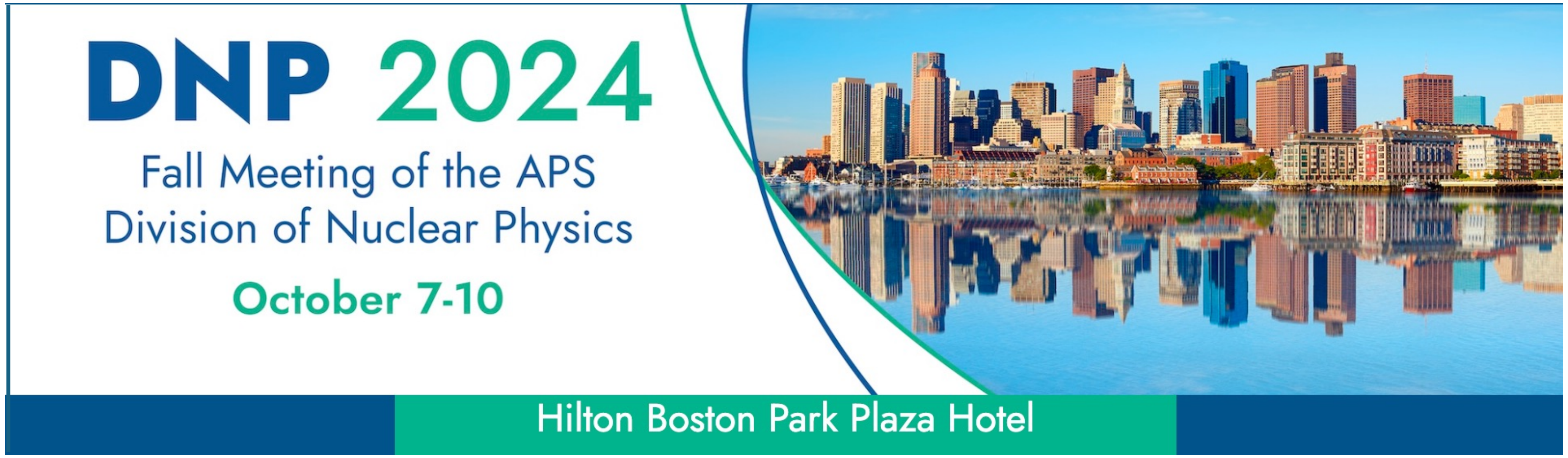
Measurement of Transverse Spin Dependent Azimuthal Correlations of Charged hadron Pairs in $p^{\uparrow}p$ Collisions at $\sqrt{s}$ = 200 GeV at STAR



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(For the STAR Collaboration)

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STAR

TEMPLE UNIVERSITY

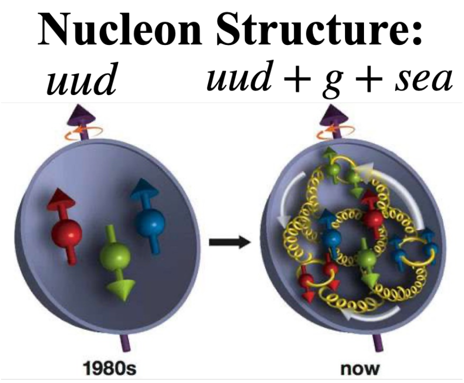
Outline

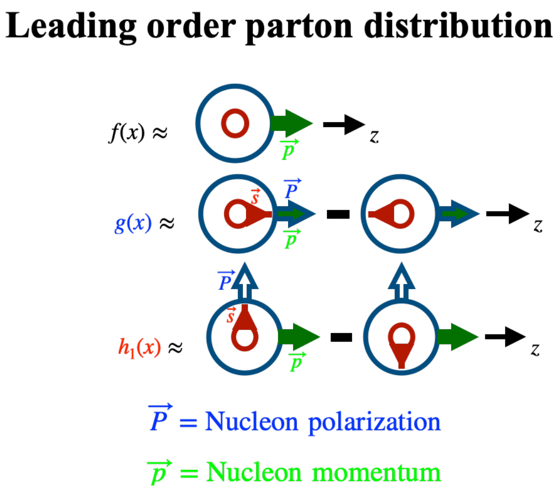
- Motivation
- Observable for Transversity
- Asymmetry Extraction
- Di-Pion Asymmetry STAR Result
- Di-Kaon Analysis
- Summary

