PHENIX Forward Neutron Single Transverse Spin Asymmetry A_N Measurements

MINJUNG [mindʒʌŋ] KIM

SEOUL NATIONAL UNIV./RIKEN

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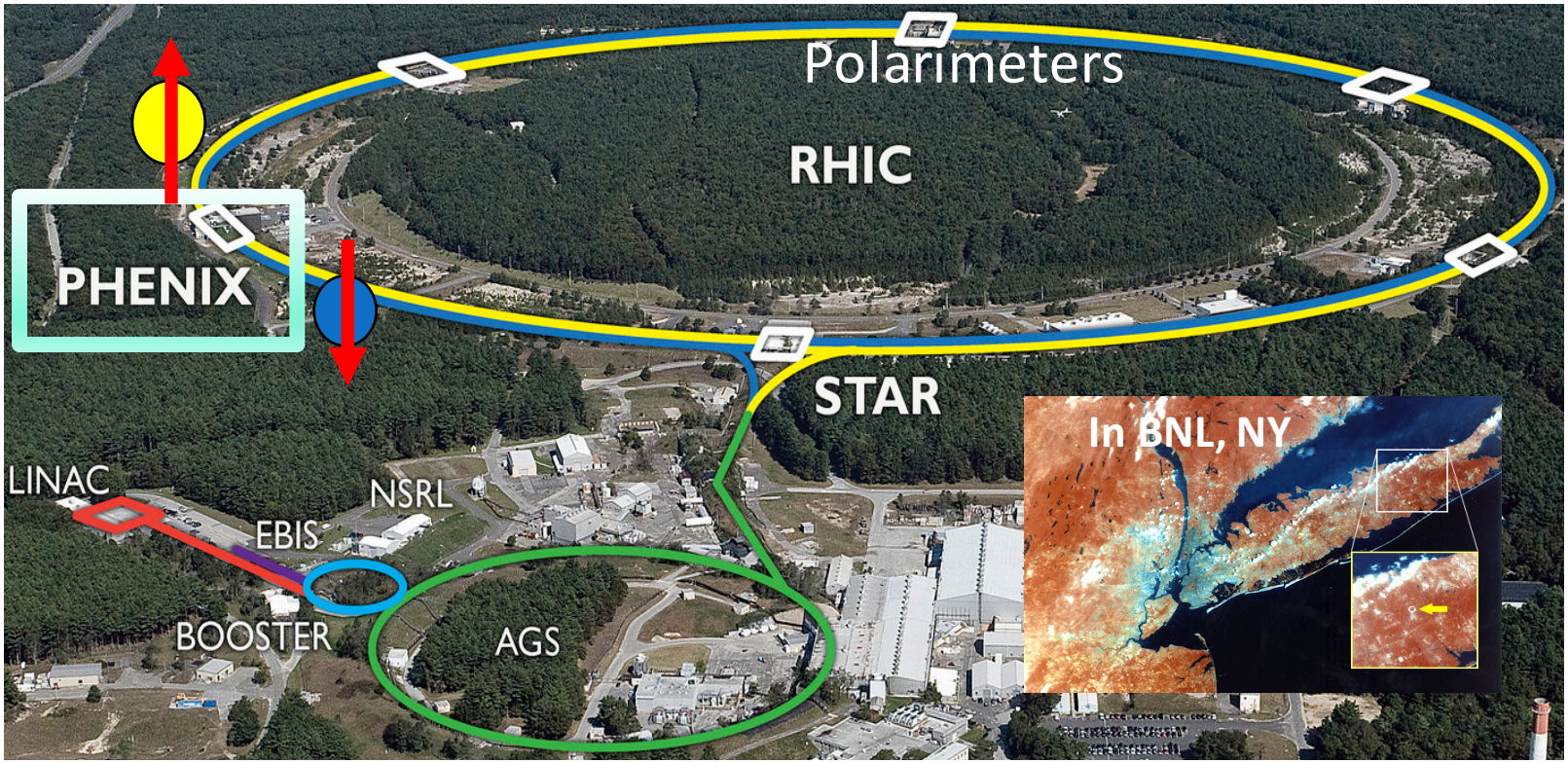
HESZ WORKSHOP @ NAGOYA

Contents

- RHIC
- PHENIX Neutron Detectors
- $\boldsymbol{A_N}$ definition
- Measurement
- **Previous measurement**: $\boldsymbol{A_N}$ for $\mathbf{p}^{\uparrow} + \mathbf{p} \rightarrow \mathbf{n} + \mathbf{X}$
  - Result
  - Theories
- **New measurement**: $\boldsymbol{A_N}$ for $\mathbf{p}^{\uparrow} + \mathbf{A} \rightarrow \mathbf{n} + \mathbf{X}$ in Run15 (2015)
  - Result
  - Discussions

