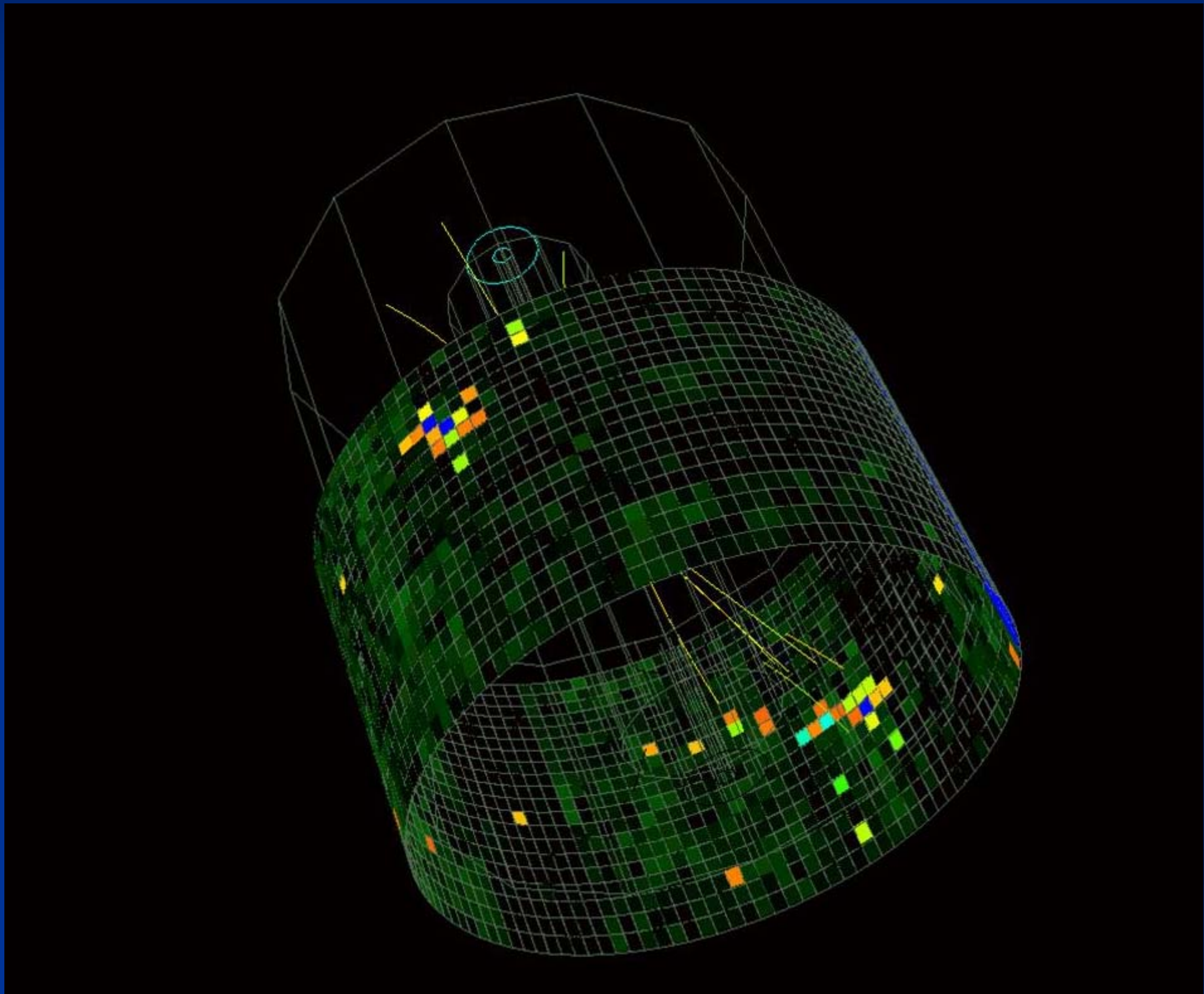
Constraining the Sivers Functions using Transverse Spin Asymmetries at STAR



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for the

STAR

Collaboration

XII International Workshop on Deep Inelastic Scattering , Strbske Pleso, High Tatras, Slovakia , April 16th 2004

Outline

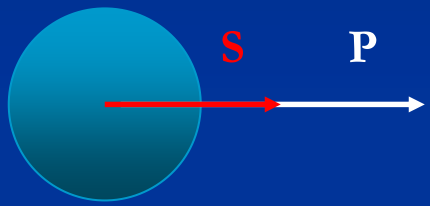
- Why Transverse Spin?
- Definition of Sivers Functions
- Access to Sivers Functions at STAR
- Spin Physics at RHIC in the STAR detector
- Forward π^0 Analysis
- Mid-Rapidity Leading Charged Particle Analysis
- Accessing Sivers Functions with Dijets
- Update on Dijet analysis
- Conclusions and Plans for Future Work

Why Transverse Spin?

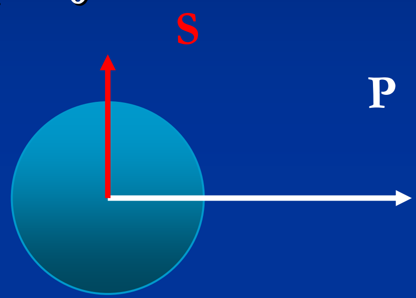
Let S and P be the spin and momentum of 2 colliding proton beams

SIDE VIEW

If $S \cdot P = \pm 1$

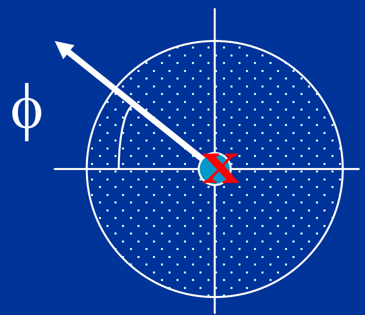


If $S \cdot P = 0$

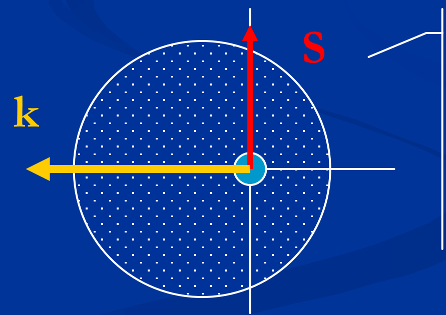


BEAM VIEW

No Azimuthal Asymmetry



Observables $\propto \cos(\phi)$



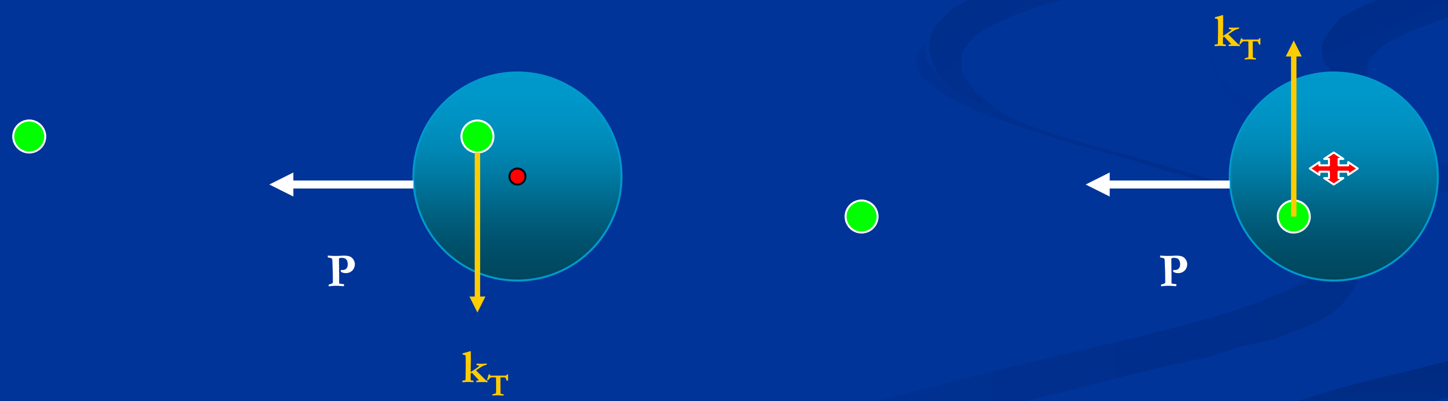
Information on asymmetries in $k = S \times P$ direction

Partonic $k_T \perp$ to $S \times P$ can give Left/Right Asymmetries

Sivers Functions

Flavor dependent correlation between the proton spin (S_p), momentum (P_p) and transverse momentum (k_T) of the unpolarized partons inside. The unpolarized parton distribution function $f_q(x,k^\perp)$ is modified to:

$$f_q(x,k^\perp,s_P) = f_q(x,k^\perp) + \frac{1}{2}\Delta_q^N f_q(x,k^\perp)\frac{S_P \cdot (P_p \times k^\perp)}{|S_P||P_P||k^\perp|}$$



Where Δ_q^N is the Sivers Function – produces "side preferences"

Sivers correlation is a time-reversal odd triple product and therefore previously thought to vanish identically. Recent theoretical results show this to be untrue!

