Forward π^0 and η production in STAR at $\sqrt{s}$= 500 GeV with transversely polarized pp collisions

Transverse momentum Dependence of π^0 SSA in FMS Run 11 CIPANP

S. Heppelmann (PSU) for STAR collaboration

June 2 , 2012

- Background
  - Physics Questions
  - **Cross Ratio** method vs. $A(\phi)=A_N \cos(\phi)$ fitting method
  - Previous FMS and STAR results
  - About P_T dependence of A_N
  - FMS Event Topology and Event Selection
- Present High Statistics A_N for STAR Run 11 $\sqrt{s}$=500 GeV
  - X_F dependence
  - P_T dependence for fixed X_F
  - Dependence on event topology

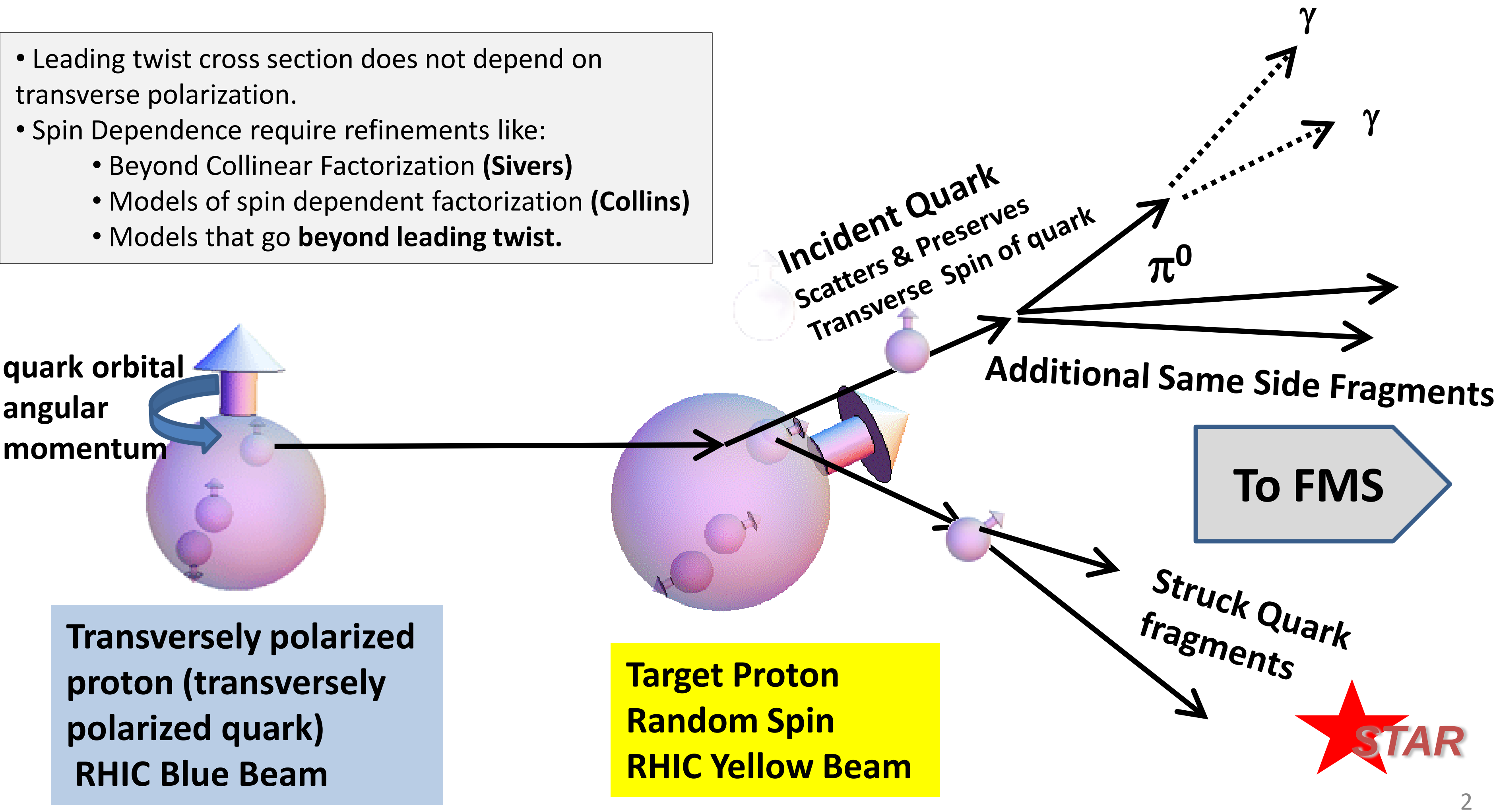
Proton Forward Scattering at High PT
QCD Perspective

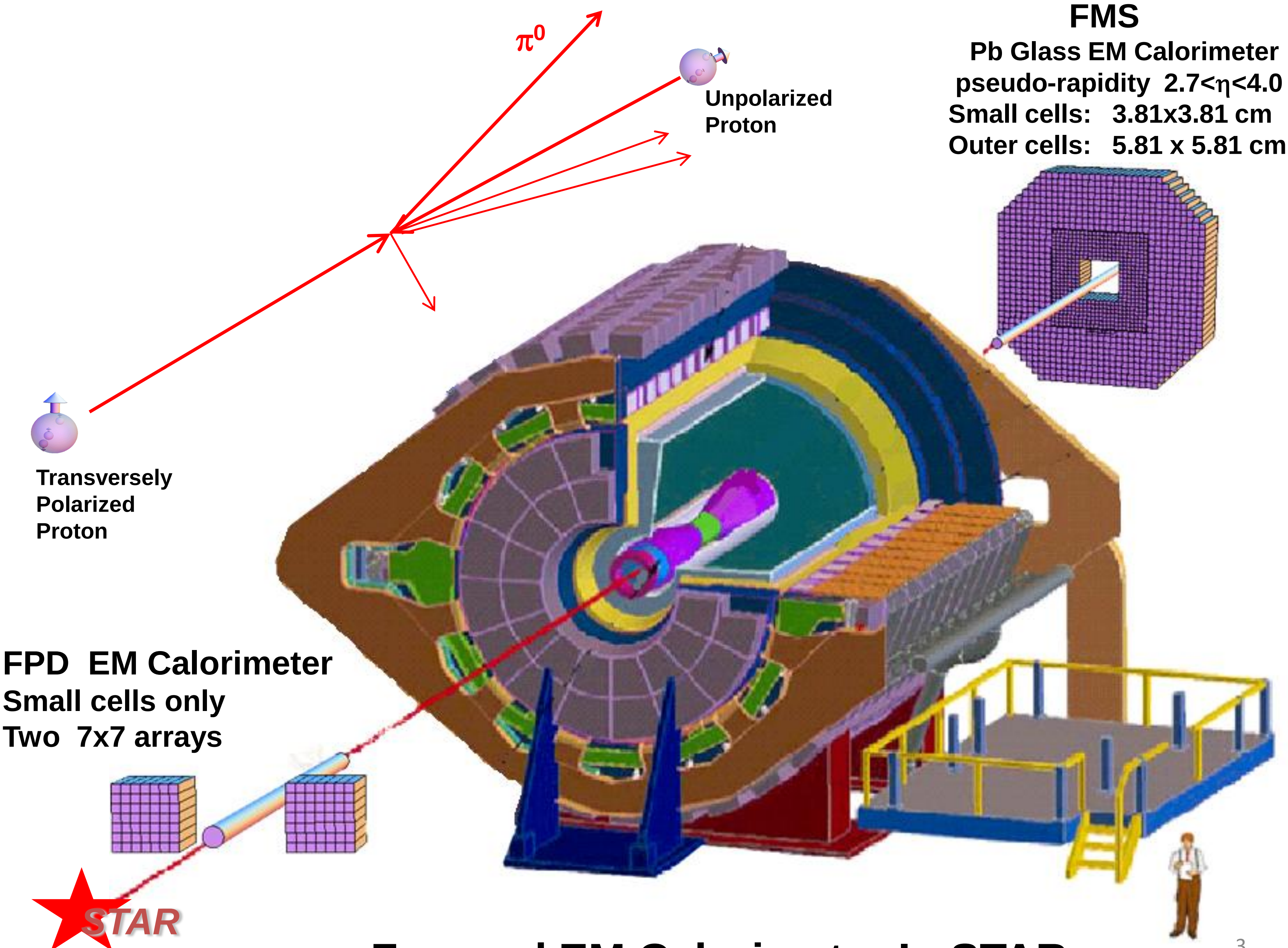
PQCD (Leading Twist):

Factorized Cross Section= (initial state) x (quark scattering) x (fragmentation)

- Does good job of predicting the spin averaged cross section.

- Leading twist cross section does not depend on transverse polarization.
- Spin Dependence require refinements like:
  - Beyond Collinear Factorization **(Sivers)**
  - Models of spin dependent factorization **(Collins)**
  - Models that go **beyond leading twist.**



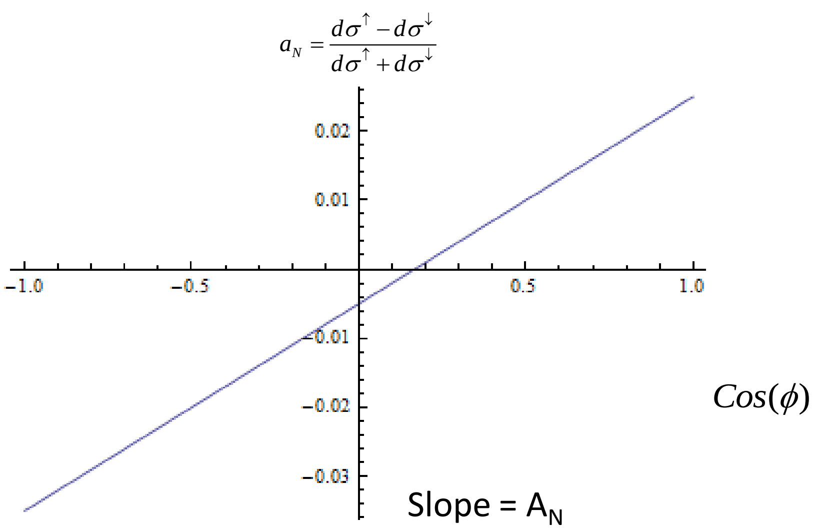


Forward EM Calorimetry In STAR.

