Forward Spin Physics

OUTLINE

- Spin puzzle and long-term goals of RHIC spin program
- Why consider forward spin physics?
- Summary

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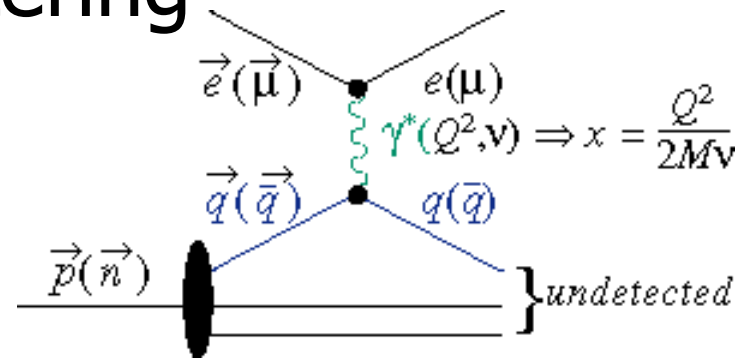
Forward Physics Workshop, 10/9/03

Polarized Deep Inelastic Scattering



Add *polarization* to DIS and measure longitudinal 2-spin asymmetry…

$$\vec{e}(\vec{\mu}) + \vec{p}(\vec{n}) \rightarrow e(\mu) + X$$

Deduce polarized structure function from measured asymmetry, $A_1 = g_1 / F_1$

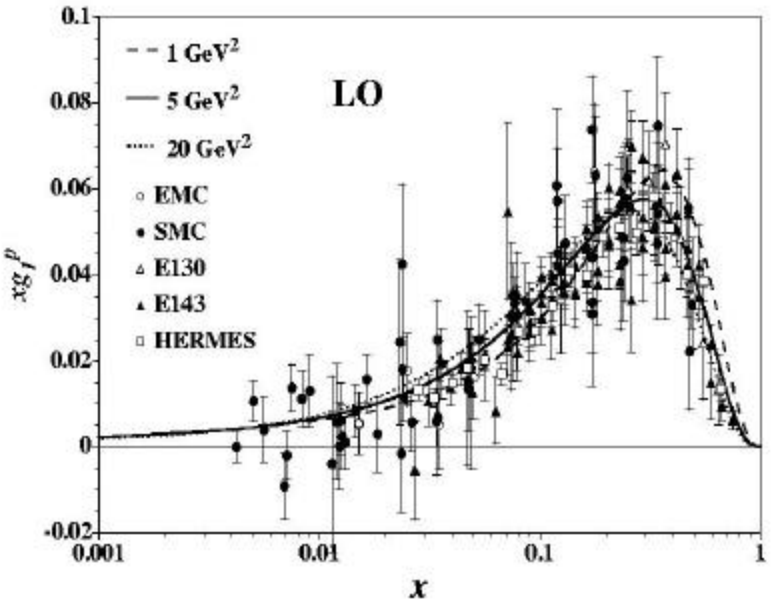
$$g_1(x,Q^2) = \frac{1}{2}\sum_q e_q^2 \left[\Delta q(x,Q^2) + \Delta\bar{q}(x,Q^2) \right]$$

Where $\Delta q(x,Q^2)$ is the difference in probability to find a quark with helicity aligned or opposite to the proton's helicity, in leading order.

$$\Delta q(x,Q^2) = q_+(x,Q^2) - q_-(x,Q^2)$$

$$\Delta\Sigma(Q^2) = \sum_q \int_0^1 \left[\Delta q(x,Q^2) + \Delta\bar{q}(x,Q^2)\right] dx$$

Defines the fraction of the proton's spin carried by quarks. It can be deduced from the integral of $g_1(x)$ measured for the proton.



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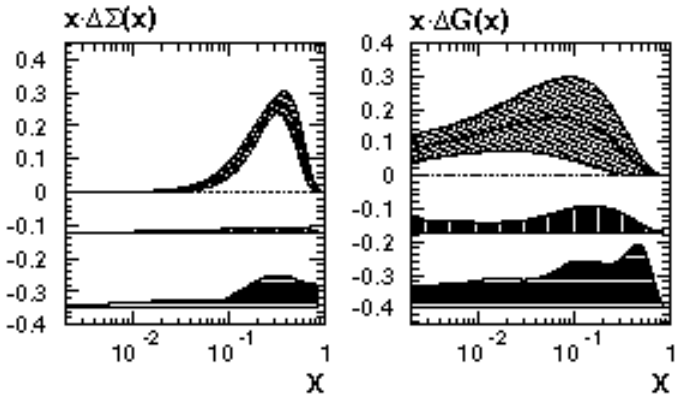
Where is the spin of the proton?

Global analyses of polarized deep inelastic scattering (pDIS) observe only a small fraction of the proton's spin carried by quarks.



First moments at $Q_0^2 = 1\ GeV^2$:

SMC , PRD 58 (1998) 112002

$$\Delta\Sigma_{(AB)} = 0.38\ ^{+0.03\ +0.03\ +0.03}_{-0.03\ -0.02\ -0.05}$$

$$\Delta G_{(AB)} = 0.99\ ^{+1.17\ +0.42\ +1.43}_{-0.31\ -0.22\ -0.45}$$

q($\bar{q}$) contribution — gluon contribution

$$S_z = \tfrac{1}{2} = \tfrac{1}{2}\Delta\Sigma + \Delta G + L_z^q + L_z^g$$

$L_z^q + L_z^g$: orbital angular momentum

At present, the gluon contribution to the proton spin (ΔG) is known only poorly from scaling violations in polarized deep inelastic scattering, spanning a small range of Q^2.

$\Rightarrow$ Require a NEW GENERATION of experiments to determine ΔG.

