RHIC SPIN: Experimental Issues

Matthias Grosse Perdekamp, UIUC and RBRC

- Physics Goals
- The Experimental Method:
  Polarized Proton Collisions
- First Results from STAR and PHENIX
- Future Runs
- Upgrades
- Summary

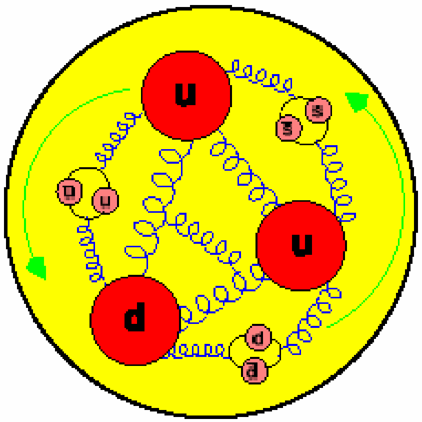
Spin Physics at RHIC

- Spin Structure of the Nucleon
  - ➔ Helicity Structure
  - ➔ Transverse Spin Structure
- Spin Dependent Effects in Fragmentation
  - ➔ Study Collins and Interference Fragmentation
  - ➔ Lambda Fragmentation

} **This talk!**

- Spin Dependence in Fundamental Interaction
  - ➔ Search for Parity Violating Interaction
- Spin Dependence in pp Elastic Scattering

Spin Structure of the Proton



Parton Distribution functions (PDF):

Helicity average distribution
quarks q(x) : well known
gluons G(x) : moderately well known

Helicity difference distribution
quarks Δq(x) : moderately well known
gluons ΔG(x) : unknown

Helicity flip (transversity) distribution
quarks δq(x) : unknown

Field started with polarized source
and targets about 1975 Yale/SLAC collaboration

- **Fixed Target**

HERMES	27 GeV pol. e^+, e^-	pol. H,D (L/T)	DIS
COMPASS	160 GeV pol. μ^+	pol. LiD (L/T)	DIS, quasi-real Photons
JLAB Hall A	6 GeV pol. e^-	pol. ^{3}He	DIS (high x)
Hall B CLAS	6 GeV pol. e^-	pol. H,D	Resonance region
Hall C RSS	6 GeV pol. e^-	pol. H,D	Resonance region
SAMPLE Bates	200 MeV pol. e^-	unpol. H,D	Elastic
MAMI A4	855 MeV pol. e^-	unpol. H,D	Elastic
JLAB G0	6 GeV pol. e^-	unpol. H,D	Elastic
Jlab HAPPEX	6 GeV pol. e^-	unpol. H,D	Elastic

- **Collider**

STAR	200 GeV pol. p	Jetproduction, direct Photons...
PHENIX	200 GeV pol. p	Jetproduction, direct Photons...
BELLE	8 GeV e^-, 3.5 GeV e^+	Fragmentation..

Current Experiments on Nucleon Structure (as reported at DIS 2004)

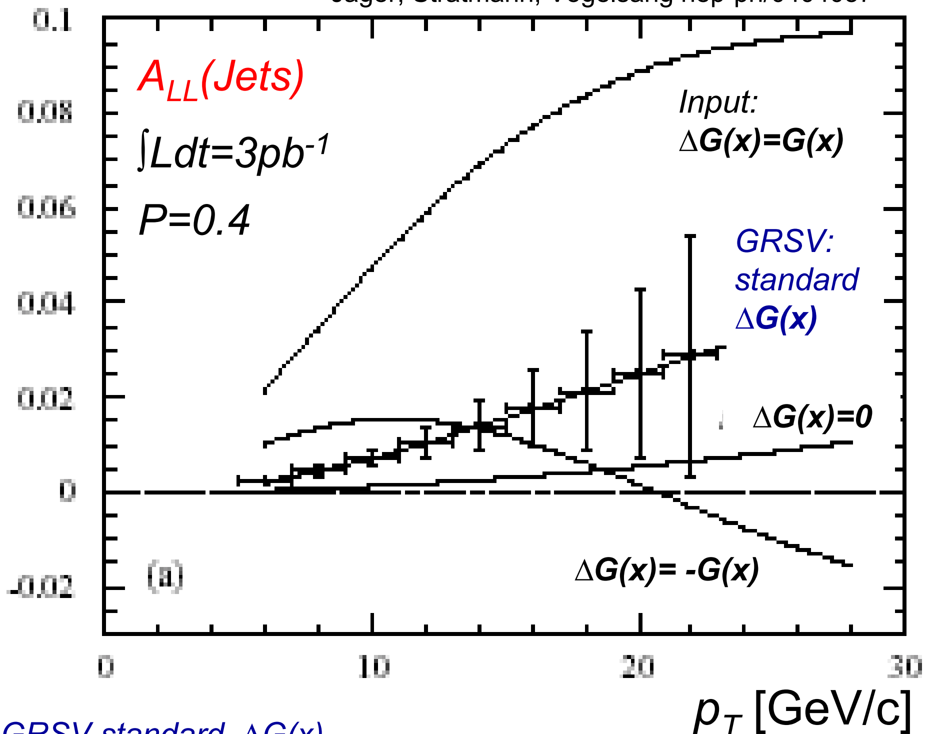
Proton Spin Structure at Hard Scales

	RHIC Spin	Elsewhere
Gluon polarization $\Delta G(x) / G(x)$	Inclusive jets, hadrons or Photons etc. in STAR and PHENIX	Open charm and/or high p_T hadron pairs at HERMES, SMC, COMPASS (Future: E160, NA59 follow-up, eRHIC, TESLA-N)
Flavor separation of quark polarizations $\Delta q(x) / q(x)$, $\Delta \bar{q}(x) / \bar{q}(x)$	Single lepton asymmetries $A_L(e,\mu)$ in W-production in STAR and PHENIX	Double spin asymmetries in semi-inclusive hadron production at HERMES and COMPASS
Transverse spin structure of the Nucleon $\delta q(x) / q(x)$	A_T in Collins- and Interference-fragmentation and A_N in STAR, PHENIX and A_N in BRAHMS	Transverse single spin asymmetries in semi-inclusive deep-Inelastic scattering at HERMES, COMPASS, Jefferson Laboratory

Gluon Polarization at Low Luminosity: Inclusive Jets and Hadrons: (1pb^{-1}< ∫Ldt < 30pb^{-1}, 0.4<P<0.6)

A_{LL} in inclusive jet production (STAR)

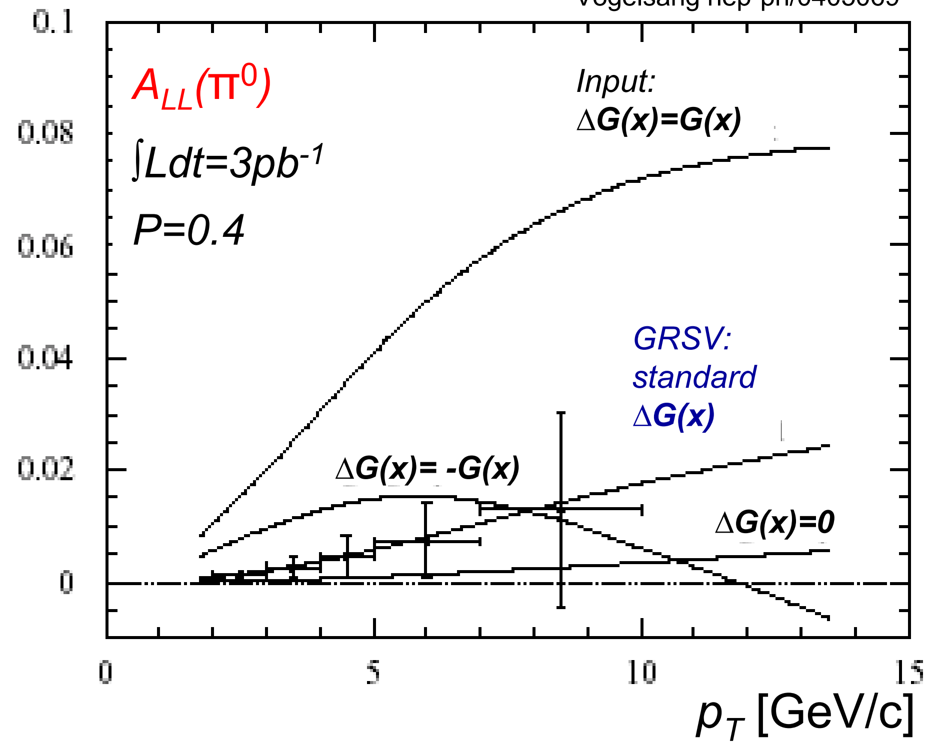
Jager, Stratmann, Vogelsang hep-ph/0404057



GRSV standard ΔG(x)

