Spin Physics at RHIC

Summary of Workshop R1b:
Spin Physics at RHIC: First Results and Status of the First Polarized Proton Collider

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12 May 2004

RHIC/AGS Users Meeting

Workshop agenda:

Organizers: S. Kretzer, A. Ogawa, M. Perdekamp, G. Rakness, W. Vogelsang

- RHIC as a polarized proton accelerator
  - M. Bai (BNL) → for summary see W. Fischer plenary talk
- Polarimetry at RHIC
  - A. Bravar (BNL) → for summary see W. Fischer plenary talk
- Inclusive observables
  - W. Vogelsang (RBRC/BNL)
- Novel Transversity Properties in Hard Scattering
  - L. Gamberg (Penn State/Berks-LeHigh Valley)
- PHENIX results
  - A. Deshpande (SUNY-Stonybrook/RBRC)
- STAR results
  - J. Kiryluk (MIT)
- pp2pp results
  - W. Guryn (BNL)

What carries the proton spin ?

- spin sum rule :

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

~ 0.1

where

* $\Delta G(Q^2) = \int_0^1 dx\, \Delta g(x, Q^2)$

$\Delta g(x) =$

* $L_{q,g}$ quark, gluon orbital angular momenta

W. Vogelsang (RBRC/BNL)

Data

- 2001-2 (Run 2)
  - ***Transversely*** polarized p+p collisions (NO Spin Rotators Magnets)
  - Average polarization of ~15%
  - Integrated luminosity 0.15 pb-1
- 2002-3 (Run 3)
  - ***Longitudinally*** polarized p+p collisions achieved
  - Average polarization of ~27%
  - Integrated luminosity 0.35 pb-1
- 2003-4 (Run 4)
  - 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!**

A. Deshpande (SUNY-Stonybrook/RBRC)

Spin Asymmetry Measurements

Single Transverse

$$A_N = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow} = \frac{1}{P} \times \frac{N_\uparrow - R_1 N_\downarrow}{N_\uparrow + R_1 N_\downarrow}$$

Double Longitudinal

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_1 P_2} \times \frac{N_{++} - R_2 N_{+-}}{N_{++} + R_2 N_{+-}}$$

Statistical significance: $P^{2(4)} \cdot \int \mathrm{L}\, dt$

Require concurrent measurements:

- magnitude of beam polarization, $P_{1(2)}$ RHIC polarimeter
- direction of polarization vector at interaction point
- relative luminosity of bunch crossings with different spin directions:

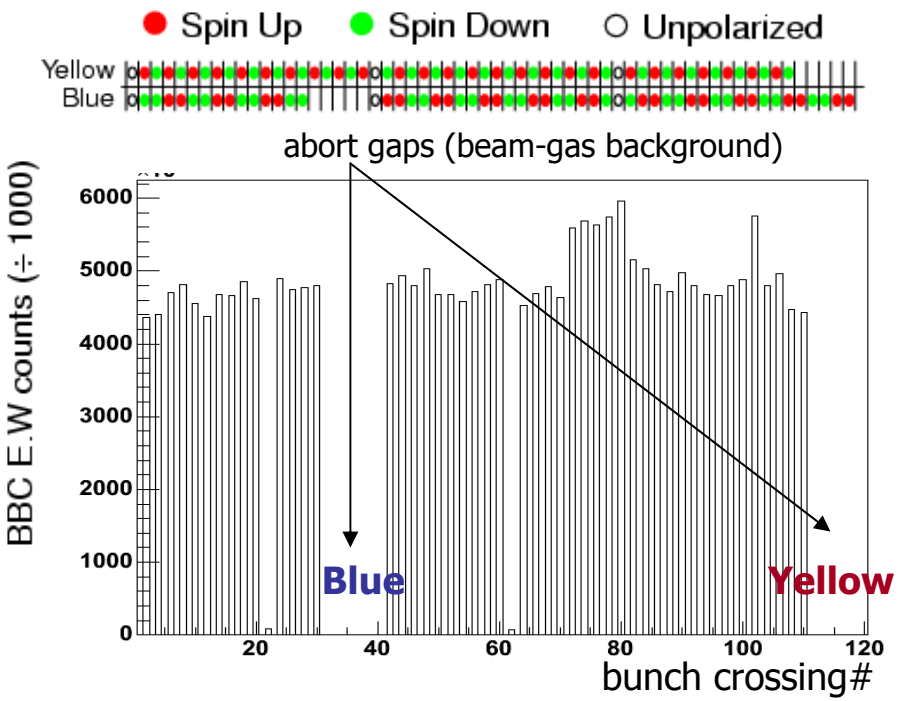
$$R_1 = \frac{L_\uparrow}{L_\downarrow} \quad \text{and} \quad R_2 = \frac{L_{++}}{L_{+-}}$$

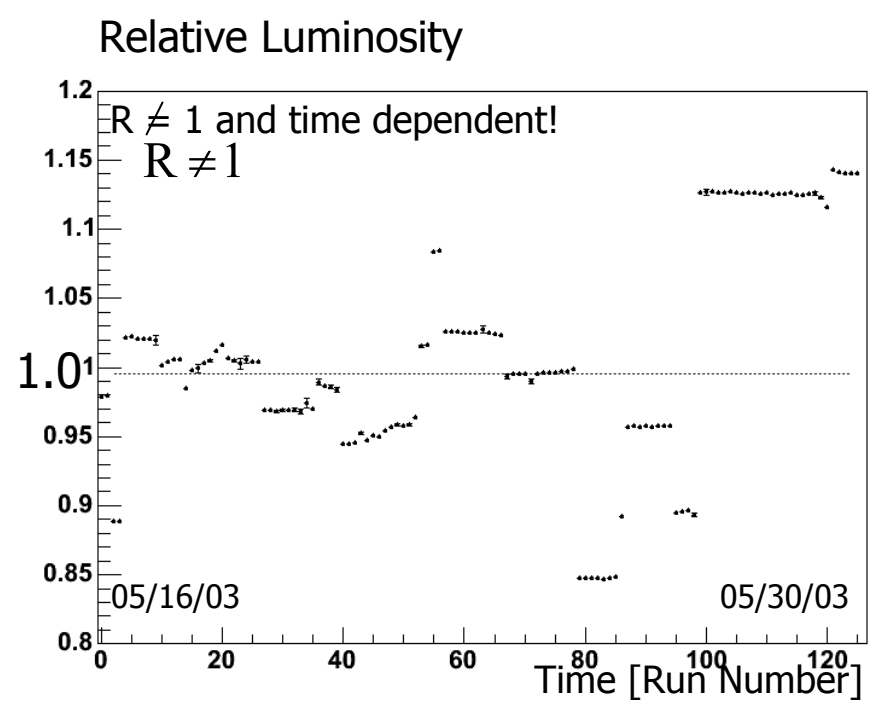
- spin dependent yields of process of interest: N_i and N_{ij}

J. Kiryluk (MIT)

Relative Luminosity Measurement (STAR BBC)

- Precision of relative luminosity monitoring critical: for A_{LL} ~1% $\delta A_{LL}/A_{LL}$ ~5% if $\delta R/R \sim 10^{-3}$
- RHIC stores up to 120 bunches per ring - different bunches injected with different spin orientations
  - collision luminosity can vary with spin combination
- Luminosity ~ BBC coincidence rate (large cross section of ~27mb)



