Transverse Spin-Dependent Azimuthal Correlation of Charged Pion Pairs in $p^{\uparrow}p$ Collisions at $\sqrt{s}$ = 510 GeV at STAR

Navagyan Ghimire
(For the STAR Collaboration)
03/30/2023

STAR
TEMPLE UNIVERSITY

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

Motivation

Nucleon Structure

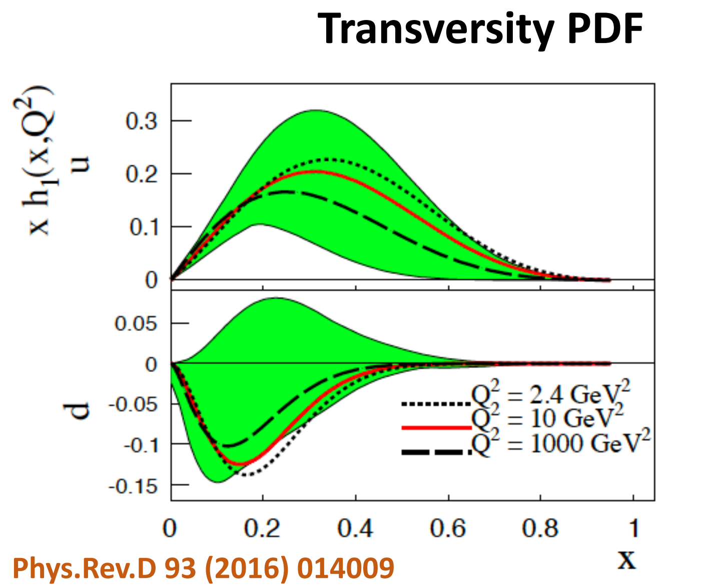
Parton Distribution Functions (PDFs):

		Quark Polarization		
		Unpolarized (U)	**Longitudinally Polarized (L)**	**Transversely Polarized (T)**
Nucleon Polarization	U	$f_1(x)$		
	L		$g_1(x)$	
	T			$h_1(x)$

Nucleon Momentum

Nucleon Polarization

Parton Polarization



Phys.Rev.D 93 (2016) 014009

- Less known from experiments than $f_1(x)$ and $g_1(x)$
- Chiral-odd quantity
- Extraction requires coupling to another chiral-odd distribution, such as Collins or Interference Fragmentation Functions (FFs)
- For estimating tensor charge (g_T), a precise determination of transversity is necessary

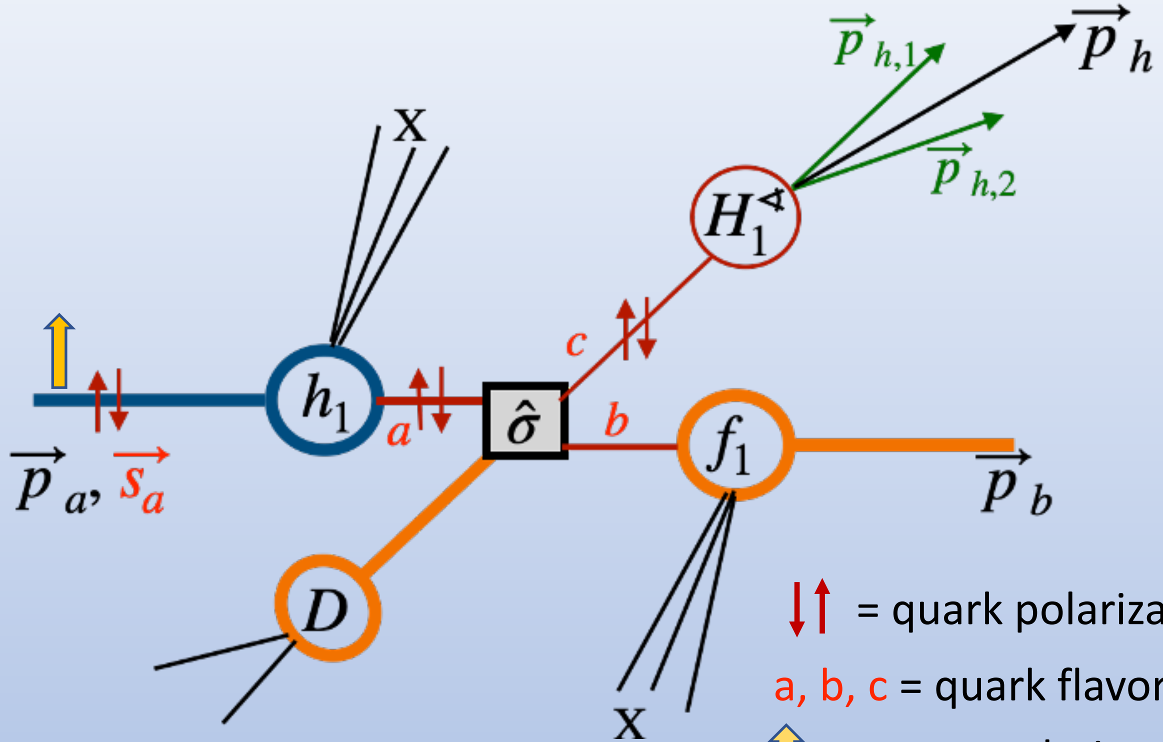
$$g_T = \int_0^1 dx[h_1^q(x) - h_1^{\bar{q}}(x)]$$

Transversity ($h_1(x)$) in $p^{\uparrow}p$ Collisions

Interference Fragmentation Function($H_1^{\measuredangle}$) channel :

$$p\uparrow + p \rightarrow h^+h^- + X$$

- Collinear framework preserved
- No jet reconstruction required
- Better access to d-quark than SIDIS



= quark polarization

a, b, c = quark flavors

= proton polarization

$$d\sigma_{UT} \propto \int dx_a dx_b f_1(x_b) h_1(x_a) \frac{d\Delta\hat{\sigma}}{d\hat{t}} H_1^{\measuredangle}(z, M)$$

