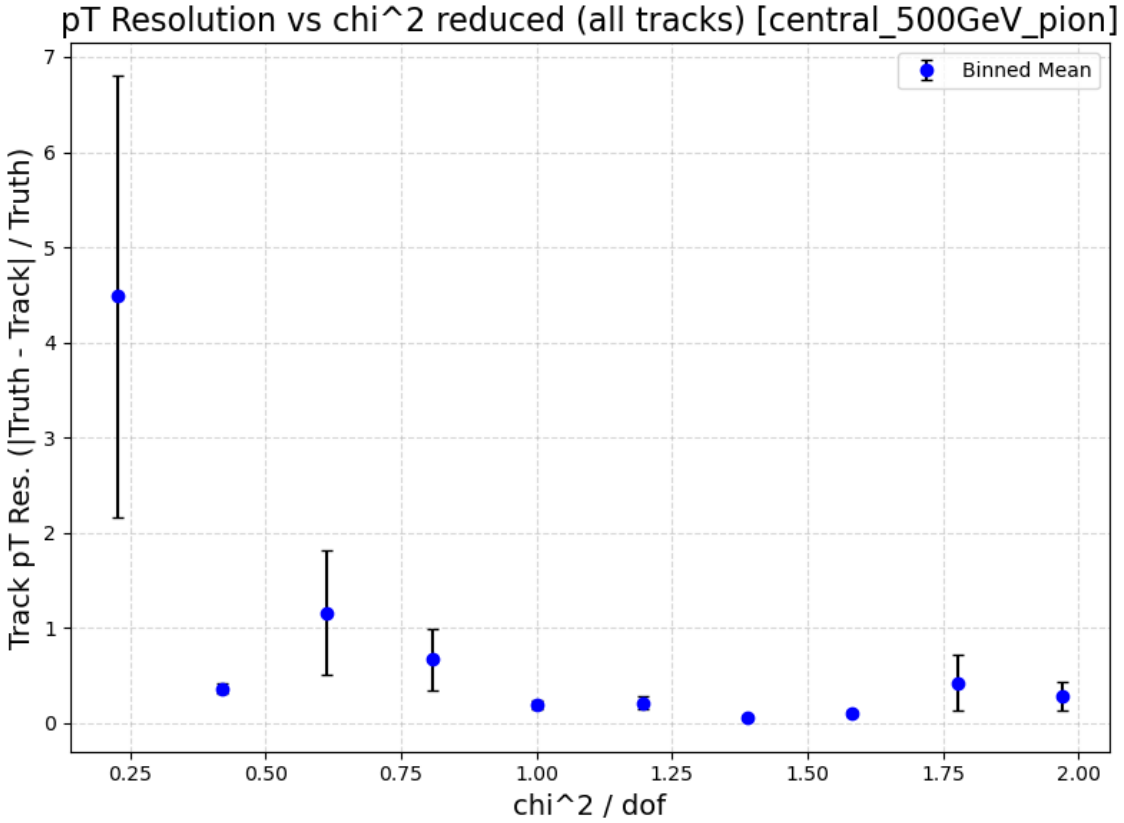
$\frac{\Delta p_T}{\text{Truth } p_T}$ vs. Truth p_T ($\frac{\Delta p_T}{\text{Truth } p_T} < 1.0$)



