Transversity Physics Results from PHENIX

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XIII International Workshop on Deep Inelastic Scattering (DIS2005)

PHENIX

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- University of Muenster, Muenster, Germany
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- Eövös Loránd University (ELTE), Budapest, Hungary
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- Kyoto University, Kyoto, Japan
- Nagasaki Institute of Applied Science, Nagasaki-shi, Nagasaki, Japan
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- Korea University, Seoul, 136-701, Korea
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- Joint Institute for Nuclear Research (JINR-Dubna), Dubna, Russia
- Kurchatov Institute, Moscow, Russia
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13 Countries; 62 Institutions; 550 Participants*

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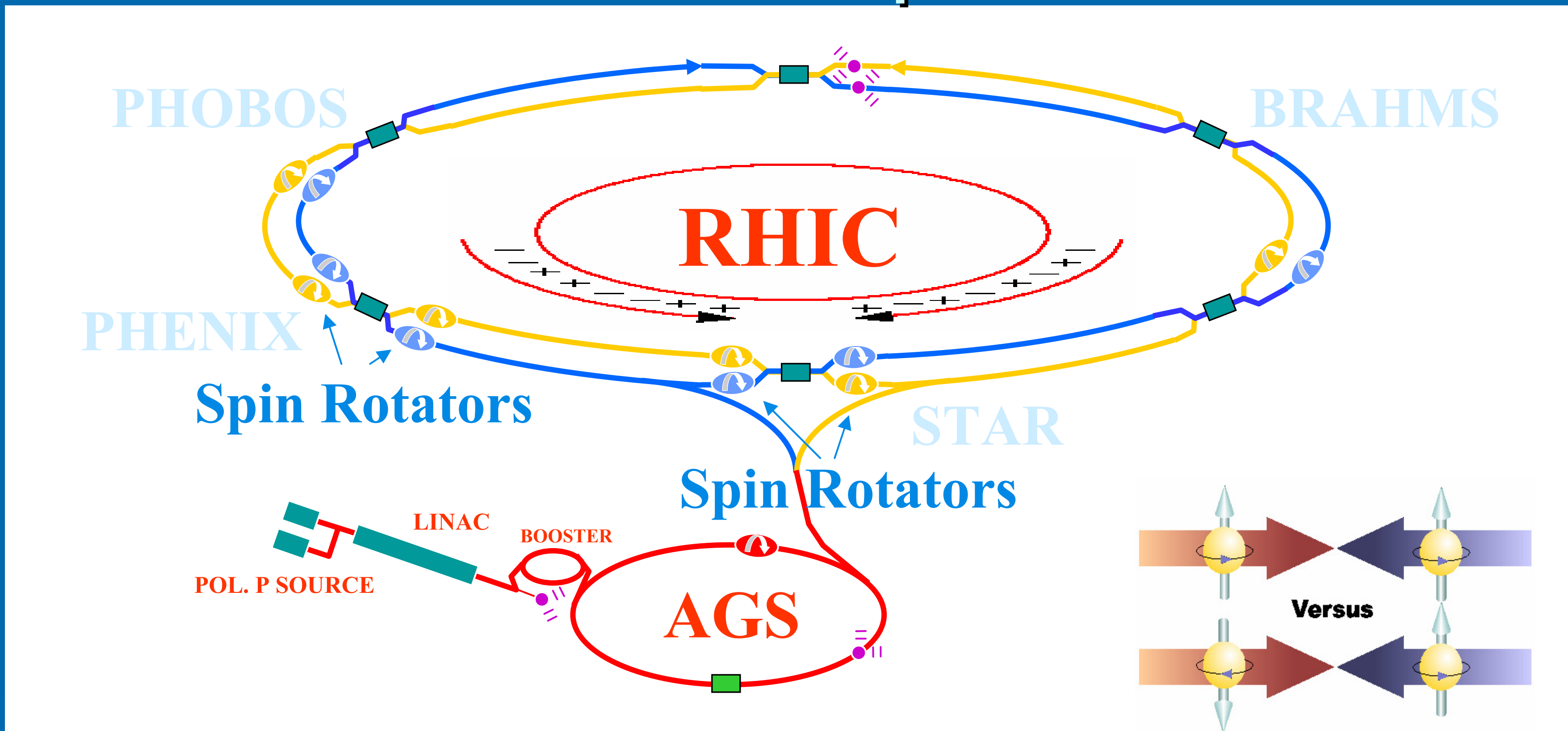
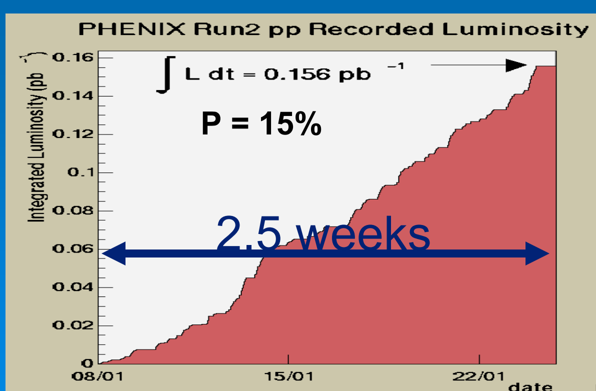
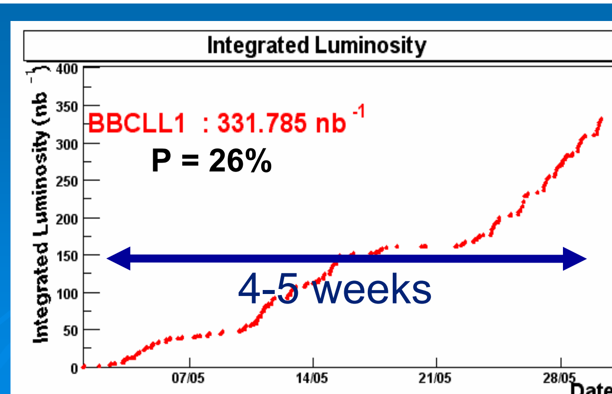
*as of March 2005

