Transverse Single Spin Asymmetry and Cross-Sections for Forward π^0 and η Meson at STAR

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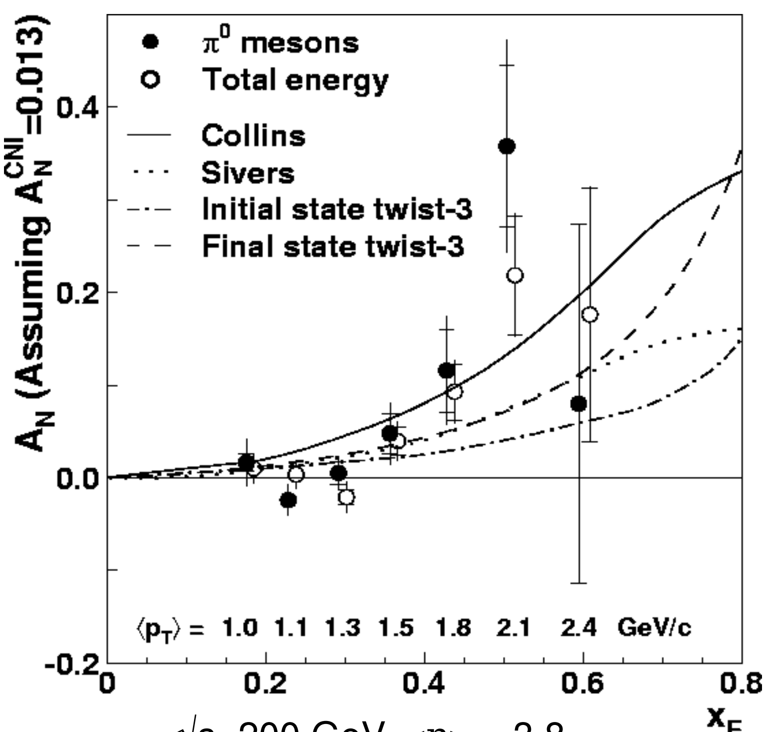
Transverse Single Spin Asymmetry

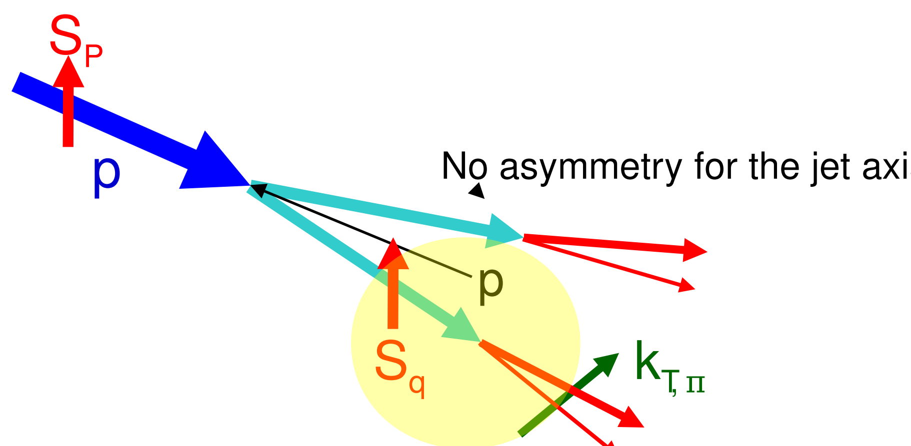
Large Transverse Single Spin Asymmetry(SSA) in forward meson production persists up to RHIC energy.

PRL 92, 171801 (2004)

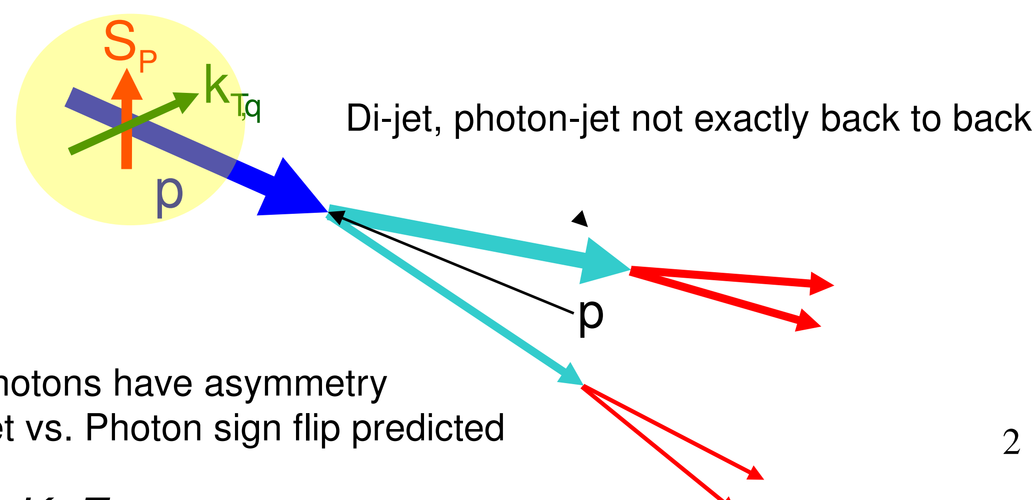


$\sqrt{s}$=200 GeV, $\langle\eta\rangle$ = 3.8

- **Collins effect**: asymmetry comes from the transversity and the spin dependence of jet fragmentation.



- **Sivers effect**: asymmetry comes from spin-correlated k_T in the initial parton distribution



Photons have asymmetry
Jet vs. Photon sign flip predicted

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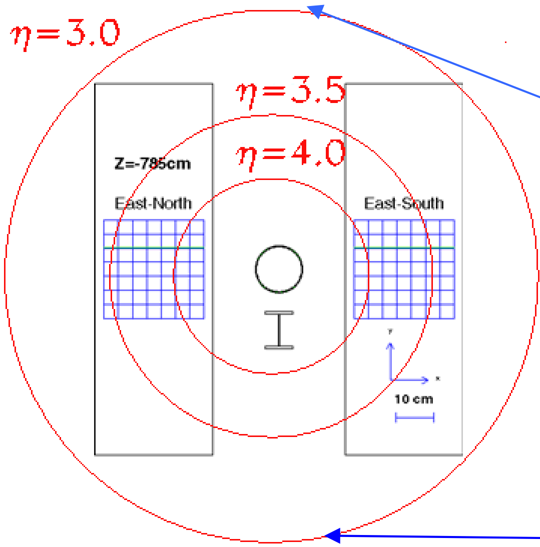
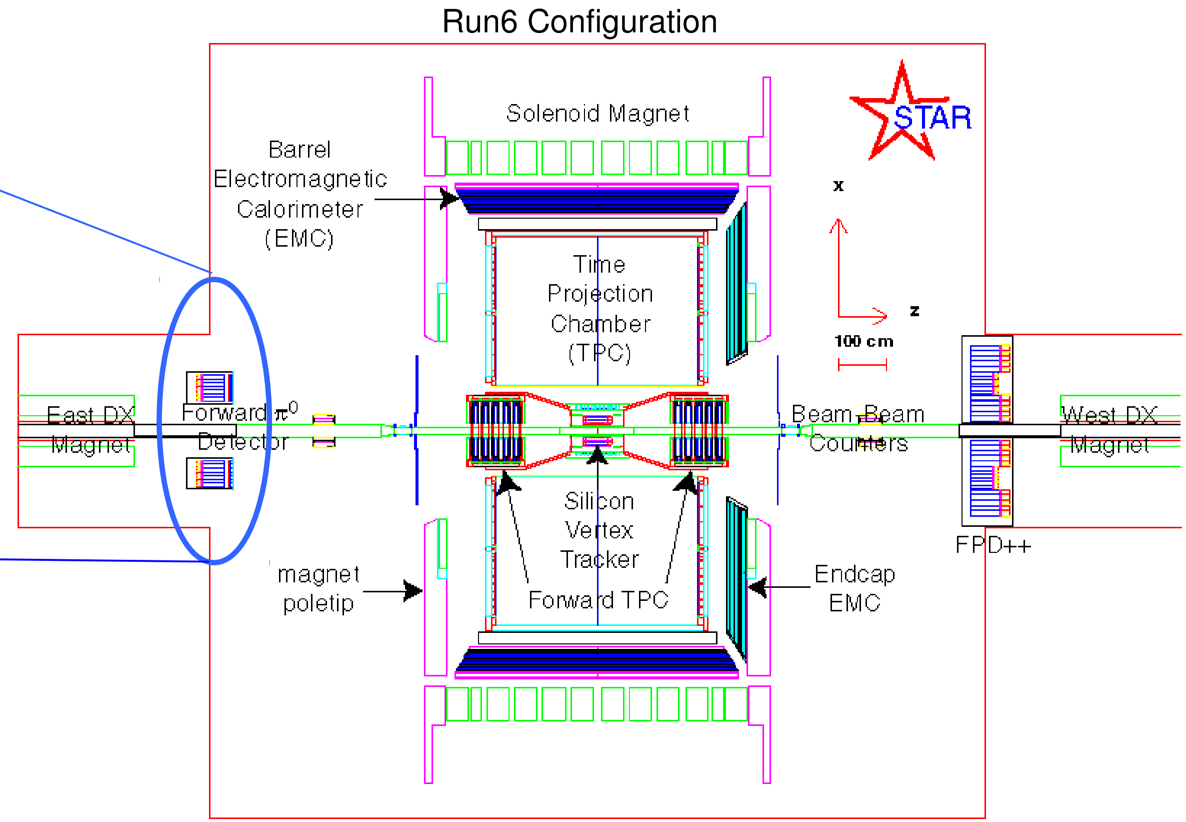
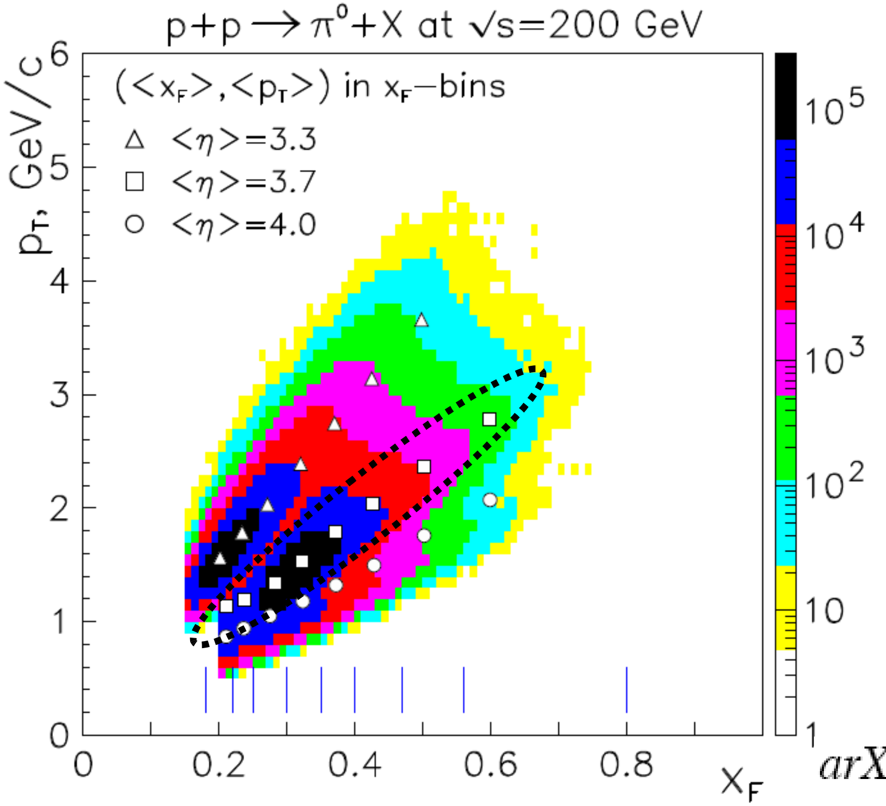
STAR Forward Pion Detector (FPD)