- Boer, P.J. Mulders, F. Pijlman, Nucl.Phys.B 667 (2003) 201
- S.J. Brodsky, D.S. Hwang and I. Schmidt, Phys. Lett. B 530 (2002) 99.
- A.V. Belitsky, X. Ji and F. Yuan, Nucl. Phys. B 656 (2003) 165
- J.C. Collins, Phys. Lett. B 536 (2002) 43

Access to Sivers Functions in STAR

- High-rapidity π^0 Production

  $p\uparrow p \rightarrow \pi^0 + X$

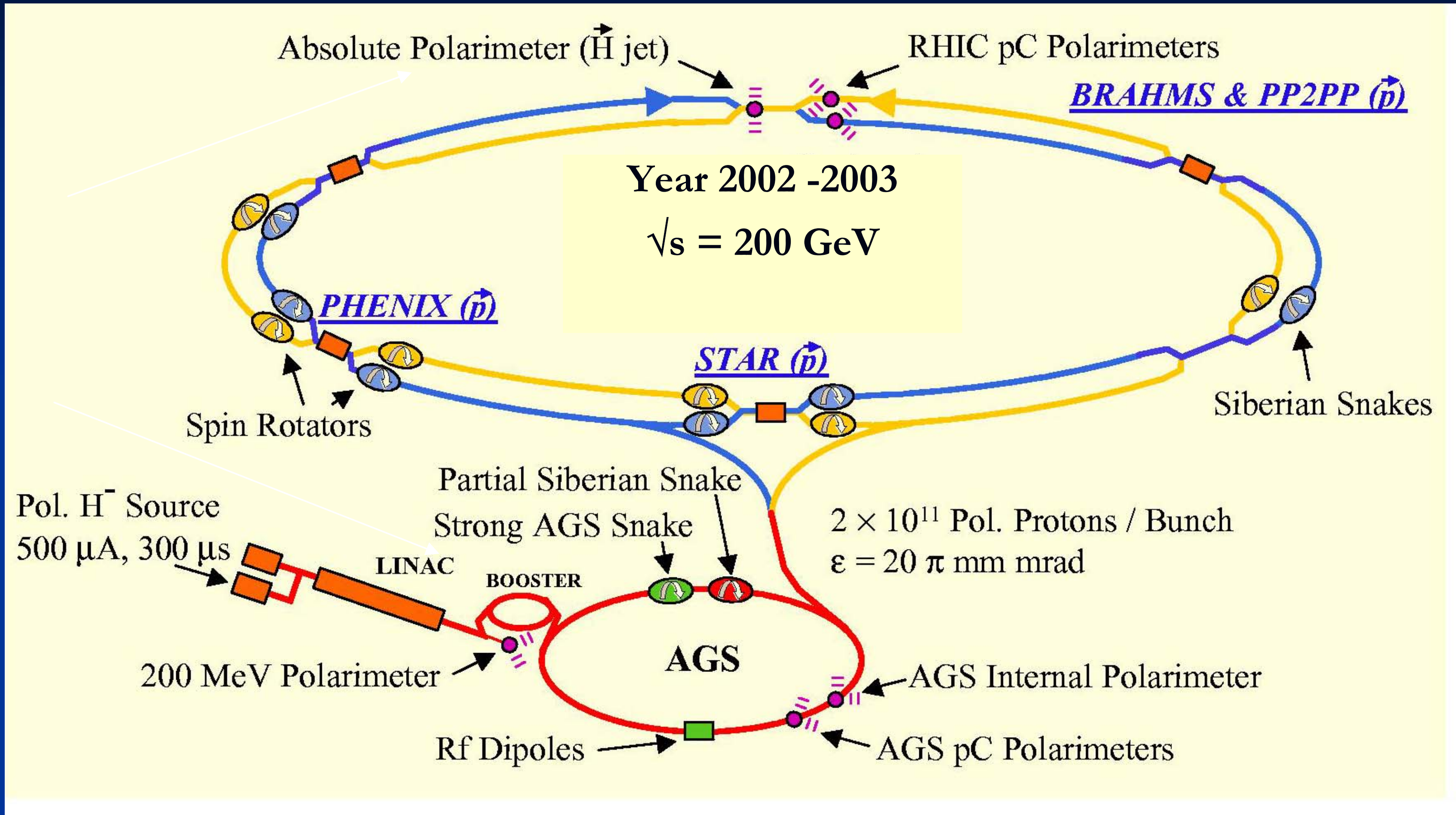
- Mid-rapidity Leading Charged Particle Analysis

