Inclusive cross section and single transverse-spin asymmetry of very forward neutron production at PHENIX

Spin2012 in Dubna

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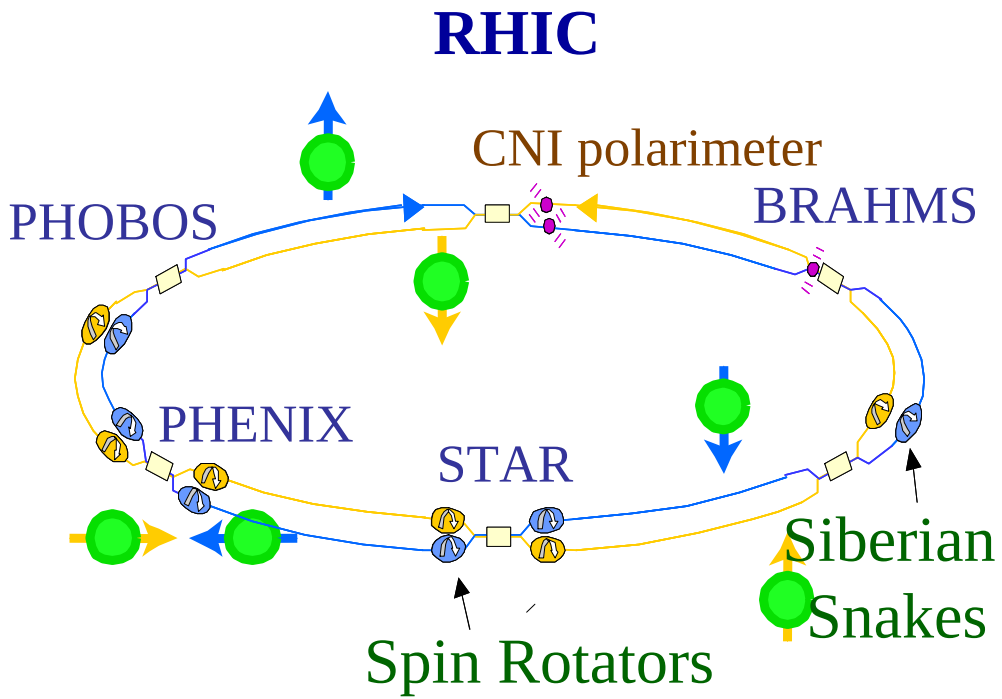
for the PHENIX Collaboration

Outline

- Very forward (and backward) neutron production in polarized *p+p* collisions at RHIC-PHENIX
- Inclusive cross section and single transverse-spin asymmetry at $\sqrt{s}$ = 200 GeV
  - x_F dependence
  - 2005 result
  - arXiv:1209.3283 [nucl-ex]
- Single transverse-spin asymmetry at $\sqrt{s}$ = 62.4 GeV, 200 GeV and 500 GeV
  - $\sqrt{s}$ dependence
  - 2006 (62.4 GeV) & 2009 (500 GeV) preliminary results

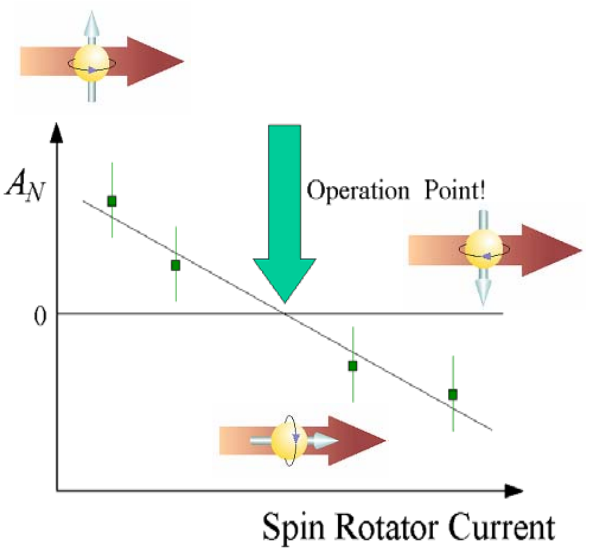
Introduction

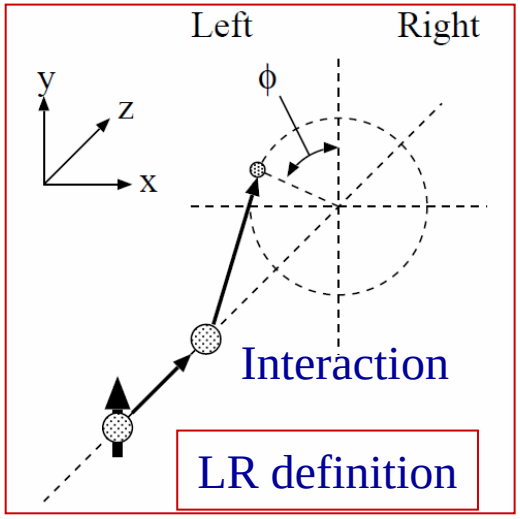
- For A_{LL} measurement at RHIC, we need a good local polarimeter at the IP (interaction point)
- At RHIC, protons are stored with transverse polarization
  - Monitored by the CNI polarimeter and polarized Hydrogen gas-jet polarimeter
- Spin rotator magnets rotate the proton polarization into the longitudinal direction at PHENIX (IP8) and STAR (IP6)



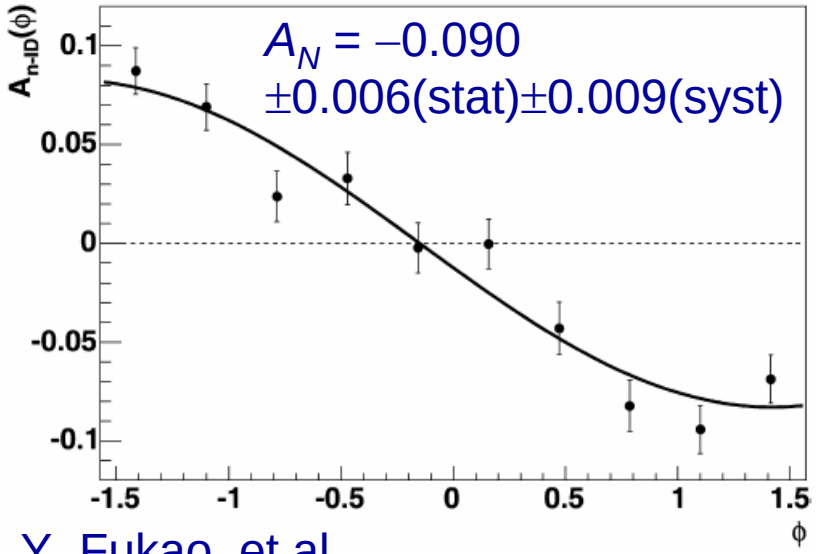
Introduction

- Longitudinal-spin is monitored by the local polarimeter by using physics processes with left-right asymmetry (A_N)
- A_N of forward π^0 found at FNAL-E704
  - Only very forward region was available at PHENIX
  - But, there was no measurement at very forward
- Measurement at IP12 in Run2 (2001-02)
  - With EM calorimeter to measure A_N of photons mainly from π^0 decay → too small to measure
  - Very large asymmetry of very forward neutron was found