1) Cross Ratio Transverse Asymmetry
vs
2) A(ϕ) Fit

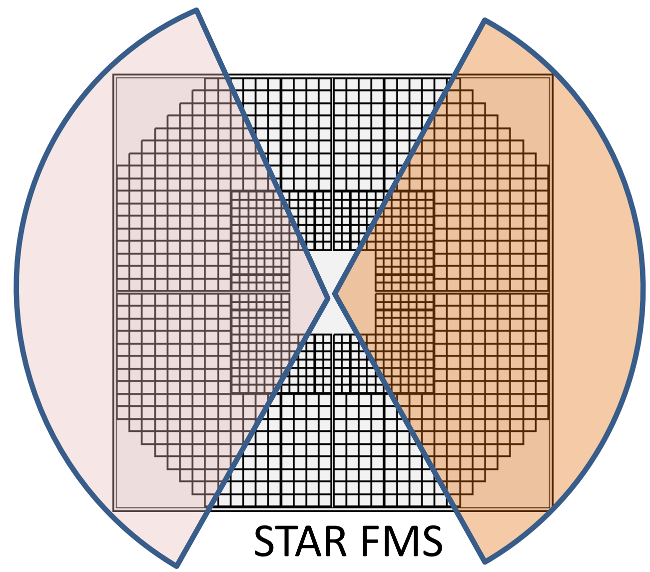
Method 1:
Cross Ratio:

$$A_N = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}} \cong \frac{1}{P} \frac{\sqrt{S^{\uparrow}N^{\downarrow}} - \sqrt{N^{\uparrow}S^{\downarrow}}}{\sqrt{N^{\uparrow}S^{\downarrow}} + \sqrt{S^{\uparrow}N^{\downarrow}}}$$



Slope = A_N
Y Intercept=Luminosity Ratio

Left(S): Cos(ϕ)>0.5



Viewed from collision point

Right(N): Cos(ϕ)<-0.5

Method 2: $$a_N(\phi) = a_0 + A_N \cos(\phi)$$

Fix a_0 for full data set
For many small data subsets ….. one parameter fit for A_N
Advantage: Every fitted value of A_N comes with error and chi^2.

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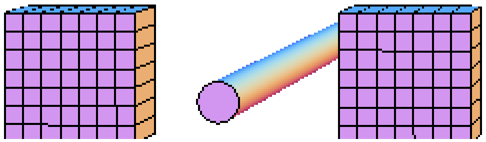
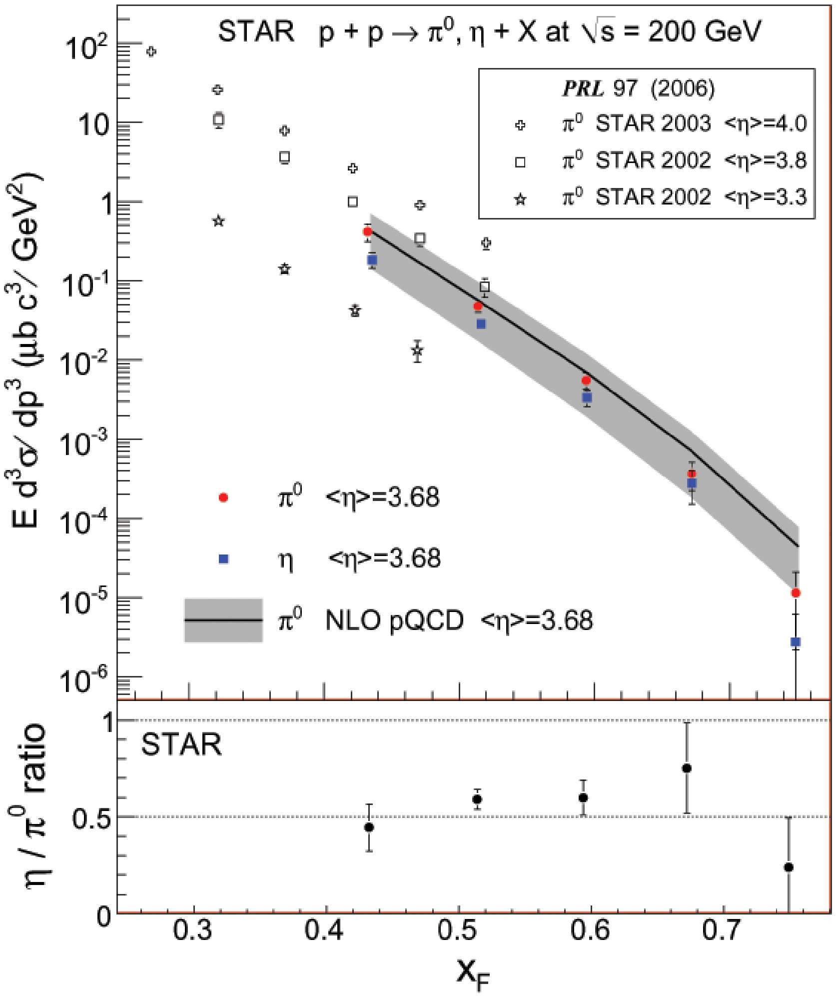
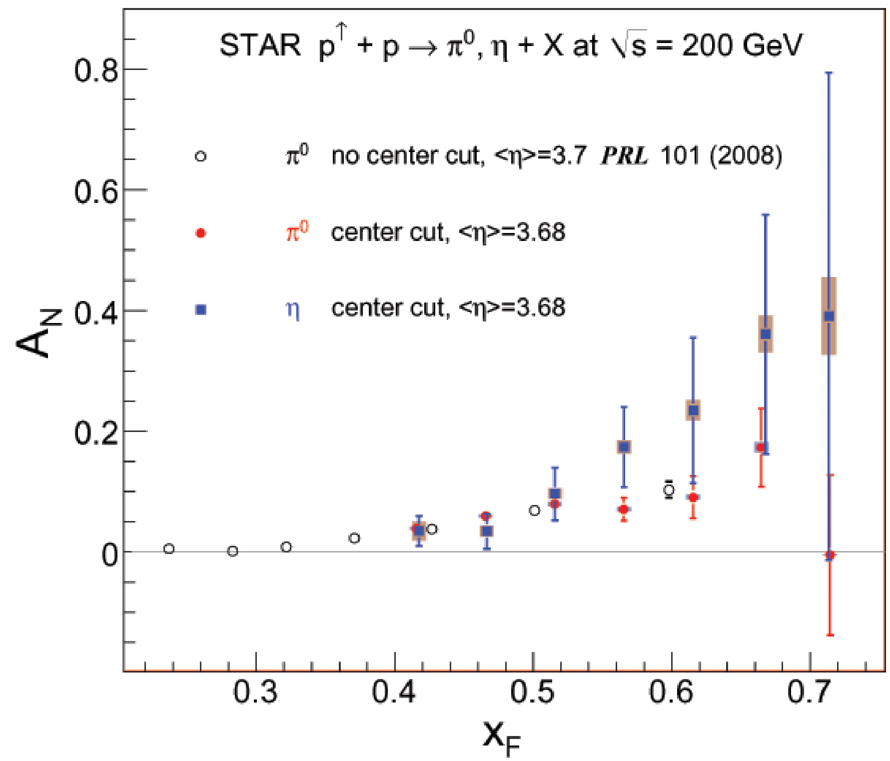
New paper on η/π^0 at $X_F>0.5$

arXiv:1205.6826v1





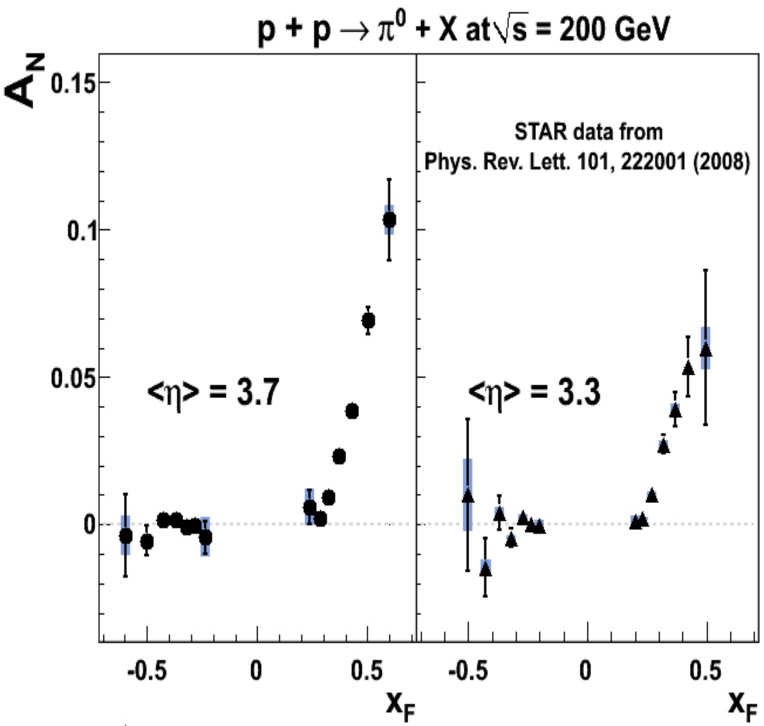
- π^0 cross section in **good agreement with PQCD calculation.**
- η/π^0 cross section ratio similar to that observed where jet fragmentation is dominant.
- $A_N(\eta) > A_N(\pi^0)$ for $X_F > 0.55$

