XXI. International Workshop on Deep-Inelastic Scattering and Related Subjects
Marseille Congress Centre Apr 22-26 2013

DIS 2013

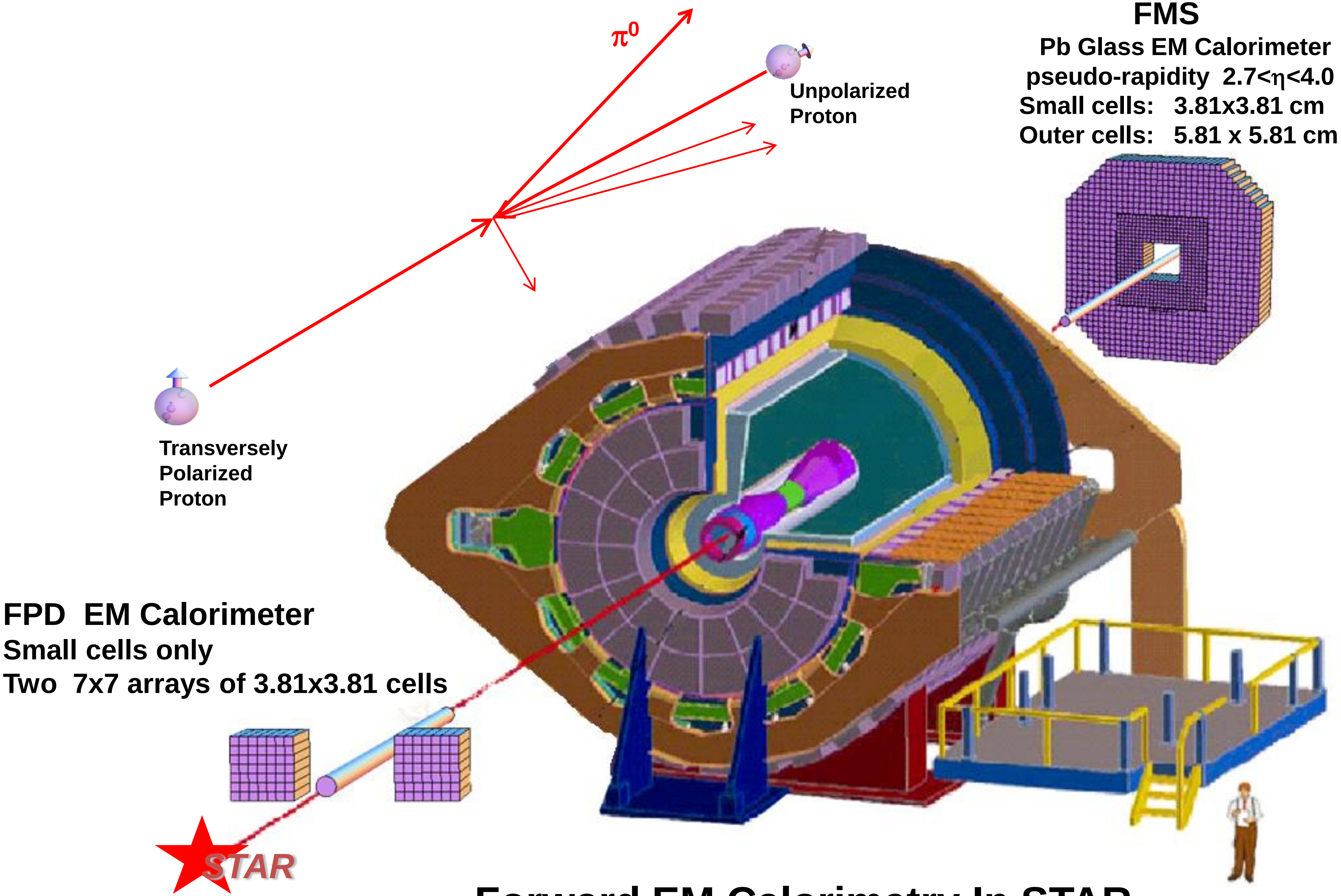
Large p_T Forward Transverse Single Spin Asymmetries of π^0 Mesons at $\sqrt{s}$= 200 and 500 GeV from STAR.