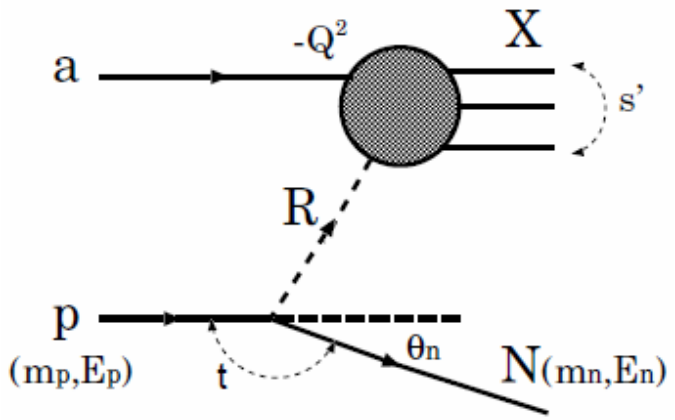
$$A_N \equiv \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}} = \frac{\sigma_L^{\uparrow} - \sigma_R^{\uparrow}}{\sigma_L^{\uparrow} + \sigma_R^{\uparrow}}$$

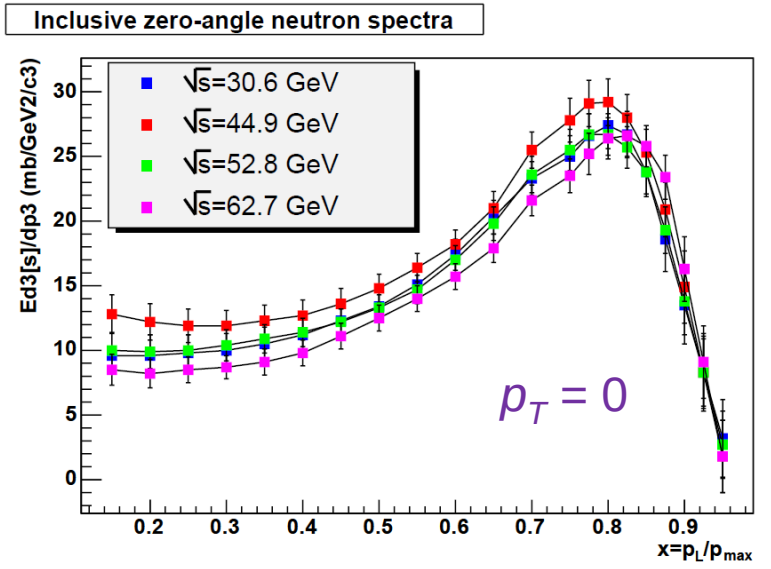


Y. Fukao, et al.,
Phys. Lett. B 650 (2007) 325.

Forward neutron production

- Cross section measurement at ISR/FNAL
  - Forward peak in the x_F distribution
    - around x_F~0.8
  - Only a small $\sqrt{s}$ dependence
- OPE (one-pion exchange) model gives a reasonable description





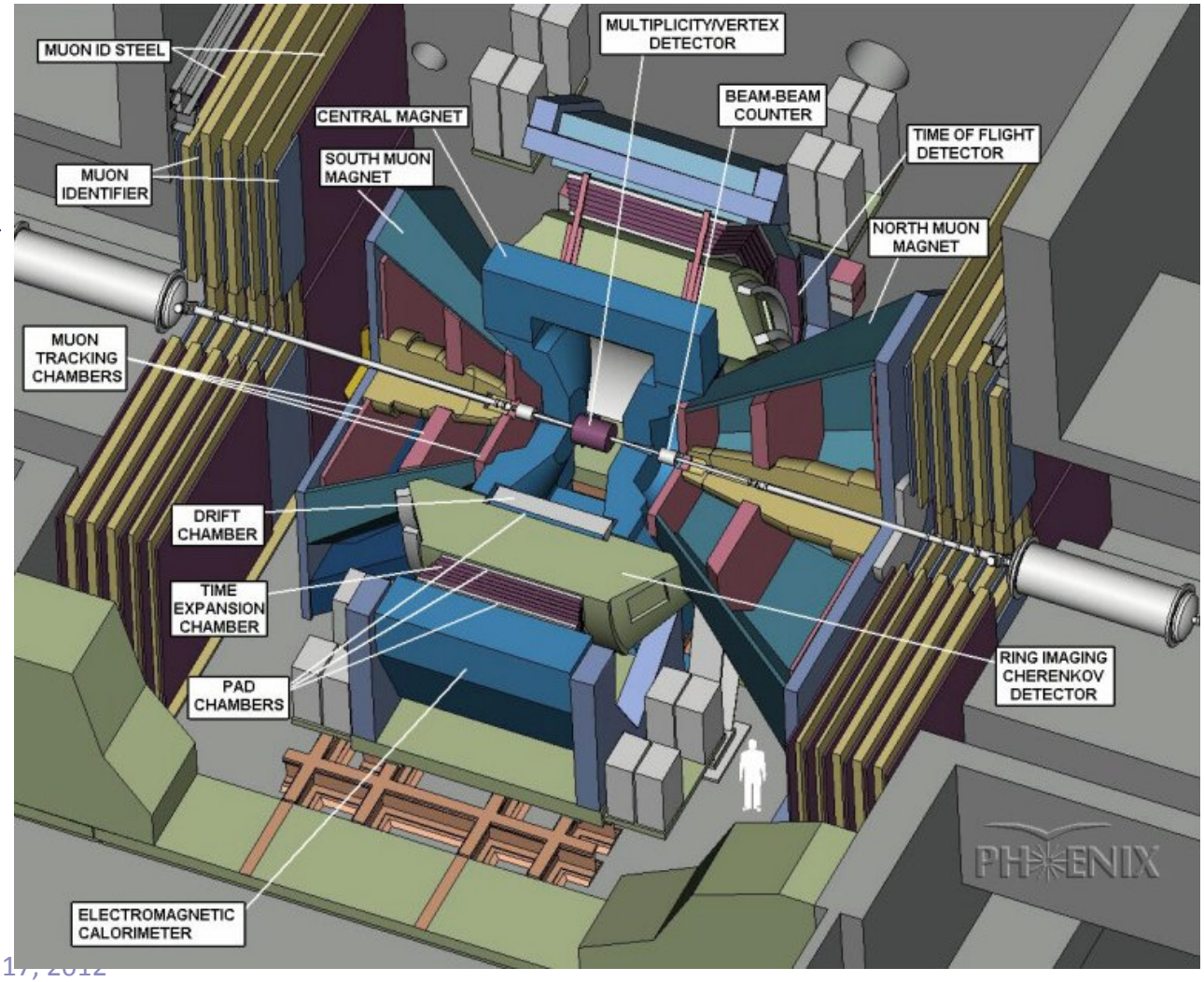
- Cross section measurement at HERA(e+p)/NA49(p+p)
  - $\sqrt{s}$ dependence indicated
  - Suppression of the forward x_F peak at high $\sqrt{s}$?
- More data necessary to understand the production mechanism
  - Asymmetry measurement as a new independent input