RHIC Spin

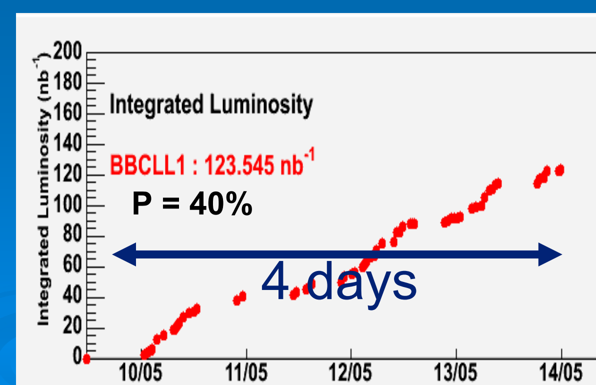




Run02

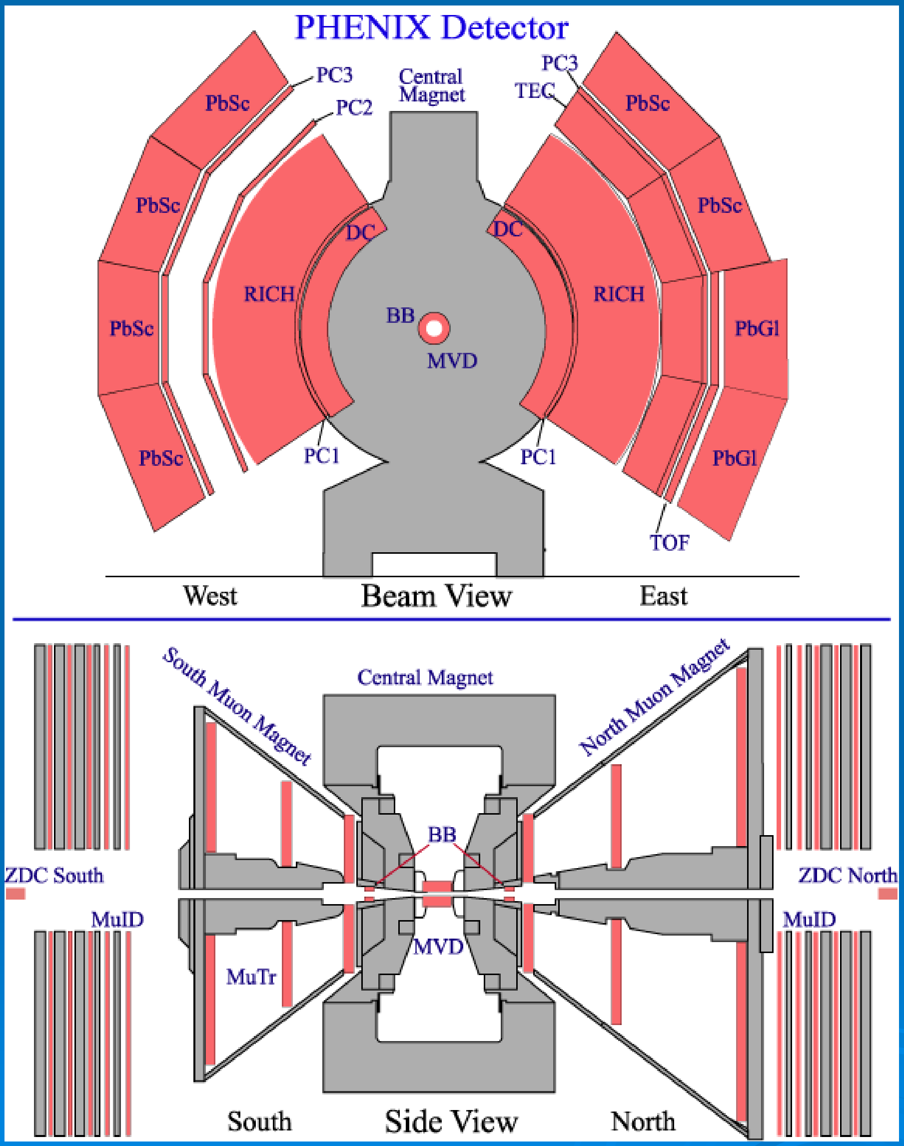


Run03



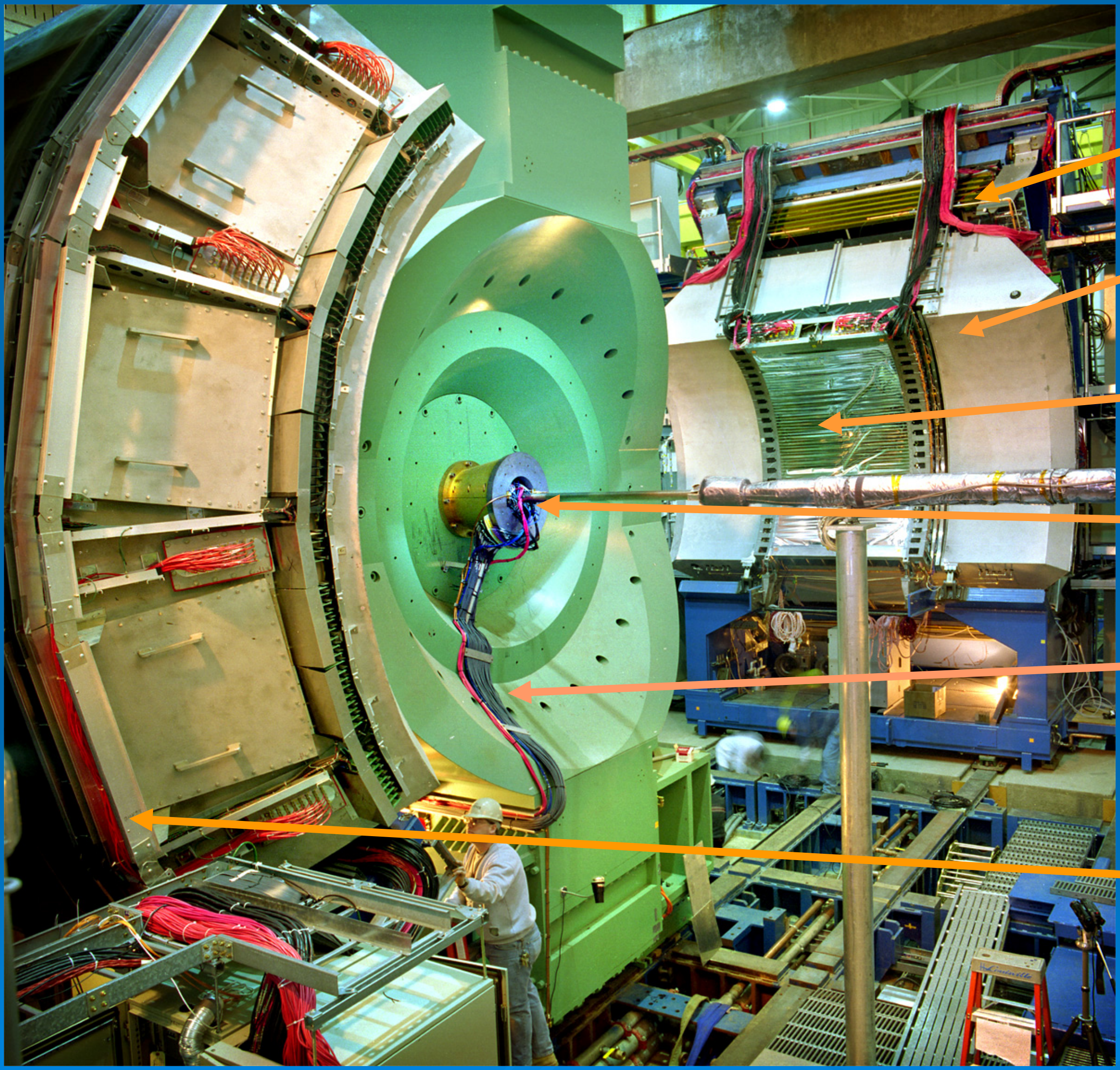
Run04

PHENIX Detector



- **Central Arm Tracking** $|\eta| < 0.35$, $x_F \sim 0$
  - Drift Chamber (DC)
    - momentum measurement
  - Pad Chambers (PC)
    - pattern recognition, 3d space point
  - Time Expansion Chamber
    - additional resolution at high pt
- **Central Arm Calorimetry**
  - PbGl and PbSc
    - Very Fine Granularity
      - Tower $\Delta\phi \times \Delta\eta \sim 0.01 \times 0.01$
    - 2 Technologies, different systematics
    - Trigger
- **Central Arm Particle Id**
  - RICH
    - electron/hadron separation
  - TOF (East Only)
    - π/K/p identification
- **Global Detectors (Luminosity,Trigger)**
  - BBC $3.0 < |\eta| < 3.9$
    - Quartz Cherenkov Radiators
  - ZDC/SMD (**Local Polarimeter)**
    - Forward Hadron Calorimeter
- **Muon Arms**