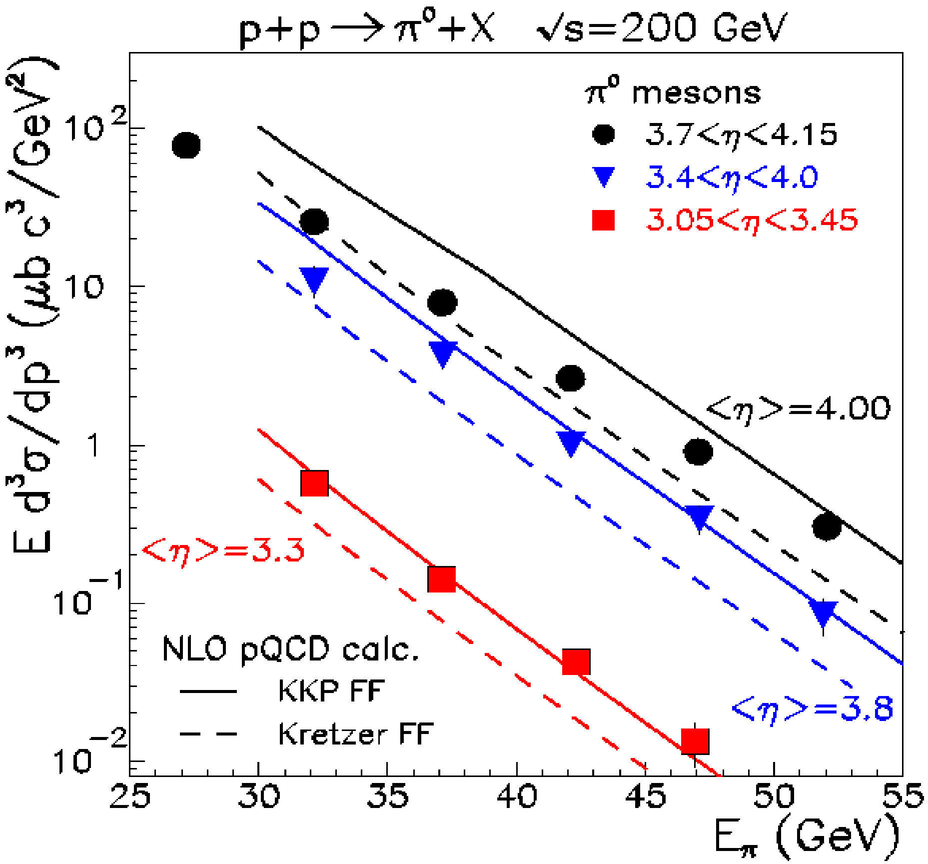


- STAR forward calorimeters have gone through significant upgrades since run3.
- In run6, the original FPD remained in the east, while the west FPD was expanded to FPD++.
- The east FPD consists of two 7X7 Pb-glass modules, EN and ES. During run6, it was placed at the "far" position. (x-offset~30cm, <η>~3.7)

arXiv:0801.2990v1 [hep-ex]

Forward π^0 Single Spin Asymmetry & Cross-Section

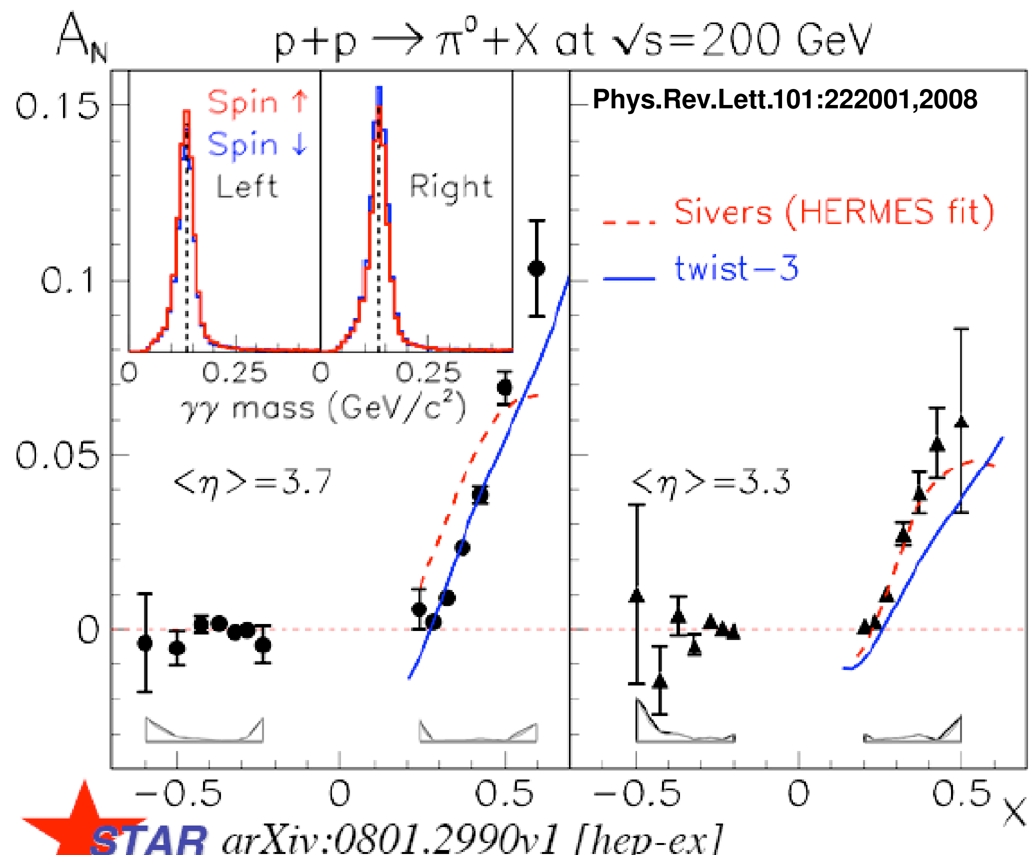
At $\sqrt{s}$=200GeV, π^0 cross-section measured by STAR FPD is consistent with the NLO pQCD calculation. Results at <η>=3.3 and <η>=3.8 have been included in the DSS global pion fragmentation function analysis. *(Phys.Rev.D75(2007) 114010)*