No cross section measurement performed at IP12 experiment
→ measurement at PHENIX

PHENIX local polarimeter

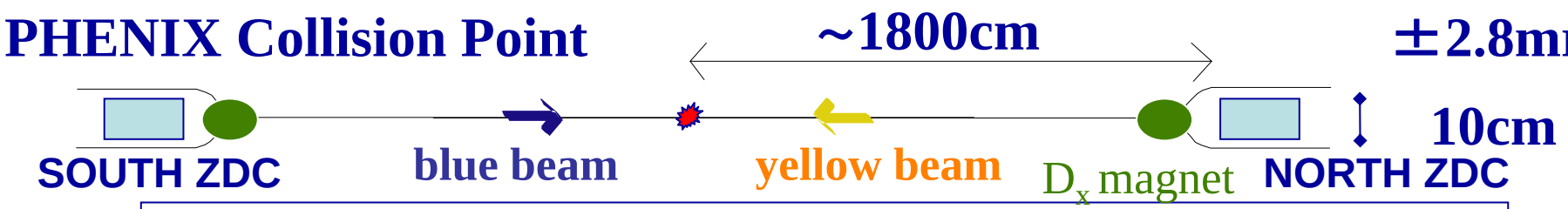
- There have existed ZDCs (Zero Degree Calorimeter) to detect neutrons at PHENIX
- SMDs (Shower Maximum Detector) were added to measure the hit position of neutrons

ZDC



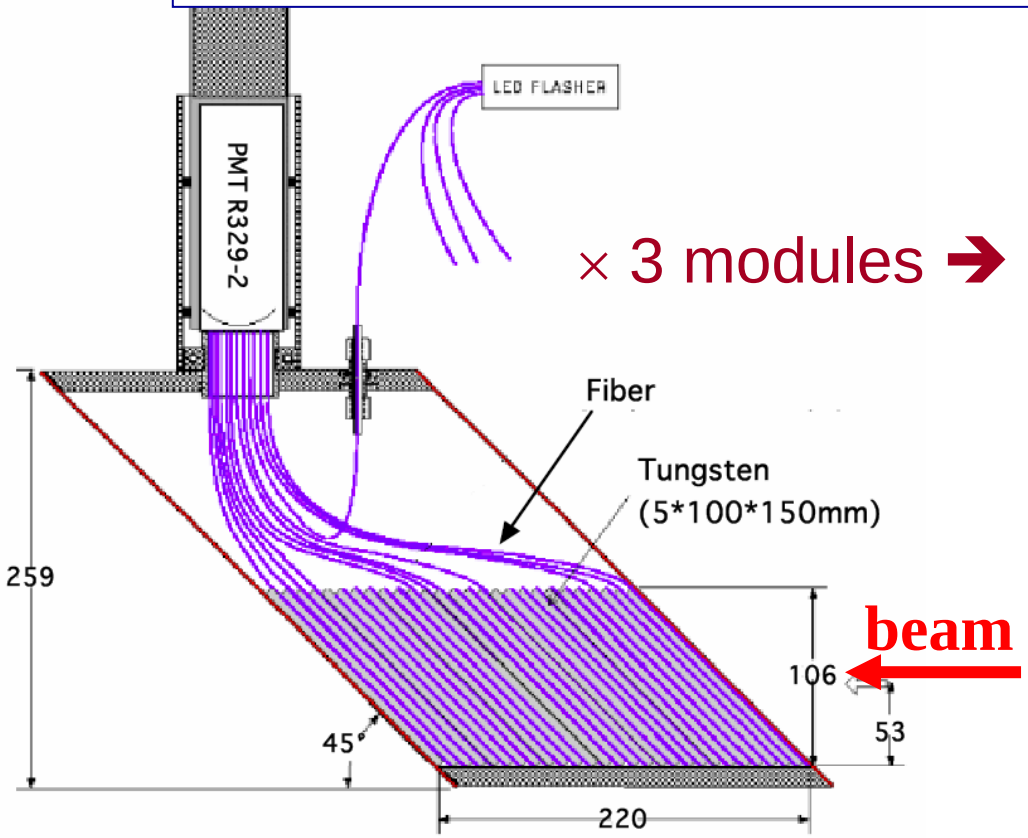
ZDC
@ 18m away
from the IP

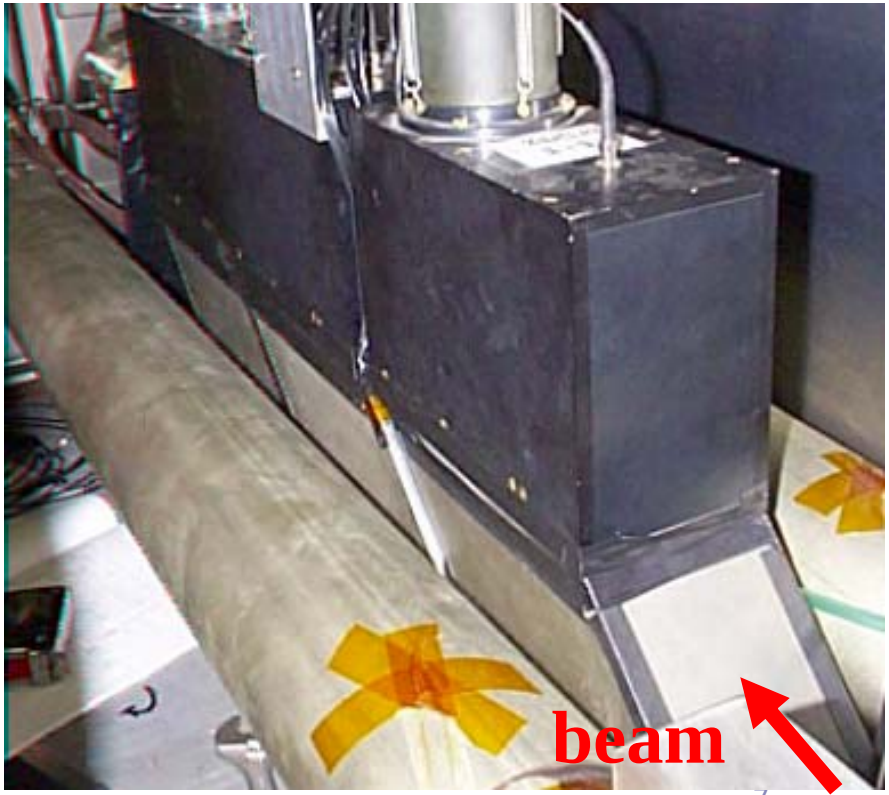
ZDC (Zero Degree Calorimeter)



