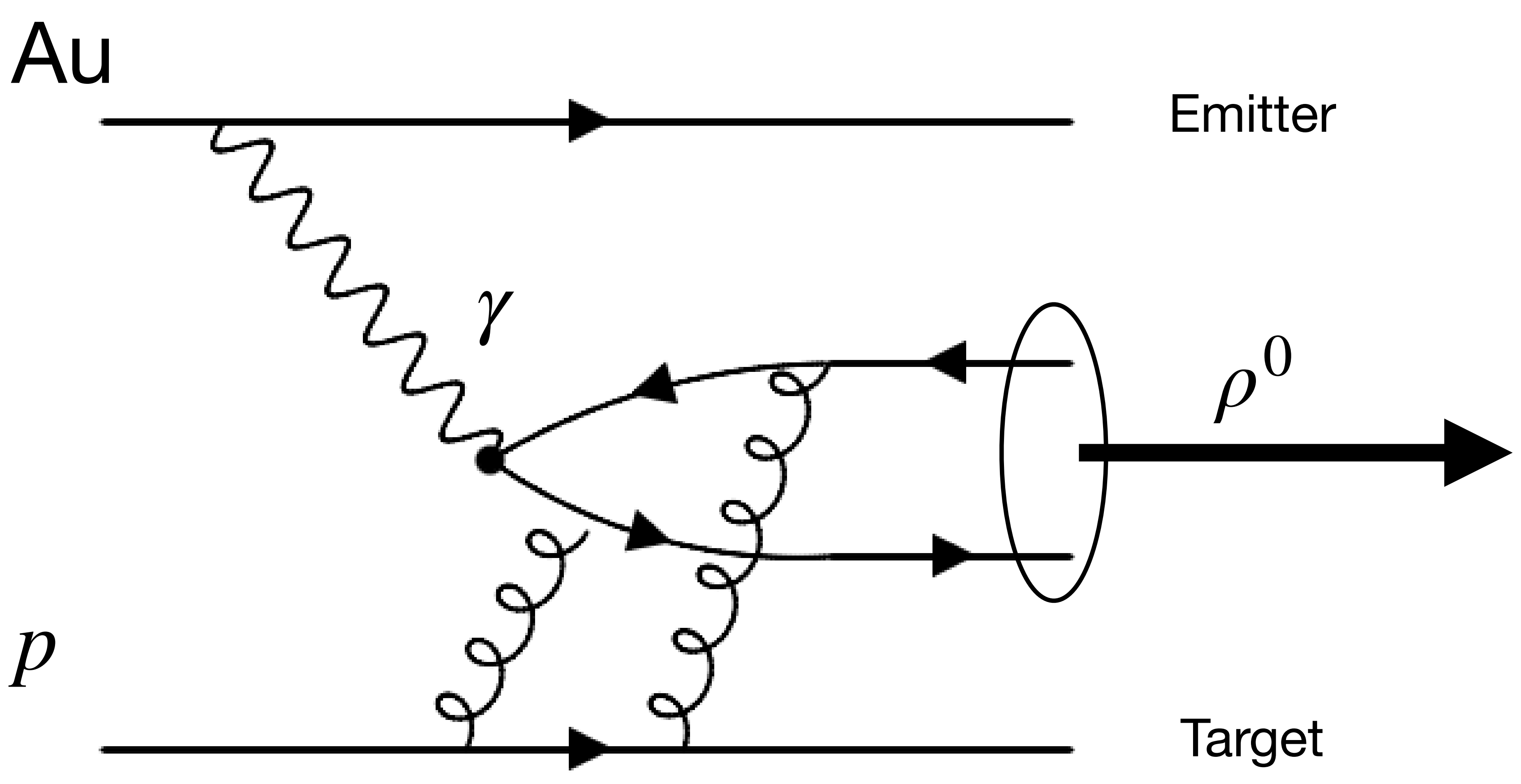
Single Spin Asymmetries in UPC

Exclusive ρ^0 photo-production

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



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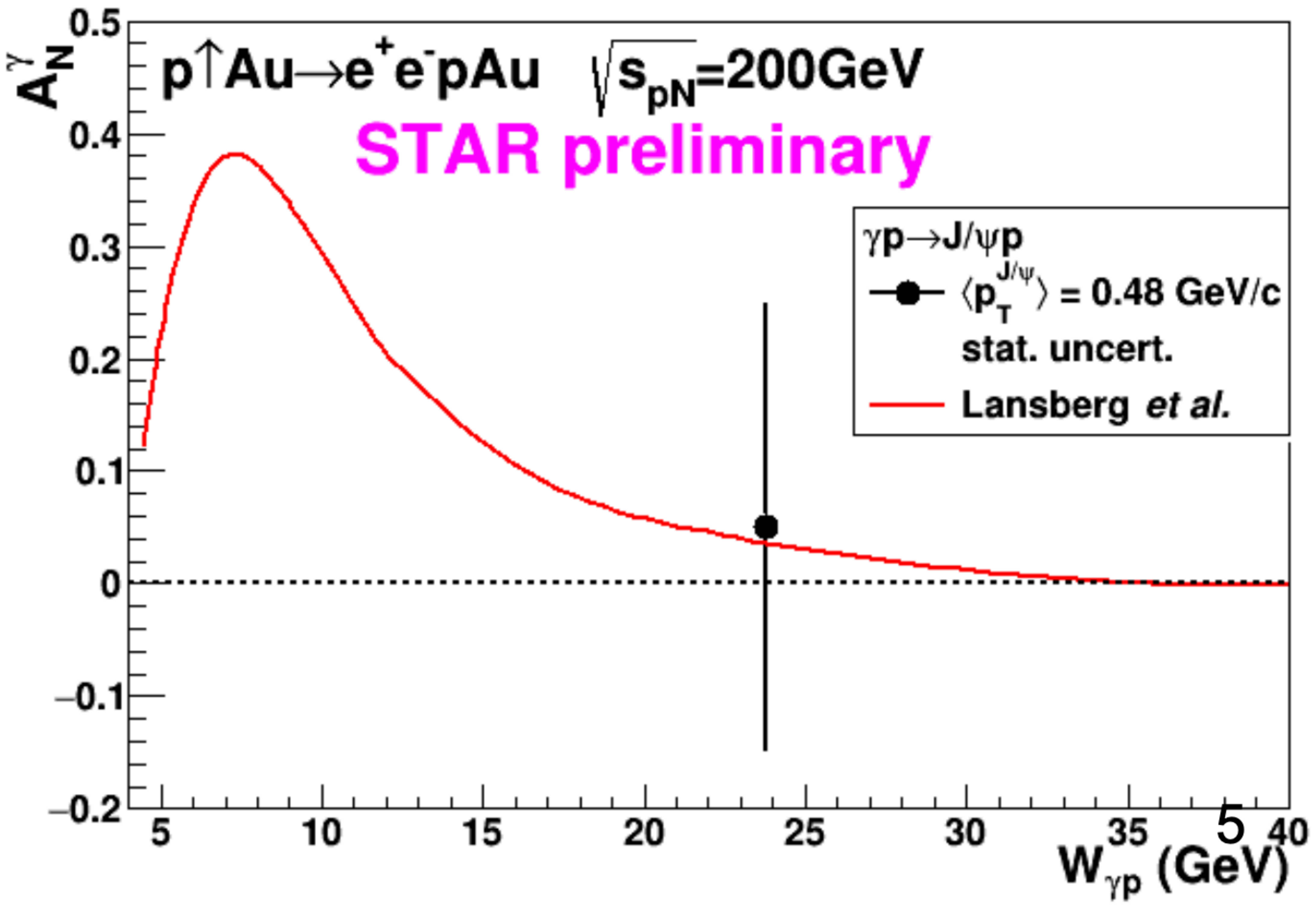
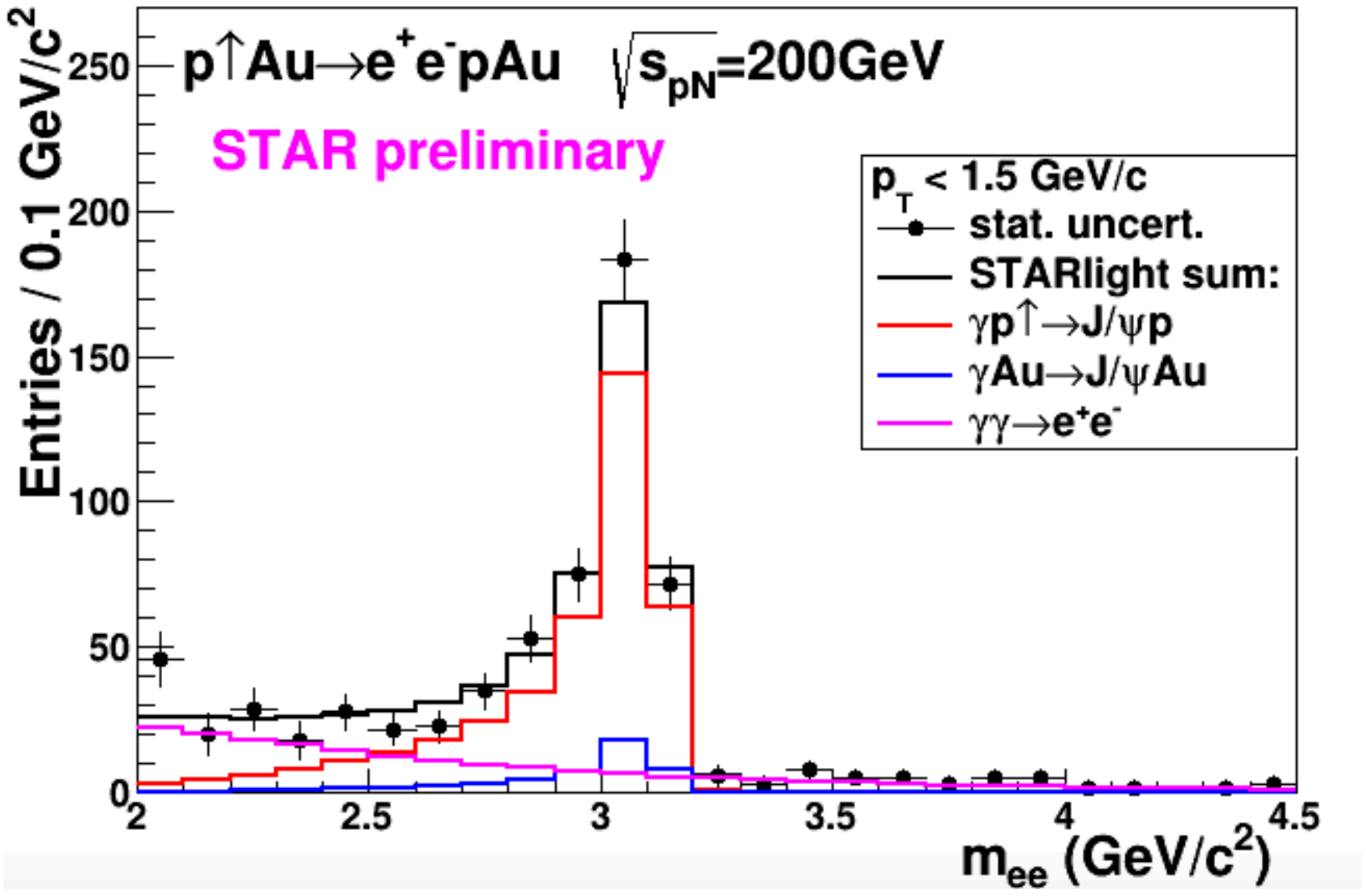
23/04/2025

Motivation

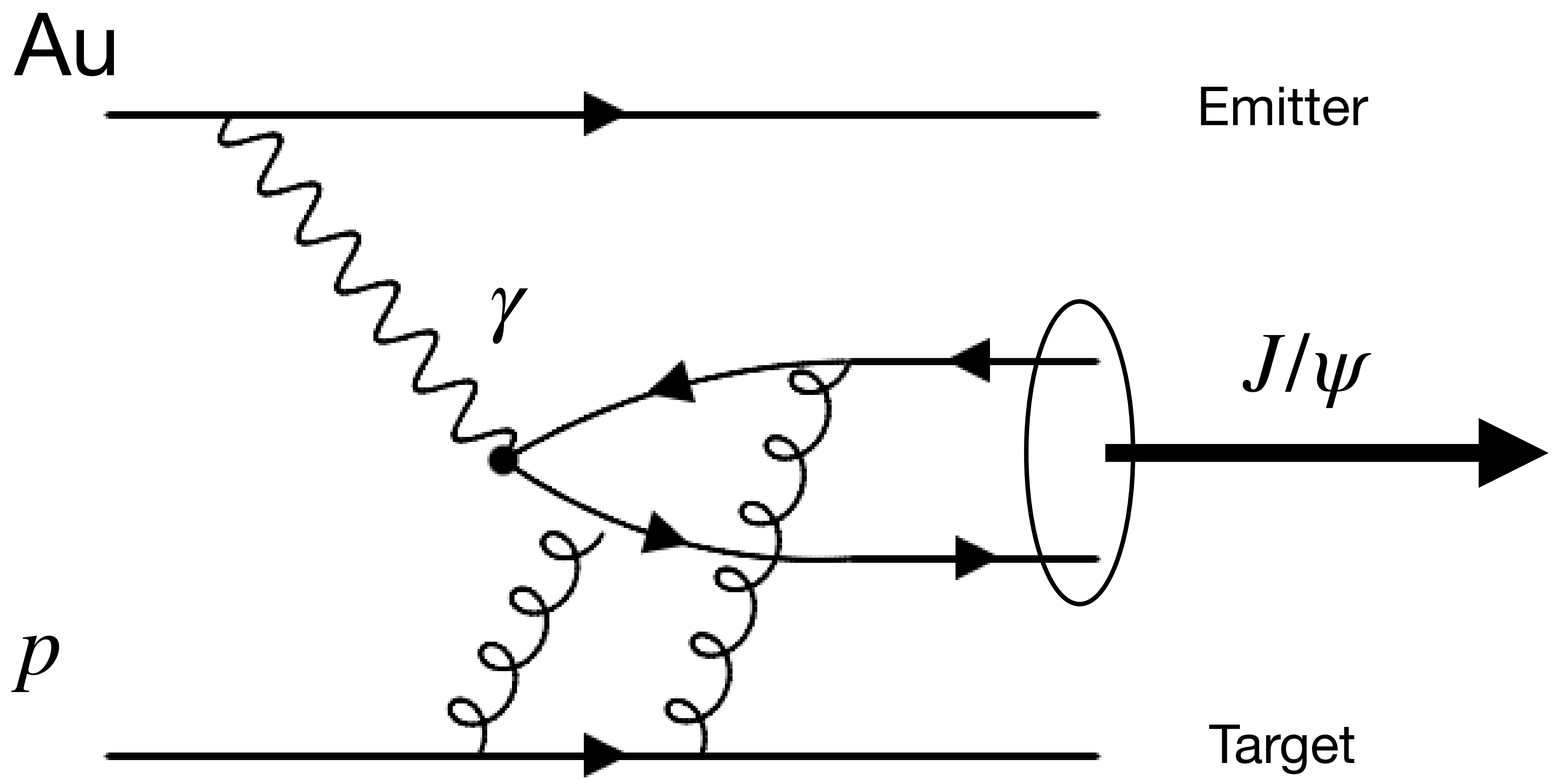
I aim to investigate single spin asymmetries (SSA) in photoproduction. A previous proof-of-principle measurement by W. Schmidke yielded a null result, but this analysis seeks to explore the potential for SSA within photoproduction processes.



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



Invariant mass spectrum for electron pairs.



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

- # of Tracks = 2
- $|V_z| \leq 100$ cm
- $q_1 q_2 = -1$

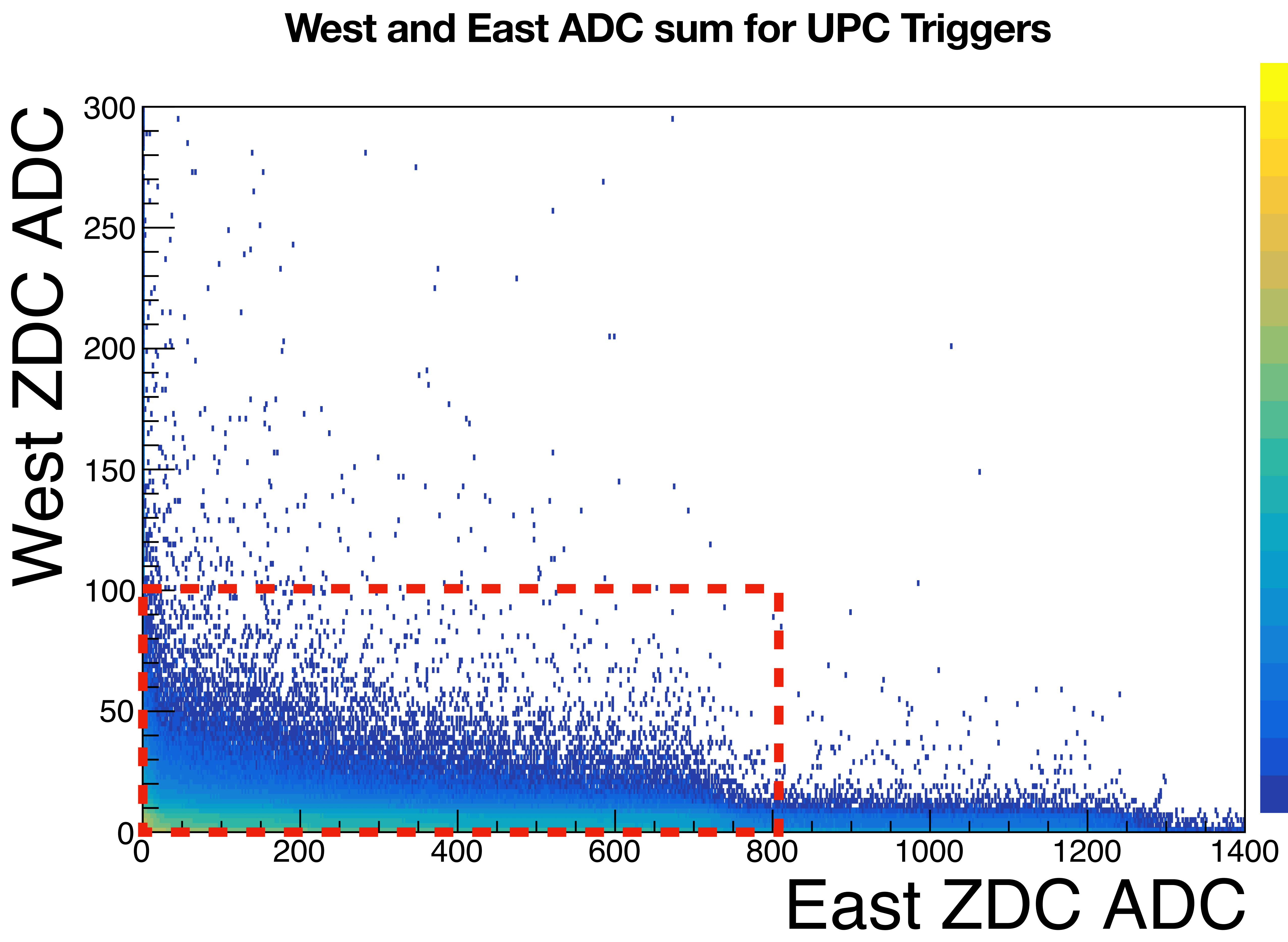
Command to get the file list:

```
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
```

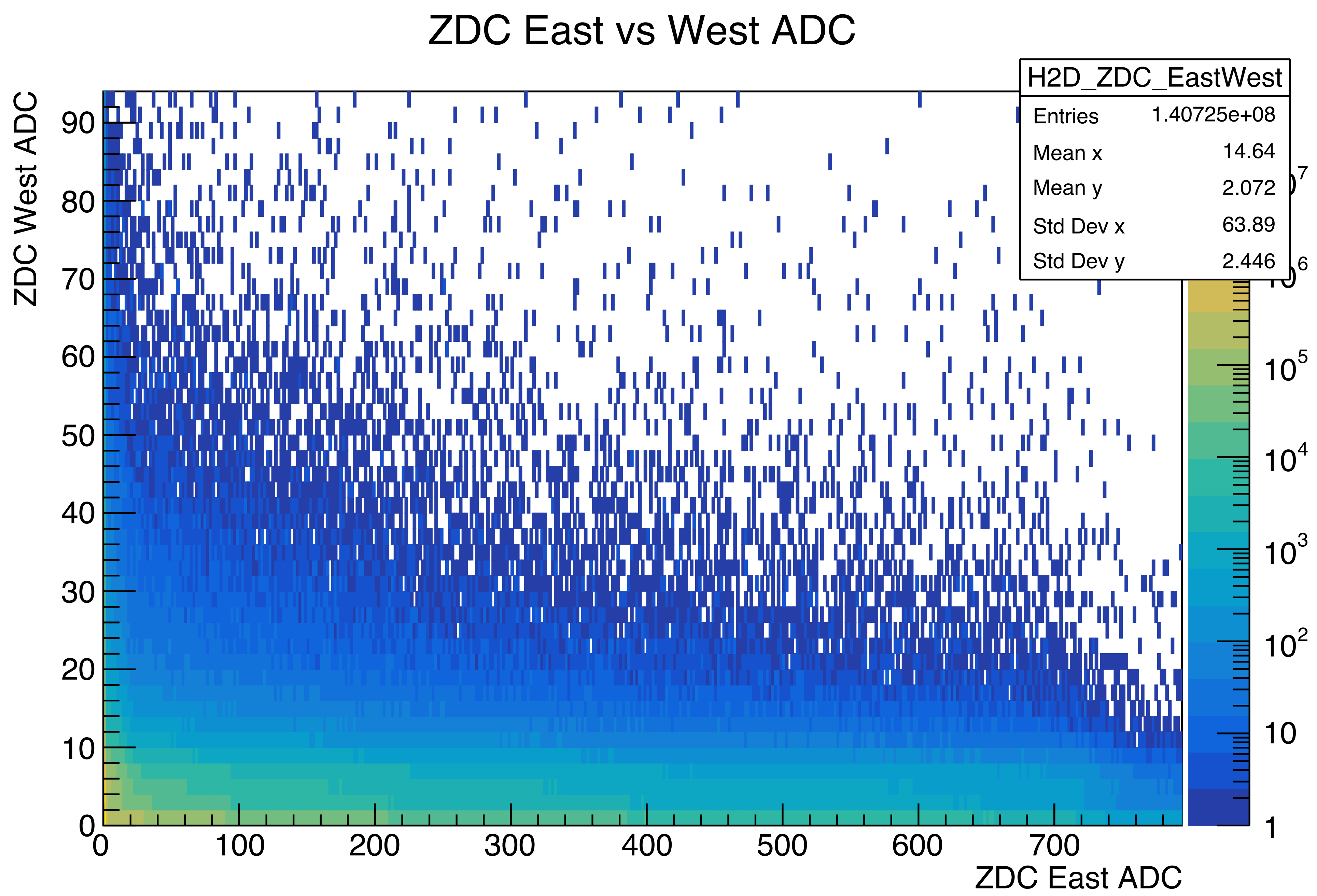
Trigger Definitions

Trigger Name	Description	Value	Trigger Use
TOFmult1	TOF multiplicity > 0	1	>
TOFmult2	TOF multiplicity < 6	6	<
RP_WOR	Roman Pot WOR?		
BBC-E	Beam-Beam Counter East (Au-going side)		❌ Veto
BBC-W	Beam-Beam Counter West (p-going side)		❌ Veto
ZDC-W	ZDC hit on West (p-going) sid	?	❌ Veto
ZDC-front-or-th1-E	ZDC East (Au-going) front detector or threshold	1200?	<

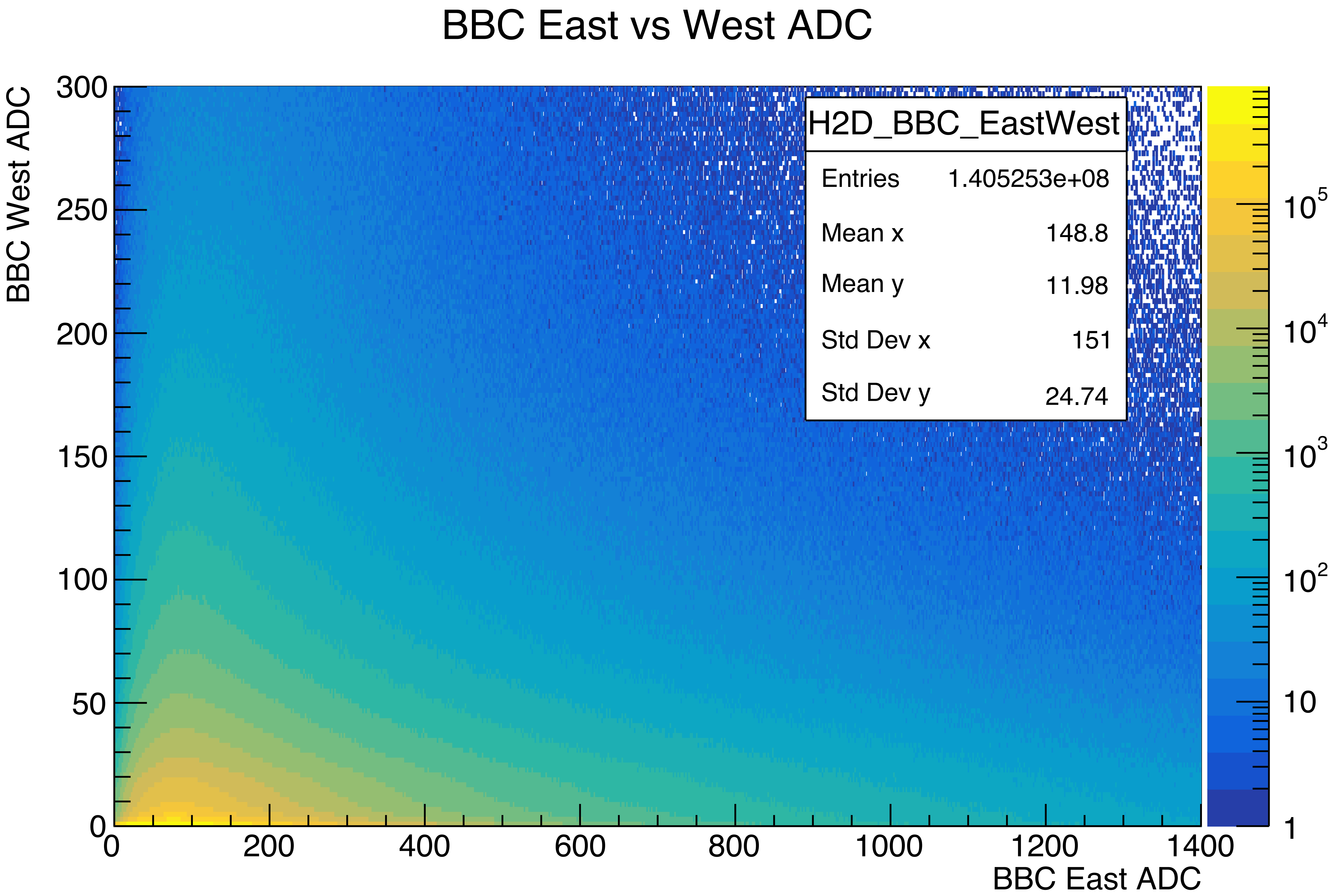
ADC sum distribution (West ZDC vs. East ZDC)



UPC Trigger ADC sum for **West (proton-going)** vs **East (gold-going)**. Different ADC thresholds were applied to the East and West ZDCs to account for the collision asymmetry, with the expectation that the proton remains intact and the gold nucleus may break up. This corresponds to selecting **0nXn** events.



