Measurement of Transverse Spin-Dependent Azimuthal Correlation of Charged Pion Pairs in $p^{\uparrow}p$ Collisions at $\sqrt{s}$ = 510 GeV using STAR 2017 Data

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STAR

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Motivation

- At leading-twist, the parton structure of hadrons is described by three parton distribution functions: unpolarized PDFs ($f_1(x)$), helicity PDFs ($g_1(x)$) and transversity PDFs ($h_1^q(x)$).
- $h_1^q(x)$ is the least known of the three PDFs.
- $h_1^q(x)$ is a chiral odd PDF and it needs to couple with a chiral-odd partner.
- For estimating tensor charge (g_T), a precise determination of transversity is necessary.

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

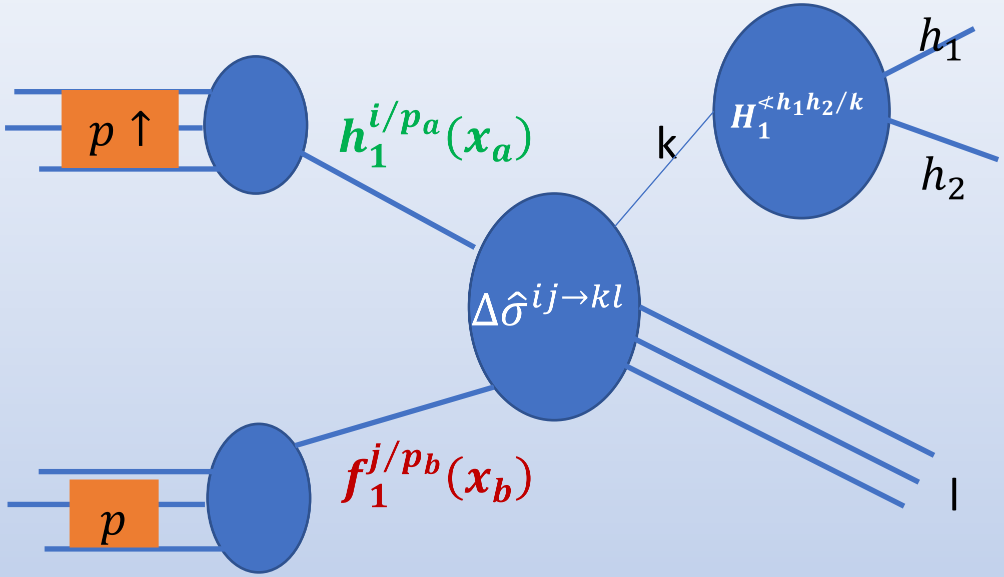
		Quark Polarization		
		Unpolarized (U)	Longitudinally Polarized (L)	Transversely Polarized (T)
Nucleon Polarization	U	$f_1(x)$		
	L		$g_1(x)$	
	T			$h_1^q(x)$