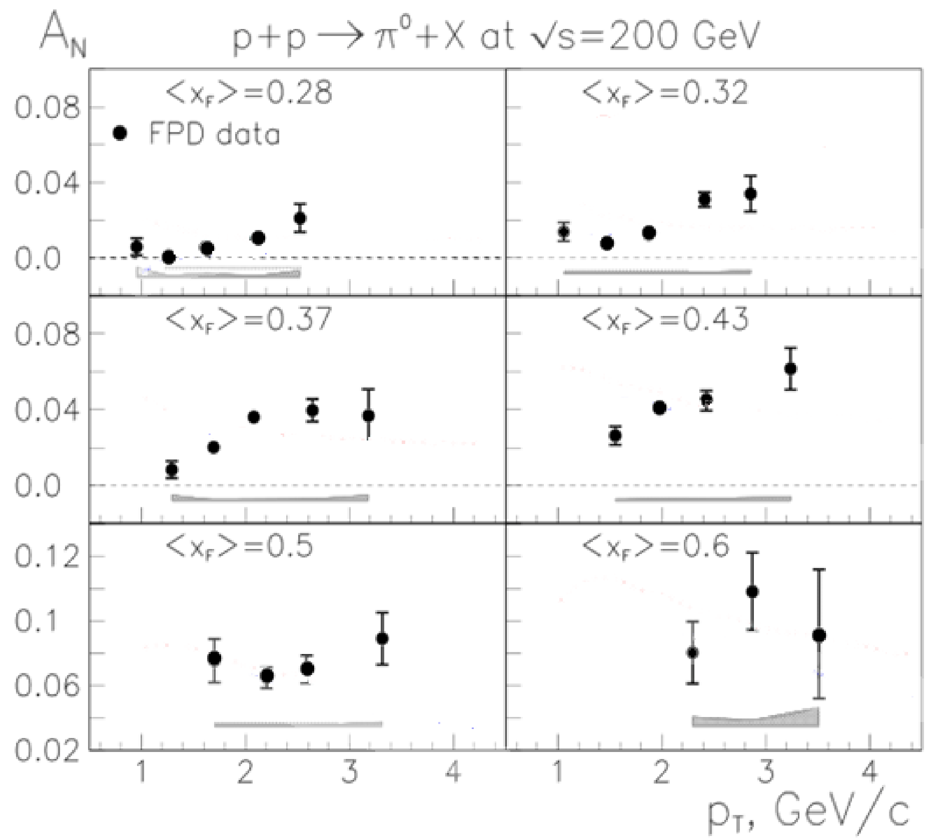


STAR Published Run 6 (FPD $\sqrt{s}$ =200GeV)

PRL 101, 222001 (2006)

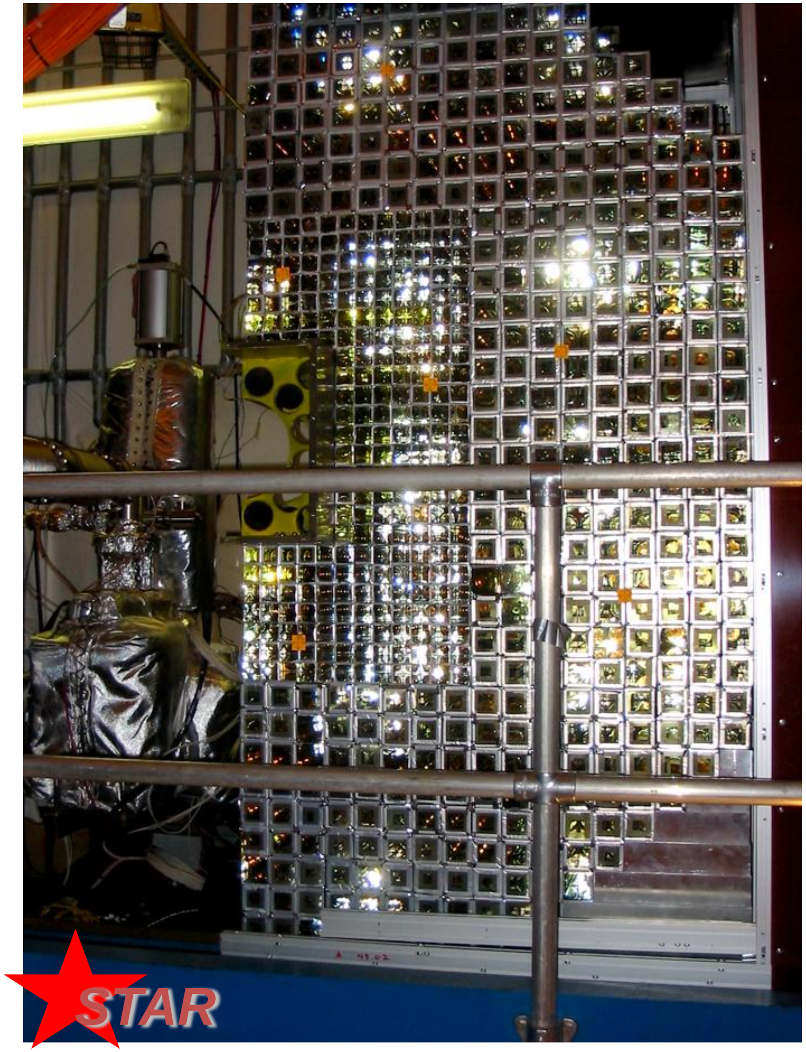
- Rising A_N with X_F ($0<X_F<0.5$) from 0% to 5-10%
- No evidence of fall in A_N with increasing P_T up to P_T ~ 3 GeV/c

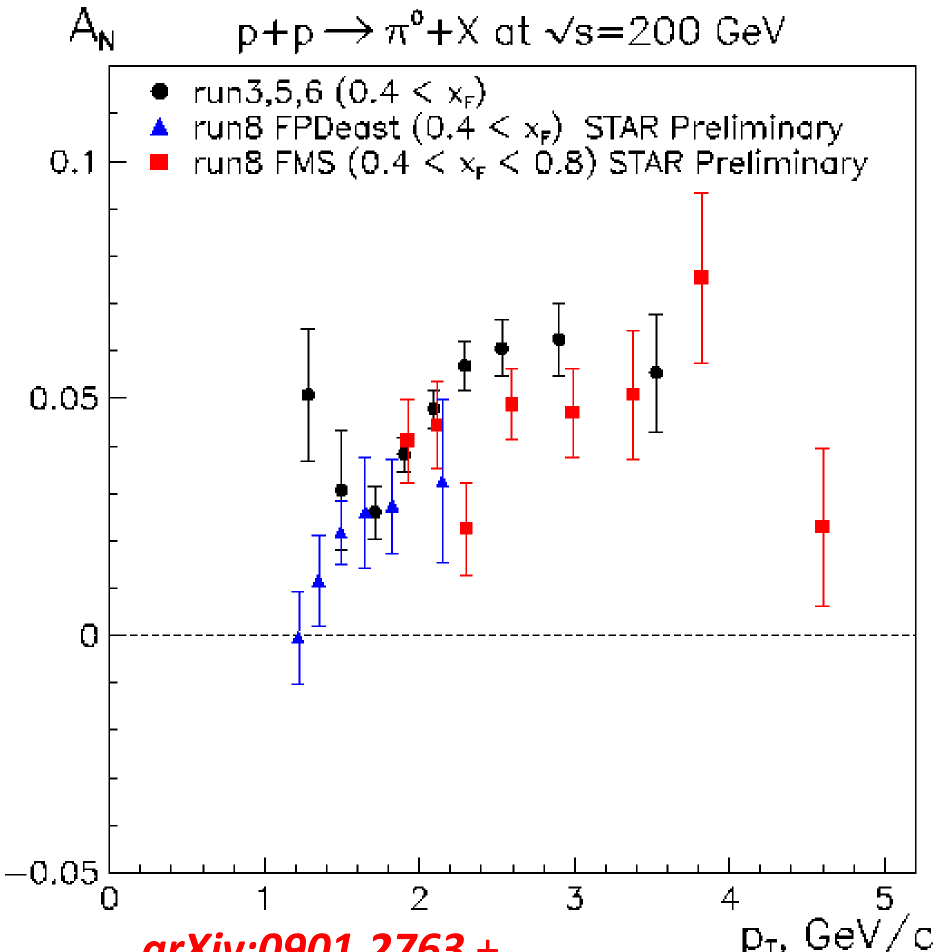




From FMS Run 8, STAR has Expanded Rapidity Coverage -1<Y<4.2

STAR Forward Meson Spectrometer
2.5 < Y < 4.0





arXiv:0901.2763 +
A.Ogawa @CIPANP09

- Leading twist cross section does not depend on transverse polarization.
- Spin Dependence require refinements like:
  - Beyond Collinear Factorization **(Sivers)**
  - Models of spin dependent factorization **(Collins)**
  - Models that go **beyond leading twist.**

<u>Sivers Model:</u> Initial quark picks up k_T from initial state wave function, proportional to orbital angular momentum.

Jet based Asymmetry, significant dependence of A_N on the details of near side jet fragments is not expected!

<u>Collins Model:</u> Final π^0 picks up k_T from fragmentation of polarized quark. Vanishing jet asymmetry. Observed A_N will depend on the details of near side fragmentation!

A toy model for proton Cross Section at large x.

$$\sigma(p_T) \sim \frac{(1-x_F)^5}{{p_T}^6}$$

<u>Suppose</u> initial state structure or final state fragmentation modifies the hard scattering $\mathbf{p_T}$.
If the spin dependent initial/final state momentum is $\mathbf{k_T}$.

