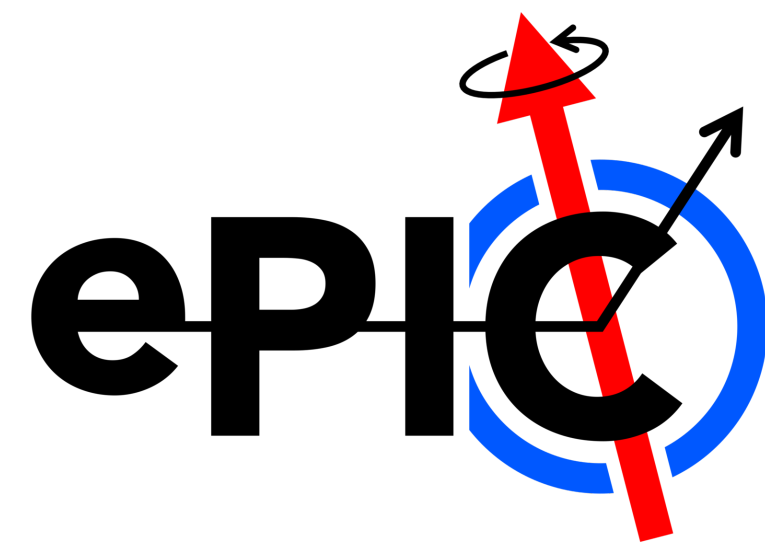


# EIC Tracking WG Update

Impact of  $\chi^2$  on Tracking Performance

Vassu Doomra, UC Berkeley

June 18, 2026



**Berkeley**  
UNIVERSITY OF CALIFORNIA

# Where does $\chi^2$ enter into the picture?

During track finding, ACTS evaluates the  $\chi^2$  contribution of each detector hit at every tracking layer and determines whether the hit should be incorporated as a measurement or rejected as an outlier.

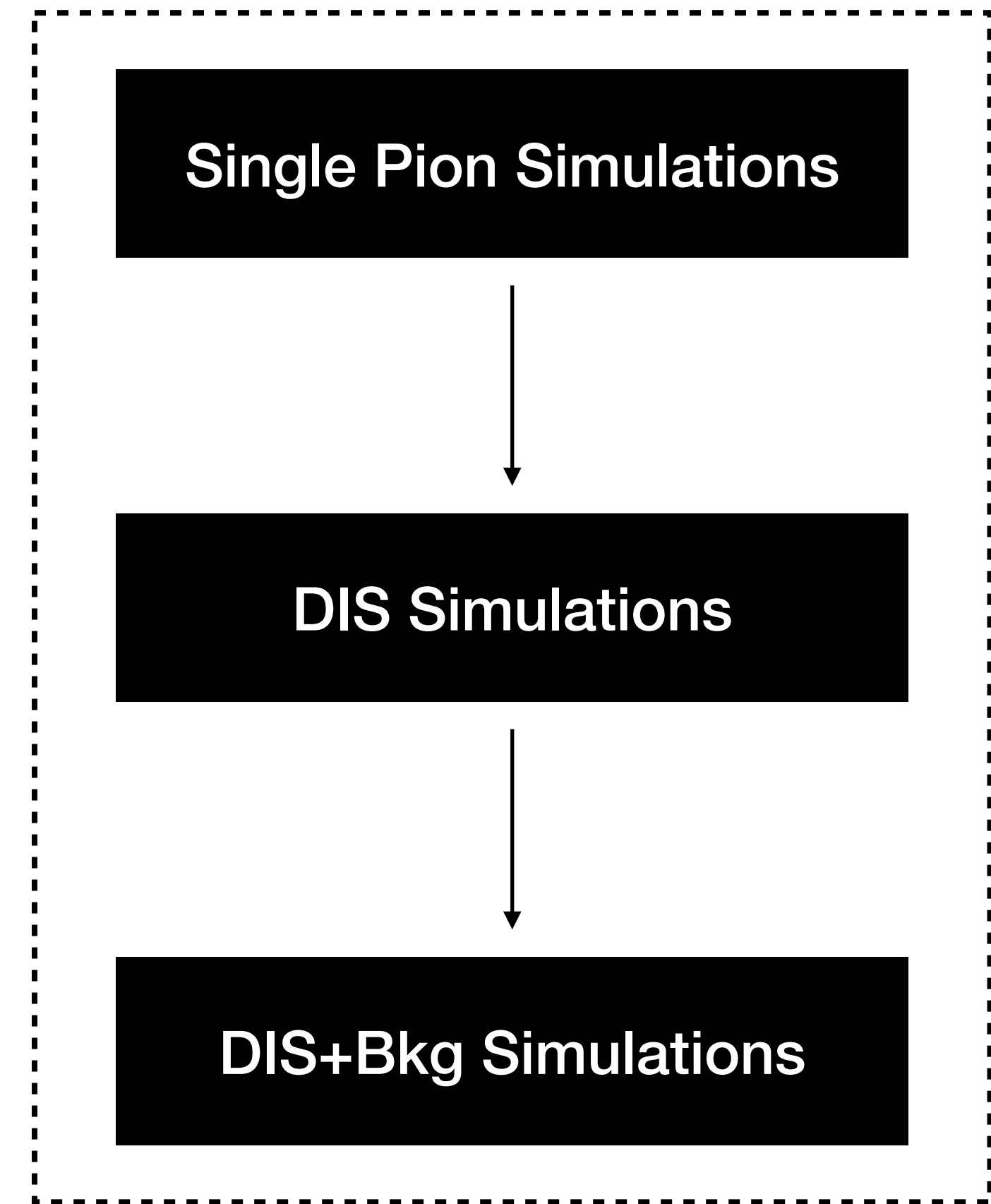
The following performance metrics will be used to quantify the effect of  $\chi^2$ :

- Track Reconstruction efficiency
- Momentum Resolution
- Purity

Throughout the presentation  $N_{\text{hits}} > 3$

Three  $\chi^2$  cutoffs were considered:

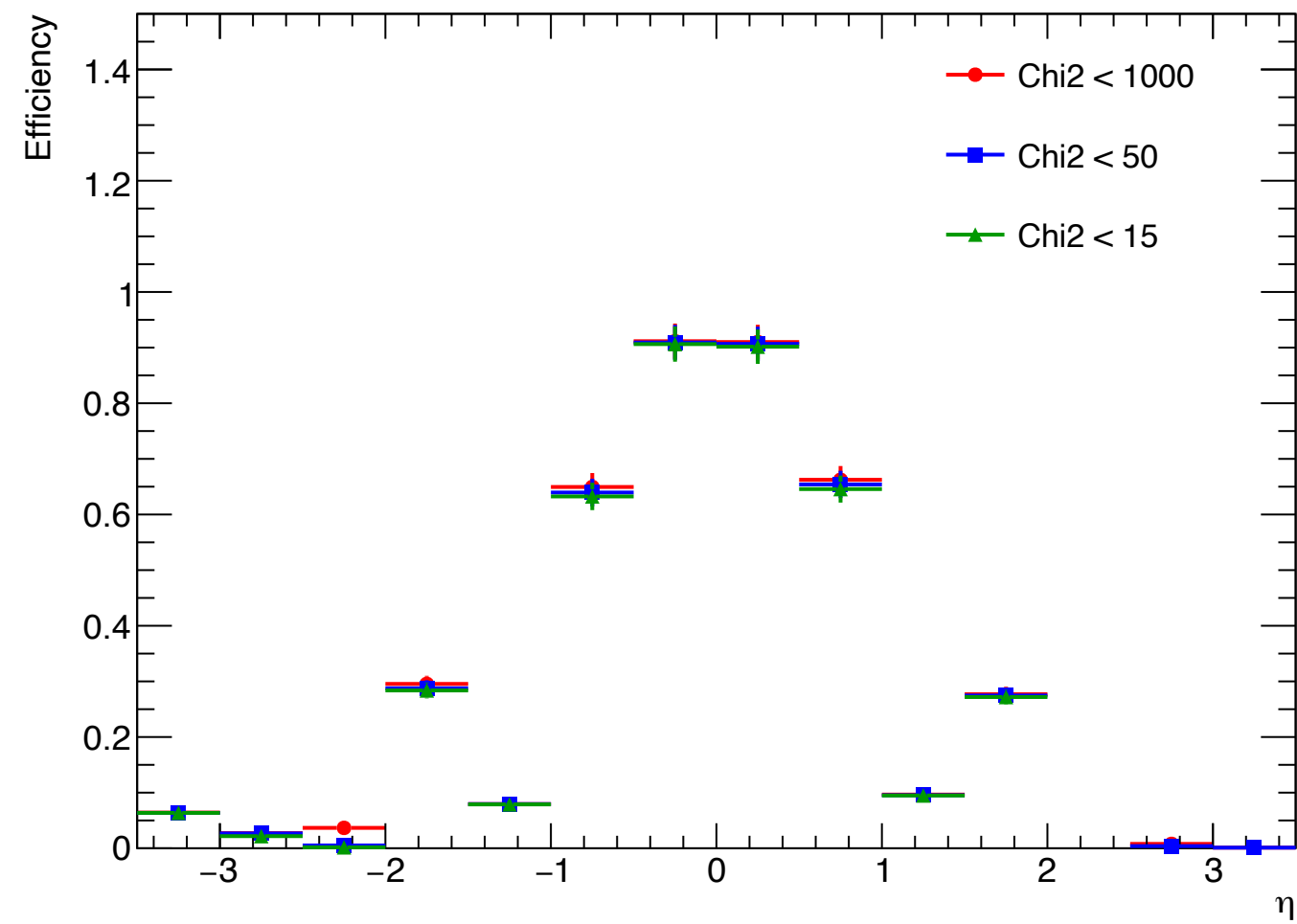
- $\chi^2 = 1000$  – an arbitrarily large value that effectively removes the cutoff, allowing ACTS to consider all detector hits near the projected track trajectory.
- $\chi^2 = 50$
- $\chi^2 = 15$  – the default cutoff value we use.



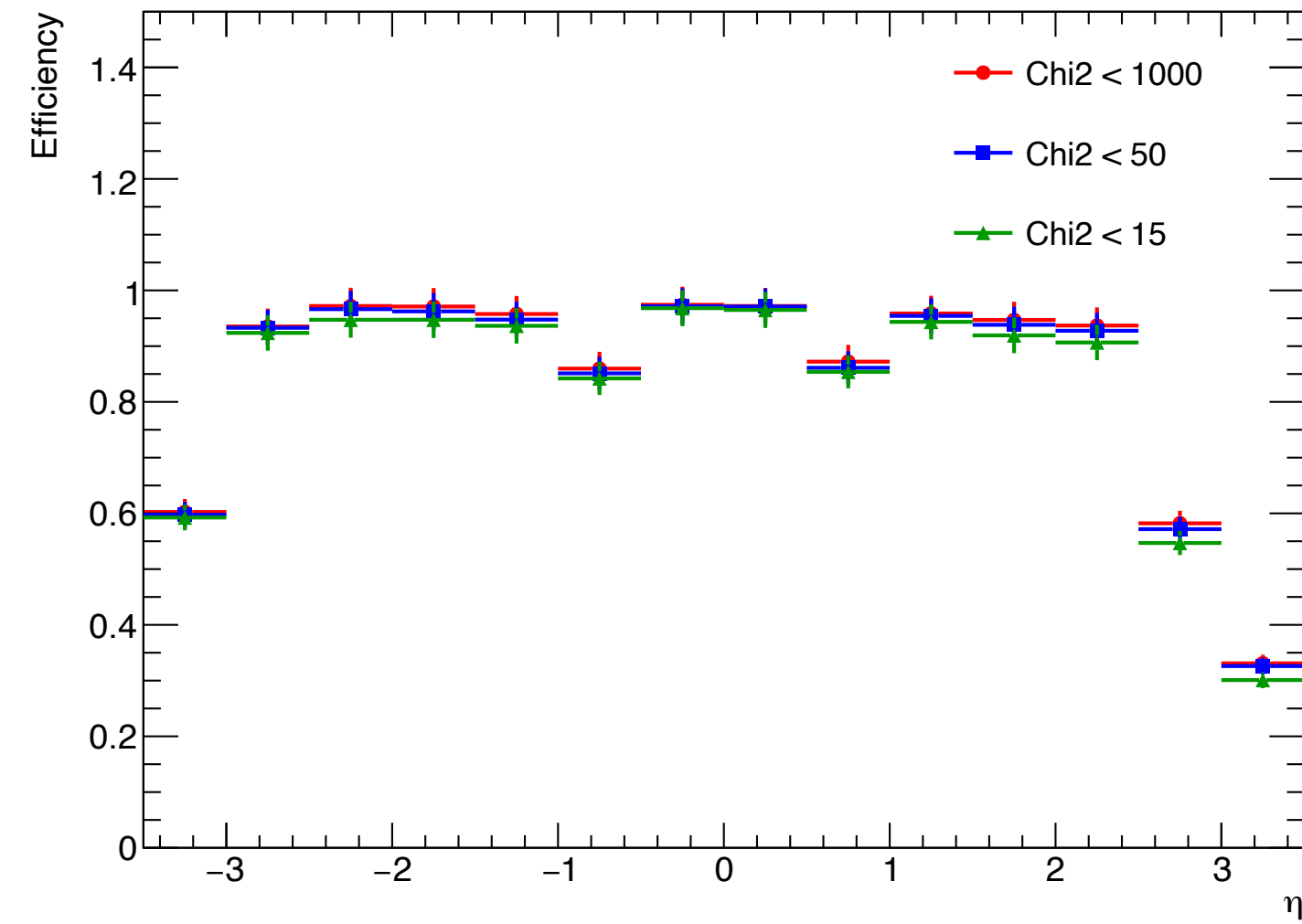
WorkFlow

# Results from Single Pion Simulations: Feb 26 Campaign

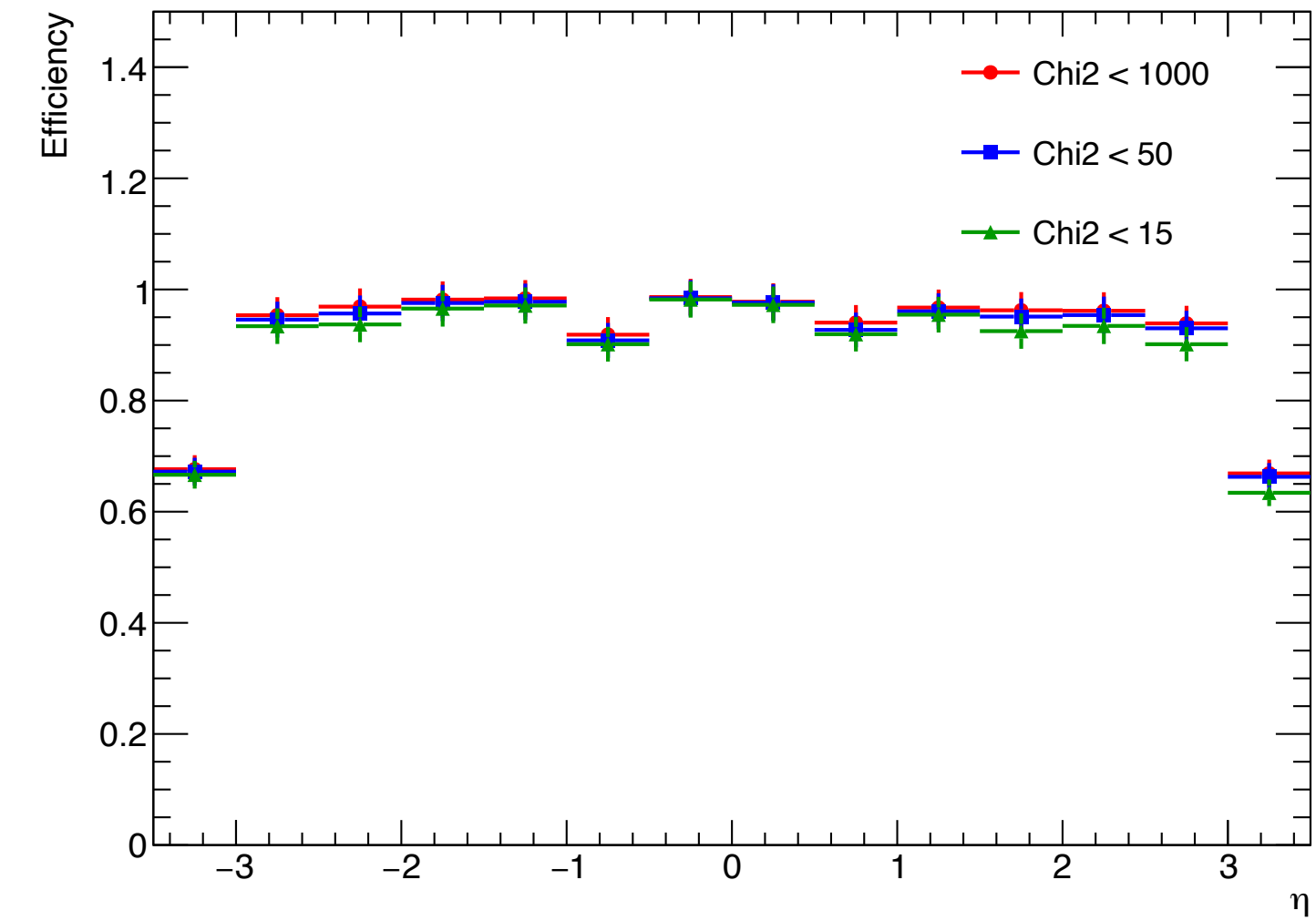
Efficiency vs Momentum for 0.5 GeV



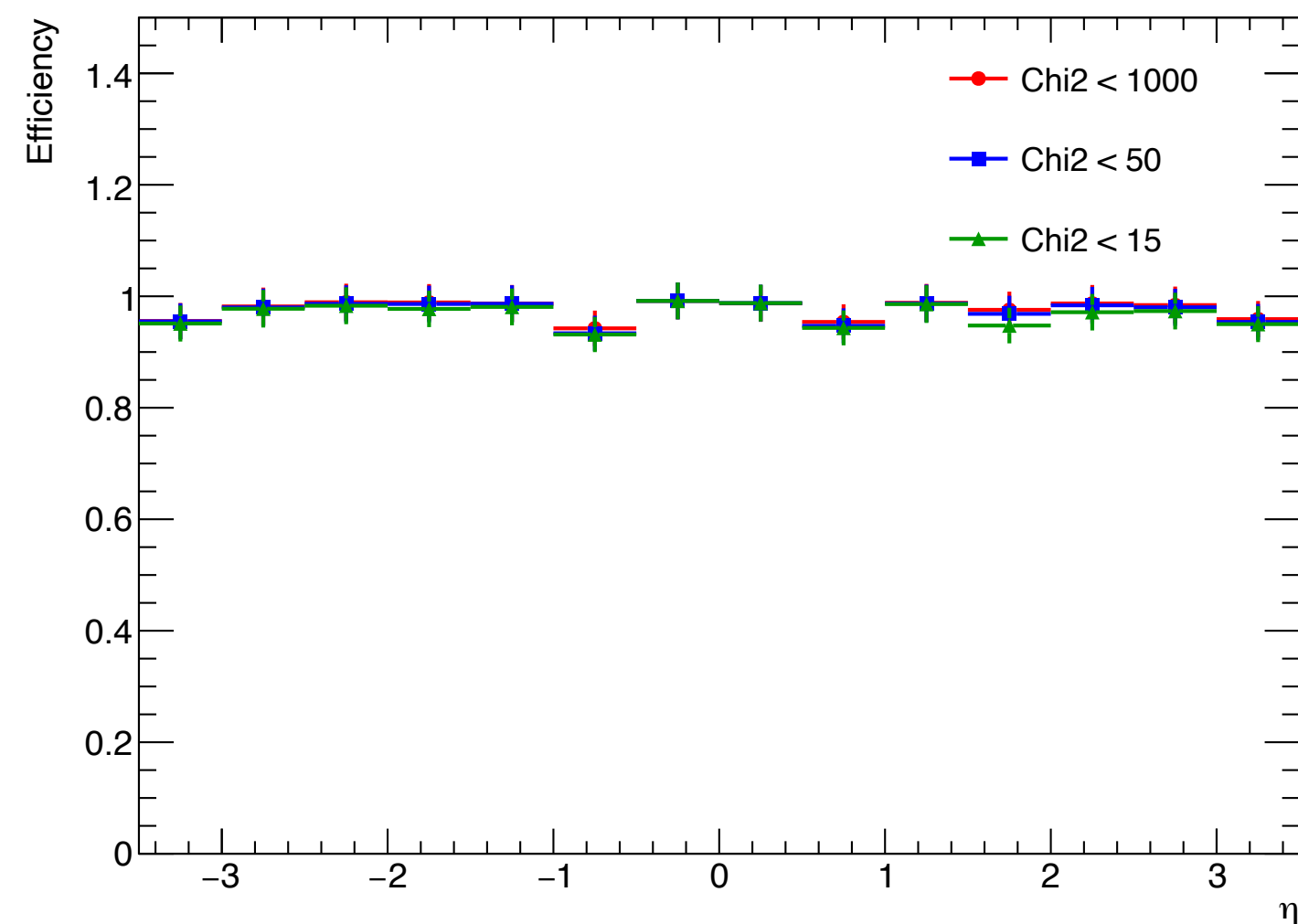
Efficiency vs Momentum for 0.8 GeV



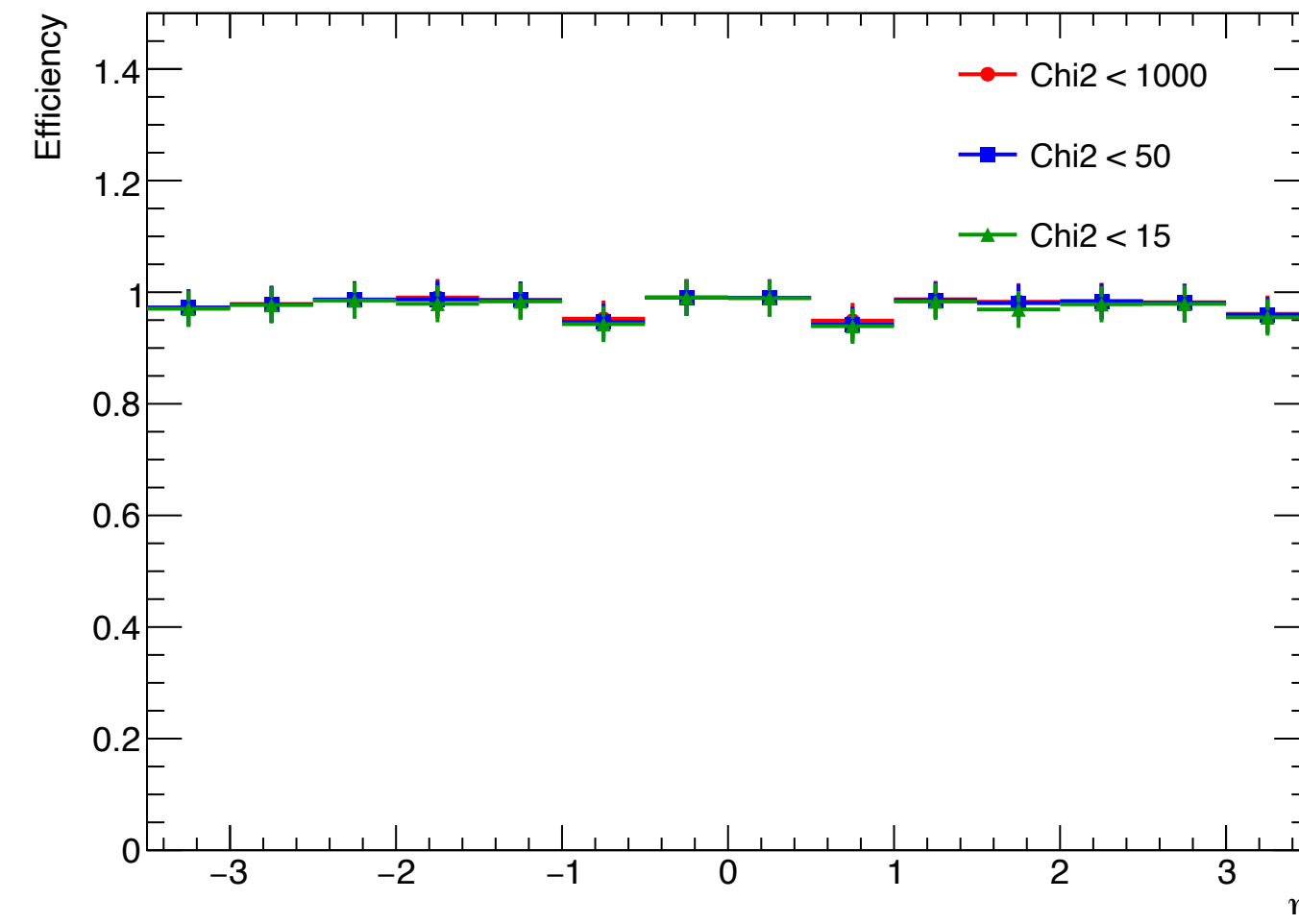
Efficiency vs Momentum for 1.0 GeV



Efficiency vs Momentum for 5.0 GeV

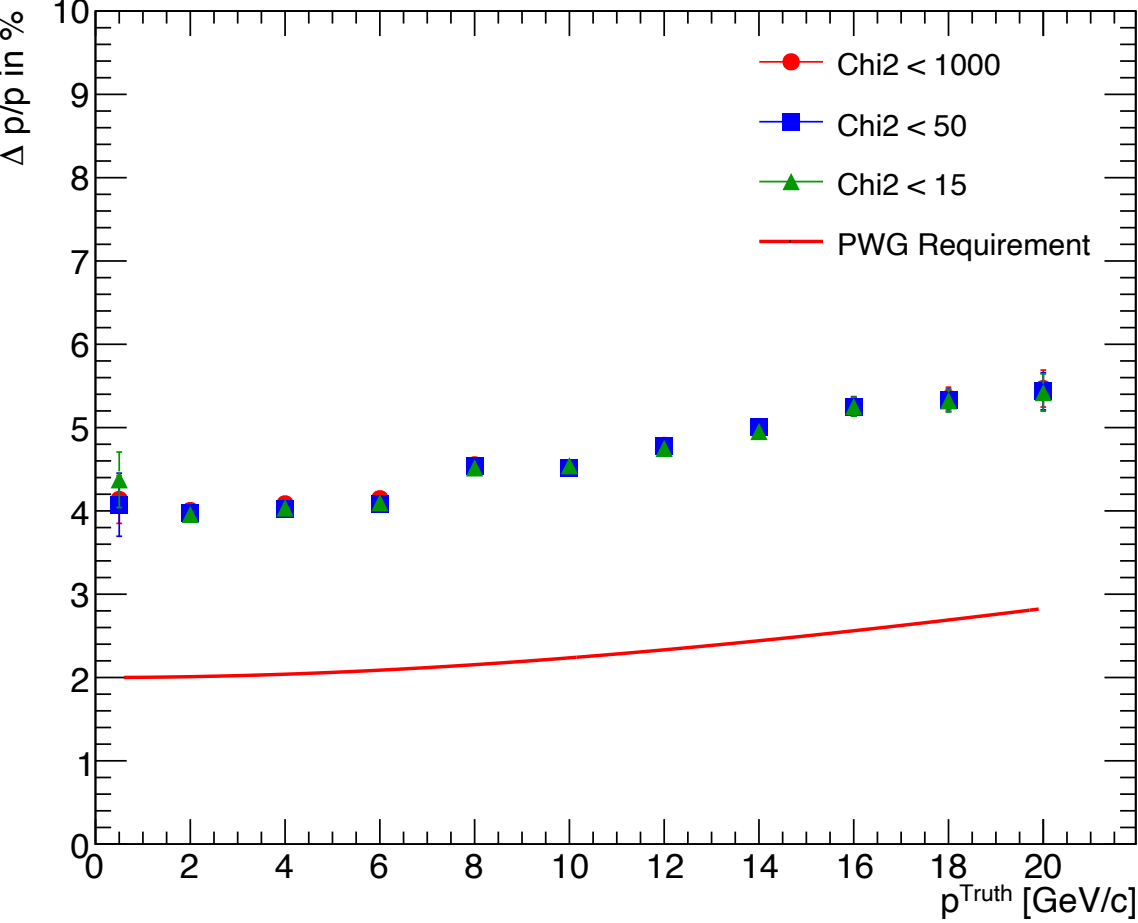


Efficiency vs Momentum for 10.0 GeV

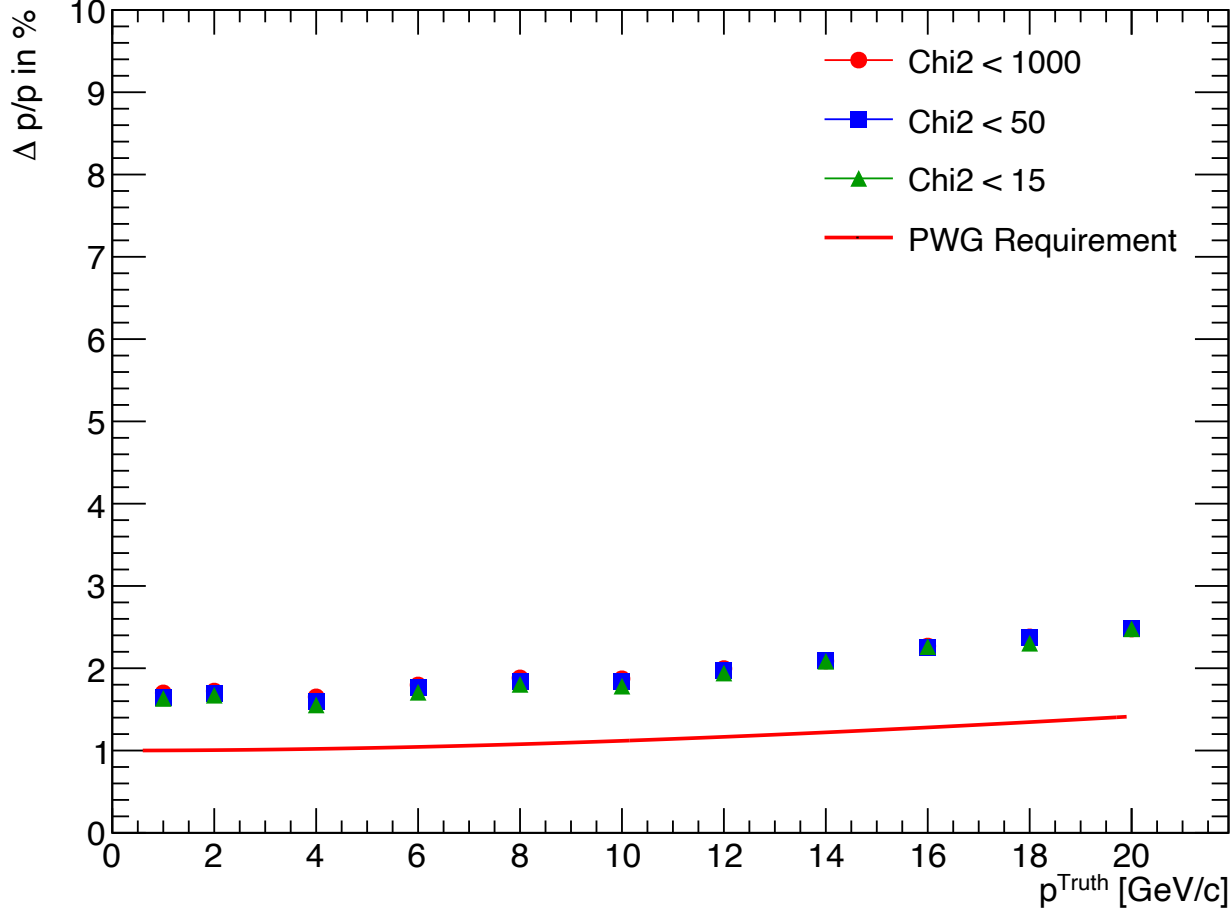


# Momentum Resolution

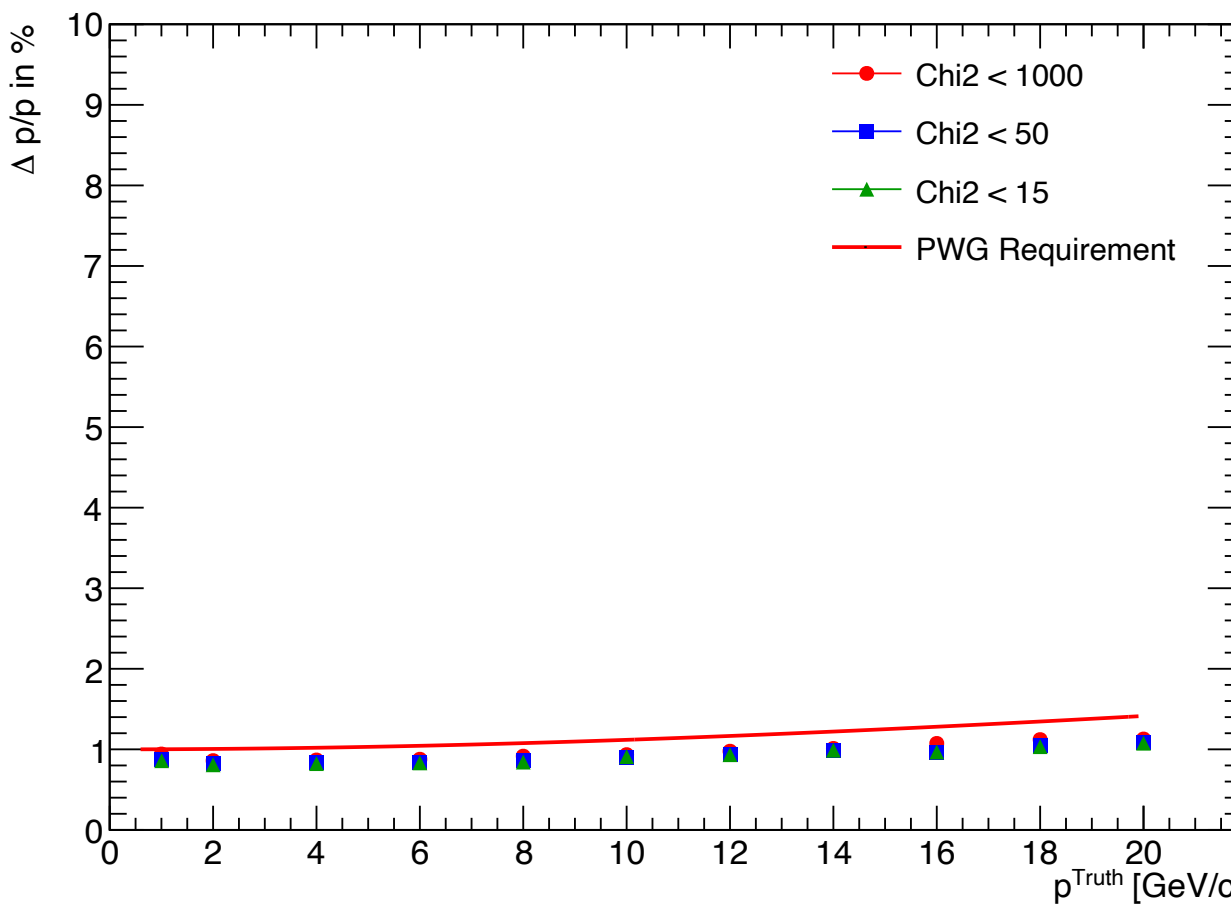
$-3.5 < \eta < -2.5$



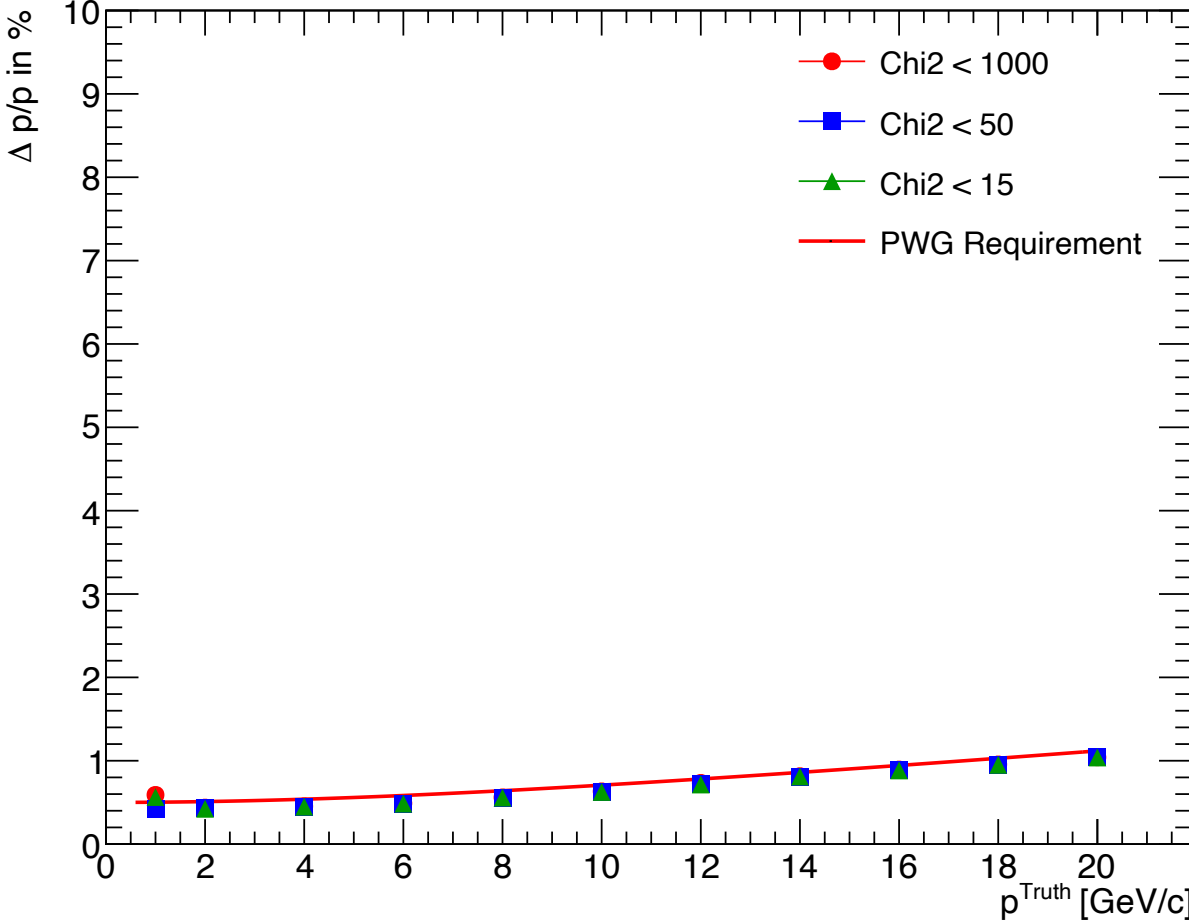
$-2.5 < \eta < -2.0$



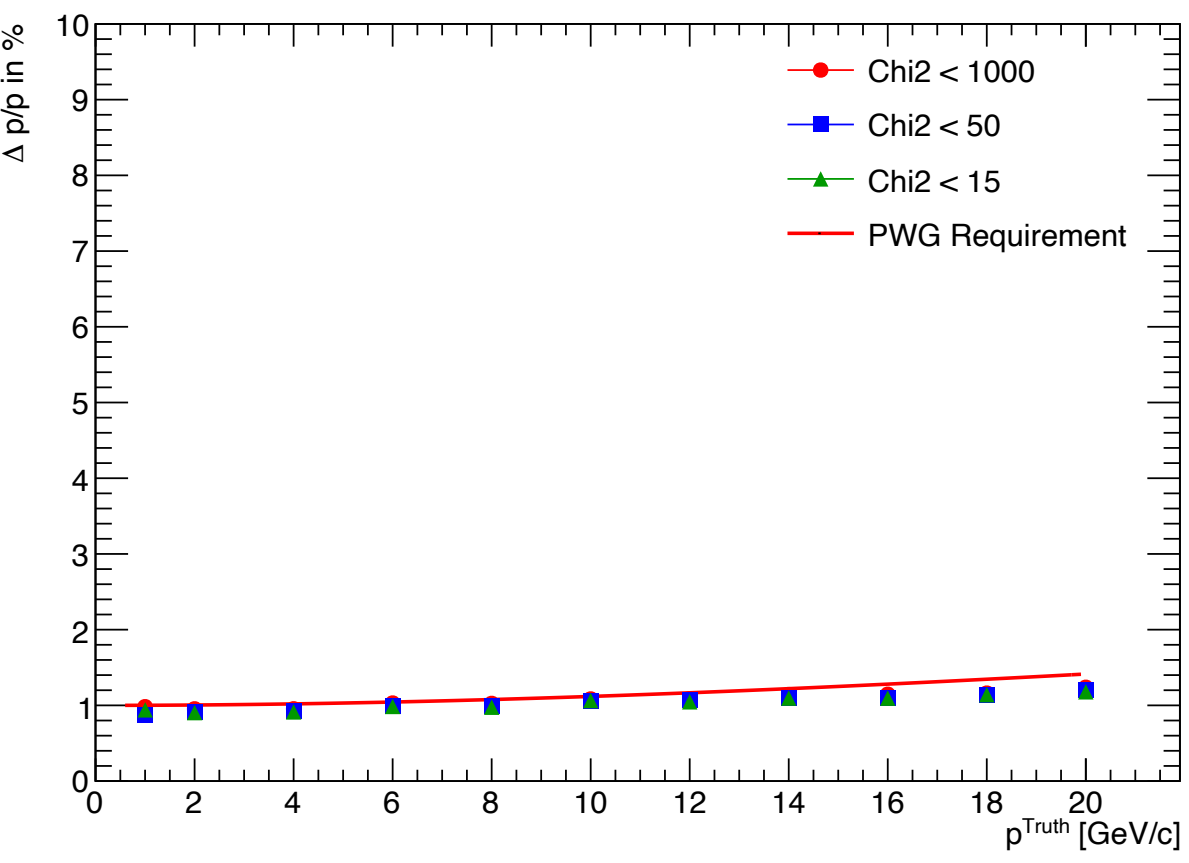
$-2.0 < \eta < -1.0$



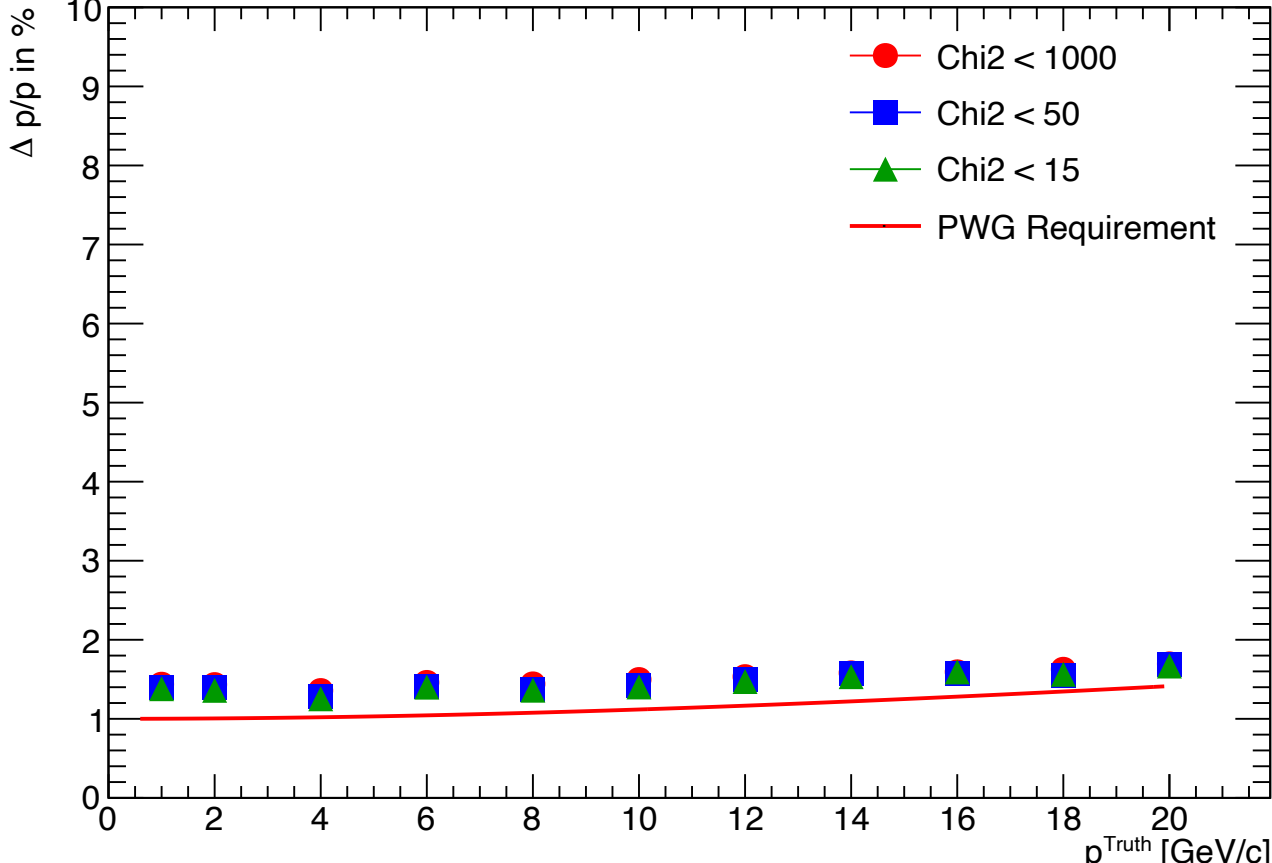
$-1.0 < \eta < 1.0$



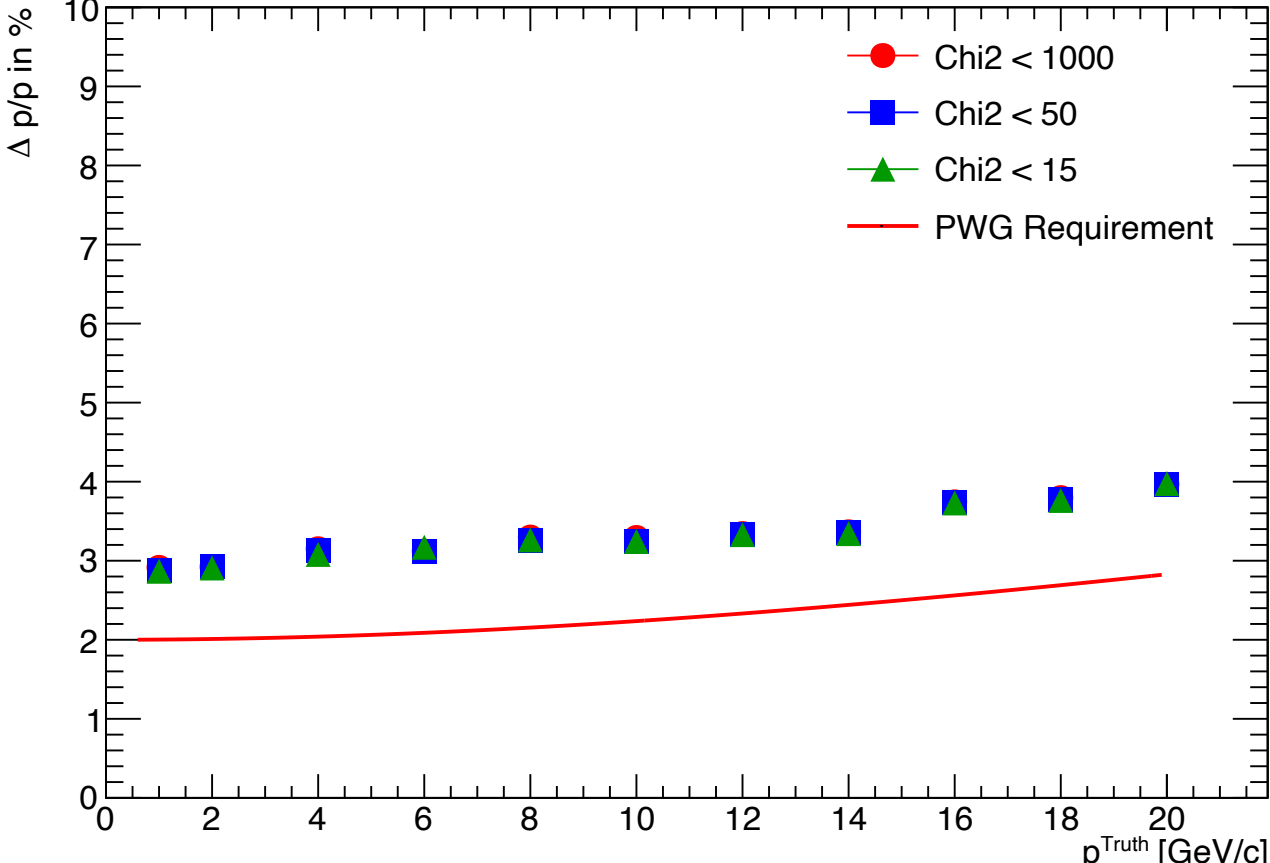
$1.0 < \eta < 2.0$



$2.0 < \eta < 2.5$



$2.5 < \eta < 3.5$



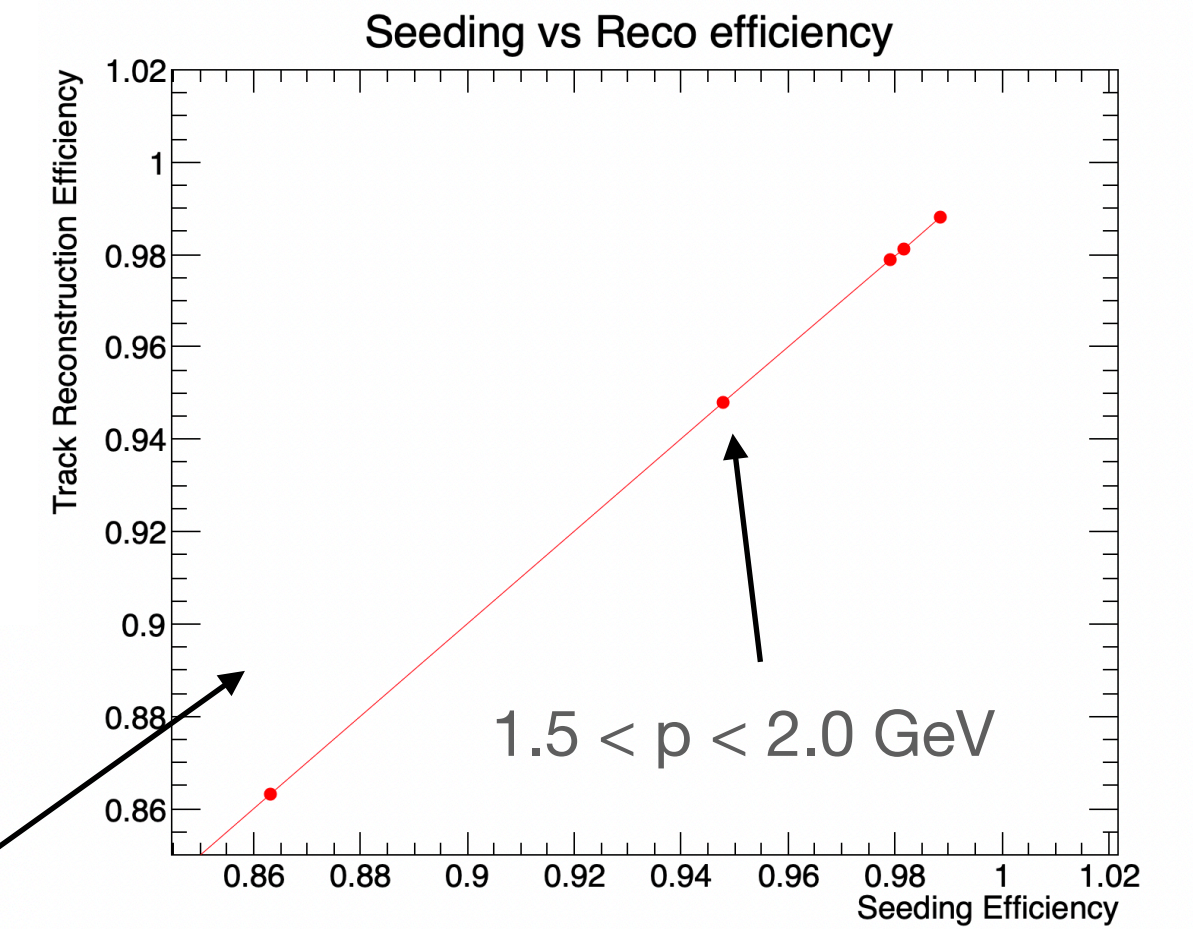
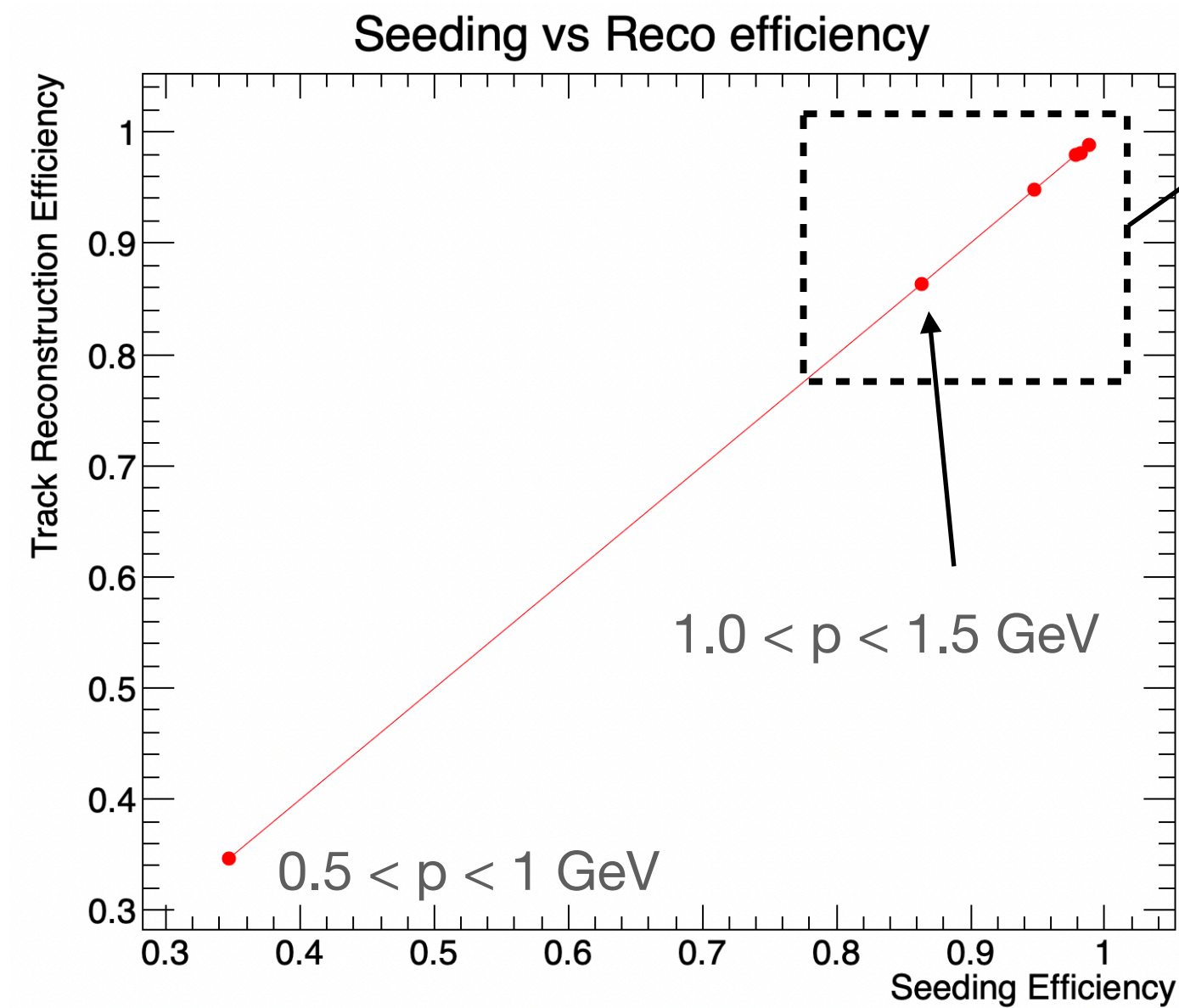
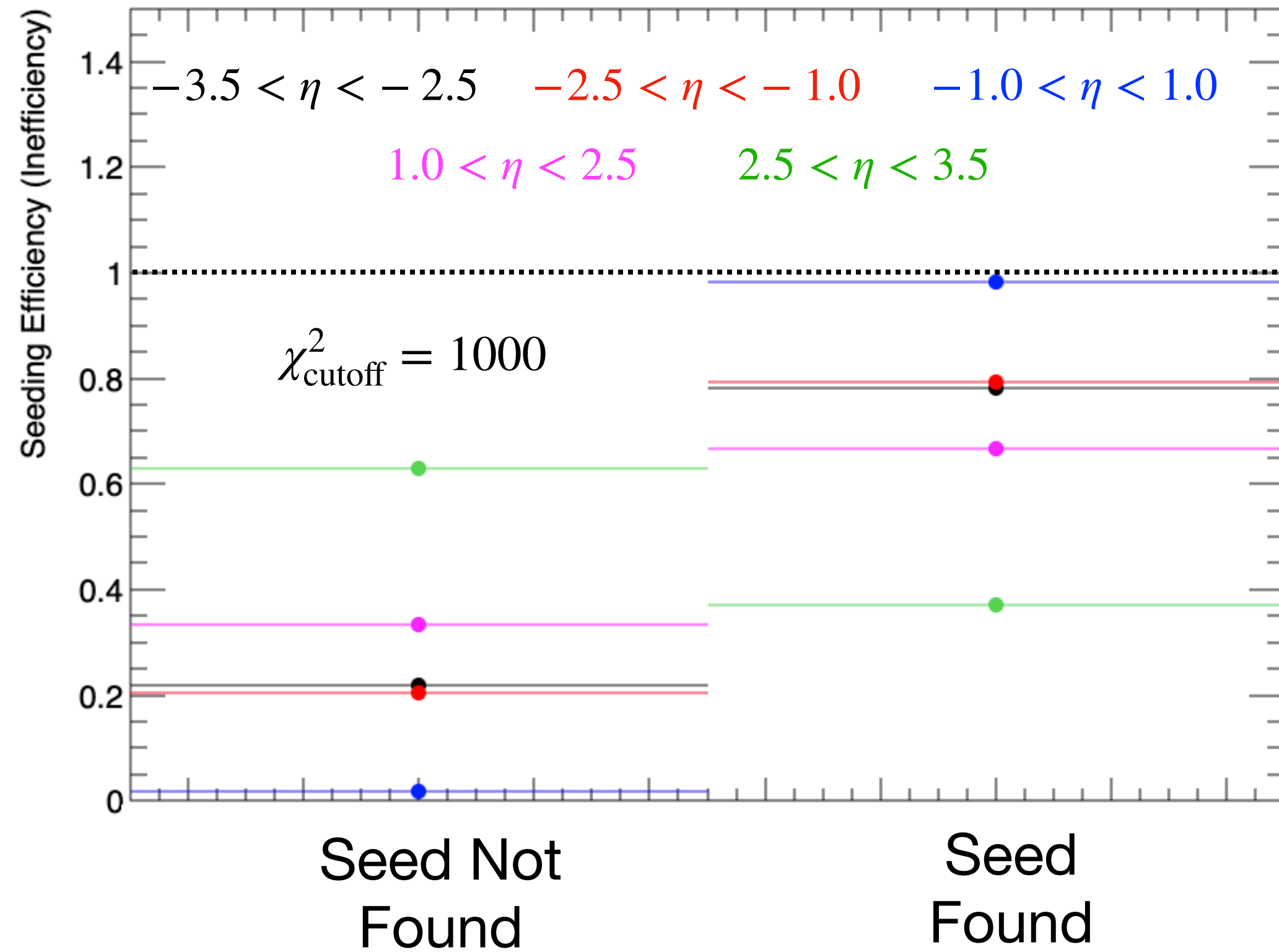
# Two Main Observations:

- From the single-pion simulations, we find that varying the  $\chi^2$  cutoff does not have a significant impact on our performance metrics. We did not evaluate the track purity in this study, as purity is not a meaningful metric for single-particle simulations.
- Another notable observation is that the reconstruction efficiency is relatively poor for low-momentum tracks. However, this behavior appears to be independent of the  $\chi^2$  cutoff.

Calculating a Seeding efficiency/inefficiency in single pion simulations with  $\chi^2 = 1000$

$$\epsilon_{\text{seed}} = \frac{N_{\text{events with a seed and an MC particle in } 0.5 < p < 1 \text{ GeV}/c}}{N_{\text{events with an MC particle in } 0.5 < p < 1 \text{ GeV}/c}} .$$

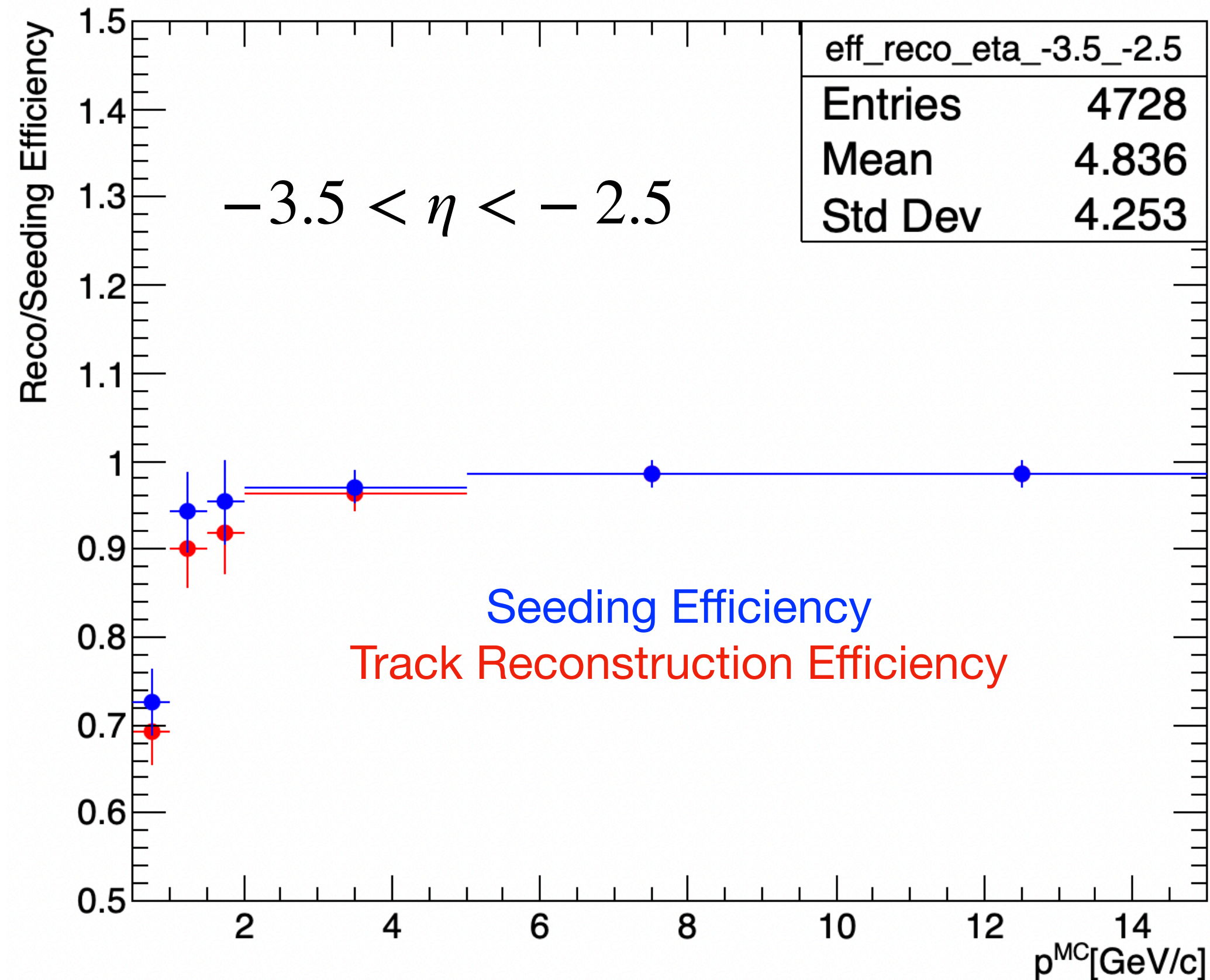
# Seeding Efficiency/Inefficiency



$2.5 < \eta < 3.5$

Seeding vs Track Reconstruction efficiency  
for 6 momentum bins  
One-to-one relation is observed.

