Charged Pions and Taus in MAIA

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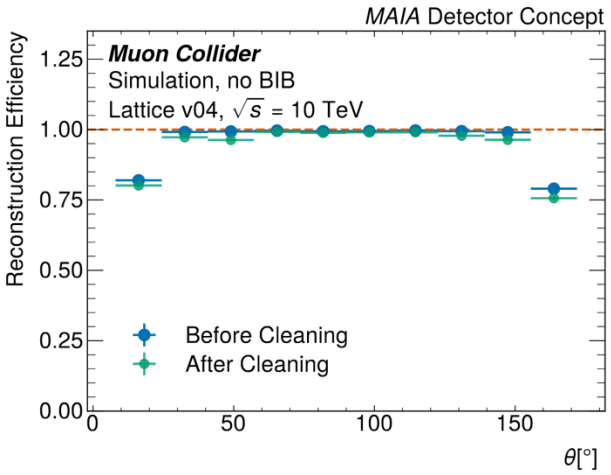
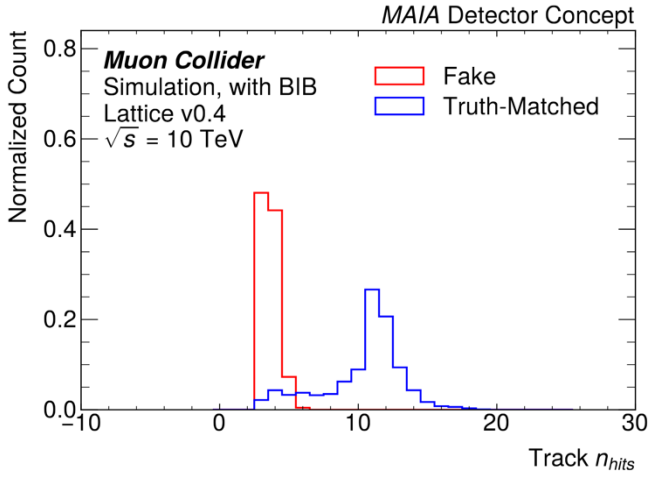
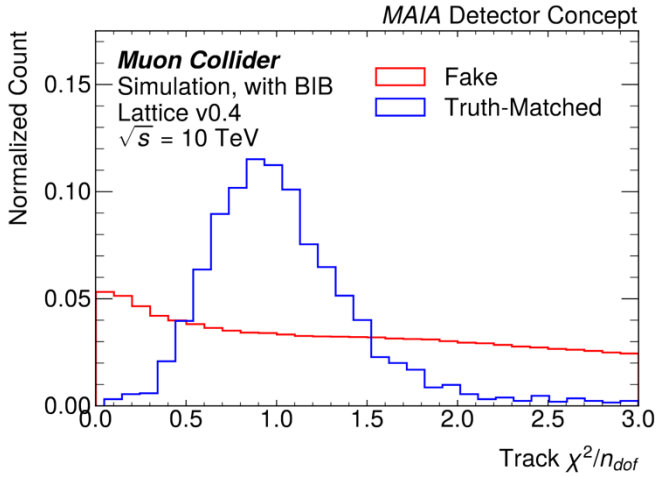
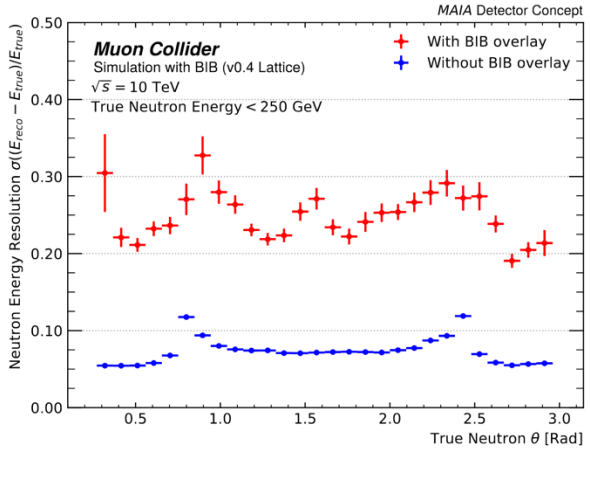
Pion Studies

- Goal with pions: Produce tracking, calorimetry plots that can be understood along with paper results









How do tracks from $\pi^{\pm}$ compare to μ's?

How does $\pi^{\pm}$ energy resolution compare to neutrons?

How efficient are we at reconstructing $\pi^{\pm}$'s?

Pion Studies

- Working with a (negatively) charged pion gun:
  - 1000 events
  - $E \subset (5, 300)$ GeV
  - $\theta \subset (10, 170)$ degrees
  - $\phi \subset (0, 2\pi)$ rad
- Initial step: take this through the Fermilab 2024 tutorial (key4hep software stack)
- No changes other than importing “MAIA_v0” geometry located here
- Verified import by inspecting digitization / reconstruction logs

50 ECal layers

Digitization log

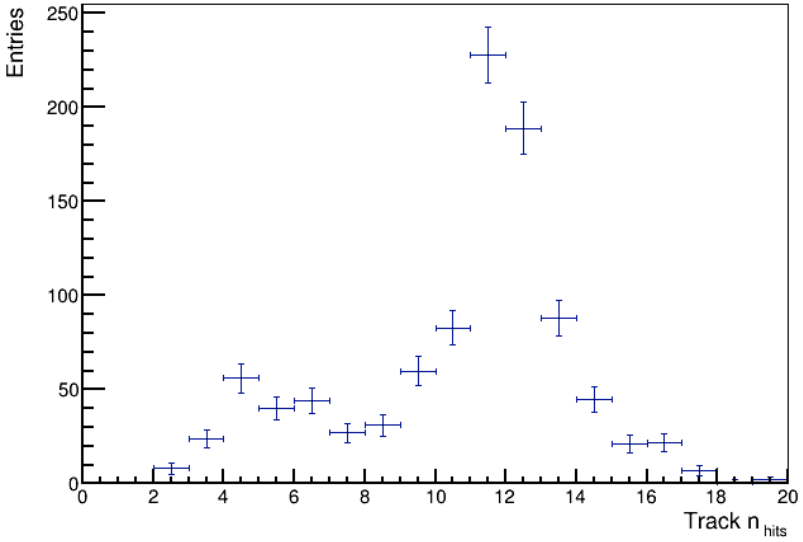
75 HCal layers

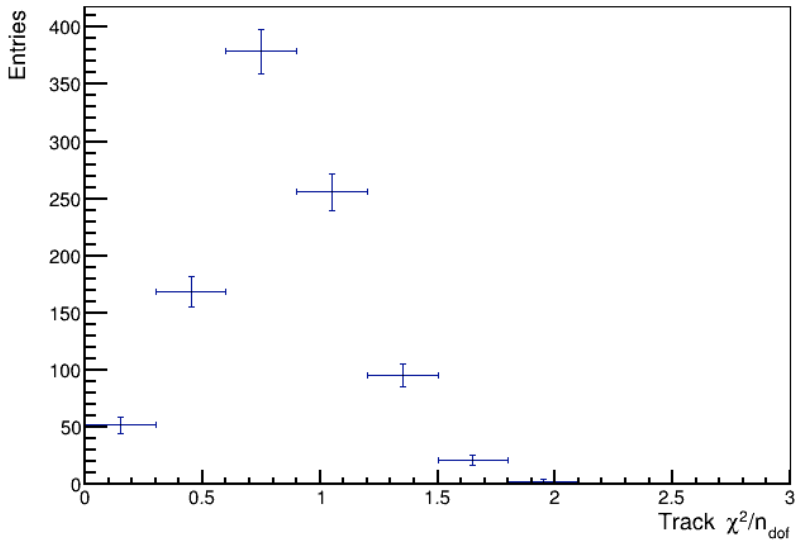
```
Compact          INFO  ++ Converted subdetector:ECalBarrel of type GenericCalBarrel_o1_v01 [calorimeter]
ECalBarrel       INFO  +++ Processing SurfaceInstaller for subdetector: 'ECalBarrel'
DD4hep_CaloFaceBarrelSurfacePlugin INFO  install tracking surfaces for :  ECalBarrel
Number of layers in group 0 : 50
Compact          INFO  ++ Converted subdetector:ECalEndcap of type GenericCalEndcap_o1_v01 [calorimeter]
ECalEndcap       INFO  +++ Processing SurfaceInstaller for subdetector: 'ECalEndcap'
DD4hep_CaloFaceEndcapSurfacePlugin INFO  install tracking surfaces for :  ECalEndcap
Layer: 0 Rmin: 212.5 layer_pos_z: -98.05 Dist: 212.5 inner_thickness: 2.1 outer_thickness: 0.55
Layer: 1 Rmin: 212.5 layer_pos_z: -95.4 Dist: 215.15 inner_thickness: 2.1 outer_thickness: 0.55
Layer: 2 Rmin: 212.5 layer_pos_z: -92.75 Dist: 217.8 inner_thickness: 2.1 outer_thickness: 0.55
Layer: 3 Rmin: 212.5 layer_pos_z: -90.1 Dist: 220.45 inner_thickness: 2.1 outer_thickness: 0.55
Layer: 4 Rmin: 212.5 layer_pos_z: -87.45 Dist: 223.1 inner_thickness: 2.1 outer_thickness: 0.55
Layer: 5 Rmin: 212.5 layer_pos_z: -84.8 Dist: 225.75 inner_thickness: 2.1 outer_thickness: 0.55
Layer: 6 Rmin: 212.5 layer_pos_z: -82.15 Dist: 228.4 inner_thickness: 2.1 outer_thickness: 0.55
Layer: 7 Rmin: 212.5 layer_pos_z: -79.5 Dist: 231.05 inner_thickness: 2.1 outer_thickness: 0.55
Layer: 8 Rmin: 212.5 layer_pos_z: -76.85 Dist: 233.7 inner_thickness: 2.1 outer_thickness: 0.55
Layer: 9 Rmin: 212.5 layer_pos_z: -74.2 Dist: 236.35 inner_thickness: 2.1 outer_thickness: 0.55
Layer: 10 Rmin: 212.5 layer_pos_z: -71.55 Dist: 239 inner_thickness: 2.1 outer_thickness: 0.55
Layer: 11 Rmin: 212.5 layer_pos_z: -68.9 Dist: 241.65 inner_thickness: 2.1 outer_thickness: 0.55
Layer: 12 Rmin: 212.5 layer_pos_z: -66.25 Dist: 244.3 inner_thickness: 2.1 outer_thickness: 0.55
Layer: 13 Rmin: 212.5 layer_pos_z: -63.6 Dist: 246.95 inner_thickness: 2.1 outer_thickness: 0.55
Layer: 14 Rmin: 212.5 layer_pos_z: -60.95 Dist: 249.6 inner_thickness: 2.1 outer_thickness: 0.55
```

