

RHIC Spin

Outline:

- BNL RHIC Spin Group members and contributions
- RBRC members and contributions
- The updated spin plan, with recent accomplishments and status included

Personnel BNL RHIC Spin Group

<http://www.phy.bnl.gov/rhicspin/>

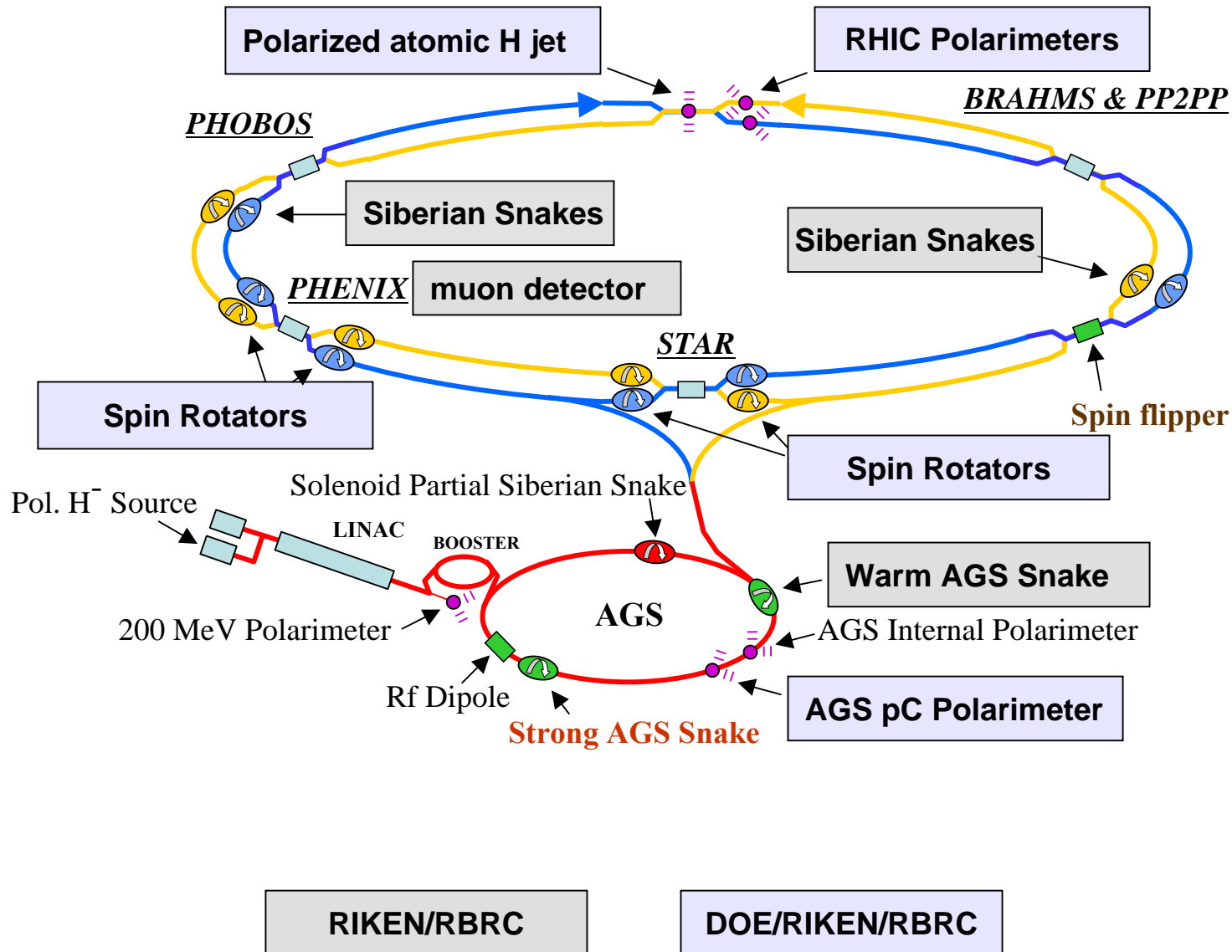
- **Gerry Bunce**—Group Leader, RHIC Spin Group; Deputy Group Leader, RBRC Experiment Group (resident Group Leader); Spokesman, RHIC Spin Collaboration (RSC wrote spin proposals for STAR and PHENIX, umbrella group to promote and coordinate program); Chair, RHIC Spin Plan (2008); polarimetry; PHENIX.
- **Les Bland**—Deputy Group Leader, leader for STAR spin in RHIC Spin Group; PI for FPD, FPD++, Forward Meson Spectrometer (FMS); co-chair, STAR Spin Physics Group 1999-2004; developed case for Endcap Calorimeter at IU.
- **Akio Ogawa**—STAR, co-chair STAR Spin Physics Group 2004-7; FPD, FPD++, FMS; organizer of RSC 2003-2005; Belle polarized quark fragmentation analysis (RBRC collaboration)
- **Sasha Bazilevsky**—PHENIX, calorimeter calibration, software, analysis; leads A_LL analysis group; $\sigma(\pi^0)$, E_T analysis; organizer of RSC 2005-present; co-chair of PHENIX Spin Physics Group (2008-); leads RHIC polarimetry analysis.
- **Ron Gill**—Polarimetry including spin tune measurements; Physics Safety Officer.
- **Boris Morozov**---Leads R&D on future RHIC polarimetry, with Tandem studies, photodiode detectors.
- **Andrew Gordon**---STAR FMS commissioning, data taking, data analysis.
- **Hiromi Okada**---STAR FMS; jet polarimeter (Post doc, joined KEK July 2008).

RBRC Experimental Group

<https://www.bnl.gov/riken/>

- H. En'yo, G. Bunce—Group leader, deputy
- (Y. Akiba), (A. Deshpande)---Group leader, deputy
- Fellows (5 year appointments): (graduated) (ongoing) (new)
 - Matthias Perdekamp (RBRC/U. Illinois) (2002-07) (tenured)
 - Abhay Deshpande (RBRC/U. Stony Brook) (2004-09)
 - Wei Xie (RBRC) (2004-07) (Purdue)
 - Dave Kawall (RBRC/U. Massachusetts) (2005-10)
 - Kensuke Okada (RBRC) (2006-11)
 - Stefan Bathe (RBRC) (2008-13)
 - Ralf Seidl (RBRC) (2008-13)
- Postdocs:
 - Patricia Liebing (RBRC) (2006-07) (Bremen)
 - Kieran Boyle (RBRC) (2008-10)
- Theory (spin):
 - Werner Vogelsang (RBRC/BNL) (2000-2005) (tenured)
 - Feng Yuan (RBRC/LBL) (2007-2012)

RHIC Polarized Collider



RHIC Spin Plan

- Charge and members of writing group
- Accelerator accomplishments, needed improvements, and polarimetry
- **Physics introduction**
- Gluon polarization—where we are and where we expect to be after 2009
- The W program—direct measurement of quark and anti-quark polarizations
- **The transverse spin program—transversity, orbital angular momentum, and tests of the underlying theoretical framework**

Appendix A: The Charge ---from S. Vigdor to writing group

I would like to ask you to organize efforts, with the help of the others copied on this e-mail and whomever else you find useful, to address one of the major recommendations from last July's S&T review:

“Brookhaven National Laboratory (BNL) should develop and document a detailed plan with milestones that demonstrates the experimental sensitivity for the proposed proton spin measurements between 2008 and 2013 using the anticipated accelerator design capabilities and detector performance as a planning base. This plan should be submitted to DOE NP by May 31, 2008 and presented at the 2008 RHIC S&T Review.”

Writers, for the RHIC Spin Collaboration and the PHENIX and STAR Collaborations

Gerry Bunce (chair), Alexander Bazilevsky, Les Bland, Abhay Deshpande, Wolfram Fischer, Carl Gagliardi, Yuji Goto, Matthias Grosse-Perdekamp, Yousef Makdisi, Pavel Nadolsky, Thomas Roser, Ralf Seidl, Jim Sowinski, Marco Stratmann, Bernd Surrow, Werner Vogelsang, Feng Yuan

Spin Plans: <http://spin2.riken.bnl.gov/rsc/>

RHIC Spin Runs

	P	L(pb⁻¹)	Results
2002	15%	0.15	first pol. pp collisions!
2003	30%	1.6	pi⁰, photon cross section, A_LL(pi⁰)
2004	40%	3.0	absolute beam polarization with polarized H jet
2005	50%	13	large gluon pol. ruled out
	(P⁴ x L = 0.8)		
2006	60%	46	first long spin run *
	(P⁴ x L = 6)		
2007			no spin running
2008	50%		(short) run

* support for 2006 run from Renaissance Tech. crucial for program

RHIC Accelerator, Polarimetry, and Experiments

Luminosity Goals (avg. over store): (w/ P=70%)

- $60 \times 10^{30} \text{cm}^{-2} \text{s}^{-1}$ for 200 GeV center of mass energy, and
- $150 \times 10^{30} \text{cm}^{-2} \text{s}^{-1}$ for 500 GeV center of mass energy,

--23 x 10³⁰ @ 200 GeV now, 58% polarization

--250 GeV acceleration with 45% polarization*

* using polarimeter analyzing power from 100 GeV

Integrated L goals:

