Transversity and Transverse-Spin Asymmetry Measurements at PHENIX

Transversity Workshop in Athens

October 7, 2003

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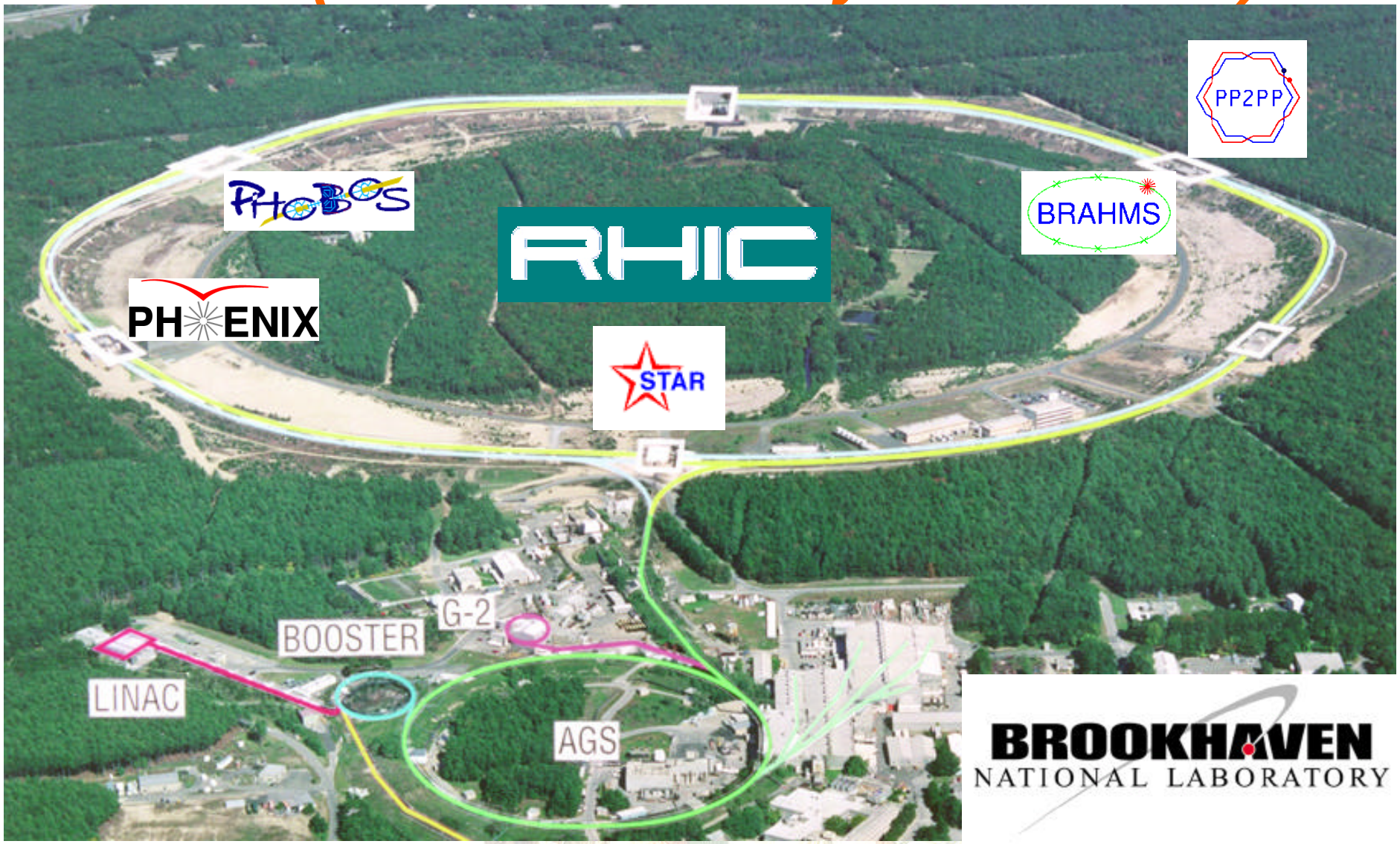
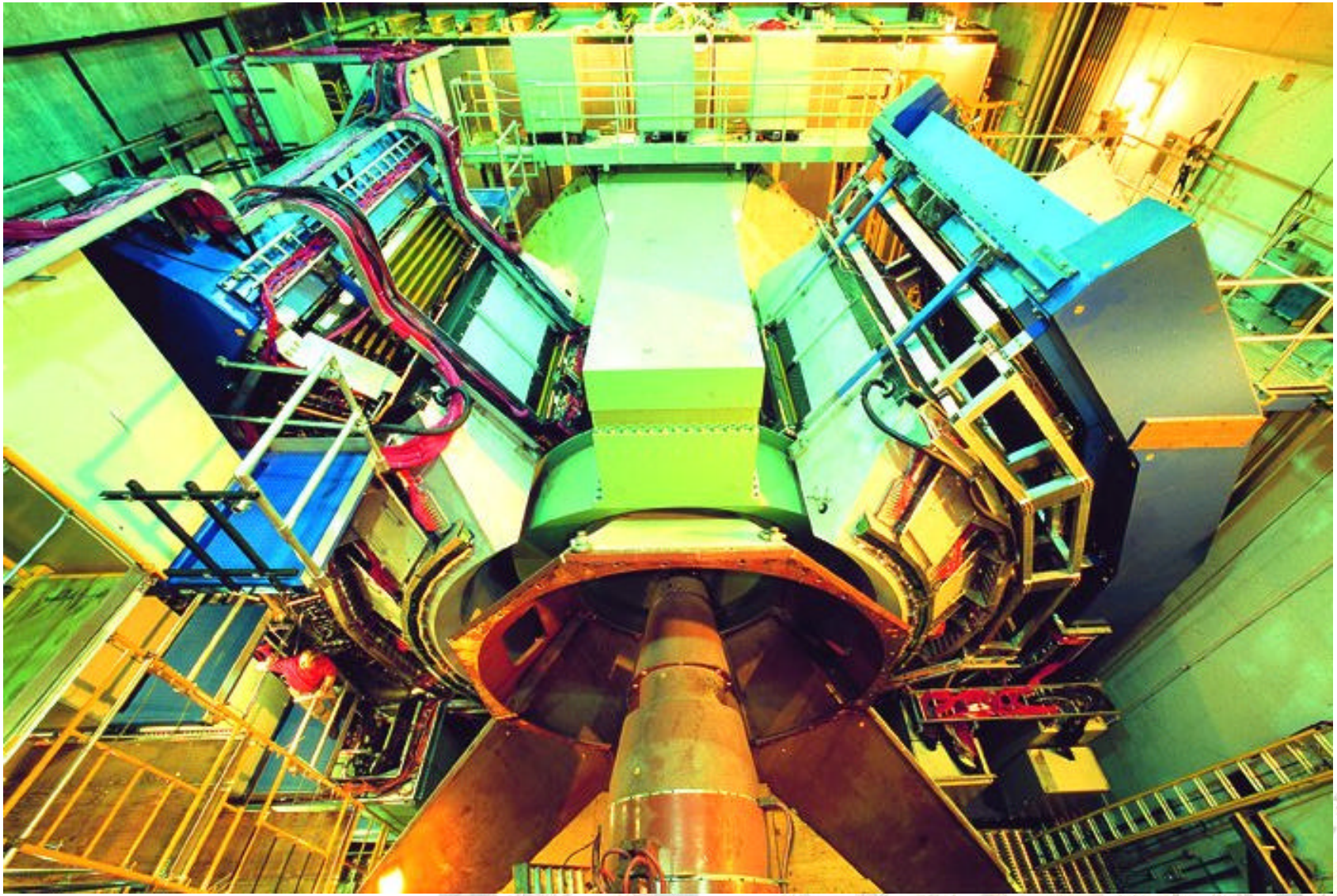
for the PHENIX collaboration

RHIC (Relativistic Heavy-Ion Collider)

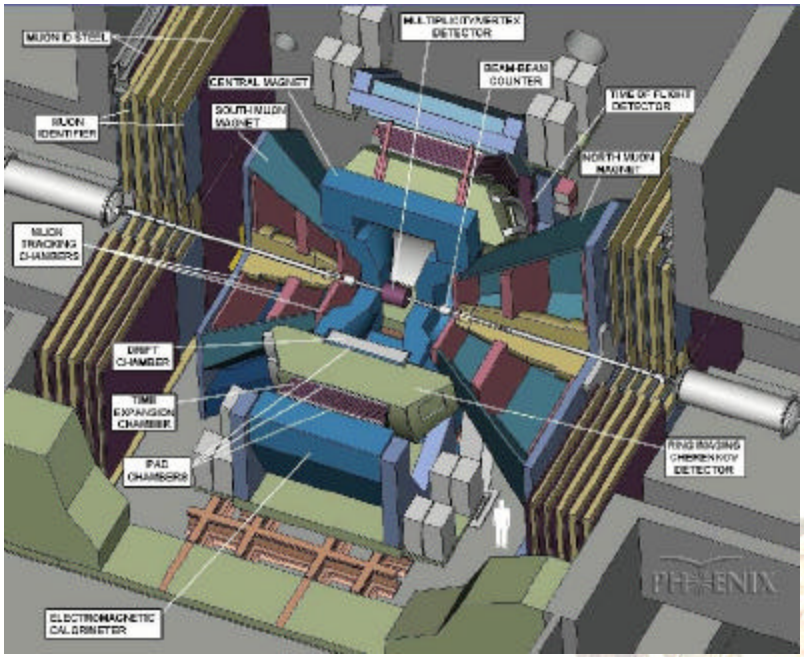


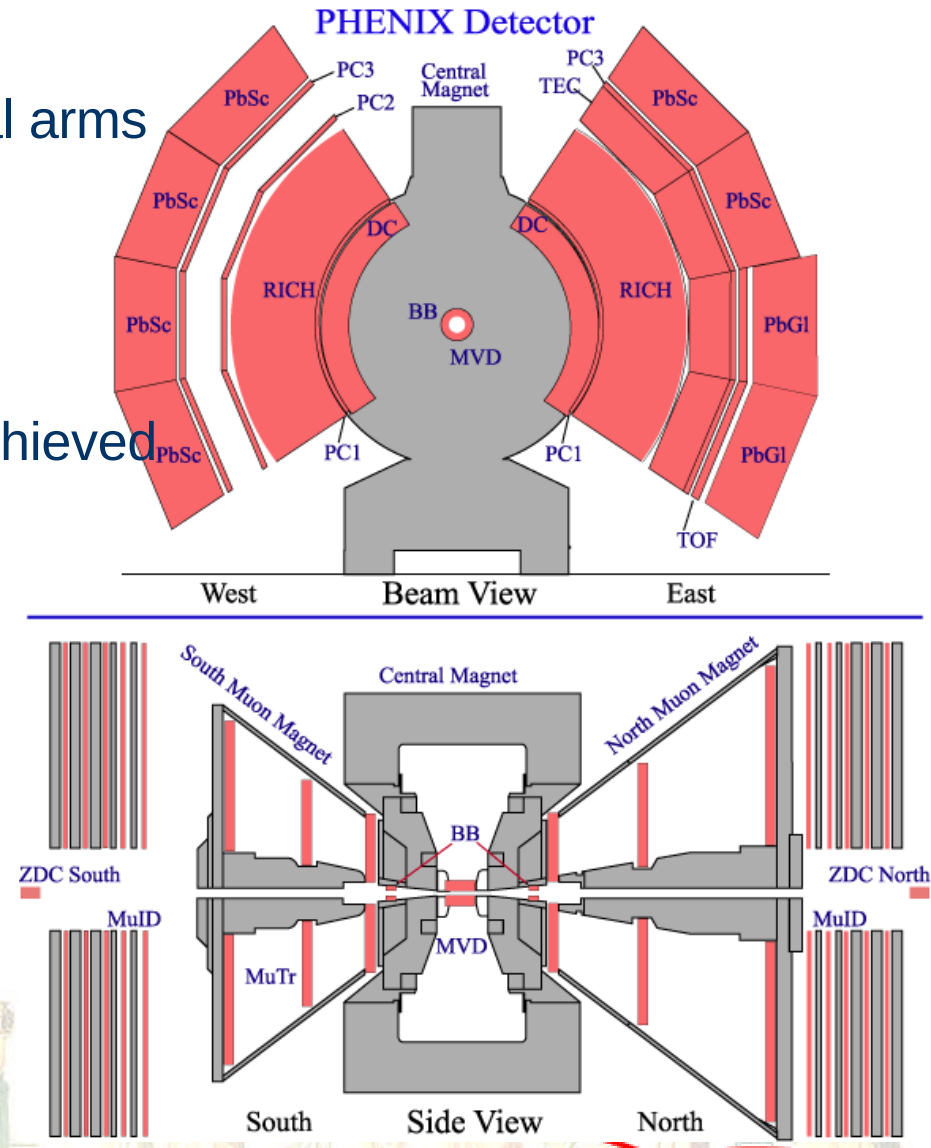
PHENIX



PHENIX

- Rare-event trigger systems
  - EMCal-RICH trigger in the central arms
  - muon trigger in the muon arms
- High-rate DAQ system
  - 1.4 kHz, 100 MB/sec achieved
  - much higher design rate to be achieved





RHIC polarized-proton collisions

- RHIC/PHENIX run summary
  - 2001-2002 (run-2)
    - polarization ~15%
    - transversely-polarized collisions: 150nb^{-1}
  - 2003 (run-3)
    - polarization ~27%
    - transversely-polarized collisions: 20nb^{-1}
    - longitudinally-polarized collisions: 350nb^{-1}

Spin physics at PHENIX

- Origin of the proton spin 1/2 ?