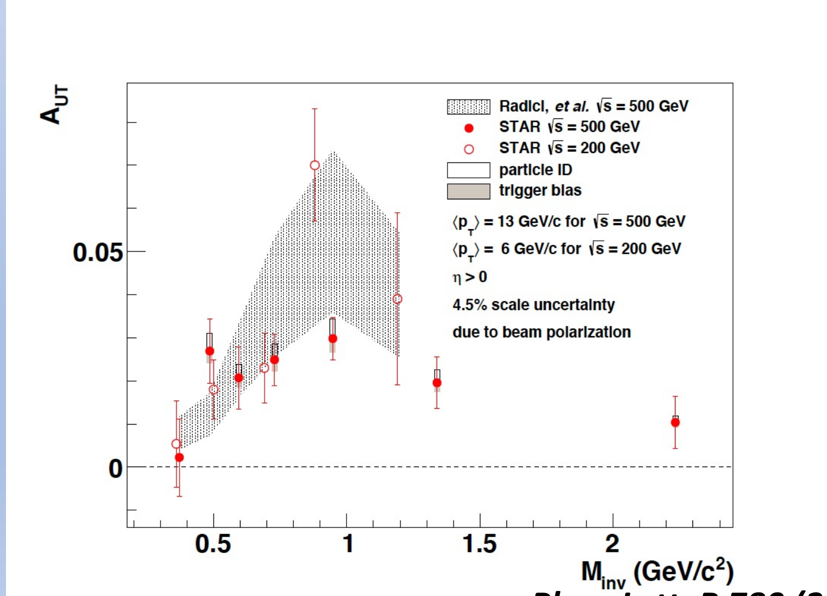
Motivation

- In $p^{\uparrow}p$ collision, $h_1^q(x)$ couples with chiral odd spin-dependent di-hadron fragmentation function $H_1^{\sphericalangle h_1 h_2/q}(z, M)$, Interference Fragmentation Function (IFF).
- Transverse polarization of the fragmenting quark influences the azimuthal distribution of the hadron pair in the final state, thus producing di-hadron correlation asymmetry, A_{UT}.

$$A_{UT} \propto \frac{\sum_{i,j,k} h_1^{i/p_a}(x_a) f_1^{j/p_b}(x_b) H_1^{\sphericalangle h_1 h_2/k}(z, M_h)}{\sum_{i,j,k} f_1^{i/p_a}(x_a) f_1^{j/p_b}(x_b)\, D_1^{\sphericalangle h_1 h_2/k}(z, M_h)}$$

- Previously, the STAR experiment at RHIC measured non-zero A_{UT} using $p^{\uparrow}p$ data from 2006 at $\sqrt{s} = 200$ GeV with $L_{int} = 1.8\, pb^{-1}$ and from 2011 at $\sqrt{s} = 500$ GeV with $L_{int} = 25\, pb^{-1}$
- In 2017, STAR collected $350\, pb^{-1}$ of $p^{\uparrow}p$ data at $\sqrt{s} = 510$ GeV which will significantly improve the statistical precision of A_{UT} measurement and thus further constrain global fits of $h_1^q(x)$.





