Supported in part by
U.S. DEPARTMENT OF ENERGY | Office of Science

TEMPLE UNIVERSITY
College of Science and Technology

Measurement of $\pi^+\pi^-$ Azimuthal Correlation Asymmetry Using $p^\uparrow p$ Data At $\sqrt{s} = 200$ GeV At STAR

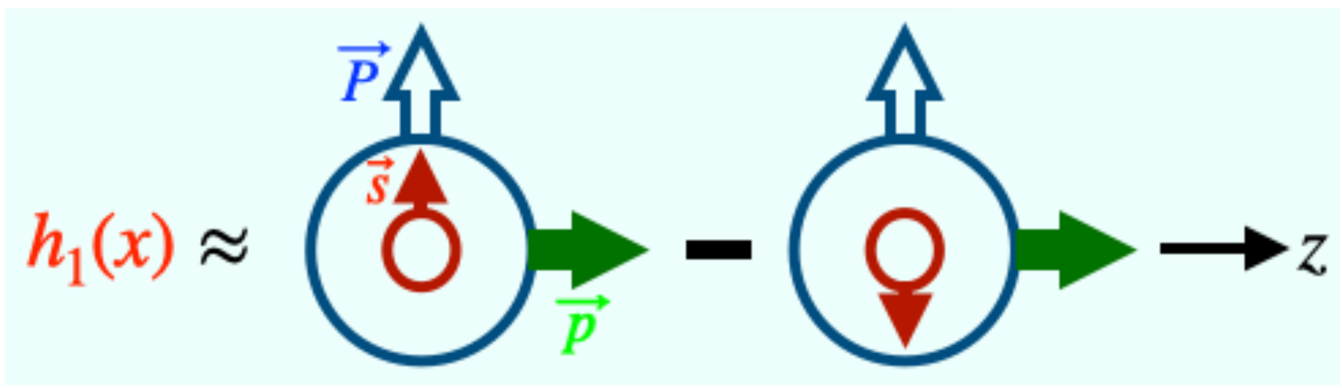
Babu Pokhrel
for the STAR collaboration
June 7 - 10, 2022

2022 RHIC/AGS ANNUAL USERS' MEETING
From RHIC to EIC
At the QCD Frontiers

STAR

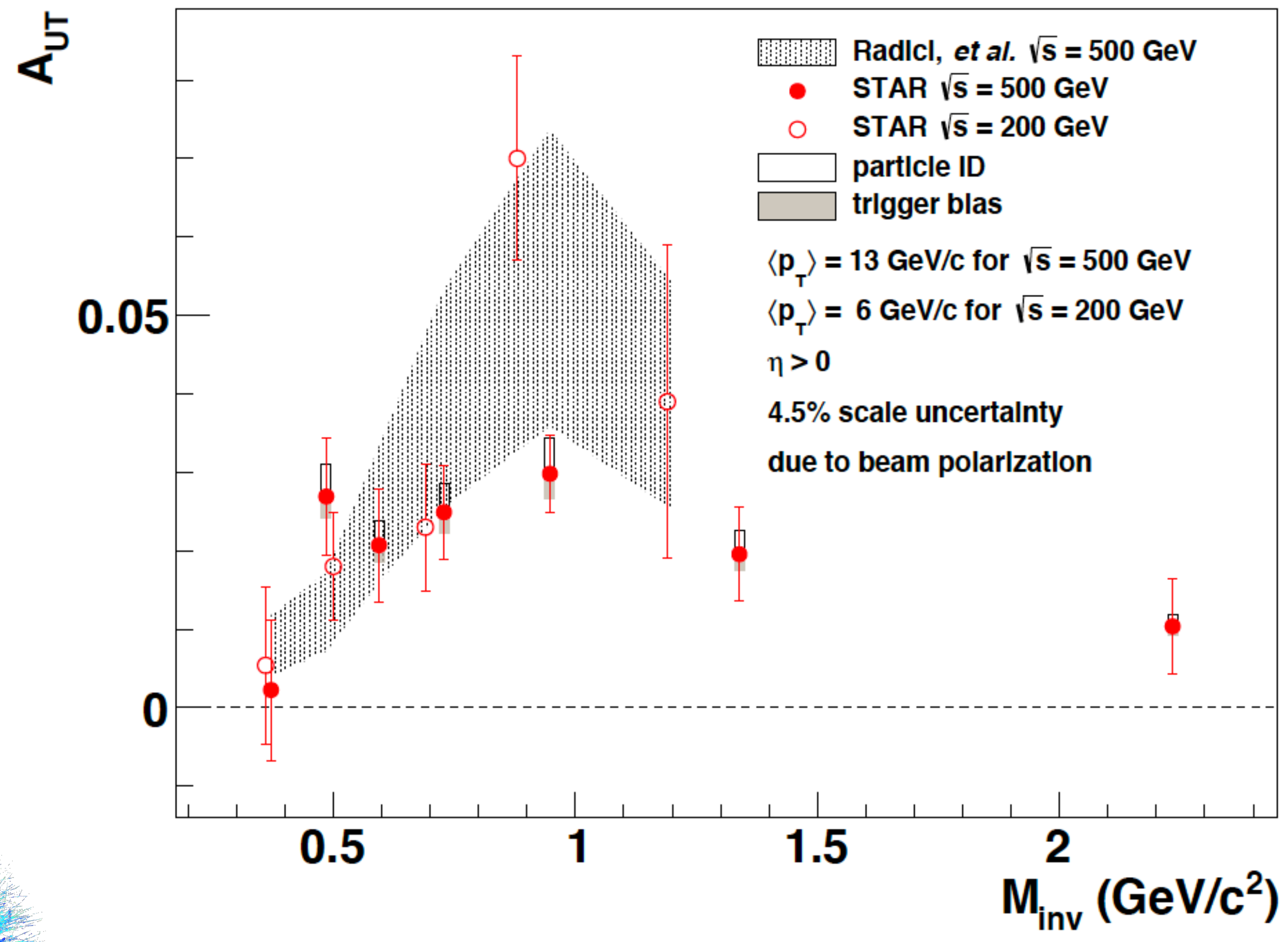
Motivation: Transversity ($h_1(x)$)

- Transversity, $h_1(x)$, is a leading order parton distribution function (PDF). It describes transverse polarization of quark in transversely polarized nucleon, which is least known from experiments.
- It is chiral-odd. It can be accessed only by coupling with another chiral-odd function, such as Interference Fragmentation Function, IFF ($H_1^{\sphericalangle}$).
- In polarized proton-proton collisions ($p^{\uparrow}p$), the $\pi^+\pi^-$ azimuthal correlation asymmetry, A_{UT}, gives rise to the sensitivity to $h_1(x)$ coupled with $H_1^{\sphericalangle}$.
- Nucleon tensor charge, g_T, is essential to characterize the nucleon spin structure.

