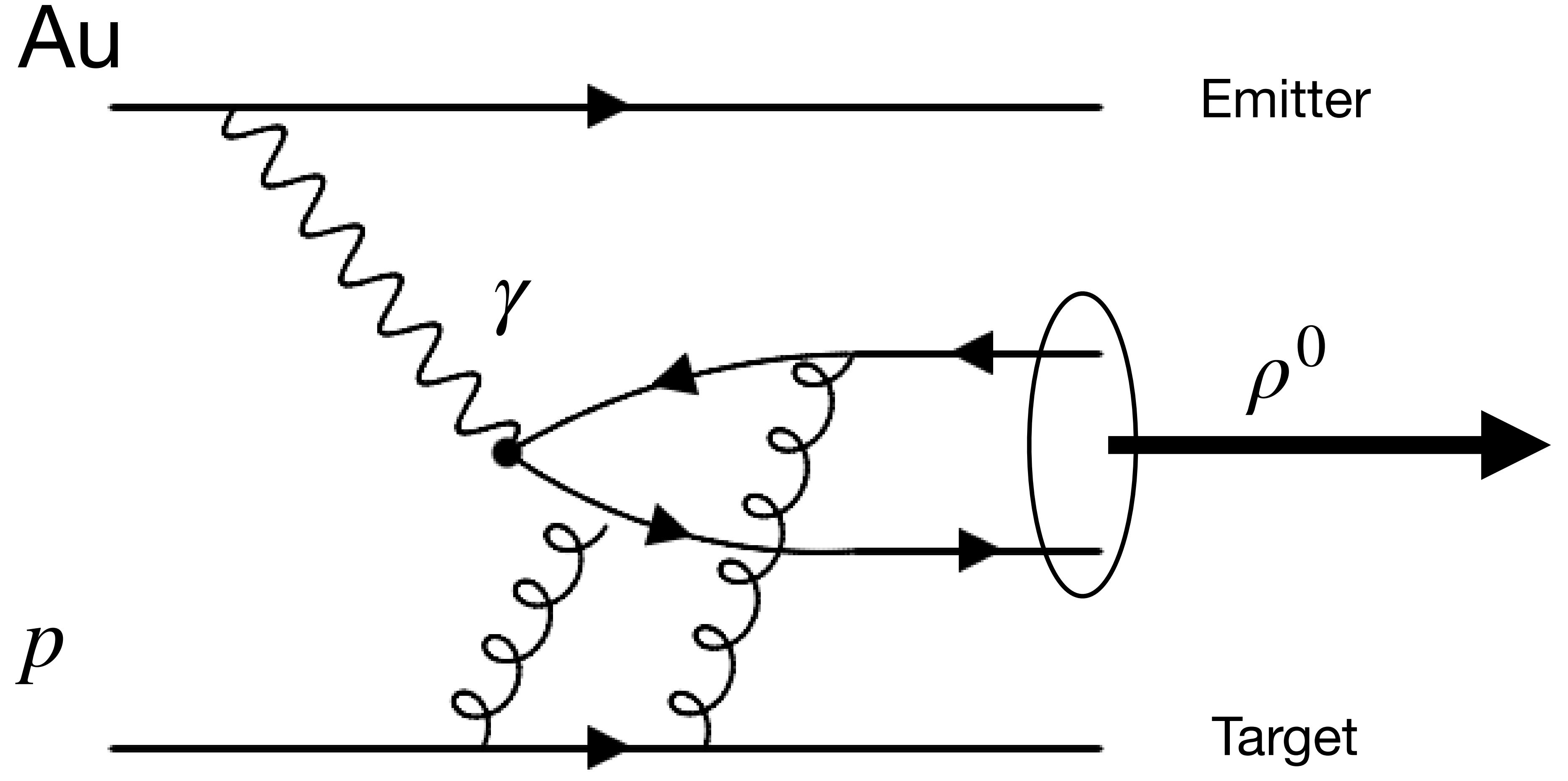
Single Spin Asymmetries in UPC

Exclusive ρ^0 photo-production

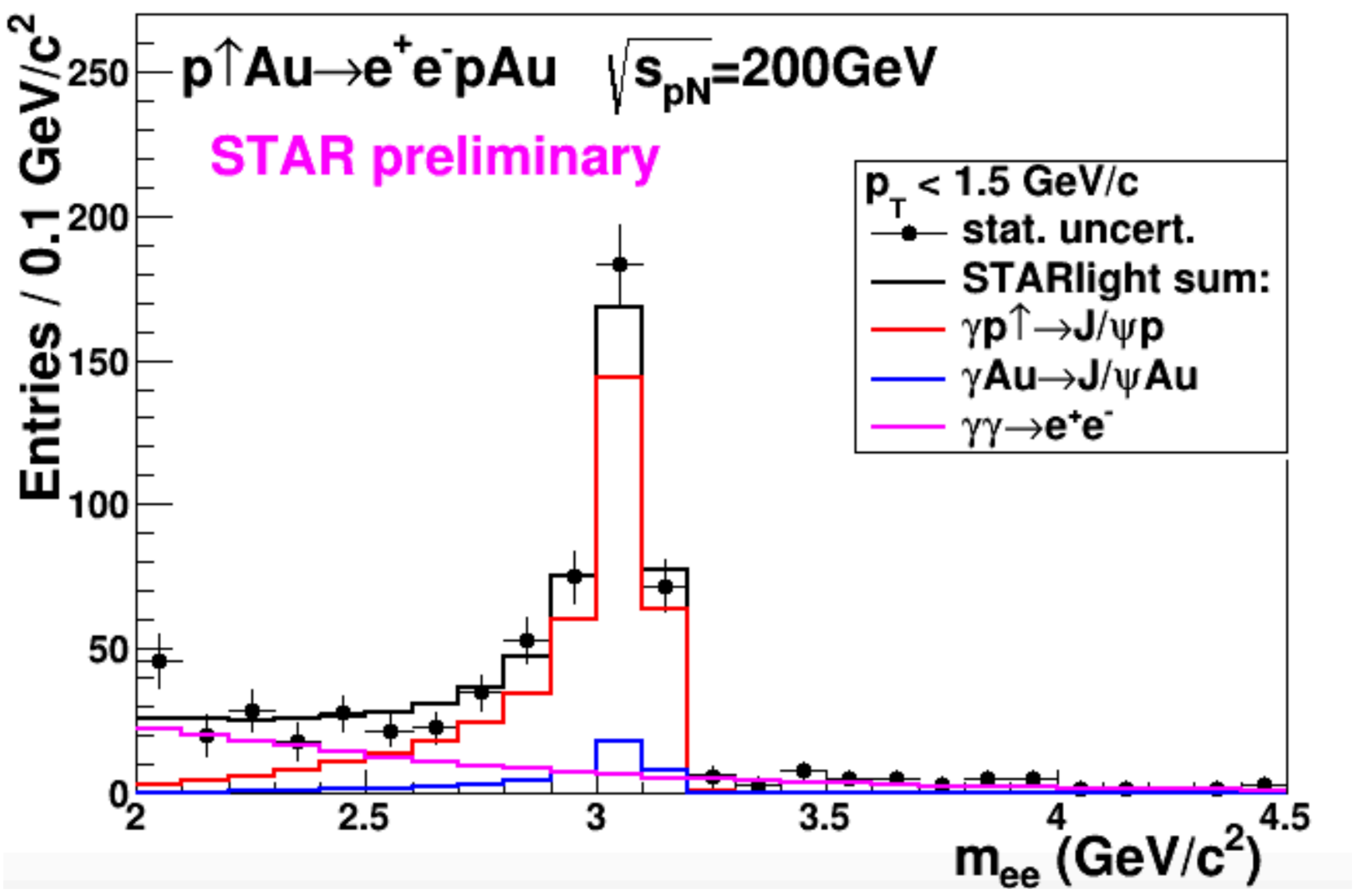
Run 15 pAu $\sqrt{s_N} = 200$ GeV



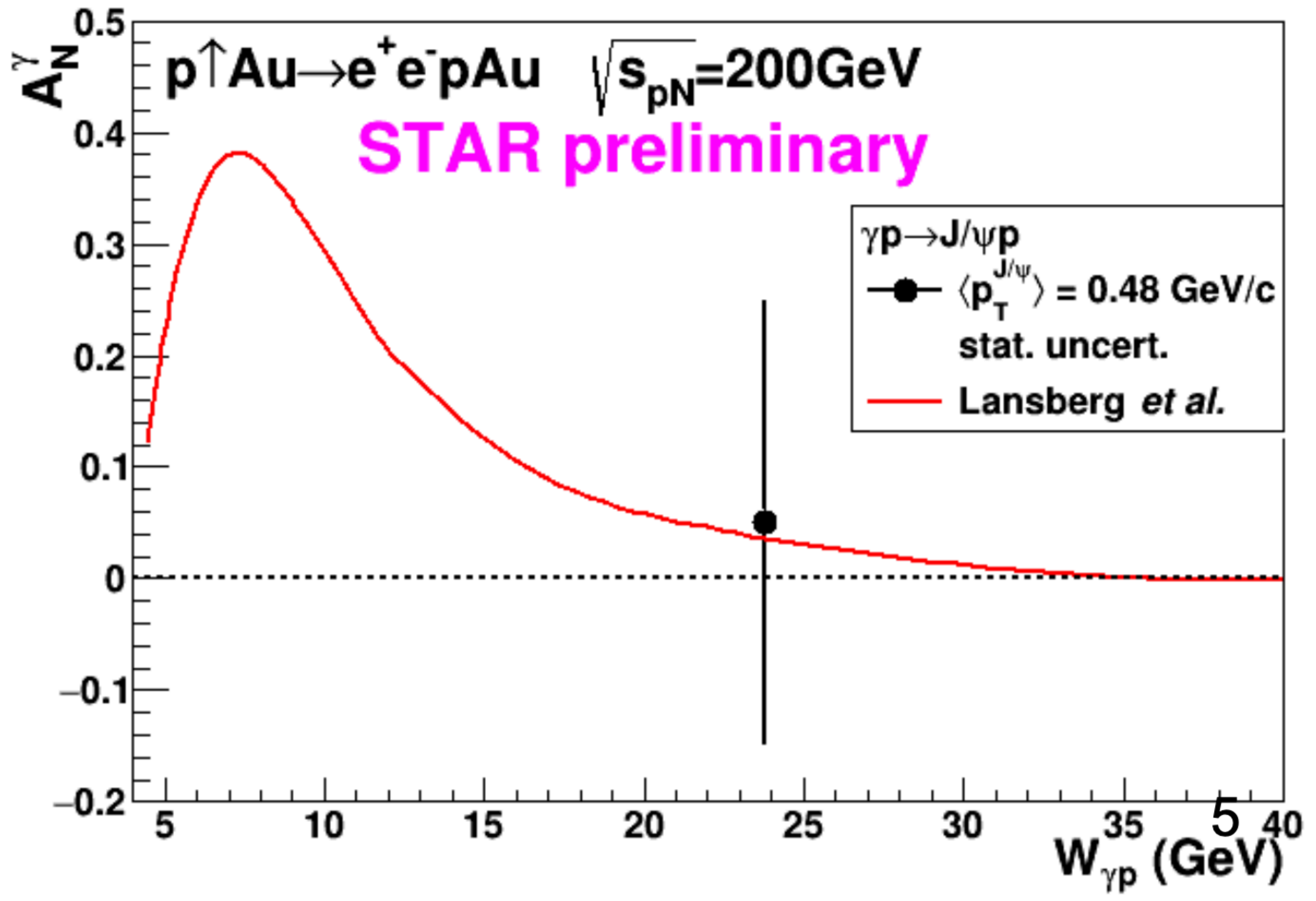
Daniel Torres Valladares
23/04/2025

Motivation

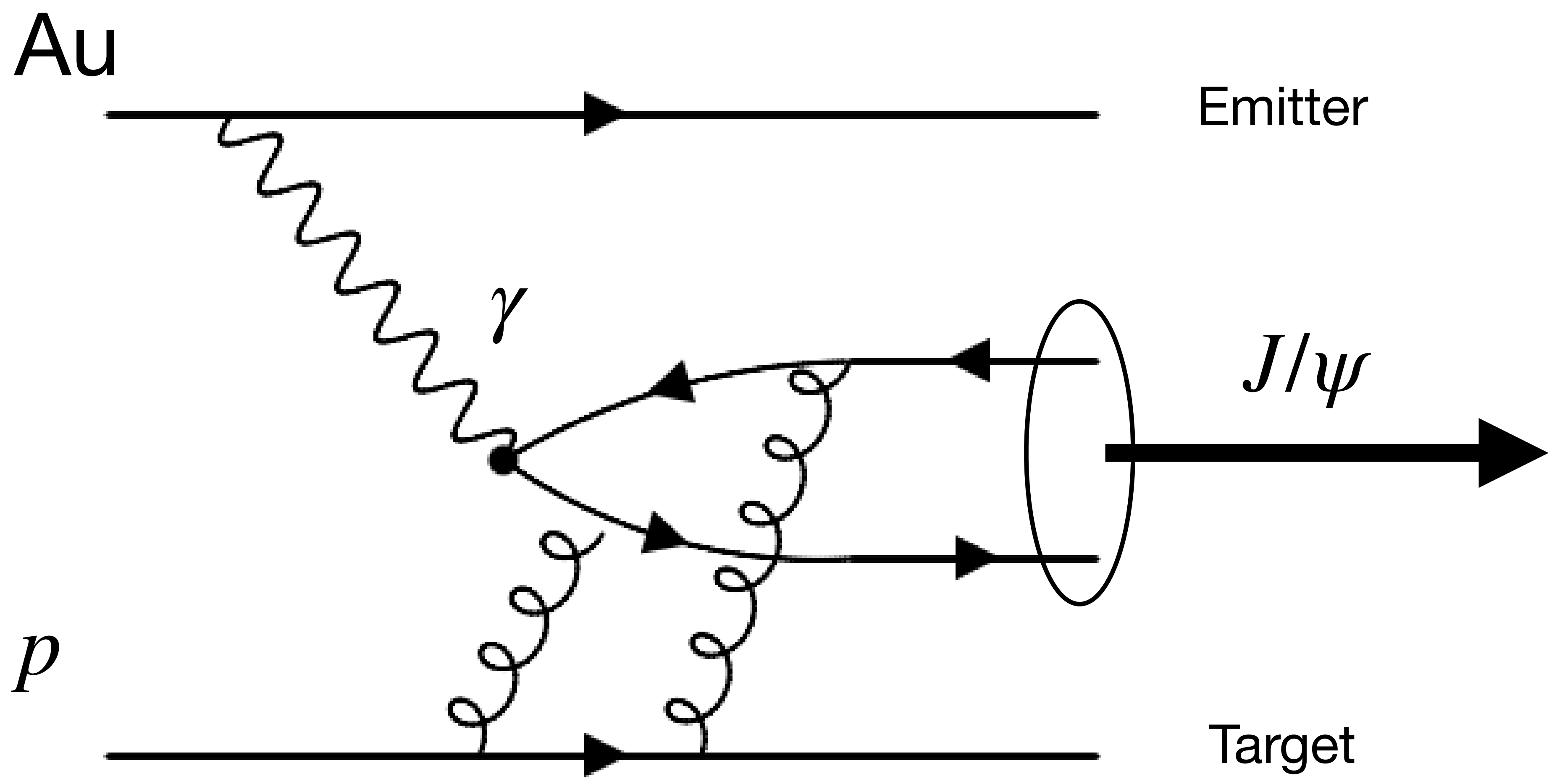
I aim to investigate single spin asymmetries (SSA) in photoproduction. A previous proof-of-principle measurement by W. Schmidke yielded a null result, but this analysis seeks to explore the potential for SSA within photoproduction processes.



Invariant mass spectrum for electron pairs.



SSA for J/Psi in Run 15 for RP_2E and 2E triggers. Plot obtained from presentation of W. Schmidke.



Dataset description

All the results shown here, unless something else is specified, come from **Run 15** pAu collisions at $\sqrt{s_{NN}} = 200$ GeV the center of mass energy.

Trigger Name	Trigger ID	Production Tag	Library	Number of Events
RP_UPC	**500020**	**P16id**	**SL16d**	**131.88 M**
RP_UPC	**500000**	**P16id**	**SL16d**	**45.49 M**

Total = **177.37** M

Track quality cuts

Requires the following condition for each track

- $DCA < 3.0$
- $P_T > 0.2$ GeV
- $|Q| = 1$
- $|\eta| < 1$
- $|nHitsFit| > 15$
- $\left|nHitsdEdx\right| > 10$
- $0.32 < rationHits < 1.05$

Event Cuts

- nTracks = 2
- $|V_z| \leq 100$ cm
- $q_1 q_2 = -1$

Command to get the file list:

```
get_file_list.pl -distinct -keys path,filename \
  -cond 'trgsetupname=production_pAu200_2015,filetype=daq_reco_MuDst,library=SL16d,filename~st_physics,production=P16id,storage!=hpss' \
  -limit 0 -distinct -delim '/' > list/file_list_all.list
```

$\pi^+\pi^-$ pair selection

- **dE/dx Selection**

For a pair of tracks we define the quantity:

$\chi^2_{AB} = n\sigma^2_A + n\sigma^2_B$

And require that:

$\chi^2_{\pi\pi} < 8$

Additionally, we require for each individual track

$n\sigma_Y > 2$, where $Y = (p, K)$

- **TOF selection**

Setting the VPD Start time to zero $(t_0 = 0)$, we define the quantity

$\Delta TOF_{\text{measured}} = t^+_{\text{bTOF}} - t^-_{\text{bTOF}}$

$\Delta TOF_{\text{expected}} = t^+_{\text{expected}} - t^-_{\text{expected}}$

With

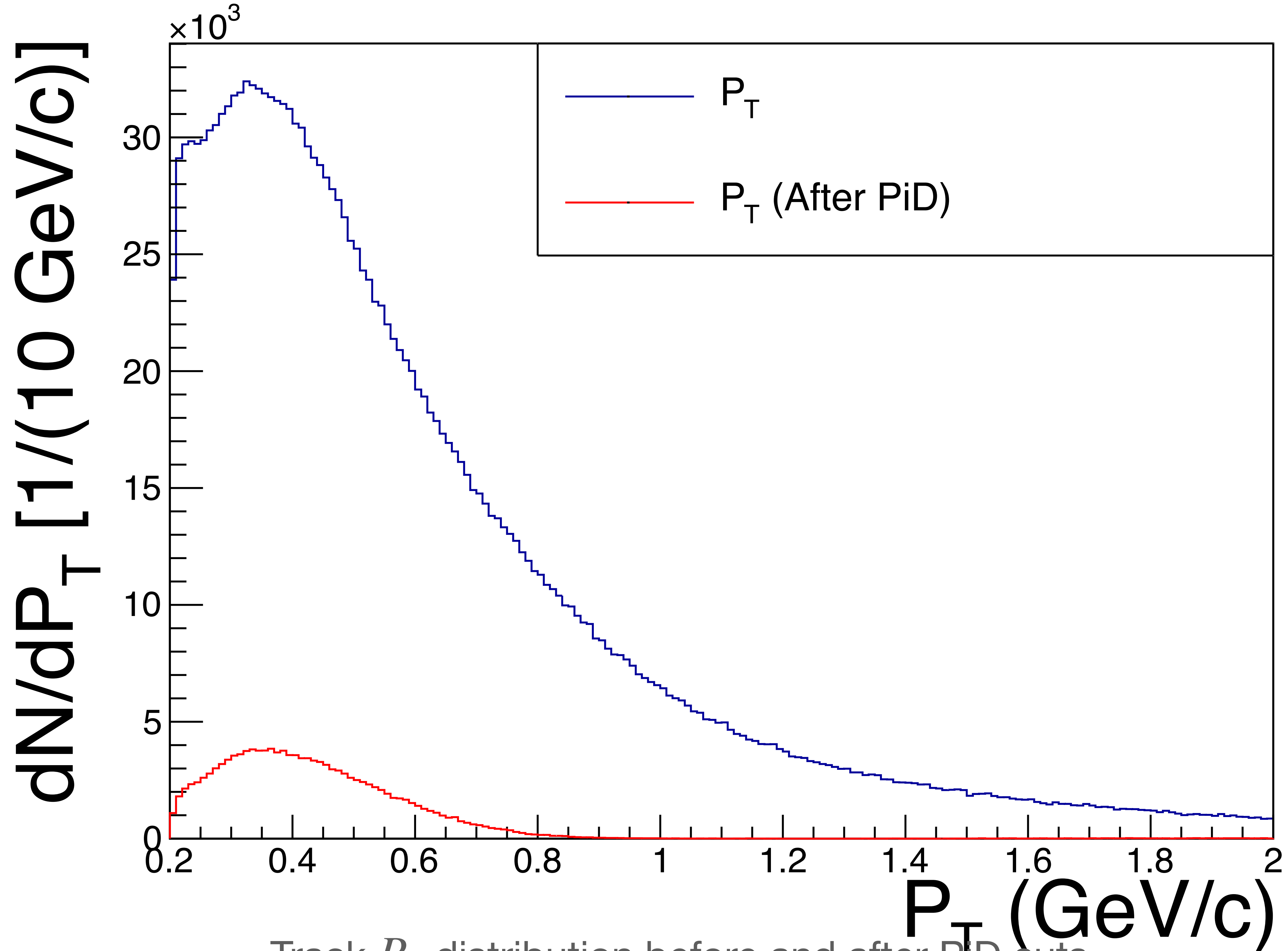
$$t_{\text{expected}} = \frac{\Delta s}{c}\sqrt{1 + \frac{m_\pi^2 c^2}{p_\pi^2}}$$

$\Delta\Delta TOF = \Delta TOF_{\text{measured}} - \Delta TOF_{\text{expected}}$

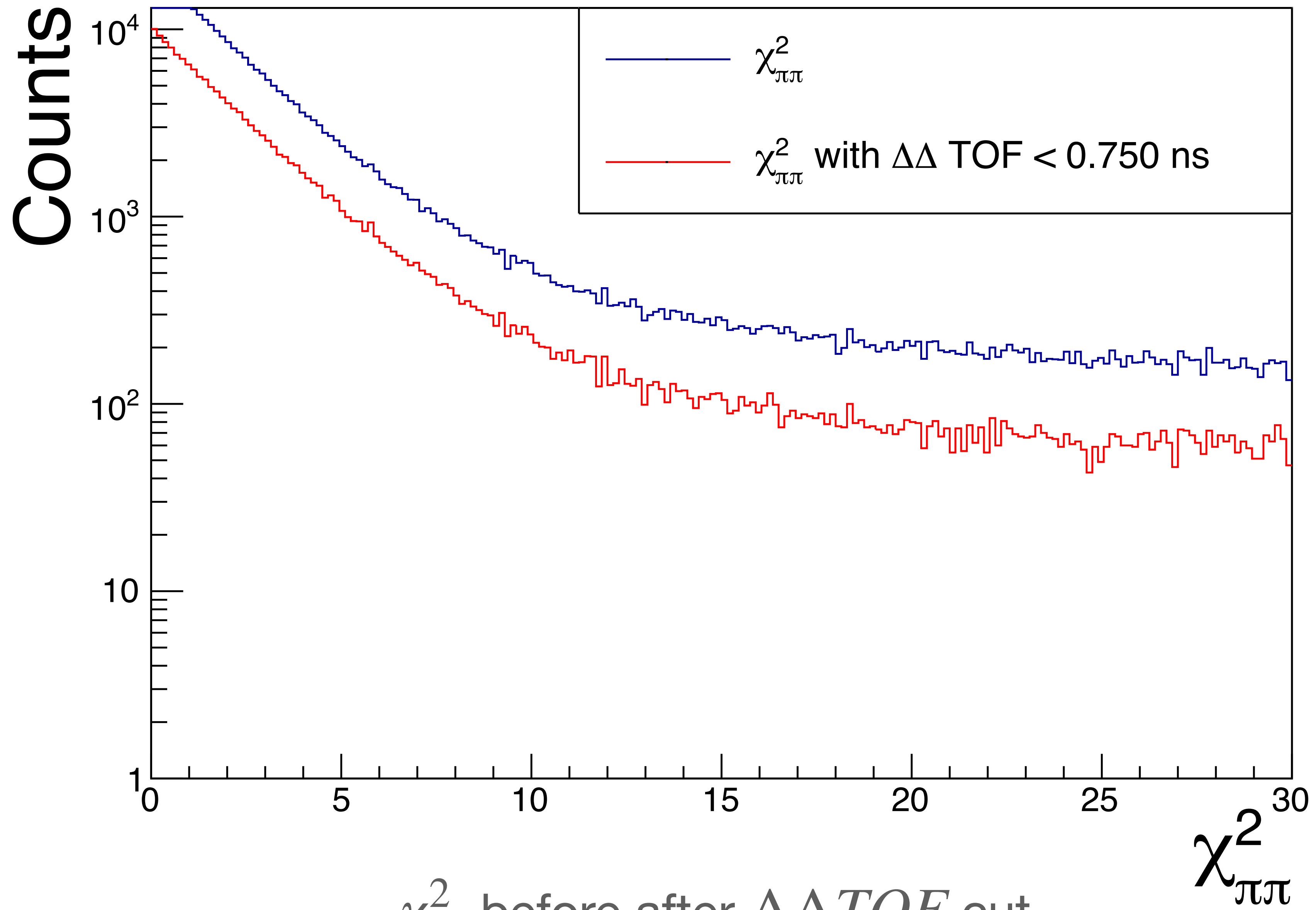
$\Delta\Delta TOF < 0.75$ ns

PiD variables plots

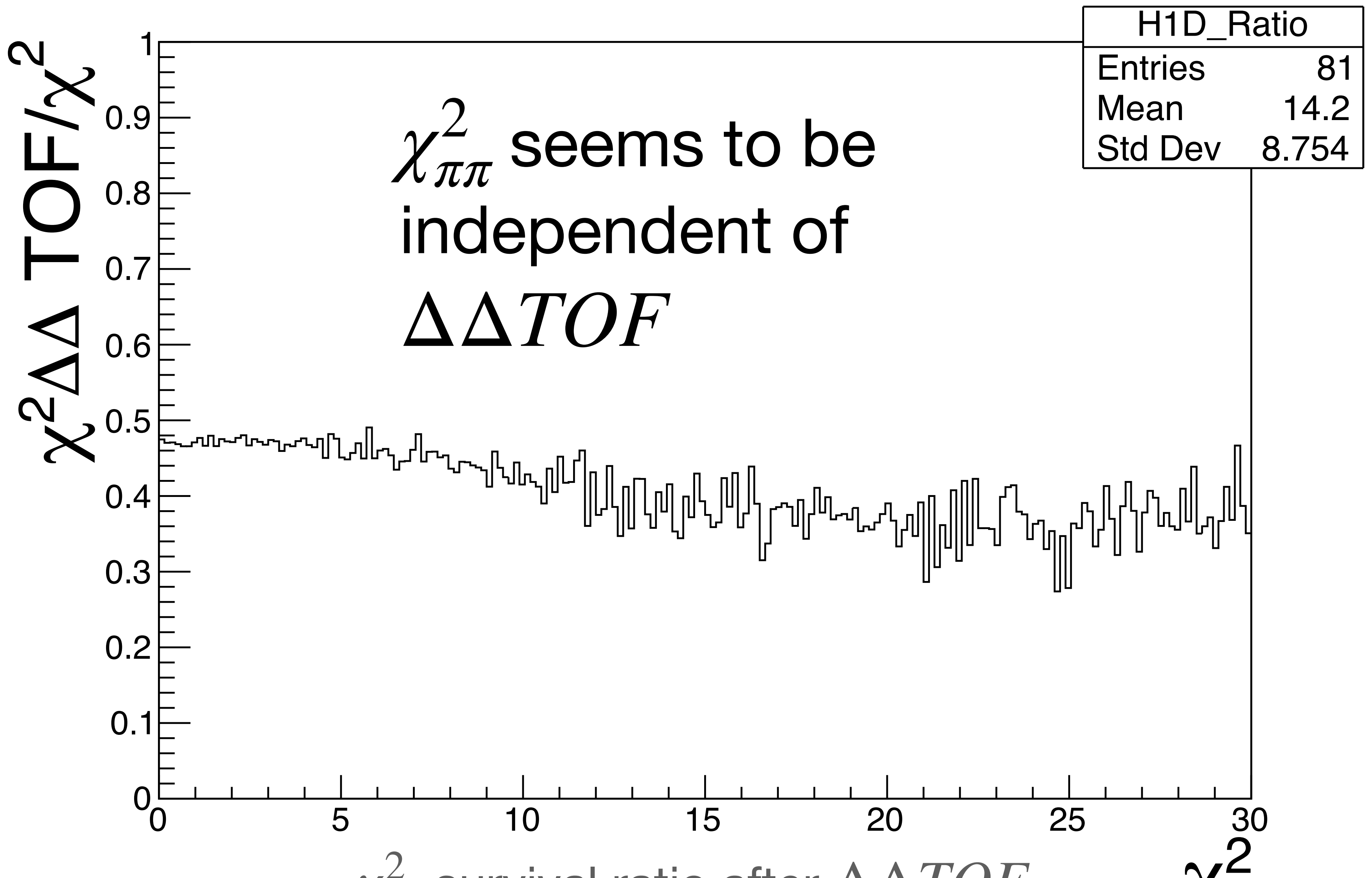
P_T^{π} **cuts:** The tail exhibits a steeper decline compared to when no PiD is applied. This is expected, as the applied cuts eliminate momentum ranges where PiD cuts are less effective in distinguishing between particles, i.e. $P_T > 1$ GeV/c



Track P_T distribution before and after PID cuts.

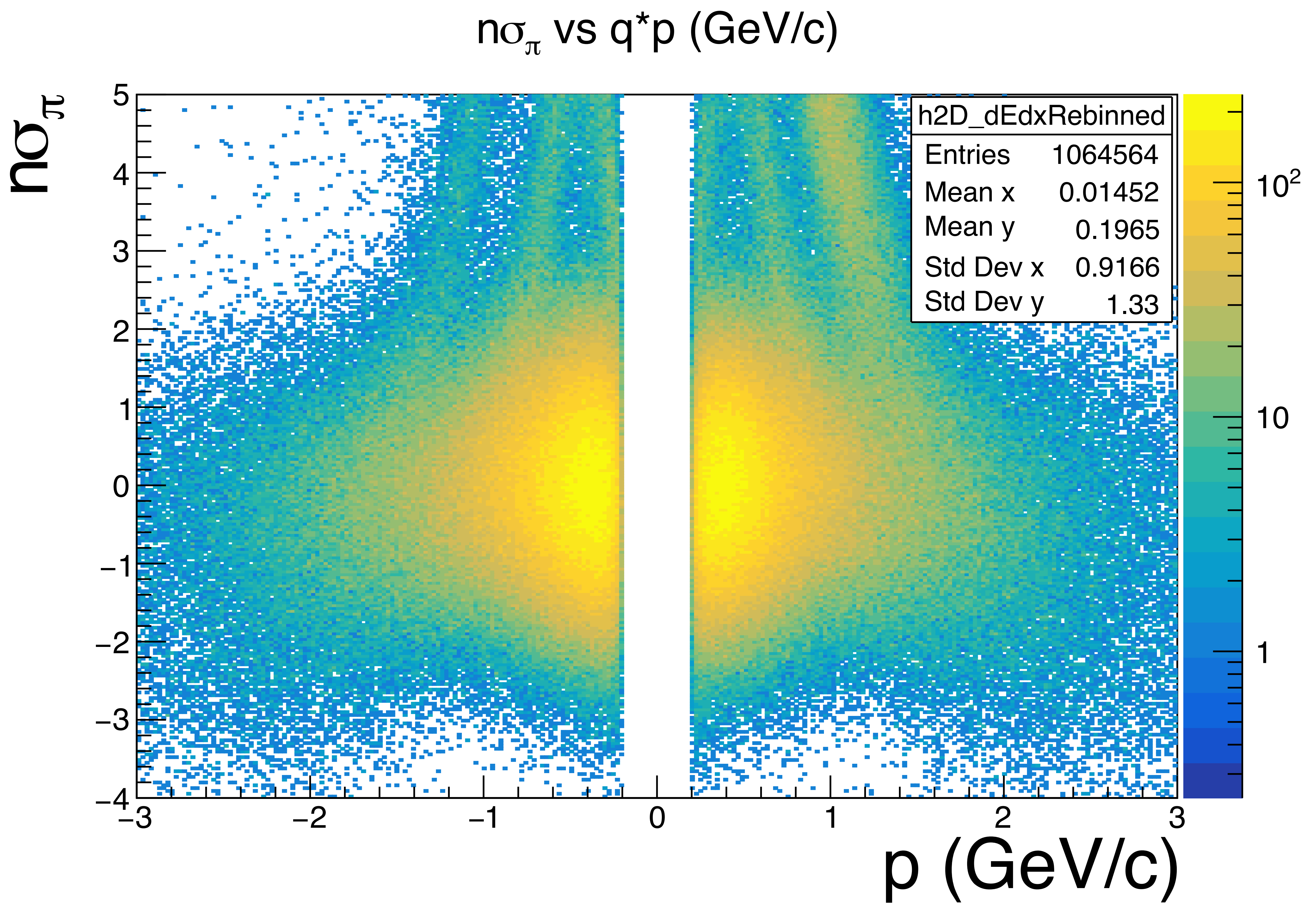


$\chi^2_{\pi\pi}$ before after $\Delta\Delta TOF$ cut.