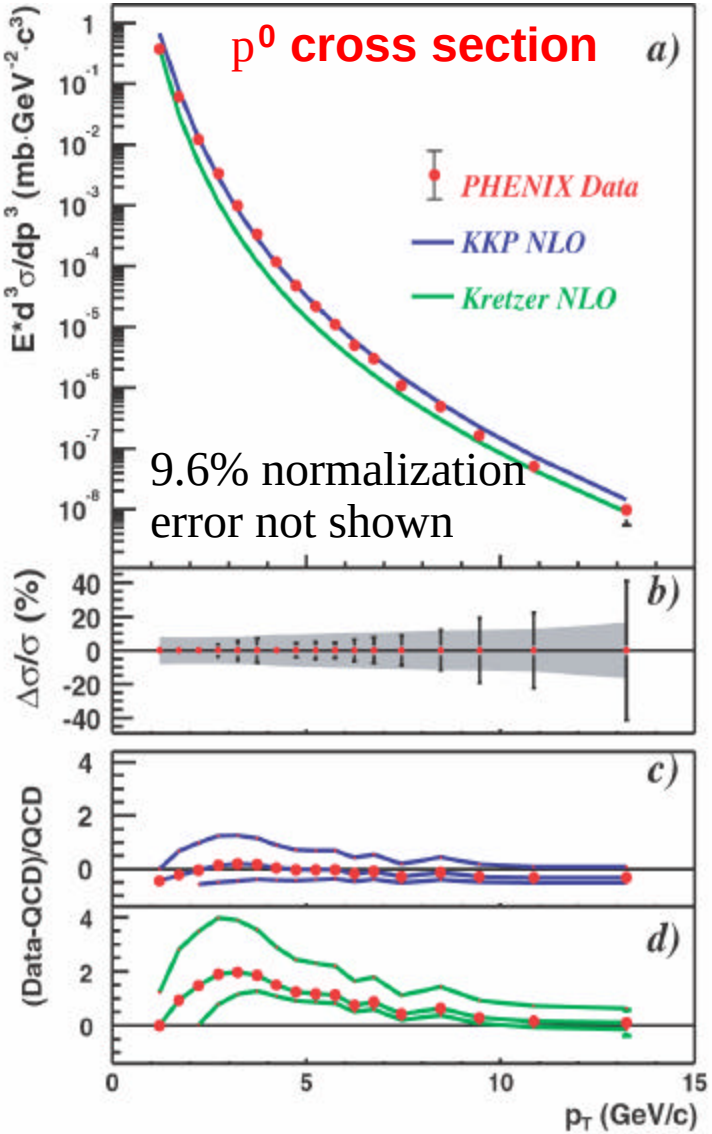
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta g + L$$

  - $\Delta\Sigma$ = 0.1-0.3: quark contribution by polarized DIS experiments
  - gluon contribution $\Delta g(x)$
    - known poorly from scaling violations in pol. DIS experiments, spanning a small range of Q^2
  - flavor decomposition of the quark/antiquark contribution $\Delta q(x), \Delta\bar{q}(x)$

- Transversity $dq(x)$
  - last unmeasured leading-twist distributions
- Parity violating asymmetries
  - physics beyond the standard model

Spin physics at PHENIX

- High precision spin physics
  - perturbative QCD applicable ?
    - scale dependence of the NLO pQCD calculation
    - though scale dependence is expected to largely cancel in the asymmetry
  - π^0 cross section measurement
    - hep-ex/0304038, to be published on PRL
    - data covers over 8 orders of magnitude
      - p_T = 1 – 13 GeV/c
    - NLO pQCD calculation is consistent with our data
      - within the scale $\mu = p_T/2 - 2p_T$
    - confidence in understanding subprocesses
    - input to the fragmentation-function uncertainty

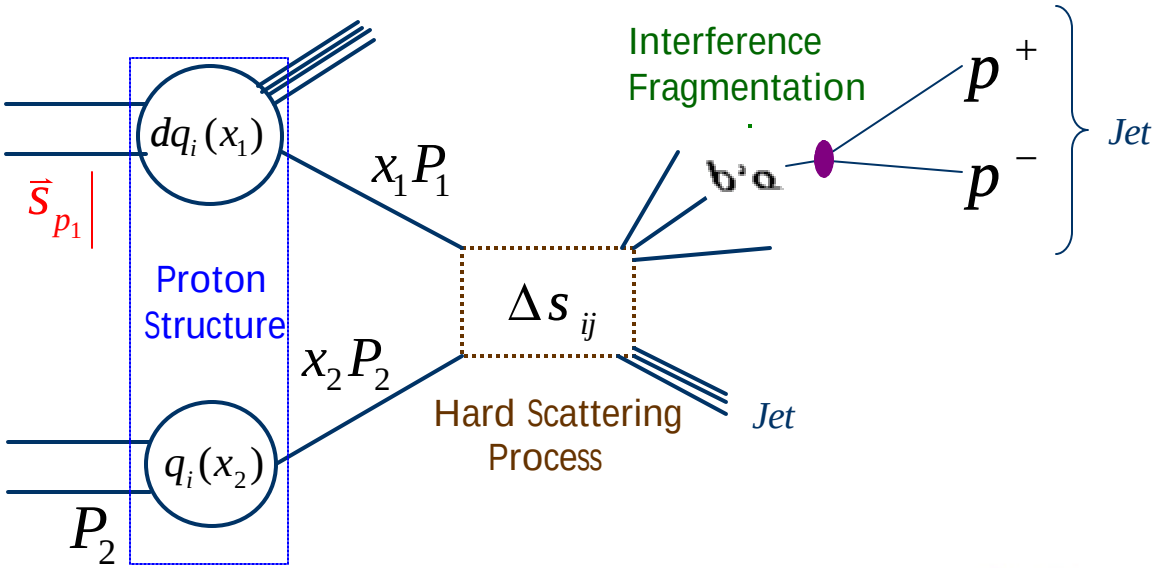


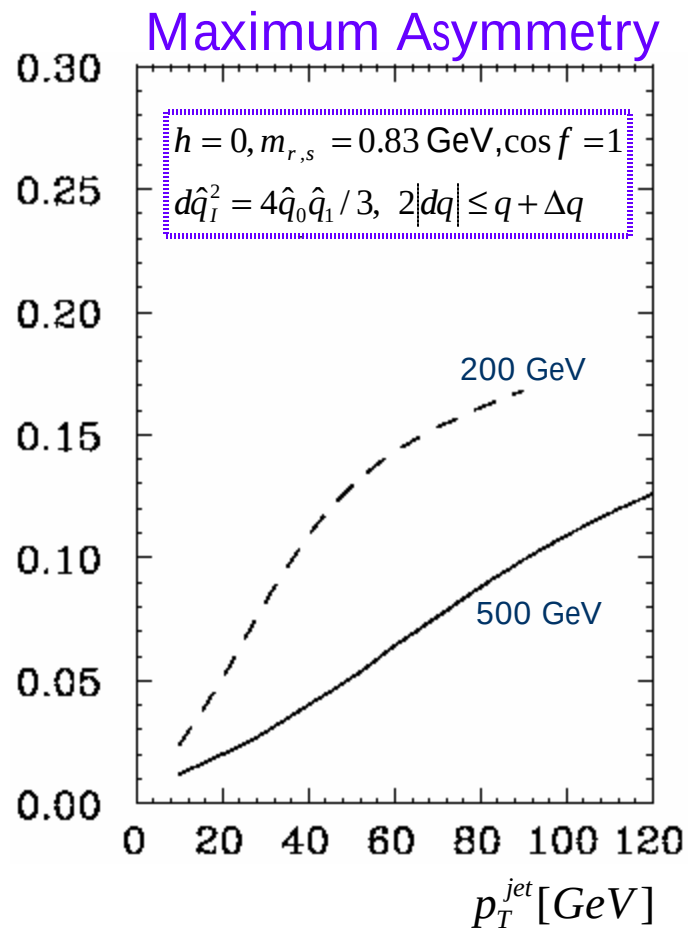
Transversity at PHENIX

- Near future
  - $\pi^+\pi^-$ interference fragmentation function $A_T\left(p_\perp p \to (p^+, p^-) + X\right)$
    - J. Collins, S. Heppelmann, and G. Ladinsky, Nucl.Phys. B420 (1994)565
    - R. Jaffe, X.Jin, J. Tang Phys. Rev. D57 (1999)5920
  - Collins effect in jets $A_T(pp_\perp \to p + Jet + X)$
    - J.C. Collins, Nucl. Phys. B396, 161(1993)
  - inclusive jet production $5 \cdot 10^{-4} \le A_{TT} \le 3 \cdot 10^{-3}$
    - W. Vogelsang and M. Stratmann, RBRC Workshop on Transversity (2000)
- Luminosity upgrade
  - direct photon
    - Collins effect in jets, interference fragmentation function
  - Drell-Yan $A_{TT}(p_\perp p_\perp \to ll) \Leftrightarrow dq \cdot d\bar{q}$
    - J.Ralston and D.E. Soper, Nucl. Phys. B152, 109(1979)

Transversity at PHENIX

- Transversity throught $\pi^+\pi^-$ interference FF
  - non-vanishing "support" only in the ρ mass region
  - sufficient mass resolution?

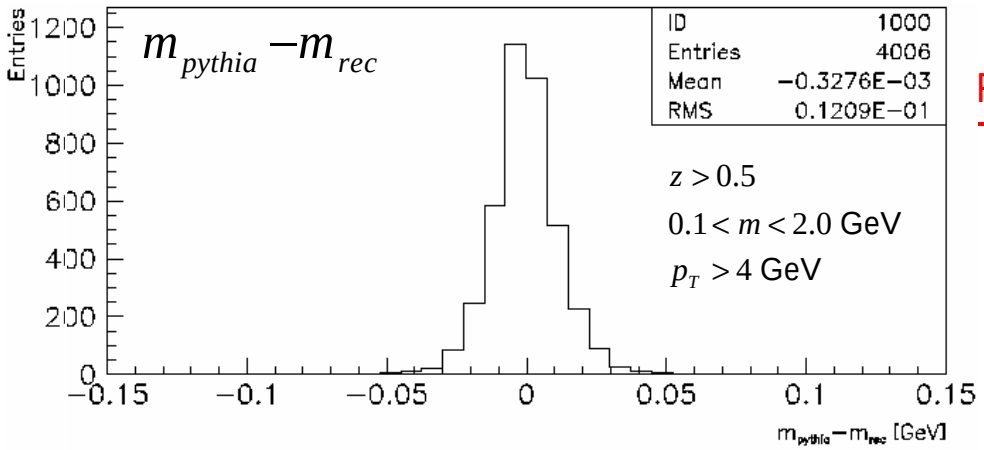




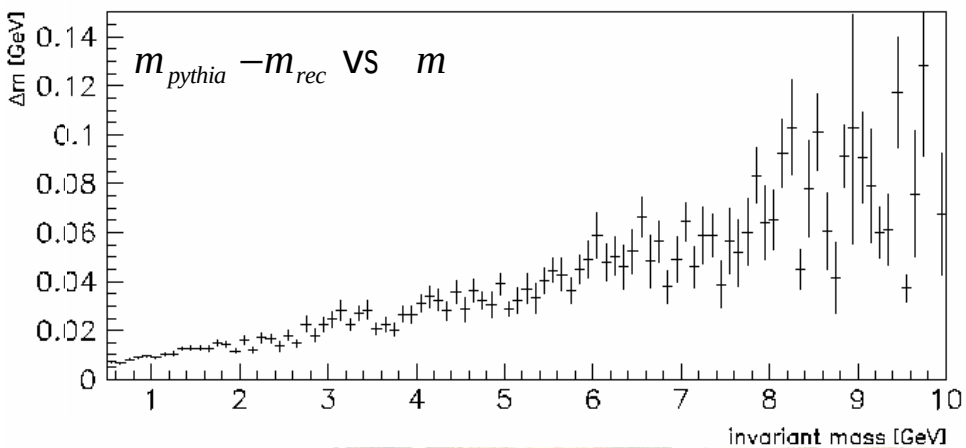
$$A_\perp = \frac{1}{P_{beam}}\frac{N^\rightarrow - N^\leftarrow}{N^\rightarrow + N^\leftarrow} = -\frac{\sqrt{6}p}{4}\sin d_0 \sin d_1 \sin(d_0 - d_1)\cdot\cos(f)\cdot\frac{[dq(x_1)\cdot G(x_2)\cdot d\hat{q}_I(z)]d\hat{s}_{qg}^{qg} + \ldots}{\{[G(x_1)\cdot G(x_2)]d\hat{s}_{gg}^{q\bar{q}} + \ldots\}\cdot[\sin^2 d_0\hat{q}_0(z) + \sin^2 d_1\hat{q}_1(z)]}$$