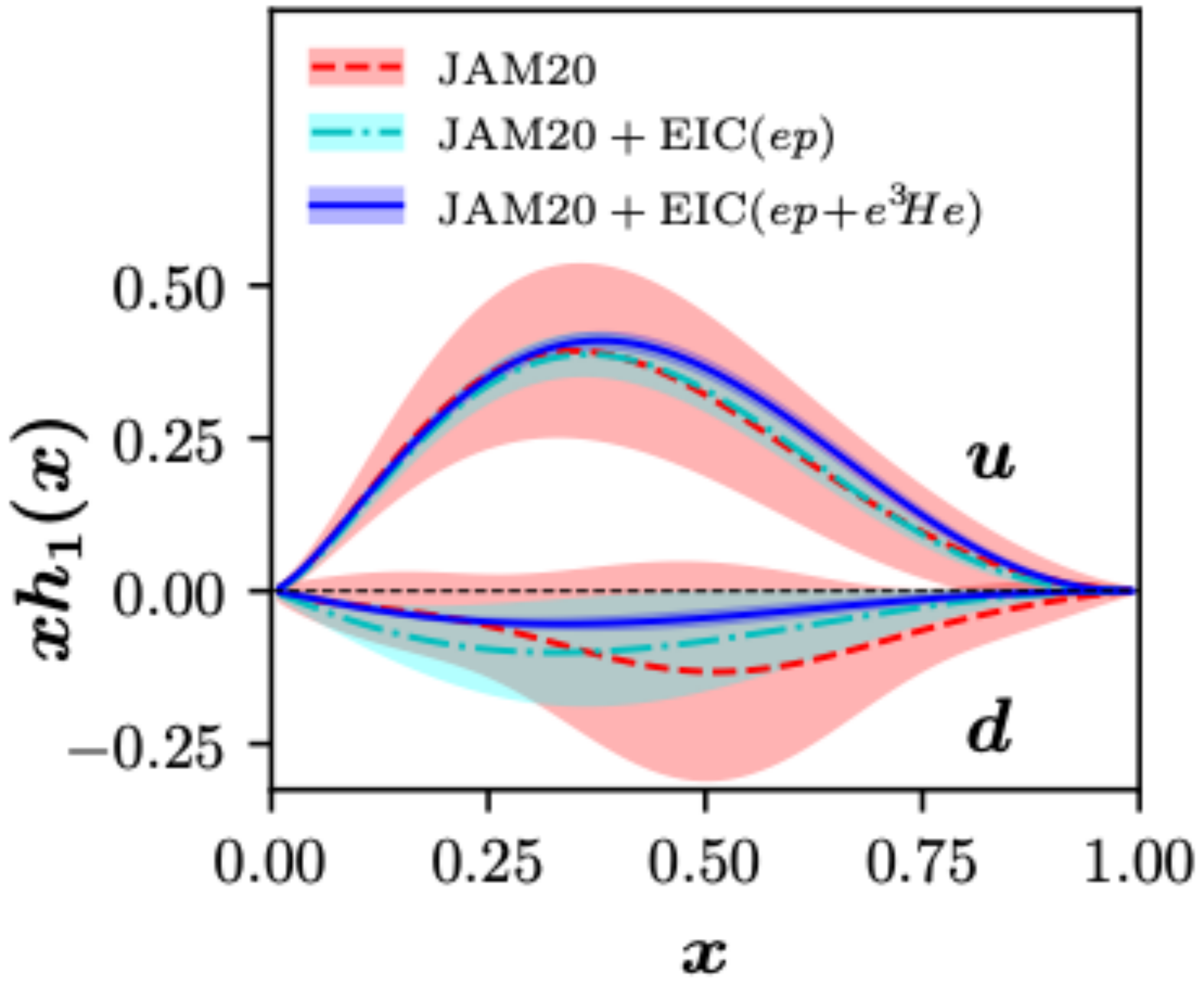


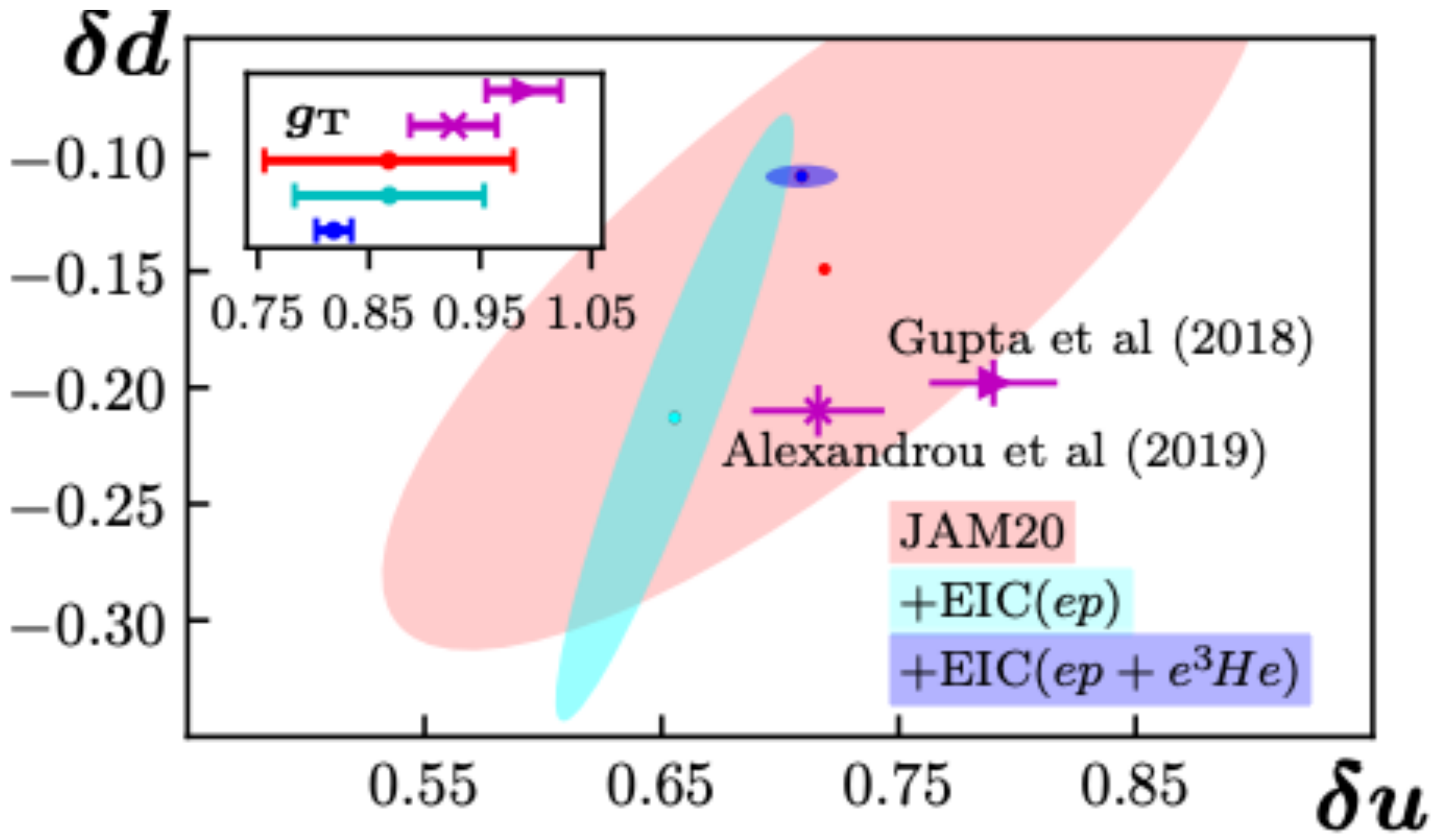
$\vec{P}$ = Nucleon polarization
$\vec{p}$ = Nucleon momentum
$\vec{s}$ = Quark polarization

