First spin results with PHENIX in RHIC Run-2 p+p collisions

Hiroki Sato, Kyoto Univ./RIKEN

DIS'03, St. Petersburg, Russia

April 24, 2003

Outline

- Spin Physics at RHIC
- Results with the PHENIX detector in Run-2 (2001-2002) p+p collisions
  - Cross sections
  - Single spin asymmetries (A_N)
- Future plan

Spin Physics at RHIC

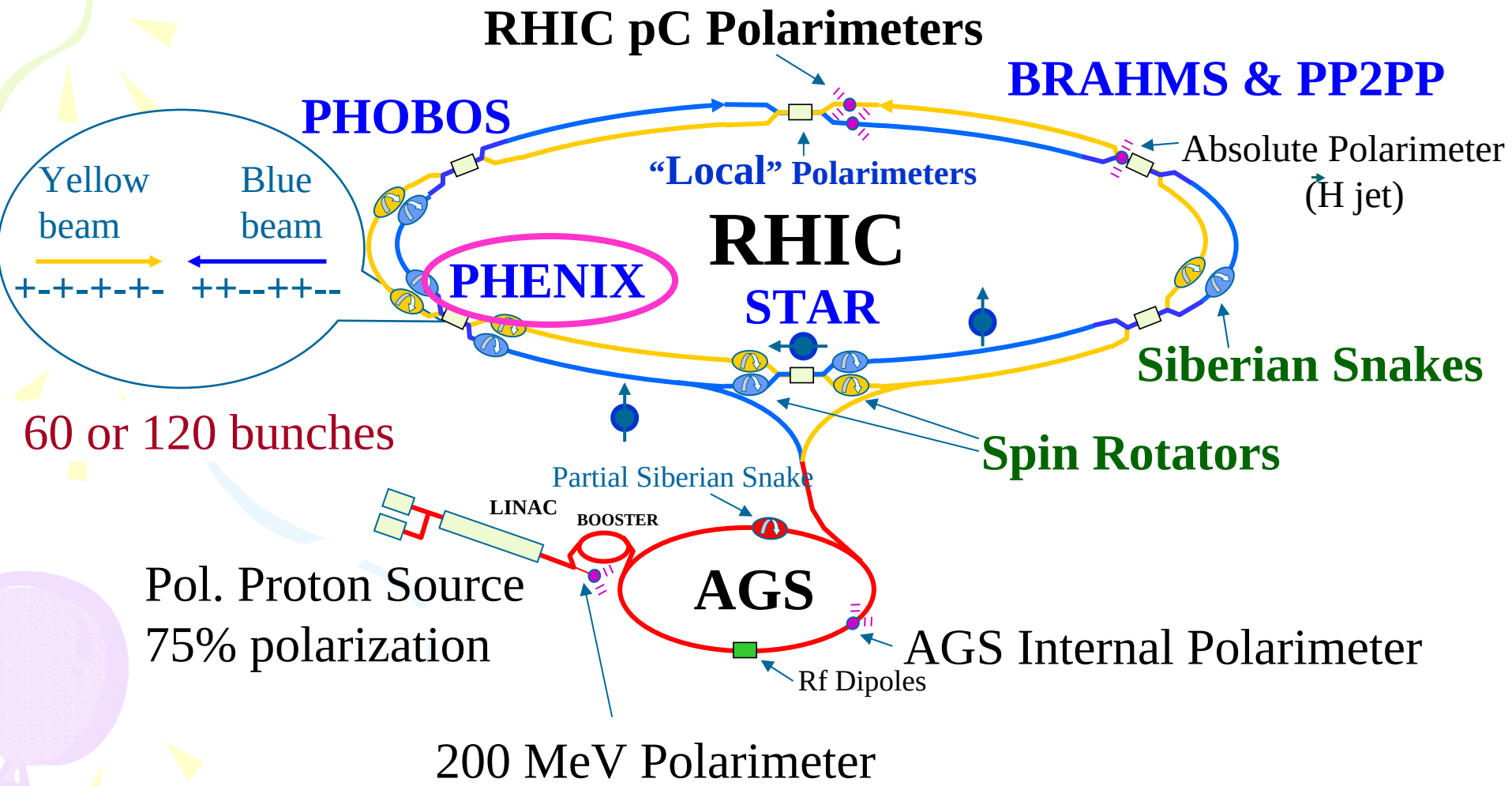
Polarized p+p collisions at high energy ($50 < \sqrt{s} < 500$ GeV) enable us to study

- Spin structure of the nucleon
  - Direct measurement of polarized gluon distribution G(x)
  - Flavor sensitive measurement of polarized anti-quark distribution $\bar{q}(x)$
- Parity violating spin symmetries for physics beyond standard model

Relativistic Heavy-Ion Collider

Polarized proton collider RHIC

70% Polarization $L_{max} = 2 \times 10^{32} s^{-1} cm^{-2}$ $50 < \sqrt{s} < 500 GeV$



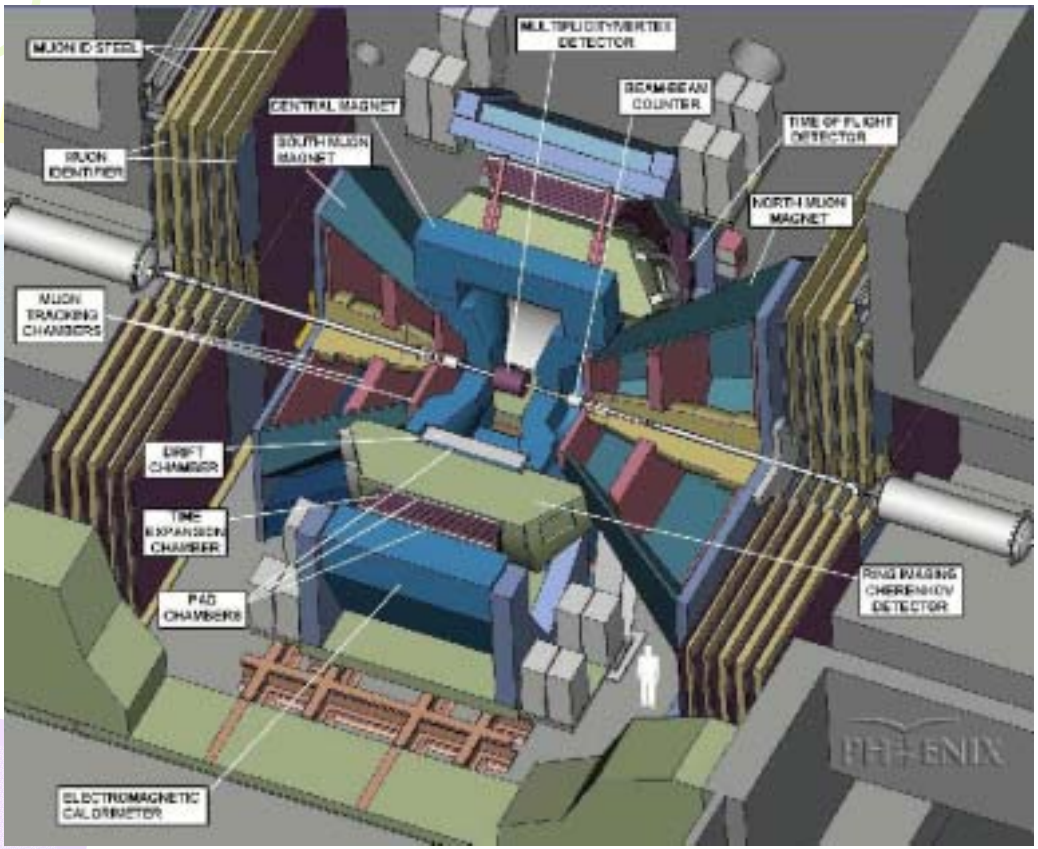
Illustrated by Thomas Roser

RHIC Run-2 p+p condition

First polarized p+p collisions has achieved at $\sqrt{s}$ = 200 GeV

- $\langle P_B \rangle_{Yellow}$ ~ 0.17, $\langle P_B \rangle_{Blue}$ ~ 0.14
- Transversely polarized protons → measurements of A_N (left-right asymmetries) with various channels
- L_{int} ~ 150nb^{-1} (triggered data) with PHENIX

