# Transverse Single Spin Asymmetry in STAR at Forward Rapidity

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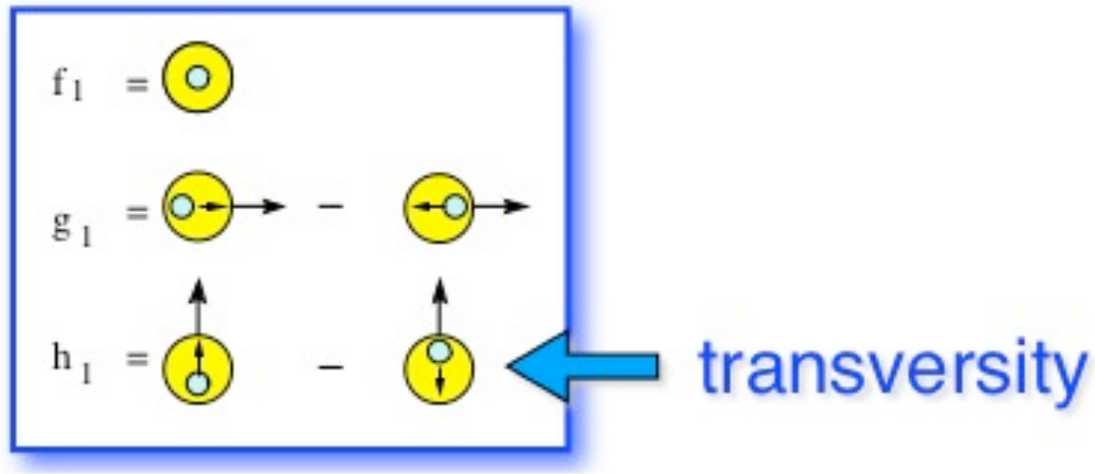
# Transverse SSA

unpolarized PDF, well-known --upolarized DIS

helicity PDF, known --polarized DIS, pp

transversity, chiral-odd, poorly constrained, inaccessible through inclusive DIS




## Transverse momentum-dependent (TMD) parton distributions and factorization

a) spin correlated $k_T$ in PDFs -->Sivers effect

--partonic orbital angular momentum contribution to proton spin

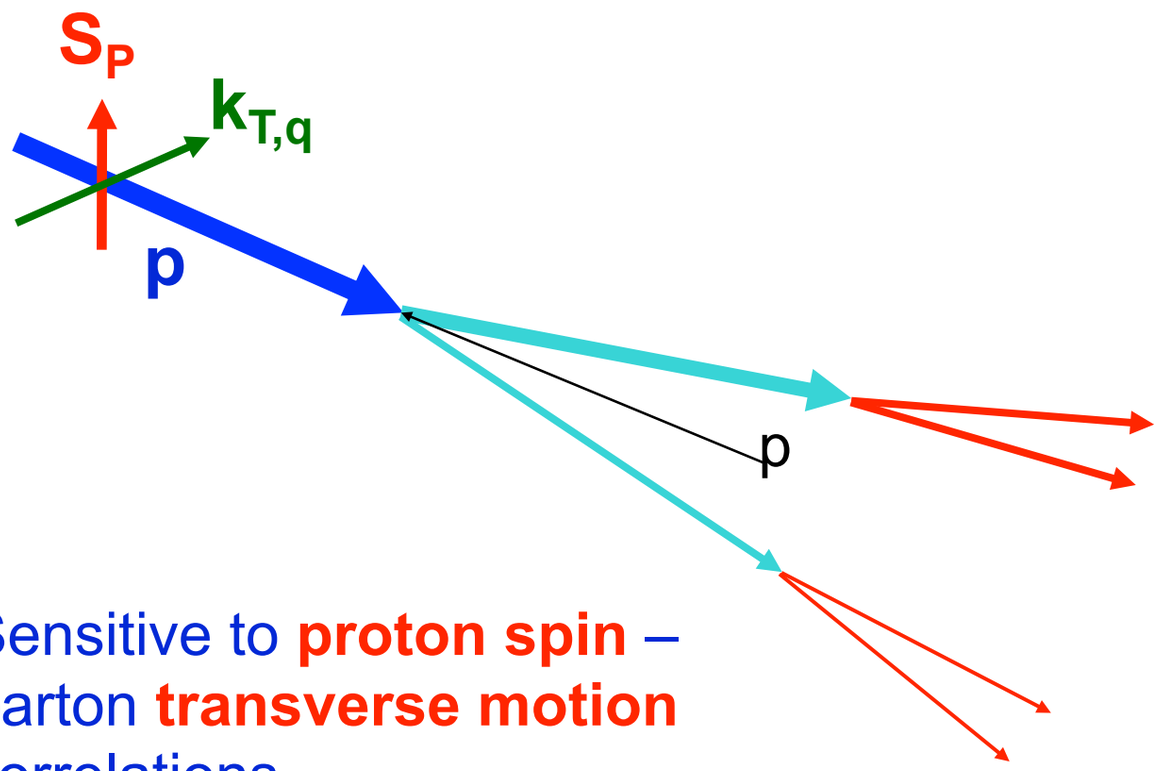
$$\langle k_T^{\text{parton}} \cdot (\vec{s}_{\text{proton}} \times \vec{p}_{\text{proton}}) \rangle \neq 0$$

b) spin correlated $k_T$ / $j_T$ in FFs -->Collins effect

--spin dependent fragmentation, chiral-odd

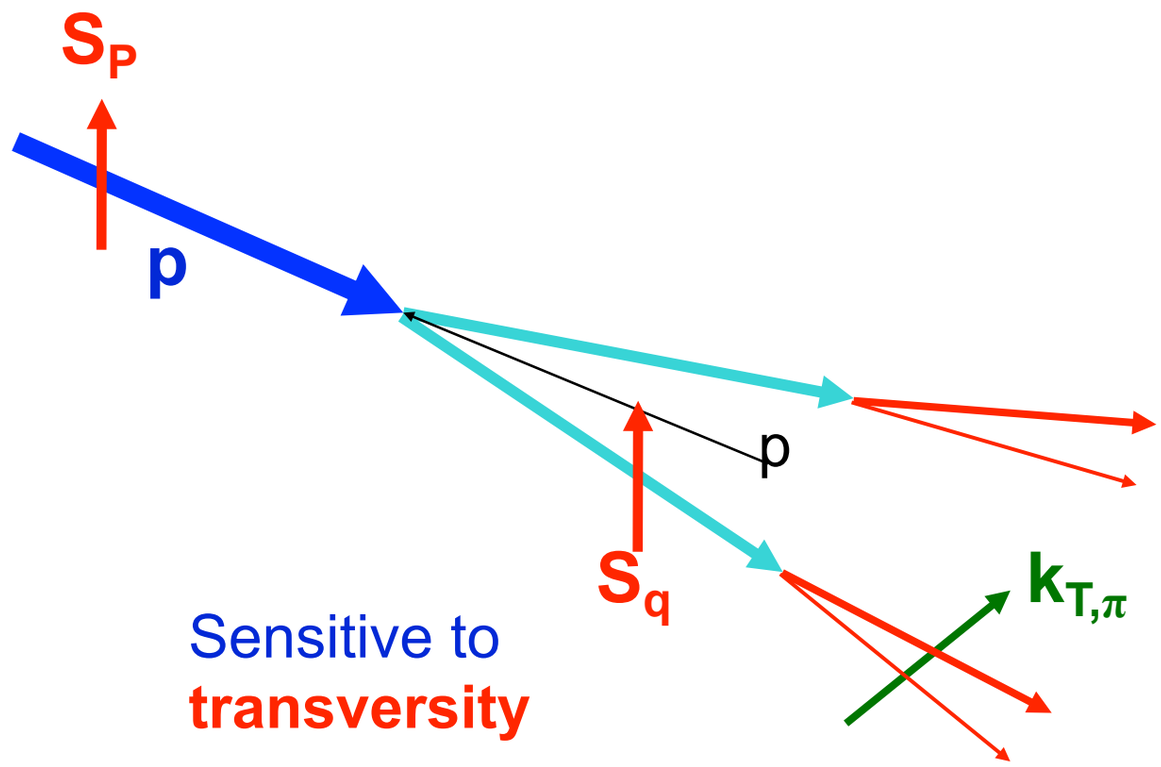
# Separating Sivers and Collins effects

**Sivers mechanism:** asymmetry in the forward jet or γ production




Sensitive to **proton spin** – parton **transverse motion** correlations

**Collins mechanism:** asymmetry in the forward jet fragmentation



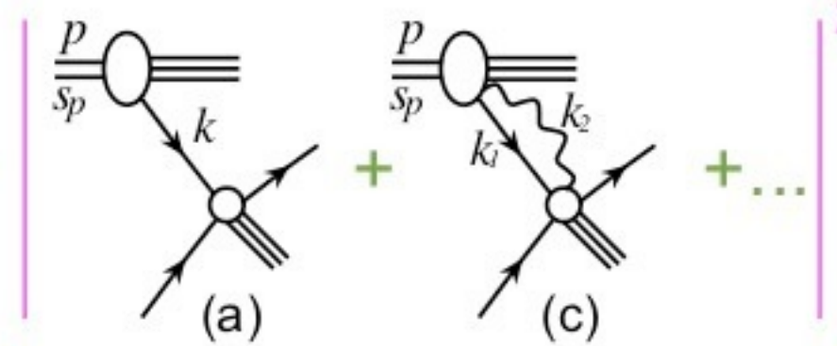

Sensitive to **transversity**

- Need to go beyond inclusive $\pi^0$ to measurements of jets or direct γ

# $p_T$ dependence

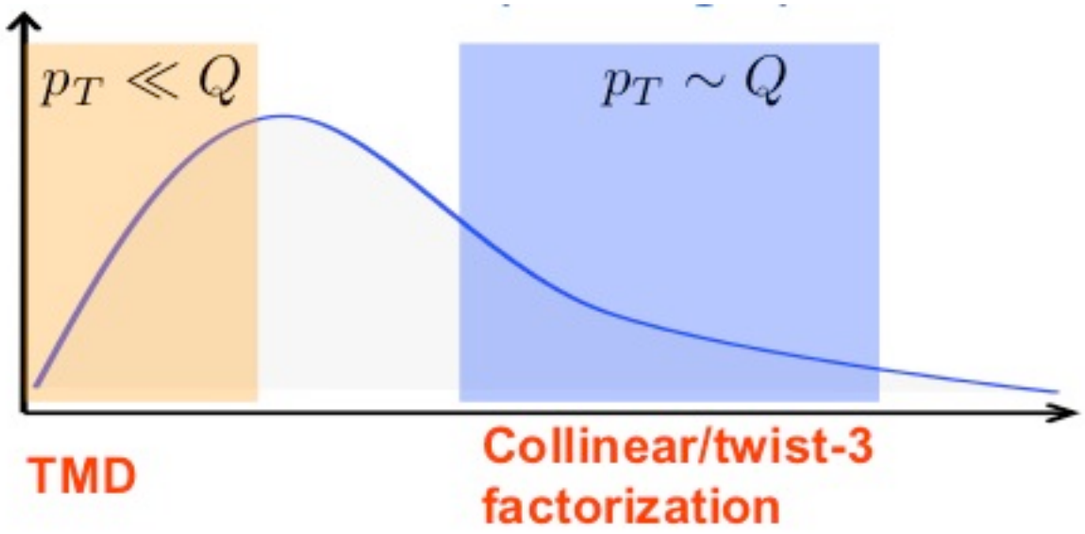
To test our understanding of QCD at amplitude level