Steven Heppelmann (for STAR collaboration)

$$p^{\uparrow} + p \rightarrow \pi^0 + X$$ ($\sqrt{s}$= 200 and 500 GeV)

- **STAR and the FMS forward electromagnetic calorimeter detector.**
- **π^0 A_N at larger transverse momentum.**
- Dependence of A_N on pion isolation cone size.
- Dependence of A_N on soft EM energy within isolation cone.
- Dependence of A_N on EM energy outside isolation cone.
- Summary

STAR



Forward EM Calorimetry In STAR.

Proton Forward Scattering at High P_T

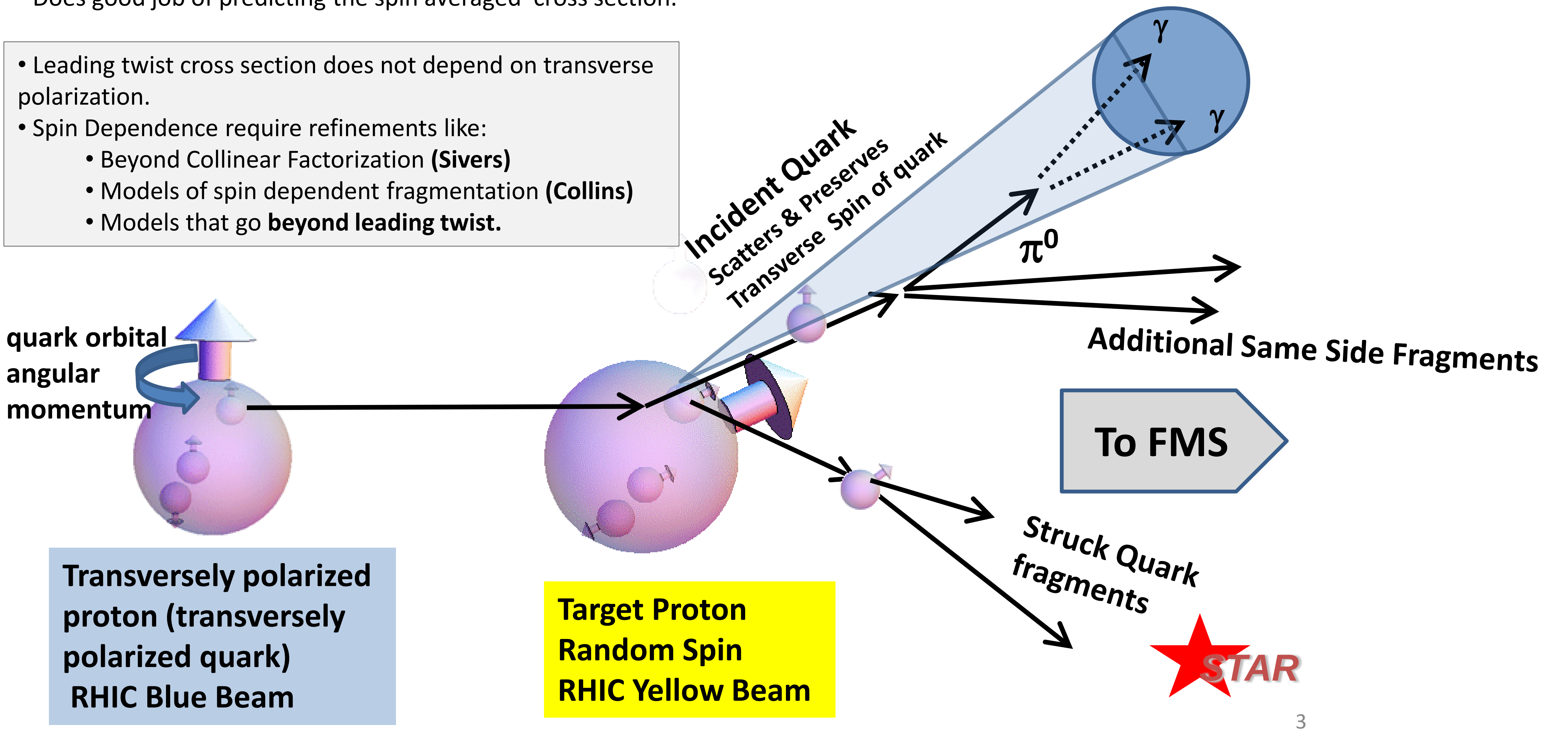
π^0s with N=2 photons in angular cone.

