

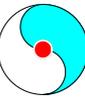
Transverse Spin Physics at RHIC II

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(University of Illinois and RBRC)

RBRC Workshop on Single Spin Asymmetries

June 1-3, 2005

Brookhaven National Laboratory, Upton, New York, USA



Transverse Spin Physics at RHIC II

- **Motivation**
 - Reconcile QCD with SSA observed in pp
 - Map out transverse proton spin structure (global QCD analysis of pp, SIDIS and e+e-)
 - Fundamental tests of QCD:
 - Tensor Charge: Lattice QCD vs experiment
 - Sivers sign in Drell Yan vs SIDIS
 - Prerequisites for a transverse spin program

- **Transverse spin physics at RHIC**
 - Polarized collider + experiments
 - Overview of available measurements vs luminosity

- **RHIC II**
 - Luminosity
 - Detector upgrades
 - A dedicated Drell Yan experiment for transverse spin physics?
 - Tensor charge at e-RHIC?

- **Summary**



Motivation: Global Transversity Analysis

RBRC workshop September 2000

SIDIS \Rightarrow

transversity \times Collins

transversity \times IFF

HERMES, COMPASS,

JLAB, e - RHIC/e - LIC

$e^+e^- \Rightarrow$ Collins FF

Interference FF

BELLE (RBRC/UIUC)

Factorization and
Universality?

Transversity
Tensor Charge

Does pQCD provide a
stable frame work for a
global transversity analysis?

pp \Rightarrow

A_N for inclusive hadrons, A_{TT} in Jets

A_T in Jets : transversity \times Collins

transversity \times IFF

A_{TT} Drell Yan :

transversity \times transversity

BRAHMS, PHENIX, STAR, GSI

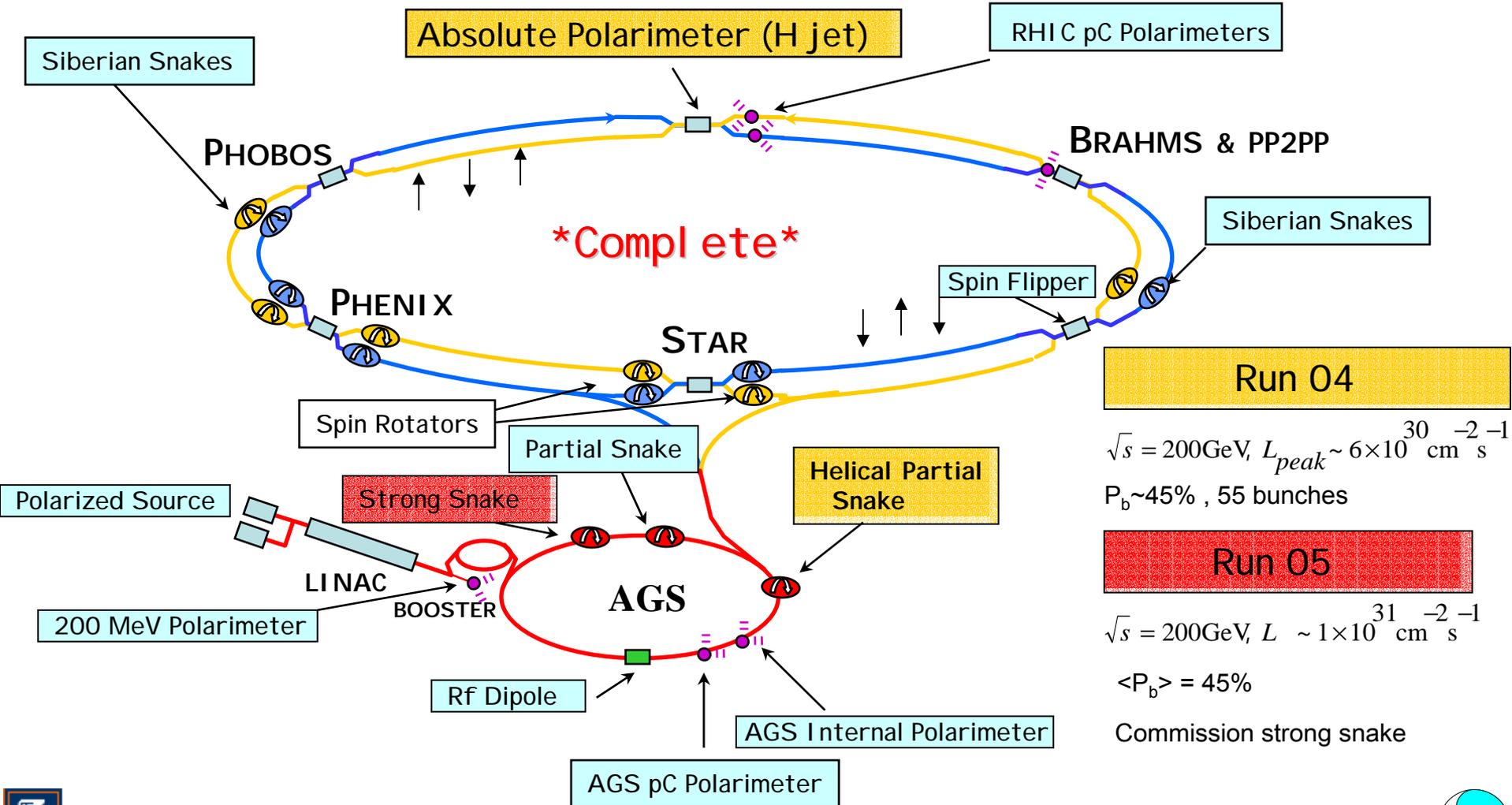
Prerequisites for a measurement of the Tensor Charge :

