



Nuclear Dependent Analyzing Power of Charged Pion in polarized $p+A$ Collision



Korea Univ.
Jaehee Yoo

The Proton Spin Structure

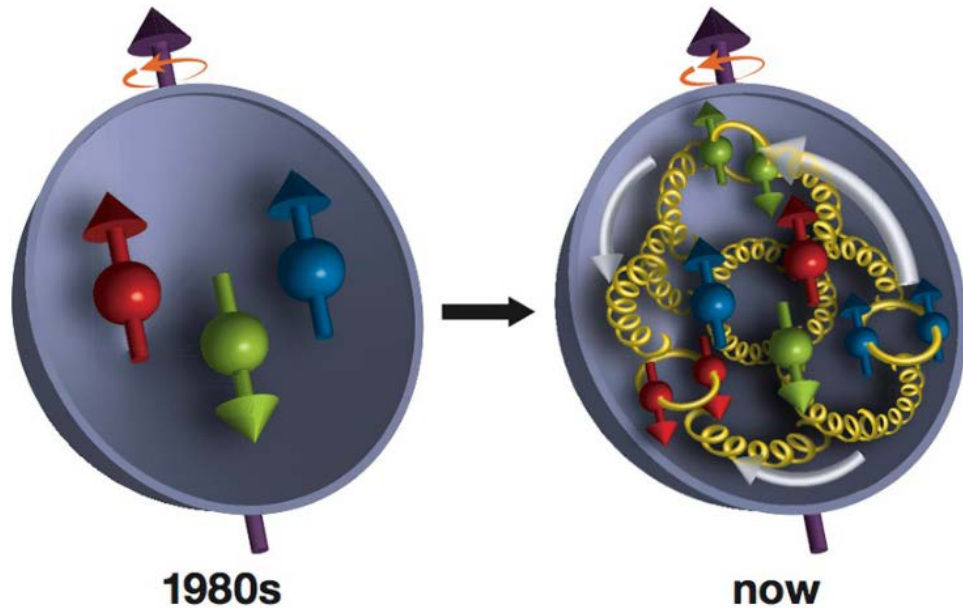


Image courtesy of Brookhaven National Laboratory

Standard Model of Elementary Particles

		three generations of matter (fermions)			interactions / force carriers (bosons)	
		I	II	III		
mass		$\approx 2.2 \text{ MeV}/c^2$	$\approx 1.28 \text{ GeV}/c^2$	$\approx 173.1 \text{ GeV}/c^2$	0	$\approx 124.97 \text{ GeV}/c^2$
charge		$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0	0
spin		$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	0
		u up	c charm	t top	g gluon	H higgs
		$\approx 4.7 \text{ MeV}/c^2$	$\approx 96 \text{ MeV}/c^2$	$\approx 4.18 \text{ GeV}/c^2$	0	
		$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	0	
		$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
		d down	s strange	b bottom	γ photon	
		$\approx 0.511 \text{ MeV}/c^2$	$\approx 105.66 \text{ MeV}/c^2$	$\approx 1.7768 \text{ GeV}/c^2$	$\approx 91.19 \text{ GeV}/c^2$	
		-1	-1	-1	0	
		$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
		e electron	μ muon	τ tau	Z Z boson	
		$< 1.0 \text{ eV}/c^2$	$< 0.17 \text{ MeV}/c^2$	$< 18.2 \text{ MeV}/c^2$	$\approx 80.39 \text{ GeV}/c^2$	
		0	0	0	± 1	
		$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
		ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	

QUARKS (left side of the table)
LEPTONS (left side of the table)
GAUGE BOSONS VECTOR BOSONS (bottom right)
SCALAR BOSONS (right side of the table)

In the 1980s, scientists discovered that a proton's three valence quarks (red, green, blue) account for only a fraction of the proton's overall spin. New measurements from RHIC's PHENIX experiment reveal that gluons (yellow corkscrews) contribute as much as or possibly more than the quarks.

The Proton Spin Structure

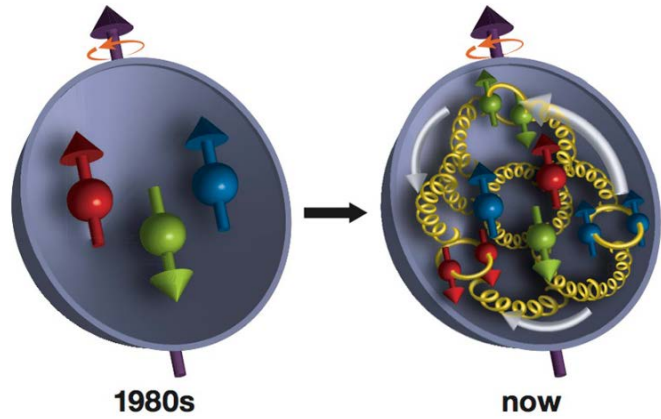


Image courtesy of Brookhaven National Laboratory

1988 EMC measured:
 $\Sigma = 0.123 \pm 0.013 \pm 0.019 \implies$ Spin Puzzle!

$$S_{proton} = \frac{1}{2} = \frac{1}{2} \Delta q + \Delta G + L_{q,g}$$

$$\frac{1}{2} = \frac{1}{2} (\Delta u_v + \Delta d_v + \underbrace{\Delta q_s}) + \Delta G + L_q + L_g$$

$$\Delta u_v + \Delta d_v + \Delta q_s + \Delta \bar{u}_s + \Delta \bar{d}_s + \Delta \bar{s}_s$$

