Single-Spin Transverse Asymmetry in Neutral Pion Production at

Christine Aidala for the PHENIX Collaboration

Columbia University

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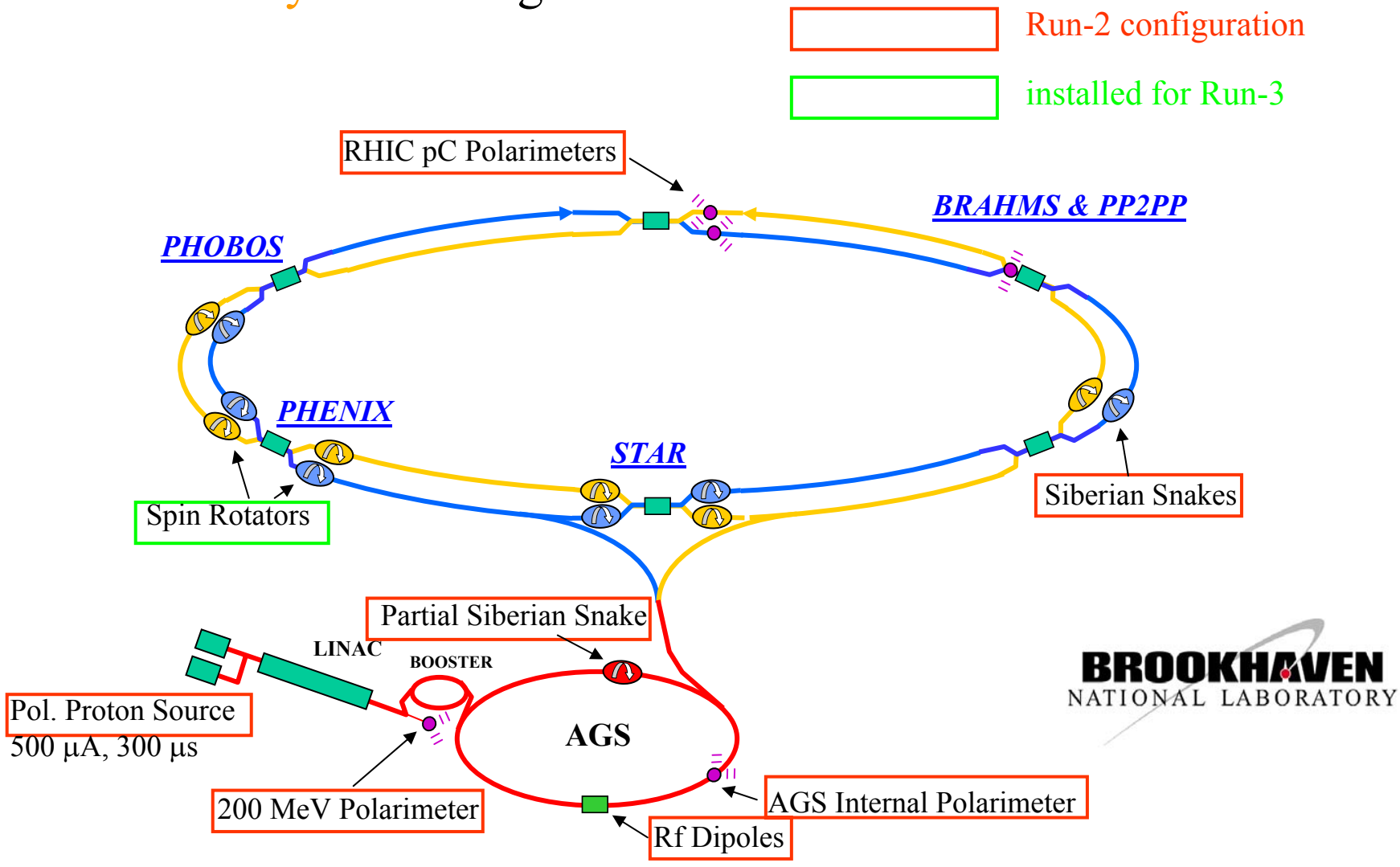
PHENIX

