Single-Spin Transverse Asymmetry in Neutral Pion and Charged Hadron Production at

PHENIX

Christine Aidala
Columbia University

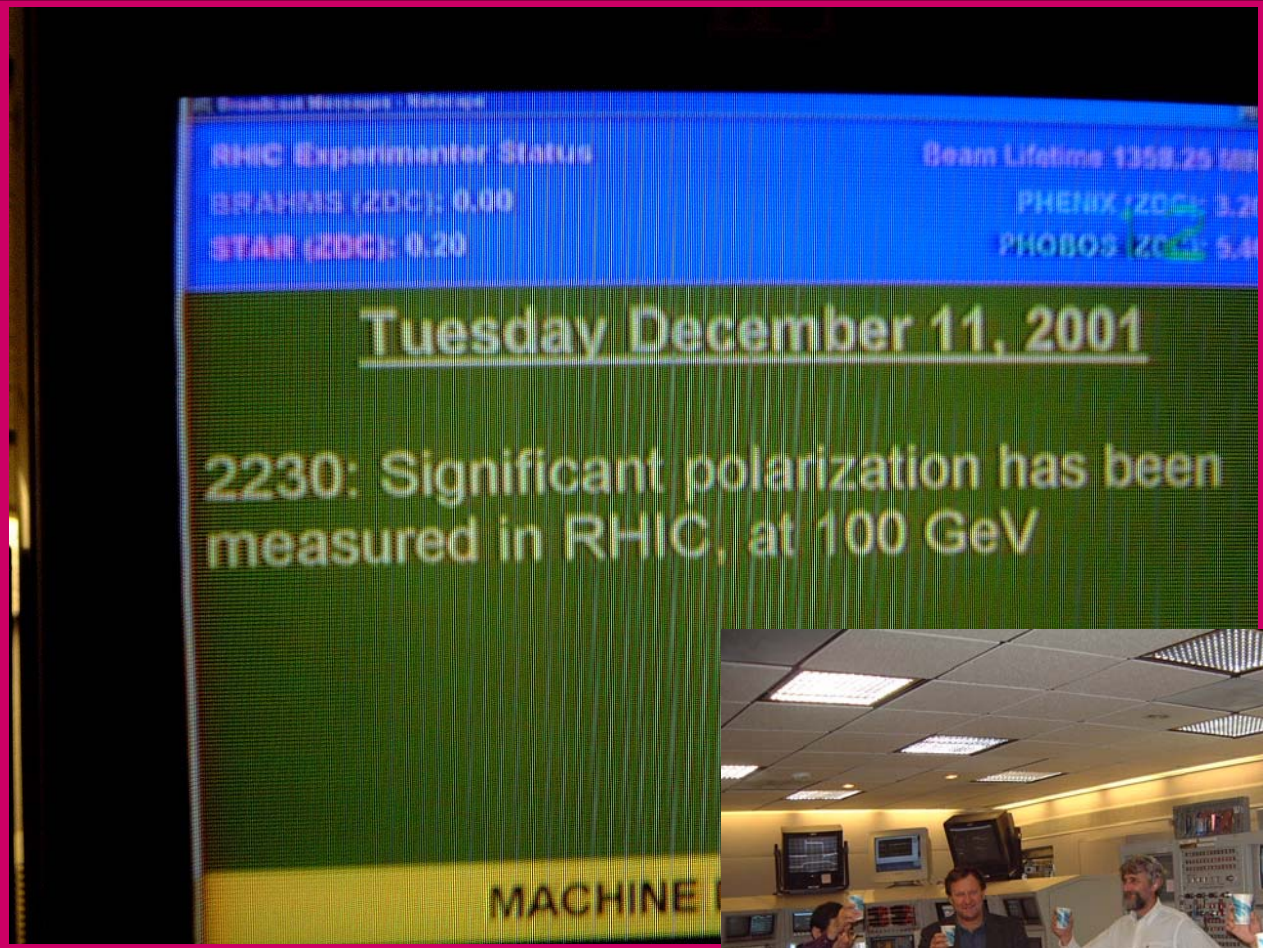
DIS 2004, Slovakia
April 16, 2004

RHIC at Brookhaven National Laboratory

BROOKHAVEN
NATIONAL LABORATORY

PHENIX

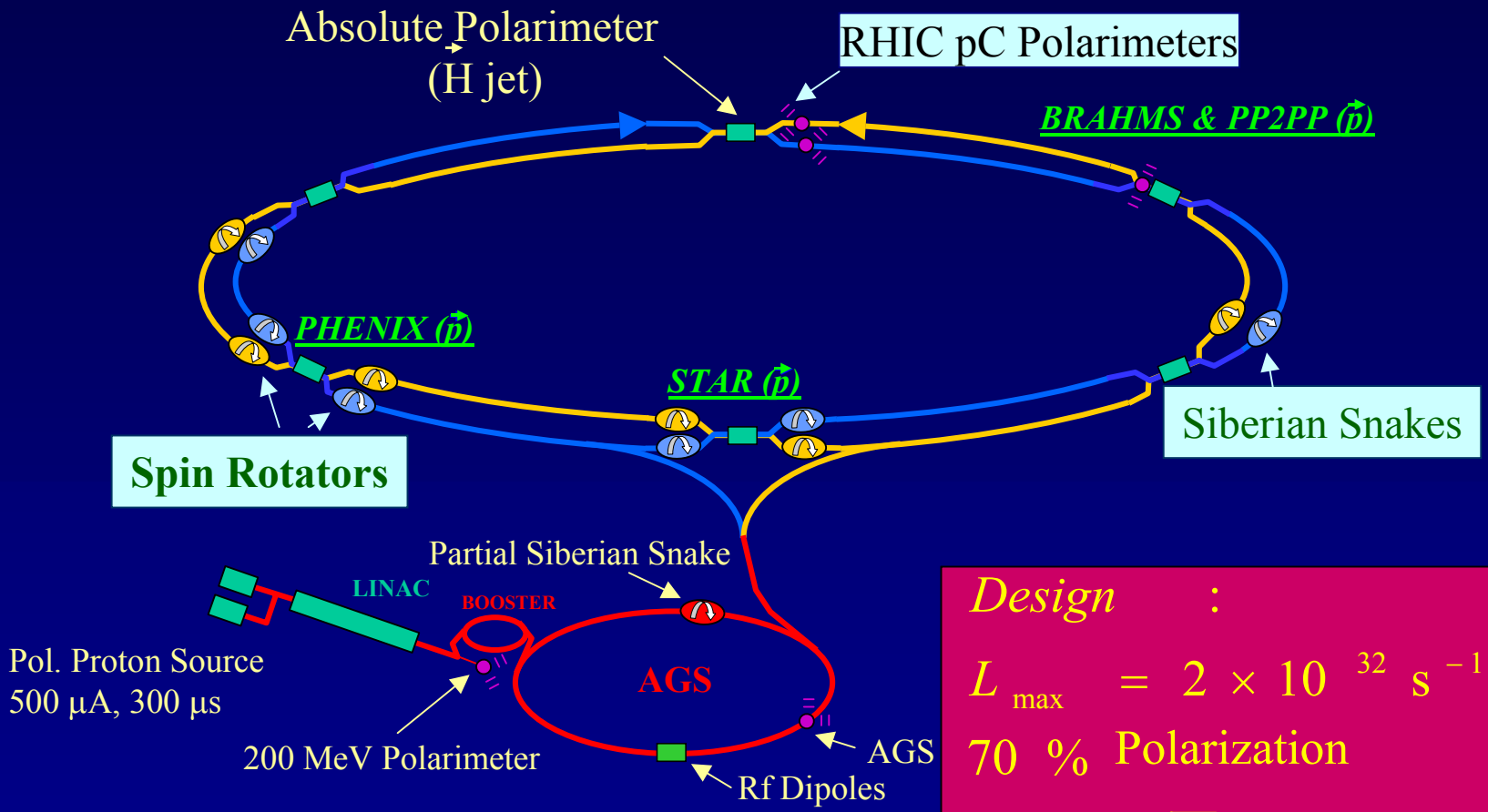
The Relativistic Heavy Ion Collider



RHIC Specifications

- 3.83 km circumference
- Two independent rings
  - Up to 120 bunches/ring
  - 106 ns crossing time
- Energy:
  - ➡ Up to 500 GeV for p-p
  - ➡ Up to 200 GeV for Au-Au (per N-N collision)
- Luminosity
  - Au-Au: 2 x 10^{26} cm^{-2} s^{-1}
  - p-p : 2 x 10^{32} cm^{-2} s^{-1} (*polarized*)

RHIC Accelerator Complex



Design :

$L_{max} = 2 \times 10^{32}\ s^{-1} cm^{-2}$

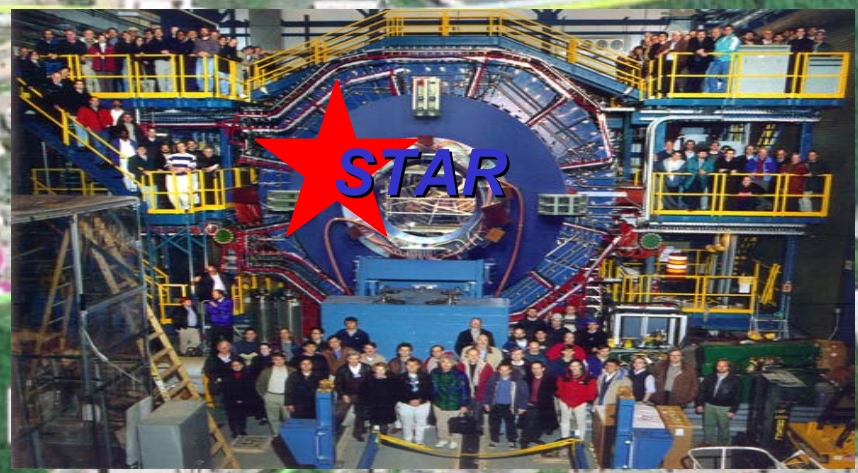
70 % Polarization

$50 < \sqrt{s} < 500$ *GeV*

2×10^{11} Pol. Protons / Bunch

$\varepsilon = 20\ \pi$ μm mrad

RHIC's Experiments



RHIC Physics Goals

- Broadest possible study of A-A, p-A, p-p collisions to
  - Investigate nuclear matter under extreme conditions
  - Examine systematic variations with species and energy
- ***Explore the spin of the proton***
  - In particular, contributions from
    - Gluon polarization (ΔG)
    - Sea-quark polarization $\left(\Delta\bar{u}, \Delta\bar{d}\right)$

Why study proton spin structure at RHIC?

