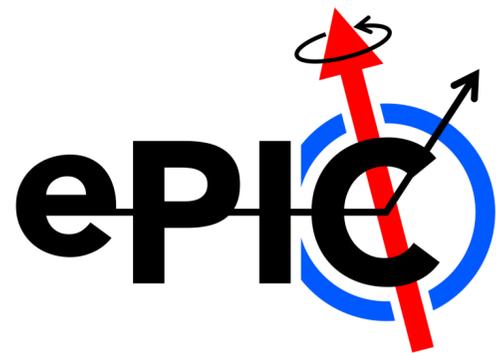


# EIC Tracking Meeting: Role of $\chi^2$ in track finding

ePIC Tracking WG Meeting,  
Vassu Doomra, UC Berkeley  
Feb 26, 2026



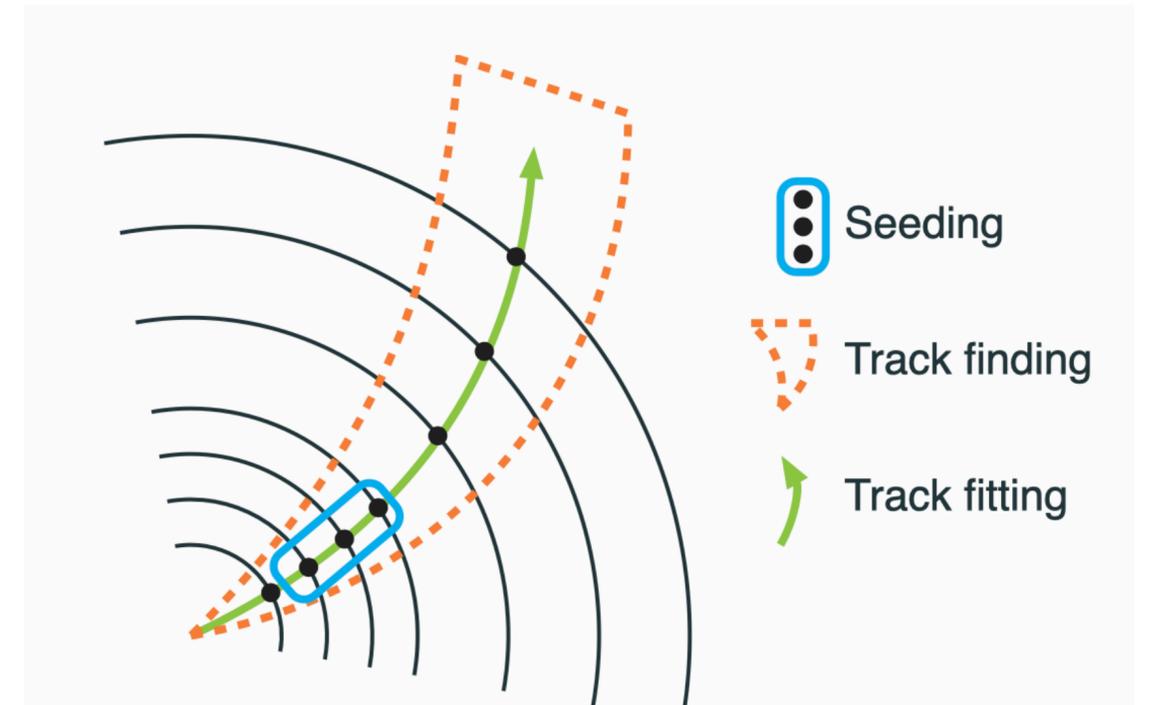
**Berkeley**  
UNIVERSITY OF CALIFORNIA

# How is $\chi^2$ evaluated?

```
// Get the residuals
ParametersVector res =
    calibrated - subspaceHelper.projectVector(predicted);
```

```
// Get the chi2
return (res.transpose() *
        (calibratedCovariance +
         subspaceHelper.projectMatrix(predictedCovariance))
        .inverse() *
        res)
    .eval()(0, 0);
});
```

## [Function Definition in ACTS](#)



## Residuals:

- Calibrated track state  $\rightarrow$  Measurement at a given detector surface in local coordinates
- Predicted track state  $\rightarrow$  Predicted track state projected onto the measurement space

## Covariance : The corresponding uncertainty in the track state

- Measurement Covariance
- Predicted Covariance

# How is $\chi^2$ evaluated?

```
double chi2 = calculateChi2(  
    trackState.effectiveCalibrated().data(),  
    trackState.effectiveCalibratedCovariance().data(),  
    trackState.predicted(), trackState.predictedCovariance(),  
    trackState.projectorSubspaceIndices(), trackState.calibratedSize());  
trackState.chi2() = chi2;
```

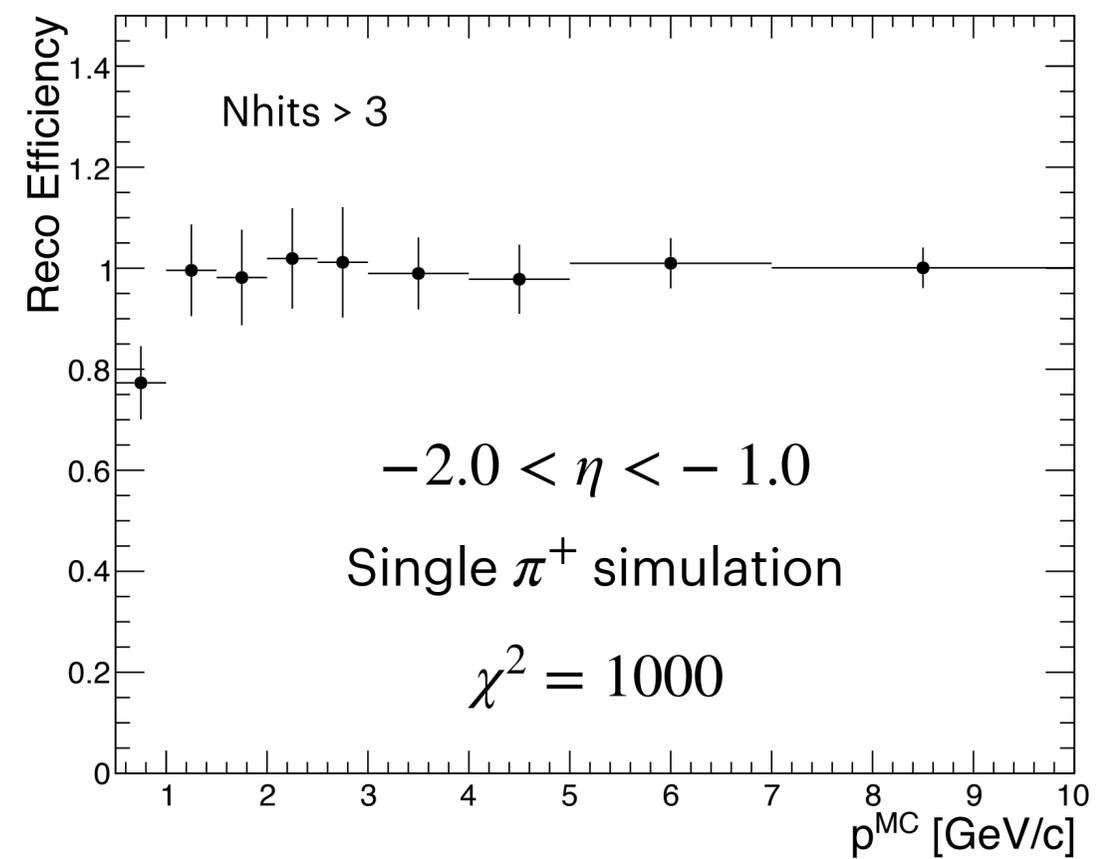
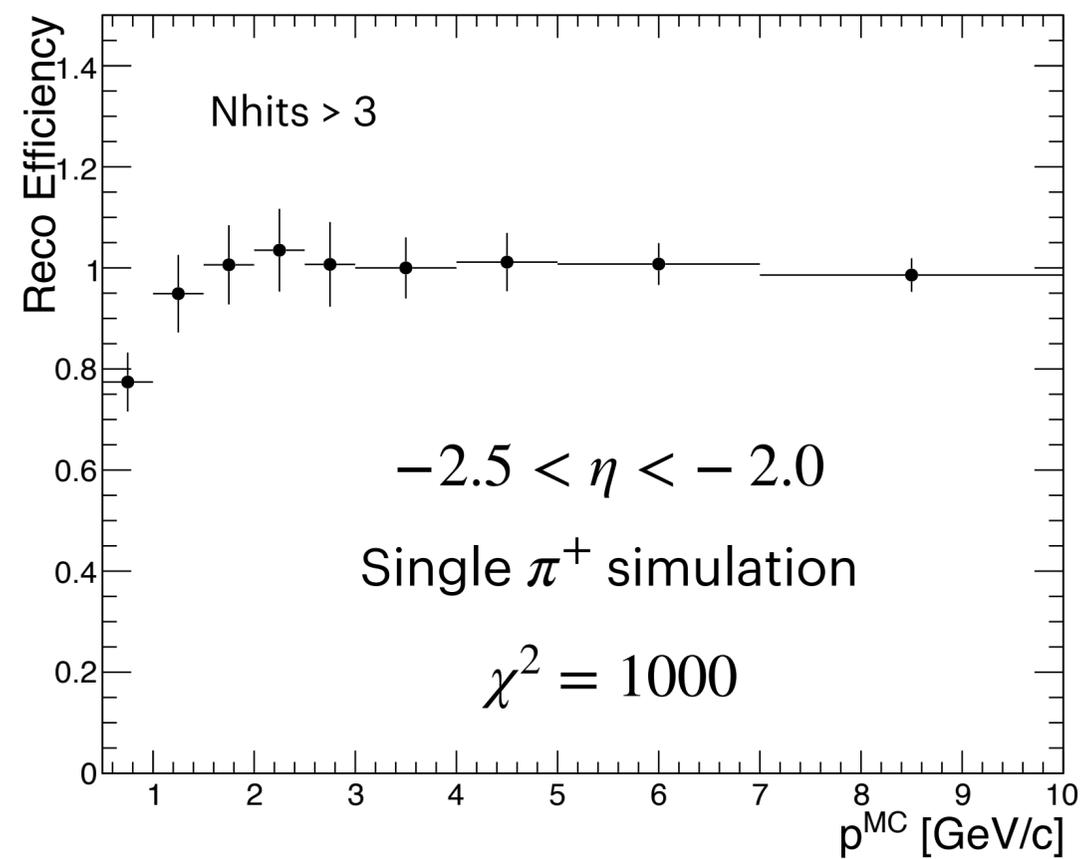
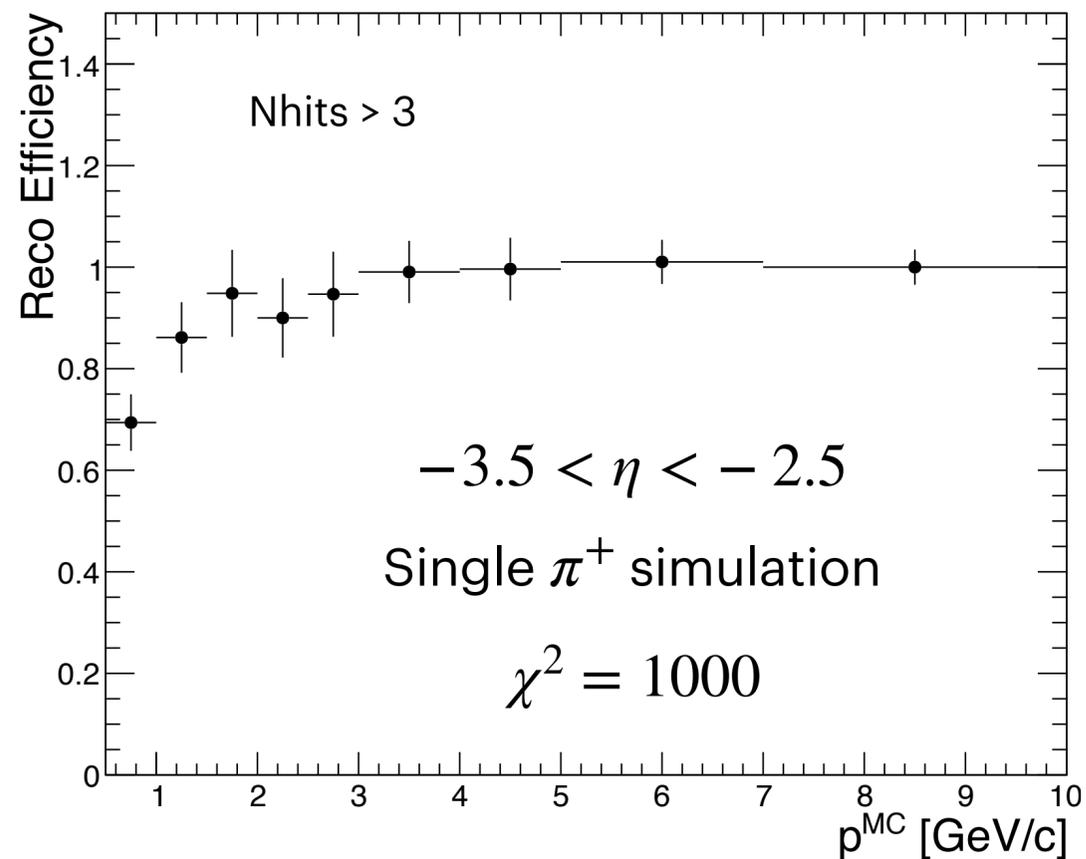
```
if (chi2 < minChi2) {  
    minChi2 = chi2;  
    minIndex = i;  
}  
  
// only consider track states which pass the chi2 cut  
if (chi2 >= cuts.chi2Measurement) {  
    continue;  
}
```

In the ACTS track Finding algorithm, a given detector hit will be considered an outlier or a track measurement is decided by if it satisfies the  $\chi^2$  cutoff which is set to 15 by default.

[ACTS definition of outliers vs measurements](#)

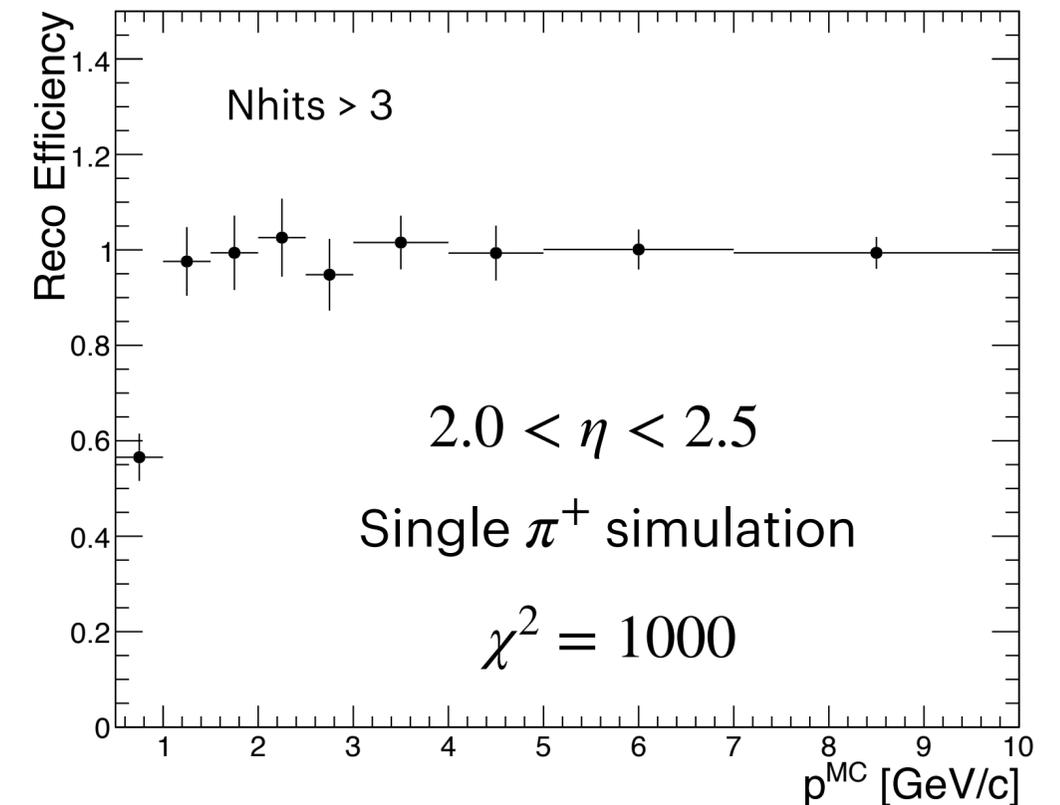
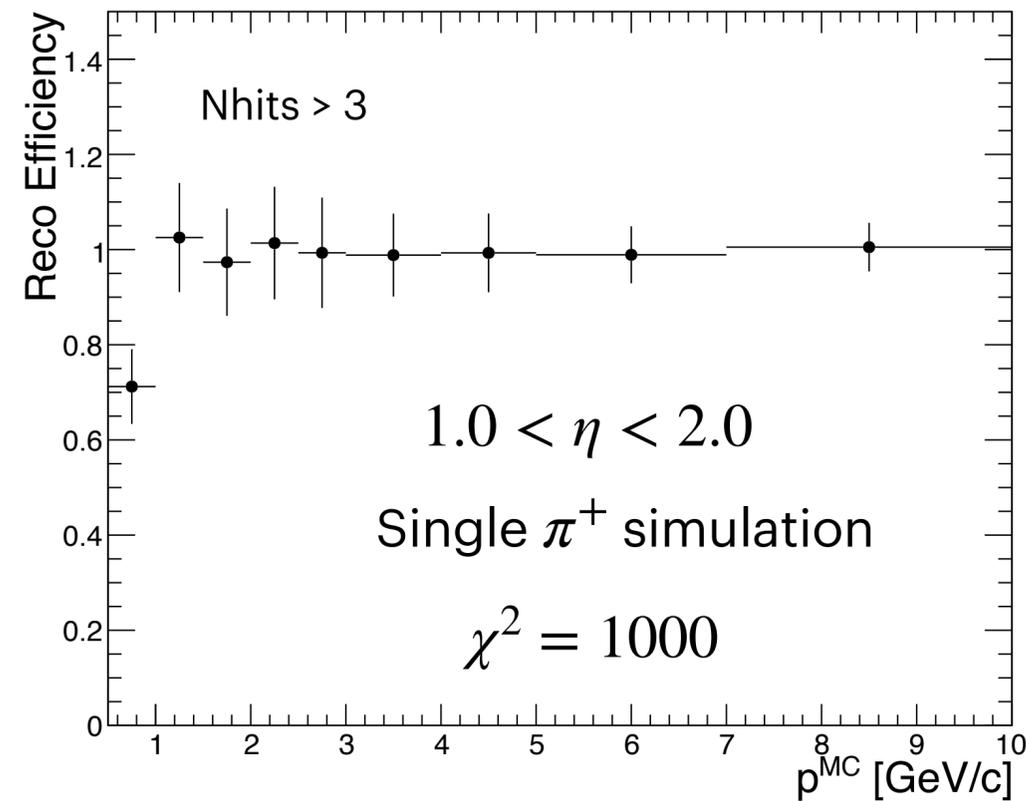
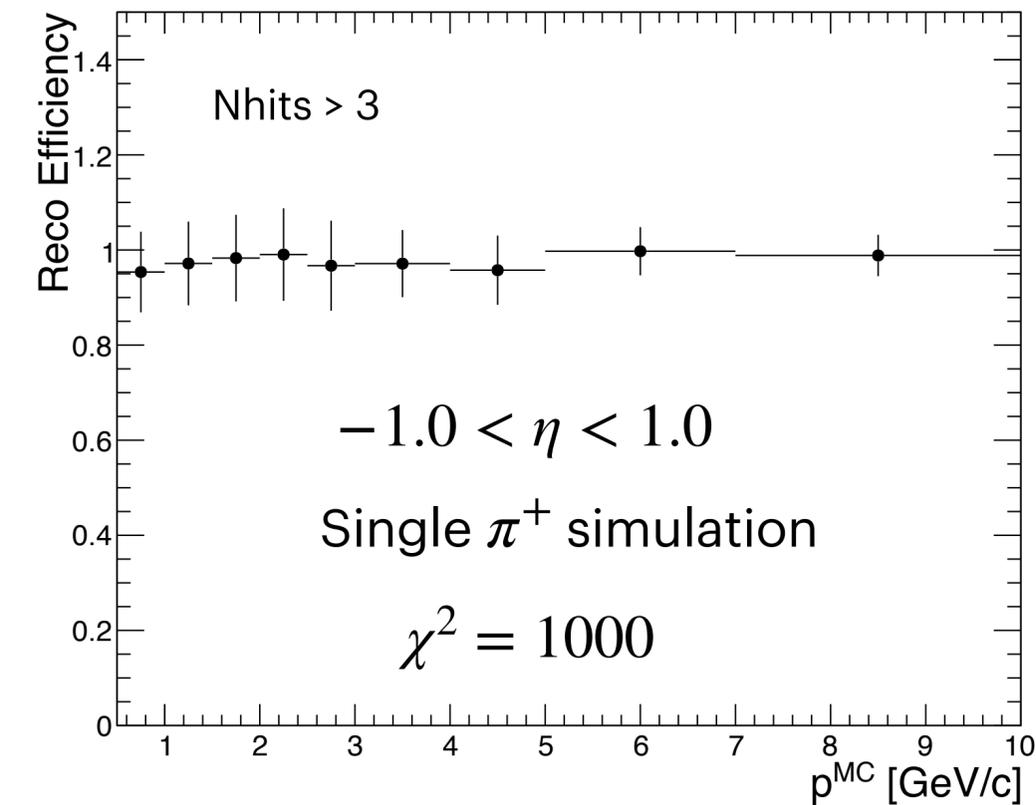
# Revisiting Track Reconstruction Efficiency with Nhits > 3 (ePIC version 26.02 Updated Material Map)