Polarized Proton Collisions at RHIC

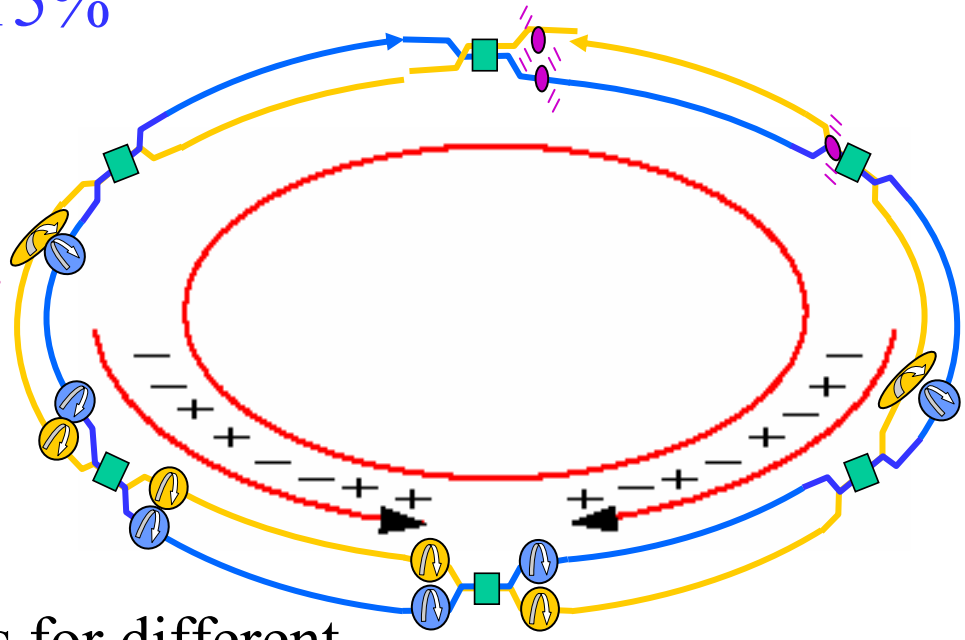
"Blue" and "yellow" rings



2001-2002 pp Run at RHIC

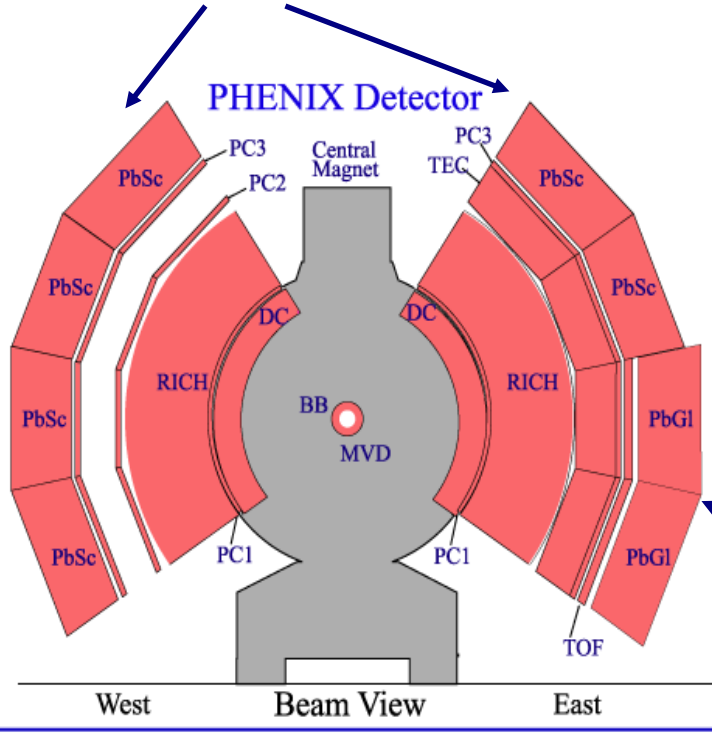
- Transversely polarized p+p collisions at $\sqrt{s} = 200$ GeV
- 150 nb^{-1} written to tape
- Average polarization of ~15%
- Single-spin asymmetries *calculated for each beam separately*, averaging over the spin states of the other

Spin direction for blue beam flipped every ~200 ns;
for yellow beam every ~400 ns.



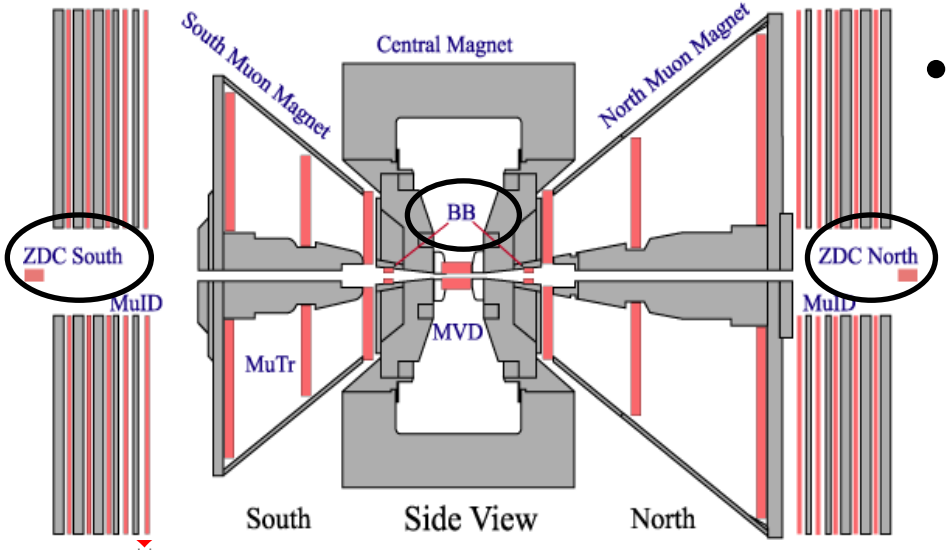
Different spin combinations for different crossings aid in canceling systematic uncertainties.

PHENIX Detector



- Central arm spectrometers
  - In the central arms, a fine-grained EMCal equipped with photon triggers enhances π^0 measurement

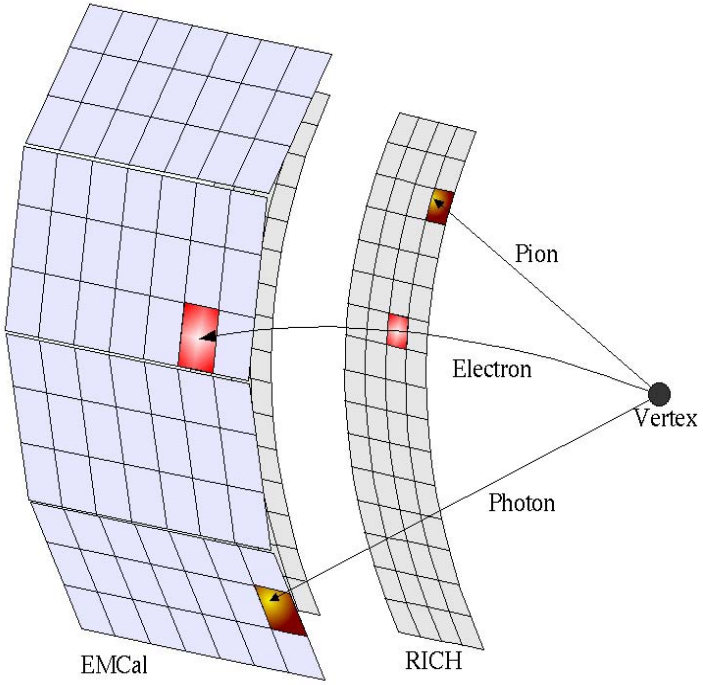
EMCal PbGl



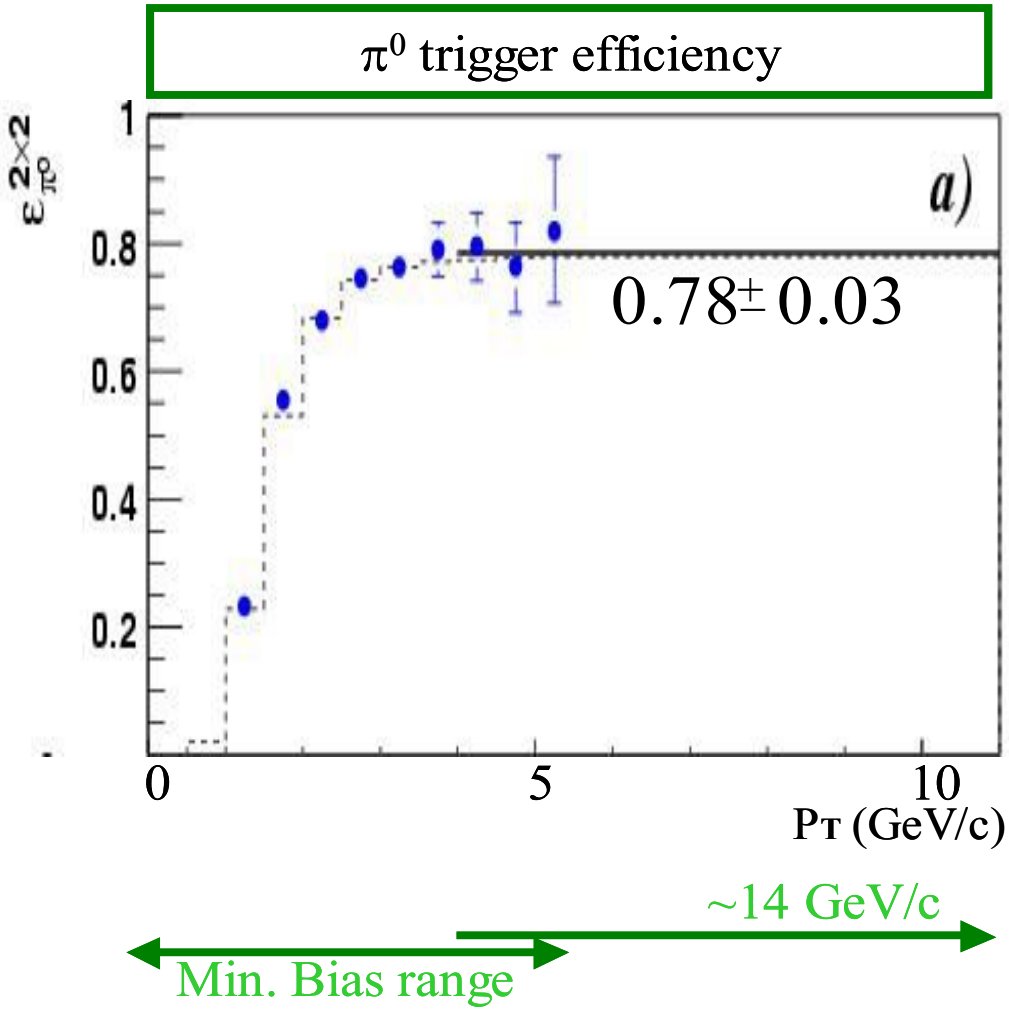
- Muon arm spectrometers
- Forward and backward luminosity detectors:
  - BBC (Beam-Beam Counters)
  - ZDC (Zero Degree Calorimeters)