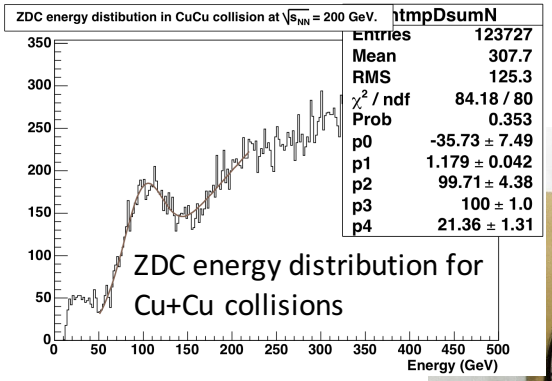
RHIC (Relativistic Heavy Ion Collider)



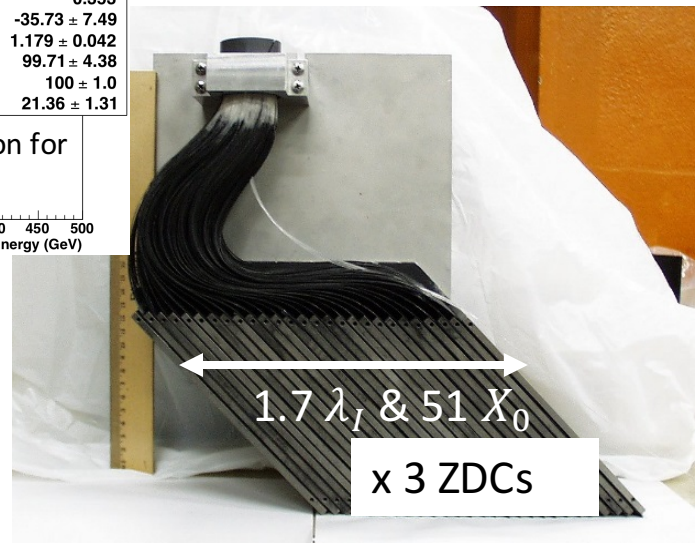
Run15 Experiment: $\mathbf{p}^{\uparrow} + \mathbf{p},\ \mathbf{Al},\ \mathbf{Au}$ collisions @ $\sqrt{s} = 200$ GeV

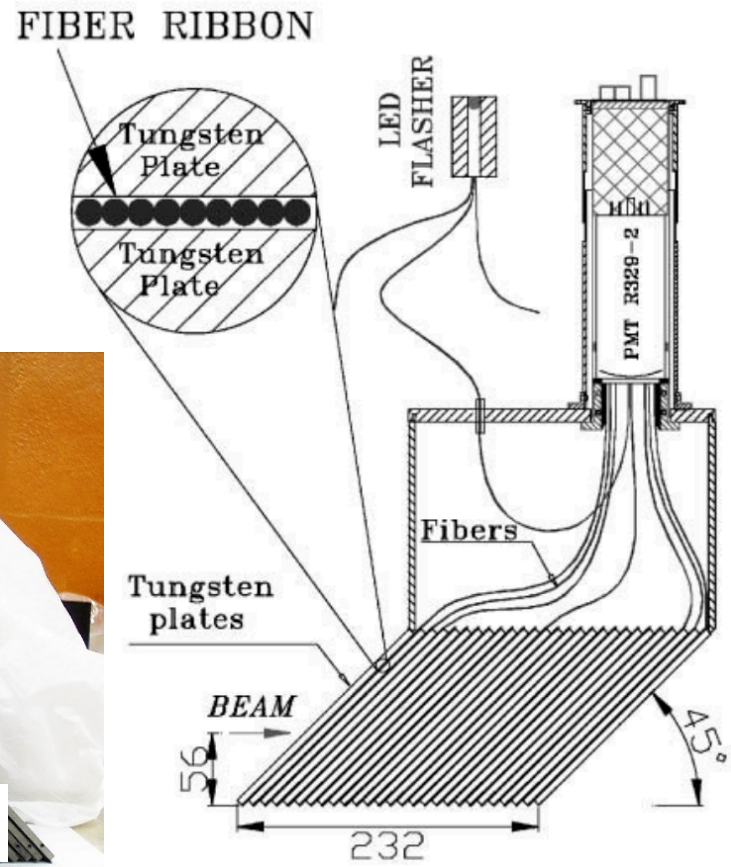
Zero Degree Calorimeter (ZDC)

- Cherenkov sampling hadron calorimeter
- Cu-W alloy + Optical fibers
- Energy resolution : ~ 20% at 50-100 GeV