connections of TMD approach with collinear twist-3 effect

$\sigma(s_T) \sim$ 

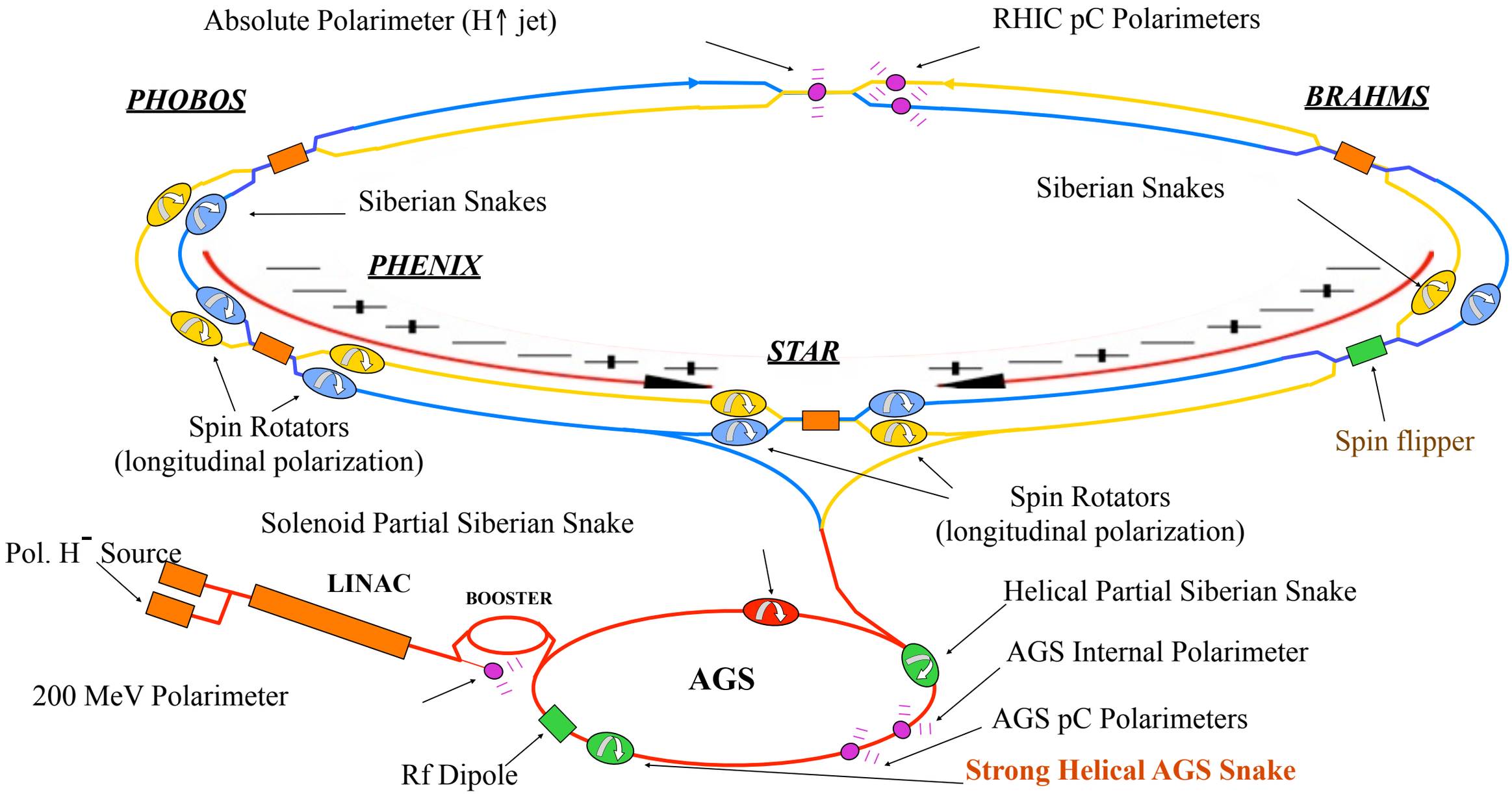
$\Rightarrow \Delta\sigma(s_T) \sim \mathrm{Re}[(a)]\cdot\mathrm{Im}[(c)]$

These 2 approaches apply to different kinematic ranges,
and have been proven to be equivalent in overlapping region

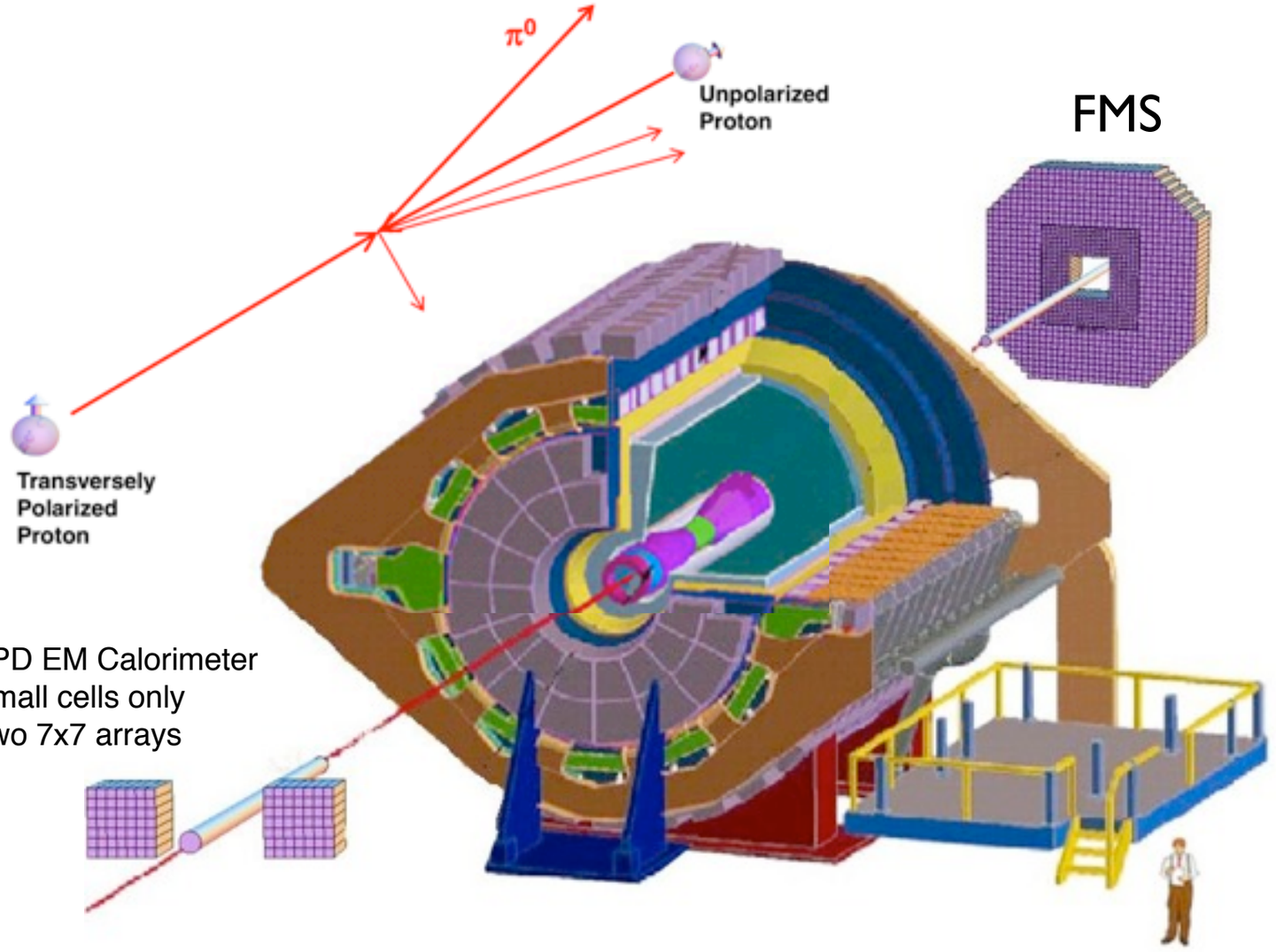



transition from low $p_T$ to high $p_T$

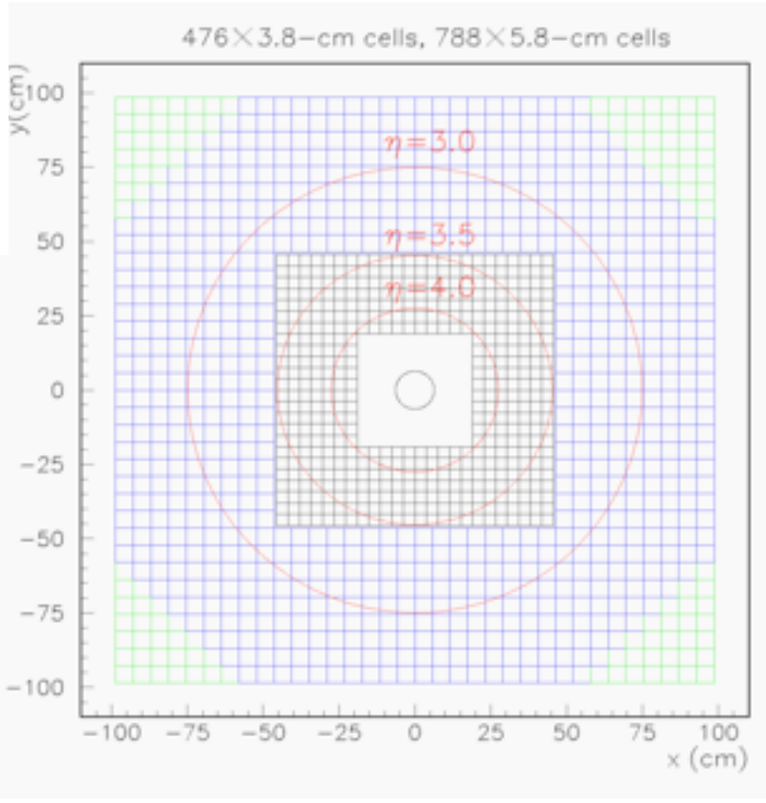
# RHIC: the world's first polarized hadron collider