- o Global analysis of SIDIS, pp and e+e- requires universality, factorization and pQCD as stable frame work for the extraction of transversity distributions.
- o Are the observed SSA from leading twist distributions?
 - Consistency between Hermes transverse and longitudinal SSA results seems to require large sub-leading twist contributions to the longitudinal asymmetries.
 - COMPASS results from deuterium targets are consistent with 0; proton target in 2006.
 - Belle results on sFFs at large scale!
- o Precision data from pp, SIDIS (-> polarized ep collider!) and e+e-

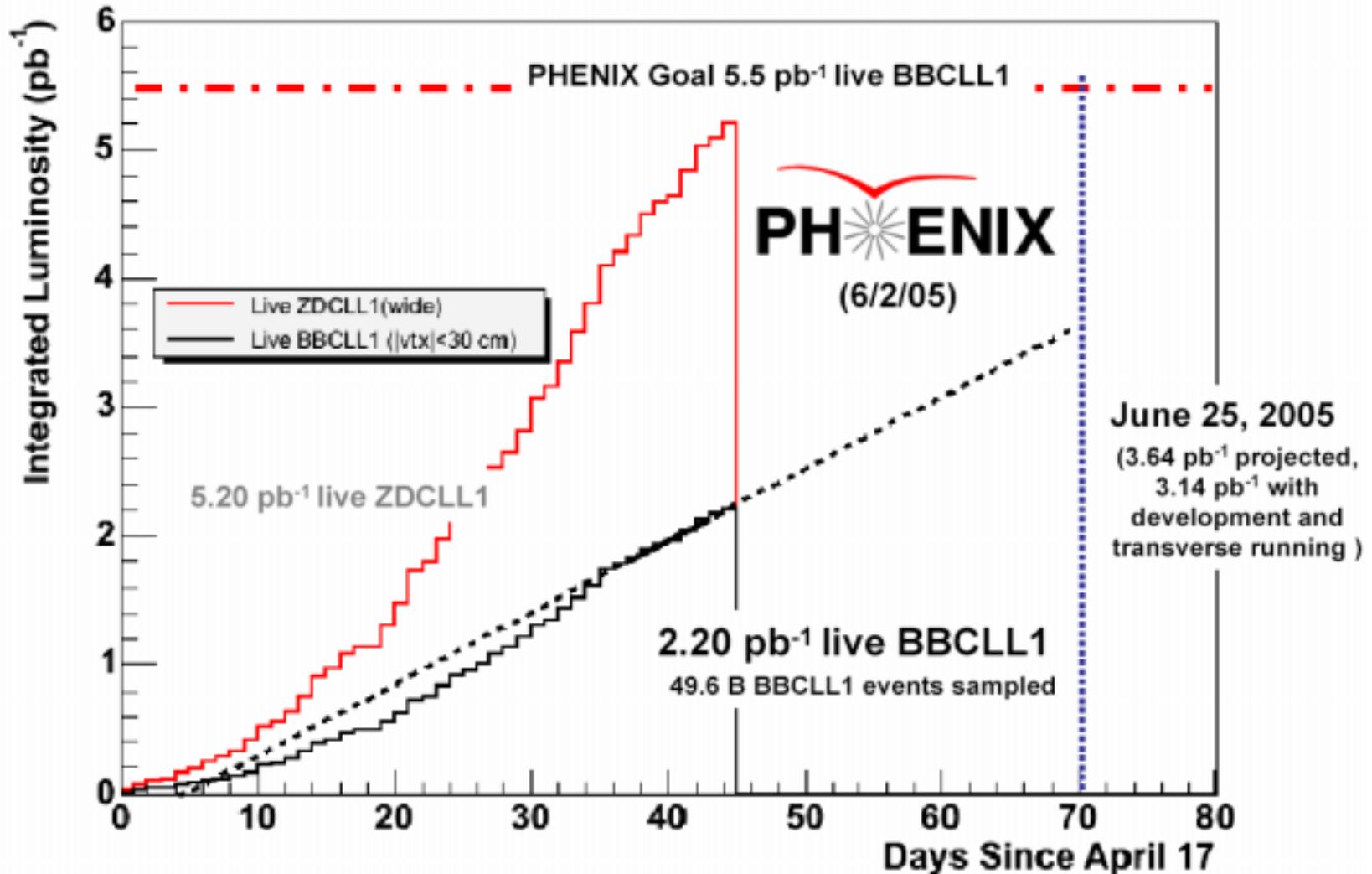


Polarized p-p at RHIC 2005:

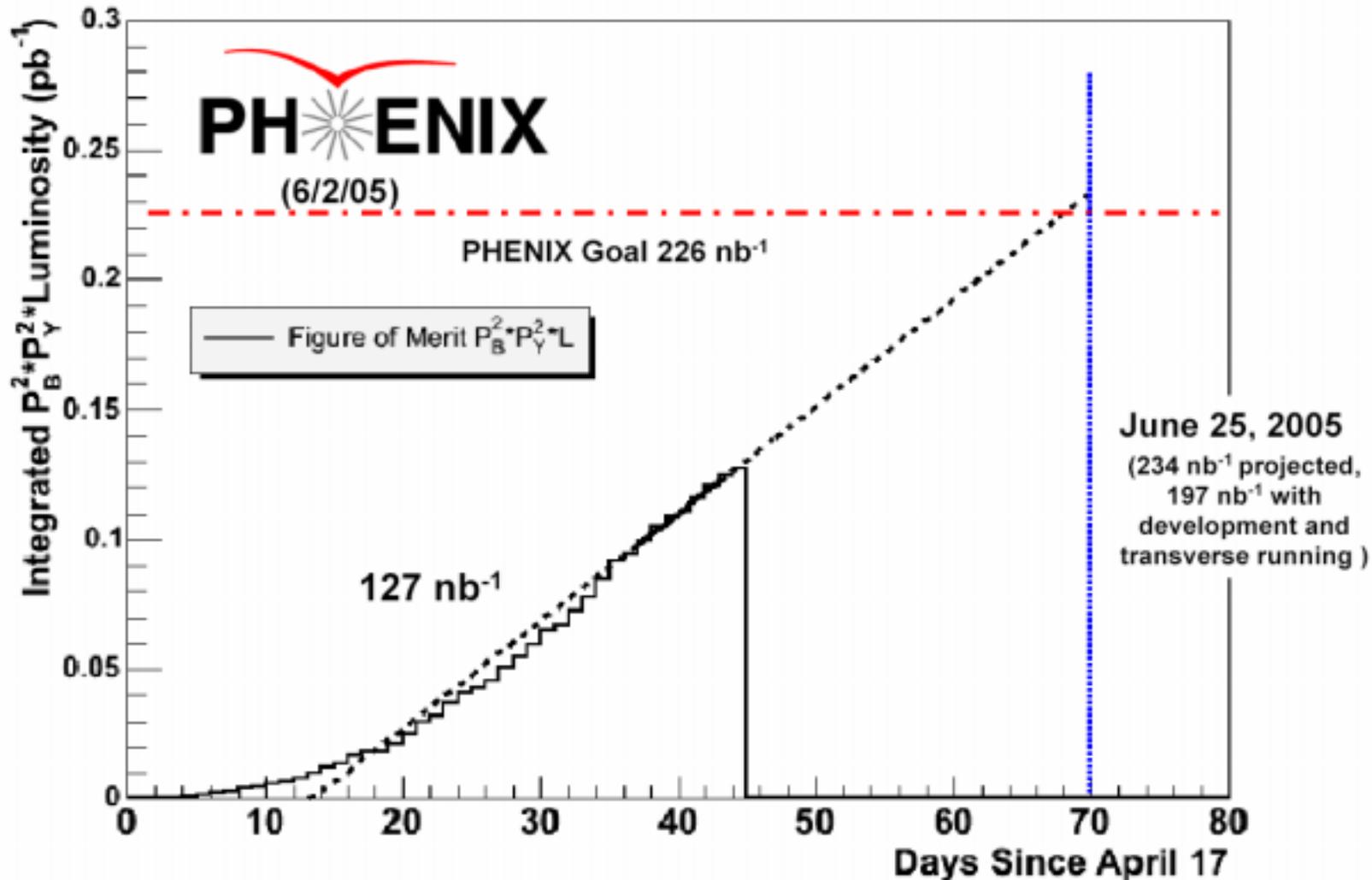
A novel experimental method to study proton spin structure (after 30 years of spin dependent DIS) !



RHIC 2005: 200 GeV pp, $\int L dt$, June 2nd



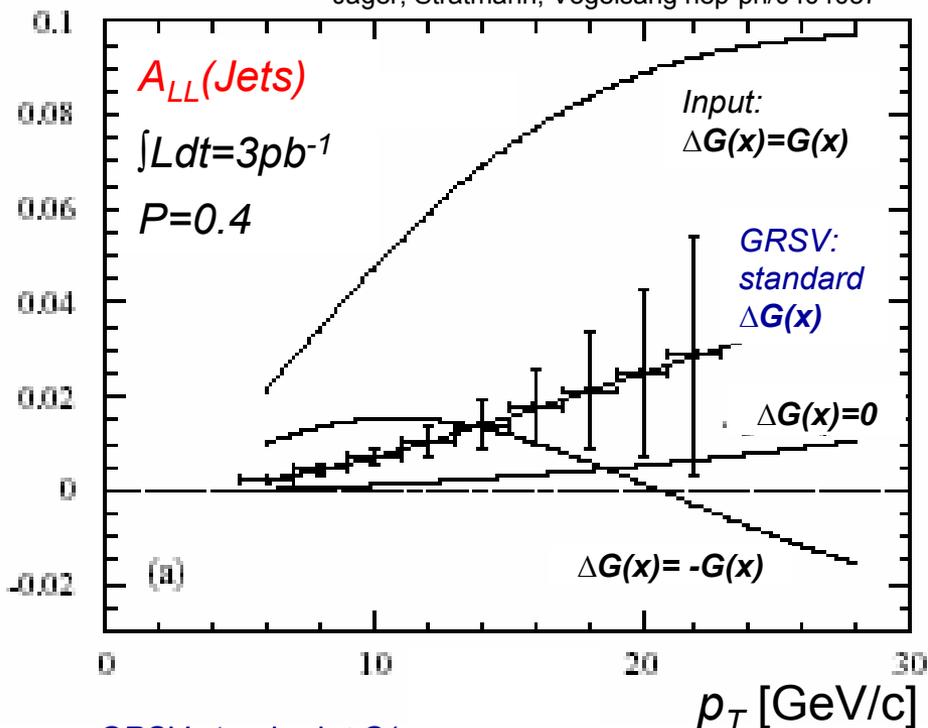
RHIC 2005: 200 GeV pp, *FoM*, June 2nd



Goals for 2005: → (a) 1st look at the Gluon Polarization (b) precision measurement of A_N

A_{LL} in inclusive jet production (STAR)