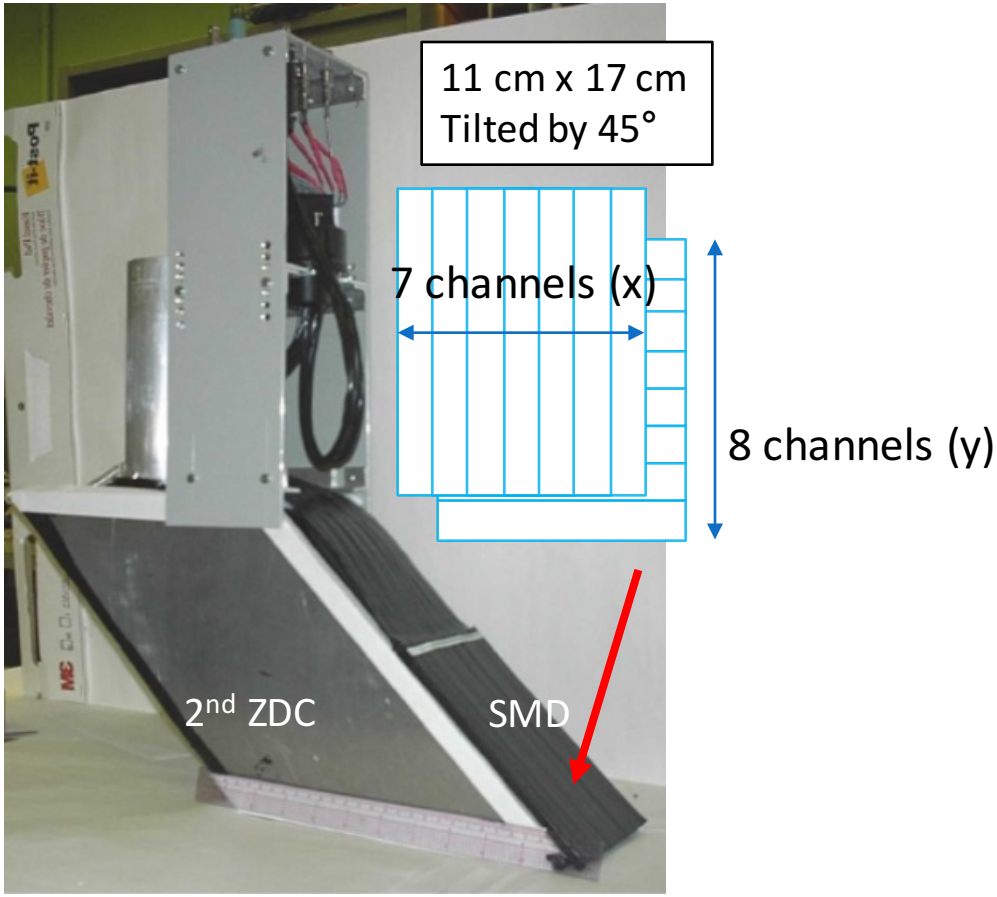


ZDC energy distribution for Cu+Cu collisions





Shower Max Detector (SMD)

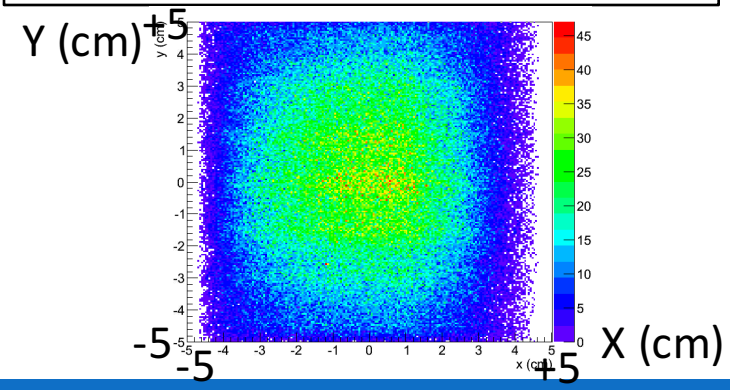


- Plastic scintillator strips
- Position calculation: centroid of shower

$$x, y = \frac{\sum_{ch\ (channel)}^{\#\ SMD} energy(ch) * position(ch)}{\sum energy(ch)}$$

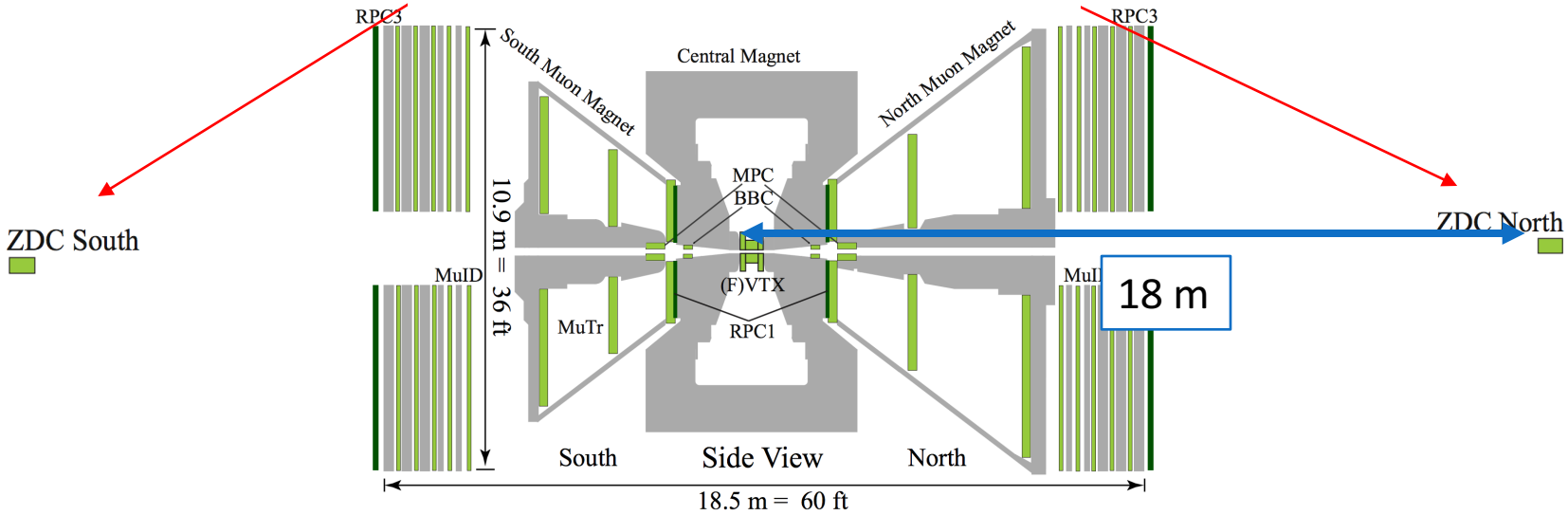
- Position resolution: ~1 cm at 50-100 GeV