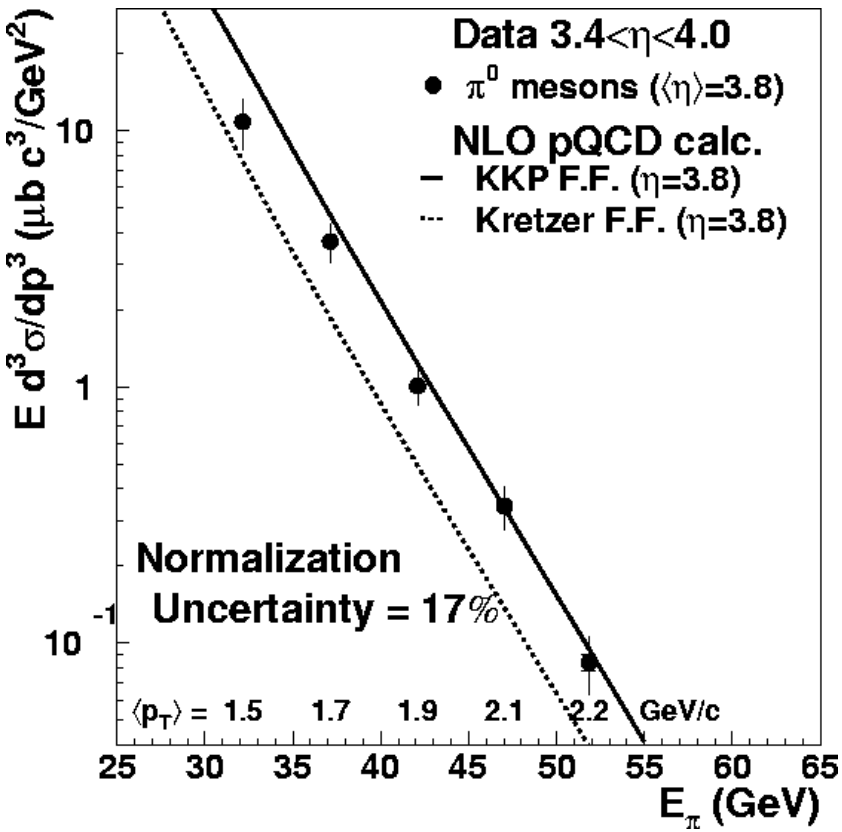


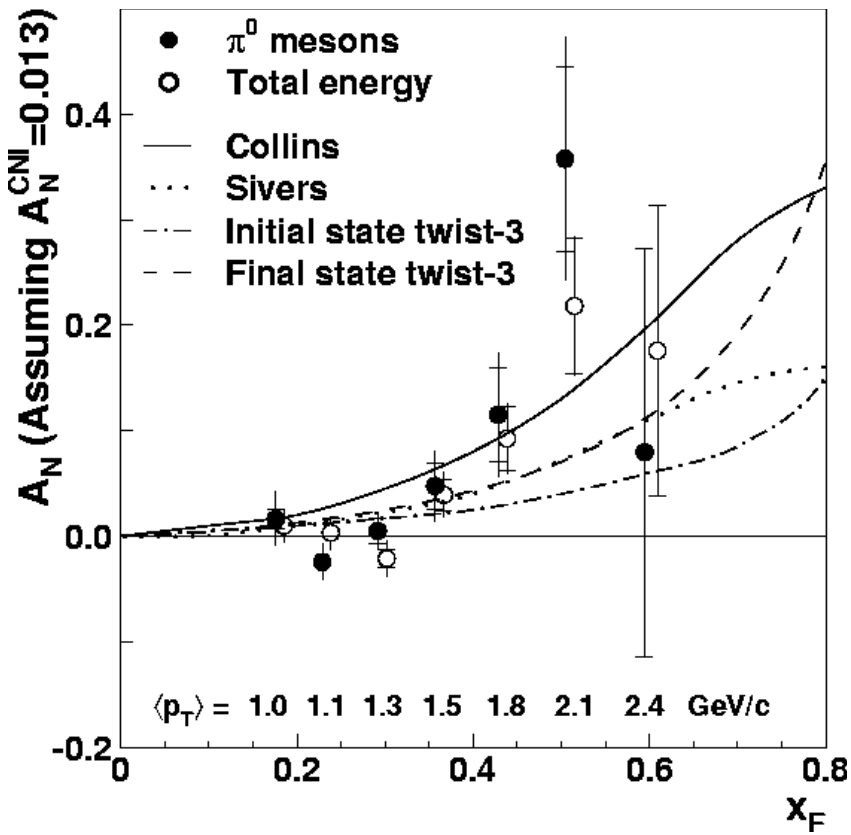
- relative luminosities calculated for each STAR run, statistical uncertainty $\delta R_{stat} \sim 10^{-4} - 10^{-3}$
- systematic uncertainty $\delta R_{syst} < 10^{-3}$

J. Kiryluk (MIT)

Forward π^0 Production

Run-2 STAR collaboration, PRL **92**, 171801 (2004)



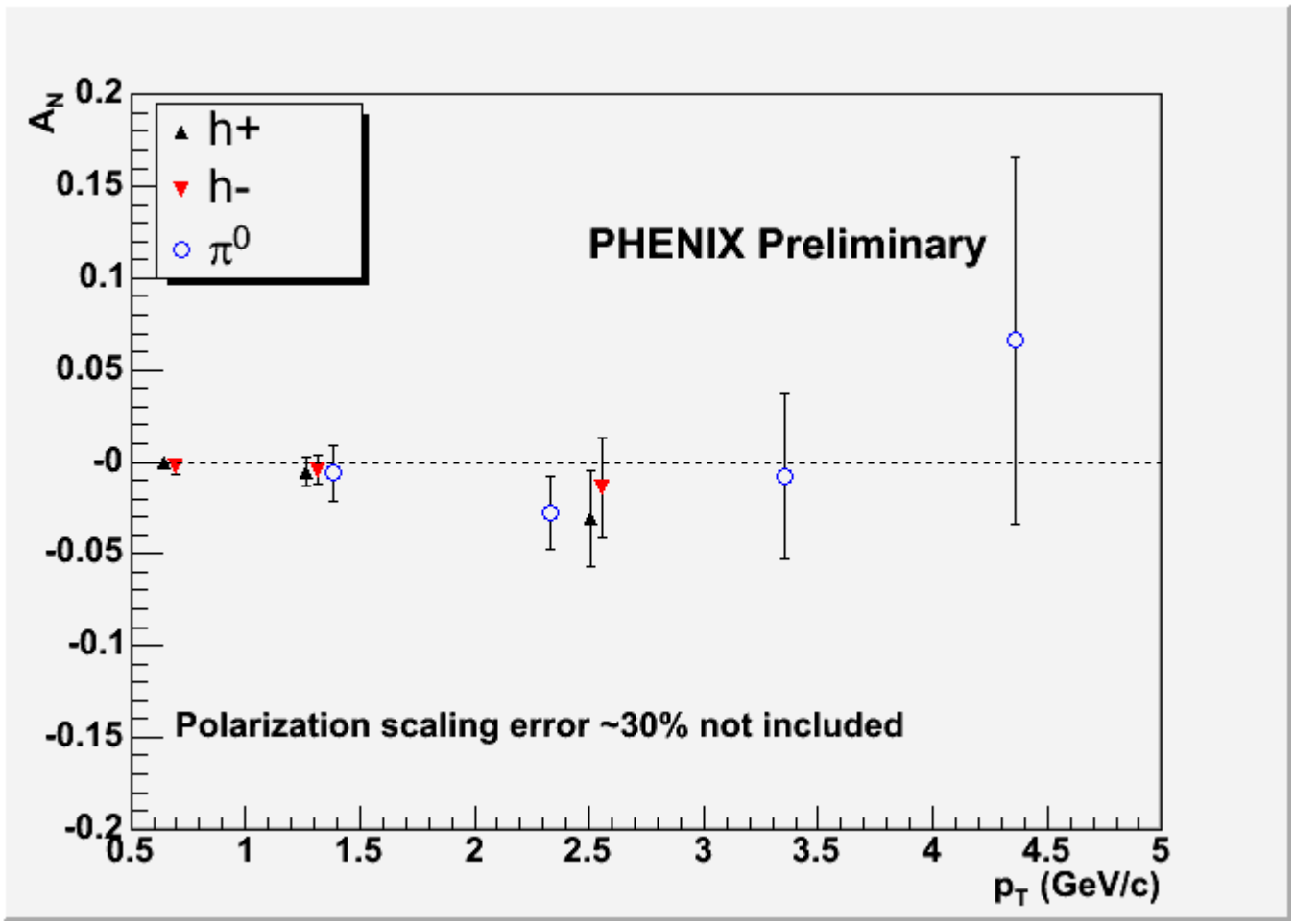


- pQCD calculations consistent with measured large-η π^0 cross sections
- Large transverse single-spin effects observed for $\sqrt{s}$ = 200 GeV *pp* collisions