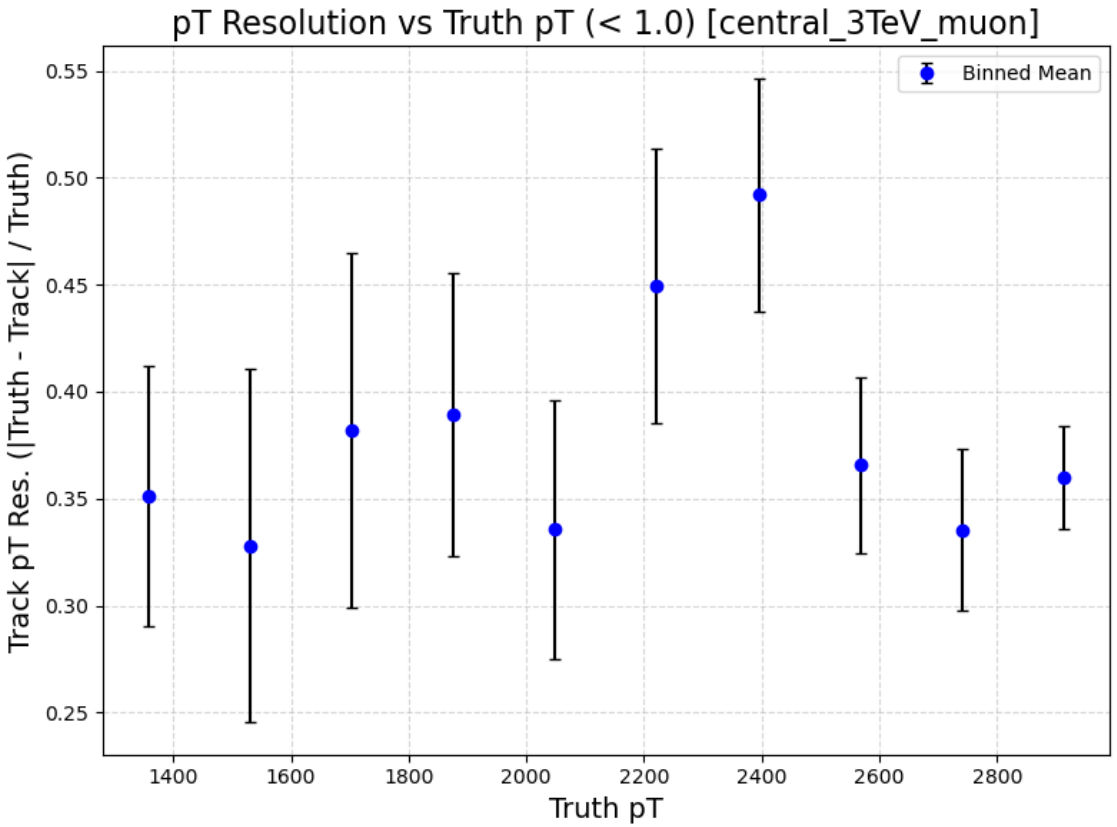


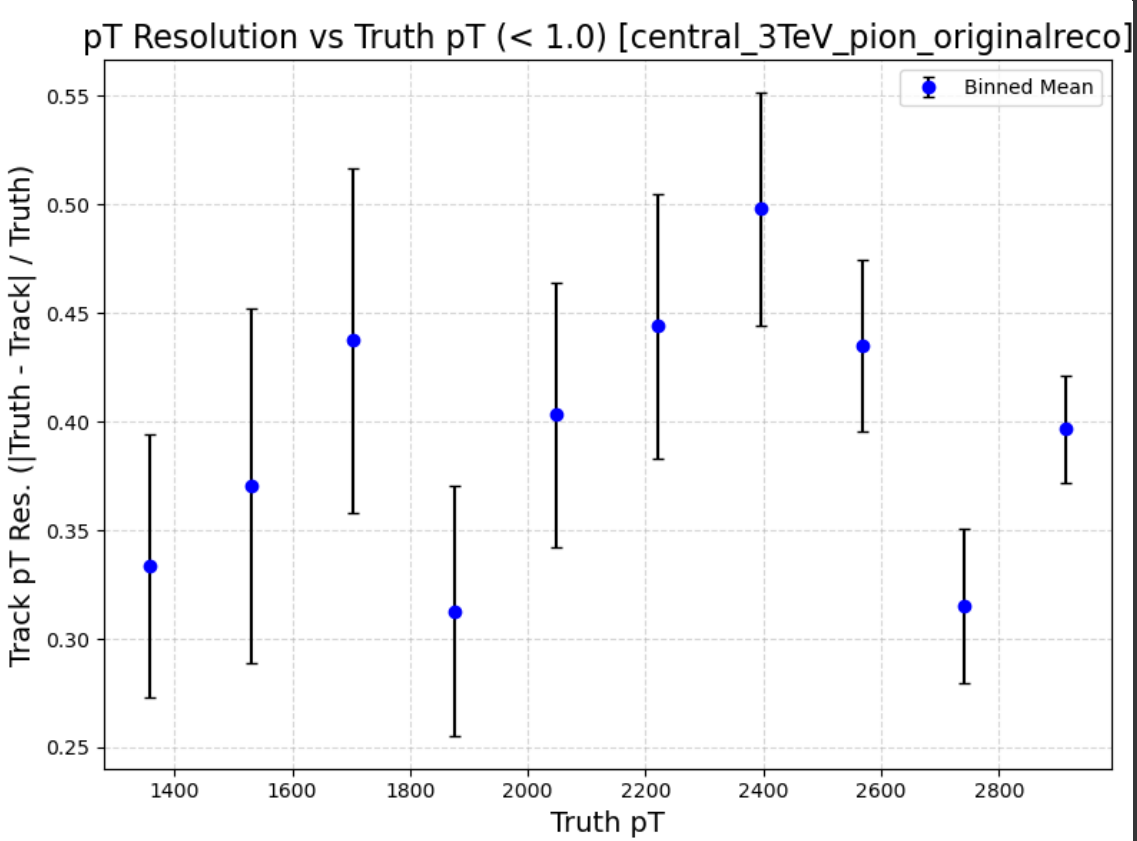
$\frac{\Delta p_T}{\text{Truth } p_T}$ vs. χ^2_{red}



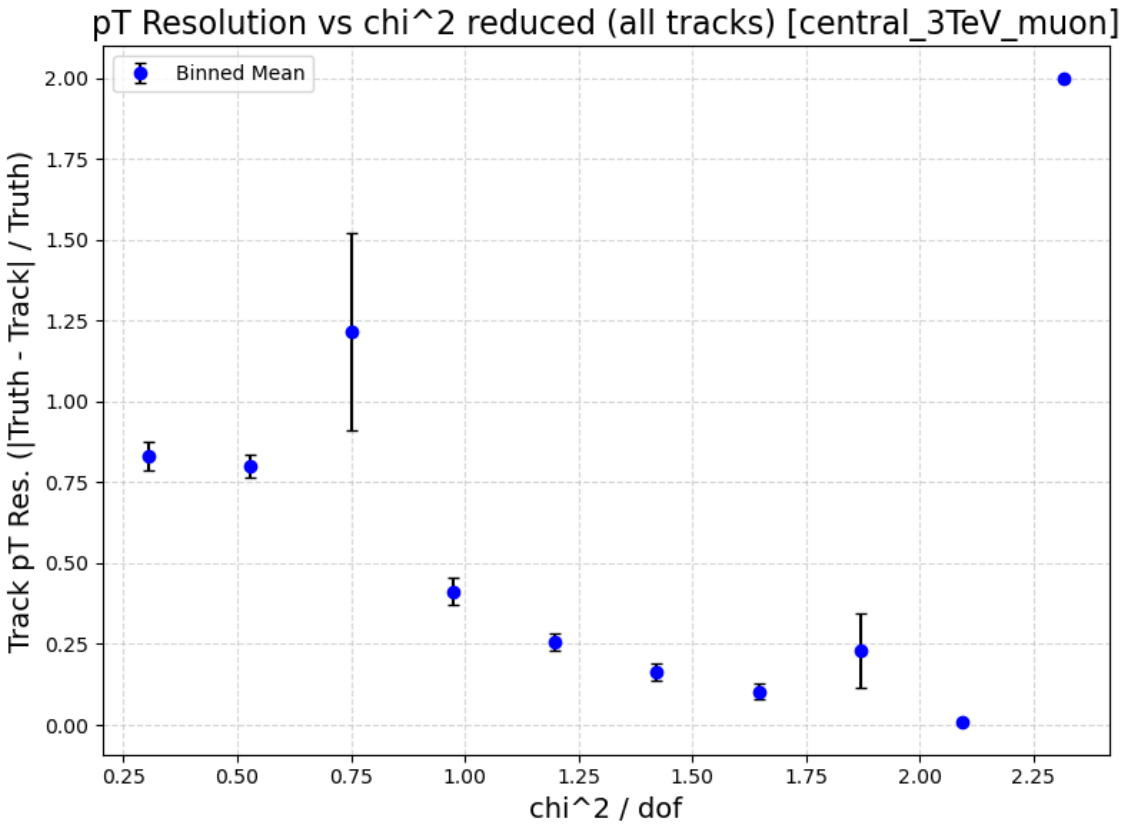


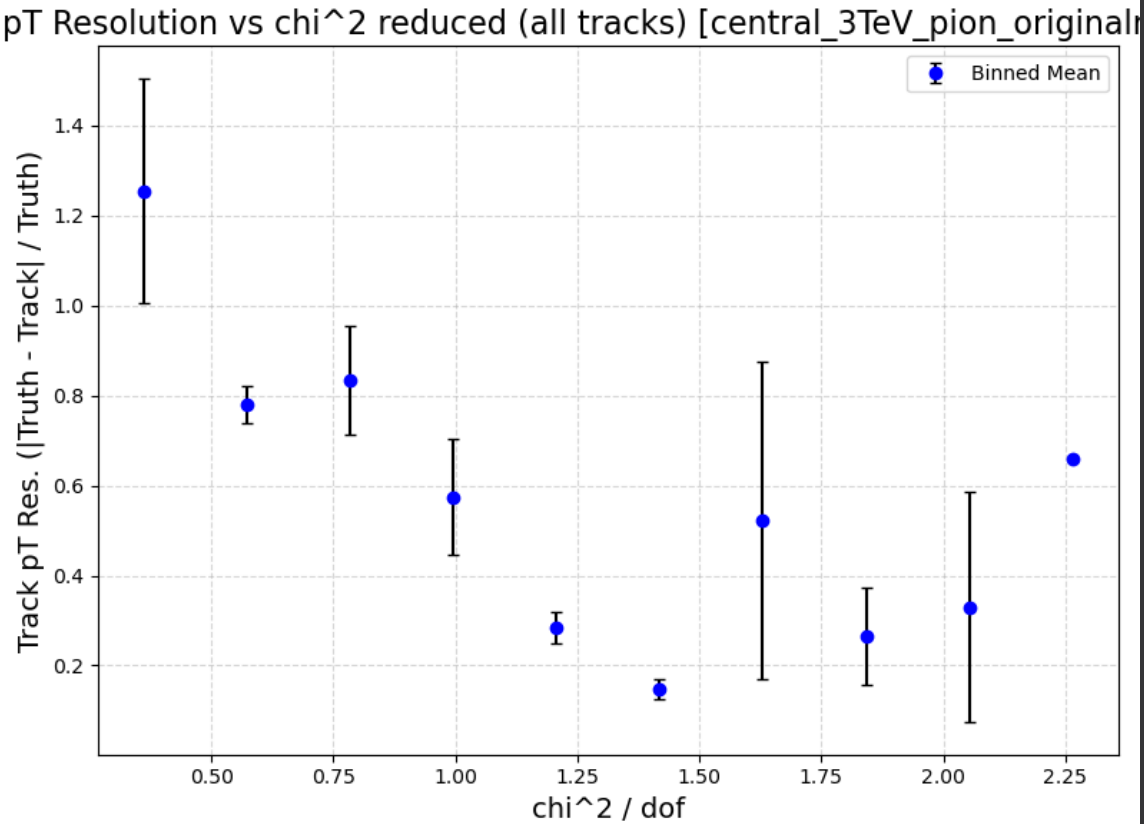
$\frac{\Delta