EMCal-RICH 2x2 Trigger

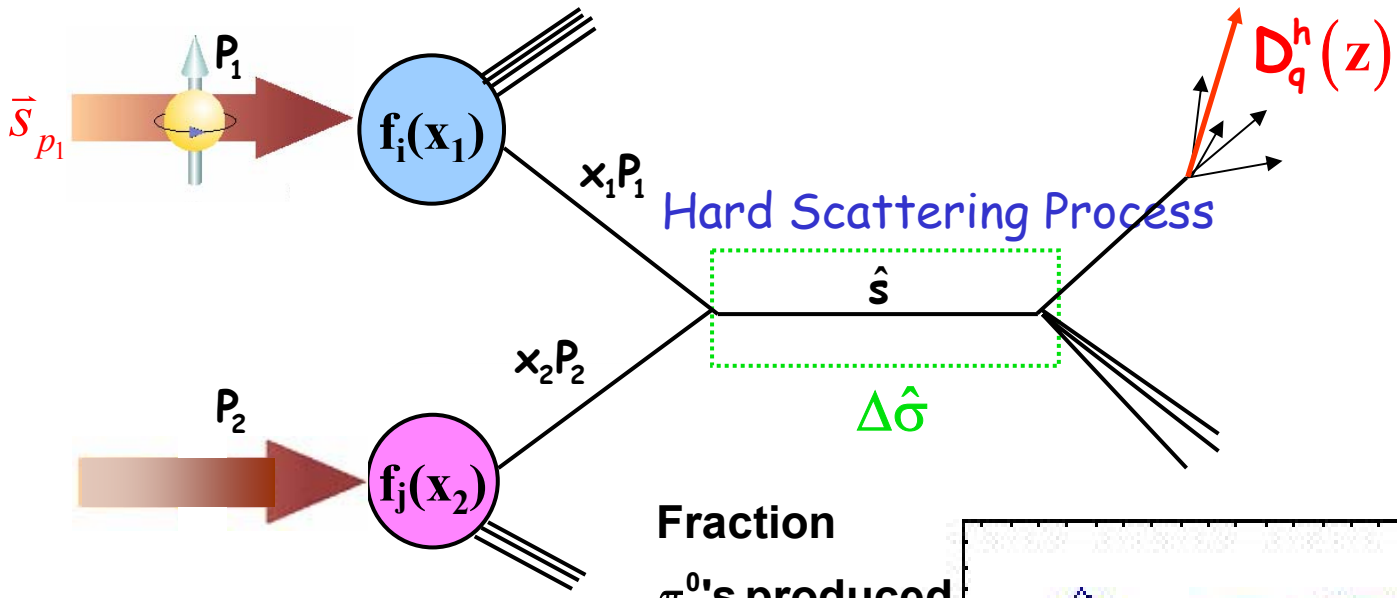
- 2x2 towers non-overlapping sum
- Threshold ~ 0.8 GeV
- Also used in conjunction with RICH to form an electron trigger

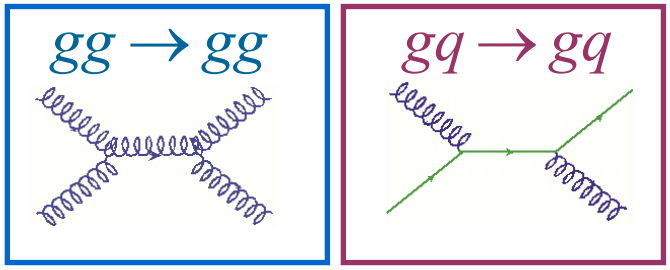


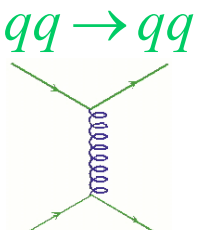
2x2 Trigger in 2001-2002 run.

