Status of RHIC-Spin Program

OUTLINE

- Motivation / long-term goals of RHIC-spin program
- Who we are / new members of RHIC spin collaboration
- Accomplishments from Runs 2,3
- Issues for the future
- Progress towards Run 4 and beyond

L.C. Bland, for the RHIC Spin Collaboration
Brookhaven National Laboratory
RHIC Program Review, 9 July 2003

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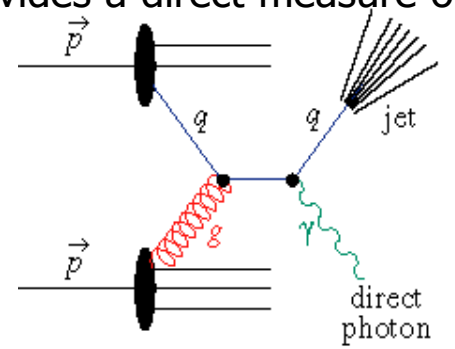
Gluon Contribution to the proton's spin

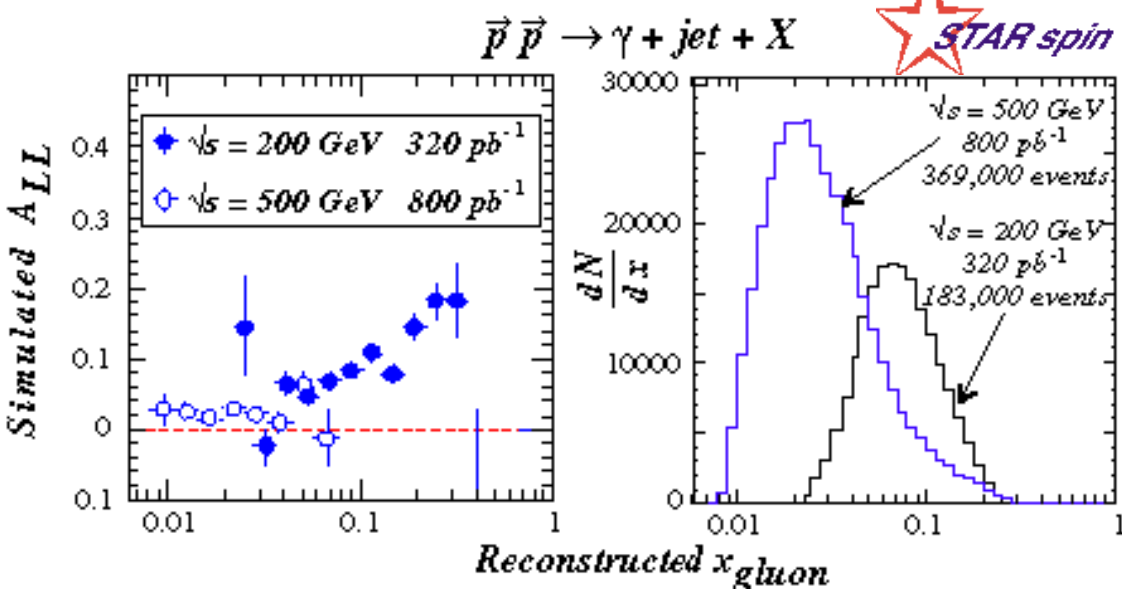
qg Compton scattering with polarized protons provides a direct measure of gluon polarization.



Quark-Gluon Compton scattering

$$\vec{p} + \vec{p} \rightarrow \gamma\,(+\,jet) + X$$

Coincident detection of γ and away-side jet ⇒ event determination of initial-state partonic kinematics.



Measure spin-correlation parameter (A_{LL}) with longitudinally polarized protons

$$P_{b1} P_{b2} A_{LL} = \frac{N_{++} - R N_{+-}}{N_{++} + R N_{+-}}$$

$P_{b1(2)}$ — *beam pol'n (~70%)*

$N_{++(+-)}$ — *equal (opposite) helicity yield*

R — *relative luminosity*

Interpret measured asymmetry within leading-order pQCD

$$A_{LL} = \underbrace{P_{part.\,1} P_{part.\,2}}_{\text{parton pol'ns.}} \hat{a}_{LL} = \underbrace{\frac{\Delta f_1}{f_1} \frac{\Delta f_2}{f_2}}_{\text{pol struct fncs.}} \hat{a}_{LL}(\hat{s}, \hat{t}, \hat{u}) \xrightarrow{\text{QCD Compton}} \boxed{\frac{\Delta G(x_g)}{G(x_g)}} A_1^p(x_q)\, \hat{a}_{LL}$$

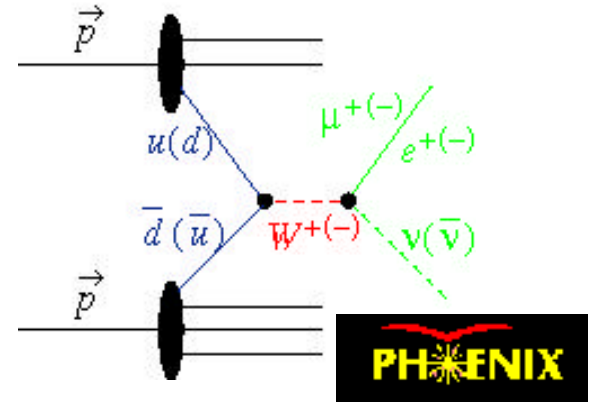
unpol struct fncs.

pQCD result for specific process

gluon polarization

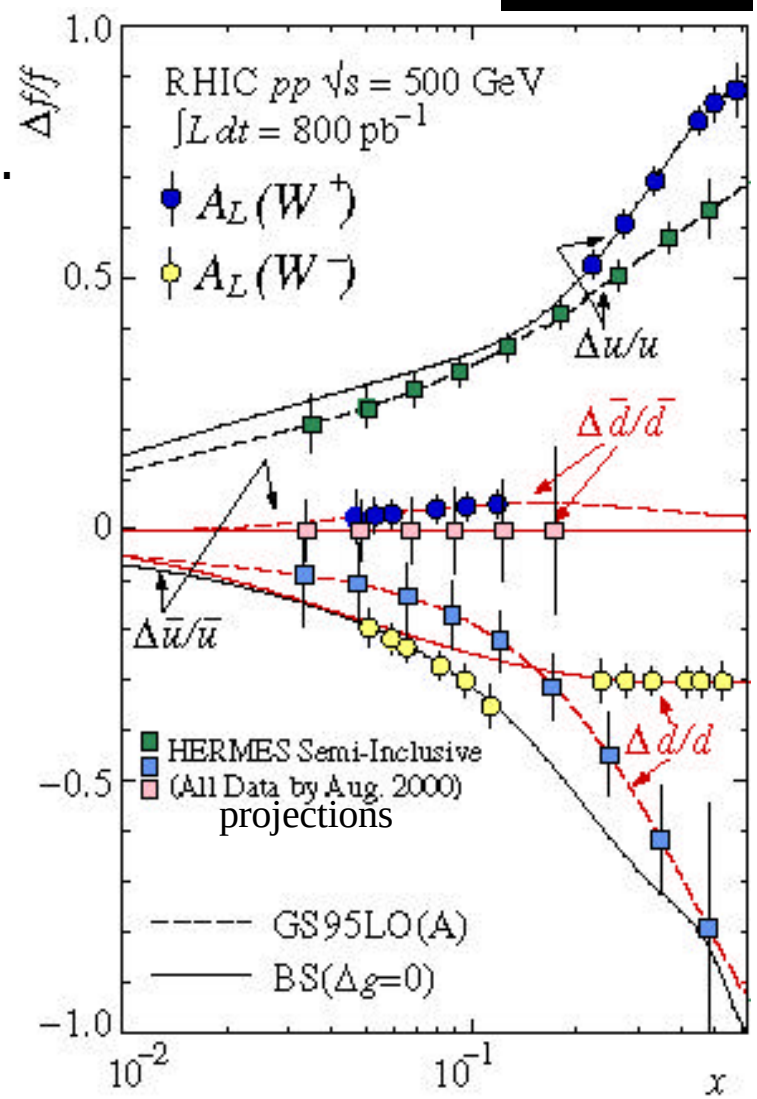
Measured in polarized deep-inelastic scattering

Flavor Decomposition of the proton's spin



- W ± production probes flavor structure analogous to ν deep inelastic scattering.
- Polarized proton beams allows the measurement of (the expected large) parity violation in W ± production.
- Forward μ,e detection (dominated by production of W 's with large longitudinal momentum) gives direct probe of quark (antiquark) polarization:

$$A_L \xrightarrow[x_1 >> x_2]{} \begin{cases} \dfrac{\Delta q(x_1)}{q(x_1)}, & \textit{when lepton is mostly parallel to the polarized proton} \\[2ex] \dfrac{\Delta \bar{q}(x_2)}{\bar{q}(x_2)}, & \textit{when lepton is mostly antiparallel to the polarized proton} \end{cases}$$



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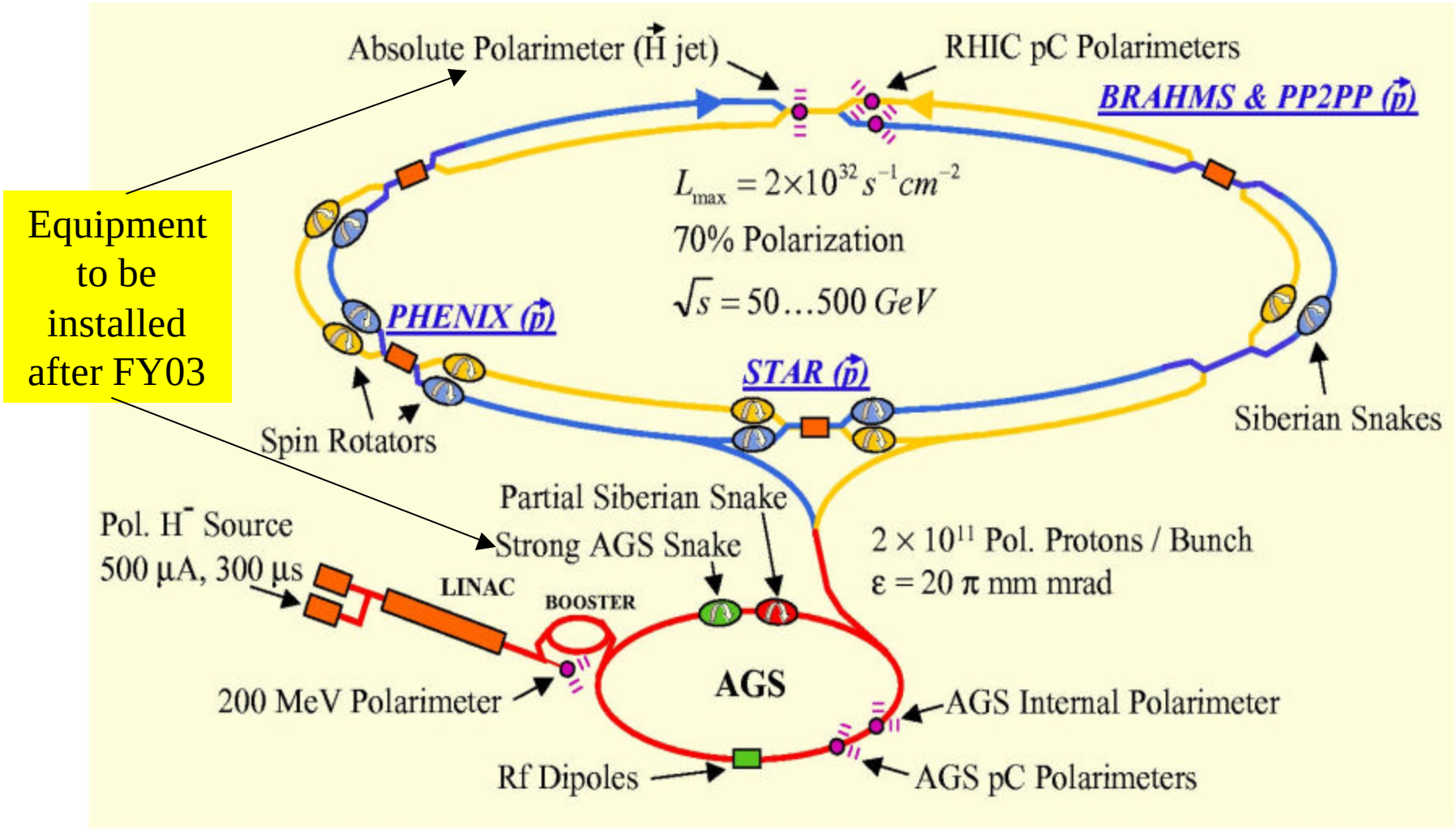
Polarized Proton Operation at RHIC



Equipment/developments for run 3 (3/03 → 5/03)…

- Siemens motor generator in AGS
- CNI polarimeter in AGS → fast feedback
- β*=1m 'squeeze' after acceleration
- spin rotators → longitudinal polarization

What is required for a spin experiment at RHIC?

(a summary of the multiple concurrent experiments)

Run 2 (12/01→1/02) Run 3 (3/03→5/03)

Stages of the RHIC-spin Project

Concept → Learning → Production

- Production of high-energy/intensity/polarization proton bunches that collide
  - ⇒ A successful accelerator physics experiment employing 'snakes',rotators,etc.
  - Rarest probes require P_{beam}=70% and $\int \mathcal{L}\, dt$ = 320(800) pb^{-1} at $\sqrt{s}$ = 200(500) GeV
- Large experimental facilities capable of detecting hadrons/jets, γ, $e^{\pm}$,$\mu^{\pm}$ …
  - ⇒ Experimental sophistication comparable to other colliders (Tevatron, HERA,…)
- Polarimeters to monitor polarization and establish its absolute magnitude
  - ⇒ Coulomb-nuclear interference / polarized gas jet target / local polarimeters
  - Require ΔP_{beam} / P_{beam} ~ 5%
- Interaction-region monitors of spin-dependent relative luminosity
  - ⇒ Precision experiments to minimize systematic errors in final answer

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RHIC Spin Collaboration Organization

- **RHIC Spin Collaboration** (Spokesman: G. Bunce)

Develops overall spin plan; forum to coordinate spin issues for RHIC accelerator and experiments.

Spin physics is an integral part of the goals of the STAR, PHENIX and pp2pp experiments.

- **RHIC Accelerator Spin Group** (Spokesman: T. Roser, Project Manager: W. Mackay)

Accelerator physics for spin (Siberian Snakes, Spin Rotators,`Spin Flipper'); polarized ion source; polarimeters.

- **RIKEN and RIKEN/BNL Research Center** (Group Leaders: H. En'yo, G. Bunce)

Funds spin physics equipment; develops polarimetry; organizes spin workshops; supports young physicists.

- **STAR Spin Physics Working Group** (Conveners: L. Bland, G. Eppley)
- **PHENIX Spin Physics Working Group** (Conveners: Y. Goto, K. Barish)
- **pp2pp Experiment** (Spokesman: W. Guryn)
- **BNL Groups: RHIC Spin Group** (Group Leader: G. Bunce); **RBRC/Nuclear Theory**

Develop / exploit spin capability of RHIC; coordinates accelerator / experiment activities; complete measurements; members in STAR, PHENIX and pp2pp experiments.