  $p\uparrow p \rightarrow h^{+/-} + X$

- $\Delta\phi$ Di-jet production

  $p\uparrow p \rightarrow jet + jet + X$

Polarized Proton Operation at RHIC



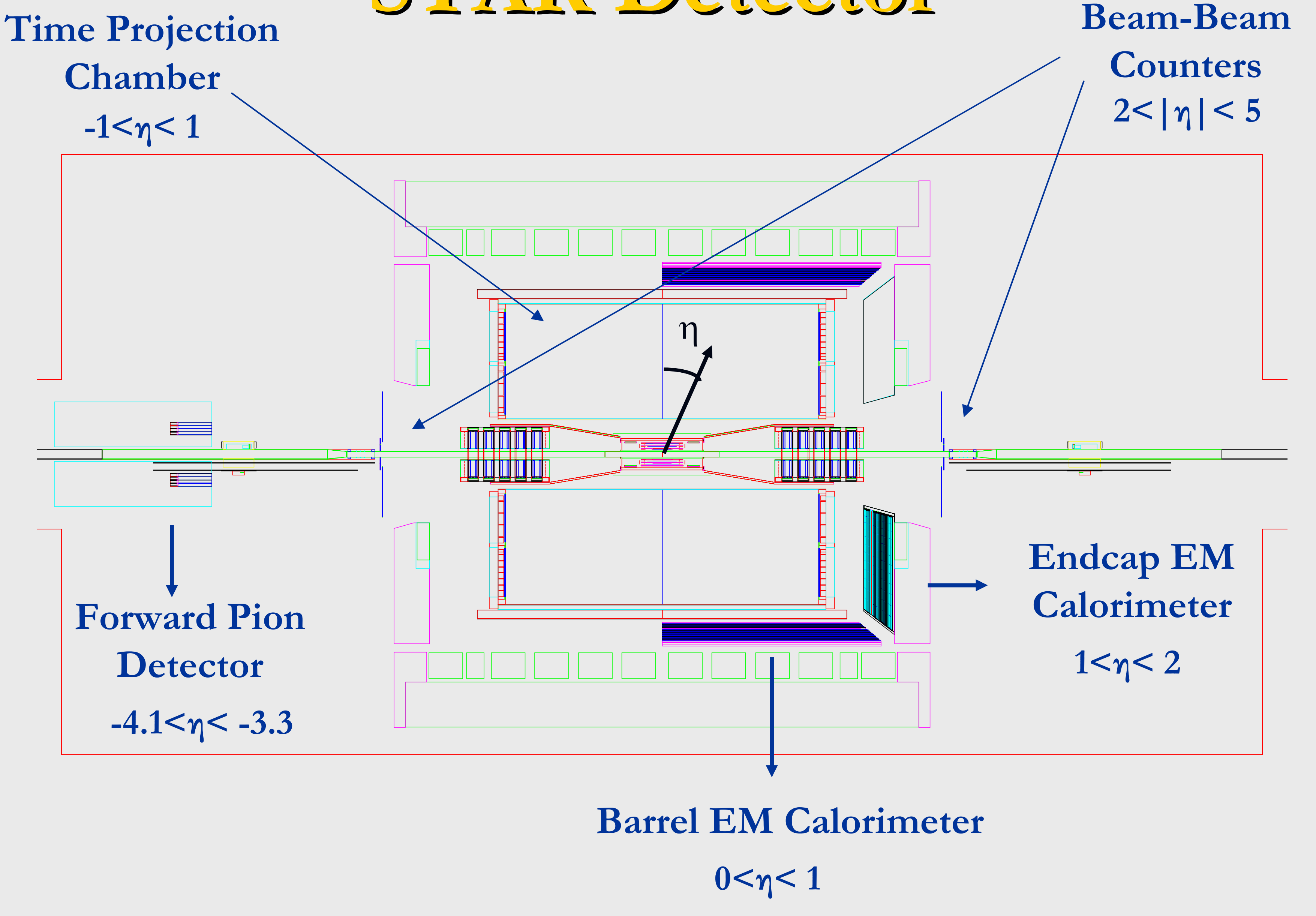
YEAR 2002

- Luminosity = $5x10^{29}$ $s^{-1}cm^{-2}$
- Integrated Luminosity = 0.3 pb^{-1}
- Polarization = 0.2

YEAR 2003

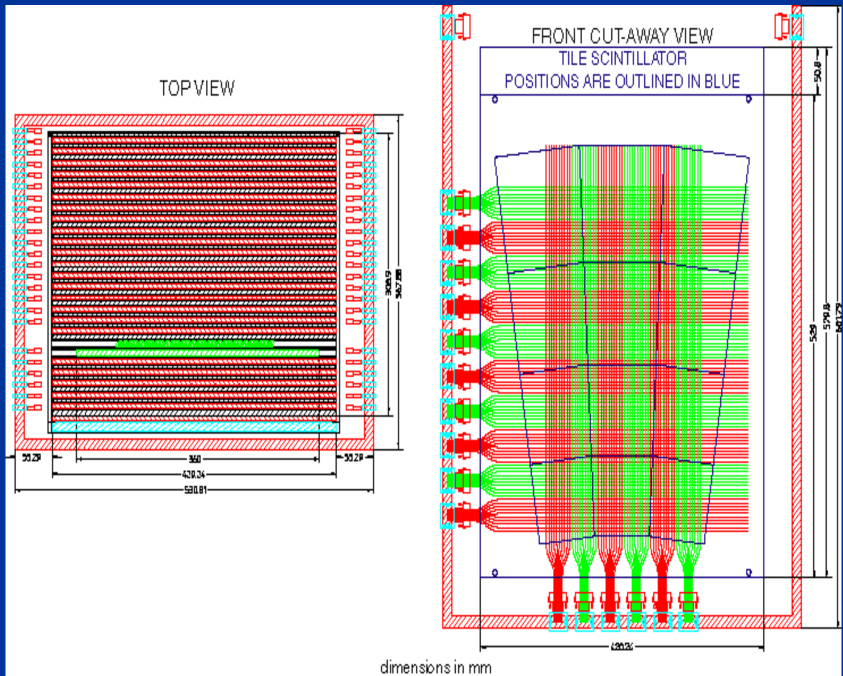
- Luminosity = $2x10^{30}$ $s^{-1}cm^{-2}$
- Integrated Luminosity = 0.5/0.4 pb^{-1} T/L
- Polarization = 0.3

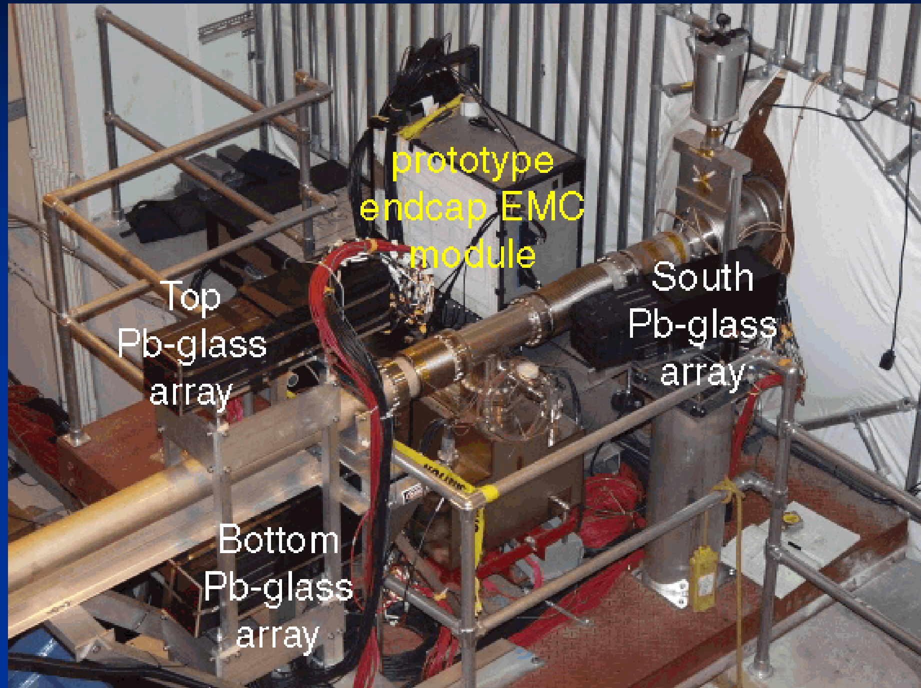
STAR Detector



Prototype Forward Pion Detector

- 24 layer Pb-Scintillator Sampling Calorimeter
- 12 towers
- Shower-Maximum Detector - 2 orthogonal layers of 100 x 60 strips
- 2 Preshower Layers





Top-Bottom-South Detectors

- 4x4 array of Lead-Glass
- No Shower Max
- Used for systematic error studies

TRIGGER $E_{DEP} > 15$ GeV

Single Spin π^0 Asymmetry

$$A_N = \frac{1}{Pol} \times \frac{Y_{\pi^0}^{\uparrow} - Y_{\pi^0}^{\downarrow}}{Y_{\pi^0}^{\uparrow} + Y_{\pi^0}^{\downarrow}}$$