PHENIX Central



East Carriage

Ring Imaging Cerenkov

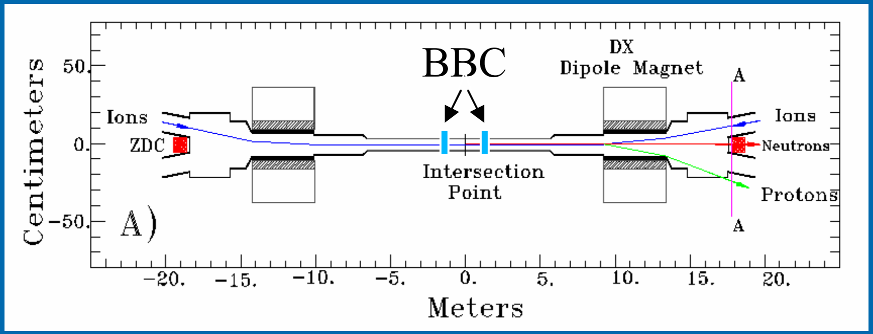
Drift Chamber

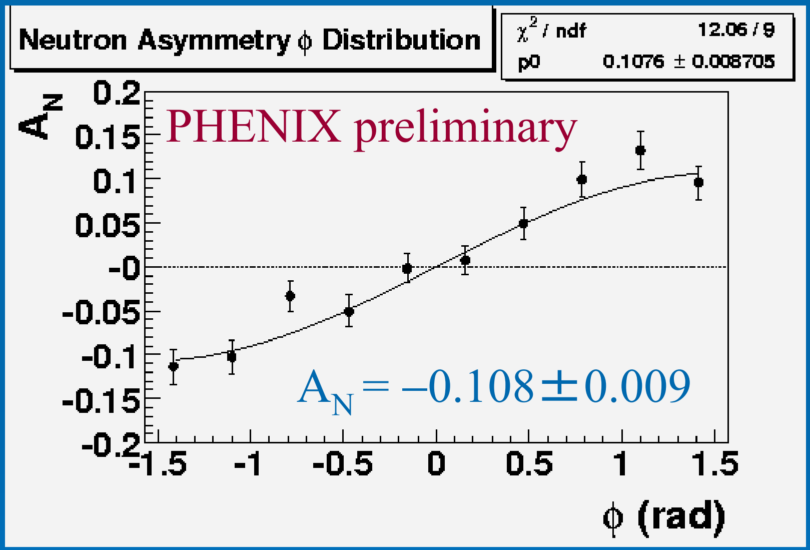
Beam-Beam Counter

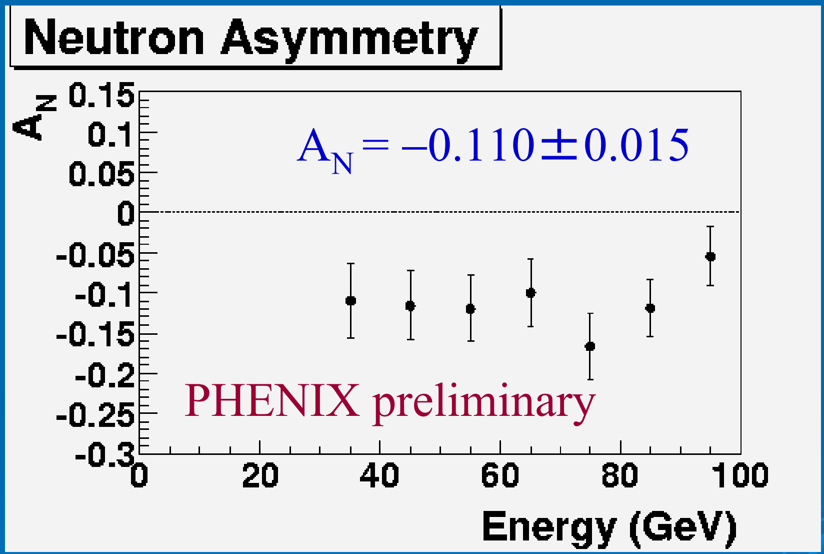
Central Magnet

West Carriage

Very Forward Neutron Asymmetry



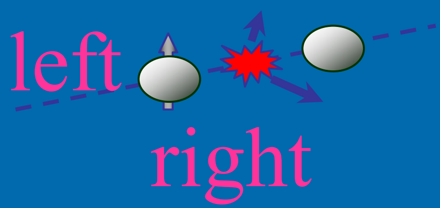




- Large Neutron A_N was discovered by PHENIX
- Cause not yet well understood
  - A possible diffractive process?
  - Charge Exchange?
- ZDC/SMD can make a local polarimetry measurement at PHENIX

Single Transverse Spin Asymmetries

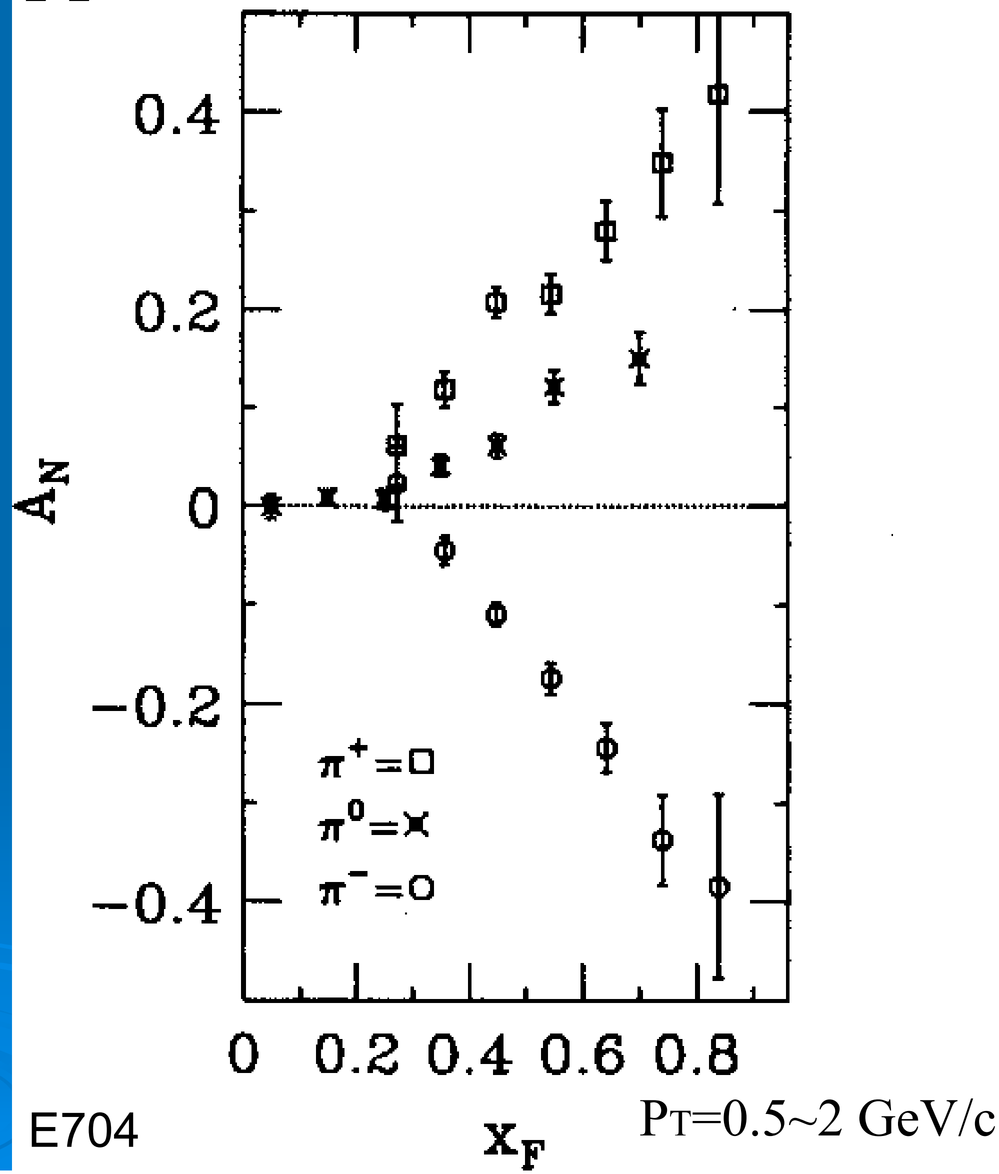
- Fermilab E-704 reported Large Asymmetries A_N in pion productions