- High energy ➡ factorization
- Polarized hadrons ➡ gq, gg collisions
- High energy ➡ new probes (W's)

Measurement of Proton Spin Structure at PHENIX

Gluon Polarization

ΔG

- π Production $A_{LL}(gg, gq \to \pi + X)$
- Prompt Photon $A_{LL}(gq \to \gamma + X)$
- Heavy Flavors $A_{LL}(gg \to c\bar{c}, b\bar{b} + X)$

Flavor decomposition

$\frac{\Delta u}{u}, \frac{\Delta \bar{u}}{\bar{u}}, \frac{\Delta d}{d}, \frac{\Delta \bar{d}}{\bar{d}}$

W Production

$A_L(u + \bar{d} \to W^+ \to \ell^+ + \nu_l)$

$A_L(\bar{u} + d \to W^- \to \ell^- + \bar{\nu}_l)$

Transverse Spin

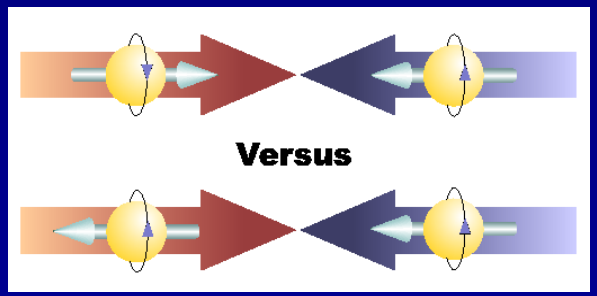
Transversity δq:

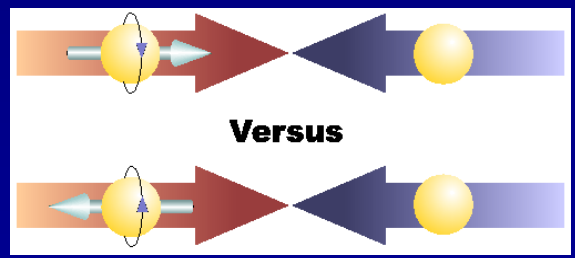
π^+, π^- **Interference fragmentation:**

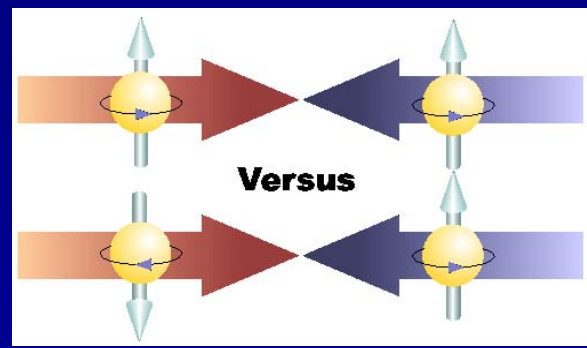
$A_T(p_L p \to (\pi^+, \pi^-) + X)$

Drell Yan A_{TT}

Single Asymmetries A_N



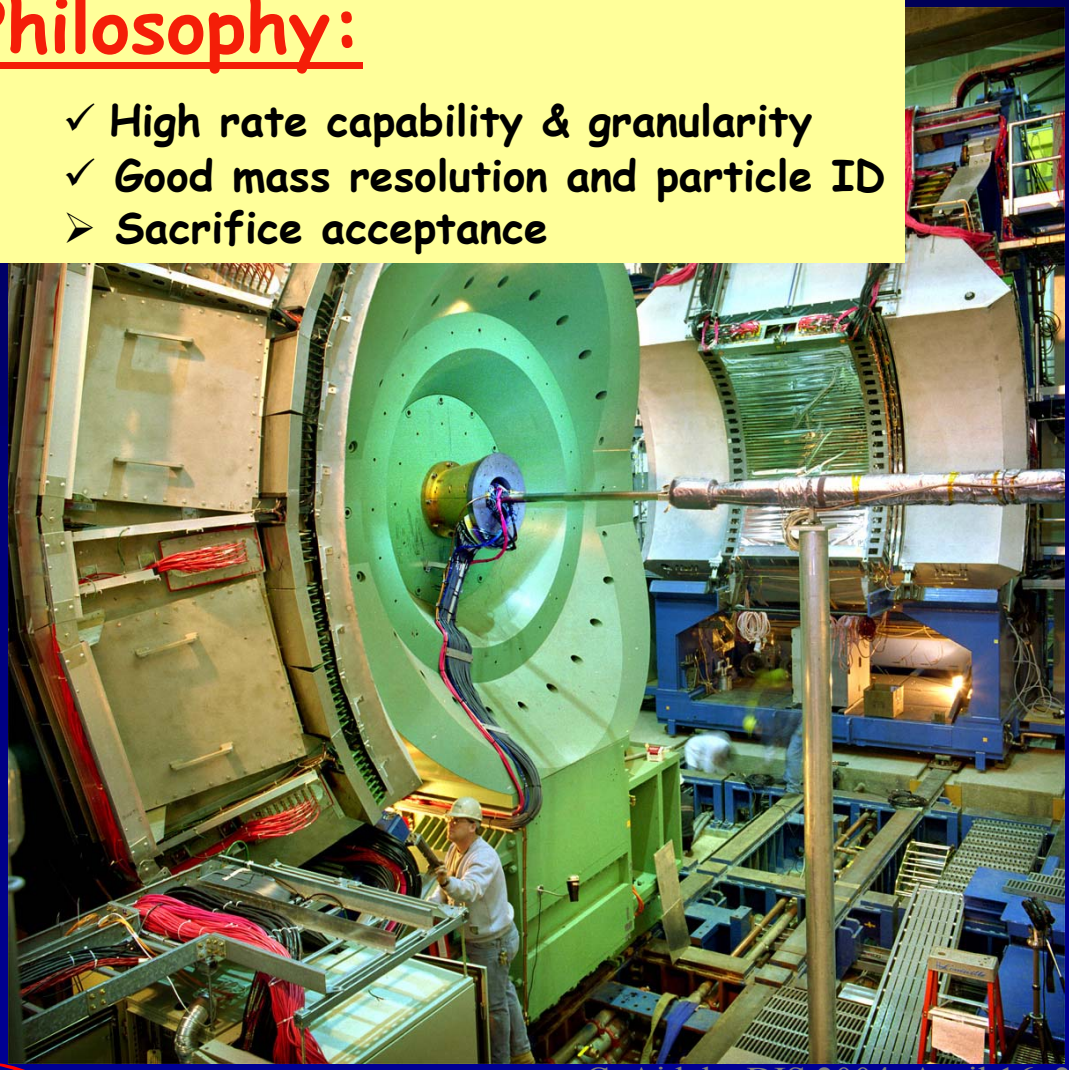




The PHENIX Detector

Philosophy:

- ✓ High rate capability & granularity
- ✓ Good mass resolution and particle ID
- ➢ Sacrifice acceptance



2 central spectrometers

- Track charged particles and detect electromagnetic processes

2 forward spectrometers

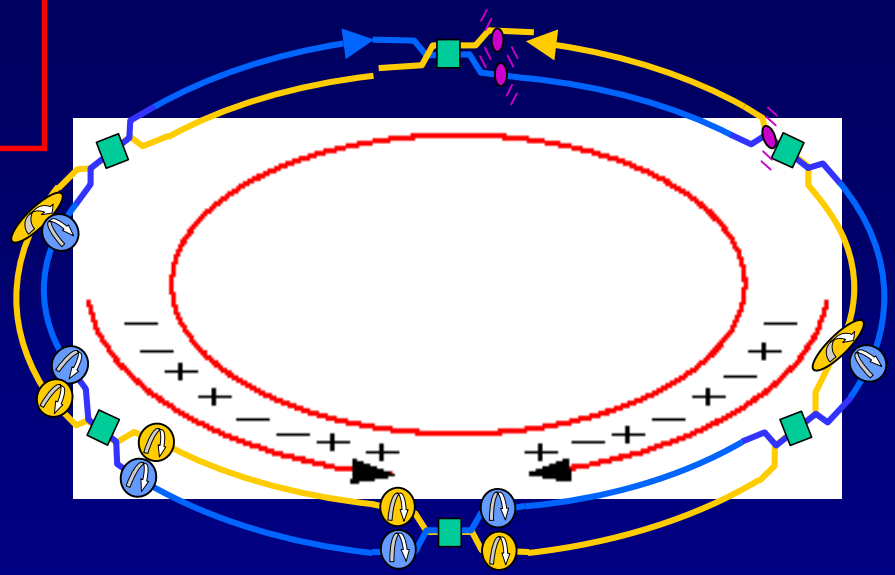
- Identify and track muons

3 global detectors

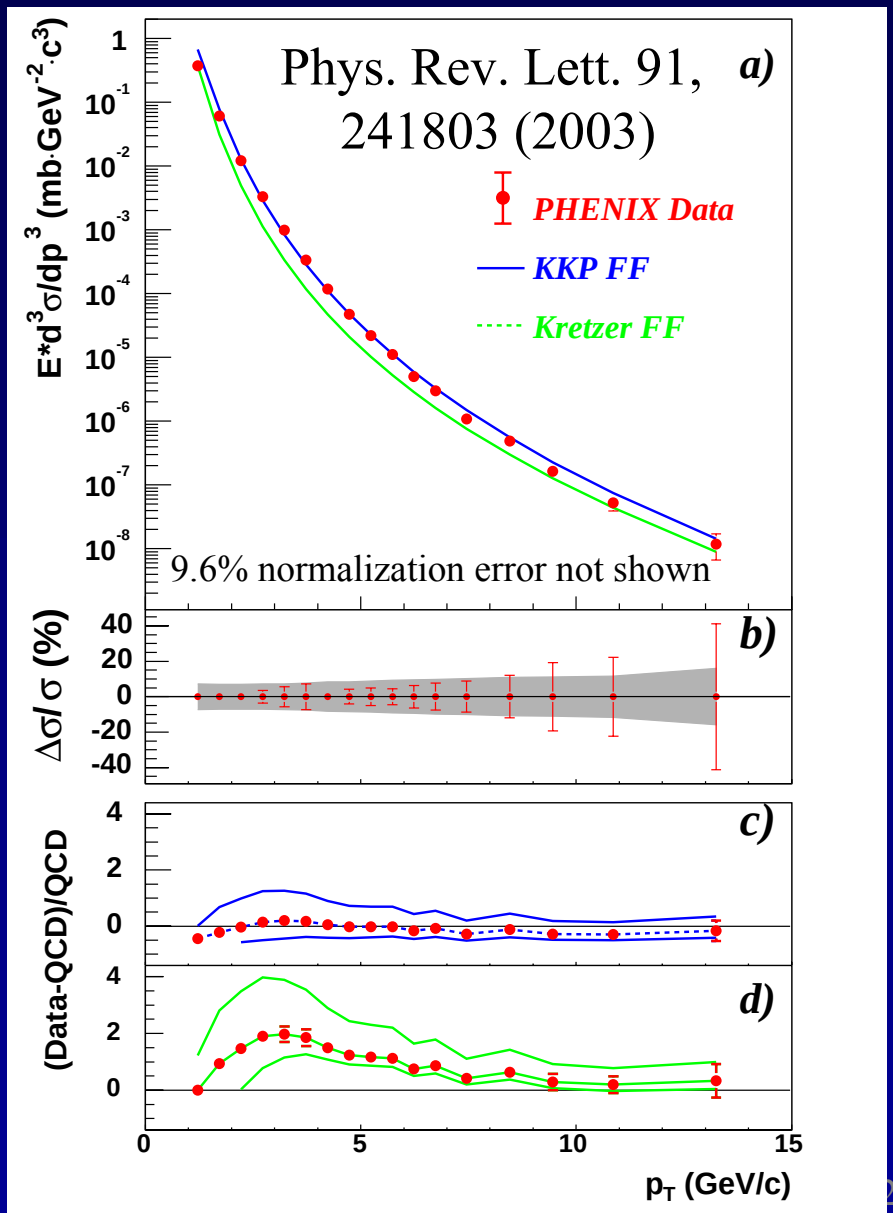
- Determine when there's a collision

Spin Running at RHIC

- 2001-2
  - ***Transversely*** polarized p+p collisions
  - Average polarization of ~15%
  - Integrated luminosity 0.15 pb^{-1}
- 2003
  - ***Longitudinally*** polarized p+p collisions achieved
  - Average polarization of ~27%
  - Integrated luminosity 0.35 pb^{-1}
- 2004
  - 5 weeks polarized p+p commissioning
    - Started April 2nd!
    - Specifically to work on spin tune and AGS polarization
    - Commission hydrogen jet polarimeter
- 2005
  - Long spin run planned!