Jager, Stratmann, Vogelsang hep-ph/0404057

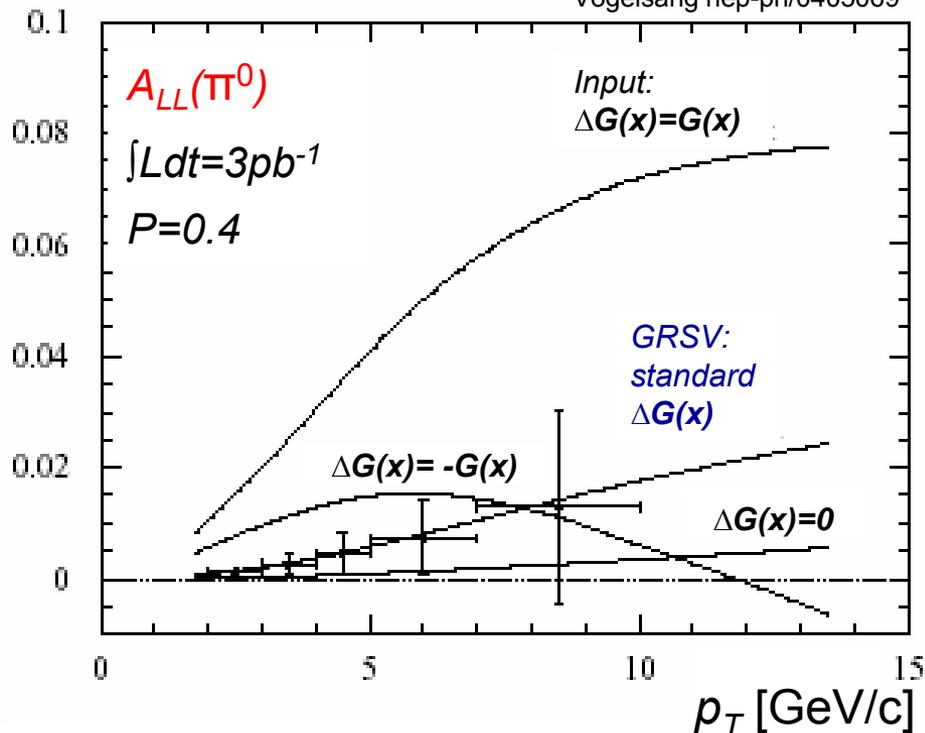


GRSV standard $\Delta G(x)$

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

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

Vogelsang hep-ph/0405069



Experiments with polarized protons at RHIC

polarization

measurements

STAR

75% longitudinal, 25% transverse

A_{LL} (hadrons, jets, heavy flavor, direct photons)
 A_L (W-bosons)
 A_N (hadrons, jets)
 A_T (Drell Yan, Collins, IFF)
 A_{TT} (Jets, Drell Yan)

PHENIX

75% longitudinal, 25% transverse

BRAHMS

100% transverse

A_N (identified charged hadrons)

PHOBOS, pp2pp → no “active” spin program



Future: RHIC Spin Longitudinal vs Transverse Running

$$L = 1 \times 10^{31} \text{cm}^{-2} \text{s}^{-1}$$

$$6 \times 10^{31} \text{cm}^{-2} \text{s}^{-1}$$

$$P = 0.5$$

$$0.6$$

$$0.7$$

$$\sqrt{s} = \dots\dots\dots 200 \text{ GeV} \dots\dots\dots 500 \text{ GeV}$$

2005

2006

2007

2008

2009

....

2012 (RHIC II)

5pb⁻¹

→ 275pb⁻¹

Inclusive hadrons + Jets

~ 25% Transverse Physics

Charm Physics

direct photons

bottom physics

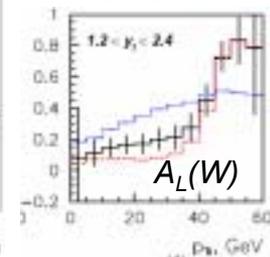
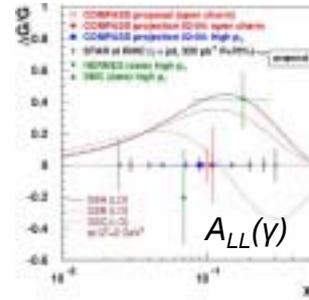
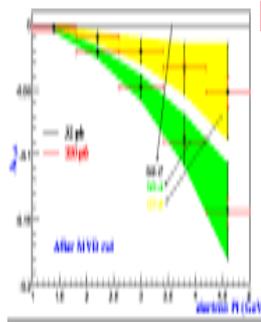
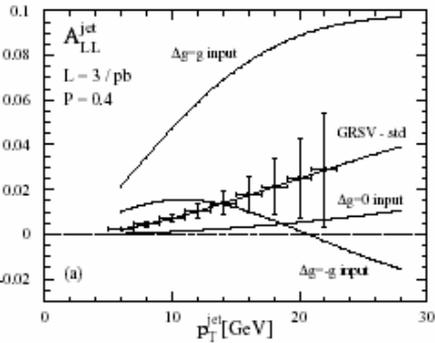
W-physics

$A_{LL}(\text{hadrons, Jets})$

$A_{LL}(\text{charm})$

$A_{LL}(Y)$

$A_L(W)$



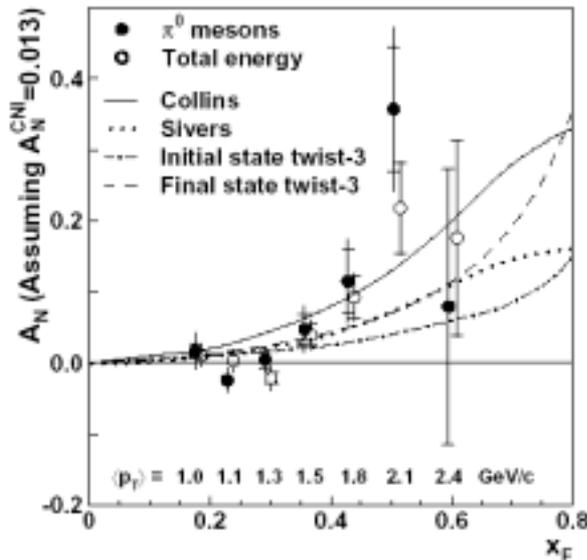
(A) Transverse Spin Physics Channels at RHIC for “Low” Luminosity

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

STAR, PHENIX and BRAHMS

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

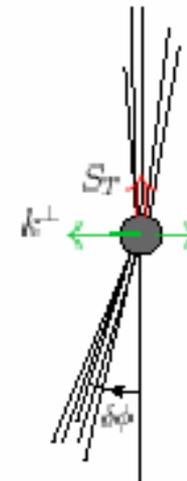
STAR Phys. Rev. Lett. 92:171801, 2004



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

STAR and PHENIX

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



Clean channel for Sivers effect!