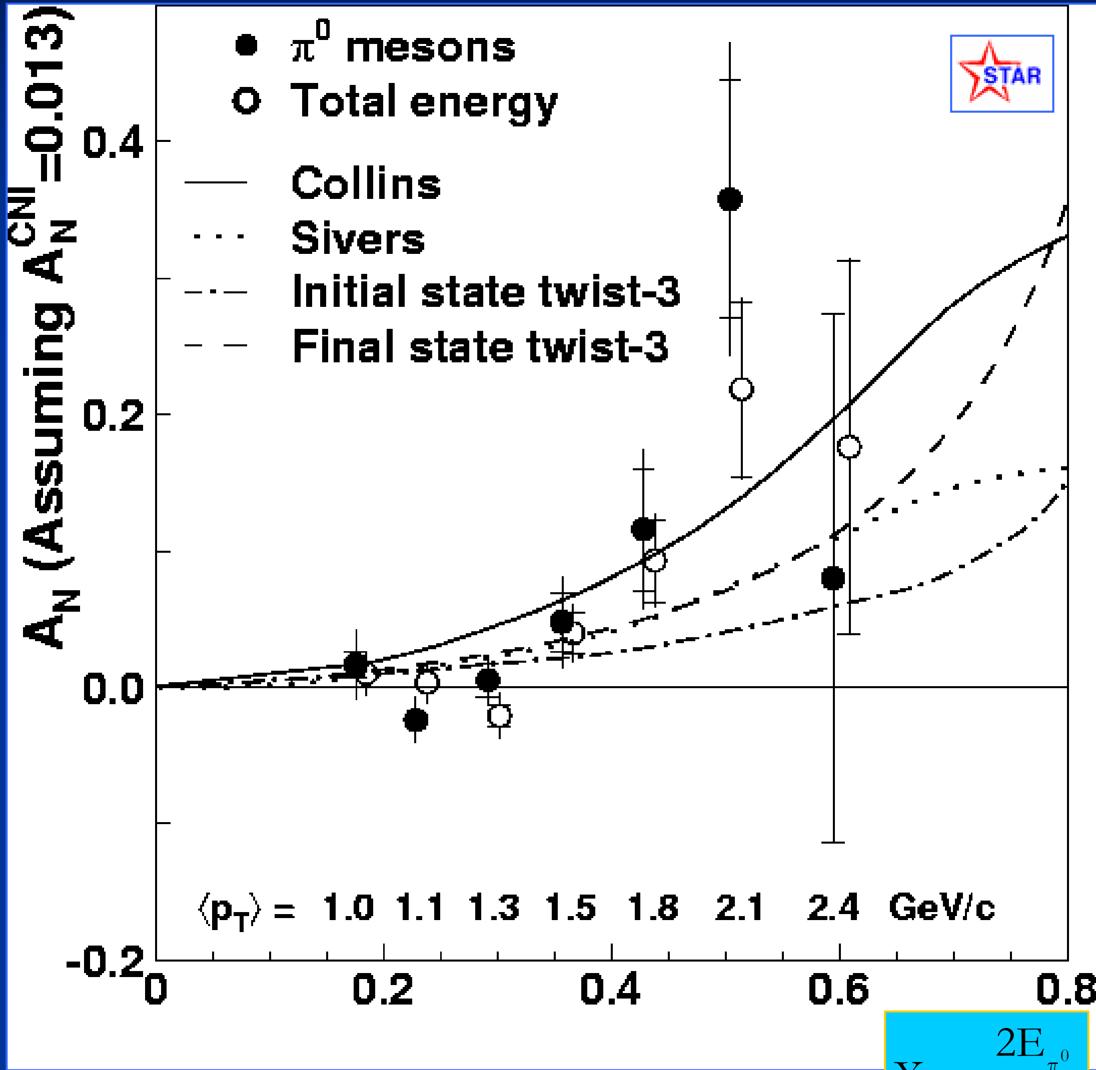
For $<\eta> = 3.7$ possible contributions to A_N are:

Sivers Effect – Spin dependent initial partonic transverse momentum

Collins Effect – Spin dependent transverse momentum kick in fragmentation

Sterman and Qiu – Initial State twist 3

Koike – Final State twist 3

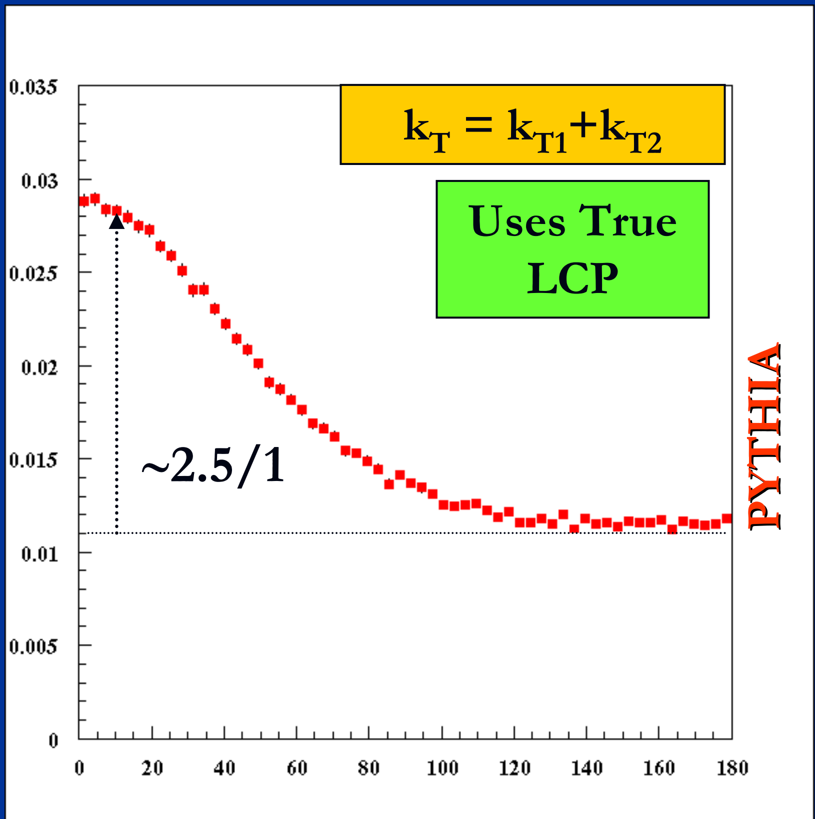


$$X_F = \frac{2E_{\pi^0}}{\sqrt{s}}$$

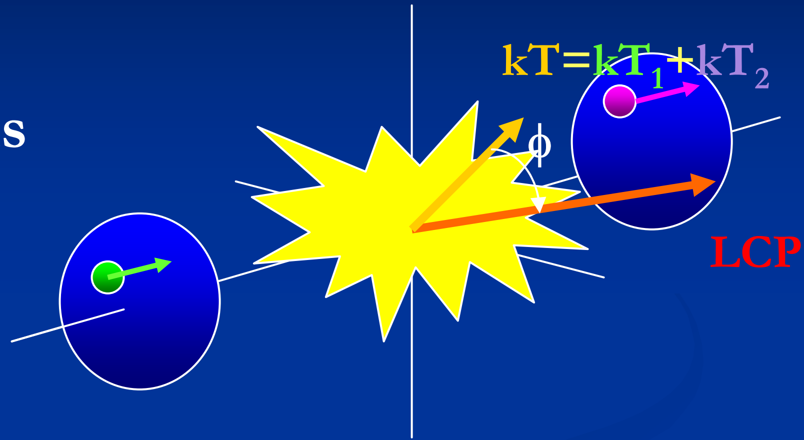
hep-ex/0310058

Sivers at Mid-rapidity?

Need an observable which is correlated with Partonic k_T. The Leading Charged Particle (LCP) is a high statistics candidate!



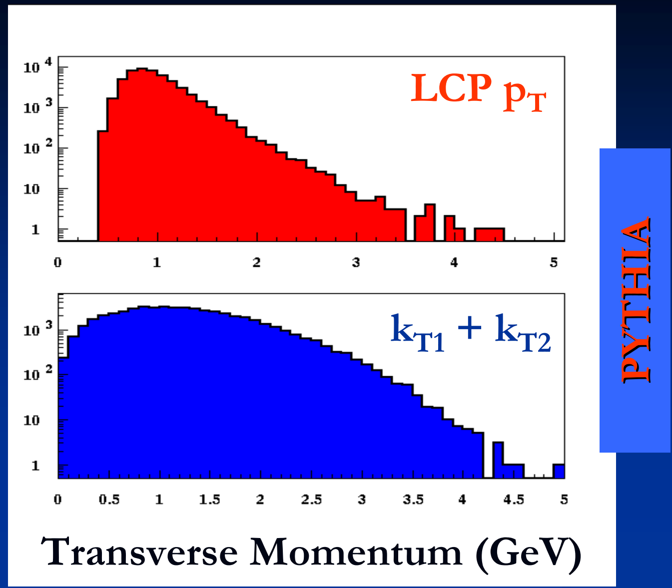
ϕ (degrees)