Transversity throught p^+p^- interference FF

- Invariant mass resolution at PHENIX



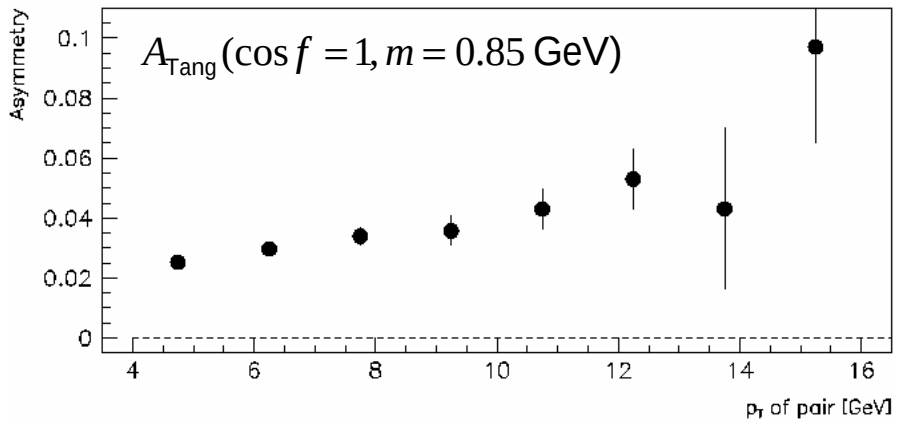
RMS = 12 MeV

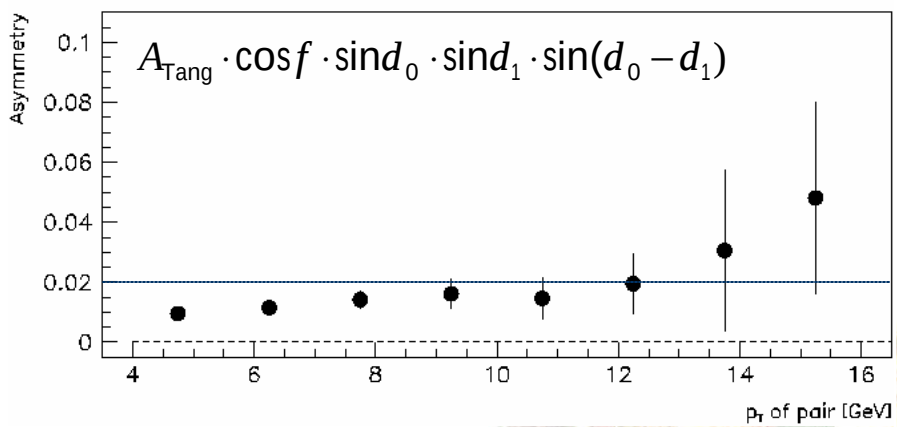


Transversity throught p^+p^- interference FF

- Projected asymmetry

$A_T(p_\perp \to p^+p^- + X)$ vs p_T^{pair}





For 32pb^{-1} (1 week of running)

$$\int L dt = 32\, pb^{-1}$$

$$E_{p_1, p_2} > 4\ \text{GeV}$$

$$\sqrt{p_{1T}^2 + p_{2T}^2} > 4\ \text{GeV}$$

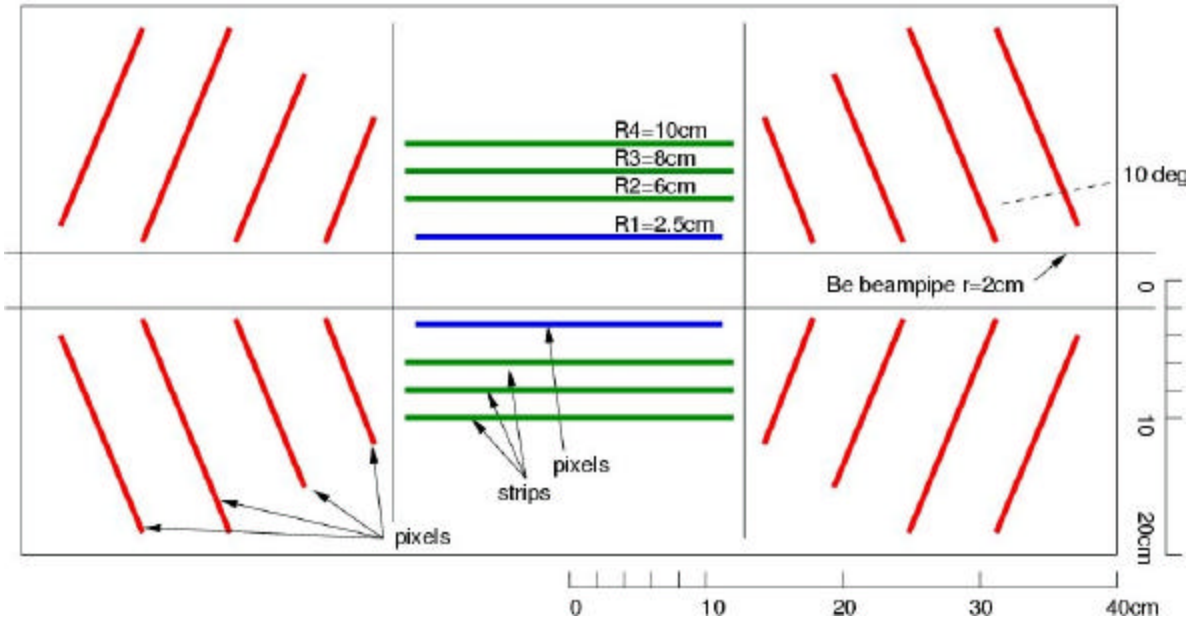
$$800\ \text{MeV} < m < 950\ \text{MeV}$$

5.2 Million events in 32 pb^{-1}
15% with pair after cuts

→ Small aymmetry below 5% but good rate!

Transversity at PHENIX

- Detector upgrade
  - vertex tagging for charm/bottom production
  - jet axis measurement

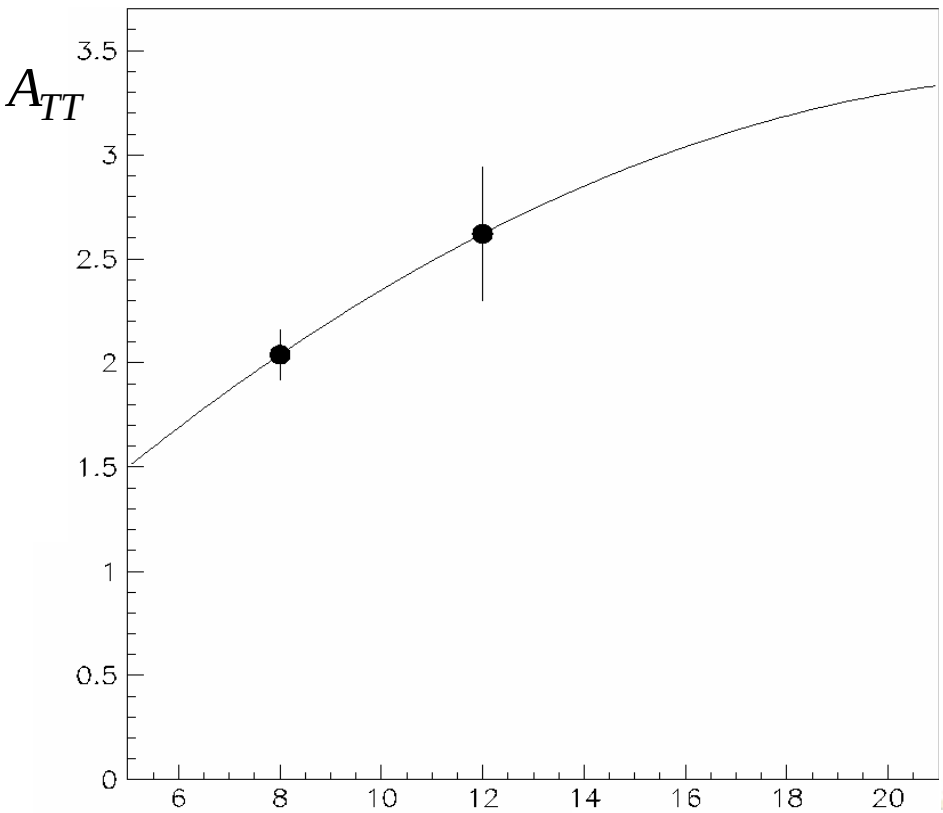


- Transversity through …
  - Collins effect in jets
  - inclusive jet production

Transversity at PHENIX

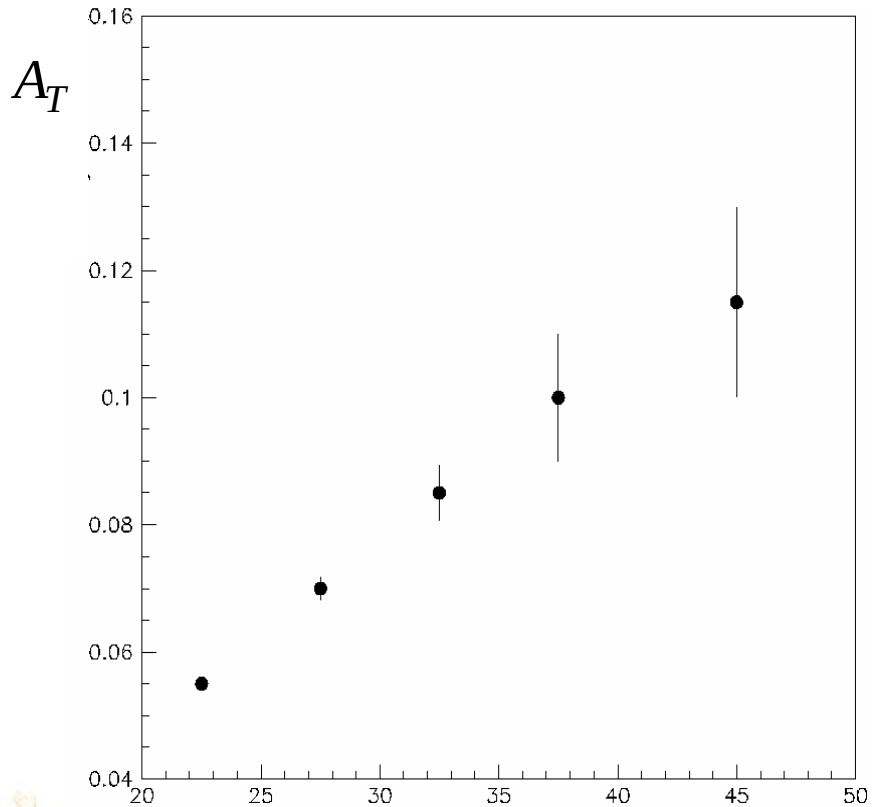
- Luminosity upgrade: 8 fb^{-1}

Drell Yan: Martin et al.



lepton pair mass [GeV]

