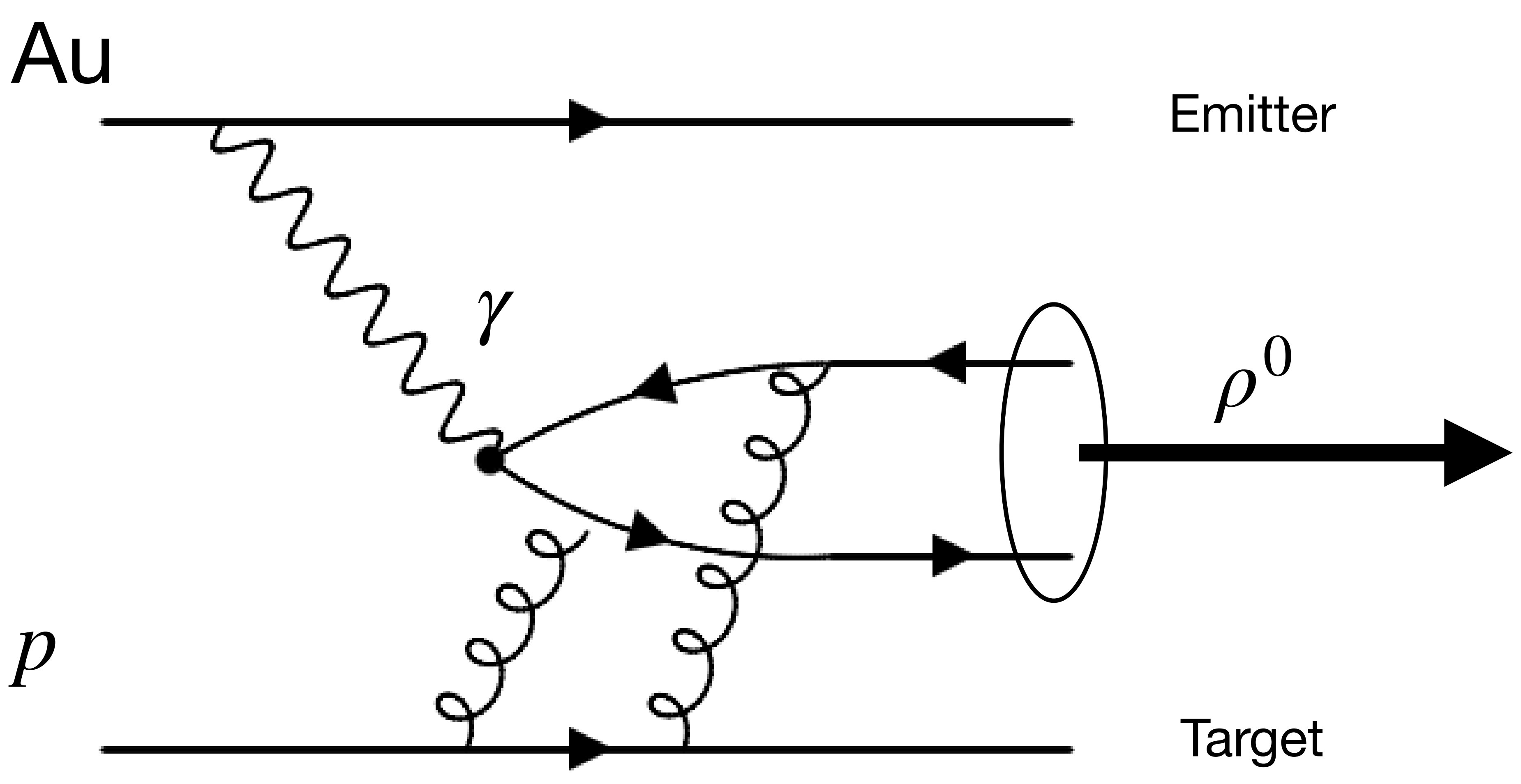
Updates: Single Spin Asymmetries in UPC

Exclusive ρ^0 photo-production

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



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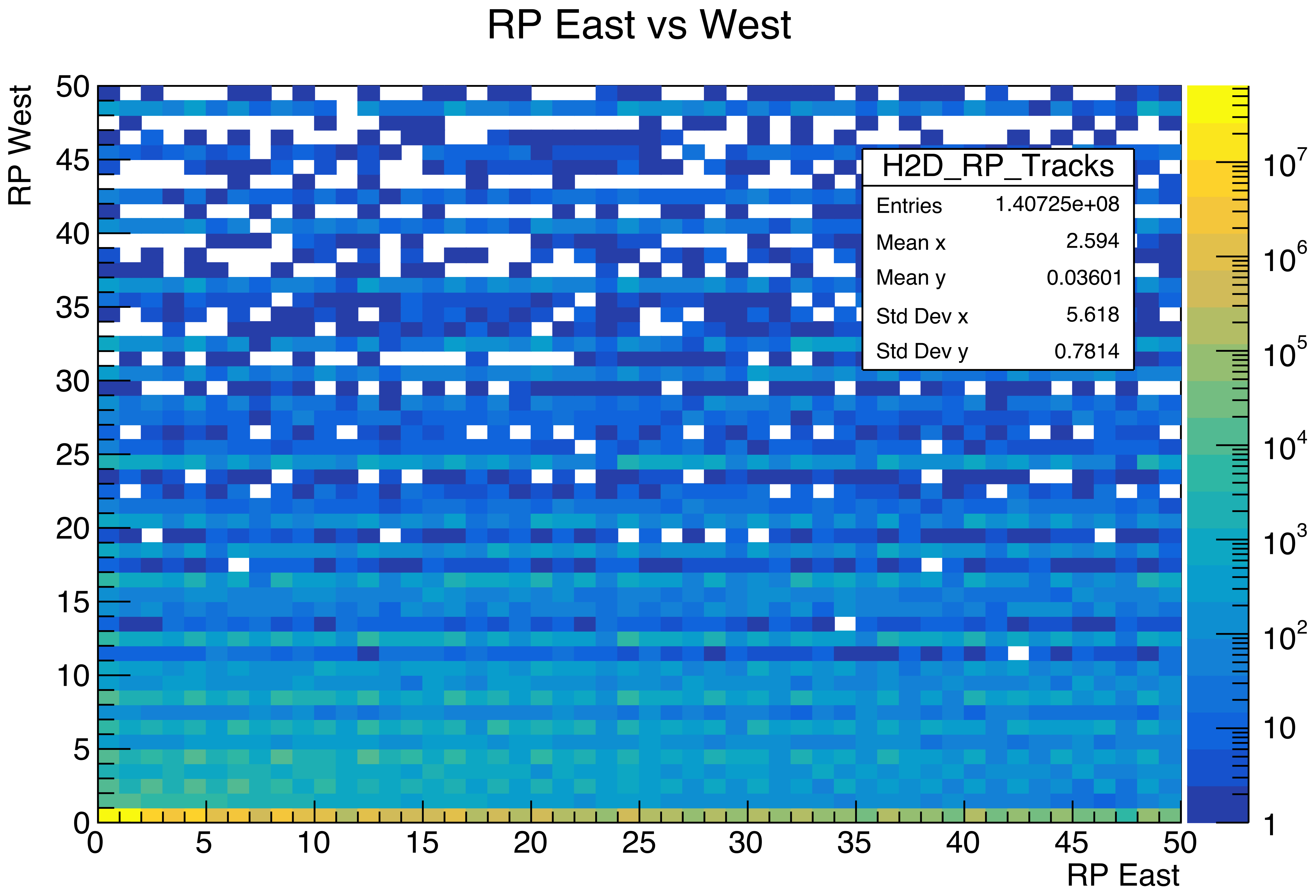
Feedback from Previous Session

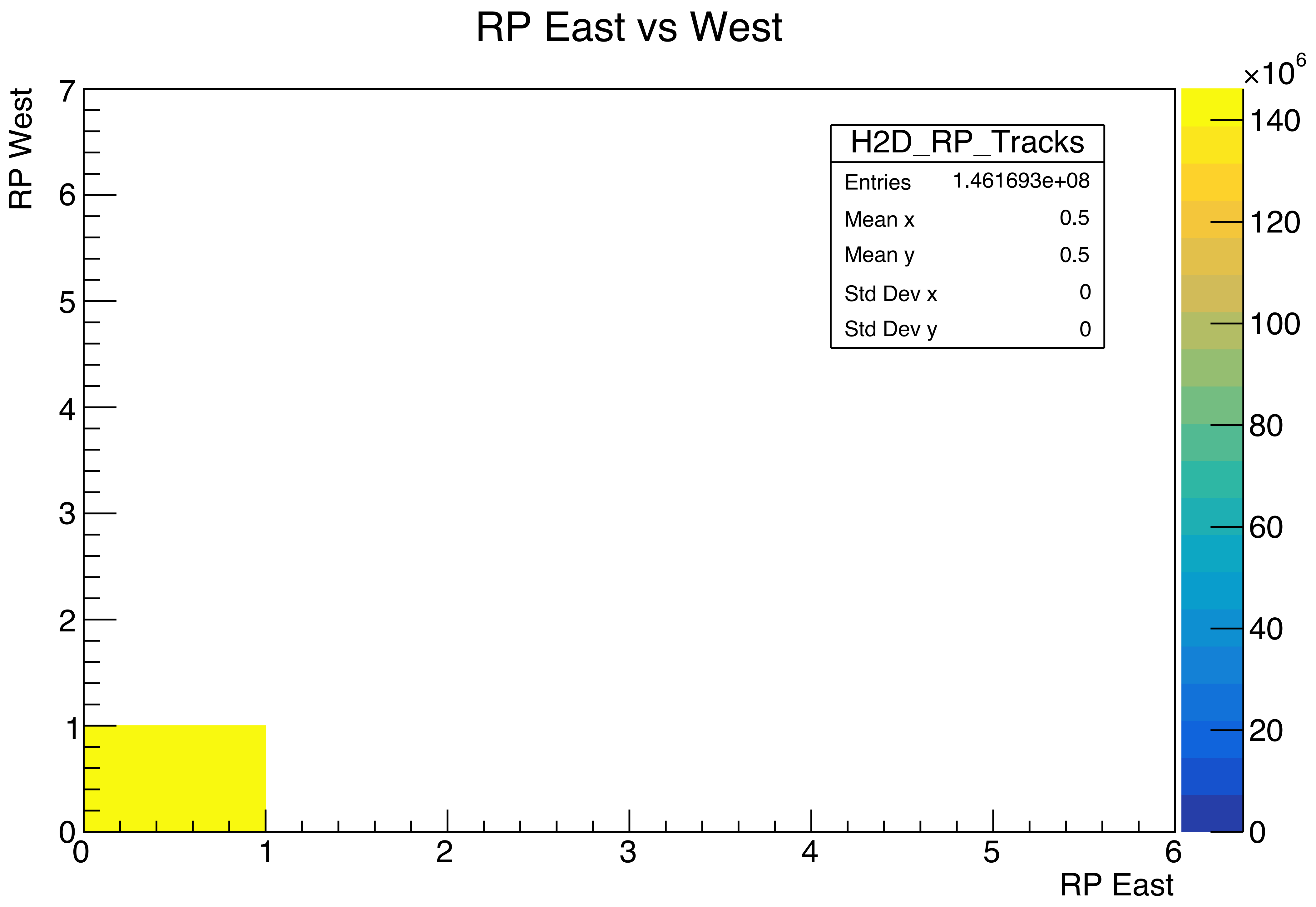
- Roman Pot plots **had no minimum plane requirement**, which could lead to **background contamination**.
- Consider replicating the asymmetry signal by **pairing random events as a control test**.
- Double counting when computing the cross-ratio.
- Noted inconsistency between two results:
  - Cross-ratio method indicates **left/right** asymmetry
  - 2-bin method suggests **up/down** asymmetry
- Suggestion to add more plots for the cross-ratio method to study **asymmetry scaling with** P_T**.**
- Interpretations of having a parity-odd observable for Single Spin Asymmetries.