Motivation

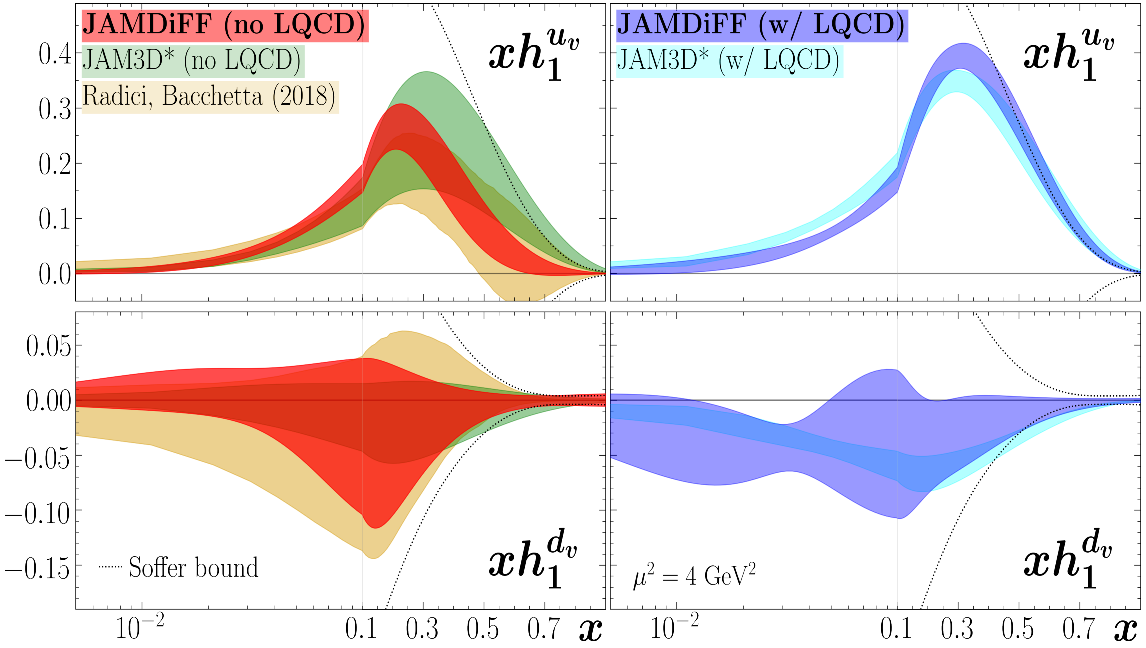
Transversity, $h_1^q(x)$:

- Three leading twist PDFs: Unpolarized PDF($f_1(x)$), helicity PDF$\big(g_1(x)\big)$, and transversity PDF($h_1^q(x)$).
- $h_1^q(x)$ is least known from the experiments due to its chiral odd nature.
- In $p^{\uparrow}$p collision, $h_1^q(x)$ can be coupled with interference fragmentation function(IFF) which is extracted from e^+e^- data.
- $h_1^q(x)$ is mostly constrained by SIDIS and pp data to date.

