PANIC 2008
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Measurement of Transverse Single Spin Asymmetry A_N in Eta Mass Region at Large Feynman X_F with the STAR Forward Pion Detector

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For STAR Collaboration

Previous observation of Single Spin Transverse Asymmetry for Forward Production of Eta Meson by FNAL Exp 704.
They reported:

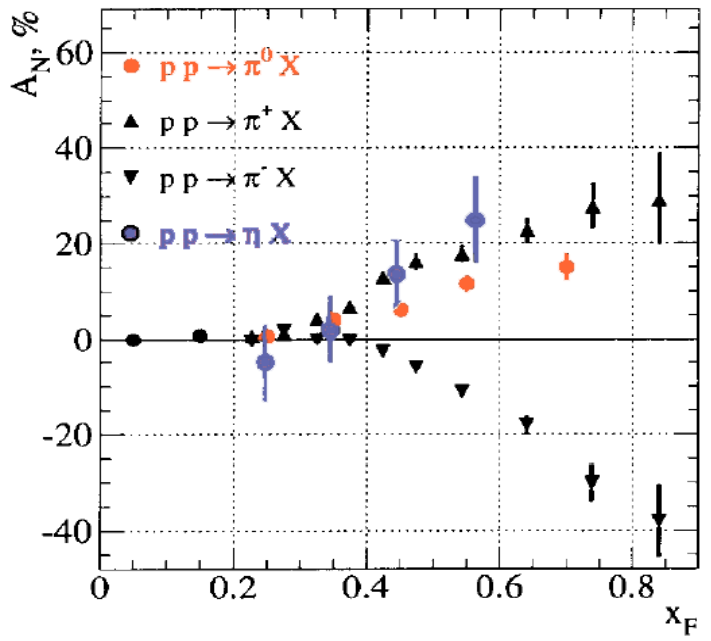
1) Nominally (perhaps not significantly) larger asymmetry for Eta than Pi0.
2) Large Uncertainty in Eta A_N.

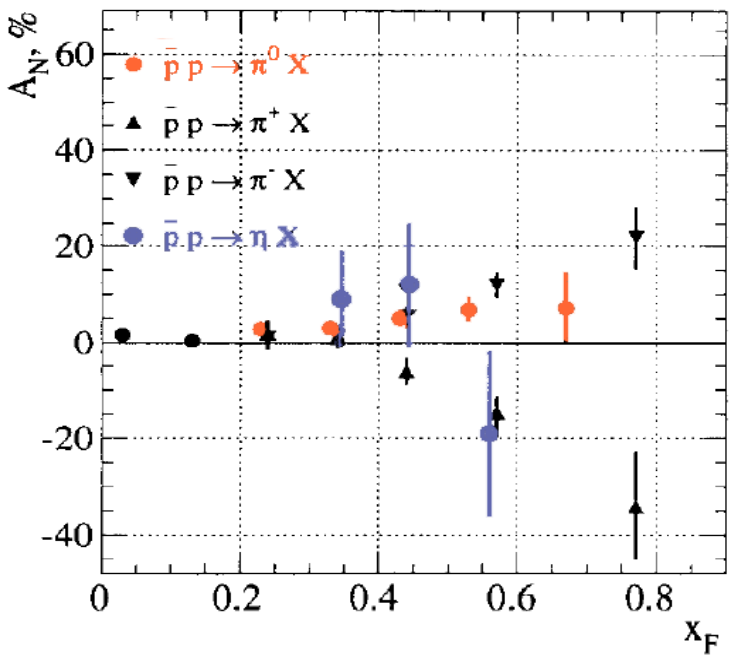
$$p^{\uparrow} + p \rightarrow M + X$$
$$\bar{p}^{\uparrow} + p \rightarrow M + X$$

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

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

FNAL E704 Collaboration/Nuclear Physics B 510 (1998) 3–11





Should A_N be larger for Eta production than Pi0 production?

• Gluons have Isospin I=0. Fragmentation to I=0 Eta mesons at large fragmention fraction Z may be enhanced for gluon jets.

• But in PQCD (both Collins or Sivers models), we expect these mesons to come from fragmentation of quark jets.

$$I=0 \begin{cases} \eta \simeq \frac{1}{\sqrt{3}}\left(u\bar{u}+d\bar{d}-s\bar{s}\right) \\ \eta' \simeq \frac{1}{\sqrt{6}}\left(u\bar{u}+d\bar{d}+2s\bar{s}\right) \end{cases}$$

$$I=1 \begin{cases} \pi^0 = \frac{1}{\sqrt{2}}\left(u\bar{u}-d\bar{d}\right) \end{cases}$$

*Assume η, η' mixing angle: $\theta_P \sim -19.5°$

•For Sivers Effect: Asymmetry is in the jet and should not depend on the details of fragmentation. Do Eta's and Pi0's come from different kinds of jets?

•For Collins Effect: Asymmetry reflects transverse quark polarization through transverse momentum dependence in the fragmentation of the quark jet to a leading Pi0 or Eta meson. Differences in fragmentation could relate to:

•Mass differences?
•Isospin differences?
•Role of Strangeness?