A_{LL} in inclusive π^0 production (PHENIX)

Vogelsang hep-ph/0405069



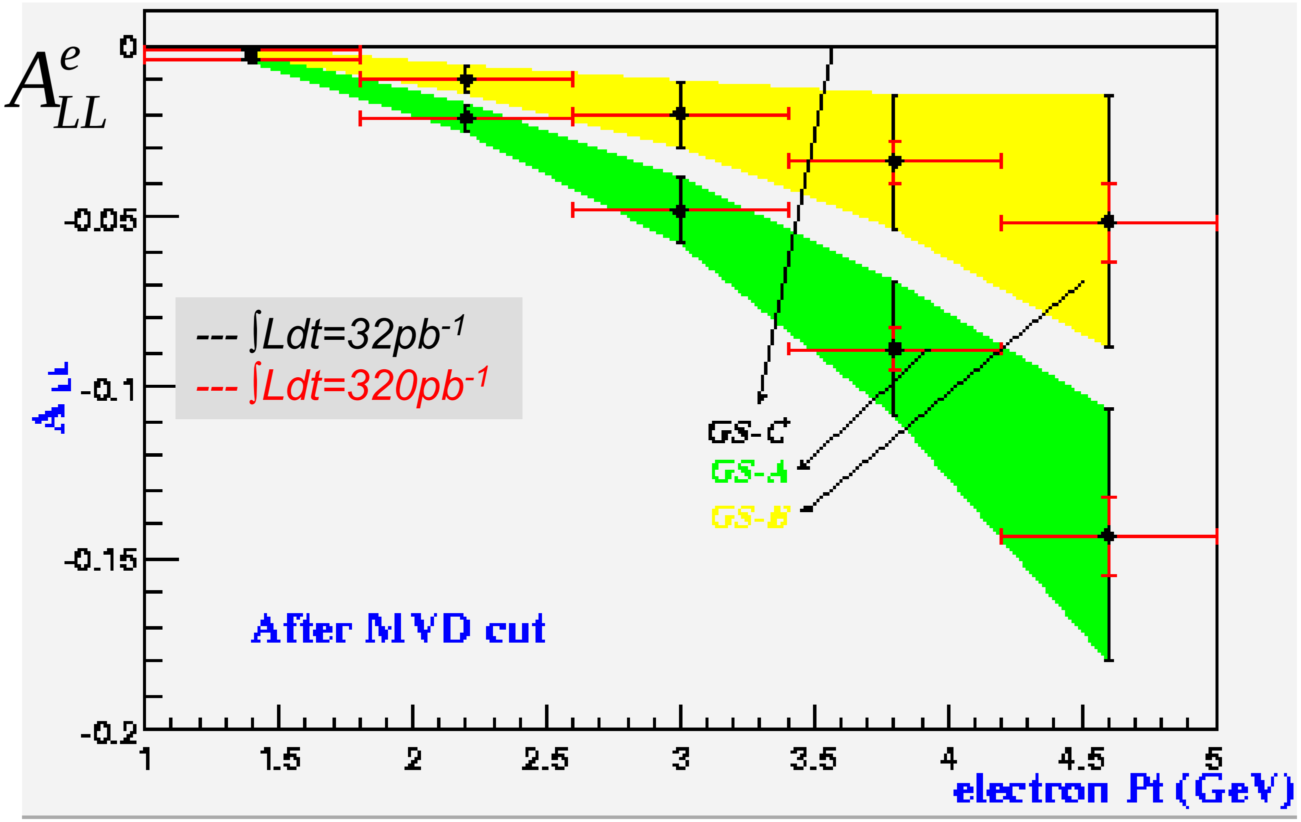
➔ Gluon distribution from NLO pQCD fit to DIS data on A_1, Gluck Reya, Stratmann, Vogelsang Phys. Rev. D63:094005, 2001

Expected in run 05: *∫Ldt =5pb^{-1} P =0.5*
All required instrumentation in STAR and PHENIX is in place!

Gluon Polarization at Moderate Luminosity: Charm Production: *(∫Ldt > 30pb⁻¹, P>0.6)*

from Wei Xie, PHENIX

A_{LL} for single electrons in PHENIX



Silicon Vertex Detector Upgrade!

GS-A/B/C:

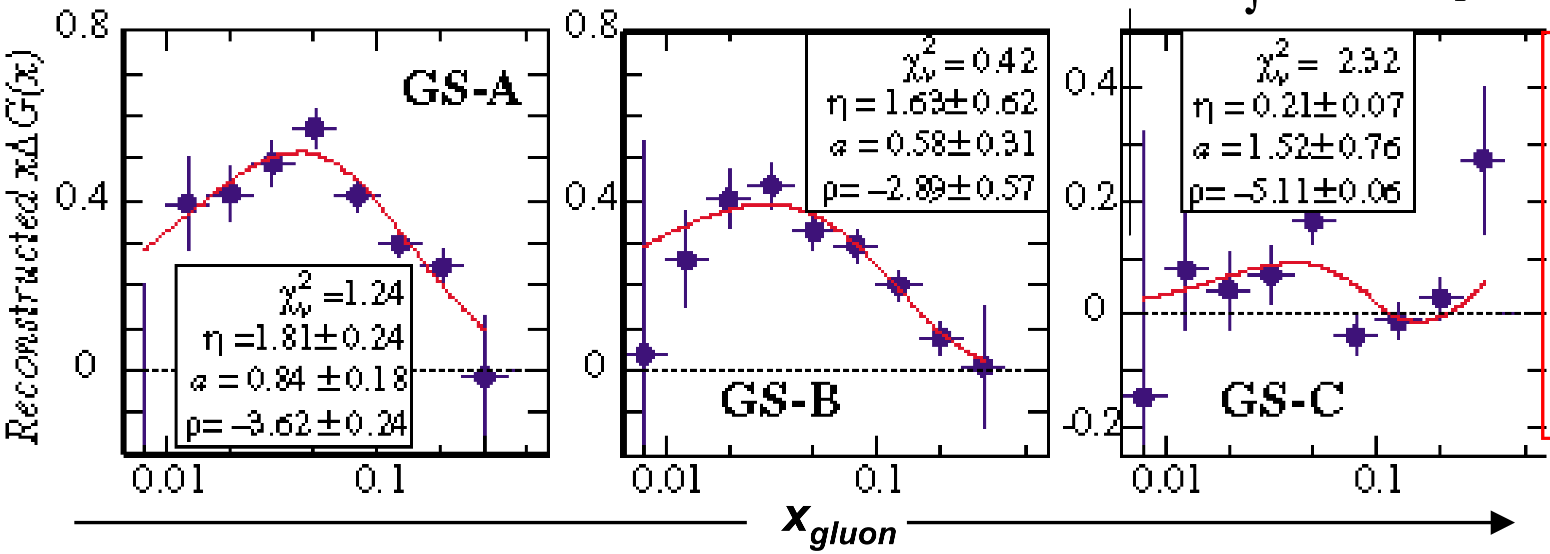
$\Delta G(x_g)$ parametrization from Gehrmann and Stirling Phys.Rev. D53 6100-6109,1996

$\int G_A(x)dx = 1.8$
$\int G_B(x)dx = 1.6$
$\int G_C(x)dx = 0.2$

Sensitivity to Gluon Polarization at RHIC

from Les Bland, STAR

$$\vec{p} + \vec{p} \to \gamma + jet + X\,,\;\; P_b = 0.7 \quad \begin{cases} \sqrt{s} = 200\ \text{GeV}\,, & \int \text{Ldt} = 320\ \text{pb}^{-1} \\ \sqrt{s} = 500\ \text{GeV}\,, & \int \text{Ldt} = 800\ \text{pb}^{-1} \end{cases}$$



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$\int G_A(x)dx = 1.8$
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$\int G_C(x)dx = 0.2$