# Electron going direction



- Seeding performance still requires further tuning.
- In the electron-going direction, a residual ~5% difference is observed between seeding efficiency and full track reconstruction efficiency.

$$\epsilon_{\text{seed}}(p, \eta) = \frac{N_{\text{MC}}^{\text{seed}}(p, \eta)}{N_{\text{MC}}(p, \eta)} \quad \epsilon_{\text{reco}}(p, \eta) = \frac{N_{\text{MC}}^{\text{reco}}(p, \eta)}{N_{\text{MC}}(p, \eta)}$$

$N_{\text{MC}}(p, \eta)$  = number of generated single-particle in  $(p, \eta)$

$N_{\text{MC}}^{\text{seed}}(p, \eta)$  = number of MC particles in  $(p, \eta)$  with at least one seed

$N_{\text{MC}}^{\text{reco}}(p, \eta)$  = number of MC particles in  $(p, \eta)$  with at least one reconstructed track

# Looking at the DIS Events

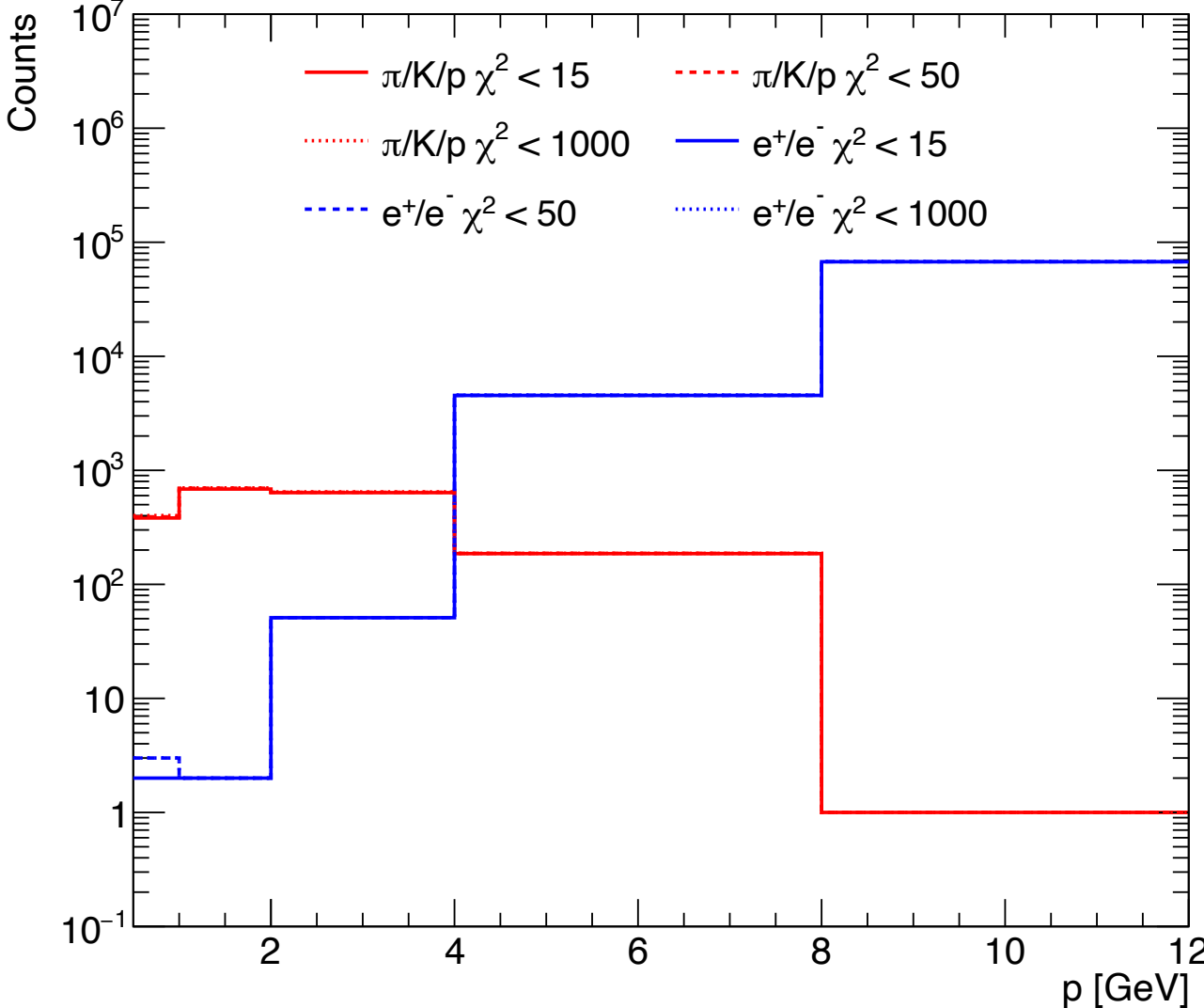
**Sample Used : 10x275 GeV DIS Events February  
Campaign with 5 microns Au Coating**

**Events sample ~ 126k events**

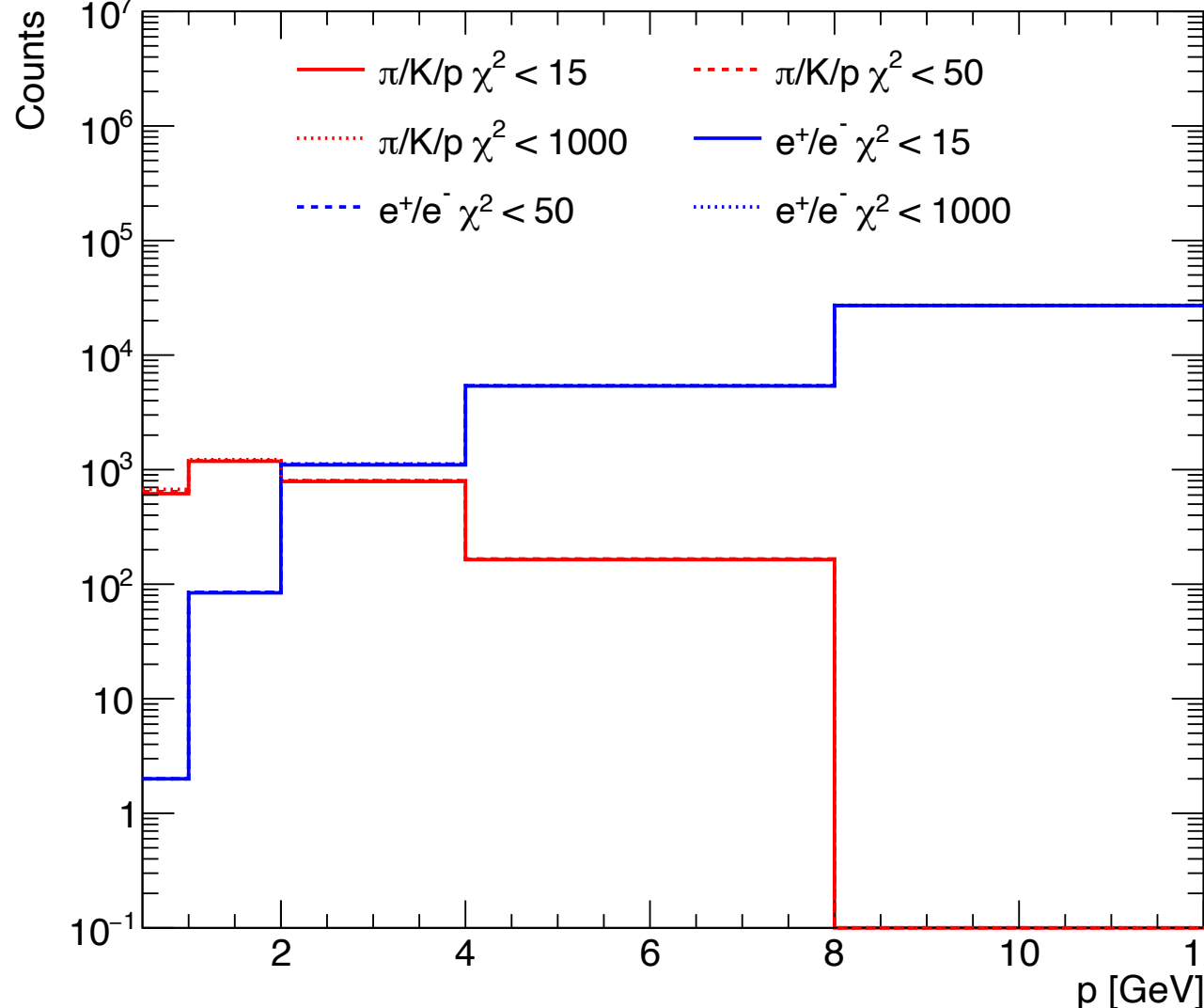
**Only reconstructed tracks that are associated with a  
primary e or hadron track are considered.**

# Comparison of the Reco Momentum Spectra

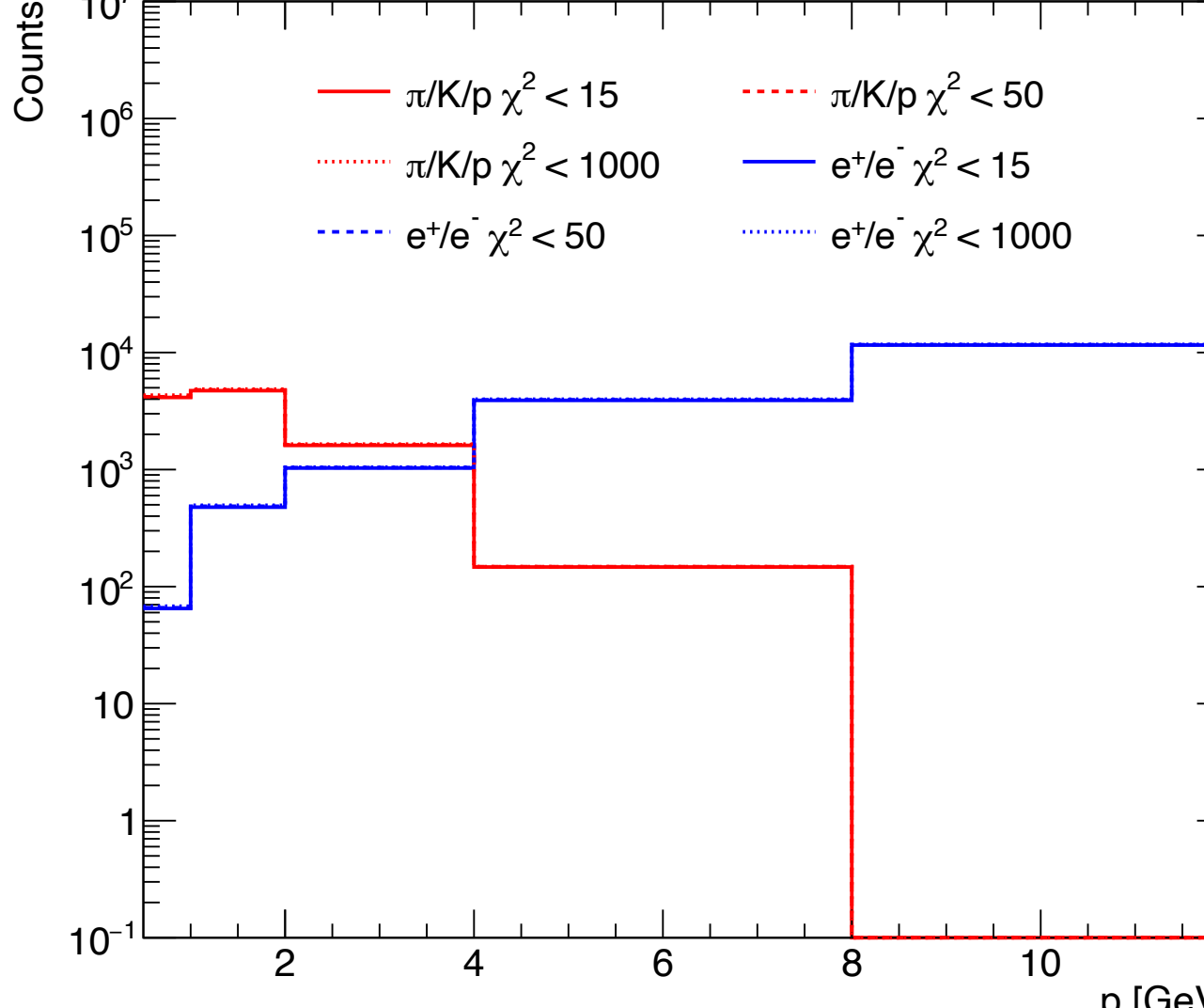
$-3.5 < \eta < -2.5$



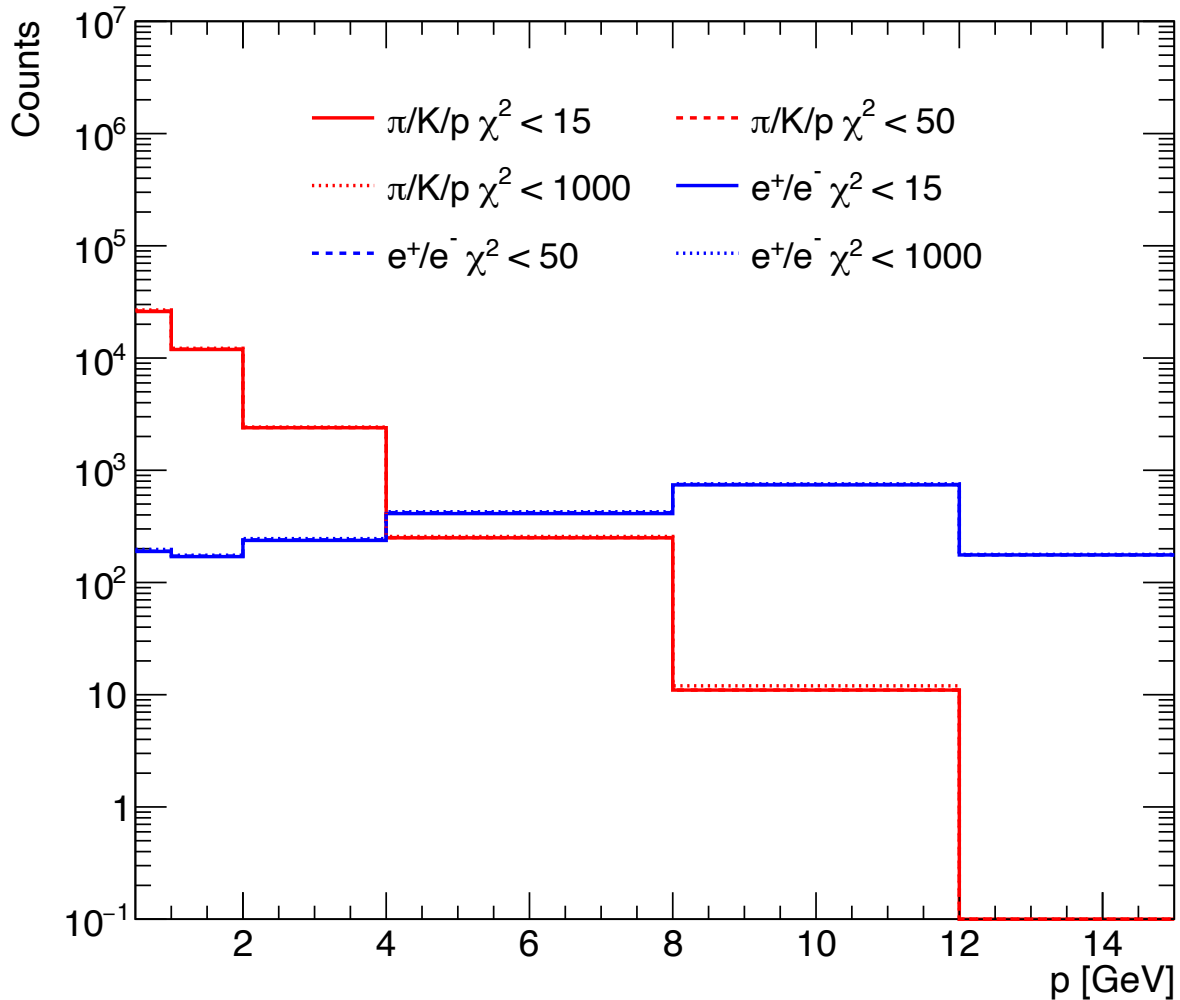
$-2.5 < \eta < -2.0$



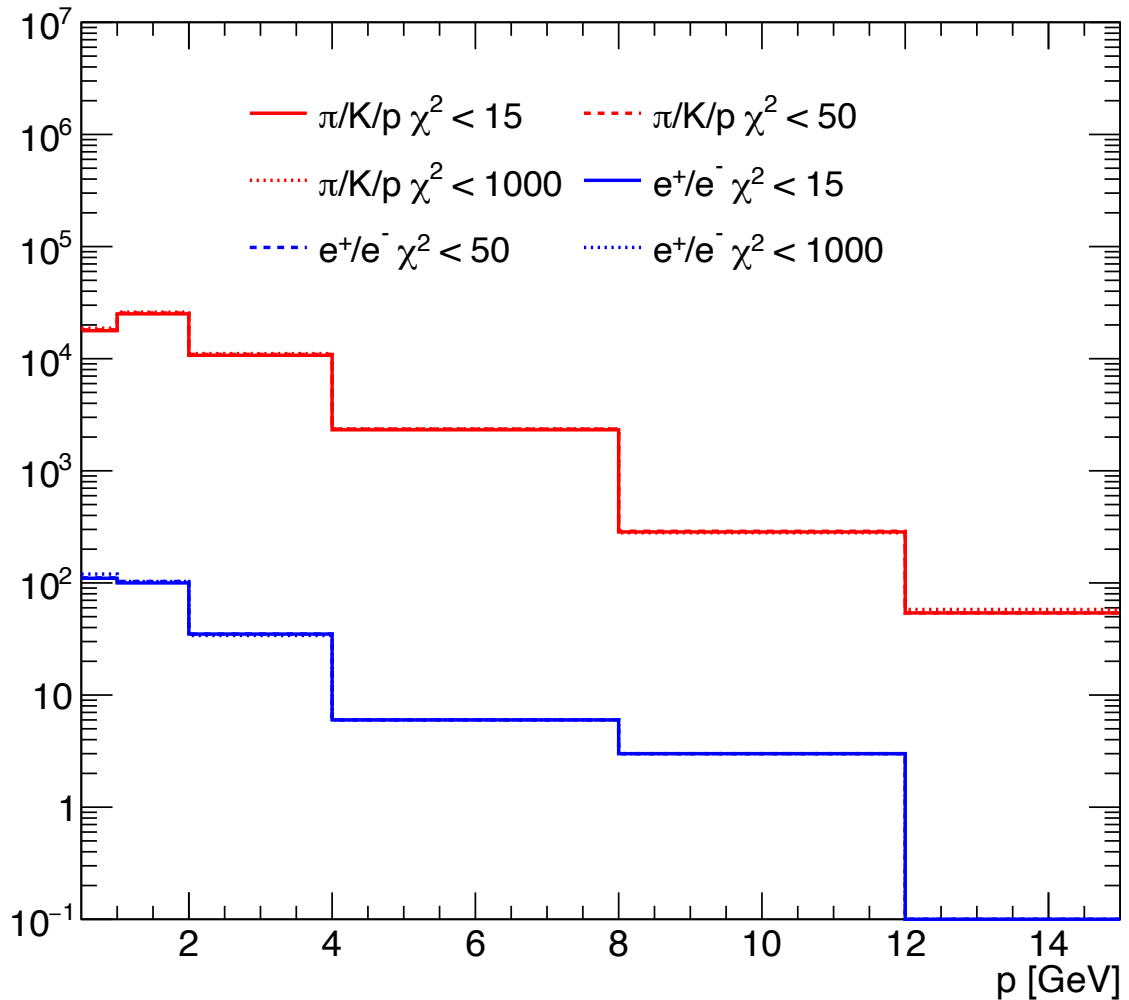
$-2.0 < \eta < -1.0$



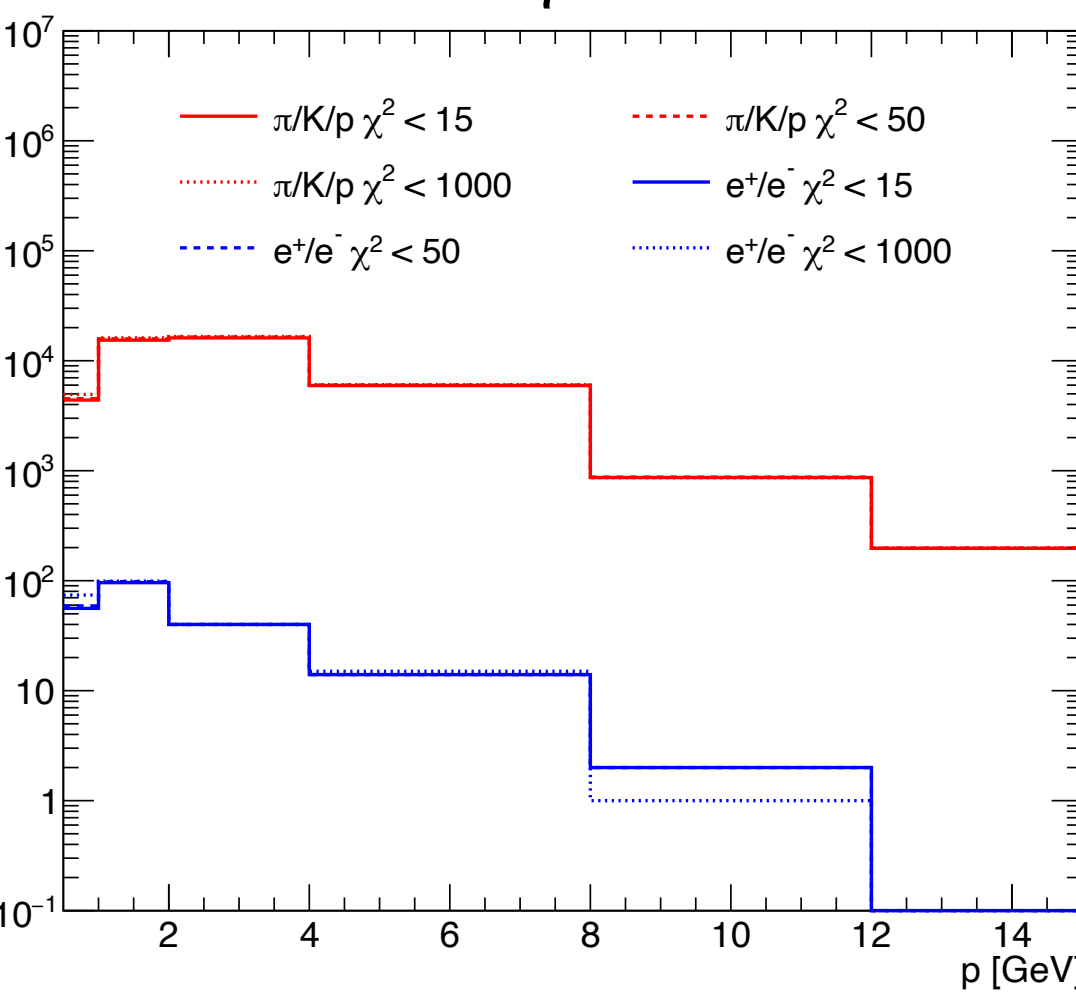
$-1.0 < \eta < 1.0$



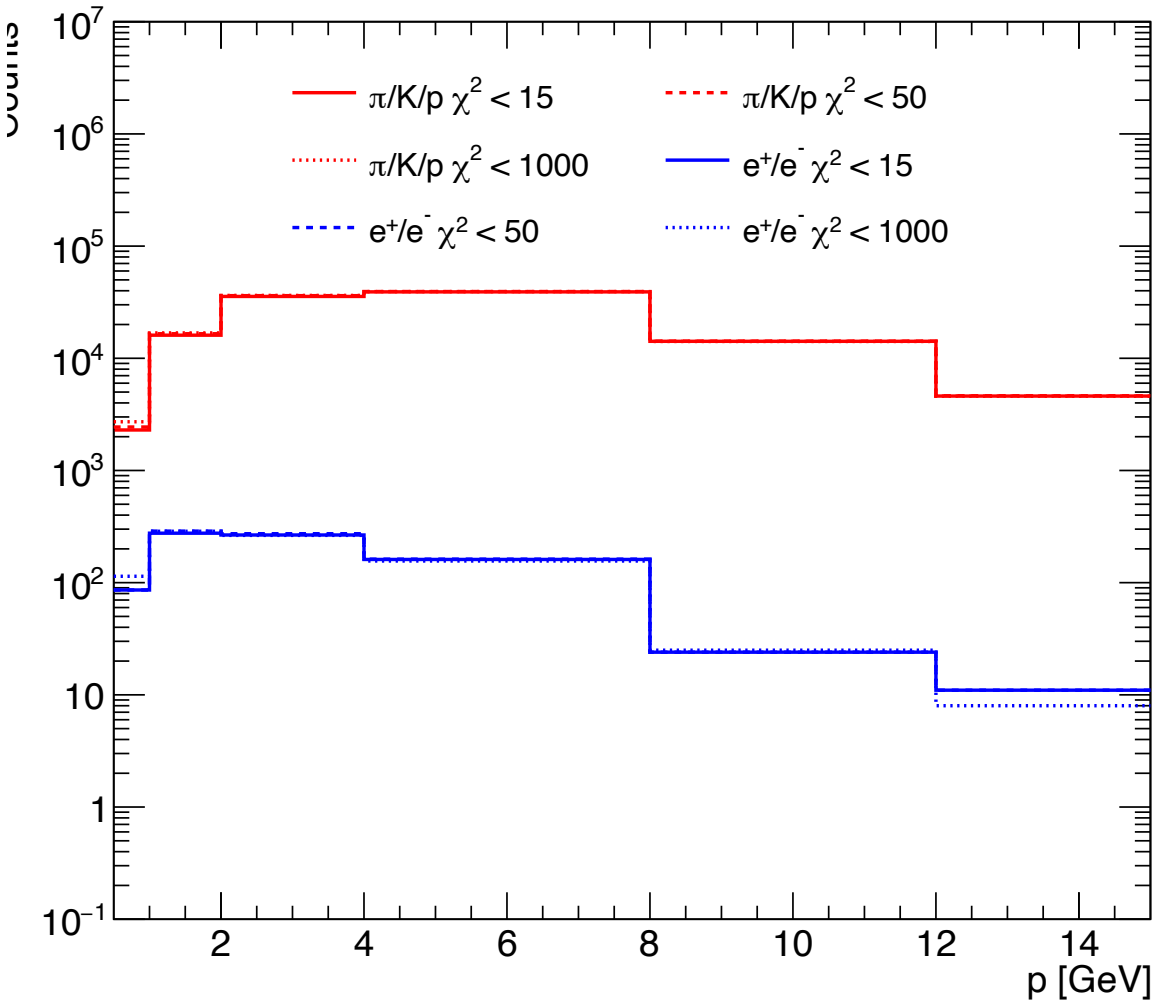
$1.0 < \eta < 2.0$



$2.0 < \eta < 2.5$

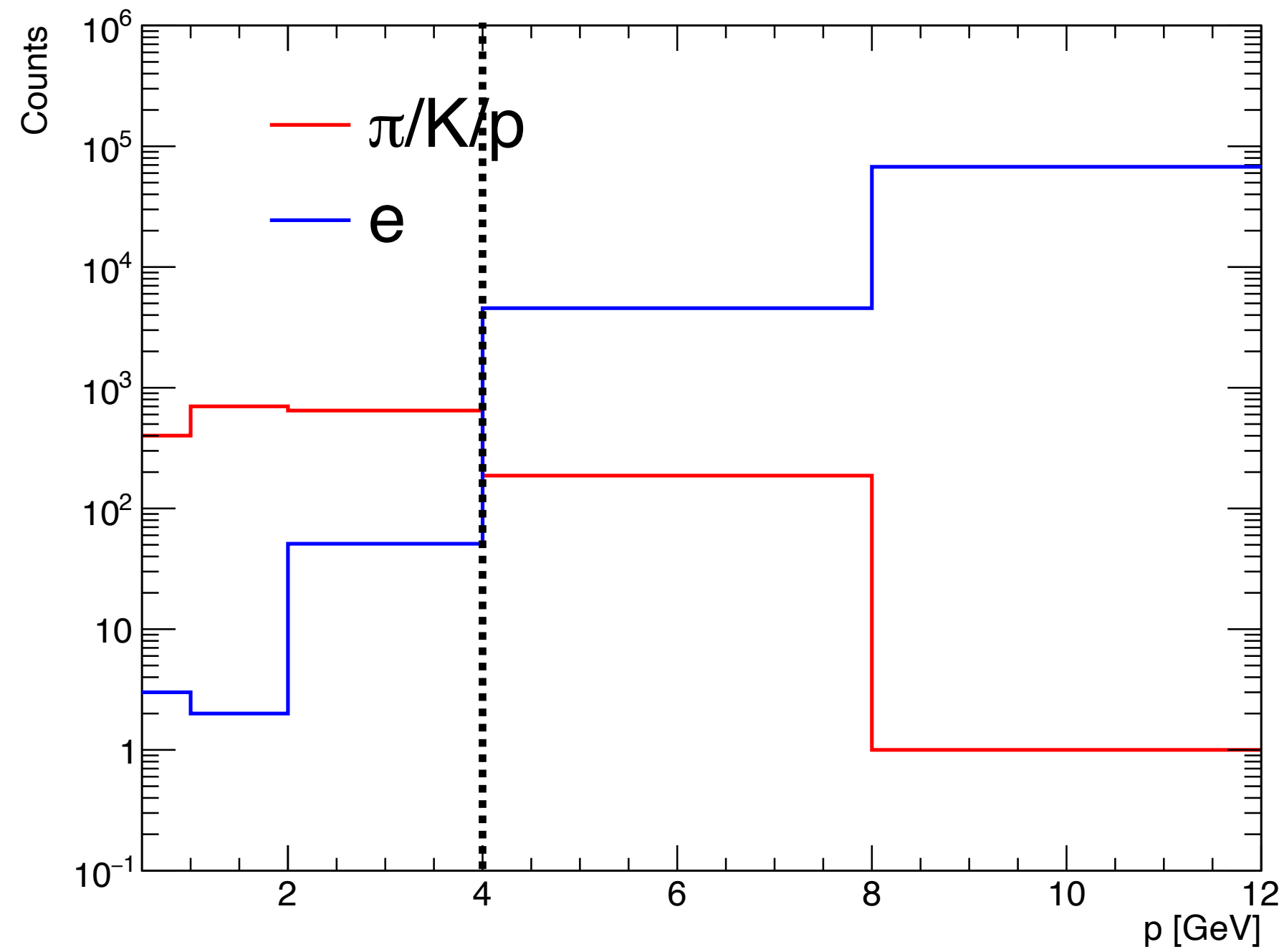


$2.5 < \eta < 3.5$



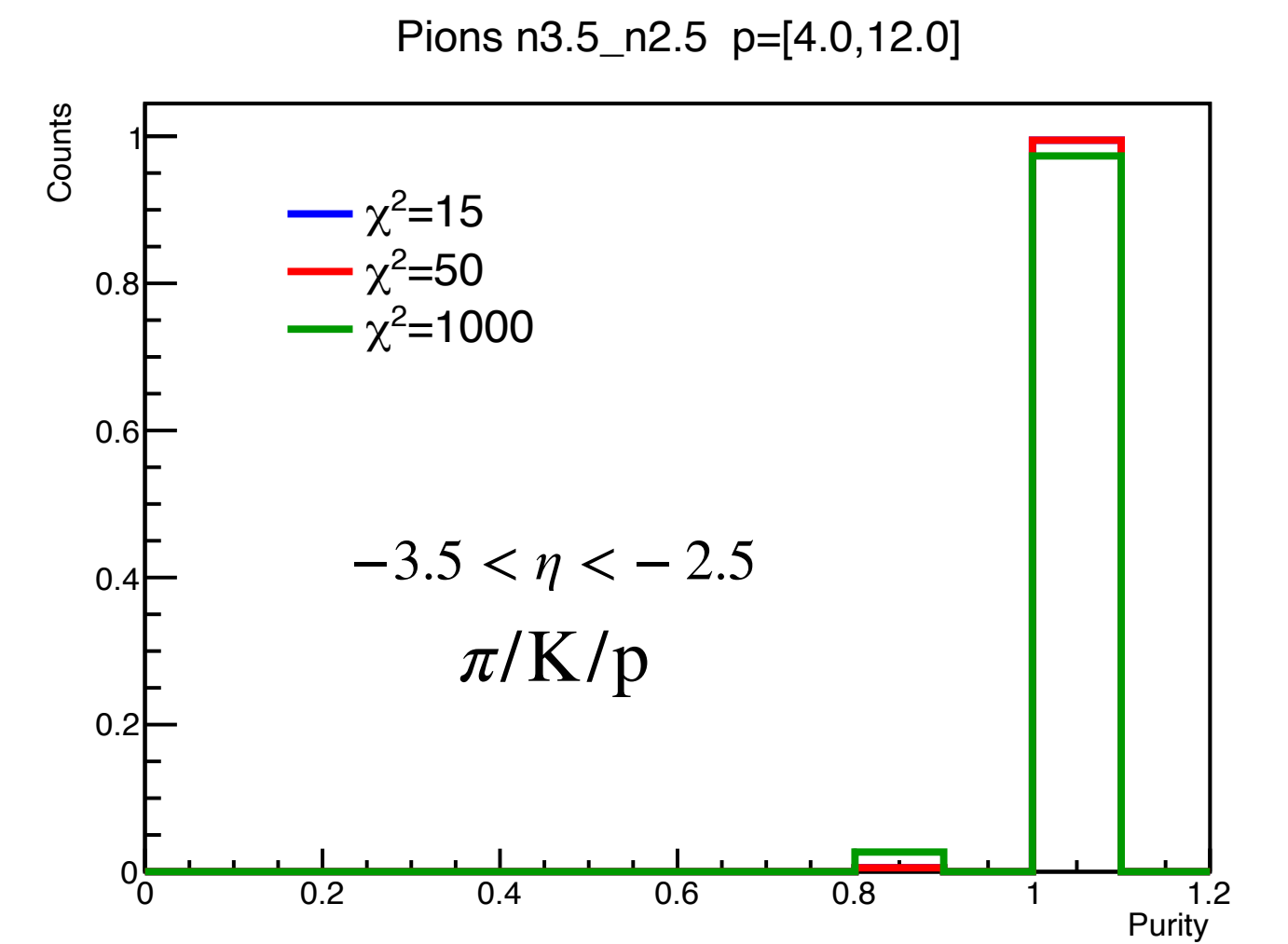
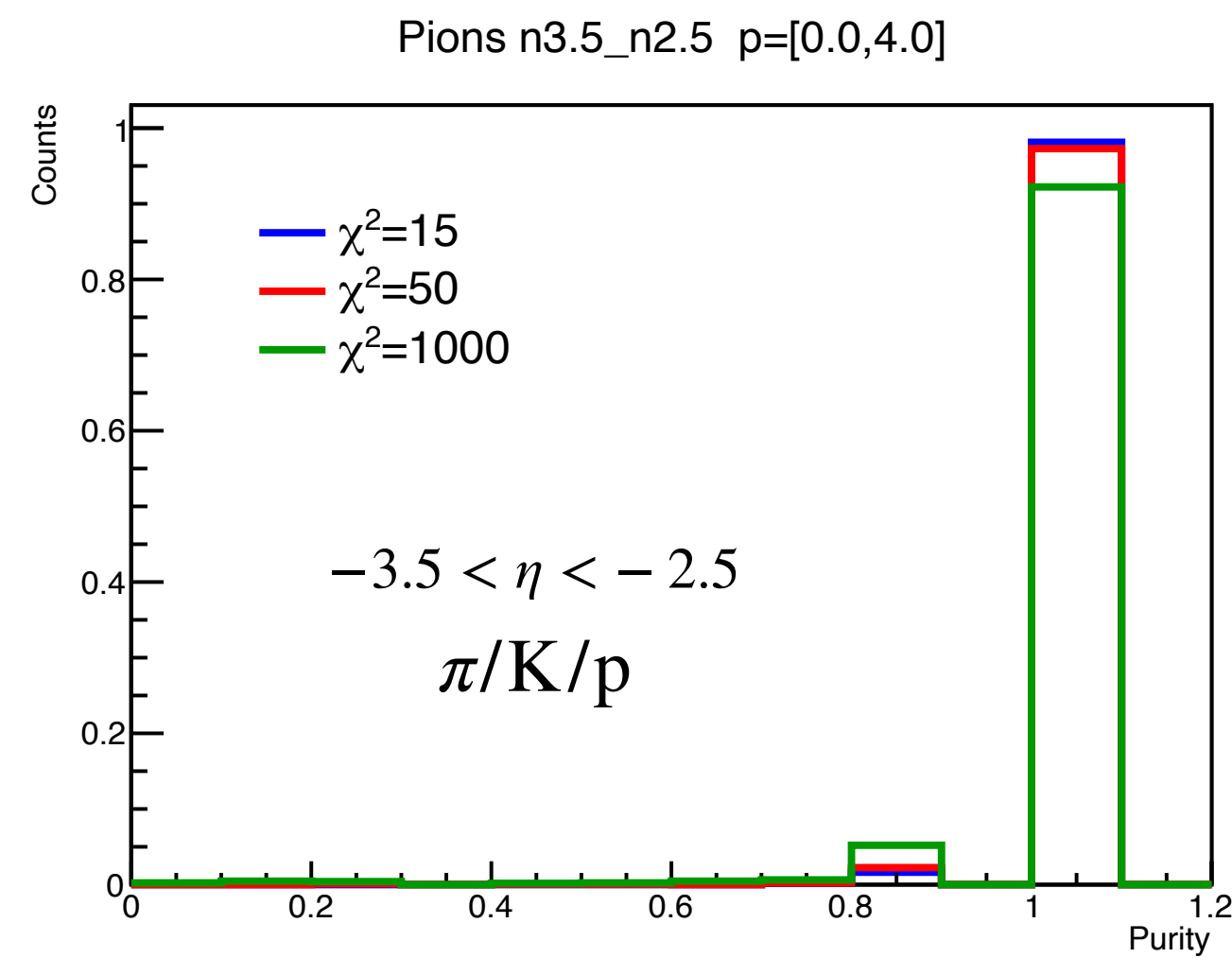
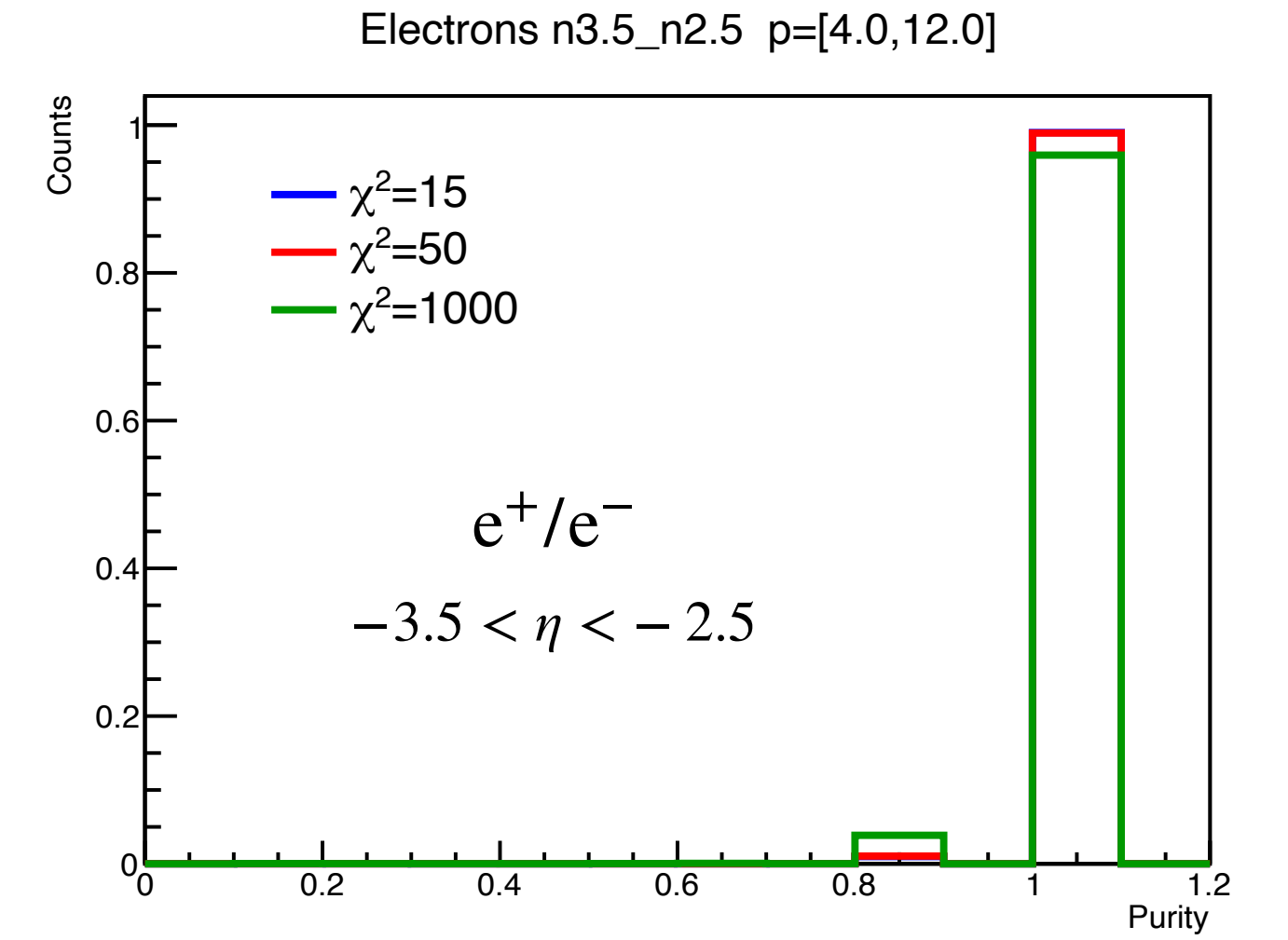
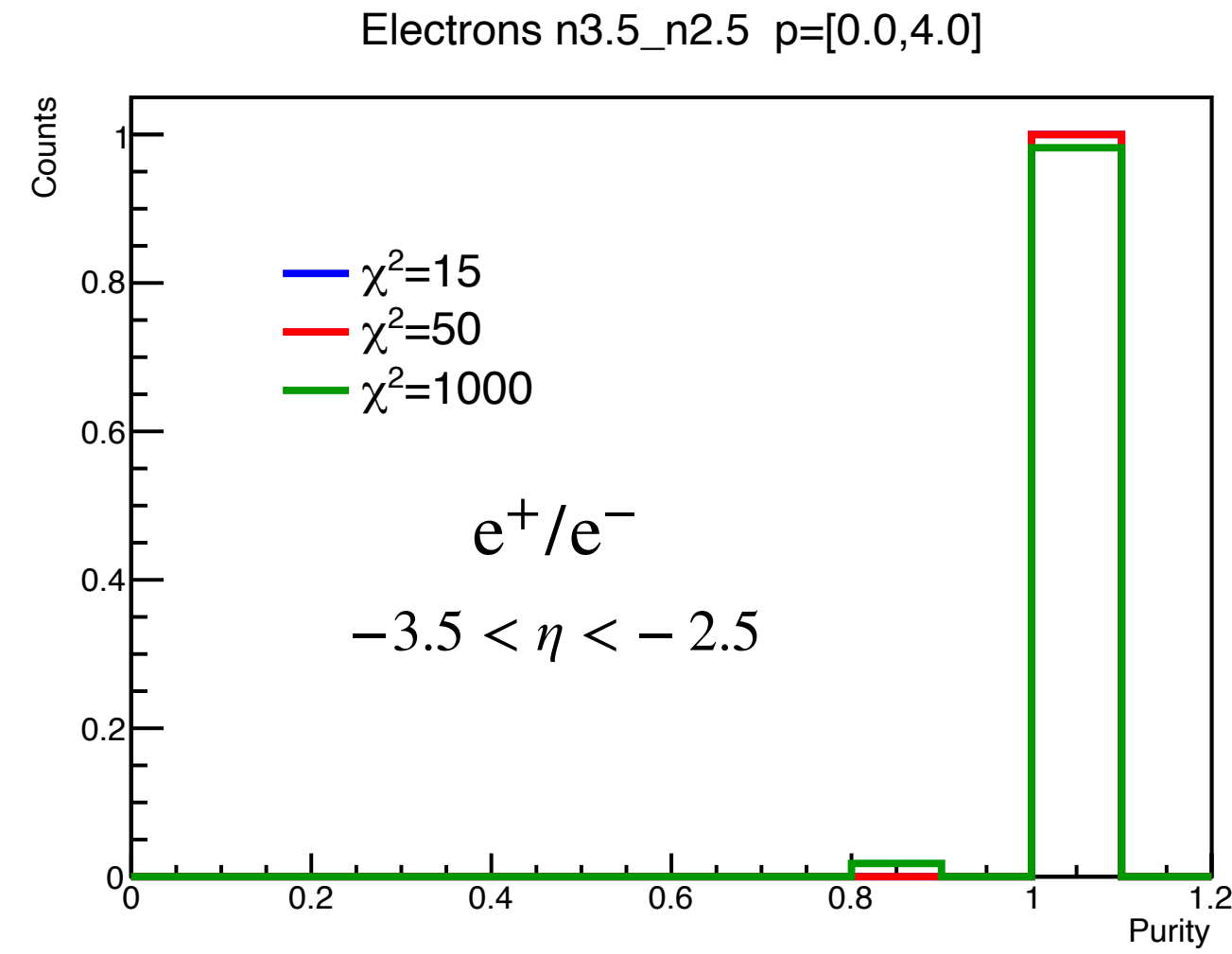
# Purity Distributions

Reconstructed tracks corresponding to primary electron/hadron tracks are considered.

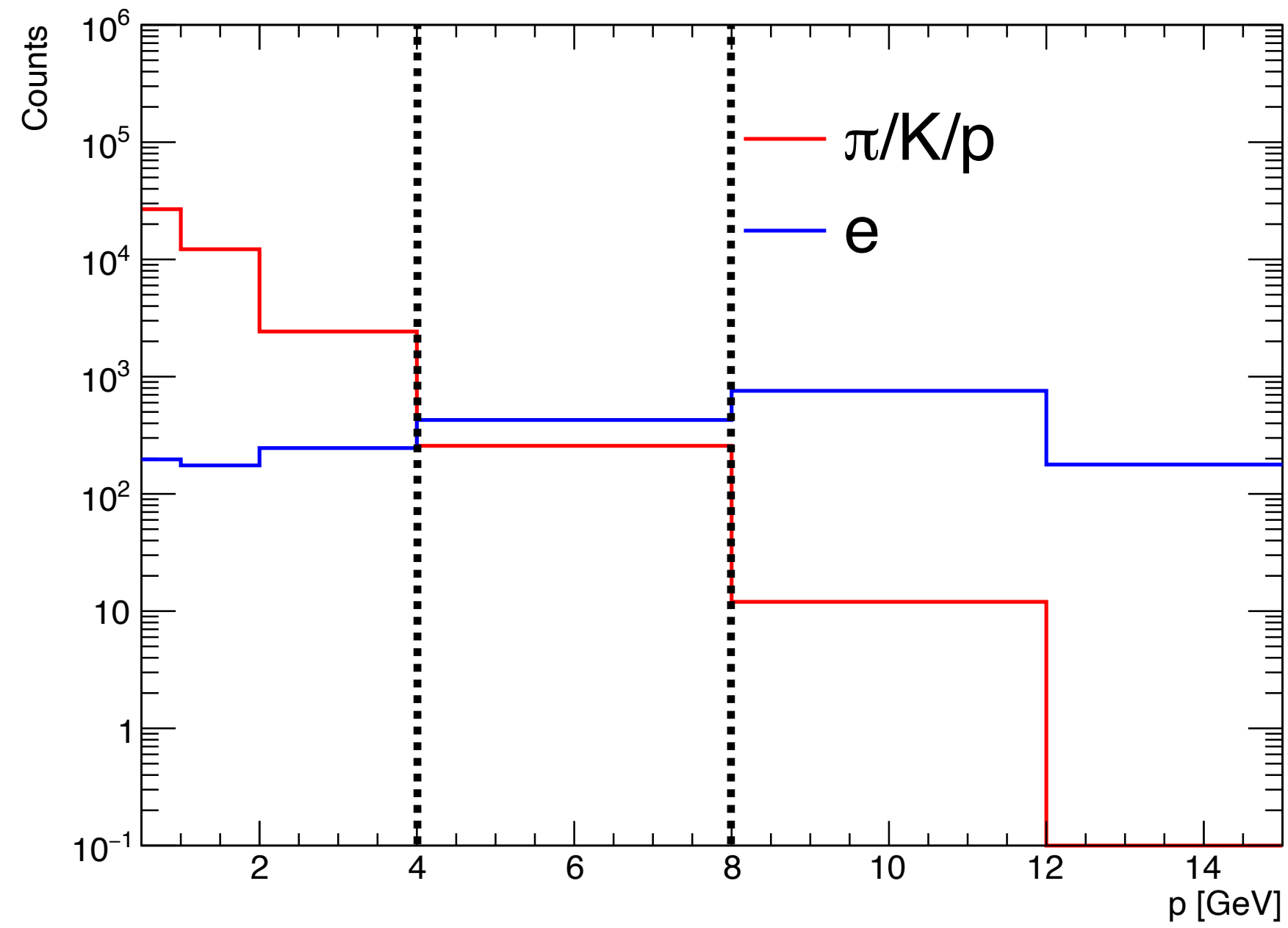


$$-3.5 < \eta < -2.5$$

$$\text{Purity} = \frac{N_{\text{Hits}}^{\text{primary}}}{N_{\text{Hits}}^{\text{Total}}}$$

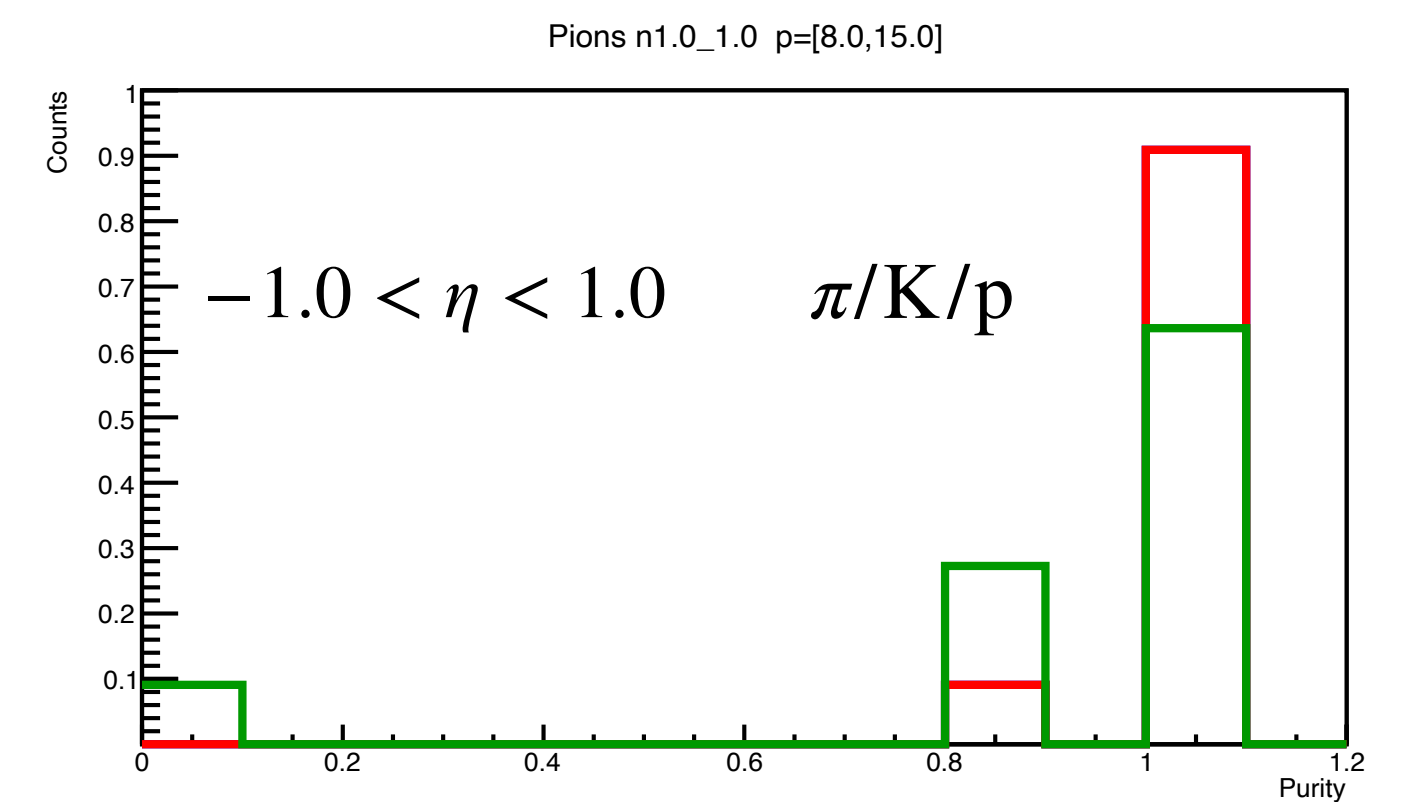
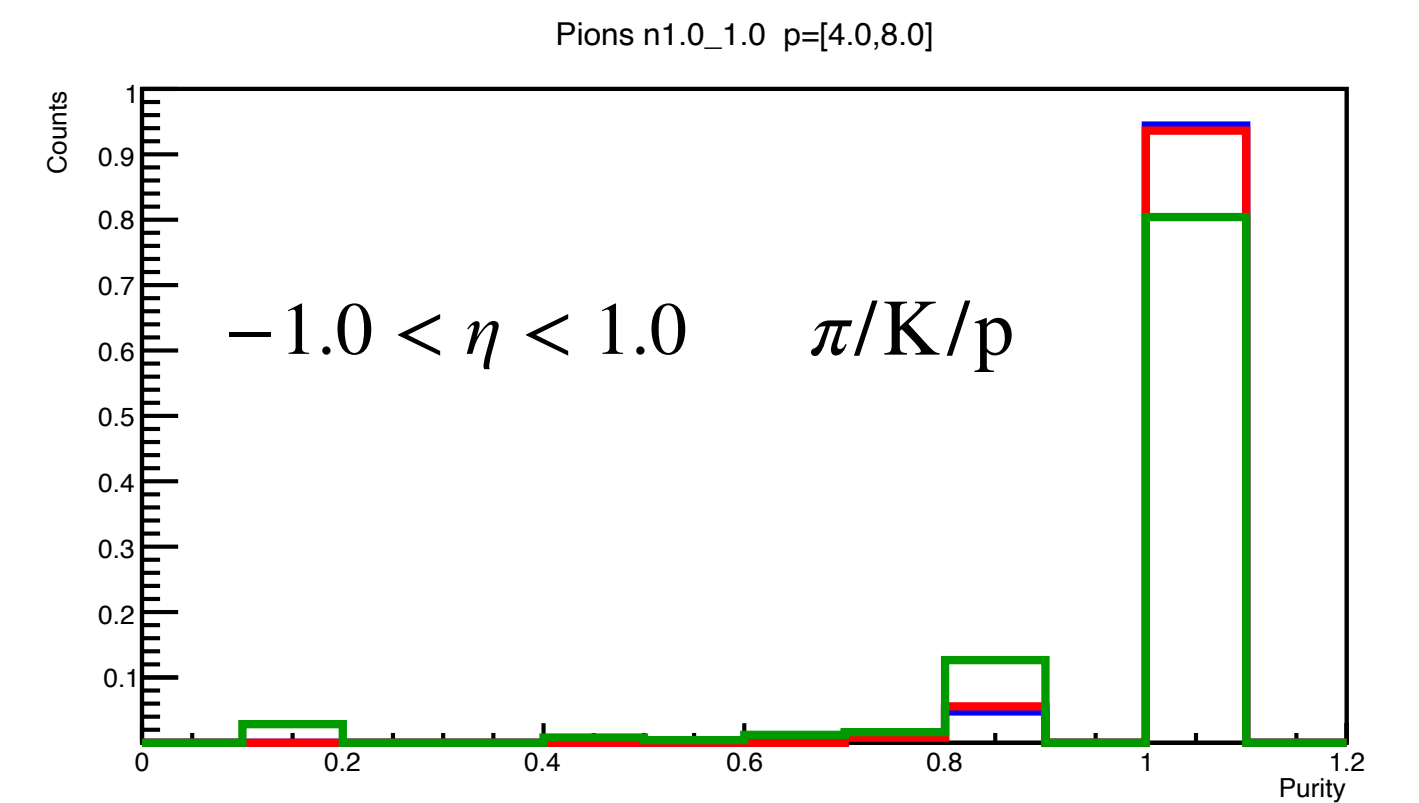
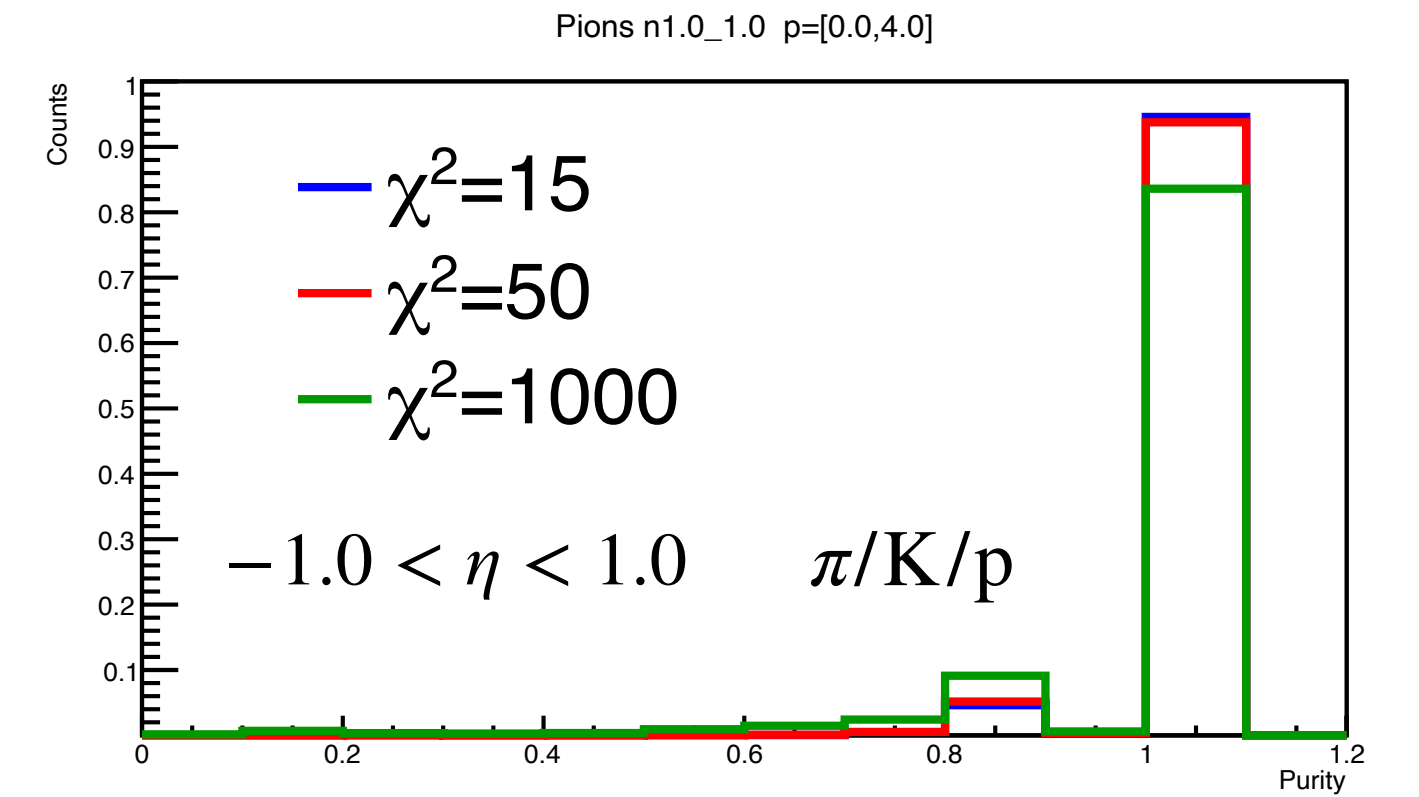
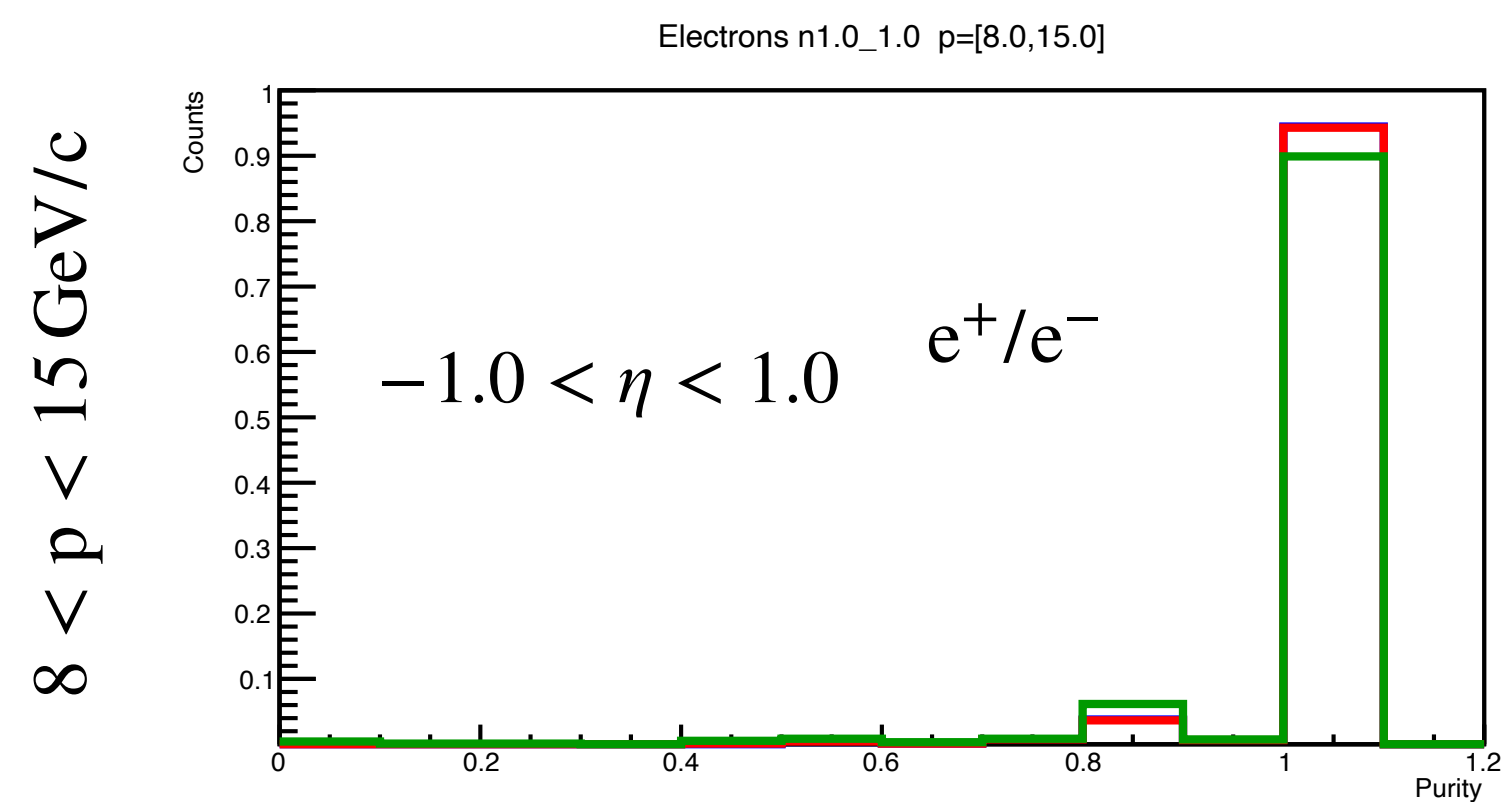
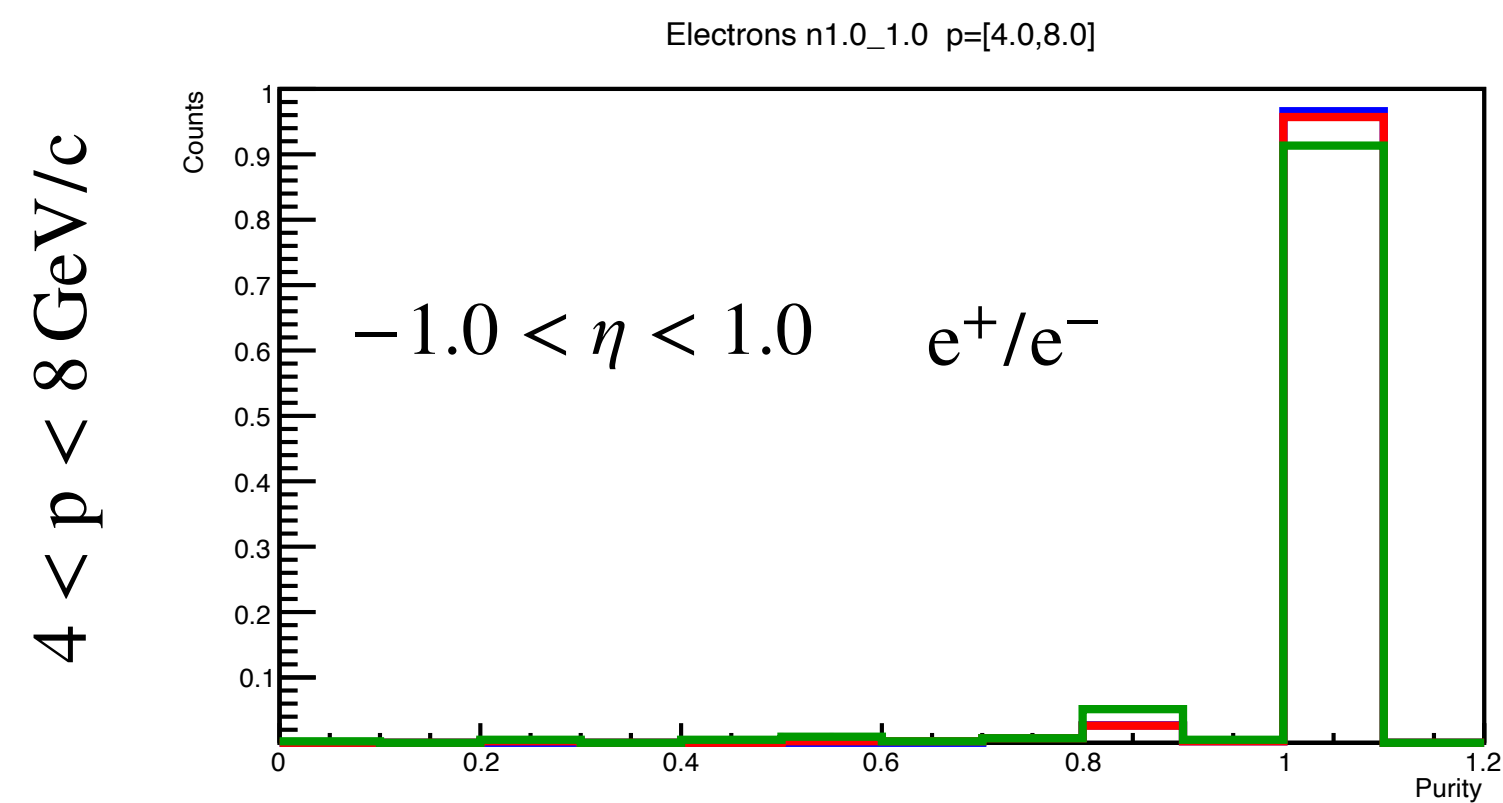
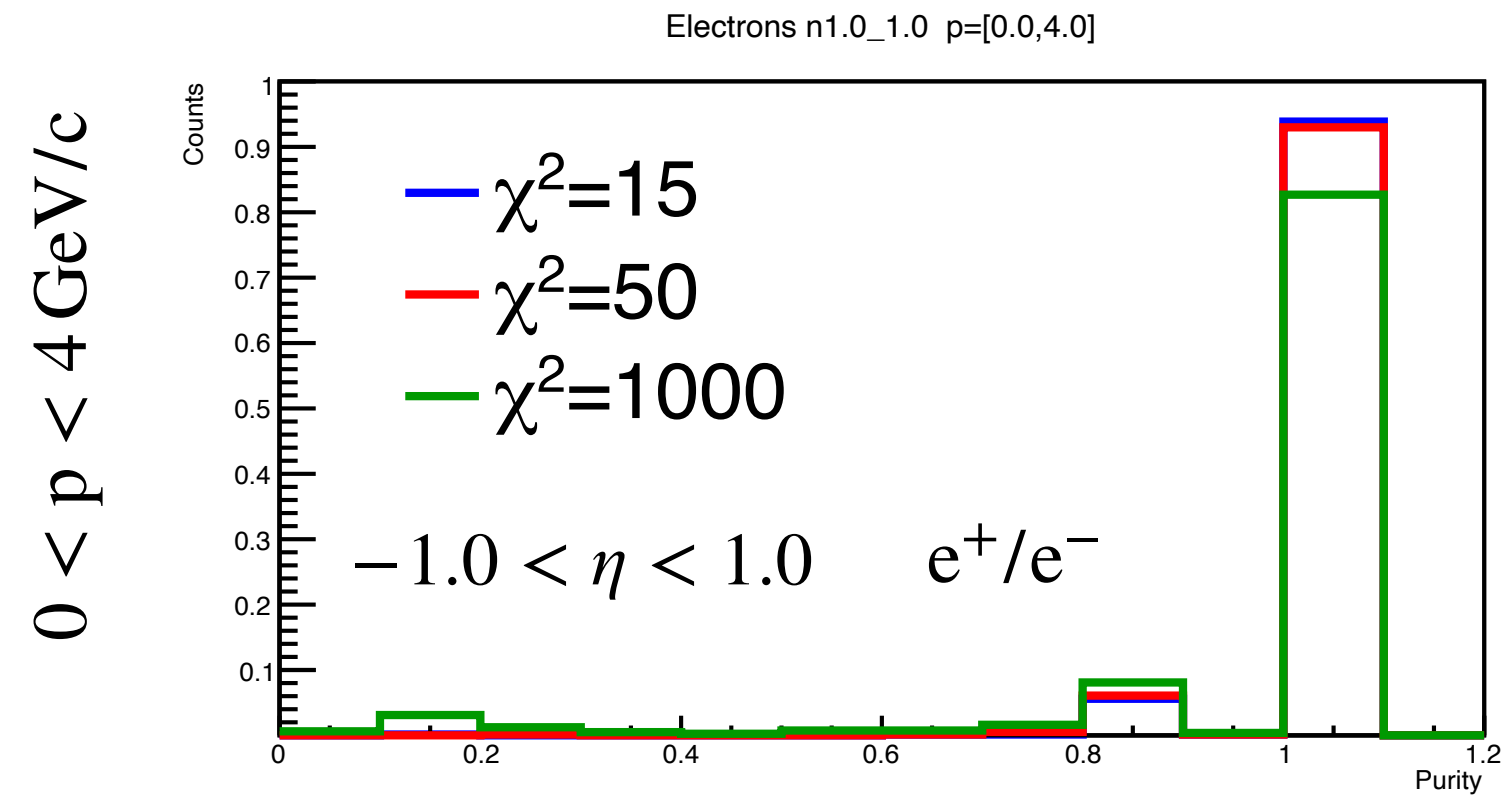


# Purity Distributions

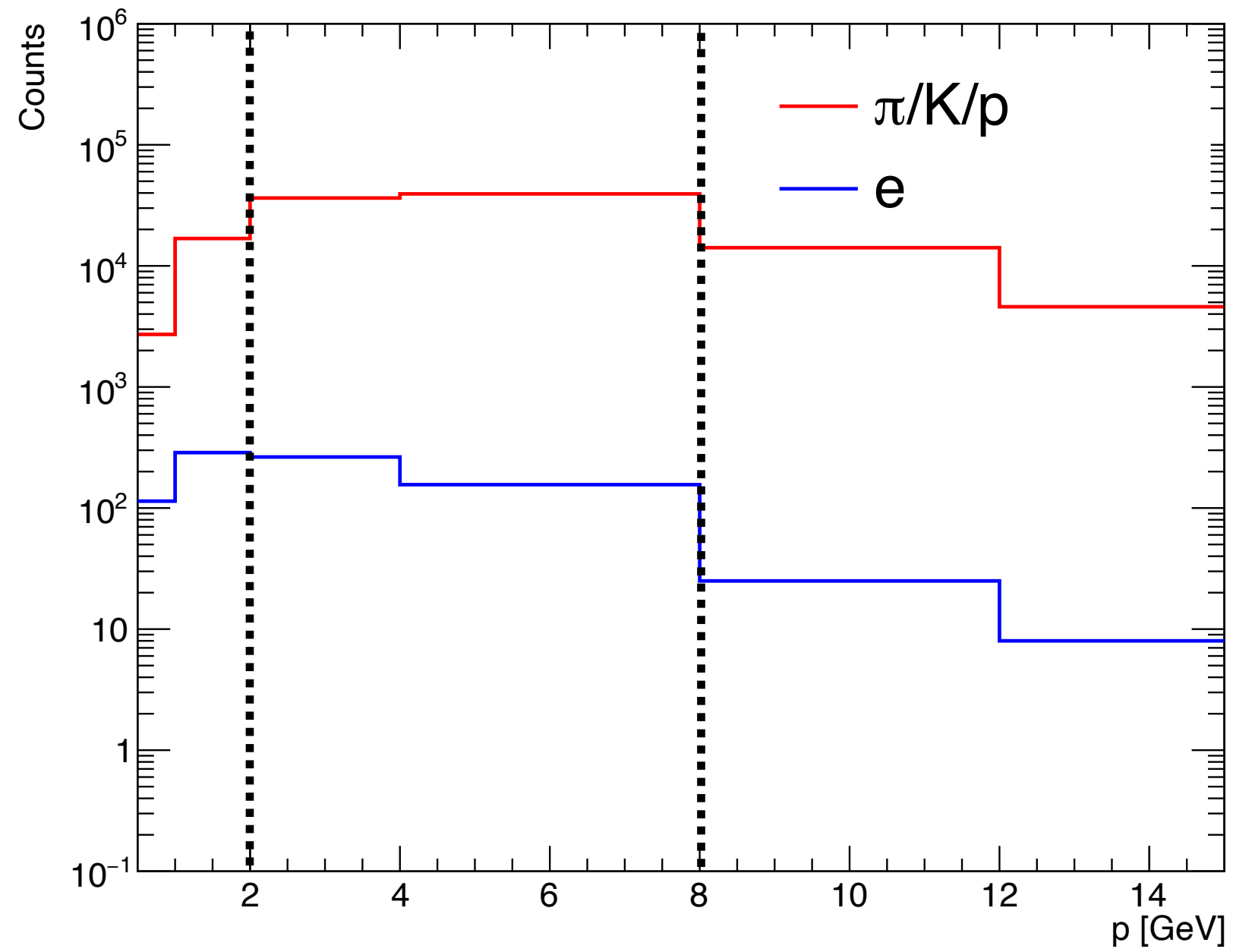


$$-1.0 < \eta < 1.0$$

$$\text{Purity} = \frac{N_{\text{Hits}}^{\text{primary}}}{N_{\text{Hits}}^{\text{Total}}}$$