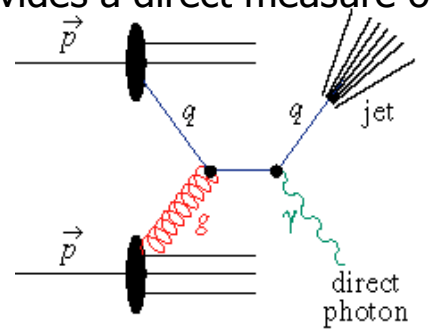
$\Rightarrow$ RHIC Spin

- determine the gluon contribution to the proton's spin
- determine the flavor decomposition of the quark (antiquark) polarization
- probe transversity: the unknown, remaining leading-twist structure function

$$\delta q(x,Q^2) = q_{\uparrow}(x,Q^2) - q_{\downarrow}(x,Q^2)$$

Gluon Contribution to the proton's spin

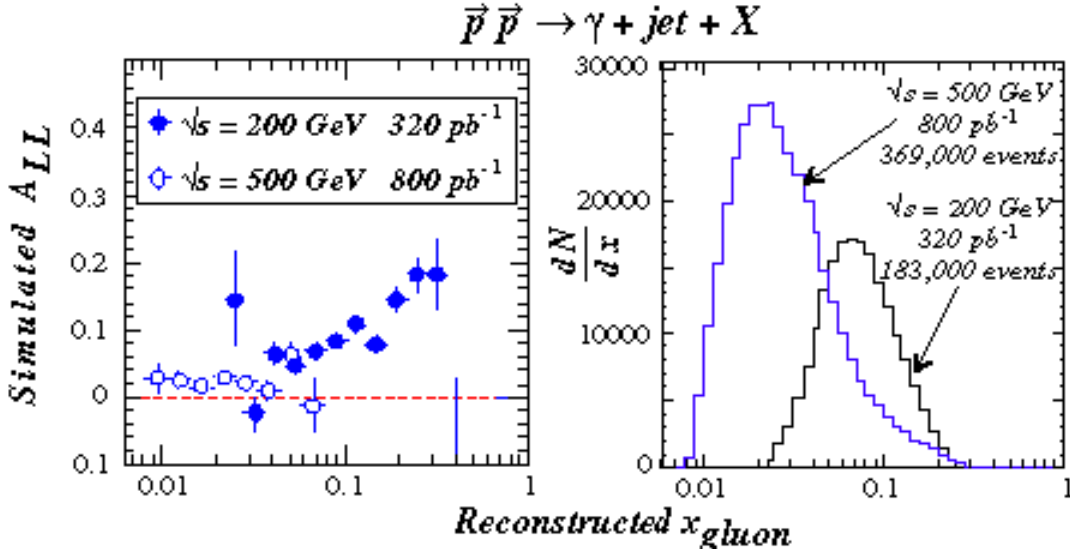
qg Compton scattering with polarized protons provides a direct measure of gluon polarization.



Quark-Gluon Compton scattering

$$\vec{p}+\vec{p}\rightarrow\gamma\,(+\,jet)+X$$

Coincident detection of γ and away-side jet ⇒ event determination of initial-state partonic kinematics.



Measure spin-correlation parameter (A_{LL}) with longitudinally polarized protons

$$P_{b1}P_{b2}A_{LL}=\frac{N_{++}-RN_{+-}}{N_{++}+RN_{+-}}$$

$P_{b1(2)}$ — *beam pol'n (~70%)*

$N_{++(+-)}$ — *equal (opposite) helicity yield*

R — *relative luminosity*

Interpret measured asymmetry within leading-order pQCD

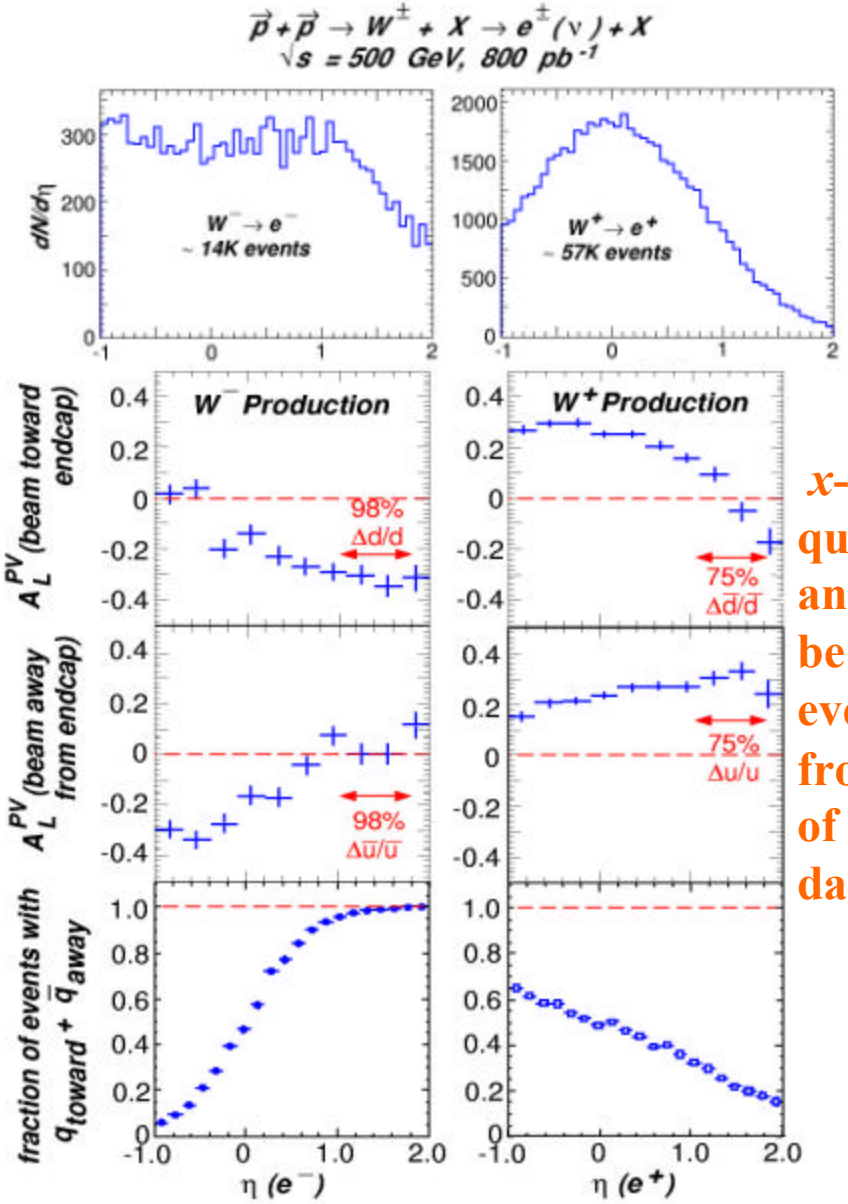
$$A_{LL}=\overbrace{P_{part.\,1}P_{part.\,2}}^{parton\ pol'ns.}\ \hat{a}_{LL}=\overbrace{\frac{\Delta f_1}{f_1}\frac{\Delta f_2}{f_2}}^{pol\ struct\ fncs.}\ \underbrace{\hat{a}_{LL}(\hat{s},\hat{t},\hat{u})}_{pQCD\ result\ for\ specific\ process}\xrightarrow[QCD\ Compton]{}\frac{\Delta G(x_g)}{G(x_g)}\,A_1^p(x_q)\,\hat{a}_{LL}$$

unpol struct fncs.