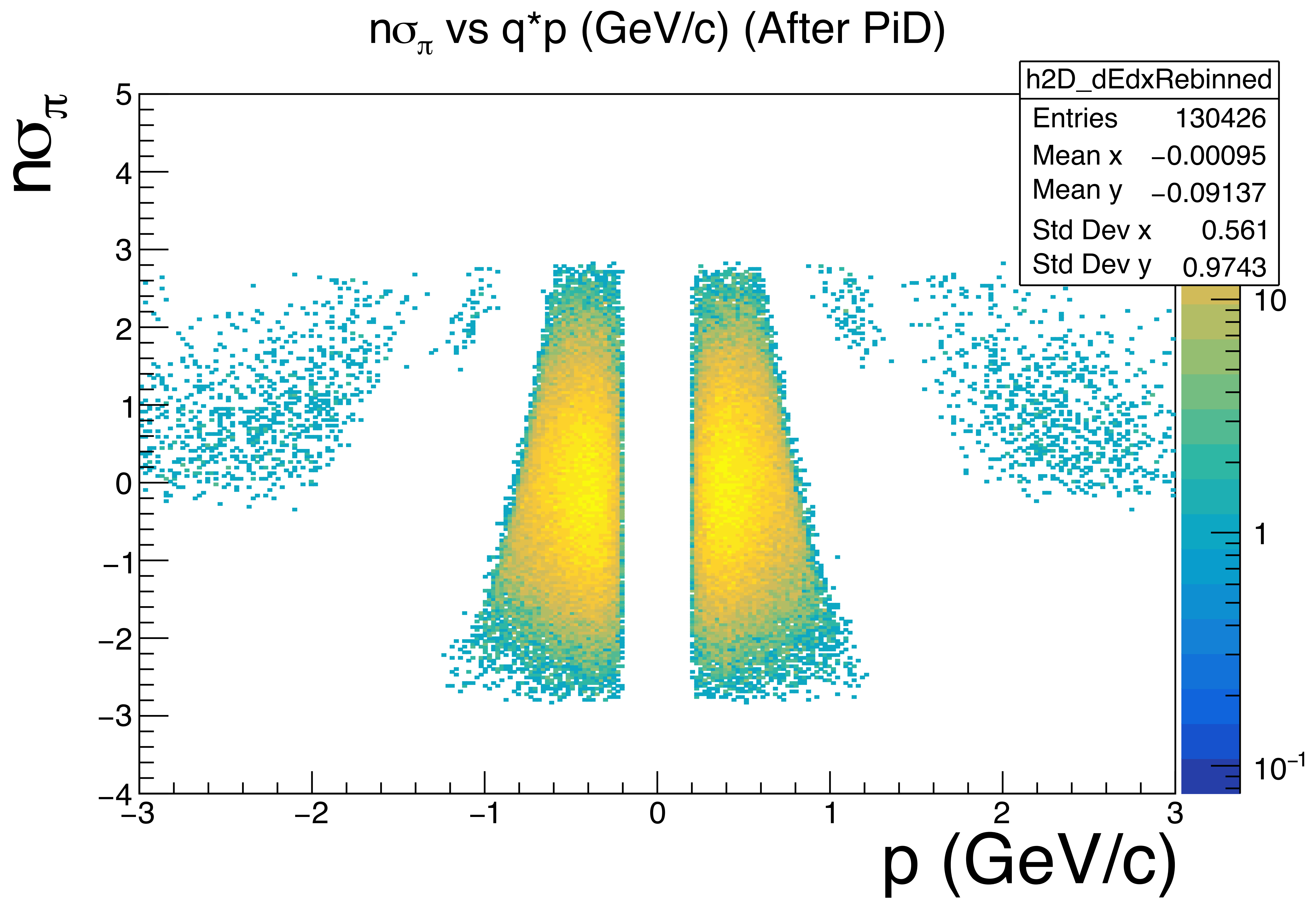


$\chi^2_{\pi\pi}$ survival ratio after $\Delta\Delta TOF$

PiD variables plots

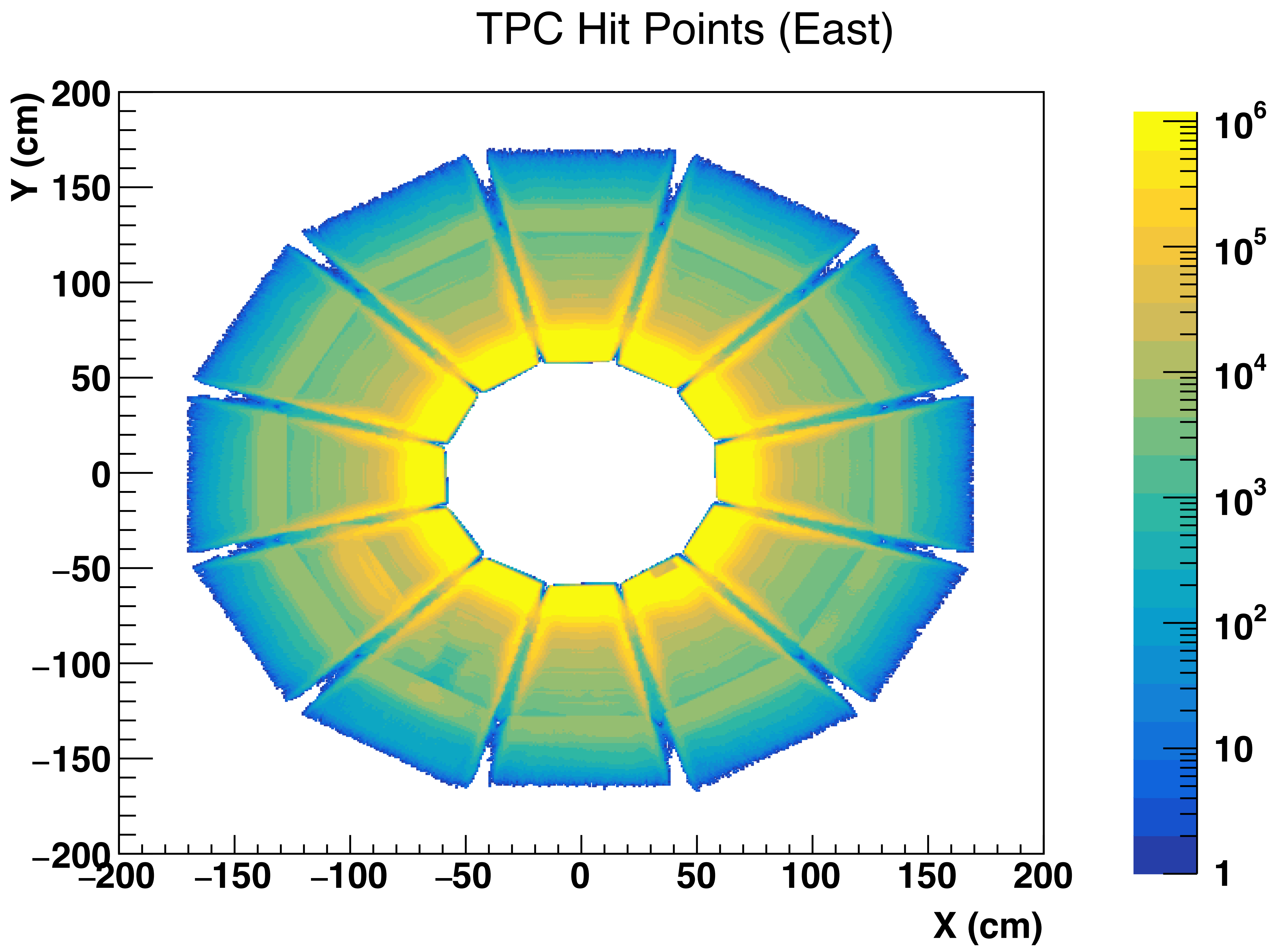


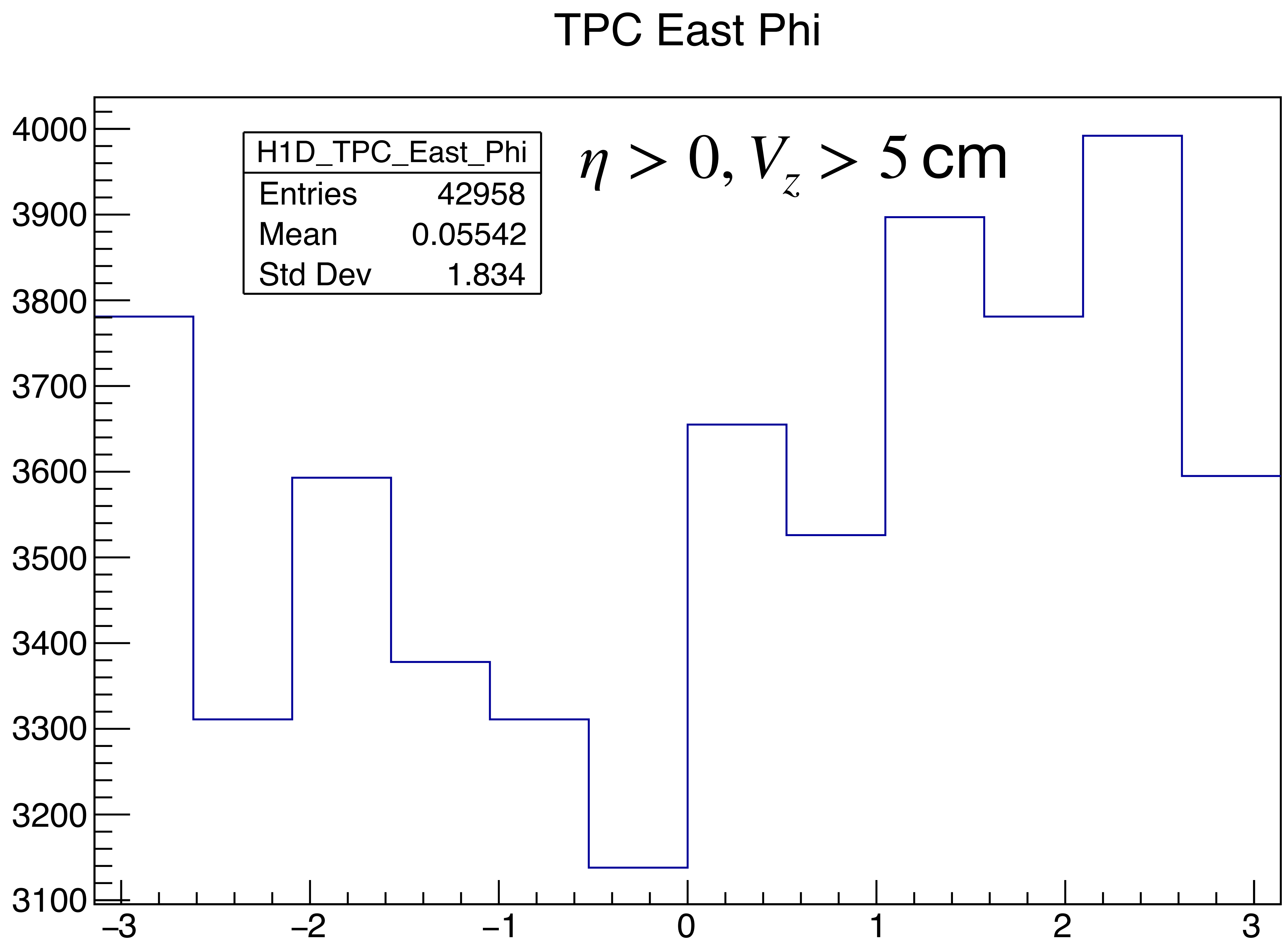
$n\sigma_\pi$ vs charge*momentum after PiD



$n\sigma_\pi$ vs charge*momentum after PiD

Q&A Plots

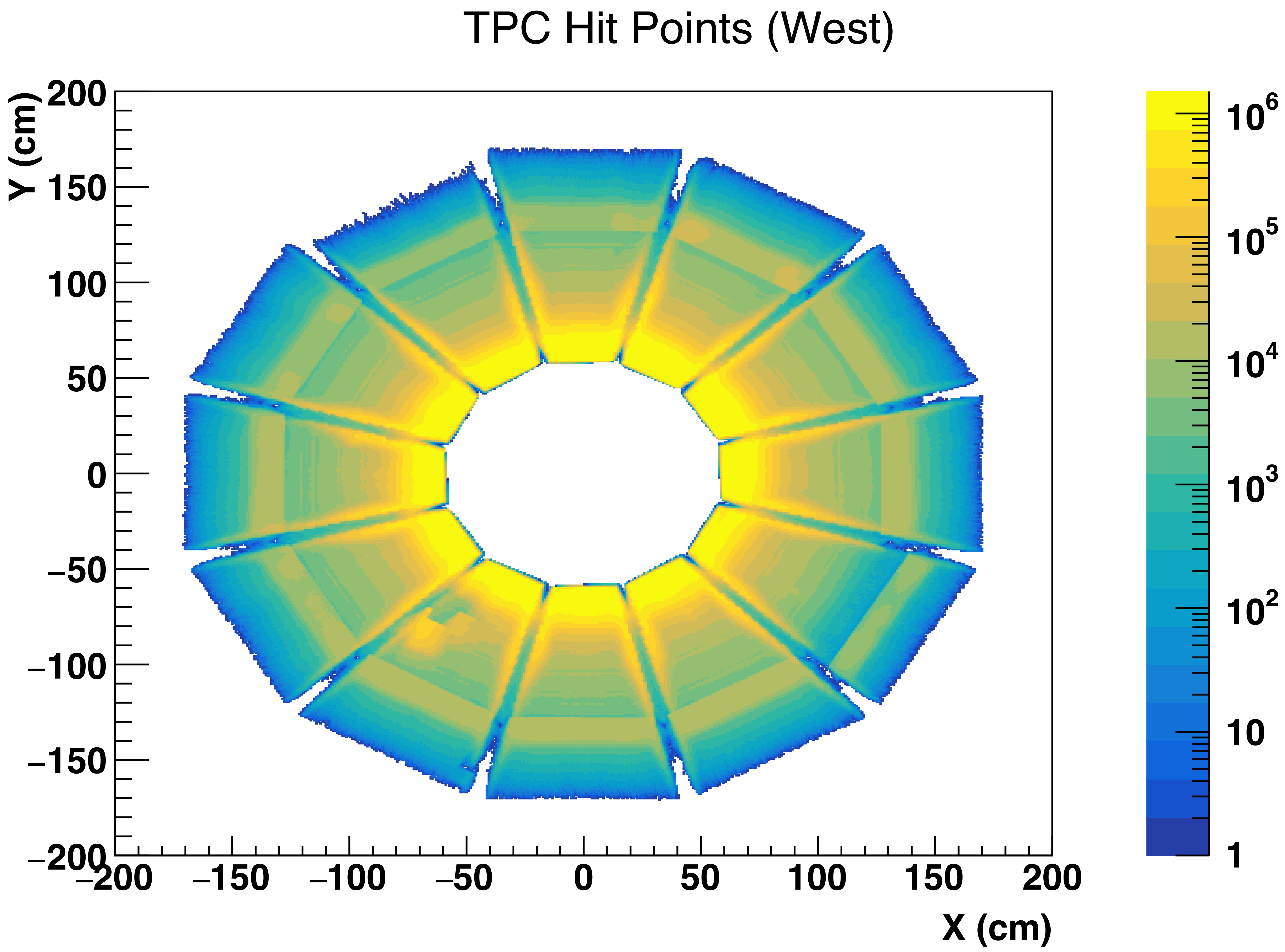


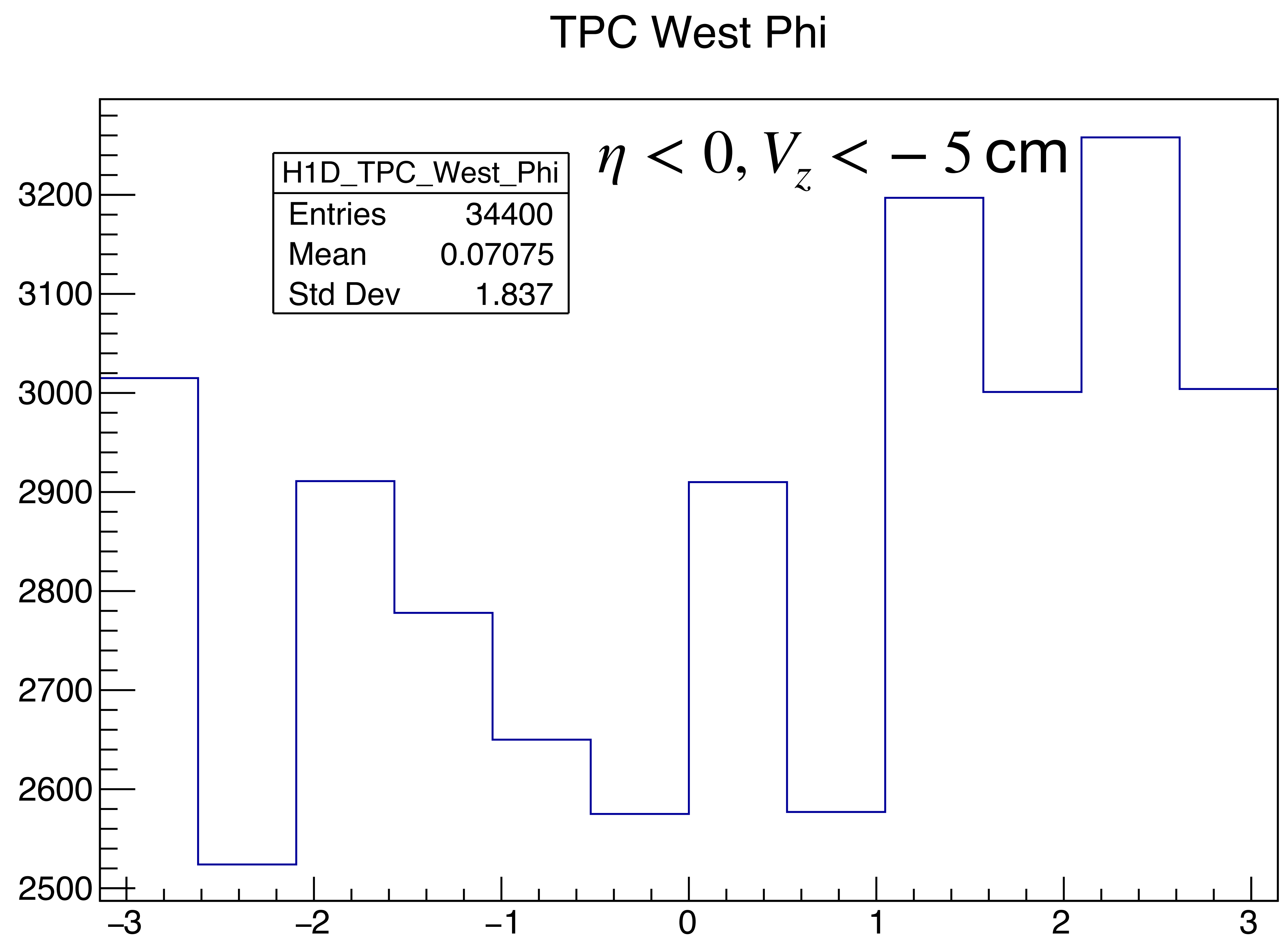


Track quality cuts + PiD cuts

- $|n\sigma_\pi| < 2$
- $|n\sigma_p| > 2$
- $|n\sigma_K| > 2$
- $|n\sigma_e| > 3$

Q&A Plots





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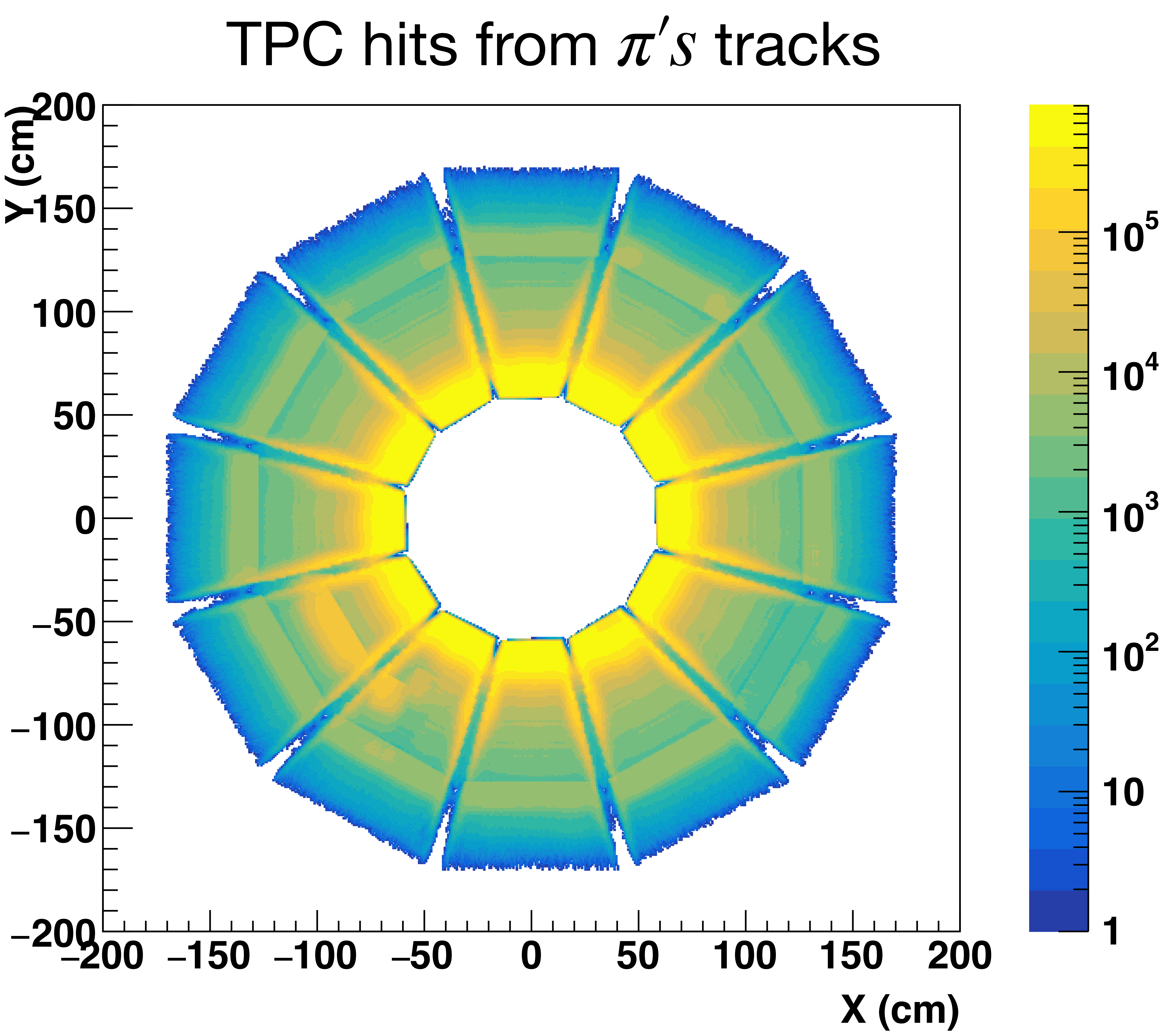
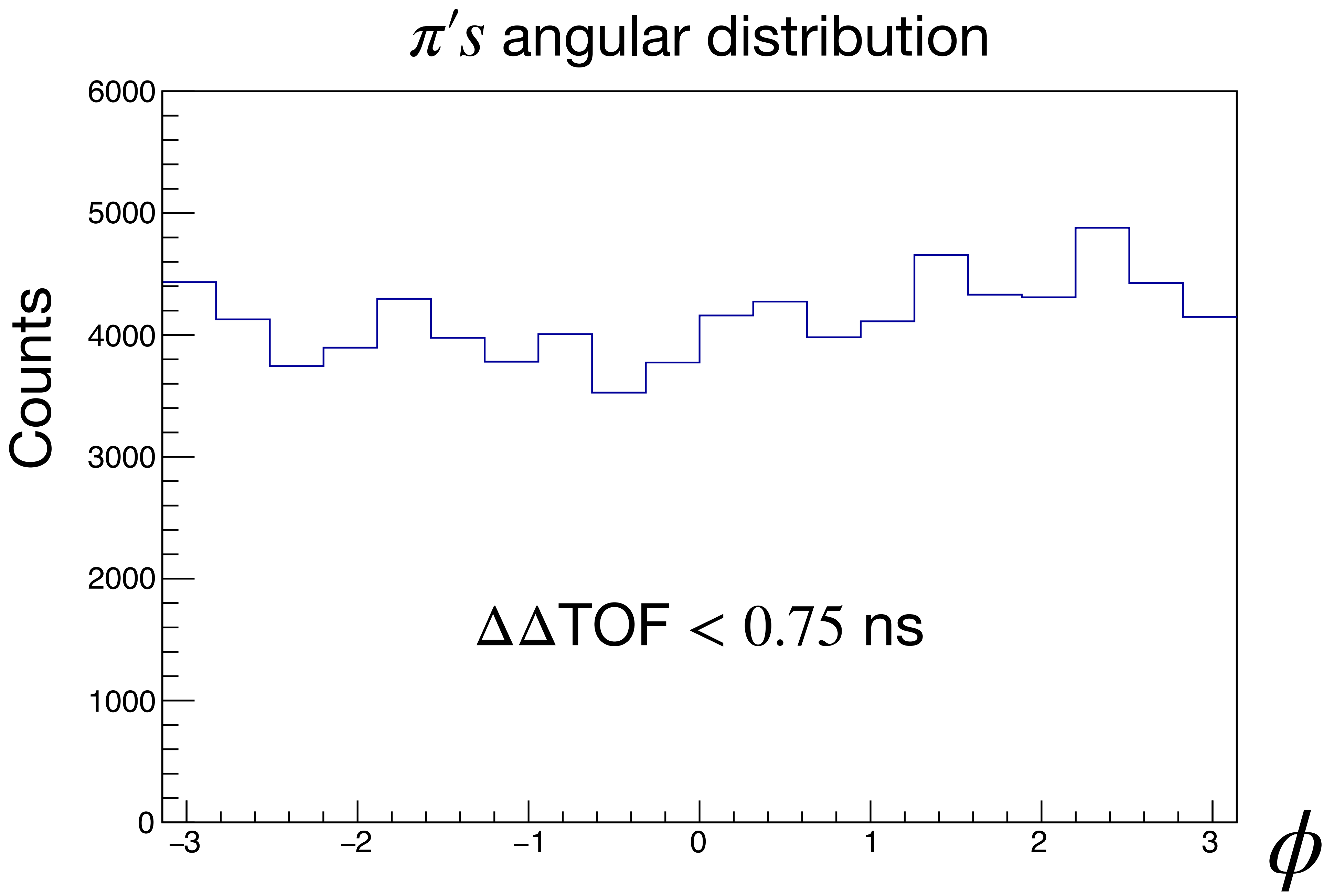
Q&A Plots