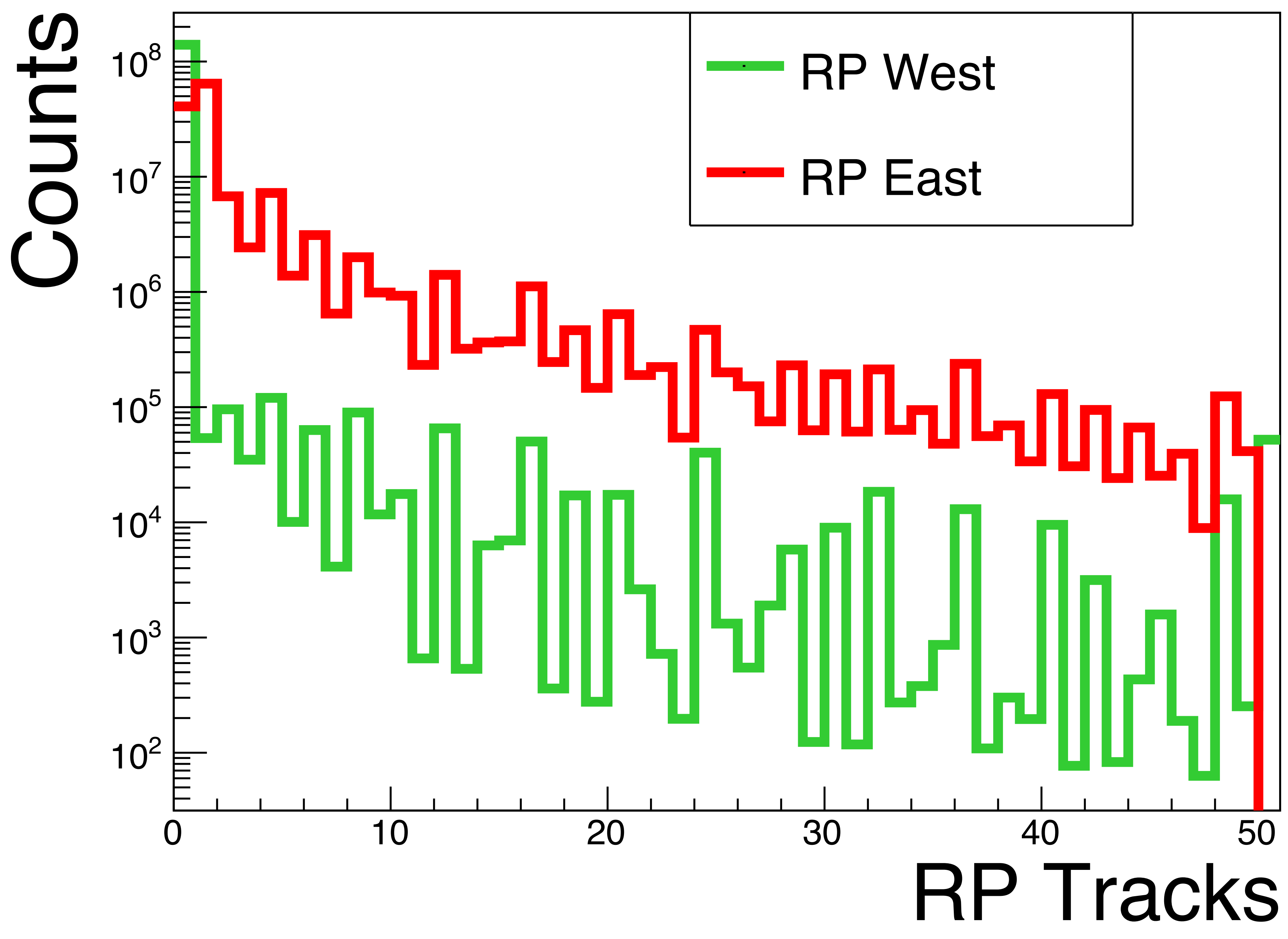
BBC (West vs. East)

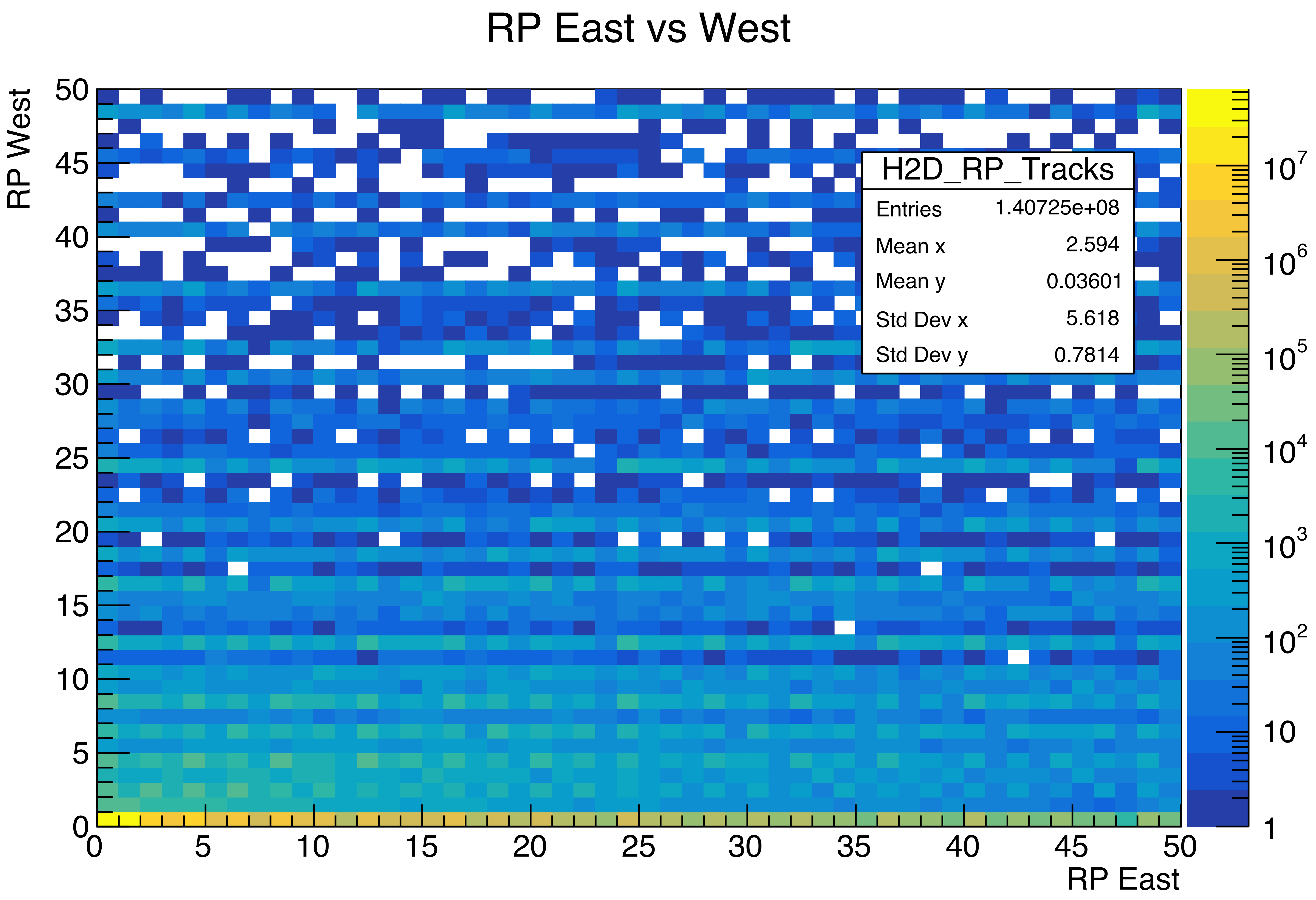


- **East BBC** is the most active channel, as expected, since nuclear breakup can occur on the gold-going side (East), producing forward-moving charged fragments.
- **West BBC** shows minimal activity, consistent with the proton-going side remaining mostly intact in Ultra-Peripheral Collisions (UPCs).
- **Peak:**
- **Repeated bands** are observed in the ADC distribution, indicating …

Roman Pots Tracks

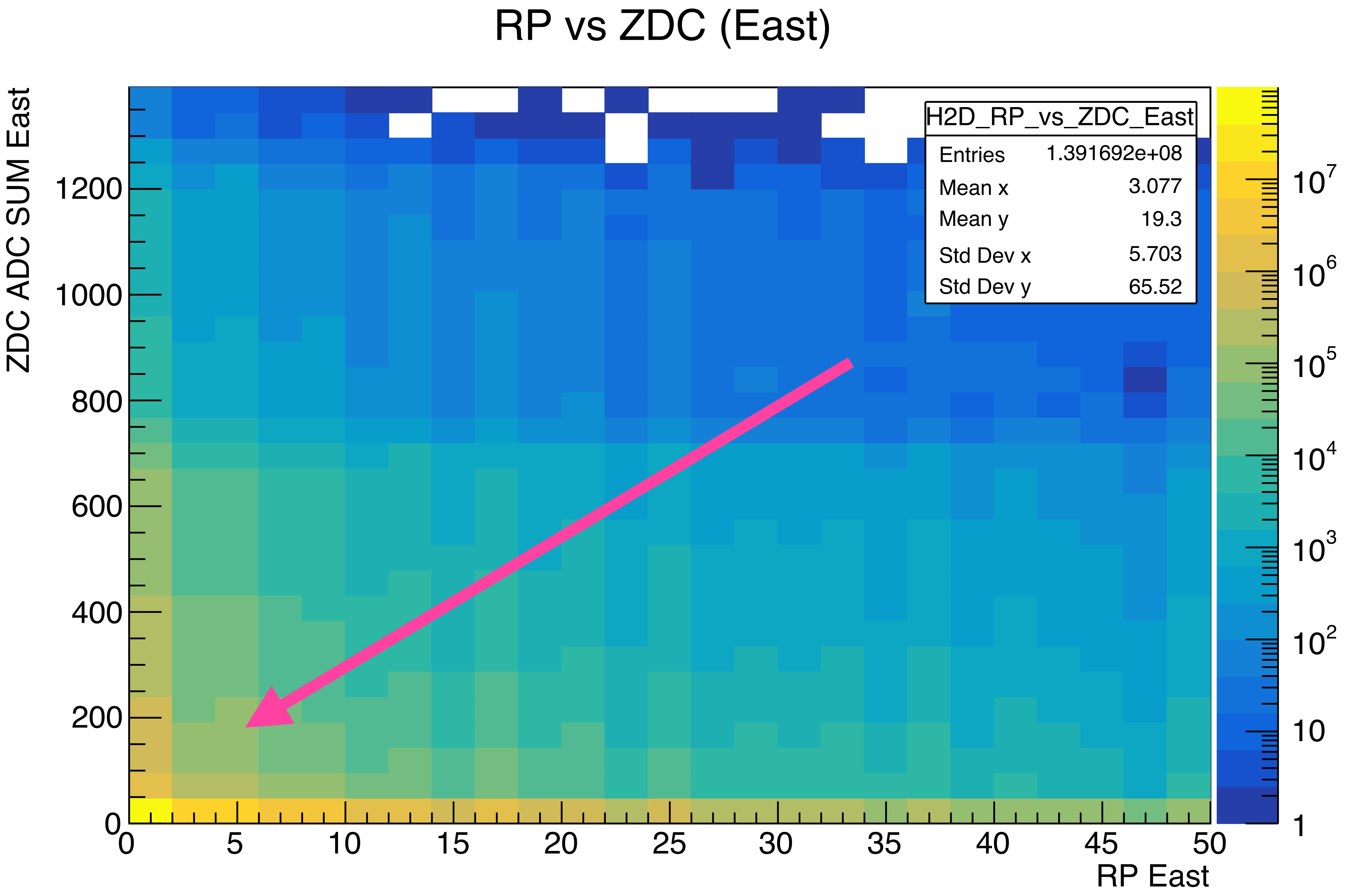
The Roman Pot West detectors remain mostly empty throughout the run in UPC-triggered events, as expected for the proton-going side. In contrast, the East detectors record multiple hits, likely resulting from charged debris produced by nuclear breakup on the gold-going side.

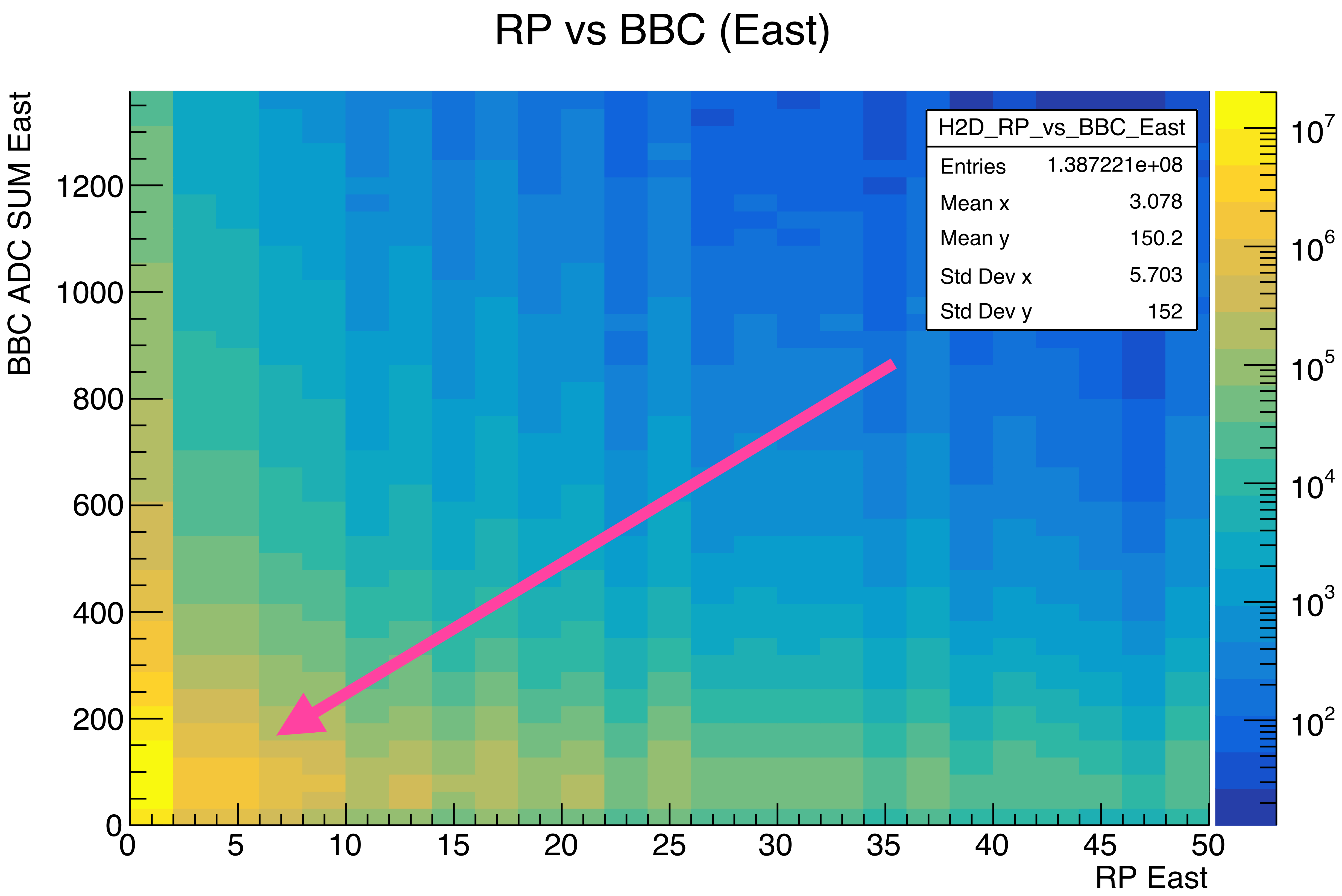




Roman Pots vs ZDC and BBC

The Roman Pot track multiplicity shows strong correlation with BBC and ZDC ADC values. Most events exhibit low activity across all detectors, consistent with exclusive processes. Only a few events show significant energy deposition or multiple RP tracks, suggesting rare inelastic or non-exclusive interactions.





$\pi^+\pi^-$ 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

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

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

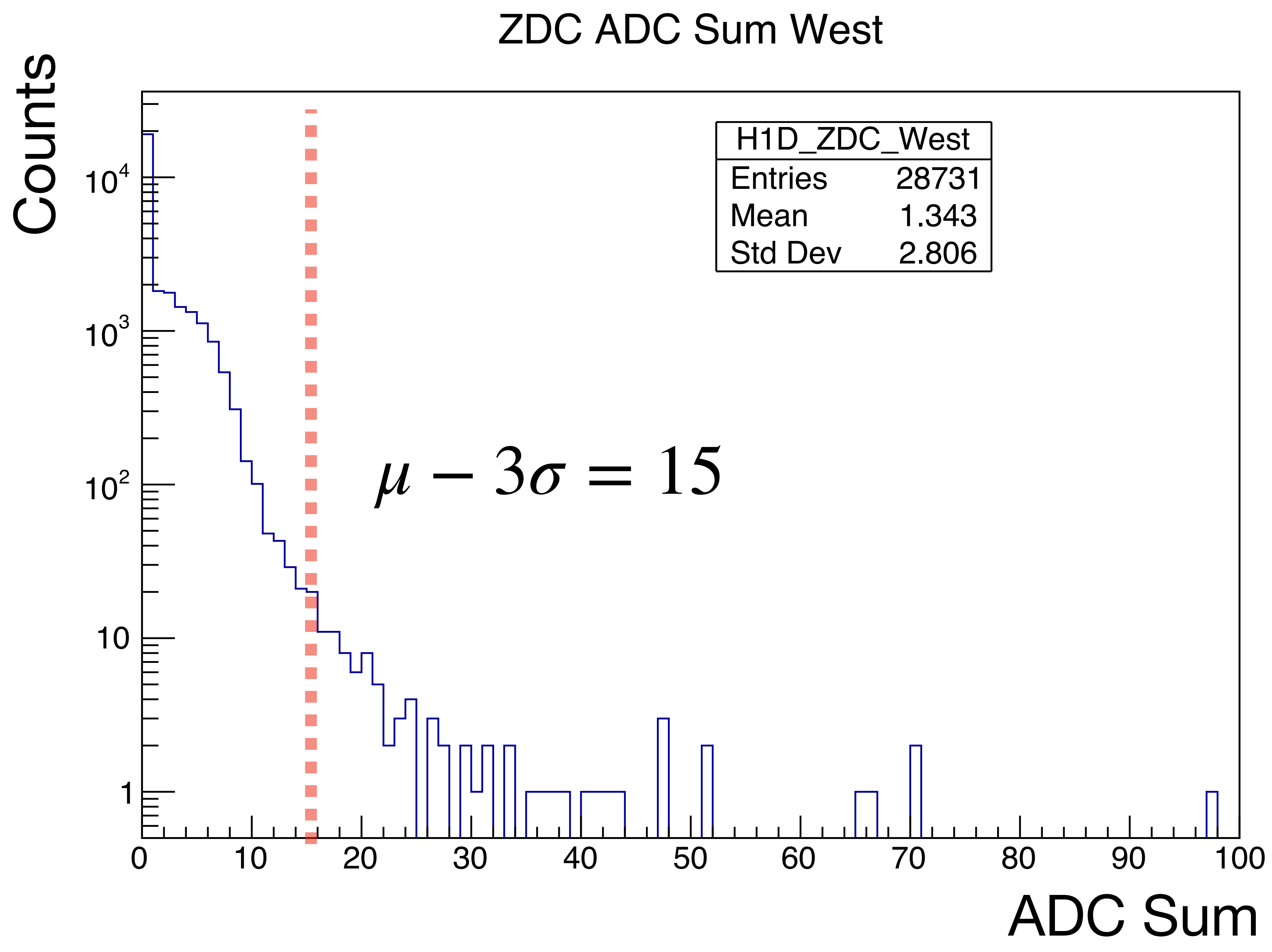
With

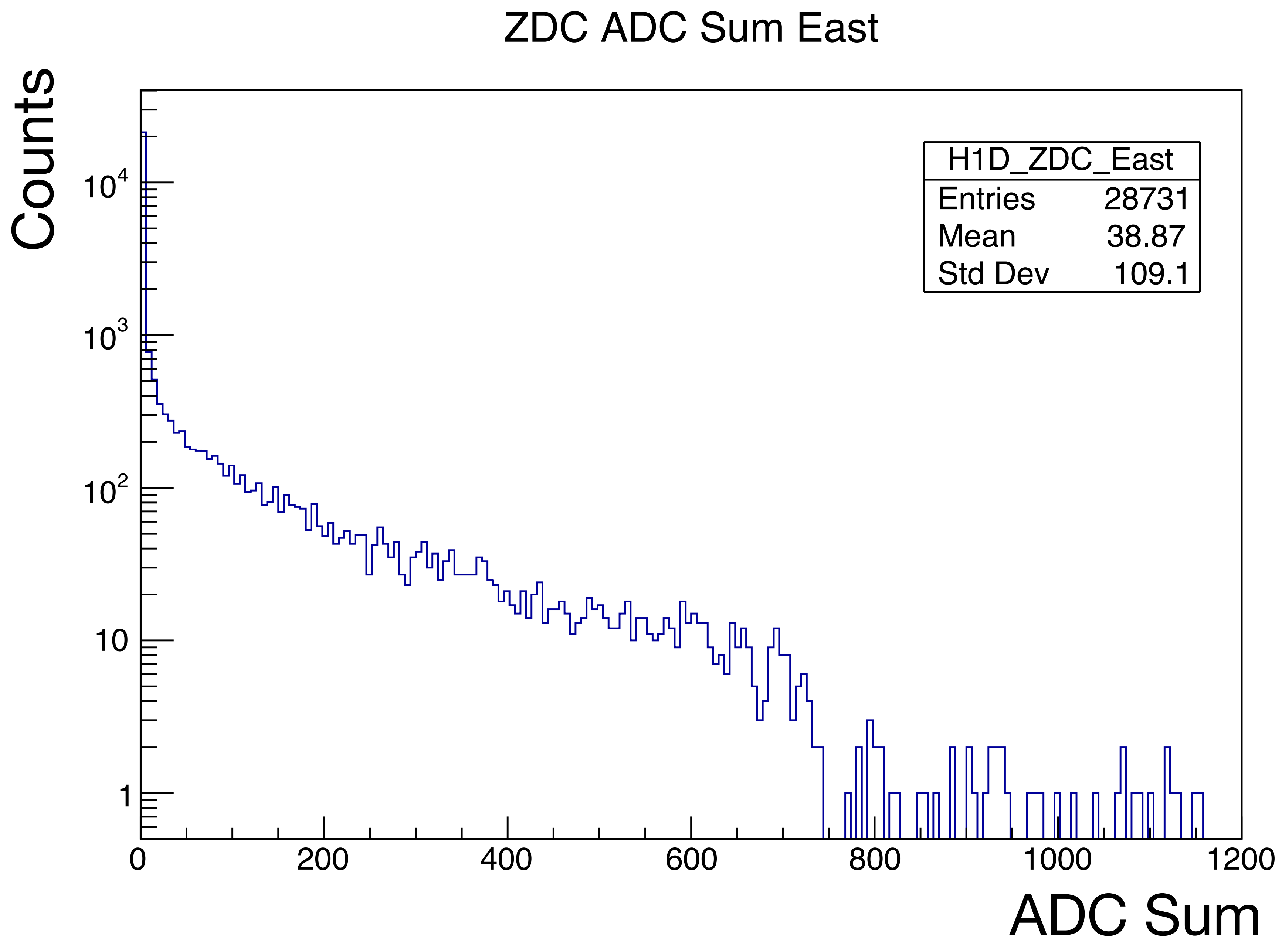
$$t_{\text{expected}} = \frac{\Delta s}{c}\sqrt{1 + \frac{m^2_\pi c^2}{p^2_\pi}}$$