The PHENIX Detector



- e, γ, $h^{\pm}$ (Central Arms)
  - $|\eta| < 0.35$, $\Delta\varphi = \pi$
  - $p_T > 0.2$ GeV/c
- μ (Muon Arms)
  - $1.2 < |\eta| < 2.4$, $\Delta\varphi = 2\pi$
  - $p_{tot} > 2$ GeV/c
- Interaction-trigger and vertex Detectors
  - Beam-Beam Counters ($3.0 < |\eta| < 3.9$)
  - Zero-Degree Calorimeters ($|\eta| > 6.2$)
  - Normalization Trigger Counters ($1.1 < |\eta| < 2.8$)

The Beam-Beam Counters (BBC)

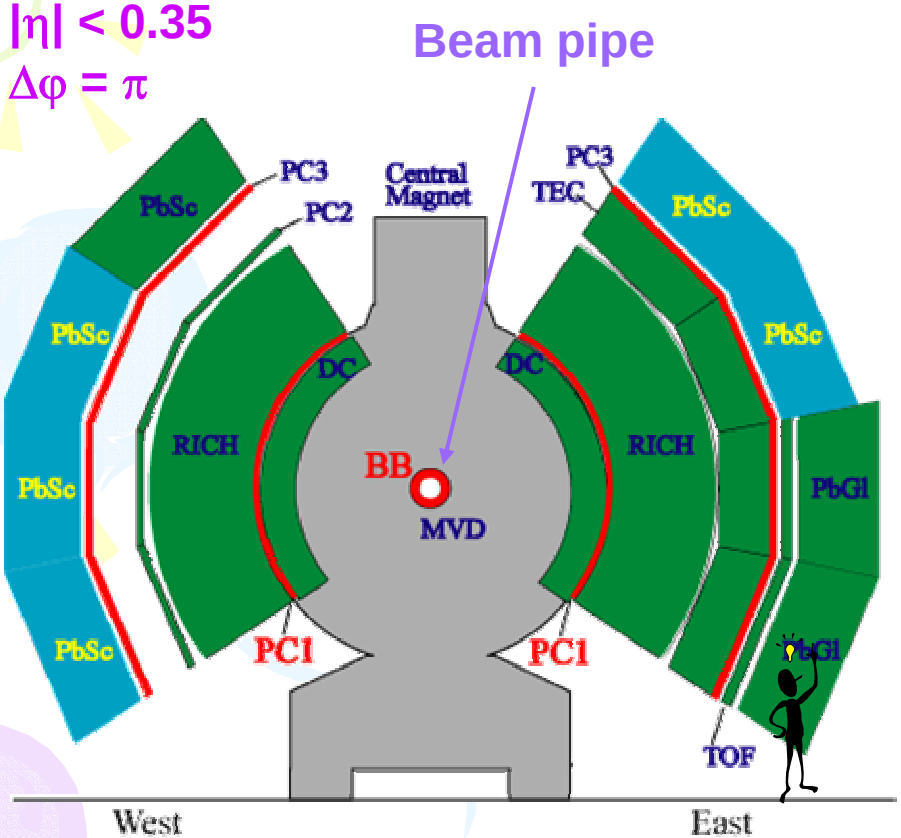
- Cherenkov radiators (Quartz) each mounted on a PMT
- Sensitive to charged particles with $\beta > 0.7$
- Cover $3.0 < |\eta| < 3.9$ with a full azimuth
- Primary trigger counter for p+p minimum bias (inelastic) events with ~50% efficiency
- Used as a luminosity monitor
- Determine event z-vertex positions (resolution ~2 cm for p+p $\rightarrow$ good enough for J/ψ)

96 PMTs in each arm

Central Arms

$|\eta| < 0.35$

$\Delta\varphi = \pi$

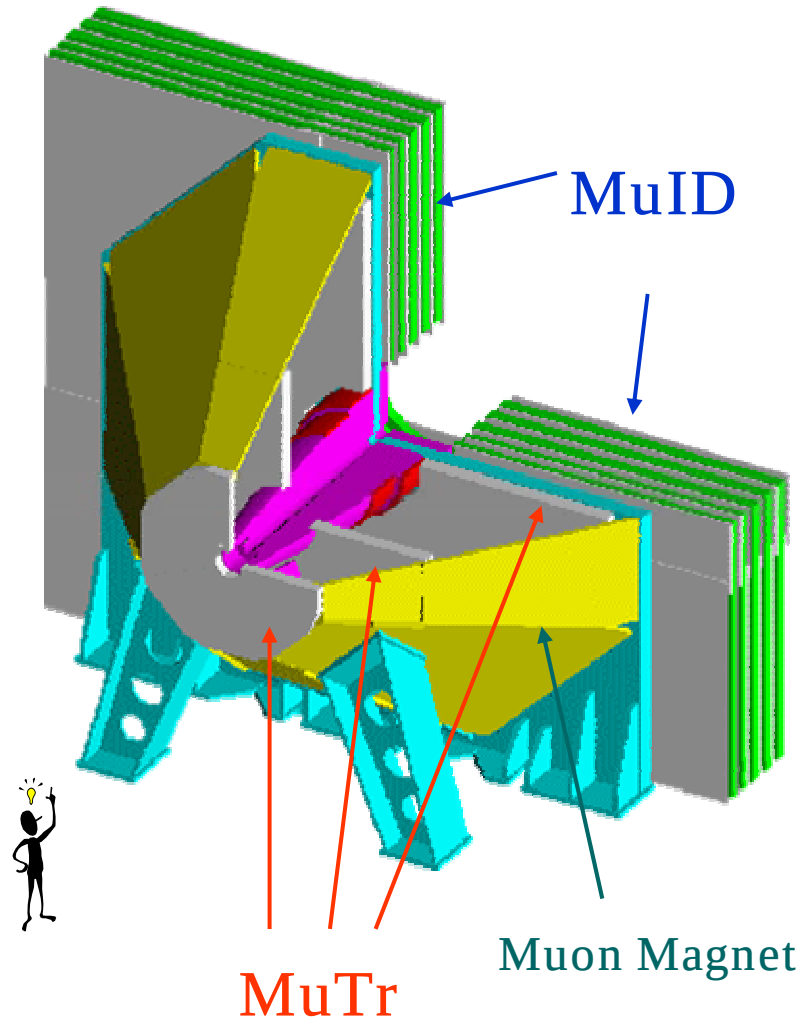


Cross section of the PHENIX Central Arms

- Tracking
  - Pad Chambers (PC1/2/3)
  - Drift Chambers (DC)
- PID and Triggering
  - Ring Imaging CHerenkov detector (RICH)
  - Electro-Magnetic Calorimeter (EMCal, PbSc/PbGl)
- Both West and East Arms were operational in Run-2

Muon Arms

- Detect muons with $p_{tot} > 2$ GeV/c, $-1.2 > \eta > -2.2$ (South Arm) or $1.2 < \eta < 2.4$ (North Arm)
- Muon Tracking Chamber (MuTr)
  - Measure momentum of muons with cathode-readout strip chambers at 3 stations inside Muon Magnet
- Muon Identifier (MuID)
  - π/μ separation with 5-layer sandwich of chambers (Iarocci tubes) and steel
  - Trigger muons
- South Muon Arm was successfully operated first time during Run-2

