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FORMAL REPORT

Proceedings of RIKEN BNL Research Center Workshop Volume 63

RHIC Spin Collaboration Meetings XXIV, XXV, XXVI *NSAC Review*

May 21, 2004
May 27, 2004
June 1, 2004

Organizers:

Akio Ogawa, BNL & Greg Rakness, BNL

RIKEN BNL Research Center

Building 510A, Brookhaven National Laboratory, Upton, NY 11973-5000, USA

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Preface to the Series

The RIKEN BNL Research Center (RBRC) was established in April 1997 at Brookhaven National Laboratory. It is funded by the "Rikagaku Kenkyusho" (RIKEN, The Institute of Physical and Chemical Research) of Japan. The Center is dedicated to the study of strong interactions, including spin physics, lattice QCD, and RHIC physics through the nurturing of a new generation of young physicists.

During the first year, the Center had only a Theory Group. In the second year, an Experimental Group was also established at the Center. At present, there are four Fellows and eight Research Associates in these two groups. During the third year, we started a new Tenure Track Strong Interaction Theory RHIC Physics Fellow Program, with six positions in the first academic year, 1999-2000. This program had increased to include ten theorists and one experimentalist in academic year, 2001-2002. With five fellows having already graduated, the program presently has eleven theorists and three experimentalists. Of these eleven RHIC Physics Fellows, five have been awarded/offered tenured positions, and this will be their final year in the program.

Beginning in 2001 a new RIKEN Spin Program (RSP) category was implemented at RBRC. These appointments are joint positions of RBRC and RIKEN and include the following positions in theory and experiment: RSP Researchers, RSP Research Associates, and Young Researchers, who are mentored by senior RBRC Scientists. A number of RIKEN Jr. Research Associates and Visiting Scientists also contribute to the physics program at the Center.

RBRC has an active workshop program on strong interaction physics with each workshop focused on a specific physics problem. Each workshop speaker is encouraged to select a few of the most important transparencies from his or her presentation, accompanied by a page of explanation. This material is collected at the end of the workshop by the organizer to form proceedings, which can therefore be available within a short time. To date there are xx proceeding volumes available.

The construction of a 0.6 teraflops parallel processor, dedicated to lattice QCD, begun at the Center on February 19, 1998, was completed on August 28, 1998. A 10 teraflops QCDOC computer in under development and expected to be completed this year.

N. P. Samios, Director
April 1, 2004

*Work performed under the auspices of U.S.D.O.E. Contract No. DE-AC02-98CH10886.

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Contact Information

3 June 2004

Hello Spinners—

This set of RHIC Spin Collaboration meetings provided information for the three spin speakers for the NSAC subcommittee (chaired by Peter Barnes) review of RHIC. The charge of the committee, the agenda, and then the three presentations follow.

The presentations were

RHIC Spin

Werner Vogelsang, Physics Overview

Matthias Grosse Perdekamp, Experimental issues/upgrades

Mei Bai, Machine Goals

Gerry and Akio

U.S. Department of Energy
and the
National Science Foundation

February 18, 2004

Professor Richard F. Casten
Chairman
DOE/NSF Nuclear Science Advisory Committee
Wright Nuclear Structure Laboratory
Yale University
New Haven, CT 06520

Dear Professor Casten:

The recent 2002 Long Range Plan (LRP) developed by the Nuclear Science Advisory Committee (NSAC) provided a set of recommendations for exploiting opportunities for research both within the United States and elsewhere. Further guidance is requested from the NSAC by the Department of Energy (DOE) at this time beyond these recommendations in the LRP in the area of heavy-ion nuclear physics. Effective use of the Relativistic Heavy Ion Collider (RHIC) and investments in new capabilities and initiatives at RHIC and elsewhere were identified as the means to exploit the potential scientific opportunities of this subprogram. The limitations on the implementation of this guidance, imposed by projected funding, make it timely for an updated assessment of the scientific priorities in this area, especially in light of new results obtained at RHIC. It is important that the available resources are directed to optimize DOE efforts, in coordination with the Nuclear Physics program at the National Science Foundation (NSF), for a strong national research program in this scientific area in the coming decade.

The NSAC is asked to examine current and proposed U.S. efforts in heavy-ion nuclear physics and identify what scientific opportunities should be pursued, in the context of U.S. and international capabilities and available resources, to ensure an optimized national research program. In your examination of these facilities and research activities, please respond to the following questions:

> What scientific opportunities should be addressed and what facility and instrumentation capabilities should be used and developed, including those supported by NSF and outside the United States, in order to maintain a strong scientific program in the coming decade?
>
> What opportunities can be pursued with funding at the FY 2005 Budget Request level ($158.9 million) and an assumed constant level of effort into the out years? What is the appropriate mix of facility operations, research, computer support, investments in instrumentation and accelerator capabilities, and detector and accelerator R&D that will be needed to optimally exploit these opportunities?

What are the priorities of the scientific opportunities that could be pursued with additional funds beyond this constant level of effort?

Your perspective should primarily focus on the 5-year period FY 2006-2010. The impacts and benefits of pursuing these prioritized activities, as well as the impact of not being able to pursue an activity, should be clearly articulated. The resulting plans should be consistent with a set of research milestones recently established for the heavy-ion subprogram and validated by NSAC, unless it can be demonstrated that new information would suggest that these milestones should be amended. We request that an interim report be submitted by July 31, 2004, and a written report responsive to this charge be provided by September 30, 2004.

Thank you very much in advance for your efforts in addressing this important issue.

Sincerely,

Raymond L. Orbach
Director
Office of Science

Michael S. Turner
Assistant Director
Directorate for Mathematical
and Physical Sciences

cc:
Bradley D. Keister, NSF

Last updated by Liz Mogavero

Last modified 05/17/2004 12:46:19

Committee Members

Chairperson: Peter Barnes

ex-officio: Richard Casten

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May 18, 2004

NSAC Subcommittee on Heavy Ion Physics

Agenda, Public Sessions
Large Seminar Room, BNL Physics Dept.
June 2 – 6, 2004

Please note: you will need Acrobat Reader 6.0 to read some of the PDF files.

8:30 AM Wednesday, June 2

I. Opening Remarks,

A. Welcome	Praveen Chaudhari
B. Charge to NSAC and Subcommittee	Dennis Kovar/Brad Keister
C. NSAC HI Review: Motivation and Process	Peter D. Barnes

II. Physics Opportunities with Heavy Ion Reactions

A. Recent Progress at RHIC

9:15 Star Collaboration assessment	Raimond Snellings [15]
9:30 Phobos Collaboration assessment	Wit Busza [10]
9:50 PHENIX Collaboration assessment	Yasuyuki Akiba [15]
10:05 Brahms Collaboration assessment	Flemming Videbaek [10]

10:25 Coffee

B. Opportunities for the Future(part 1)

10:55 Evolution of Physics-goals	Miklos Gyulassy[20]
11:35 Evolution of Physics-goals	Jean Paul Blaizot [20]
12:15 Next ten years of physics at RHIC	Bill Zajc [25]

1:00 Lunch

2:00 The physics opportunity at the LHC	Bolek Wyslouch [15]

III. Experimental Programs

A. RHIC

2:30 BNL Long-term plan for RHIC	Sam Aronson [25]
3:15 RHIC Luminosity Upgrade (Electron Cooler & EBIS Source)	Thomas Roser [25]

4:00 Coffee

Unpolarized Collisions

4:30	a. STAR- Future Program	Tim Hallman[25]
5:15	TOF Barrel Upgrade	Richard Majka[15]
5:45	Silicon MicroVertex Detector	Howard Wieman [15]

6:15 END Wednesday

6:30 Reception

May 18, 2004

8:30 AM Thursday, June 3

III.A RHIC Experimental Programs

Unpolarized Collisions (cont.)

8:30	b. PHENIX- Future Program	Axel Drees [25]
9:15	Silicon Vertex Tracker	Craig Ogilvie [15]
9:40	Nose Cone Cal/W boson trig.	Ken Barish [15]
10:05	c. Forward Physics at RHIC	Les Bland [20]

10:40 Coffee

d. New Detectors

11:10	New General Purpose Detector	Thomas Ullrich [20]

Opportunities for the Future(part 2)

11:45	Evolution of Physics-goals	Dima Kharzeev [20]
12:25	Evolution of RHIC Physics	Ed Shuryak [20]

1:05 Lunch

2:00	Evolution of Physics-goals	Berndt Mueller [20]
2:40	Lattice QCD for HI physics	Frithjof Karsch [20]

GSI

3:20	HI Physics Opportunity at GSI	Bengt Friman [20]
3:55	HI Physics and Experiments FAIR@GSI	Peter Braun-Munzinger[20]

4:30 coffee

RHIC SPIN

4:50	Objectives for Spin Physics at RHIC	Werner Vogelsang [20]
5:25	Experimental Issues/upgrades	Matthias Perdekamp [20]
6:00	Machine Goals	Mei Bai [15]

6:25 END Thursday

MAY 18, 2004

8:30 AM Friday, June 4

ELECTRON-ION COLLIDER

8:30	Overview-Electron Ion Collisions	Raju Venugopalan [20]
9:05	Realization at e-RHIC	Richard Milner[20]
9:40	Detector Issues for e-RHIC	Abhay Deshpande [15]
10:05	Realization at e-LIC	Rolf Ent [20]

10:40 Coffee

LHC

11:00	Physics Overview	Keijo Kajantie [20]
11:35	ALICE	Thomas Cormier [15]
12:05	ATLAS	Helio Takai [15]
12:35	CMS	Russell Betts [15]

1:05 Lunch

Fermilab

2:00	Gluon physics at the Tevatron	Mike Albrow[20]

IV. Physics – Computational Issues

2:35	Dynamic Modeling of RHIC collisions	Steffen Bass [10]
2:55	Data processing requirements	Bruce Gibbard [10]

3:15 Coffee

V. The HI physics community

3:45	The RHIC User Community	Vicki Greene [10]
4:00	**Comments and Discussion from the Floor** [60]	

VI. Long Range View

5:00	Theory Outlook	Larry McLerran[20]
5:30	BNL Outlook	Tom Kirk [20]

Final Questions from the Subcommittee

6:15 END **Friday**

End of Public Sessions

Subcommittee Executive Sessions:

Saturday, June 5	8:00 AM to 7:00 PM
Sunday, June 6	8:00 AM to 1:00 PM

Objectives for Spin Physics at RHIC

Werner Vogelsang

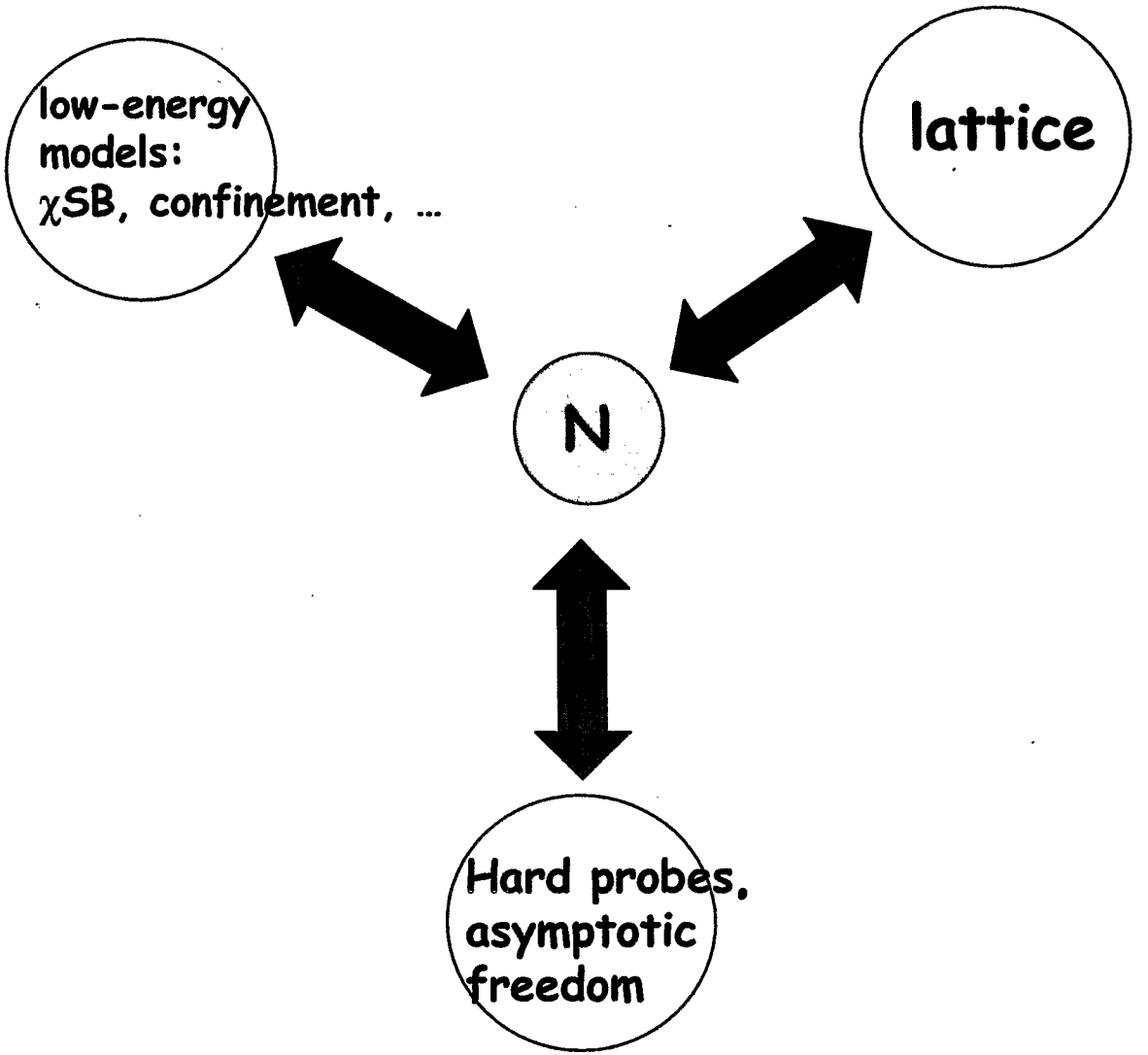
RBRC & BNL Nuclear Theory

NSAC Review Meeting 06/03

Outline:

- What have we learned so far?
- What are the challenges in QCD spin physics over the next ~10 years?
- **What do we expect from RHIC, and what is the impact of other activities ?**

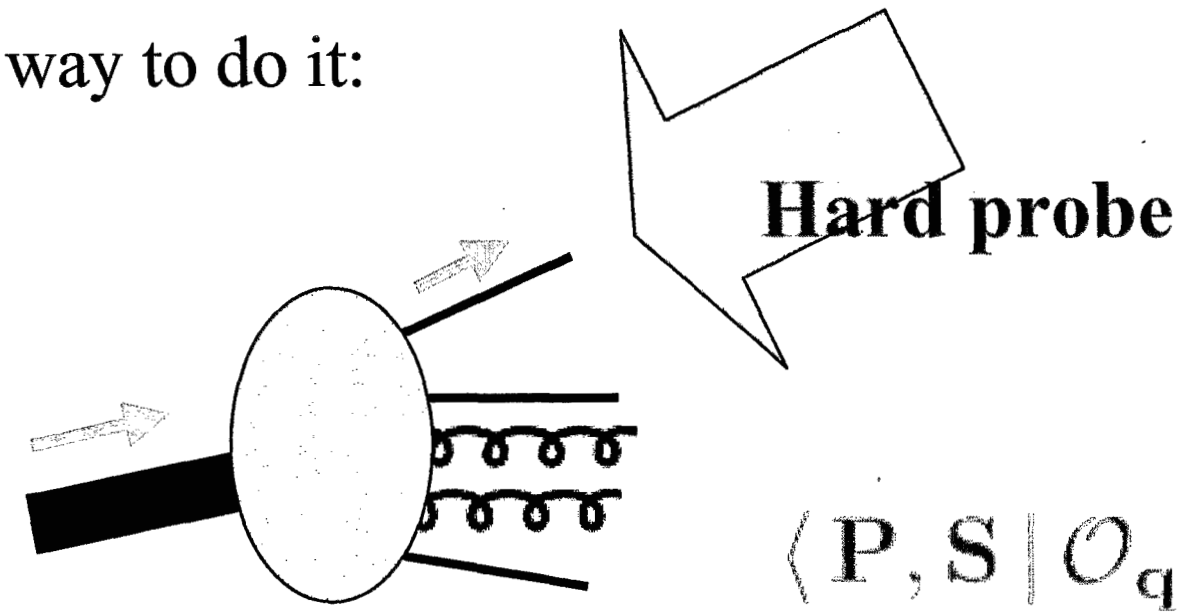
Exploring the nucleon: at the forefront of QCD



- Main goal of QCD spin physics:

To understand the spin structure of hadrons in terms of quarks and gluons

- The way to do it:



$$\langle \mathbf{P}, \mathbf{S} | O_{q,g} | \mathbf{P}, \mathbf{S} \rangle$$

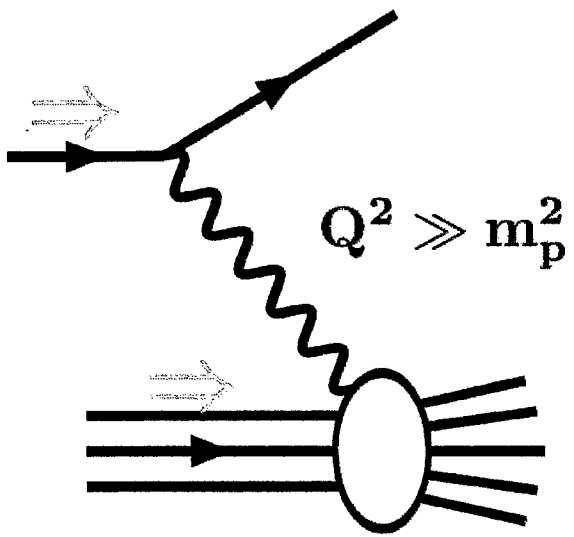
Famous examples:

$$\langle \mathbf{P}, \mathbf{S} \,|\, \bar{\mathbf{q}}\, \gamma^{\mu}\, \gamma^{5}\, \mathbf{q} \,|\, \mathbf{P}, \mathbf{S} \rangle \;\propto\; \text{axial charge}$$ **quark spin**

$$\langle \mathbf{P}, \mathbf{S} \,|\, \bar{\mathbf{q}}\, \mathbf{i}\, \sigma^{\mu\nu}\, \gamma^{5}\, \mathbf{q} \,|\, \mathbf{P}, \mathbf{S} \rangle \;\propto\; \text{tensor charge}$$ **transversity**

What are the probes ?

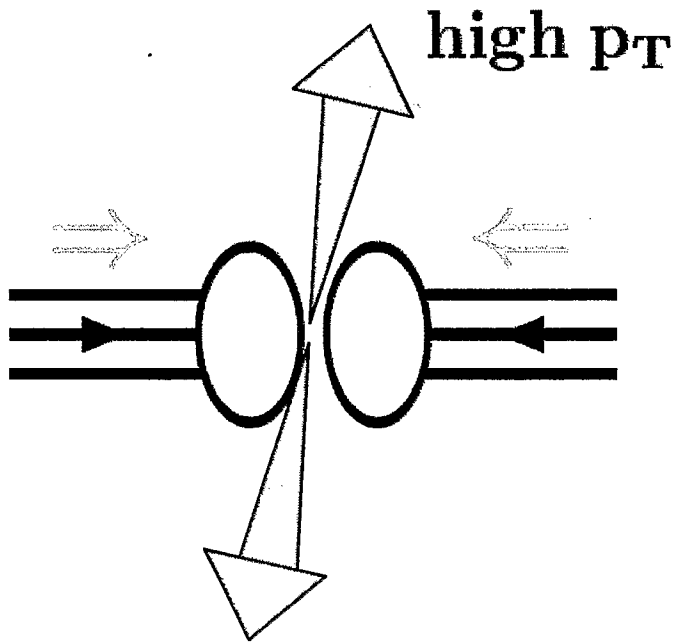
Polarized DIS



SLAC, CERN, DESY, Jlab, eRHIC

a powerful probe of quarks
(but sees gluons, too!)

pp scattering



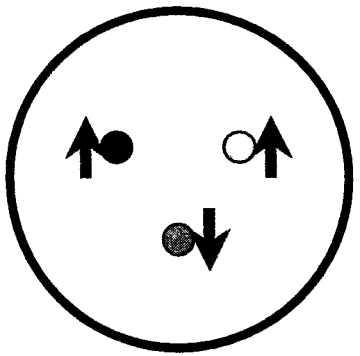
RHIC

a powerful probe of gluons
(but sees quarks, too!)

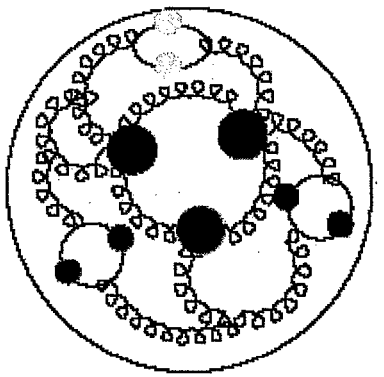
What have we learned so far ?

- **the main lesson:** The nucleon spin is quite subtle !