Roman Pots Tracks

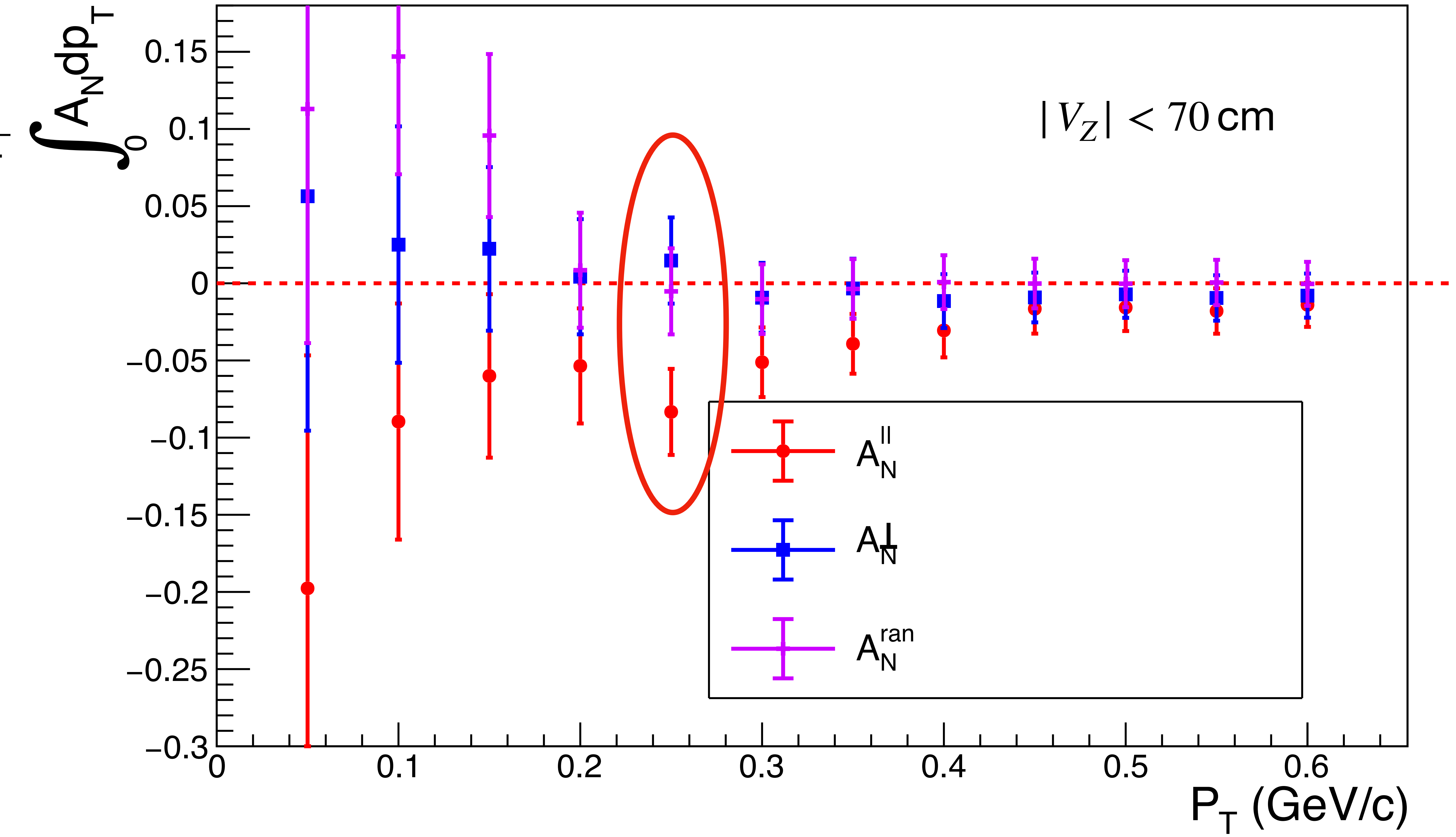
After requiring that each track have hits in at least 7 planes of the Roman Pots, we observe that all tracks disappear — indicating that the Roman Pot tracks were purely background contamination.



RP Planes > 7



$P_T^{\pi\pi}$ Scanning



The A_N^{ran} was made by generating a random number (-1, +1) using a **Bernoulli distribution**, and then computing the asymmetry.

$$A_N^{\text{ran}} = \frac{1}{P}\frac{N_{+1} - N_{-1}}{N}$$

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

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

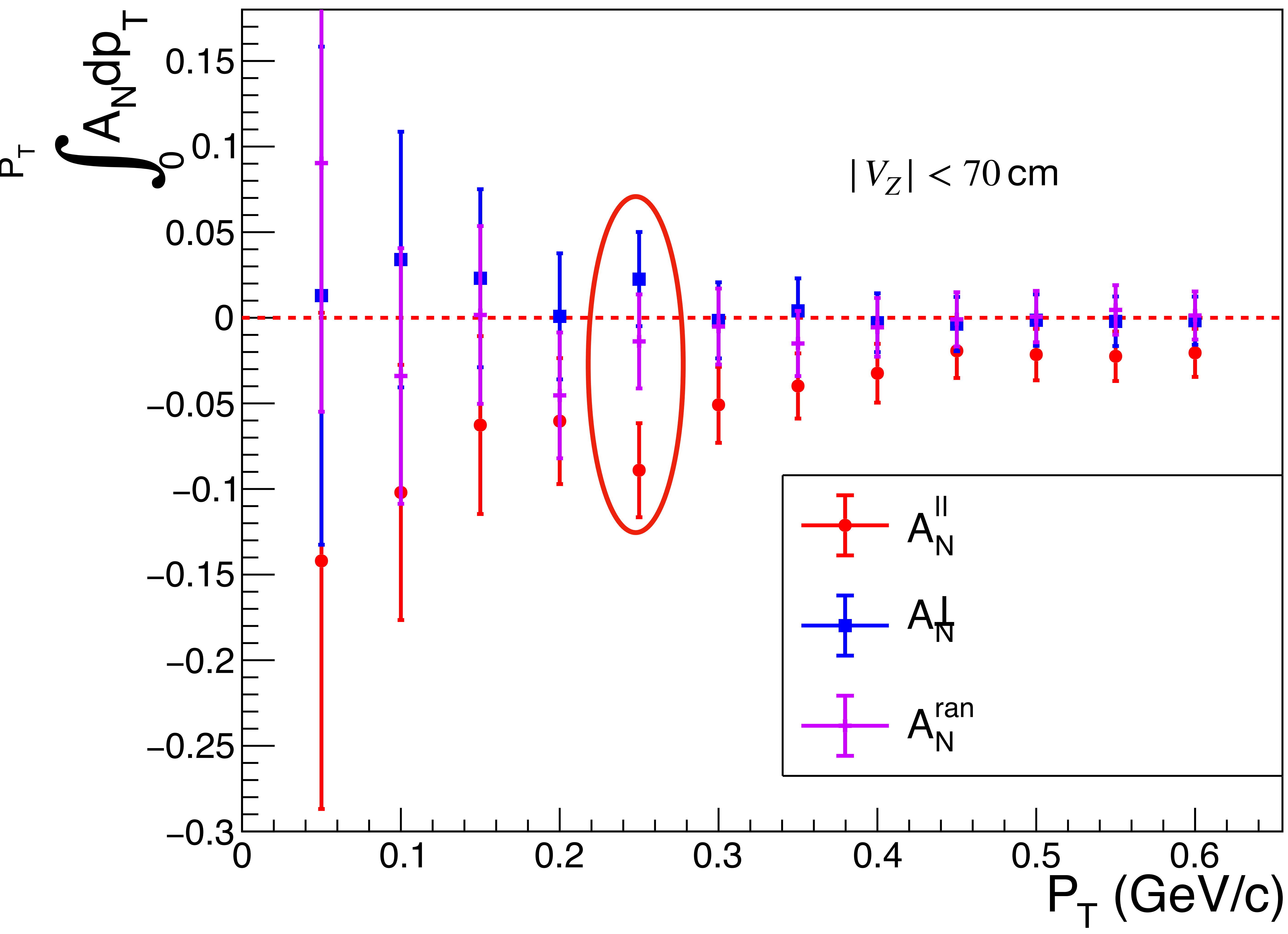
Where

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

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.

$P_T^{\pi\pi}$ Scanning



In the second iteration, we observe some variability in A_N for the first three P_T cuts, likely due to the low number of events in those bins.