Collins effect ⇒ transversity Sivers effect ⇒ orbital angular momentum

Additional measurements required to disentangle contributions

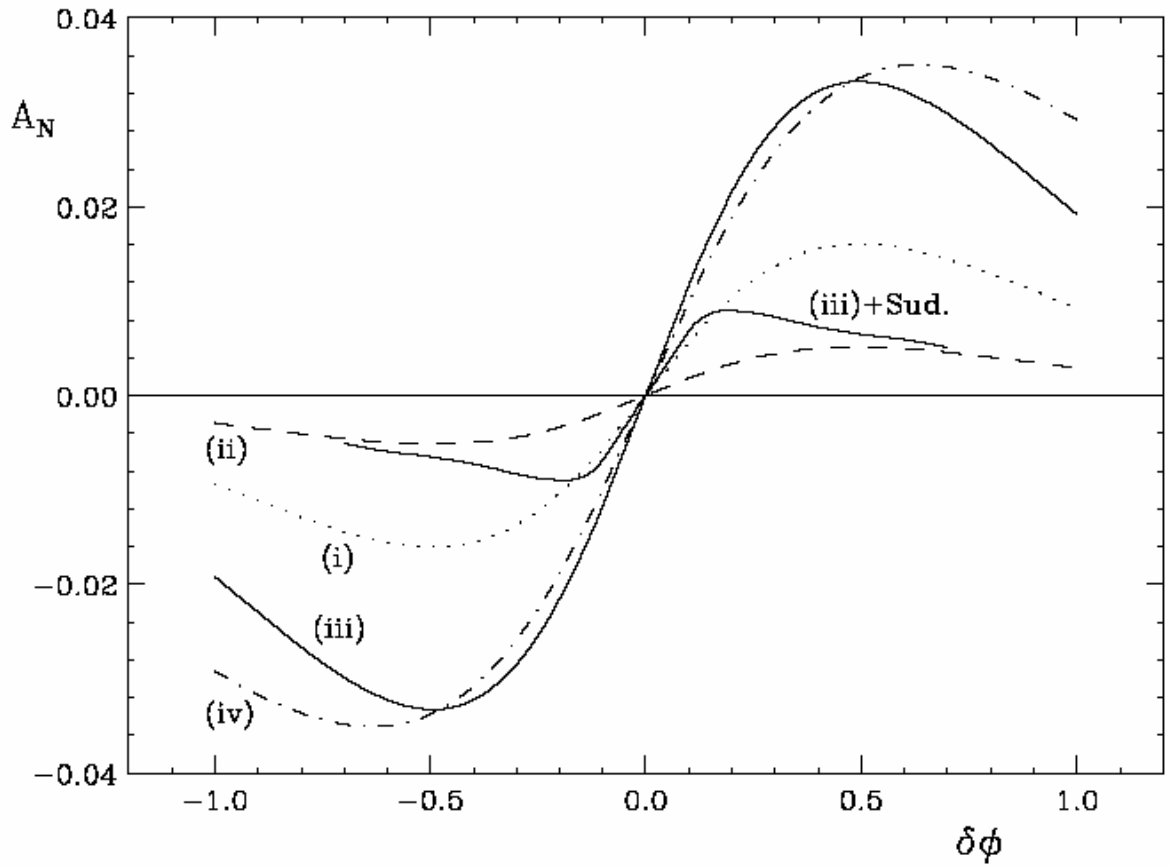
Midrapidity A_N Results from PHENIX



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

A. Deshpande (SUNY-Stonybrook/RBRC)

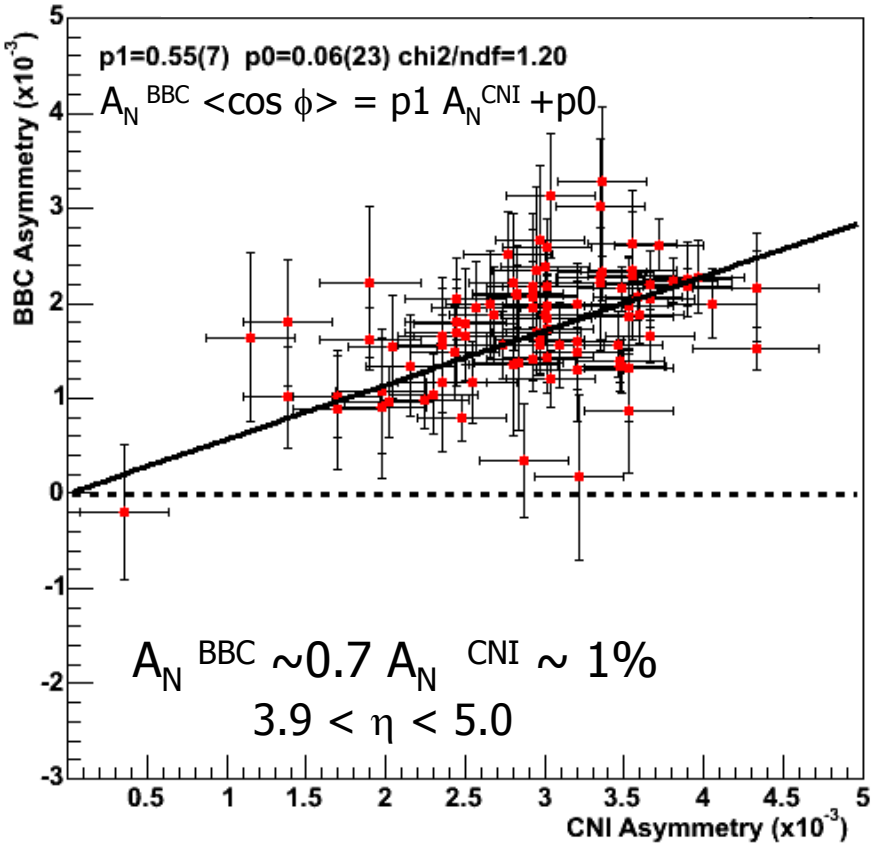
$\sqrt{S} = 200\,\mathrm{GeV},\ 8 \leq p_{T_{1,2}} \leq 12\ \mathrm{GeV},\ -1 \leq \eta_{1,2} \leq 1$ Boer,WV

