Supported in part by
U.S. DEPARTMENT OF ENERGY | Office of Science
DOE NP contract: DE-SC0013405

Measurement of $\pi^+\pi^-$ Azimuthal Correlation Asymmetry and Unpolarized Cross Section Using *pp* Data at $\sqrt{s}$ = 200 GeV at STAR

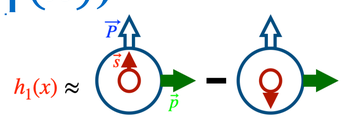
College of Science and Technology, TEMPLE UNIVERSITY

Babu Pokhrel
for the STAR collaboration
Temple University, College of Science and Technology, Philadelphia, PA

RHIC/AGS User Meeting 2023, BNL, NY, August 1 - 4

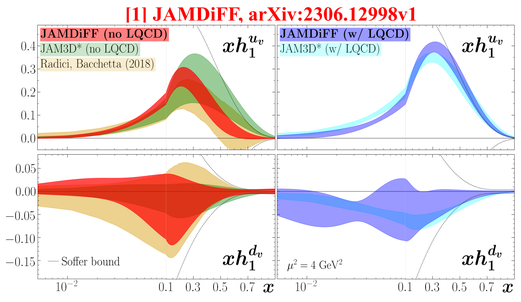
Motivation: Transversity ($h_1^q(x)$)

- At the leading twist, $h_1^q(x)$, describes transverse polarization of quark in a transversely polarized nucleon, which is least known from the experiments.
- In the $pp \to h^+h^-$ channel, the azimuthal correlation asymmetry, A_{UT}, gives rise to the sensitivity to the $h_1^q(x)$ coupled with the interference fragmentation function (IFF).
- Recent JAMDiFF $h_1^q(x)$ extraction includes STAR IFF results together with the SIDIS and e^+e^-.
- Precision measurement of A_{UT} and unpolarized FF, D_1, is required to constrain $h_1^q(x)$. The extraction of D_1 requires the measurement of the unpolarized cross section ($d\sigma_{UU}$).
- $d\sigma_{UU}$ provides access to the gluon FF, allowing model-independent extraction of $h_1^q(x)$.



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

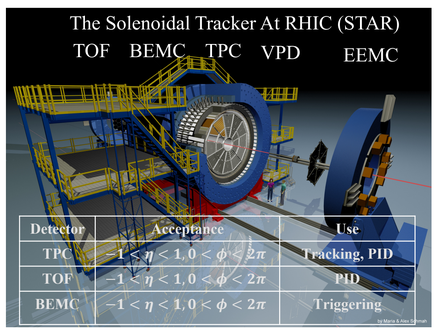
[1] JAMDiFF, arXiv:2306.12998v1

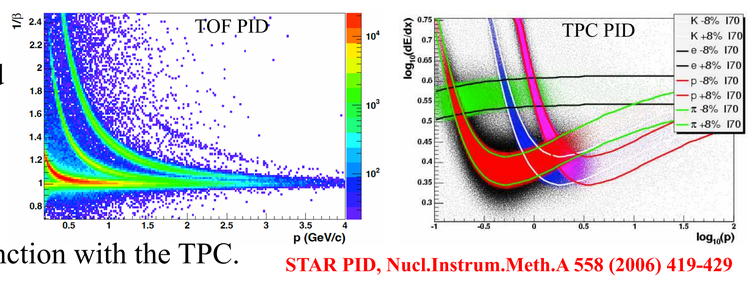


STAR IFF Measurements:
Phys.Rev.D 97 (2018) 3, 032004
Phys.Rev.Lett. 115 (2015) 242501

STAR Experiment at RHIC

- Relativistic Heavy Ion Collider is the first polarized proton-proton collider in the world.
- It is capable of colliding polarized protons and heavy ions beams up to a center of mass energy, √s, of 510 GeV and 200 GeV.
- Time Projection Chamber (TPC) is the heart of STAR detector, which provides charged particle tracking and particle identification (PID).
- STAR PID relies on the measured ionization energy loss (dE/dx) by the TPC at low p_T.
- Time of Flight (TOF) helps to improve the STAR PID, in conjunction with the TPC.