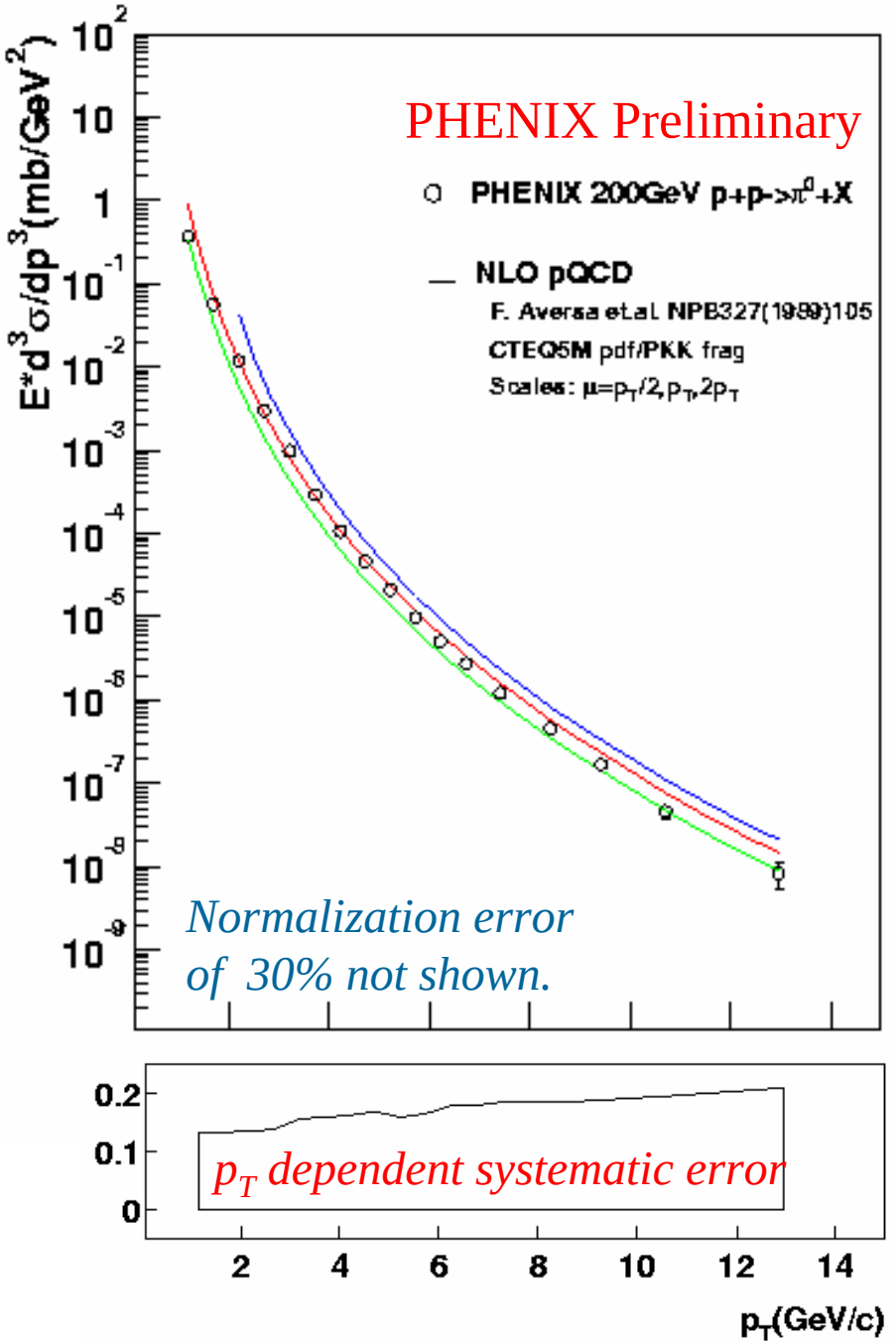


Cross sections

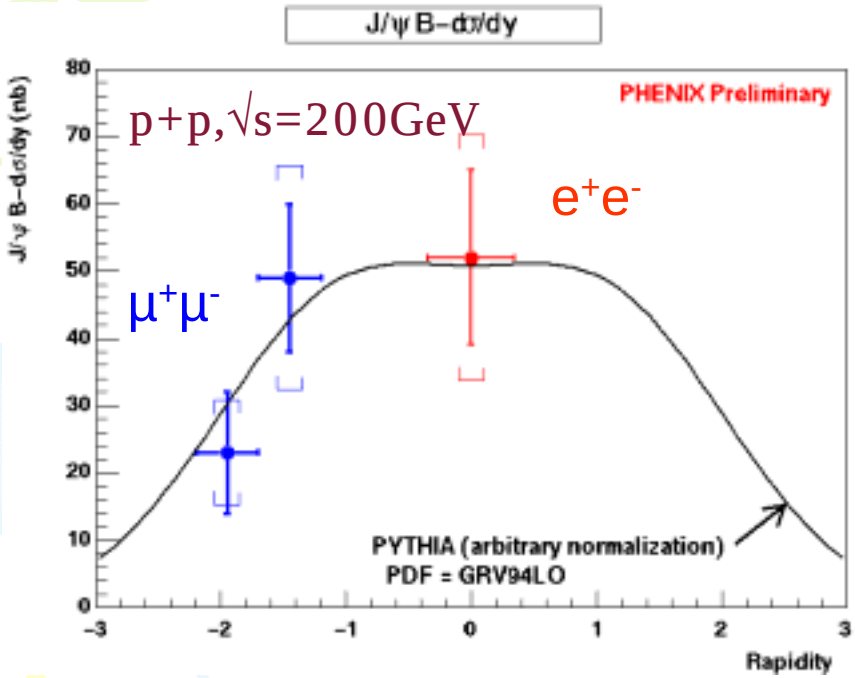
- Cross section measurements are important as the baseline for both heavy-ion and spin physics at RHIC
- Test against perturbative QCD
- Results of high-p_T π^0(p_T<13 GeV/c) and J/ψ will be shown here

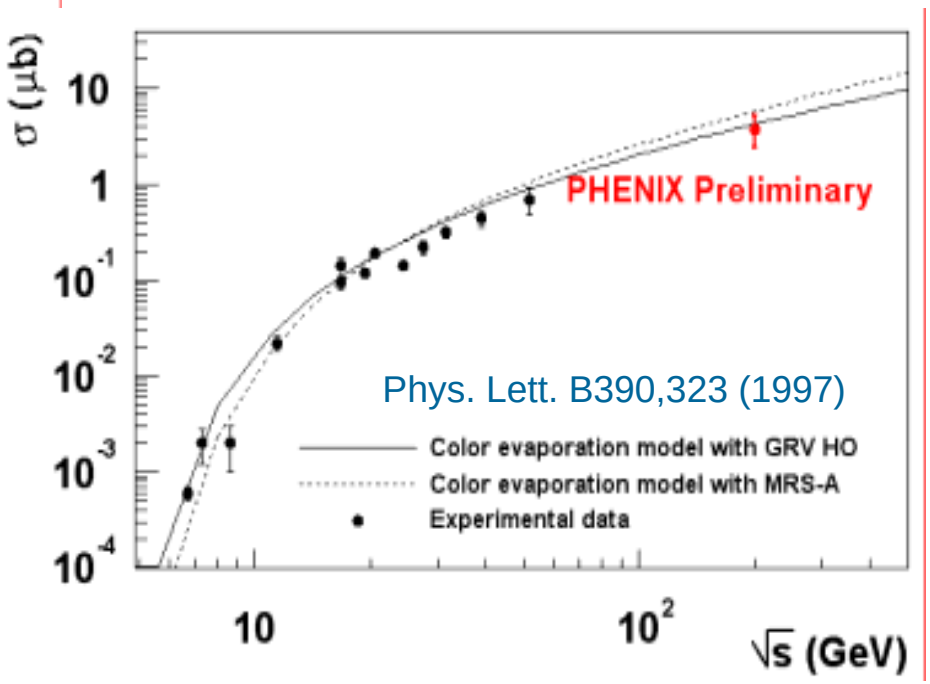
p+p → π^0X cross sections

- Up to much higher p_T compared to UA1 (p_T<6 GeV/c)
- NLO pQCD calculation
  - CTEQ5M pdf
  - Potter-Kniehl-Kramer fragmentation function
  - $\mu = p_T/2,\ p_T,\ 2p_T$
- Consistent with data within the scale dependence.



