Update / Reminder on Track p_T Resolution Studies

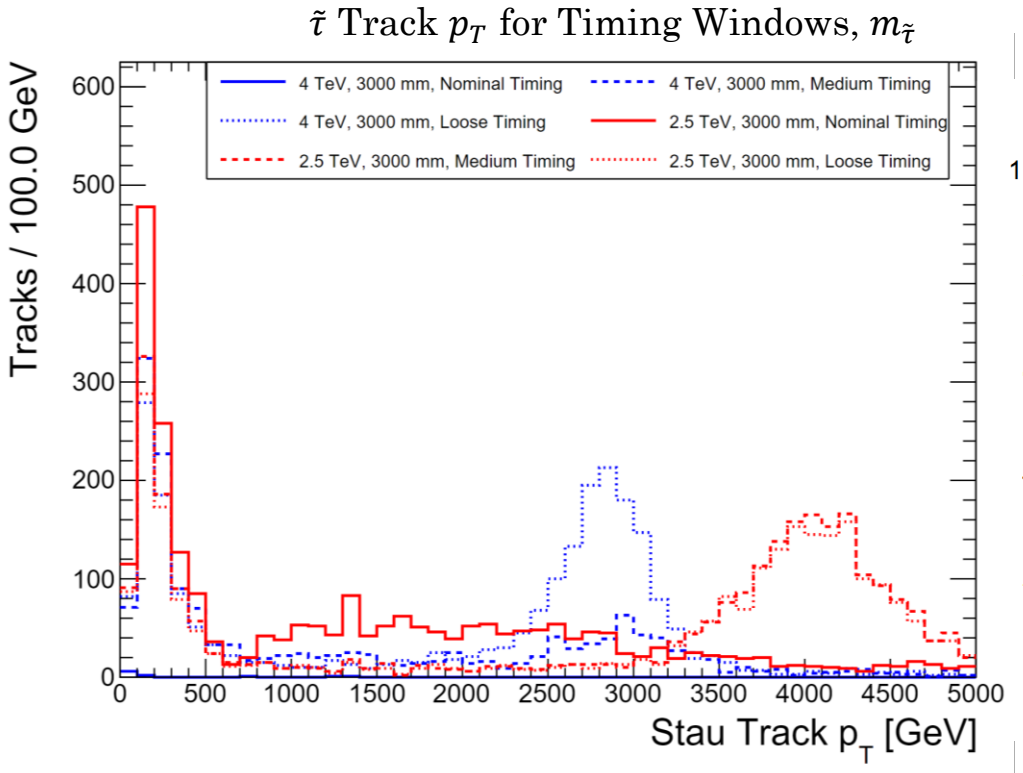
Mark Larson

University of Chicago

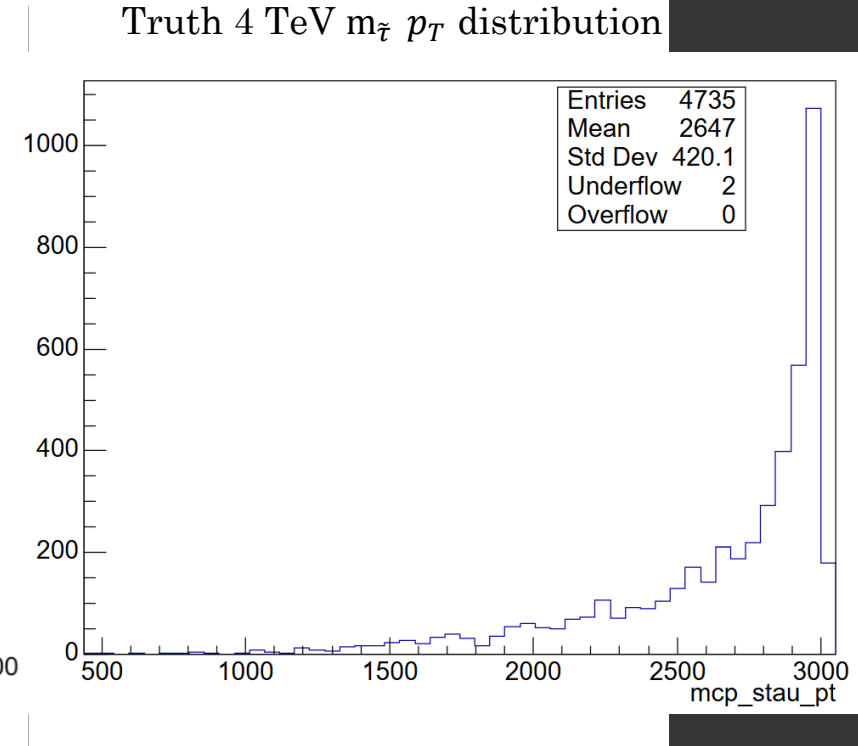
07/01/2025

Background on p_T res. Issues

- First observed issues with p_T resolution with prompt & displaced tracks in our LLP track study
  - Large number of tracks reconstructed with very low p_T, dependent in part on timing windows
  - Not significantly worsened with BIB
- Poor track p_T resolution → poor LLP mass resolution



(also, many tracks reconstructed with $p_T \gg 5$ TeV, up to $\mathcal{O}(10^3$ TeV)



Details of Studies

- To investigate, generated particle gun (μ^-, π^+) particle gun samples with momenta 50, 500, 3000 GeV in $|\eta| < 1.5$, without BIB overlay
- Using 3 TeV detector design (MuColl_v1), software v2.9
- Use tracking configuration available in mucoll-benchmarks master reco_steer.py + track truth matching (few differences w/ displaced config.)
  - Only track cleaning requires ≥ 3.5 hits, $p_T \geq 0.5$ GeV
- Findings similar to Gregory's on track fit uncertainties for pion tracks
- More detailed talk on our findings from December 2024, will show some updated (made with ~5x more events) and new plots today

Reminder: Overall Results

Note: around 25x more events for pions than muons

Momentum	Particle	Avg. $\Delta p_T/p_T$	Efficiency
50 GeV	μ^-	5.5%	94.6%
	π^+	3.9%	95.5%
500 GeV	μ^-	21.1%	87.3%
	π^+	17.1%	91.5%
3000 GeV	μ^-	41.4%	83.8%
	π^+	36.8%	89.7%

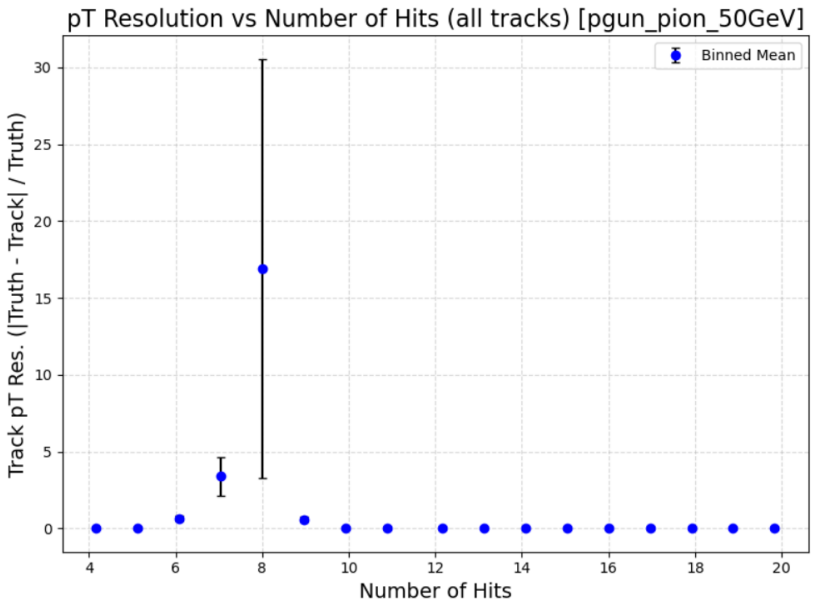
- Found correlation between poor p_T res., low N_{Hits}, momenta of tracking particle
- Overall minimal differences between muons and pions
- Found that improving spatial resolution of VXD, IT, OT by 2x led to improved p_T resolution, worsened tracking efficiency

Previously Shown Plots, Remade with More Events

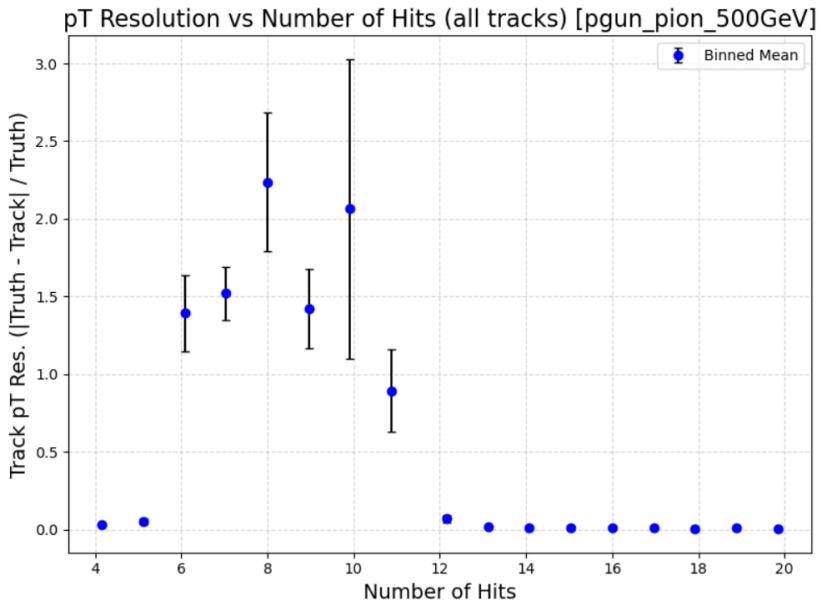
(note: also have scatter plot versions of some plots included in backup)