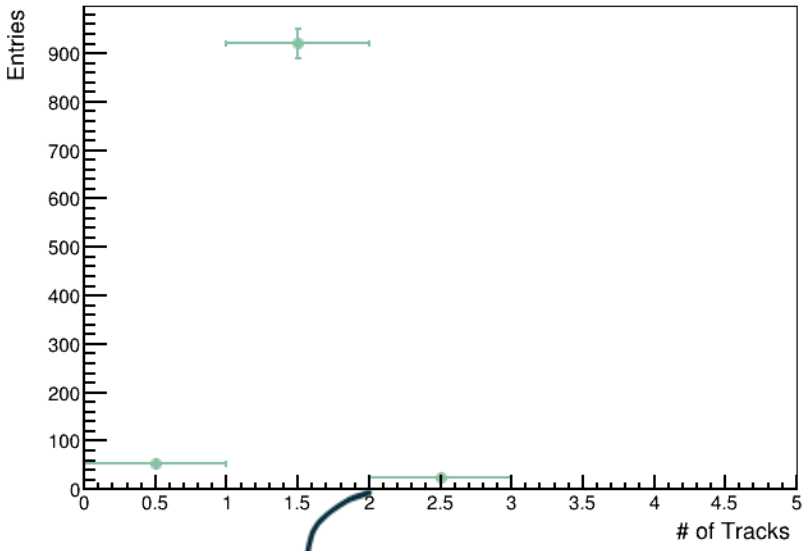
```
Compact          INFO  ++ Converted subdetector:HCalBarrel of type GenericCalBarrel_o1_v01 [calorimeter]
Utilities        INFO  +++ setDetectorTypeFlags for detector: HCalEndcaps not set.
Compact          INFO  ++ Converted subdetector:HCalEndcaps of type DD4hep_SubdetectorAssembly
Number of layers in group 0 : 15
Number of layers in group 1 : 15
Number of layers in group 2 : 15
Number of layers in group 3 : 15
Number of layers in group 4 : 15
Compact          INFO  ++ Converted subdetector:HCalEndcap of type GenericCalEndcap_o2_v01 [calorimeter]
Layer: 0 Rmin: 415 layer_pos_z: -130.8 Dist: 415 inner_thickness: 0.75 outer_thickness: 42.85
Layer: 1 Rmin: 415 layer_pos_z: -87.2 Dist: 458.6 inner_thickness: 0.75 outer_thickness: 42.85
Layer: 2 Rmin: 415 layer_pos_z: -43.6 Dist: 502.2 inner_thickness: 0.75 outer_thickness: 42.85
Layer: 3 Rmin: 415 layer_pos_z: -2.13163e-14 Dist: 545.8 inner_thickness: 0.75 outer_thickness: 42.85
Layer: 4 Rmin: 415 layer_pos_z: 43.6 Dist: 589.4 inner_thickness: 0.75 outer_thickness: 42.85
Layer: 5 Rmin: 415 layer_pos_z: 87.2 Dist: 633 inner_thickness: 0.75 outer_thickness: 42.85
Layer: 6 Rmin: 415 layer_pos_z: 130.8 Dist: 676.6 inner_thickness: 0.75 outer_thickness: 42.85
Compact          INFO  ++ Converted subdetector:YokeBarrel of type GenericCalBarrel_o1_v01 [calorimeter]
```

Pion Tracking

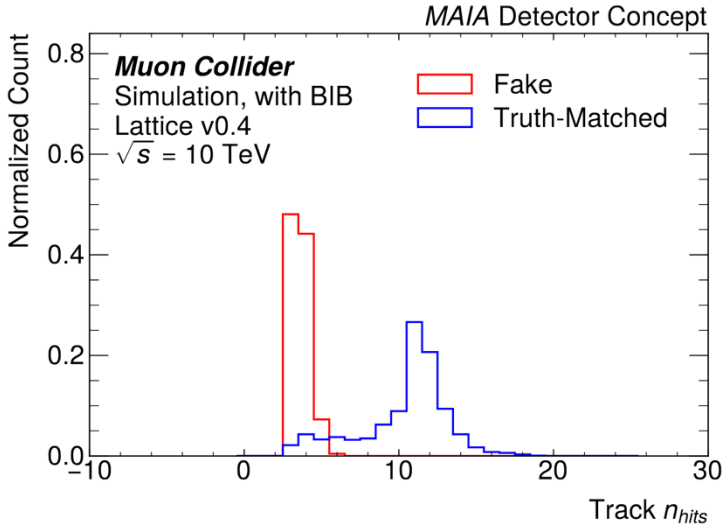
- Reading the *SiTrack* container, no changes from default ACTS config
- Track nHits, Chi^2/dof looking similar to truth-matched from paper

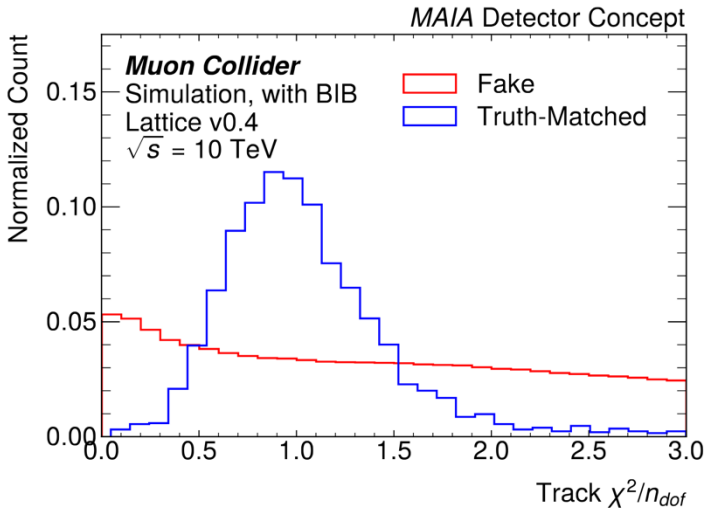






~2% fake rate

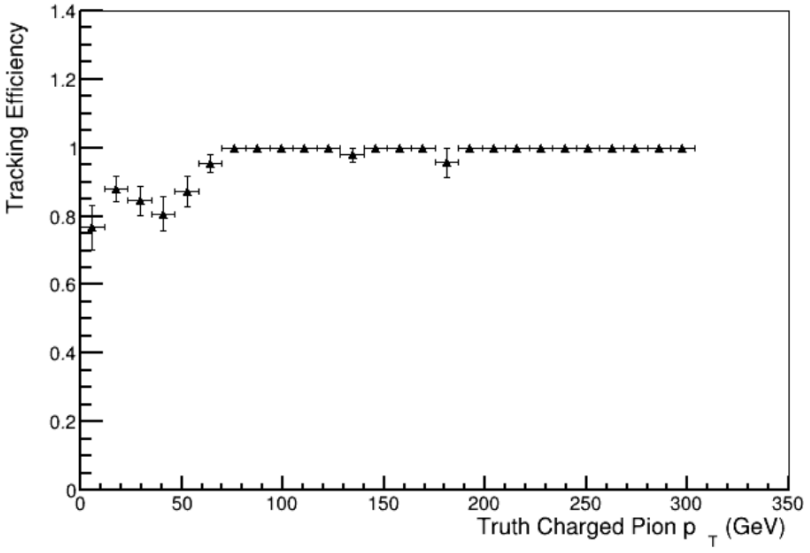


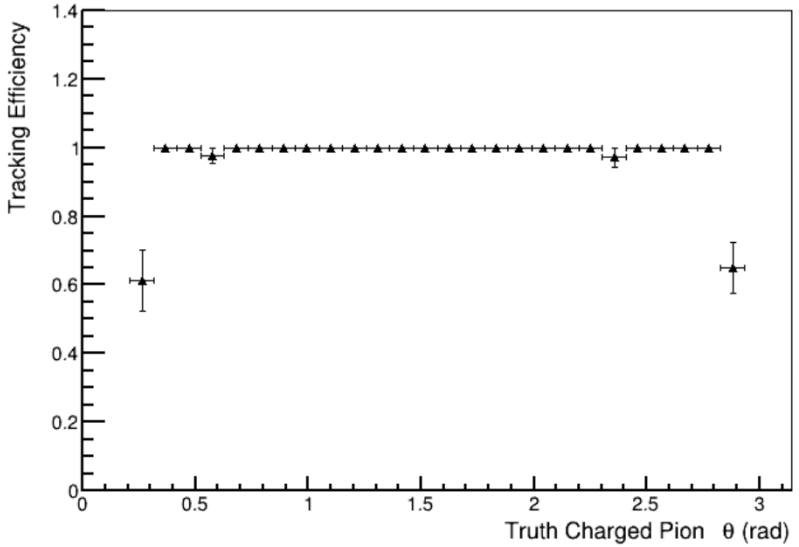


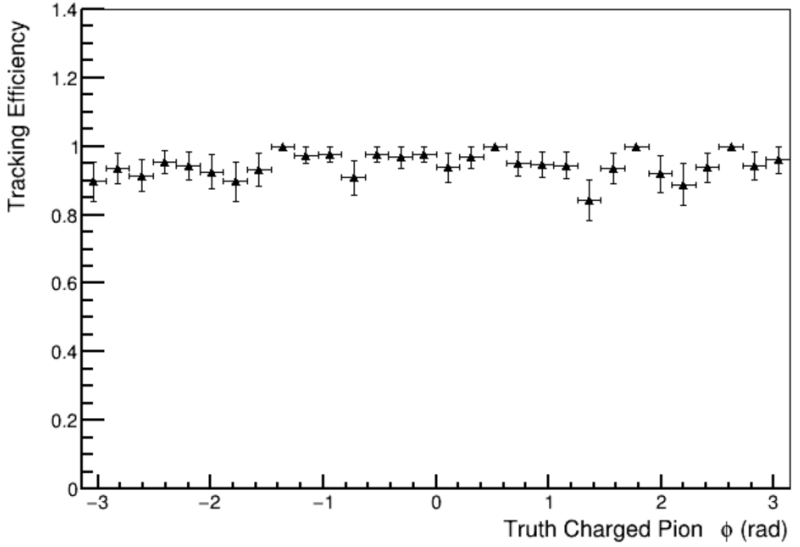
Pion Tracking

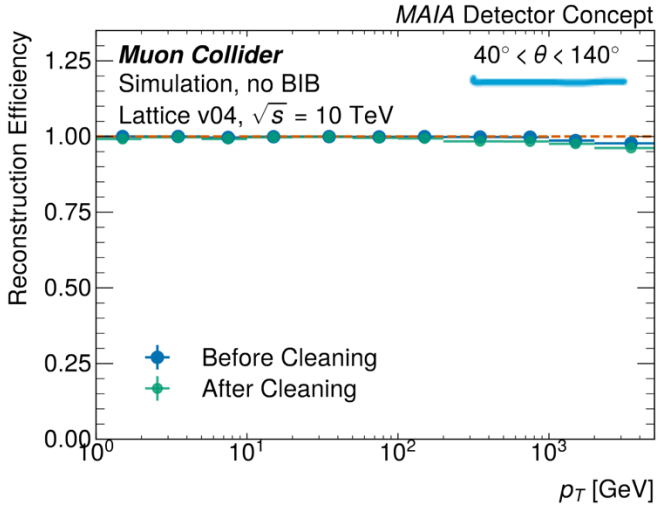
$$\text{tracking } \epsilon = \frac{\#\text{ events with } \geq 1 \text{ track}}{\#\text{ events}}$$

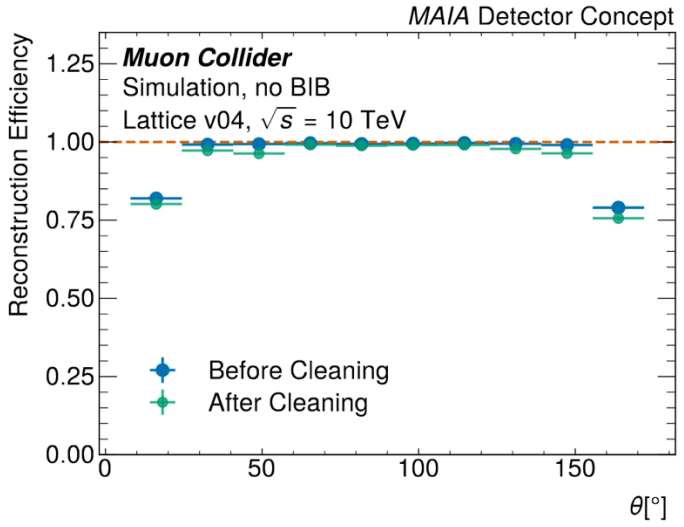
- Reading the *SiTrack* container, no changes from default ACTS config
- Near-perfect tracking efficiency outside of endcap region, lower endcap efficiency