π^0 Cross Section from 2001-2 Run

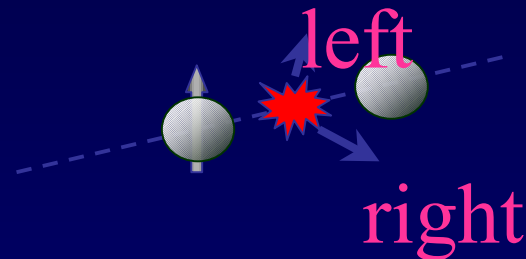


- NLO pQCD consistent with data within theoretical uncertainties.
  - PDF: CTEQ5M
  - Fragmentation functions:
    - Kniehl-Kramer-Potter (KKP)
    - Kretzer
  - Spectrum constrains D(gluon ➡ π) fragmentation function
- Important confirmation of theoretical foundation for spin program
- Data from 2003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

PHENIX

Why Measure A_N at PHENIX?

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



- π^0 cross section at $\sqrt{s} = 200$ GeV described by pQCD

  ➡ measuring π^0 A_N at midrapidity will help to separate contributions from transversity and the Sivers effect to single transverse spin asymmetries in polarized hadron collisions
- Significant asymmetries observed at STAR for forward π^0's produced at $\sqrt{s} = 200$ GeV, $x_{quark} \geq 0.6$
- PHENIX A_N measurements explore a different kinematical region: midrapidity, $x_{quark} \sim 0.1$

A_N of Neutral Pions and Non-Identified Charged Hadrons: Systematic Checks

- Independent results from two polarized beams
- Two methods of calculation
  - Square-root formula

$$A_N^{Beam} = \frac{1}{P^{Beam}} \frac{\sqrt{N_{Left}^{Beam+} N_{Right}^{Beam-}} - \sqrt{N_{Right}^{Beam+} N_{Left}^{Beam-}}}{\sqrt{N_{Left}^{Beam+} N_{Right}^{Beam-}} + \sqrt{N_{Right}^{Beam+} N_{Left}^{Beam-}}}$$

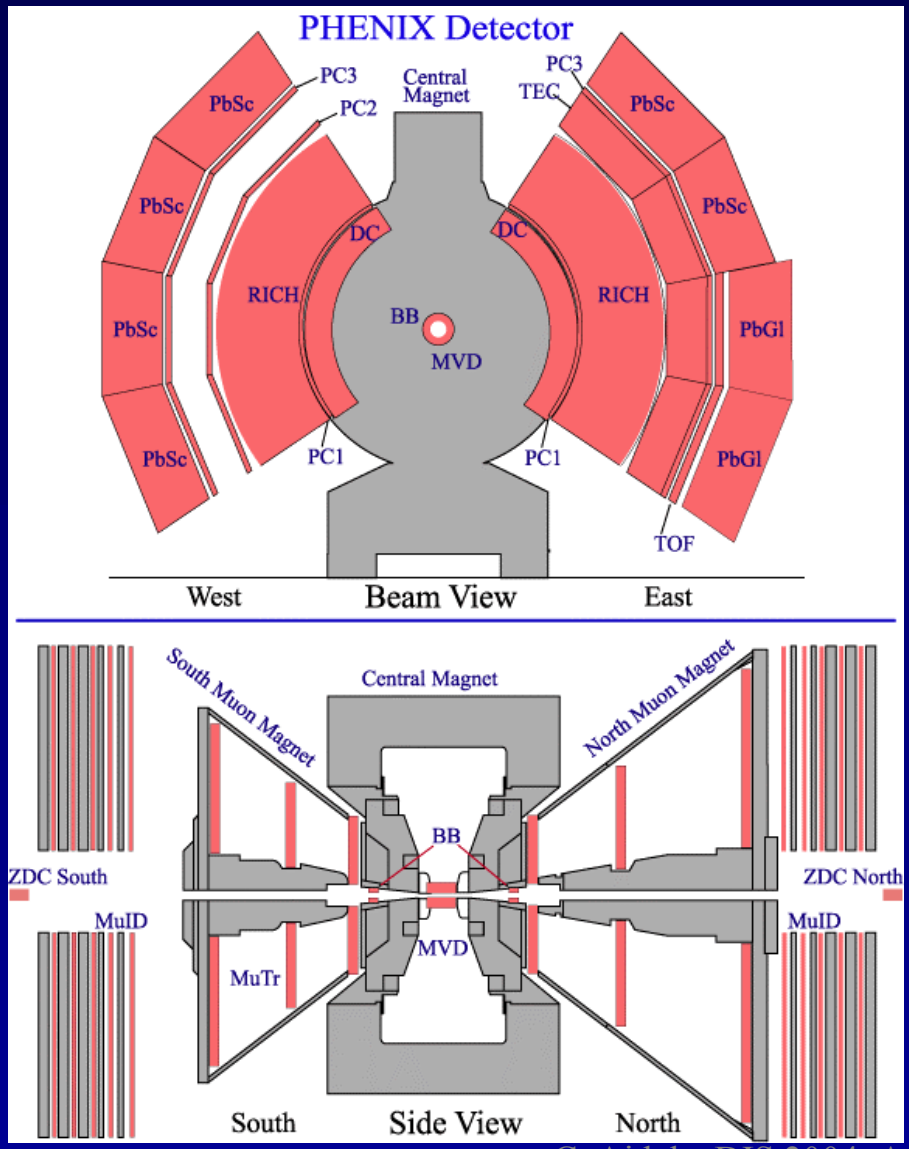
  - Luminosity formula

$$A_N^{Beam,Left} = \frac{1}{P^{Beam}} \frac{\left(N^{Beam+,Left} - RN^{Beam-,Left}\right)}{\left(N^{Beam+,Left} + RN^{Beam-,Left}\right)} \qquad R = \frac{L^{Beam+}}{L^{Beam-}}$$

- Independent results for two detector arms (luminosity formula)
- Store-by-store stability of asymmetry

PHENIX

Detecting π^0's and charged hadrons



Photons from π^0
(EMCal: Lead-glass and lead scintillator)

Charged tracks
(Beam-Beam, Drift Chamber, Pad Chambers)

+

RICH rings

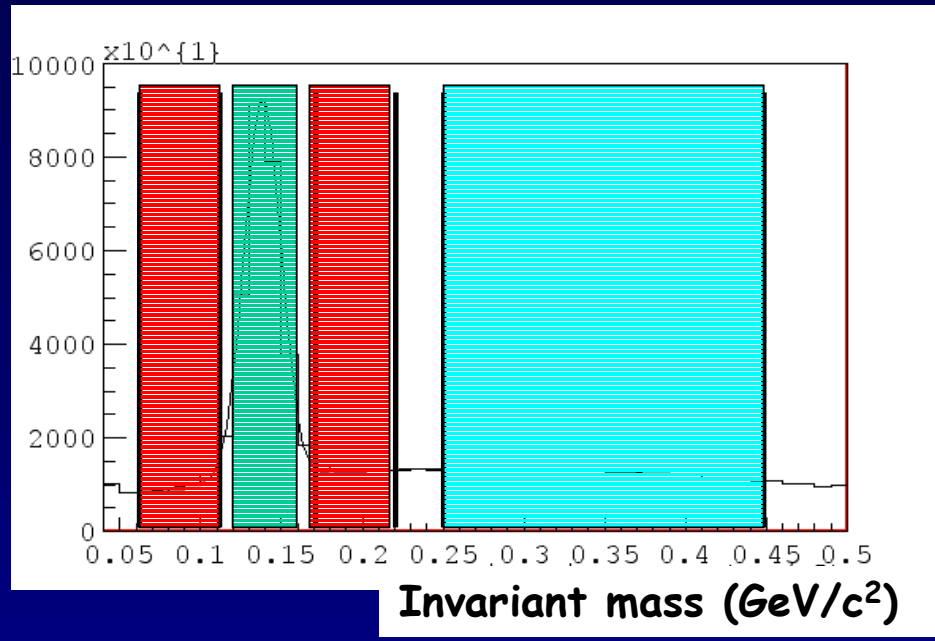
+

EM Calorimeter clusters

$|\eta| < 0.35$
$\phi = 180$ degrees

π^0 asymmetry analyses at PHENIX

- Calculate asymmetry of (signal + background) in the π^0 mass window
- Calculate the asymmetry of two different background regions
- Subtract the asymmetries

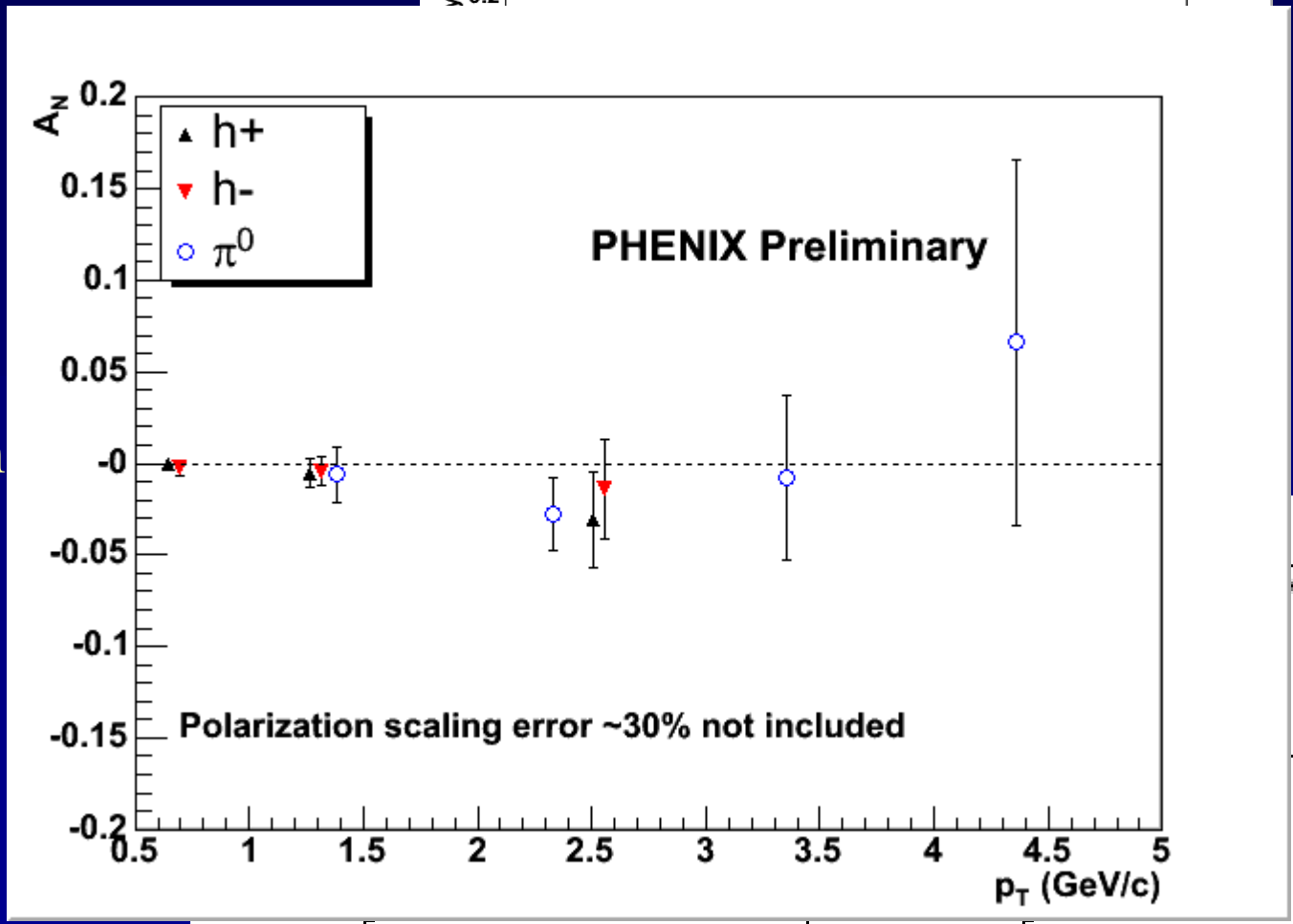


Same technique for π^0 A_N and A_{LL}.