Measured in polarized deep-inelastic scattering

gluon polarization

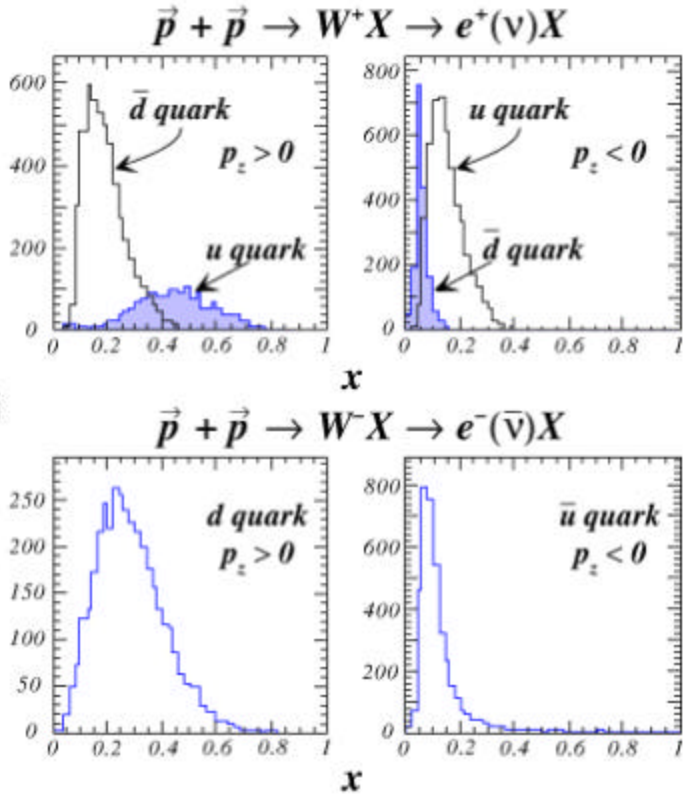
Simulations of Spin Effects for W Production



➢Different W^+ vs. W^- decay patterns Þ quite different h distributions for daughters

➢ Quark vs. antiquark polarization sensitivity are separated most cleanly for h > 1, especially for W^-

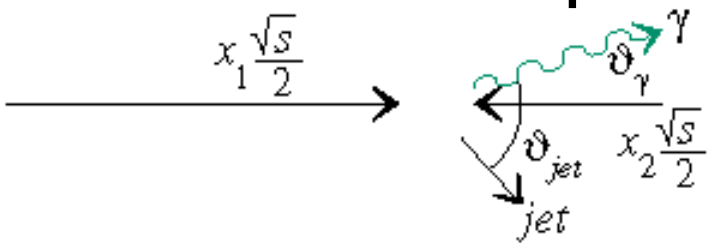
x-values of quark and antiquark can be determined event-by-event from h and p_T of detected daughter.



STAR spin

Why Consider Forward Spin Physics (A_{LL})?

• For large $x_F=x_1-x_2$, get kinematic selection of asymmetric partonic collisions.



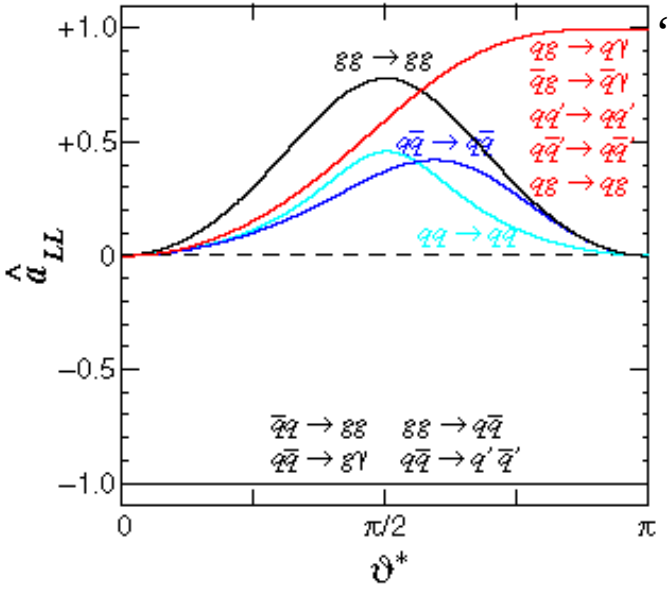
• Large x_F jet production primarily selects qg scattering from other subprocesses.

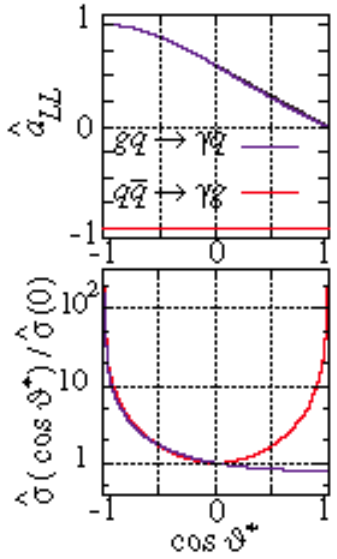
Assume collinear collisions and apply conservation of momentum $\Rightarrow$

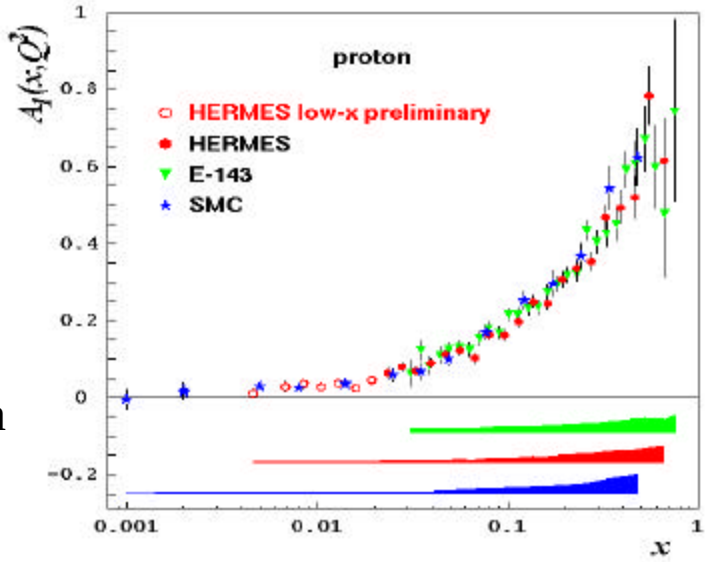
$$x_1 \sim \frac{x_T}{2}\left(e^{+\eta_\gamma}+e^{+\eta_{jet}}\right) \xrightarrow[\eta_\gamma > \eta_{jet}]{} \frac{x_T}{2}\, e^{+\eta_\gamma}$$

$$x_2 \sim \frac{x_T}{2}\left(e^{-\eta_\gamma}+e^{-\eta_{jet}}\right) \longrightarrow \frac{x_T}{2}\, e^{-\eta_{jet}}$$