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

$\Delta\Delta TOF < 0.75$ ns

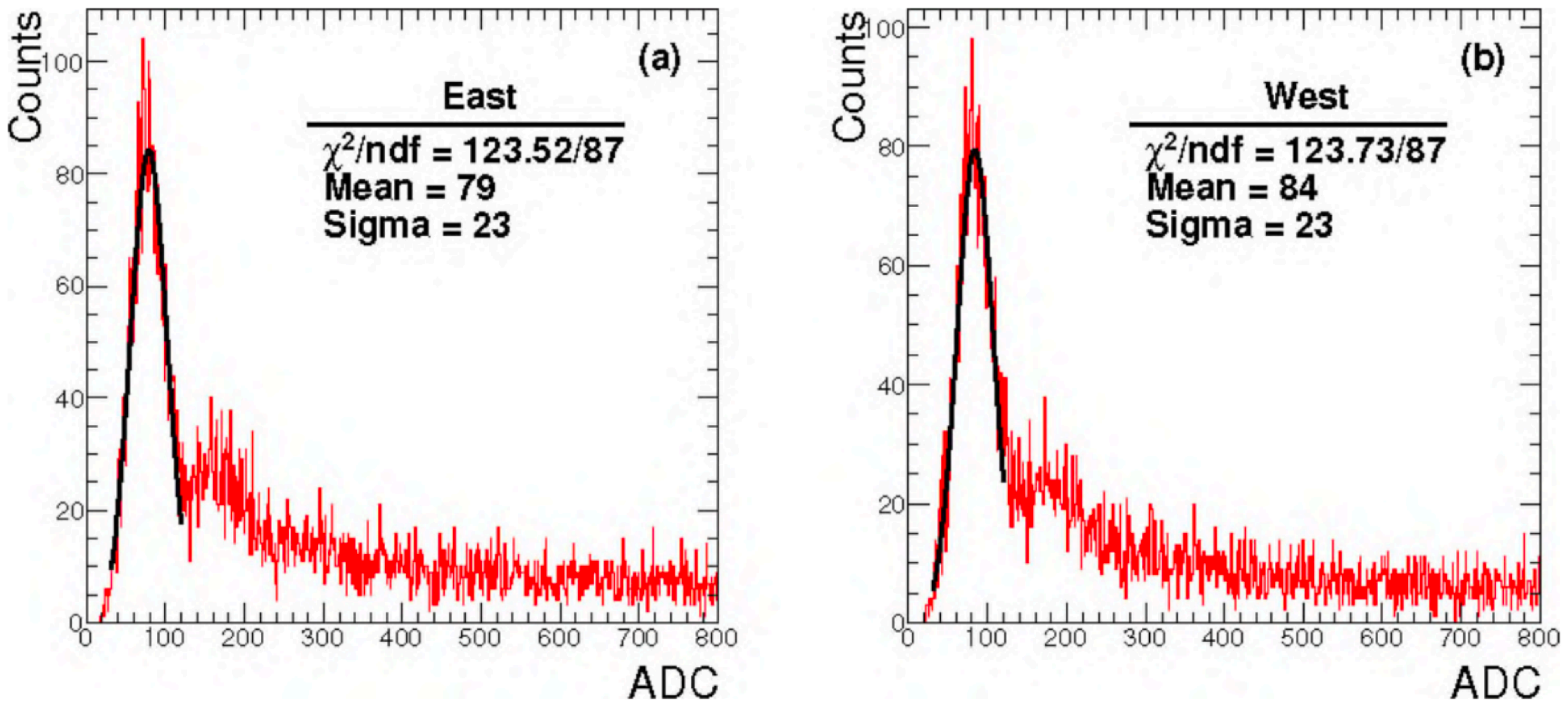
ADC sum distribution After PiDs





After applying the PID cuts, the ADC Sum on the West side is consistent with noise, indicating no hits. Combined with non-zero ADC Sum values on the East side, this pattern corresponds to **0nXn-type collisions**, an expected signature of UPC p+Au events.

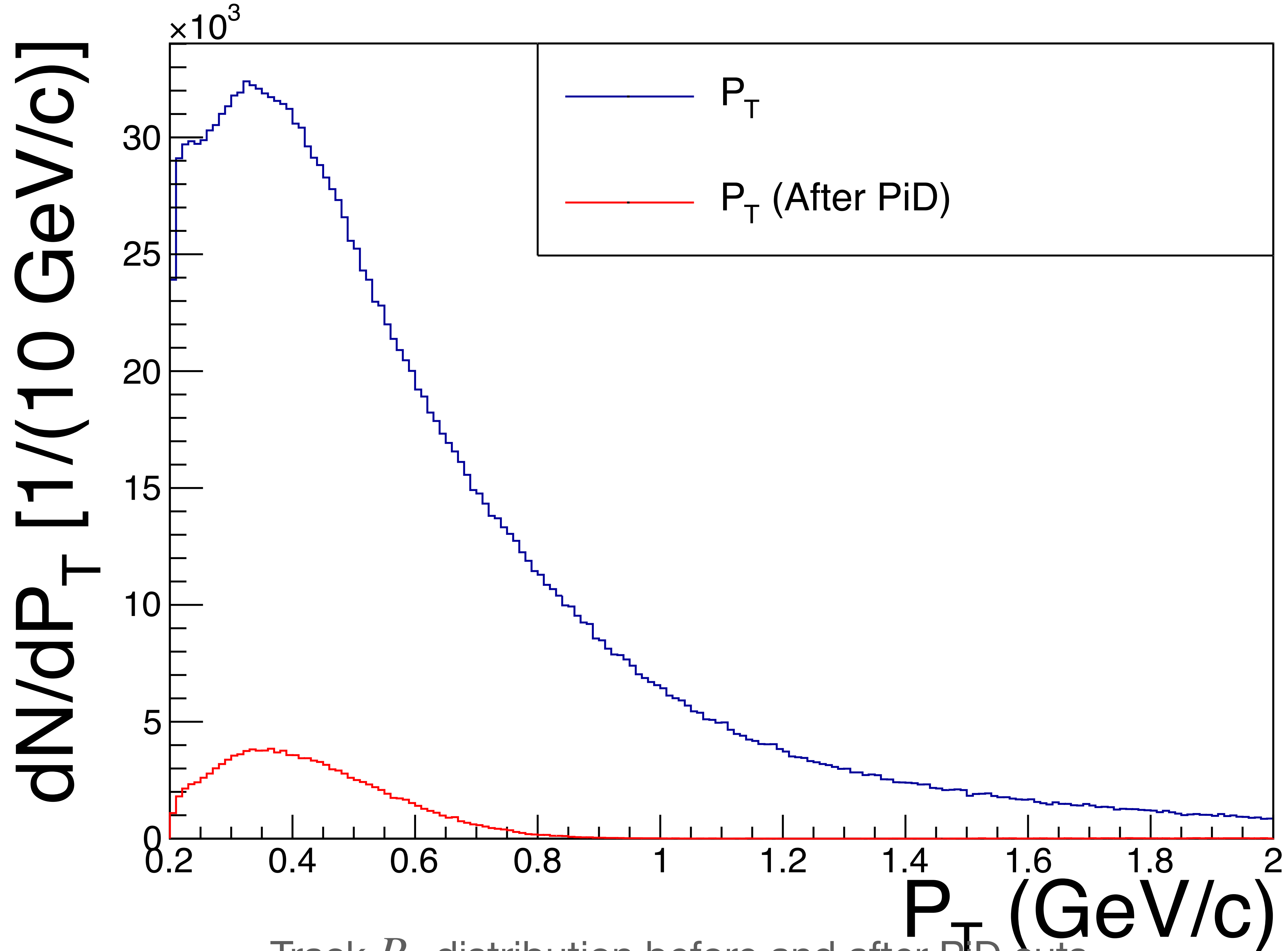
Run 14 Au+Au @200 GeV



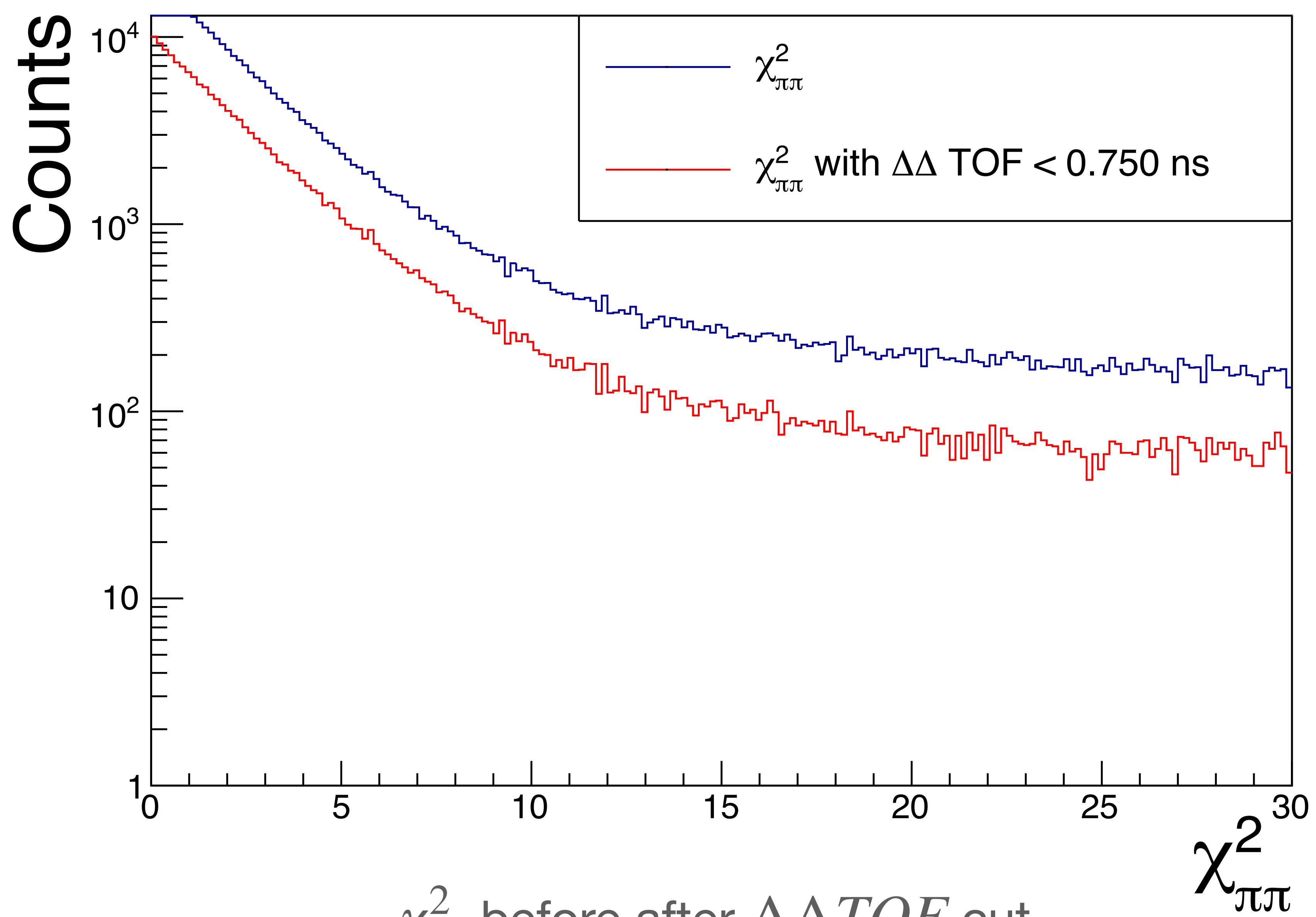
Xu, Yi-Fei, et al. "Physics performance of the STAR zero degree calorimeter at relativistic heavy ion collider." *Nuclear Science and Techniques* 27.6 (2016): 126.

PiD variables plots

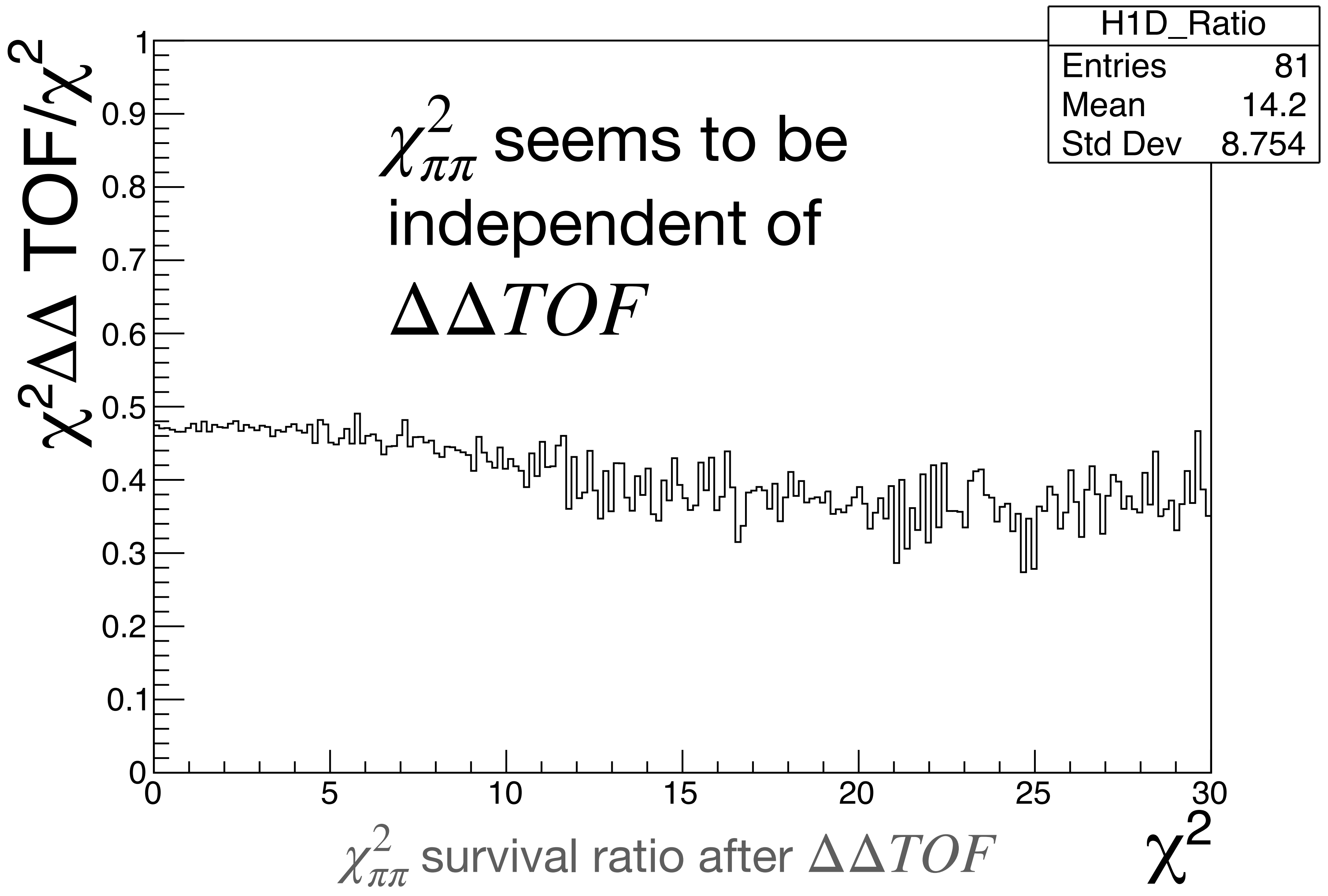
P_T^{π} **cuts:** The tail exhibits a steeper decline compared to when no PiD is applied. This is expected, as the applied cuts eliminate momentum ranges where PiD cuts are less effective in distinguishing between particles, i.e. $P_T > 1$ GeV/c



Track P_T distribution before and after PID cuts.



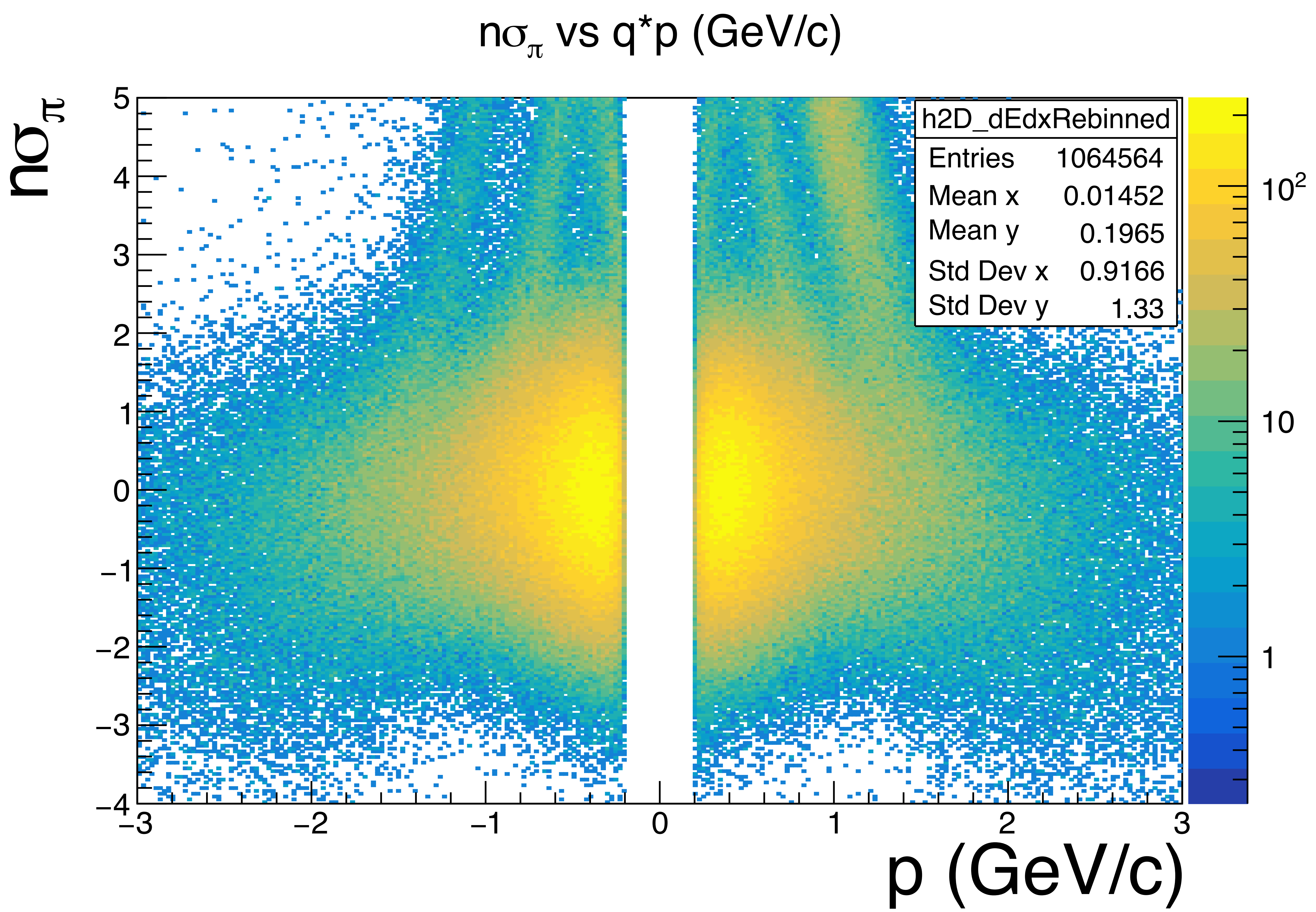
$\chi^2_{\pi\pi}$ before after $\Delta\Delta TOF$ cut.



