PRELIMINARY FIGURES REQUEST: ENTANGLEMENT ENABLED SPIN INTERFERENCE BETWEEN $\gamma A \to \pi^+\pi^-$ AND $\gamma\gamma \to \pi^+\pi^-$

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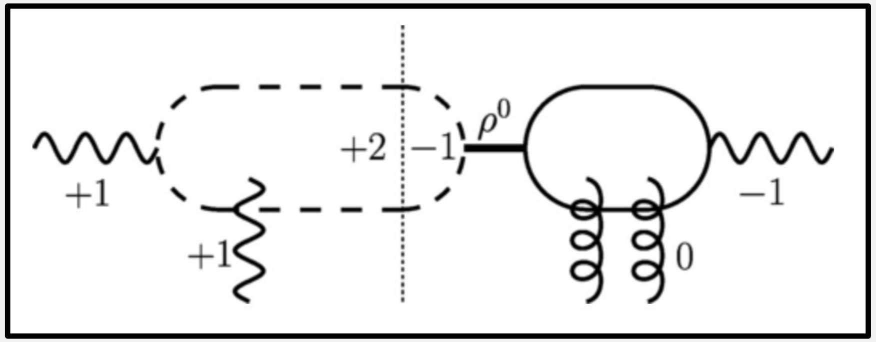
PREVIOUS TALKS IN PWG

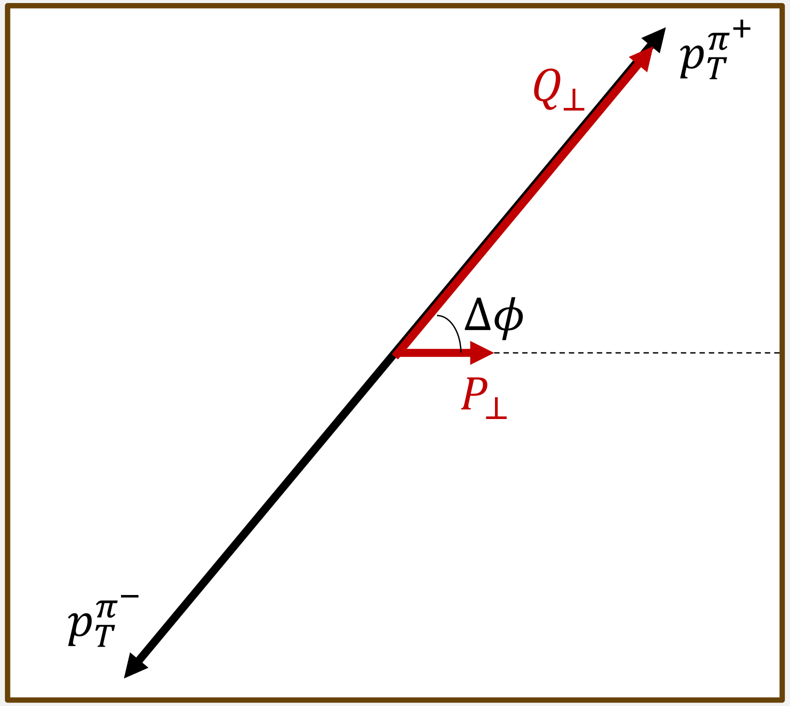
- https://drupal.star.bnl.gov/STAR/meetings/STAR-Collaboration-Meeting-March-2025/LFSUPC-PWG-Parallel-Session-I/Entanglement-Enabled-Sp
- https://drupal.star.bnl.gov/STAR/event/2025/01/27/LFSUPC-PWG-meeting/paper-proposal-Entanglement-Enabled-Spin-Interference-between--0
- https://drupal.star.bnl.gov/STAR/meetings/STAR-Collaboration-Meeting-October-2024/LFSUPC-Parallel-Session-I/Entanglement-Enabled-Sp-0
- https://drupal.star.bnl.gov/STAR/meetings/STAR-Collaboration-Meeting-March-2024/LFSUPC-Parallel-Session-II/Spin-interference-btw-phot

PHYSICS MOTIVATION

- Entanglement Enabled Spin Interference (EESI) and its main observable, $\Delta\phi$, are sensitive to the sum of the angular momentum of two interfering channels.
- In ultraperipheral collisions, pion pairs are produced in numerous channels, including $\gamma A \rightarrow \pi^+\pi^-$ (spin 1) and $\gamma\gamma \rightarrow \pi^+\pi^-$ (spin 2), and variations of both with an intermediate resonance.
- EESI provides a novel window into the hadronic light-by-light process, which has yet to be isolated in UPCs and represents one of the two dominant uncertainties of a_μ, the anomalous magnetic moment of the muon.