Standard Model of Elementary Particles

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charge	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0	0
spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	0
	up	charm	top	gluon	higgs
	$\approx 4.7 \text{ MeV}/c^2$	$\approx 96 \text{ MeV}/c^2$	$\approx 4.18 \text{ GeV}/c^2$	0	
	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	0	
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
	down	strange	bottom	photon	
	$\approx 0.511 \text{ MeV}/c^2$	$\approx 105.66 \text{ MeV}/c^2$	$\approx 1.7768 \text{ GeV}/c^2$	$\approx 91.19 \text{ GeV}/c^2$	
	-1	-1	-1	0	
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
	electron	muon	tau	Z boson	
	$< 1.0 \text{ eV}/c^2$	$< 0.17 \text{ MeV}/c^2$	$< 18.2 \text{ MeV}/c^2$	$\approx 80.39 \text{ GeV}/c^2$	
	0	0	0	± 1	
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
	electron neutrino	muon neutrino	tau neutrino	W boson	

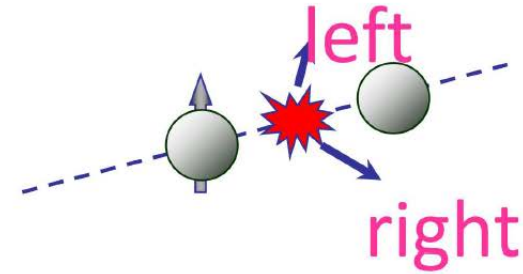
QUARKS (I, II, III)
 LEPTONS (e, μ , τ)
 GAUGE BOSONS (gluon, photon, Z, W)
 SCALAR BOSONS (higgs)
 VECTOR BOSONS (photon, Z, W)

Full description of proton's spin needs
orbital angular momentum

How is proton's spin correlated with the motion of quarks and gluons?
 -> Transverse Momentum Dependent (TMD) Functions

Transverse Single Spin Asymmetry

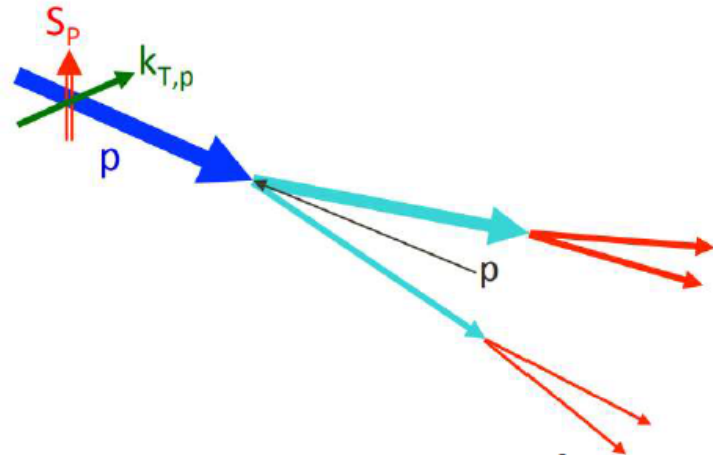
$$A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$



Sources of Transverse SSA's

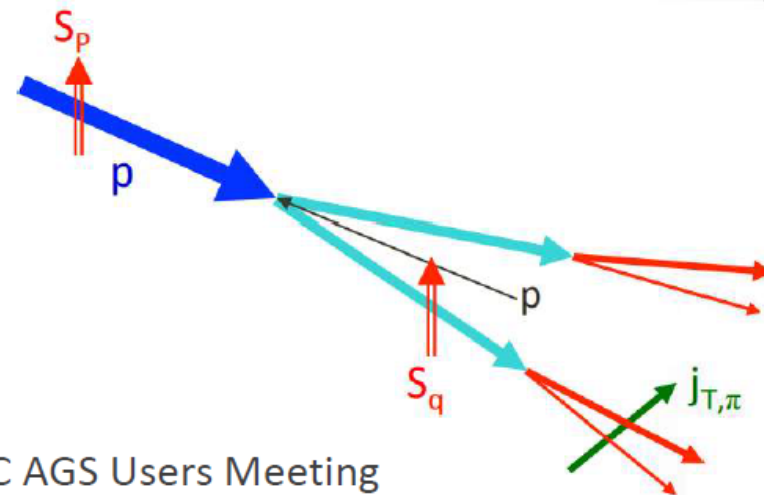
Initial State Effects:

For example Sivers functions: correlation between proton spin and parton k_T



Final State effects:

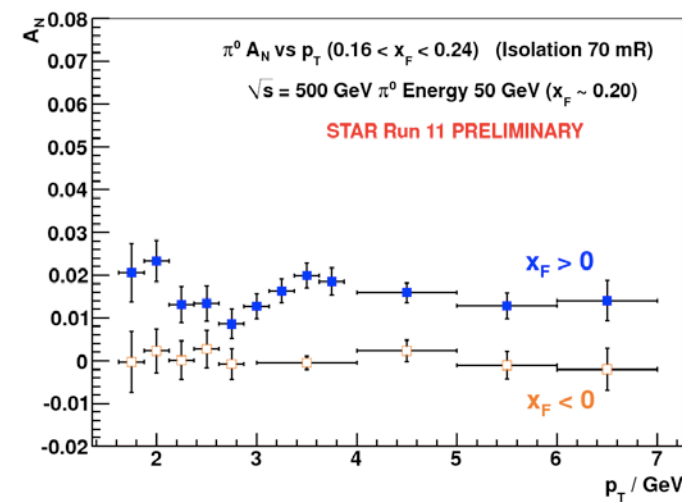
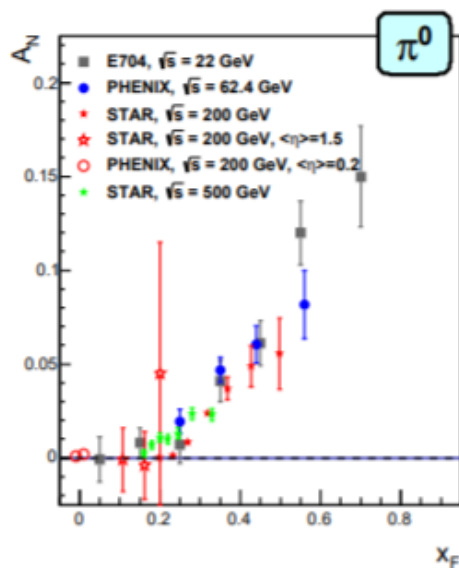
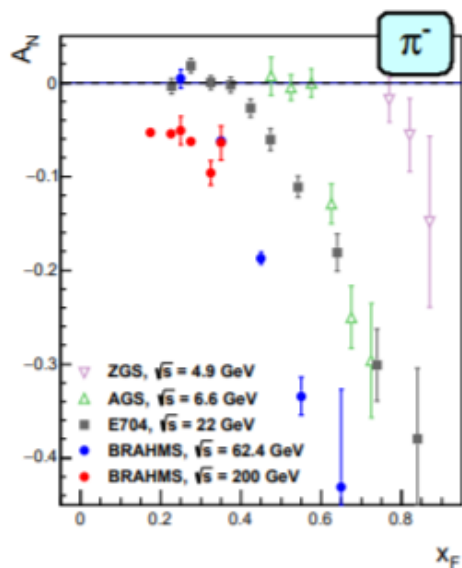
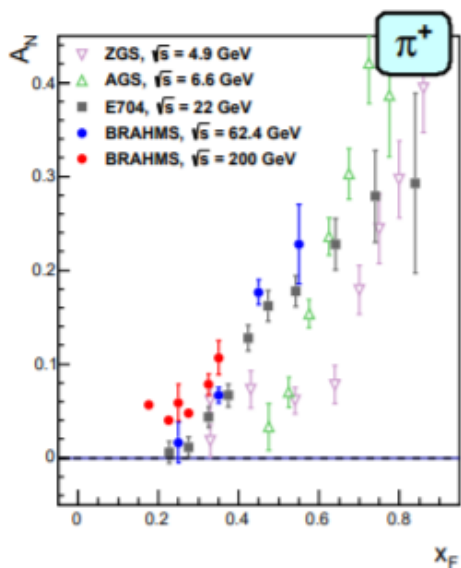
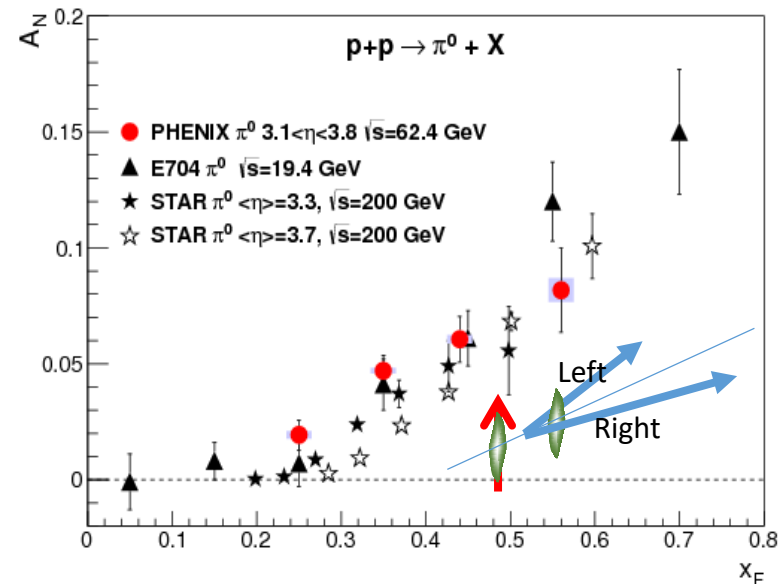
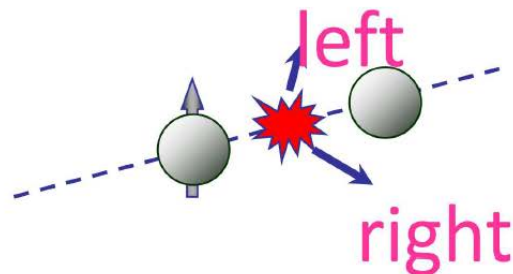
Collins Function: spin momentum correlation in a Fragmentation Function