For spin proton spin up: $\langle p_T \rangle \Longrightarrow \langle p_T \rangle - k_T$

For spin proton spin dn: $\langle p_T \rangle \Longrightarrow \langle p_T \rangle + k_T$

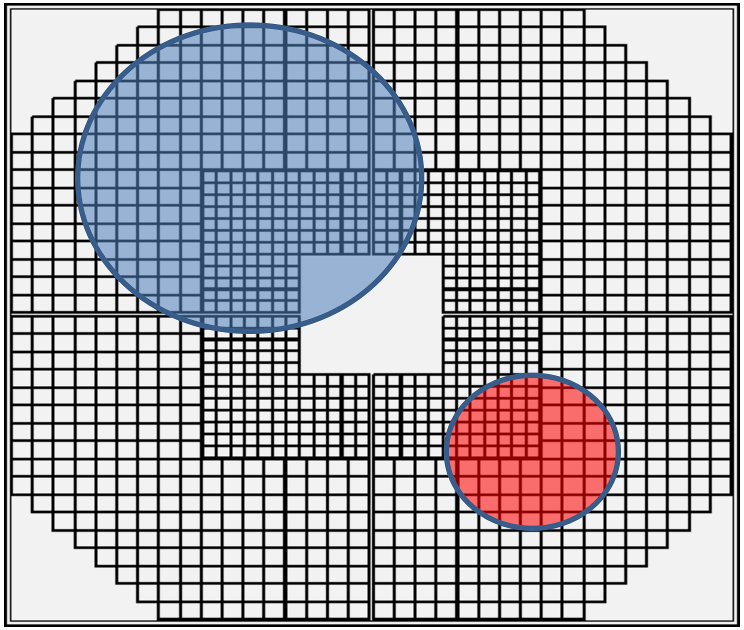
$$A_N(p_T) \sim \frac{\sigma(p_T - k_T) - \sigma(p_T + k_T)}{2\sigma(p_T)} \sim \frac{-k_T}{\sigma}\frac{d\sigma}{dp_T} \sim \frac{6k_T}{p_T} \propto \frac{1}{p_T}$$

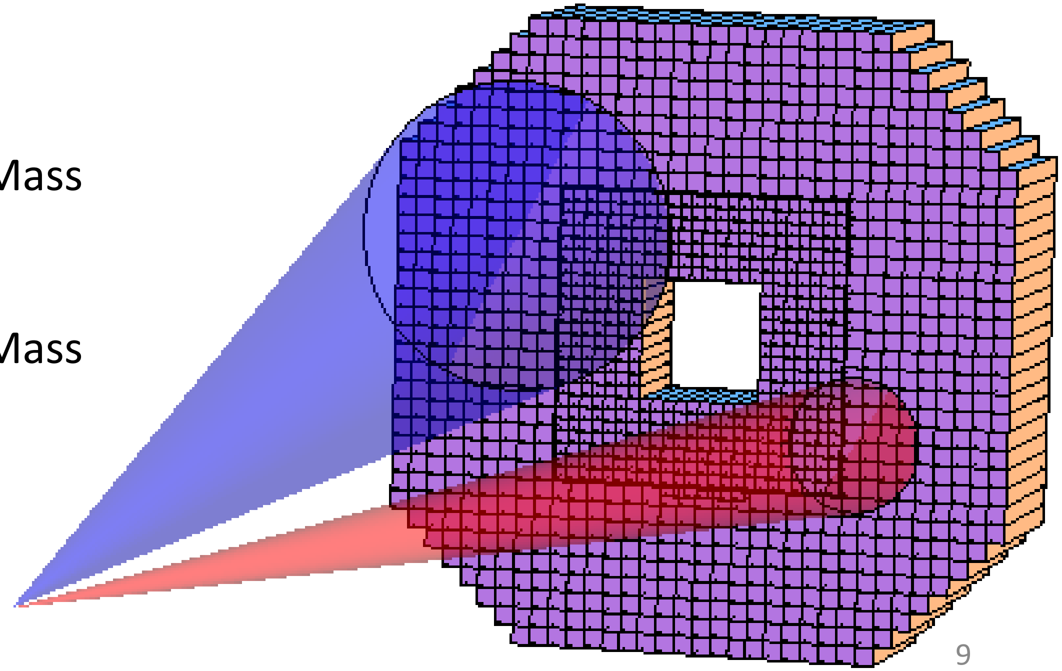
Similar for **for higher twist:** $A_N(p_T) \propto \dfrac{1}{p_T}$

Isolation of π^0 ‘s

Event Selection:

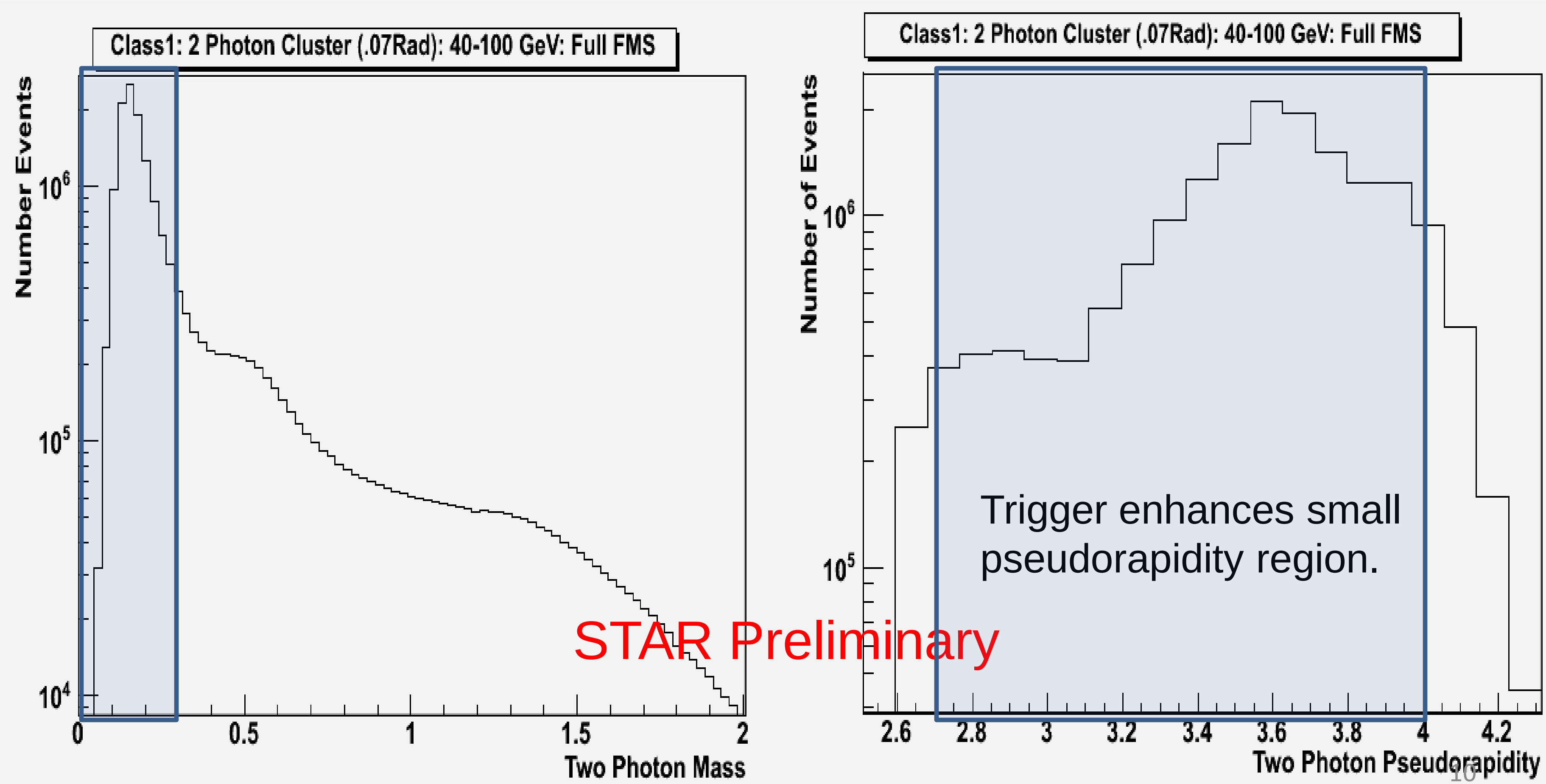
1. **Analyze FMS for all photon** candidates. (Showers that are fit successfully to photon hypothesis)
   A photon candidates must have a minimum of 6 GeV in the small inner detector or 4 GeV in the outer cells.
2. **Find Clusters of EM energy** grouping photon candidates that are within opening angle 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**).





Class 1 Events: $\Delta\theta = 0.07$ 2 Photon clusters, π^0 Mass (less inclusive)?

