30 June 2004
DOE NP Review
G. Bunce

The PHENIX Spin Program

1. The proton spin puzzle
2. RHIC spin
3. Probes
4. Polarimetry
5. PHENIX
6. Discuss the spin runs chronologically
7. Table of plan, goals
8. Organization, people, support

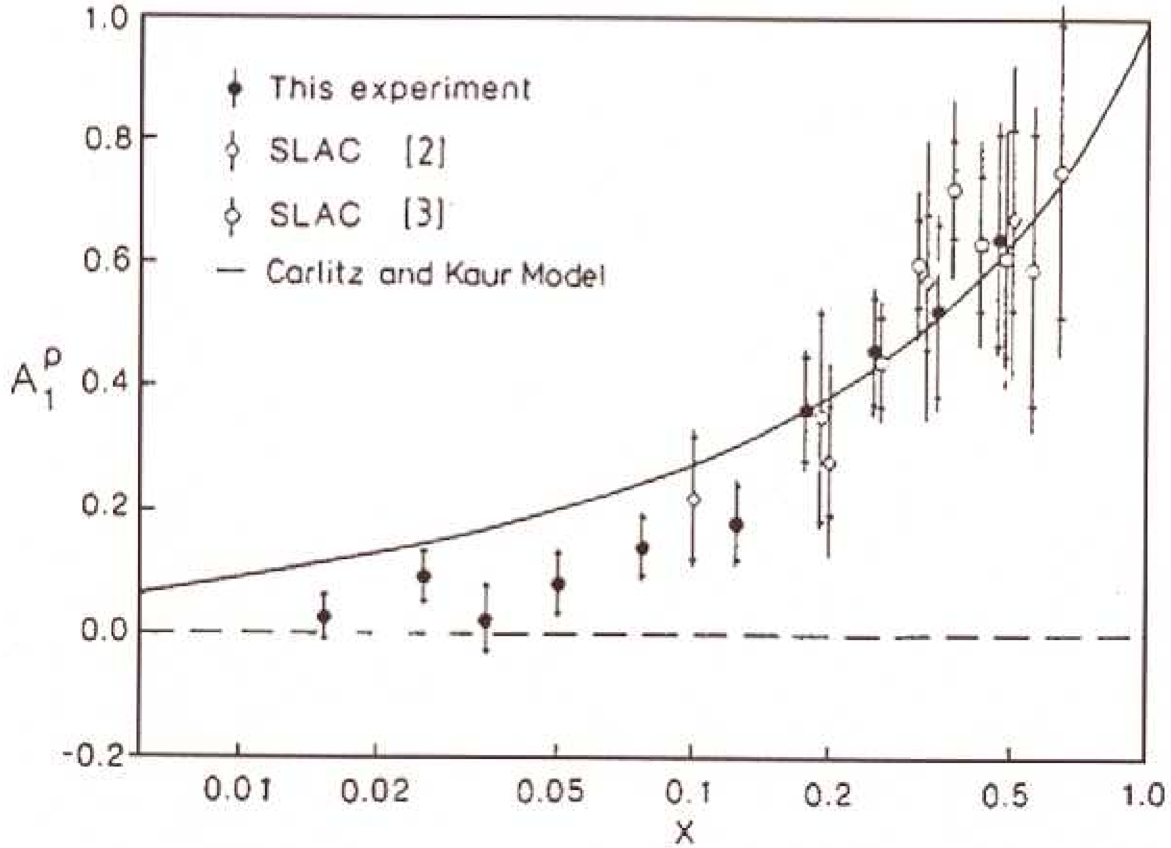
   ---including BNL Spin Group and RBRC

9. Issues
10. Appendices: responses to charge; responses to NSAC subcommittee questions

1. The proton spin puzzle

Result from the European Muon Collaboration (EMC)

A_1^p is the asymmetry for polarized leptons probing polarized protons, J. Ashman et al., Nucl. Phys. B328, 1 (1989).

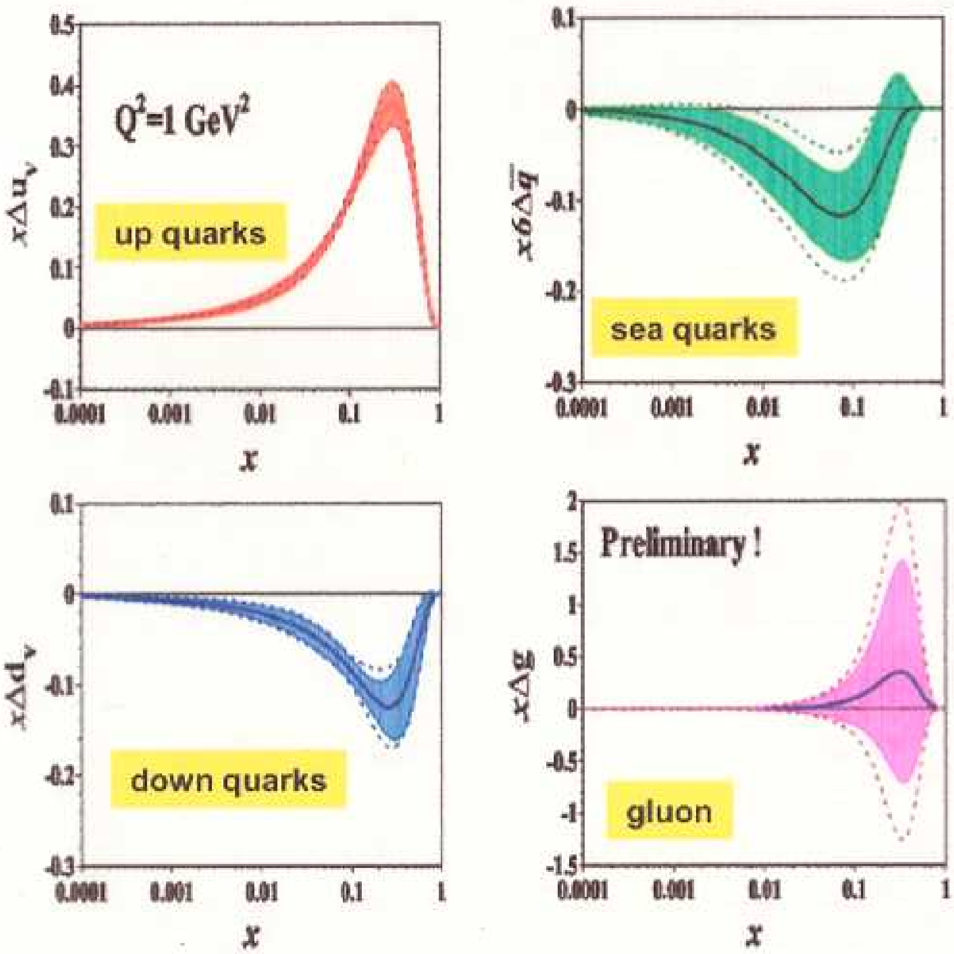


On average, the quarks and gluons do not carry the proton spin!

Subsequent polarized DIS experiments have confirmed this surprise (SMC, SLAC, HERMES).

Polarized quark and gluon distributions

M. Hirai et al (AAC collab)



$$\Delta\Sigma = \int_0^1 \Delta\Sigma(x,Q^2)dx$$ is constrained

$$\Delta G = \int_0^1 \Delta g\left(x,Q^2\right)dx$$ is largely unknown

Longitudinal Spin Sum Rule:

$$1/2 = 1/2\ (\Delta q + \Delta \text{qbar}) + \Delta G + L_q + L_G$$

$$\Delta q = q^{+}_{+} - q^{+}_{-}$$

From DIS: $1/2\ (\Delta q + \Delta \text{qbar}) = 0.1$

---Where is the proton spin?

---What is Δqbar ?

Also Transverse spin:

---gluon spin cannot contribute

---what is δq and δqbar ? (a.k.a. transversity)

---large transverse spin effects at lower energy

---and now RHIC (STAR)

2. RHIC spin: polarized proton probes at collider energy

---pQCD probes:

---factorization

---sensitivity to spin thru angular momentum selection rules for subprocesses

---universality (pp <---> DIS)

---probe polarized proton with polarized quarks and gluons

---strongly interacting probes: ΔG

---flavor from parity-violating W production

---new access to flavor: Δu, Δdbar, Δd, Δdbar

---independent control of spin direction for experiments

---spin combinations change every 100 ns

---longitudinal or transverse spin for each expt.

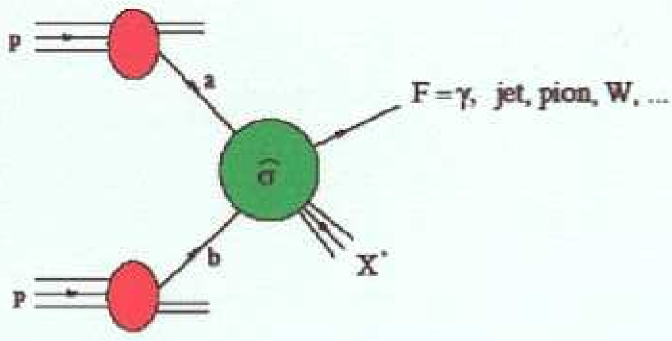
RHIC Spin:

root (s) = 200 GeV, P = 70%, L = 8 x 10^{31}, IL = 320 pb^{-1}

root(s) = 500 GeV, P = 70%, L = 2 x 10^{32}, IL = 800 pb^{-1}

Hard scattering in polarized hadron collisions

$$p_T^3 \frac{d\Delta\sigma}{dp_T d\eta} = \left| \right|^2 + \mathcal{O}\left(\frac{\lambda}{p_T}\right)^n$$

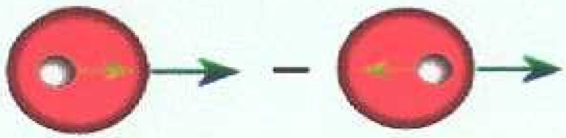


$$p_T^3 \frac{d\Delta\sigma^{pp\to FX}}{dp_T d\eta} = \sum_{abc} \int dx_a\, dx_b\, \Delta f_a(x_a,\mu)\, \Delta f_b(x_b,\mu) \times p_T^3 \frac{d\Delta\hat{\sigma}^{ab\to FX'}}{dp_T d\eta}(x_a P_a, x_b P_b, P^F, \mu) \;+\; \text{P.C.}$$

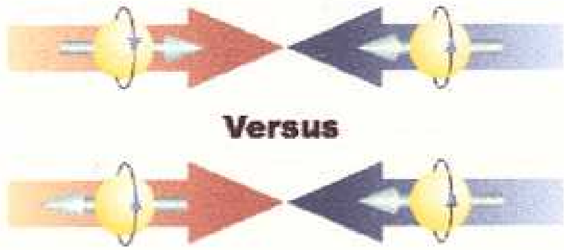
$$\Delta\sigma = \sigma_{++} - \sigma_{+-}$$

$\Delta\hat{\sigma}^{(0)} + \alpha_s \Delta\hat{\sigma}^{(1)} + \ldots$ perturb.