(B) Transverse Spin Physics Channels at RHIC for “High” Luminosity

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

STAR and PHENIX

- Collins Effect in Jets:

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

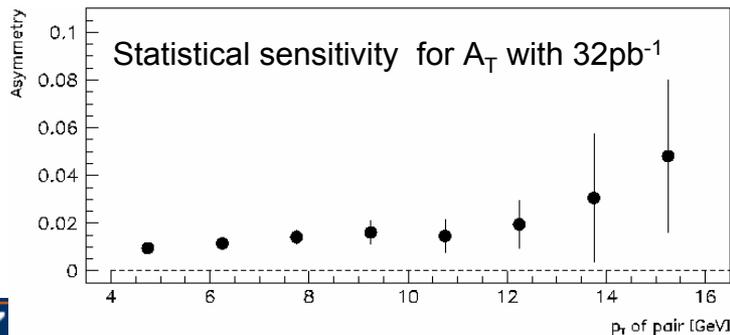
J.C. Collins, Nucl. Phys. B396, 161(1993)

- π^+, π^- Interference Fragmentation:

$$A_T(p_{\perp} p \rightarrow (\pi^+, \pi^-) + X)$$

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

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



STAR and PHENIX

- Inclusive jet production

$$5 \cdot 10^{-4} \leq A_{TT} \leq 3 \cdot 10^{-3}$$

W. Vogelsang and M. Stratmann, RBRC
Wrkshp on Transversity (2000)



Transverse spin program at RHIC is luminosity limited

luminosity sufficient?

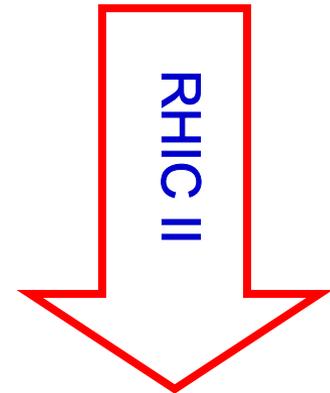
| | |
|--|----------------------------|
| A_N | yes, very good |
| A_N (back-to-back) | good (Sivers signature!) |
| A_T (Collins FF) | ok |
| A_T (Interference FF) | poor |
| A_{TT} (Jets) | not studied experimentally |
| A_T (Drell Yan) | --- |
| A_{TT} (Drell Yan) | --- |
| Direct photons (A_N, A_T (CFF, IFF)) | --- |

RHIC by 2009 at 200 GeV

$\int L dt \sim 275 \text{ pb}^{-1}$ delivered

$\int L dt \sim 100 \text{ pb}^{-1}$ accepted
(eg. PHENIX: vertex cut,
trigger efficiencies, duty
factor)

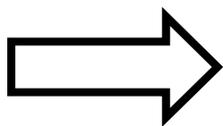
→ $\int L dt \sim 25 \text{ pb}^{-1}$ transverse



Definition: RHIC II (an attempt)

- (I) Electron Cooling in RHIC to increase luminosity for HI by factor 10
- (II) Detector Upgrades in PHENIX and STAR
- (III) New detector (a new general purpose detector for HI and pp physics has been proposed).