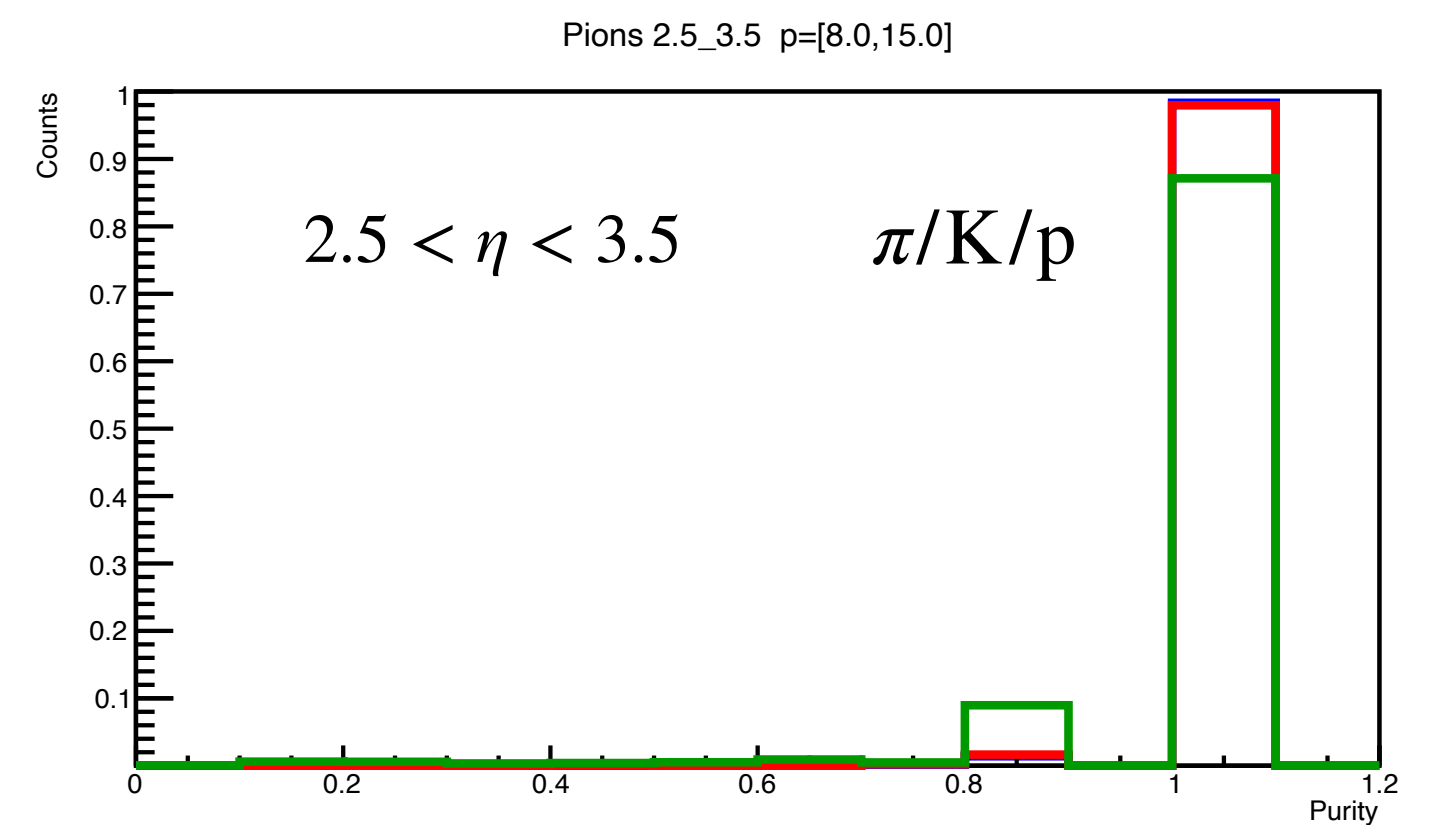
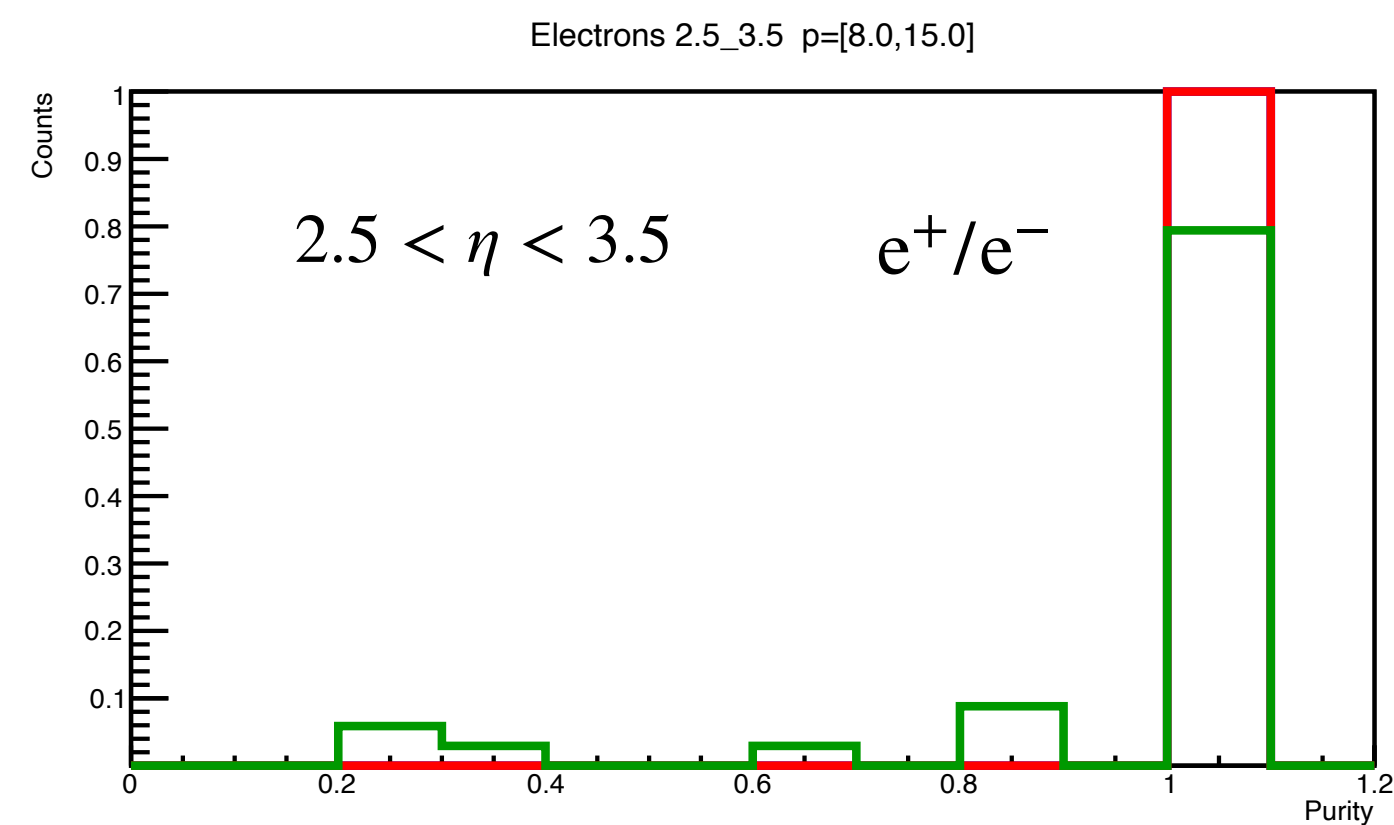
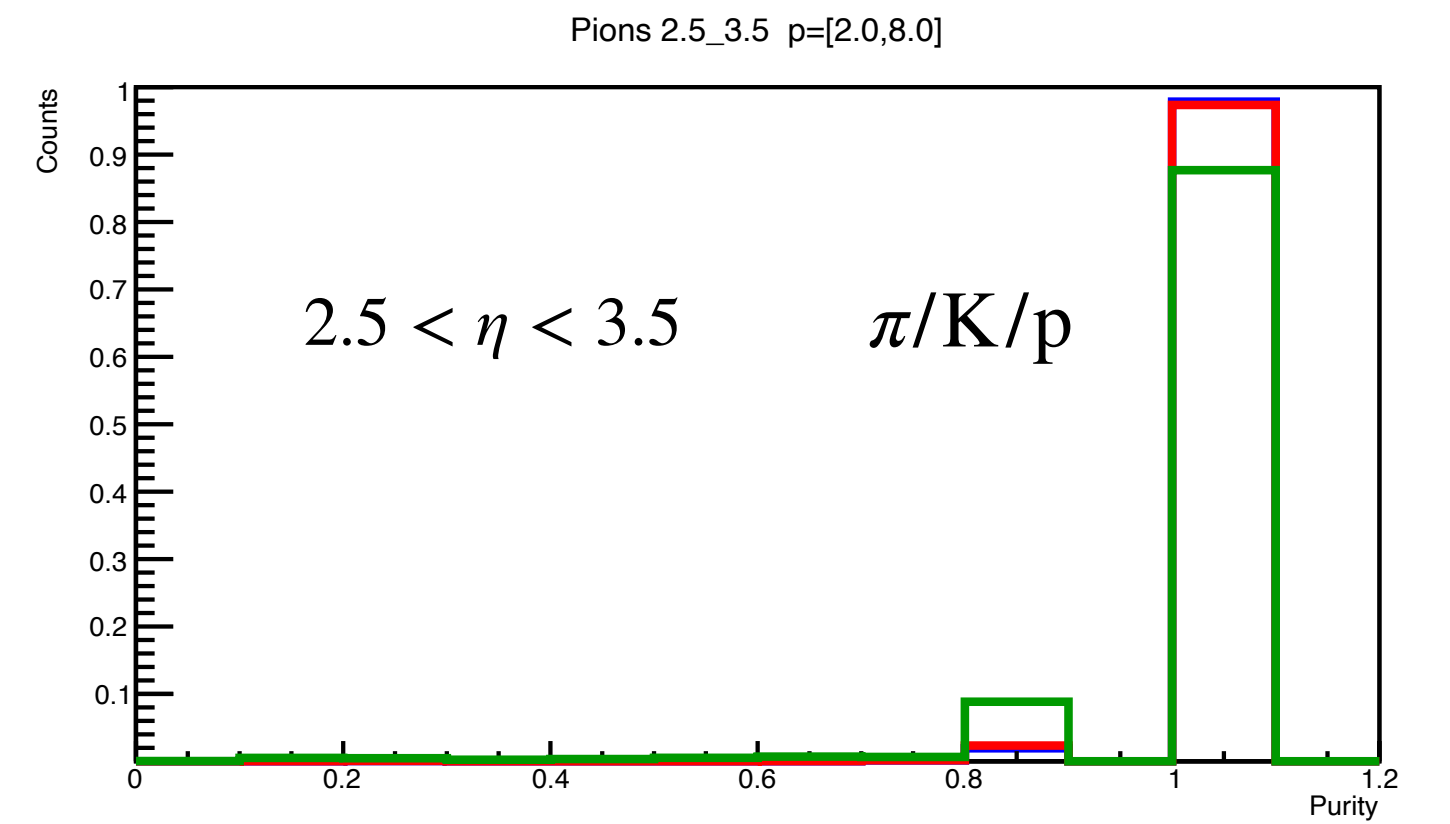
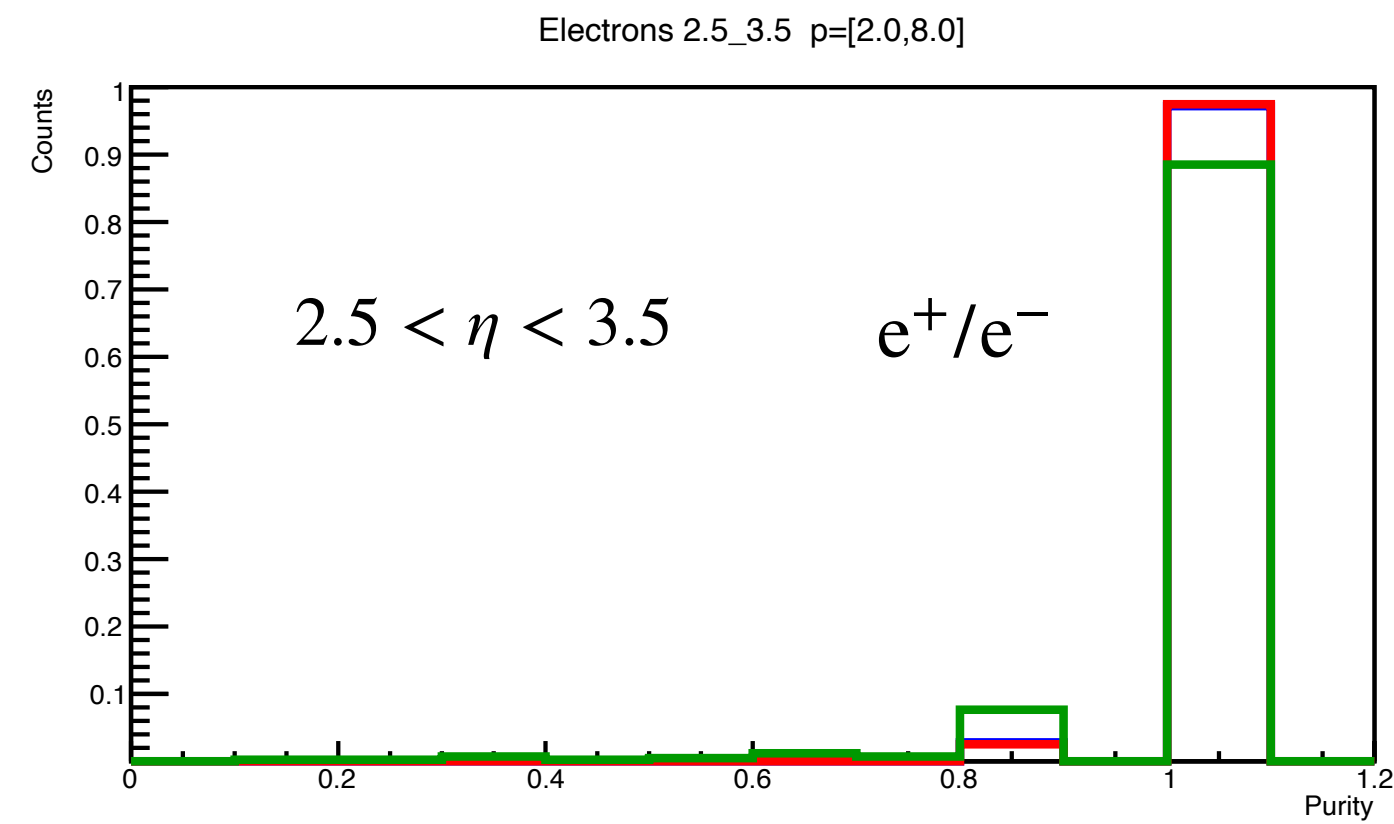
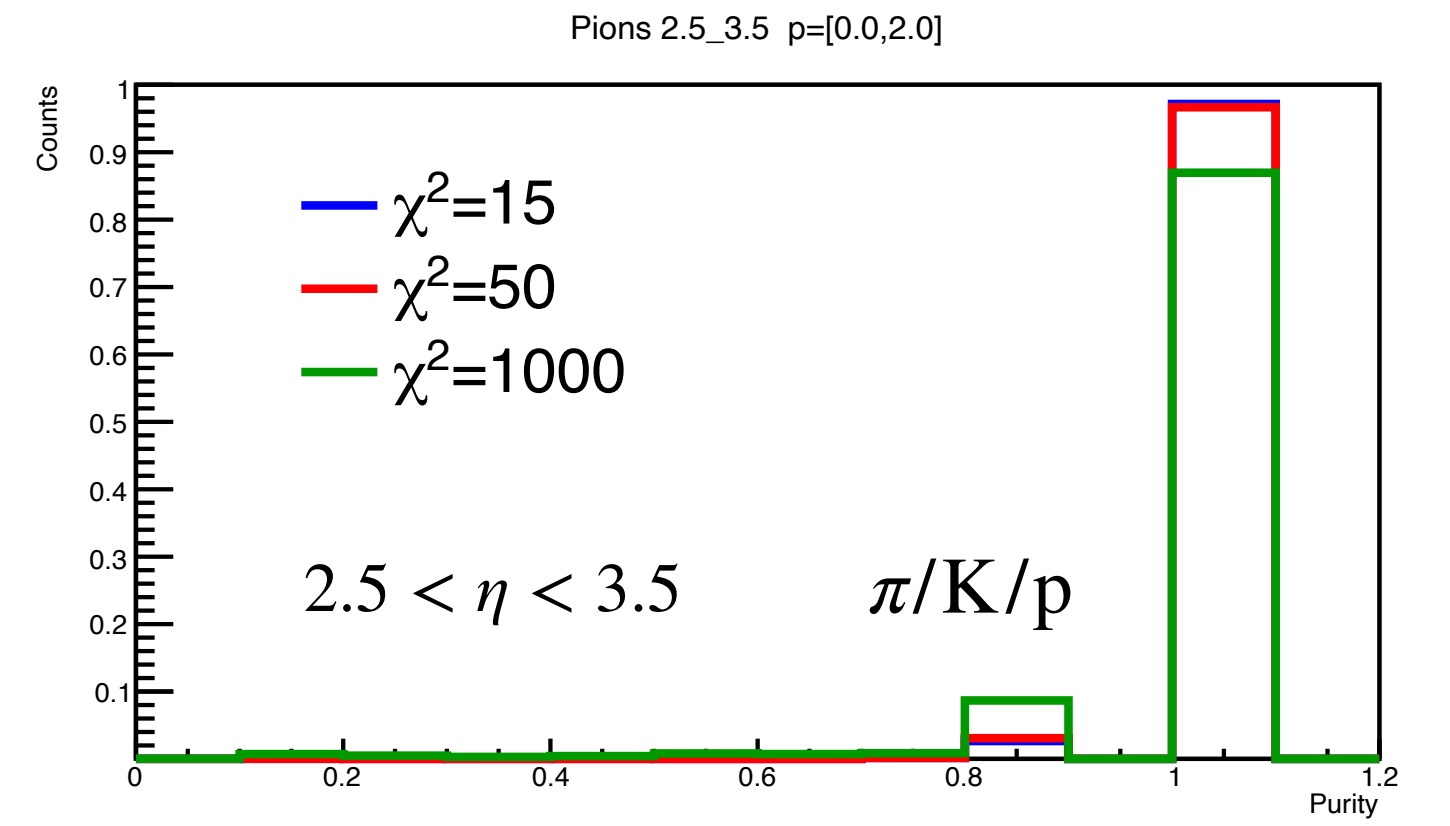
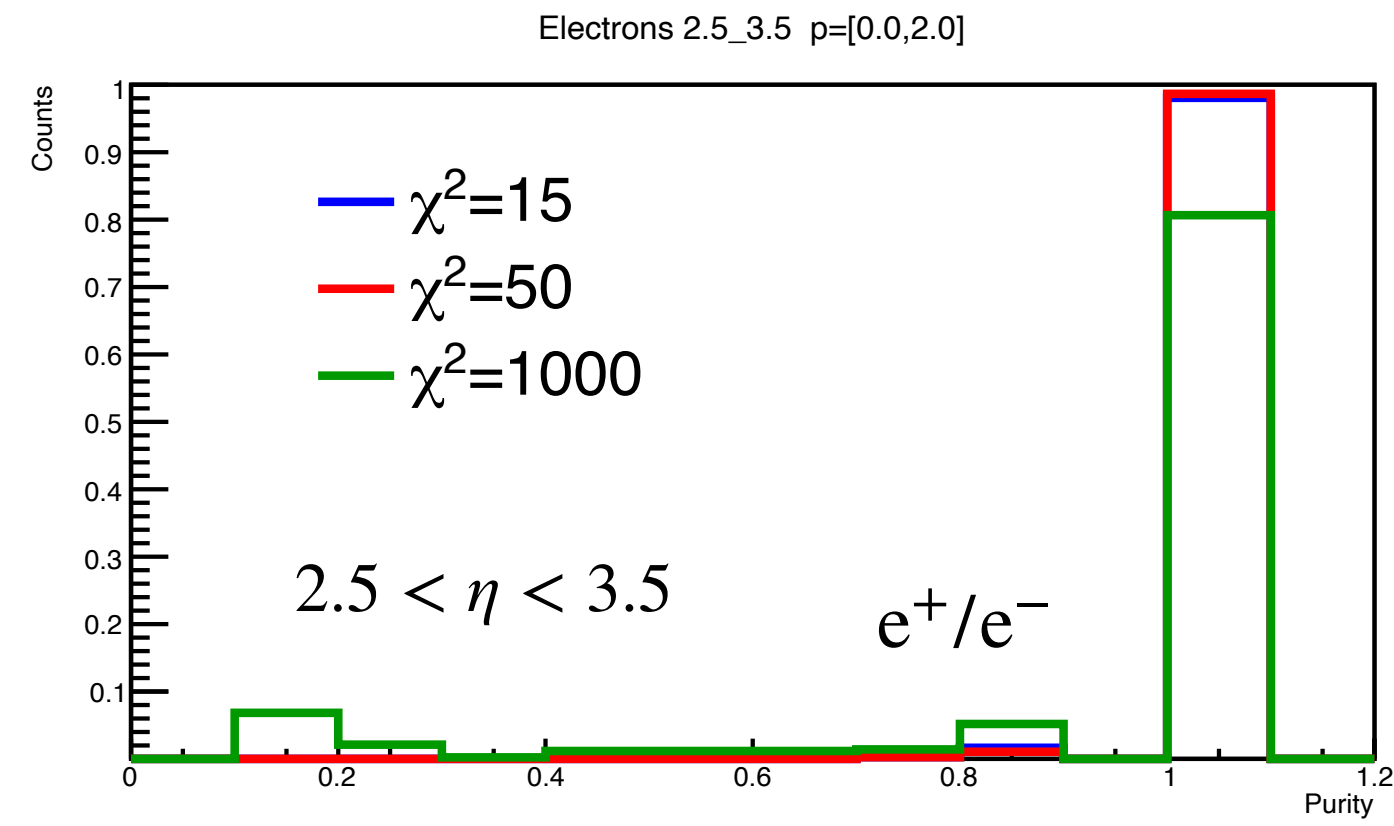


# Purity Distributions



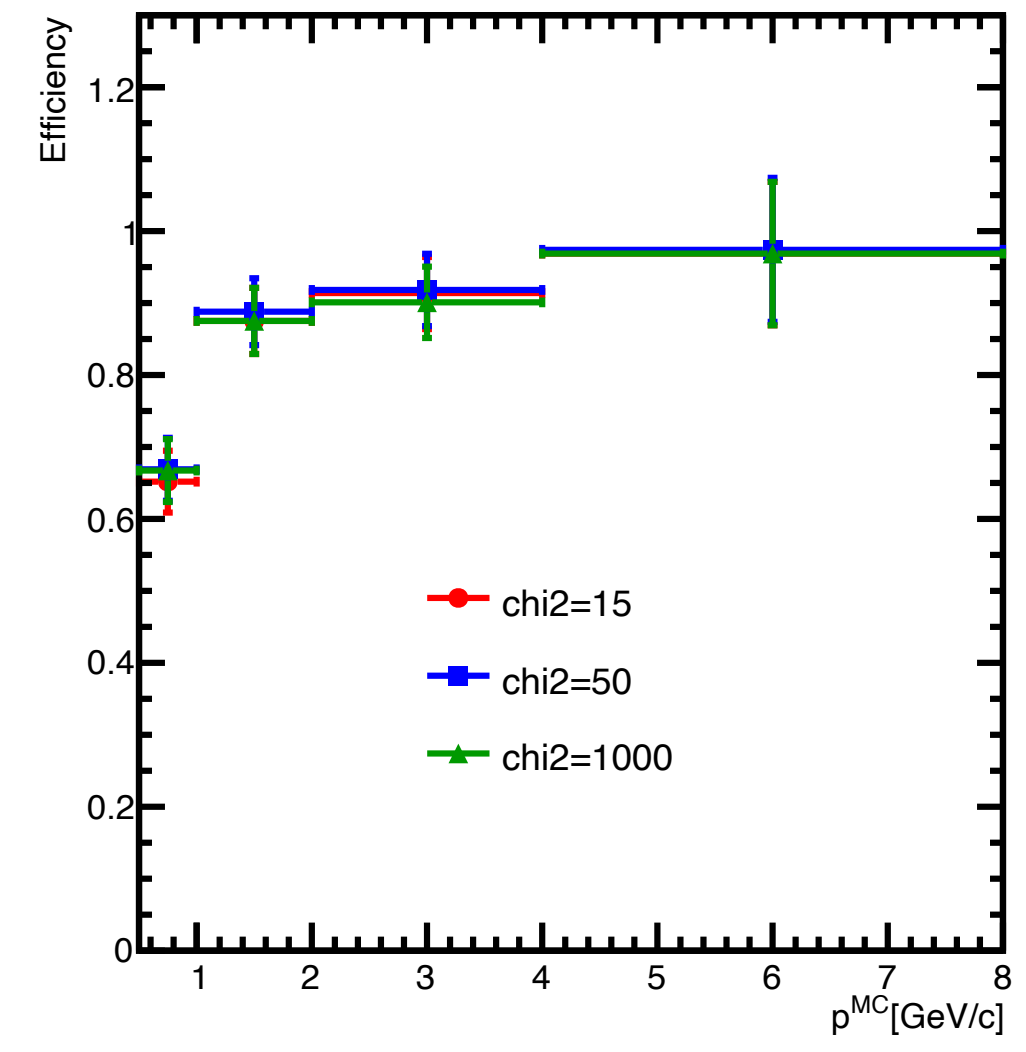
$$2.5 < \eta < 3.5$$

$$\text{Purity} = \frac{N_{\text{Hits}}^{\text{primary}}}{N_{\text{Hits}}^{\text{Total}}}$$

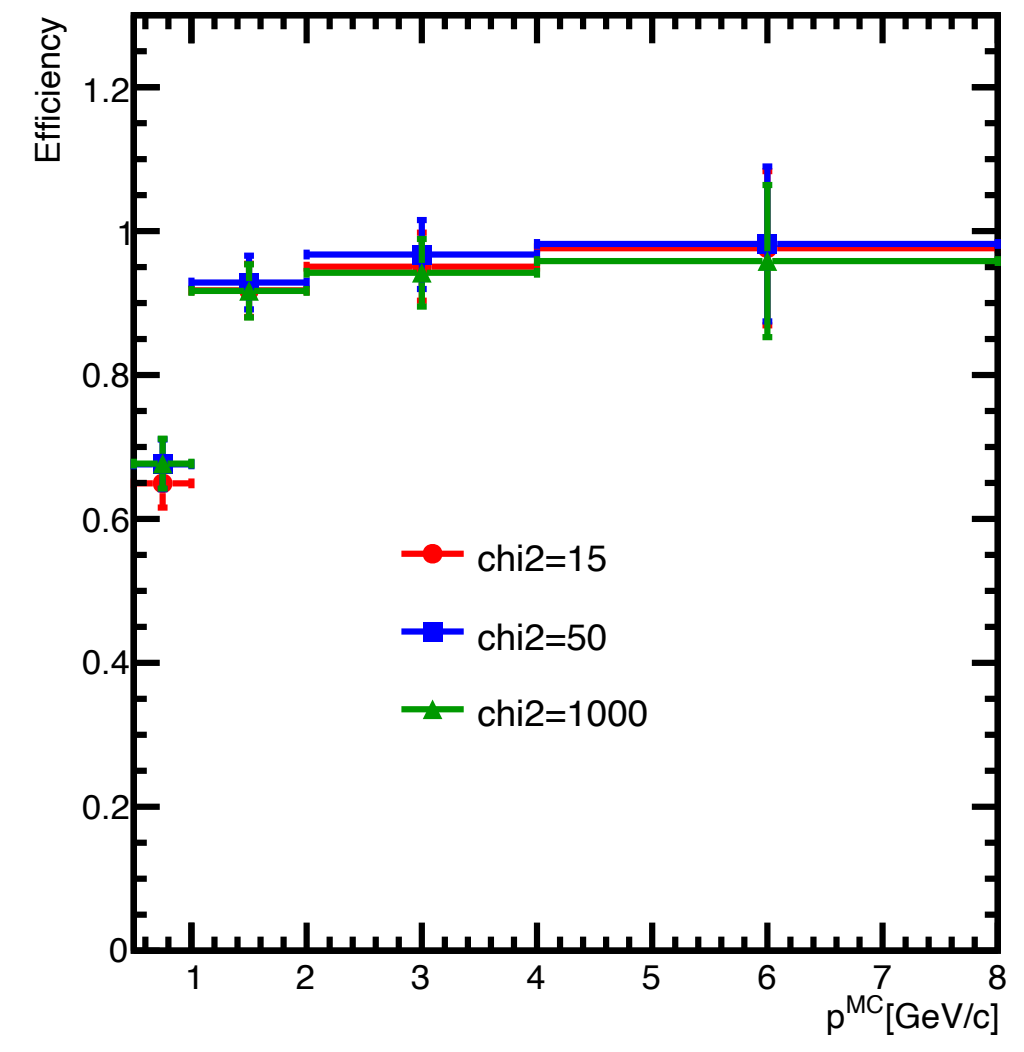


# Reconstruction efficiency ( $\pi/K/p$ )

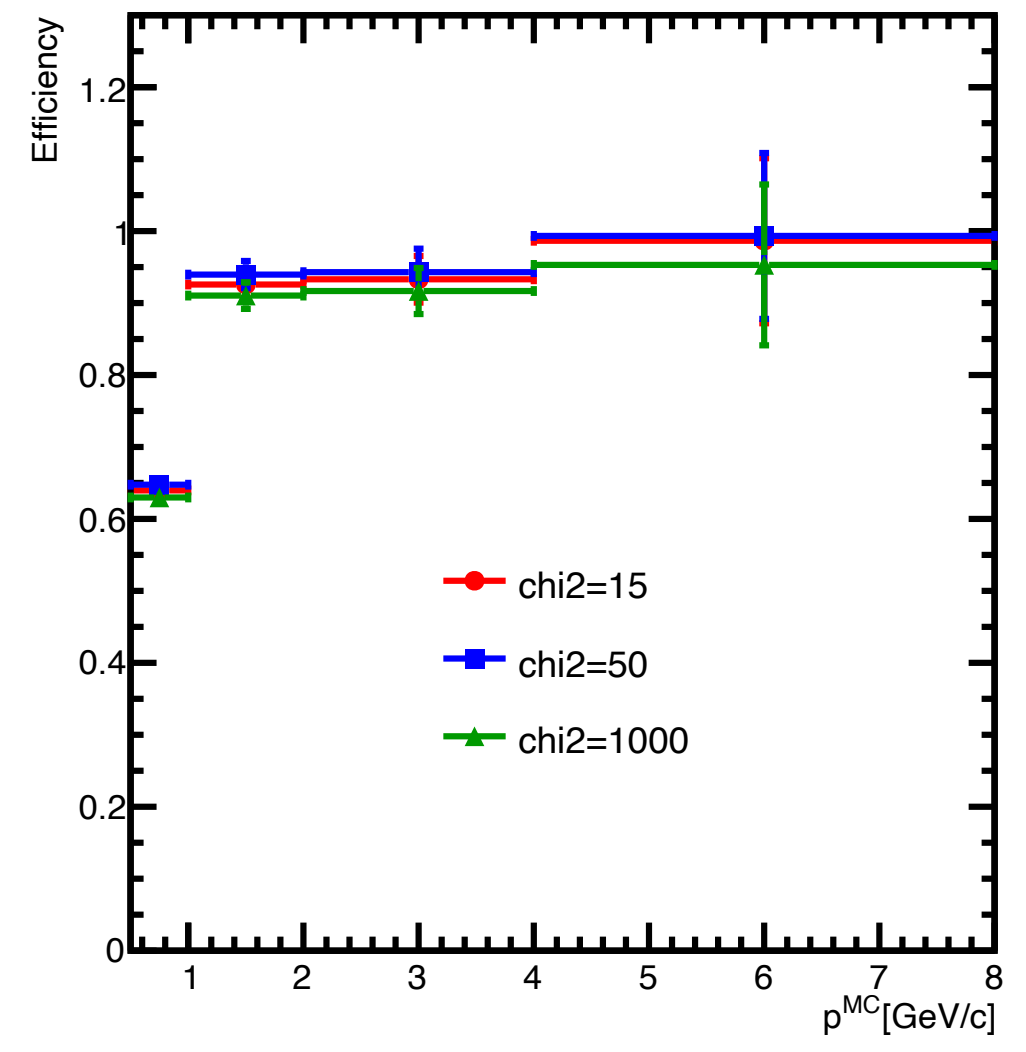
$-3.5 < \eta < -2.5$



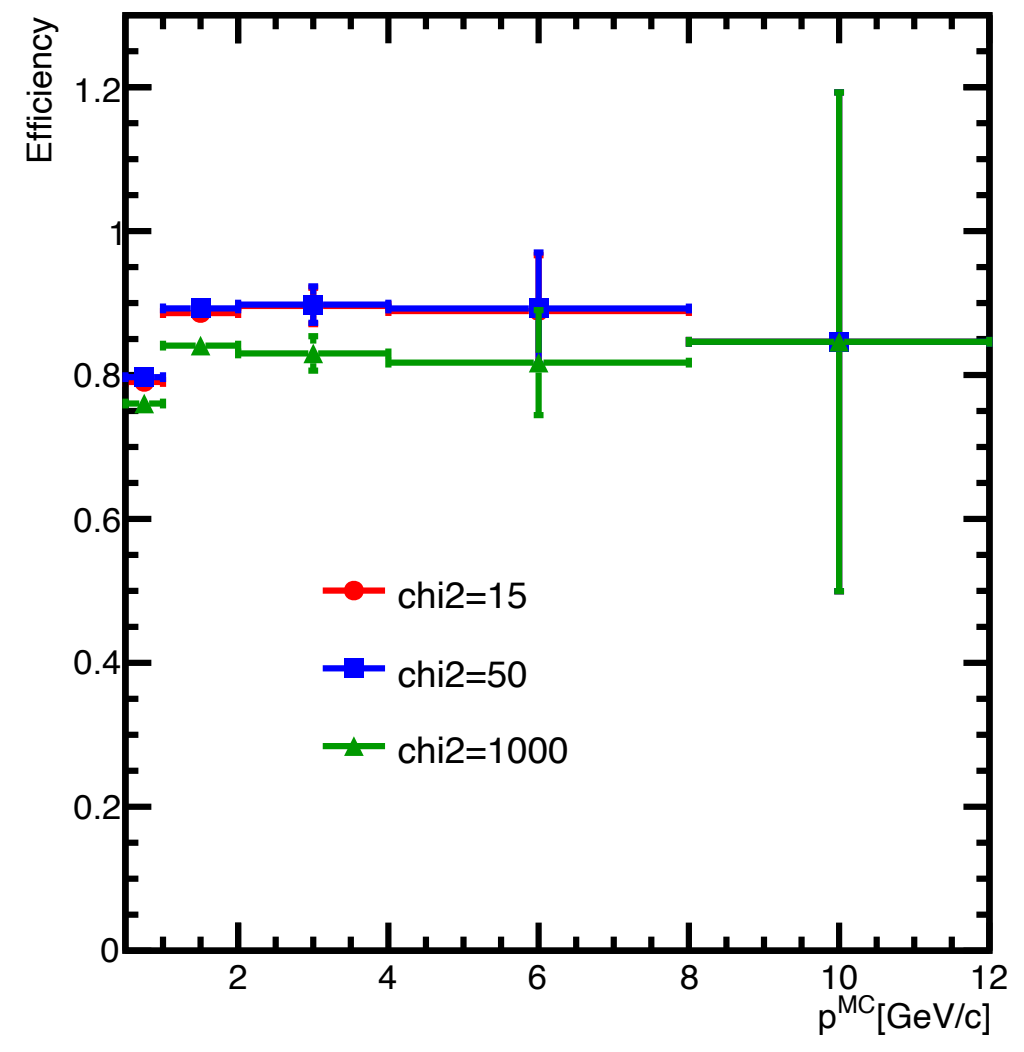
$-2.5 < \eta < -2.0$



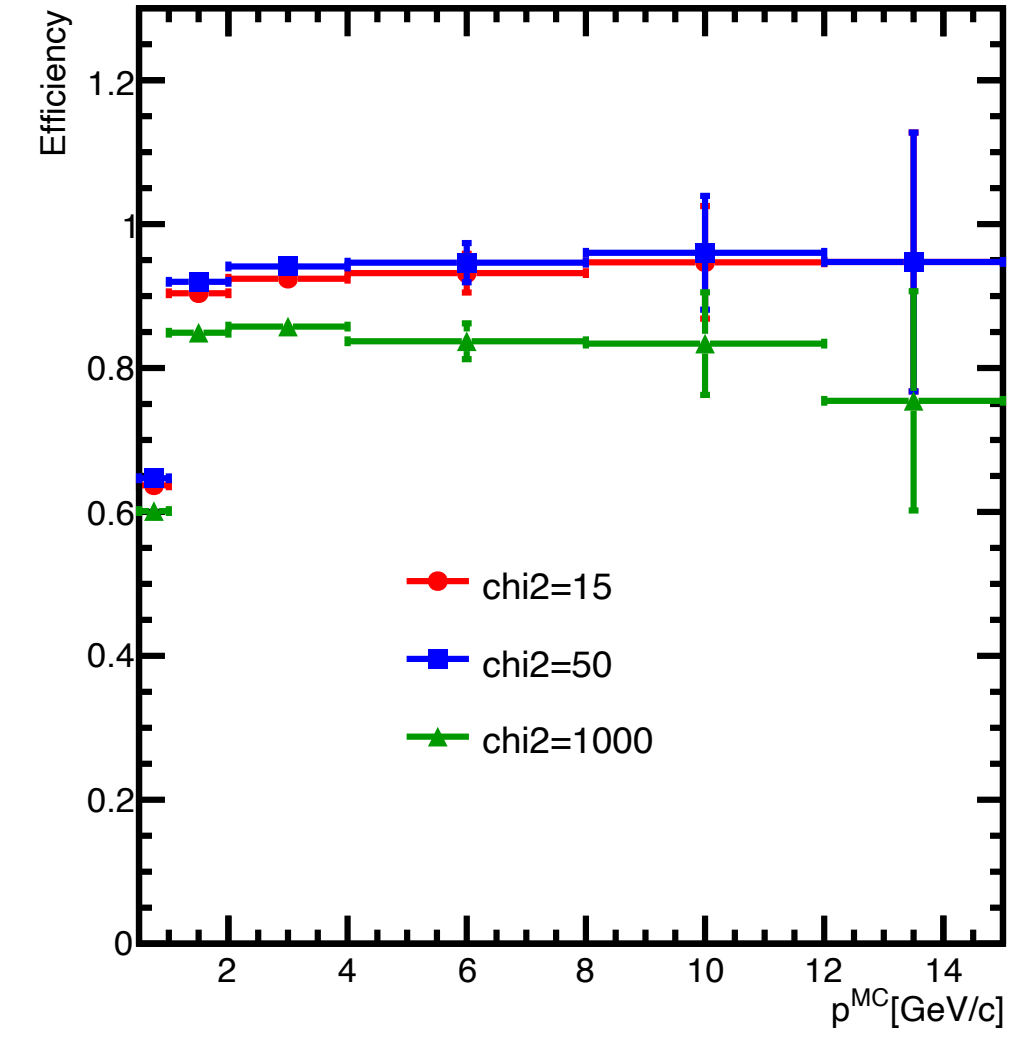
$-2.0 < \eta < -1.0$



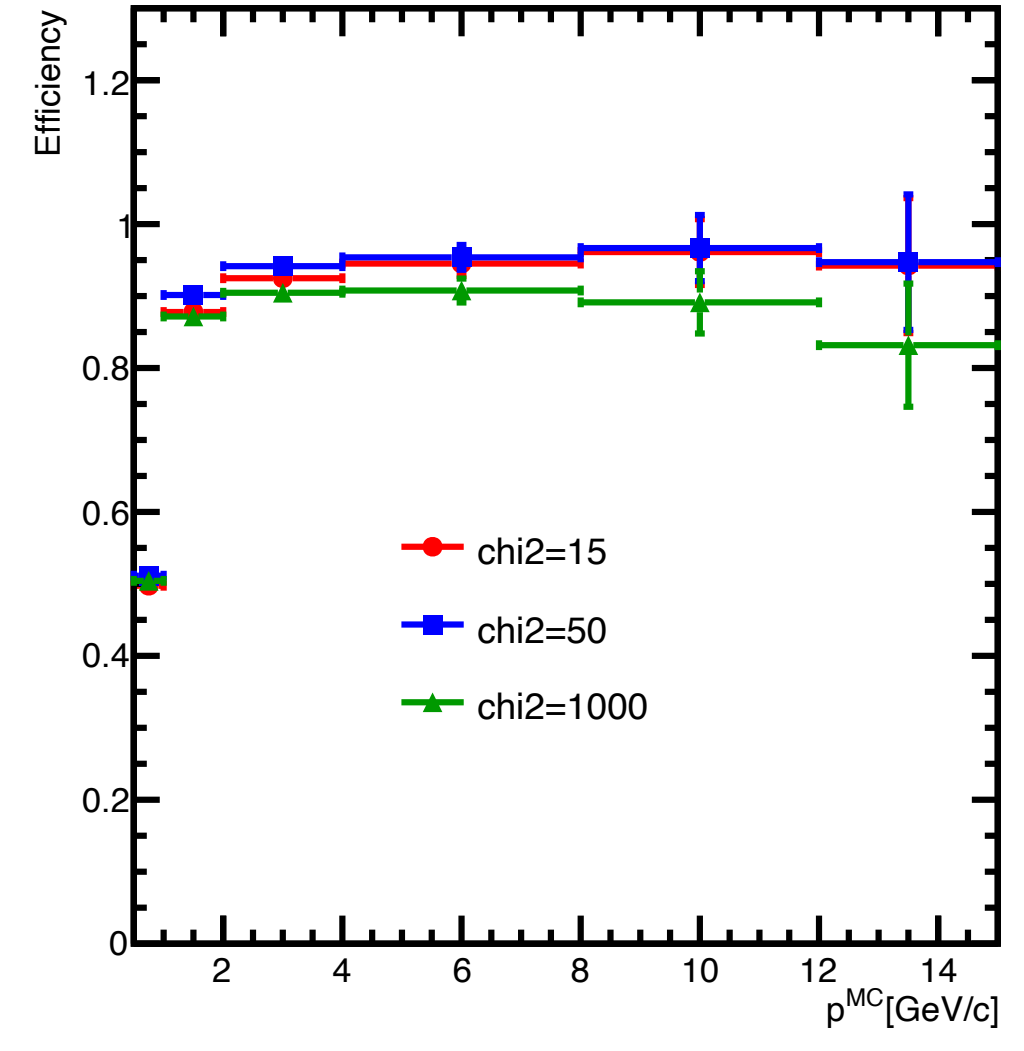
$-1.0 < \eta < 1.0$



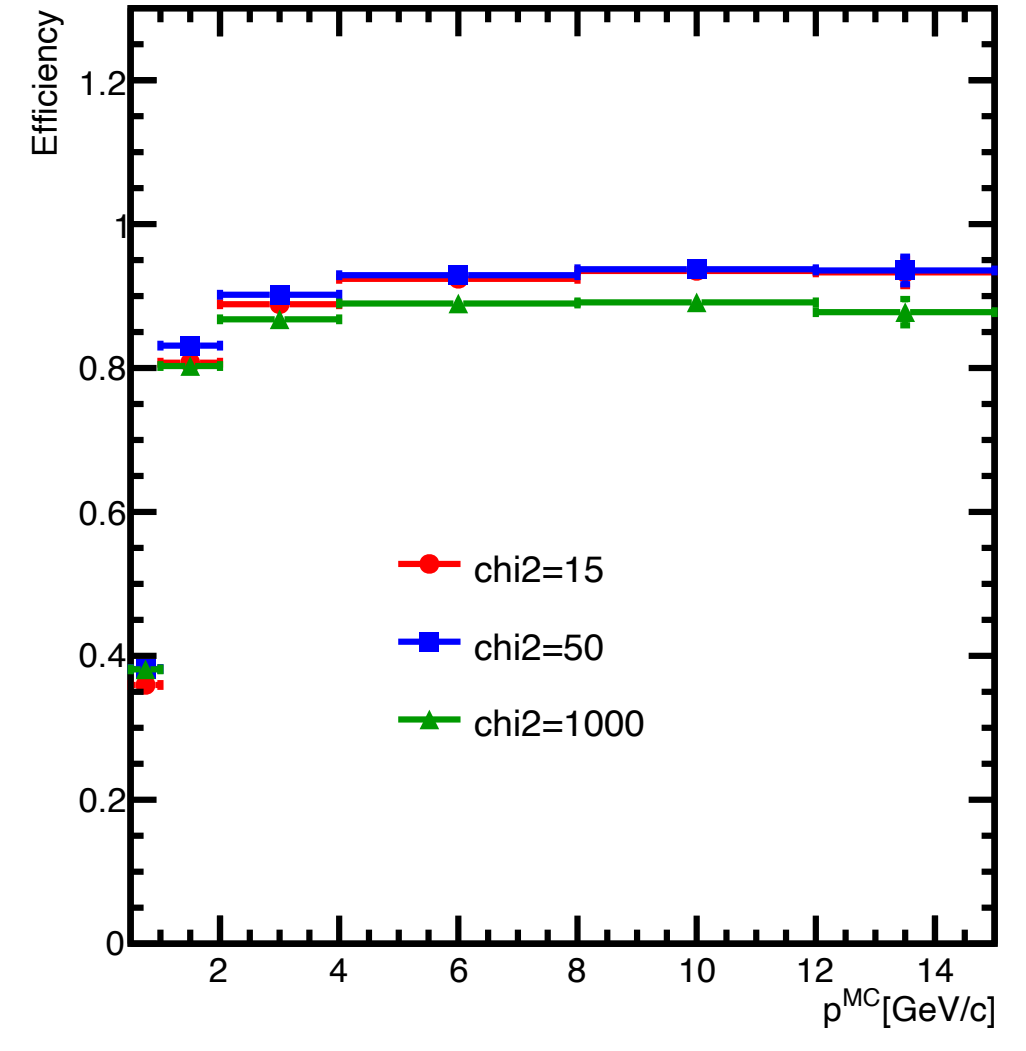
$1.0 < \eta < 2.0$



$2.0 < \eta < 2.5$



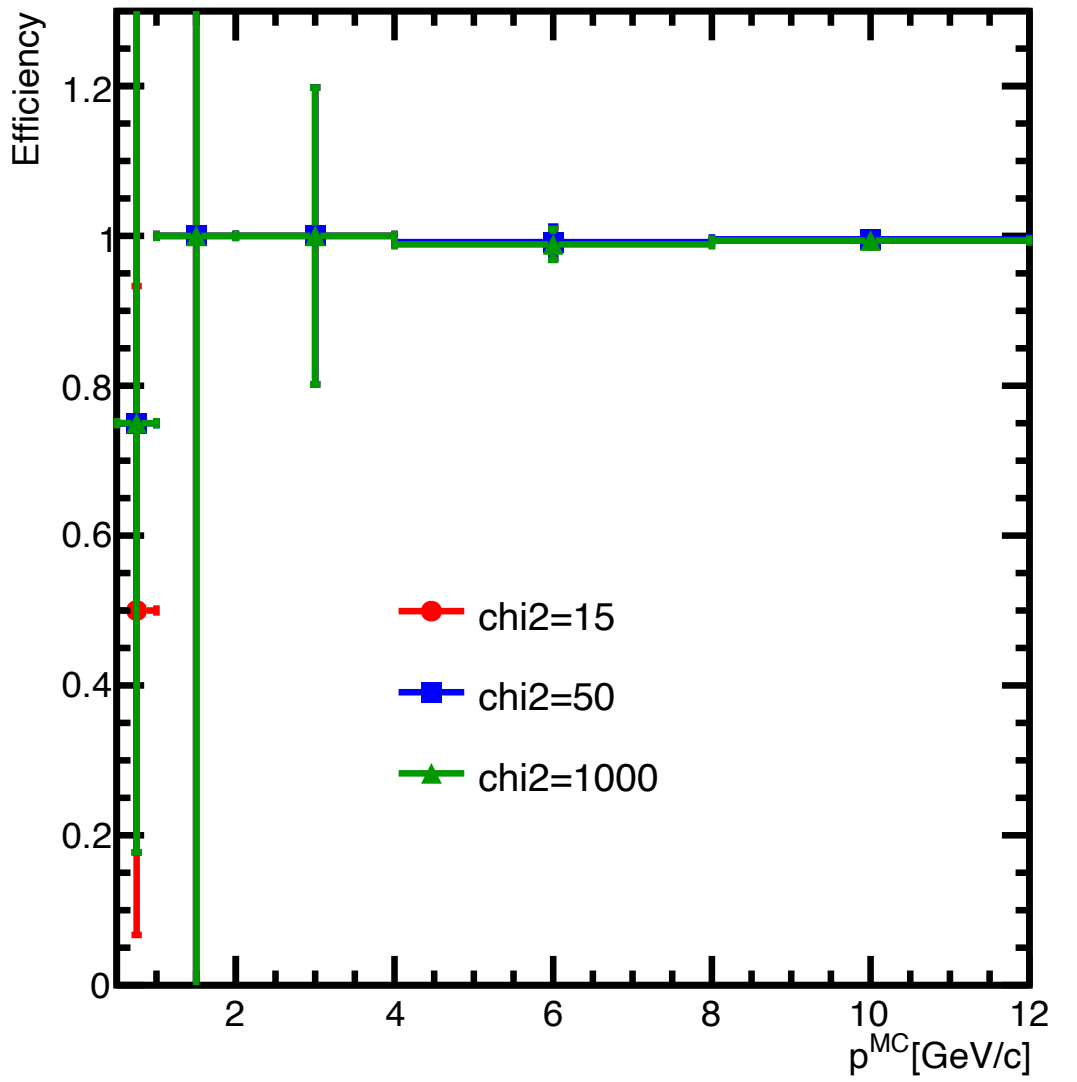
$2.5 < \eta < 3.5$



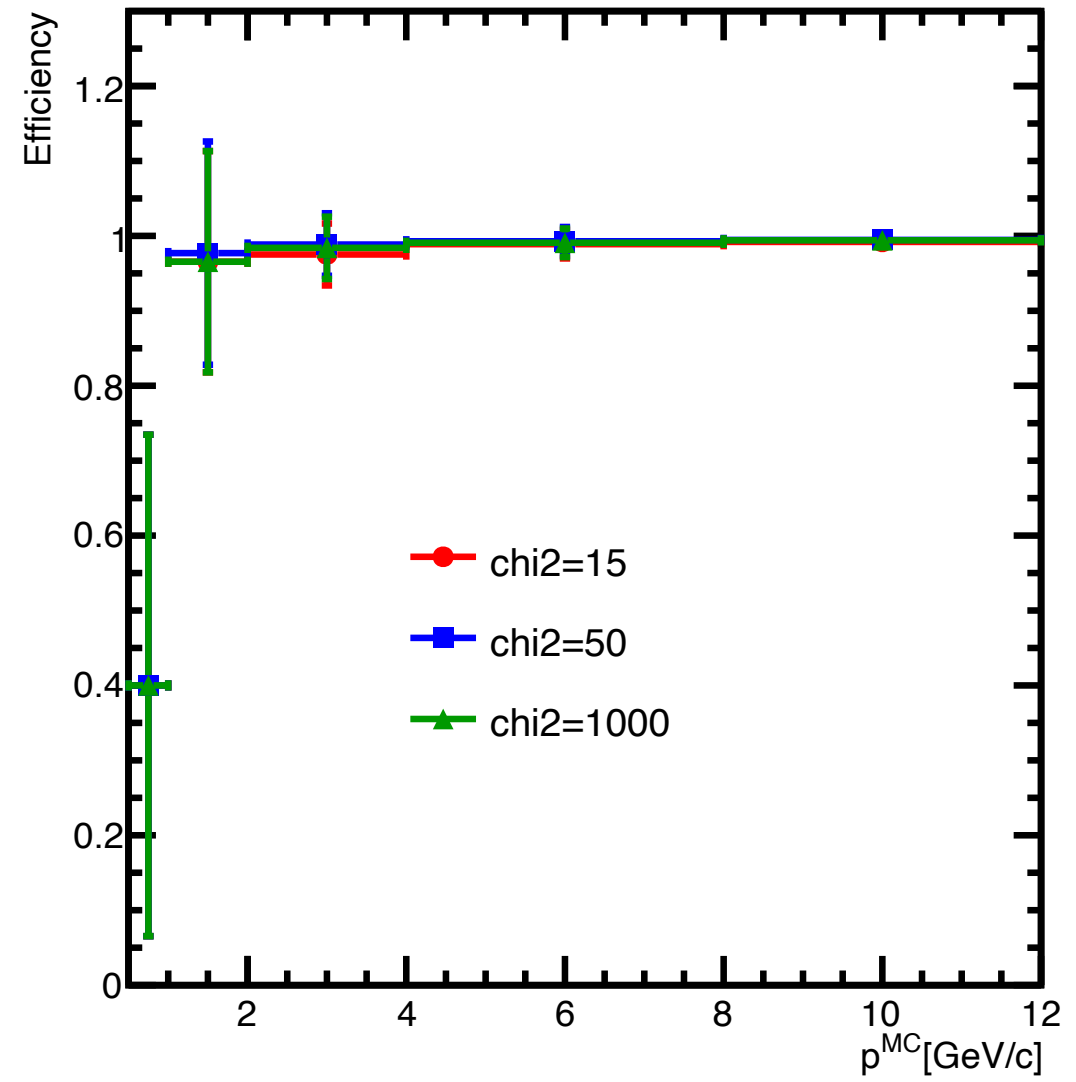
Here we only look at reconstructed tracks with purity above 0.8 and that have an associated primary track.

# Reconstruction efficiency (electrons)

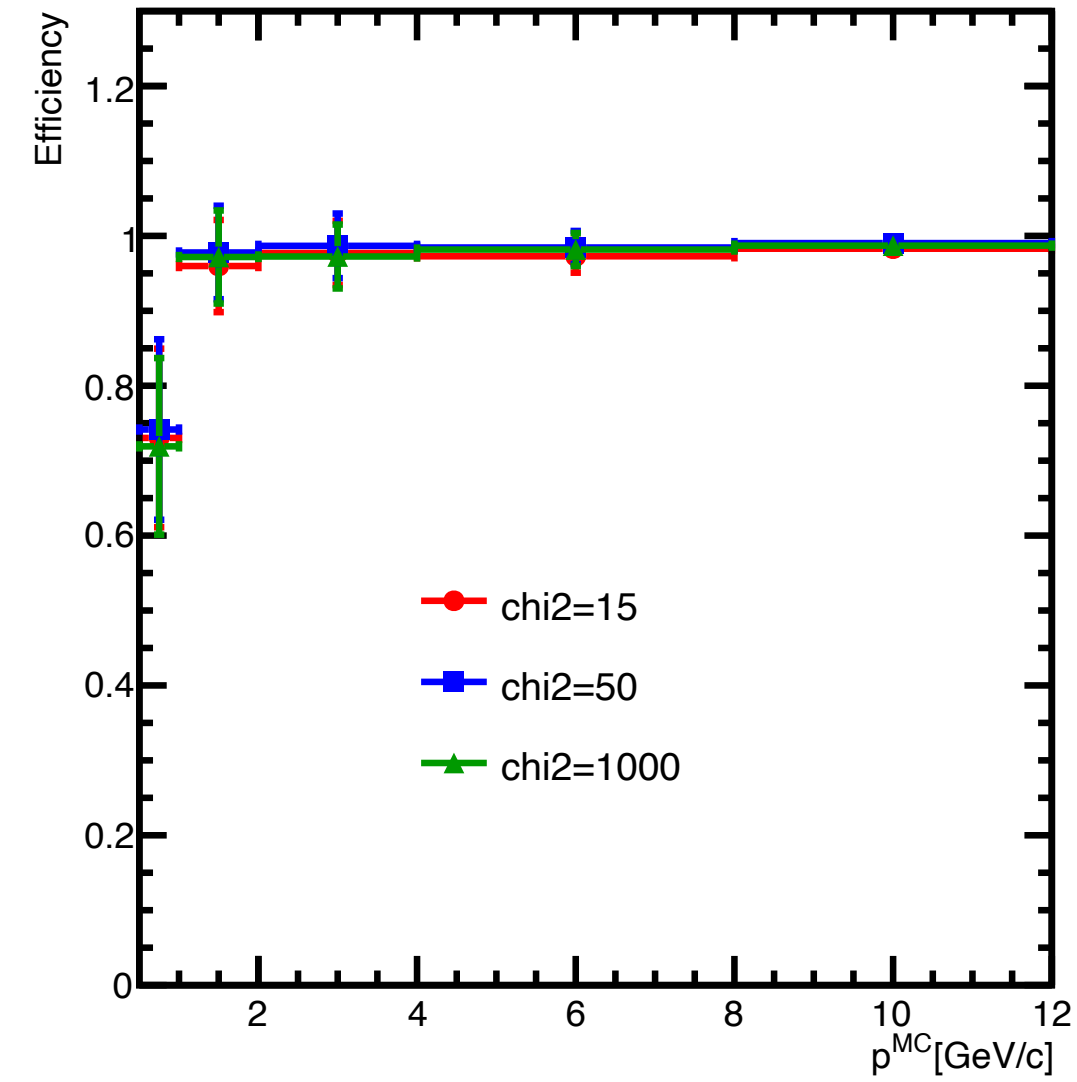
$-3.5 < \eta < -2.5$



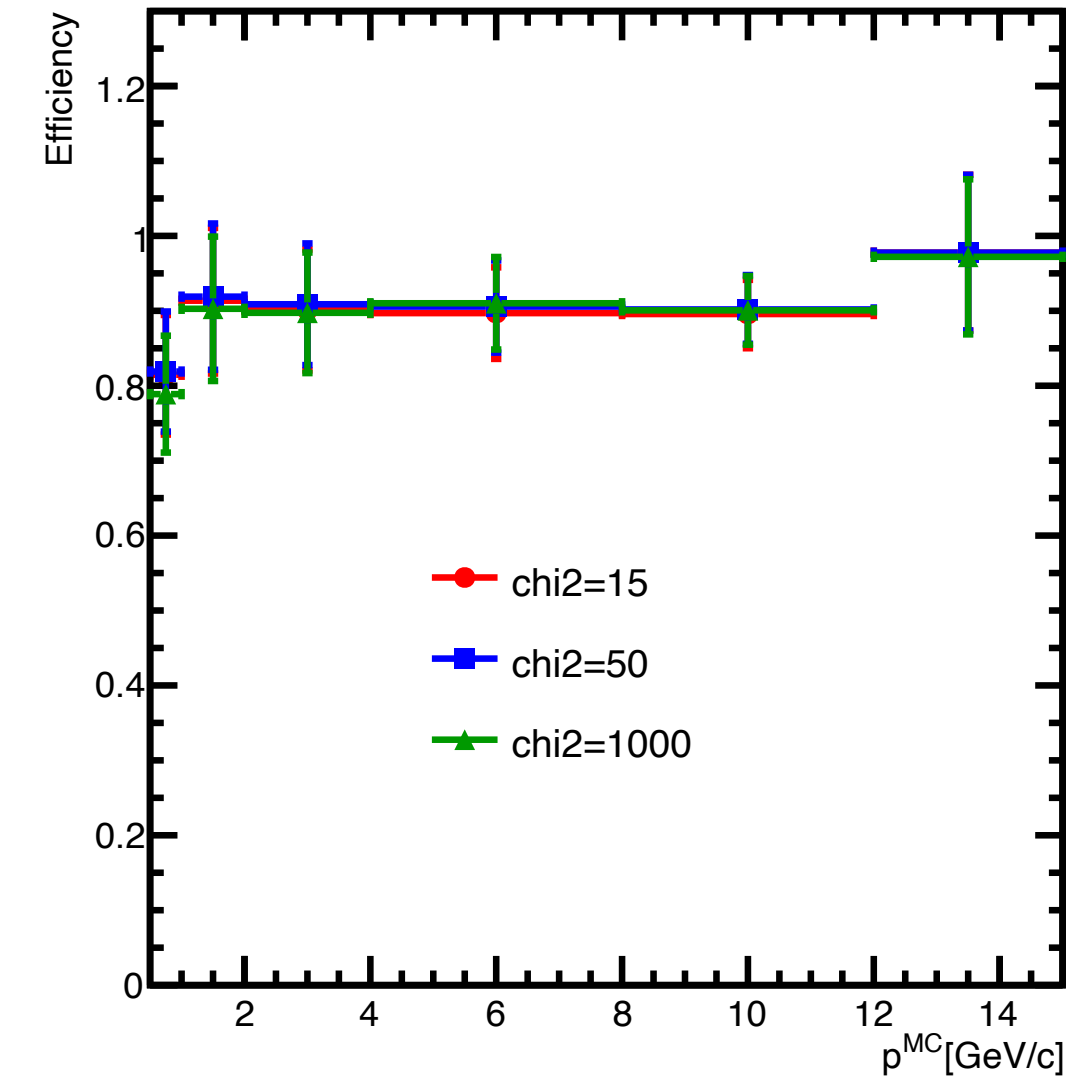
$-2.5 < \eta < -2.0$



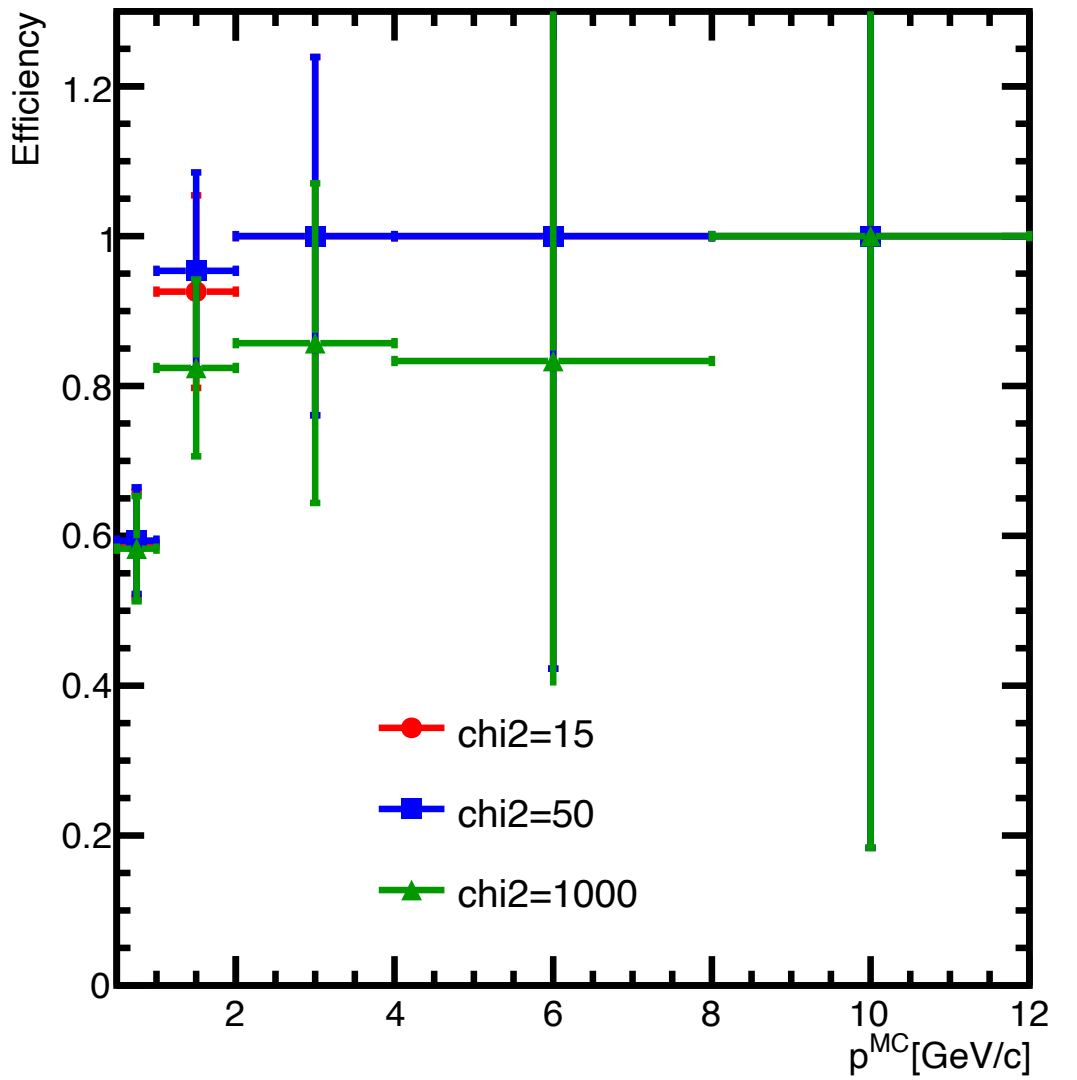
$-2.0 < \eta < -1.0$



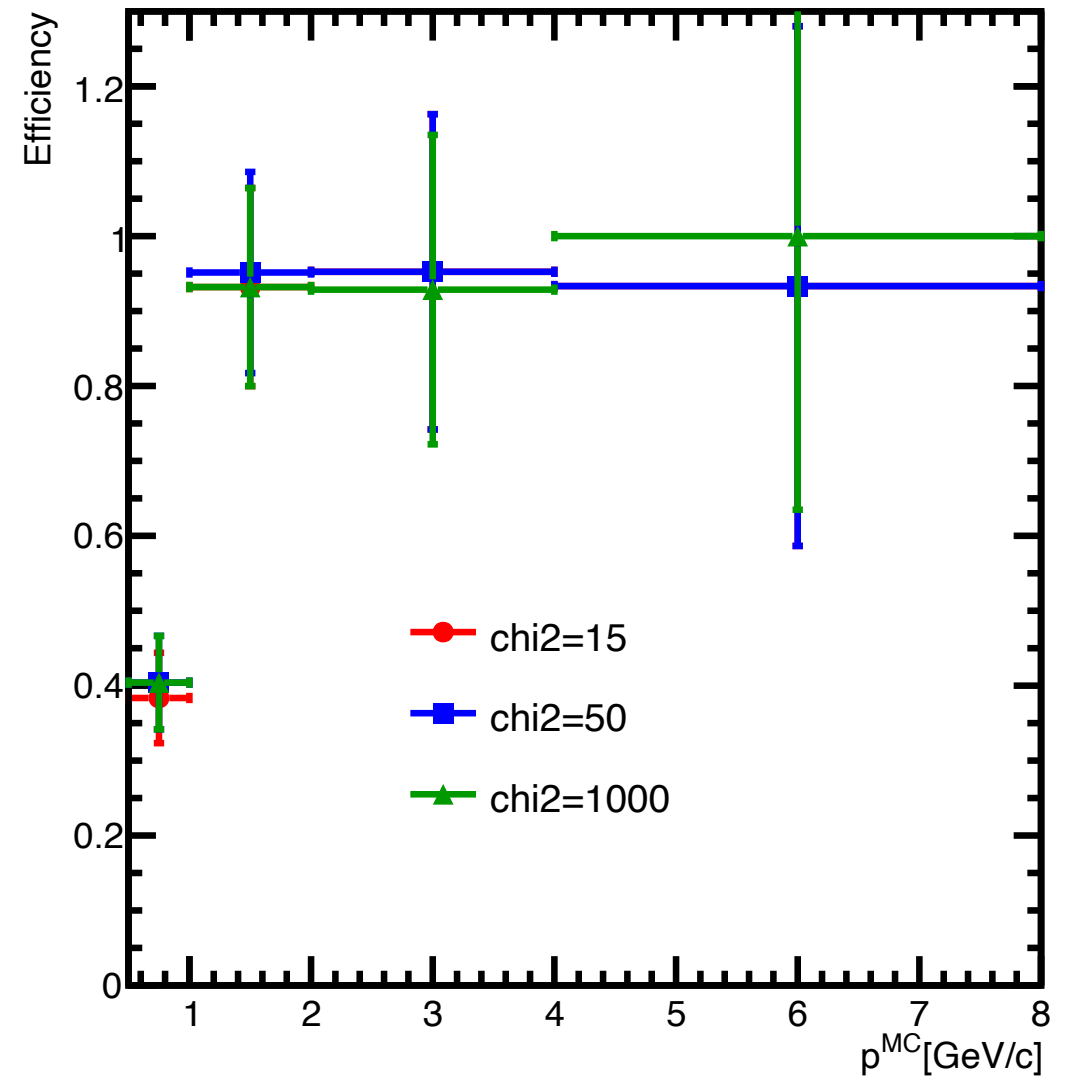
$-1.0 < \eta < 1.0$



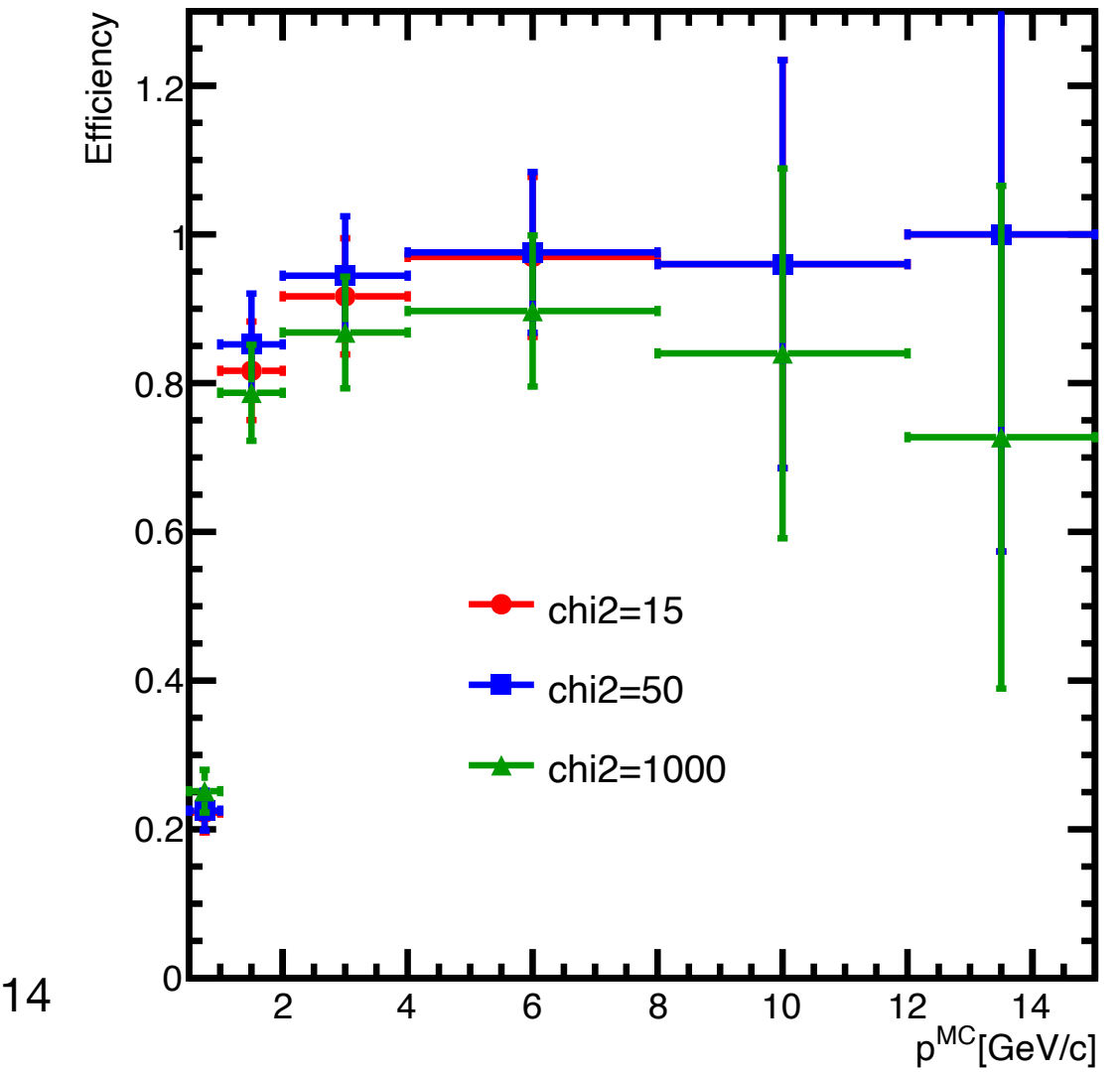
$1.0 < \eta < 2.0$



$2.0 < \eta < 2.5$



$2.5 < \eta < 3.5$



Here we only look at reconstructed tracks with purity above 0.8 and that have an associated primary track.