$\frac{|\Delta p_T|}{\text{Truth } p_T}$ vs. N_{Hits}

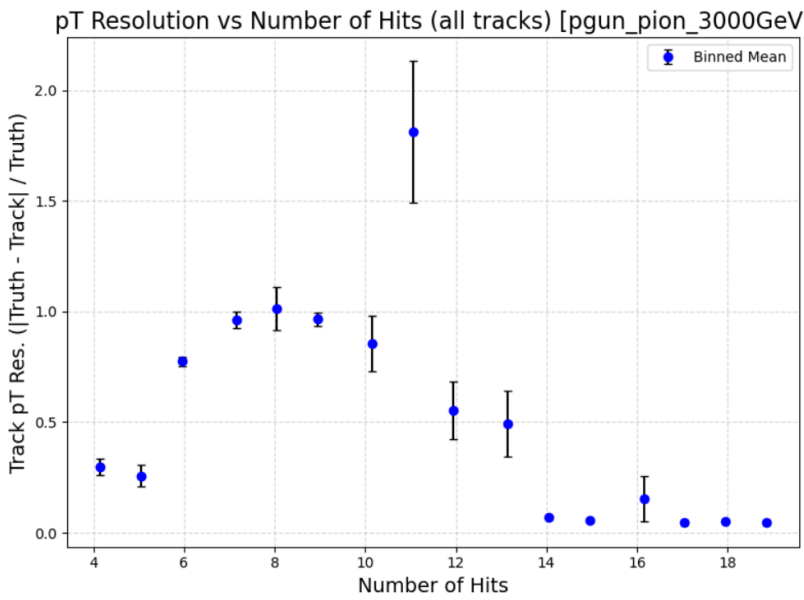
50 GeV



500 GeV



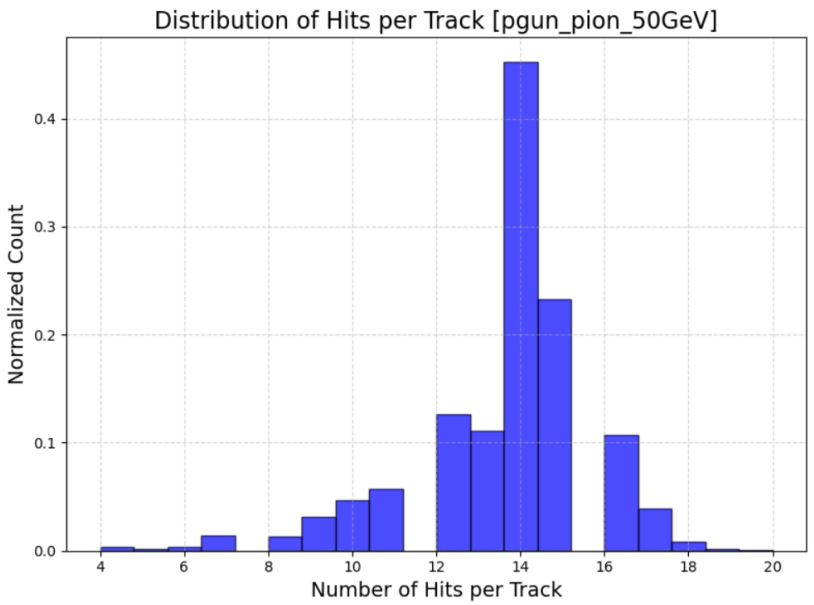
3000 GeV



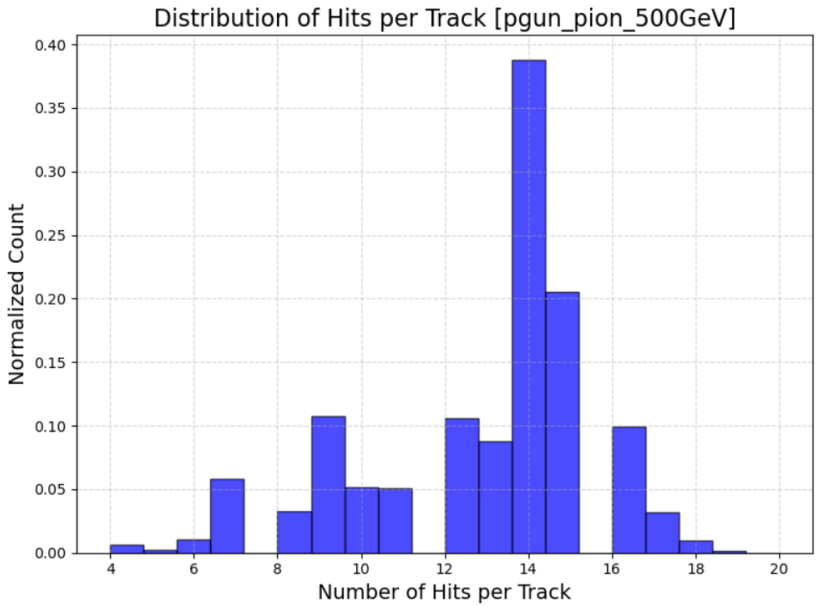
Increasing π^+ momentum

N_{Hits} Distribution

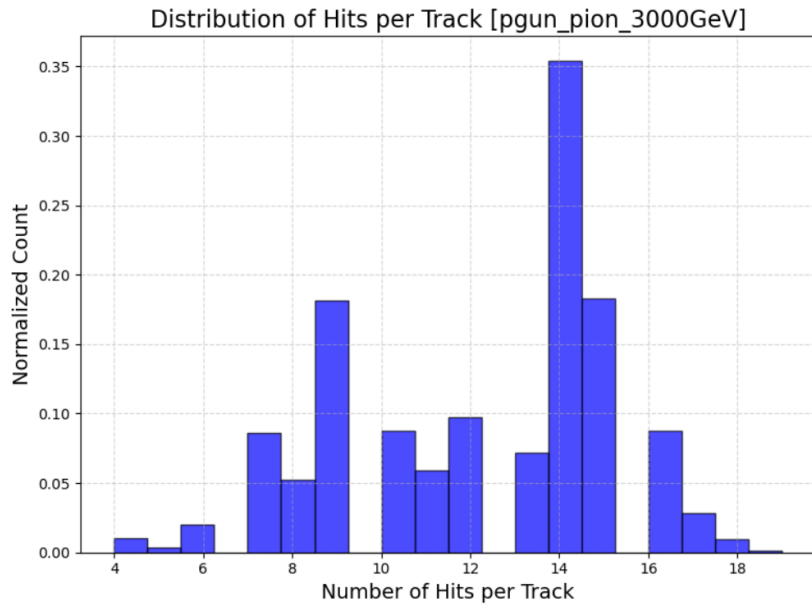
50 GeV



500 GeV



3000 GeV

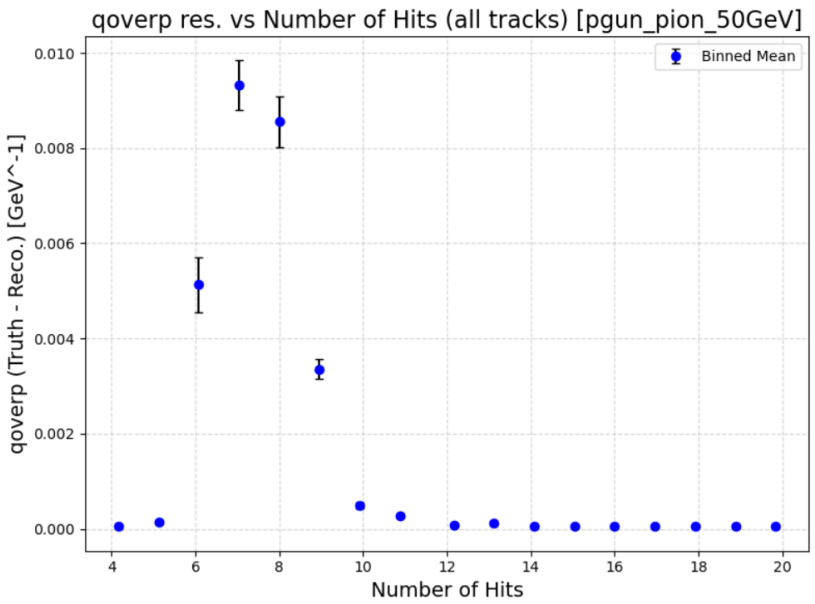


More and more tracks with low N_{Hits} as momentum increases

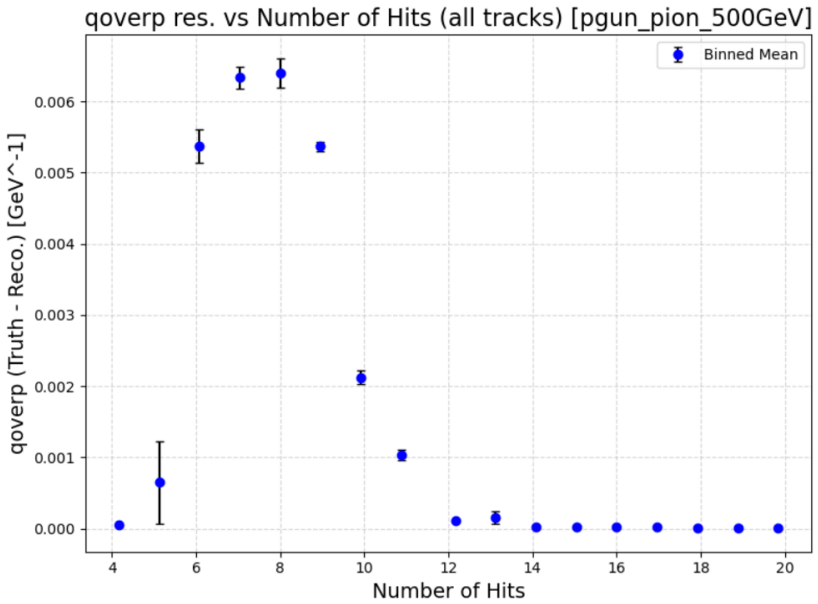
$|\Delta\left(\frac{q}{p}\right)|$ vs. N_{hits}

($\frac{q}{p}$ is the actual parameter being fitted by ACTS)