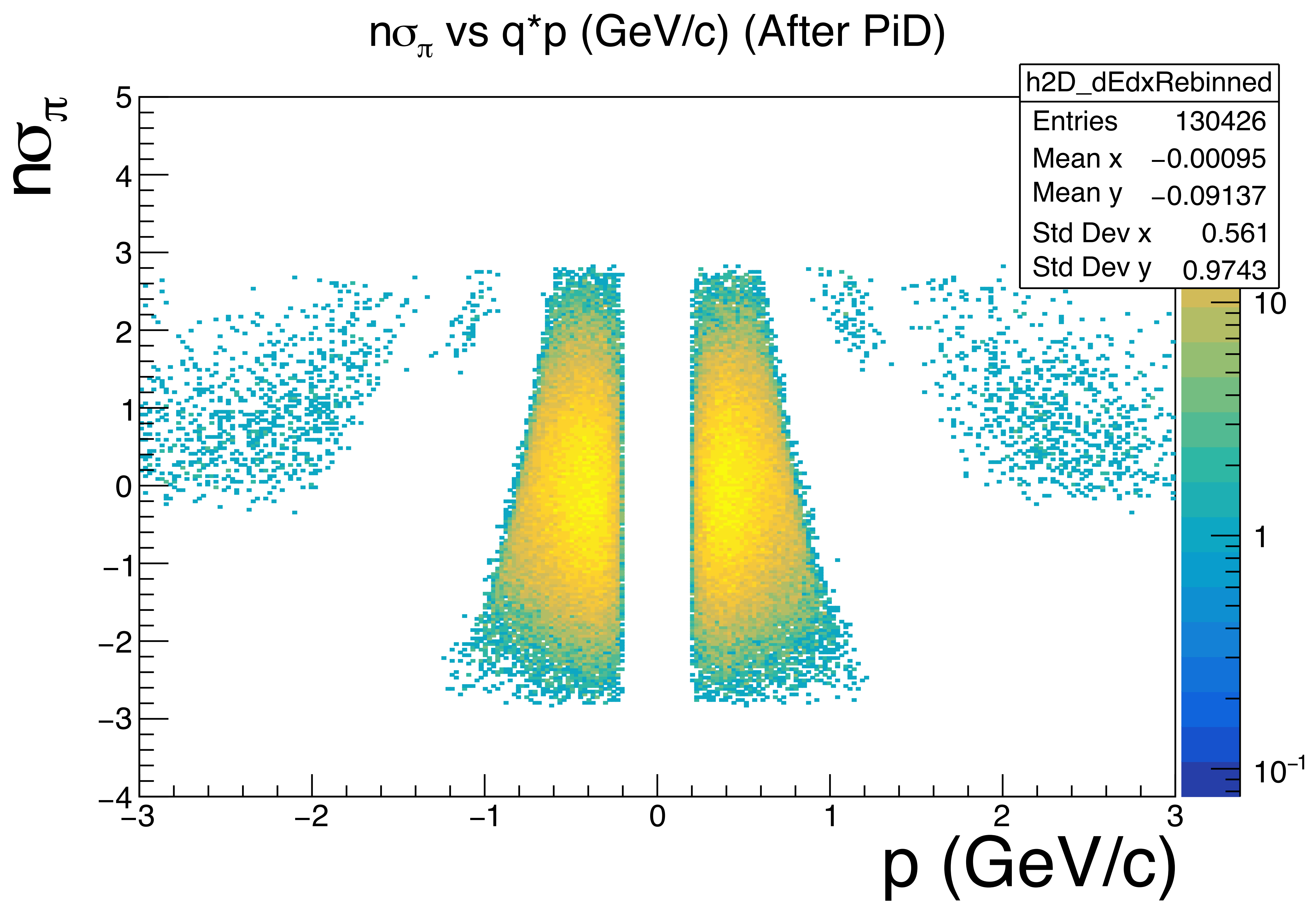
$\chi^2_{\pi\pi}$ seems to be independent of $\Delta\Delta TOF$

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

PiD variables plots

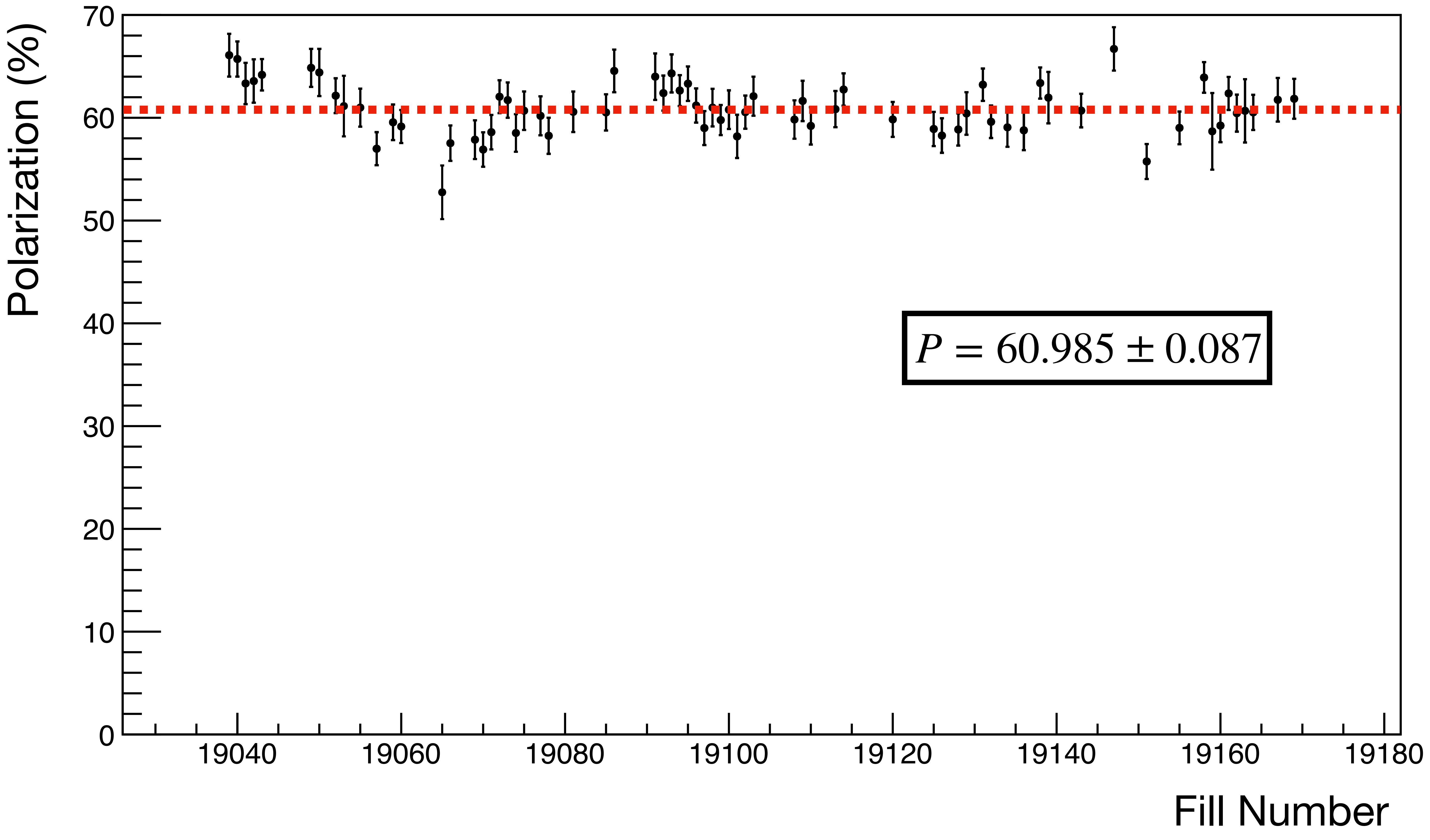


$n\sigma_{\pi}$ vs charge*momentum after PiD

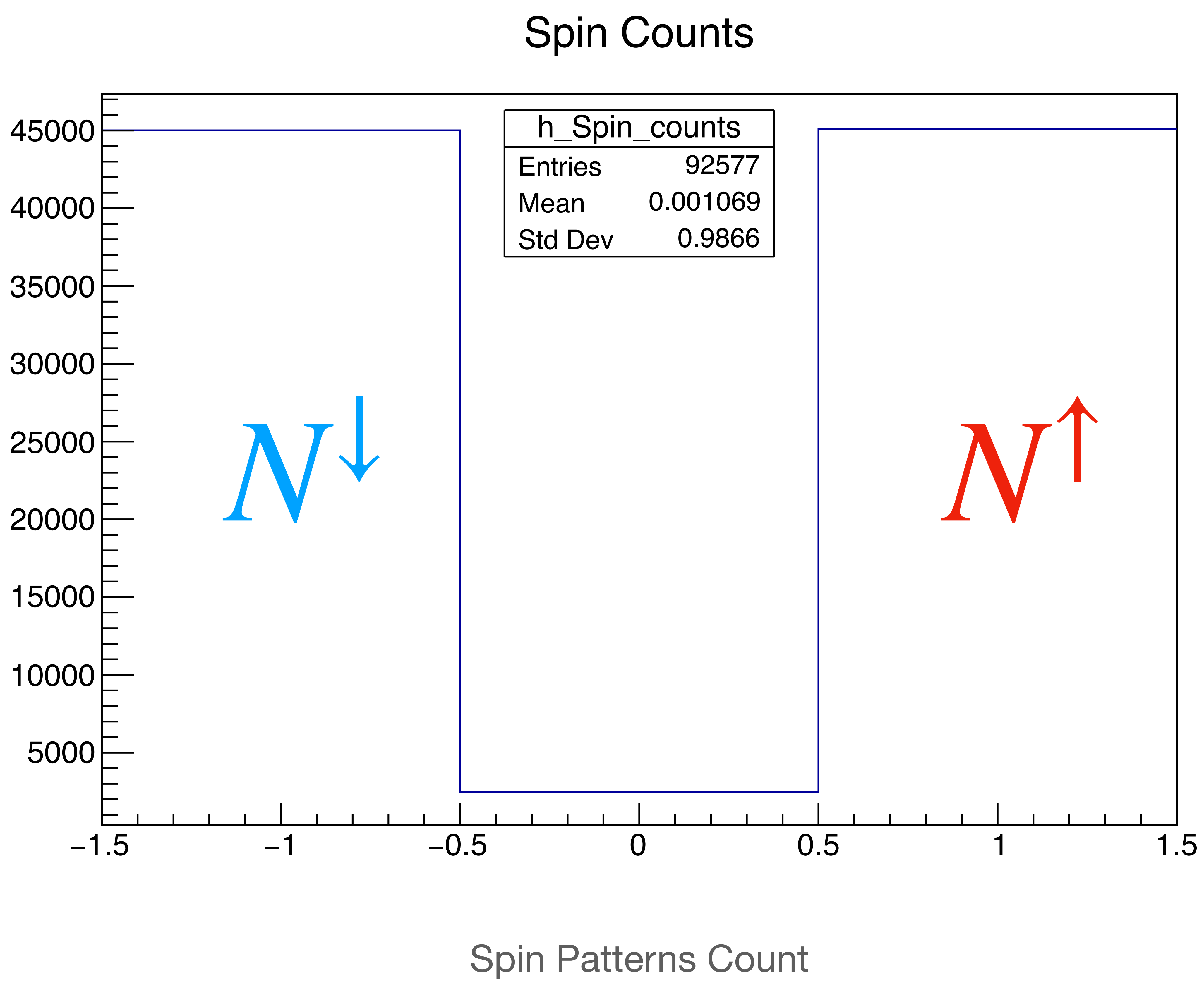


$n\sigma_{\pi}$ vs charge*momentum after PiD

QA Polarization Plot



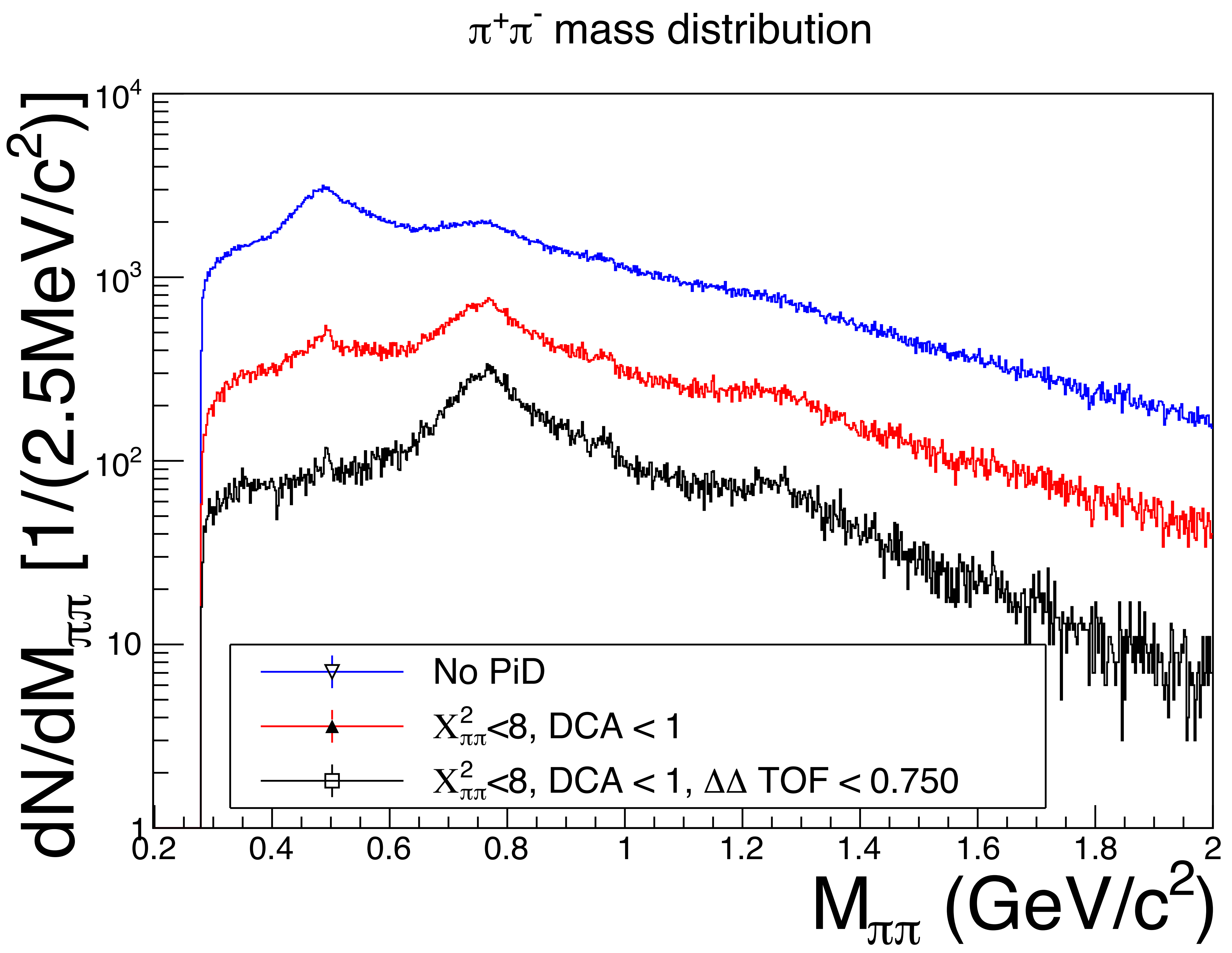
- **Fill Pattern:** shows the measured beam polarization values as a function of RHIC fill number during the data-taking period.



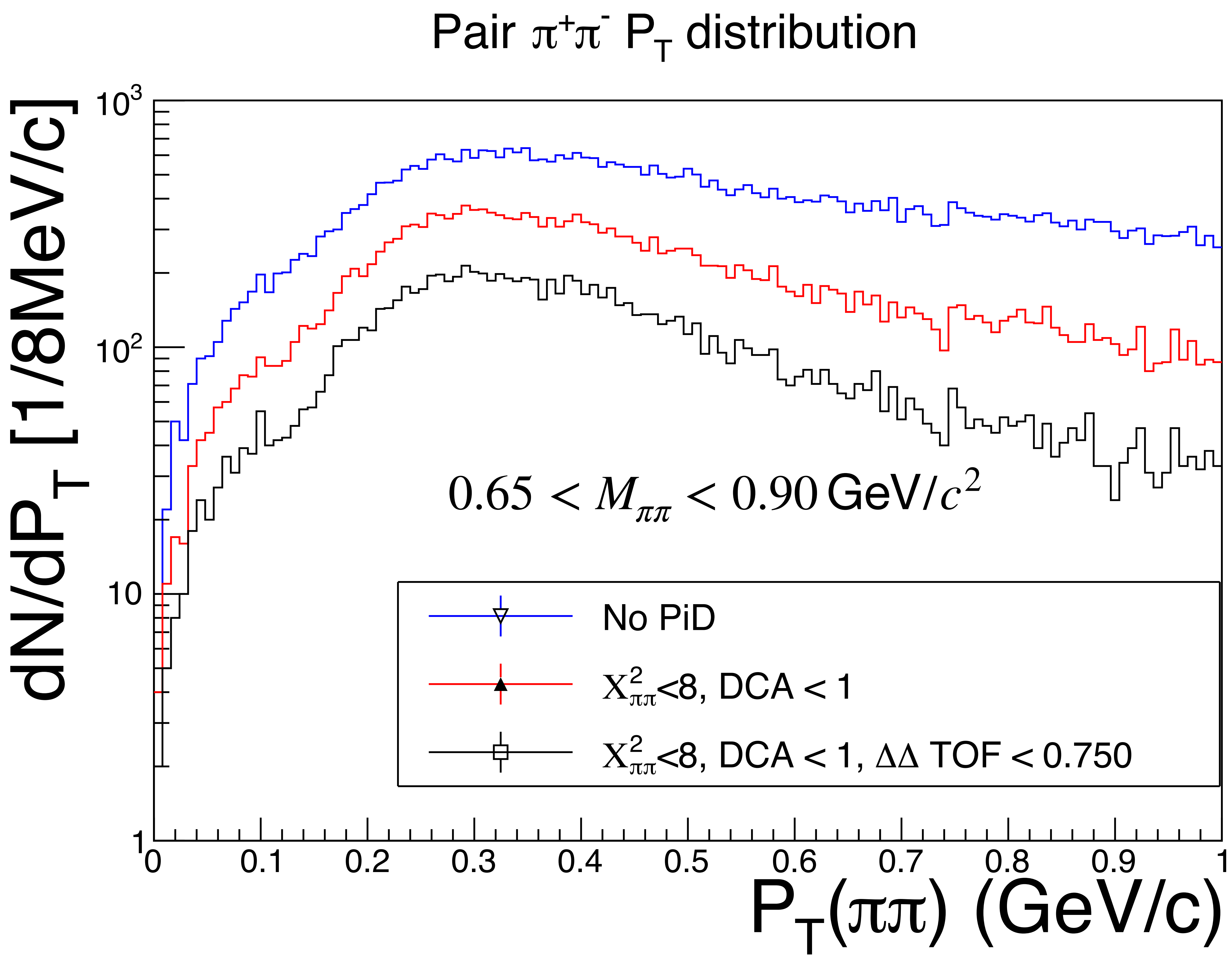
- **Equal Number of Events:** The dataset contains an equal number of events with the proton spins oriented in the positive and negative y-axis directions.

Mass and Momentum after PiD

A clear ρ^0 appears after after $\chi^2_{\pi\pi}$ and $\Delta\Delta TOF$ are applied. Some contamination is expected in these plots as no Kaons and protons were excluded by using $n\sigma_Y > 2$, where $Y = (p, K)$.

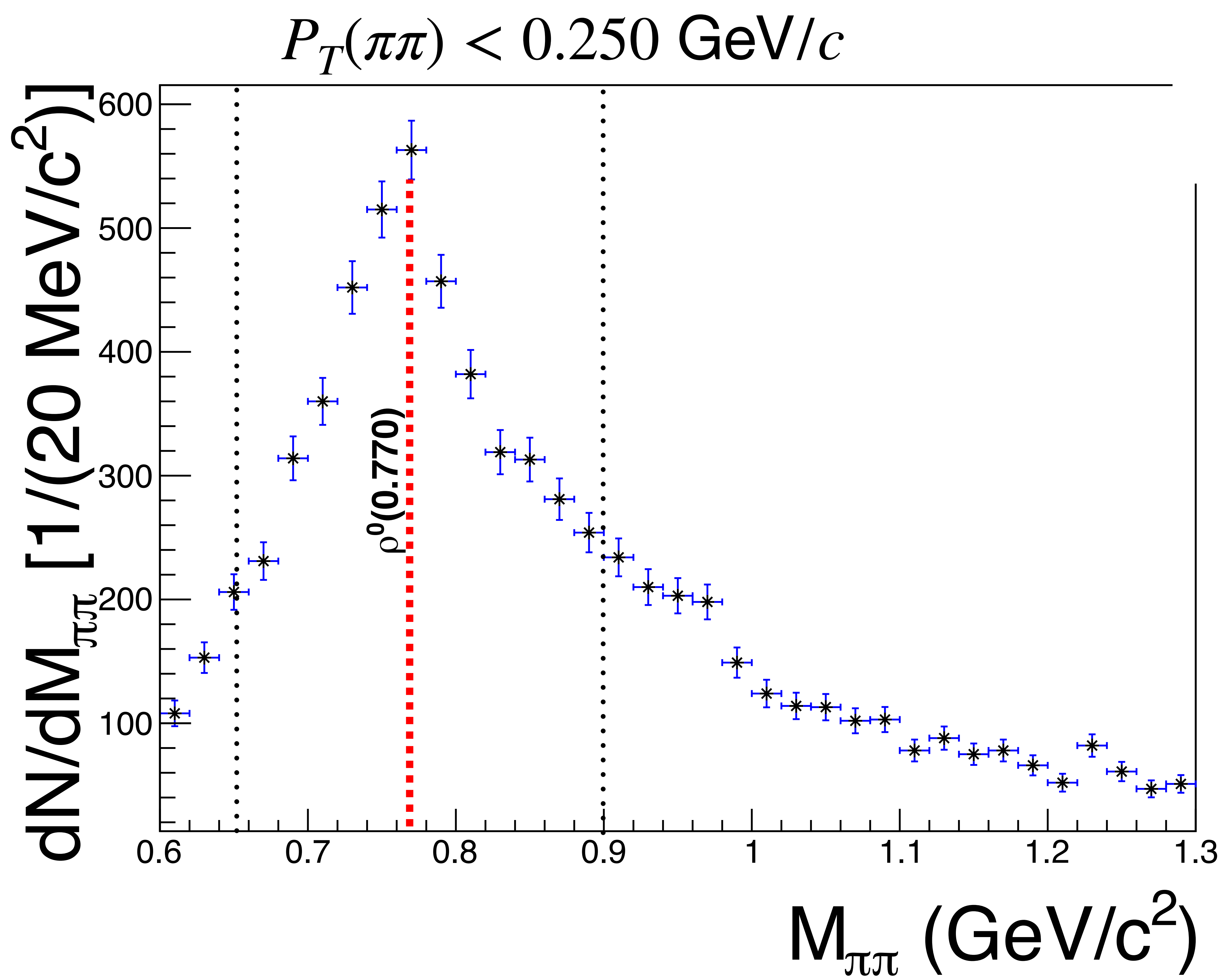


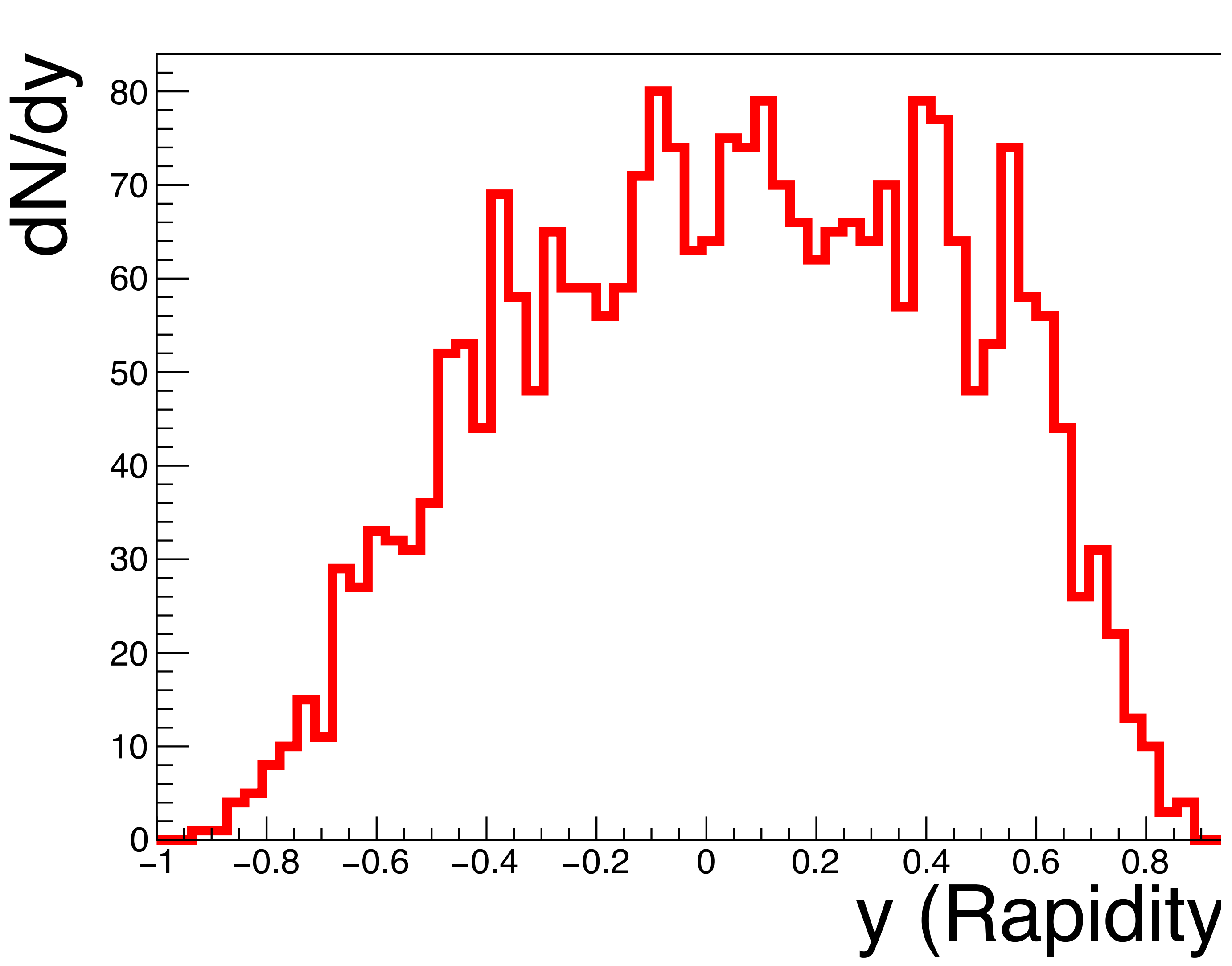
Invariant mass histogram for Run 15 AuAu collisions at $\sqrt{s_{NN}} = 200$