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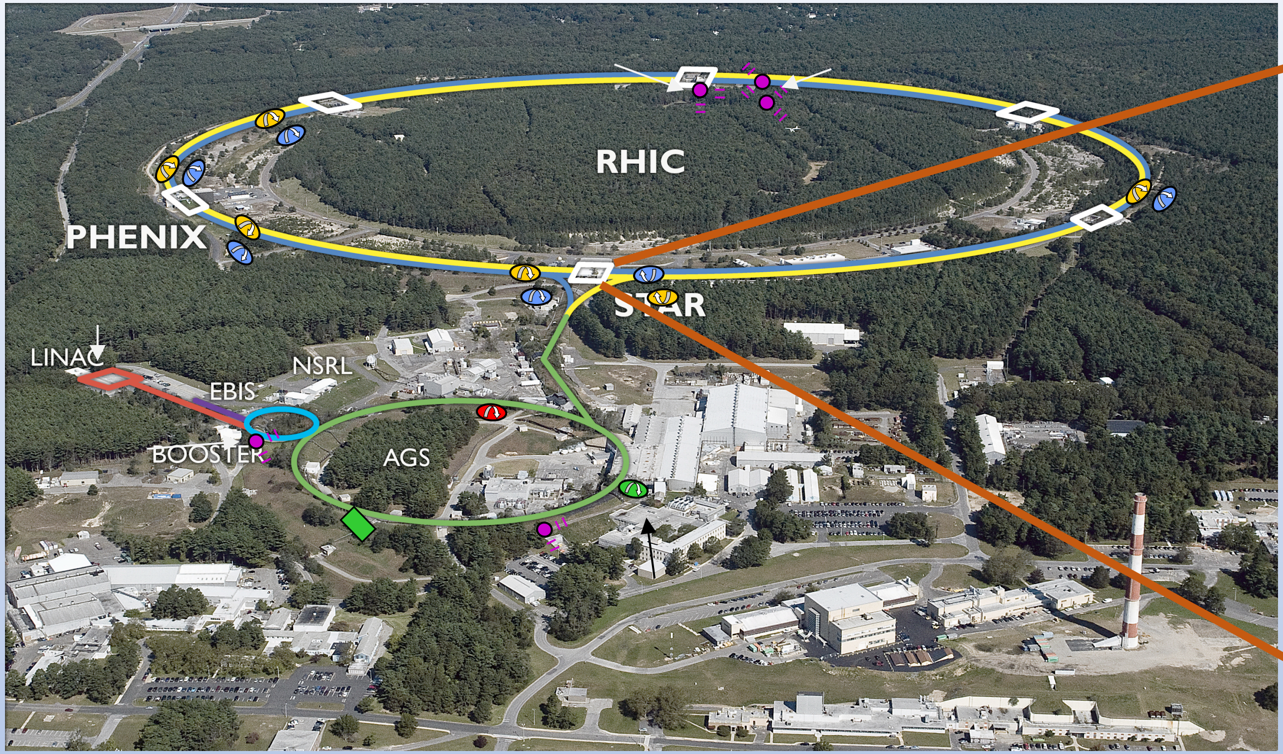
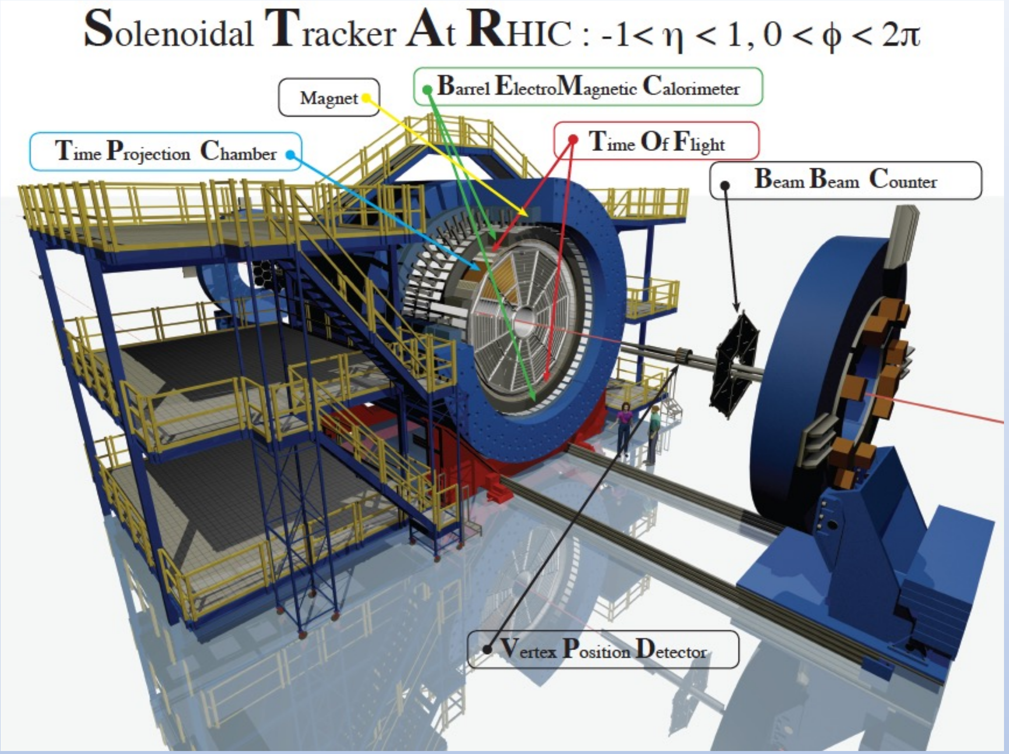
STAR Experiment At RHIC