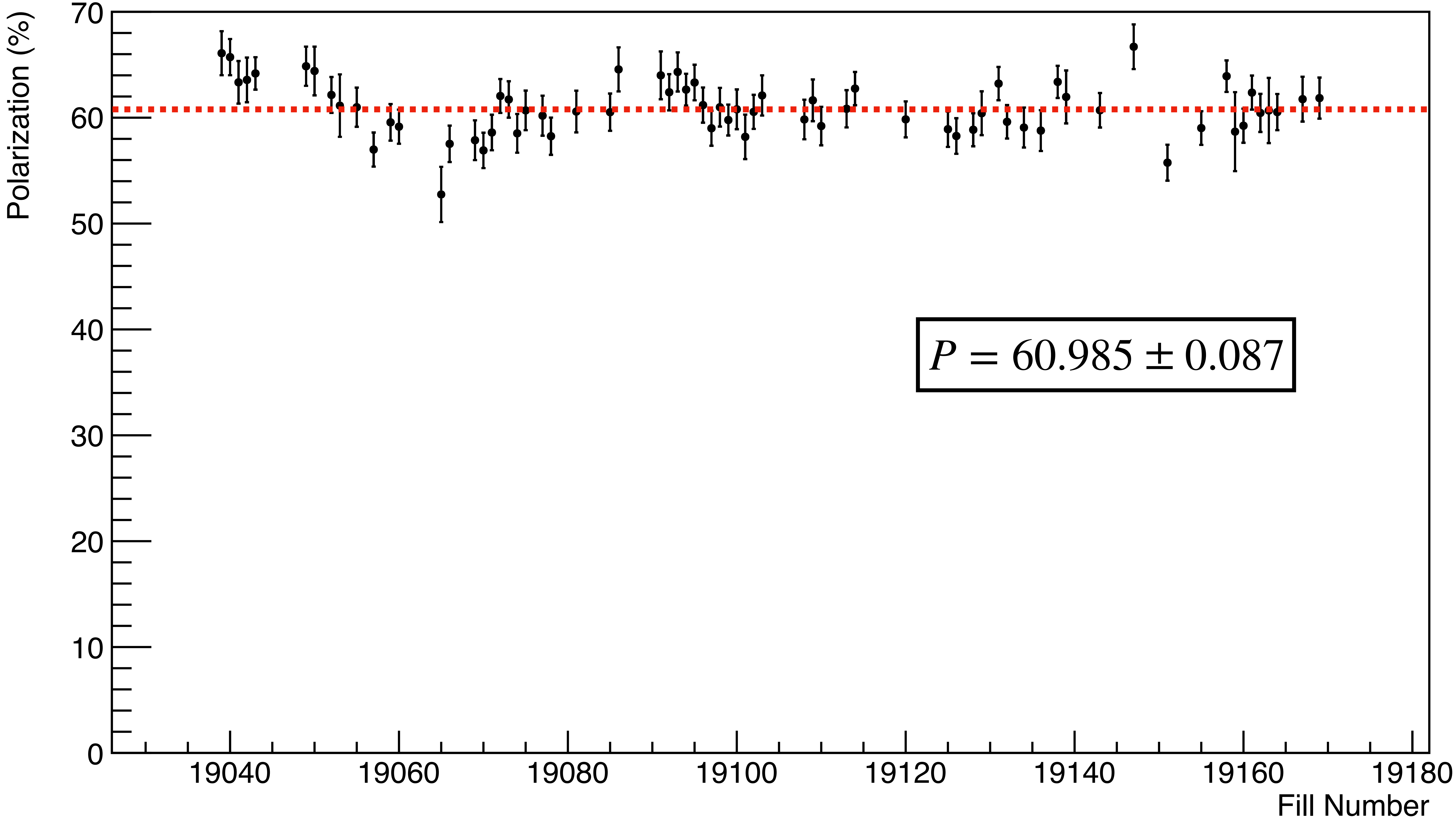


Track quality cuts + PiD cuts

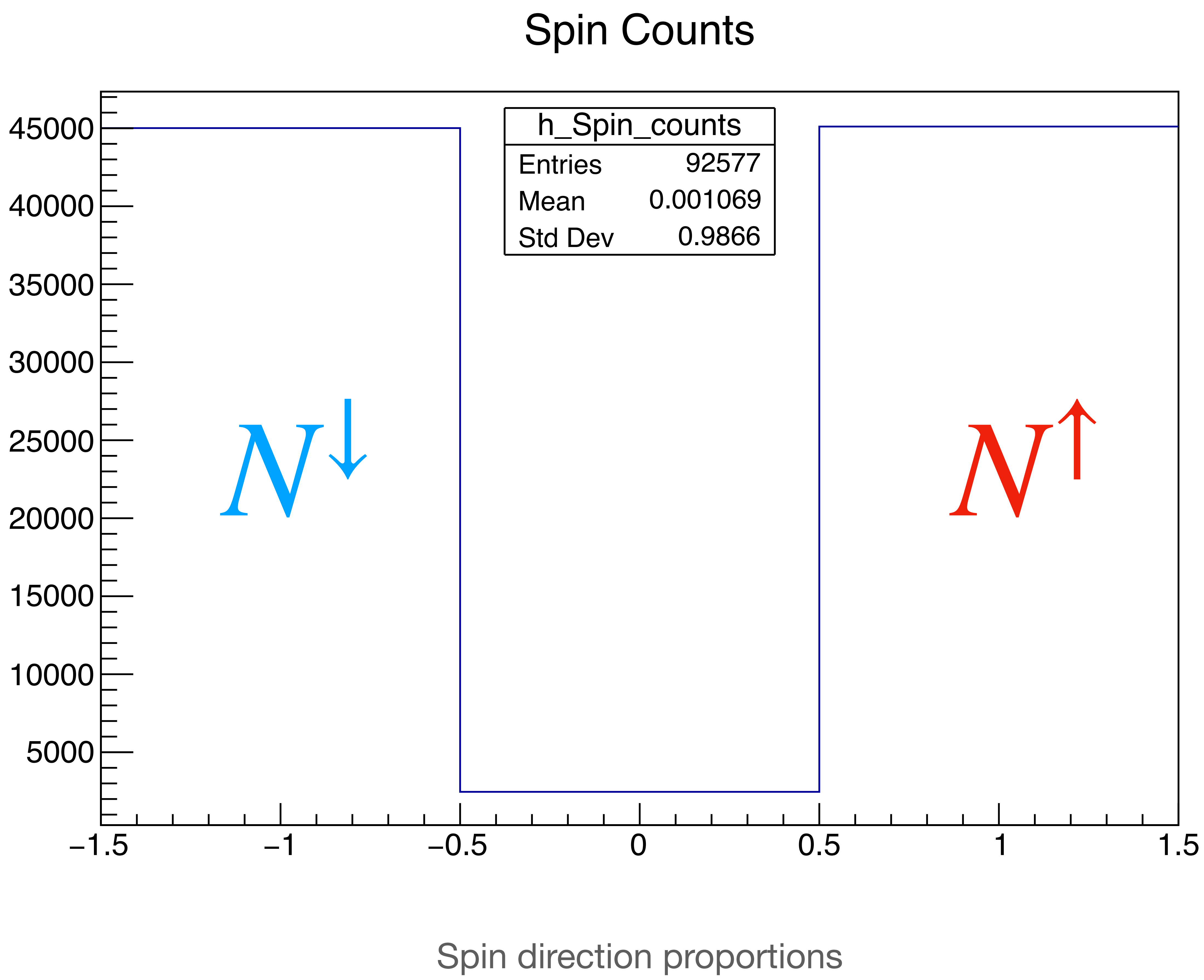
- $|n\sigma_\pi| < 2$
- $|n\sigma_p| > 2$
- $|n\sigma_K| > 2$
- $|n\sigma_e| > 3$

A roughly uniform angular distribution can be observed in the TPC sectors.

QA Polarization Plot

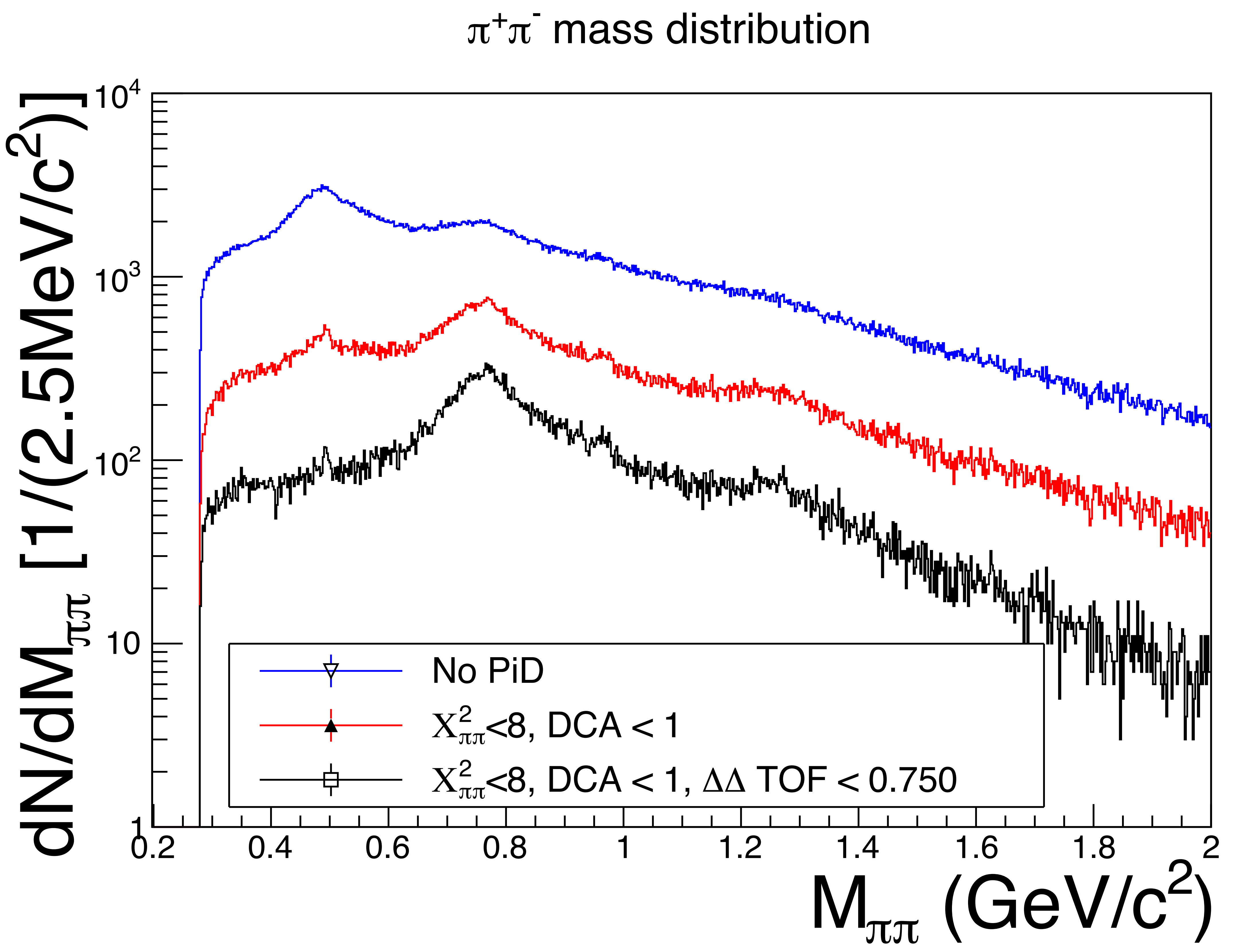


QA Spin Ratios

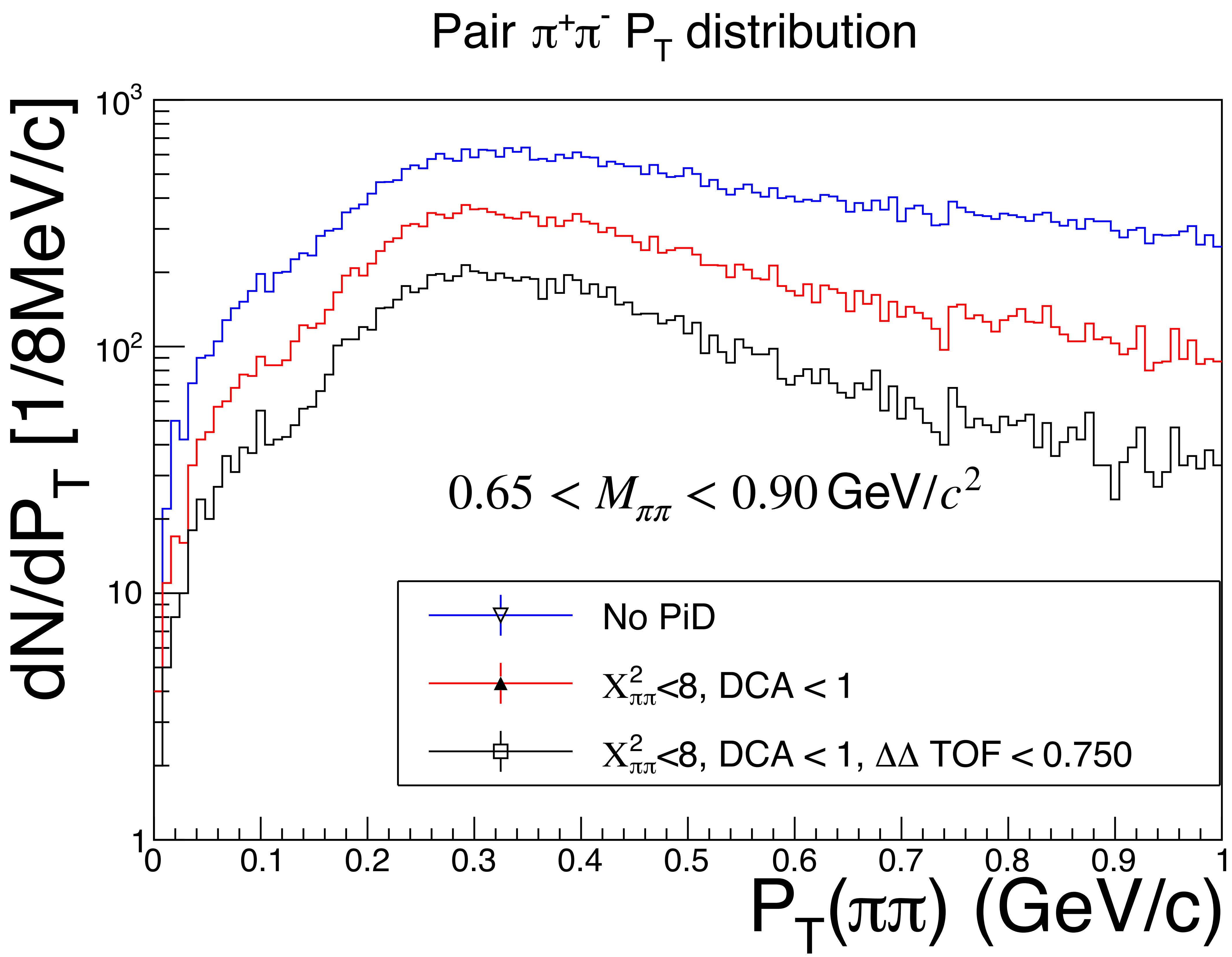


- **Equal Number of Events:** The dataset contains an equal number of events with the proton spins oriented in the positive and negative y-axis directions.
- **Zero Spin Designation:** A spin value of zero is assigned when the bunch ID corresponds to an empty beam pipe or indicates no polarization information for the proton.