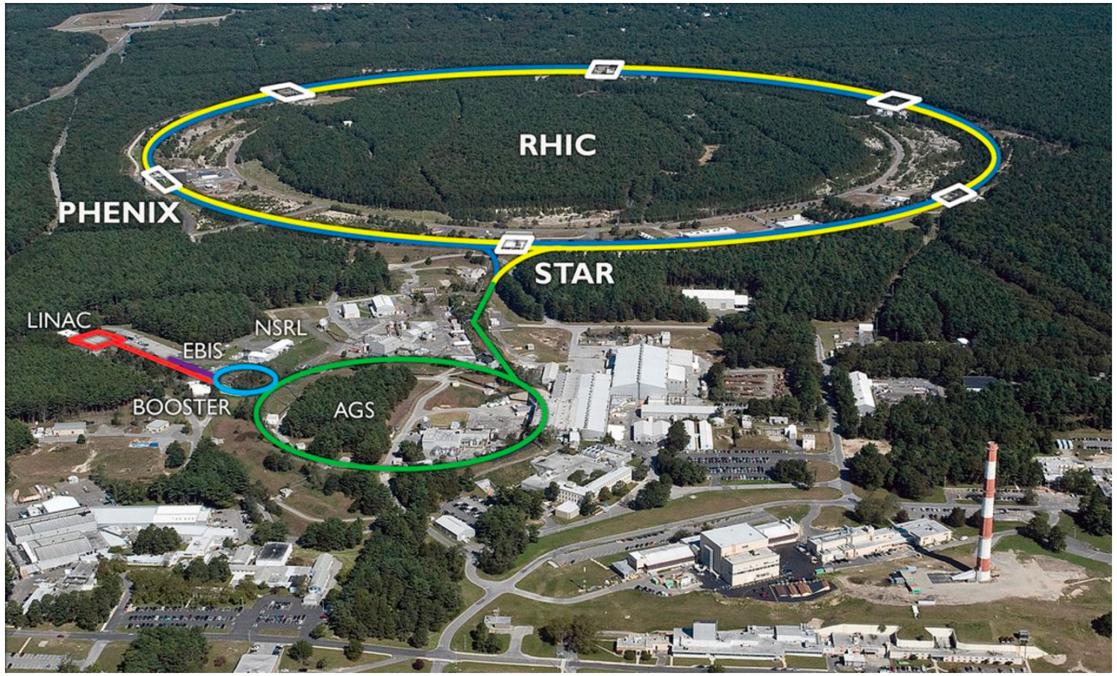


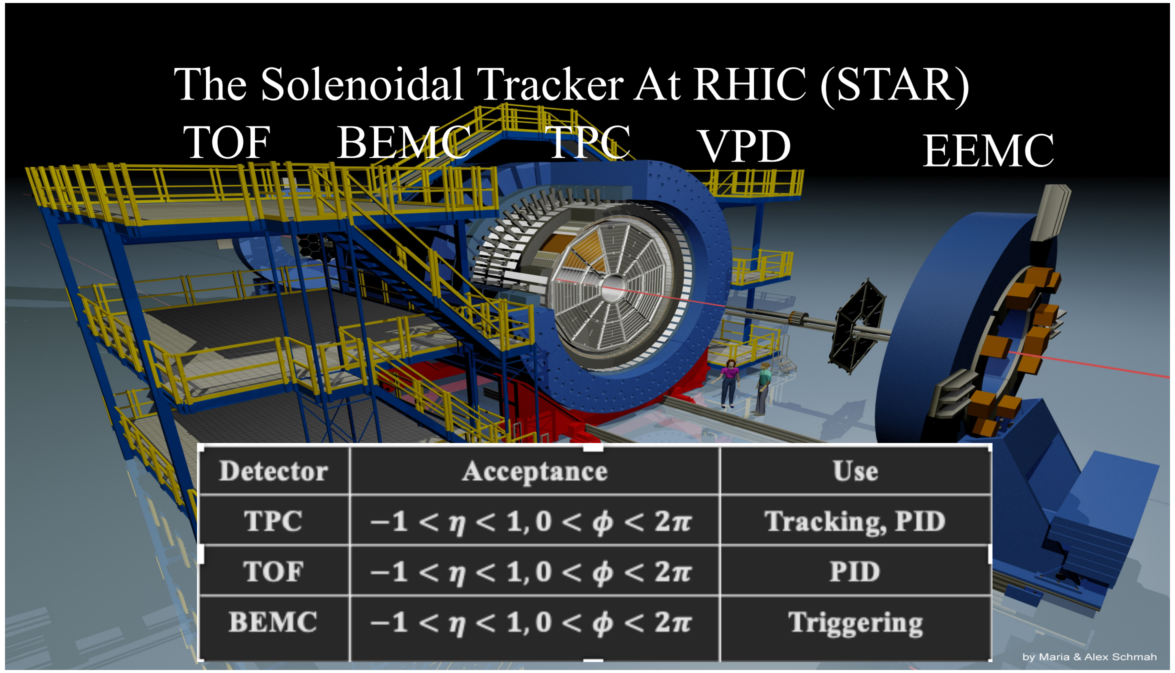


JAM,Phys. Rev. Lett. **132**, 091901



STAR Experiment at RHIC





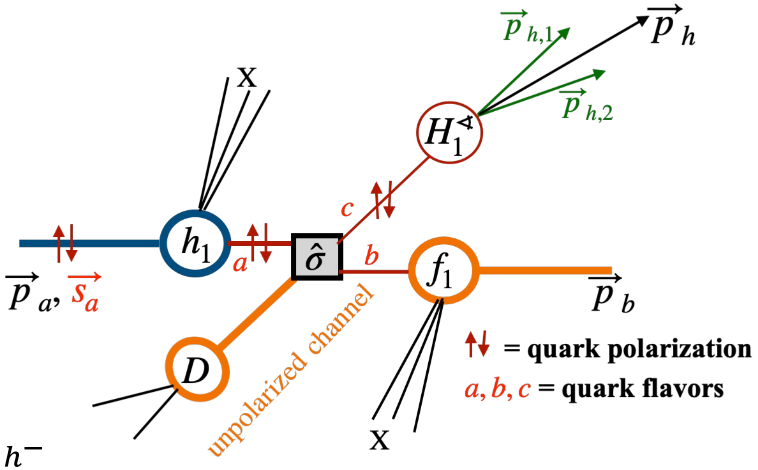
Detector	Acceptance	Use
TPC	$-1 < \eta < 1, 0 < \phi < 2\pi$	Tracking, PID
TOF	$-1 < \eta < 1, 0 < \phi < 2\pi$	PID
BEMC	$-1 < \eta < 1, 0 < \phi < 2\pi$	Triggering

- Only polarized proton-proton collider.
- Center-of-mass energy up to 510 GeV.
- Transverse and longitudinal beam polarization.