- 40 GeV < Epair <100 GeV
- $Z = |(E1-E2)/(E1+E2)| < .7$
- 2.7 < Y < 4.0 (Full FMS Pseudo-rapidity)
- Selection of π^0 Peak (0.02 <Mass<.3)
- Average polarization: 51.6% ±6.7% (RHIC Spin CNI Group http://www.phy.bnl.gov/cnipol/)
- Integrated Luminosity: 22 pb^{-1}

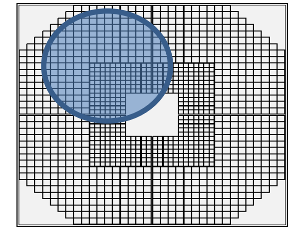


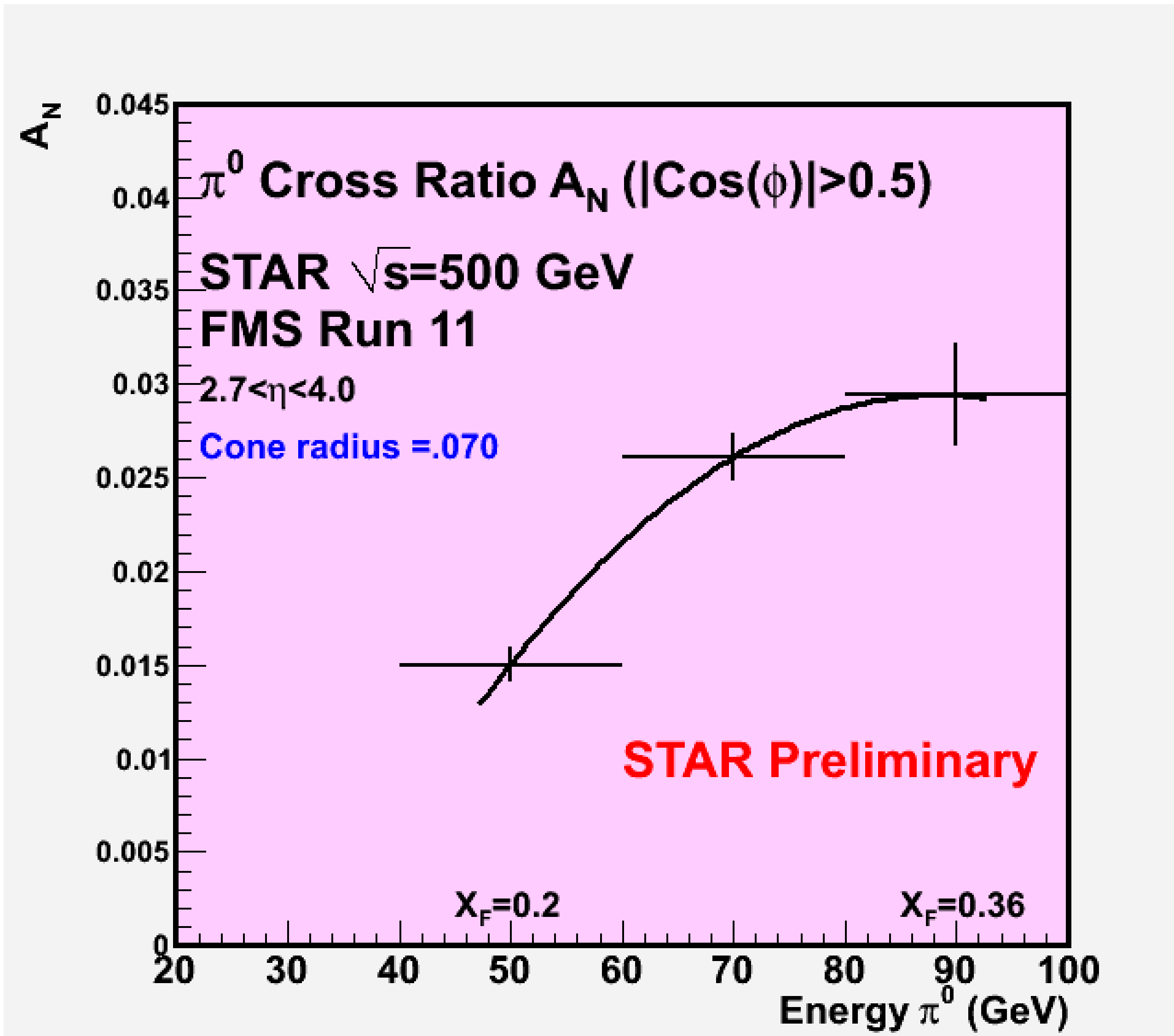
Cross Ratio Transverse Single Spin Asymmetry for Run 11

π^0 (2 Photon Cluster) Cluster size = 0.07 Rad

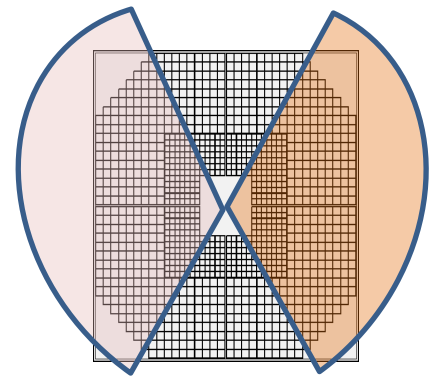
For Blue Beam (Forward)

Full FMS rapidity range (2.6<Y<4.1)



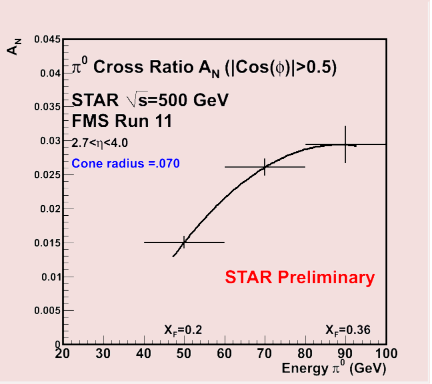


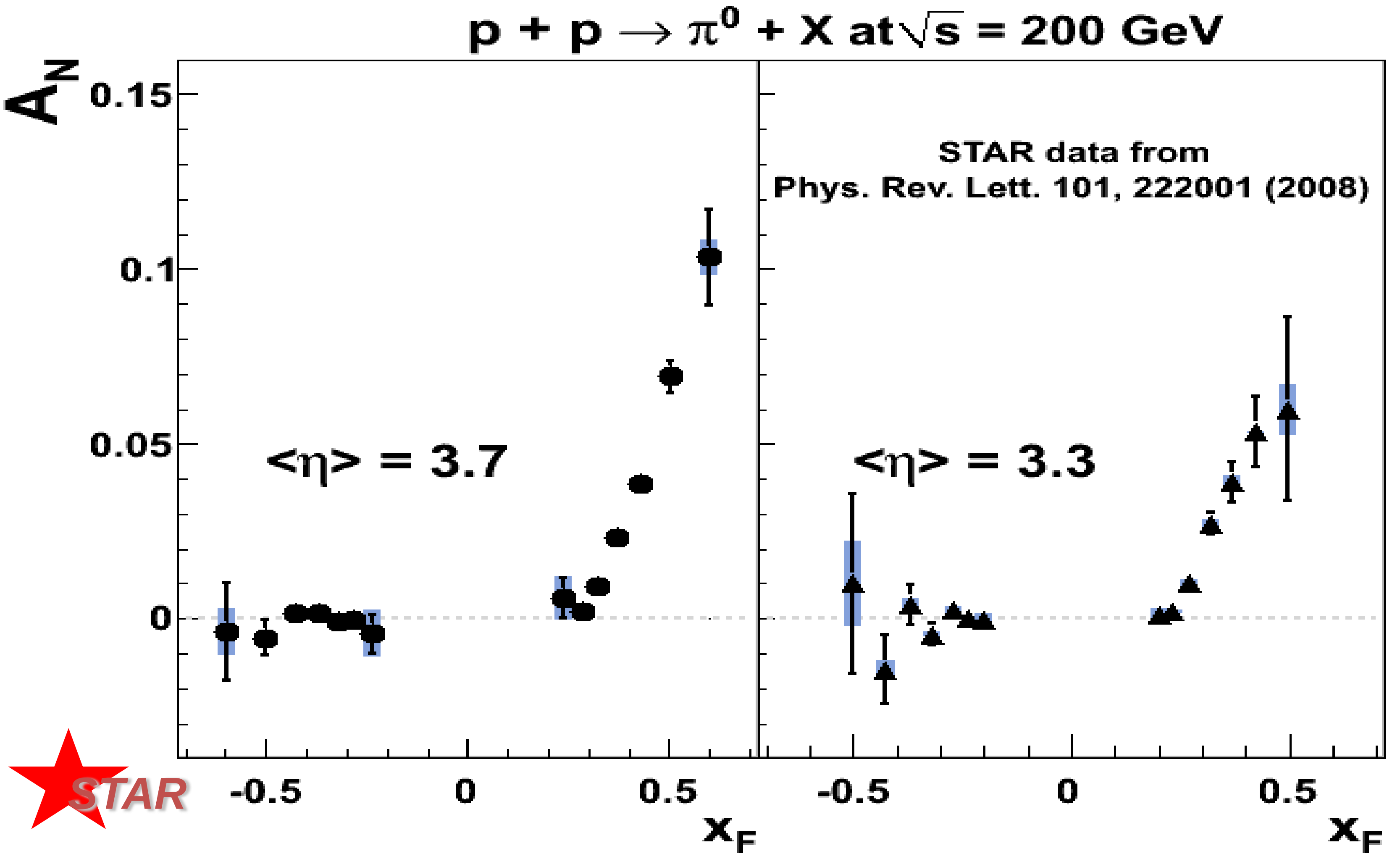
Left(S): Cos(ϕ)>0.5



Right(N): Cos(ϕ)<-0.5

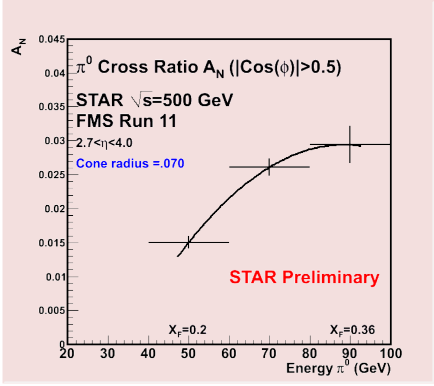
Compare **new √s=500 GeV Run 11** Full FMS Data on right with **Run 6 √s=200** published data below.