- 50-MeV/c^2 windows around the π^0 peak (60-110 and 170-220 MeV/c^2)
- 250-450 MeV/c^2 (between π^0 and η)

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

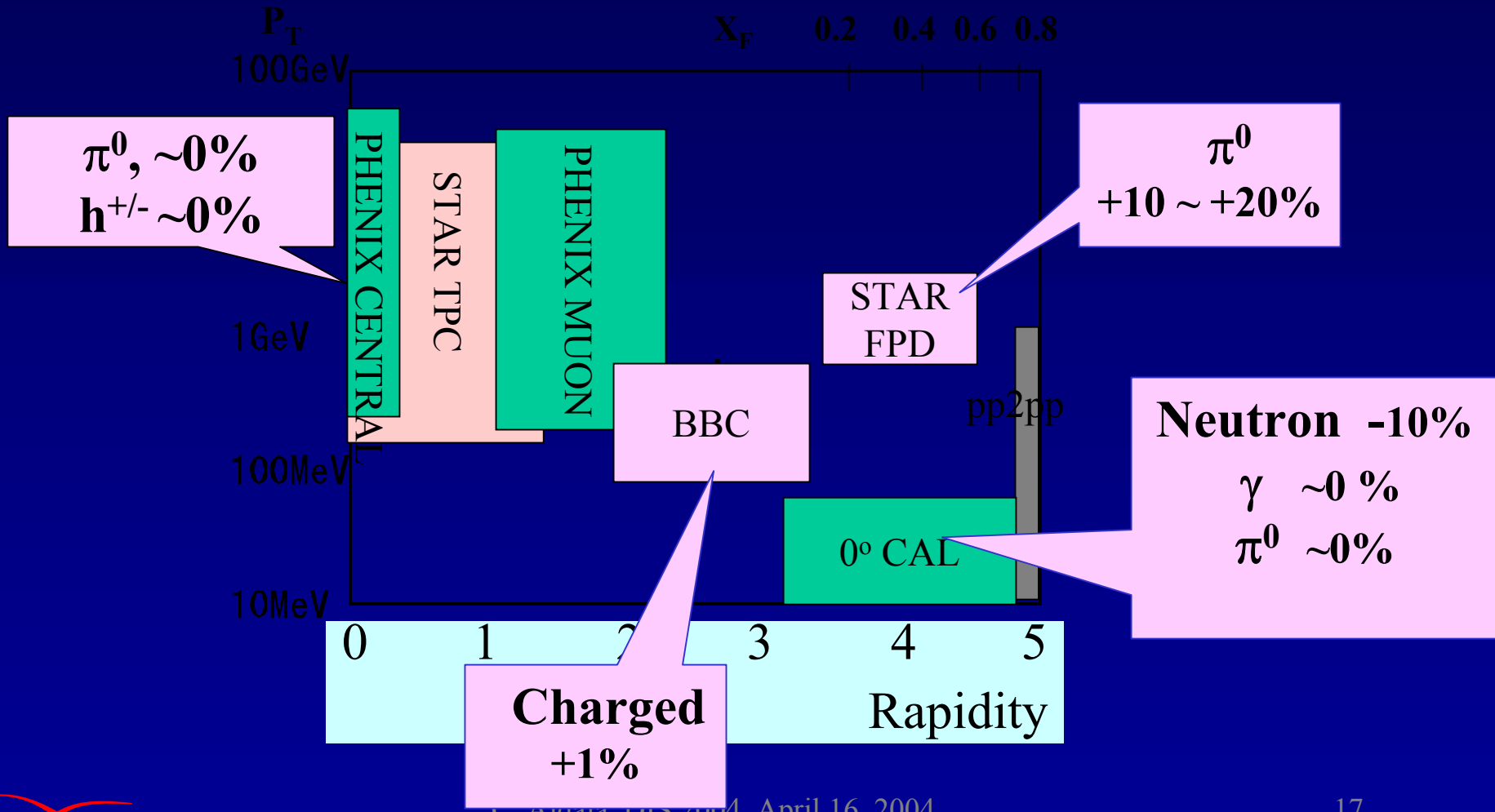
A_N of Neutral Pions and Non-Identified Charged Hadrons: Results



Ch

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

Single-spin asymmetries seen at RHIC so far…



Summary

- RHIC has been successful as the world's first polarized proton collider, opening up new kinematic regions for investigating the spin of the proton

- The first spin results from PHENIX are out and stimulating discussion within the theoretical community
  - A_N of neutral pions and non-identified charged hadrons
  - A_{LL} of neutral pions (talk by F. Bauer)

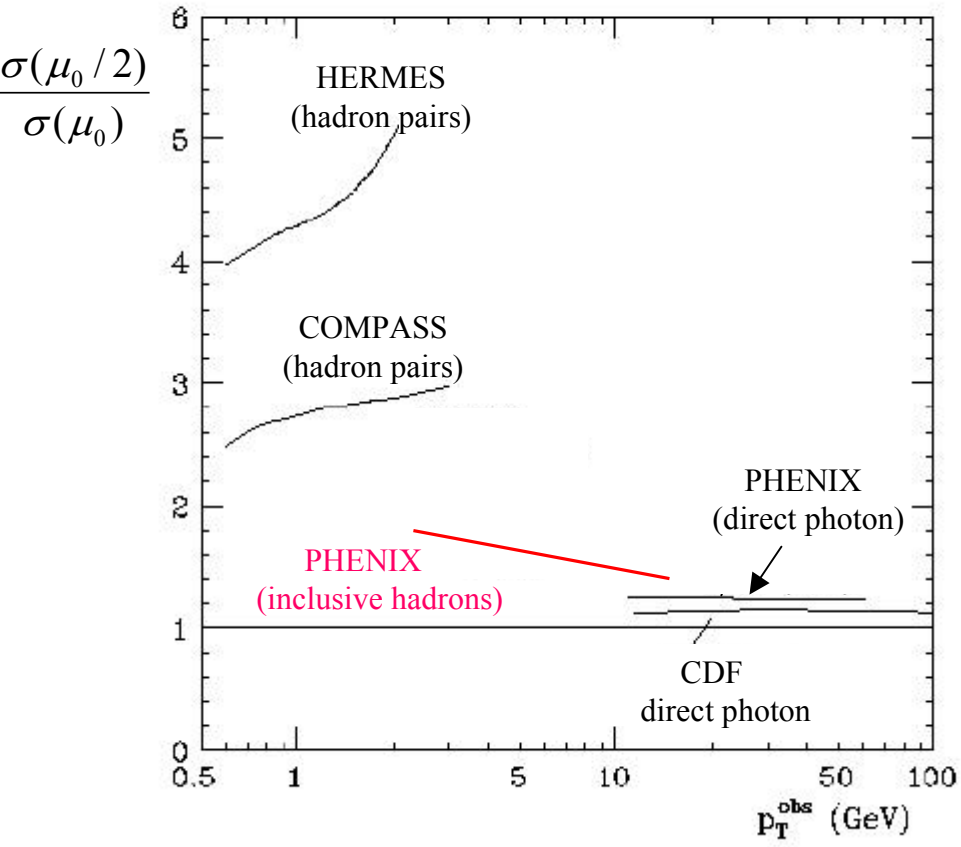
Many more years of exciting data and results to look forward to!

- Spin physics at PHENIX planned for 2005 and beyond
  - Measure gluon polarization via direct photon double longitudinal asymmetry
  - Probe gluon polarization from heavy flavor production (gg fusion) via electrons
  - Probe polarization of sea quarks via W boson single longitudinal asymmetry