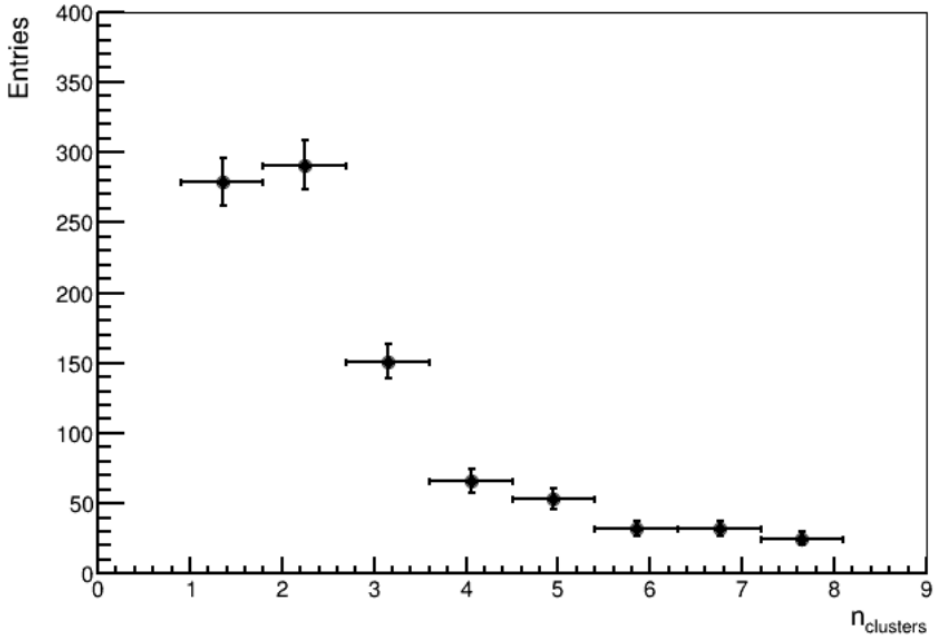


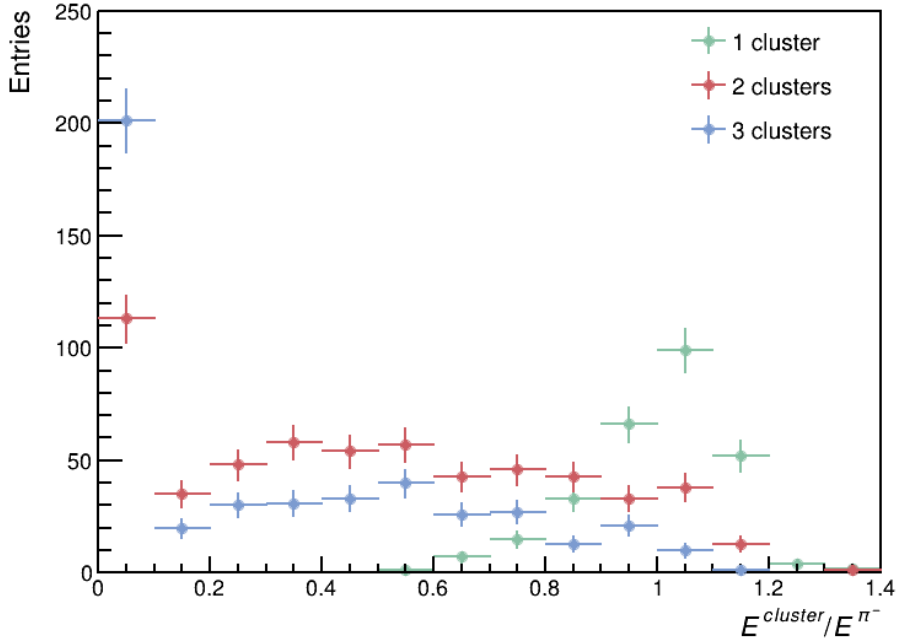




Clustering

- Checking how many clusters are made, and their share of the pion energy





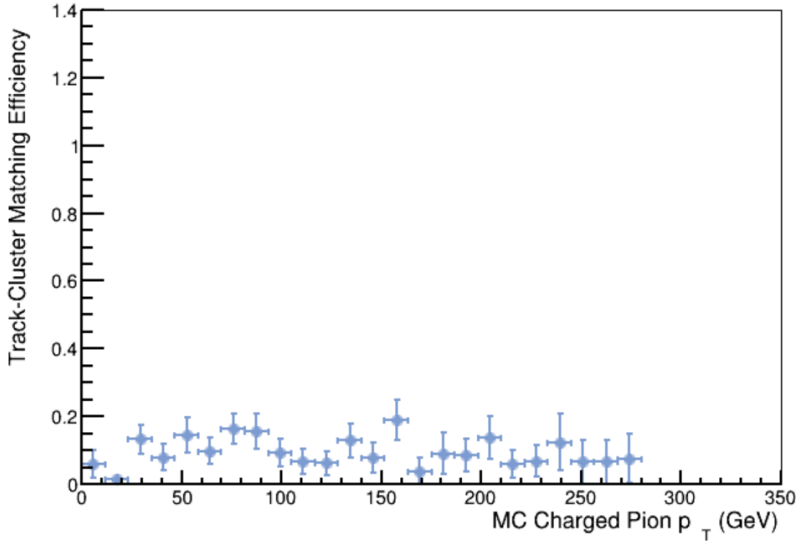
- Charged pion tends to get split into multiple clusters
  - Not ideal
- When there are multiple clusters, many have significant energy and cannot be ignored
- Needs supporting plots: How far apart are these clusters, etc…

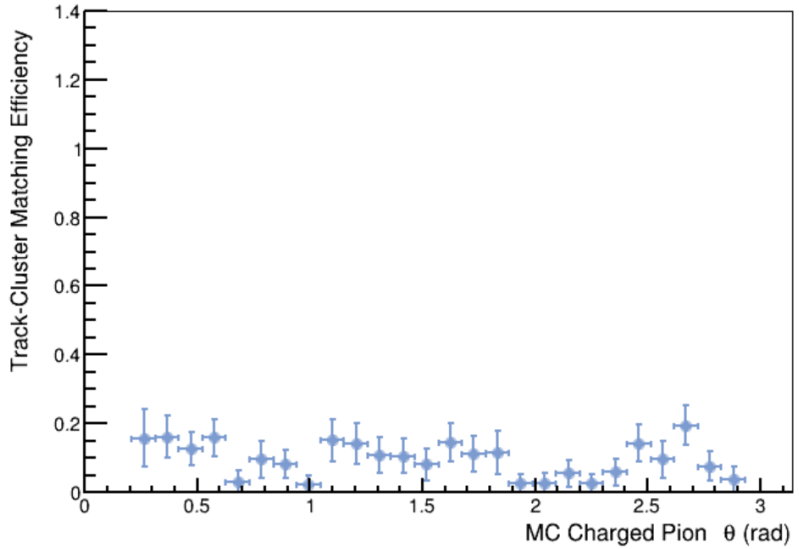
Clustering looks like it will need work!

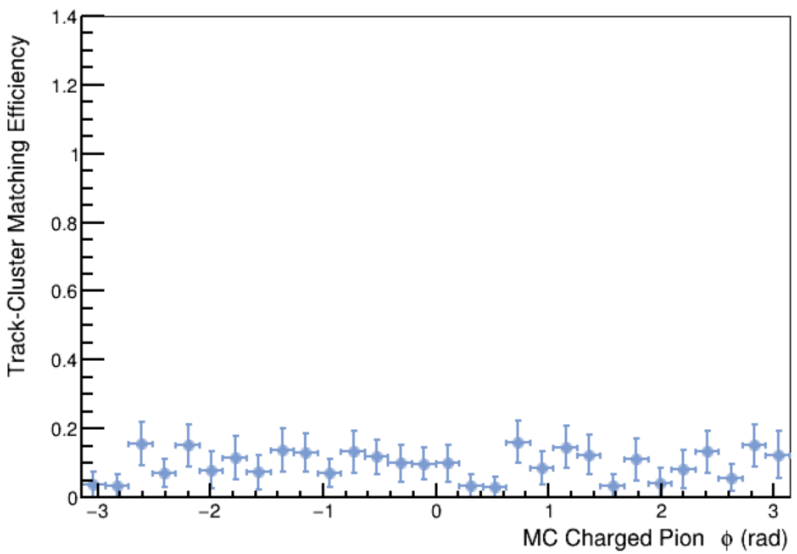
Track-Cluster Matching

- Checked that there is always a PFO created
- Charged pion ID requires a track associated with a cluster – isolate track-cluster matching efficiency

$$\text{track-cluster matching } \epsilon = \frac{\#\text{events containing a PFO w/ a track}}{\#\text{events with a track}}$$







Quite bad - more on this later

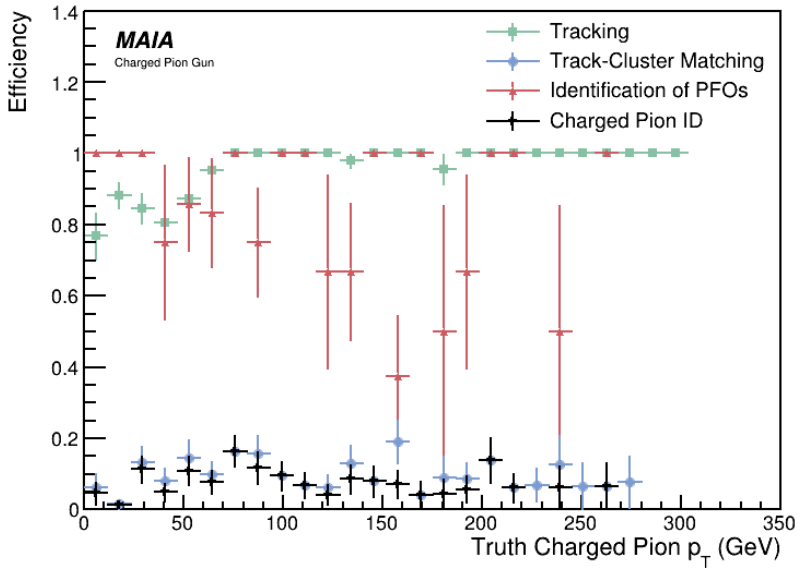
Charged Pion ID Efficiency

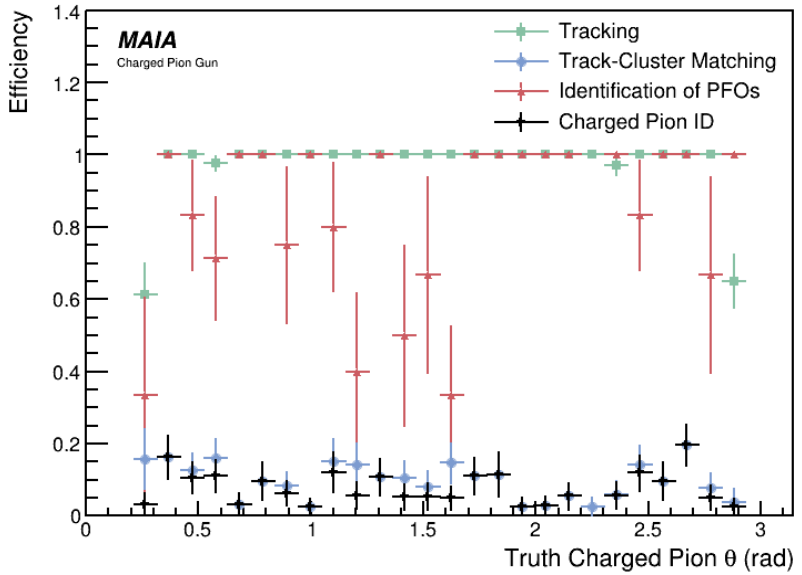
- All efficiencies together, adding charged pion ID of PFOs