Interference FF in direct photon production

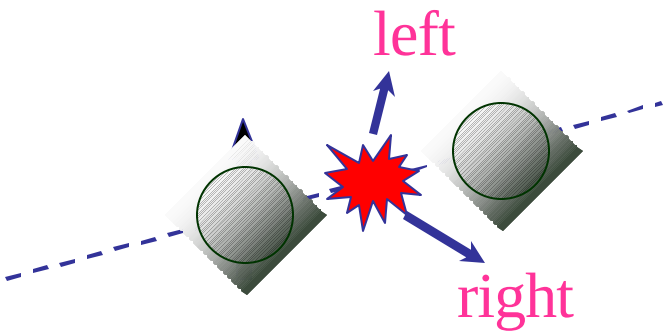


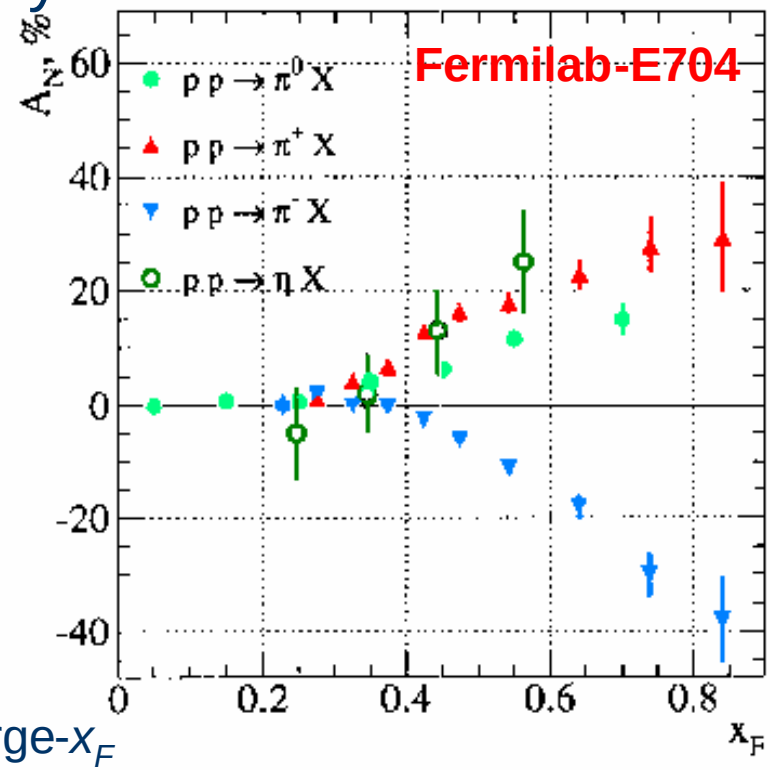
E_{jet} [GeV]

Rate poses serious challenge to experiments (PHENIX!).

Transverse-spin asymmetries at PHENIX

- Single transverse-spin asymmetry
  - left-right asymmetry (A_N)

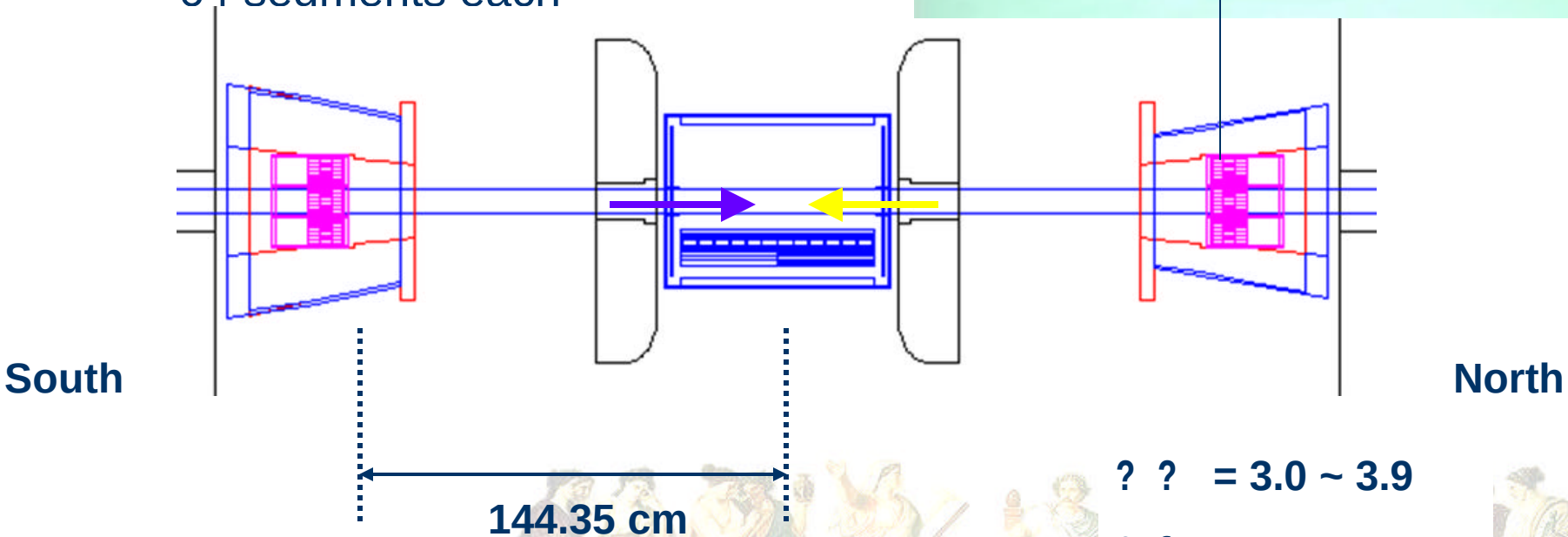




  - Fermilab-E704
    - $\sqrt{s}$ = 20 GeV
    - unexpected large asymmetry at large-x_F
    - $0.2 < p_T < 2.0$ GeV/c
  - many theoretical model calculations
    - higher-twist effect
    - Collins fragmentation function

BBC asymmetry

- PHENIX BBC
  - BBC: Beam-Beam Counter
  - 2 identical parts (BBC-north and -south)
  - quartz Cherenkov counter, 64 segments each