hadron sampling calorimeter made of Tungsten plate and fibers

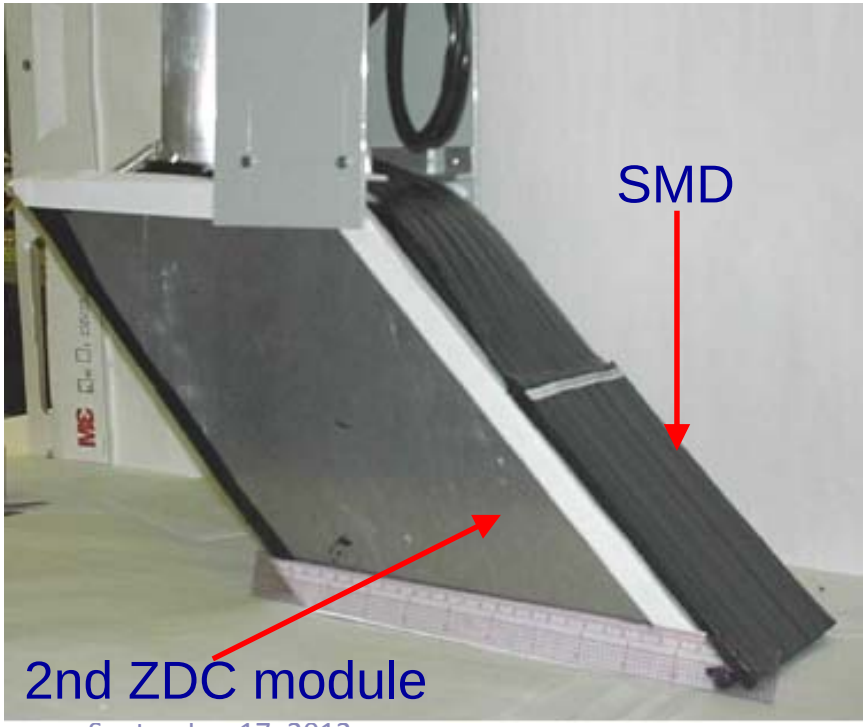
5.1 λ_T 149X_0 (3 ZDCs), Energy resolution ~ 20% @ 100GeV

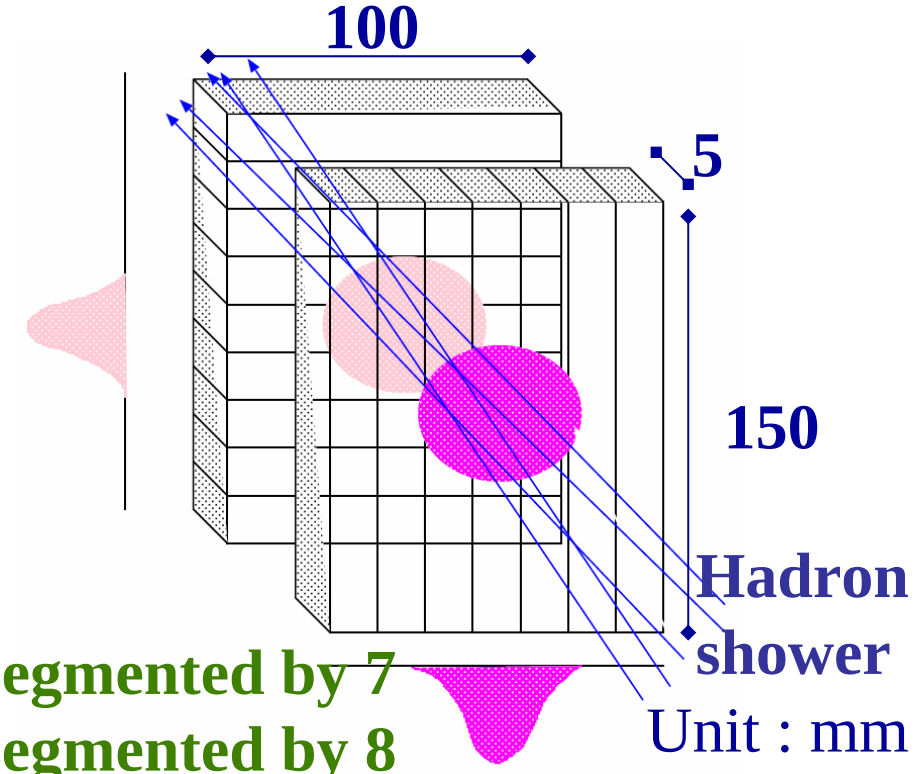




Shower Maximum Detector

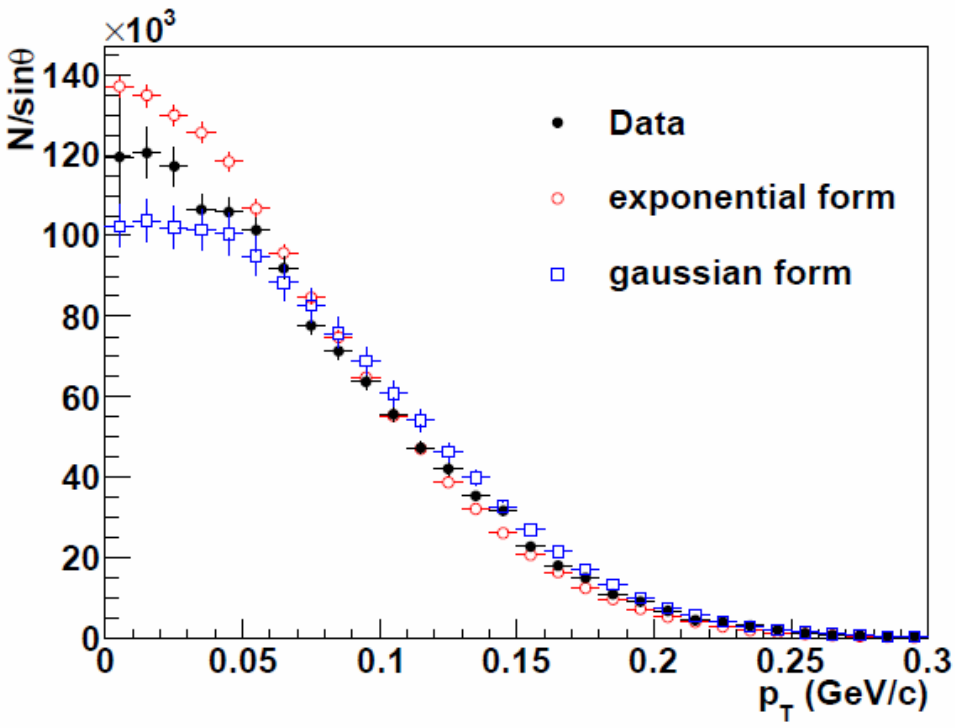
- To measure the neutron hit position, SMDs (Shower Maximum Detector) were installed between 1st and 2nd modules of ZDC
  - arrays of plastic scintillators
  - giving a position by calculating the center of gravity of shower generating in the 1st ZDC module
  - position resolution ~1cm @ 50GeV neutron (simulation study)