p+p → J/ψX cross sections





Rapidity Fit gives

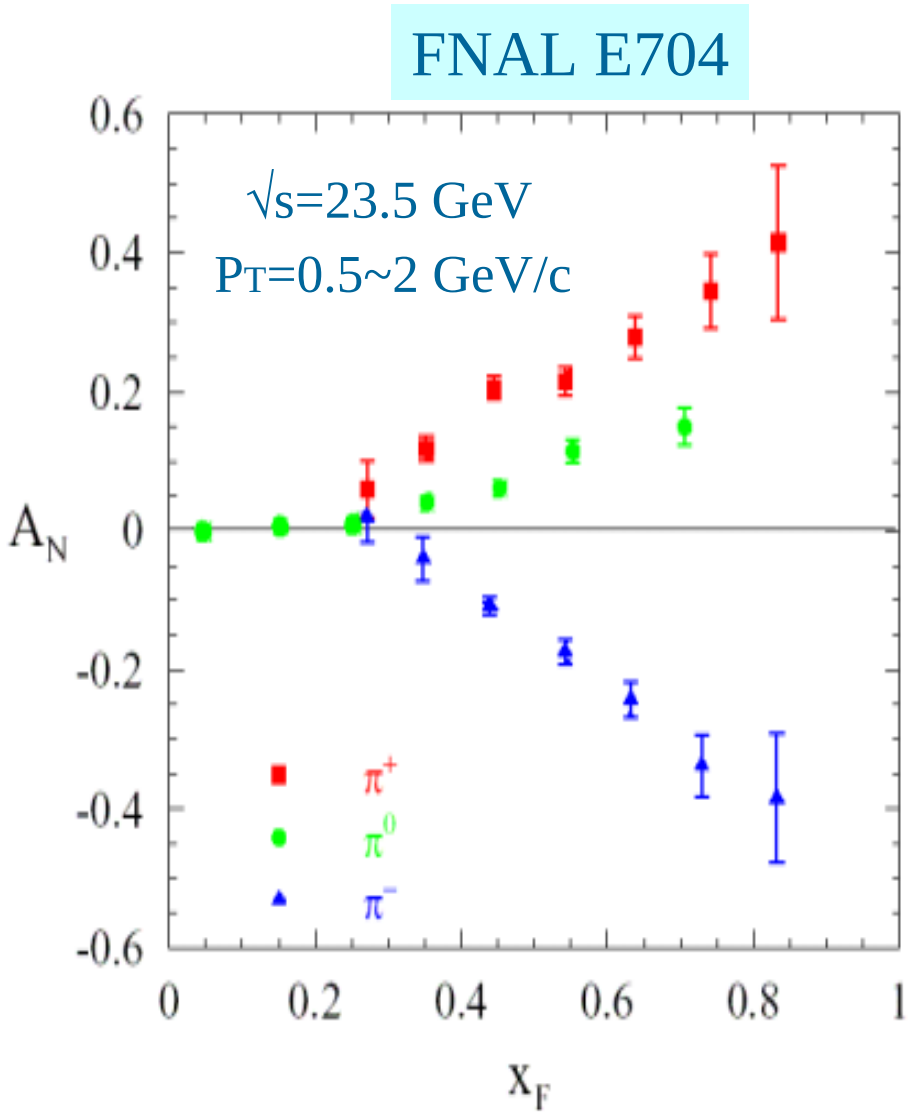
$$Br\,(J/\psi \to l^+l^-)\;\sigma\,(p+p \to J/\psi X)$$
$$= 226 \pm 36\ (stat.) \pm 79\ (syst.)\ nb$$
$$\sigma\,(p+p \to J/\psi X)$$
$$= 3.8 \pm 0.6\ (stat.) \pm 1.3\ (syst.)\ \mu b$$

- Our result is consistent with $\sqrt{s}$ scaling from lower energy results

Single-spin asymmetries (A_N)

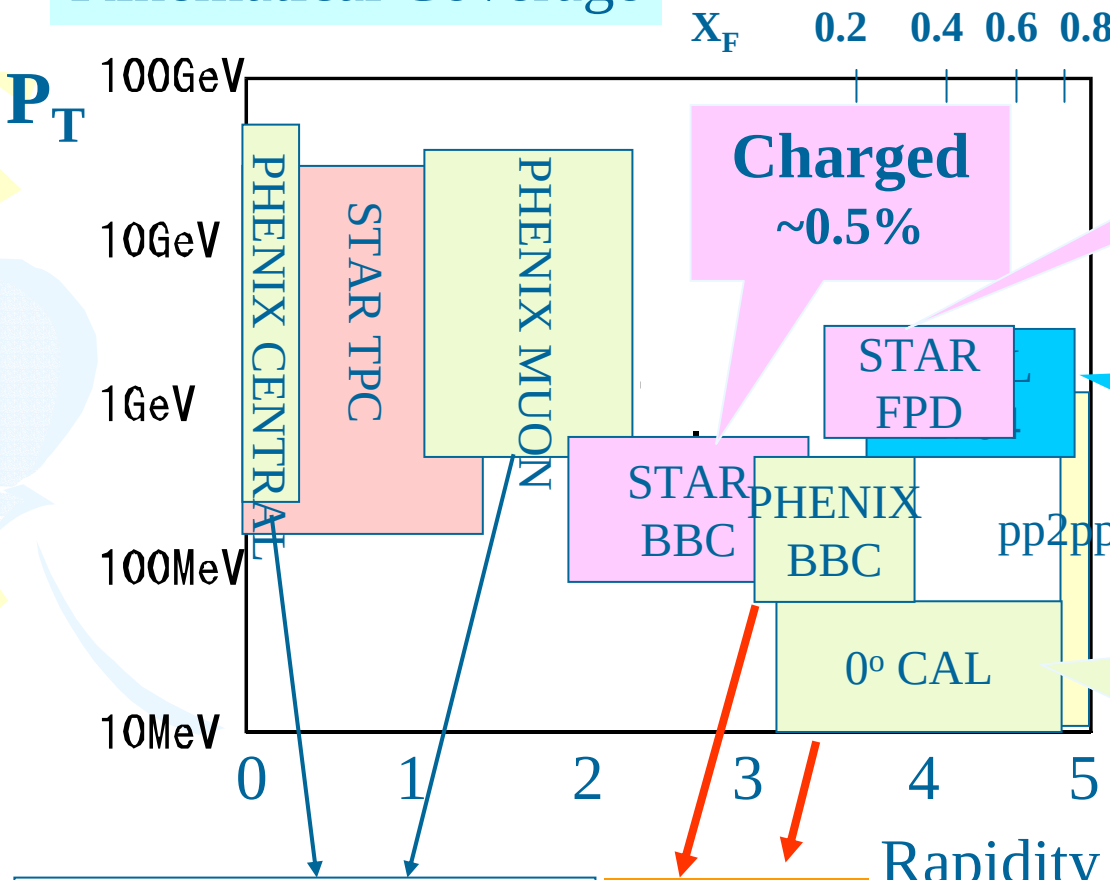
$$A_N = \frac{1}{P} \cdot \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

- Motivated by large A_N measured by the FNAL-E704 experiment at high-x_F at $\sqrt{s}$ = 19.4 GeV
- Origin has not well understood theoretically
  - Quark-gluon correlation (higher-twist)?
  - ΔL ?
- Application for high-energy polarized proton polarimetry