$\Delta f =$



A_{LL}



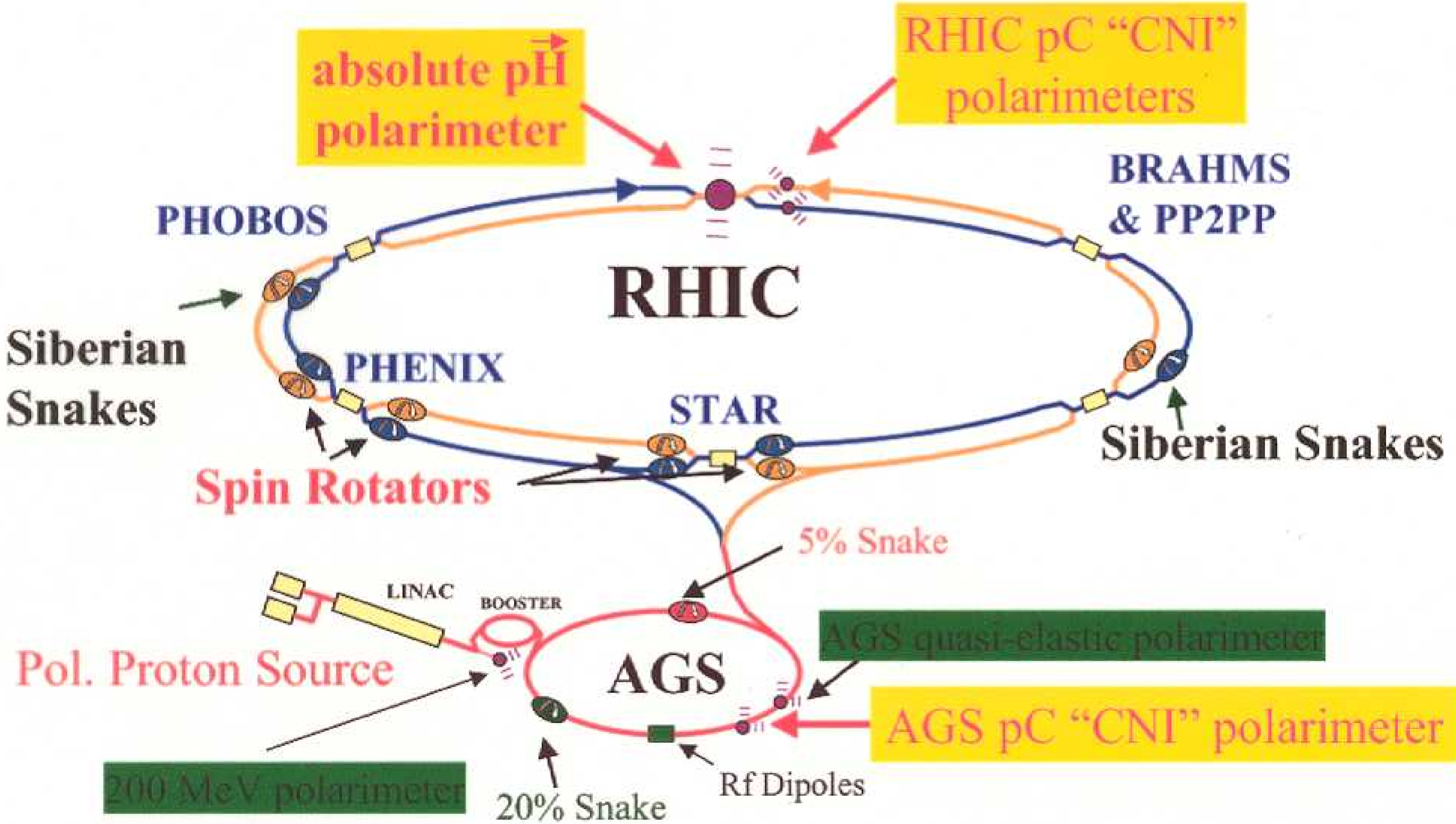
$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{|P_B P_Y|} \frac{N_{++}/L_{++} - N_{+-}/L_{+-}}{N_{++}/L_{++} + N_{+-}/L_{+-}}$$

++ same helicity
+– opposite helicity

(P) Polarization
(L) Relative Luminosity
(N) Number of pi0s

PHENIX

RHIC *pp* accelerator complex & Polarimeters



3. Probes:

Longitudinal spin

--- π, jets ---high cross section, very sensitive to ΔG

--- γ ---single subprocess, high precision for ΔG

--- c, b ---$A_{LL} \propto (\Delta G)^2$, lower x reach

--- W ---very powerful detailed study of Δubar, Δdbar

Transverse spin

--- jet spin analyzing power? ---Belle

--- π–π interference

--- A_N for π, vs. jet

---δq vs. k_T in polarized proton

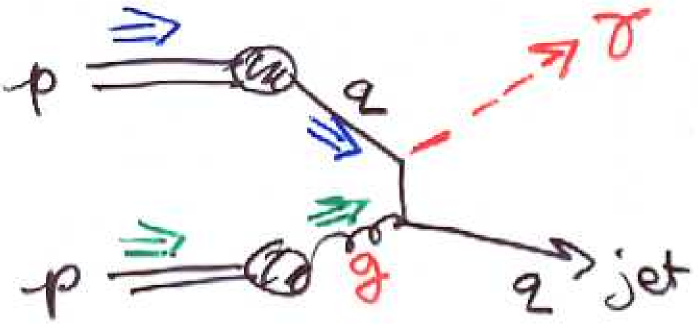
---forward vs. mid-rapidity vs. backward

---control x, gluon vs. quark
(the gluon can only contribute via k_T)

RHIC Spin Probes

Gluon polarization:

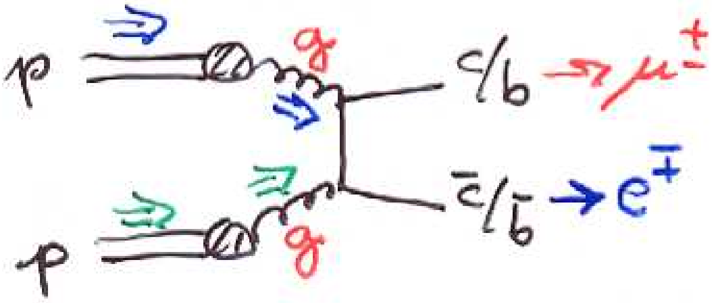
$$A_{LL} = \frac{1}{P^2} \frac{N_{++}(\gamma) - N_{+-}(\gamma)}{N_{++} + N_{+-}}$$



$$A_{LL} = \frac{\Delta G}{G}(x_g)\, A_1^p(x_q)\, \hat{a}_{LL}$$

(.3) (.6)

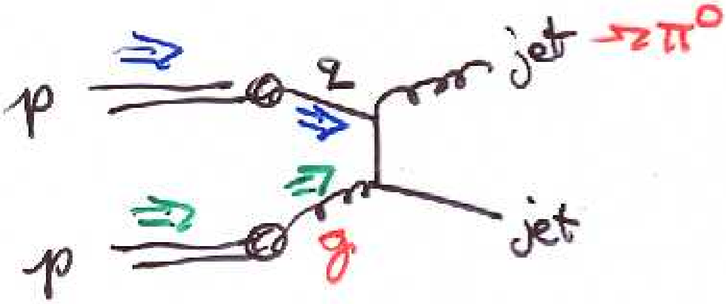
$$\simeq \frac{1}{5} \frac{\Delta G}{G}(x_g)$$



$$A_{LL} = \frac{\Delta G}{G}(x_1)\, \frac{\Delta G}{G}(x_2)\, \hat{a}_{LL}$$

(.5?) (.15)

$$\overset{?}{\simeq} \frac{1}{12} \frac{\Delta G}{G}(x_1)$$



$$A_{LL} = \frac{\Delta G}{G}(x_1)\, \frac{\Delta u}{u}(x_2)\, \hat{a}_{LL}$$

(.4) (.6)

$$\simeq \frac{1}{4} \frac{\Delta G}{G}(x_1)$$

$+\, gg \to gg/q\bar{q}$

also J/Ψ (but production mechanism)

4. Polarimetry

---develop machine

---normalize physics results

---monitor polarization direction at experiments

The experiments play a lead role in polarimetry.

5. Use the beautiful PHENIX detector with fast, high rate capability, built-in collision monitors, superb granularity (emcal, RICH, etc.), superb particle I.D. (RICH, muon I.D., TOF)

---> add Level 1 triggering (photon, e, $\pi^{\pm}$, μ)

---> add crossing luminosity capability

---> add north muon arm

---> add CC-J (computing facility in Japan)

---> customer for fast detector, high DAQ rate (1 kHz)

---> to add muon trigger background rejection for W

---> to add vertex detector for jet axis, heavy flavor, photon isolation

---> to add nose cone calorimeter for W isolation, jet axis

6. Discuss PHENIX spin program chronologically.

The PHENIX Detector

Philosophy:

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

Central Arm Tracking
Drift Chamber, Pad Chambers, Time Expansion Chamber

Muon Arm Tracking
Muon Tracker

Calorimetry
PbGl and PbSc

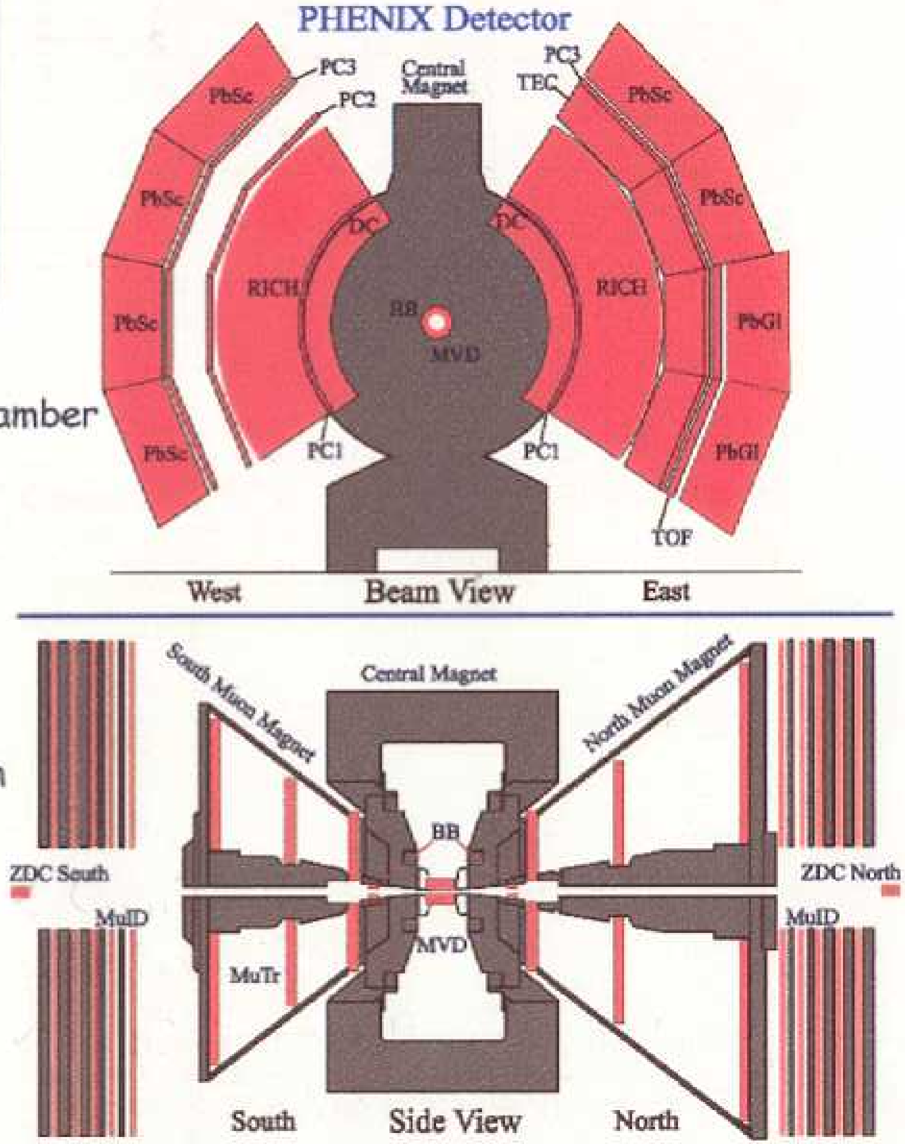
Particle Id
Muon Identifier, RICH, TOF, TEC

Luminosity Counters/Vertex Detectors
BBC, ZDC/SMD, Local Polarimeter, forward hadron calorimeters, NTC, MVD

DAQ
High bandwidth

Trigger
Level 2
Level 1 (GL1P, muId, EMC/RICH)

Online
Calibration and production



Run 2: root(s) = 200 GeV polarized proton collisions

2001-2002, 8 weeks, $L = 5 \times 10^{29}$, $IL = 0.3\ pb^{-1}$, $P = 20\%$.

---first ever!

---transverse spin

---search for process to monitor spin direction at collision

---develop Level 1 triggering (high p_T photon, e, $\pi^{\pm}$, μ)

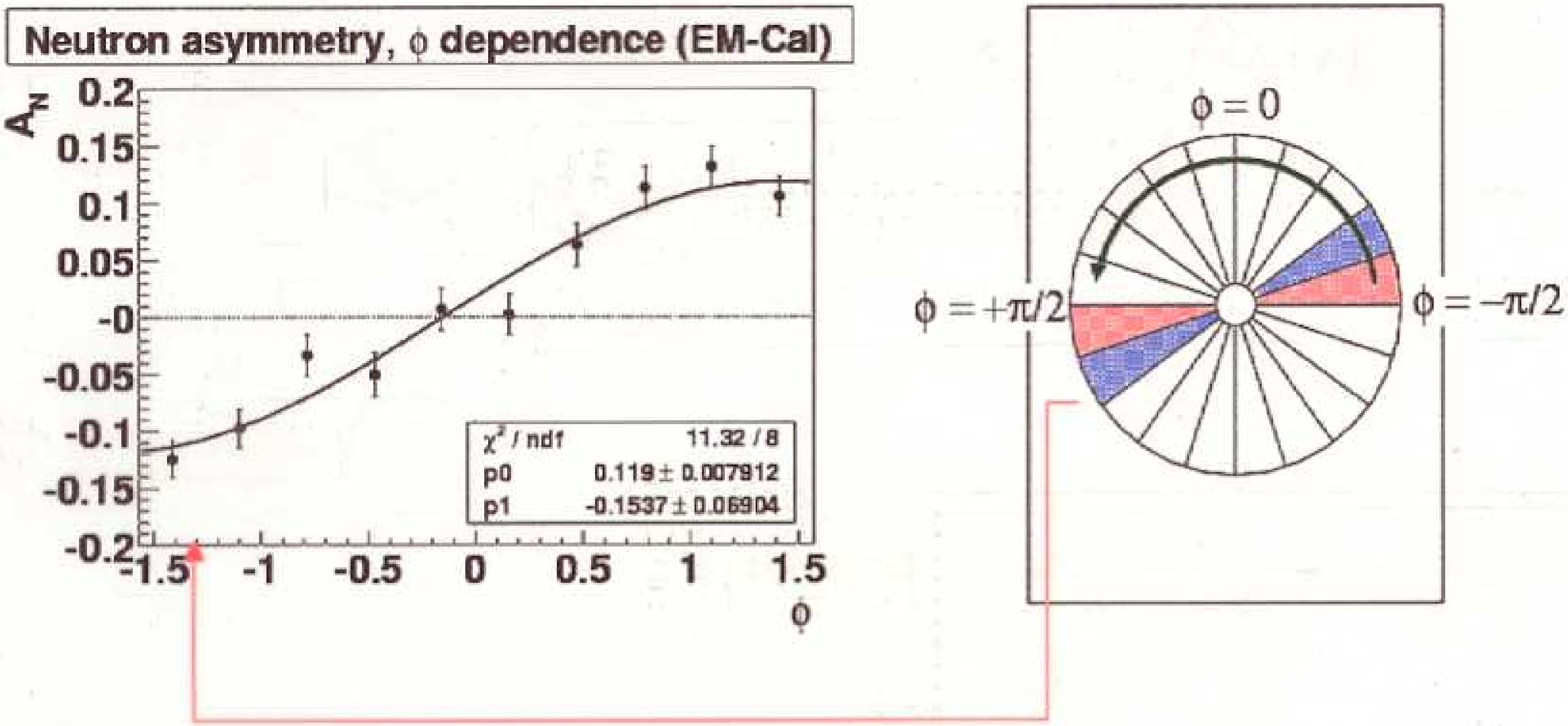
---develop spin monitoring (tracking crossing, luminosities for crossings, backgrounds)

---measure cross sections first!

- ---is pQCD applicable and where?
- --- π^0 cross section for 8 orders of magnitude
- ---> NLO pQCD describes cross section, to p_T = 1.5 GeV

---measure A_N for π^0, $h^{\pm}$ at mid-rapidity

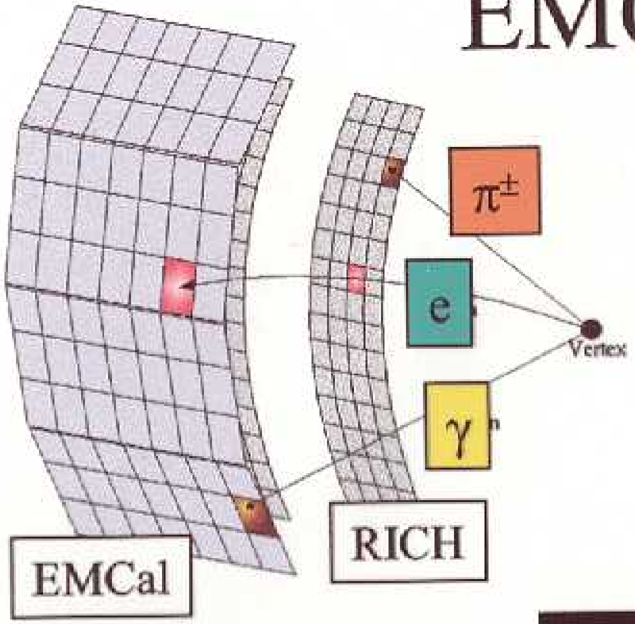
Neutron asymmetry phi dependence



Very clear azimuthal asymmetry

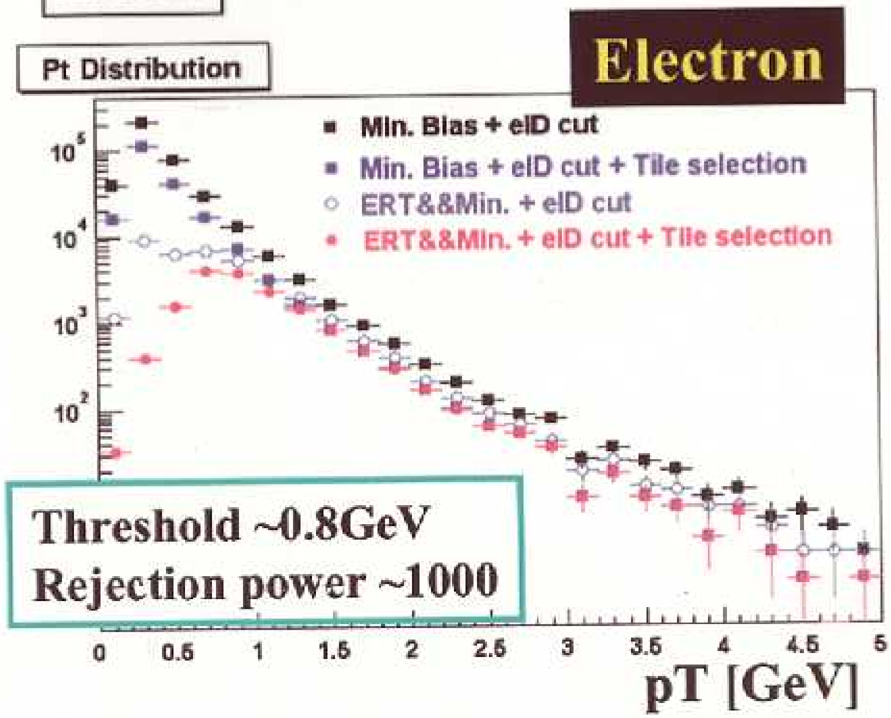
Large asymmetry gives good figure of merit for local (PHENIX) polarimetry.