Inclusive cross section at $\sqrt{s}$ = 200 GeV

- x_F distribution measurement
  - With hadron calorimeter
- p_T range & resolution limited
  - $0 < p_T < 0.11\ x_F$ GeV/c
  - Limited by ZDC acceptance
  - Limited by SMD position resolution
- p_T shape assumed
  - gaussian form (HERA form)
  - exponential form (ISR form)
- Comparison of p_T distribution from experimental data and two simulations including p_T resolution



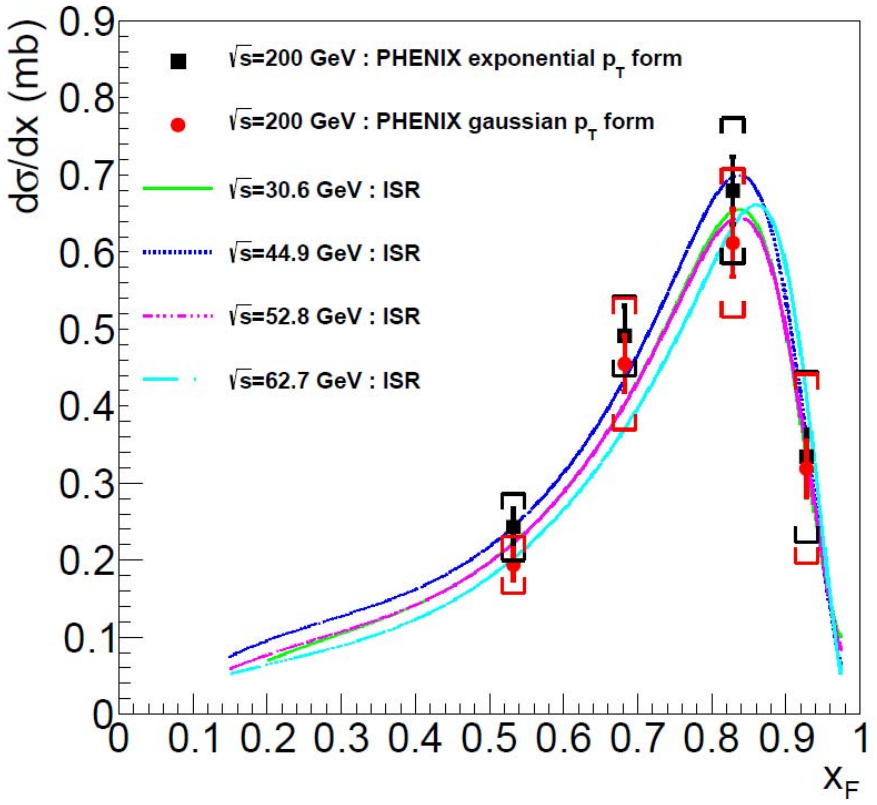
Difference between data and two simulations are not large

Inclusive cross section at √s = 200 GeV

- Systematic uncertainties
  - p_T distribution form
  - Beam center shift
    - Possible ~1 cm shift
  - Proton background
    - Scattered forward proton could hit the DX magnet or beam pipe
  - Multiple hit
- Absolute normalization
  - 9.7% (22.9±2.2 mb for the BBC trigger cross section)
- Energy unfolding
  - ref. V. Blobel, arXiv:hep-ex/0208022

TABLE II: Systematic uncertainties for the cross section measurement. The absolute normalization error is not included in these errors. The absolute normalization uncertainty was estimated by BBC counts to be 9.7% (22.9±2.2 mb for the BBC trigger cross section).

	exponential p_T form	Gaussian p_T form
p_T distribution	3 – 10%	7 – 22%
beam center shift	3 – 31%	
proton background	3.6%	
multiple hit	7%	
total	11 – 33%	16 – 39%



Consistent with x_F scaling from ISR results

Single transverse-spin asymmetry at $\sqrt{s}$ = 200 GeV

PHENIX

- Square-root formula
  - P: polarization, C_ϕ: smearing correction
  - sine fit $\rightarrow A_N$
- Systematic uncertainties
  - p_T correlated
    - Beam center shift
  - Scale uncertainties
    - Proton background
    - Multiple hit
    - Smearing by position resolution
- Polarization scale uncertainties from RHIC polarimeters
  - 6.2% for the Yellow beam
  - 5.9% for the Blue beam

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

$$\mathcal{A}(\phi) = \frac{1}{P}\frac{1}{C_\phi}\epsilon_N(\phi)$$

$$\mathcal{A}(\phi) = A_N \sin(\phi - \phi_0)$$

TABLE IV: Scale uncertainties for the A_N measurements.