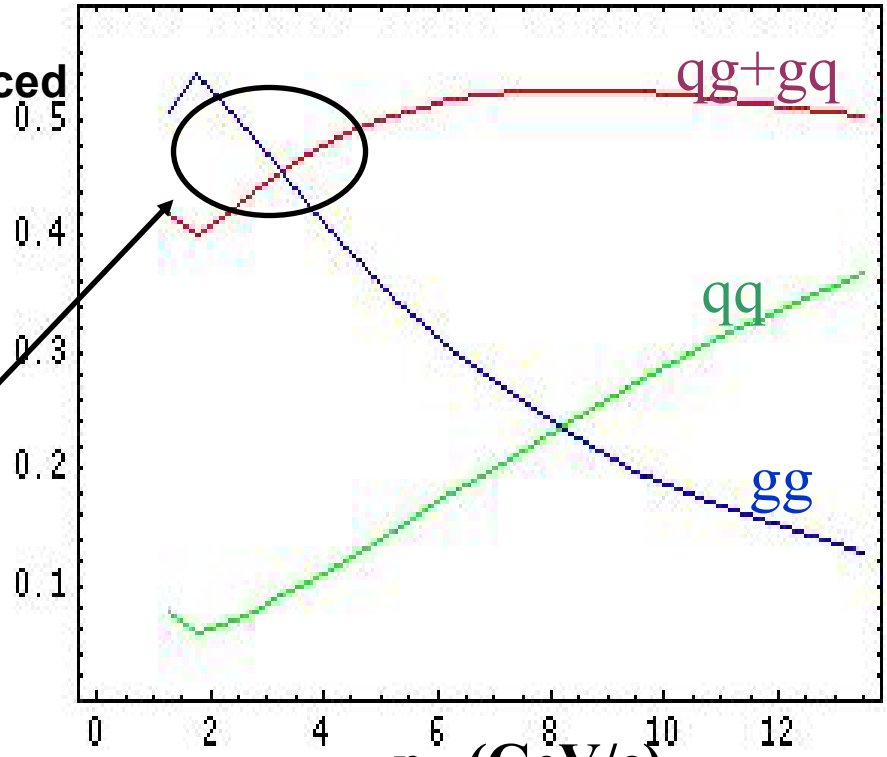


Leading Hadrons as Jet Tags



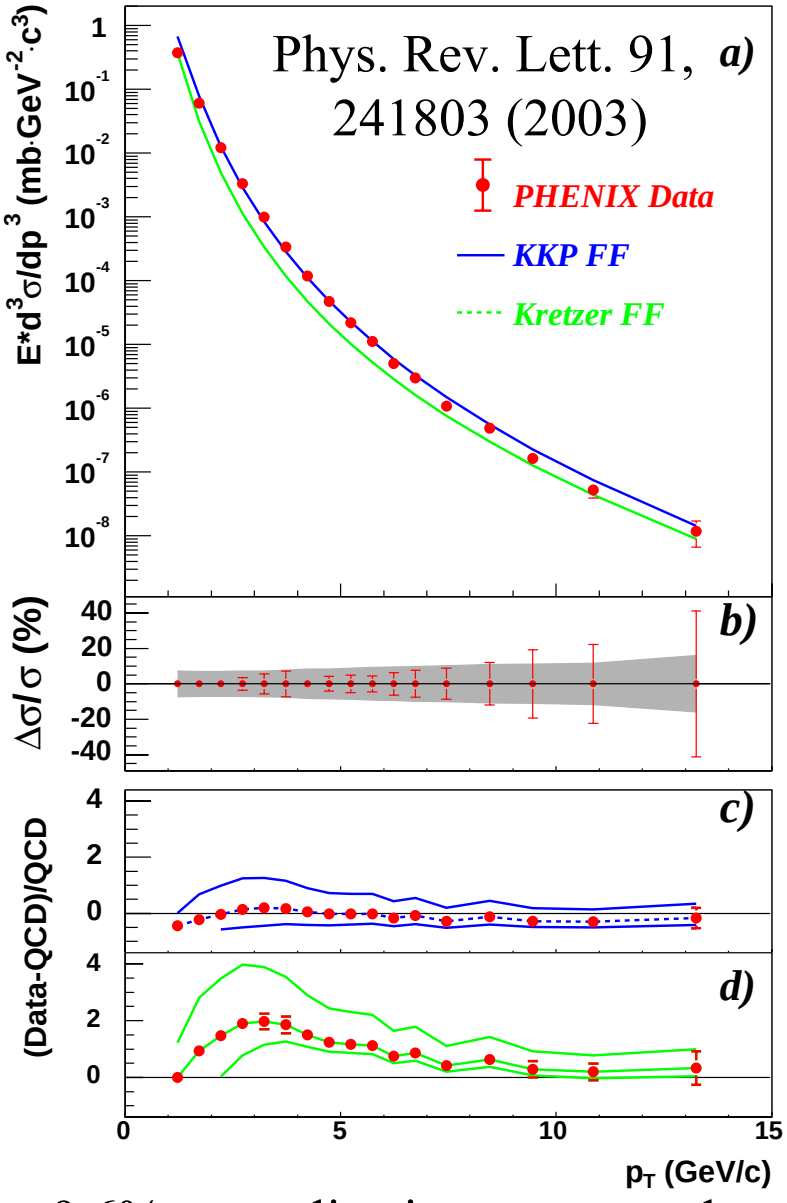






In current measurement, π^0's mainly produced by gg and qg scattering

π^0 Cross Section from 2001-2 Run

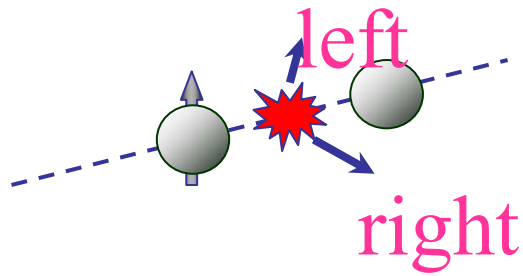


9.6% normalization error not shown

- NLO pQCD consistent with data within theoretical uncertainties.
  - PDF: CTEQ5M
  - Fragmentation functions:
    - Kniehl-Kramer-Potter (KKP)
    - Kretzer
  - Spectrum constrains D(gluon ➡ π) fragmentation function
- Important confirmation of theoretical foundation for spin program
- Data from 2003 run reproduce 2001-2 results and extend the p_T range
  - Will be released soon

Why Measure π^0 A_N at PHENIX?

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

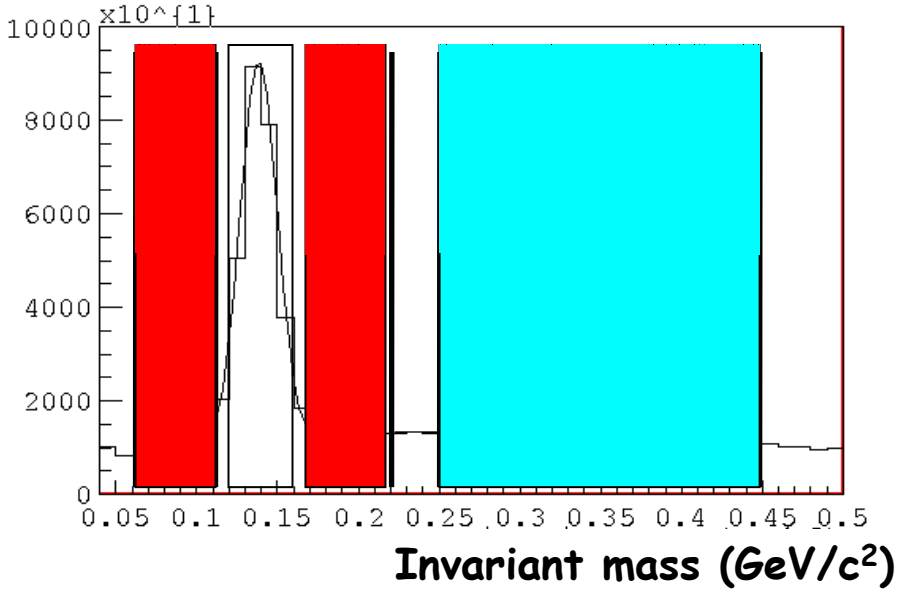


- Significant asymmetries observed at fixed target energies (E704 at FNAL, $\sqrt{s}$ = 20 GeV)
- Significant asymmetries observed at STAR for *forward* π^0's produced at $\sqrt{s}$ = 200 GeV, $x_{quark} \sim 0.6$ (talk by D. Thein)
- Mechanism for producing these asymmetries still not understood theoretically
  - "transversity" x "Collins effect": [degree to which quarks in transversely polarized proton are transversely pol.] x [spin-dependent fragmentation]
  - "Sivers effect": spin-dependent initial partonic transverse momentum
- PHENIX π^0 A_N measurement explores a different kinematic region: *midrapidity*, $x_{quark} \sim 0.1$
- NLO pQCD calculation of the π^0 cross section at $\sqrt{s}$ = 200 GeV suggests that measuring π^0 A_N at PHENIX will help to separate contributions from the Collins and Sivers effects to single transverse spin asymmetries in polarized hadron collisions