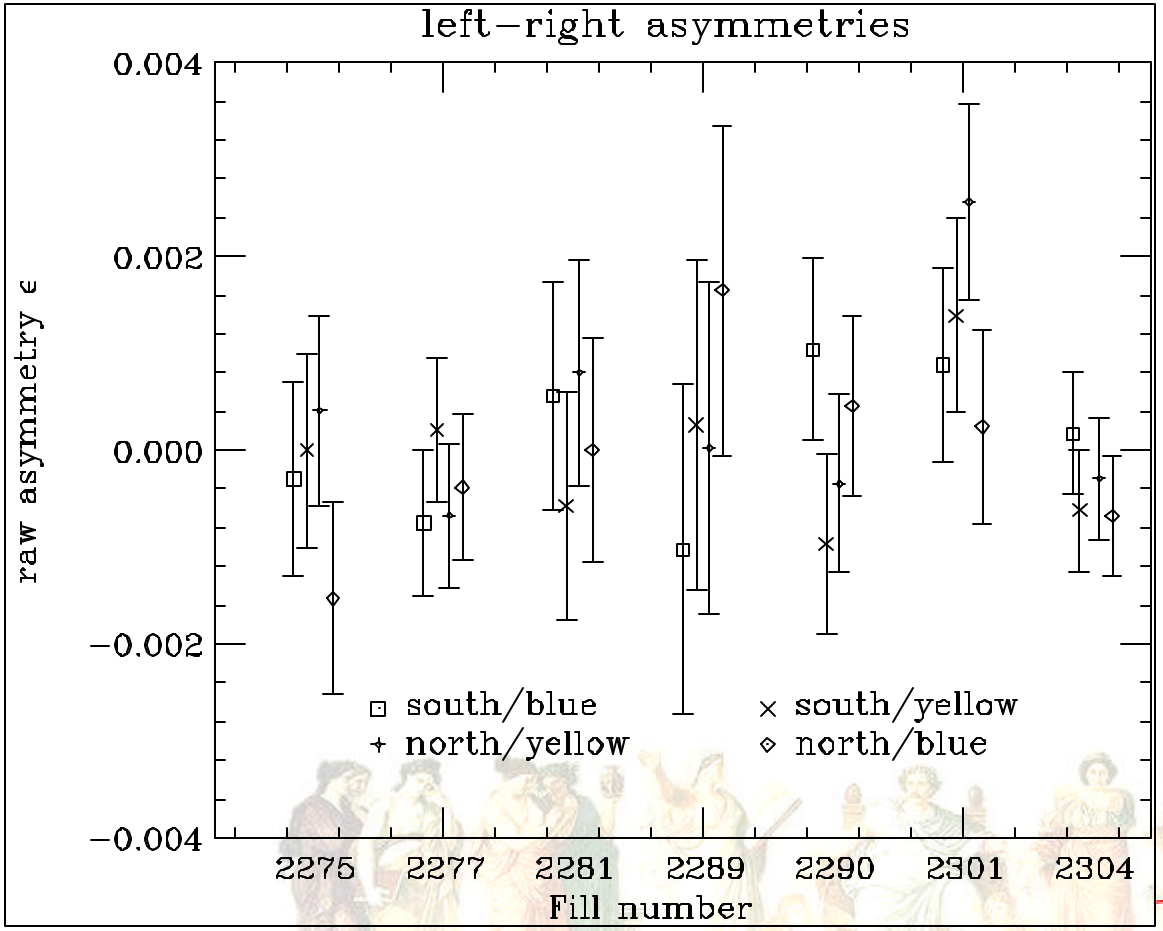
? ? = 3.0 ~ 3.9

? f = 2p

BBC asymmetry

- PHENIX BBC
  - no finite asymmetry was found

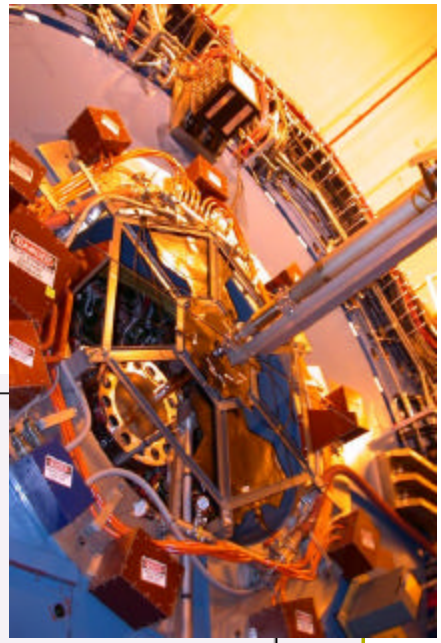
PHENIX BBC
$|A_N| < 0.3\%$
η: 3.0 - 3.9

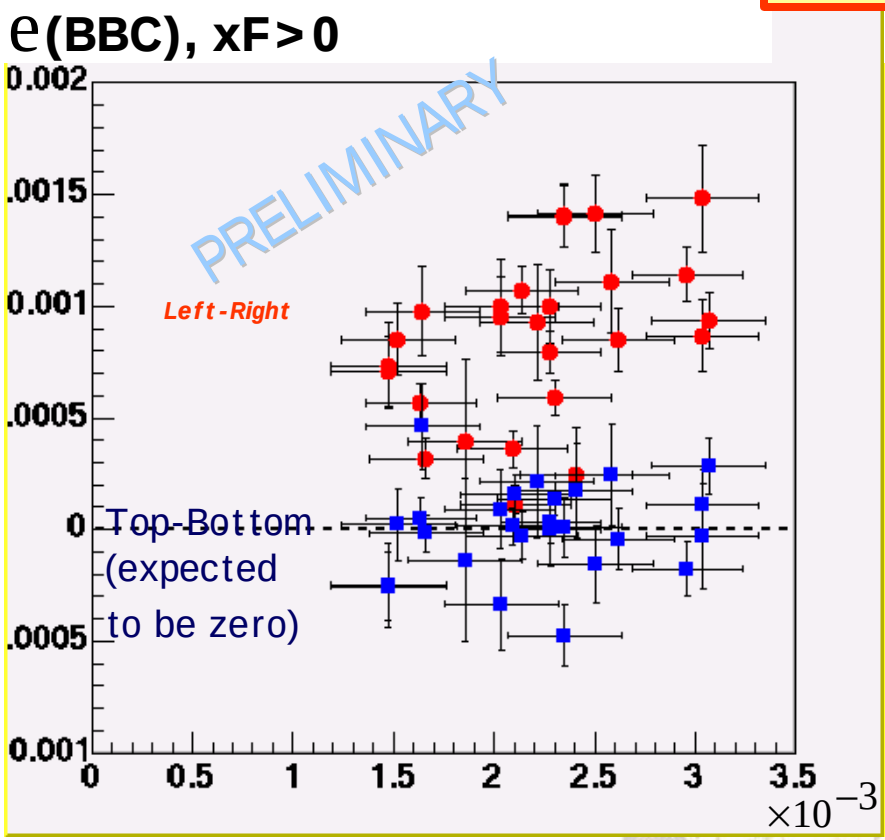


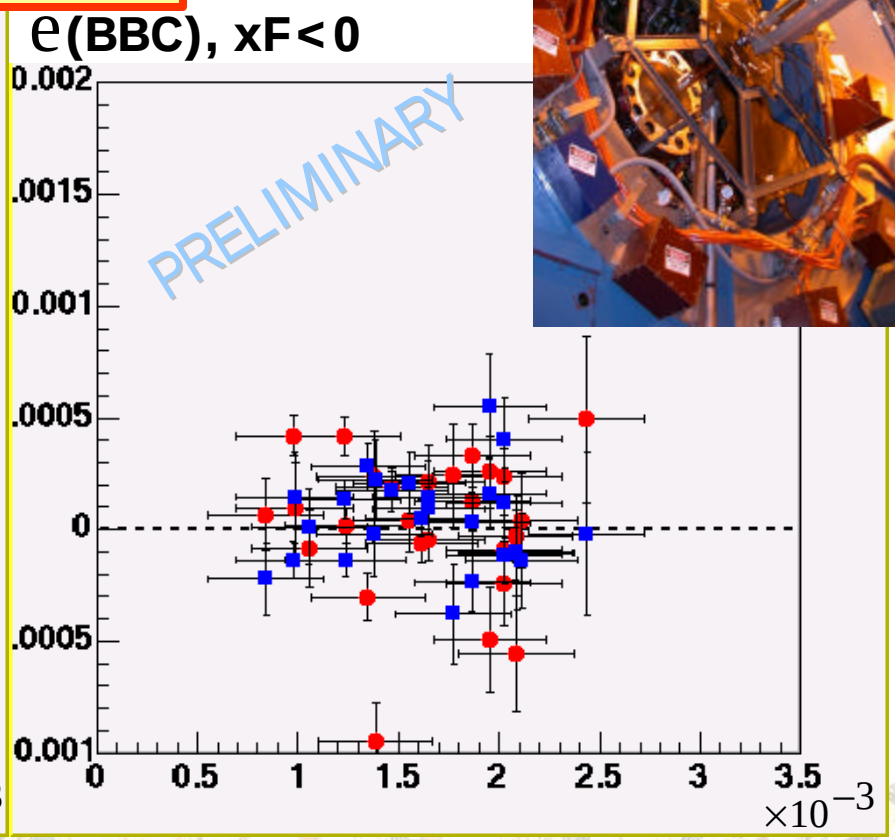
BBC asymmetry

- STAR BBC

STAR BBC
$A_N \sim +0.5\%$
η: 2 - 5





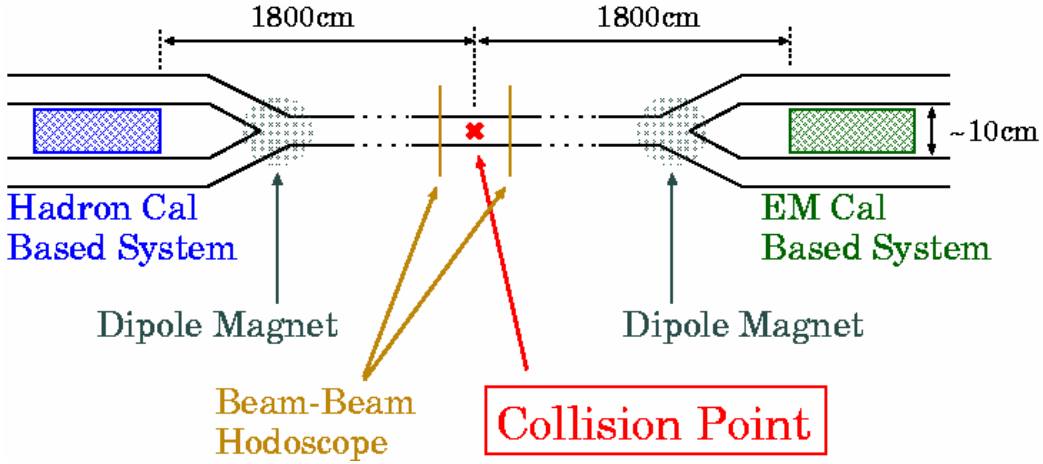


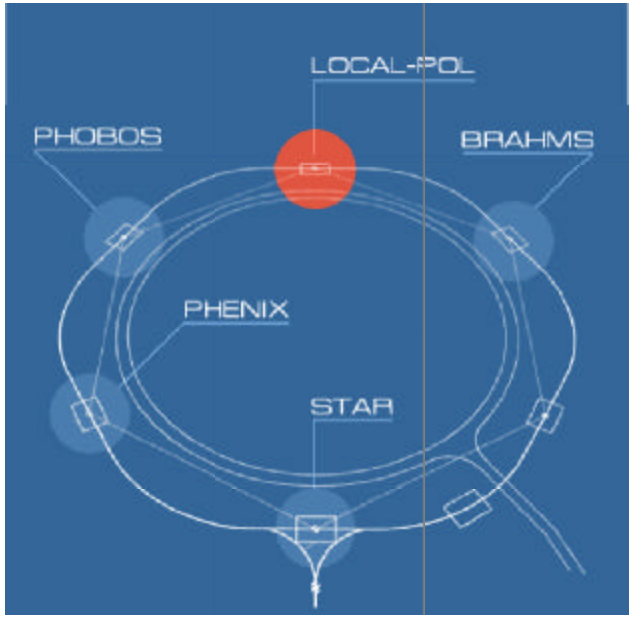
e(CNI) (Yellow)

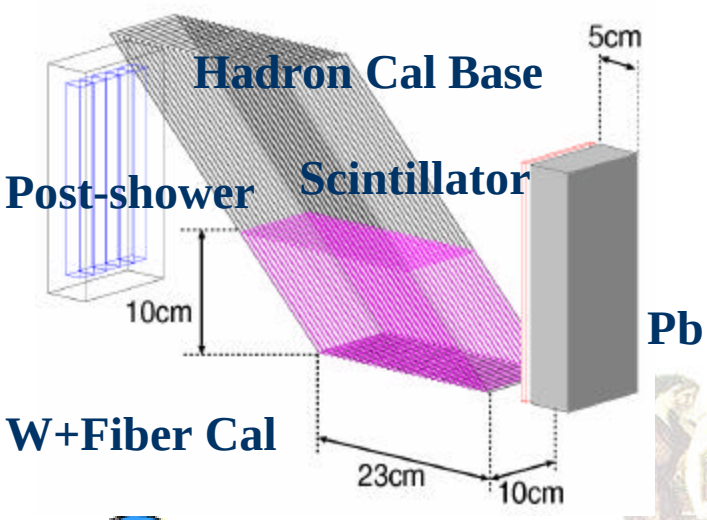
e(CNI) (Blue)