# FMS in STAR




FPD EM Calorimeter
Small cells only
Two 7x7 arrays



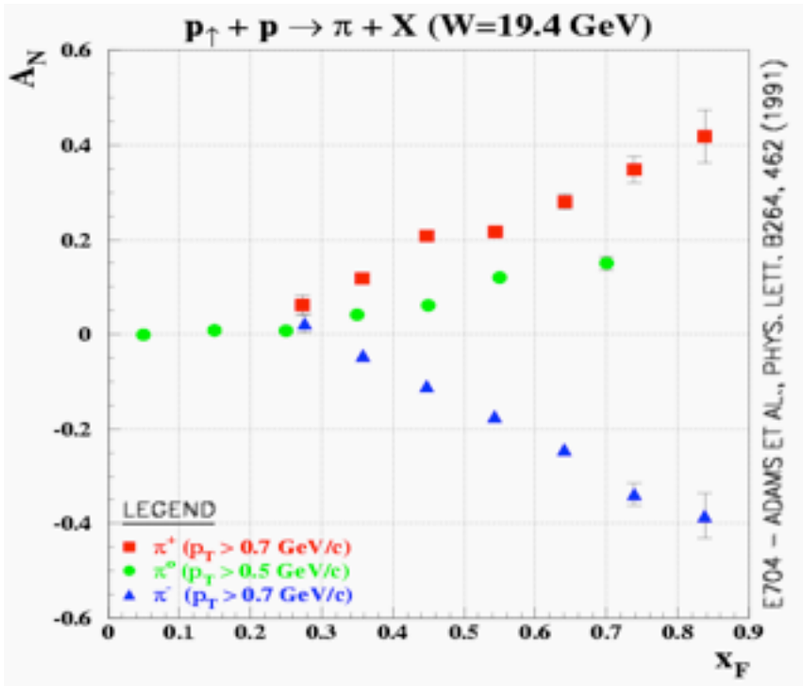

Forward Meson Spectrometer (FMS) :

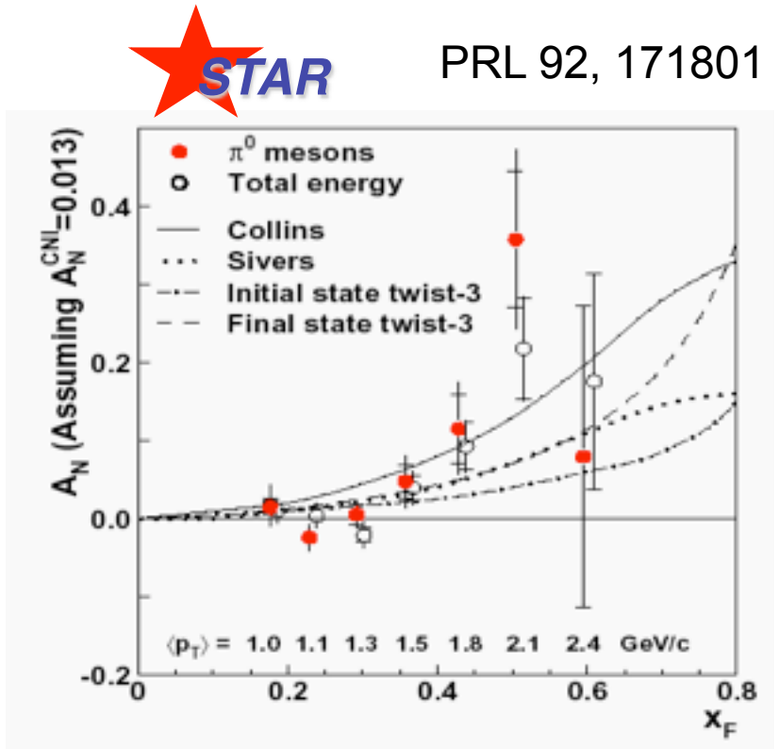
Pb glass EM calorimeter covering 2.5< η <4.0

Detect $\pi^0$,η, direct photons and jet-like events in the kinematic region where asymmetries are known to be large.

# Large inclusive TSSA

$$A_N = \frac{d\sigma\uparrow - d\sigma\downarrow}{d\sigma\uparrow + d\sigma\downarrow}$$



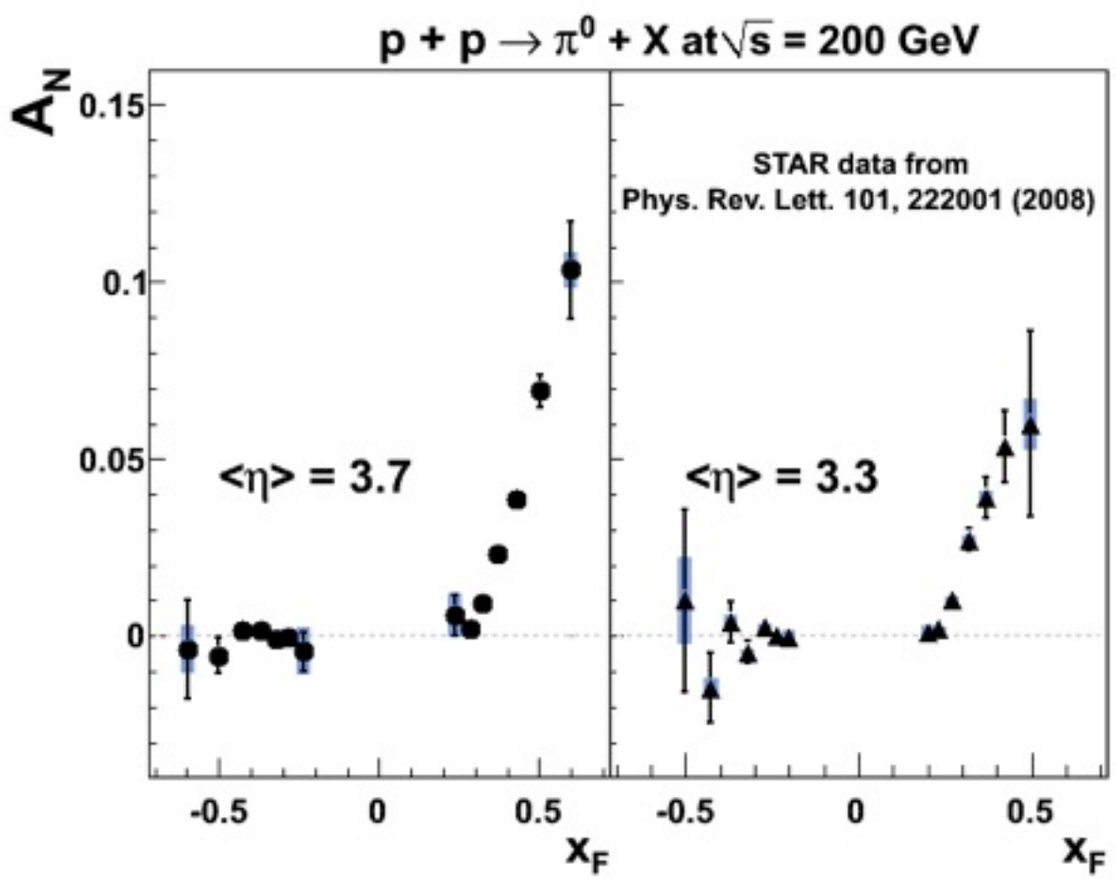



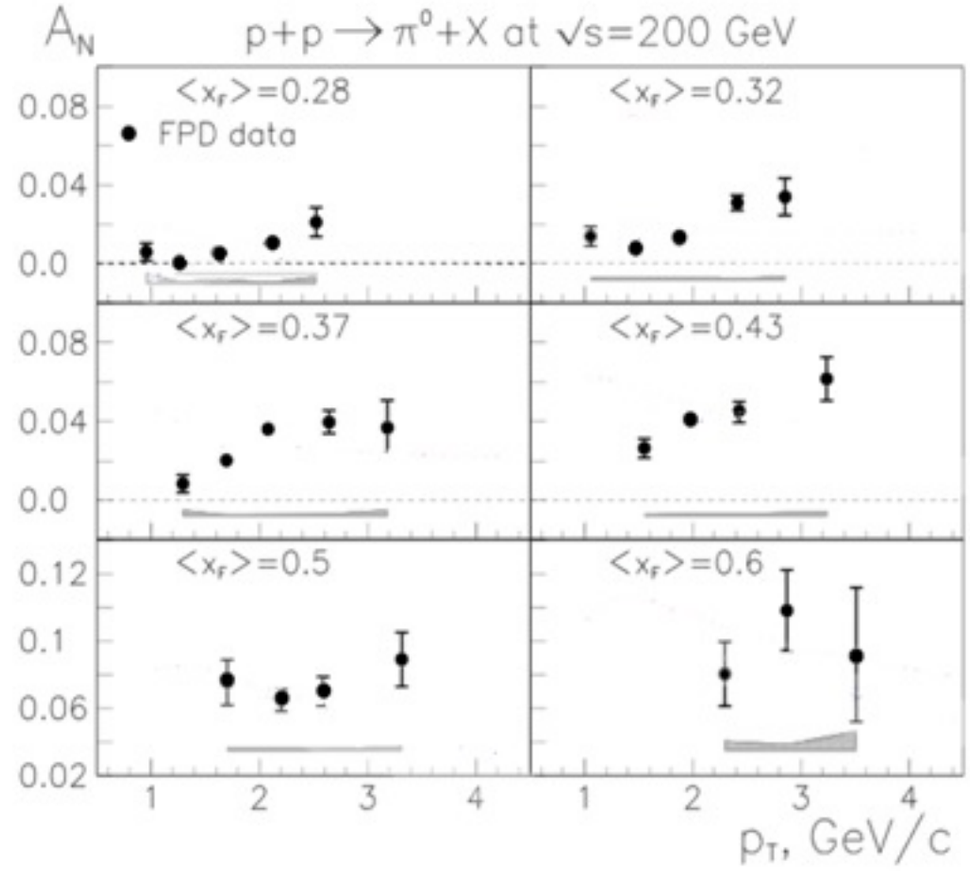

PRL 92, 171801

- Large single-spin asymmetries at CM energies of 20 and 200 GeV
- May arise from the Sivers effect, Collins effect, or a combination