• there are large spin effects in QCD hard scattering processes at 'forward' angles. Note: $qg \rightarrow \gamma q$ also has large σ as $\theta^* \rightarrow \pi$

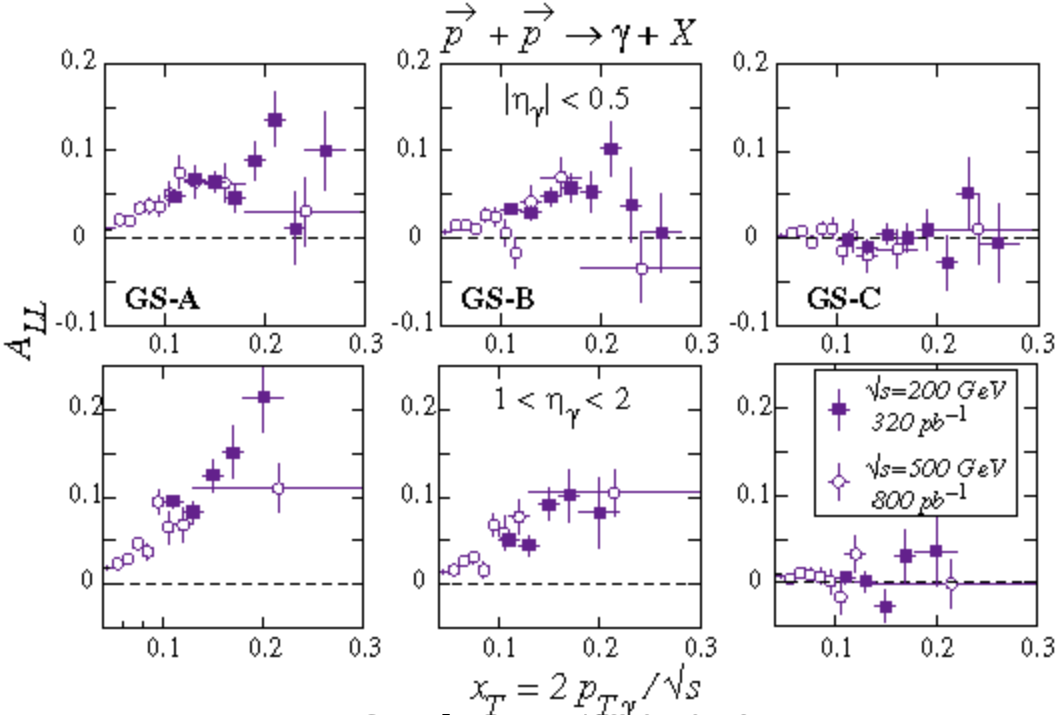


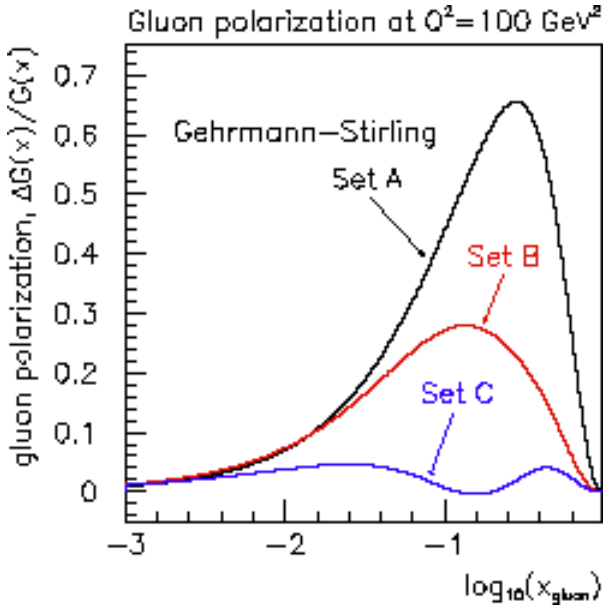




• charge-squared weighted quark polarizations (g_1/F_1) within the proton are large in the large-x valence region.

η dependence of A_{LL} for inclusive γ production





LCB, hep-ex/9907058

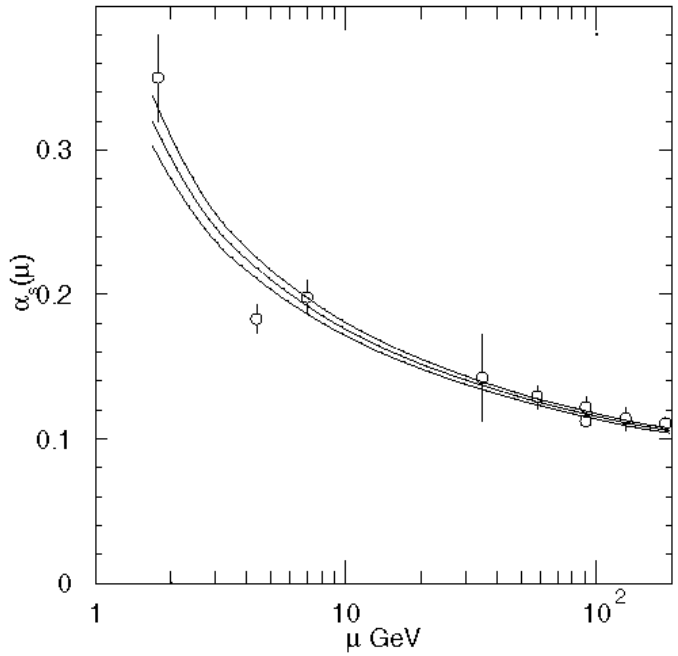
• larger spin effects at more forward angles. Expect at even more forward angles that the *sensitivity* (convolution $\hat{a}_{LL}$ Ä A_1^p) will increase. Since large η probes small x_{gluon}, gluon polarization may decrease because of sharp increase of unpolarized gluon density as $x_{\text{gluon}} \rightarrow 0$.

• expect the $(\pi^0+\eta^0)/\gamma$ ratio to be more favorable at forward angles than at midrapidity.

• expect sensitivity to gluon polarization for forward jet (as well as γ) production.

Possible Problems at Forward Angles

• Is it possible to access large enough p_T where NLO pQCD is applicable?