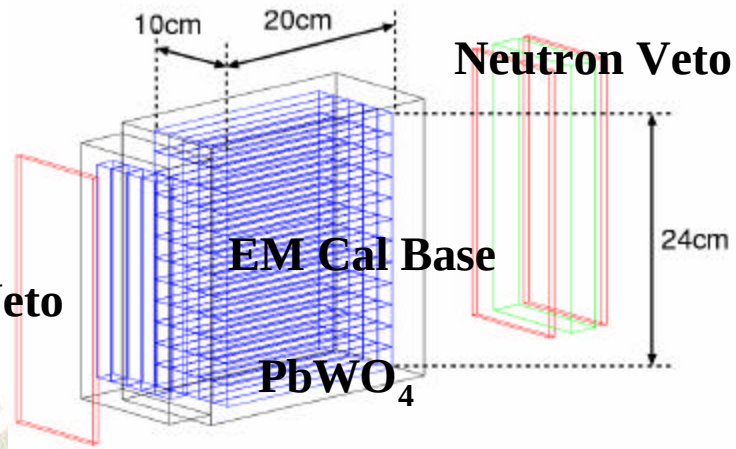
Neutron asymmetry at IP12

- PHENIX local polarimeter R&D

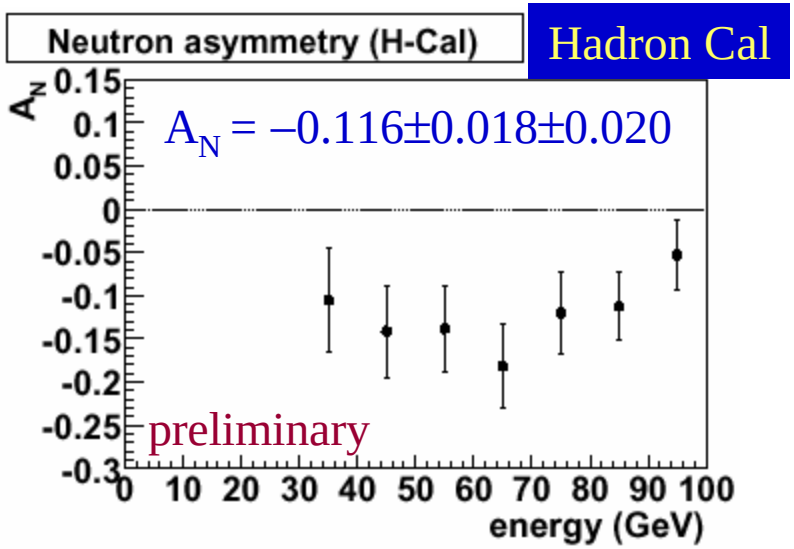


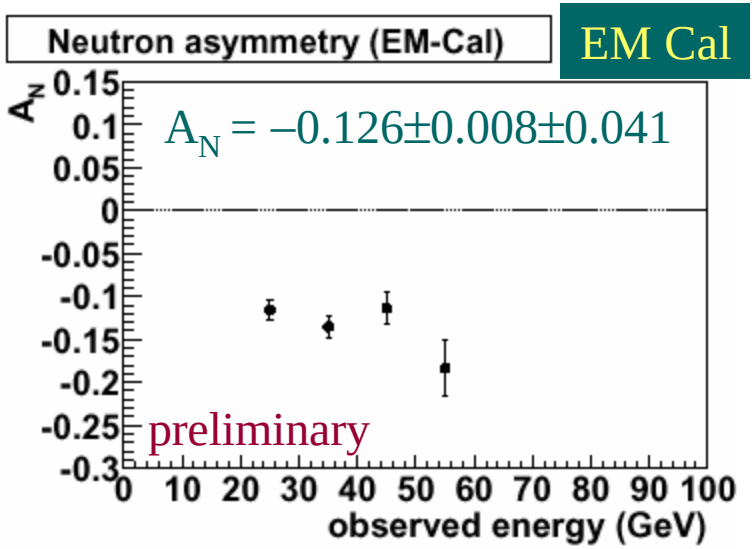


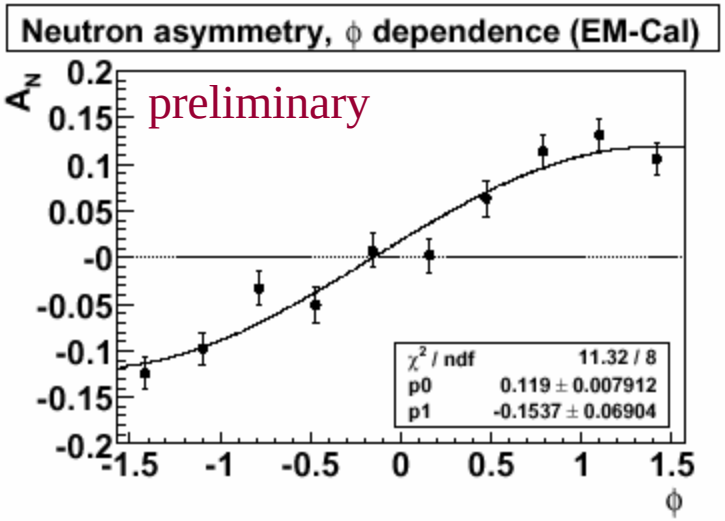




Neutron asymmetry at IP12



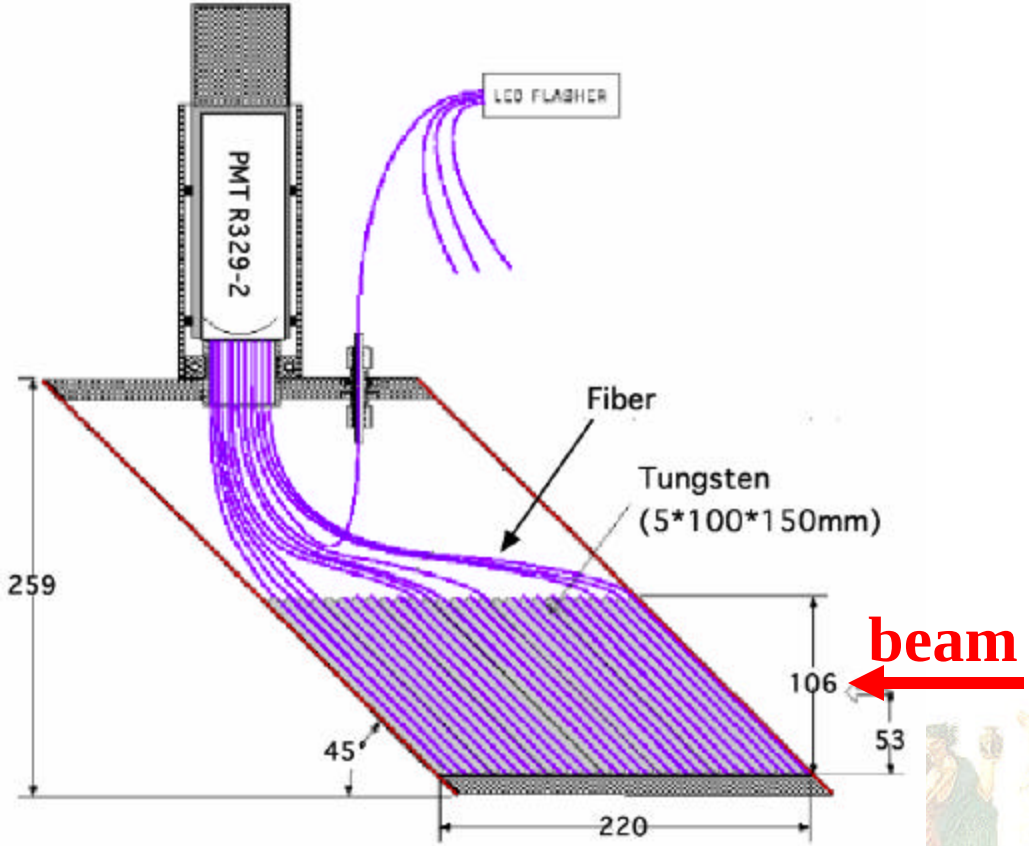


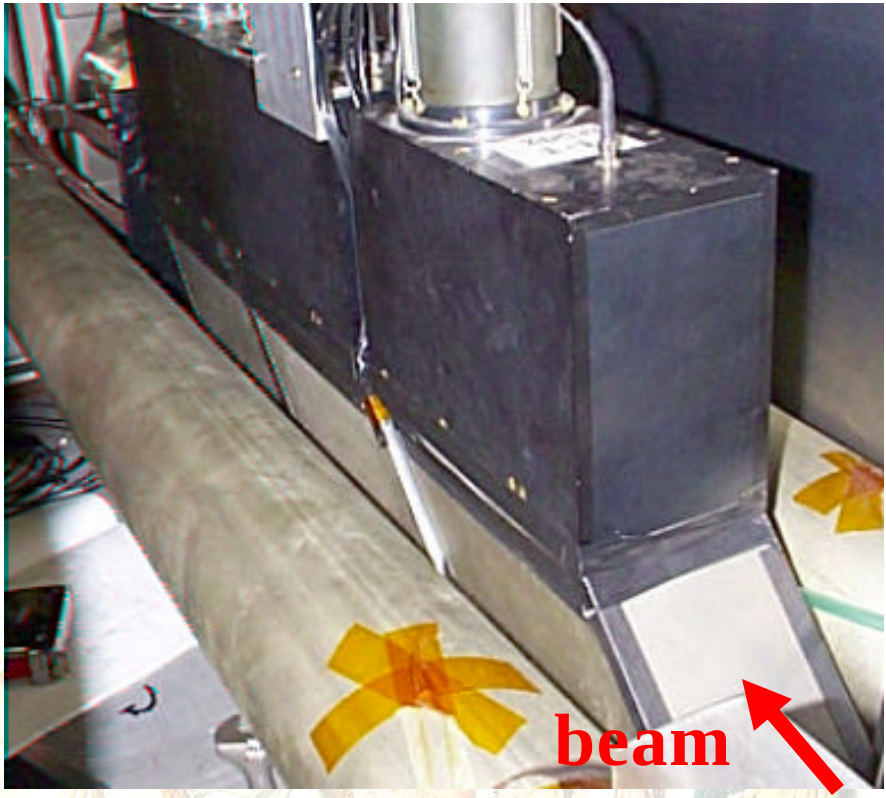


very forward neutron
$A_N \sim -12\%$
$x_F > 0.2$
$p_T < 0.3$ GeV/c

PHENIX ZDC

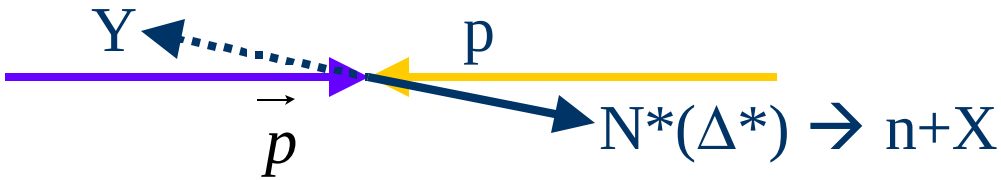
- Zero-Degree Calorimeter (ZDC)
  - tungsten + scintillating fiber hadron calorimeter
  - 5.1 λ_I, 149 X_0 (3 modules)





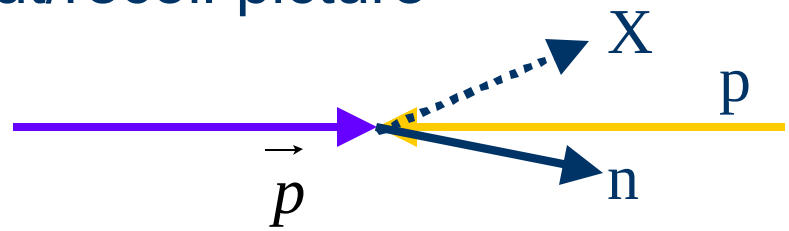
BBC asymmetry with tagged neutron

- Diffractive-like process



$A_N(X) < 0,\ A_N(Y) > 0$

- Kick-out/recoil picture

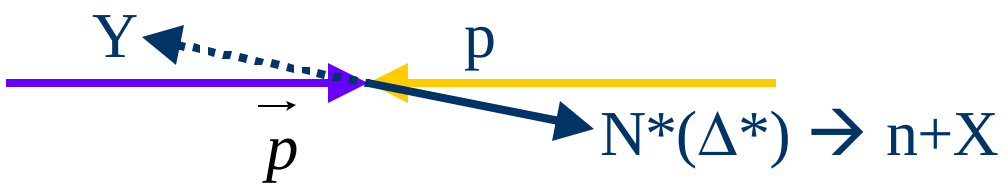


$A_N(X) > 0,\ A_N(Y) \sim 0$

→ gives information on mechanism for neutron A_N

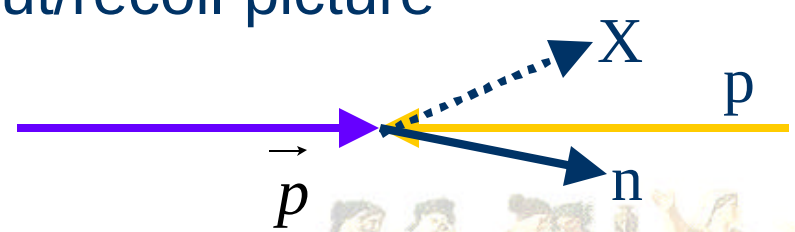
BBC asymmetry with tagged neutron

- The asymmetries for forward neutron tagged data are:
  - –5% (forward BBC)
  - +3% (backward BBC)
- Diffractive-like process



$A_N(X) < 0$, $A_N(Y) > 0$ → OK

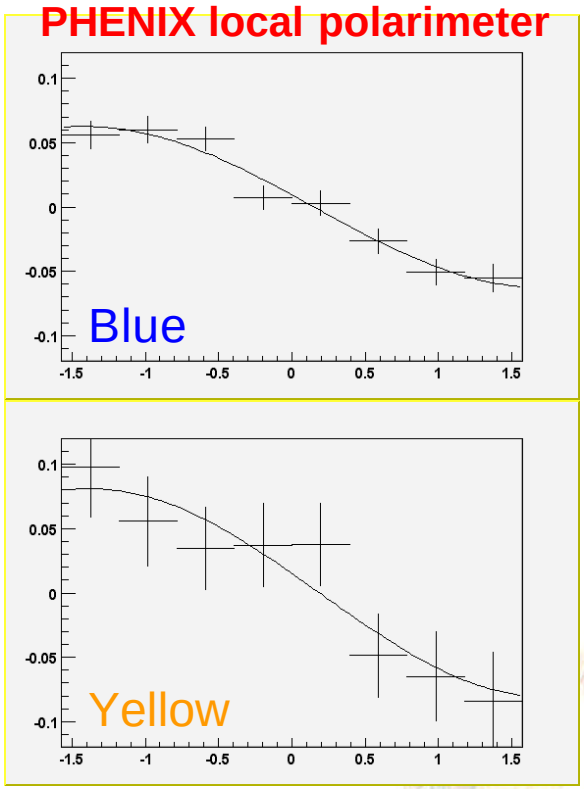
- Kick-out/recoil picture



$A_N(X) > 0$, $A_N(Y)$?? → doesn't match

PHENIX local polarimeter

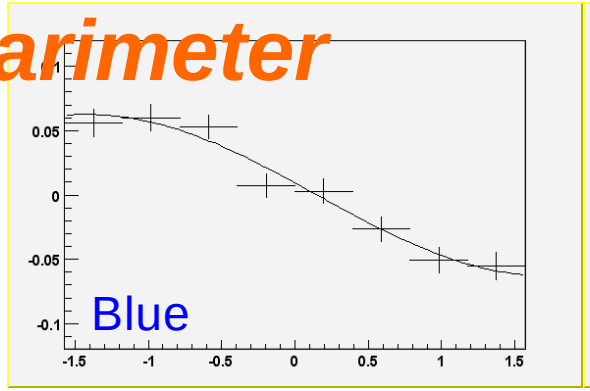
- ZDC + SMD
  - SMD: Shower-Maximum Detector
  - plastic scintillator array
    - X: 7 array
    - Y: 8 array

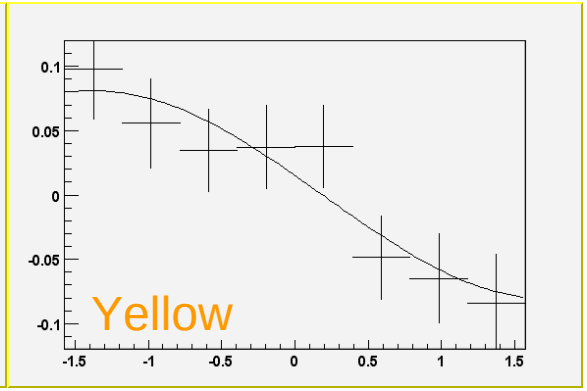


PHENIX local polarimeter

Spin Rotators OFF

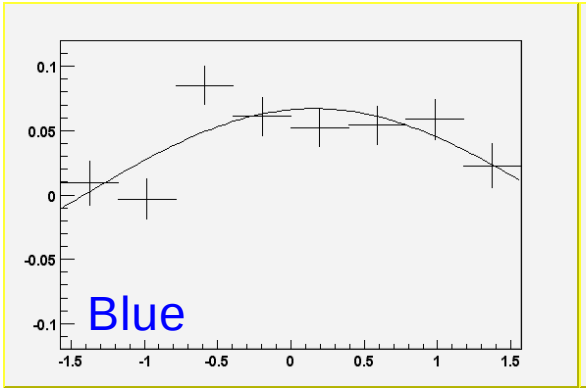
transversely-polarized proton collisions

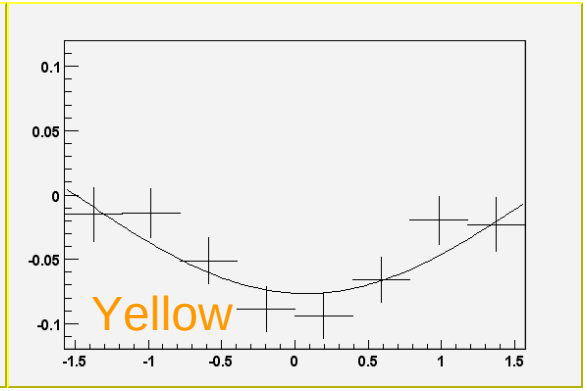




Spin Rotators ON
Current Reversed

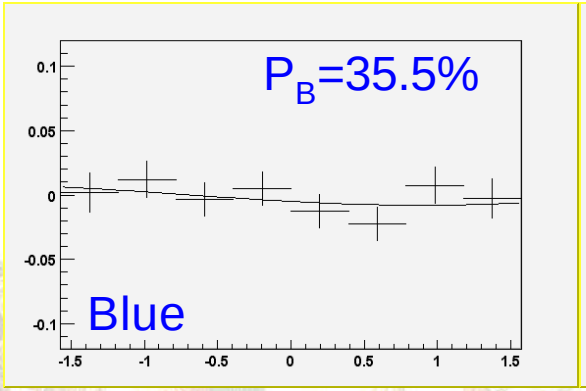
radially-polarized proton collisions

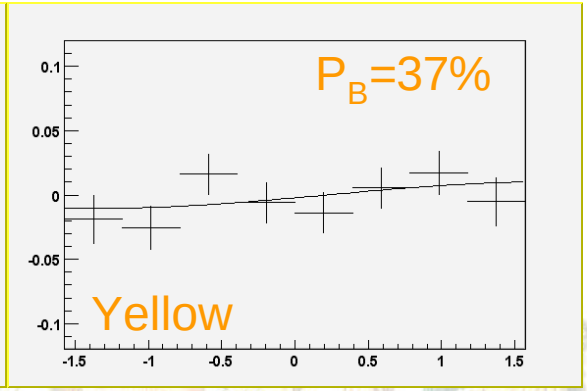




Spin Rotators ON
Correct Current !