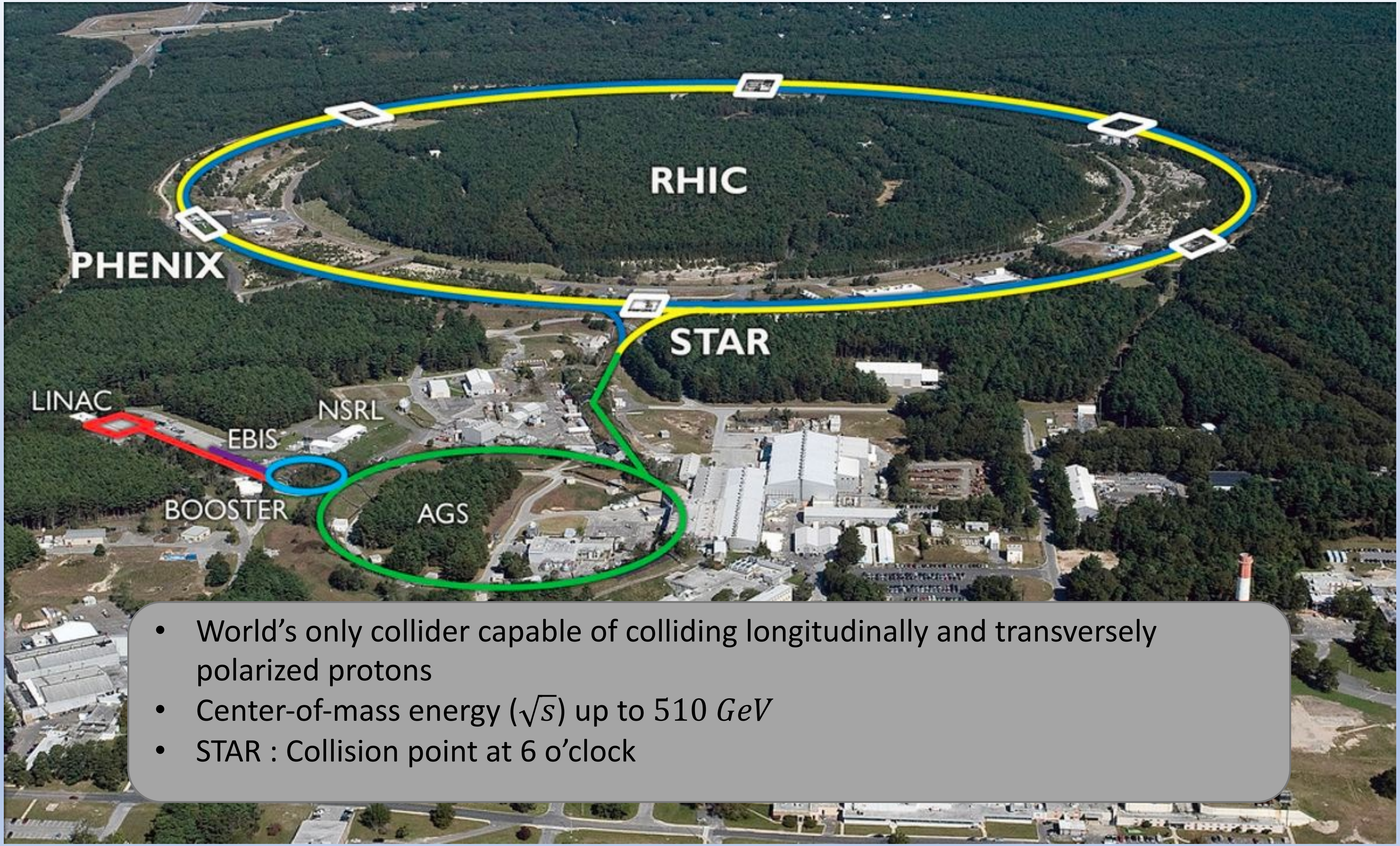
A. Bacchetta and M. Radici
Phys. Rev. D 70 (2004) 094032

Di-hadron correlation asymmetry

$$A_{UT} = \frac{d\sigma\uparrow - d\sigma\downarrow}{d\sigma\uparrow + d\sigma\downarrow} \propto h_1(x) H_1^{\measuredangle}(z, M)$$

$z = \frac{E^{h^+h^-}}{E^{parton}}$, M_{inv} = Invariant mass of hadron pair

Relativistic Heavy Ion Collider(RHIC)