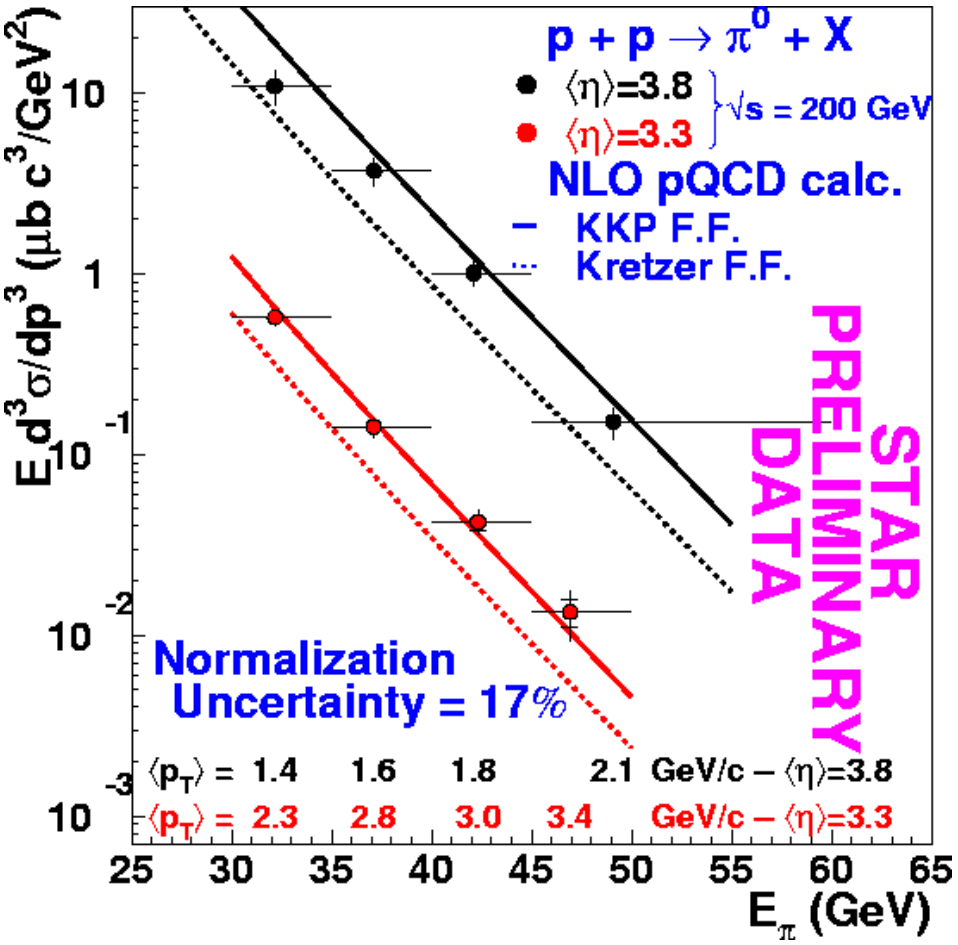


Although α_S does not vary much over accessible scales at RHIC, large η will primarily probe small p_T ⇒ need to understand scale dependence of fixed order calculations.

• Large x_F means high energy particles. Detection is best accomplished using electromagnetic + hadronic calorimetry + charge-sign determination from tracking through a magnetic field.

• For increasing p_T at large x_F, faced with increasingly steep falloff of $dN/d\eta$ distributions.

Forward Cross Sections vs. NLO pQCD

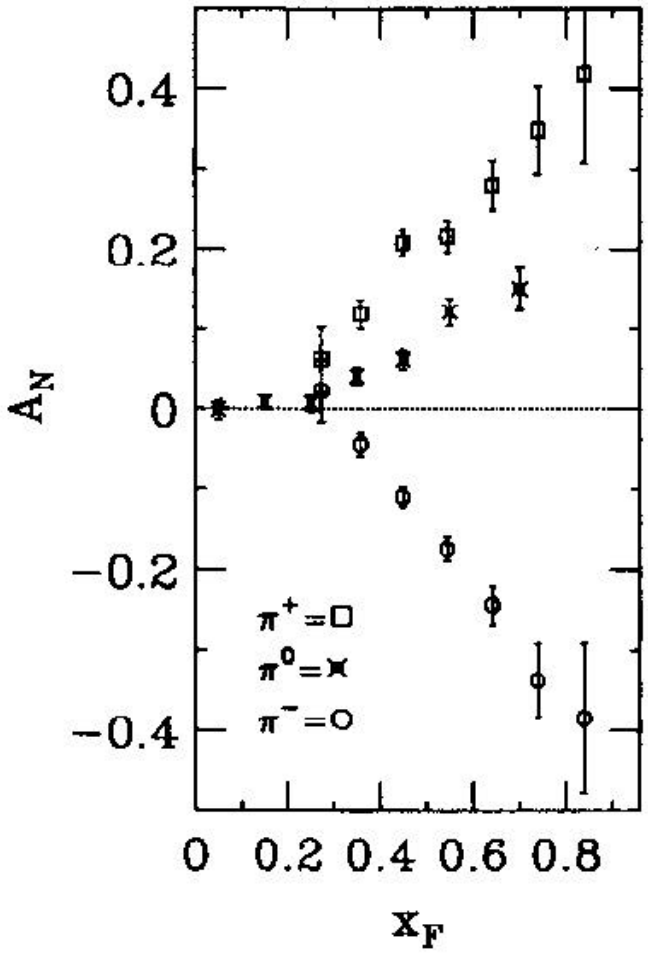


- Preliminary results for forward π^0 production cross sections measured at STAR are in fair agreement with NLO pQCD calculations that use factorization and renormalization scales equal to p_T of the π^0.
- Data compares much more favorably to NLO pQCD for forward π^0 production at RHIC than for fixed target ($\sqrt{s} \sim 20$ GeV) or ISR energies ($\sqrt{s} \sim 60$ GeV).

- G. Rakness (DIS03);
- S. Heppelmann (Transversity Workshop, Athens)
- Publication of results well underway

STAR spin

Forward Transverse Spin Physics



Non-zero values of A_N have been observed in FNAL E704…

$$p_\uparrow + p \rightarrow \pi + X$$

$$\sqrt{s} = 20 \text{ GeV}, \; 0.5 < p_T < 2.0 \text{ GeV/c}$$

Theoretical models that explain the E704 data also predict non-zero A_N for pion production at RHIC at $\sqrt{s} = 200$ GeV. There are multiple possible dynamical sources:

- Collins effect $\Rightarrow$ *transversity* $\otimes$ spin-dependent fragmentation
- Sivers effect $\Rightarrow$ spin- and $k_\perp$-dependent distribution function
- Higher-twist effect

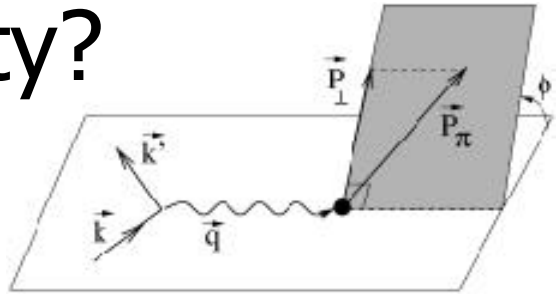
π^0 - D.L. Adams, et al. Phys. Lett. B261 (1991) 201.