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 fragmentation **(Collins)**
  - Models that go **beyond leading twist.**



Data Sets and π^0 Isolation Cone Sizes

RHIC Run 11 (2011) pp @ $\sqrt{s}$=500 GeV

Average Blue Beam Polarization = 51.6% (Transverse)

Luminosity =22 pb^{-1}

30 mR isolation cone

70 mR isolation cone

RHIC Run 12 (2012) pp @ $\sqrt{s}$=200 GeV

Average Blue Beam Polarization 60.7% (Transverse)

Luminosity =18 pb^{-1}

200 mR isolation cone

35 mR isolation cone

70 mR isolation cone

Event Selection for π^0 events:

1. **Analyze FMS for all photon** candidates.
   Here a photon (γ) is an EM shower that has been fit successfully to photon hypothesis

2. Two photon events include two **photon candidate** (**γ's)**,

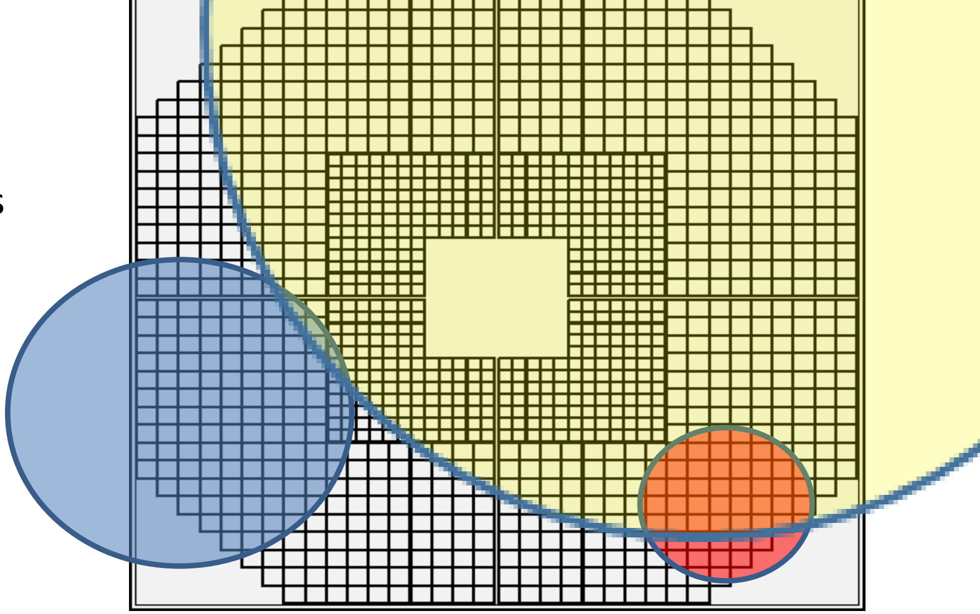
   a. Each photon has
      i. a minimum energy of 6 GeV in the small inner detector
      ii. or a minimum of 6 (4) GeV in the large outer cells for Run 12 (11) analysis.

   b. Two γ are found within a fixed cone size. There may also be additional FMS **γ's** outside isolation cone.

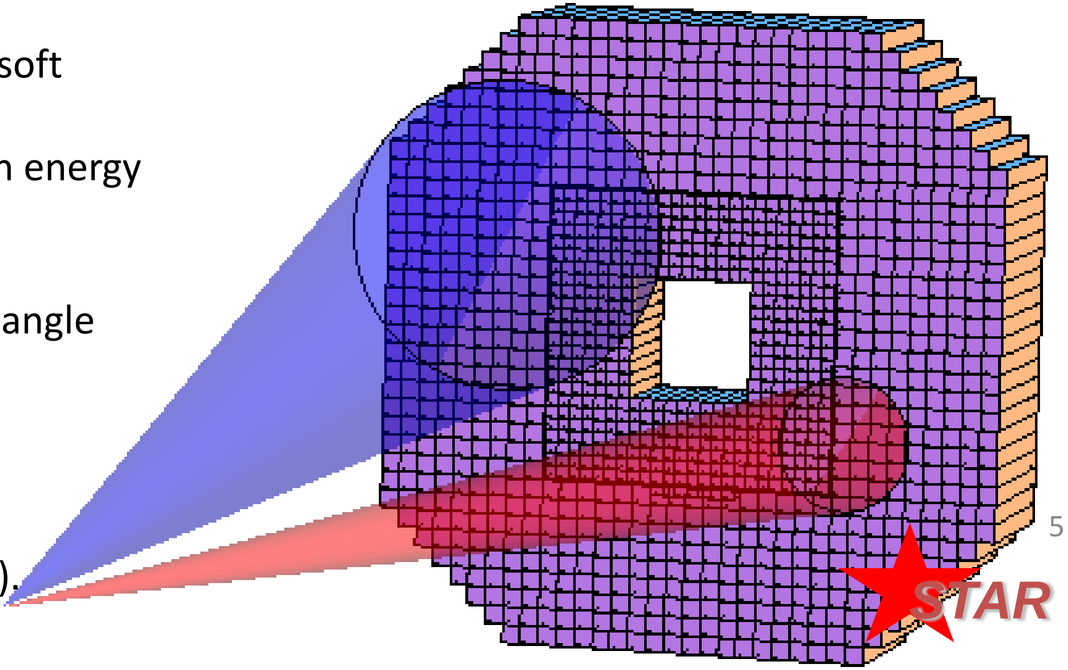
   c. Within the isolation cone, soft energy photons are sometimes observed
      i. For small cells, the variable **Esoft** represents the sum of energy of soft photons, (**γ's** with energy between 2 and 6 GeV).
      ii. For large cells **Esoft** is the sum of energy of soft photons (γ **'s)** with energy between 0.7 and 6 (4) GeV for Run 12 (11).