$$g_T = \delta u - \delta d,$$
$$\delta u = \int_0^1 dx(h_1^u(x) - h_1^{\bar{u}}(x)),$$
$$\delta d = \int_0^1 dx(h_1^d(x) - h_1^{\bar{d}}(x))$$



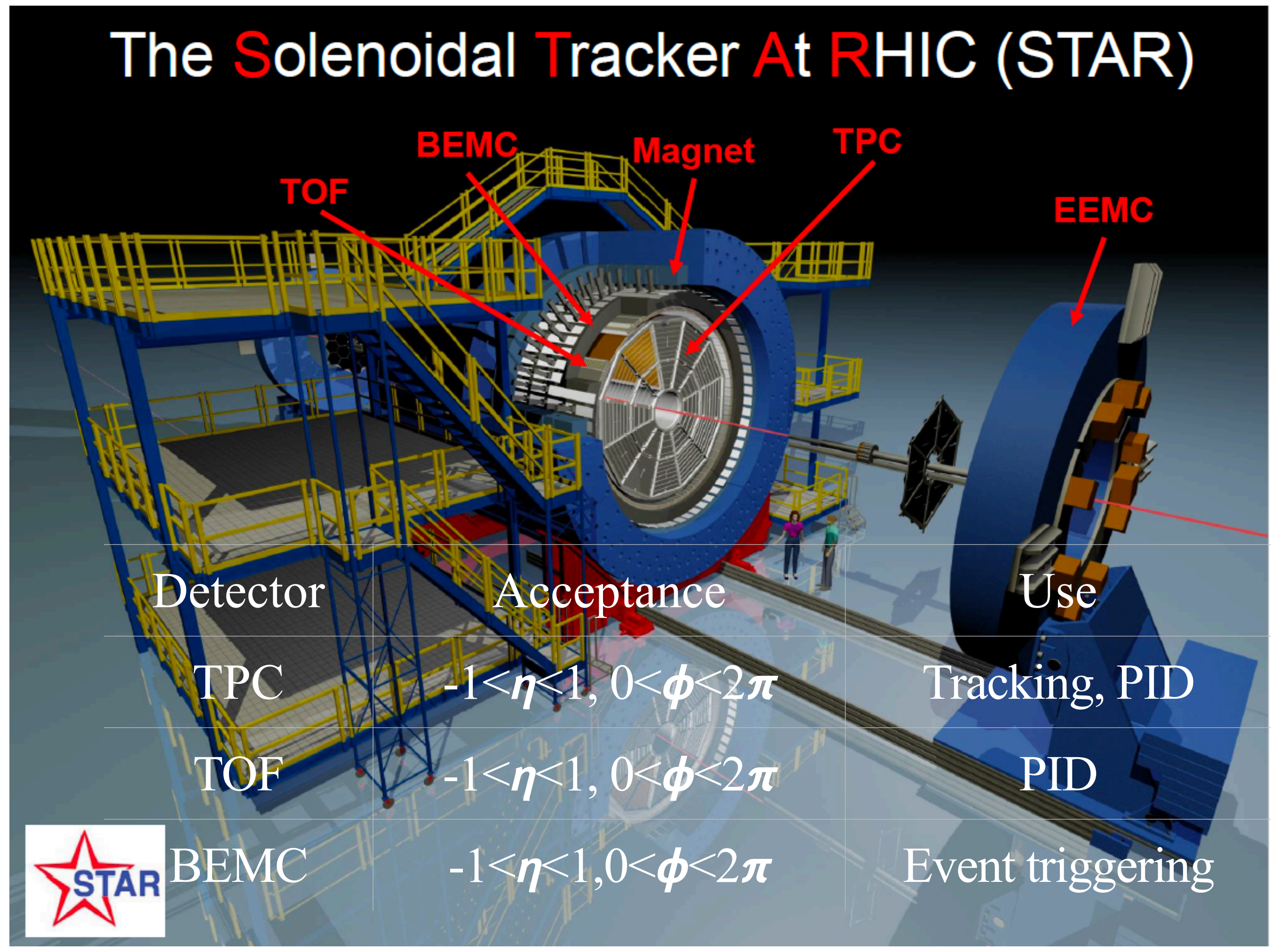
STAR Collab. (Phys. Lett. B 780 (2018) 332)