Phys. Rev. Lett. 97 (2006) 152302

In the same kinematic region, STAR FPD has measured a large transverse single spin asymmetry, A_N.

$$A_N = \frac{d\sigma_\uparrow - d\sigma_\downarrow}{d\sigma_\uparrow + d\sigma_\downarrow} \simeq \frac{1}{P}\frac{\sqrt{N_\uparrow S_\downarrow} - \sqrt{N_\downarrow S_\uparrow}}{\sqrt{N_\uparrow S_\downarrow} + \sqrt{N_\downarrow S_\uparrow}}$$



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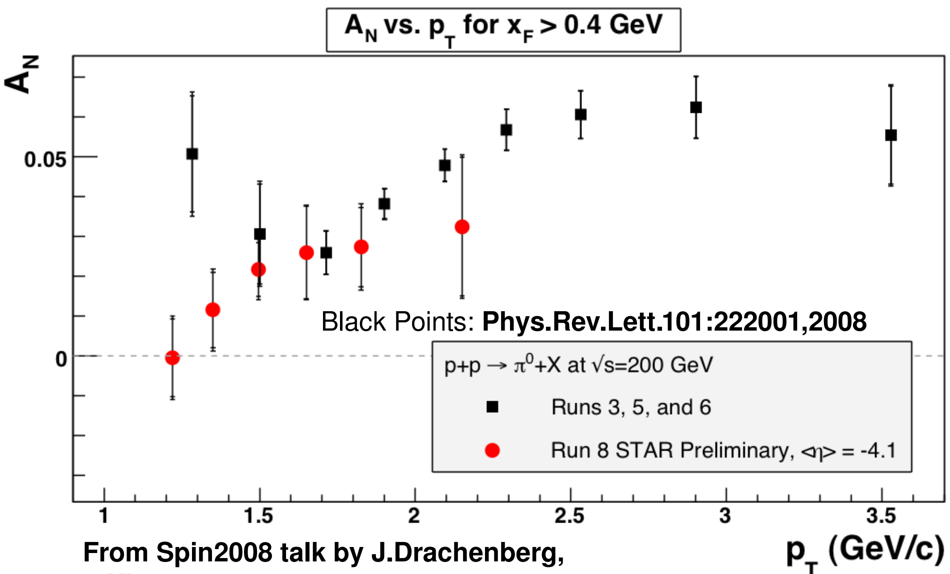
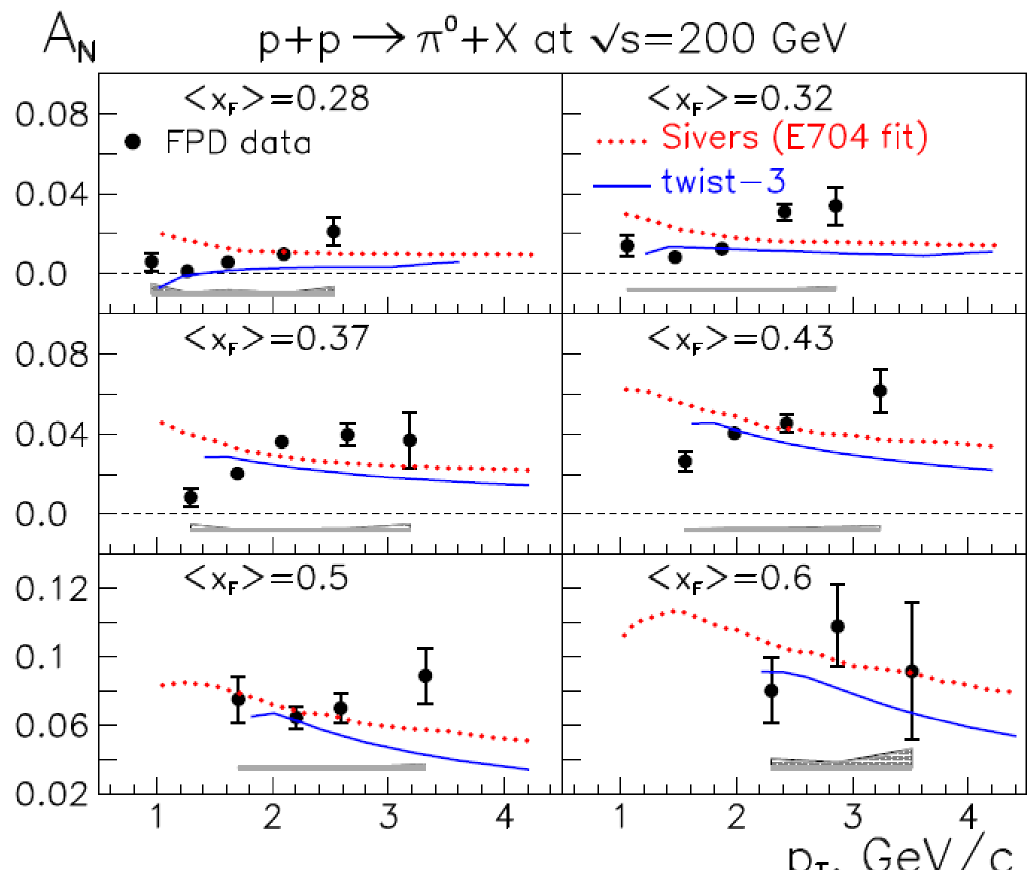
p_T Dependence of A_N

For Fixed X_F, the asymmetry A_N does not fall with p_T as predicted by models, and perhaps expected on very general grounds.



From Spin2008 talk by J.Drachenberg, arXiv:0901.2763



Phys.Rev.Lett.101:222001,2008

U. D'Alesio, F. Murgia, Phys. Rev. D **70**, 074009 (2004).

J. Qiu, G. Sterman, Phys. Rev. D **59**, 014004 (1998).

Sivers/Collins Effects:

Introduces a spin dependent offset in p_T, independent of the details of the hard scattering. (factorization)

$\sigma \sim (1/p_T)^N$ as measured at STAR → $A_N \sim 1/p_T$

Higher Twist Effects:

Qiu and Sterman

Kouvaris et. al. **Phys.Rev.D74:114013,2006**.

A_N Fall as $1/P_T$ as required by the definition of higher twist.

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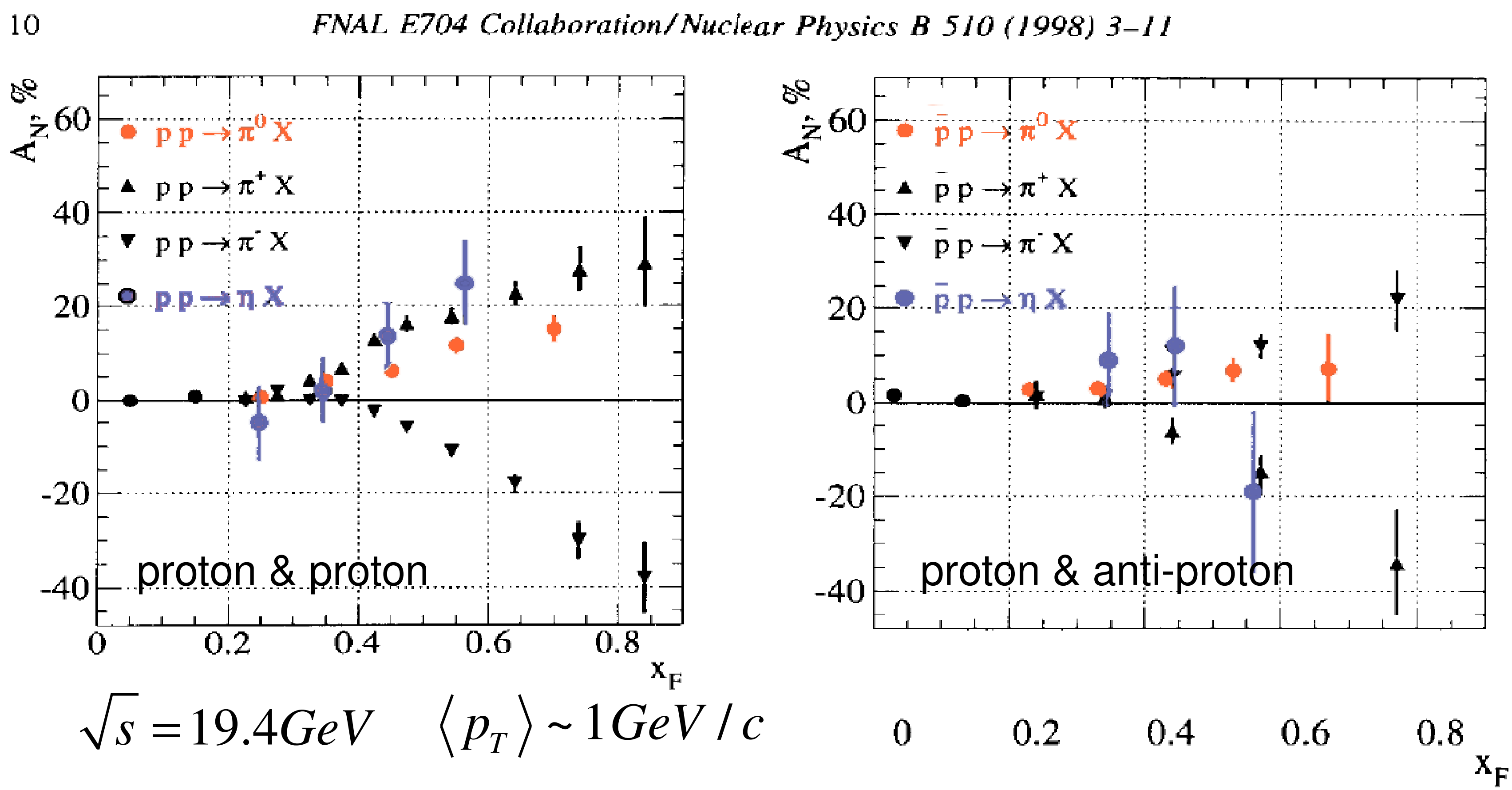
Previous Observation of Transverse SSA Forward Production of Eta Meson by FNAL Exp 704