Phys. Rev. D 103, 074013



DATASET

- Dataset: Au+Au $\sqrt{s_{NN}} = 200\ GeV$
- Year: 2010, 2011, 2014
- Production Tag: P10ik, P11id, P16id
- Trigger: UPC_Main

CUTS

- Event Level:
  - $|v_z| < 100$ cm

- Track Level:
  - $|\eta_\pi| < 1$
  - $p_T^\pi > 200$ MeV/c
  - DCA<1 cm
  - Both tracks match to ToF
  - Both tracks nHitsFit>15
  - Both tracks nHitsdEdx>10
- PID:
  - $\chi^2_{\pi\pi} = n\sigma^2_{\pi_1} + n\sigma^2_{\pi_2} < 8$
  - $\Delta\Delta ToF < 5\sigma$

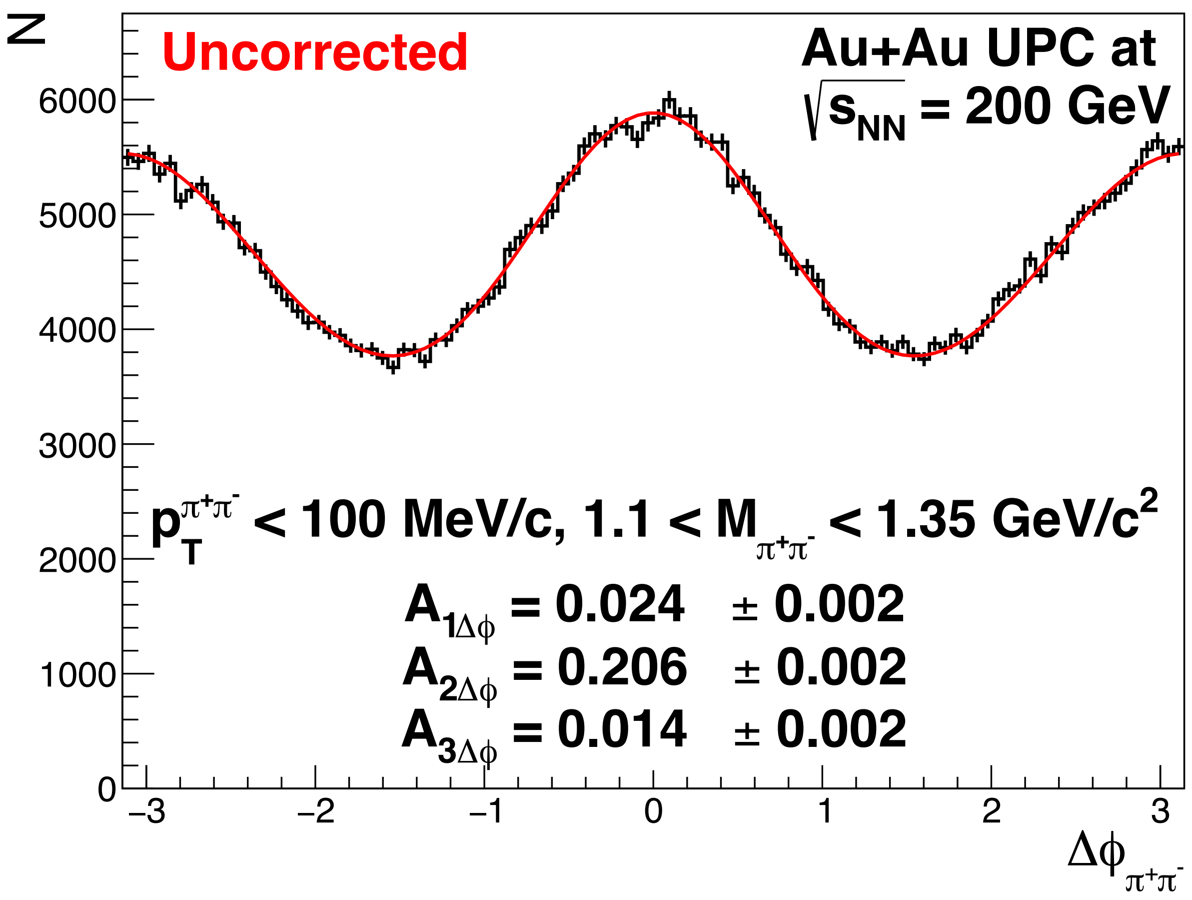
Before: 1.63e7 events

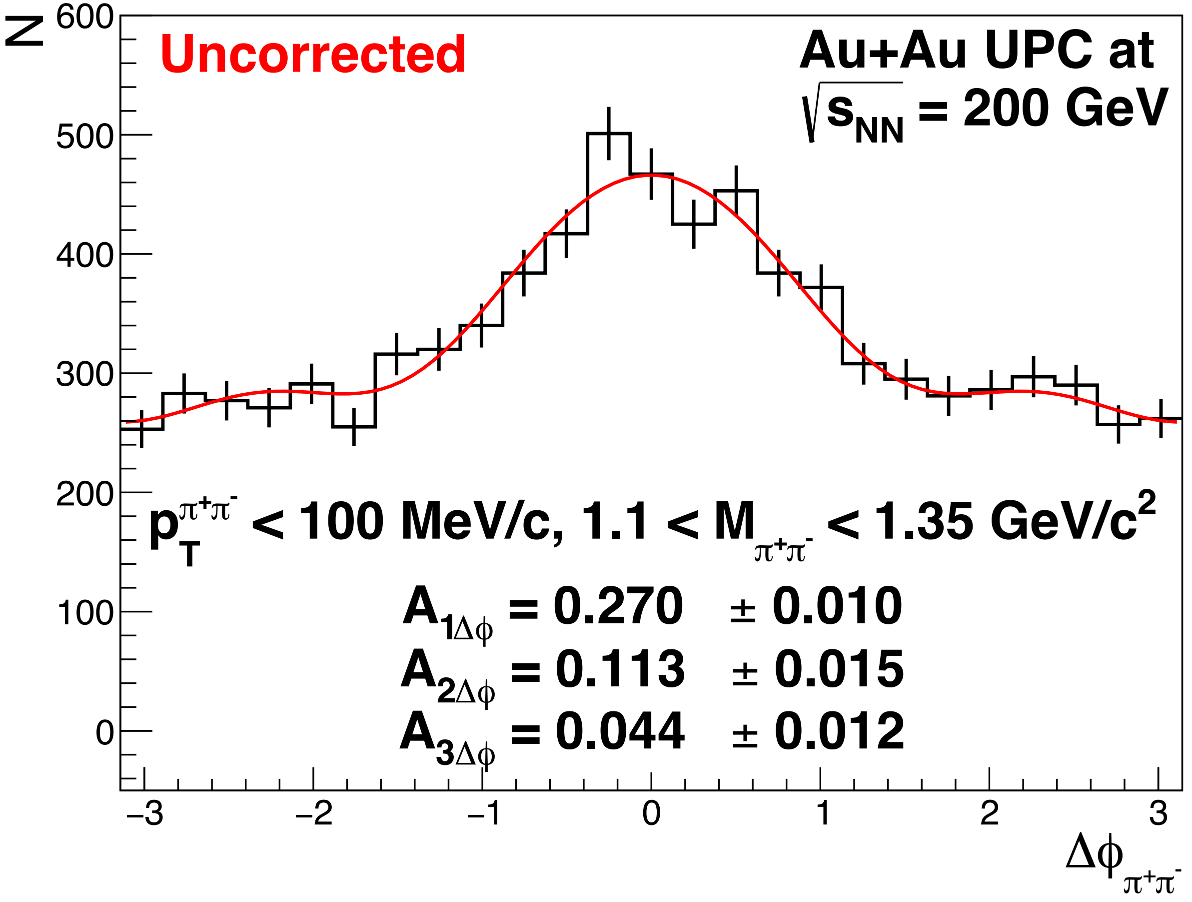
After: 1.25e6 events

ANALYSIS PROCEDURE

- From the data, extract $A_{n\Delta\phi} =< 2\cos(n\Delta\phi) >$ as a function of pair p_T and $M_{\pi\pi}$
- Use toy model informed by the pion kinematics from the data to accurately determine the acceptance effect on $A_{n\Delta\phi}$.
  - This is used to study the effects of momentum resolution and $\pi \to \mu + \nu$ decay on the $A_{n\Delta\phi}$. For the odd harmonics, the effect is very small and is part of the study on systematics.
- Correct the data using $\alpha_{n\Delta\phi} = \frac{-2(\gamma_{n\Delta\phi} - \omega_{n\Delta\phi})}{\gamma_{n\Delta\phi} \times \omega_{n\Delta\phi} - 2}$, where α is the corrected signal, γ is the measurement, and ω is the baseline from the toy model.
  - This is done bin by bin in 2D $(\mathrm{p_T}, \mathrm{M}_{\pi\pi})$.
- Project into 1D for final value and statistical error bars.
- Calculate systematics using Barlow method, varying cuts and versions of the toy model with and without the effects of momentum resolution and $\pi \to \mu + \nu$ decay.