This is the ideal case scenario with respect to  $\chi^2$  as we are directing ACTS to consider all measurements in its track finding algorithm



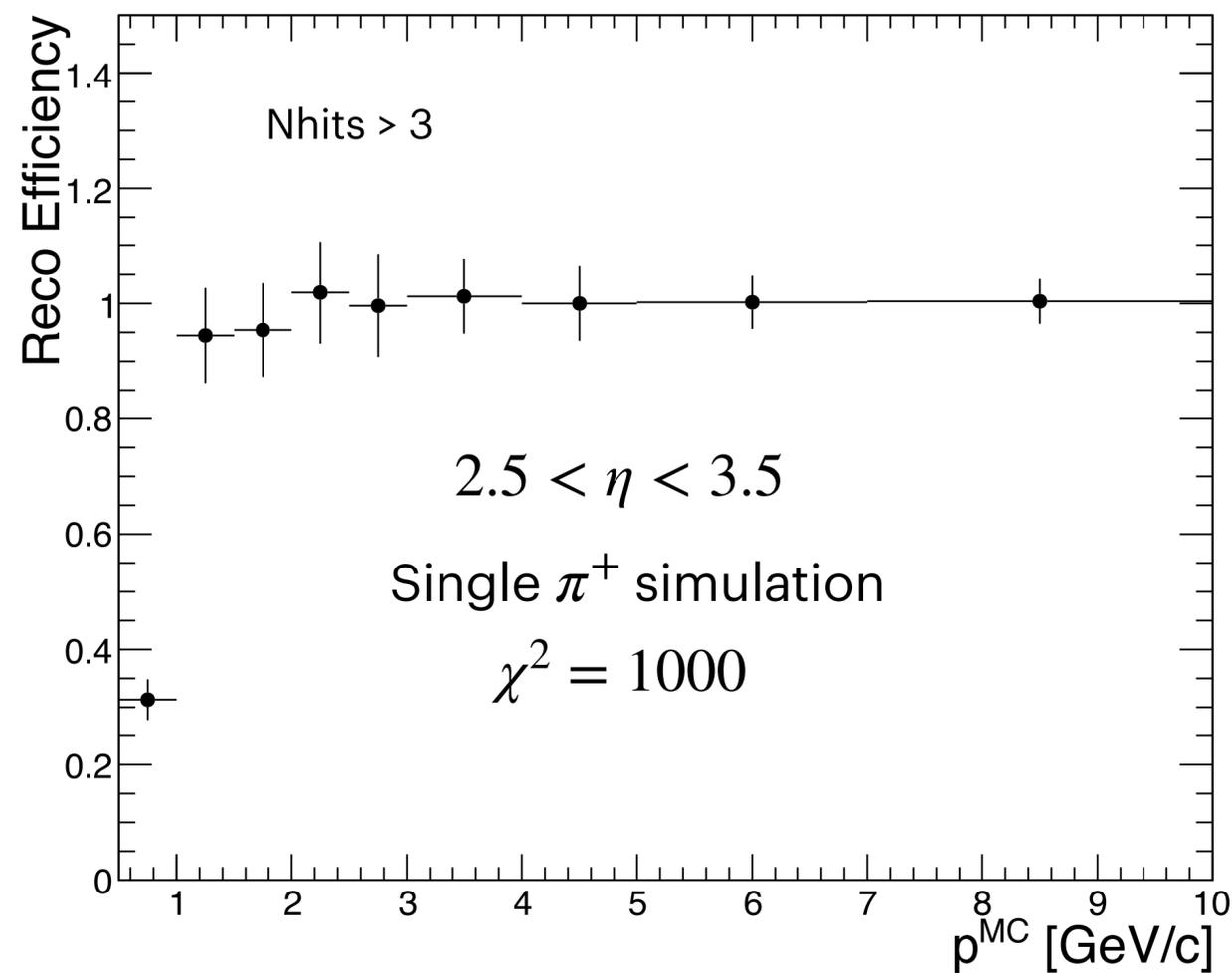
# Revisiting Track Reconstruction Efficiency with $N_{\text{hits}} > 3$ (ePIC version 26.02 Updated Material Map)

This is the ideal case scenario with respect to  $\chi^2$  as we are directing ACTS to consider all measurements in its track finding algorithm



# Revisiting Track Reconstruction Efficiency with $N_{\text{hits}} > 3$ (ePIC version 26.02 Updated Material Map)

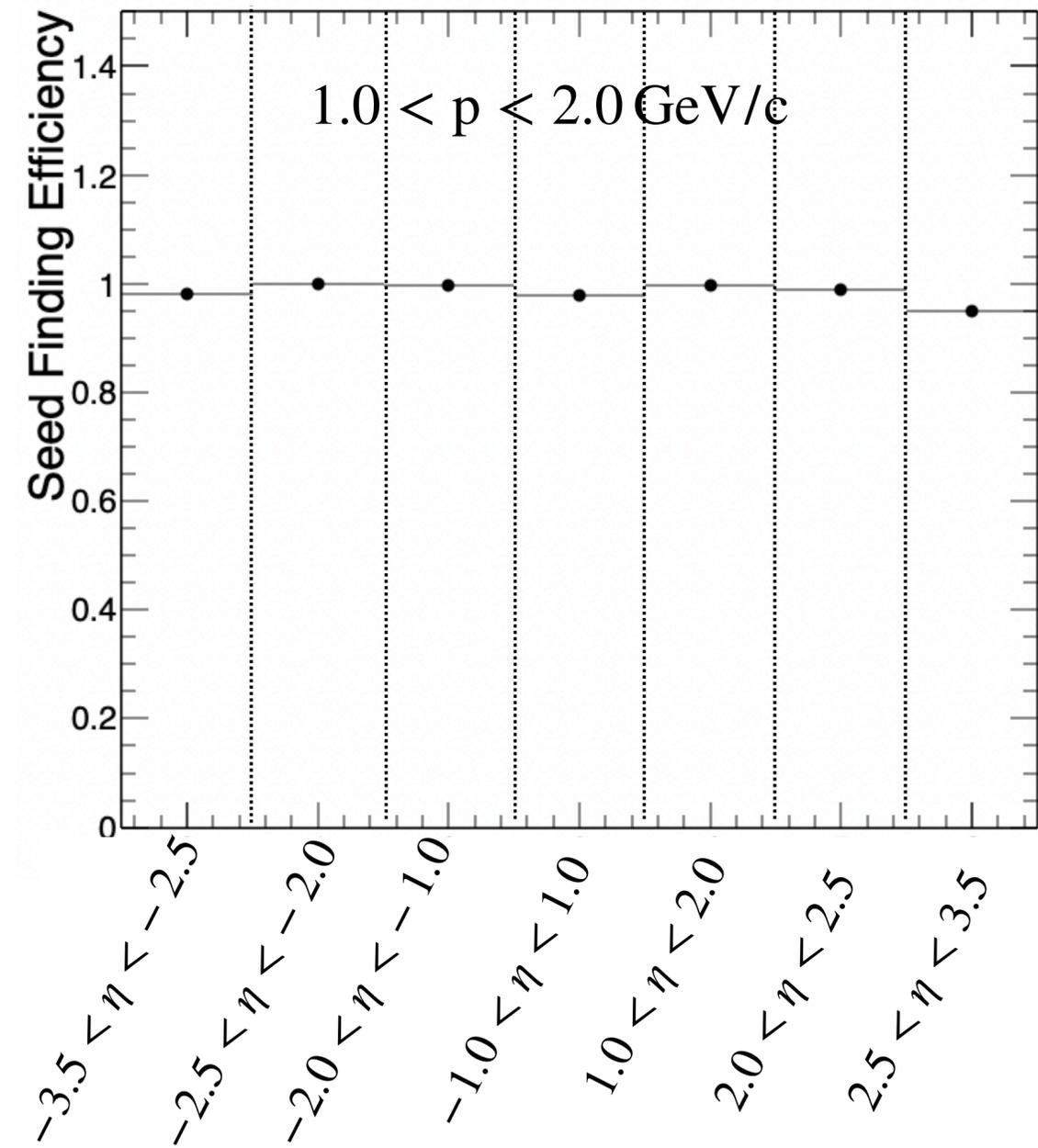
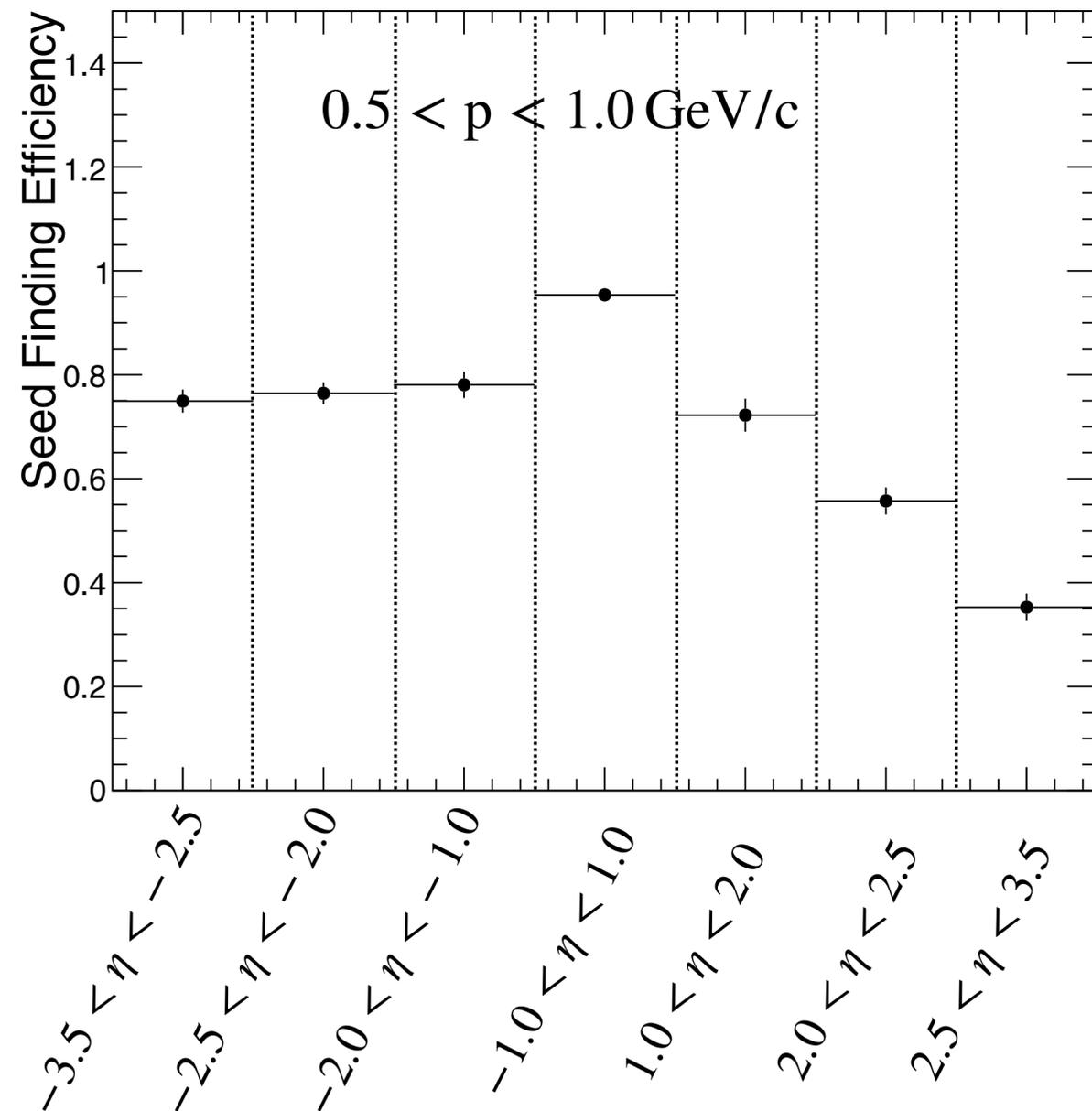
This is the ideal case scenario with respect to  $\chi^2$  as we are directing ACTS to consider all measurements in its track finding algorithm



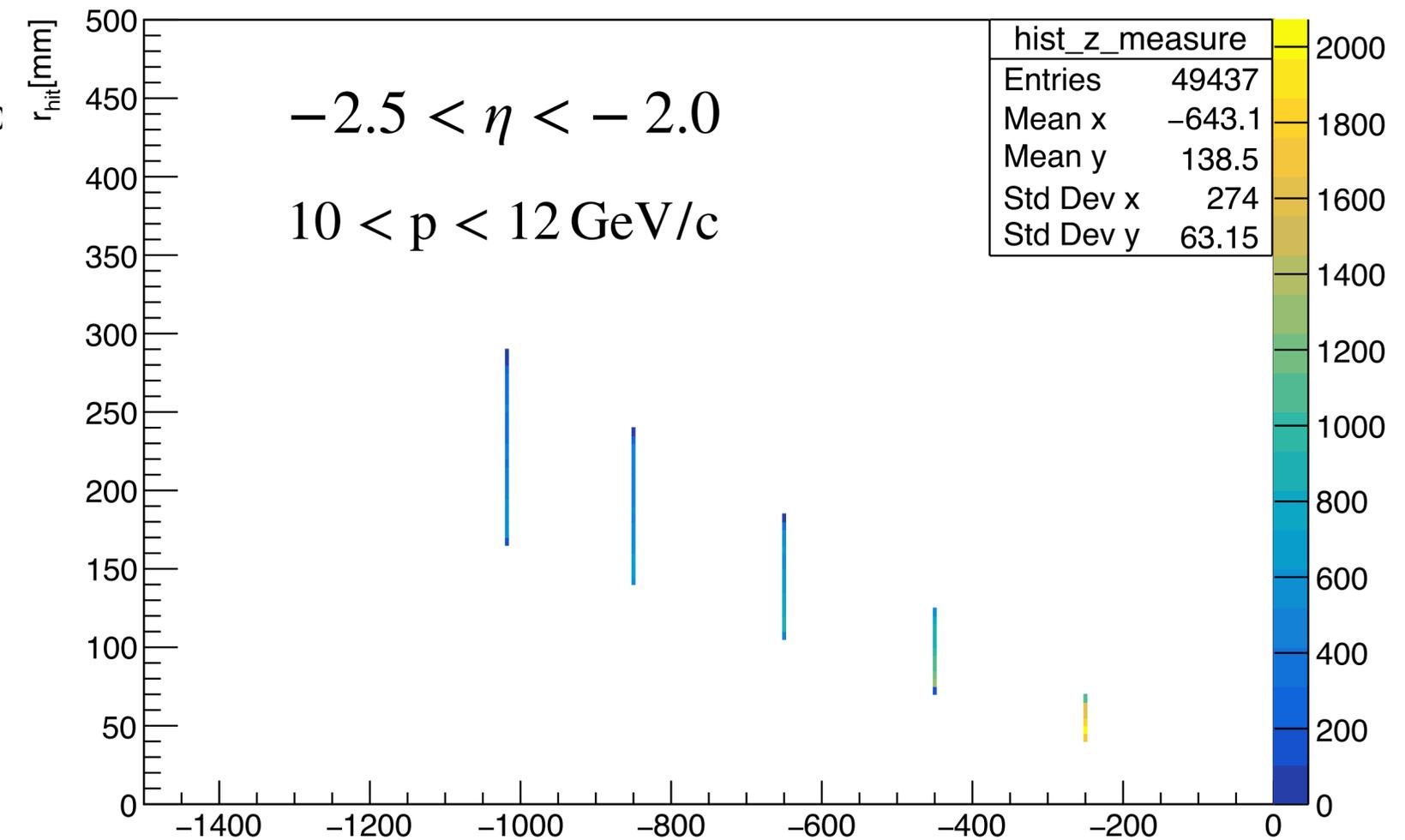
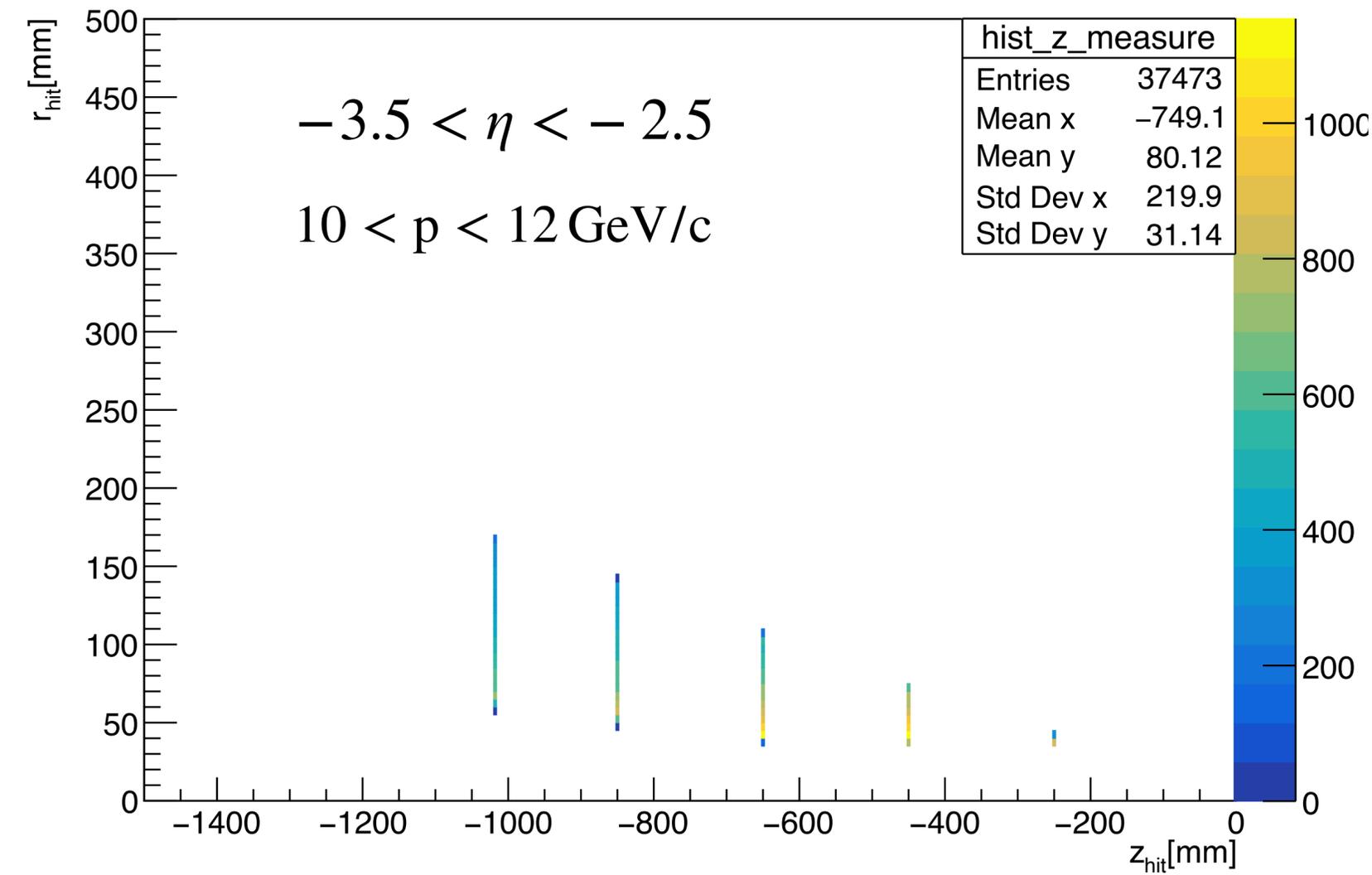
- Track reconstruction efficiency is generally good under this ideal condition, except in the lowest momentum bin, where performance drops.
- Efficiency decreases moving away from the central barrel region.
- Between the end-caps, efficiency is lowest in the hadron end-cap region.

# Before moving onto the $\chi^2$ distributions let's first address the poor tracking efficiency in the lowest momentum bin $0.5 < p < 1.0 \text{ GeV}/c$

Seeding seems to be causing this effect!