- **Laboratory / University participation**

BRAHMS collaboration, PHENIX collaboration, pp2pp collaboration, STAR collaboration

New groups: Cal Tech, Colorado, Illinois, MIT

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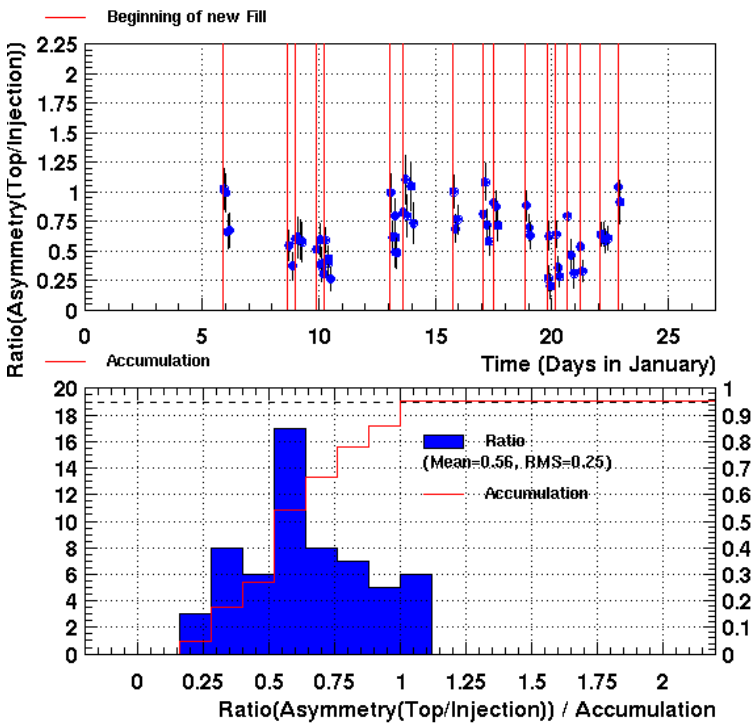
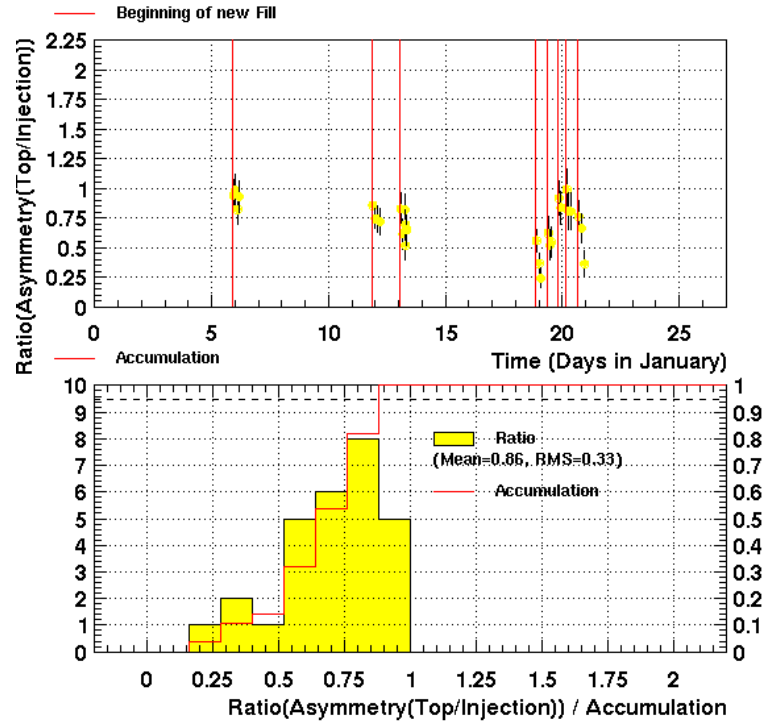
Run 2 Progress / Results



Siberian Snakes work to preserve polarization through acceleration and store.



- $\int \mathcal{L}\, dt \sim 350\ nb^{-1}$ and $\langle P_{beam} \rangle \sim 18\%$ (Yellow) / 15% (Blue) delivered to experiments. Polarization limited by performance of AGS.
- STAR / PHENIX / pp2pp experiments commissioned for *pp* collisions at $\sqrt{s} = 200$ GeV.
- Critical *pp* reference measurements for heavy-ion program completed providing important physics results.
- Transverse single-spin measurements completed providing physics results + local polarimeters for spin-rotator tuning in Run 3.

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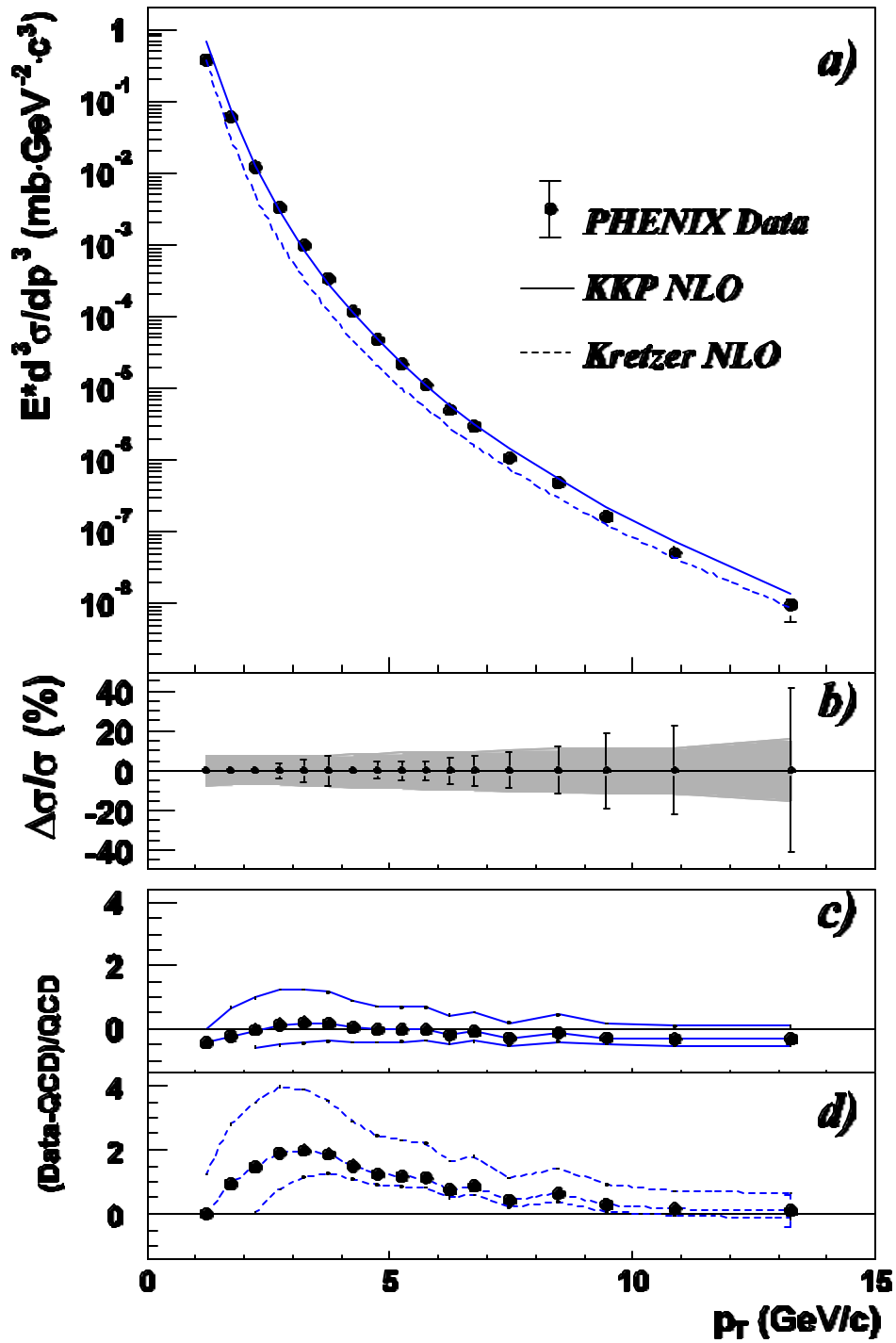
π^0 Cross Section

- The data covers over 8 order of magnitude
  - –by combining minimum bias trigger and EMCal trigger data
- NLO pQCD calculation is consistent with data
  - –CTEQ5M PDF + KKP FF



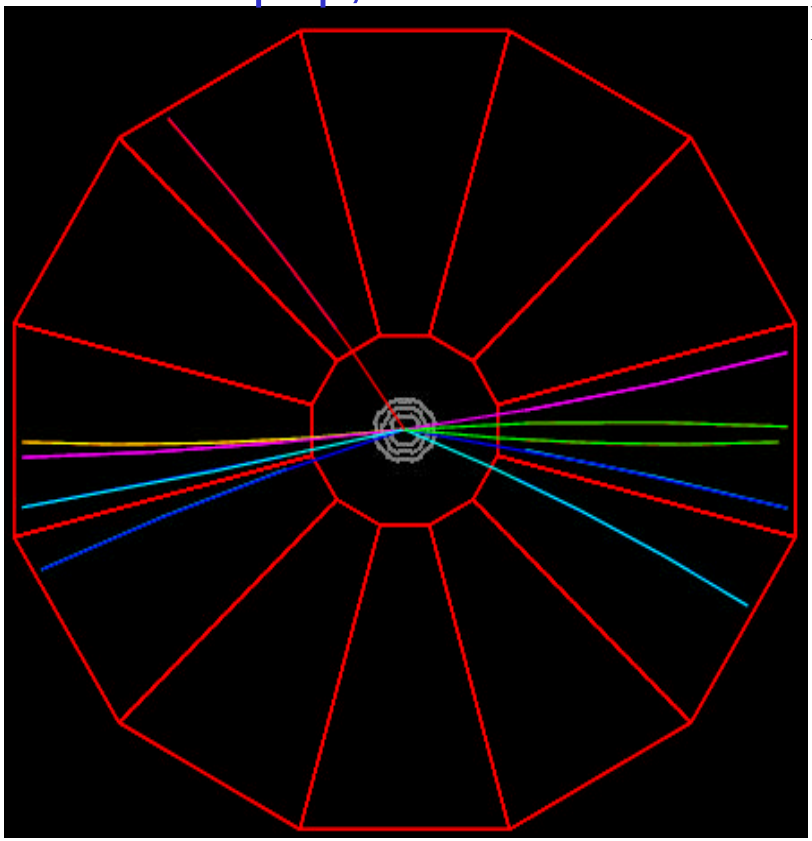
H. Torii, Kyoto University
B. Fox (BNL), SPIN 2002

submitted to PRL, hep-ex/0304038

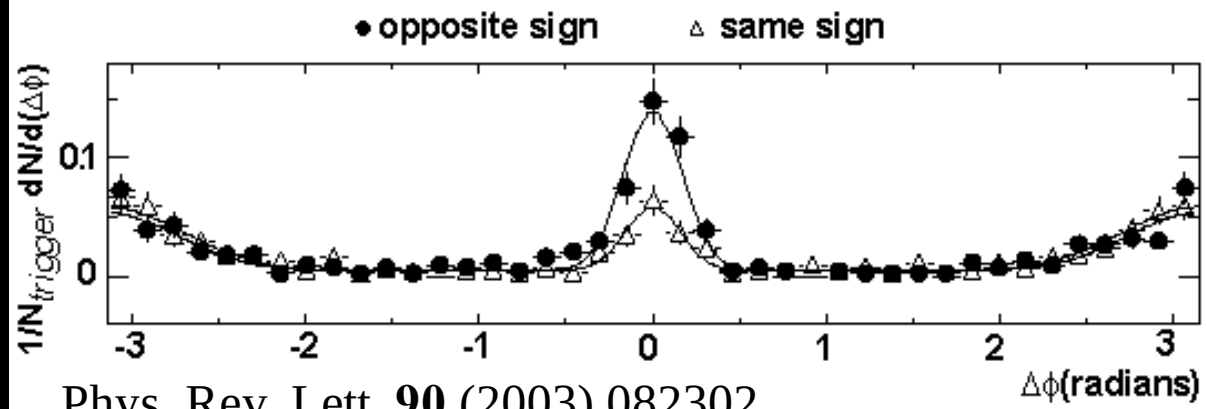
Di-jet Reference for Heavy-Ion Physics

(jet physics is central to spin program)

STAR p+p, √s = 200 GeV



Hadronic high-p_T azimuthal correlations in *pp* collisions

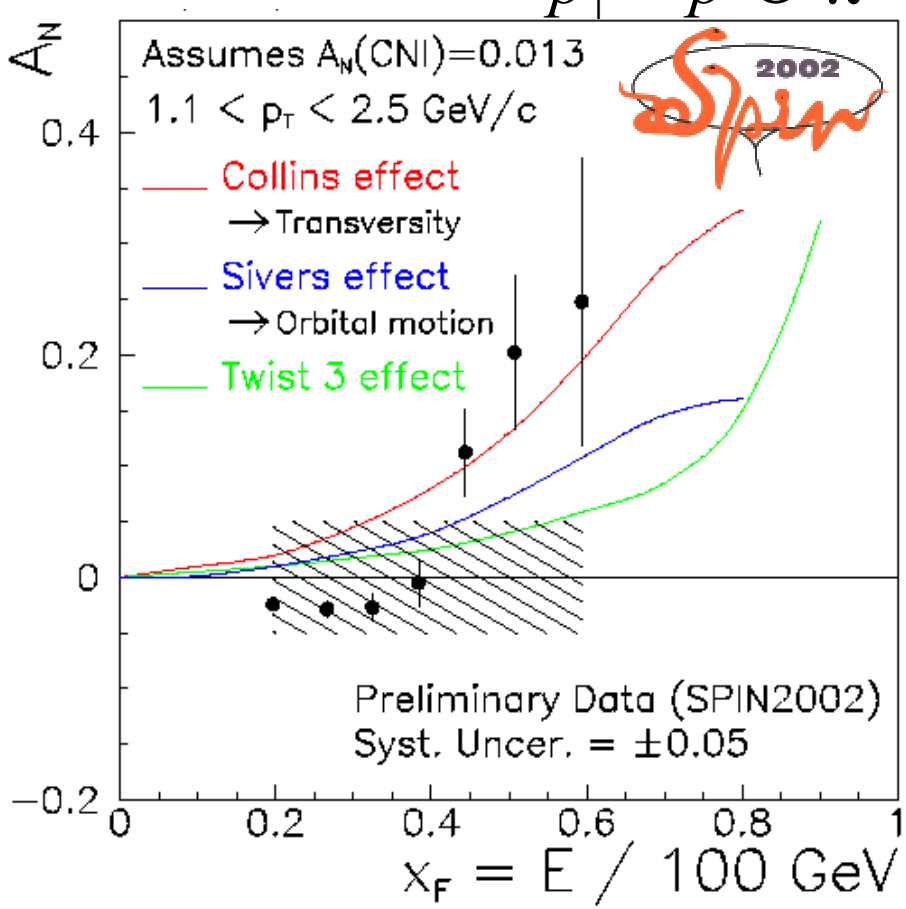


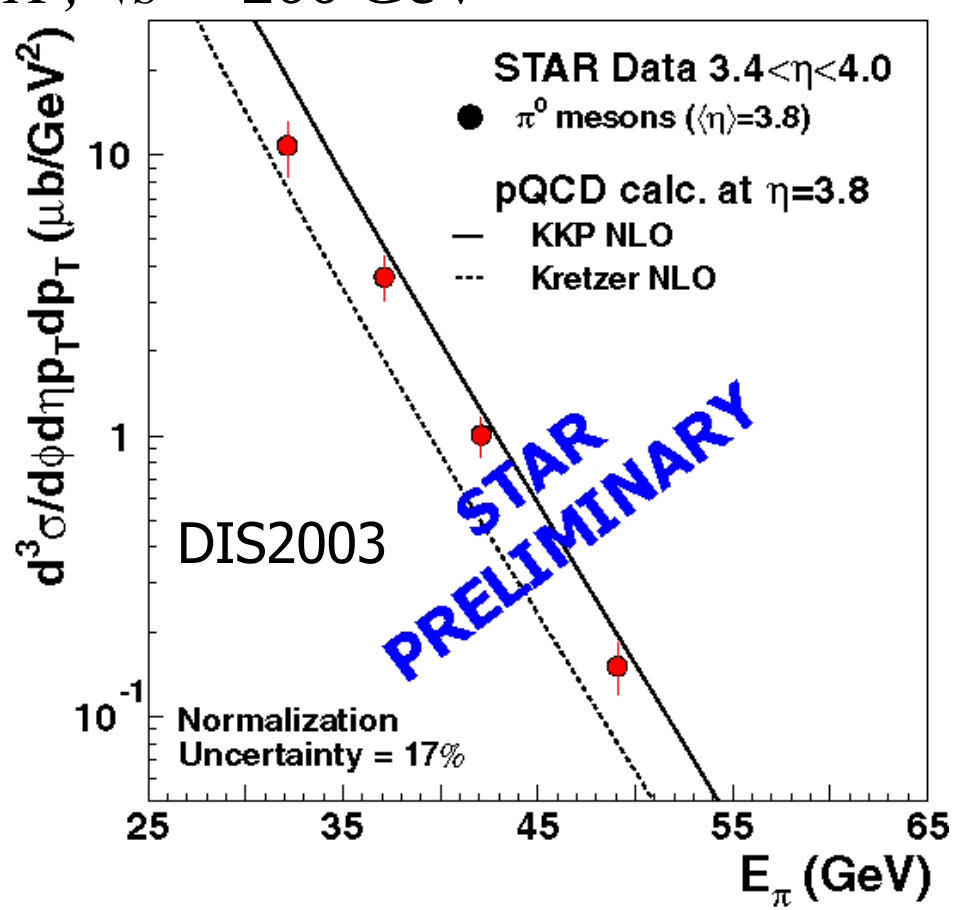
Phys. Rev. Lett. **90** (2003) 082302

- di-jet events clearly observed in *pp* collisions at $\sqrt{s}$ = 200 GeV.
- di-hadrons serve as di-jet surrogates for heavy-ion collisions.
- clear near-side and away-side di-hadron correlations in *pp* collisions serve as contrast for central AuAu collisions where away-side correlations are strongly suppressed.