- Time Projection Chamber (TPC) helps in charge determination and particle momentum reconstruction
- Time of flight (TOF) acts as stopwatch for particles.
- Particle identification (PID) is done via measuring ionization energy loss (dE/dx) in TPC.
- TOF gives velocity of particle and combining velocity with momentum (from TPC), TOF helps in PID by identifying mass of a particle.

Probing $h_1^q(x)$ via h^+h^- channel

STAR,Phys.Rev.D 70 (2004) 094032



- Reaction channel: $p_a^{\uparrow}p_b \rightarrow h^+h^- + X$
- Polarized cross section:

$$d\sigma_{UT}^{\uparrow} \propto \sin(\phi_S - \phi_R) \int dx_a dx_b f_1(x_b) h_1(x_a) \frac{d\Delta\hat{\sigma}}{d\hat{t}} \boldsymbol{H_1^{\sphericalangle}(z, M^2)},$$

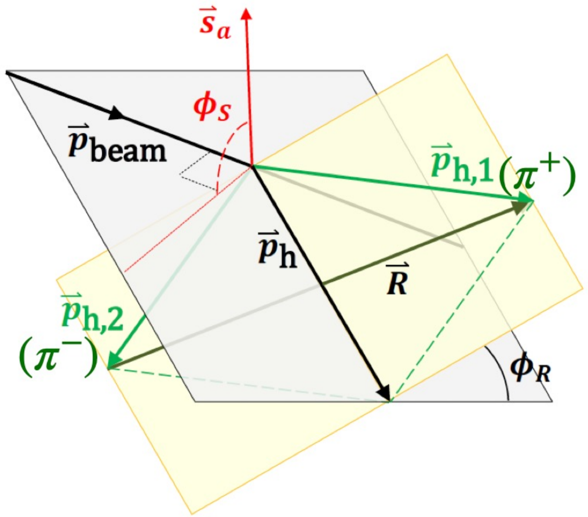
where $M = h^+h^-$ invariant mass , $z = \frac{E^{h^+h^-}}{E^q}$

- Unpolarized cross section:

$$d\sigma_{UU} \propto \int dx_a dx_b f_1(x_b) f_1(x_a) \frac{d\Delta\hat{\sigma}}{d\hat{t}} \boldsymbol{D_1(z, M^2)}$$

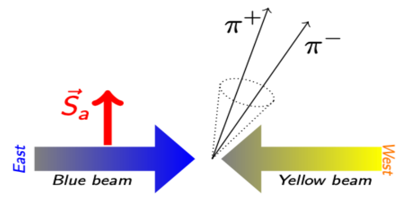
- D_1 can be extracted from the measurement of the unpolarized di-hadron cross section ($d\sigma_{UU}$).
- Di-hadron azimuthal correlation asymmetry, A_{UT} is given by,

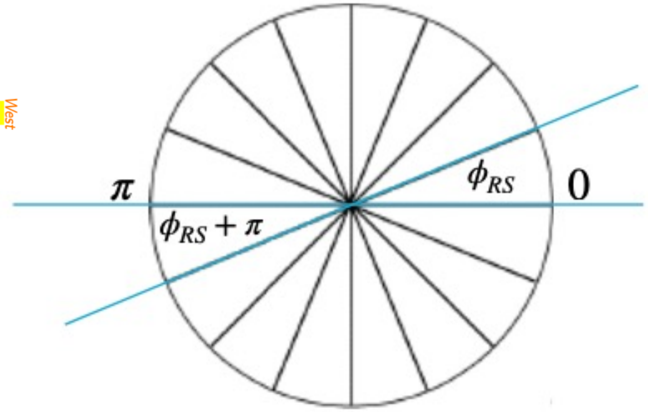
$$A_{UT} = \frac{d\sigma_{UT}}{d\sigma_{UU}} = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}} \propto \sum_{i,j,k,l} \frac{f_1^{j/b}(x_b)\, h_1^{i/a}(x_a)\, H_1^{\sphericalangle h_1 h_2/k}(z_h, M_h^2)}{f_1^{j/b}(x_b)\, f_1^{i/a}(x_a)\, D_1^{h_1 h_2/l}(z_h, M_h^2)}$$



Azimuthal angle definitions:
ϕ_S = angle between quark spin vector, s_a , and scattering plane
ϕ_R = angle between scattering plane and di-hadron plane

Asymmetry Extraction





ϕ_{RS} Binning Scheme

- Cross Ratio Formula

$$A_{UT}.\sin(\phi_{RS}) = \frac{1}{P}\cdot\frac{\sqrt{N\uparrow(\phi_{RS})N\downarrow(\phi_{RS}+\pi)} - \sqrt{N\downarrow(\phi_{RS})N\uparrow(\phi_{RS}+\pi)}}{\sqrt{N\uparrow(\phi_{RS})N\downarrow(\phi_{RS}+\pi)} + \sqrt{N\downarrow(\phi_{RS})N\uparrow(\phi_{RS}+\pi)}}$$

where, N is number of h^+h^- pairs when beam polarization is up or down.