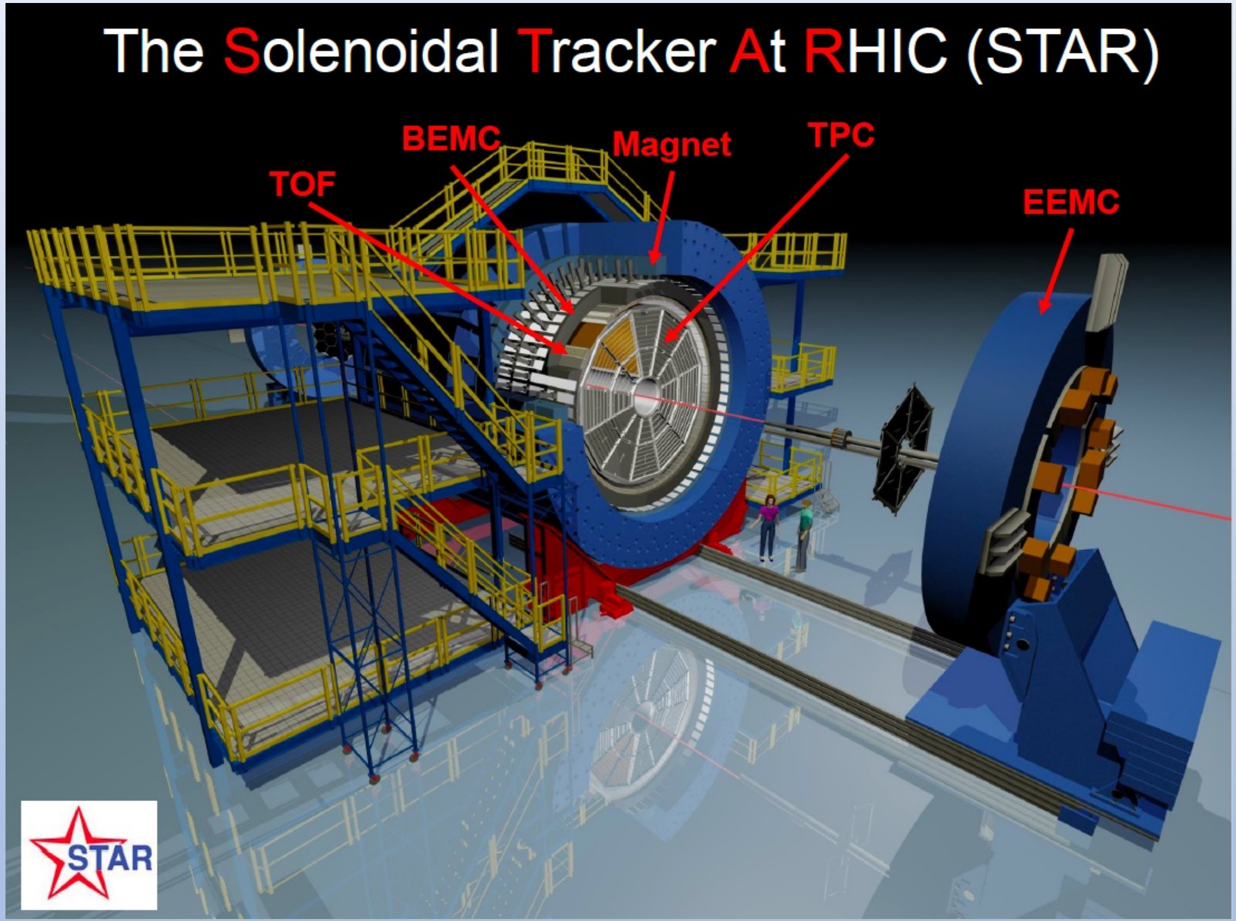


- World's only collider capable of colliding longitudinally and transversely polarized protons
- Center-of-mass energy ($\sqrt{s}$) up to 510 GeV
- STAR : Collision point at 6 o'clock

Solenoidal Tracker At RHIC(STAR)

Magnet

- Uniform magnetic field of 0.5 T



Time Projection Chamber(TPC)

- $|\eta| < 1, 0 \leq \phi \leq 2\pi$
- Charge determination and particle momentum reconstruction
- PID via measuring ionization energy loss

Barrel Electromagnetic Calorimeter(BEMC)

- $|\eta| < 1, 0 \leq \phi \leq 2\pi$
- Event triggering

Time Of Flight(TOF):

- $|\eta| < 1, 0 \leq \phi \leq 2\pi$
- Stopwatch for particles
- Helps to improve PID

Particle Identification (PID) at STAR

- At STAR PID is done by measuring average specific ionization energy loss $\left\langle \frac{dE}{dx} \right\rangle$ in TPC.

- When the $\frac{dE}{dx}$ vs p bands for two different particle types are close together or cross, TOF is extremely useful for PID.
  - TOF detector is capable of separating proton from kaon and pion for momenta up to 3 GeV/c.

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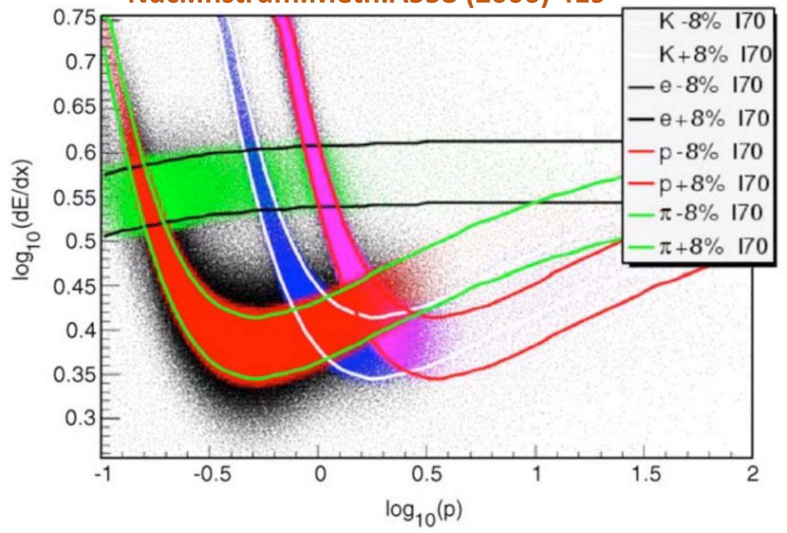
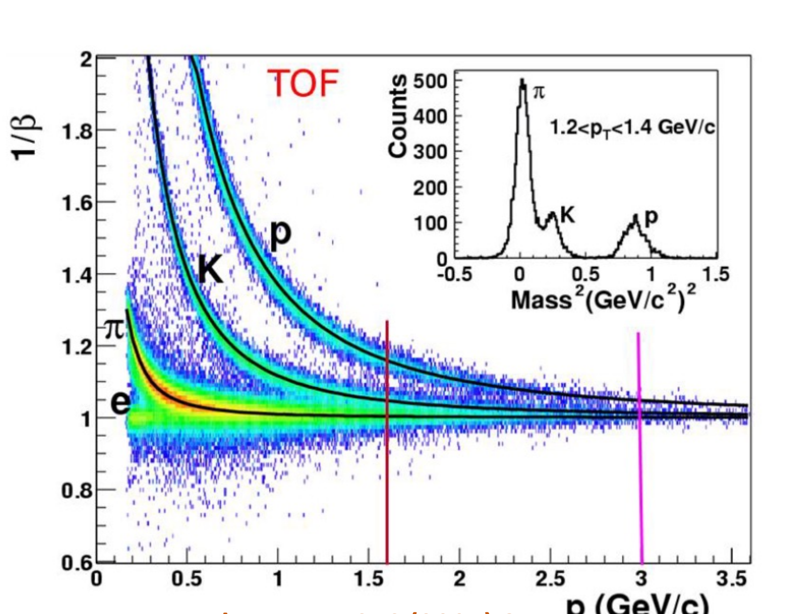
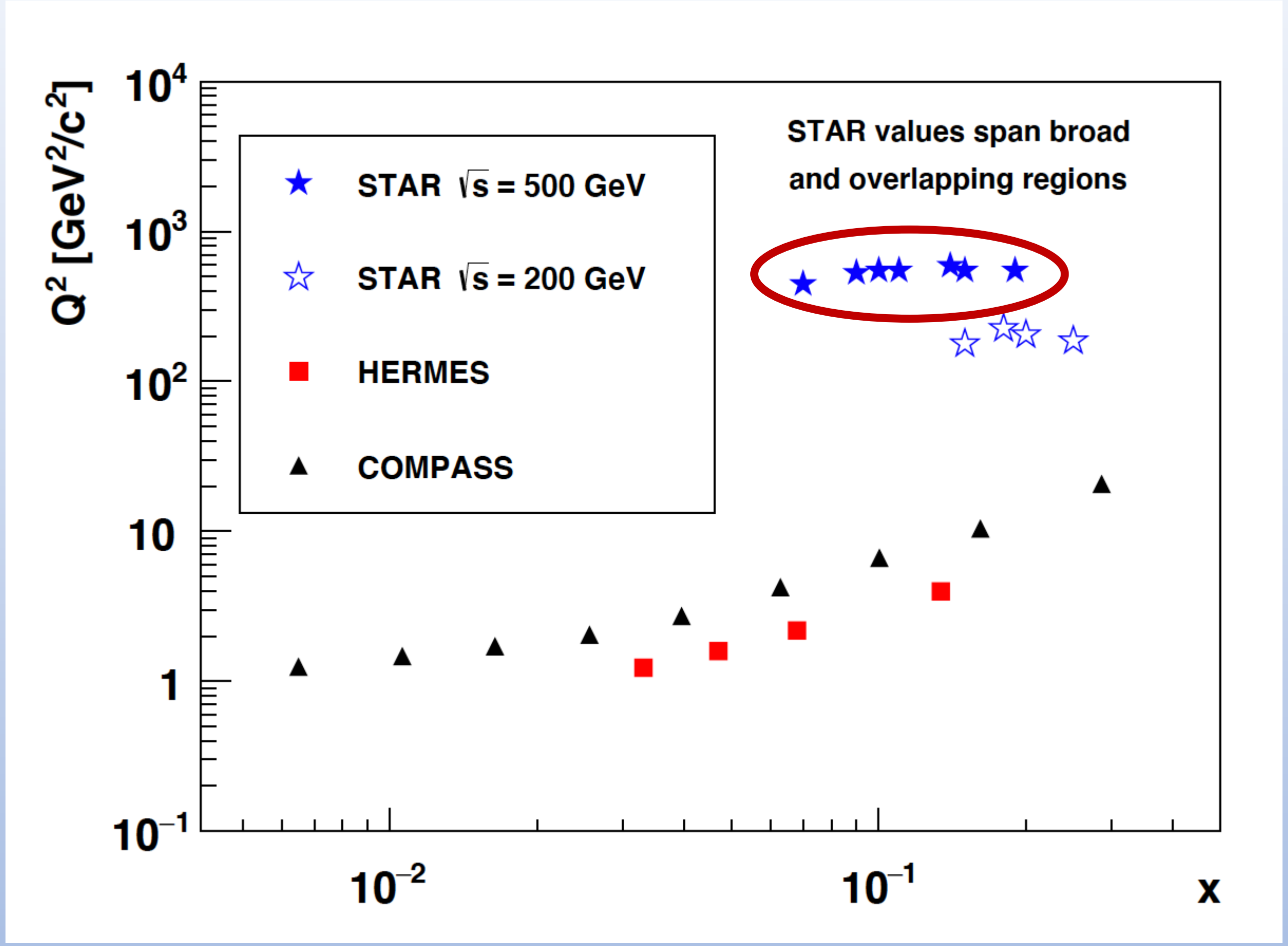