	ZDC trigger	ZDC⊗BBC trigger
proton background	2.1%	1.5%
multiple hit	6.5%	5.9%
smearing	4.2%	
total	8.0%	7.4%

Single transverse-spin asymmetry at $\sqrt{s}$ = 200 GeV

PHENIX

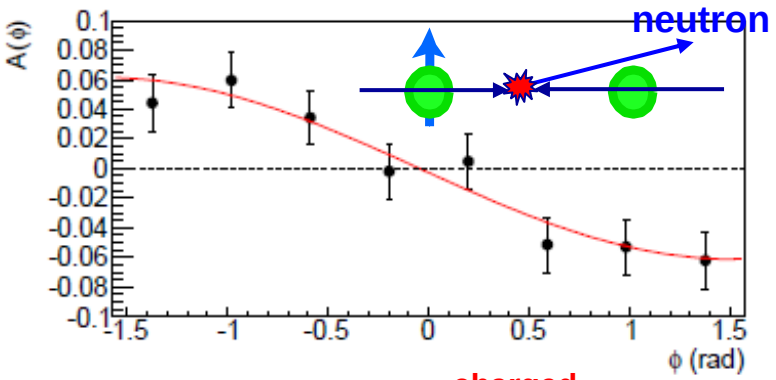
Inclusive neutron trigger (ZDC trigger)

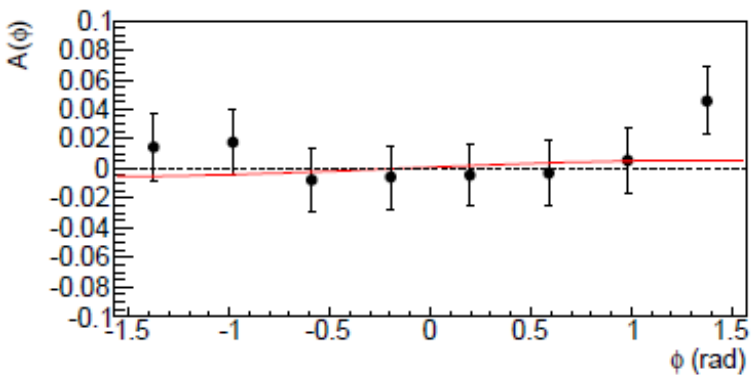
Forward asymmetry

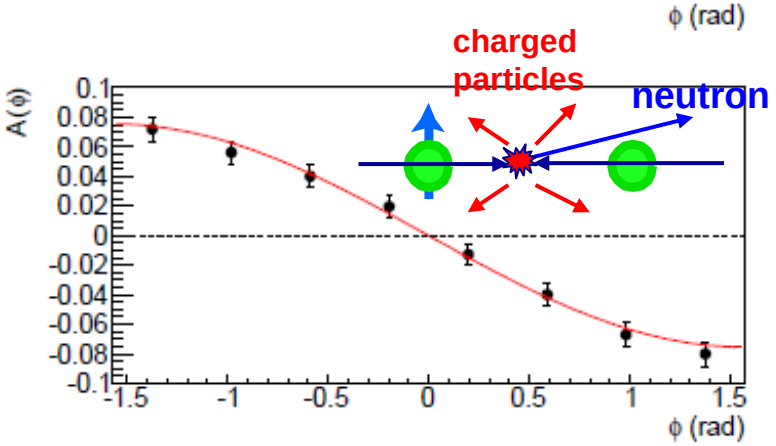
A_N = –0.061±0.010(stat)±0.004(syst)

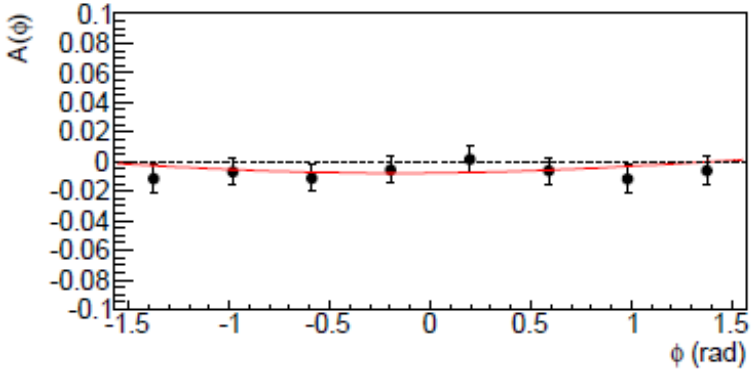
Backward asymmetry

A_N = –0.006±0.011(stat)±0.004(syst)









Interaction trigger with charged particles in beam-beam counter (ZDC⊗BBC trigger)

Forward asymmetry

A_N = –0.075±0.004(stat)±0.004(syst)

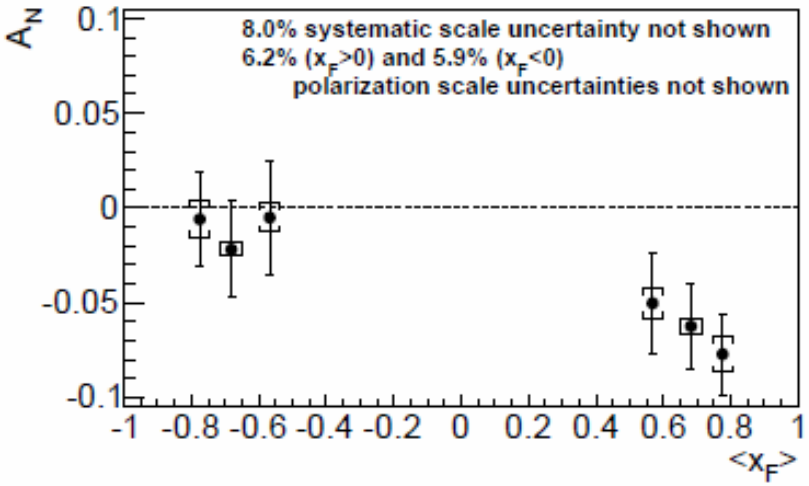
Backward asymmetry

A_N = –0.008±0.005(stat)±0.004(syst)

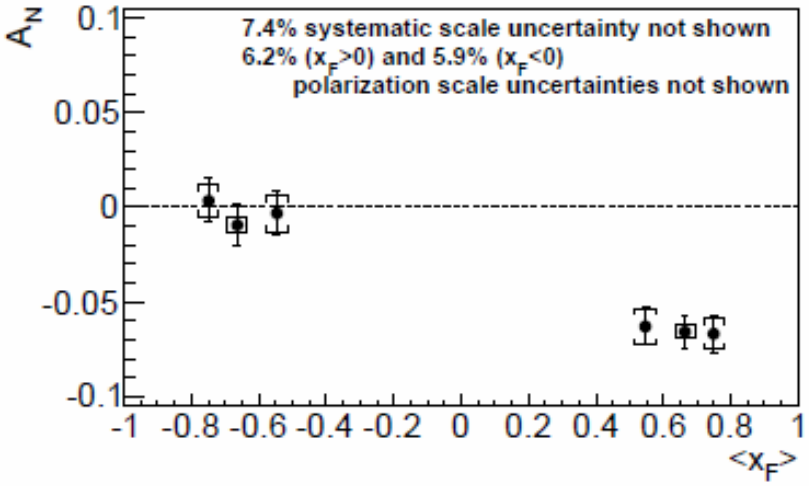
Single transverse-spin asymmetry at √s = 200 GeV