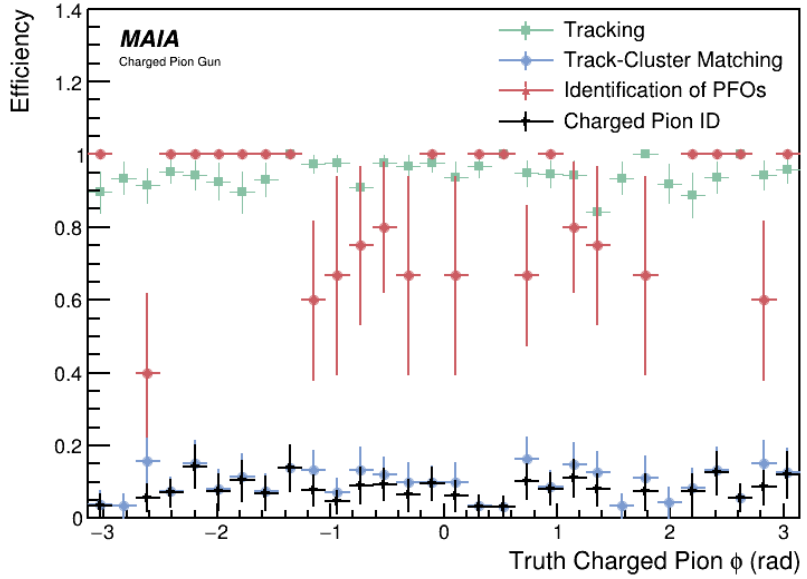
$$\text{tracking } \epsilon = \frac{\#\text{ events w/ } \geq 1 \text{ trk}}{\#\text{ events}} \qquad \text{track-cluster matching } \epsilon = \frac{\#\text{events containing a PFO w/ a track}}{\#\text{events with a track}}$$

$$\text{Identication of PFOs } \epsilon = \frac{\#\text{ events w/ a reco } \pi^{\pm}}{\#\text{ events containing a PFO w/ a track}}$$

$$\pi^{\pm}\text{ ID } \epsilon = \frac{\#\text{ of events w/ a reco } \pi^{\pm}}{\#\text{ of events}}$$







Dominated by track-cluster matching issues

Refitting Tracks

- In attempt to reproduce previous results, we tested CERN 2023 tutorial
  - Before the transition to key4hep software stack
- All steps through digitization gave same results, but tracking config in reconstruction was different
  - Addition of track “refit” (code here, haven’t extensively read it yet)
  - Mildly different CKF parameters – tested to not be impactful
- Primary difference: Refit tracks (*SiTracks_Refitted* container*)* are fed into Pandora in place of SiTracks
  - (I admit that currently I’m not sure what this refit does)

added to

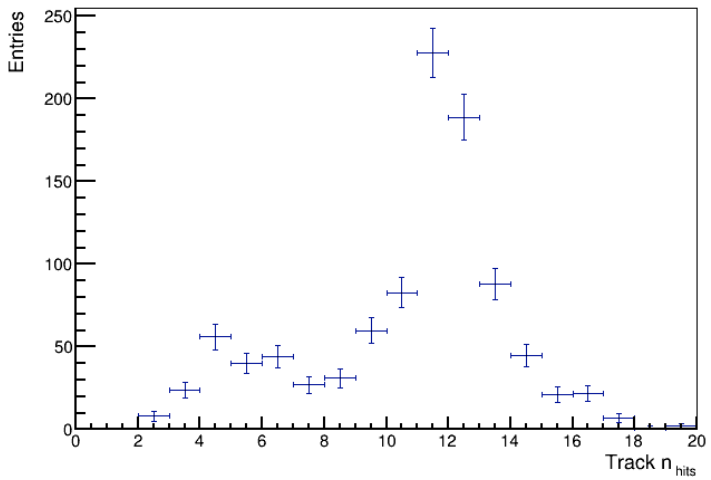
reco_steer.py

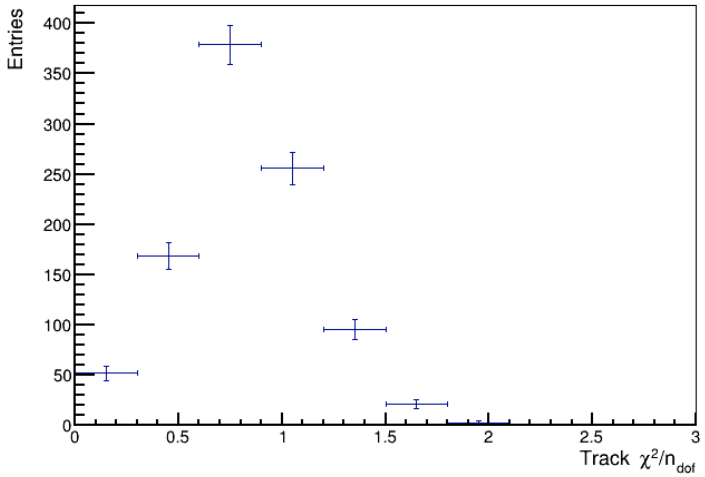
```
TrackRefit = MarlinProcessorWrapper("TrackRefit")
TrackRefit.OutputLevel = INFO
TrackRefit.ProcessorType = "RefitFinal"
TrackRefit.Parameters = {
                        "EnergyLossOn": ["true"],
                        "DoCutsOnRedChi2Nhits": ["true"],
                        "ReducedChi2Cut": ["3."],
                        "NHitsCuts": ["1,2 1 3,4 1 5,6 0 "],
                        "InputRelationCollectionName": ["SiTracksRelations"],
                        "InputTrackCollectionName": ["SiTracks"],
                        "Max_Chi2_Incr": ["1.79769e+30"],
                        "MultipleScatteringOn": ["true"],
                        "OutputRelationCollectionName": ["SiTracks_Refitted_Relations"],
                        "OutputTrackCollectionName": ["SiTracks_Refitted"],
                        "ReferencePoint": ["-1"],
                        "SmoothOn": ["false"],
                        "Verbosity": ["DEBUG3"],
                        "extrapolateForward": ["true"],
                        "MinClustersOnTrackAfterFit:": ["3"]
                        }
```