STAR-Spin Results from Run 2

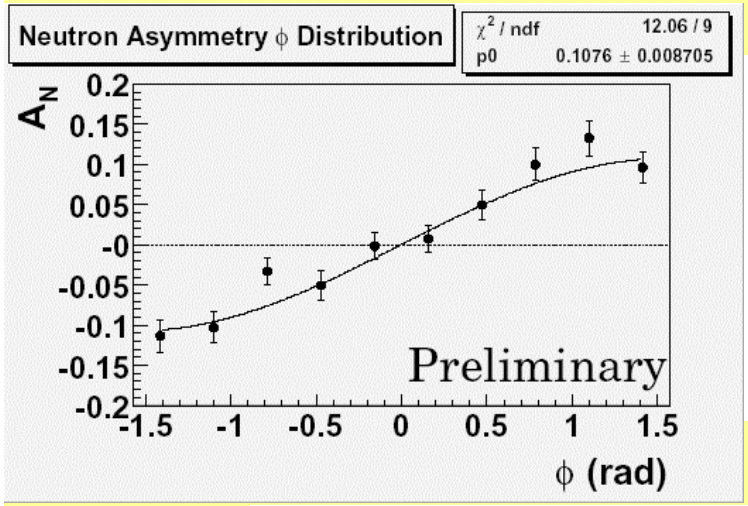
$p_{\uparrow} + p \rightarrow \pi^0 + X$, $\sqrt{s} = 200$ GeV



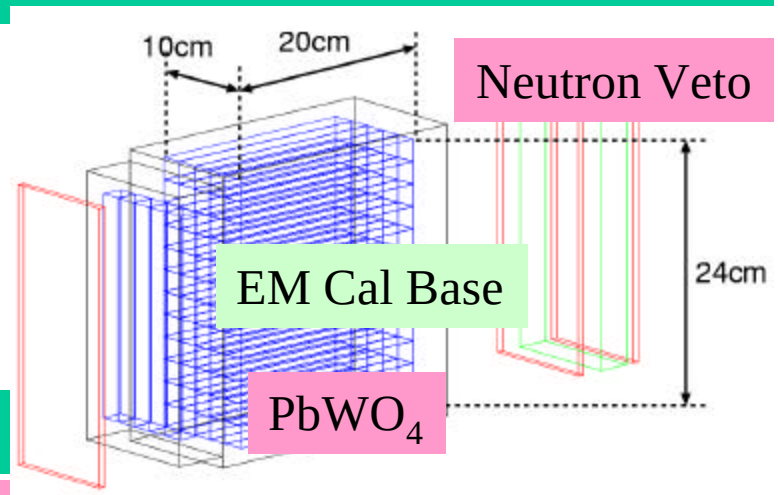


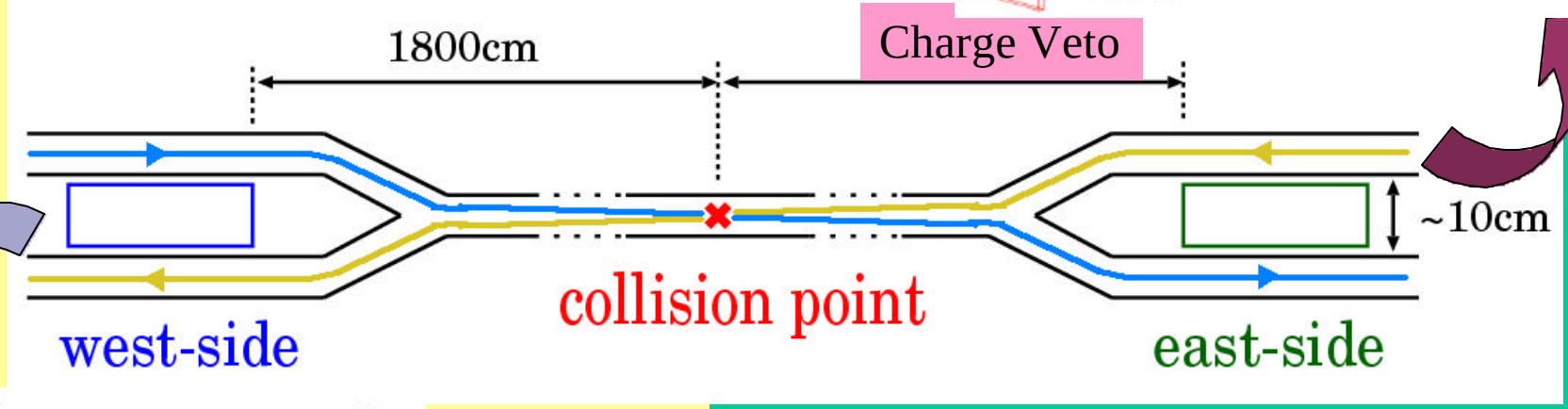
- Measured cross sections consistent with pQCD calculations
- Large spin effects observed for $\sqrt{s} = 200$ GeV pp collisions

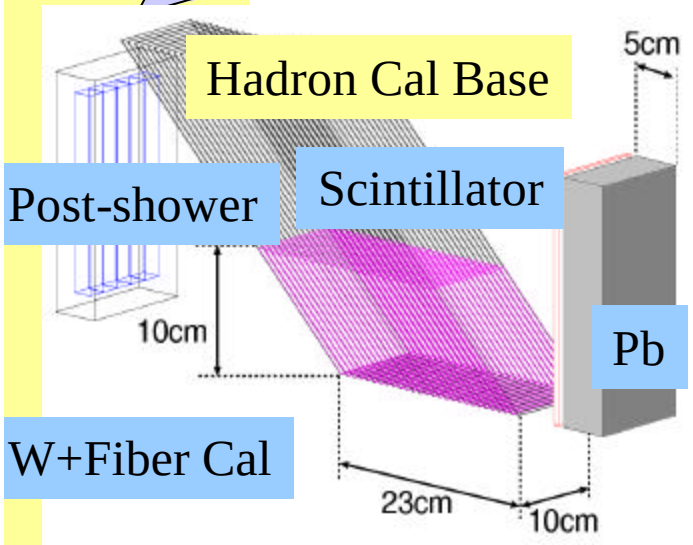
Status: final analysis complete / paper in preparation



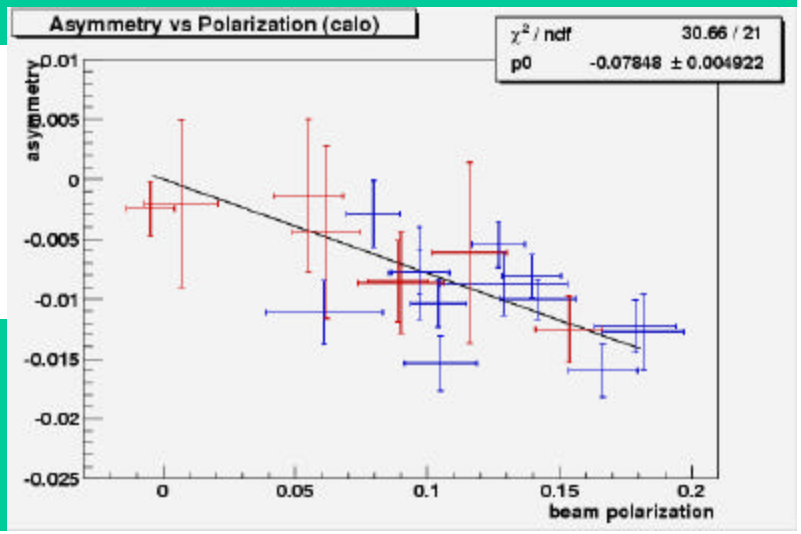
Analyzing Power for Forward Neutron Production at √s = 200 GeV (Run 2 Result)







Results from run 2 are basis for PHENIX local polarimeter used in run 3



Y. Fukao (Kyoto)
SPIN 2002

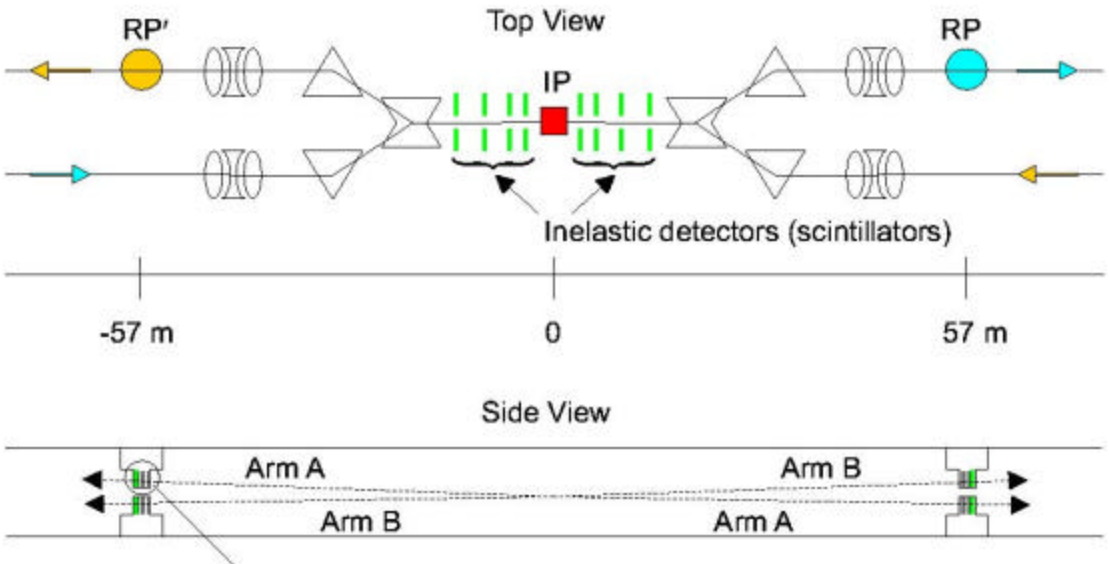
pp2pp
Run-2 Results

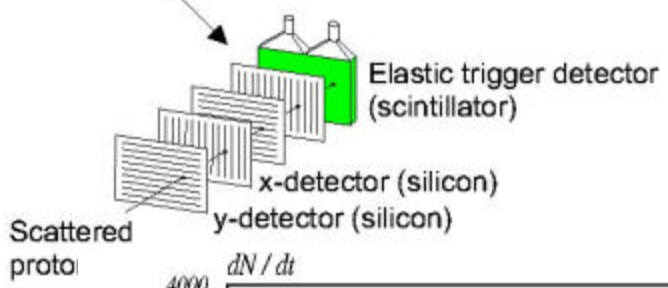
Measurement of small-angle $p_{\uparrow}p_{\uparrow}$ elastic scattering at

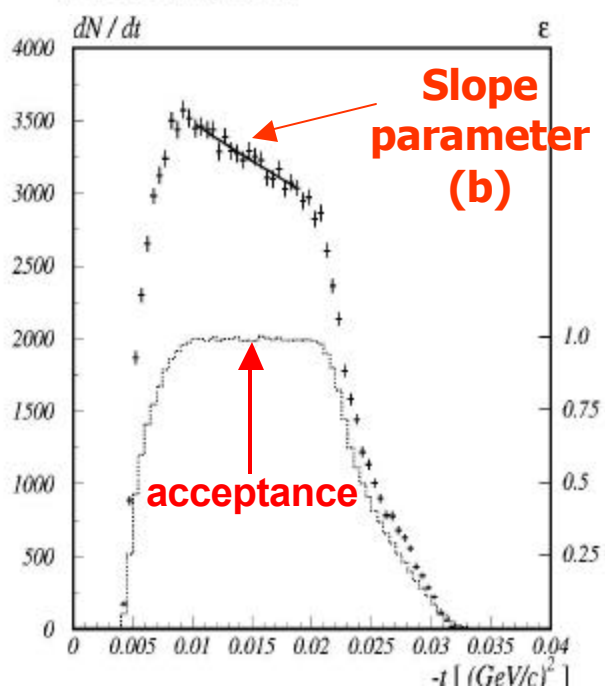
$50 \leq \sqrt{s} \leq 500$ GeV;

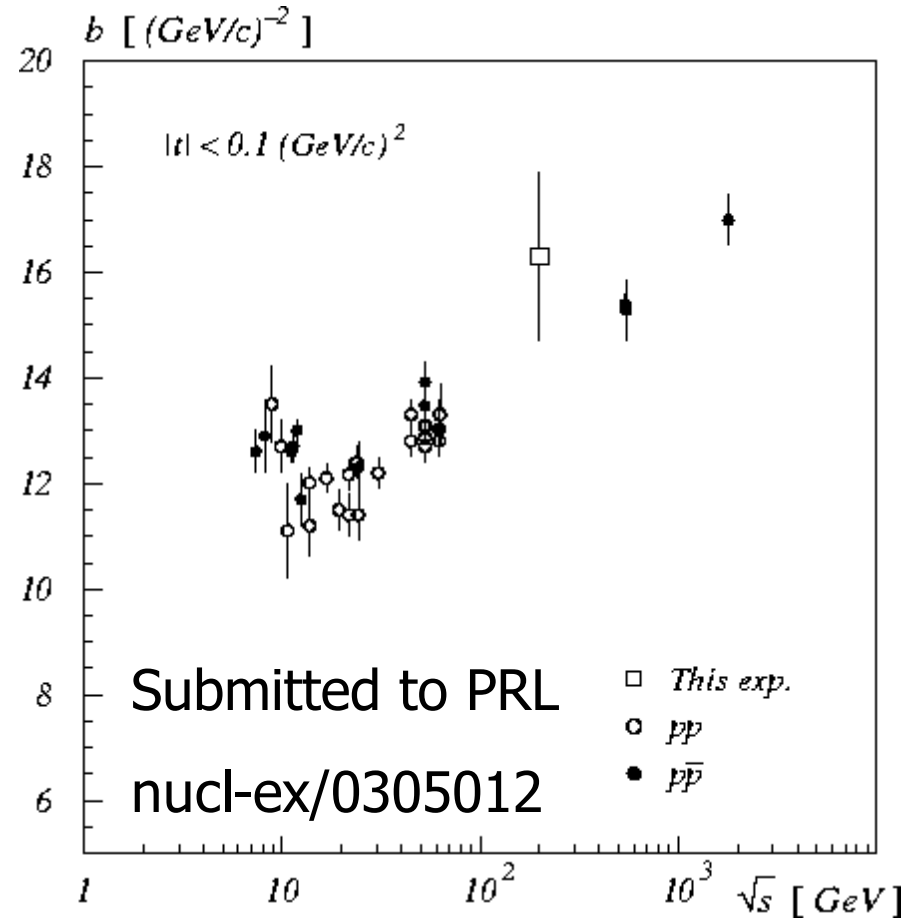
$4 \times 10^{-4} \leq |t| \leq 1.3$ (GeV/c)^2

using Si strip detectors in Roman Pots above and below the beam.