# Acceptance also plays a role!



# Output at the Simulated Level for different Collections

$$2.5 < \eta < 3.5$$

```

For event 99:
Number of SimHit collections = 9

Number of VertexBarrelHits = 0
Hit Collection ID | Hit Index | Hit CellID | Hit Quality | MC Index | MC PDG ID | MC Status

Number of SiBarrelHits = 0
Hit Collection ID | Hit Index | Hit CellID | Hit Quality | MC Index | MC PDG ID | MC Status

Number of TrackerEndcapHits = 4
Hit Collection ID | Hit Index | Hit CellID | Hit Quality | MC Index | MC PDG ID | MC Status
1948551886 | 0 | 16066590966286397774 | 0 | 0 | 211 | 1
1948551886 | 1 | 16444330750104322639 | 0 | 0 | 211 | 1
1948551886 | 2 | 16838959346057499471 | 0 | 0 | 211 | 1
1948551886 | 3 | 17270180174314366031 | 0 | 0 | 211 | 1

Number of MPGDBarrelHits = 0
Hit Collection ID | Hit Index | Hit CellID | Hit Quality | MC Index | MC PDG ID | MC Status

Number of BackwardMPGDEndcapHits = 0
Hit Collection ID | Hit Index | Hit CellID | Hit Quality | MC Index | MC PDG ID | MC Status

Number of ForwardMPGDEndcapHits = 2
Hit Collection ID | Hit Index | Hit CellID | Hit Quality | MC Index | MC PDG ID | MC Status
3309489006 | 0 | 18412967119454019922 | 0 | 0 | 211 | 1
3309489006 | 1 | 18420285413013922386 | 0 | 0 | 211 | 1

Number of OuterMPGDBarrelHits = 0
Hit Collection ID | Hit Index | Hit CellID | Hit Quality | MC Index | MC PDG ID | MC Status

Number of TOFBarrelHits = 0
Hit Collection ID | Hit Index | Hit CellID | Hit Quality | MC Index | MC PDG ID | MC Status

Number of TOFEndcapHits = 2
Hit Collection ID | Hit Index | Hit CellID | Hit Quality | MC Index | MC PDG ID | MC Status
337981489 | 0 | 17735053859258746 | 0 | 0 | 211 | 1
337981489 | 1 | 16609360110846330 | 0 | 1 | 11 | 0
    
```

Hits are present at the MC level

```

Number of RecHit collections = 9

Number of SiBarrelVertexRecHits = 0
Hit Collection ID | Hit Index | Hit CellID

Number of SiBarrelTrackerRecHits = 0
Hit Collection ID | Hit Index | Hit CellID

Number of SiEndcapTrackerRecHits = 4
Hit Collection ID | Hit Index | Hit CellID
480846150 | 0 | 17270180174314366031
480846150 | 1 | 16838959346057499471
480846150 | 2 | 16444330750104322639
480846150 | 3 | 16066590966286397774

Number of MPGDBarrelRecHits = 0
Hit Collection ID | Hit Index | Hit CellID

Number of BackwardMPGDEndcapRecHits = 0
Hit Collection ID | Hit Index | Hit CellID

Number of ForwardMPGDEndcapRecHits = 2
Hit Collection ID | Hit Index | Hit CellID
695150340 | 0 | 18420285413013922386
695150340 | 1 | 18412967119454019922

Number of OuterMPGDBarrelRecHits = 0
Hit Collection ID | Hit Index | Hit CellID

Number of TOFBarrelRecHits = 0
Hit Collection ID | Hit Index | Hit CellID

Number of TOFEndcapRecHits = 2
Hit Collection ID | Hit Index | Hit CellID
484488104 | 0 | 16609360110846330
484488104 | 1 | 17735053859258746
Total Measure2D Hits = 4
    
```

Hits are present at the reco level as well

Seems like it's a seed finding problem!

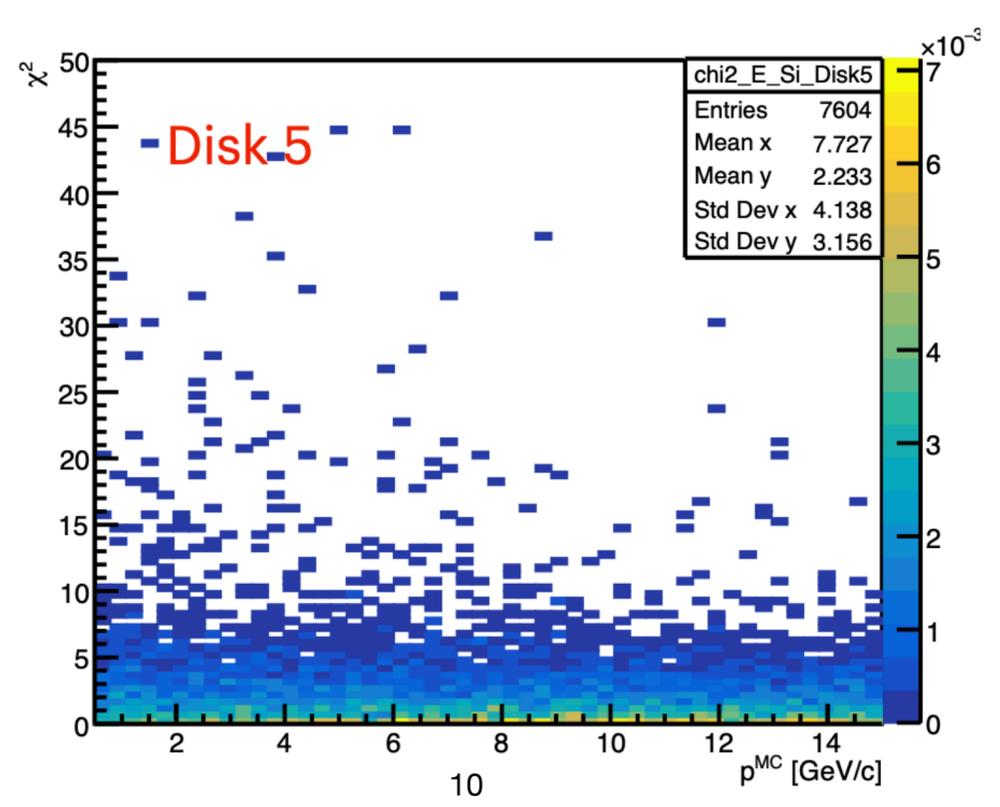
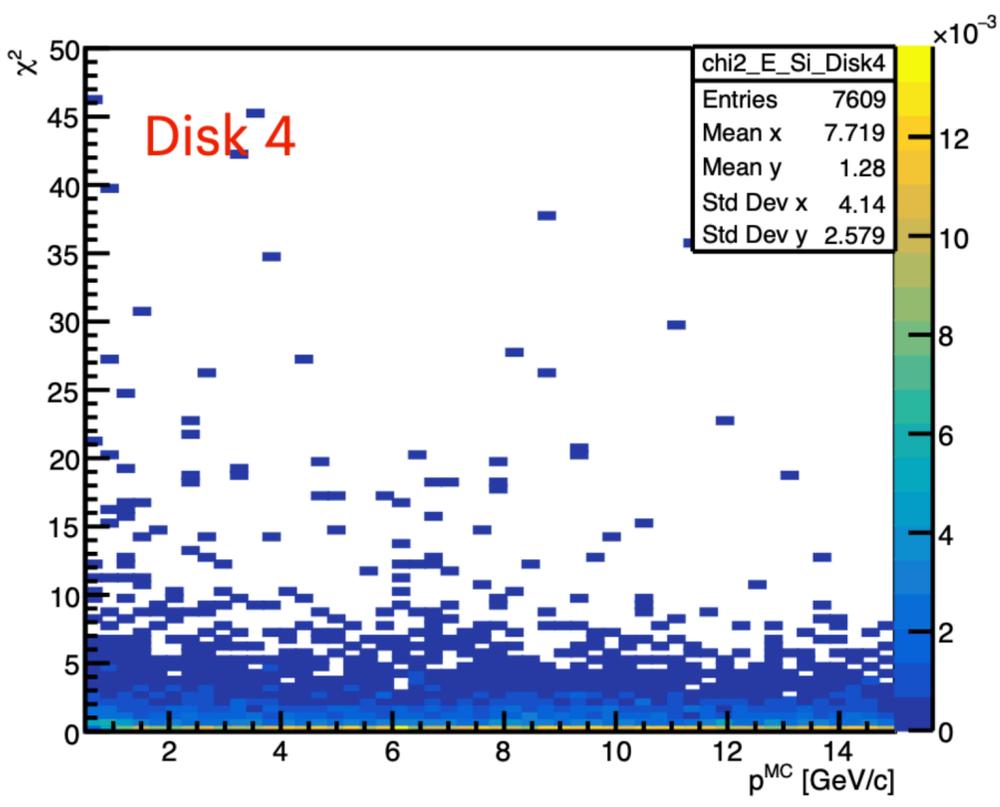
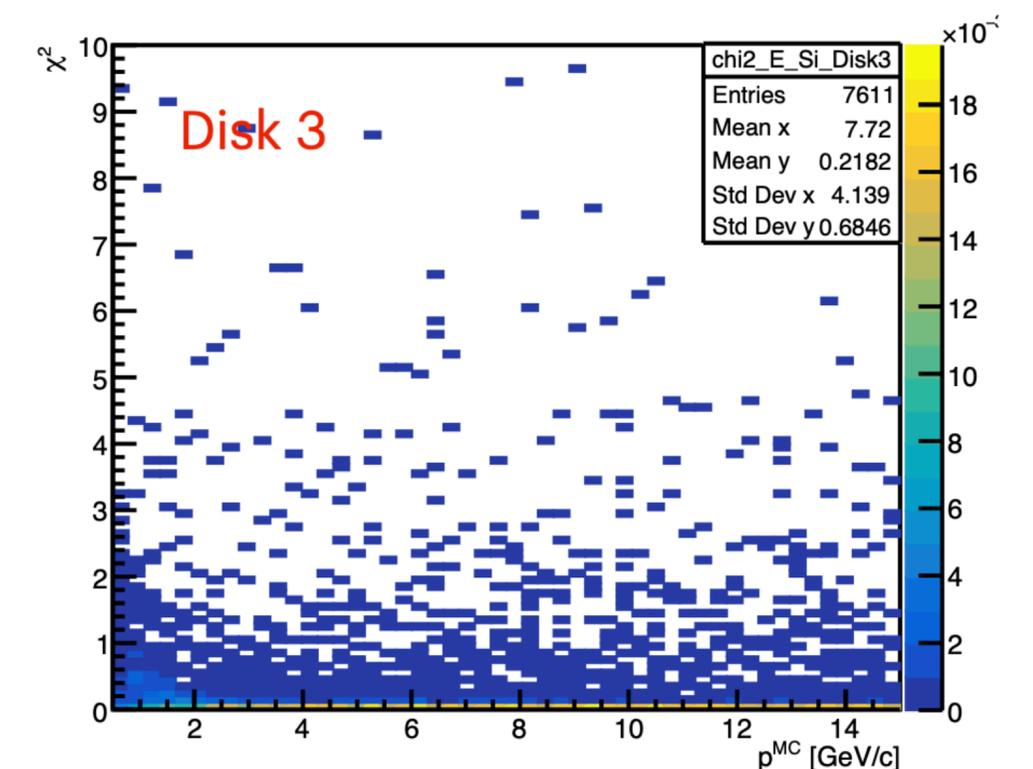
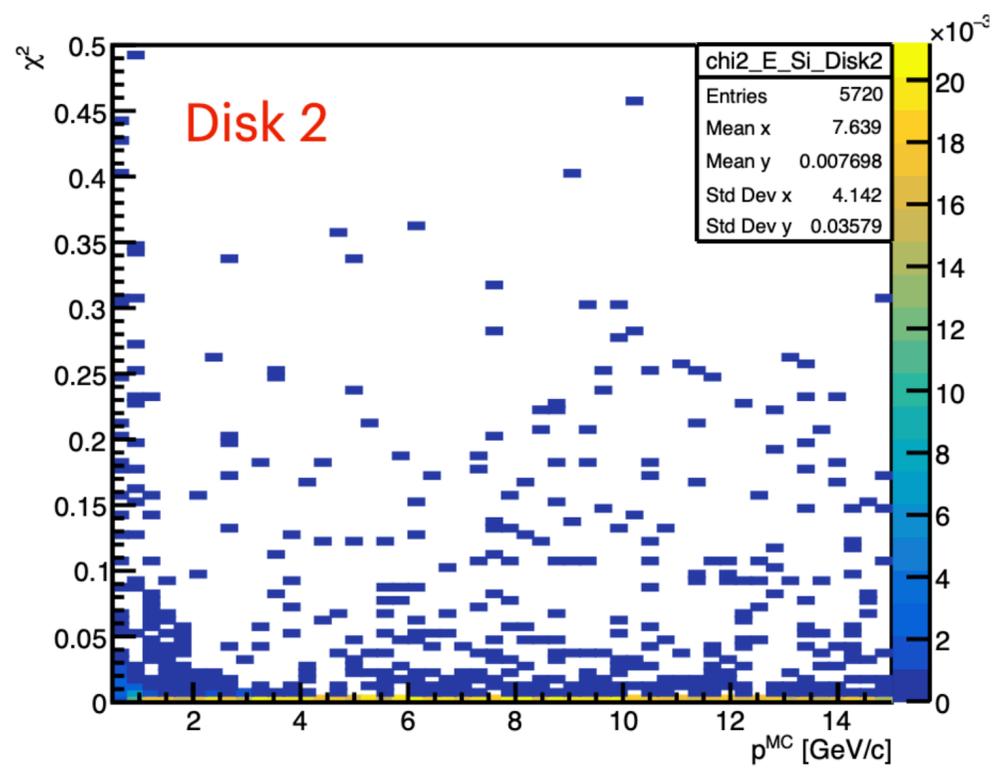
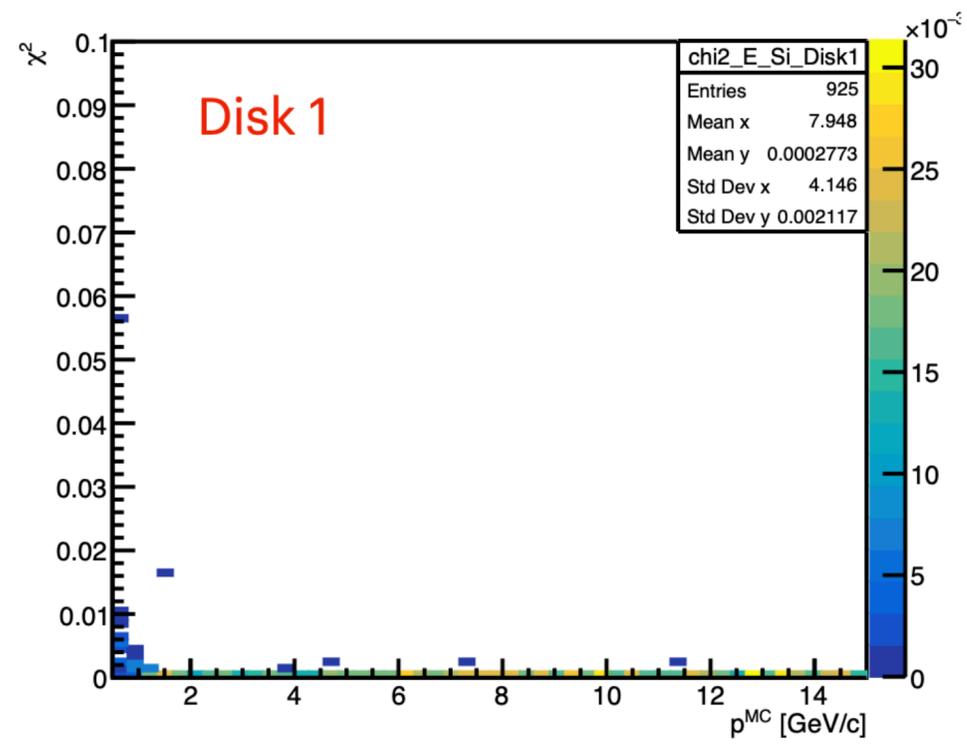


```

Number of tracks = 0

Event statistics:
SimHits (Barrel MPGD corrected) associated with primary particle = 7 / 8
RecHits associated with primary particle = 7
Number of correctly-identified measurement hits = 0 / 0
Number of outlier hits that should be measurement hits = 0 / 0
Number of RecHits associated with primary particle completely missing from track = 7 / 7
    
```

# $\chi^2$ Distributions

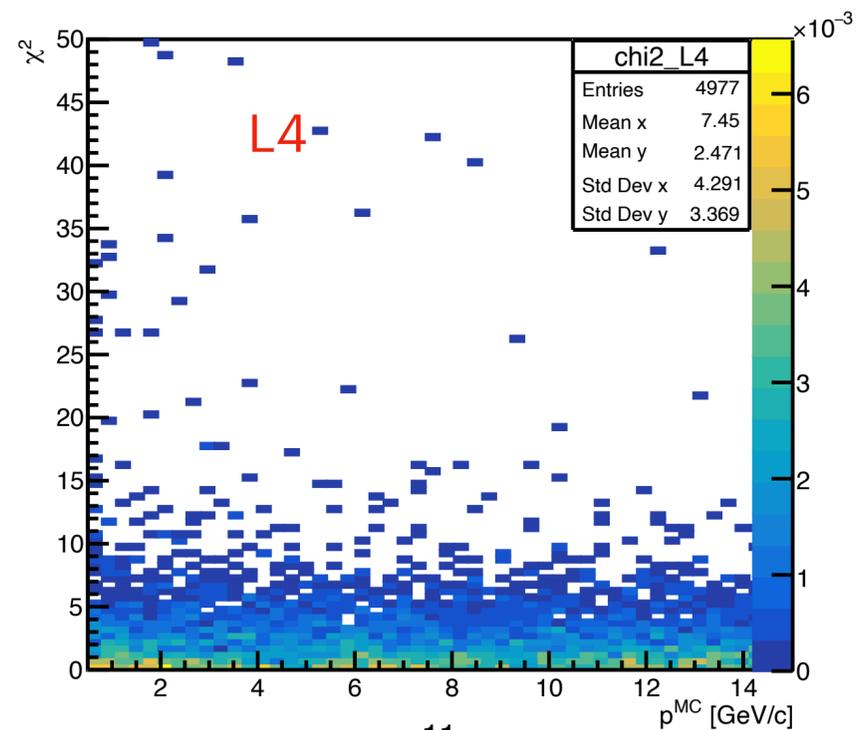
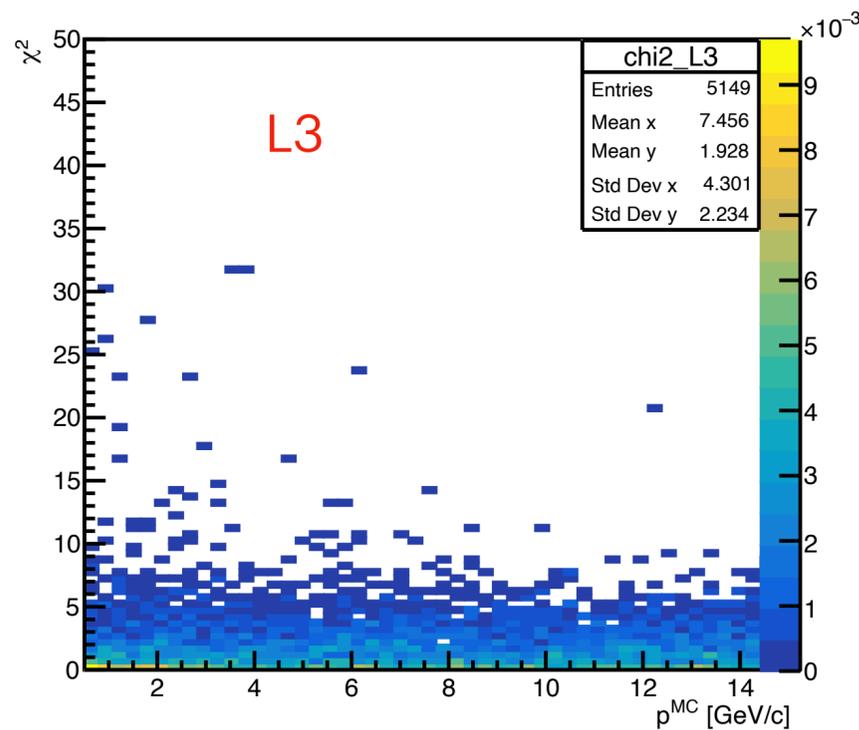
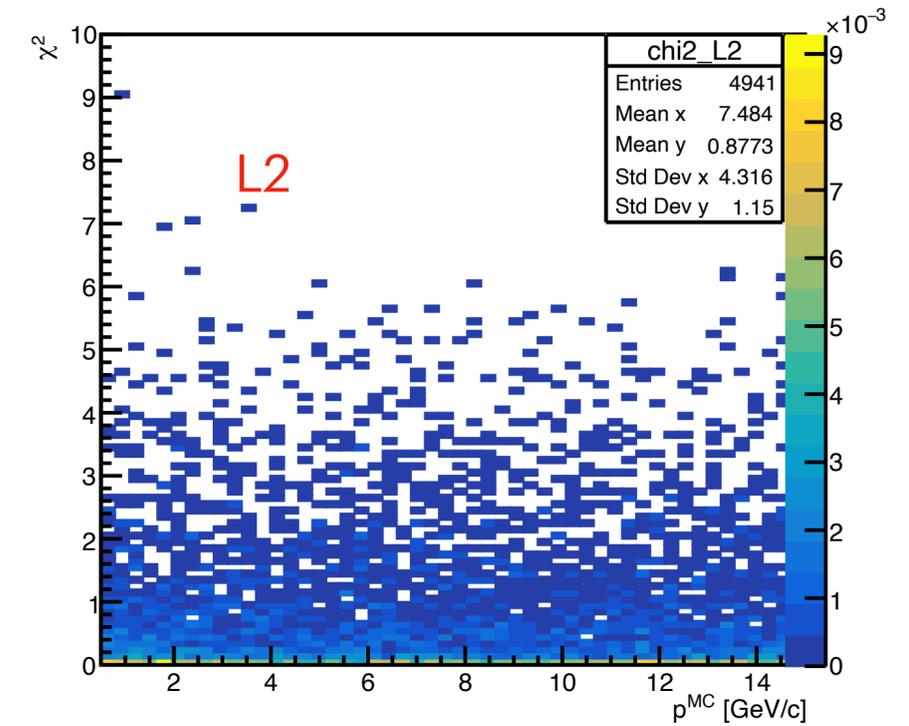
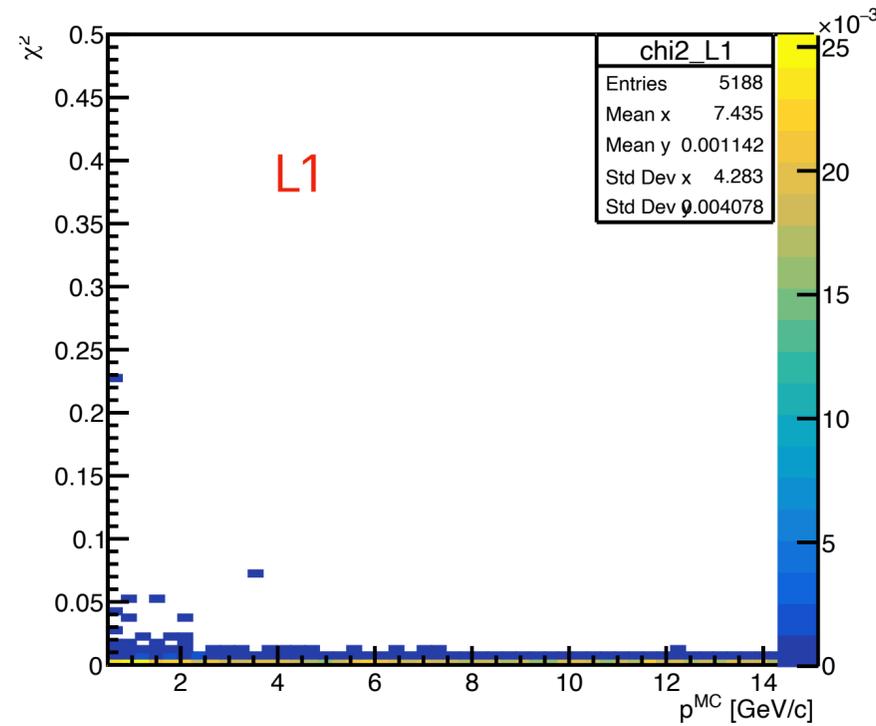
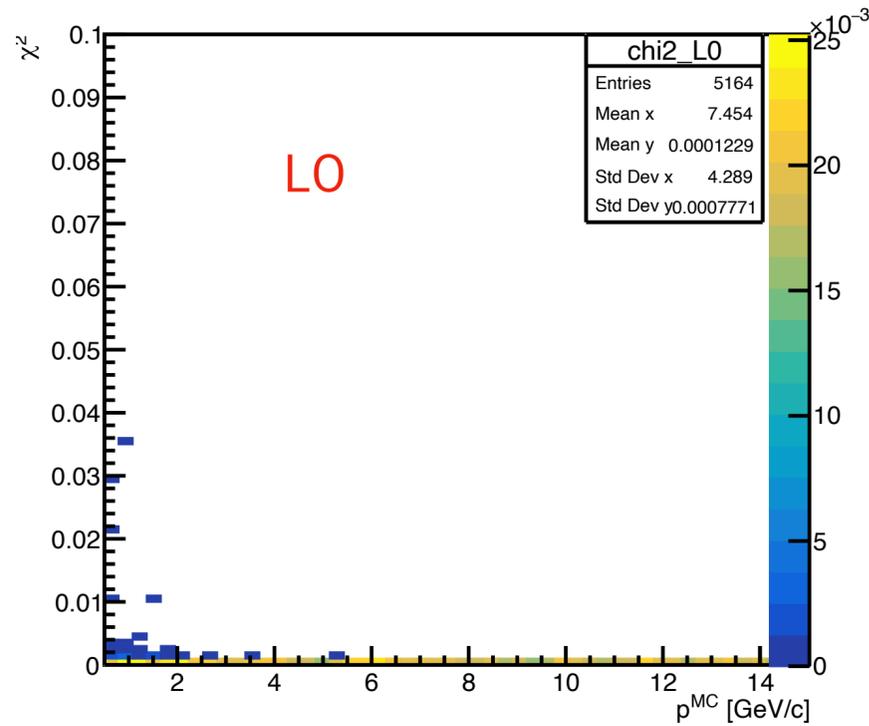