$N(P_T < 0.05) \approx 100,$

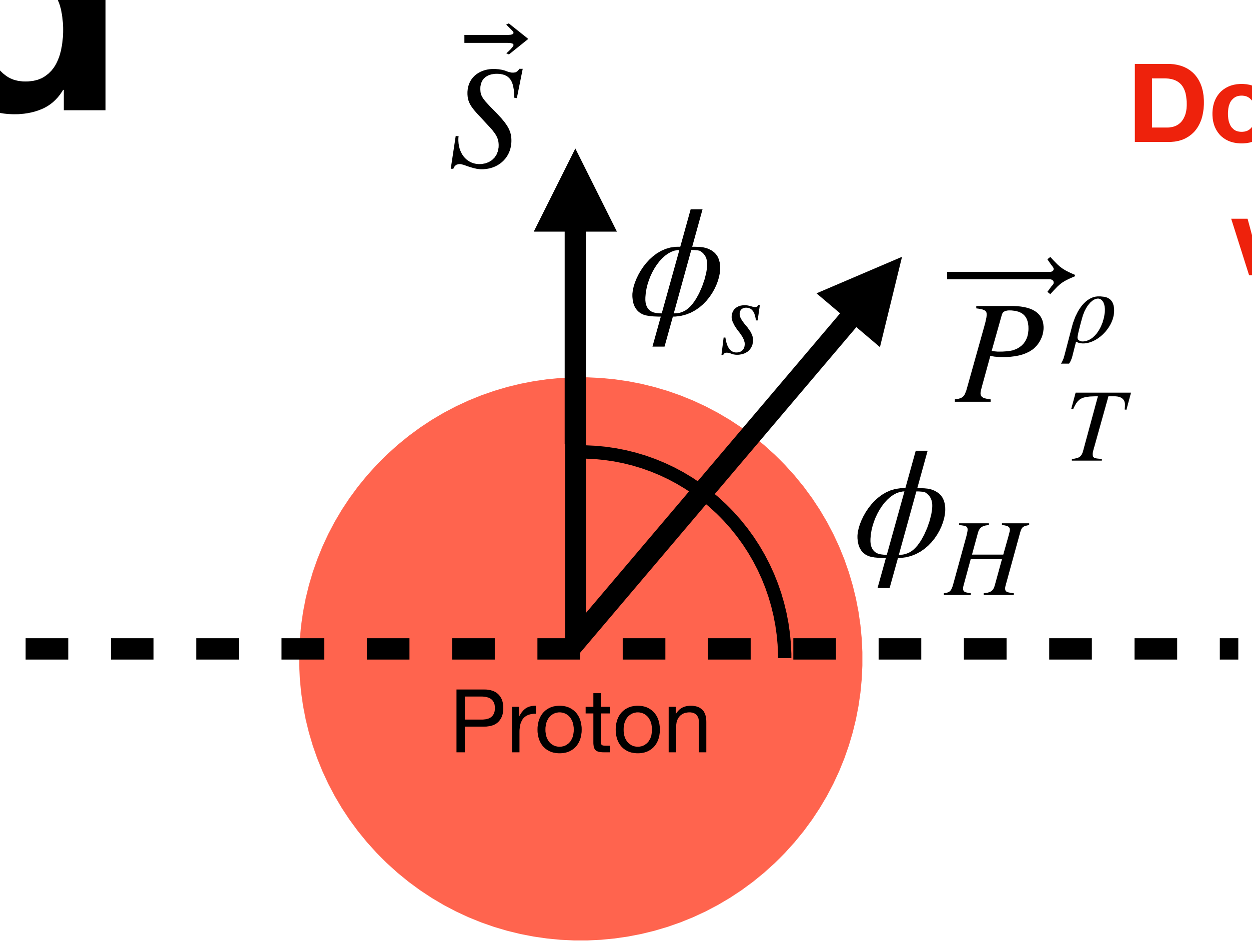
$N(P_T < 0.10) \approx 200,$

$N(P_T < 0.15) \approx 500,$

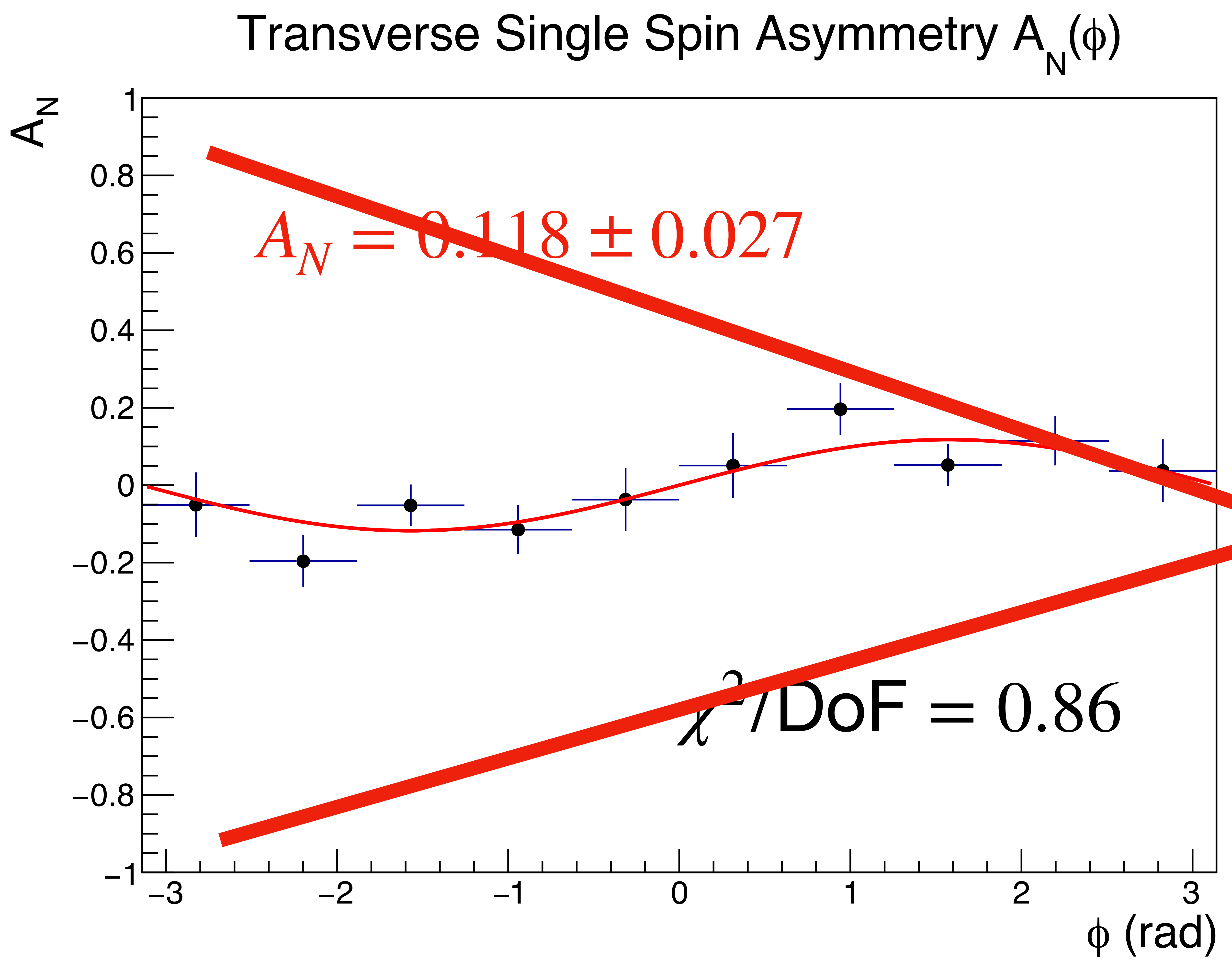
But for $P_T > 0.2$ we have $N > 1000$ and results consistent with zero up to 1σ are observed.

Cross-Ratio Method

ϕ is not ϕ_s but rather ϕ_H



Double counting was avoided



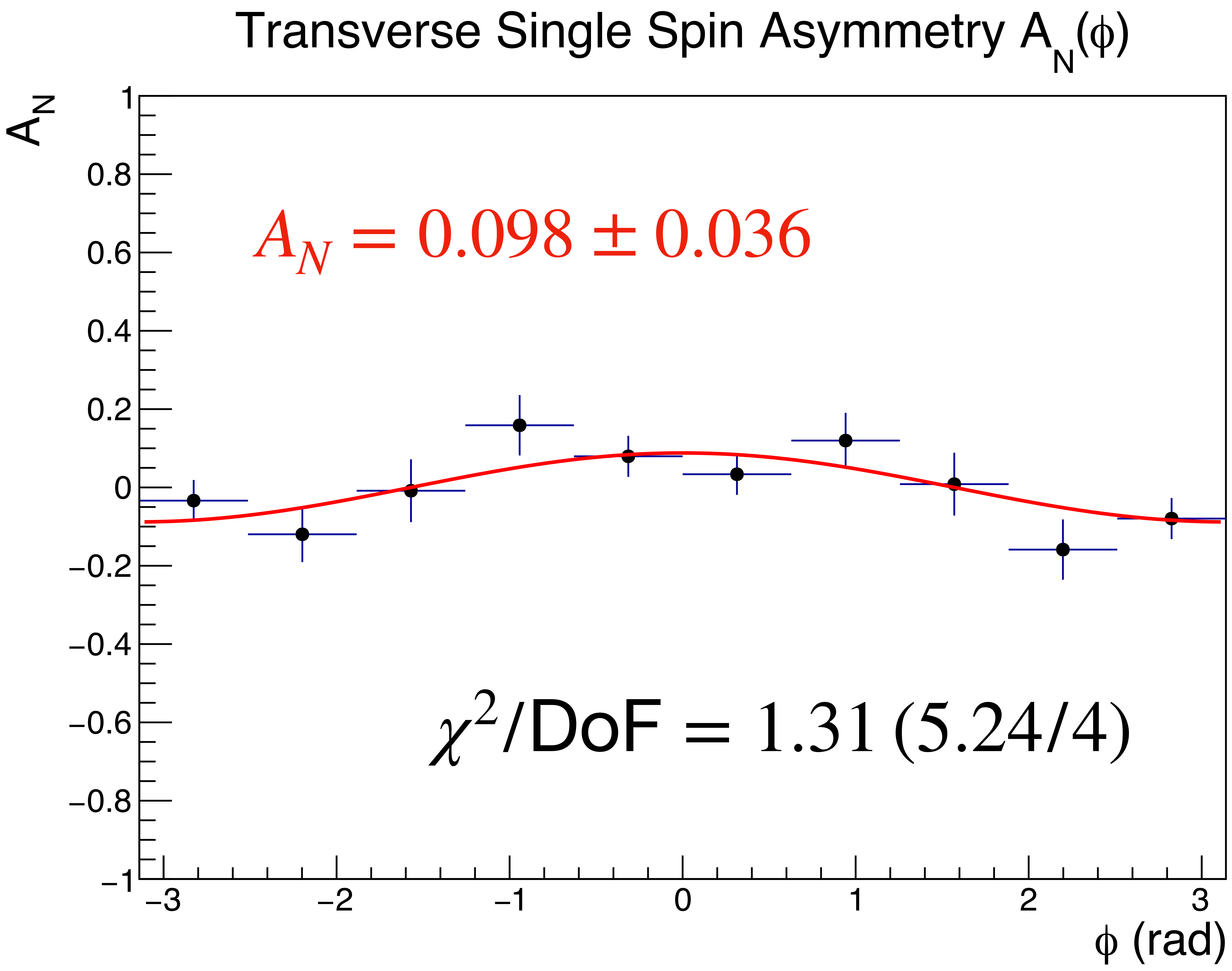
A more traditional/conventional method for searching for asymmetries is the cross-ratio method:

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

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

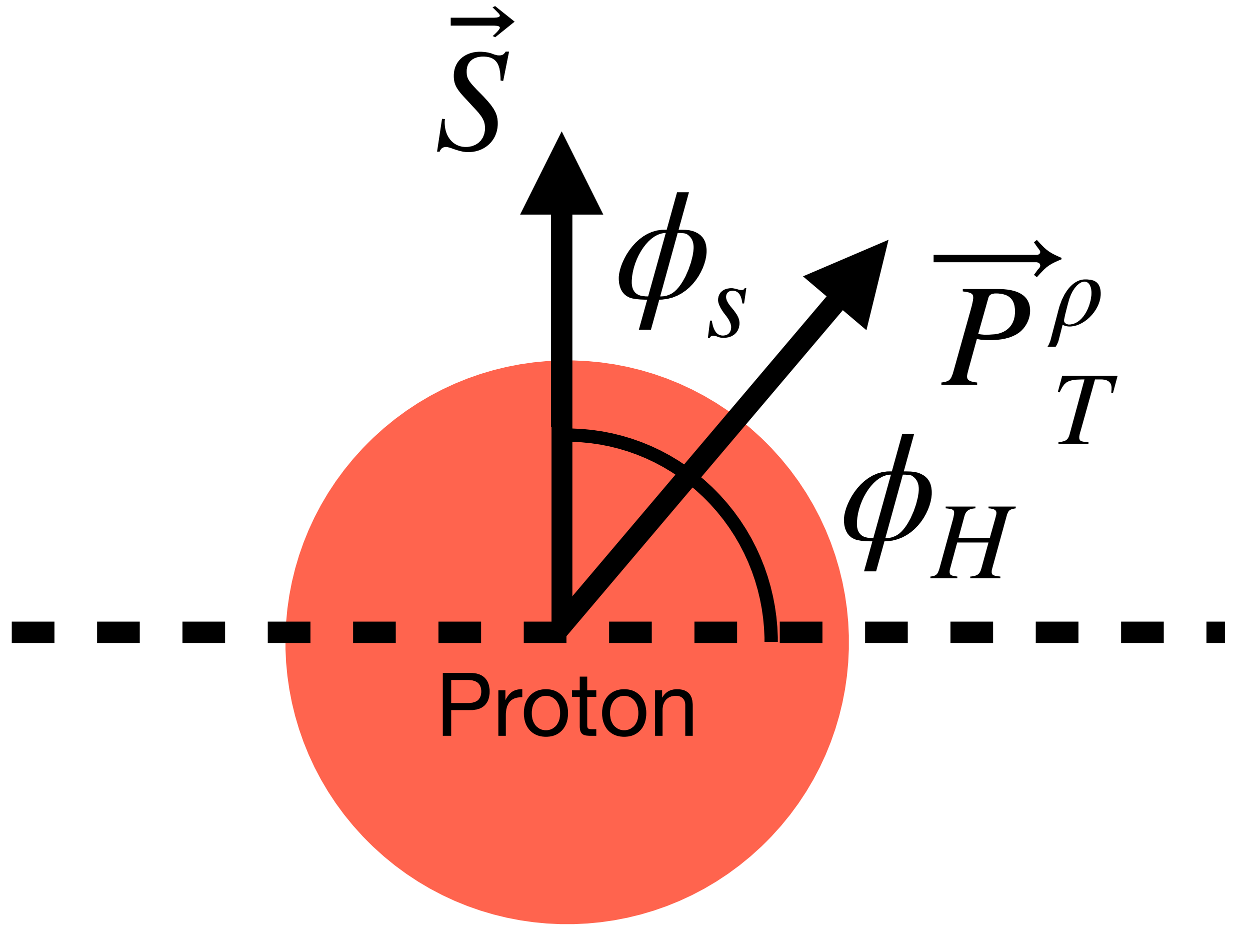
Cross-Ratio for different $P_T^{\pi\pi}$



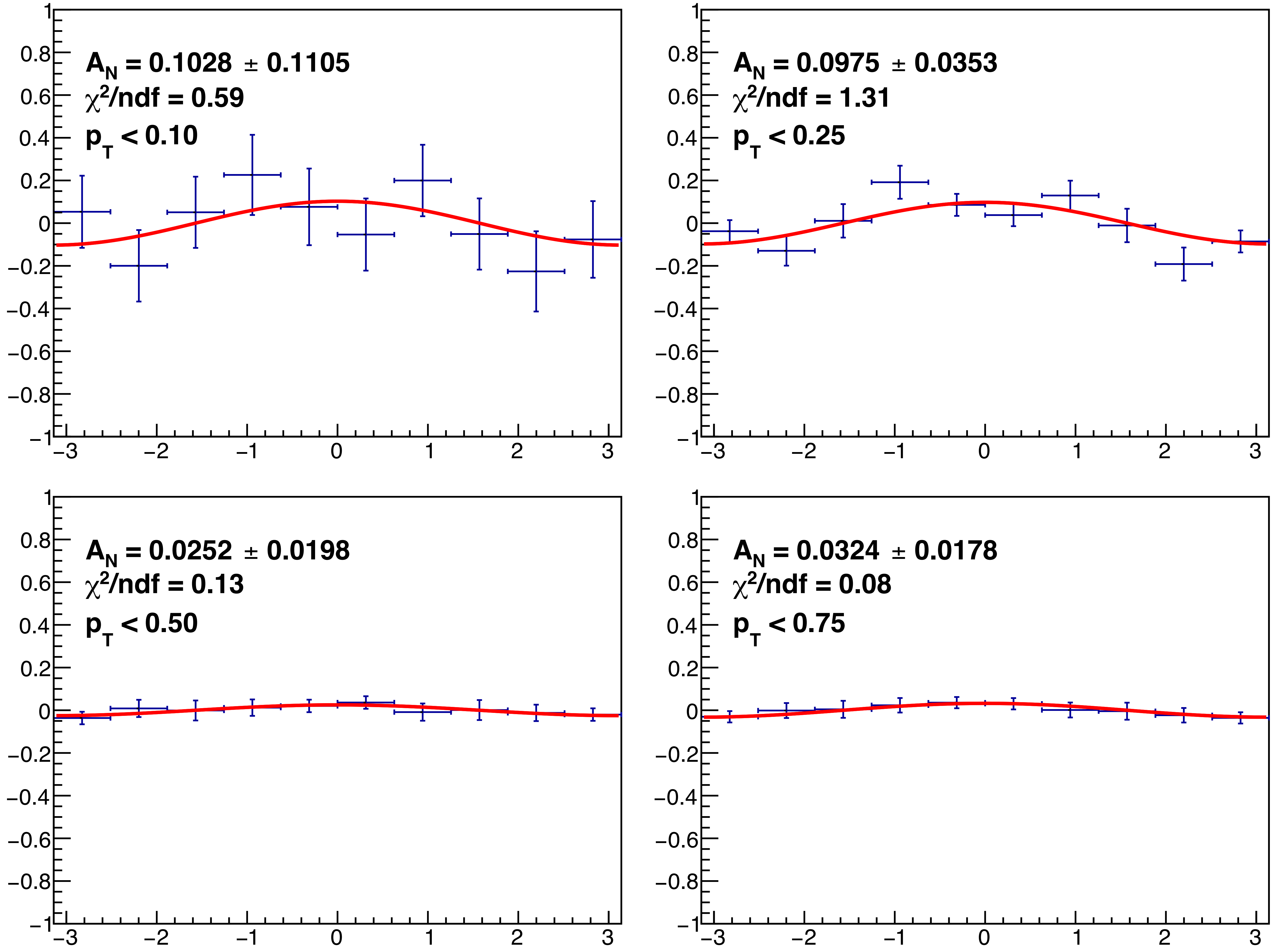
Using the cross-ratio method:

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

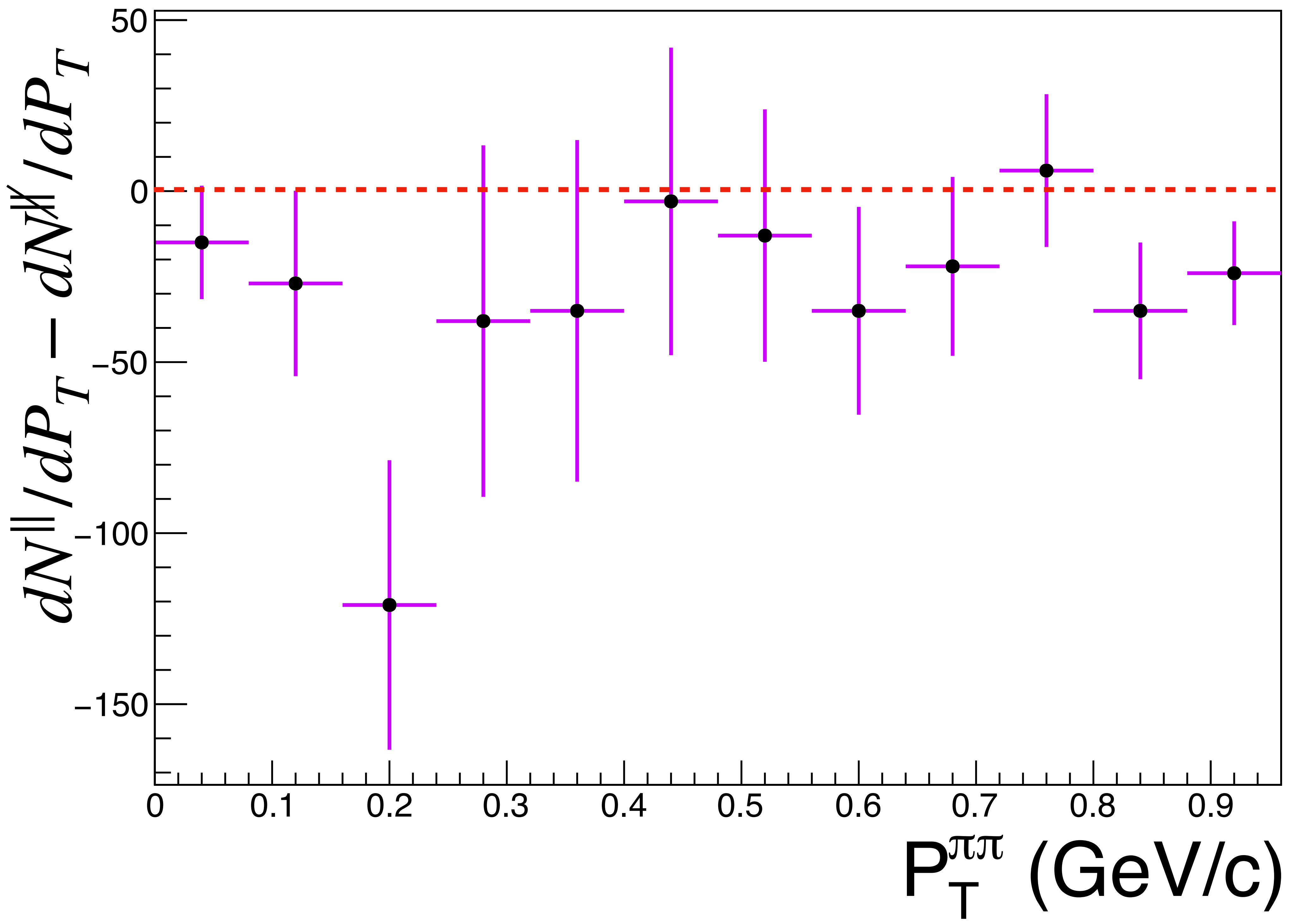
where ϕ_s is the angle between the spin direction and the transverse momentum of the ρ^0 ; $N^{\uparrow,\downarrow}$ represent the yields for the two different spin patterns. We observe an asymmetry that matches with our previous result.