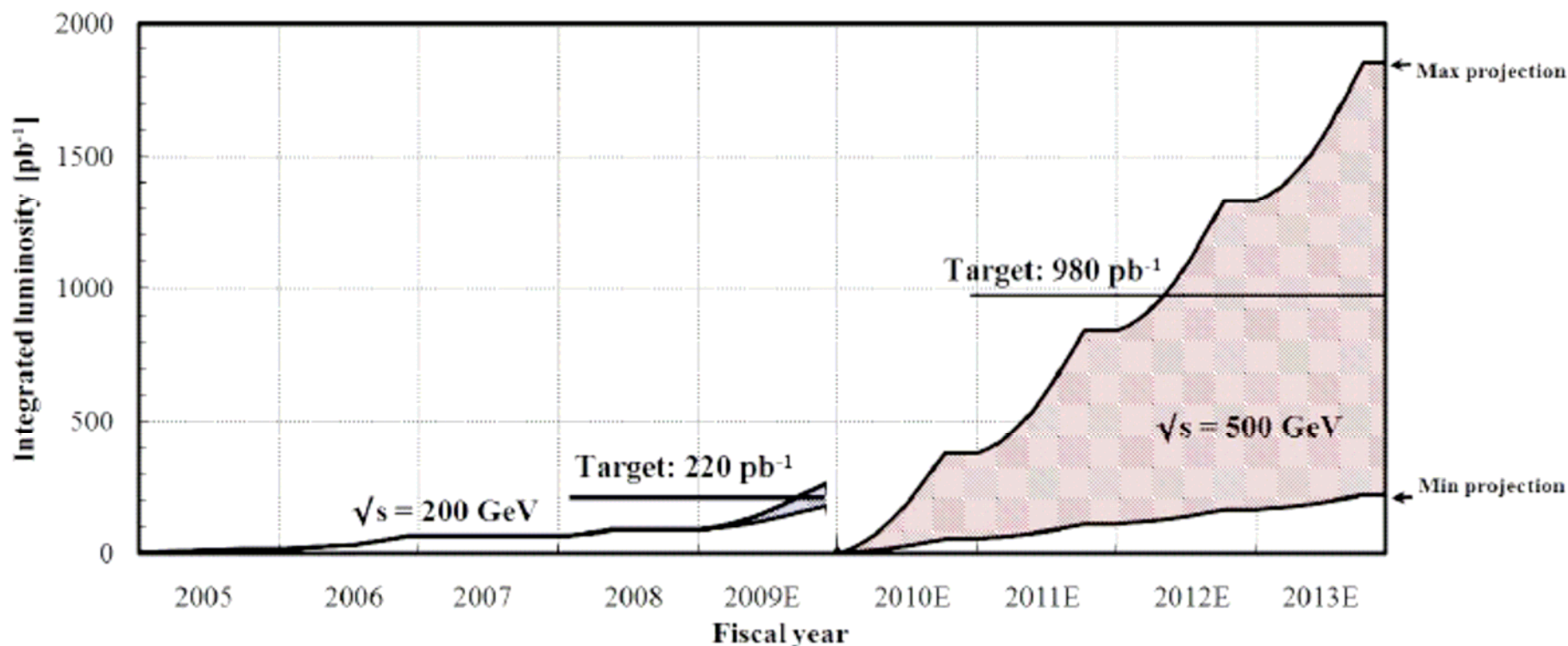


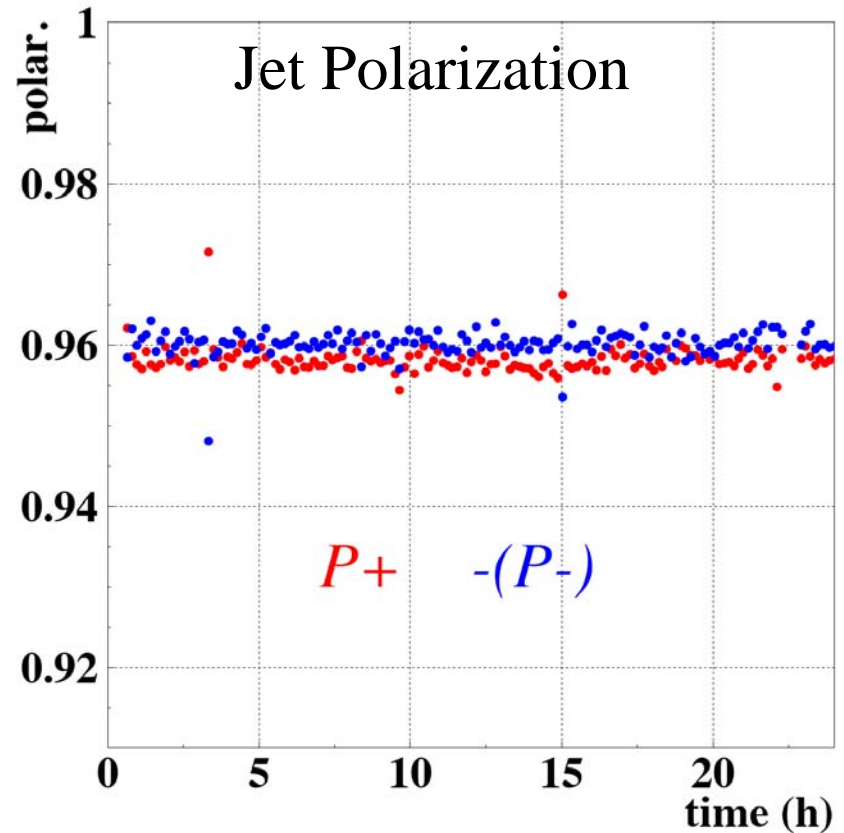
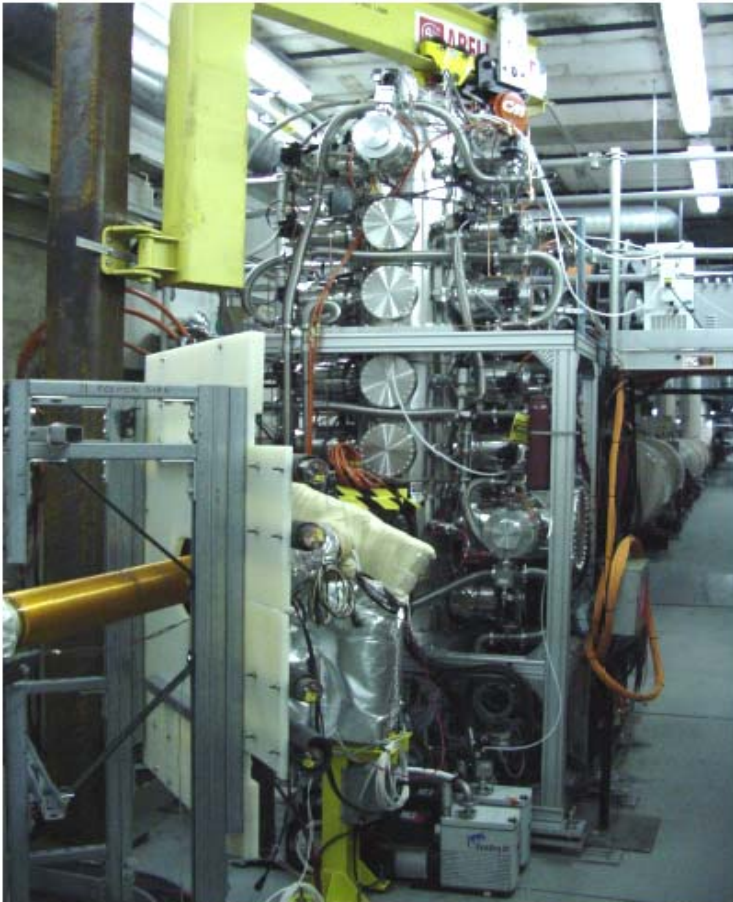
Figure 1: Minimum and maximum projected integrated luminosity through FY2013. Delivered luminosity numbers are given for one of two interaction points, and a physics running time of 15 weeks in FY2009, and 10 weeks of physics operation per year thereafter. The assumed center of mass energy is 200 GeV until the end of FY2009, and 500 GeV thereafter:

How we get there--

- factor x 3 in luminosity
- improvement in P from 58% to 70% @ 200 GeV
- P = 70% @ 500 GeV

**--discussed by Thomas Roser this afternoon
(and in Spin Plan)**

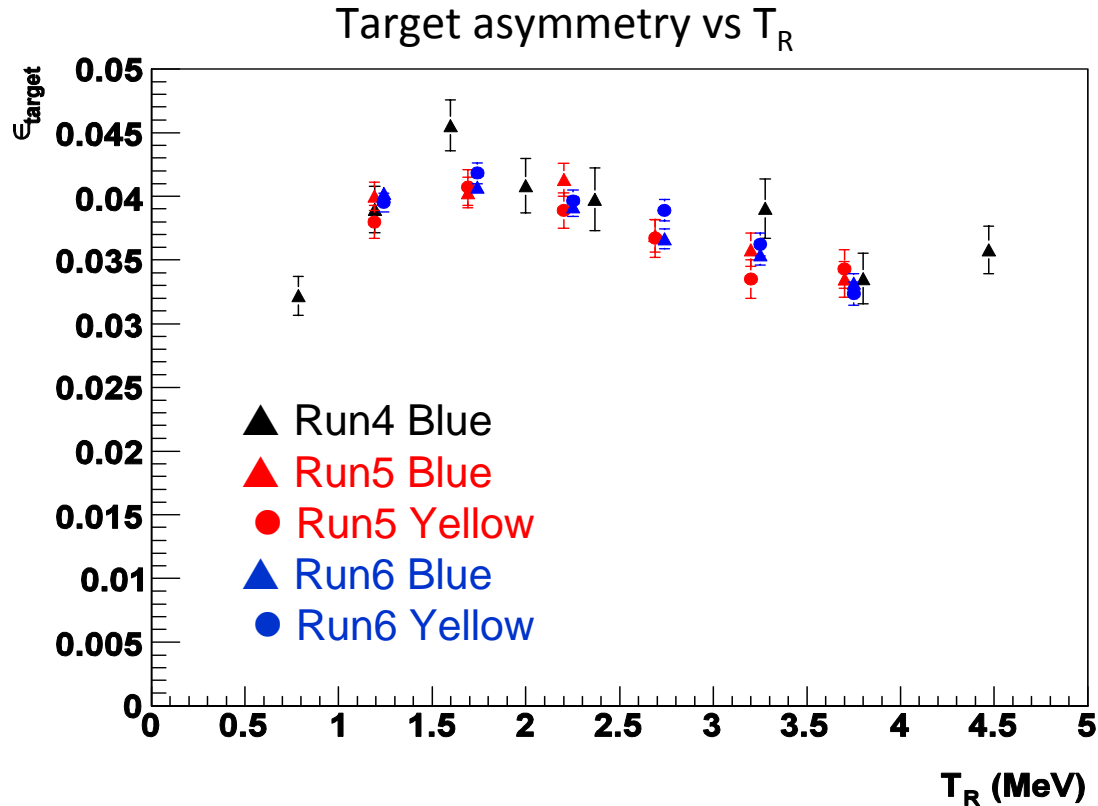
RHIC Polarimetry



$$P_{Beam} = P_{Jet} \times \frac{\epsilon_{Beam}}{\epsilon_{Jet}} \quad \text{where } \epsilon = \frac{N_{up} - N_{down}}{N_{up} + N_{down}}$$

→ for proton-proton elastic scattering

HJet



Agreement within stat. errors

HJet performance is very stable through the Years

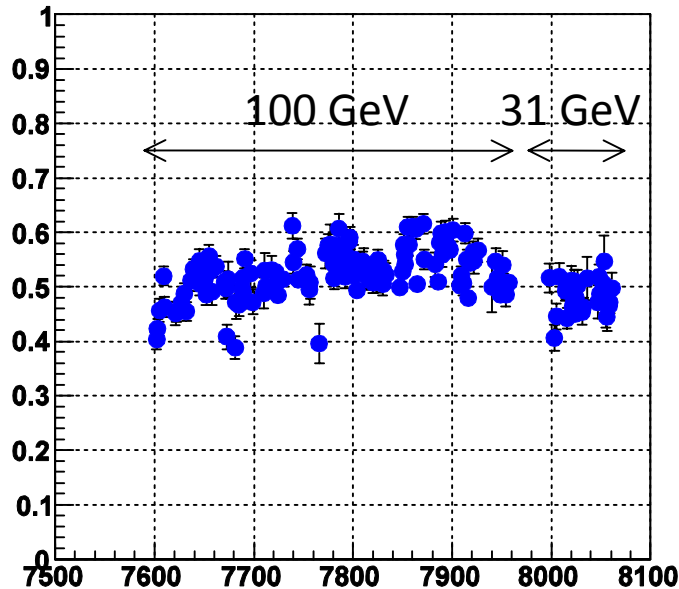
Background is small and doesn't change from Year to Year, for Blue and Yellow (within 2-3%)

⇒ Beam polarization is measured reliably by HJet

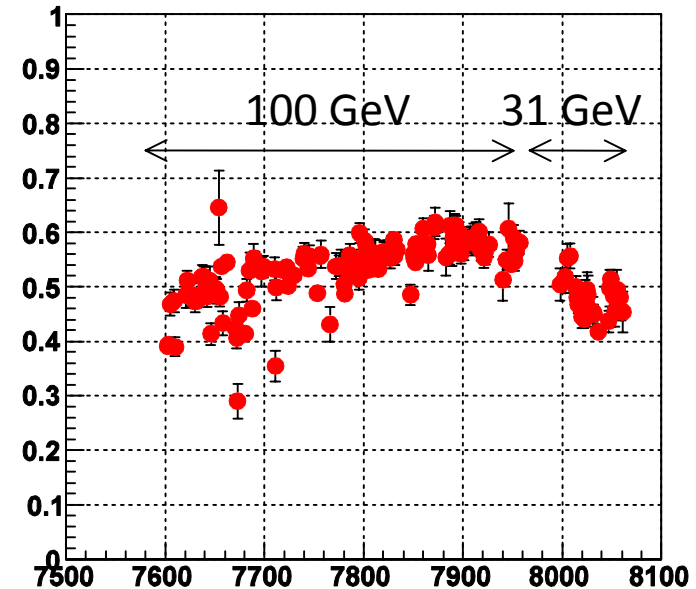
pC: Polarization vs Fill

Run6 results

Polarization vs fill



Polarization vs fill



- ✓ Normalized to Hjet
- ✓ Corrected for polarization profile

$$\frac{\delta P_B}{P_B} = 4.7\%$$

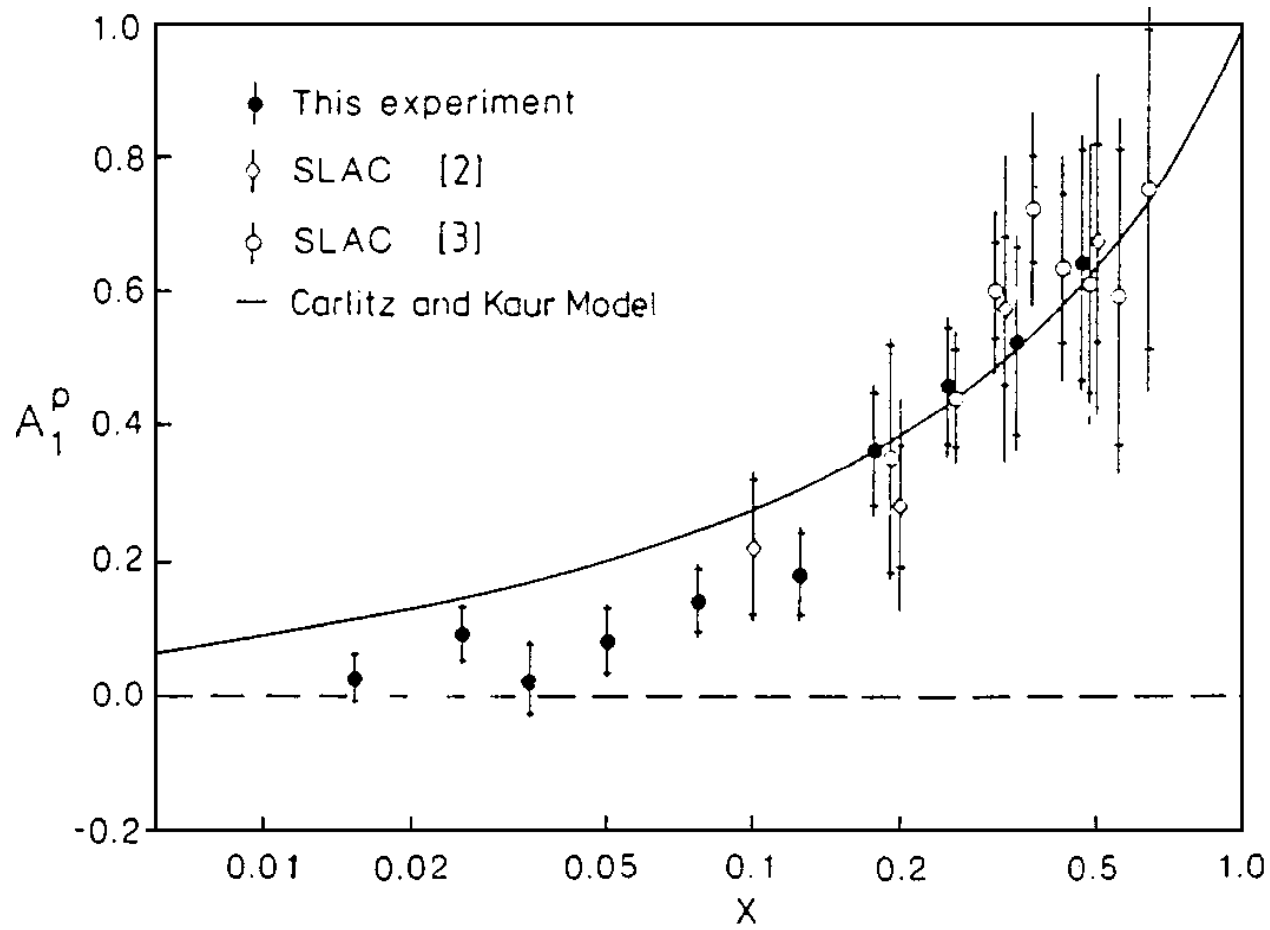
$$\frac{\delta P_Y}{P_Y} = 4.8\%$$

$$\frac{\delta(P_B P_Y)}{P_B P_Y} = 8.3\%$$

Goal: 10%

Physics Introduction: RHIC Spin

EMC at CERN: J. Ashman et al., NPB 328, 1 (1989): polarized muons probing polarized protons



$$\Delta\Sigma = \Delta u + \Delta d + \Delta s = 12 \pm 9(\text{stat}) \pm 14(\text{syst})\%$$

“proton spin crisis”

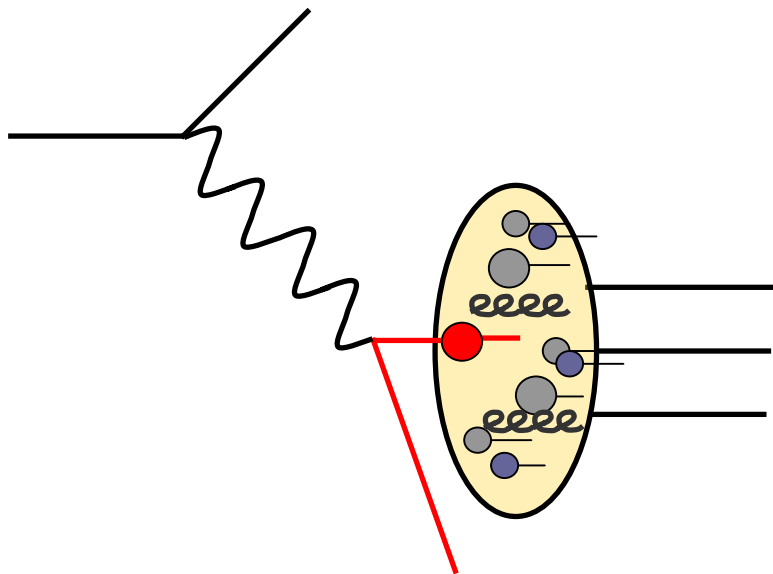
What else carries the proton spin ?