UNCORRECTED $\Delta\phi$ DISTRIBUTIONS





- I would like to include these plots on my QM2025 poster.

For all of these variations, see backups!

SYSTEMATICS

Cut:	$\chi^2_{\pi\pi} < X$	DCA$< X$	nHitsFit$> X$	nHitsDedx $?X$	$N_{\sigma_{\Delta\Delta ToF}} < X$	$v_z < X$	$\eta_\pi < X$	Use ToF, p_T min?	$\pi \to \mu + \nu$, p resolution?
Default:	8	1.0 cm	15	10	5.0	100 cm	1	Yes, $p_T^\pi >$ 200 MeV/c	No, No
Variations	20	3.0 cm	10	5	3.0	70 cm	0.8	Yes, No No, No	Yes, No No, Yes
Percent uncertainty (min, max, mean)	1, 21, 6	0, 18, 7	0, 17, 5	0, 19, 5	0, 38, 1	0, 44, 9	0, 50, 10	0, 43, 12	0, 40, 10
Absolute uncertainty (min, max, mean)	0, 0.013, 0.003	0, 0.011, 0.004	0, 0.01, 0.003	0, 0.012, 0.004	0, 0.012, 0.005	0, 0.012, 0.004	0, 0.008, 0.002	0, 0.012, 0.004	0, 0.01, 0.003

Analyze the data varying these parameters one at a time.

Calculate the systematic error bars with Barlow method.

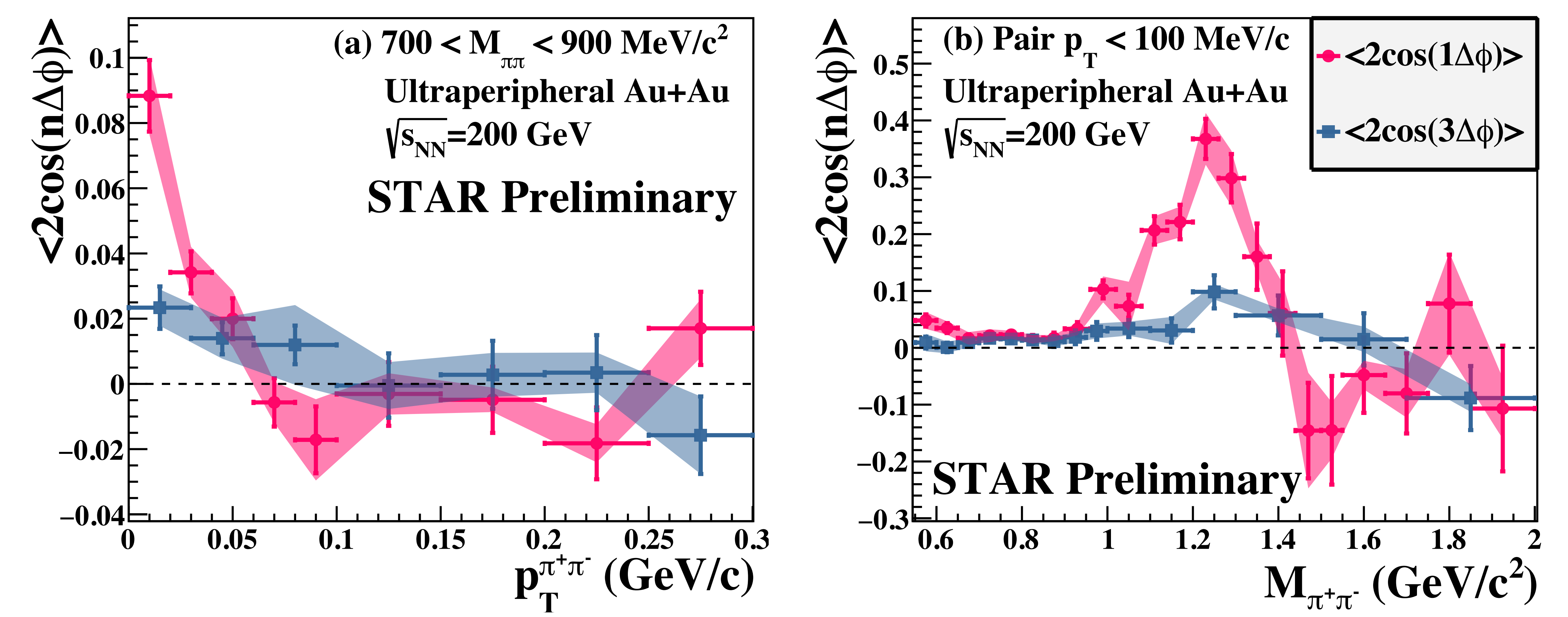
Not included: Correction for presence of non-interfering hadronic background