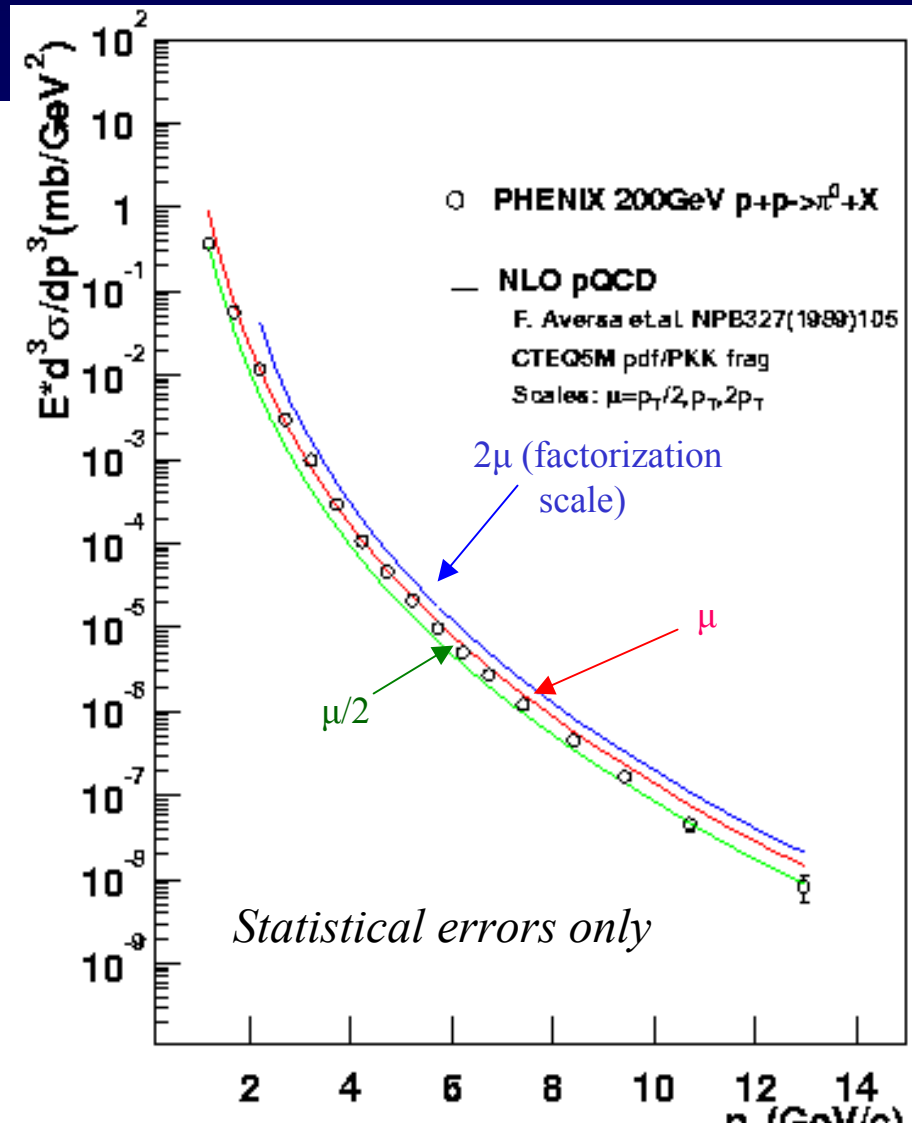
Extra Slides

pQCD Scale Dependence at RHIC

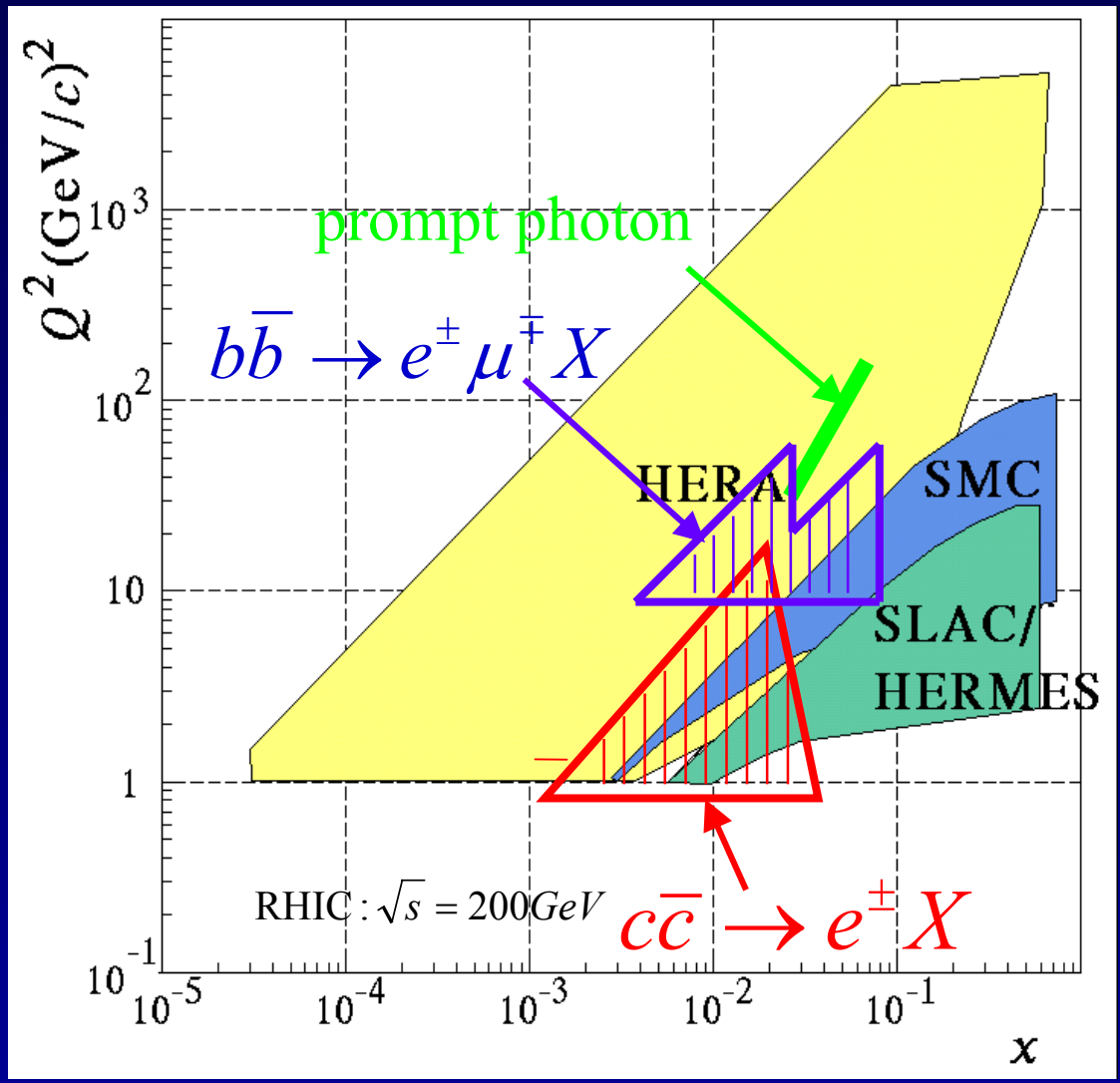
Theoretical uncertainty of pQCD calculations in channels relevant for gluon polarization measurements:



π^0 data vs pQCD with different factorization scales:



RHIC vs. DIS Kinematic Coverage

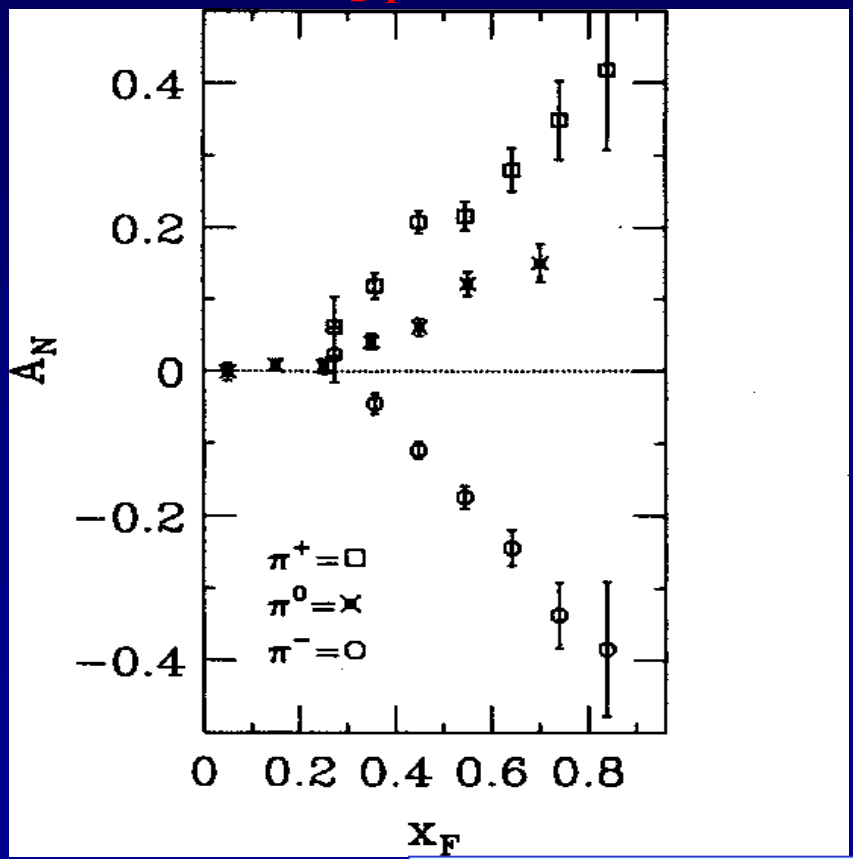


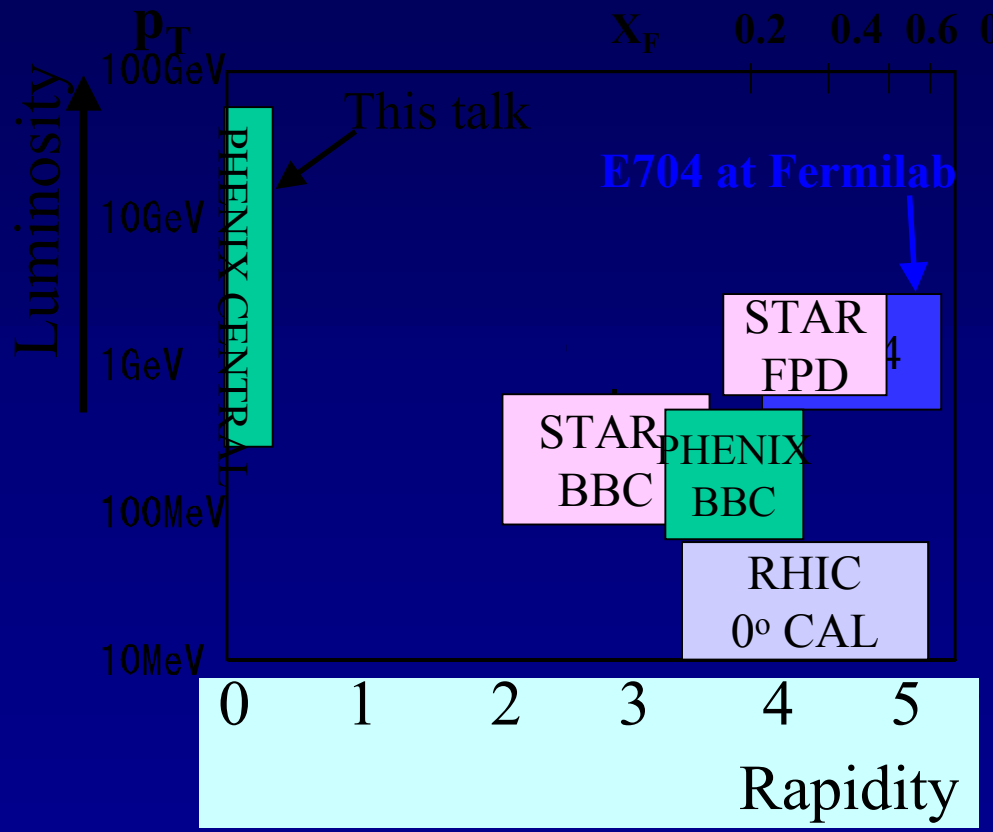
Single spin asymmetries: L-R

Essential for proton spin orientation information at IPs

E704 at Fermilab

at $\sqrt{s}$=20 GeV, p_T=0.5-2.0 GeV/c:





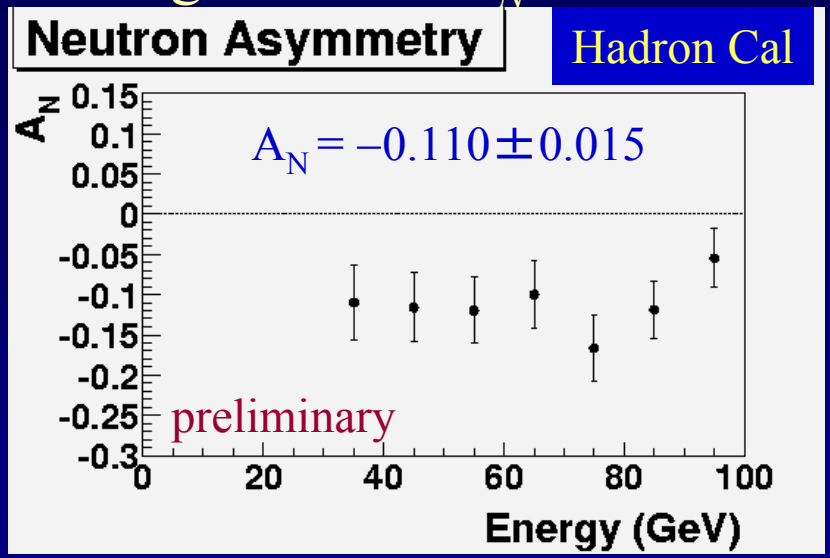
Models:: Transversity, Higher Twist, Fragmentation, k_T, Orbital Ang. Mom., etc.