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

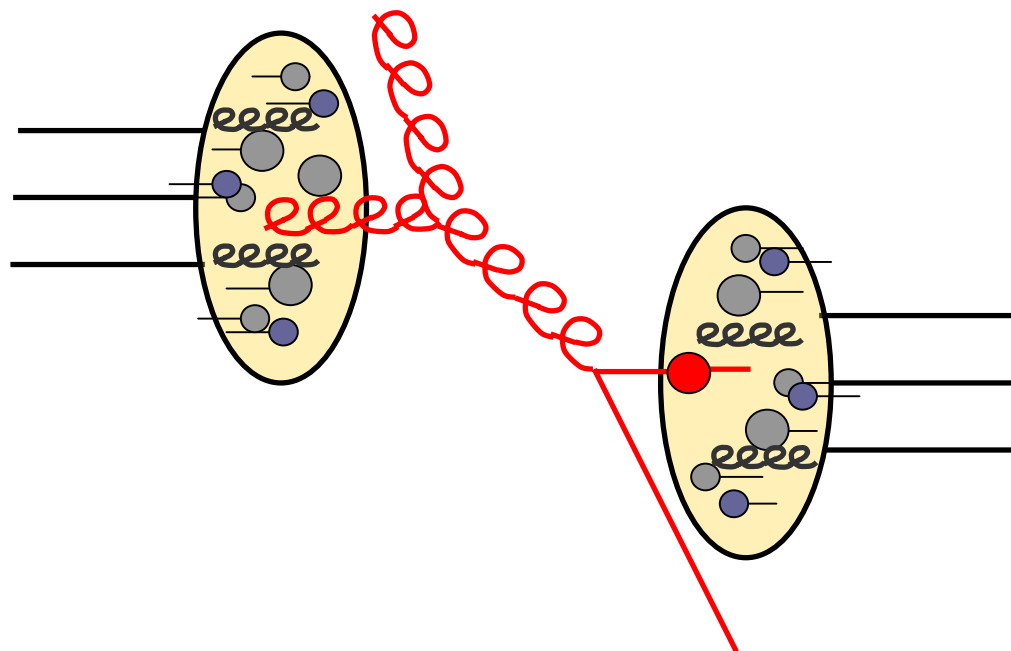
→ **How are gluons polarized ?**

→ **How large are parton orbital angular mom.?**

DIS



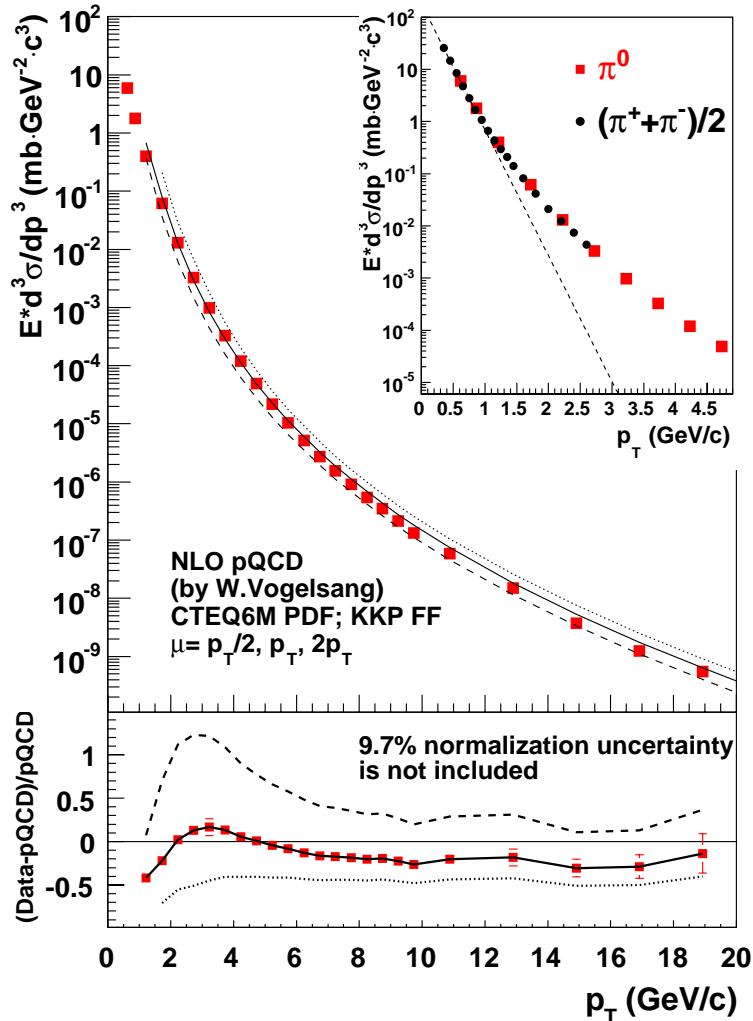
pp



Cornerstones to the RHIC Spin program

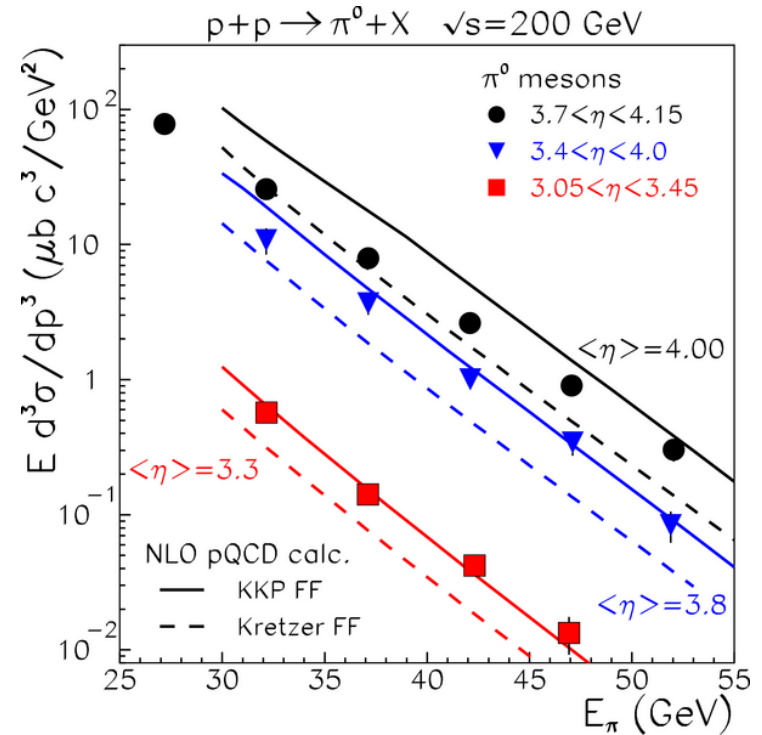
Mid-rapidity: PHENIX

$pp \rightarrow \pi^0 X$



PR D76, 051106 (2007)

Forward: STAR

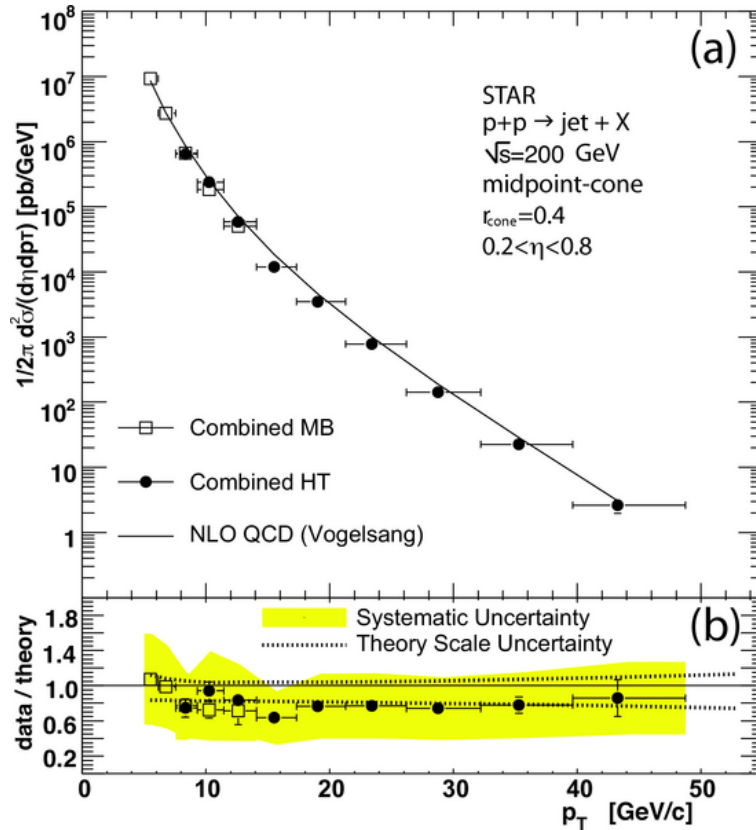


PRL 97, 152302 (2006)

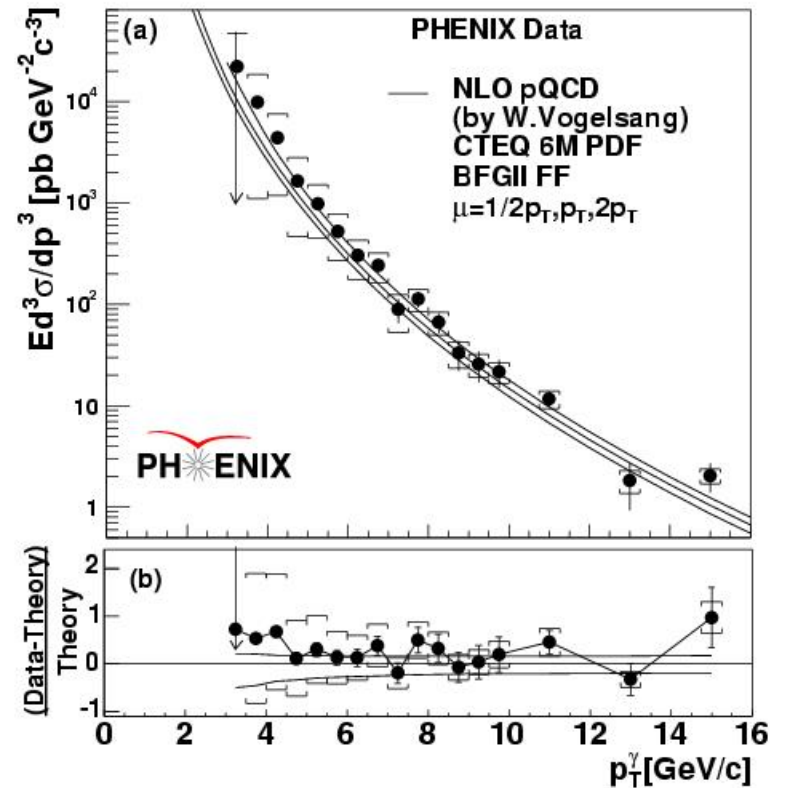
And Jets and Direct γ

pp \rightarrow jet X : STAR

pp $\rightarrow \gamma$ X : PHENIX



PRL 97, 252001 (2006)