Estimate: 2%, see backups for result of that correction.

This 2% is added to the error bars on the next slide.

Note: the large maximum percent uncertainties are a result of certain points being very near 0 (0.15 GeV pT for example), making relative errors blow up. For this reason I suggest comparing absolute uncertainties to the size of the maximum signal.

FIGURE 1



Total percent uncertainty (min, max, mean): 13, 200, 71

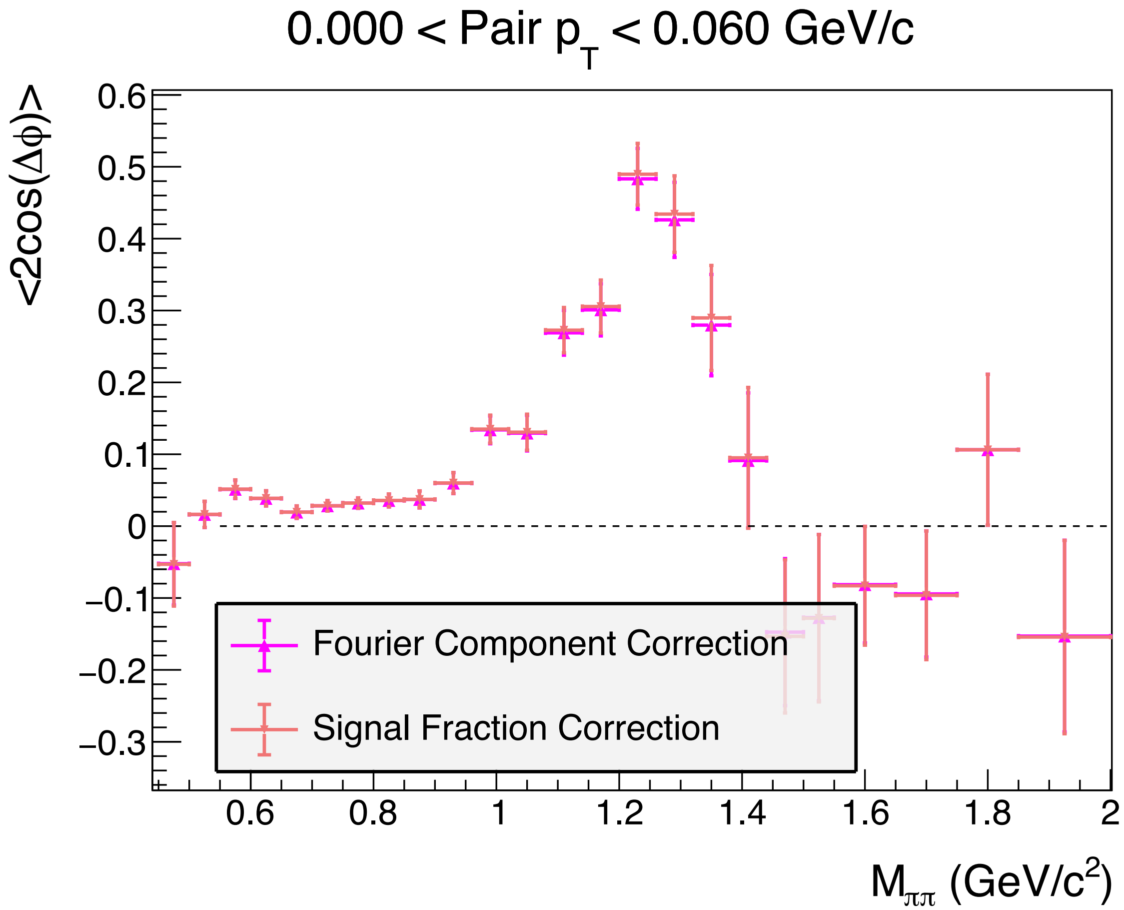
Total absolute uncertainty (min, max, mean): 0.004, 0.012, 0.008 (add the variations from previous slide in quadrature and divide by sqrt(12))