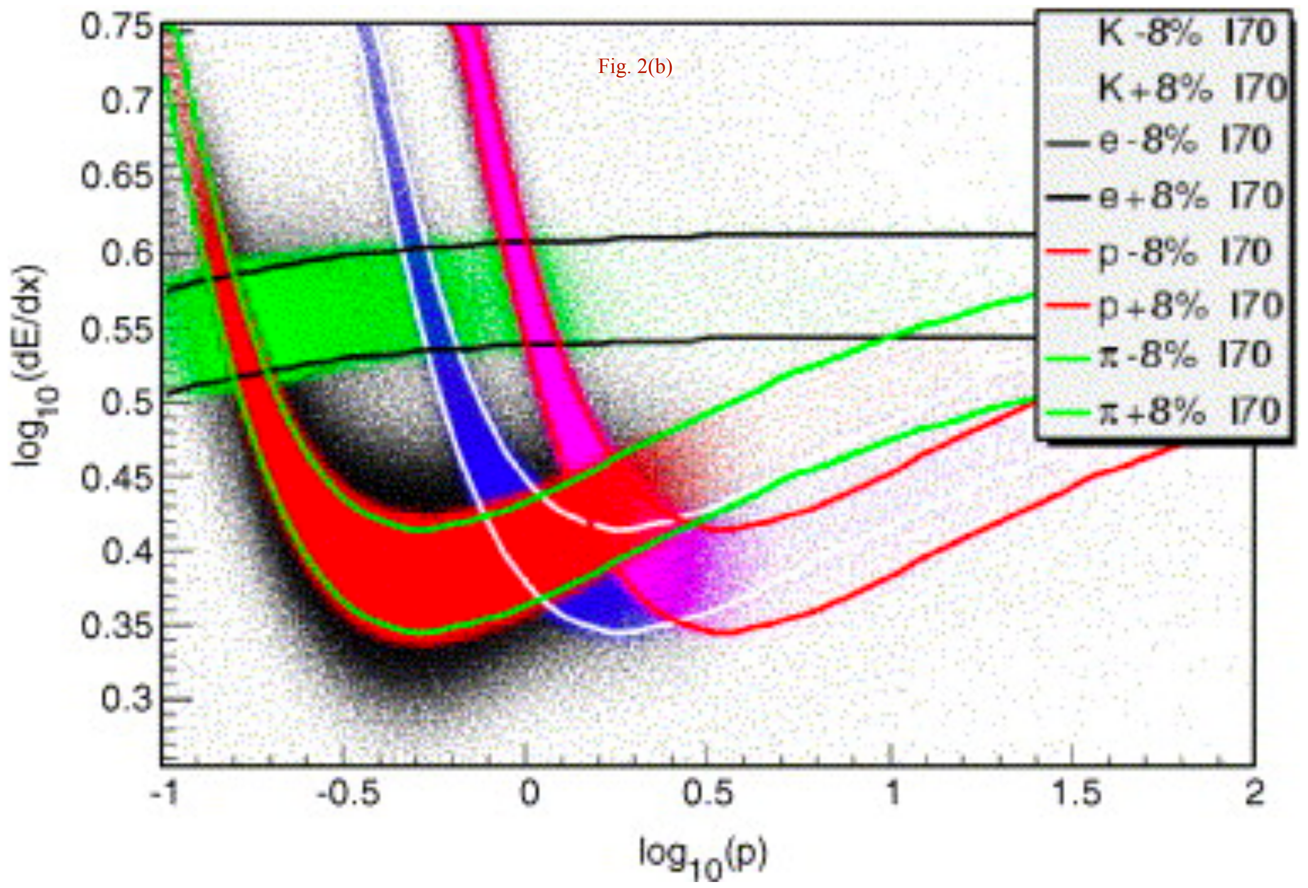
JAM Collab. (Phys.Lett.B 816 (2021) 136255)

STAR Experiment, Datasets, And Kinematics



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

- ✦ **R**elativistic **H**eavy **I**on **C**ollider is the first polarized proton-proton collider in the world.
- ✦ It is capable of colliding polarized proton beams up to a center-of-mass energy, $\sqrt{s}$, of 510 GeV.
- ✦ STAR's particle identification relies on the measured ionization energy loss (dE/dx) by the **T**ime **P**rojection **C**hamber (TPC).

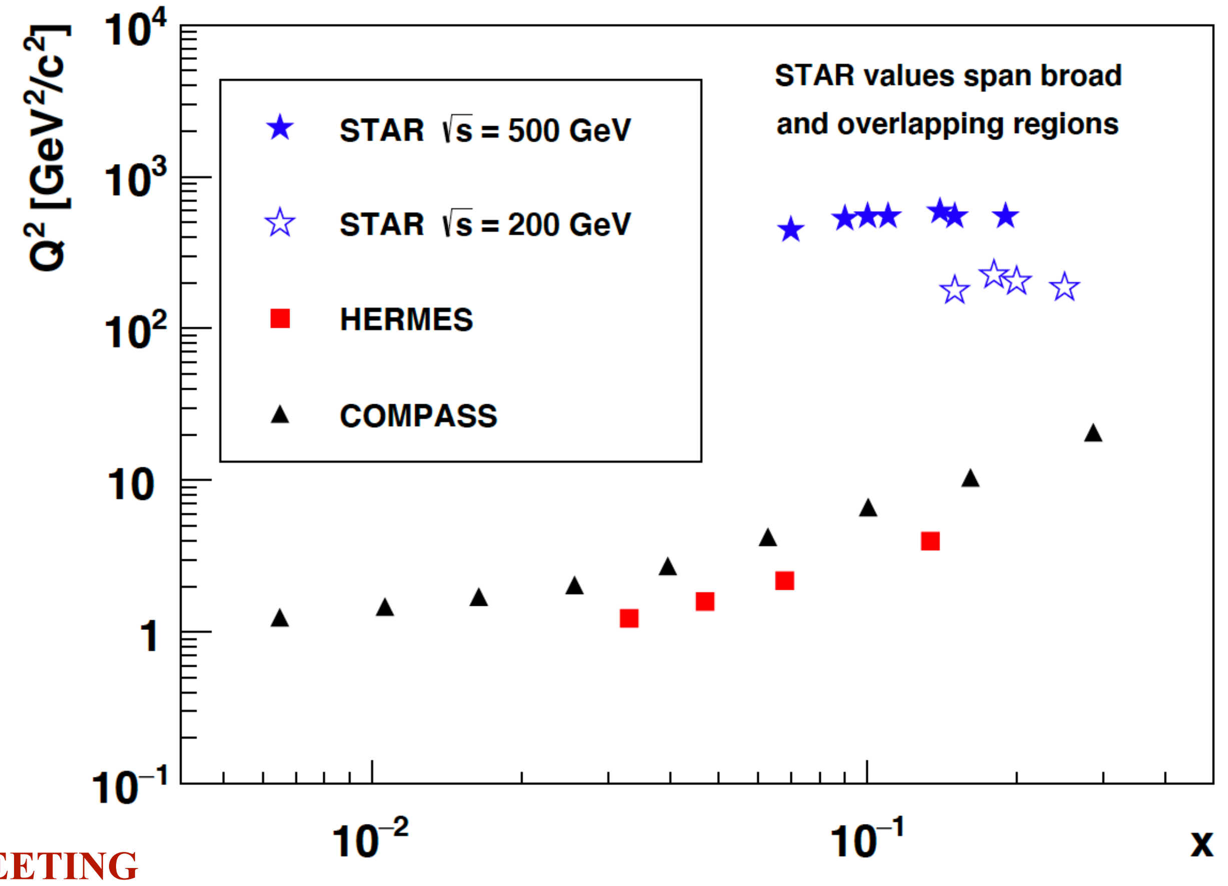


- ✦ The PID capability based on the TPC is limited for $p > 1$ GeV/c, resulting in large systematic uncertainties.
- ✦ Time of Flight (TOF) detector helps to improve PID for $p > 1$ GeV/c, in conjunction with the TPC.