$$X_{quark} = p_T/zE_{beam}$$

Calculating $\pi^0 A_N$

$$\frac{dN}{d\phi} \propto 1 + A_N P \sin\phi$$



- 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 π^0 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

- Then measure and subtract asymmetry of background in two different mass regions.

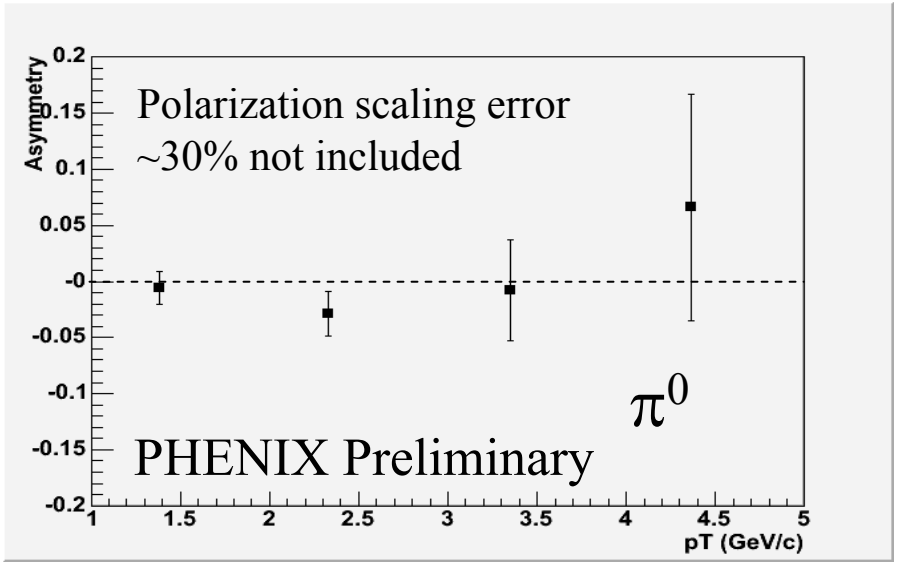
Systematic Errors

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

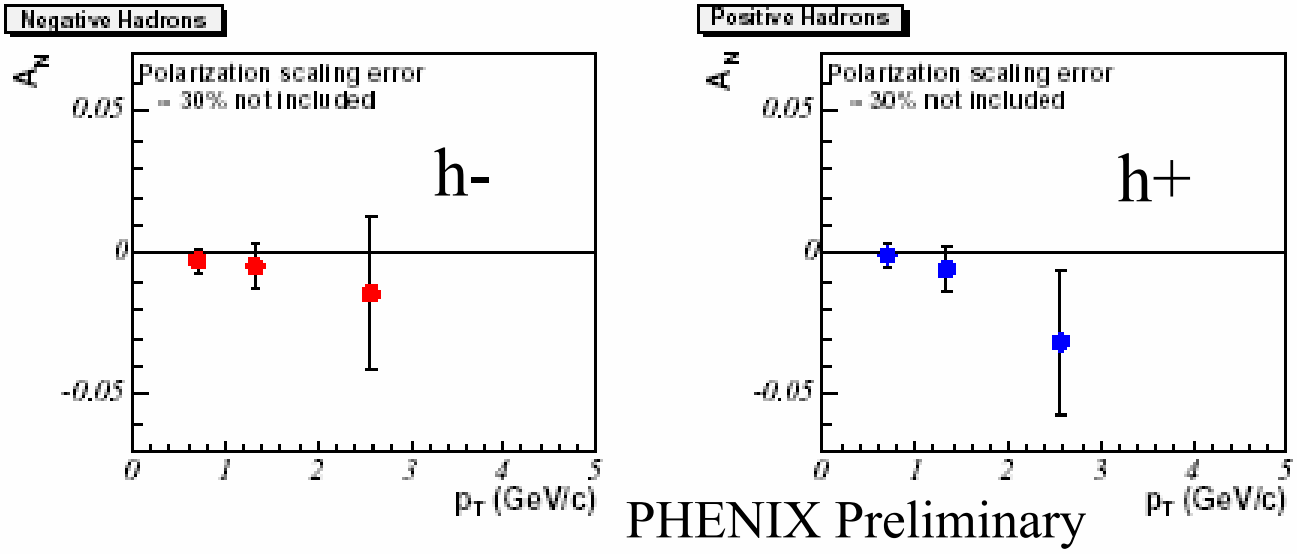
- Measured asymmetry of background
  - Immediately outside the π^0 mass peak
  - In the mass region between the π^0 and the η
- Compared independent measurements for two polarized beams
- Compared results for left and right sides of detector
- Compared minimum bias and triggered data samples
- Examined 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