Mass and Momentum after PiD



Invariant mass histogram for Run 15 AuAu collisions at $\sqrt{s_{NN}} = 200$



Transverse momentum of two opposite sign pions histogram for Run 15 AuAu collisions at $\sqrt{s_{NN}} = 200$

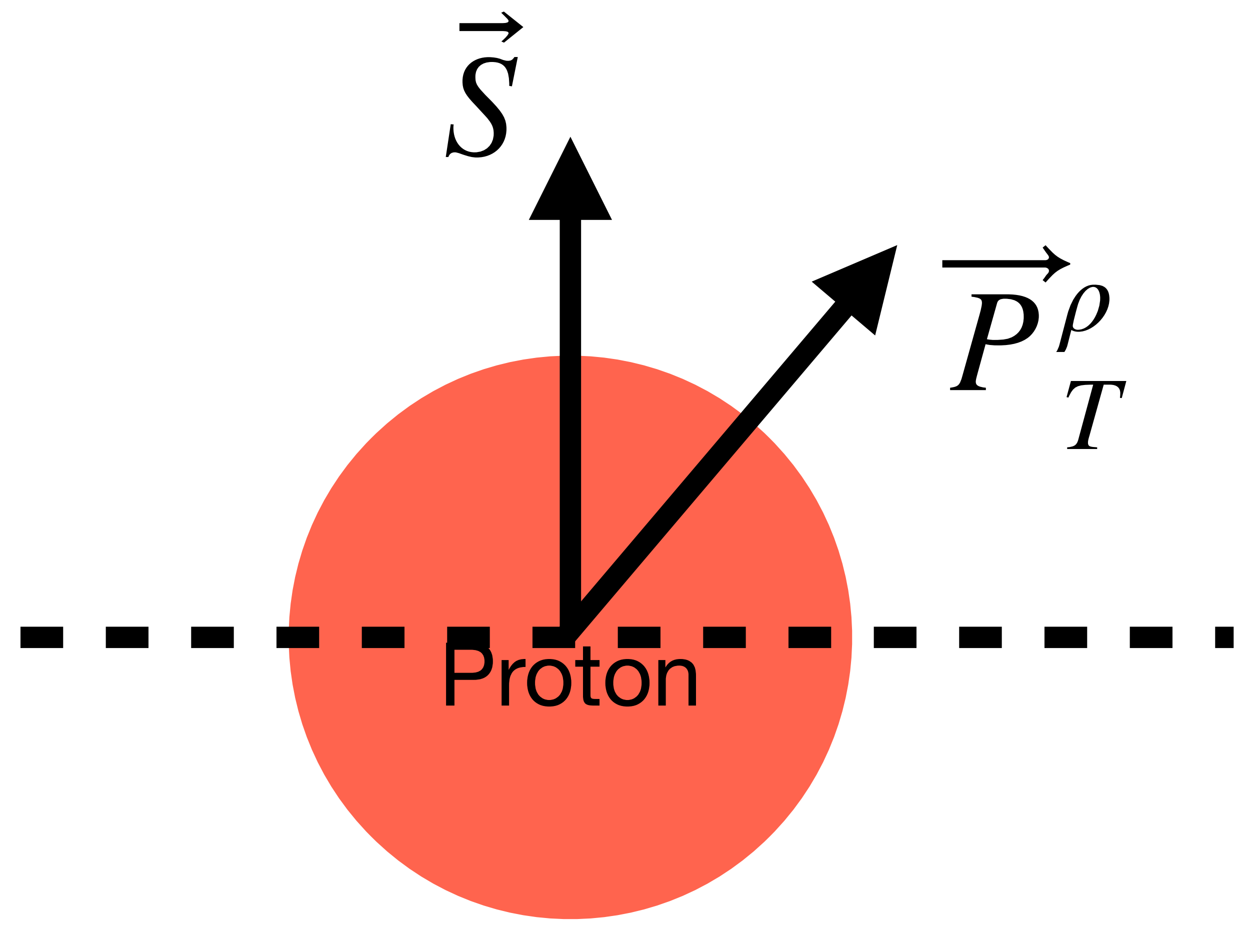
A_N Definition

The A_N asymmetry quantifies the imbalance in particle production relative to the proton's spin direction, usually defined as:

$$A_N = \frac{1}{P}\frac{\sigma_{\parallel} - \sigma_{\nparallel}}{\sigma_{\parallel} + \sigma_{\nparallel}} = \frac{1}{P}\frac{\sigma_{\parallel} - \sigma_{\nparallel}}{N}$$

Here, $\sigma_{\uparrow}$ and $\sigma_{\downarrow}$represent the particle production rates with momentum components parallel and anti-parallel to the proton's spin, respectively. And, $P = 60\,\%$ represents the average polarization for the proton's beam.

$$\sigma_{\parallel} = N\left(\vec{P}_T \cdot \vec{s} > 0\right)$$



$$\sigma_{\nparallel} = N\left(\vec{P}_T \cdot \vec{s} < 0\right)$$

Transverse Plane

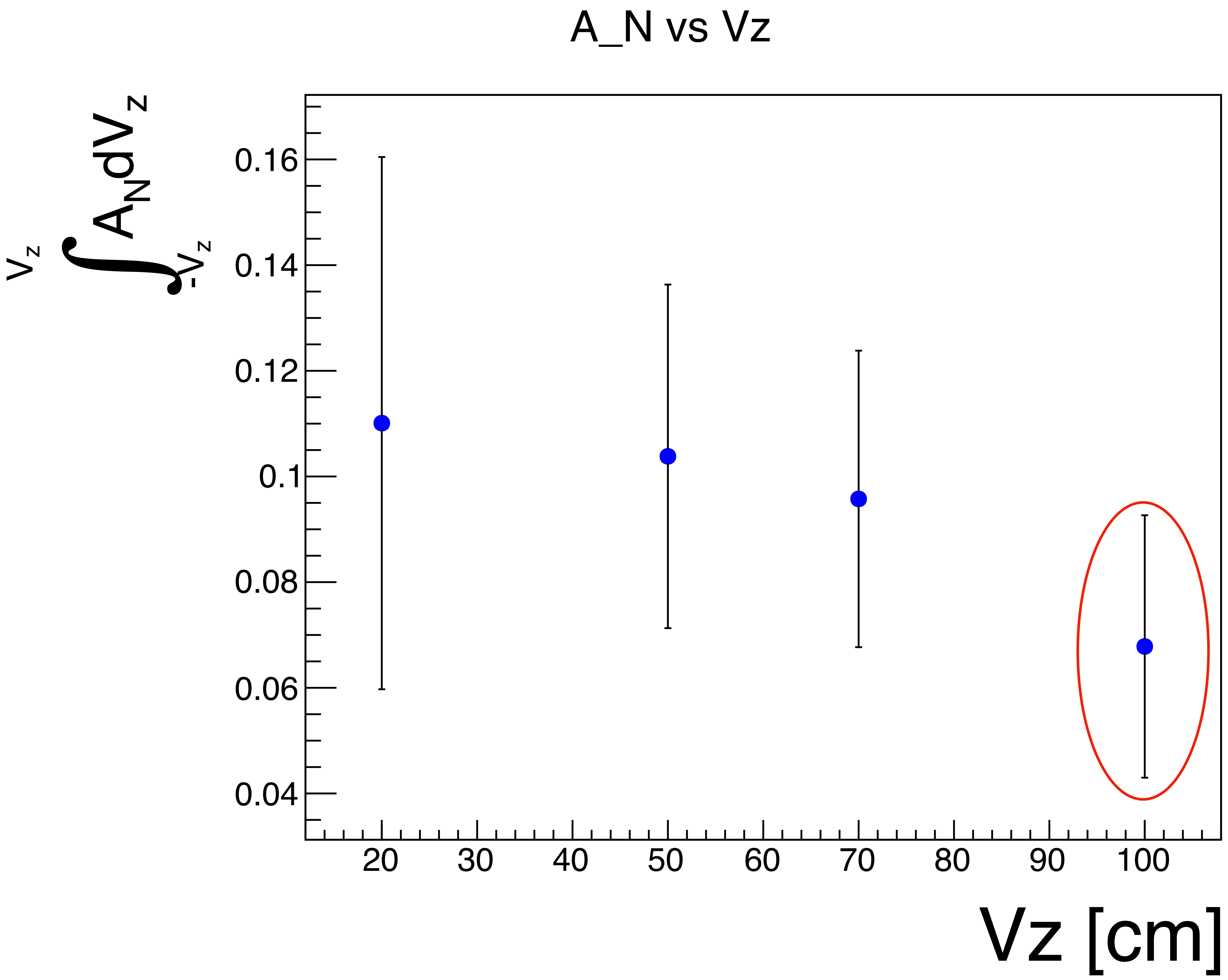
- A_N **Uncertainty**

$$\Delta A_N = \sqrt{\left(\frac{\partial A_N}{\partial \sigma_{\parallel}}\right)^2 \Delta\sigma_{\parallel} + \left(\frac{\partial A_N}{\partial \sigma_{\nparallel}}\right)^2 \Delta\sigma_{\nparallel}}$$

$$\left|\frac{\partial A_N}{\sigma_{\parallel,\nparallel}}\right| = \frac{2\sigma_{\nparallel,\parallel}}{N^2}$$

$$\Delta A_N = 2\frac{\sqrt{\sigma_{\parallel}\Delta\sigma_{\nparallel} + \sigma_{\nparallel}\Delta\sigma_{\parallel}}}{N^2}$$

Raw Results vs Vz Cuts



The values for the asymmetry for the different V_Z cuts are:

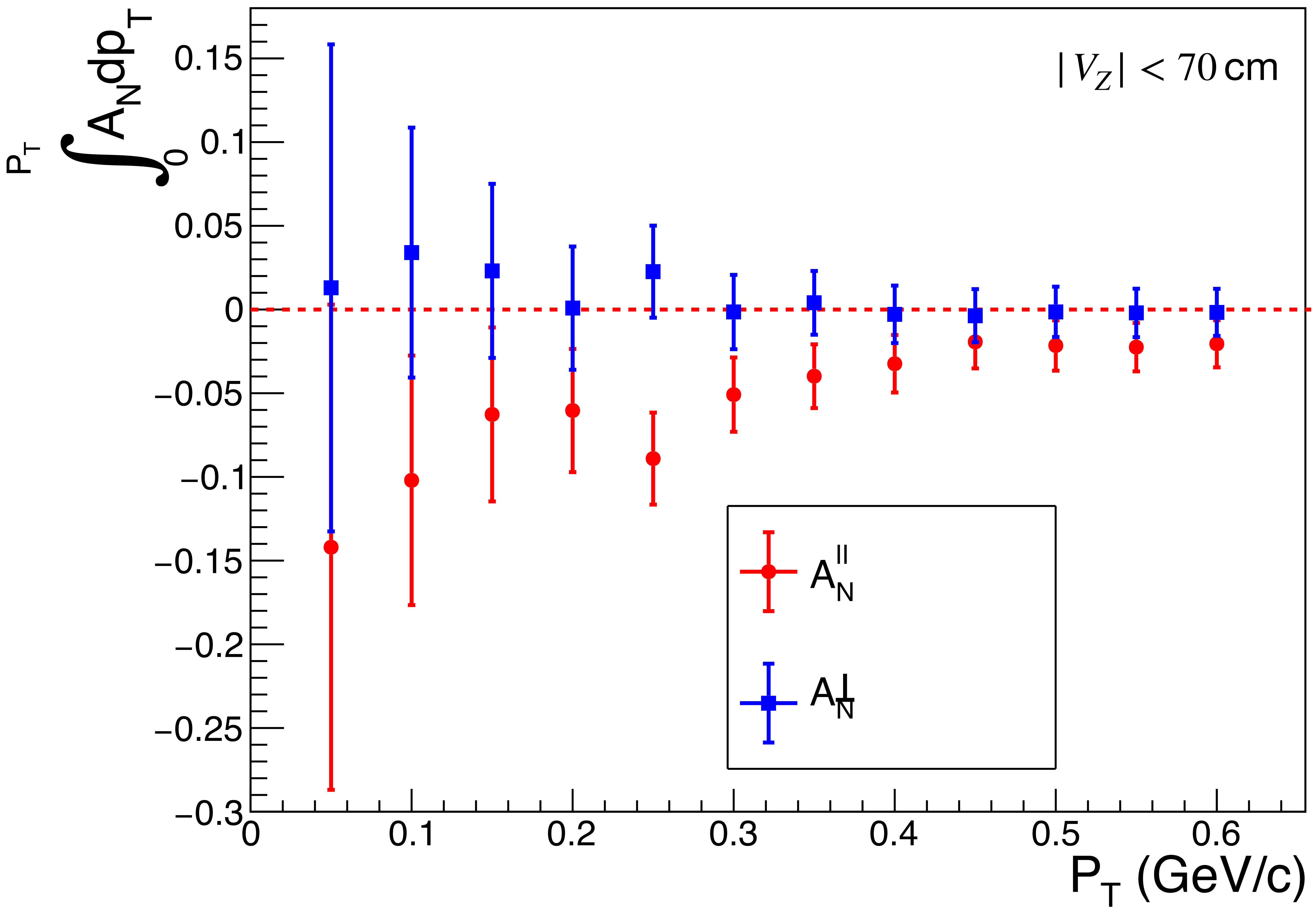
$A_N(|V_z| < 20 \text{ cm}) = 0.110 \pm 0.050 \text{ (stat.)}$

$A_N(|V_z| < 50\text{cm}) = 0.104 \pm 0.036 \text{ (stat.)}$

$A_N(|V_z| < 70 \text{ cm}) = 0.096 \pm 0.028 \text{ (stat.)}$

$A_N(|V_z| < 100 \text{ cm}) = 0.068 \pm 0.025 \text{ (stat.)}$

Raw Results



The A_N $\perp$ to Spin axis is described as follows:

$$A_N^{\perp} = \frac{1}{P}\frac{\sigma_{\rightarrow} - \sigma_{\leftarrow}}{N}$$

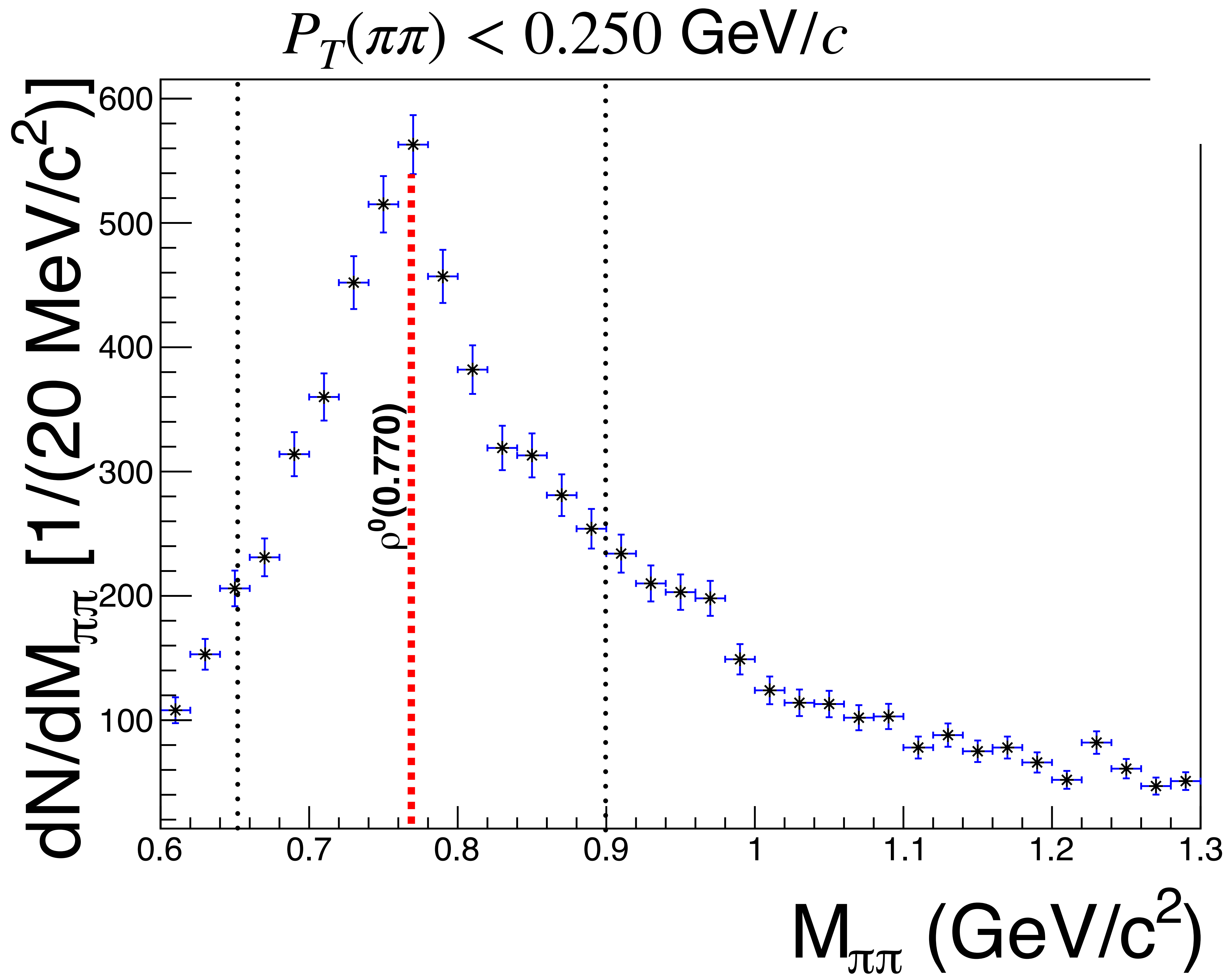
Where

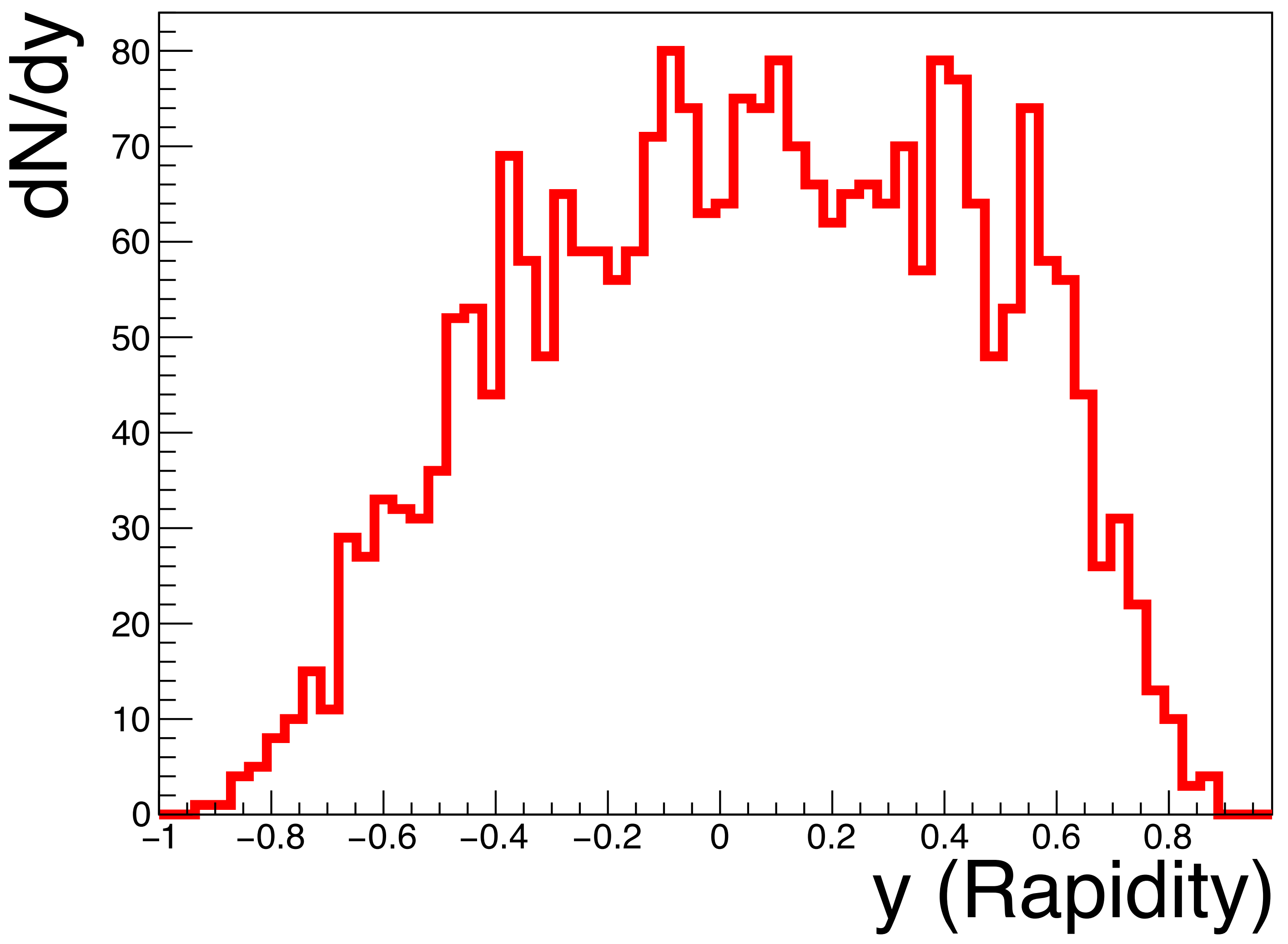
$$\sigma_{\rightarrow} = N((\overrightarrow{P}_T^{\pi\pi} \times \vec{S}) \cdot \hat{x} > 0)$$
$$\sigma_{\leftarrow} = N((\overrightarrow{P}_T^{\pi\pi} \times \vec{S}) \cdot \hat{x} < 0)$$