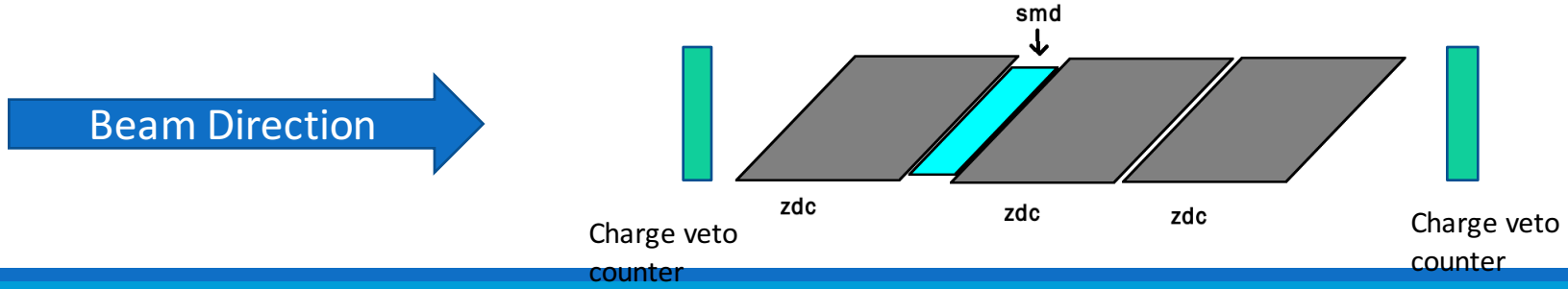
Reconstructed position distribution for $p^{\uparrow} + Au \rightarrow n + X$



Detector Layout

Neutron Detectors @ Zero Degree
Behind the Dx Magnets





Single Transverse Spin Asymmetry A_N

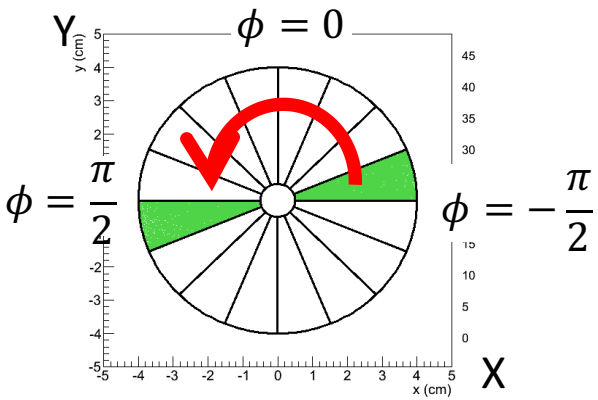
$$A_N \equiv \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}}$$

Also,

$$A_N = \frac{\sigma_L^{\uparrow} - \sigma_L^{\downarrow}}{\sigma_L^{\uparrow} + \sigma_L^{\downarrow}} = \frac{\sigma_R^{\downarrow} - \sigma_R^{\uparrow}}{\sigma_R^{\downarrow} + \sigma_R^{\uparrow}} = \frac{\sigma_L^{\uparrow} - \sigma_R^{\uparrow}}{\sigma_L^{\uparrow} + \sigma_R^{\uparrow}} = \frac{\sqrt{\sigma_L^{\uparrow}\sigma_R^{\downarrow}} - \sqrt{\sigma_L^{\downarrow}\sigma_R^{\uparrow}}}{\sqrt{\sigma_L^{\uparrow}\sigma_R^{\downarrow}} + \sqrt{\sigma_L^{\downarrow}\sigma_R^{\uparrow}}}$$