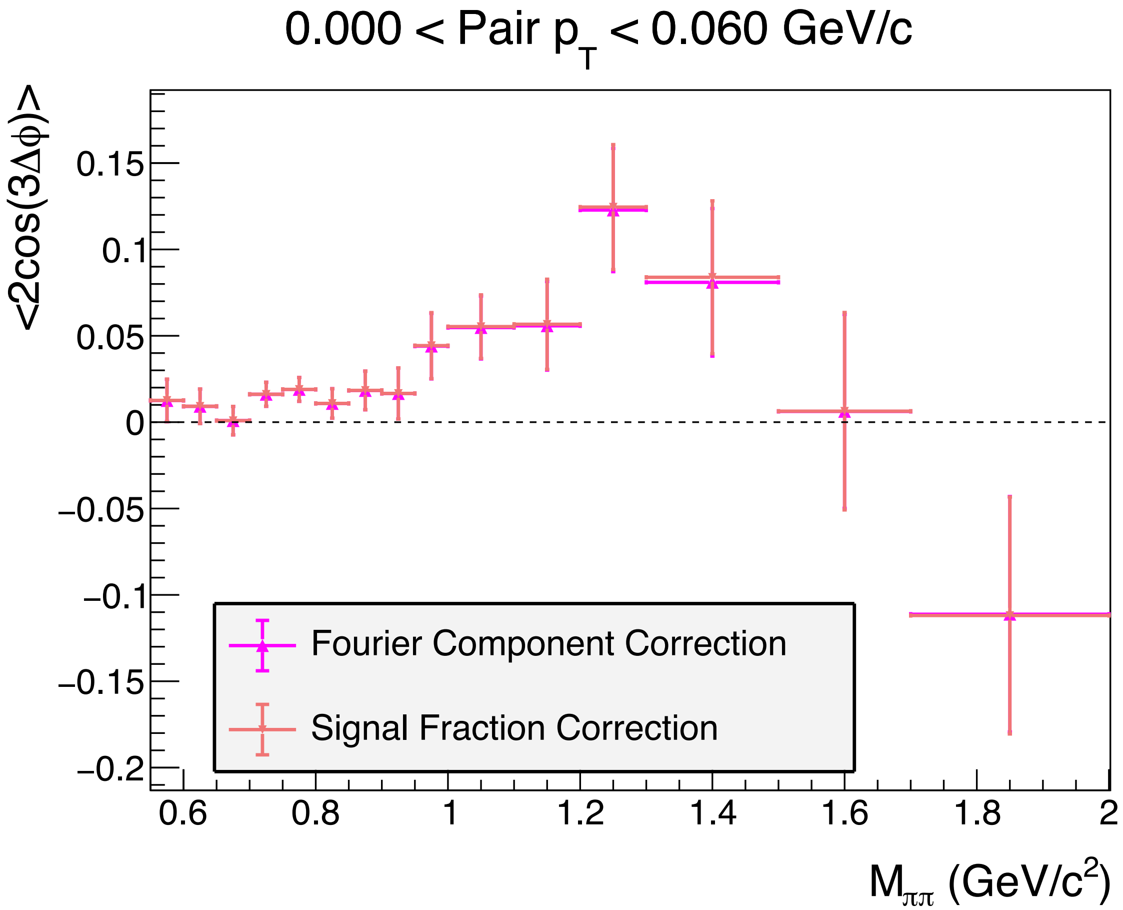
BACKUPS

CORRECTION FOR NON-INTERFERING BACKGROUND: IDEA

- There is a (small) background of pion pairs produced by something other than $\gamma A, \gamma\gamma$, historically thought of as primarily hadronic background.
- The magnitude of that background is obtained by looking at same-sign pairs in the data.
- Then, assuming this background is non-interfering ($\mathrm{A}_{n\Delta\phi}^{background} = 0$ if acceptance is properly handled), then the true signal is $A_n^{true} = \frac{A_n^{measured}}{s}$

CORRECTION FOR NON-INTERFERING BACKGROUND: RESULTS





Generally a <2% effect.

ALL SYSTEMATIC VARIATIONS