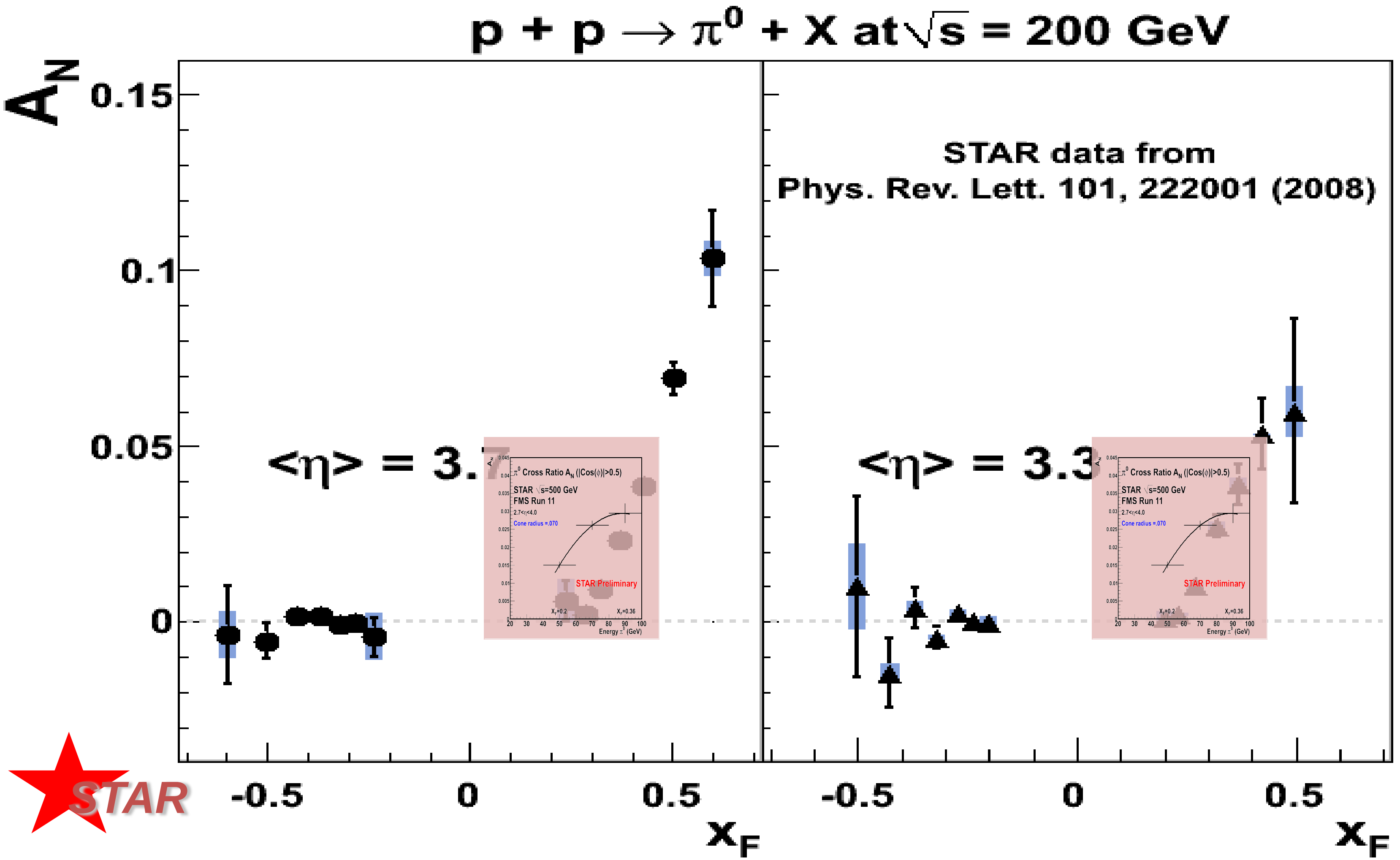


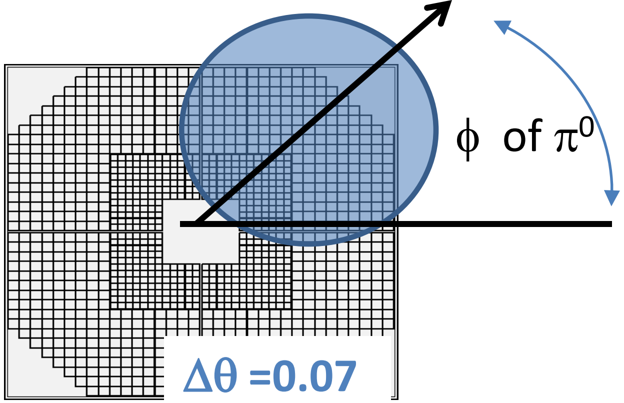


Compare **new √s=500 GeV Run 11** Full FMS Data on right with **Run 6 √s=200** published data below.

Scale of A_N similar but starts at lower X_F in Run 11 data.







Blue Beam A_N

As and alternative to Cross Ratio, the raw asymmetry can be plotted as a function of Cos(ϕ)

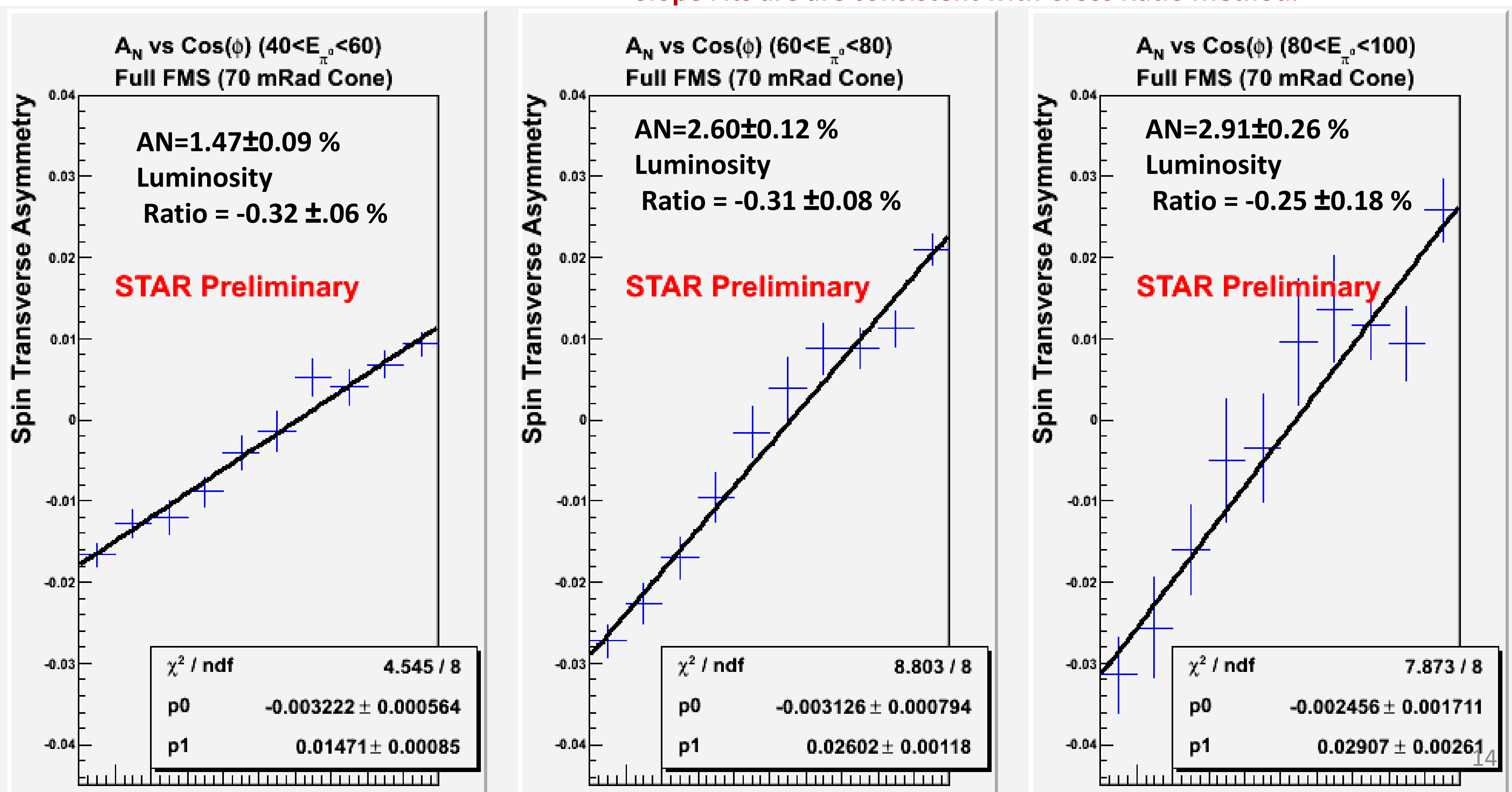
(with polarization axis at Phi=π/2)

Slope =A_N

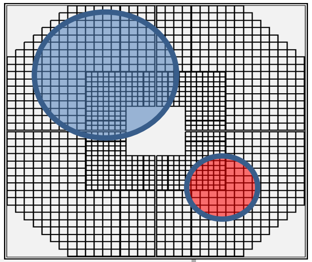
Intercept = Luminosity Ratio for data set