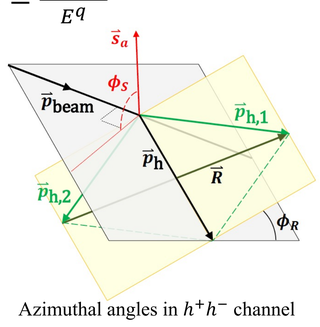


STAR PID, Nucl.Instrum.Meth.A 558 (2006) 419-429

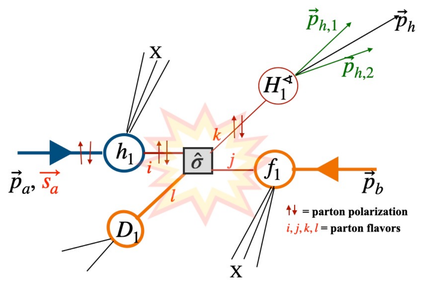
Probing Transversity via h^+h^- Channel

[2] Radici et. al., Phys.Rev.D 70 (2004) 094032

- Reaction channel: $p_a^{\uparrow} p_b \to h^+h^- + X$
- Polarized cross section:
  $d\sigma^{\uparrow} \propto \sin(\phi_S - \phi_R) \int dx_a dx_b f_1(x_b) h_1(x_a) \frac{d\Delta\hat{\sigma}}{d\hat{t}} H_1^{\sphericalangle}(z, M^2)$, where $M = h^+h^-$ invariant mass , $z = \frac{E^{h^+h^-}}{E^q}$



Azimuthal angles in h^+h^- channel



Detailed mechanism for the h^+h^- channel

- f_1= unpolarized PDF, $H_1^{\sphericalangle}$ = Interference fragmentation function (IFF), $d\hat{\sigma}$ = perturbatively calculable hard scattering cross section.
- No jet reconstruction is required while preserving collinearity.
- Access to quark polarization ~ $\vec{s}_a \cdot \vec{R} \times \vec{p}_h$, where $\vec{R} = \frac{1}{2}(\vec{p}_{h_1} - \vec{p}_{h_2})$, $\vec{p}_h = \vec{p}_{h_1} + \vec{p}_{h_2}$
- The coupling of $h_1(x)$ and IFF results in the azimuthal correlation asymmetry,
  $$A_{UT} = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} - d\sigma^{\downarrow}} \propto h_1(x) H_1^{\sphericalangle}(z, M^2)$$
- $H_1^{\sphericalangle}$ can be measured independently, for example, in e^+e^-.

$\pi^+\pi^-$ Azimuthal Correlation Asymmetry

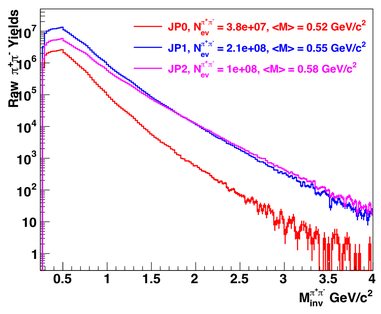
- STAR run 2015 data at √s = 200 GeV and L_{int} ~ 52 pb^{-1} is used, which provides the most precise A_{UT} in the range $0.1 < x < 0.3$.
- The observed resonance peak at $M_\rho \sim 0.8$ GeV/c^2 in $\eta > 0$ is due to the interference between $\pi^+\pi^-$ from relative *s* and *p* wave channels [2], which is consistent with the theory.
- Large A_{UT} signal in $\eta > 0$ region, which is a surrogate of *x*, suggests the *x* dependence of $h_1(x)$. (See Ref. [3] for details.)

[3] **B. Pokhrel, SciPostPhys.Proc. 8 (2022) 047**

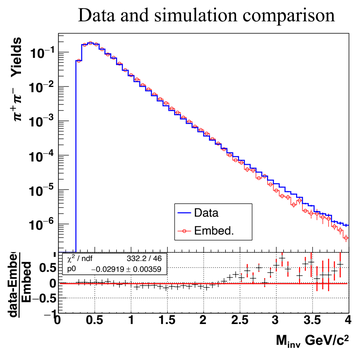
Theory curve is obtained from Radici et. al., (Private communication).

Unpolarized $\pi^+\pi^-$ Cross Section

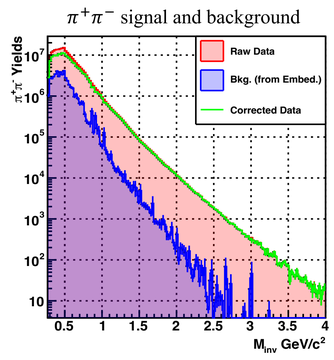
- **Dataset**
  - STAR Run 12 *pp* data at √s = 200 GeV with L_{int} ~14 pb^{-1} offers higher gluons sensitivity due to lower trigger threshold.
- **Simulation**
  - PYTHIA simulated events reconstructed with the GEANT3 package is used, which simulates the STAR detector response.
  - The embedding sample has a good description of the data.