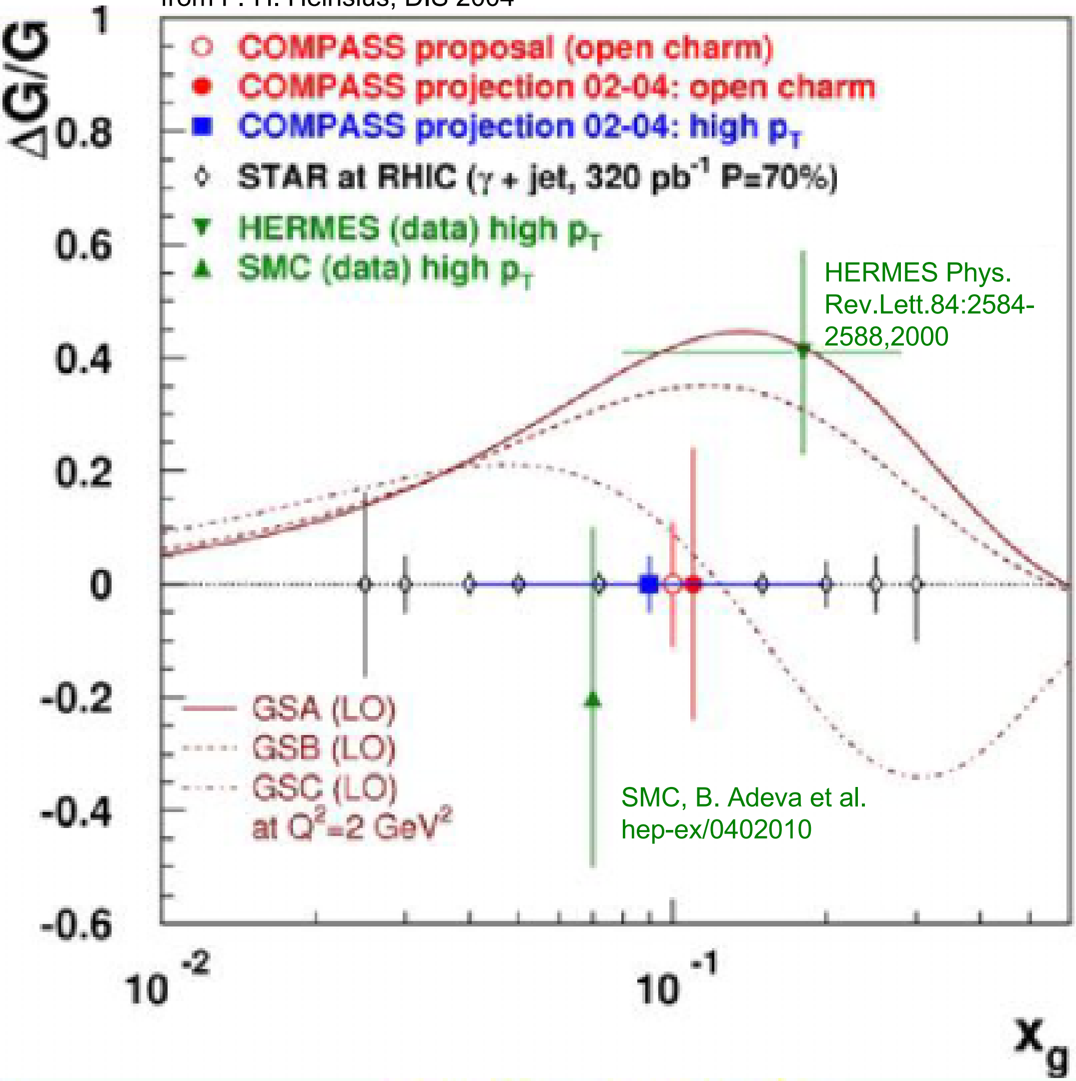
PHENIX and STAR are sensitive to ΔG through several independent channels:

Inclusive photons, inclusive jets, jet-photon, J/ψ production, heavy flavor production

Good control of experimental and theoretical uncertainties!

Sensitivity to Gluon Polarization at RHIC

from F.-H. Heinsius, DIS 2004



(I) RHIC data at hard scale → pQCD applicable for the extraction of polarized pdfs.

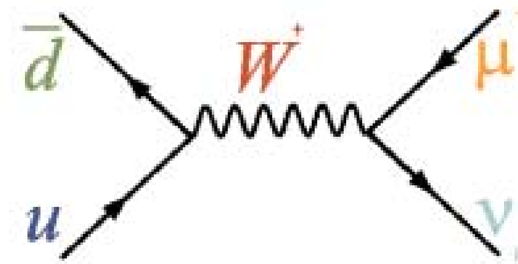
(II) RHIC spans a broad range of x_{gluon}

→ Determine first moment $\int\Delta G(x)dx$ = gluon contribution to the proton spin!

(III) Assumes data sample of 320pb^{-1} at $\sqrt{s}$=200 GeV and 800pb^{-1} at $\sqrt{s}$=500 GeV; P=0.7. (This is baseline spin!)

(IV) Upgrades extending kinematic coverage to low x decrease error on $\int\Delta G(x)dx$ *(low x behavior has been critical in proton spin structure in the past: SLAC E80/E130 vs EMC → spin crisis)*

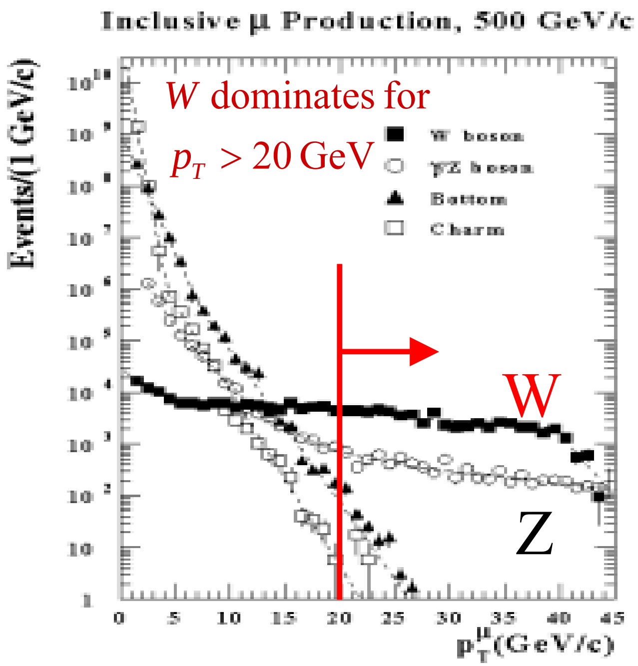
W Production in Polarized pp Collisions



Single Spin Asymmetry in the naive Quark Parton Model

$$A_L^{W^+} = \frac{\Delta u(x_1, M_W^2)}{u(x_1, M_W^2)}, \quad x_1 > x_2$$

Parity violation of the weak interaction in combination with control over the proton spin orientation gives access to the flavor spin structure in the proton!



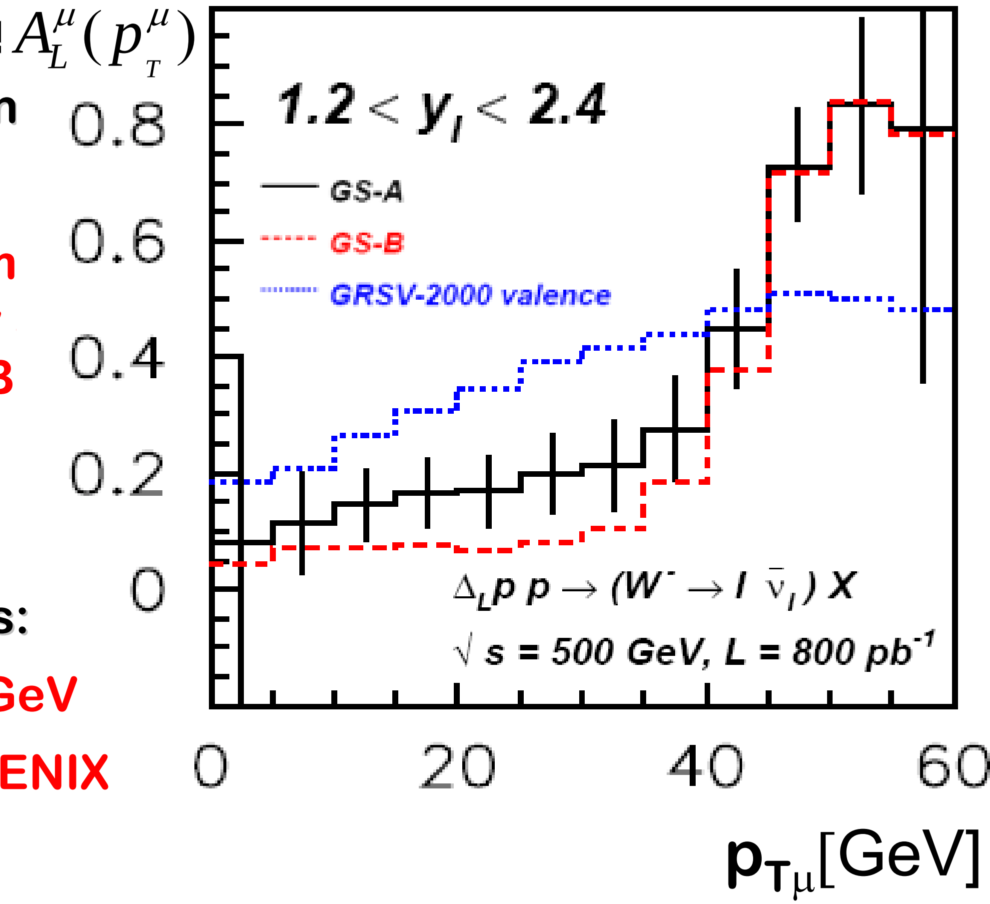
Experimental Requirements:

➔ tracking at high p_T

➔ event selection for muons difficult due to hadron decays and beam backgrounds.