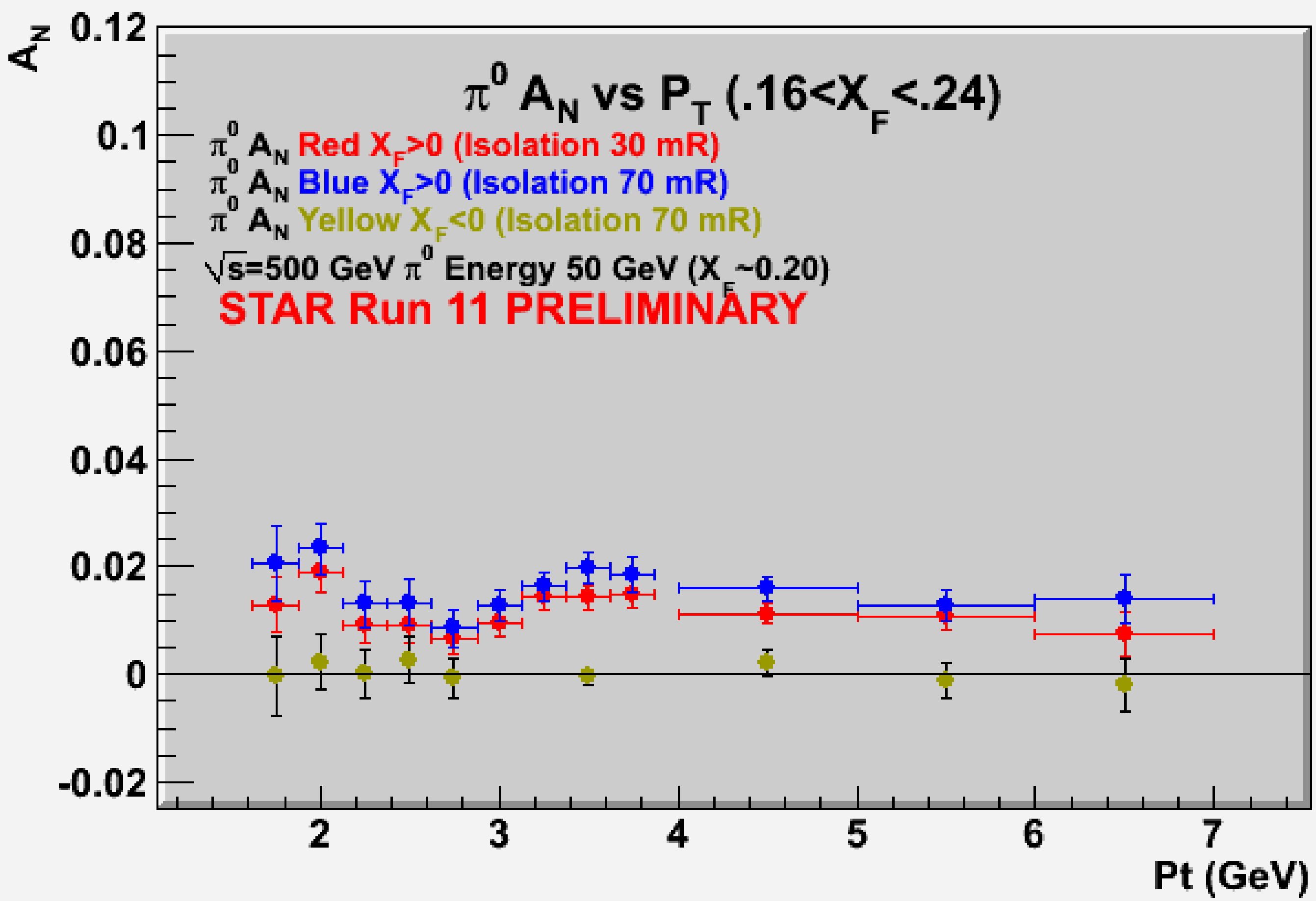
Luminosity ratio for all **~ - 0.31 ±.05 %**

Slope Fits are are consistent with Cross Ratio Method.



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





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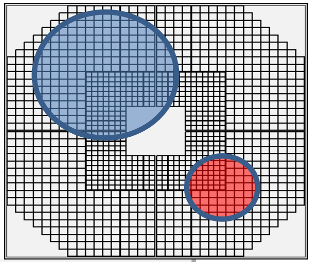