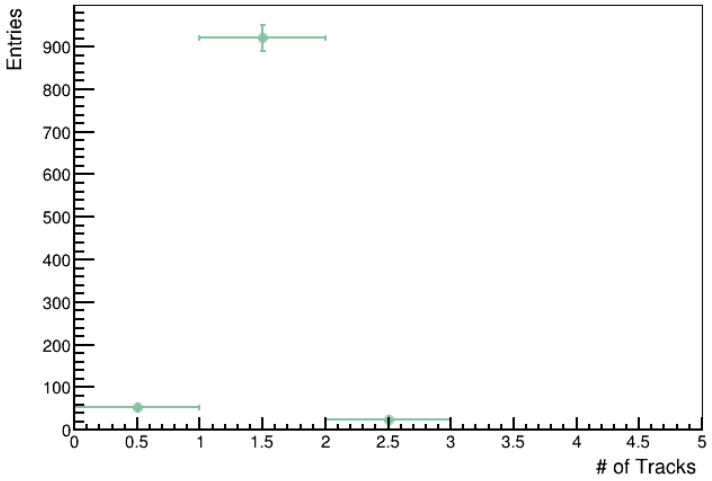
Pion Tracking, re-fit tracks

- Re-run Pandora, with SiTracks_Refitted swapped in for SiTracks

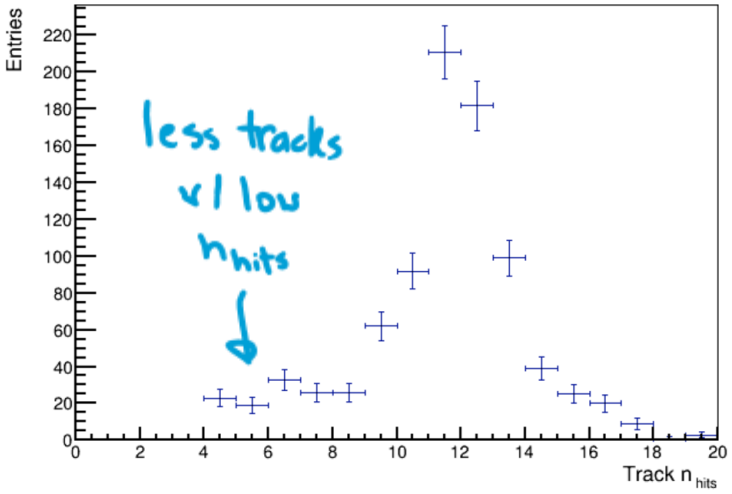
SiTrack

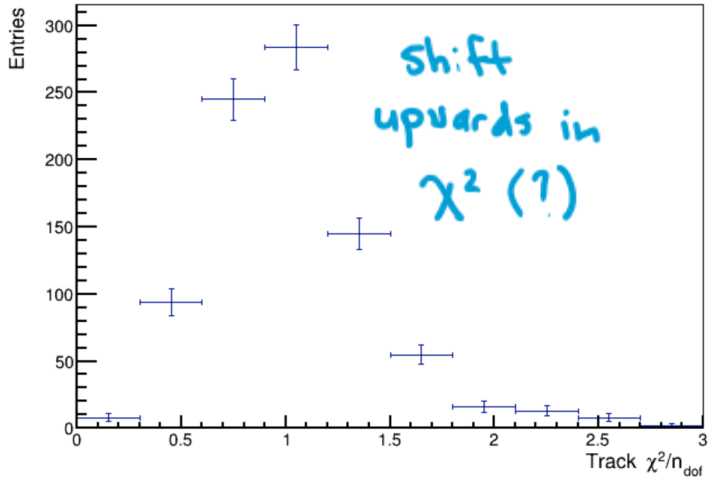


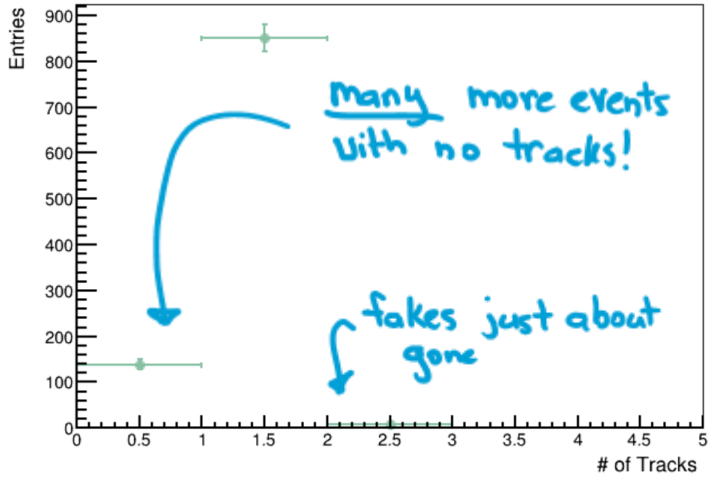




SiTrack_Refitted



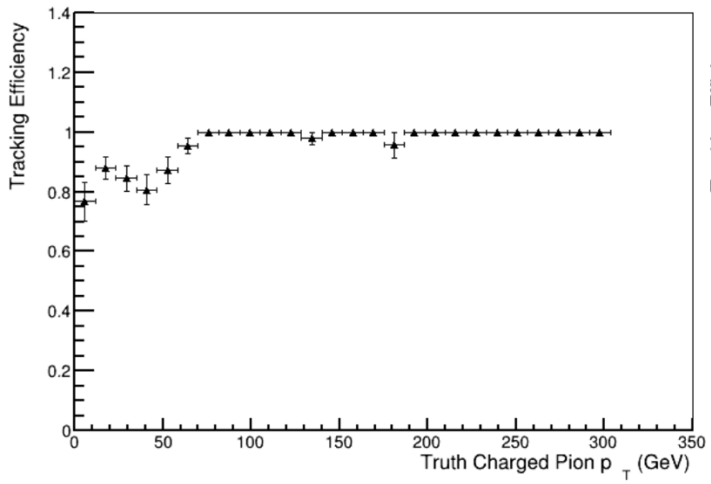


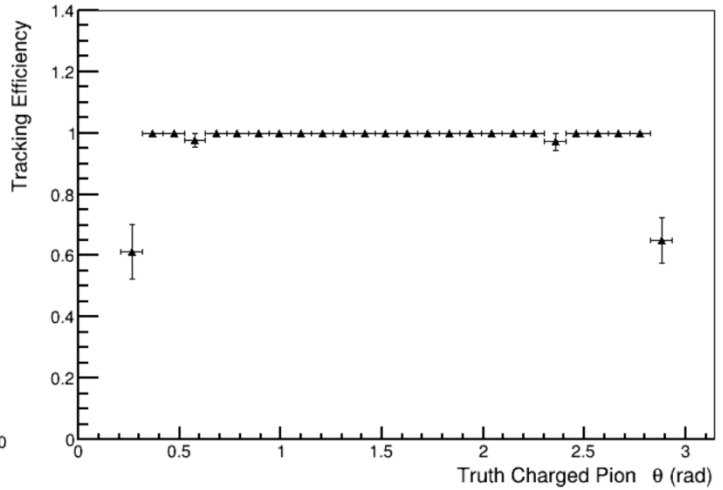


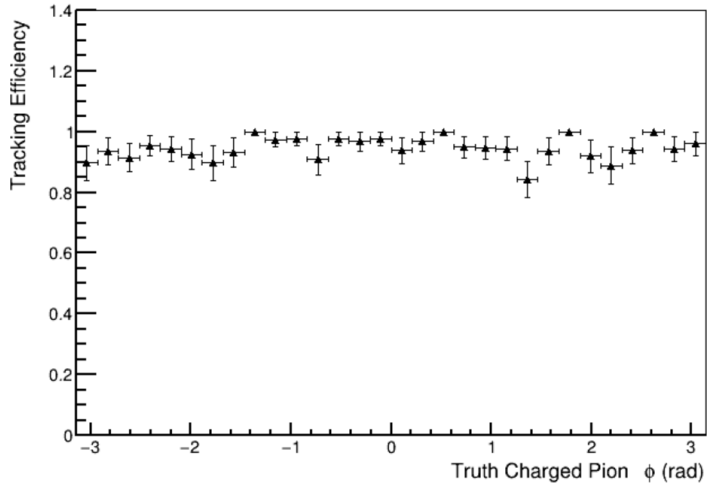
Pion Tracking, re-fit tracks

- Re-run Pandora, with SiTracks_Refitted swapped in for SiTracks
- Much harsher efficiency dropoff vs. θ

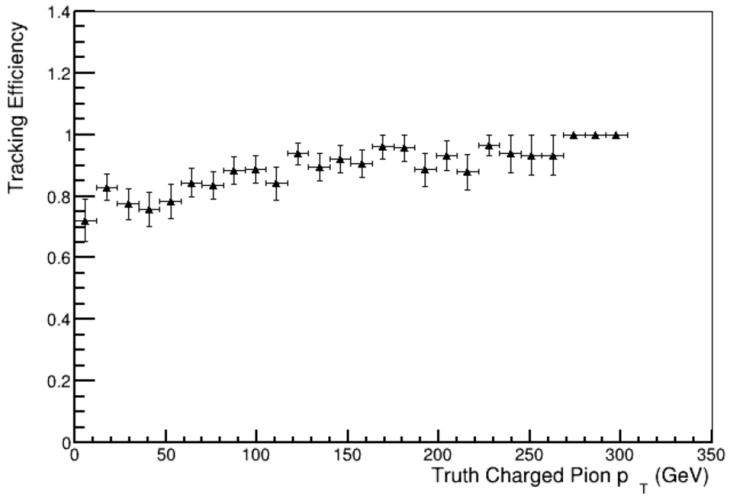
SiTrack

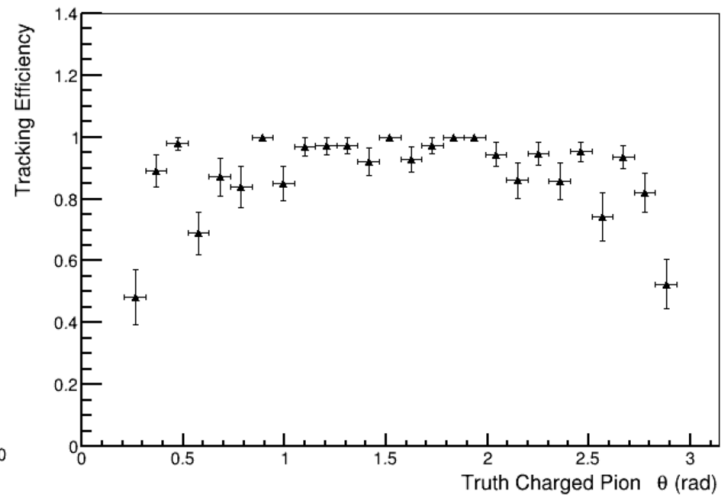


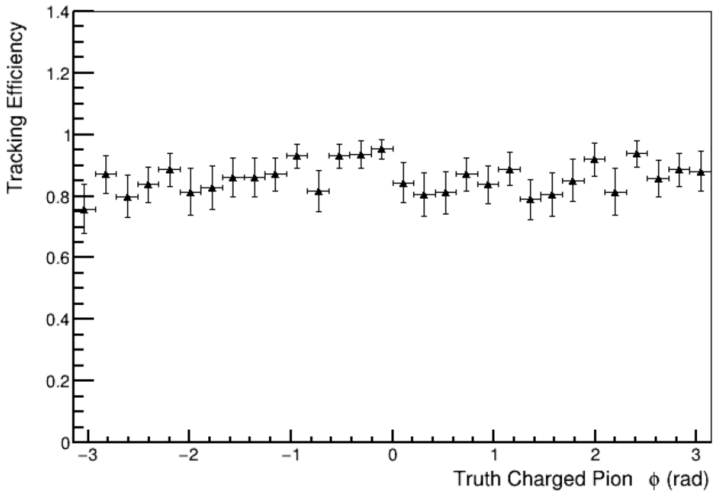




SiTrack_Refitted



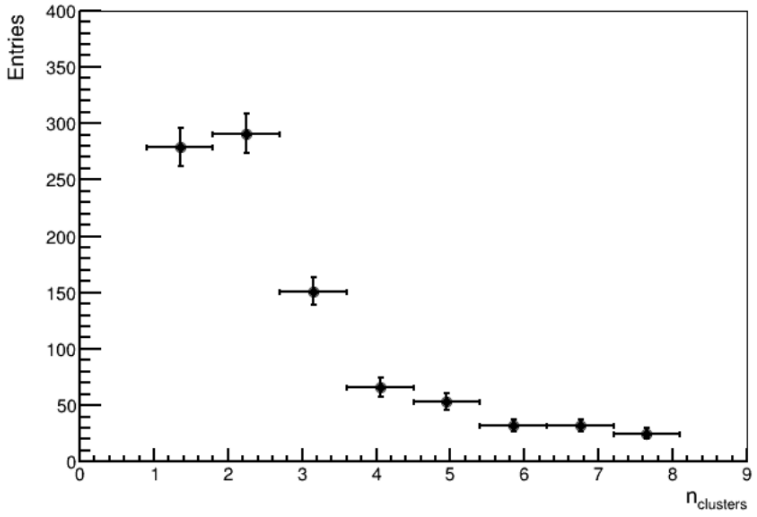


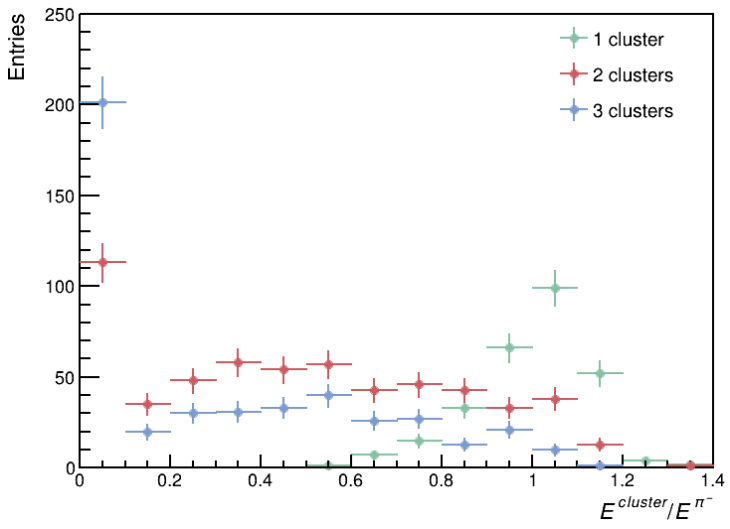


Clustering, re-fit tracks

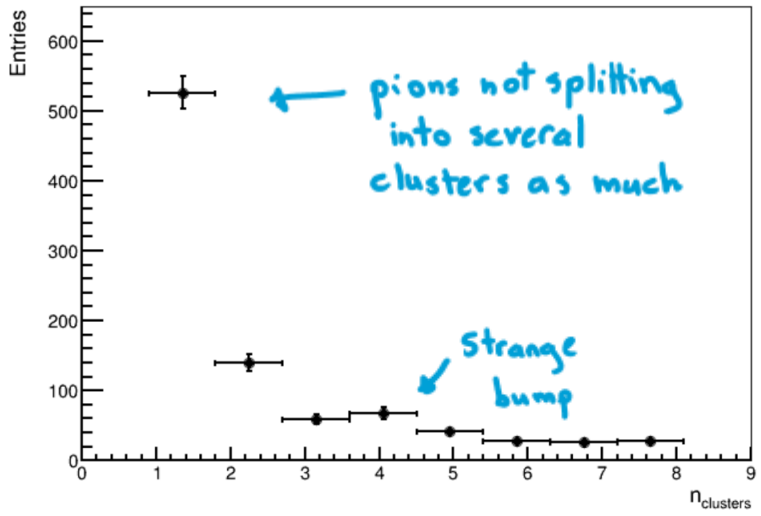
- Naively, I'd expect this to be independent of the tracking…
- Not sure why these two scenarios look different