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

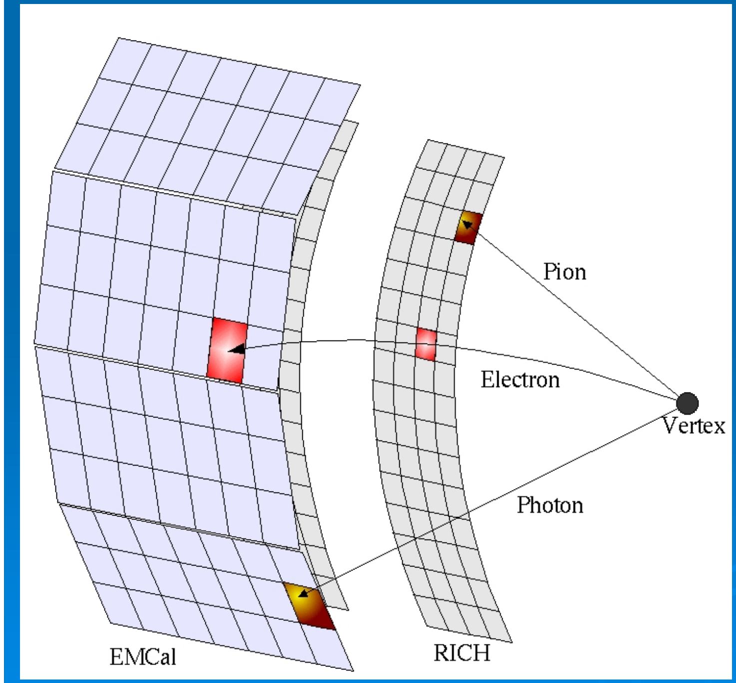
1. Transversity x Spin-dep fragmentation (Collins-Heppelmann effect), or
2. Intrinsic-k_T imbalance (Sivers effect) , or
3. Higher-twist effects
   1. Sterman and Qiu Initial State Twist 3
   2. Koike Final State Twist 3
4. Or combination of above

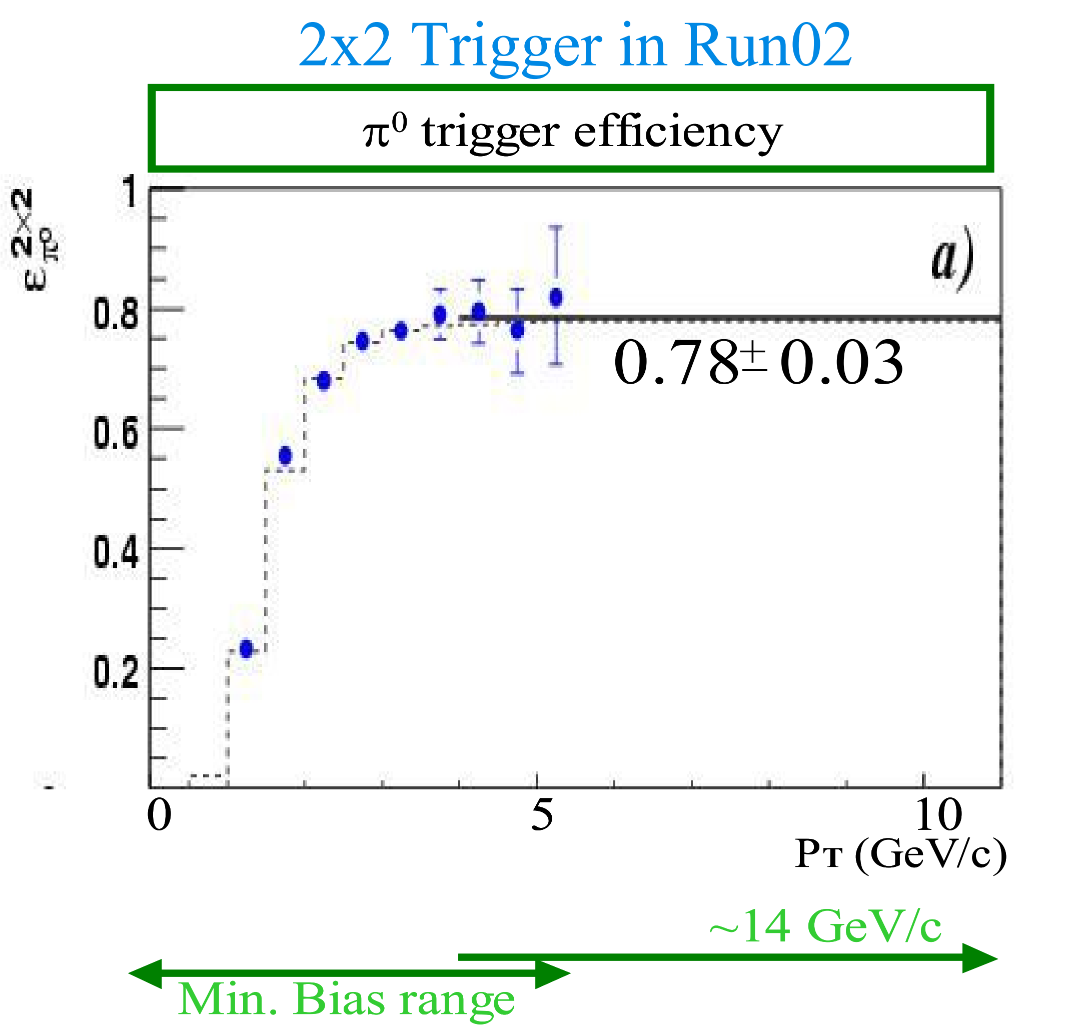
$$pp \rightarrow \pi X \text{ at } \sqrt{s} = 19.4 \text{ GeV}$$



EMCal-RICH 2x2 Trigger

- 2x2 towers non-overlapping sum
- Threshold ~ 0.8 GeV
  - •PbSc λ_{int} ~ 1, some trigger sensitivity to hadrons as well
- •Future Runs used overlapping 4x4 tower sum for better photon efficiency





Calculating A_N for π^0, charged hadrons

- Look for left-right asymmetry with respect to beam spin and direction

$$A_N P = \frac{N_L - N_R R_{acc}}{N_L + N_R R_{acc}}$$

R_{acc} = relative acceptance of left and right detectors

- OR look either on left or right side and compare production for + and - spin states

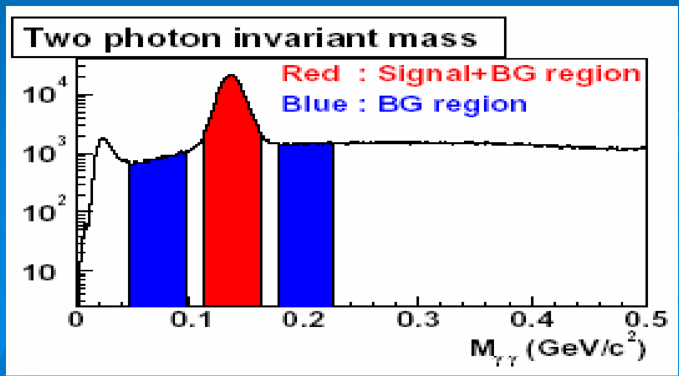
$$A_N^L P = \frac{N_L(+) - N_L(-) R_{lumi}}{N_L(+) + N_L(-) R_{lumi}}$$