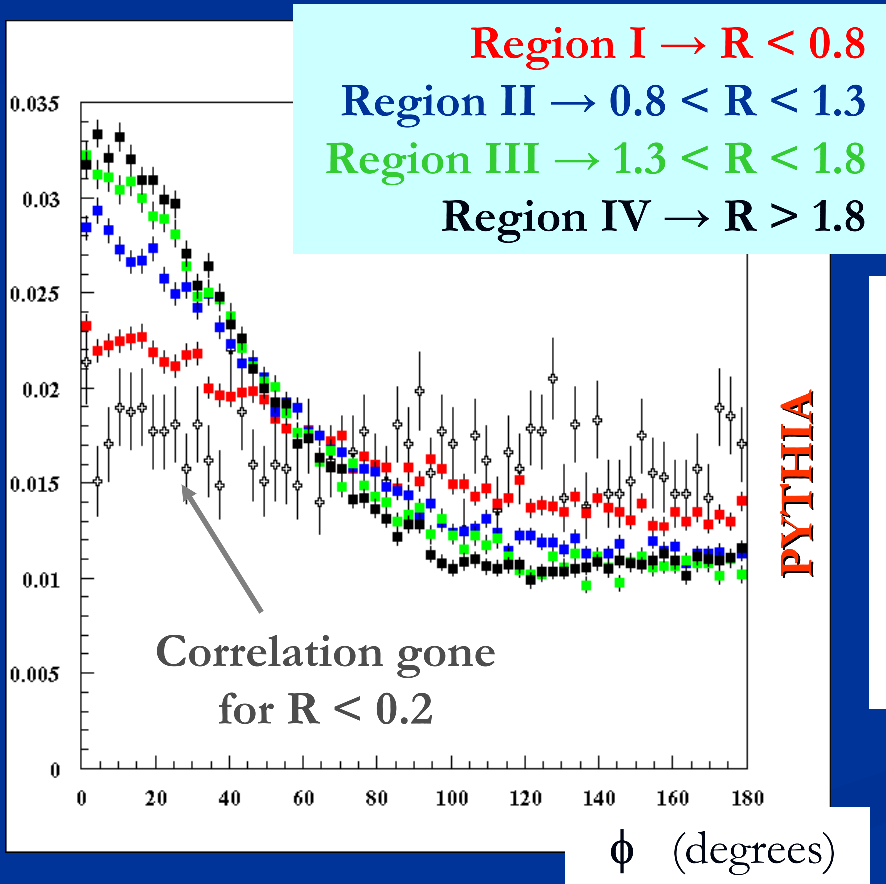


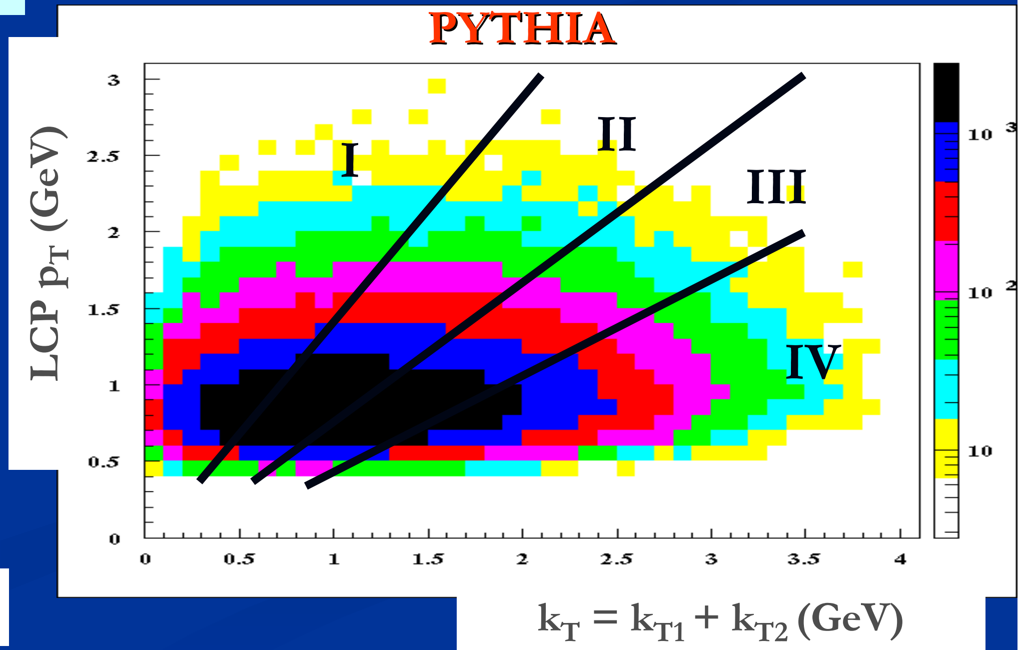
- Use PYTHIA 6.2 to simulate pp collisions for $\sqrt{s}$ = 200 GeV
- Identify true LCP in event with $0.4 < p_T < 5$ GeV
- Calculate vector sum of Initial Partonic k_T
- Calculate opening angle, ϕ, between LCP and k_T directions