- ✦ This analysis uses 2015 data, which provides the most precise A_{UT} measurement in the range $0.1 < x < 0.4$.

Collision	proton-proton					
Polarization	transverse					
Year	2006	2011	2012	2015	2017	2022
√s (GeV)	200	500	200	200	510	508
Lumi. (pb^-1)	~1.8	~25	~14	~52	~350	~400
Avg. Polz.(%)	~60	~53	~57	~57	~58	~50

- ✦ STAR covers much higher Q^2 than HERMES and COMPASS and probes $h_1(x)$ in the valence quark region ($0.1 < x < 0.4$).



Extraction of $\pi^+\pi^-$ Azimuthal Correlation Asymmetry (A_{UT})

✦ **Reaction channel**: $p^\uparrow + p \rightarrow h^+h^- + X$

✦ **Detailed subprocess and the final state:**

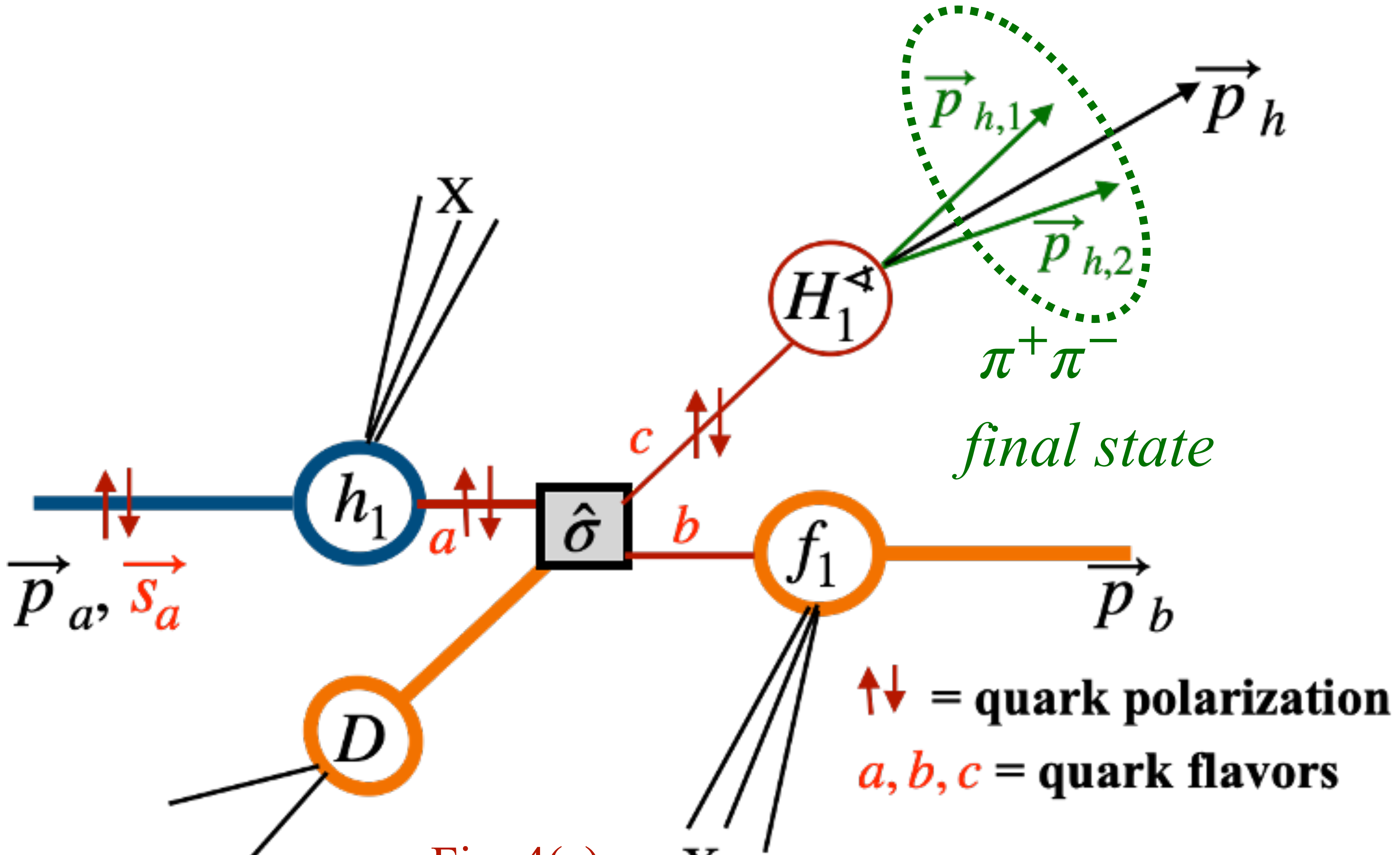


Fig. 4(a)

✦ **Polarized cross-section:**

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

✦ **Di-hadron azimuthal correlation asymmetry:**

$$A_{UT} = \frac{d\sigma^\uparrow - d\sigma^\downarrow}{d\sigma^\uparrow + d\sigma^\downarrow} \propto h_1 H_1^\sphericalangle$$

Bacchetta et.al. (Phys.Rev.D 70 (2004) 094032)

✦ Di-hadron azimuthal angle definitions are shown in Fig. 4(b).

✦ A_{UT} is an amplitude of the sinusoidal modulation of di-hadron azimuthal angle $\phi_{RS}(=\phi_s - \phi_R)$.