R_{lumi} = relative luminosity of + and - spin states

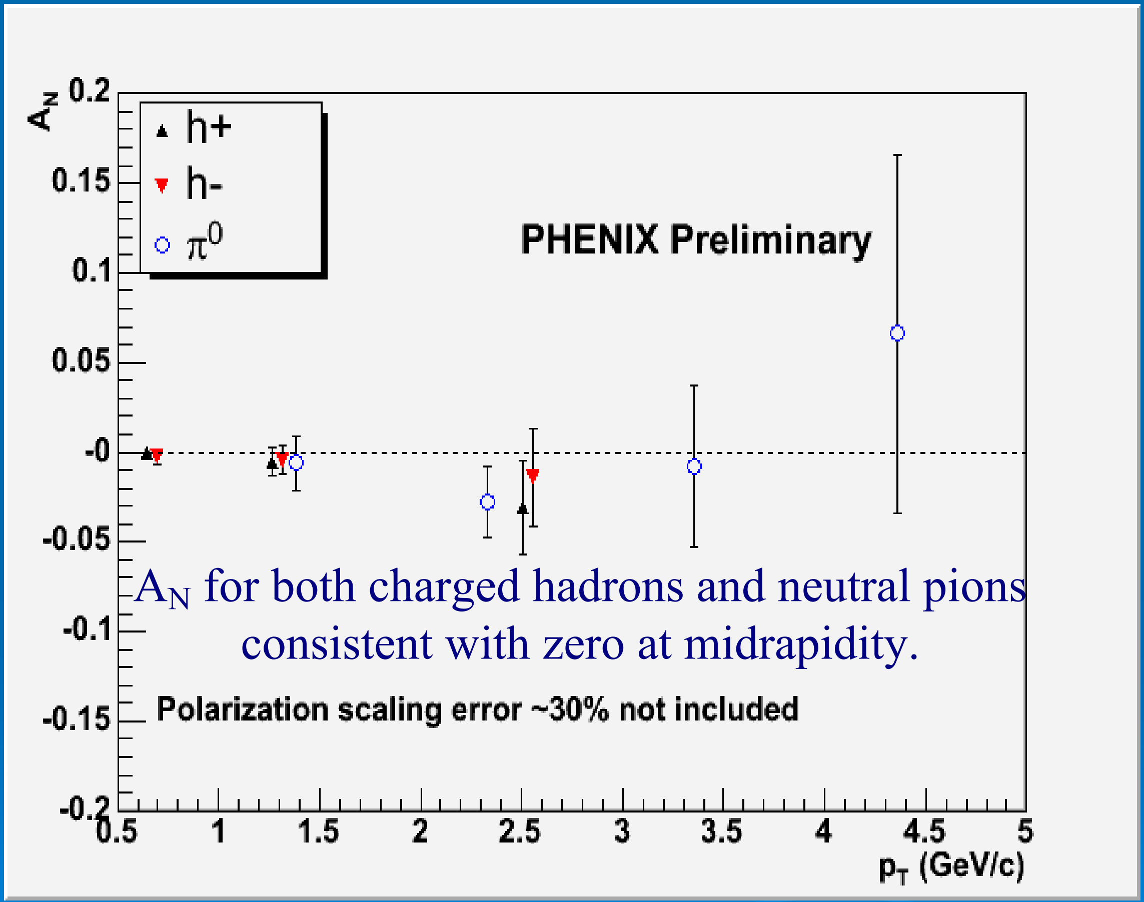
Two methods provide important check of systematic errors

- *For π^0, additional subtraction of combinatoric background is necessary*

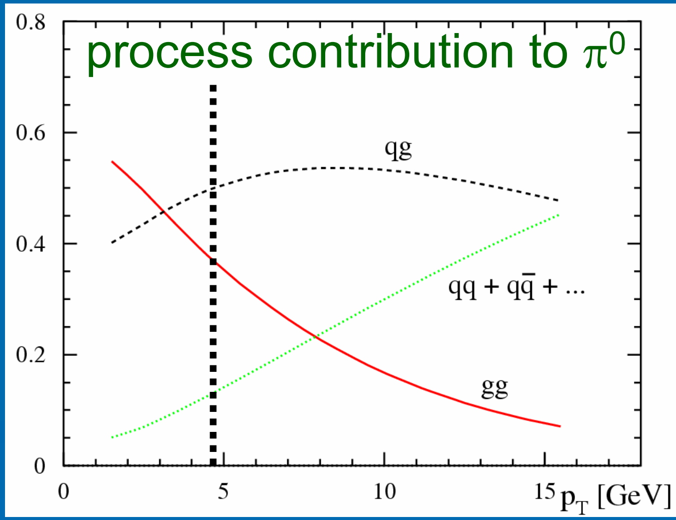
$$A_N^{\pi^0} = \frac{A_N^{\pi^0+bkg} - rA_N^{bkg}}{1-r}$$



Single Spin Asymmetry of π^0 and Non-Identified Charged Hadrons at $x_F \sim 0$ vs p_T



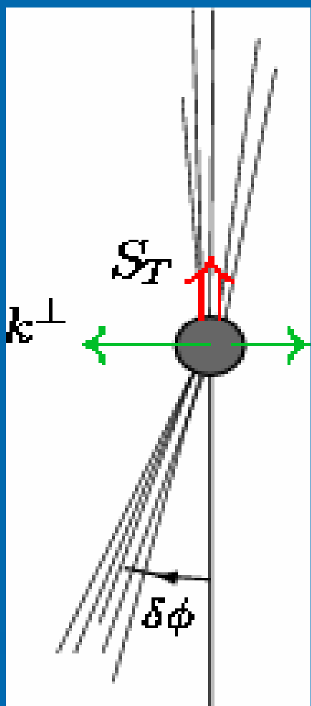
Data taken 0.15 pb^{-1} and 15 % beam polarization



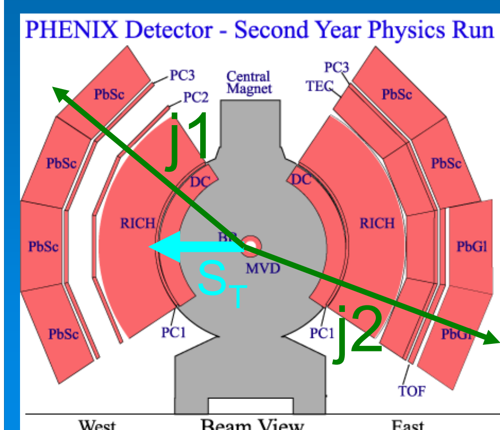
More statistics needed to map out pT↔ x ↔ g/q dependence