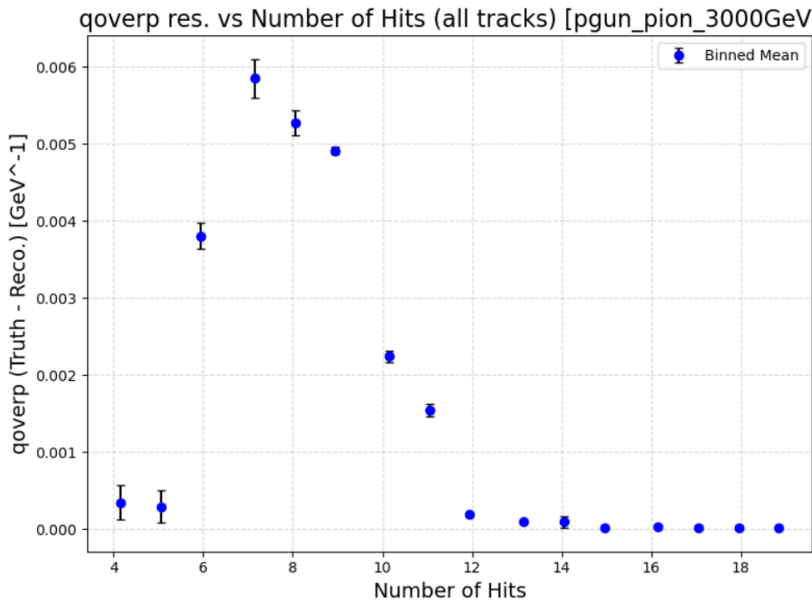
50 GeV



500 GeV



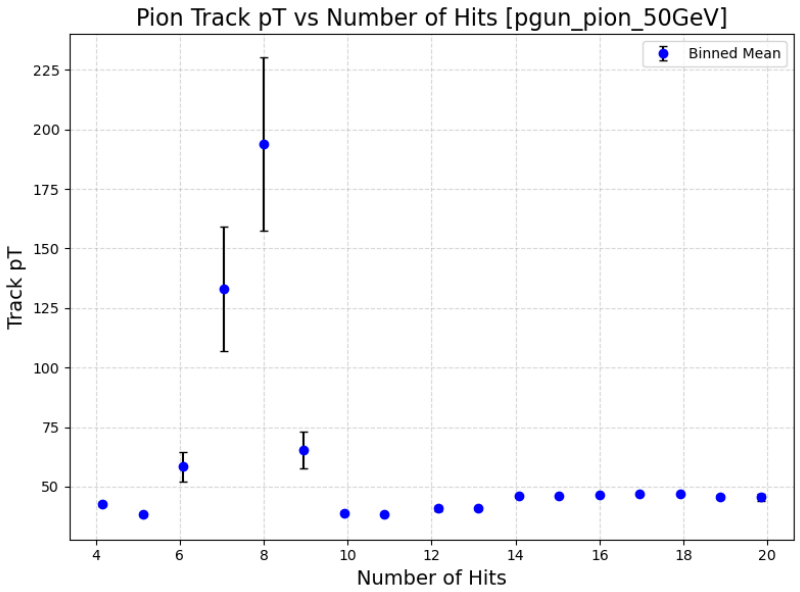
3000 GeV



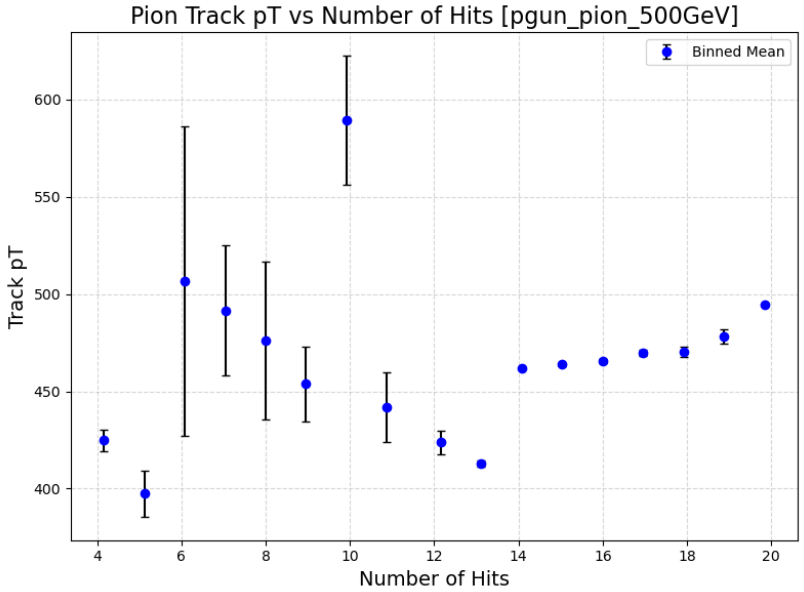
As momentum increases, see poor curvature resolution for tracks with fewer hits

Track p_T vs. N_{hits}

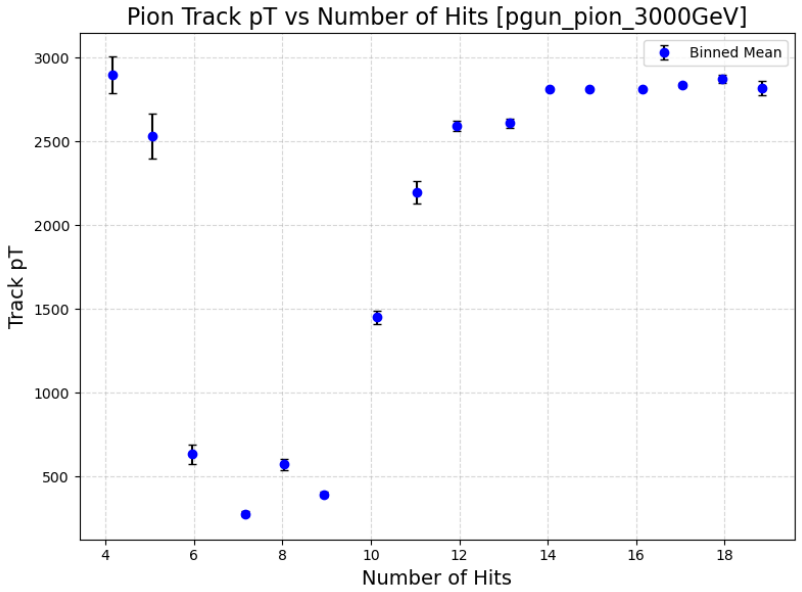
50 GeV



500 GeV



3000 GeV

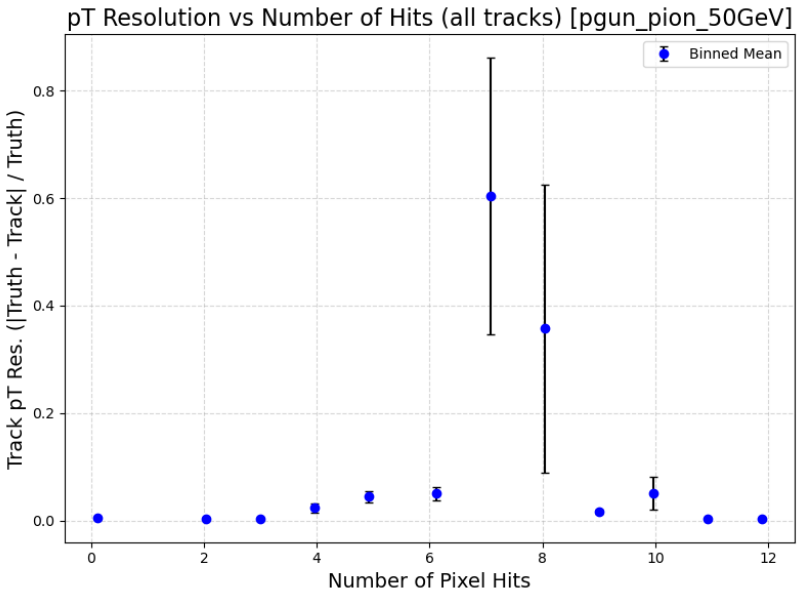


Worst effects on resolution comes from overestimating p_T at low momenta, a mix at moderate momenta, and underestimating p_T at high momenta