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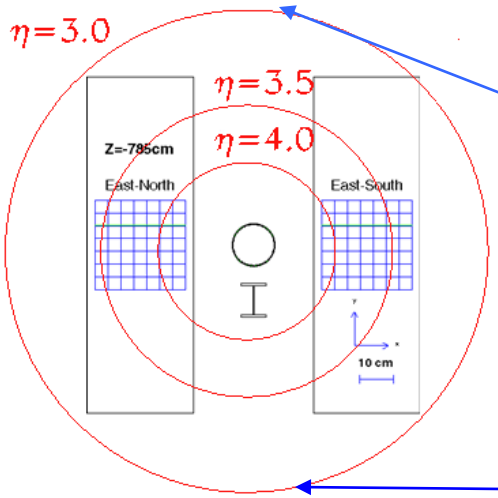
***Pattern from Previous Transverse Single Spin Asymmetry Measurements of Forward Pion/Eta Production with High Energy Polarized Proton/Antiproton Beams*.**

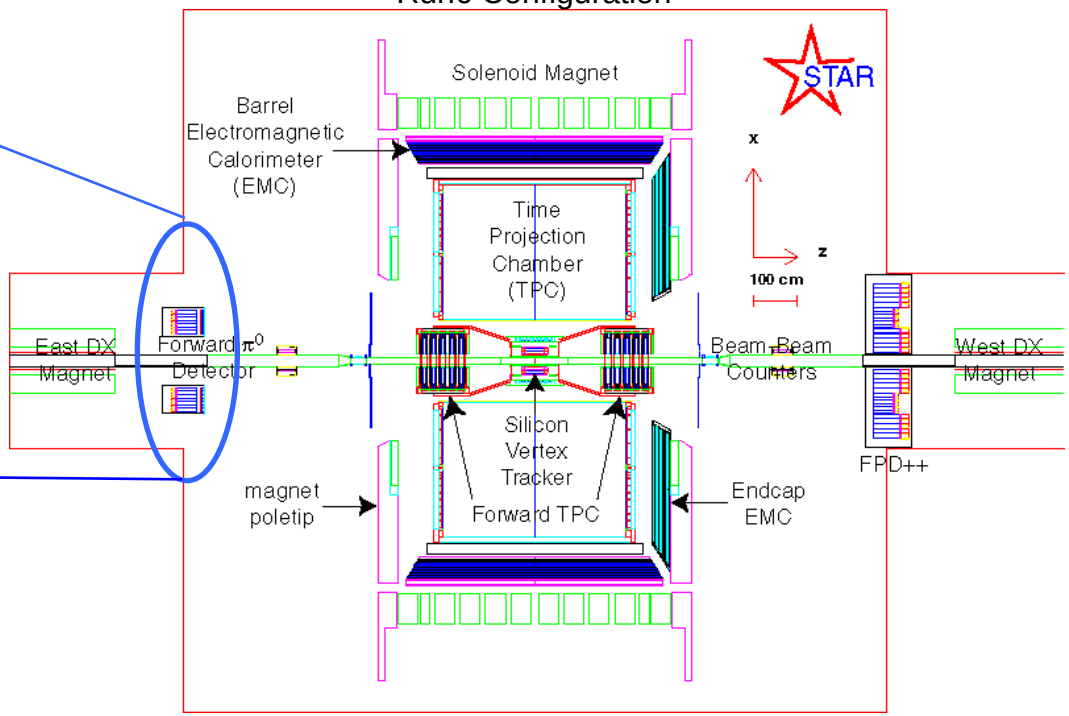
1. Majority valence quark in polarized proton.
   - u for proton
   - $\bar{u}$ for antiproton.
2. Minority valence quark
   - d for proton
   - $\bar{d}$ for antiproton.
3. Pion containing only majority quarks gets **large positive A_N**.
4. Pion containing only minority quarks gets **large negative A_N.**
5. Pion containing both majority and minority quarks (neutral pions) **have intermediate positive A_N.**

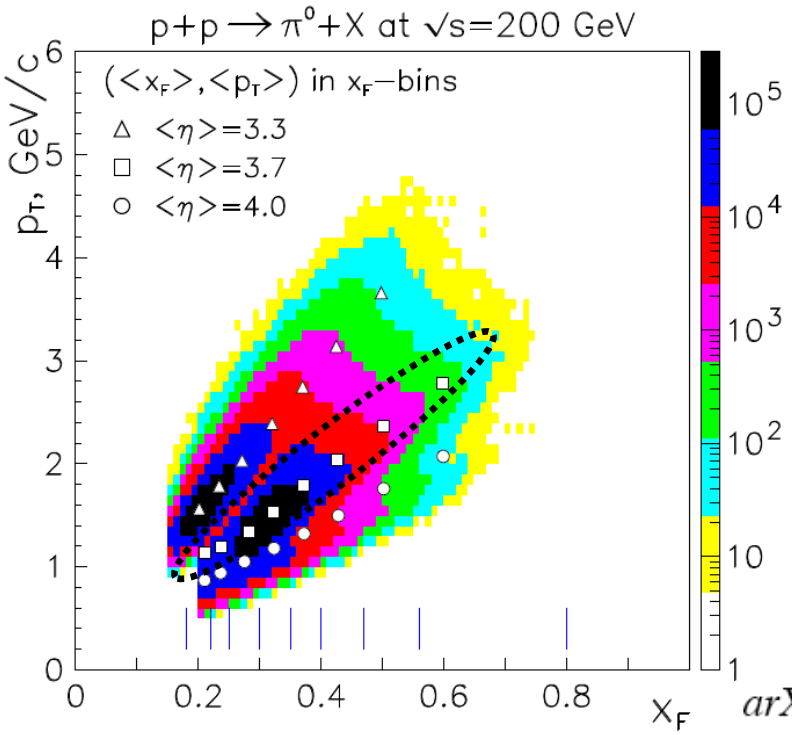
Polarized Beam	Observed Meson	Exp.	$\langle s \rangle$	$\langle p_T \rangle$	$\sim X_F$	$\sim A_N$	Comment on A_N
Proton uud	$\pi^+ : \; u\bar{d}$	E 704 BRAHMS	19.4 GeV 62.4 GeV	~ 1 GeV/c ~ 1 GeV/c	0.5 - 0.7 0.4 – 0.6	+0.15 to +0.25 +0.2 to +0.25	Large Positive
Proton uud	$\pi^0 : \frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})$	E 704 **STAR**	19.4 GeV **200 GeV**	~ 1 GeV/c **~ 2.5 GeV/c**	0.5 - 0.7 **0.5 - .065**	+0.10 to +0.15 +0.06 to + 0.1	Medium Positive
Proton uud	$\pi^- : \; d\bar{u}$	E 704 BRAHMS	19.4 GeV 62.4 GeV	~ 1 GeV/c ~ 1 GeV/c	0.5 - 0.7 0.4 – 0.6	-0.10 to -0.25 -0.25 to -0.3	Large Negative
Anti Proton $\bar{u}\bar{u}\bar{d}$	$\pi^- : \; d\bar{u}$	E 704	19.4 GeV	~ 1 GeV/c	0.5 - 0.7	0.10 to +0.20	Large Positive
Anti Proton $\bar{u}\bar{u}\bar{d}$	$\pi^0 : \frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})$	E 704	19.4 GeV	~ 1 GeV/c	0.5 - 0.7	0.05 to +0.10	Medium Positive
Anti Proton $\bar{u}\bar{u}\bar{d}$	$\pi^+ : \; u\bar{d}$	E 704	19.4 GeV	~ 1 GeV/c	0.5 - 0.7	-0.10 to -0.25	Large Negative
Proton uud	$\eta : \frac{1}{\sqrt{3}}(u\bar{u} + d\bar{d} - s\bar{s})$	E 704	19.4 GeV	~ 1 GeV/c	0.50 - 0.60	$0.25 \pm .09$	Possibly Larger than for π^0