$\pi^\pm$ - D.L. Adams, et al. Phys. Lett. B264 (1991) 462

Hints of Transversity?

Semi-inclusive DIS (27.5 GeV) : $e + p_{\uparrow} \rightarrow e + \pi^{\pm,0} + X$

$\Rightarrow$ transversity $\otimes$ *chiral-odd* fragmentation (Collins) function?



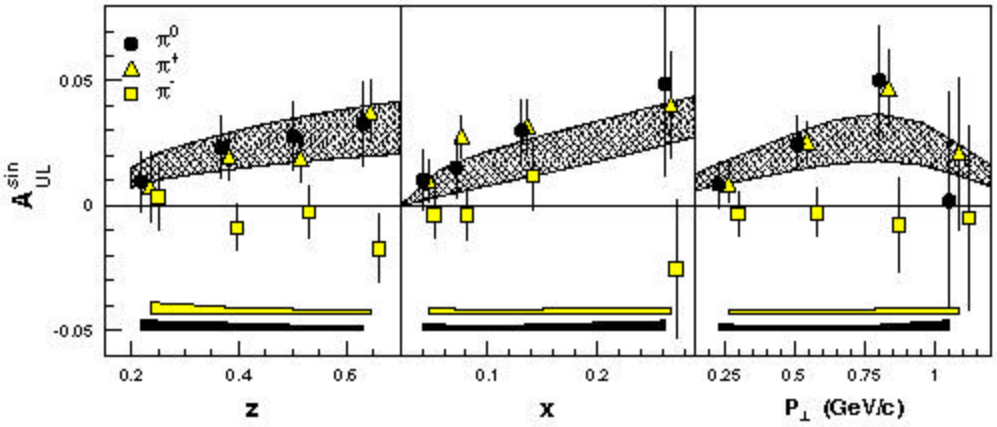
$$H_1^{\perp}(z,k_{\perp}) \propto \boldsymbol{P} \cdot \boldsymbol{q} \times \boldsymbol{k}$$

$\boldsymbol{P}$ polarization
$\boldsymbol{q}$ γ^* momentum
$\boldsymbol{k}$ π momentum

With (small) component of target polarization $\perp$ to γ^*, results in azimuthal (ϕ) asymmetries for produced pion.

$\Rightarrow$ Sivers effect?

$\Rightarrow$ Higher twist?



• Azimuthal asymmetries (A_{UL}) have recently been reported by the HERMES collaboration (PRL 84, (2000) 4047) for π^+ and π^0 production (asymmetries consistent with zero for π^-).

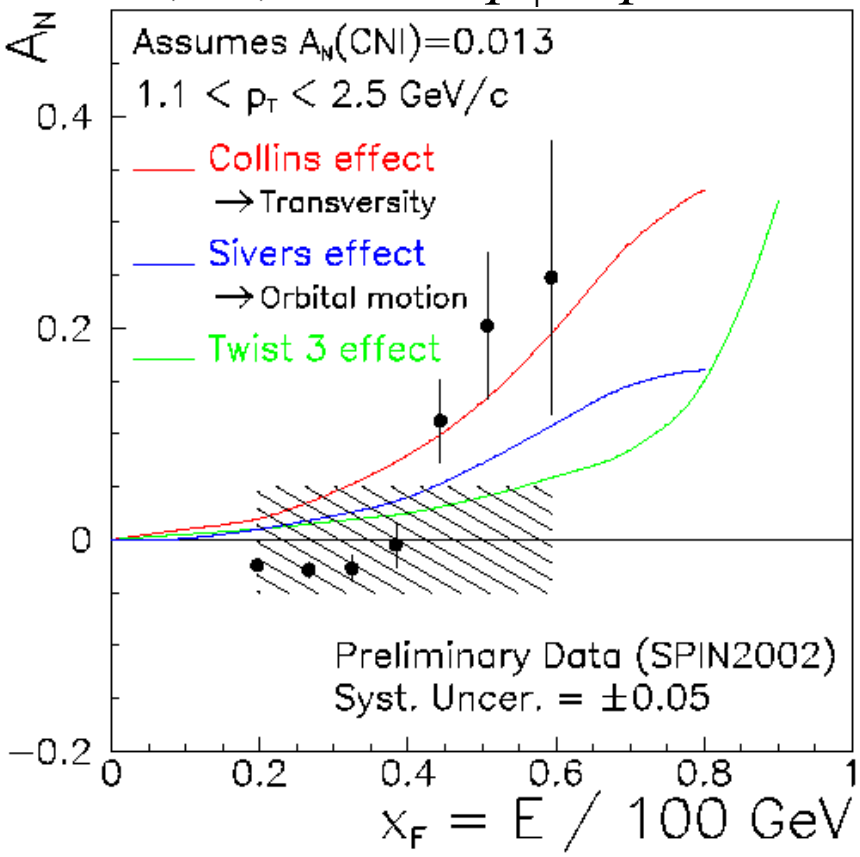
• This data has stimulated significant activity in the theoretical spin physics community (see review by Barone, Drago and Ratcliffe, Phys. Rep. **359** (2002) 1).

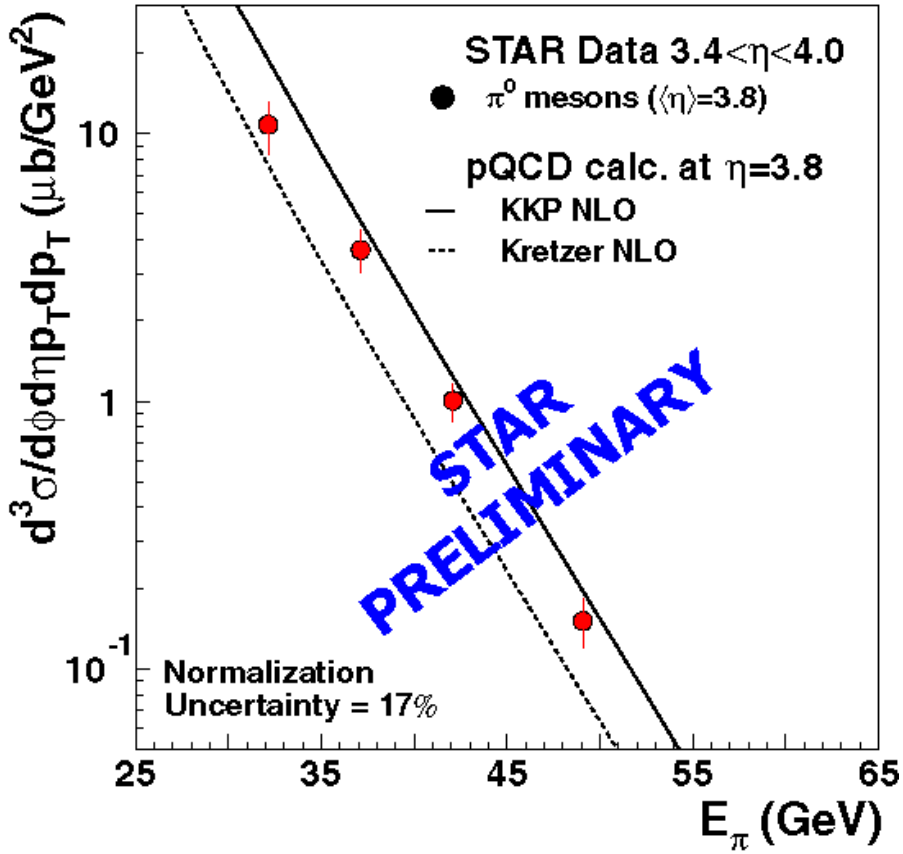
• More recently, asymmetries were also observed in low Q^2 polarized SIDIS at JLab (5.7 GeV).