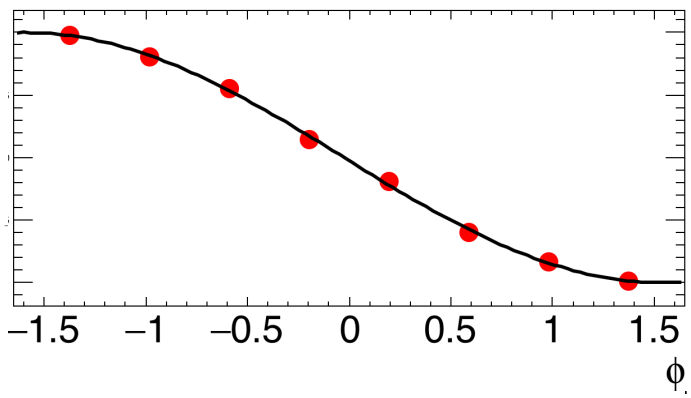
(Left-Right Asymmetry)

Measurement



- Raw asymmetry of neutron yields

$$e_N(\phi) \equiv \frac{\sqrt{N_\phi^\uparrow N_{\pi-\phi}^\downarrow} - \sqrt{N_\phi^\downarrow N_{\pi-\phi}^\uparrow}}{\sqrt{N_\phi^\uparrow N_{\pi-\phi}^\downarrow} + \sqrt{N_\phi^\downarrow N_{\pi-\phi}^\uparrow}}$$



- Normalization by polarization P
- Correction C_ϕ

$$A_N = \frac{e_N(\phi)}{\sin(\phi - \phi_0)} \frac{1}{C_\phi} \frac{1}{P}$$

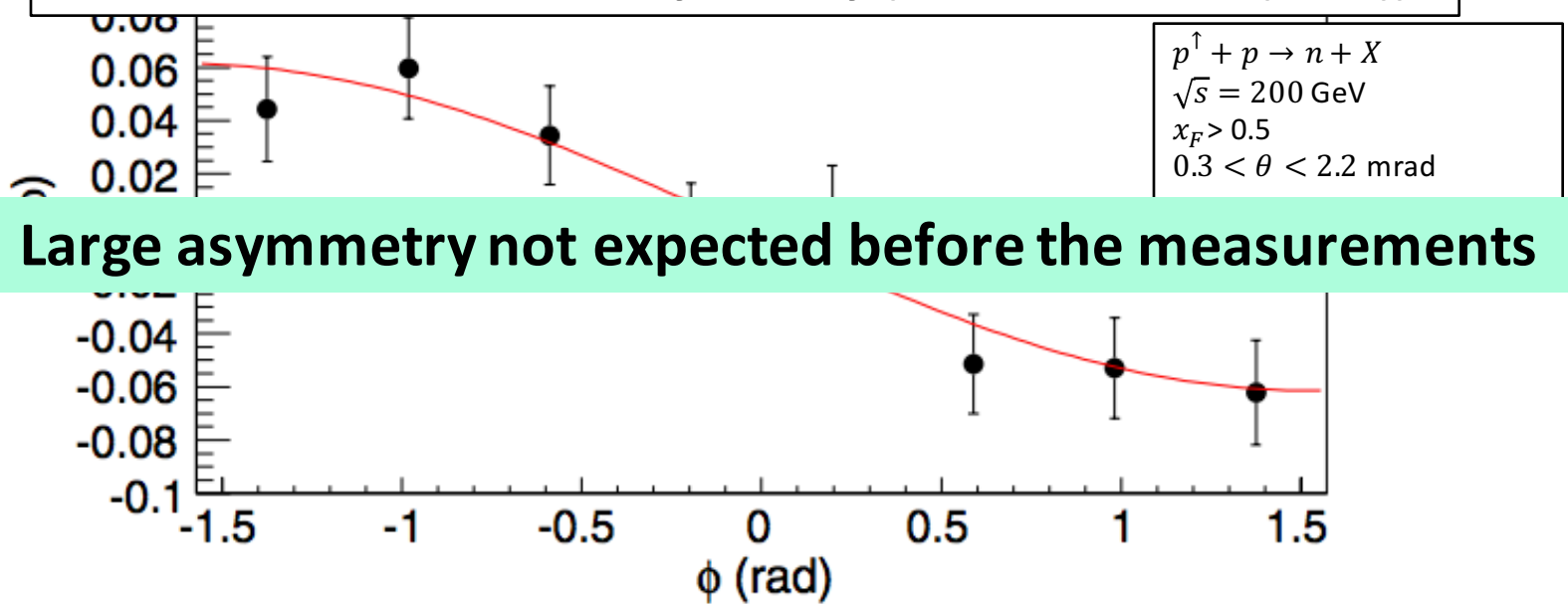
Previous Measurement

$$p^{\uparrow} + p \rightarrow n + X$$

A_N Result at PHENIX

- **Large forward neutron A_N discovered @ RHIC IP12 experiment (2002)**
- **Large forward neutron A_N measured @ PHENIX with dedicated neutron detectors (2006)**

PHENIX Forward Neutron Asymmetry (PRD 88, 032006 (2013))