STAR Forward Pion Detector (FPD)



Run6 Configuration





- 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 is consisted of two 7X7 Pb-glass modules, EN and ES. During run6, it was placed at x-offset~30cm, <η>~3.7.

arXiv:0801.2990v1 [hep-ex]

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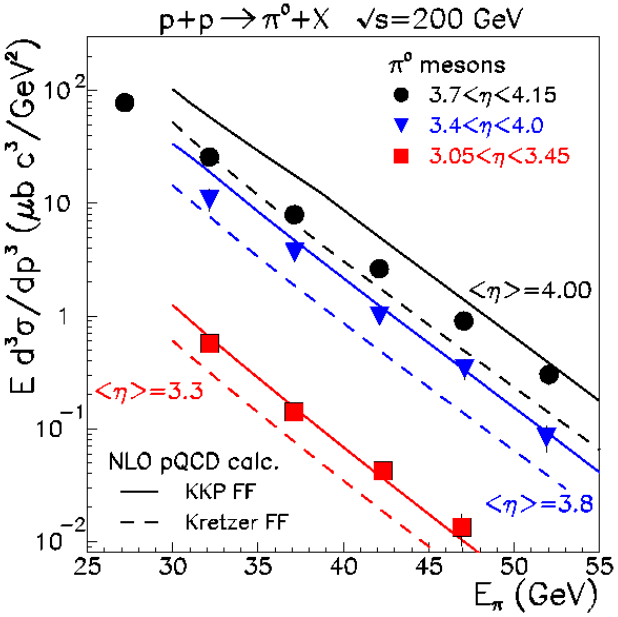
Forward π^0 Single Spin Asymmetry

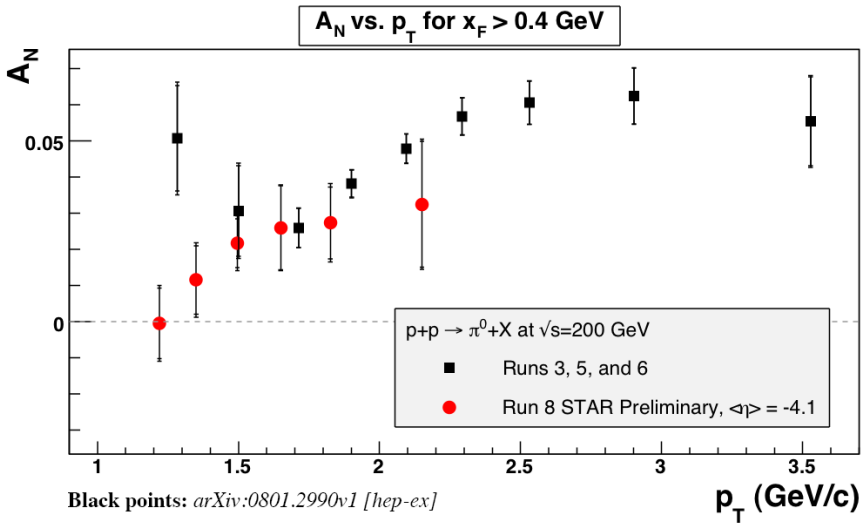


Phys. Rev. Lett. 97 (2006) 152302

At √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)*

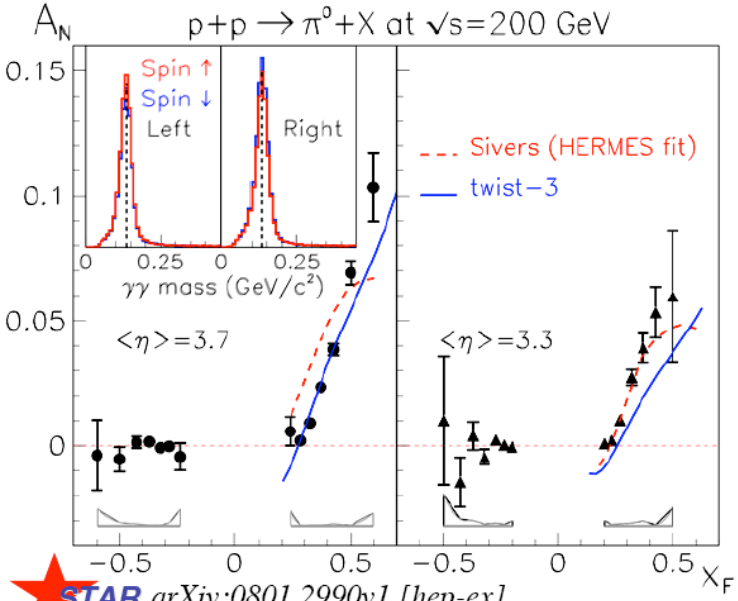
$$A_N = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}} \cong \frac{1}{P} \frac{\sqrt{N^{\uparrow}S^{\downarrow}} - \sqrt{S^{\uparrow}N^{\downarrow}}}{\sqrt{N^{\uparrow}S^{\downarrow}} + \sqrt{S^{\uparrow}N^{\downarrow}}}$$