target date
2012

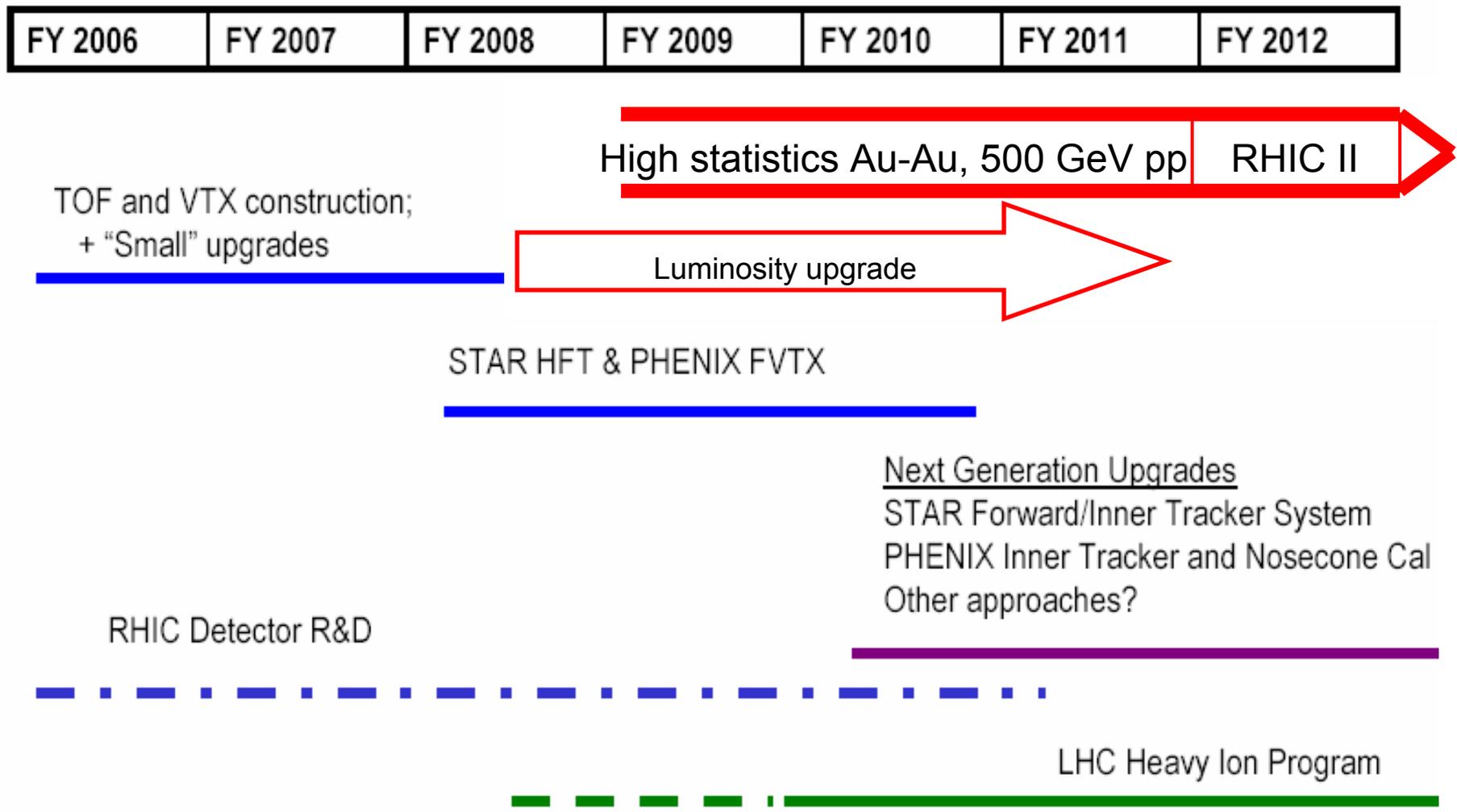


Increasingly there is the view that RHIC II upgrades need to be carefully coordinated with the effort to build a electron ion collider!



RHIC II Schedule: Detector Upgrades + Luminosity

(from Tom Ludlam)



RHIC II: Luminosity Upgrade with Electron Cooling

(from Thomas Rose)

RHIC Luminosity Upgrade with Electron Cooling

| Gold collisions (100 GeV/n x 100 GeV/n): | w/o e-cooling | with e-cooling |
|--|----------------------|-----------------------|
| Emittance (95%) $\pi\mu\text{m}$ | 15 \rightarrow 40 | 15 \rightarrow 3 |
| Beta function at IR [m] | 1.0 | 1.0 \rightarrow 0.5 |
| Number of bunches | 112 | 112 |
| Bunch population [10^9] | 1 | 1 \rightarrow 0.3 |
| Beam-beam parameter per IR | 0.0016 | 0.004 |
| Ave. store luminosity [$10^{26} \text{ cm}^{-2} \text{ s}^{-1}$] | 8 | 70 |
| Pol. Proton Collision (250 GeV x 250 GeV): | | |
| Emittance (95%) $\pi\mu\text{m}$ | 20 | 12 |
| Beta function at IR [m] | 1.0 | 0.5 |
| Number of bunches | 112 | 112 |
| Bunch population [10^{11}] | 2 | 2 |
| Beam-beam parameter per IR | 0.007 | 0.012 ? |
| Ave. store luminosity [$10^{32} \text{ cm}^{-2} \text{ s}^{-1}$] | 1.5 | 5.0 |



pp expectations from the RHIC II luminosity upgrade

- Expect factor 2-3 increase in pp luminosity
- Expect only small improvements in polarization
- Luminosity at lower energies scales with γ^2
- Operation at 20-30% higher energy possible
- Can have polarized $^3\text{He}^{2+}$ and d^+ (difficult) beams
- Mini-quads at one IP can boost luminosity by a factor 3-5

What is RHIC Spin (and not RHIC II) ?

- Measurement of ΔG at 200 and 500 GeV
- Measurement of Δq and $\Delta\bar{q}$ at 500 GeV in W production
- Transverse spin physics: A_N , correlations, A_T (Collins), A_T (Interference FF)



Physics Suggestions for pp at RHIC II

- Associate charm in W-production (strange tag!)
- Dedicated experiment for Drell Yan and transverse spin physics
- Forward pp
- Physics beyond the standard model ?
- What can be done with ^3He or deuteron beams?
- What can be done with different beam energies?
(maximum center of mass energy: 650 GeV)



Dedicated Experiment for Drell Yan

Idea: Large acceptance calorimeter experiment at PHOBOS interaction point (10 o'clock)

Physics: $A_{TT}(DY) \rightarrow$ transversity
 $A_{UT}(DY) \rightarrow$ Sivers
 $A_{TT}(\text{Jets}) \rightarrow$ transversity, correlations
unpolarized DY?

Exp. Param.: Re-use existing EMC + HCAL elements, pad-chamber layer for charged particle tagging, BBC, ZDC (exists), utilize PHENIX FEE, DAQ and trigger for dead time free read out
 $\rightarrow -3 < \eta < 3$, sample all vertices.

Low cost?