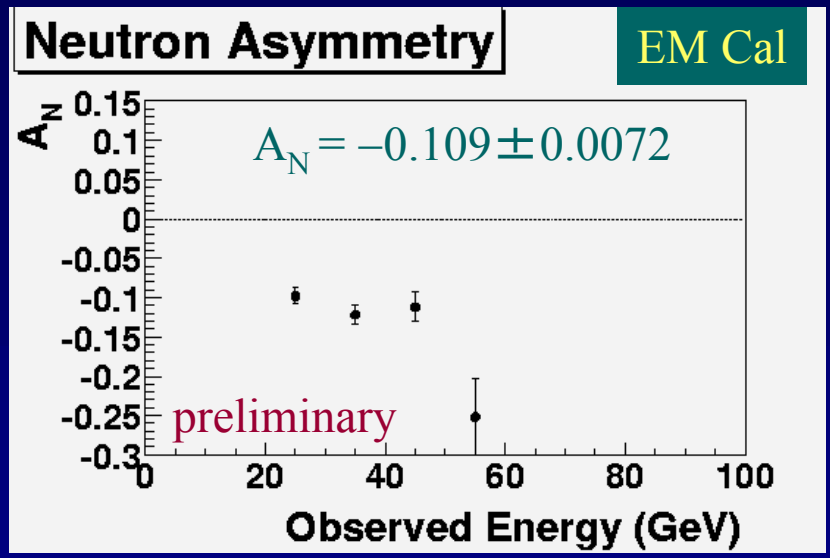
PHENIX

Neutron A_N at IP12

- A_N measurement at IP12
  - large neutron A_N was discovered

Y. Fukao



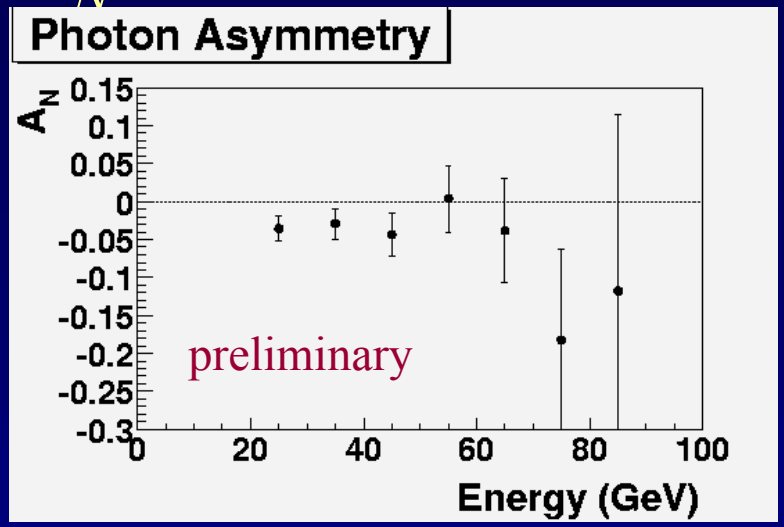


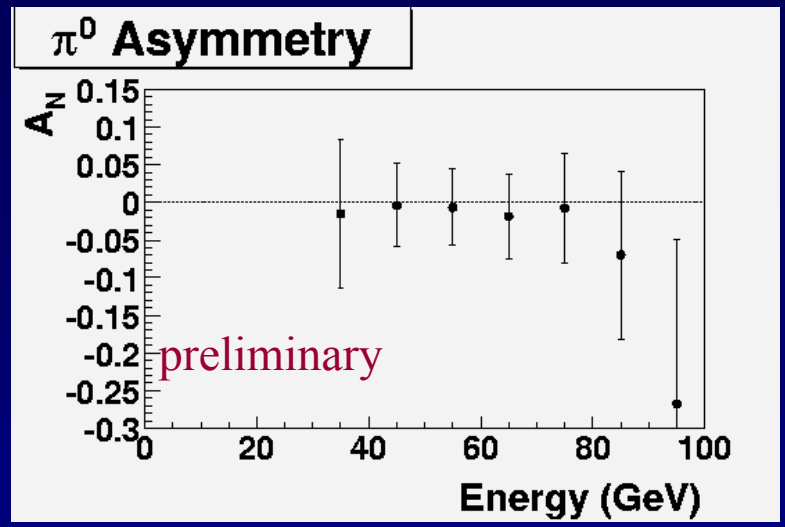
➔ Local polarimeter at PHENIX

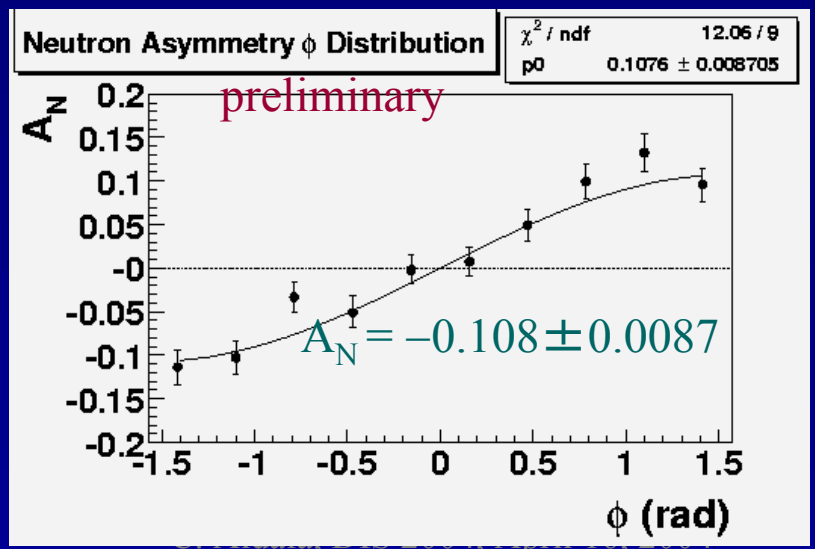
- ZDC + position sensitive counters to measure the neutron A_N
- 8-ch hodoscopes for both X- and Y-directions at the shower maximum position of the ZDC (between 1st and 2nd modules)

A_N at IP12

- A_N measurement at IP12

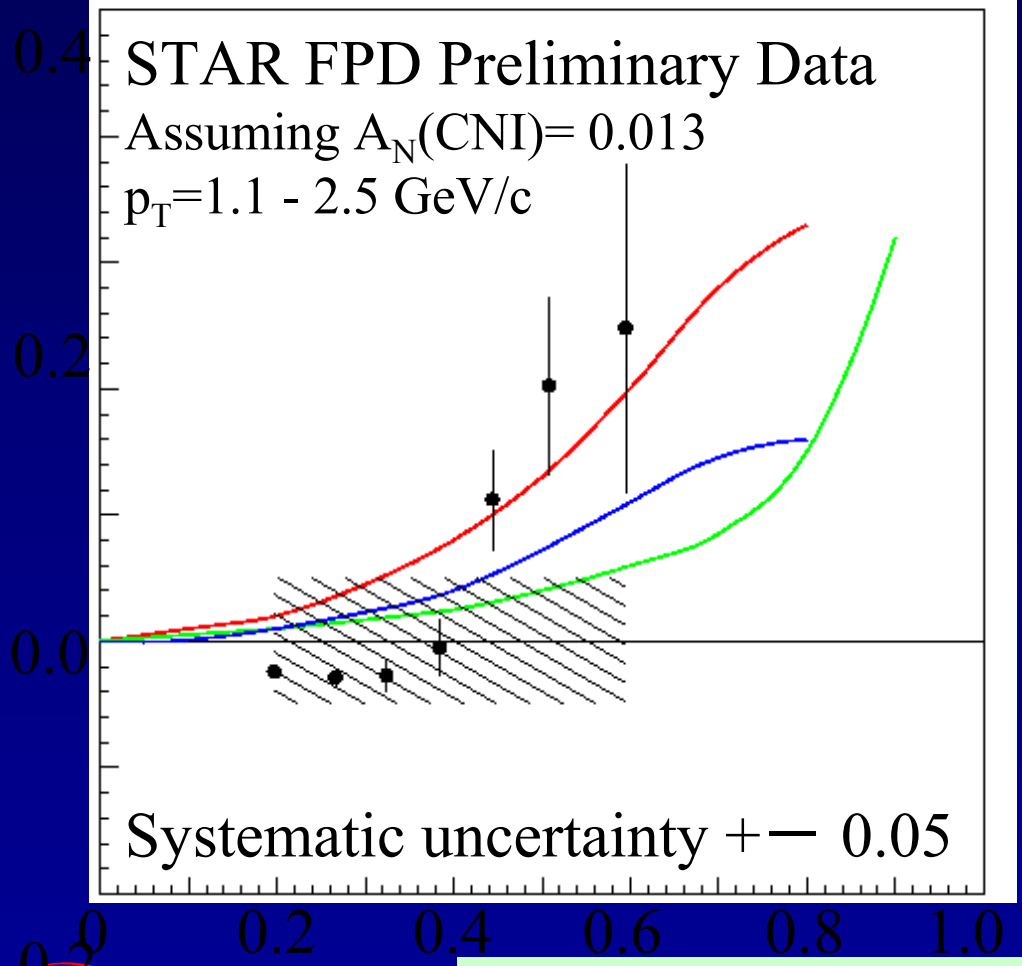






STAR Forward rapidity high x_F π^0 A_N

$A_N(\pi^0)$ $p^{\uparrow} p \to \pi^0 X$ at $\sqrt{s} = 200 GeV$



Theory predictions
at p_T = 1.5 GeV/c

Collins effect
Anselmino, et al.
PRD 60 (1999) 054027.

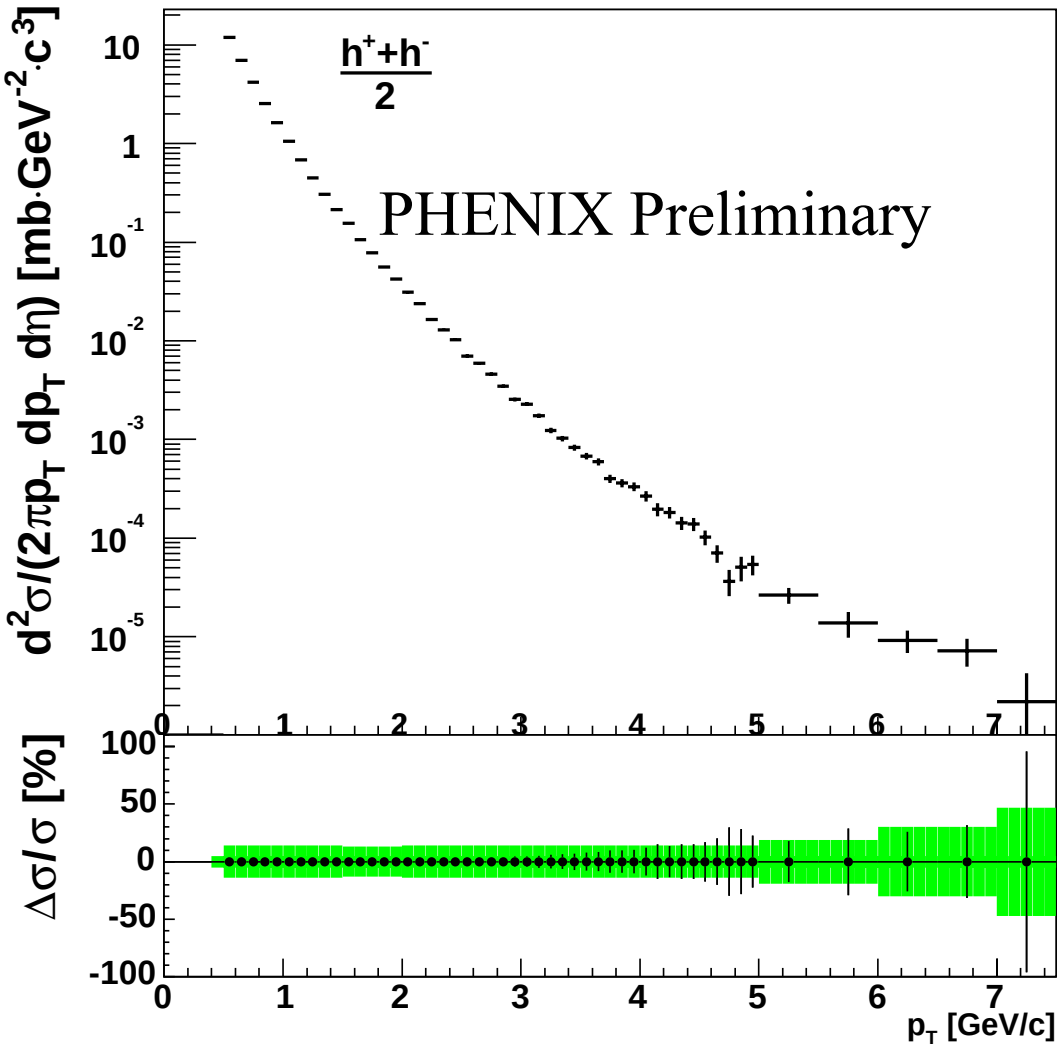
Sivers effect
Anselmino, et al.
Phys. Lett. B442 (1998) 470.

Twist 3 effect
Qiu and Sterman,
Phys. Rev. D59 (1998) 014004.