# STAR Published Run 6 (FPD √s =200GeV)

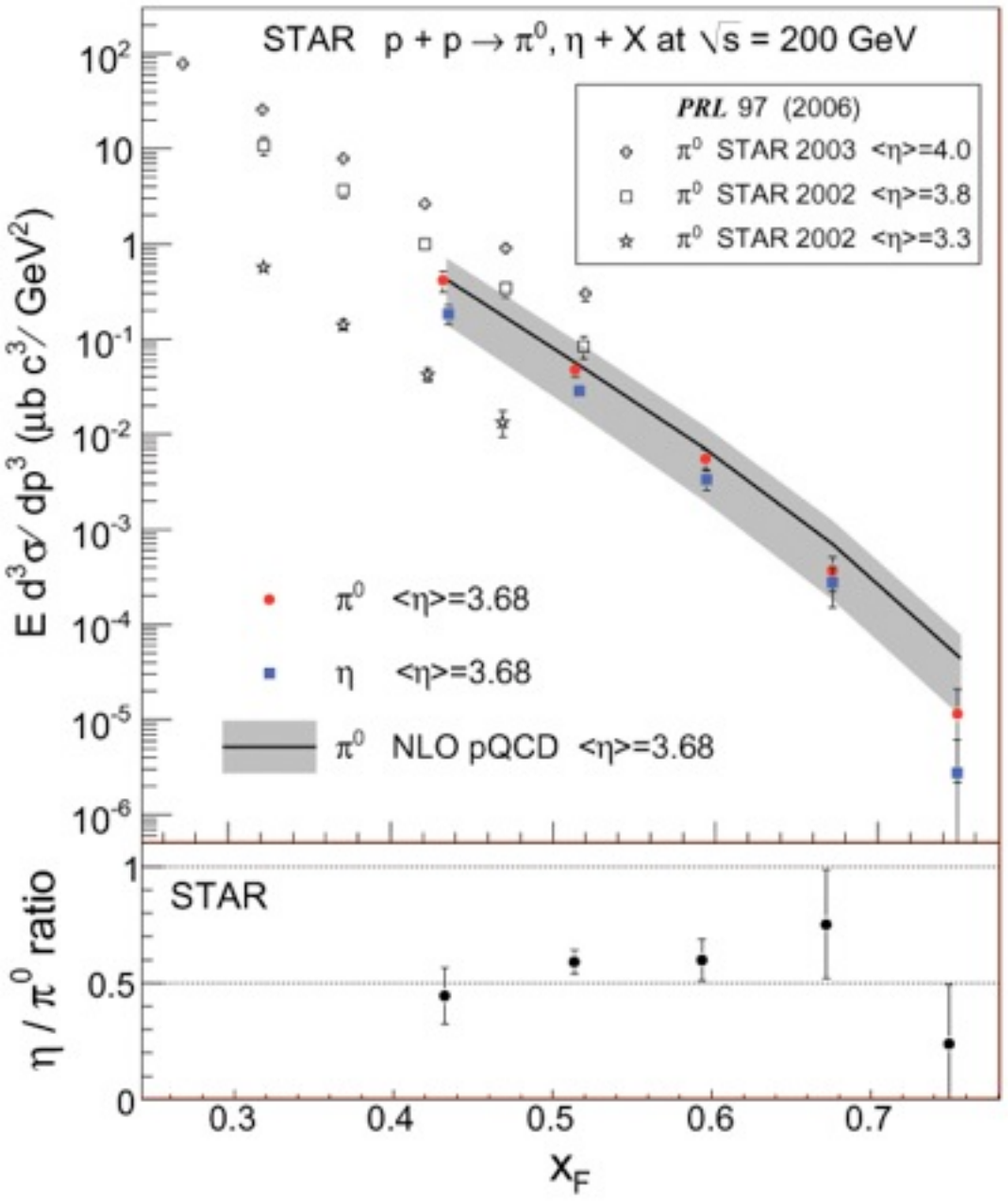
PRL 101, 222001 (2006)

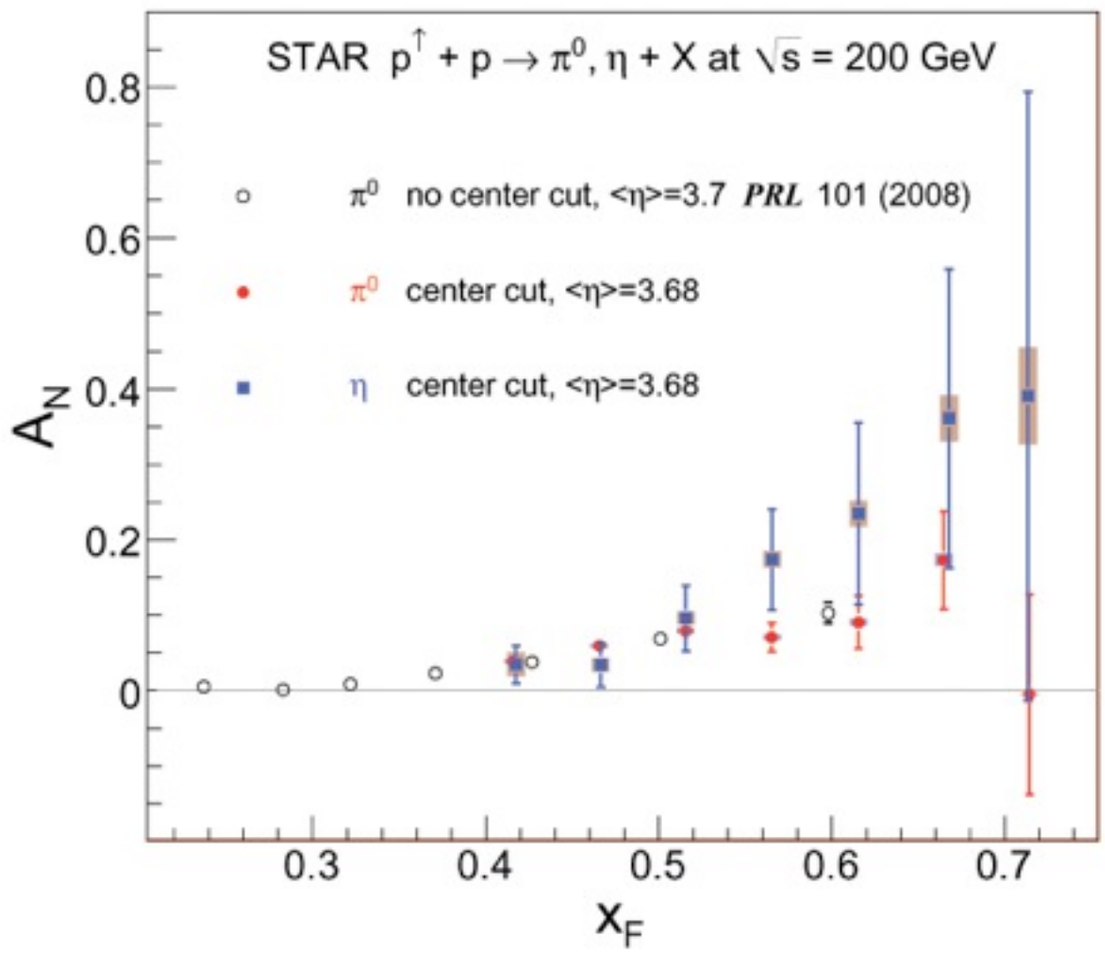



- Rising $A_N$ with $X_F$ ($0.25 < X_F < 0.5$) from 0% to 5-10%
- No evidence of fall in $A_N$ with increasing $P_T$ up to $P_T \sim 3$ GeV/c

# $\eta/\pi^0$ at $X_F$>0.5 Phys. Rev. D 86, 051101



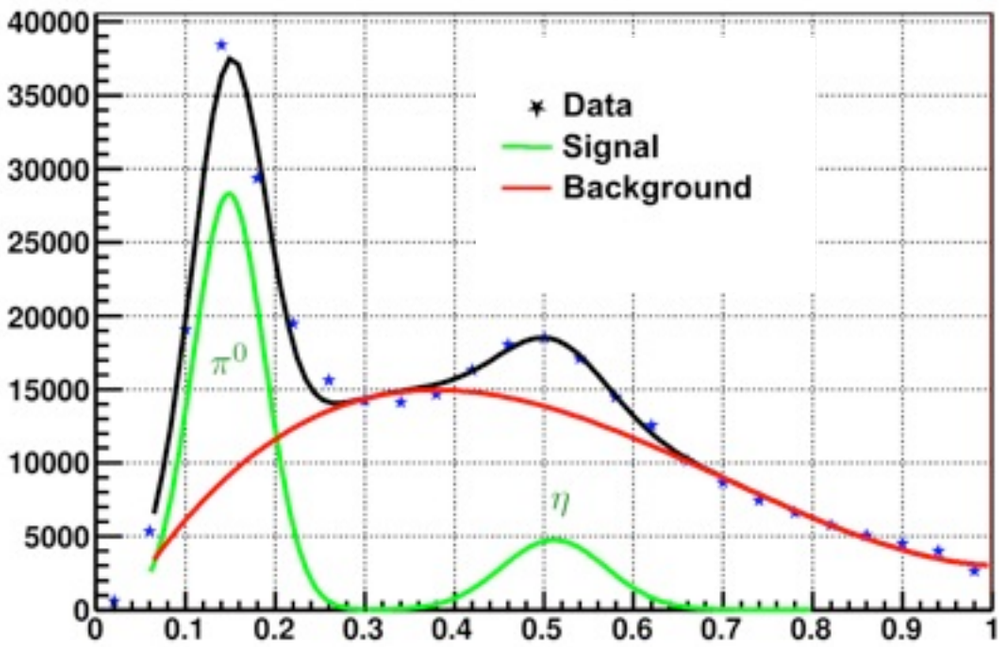

$\pi^0$ cross section in good agreement with PQCD calculation.