$$-3.5 < \eta < -2.5$$

Please notice the difference in the vertical scales!

We can see a slight momentum dependence

# $\chi^2$ Distributions

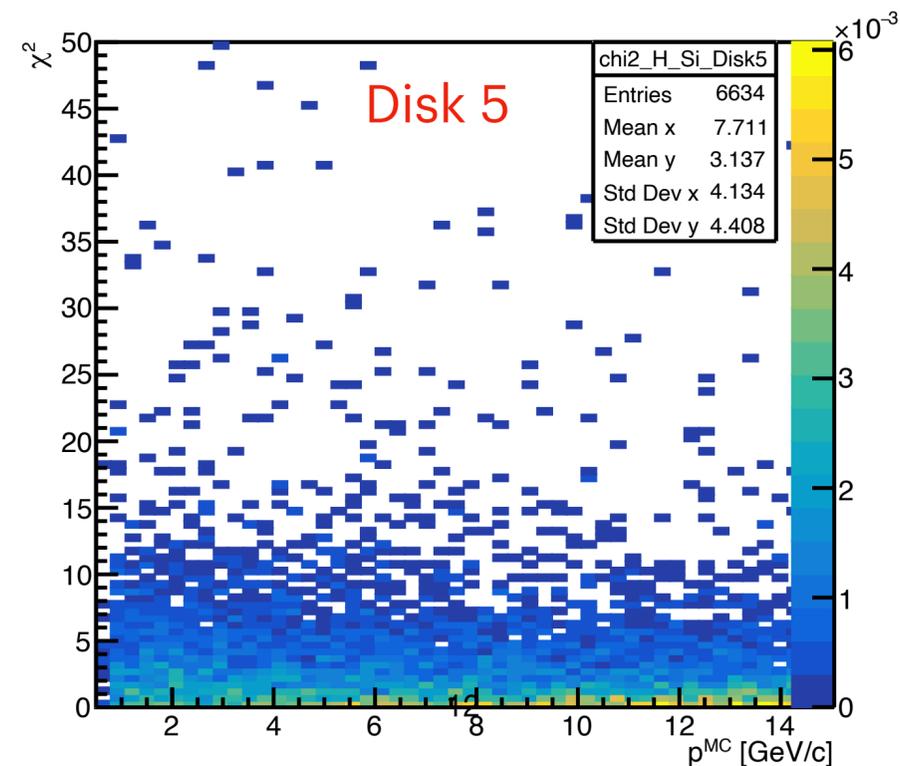
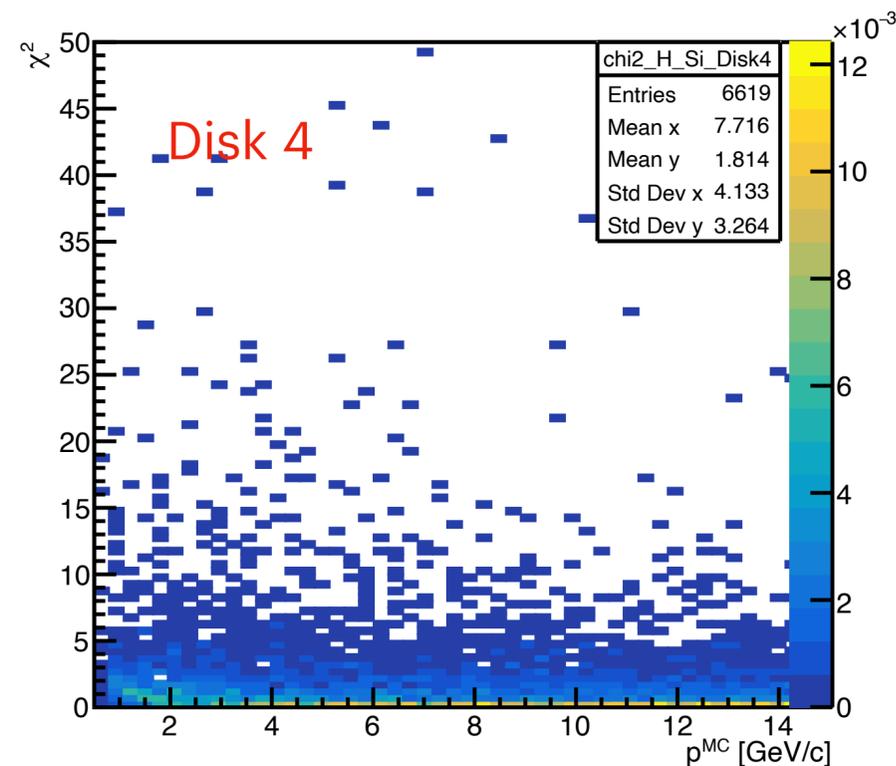
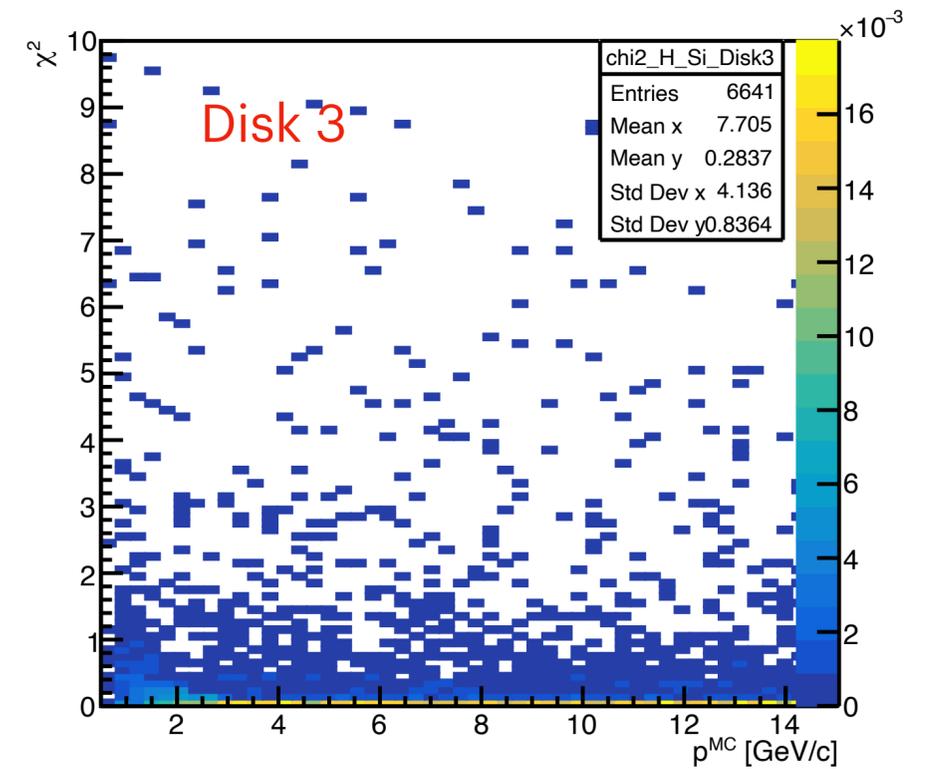
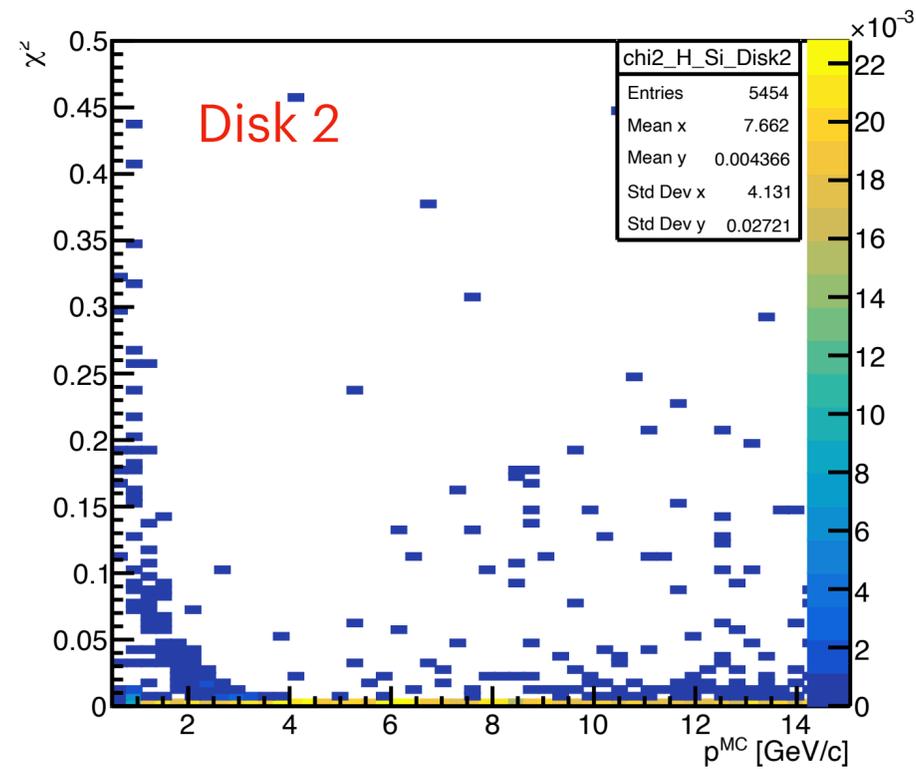
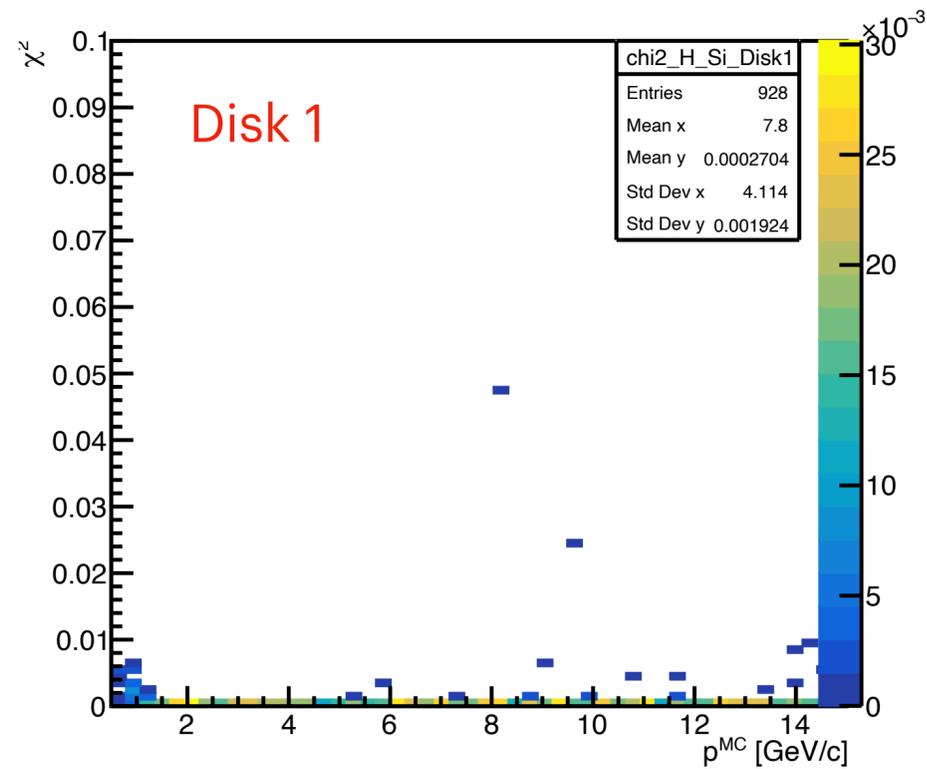


$$-1.0 < \eta < 1.0$$

Please notice the difference in the vertical scales!

We can see a slight momentum dependence

# $\chi^2$ Distributions



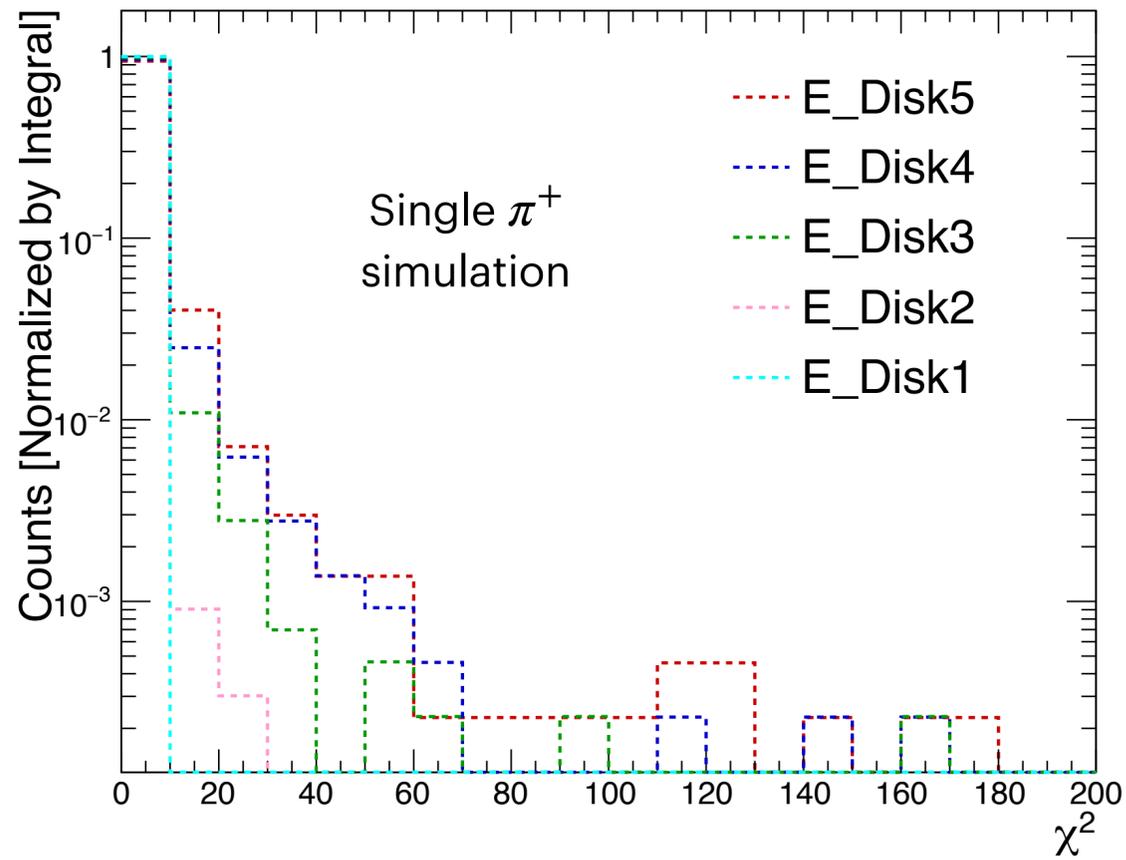
$$2.5 < \eta < 3.5$$

Please notice the difference in the vertical scales!