Nominally (perhaps not significantly) larger asymmetry at high x_F for Eta than π^0. Large Uncertainty in Eta A_N.

$$p_{\uparrow} + p \rightarrow M + X$$
$$\bar{p}_{\uparrow} + p \rightarrow M + X$$

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

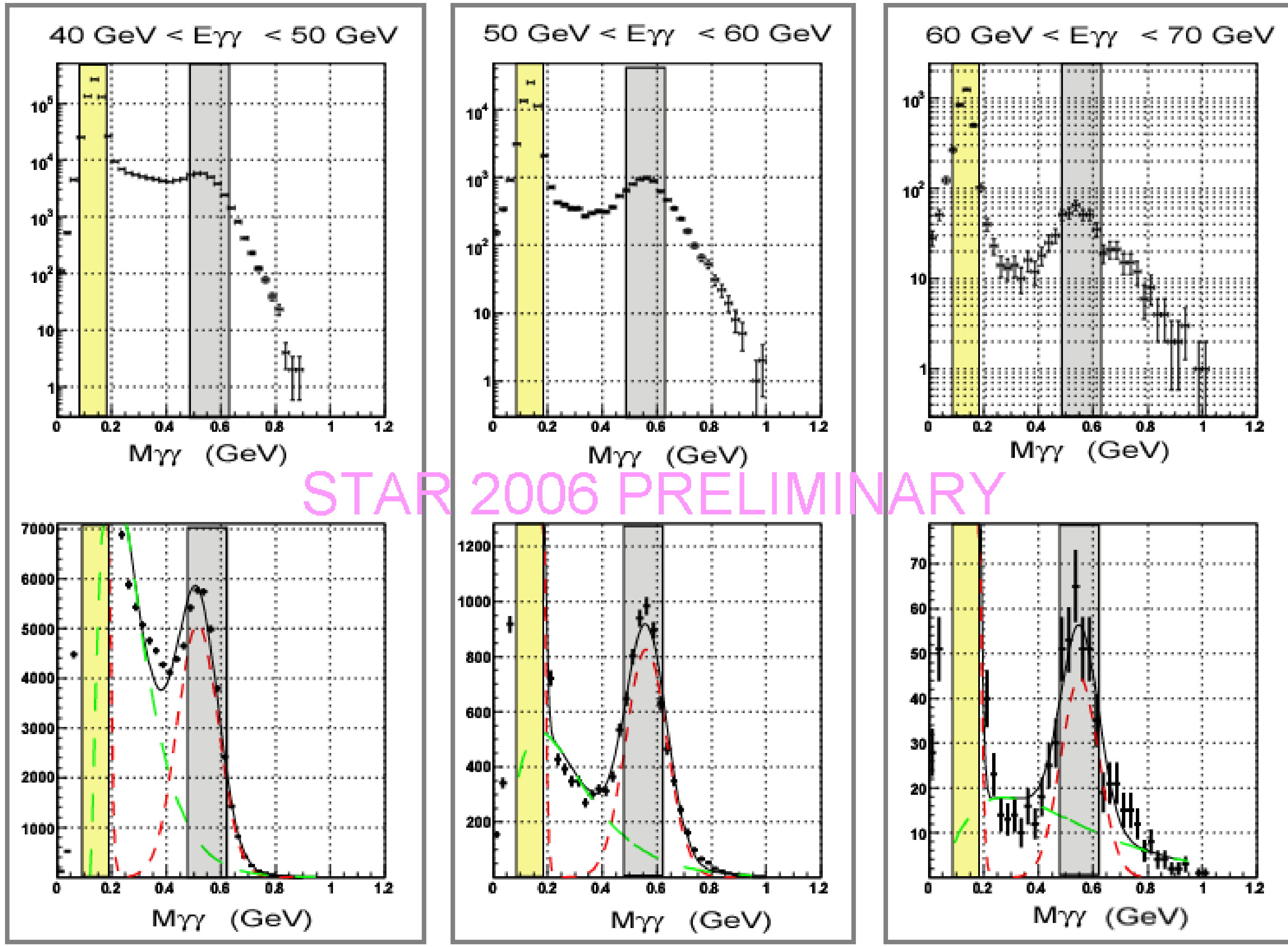


$$\sqrt{s} = 19.4 GeV \quad \langle p_T \rangle \sim 1 GeV/c$$

Eta Signal in Run6 FPD

Di-Photon Invariant Mass Spectra in 3 Energy Bins

- Center Cut
- 3 columns for 3 energy bins
- Each column shows a single plot in log and linear scale.