A_N of Neutral Pions and Non-Identified Charged Hadrons: Results

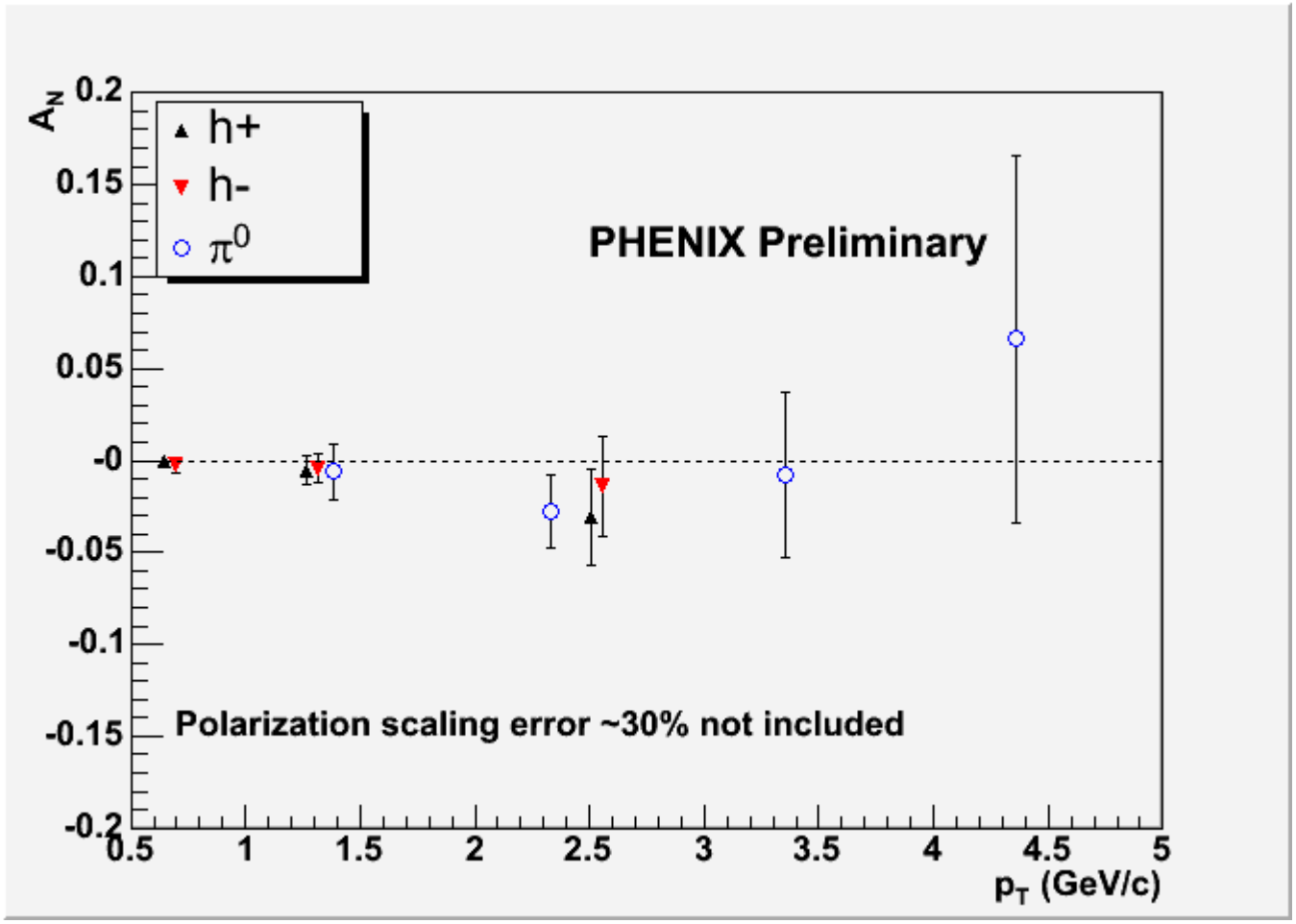
Neutral pions



Charged hadrons

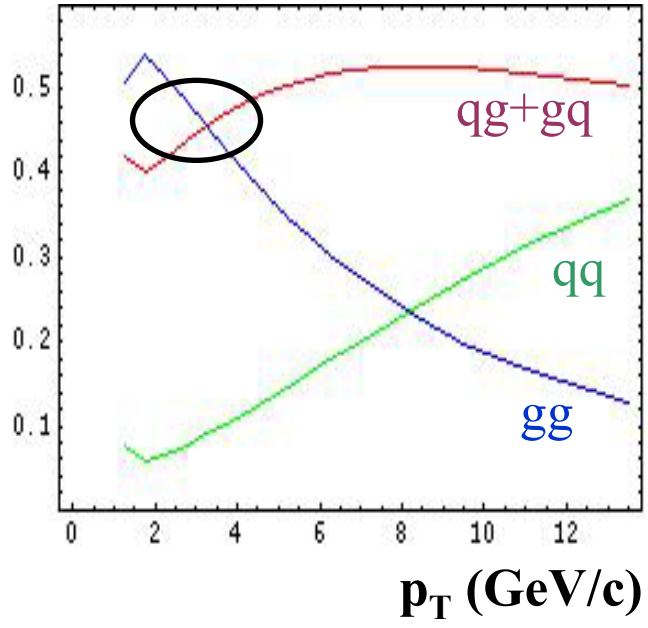


A_N of Neutral Pions and Non-Identified Charged Hadrons: Results



A_N for both charged hadrons and neutral pions consistent with zero at midrapidity.

Conclusions



- The single-spin transverse asymmetry A_N has been measured at midrapidity for neutral pions and charged hadrons and is consistent with zero.

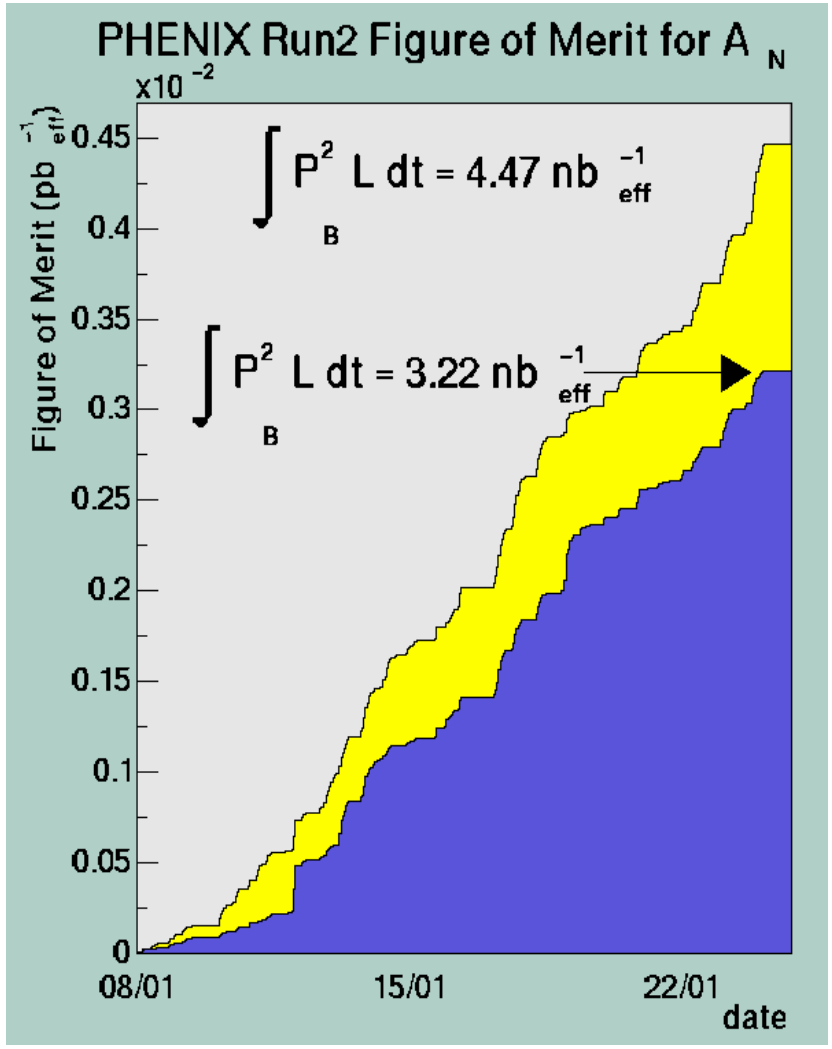
- Most of the π^0 production in the kinematic region currently measured by PHENIX is from gluon scattering, which cannot contribute to transversity x Collins, so this asymmetry measurement mainly probes the Sivers effect.