Can We Connect Observables: inclusive A_L(lepton) with quark polarizations?

- **Access to quark polarizations throu[gh] measurements of inclusive longitudin[al] single spin asymmetry?**
  - **Yes! Complete theoretical treatm[ent] from first principles by Nadolsky [and] Yuan at NLO pQCD (Nucl. Phys.B 666(2003) 31).**

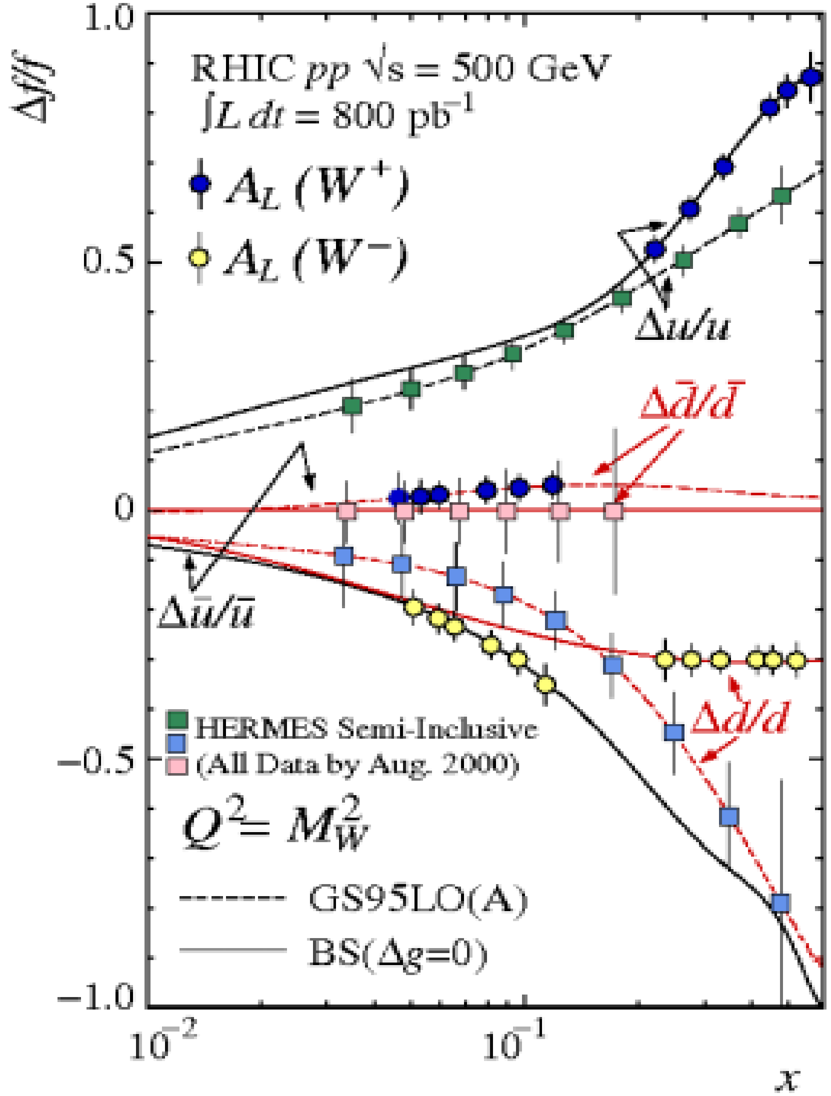


- **Machine and detector requirements:**
  - **∫Ldt=800pb-1, P=0.7 at √s=500 GeV**
  - **Upgrades: o Muon trigger in PHENIX**
    o Forward tracking in STAR

Quark Polarization: RHIC vs HERMES

from Naohito Saito, PHENIX

- W-production at RHIC
  - No fragmentation ambiguity
  - *x*-range limited
- Semi-inclusive DIS
  - Wide *x*-range
  - Limited sensitivity to sea flavors
  - Fragmentation functions poorly known at low scales (HERMES)



Transverse Spin at RHIC

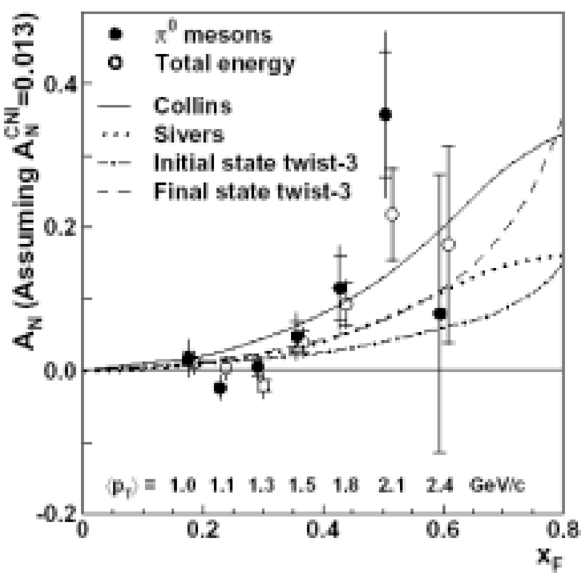
(A) Physics Channels for Low Luminosity

$$\int L dt = 1 - 10\,\text{pb}^{-1}, \sqrt{s} = 200\,\text{GeV}$$

STAR, PHENIX and BRAHMS

(I) Measure A_N : $A_N(pp_{\perp} \rightarrow h + X)$

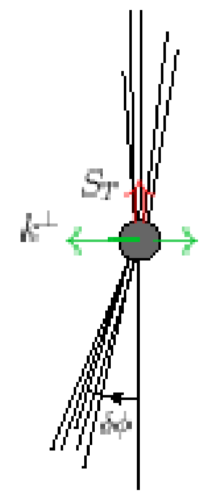
STAR Phys. Rev. Lett. 92:171801, 2004



Separation of intrinsic transverse quark spin (transversity) from transverse momentum effects (Sivers)?

STAR and PHENIX

(II) Boer and Vogelsang (hep-ph/0312320): azimuthal back to back correlation between hadrons in opposite hemisphere jets:



Clean channel for Sivers effect!

Transverse Spin at RHIC

(B) Physics Channels for high L

$$\int Ldt = 30\text{-}100\ \text{pb}^{-1}, \sqrt{s} = 200\ \text{GeV}$$

STAR and PHENIX

- Collins Effect in Jets:

$$A_T(pp_\perp \rightarrow \pi + Jet + X)$$

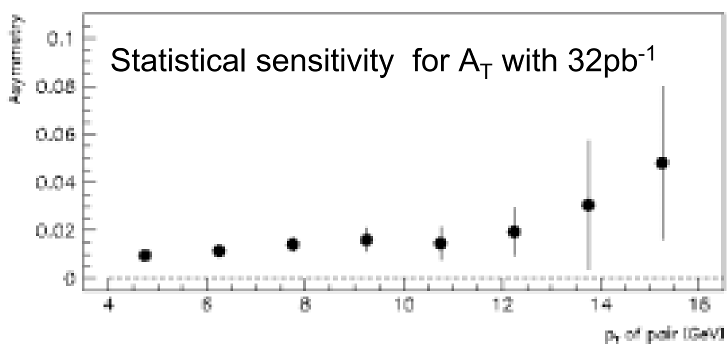
J.C. Collins, Nucl. Phys. B396, 161(1993)

- π^+, π^- Interference Fragmentation:

$$A_T\left(p_\perp p \rightarrow (\pi^+, \pi^-) + X\right)$$

J. Collins, S. Heppelmann, G. Ladinsky,
Nucl.Phys. B420 (1994)565

R. Jaffe, X.Jin, J. Tang Phys. Rev. D57 (1999)5920



Transverse Spin Physics Elsewhere

HERMES, COMPASS and Jefferson Lab

Separate transverse quark spin (transversity) and transverse momentum contributions (Sivers) in semi-inclusive deep Inelastic scattering:

- o low scale leads to significant theoretical ambiguities
- o Final data set from HERMES available in mid 2005

→ Brahms A_N measurements from 2004 and 2005 polarized proton runs!

→ Brief PHENIX and STAR runs on A_N and back-to-back correlations as $\int$ Ldt/week>1pb^{-1}/week (2006?)