p_T}{\text{Truth } p_T}$ vs. Truth p_T ($\frac{\Delta p_T}{\text{Truth } p_T} < 1.0$)



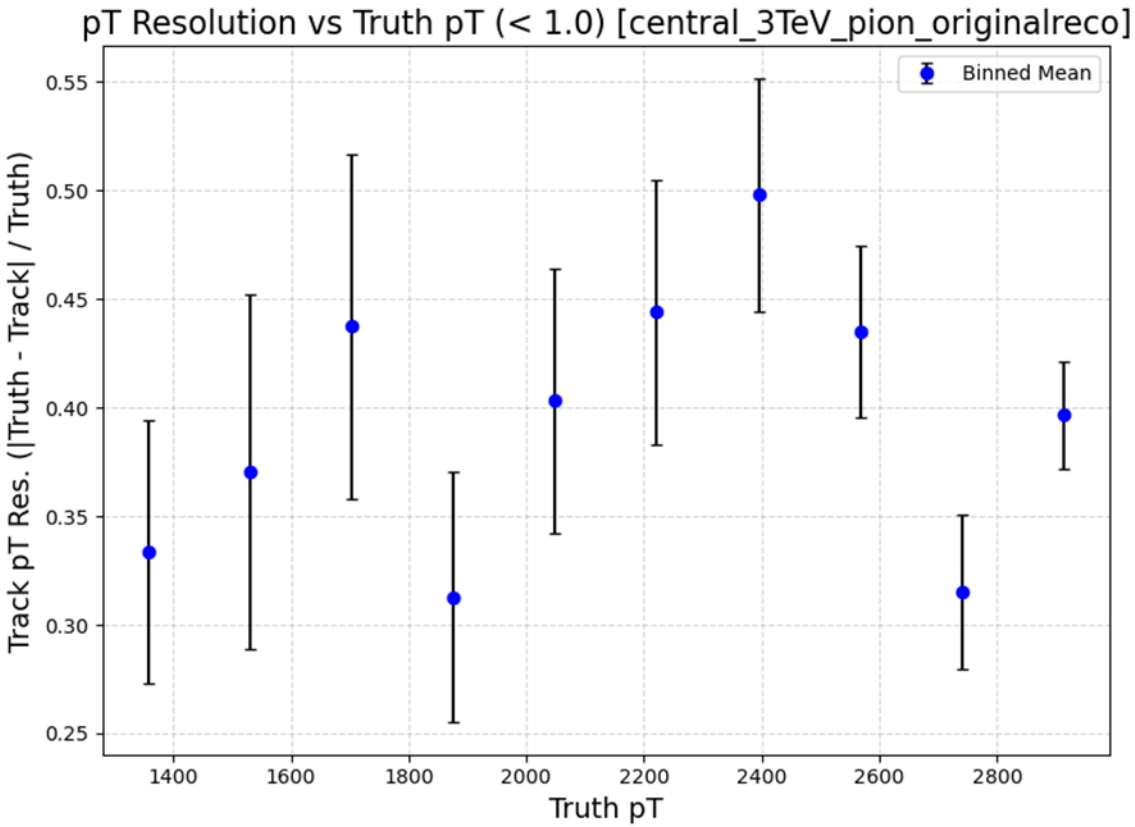