Submitted to PRL

nucl-ex/0305012

Run 3 Plans / Performance / Progress

Commissioning…

- Fast polarimeter for AGS / polarization measurements along the ramp.
- high-luminosity (β^*=1 m) optics at PHENIX and STAR interaction regions.
- tuning RHIC spin rotators $\Rightarrow$ producing longitudinal polarization at PHENIX and STAR / measuring residual transverse polarization components with local polarimeters.

Physics measurements…

- transverse single spin asymmetries for $p_{\uparrow}+p \rightarrow \pi^0+X$ at $\sqrt{s}$=200 GeV to discriminate underlying dynamics.
- probing ΔG via first measurements of A_{LL} for hadrons and jets produced at mid-rapidity.

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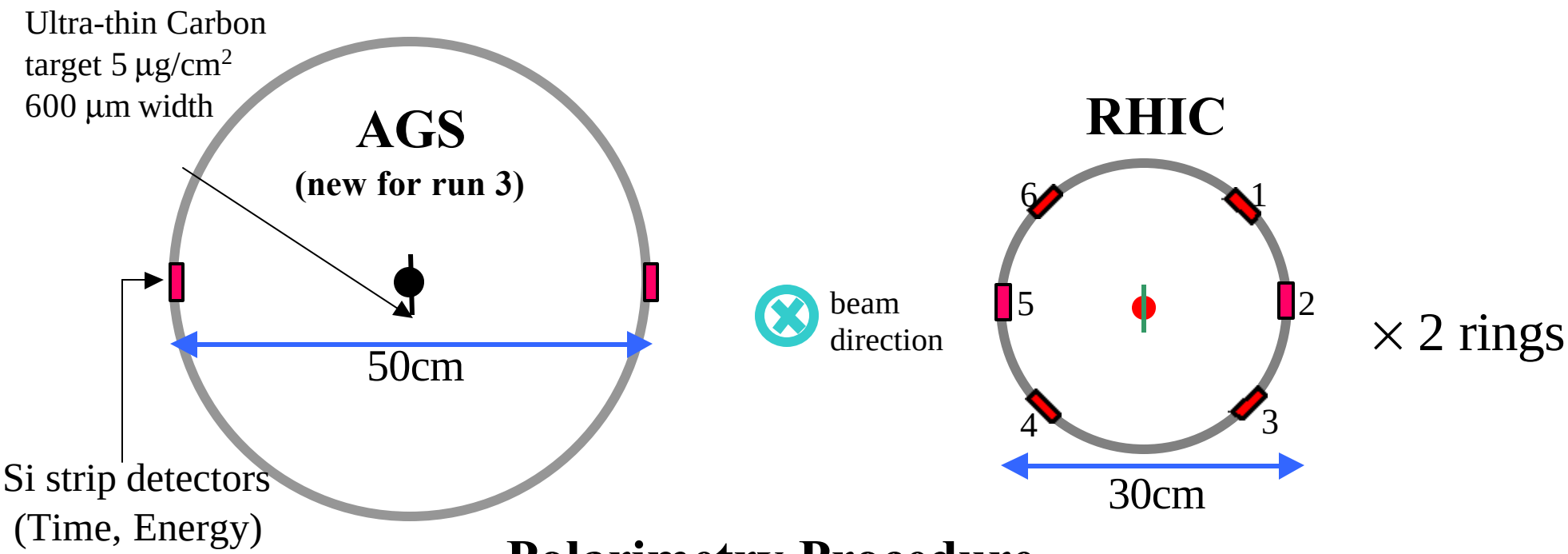
CNI Polarimeters



Polarimetry Procedure

- Measure recoil carbons from $p^{-}C \rightarrow p^{-}C$ elastic scattering

- Exploit analyzing power, $A_N \approx 0.01$, originating from anomalous magnetic moment of proton. Calibration of A_N required.

- Measure left/right (more generally, azimuthal variation) spin-dependent asymmetry

$$\varepsilon_{LR} = \frac{\sqrt{N_{L-}N_{R-}} - \sqrt{N_{L-}N_{R-}}}{\sqrt{N_{L-}N_{R-}} + \sqrt{N_{L-}N_{R-}}}\ ,\ P_{beam} = \frac{\varepsilon_{LR}}{A_N}$$

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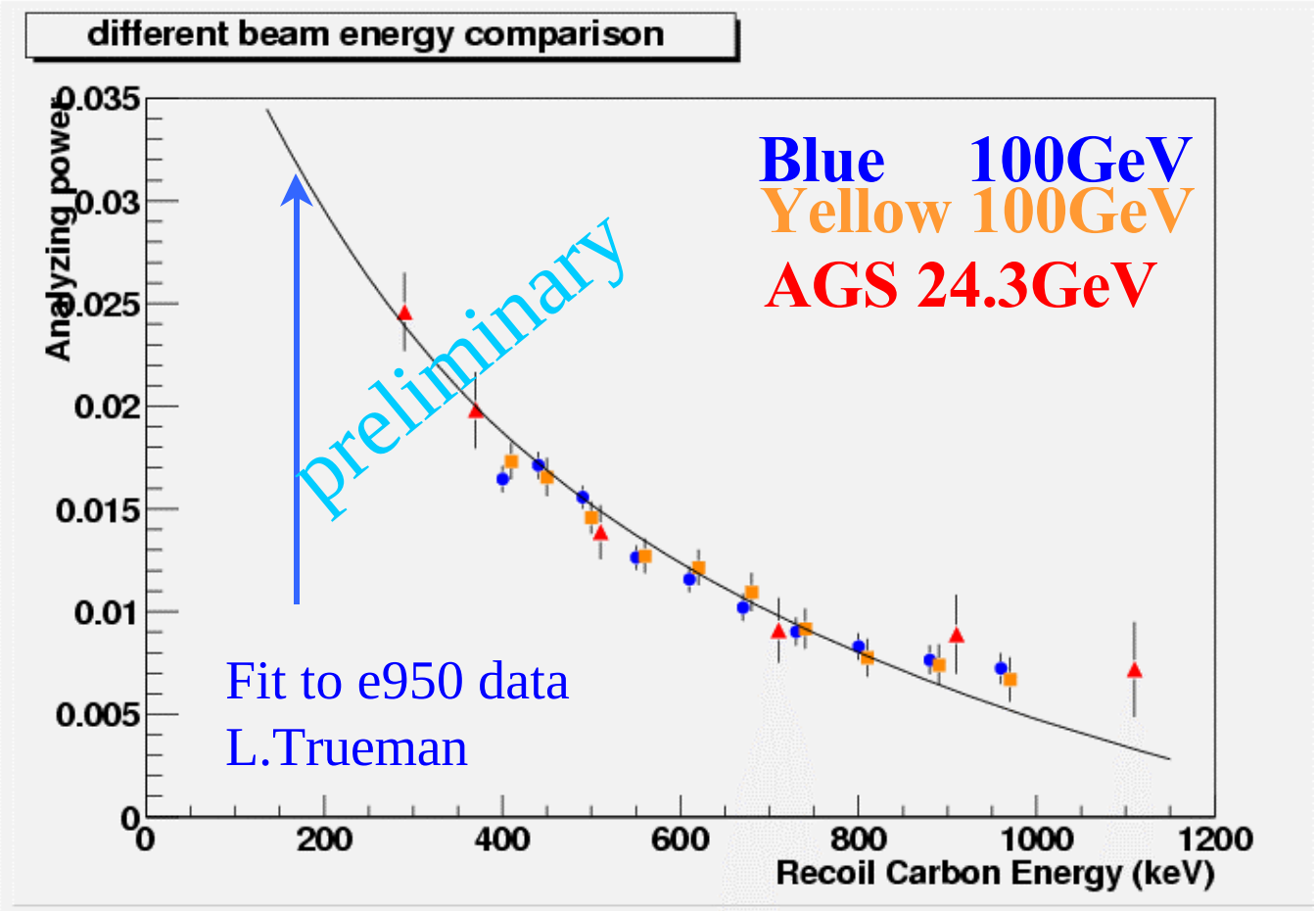
-t Dependence of CNI Analyzing Power

(Run 3 Result)



- Normalization of the data points are assumed
- A_N has a very small dependence on beam energy

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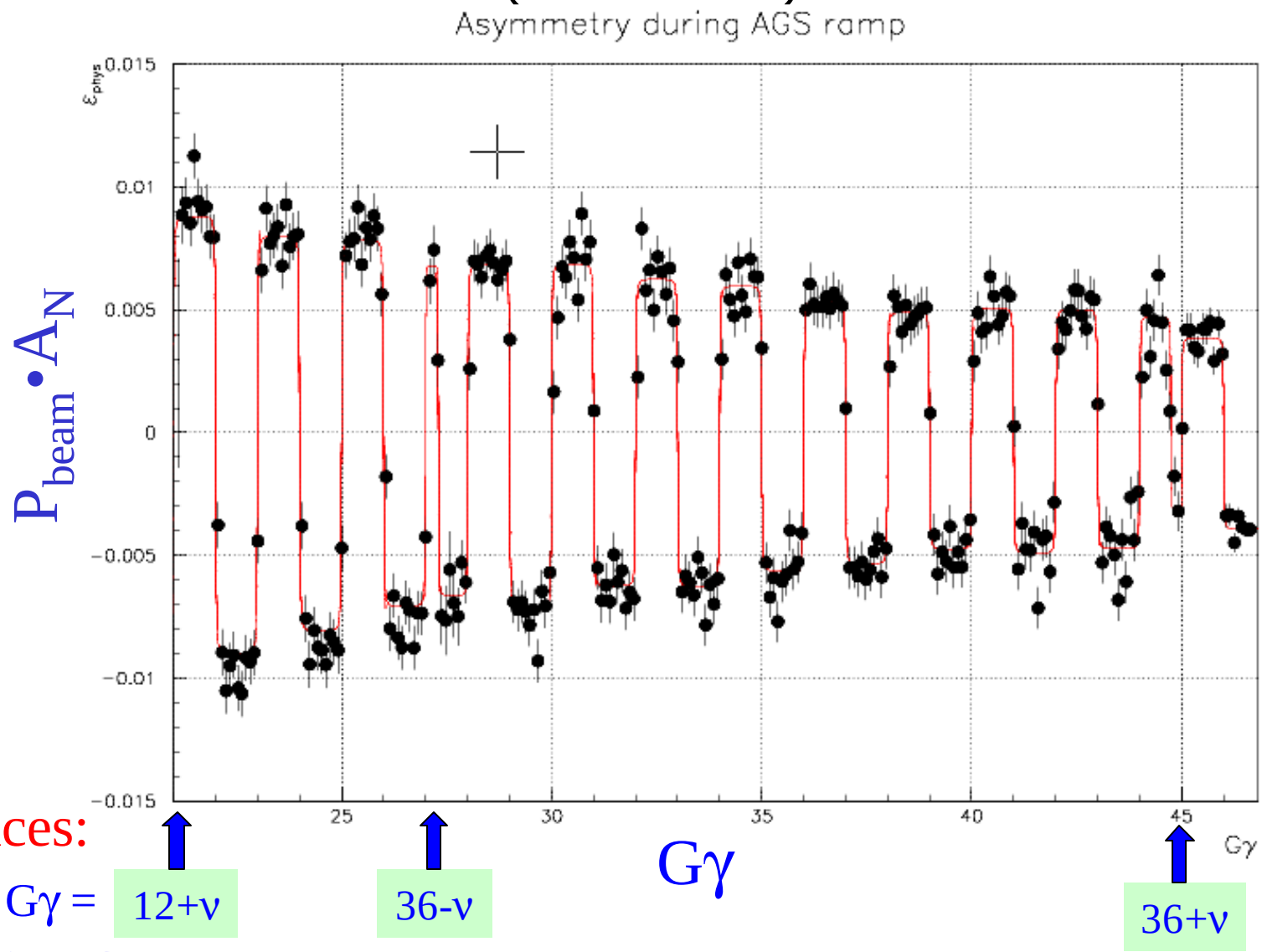
Polarization Measurements Along AGS Ramp

(Run 3 Result)



resonances:

intrinsic: Gγ = 12+ν, 36-ν, 36+ν

imperfection: Gγ = n

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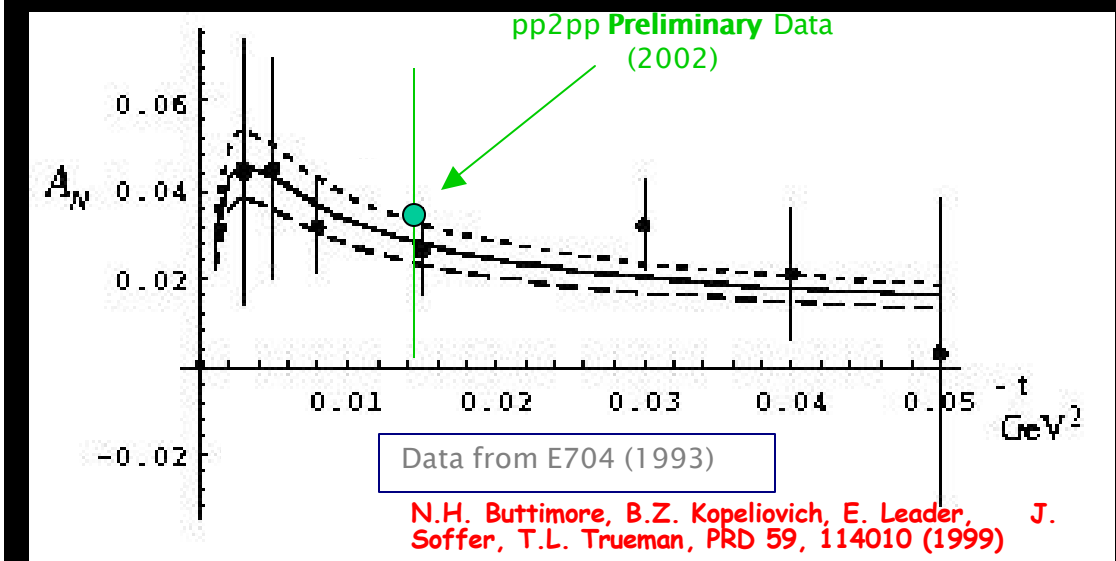
pp2pp

Single spin asymmetry A_N arises in CNI region from interference of hadronic non–flip amplitude with electromagnetic spin–flip amplitude

Measure dependence on |t | and on azimuthal scattering angle f

Deviation of |t |–dependence from calculation with above assumption will give access to hadronic spin–flip contribution to amplitude

Also measure double spin asymmetry A_{NN} to probe possible contribution of Odderon exchange to dominant Pomeron exchange in same |t | region



Review of achievements of runs in 2002 and 2003

	2002	2003
p^+ intensity / beam	$0.5 \cdot 10^{12}$	$1.9 \cdot 10^{12}$
p^+ polarization	0.24	0.37
Beam tune b*	10 m	10 m
Beam momentum	100 GeV	100 GeV
Elastic events	300,000	3 Million