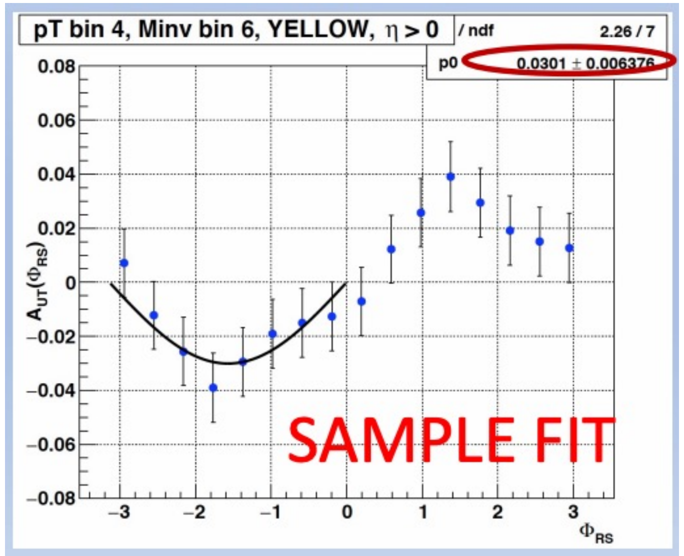
$\phi_{RS} = \phi_R - \phi_s$

ϕ_s = angle between quark spin vector, s_a , and scattering plane

ϕ_R = angle between scattering plane and di-hadron plane

- Free from uncertainty arising from detector effect and spin-dependent luminosities.
- No jet reconstruction required.

- A_{UT} is extracted from the amplitude of cross ratio fit.



STAR $\pi^+\pi^-$ Asymmetry Result

Year	2006	2011	2015	2017	2022	2024
$\sqrt{s}$ GeV	200	500	200	510	508	200
L_{int} (pb^{-1})	~ 1.8	~ 25	~ 52	~ 350	~ 350	~ 160[projection]

Published

1st Proof-of-Principal measurements

[1] STAR,Phys.Rev.Lett.115(2015) 242501

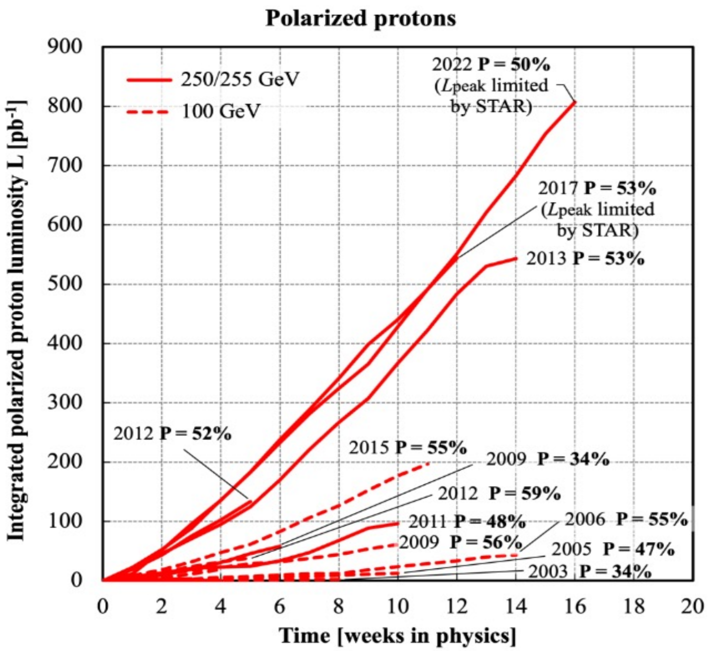
[2] STAR,Physics Letters B 780 (2018) 332-339

Preliminary $\pi^+\pi^-$ results with improved precision

STAR,PoS, SPIN2023(2024), 052

STAR,PoS, SPIN2023(2024), 063

Further improvement



STAR $\pi^+\pi^-$ Asymmetry Result

- A_{UT} as a function of η_{pair} integrated over pT_{pair} and M_{inv} is shown in Figure:1.
- For η >0, where partonic x is greater, a larger A_{UT} is seen.