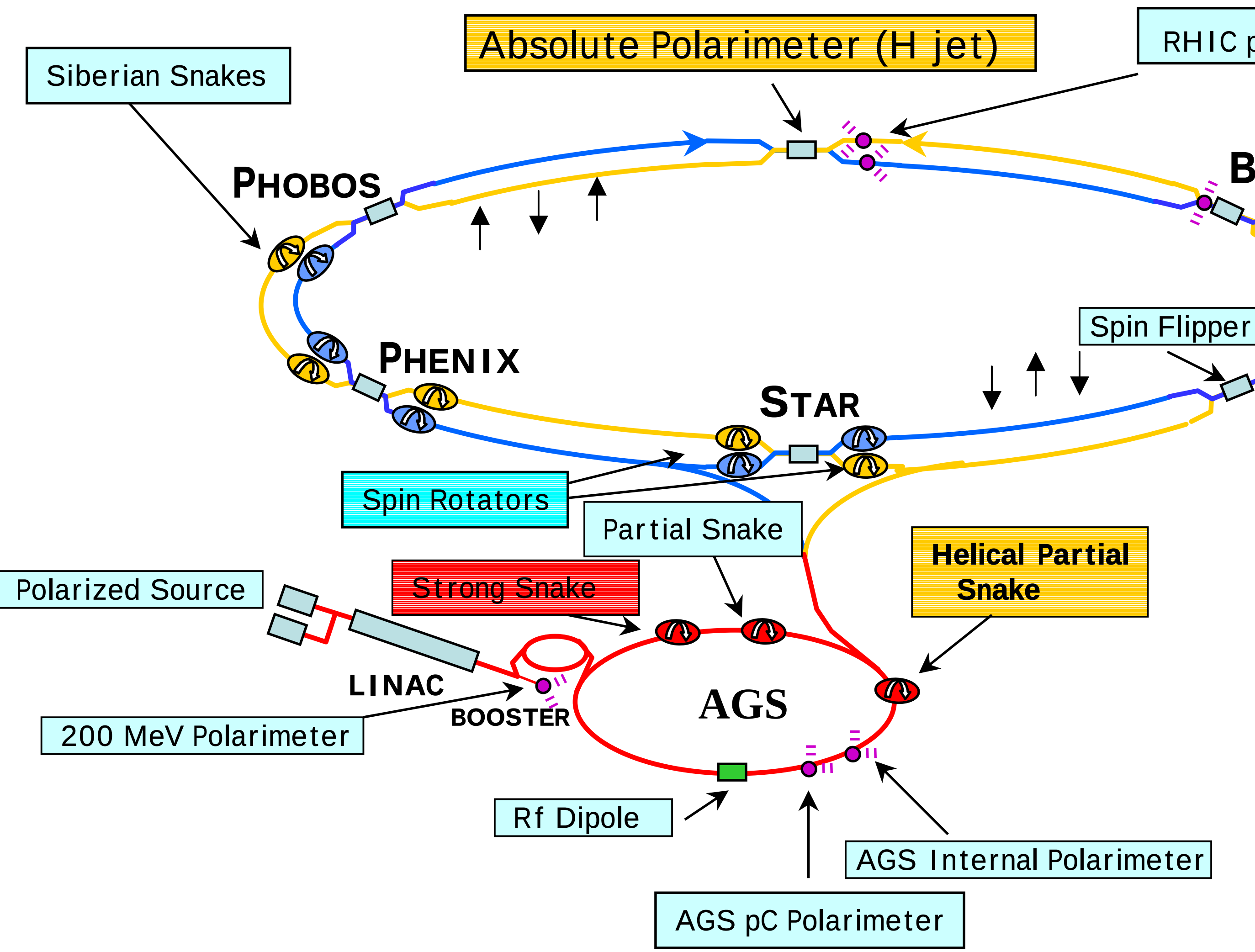
→ Brief PHENIX and STAR runs on A_T as $\int$ Ldt/week>10pb-1/week

Spin Rotators: Give flexibility!

The successful Development of a novel Experimental Method:

Polarized Proton Collisions!

source: Thomas Roser, BNL



Run 04 achieved:

$\sqrt{s} = 200\text{GeV},\ L_{peak} \sim 6\times10^{30}\ \text{cm}^{-2}\text{s}^{-1}$

P_b~45% , 55 bunches

New working point with long beam and polarization lifetimes

Run 05 planned:

Time to tune accelerator complex

Measure: A_{LL}(jets), $A_{LL}(\pi^0)$

Commission strong supercon-ducting AGS snake (see M. Bai's talk)

An Example: High Energy Proton Polarimeters for p=20-250 GeV/c

High Energy Polarimeter Requirement for RHIC Spin

- ❑ Absolute RHIC polarimeter
- ❑ Fast relative RHIC and AGS polarimeters for monitoring and tuning
- ❑ Local Polarimeters to confirm spin orientation at collision point

RHIC polarimetery relies on newly observed spin asymmetries:

- o Sizeable elastic proton-Carbon spin asymmetries at high energies
  - → J. Tojo et al. Phys. Rev. Lett. 89:052302, 2002
- o Very forward neutron asymmetries
  - → A. Bazilevsky et al. AIP Conf. Proc. 675: 584-588, 2003
- o Spin asymmetries in forward multiplicity production as seen by beam-beam counters in STAR
  - → J. Kiryluk, AIP Conf. Proc. 675, 424 (2003)

Run 04: The Polarized Jet Target for RHIC

Courtesy Sandro Bravar, STAR
and Yousef Makdisi, CAD

Polarized Hydrogen Gas Jet Target

thickness of > 10^{12} p/cm^2

polarization > 93% (+1 −2)%!

no depolarization from beam wake fields

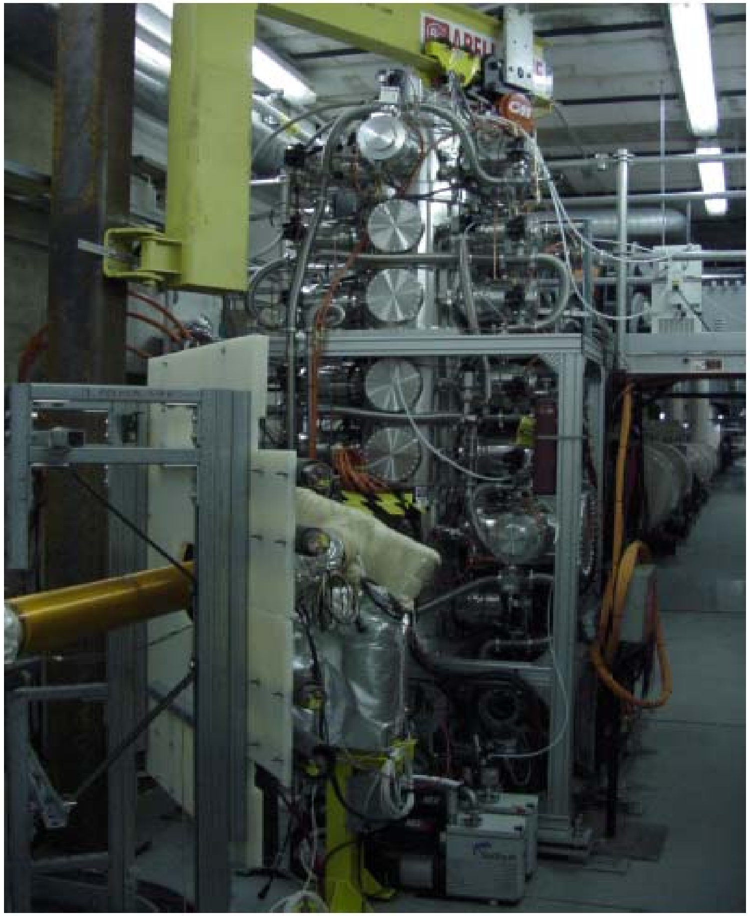
Silicon recoil spectrometer to measure

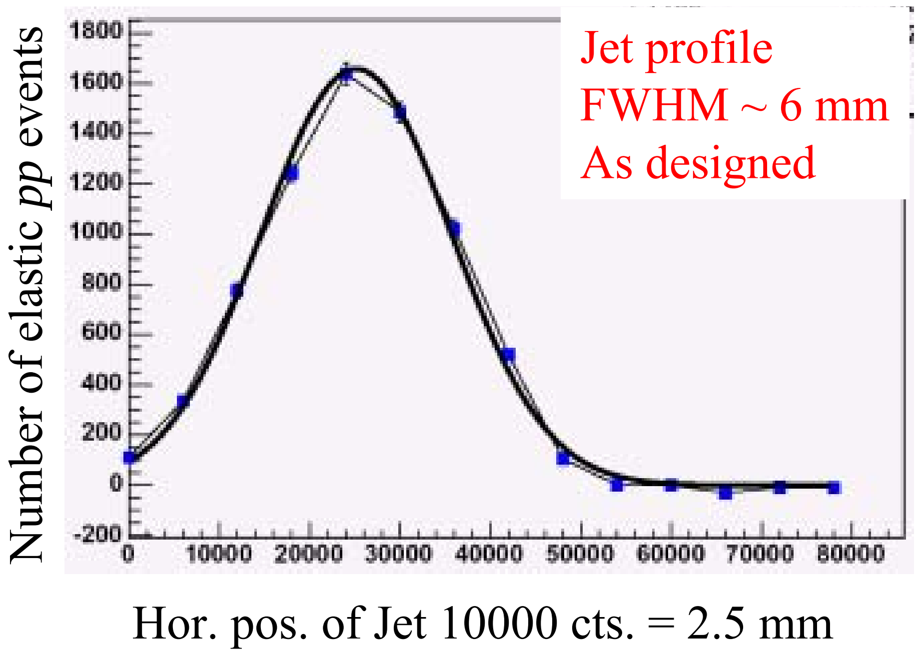
• The left-right asymmetry A_N in pp elastic scattering in the CNI region to $\Delta A_N < 10^{-3}$ accuracy.