A_N from RHIC $\sqrt{s}$=200 GeV

Kinematical Coverage



Charged ~0.5%

π^0 (at high x_F) +10 ~ +20%

FNAL-E704 $\sqrt{s}$=20 GeV

π^+, π^- (at high x_F) +10 ~ +30%

Neutron -10%

γ ~0%

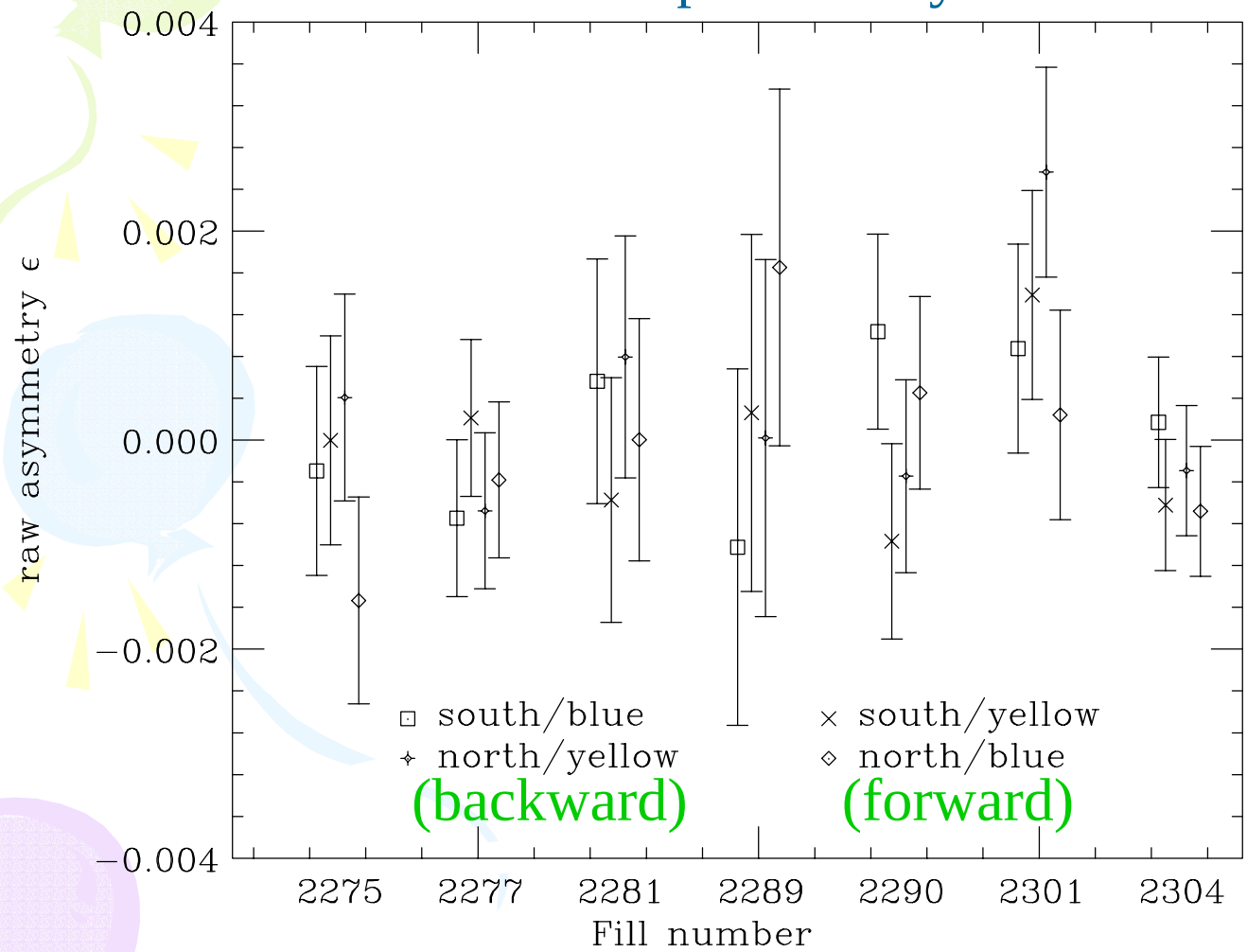
π^0 <3%

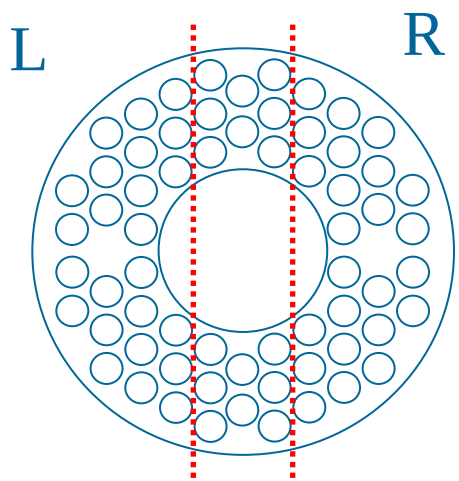
Work in progress!
Results expected soon

This talk

BBC Asymmetries

PHENIX preliminary





$A_F = 1.3 \pm 1.8$

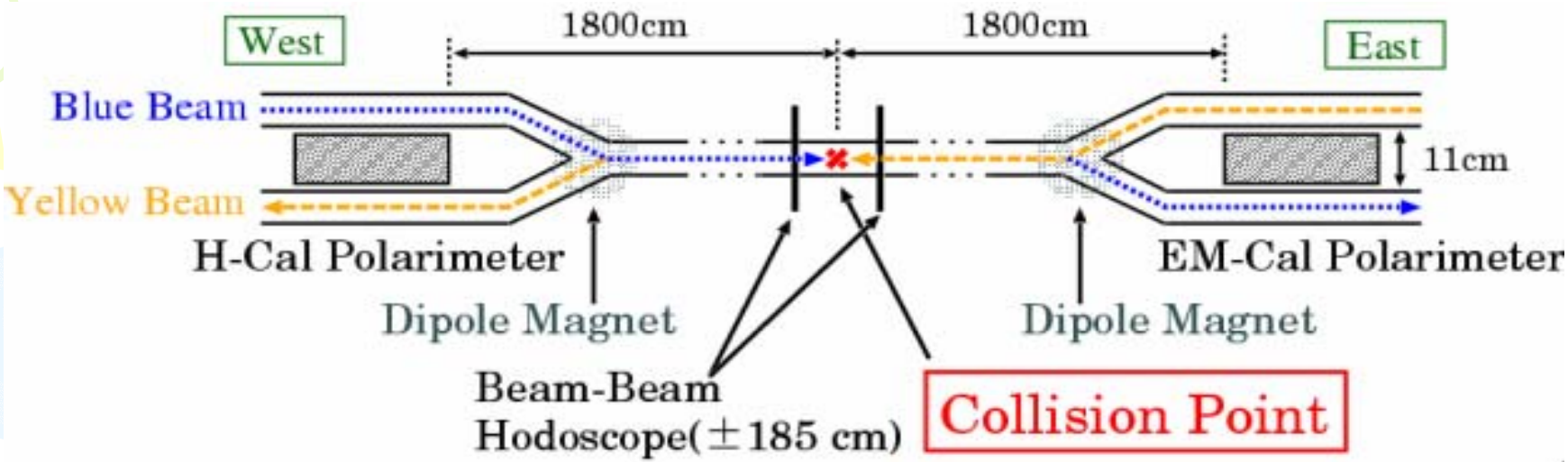
$A_B = 1.2 \pm 1.8$

$\times 10^{-3}$

assuming A_N (RHIC pol.) = 0.0132

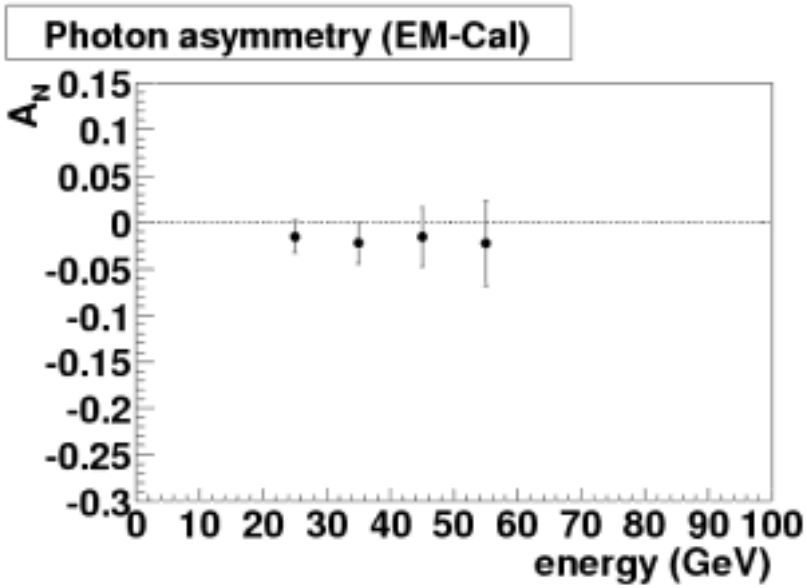
Results are consistent with 0

Very-Forward γ and n

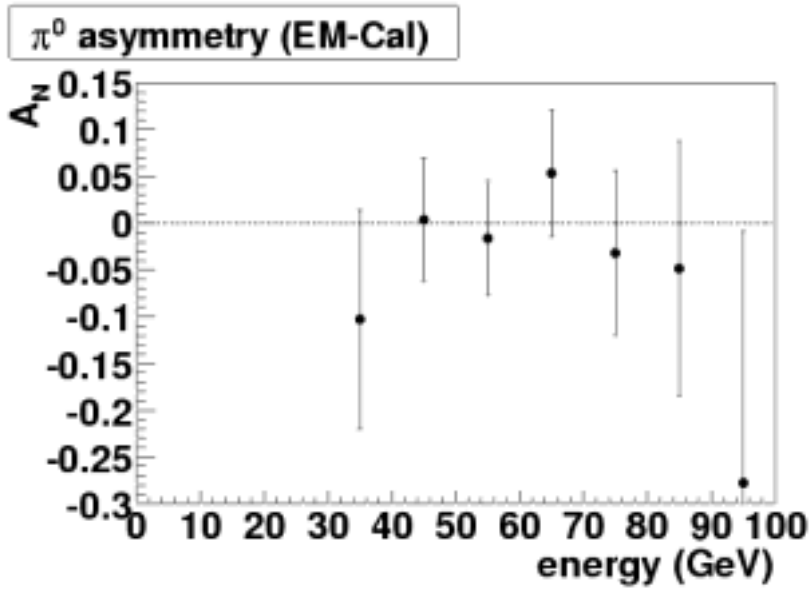


- Introduced as a polarized proton polarimeter at interaction region (thus called “Local” polarimeter)