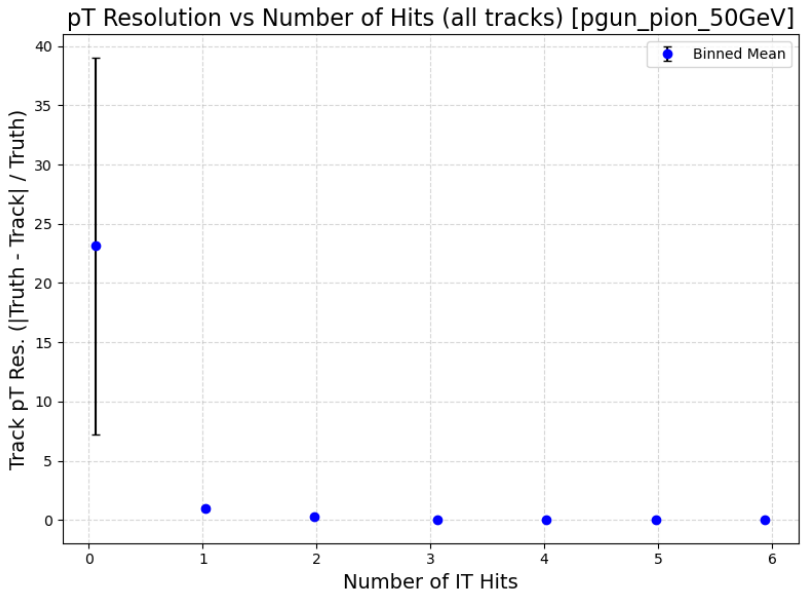
New Plots / Updates

$\frac{|\Delta p_T|}{\text{Truth } p_T}$ vs. N_{Hits} (by sub-detector) 50 GeV

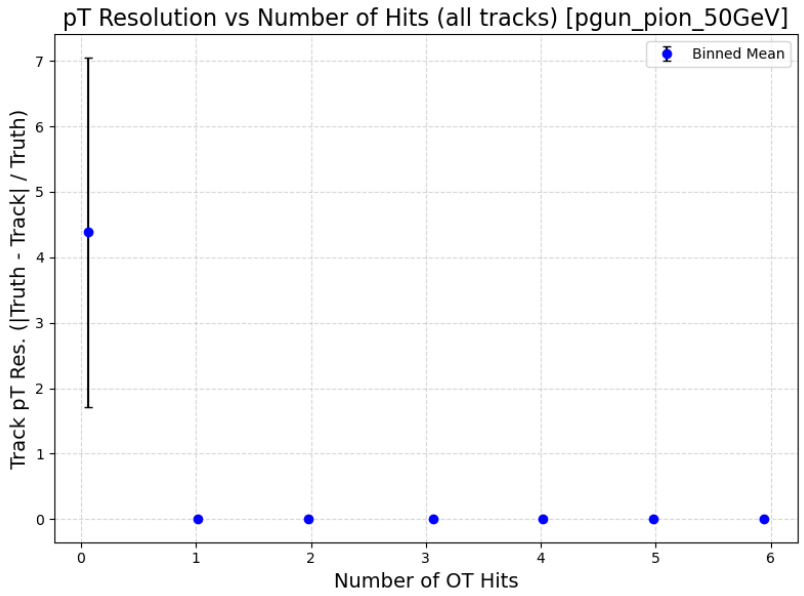
VXD



IT



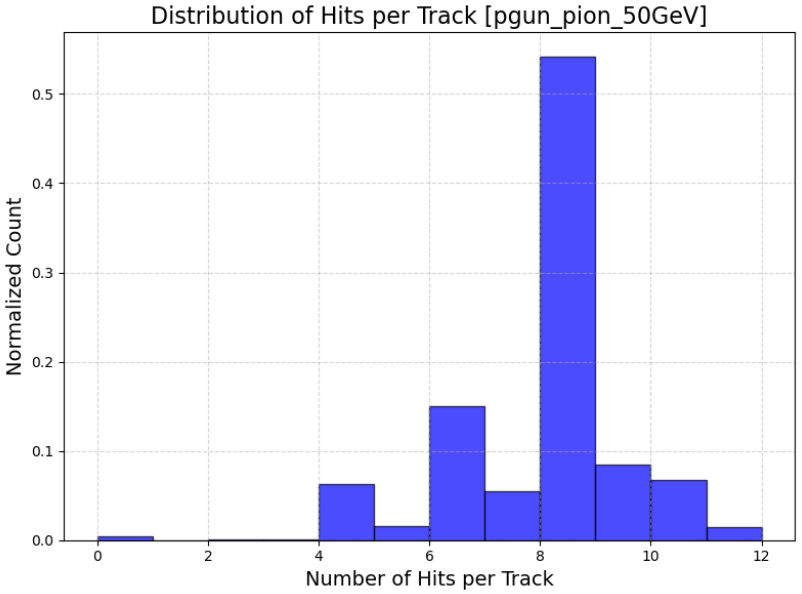
OT



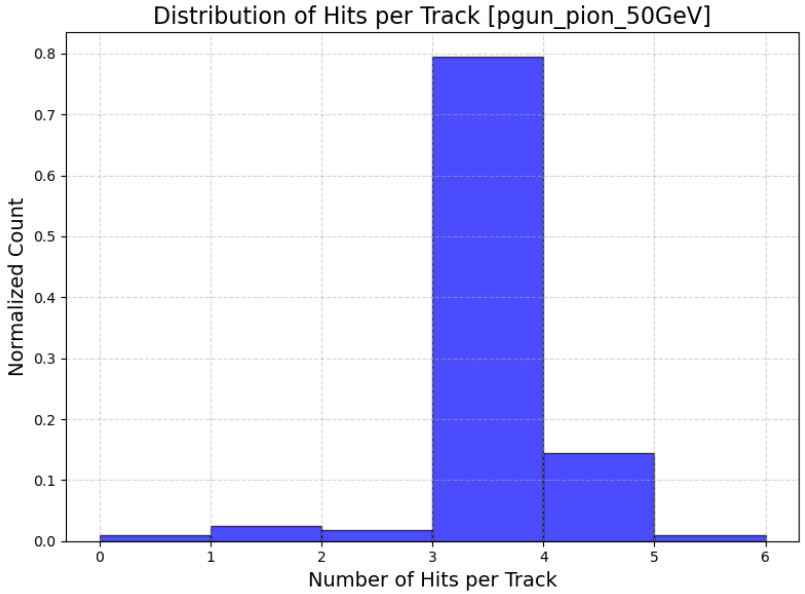
Only see poor resolution when track is without IT, OT hits