# Momentum Resolution Plots (Electrons)

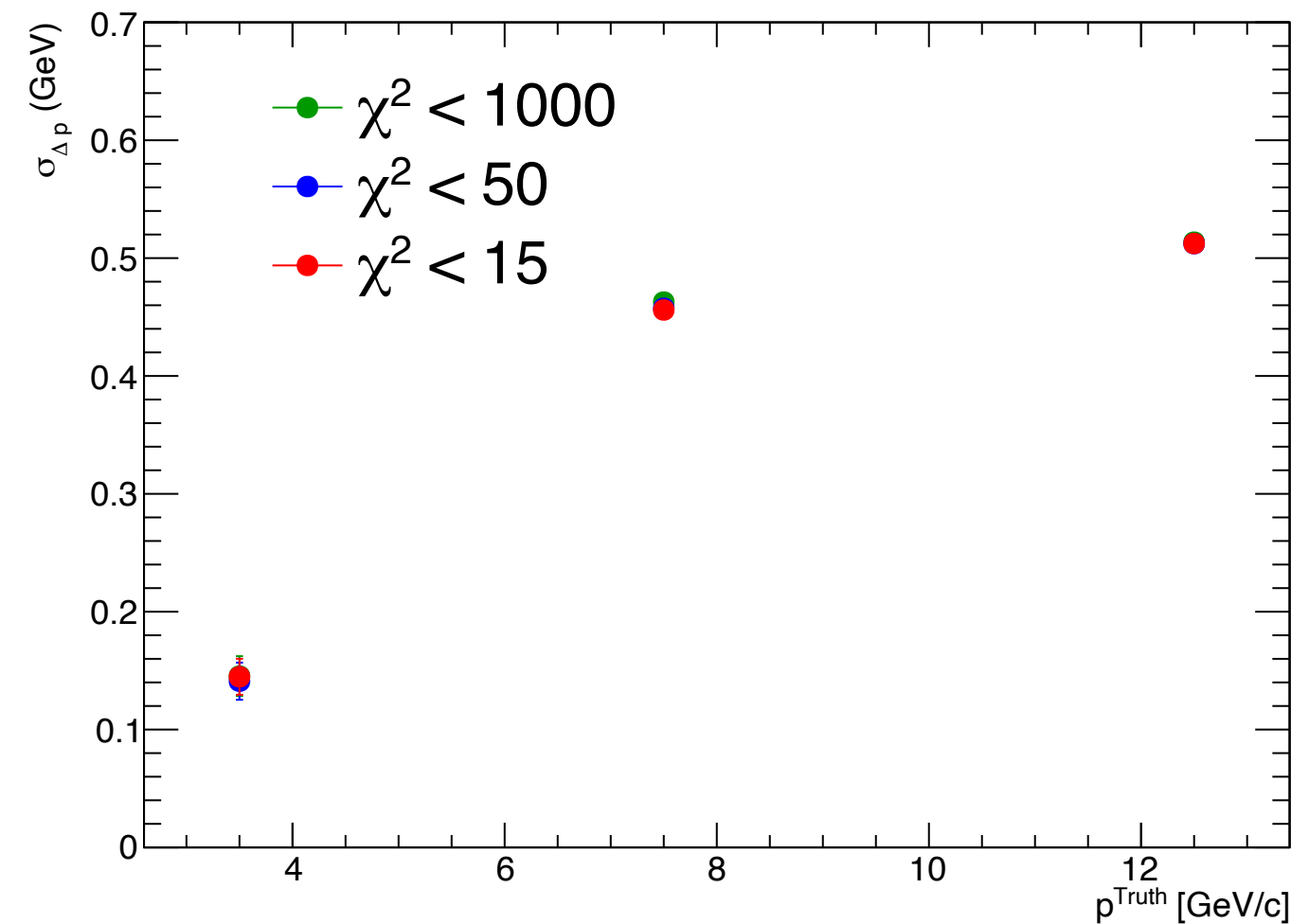
- In contrast to single-particle simulations (fixed momentum), DIS has limited statistics, requiring wide momentum bins; the resolution is shown at the bin-averaged  $p$ , which only approximates the true momentum dependence.

- The goal is a relative comparison between different  $\chi^2$  cuts, so despite these limitations, the comparison remains value.

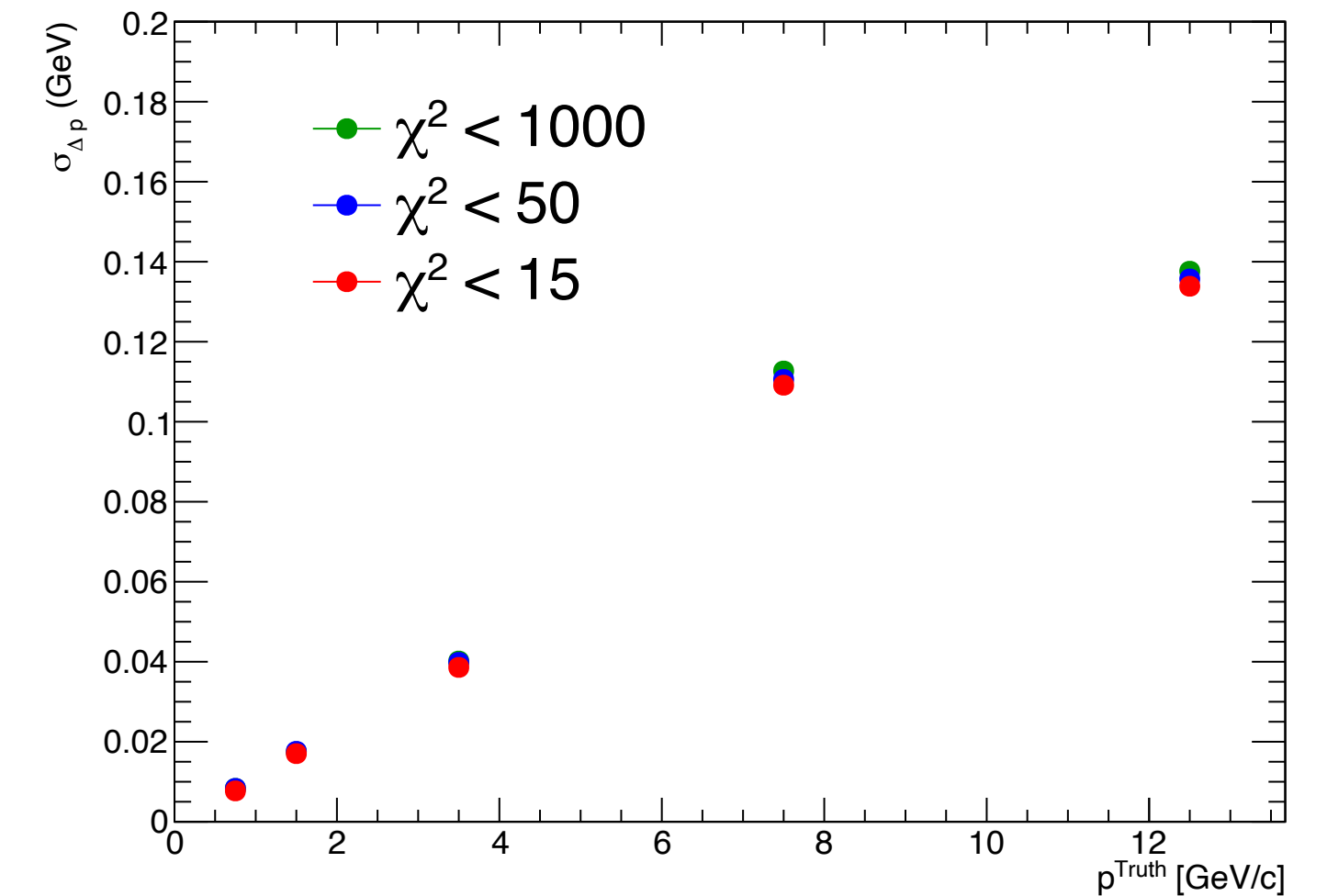
No visible  $\chi^2$  dependence

Here we only look at reconstructed tracks with purity above 0.8 and that have an associated primary track.

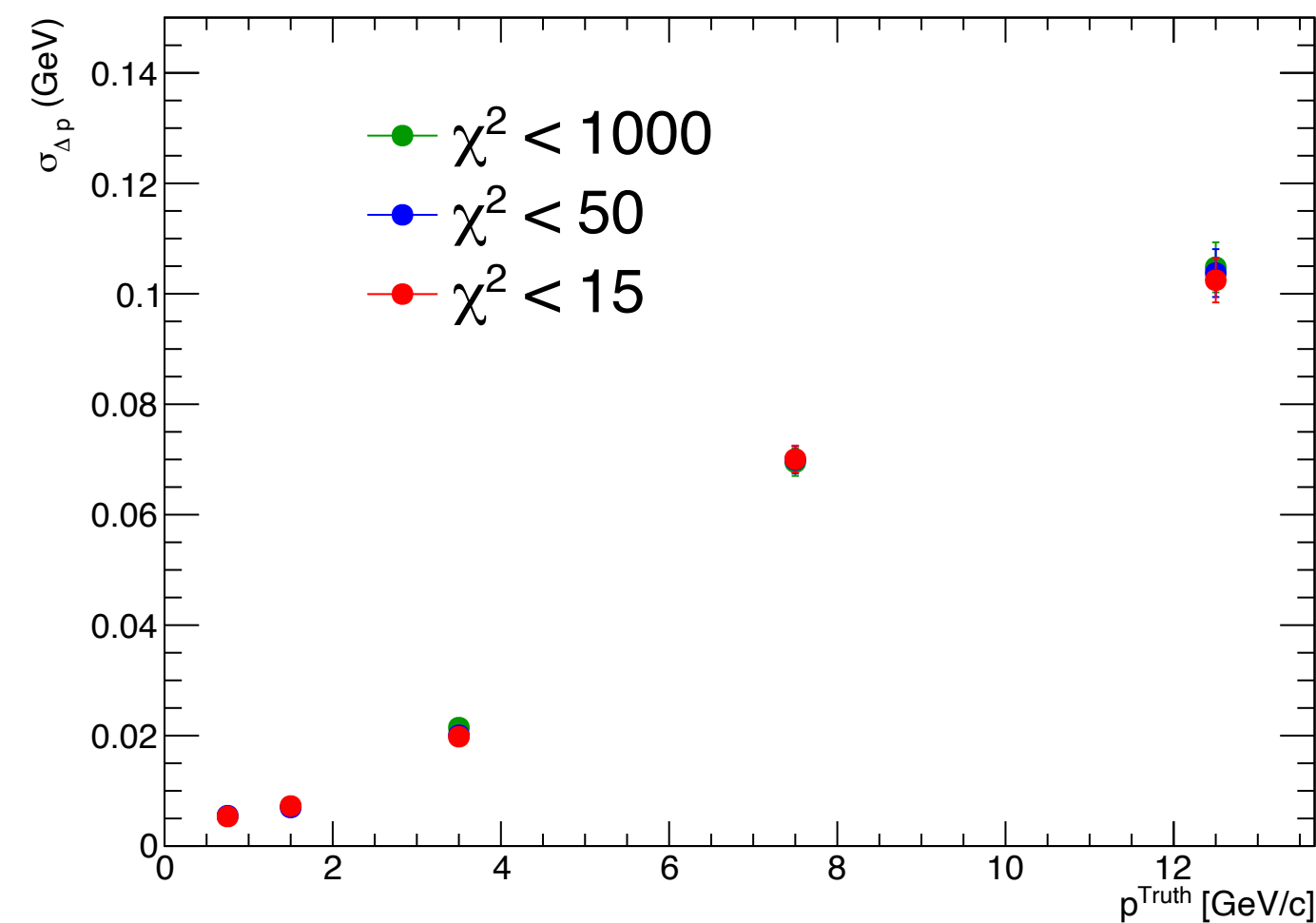
$-3.5 < \eta < -2.5$



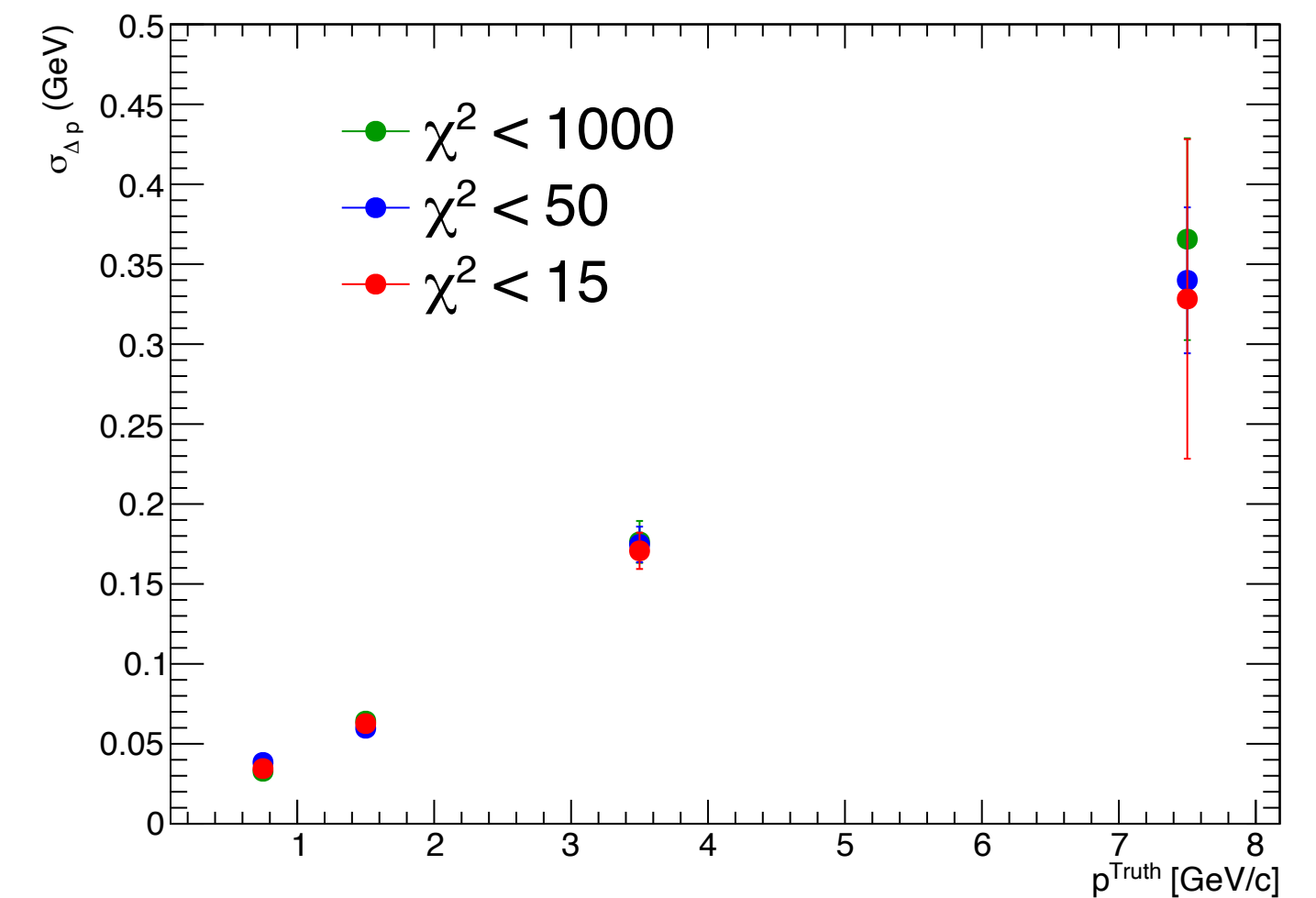
$-2.0 < \eta < -1.0$



$-1.0 < \eta < 1.0$



$2.5 < \eta < 3.5$



# Momentum Resolution Plots ( $\pi/K/p$ )

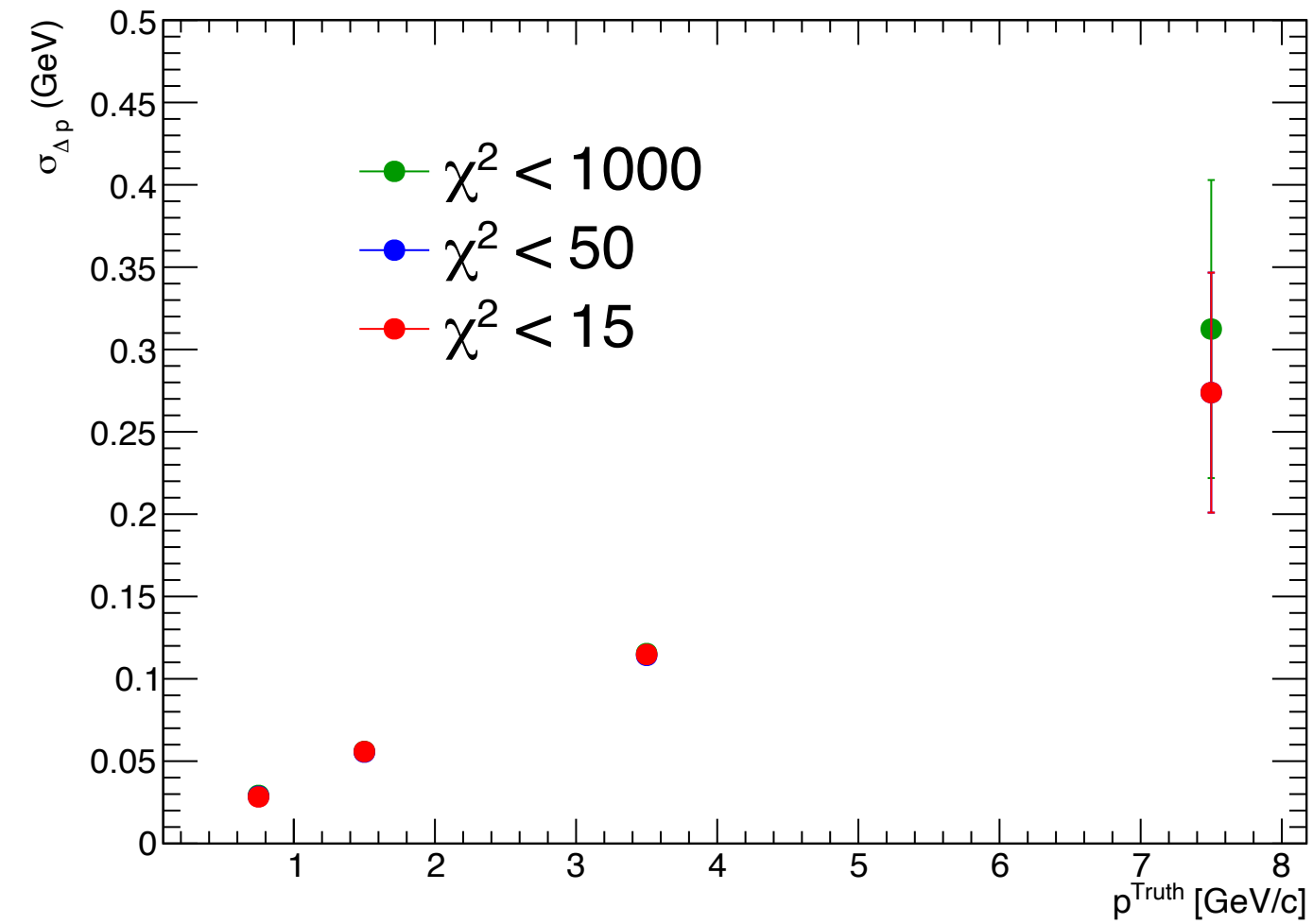
- In contrast to single-particle simulations (fixed momentum), DIS has limited statistics, requiring wide momentum bins; the resolution is shown at the bin-averaged  $p$ , which only approximates the true momentum dependence.

- The goal is a relative comparison between different  $\chi^2$  cuts, so despite these limitations, the comparison remains value.

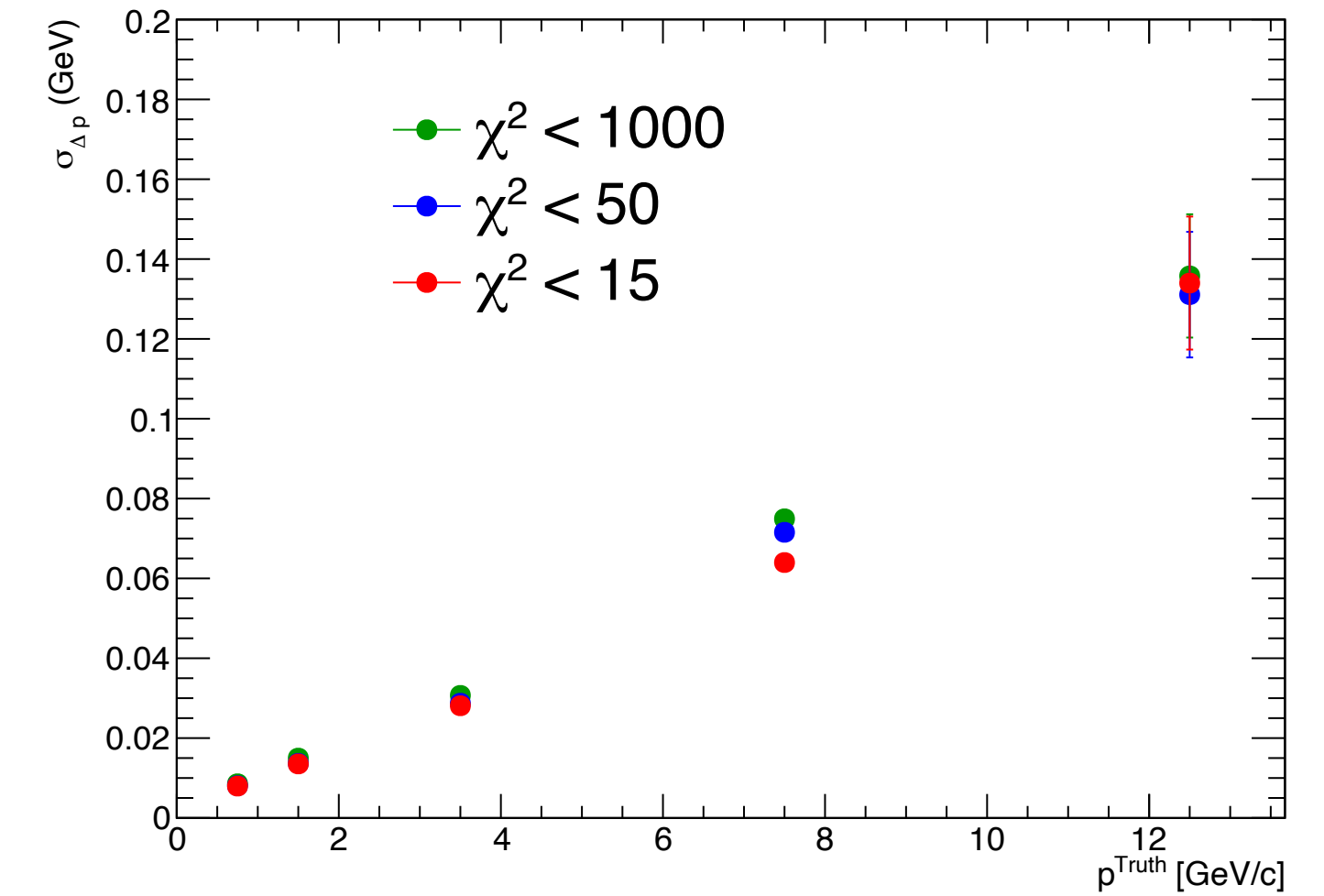
No visible  $\chi^2$  dependence

Here we only look at reconstructed tracks with purity above 0.8 and that have an associated primary track.

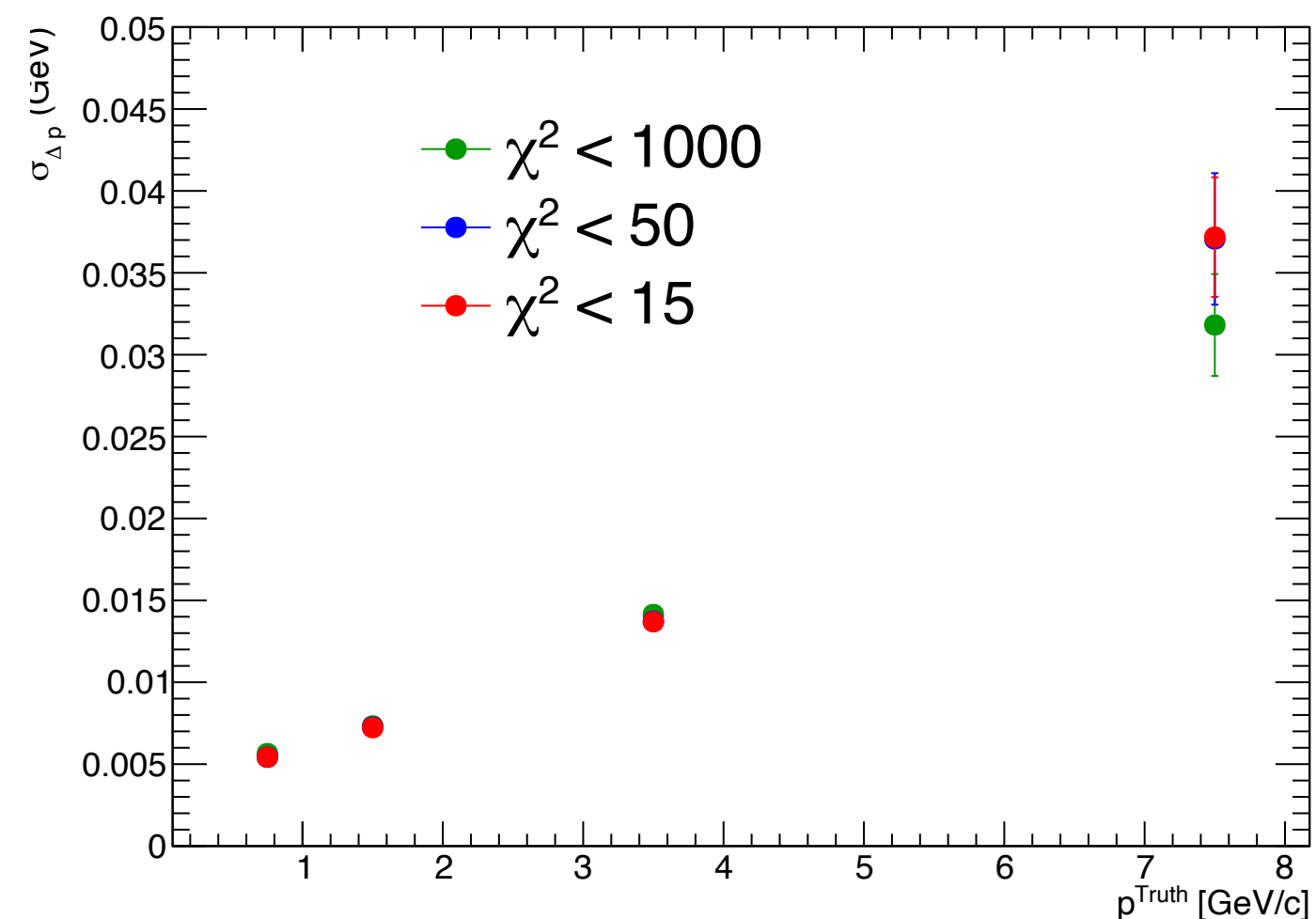
$-3.5 < \eta < -2.5$



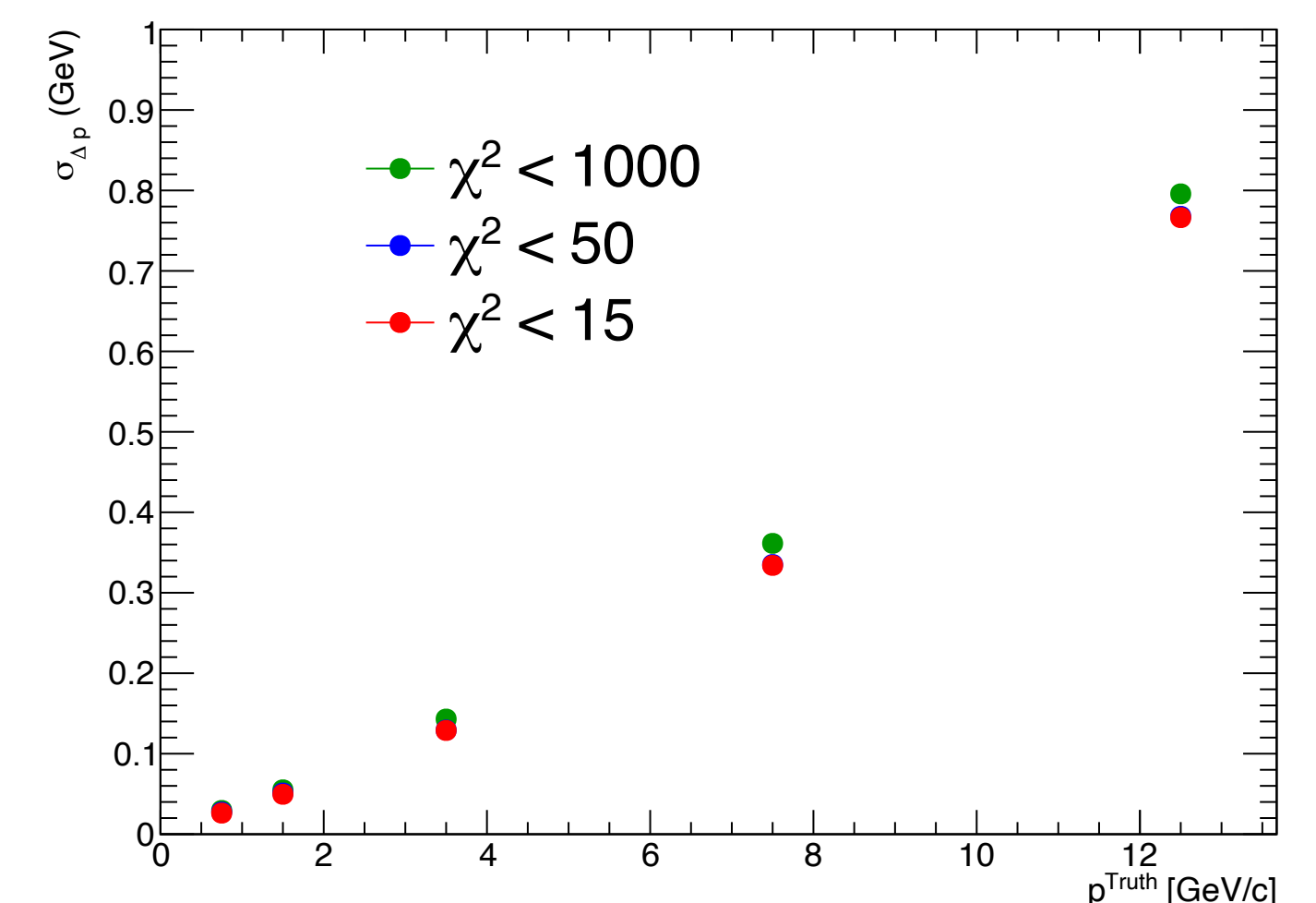
$1.0 < \eta < 2.0$



$-1.0 < \eta < 1.0$



$2.5 < \eta < 3.5$



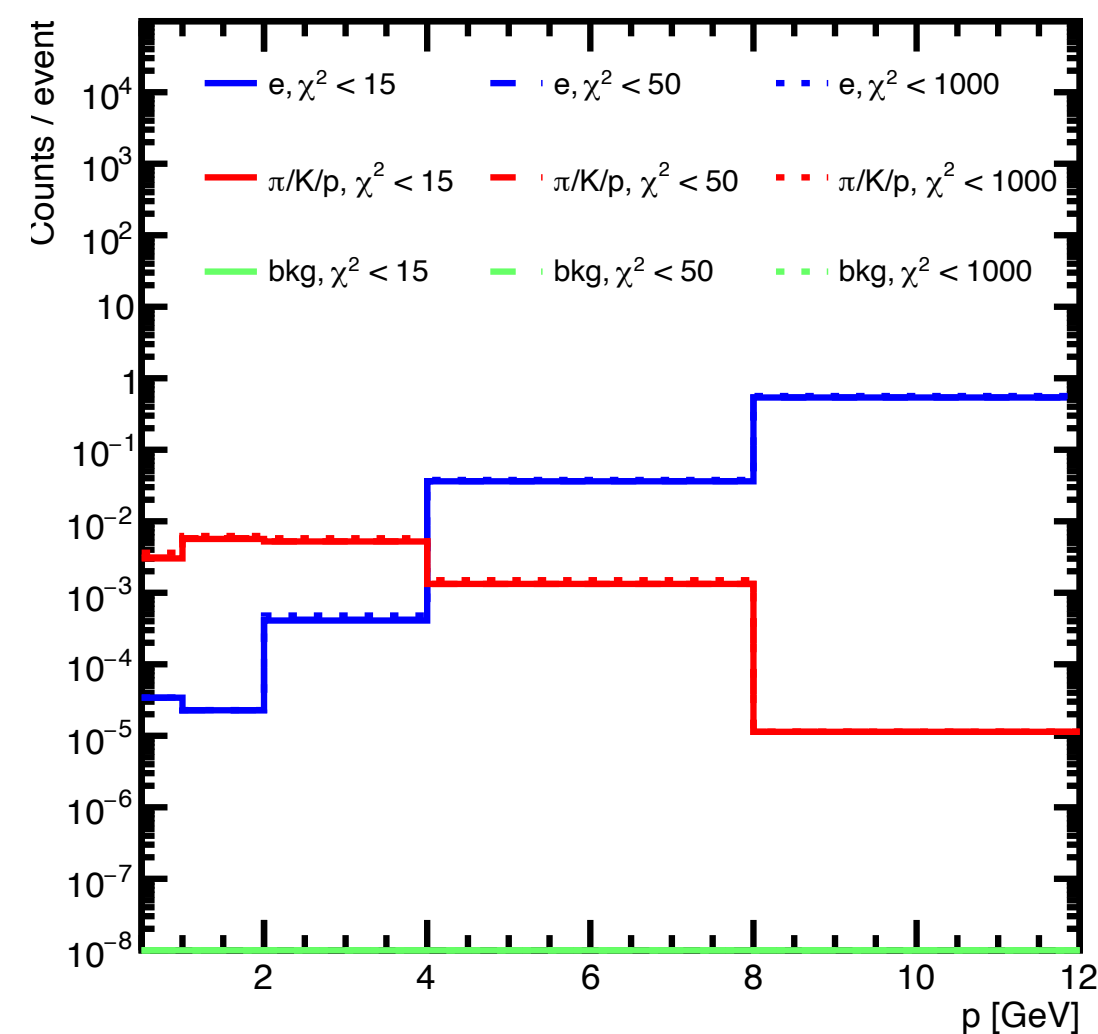
# **Looking at the DIS + Bkg Events**

**Sample Used : 10x275 GeV DIS Events March  
Campaign with 10 microns Au Coating  
Events sample ~ 87k events**

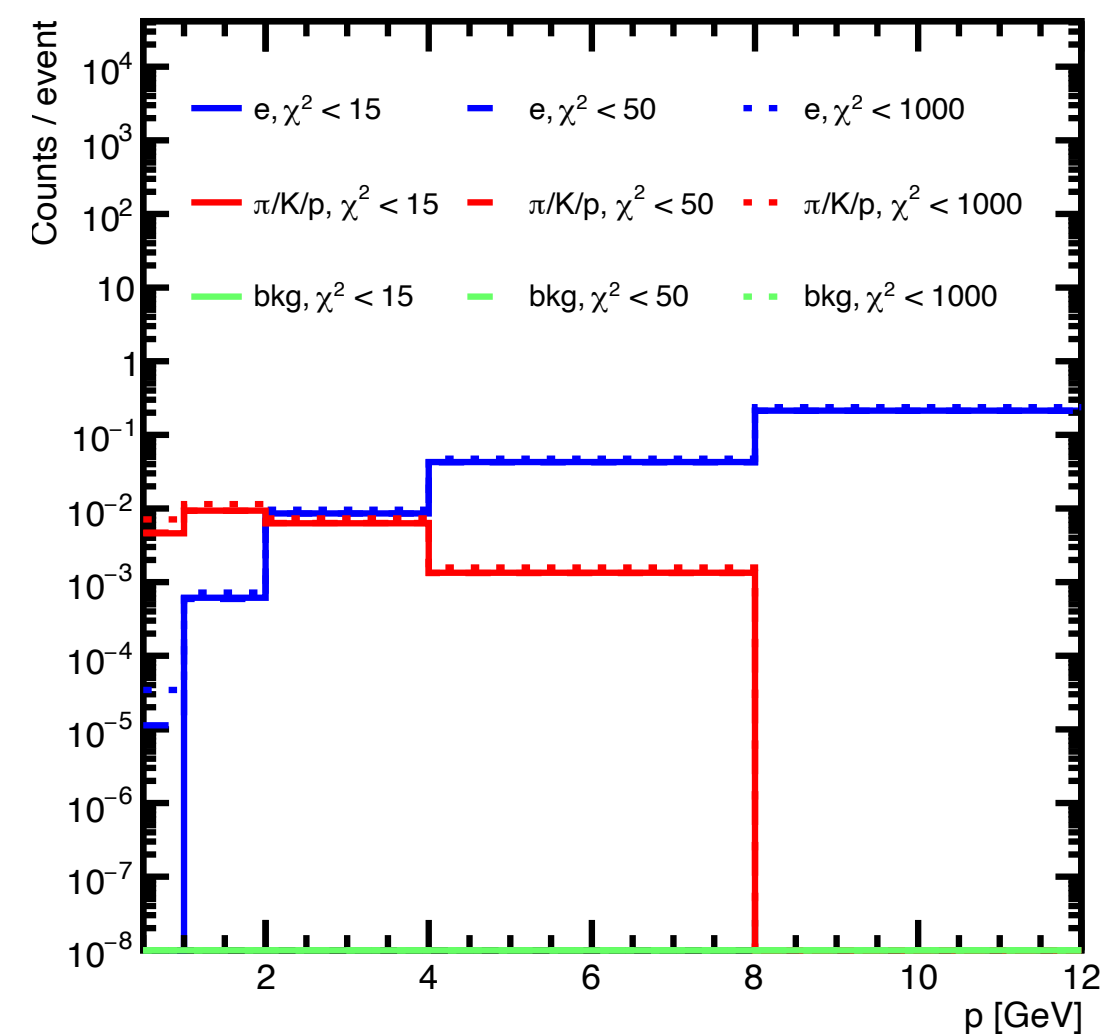
**Only reconstructed tracks that are associated with a primary  
e or hadron or bkg track are considered. Track originating  
from a bkg source are given status code of 2001 — 6001**

# Momentum Spectra: No track purity cut applied

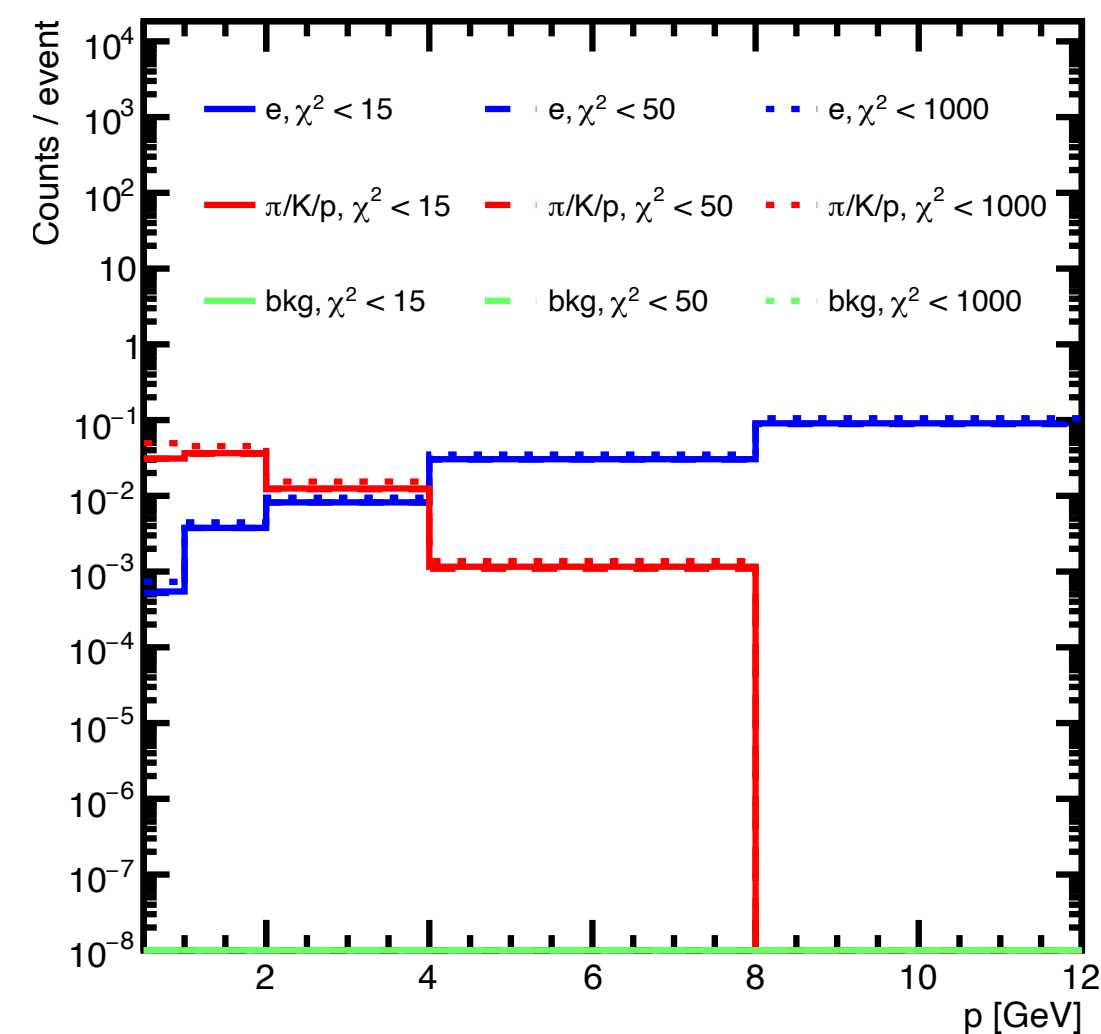
$\eta$  bin 1  $-3.5 < \eta < -2.5$



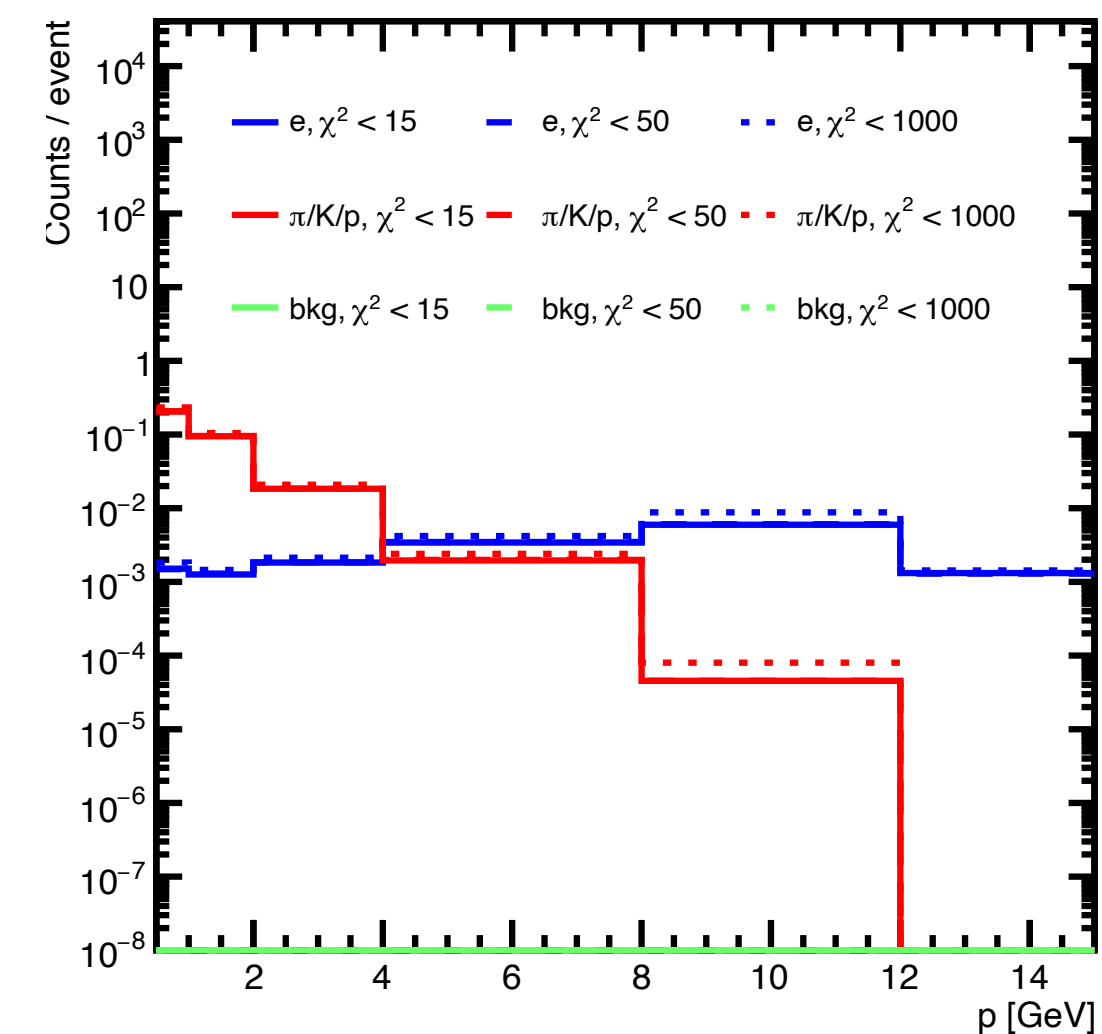
$\eta$  bin 2  $-2.5 < \eta < -2.0$



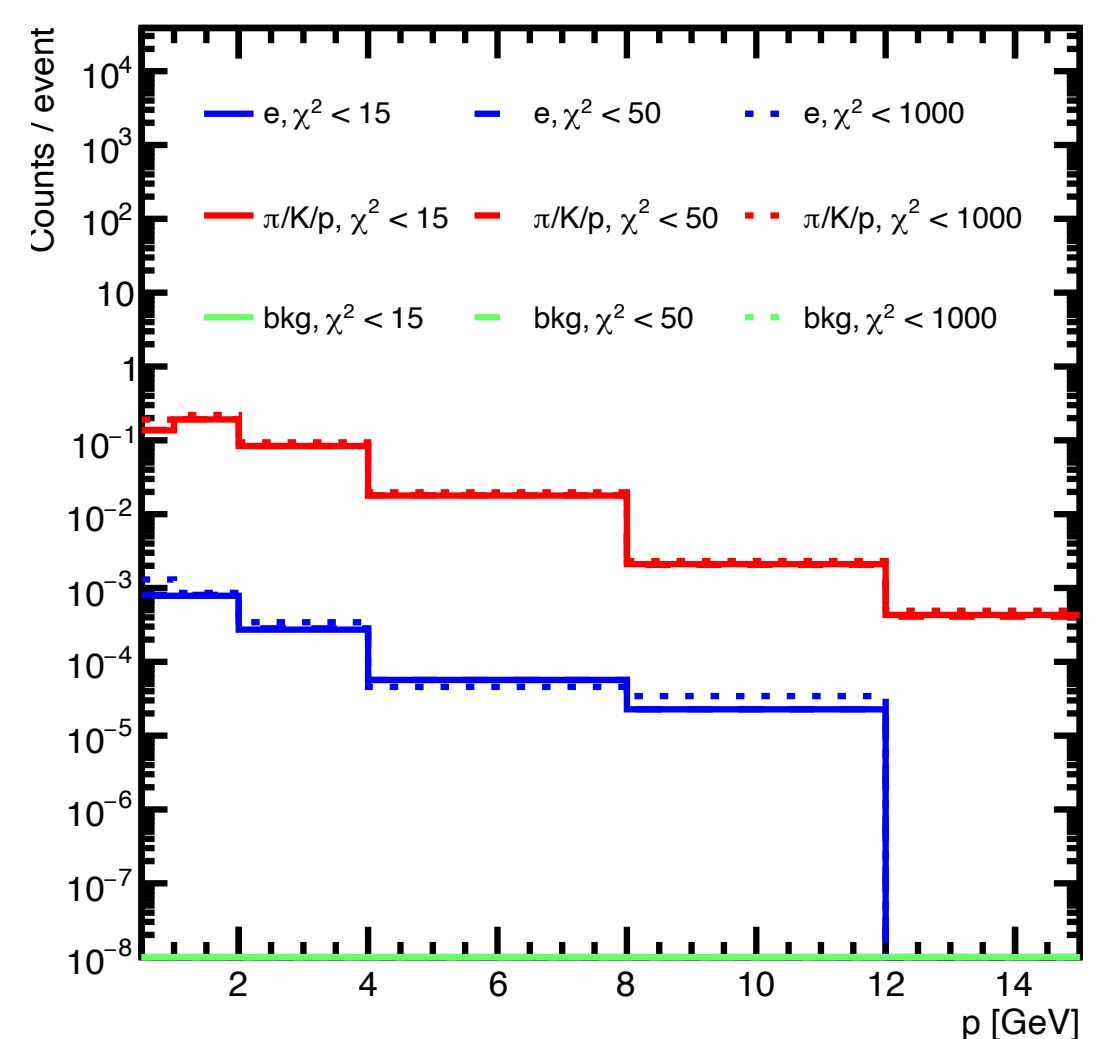
$\eta$  bin 3  $-2.0 < \eta < -1.0$



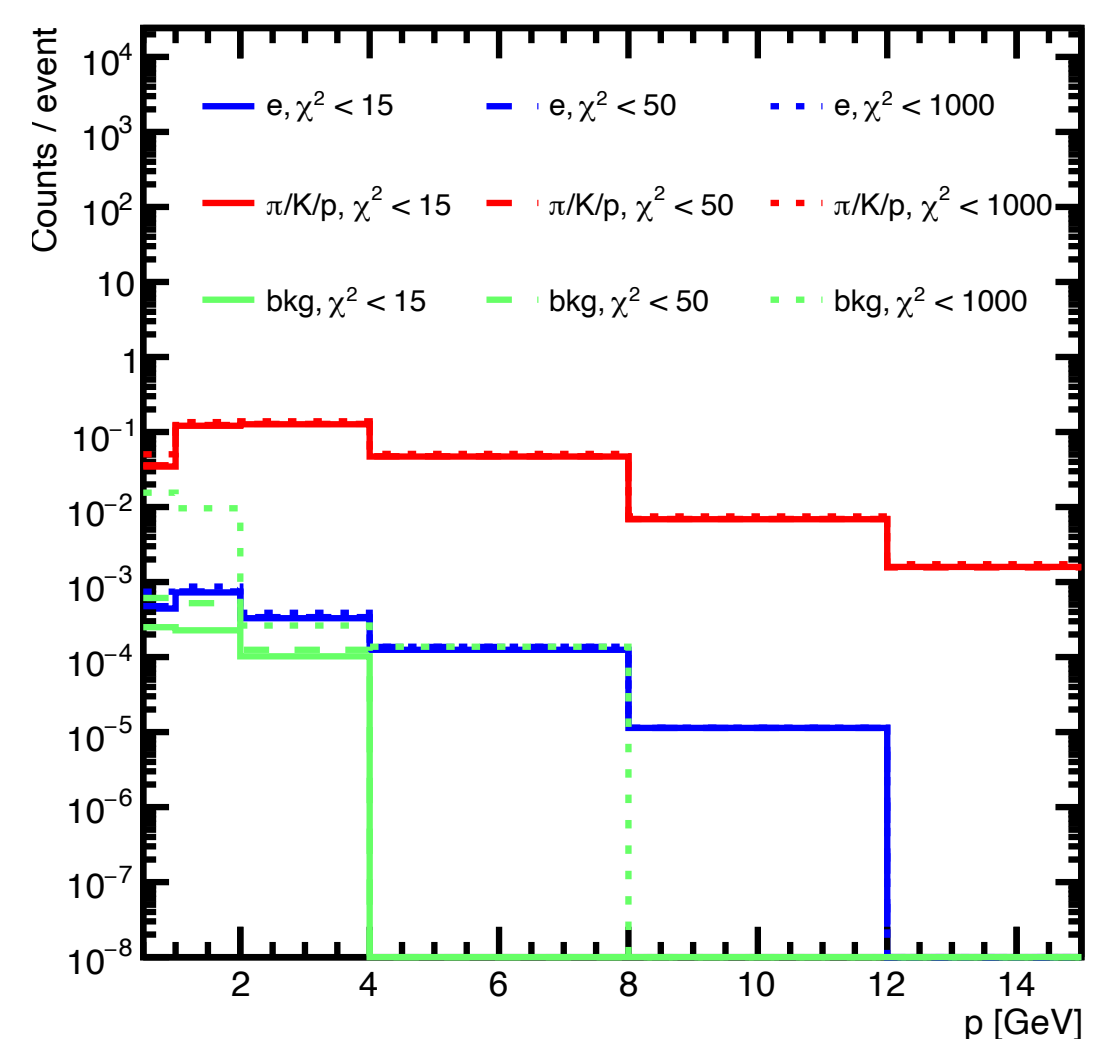
$\eta$  bin 4  $-1.0 < \eta < 1.0$



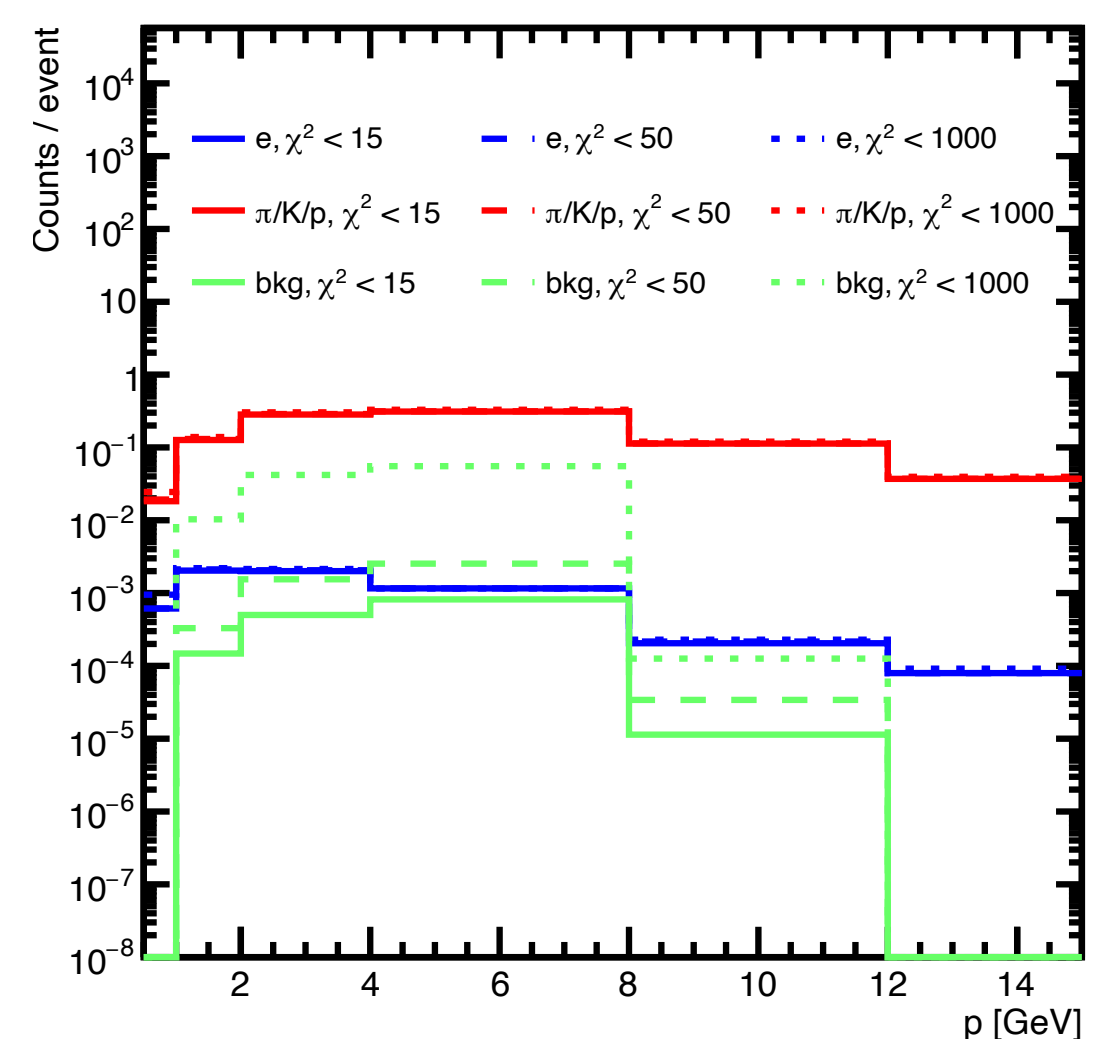
$\eta$  bin 5  $1.0 < \eta < 2.0$



$\eta$  bin 6  $2.0 < \eta < 2.5$



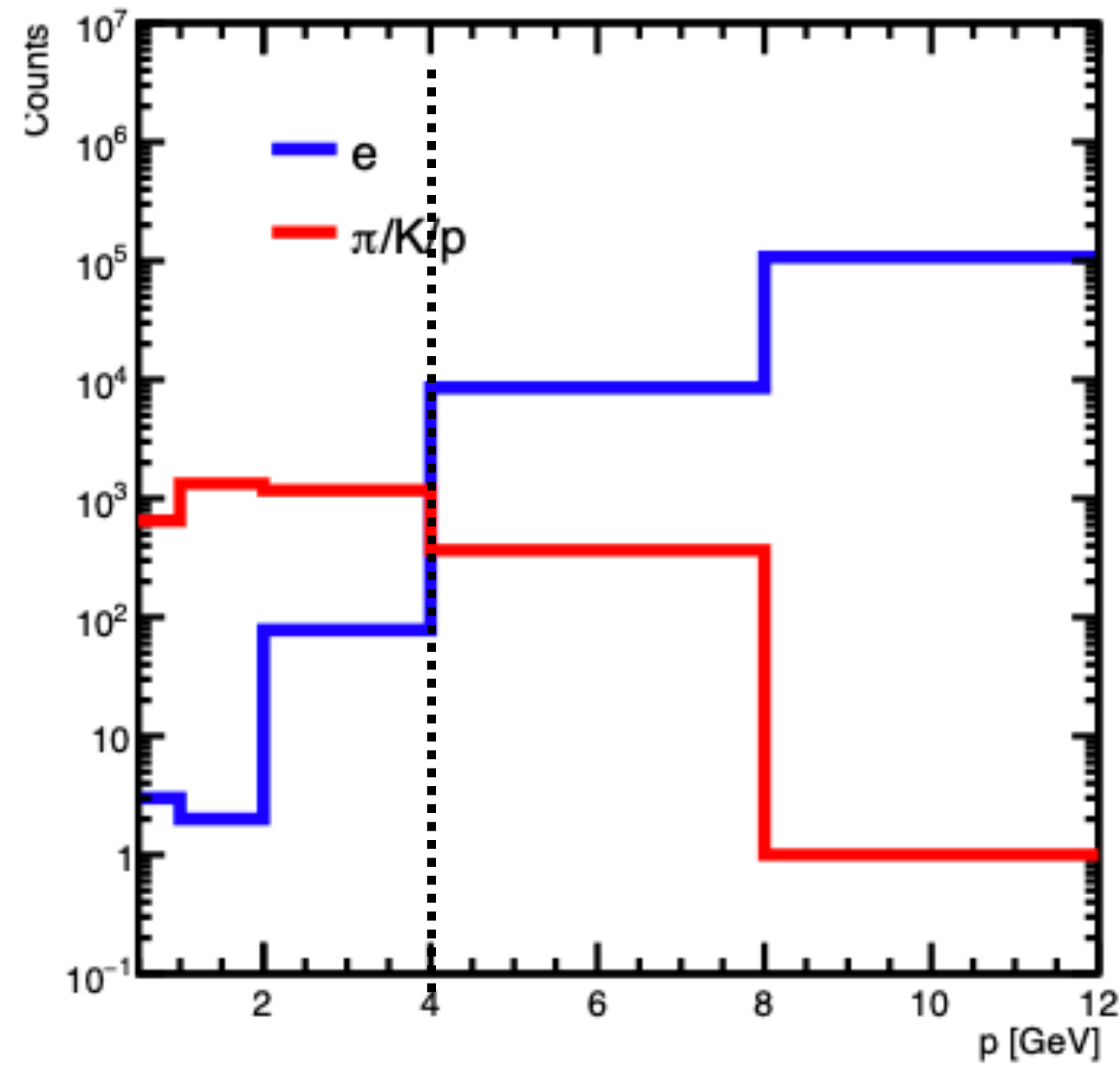
$\eta$  bin 7  $2.5 < \eta < 3.5$



While the electron and hadron tracks are largely unaffected by the  $\chi^2$  cut, the background tracks show a clear dependence on the selection.