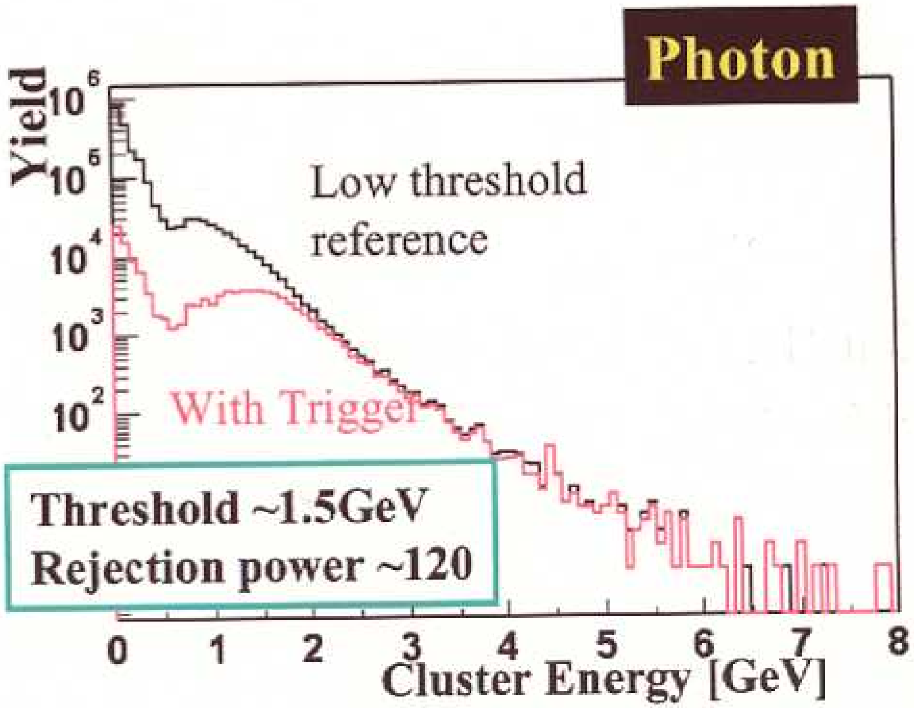
EMCal-RICH Trigger



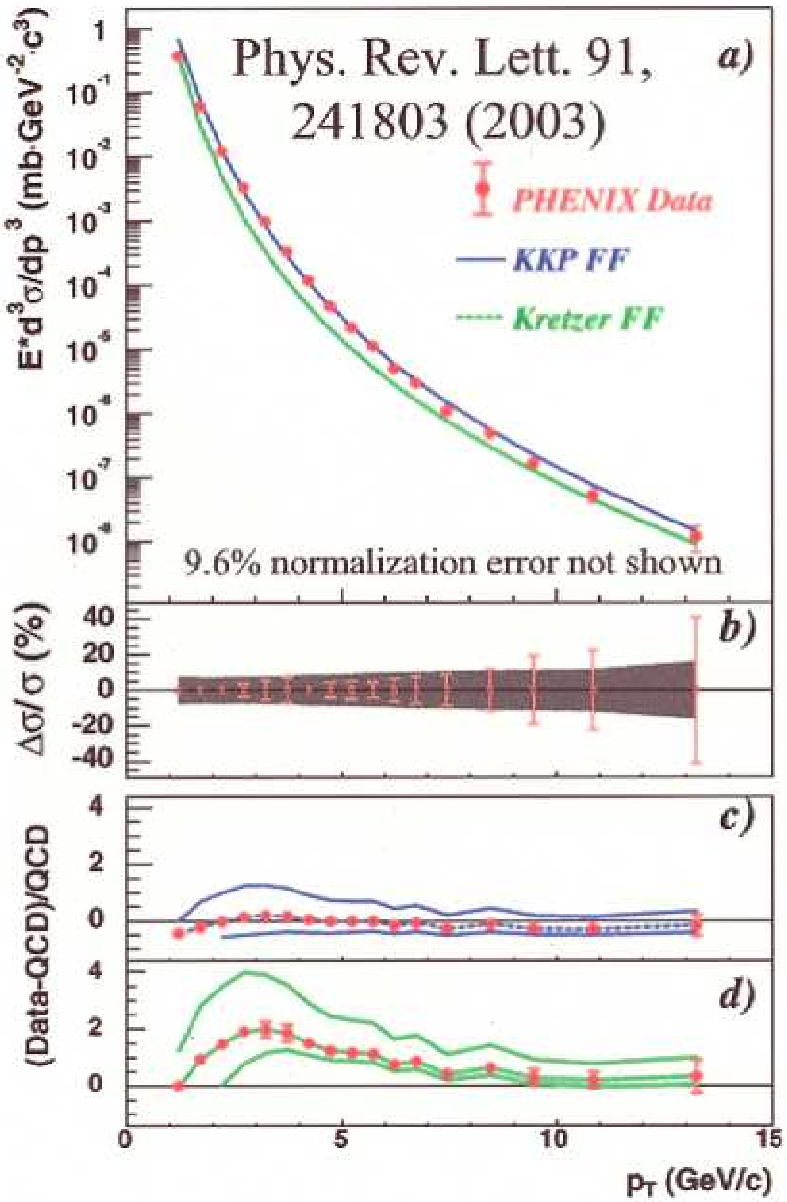
Requirement ~75kHz (collision rate in Run3)
→ ~1kHz (Data acquisition rate)

Trigger for photons and electrons with the segmented EMCal and RICH.
We can set 4 EMCal trigger energy thresholds.





π^0 Cross Section in *pp*



- NLO pQCD consistent with data within theoretical uncertainties
  - PDF: CTEQ5M
  - Fragmentation functions:
    - Kniehl-Kramer-Potter (KKP)
    - Kretzer
  - Spectrum constrains D(gluon$\rightarrow\pi$) fragmentation function
- Important confirmation of theoretical foundation for spin program
- Data from Run3 reproduce Run2 results and extend the p_T range to 17 GeV/c
  - Will be released soon

Run 3: root(s) = 200 GeV polarized proton collisions

2003, 10 weeks, $L = 2 \times 10^{30}$, $IL = 0.2\ pb^{-1}$, $P = 27\%$.

---new spin rotators

---longitudinal spin, $P^2 \times \sqrt{IL} = 0.03\ pb^{-1/2}$

---set up and monitored spin rotators with new local polarimeters (very forward neutrons in ZDCs with SMDs)

---measured crossing luminosity to $\Delta(L_{++}/L_{+-}) < 2.5 \times 10^{-4}$

---A_{LL} of luminosity monitors zero to $\Delta A_{LL} < 2 \times 10^{-3}$

---first $A_{LL}(\pi^0)$, $A_L(\pi^0)$

---measure expt. systematic uncertainties by mixing crossings (++, +–, –+,—)

---physics: $A_{LL} \propto (\Delta G/G)^2$ at mid-rapidity and low p_T

---NLO pQCD comparisons with large, small $\Delta G(x)$

---result prefers smaller $\Delta G/G$ at $x \approx 0.03 - 0.1$

---sensitivity to $\Delta G/G$ at level of global fits for gluon polarization for inclusive DIS

---studied backgrounds for muon trigger → shielding plan

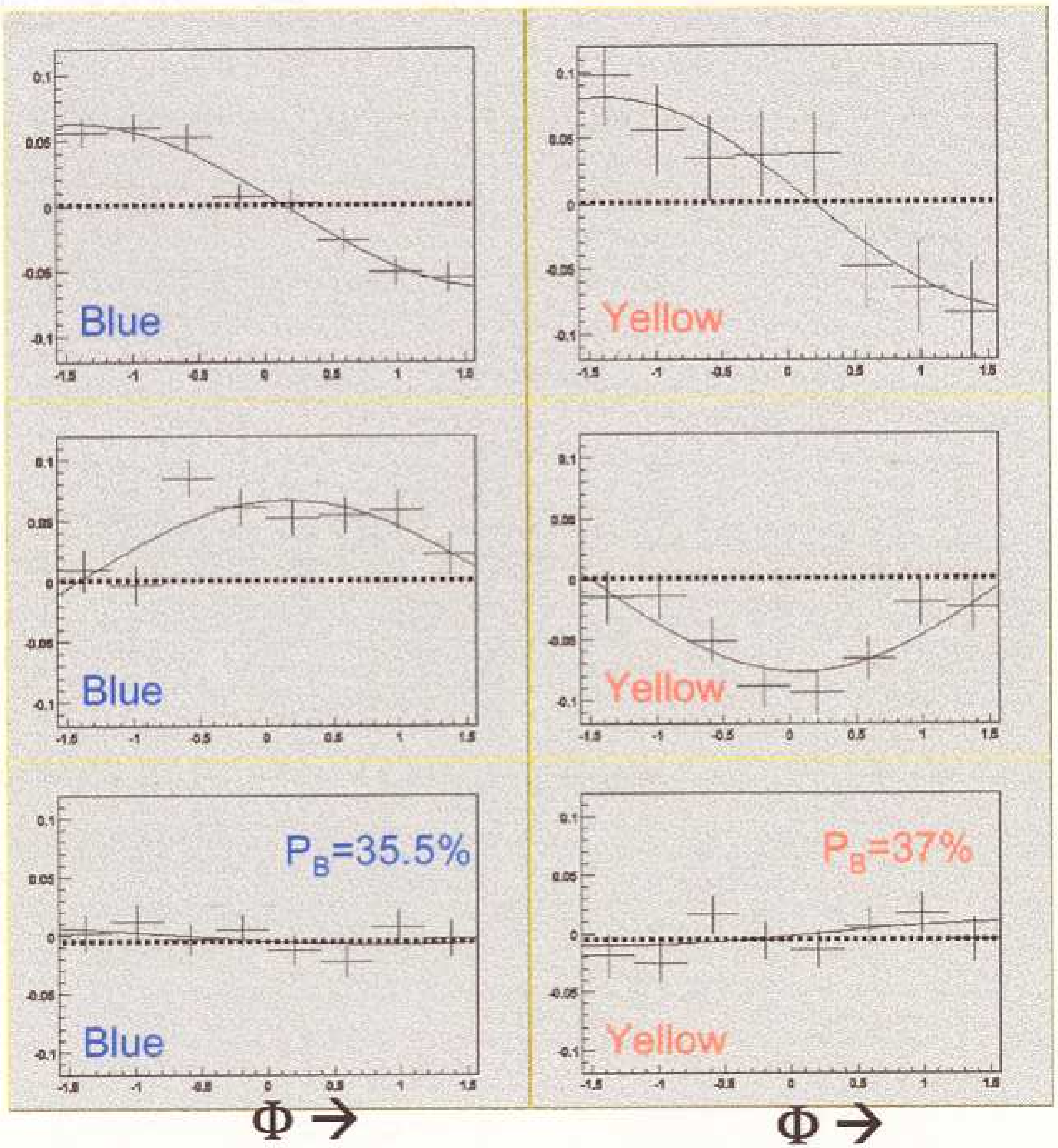
---in progress: $d\sigma/dp_T$(direct γ), A_{LL} and A_L for e, μ