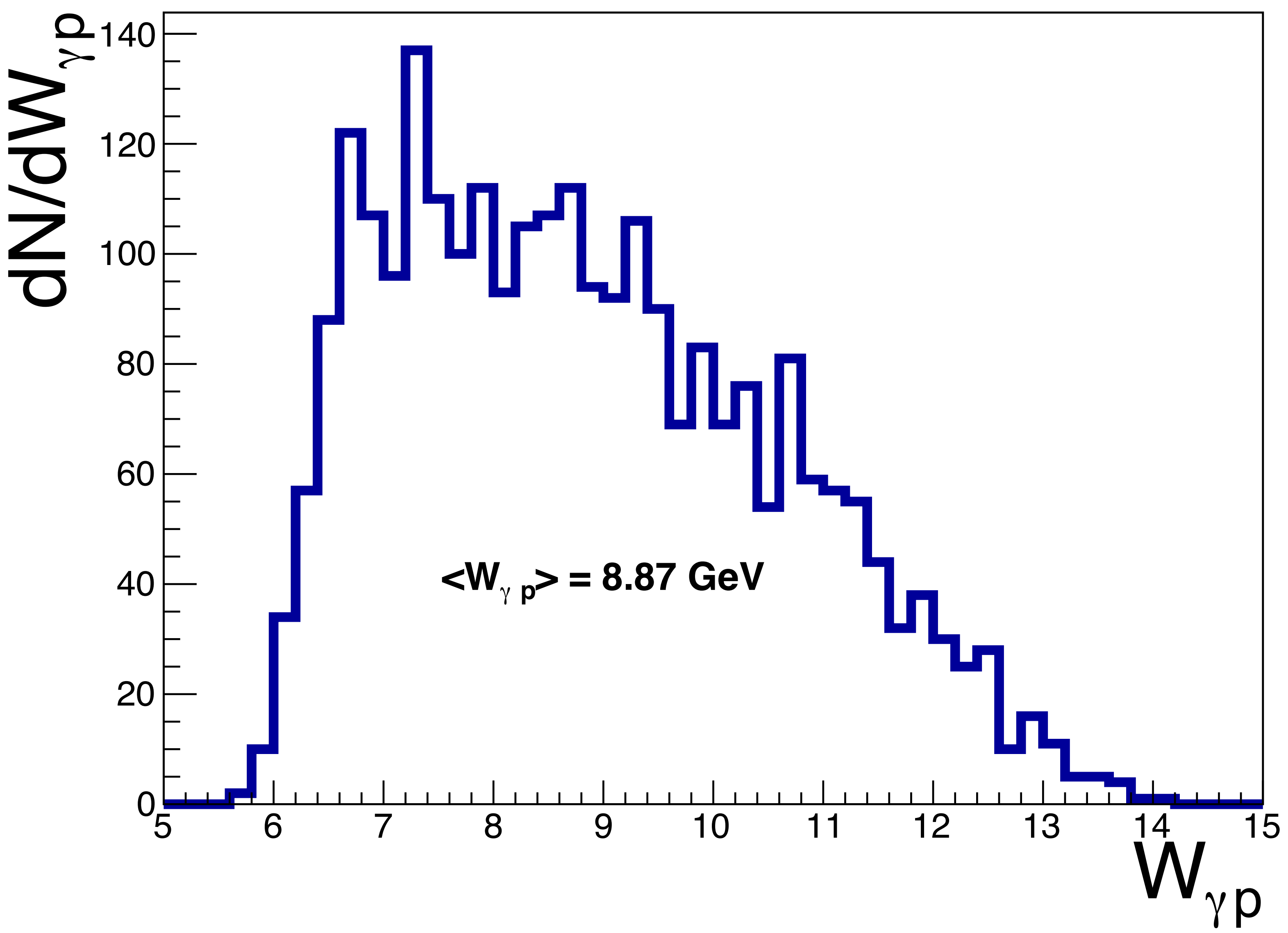


Transverse momentum of two opposite sign pions histogram for Run 15 AuAu collisions at $\sqrt{s_{NN}} = 200$

Characterization of ρ^0 peak







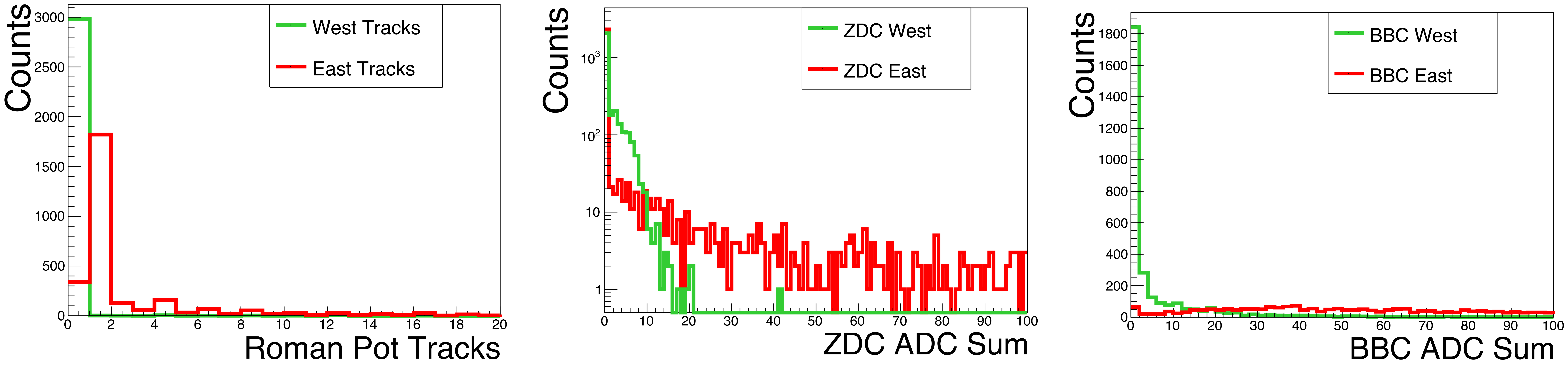
- Clear ρ^0 peak
- Define region of interest $m_{\pi\pi} \in (0.65, 0.90)$ GeV/c
- $E_T^{\gamma} = \hbar c / r_p \sim 250$ MeV for coherent process only.
- Photon-Proton center of mass energy:
  $W_{\gamma p} \approx \sqrt{2 M_{\rho^0} E_p} e^{-y/2} \rightarrow \left\langle W_{\gamma p} \right\rangle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

Trigger Topology in the Exclusive ρ^0 Region

The observed topology is consistent with exclusive ρ^0 meson photo-production in ultra-peripheral p+Au collisions. We see a clean $\pi^+\pi^-$ pair with minimal additional activity: both BBC and ZDC signals are near zero, indicating no nuclear breakup (**0n0n**), and Roman Pot detectors show no significant forward proton activity. This suggests a coherent, exclusive process with no additional particle production, as expected for ρ^0 production via photon exchange.



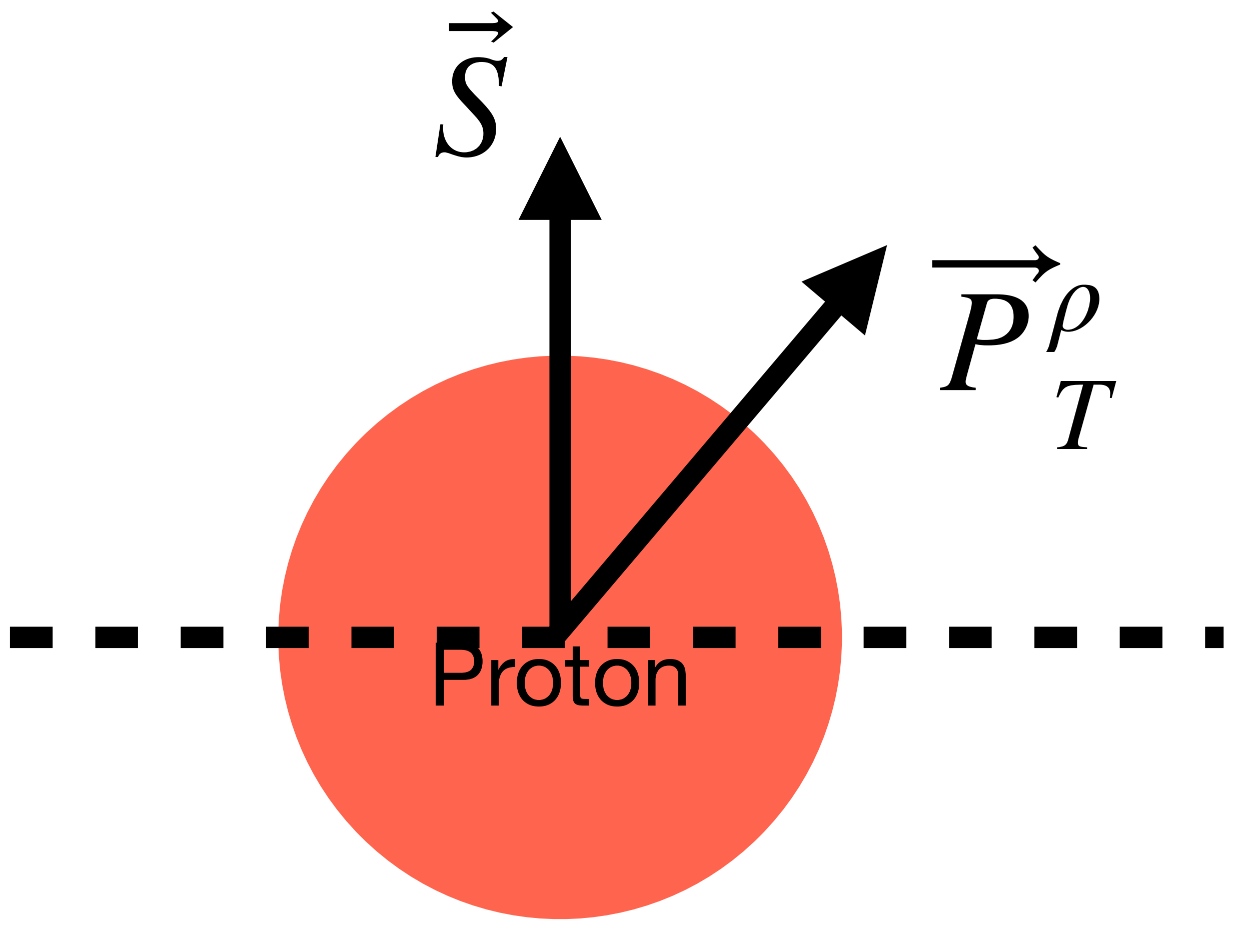
A_N Definition

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

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

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, $P = 60.99 \pm 0.09\ \%$ represents the average polarization for the proton's beam.

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



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

Transverse Plane

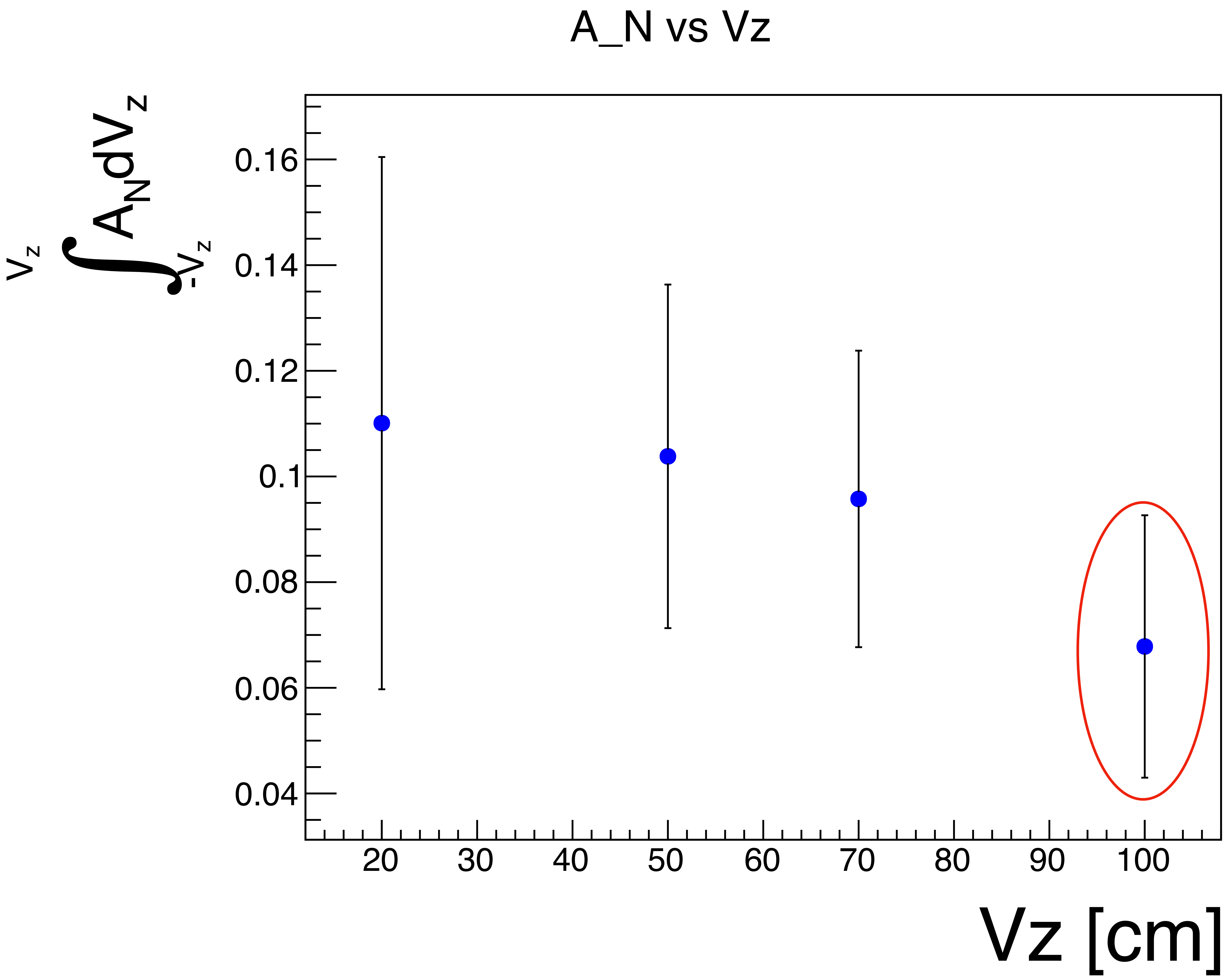
- **A_N Uncertainty**

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

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

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

Vz Scanning



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

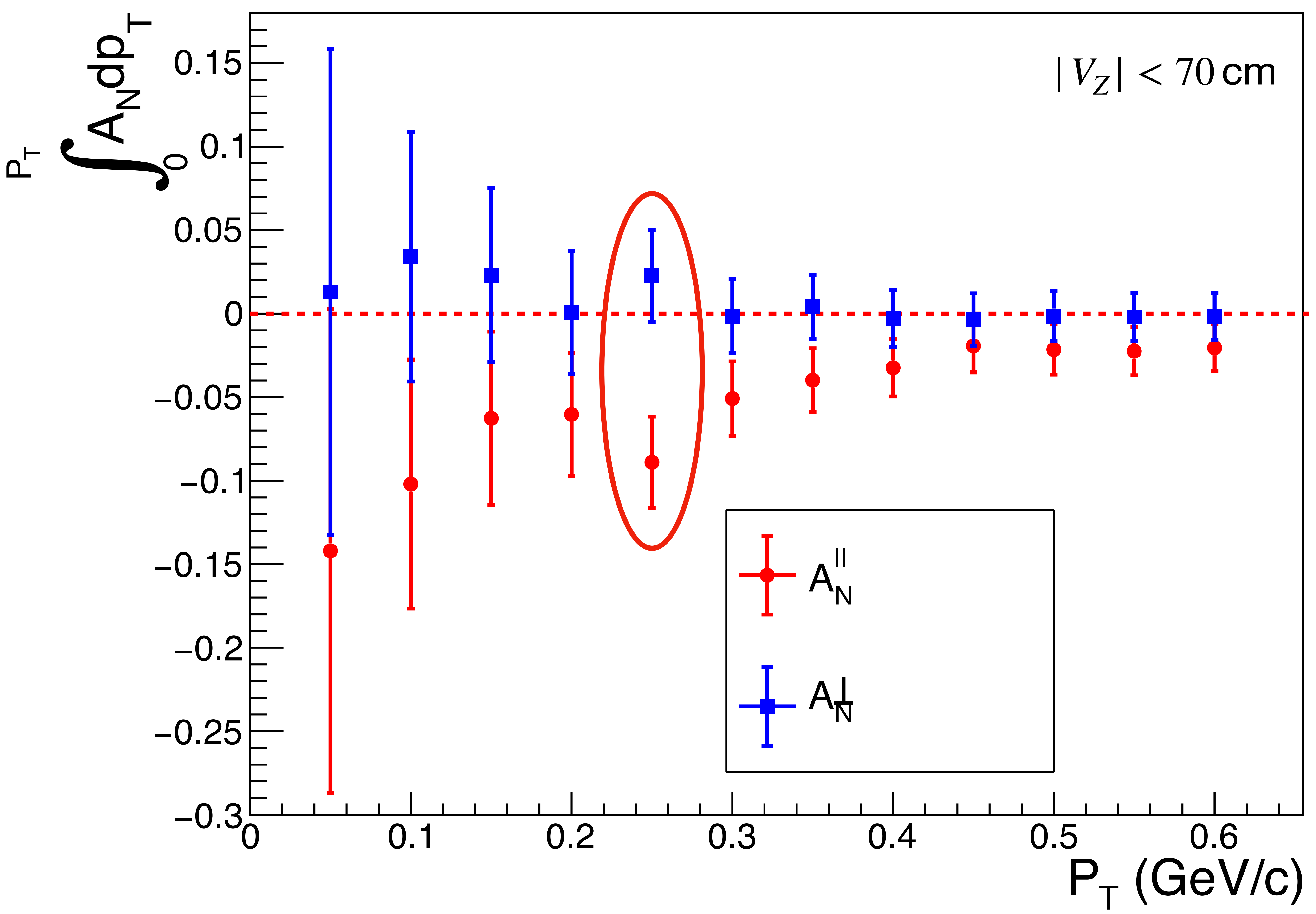
$A_N(|V_z| < 20\text{ cm}) = 0.110 \pm 0.050\,(\text{stat.})$

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

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

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

$P_T^{\pi\pi}$ Scanning



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

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

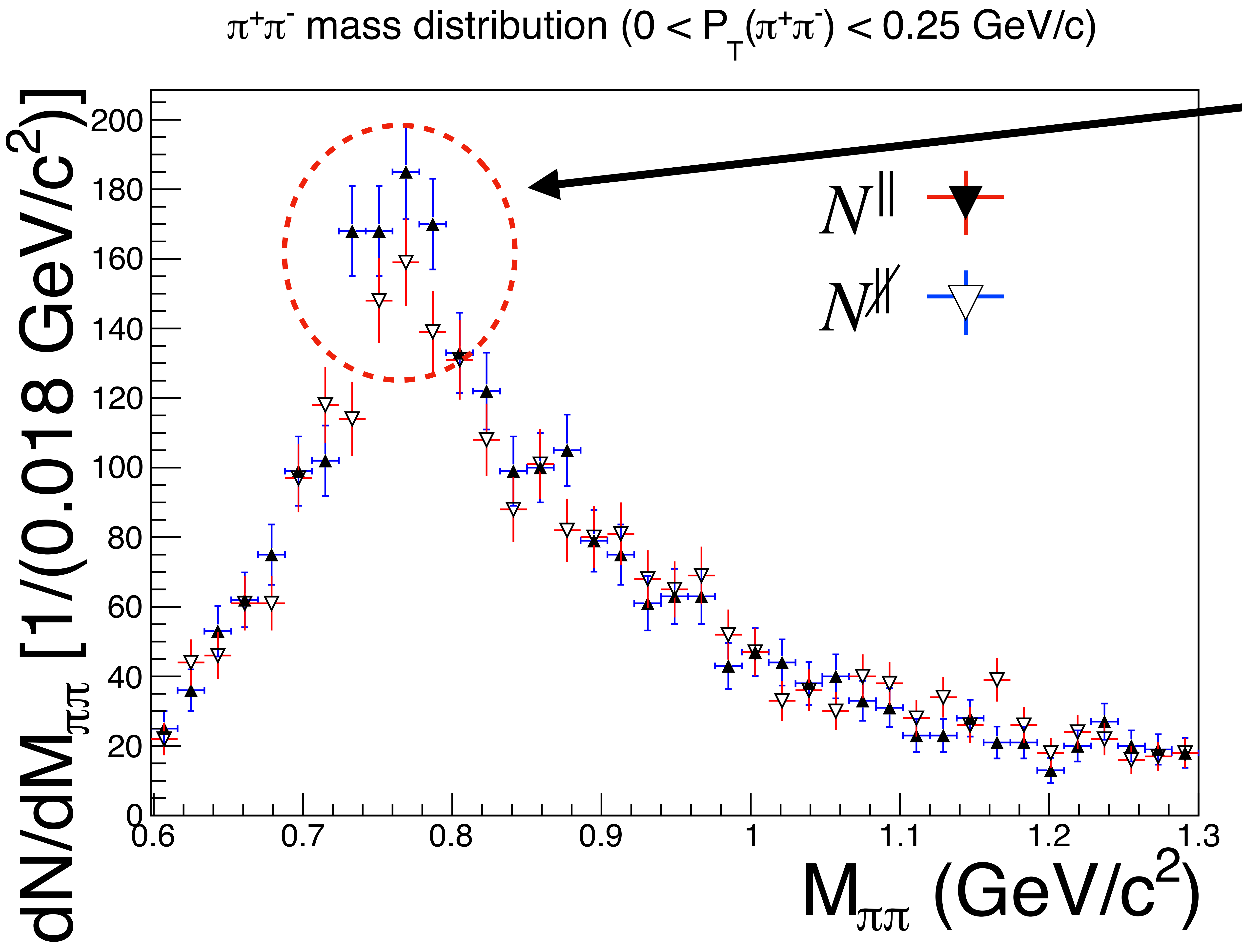
Where

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

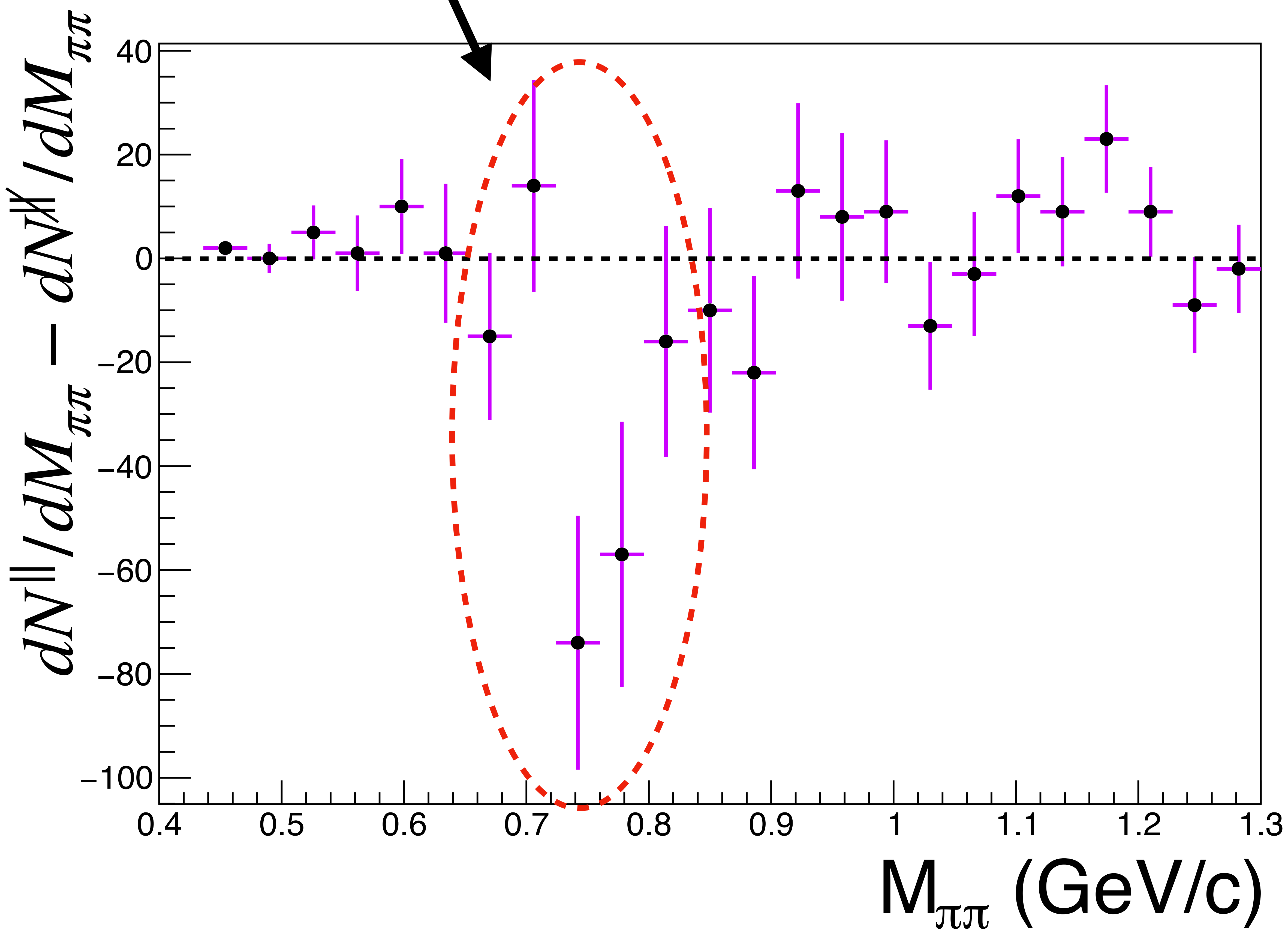
In the direction perpendicular to the spin direction we do not expect to see any asymmetries.