Sivers Fcn from Back2Back Analysis

Boer and Vogelsang, Phys.Rev.D69:094025,2004, hep-ph/0312320

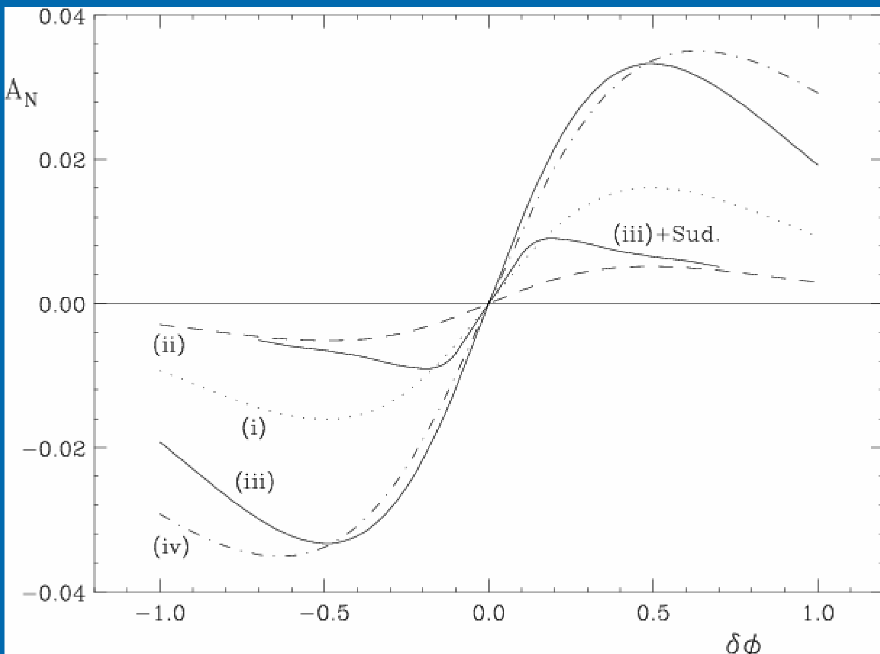


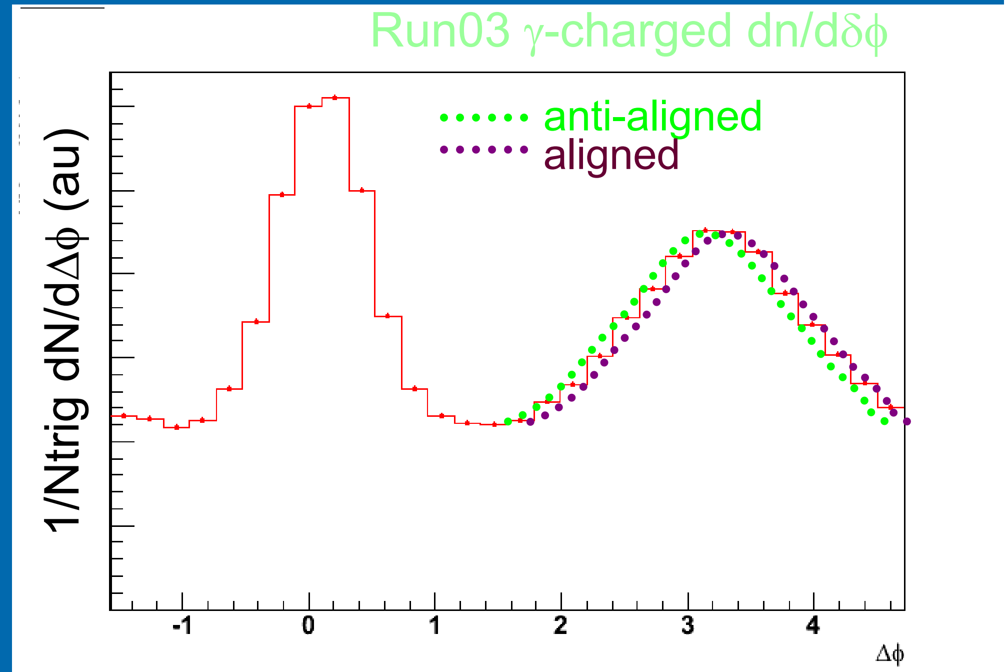
- Boer and Vogelsang find that this parton asymmetry will lead to an asymmetry in the $\delta\phi$ distribution of back-to-back jets
  - There should be more jets to the left (as in picture to the left).
- Should also be able to see this effect with fragments of jets, and not just with fully reconstructed jets?
  - Take some jet trigger particle along S_T axis (either aligned or anti-aligned to S_T)
  - Trigger doesn't have to be a leading particle, but does have to be a good jet proxy
  - Then look at $\delta\phi$ distribution of away side particles



Unpolarized Results from Run03 p+p

Boer and Vogelsang, PRD69:094025,2004





•Asymmetry $A_N \equiv \dfrac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$

- •numerator is difference between aligned and anti-aligned δφ dist's, where aligned means trigger jet and spin in same direction
- •denominator is simply unpolarized δφ distribution

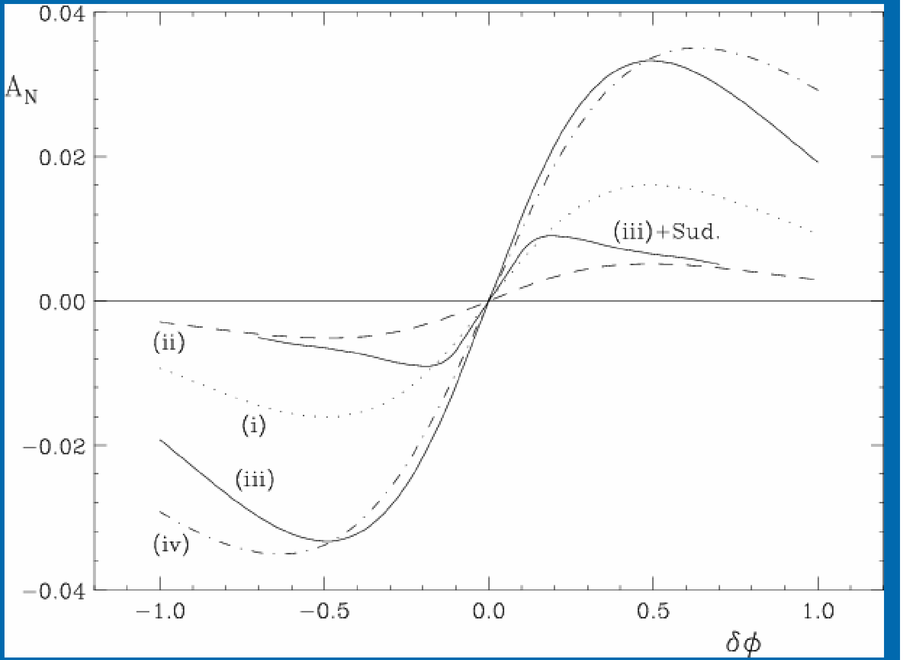
•On left are some theoretical guesses on expected magnitude of AN from Siver's

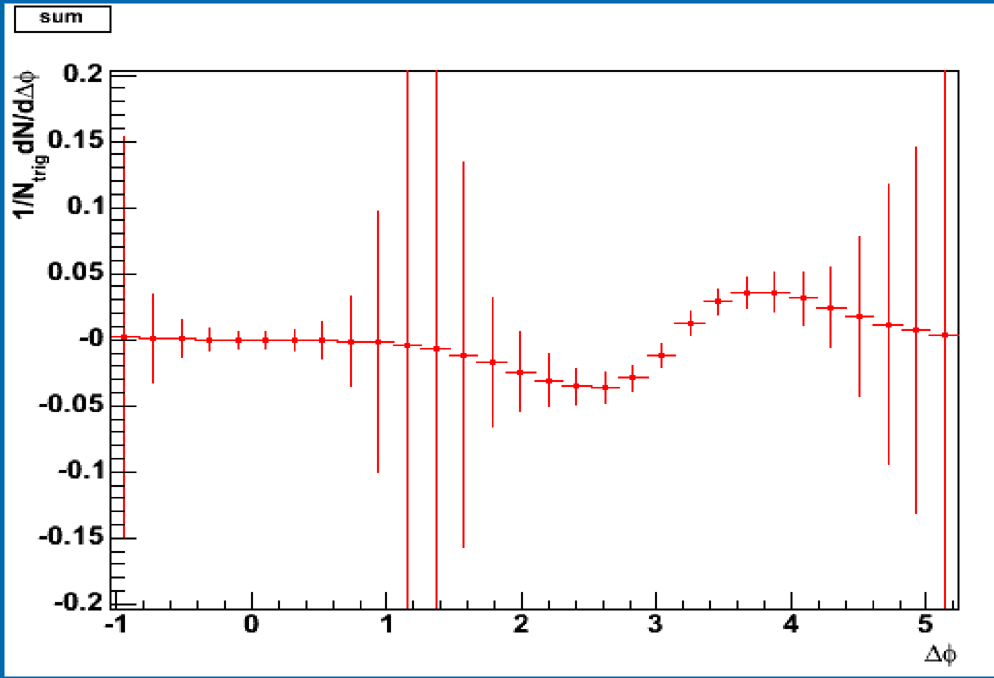
•On right are gamma-charged hadron δφ dist's from Run03 p+p