Expected statistical errors (on single data point)

dA_N	0.025	0.005
db	1.60	0.35

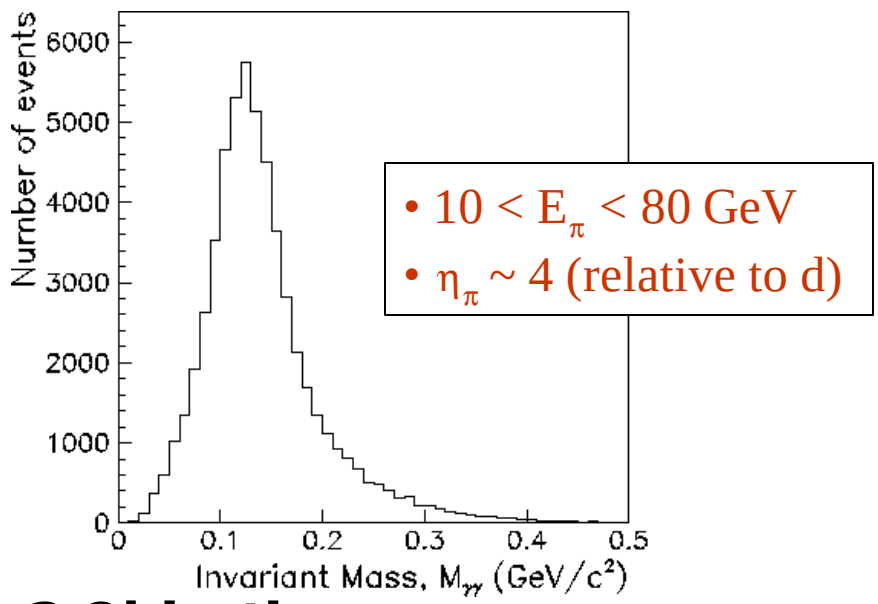
Improvement of systematic error due to

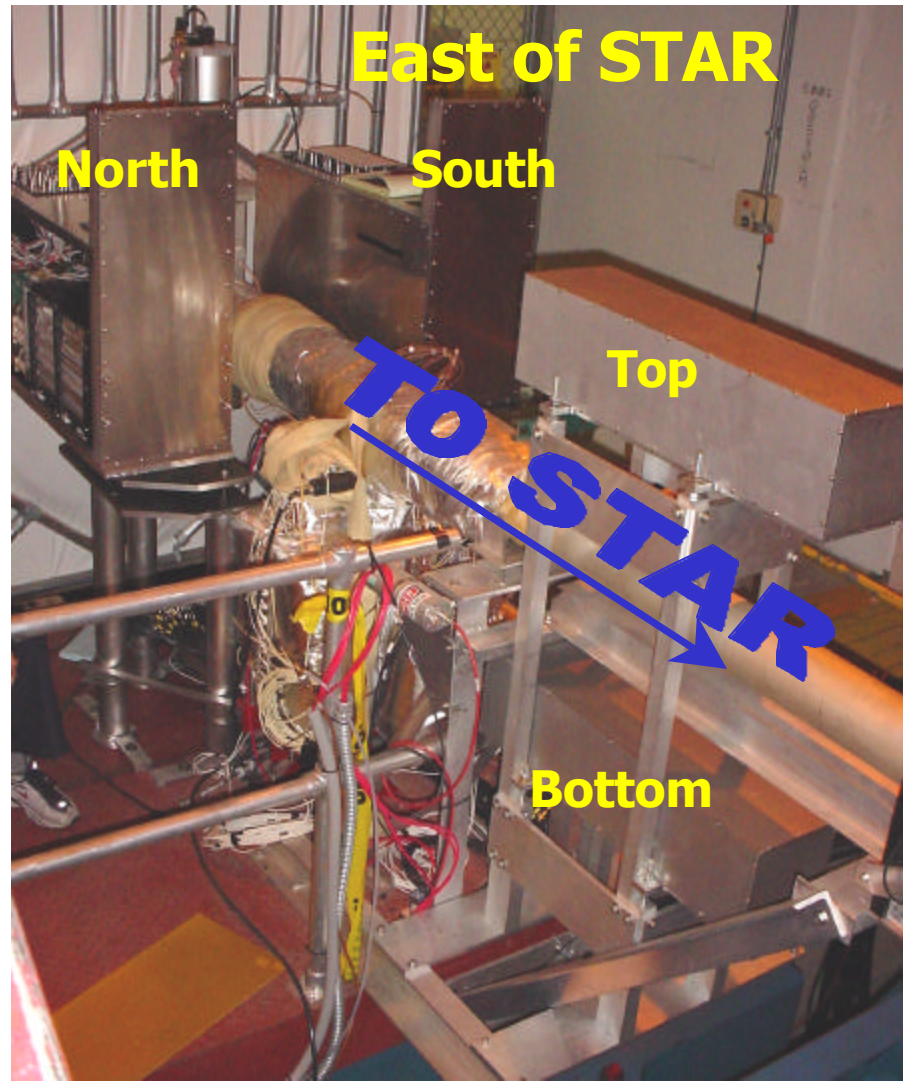
- Measurement of local angle with Roman Pot station set added in 2003
- Beam tune measurement

STAR Forward Pion Detector

(Construction for Run 3)

$d+Au \rightarrow \pi^0+X$, $\sqrt{s_{NN}} = 200$ GeV



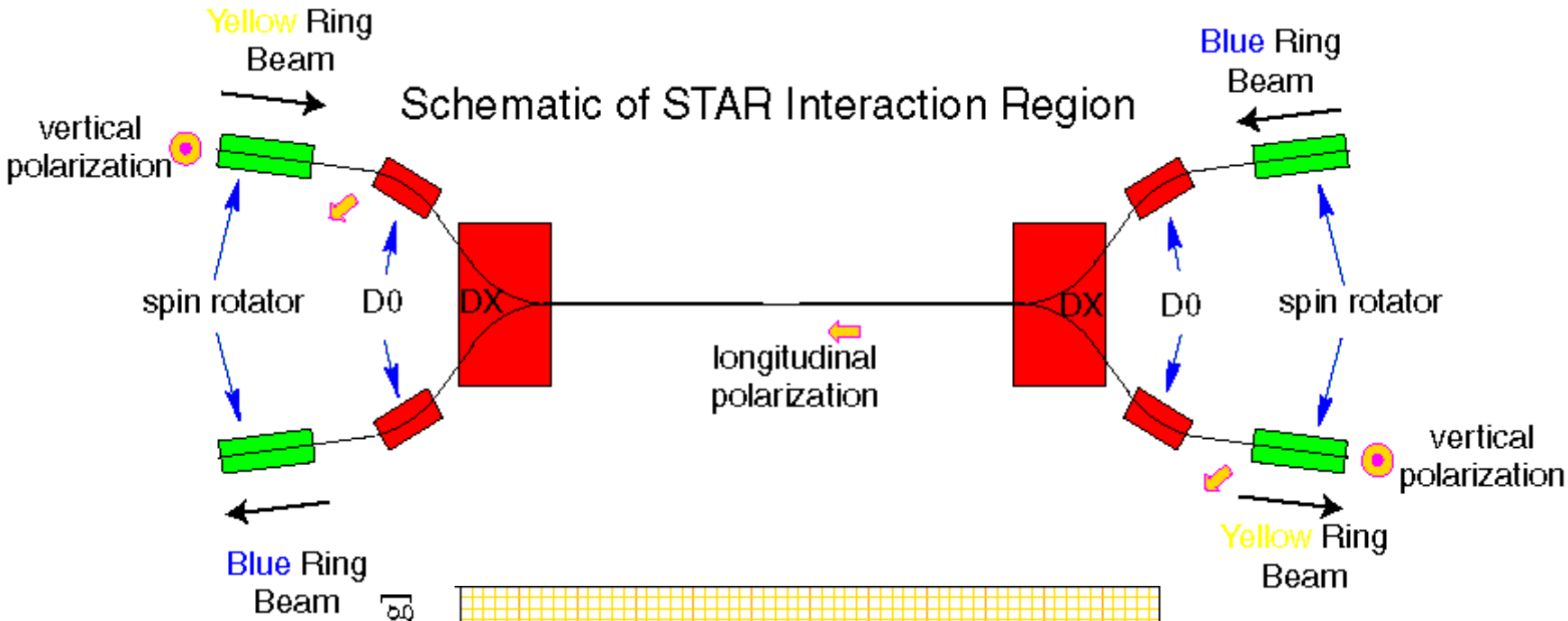


Run 3 Objectives:

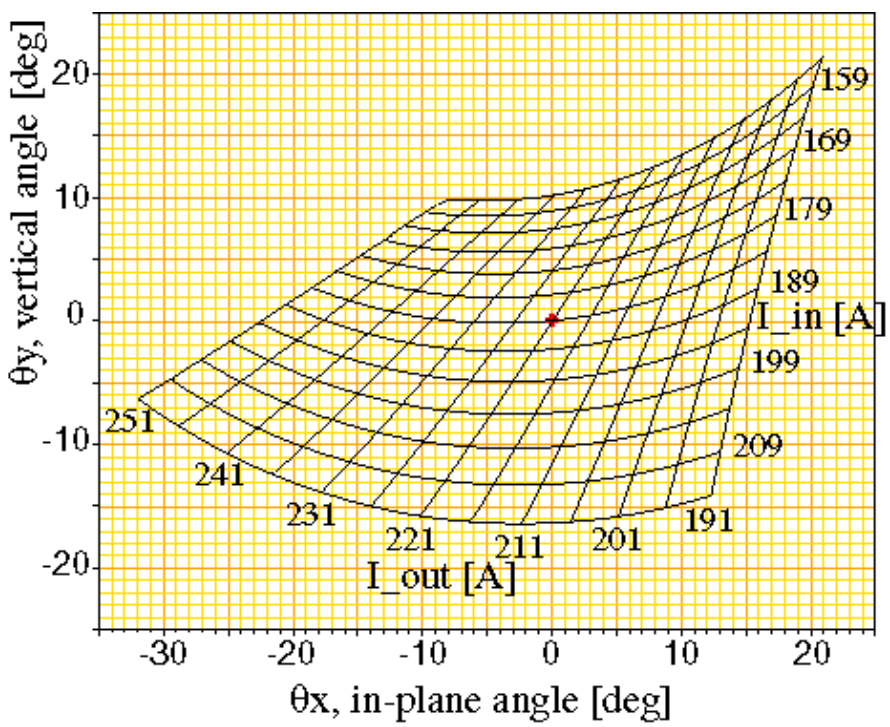
- probe of Color Glass Condensate in d+Au
  - $\Rightarrow p_T$ dependence of large η yield
- improve understanding of dynamical origin of A_N in $p_\uparrow+p \rightarrow \pi^0+X \Rightarrow$
  - ➢ Collins effect $\rightarrow$ sensitivity to transversity
  - ➢ Sivers effect $\rightarrow$ sensitivity to orbital motion
  - ➢ twist-3 effect $\rightarrow$ quark/gluon correlations
- serve as local polarimeter at STAR IR

BNL, Penn State, IHEP-Protvino, UC Berkeley/SSL, UCLA, ANL

Spin Rotators and Local Polarimetry



Calculations establish a working point and the dependence of transverse polarization components on spin rotator currents.



Local polarimeters are needed to measure vertical,radial polarization components at interaction region.

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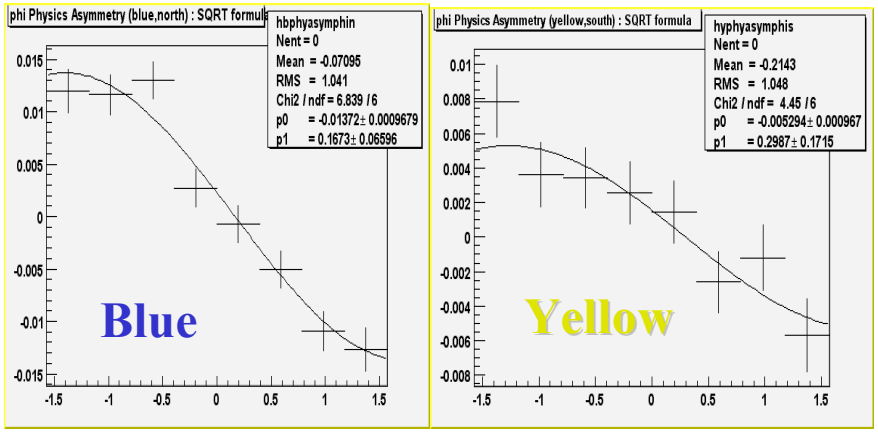
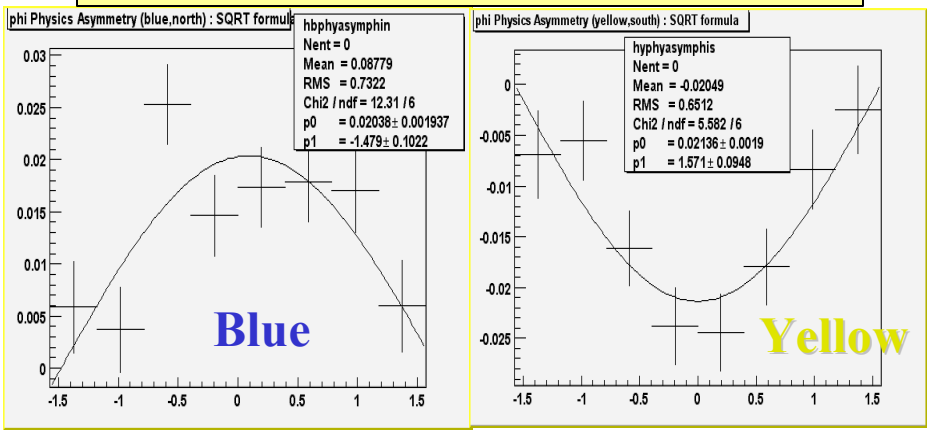
Local Polarimeter at PHENIX

Run-03 Result

Spin Rotators OFF

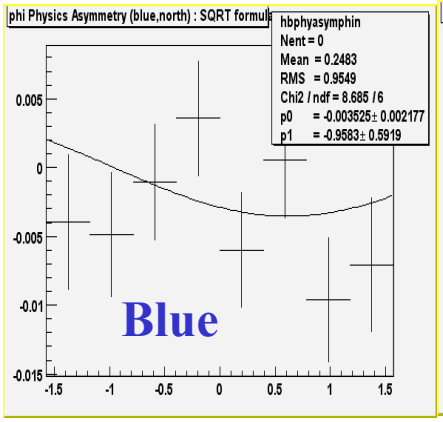


Spin Rotators ON, Current Reversed

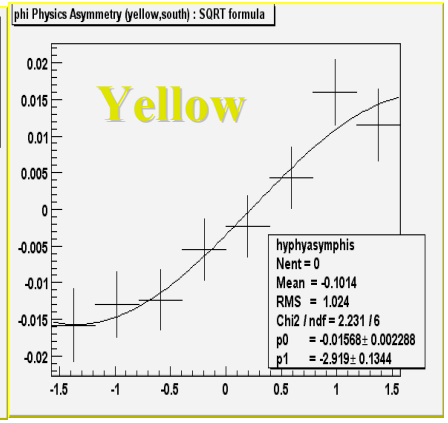


Spin Rotators ON, Almost…

|P|=30%, P_T=0% → P_L=30%)

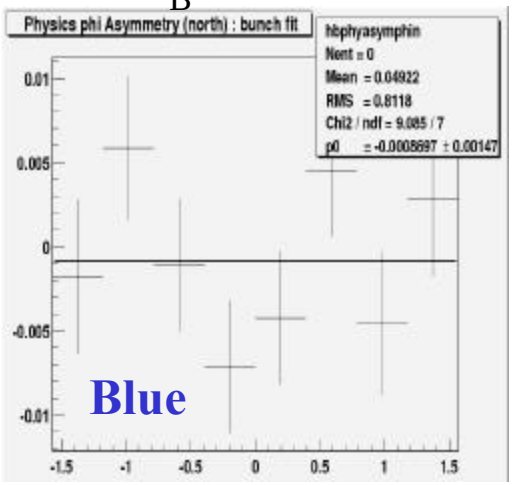


|P|=37%, P_T=24% →P_L=28%)

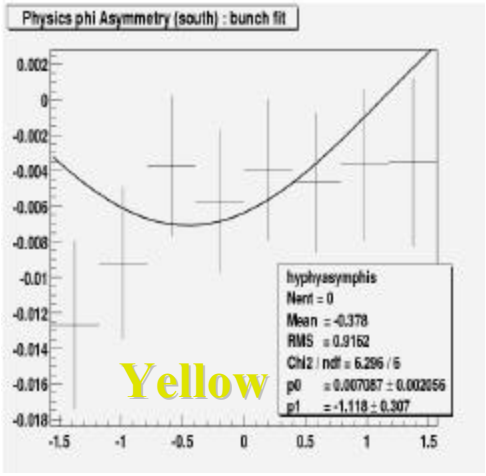


Spin Rotators ON, Correct!