Cross-Ratio for different $P_T^{\pi\pi}$



The cross-ratio method for different P_T cuts confirms that as we increase the P_T upper limit our

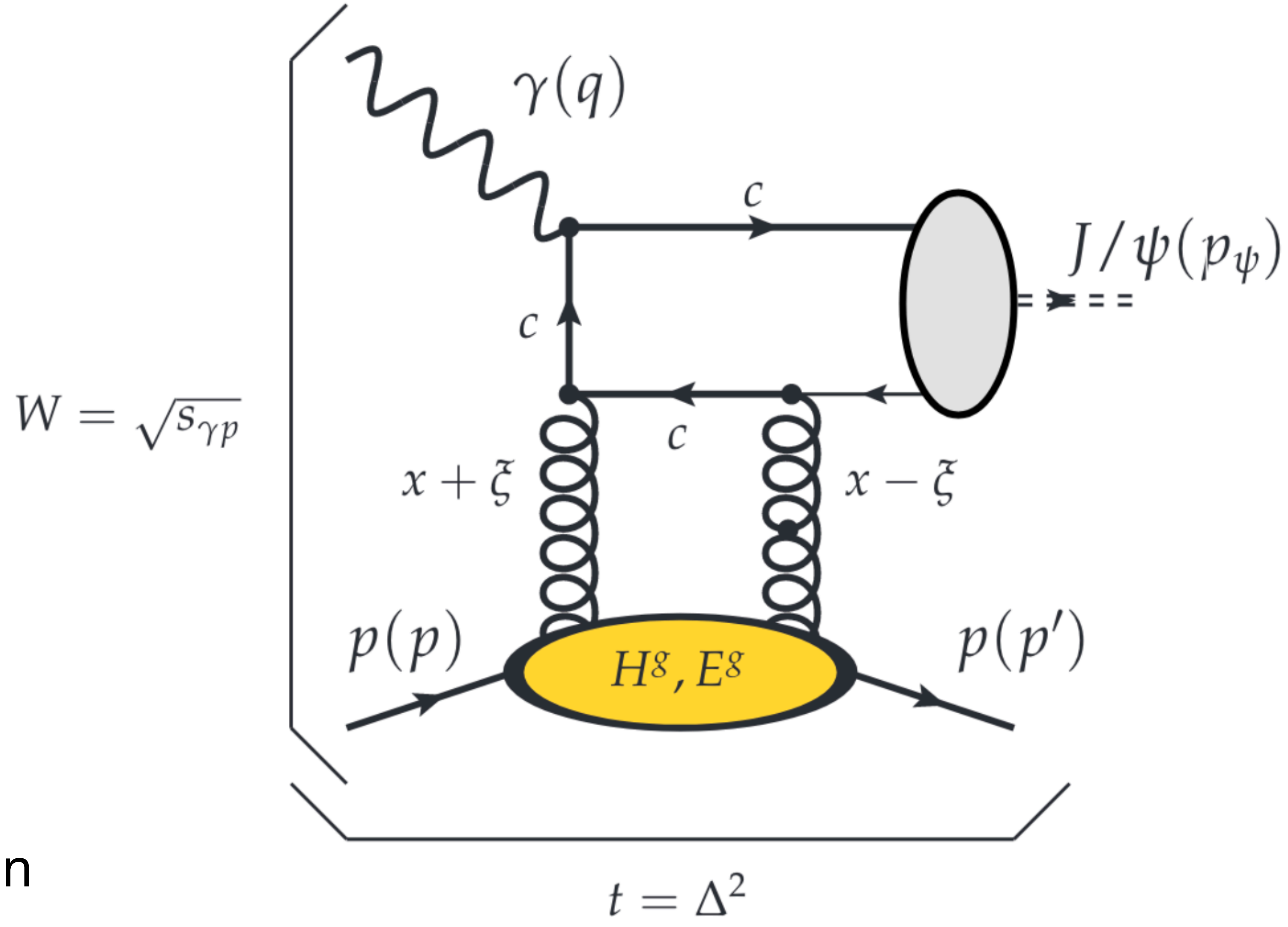


Measuring P-odd in $\gamma p^{\uparrow}$

Lansberg et al. (2018) proposed the following observable for SSA in UPC:

$$A_N^{\gamma} = \frac{\frac{1}{2m_N}(1+\xi)\,|\vec{\Delta}_T|\,\sin(\phi_{\vec{\Delta}})\,\mathfrak{I}(H_g E_g^*)}{(1-\xi^2)\,|H_g|^2 + \frac{\xi^4}{1-\xi^2}\,|E_g|^2 - 2\xi^2\,\mathfrak{R}(H_g E_g^*)}$$

which is a parity-odd observable due to the factor $\frac{1}{2}(s_x\Delta_y - s_y\Delta_x) = \frac{1}{2}|\Delta_T|\sin(\phi_{\vec{\Delta}})$ in the numerator.



The derivation, performed within the **Generalized Parton Distribution (GPD)** framework using collinear factorization in QCD, does not rely on any assumption of parity-violating interactions.

Lansberg, J. P., L. Massacrier, L. Szymanowski, and J. Wagner. "Single-Transverse-Spin Asymmetries in Exclusive Photo-Production of J/ψ in Ultra-Peripheral Collisions in the Fixed-Target Mode at the LHC and in the Collider Mode at RHIC." *Physics Letters B* 793 (June 10, 2019): 33–40. https://doi.org/10.1016/j.physletb.2019.03.061.

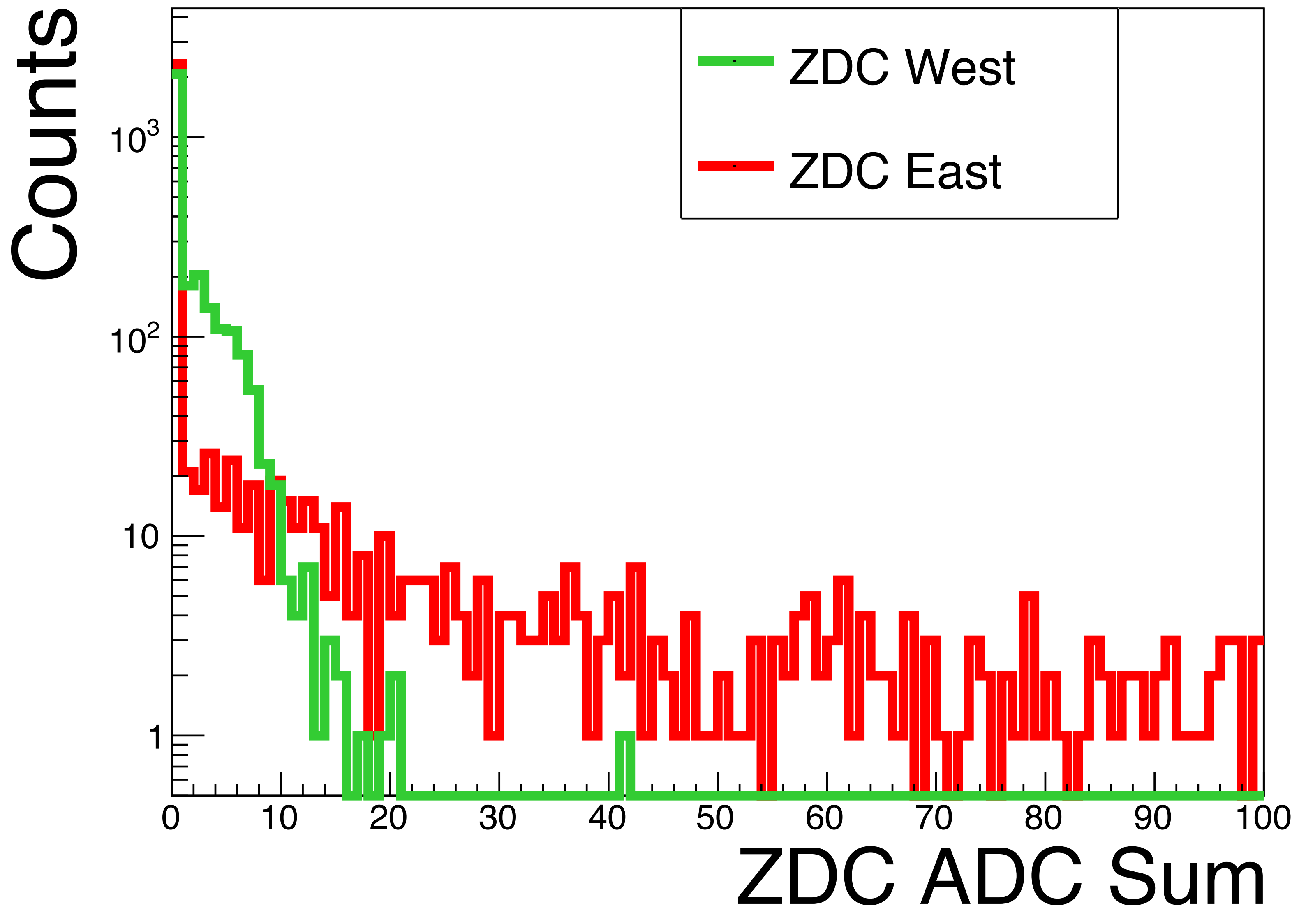
Conclusions

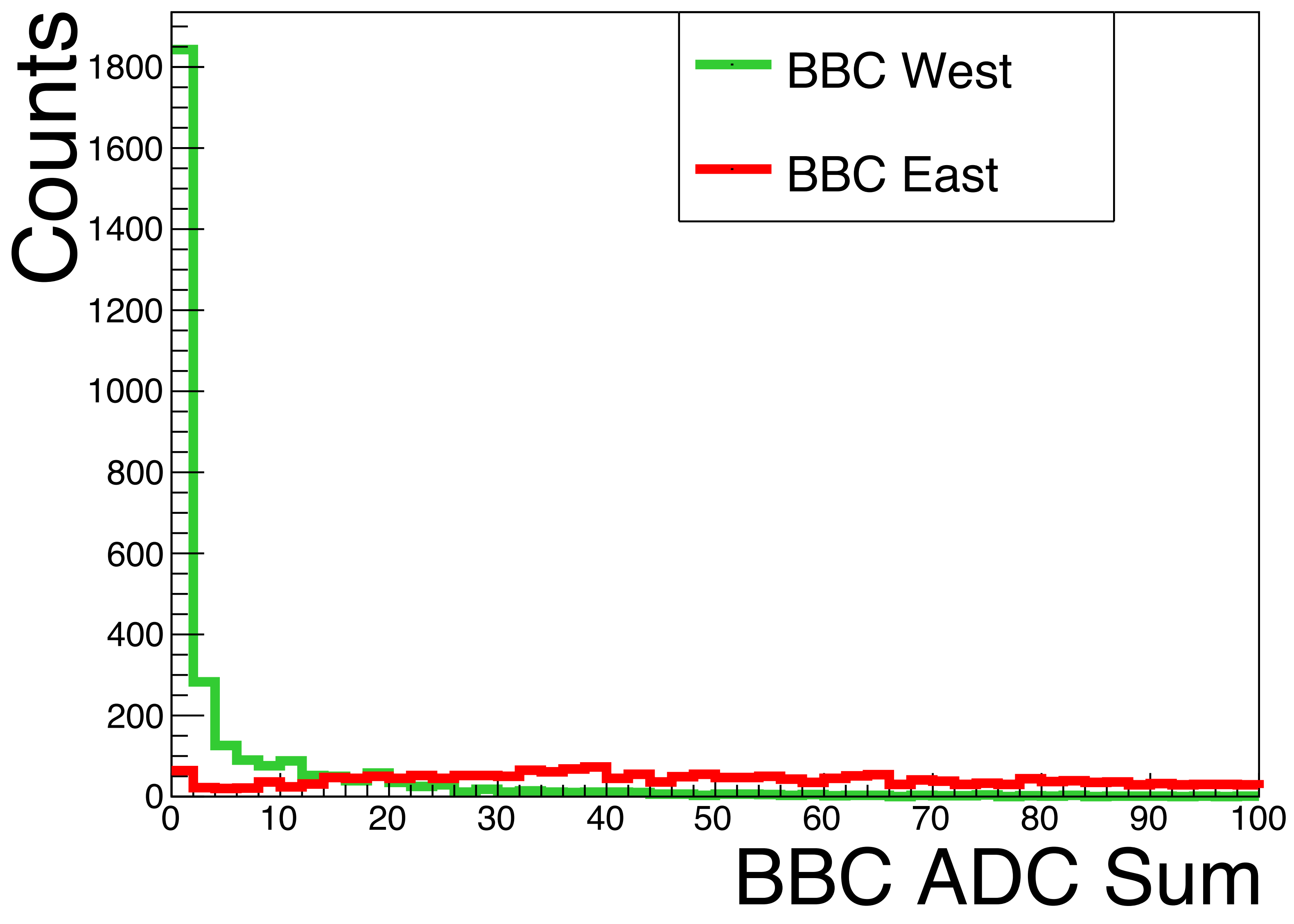
- Roman Pots are empty though out the events of interest.
- No asymmetry can be distinguished for $P_T > 0.2$ GeV/c when pairing random events.
- Fixed error code that was causing inconsistency between the 2-bin and cross-ratio method.
- Double counting when applying the cross-ratio method was fixed.