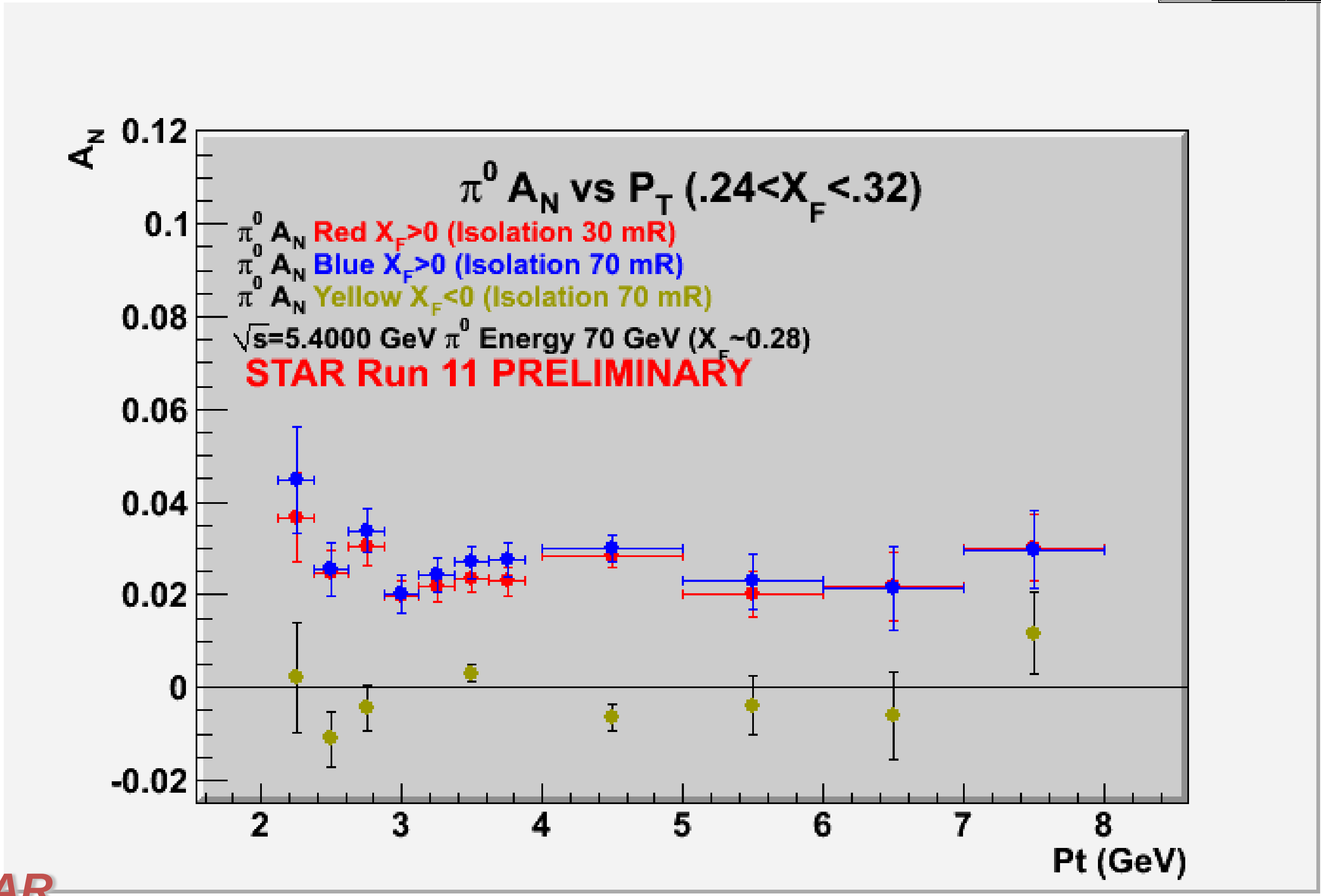

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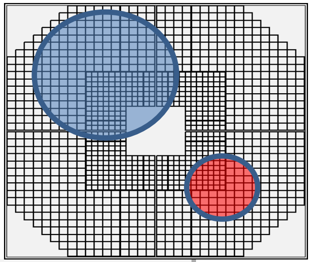
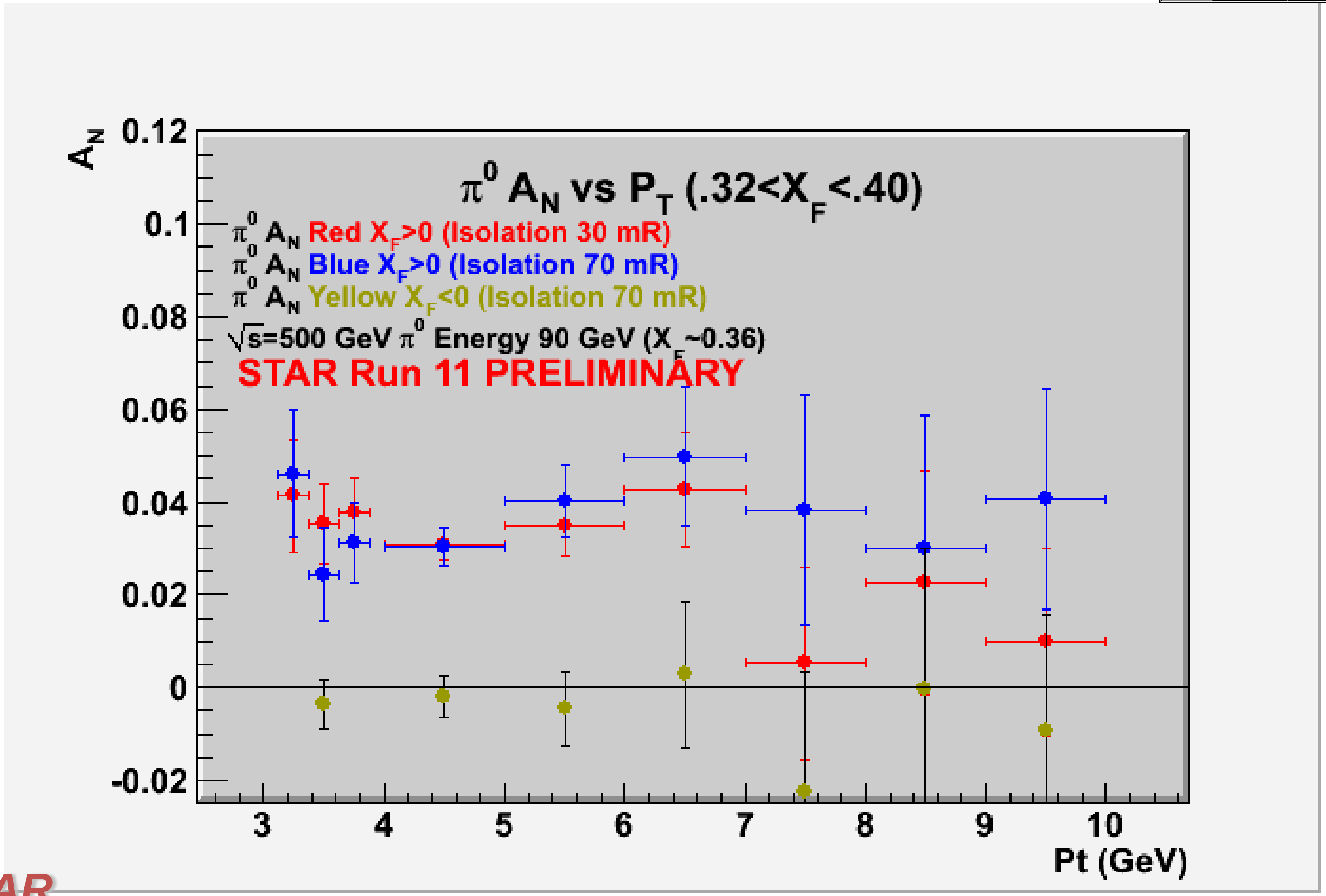
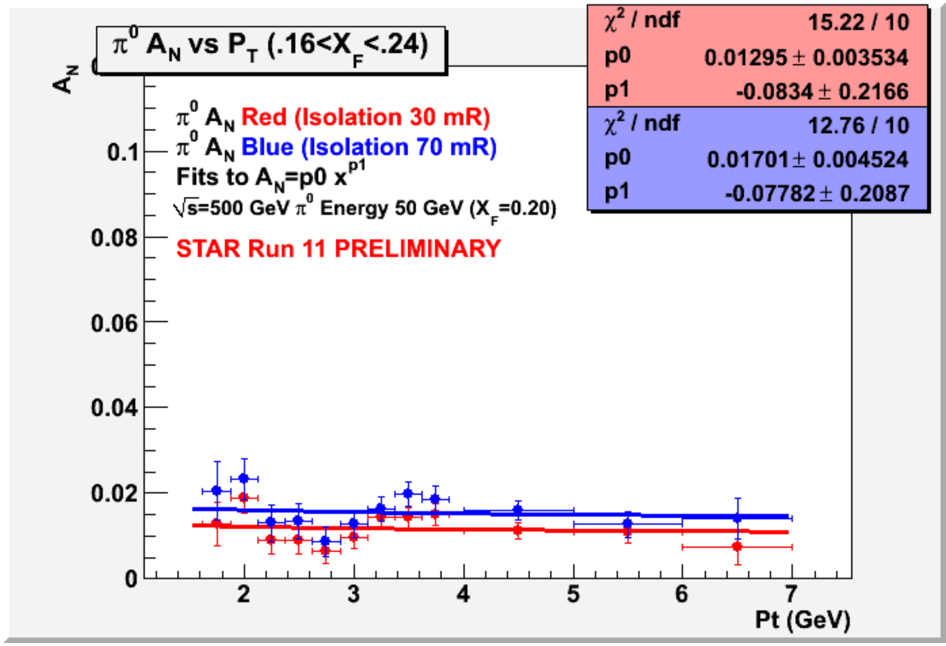




Transverse Single Spin π^0 Asymmetry vs P_T for small and large π^0 isolation cones. (Errors shown are statistical)

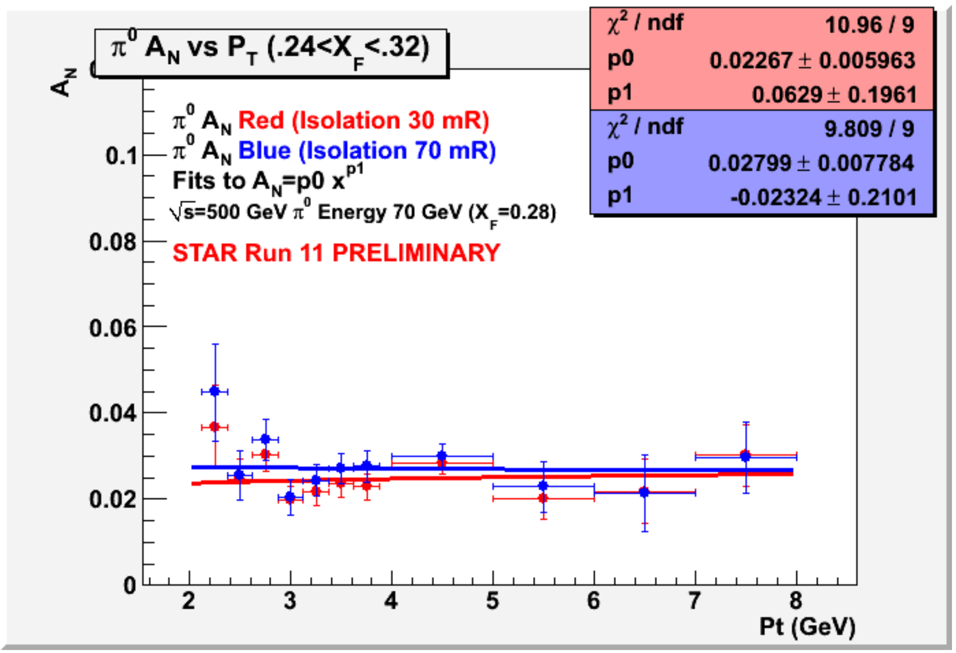


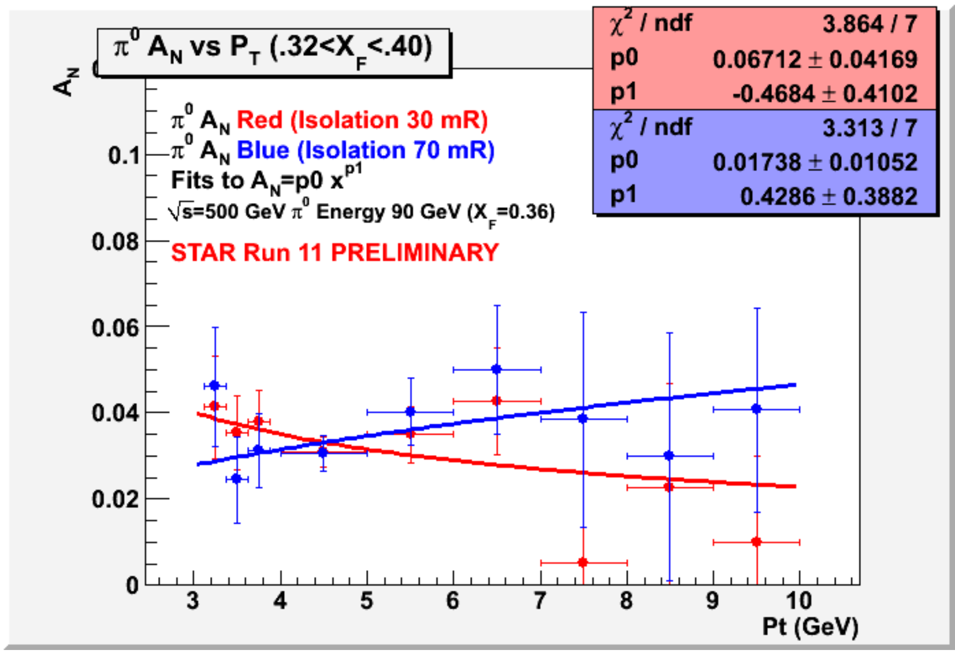
Higher Twist or other pQCD related models suggest
<u>A_N should fall at large P_T with at least 1 power of P_T.</u>

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.





Systematic Errors

- Run 11 blue beam polarization 51.6% ±6.7

$$\frac{\Delta A_N}{A_N} < 13\%$$

- Non π^0 signal <10%
- Similar asymmetries for Background:

$$\frac{\Delta A_N}{A_N} < 5\%$$

$$\frac{\Delta P_T}{P_T} < 12\%$$

$$\frac{\Delta A_N}{A_N} < 5\%$$

- P_T uncertainty
  - Energy 10%
  - Angle 6%

$$\frac{\Delta P_T}{P_T} < 12\%$$

$$\frac{\Delta A_N}{A_N} < 5\%$$

Total Systematic Asymmetry Error
Common to all data points.

$$\frac{\Delta A_N}{A_N} < 15\%$$

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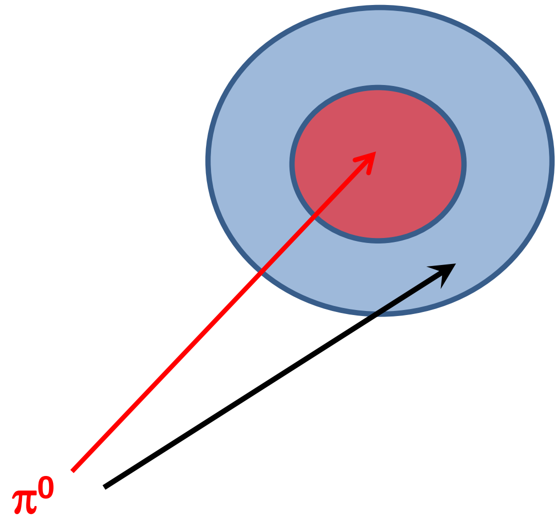
Conclusion

STAR π^0 A_N at $\sqrt{s}$=500 GeV

- 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 π^0s are more isolated (0.07 Rad).

  Additional E&M signals in the same general direction as the π^0 (>~5 GeV between 0.03 and 0.07 radians from the π^0) contribute little to the observed Transverse Single Spin Asymmetry.



- **New Data Coming RHIC RUN 12**
  - **~20 pb^{-1} of $\sqrt{s}$=200 GeV pp**
  - **~Transversely Polarized FMS data**
  - **~ Similar measurement up to P_T >6 GeV/c**

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