• HERMES recently completed measurements with transverse target polarization providing sensitivity to separation of Sivers and Collins effects. Preliminary results suggest contributions from both mechanisms.

STAR-Spin Results from Run 2

$p_{\uparrow} + p \rightarrow \pi^0 + X$, $\sqrt{s} = 200$ GeV





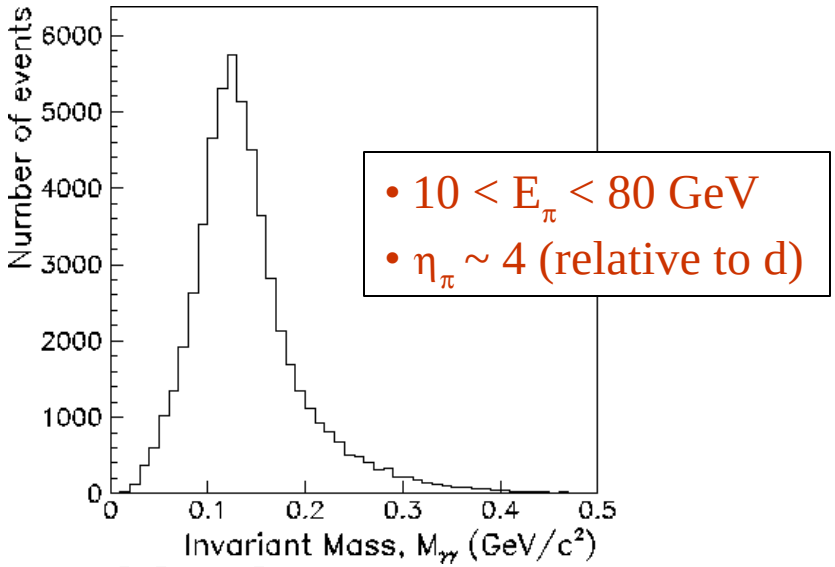
- Measured cross sections consistent with pQCD calculations
- Large spin effects observed for $\sqrt{s} = 200$ GeV pp collisions

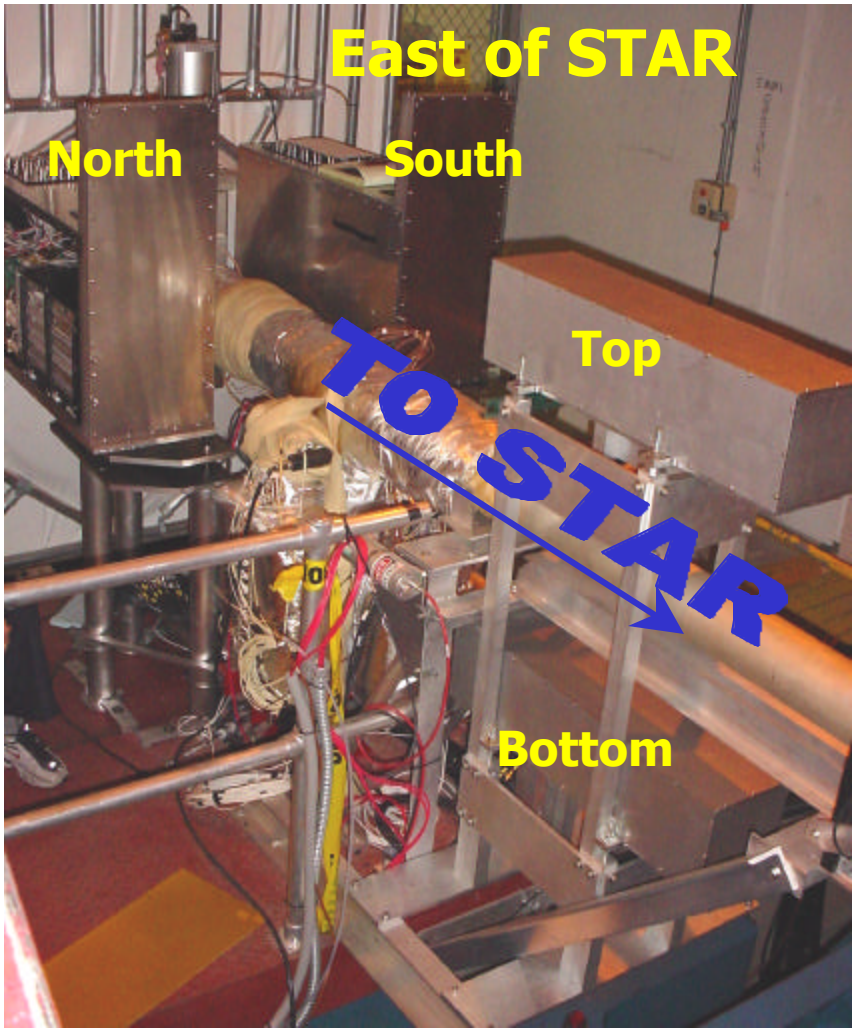
Status: final analysis complete / paper in collaboration review

STAR Forward Pion Detector

(Construction for Run 3)