- Comparison to IP12 experiment
  - ZDC⊗BBC trigger results
  - PHENIX
    - $A_N = -0.075 \pm 0.004(\text{stat}) \pm 0.004(\text{syst})$
  - IP12
    - $A_N = -0.090 \pm 0.006(\text{stat}) \pm 0.009(\text{syst})$
  - Consistent within the errors
  - Higher precision
- x_F dependence
  - Significant negative A_N in the forward region
    - No x_F dependence within the uncertainties
  - No significant backward asymmetry

ZDC trigger

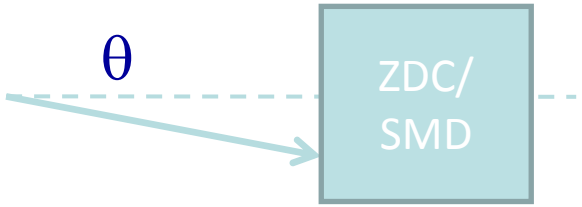


ZDC⊗BBC trigger



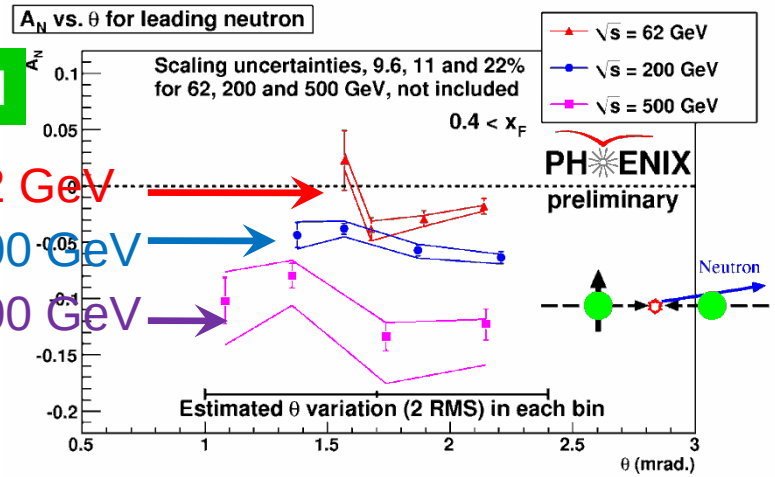
√s dependence

- θ distribution
  - Inclusive neutron

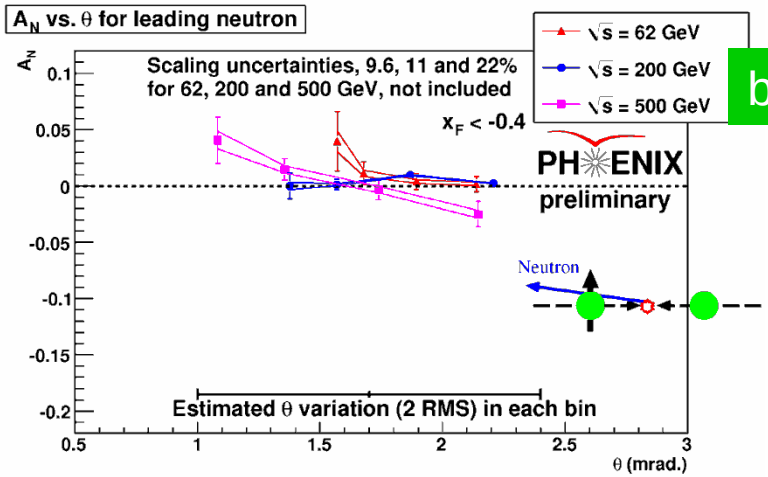


forward

√s = 62 GeV
√s = 200 GeV
√s = 500 GeV

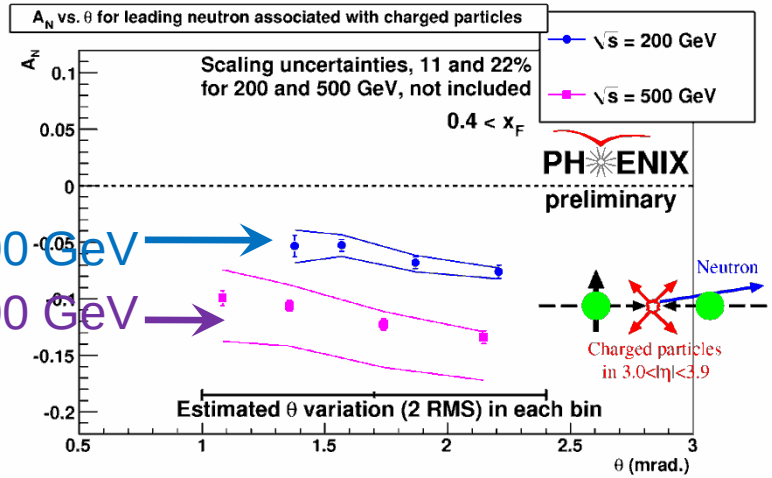


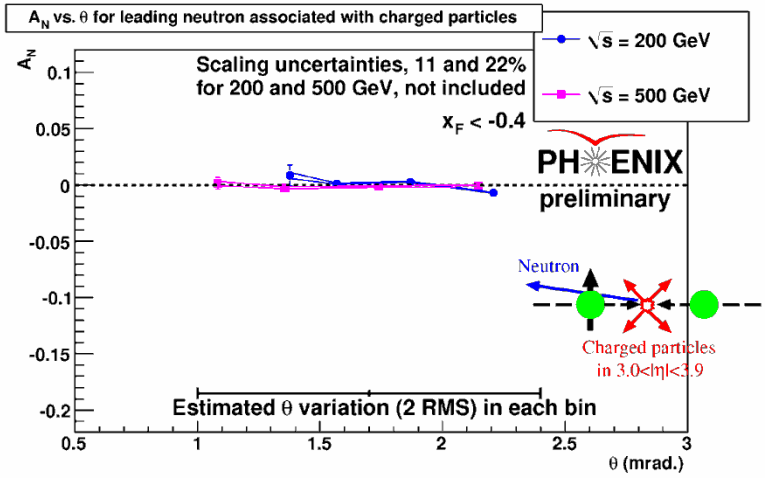
backward



  - Neutron with charged particles (in beam-beam counter)