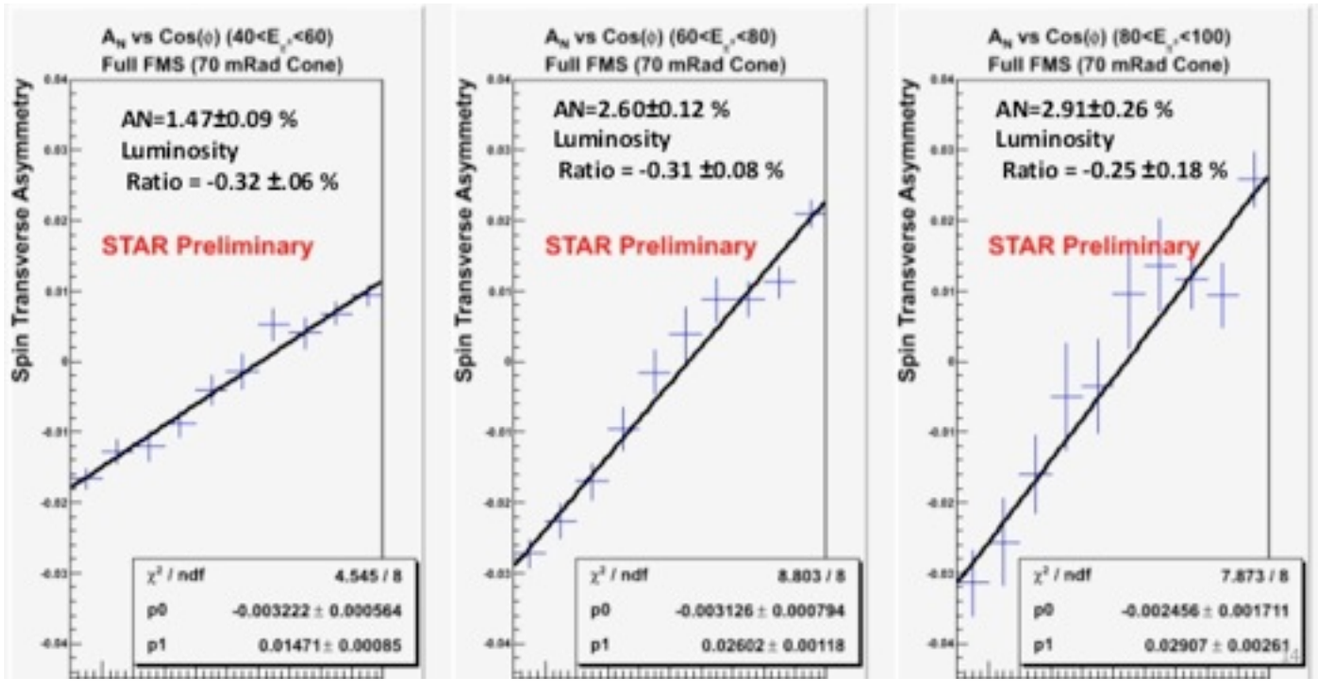
$\eta/\pi^0$ cross section ratio similar to that observed where jet fragmentation is dominant.

$A_N(\eta) > A_N(\pi^0)$ for $X_F > 0.55$

# Ongoing analysis on run-II pp 500GeV data

$\pi^0$ production measured at STAR Forward Meson Spectrometer ($2.5 < \eta < 4.0$)




production asymmetry extracted from the slope of azimuthal dependence of the raw yield asymmetry :

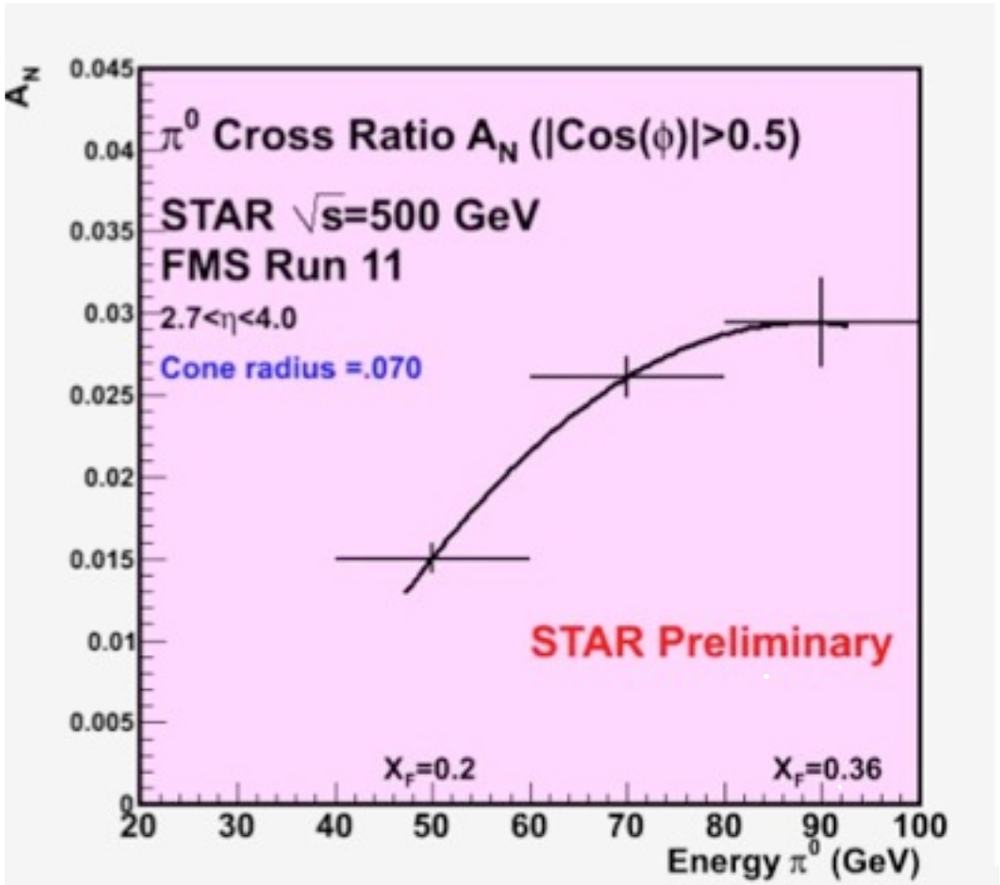
Cos(Φ)

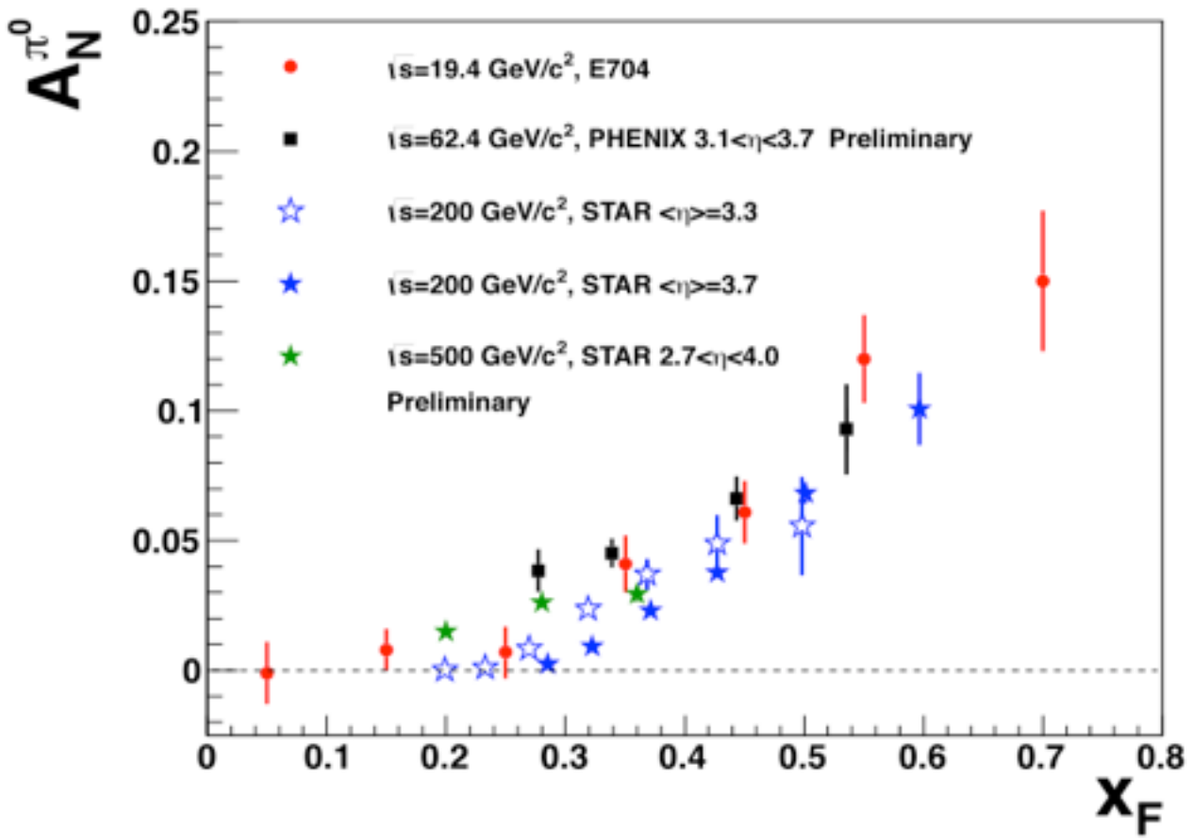
$$Yield\ asy. = (N\uparrow - N\downarrow)/(N\uparrow + N\downarrow) = R_{lumi} + Pol. * A_N cos(\phi)$$