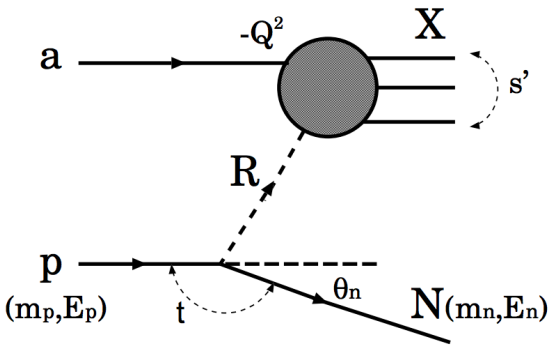
Large asymmetry not expected before the measurements

Origin of Nonzero A_N

$$A_N \equiv \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}} = \frac{\sum_X |< nX|T| \uparrow>|^2 - \sum_X |< nX|T| \downarrow>|^2}{\sum_X |< nX|T| \uparrow>|^2 + \sum_X |< nX|T| \downarrow>|^2}$$

$$p^{\uparrow} + a \rightarrow n + X$$

Reggeon exchange model



Using

$$| \uparrow> = \frac{1}{\sqrt{2}}(|+> + i|->) \ \& \ | \downarrow> = \frac{1}{\sqrt{2}}(|+> - i|->)$$

$$\sum_X |< nX|T| \uparrow>|^2 - \sum_X |< nX|T| \downarrow>|^2 =$$
$$\mathbf{-2Im\sum_X < nX|T|->< +|T^+|nX >}$$

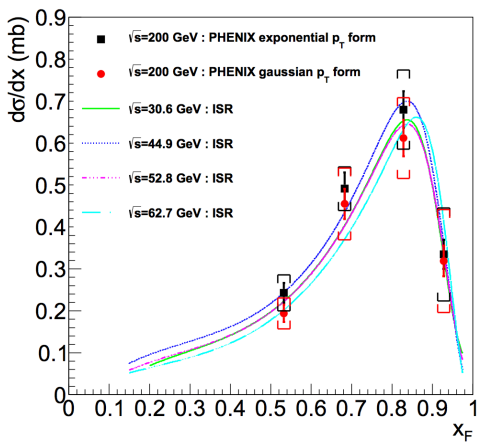
$A_N \neq 0$ if

$\exists$ Nonzero term for interference between spin-flip and nonflip interaction with different phase

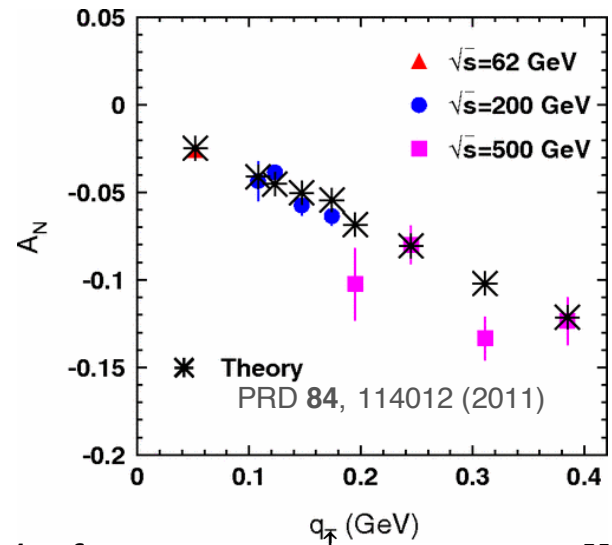
$p + p \rightarrow n + X$
Theory & PHENIX Data

Non-perturbative ($p_T < 0.22$GeV @ $\sqrt{s} = 200$ GeV)-> pQCD not applicable

There are theories to describe cross-section, and A_N of very forward neutron production **: One Pion Exchange model in Regge framework explain pp collision data well.**



✓ Peak at $x_F \cong 0.8$



✓ A_N for PHENIX $p^{\uparrow} + p \rightarrow n + X$ data

Theoretical Development

Approach	Cross section description	A_N description	Details
1. One π exchange with Born approximation	△	✗	• π pole at wave function $\frac{1}{m_\pi^2 - t}$ -> cross section peak at $x_F \cong 0.8$ • Overshoots cross section • $A_N = 0$: No phase shift with Born Approx.
2. One π exchange with absorptive correction	○	△	• Survival probability multiplied to final state function -> suppressed cross section • $A_N \neq 0$, but too small
3. <u>π exchange + Interference btw π and a_1 Reggeon</u>	○	○	• Interference btw π and a_1 makes large A_N • a_1 form factor is not known. A model is applied for this calculation.