π^0 Mass Cut

$$.085GeV < M_{\gamma\gamma} < .185GeV$$

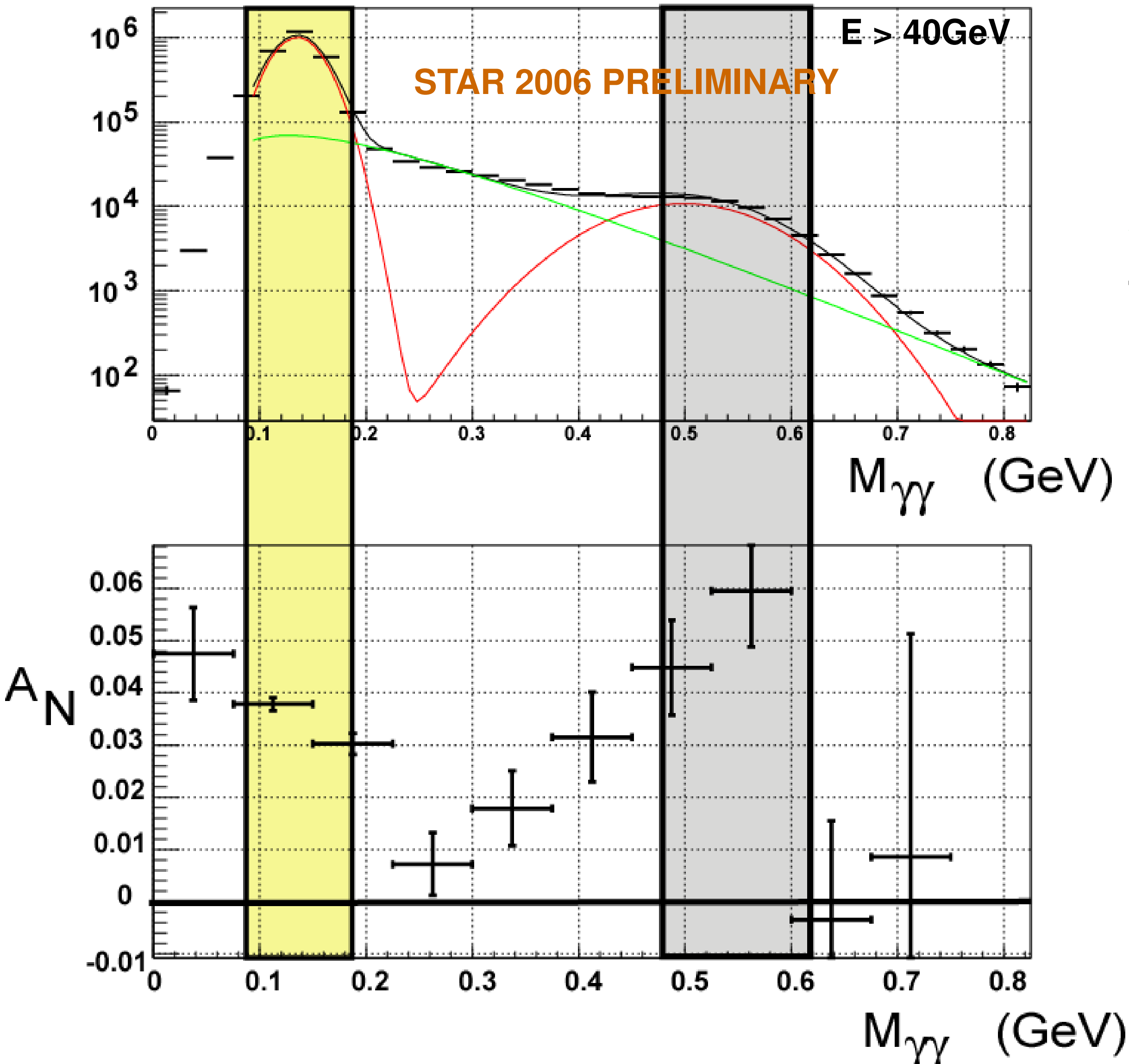
Eta Mass Cut

$$.48GeV < M_{\gamma\gamma} < .62GeV$$

$A_N(x_F)$ is reported for di-photon events in these two shaded mass regions. We do not separate contributions from backgrounds under the Eta and π^0 peaks.

Mass Dependence of A_N

$$p_{\uparrow} + p \rightarrow M + X$$
$$M \rightarrow \gamma + \gamma \qquad \sqrt{s} = 200\,GeV$$



1. Nphoton = 2
2. Etotal > 40GeV
3. No Center Cut*
4. Average Beam Polarization = 56%

- Asymmetry clearly reveals the shape of two mass resonances.
- There is an "asymmetry valley" in between π^0 and Eta mass regions.

*Center Cut

$\rightarrow$ $(\eta - 3.65)^2 + Tan(\phi)^2 < (0.15)^2$

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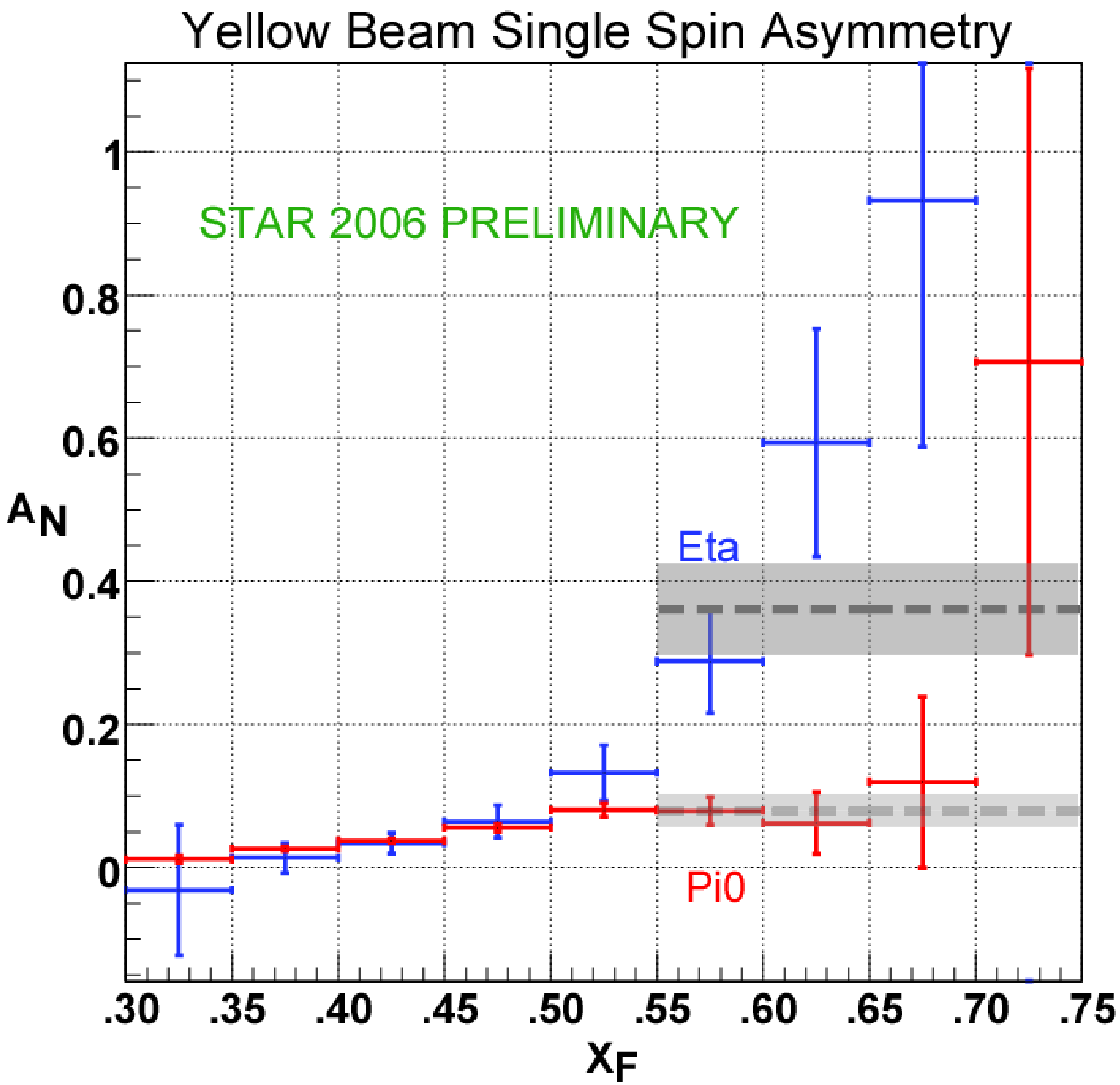
$A_N(x_F)$ in π^0 and Eta Mass Regions

$$p_{\uparrow} + p \rightarrow M + X$$
$$M \rightarrow \gamma + \gamma \quad \sqrt{s} = 200\,GeV$$



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1. Nphoton = 2
2. Center Cut (η and ϕ)
3. Pi0 or Eta mass cuts
4. Average Beam Polarization = 56%

$$.55 < X_F < .75$$
$$\langle A_N \rangle_\eta = 0.361 \pm 0.064$$
$$\langle A_N \rangle_\pi = 0.078 \pm 0.018$$

For $0.55 < X_F < 0.75$, the asymmetry in the Eta mass region is greater than 5 sigma above zero, and about 4 sigma above the asymmetry in the π^0 mass region.

Theory Score Card For Factorized QCD Picture for π^0 & η Transverse A_N

✓ Cross Section for π^0 agrees with PQCD (Normalization and Shape)

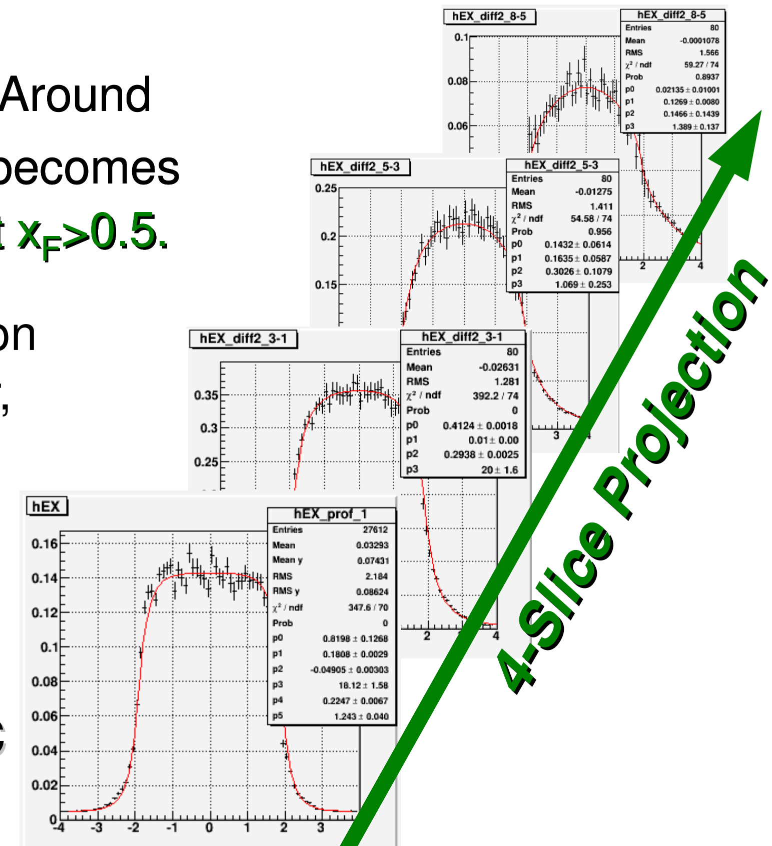
✓ Model calculations (Sivers, Collins, or Twist-3) can explain the x_F dependence of π^0 A_N

X Pt dependence of π^0 A_N. Inconsistent with $A_N \sim 1/p_T$

? Large difference in A_N between π^0 and η Can Collins or SIvers Model explain it?