Back Up Slides

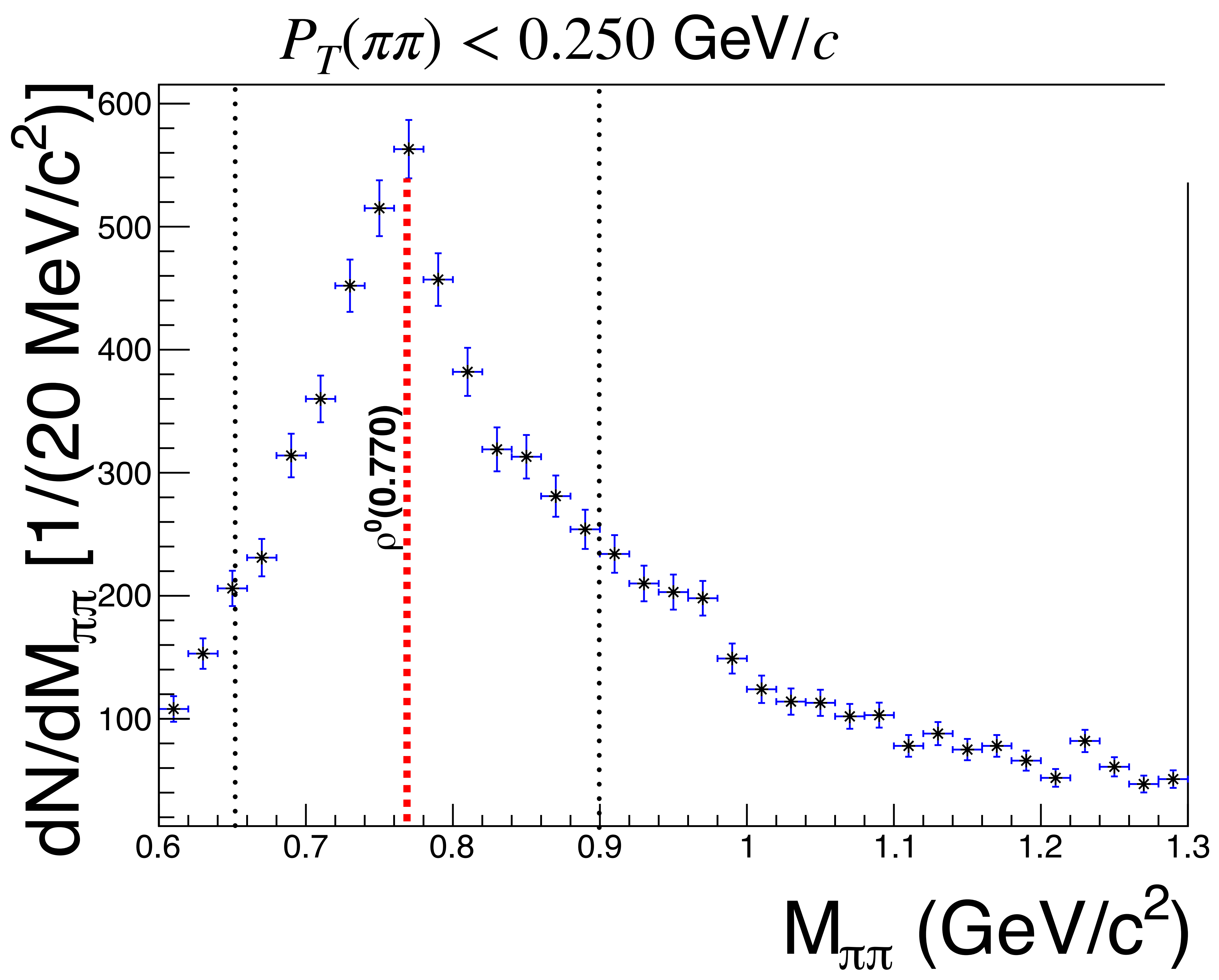
Trigger Topology in the Exclusive ρ^0 Region

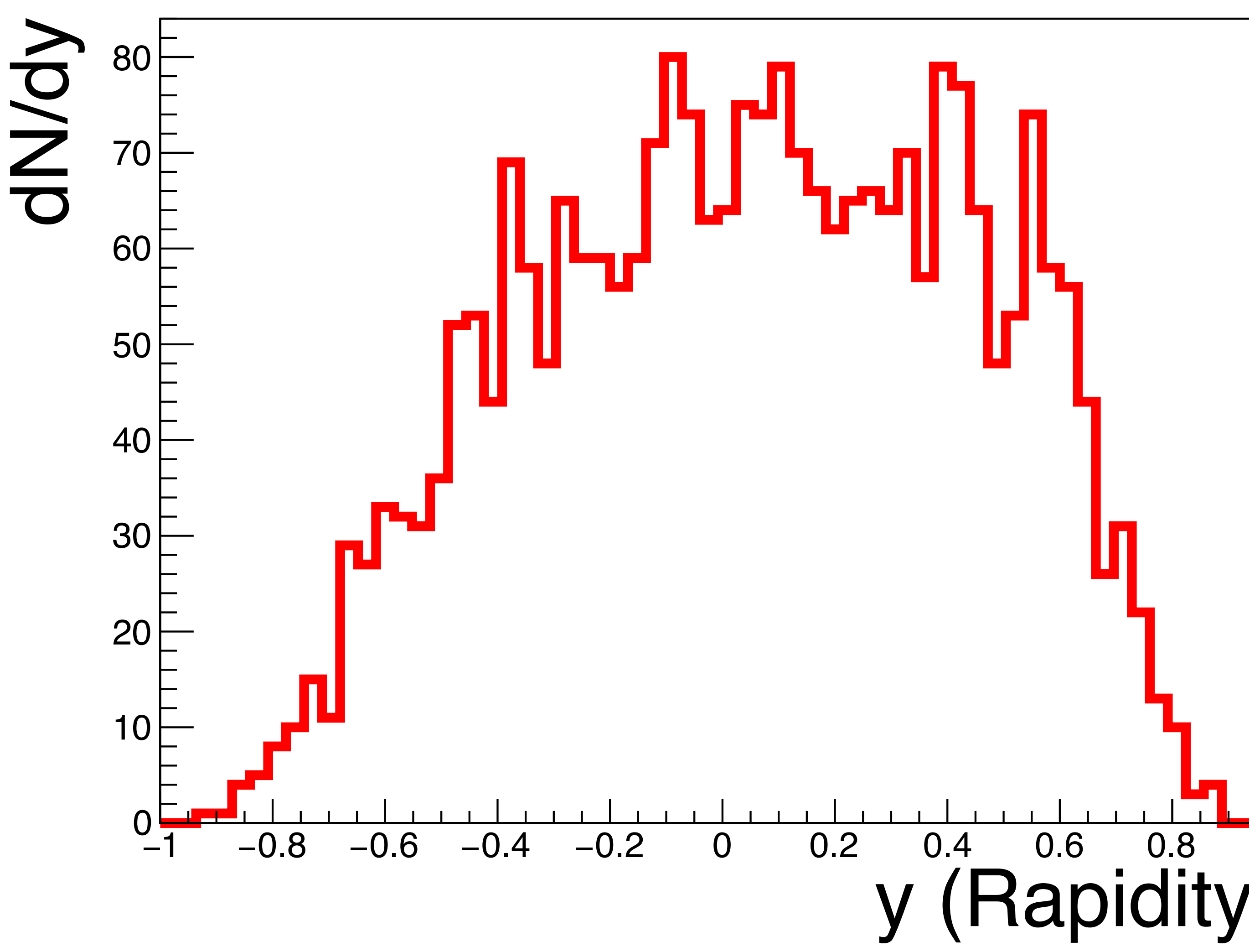
The observed topology is consistent with exclusive ρ^0 meson photo-production in ultra-peripheral p+Au collisions. We see a clean $\pi^+\pi^-$ pair with minimal additional activity: both BBC and ZDC signals are near zero, indicating no nuclear breakup (**0nXn**), and Roman Pot detectors show no significant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