$$\mathrm{R_{lumi}} = \frac{L_{up} - L_{down}}{L_{up} + L_{down}}$$

# $\pi^0$ $A_N$ vs $x_F$

$$x_F = 2p_L/\sqrt{(s)} \simeq E_{\pi^0}/E_{beam}$$




Scale of $A_N$ similar like other energies

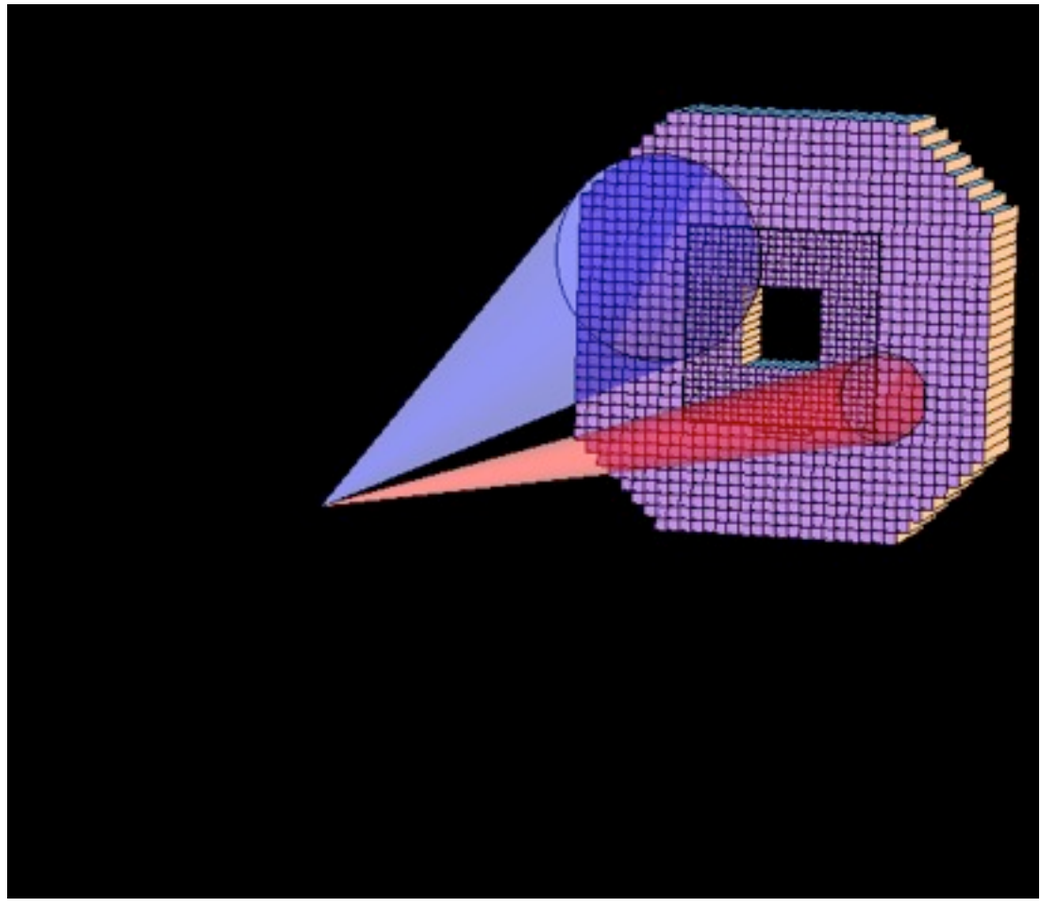
# Forward rapidity hadron production

**Isolation of $\pi^0$ 's** Event Selection:

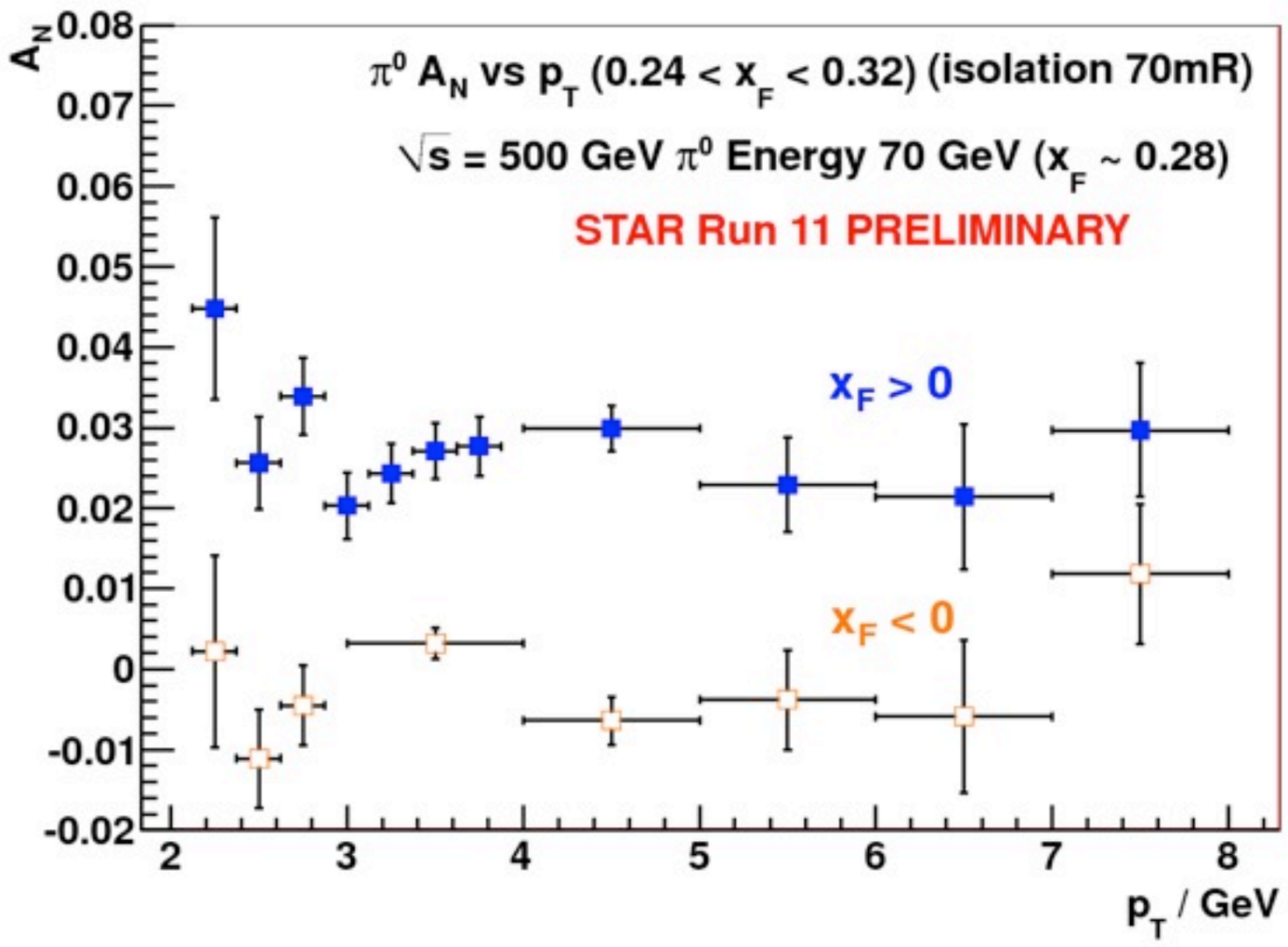
1. Analyze FMS for all photon candidates. (Showers that are fit successfully to photon hypothesis)
Photon candidates must have a minimum of 6 GeV in the small inner detector or 4 GeV in the outer cells.

2. Find Clusters of EM energy grouping photon candidates that are within opening angle cone $\Delta\theta$ (relative to energy weighted center)

3. We consider 2 event classes {1 and 2}
1. $\Delta\theta$ =0.07 2 Photon clusters, Pi0 Mass **(isolation radius of .07 radians)**.
2. $\Delta\theta$ =0.03 2 Photon clusters ,Pi0 Mass **(isolation radius of .03 radians)**.