Phys.Lett.B616 (2005) 8

STAR Kinematics



- STAR covers much higher Q^2 than HERMES and COMPASS.
- Results from $p^{\uparrow}p$ at 510 GeV will provide valuable information about evolution and allow to access lower x compared to 200 GeV.

A_{UT} Geometry

A_{UT} is measured using a transversely polarized beam colliding with another unpolarized beam (integrating over all spin states).

Two hadrons in final state allow to relate spin with di-hadron momentum.

$$\overrightarrow{s_a} \cdot (\vec{R} \times \overrightarrow{p_h})$$

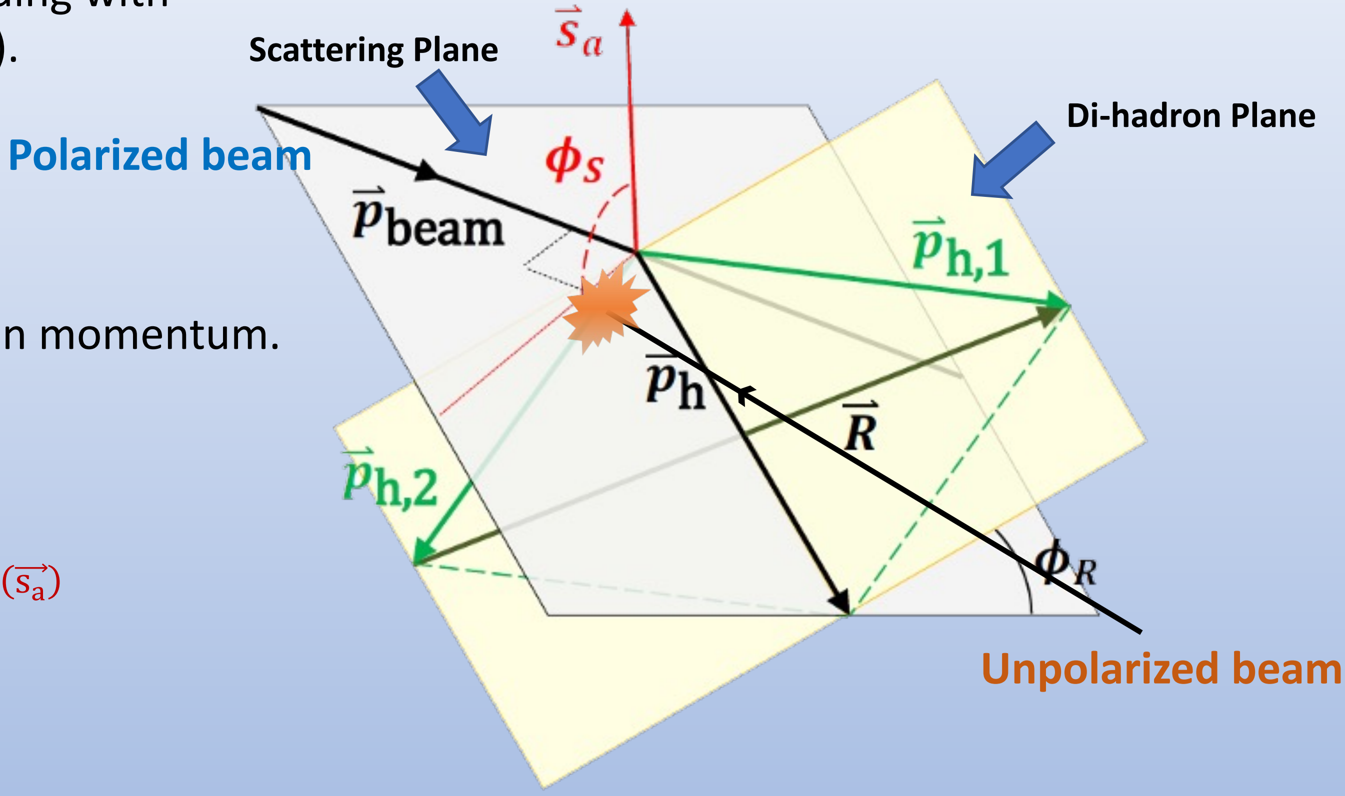
ϕ_s = Angle between scattering plane and polarization of incident beam($\overrightarrow{s_a}$)