? Ratio η / π^0 → nominal 40% - 50% Preliminary Result!

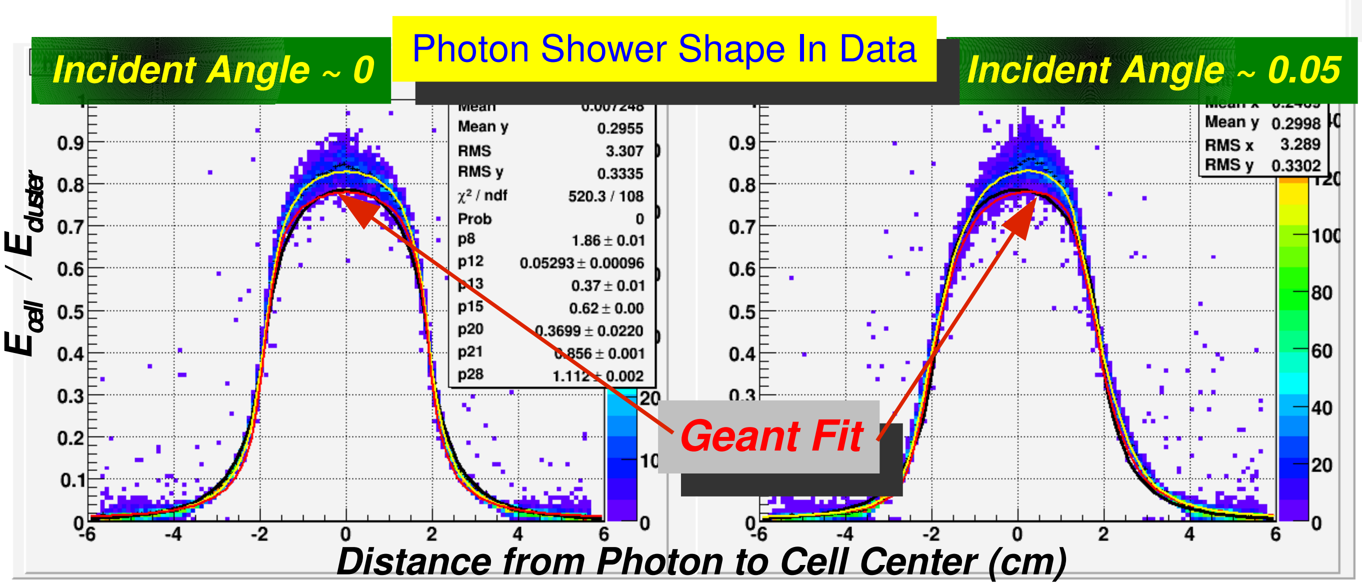
Measuring Cross-sections for Large x_F π^0 and η



- Previous π^0 cross-section measurement reached x_F of 0.55. Around this point, the average separation between π^0 decay photons becomes less than 1 cell width. Our η acceptance, however is mostly at x_F>0.5.

- For the purposes of the spin measurement, our reconstruction algorithm proved to be adequate for x_F of up to 0.75. However, for the X-section measurement, substantial reworking was needed to achieve the required precision.

Incident angle effect → Geant based discrete projection
Improved π^0-γ separation → Based on cluster shape
Revised error function → More fluctuation in the data than MC

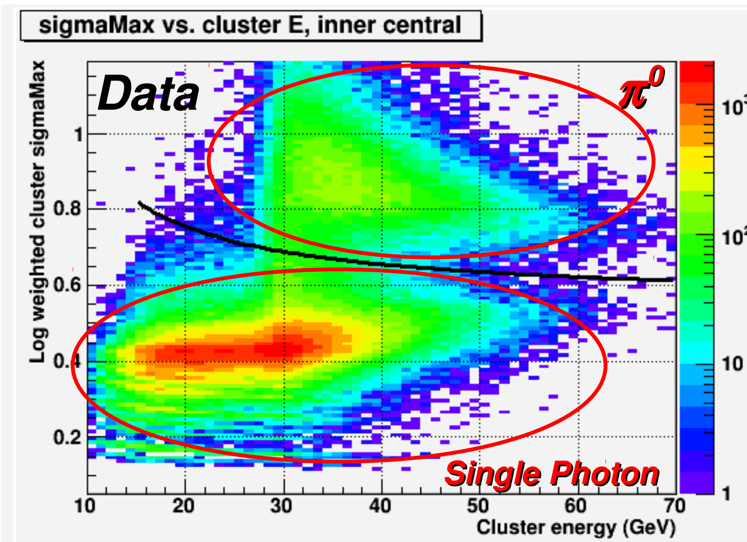


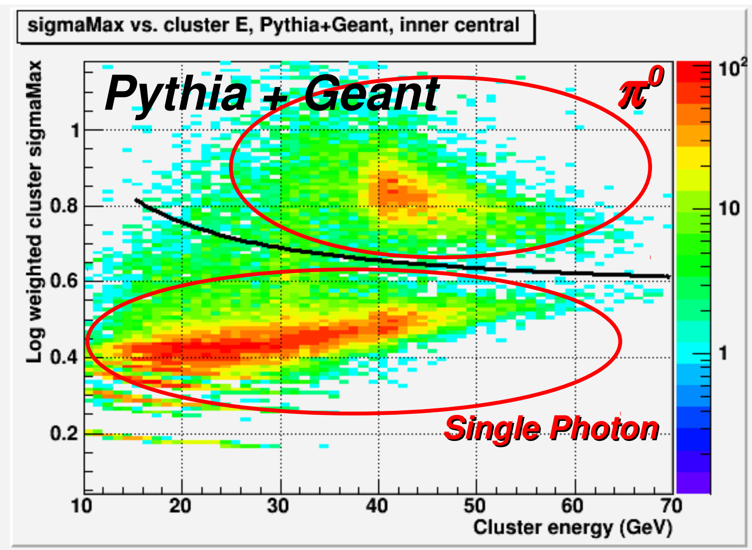
- Furthermore, there is an apparent discrepancy in shower shape between the data and Geant 4 simulation (*the data has a narrower shower*) → Increases calibration uncertainty

Background Correction

1. Single photon background for high-energy / small-separation π^0 signal

→ Potentially stronger prompt photon X-section at high x_F can aggravate it



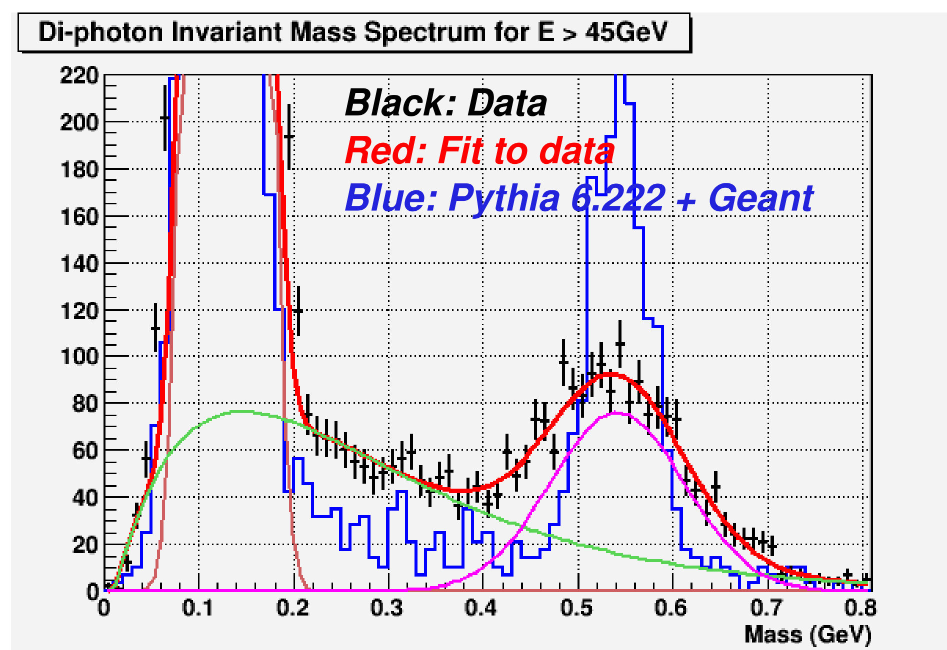


Log weighted 2nd moment of the cluster is an excellent tag to distinguish two type of clusters, up to x_F of 0.75, and potentially higher.