We find that A_N increases with x_F, roughly consistent with theoretical predictions. Contrary to predictions, however, A_N does not fall as a function of p_T at fixed x_F in this kinematic region.



Black points: *arXiv:0801.2990v1 [hep-ex]*

From Spin2008 talk by J.Drachenberg



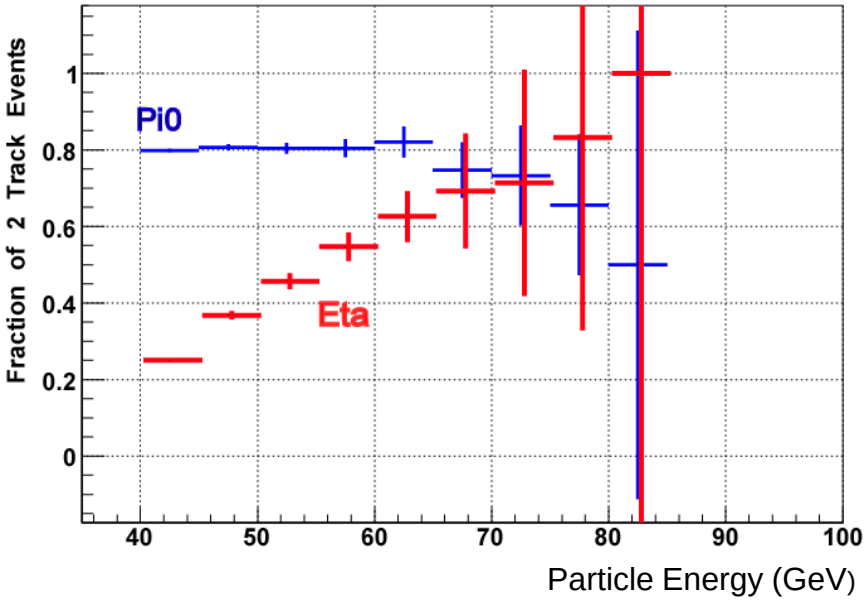
STAR *arXiv:0801.2990v1 [hep-ex]*

Accepted by PRL

Acceptance and Reconstruction

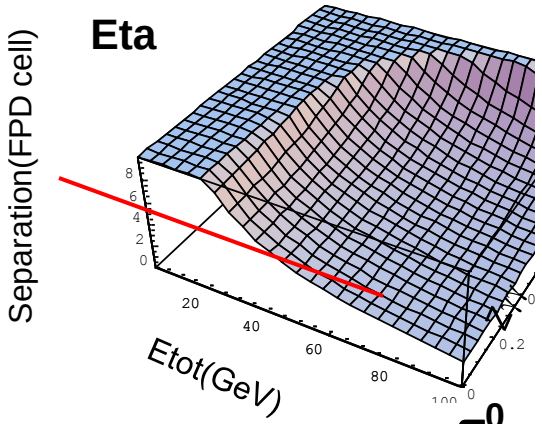
Fast Simulator

The ratio of N(reconstructed particles) to N(generated particles whose center of mass falls within Forward Pion Detector)

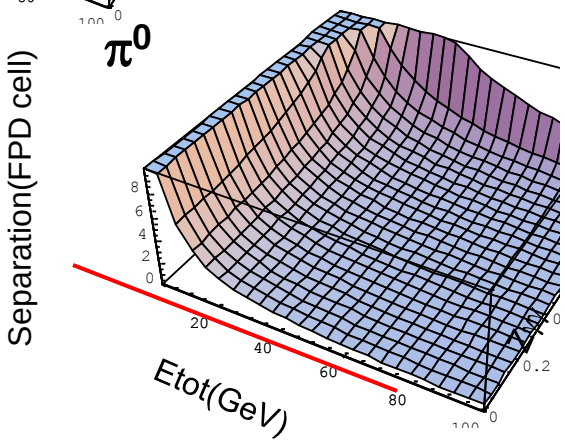


$$m_{\gamma\gamma} = E_{tot}\sqrt{1-(Z_{\gamma\gamma})^2}\,Sin\frac{\theta}{2}$$

$$\rightarrow Separation\ (FPDcell) \cong \frac{425 m_{\gamma\gamma}}{E_{tot}\sqrt{1-(Z_{\gamma\gamma})^2}}$$



$$z_{\gamma\gamma} = \frac{E_{\gamma 1} - E_{\gamma 2}}{E_{\gamma 1} + E_{\gamma 2}}$$



- 7x7 FPD has limited acceptance for Eta mesons. At 40GeV, a symmetrically decaying Eta needs to point to the center of the FPD to fit in. Acceptance improves greatly at higher energy.
- The reconstruction efficiency for π^0 starts to drop at E>60GeV, where the separation between two photons for symmetric decay becomes ~1 cell width.