P_B=35.5%

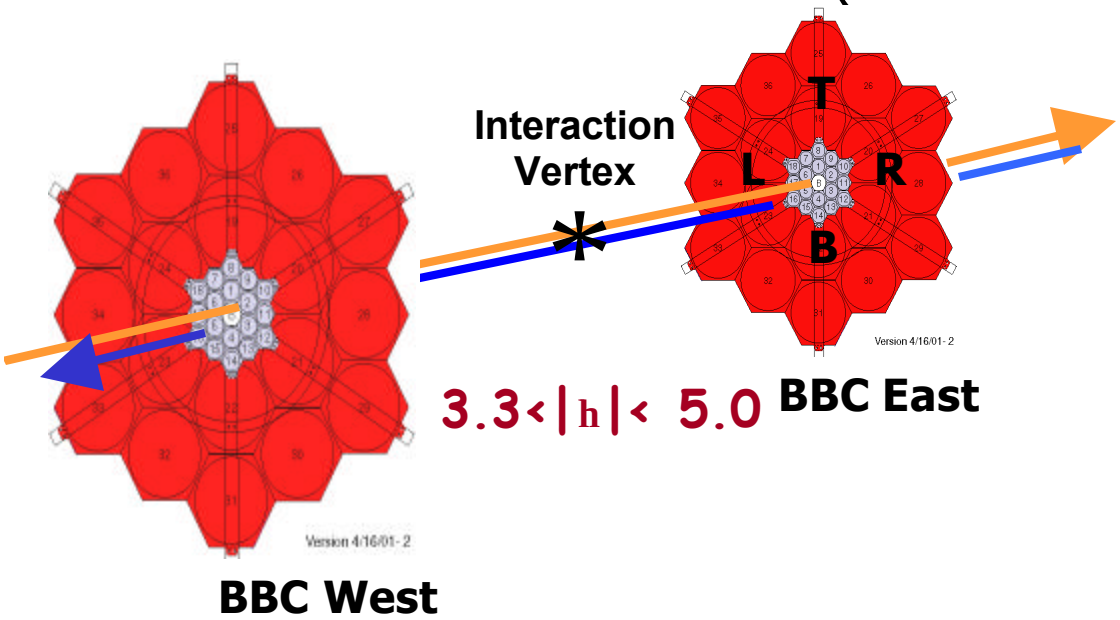


PB=37%



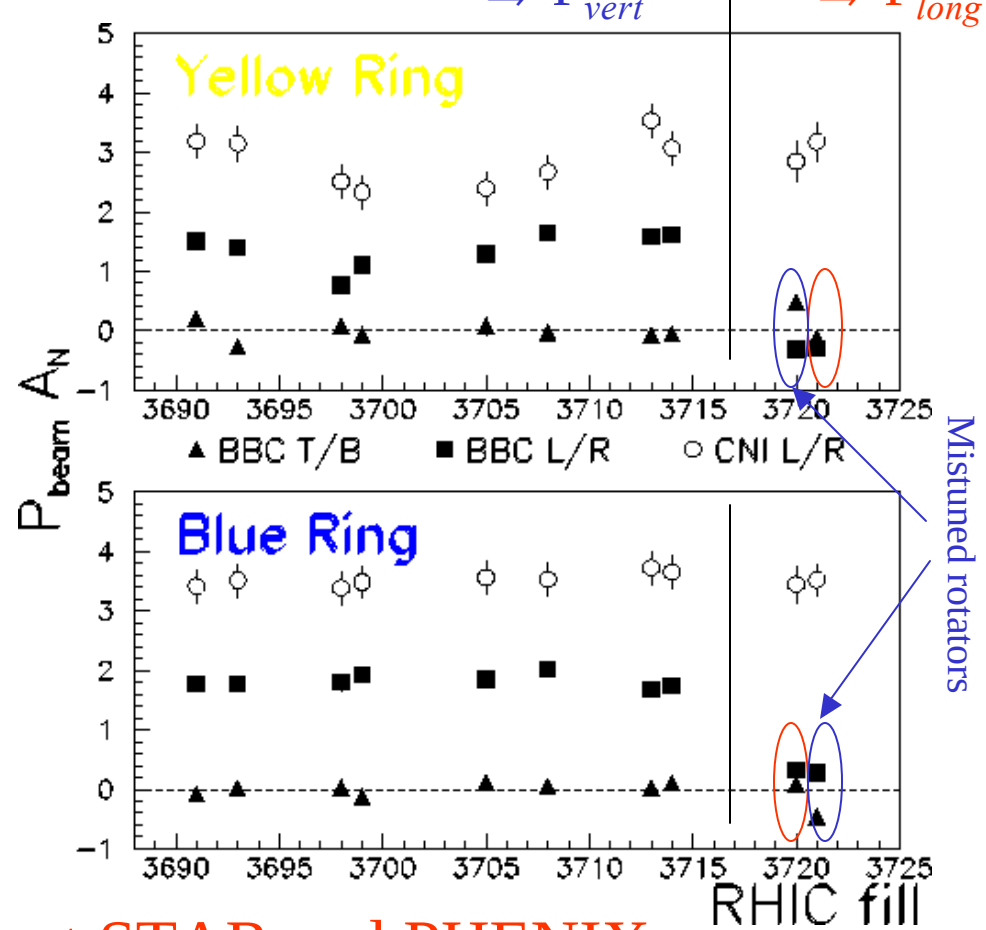
STAR Spin Rotator Magnet Tuning

(Run 3 Result)



- *RHIC polarimeter* (CNI) establishes polarization *magnitude.*
- *Local polarimeter* (BBC) establishes polarization *direction* at STAR.

STAR spin rotator: OFF ⇒ P_{vert} ← | → ON ⇒ P_{long}



- use segmentation of inner tiles of BBC as a *Local Polarimeter* monitoring *pp* collisions.
- Rotators OFF ⇒ BBC L/R spin asymmetries comparable to RHIC polarimeter (CNI).
- Rotators ON ⇒ adjust rotator currents to minimize BBC L/R and T/B spin asymmetries.

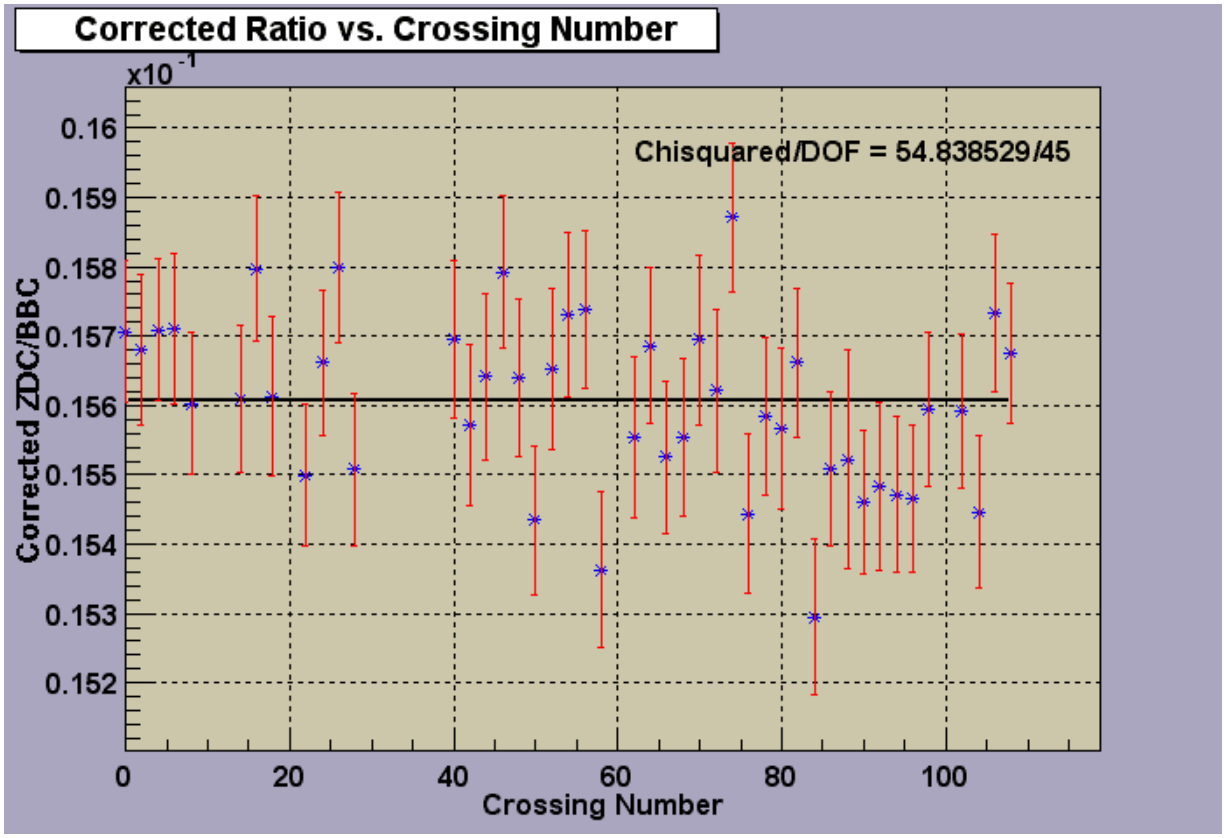
⇒ Longitudinal Polarization at STAR and PHENIX

Limit on Relative Luminosity Measurement
(Run 3 Result)

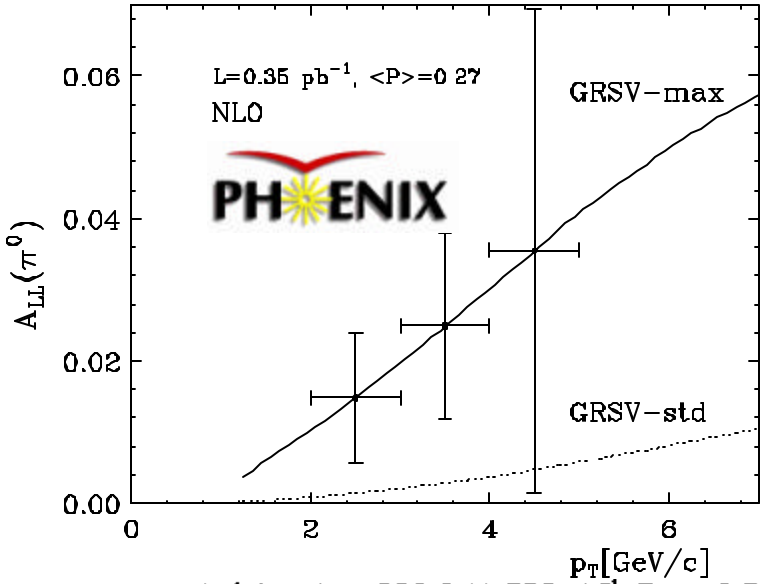
- After correction for (measured) vertex width, the ratio of counts in the ZDC and BBC is consistent with a constant up to our level of statistics
- This means that if we apply correction for vertex width the precision on R goes from:

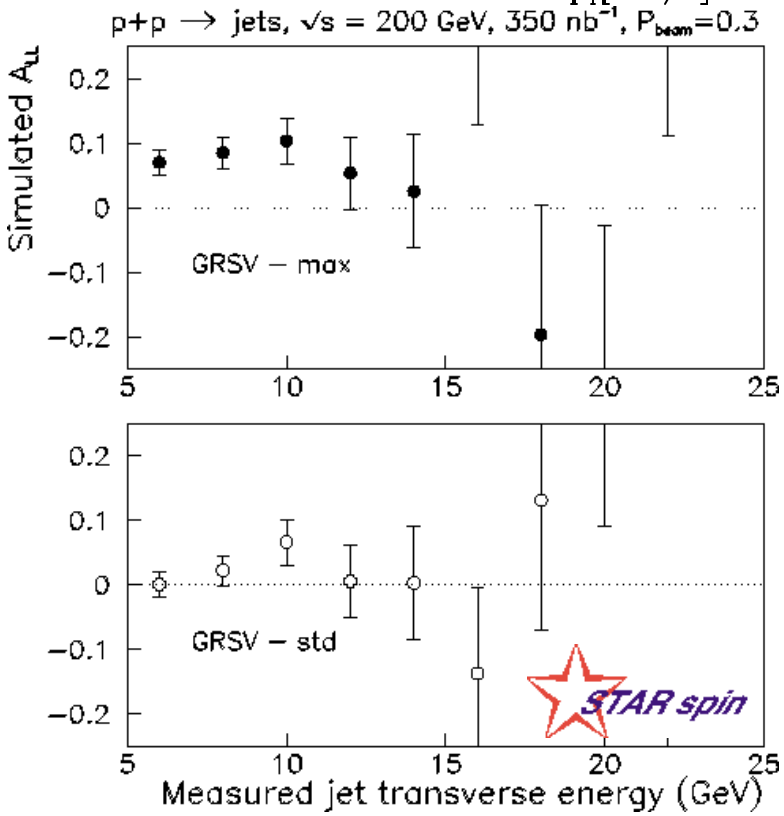
  0.11% → 0.06%

(syst. limited) (stat. limited)



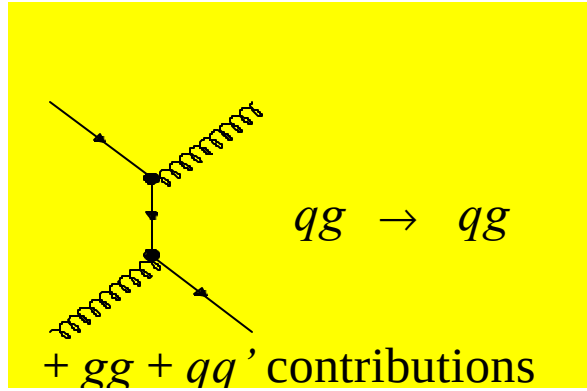
Projections for Sensitivity to ΔG from Run 3