# Purity Distributions: Normalized by Integral

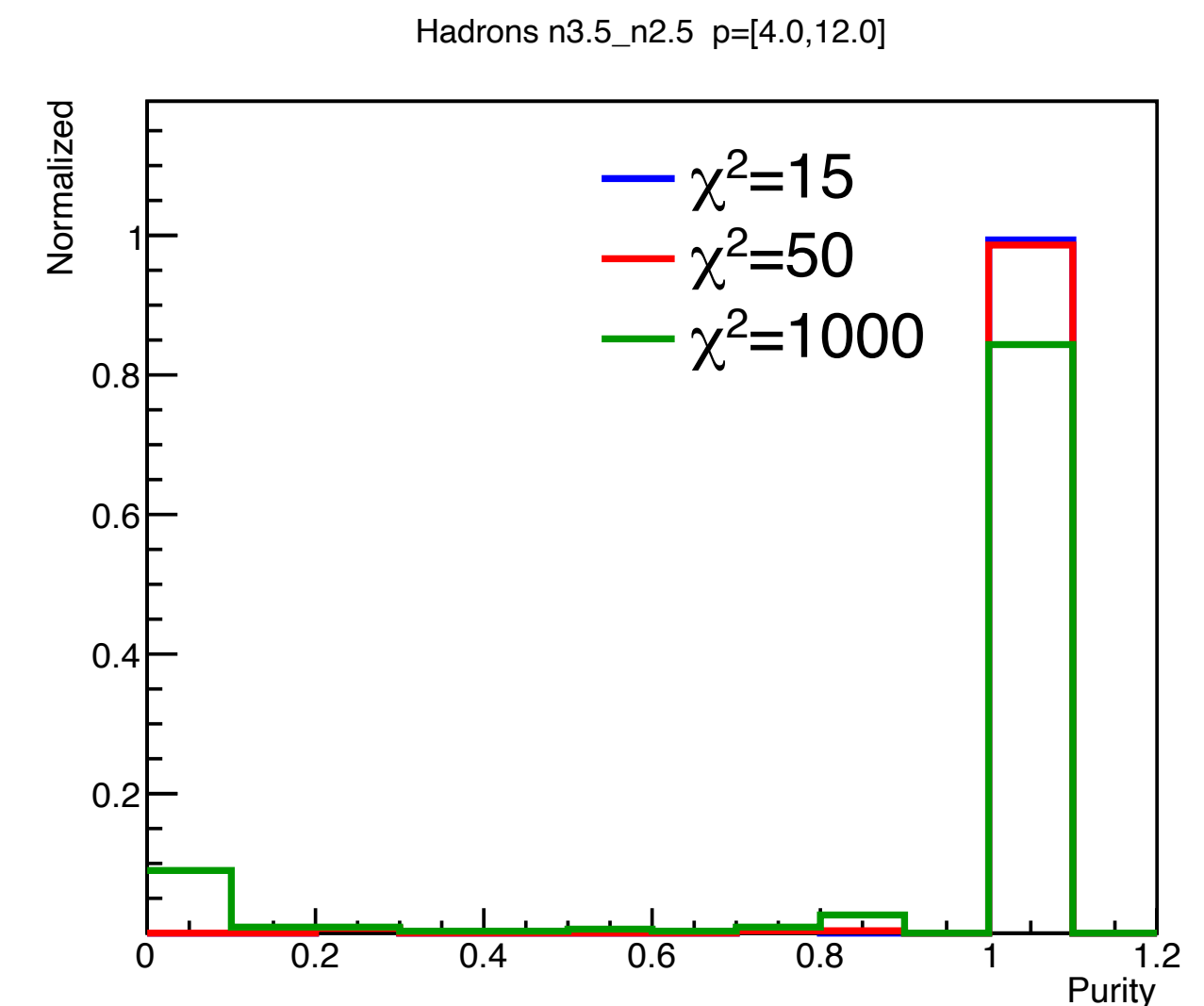
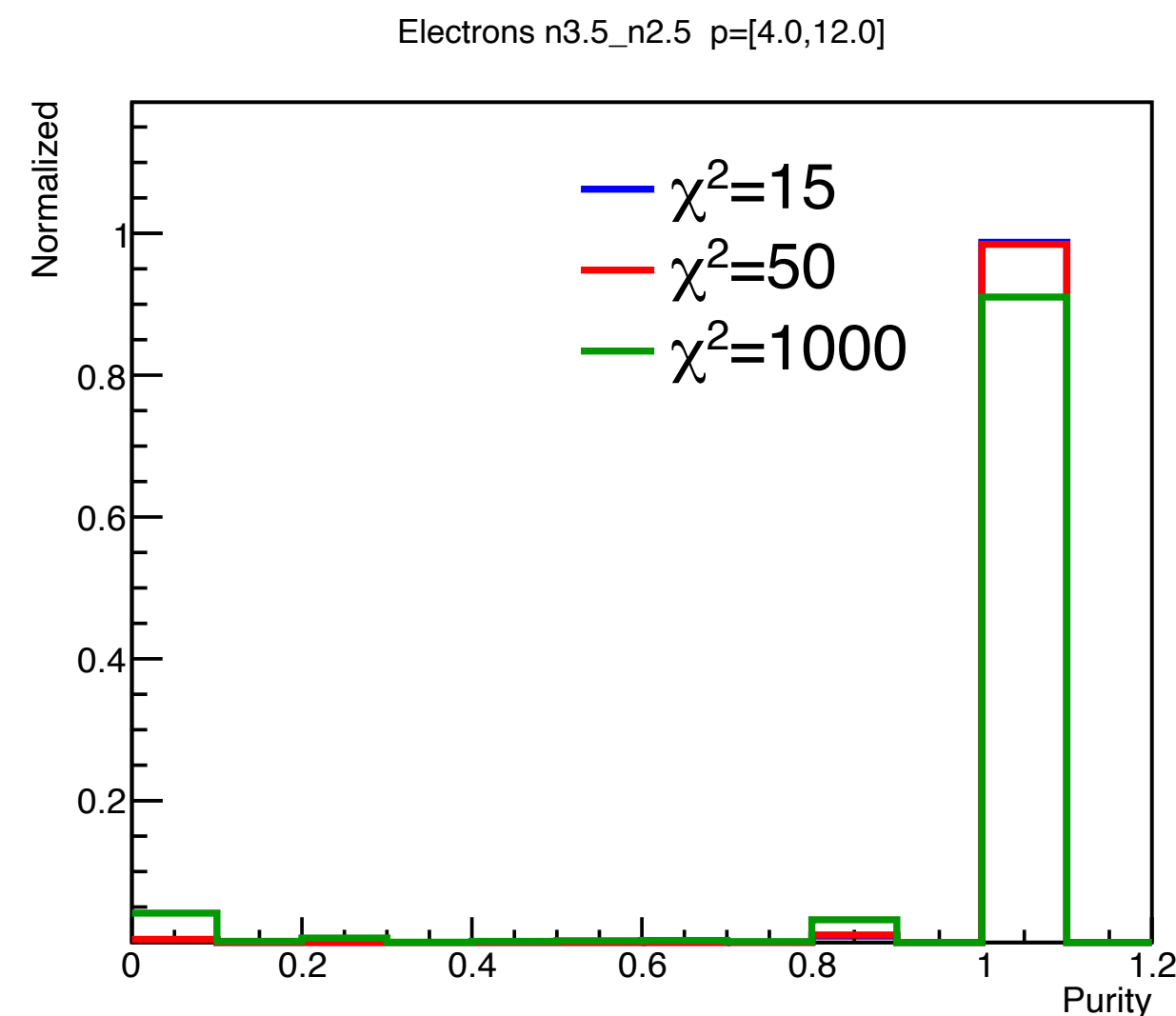
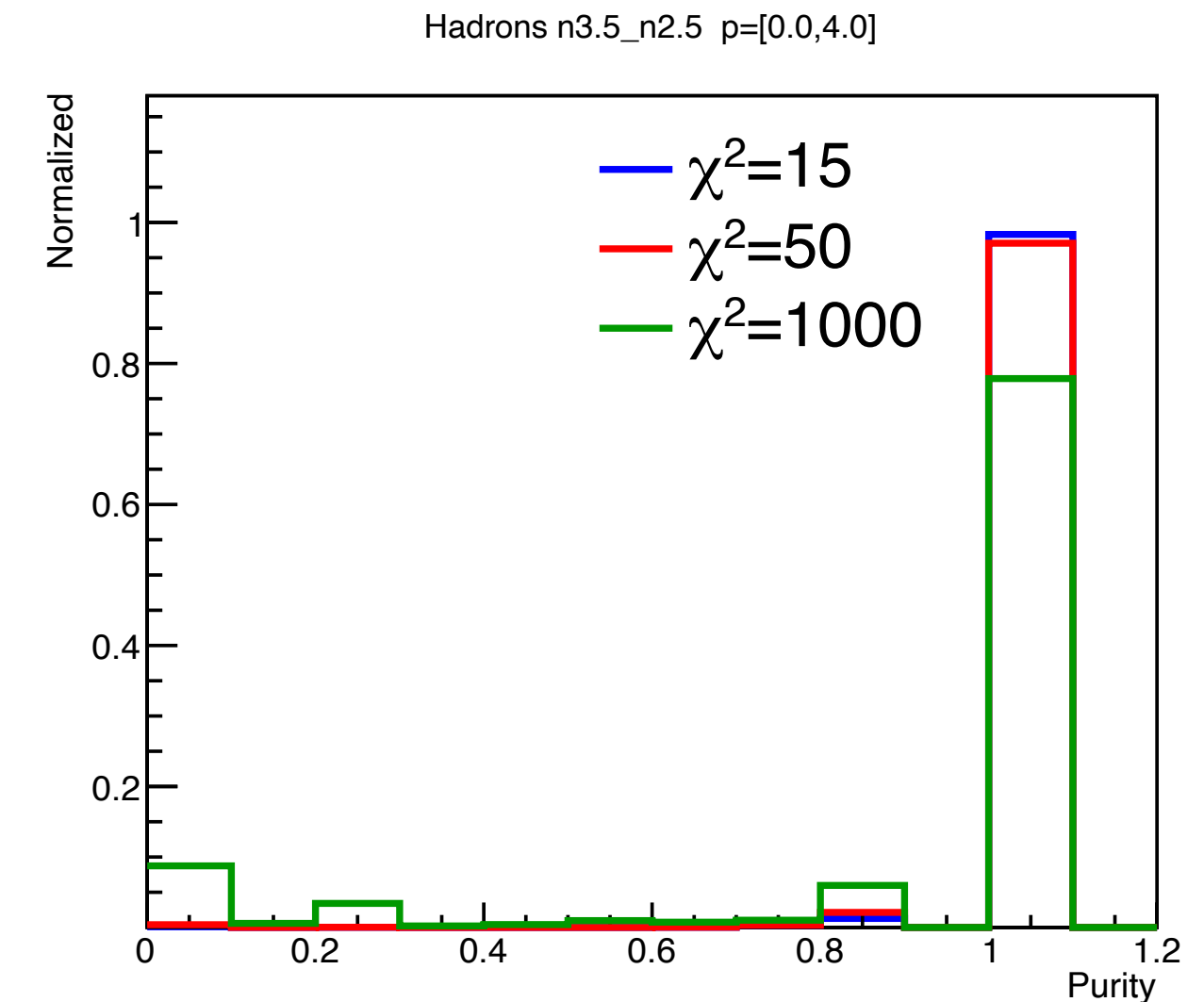
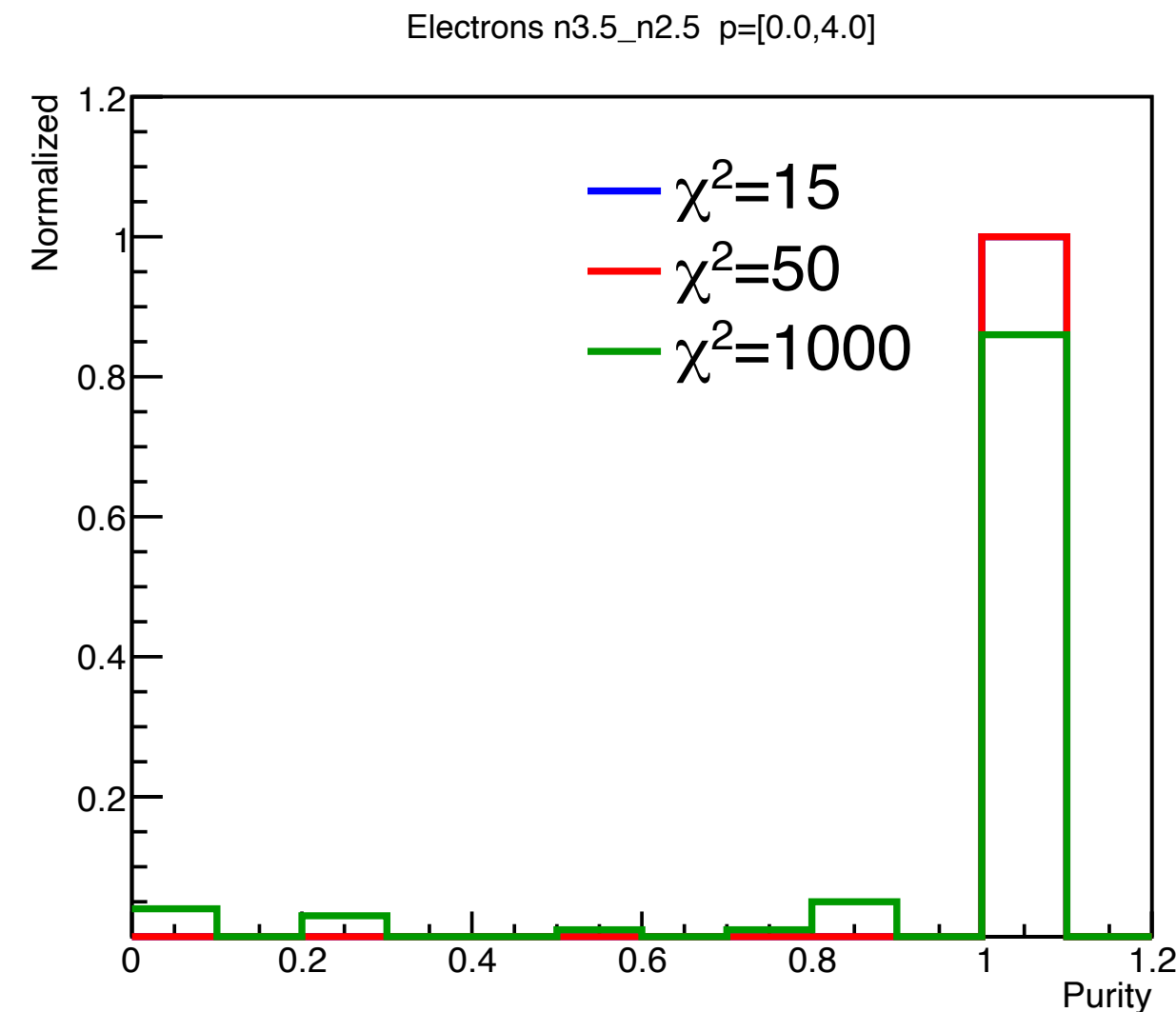
10x275 GeV DIS+Bkg



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

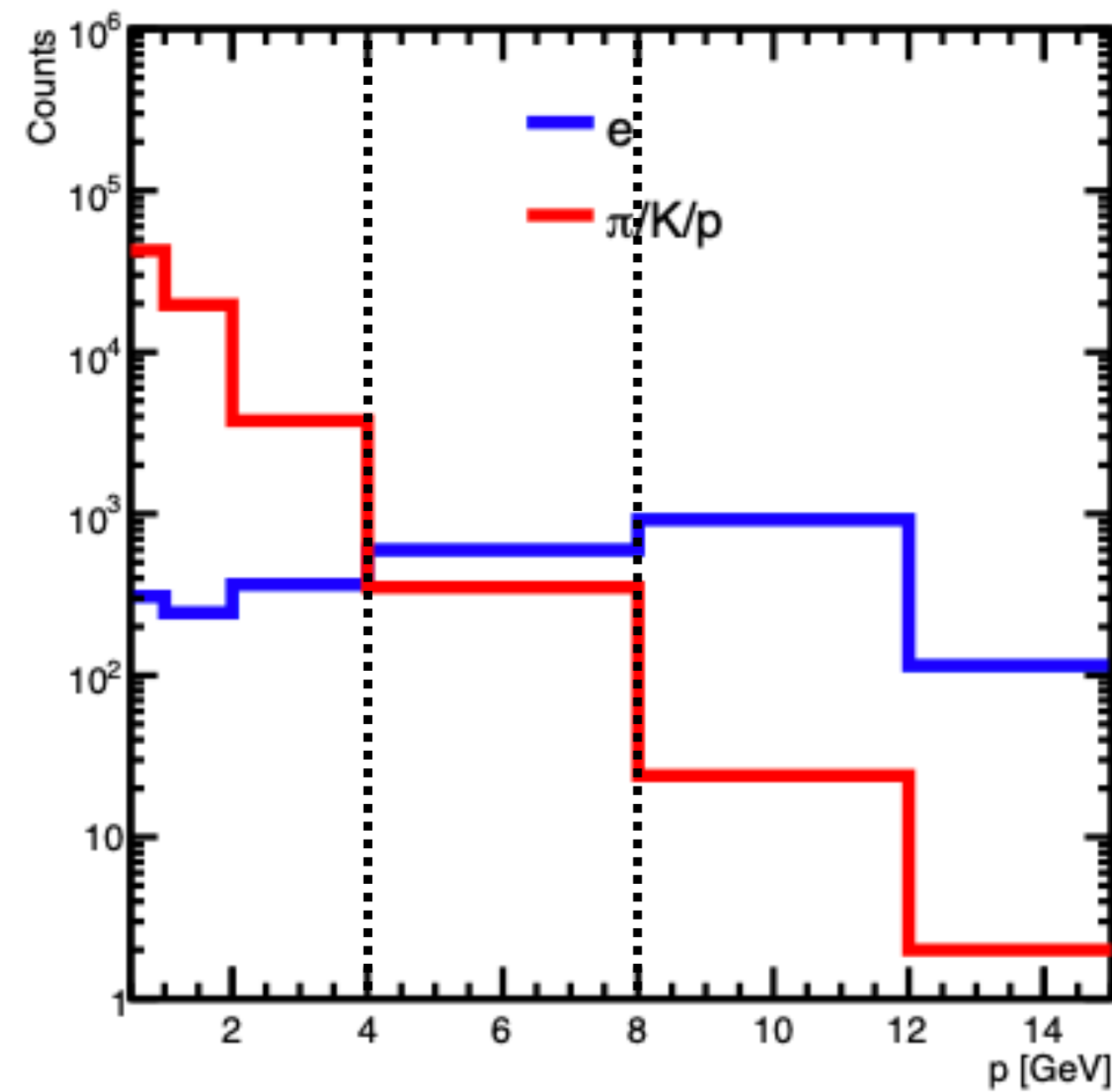
$$\text{Purity} = \frac{N_{\text{Hits}}^{\text{primary}}}{N_{\text{Hits}}^{\text{Total}}}$$

Reconstructed tracks corresponding to primary electron/hadron tracks are considered.



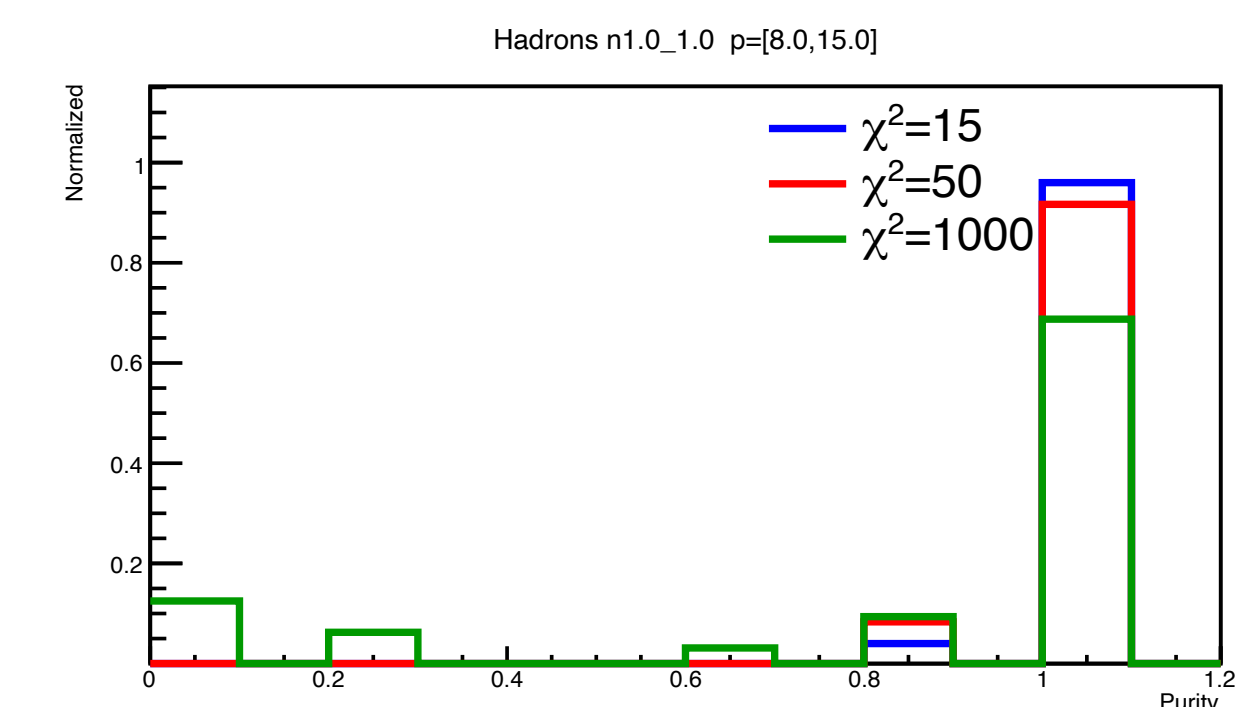
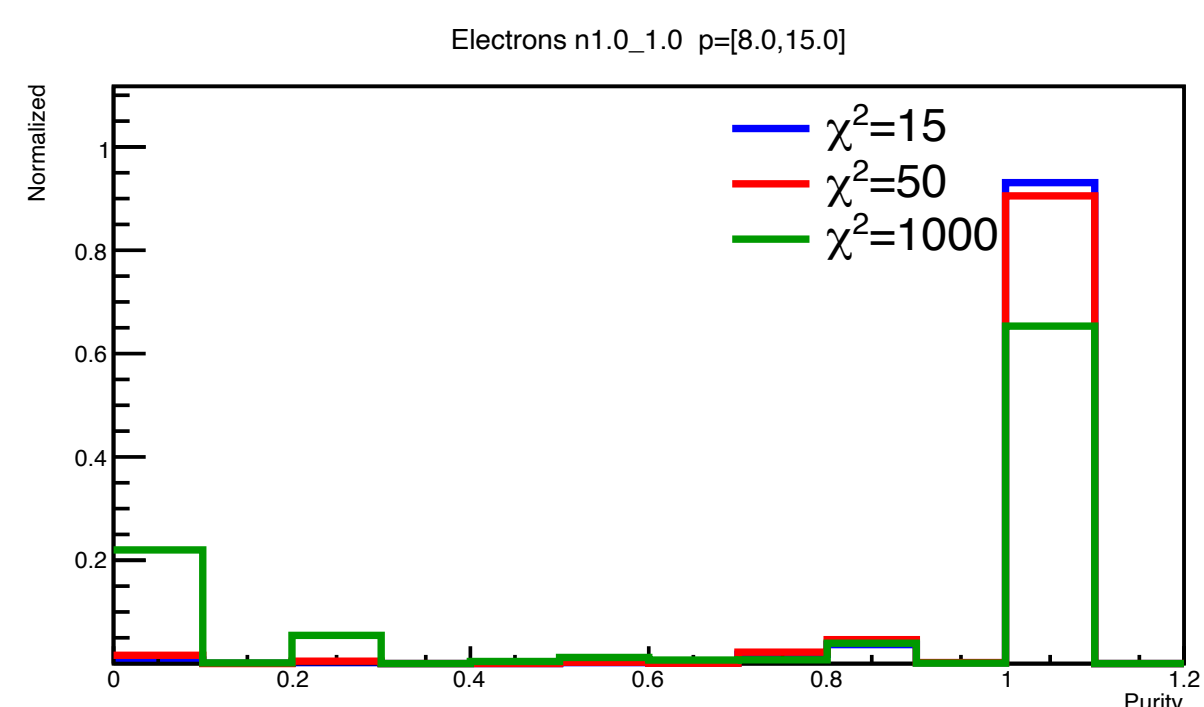
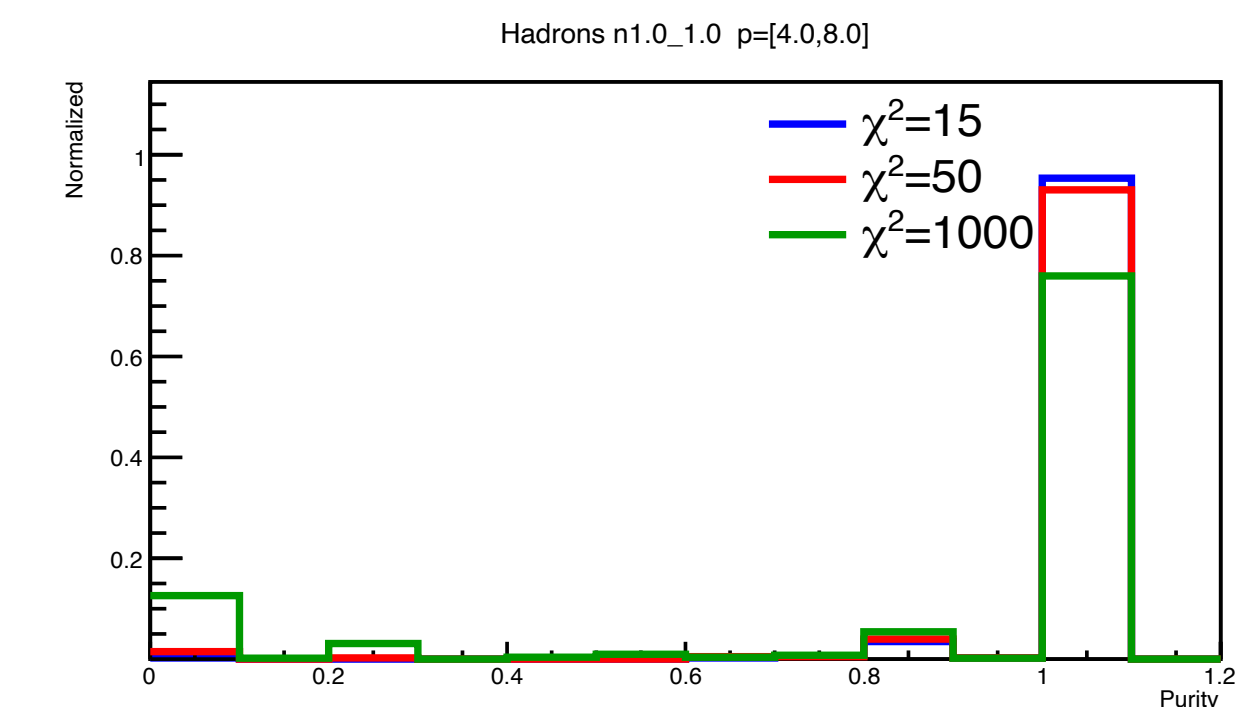
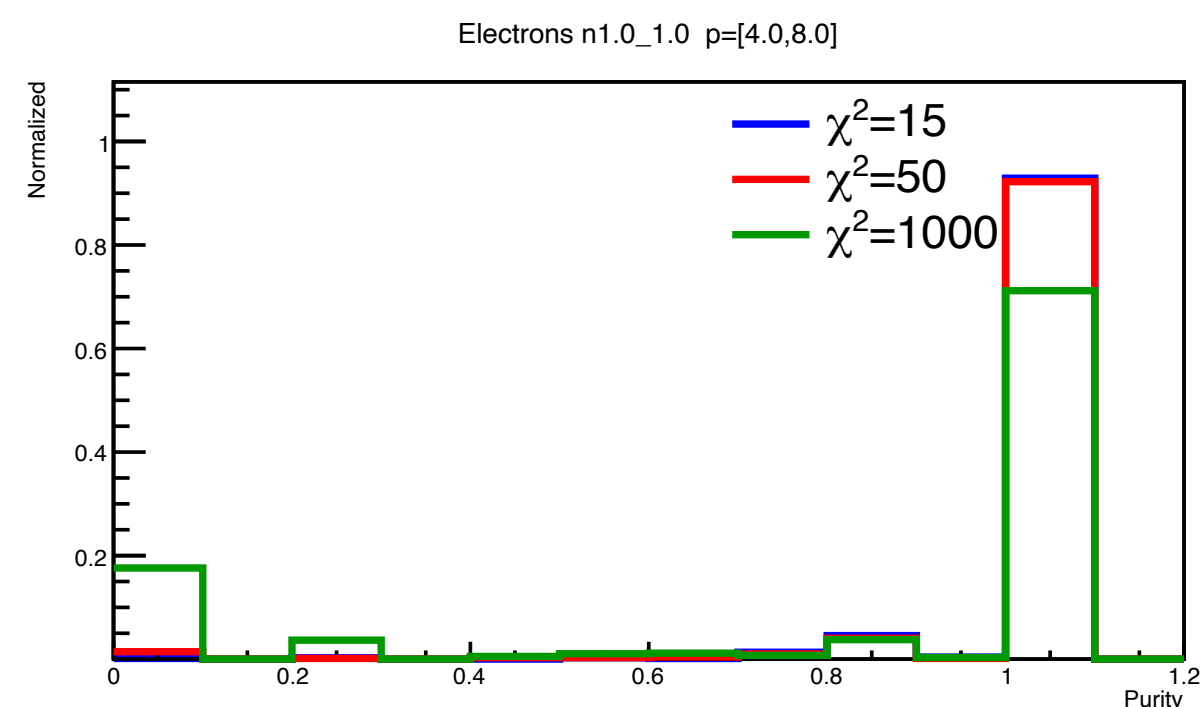
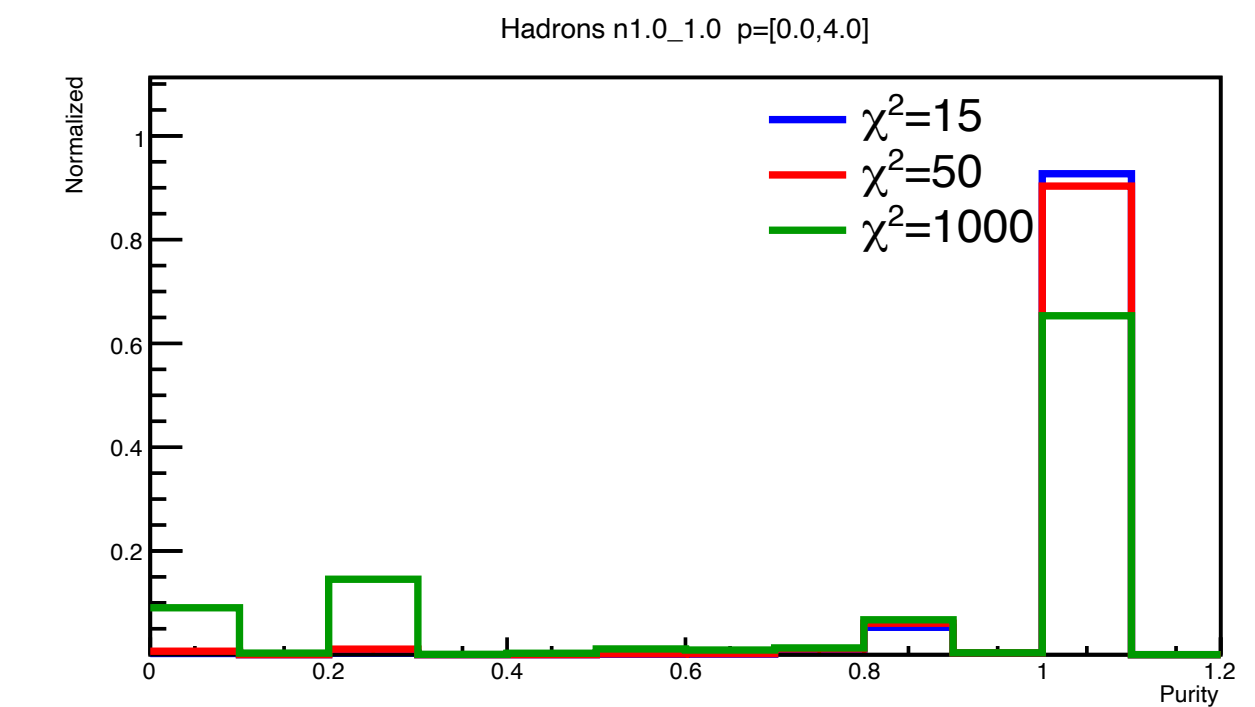
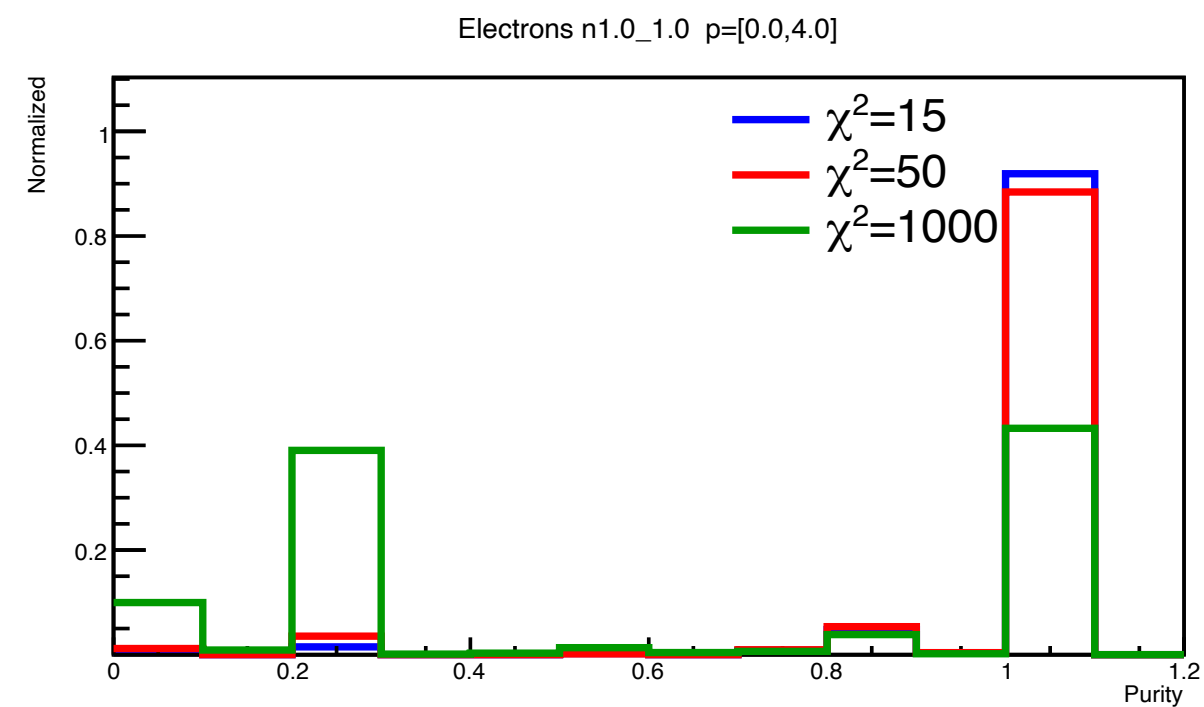
# Purity Distributions: Normalized by Integral

10x275 GeV DIS+Bkg



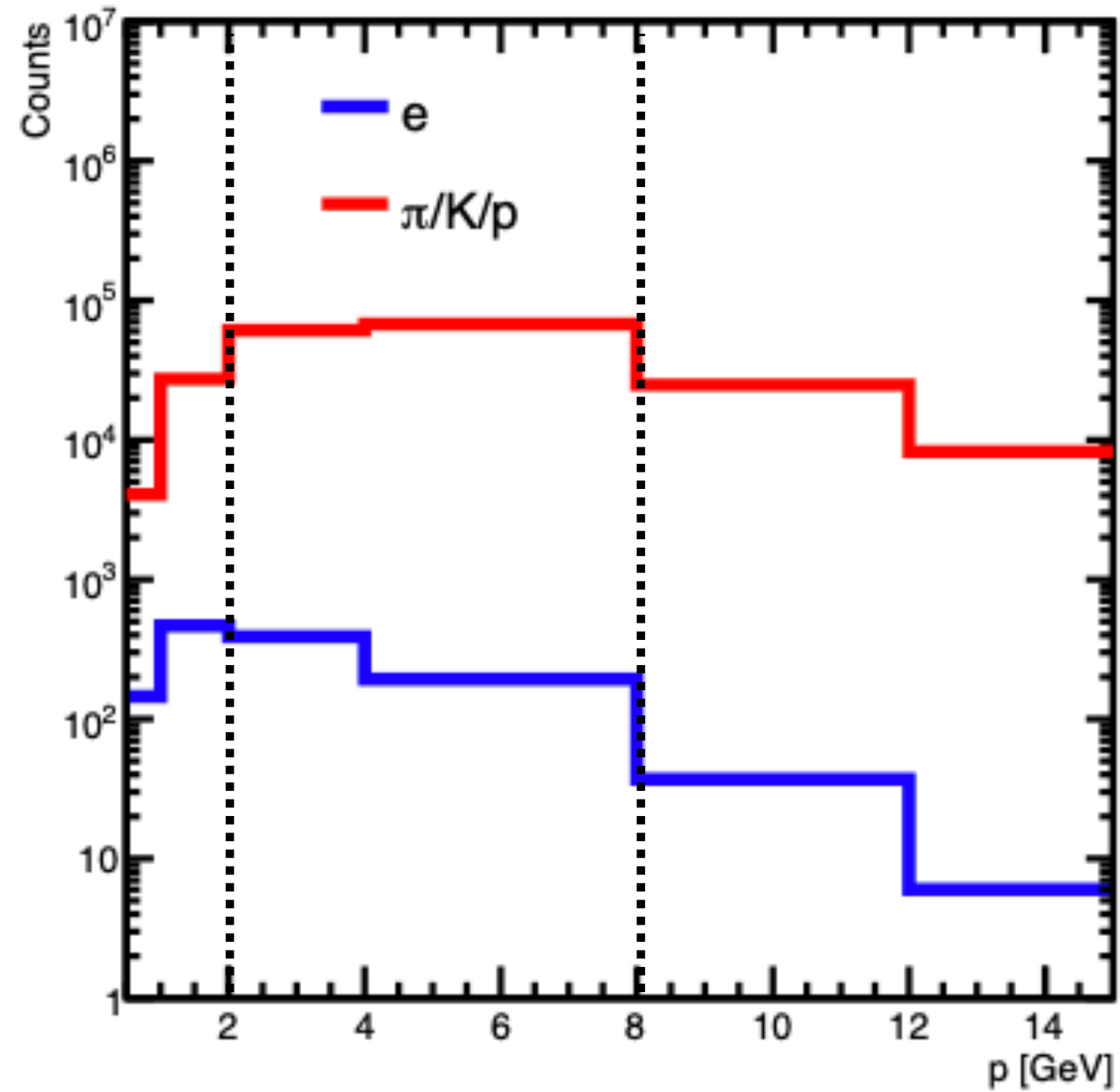
$$-1.0 < \eta < 1.0$$

$$\text{Purity} = \frac{N_{\text{Hits}}^{\text{primary}}}{N_{\text{Hits}}^{\text{Total}}}$$



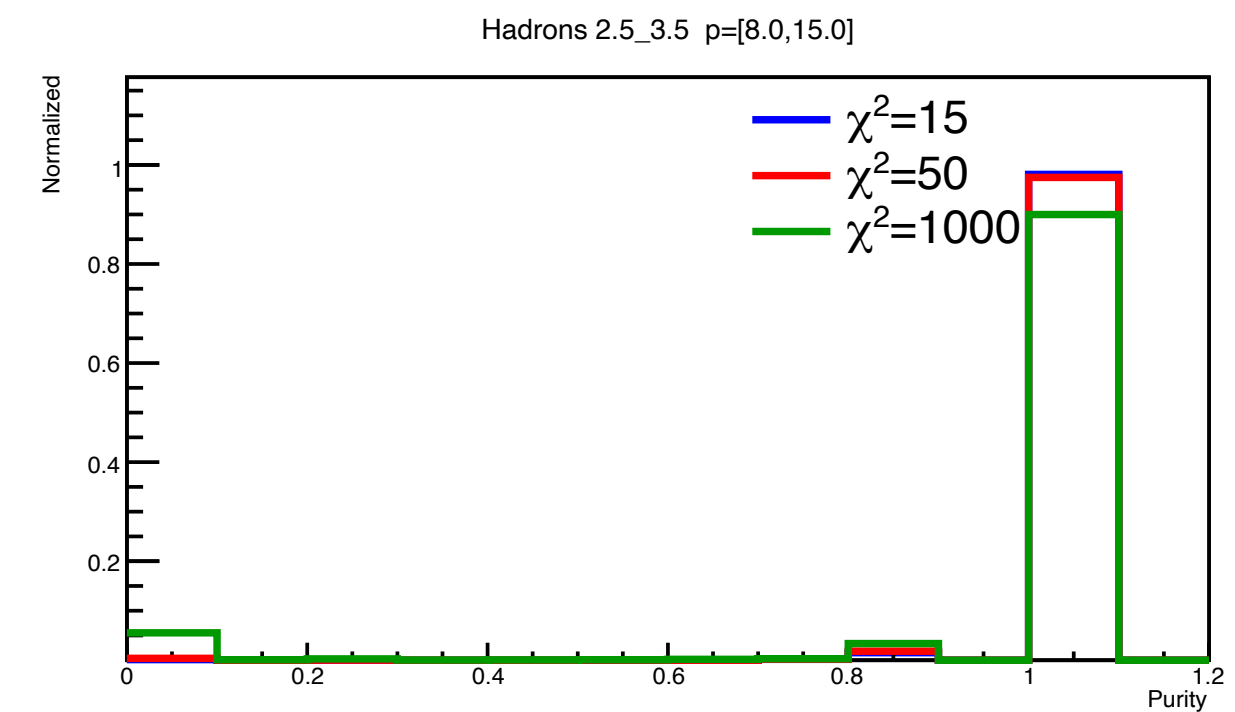
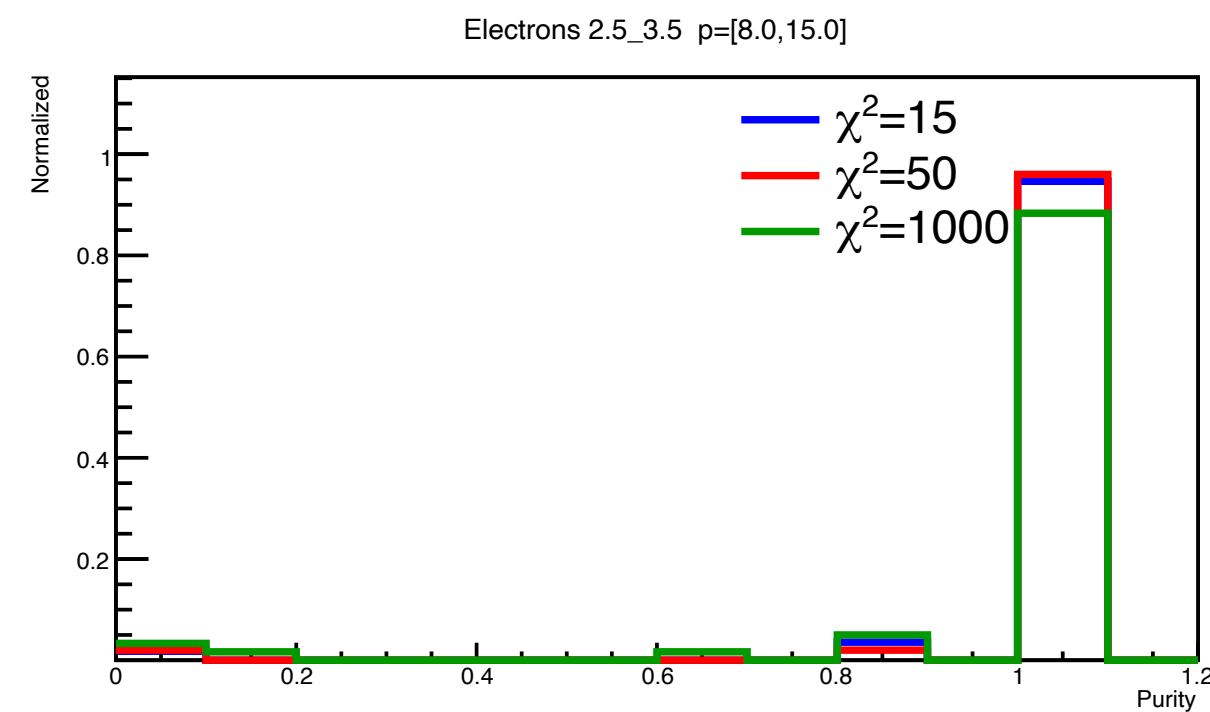
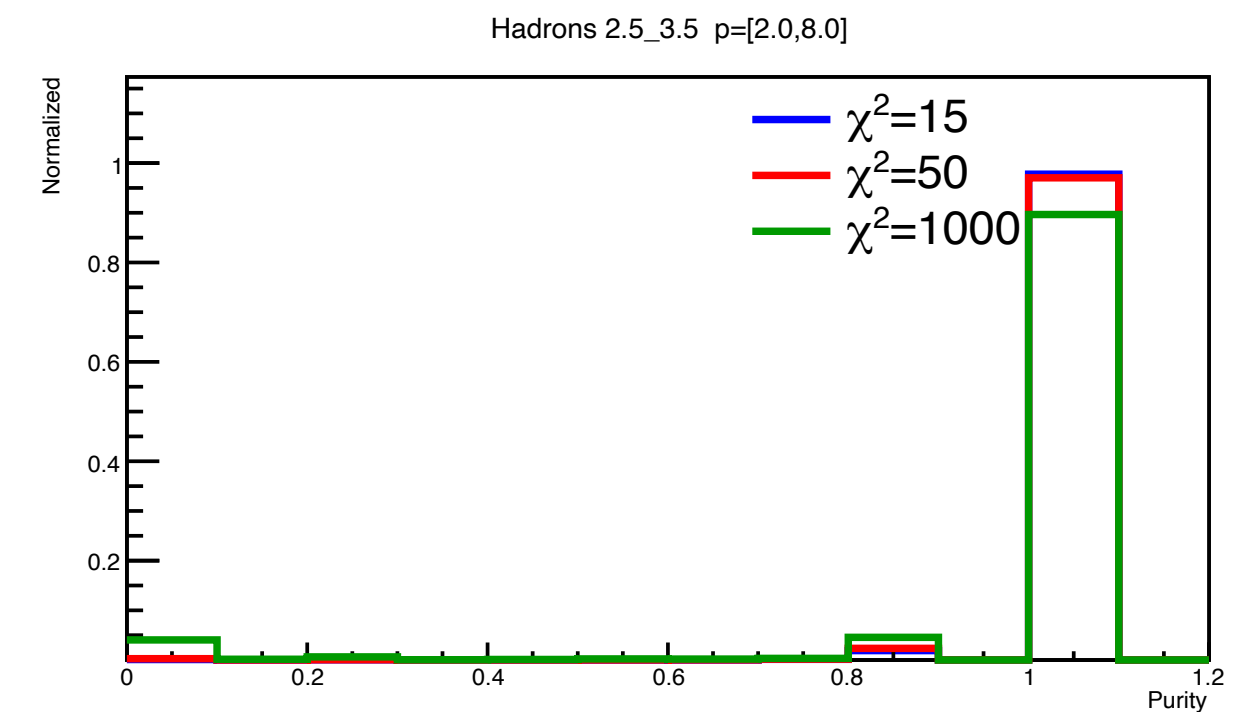
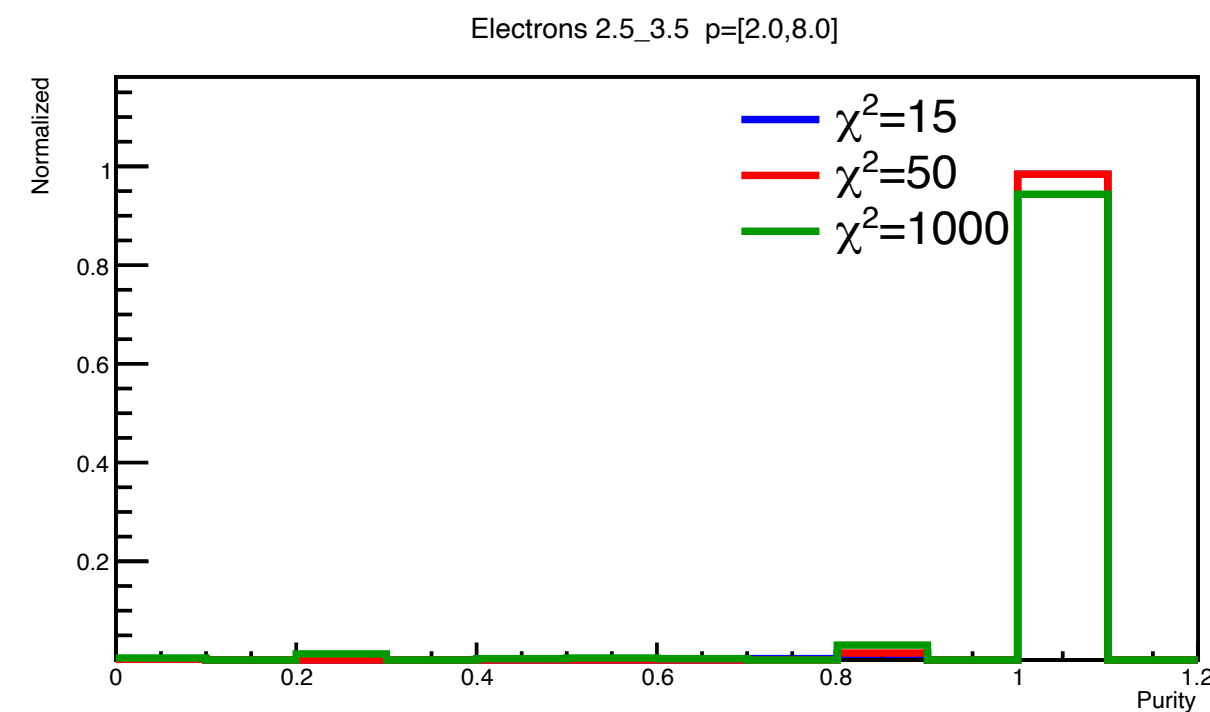
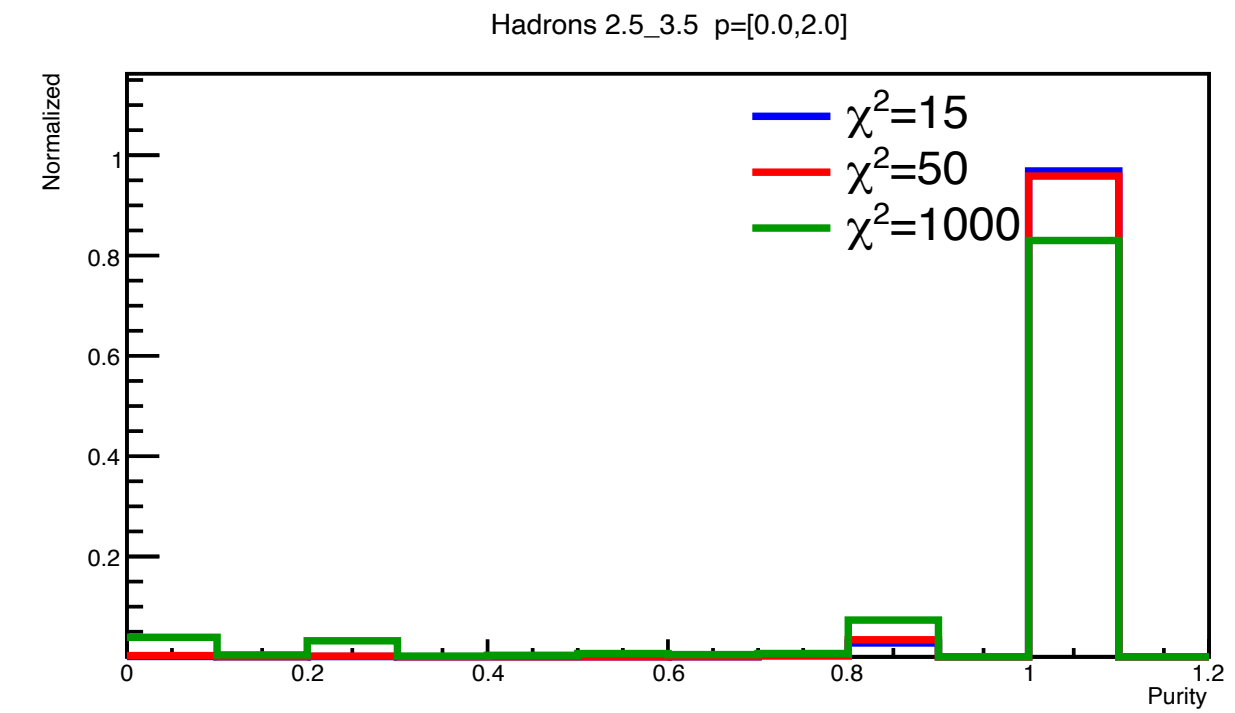
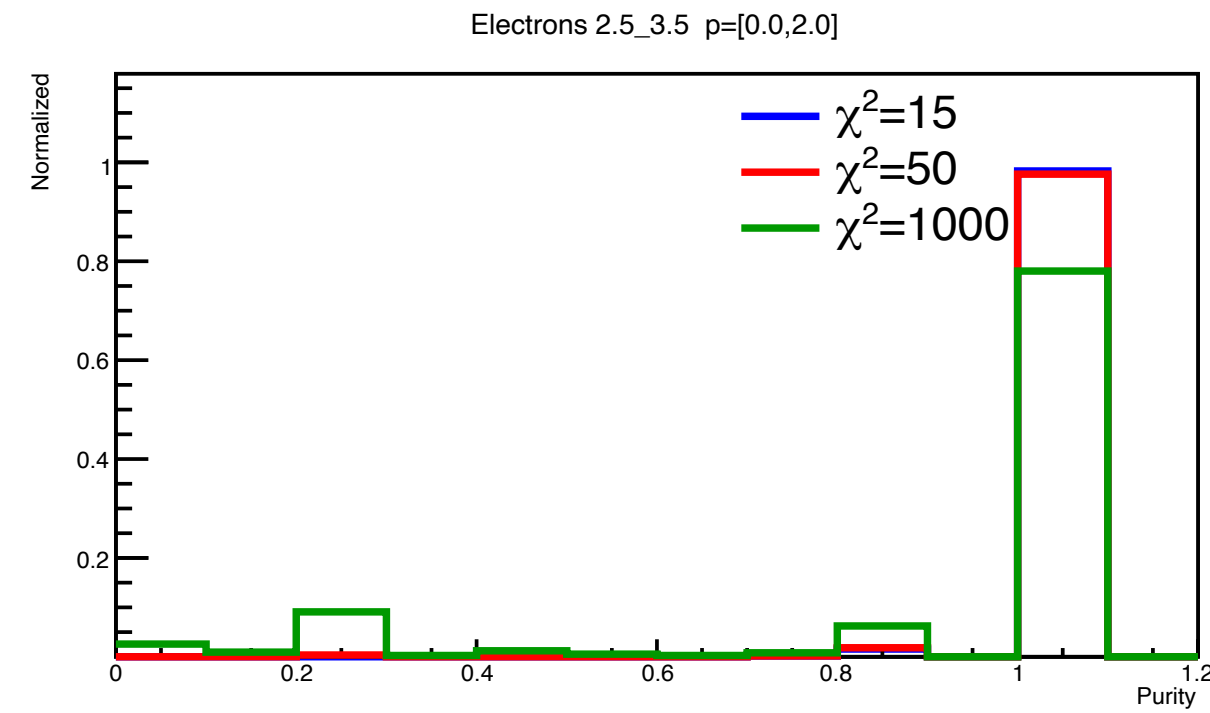
# Purity Distributions: Normalized by Integral

10x275 GeV DIS+Bkg



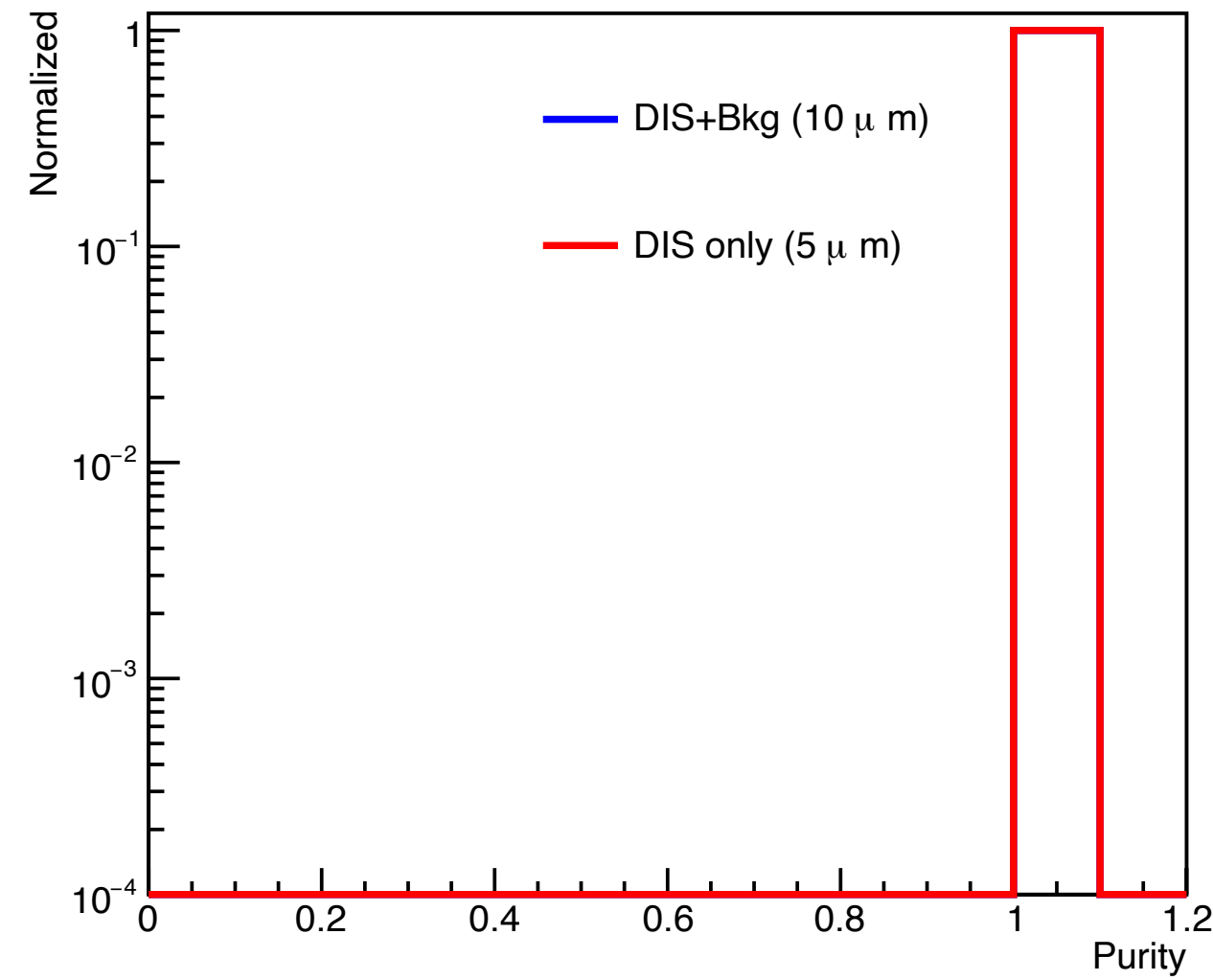
$$2.5 < \eta < 3.5$$

$$\text{Purity} = \frac{N_{\text{Hits}}^{\text{primary}}}{N_{\text{Hits}}^{\text{Total}}}$$

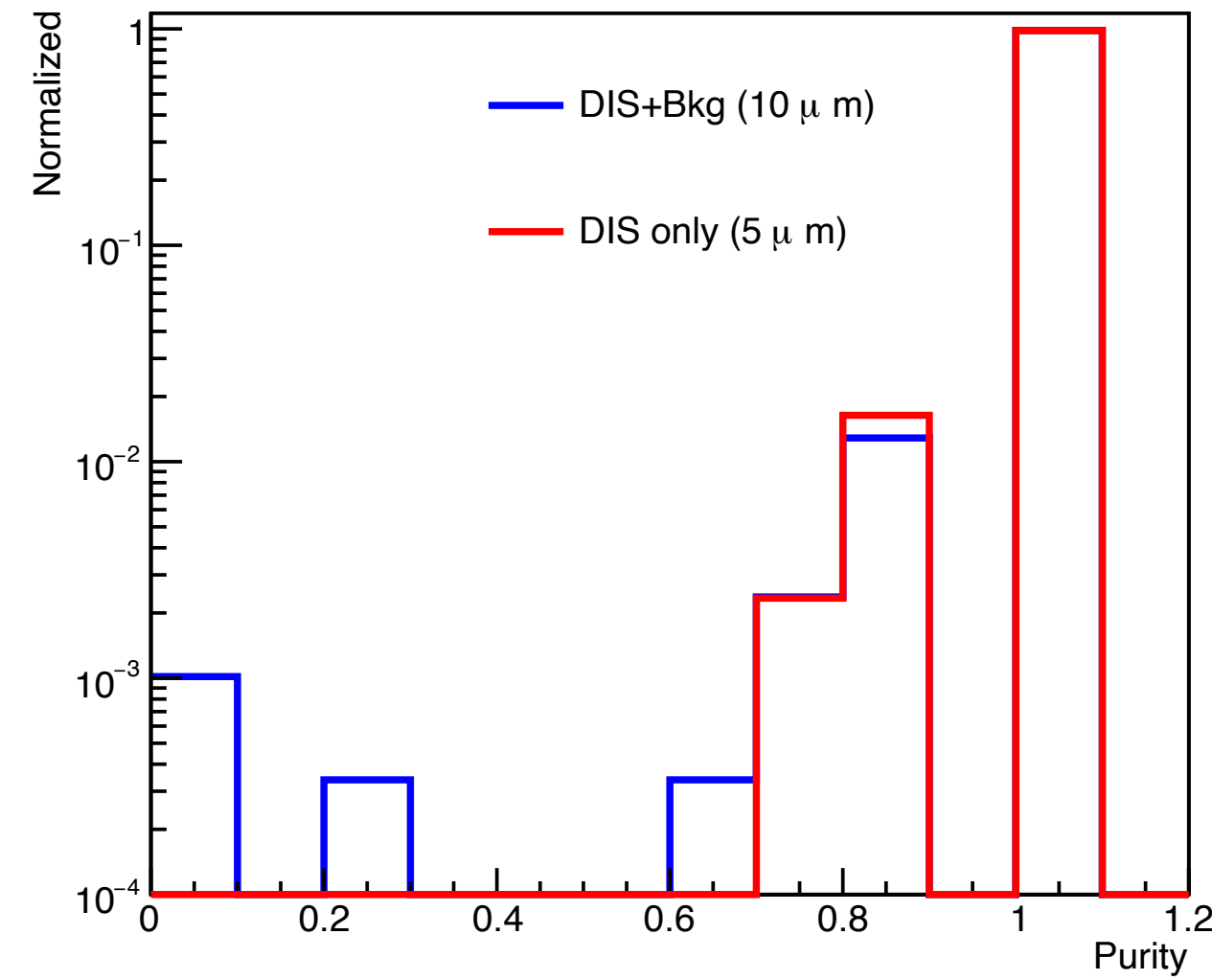


# Comparison of the purity distributions

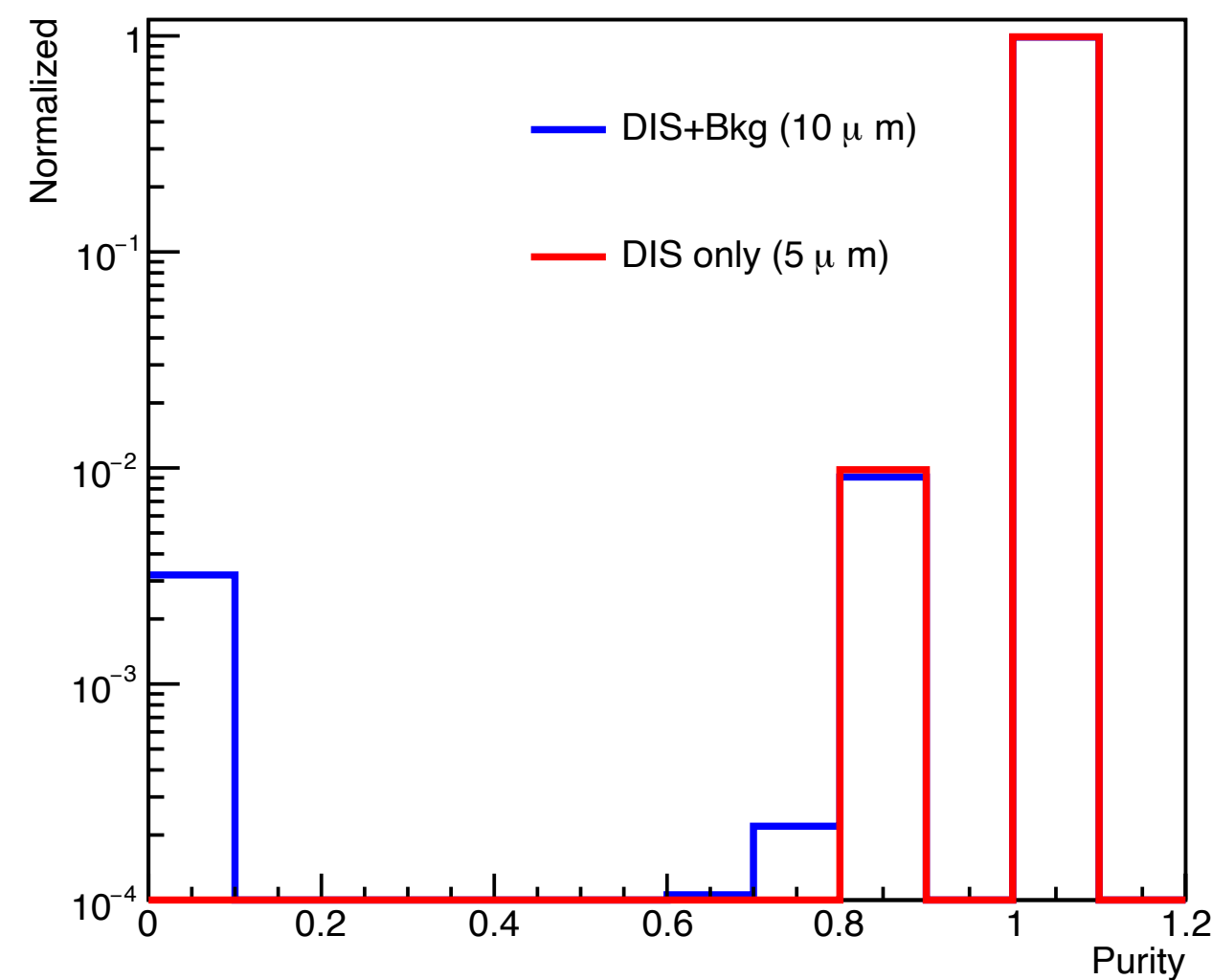
Electrons n3.5\_n2.5 p=[0.0,4.0]



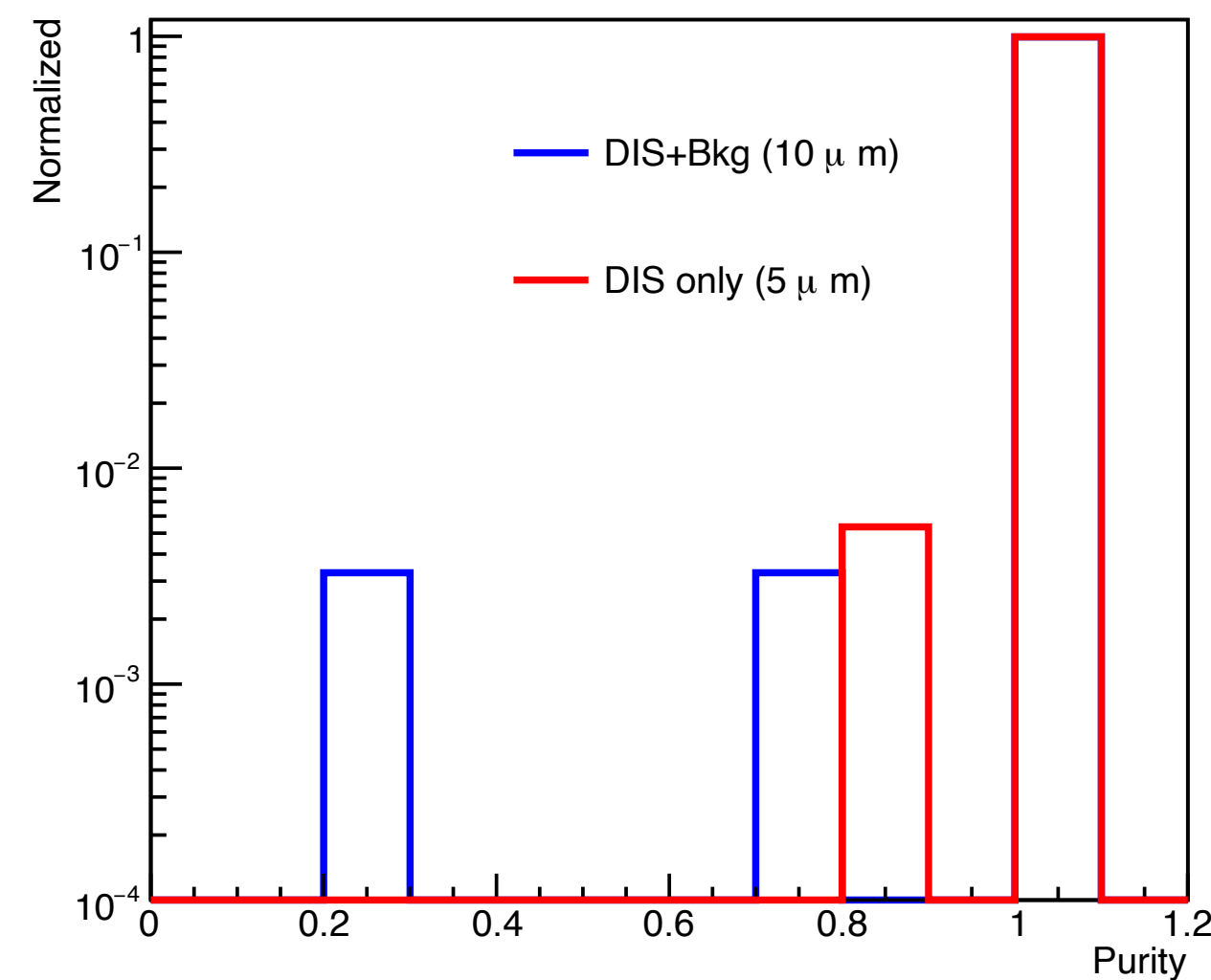
Hadrons n3.5\_n2.5 p=[0.0,4.0]



Electrons n3.5\_n2.5 p=[4.0,12.0]



Hadrons n3.5\_n2.5 p=[4.0,12.0]