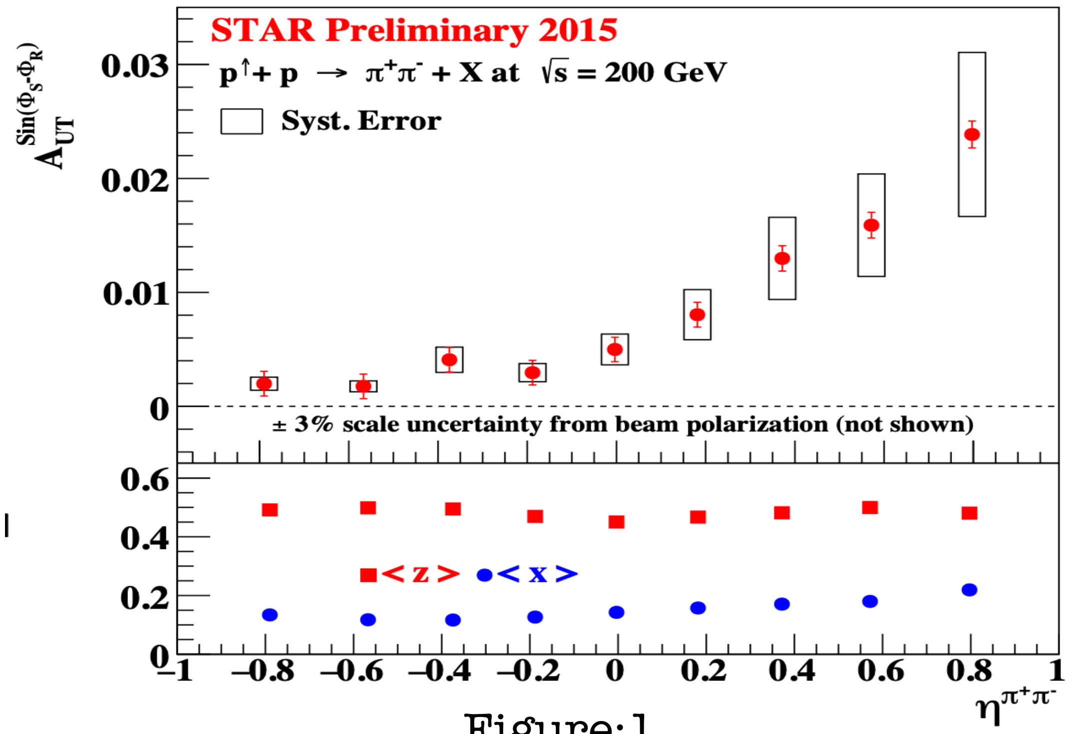
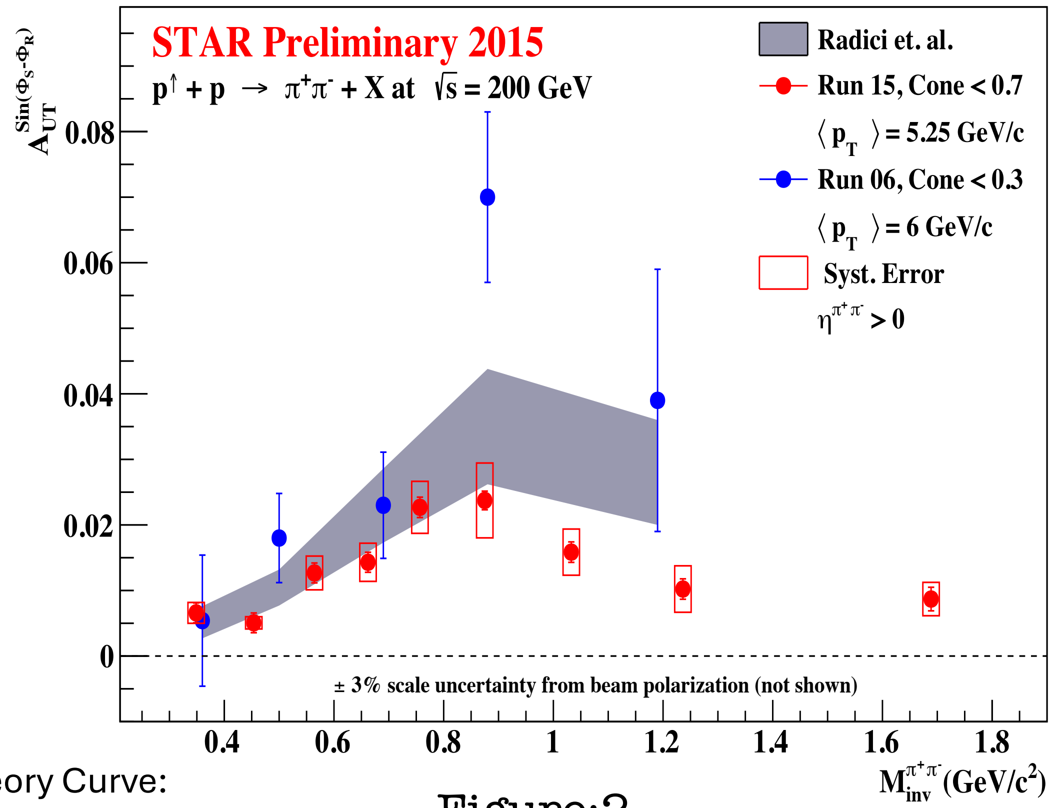


Figure:1

- A_{UT} is enhanced around $M_\rho \sim 0.8\ \mathrm{GeV}/c^2$, consistent with theory.