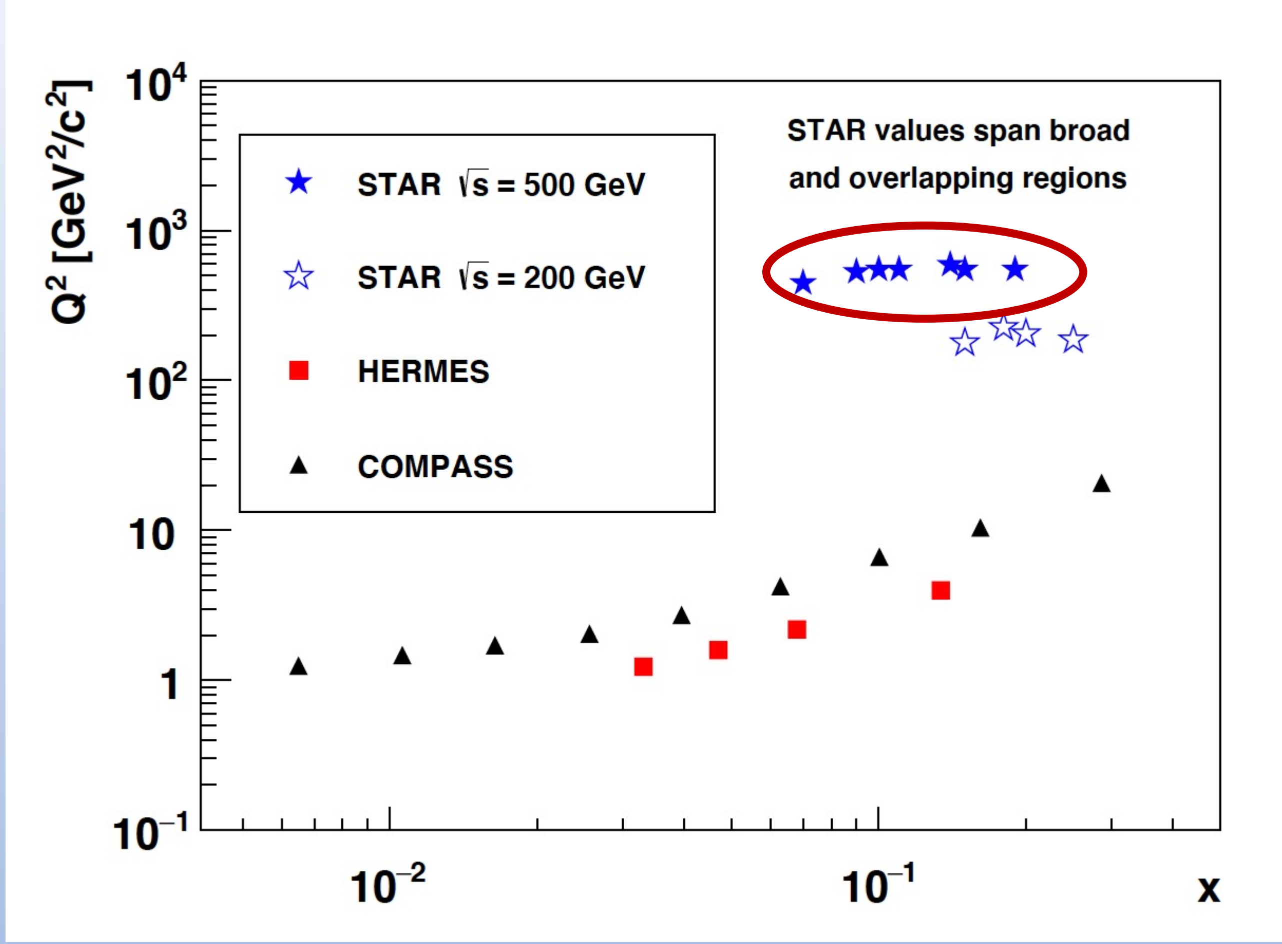
Relativistic Heavy Ion Collider

- RHIC is the world's only collider of longitudinally and transversely polarized protons with $\sqrt{s}$ up to 510 GeV