ϕ_R = Angle between scattering plane and dihadron plane

$\vec{p}_h = \vec{p}_{h_1} + \vec{p}_{h_2}$

$\vec{R} = \vec{p}_{h_1} - \vec{p}_{h_2}$

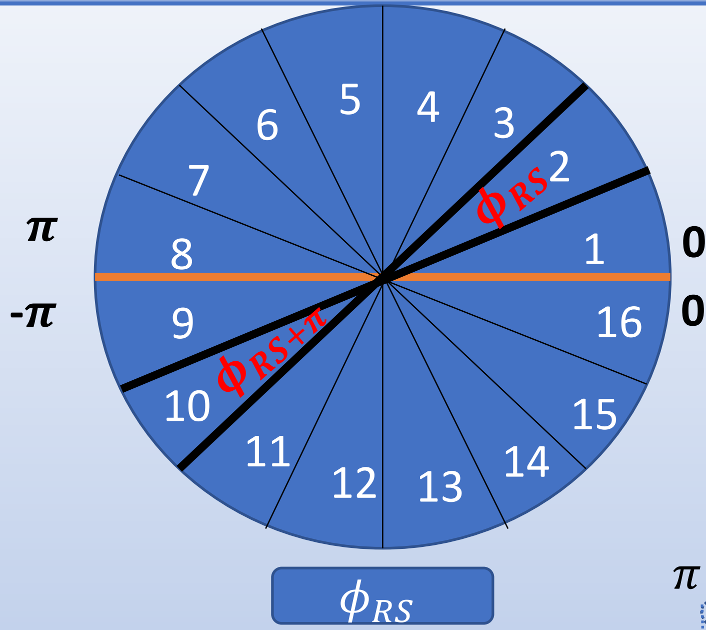
$\phi_{RS} = \phi_R - \phi_s$

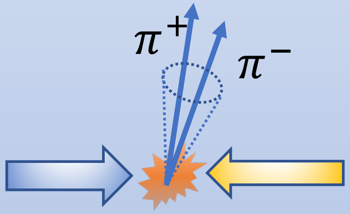


A_{UT} Extraction

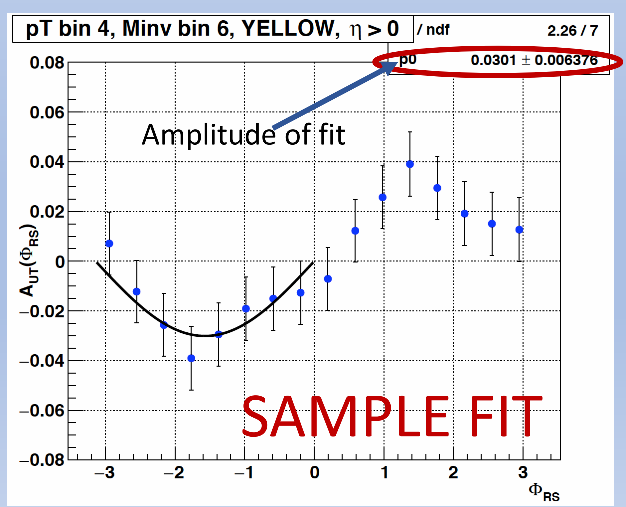
- For a symmetric detector like STAR (in azimuthal space),
  - A_{UT} can be extracted from cross-ratio formula.
  - Free from effects related to detector efficiencies and spin-dependent luminosities.
  - No jet reconstruction required.

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





- Two oppositely charged pions in the final state are paired if they are close (<0.7) in $\eta - \phi$ space.
- The angle ϕ_{RS} modulates the A_{UT} by $sin(\phi_{RS})$.
- ϕ_{RS} is divided into 16 bins of uniform bin-width in the range $[-\pi, +\pi]$ and $N\uparrow(\downarrow)$ in each ϕ_{RS} bin is counted.
- For each kinematic bin, the cross-ratio is calculated for each ϕ_{RS} and fitted with a sinusoidal function.
- The amplitude of this sin fit gives the A_{UT}.