Quark Model



QCD

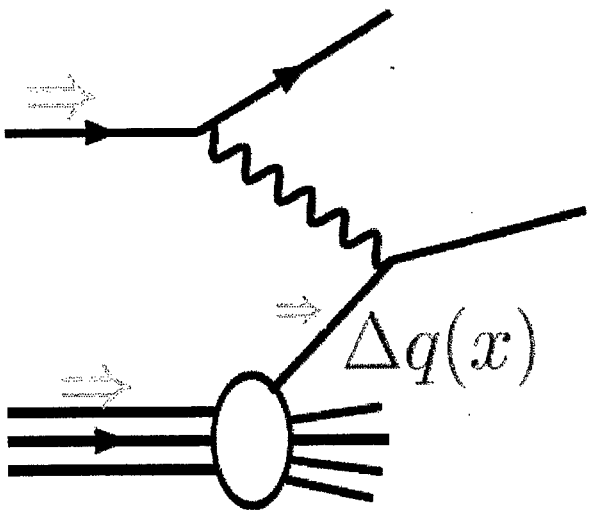


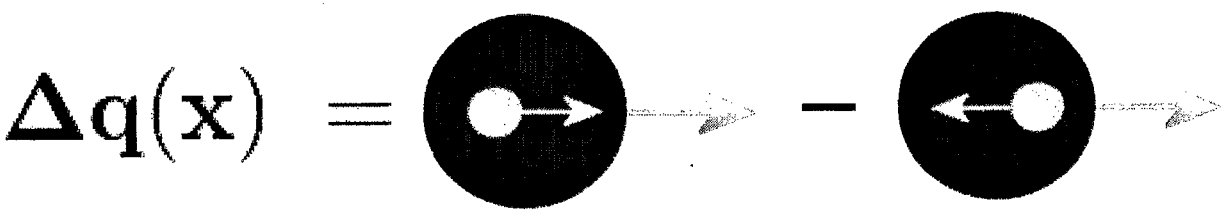
gluons, $q\bar{q}$ pairs, orbital, interactions, renormalization

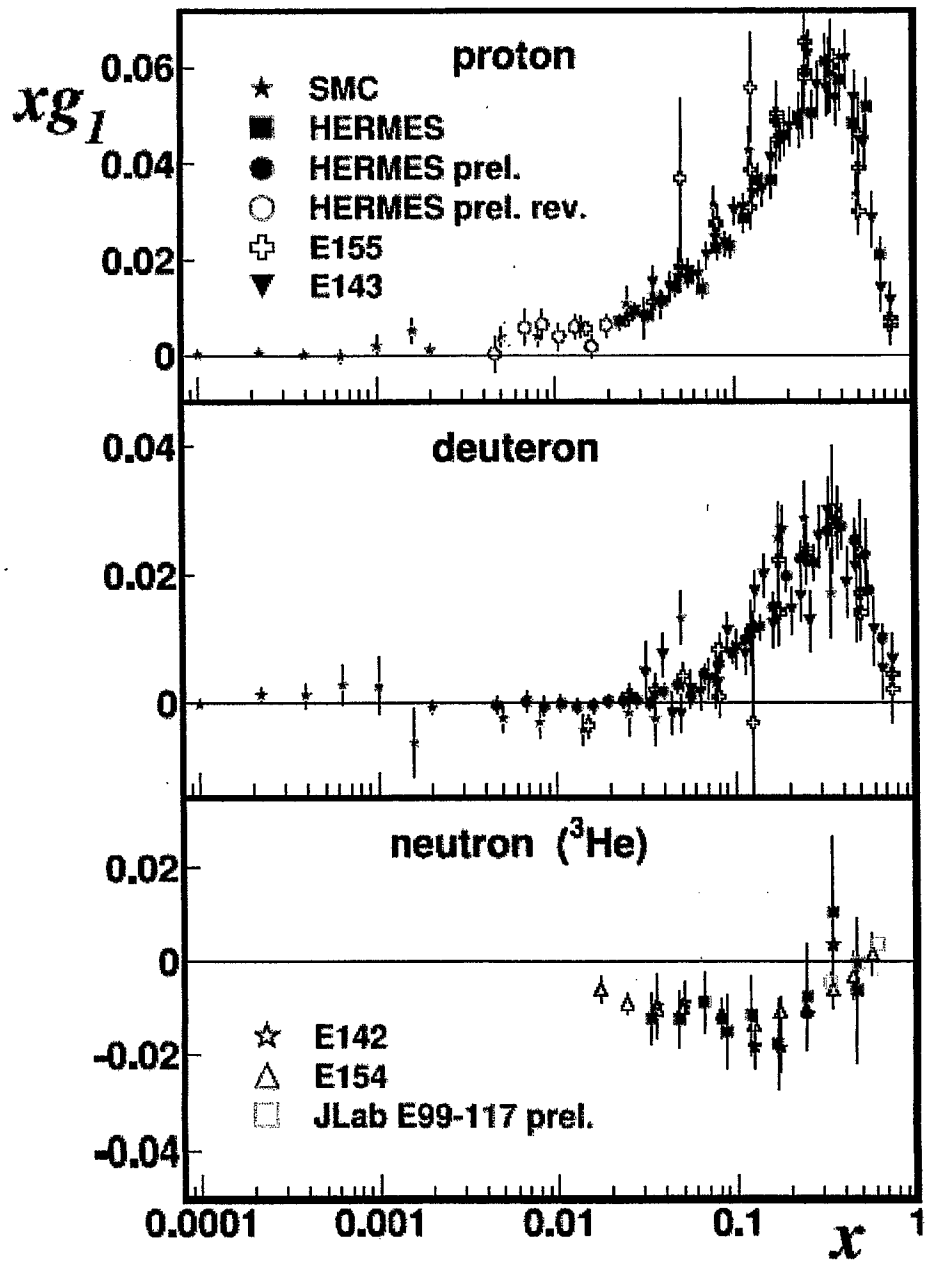
$$\frac{1}{2} = \langle \mathbf{S_q} \rangle + \langle \mathbf{S_g} \rangle + \langle \mathbf{L_q} \rangle + \langle \mathbf{L_g} \rangle \Big|_{Q^2}$$

$$\langle \mathbf{S_q} \rangle \approx 0.1$$

* **Result of the hugely successful program of polarized DIS**



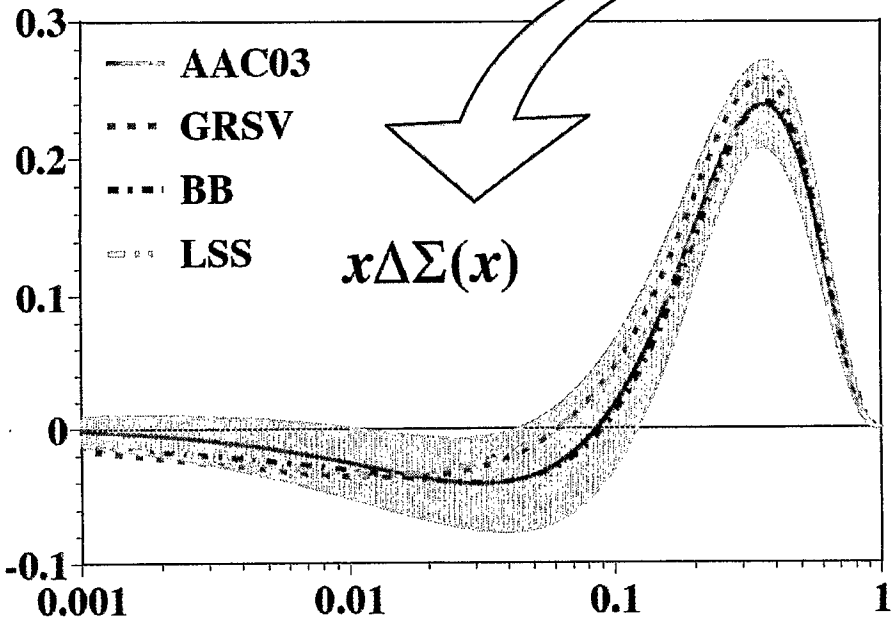




$$g_1 \sim \sum_q e_q^2 \left[\Delta q(x) + \Delta \bar{q}(x) \right]$$

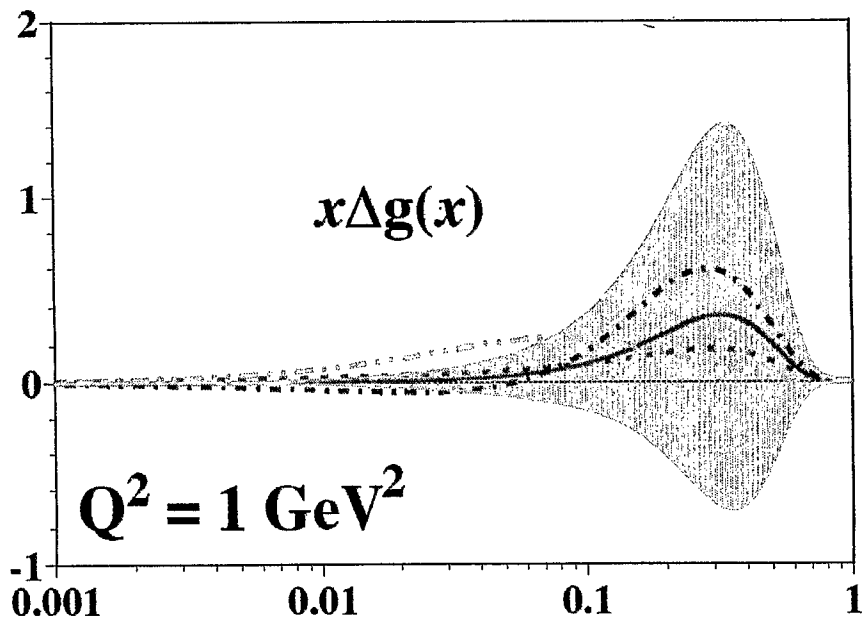
+ QCD scaling violations

Hirai, Kumano, Saito

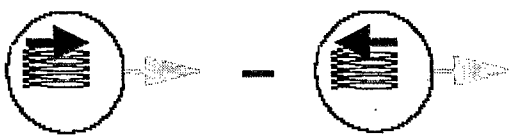


$$\Delta\Sigma = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}$$

$$\langle S_q \rangle = \frac{1}{2}\int_0^1 dx\, \Delta\Sigma(x)$$



gluon polarization ?

$\Delta g(x) =$ 

weak constraint from scaling violations

Challenges in QCD spin physics

RHIC

- What else carries the proton spin ?
  - → How are gluons polarized ?
  - → How large are parton orbital ang. mom. ?

"DVCS"
$\gamma^* p \rightarrow \gamma p$

- What are the detailed patterns of quark & antiquark polarizations ?
  - → Flavor asymmetries in sea ?

- Is there significant transversity in the nucleon ?

- What are the origins of large observed single-spin asymmetries ?
  - → Correlations between transverse spin and parton k_T ?

Complementary information : HERMES, COMPASS, Jlab, eRHIC

Challenges in QCD spin physics

- What else carries the proton spin ?

  → How are gluons polarized ?

  → How large are parton orbital ang. mom. ?

- What are the detailed patterns of quark & antiquark polarizations ?
  → Flavor symmetry breakings in sea ?

- Is there significant transversity in the nucleon ?

- What are the origins of large observed single-spin asymmetries ?
  → Correlations between transverse spin and parton k_T ?

Gluon polarization

- **a key contributor to the proton spin ?**
- $\langle S_g \rangle = \int_0^1 dx\, \Delta g(x, Q^2) \propto \frac{1}{\alpha_s(Q^2)}$ **in QCD**
- **some model predictions (Q ≈ 0.5 GeV) :**

$\langle S_g \rangle = -0.4$ (Jaffe, bag model)

$\langle S_g \rangle = +0.25$ (Barone et al., Isgur – Karl)

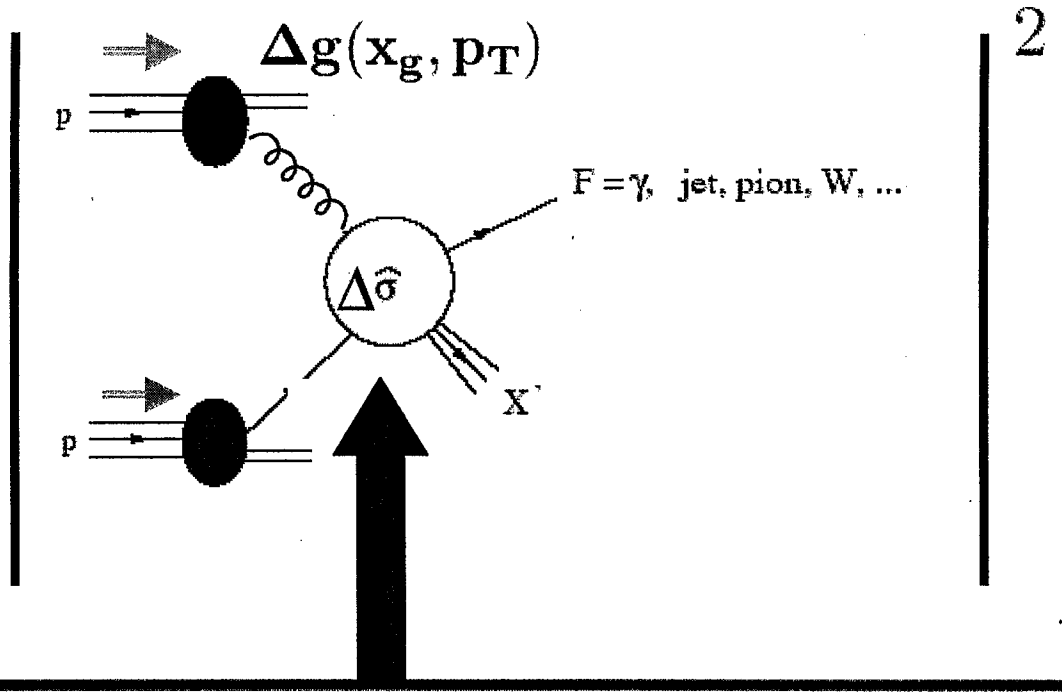
$\langle S_g \rangle = +0.3$ (Rho et al., chiral bag)

...

- **gluons subdominant in inclusive DIS**
  - Q^2 evolution $\rightarrow$ need large lever arm
  - single out "photon-gluon fusion"

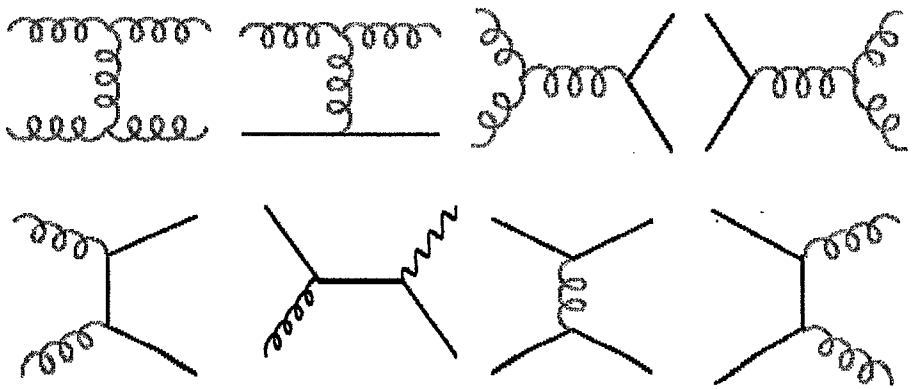
    $\gamma \mathbf{g} \rightarrow \mathbf{c\bar{c}}$, $\gamma \mathbf{g} \rightarrow \mathbf{h^+ h^- X}$ [very difficult theory !]

- **gluons are "leaders" at hadron colliders ...**



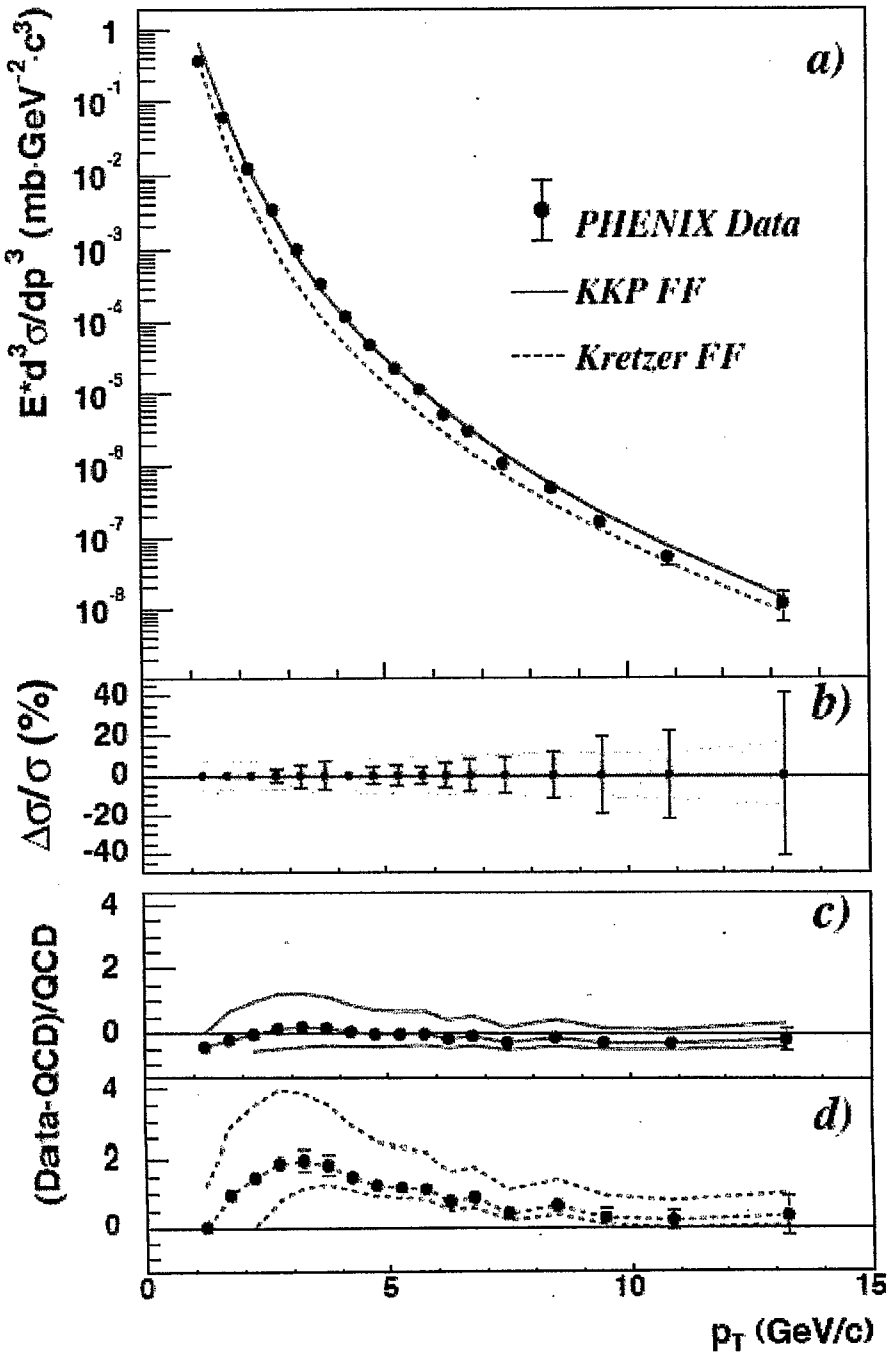
2

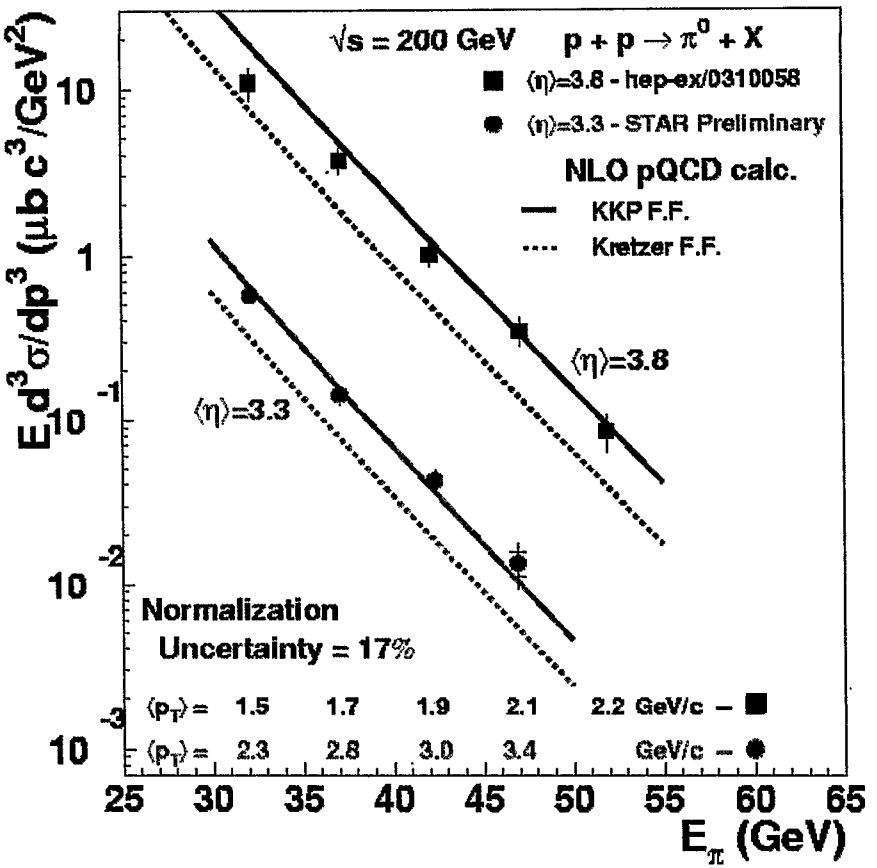
pQCD:

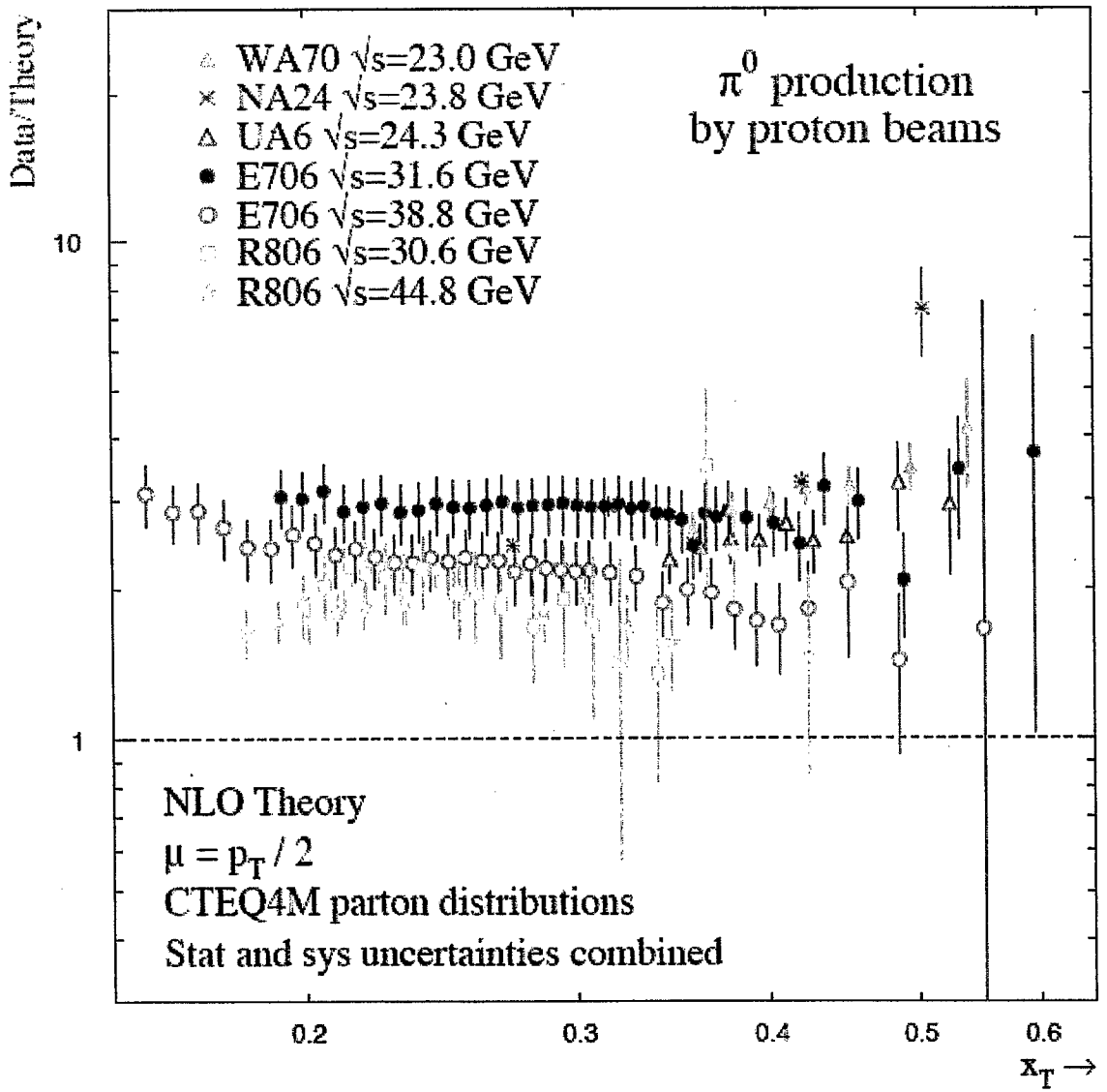


+NLO

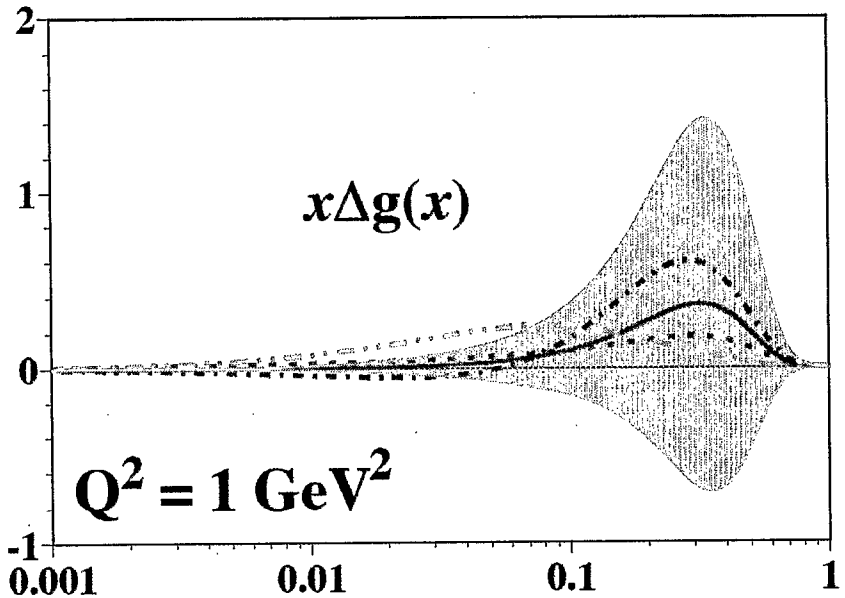
$pp \to \text{jet}\, X,\ pp \to \pi X,\ pp \to \gamma X,\ pp \to Q\bar{Q}\, X, \ldots$

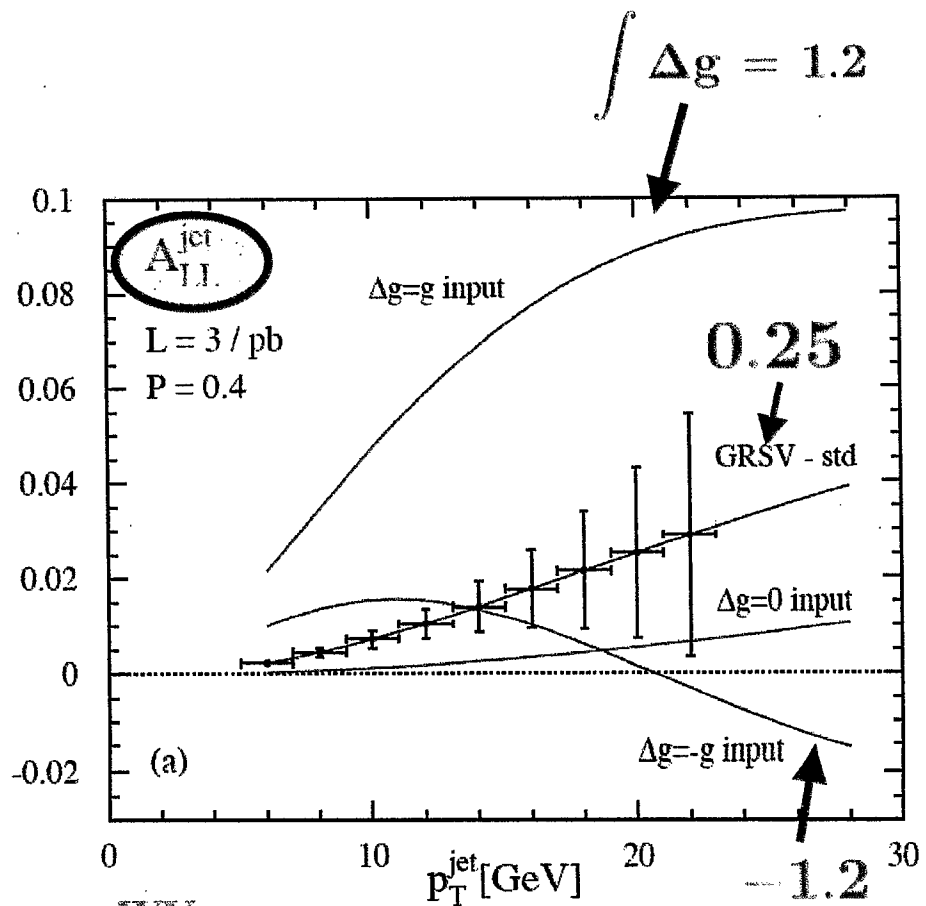

a)
PHENIX Data
KKP FF
Kretzer FF
$E^*d^3\sigma/dp^3$ (mb·GeV^{-2}·c^3)
b)
$\Delta\sigma/\sigma$ (%)
c)
d)
(Data-QCD)/QCD
p_T (GeV/c)


$\sqrt{s}$ = 200 GeV
$p + p \rightarrow \pi^0 + X$
⟨η⟩=3.8 - hep-ex/0310058
⟨η⟩=3.3 - STAR Preliminary
NLO pQCD calc.
KKP F.F.
Kretzer F.F.
⟨η⟩=3.8
⟨η⟩=3.3
Normalization
Uncertainty = 17%
⟨p_T⟩ = 1.5 1.7 1.9 2.1 2.2 GeV/c
⟨p_T⟩ = 2.3 2.8 3.0 3.4 GeV/c
E_π (GeV)
$Ed^3\sigma/dp^3$ (μb c^3/GeV^2)


Data/Theory
WA70 √s=23.0 GeV
NA24 √s=23.8 GeV
UA6 √s=24.3 GeV
E706 √s=31.6 GeV
E706 √s=38.8 GeV
R806 √s=30.6 GeV
R806 √s=44.8 GeV
π0 production
by proton beams
10
1
NLO Theory
μ = pT / 2
CTEQ4M parton distributions
Stat and sys uncertainties combined
0.2
0.3
0.4
0.5
0.6
xT →

Near-term example: spin asymmetry for jet production





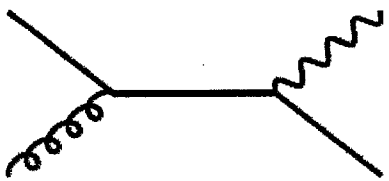
Jager, Stratmann, WV

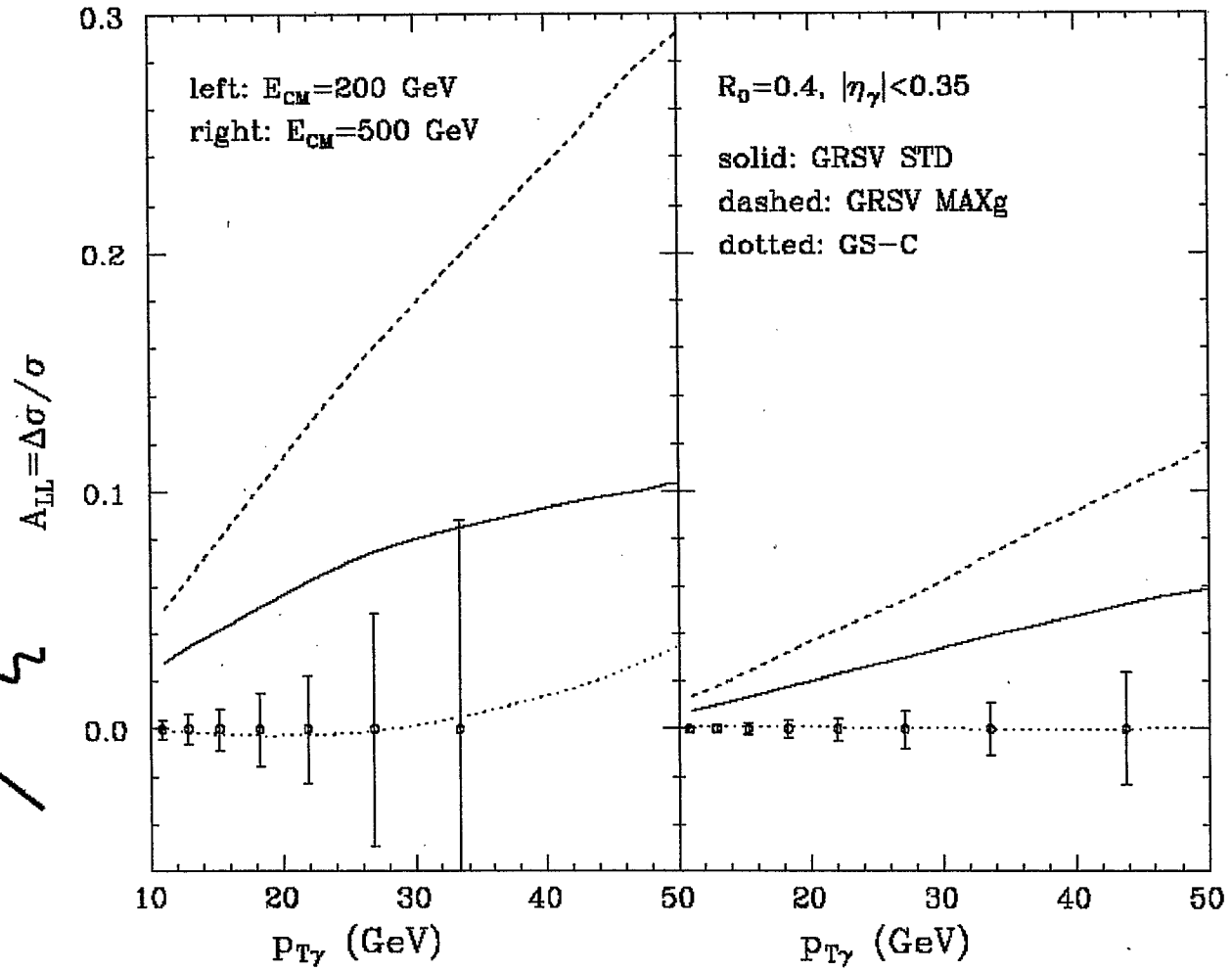
Mid / long-term at RHIC: **"rare probes"**

- gluon polarization from $\mathbf{pp \rightarrow \gamma X}$

L=100/pb

Frixione,WV





- **main information is at** $x_g \sim 2\,p_T/\sqrt{s}$

  typically, $0.025 < x_g < 0.3$ @ $\sqrt{s} = 200$ GeV

  $0.01 < x_g < 0.1$ @ $\sqrt{s} = 500$ GeV

- **to get integral, may need to expand this:**
  - * forward pp scattering
  - * scaling violations at small-x at **eRHIC**

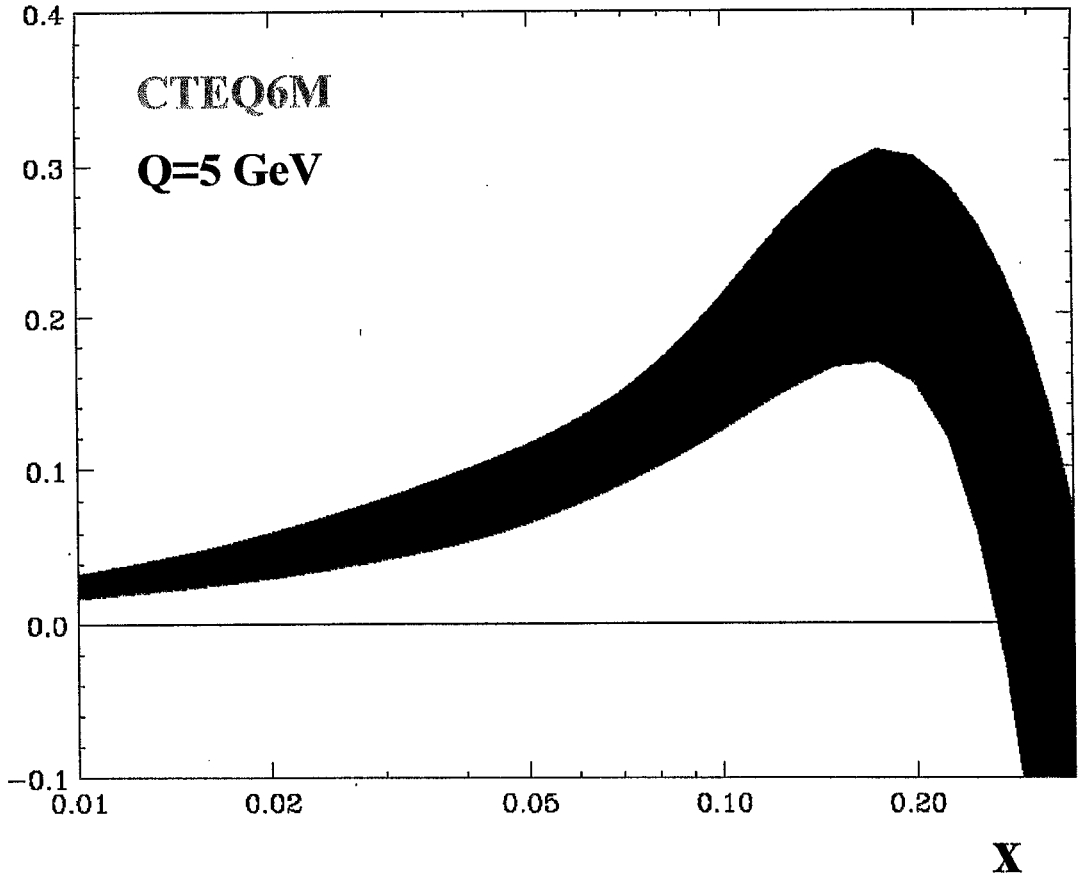
Challenges in QCD spin physics

- What else carries the proton spin ?
  - → How are gluons polarized ?
  - → How large are parton orbital ang. mom. ?
- What are the detailed patterns of quark & antiquark polarizations ?

  → Flavor asymmetries in sea ?
- Is there significant transversity in the nucleon ?
- What are the origins of large observed single-spin asymmetries ?
  - → Correlations between transverse spin and parton k_T ?

Detailed information on (anti)quarks

$$\frac{\bar{d} - \bar{u}}{\bar{d} + \bar{u}}$$



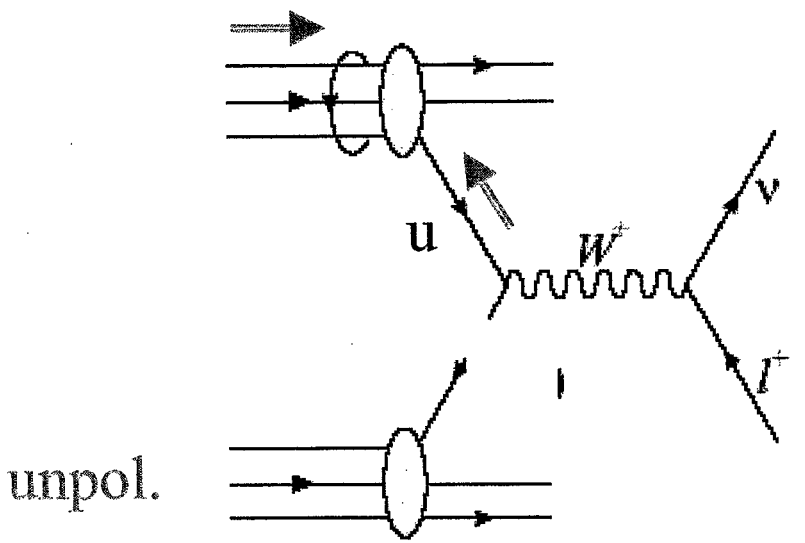
Polarized case: $\Delta\bar{u} - \Delta\bar{d} \gtreqless 0$?

most models predict $\Delta\bar{u} > 0 \quad \Delta\bar{d} < 0$

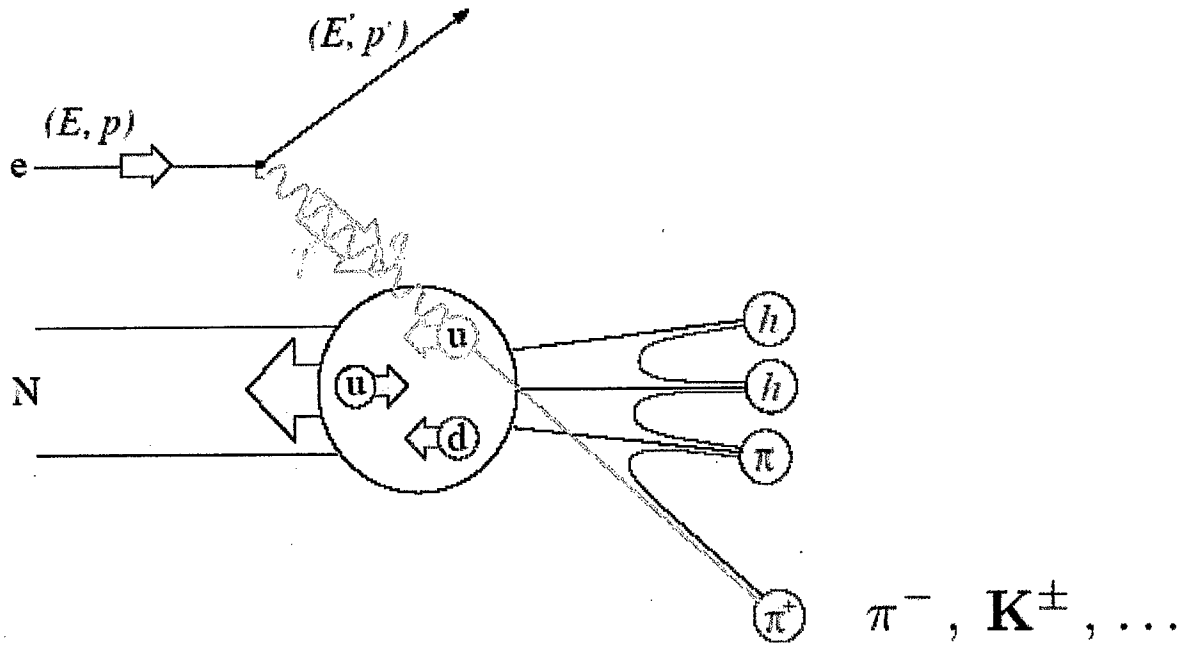
- **remarkably, there is a very powerful way at RHIC:**

$$\mathbf{A_L} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

parity violating



- **complementary to semi-inclusive DIS :**



HERMES, COMPASS, JLab $\longrightarrow$ eRHIC

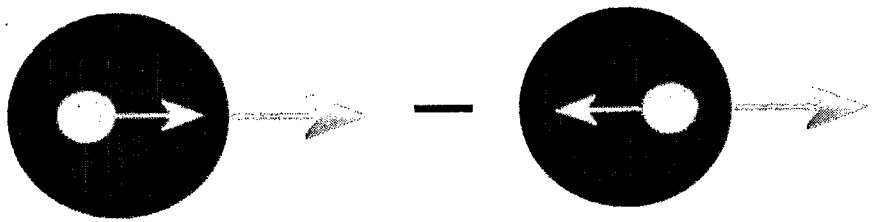
- **probe properties of nucleon on very different scales !**

Challenges in QCD spin physics

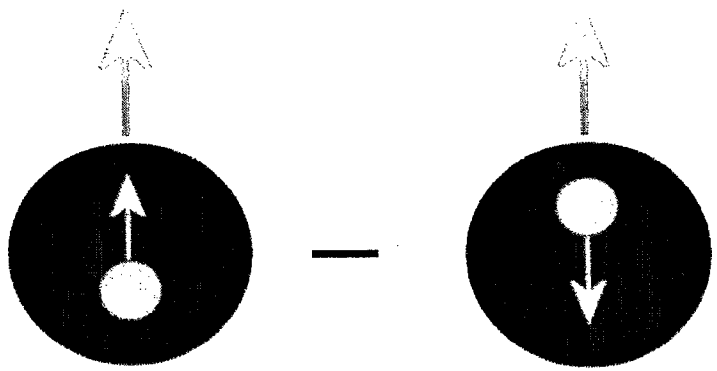
- What else carries the proton spin ?
  - → How are gluons polarized ?
  - → How large are parton orbital ang. mom. ?
- What are the detailed patterns of quark & antiquark polarizations ?
  - → Flavor symmetry breakings in sea ?
- **Is there significant transversity in the nucleon ?**
- What are the origins of large observed single-spin asymmetries ?
  - → Correlations between transverse spin and parton k_T ?