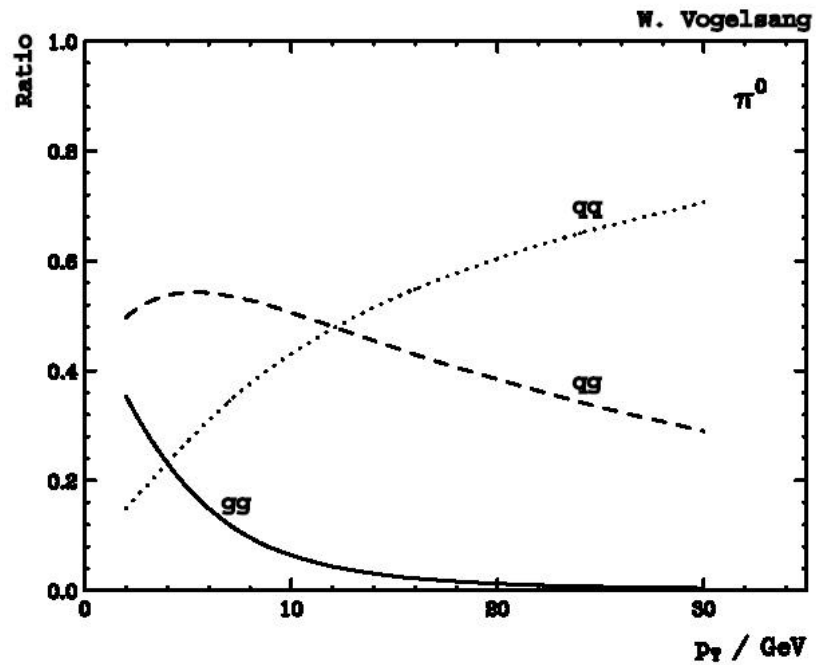




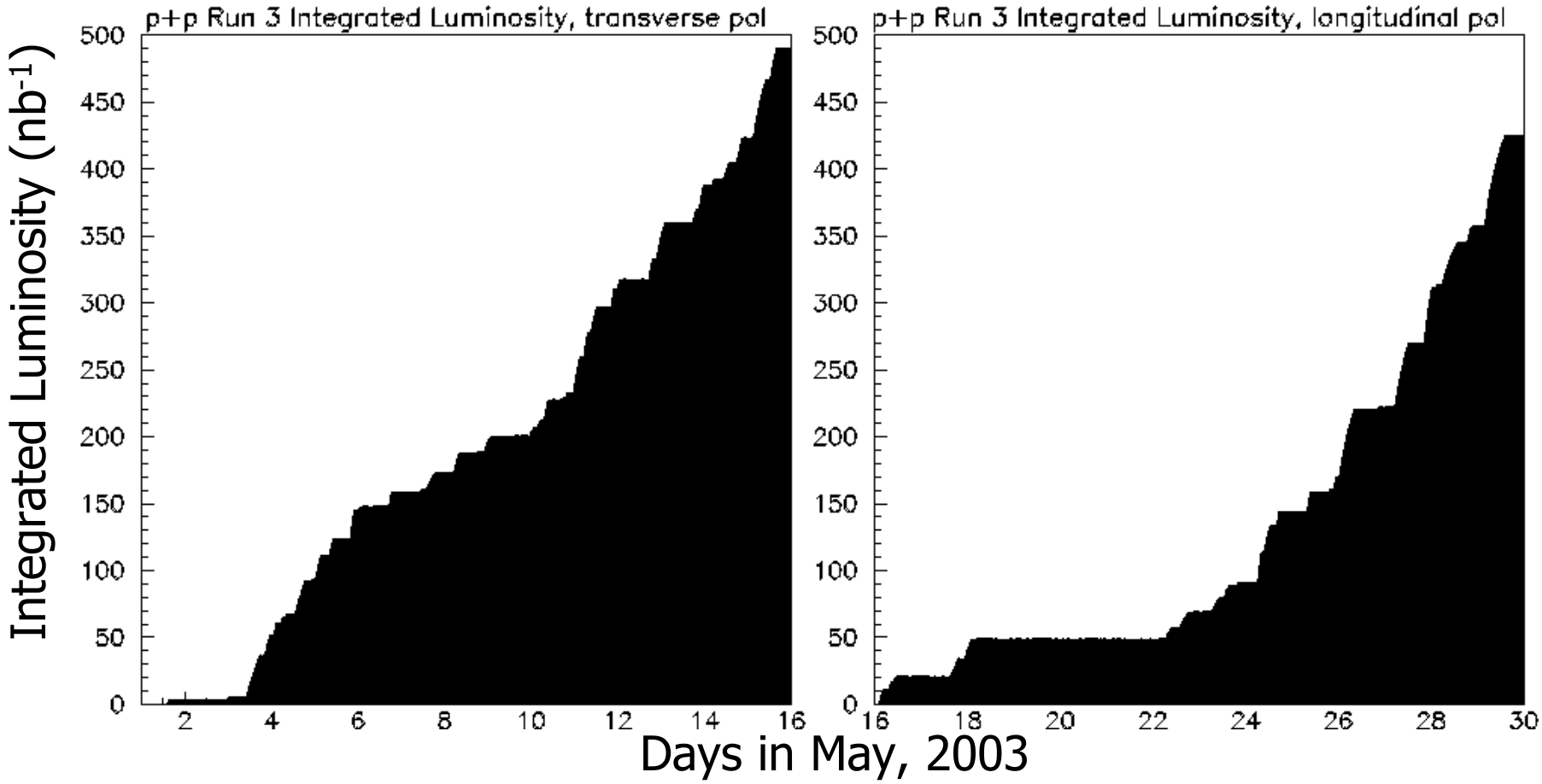
Longitudinal spin asymmetry (A_{LL}) for mid-rapidity jet production

$\Rightarrow$ first measurements sensitive to gluon polarization





p+p Integrated Luminosity for Run 3 Delivered to STAR IR



Integrated luminosity from STAR BBC, selected on signal:background > 3

Delivered luminosity limited by ‘beam-beam tune shifts’ but should be adequate to accomplish physics goals from Run 3.

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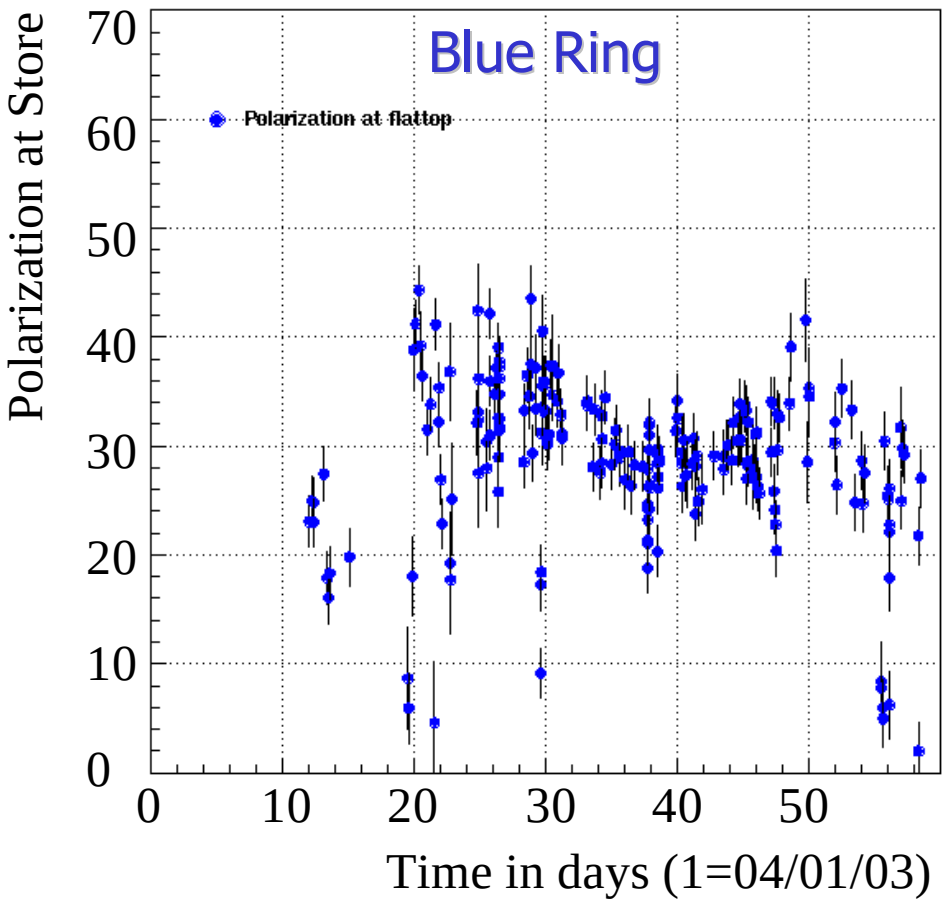
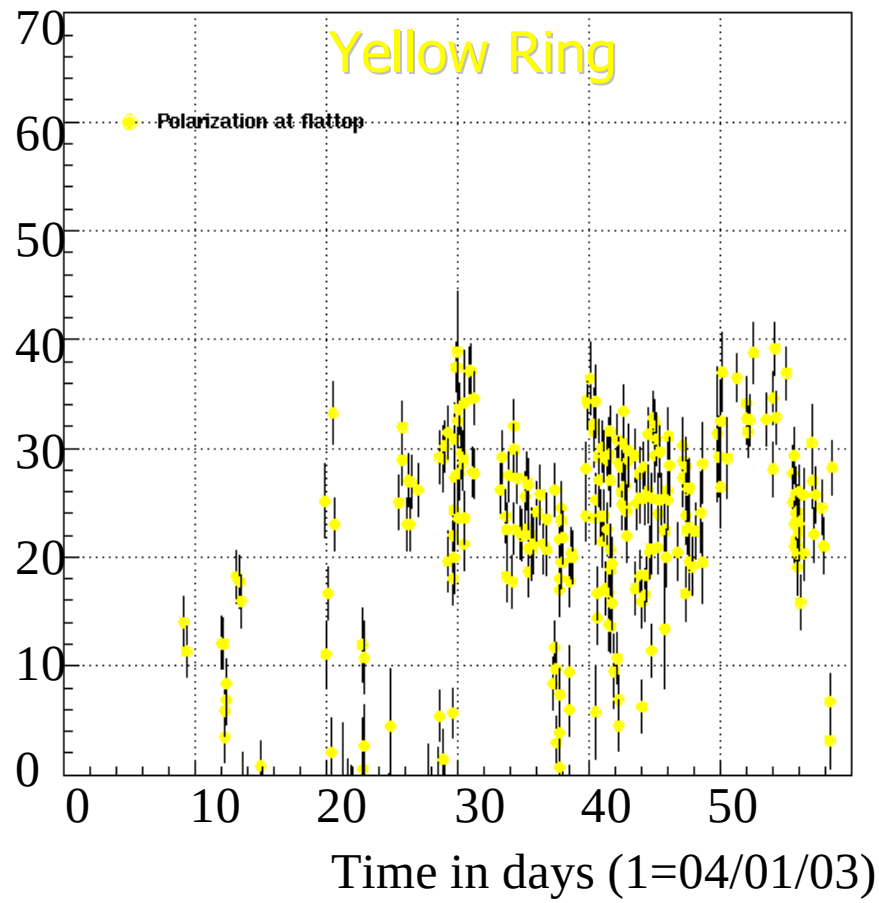
RHIC Polarization at store for Run 3





- RHIC polarization improved by factor of ~2 compared to run 2
- Yellow ring affected by problem with snake magnet

(failure of inner helical windings of Yellow ring magnet).

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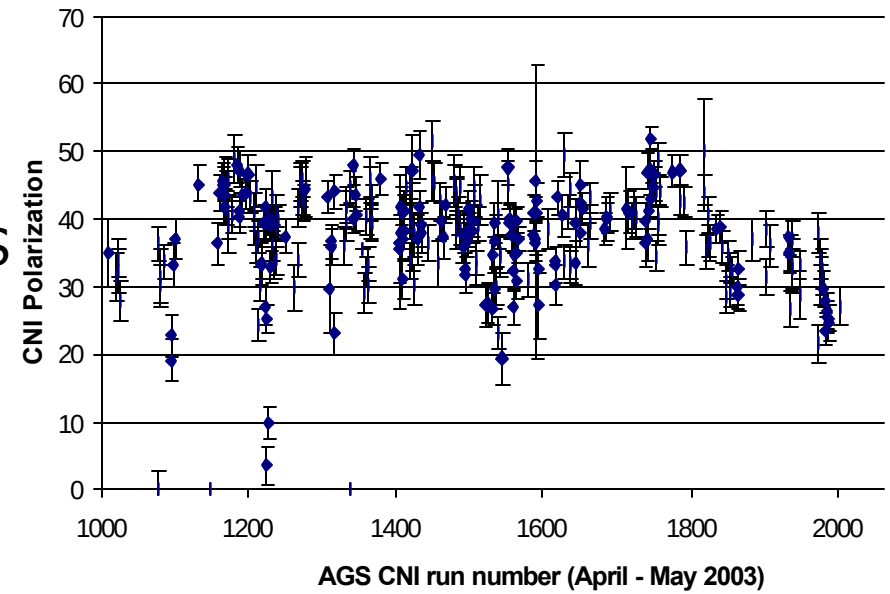
Run 3 Polarized pp Summary

Accomplishments…

- x2 improvement in polarization from AGS relative to run 2.
- commissioning of fast CNI polarimeter for AGS and first measurements along energy ramp.
- transverse single spin measurements:
  - STAR Forward π^0 Detector: $p_\uparrow + p \rightarrow \pi^0 + X$
  - pp2pp: $p_\uparrow p$ elastics at small $|t|$
- successful commissioning of spin rotator magnets and local polarimeters

⇒ longitudinal polarization at PHENIX and STAR

- determine that spin-dependent relative luminosity is not limiting systematic error for A_{LL}
- first measurements of A_{LL} for mid-rapidity hadron,jet production at STAR and PHENIX



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Issues for Polarized pp Running

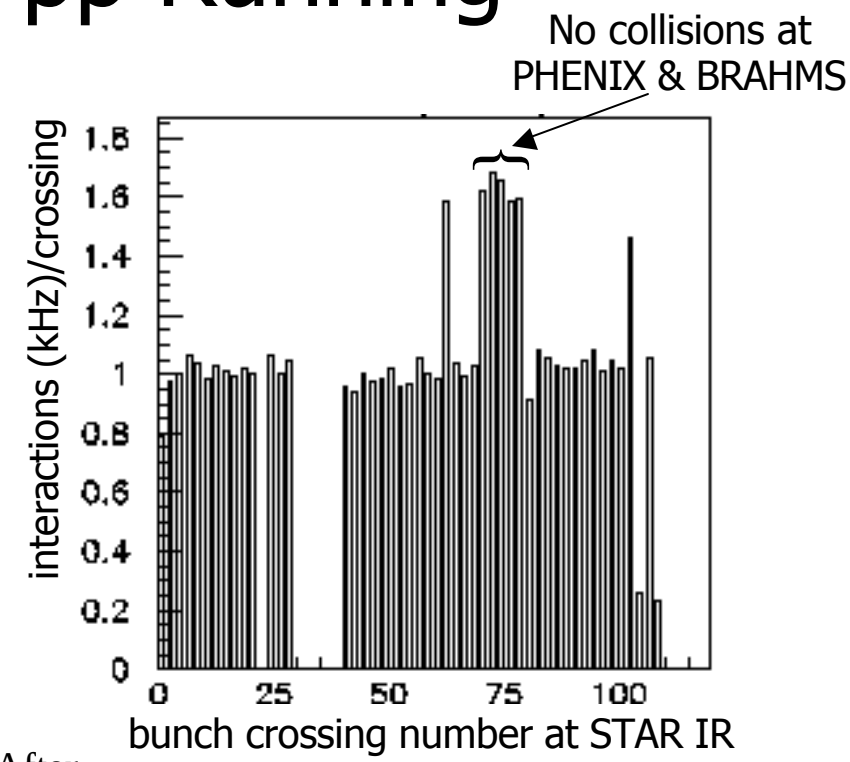
1) Peak and average luminosity smaller than required (20 $\mu b^{-1}s^{-1} \Rightarrow$ ~50 pb^{-1}/week at $\sqrt{s}$=500 GeV) for measuring spin asymmetries for γ,$W^{\pm}$ production.

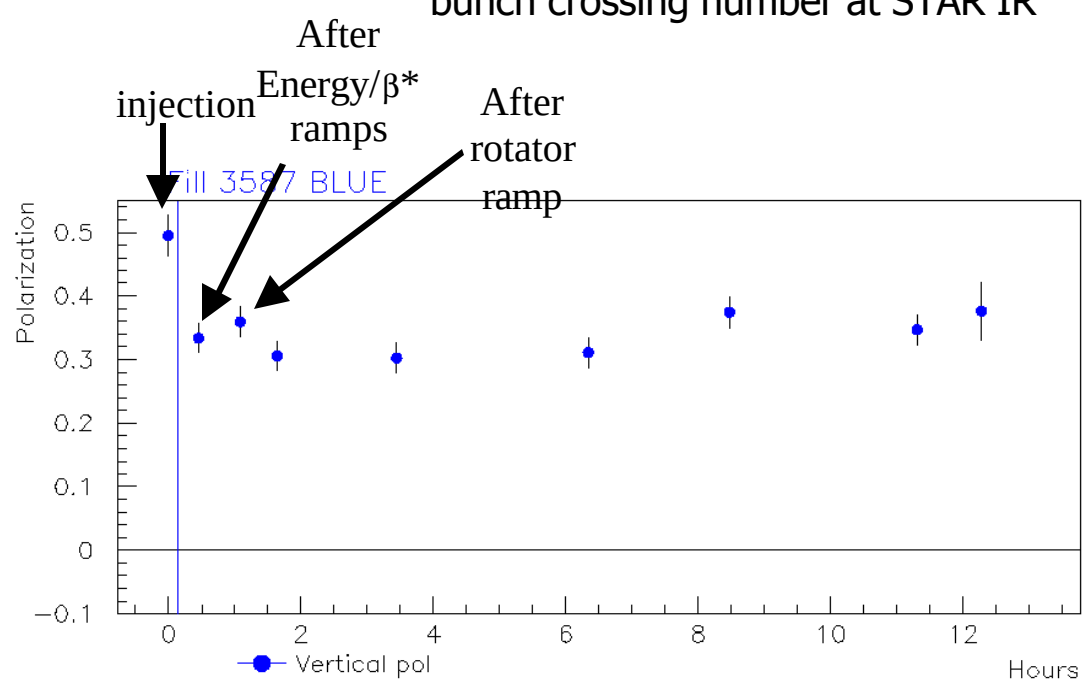
2) Evidence that bunches with fewer interactions produce larger luminosity $\rightarrow$ onset of beam-beam tune shift/spread effects.