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.

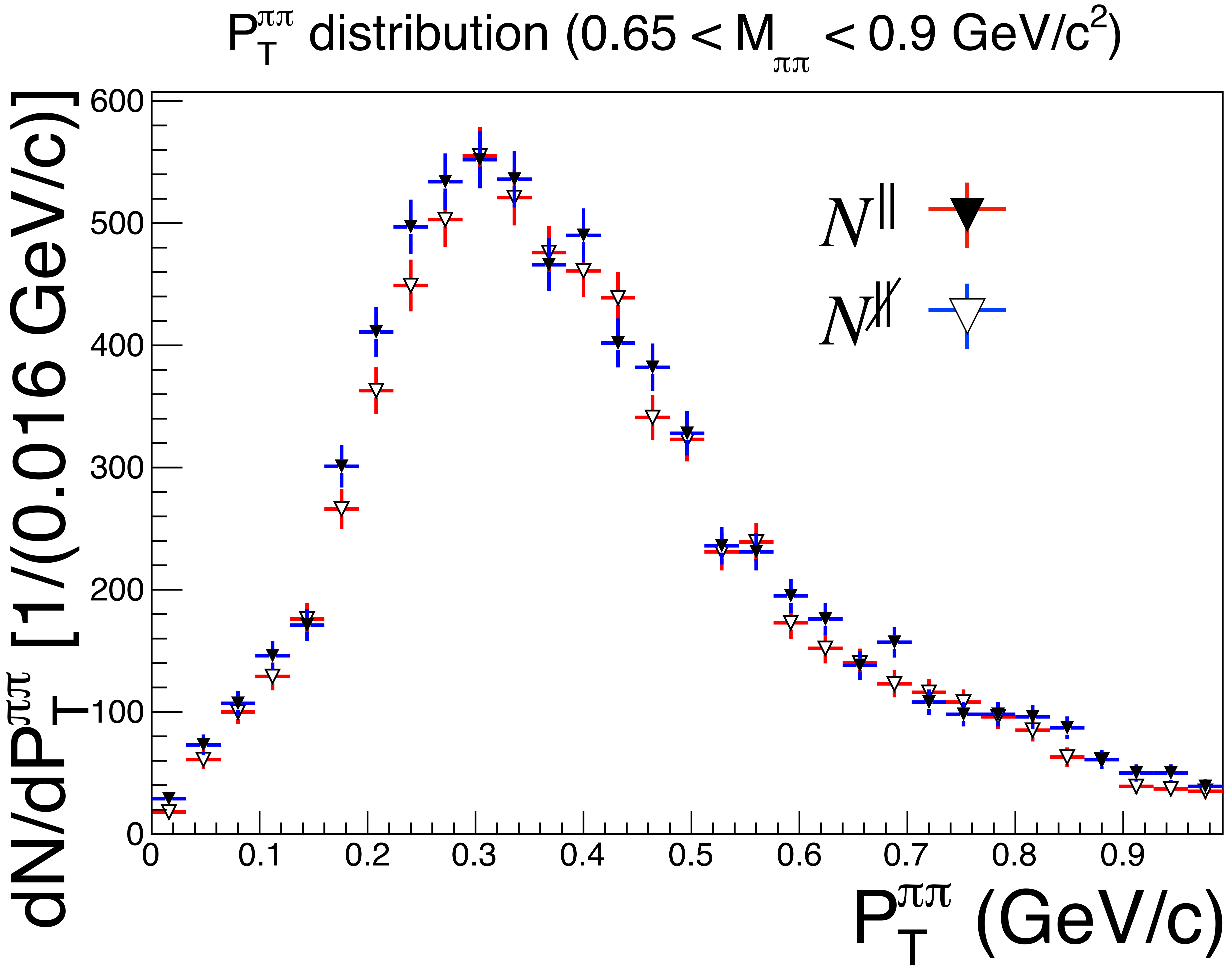
$M_{\pi\pi}$ Differential Plots



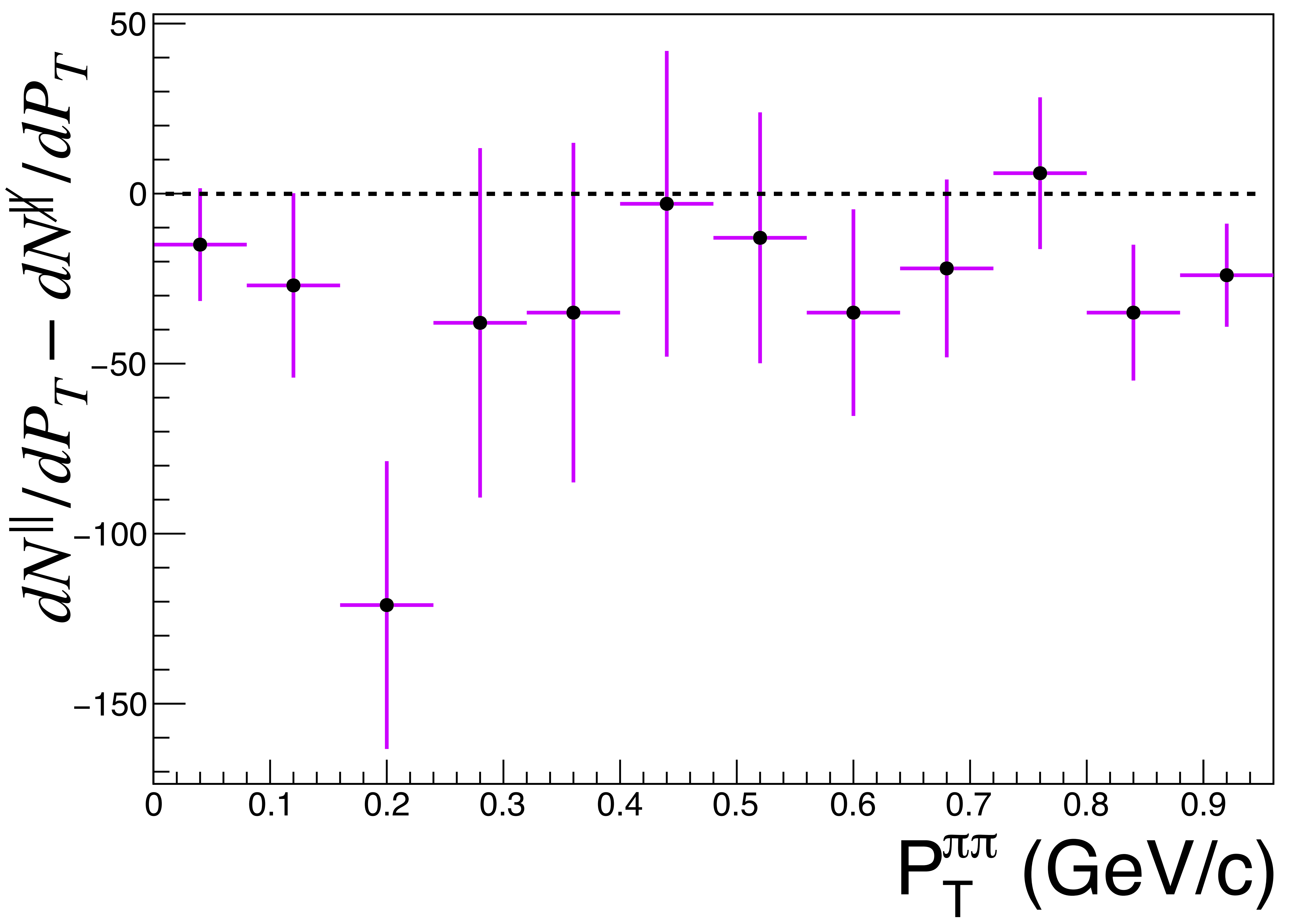
The A_N asymmetry is enhanced around the mass of the $\rho^0(0.770)$



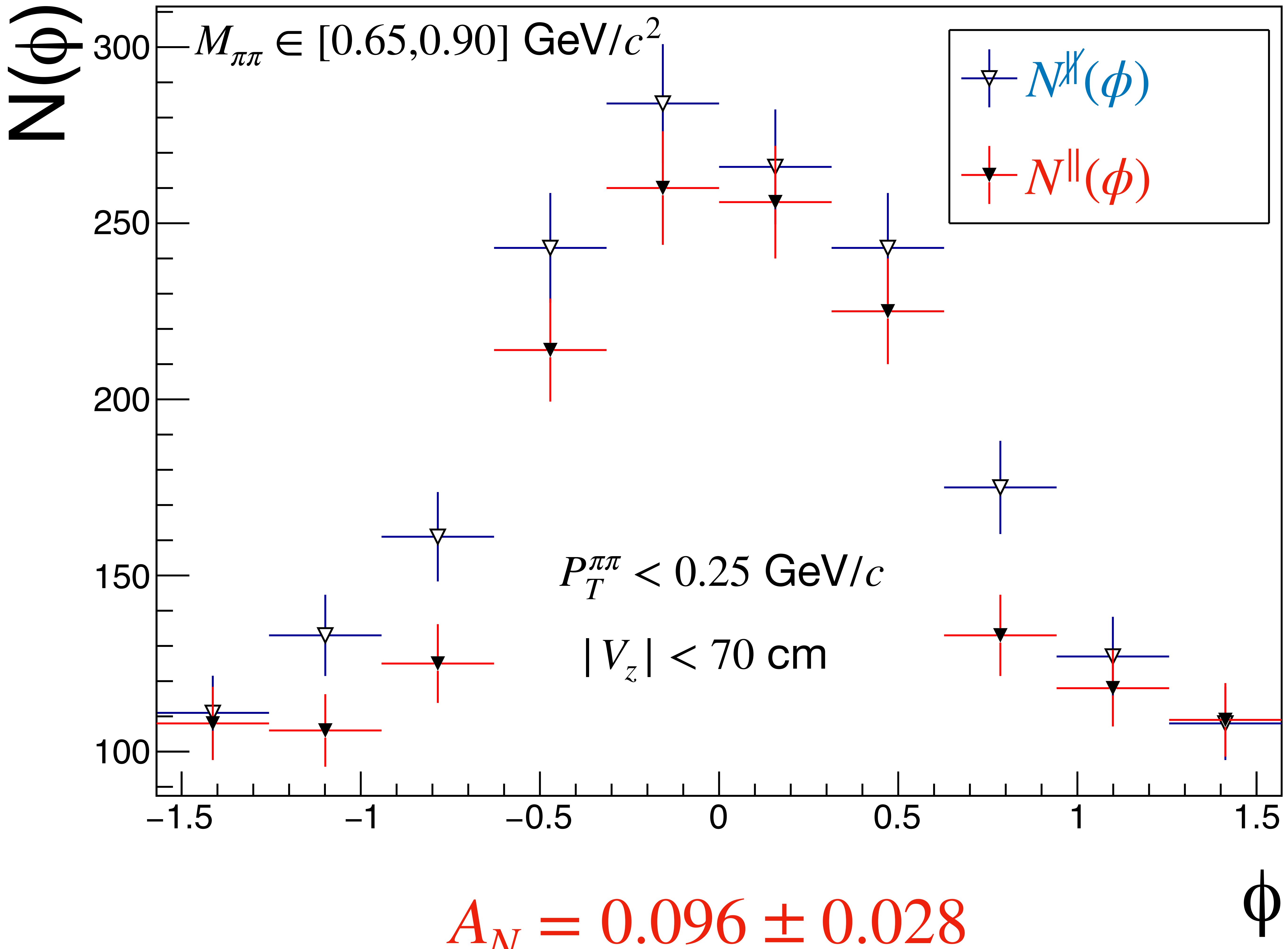
$P_T^{\pi\pi}$ Differential Plots



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



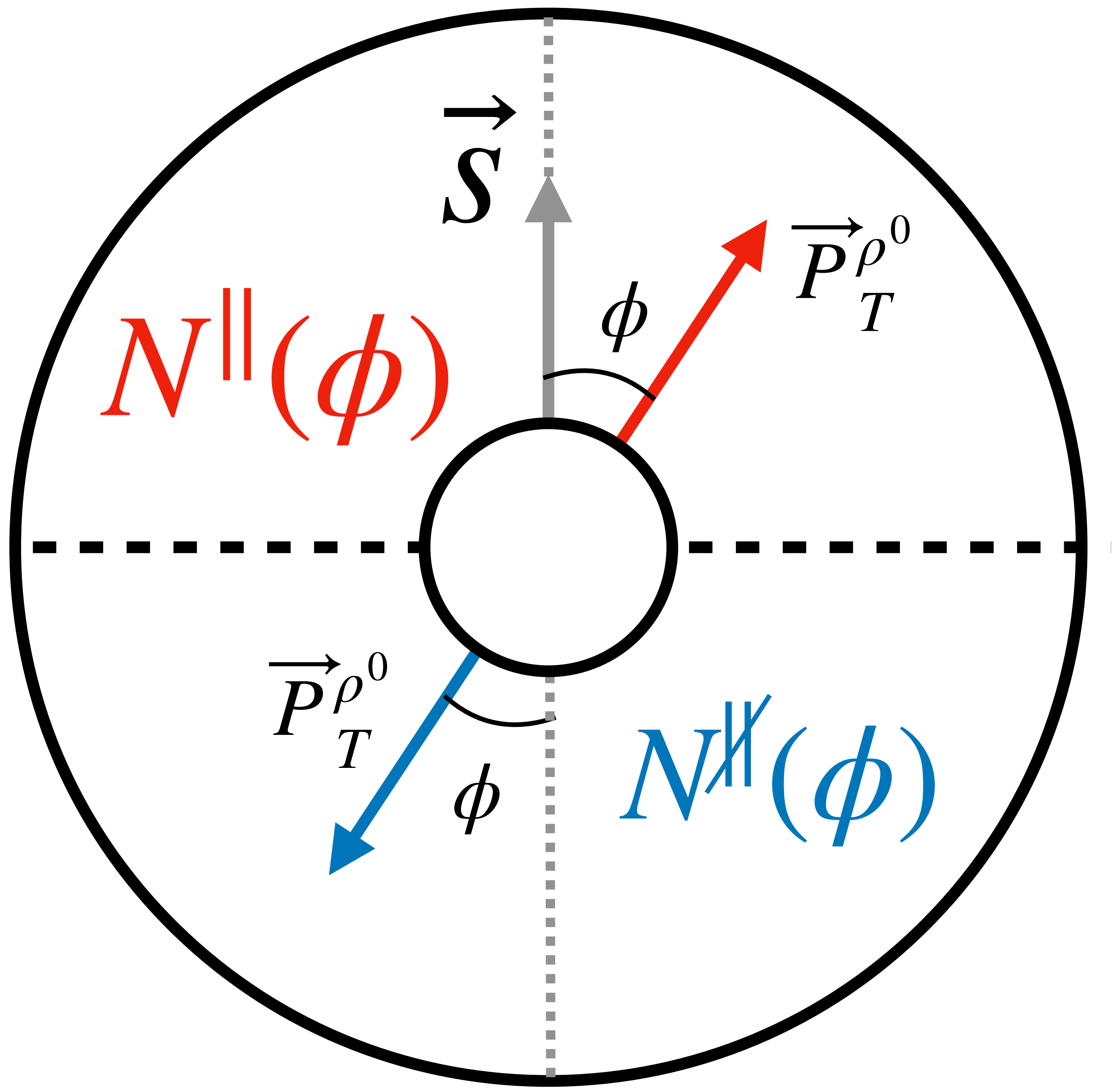
Angular Distribution



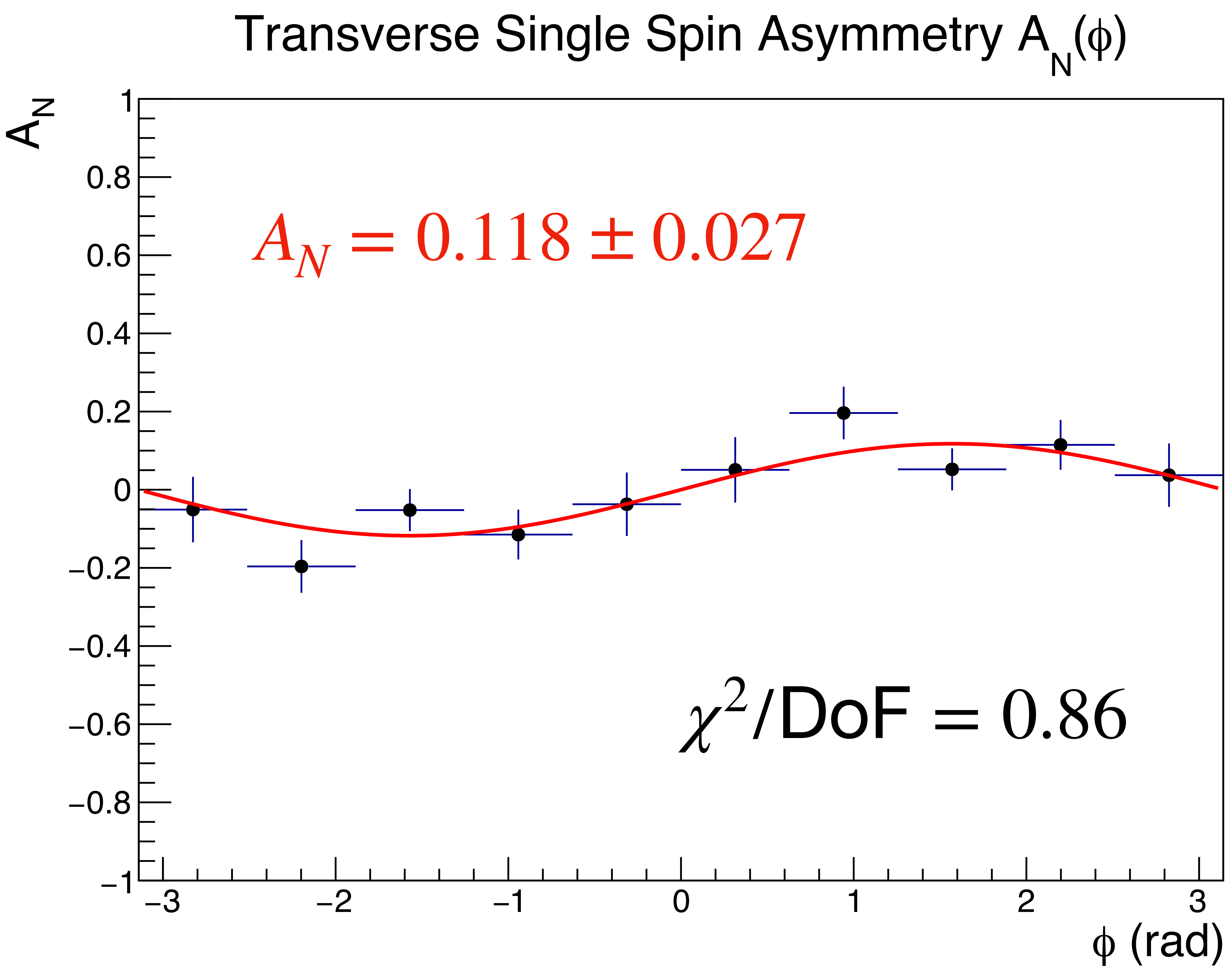
$A_N = 0.096 \pm 0.028$

$N^{\parallel,\not\parallel}(\phi)$: 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:

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

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

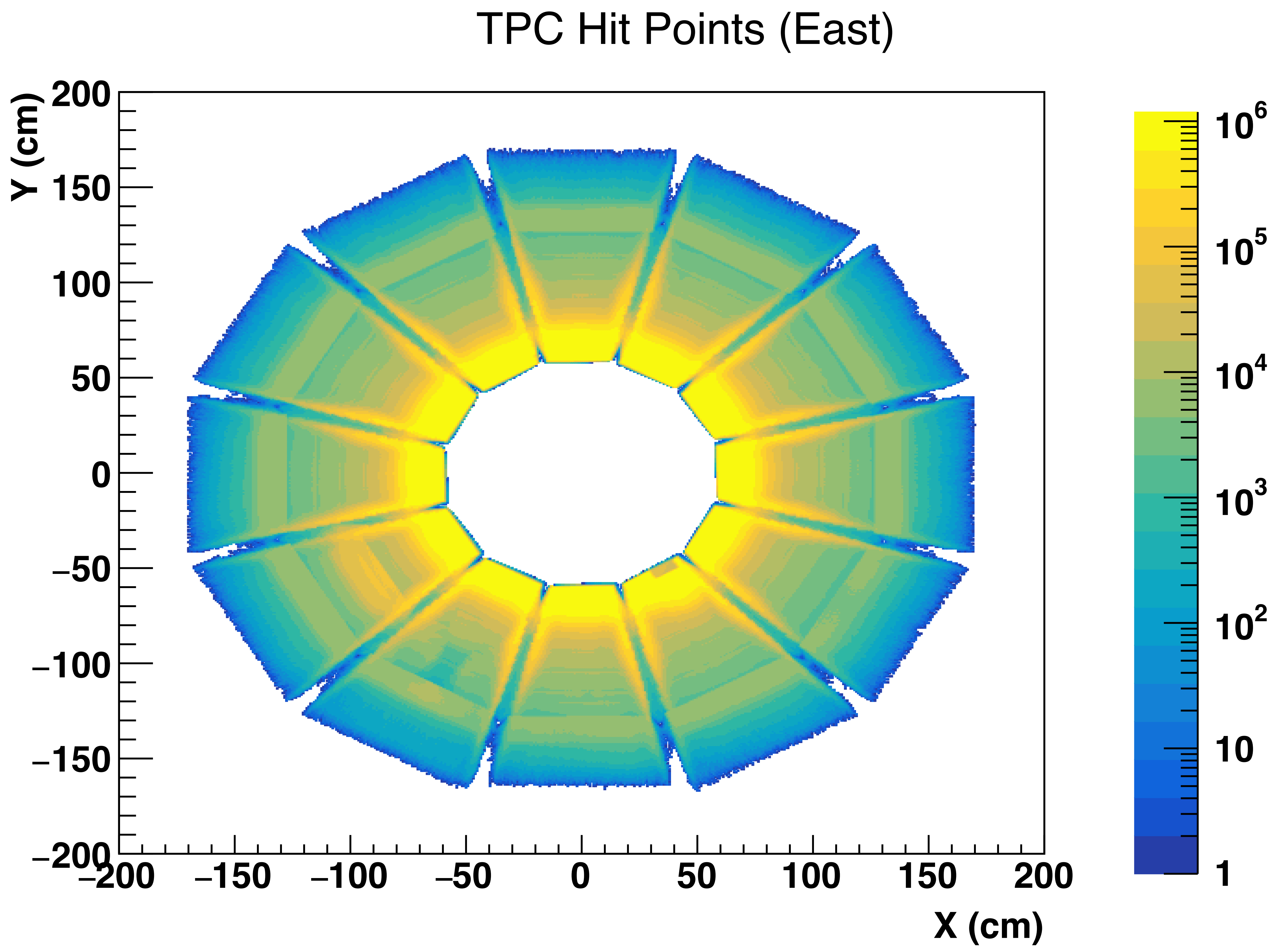
- Triggers are consistent with really clean 0n0n UPC collisions meaning exclusive ρ^0 photo-production.
- A up and down asymmetry was measured with a unconventional technique.
- It appears to be a clear excess of ρ^0 photo-production along the proton's spin direction.
- A $\sin - \cos$ modulation is visible with the more standard cross-ratio technique.