Transversity

$$\Delta q(x) =$$



$$\delta q(x) =$$



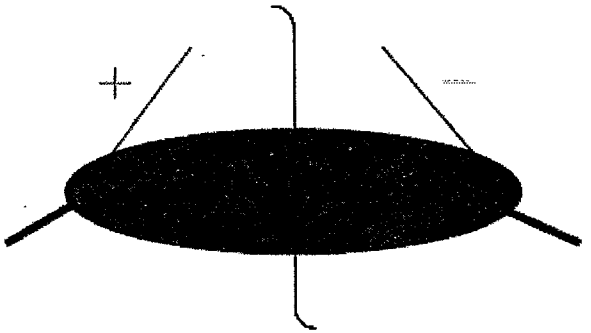
- **the unknown "leading-twist" distribution functions**

- **the physics involved:**

  * relativistic / dynamical effects

  * "odd chirality" $\rightarrow$ helicity-flip, χSB

  * no mixing with gluons

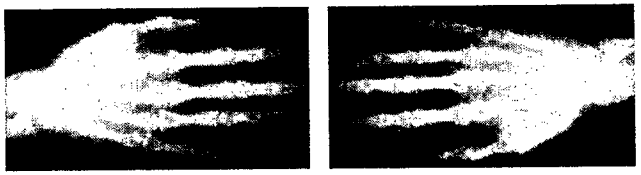


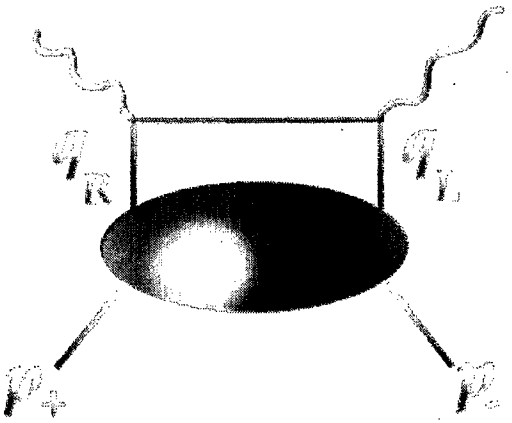
  * tensor charge (relevant for EDM)

$$\langle \mathbf{P} \,|\, \bar{\mathbf{q}}\, \mathbf{i}\, \sigma^{\mu\nu} \gamma^{5}\, \mathbf{q} \,|\, \mathbf{P} \rangle = \int_{0}^{1} \mathbf{dx}\, [\, \delta \mathbf{q}(\mathbf{x}) - \delta \bar{\mathbf{q}}(\mathbf{x}) \,]$$

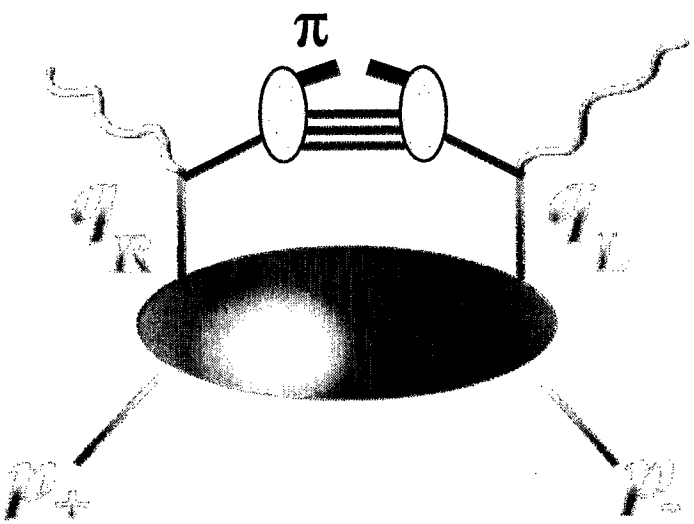
• Opportunities for measurement ?

* not in inclusive DIS:





* helicity-flip from final-state effect ?



"Collins effect"

* opens numerous possibilities in $ep^{\uparrow}$ & $pp^{\uparrow}$ scattering

Challenges in QCD spin physics

- What else carries the proton spin ?

  → How are gluons polarized ?

  → How large are parton orbital ang. mom. ?

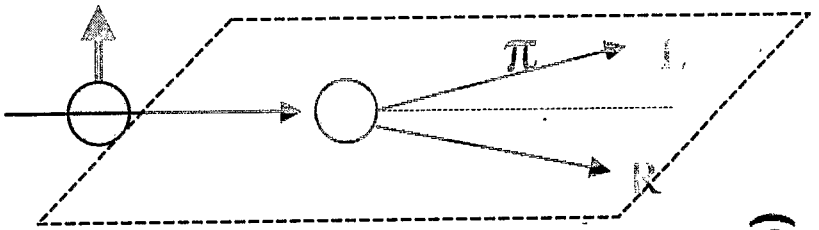
- What are the detailed patterns of quark & antiquark polarizations ?

  → Flavor symmetry breakings in sea ?

- Is there significant transversity in the nucleon ?

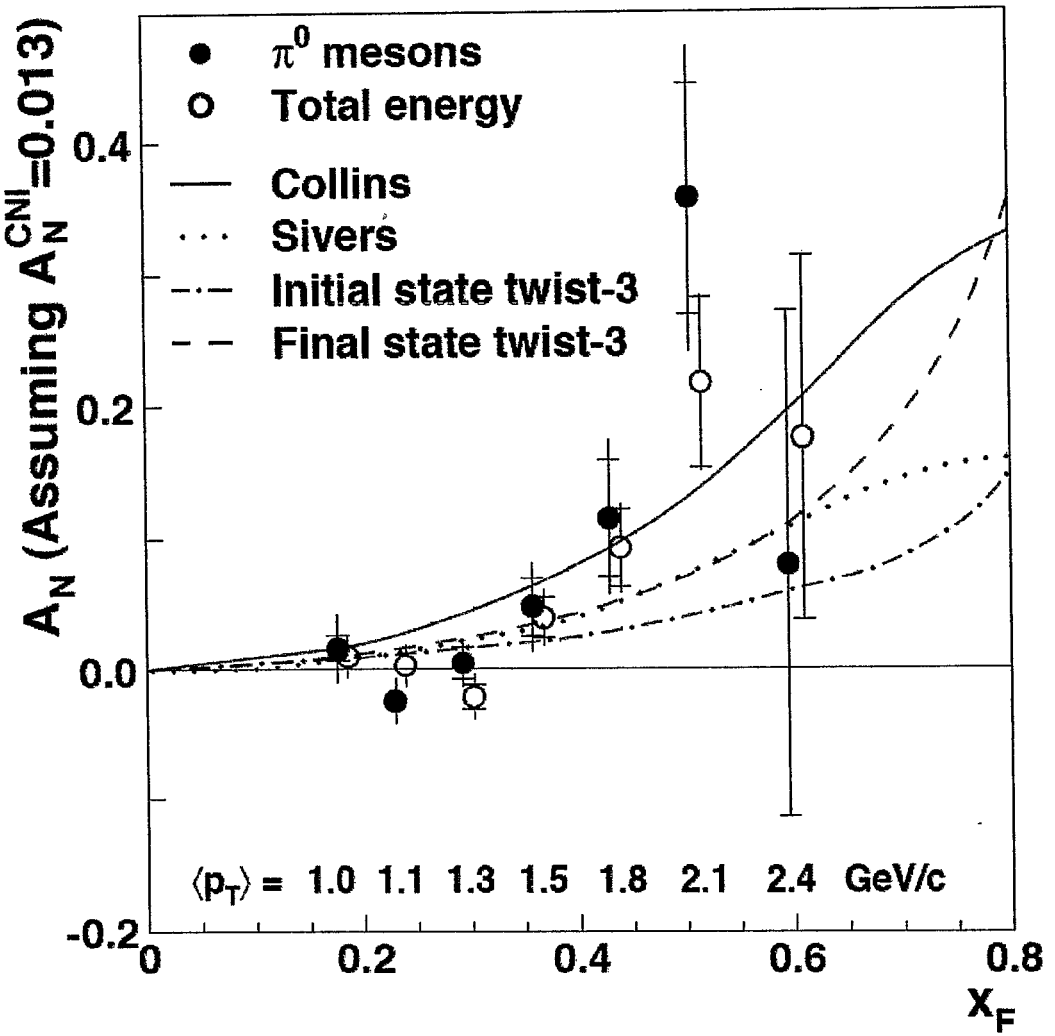
- **What are the origins of large observed single-spin asymmetries ?**

  → Correlations between transverse spin and parton k_T ?



$$A_N = \frac{L - R}{L + R}$$

STAR



- **not really understood so far**

  * simple collinear hard scattering: **no asymmetry**

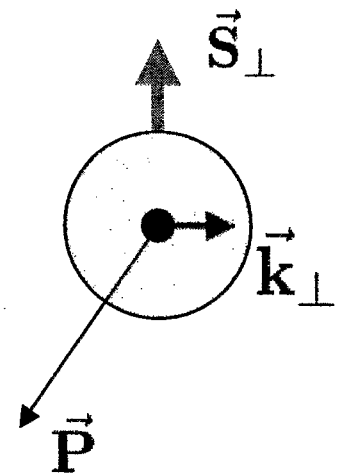
  * transversity & Collins effect are probably involved

  * multi-parton correlations ?

  * exciting possibility:

Sivers

$$\vec{S}_\perp \cdot \left(\vec{P} \times \vec{k}_\perp\right)$$

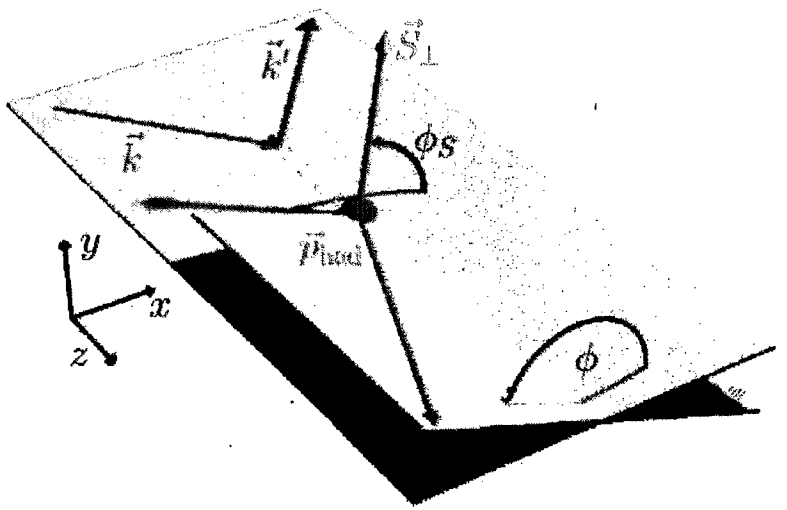


knows about **parton orbital angular momentum**
[connection to "generalized parton distributions" of DVCS ?]

* many exciting theory issues: factorization, universality, …

- **Excellent opportunities for direct measurement:**

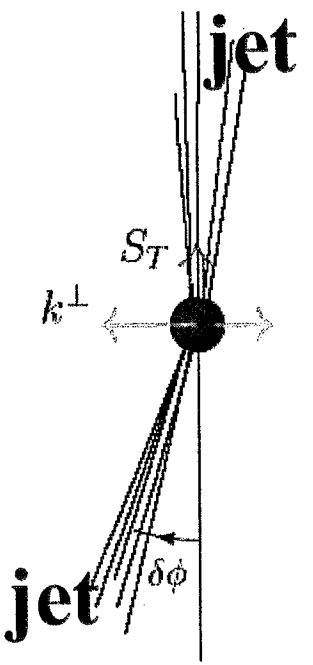
lepton-nucleon: $ep^{\uparrow} \to e\pi X$



$$\textbf{Sivers} \leftrightarrow \sin(\Phi - \Phi_S)$$

$$\textbf{Collins} \leftrightarrow \sin(\Phi + \Phi_S)$$

proton-proton:



+ Drell-Yan, ...

Conclusions

Over the next ~10 years, RHIC will provide new and groundbreaking information on most open questions

- **important interplay with:**

  * **complementary information from lepton scattering**

    fixed-target HERMES, COMPASS, Jlab $\longrightarrow$ eRHIC

  * **efforts to understand nucleon spin structure *from* QCD: lattice, models, ...**

RHIC SPIN: Experimental Issues

Matthias Grosse Perdekamp, UIUC and RBRC

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

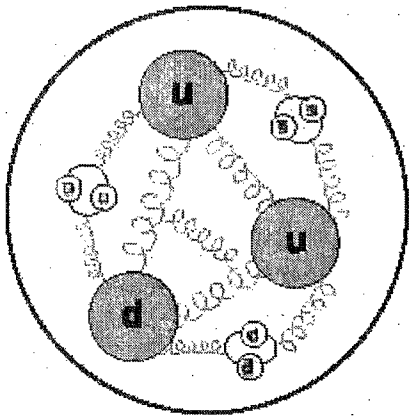
Spin Physics at RHIC

- 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 $\Delta q(x)$: moderately well known
gluons $\Delta G(x)$: unknown

Helicity flip (transversity) distribution
quarks $\delta q(x)$: 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)

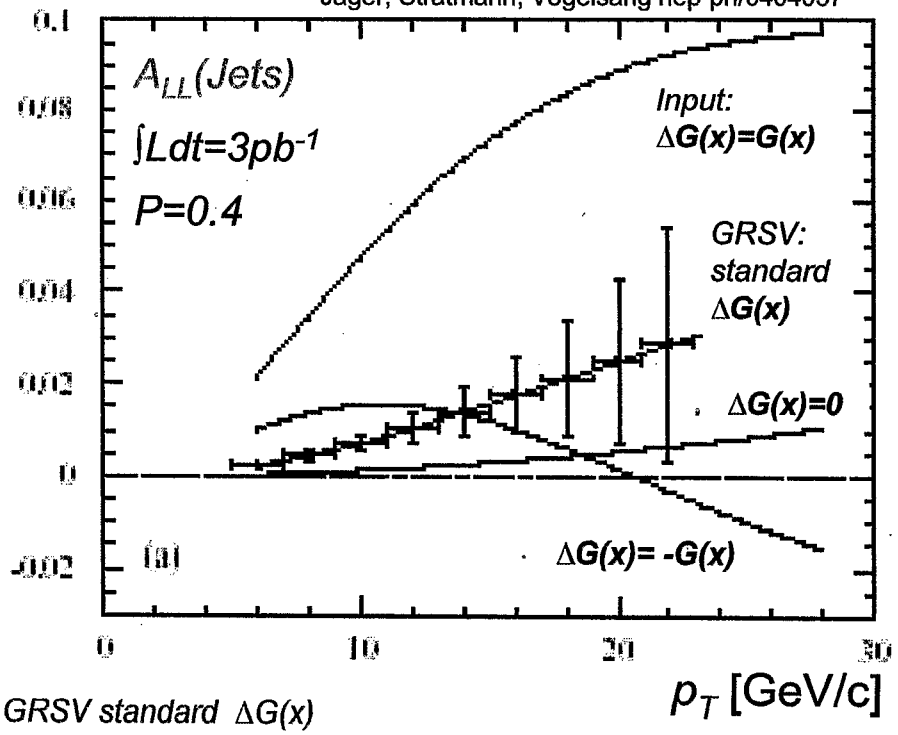
Proton Spin Structure at Hard Scales

	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: ($1pb^{-1} < \int Ldt < 30pb^{-1}$, $0.4<P<0.6$)

A_{LL} in inclusive jet production (STAR)

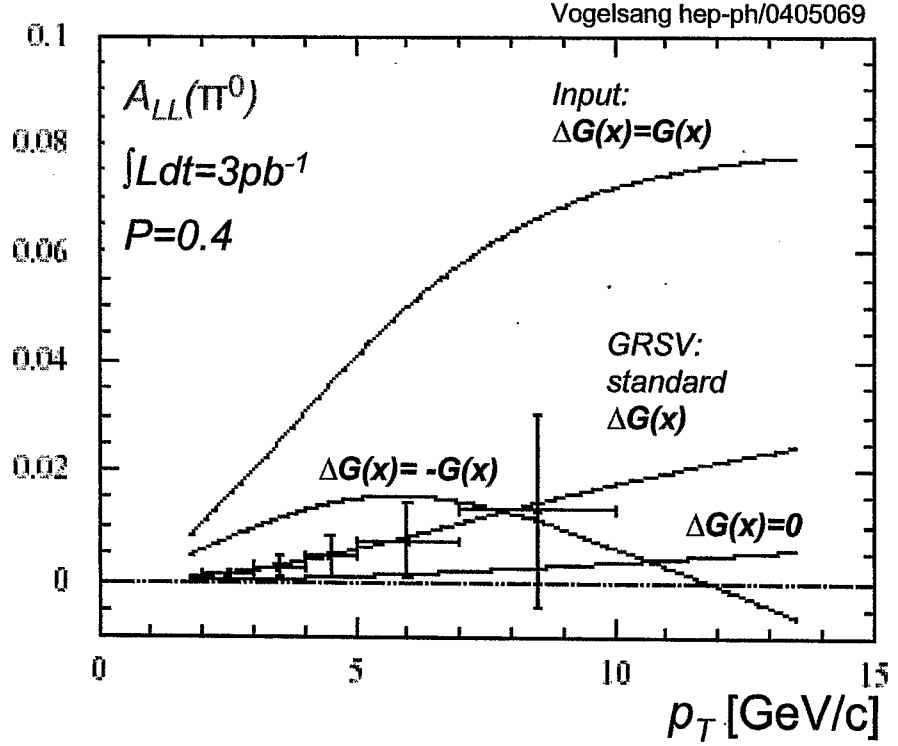
Jager, Stratmann, Vogelsang hep-ph/0404057



GRSV standard $\Delta G(x)$

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

Vogelsang hep-ph/0405069



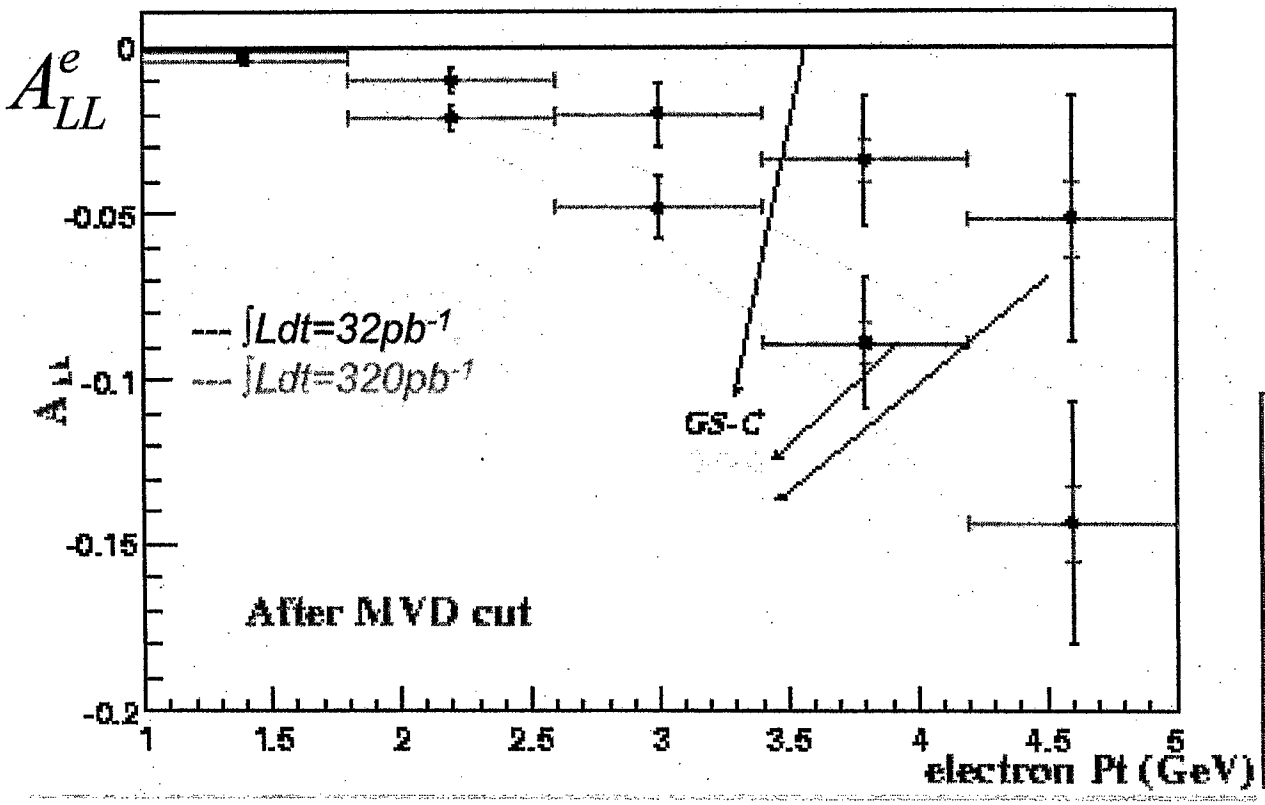
➔ Gluon distribution from NLO pQCD fit to DIS data on A_1, Gluck Reya, Stratmann, Vogelsang Phys. Rev. D63:094005, 2001

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

Gluon Polarization at Moderate Luminosity: Charm Production: ($\int Ldt > 30pb^{-1}$, $P>0.6$)

from Wei Xie, PHENIX

A_{LL} for single electrons in PHENIX



Silicon Vertex Detector Upgrade!