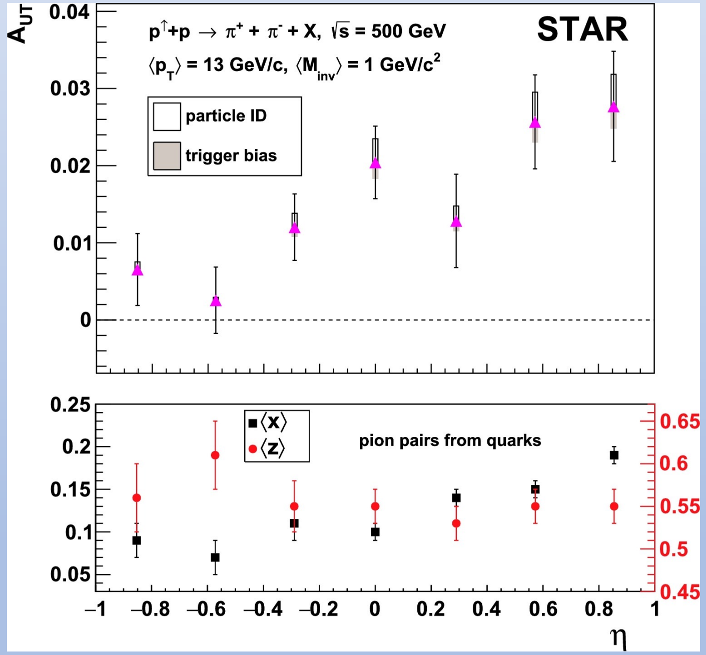


Kinematic Observables

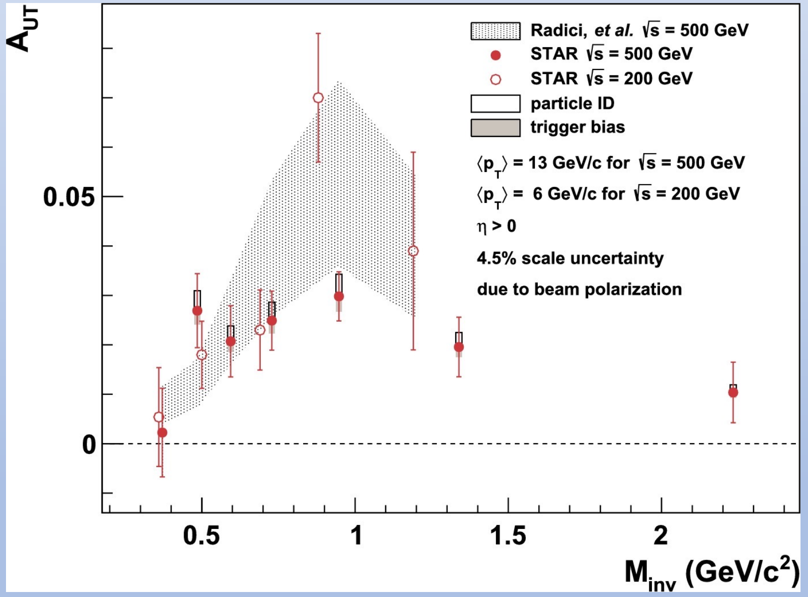
- A non-zero A_{UT} singal is expected to be observed for different kinematic observables of pion pairs in final state.

$$A_{UT} \propto h_1(x) H_1^{\measuredangle}(z, M)$$

For η>0, where higher x is probed, a larger A_{UT} is expected.



For IFF channel, model calculation shows enhancement of A_{UT} around ρ mass region.



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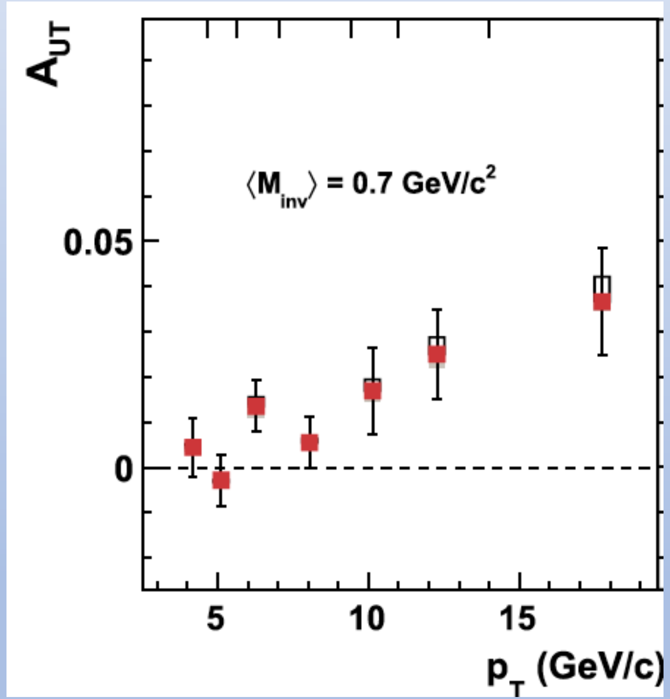
A_{UT} increases as pair p_T increases.



A_{UT} at STAR

- A non-zero A_{UT} signal has been observed against different kinematic observables ($\eta_{pair}, p_{T\,pair}, M_{inv}$) of the pion pairs ($\pi^+\pi^-$) in final state.

A_{UT} *with* $p^{\uparrow}p$ at STAR				
Year	**2006**	**2011**	**2015**	**2017**
$\sqrt{s}\ (GeV)$	**200**	**500**	**200**	**510**
$L_{int}(pb^{-1})$	~ 1.8	~ 25	~ 52	~ 350

2006, 2011 → **Published**
- Phys. Rev. Lett. 115, 242501 (2015)
- Phys. Lett. B 780 (2018) 332

2015 → **STAR Preliminary**

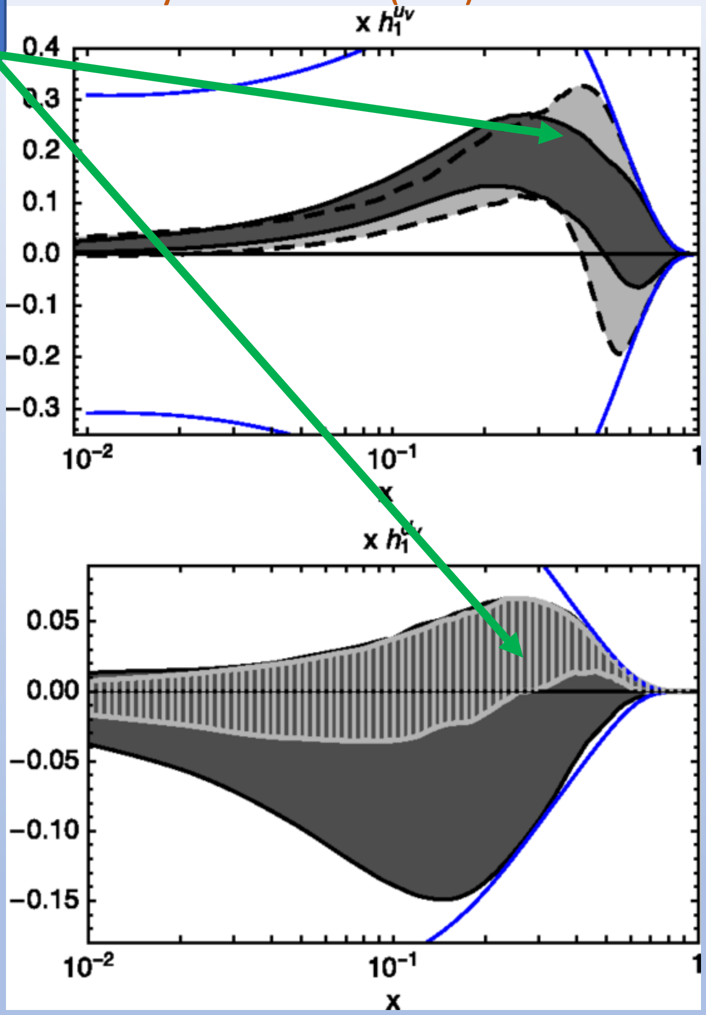
Refer to Babu Pokhrel's Talk 03/30, DIS2023