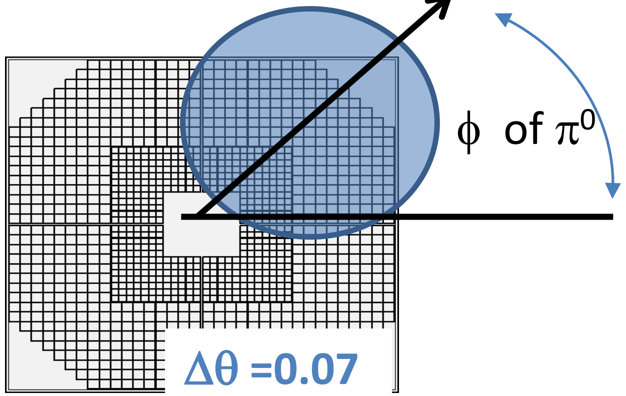
3. **Find Clusters of photons** grouping photon candidates that are within opening angle cone $\Delta\theta$ (relative to energy weighted center)

4. For Run 12, we consider **3 event classes**
   1. **$\Delta\theta$ =0.07 R** 2 Photon clusters, Pi0 Mass (**isolation radius of .07 radians**).
   2. **$\Delta\theta$ =0.035 R** 2 Photon clusters ,Pi0 Mass (**isolation radius of .035 radians**).
   3. **$\Delta\theta$ =0.20 R** 2 Photon clusters ,Pi0 Mass (**isolation radius of .20 radians**).



Isolation of π^0 's





From Run 11 $\sqrt{s}$= 500 GeV

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)