Advantages: - 100% transverse spin
- take advantage of luminosity upgrades, large acceptance, wide vertex cuts and dead time free read out for maximum $\int L dt$



Expected effective Luminosity in 10 weeks

100% transverse running

→ 125 pb⁻¹ delivered in 10 weeks (projected 2008 number)

x 0.6 (vertex, trigger efficiency, DAQ dead time, up-time)

x 2.5 (e-cooling)

x 4 (mini quads)

x 8 (acceptance)

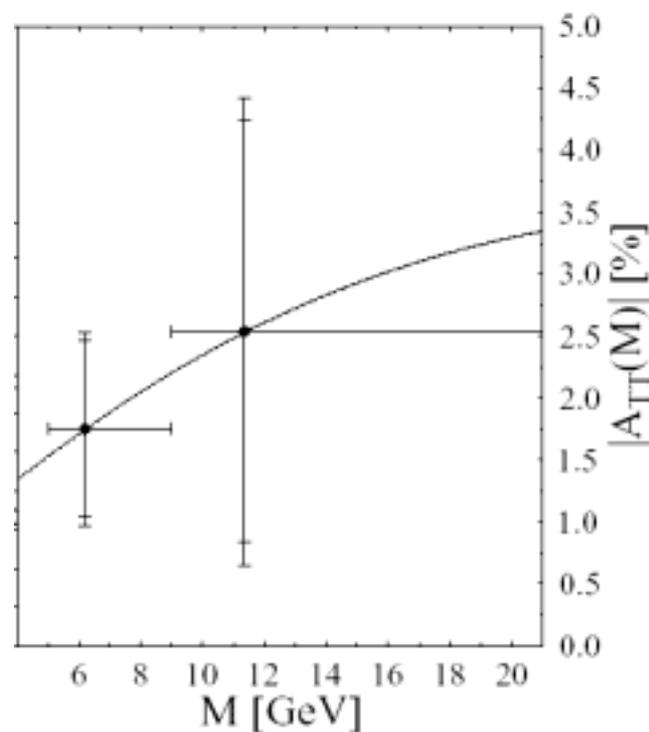
= 6000 pb⁻¹

Projections for pp at 200 GeV and 320pb⁻¹

O. Martin, M. Stratmann, A. Schaefer, W. Voglesang, Phys.Rev.D60:117502,1999

A_{TT} for Drell Yan with PHENIX

$$\frac{d\delta\sigma}{dMdyd\phi} = \sum_q \tilde{e}_q^2 \int_{x_1^0}^1 dx_1 \int_{x_2^0}^1 dx_2 [\delta q(x_1, \mu_F^2) \delta \bar{q}(x_2, \mu_F^2) + \delta \bar{q}(x_1, \mu_F^2) \delta q(x_2, \mu_F^2)] \frac{d\delta\hat{\sigma}}{dMdyd\phi}$$

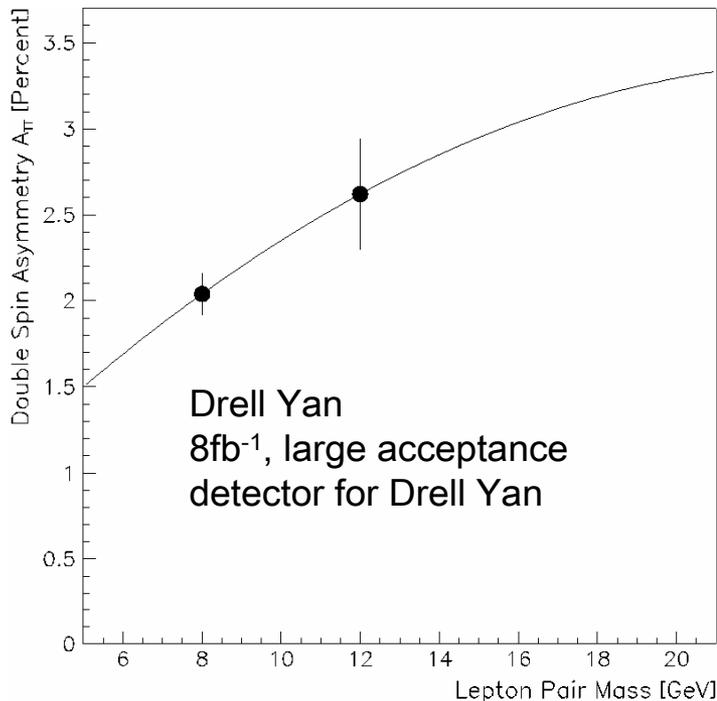


Result includes acceptance for PHENIX muon arms or alternatively for muon arms + central arms

Projections for pp at 200 GeV and 8000 pb⁻¹

A_{TT} for Drell Yan with PHENIX

$$\frac{d\delta\sigma}{dMdyd\phi} = \sum_q \tilde{e}_q^2 \int_{x_1^0}^1 dx_1 \int_{x_2^0}^1 dx_2 [\delta q(x_1, \mu_F^2) \delta \bar{q}(x_2, \mu_F^2) + \delta \bar{q}(x_1, \mu_F^2) \delta q(x_2, \mu_F^2)] \frac{d\delta\hat{\sigma}}{dMdyd\phi}$$



projections for 10 weeks of running,
5-10% higher polarization, with RHIC II
luminosities and large acceptance

This measurement appears to be
also possible at 500 GeV



Projections for A_{UT} in Drell Yan

Ongoing work by J. Collins, K. Goeke, S. Menzel, A. Metz and P. Schweitzer

$$A_{UT}^{\sin(\phi-\phi_S)\frac{q_T}{M}} \propto \frac{\sum_{flavors} x_1 \cdot \text{Sivers} - df \cdot x_2 \cdot a - \text{quark} - df}{\sum_{flavors} x_1 \cdot \text{quark} - df \cdot x_2 \cdot a - \text{quark} - df}$$

Using parametrizations of the Sivers function first estimates of the asymmetry at 200 GeV and $Q \sim 5$ to 20 GeV give about 5%. The statistical error in two invariant mass bins will be less than 0.3%.



Comments

Pending careful evaluation of the experimental resolution, it appears that a dedicated Drell Yan experiment taking advantage of RHIC II luminosity upgrades and large acceptance will be able to carry out clean transversity and Sivers function measurements with good statistical resolution.