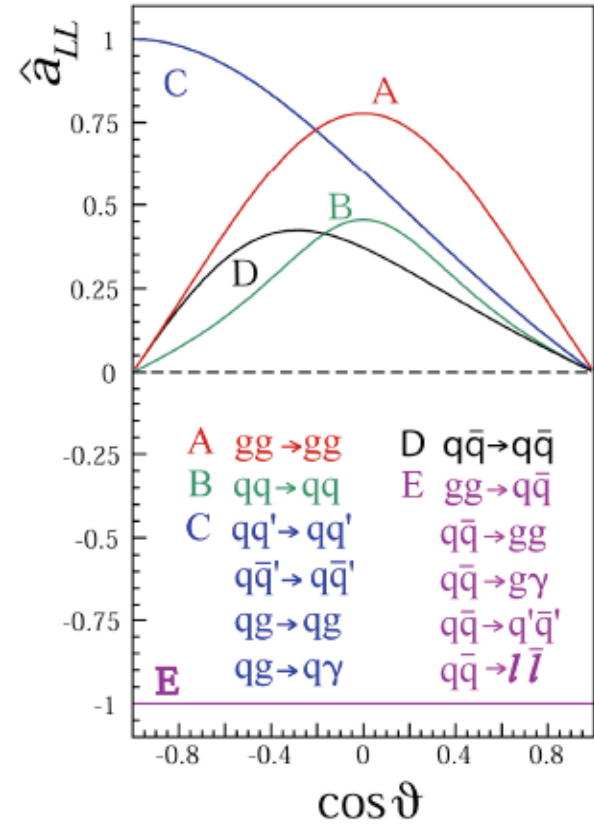
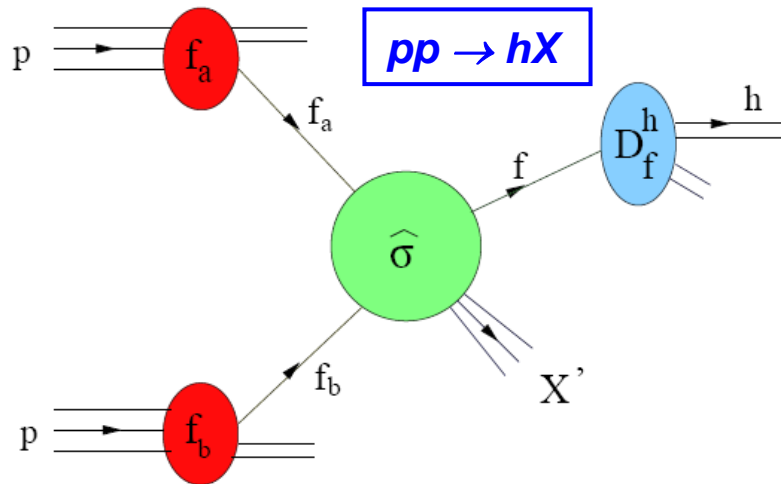


PRL 98, 012002 (2007)

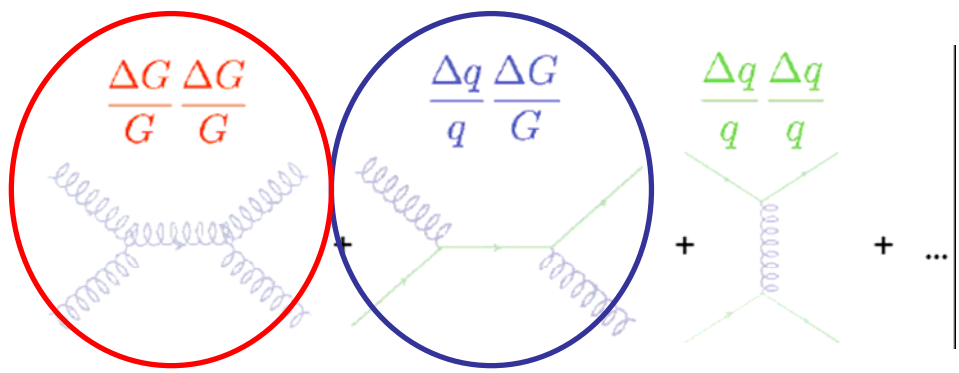
Gluon Polarization

- Inclusive measurements at PHENIX and STAR
- New global fit with RHIC and DIS data
- Future sensitivity (2009)
- Future dijet correlation measurements (2009)
- (--Future sensitivity with 500 GeV)
- (--Lower x_{gluon} with forward photon + jet)

Probing ΔG in pp Collisions



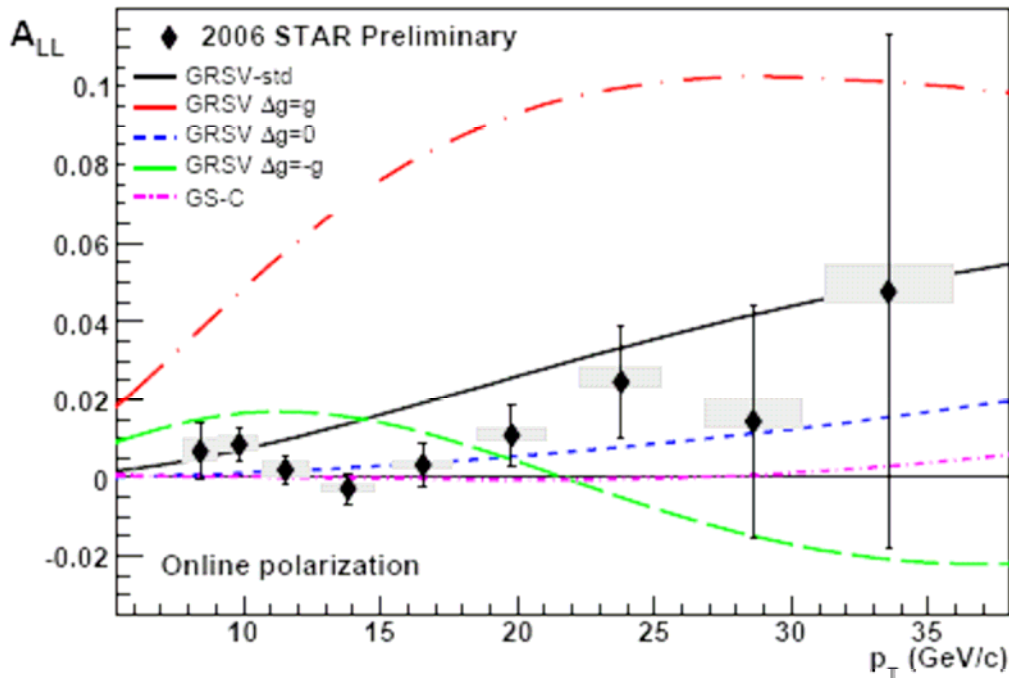
$$A_{LL} = \frac{d\sigma^{++} - d\sigma^{+-}}{d\sigma^{++} + d\sigma^{+-}} = \frac{\sum_{a,b} \Delta f_a \otimes \Delta f_b \otimes d\hat{\sigma}^{f_a f_b \rightarrow fX} \cdot \hat{a}_{LL}^{f_a f_b \rightarrow fX} \otimes D_f^h}{\sum_{a,b} f_a \otimes f_b \otimes d\hat{\sigma}^{f_a f_b \rightarrow fX} \otimes D_f^h}$$



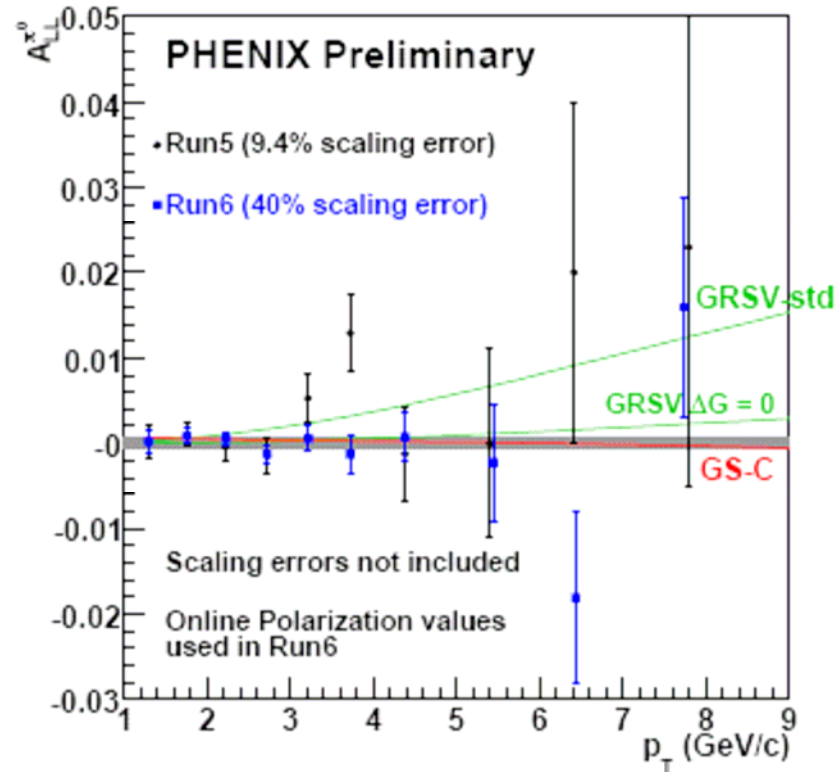
Double longitudinal spin asymmetry A_{LL} is sensitive to ΔG

Inclusive Measurements

Jet



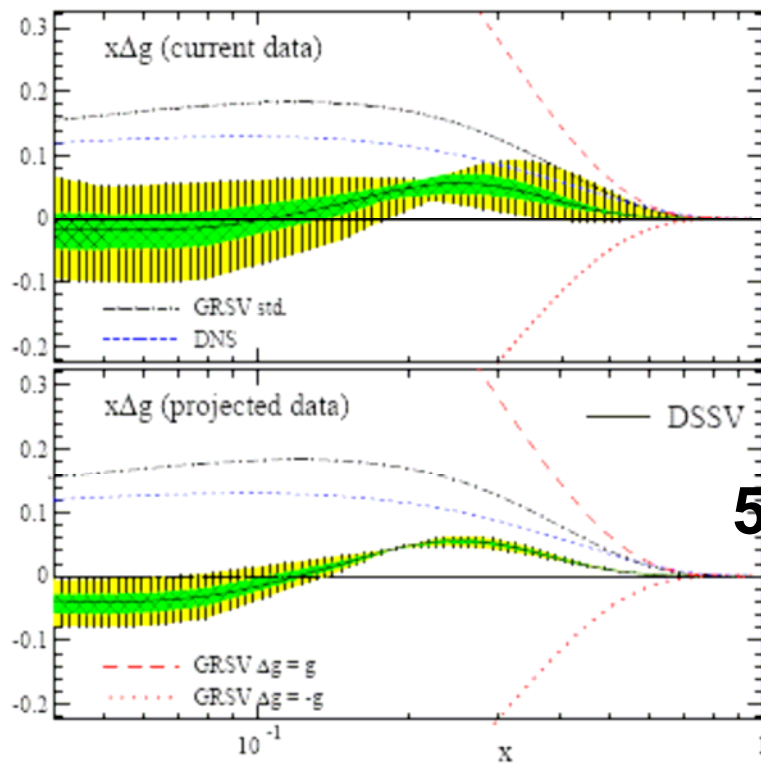
π^0



(Scaling uncertainty from polarization will be < 10%)

Global fit with RHIC + DIS

de Florian, Sassot, Stratmann, Vogelsang, arXiv:0804.0422



Now

50 pb⁻¹

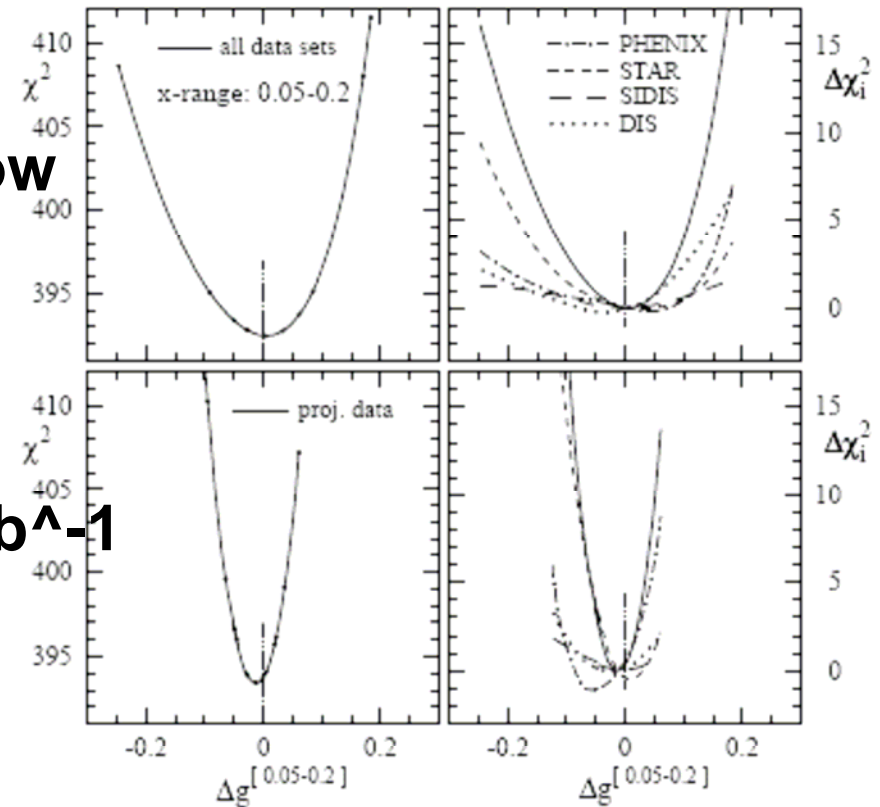


Figure 5: Upper row: $x\Delta g$ ($Q^2 = 10 \text{ GeV}^2$) from the global NLO QCD analysis by DSSV [14] (left) and partial contributions $\Delta\chi_i^2$ of the fitted data sets to the total χ^2 for variation of $\int_{0.05}^{0.2} \Delta g(x) dx$ (right). The uncertainty bands correspond to $\Delta\chi^2 = 1$ (green/cross-hatched) and $\Delta\chi^2/\chi^2 = 2\%$ (yellow/vertically hatched). Also shown are results for $\Delta g(x)$ from previous GRSV [45] and DNS [47] analyses. Lower panels: same as above when the RHIC data errors are scaled down by a factor of 4 as expected from the next long RHIC pp run at 200 GeV (50 pb^{-1} with a polarization of 60%).