$d+Au \rightarrow \pi^0+X$, $\sqrt{s_{NN}} = 200$ GeV





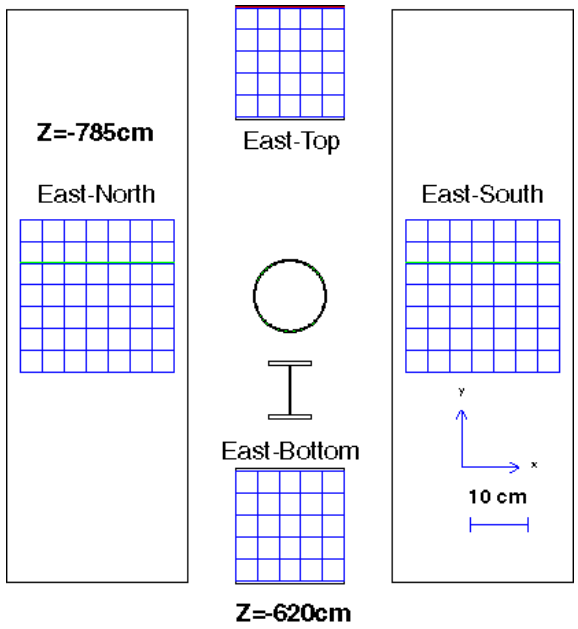
Run 3 Objectives:

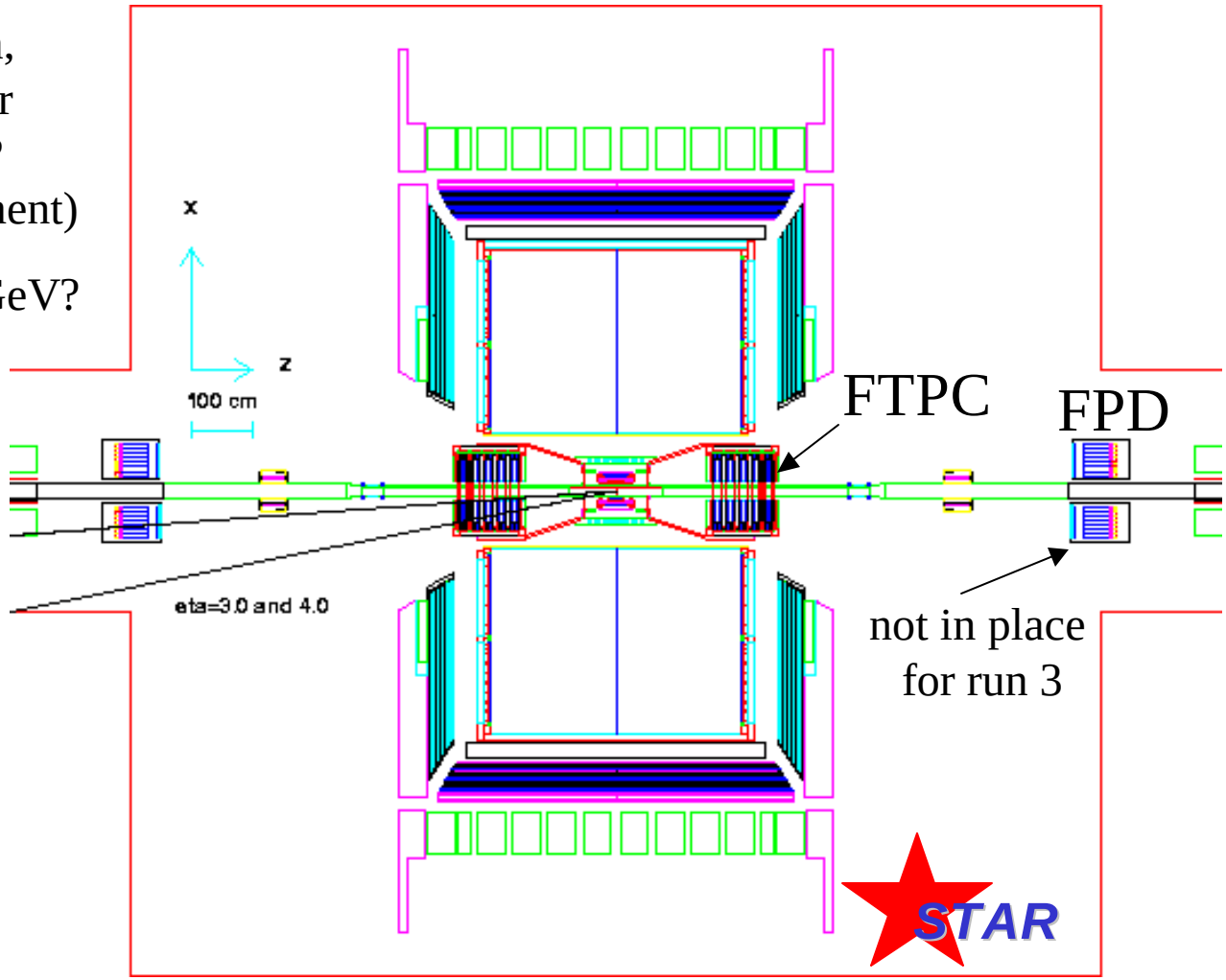
- probe of Color Glass Condensate in d+Au
  - $\Rightarrow$ p_T dependence of large η yield
- improve understanding of dynamical origin of A_N in $p_\uparrow+p \rightarrow \pi^0+X \Rightarrow$
  - ➢ Collins effect $\rightarrow$ sensitivity to transversity
  - ➢ Sivers effect $\rightarrow$ sensitivity to orbital motion
  - ➢ twist-3 effect $\rightarrow$ quark/gluon correlations
- serve as local polarimeter at STAR IR

BNL, Penn State, IHEP-Protvino,
UC Berkeley/SSL, UCLA, ANL

Towards Disentangling the Dynamics…

- Partial reconstruction of the forward jet may be possible for run-3 data by exploiting the overlap of the STAR Forward π^0 Detector (FPD) and Forward Time Projection Chamber (FTPC). Full reconstruction of forward jet will likely require the addition of hadronic calorimetry to supplement FPD. $\Rightarrow$ Do jets have large A_N? Is the large A_N correlated with the Collins angle (azimuthal angle between π^0 and jet thrust axis?)
- Are large, and opposite sign, analyzing powers observed for large x_F π^+ and π^- production? (Natural BRAHMS measurement)
- What happens at $\sqrt{s}$ = 500 GeV?





Summary

- Large rapidity γ,jet detection may provide interesting corners of phase space to probe for gluon polarization (A_{LL} measurements).
- Large rapidity π^0 production cross sections in fair agreement with NLO pQCD at $\sqrt{s}$ = 200 GeV.
- Large analyzing powers observed for large-rapidity π^0 production for $p_{\uparrow}p$ collisions at RHIC ($\sqrt{s}$ = 200 GeV) may probe transversity (Collins effect) or orbital motion of partons (Sivers effect). Further measurements are needed…
    - o analyzing power for π^+ and π^- production
    - o measurements of p_T dependence at fixed x_F
    - o analyzing power for forward jet production