2017 → **On-going**

- STAR just completed taking another large pp dataset at 508 GeV (2022) ($L_{int}(pb^{-1}) \sim 400$) and is planning to take another pp 200 GeV ($L_{int}(pb^{-1}) \sim 265$) dataset in 2024.

M. Radici and A. Bacchetta
Phys. Rev. Lett. 120 (2018) 192001

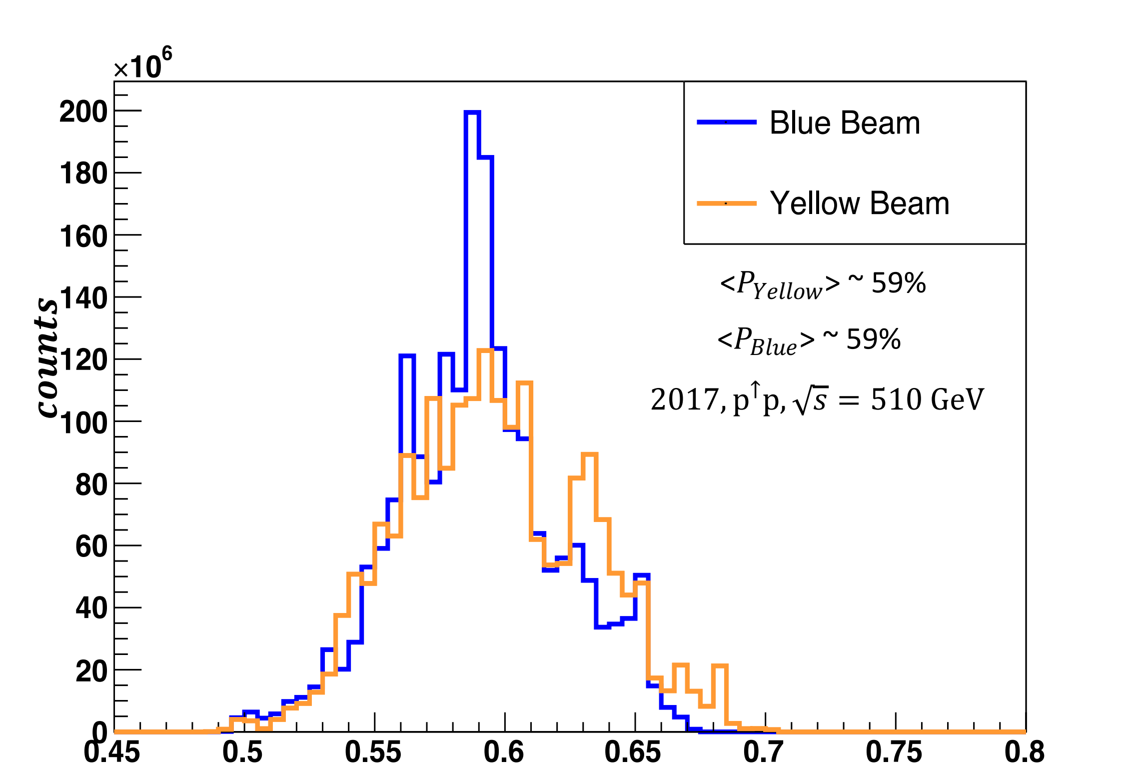
Including STAR 2006 results



STAR results play a crucial role in constraining the global fit of transversity.

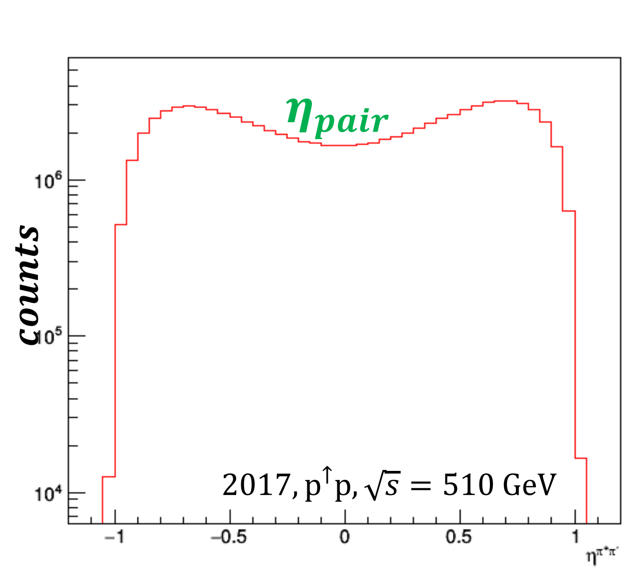
STAR 2017 $p^{\uparrow}p$ Collisions at $\sqrt{s} = 510$ GeV

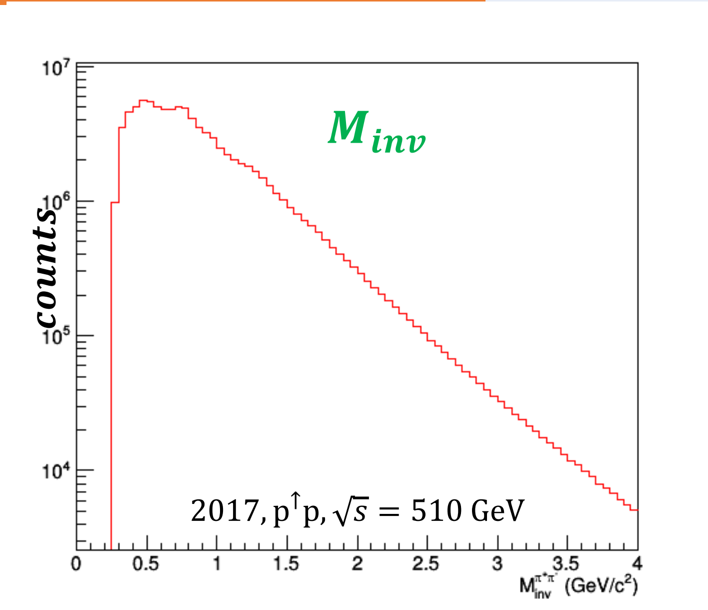
- IFF analysis of STAR 2017 $p^{\uparrow}p$ at $\sqrt{s} = 510$ GeV is underway.