Figures from L. Nogach 2006 RHIC AGS Users Meeting

Transverse Single Spin Asymmetry

$$A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$

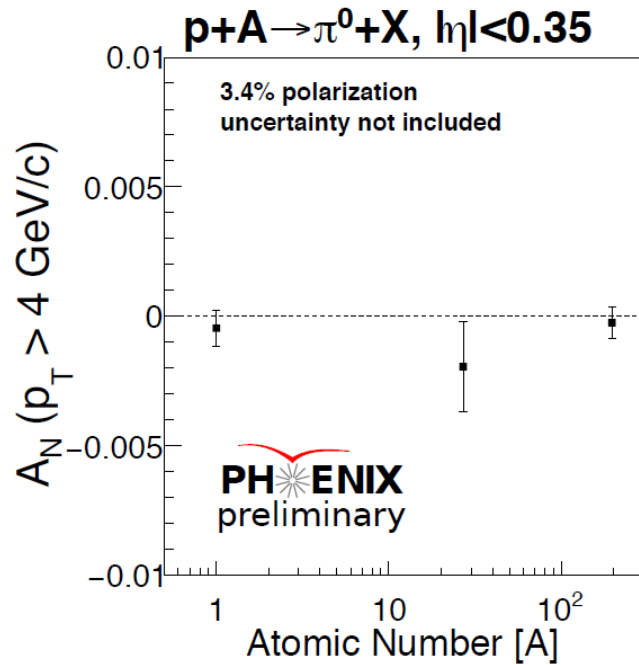


Motivation

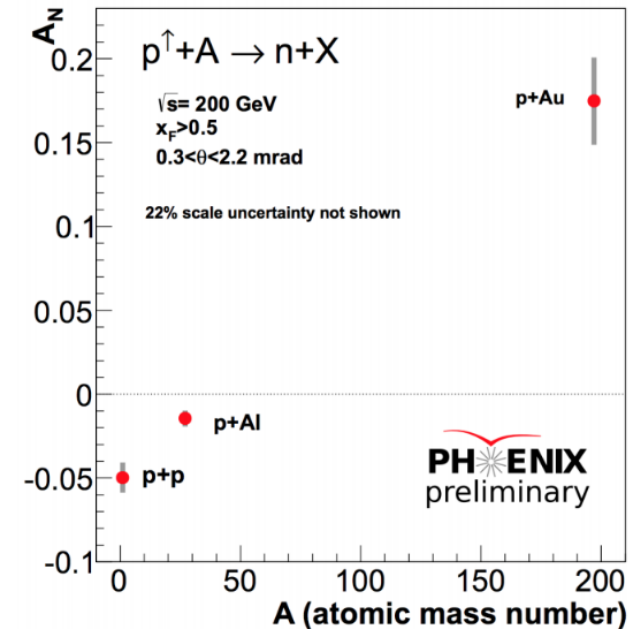
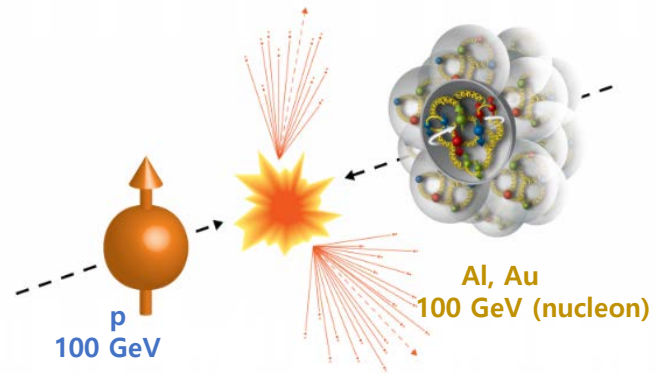
Nuclear Dependent Analyzing Power of Charged Pion in polarized p+A Collision

How does it change from p+p to p+A collision?