New Measurement

$$p^{\uparrow} + A \rightarrow n + X$$

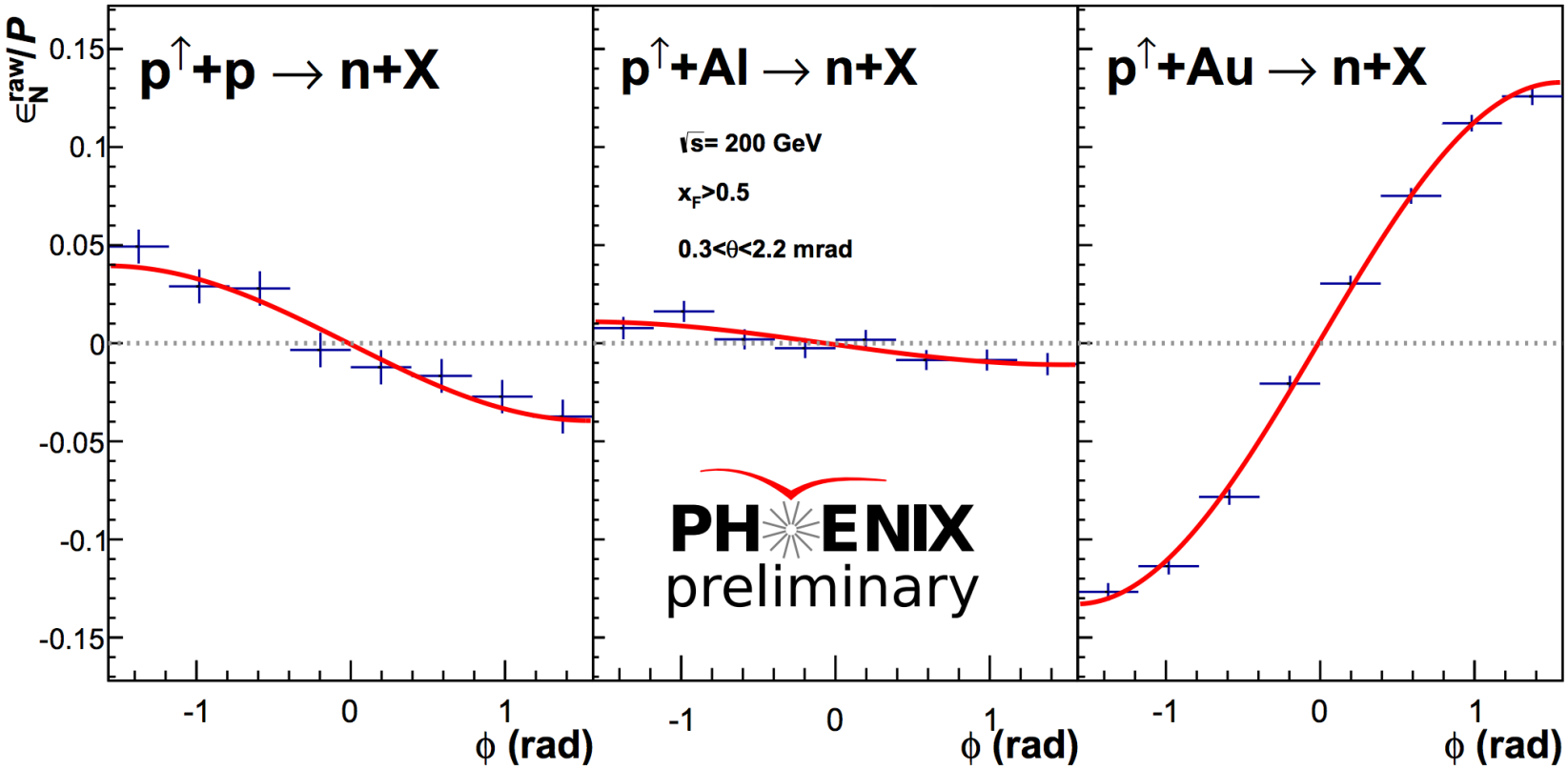
What's new?

- We had $\mathbf{p}^{\uparrow} + \mathbf{p}$, $\mathbf{Al}$, & $\mathbf{Au}$ collisions in Run15.
- The first high energy asymmetry measurement with polarized proton-nucleus collision

Q:

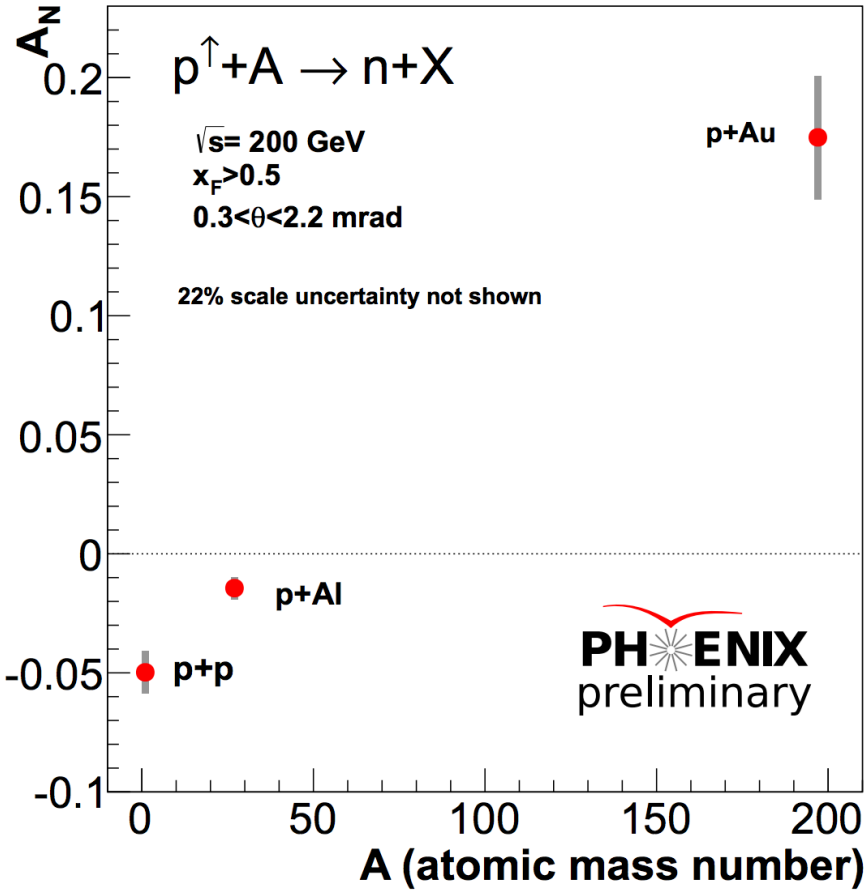
- A_N vs A?
- Theory for $\mathbf{p}^{\uparrow} + \mathbf{p}$ still fits $\mathbf{Al}$ & $\mathbf{Au}$ result?