PHENIX Spin Rotator Commissioning using neutron asymemtries vs. ϕ

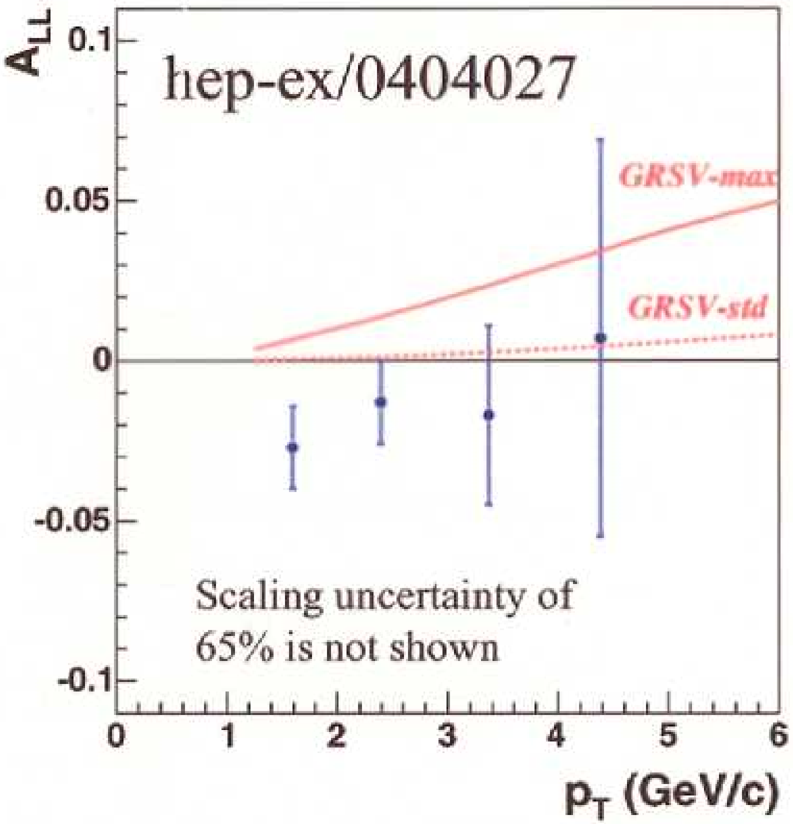
Spin Rotators OFF

Spin Rotators ON
Current Reversed

Spin Rotators ON
Correct Current !

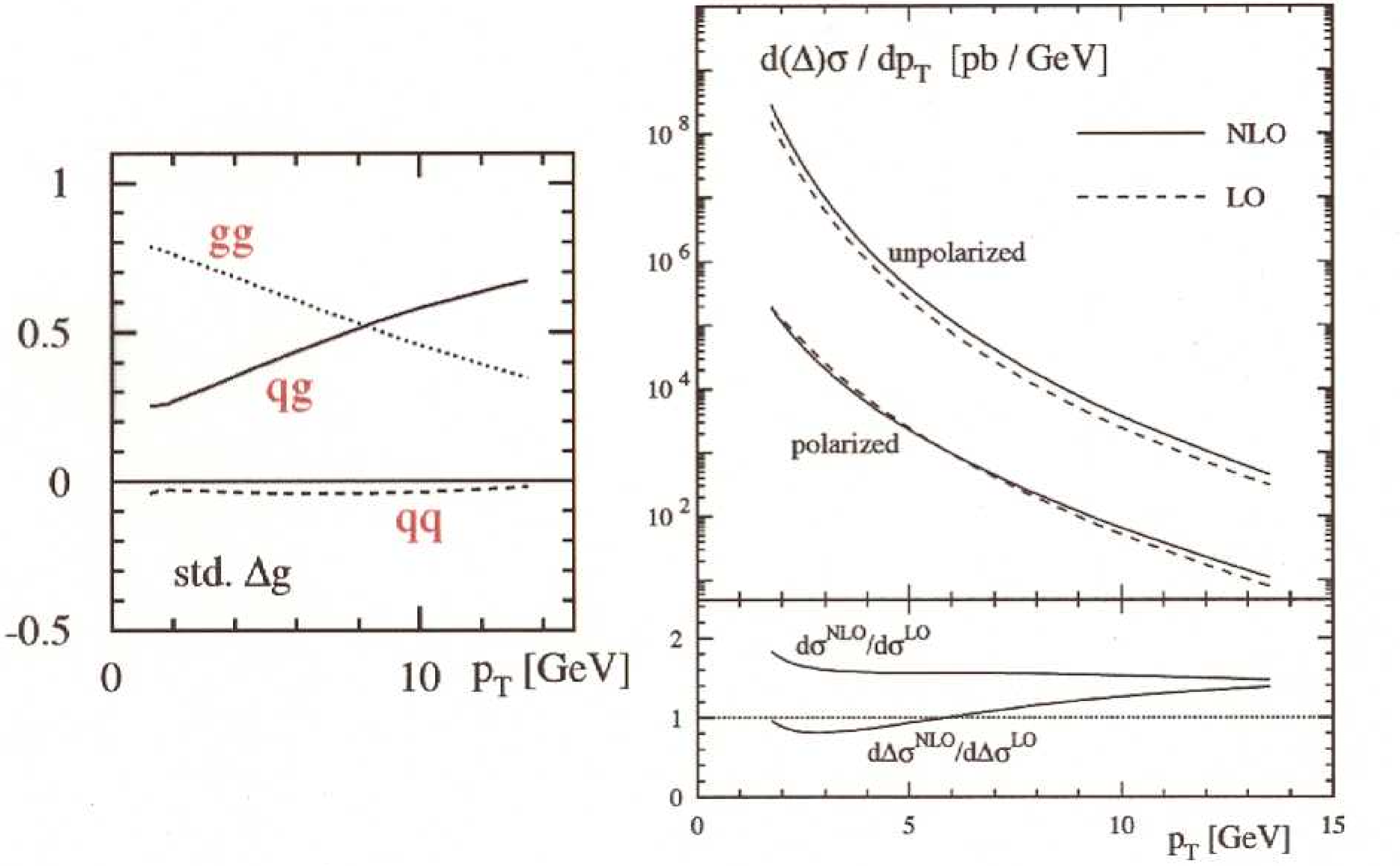


π^0 A_{LL} from pp at 200 GeV



GRSV Curves from B.Jaeger et al., PRD67, 054005 (2003)

Not including theory uncertainty
GRSV-std CL: 16-20%
GRVS-max CL: 0.02-5%



1
0.5
0
-0.5
gg
qg
qq
std. Δg
0
10
p_T [GeV]
d(Δ)σ / dp_T [pb / GeV]
10^8
10^6
10^4
10^2
NLO
LO
unpolarized
polarized
dσ^NLO/dσ^LO
dΔσ^NLO/dΔσ^LO
2
1
0
5
10
15
p_T [GeV]

Run 4: root(s) = 200 GeV polarized proton collisions

2004, 6 weeks, $L = 5 \times 10^{30}$, $IL = 0.2\ pb^{-1}$, $P = 42\%$.

---machine R&D emphasized

---longitudinal spin, $P^2 \times \sqrt{IL} = 0.08\ pb^{-1/2}$

---$\Delta P/P_{beam} < 10\%$ from jet !

---superb run!

---new muon shielding and automatic beam scraping work!

---develop luminosity telescope monitor with vertex cuts

---for future high L

Run 5: root(s) = 200 GeV polarized proton collisions

2005, 15? weeks, $L = 9 \times 10^{30}$, $IL = 7\ pb^{-1}$, $P = 50\%$.

--- $P^2 \times \sqrt{IL} = 0.7\ pb^{-1/2}$, 20 x run 3

---$A_{LL}(\pi^0)$ expectation

   ---reach qg region, very sensitive to gluon polarization

---first long spin run, expect high statistics for π, μ, e, direct γ cross section, e–μ, studies of systematics

---

Run 6: root(s) = 200 GeV polarized proton collisions

2006, 16? weeks, $L = 2 \times 10^{31}$, $IL = 50\ pb^{-1}$, $P = 70\%$.

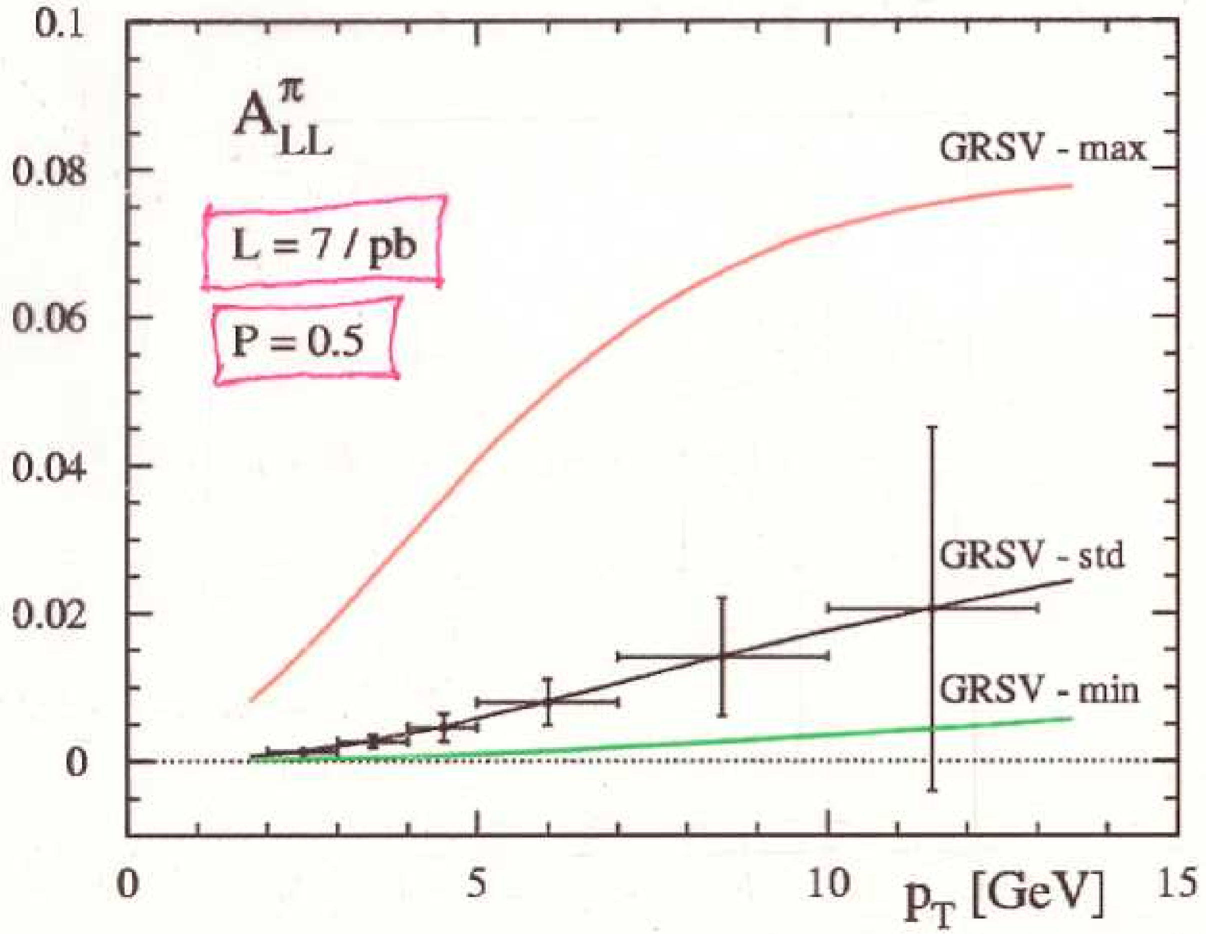
---first run with full L, P

---begin precise measurement of gluon polarization using direct γ

---also high statistics for π, e, μ

π^0 Production and ΔG

π^0 can be used to determine ΔG with limited L & P



Jager, Schafer, Stratmann, Vogelsang

Run 7–10:

---complete 150 pb^{-1} for direct photon, $\sqrt{s} = 200$ GeV

---precise measurement of $\Delta G/G(x)$

---install and commission muon trigger improvements, vertex detector, nose cone calorimeter

---$\sqrt{s} = 500$ GeV collisions, $L = 1.5 \times 10^{32}$, IL = 500 pb^{-1}, P = 70%

---parity-violating W production for flavor-tagged anti-quark polarizations

---lower x reach for γ, π measurements for gluon pol.

---heavy quark (using micro vertex), jet axis for γ + jet

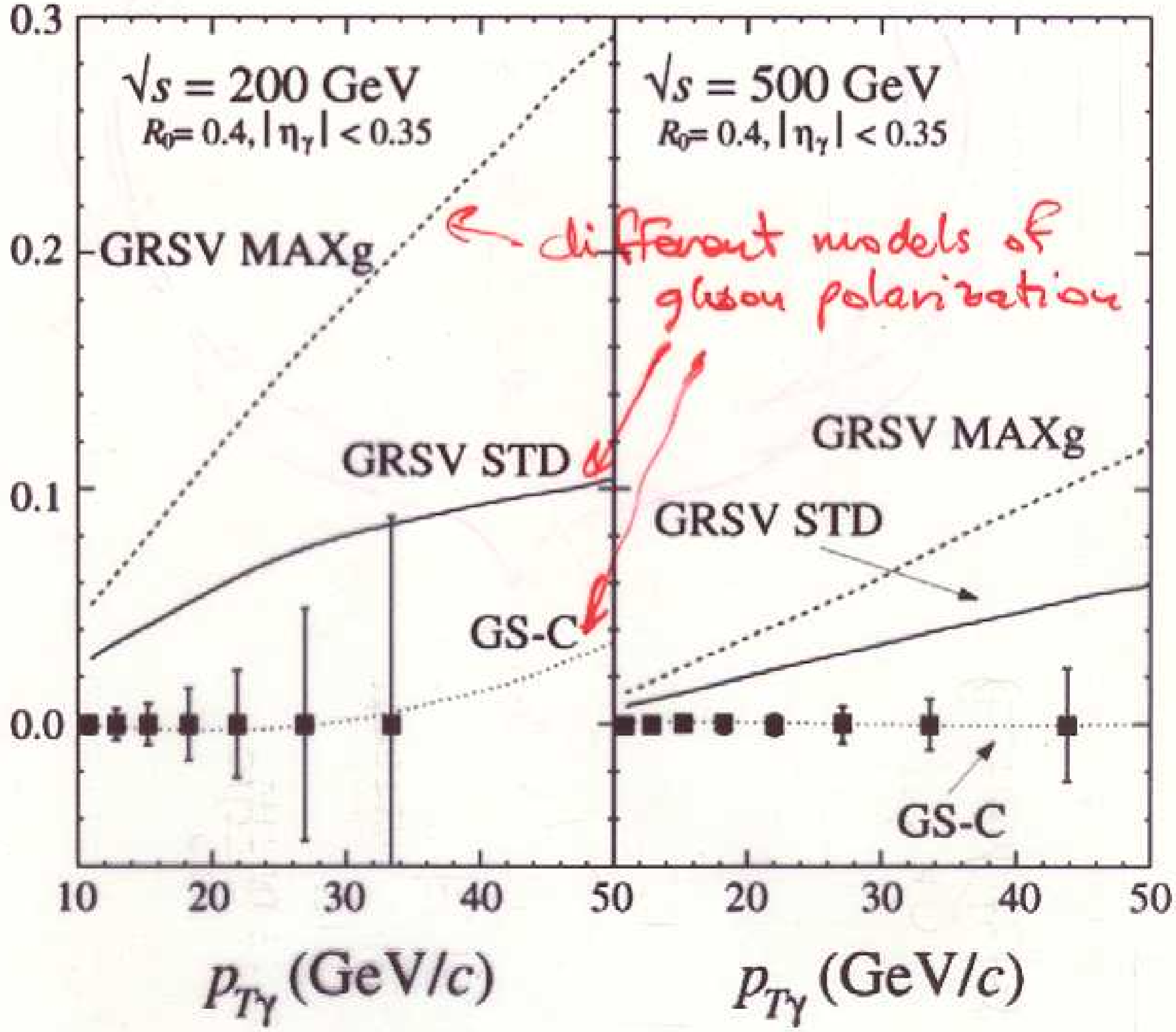
---lower x reach, universality (test our understanding of the sub-processes)

Sensitivity at PHENIX for gluon pol.

$\int L\,dt = 320\ pb^{-1}$ $\quad \sqrt{s} = 200$

$\quad\quad\; = 800\ pb^{-1}$ $\quad\quad\quad 500$

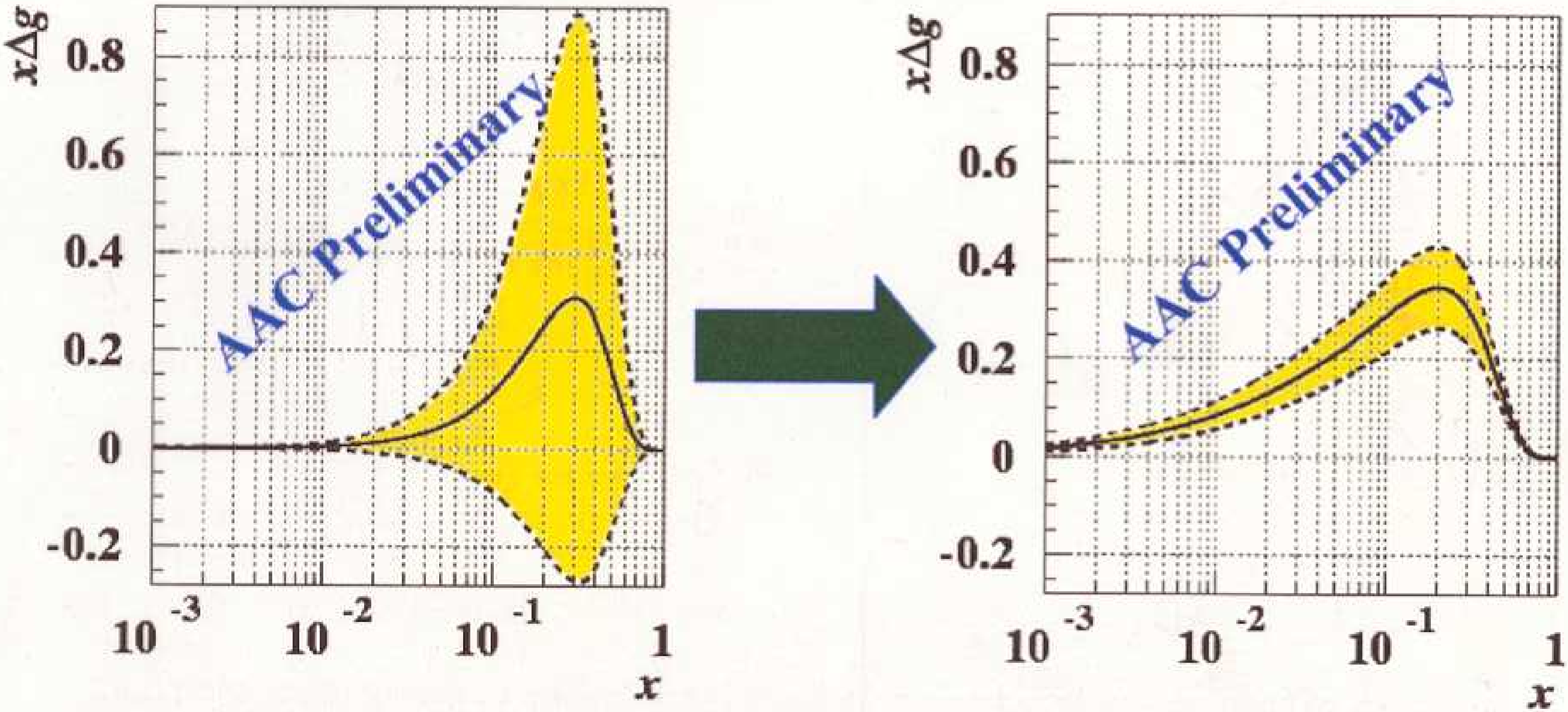
$P_{beams} = 70\%$



$p^{\uparrow\uparrow} + p^{\uparrow\uparrow} \to \gamma + X \;:\; A_{LL}$

Prompt γ measurement: impact on ΔG

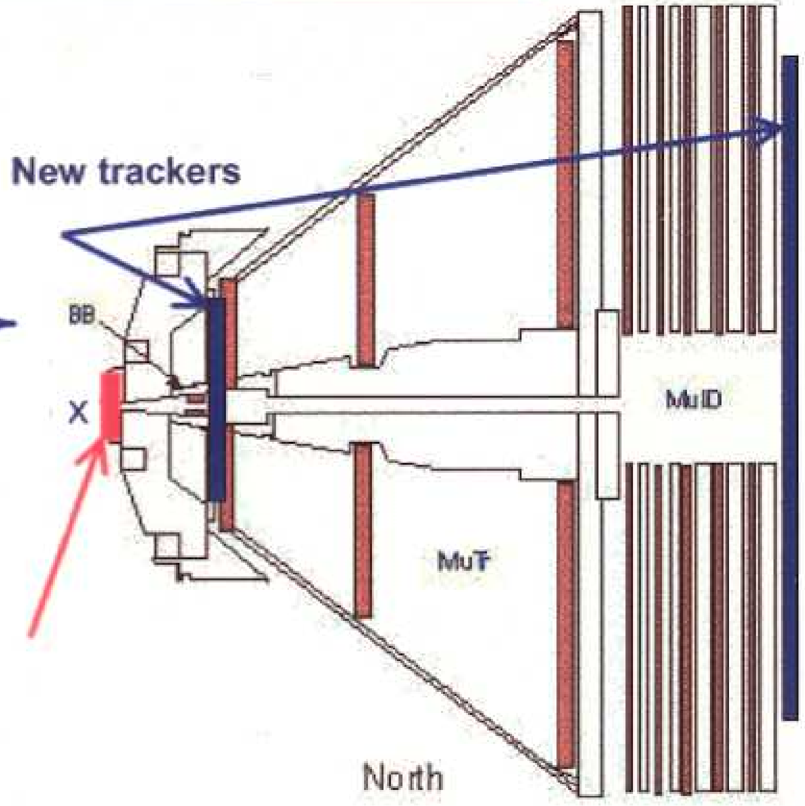
If the projected PHENIX Prompt Photon Data are included in a Global QCD Analysis:



M. Hirai, H.Kobayashi, M. Miyama *et al.*

What is proposed?