Correlation is Kinematic Effect dependent on

$$R = \frac{k_{T_1} + k_{T_2}}{LCPp_T}$$



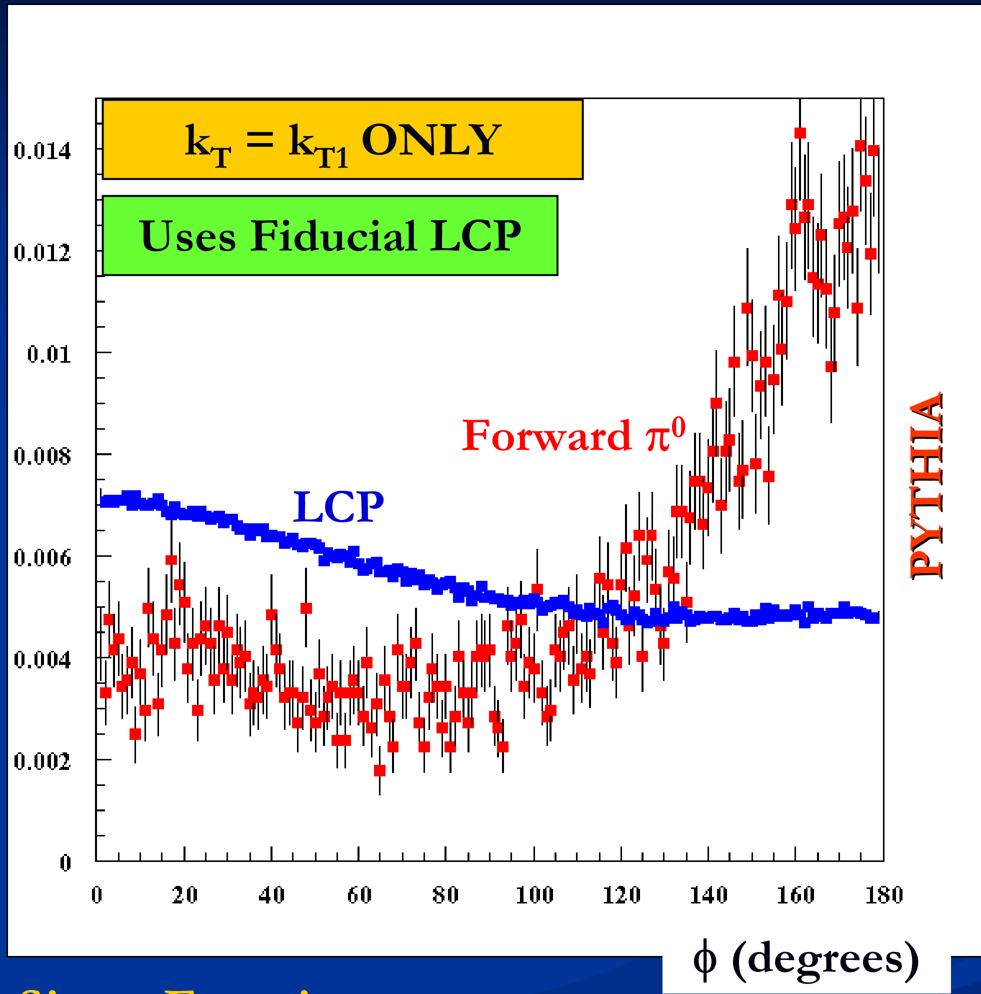




Compare Forward π^o correlation with Mid-rapidity LCP

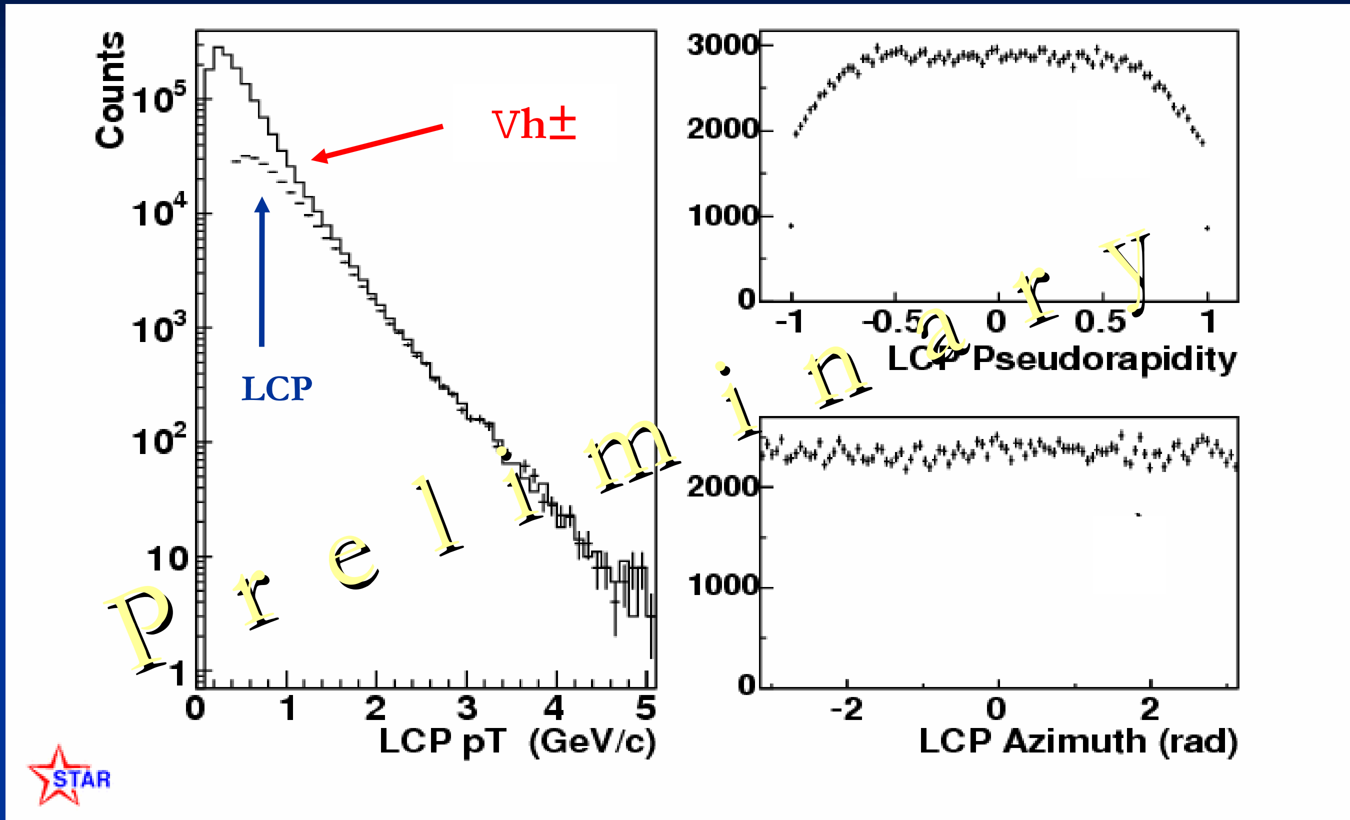
- Track partonic $k_T = k_{T1}$
- Find LCP in $|\eta| < 1$

  $0.4 < p_T < 5$ GeV
- Find leading π^0 with E > 20 Gev and $3.3 < \eta < 4.1$
- Calculate opening angle, ϕ, between k_T and π^0 p_T (LCP p_T)
- Forward π^0 correlation ~ 4/1
- LCP correlation ~ 1.4/1
- LCP correlation reduced 2x from ideal case



- Forward region → Valence Quark Sivers Functions
- Mid-rapidity → Gluon Sivers Functions
- π^0 has stronger Correlation with Initial k_T then LCP
- LCP less sensitive than π^0 to Collins Effect, both sensitive to higher twist effects

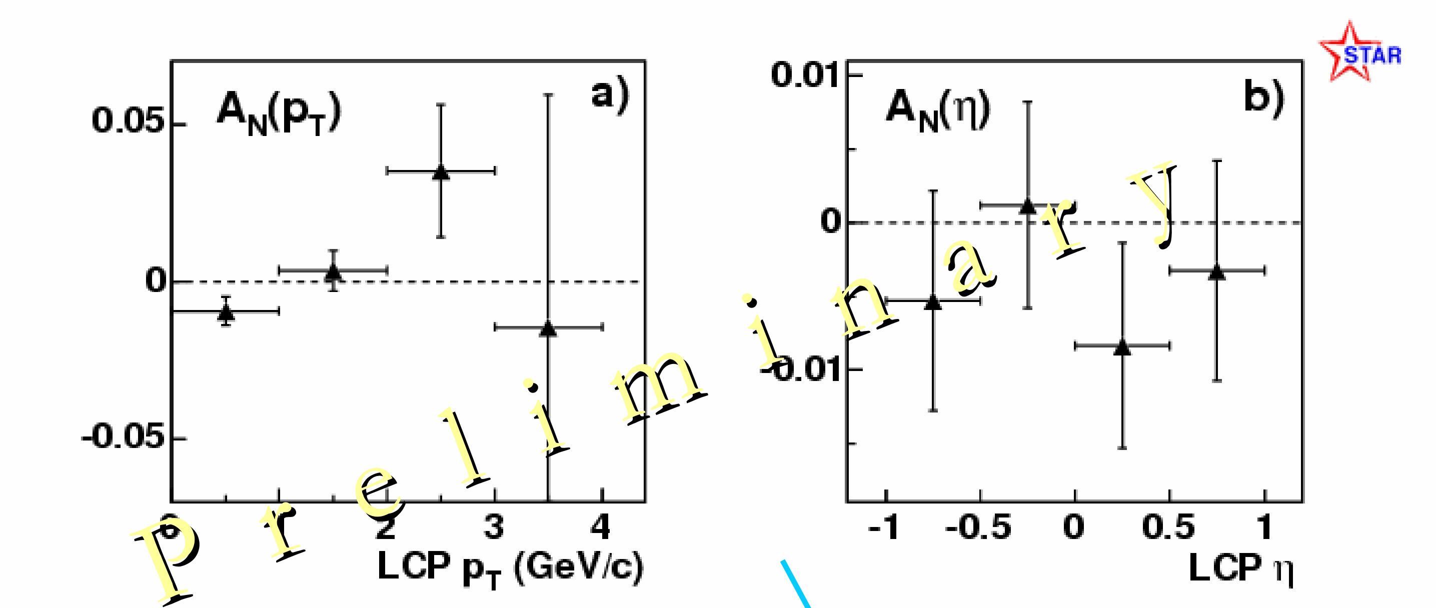
Mid-rapidity Leading Charged Particle Analysis



§ 1.5 Million Minbias Triggers

- Use TPC to identify charged hadron with largest p_T
- 0.4 < p_T < 5 GeV, | ª |< 1.0, $\sqrt{s}$ = 200 GeV
- LCP p_T agrees with inclusive charged particle p_T spectrum at p_T > 1.5 Gev