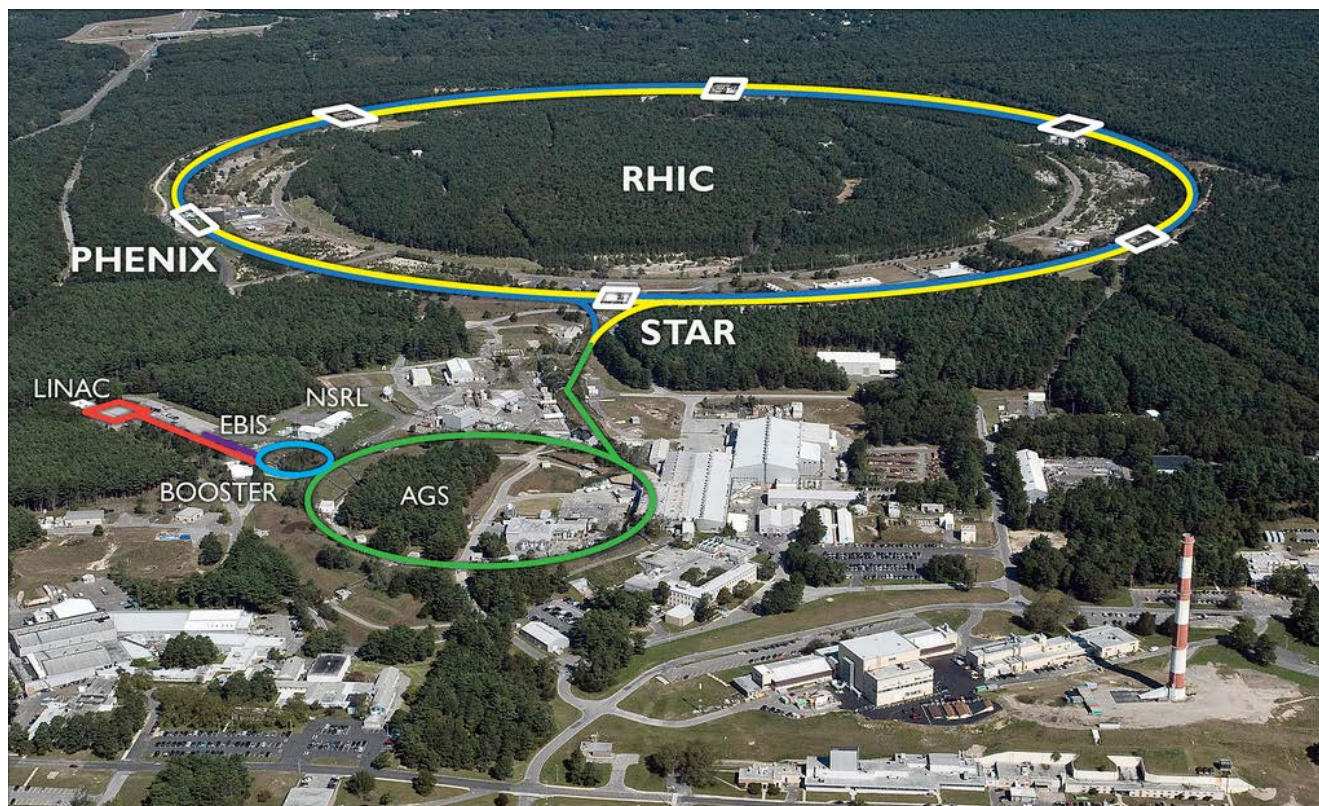
Asymmetry in mid-rapidity



RHIC Run15
The world 1st high energy polarized proton+nucleus collision

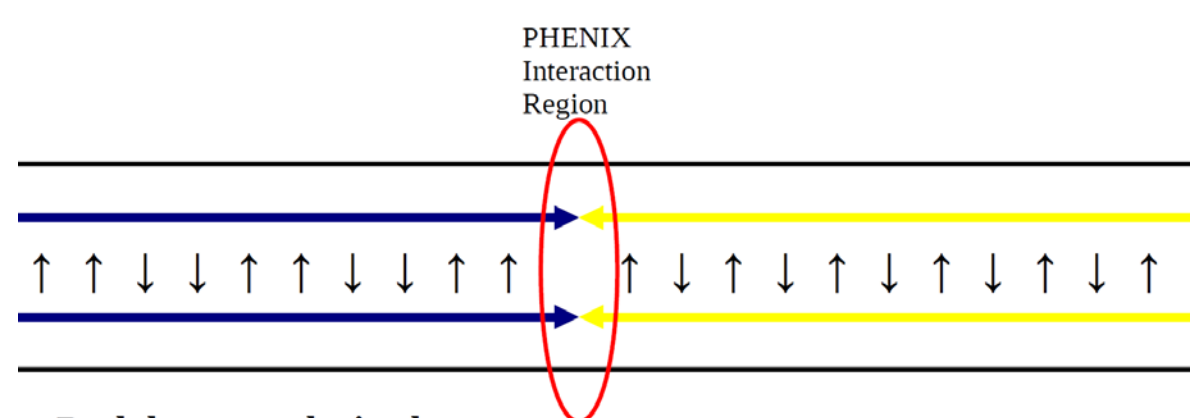


- The asymmetry of π^0 and η in midrapidity
- Consistent with zero within errors



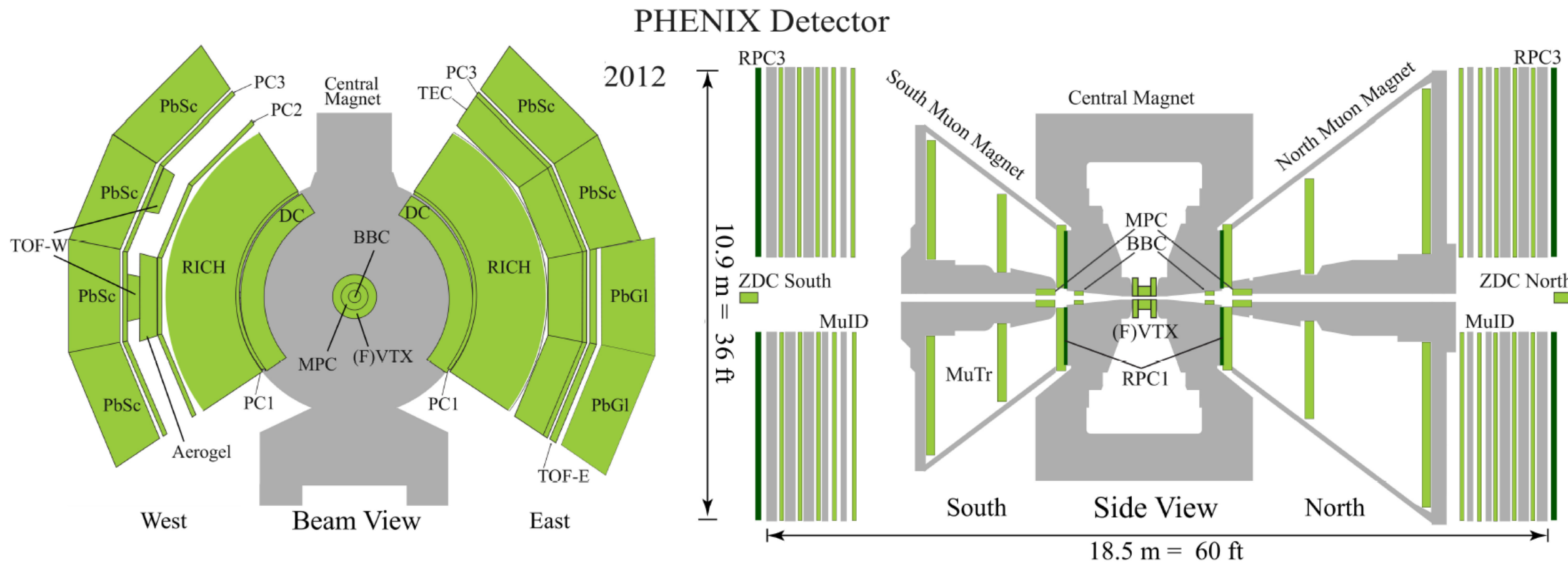
View of the Brookhaven National Laboratory, NY, USA