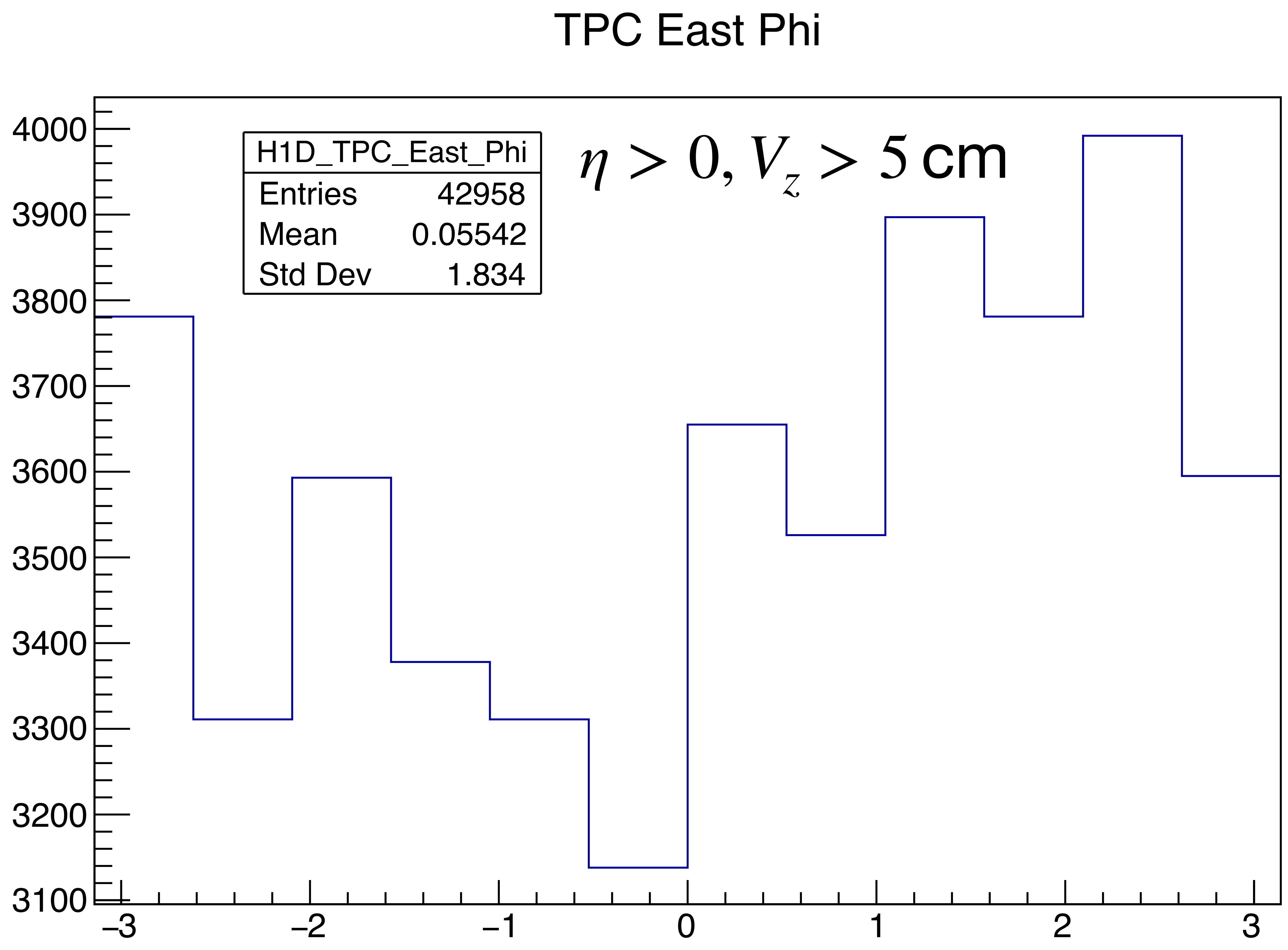
Outlook

- 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

Q&A Plots

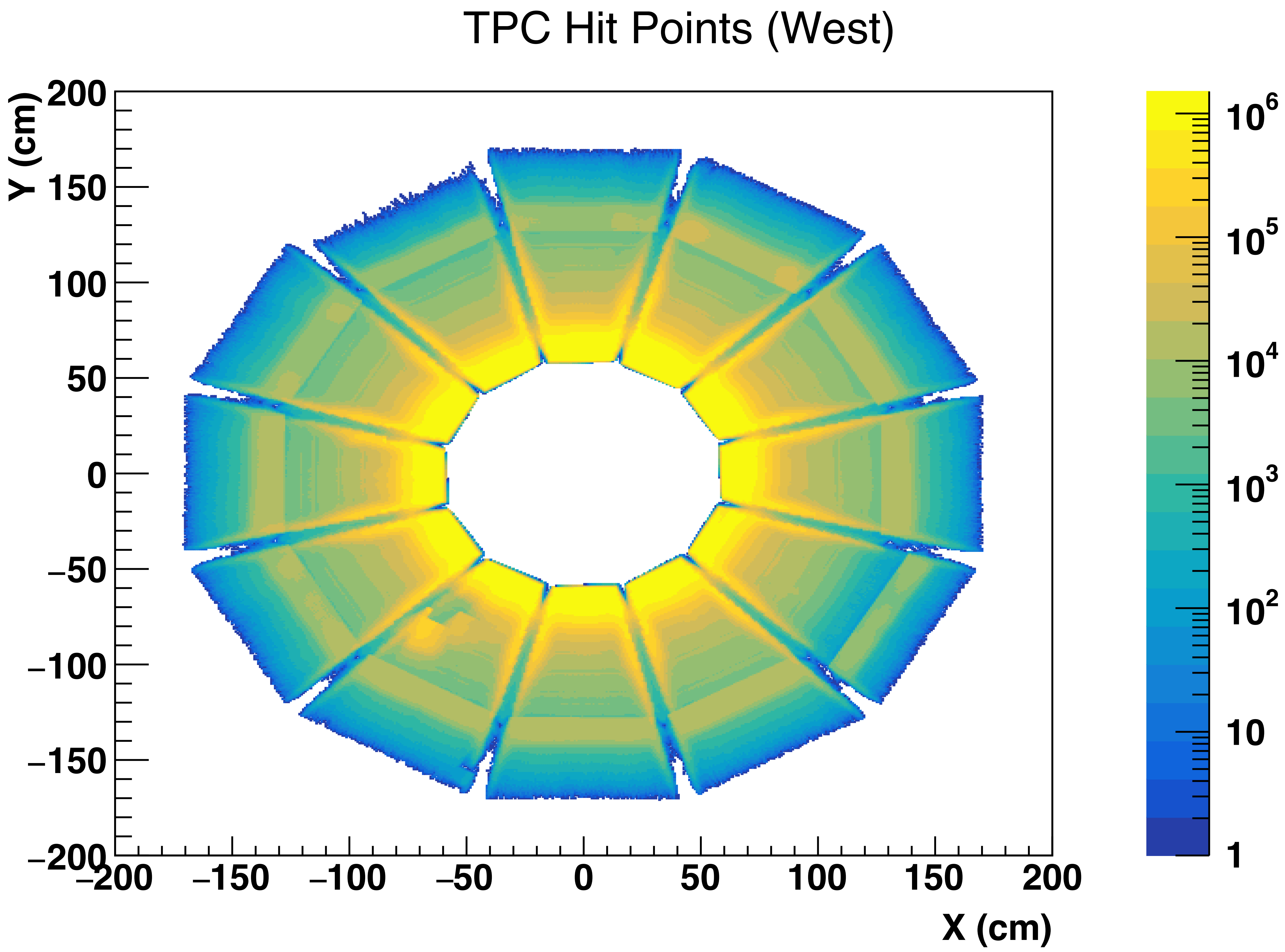


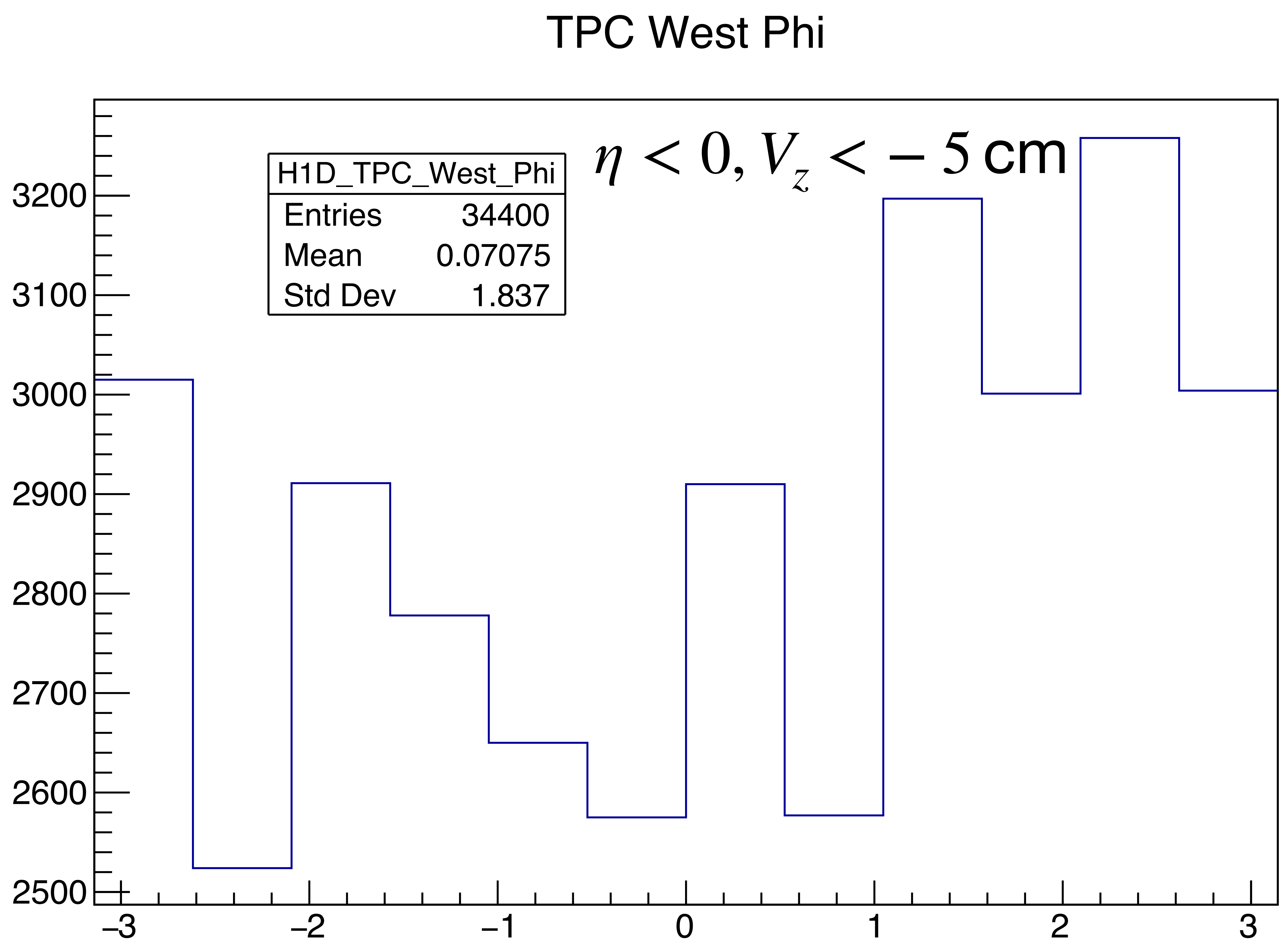


Track quality cuts + PiD cuts

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

Q&A Plots





Track quality cuts + PiD cuts

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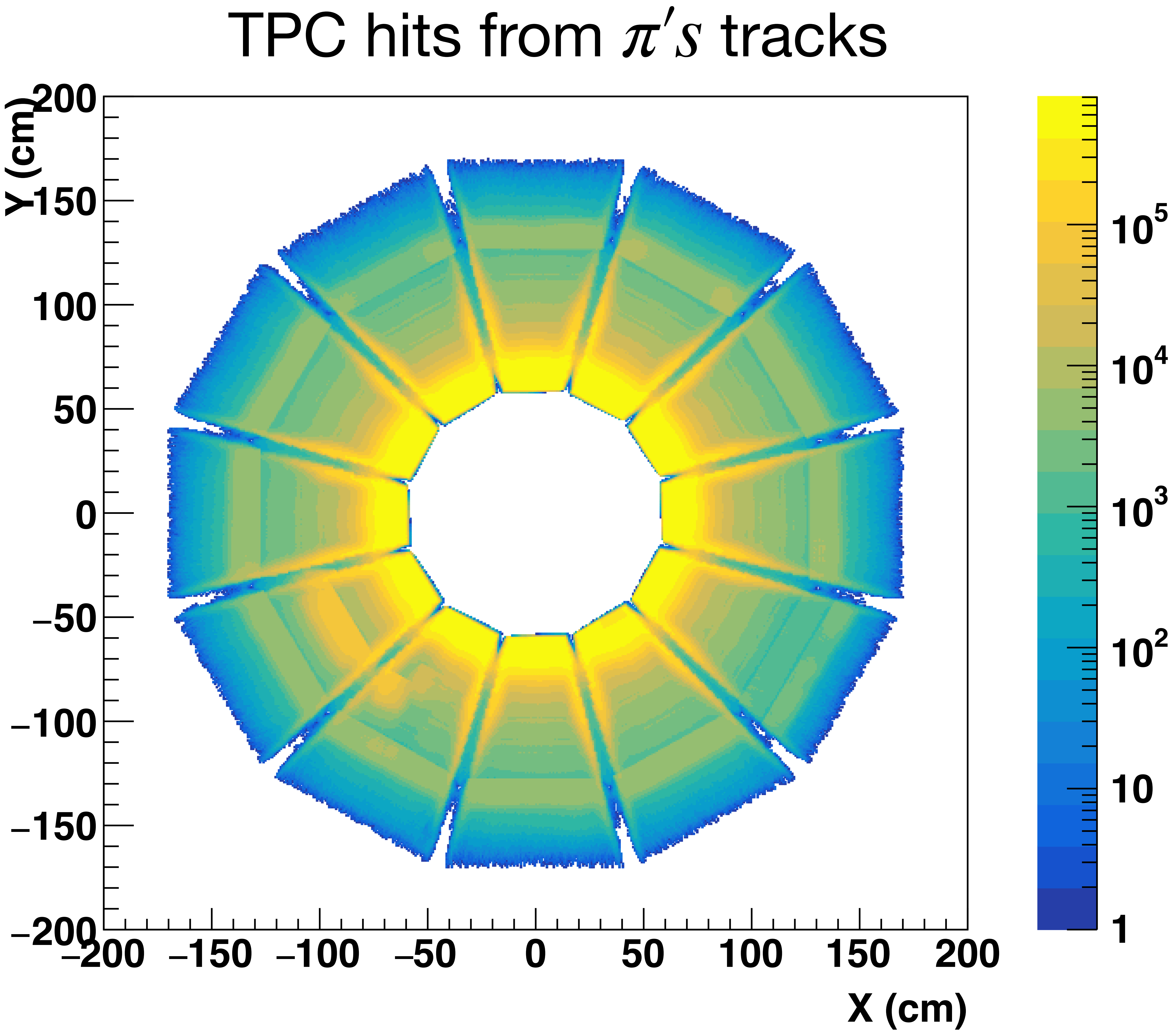
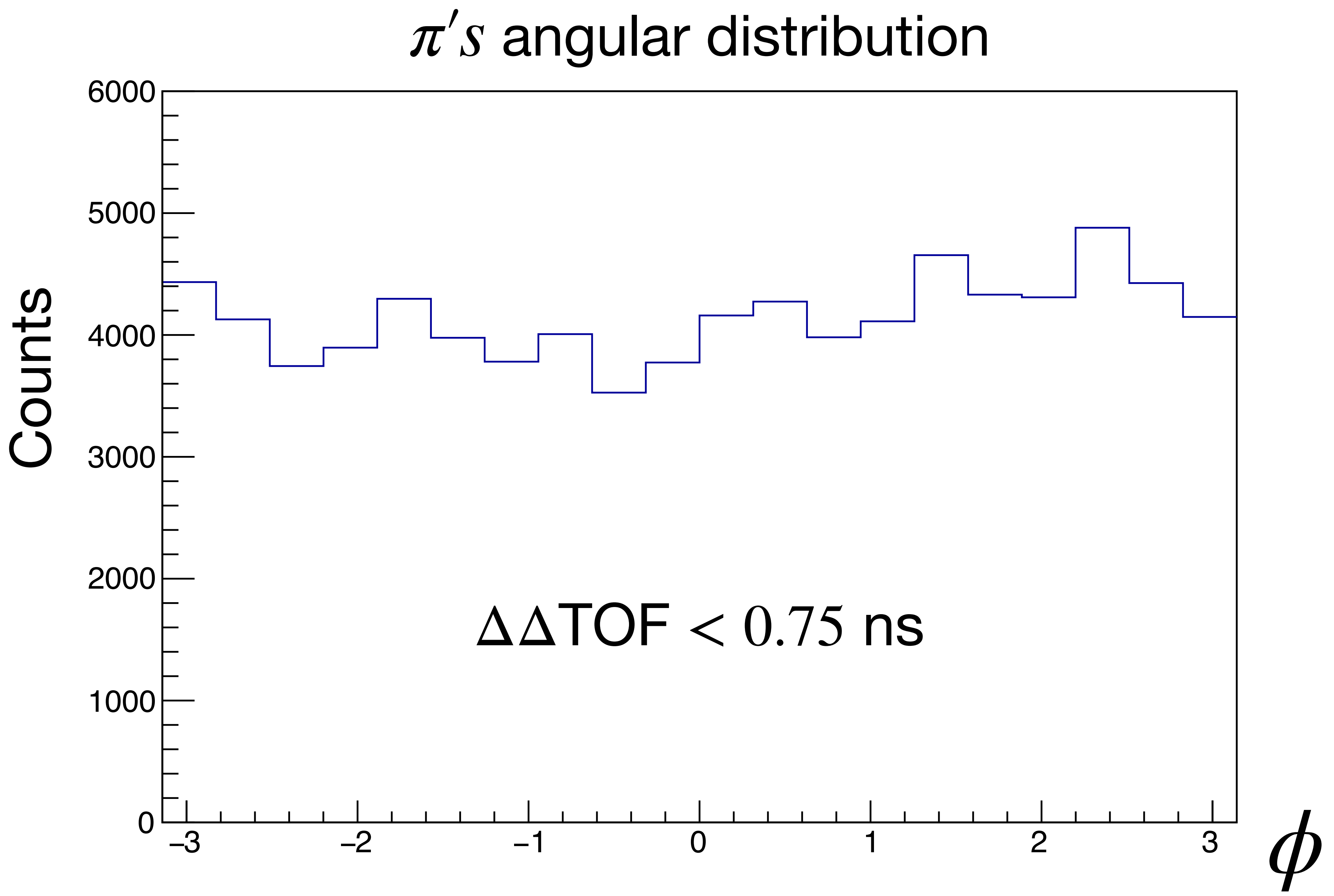
Q&A Plots





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.