- •2.25 GeV gamma's as jet trigger, 0.6-4.0 GeV charged hadrons to map out jet shape
- •Dotted lines are schematic effect on away side δφ dist due to Siver's Fn (not to scale)

Unpolarized Results from Run03 p+p

Boer and Vogelsang, PRD69:094025,2004





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

- •numerator is difference between aligned and anti-aligned $\delta\phi$ dist's, where aligned means trigger jet and spin in same direction
- •denominator is simply unpolarized $\delta\phi$ distribution

•On left are some theoretical guesses on expected magnitude of AN from Siver's

•On right are gamma-charged hadron $\delta\phi$ dist's from Run03 p+p

- •2.25 GeV gamma's as jet trigger, 0.6-4.0 GeV charged hadrons to map out jet shape
- •Dotted lines are schematic effect on away side $\delta\phi$ dist due to Siver's Fn (not to scale)

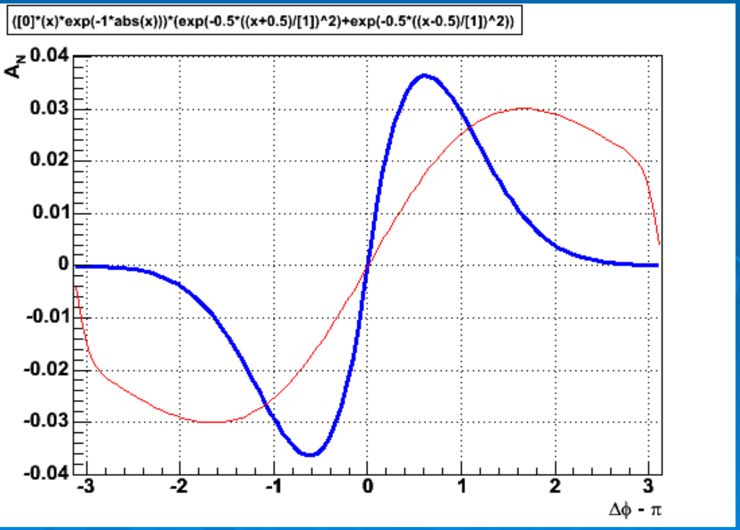
A More Realistic Estimate for PHENIX

- Polarization P < 1 just reduces A_N by P
- Besides that, most of the time the jet is not aligned exactly along the polarization axis, which means $A_N = A_N(\phi_{j1}, \delta\phi)$ and also the polarization is reduced by $\cos(\phi_{j1})$

$$A_N(\delta\phi) = \int d\phi_{j1} \cos(\phi_{j1}) A_N(\phi_{j1}, \delta\phi)$$

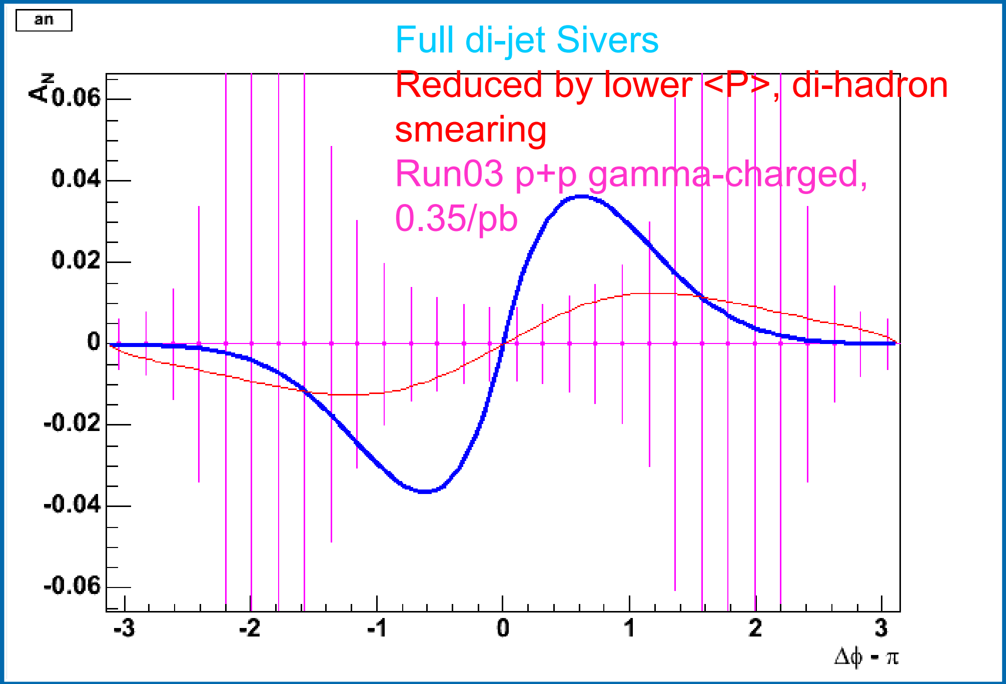
$$\langle P \rangle = \frac{\int_{-\pi/4}^{\pi/4} d\phi_{j1} \cos(\phi_{j1})}{\int_{-\pi/4}^{\pi/4} d\phi_{j1}} \approx 0.9$$

- Since we don't reconstruct jets fully, we have to use di-hadron correlations to measure jet $\delta\phi$.
  - The di-hadron A_N relative to the di-jet A_N is smeared out
  - Estimated effect with smearing function g (assumed here to be a gaussian, with σ_{jT}=0.35).



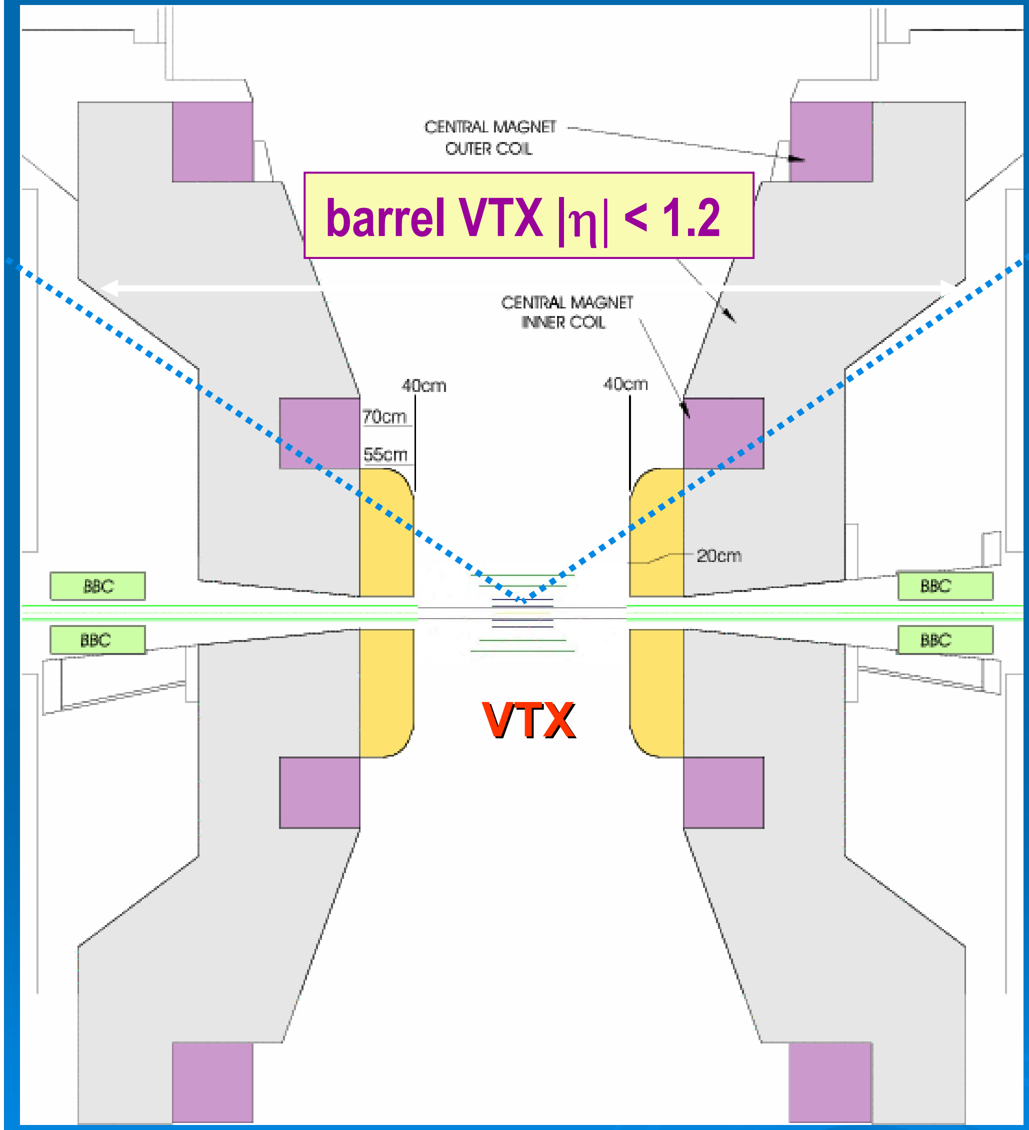
$$A_N^{dihad}(\Delta\phi) = \frac{\iint (N^{\uparrow}_{dijet}(x) + N^{\downarrow}_{dijet}(x)) A_N^{dijet}(x) g(x') \delta(x' - (\Delta\phi - x)) dx dx'}{\iint (N^{\uparrow}_{dijet}(x) + N^{\downarrow}_{dijet}(x)) g(x') \delta(x' - (\Delta\phi - x)) dx dx'}$$