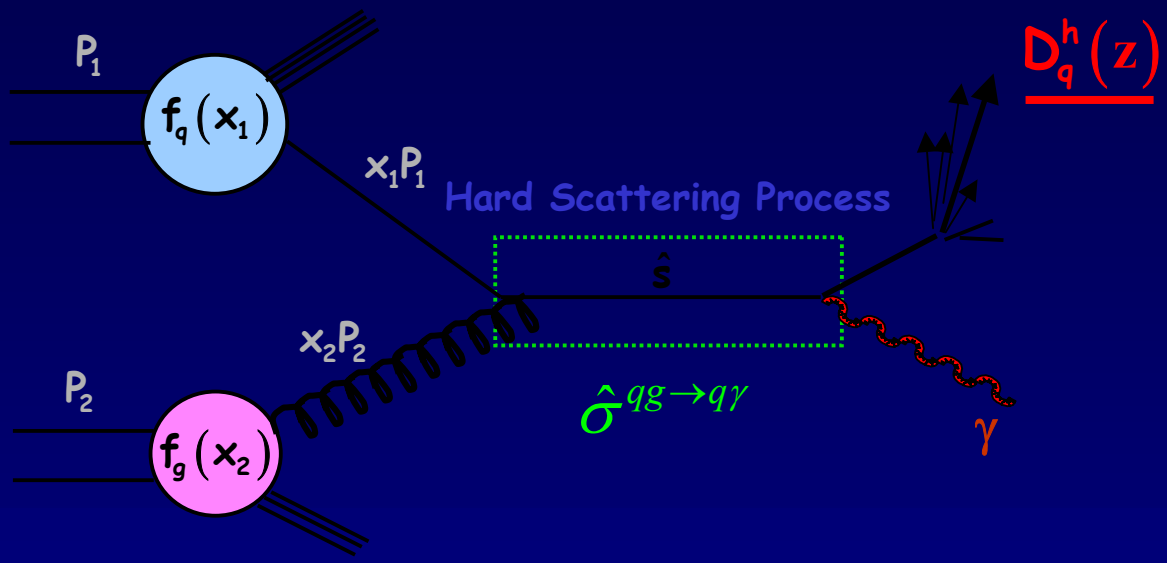
Y.Koike
PaNic02

$x_F \sim E / 100$ GeV

Charged Hadron Cross Section from 2001-2 Run



Hard Scattering Processes in p+p



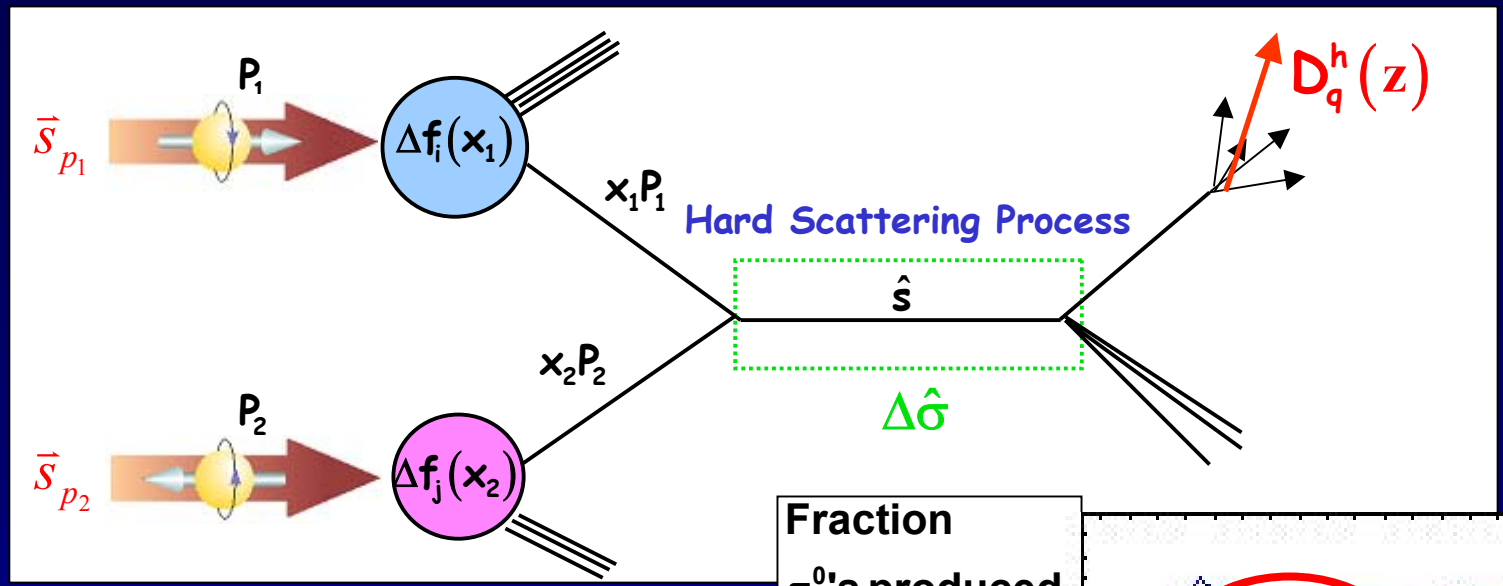
$$\sigma(pp \to \gamma X) \propto f_q(x_1) \otimes f_g(x_2) \otimes \hat{\sigma}^{qg\to q\gamma}(\hat{s})$$

"Hard" probes have predictable rates given:

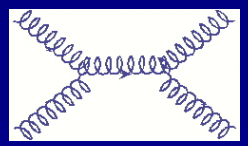
- Parton distribution functions (need experimental **input**)
- **pQCD hard scattering rates (calculable in pQCD)**
- **Fragmentation functions (need experimental input)**

Universality

Leading hadrons as jet tags

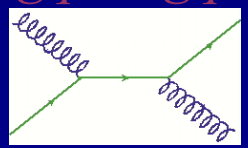


$gg \to gg$



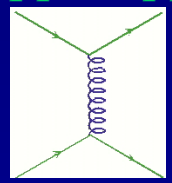
$$\propto \frac{\Delta G}{G}\frac{\Delta G}{G}$$

$gq \to gq$

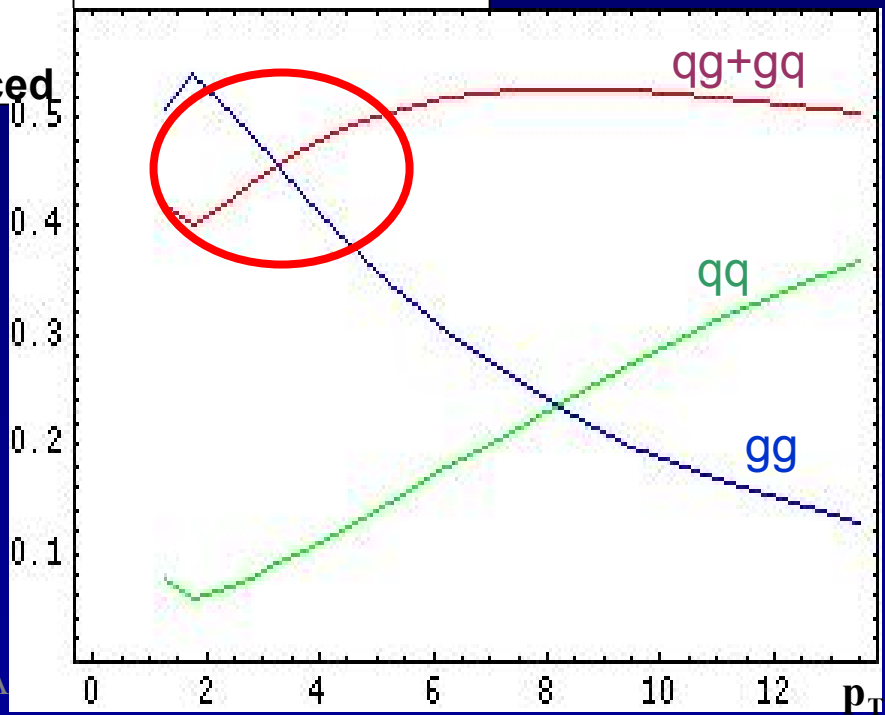


$$\propto \frac{\Delta q}{q}\frac{\Delta G}{G}$$

$qq \to qq$



$$\propto \frac{\Delta q}{q}\frac{\Delta q}{q}$$

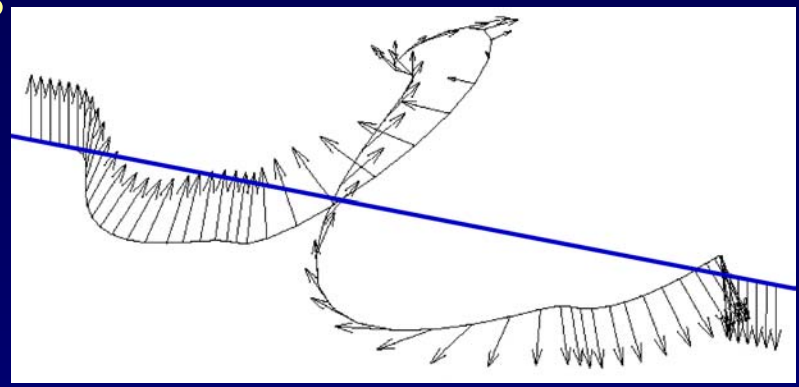


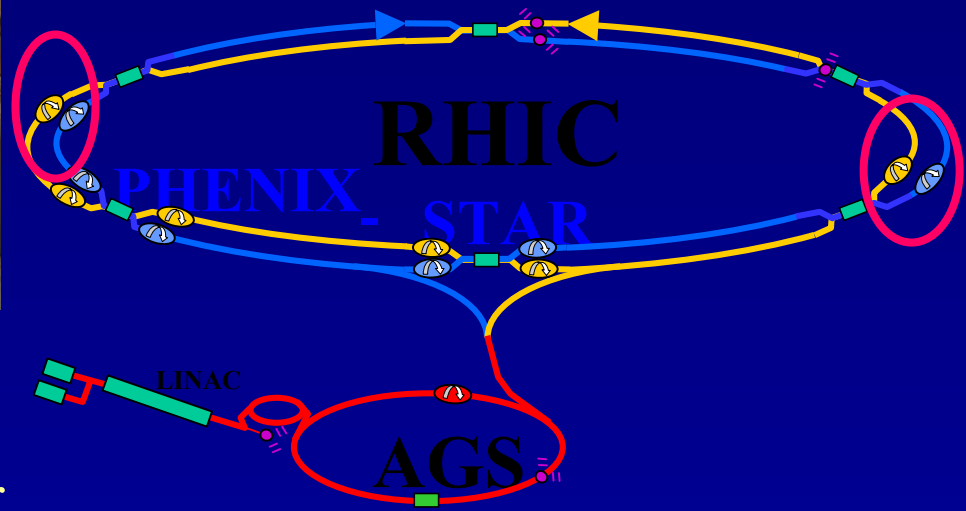
C. Aidala, DIS 2004, A

PHENIX

Siberian Snakes

Effect of depolarizing resonances averaged out by rotating spin by 180 degrees on each turn





- 4 helical dipoles ➔ S. snake
- 2 snakes in each ring
  - axes orthogonal to each other