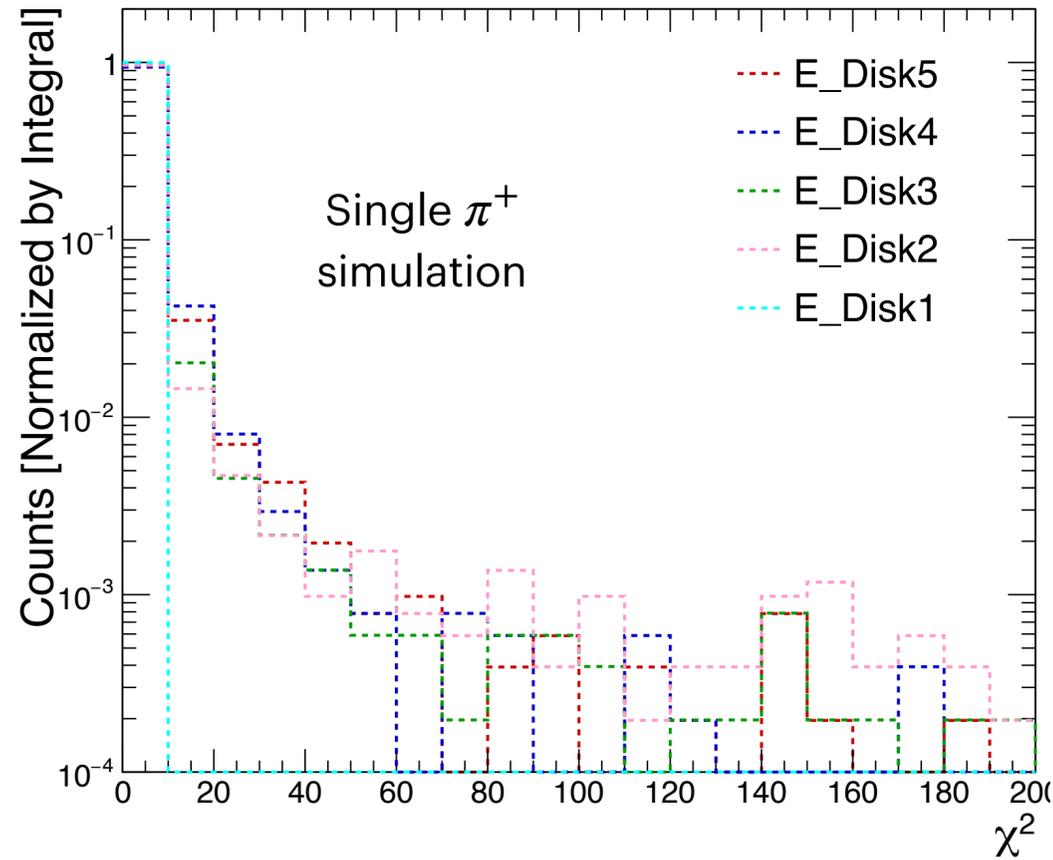
We can see a slight momentum dependence

# $\chi^2$ Distributions

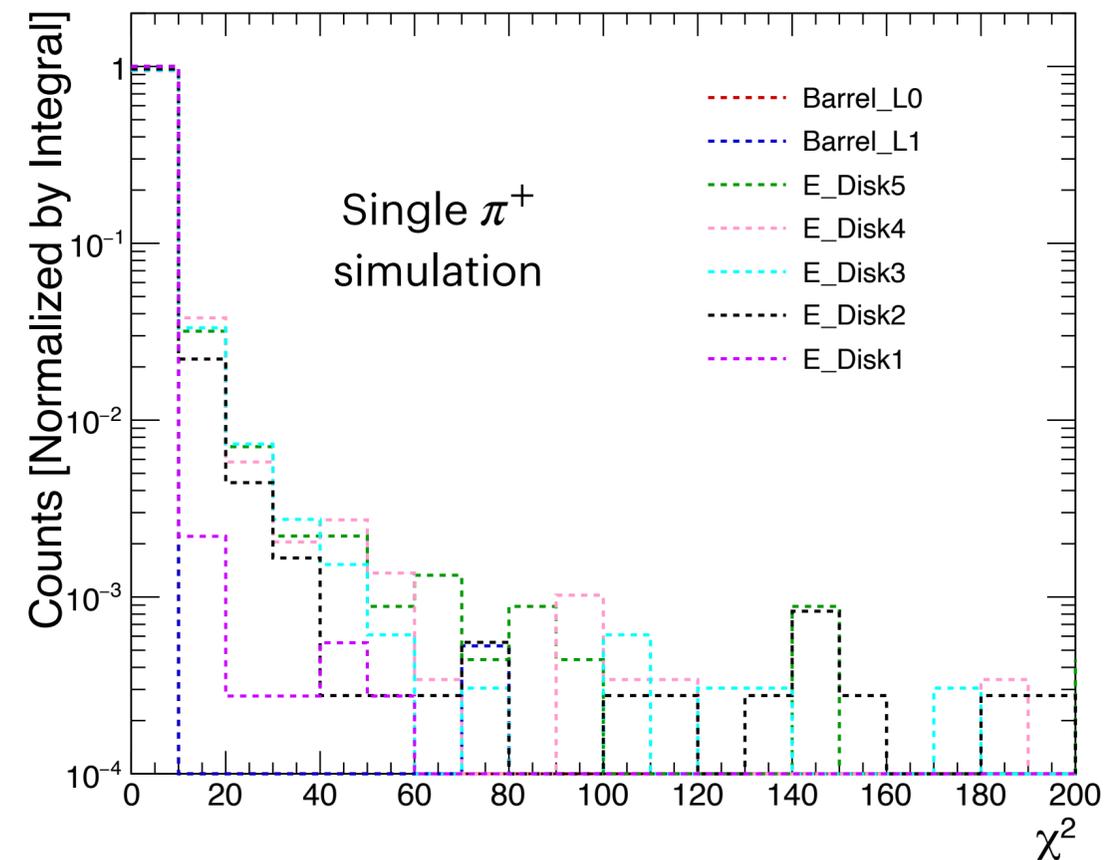
$0.5 < p < 1.0 \text{ GeV}/c$   $-3.5 < \eta < -2.5$



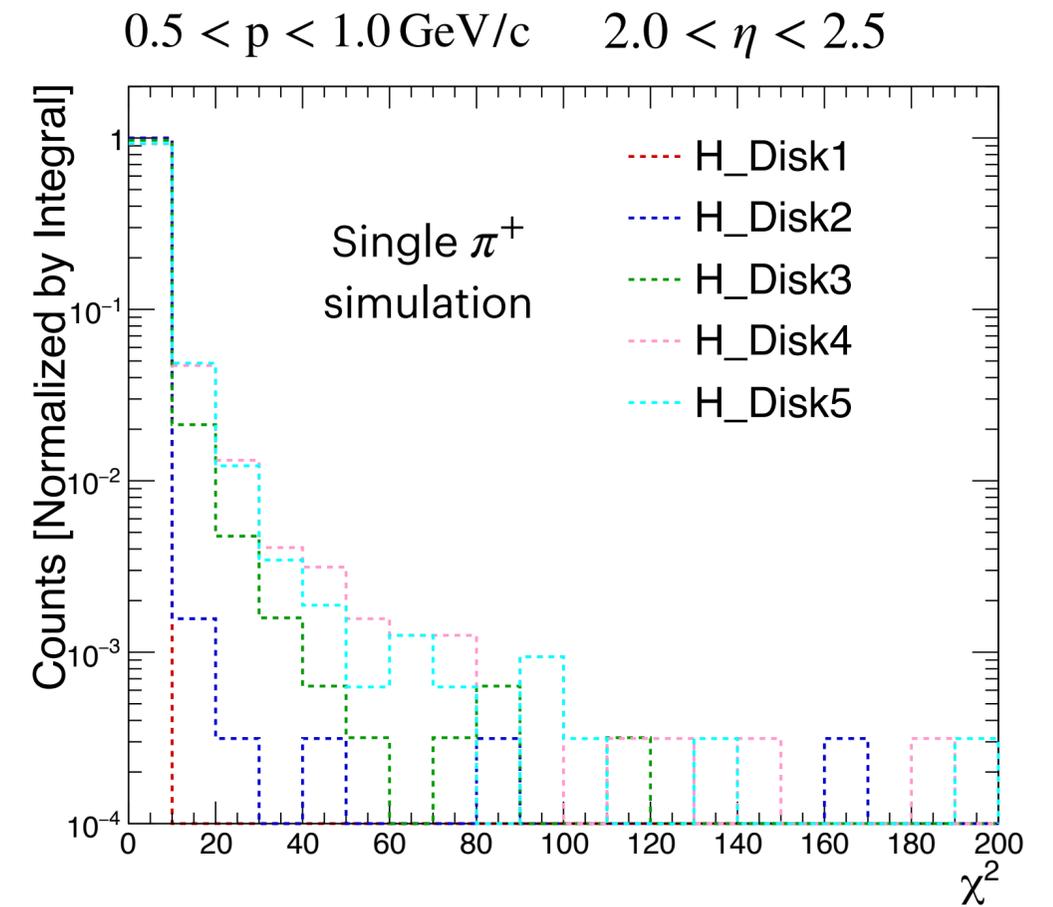
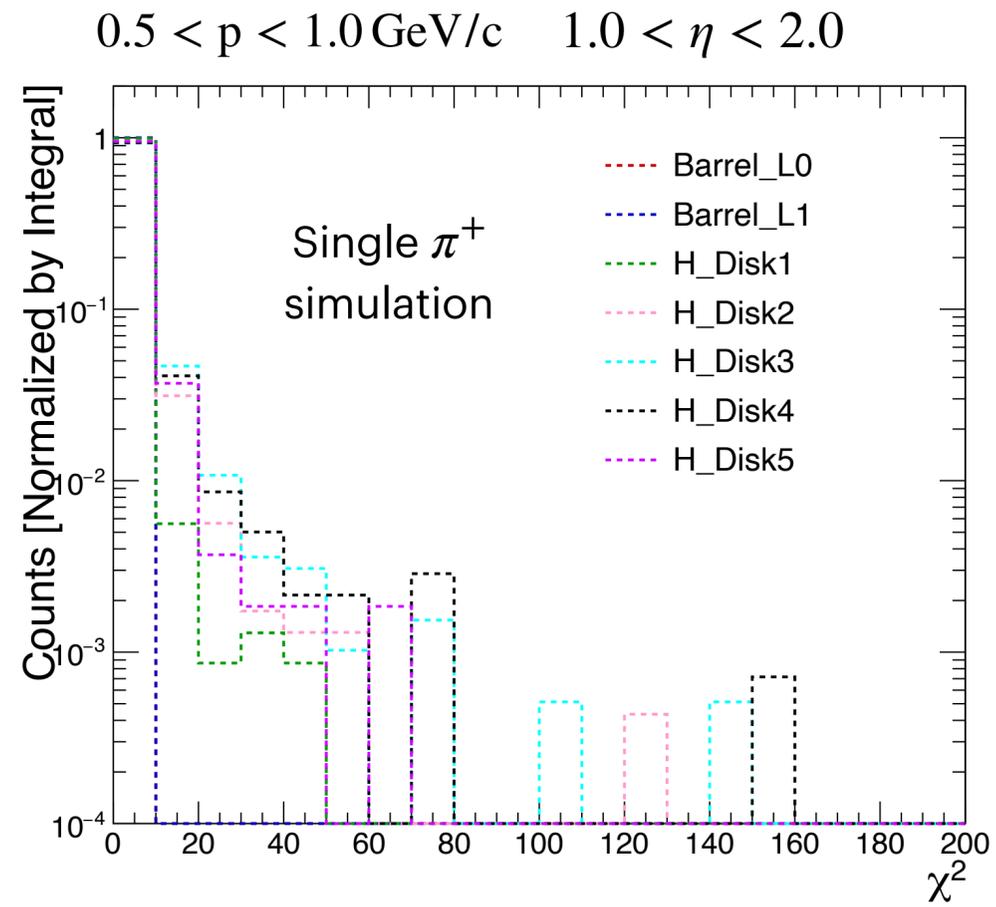
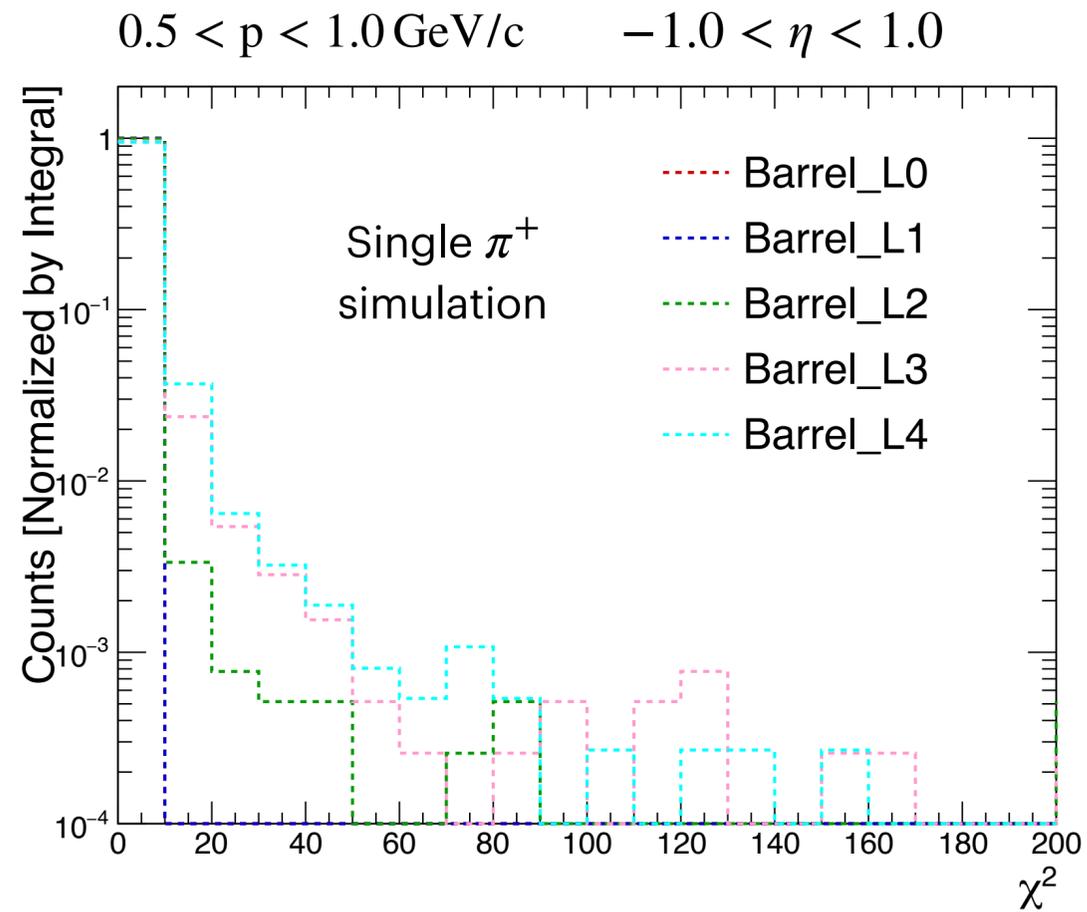
$0.5 < p < 1.0 \text{ GeV}/c$   $-2.5 < \eta < -2.0$



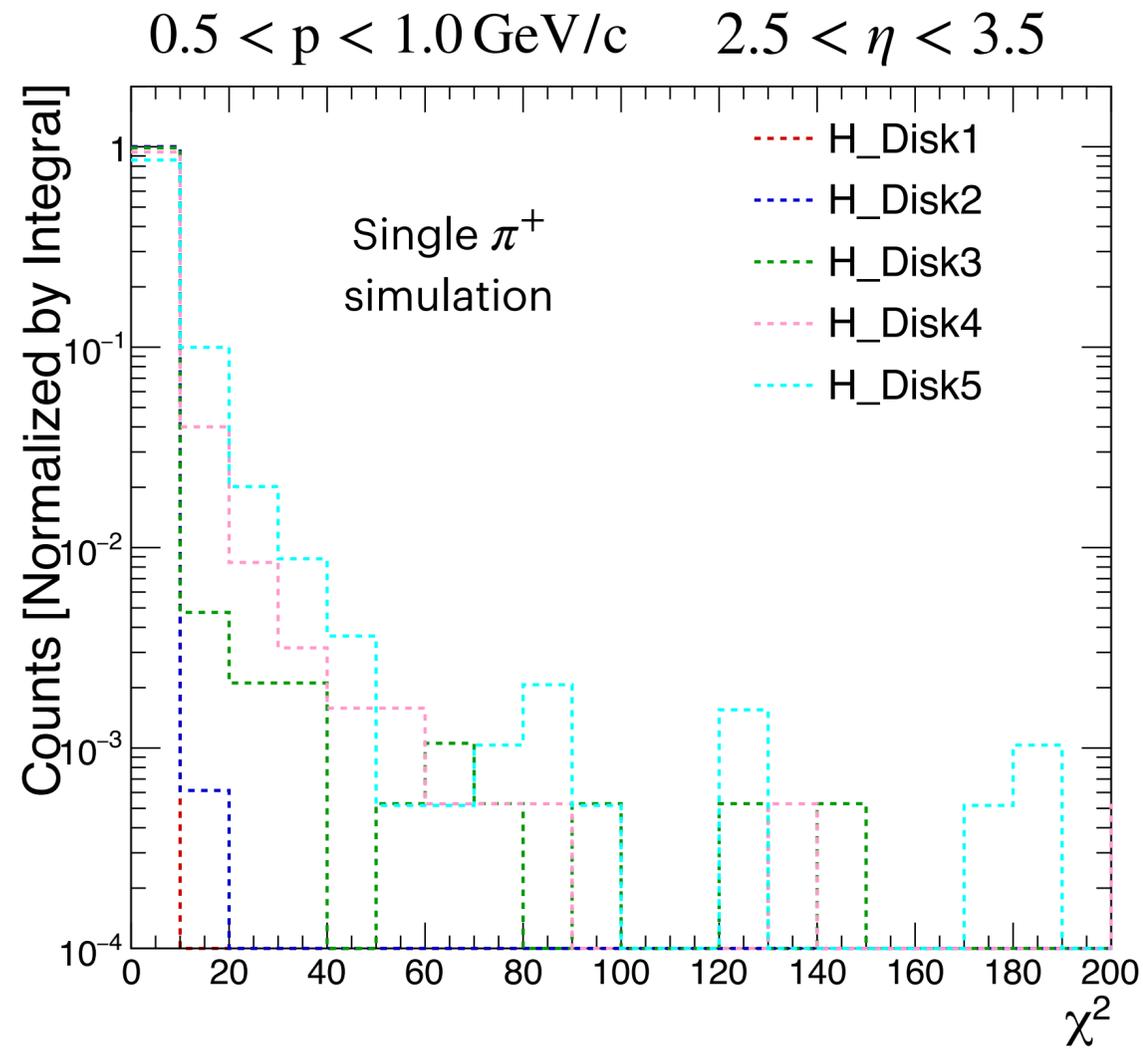
$0.5 < p < 1.0 \text{ GeV}/c$   $-2.0 < \eta < -1.0$



# $\chi^2$ Distributions



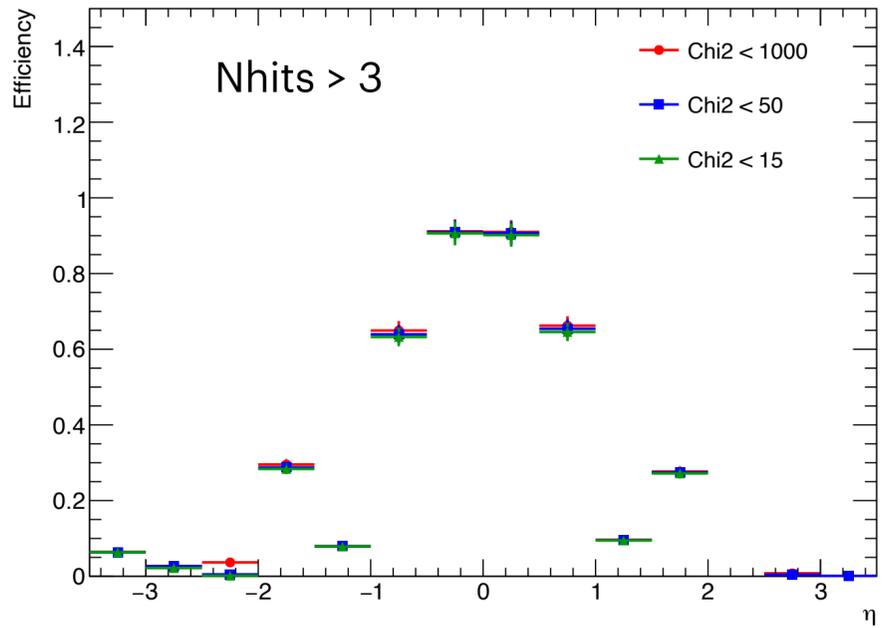
# $\chi^2$ Distributions



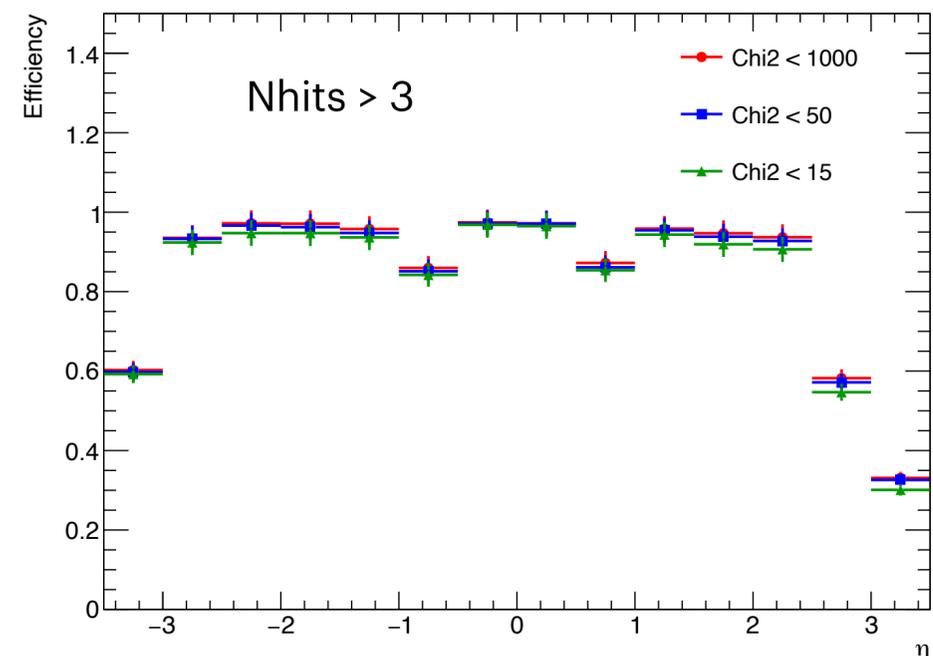
- The distributions across all regions appear quite similar and are much better controlled with the updated material map.
- These distributions suggest that an  $\eta$ -dependent  $\chi^2$ -cutoff might not be necessary at this point.
- We could also consider a cut at 50; this option looks more viable and may provide a slightly better selection without significant loss.