Possible measurements in un-polarized DY need to be evaluated.

The experiment could be based on existing detector hardware and utilize front end-, DAQ and trigger electronic designs developed for RHIC experiments. This will keep the cost low.

Running could start well before RHIC II upgrades are completed. From 2012 full RHIC II luminosity should be available.

The experiment offers interesting physics during the transition between the present Hermes and COMPASS experiments and future efforts: e-RHIC and GSI.



Collins Effect in SIDIS at e-RHIC

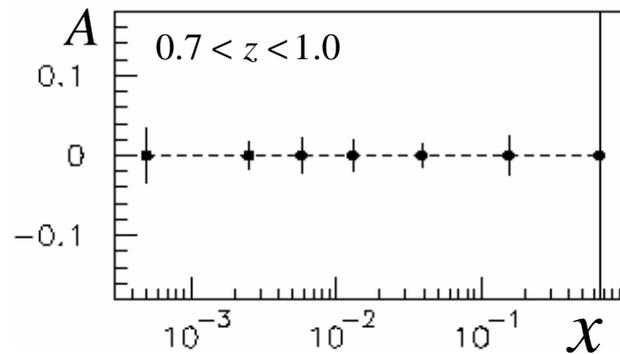
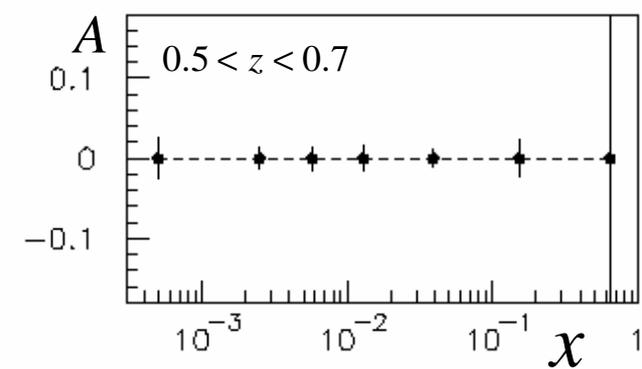
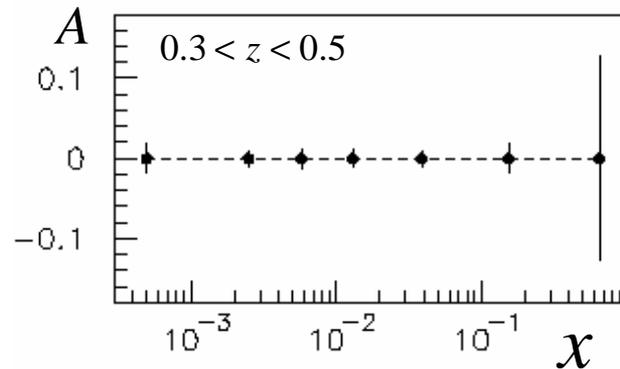
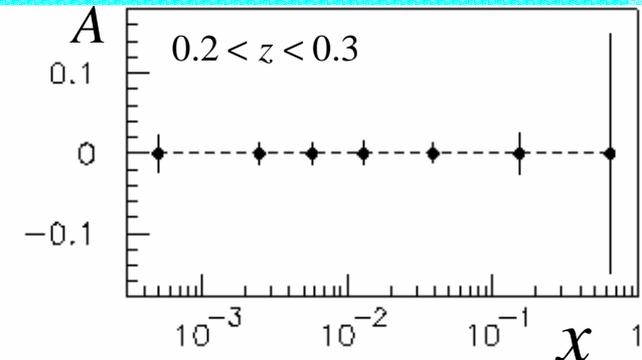
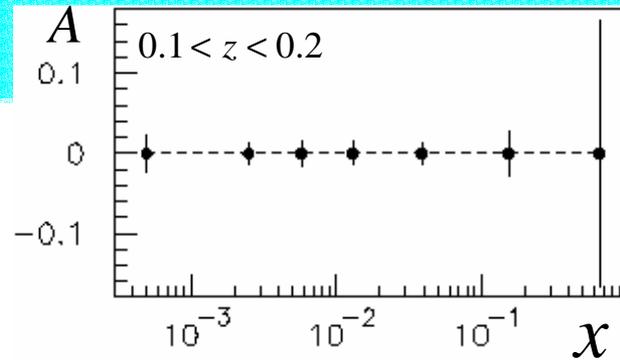
$$A_T^{\pi^+} (lp_{\perp} \rightarrow e + \pi + X)$$

Detector Acceptance
 $-3.6 < \eta < 3.6$

Integrated Luminosity
 $20 pb^{-1}$ (less than 1 day)

Cuts: $Q^2 > 1 GeV^2$
 $x_F > 0$
 $z > 0.1$

Projected errors on A in 5 z- bins



Statistical resolution
 similar to TESLA-N
 should be possible
 → Measurement of
 tensor charge!

Transverse spin at RHIC + RHIC II

- First results on A_N
 - 2005 precision measurements
 - comparisons between pions, kaons and protons
 - what can be learned from a QCD analysis of precision A_N data at forward and mid-rapidity?
- Broad program with transverse spin with increasing luminosity in RHIC II:
 - A_N in inclusive hadrons and jet production
 - Sivers type back-to-back correlation between jets
 - A_T for Collins and IFF analysis
 - A_T and A_{TT} for Drell Yan (RHIC II)
- Supporting effort to measure spin dependent fragmentation functions at Belle (RBRC/UIUC)



RHIC II schedule

Mailing list: rhicii-spin-1@bnl.gov

Next meetings: (1) Wednesday June 22nd (AGS&RHIC user meeting)
(2) 3 day meeting in either the week of Sep-12th or 26th
(3) joint meeting with e-RHIC

Additional suggestions, guidance and help are highly welcome!