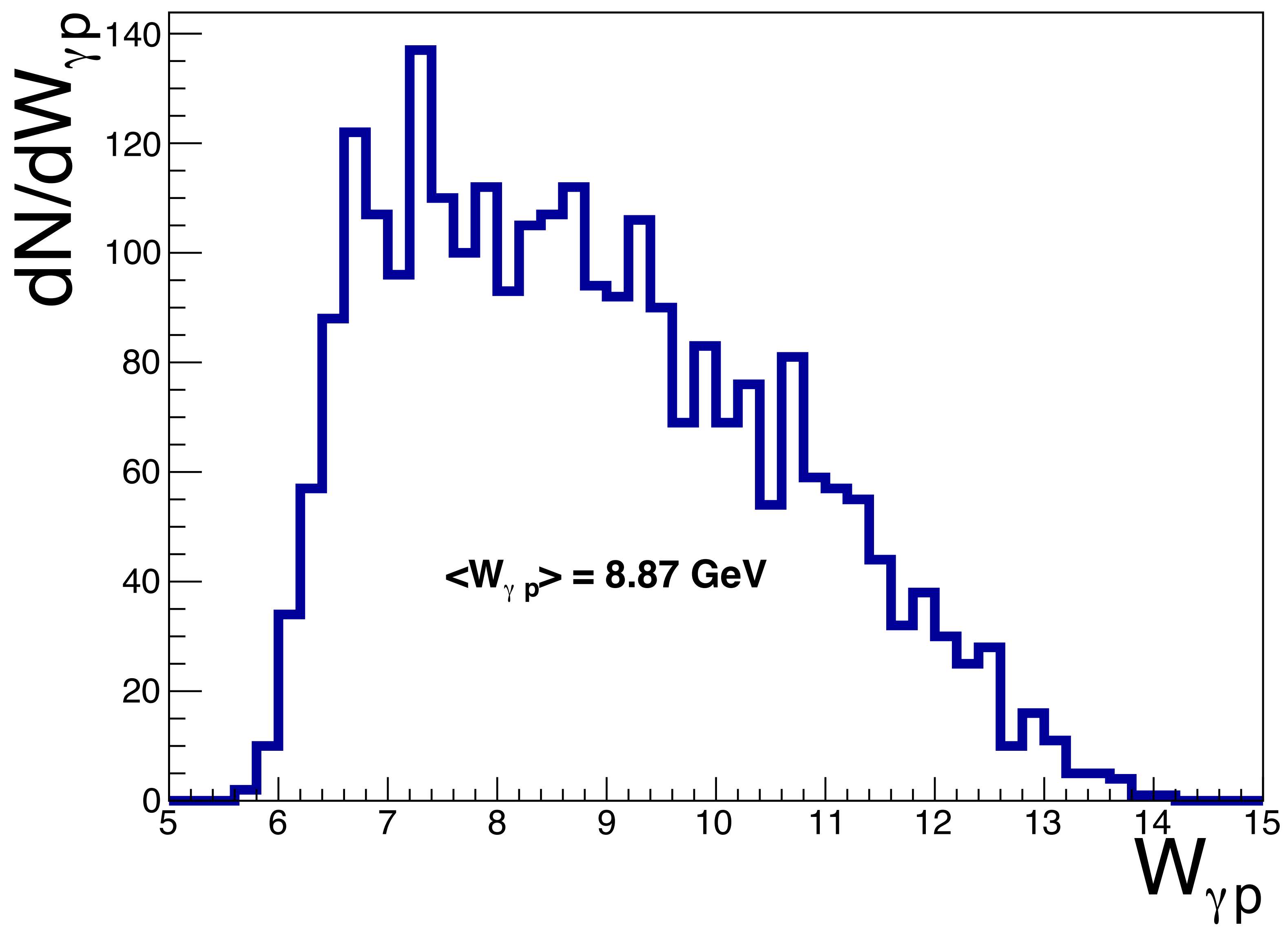
In the direction perpendicular to the spin direction we do not expect to see any asymmetries.

We can also observe an asymmetry $3\sigma_{A_N}$ above zero at $E_\gamma = \hbar c / r_p \sim 250$ MeV which corresponds to the coherent interaction transverse momentum regime regime.

Characterization of ρ^0 peak





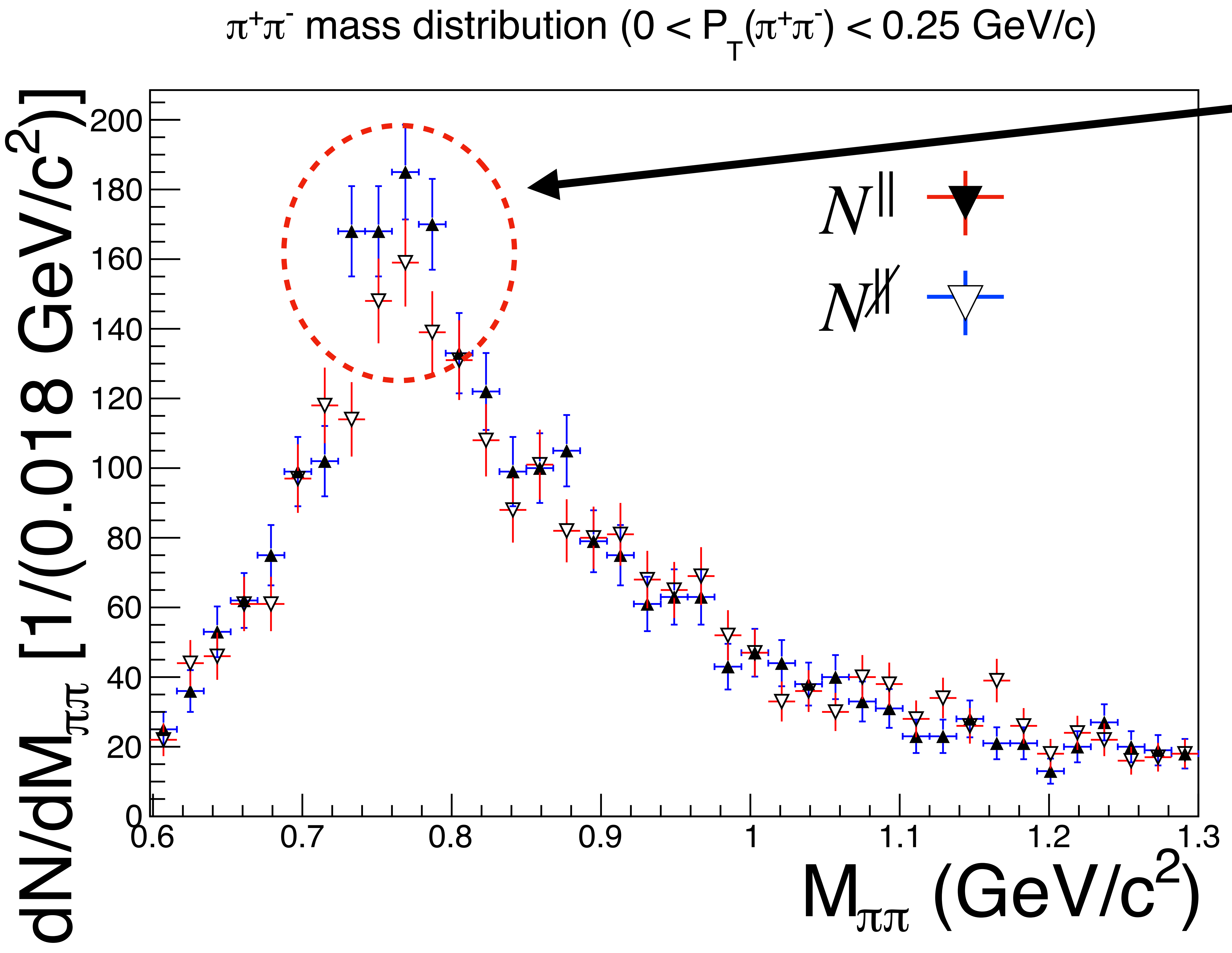


- Clear ρ^0 peak
- Define region of interest $m_{\pi\pi} \in (0.65, 0.90)$ GeV/c
- $E_T^\gamma = \hbar c / r_p \sim 250$ MeV for coherent process only.
- Photon-Proton center of mass energy:
  $W_{\gamma p} \approx \sqrt{2 M_{\rho^0} E_p} e^{-y/2} \rightarrow \left\langle W_{\gamma p} \right\rangle = 8.87$ GeV
- For $\left\langle P_T \right\rangle = 0.18$ GeV/c

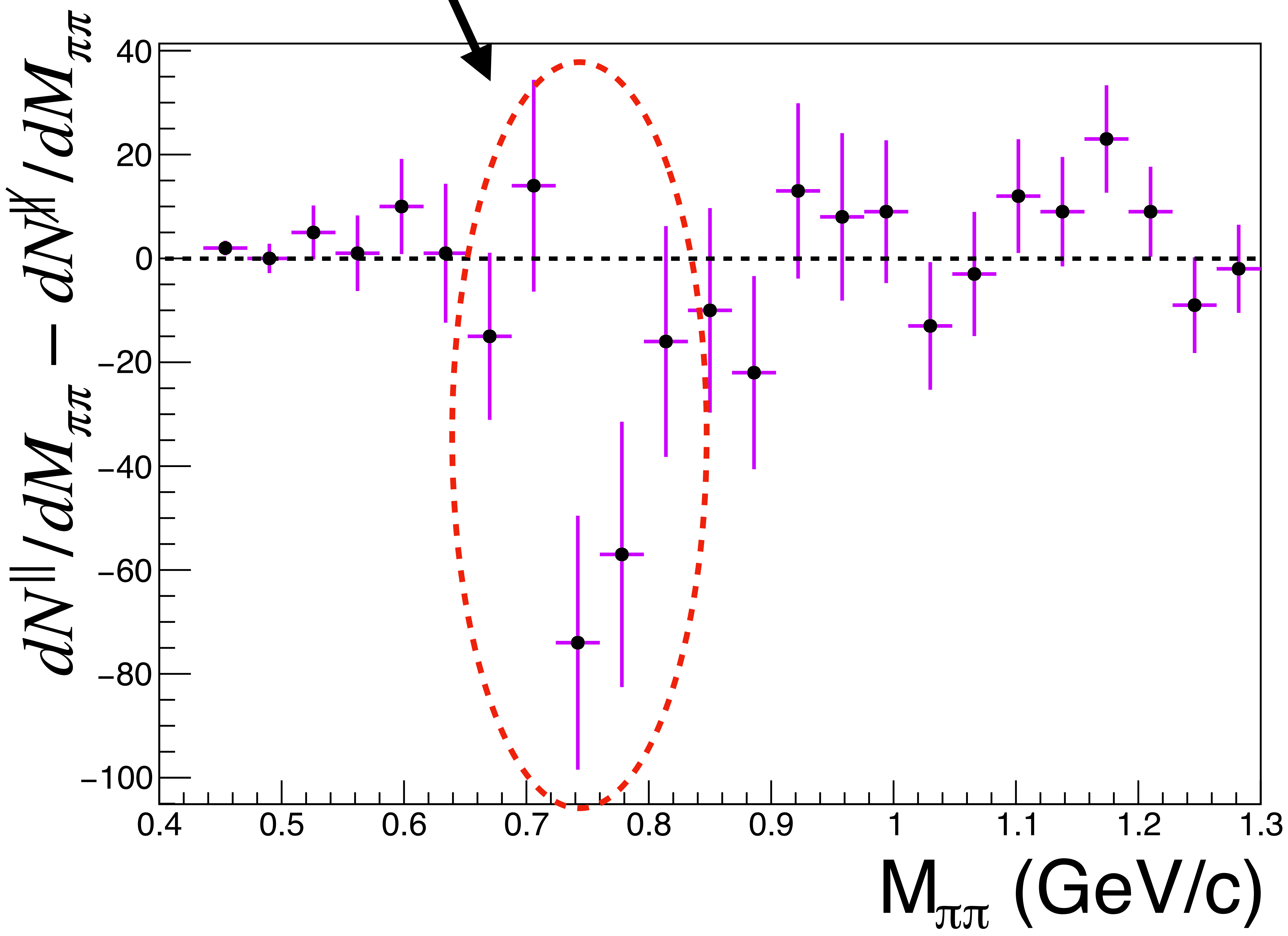
$A_N = 0.096 \pm 0.028$

No possible comparison with the same theory plot that Schmidke's did

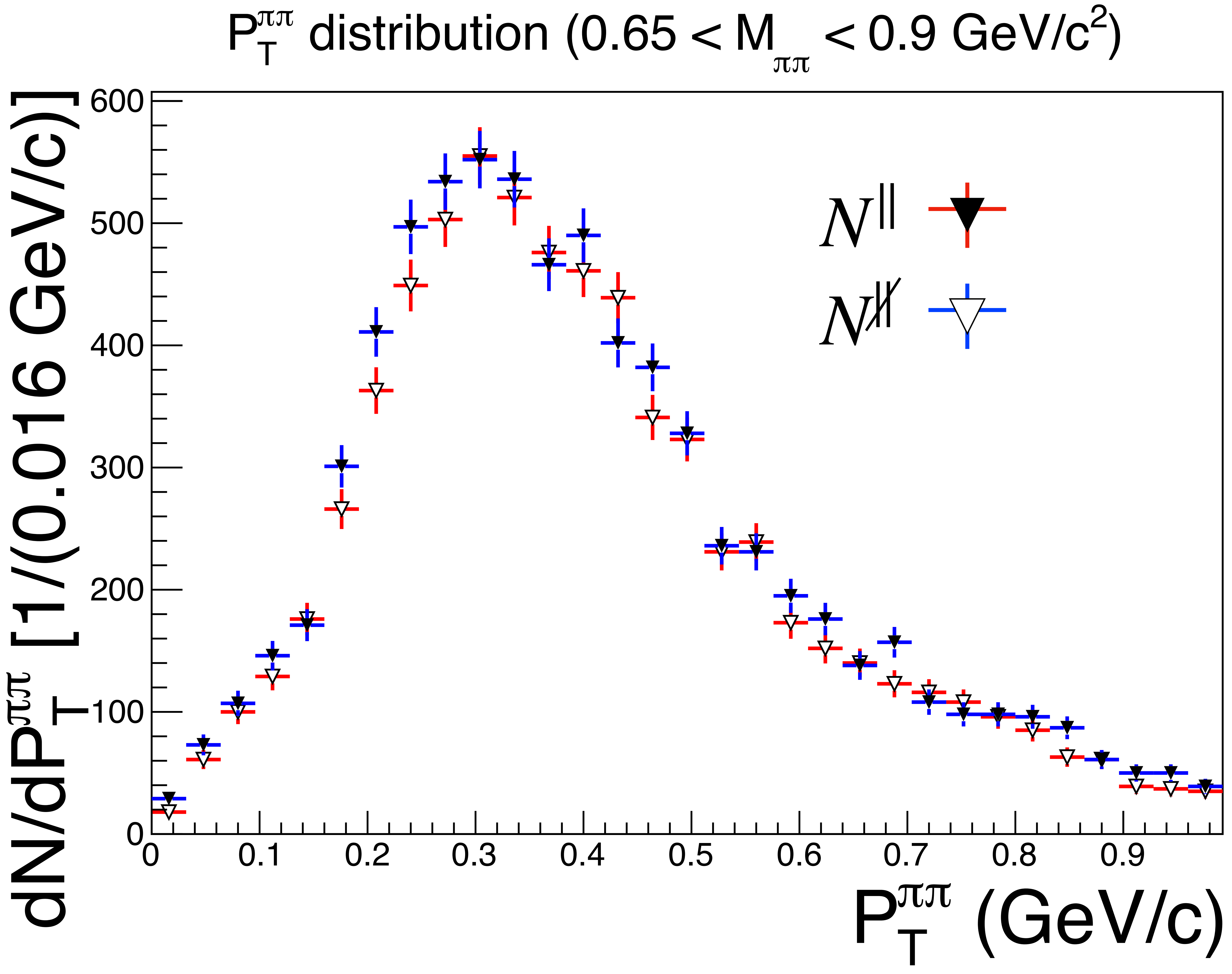
$M_{\pi\pi}$ Differential Plots



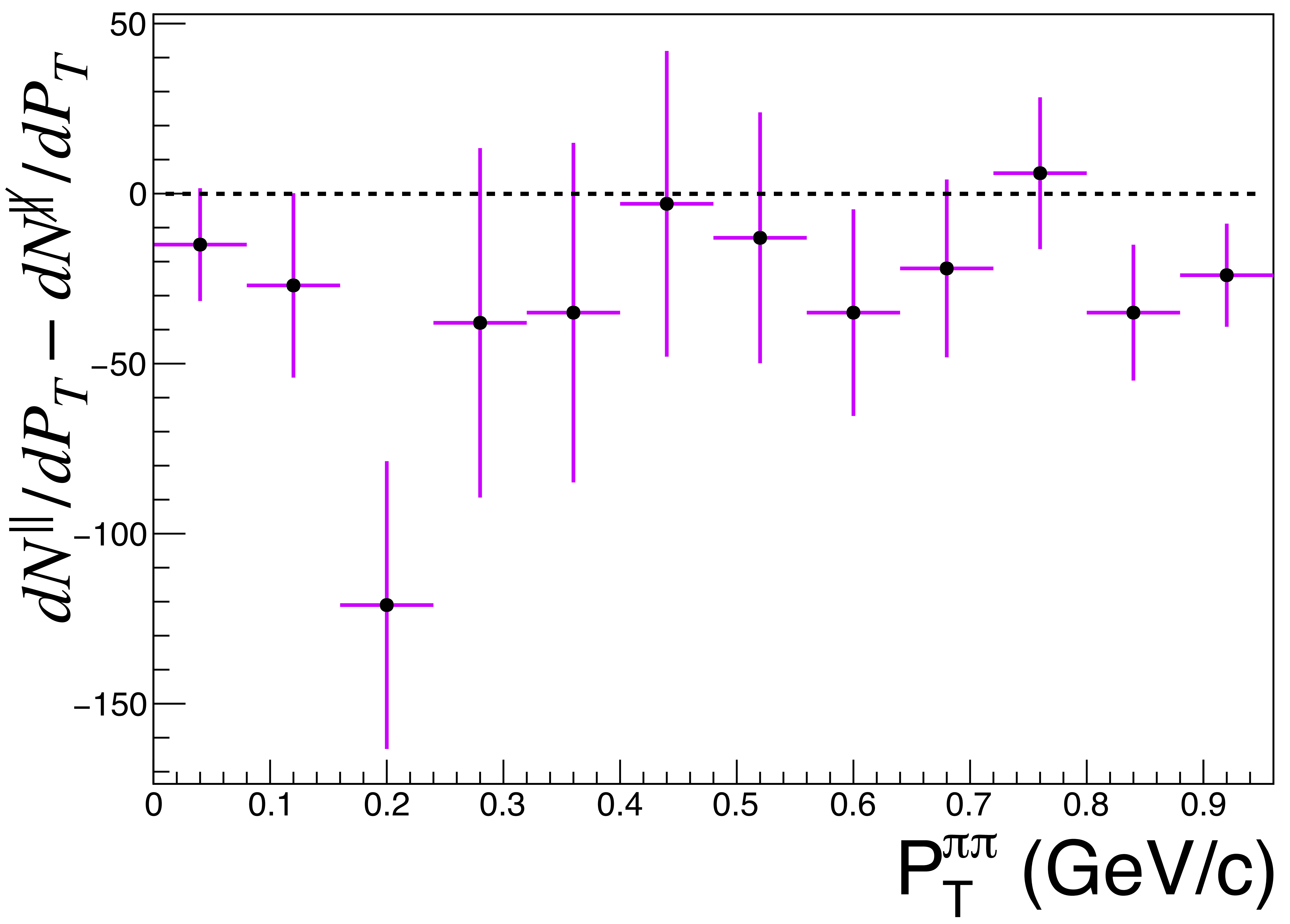
The A_N asymmetry is enhanced around the mass of the $\rho^0(0.770)$