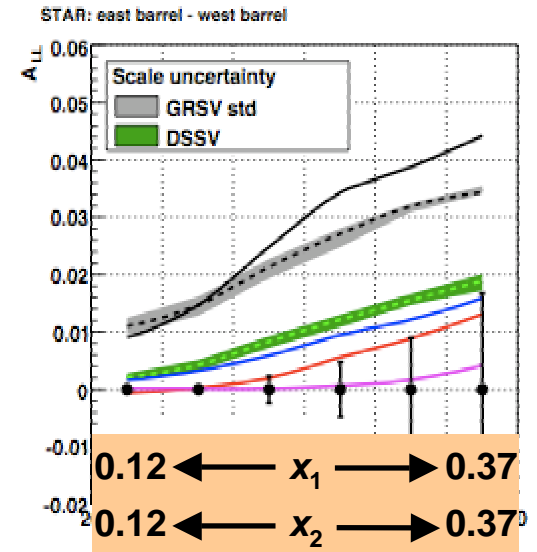
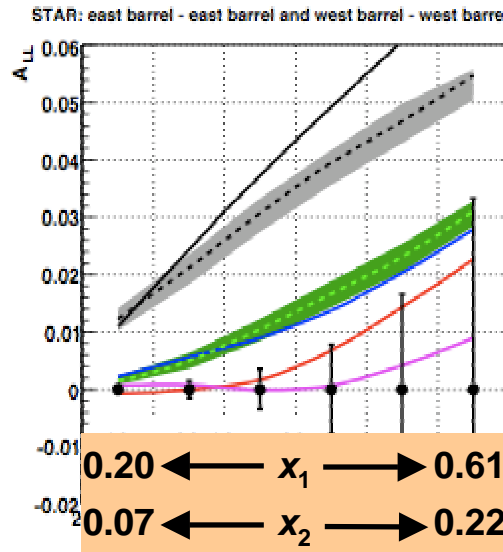
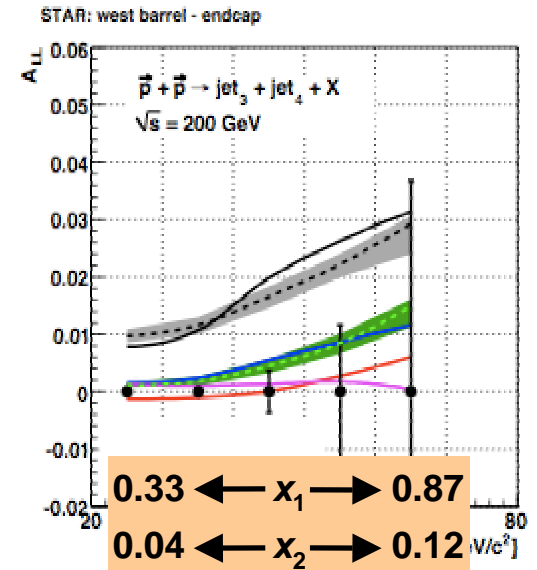
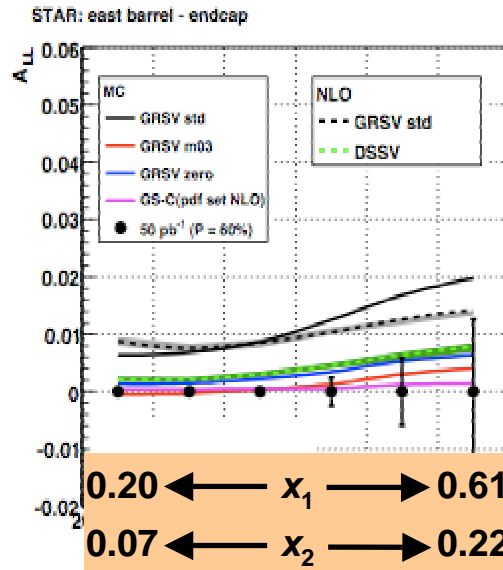


Future RHIC gluon program: dijets (STAR)

Substantial improvement in Run 9 from Di-Jet production

Good agreement between LO MC evaluation and full NLO calculations

$$M = \sqrt{x_1 x_2 s} \quad \eta_3 + \eta_4 = \ln \frac{x_1}{x_2}$$



Conclusions on gluons

- Sensitivity to the gluon spin contribution to the proton spin will improve significantly, by about a factor of four in uncertainty, with additional measurements of inclusive π^0 and jets planned for 2009. Asymmetry correlations of di-jets in 2009 will provide information regarding the momentum dependence of the gluon polarization and significant improvement in sensitivity over the inclusive data. These measurements will make a major contribution to the world's quest to understand the proton's structure. Further measurements using very forward direct photon production and measurements at $\sqrt{s} = 500$ GeV are expected to significantly expand the sampled gluon momentum range. Measurements in later years, with even higher luminosity, will add the direct photon and γ +jet probes. The direct photon measurements provide direct access to the gluon polarization and the gluon momentum fraction. Overall, this program will provide direct constraints on the gluon polarization over the momentum range from a few times 10^{-3} to 0.3.

W Measurements

- Use parity violating production of W bosons to directly measure anti-q and q polarizations in proton
- Required L and P
- Required upgrades for both experiments
- Simulations for signal to background
- Charge identification of high momentum leptons
- Expected sensitivities
- What will/should we have by 2013 DOE Milestone?

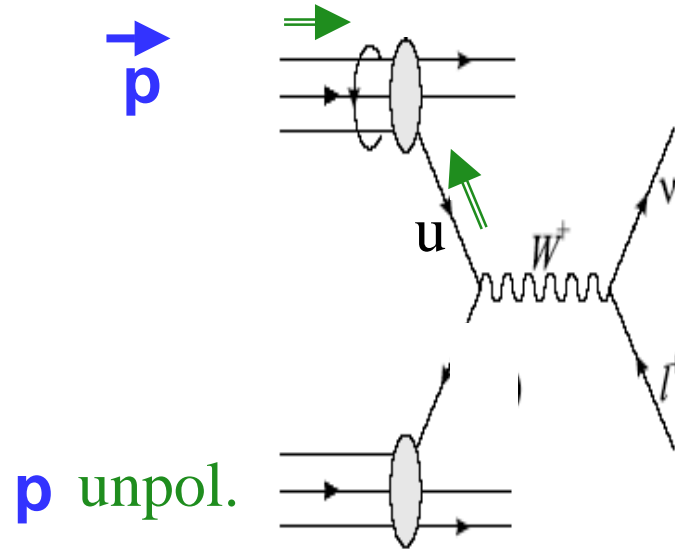
$\Delta q - \Delta \bar{q}$ at RHIC via W production

$$\Delta d + \bar{u} \rightarrow W^-$$

$$\Delta \bar{u} + d \rightarrow W^-$$

$$\Delta \bar{d} + u \rightarrow W^+$$

$$\Delta u + \bar{d} \rightarrow W^+$$



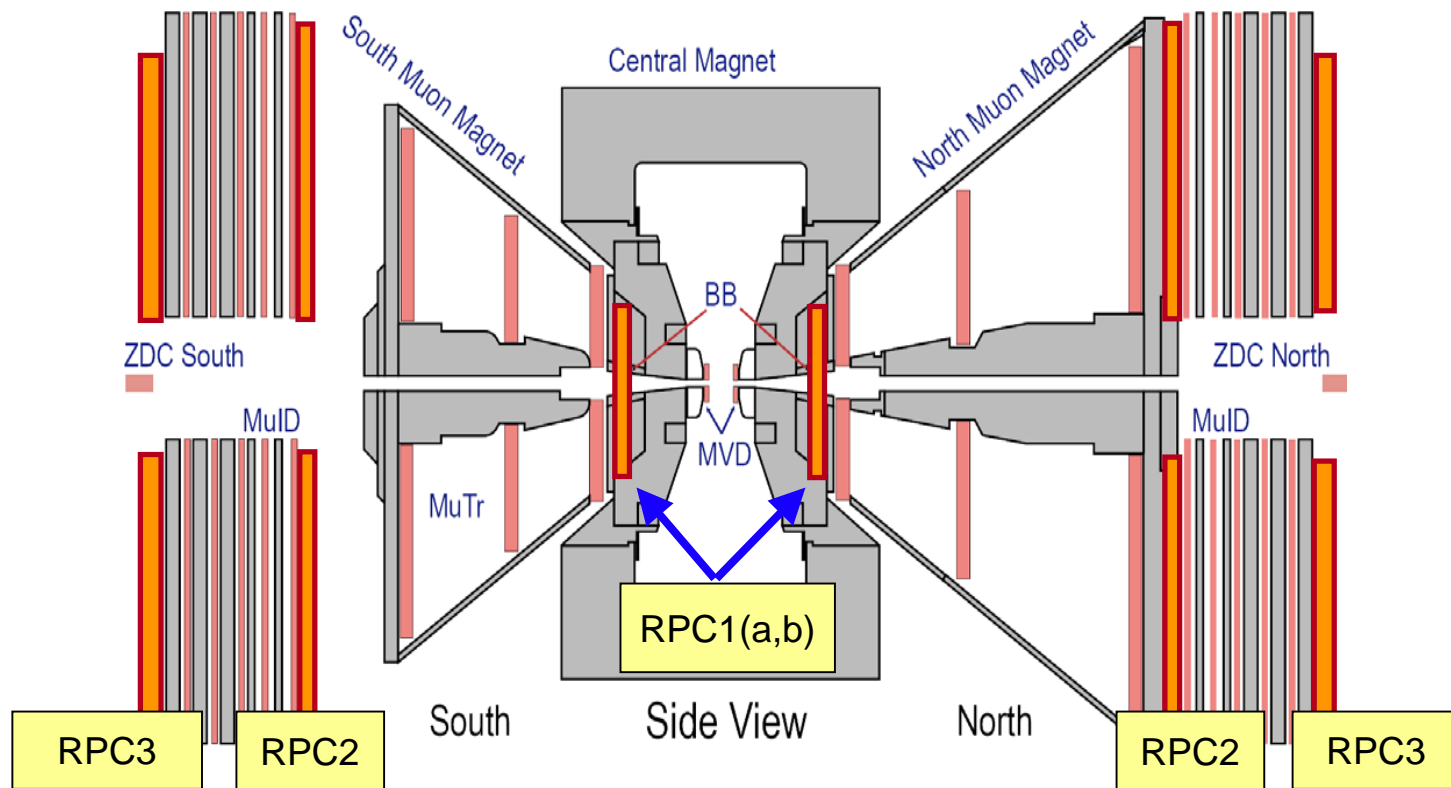
100% Parity-violating:
$$-A_L = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

Expected start: 2010

W Requirements

- **500 GeV, 300 pb⁻¹, P = 0.7**
- Upgrade for PHENIX trigger—muon arm momentum selection (underway, tests 2009, trigger ready for 2010)
- Upgrade for STAR forward tracking—electron charge sign for W decays (completed design and reviews, ready for 2011)
- **Additional forward absorber for PHENIX (test 2009) (2 int. lengths)**

Quark / Anti-Quark polarization program at PHENIX: [muon trigger upgrade](#)



3 RPC planes for each muon chamber - Expected installation: Stations 2/3-North in 2009 - 2/3-South in 2010

FEE upgrade of muon tracking - Expected installation: North in Summer 2008 / South in Summer 2009

Low p_T false triggers /10,000, 800 Hz trigger rate

□ Quark / Anti-Quark polarization program at STAR: forward tracking upgrade

Forward GEM Tracker: FGT

Charge sign identification for high momentum electrons from W^\pm decay (Energy determined with EEMC)

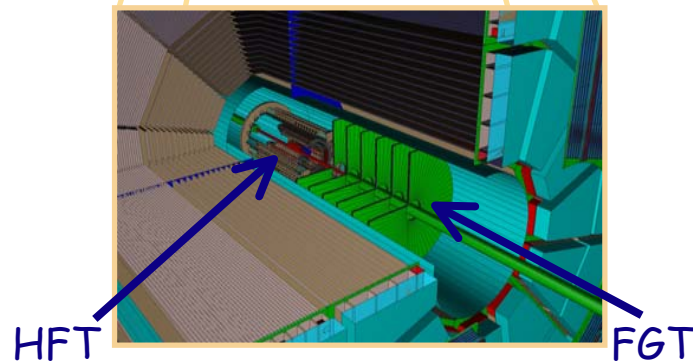
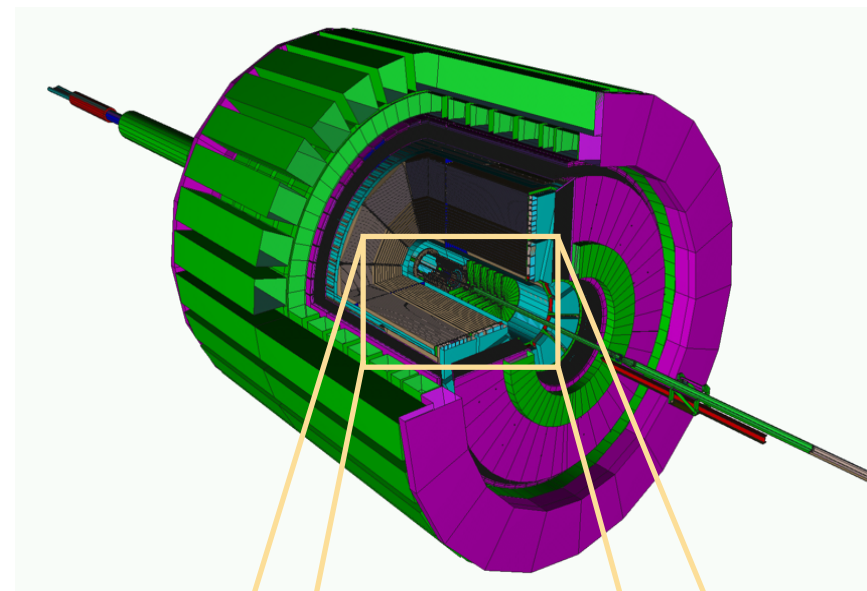
Triple-GEM technology

FGT project:

ANL, IUCF, LBL, MIT, University of Kentucky, Valparaiso University, Yale

Successful project review (Capital equipment funding): January 2008

Expected installation: Summer 2010



**Charge sign with 90% i.d.
for $p_e > 30$ GeV/c**

W Backgrounds: PHENIX study

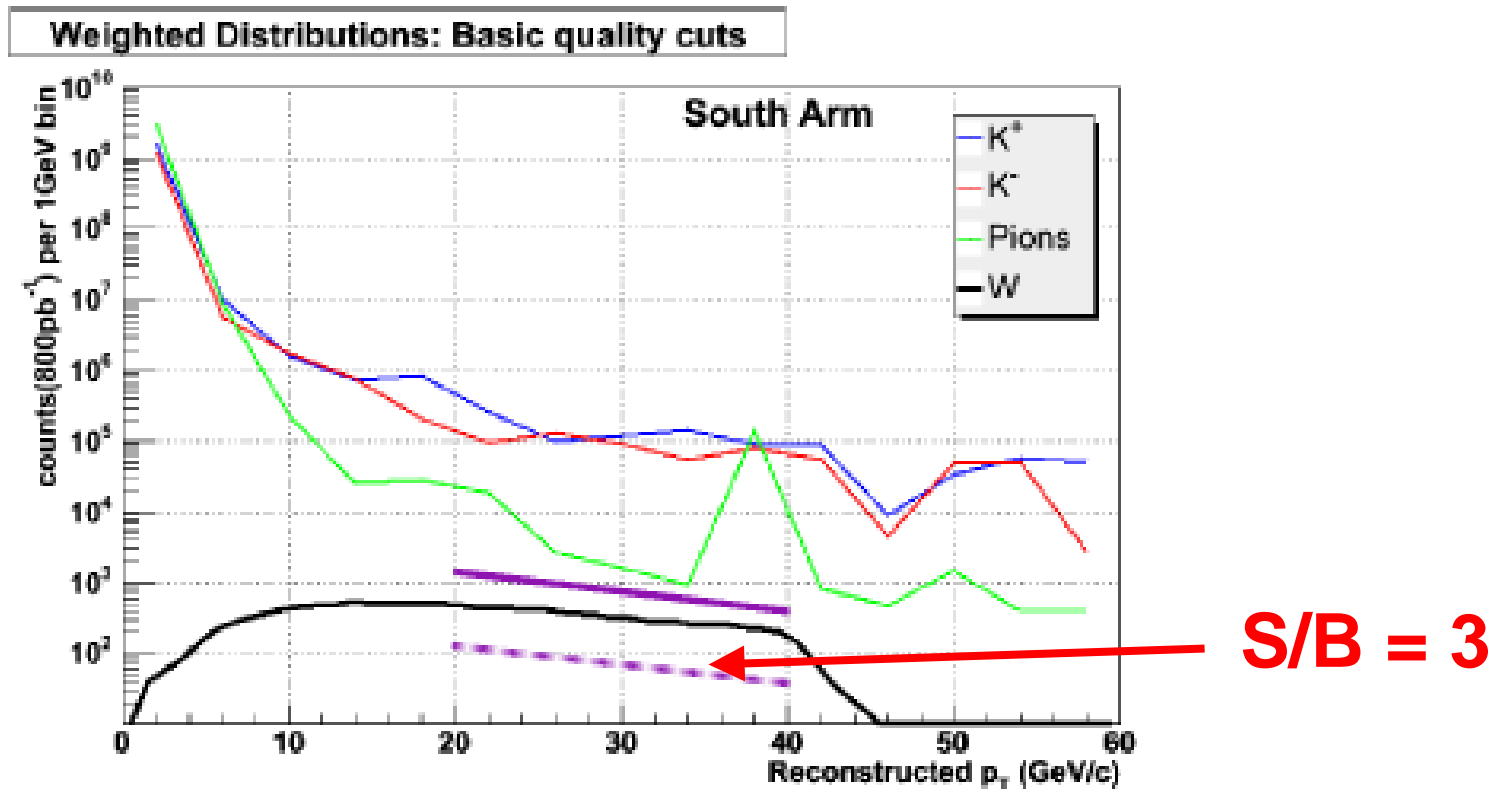


Figure 15: *Background distribution of false high- p_T muons from hadron decays in the forward region of PHENIX using basic cuts (lines) and, schematically, after application of tight cuts (purple line) and after installation of an additional absorber (dashed purple line). The W signal as obtained from Pythia is also shown.*

PHENIX muon sensitivities:
RHICBOS simulations,
S/B=3;
300 pb⁻¹, P=.7
(full symbols);
1300 pb⁻¹
(open symbols)

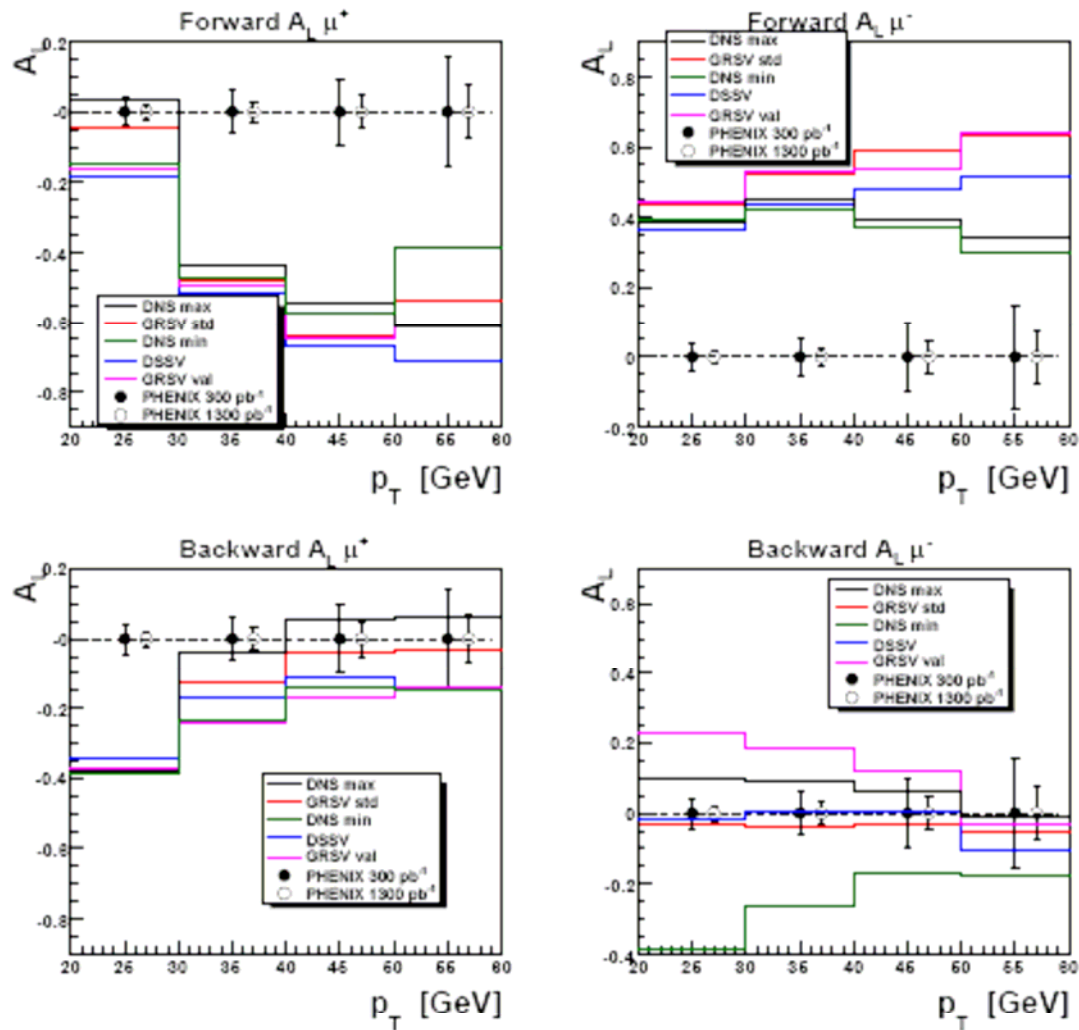


Figure 16: Longitudinal single spin asymmetries for μ^+ and μ^- in the forward (top plots) and backward (bottom plots) regions of the PHENIX detector as a function of the reconstructed muon p_T . The data has been obtained for GRSV standard, GRSV valence [45], DSSV [14], and DNS [47] using a maximal and minimal sea polarization scenario in RHICBOS [58] after detector simulation and inclusion of background for 300 pb⁻¹ (full symbols) and 1300 pb⁻¹ (open symbols) assuming 70% beam polarization.

PHENIX Central Arm sensitivities (electron):

300 pb⁻¹ (full symbols); 70 pb⁻¹ (open symbols)

Note: backgrounds not included yet

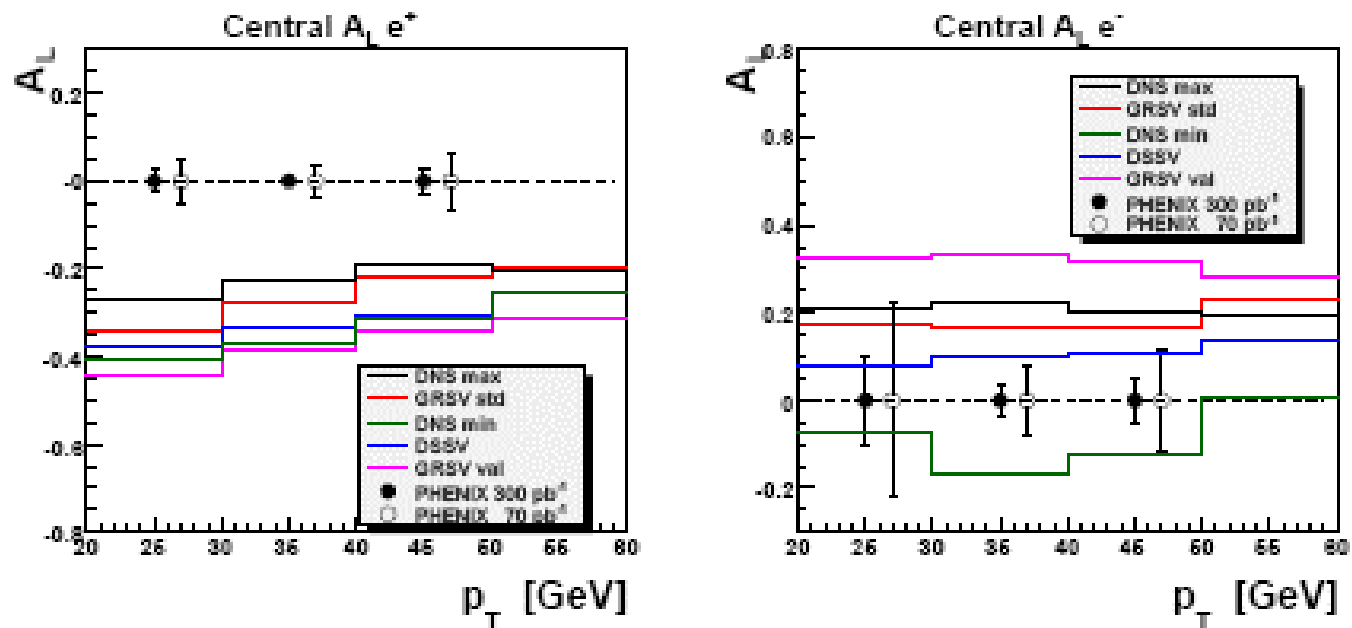
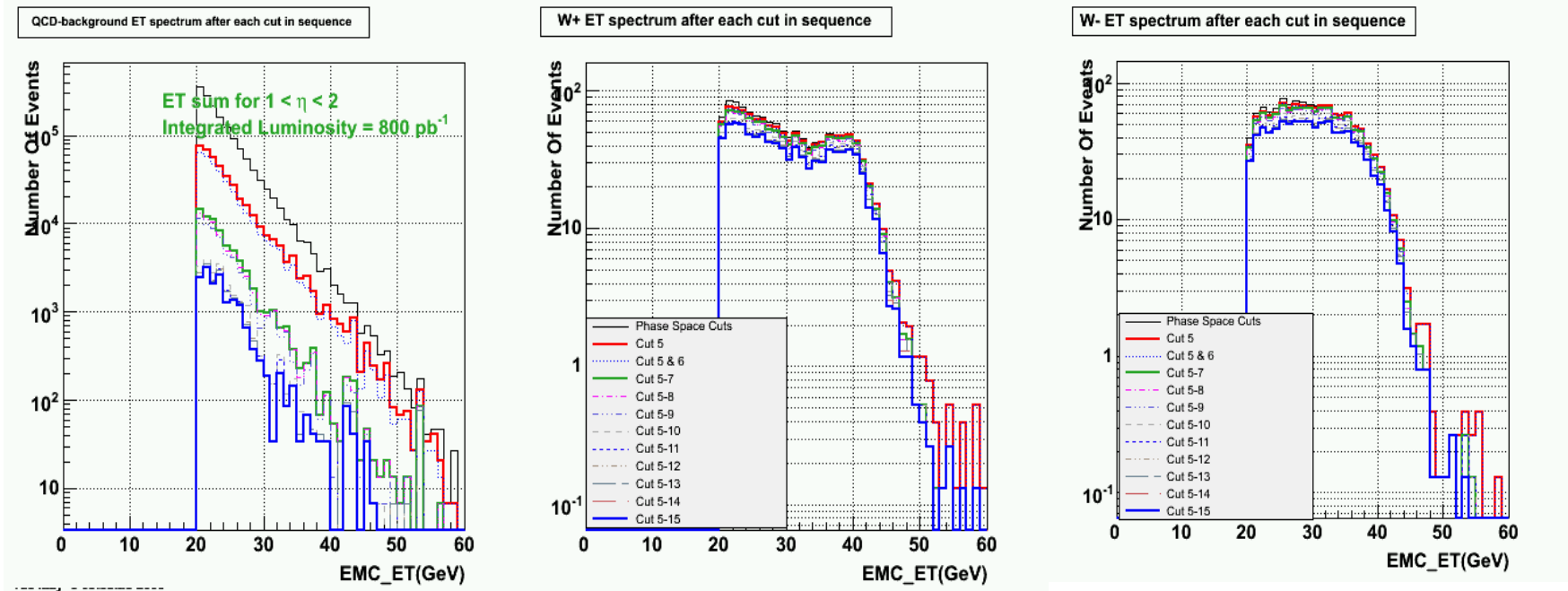


Figure 17: Simulated asymmetries in the PHENIX central arms for $W^+ \rightarrow e^+ \nu$ (left plot) and $W^- \rightarrow e^- \bar{\nu}$ as functions of p_T . The data has been obtained for GRSV standard, GRSV valence [45], DSSV [14], and DNS [47] using a maximal and minimal sea polarization scenario in RHICBOS [58] for 300 pb⁻¹ (full symbols) and 70 pb⁻¹ (open symbols) assuming 70% beam polarization.