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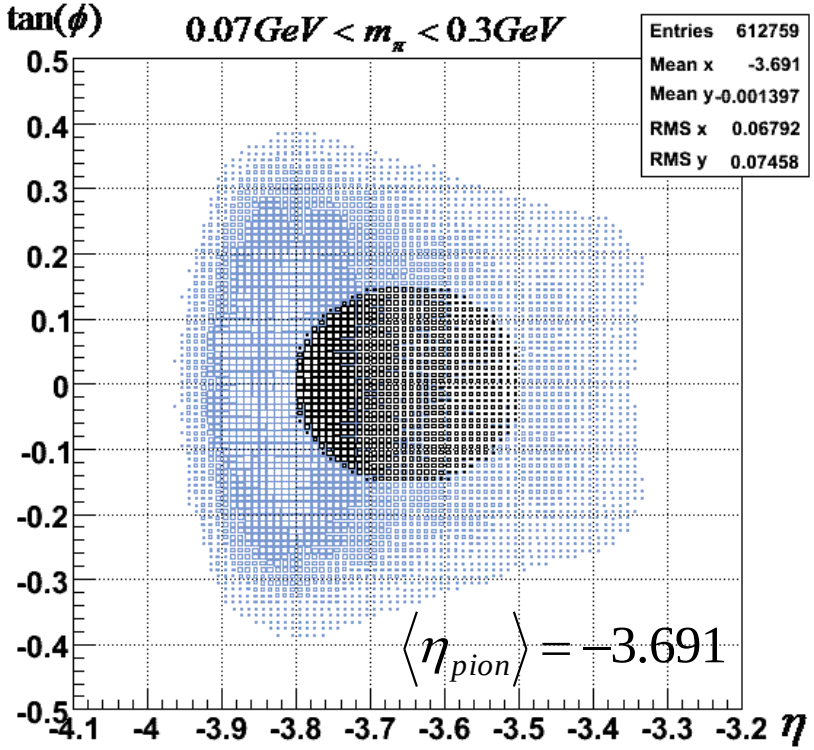
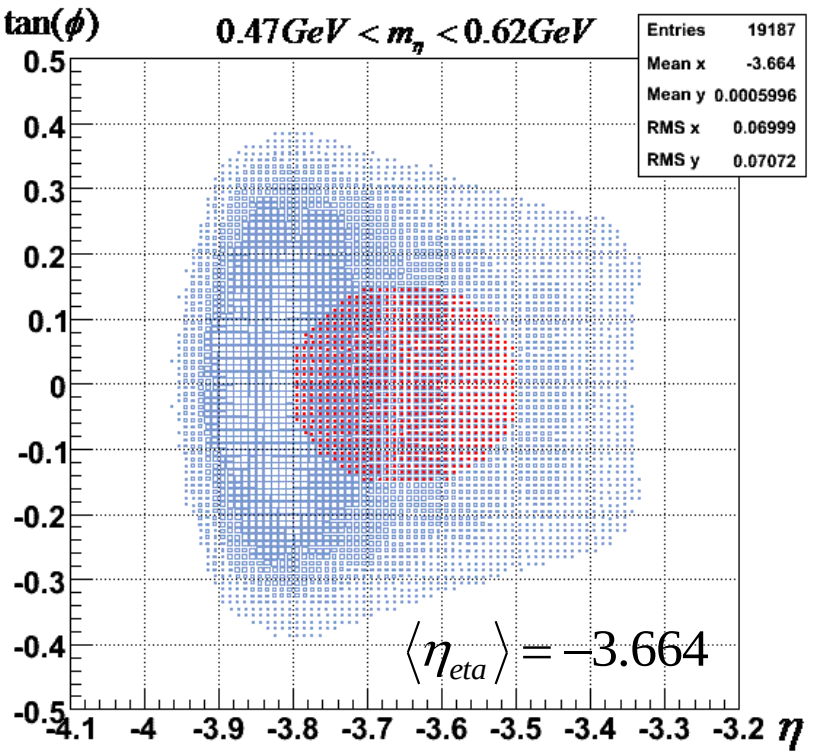
Event Selection and Mass Reconstruction

Di-Photon Center of Mass Distributions



π^0 mass region with Center Cut in black



η mass region with Center Cut in red

Event Cuts

- 2 photon events
- E_{total}>25GeV
- Hardware threshold nominally at 25GeV
- "Center Cut" for 2γ CoM defined as

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

$$m_{\gamma\gamma} = E_{tot}\sqrt{1-(Z_{\gamma\gamma})^2}\,Sin\frac{\theta}{2}$$

- Etot: Detector summed energy
- Zγγ and photon separation: Fitted photon energy/locations
- Reconstructs on the entire FPD
- Vertex set at zero for all events