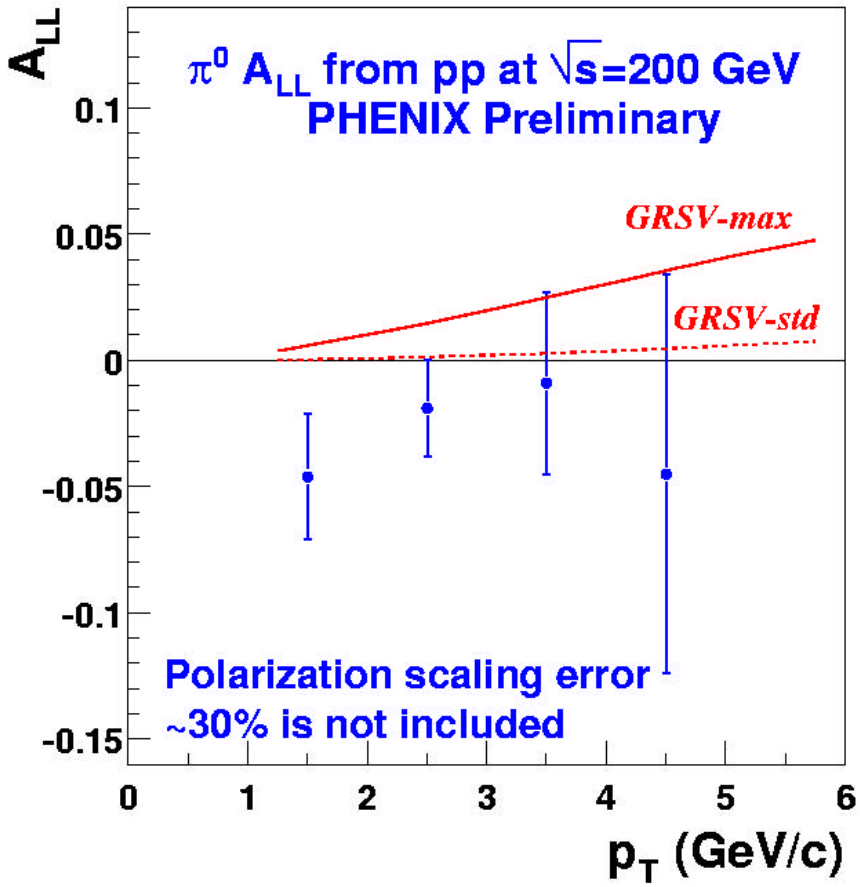
longitudinally-polarized proton collisions





Longitudinal-spin asymmetry

- $A_{LL}(p^0)$ at mid-rapidity region ($x_F \sim 0$)



GRSV model:

B. Jäger et al., Phys. Rev. D 67 (2003) 054005

next-to-leading order pQCD calculations

GRSV-max: DG = 1.84

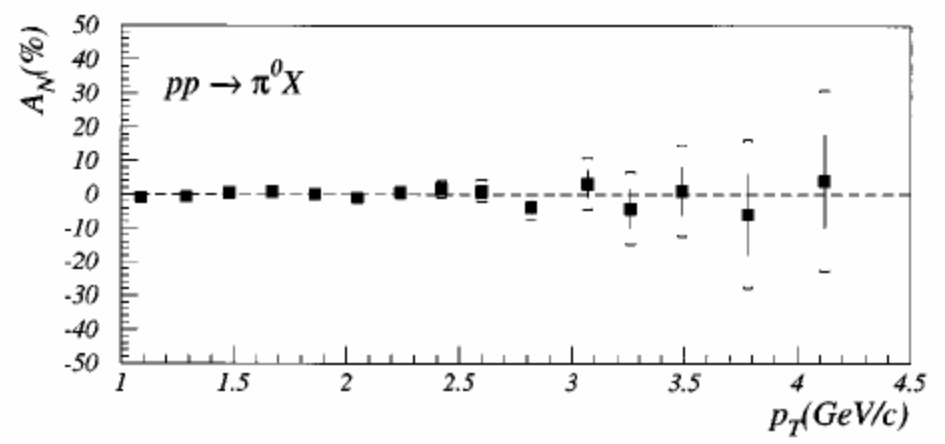
GRSV-std: DG = 0.42 (at *Q2* = 1 GeV2)

Polarization scaling error *dP* ~30%: is not included

- ✓ Analyzing power A_N(100 GeV) = A_N(22GeV) is assumed
- ✓ *dP/P*~30%: combined stat. and syst. error for A_N(22GeV) (AGS E950)

Transverse-spin asymmetries at PHENIX

- $A_N(p^0)$, $A_N(h^{\pm})$ at mid-rapidity region ($x_F \sim 0$)
  - E704 $A_N(p^0)$
    - small asymmetry: consistent with zero
    - no large asymmetry like lower energy data
    - small statistics, especially at high-p_T: more than 10% error



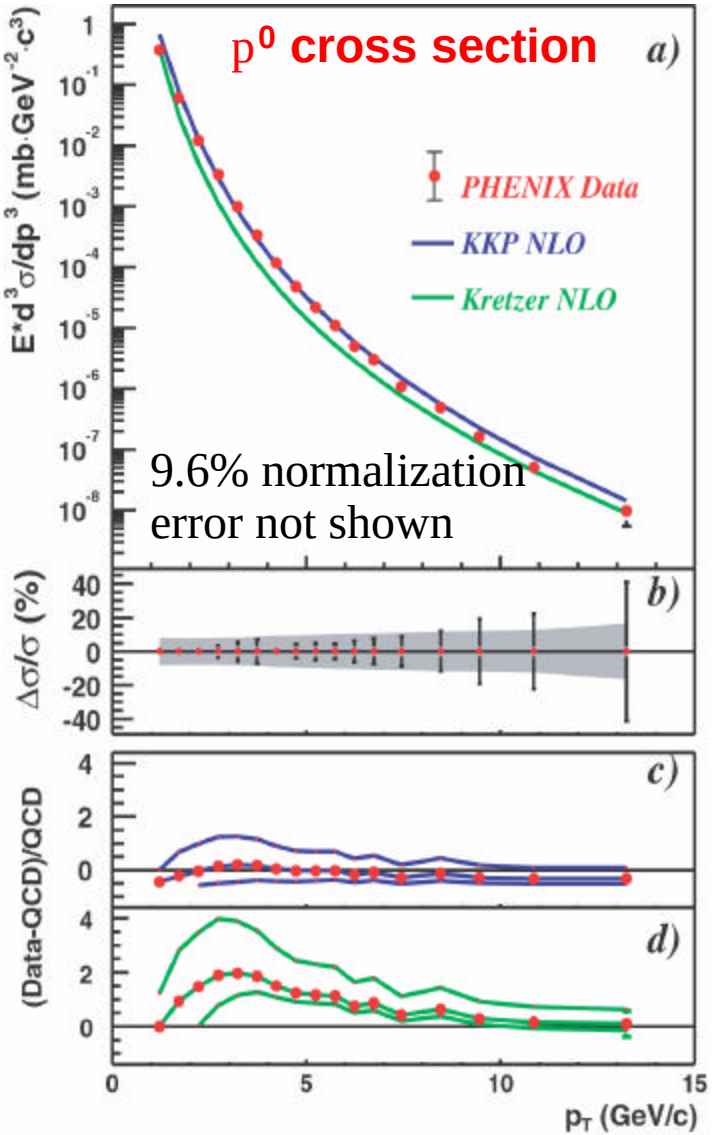
  - PHENIX $A_N(p^0)$, $A_N(h^{\pm})$
    - $p_T < 8$ GeV/c
    - important comparison data with A_{LL}
    - analysis ongoing …

Summary

- Transversity measurement at PHENIX
  - $\pi^+\pi^-$ interference fragmentation function
  - Collins effect in jets
  - inclusive jet production
- Transverse-spin asymmetry measurements at PHENIX
  - forward neutron asymmetry at IP12
    - $x_F > 0.2$, $p_T < 0.3$ GeV/c
    - $A_N \sim -12\%$
    - PHENIX local polarimeter
  - PHENIX BBC
    - η: 3.0 - 3.9
    - no finite asymmetry was found: $|A_N| < 0.3\%$
  - BBC with tagged neutron
    - –5% (forward BBC), +3% (backward BBC)
    - diffractive-like process ?
  - $A_N(p^0)$, $A_N(h^\pm)$ at mid-rapidity region ($x_F \sim 0$)
    - important comparison data with A_{LL}
    - analysis ongoing …

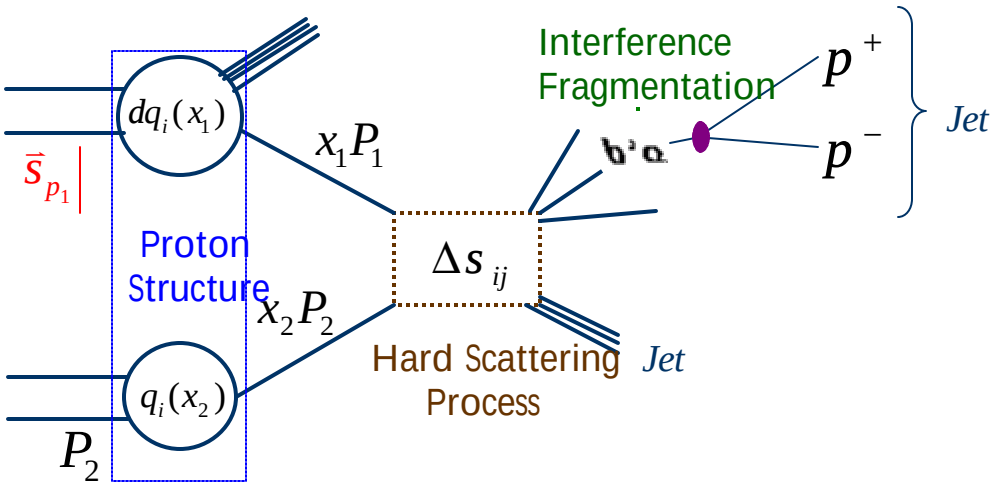
Summary 1

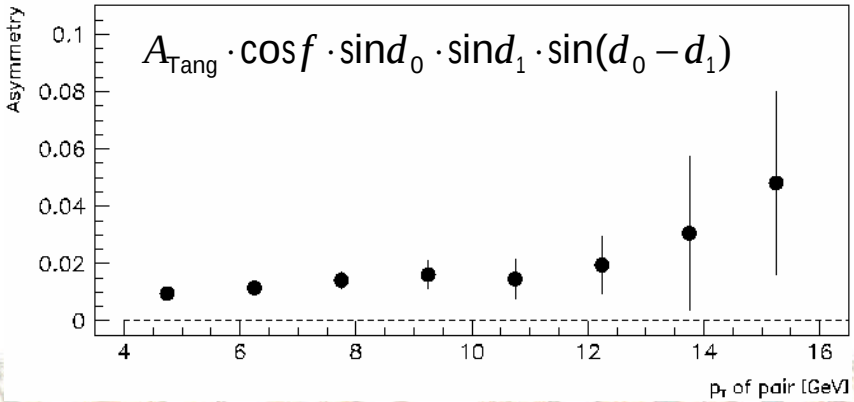
- Spin physic at PHENIX
  - high precision spin physics
    - π^0 cross section measurement
      - data covers over 8 orders of magnitude
      - NLO pQCD calculation is consistent with our data
      - confidence in understanding subprocesses
  - origin of the proton spin 1/2 ?
    - gluon polarization
    - flavor decomposition of the quark/antiquark polarization
  - transversity
  - parity violating asymmetries
  - transverse-spin asymmetries