2. Di-photon background (π^0 – η continuum)

→ Negligible for $x_F > 0.55$

- Forward X-sections are extremely version dependent in Pythia.
- Pythia v. 6.222 seems to have the most realistic forward X-section, but it does not reproduce the full di-photon mass spectrum seen in data.
- We proceed with a purely emprical fit consisting of two Gaussians and a gamma function.

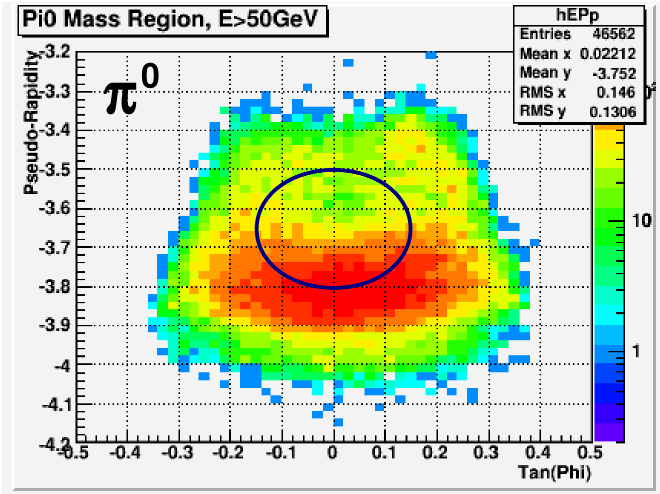


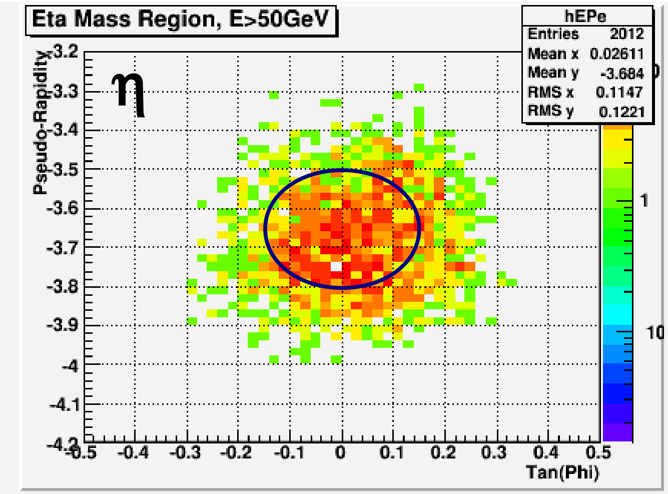
Efficiency/Acceptance Correction

As with the A_N measurement, we look at π^0 and η signals in the kinematic region defined by

$$(\eta - 3.65)^2 + Tan(\phi)^2 < (0.15)^2$$

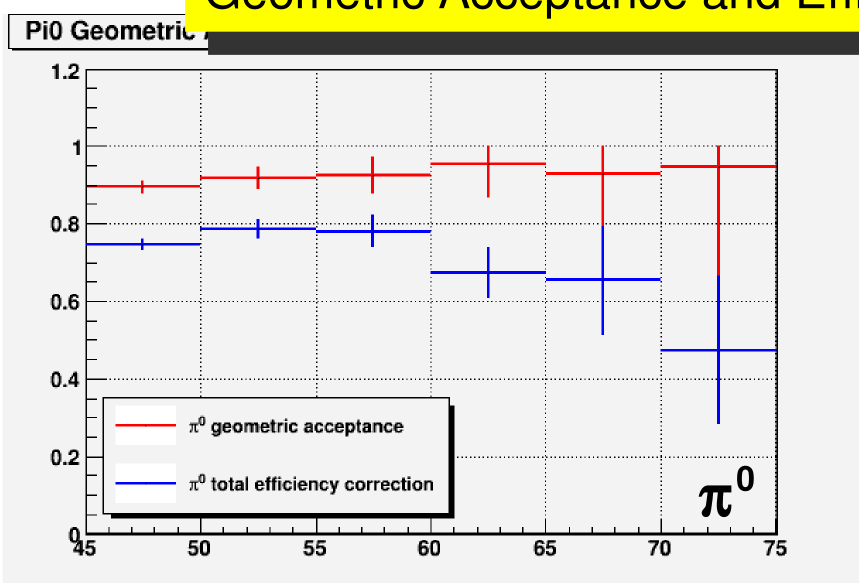
~1 nb^{-1} Pythia 6.222 + Geant 4 sample was used