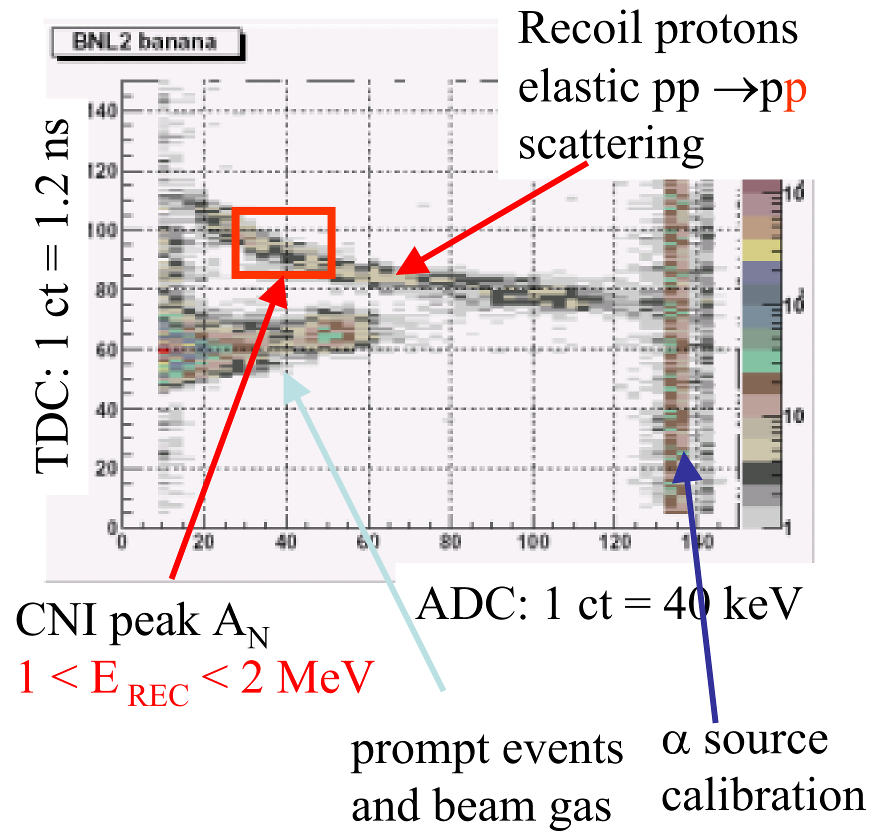
• Transfer this to the beam polarization

• Calibrate the p-Carbon polarimeters

• In 2004 we expect to measure P_B to 10%







Data collected so far in this run:

• 100 GeV ~ 700,000 events at the peak of the analyzing power (~ 3 x 10^6 total useful *pp* elastic events)
• 24 GeV ~ 120,000 events at the peak of the analyzing power (~ 5 x 10^5 total useful *pp* elastic events)

The RHIC Spin Collaboration

Forum to Coordinate Spin Issues for RHIC accelerator and Experiments: Develop overall Spin Plan

Participating groups:

RHIC-accelerator-spin group

RHIC Experimental Collaborations:

STAR, PHENIX, BRAHMS, pp2pp

Spokesman: Gerry Bunce

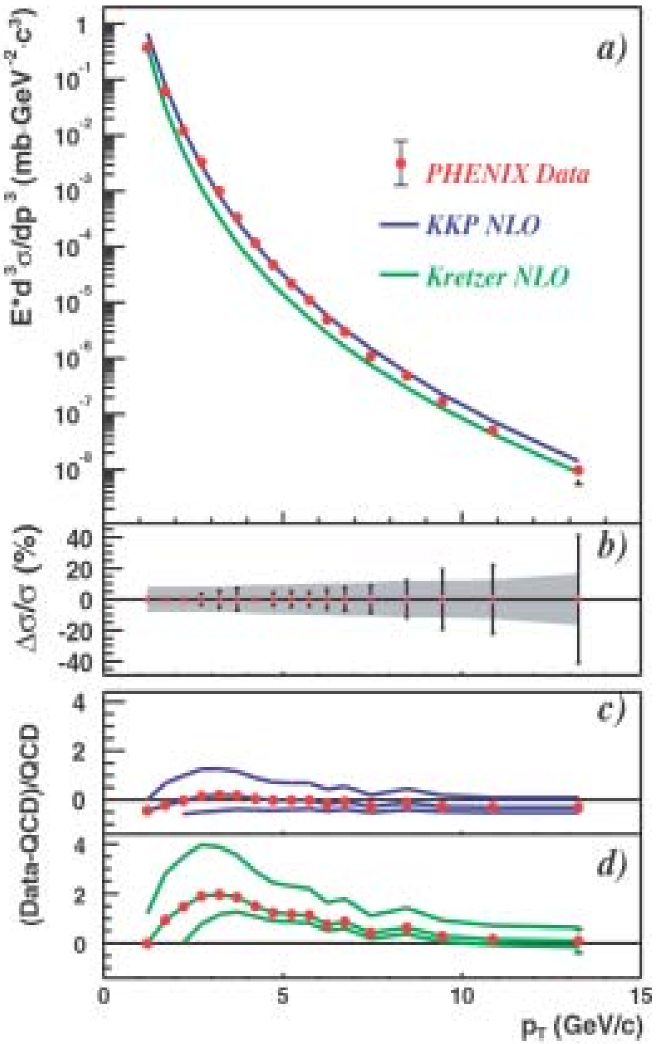
Two groups bring significant additional (to DOE) funding for RHIC physics (HI + spin):

- o IUCF NSF grant for STAR endcap EM-calorimeter: ~$6M
- o RIKEN support for PHENIX (eg. funding for one muon spectrometer), RHIC + AGS snakes and RBRC: ~ $70 M from 95-04.