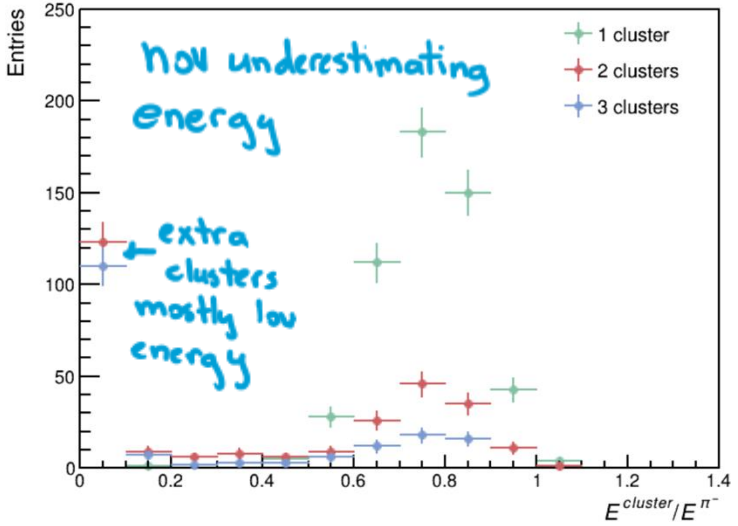
Si Track





Si Track _ Refitted



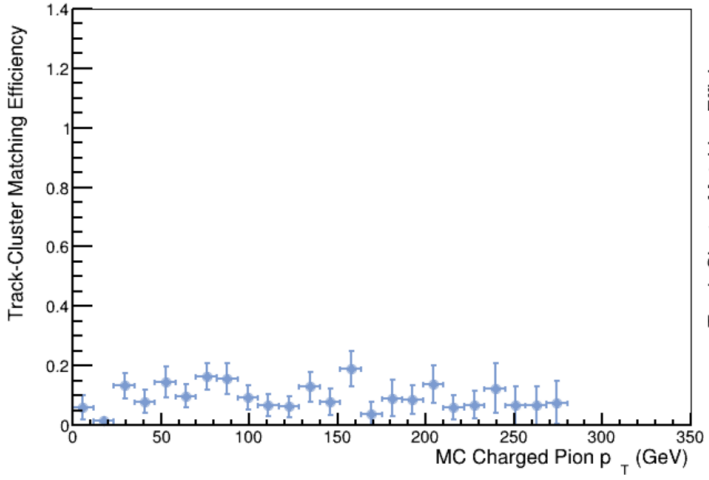


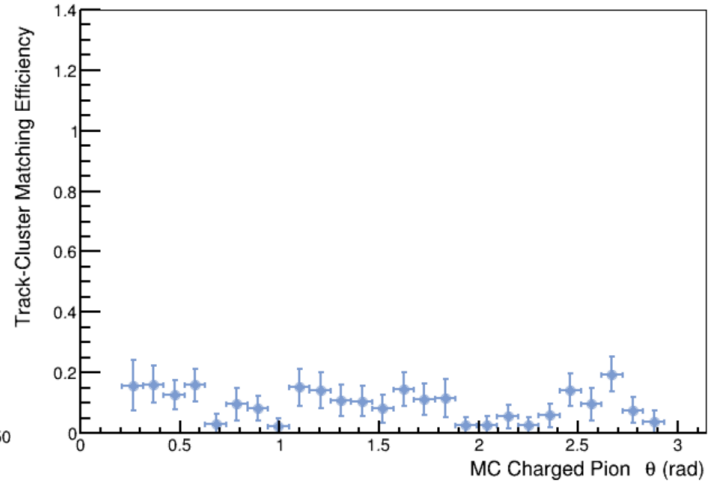
Track-Cluster Matching, re-fit tracks

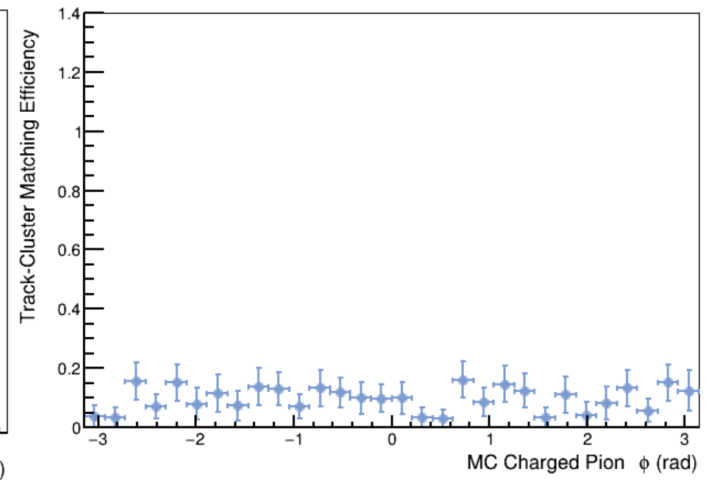
Huge improvement (!/?)

track-cluster matching ε = #events containing a PFO w/ a track / #events with a track

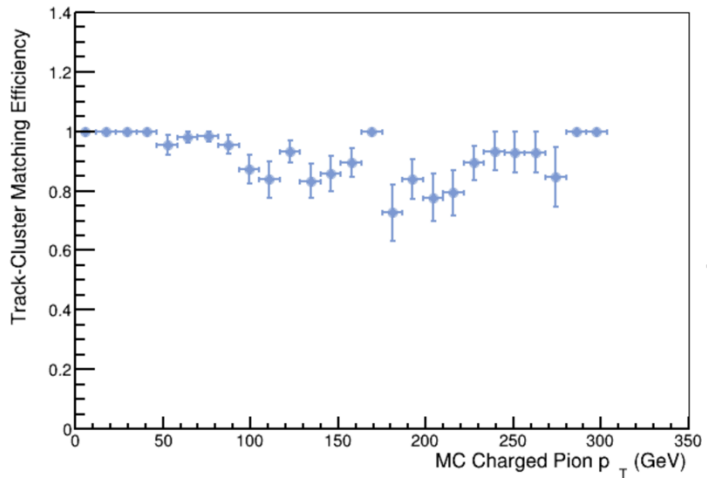
SiTrack

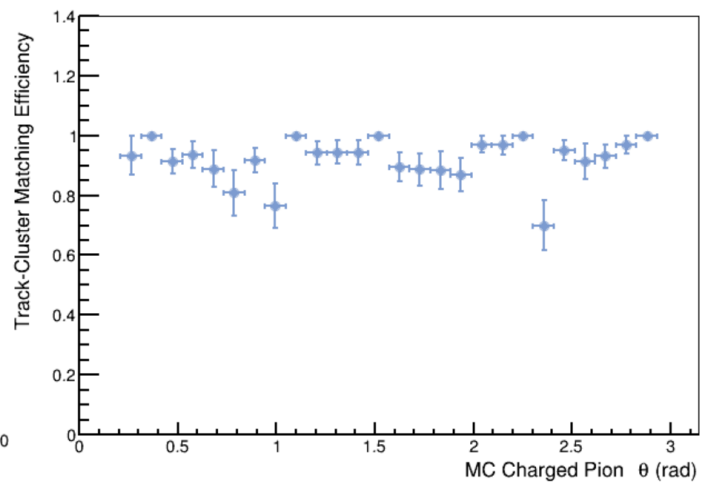


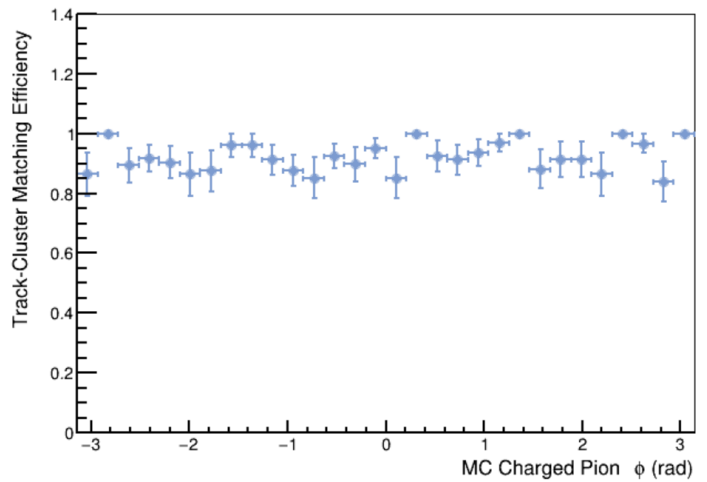




SiTrack_Refitted





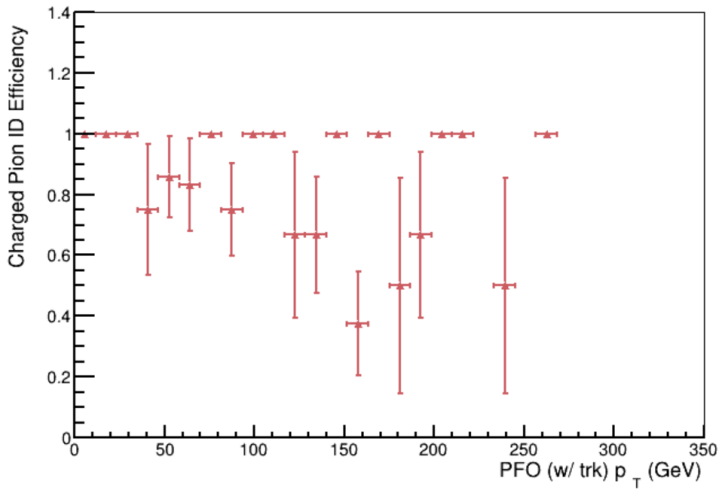


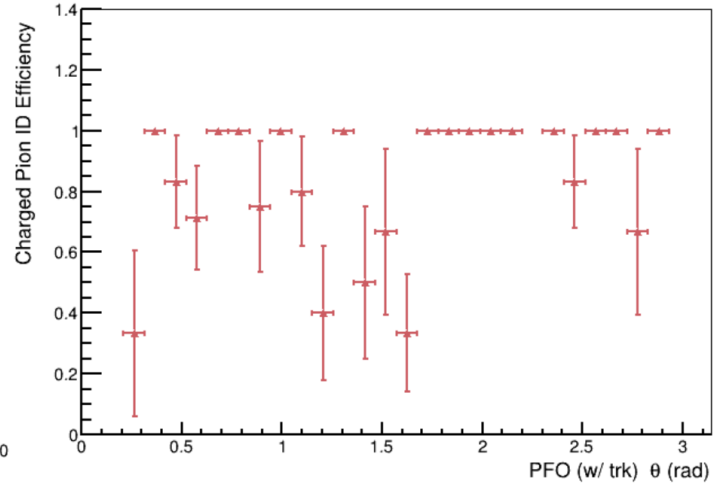
ID of PFOs, re-fit tracks

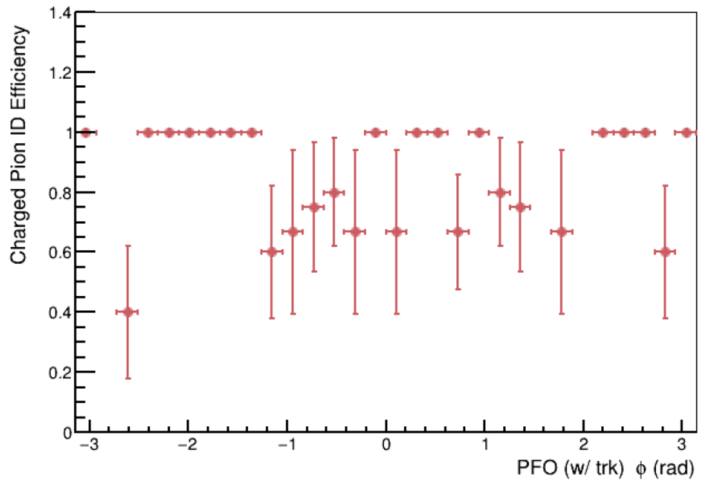
- With *SiTracks*, there weren't enough PFOs w/ track
- Now enough statistics – ID eff of PFOs looking ~95%

$$\text{Identication of PFOs } \epsilon = \frac{\#\text{ events w/ a reco } \pi^{\pm}}{\#\text{ events containing a PFO w/ a track}}$$