Solenoidal Tracker At RHIC

- STAR is the only experiment currently running at RHIC.
- TPC (tracking, PID)
- BEMC (electromagnetic calorimeter, event triggering)
- TOF (PID)

STAR Kinematics



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

Data Set

A_{UT} at STAR				
Year	2006	2011	2015	2017
$\sqrt{s}$ (GeV)	200	500	200	510
$L_{int}(pb^{-1})$	~ 1.8	~ 25	~ 48	350

Published (2006, 2011)

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

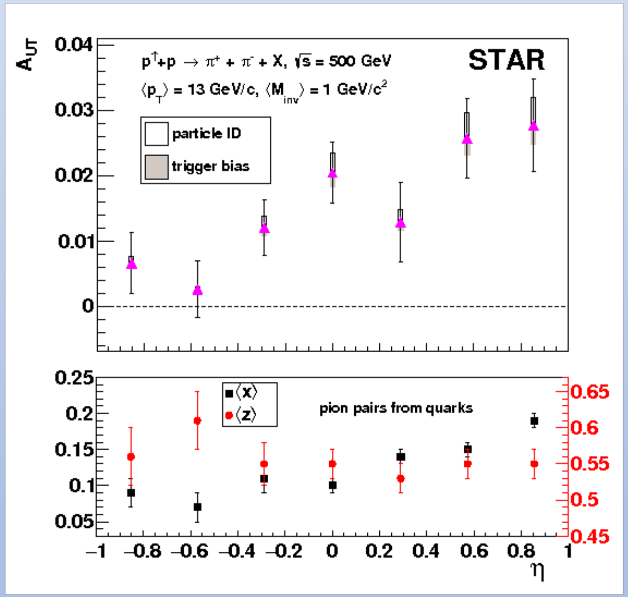
STAR preliminary (2015)

On-going (2017)