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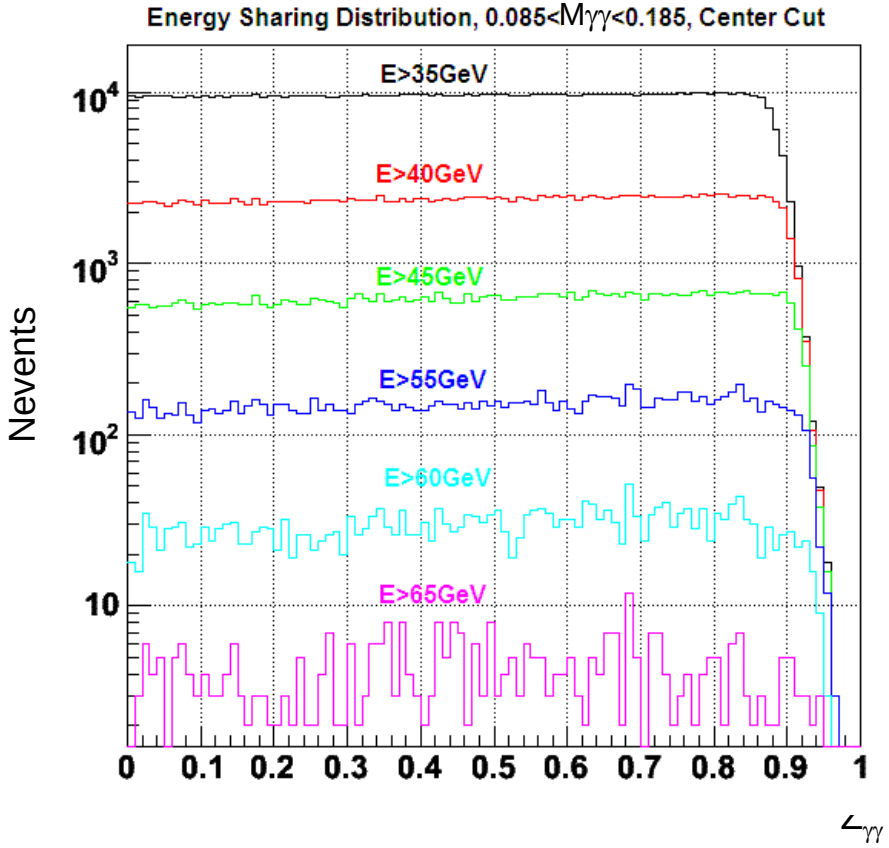
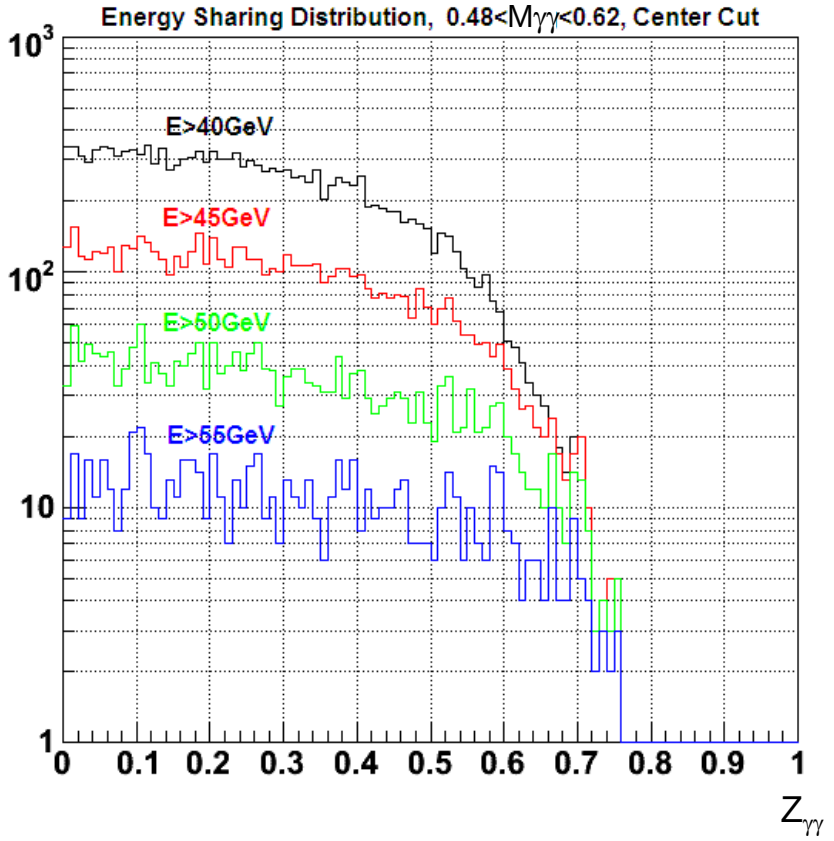
η and π^0 Energy Sharing ($Z_{\gamma\gamma}$) Distribution

$$z_{\gamma\gamma} = \frac{E_{\gamma 1} - E_{\gamma 2}}{E_{\gamma 1} + E_{\gamma 2}}$$