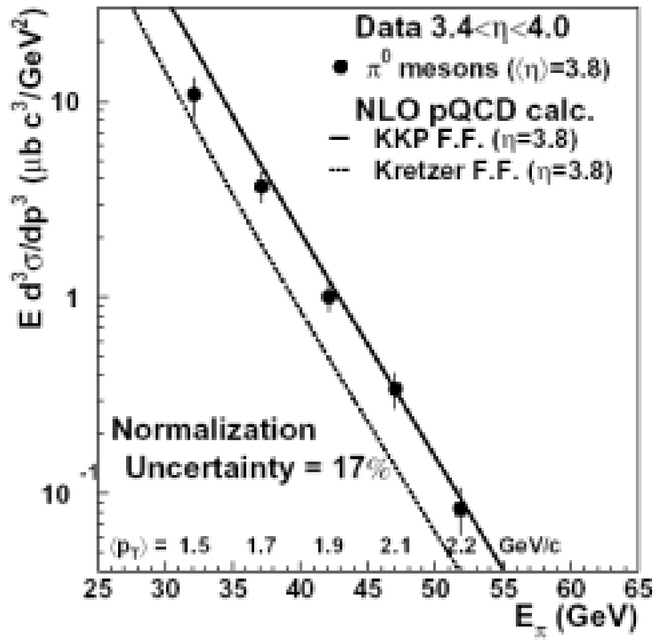
First Results: π^0 Cross sections

Run 02, $\int Ldt \sim 0.2pb^{-1}$

PHENIX π^0 cross section a $|\eta|<0.35$
Phys.Rev.Lett.91:241803,2003



STAR π^0 cross section a $3.4<\eta<4.0$
Phys.Rev.Lett.92:171801,2004



- o Good agreement between NLO pQCD calculations and experiment

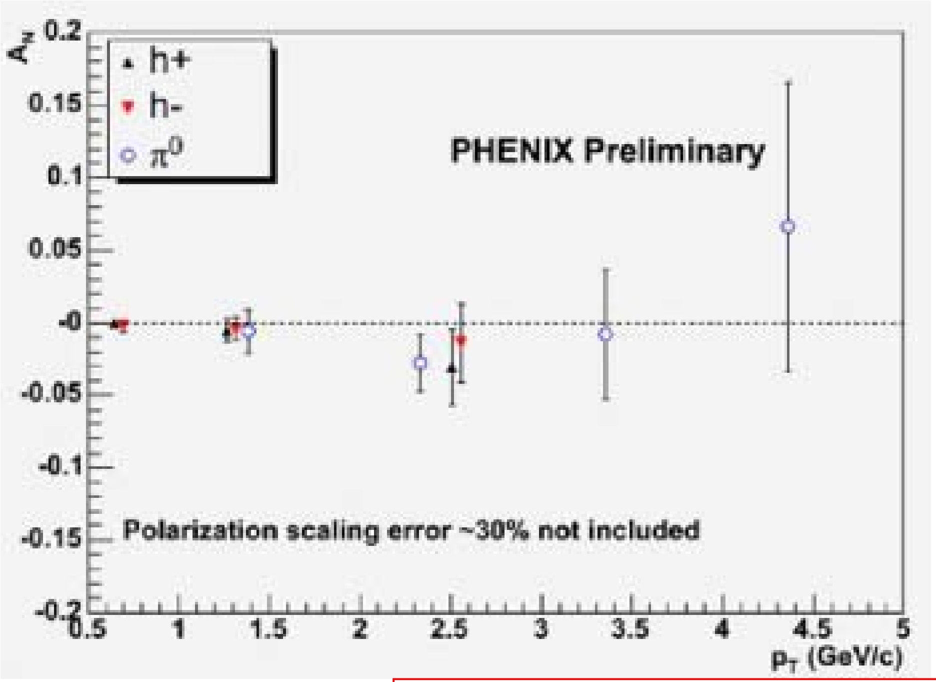
→ can use a NLO pQCD analysis to extract spin dependent pdfs from RHIC data!

First Results: A_N

Run 02, $\int Ldt \sim 0.2pb^{-1}$, P~0.15

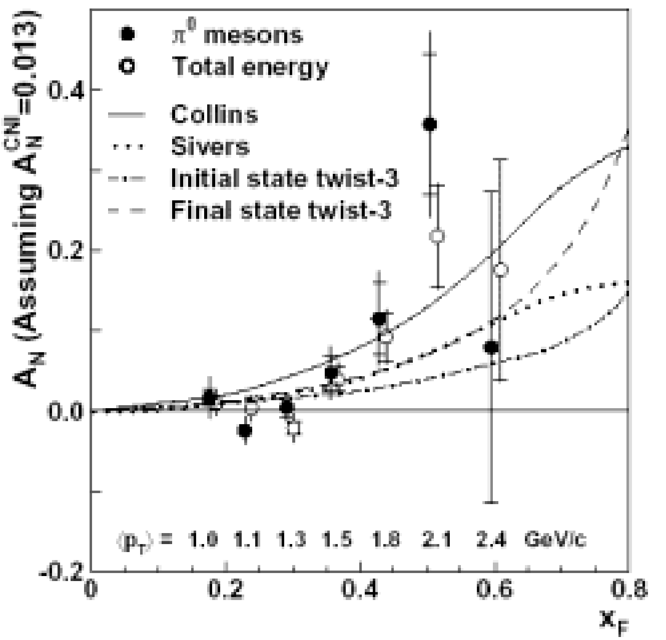
PHENIX $A_N(\pi^0)$ and $A_N(\pi 0)$ at $|\eta|<0.35$

C. Aidala, DIS 2004, to be published



STAR $A_N(\pi^0)$ at $3.4<\eta<4.0$

Phys.Rev.Lett.92:171801,2004

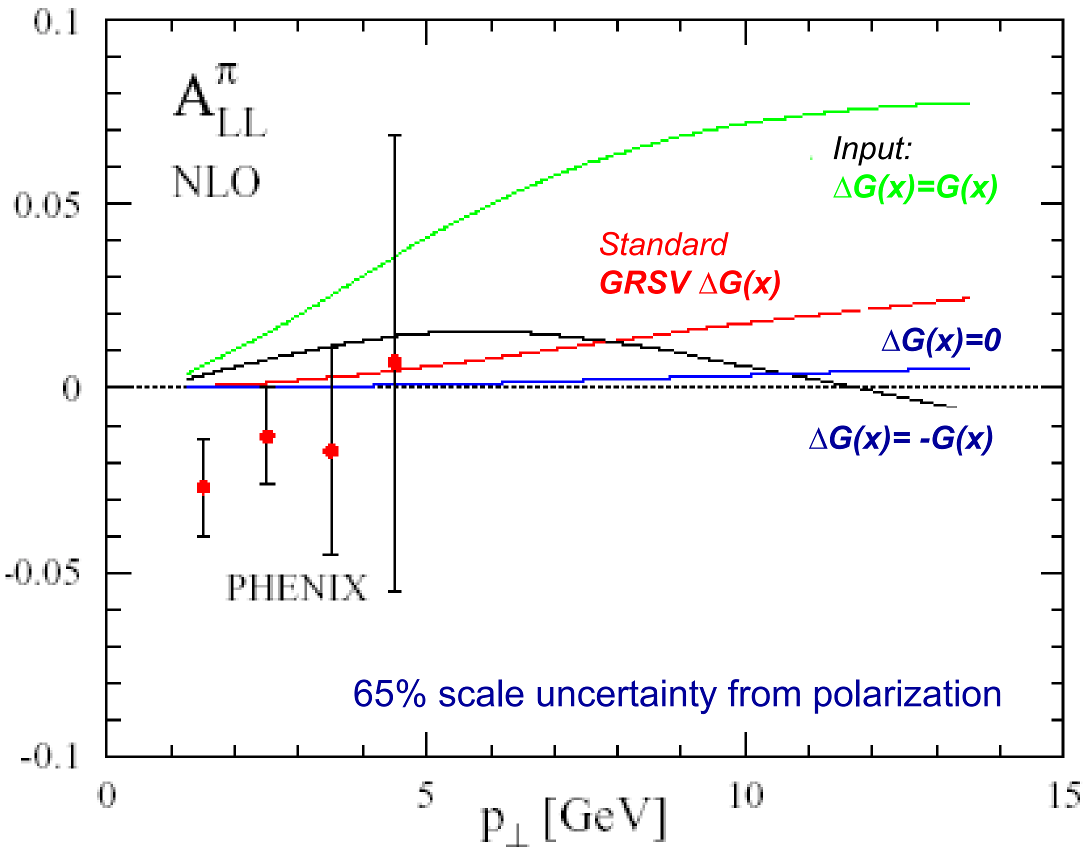


- First spin results from RHIC
  - → A_N sizeable in forward X_F
  - → A_N compatible with 0 at η~0 (as expected from pQCD)

- Experiments are ready for spin measurements at low luminosity
  - → relative luminosity ~ 5×10^{-4}
  - → trigger
  - → polarization analysis
  - → data analysis

First Results: A_{LL} Run 03, ∫Ldt ~ $0.2pb^{-1}$, P~0.25

PHENIX $A_{LL}(\pi^0)$ at |η|<0.35, hep-ex/0404027
plot from Vogelsang hep-ph/0405069



First results on longitudinal double spin asymmetries from RHIC

→consistent with DIS sample
→result disfavors large ΔG
→eg ∫Ldt = $3pb^{-1}$ and P-0.4 (2005) errors will reduce by factor 8

Experiments are ready for spin measurements at low to moderate luminosities!

→ relative luminosity ~$5x10^{-4}$
→ trigger
→ polarization analysis
→ data analysis

Future Operations for Polarized Protons

Highest Priority for Polarized Protons: Long polarized proton runs for optimization of the accelerator complex for polarized protons

Use 32 week scenario from the 20 year planning study for RHIC at BNL, December 31st, 2003:
(http://www.bnl.gov/henp/docs/20year_BNL71881.pdf)

“A very modest 3% ($4M) increment in the constant-effort annual RHIC funding will increase the running to 32 weeks per year and, most importantly, result in as much as a *30% gain in physics data taking time* and, in 6 some scenarios, *nearly double the net physics output* over a four-year sequence of runs. In fact, we concluded and indicate in this report, that 27 weeks per year is sub-critical for the type of running required for the RHIC program and 32 weeks is really the proper threshold level for a healthy program in both heavy ion and spin physics at RHIC.

Possible Schedule for Future Runs

example: STAR 32 week scenario → all schedules subject to further advances in RHIC operations!