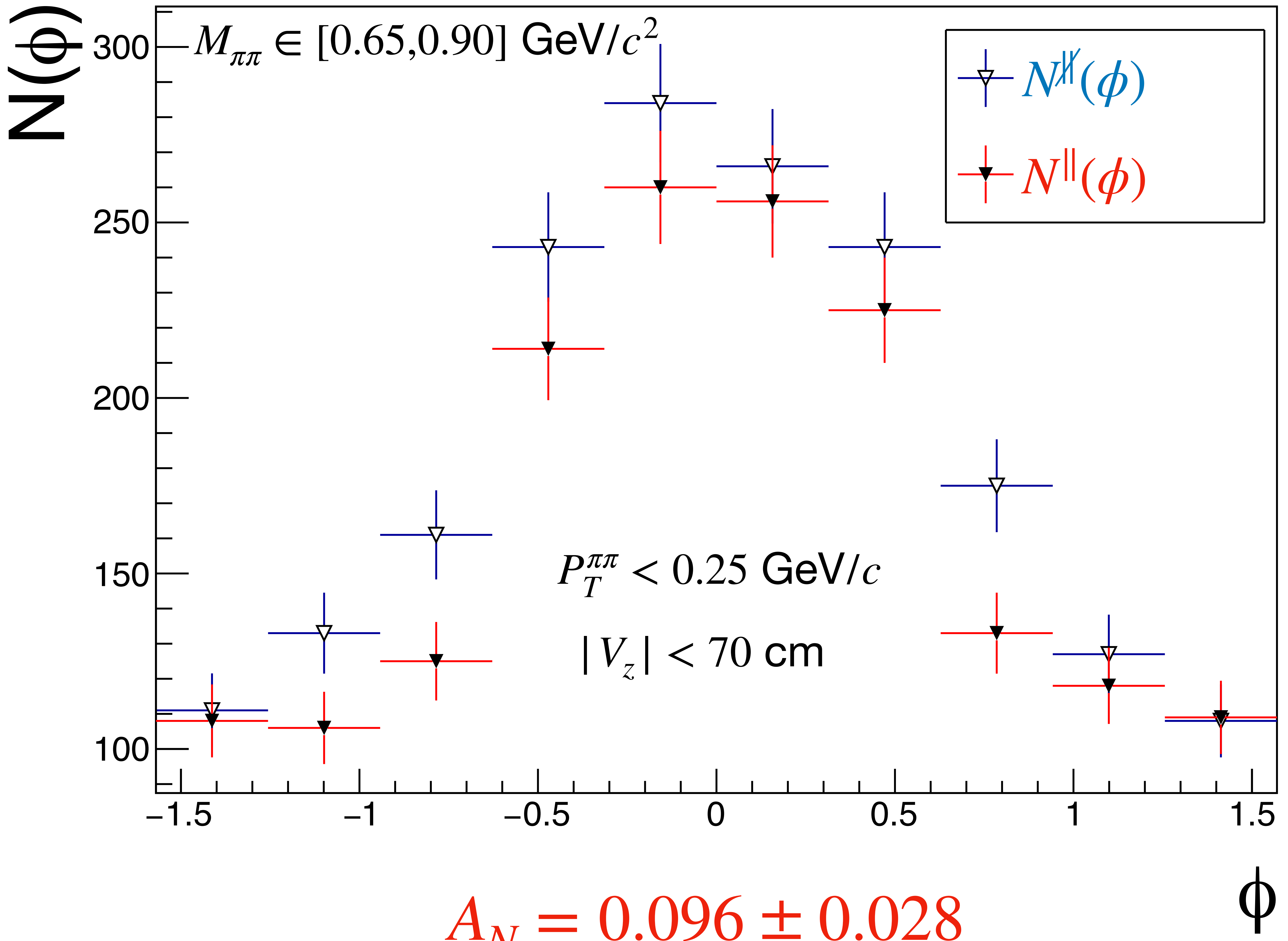
$P_T^{\pi\pi}$ Differential Plots



The A_N asymmetry seems to be enhanced around $P_T^{\pi\pi} \sim 0.2$ GeV/c.



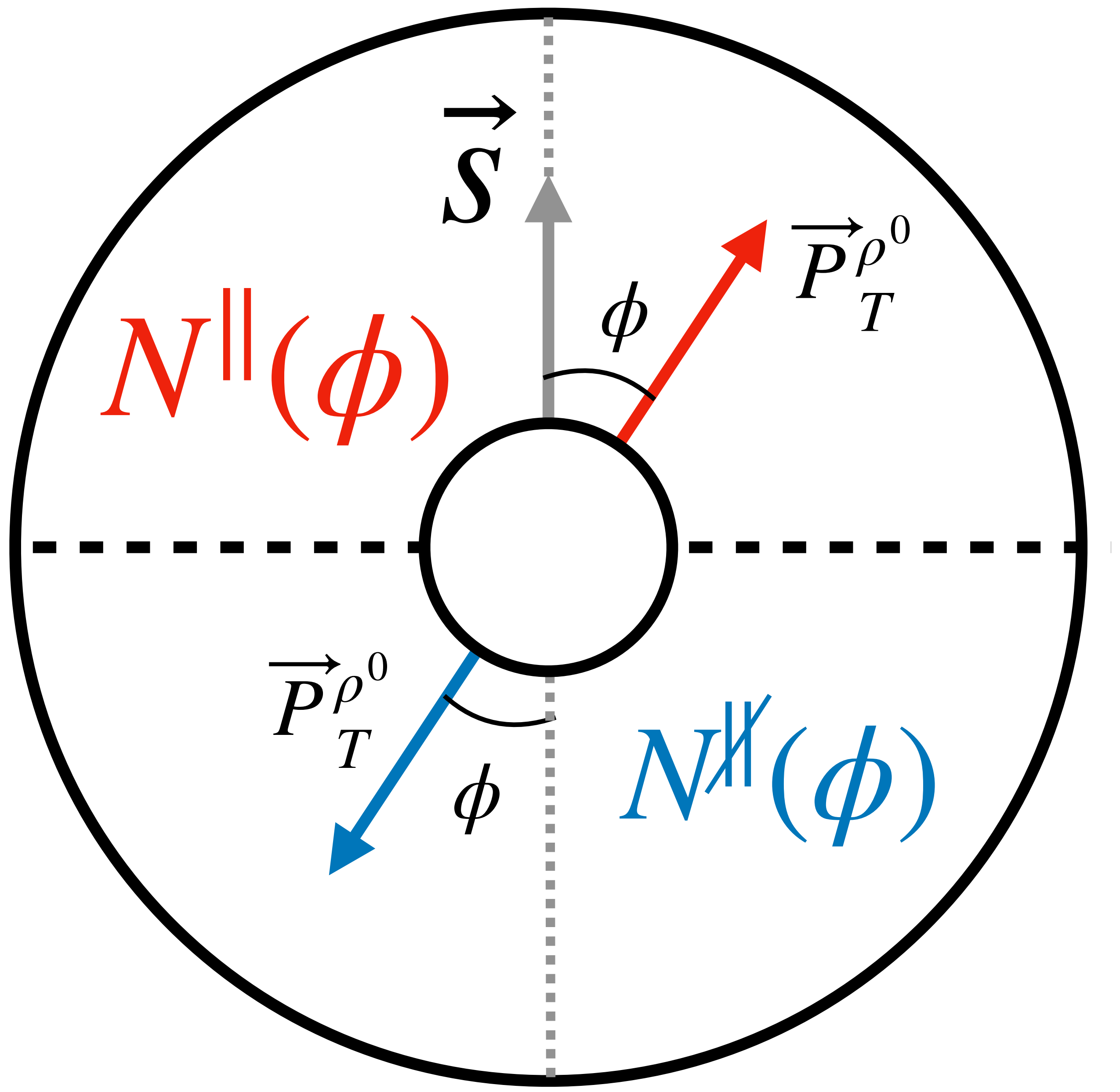
Angular Distribution



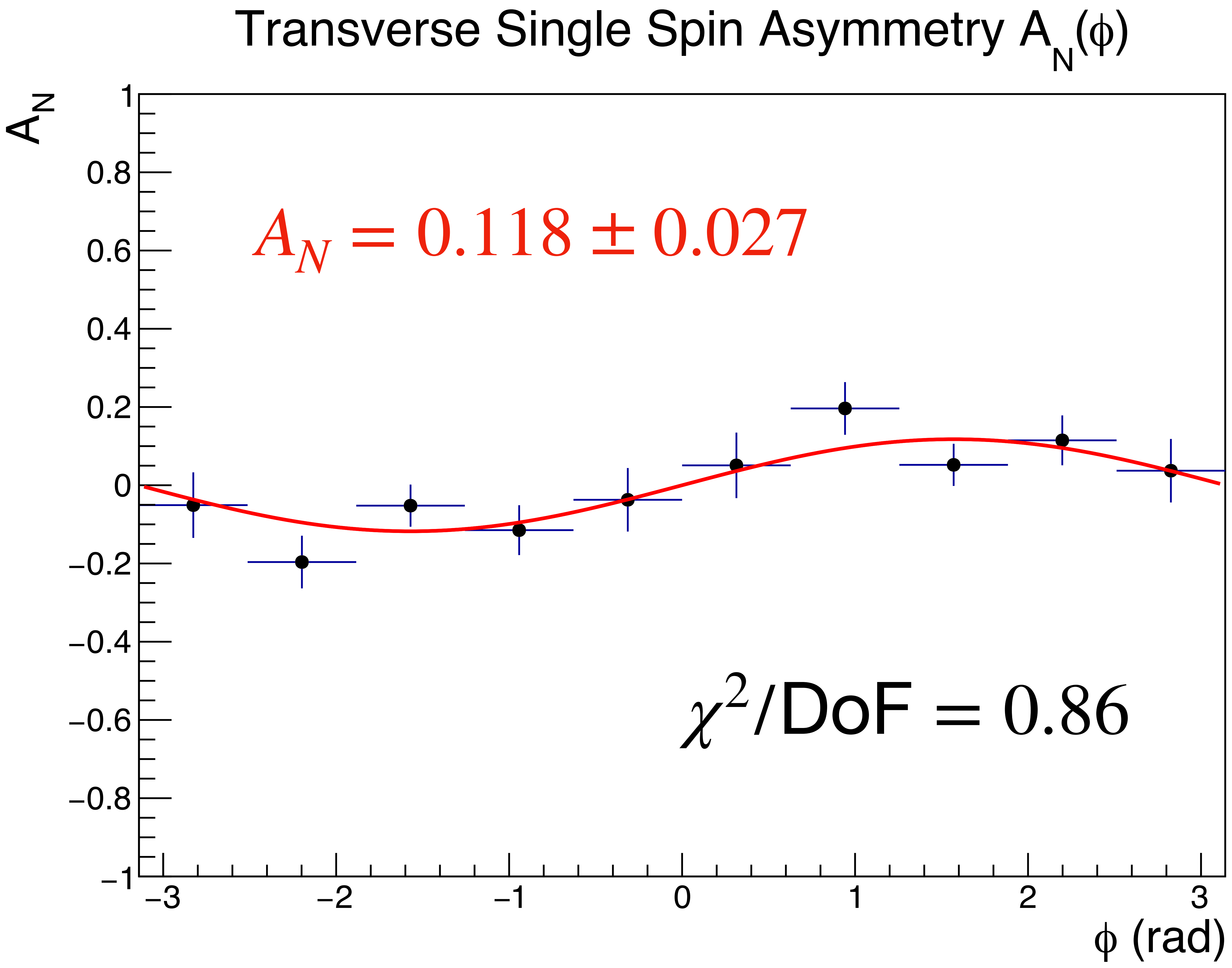
$A_N = 0.096 \pm 0.028$

$N^{\parallel,\nparallel}(\phi)$: Is the number of particles aligned (anti-aligned) with respect to proton's spin

ϕ: Angle with respect to the spin axis.



Cross-Ratio Method



A more traditional/conventional method for searching for asymmetries is the cross-ratio method:

$$A_N^{\text{raw}} \cos\phi = \frac{1}{P} \frac{\sqrt{N^{\uparrow}(\phi)N^{\downarrow}(\phi+\pi)} - \sqrt{N^{\downarrow}(\phi)N^{\uparrow}(\phi+\pi)}}{\sqrt{N^{\uparrow}(\phi)N^{\downarrow}(\phi+\pi)} + \sqrt{N^{\downarrow}(\phi)N^{\uparrow}(\phi+\pi)}}$$

where ϕ is the angle between the spin direction and the transverse momentum of the ρ^0 ; $N^{\uparrow,\downarrow}$ represent the yields for the two different spin patterns

1. STAR Collaboration, Phys. Rev. D 103, 092009 (2021).
2. Lewis N. https://arxiv.org/pdf/2008.04283

Conclusions

- A up and down asymmetry was measured with a unconventional technique.
- It appears to be a clear excess of ρ^0 photo-production along the proton's spin direction.
- A $\sin - \cos$ modulation is visible with the more standard cross-ratio technique.

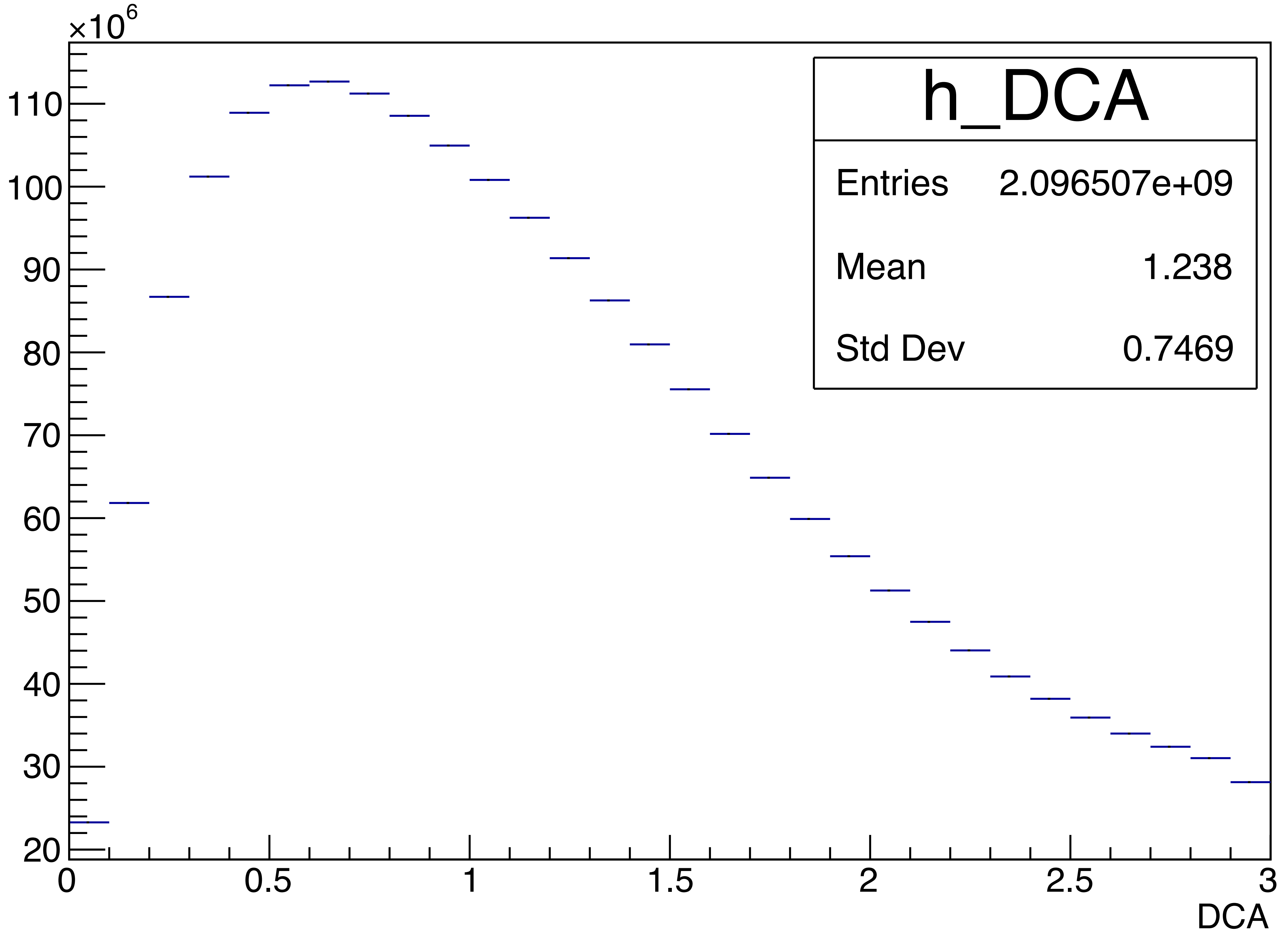
Outlook

- Background estimations still need to be done.
- Keep looking for some theory to compare these results with.
- Address any suggestions and comments coming out of this meeting.