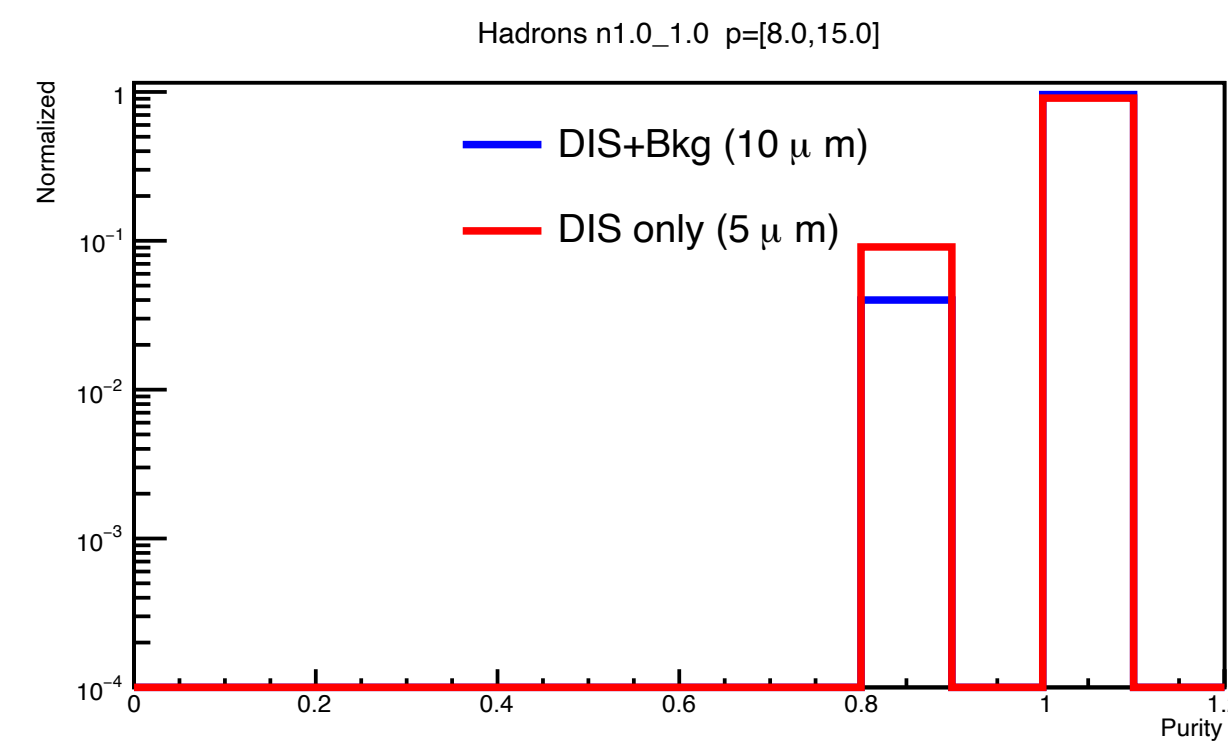
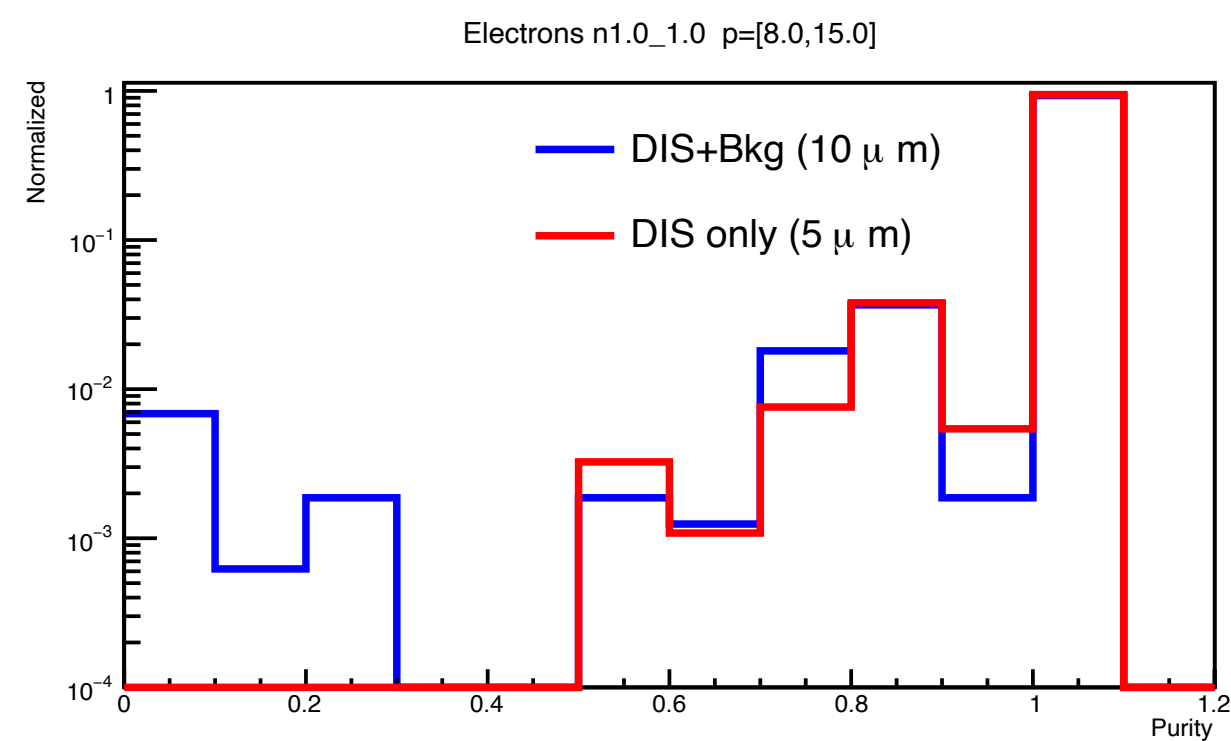
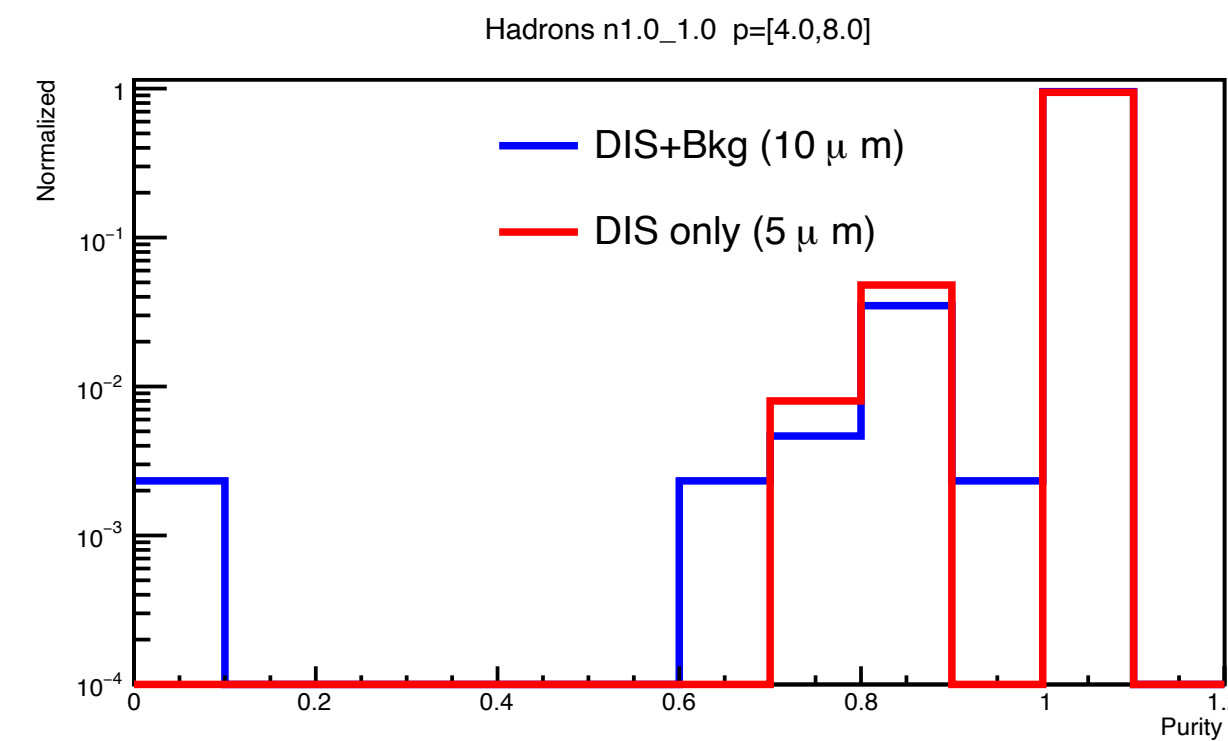
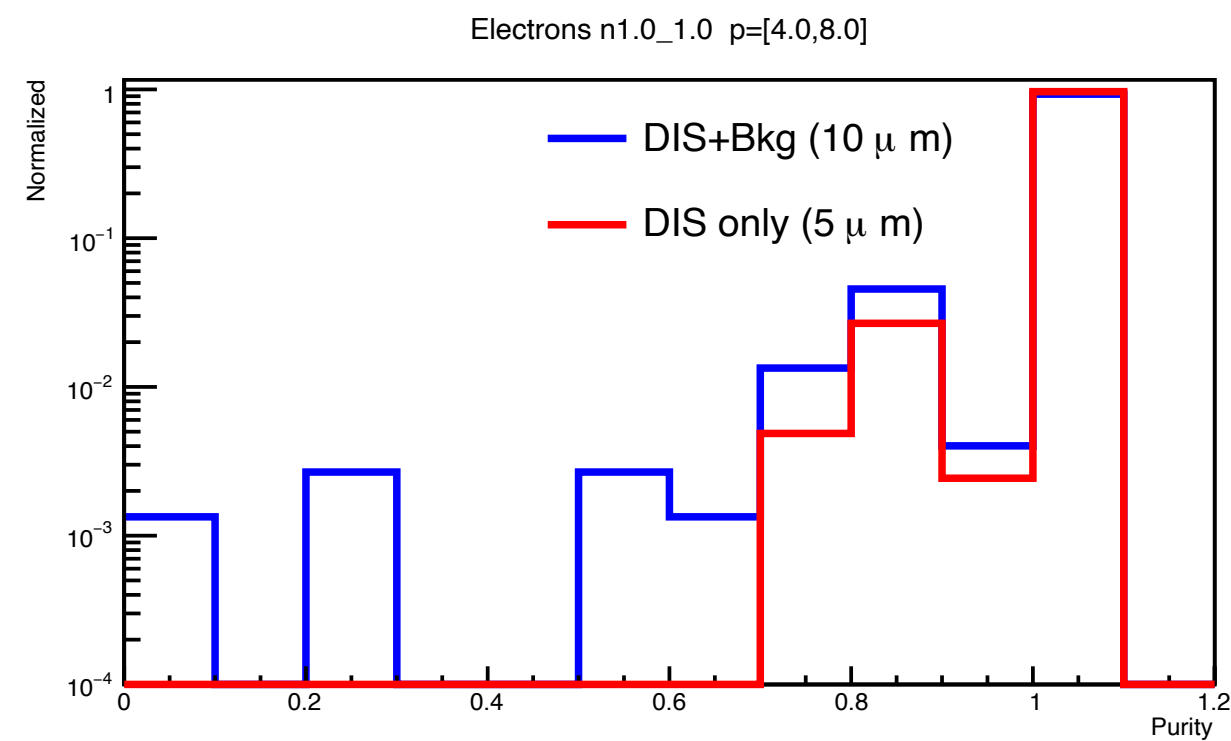
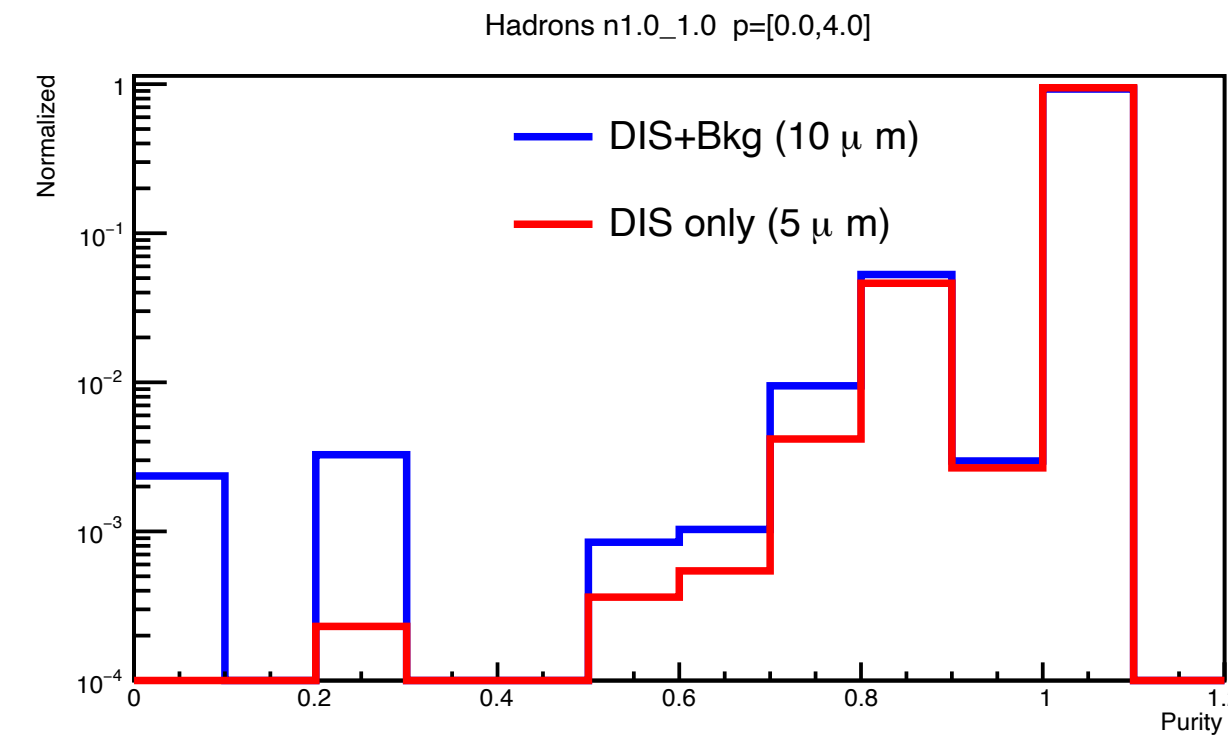
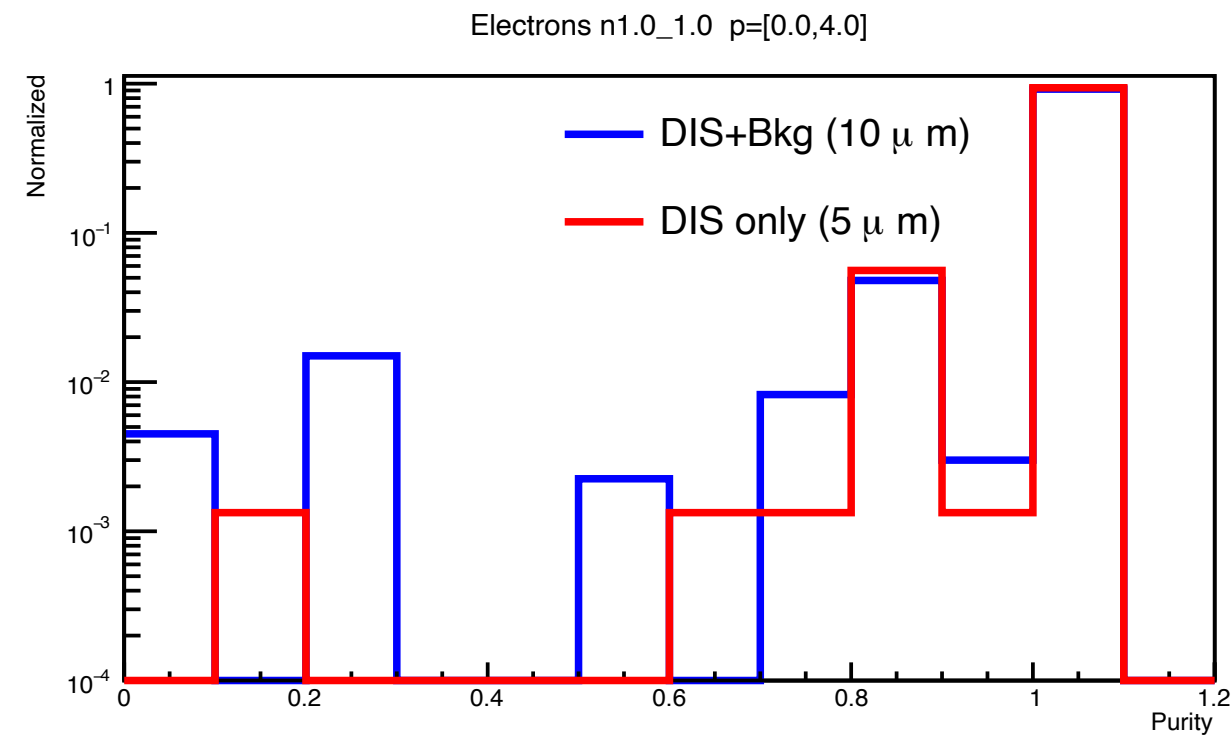


$$-3.5 < \eta < -2.5$$

$$\text{Purity} = \frac{N_{\text{Hits}}^{\text{primary}}}{N_{\text{Hits}}^{\text{Total}}}$$

$$\chi^2 = 15$$

# Comparison of the purity distributions

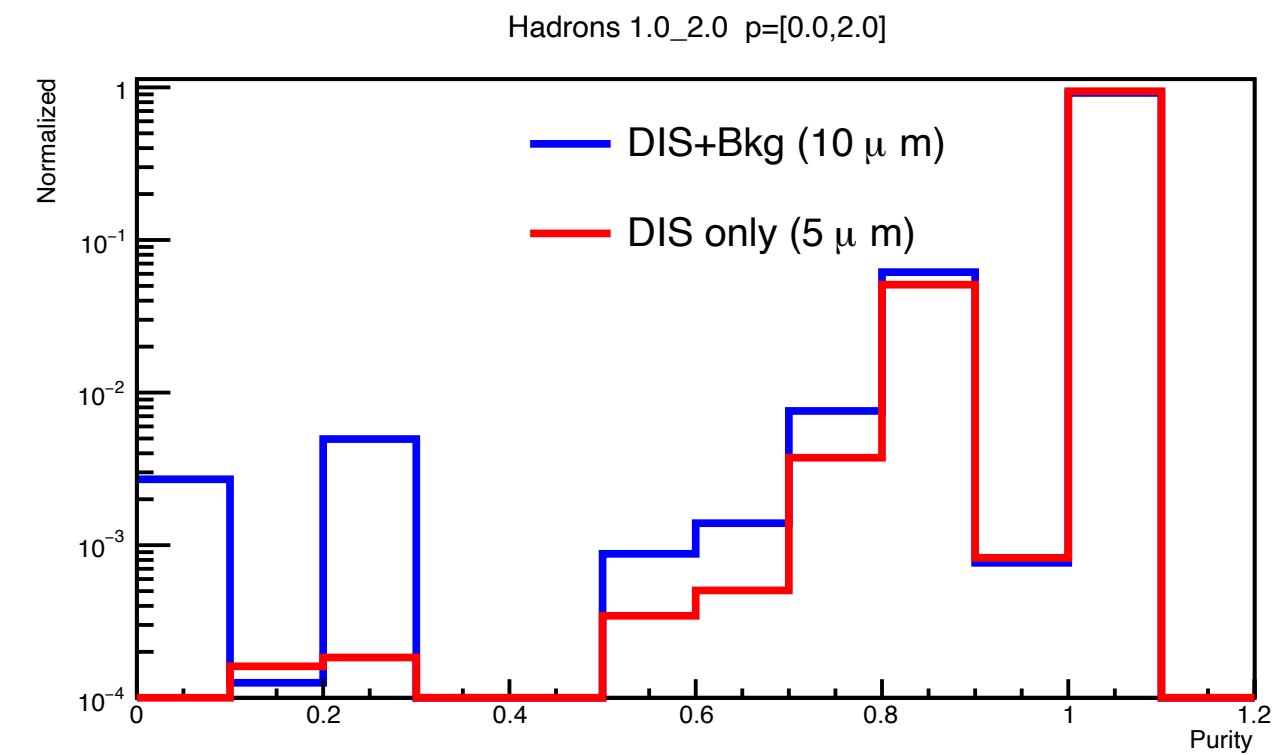
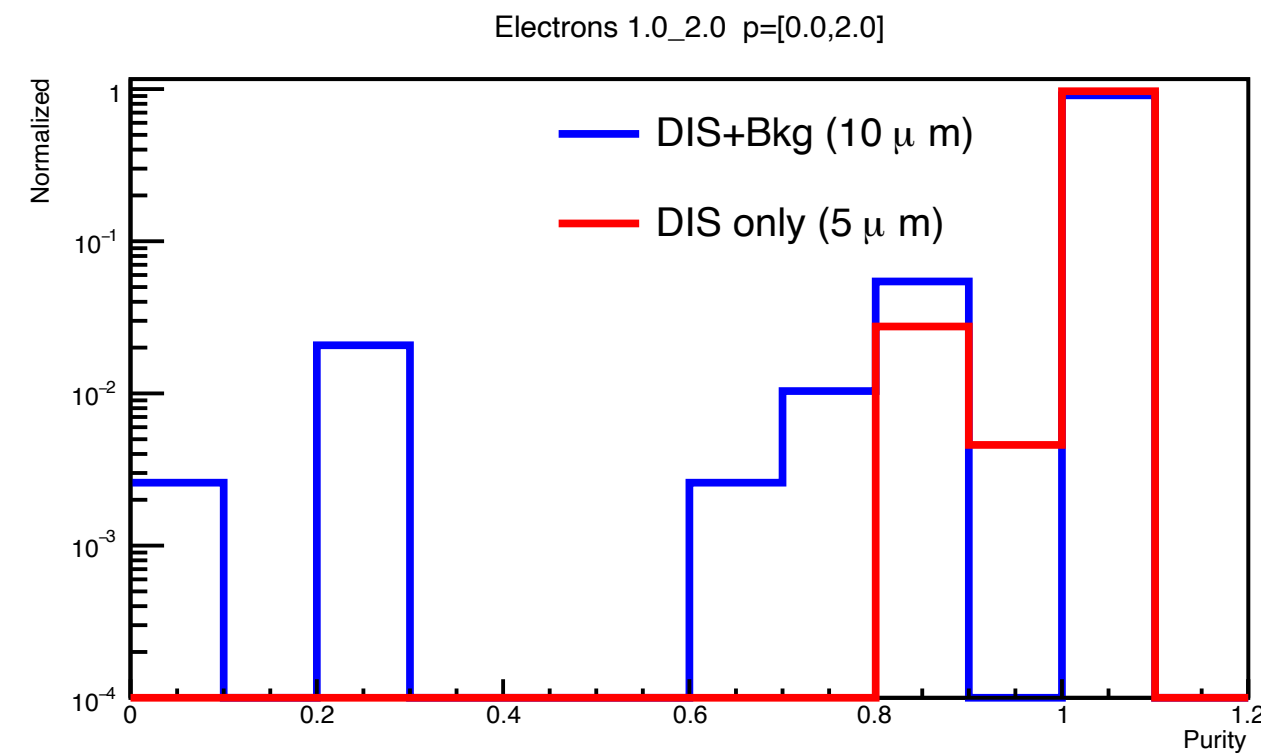


$$-1.0 < \eta < 1.0$$

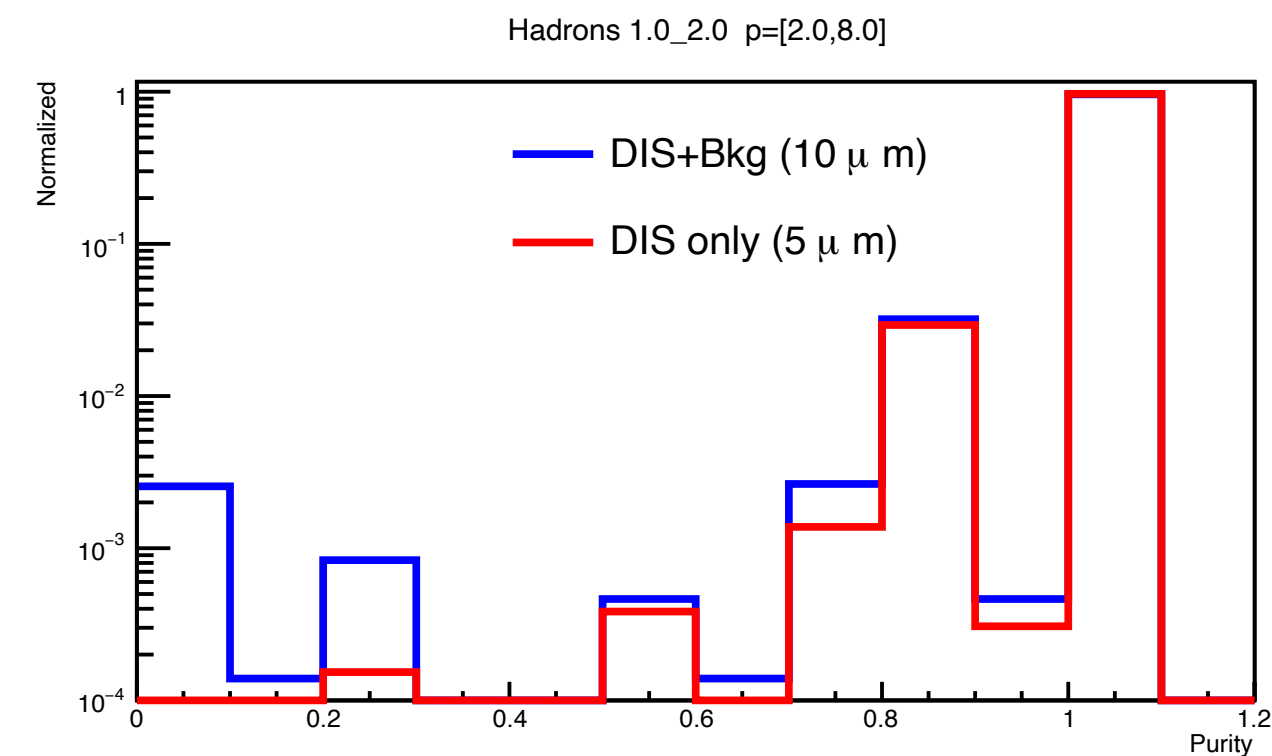
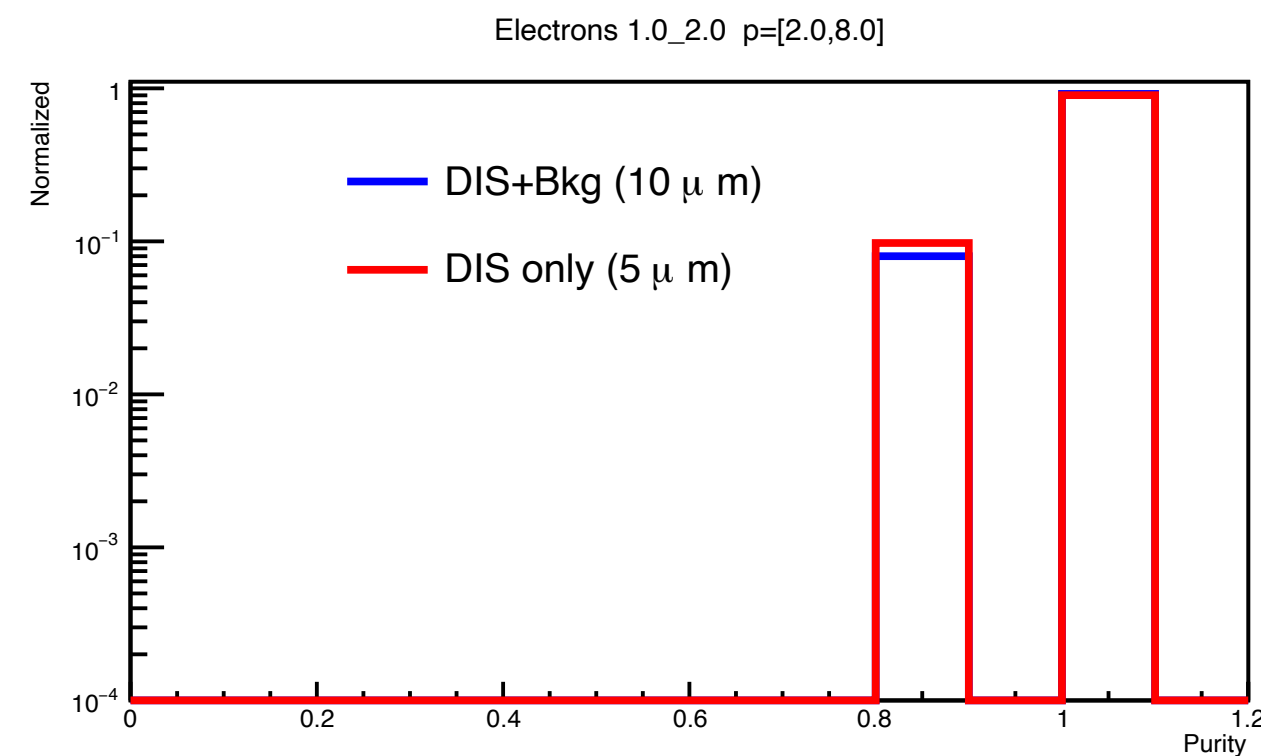
$$\text{Purity} = \frac{N_{\text{primary Hits}}}{N_{\text{Total Hits}}}$$

$$\chi^2 = 15$$

# Comparison of the purity distributions

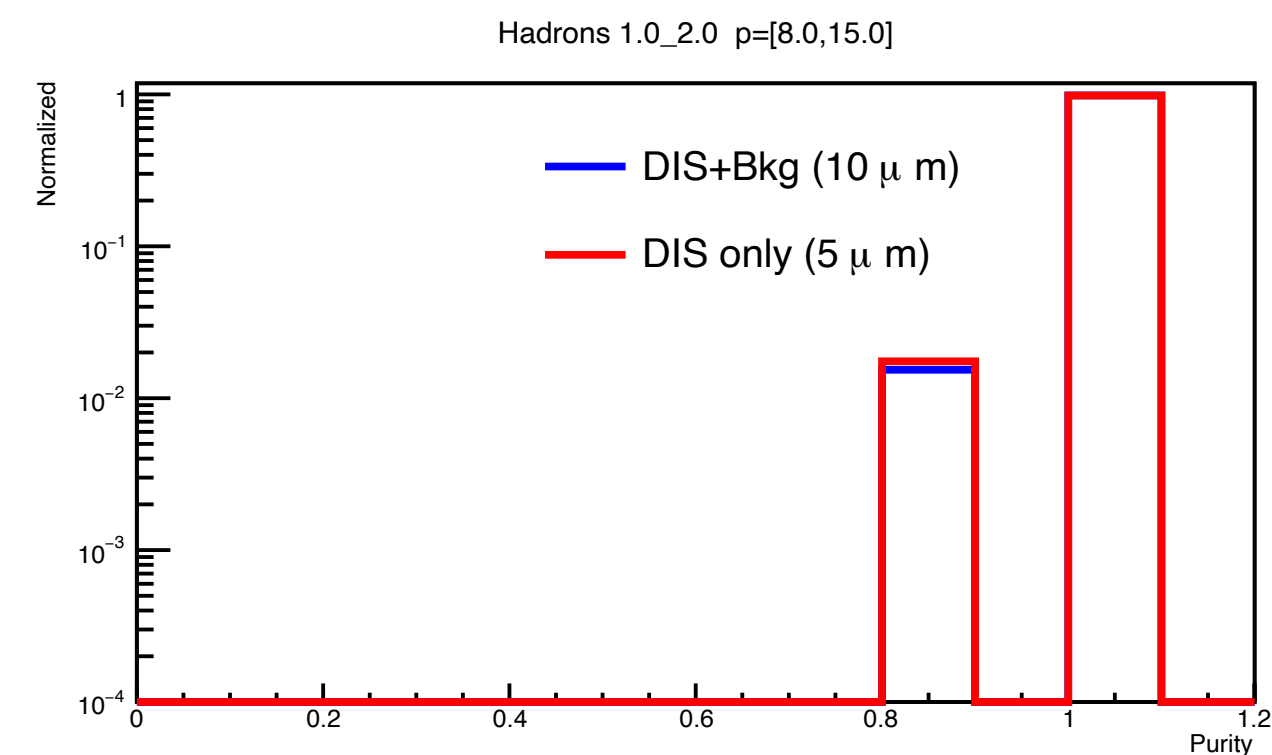
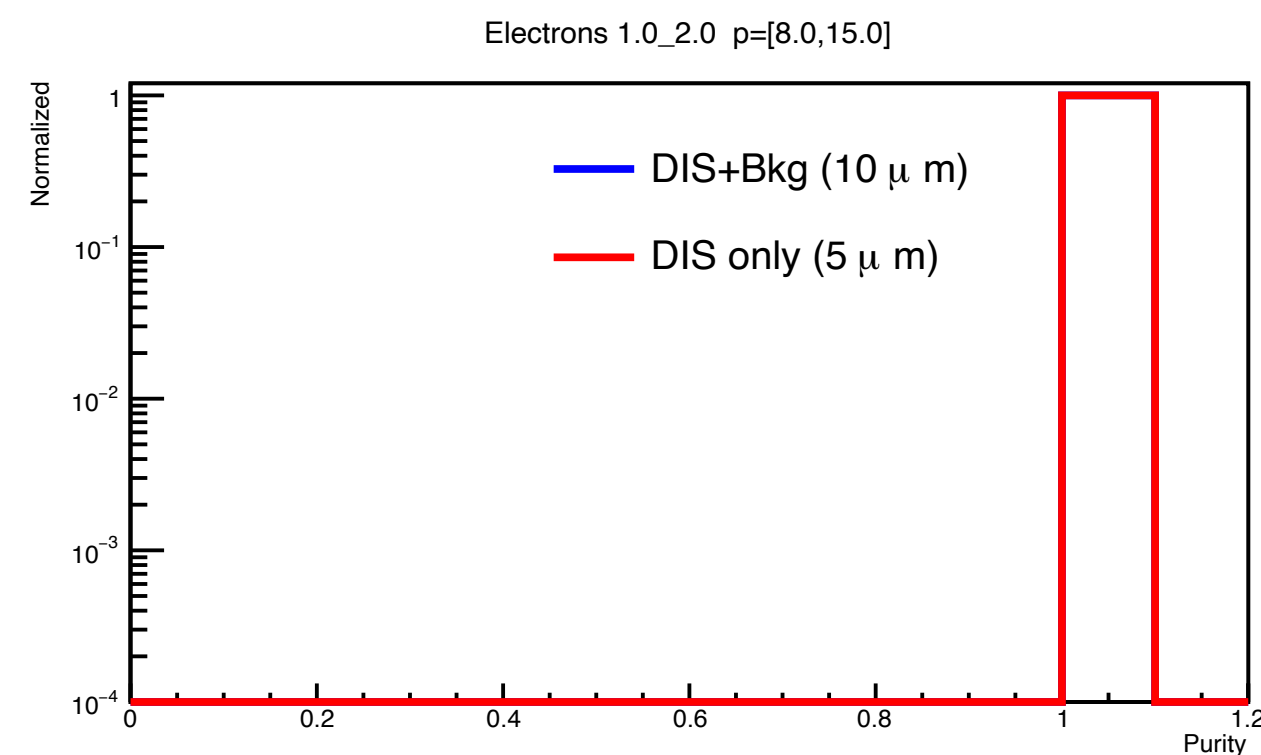


$$1.0 < \eta < 2.0$$

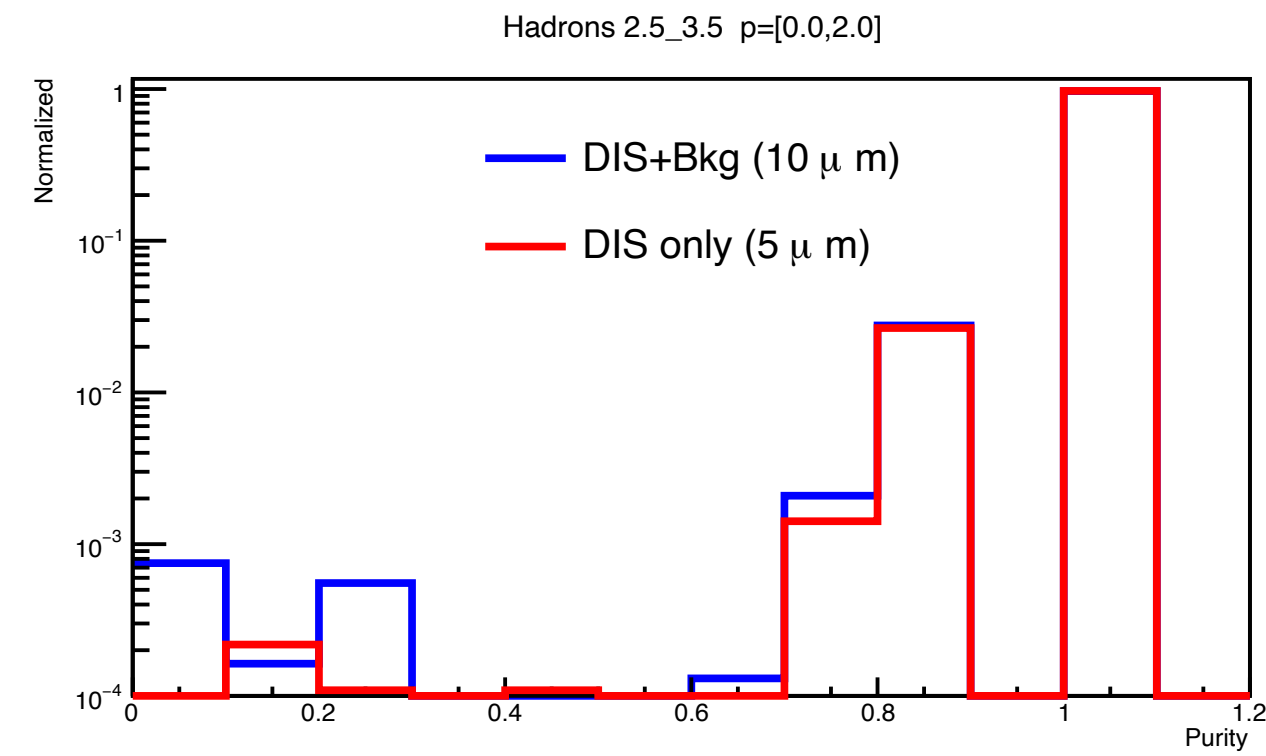
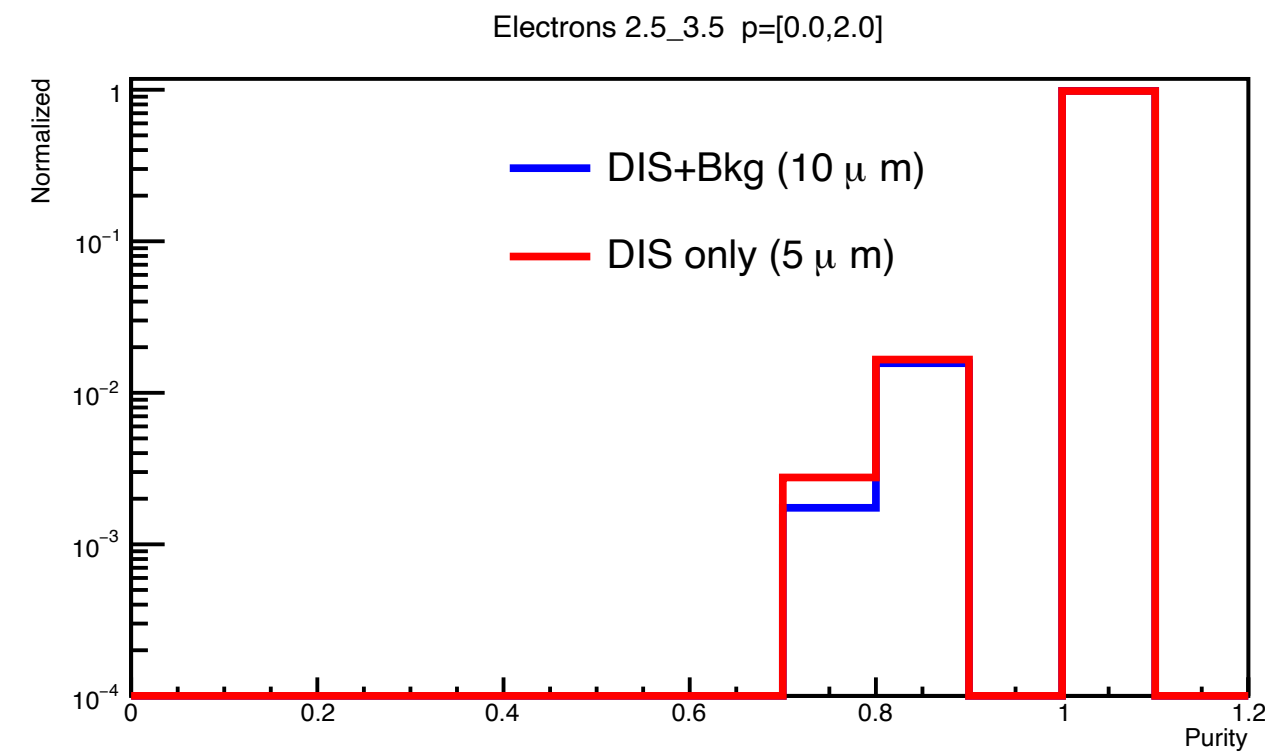


$$\text{Purity} = \frac{N_{\text{primary Hits}}}{N_{\text{Total Hits}}}$$

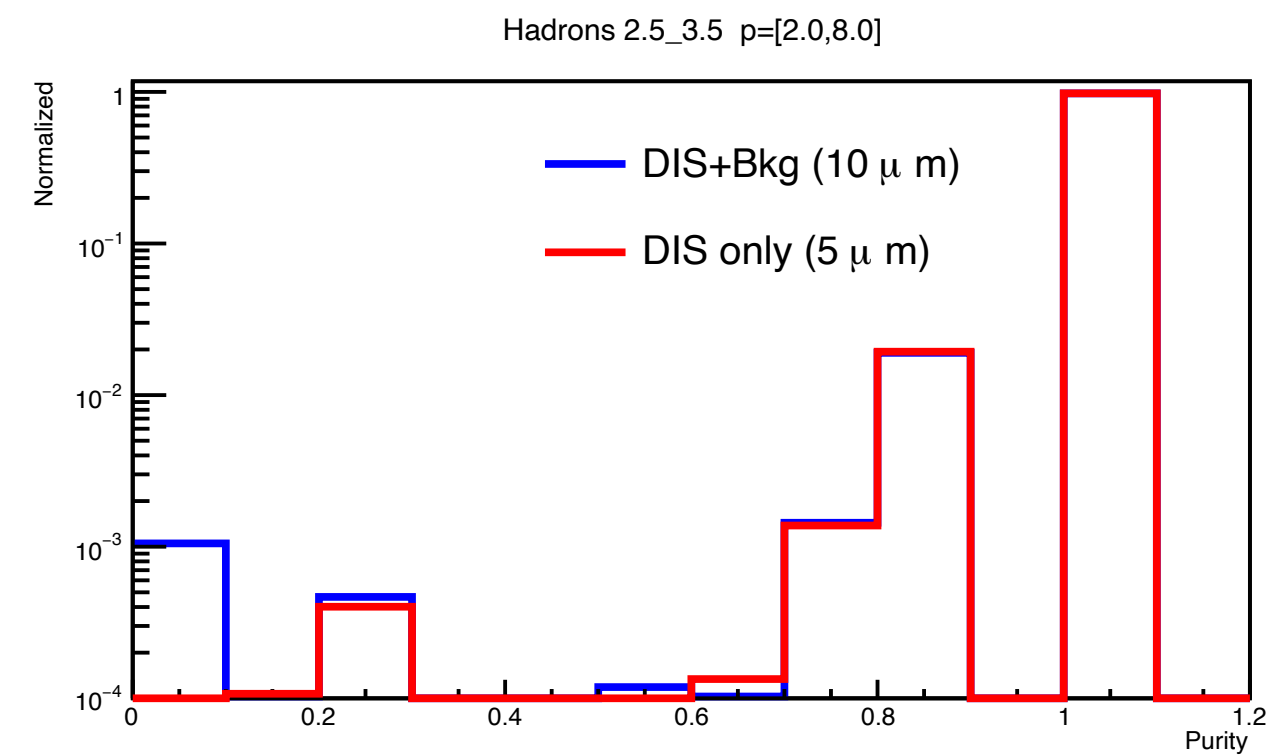
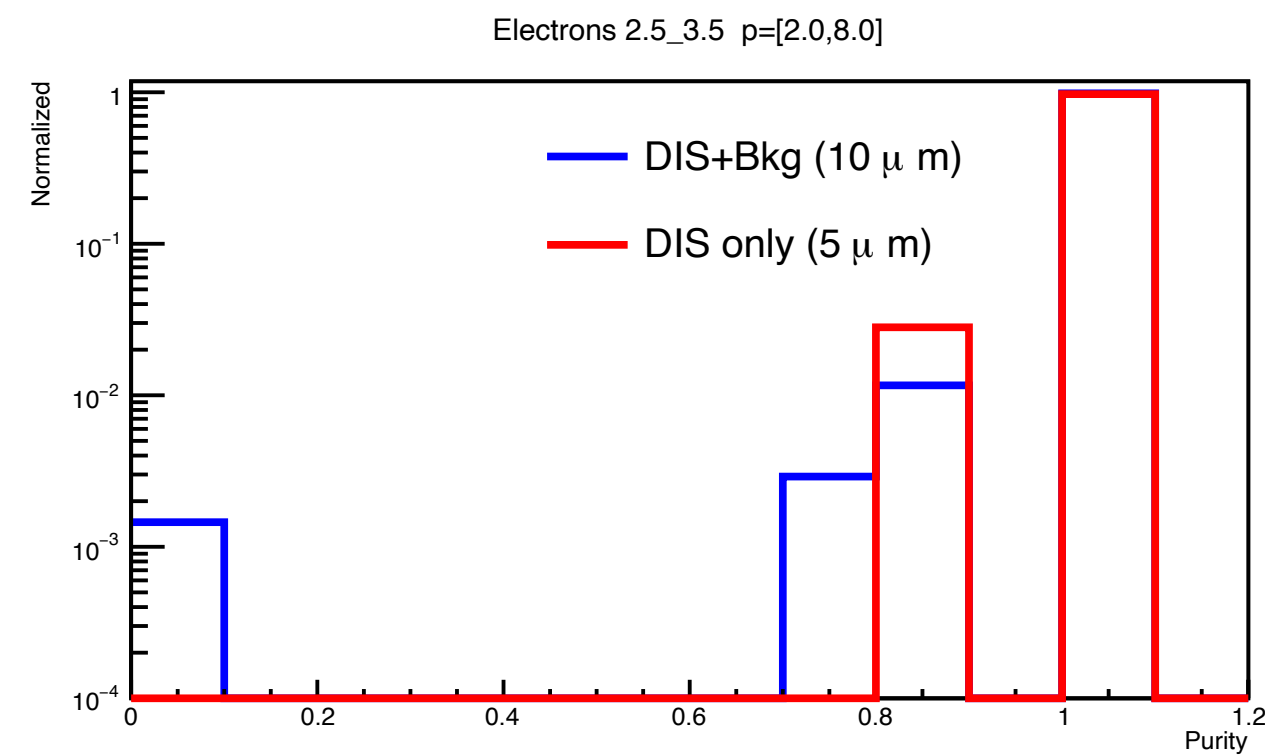
$$\chi^2 = 15$$



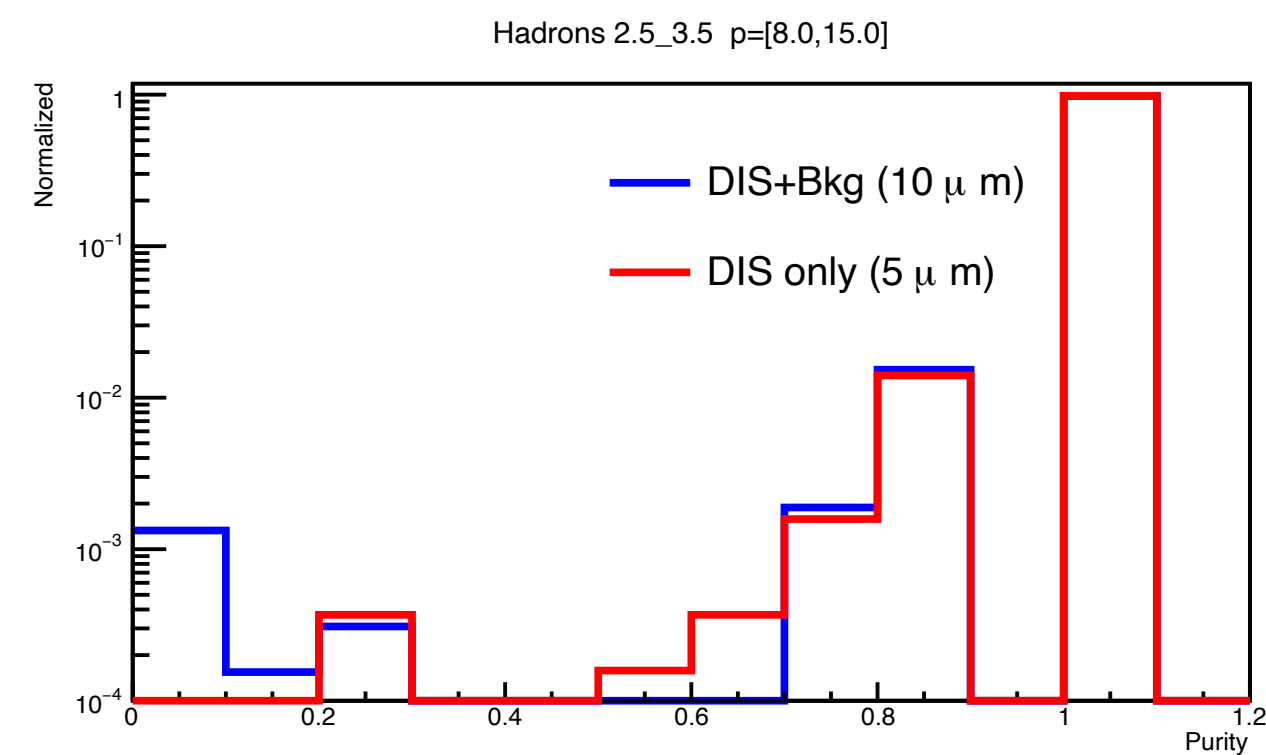
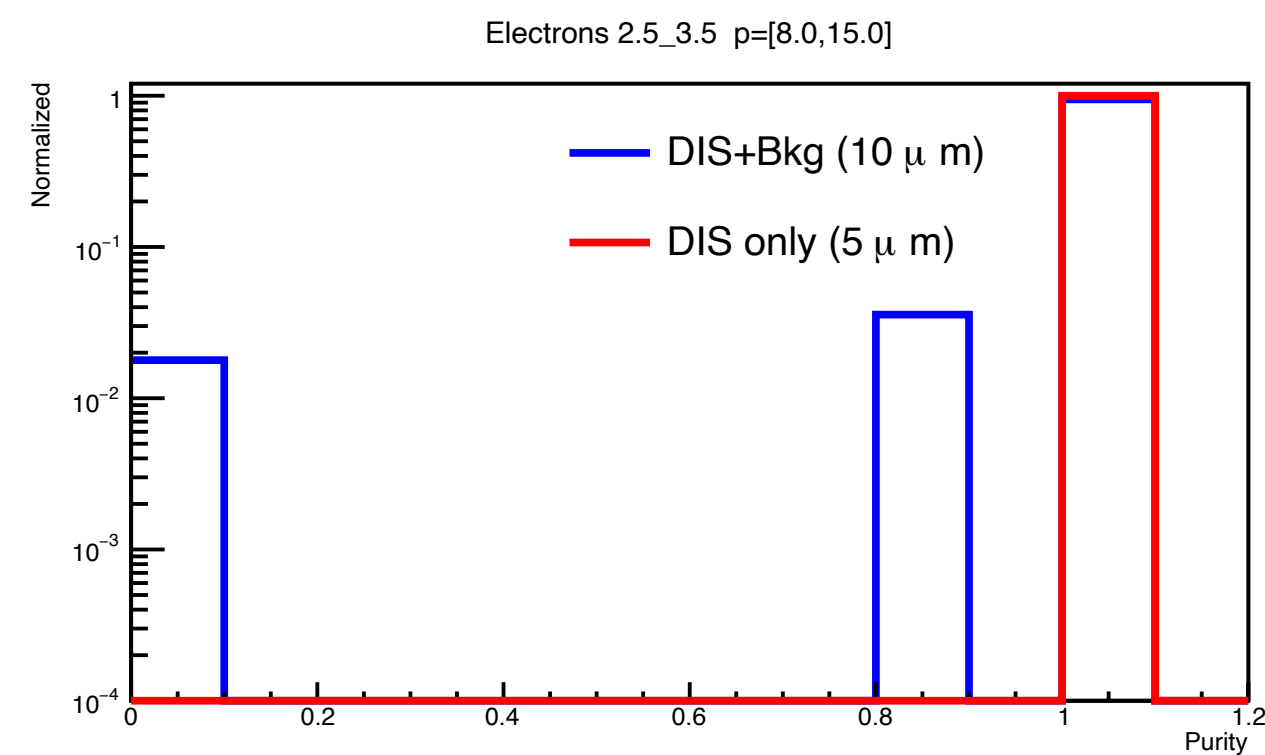
# Comparison of the purity distributions



$$2.5 < \eta < 3.5$$



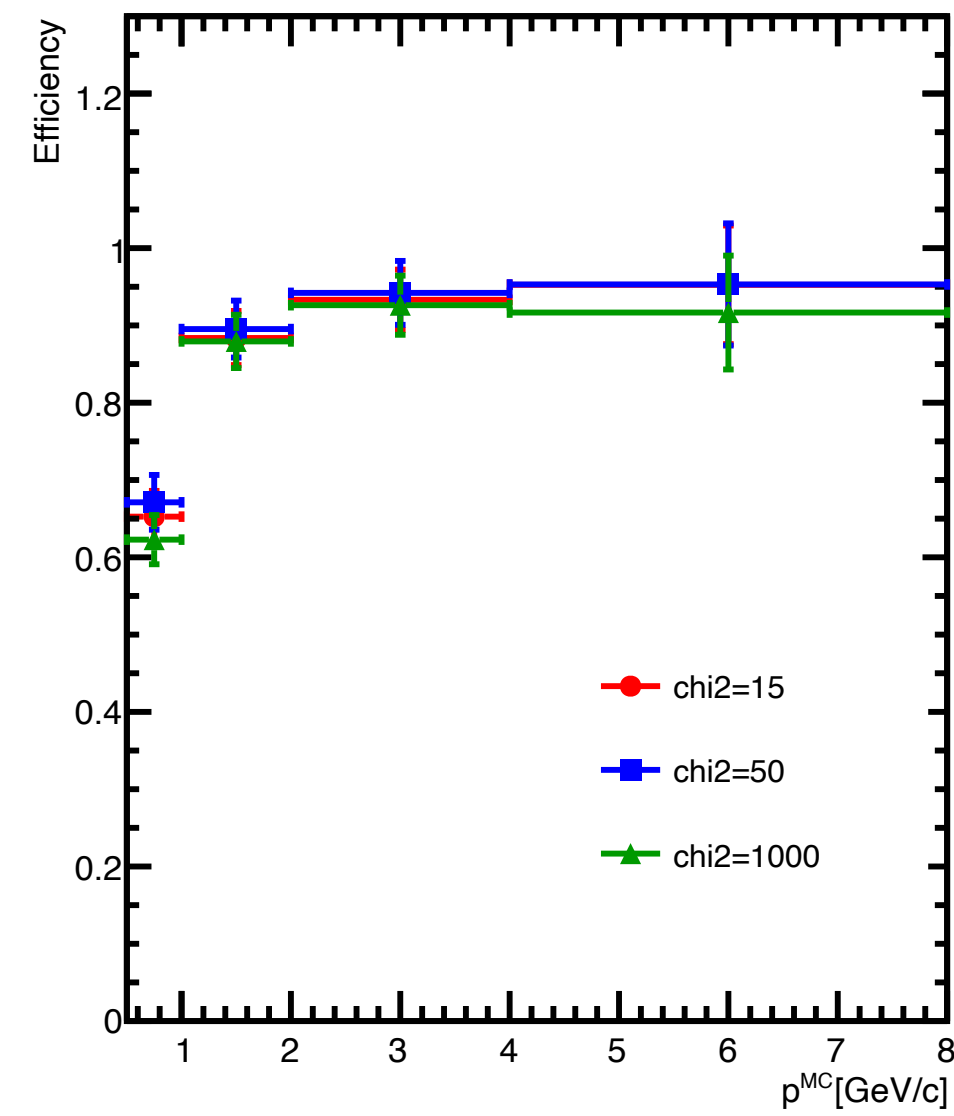
$$\text{Purity} = \frac{N_{\text{primary Hits}}}{N_{\text{Total Hits}}}$$



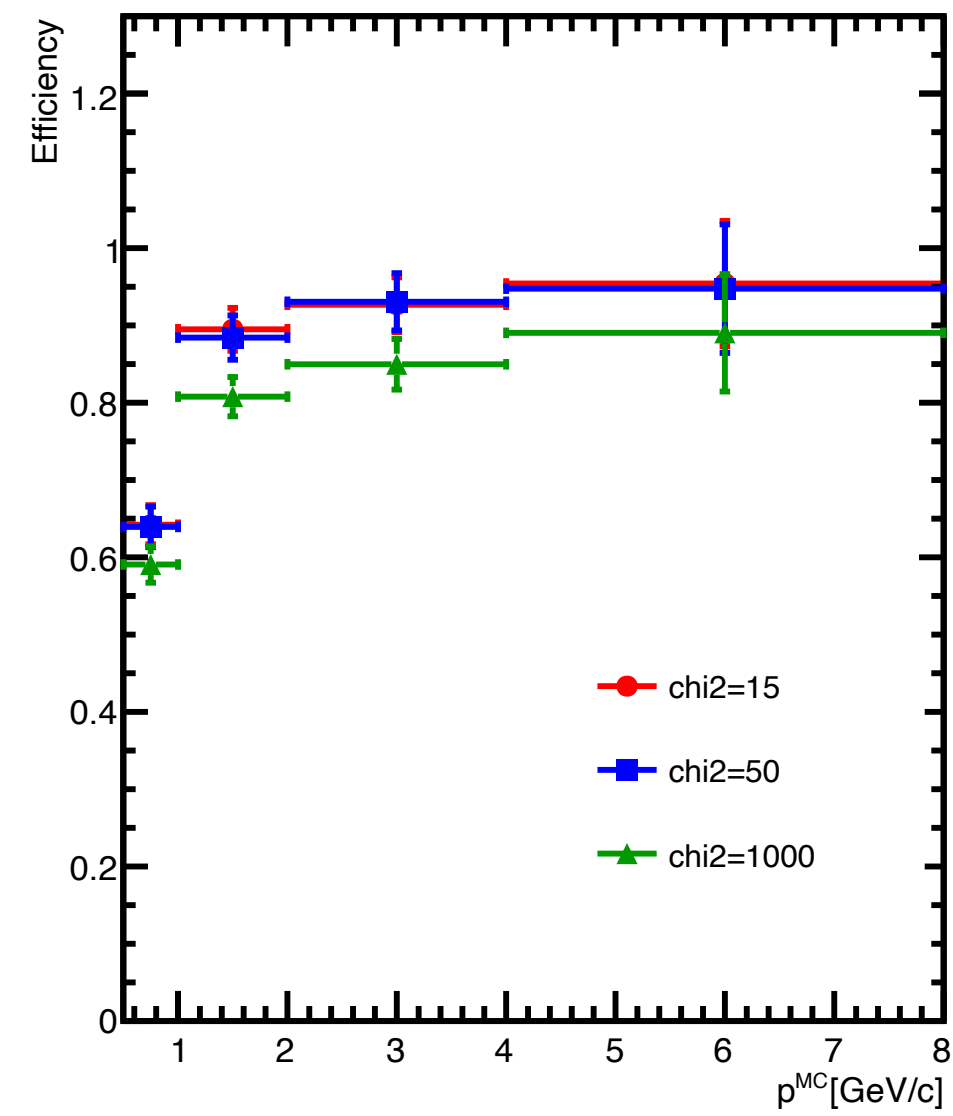
$$\chi^2 = 15$$

# Reconstruction Efficiency ( $\pi/K/p$ )

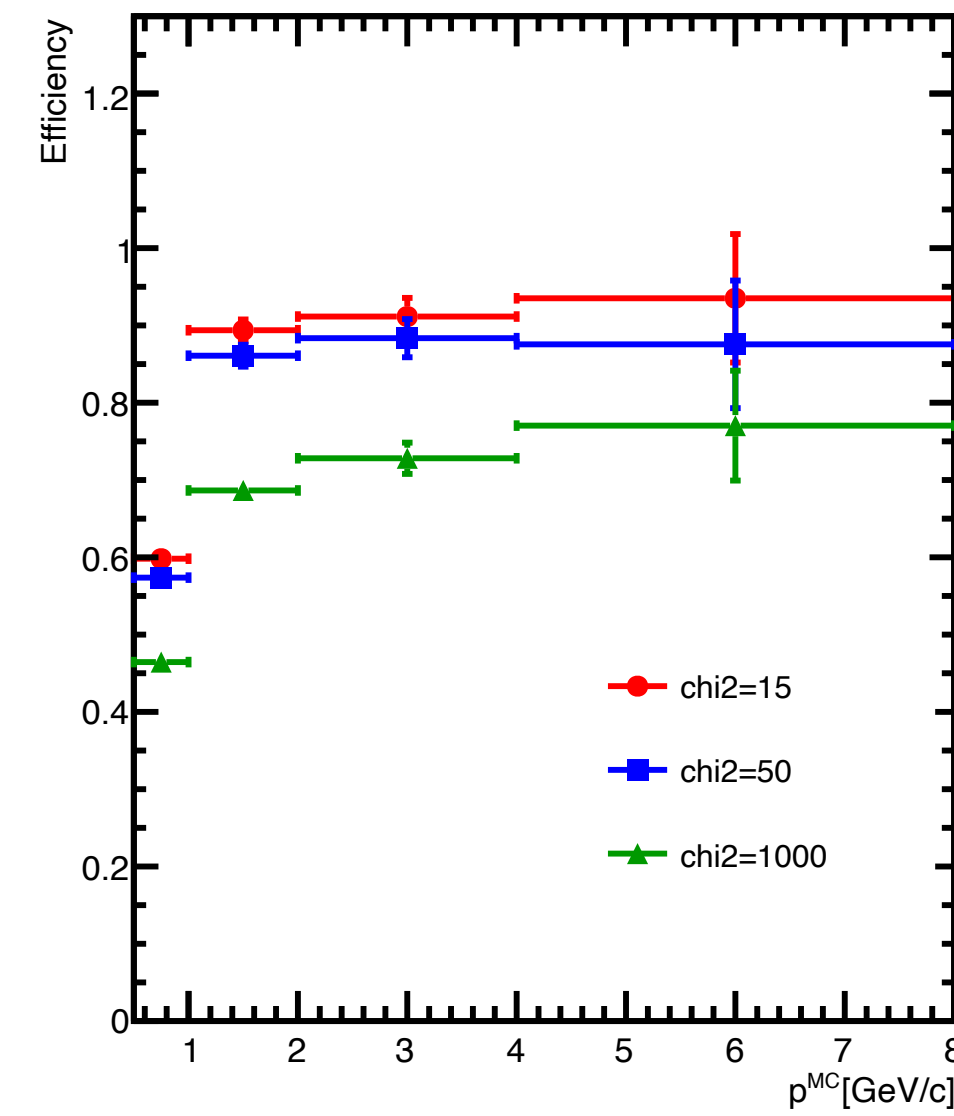
$-3.5 < \eta < -2.5$



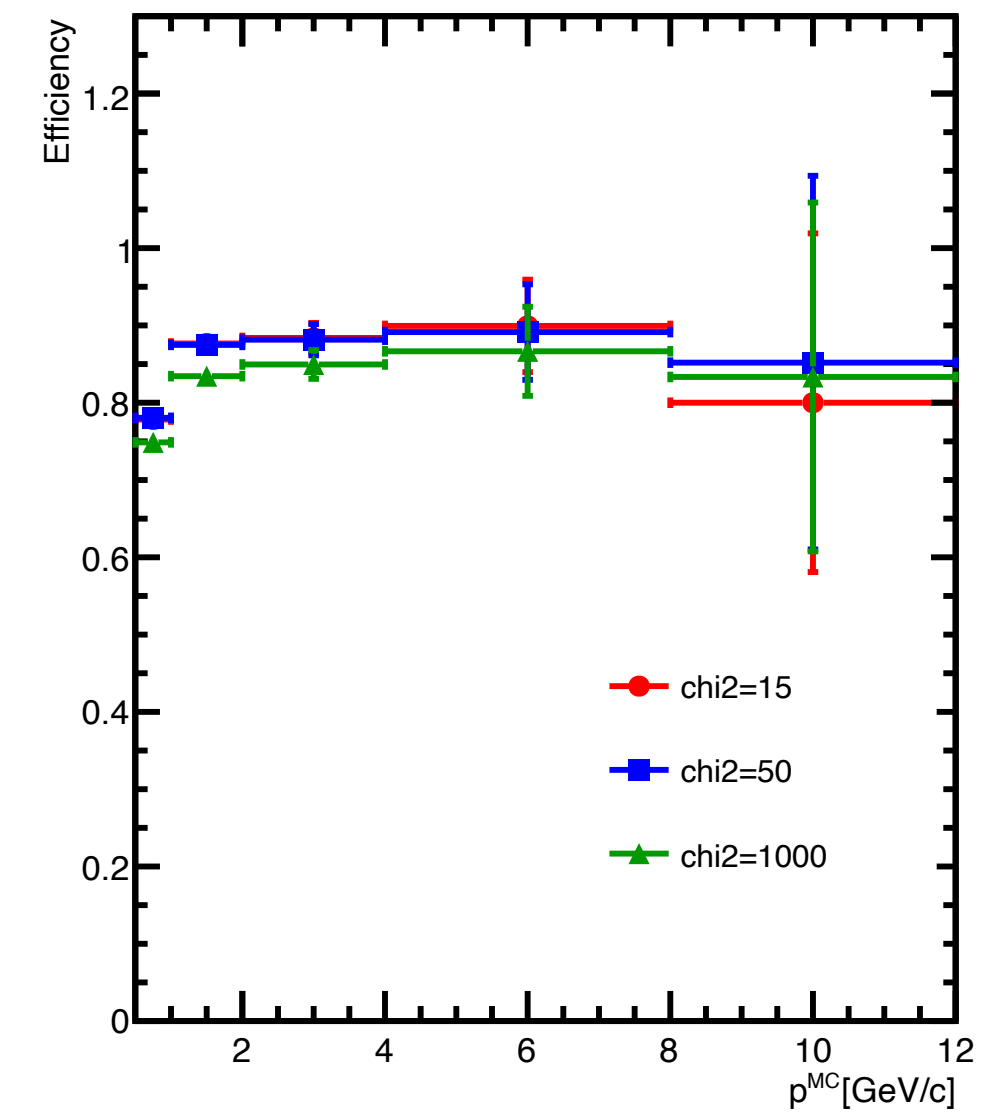
$-2.5 < \eta < -2.0$



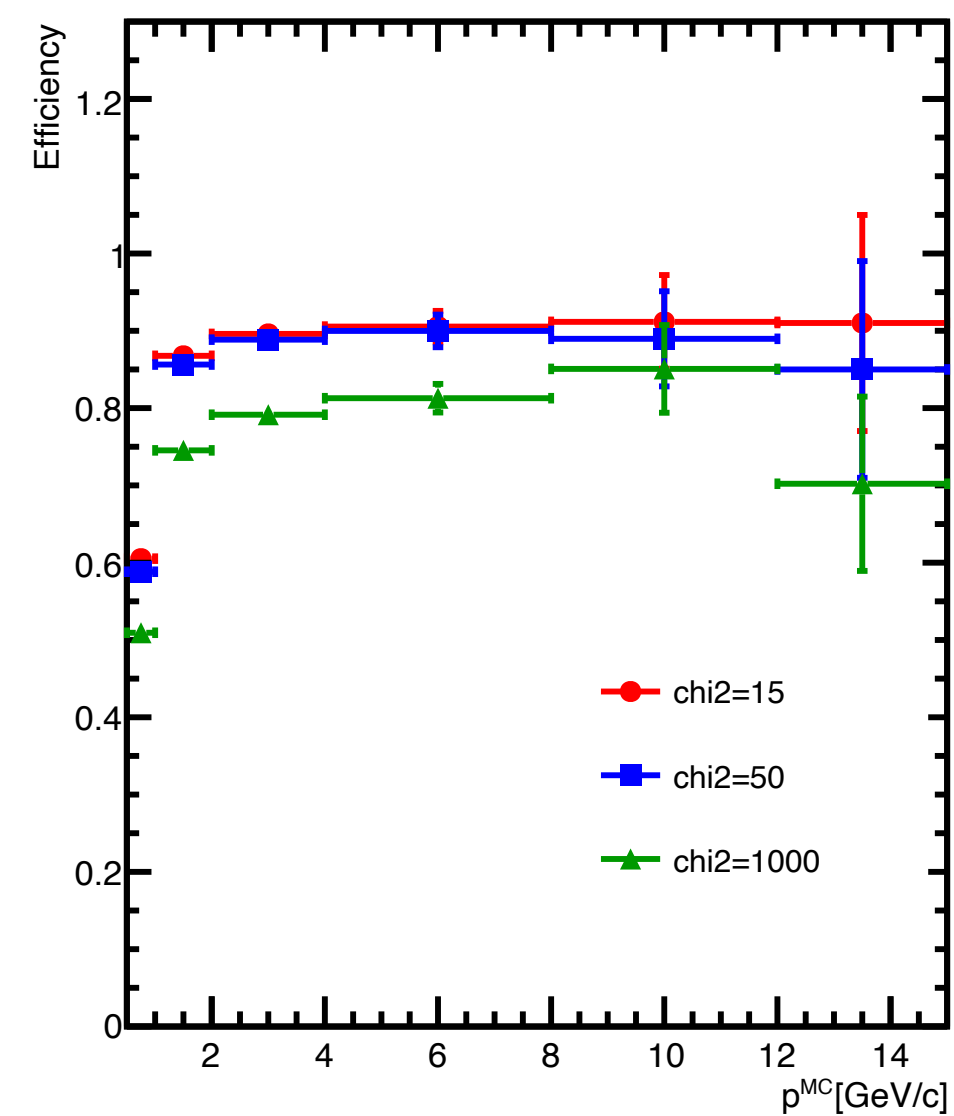
$-2.0 < \eta < -1.0$



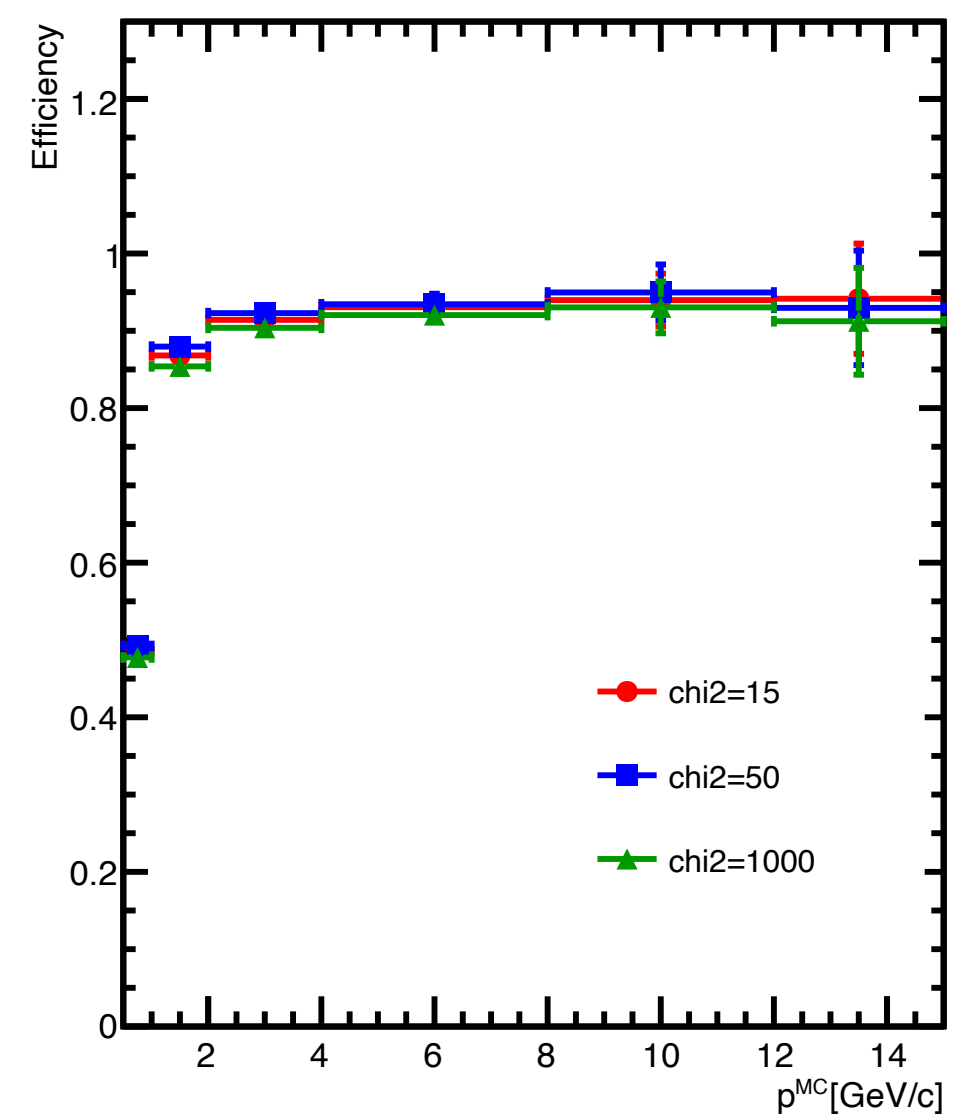
$-1.0 < \eta < 1.0$



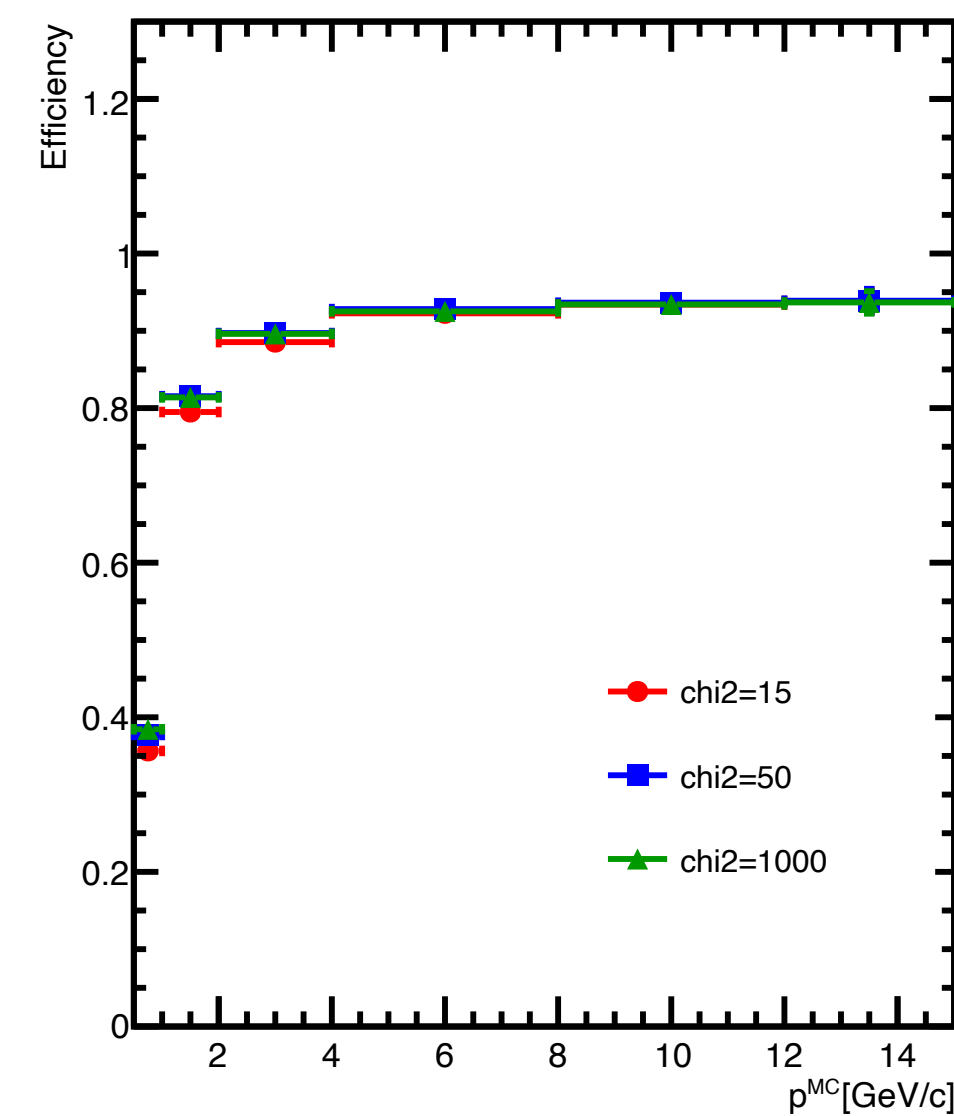
$1.0 < \eta < 2.0$



$2.0 < \eta < 2.5$



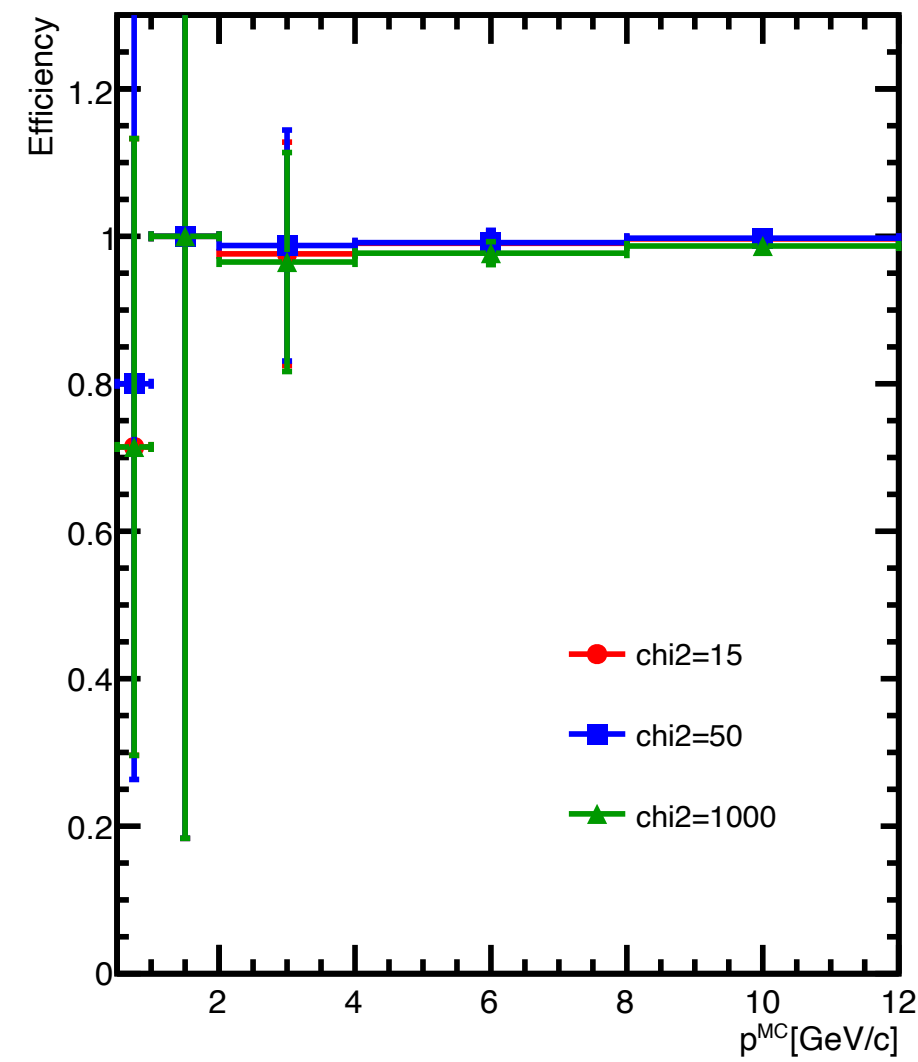
$2.5 < \eta < 3.5$



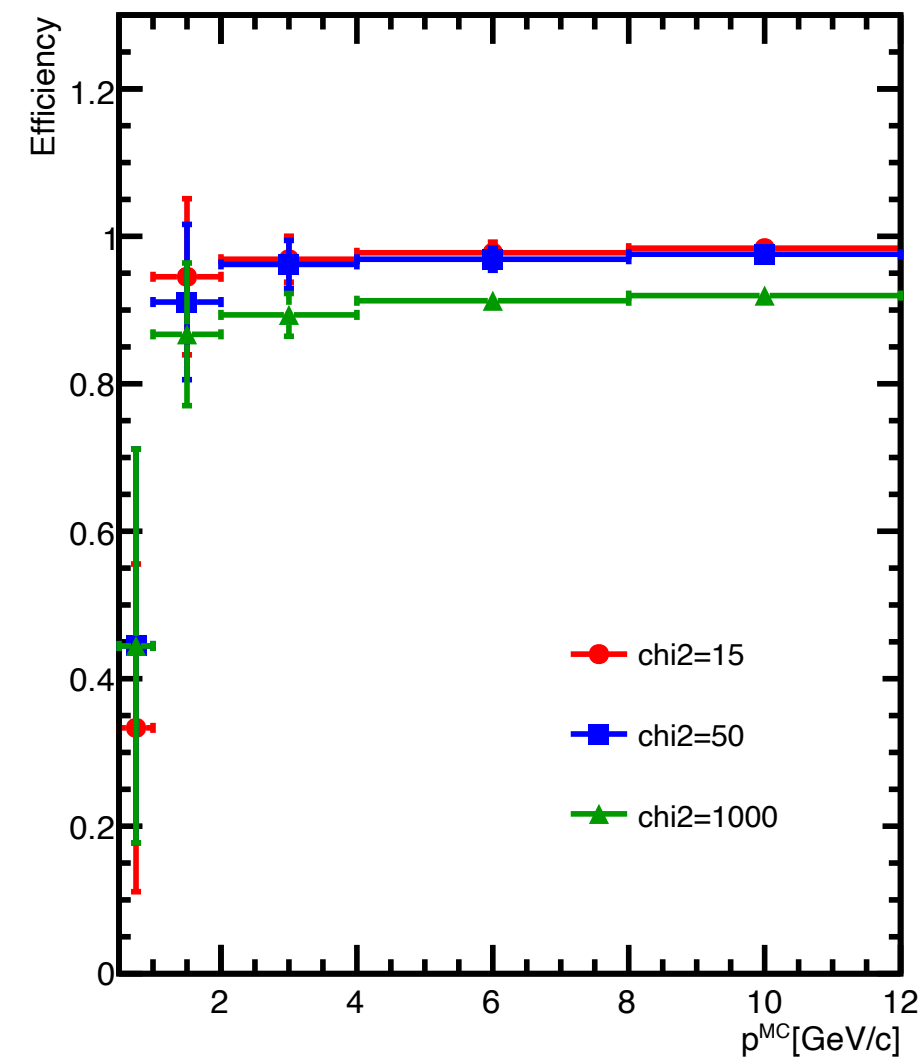
Here we only look at reconstructed tracks with purity above 0.8 and that have an associated primary track.