- **Upgraded muon trigger**
  - Add momentum information into muon trigger for highest luminosities in p-p, d-A and A-A
  - Gives robustness against beam and collision related backgrounds.
  - Support muon tracking
  - eg. RPC in gap 5 and upgrade station I front end electronics to provide output to LL1
- **Nose cone calorimeter (NCC)**
  - $0.9 < |\eta| < 3.0$
  - Tungsten-Silicon sampling calorimeters
  - Electromagnetic and shallow hadronic compartment
  - Expands PHENIX's kinematical coverage for jets, inclusive neutral pions, electrons, and photons to forward rapidity
  - For p-p, d-A and A-A collisions.



similar in the south arm!

Parity Violation in W^+ Production

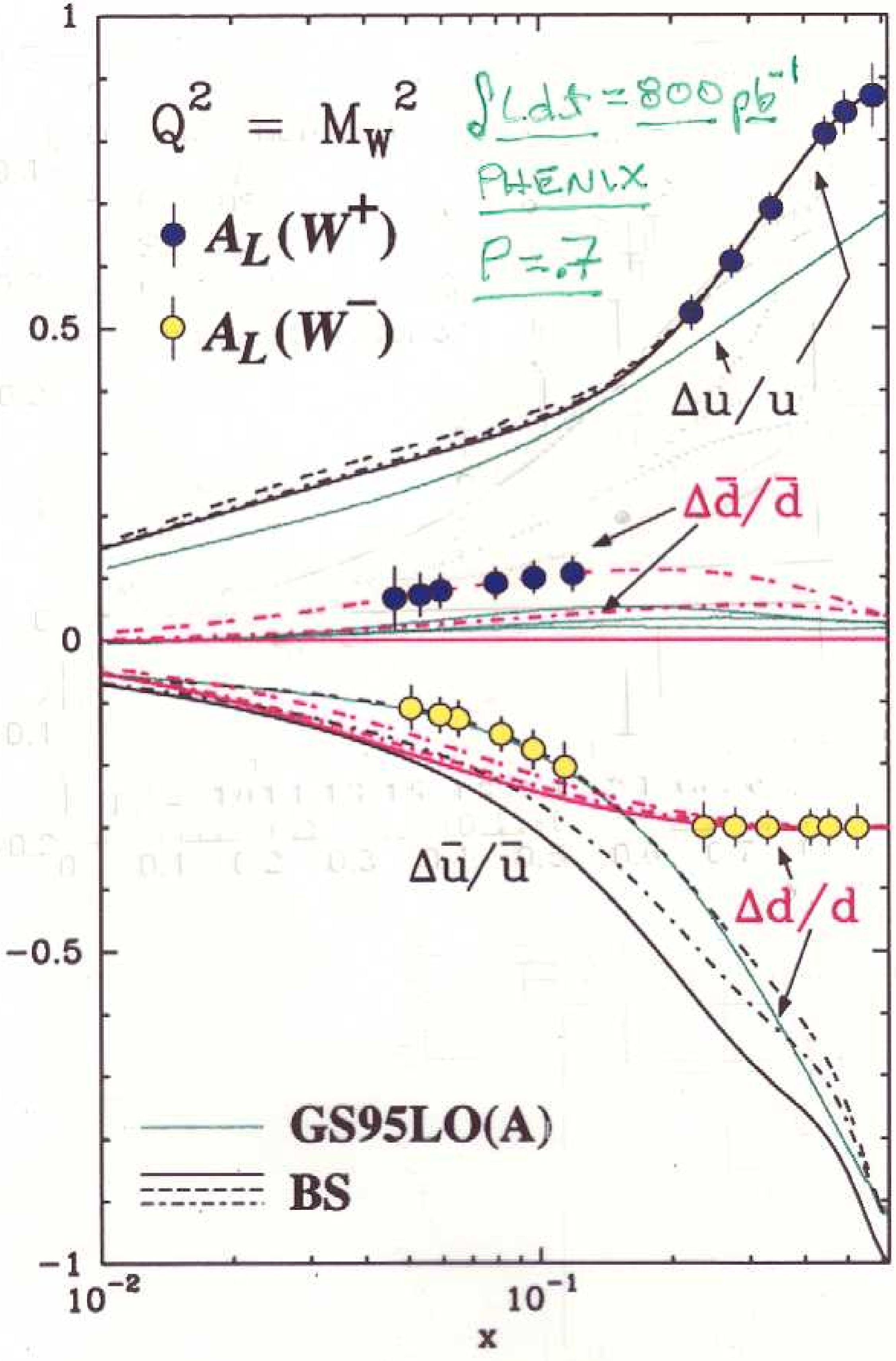
One beam is longitudinally polarized :
$$A_L = \frac{1}{Pol.} \frac{N_+ - N_-}{N_+ + N_-}$$

- if W^+ is produced to $+y \Rightarrow$ large x_1, small x_2
  u $\bar{d}$

- but proton 1 is polarized $\Rightarrow$
  u quark is polarized and
  $$A_L(+y) = \frac{\Delta u}{u}$$

- if W^+ is produced to $-y \Rightarrow$ small x_1, large x_2
  $\bar{d}$ u

- proton 1 is polarized $\Rightarrow$
  $\bar{d}$ is polarized and
  $$A_L(-y) = \frac{\Delta \bar{d}}{\bar{d}}$$

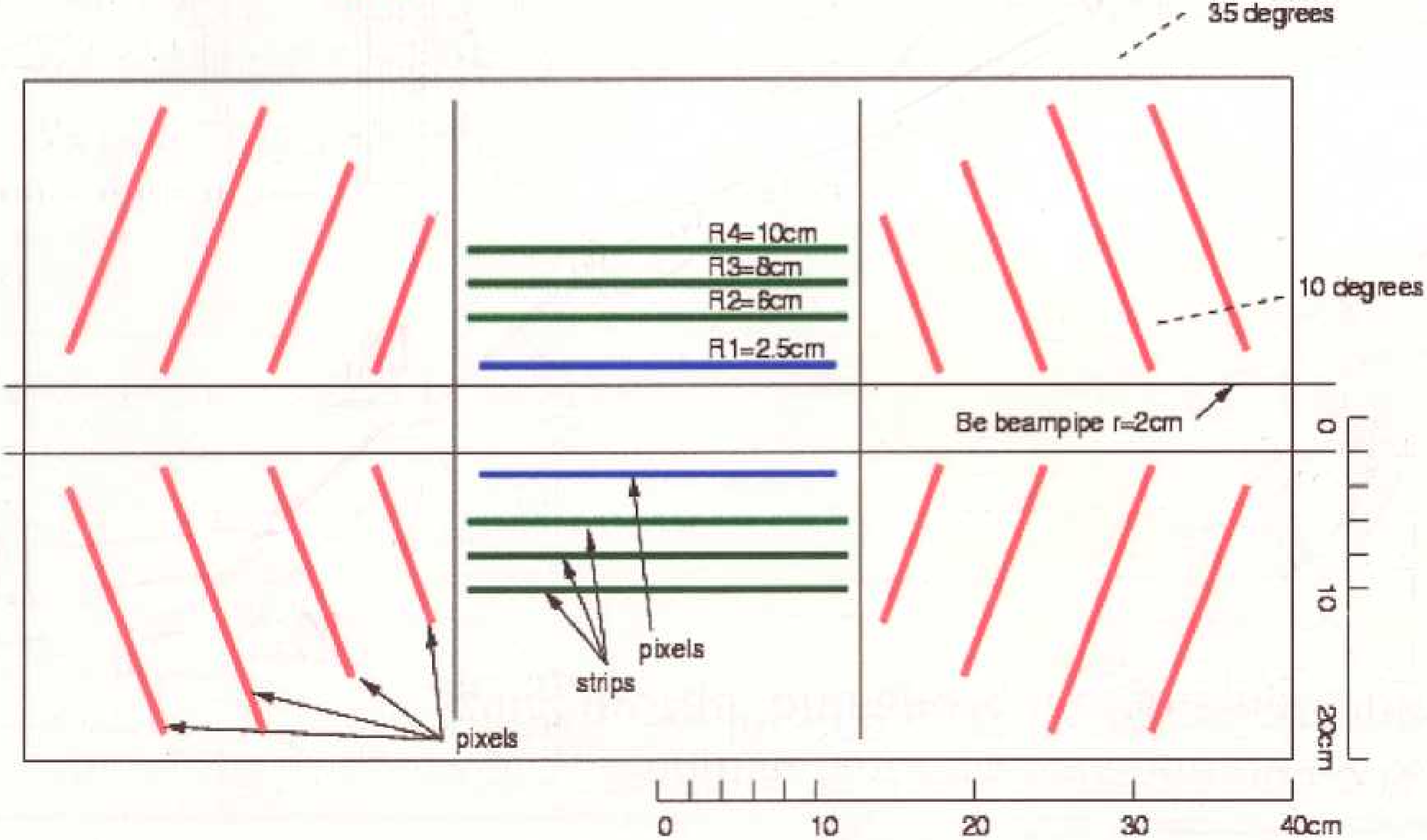


courtesy of Jacques Soffer & Claude Bourrely

Plans for PHENIX upgrade

Detection of heavy flavors (charm,bottom)