# Comparison between $\chi^2$ cutoffs

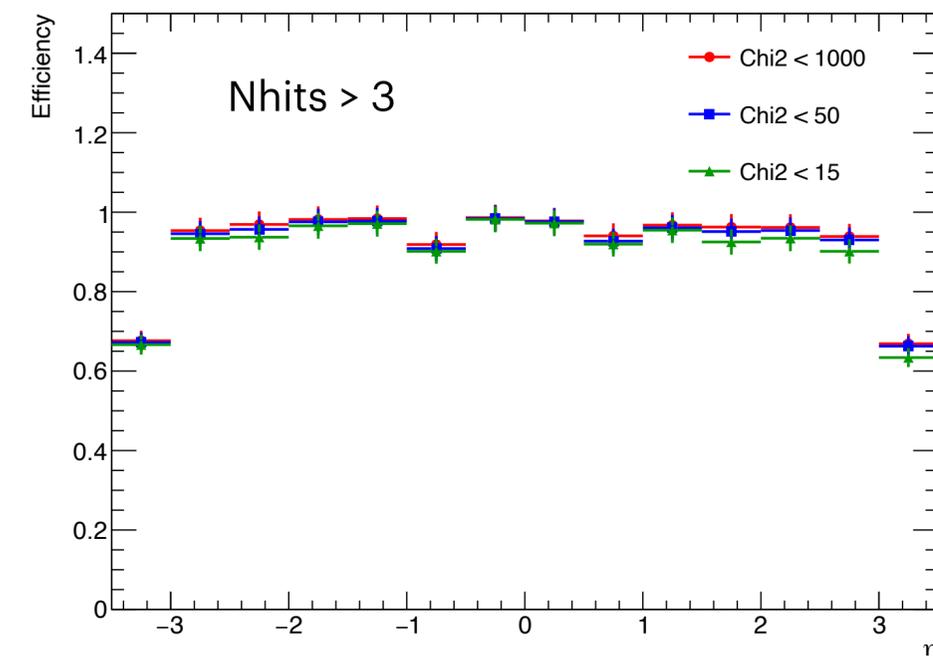
Efficiency vs Momentum for 0.5 GeV



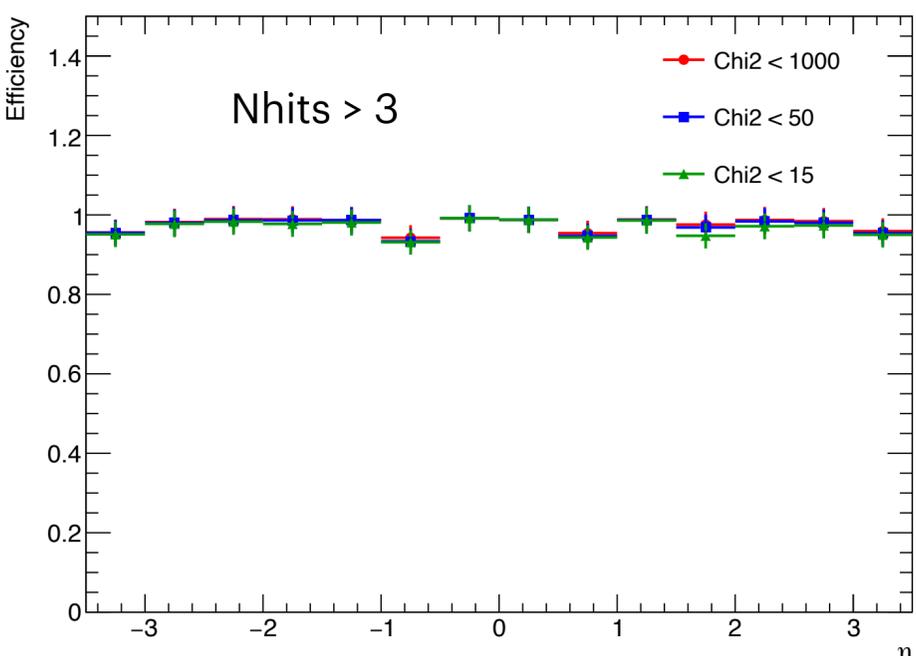
Efficiency vs Momentum for 0.8 GeV



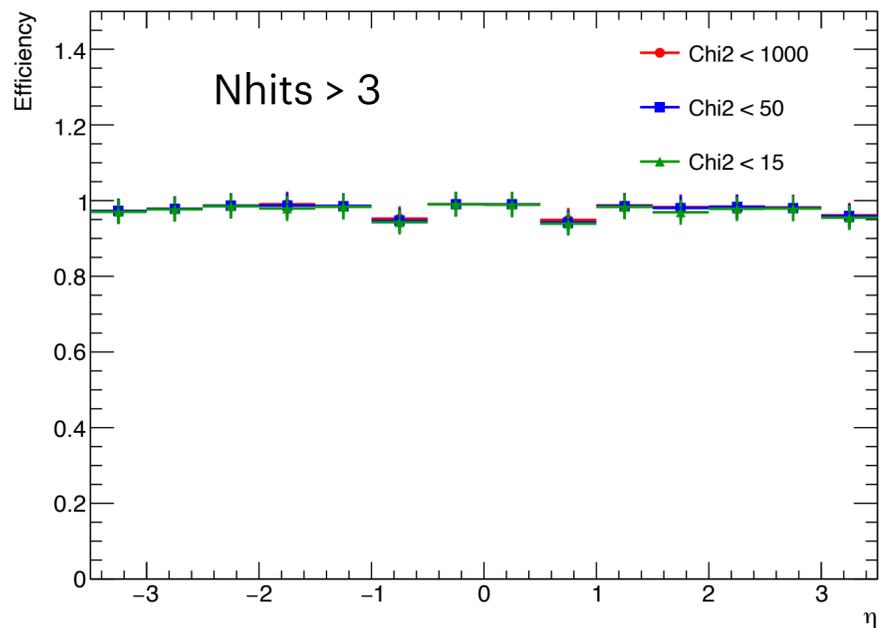
Efficiency vs Momentum for 1.0 GeV



Efficiency vs Momentum for 5.0 GeV



Efficiency vs Momentum for 10.0 GeV



No Significant difference!

# Summary & Outlook

- The  $\chi^2$  distributions appear to be significantly better controlled with the updated material map, showing improved stability across the studied regions.
- A comparison of different  $\chi^2$  cutoffs applied to the track reconstruction efficiency indicates that the default cutoff value of 15 already provides satisfactory performance.
- The impact of the cutoff choice on the pointing resolution still needs to be evaluated by systematically varying the cutoff. The final decision on the optimal cutoff should be made after including DIS + background samples, so that it reflects the full physics environment and achieves the best overall performance.

# BACKUP

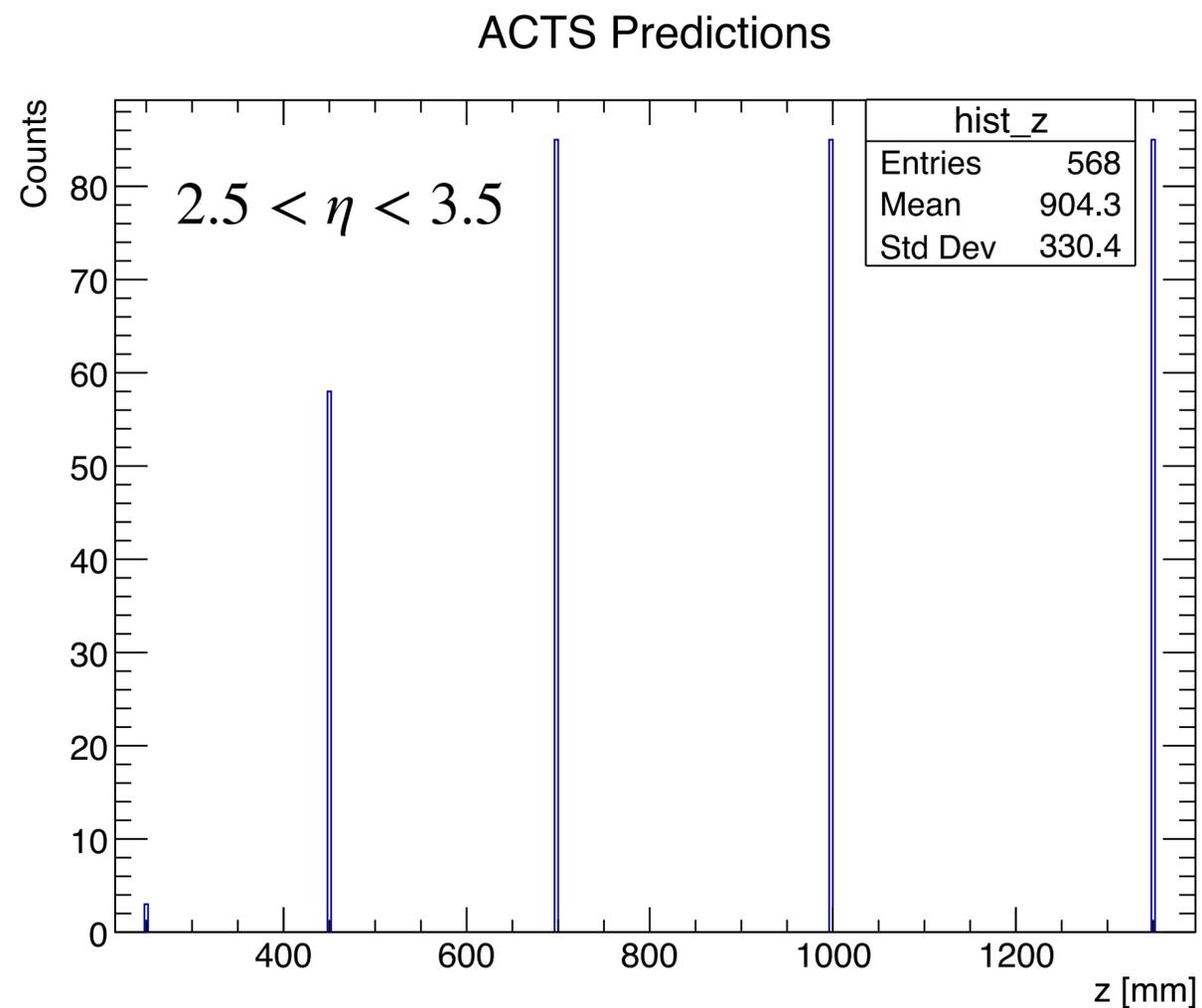
# For 0.5 GeV Pions

	Number of MC Tracks	Number of reconstructed tracks with N >3 Hits	Total Number of Reconstructed Tracks
$2.5 < \eta < 3.5$	20k	85	85
$2.0 < \eta < 2.5$	20k	13	13
$1.0 < \eta < 2.0$	20k	3941	3956
Central Barrel	20k	15747	15919
$-2.0 < \eta < -1.0$	20k	3629	3642
$-2.5 < \eta < -2.0$	20k	734	734
$-3.5 < \eta < -2.5$	20k	985	1152

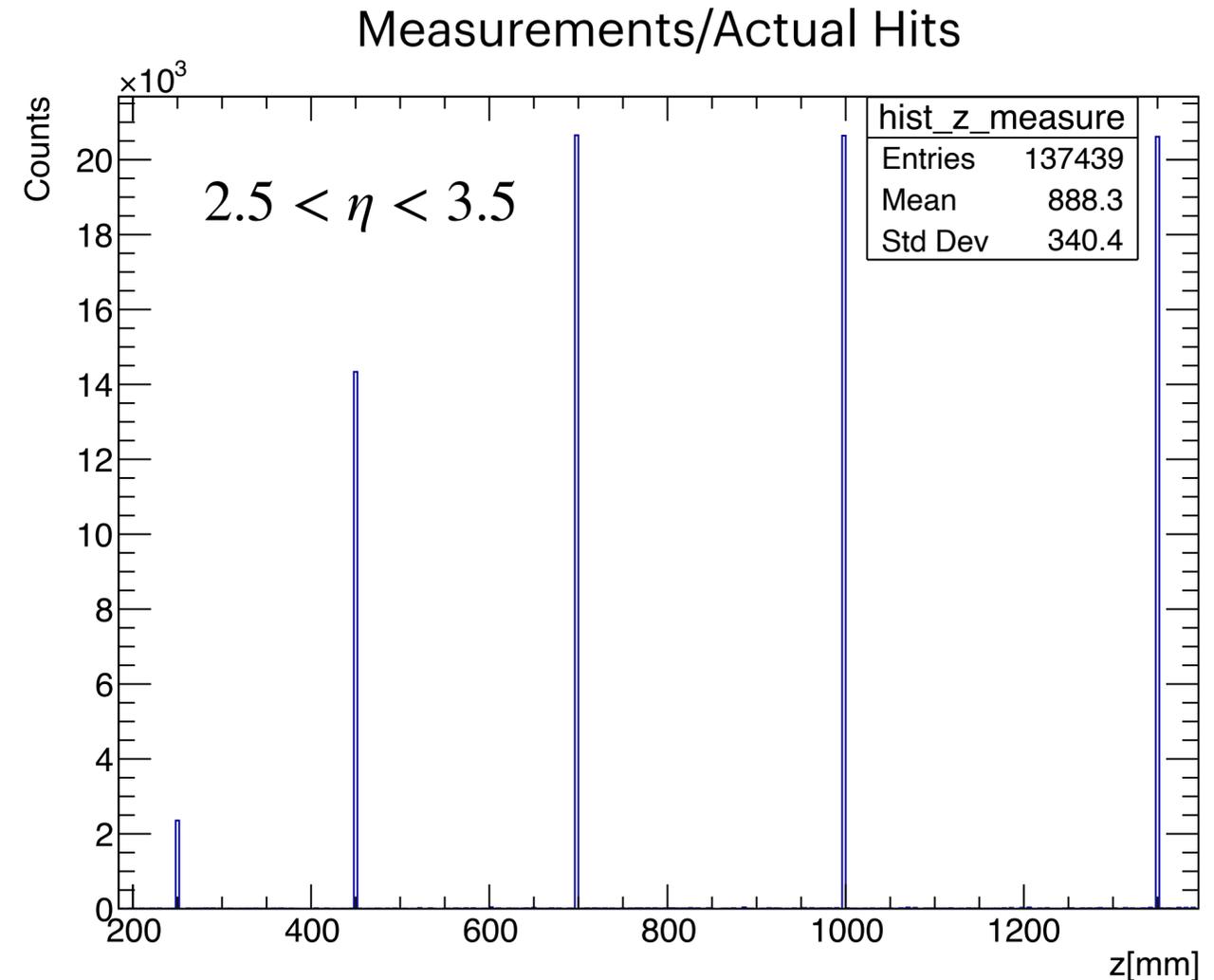
# For 10 GeV Pions

	Number of MC Tracks	Number of reconstructed tracks with N >3 Hits	Total Number of Reconstructed Tracks
$2.5 < \eta < 3.5$	20k	19549	19589
$2.0 < \eta < 2.5$	20k	19654	19683
$1.0 < \eta < 2.0$	20k	19697	19735
Central Barrel	20k	19388	19430
$-2.0 < \eta < -1.0$	20k	19803	19836
$-2.5 < \eta < -2.0$	20k	19763	19780
$-3.5 < \eta < -2.5$	20k	19514	19581