✦ A_{UT} can be extracted using cross-ratio formula,

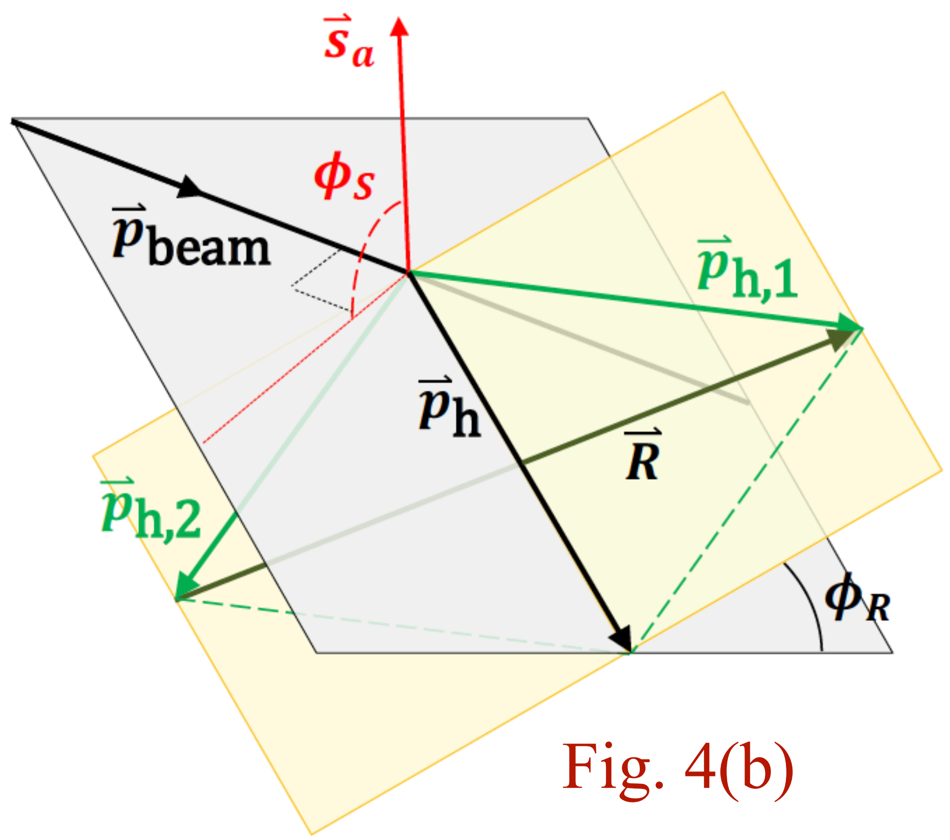


Fig. 4(b)

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

where, $N^{\uparrow(\downarrow)}$ is the number of $\pi^+\pi^-$ in respective ϕ_{RS} bin when the beam polarization is $\uparrow$ ($\downarrow$).

✦ It is free from detector effects, which leads to the reduced systematic uncertainties.

Preliminary Results

✦ **Fig. 5(a): A_{UT} (top panel) and fractional momentum of proton carried by scattered quark (x) and fractional energy of quark carried by outgoing $\pi^+\pi^-$ (z) (bottom panel) vs $\pi^+\pi^-$ pseudorapidity ($\eta^{\pi^+\pi^-}$).**

- x and z are estimated from simulation. x increases linearly from ~ 0.1 to 0.22, but z doesn't show a clear dependence ($< z >$ ~ 0.46) over the measured $\eta^{\pi^+\pi^-}$ range.
- A_{UT} increases linearly in $\eta^{\pi^+\pi^-} > 0$ region, corresponding to high-x, where $h_1(x)$ is expected to be sizeable.

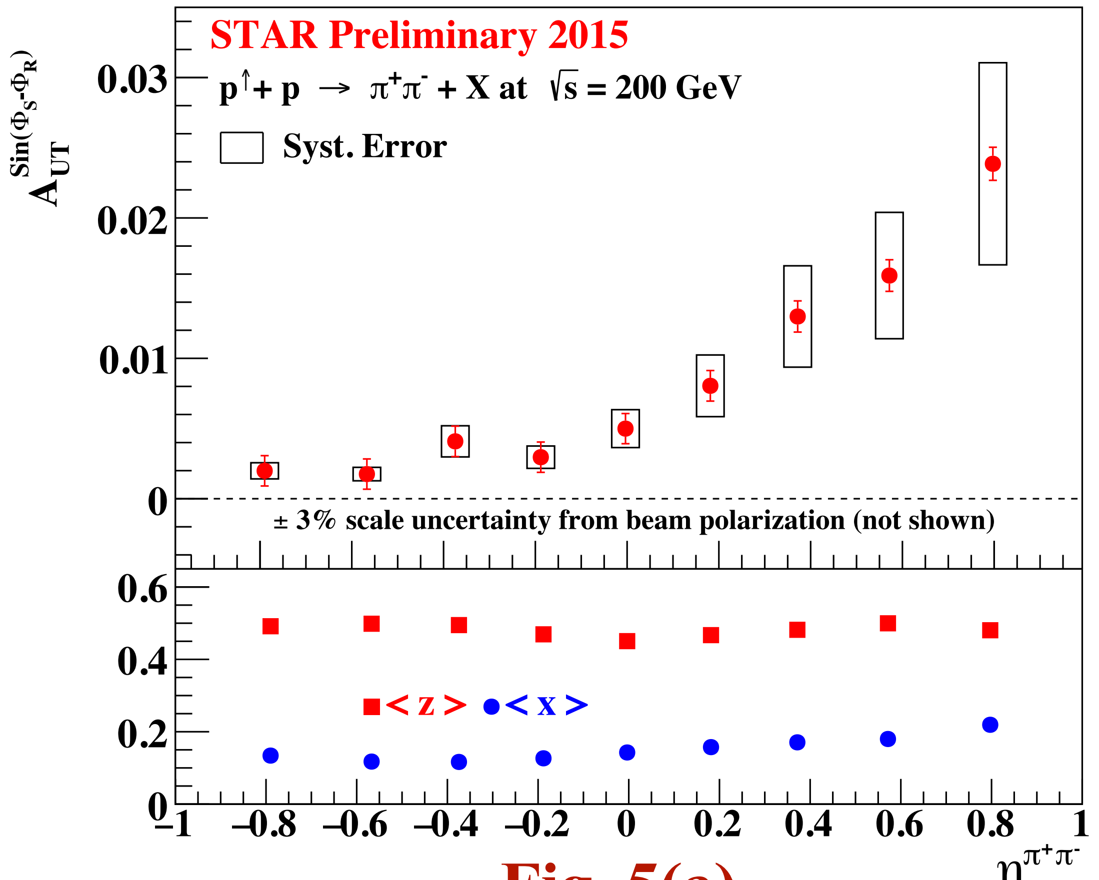


Fig. 5(a)