Theory Curve:
Phys. Lett. B 780 (2018) 332

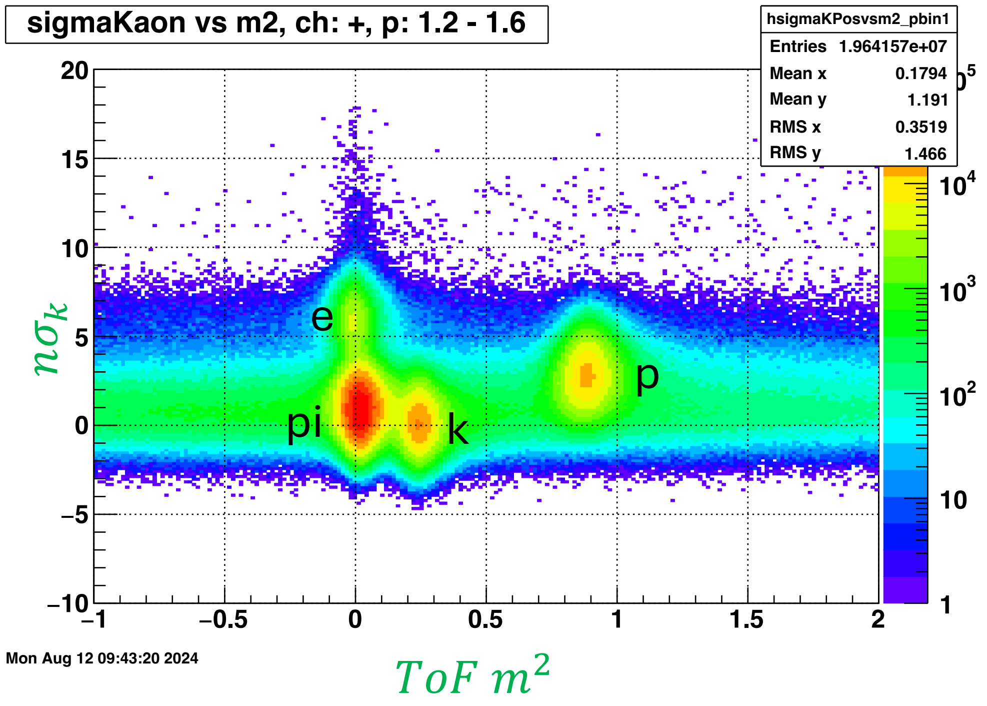
Figure:2

STAR, PoS, SPIN2023(2024), 052

Transition to K^+K^- Asymmetry

- Extending to K^+K^- pairs enhances transversity studies by revealing insights into strange quarks beyond $\pi^+\pi^-$ results.
- Di-Kaon Analysis will be done by using 2015 data set with $\sqrt{s}$ = 200GeV and L_{int} 52 pb^{-1}.