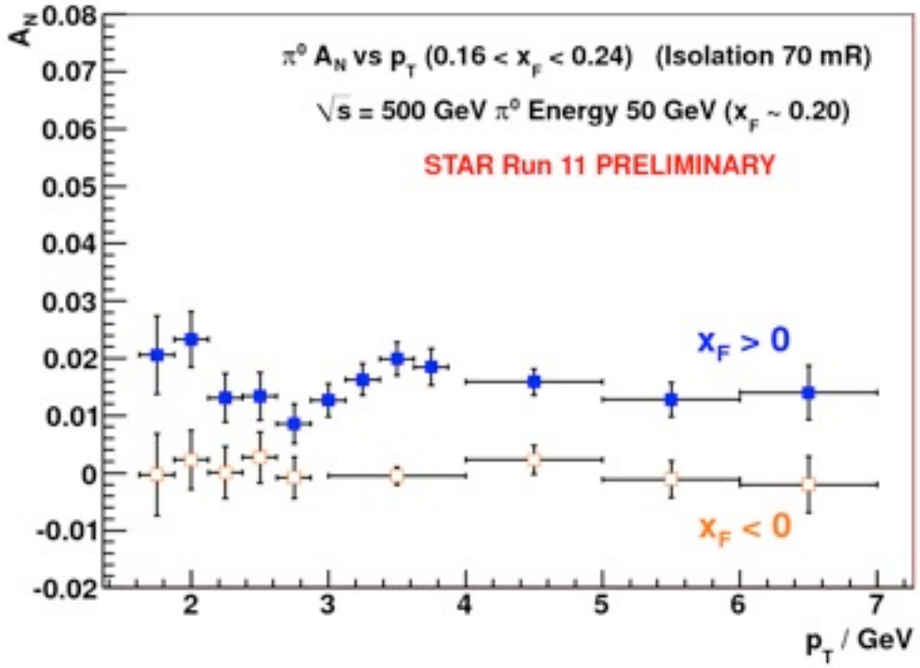


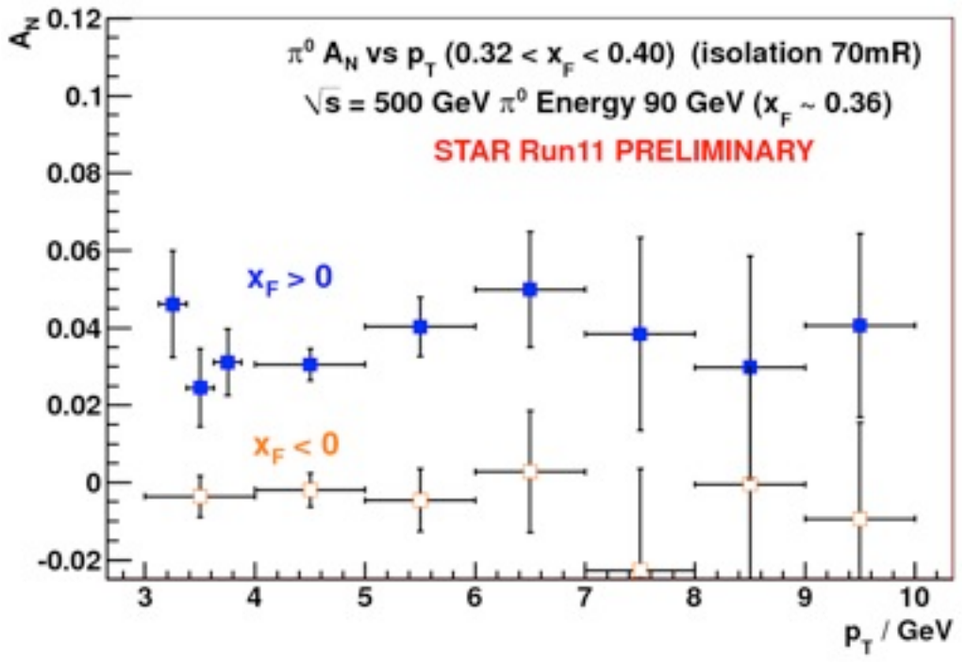
# $\pi^0$ $A_N$ vs $p_T$



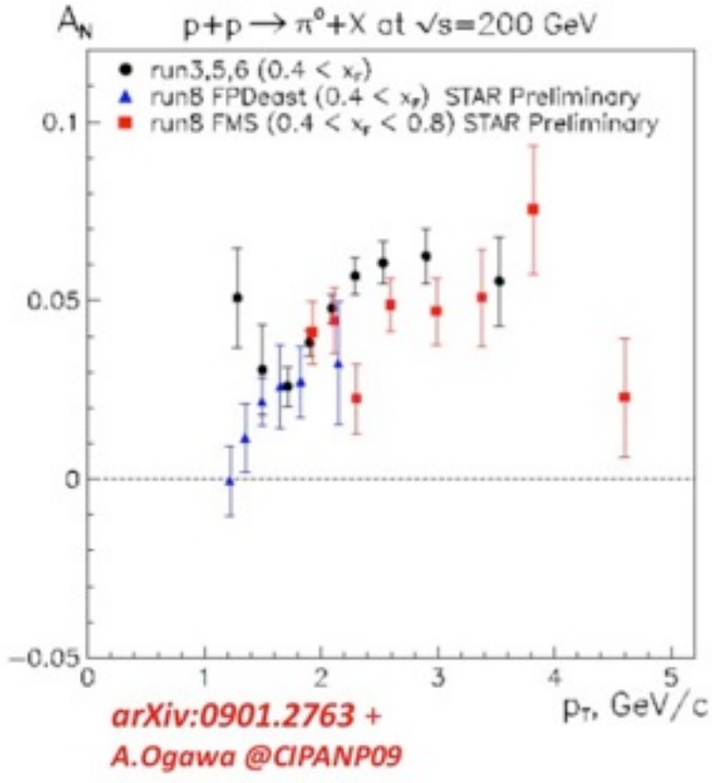

No indication of falling $A_N$ as $p_T$ as opposed to twist-3 expectations

# $\pi^0$ $A_N$ vs $p_T$




same trend observed for different $x_F$



# $A_N$ at various isolation cones

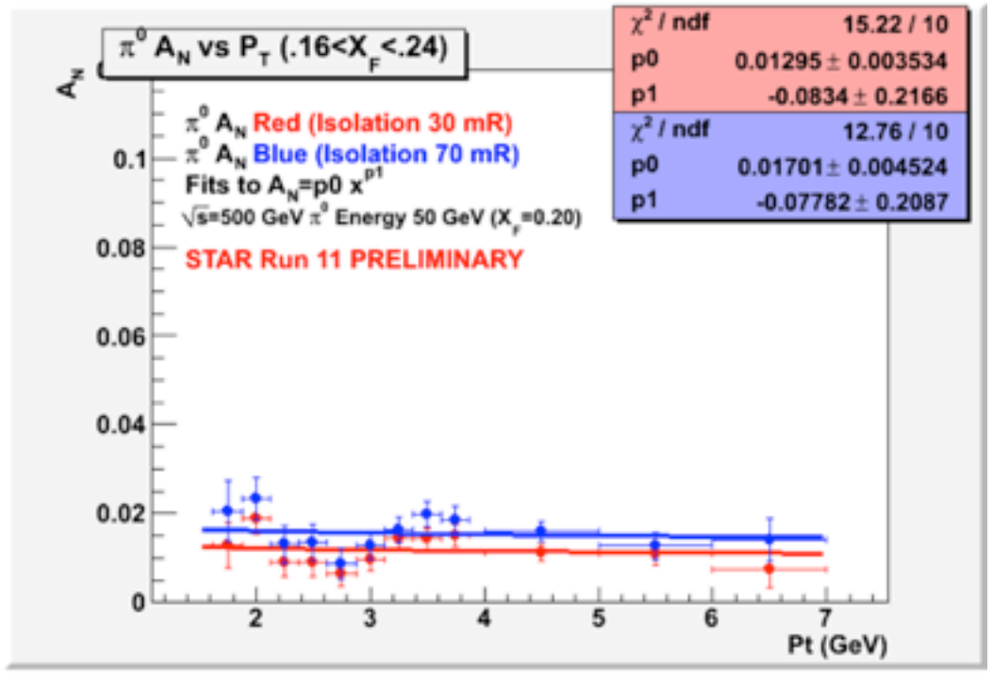
**Transverse Single Spin $\pi^0$ Asymmetry vs $P_T$ for small and large $\pi^0$ isolation cones. (Errors shown are statistical)**

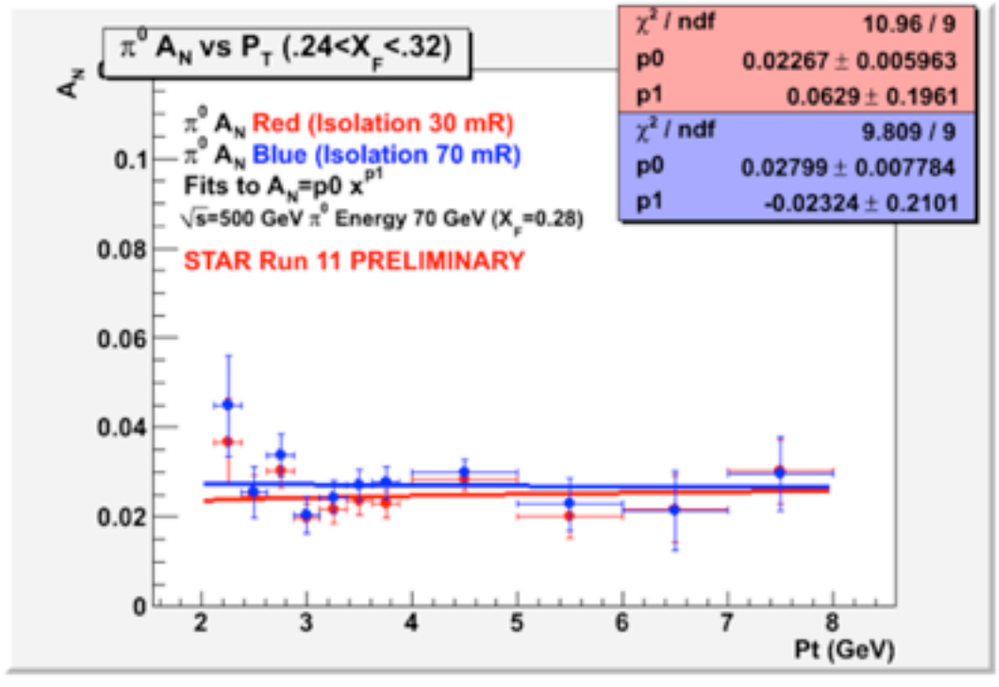
Higher Twist or other pQCD related models suggest **$A_N$ should fall at large $P_T$ with at least 1 power of $P_T$.**

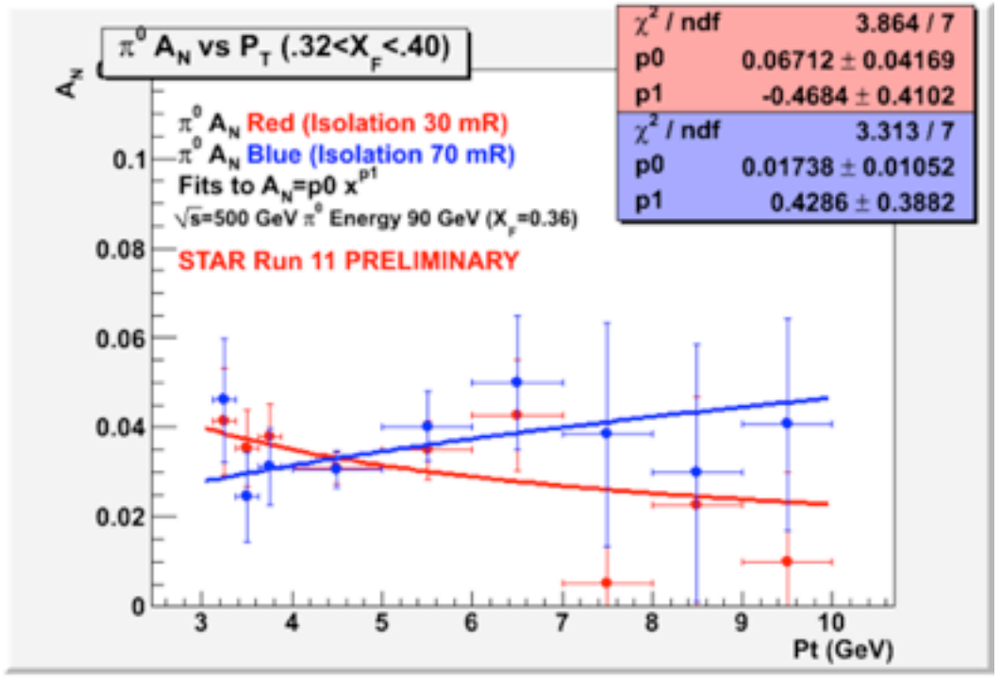
These plots include 2 parameter fits for $A_N$ vs $P_T$ :

$$A_N(P_T) = [p_0] \times (P_T)^{[p_1]}$$

Fits are shown for both the **70 mRad** and **30 mRad** isolation cones.