# Reconstruction Efficiency (electrons)

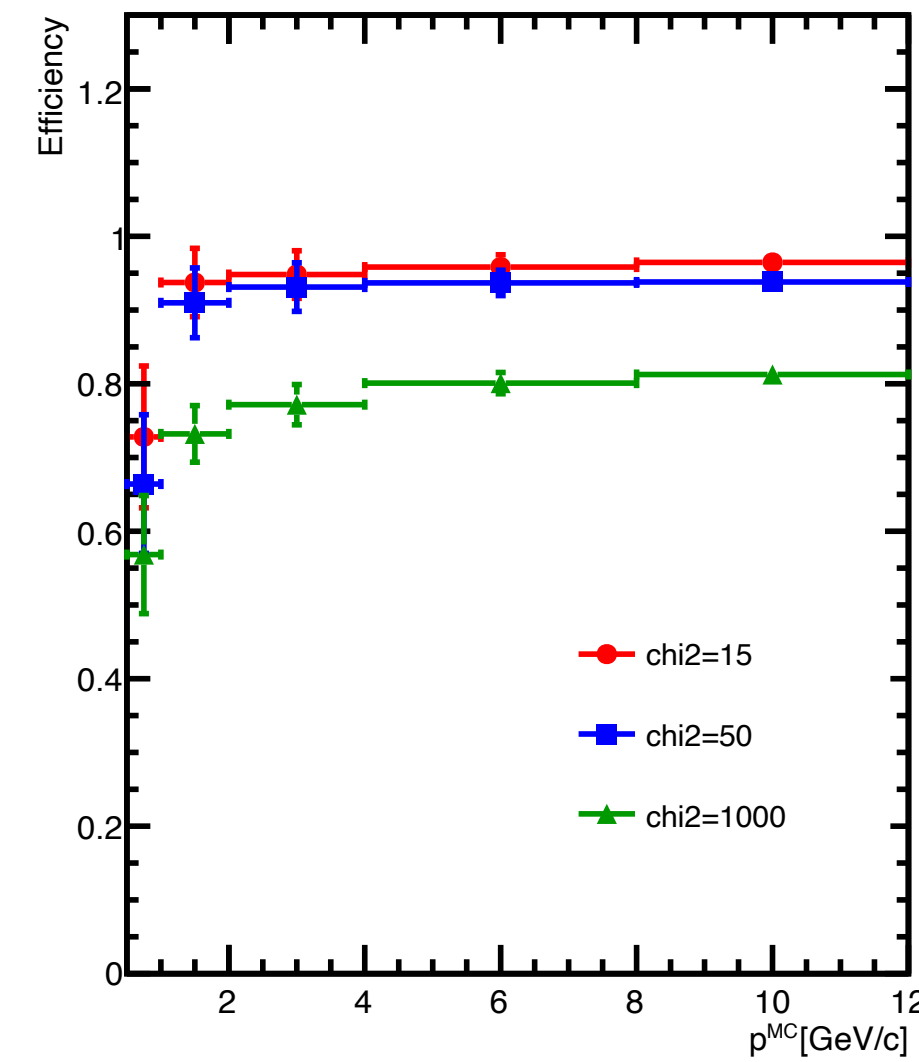
$-3.5 < \eta < -2.5$



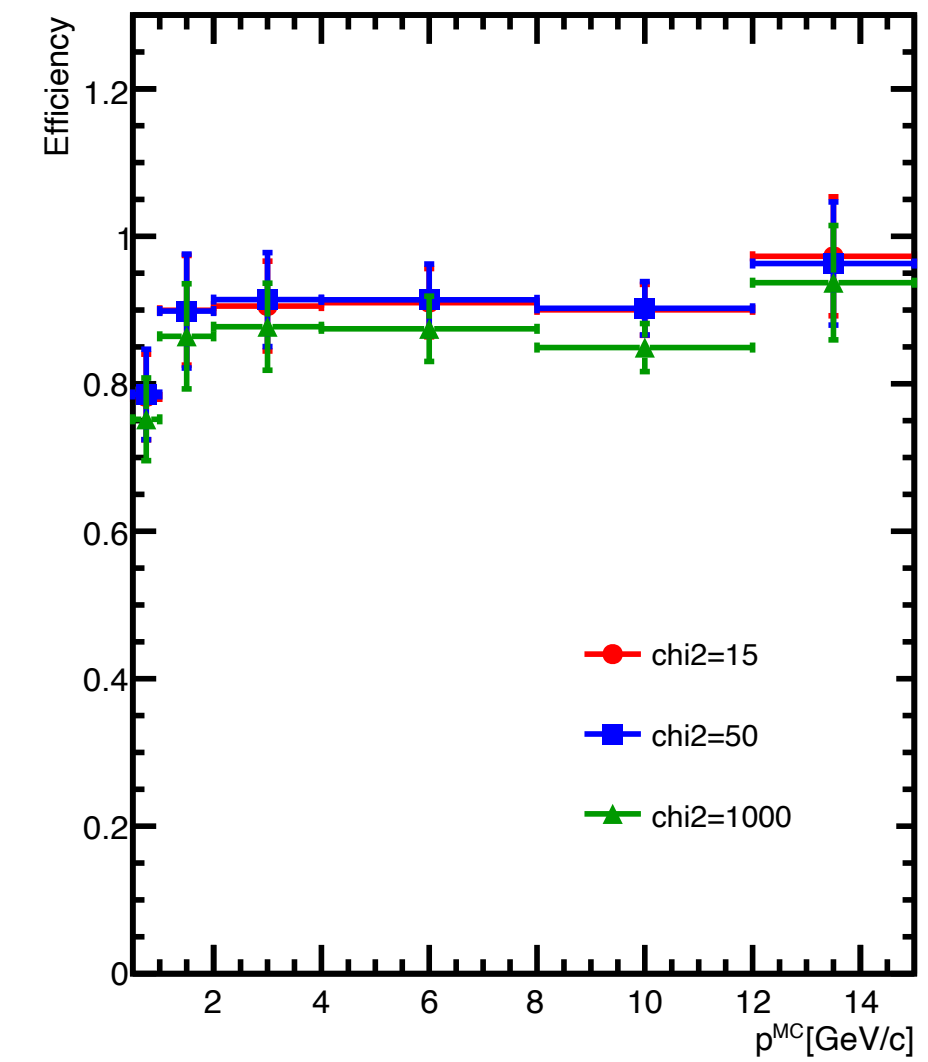
$-2.5 < \eta < -2.0$



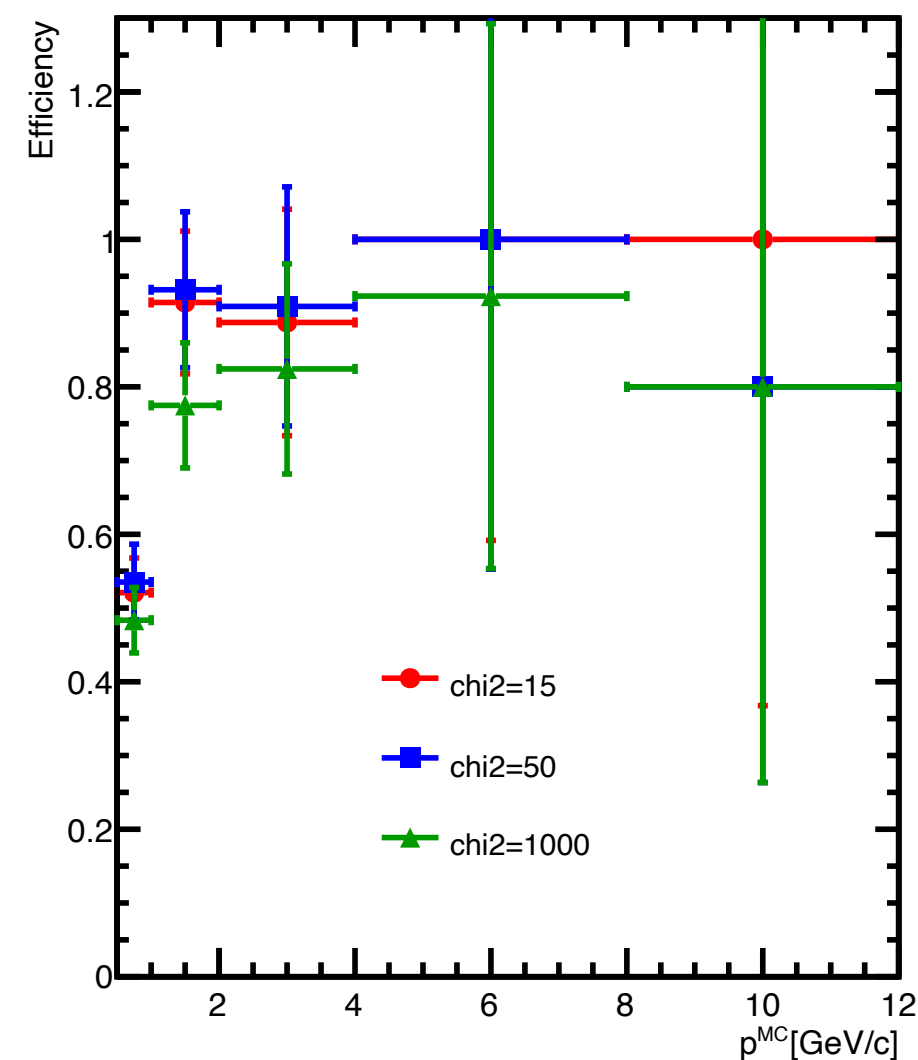
$-2.0 < \eta < -1.0$



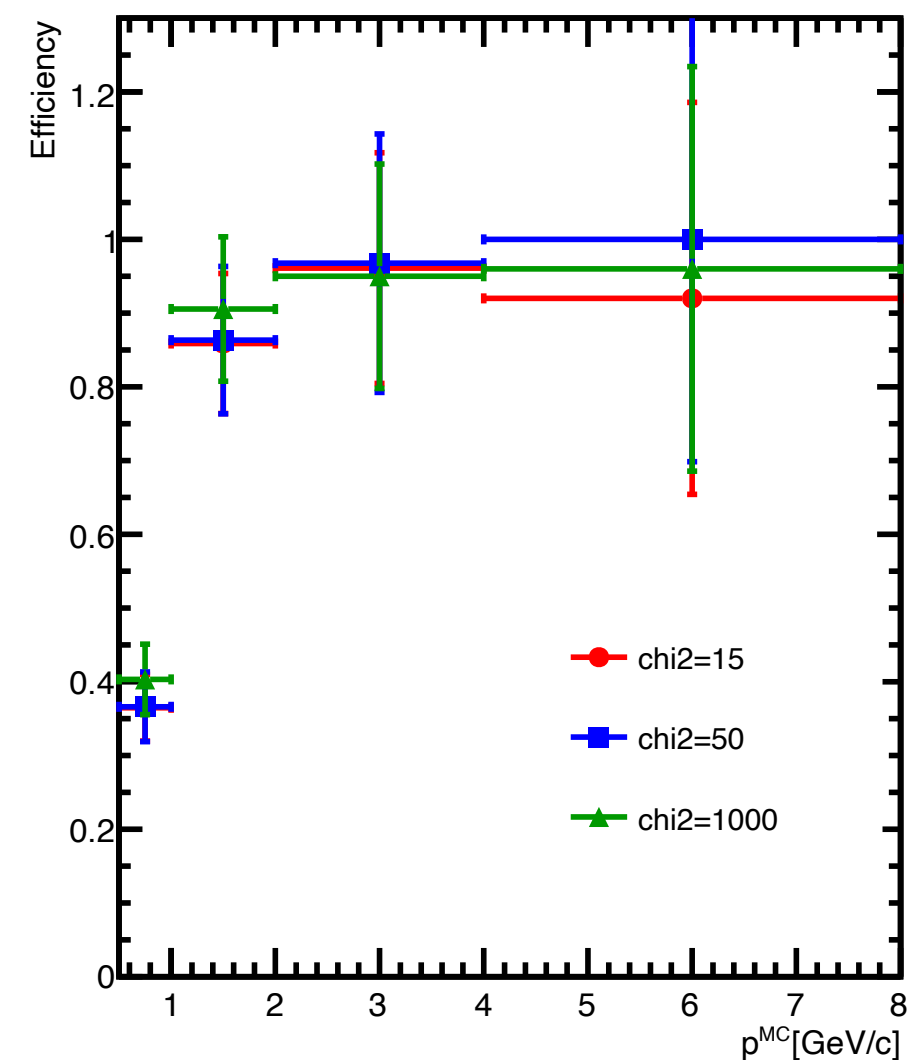
$-1.0 < \eta < 1.0$



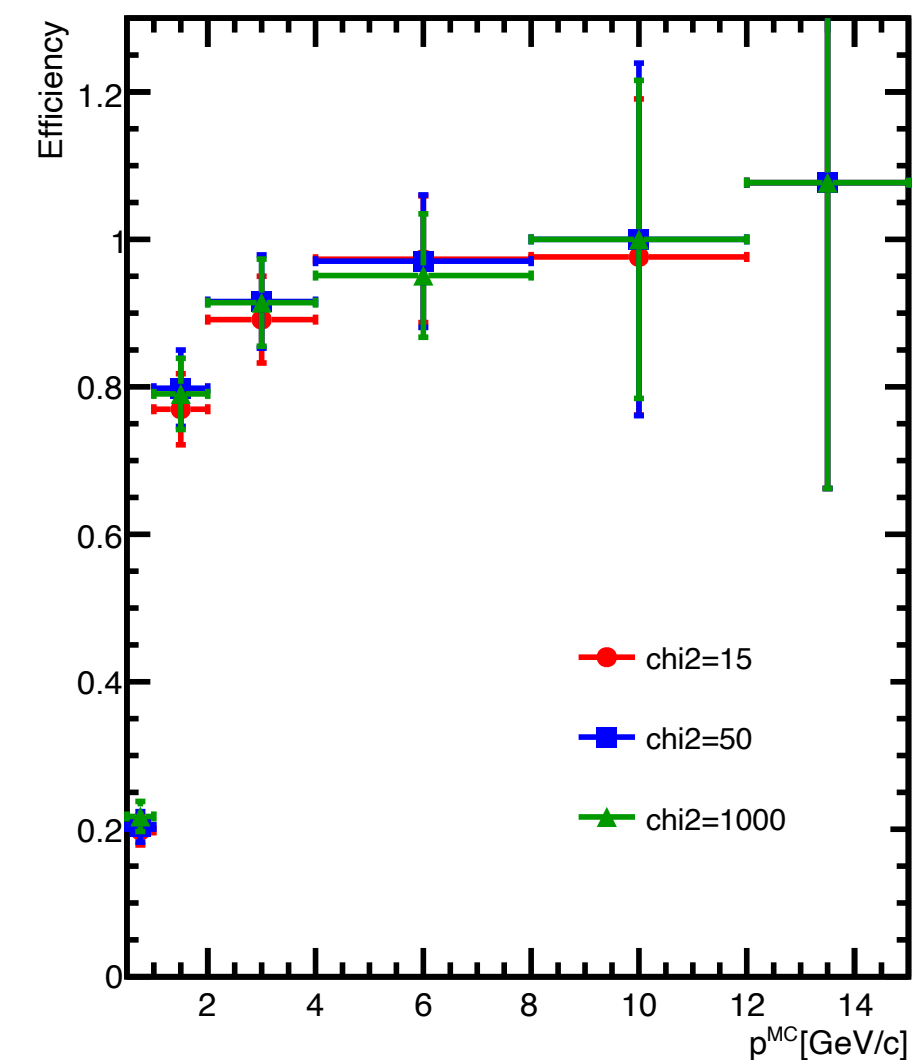
$1.0 < \eta < 2.0$



$2.0 < \eta < 2.5$



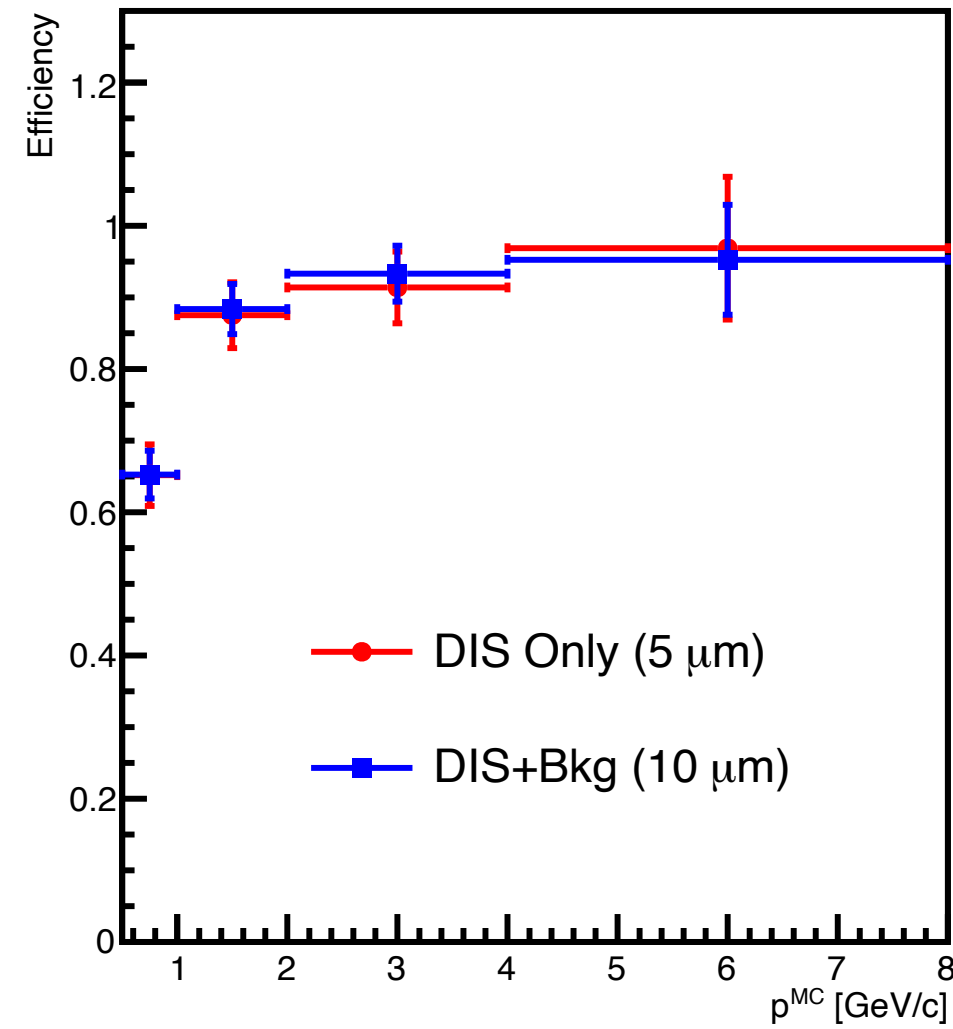
$2.5 < \eta < 3.5$



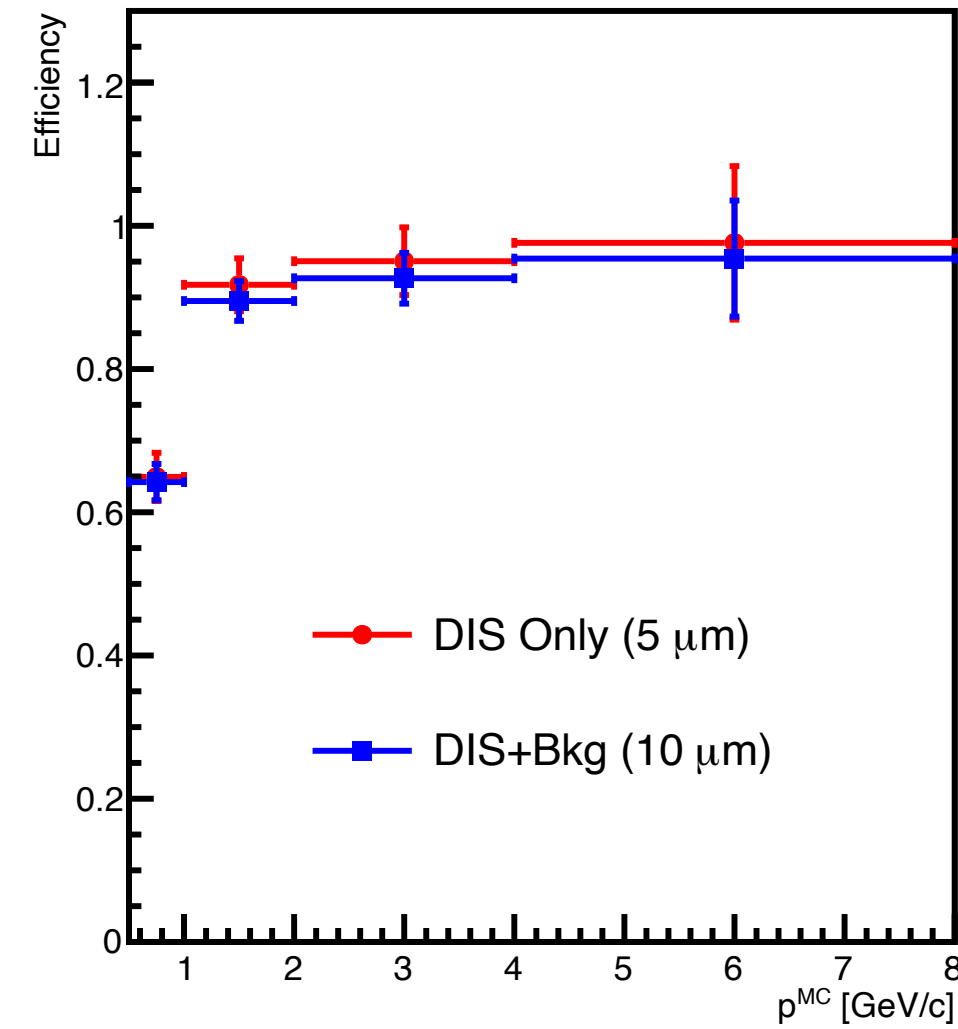
Here we only look at reconstructed tracks with purity above 0.8 and that have an associated primary track.

# Reconstruction Efficiency Comparison ( $\pi/K/p$ )

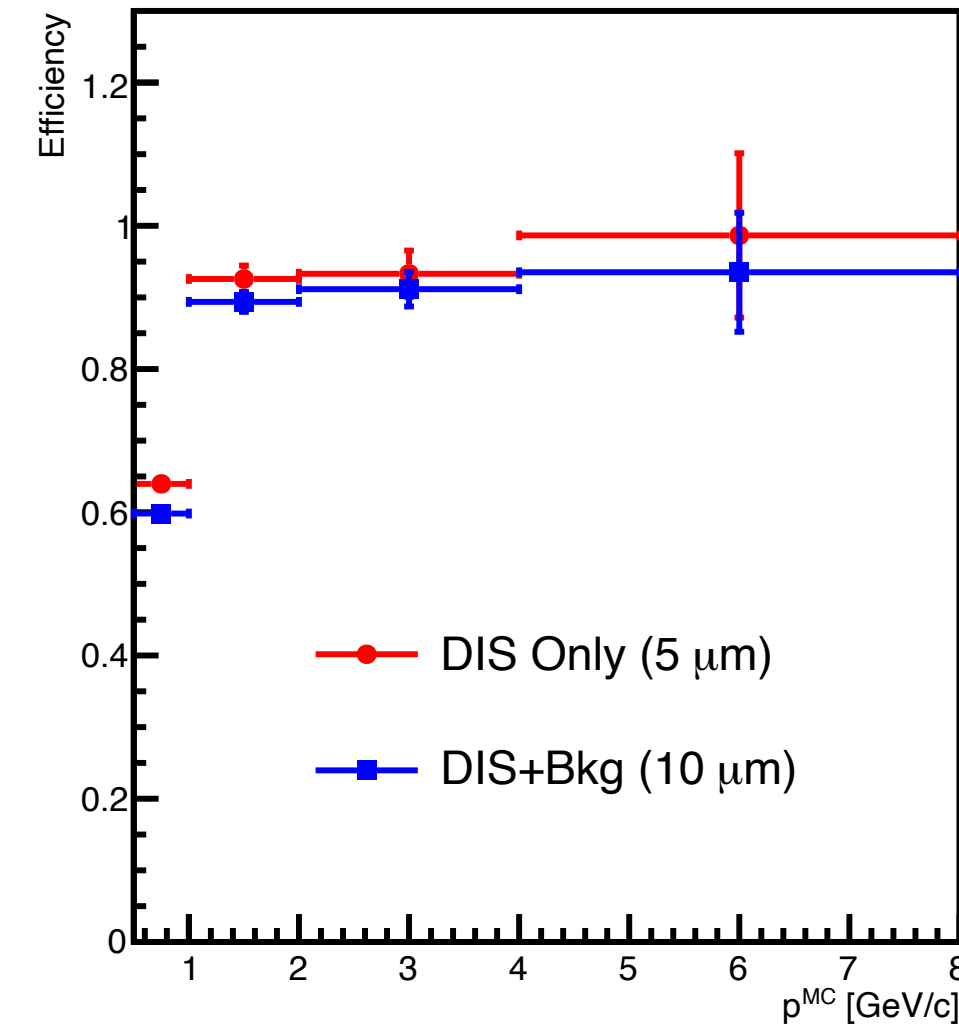
$-3.5 < \eta < -2.5$



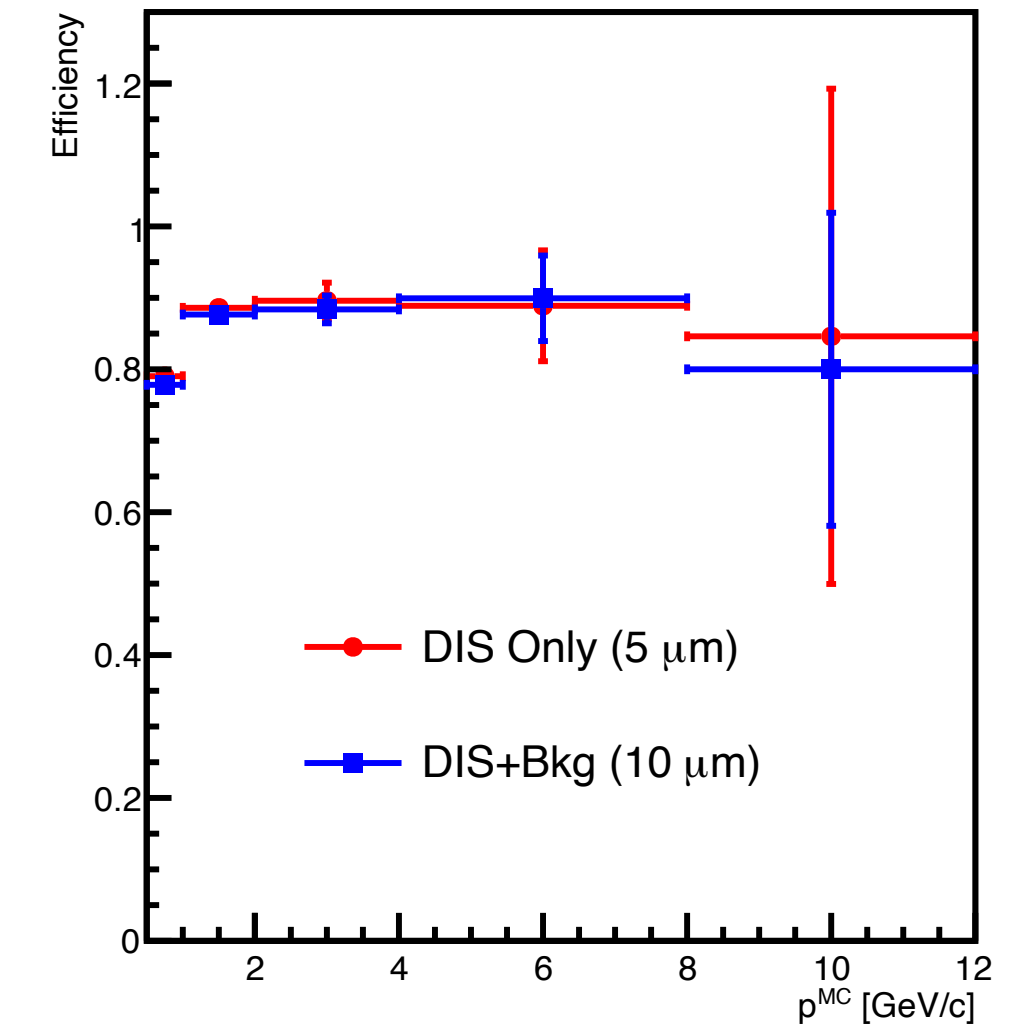
$-2.5 < \eta < -2.0$



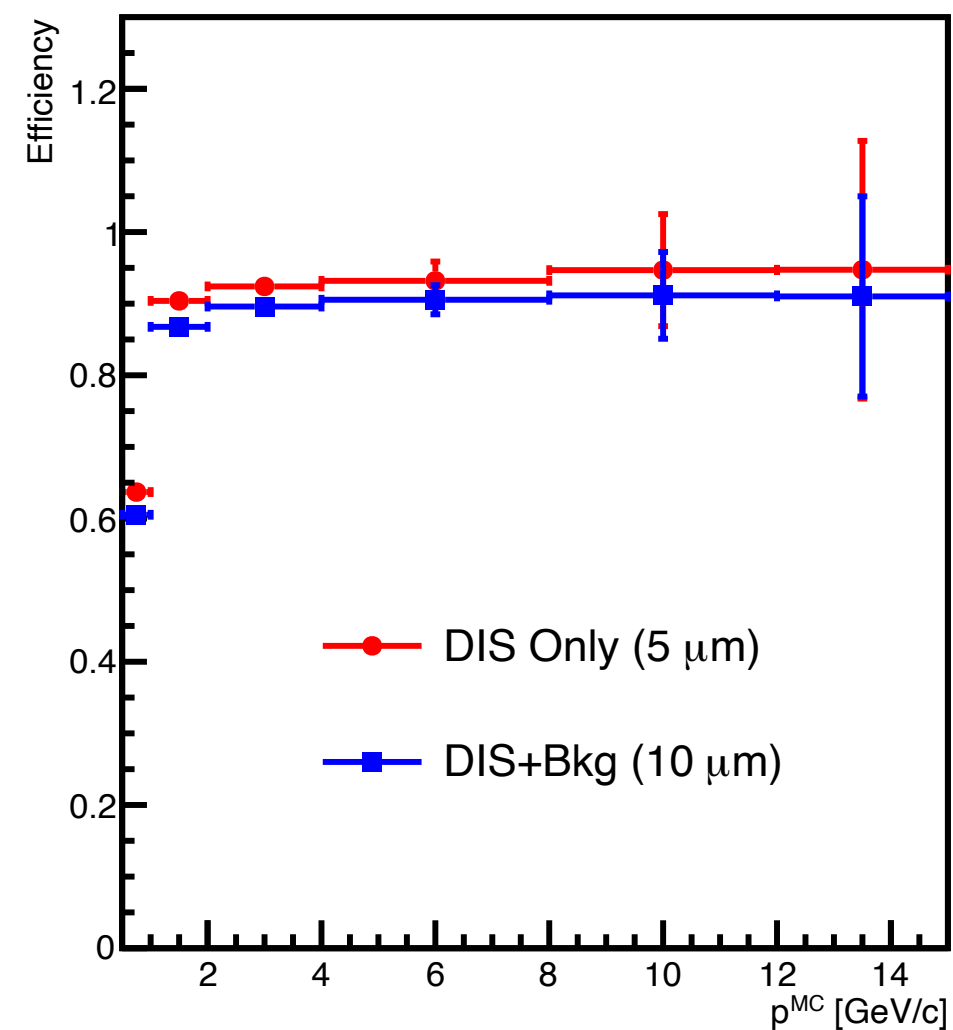
$-2.0 < \eta < -1.0$



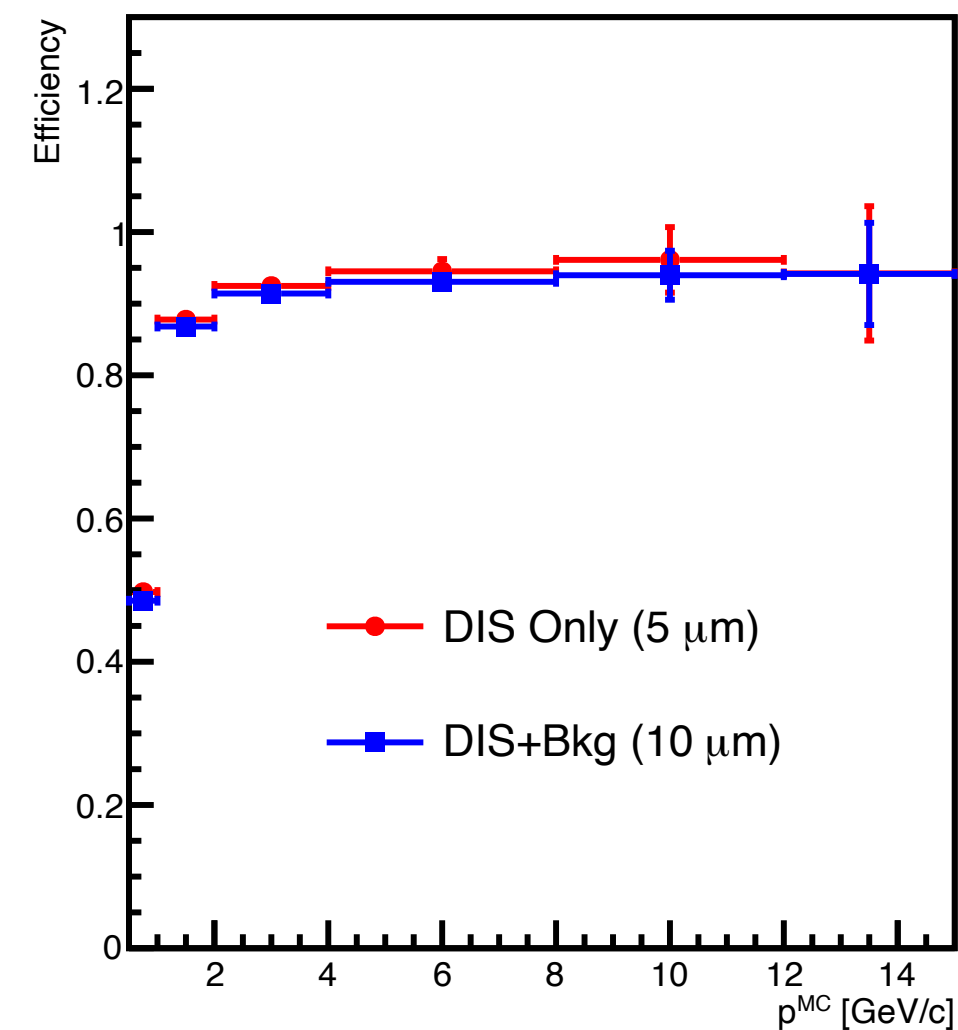
$-1.0 < \eta < 1.0$



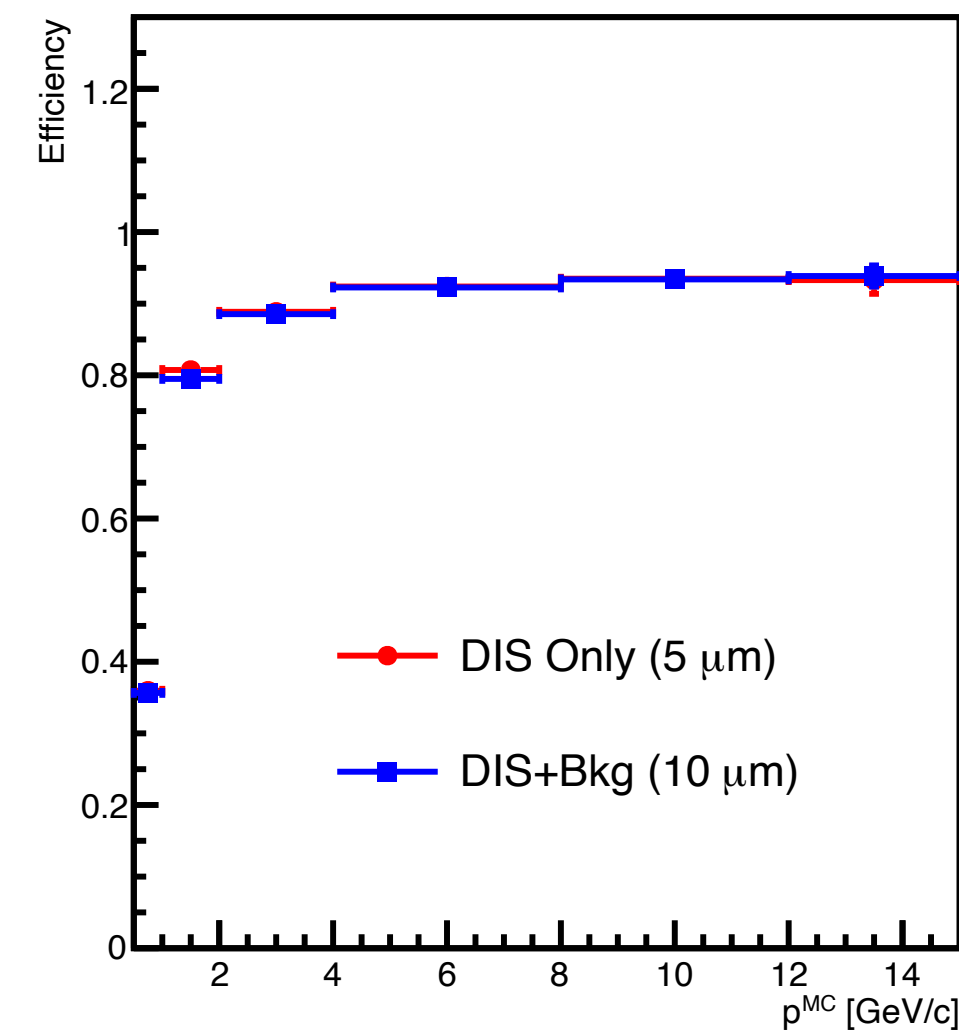
$1.0 < \eta < 2.0$



$2.0 < \eta < 2.5$



$2.5 < \eta < 3.5$



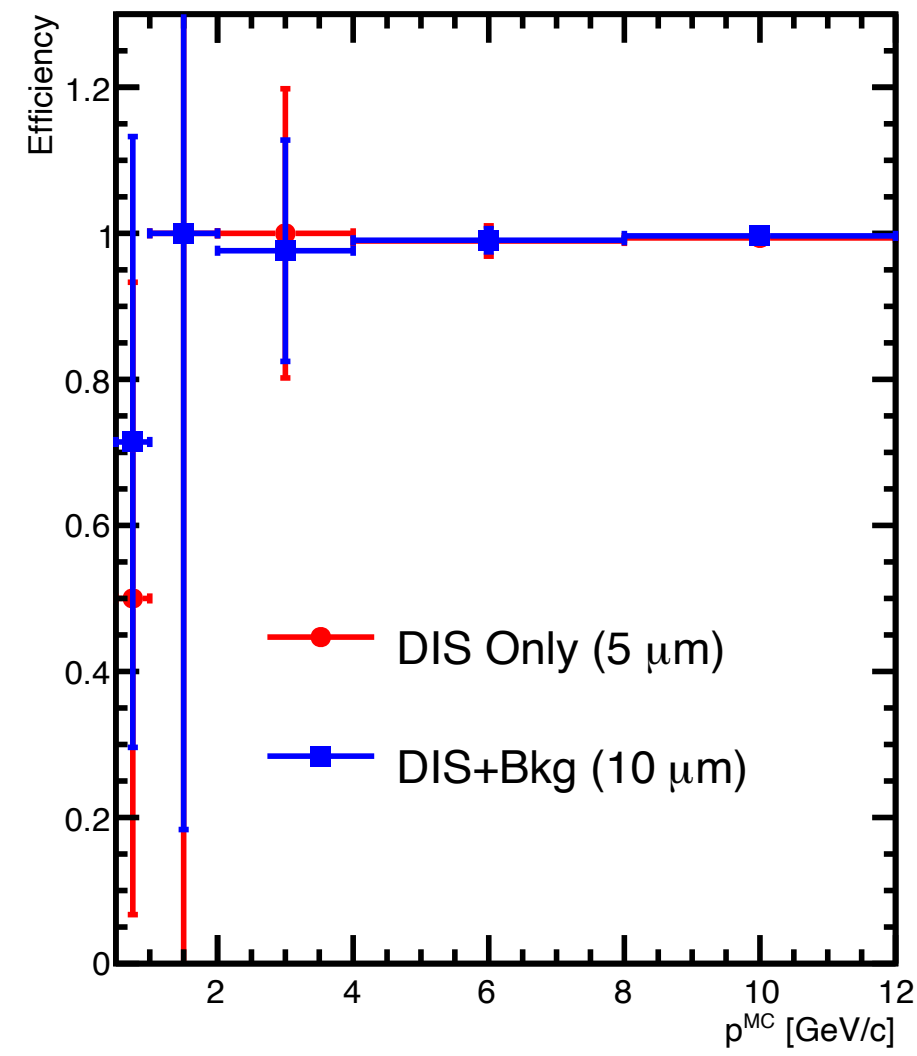
$$\chi^2 = 15$$

Here we only look at reconstructed tracks with purity above 0.8 and that have an associated primary track.

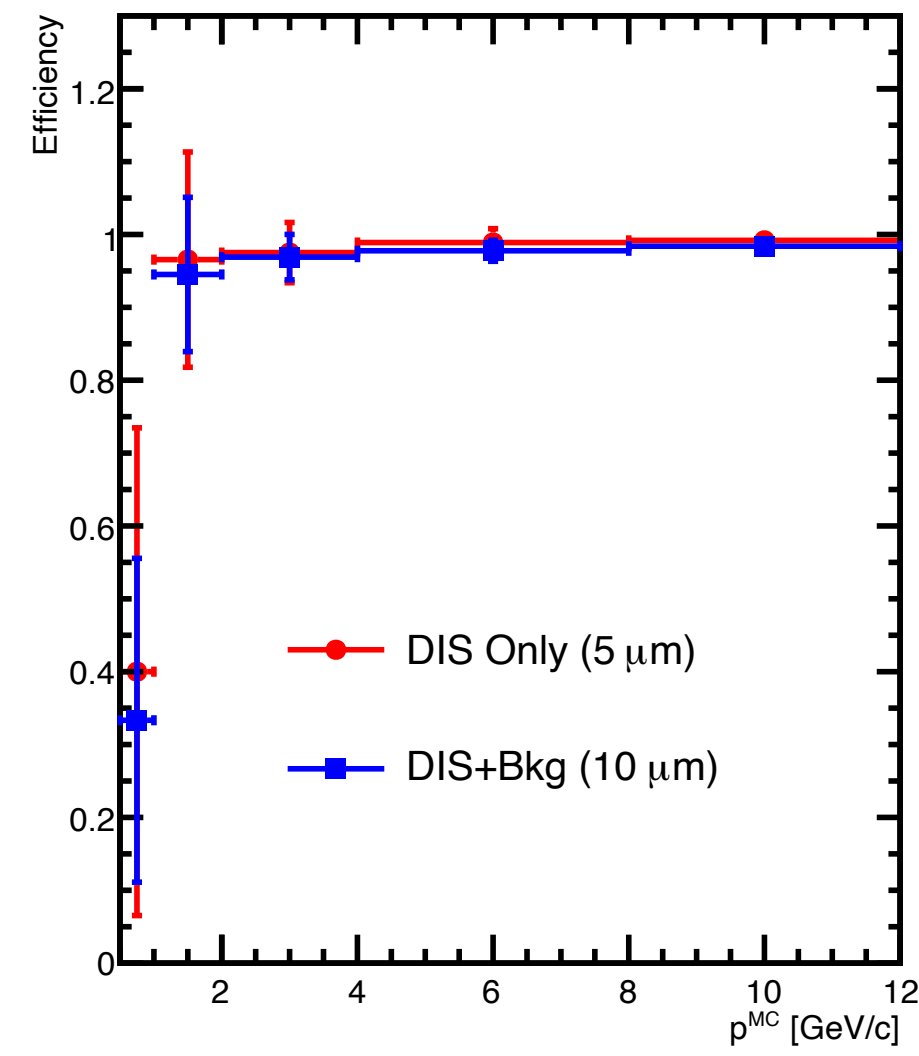
Wherever applicable the effect of adding Bkg is  $\sim 5\%$

# Reconstruction Efficiency Comparison (electrons)

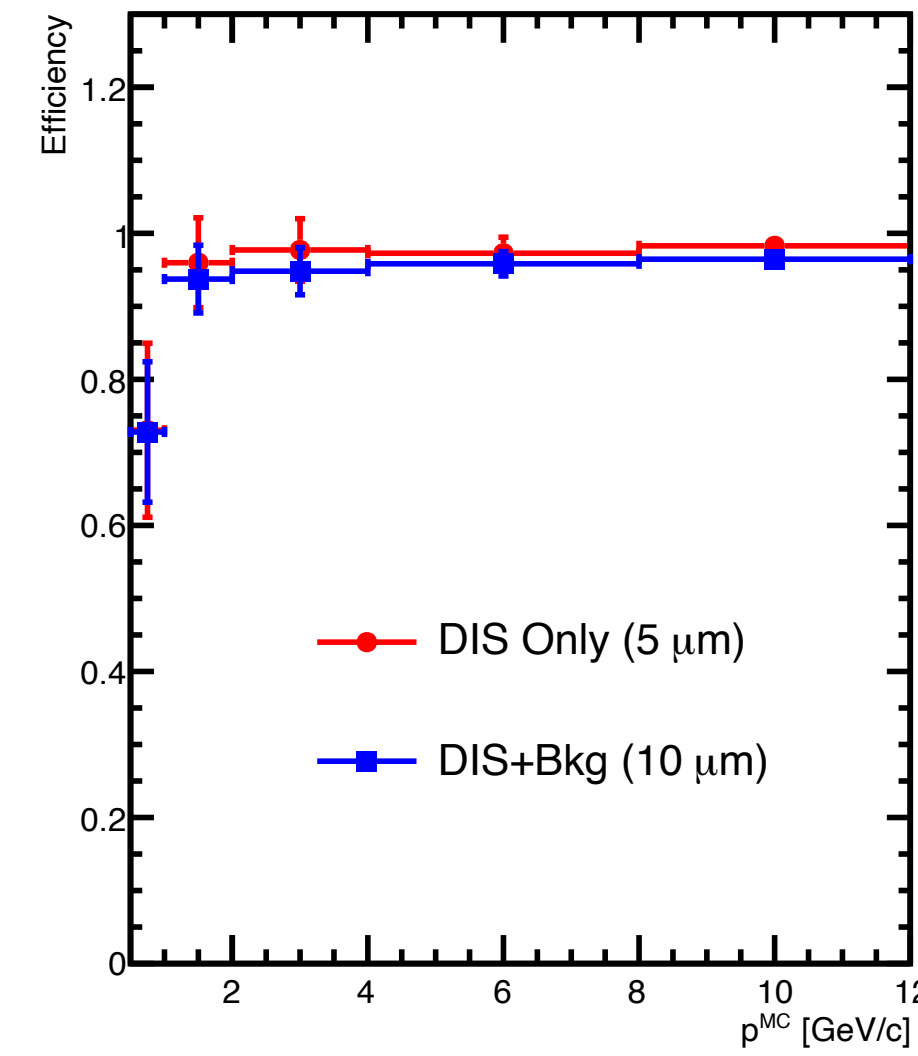
$-3.5 < \eta < -2.5$



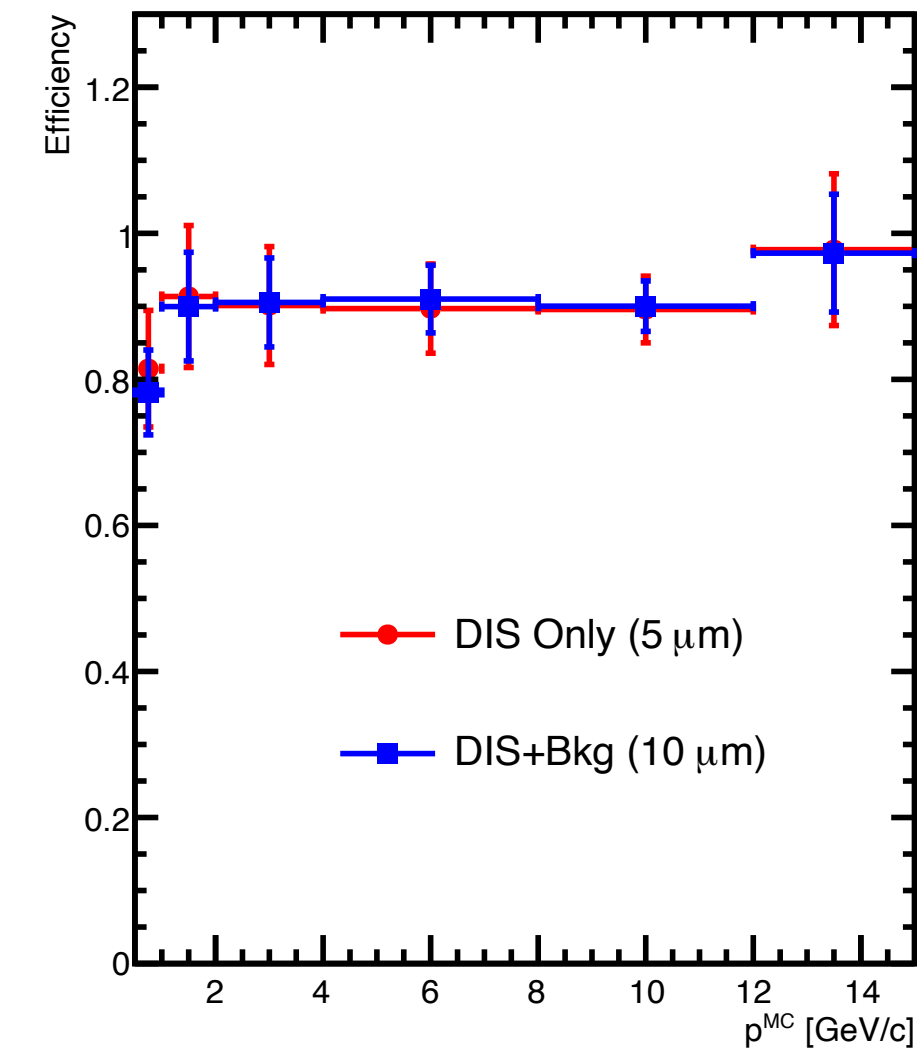
$-2.5 < \eta < -2.0$



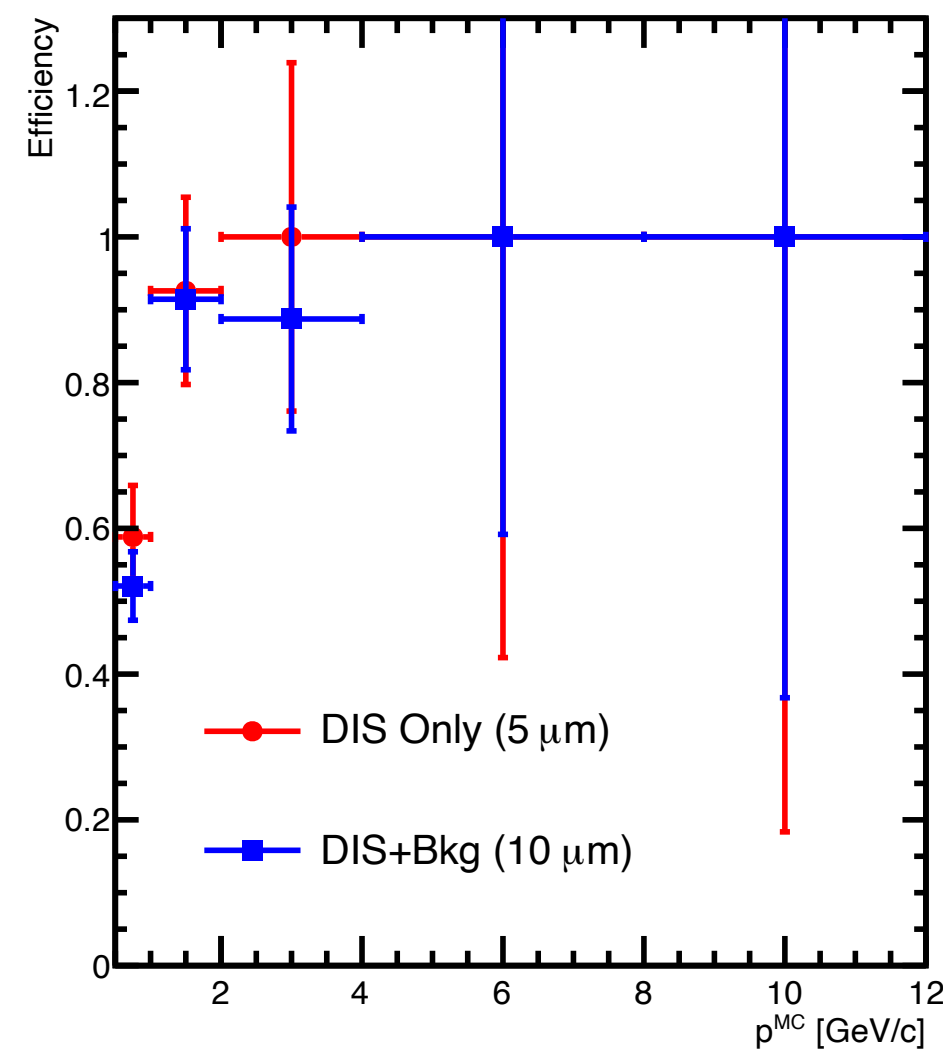
$-2.0 < \eta < -1.0$



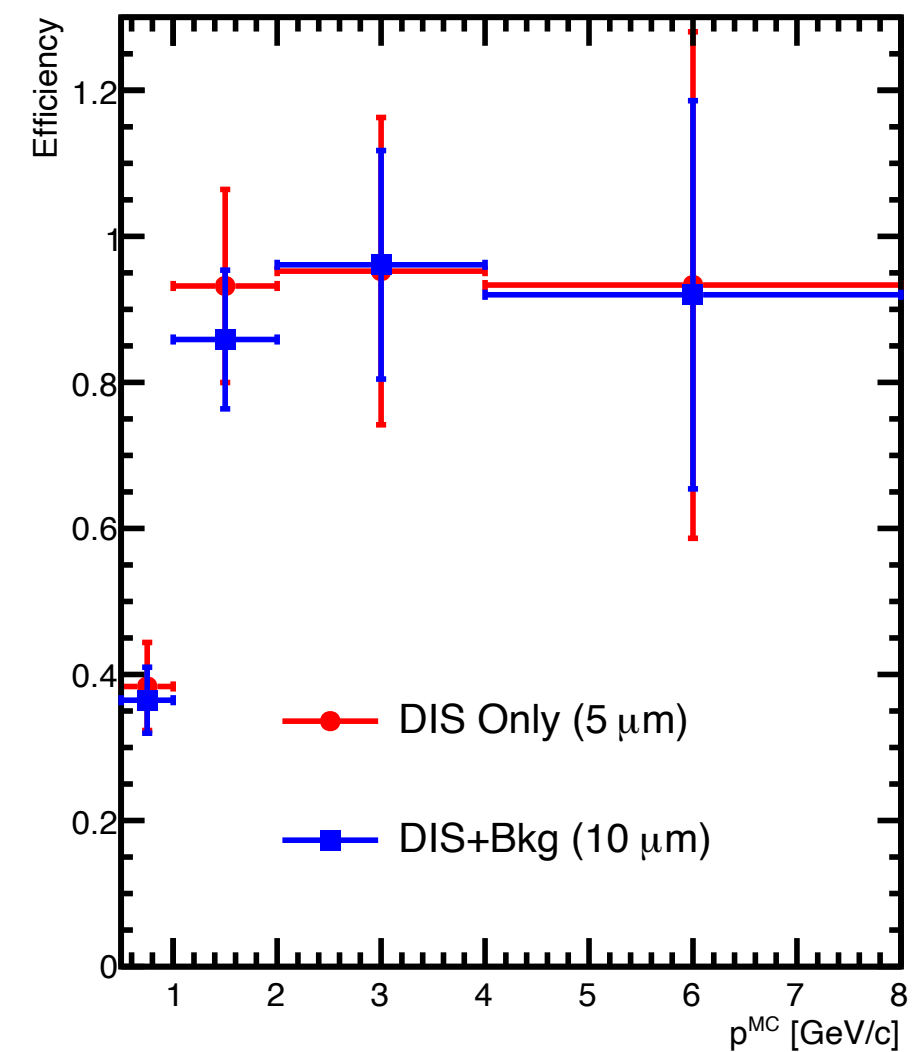
$-1.0 < \eta < 1.0$



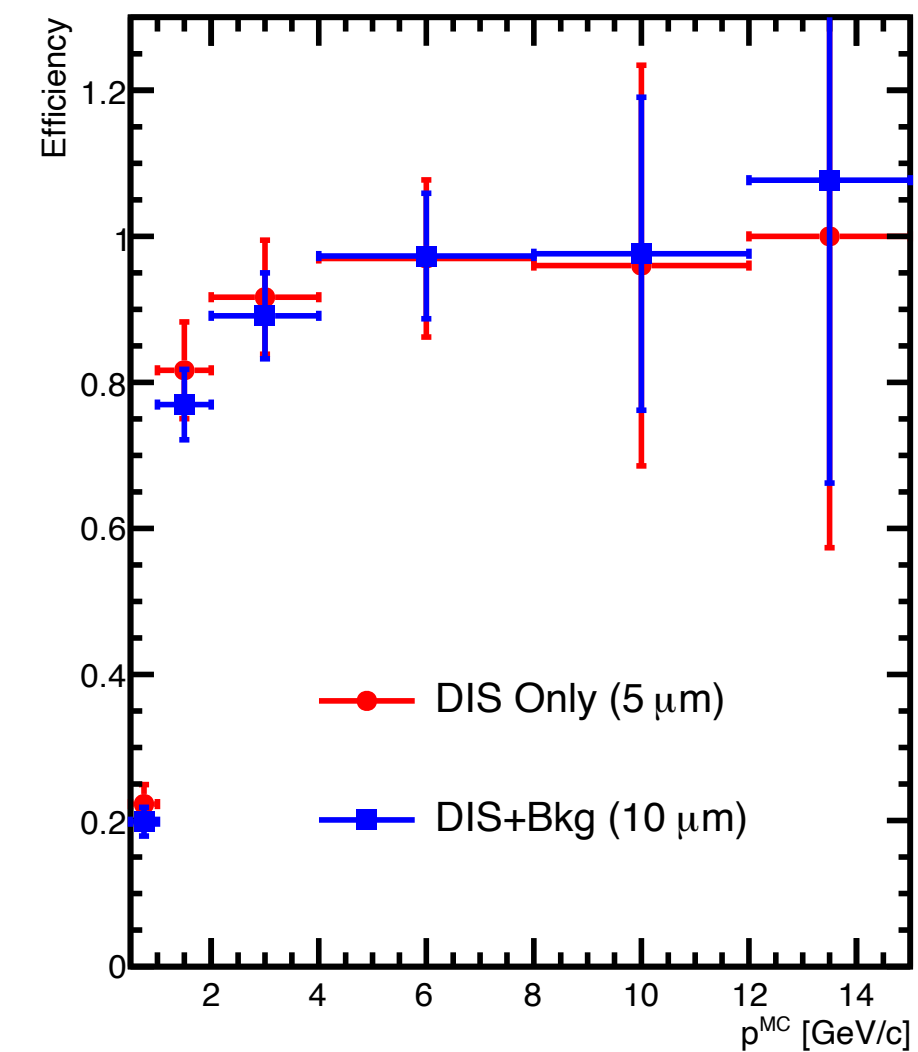
$1.0 < \eta < 2.0$



$2.0 < \eta < 2.5$



$2.5 < \eta < 3.5$



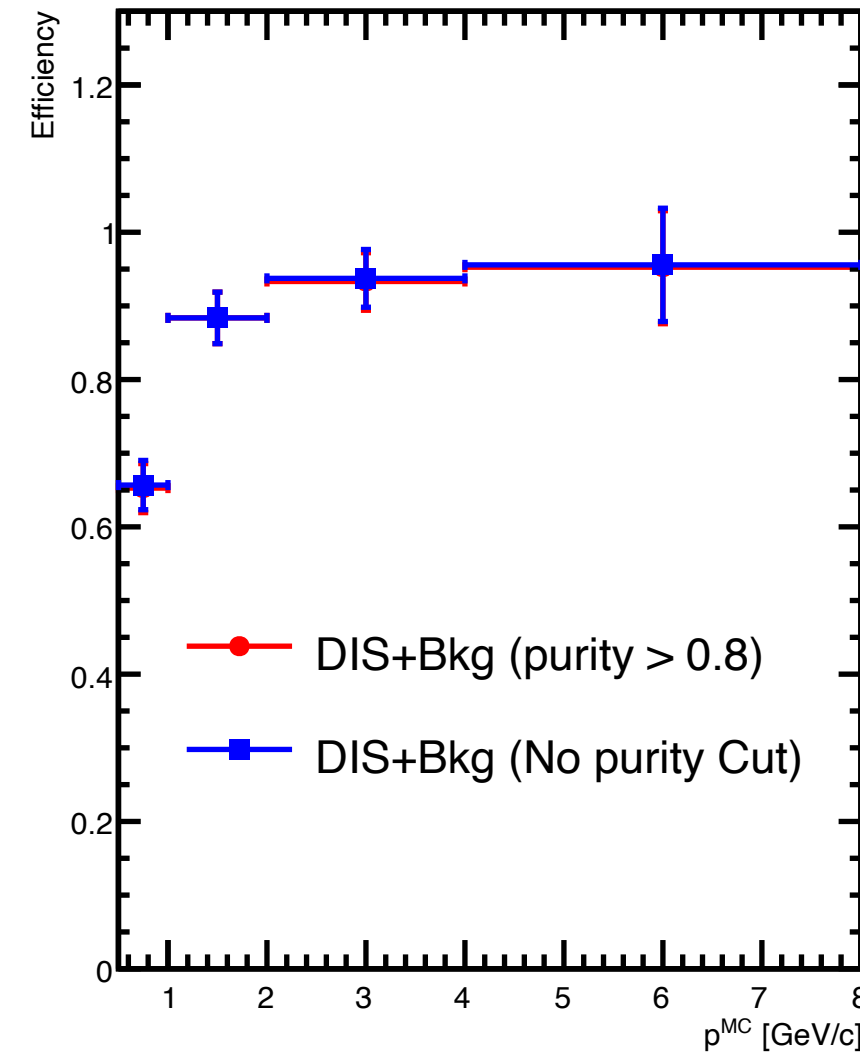
$$\chi^2 = 15$$

Here we only look at reconstructed tracks with purity above 0.8

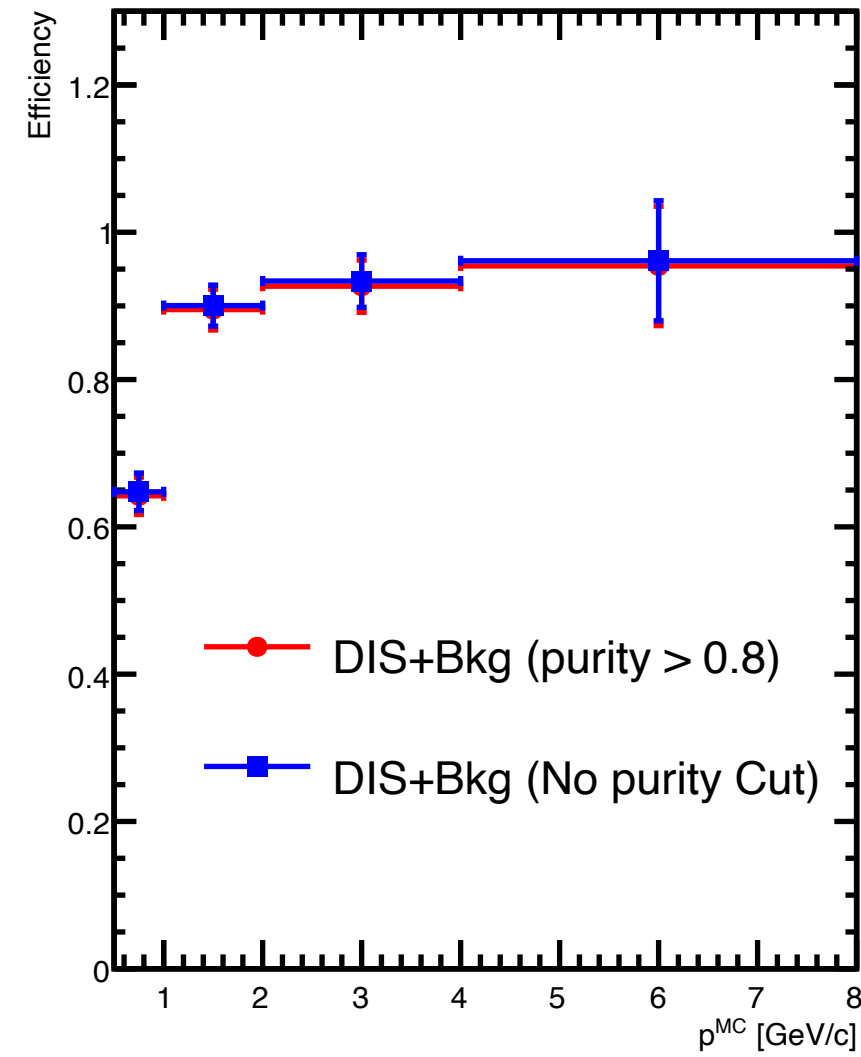
The effect on electrons is much smaller!!