√s = 200 GeV
√s = 500 GeV

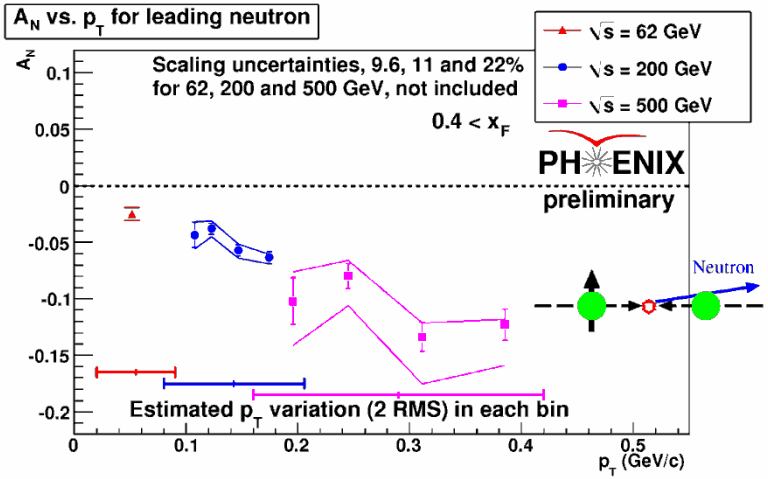




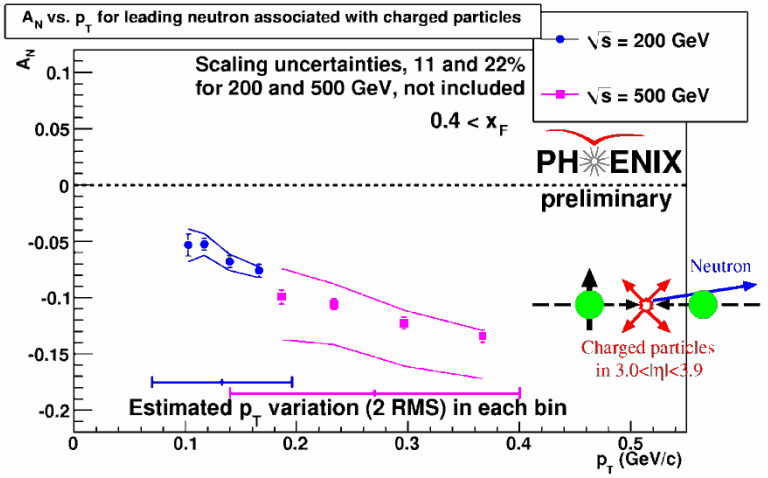
√s dependence

- p_T distribution
  - $p_T \sim x_F \cdot \sqrt{s} / 2 \cdot \theta$
  - Assuming p_T shape of ISR
  - No smearing correction (no-unfolding)
    - wide p_T deviation for each bin

Inclusive neutron



Neutron with charged particles



- $A_N(62\ \text{GeV}) < A_N(200\ \text{GeV}) < A_N(500\ \text{GeV})$
- √s dependence or p_T dependence?

Forward neutron production

- Interference between spin-flip and non-flip with a relative phase

$$A_N \approx \frac{2\,\mathrm{Im}\left(fg^*\right)}{|f|^2+|g|^2}$$

f : spin non-flip amplitude
g : spin flip amplitude

- Pion exchange
  - Kopeliovich, Potashnikova, Schmidt, Soffer: Phys. Rev. D 78 (2008) 014031.
  - Spin-flip amplitude and non-flip amplitude have the same phase
    - No single transverse-spin asymmetry can appear
  - Absorption correction for a relative phase
    - Initial/final state interaction
    - Also important for cross section calculation
    - Gained shift between spin-flip and non-flip amplitudes is too small to explain the large asymmetry
- Interference with other Reggeons
  - Kopeliovich, Potashnikova, Schmidt, Soffer: Phys. Rev. D 84 (2011) 114012.
  - a_1 axial-vector meson
    - Pion-a_1 interference
    - π-ρ in 1^+S state instead of a_1

Forward neutron production

- Pion-a_1 interference: results
  - The data agree well with independence of energy
- The asymmetry has a sensitivity to presence of different mechanisms, e.g. Reggeon exchanges with spin-non-flip amplitude, even if they are small amplitudes

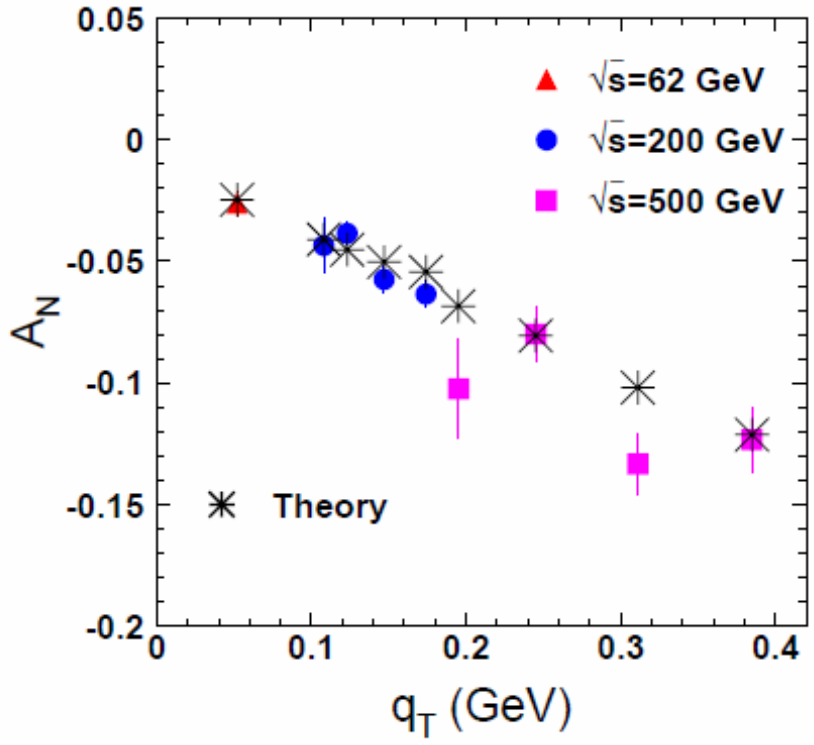


FIG. 1: (Color online) Single transverse spin asymmetry A_N in the reaction $pp \to nX$, measured at $\sqrt{s} = 62,\ 200,\ 500\,\text{GeV}$ [1] (preliminary data). The asterisks show the result of our calculation, Eq. (38), which was done point by point, since each experimental point has a specific value of z (see Table I).

Summary

- Very forward (and backward) neutron production in polarized *p+p* collisions at PHENIX
  - Inclusive cross section at $\sqrt{s}$ = 200 GeV
    - consistent with x_F scaling from ISR results
  - Single transverse-spin asymmetry at $\sqrt{s}$ = 200 GeV
    - consistent with IP12 measurement with higher precision
    - x_F dependence
  - Single transverse-spin asymmetry at $\sqrt{s}$ = 62.4 GeV, 200 GeV and 500 GeV
    - $\sqrt{s}$ dependence or p_T dependence
- Production mechanism
  - Pion-a_1 interference (Kopeliovich et al.)
  - Sensitivity of asymmetry measurement to presence of different mechanism
- Local polarimeter
  - to monitor beam polarization and polarization direction