GS-A/B/C:

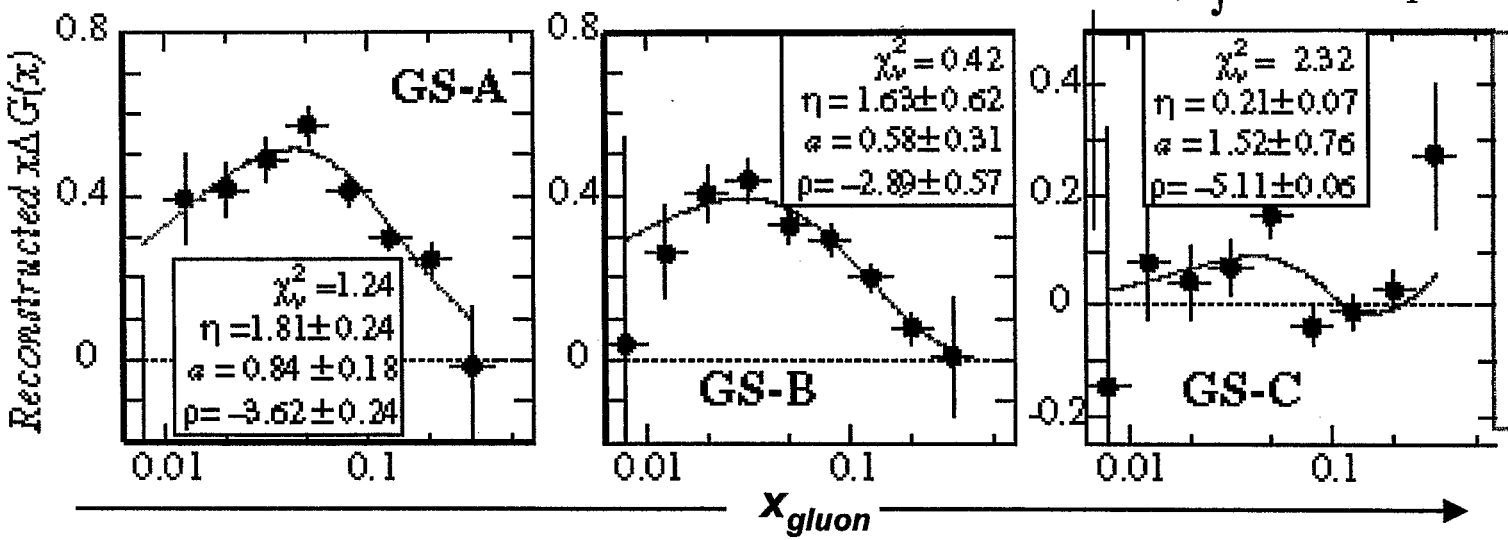
$\Delta G(x_g)$ parametrization from Gehrmann and Stirling Phys.Rev. D53 6100-6109,1996

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

Sensitivity to Gluon Polarization at RHIC

from Les Bland, STAR

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



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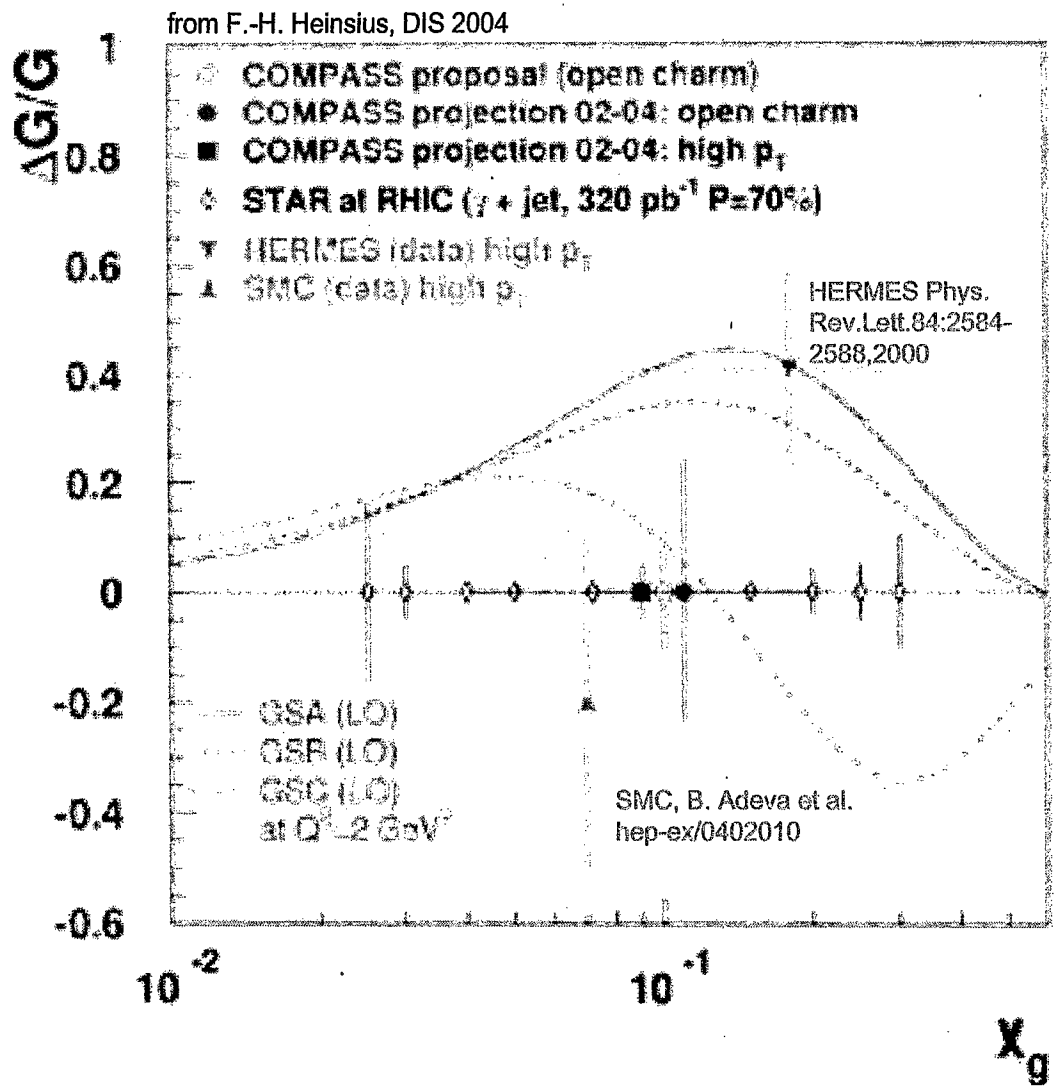
$\int G_A(x)dx = 1.8$
$\int G_B(x)dx = 1.6$
$\int G_C(x)dx = 0.2$

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



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

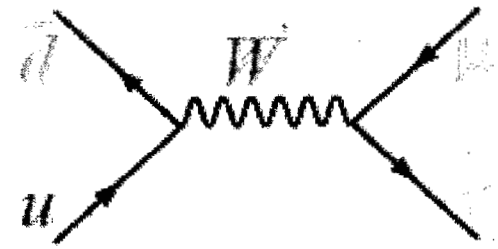
(II) RHIC spans a broad range of x_{gluon}

➔ 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)*

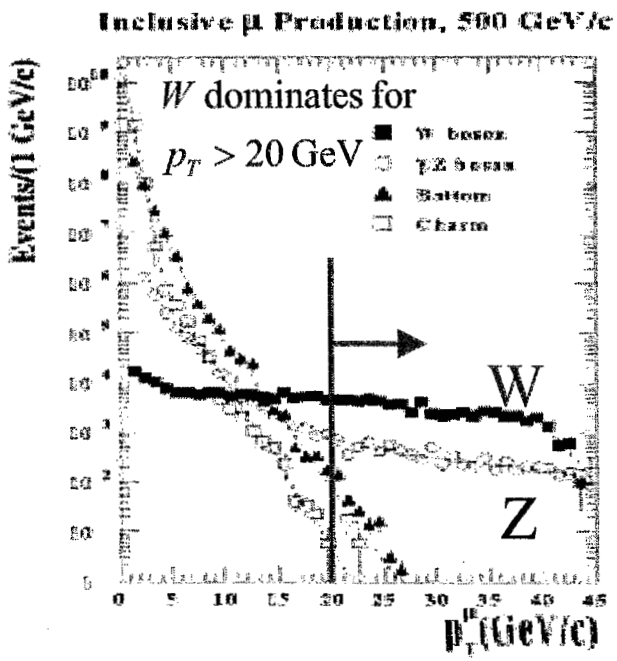
W Production in Polarized pp Collisions



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!

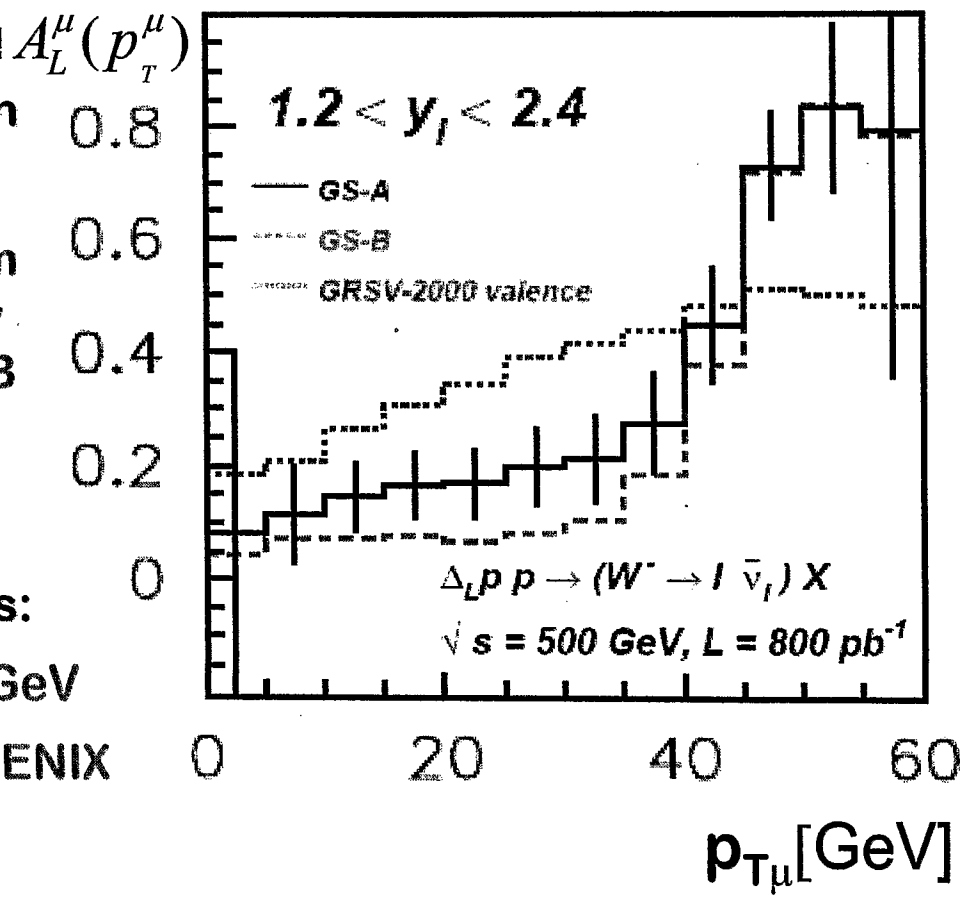


Experimental Requirements:

- ➔ 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 measurements of inclusive longitudin single spin asymmetry?**
  - **Yes! Complete theoretical treatm from first principles by Nadolsky Yuan at NLO pQCD (Nucl. Phys.B 666(2003) 31).**

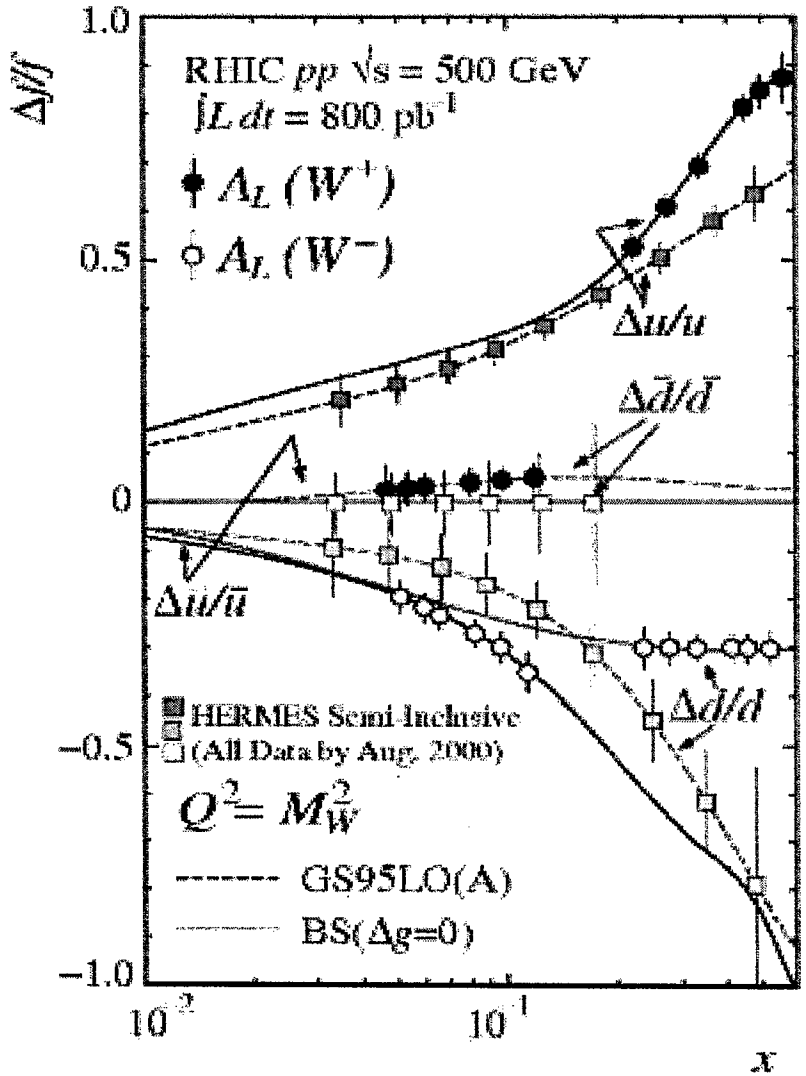


- **Machine and detector requirements:**
  - ∫Ldt=800pb-1, P=0.7 at √s=500 GeV
  - Upgrades: o Muon trigger in PHENIX
    o Forward tracking in STAR

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

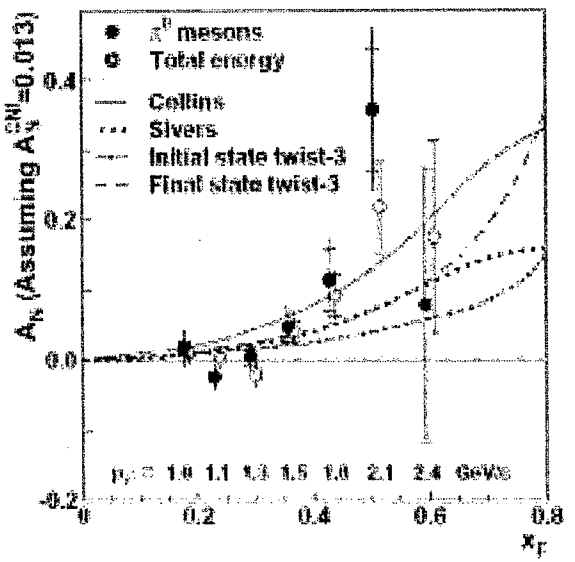
(A) Physics Channels for Low Luminosity

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

STAR, PHENIX and BRAHMS

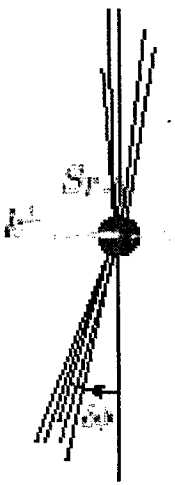
(I) Measure A_N : $A_N(pp_\perp \to h + X)$

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



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

(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:

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

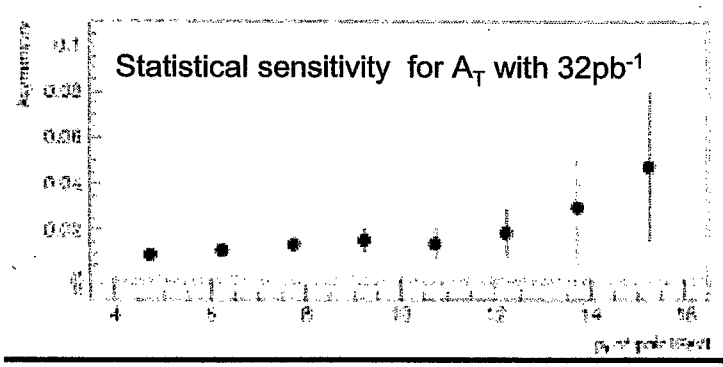
J.C. Collins, Nucl. Phys. B396, 161(1993)

- π^+, π^- Interference Fragmentation:

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

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?)

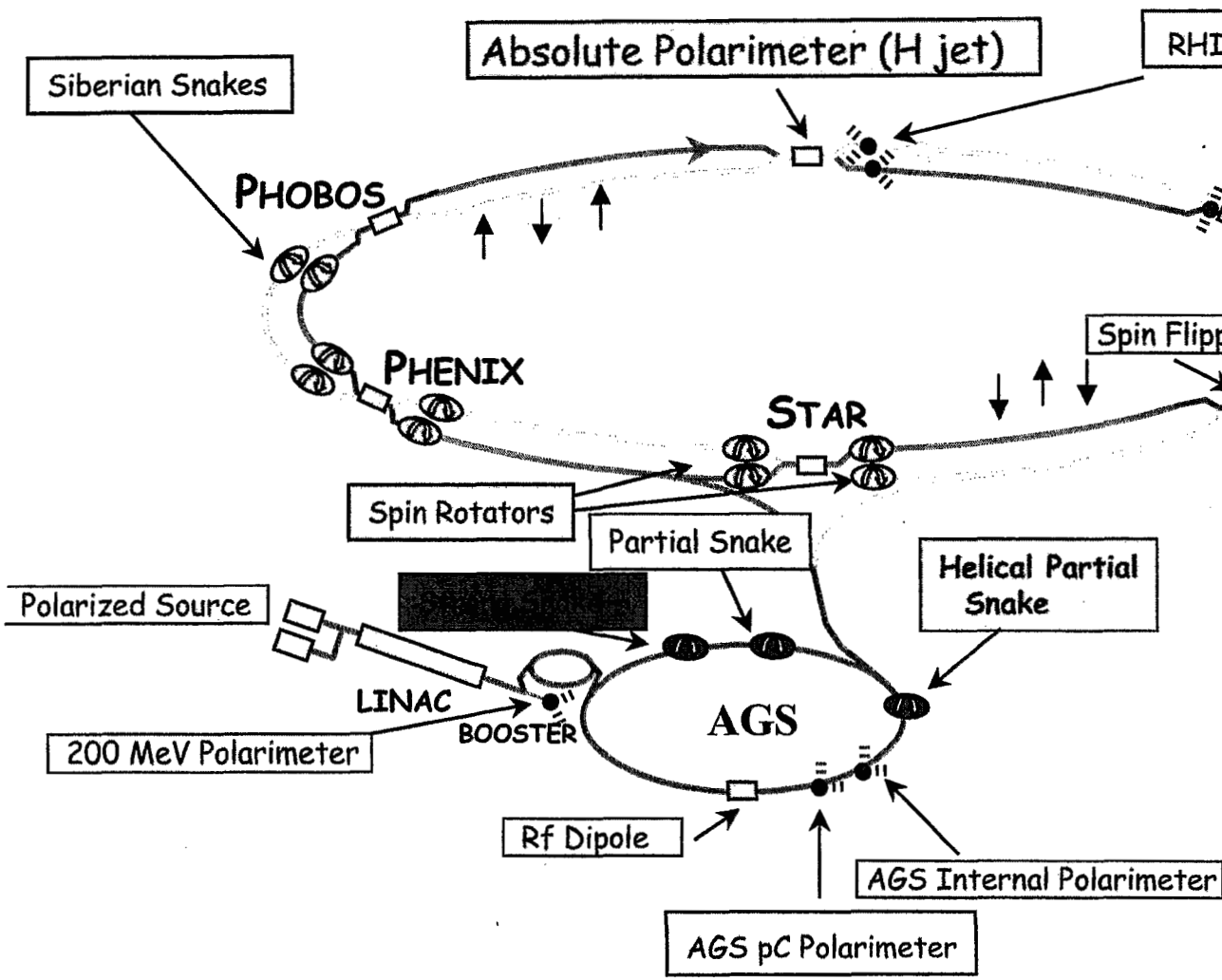
➡ Brief PHENIX and STAR runs on A_T as $\int$ Ldt/week>10pb-1/week

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

[redacted]

Time to tune accelerator complex

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

Commission strong superconducting 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