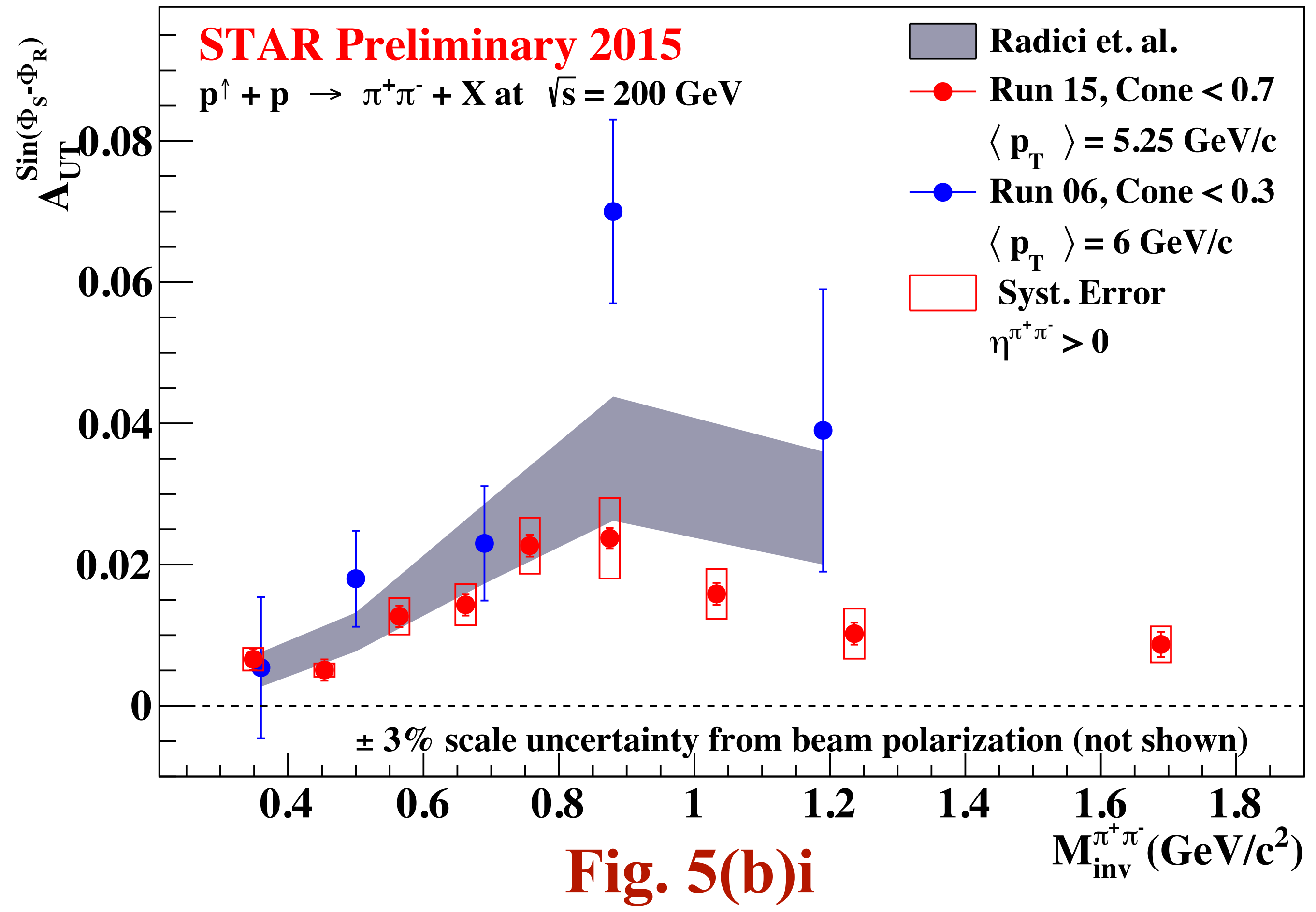


Fig. 5(b)i

✦ **Fig. 5(b)i: A_{UT} vs di-pion invariant mass ($M_{inv}^{\pi^+\pi^-}$) in $\eta^{\pi^+\pi^-} > 0$ region integrated over the di-pion transverse momentum ($p_T^{\pi^+\pi^-}$) compared with the theory calculation and the previous STAR result.**

✦ **Fig. 5(b)ii: A_{UT} vs $M_{inv}^{\pi^+\pi^-}$ in different $p_T^{\pi^+\pi^-}$ bins.**

- A resonance peak at $M_{inv}^{\pi^+\pi^-}$ ($\approx M_\rho$) ~ 0.8 GeV/c^2 is observed, which is expected due to the interference between the $\pi^+\pi^-$ produced from different production channel.
- A_{UT} evolves with the $p_T^{\pi^+\pi^-}$ with the prominent resonance peak at the highest $p_T^{\pi^+\pi^-}$ bin in $\eta^{\pi^+\pi^-} > 0$. In $\eta^{\pi^+\pi^-} < 0$, A_{UT} is small as expected.

The systematic uncertainty includes those from the trigger bias and PID with the dominance from the PID. The PID systematic effect is well understood, and expected to be reduced by more than 50% after including TOF.