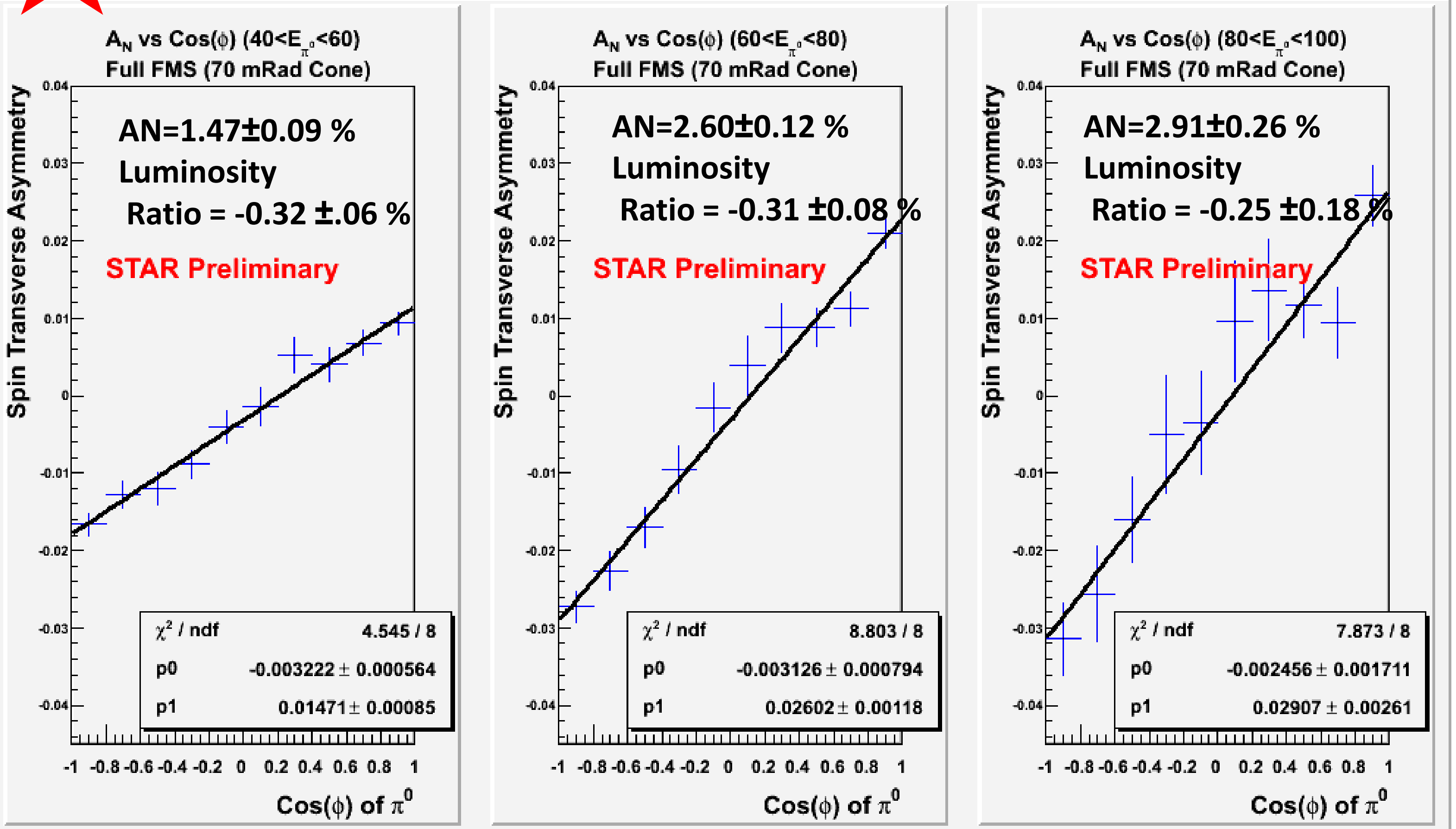
Slope =A_N

Intercept = Luminosity Ratio for data set

Luminosity ratio for all ~ - 0.31 ±.05 %

Slope Fits are consistent with Cross Ratio Method.

STAR

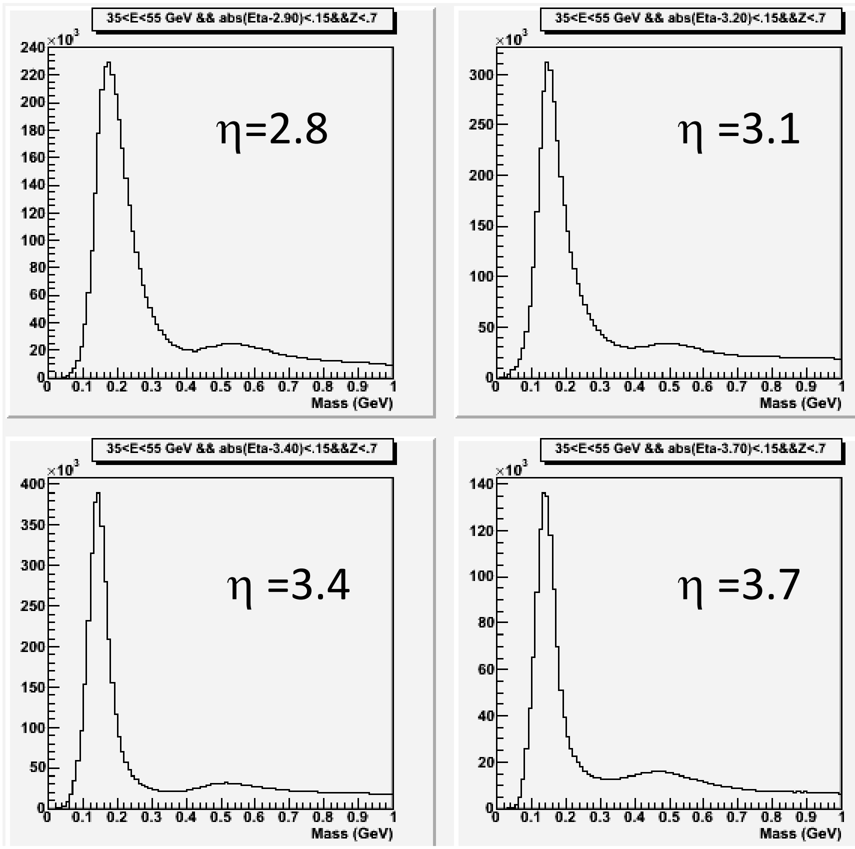


Example Run 11 Mass Distribution:

2 photons in 70 mR cone,

35<(E1+E2)<55GeV, Z=(E1-E2)/(E1+E2)<0.7

Four pseudo-rapidity (η) regions.



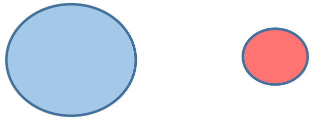
$\sqrt{s}$= 500 GeV (Run 11) Transverse Single Spin π^0 Asymmetry vs P_T for small and large π^0 isolation cones. (Errors shown in these ane following plots are statistical)

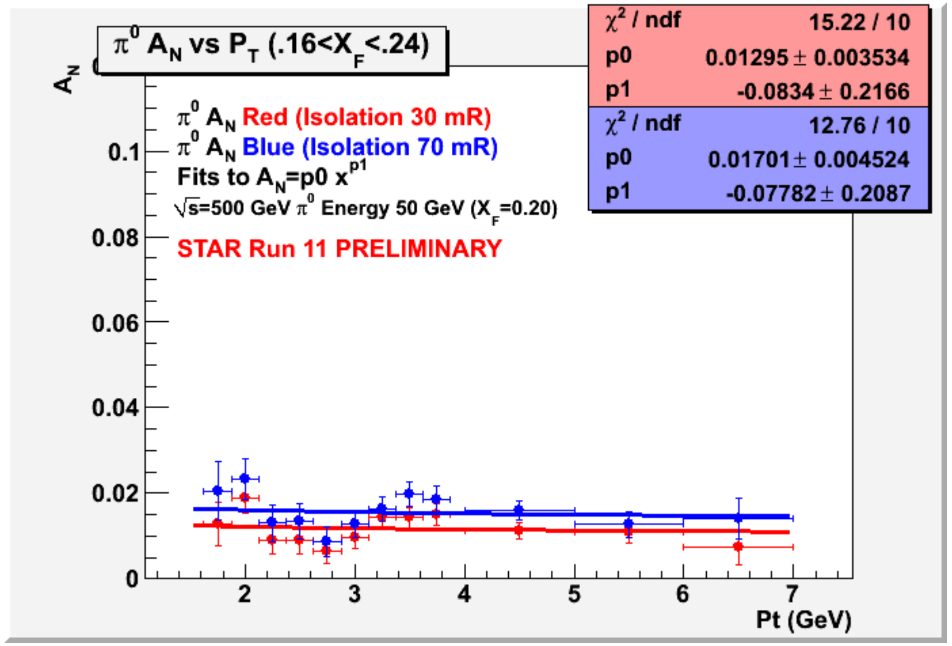
Higher Twist or other pQCD related models suggest
A_N should fall at large P_T with at least 1 power of P_T.

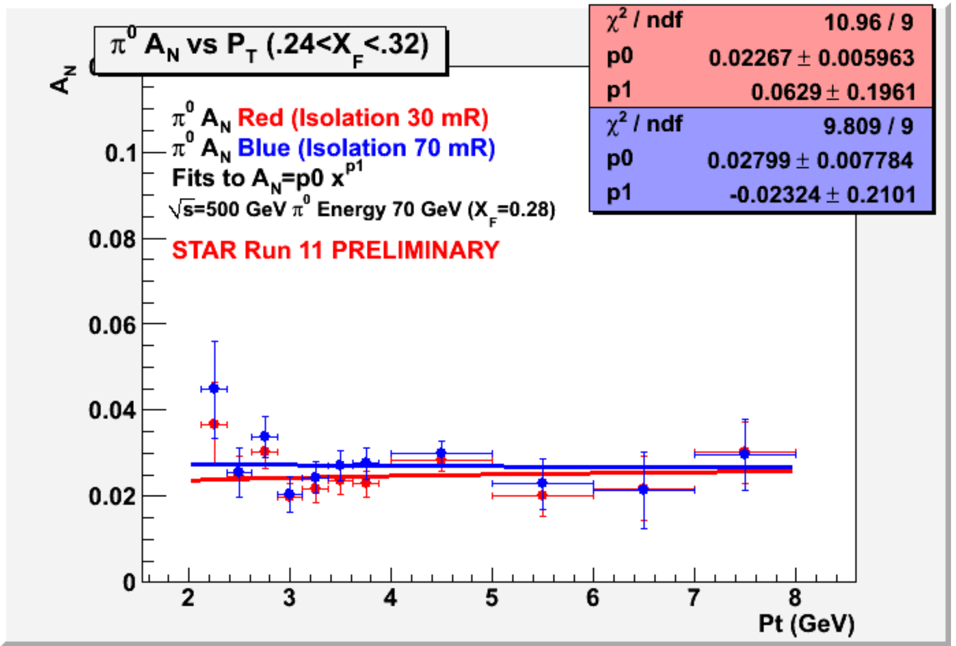
These plots include 2 parameter fits for A_N vs P_T :