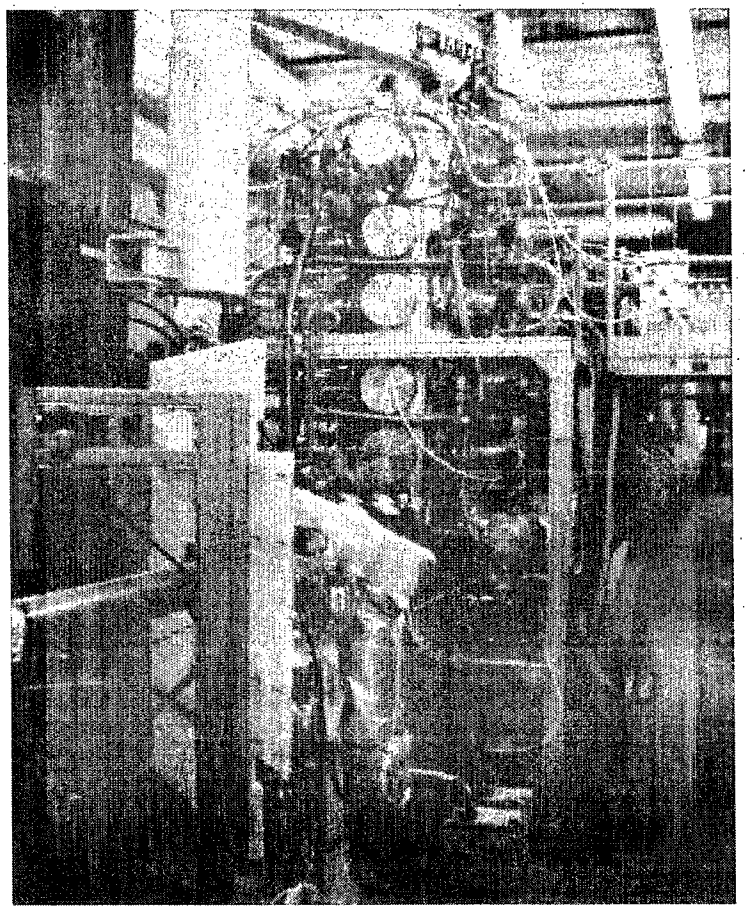
Courtesy Sandro Bravar, STAR and Yousef Makdisi, CAD

Polarized Hydrogen Gas Jet Target

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

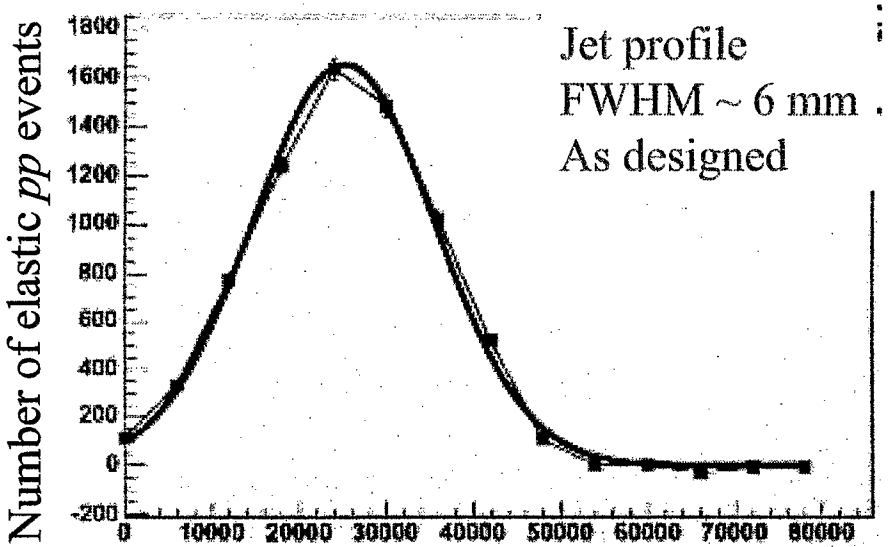
polarization > 93% (+1 −2)%!

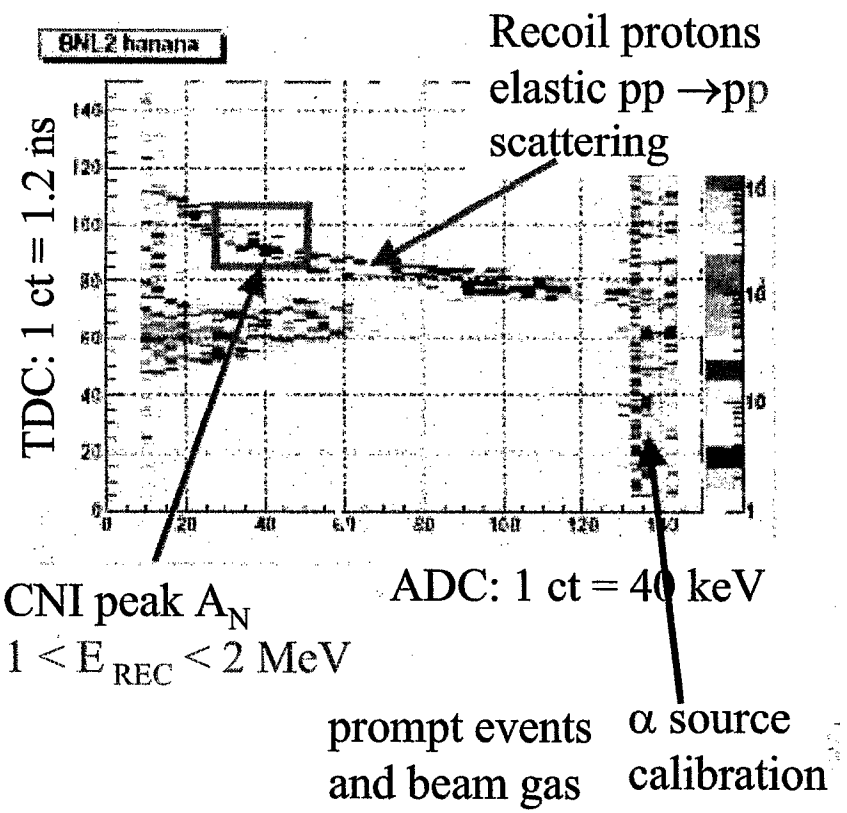
no depolarization from beam wake fields



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

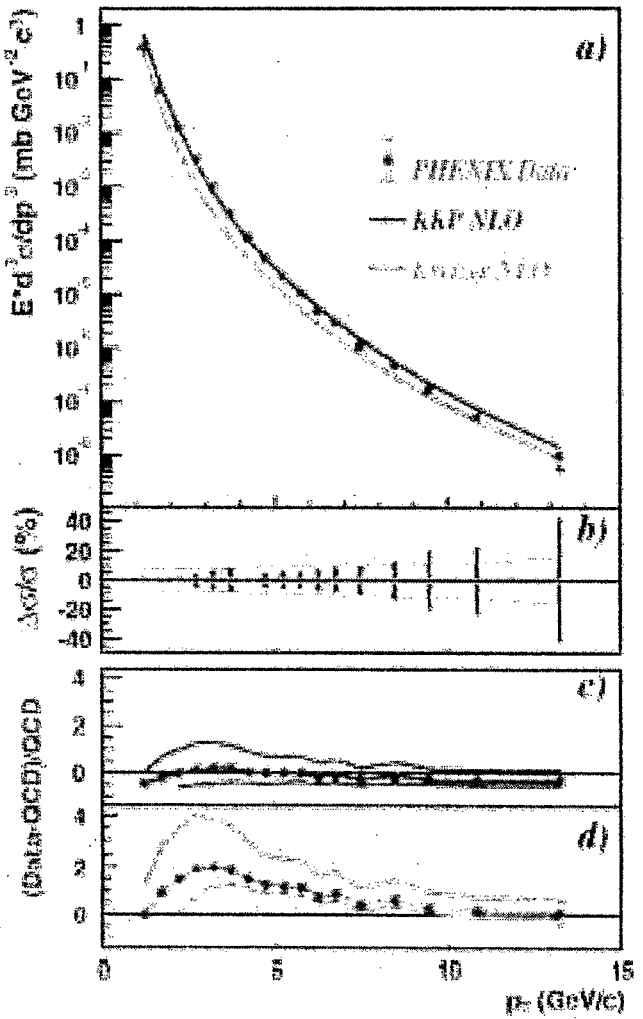
Two groups bring significant additional (to DOE) funding for RHIC physics (HI + spin):

- 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.

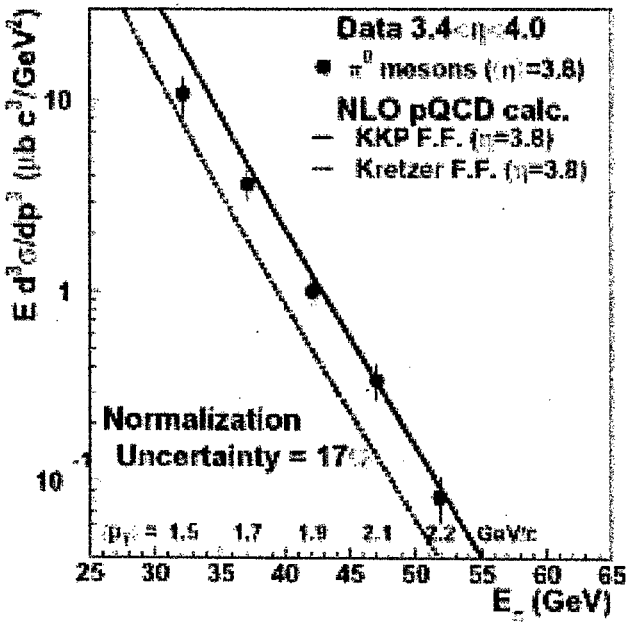
First Results: π^0 Cross sections

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

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



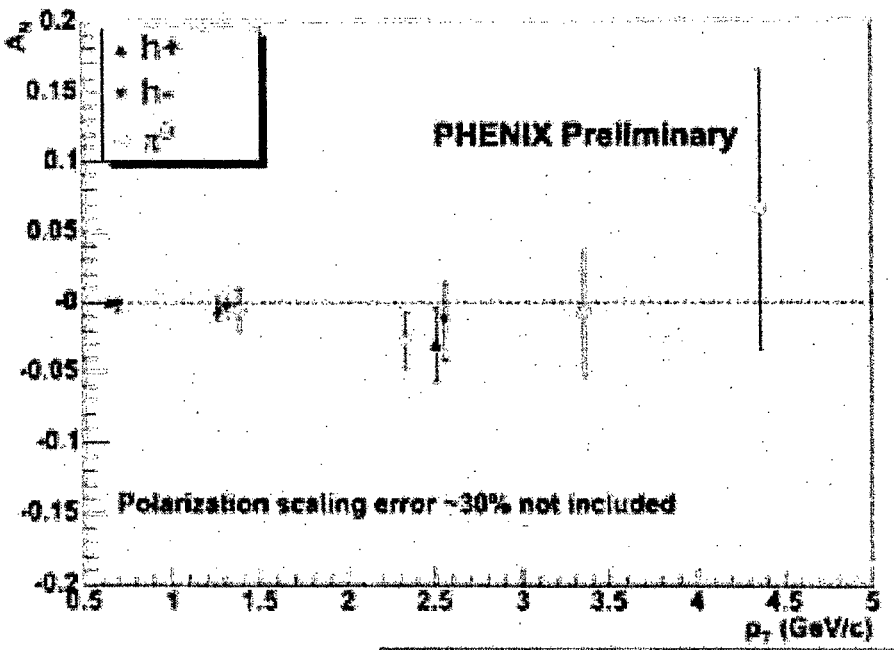
- o Good agreement between NLO pQCD calculations and experiment
- → can use a NLO pQCD analysis to extract spin dependent pdfs from RHIC data!

First Results: A_N

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

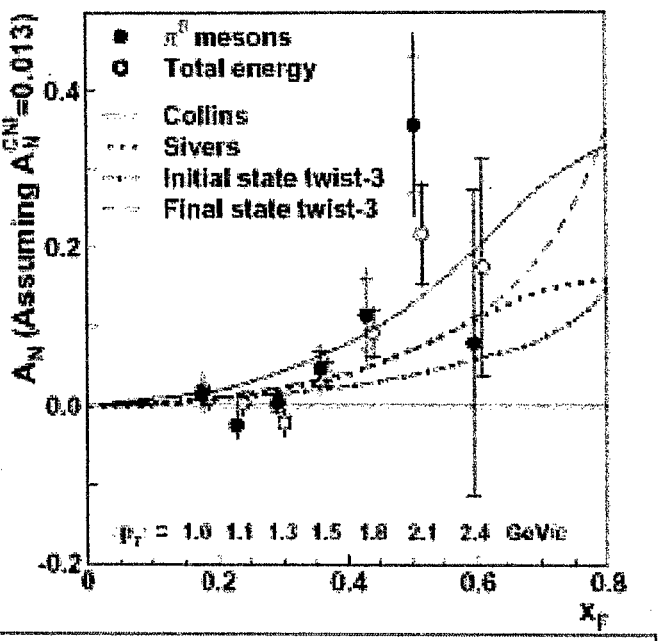
PHENIX $A_N(\pi^0)$ and $A_N(\pi 0)$ at $|\eta|<0.35$

C. Aidala, DIS 2004, to be published



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

Phys.Rev.Lett.92:171801,2004



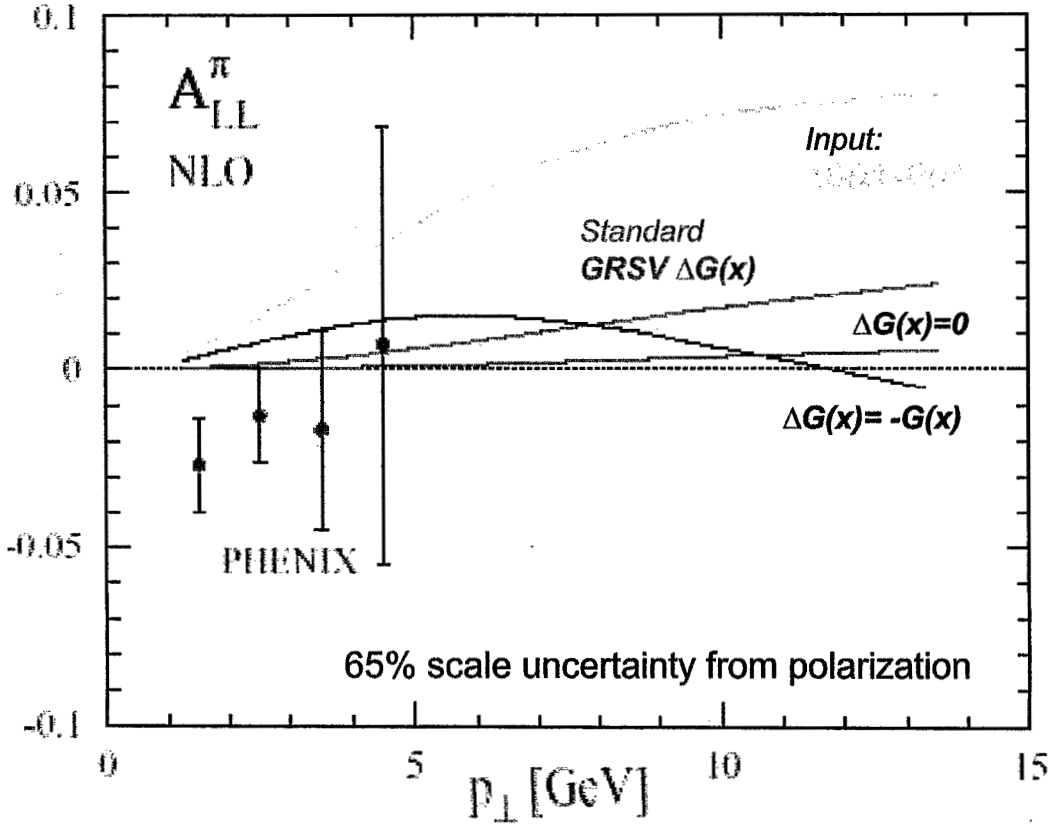
- First spin results from RHIC
  - → A_N sizeable in forward X_F
  - → A_N compatible with 0 at η~0 (as expected from pQCD)

- 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, $\int Ldt \sim 0.2 pb^{-1}$, P~0.25

PHENIX $A_{LL}(\pi^0)$ at $|\eta|<0.35$, 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 $\int Ldt = 3pb^{-1}$ and P-0.4 (2005) errors will reduce by factor 8

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

→ relative luminosity ~5×10^{-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= $6\times10^{30}cm^{-2}s^{-1}$ $8\times10^{31}cm^{-2}s^{-1}$

P= 0.45 0.5 0.7 .....

√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 →

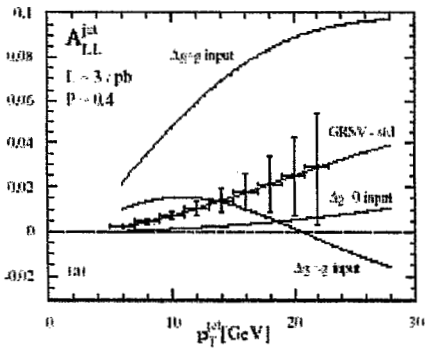
Charm Physics →

direct photons →

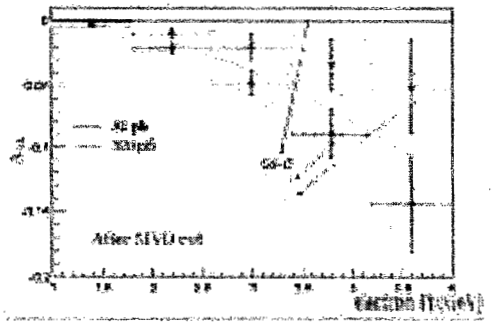
Bottom physics →

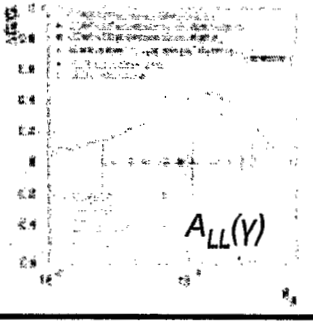
W-physics →

A_{LL}(hadrons, Jets)

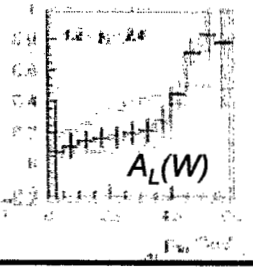


A_{LL}(charm)





$A_{LL}(\gamma)$



$A_L(W)$

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

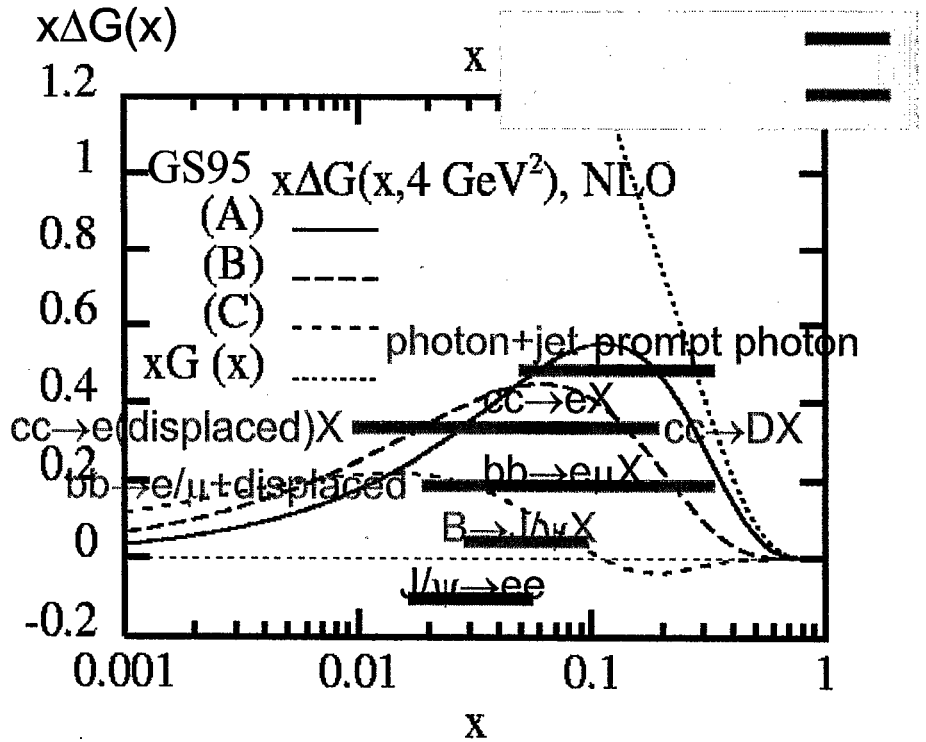
II) Upgrades aimed at a precision measurement of
the first moment $\int \Delta G(x)dx$ ➔ constrain orbital angular mometum?

STAR: micro vertex detector

PHENIX: Silicon Vertex Detector, nose cone calorimeter

Measuring the First Moment of $\Delta G(x)$

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



Summary: Polarized Proton Collisions

- o A new experimental method has been successfully developed and we are beginning to exploit a truly novel experimental tool on proton spin structure.
- o Fixed target DIS experiments are carried out at comparably soft scales and are subject to diverse theoretical uncertainties. Leadership in the field will shift from DIS experiments to RHIC spin.
- o Focus on sufficient operation time for polarized protons to optimize accelerator performance early ➔ maximum physics output.
- o Integrated forward tracking (STAR) and muon trigger upgrades (PHENIX) are necessary for W-physics.
- o 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.