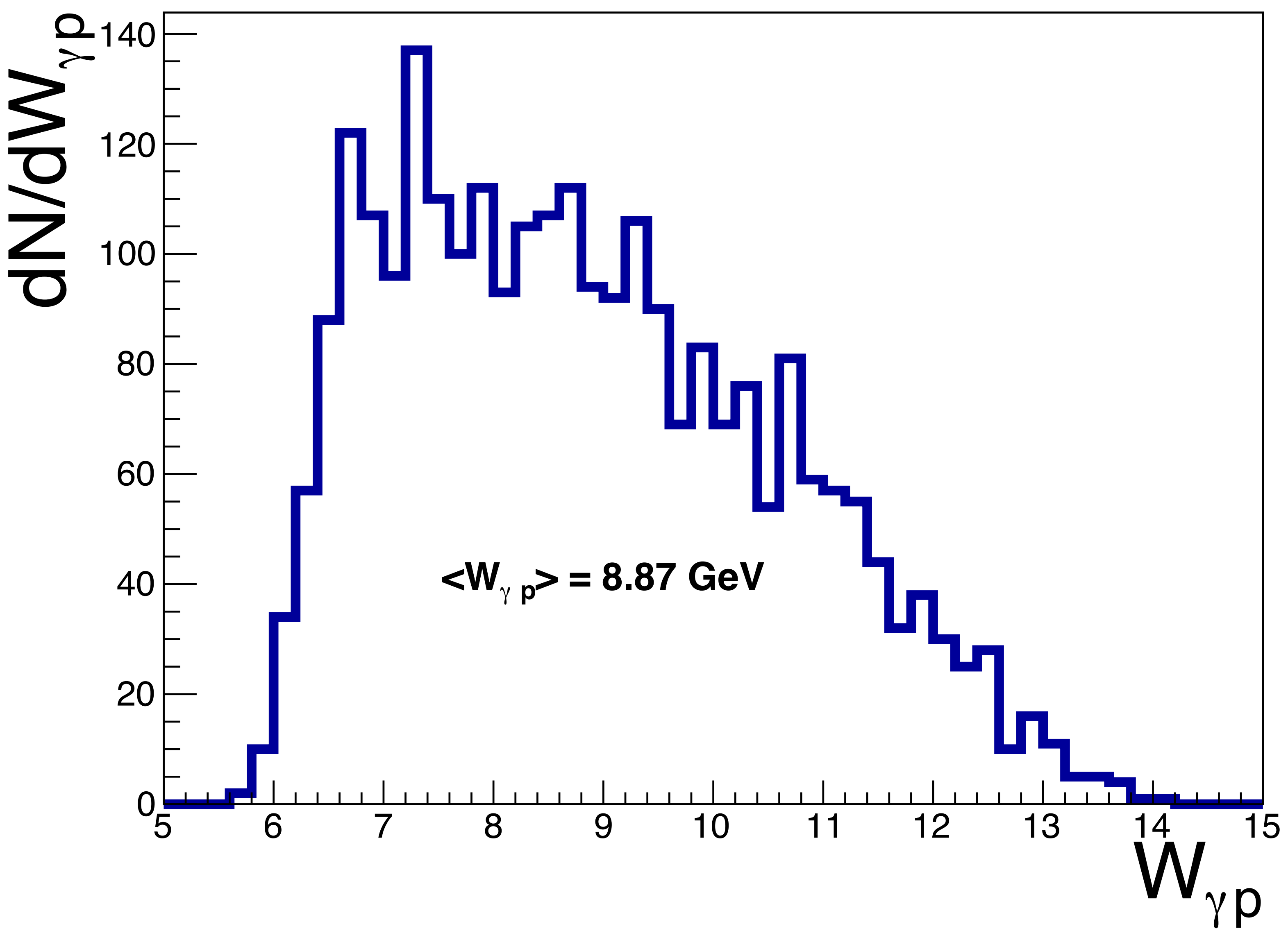




Characterization of ρ^0 peak

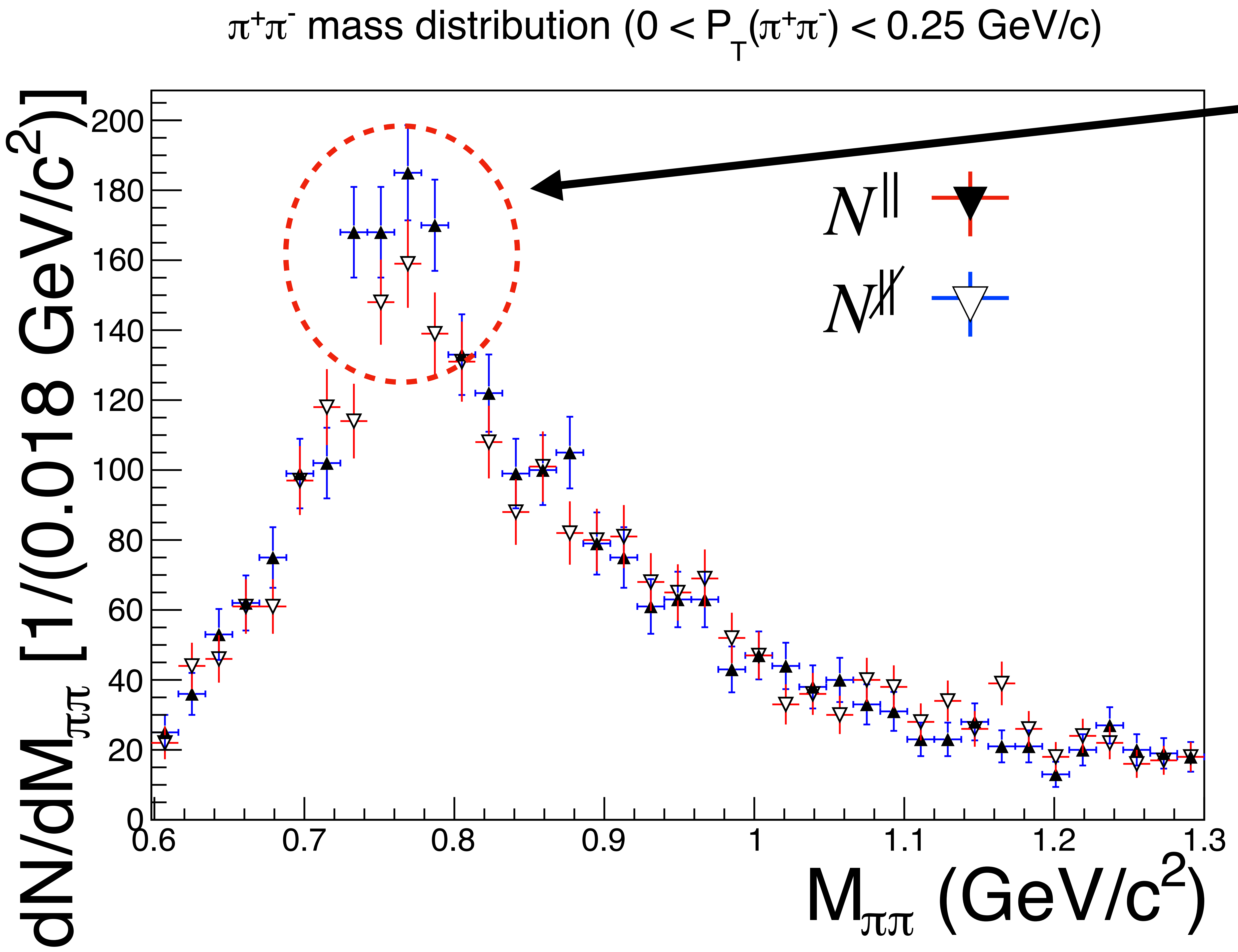




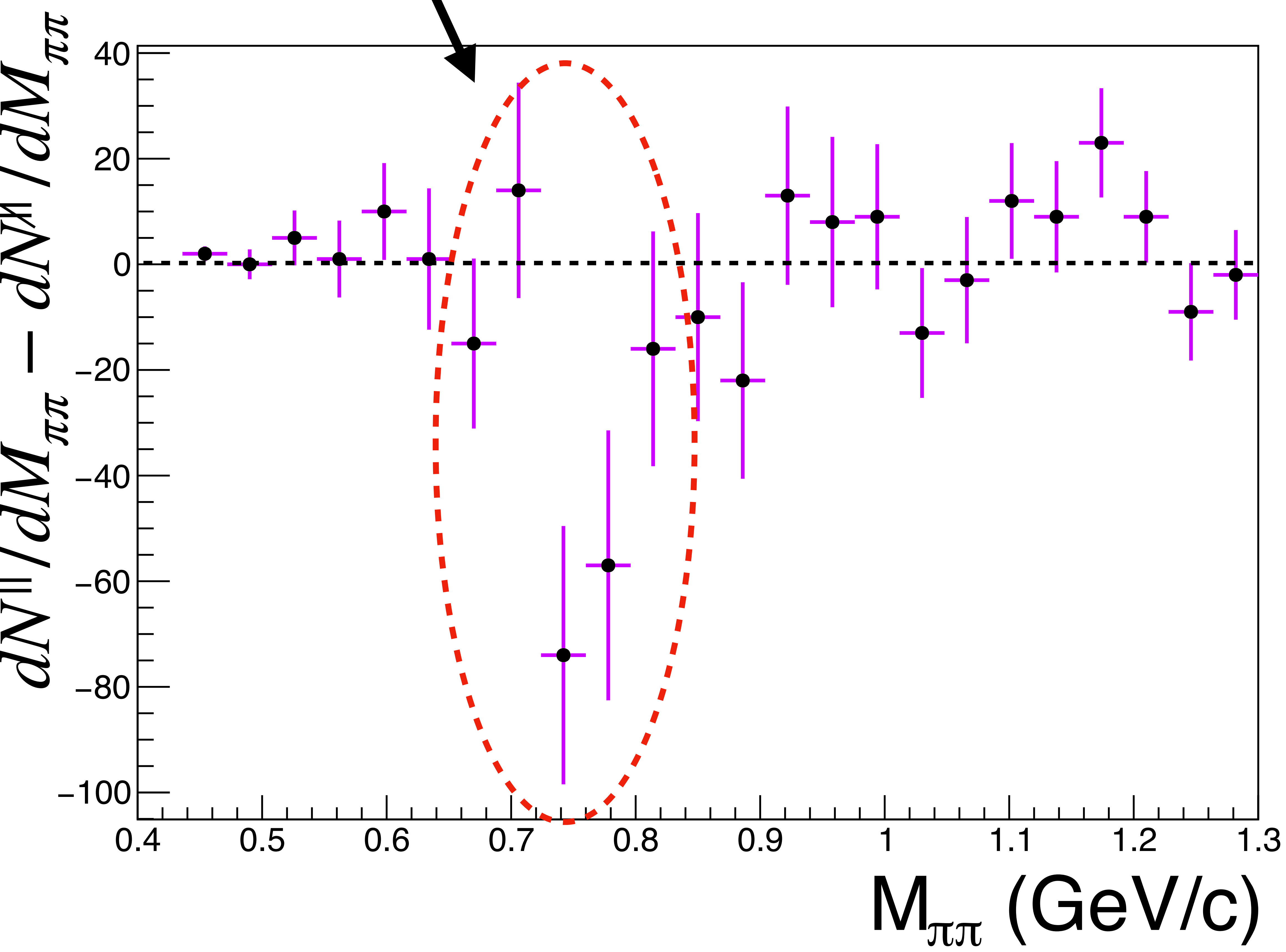


- Clear ρ^0 peak
- Define region of interest $m_{\pi\pi} \in (0.65, 0.90)$ GeV/c
- $E_T^{\gamma} = \hbar c / r_p \sim 250$ MeV for coherent process only.
- Photon-Proton center of mass energy:
  $$W_{\gamma p} \approx \sqrt{2M_{\rho^0}E_p}e^{-y/2} \rightarrow \left\langle W_{\gamma p} \right\rangle =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