Polarized Beams



- **Both beams polarized**
- Variation of bunch polarization direction minimizes systematic uncertainties in measurement
- For transversely polarized beams, allows for two independent A_N measurements

PHENIX Detector System



2 central arm: Mid rapidity, $|\eta| < 0.35$
 - Identified charged hadrons : π^0 , η , direct photon, J/ψ , heavy flavor.

Analysis step



1. RunQA
2. Calibration
3. Data selection
4. Event cuts
5. Track cuts : π^\pm identification
6. Simulation for Reconstruct eff.
7. Calculate Cross-Section
8. Calculate A_N

To measure the Cross-Section

$$E \frac{d^3 \sigma}{dp^3} = \frac{1}{2\pi p_T} \frac{1}{L} \frac{\Delta N_{\pi^\pm}^{meas}}{\epsilon \Delta \eta \Delta p_T}$$

$$N_{\pi^\pm}^{meas} = \epsilon N_{\pi^\pm}$$

$$\epsilon_\eta = \epsilon_{geo} \wedge \epsilon_{det} \wedge \epsilon_{trig} = \epsilon_{reco} \wedge \epsilon_{trig}$$

- 1. Integrated Luminosity
- 2. Measured Yield
- 3. Efficiency of central arm detectors to measure an charged pion.
 - 3-1) Reconstruction Efficiency
 - 3-2) Trigger Efficiency

Integrated Luminosity

- I'm Using 204 runs in pAu.
- Int_Lumi : 1.113 pb⁻¹

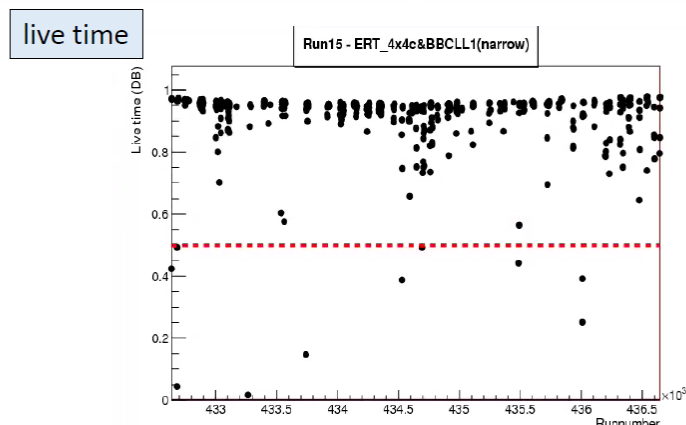
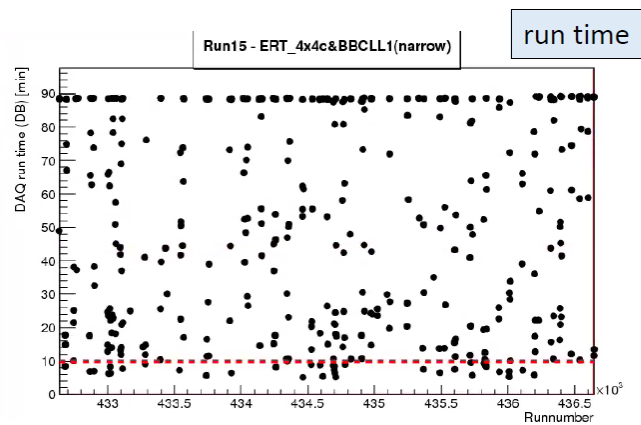
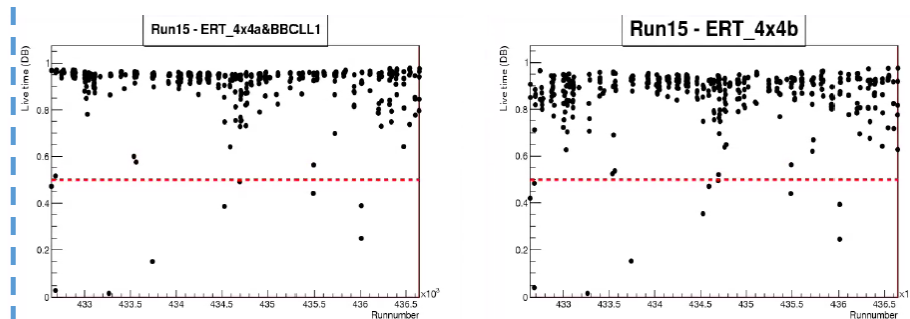
Year	\sqrt{s} (GeV)	Recorded Luminosity for longitudinally / transverse polarized p+p STAR	Recorded Luminosity for longitudinally / transverse polarized p+p PHENIX	<P> in %
2006	62.4 200	-- pb ⁻¹ / 0.2 pb ⁻¹ 6.8 pb ⁻¹ / 8.5 pb ⁻¹	0.08 pb ⁻¹ / 0.02 pb ⁻¹ 7.5 pb ⁻¹ / 2.7 pb ⁻¹	48 57
2008	200	-- pb ⁻¹ / 7.8 pb ⁻¹	-- pb ⁻¹ / 5.2 pb ⁻¹	45
2009	200 500	25 pb ⁻¹ / -- pb ⁻¹ 10 pb ⁻¹ / -- pb ⁻¹	16 pb ⁻¹ / -- pb ⁻¹ 14 pb ⁻¹ / -- pb ⁻¹	55 39
2011	500	12 pb ⁻¹ / 25 pb ⁻¹	18 pb ⁻¹ / -- pb ⁻¹	48
2012	200 510	-- pb ⁻¹ / 22 pb ⁻¹ 82 pb ⁻¹ / -- pb ⁻¹	-- pb ⁻¹ / 9.7 pb ⁻¹ 32 pb ⁻¹ / -- pb ⁻¹	61/56 50/53
2013	510	300 pb ⁻¹ / -- pb ⁻¹	155 pb ⁻¹ / -- pb ⁻¹	51/52
2015	200	52 pb ⁻¹ / 52 pb ⁻¹	-- pb ⁻¹ / 60 pb ⁻¹	53/57