- Measure very-forward ($|\eta|>6.5$) photon and neutrons with low p_T ($p_T<0.3$ GeV/c)
- In Run-2, installed in IP-12 region. In Run-3, installed also in IP-8 (PHENIX)

Photon and π^0 asymmetry



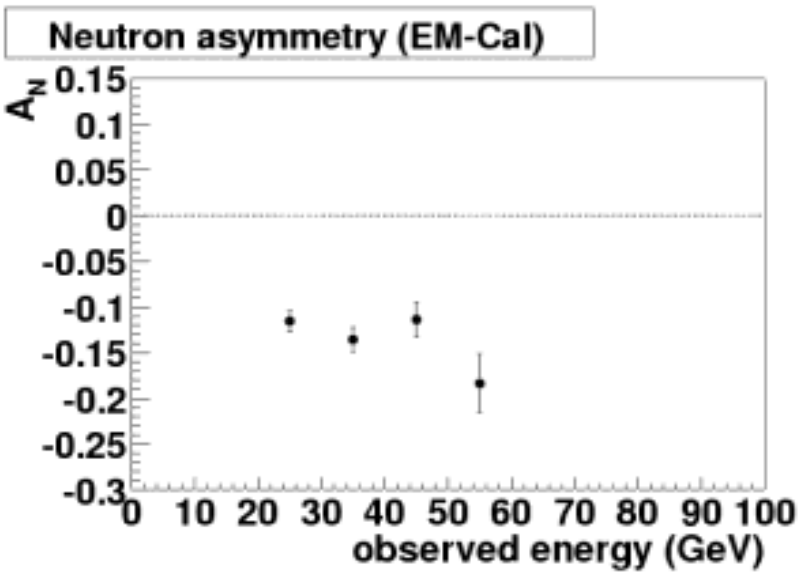
$$A_N = -0.018 \pm 0.012 \pm 0.023$$



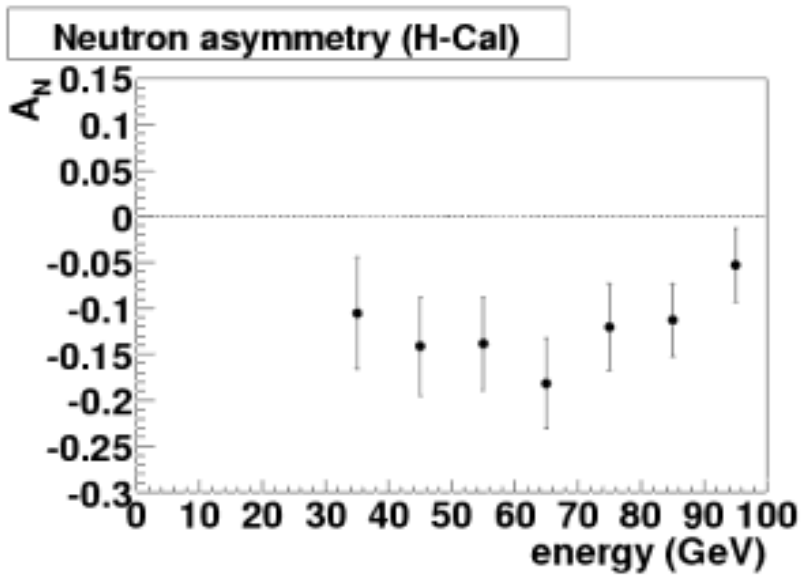
$$A_N = -0.010 \pm 0.032 \pm 0.002$$

- A_N is Consistent with 0

Neutron asymmetry



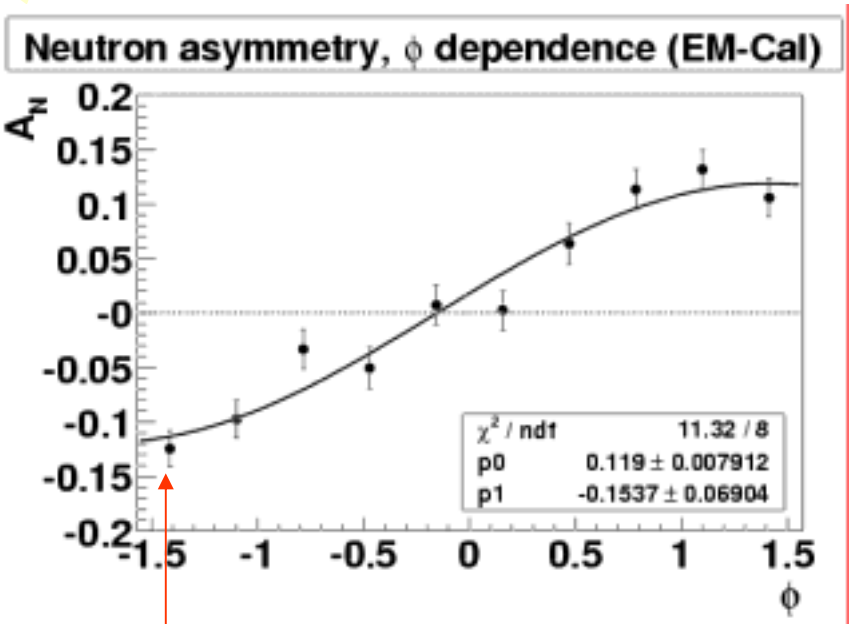
$$A_N = -0.126 \pm 0.008 \pm 0.041$$

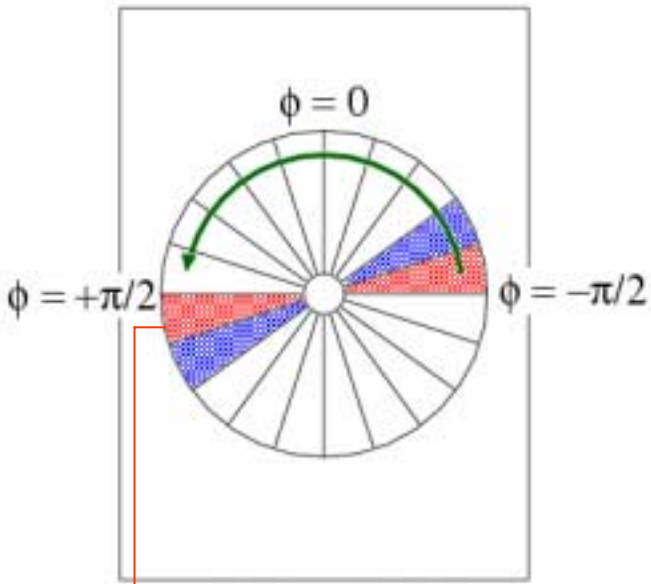


$$A_N = -0.116 \pm 0.018 \pm 0.020$$

- Unexpectedly large asymmetry has found -> No theoretical explanation so far
- EM-Cal results and H-Cal results are consistent