L= $6x10^{30}cm^{-2}s^{-1}$ $8x10^{31}cm^{-2}s^{-1}$

P= 0.45 0.5 0.7 ……………………………………………

$\sqrt{s}$= ……………………….. 200 GeV ………………………..|

	2004	2005	2006	2007	2008	2009 ….
pp	5+1	5+10	5+11	0	5+9 ➔ $156pb^{-1}$	

Inclusive hadrons + Jets →

Transverse Physics →

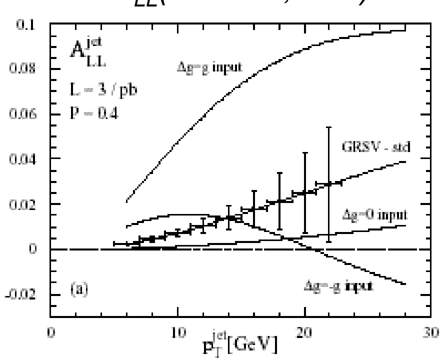
Charm Physics →

direct photons →

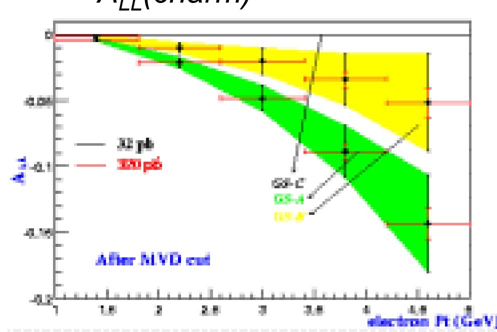
Bottom physics →

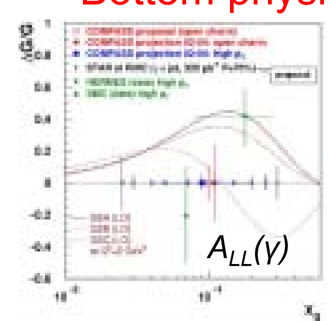
W-physics →

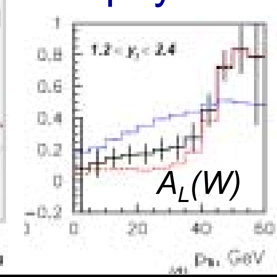
A_{LL}(hadrons, Jets)



A_{LL}(charm)







Impact of Upgrades on RHIC Spin

I) Upgrades required for core spin program
flavor separation of spin dependent quark distribution
in W-production

STAR: integrated forward tracking

PHENIX: muon trigger

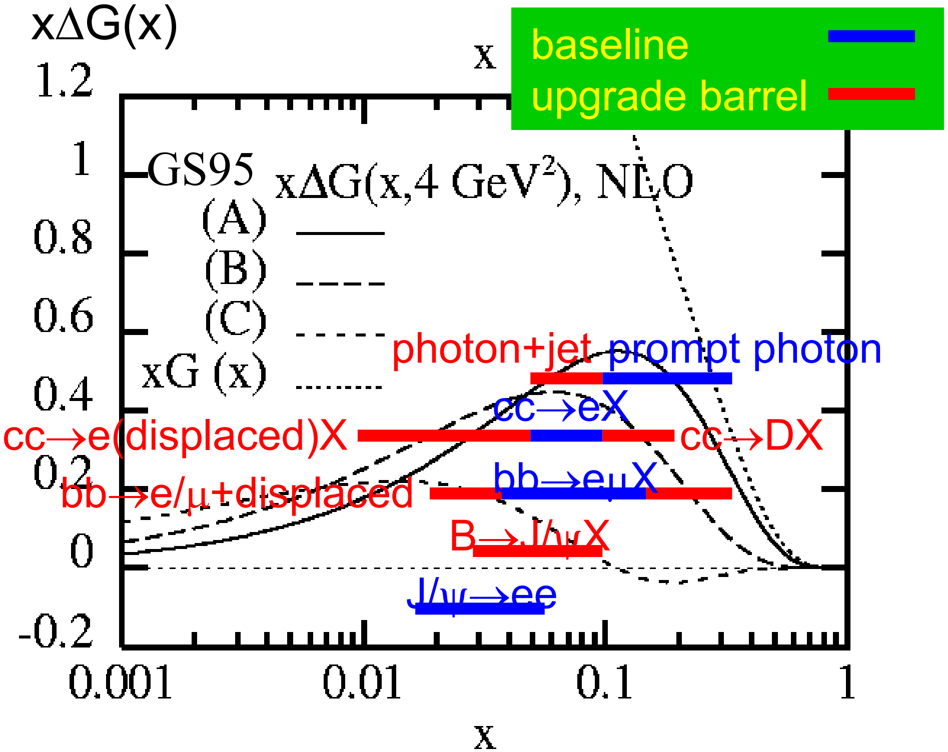
II) Upgrades aimed at a precision measurement of
the first moment $\int \Delta G(x)dx$ ➔ constrain orbital angular mometum?

STAR: micro vertex detector

PHENIX: Silicon Vertex Detector, nose cone calorimeter

Measuring the First Moment of ΔG(x)

- cc→eX
  - better S/N at low p_T
    - p_T=2-4GeV/c → 1-4GeV/c
    - x=0.05-0.1 → 0.01-0.1
- bb→e/μ+displaced-vertex
  - larger statistics comparing with eμ coincidence channel
    - x=0.04-0.15 → 0.02-0.3
- cc→DX, B→J/ψ
- photon+jet



Summary: Polarized Proton Collisions

- A new experimental method has been successfully developed and we are beginning to exploit a truly novel experimental tool on proton spin structure.

- Fixed target DIS experiments are carried out at comparably soft scales and are subject to diverse theoretical uncertainties. Leader-ship in the field will shift from DIS experiments to RHIC spin.

- Focus on sufficient operation time for polarized protons to optimize accelerator performance early ➔ maximum physics output.

- Integrated forward tracking (STAR) and muon trigger upgrades (PHENIX) are necessary for W-physics.

- Measurement of gluon spin (first moment) contribution to the proton spin requires larger kinematic range → eg. silicon vertex detector in PHENIX

Comments on Charge and Questions

Questions communicated by Carl Gagliardi

1) How does the anticipated time-line for the spin program mesh with those of the competition?

From 2005 double spin asymmetries in inclusive jet and hadron production will compete successfully in accessing gluon polarization. In general the DIS experiments are in a difficult situation due to (a) theoretical uncertainties at low scales (b) limited statistical precision (c) limited kinematic coverage. In transverse spin physics early A_N measurements at Brahms play an Important role and will be complementary to information from SIDIS.

2) How do the planned/required PHENIX and STAR detector upgrades impact the spin program?

Two upgrades: integrated forward tracking in STAR and the muon trigger upgrade are needed for the core spin program (W-physics).

Upgrades which add channels (heavy flavor) and in particular increase the kinematic coverage will make it possible to measure the first moment of the gluon polarization with increasing precision. This will be important in Discussing the spin sum rule for the proton (-> orbital angular momentum Contribution?)

Comments on Charge and Questions

Questions communicated by Carl Gagliardi

3) How do PHENIX and STAR plan to trade off between longitudinal and transverse spin running over the next several years in order to maximize the physics output?

This depends on the luminosity profile. Separate rotators at STAR and PHENIX give the possibility to re-act flexible and on short time scale. An example is given in the Talk: measure A_N whenever the weekly integrated luminosity is high enough to carry this measurement out quickly!

4) What is the minimum amount of beam time required by the RHIC Spin program over the coming years in order for it to meet its primary goals? What additional physics impact would be achieved with 25% more beam time?

We endorse the position in the 20 year plan that 32 weeks are best suited for the parallel advance of the heavy ion and spin physics program at RHIC. 25% more beam in the near future is likely to accelerate the learning curve and lead to high Integrated luminosity sooner (similar to the order of magnitude breakthrough in HI running in the 2004 run).

Comments on Charge and Questions

Charge from Peter Barnes

a. What has been accomplished so far in the RHIC spin program

1) Design, construction, installation and commissioning of all accelerator spin related hardware but the strong superconducting helical snake in the AGS (expected 2005).
2) Development of high energy proton polarimeters for RHIC and the AGS: relative CNI polarimeters, absolute hydrogen gas jet.
3) Precision control of the betatron tune of the machine and a working point with long beam and polarization life time.
4) Experimental verification (pi0 cross sections) that pQCD at RHIC energies provides a solid framework which can be used for extracting spin pdfs.
5) First spin asymmetry measurements. Development of required analysis techniques.

b. Physics goals over the next 10 years:

a) determine the gluon polarization over a broad kinematic range
b) study the spin flavor structure of the sea in the proton (W-production)
c) Study and characterize novel transverse effects found in SIDIS (transversity vs Sivers)
d) Precision measurement of the first moment of the gluon polarization.

Comments on Charge and Questions

Charge from Peter Barnes

c. What specific machine and detector capabilities and investments are essential to drive the program forward.

1) sufficient operation with polarized protons (32 week scenario)
2) upgrades to make W-physics possible
3) upgrades to extend kinematic range for the experiments: precision measurement of the first moment of ΔG.