2015 200 p Au total delivered Luminosity = 1.27 pb⁻¹ 60
 2015 200 p Al total delivered Luminosity = 3.97 pb⁻¹ 54

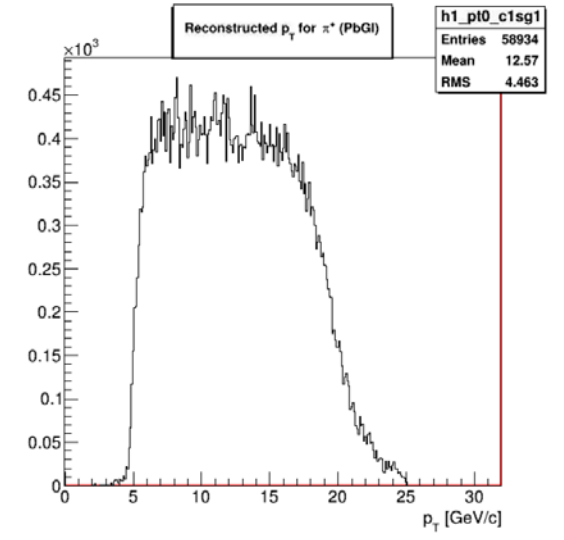
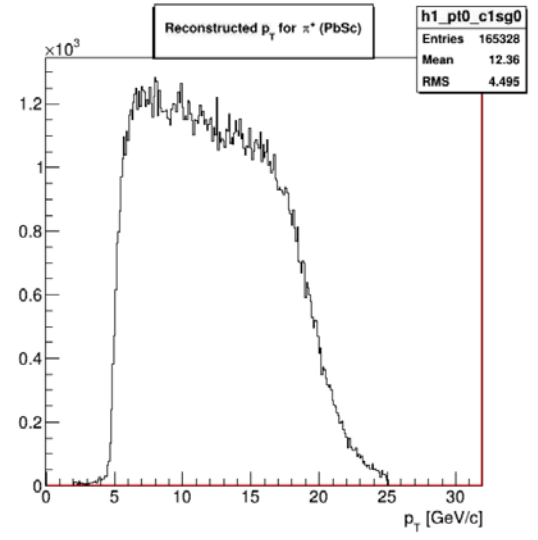
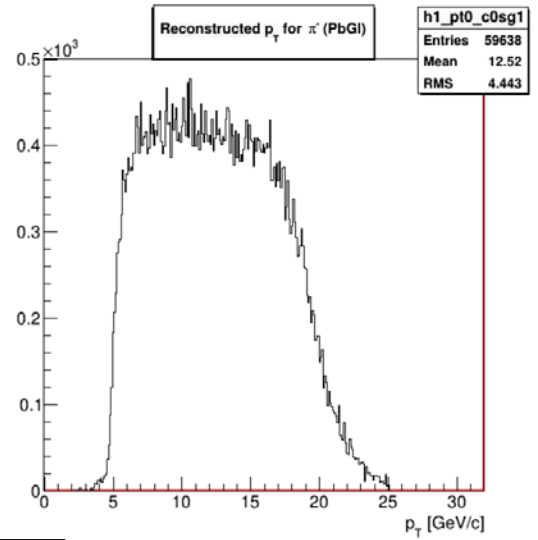
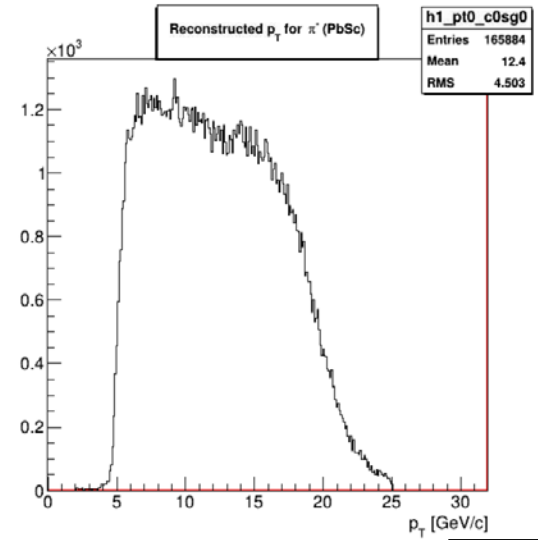
○ : Trasversely polarized