Single Spin LCP Asymmetry



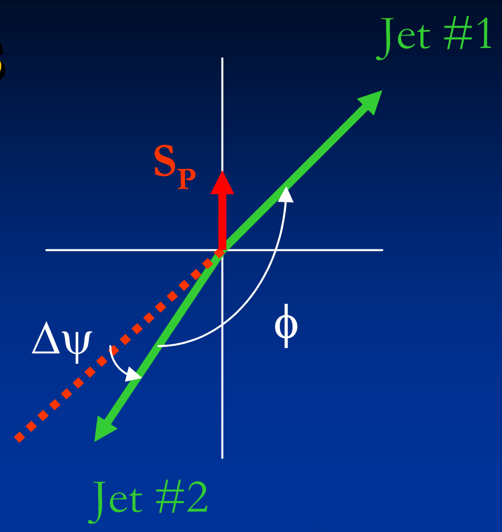
- Averaged A_N for both beams
- Yellow/Blue Beam Pol = ~ 0.2
- Error bars statistical + CNI

A_N Consistent with 0

A_N for charge separated LCP also consistent with 0

Sivers Effect in Dijets

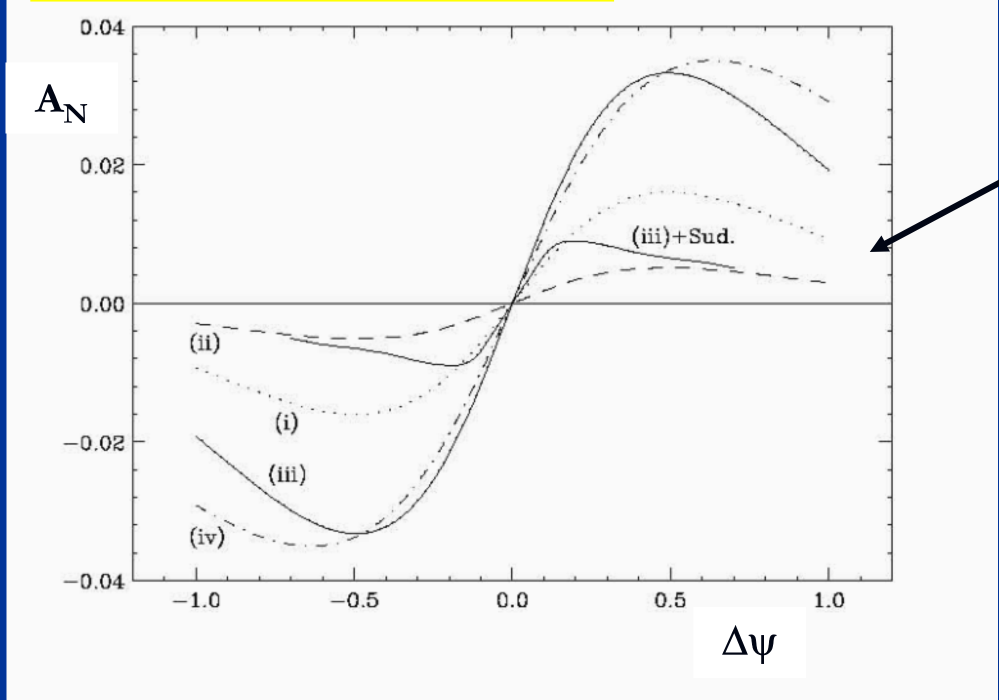
Deviations from $\phi = \pi$ due to Partonic k_T



$$A_N = \frac{1}{Pol} \frac{Y^{\uparrow}_{Dijet} - Y^{\downarrow}_{Dijet}}{Y^{\uparrow}_{Dijet} + Y^{\downarrow}_{Dijet}}$$

$8 < p_{T1,2} < 12$ GeV

| ª $_{1,2}$ | < 1



Theoretical Results by W.Vogelsang and D.Boer, hep-ph/0312320

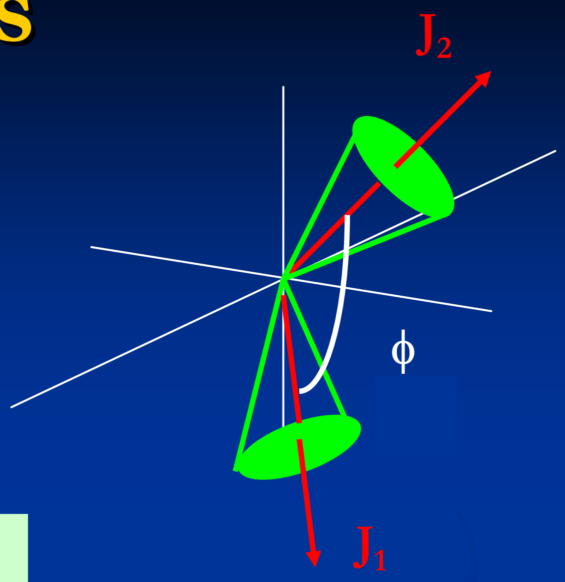
Very Sensitive to Gluon Sivers !

- Gluon = U + D / 2
- Gluon = 0
- Gluon = D
- Gluon = D + ô k_T^2 = 2.5

Dominated by Leading Twist!

Maximal Effects at $\Delta\psi$ = 0.4-0.5
This region experimentally available!

Dijet Analysis



Jet Finder

- Use Cone Jet Finder R = 0.7
- Charged Energy from TPC
- Neutral Energy from BEMC
- Use HT trigger Data

Trigger Jet

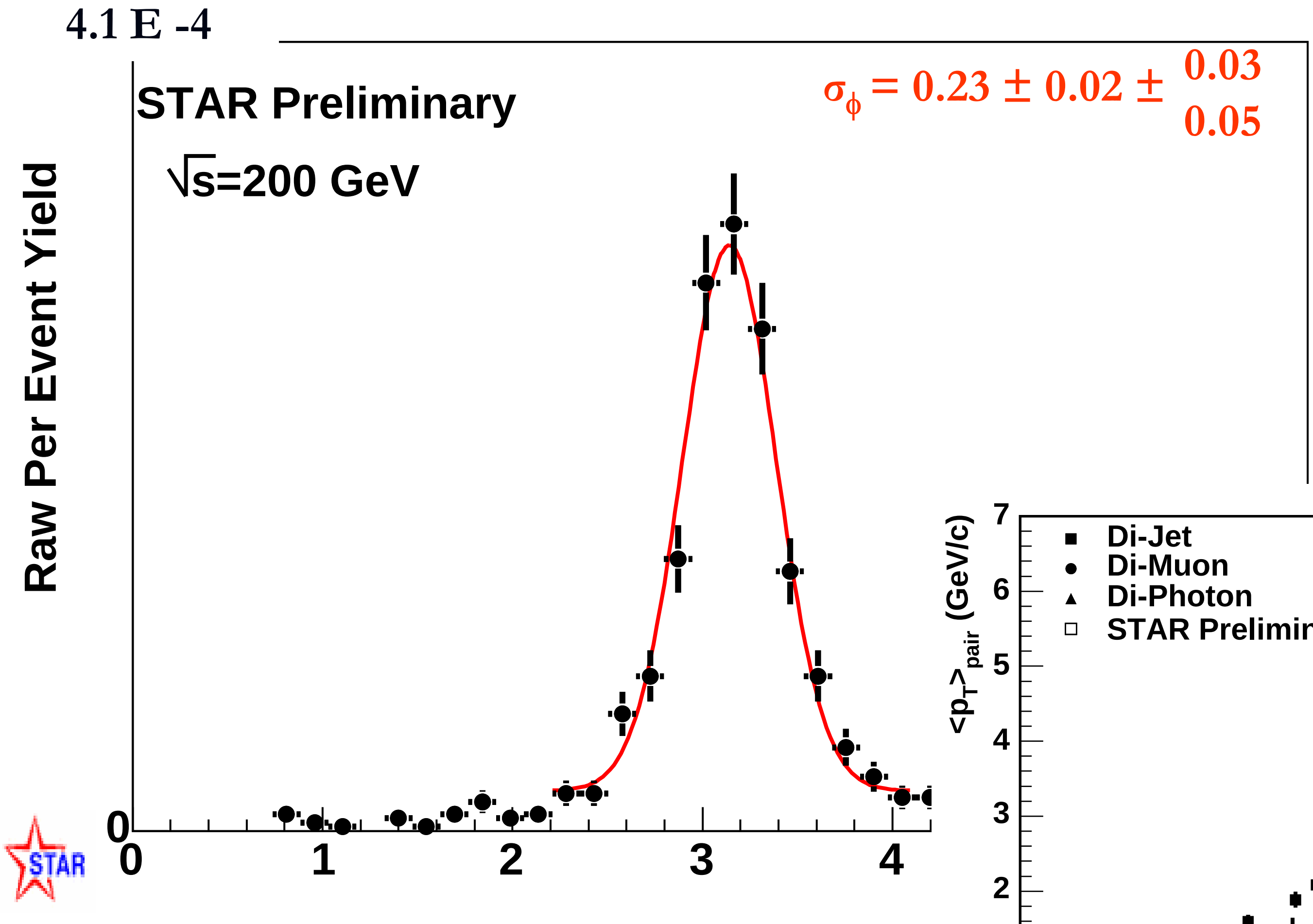
- Reconstructed from EMC and TPC
- Includes high tower trigger
- Defines energy scale and first thrust axis
- $0.2 < \eta < 0.65$ and $4.2 < \phi_{J1} < 6$
- Et > 7 GeV