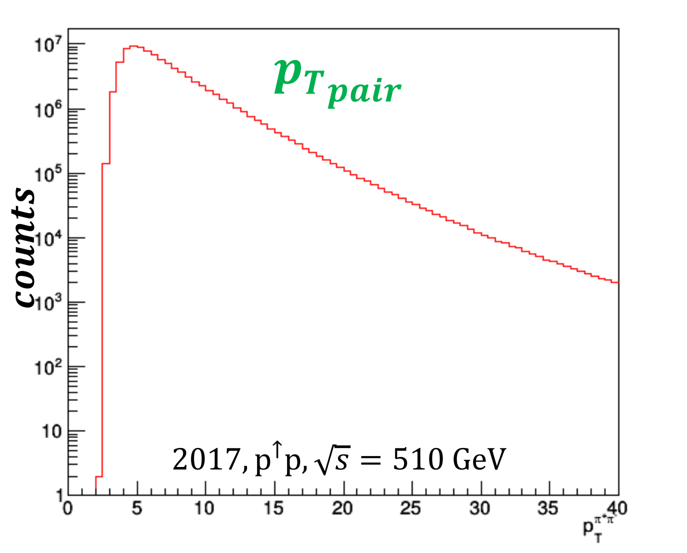


Beam Polarization

Kinematic Observables for A_{UT} Measurement

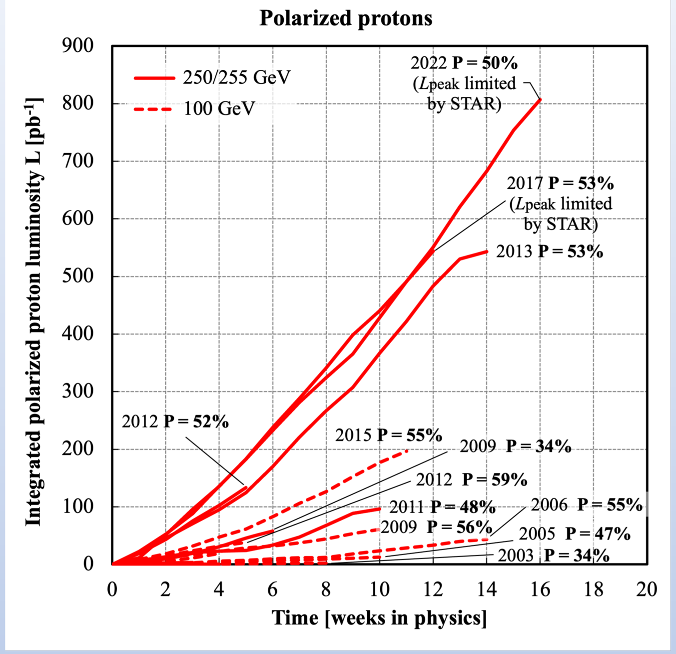




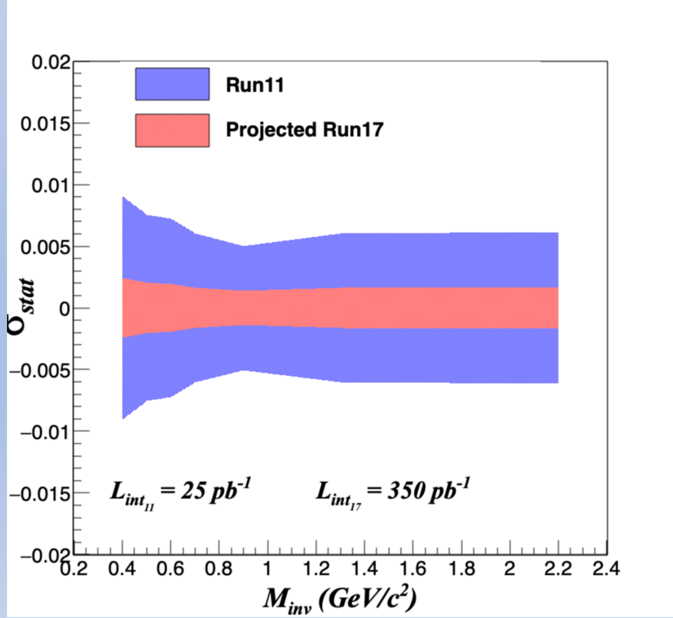


STAR 2017 $p^{\uparrow}p$ Collisions at $\sqrt{s} = 510$ GeV

- Previously published A_{UT} results at $\sqrt{s}$ = 500 GeV are statistically limited.
- Figure of merit $(P^2 L_{int})$ for new data is ~15 times larger.
- The statistical precision improvement by about a factor of 4 is expected compared to that of previously published result at $\sqrt{s} = 500$ GeV.



- Data analysis is ongoing.
- Systematic uncertainty is expected to improve with combined TPC and TOF PID.



Summary

- Di-hadron correlation asymmetry A_{UT} of final state pion pairs, as functions of various kinematic observables (η, p_T, M_{inv}), is expected to be sensitive to transversity.
- The IFF study of STAR new pp dataset (2017) at $\sqrt{s} = 510$ GeV is now underway; new larger $p^{\uparrow}p$ data sample will increase the statistical precision by a factor of 4 compared to that of previously published result at $\sqrt{s} = 500$ GeV.
- Results of this analysis will help to probe transversity at much higher Q^2 than SIDIS and test the universality of the mechanism which produces azimuthal correlations amongst SIDIS, e^+e^-, and $p^{\uparrow}p$ collisions.
- Planning for unpolarized di-hadron cross-section measurement at 500 GeV, which could reduce uncertainties in transversity extraction.