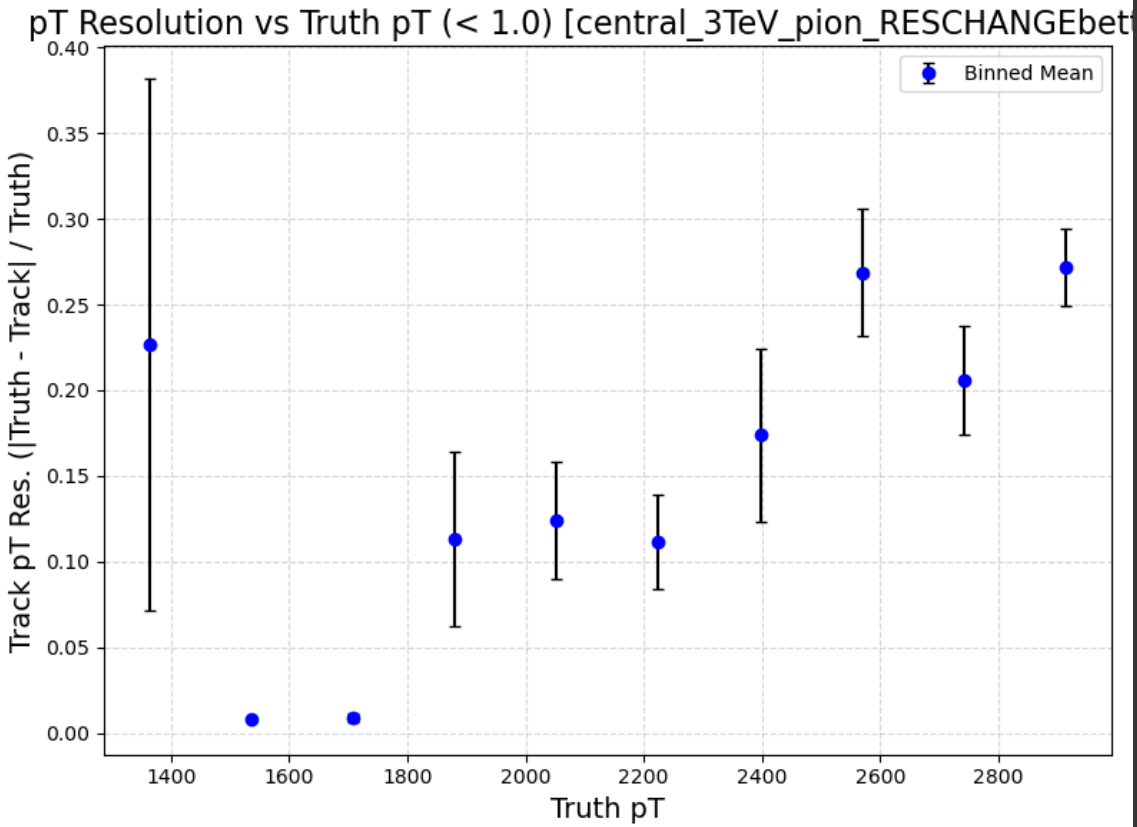
$\frac{\Delta p_T}{\text{Truth } p_T}$ vs. χ^2_{red}



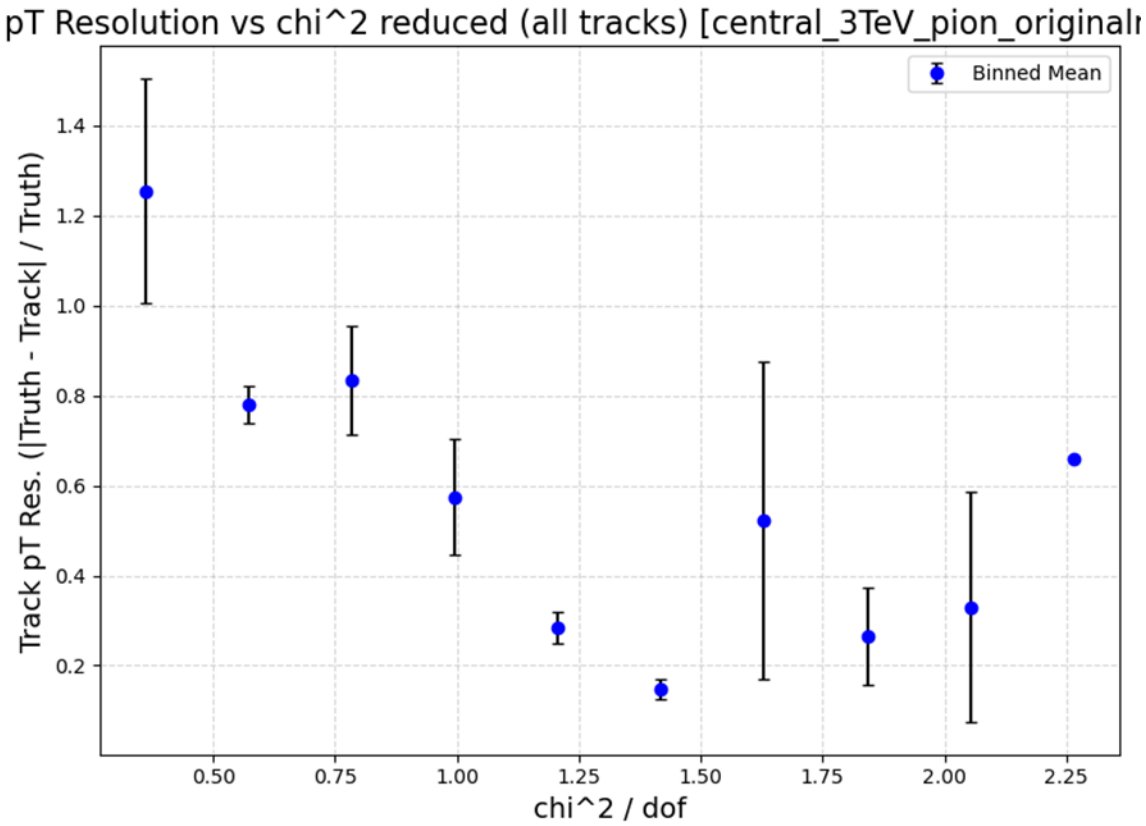