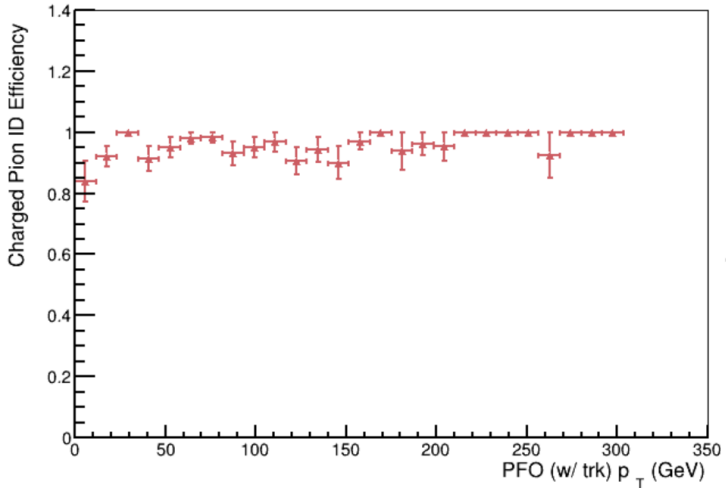
SiTrack

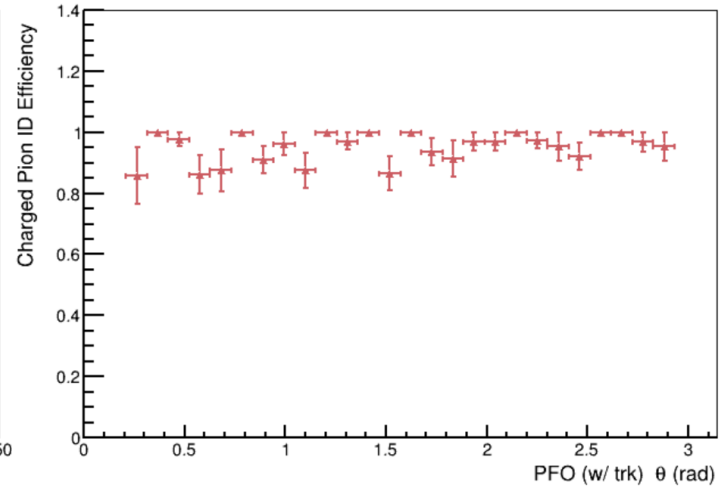


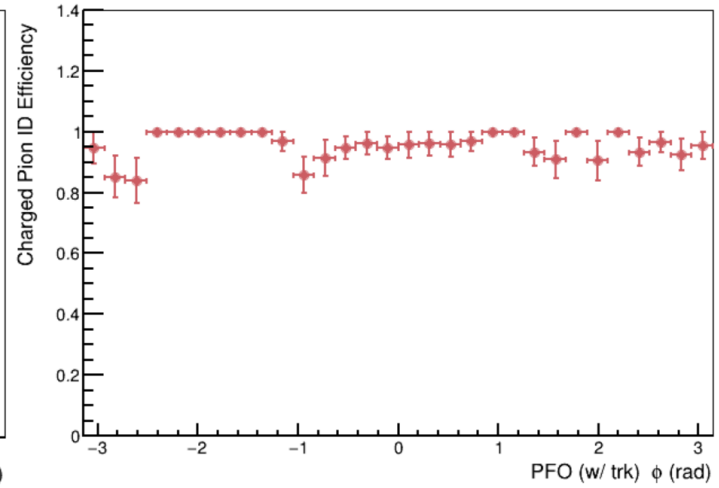




SiTrack_Refitted





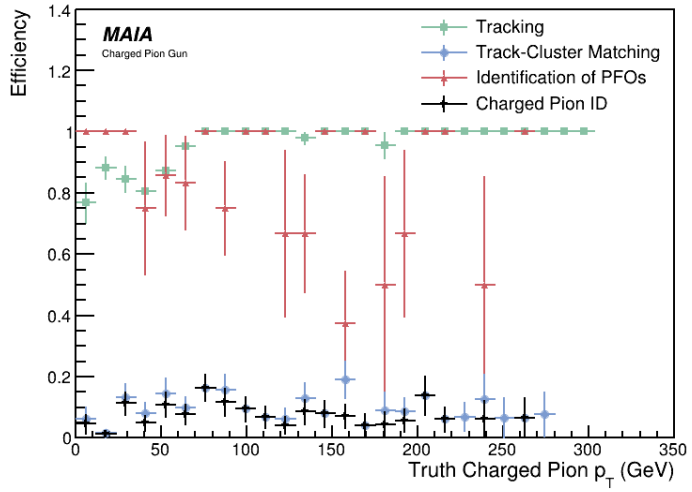


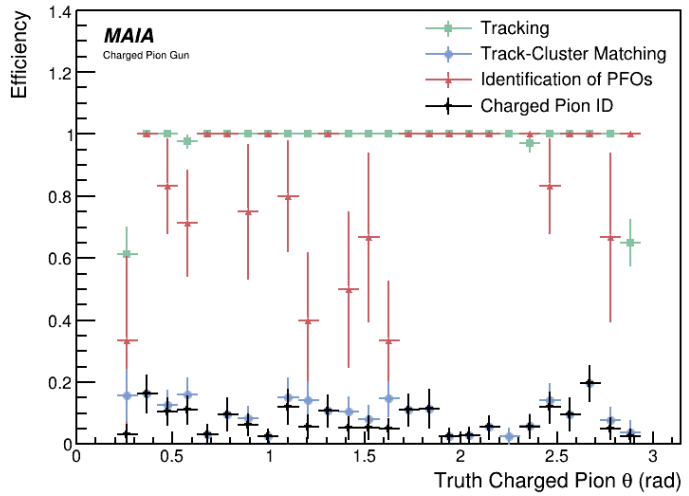
Charged Pion ID Efficiency, re-fit tracks

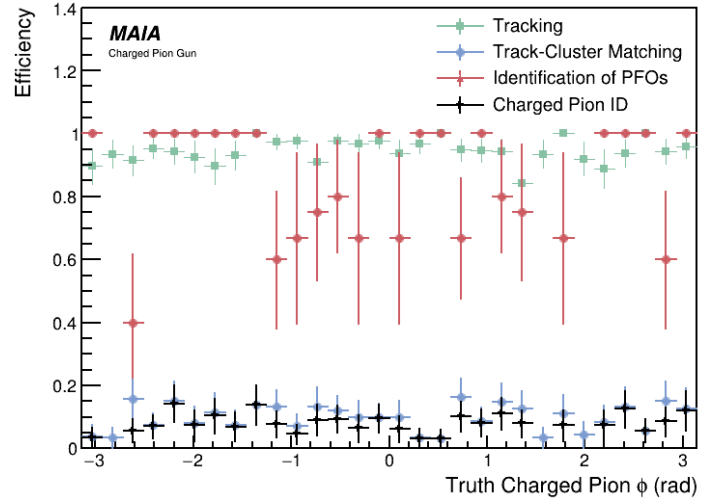
- Definitions on slide 8

Large improvement in $\pi^{\pm}$ ID ϵ, but significant loss in tracking performance

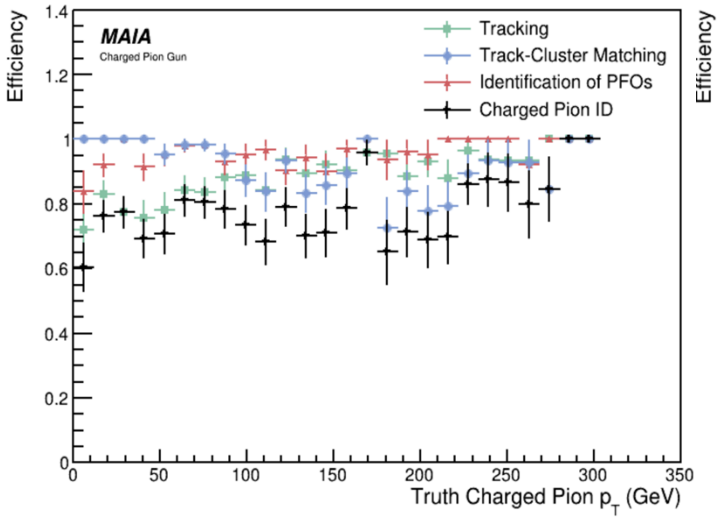
Si Track

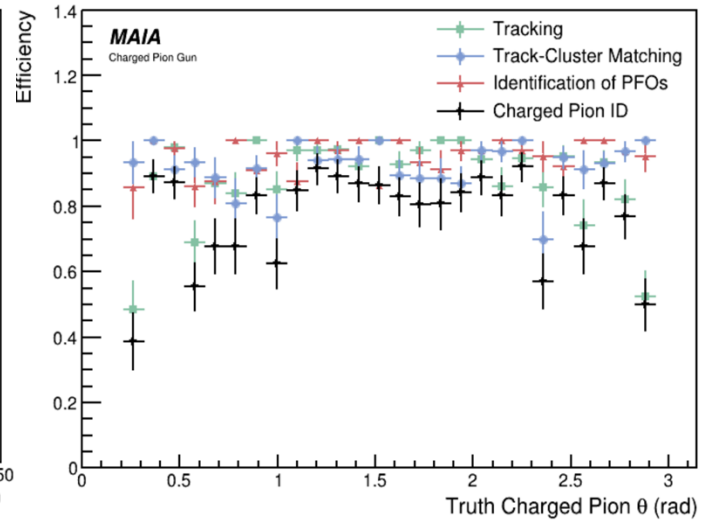


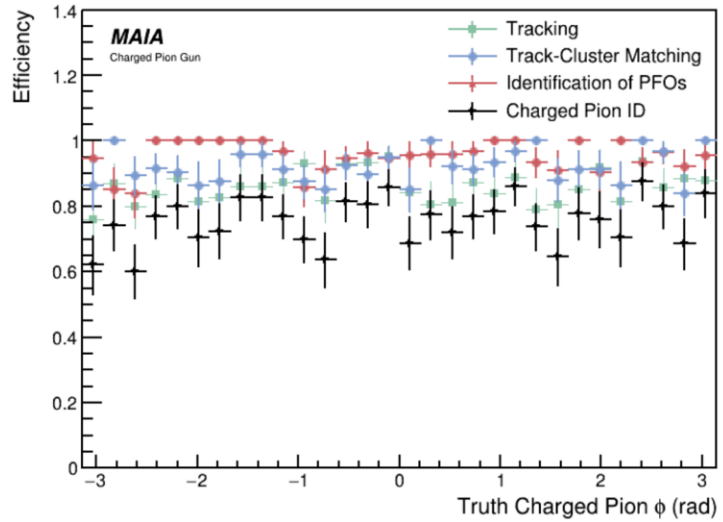




Si Track _ Refitted







Summary

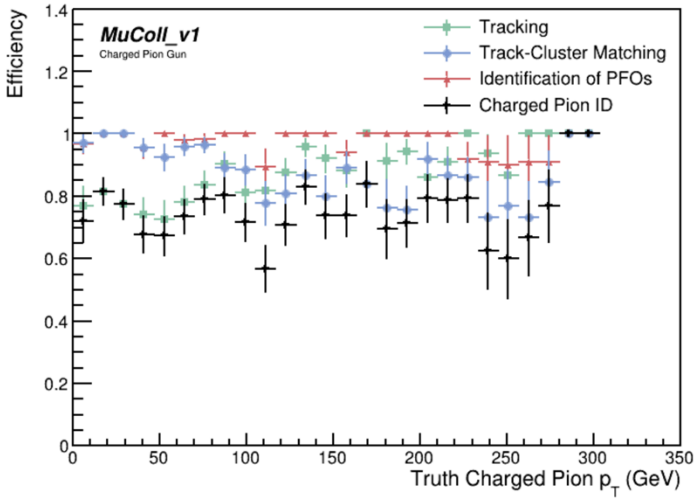
- Refitting tracks gives worse tracking performance, but better charged pion ID down the line
  - I need to read the code to understand what the refit does
  - At this stage, no clear preference for refitting vs. not refitting
- What steps should we take to harmonize with the tracking studies?
  - Which track container is input to Pandora? Refitted, not refitted, something else, etc..
  - Is there an optimized CKF config for muons that we can check on charged pions?
- Moving forward on charged pions:
  - Any other helpful tracking plots that we don't have?
  - More clustering plots, such as distances between multiple clusters
  - PFOs: Track-cluster distances
  - Pion ID variables