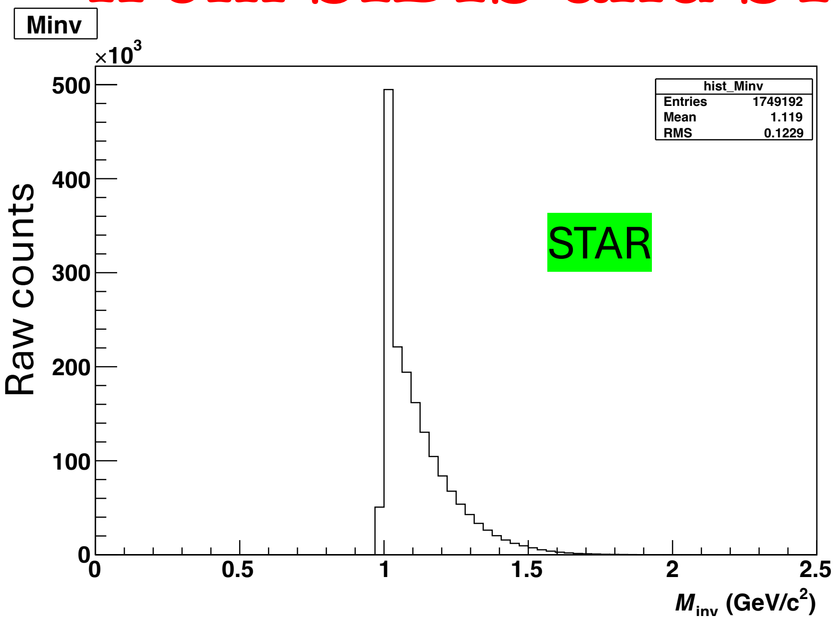
Particle Identification



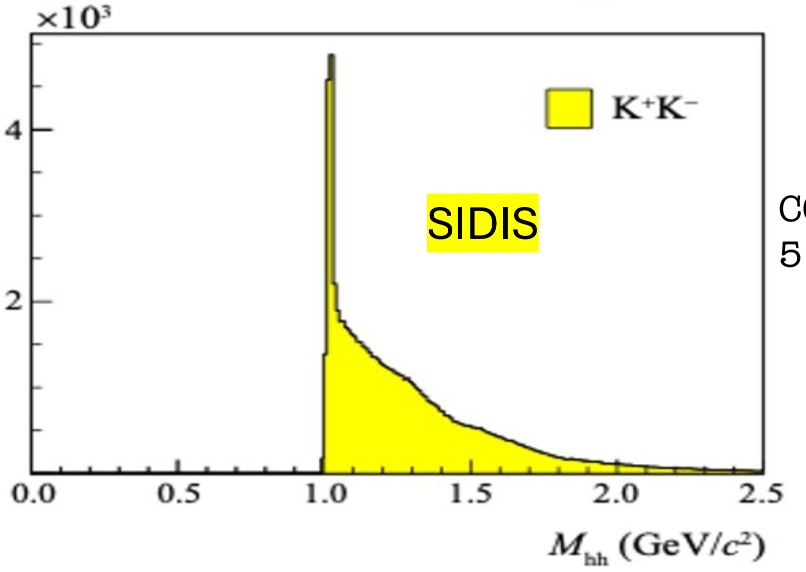
- Kaon identification will be done from 2D histogram of nSigmaKaon and ToF mass square.

- $$n\sigma_k = \frac{1}{\sigma} \ln \left(\frac{dE/dx_{obs}}{dE/dx_{calc}}\right)$$

Comparison of M_{inv} of K^+K^- from SIDIS and STAR

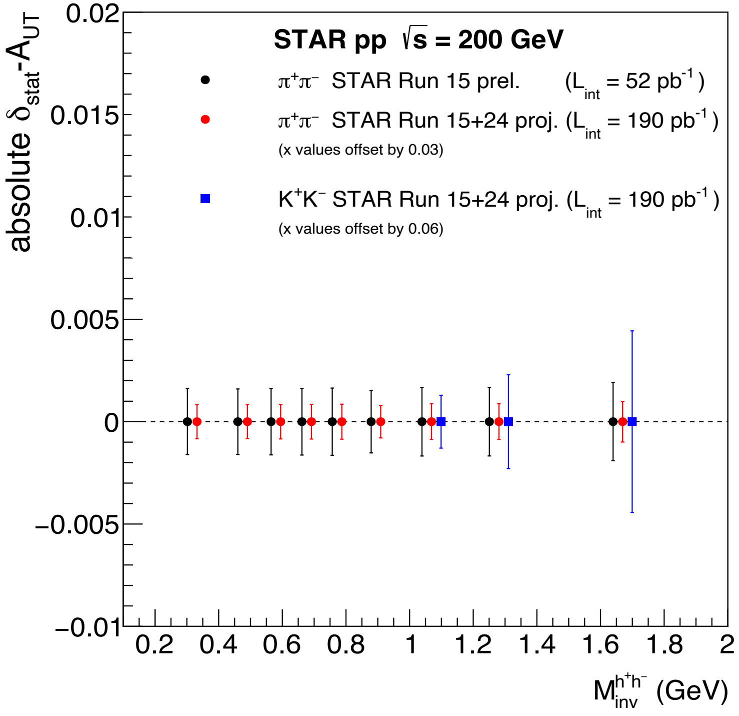


M_{inv} from reconstructed Kaon Pairs looks similar to M_{inv} from SIDIS.



COMPASS,Phys.Lett.B 84 5 (2023) 138155

K^+K^- Projection Plot



- Precision measurement of $\pi^+\pi^-$ A_{UT}
  - ∗ By combining Run24 data, statistical uncertainty will be improved by more than 50% compared to Run15.
- First projection of K^+K^- A_{UT}
  - ∗ The K^+K^- A_{UT} probes the strange quark transversity.

Summary

- STAR has measured A_{UT}, sensitive to transversity, as a function of various kinematic observables for the final state pion pairs.
- This result contributes to global analyses aimed at constraining transversity, for up and down quarks.
- Kaons, being sensitive to **strange quarks**, will provide additional insights into transversity beyond the pion results.
- K^+K^- analysis will be performed with Run 15 data set at $\sqrt{s}$ = 200 GeV, corresponding to $L_{int} \sim 52\ pb^{-1}$ for asymmetry in different mass, momentum and eta bins.
- PID will be done based on both TPC and ToF information.