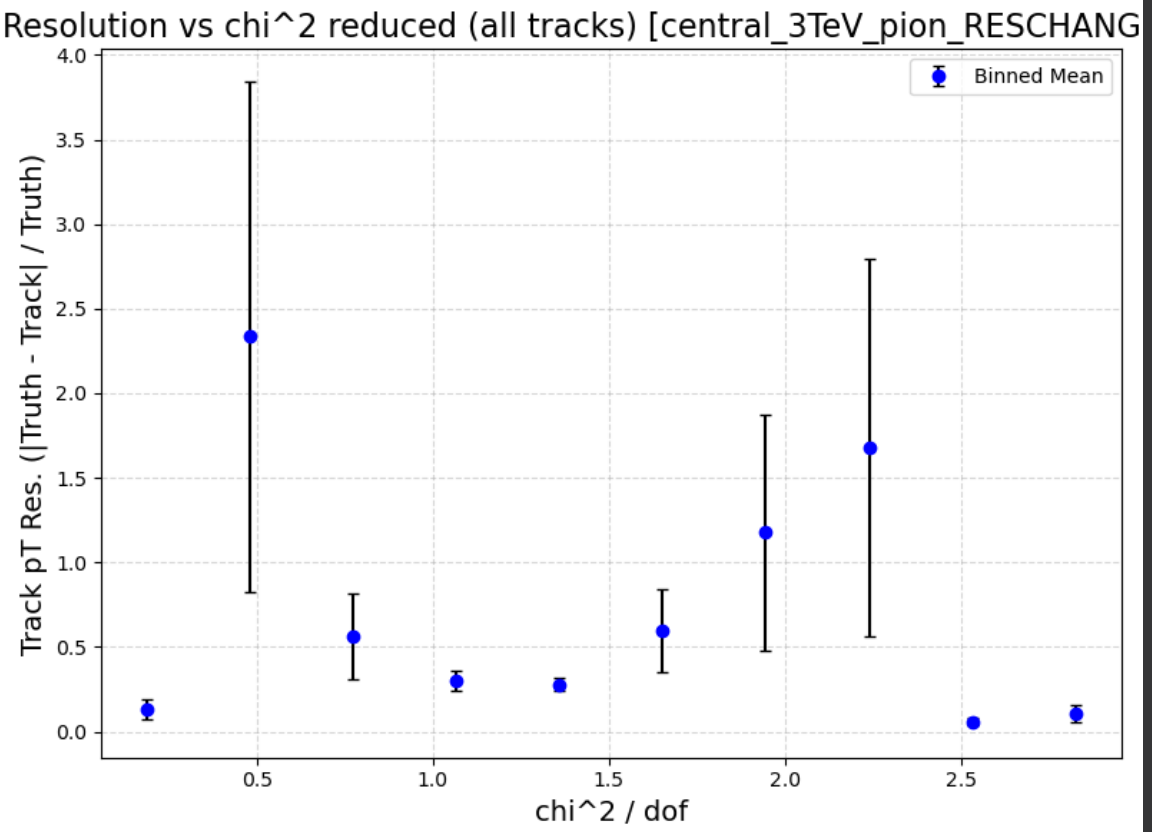
$\frac{\Delta p_T}{\text{Truth } p_T}$ vs. Truth p_T ($\frac{\Delta p_T}{\text{Truth } p_T} < 1.0$)





$\frac{\Delta p_T}{\text{Truth } p_T}$ vs. χ^2_{red}





$\frac{\Delta p_T}{\text{Truth } p_T}$ vs. Track η