- Trigger
 - ERTLL1_4x4a&BBCLL1
 - ERT_4x4b
 - ERT_4x4c&BBCLL1(narrow)

- Cut
 - DAQ Run time > 10 min
 - DAQ live time > 0.5

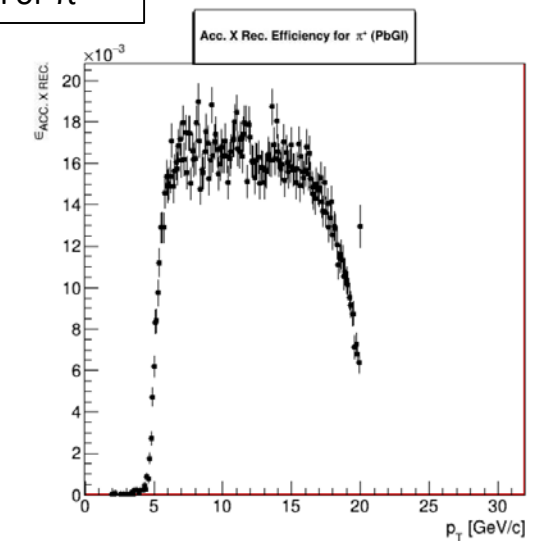
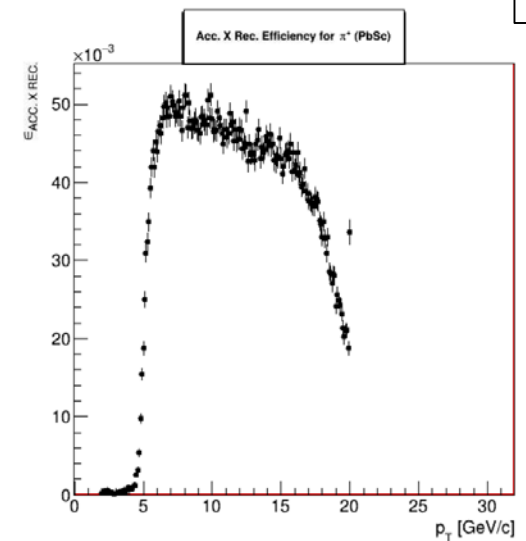
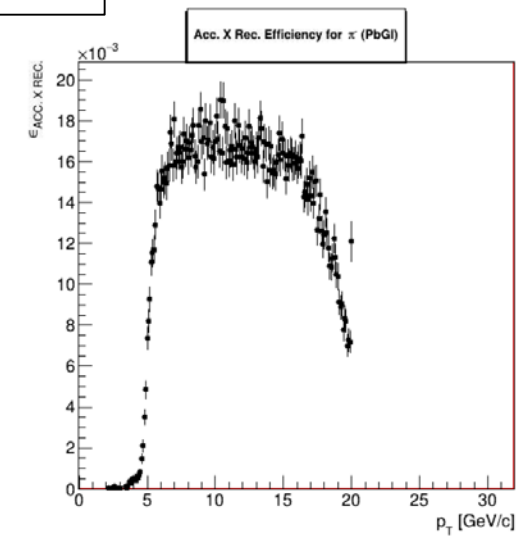
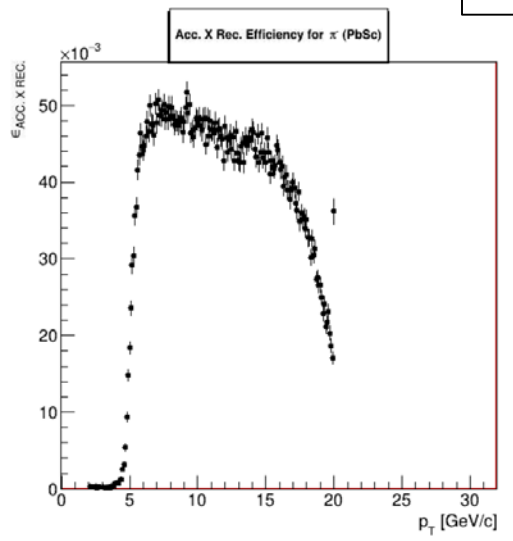


Reconstructed efficiency of pions



For π^-

For π^+



Trigger Efficiency



For π^-

For π^+

Summary



- The $\pi^\pm A_N$ in mid-rapidity in p+p, p+Au and p+Al collisions at $\sqrt{s} = 200$ GeV was measured by PHENIX.
- π^\pm transverse asymmetry from p+p to p+A are comparable in mid-rapidity and π^0 .
- The π^\pm production in p+p vs p+A will answer outstanding question considering nuclear effects.



Thank you.