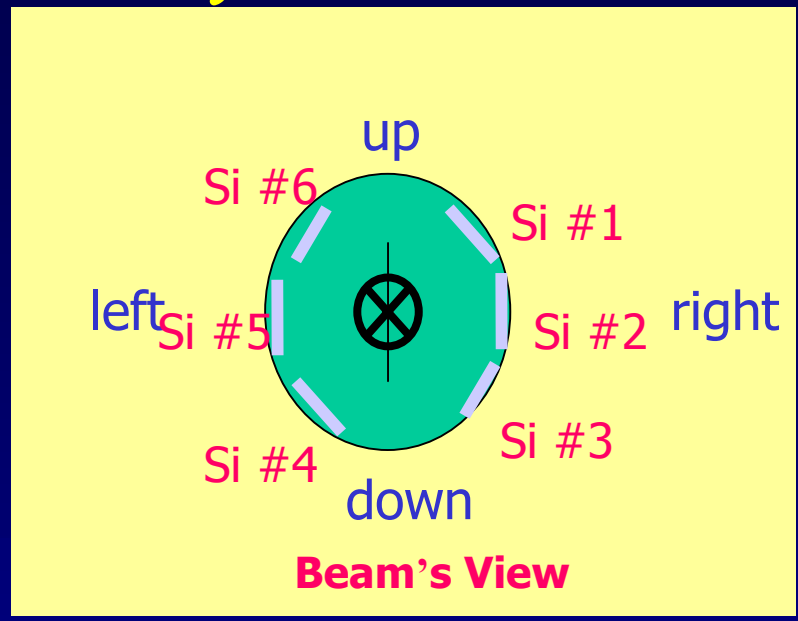
RHIC Polarimetry

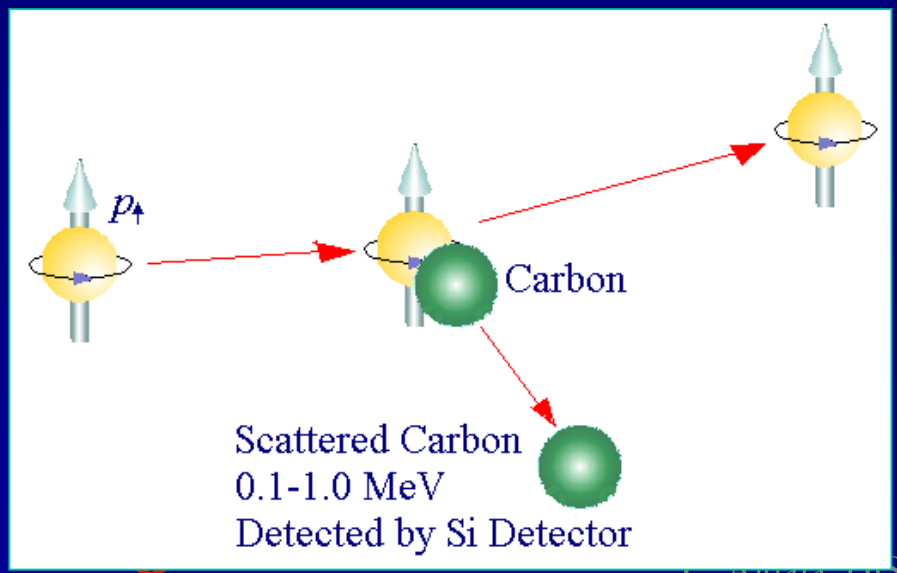
Carbon filament target ($5\mu g/cm^2$) in the RHIC beam

Measure recoil carbon ions at $\theta \sim 90^\circ$

$100\ keV < E_{carbon} < 1\ MeV$

E950 Experiment at AGS (1999)
→→→ RHIC polarimetry now

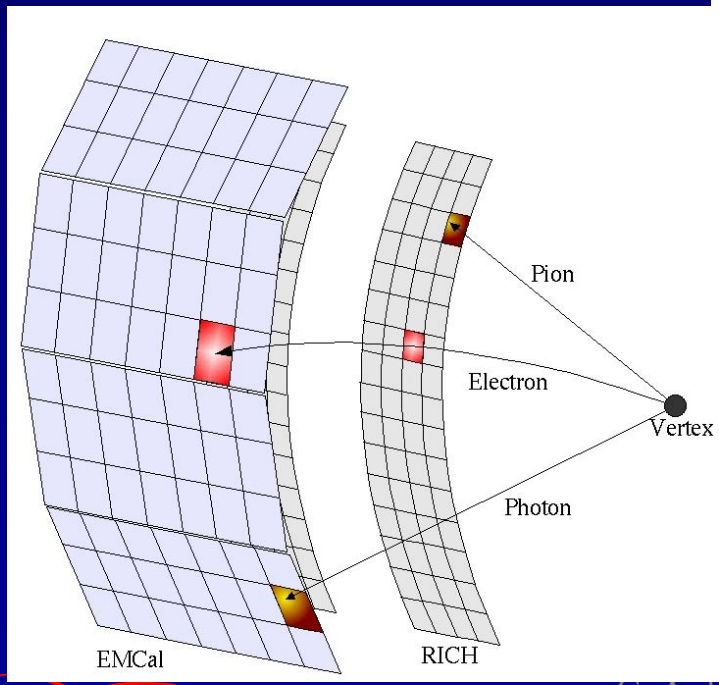




PHENIX

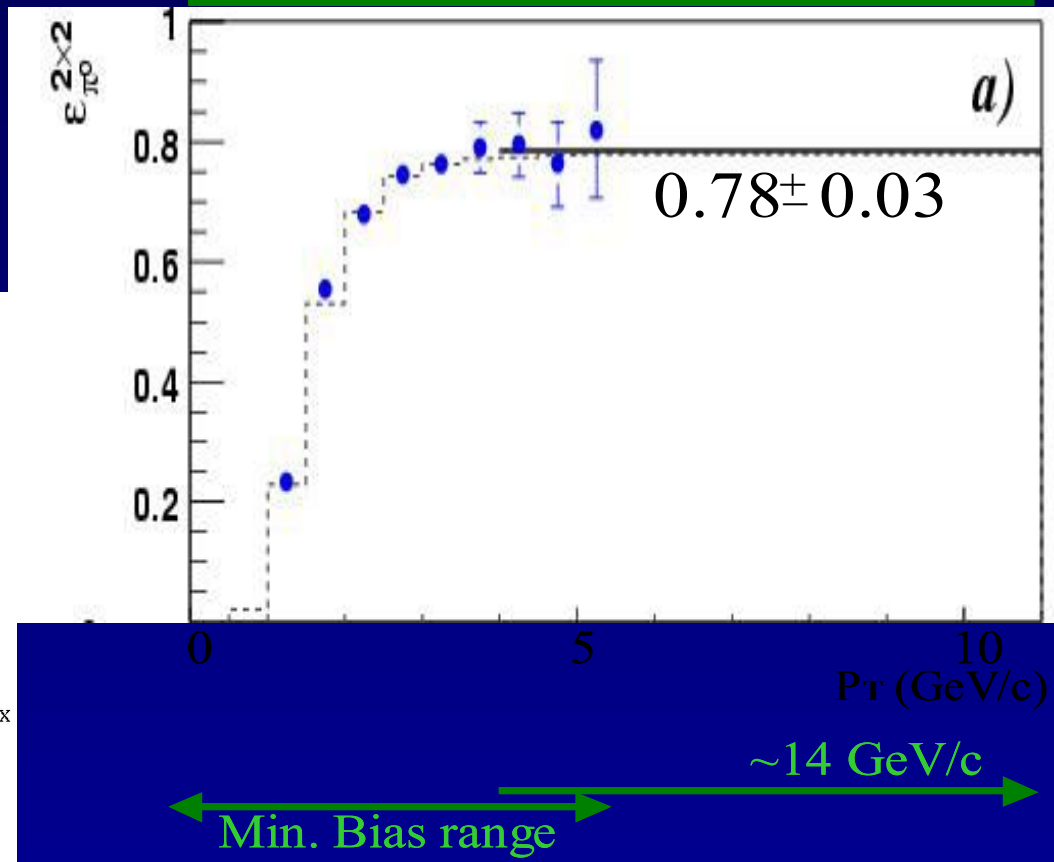
EMCal-RICH 2x2 Trigger

- 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.

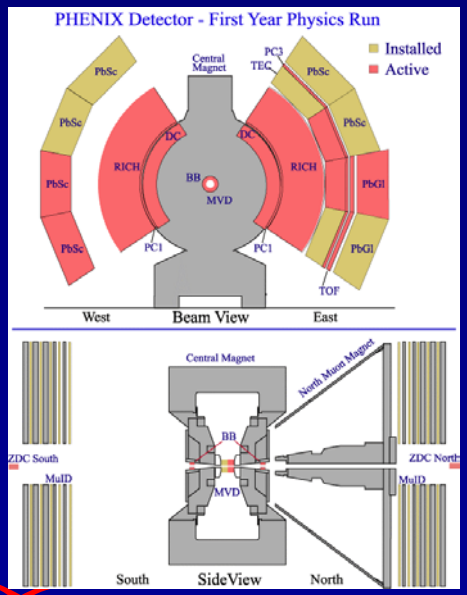
π^0 trigger efficiency



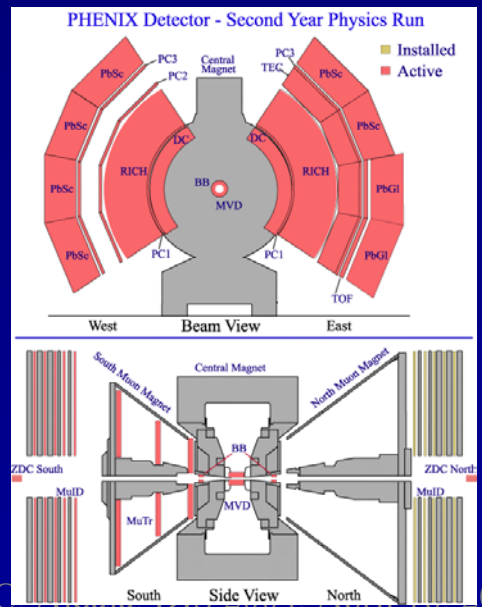
PHENIX Run History

Run	Year	Species	$s^{1/2}$ [GeV]	∫Ldt	N_{tot}	P
01	2000	Au-Au	130	1.0 mb^{-1}	10M	
02	2001/2002	Au-Au	200	24 mb^{-1}	170M	
		p-p	200	0.15 pb^{-1}	3.7G	~15%
03	2002/2003	d-Au	200	2.74 nb^{-1}	5.5G	
		p-p	200	0.35 pb^{-1}	6.6G	~27%

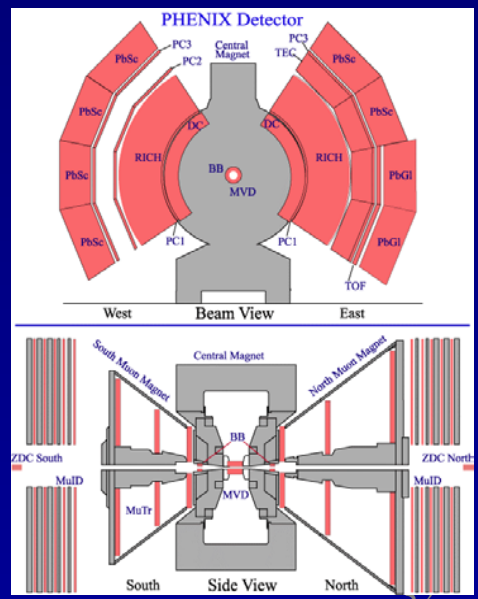
2000



2001/2002



2002/2003



PHENIX

2002 p+p run

- **Polarization – transverse**
  - $\langle P_{yellow} \rangle = 17\ \%$, $\langle P_{blue} \rangle = 14\ \%$
- **Luminosity**
  - integrated luminosity 0.15 pb^{-1}
  - $L = 1.5 \times 10^{30}\ cm^{-1} sec^{-1}$
- **Cross section measurement**
  - p^0, J/ψ, …
- ***A_N* measurements**
- **Systematic studies**
  - beam polarimeters
  - relative luminosity
  - local polarimeter development at IP12