The RHIC spin program looks forward to many more years of polarized proton results in the new energy regime opened up by a polarized collider.

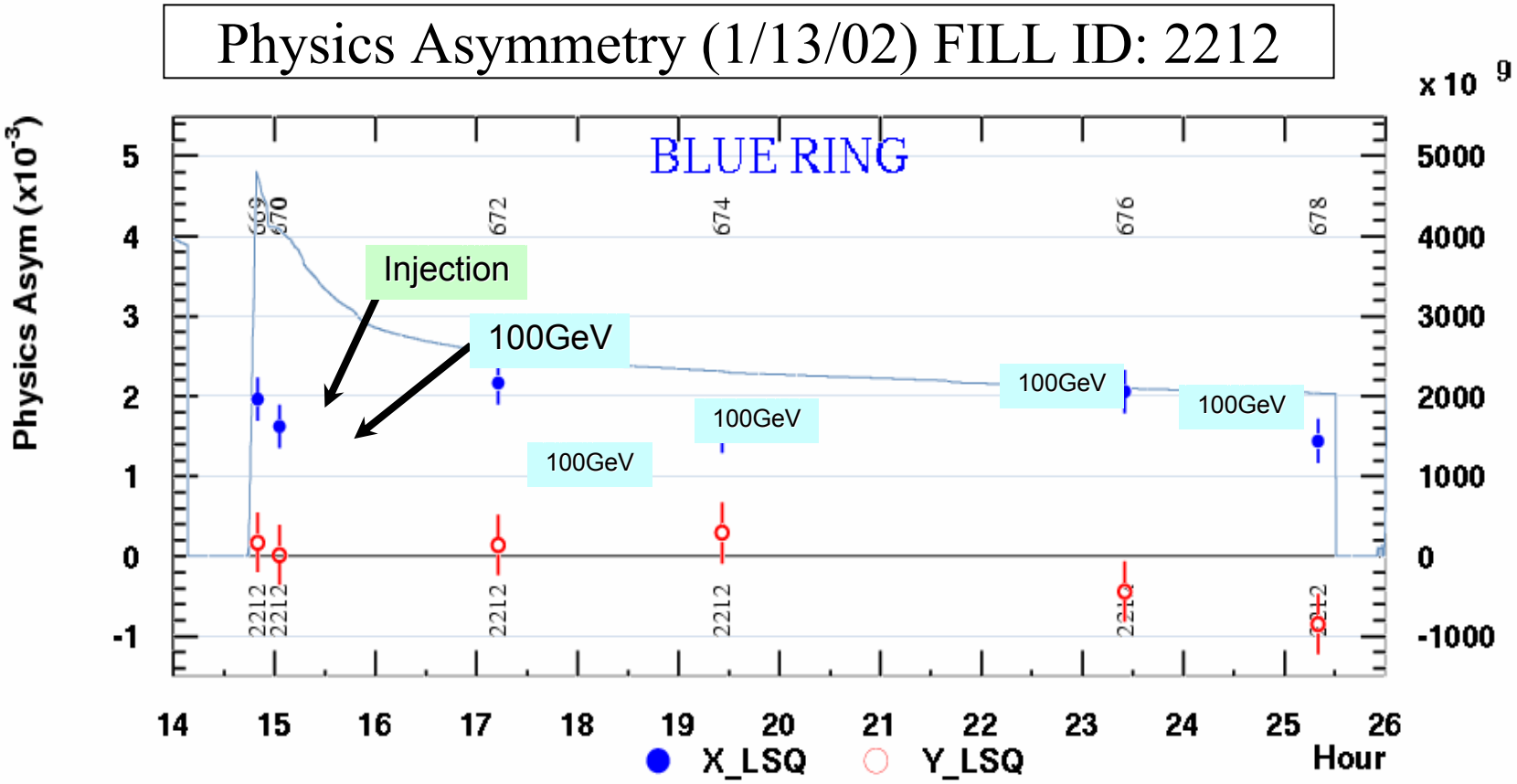
Extra Slides

2001-2002 p+p run

- **Luminosity**
  - integrated luminosity 0.15 pb^{-1}
  - $L = 1.5 \times 10^{30}$ $cm^{-1}sec^{-1}$ at max
- **Polarization – transverse**
  - $<P_{yellow}>=17$ %, $<P_{blue}>=14$ %
- **Cross section measurement**
  - π^0, J/ψ, …
- ***A_N* measurement** (analysis ongoing …)
  - central arm (mid-rapidity, $x_F \sim 0$)
    - π^0, charged hadrons, J/ψ, …
- **Systematic studies**
  - relative luminosity study
  - local polarimeter development at IP12