Machine Goals of the RHIC SPIN program

Mei Bai
Collider-Accelerator Department
Brookhaven National Laboratory

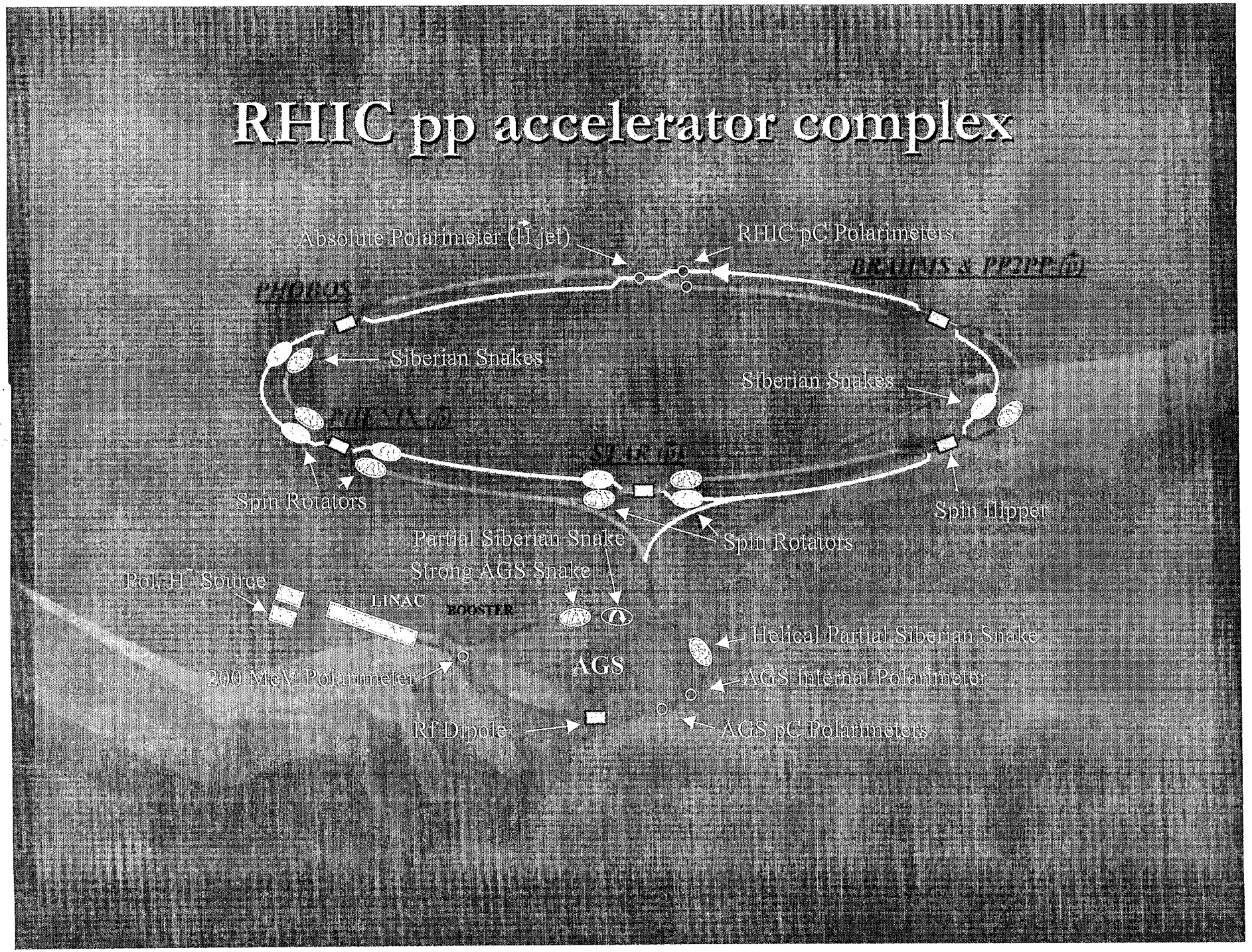
Charges from Peter Barnes

- What has been accomplished so far in the development of the RHIC spin capability .
- What are the machine goals for the RHIC spin program over the next 5-10 years
- Where are the technical risks in the development of this spin capability?

Outline

- What has been accomplished so far in the development of the RHIC spin capability
  - Polarization capability
  - Luminosity capability
- What are the machine goals for the RHIC spin program over the next 5-10 years
- Important technical issues to improve the RHIC spin capability

RHIC pp accelerator complex



Machine configuration for FY2004

RHIC

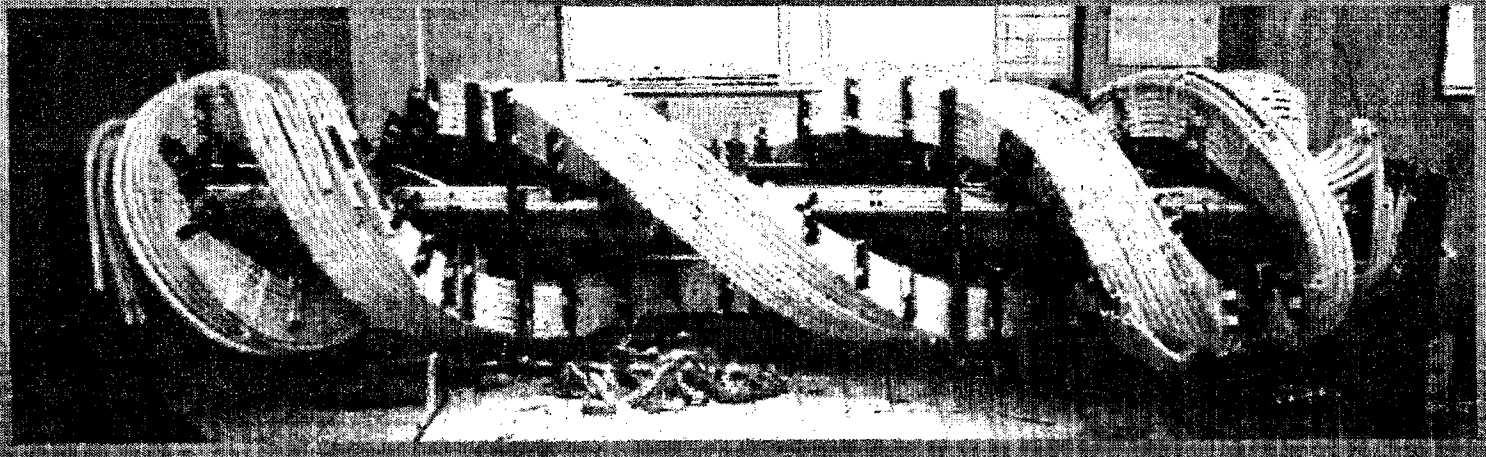
- Energy
  - Injection: 24.3 GeV/c
  - Store: 100.2 GeV/c
- Spin setup
  - 2 Full snakes for each ring
  - Longitudinal polarization at STAR and Phenix
  - Transverse polarization elsewhere
- Polarimetry: IP 12
  - CNI polarimeter: pC scattering
  - Hydrogen jet: pp scattering

AGS

- Energy
  - Injection: 2.2 GeV/c
  - Extraction: 24.3 GeV/c
- Scheme for correcting spin resonance:
  - 5% warm helix snake plus the Rf dipole
- Polarimetry
  - CNI polarimeter
  - E880 polarimeter

What have been achieved in the AGS

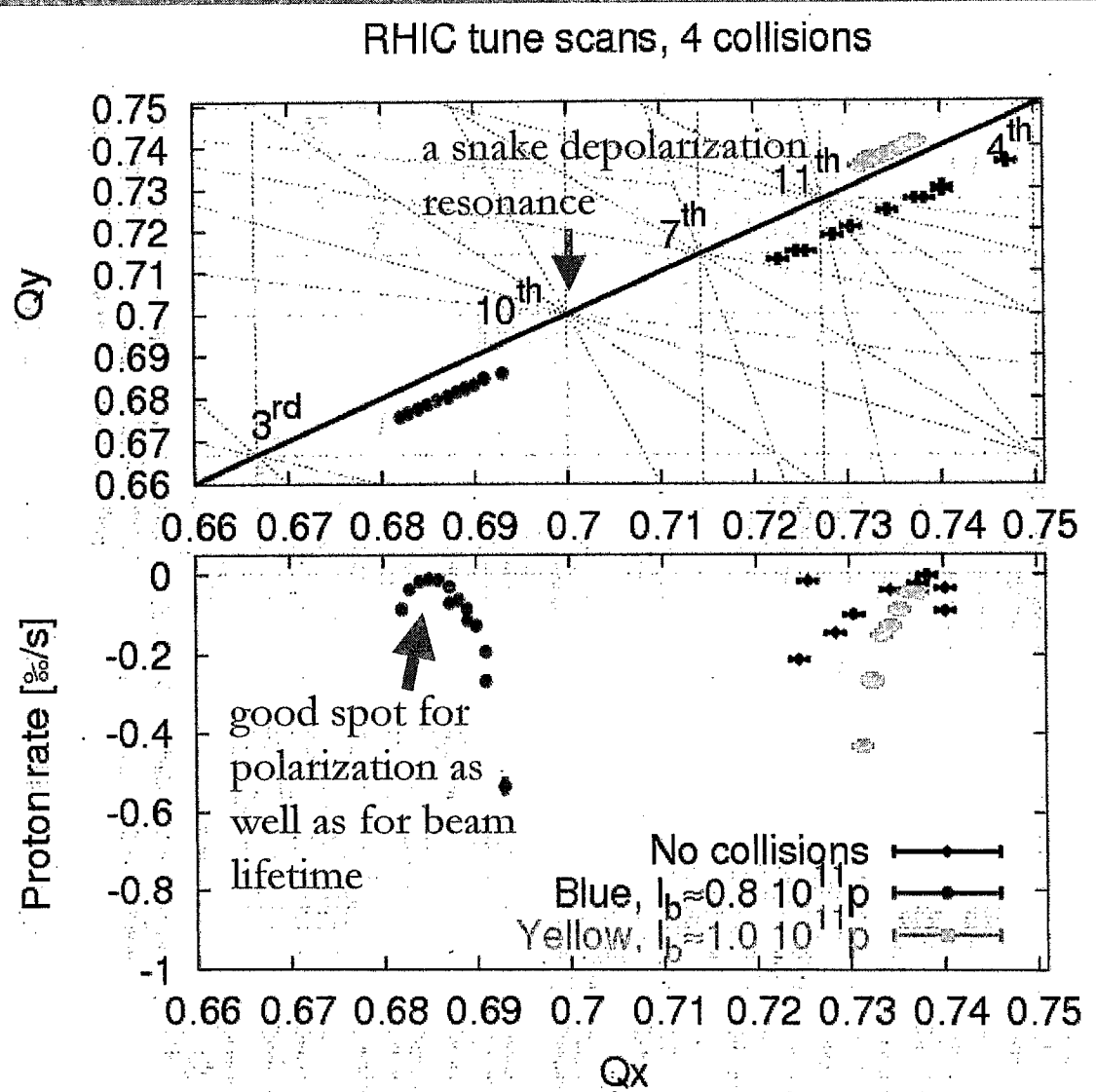
- Successfully commissioned the warm helical partial snake which is provided by RIKEN, Japan. This new snake greatly reduced the polarization loss due to the linear coupling between the horizontal and vertical betatron oscillations.
- Routinely provide 0.7×10^{11} protons per bunch with 45% - 50% polarization and 1.0×10^{11} protons per bunch with 40% polarization at AGS extraction energy
- Capable of providing more than 1.0×10^{11} protons per bunch with 45% at the end of the run



What has been achieved RHIC outline

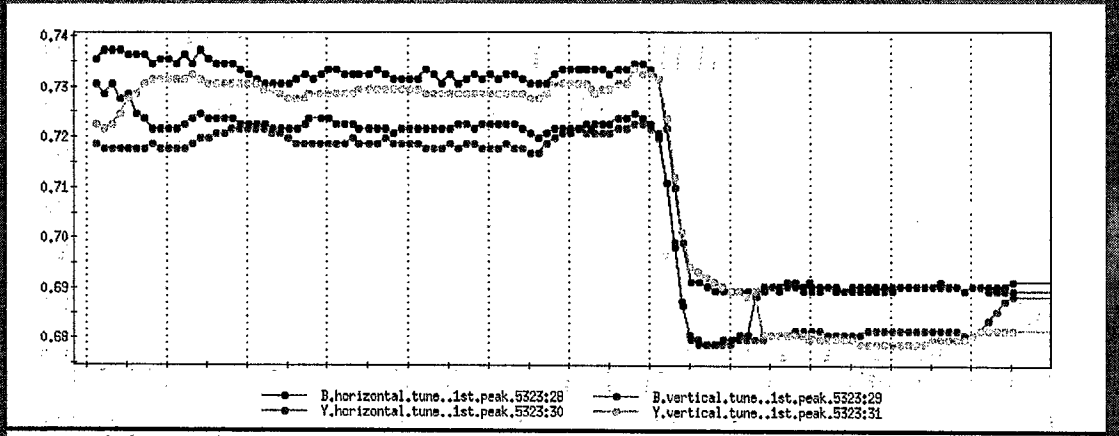
- New working point development. The new working points demonstrated they are benign to both beam lifetime and beam polarization
- Absolute polarization was measured at RHIC injection energy as well as store energy with the newly installed H target. Polarization was also measured at the same time with the CNI polarimeter. This allows one to calibrate the pC analyzing power at these two energies.
- Routinely provided stores with average store luminosity $4x10^{30}cm^{-2}s^{-1}$, average blue polarization 45% and average yellow polarization 40%.
- High luminosity development with un-polarized proton source yielded $1x10^{31}$ $cm^{-2}s^{-1}$ average store luminosity with 2 collisions at STAR and Phenix.
- Explored the total beam intensity limit due to vacuum pressure. A total of 45 bunches per ring with 1.5-2.0$x10^{11}$ protons per bunch yielded an vacuum pressure of $3x10^{-7}$ Torr at both IP10 and IP12.