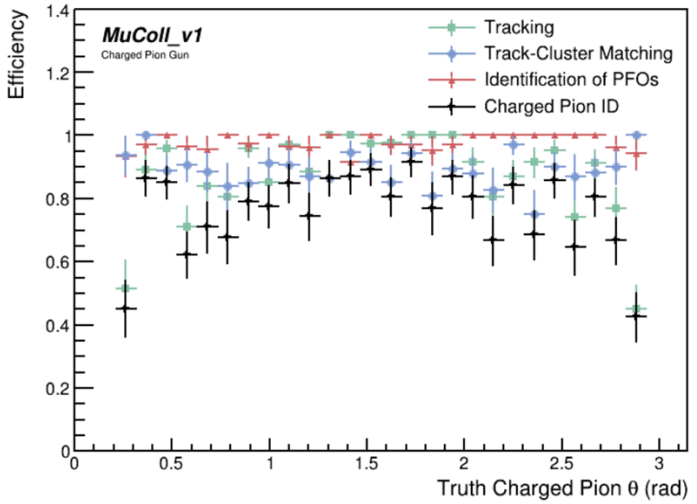
- On taus: Ethan is working on writing standalone implementation of "TauFinder" algorithm
  - Code development can be done in parallel with these pion studies
  - Initial focus on 1-prong no-neutrals hadronic tau decays
  - More soon!

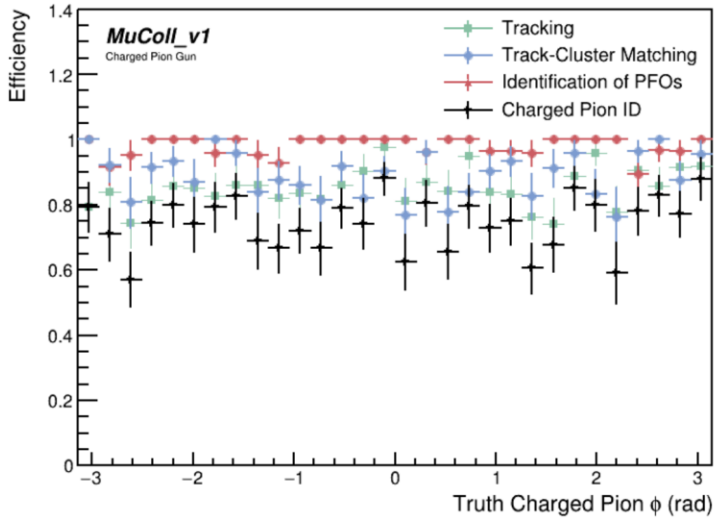
- Misc points (in backup):
  - Charged Pion ID not as dependent on Hcal cell threshold as Lorenzo found in MuColl_v1
  - Performance in MAIA and MuColl_v1 is similar

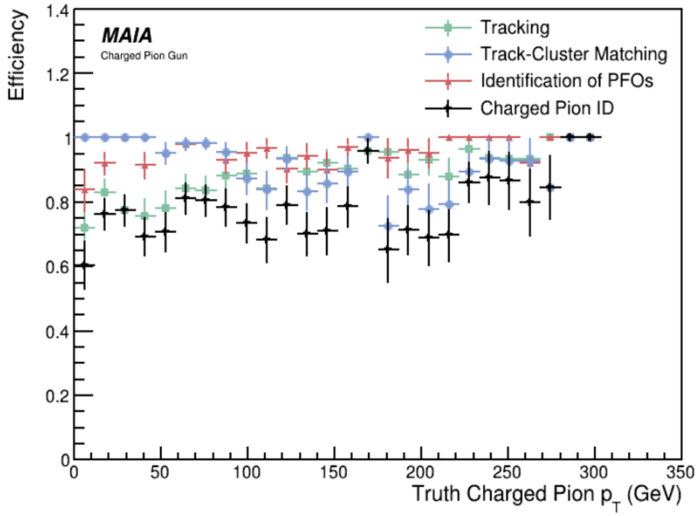
MAIA vs. MuColl_v1 (refit tracks)

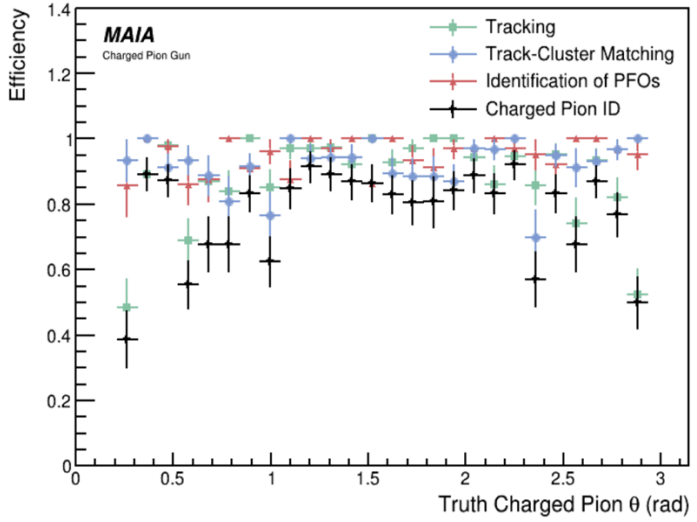
- Track, cluster variables are similar
- Very similar performance

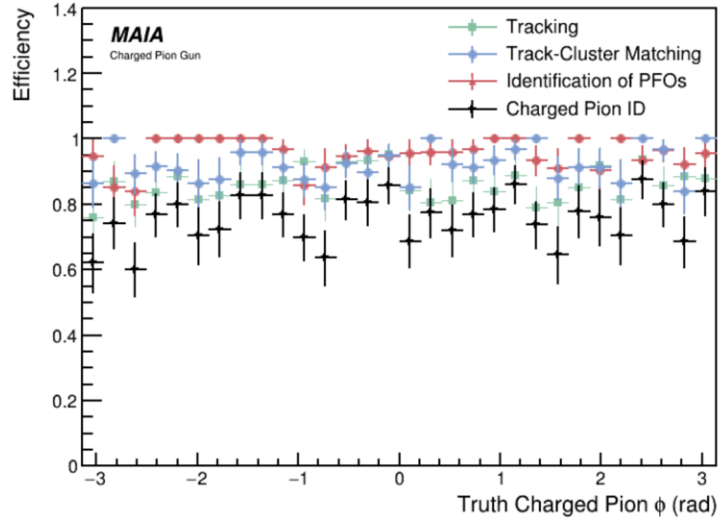








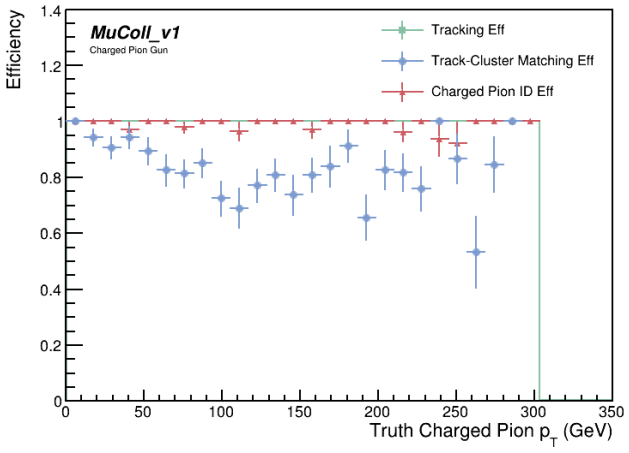


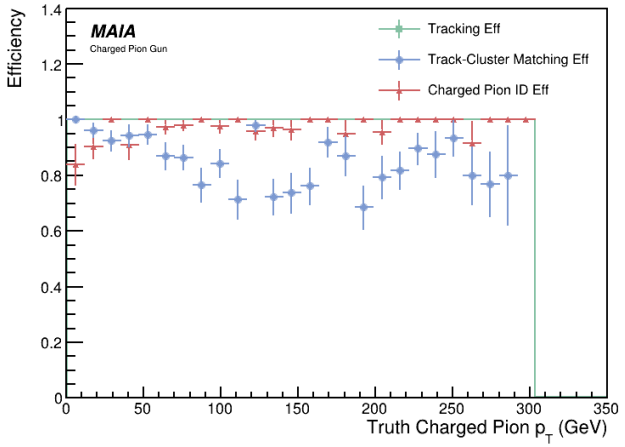


Hcal Cell Thresholds

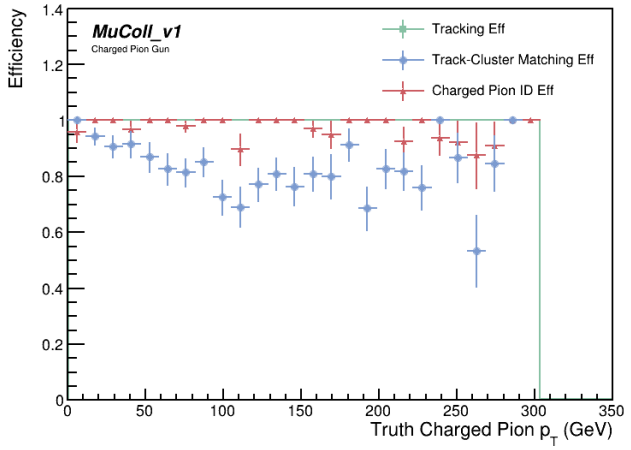
- Lorenzo Valla found that in MuColl_v1, charged pion ID performance was sensitive to HCal cell threshold
- We aren't seeing this effect

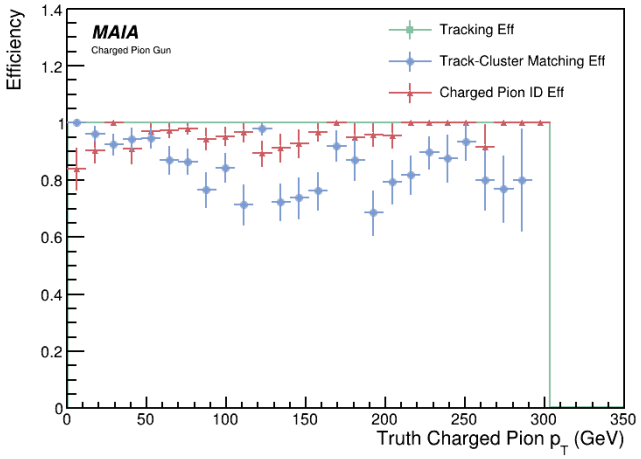
HCal Cell Threshold:
250 keV





HCal Cell Threshold:
2 MeV





HCal Cell Threshold:
1 GeV