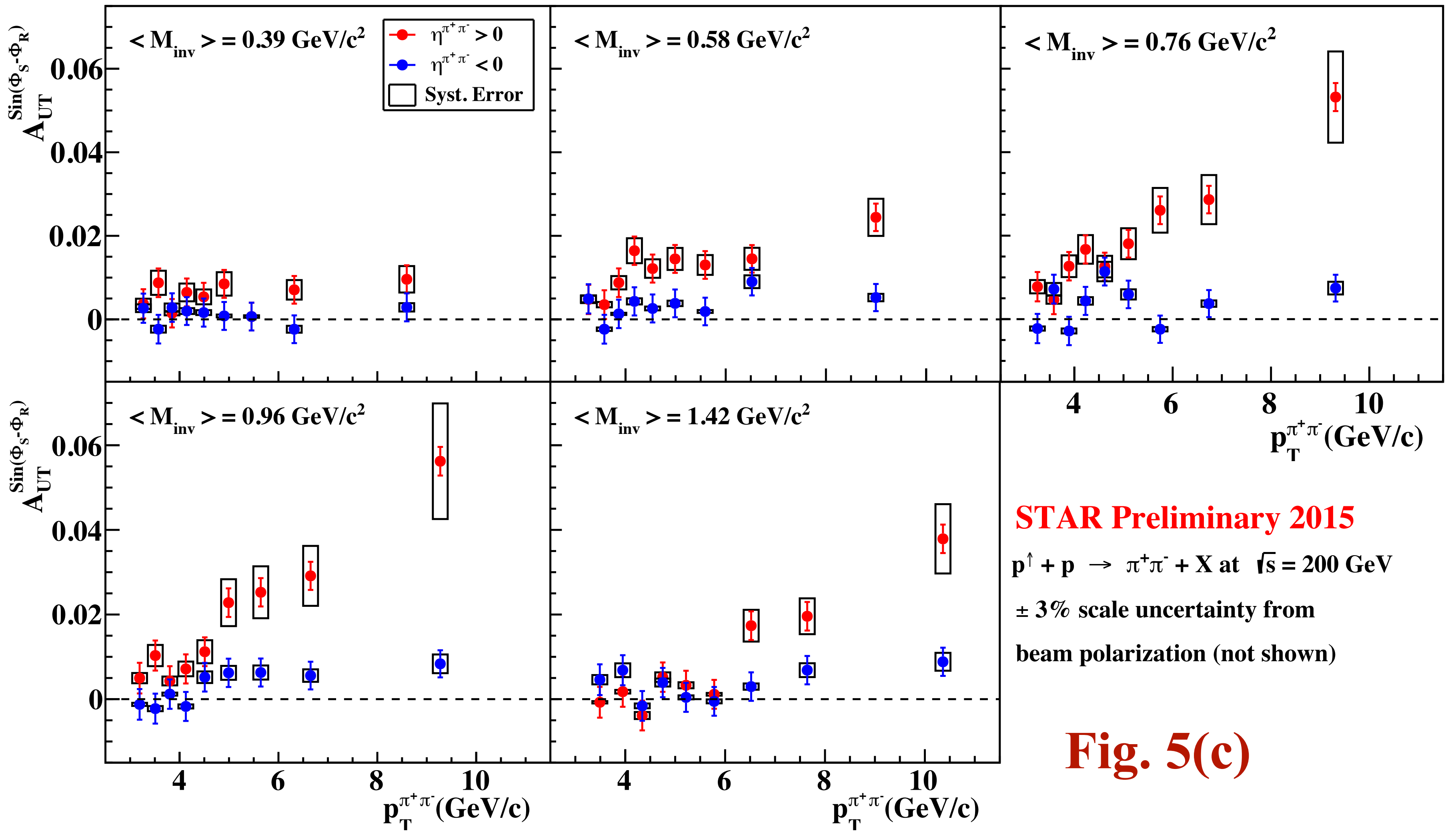


Fig. 5(c)

✦ **Fig. 5(c): A_{UT} vs $p_T^{\pi^+\pi^-}$ at different $M_{inv}^{\pi^+\pi^-}$ bins.**

- A_{UT} increases linearly with the $p_T^{\pi^+\pi^-}$ in the $\eta^{\pi^+\pi^-} >$ 0 region. The rise is stronger when $M_{inv}^{\pi^+\pi^-}$ ~ 0.8 GeV/c^2. Smaller A_{UT} in $\eta^{\pi^+\pi^-} < 0$ region.

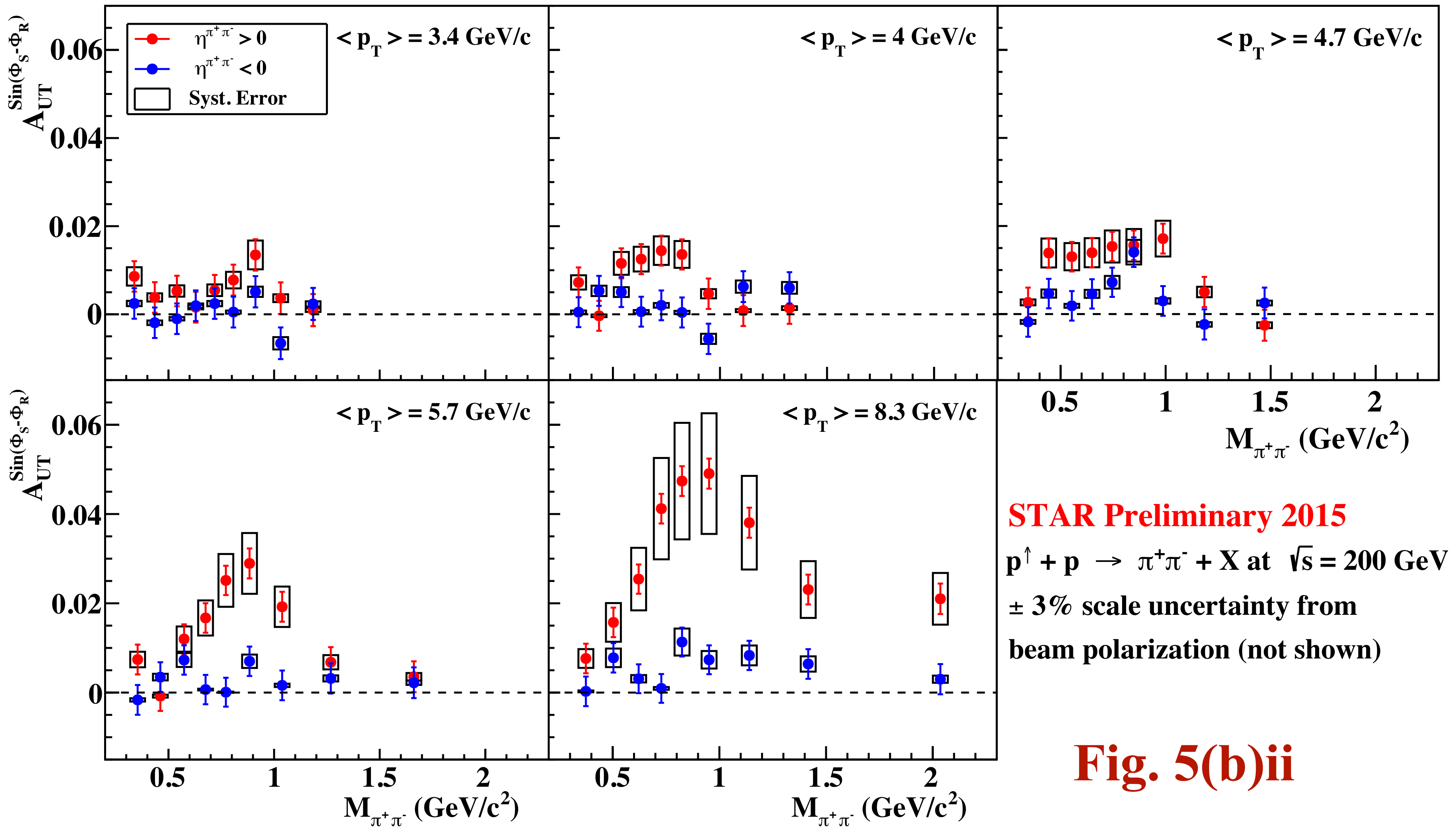


Fig. 5(b)ii