Quark / Anti-Quark polarization program at STAR: Background Study

e/h separation: Full PYTHIA QCD background and W signal sample including detector effects



e/h separation based on global cuts (isolation/missing E_T) and EEMC specific cuts as

With current algorithm: $E_T > 25 \text{ GeV}$ yields $S/B > 1$ (For $E_T < 25 \text{ GeV}$ $S/B \sim 1/5$) used for A_L

uncertainty estimates

STAR sensitivity:
forward/backward
 full simulation with
 $S/B=3-10$ for
 $p_T=25-40 \text{ GeV}/c$,
 70% efficiency in
 endcap cal.,
 RHICBOS,
 300 pb^{-1} , $P=.7$

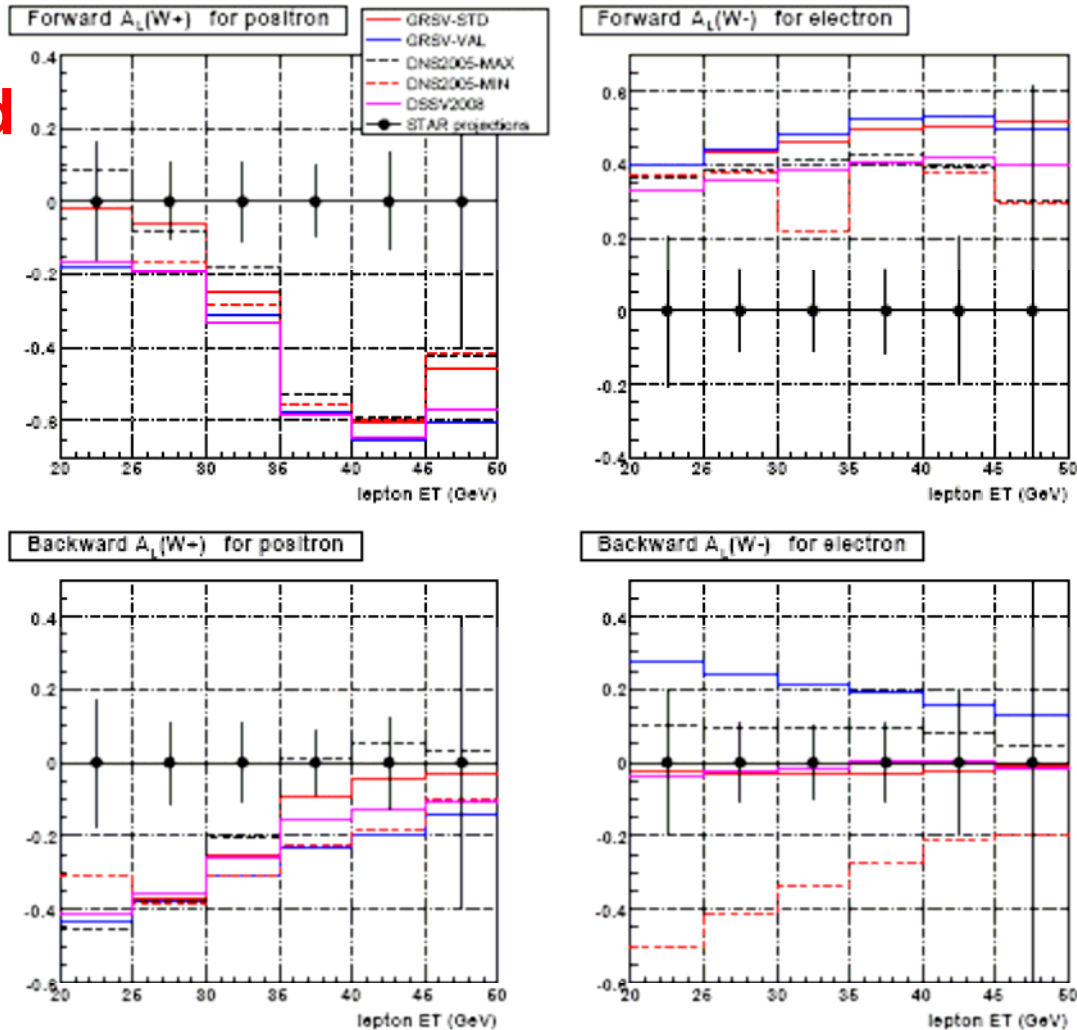


Figure 13: Projected asymmetries in the forward/backward STAR region as a function of lepton transverse energy, E_T . The data has been obtained for GRSV standard, GRSV valence [45], DSSV [14], and DNS [47] using a maximal and minimal sea polarization scenario in RHIC-BOS [58] after detector simulation and inclusion of background for 300 pb^{-1} assuming 70% polarization.

STAR sensitivity: mid-rapidity

300 pb⁻¹, P=.7 ; Note: assumes same background and efficiency as for forward/backward study.

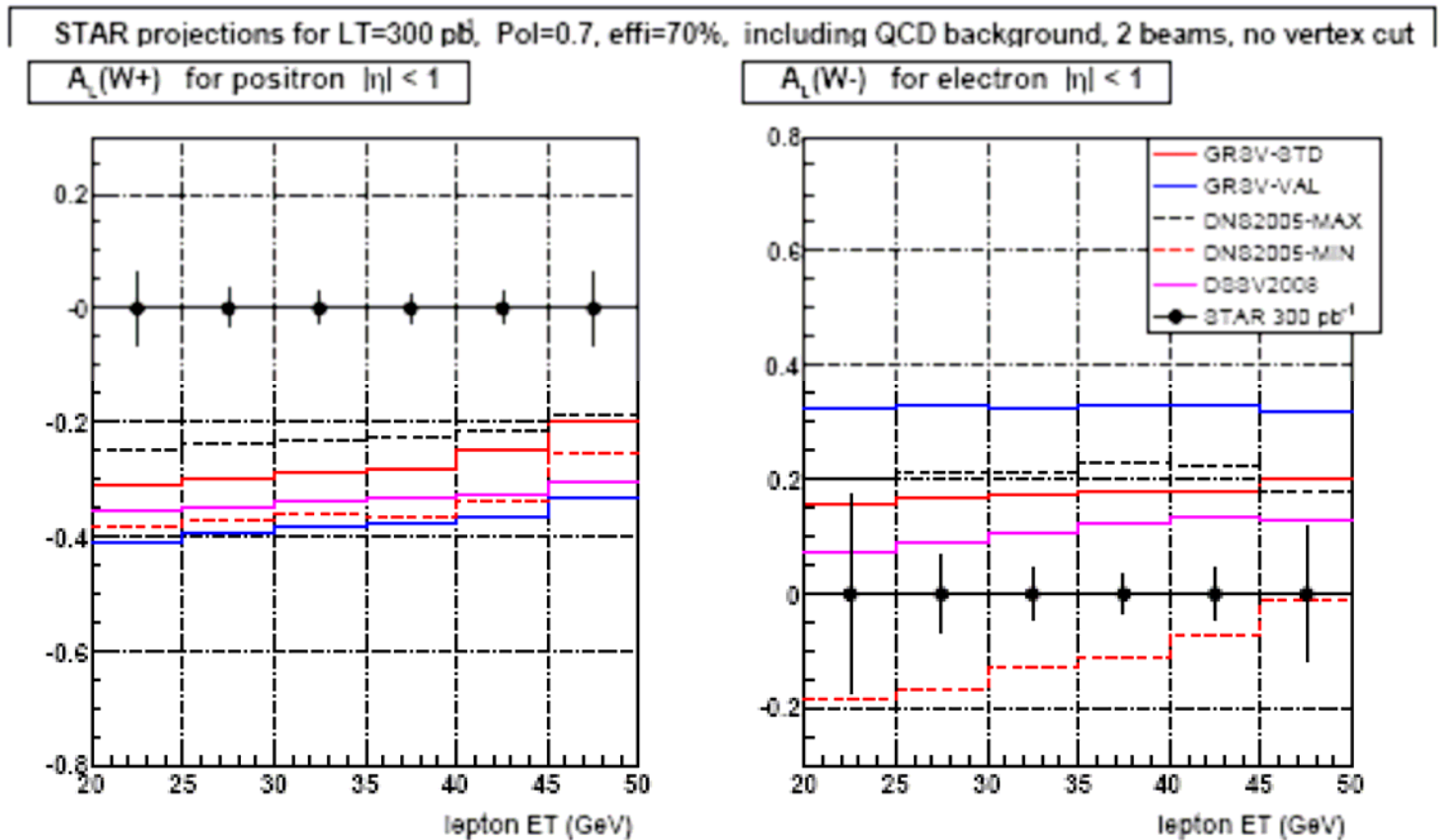


Figure 14: Projected uncertainties for 300 pb⁻¹ and 70% beam polarization of A_L as a function of E_T in the mid-rapidity acceptance region of the STAR BEMC ($-1 < \eta < 1$).

Conclusions on W

--note: numbering follows spin plan charge

1. Luminosity recorded by the experiments of 300 pb^{-1} , accumulated over the next five years, will provide precise, direct measurements of anti-quark polarizations separated by flavor at the weak scale of real- W production.
2. The upgrades that are required for these measurements are underway for the PHENIX μ trigger system and the STAR forward tracking capabilities.
3. Signal to background levels of better than 1:1 are expected in the forward/backward region for both PHENIX and STAR, based on realistic simulations that include full QCD backgrounds. The expected background levels have been included in the sensitivity estimates that are presented. Central rapidity backgrounds have been estimated, with simulation studies not yet done. A short 500 GeV run is proposed for either 2009 or 2010 to measure these levels directly.
4. Tracking provides an estimated $>97\%$ correct identification of the charge of the measured muon from W decay, for PHENIX. The STAR upgrade will provide 80 to 95% estimated correct identification for W decay electrons and positrons in the endcap calorimeter.

W conclusions (cont.)

5. Final extraction of the sea quark polarized distribution functions will use a global fit, as has been recently presented.
6. The program is proposed to begin in 2010, through 2013. If the program runs an average of 10 weeks per year, 300 pb^{-1} would be expected to be accumulated by the experiments. Results by the DOE milestone in 2013 will include significant direct measurements of the sea quark polarizations and the sea quark asymmetry, $\Delta\bar{u} - \Delta\bar{d}$.

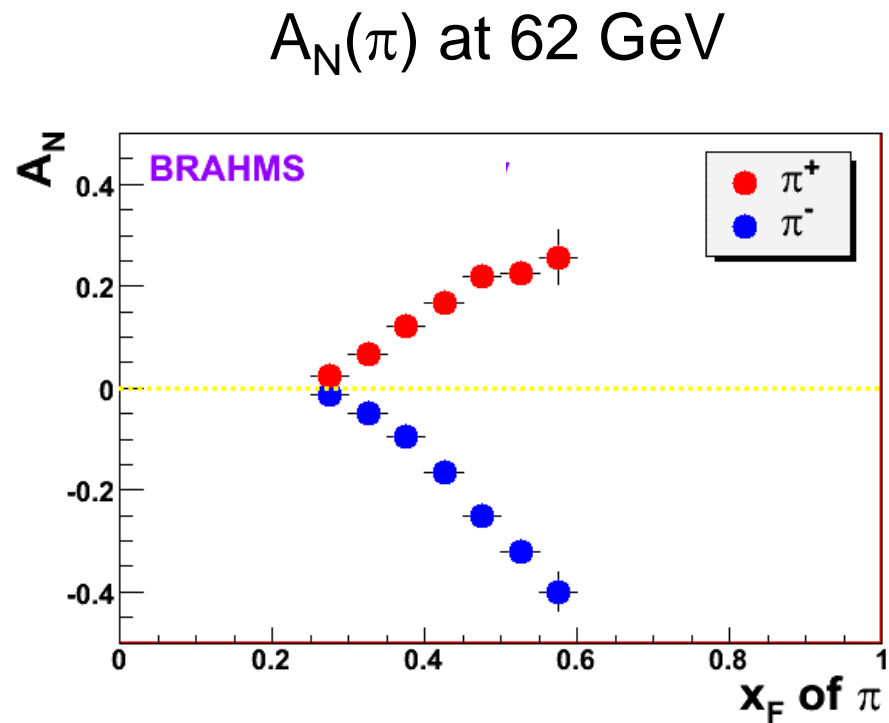
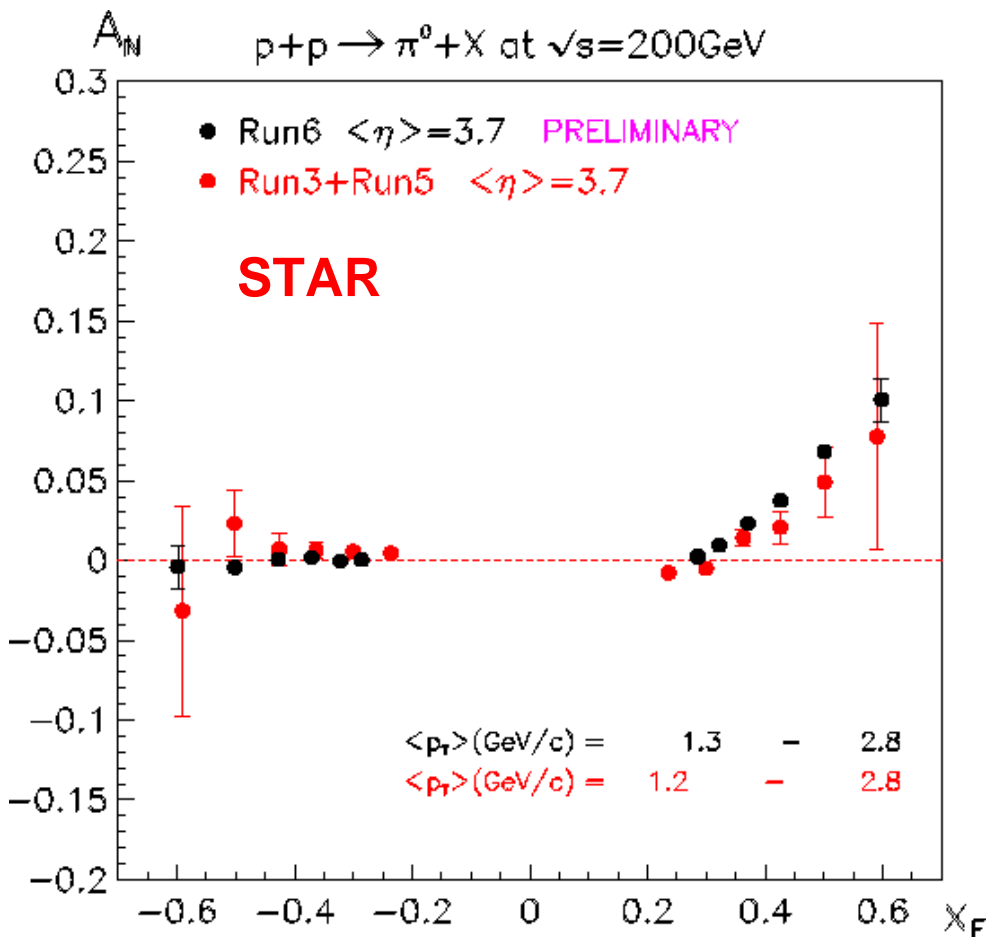
W asymmetry measurements will remain statistics-limited after 300 pb^{-1} . Future RHIC luminosity and polarization improvements would make it practical to obtain significantly more data in later years, leading to very precise determinations of the sea quark polarizations.