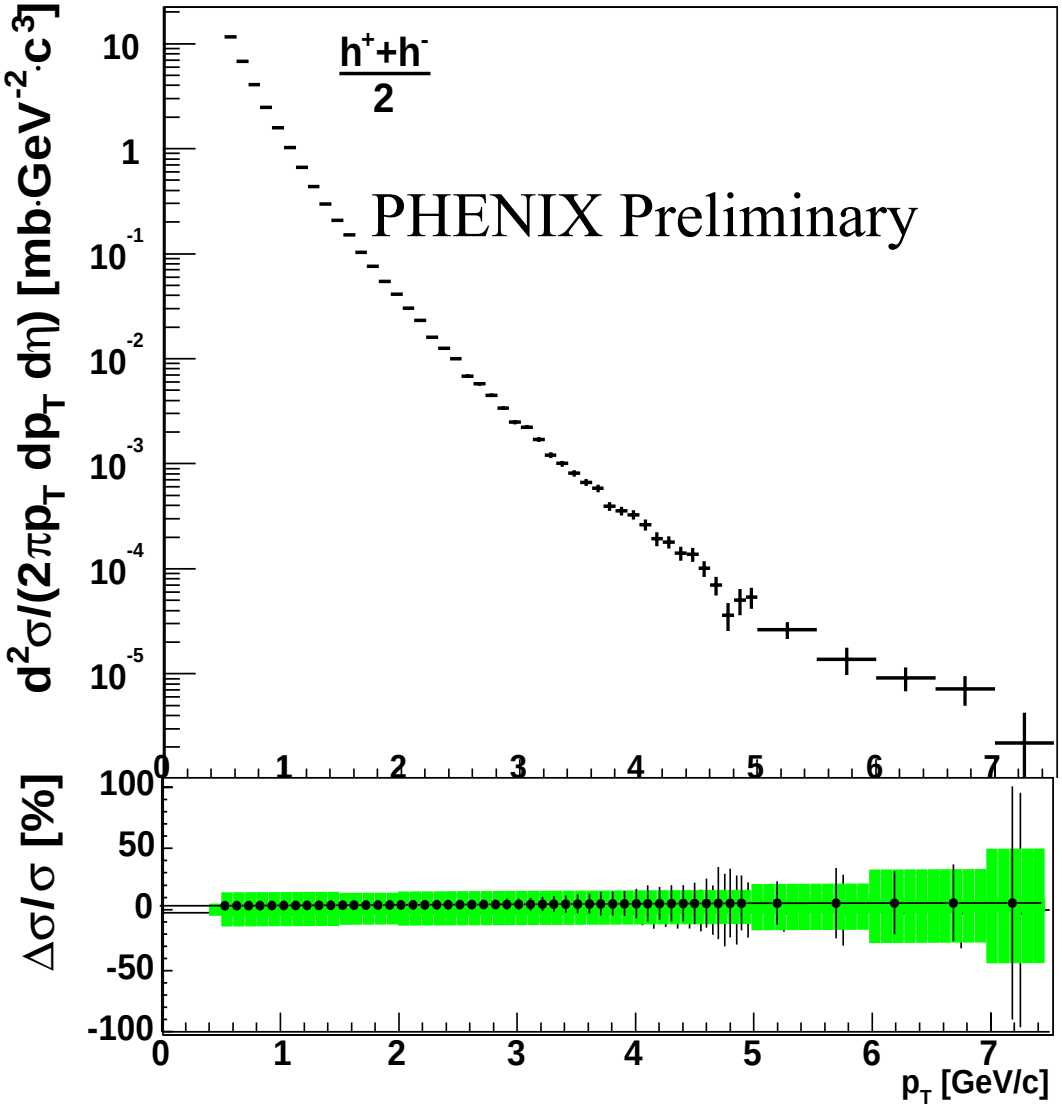


Polarization Measurements



- X asymmetry (physics) and Y asymmetry (false) are plotted as a function of the beam lifetime
- Measurements are carried out at injection, right after ramp-up, two hours each at 100 GeV
- **Polarization remained stable over fills of many hours**

Charged Hadron Cross Section from 2001-2 Run



Single-Spin π^0 Asymmetry at STAR

$$A_N = \frac{1}{Pol} \times \frac{Y_{\pi^0}^{\uparrow} - Y_{\pi^0}^{\downarrow}}{Y_{\pi^0}^{\uparrow} + Y_{\pi^0}^{\downarrow}}$$

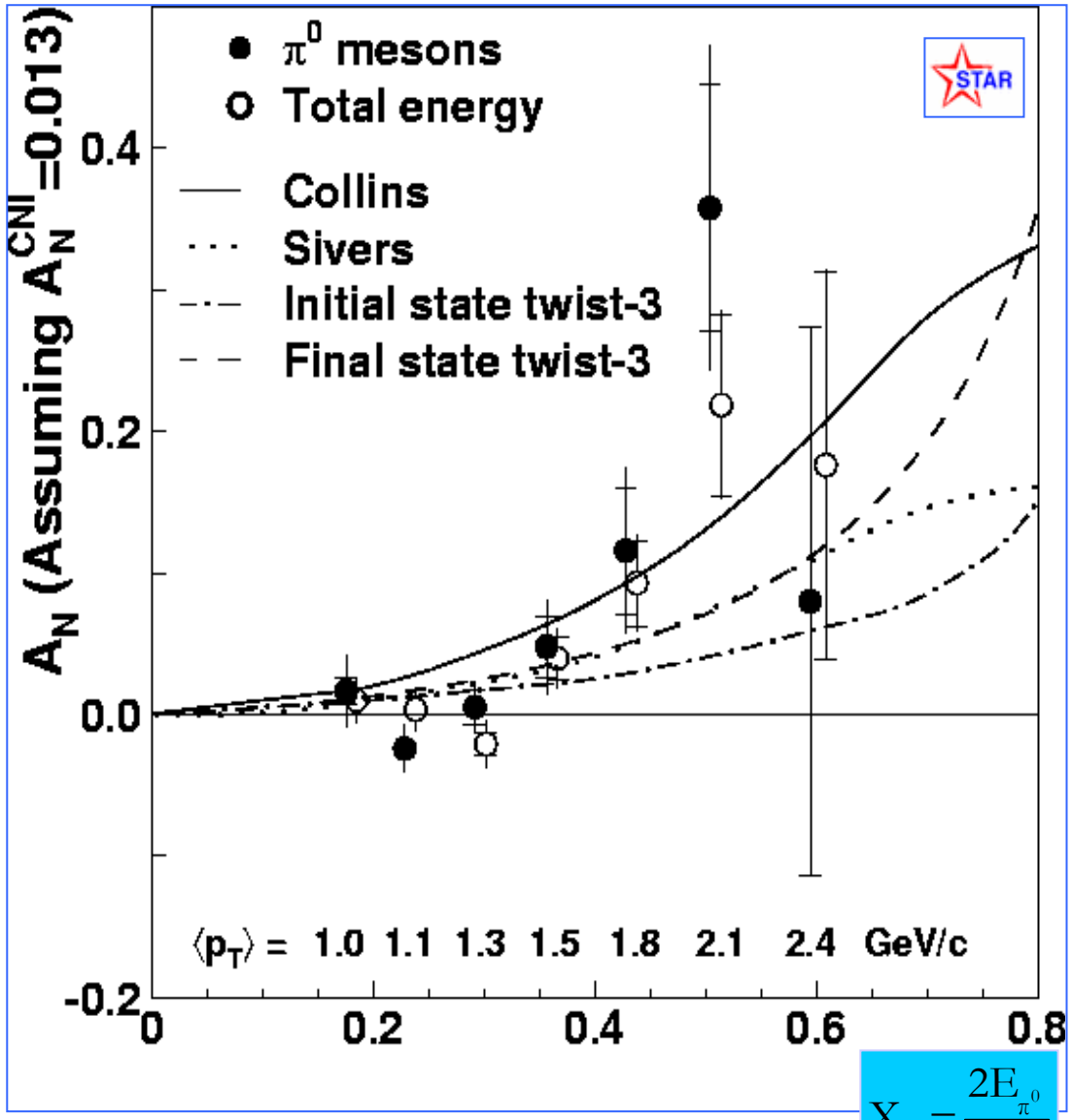
For $\langle\eta\rangle = 3.7$ possible contributions to A_N are:

Sivers Effect – Spin dependent initial partonic transverse momentum

Collins Effect – Spin dependent transverse momentum kick in fragmentation

Sterman and Qiu – Initial State twist 3

Koike – Final State twist 3



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$$X_F = \frac{2E_{\pi^0}}{\sqrt{s}}$$

E704 Results

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