# Reconstruction Efficiency Comparison ( $\pi/K/p$ )

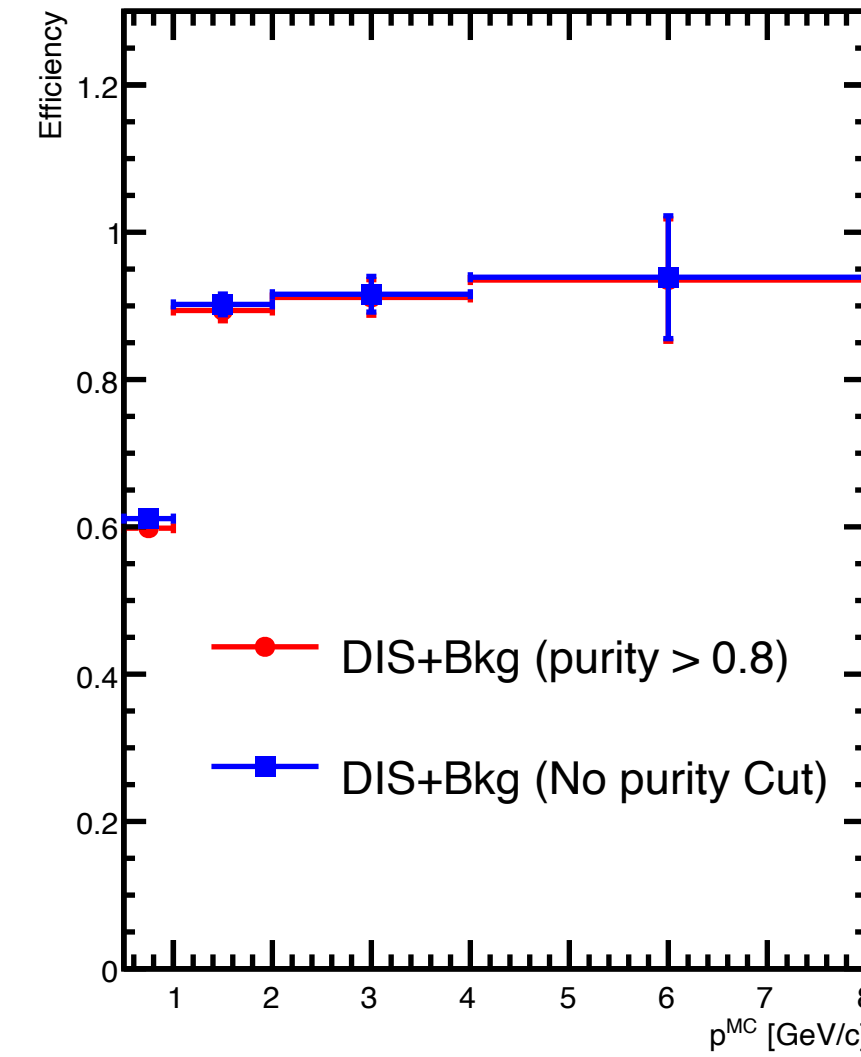
$-3.5 < \eta < -2.5$



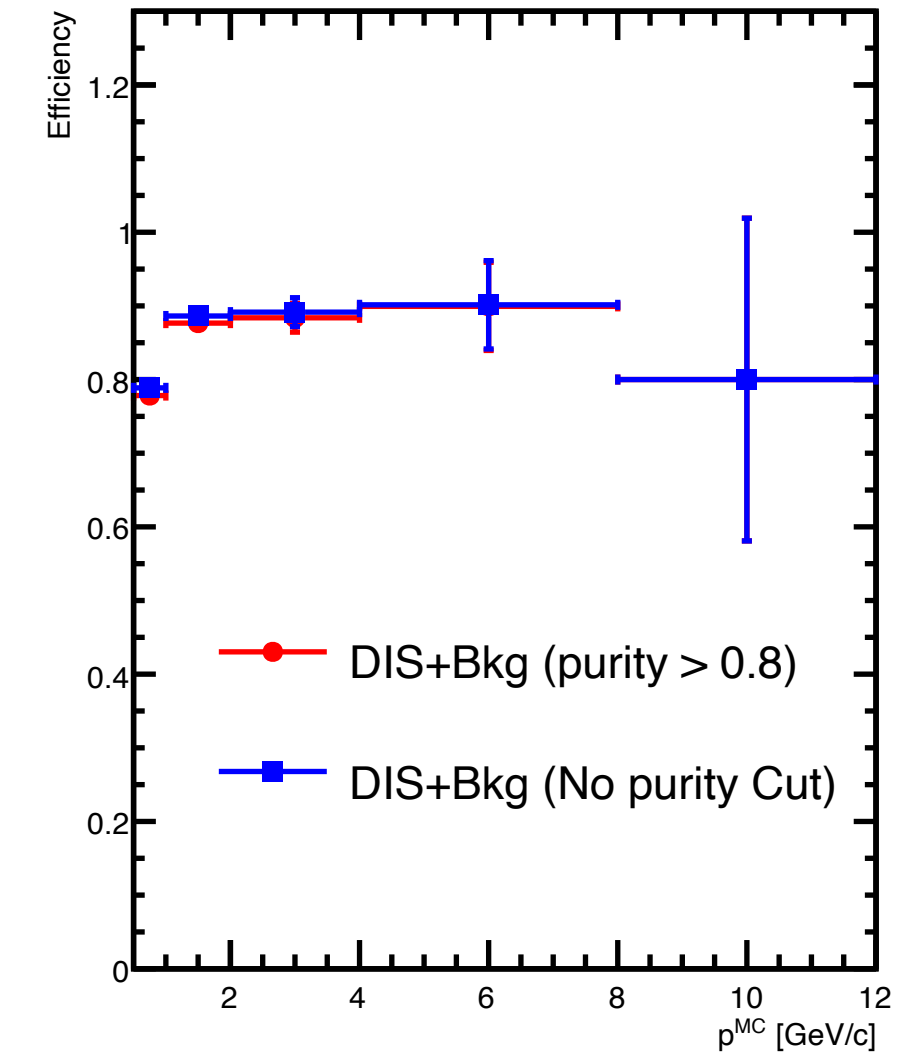
$-2.5 < \eta < -2.0$



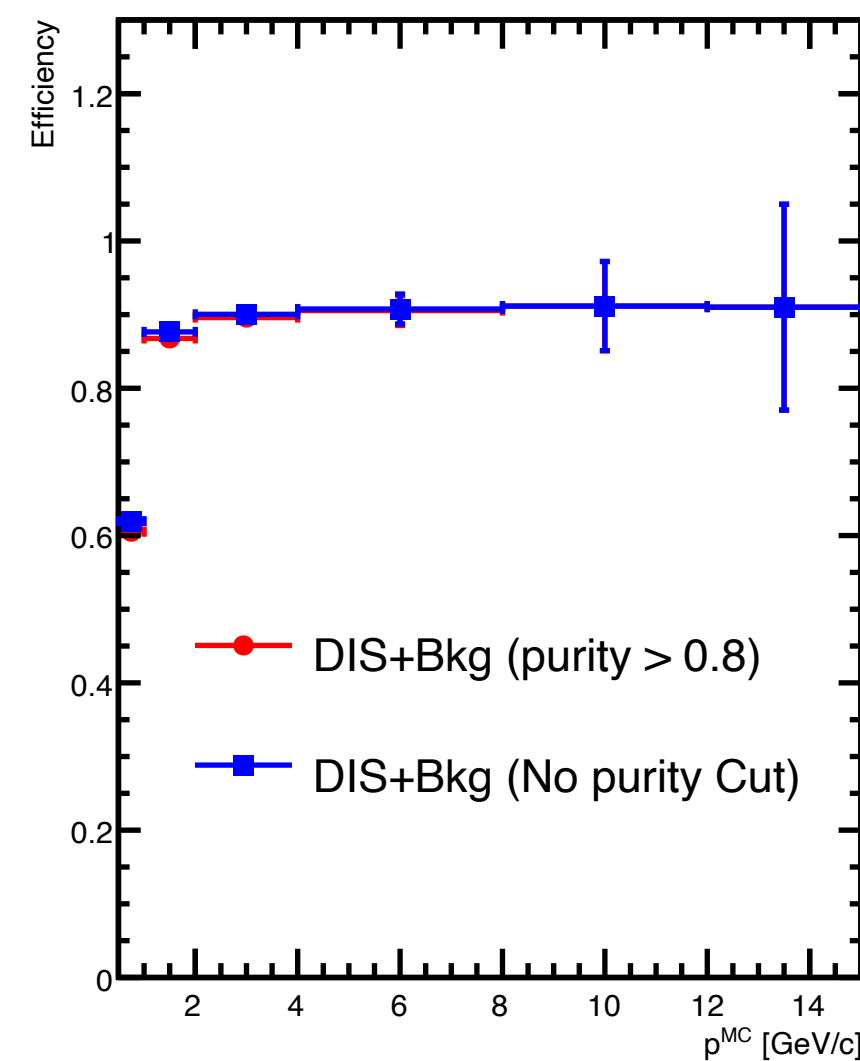
$-2.0 < \eta < -1.0$



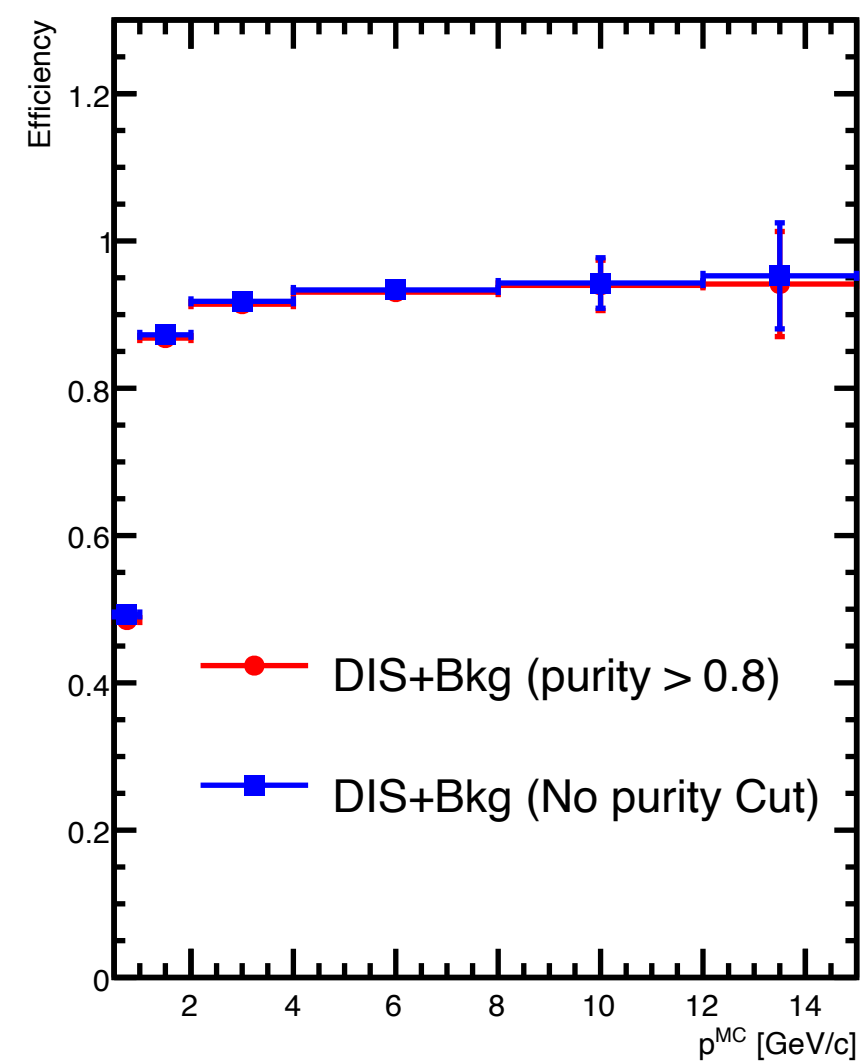
$-1.0 < \eta < 1.0$



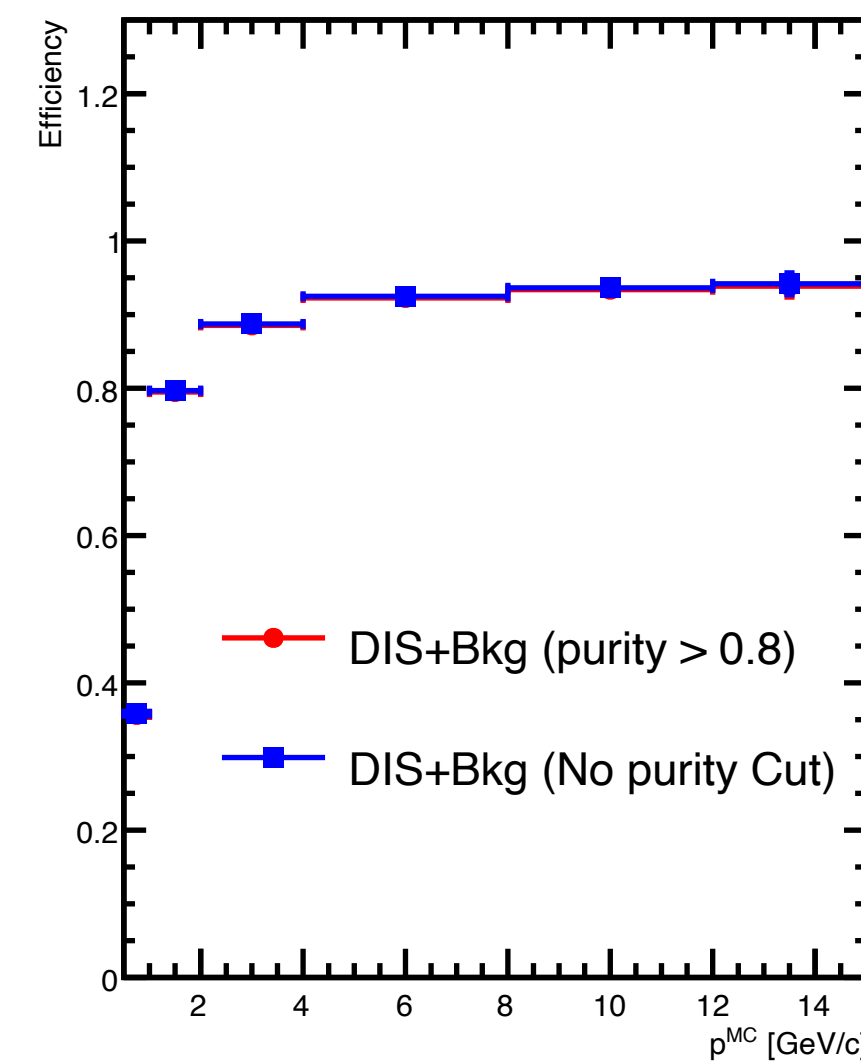
$1.0 < \eta < 2.0$



$2.0 < \eta < 2.5$



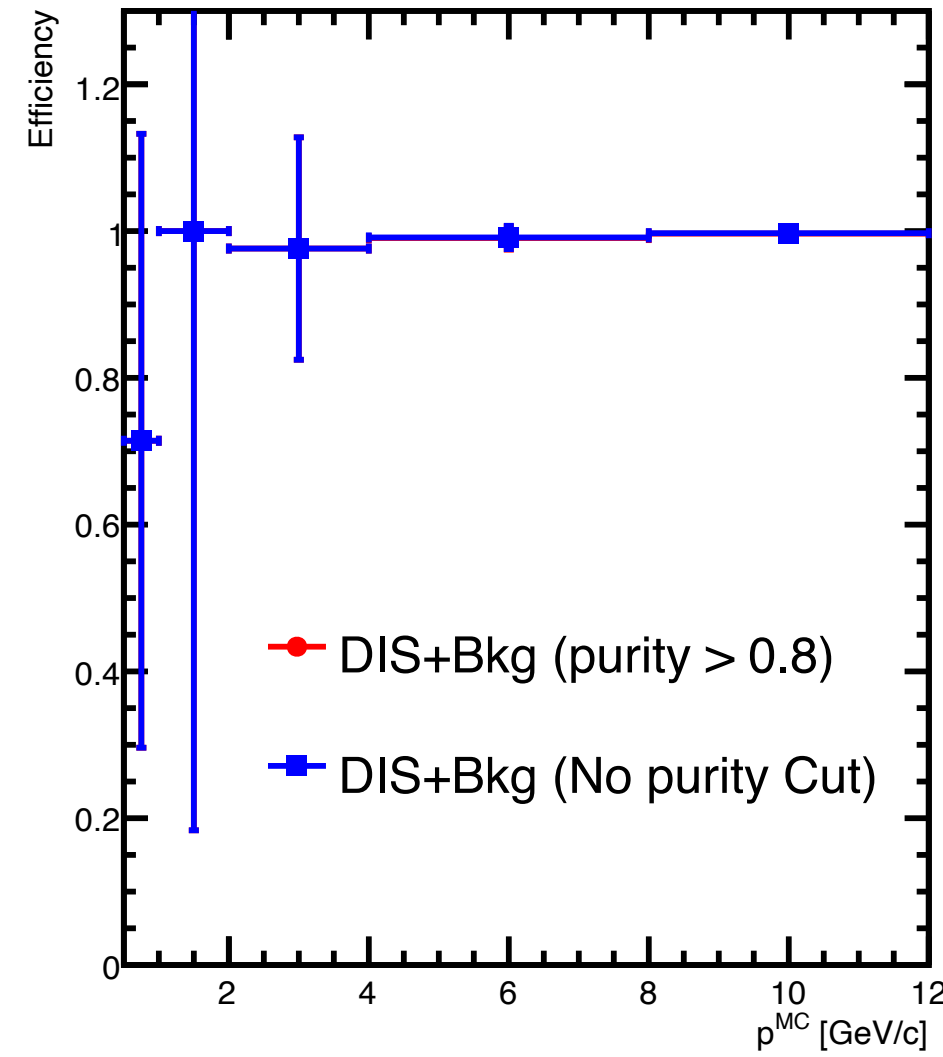
$2.5 < \eta < 3.5$



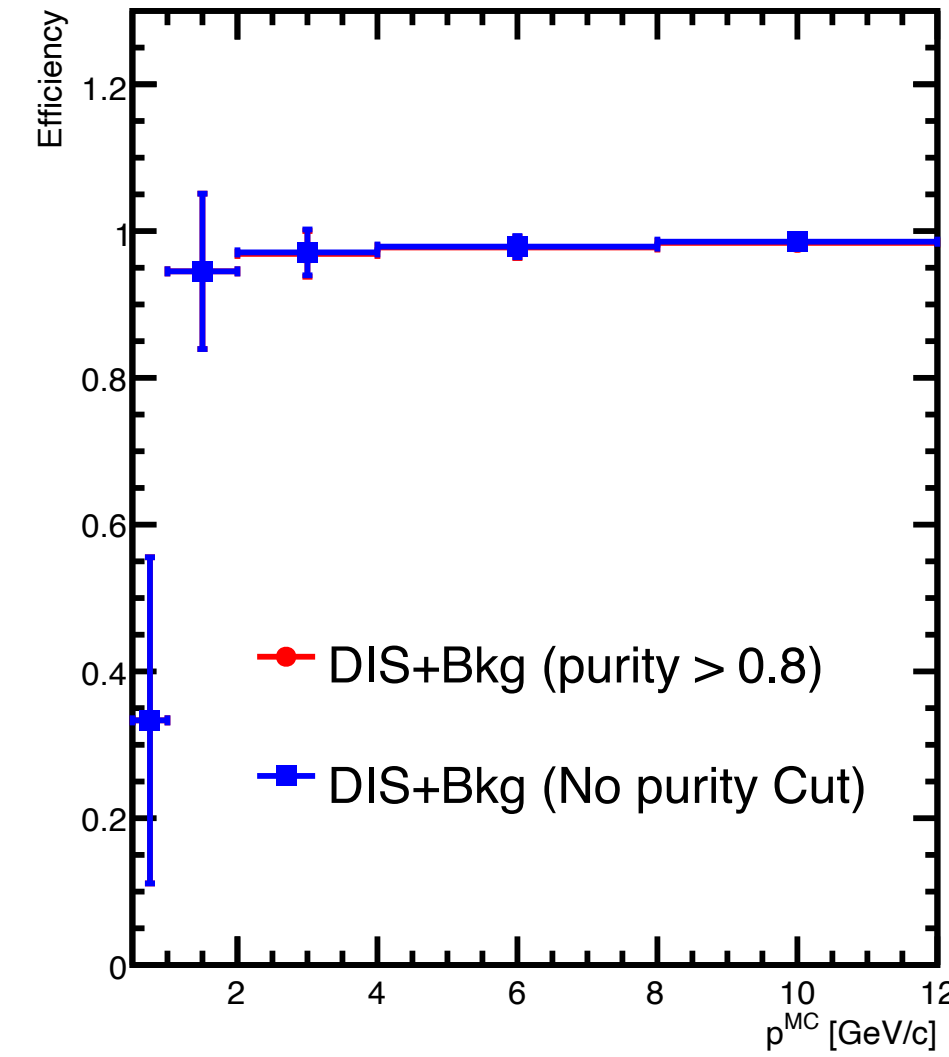
$\chi^2 = 15$   
DIS+Bkg

# Reconstruction Efficiency Comparison (electrons)

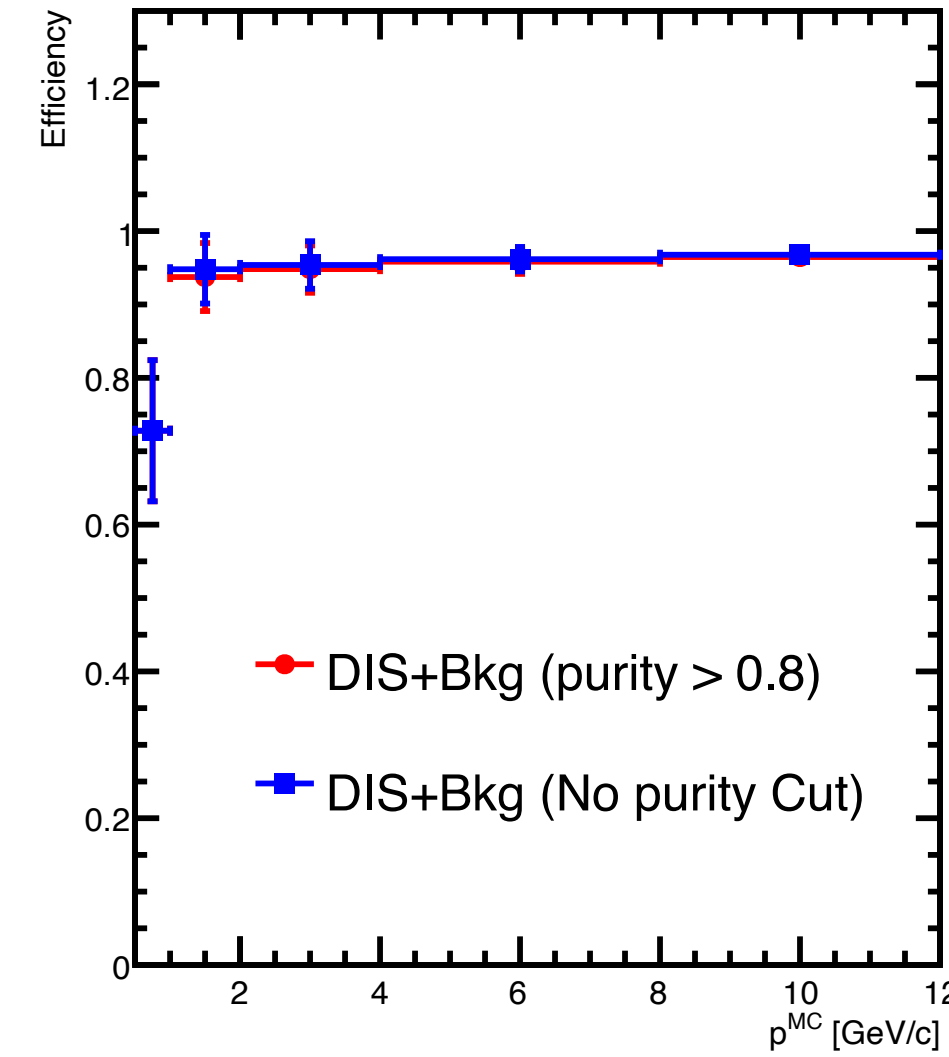
$-3.5 < \eta < -2.5$



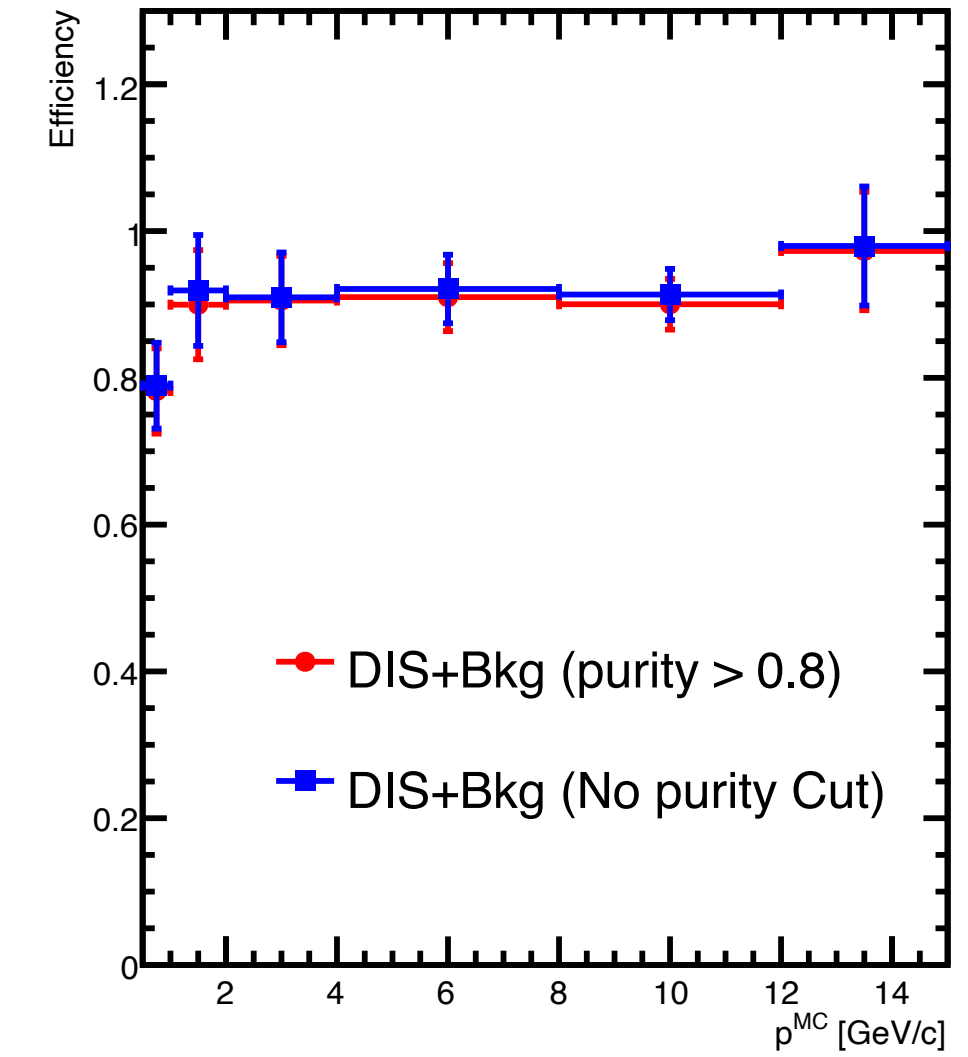
$-2.5 < \eta < -2.0$



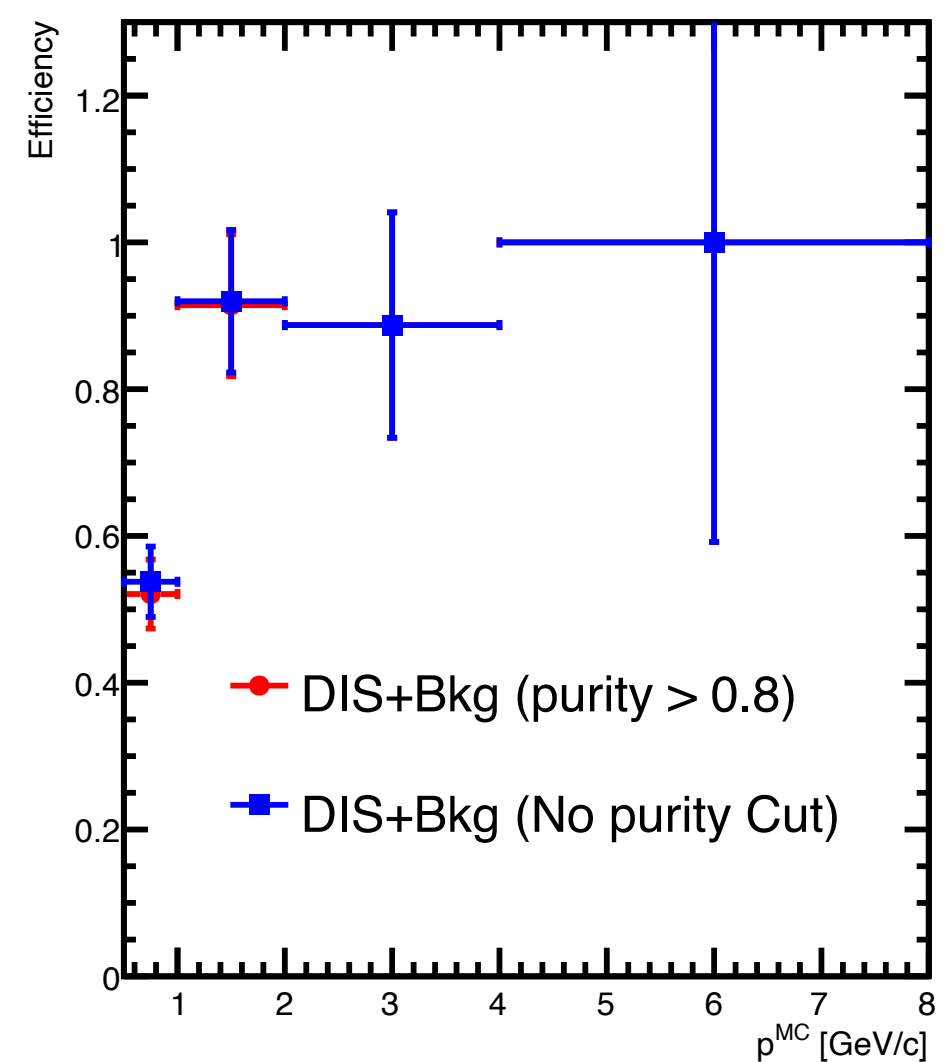
$-2.0 < \eta < -1.0$



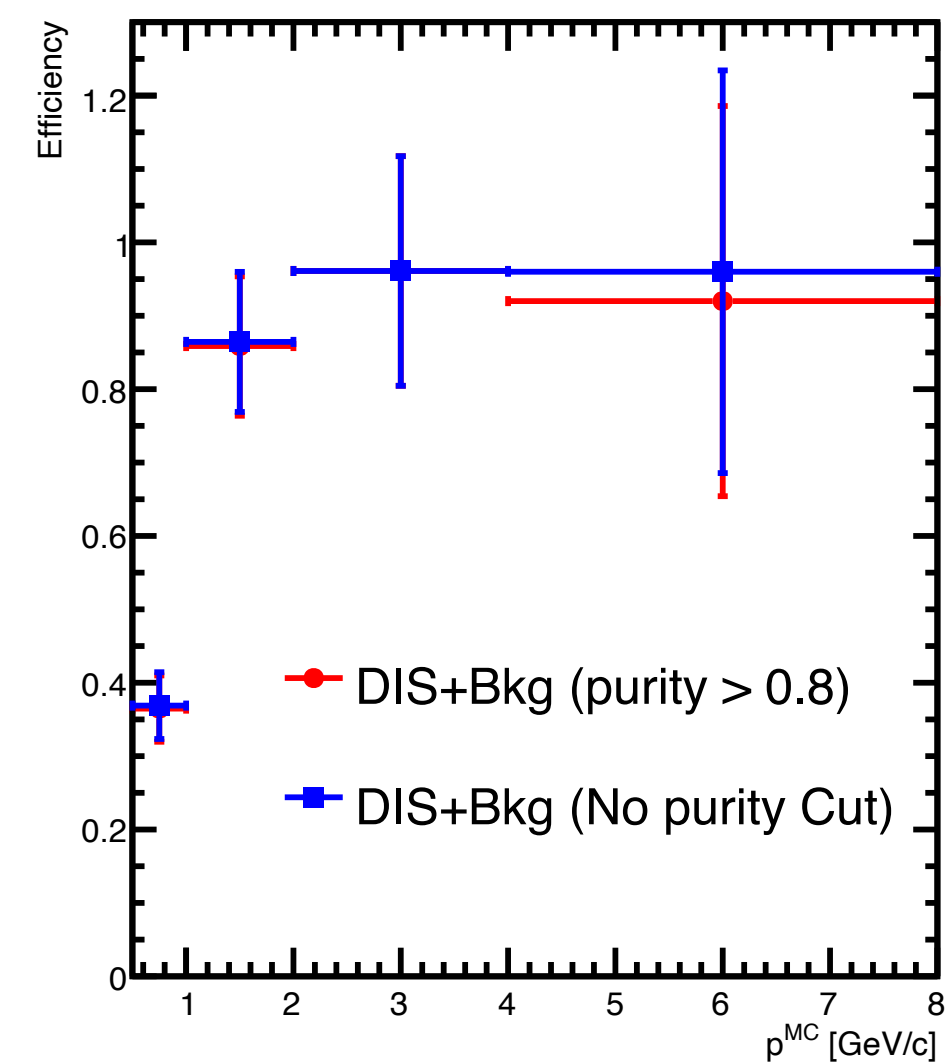
$-1.0 < \eta < 1.0$



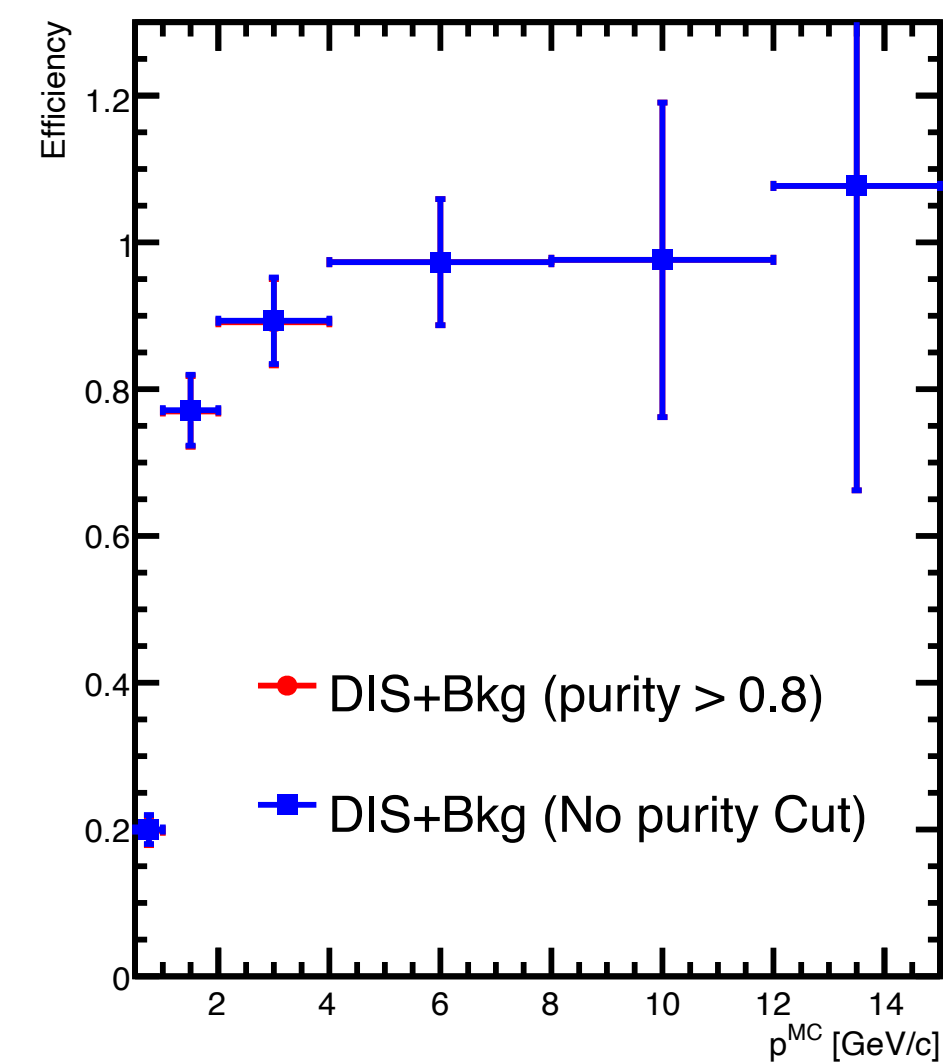
$1.0 < \eta < 2.0$



$2.0 < \eta < 2.5$



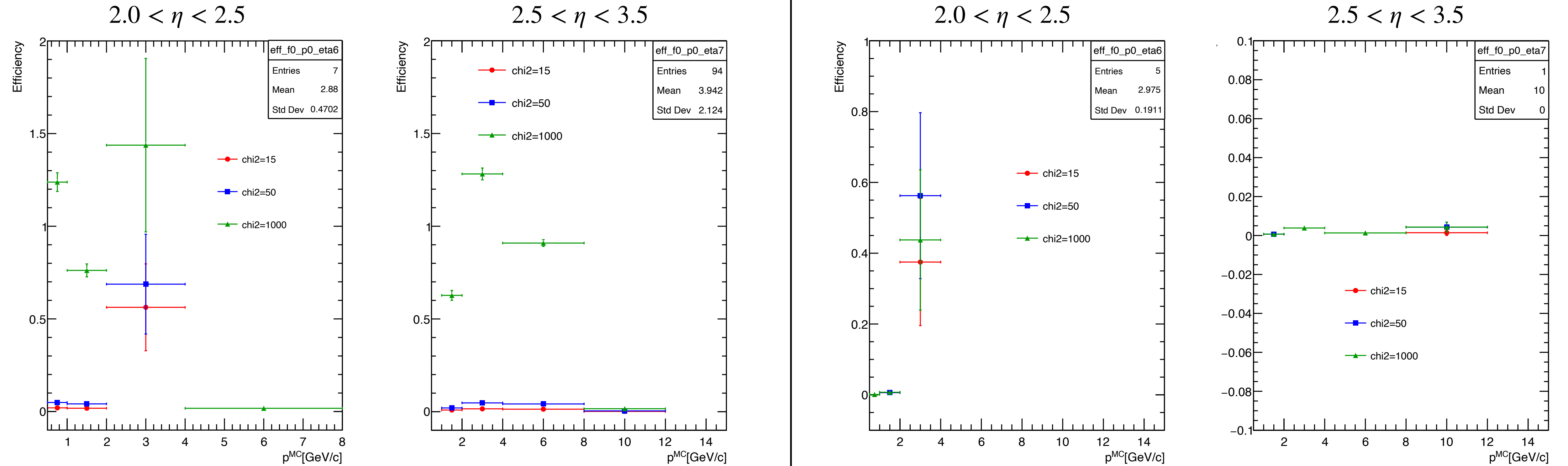
$2.5 < \eta < 3.5$



$\chi^2 = 15$

DIS+Bkg

# Reconstruction Efficiency Comparison (Bkg)



Without the purity cut

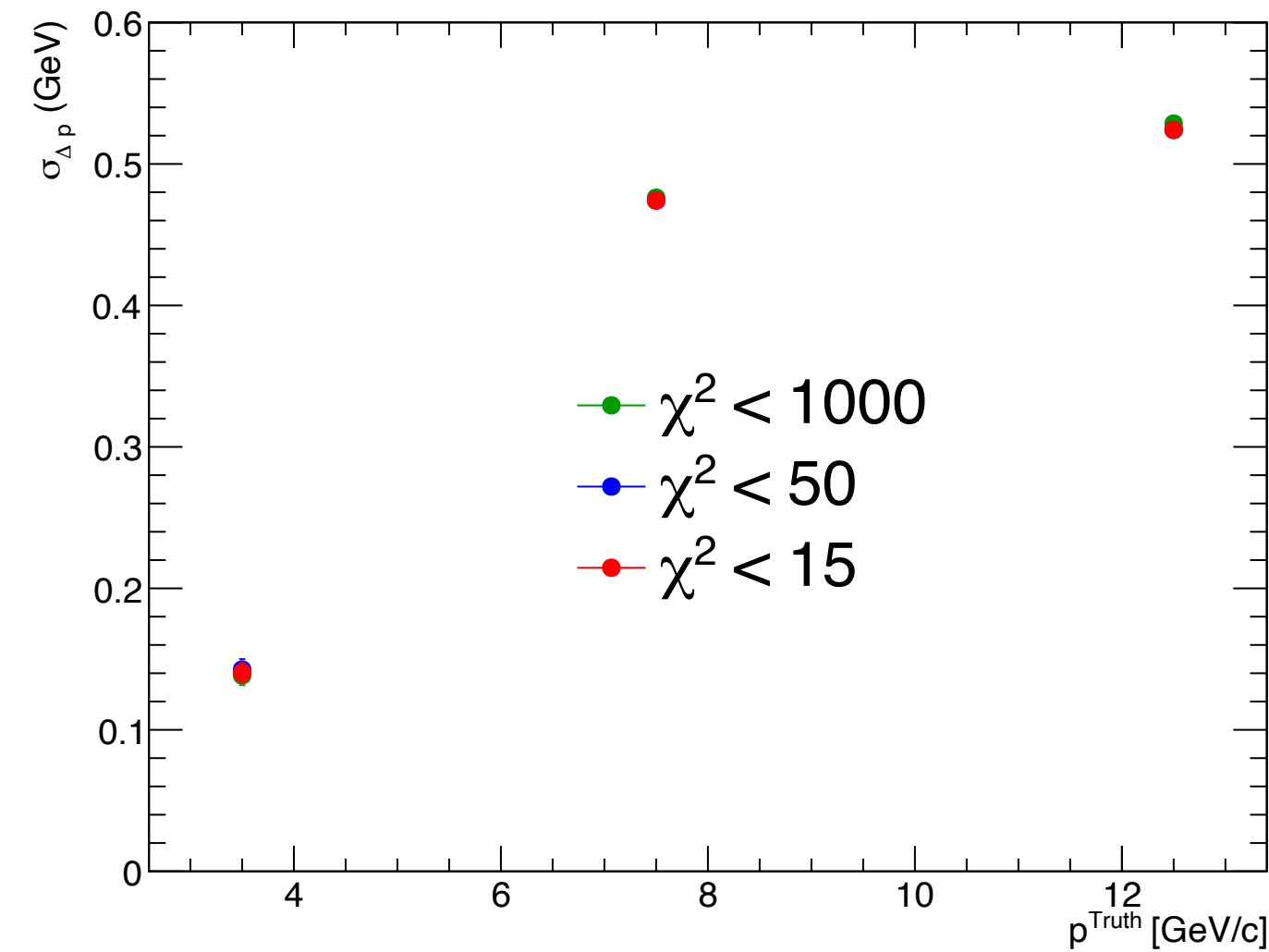
With the purity cut of 0.8

# Momentum Resolution Plots (Electrons)

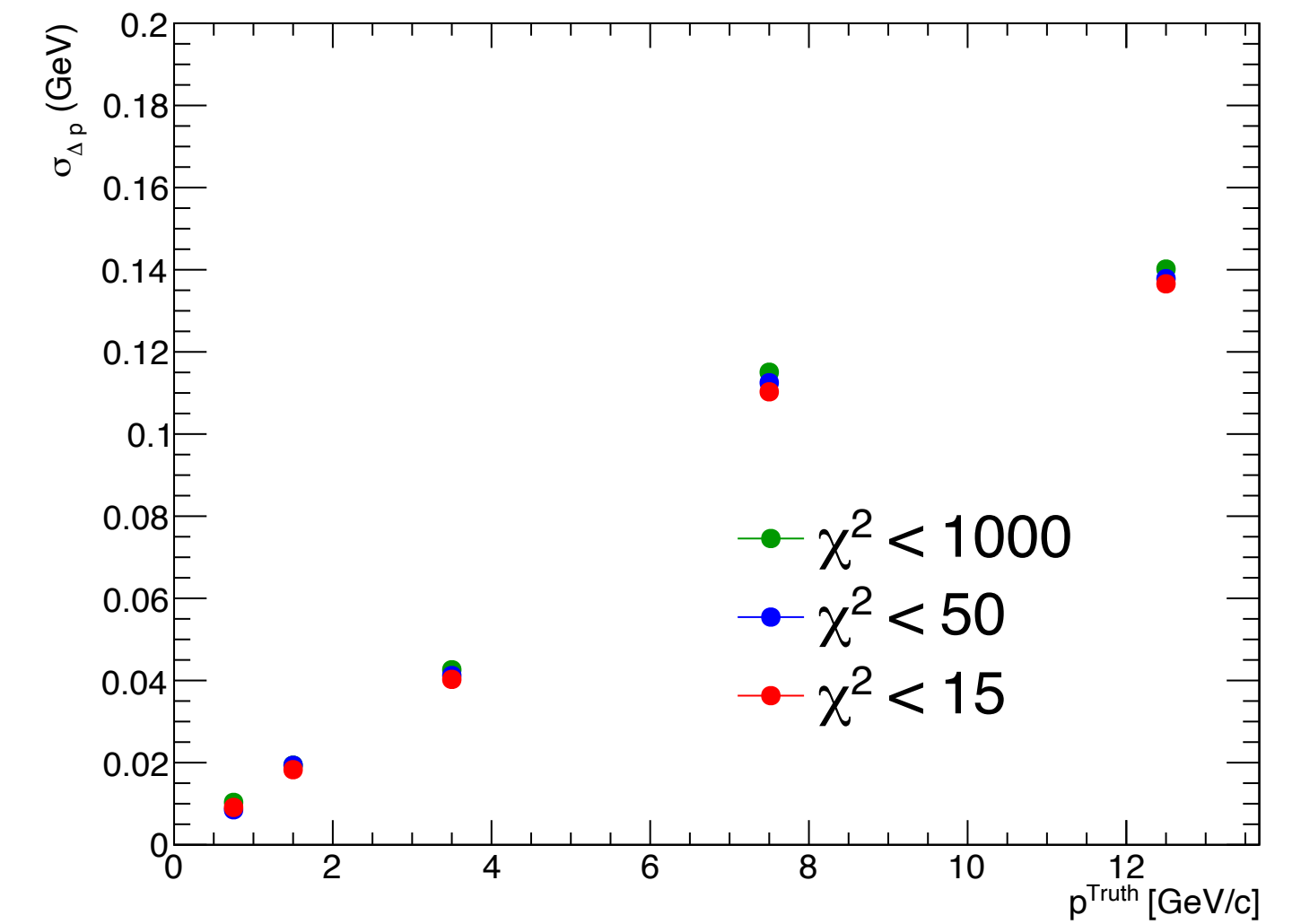
No visible  $\chi^2$  dependence

Here we only look at reconstructed tracks with purity above 0.8 and that have an associated primary track.

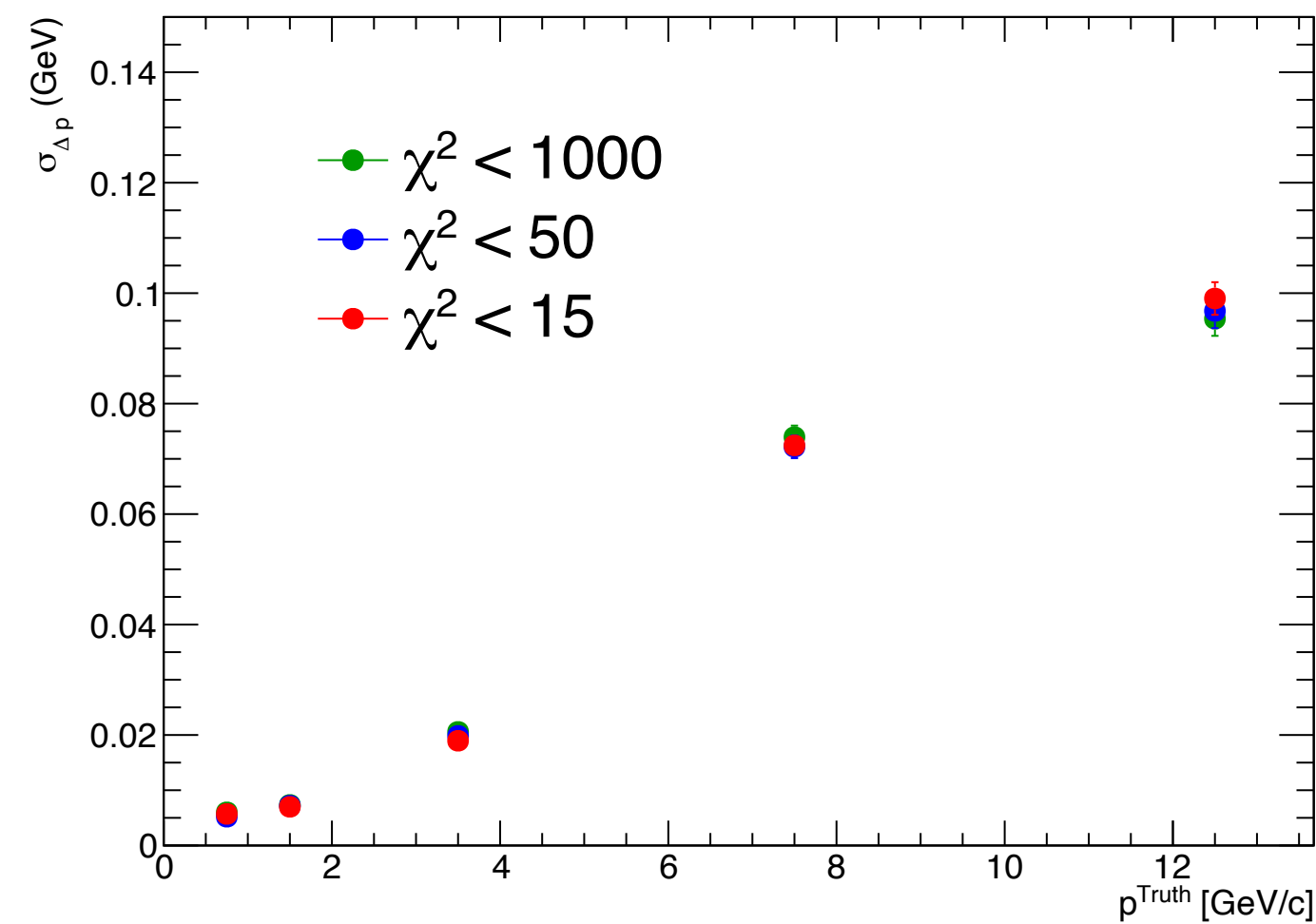
$$-3.5 < \eta < -2.5$$



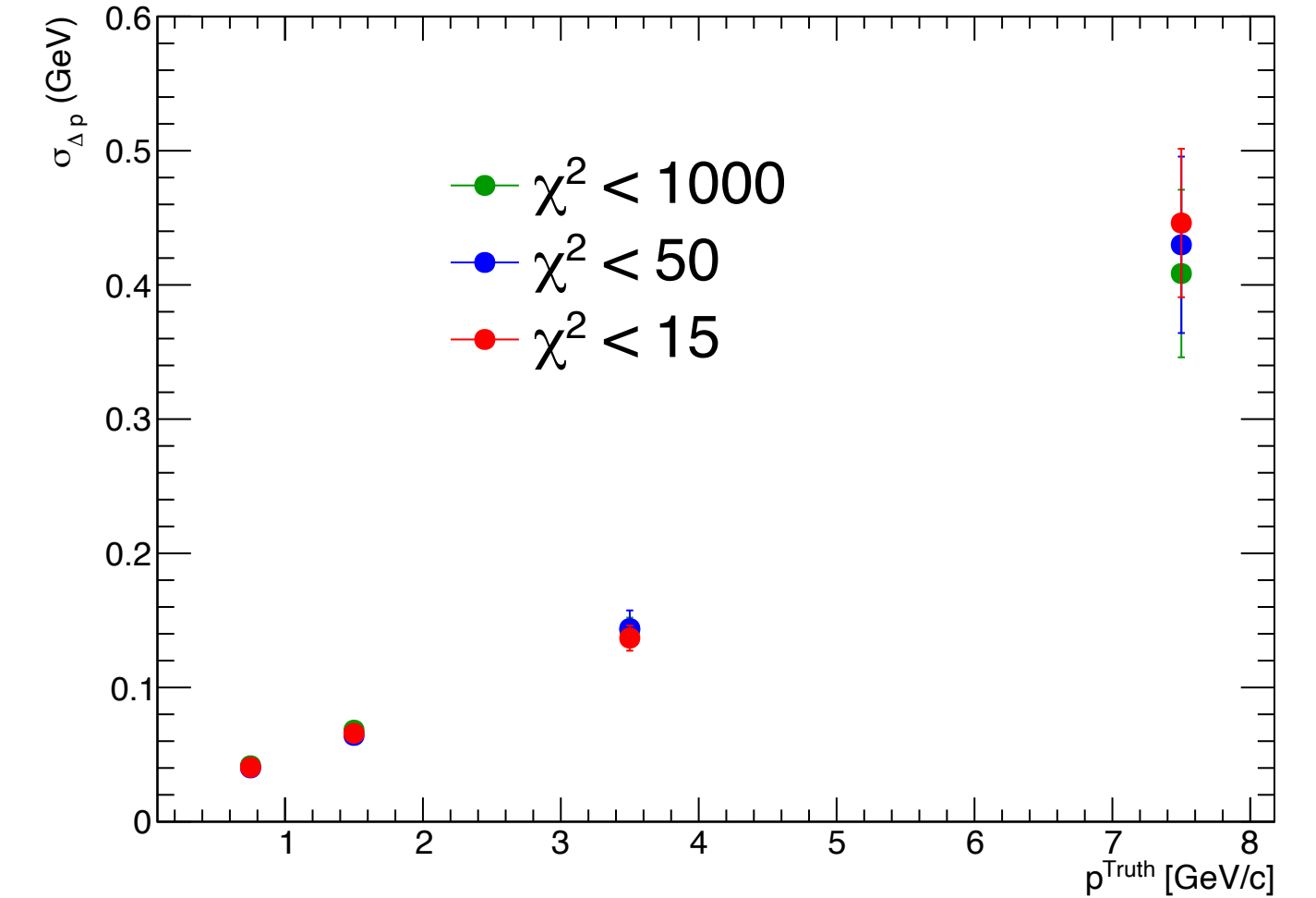
$$-2.0 < \eta < -1.0$$



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



$$2.5 < \eta < 3.5$$

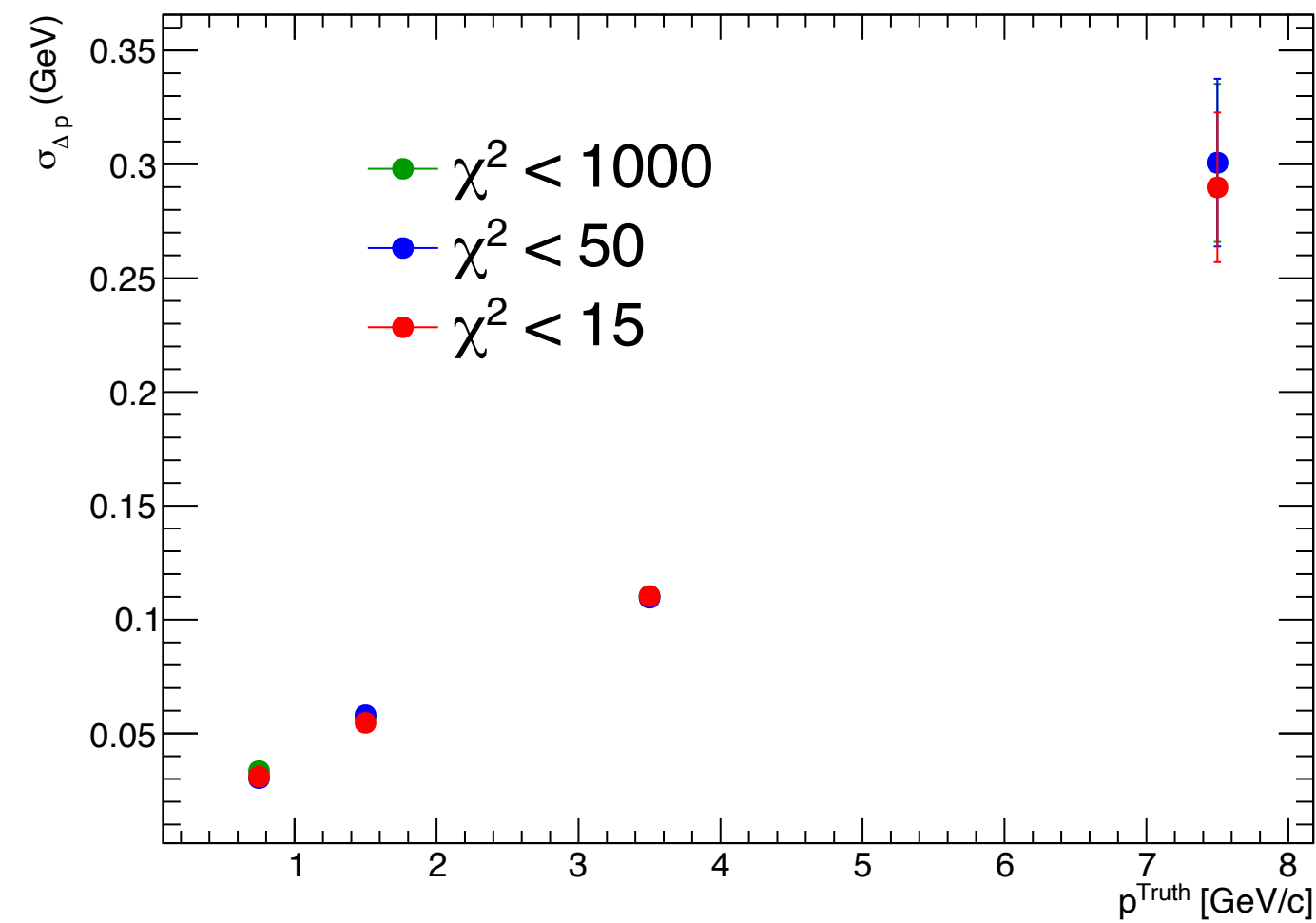


# Momentum Resolution Plots ( $\pi/K/p$ )

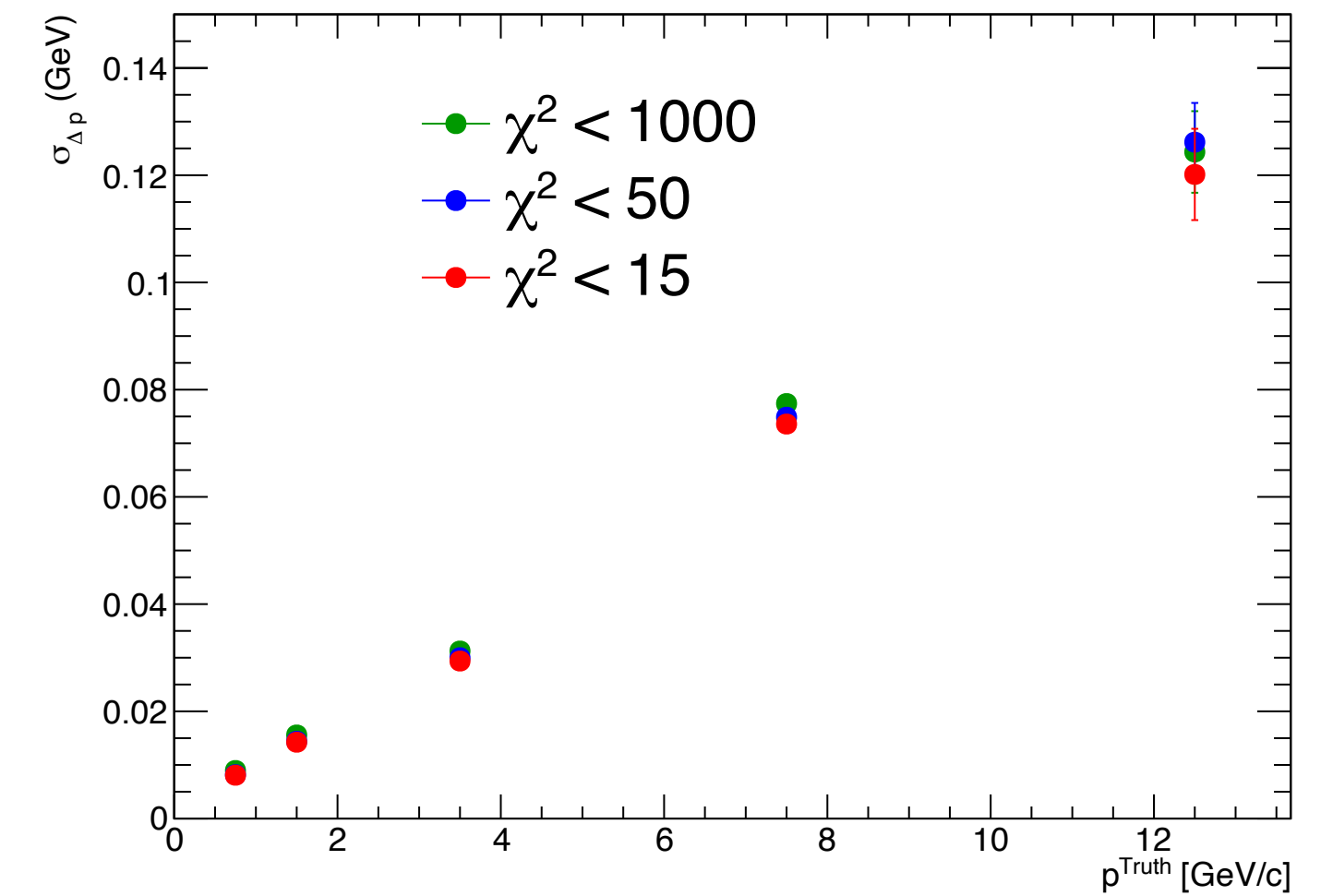
No visible  $\chi^2$  dependence

Here we only look at reconstructed tracks with purity above 0.8 and that have an associated primary track.

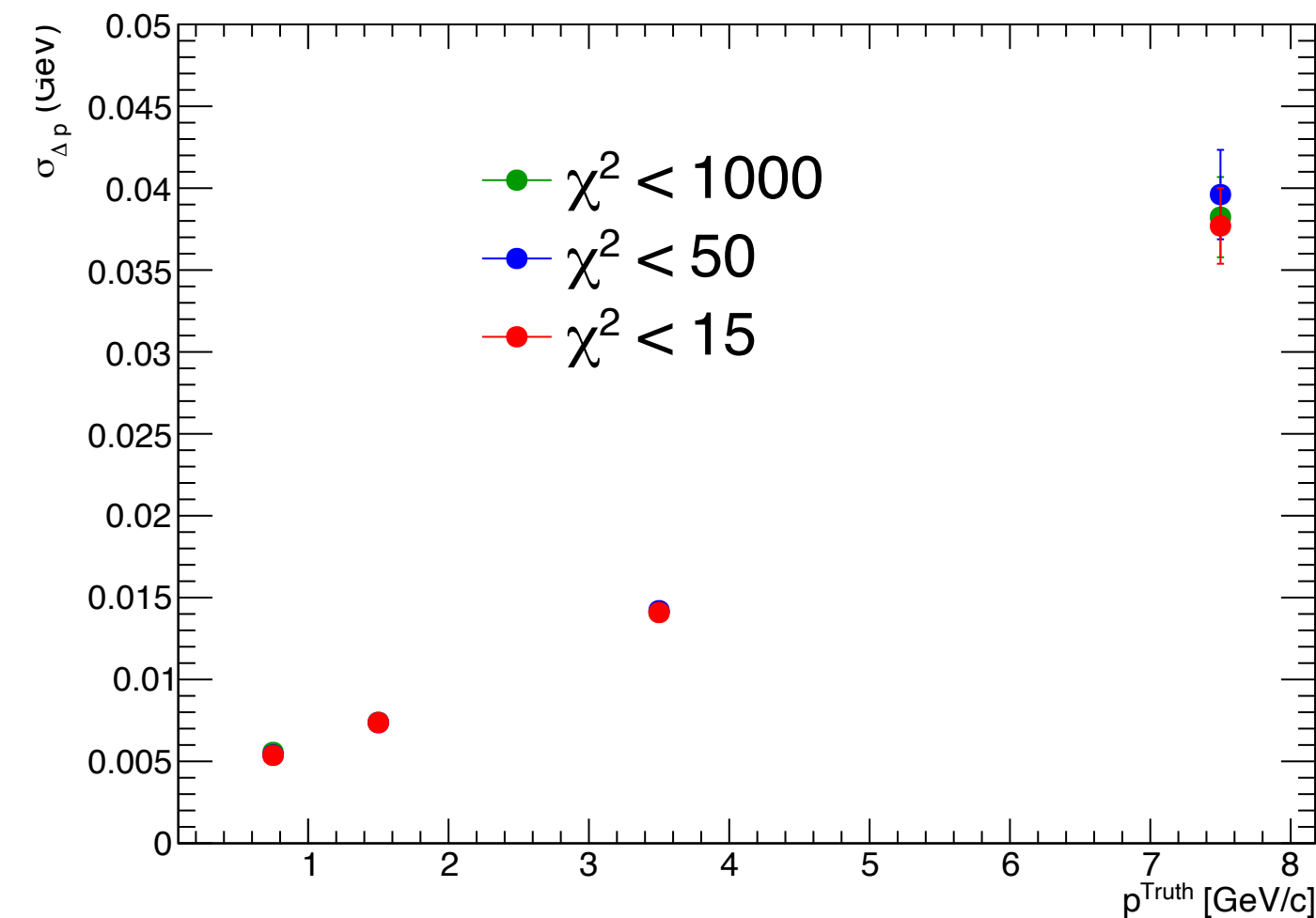
$$-3.5 < \eta < -2.5$$



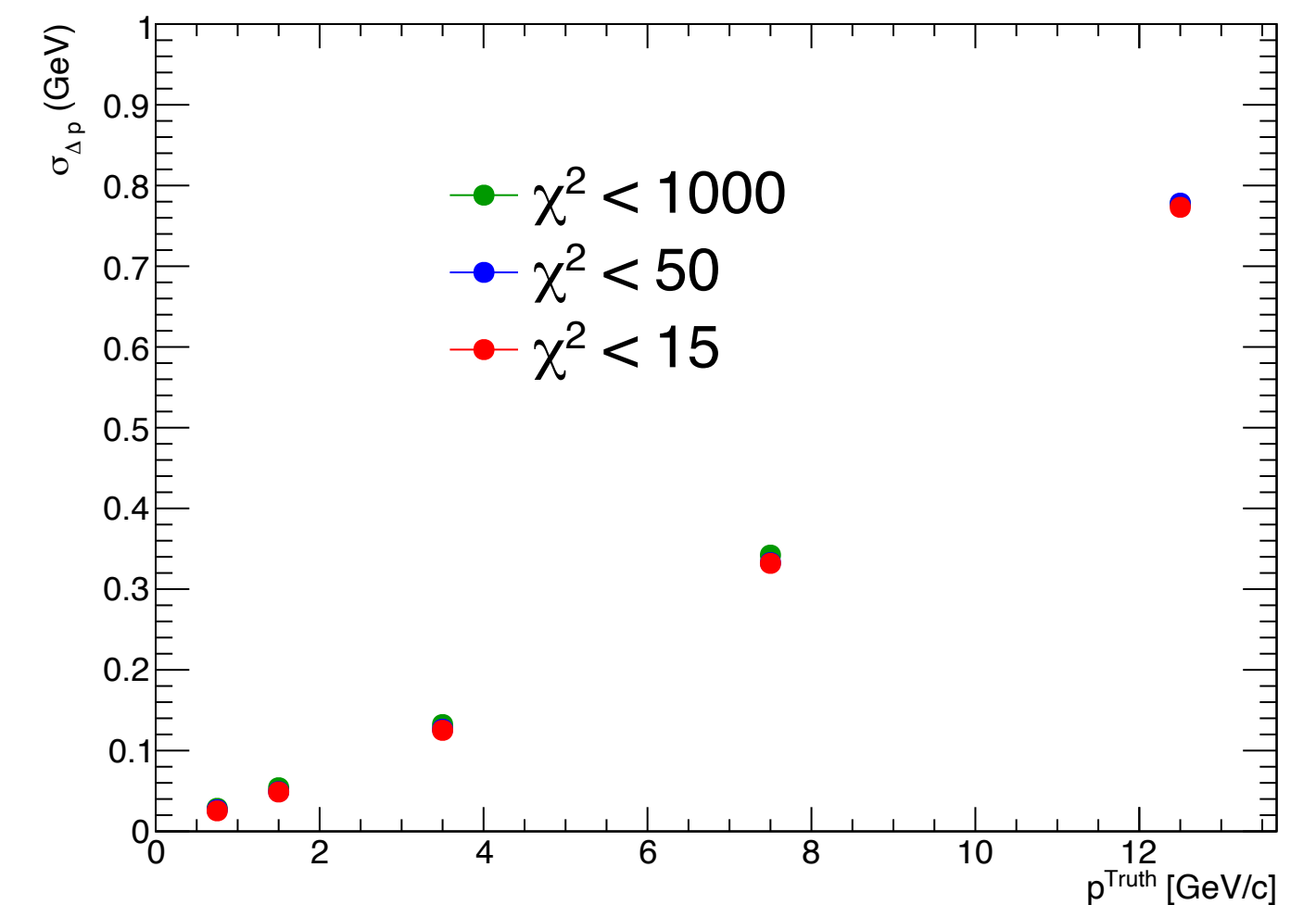
$$1.0 < \eta < 2.0$$



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



$$2.5 < \eta < 3.5$$



# Conclusion

## Background Tracks:

- Primarily leave hits in inner tracking layers; when satisfying  $N_{\text{hits}} > 3$  requirement, pick up spurious hits from other tracks
- This causes wider  $\chi^2$  distributions, creating strong sensitivity to  $\chi^2$  cutoff
- $\chi^2 = 15$  effectively rejects background while maintaining signal integrity

## Electron & Hadron Tracks (Signal):

- Produce clean, coherent hit patterns with tight  $\chi^2$  distributions
- Robust to  $\chi^2$  selection due to consistent, well-defined track signatures
- Largely unaffected by background contamination in sample

## Key Results:

- Default  $\chi^2 = 15$  cutoff limits impact of background on reconstructed primary e/hadron tracks to ~5%
- Reconstructed signal tracks maintain high purity
- Low-momentum track losses attributed to **seeding inefficiency**, not  $\chi^2$  selection