Summary 2

- Transversity measurement at PHENIX
  - near future
    - $\pi^+\pi^-$ interference fragmentation function
      - for 32pb^{-1}, small aymmetry below 5% but good rate

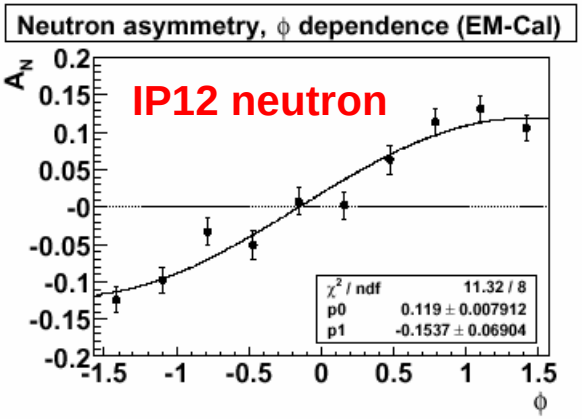


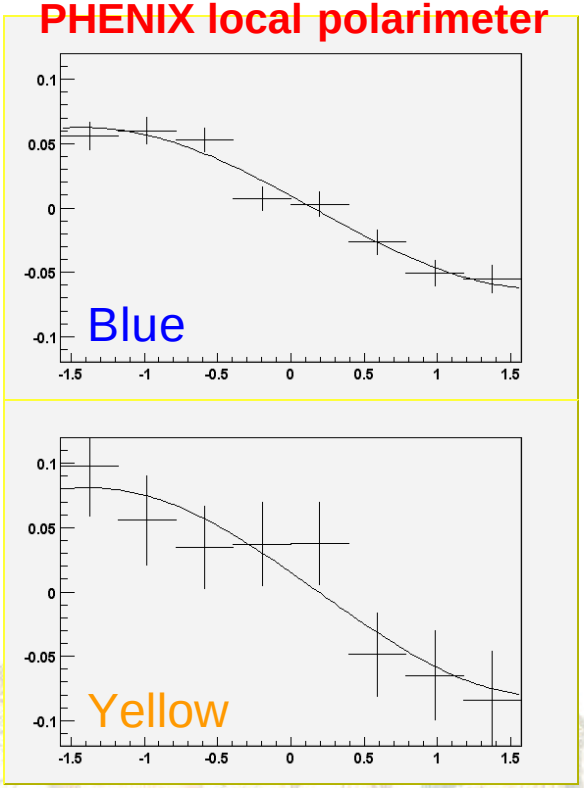


    - Collins effect in jets
    - inclusive jet production
  - luminosity upgrade: 8pb^{-1}
    - direct photon
    - Drell-Yan

Summary 3

- Transverse-spin asymmetry measurements at PHENIX
  - forward neutron asymmetry at IP12
    - $x_F > 0.2$, $p_T < 0.3$ GeV/c
    - $A_N \sim -12\%$
    - PHENIX local polarimeter
  - PHENIX BBC
    - η: 3.0 - 3.9
    - no finite asymmetry was found: $|A_N| < 0.3\%$
  - BBC with tagged neutron
    - –5% (forward BBC), +3% (backward BBC)
    - diffractive-like process ?
  - $A_N(p^0)$, $A_N(h^{\pm})$ at mid-rapidity region ($x_F \sim 0$)
    - important comparison data with A_{LL}
    - analysis ongoing …



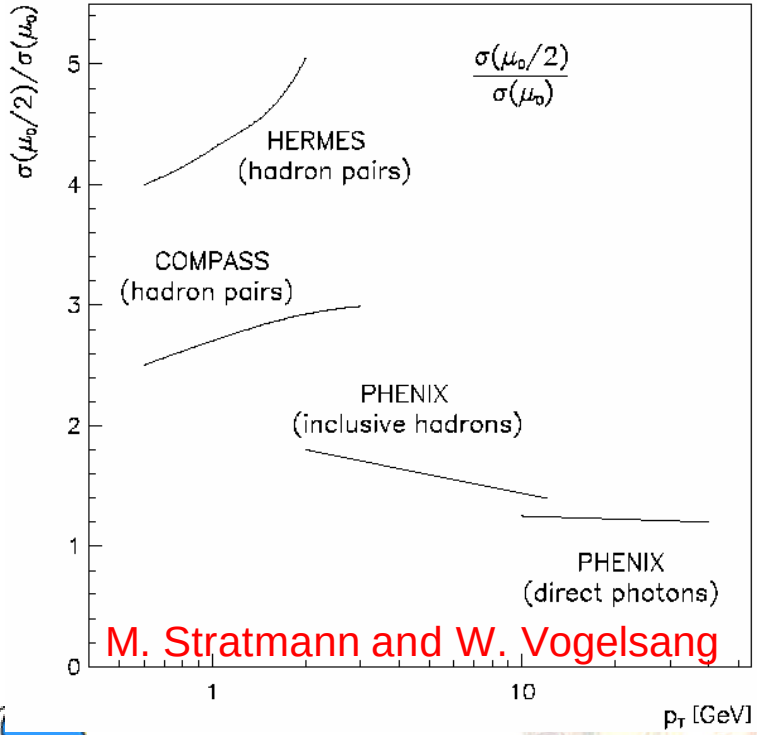


Spin physics at PHENIX

- For precision spin physics
- High energy and high transverse-momentum
  - $\sqrt{s}$ = 200 GeV & 500 GeV
    - more than 10 times higher than Fermilab E704 ($\sqrt{s}$ = 20 GeV)
  - new tools
    - weak boson, heavy flavors, …
  - perturbative QCD applicable
- Cancels out systematic uncertainty

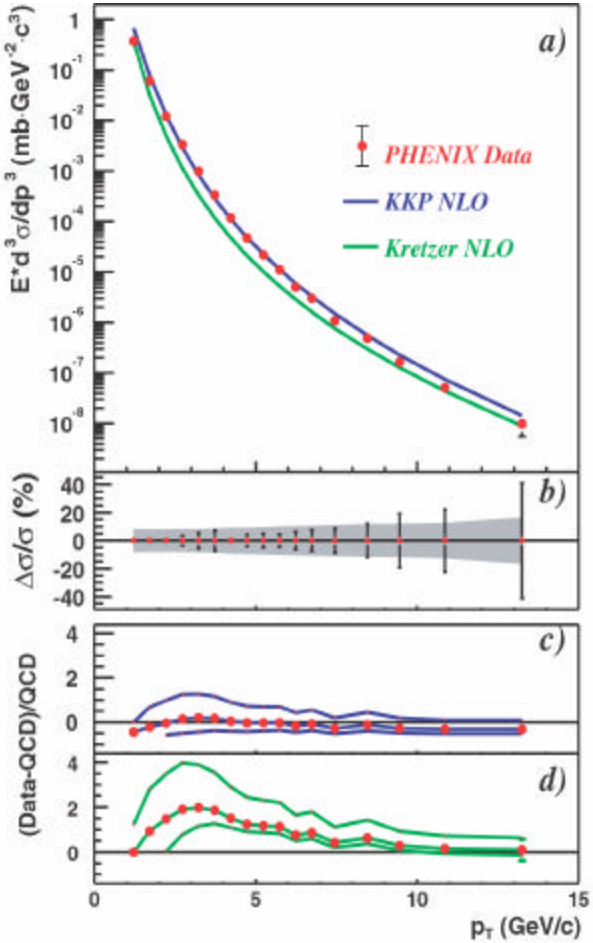
Spin physics at PHENIX

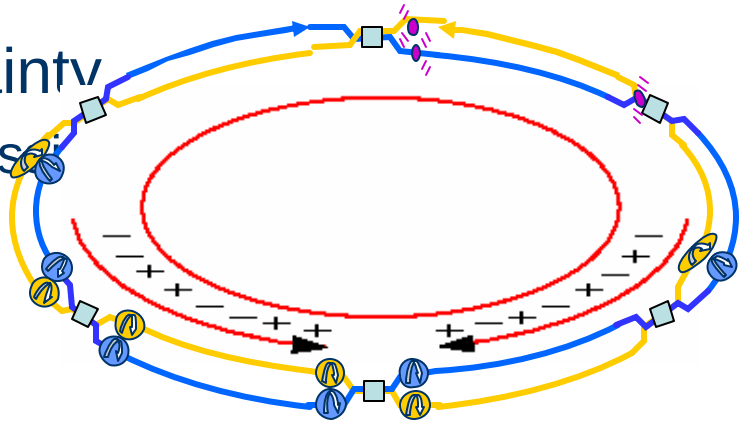
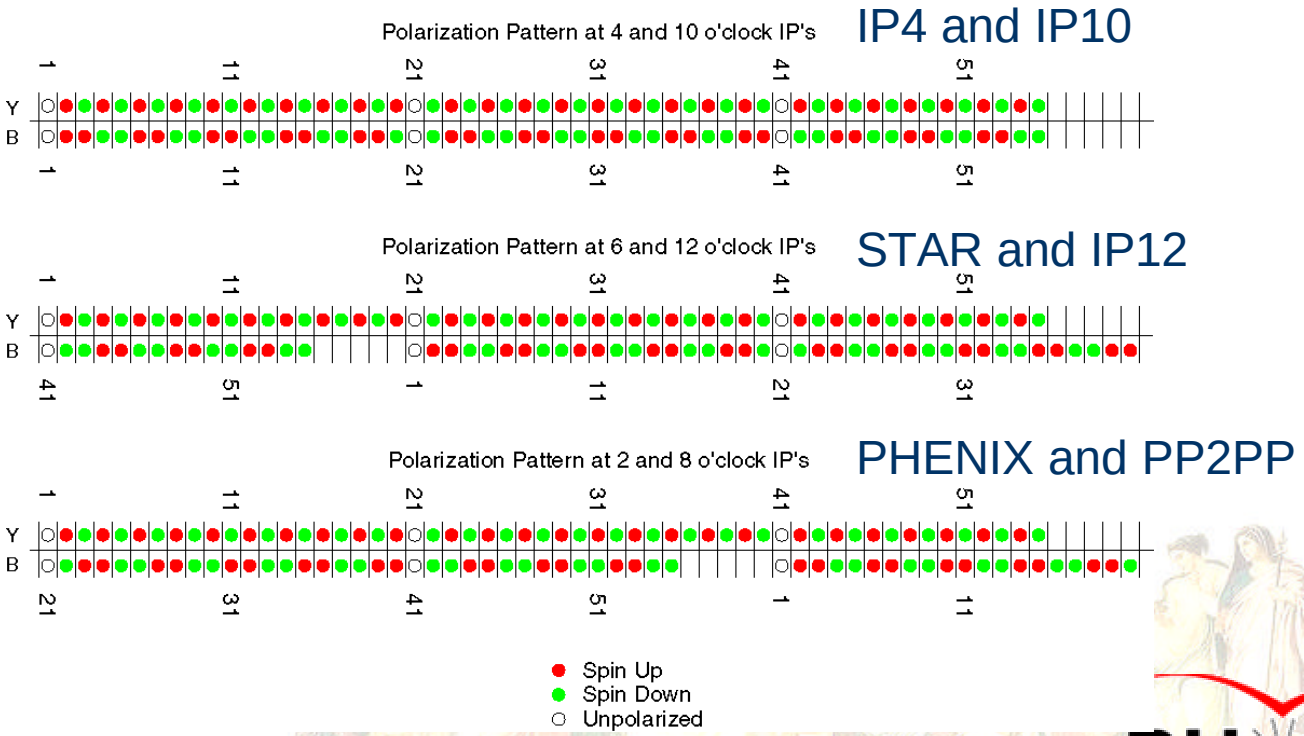
- Perturbative QCD applicable ?
  - Scale dependence of the NLO pQCD calculation
  - Though scale dependence is expected to largely cancel in the asymmetry



M. Stratmann and W. Vogelsang

  - Calculation agrees with the data within 50% for p_T > 2 GeV/*c*



Spin physics at PHENIX

- To cancel out systematic uncertainty
  - Different spin combination every cross
    2001-2002, 110 crossings in 2003)
  - Spin flip and recogging (2003 -)