$\frac{e_N(\phi)}{P}$: Raw asymmetries e_N normalized by polarizations P (Run15)



$A_N < 0$ $A_N < 0$ $A_N > 0$

A_N dependence on A (Run15)



What's going on p+Al, p+Au?

Unexpected A dependence of A_N is observed.

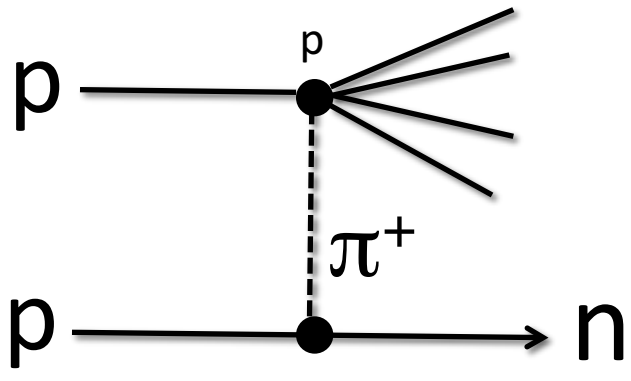
- A_N changes sign from p+p to p+Au.
- The A_N magnitude increases by factor of ~3 from p+p to p+Au.

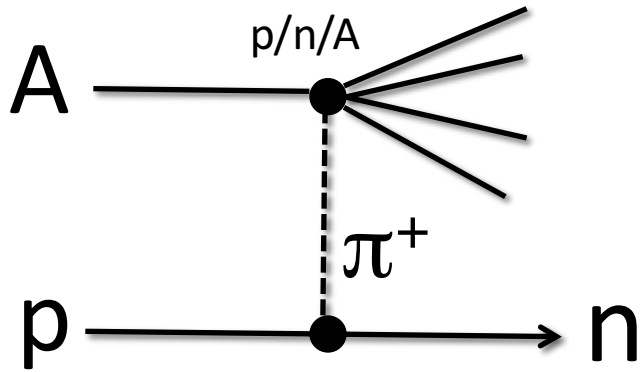
No theoretical prediction is made for p+Al, p+Au before the experiment.

Major theoretical development?

- Any isospin effect taken account for neutron?
- Nuclear effect (nucleus size, neutron skin, coherent effect, etc.)?

Discussion





	Z	N	A
p	1	0	1
Al	13	14	27
Au	79	118	197

- Interference btw π and a_1 Reggeon plays important role in A_N^{pp}.
- Comparing A_N^{pp}, A_N^{pAl} and A_N^{pAu} may give hint if A_N depends on A (coherent effect), N (isospin effect), or else.

Summary

- Cross section, and A_N of PHENIX $\mathrm{p}^{\uparrow} + \mathrm{p}$ collision are well described by π exchange and interference between π and a_1 Reggeon in Regge framework.
- In Run15, forward neutron A_N was measured for $\mathrm{p}^{\uparrow} + \mathrm{p},\ \mathrm{Al},\ \&\ \mathrm{Au}$ collisions @ $\sqrt{s} = 200$ GeV – the first measurement of the role of isospin, and nuclear effects on the asymmetry.
- A_N changes sign from p+p to p+Au.
- A_N magnitude increases by factor of ~3 from p+p to p+Au.
- The result is quite unexpected from current theory.

Thank you!

Back up

Basic Analysis Cut

- Trigger : ZDCN || ZDCS for pp, ZDCN for pA
- ADC gate open (Event QA):
  - TDC < 3800 & ADC > 470 (already cut by energy cut)
- #SMD strips over the threshold
  - #SMD>1 both X,Y (photon rejection)
- Timing cut
  - TDC > 1000 – 10*energy (To remove events not from collisions)
- Front charge veto:
  - ADC value –pedestal < 50 ADC
- (Rear charge veto):
  - (ADC value –pedestal < 50 ADC)
- Energy:
  - 40-120 GeV (before unfolding)
- Acceptance:
  - 0.5 cm < r < 4.0 cm