N_{Hits} (by sub-detector) 50 GeV

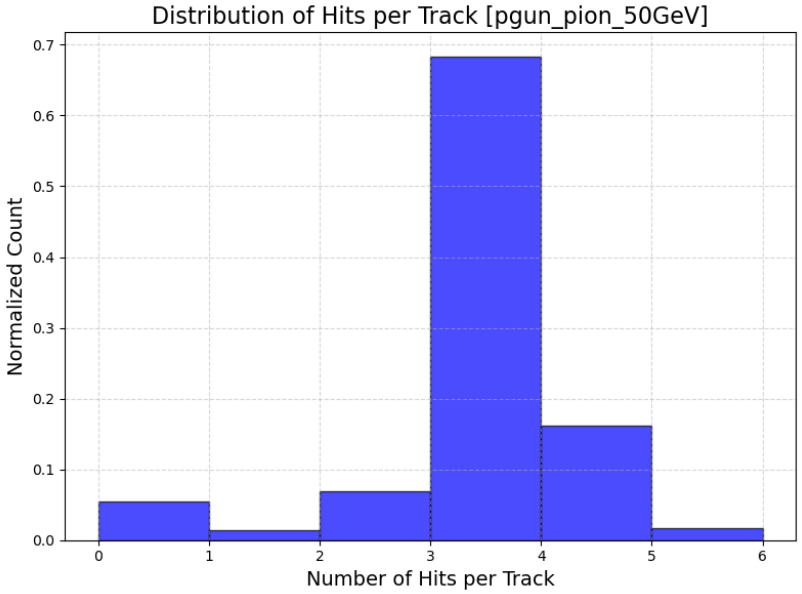
VXD



IT

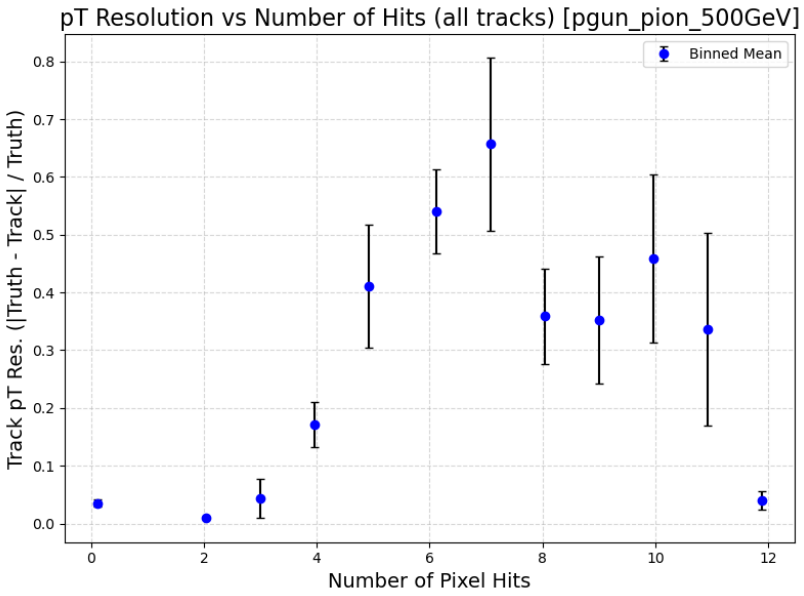


OT

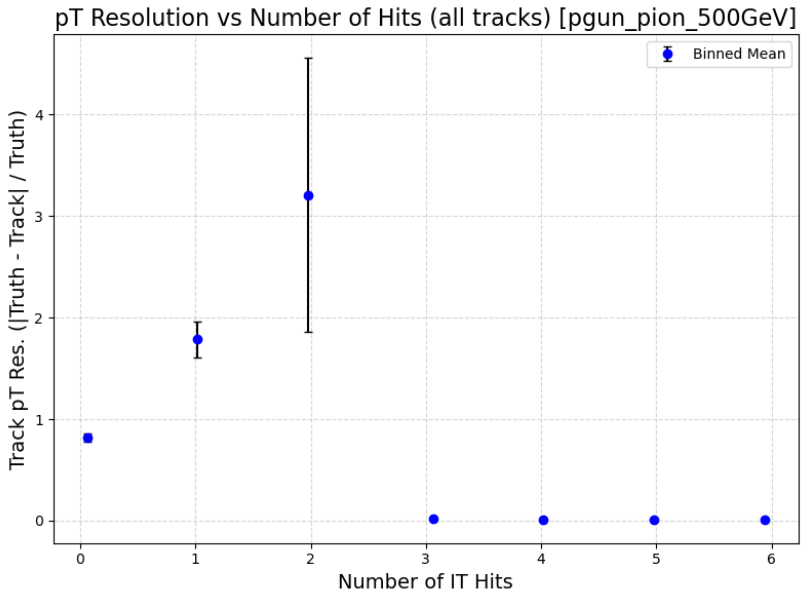


$\frac{|\Delta p_T|}{\text{Truth } p_T}$ vs. N_{Hits} (by sub-detector) 500 GeV

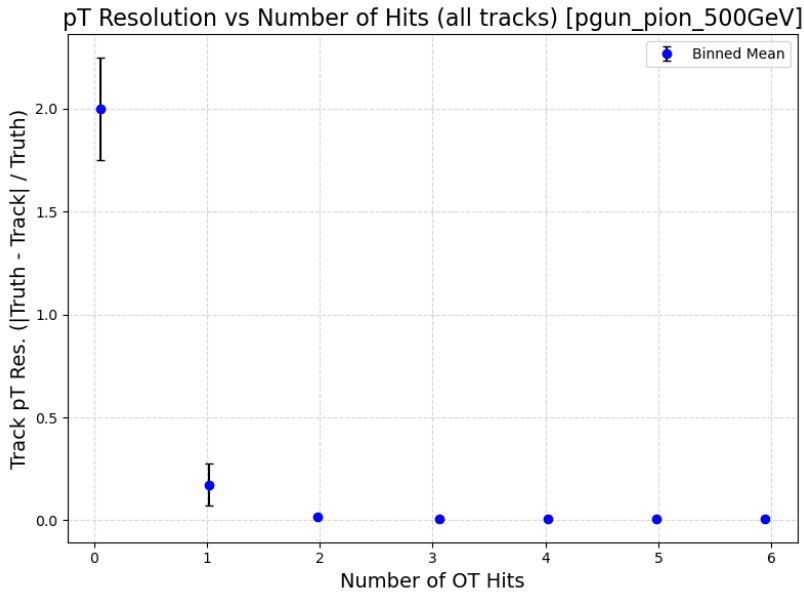
VXD



IT



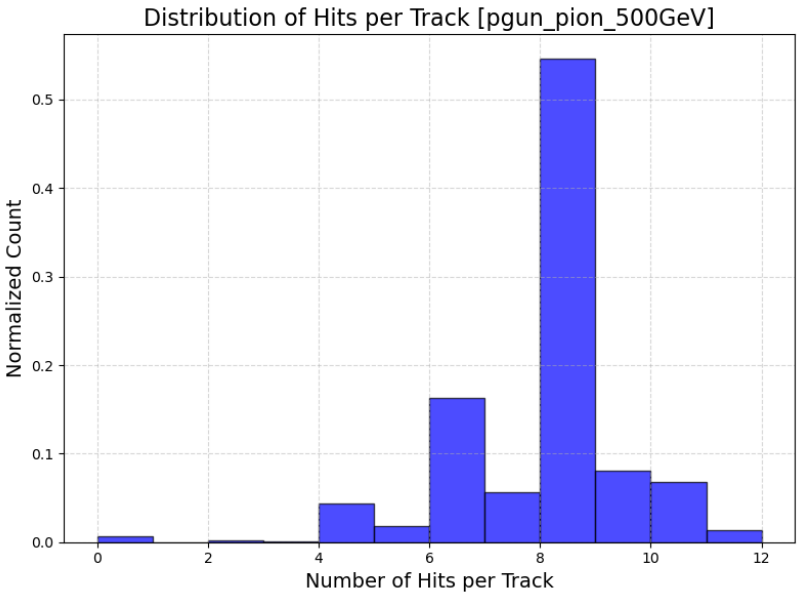
OT



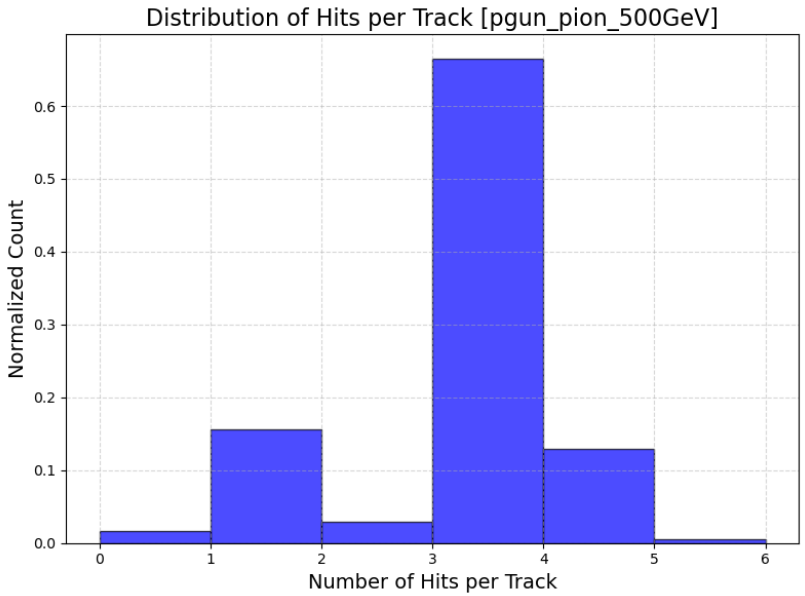
Only see poor resolution when track is without IT, OT hits