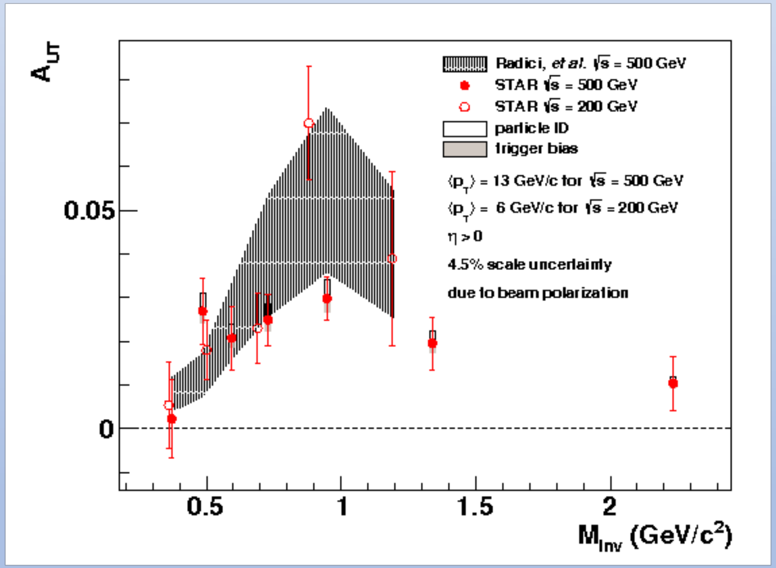
Kinematic Observables

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

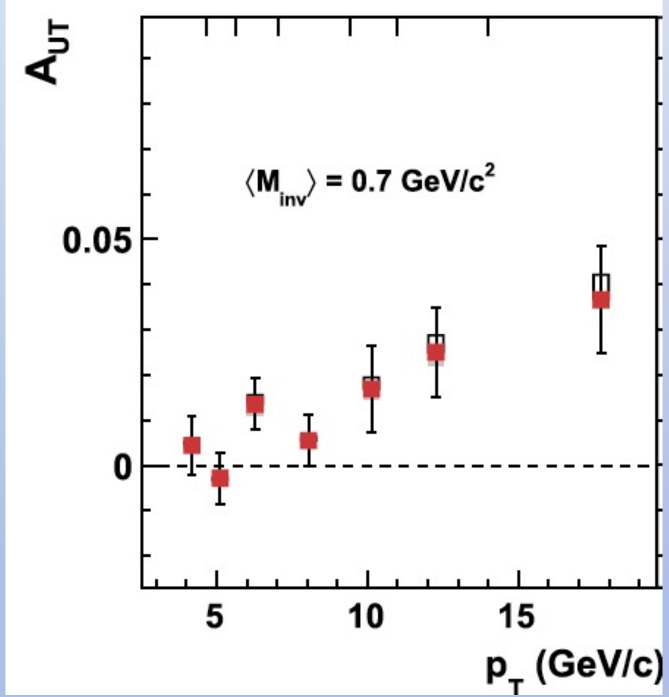
For η>0, where partonic x is greater, a larger A_{UT} is expected.



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



A_{UT} increases as pair p_T increases.



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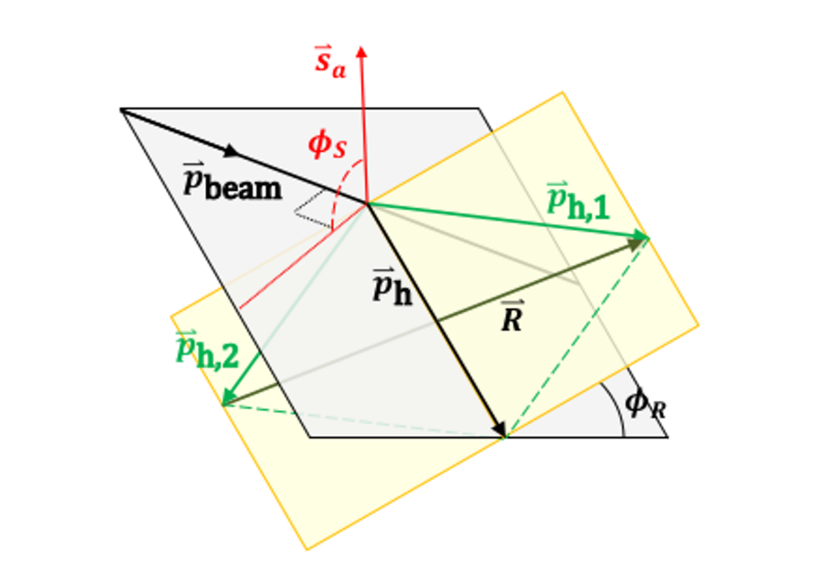
Asymmetry Extraction

$$A_{UT} = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}}$$

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

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



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

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

φ_S = *Angle between scattering plane and polarization of incident beam*

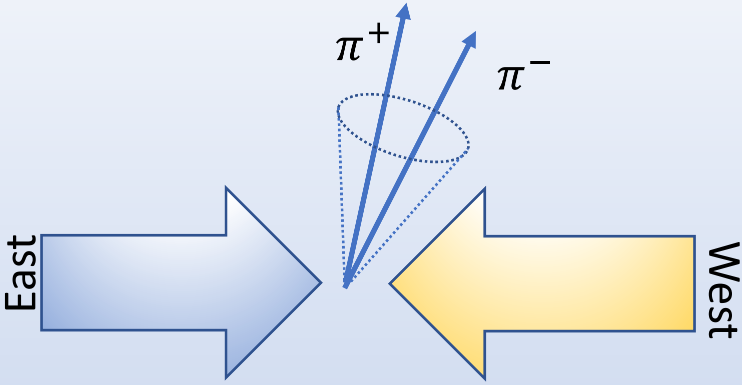
φ_R = *Angle between scattering plane and dihadron plane*