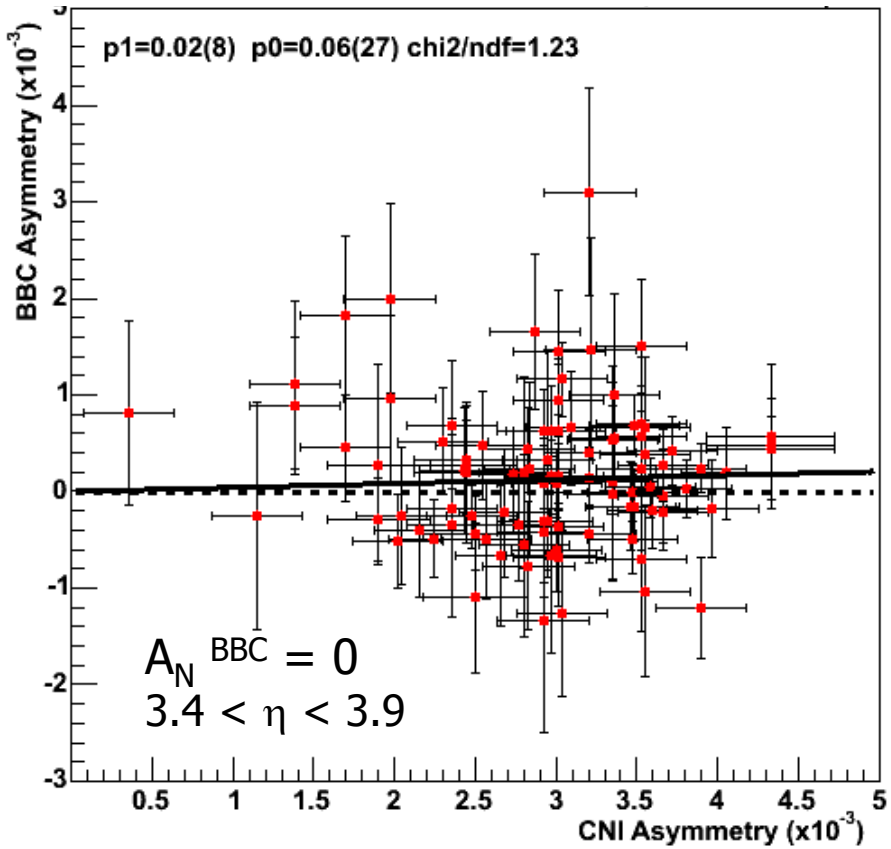


- Sudakov effects
- factorization ?

W. Vogelsang (RBRC/BNL)

Transverse Single Spin Asymmetries BBC Run-3 (Preliminary) Results

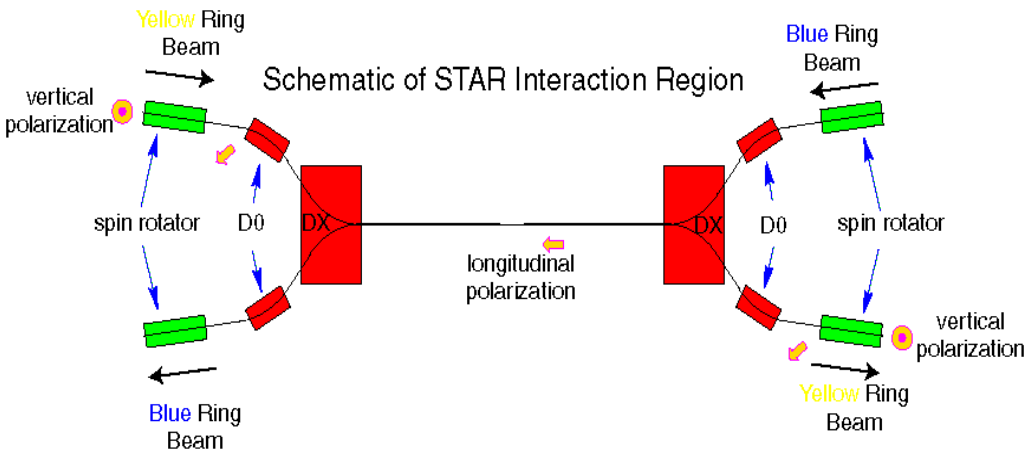




Strong pseudorapidity dependence

J. Kiryluk (MIT)

How do we get longitudinal polarization?



- Stable spin direction at RHIC is vertical
- Spin Rotater brings to almost radial
- D0/DX magnet causes spin precession
- Longitudinal at IR
- DX/D0/Spin Rotater put back to vertical

BBC - local polarimeter at STAR

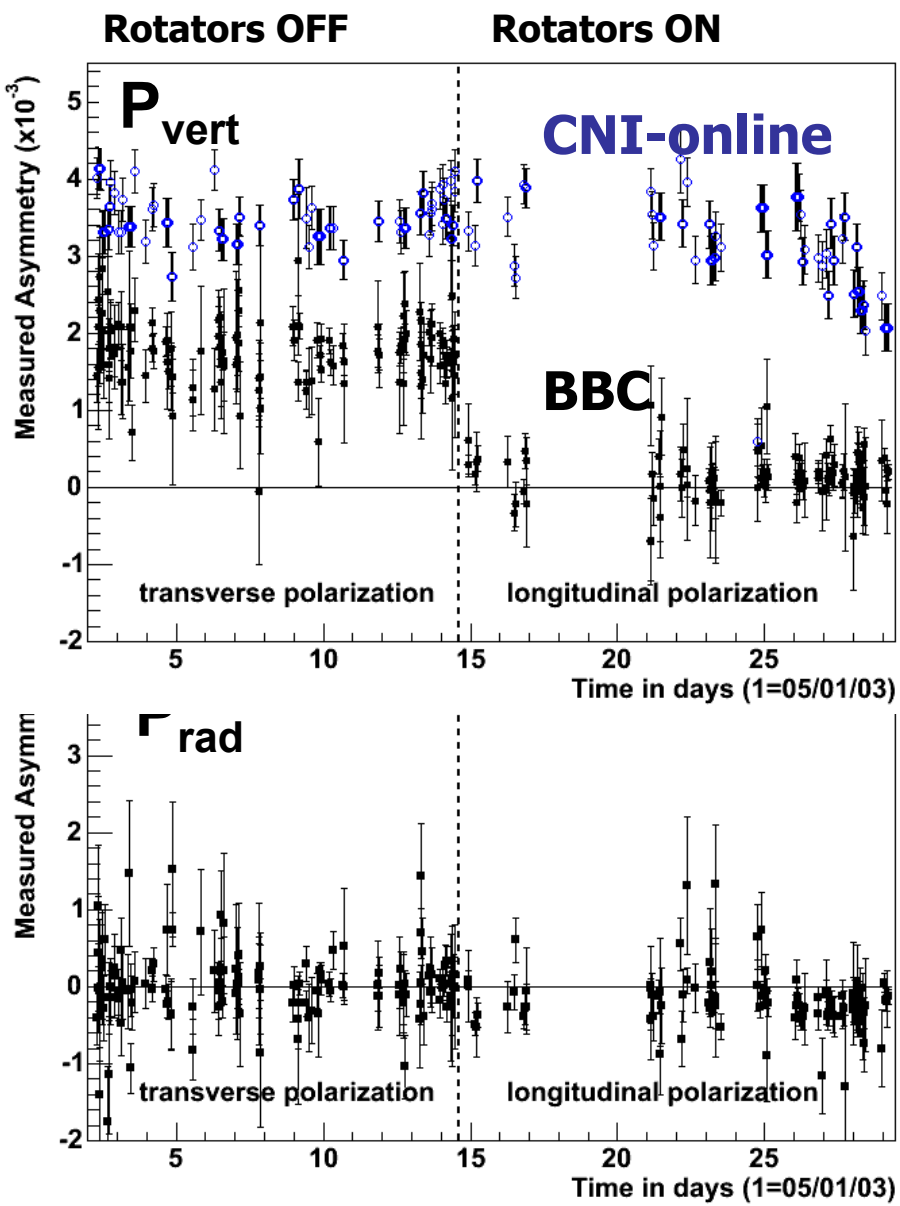
$\text{asymmetry}_i \sim A_N P_i$

Left-Right asymmetry - sensitive to verical polarization

Top-Bottom asymmetry - sensitive to radial polarization

Rotators		OFF	ON
CNI polarimeter		non-zero	non-zero
BBC Left-Right	(vertical)	NON_ZERO	ZERO
BBC Top-Bottom	(radial)	zero	zero