Neutron asymmetry phi dependence





Very clear azimuthal asymmetry

RHIC/Spin Present and Future

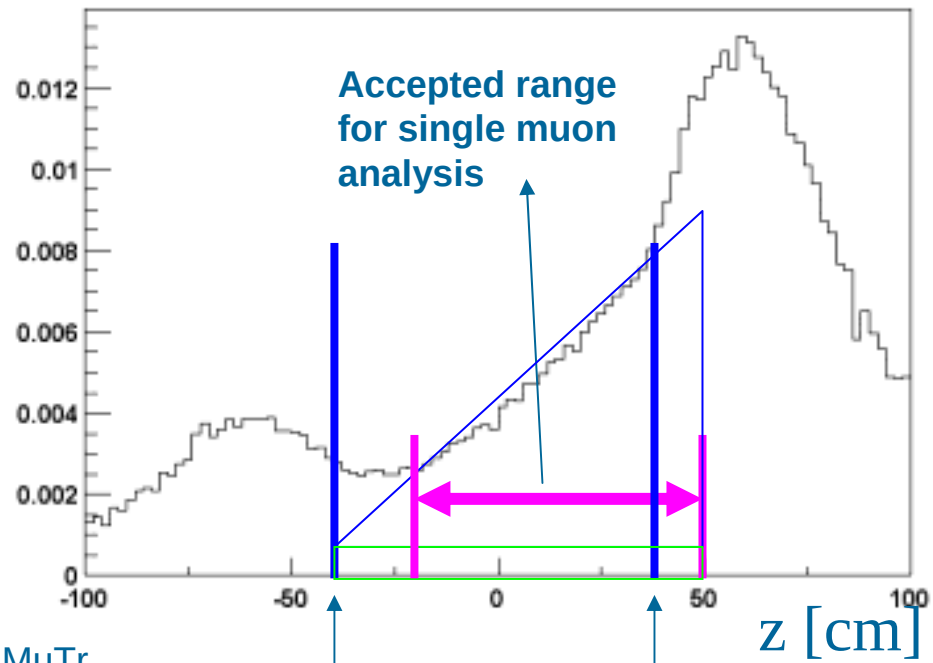
- Run-3 (2003, just started!)
  - $\sqrt{s}$ = 200 GeV, 3pb^{-1}
  - p_B ~ 40%
  - A_{LL} for π^0 and charged hadrons -> $\Delta G(x)$
- Run-4 (2003-2004)
  - $\sqrt{s}$ = 200 GeV, 30pb^{-1}
  - p_B ~ 50%
  - A_{LL} for heavy flavors (single leptons, eμ, J/ψ) -> $\Delta G(x)$
- Run-5 and later
  - $\sqrt{s}$ = 500 GeV
  - P_B ~ 70%
  - A_{LL} for Direct photons -> $\Delta G(x)$
  - A_L for W bosons-> $\Delta \bar{q}(x)$

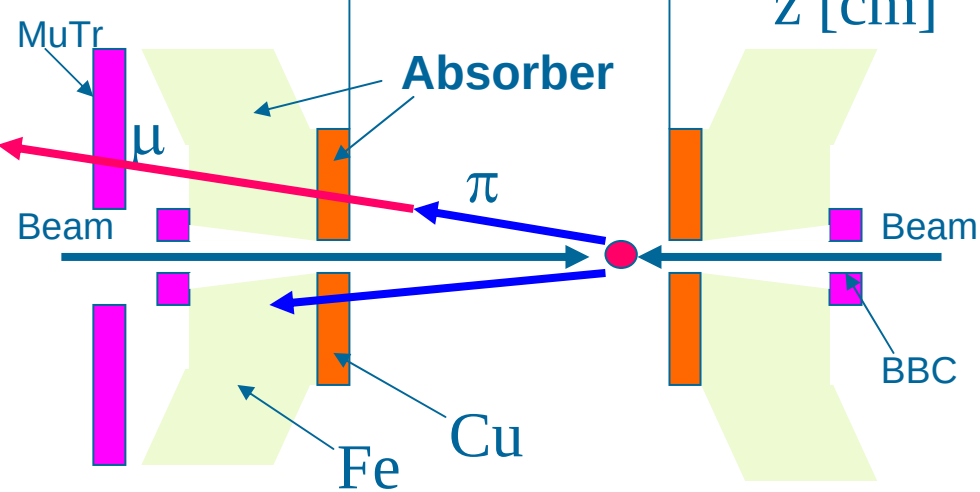
Summary

- In Run-2, RHIC has successfully accomplished transversely polarized p+p collisions at $\sqrt{s}$ = 200 GeV and PHENIX has accumulated $L_{int} \sim 150 nb^{-1}$
- Cross sections for high-p_T π^0 and J/ψ are consistent with pQCD predictions
- Preliminary results of A_N measurements are presented
  - Unexpectedly large asymmetry ($A_N \sim 0.12$) for neutron production at very-forward rapidity

Single Muons

Event vertex distribution containing μ





Asymmetric z-vertex distribution indicate $\pi/K \rightarrow \mu$ is dominant in inclusive single-muon yield

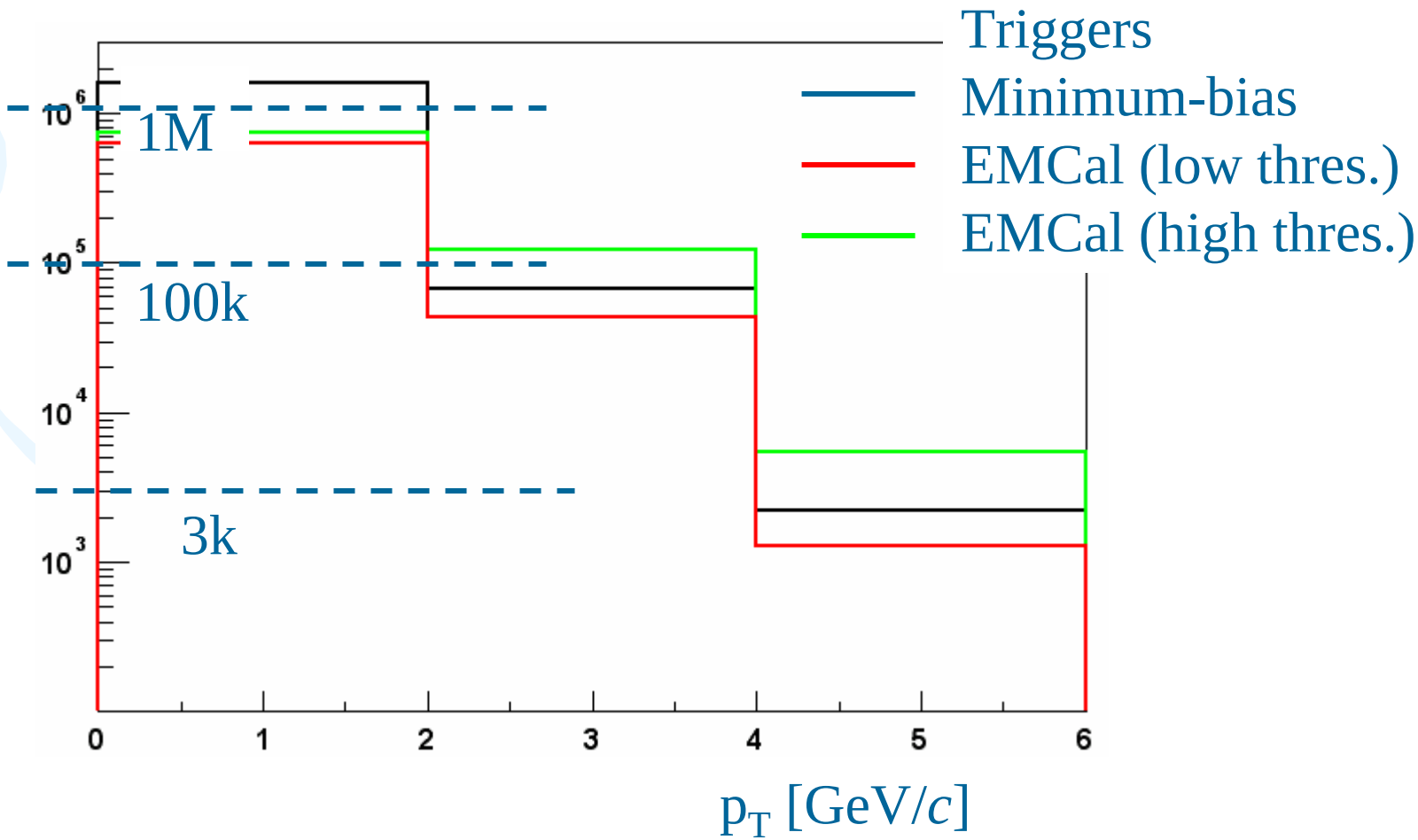
A_N of π/K can be obtained using single muons