N_{Hits} (by sub-detector) 500 GeV

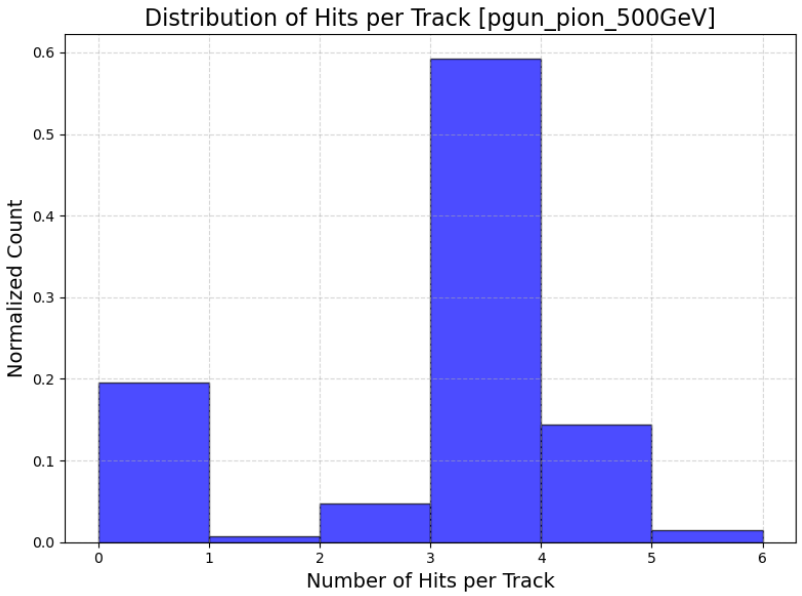
VXD



IT

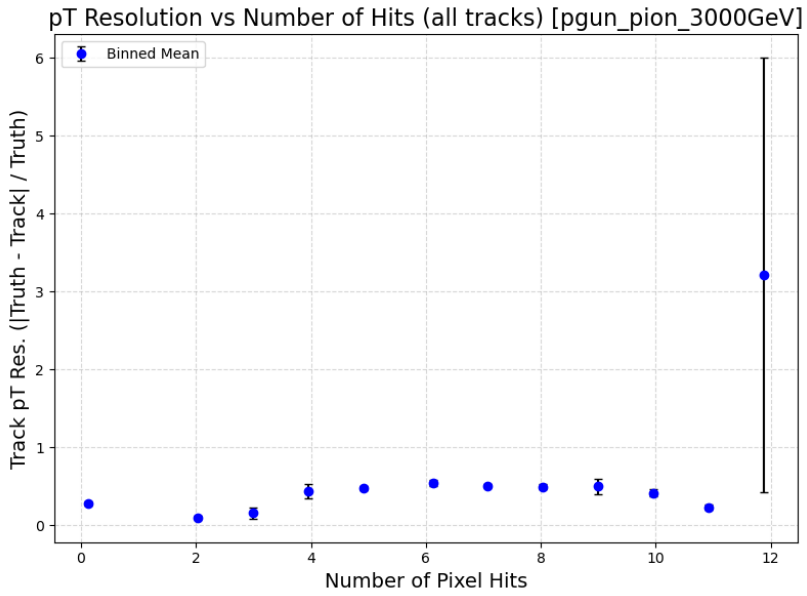


OT

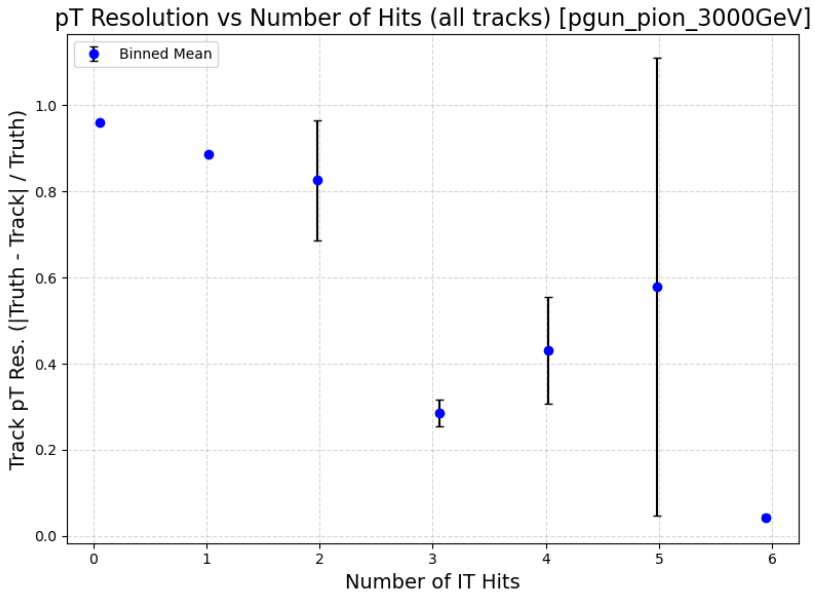


$\frac{|\Delta p_T|}{\text{Truth } p_T}$ vs. N_{Hits} (by sub-detector) 3000 GeV

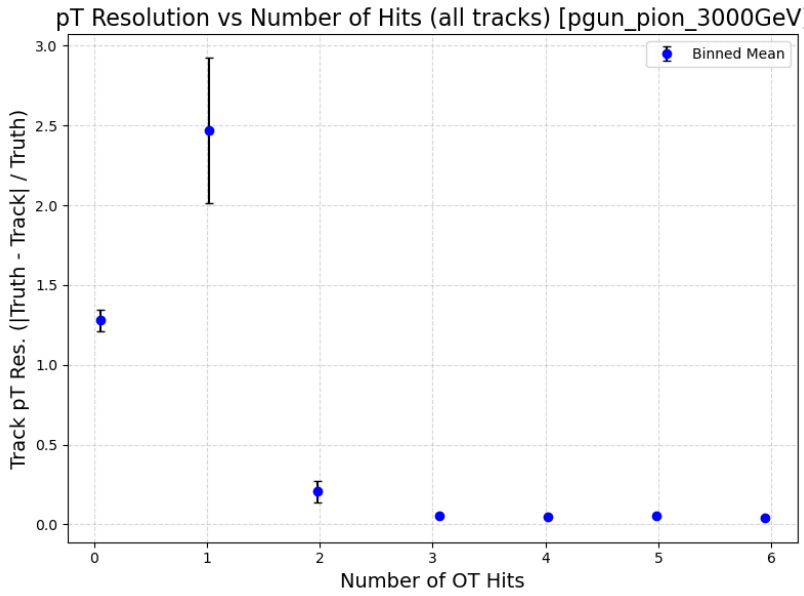
VXD



IT

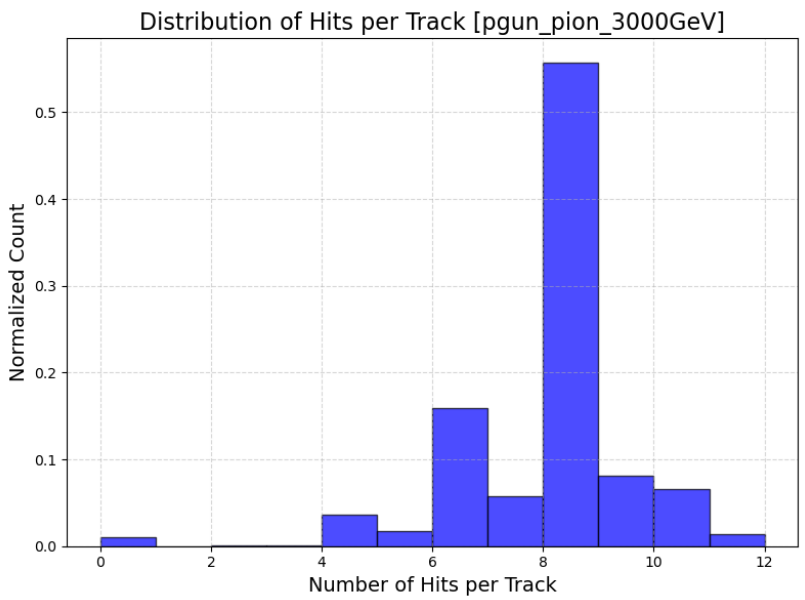


OT

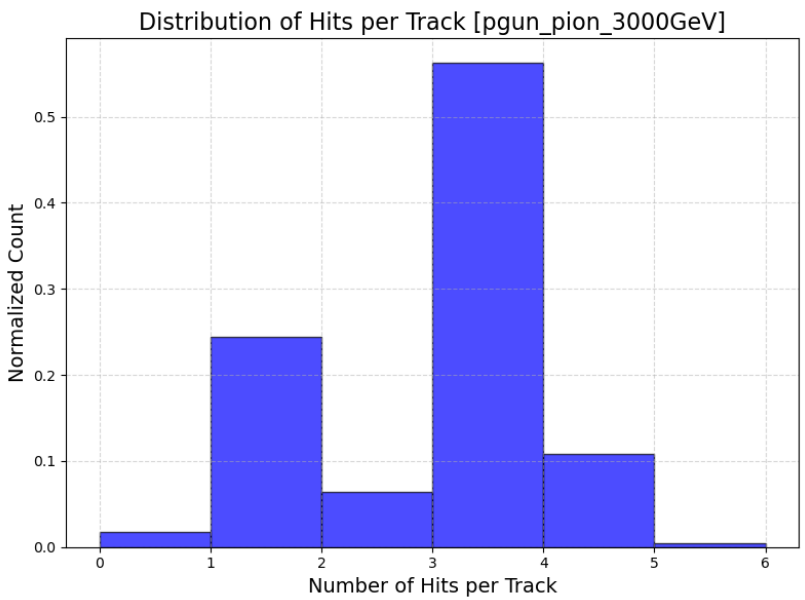


N_{Hits} (by sub-detector) 3000 GeV

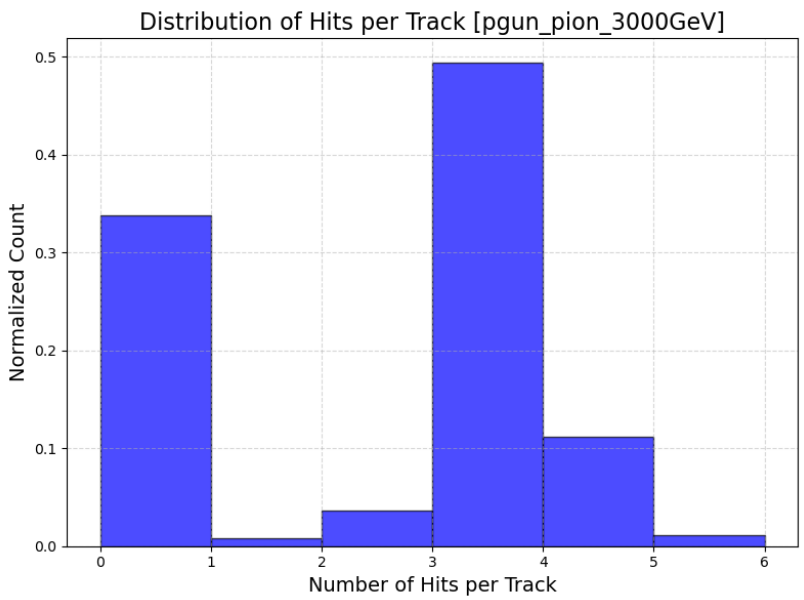
VXD



IT



OT



As momentum increases, have more and more trouble associating hits in IT, and especially OT

Debugging of Potential ACTS Issues

- Noted in MuonColliderSoft ACTSTracking Github issue – anyone know of any updates to this?
- Checked out ACTS, added print statements to acts source code & MuCol ACTSTracking, rebuilt mucoll software with custom ACTS
- Found that for 3 TeV $\tilde{\tau}$ tracks, over/underestimation of p_T occurred already when estimating track params from seed (acts source)
  - Recently (May 6th) merged acts PR changes $\sigma\left(\frac{q}{p}\right)$ estimation, but meant to fix problems at high η – worth reaching out to ACTS experts?
- Verified that expected spatial resolution is being used, at least at seeding stage, by ACTS for VXD, IT, OT
- Tested enabling 'IsStrip = True' for OT in digi steering file, this worsened p_T resolution

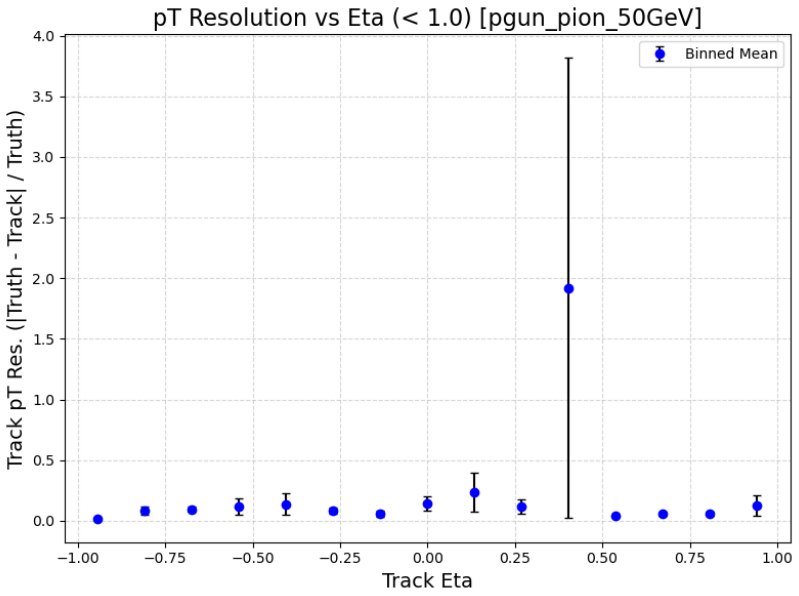
Conclusions

- Observe correlation between poor track p_T res., low N_{Hits}, high momentum
  - Seems very similar to what Gregory has observed!
- Seems in part due to hits in IT, OT considered as outliers, due to incorrect spatial uncertainties in IT, OT used by ACTS
  - Potentially also effects of bremm not included in χ^2 calculation of fit (per Simone)
- Found one point in ACTS where over/underestimation of p_T occurring (estimating track params from seed)