Beam-Beam Counters
- local polarimeter at STAR



BC worked very well as a local
olarimeter. In Run3
ertical and radial polarizations < 3%

Longitudinal polarization
at STAR -

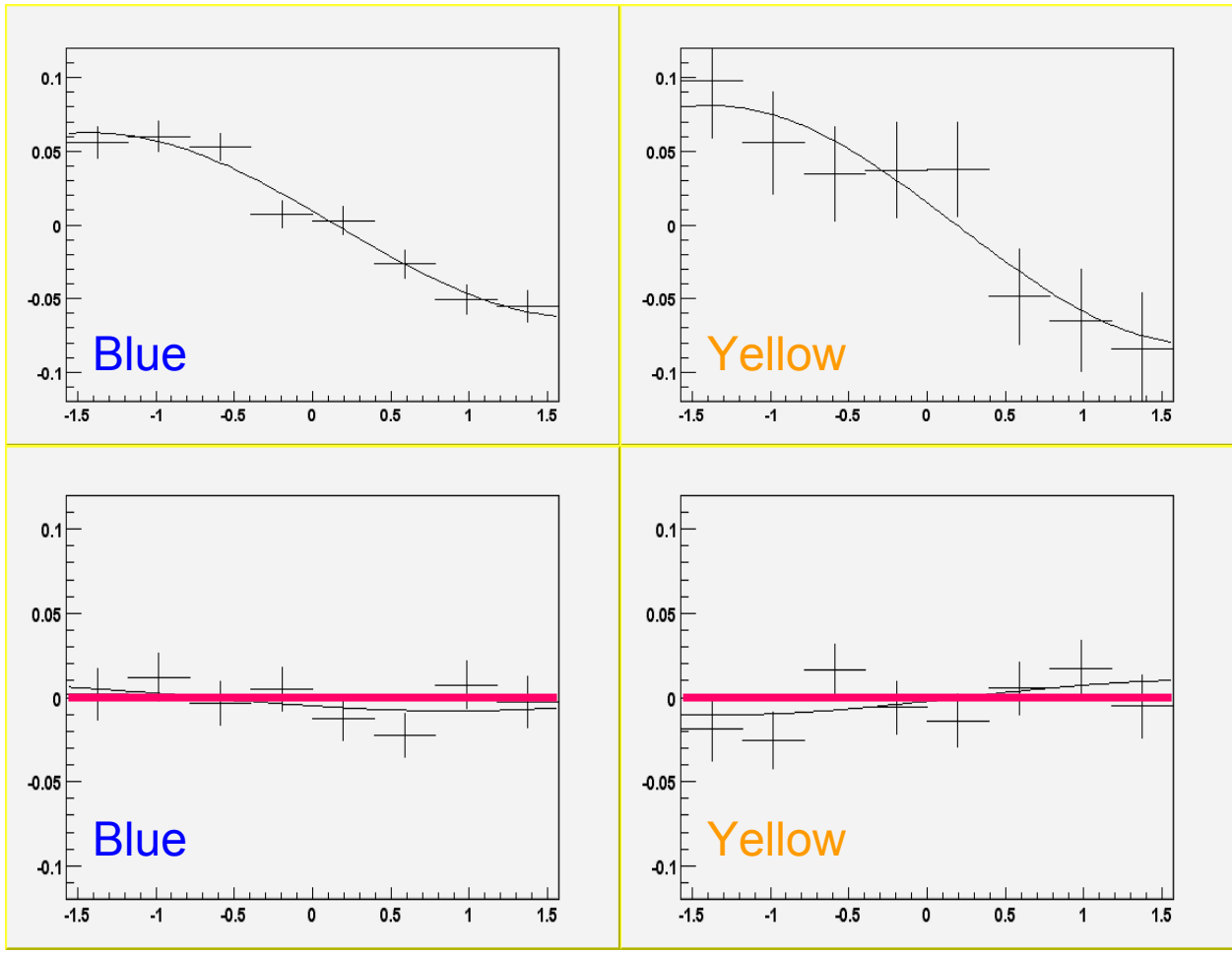
first step to A_{LL} measurement

J. Kiryluk (MIT)

Longitudinal Polarization at PHENIX

Spin Rotators OFF
Vertical polarization

Spin Rotators ON
Correct Current !
Longitudinal polarization!



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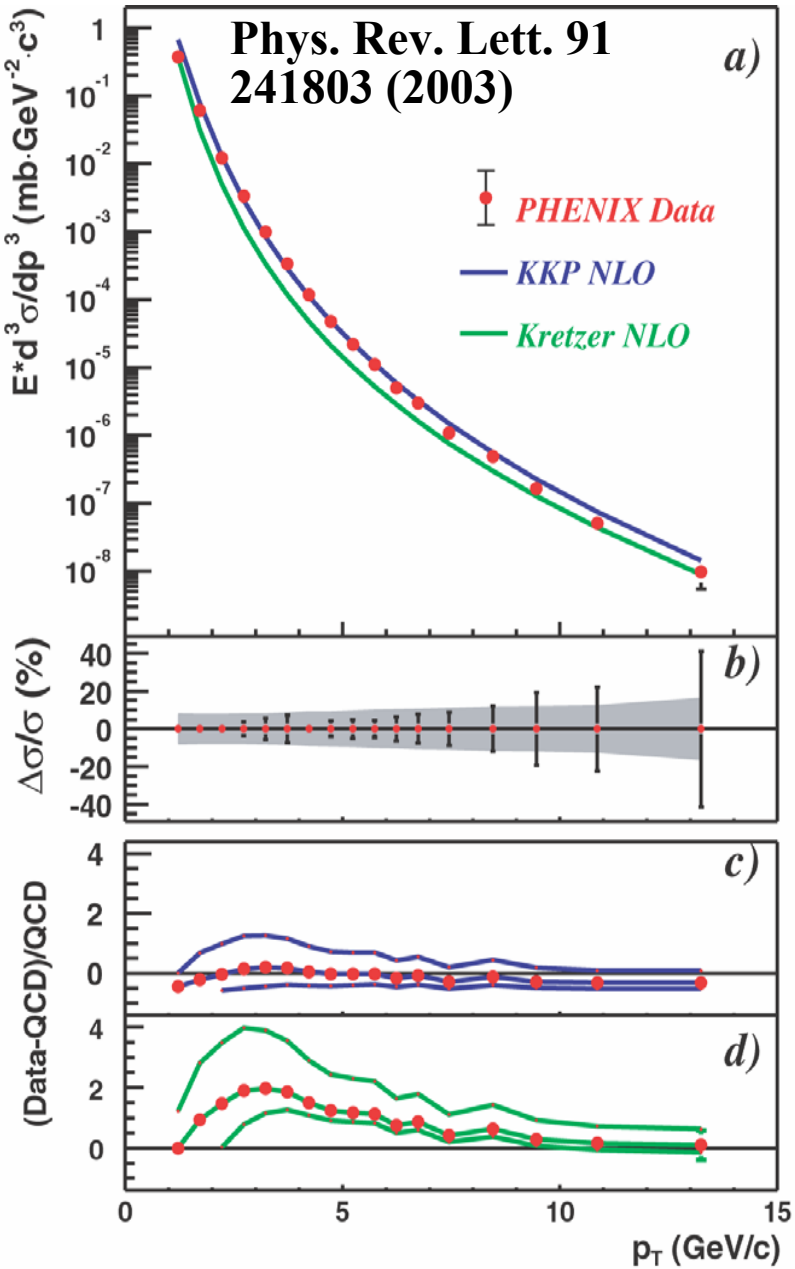
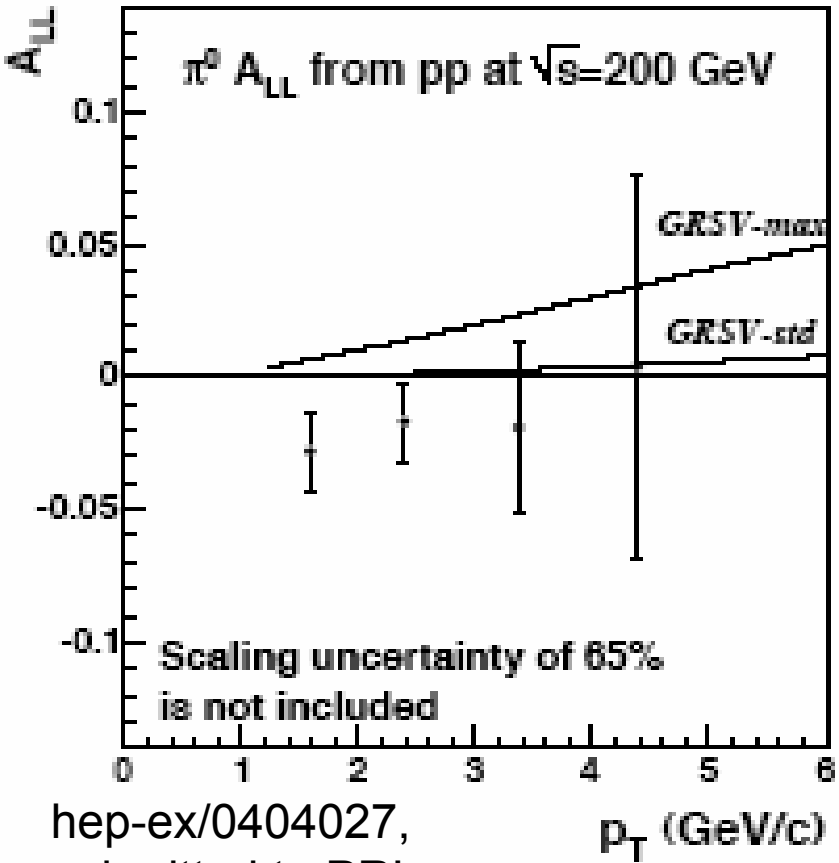
PHENIX midrapidity π^0 cross section (2002 Run2)