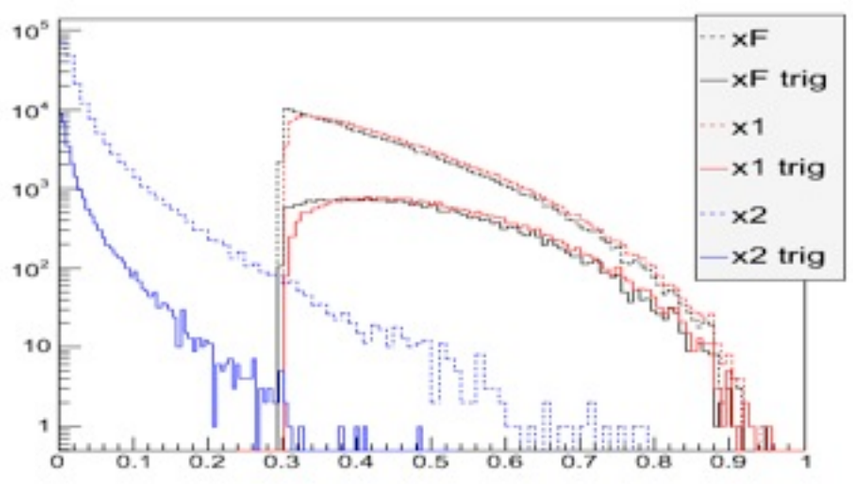

Asymmetries seem to be larger when the $\pi^0$ is isolated within a larger cone

# Neutral Jets in FMS

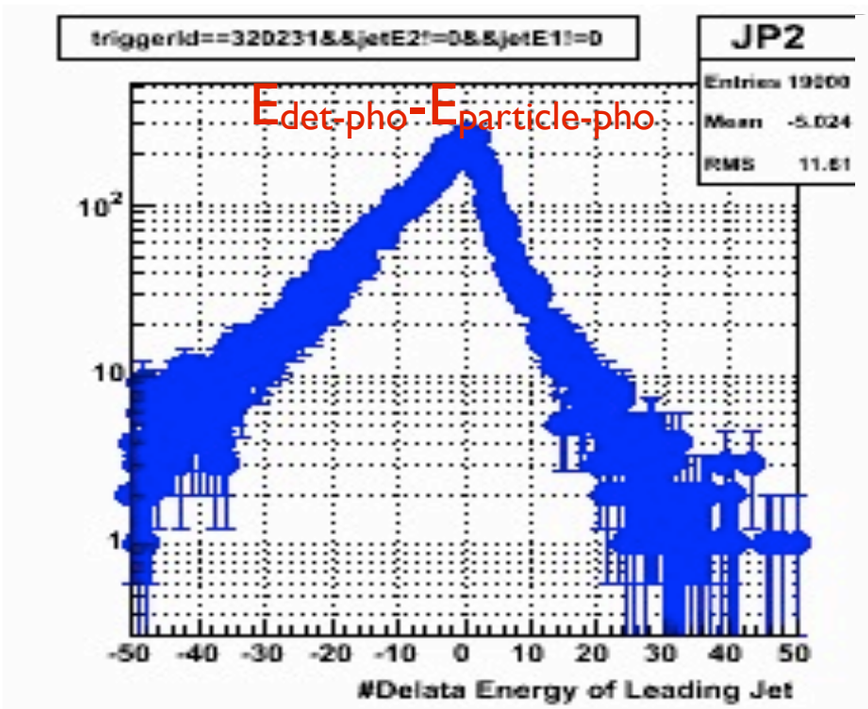
Goals : to correlate jets with neural energy in FMS with that of EEMC+BEMC(-1<η<2) and find $A_N$ for jets and inclusive pions for various event topologies

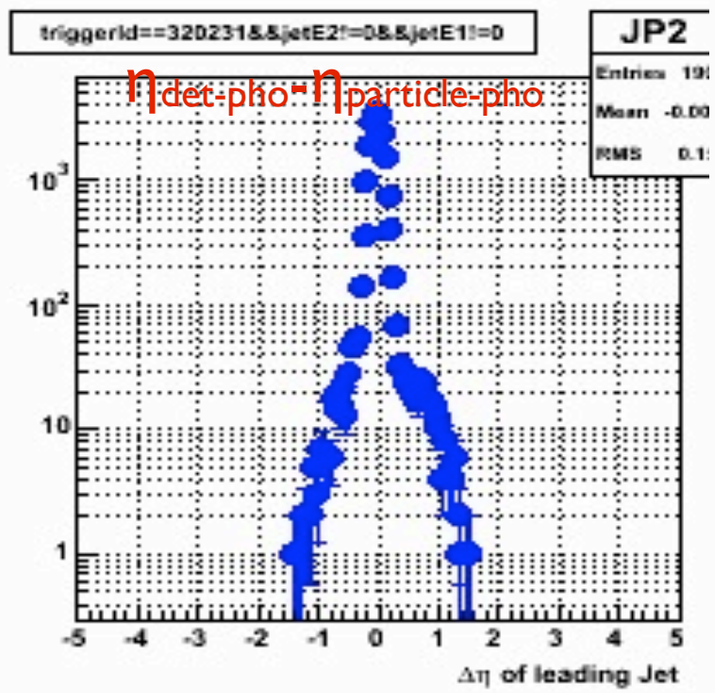
simulation study on PYTHIA events with FMS only

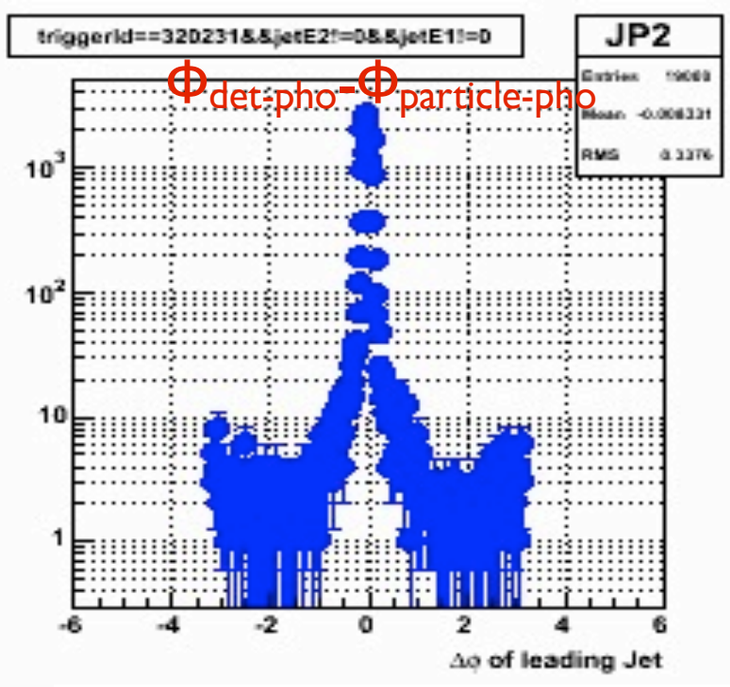
PYTHIA is used for p+p at $\sqrt{s}$ =*500GeV*
lager fraction of jets in FMS :
$x_F$ > 0.3
pt-hard >7GeV/c




After associating a detector-photon jet with a particle-photon jet in FMS



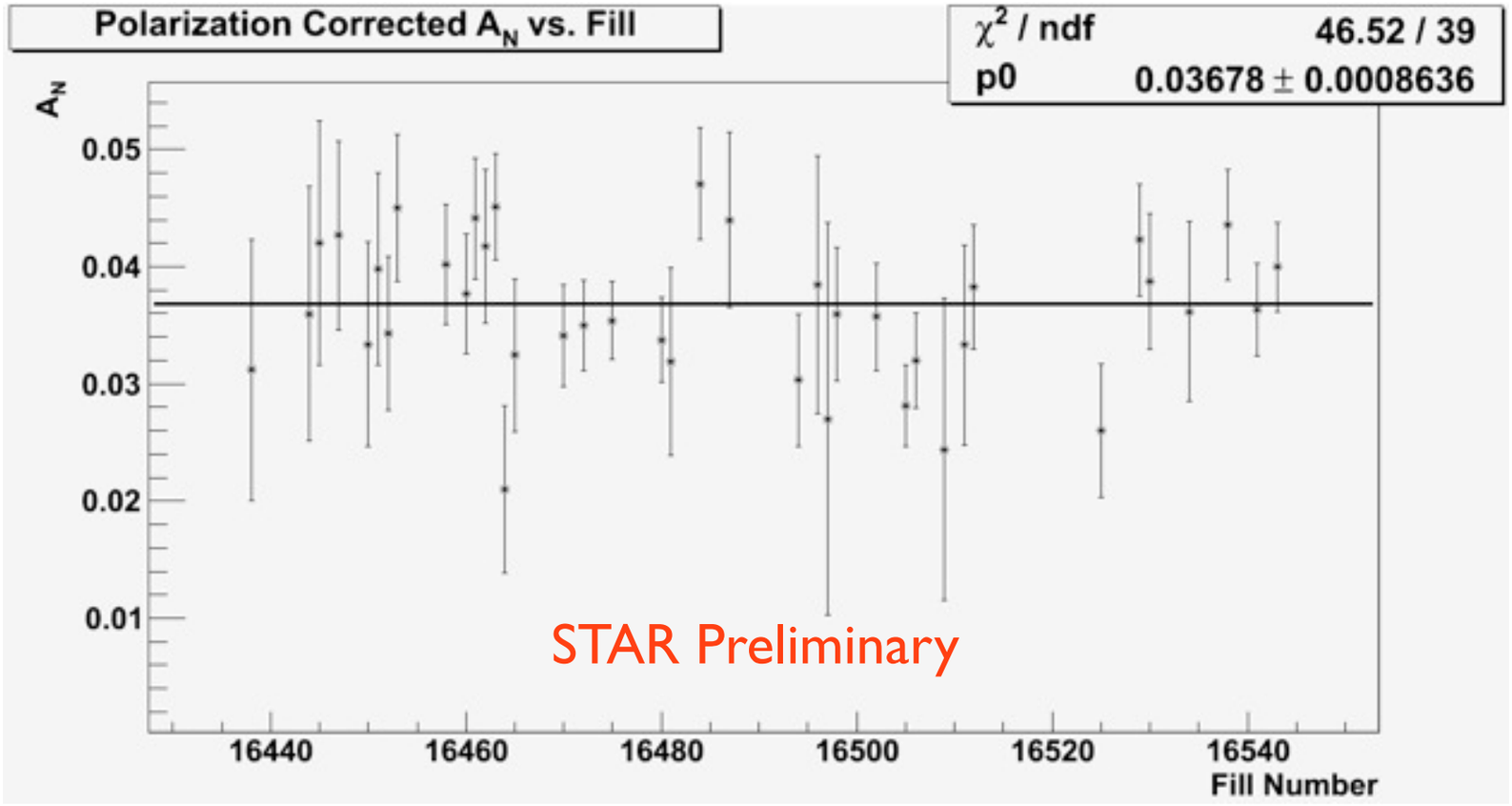




analysis on pp 500 transverse data is undergoing...

# Status on run-12 pp 200GeV transverse running

**Results of 12 run from full datasets of 627 runs**




2-photons (E>6 GeV)
35<energy$_{\gamma\gamma}$<75 GeV
2.55<η<3.85
0.035<m$_{\gamma\gamma}$<.235 GeV

First physics results from run 12 will be presented in DIS ...

# Conclusions

- STAR FMS is very useful in transverse spin study of quarks in a transversely polarized proton. TSSA for inclusive pions and eta mesons for 200 GeV are published.
- Recent 500 GeV asymmetry concludes :
- $A_N$ increases with $X_F$ (as seen at lower energies).
- $A_N$ less dependent on $P_T$ than models predict to $P_T$~ 10 GeV/c. Data may be consistent with flat dependence on $P_T$.
- For data points at $X_F$ <0.32, $A_N$ is significantly larger when the $\pi^0$s are more isolated (0.07 Rad).

- Future analysis will contain more rigorous standard jets with neutral energies in addition of involvement of central detectors.
- Results for new 2012 transverse data for pp 200 GeV with average polarization ~60% are coming soon.