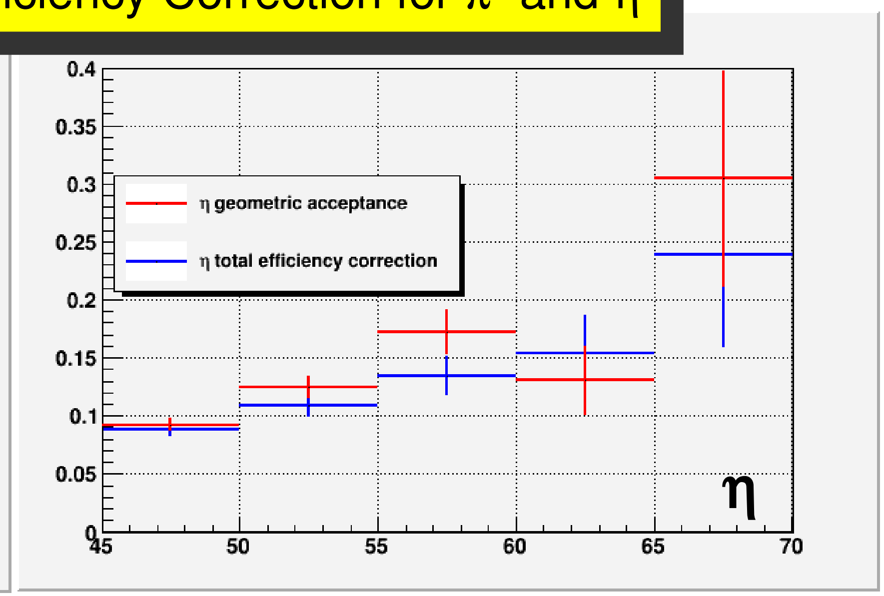




Full reconstruction with trigger emulation and shower function fit to Geant

Geometric Acceptance and Efficiency Correction for π^0 and η

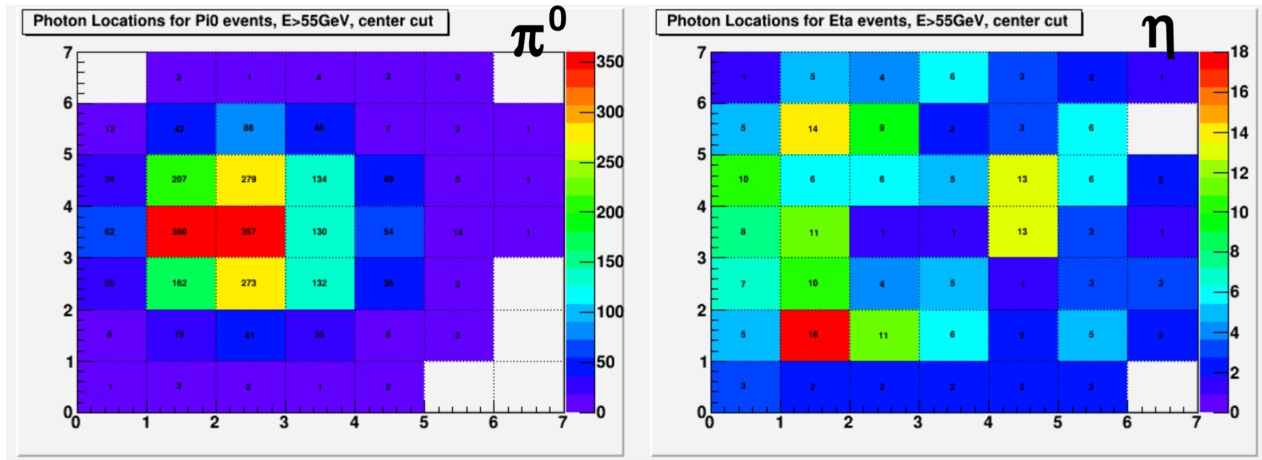




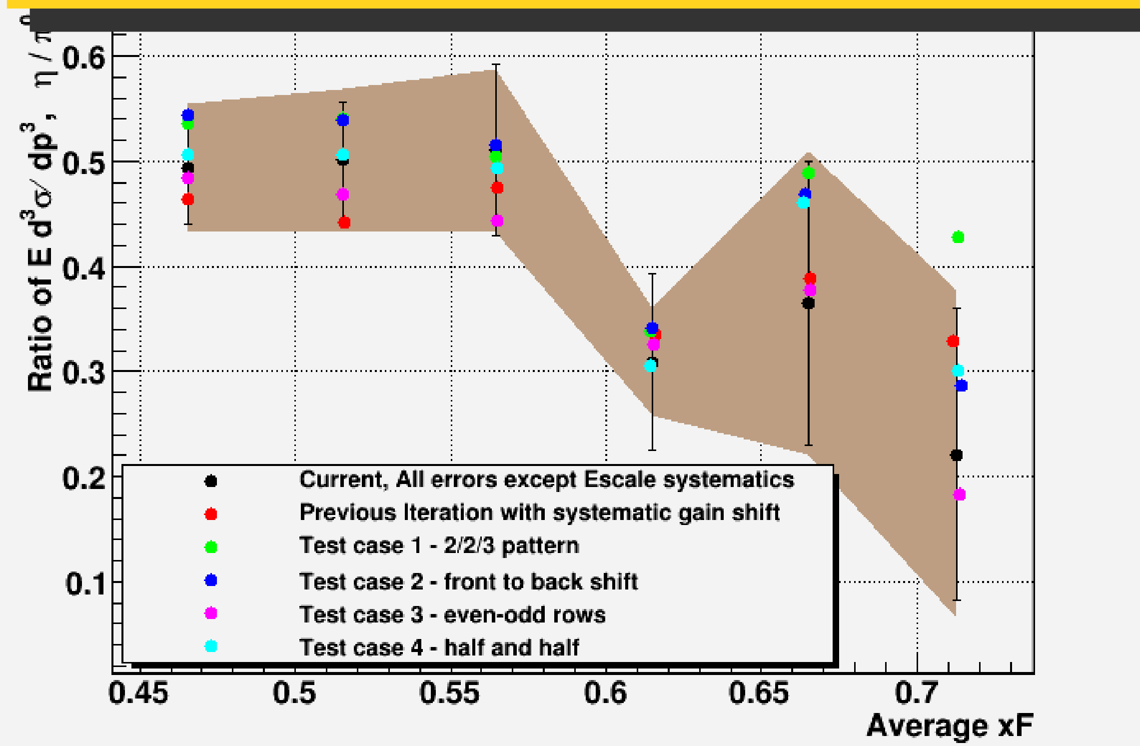
Relative Energy Scale Systematics

The leading systematics for the X-section ratio analysis is **the relative energy scale between π^0 and η.**
→ Systematic cell by cell calibration non-uniformity is possible.
→ The two mesons populate somewhat different regions of the detector.

Photon Locations for π^0 and η with Epair > 55GeV



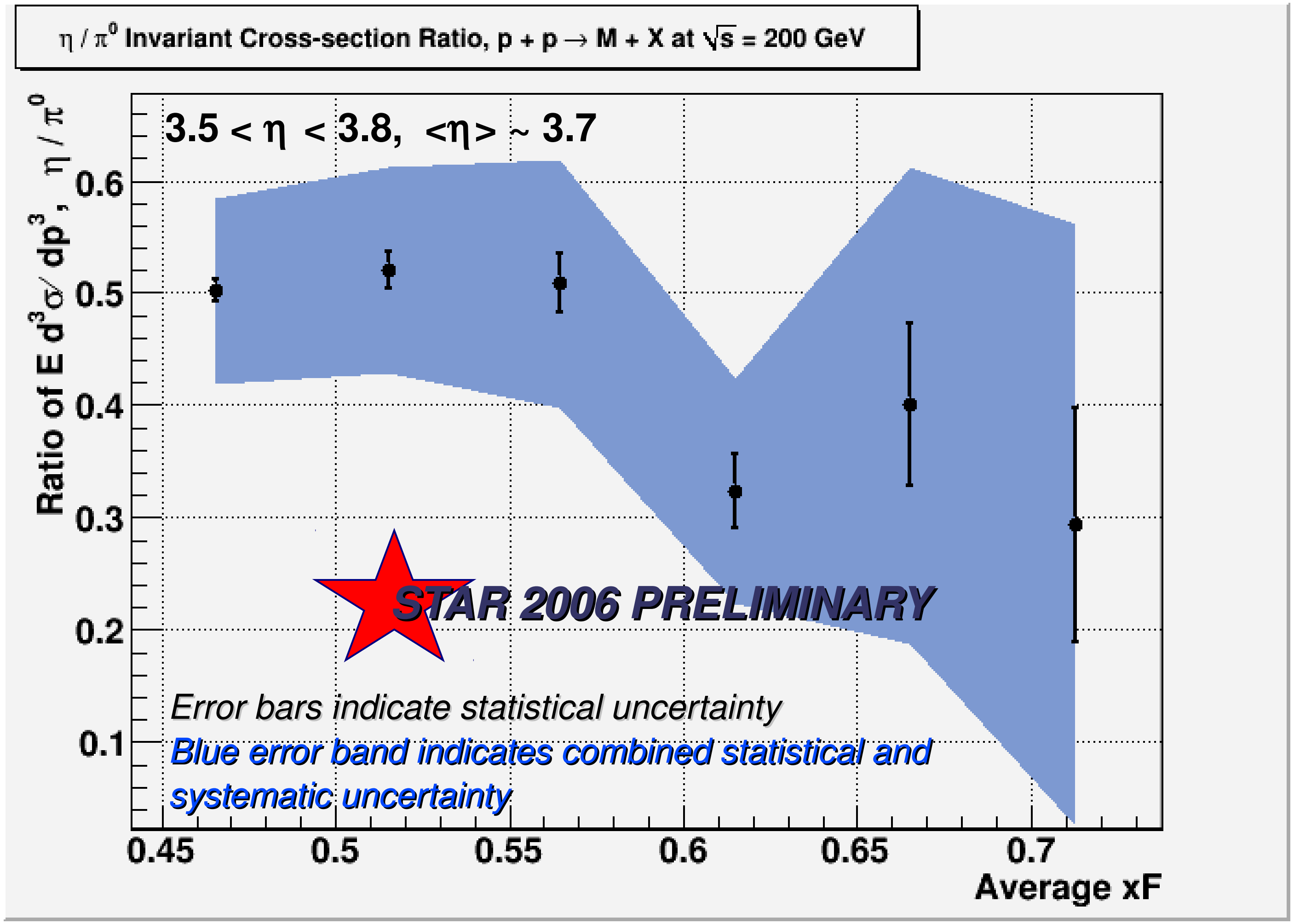
Evaluation of the Energy Scale Uncertainty



In order to estimate the effects of the gain non-uniformity including potential cancellations, we tried **artificially generated, severely pathological examples of the most likely patterns that could appear in the calibration.**

The X-section ratio was measured in each case, and the envelope for the energy scale systematics was determined.

Preliminary η / π^0 Cross-section Ratio



Points are plotted at the average x_F point for each bin, with a uniform bin size of 0.05 in x_F to make 6 bins from x_F of 0.45 to x_F of 0.75.

Summary

1. The STAR Forward Pion Detectors (FPD) at RHIC measured cross-section for π^0 meson in $\langle\eta\rangle=3.3\sim4.0$ region during $\sqrt{s}=200$GeV p+p collision. It was found to be consistent with pQCD calculations.

2. From RHIC run3 to run8, the FPD measured large forward single spin asymmetry, A_N, for π^0. The x_F dependence of A_N was qualitatively consistent with theoretical predictions. p_T dependence, however, differed significantly from predictions based on all currently existing models

3. In addition to π^0, η mesons were observed in the east FPD during RHIC run6. We measured the single spin asymmetry in the π^0 and the η mass regions, at $\langle\eta\rangle\sim3.65$ and x_F above 0.4. **We found the A_N in η mass region to be ~4 standard deviation greater than the A_N in π^0 mass region from 55GeV to 75GeV. ($x_F=0.55\sim0.75$)**

4. Based on the same RHIC run6 east FPD data set used for the η asymmetry measurement, **we now have the preliminary result for the cross-section ratio between π^0 and η for $x_F>0.45$. While systematics are relatively large, the result is consistent with the expected origin of the observed π^0's and η's from jet fragmentation.**

5. For the cross-section measurement, energy scale uncertainty remains the primary systematics. The culprit here is the shower shape discrepancy between the data and Geant 4, which limits the absolute energy scale uncertainty to no better than 4~5%. We are currently working on this issue, and **we aim to measure the absolute cross-section for both π^0 and η for $x_F>0.45$ in the near future.**