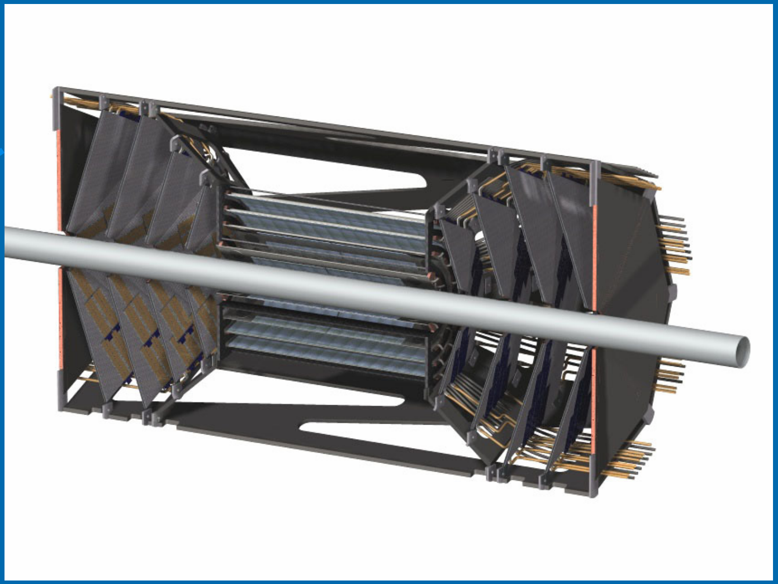
Combined Effects



- Given 0.35/pb of data, we should be able to get 1% statistical significance in A_N using gamma-charged measurements of jet dphi
- Expected raw A_N could be 3.5%
  - Could also be as low as 0.5%, or as large as 10%
  - x-dependence of Sivers?
- Effects from P=0.5, jet angle not aligned with transverse polarization, and fragmentation to dihadrons reduces raw A_N to ~1.0%
- Have not evaluated systematic errors yet (underlying event…)

Silicon Tracker Upgrade (Year 2008)



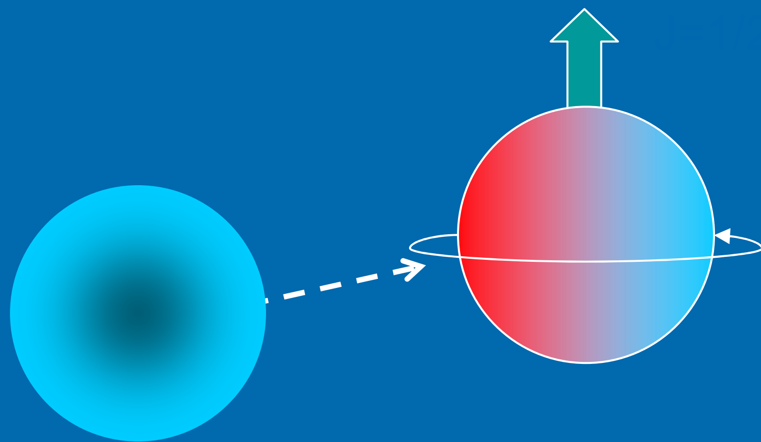


- Covers df ~ 2p and |η| < 1.2
- Jet Reconstruction Possible, and allows PHENIX ability to measure
  - Collins FF
  - Interference FF (di-hadron)
- Expect Installation in Run08

Transverse Physics Summary at PHENIX

- There are a variety of QCD phenomena that are not well understood in *the* QCD ground state object, the proton
  - Surprises in transverse spin physics hint at a path toward deeper understanding of the dynamics of the quarks and gluons inside the nucleon.
- Inclusive A_N for forward n, π^0, h±, (e, μ, J/Ψ, Λ)
  - Beginning of PHENIX transverse program
  - Need to map out x_F, p_T, and flavor dependence
- Back to back di-hadron correlations
  - Identifies Sivers effect (deconvolute specific effects in A_N)
- A_{TT} of high pT particle, charm, J/Ψ, (Drell-Yan)
  - Small unless out of gluon dominated regime
  - Drell-Yan statistics limited at RHIC
- Di-Hadron correlations within a jet (Requires Silicon Tracker Upgrade)
  - Collins-Heppelmann effect
  - Interference FF

Sivers ↔ Orbital Angular Momentum



$$\hat{f}(x,k_T,S_T) = f(x,k_T) + \frac{1}{2}\Delta^N f(x,k_T)\frac{S_T\cdot(P\times k_T)}{|S_T||P||k_T|}$$

- Non-Zero Sivers function means that there is a left/right asymmetry in the k_T of the partons in the nucleon
- Probes space-time structure of nucleon wave-function
  - Testable k_T dependence of nucleon wave-function testable
  - Sivers requires quark orbital angular momentum
  - Centrality dependent effects
    - Quark Shadowing in central region causes k_T asymmetry?
    - Red Shift/Blue Shift effects in peripheral regions?
- $S_T \cdot (P \times k_T)$ is T-odd and naively thought to vanish
  - FSI effects found by Brodsky et.al. that allow T-odd function to be non-zero

Backup Slides

Run02 A_N Systematic Errors

In addition to calculating the asymmetry using more than one method, potential systematic errors have been investigated in the following ways:

- Measured asymmetry of background
  - Immediately outside the π^0 mass peak
  - In the mass region between the π^0 and the η
- Compared independent measurements for two polarized beams
- Compared results for left and right sides of detector
- Compared minimum bias and triggered data samples
- Examined fill-by-fill consistency of asymmetry values
- Used the "bunch shuffling" technique to check for systematic errors
  - Randomly reassign the spin direction to each bunch in the beam
  - Recalculate the asymmetry
  - Repeat many times (1000) to produce a "shuffled" asymmetry distribution centered around zero
  - Compare width of shuffled distribution to statistical error on physics asymmetry