A_N is a pseudo-scalar

The A_N asymmetry is a pseudo-scalar quantity since under parity transformation:

$$\vec{S} \xrightarrow{\hat{P}} \vec{S}$$

$$\vec{P}^{\rho}_{T} \xrightarrow{\hat{P}} -\vec{P}^{\rho}_{T}$$

$\Rightarrow$

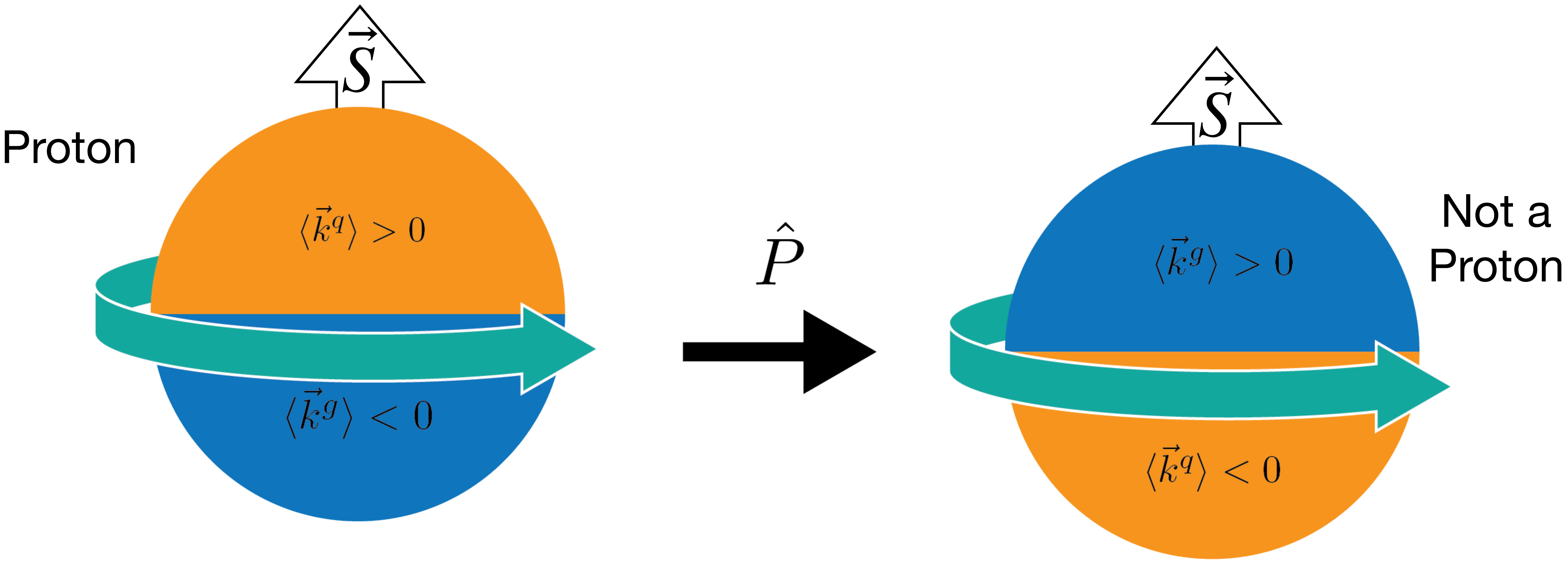
$$N_{\parallel} \xrightarrow{\hat{P}} N_{\nparallel}$$

$$N_{\nparallel} \xrightarrow{\hat{P}} N_{\parallel}$$

$\Rightarrow$

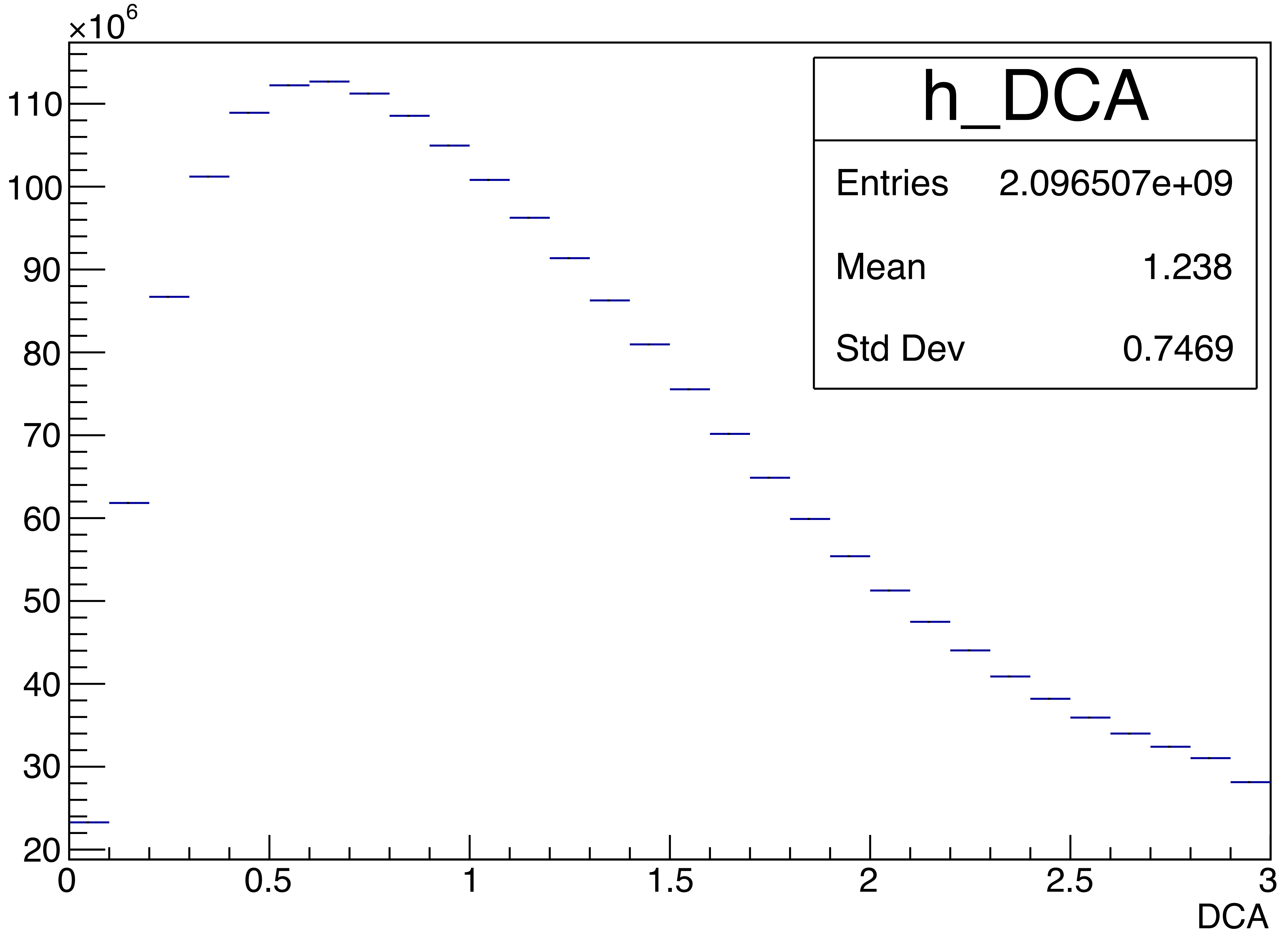
$$\boxed{A_N \xrightarrow{\hat{P}} -A_N}$$

But if there is an up-down asymmetry our **initial state (the proton) is not parity-invariant** therefore a non-zero value of A_N does not mean a parity-violation in QCD but rather that the **proton is not an eigenstate** of the parity operator.

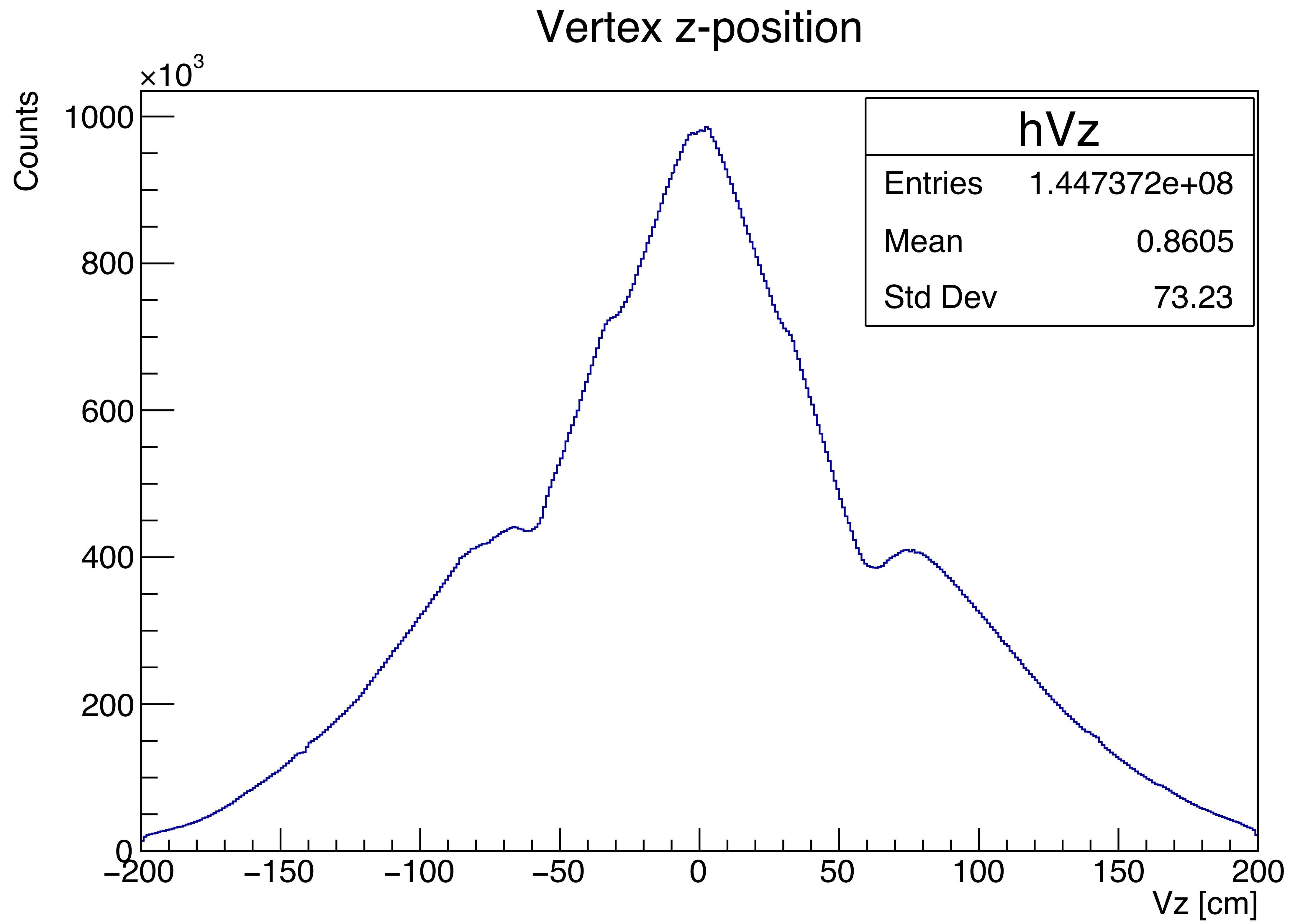


General QA Plots

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

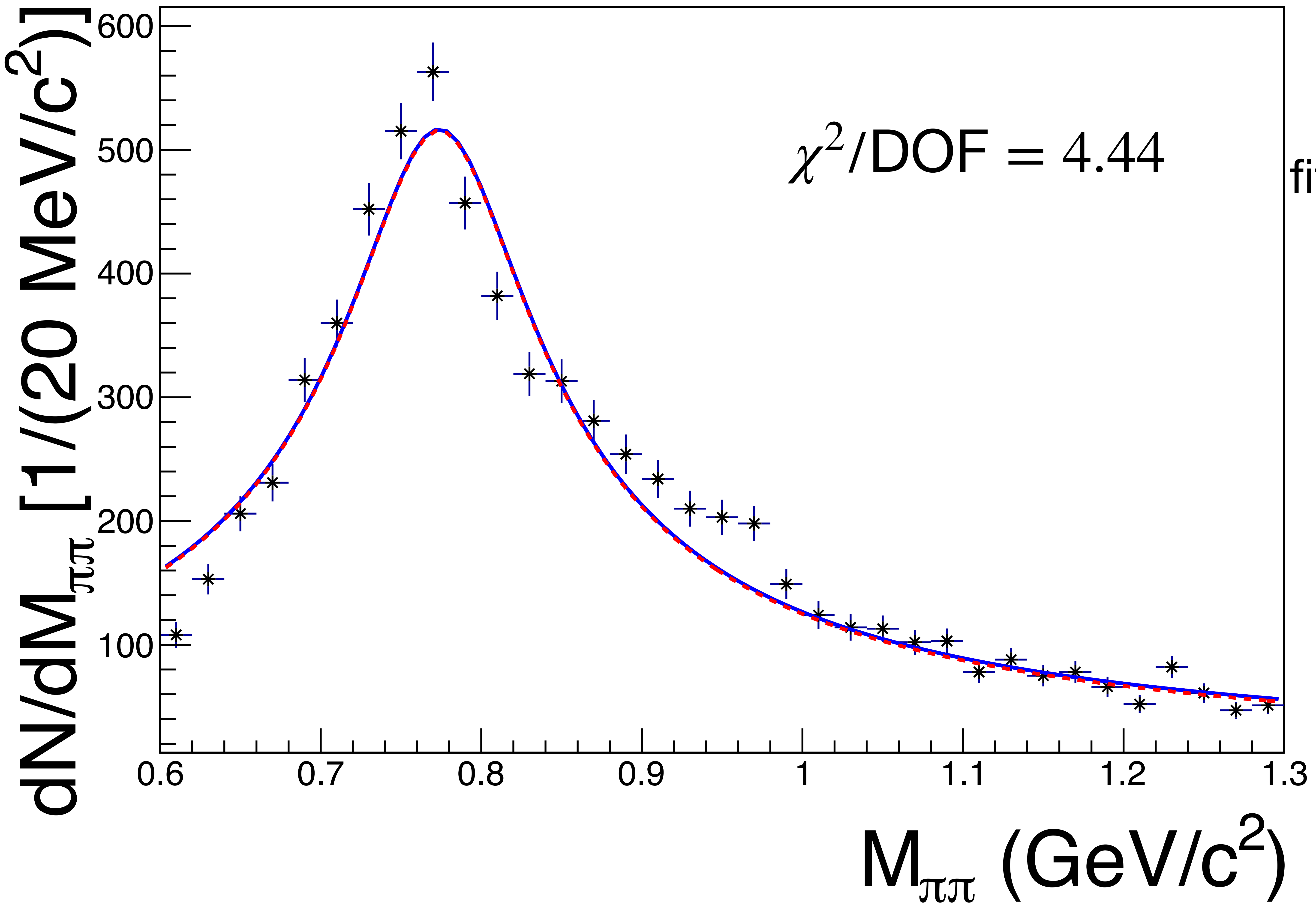


Distance of closest approach run 15 pAu UPC triggers



Z-vertex position distribution.

Background Estimations



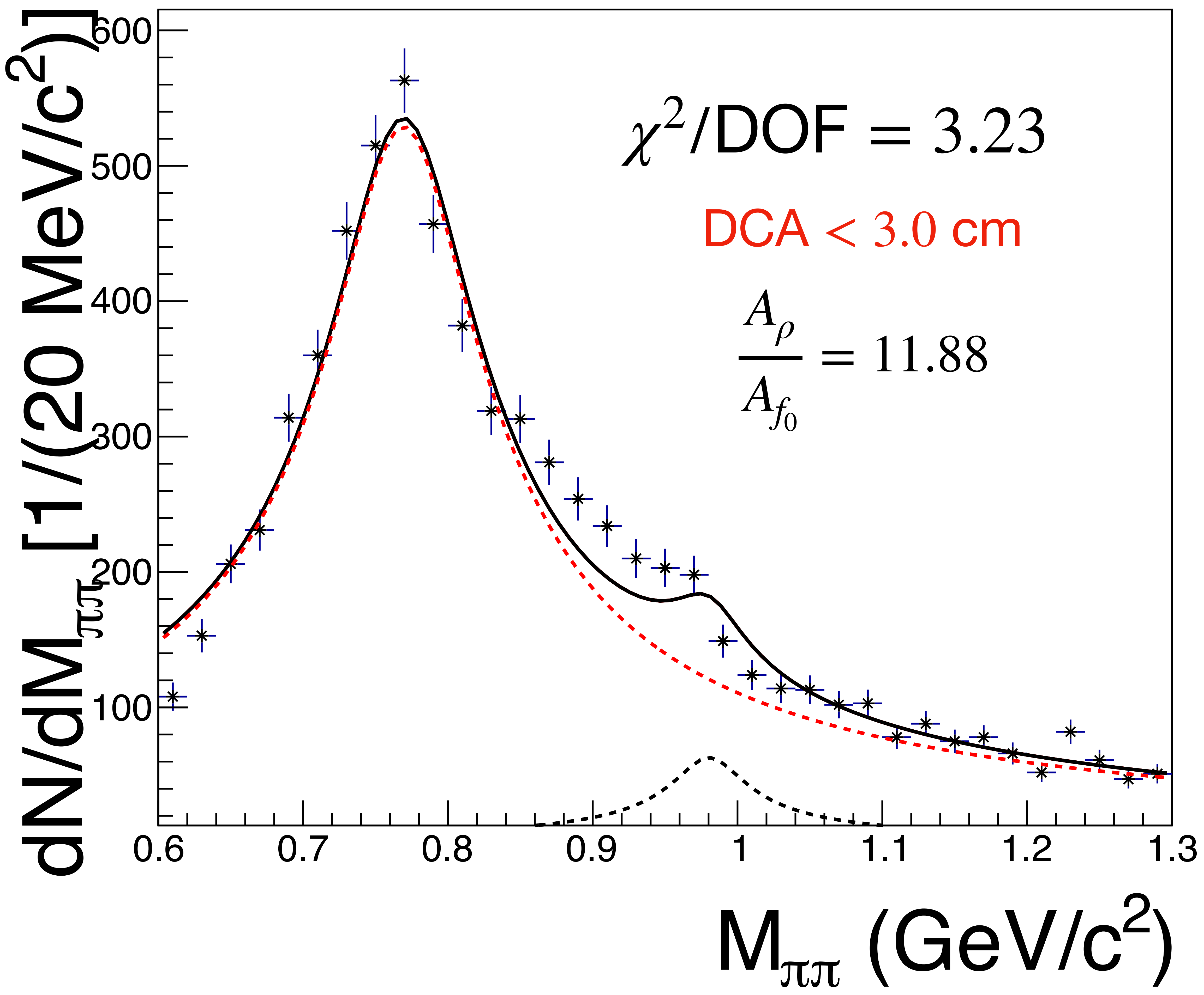
$$\text{fitfunc} = A_\rho \left| \frac{\sqrt{M_{\pi\pi} M_\rho \Gamma_\rho}}{M_{\pi\pi}^2 - M_\rho^2 + i\Gamma_\rho M_\rho} \right| + aM_{\pi\pi} + b$$

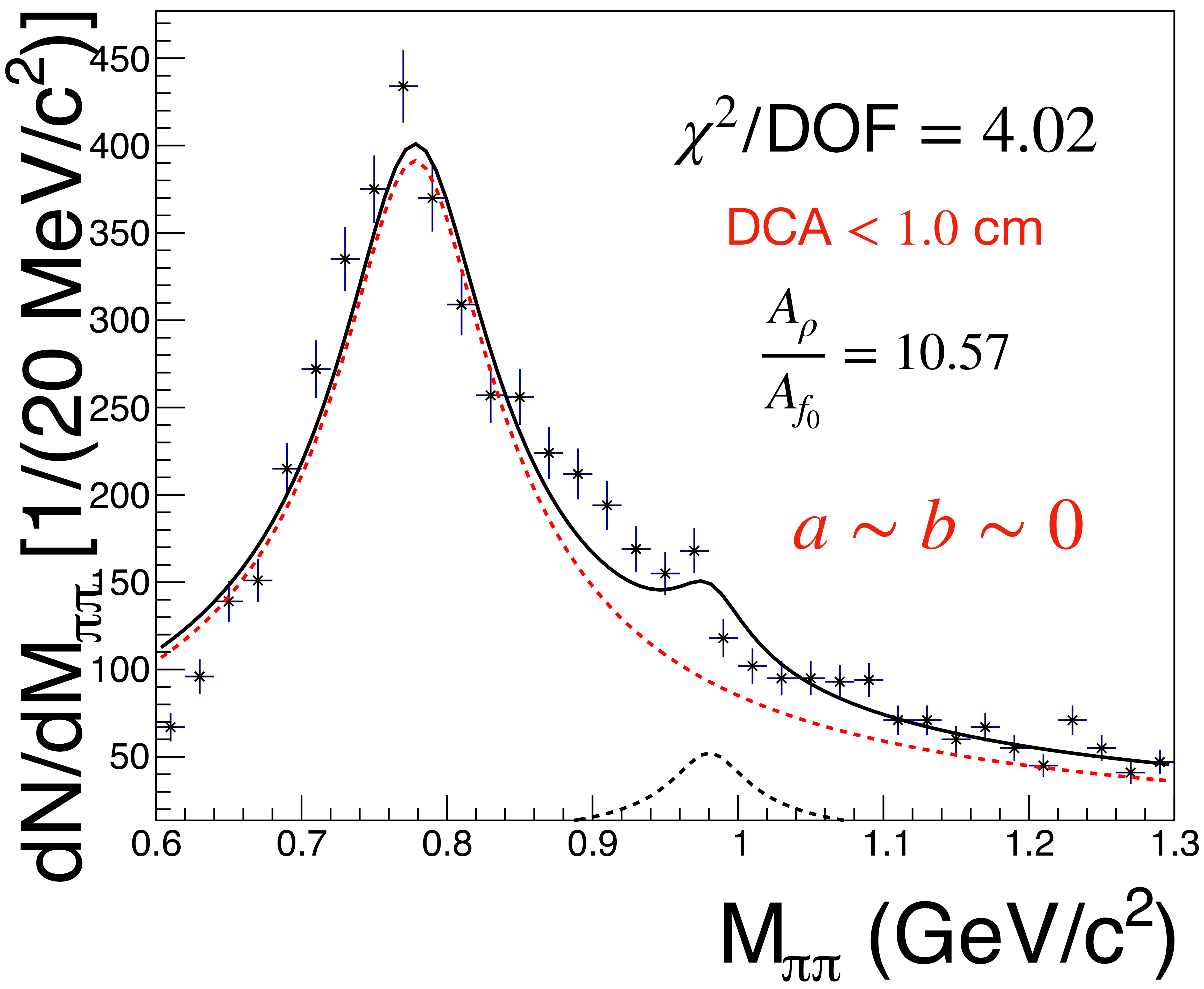
A_ρ	= 174.14	+/-	3.07818
M_ρ	= 0.771699	+/-	0.00198666
Γ_ρ	= 0.114254	+/-	0.00586319
a	= 1.61083	+/-	3.38262
b	= 9.31097e-06	+/-	3.28084

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

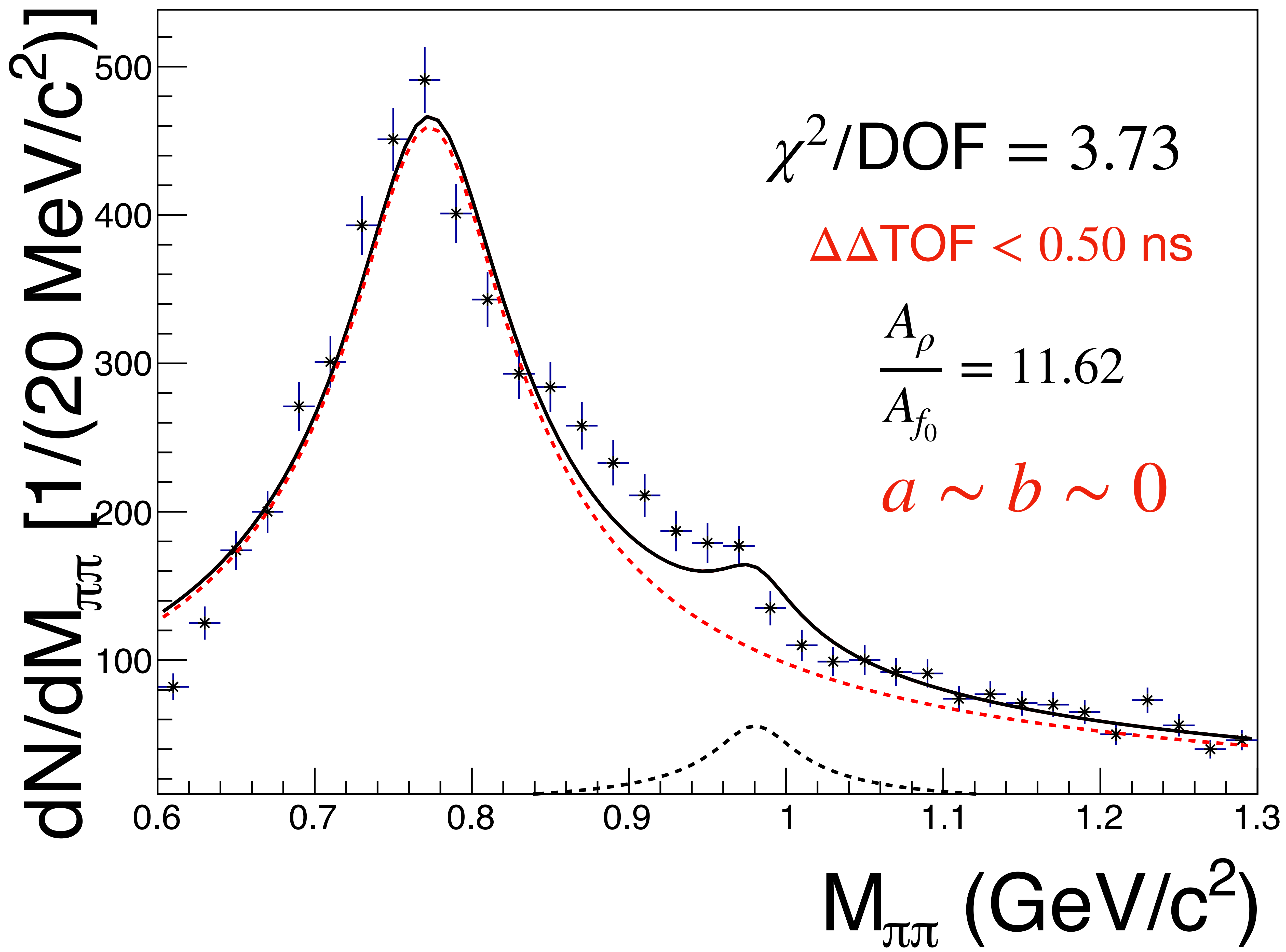
Background Estimations $|V_z| < 70\,\mathrm{cm}$

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





Background Estimations



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

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

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