- Results consistent with pQCD calculation
- Favors a larger gluon-to-pion FF (Kniehl Kramer Potter)
- Important confirmation of theoretical foundations for spin program
- Run3 results reproduce Run2 results
  - ✓ Confirm the Run-3 data reliability and consistency
  - ✓ Run3 data reaches even higher p_Ts; results will be finalized soon

A. Deshpande (SUNY-Stonybrook/RBRC)

PHENIX A_{LL} Result and Discussion



hep-ex/0404027, submitted to PRL

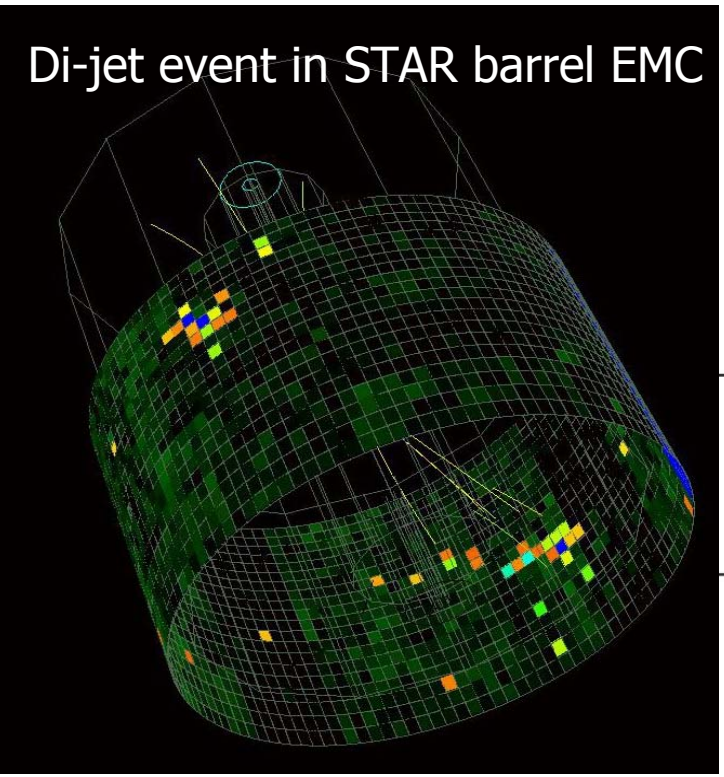
- GRSV Curves from B.Jaeger et al., PRD67, 054005 (2003)
  - >input scale Q^2=0.6 GeV^2
  - >both curves positive
- B. Jaeger et al. Hep/ph-0310197 argue: Negative A_{LL} difficult to accommodate
- Not including theory uncertainty
  GRSV-std CL: 16-20%
  GRVS-max CL: 0.02-5%

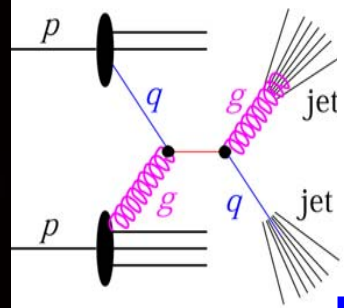
$p_T(GeV/c)$	Bckg. contr.	$A_{LL}^{\pi^0+bckg}$	A_{LL}^{bckg}	$A_{LL}^{\pi^0}$
1-2	27%	-0.015 ± 0.010	-0.018 ± 0.016	-0.028 ± 0.015
2-3	15%	-0.019 ± 0.013	-0.031 ± 0.028	-0.017 ± 0.015
3-4	9%	-0.018 ± 0.029	-0.008 ± 0.079	-0.019 ± 0.032
4-5	8%	0.025 ± 0.066	0.26 ± 0.20	0.004 ± 0.072

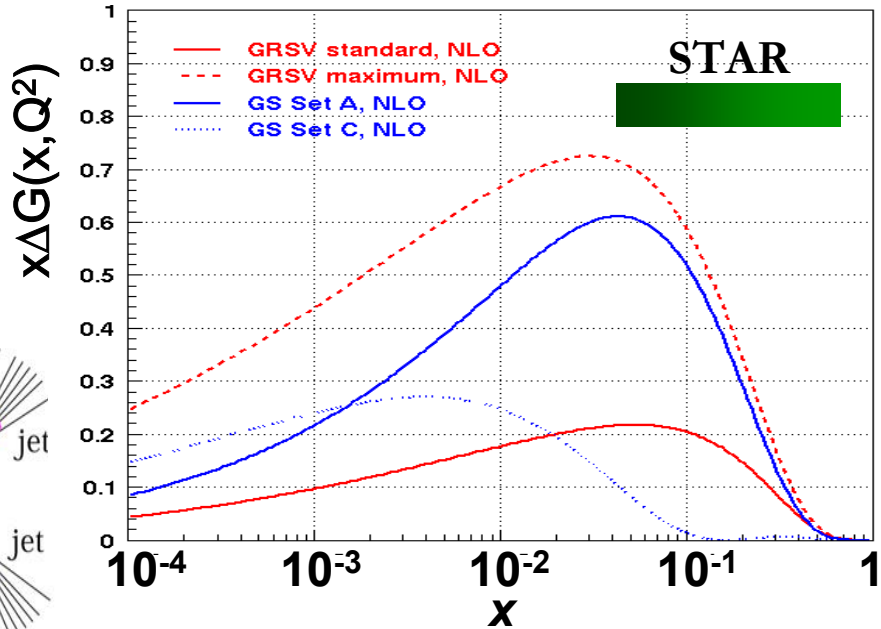
A. Deshpande (SUNY-Stonybrook/RBRC)