# Let's look at the ACTS predictions

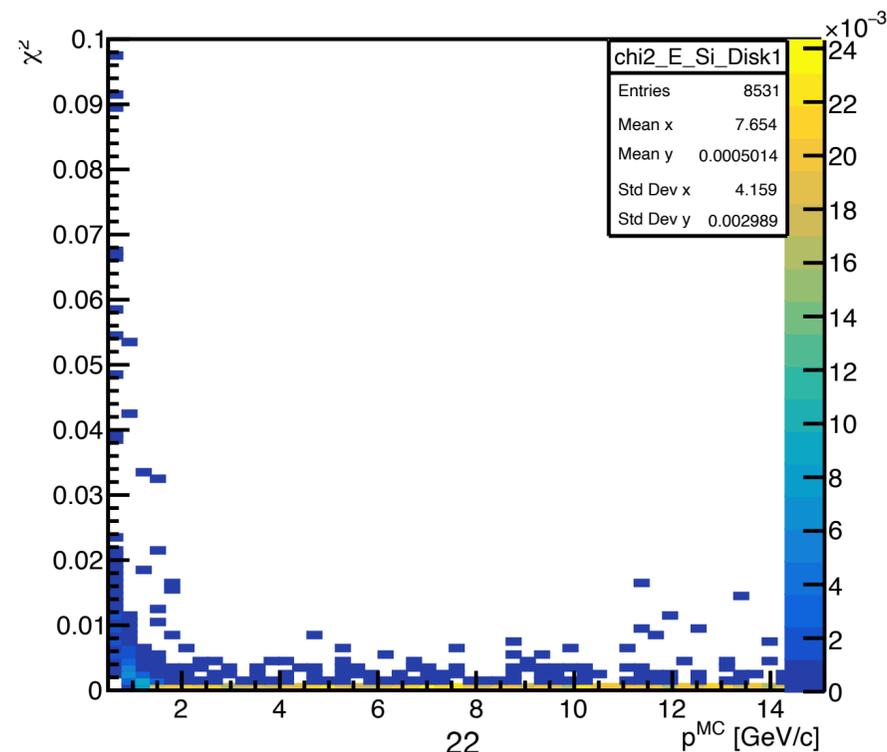
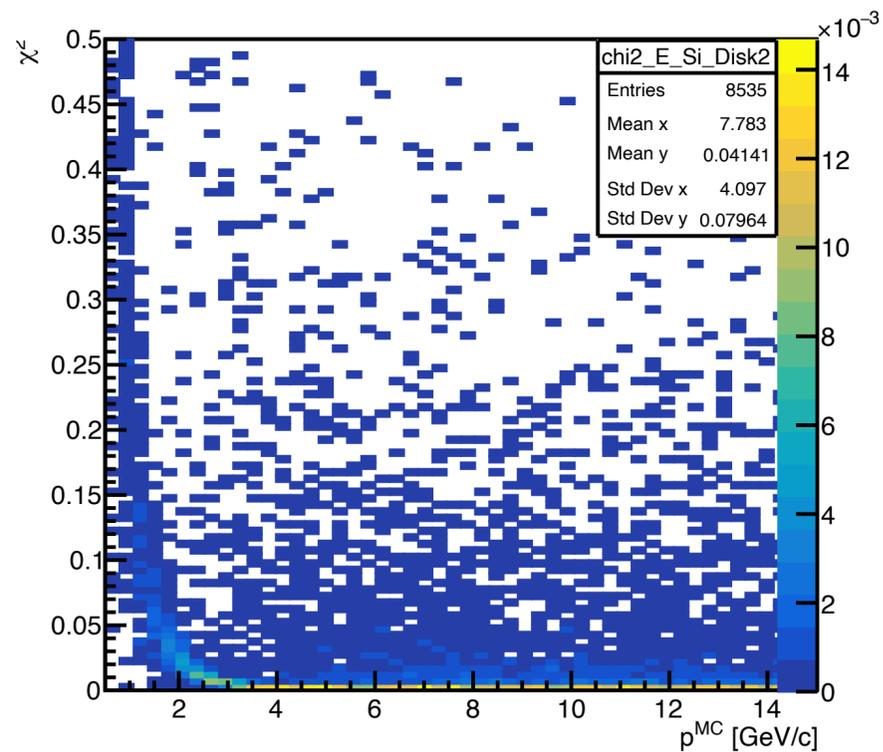
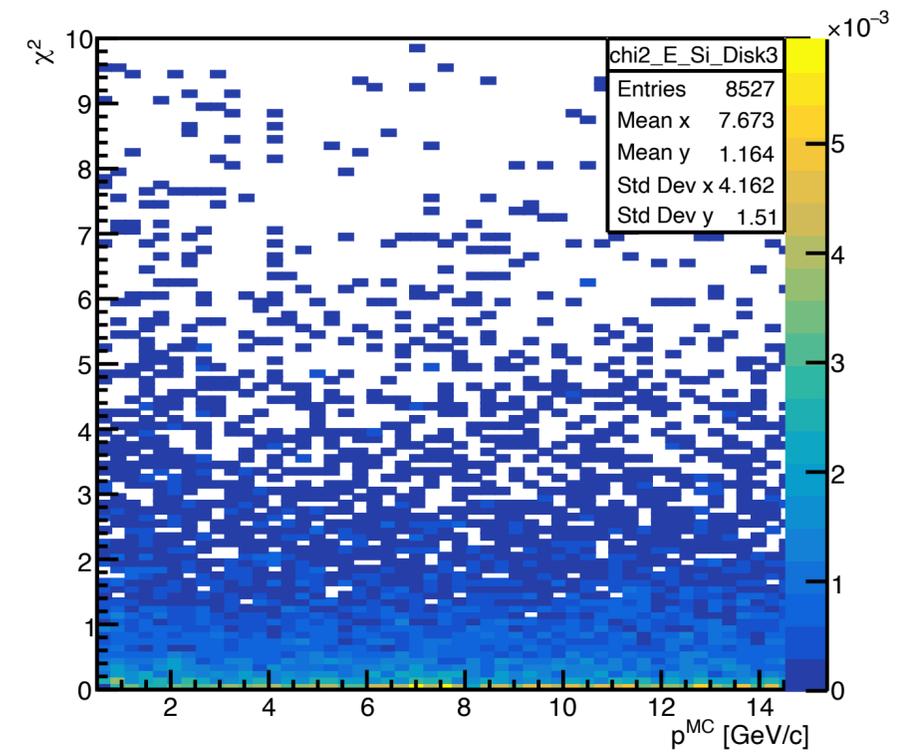
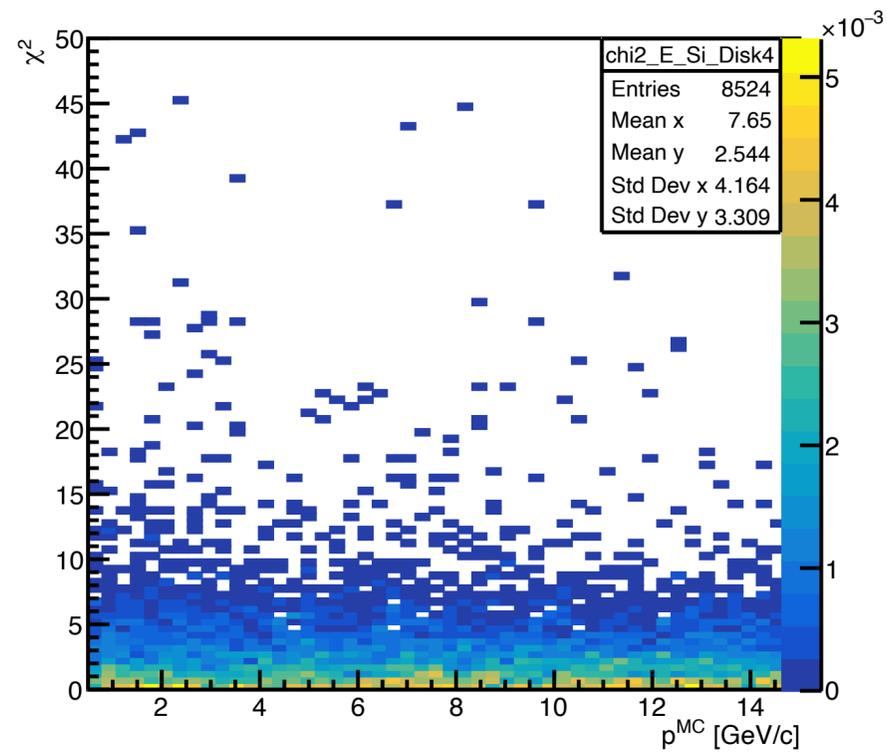
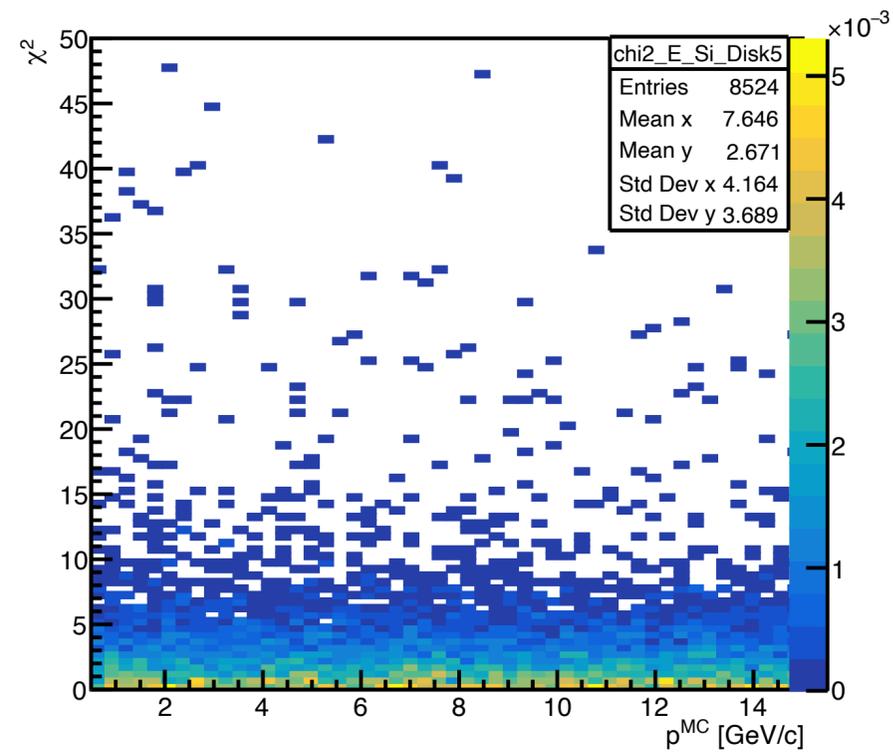


No requirement of a reconstructed track is imposed.



These are all the measurements, not just the ones corresponding to a reconstructed track

# $\chi^2$ Distributions

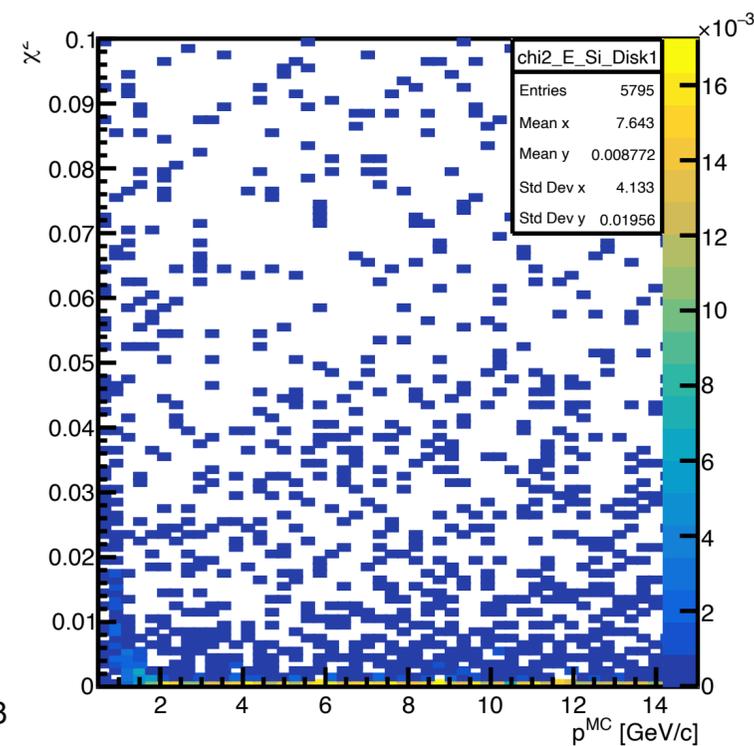
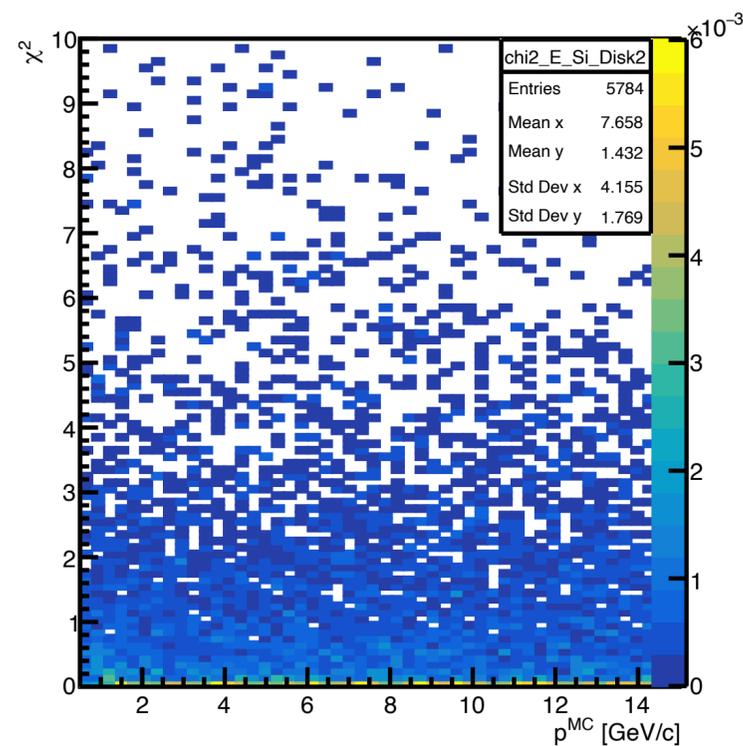
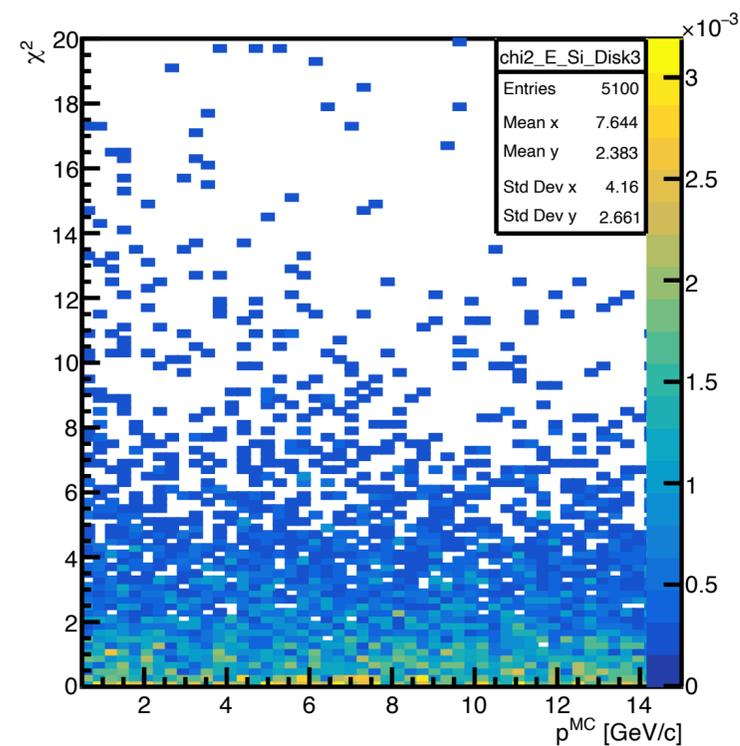
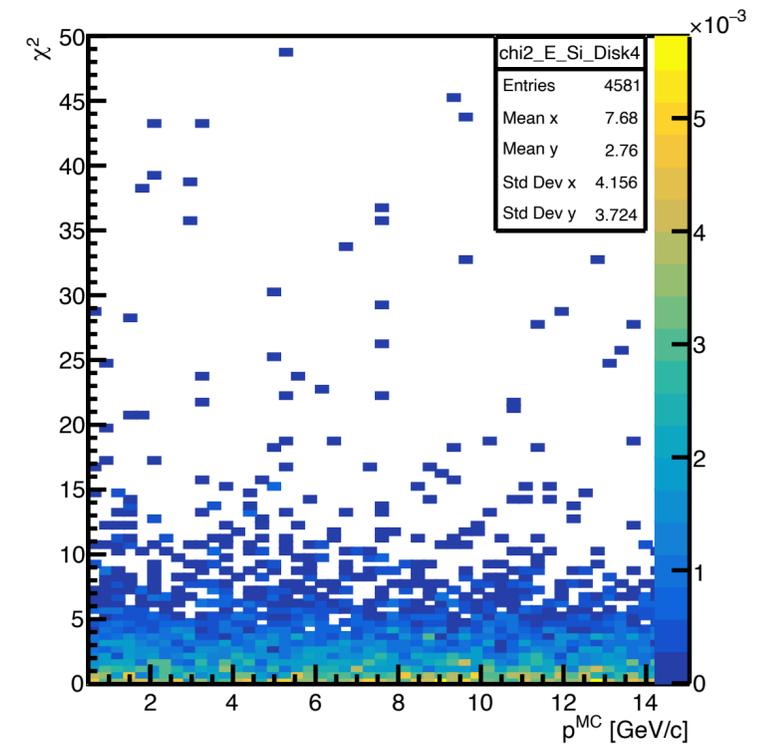
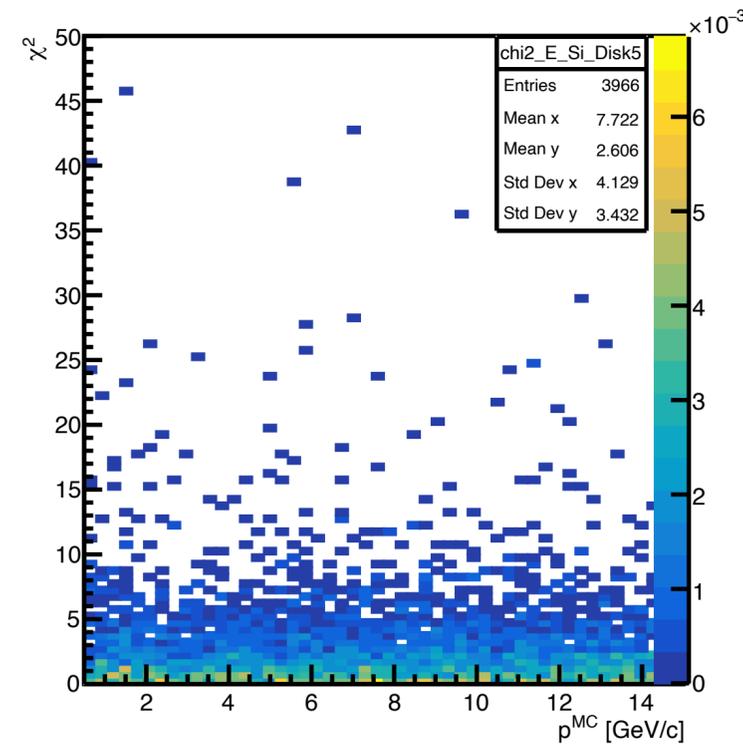
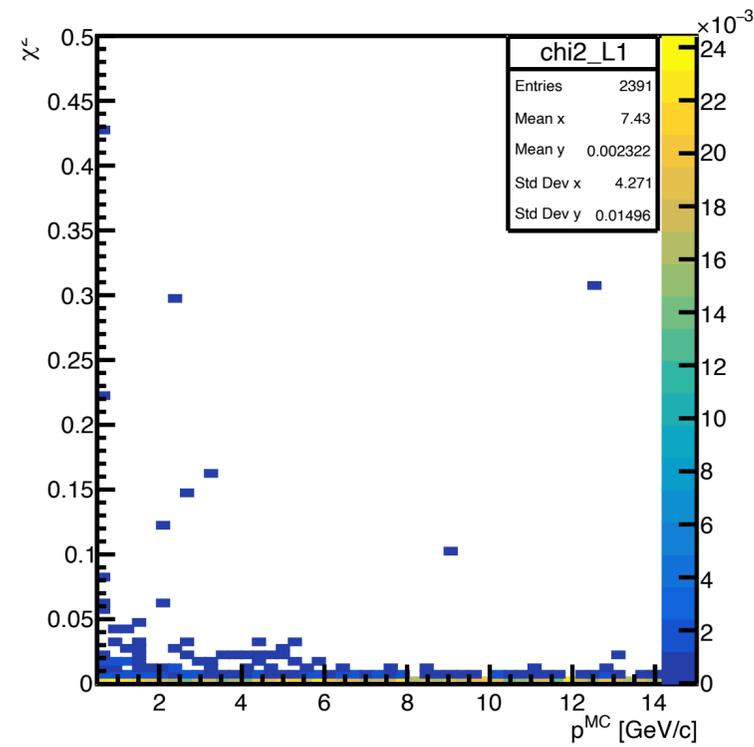
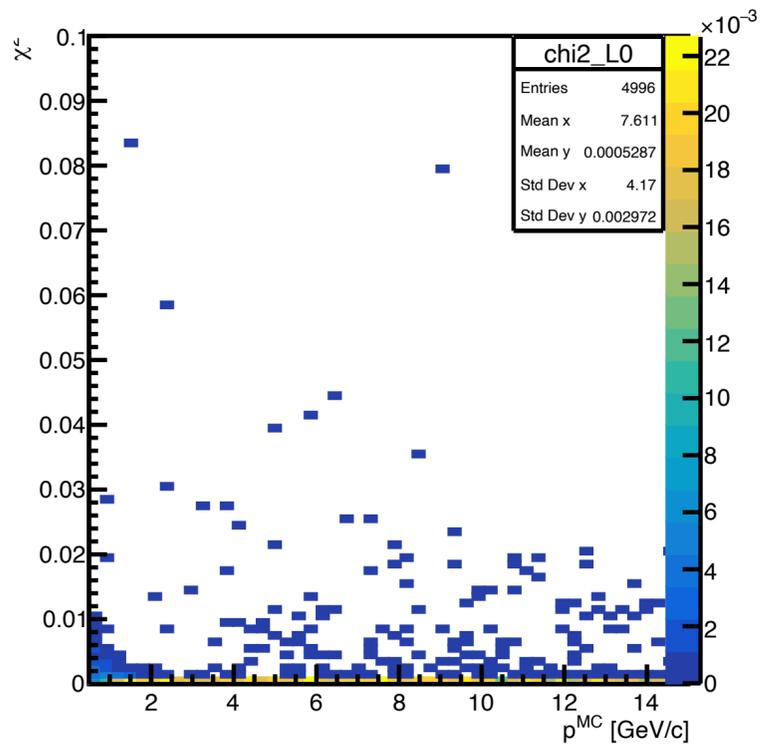


$$-2.5 < \eta < -2.0$$

Please notice the difference in the vertical scales!