Away Side Jet

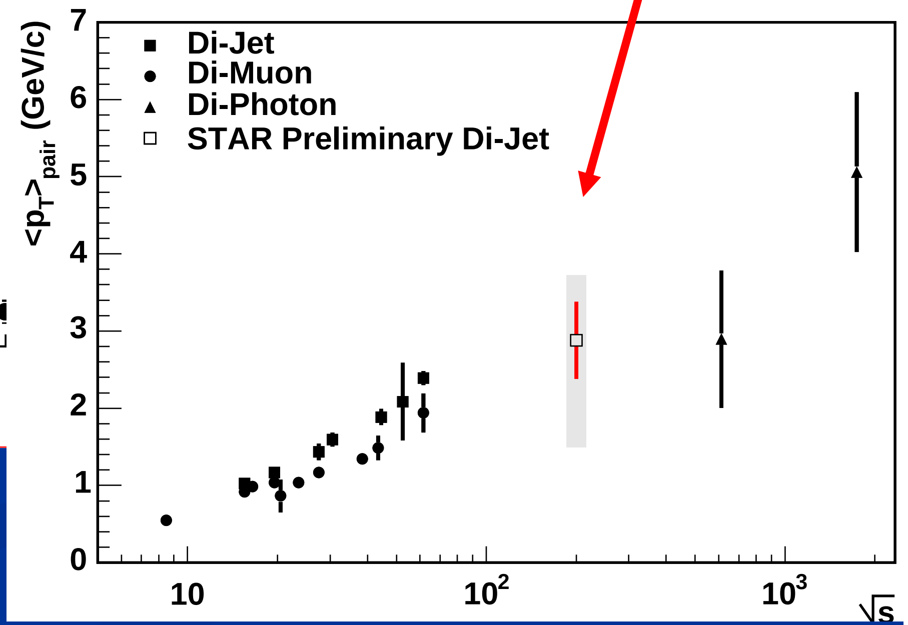
- Charged particles only
- Determines second thrust axis
- $-0.5 < \eta < 0.5$

Requires Full Jet Reconstruction. Dihadron Analysis not sufficient!

Partonic kT from Dijet Analysis



STAR agrees well with World Data on Partonic k_T



$kT = \sqrt{<kT>^2} = E_T \sin(\sigma_\phi)$

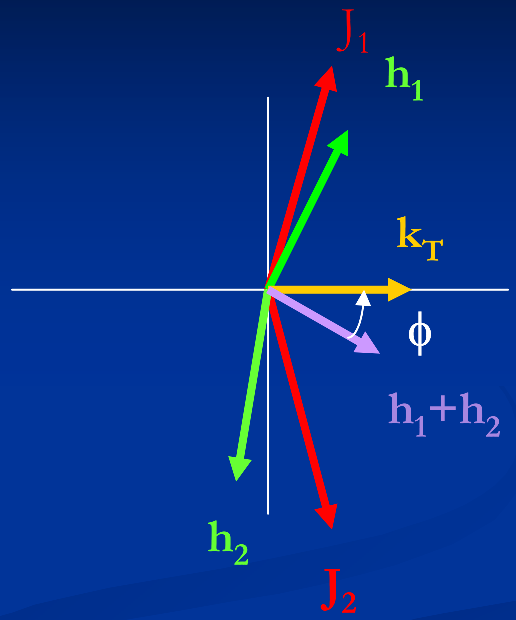
$E_T = 13.0 \pm 0.7_{sys} \rightarrow$ Trigger Jet

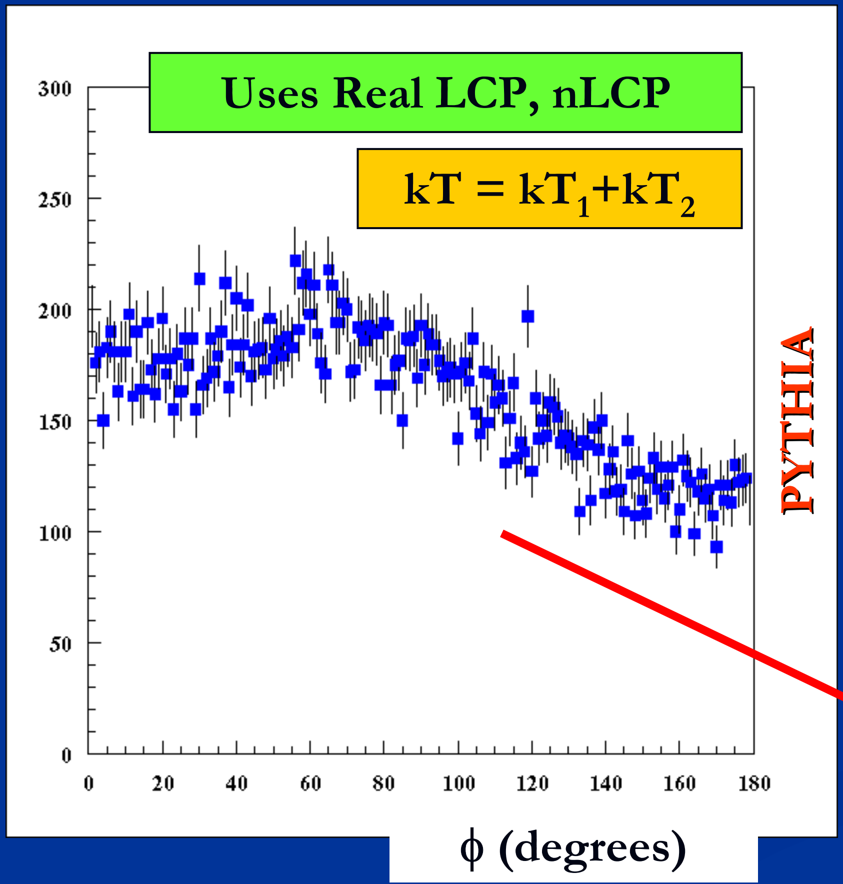
Conclusions and Future Plans

- Transverse Spin Collisions provide insight into partonic transverse momentum
- Need to find observables which isolate Collins, Sivers and Twist 3 mechanisms
- LCP, Dijets and Forward π^0 all sensitive to Sivers effects
- Next step in Dijet analysis is spin sorting
- Plans to extend LCP analysis to include Y2003 minbias events
- Need more polarized proton running to get meaningful results from LCP and Dijet analysis !

Dihadron Asymmetries

Higher statistics and simpler analysis make Di-hadrons cheaper. But is the correlation with kT strong enough?





Use PYTHIA 6.2 to simulate pp collisions. Find LCP and next to LCP (nLCP). Require $0.4 < p_T < 5$ GeV. If they are separated by $180 +/- 60^0$ then find opening angle, ϕ, between their bisector and 1 of the initial parton kT directions.

- Correlation 1.3/1 - weak for ideal case
- kT seems to point in direction of LCP