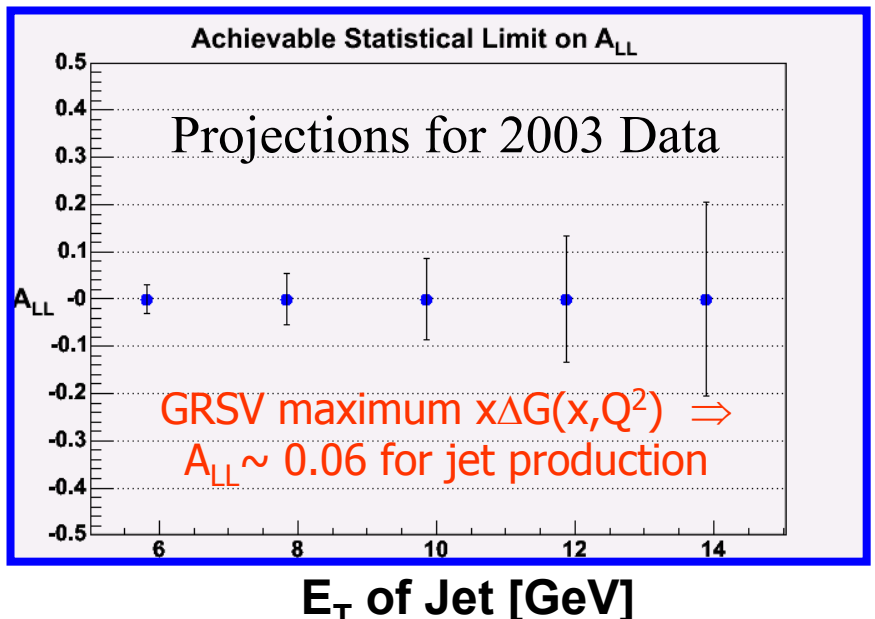
A_{LL} for $\vec{p} + \vec{p} \rightarrow jets$ at $\sqrt{s}$ = 200 GeV

⇒ sensitivity to gluon polarization







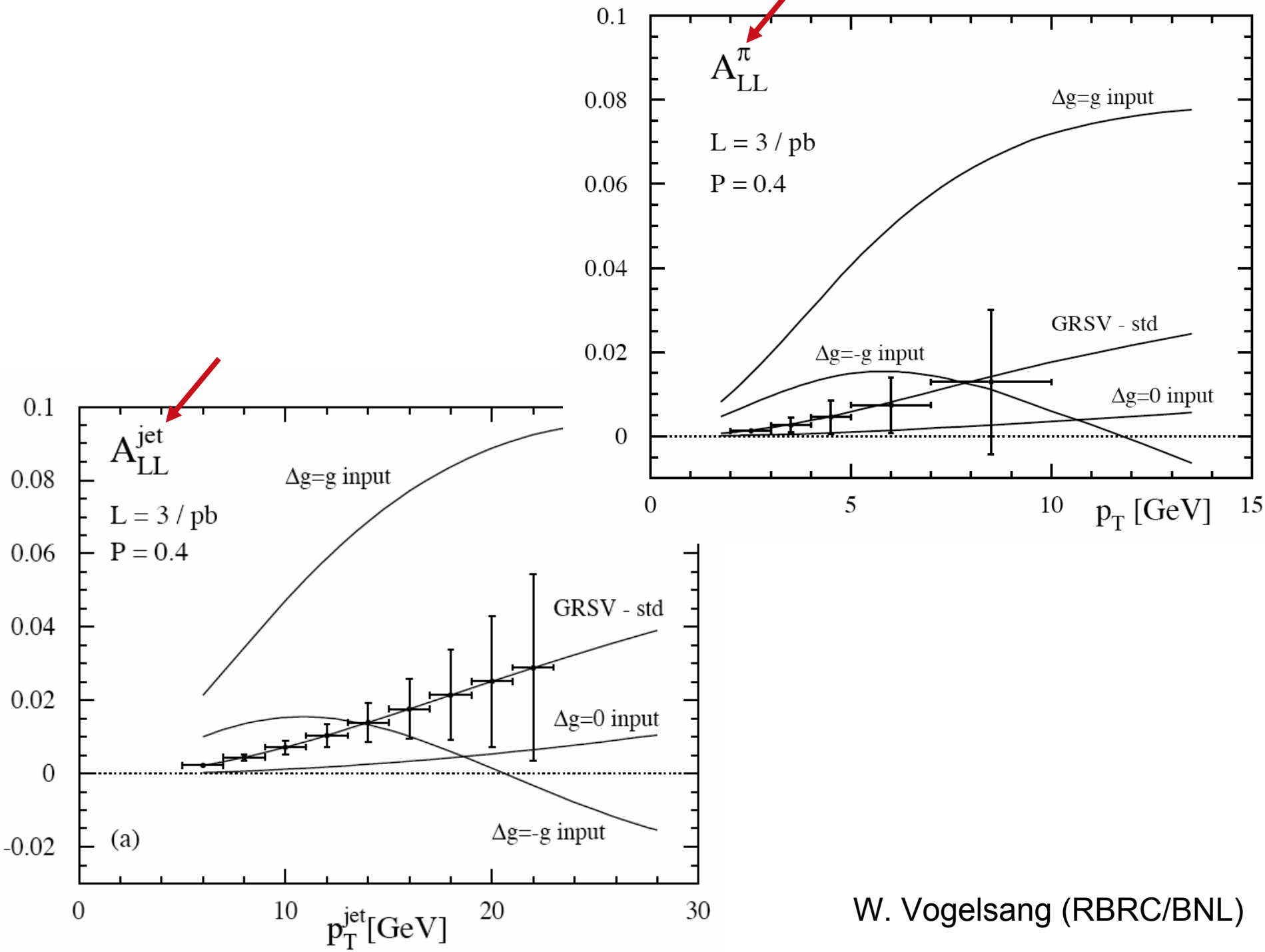


Achieved in 2003:

- **Ave Polarization / Beam ~ 0.25**
- **RHIC Delivered Integrated Luminosity ~ 0.4 pb^{-1}**

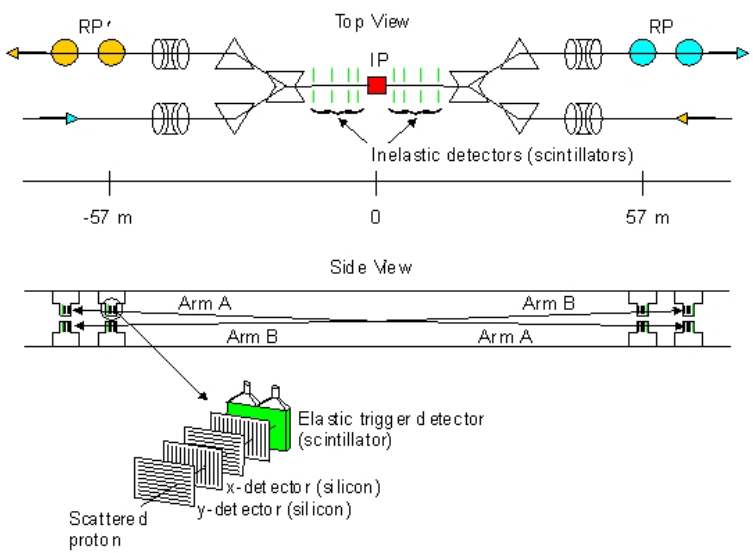
Goal for 2005

- **Ave Polarization / Beam ~ 0.40**
- **RHIC Delivered Integrated Luminosity ~ 5 pb^{-1}**