Analysis is work in progress

Charged particle yield in Central Arm

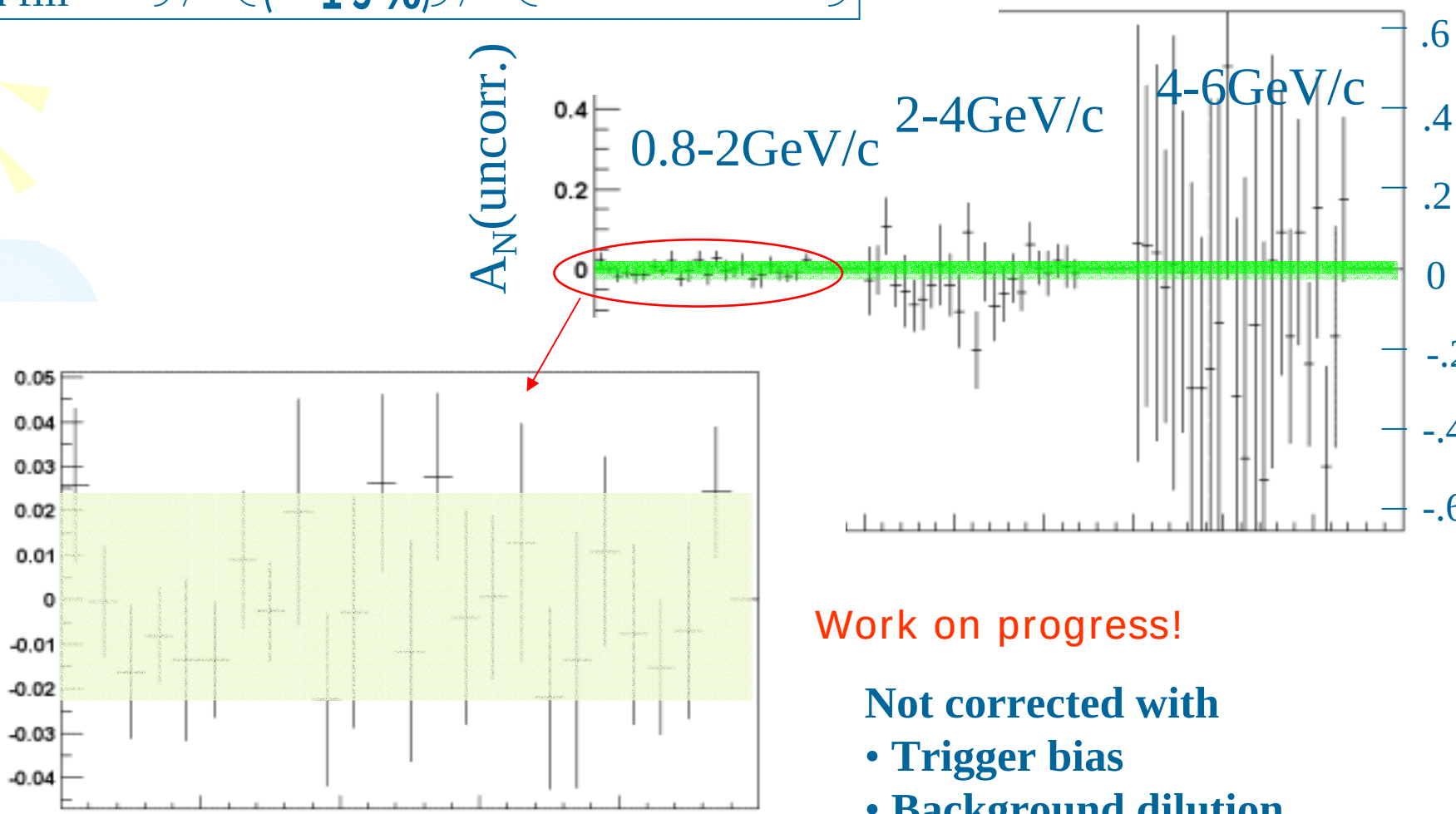
$3p_T$ bins, 0.8-2GeV/c, 2-4GeV/c, 4-6GeV/c

Number of min-bias triggers = 31×10^6



Charged-hadron Asymmetries

Raw asymmetry of each fill / polarization (~15%) / ϕ Acceptance correction (0.88)



Work on progress!

Not corrected with

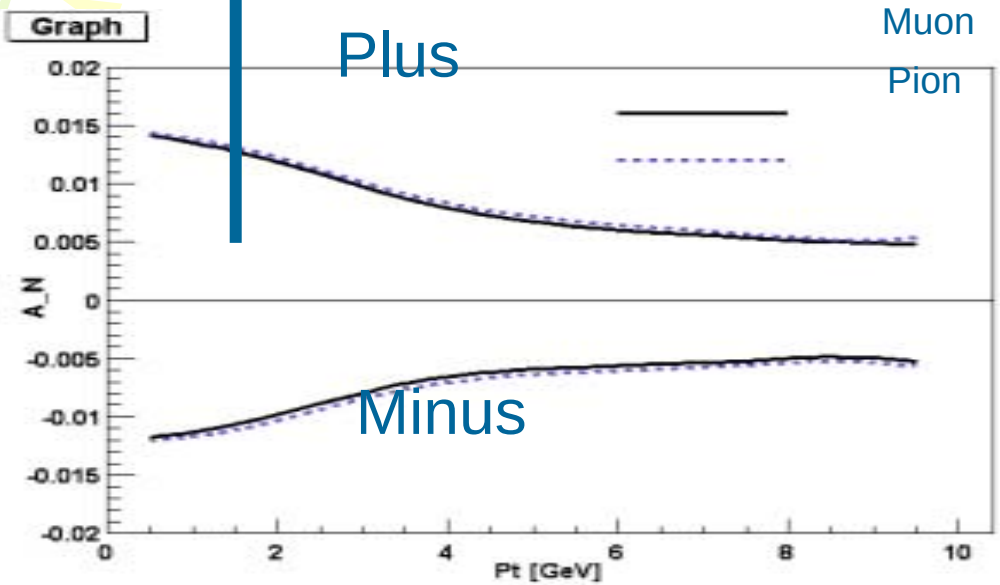
- **Trigger bias**
- **Background dilution**

Expected A_N by Single Muons

Expected Error Bar (stat only)

Qiu-Sterman model

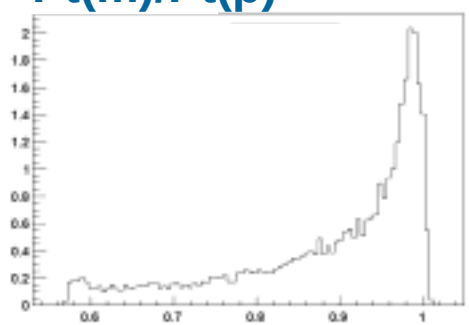
<Xf>~0.04@Pt~1.5GeV



Pt [GeV]

- P(m) carries most of original P(p)
- A_N(m) should be similar to A_N(p)
- Xf(m) ~ 0.9 Xf(p)

Pt(m)/Pt(p)



0.6 1