π^0 mass region with Center Cut



Eta mass region with Center Cut



Observation of Eta Signal

Di-Photon Invariant Mass Spectra in 3 Energy Bins

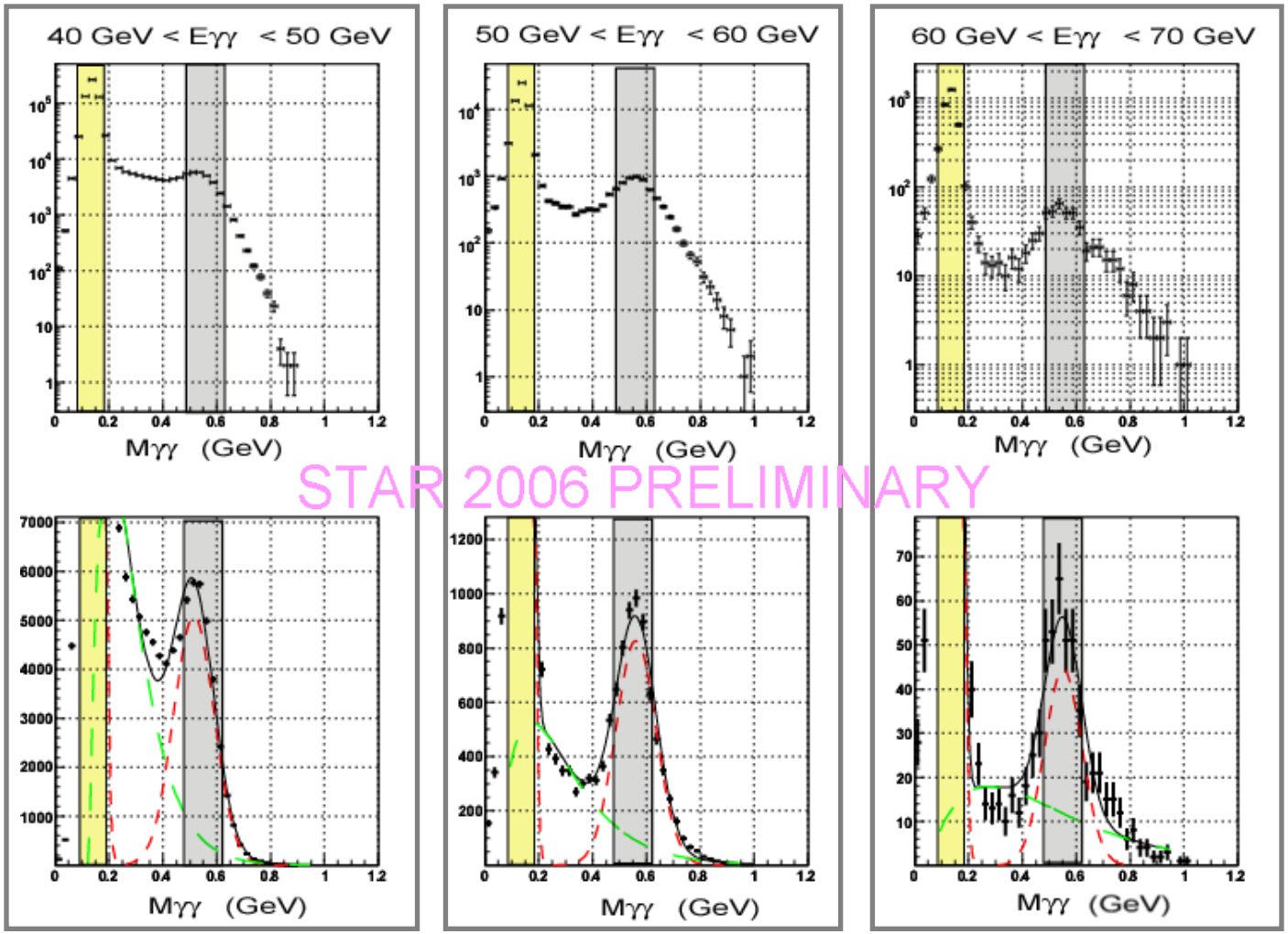
- Center Cut
- 3 columns for 3 energy bins
- Each column shows a single plot in log and linear scale.