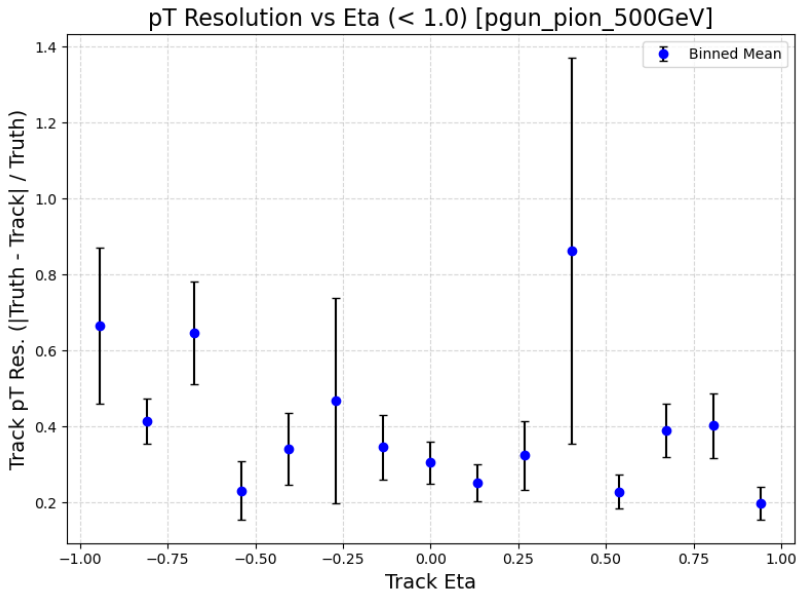
Backup

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

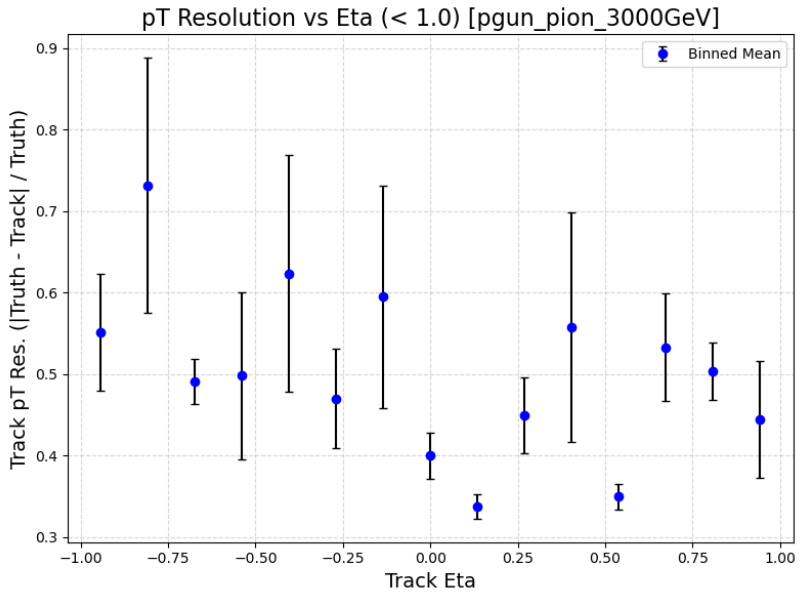
50 GeV



500 GeV



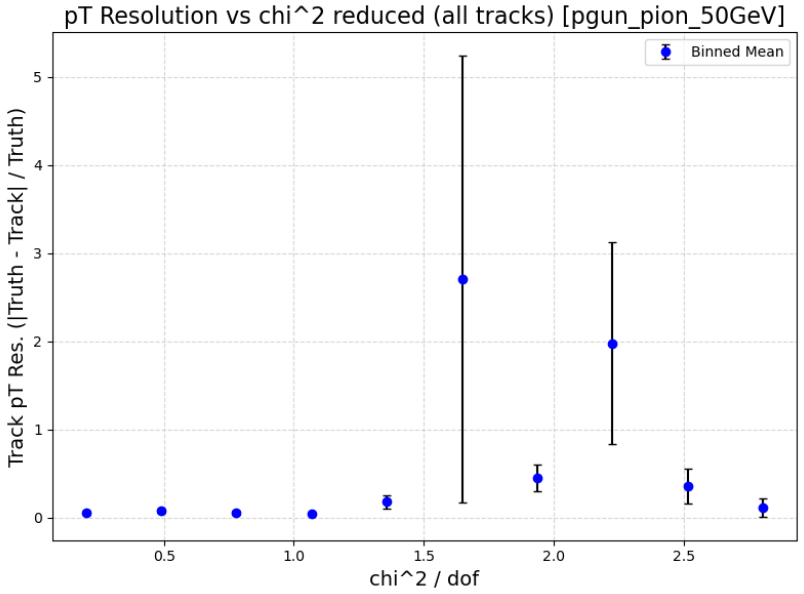
3000 GeV



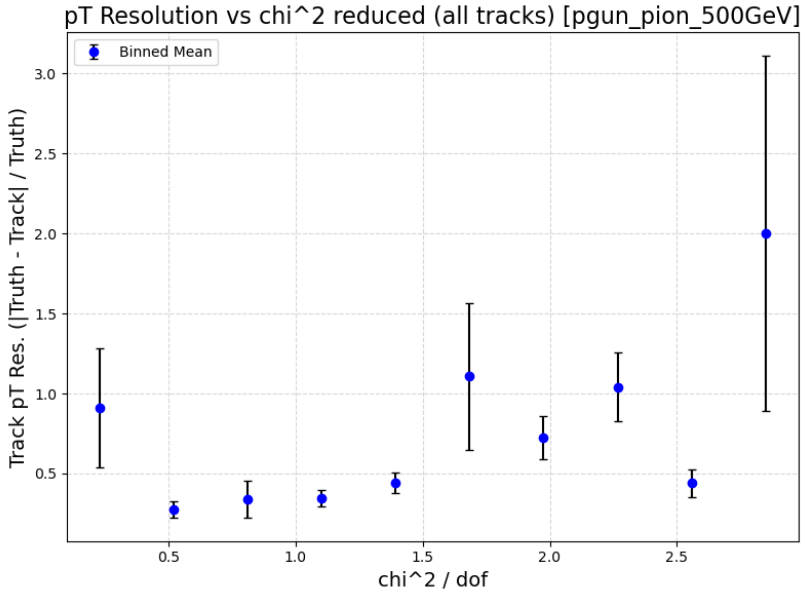
For $|\eta| < 1.0$, minimal correlation between pt res., η

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

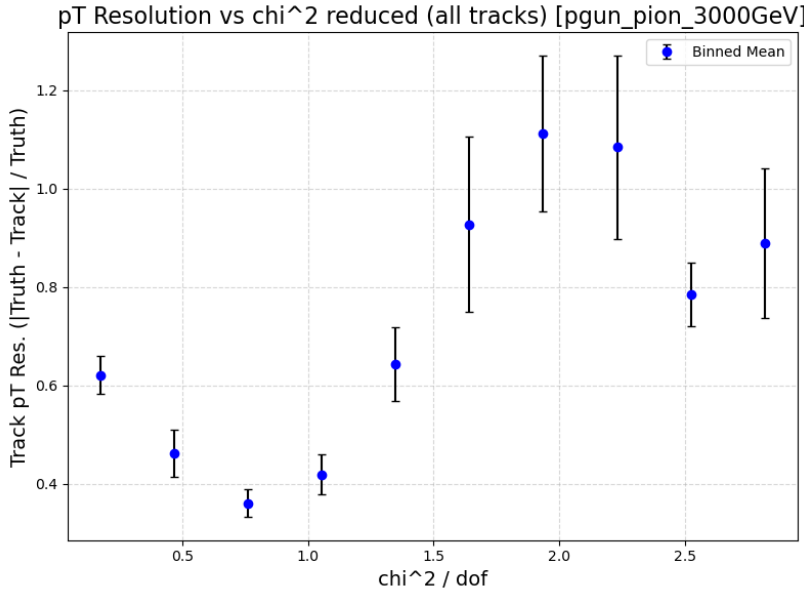
50 GeV



500 GeV



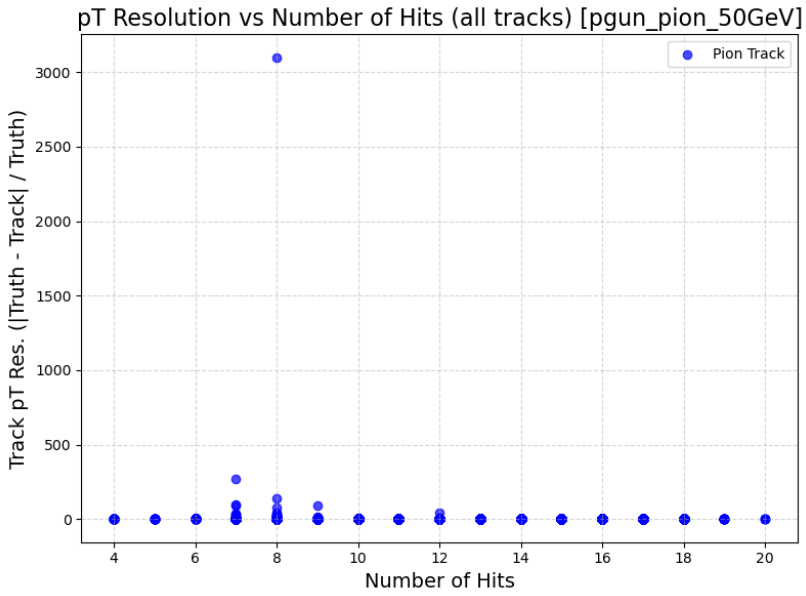
3000 GeV



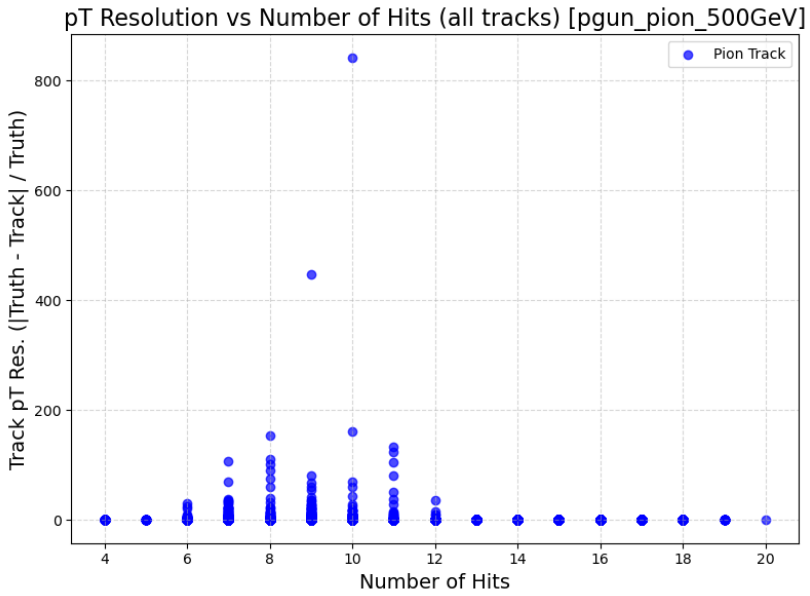
Some correlation between pt res, χ^2_{red}