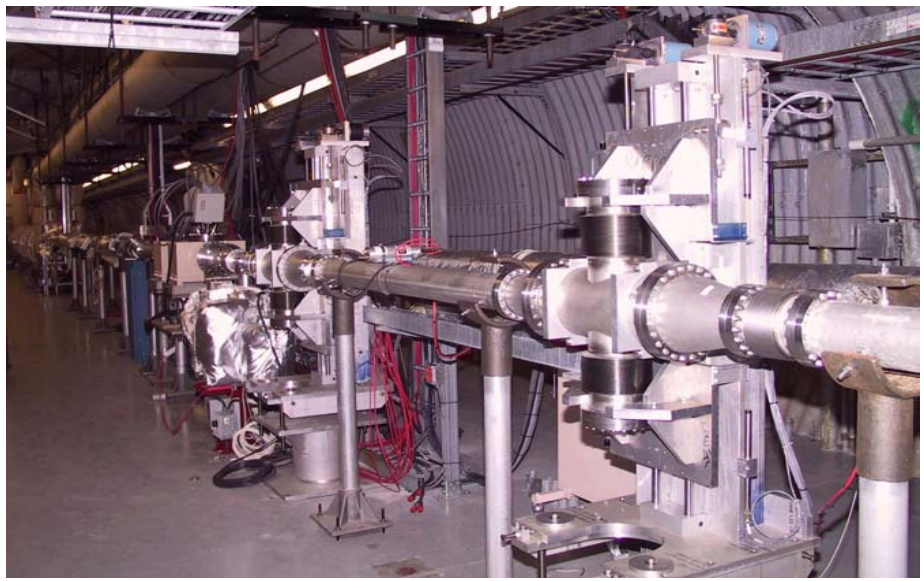


W. Vogelsang (RBRC/BNL)

The pp2pp Experimental Setup



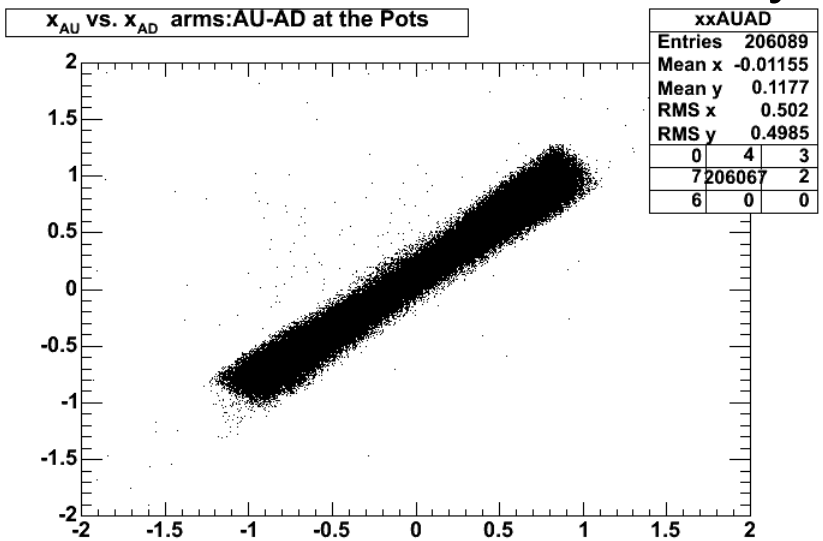
- Elastically scattered protons have very small scattering angle θ^*, hence beam transport magnets determine trajectory of scattered protons
- The optimal position for the detectors is where scattered protons are well separated from beam protons
- Need Roman Pot to measure scattered protons close to the beam without breaking accelerator vacuum

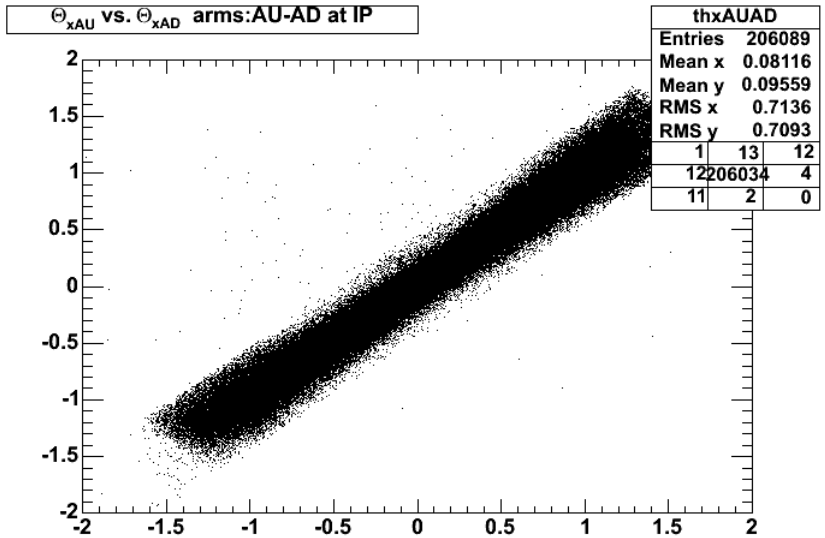


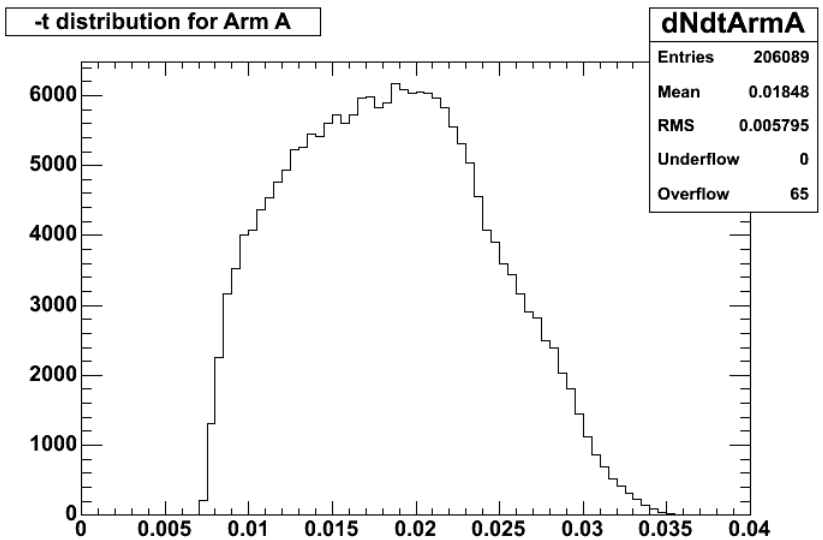
W. Guryn (BNL)

Elastic Events: Co-linearity and dN/dt

Note very clean data set!







Est. of stat. error	Run 2002	Run 2003
Nuclear slope ΔB	1.6 GeV/c)$^{-2}$	0.35 (GeV/c)$^{-2}$
Raw asymmetry $\Delta\varepsilon_N$	0.007	0.001
Total cross section $\Delta\sigma_{Tot}$		2-3 mb

W. Guryn (BNL)

Some plans for polarized proton run in 2004-2005

- Longitudinal:
  - Midrapidity jets
  - Midrapidity π^0
  - Forward rapidity π^0
- Transverse:
  - A_N for forward rapidity π^0 vs. x_F and p_T
  - Midrapidity di-jets

Lots of physics to come from this burgeoning program at RHIC!