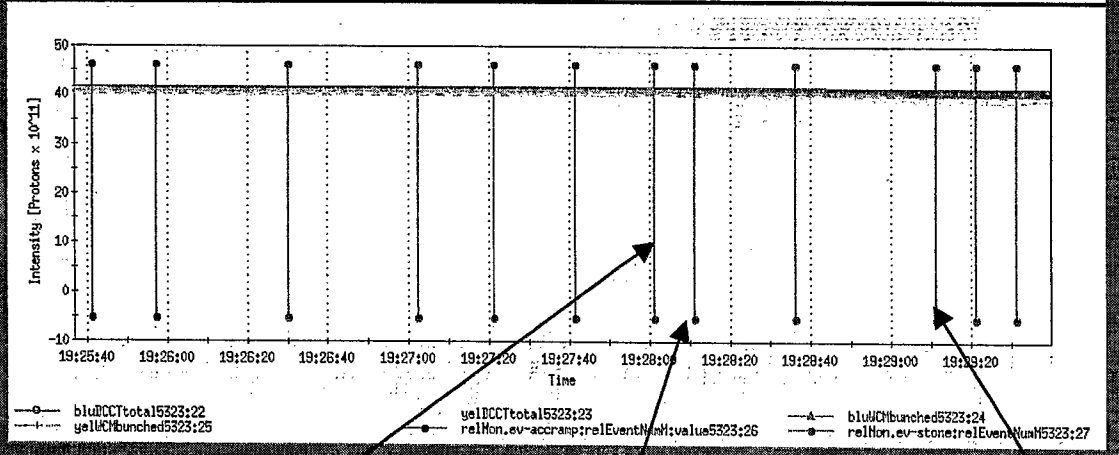
RHIC New Working Point



A typical ramp

cross 7th order
Resonance at 0.717
around beta* 2m w.o.
any beam loss



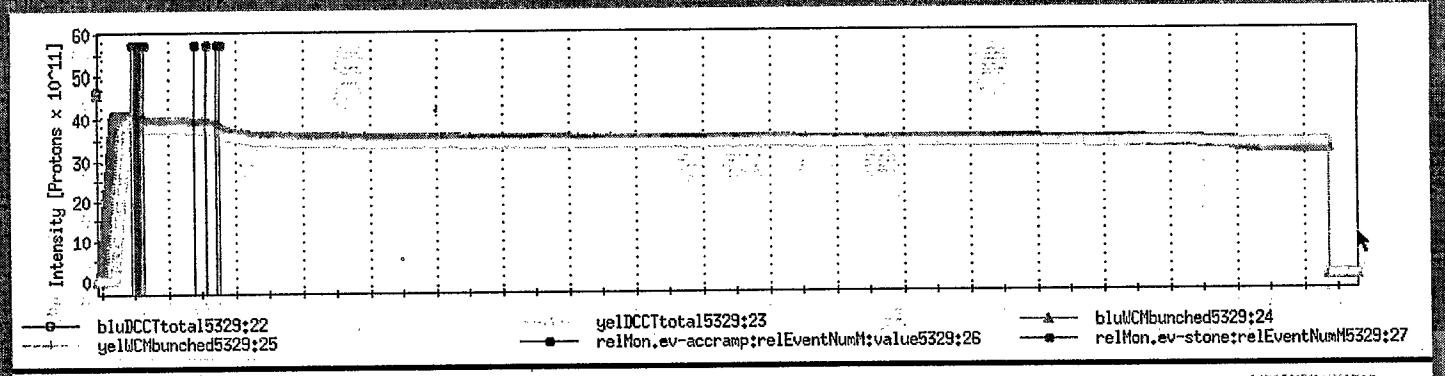


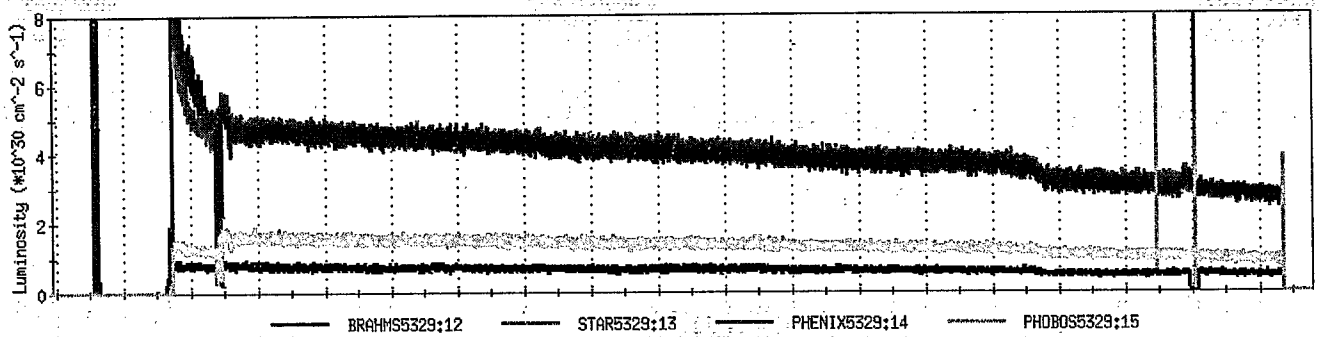
flattop
β*=2m

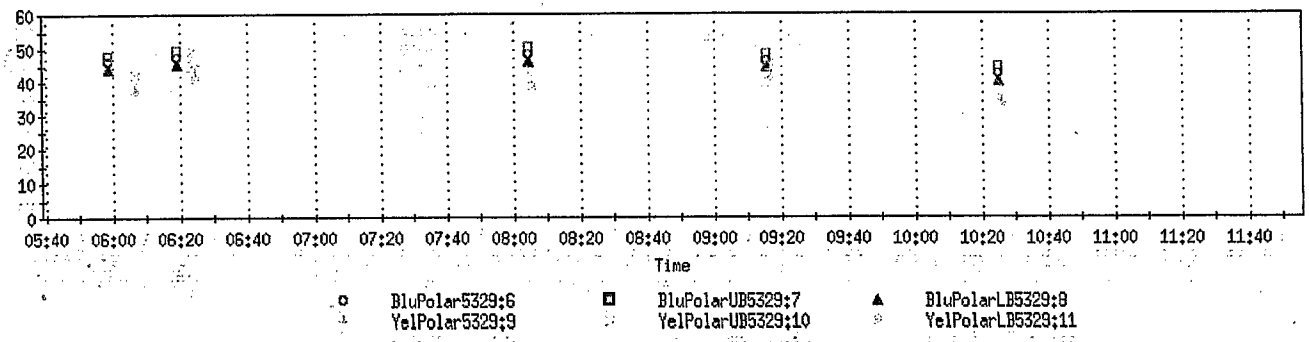
10 seconds after flattop

beta1
β*=1m

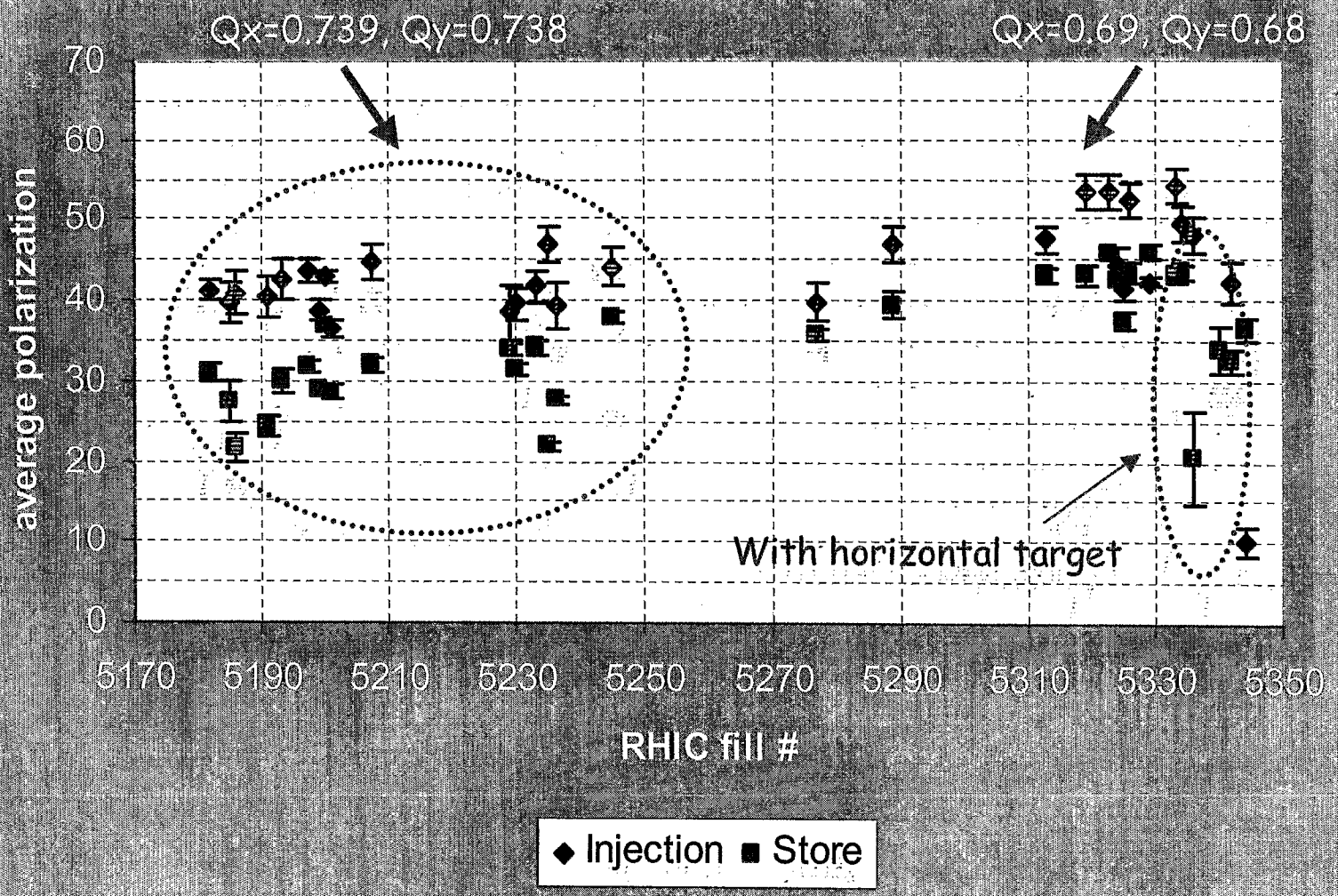
A typical store



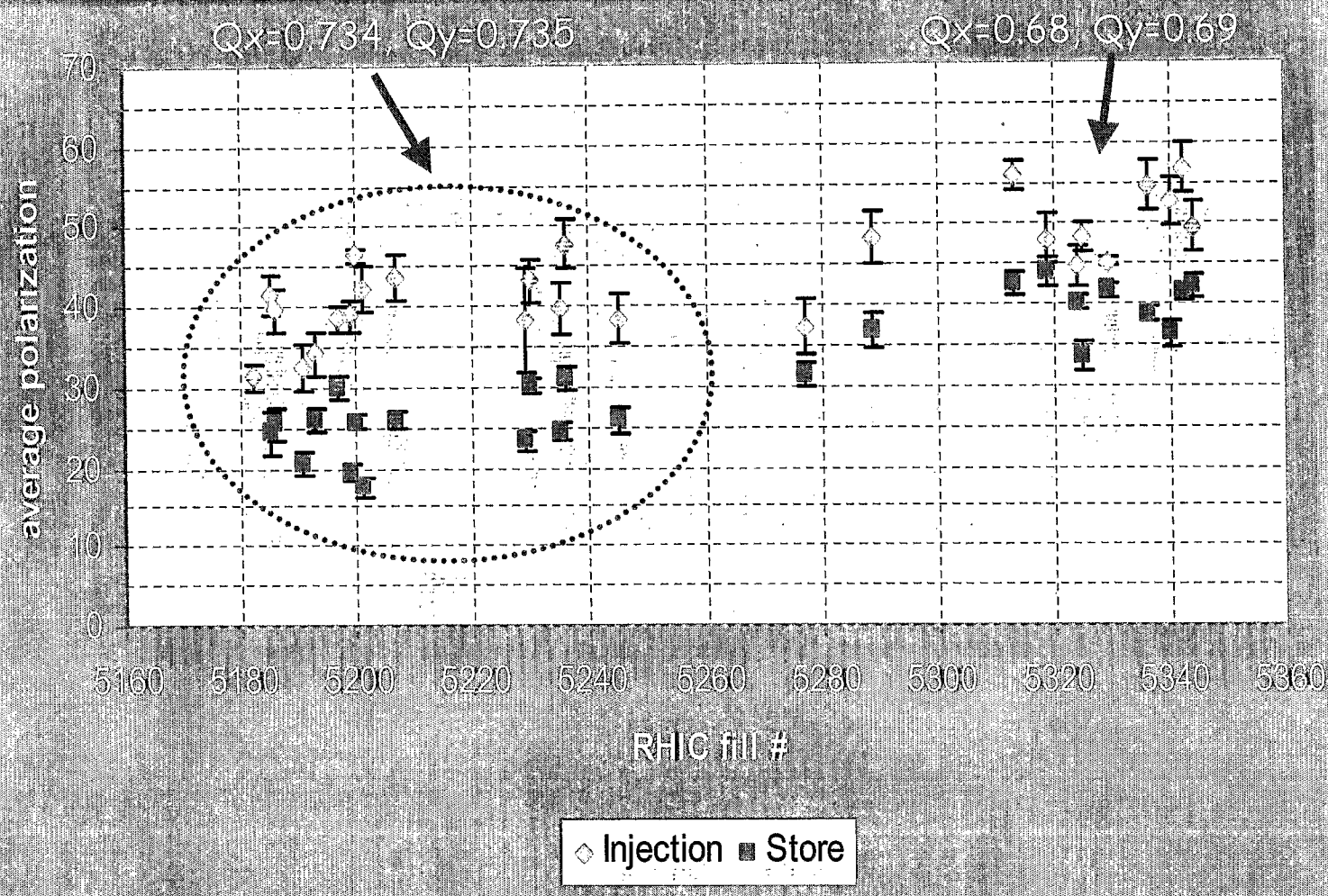




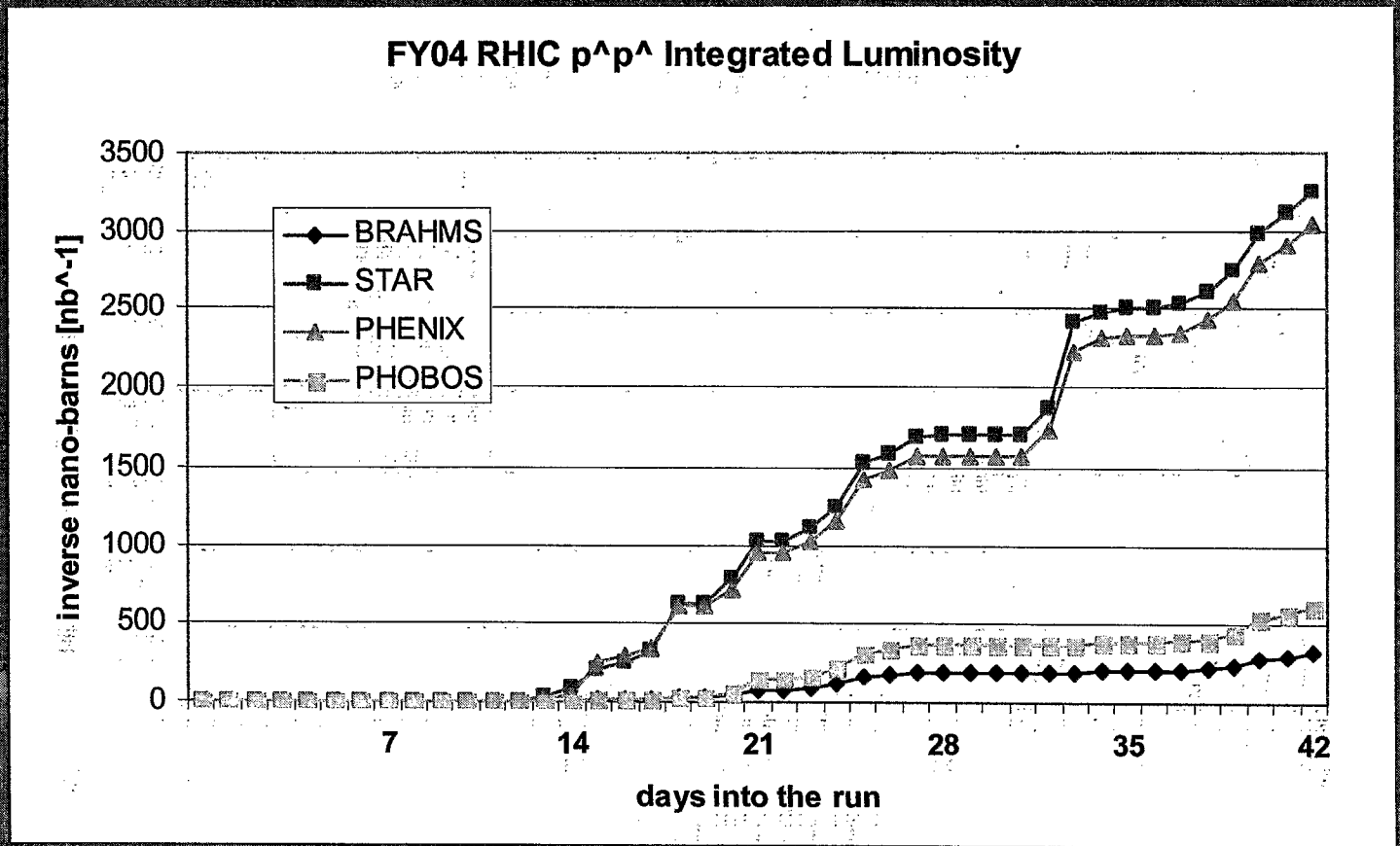
Blue Polarization Performance FY04



Yellow Polarization Performance FY04



Delivered Integrated Luminosity of RHIC PP FY04



Projection for FY05 Run

	collision energy [GeV/c]	bunch intensity [10^{11}]	# of bunch	# of collision points	$\mathcal{L}_{\text{store average}}$ [10^{30} cm^{-2}s^{-1}]	polari-zation at store
FY05 min	100	0.7	56	4	4.0	45%
FY05 goal	100	0.7	112	4	8.0	50%
FY05 alternative	100	1.0	56	4	8.2	40%

Machine Goals for the Next 4 years

- Polarization
  - 70% or more beam polarization at RHIC injection
  - 70% beam polarization at RHIC store energy 250GeV/c
- Luminosity
  - bunch intensity: 2×10^{11} protons per bunch
  - 112 bunch per ring
  - with a normalized beam emittance of 20π mm-mrad, a luminosity of
    - 60×10^{30} $cm^{-2}s^{-1}$ is expected at 250 GeV/c
    - 150×10^{30} $cm^{-2}s^{-1}$ is expected at 100 GeV/c

Available Techniques to Achieve the Goal

- Polarization:
  - AGS cold snake is expect to yield 100% polarization transmission from its injection energy to the RHIC extraction energy. The expected absolute polarization is 70%
  - A survey and alignment of the whole machine are expected to reduce the effect of the depolarization resonance strength in RHIC
  - polarization ramp measurement will also allow one to identify the depolarization location quickly
- Luminosity:
  - The AGS cold snake is also expect to deliver high polarization beam with high bunch intensity
  - by NEG coating all the IR beam pipe, the total beam intensity is also expect to be raised significantly

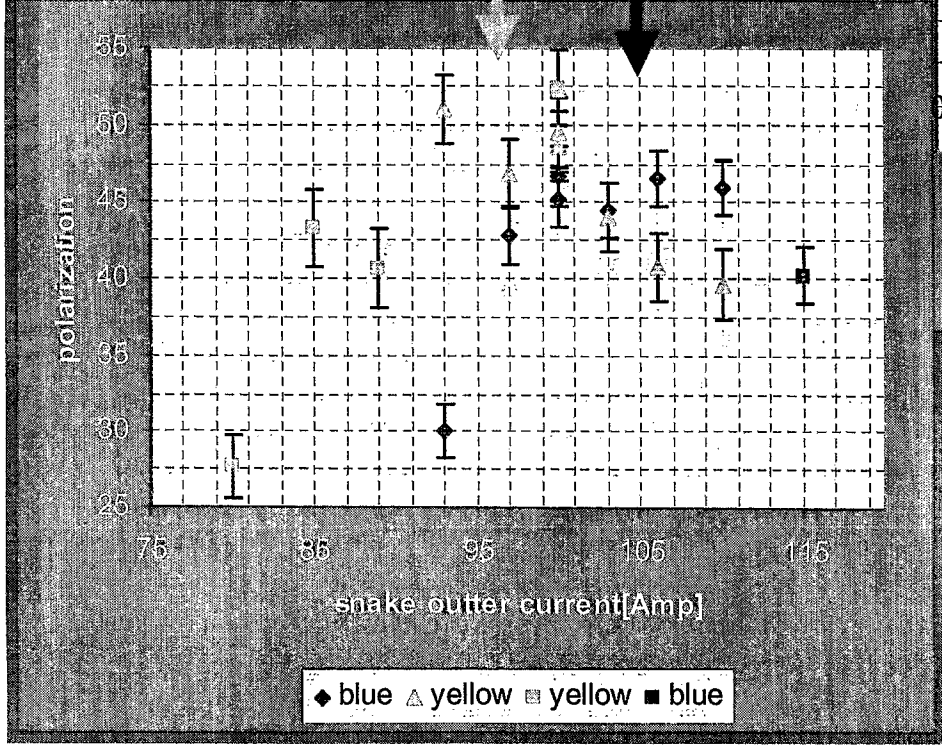
Important Technical Issue for Improving RHIC Spin Capability

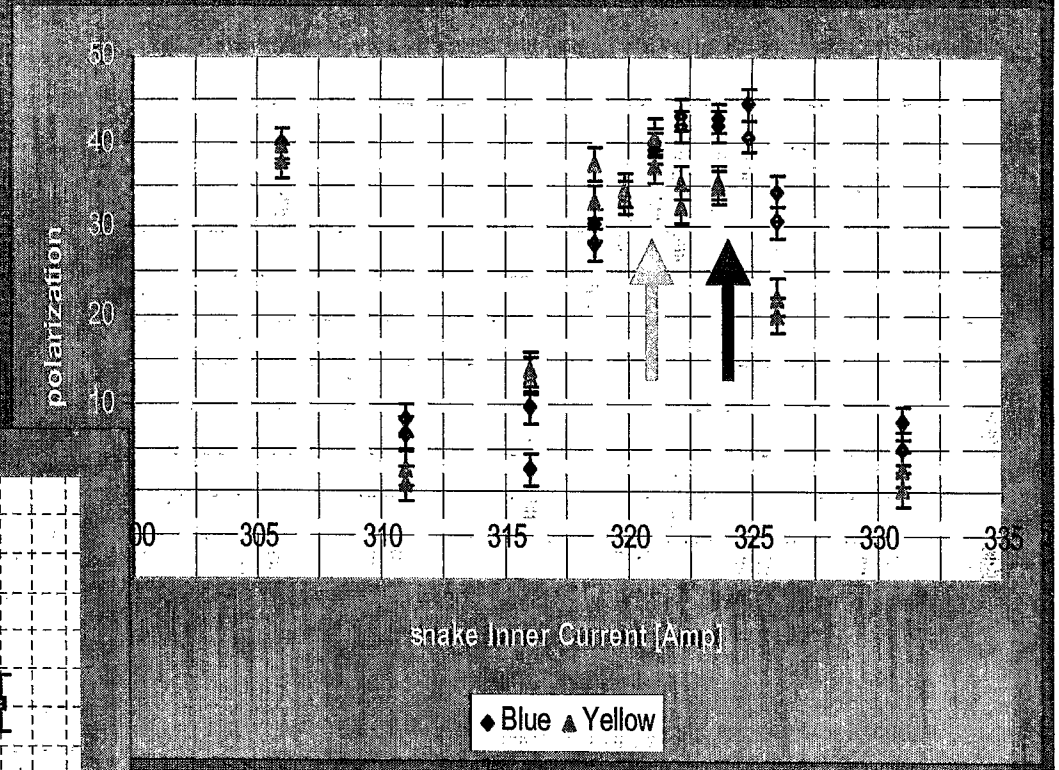
- high polarization at 250 GeV
  - needs a major upgrade of the RHIC orbit control system
- more robust polarization measurement
  - improve lifetime of the polarimeter target
  - improve the polarimeter target control
- improve the working point control during the ramp
  - Improve the on-line model
  - tune control using PLL

Summary

- Things achieved in FY04
  - commissioned the new working point which is benign to both the beam lifetime as well as the beam polarization
  - demonstrated providing stores with an average luminosity of $4x10^{30}cm^{-2}s^{-2}$ and beam polarization of 45% in blue ring and 40% in yellow ring
  - Measured absolute polarization with H Jet target at RHIC injection and store energy
- Machine goals for the next 4 years
  - provide collisions of 112 bunches per ring with $2x10^{11}$ protons per bunch and beam polarization of 70%.
- Approaches for achieving the goal
  - AGS cold snake
  - NEG coating the beam pipes in all the IPs to eliminate the electron multipacing induced vacuum pressure rise

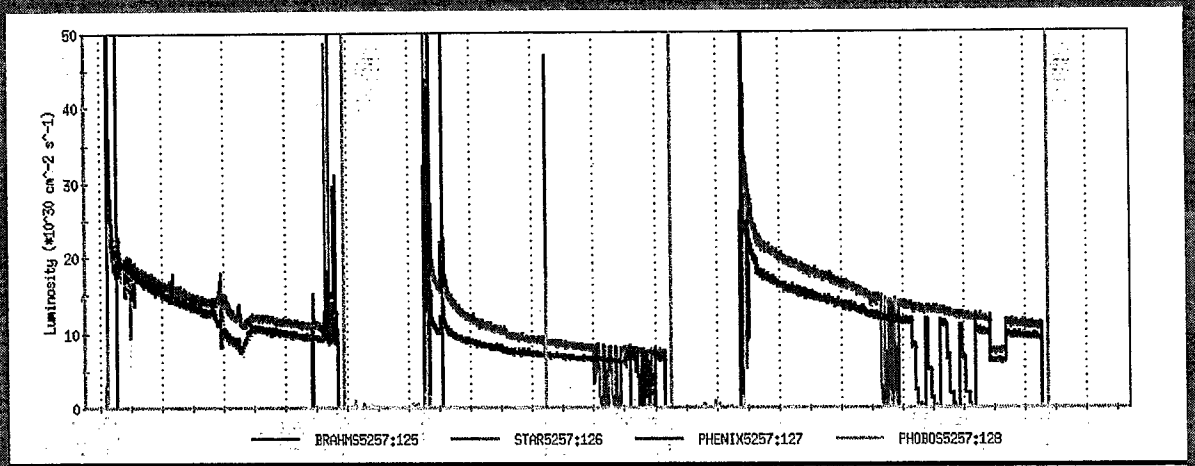
Optimized snake current

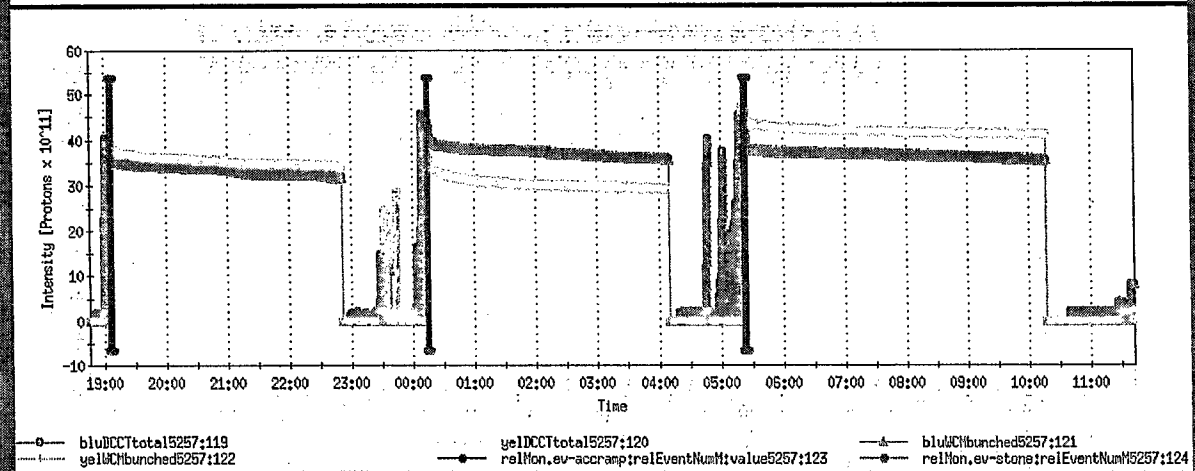




High Luminosity Development

- collisions at STAR and Phenix
- the difference between beam lifetime and the luminosity lifetime indicates the transverse size growth due to the beam-beam force.





Achieved Beam-beam Limit

	# of collisions	Luminosity [$\times 10^{30} cm^{-2} s^{-1}$]	bunch intensity at store[$\times 10^{11}$]	Total beam-beam parameter
RHIC FY04	4	5.0	1.7	0.016
RHIC FY04	2	10	1.7	0.005
RHIC FY03	4	5.0	0.7	0.01

Note:

- total beam intensity is limited by the vacuum pressure rise
- high luminosity development was done with un-polarized proton source and brighter beam from AGS

Machine Goals for the Next 5-10 years

	bunch intensity [10^{11}]	# of bunches	β^* [m]	$\mathcal{L}_{store\ average}$ [$cm^{-2}s^{-1}$]	Time in store	Polazation at store
FY05	1.0	56	1	1.0×10^{31}	45%	50%
FY06	2.0	56	1	3.2×10^{31}	55%	65%
FY07	2.0	90	1	5.7×10^{31}	60%	70%
FY08	2.0	112	1	7.2×10^{31}	60%	70%

Store statistics

	Total time[hr]	Time in store [hr]	Average store to store time[hr]	Minimum store to store time[hr]
RHIC FY03	557	227	5.7	1.1
RHIC FY04	144	52.8	10.0	0.8

- RHIC FY04 is using the last week as the data sample
- during the last week of RHIC FY04, there were on the average 6-8 hours machine development on the daily bases.
- Assuming:
  - average store luminosity: 4×10^{30} cm^{-2}s^{-1}
  - time in store: 45%
  - 1.1pb-1 per week

RHIC Spin Collaboration Meeting XXIV
May 21, 2004
RIKEN BNL Research Center

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RIKEN BNL RESEARCH CENTER

RHIC Spin Collaboration Meetings XXIV, XXV, XXVI *NSAC Review*

May 21, 2004 * May 27, 2004 * June 1, 2004

Li Keran

Nuclei as heavy as bulls
Through collision
Generate new states of matter.
T.D. Lee

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Speakers:

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Gerry Bunce
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