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

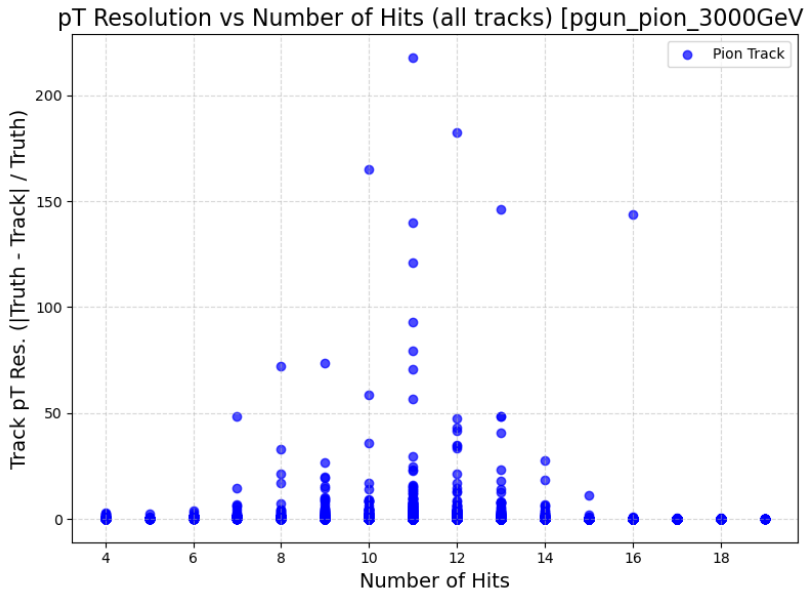
50 GeV



500 GeV



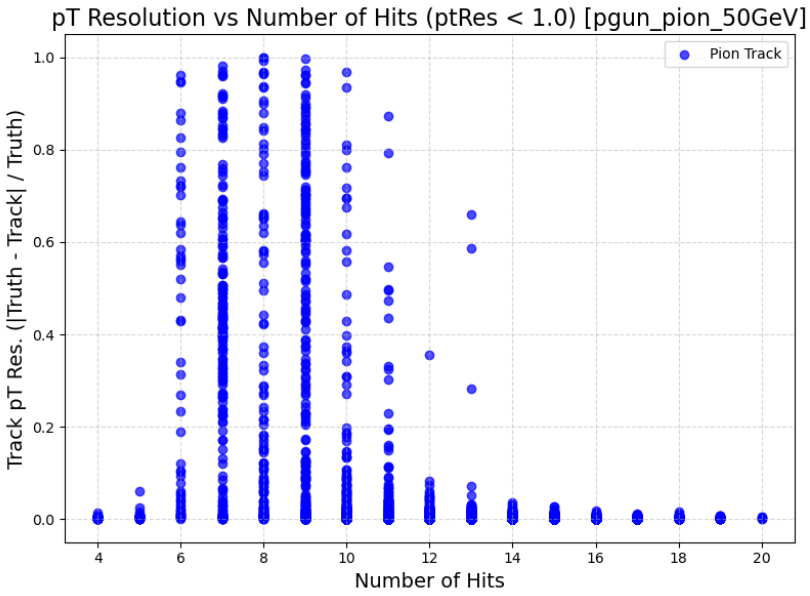
3000 GeV



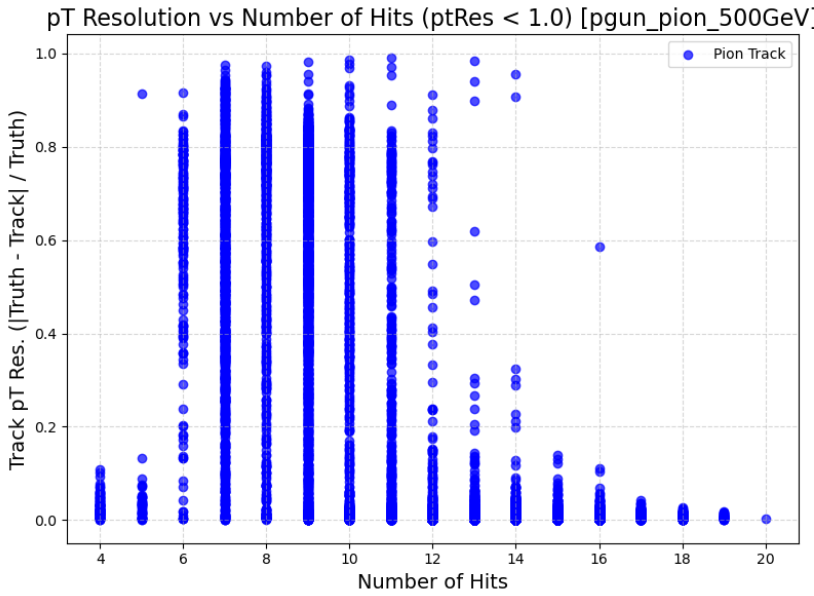
Many outliers!!

$\frac{\Delta p_T}{\text{Truth } p_T}$ vs. N_{Hits} (excluding outliers)

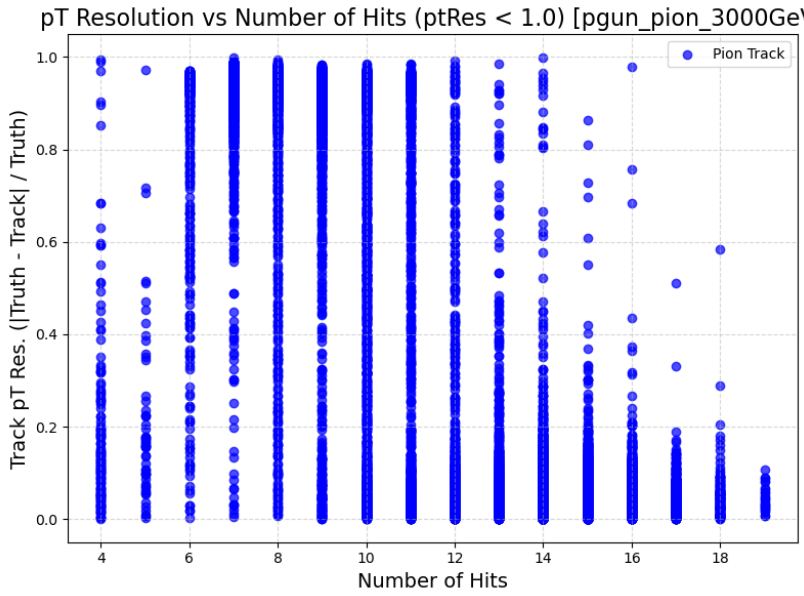
50 GeV



500 GeV

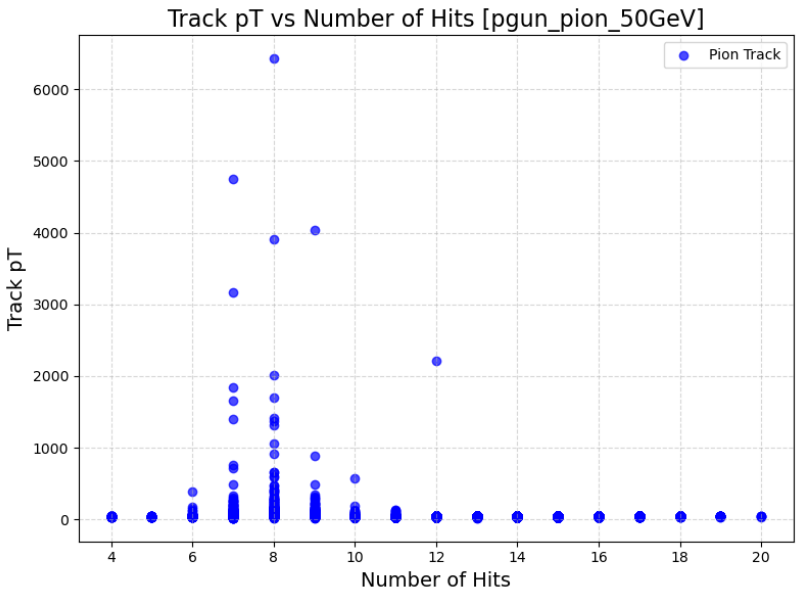


3000 GeV

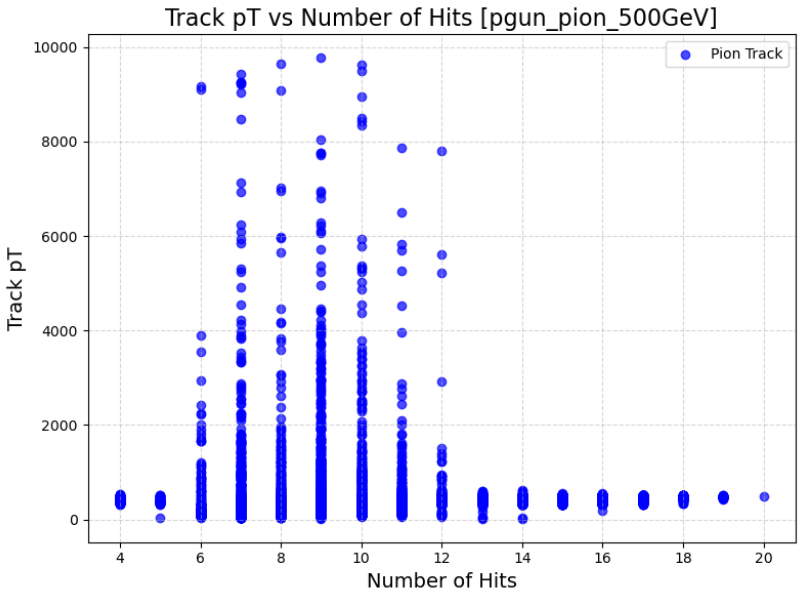


Track p_T vs. N_{hits} (scatter)

50 GeV



500 GeV



3000 GeV