→ Silicon strip/pixel detectors

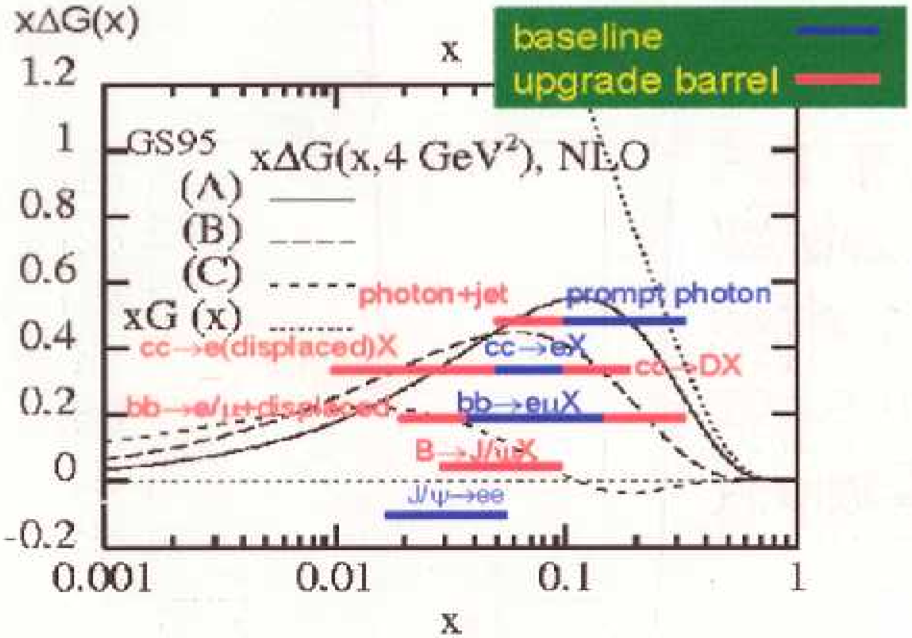


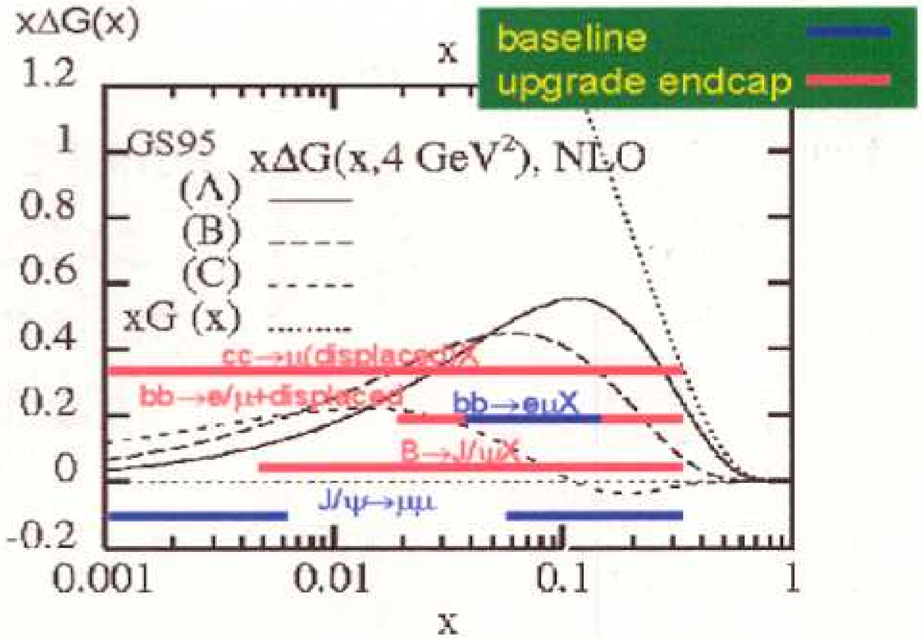
Spin Physics with Vertex Upgrade

Jet-axis for photon+jet-axis → constraint on x

c→e, μ displaced vertex low-x S/B, D→Kπ high-x

b→displaced J/ψ low/high-x, b→e, displaced vertex high -x





Schedule: RHIC I leads to the design luminosities for RHIC spin!

L= $6\times10^{30}cm^{-2}s^{-1}$ ... $8\times10^{31}cm^{-2}s^{-1}$

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 ➔ $156pb^{-1}$	

NCC + Muon Trigger!

Inclusive hadrons + Jets →

Transverse Physics →

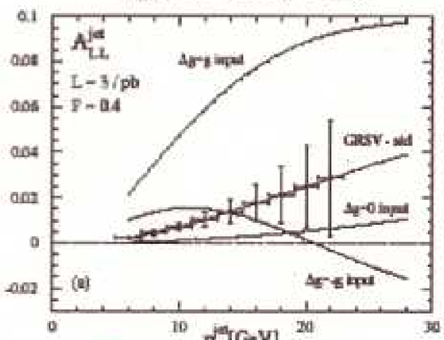
Charm Physics →

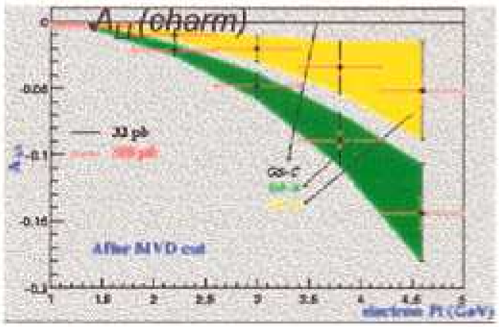
direct photons →

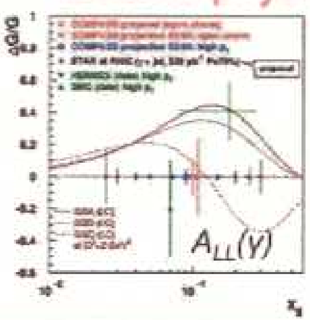
Bottom physics →

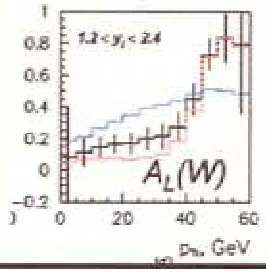
W-physics →

A_{LL}(hadrons, Jets)









8. Organization, people, support

From BNL Spin Group perspective!

---polarimetry developed with collaboration with machine and theory

---RHIC Spin Collaboration coordinates experiments, machine, theory

---meets weekly in session, monthly now

---RBRC, RIKEN, BNL Spin, expanding university base

---pp2pp (result due soon), BRAHMS (2004,5 $A_N(\pi^{\pm})$)

---major technical contributions for heavy ion program, and vice-versa (PHENIX detector, RHIC!)

---support for program very strong! ---DOE, NSF, RIKEN

---spin groups at BNL and universities (expanding)

---polarimetry (carbon, hydrogen jet)

---running time each year, with crucial extensions in 2003, 2004

---for important apparatus as it is identified

---jet

---cold snake

---warm snake

Spin Groups at BNL:

RBRC: (PHENIX and Polarimetry) (Enyo, Bunce)

Fellows: Wei Xie, Dave Kawall (University Fellow beginning 1/2005 with UMass)

University Fellows: Matthias Perdekamp (Illinois), Doug Fields (New Mexico), Abhay Deshpande (Stony Brook)

Post Docs: Masashi Kaneta, Osamu Jinnouchi, Kensuke Okada, Tsuguchika Tabaru, Junkichi Asai

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Staff based at BNL: (PHENIX)

RIKEN: Yuji Goto, Yasuyuki Akiba
Illinois: Hiroyoshi Hiejima, Mickey Chiu
Kyoto: Marcus Wagner
New Mexico: Imran Younus

Ph. D. Students at BNL:

Hiromi Okada (Kyoto)—jet polarimetry
Yoshi Fukao (Kyoto)---$A_{LL}(\pi^0)$ run 3,4
Manabu Togawa (Kyoto)---e (heavy flavor)
Takuma Horaguchi (Tokyo Tech)---direct photon
Kenichi Nakano (Tokyo Tech)---jet structure
Kieran Boyle (Stony Brook)--- $A_{LL}(\pi^0)$ run 5
Robert Bennett (Stony Brook)--- Crawford scalers
Christine Aidala (Columbia)--- $A_N(\pi^0)$

BNL Spin Group: (Bunce, Bland)

PHENIX: Gerry Bunce (also polarimetry), Sasha Bazilevsky

STAR: Les Bland, Akio Ogawa, Greg Rakness (with Penn St.)

Polarimetry: Sandro Bravar (also STAR), Ron Gill (also pp2pp)

pp2pp: Wlodek Guryn

Plan for BNL Spin Group:

---add Post Doc for polarimetry (2005)

---add 2 positions for STAR spin (staff + post doc), focus on forward physics and mid-rapidity spin measurements (2005)

---add positions for PHENIX as necessary (issue is staff positions vs. fixed term RBRC positions and RIKEN staff at BNL---this has been an excellent situation with the RIKEN contributions)

Budget for BNL Spin:

---operating covers 8 staff physicists, 1/2 post doc
  ---issue of pp2pp (Wlodek), hypernuclear (Morgan May)

---equipment covers polarimeter detectors

---equipment funds for experiment work from expts.

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.

9. Issues

---sufficient running time for RHIC each year

---identified 32 cryo weeks to allow 2 major runs each year

---support for muon trigger improvements for W

---support for micro vertex detector, nose cone calorimeter

---continued responsiveness to development of program, spin groups

---PHENIX in U.S.: Riverside, Illinois, New Mexico, Colorado, Stony Brook, UMass

---organization of polarimetry as this becomes routine

---continued and additional support for spin theory

---now: Werner Vogelsang, Stephen Kretzer (post doc)

---L and P are not solved until they are solved

---also: I support another pp2pp run (few day run), with the expectations of longer runs for spin (and the remarkable 2004 run). pp2pp is independent physics that connects to results we are getting with the polarimeters, and we will not be available to get otherwise (σ, A_{NN}, A_N in CNI region, root(s)=200 GeV).

11. Appendices: responses to charge; responses to NSAC subcommittee (Barnes) questions.

Spin Publications:

G. Bunce, N. Saito, J. Soffer, and W. Vogelsang, Ann. Rev. Nucl. Part. Sci. 2000 V50, 525 (2000). Prospects for Spin Physics at RHIC.

J. Tojo et al., PRL 89, 052302 (2002). Proton-carbon polarimeter in AGS, analyzing power at 22 GeV.

S.S. Adler et al. (PHENIX), PRL 91, 241803 (2003). π^0 cross section, mid-rapidity, root(s)=200 GeV.

S.S. Adler et al. (PHENIX), hep-ex/0404027, submitted to PRL(2004). A_{LL} for π^0.

Numerous contributions to PHENIX heavy ion publications.

Invited Talks: Spin Group, RBRC

In past year: Seattle Spin 2003 (2), Dubna Spin 2003 (4), many others. (estimate 20)

Numerous RHIC spin workshops.

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?)

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.

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.