3) Evidence of polarization loss in RHIC.

4) β*=1m optics produces significant background at interaction regions.

5) Adequate time for commissioning/luminosity development in upcoming runs.





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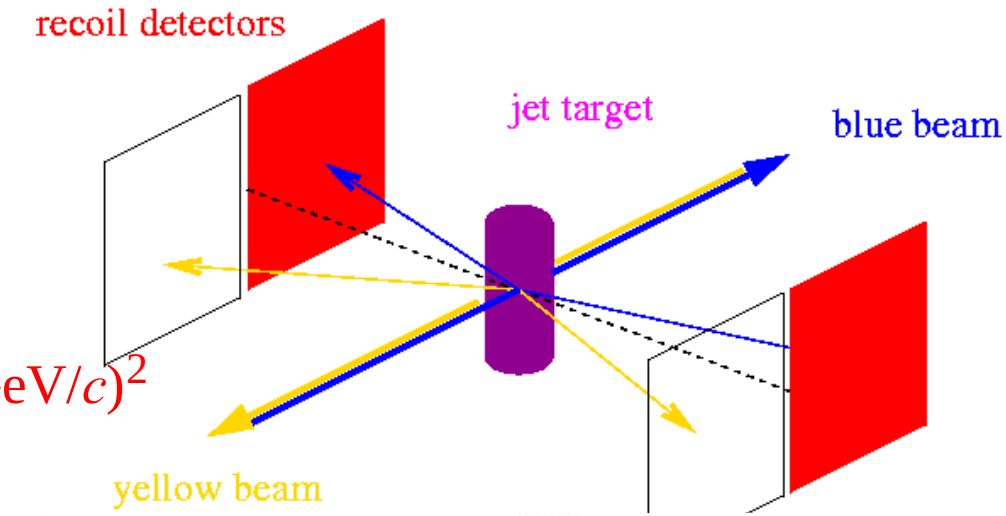
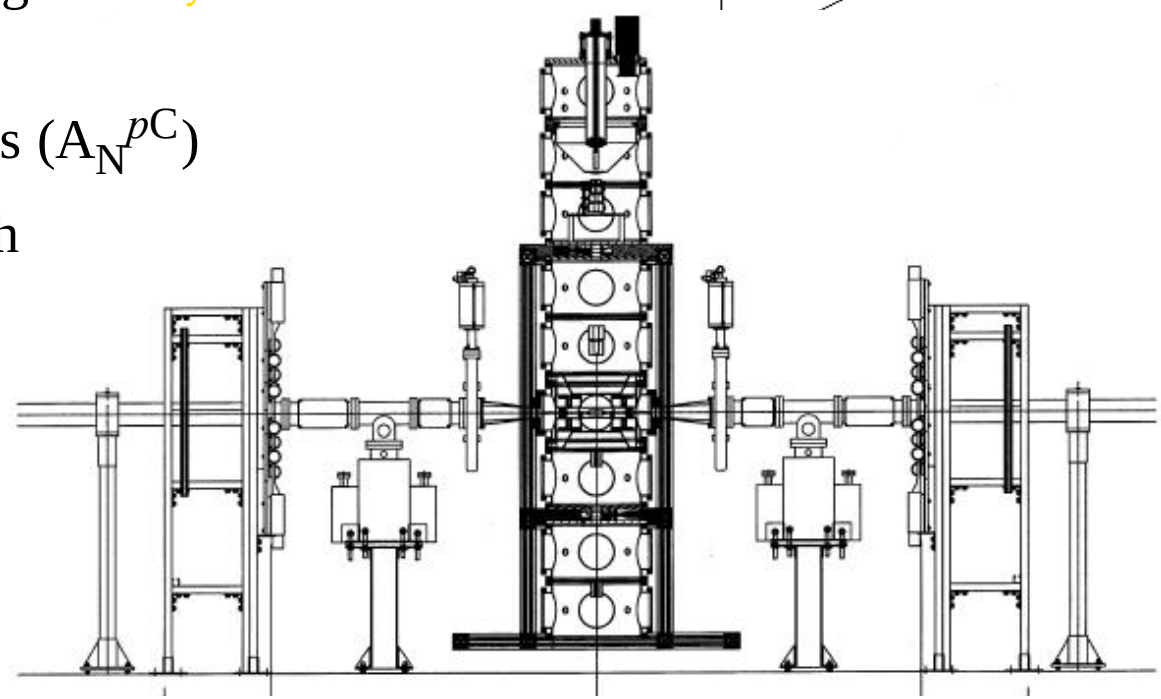
$p\uparrow p$, $p\uparrow p\uparrow$ and $p\uparrow p\uparrow$ with a Polarized Gas Jet Target

- Polarized Hydrogen Gas Jet Target
  thickness of 5×10^{11} p/cm^2
  polarization > 90%
- Silicon recoil detectors
- Rate: 125 Hz for $0.001 < |t| < 0.02$ (GeV/c)^2
- Measure A_N^{pp} in pp elastic scattering in the CNI region to a 3% accuracy
- Transfer A_N^{pp} to the pC polarimeters (A_N^{pC})
- Expected accuracy on P_B of 6% with "calibrated" pC CNI polarimeters
- Install for the '04 run
- Initially measure P_{beam} to 10%





The Polarized Jet Target

Electronics racks

Vac. gauges monitors

Turbo pump controllers

Dissociator RF systems

Dissociator stage

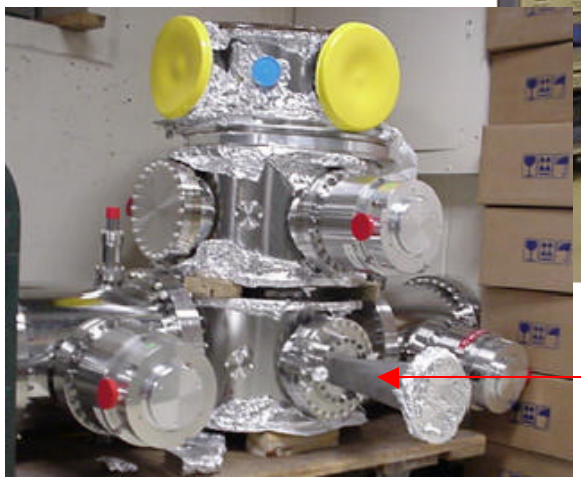
Baffle location

Sextupoles 1-4

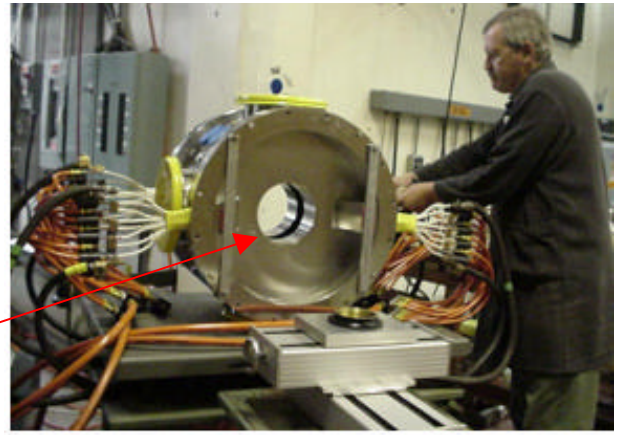
Sextupoles 5-6

Profile measurement

BRP vacuum vessel

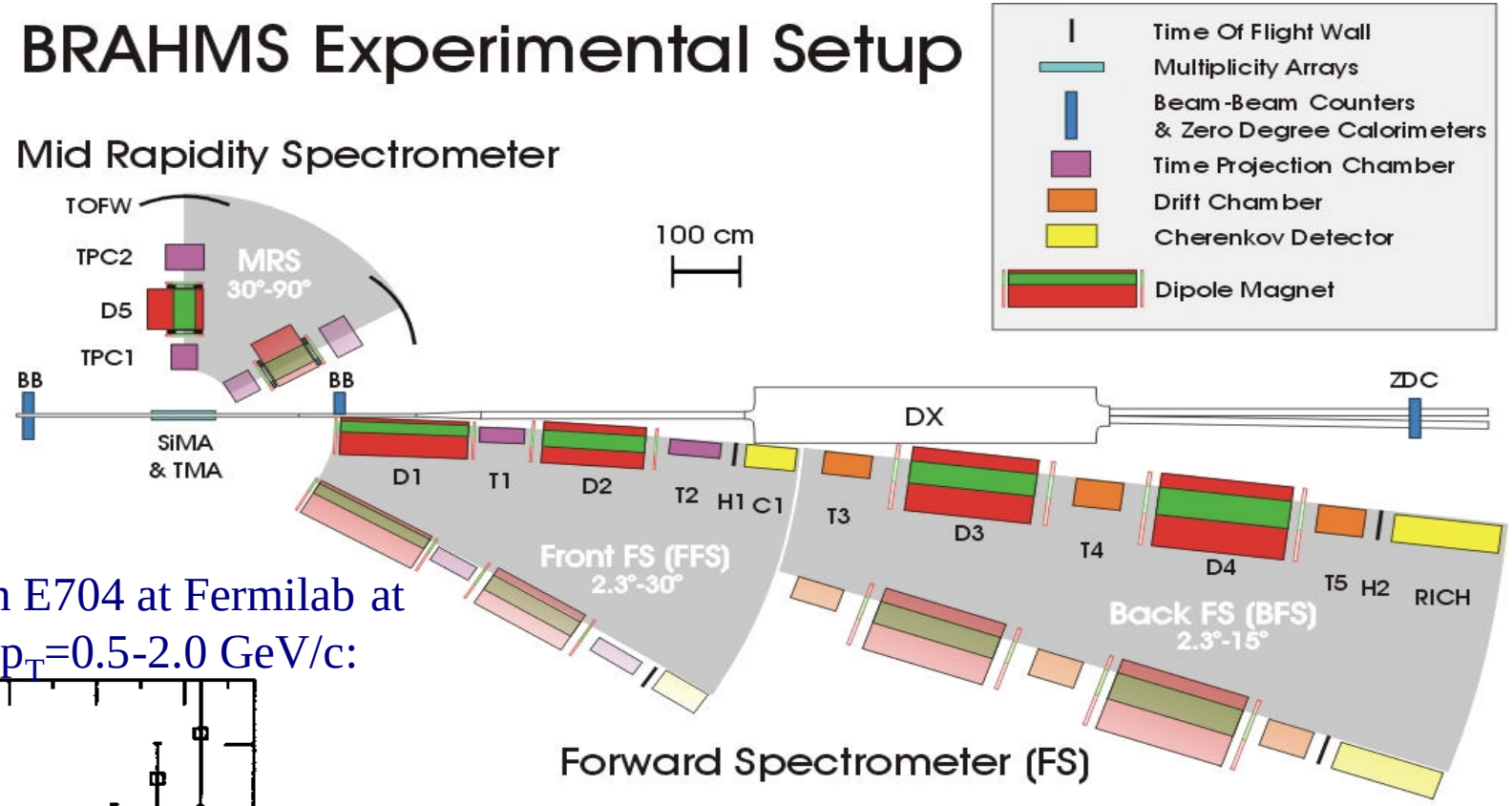


Target chamber &
beam pipe adapters

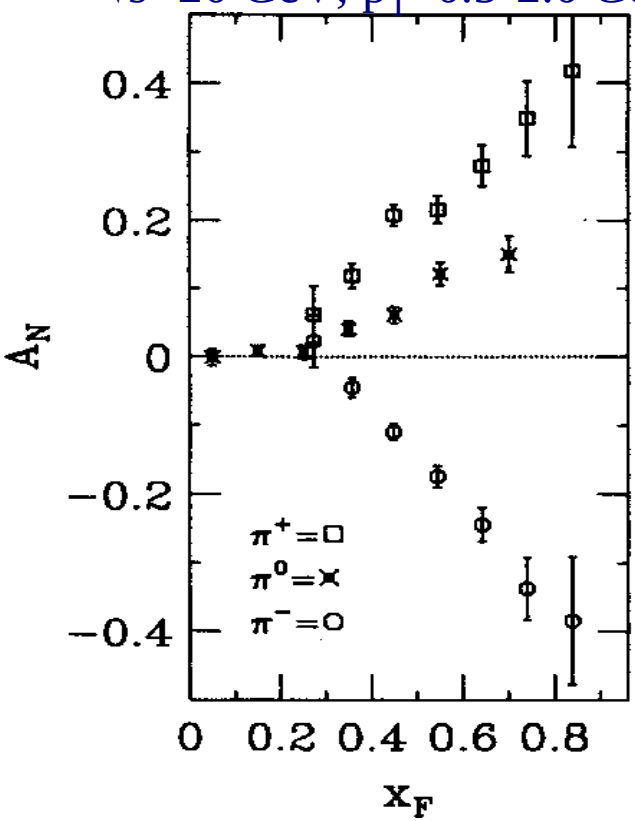


Magnet ready
for measurements

BRAHMS Experimental Setup



A_N measured in E704 at Fermilab at $\sqrt{s}$=20 GeV, p_T=0.5-2.0 GeV/c:



BRAHMS proposal:

measure A_N for $p_{\uparrow}p \rightarrow \pi^{\pm} + X$ at $\sqrt{s}$=200 GeV, η_{π}~3.9

π^+ measurements			*π^- measurements*		
x_F	p_T(GeV/c)	Cts/hour	x_F	p_T(GeV/c)	Cts/hour
0.21	1.0	6454	0.21	1.0	5296
0.25	1.4	1068	0.25	1.4	807
0.30	1.9	163	0.30	1.9	91
0.35	2.5	24	0.35	2.5	12

Rate estimates
Assume
$\mathcal{L} \sim 1.5\ \mu b^{-1}s^{-1}$

Scenario for Evolution of RHIC Spin Program

RHIC Run	$\sqrt{s}$ (GeV)	$\langle\mathcal{L}_{peak}\rangle$ ($\mu b^{-1}s^{-1}$)	$\langle P_{beam}\rangle$	$\int\mathcal{L}\,dt$ (pb^{-1})	Commission
2	200	0.5	0.15 (vertical)	0.35	Snakes/polarimeters/experiments
3	200	2	0.25 (vert.+long.)	1	Rotators/AGS+local polarimeters
4+5	200	10	>0.30 (long.)	5	Pol. Jet target/spin flipper/P_{beam}/$\mathcal{L}$
>5	200	80	0.70 (long.)	320	Production
	500	200	0.70 (long.)	800	Production

Where we are in the program…

- ✓ Siberian Snakes – demonstrated to work
- P_{beam} at RHIC injection energy – now 0.4 / goal is 0.7
- ✓ Fast polarimeters in AGS and RHIC – demonstrated to work
- ✓ P_{beam} transfer AGS→RHIC – demonstrated to work
- ✓ P_{beam} preserved in RHIC ramp to 100 GeV– demonstrated to work
- P_{beam} preserved in RHIC ramp to 250 GeV – to do
- ✓ P_{beam} maintained during RHIC store – 14 hours observed
- ✓ longitudal P_{beam} at PHENIX,STAR / local polarimetry – demonstrated to work
- $\Delta P_{beam} / P_{beam}$ to ±5% – commission gas jet in 2004; ±10% in 2004; ±5% in 2005
- $\mathcal{L}_{avg\ week}$ to 20(50) pb^{-1} at $\sqrt{s}$=200(500) GeV – now ~0.3 pb^{-1} at $\sqrt{s}$=200 GeV
- Polarization reversal of stored beam – to do