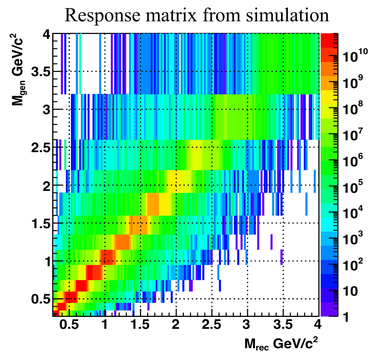
Data and simulation comparison



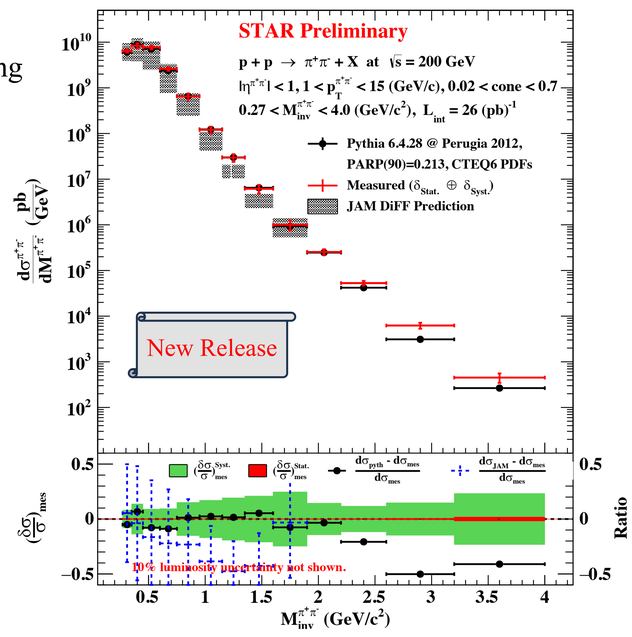
$\pi^+\pi^-$ signal and background



Response matrix from simulation



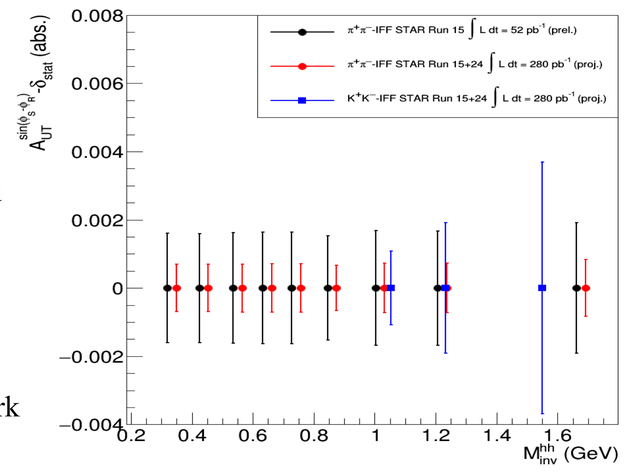
- **Unfolding**
  - The TUnfoldDensity algorithm is used to unfold detector level $\pi^+\pi^-$ yields to the particle level in invariant mass bins subtracting backgrounds prior to the unfolding. The response matrix facilitates the unfolding connecting the detector to the particle level quantity.
- **Corrections**
  - Bin-by-bin corrections from the embedding sample are applied to the unfolded cross section, accounting for trigger efficiency, tracking efficiency, and PID.
- **Result**
  - The final cross section is the weighted average of JP0, JP1, and JP2 triggered cross sections differential in $M_{inv}^{\pi^+\pi^-}$.
  - The theory prediction [1, 4] and PYTHIA cross sections show promising agreement with the measured cross section.
  - Systematic uncertainty accounts for the trigger efficiency, trigger bias, PID, and simulation statistics.



[4] C. Cocuzza et. al., Private communication

A_{UT} projections for the STAR run 2015 + 2024

- STAR has scheduled for *pp* collision run at √s = 200 GeV with promising luminosity of ~100 – 300 pb^{-1} (projected) in 2024, higher than ever before.
- Combining run 2015 and 2024 data will provide the most precise h^+h^- azimuthal correlation asymmetry and cross section.
- Planned measurements using run 2015 and 2024 data:
  - **Precision measurement of $\pi^+\pi^-$ A_{UT}**
    - Statistical uncertainty will be improved by more than 50%.
  - **First measurement of K^+K^- A_{UT}**
    - Decent statistics will be available by combining run 15 and 24 for the $K^+K^-A_{UT}$ measurement.
    - The K^+K^- A_{UT} probes the strange quark transversity.



- All projections are purely statistical based on the run 2015 data.

Summary and Outlook

- The $\pi^+\pi^-$ azimuthal correlation asymmetry has been measured. Large forward signal is observed, with a resonance peak at $M_\rho \sim 0.8$ GeV/c^2, consistent with the theory and previous STAR results..
- The unpolarized $\pi^+\pi^-$ cross section has been measured for the first time in *pp* collisions, showing good agreement with the PYTHIA cross section and theory prediction.
- The cross-section result provides constraints on the D_1, specifically for the gluon fragmentation, enabling a model-independent extraction of $h_1(x)$.
- Precision measurement of A_{UT} is planned combining the STAR run 15 and 24 data for the $\pi^+\pi^-$ and K^+K^- channel. K^+K^- channel probes the (anti-)strange quark transversity.