We can see a slight momentum dependence

# $\chi^2$ Distributions

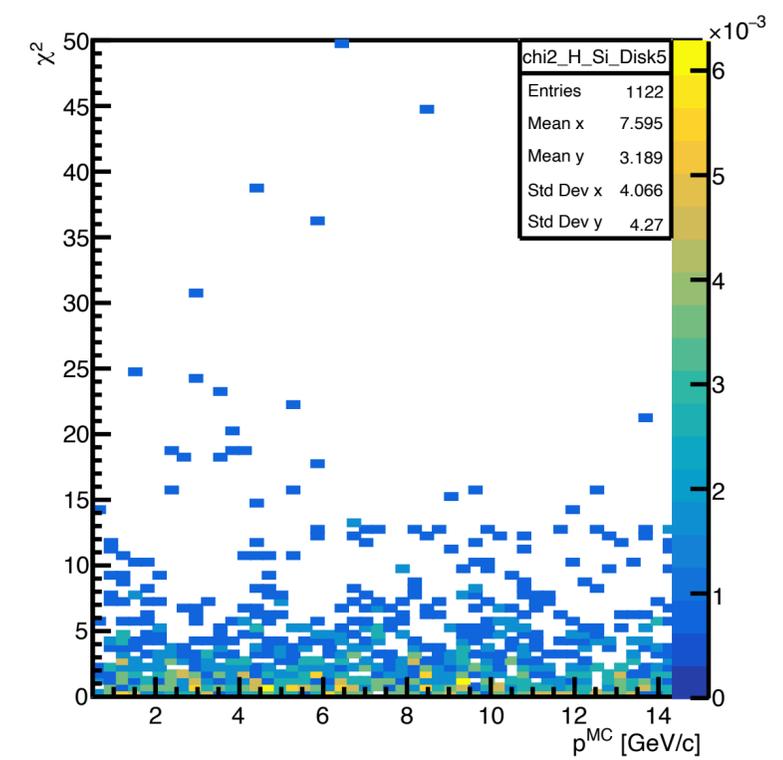
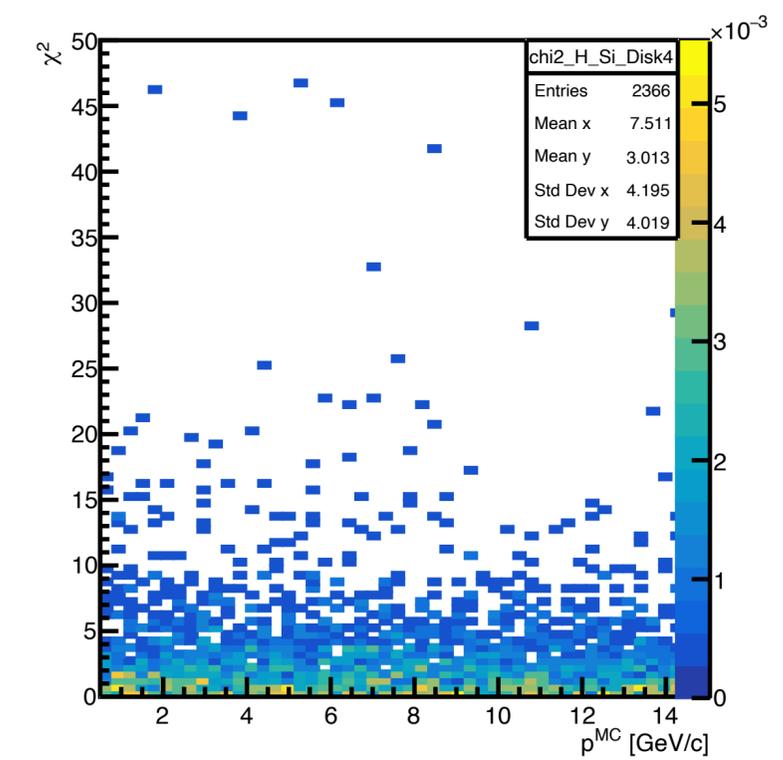
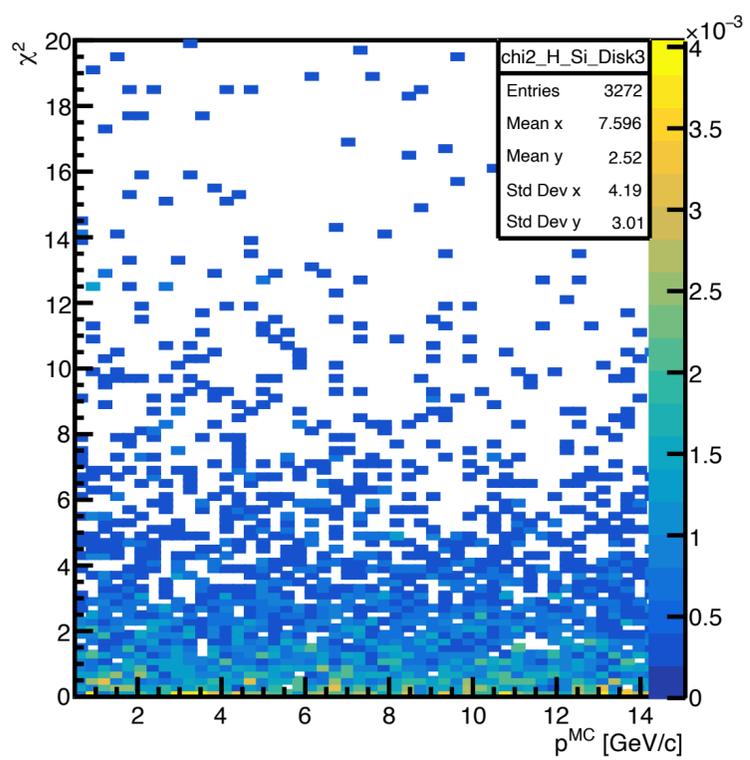
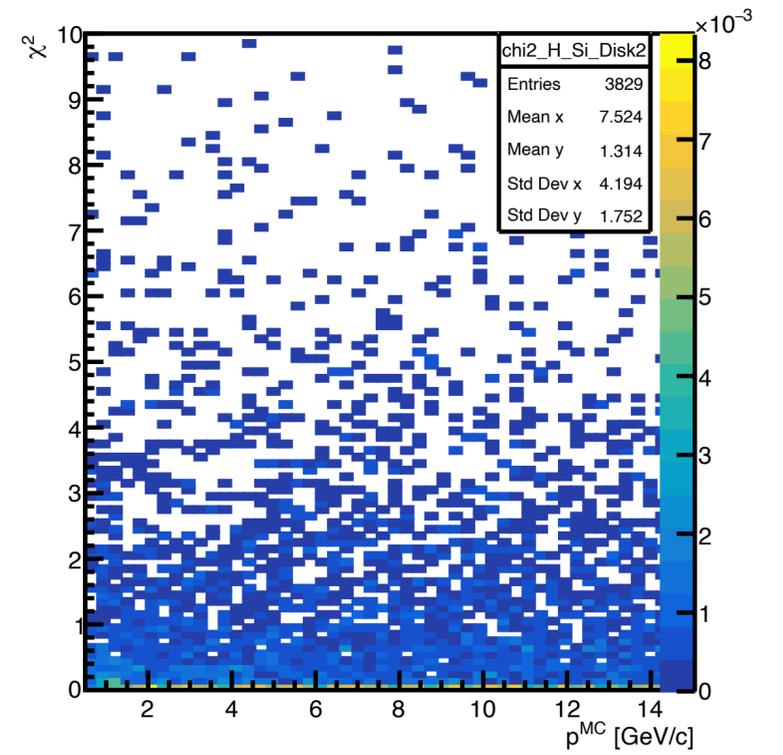
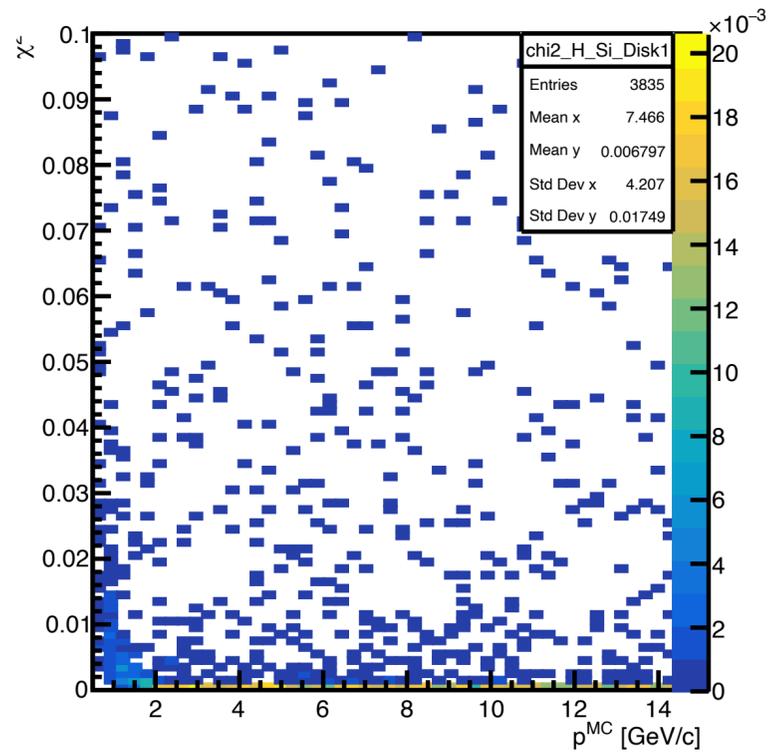
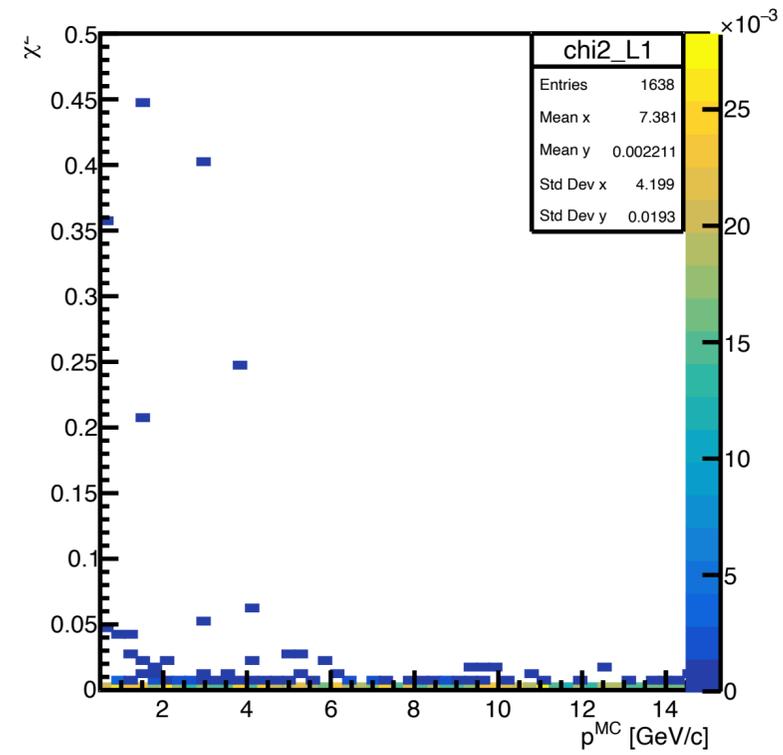
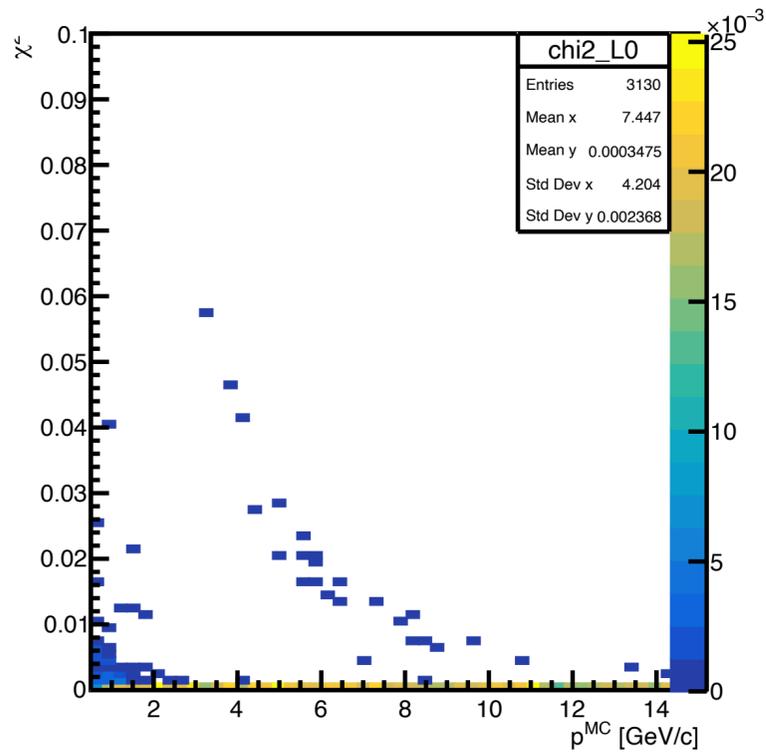


$$-2.0 < \eta < -1.0$$

Please notice the difference in the vertical scales!

We can see a slight momentum dependence

# $\chi^2$ Distributions

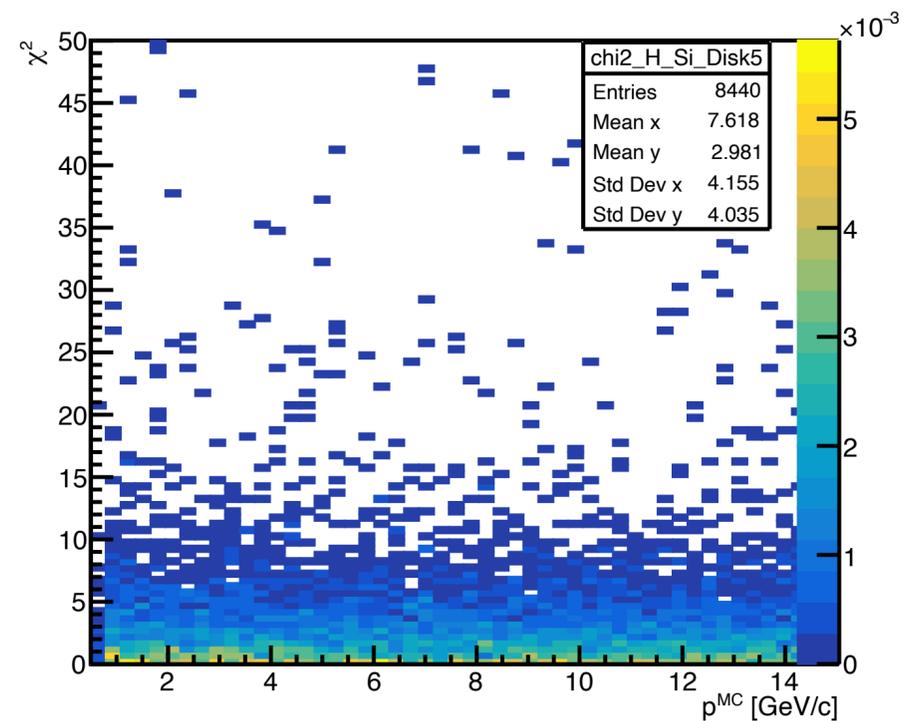
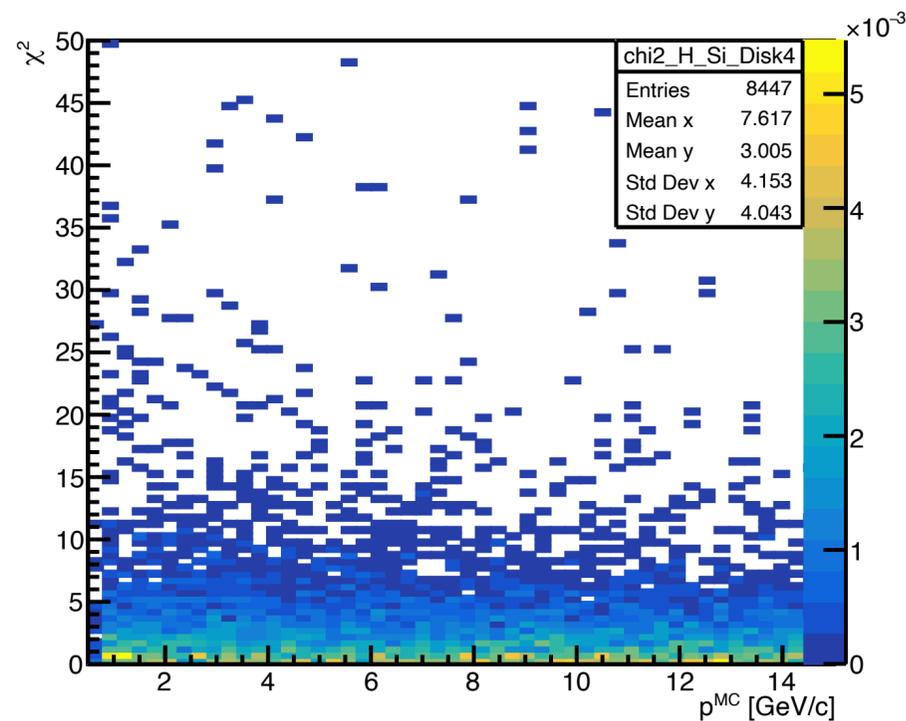
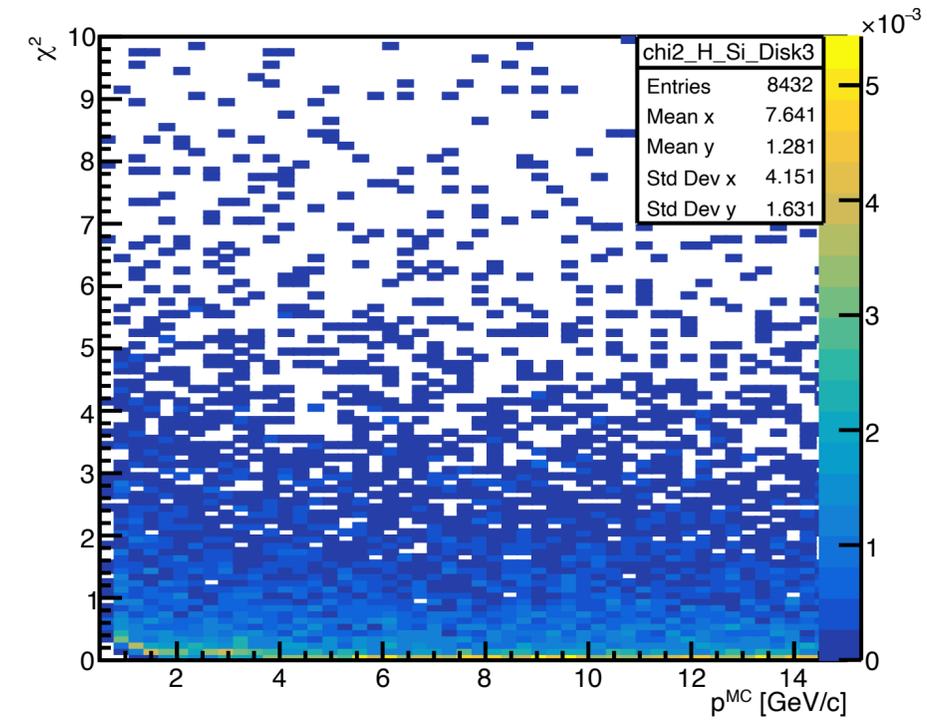
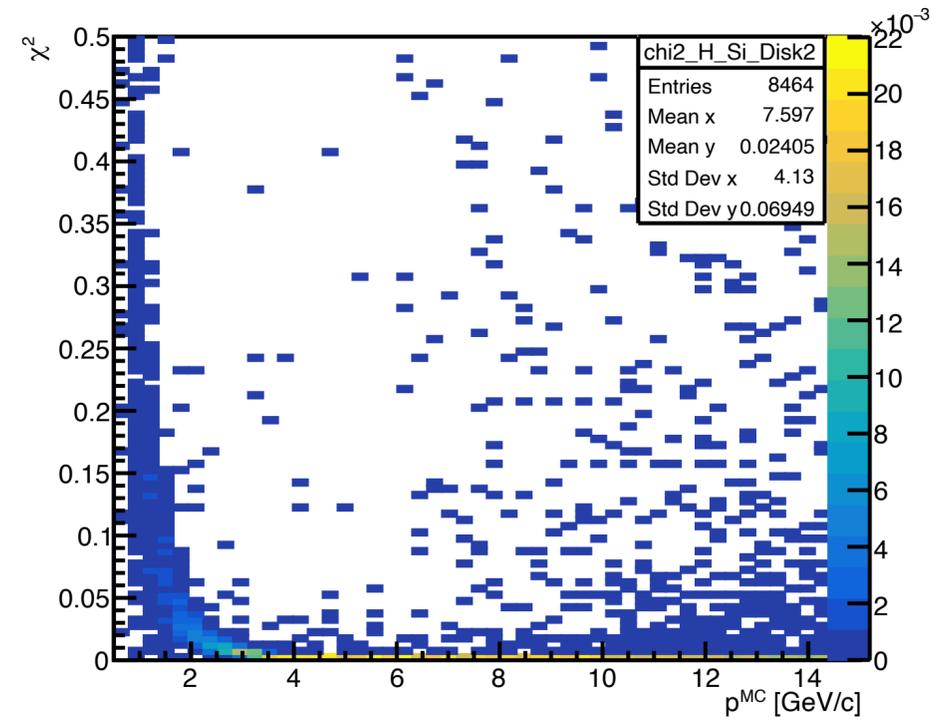
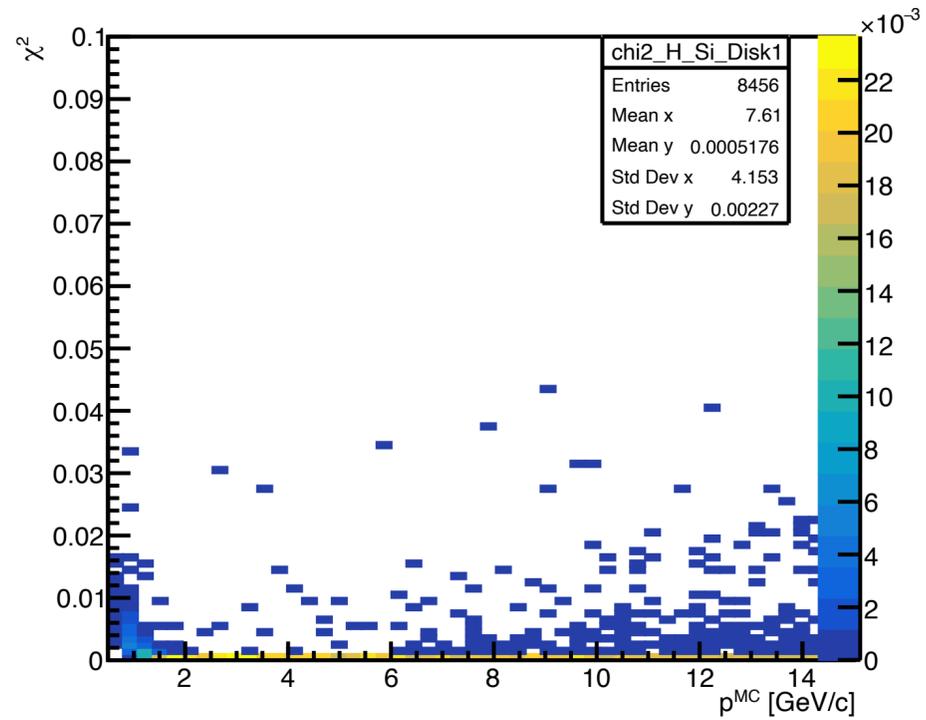


$1.0 < \eta < 2.0$

Please notice the difference in the vertical scales!

We can see a slight momentum dependence

# $\chi^2$ Distributions



$$2.0 < \eta < 2.5$$

Please notice the difference in the vertical scales!

We can see a slight momentum dependence