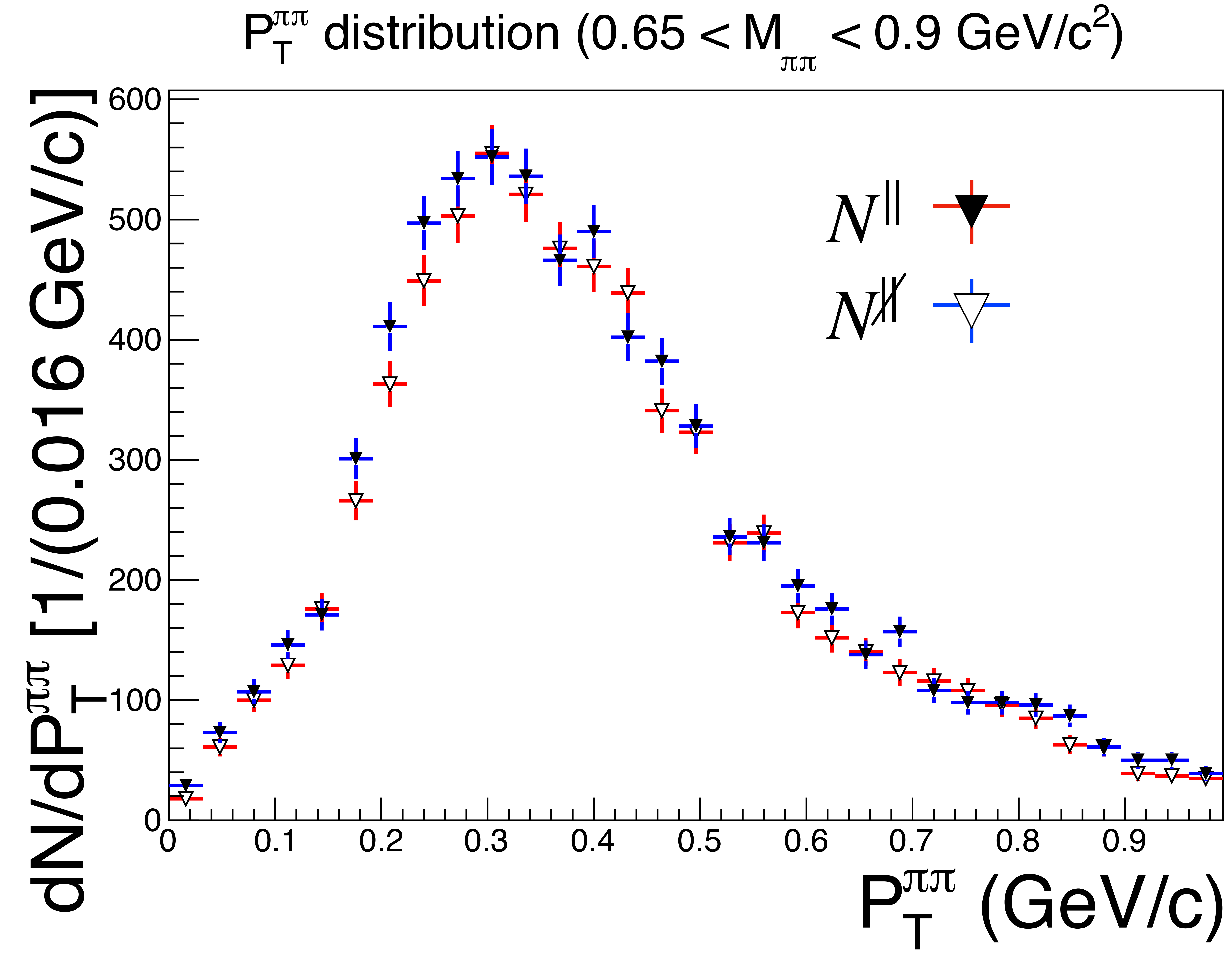
$M_{\pi\pi}$ Differential Plots



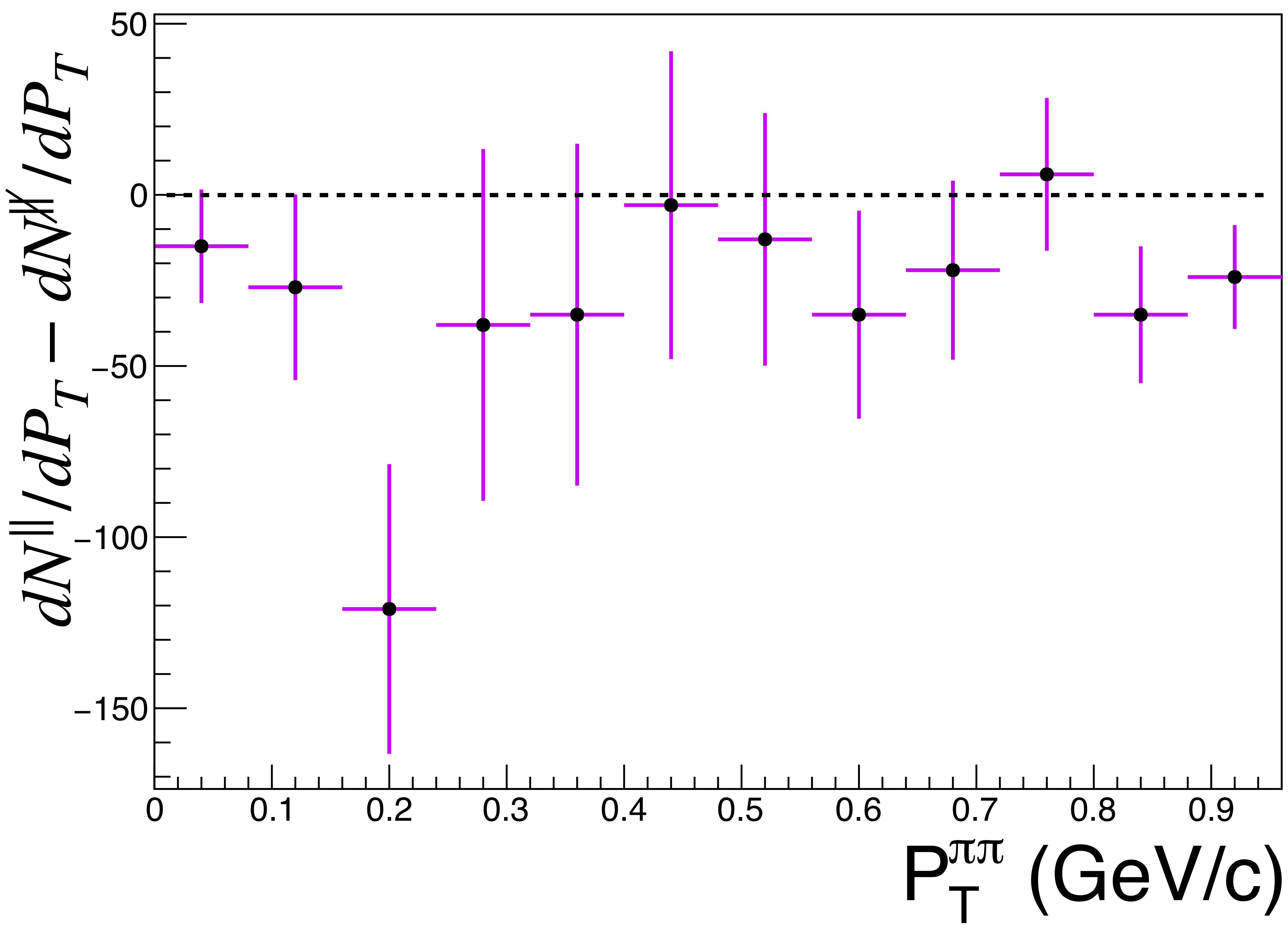
The A_N asymmetry is enhanced around the mass of the $\rho^0(0.770)$



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



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



A_N^γ variables

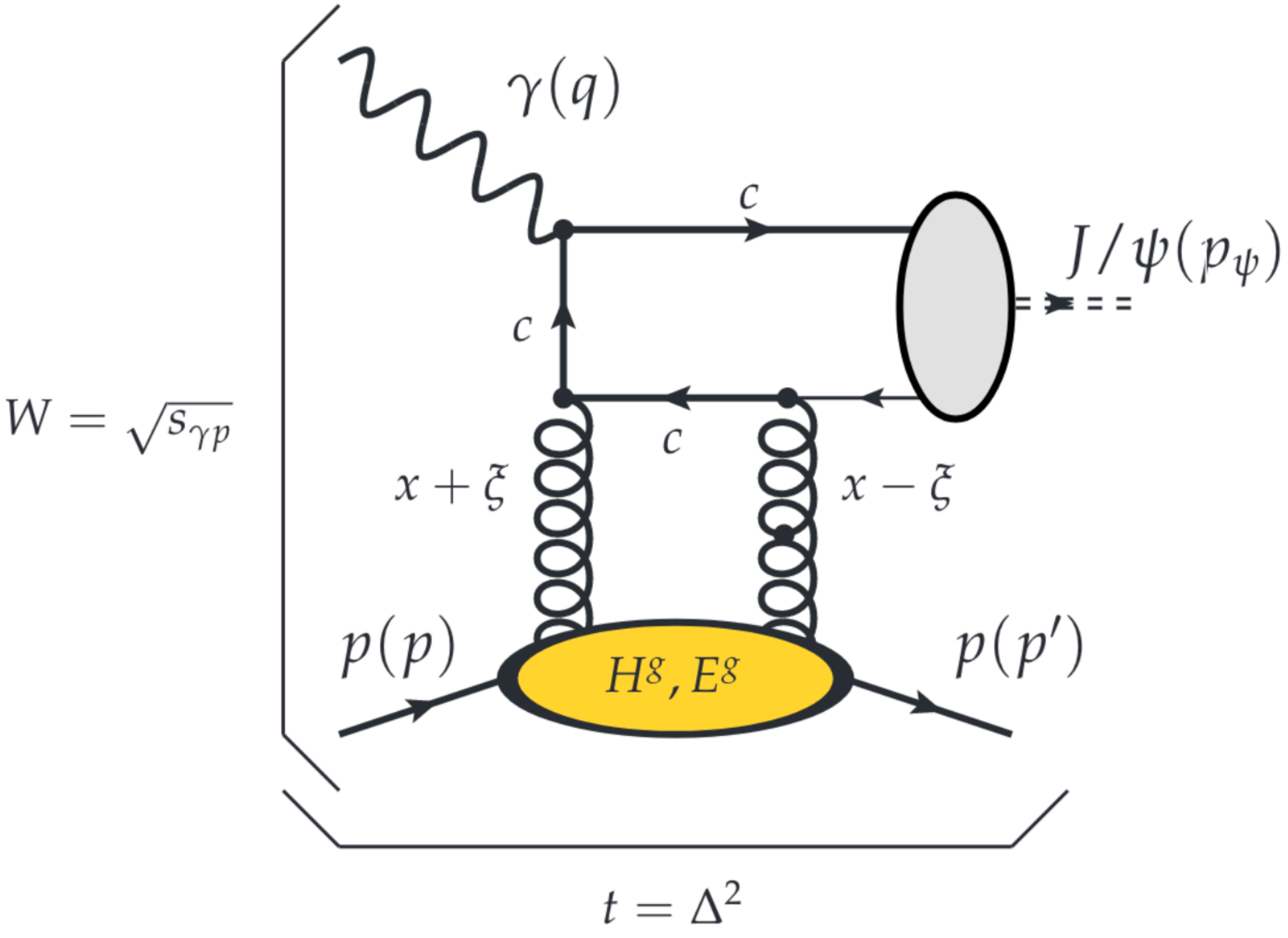
$$\Delta = p - p'$$

$$\xi = \frac{M_\psi}{2W\gamma p - M_\psi}$$

$$\mathcal{H}^g(\xi, t)\int_{-1}^{1} dx T_g(x,\xi) H^g(x,\xi,t)$$

$$\mathcal{E}^g(\xi, t)\int_{-1}^{1} dx T_g(x,\xi) E^g(x,\xi,t)$$

$$T_g(x,\xi) = \frac{\alpha(\mu_R)\xi}{(x - \xi + i\epsilon)(x + \xi - i\epsilon)}$$



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