π^0 Mass Cut

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

Eta Mass Cut

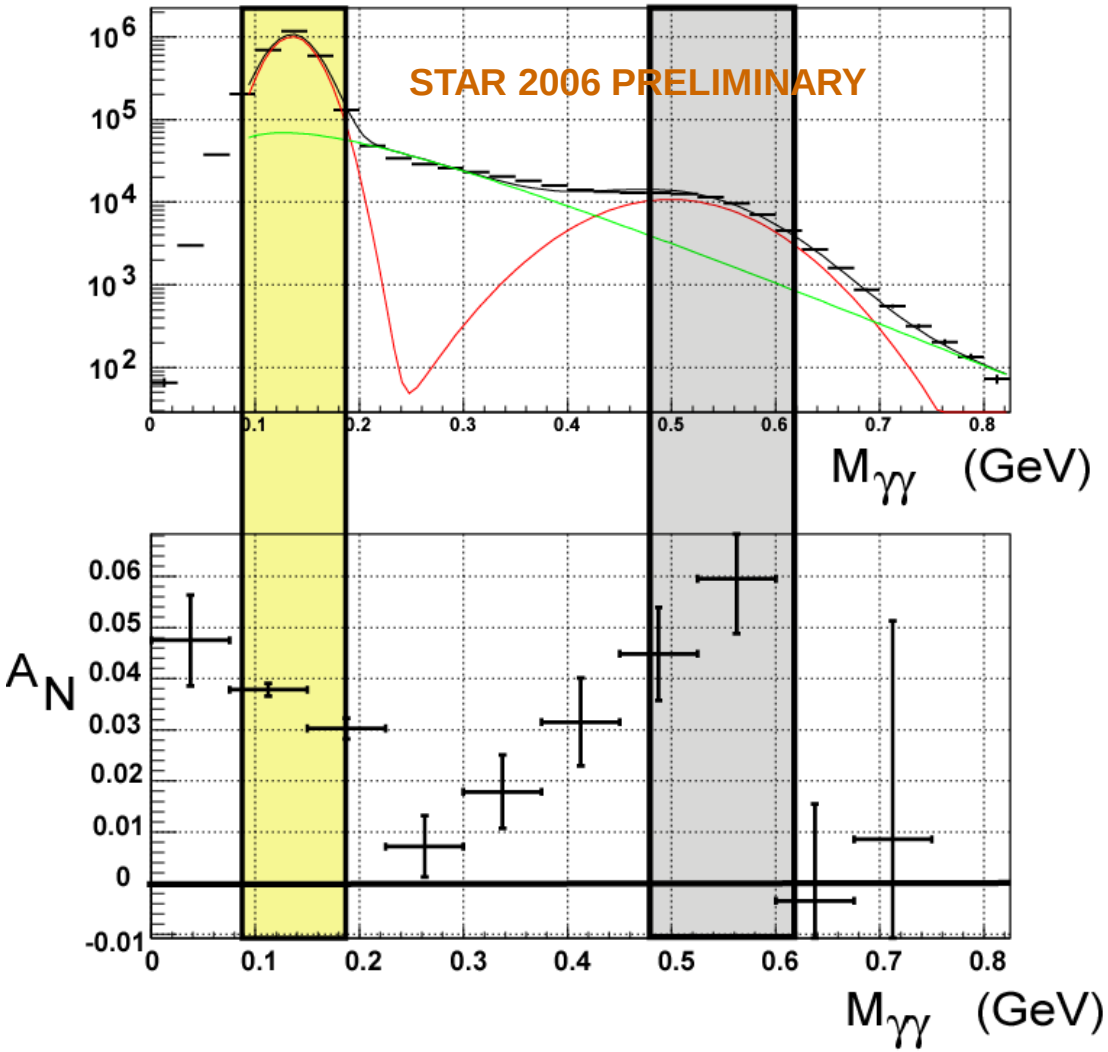
$.48\ GeV < M_{\gamma\gamma} < .62 GeV$



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

Mass Dependence of A_N

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



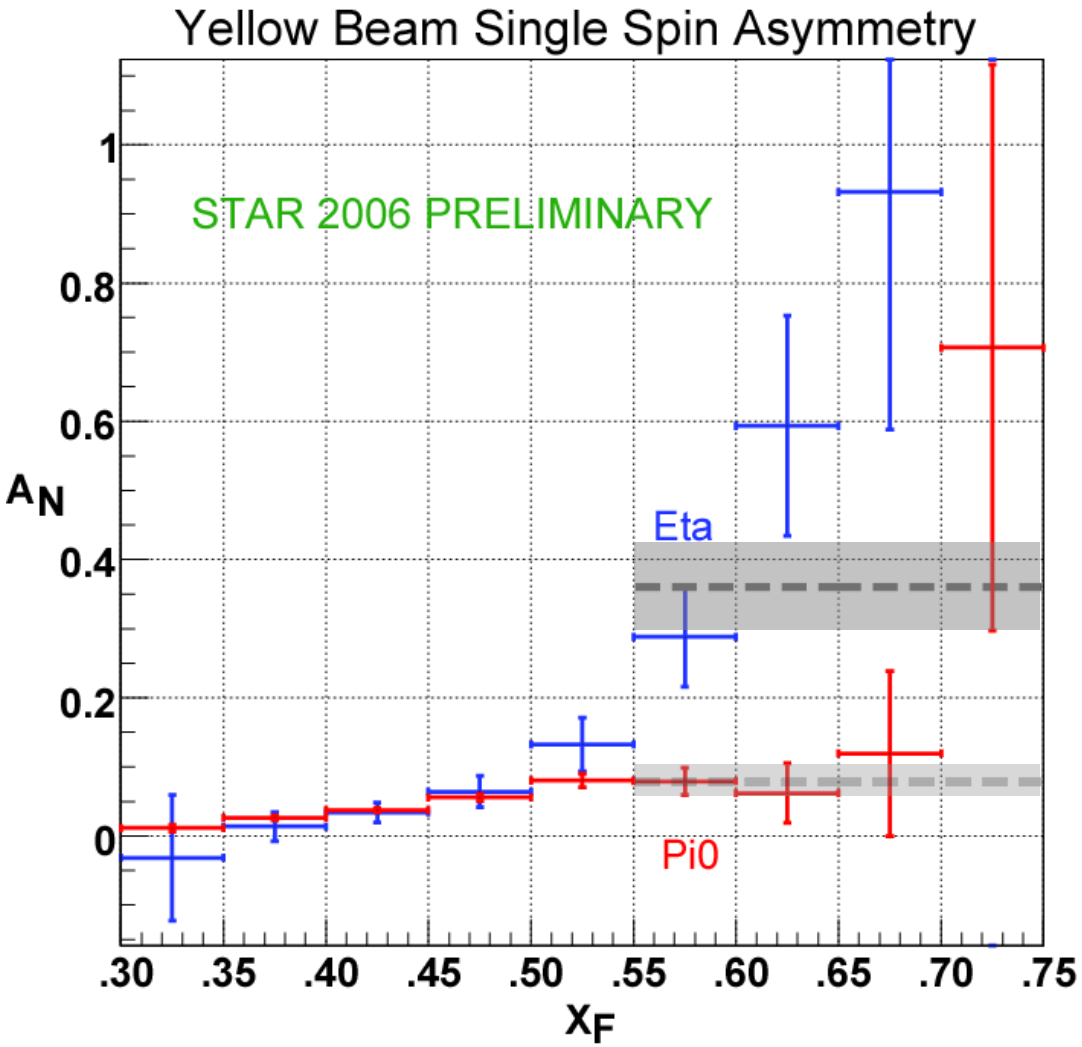
1. $N_{photon} = 2$
2. $E_{total} > 40GeV$
3. No Center Cut
4. Average Yellow Beam Polarization = 56%

• Yellow beam asymmetry clearly reveals the shape of two mass resonances.

• There is an "asymmetry valley" in between π^0 and η mass regions.

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

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



1. $N_{photon} = 2$
2. Center Cut (η and ϕ)
3. Pi0 or Eta mass cuts
4. Average Yellow 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 $.55 < X_F < .75$, the asymmetry in the η mass region is greater than 5 sigma above zero, and about 4 sigma above the asymmetry in the π^0 mass region.

Summary

1. Previously, the STAR Forward Pion Detectors at RHIC (Brookhaven National Laboratory) have been used to successfully measure the forward single spin asymmetry, A_N, for π^0 meson in $<\eta>=3.3\sim4.0$ region.

2. In RHIC run 6, during $\sqrt{s}=200$ GeV p+p collisions, π^0 and Eta mesons were observed in the east FPD. We measured and compared the single spin asymmetry in the π^0 and the Eta mass regions, at $<\eta>\sim3.65$ and x_F above 0.4.

3. A_N as a function of the invariant mass reveals π^0 and Eta resonance peaks.

4. From 55GeV to 75GeV, ($x_F=0.55\sim0.75$) the average transverse single spin asymmetry in the Eta mass region was measured to be $A_N = 0.361 \pm 0.064$, about 4 standard deviations greater than the average A_N in the π^0 mass region.

5. Preliminary estimates of possible systematic effects show that the systematic uncertainties are considerably smaller than the statistical uncertainties.