Transverse Spin

- **Striking measurements at RHIC and SIDIS**
- **Theoretical advances in field driven by RHIC and SIDIS results (and by e^+e^-)**
- **Orbital angular momentum description of asymmetries: Drell-Yan vs. SIDIS**
- **New DOE Milestone on Transverse Spin**

Transverse spin: pion A_N

--very large forward asymmetries

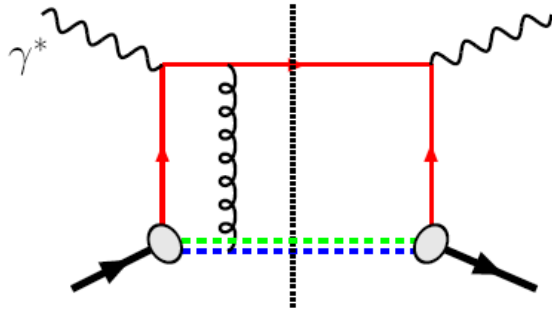


Kyoto Spin2006
Accepted PRL

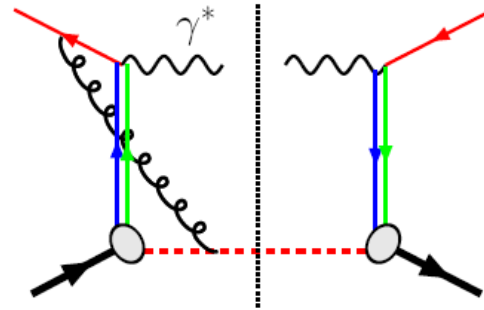
Attractive vs Repulsive “Sivers” Effects

Unique Prediction of Gauge Theory !

DIS: attractive



Drell-Yan: repulsive



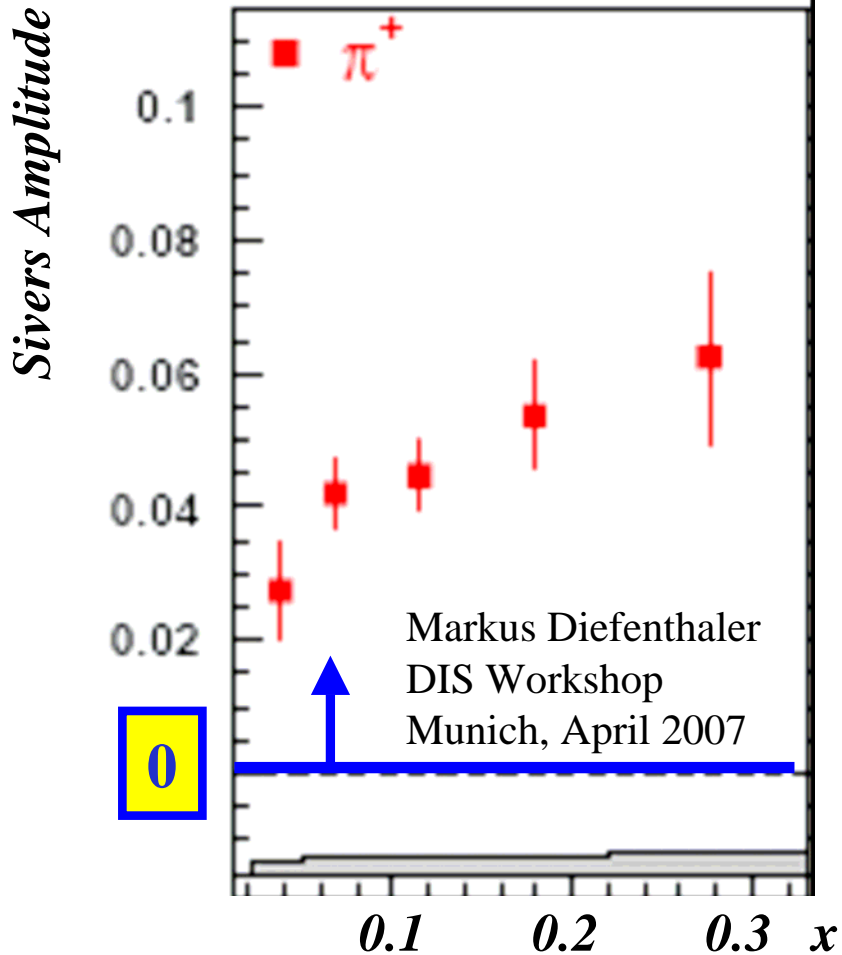
$$\text{Sivers}|_{\text{DIS}} = -\text{Sivers}|_{\text{DY}}$$

Sivers = Dennis Sivers (predicted orbital angular momentum origin of transverse asymmetries)

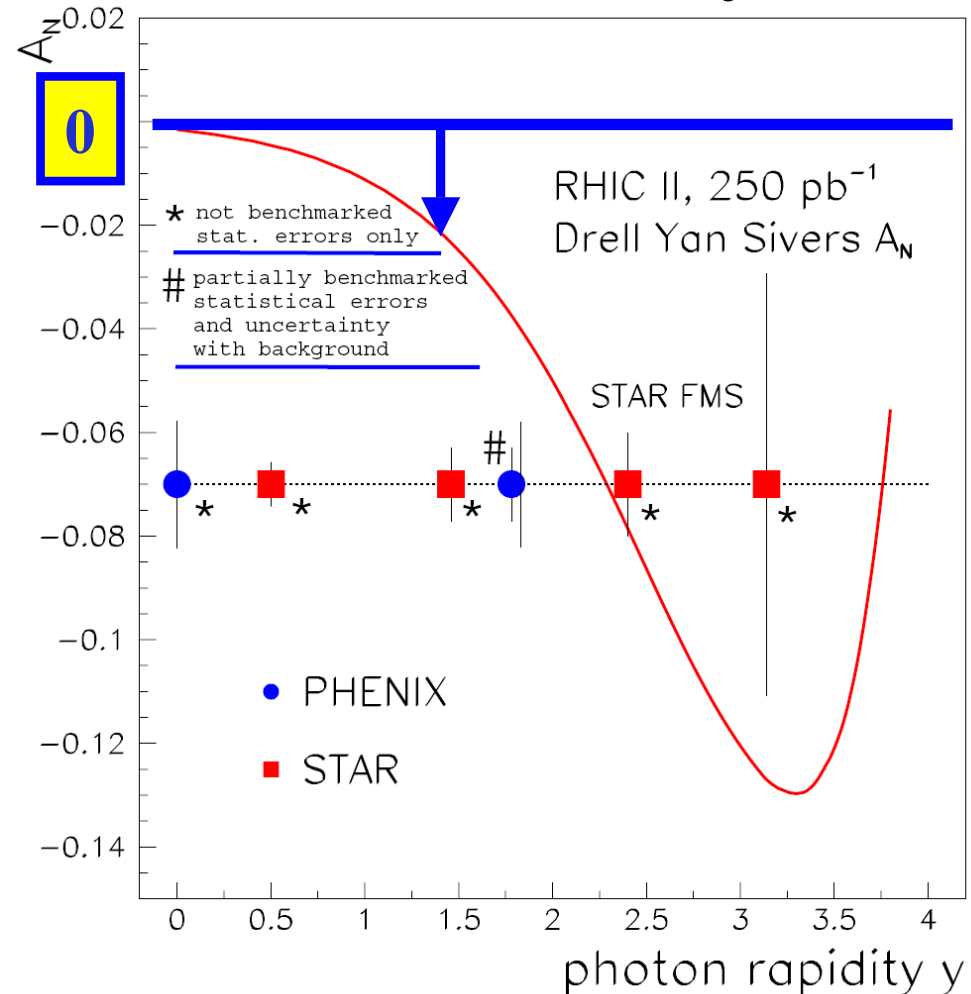
Experiment SIDIS vs Drell Yan: $\text{Sivers}|_{\text{DIS}} = -\text{Sivers}|_{\text{DY}}$

*** Probes QCD attraction and QCD repulsion ***

HERMES Sivers Results



RHIC II Drell Yan Projections



New DOE Milestone on transverse spin:

2015 HP13(new): Test unique QCD predictions for relations between single-transverse spin phenomena in p-p scattering and those observed in deep-inelastic lepton scattering



- We propose a precision transverse spin program for RHIC exploring and exploiting large transverse asymmetries that have been measured world-wide, at RHIC and in DIS. Quark transversity, the degree of quark polarization in a transversely polarized proton, and quark orbital angular momentum are believed to generate the observed asymmetries. Quark transversity will be measured through single jet production and through di-hadron correlations. The orbital angular momentum description of the observed asymmetries leads to a pQCD prediction connecting forward direct photon production at RHIC to asymmetries observed in DIS. This measurement will test our understanding of the underlying physics and the orbital angular momentum origin of these asymmetries. A future feature of the transverse spin program requires a new step in luminosity from RHIC. A transversely polarized beam producing Drell-Yan pairs at RHIC tests a predicted direct connection between DIS and Drell-Yan asymmetries. The gauge structure of QCD leads to the prediction that the Drell-Yan and DIS asymmetries must have opposite signs. We see Drell-Yan measurements, by both the PHENIX and STAR detectors, as being a focus of the program beginning about 2015.

Summary and Outlook

Recorded Luminosity	Main physics Objective	Remarks
$\sim 50\text{pb}^{-1}$	Gluon polarization using di-jets and precision inclusive measurements	200 GeV
$\sim 100\text{pb}^{-1}$	W production (Important consistency check to DIS results - Phase I) Gluon polarization (Di-Jets / Photon-Jets)	500 GeV
$\sim 300\text{pb}^{-1}$	W production (Constrain antiquark polarization - Phase II) Gluon polarization (Di-Jets / Photon-Jets)	500 GeV
$\sim 30\text{pb}^{-1}$	Transverse spin gamma-jet	200 GeV
$\sim 250\text{pb}^{-1}$	Transverse spin Drell-Yan (Long term)	200 GeV

P=.7; running time is critical.

Backup slides

Achieved and projected pol p parameters

Fiscal year		2006	2008	2009E	2010E	2011E	2012E	2013E
No of bunches	...	111	111	111	111	111	111	111
Protons/bunch, initial	10^{11}	1.4	1.5	1.8	1.9	2.0	2.0	2.0
Avg. beam current/ring	mA	187	205	250	264	280	280	280
β^*	m	1.0	1.0	0.8	0.7	0.6	0.6	0.5
Beam-beam parameter/IP	10^{-3}	5.6	4.9	6.1	7.4	7.5	7.5	7.5
Peak luminosity (200 GeV)	$10^{30}\text{cm}^{-2}\text{s}^{-1}$	28	35	63	96	121	129	137
Avg./peak luminosity	%	64	65	63	62	60	60	60
Avg. store luminosity (200 GeV)	$10^{30}\text{cm}^{-2}\text{s}^{-1}$	18	23	40	60	73	77	82
Time in store	%	46	60	60	60	60	60	60
Max luminosity/week (200 GeV)	pb^{-1}	6.5	7.5	14.5	21.6	26.4	28.0	29.8
Min luminosity/week (200 GeV)	pb^{-1}			7.5	7.5	7.5	7.5	7.5
Max luminosity/run (200 GeV)	pb^{-1}	46	19	130	150	180	200	210
Min luminosity/run (200 GeV)	pb^{-1}			70	50	50	50	50
Max luminosity/run (500 GeV)	pb^{-1}				375	450	500	525
Min luminosity/run (500 GeV)	pb^{-1}				125	125	125	125
AGS polarization, extraction, min/max	%	65 ¹	55 ¹	55/65	55/70	55/70	55/75	55/75
RHIC avg. store polarization, min/max	%	58	45	50/60	50/65	50/70	50/70	50/70

¹The AGS polarization may be restated in the future after the used analyzing power is calibrated in RHIC at injection in a polarization measurement with the polarized hydrogen jet.

Table 1: *Achieved and projected polarized proton beam parameters through FY2013. Delivered luminosities are given for one of two interaction points. Luminosities above a center of mass energy of 200 GeV increase proportionally with γ from the reduction in the transverse emittance. 15 weeks of physics operation are assumed for FY2009, and 10 weeks in the following years.*