$\varphi_{RS} = \varphi_R - \varphi_s$

$N\uparrow(\downarrow)$ = *# of pion pairs when beam polarization up(down)*

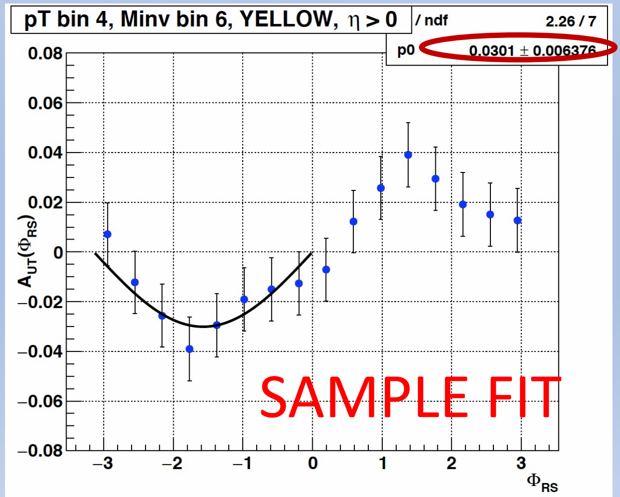
P = *Average beam polarization*

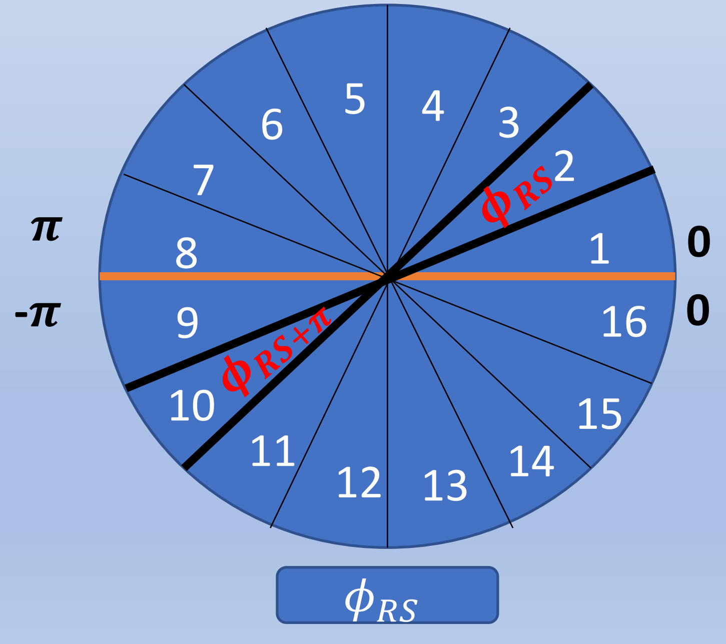
Asymmetry Extraction



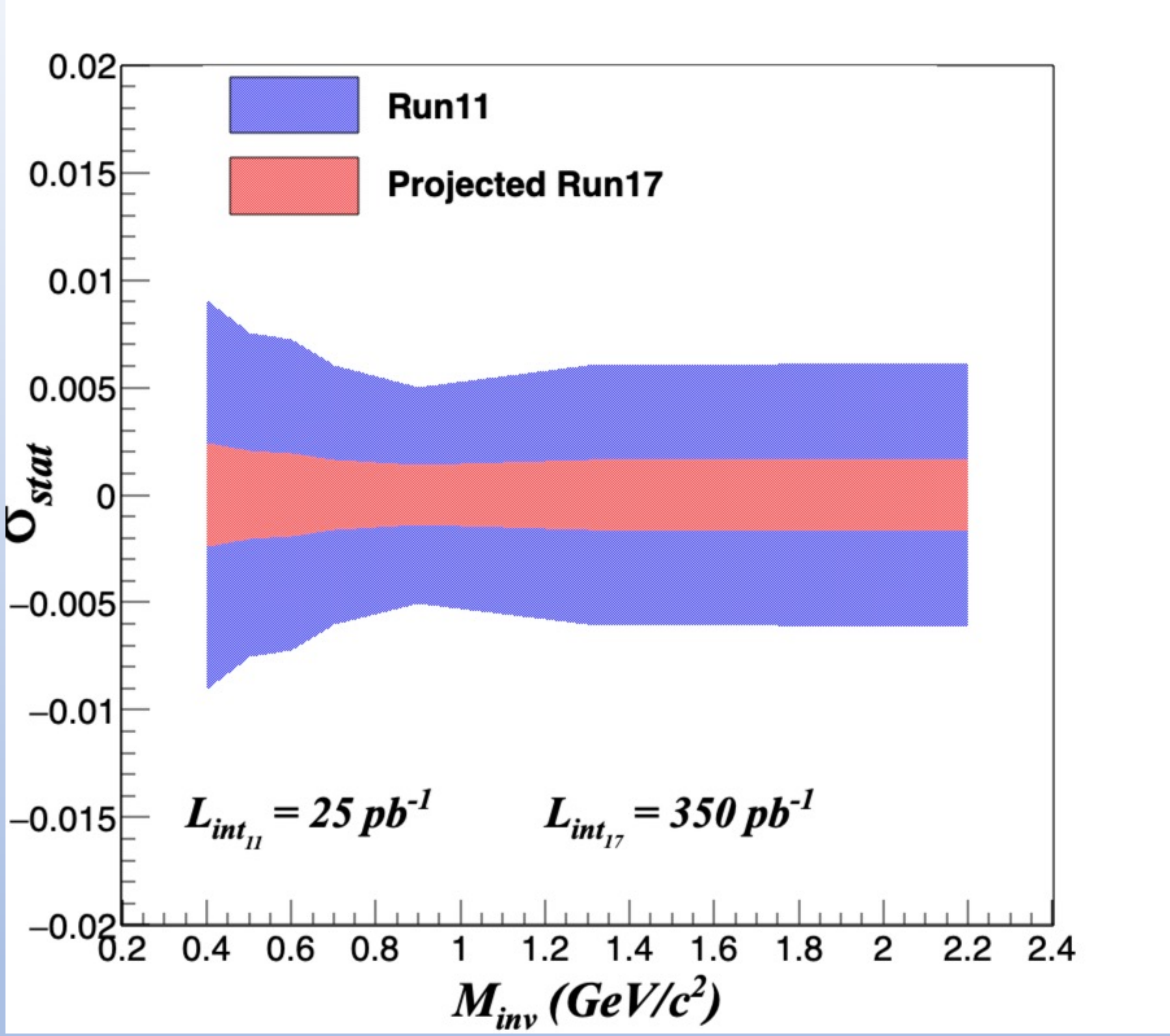
- Two oppositely charged pions in the final state are paired if they are close in $\eta - \phi$ space.
- ϕ_{RS} is divided into 16 bins of uniform bin-width in the range $[-\pi, +\pi]$ and $N\uparrow(\downarrow)$ in each ϕ_{Rs} bin is counted.
- The angle ϕ_{RS} modulates the A_{UT} by $sin(\phi_{RS})$.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

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





Statistical Error Projection



- Figure of Merit $(P^2 L_{int})$ for 2017 data is ~15 times larger than that of 2011 data.
- The statistical precision improvement by about a factor of 4 is expected.

Summary

- IFF 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 2017 data is now underway; a larger $p^{\uparrow}p$ data sample from 2017 will increase the statistical precision compared to prior measurements using 2011 data.
- Results of this analysis will help to probe transversity at much higher Q^2 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, which could reduce uncertainties in transversity extraction.