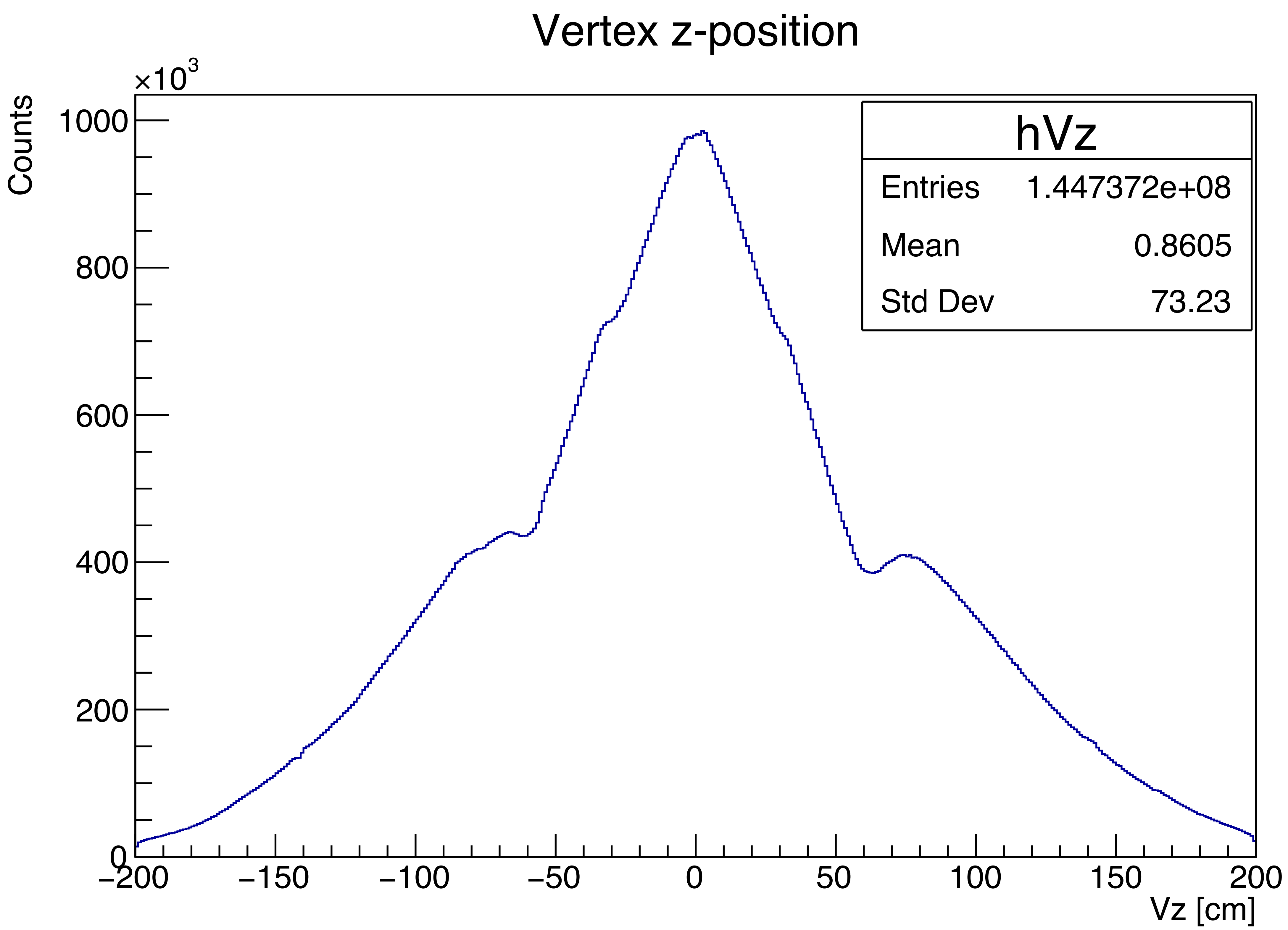
Back Up Slides

General QA Plots

No unusual behavior in DCA or Vz plots (No PiD applied).

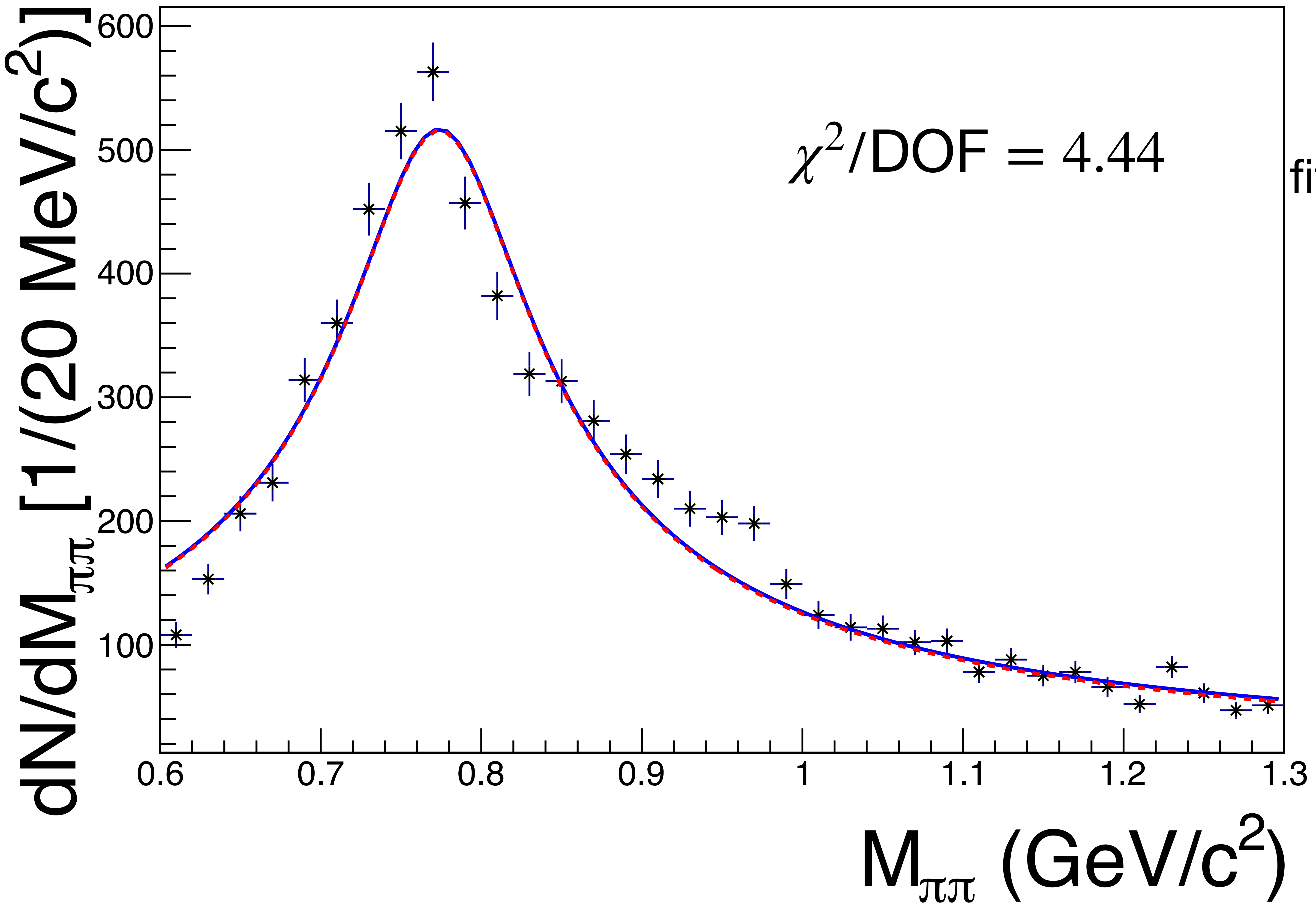


Distance of closest approach run 15 pAu UPC triggers



Z-vertex position distribution.

Background Estimations



$$\text{fitfunc} = A_\rho \left| \frac{\sqrt{M_{\pi\pi} M_\rho \Gamma_\rho}}{M_{\pi\pi}^2 - M_\rho^2 + i\Gamma_\rho M_\rho} \right| + aM_{\pi\pi} + b$$

A_ρ = 174.14 +/- 3.07818

M_ρ = 0.771699 +/- 0.00198666

Γ_ρ = 0.114254 +/- 0.00586319

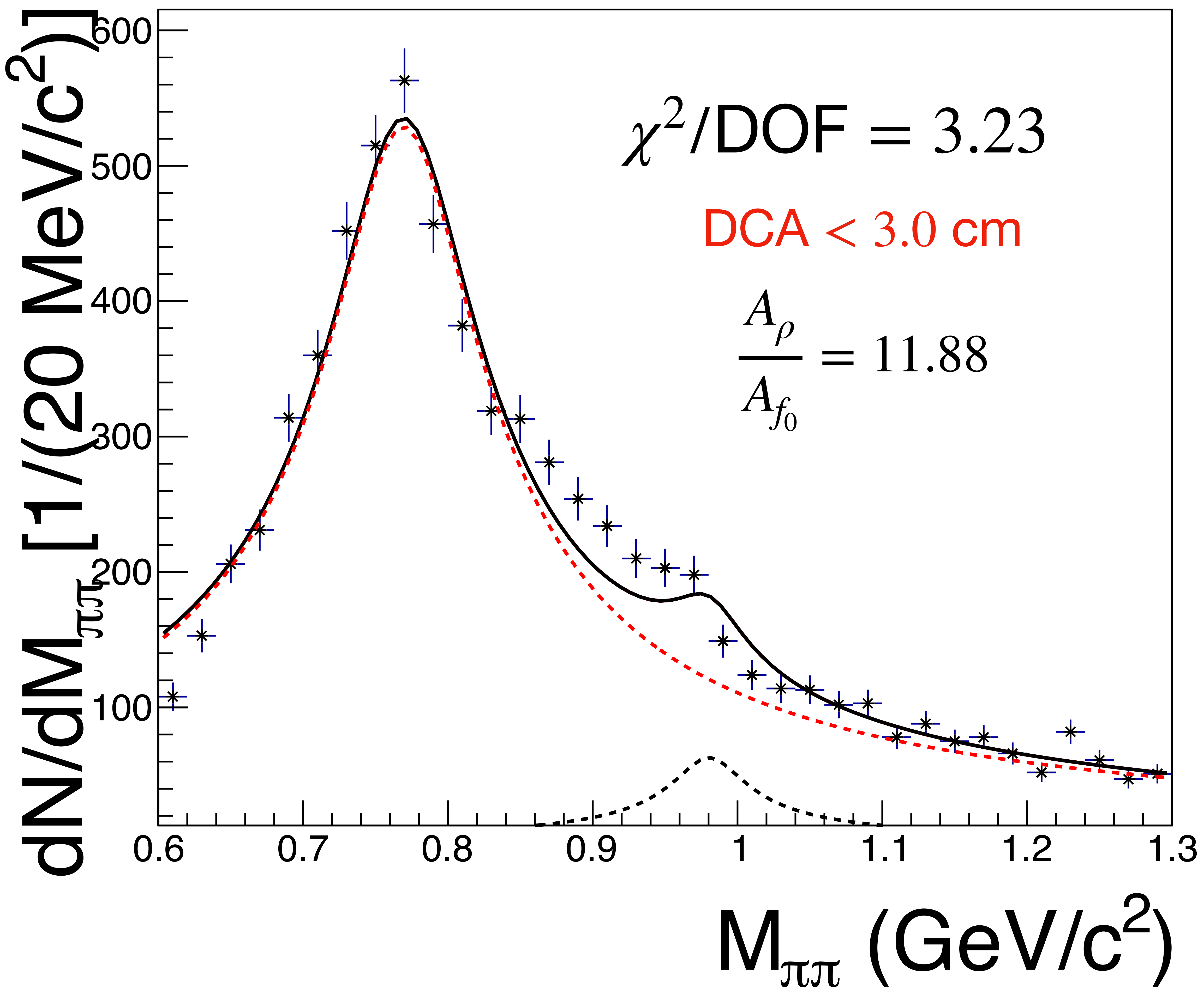
a = 1.61083 +/- 3.38262

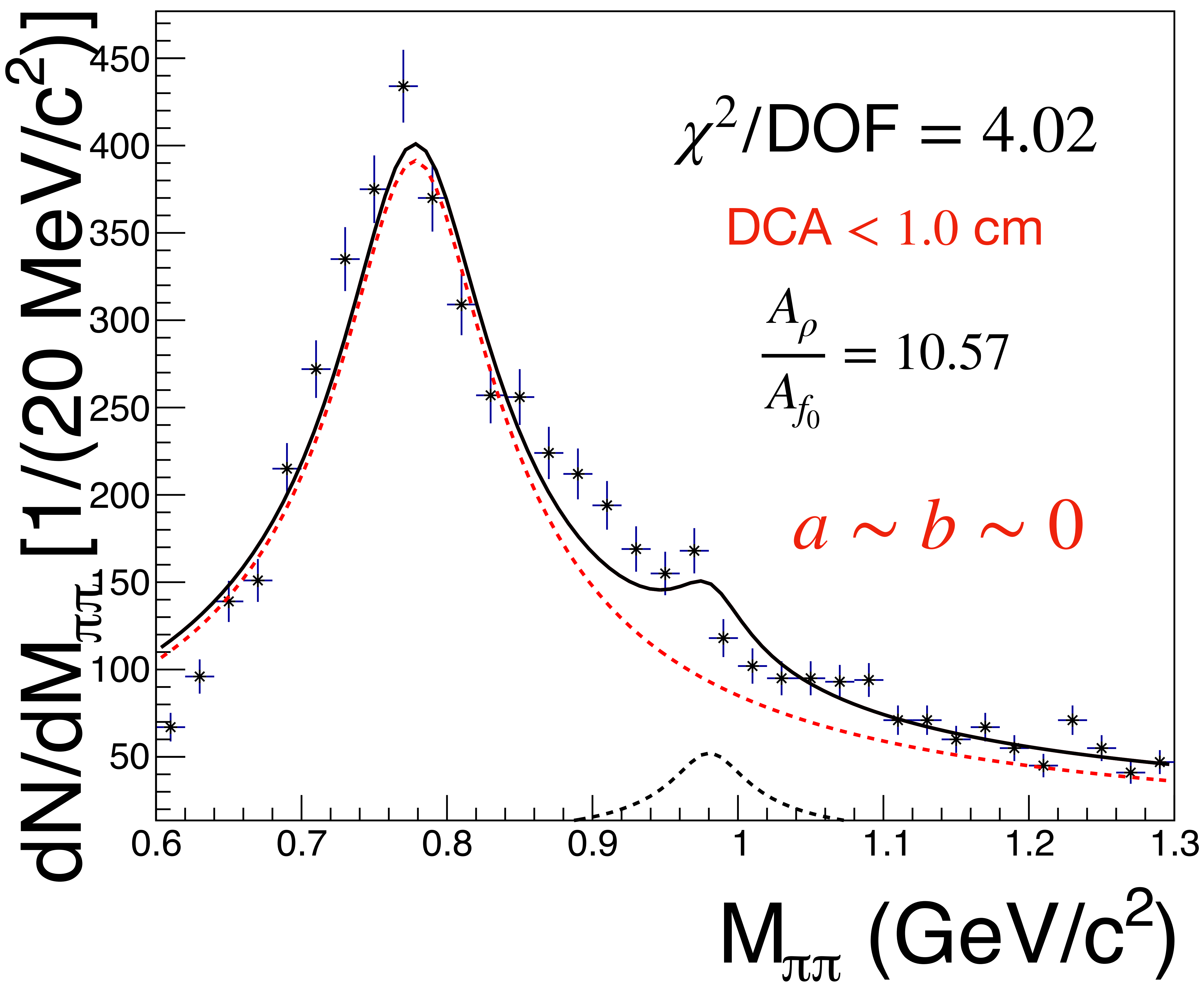
b = 9.31097e-06 +/- 3.28084

$|V_z| < 70$ cm

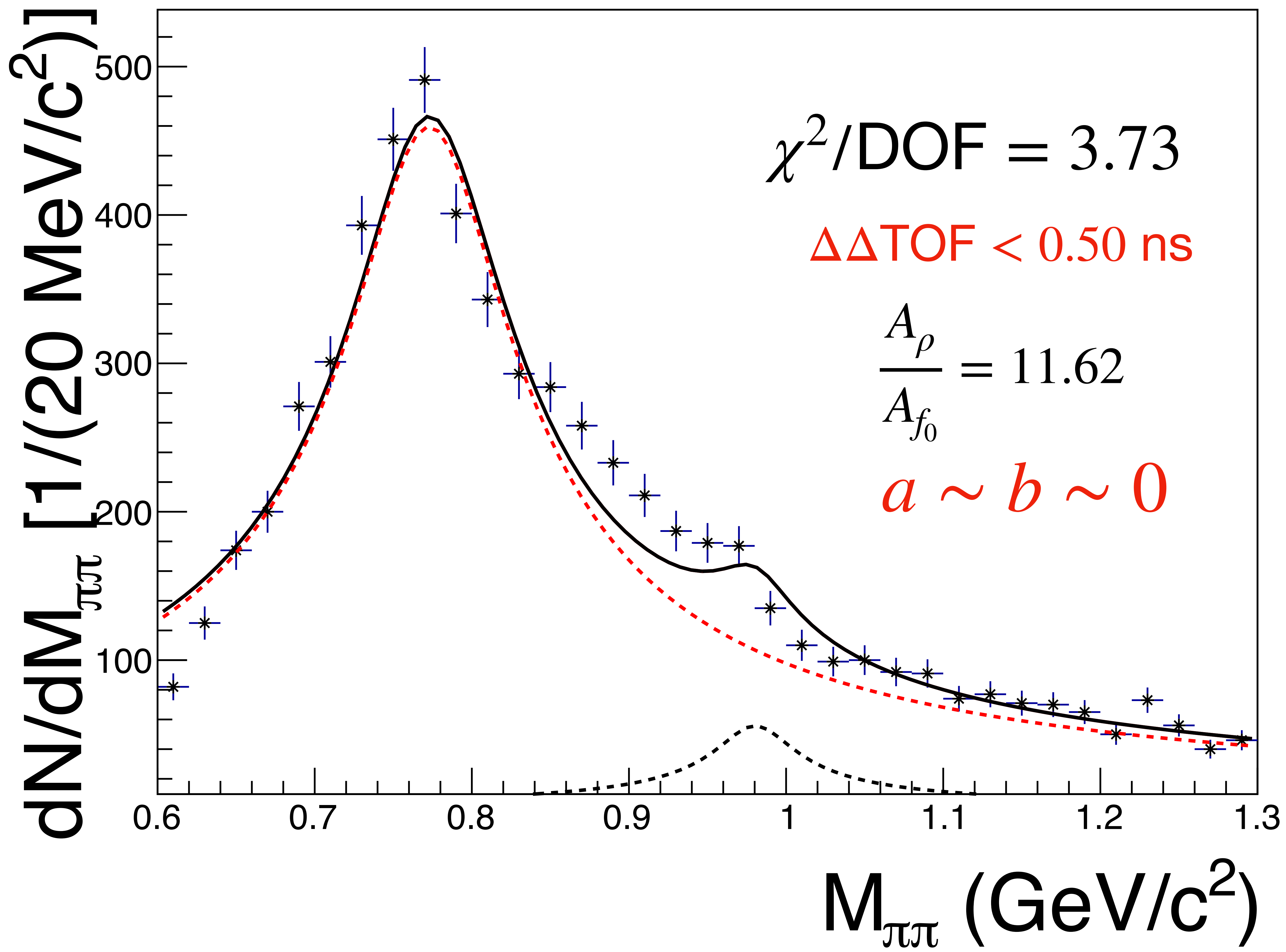
Background Estimations $|V_z| < 70\,\mathrm{cm}$

$$\text{fitfunc} = A_\rho \text{BW}(M_\rho, \Gamma_\rho) + A_{f_0}\text{BW} + aM_{\pi\pi} + b$$





Background Estimations



$\text{fitfunc} = A_\rho \text{BW}(M_\rho, \Gamma_\rho) + A_{f_0}\text{BW} + aM_{\pi\pi} + b$

$|V_z| < 70\,\text{cm}$

No significant effect on the ratio A_ρ/A_{f_0} as we change ΔΔTOF. The background still looks to be negligible.