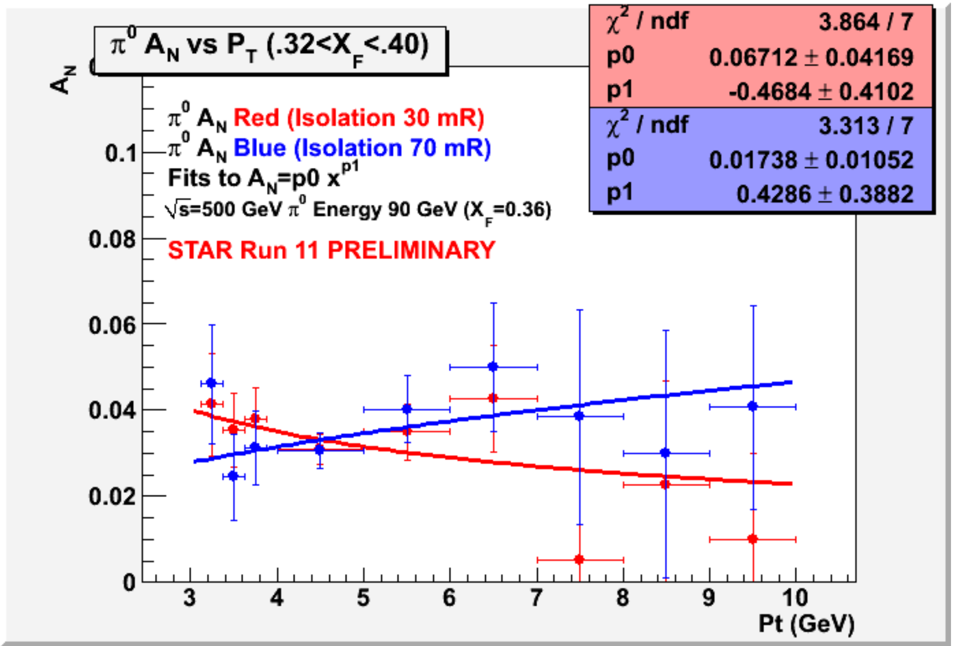
$$A_N(P_T)=[p_0]\times(P_T)^{[p_1]}$$

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









RHIC Run 12 2012

STAR FMS @ √s=200 GeV

Selection:

$$N_{photons} = 2 (in\ cone)$$

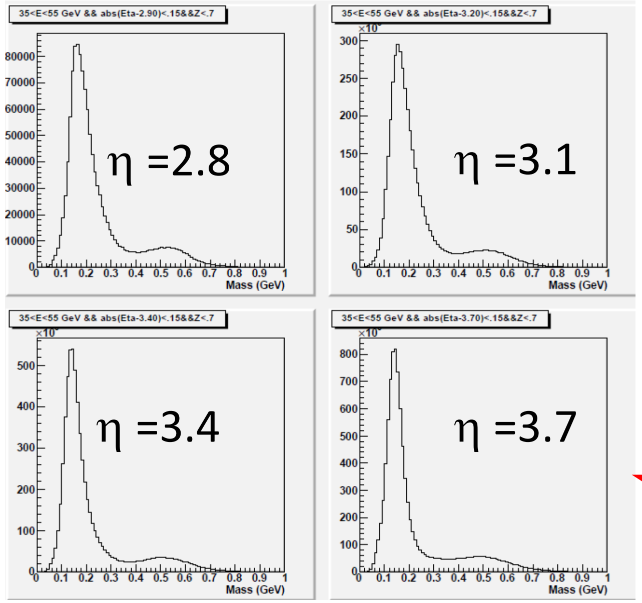
$$E_1 > 6\ GeV\ \ \&\ \ E_2 > 6\ GeV$$

$$Z = \left| \frac{E_2 - E_1}{E_2 + E_1} \right| < 0.7$$

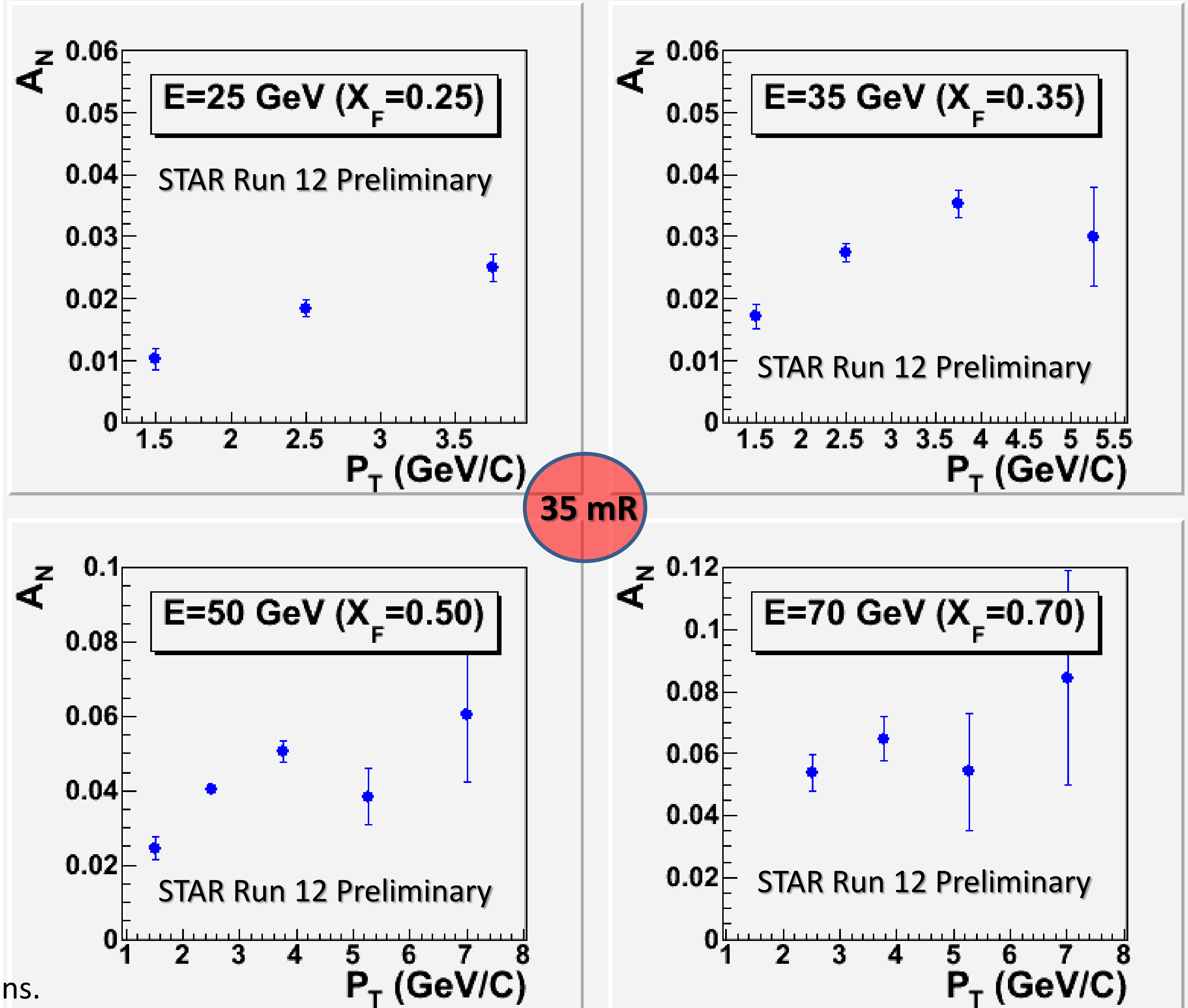
$$M_{1,2} < 0.4\ GeV$$

$$E_{soft} < 0.5\ GeV$$

$$Cone: 35 mR$$

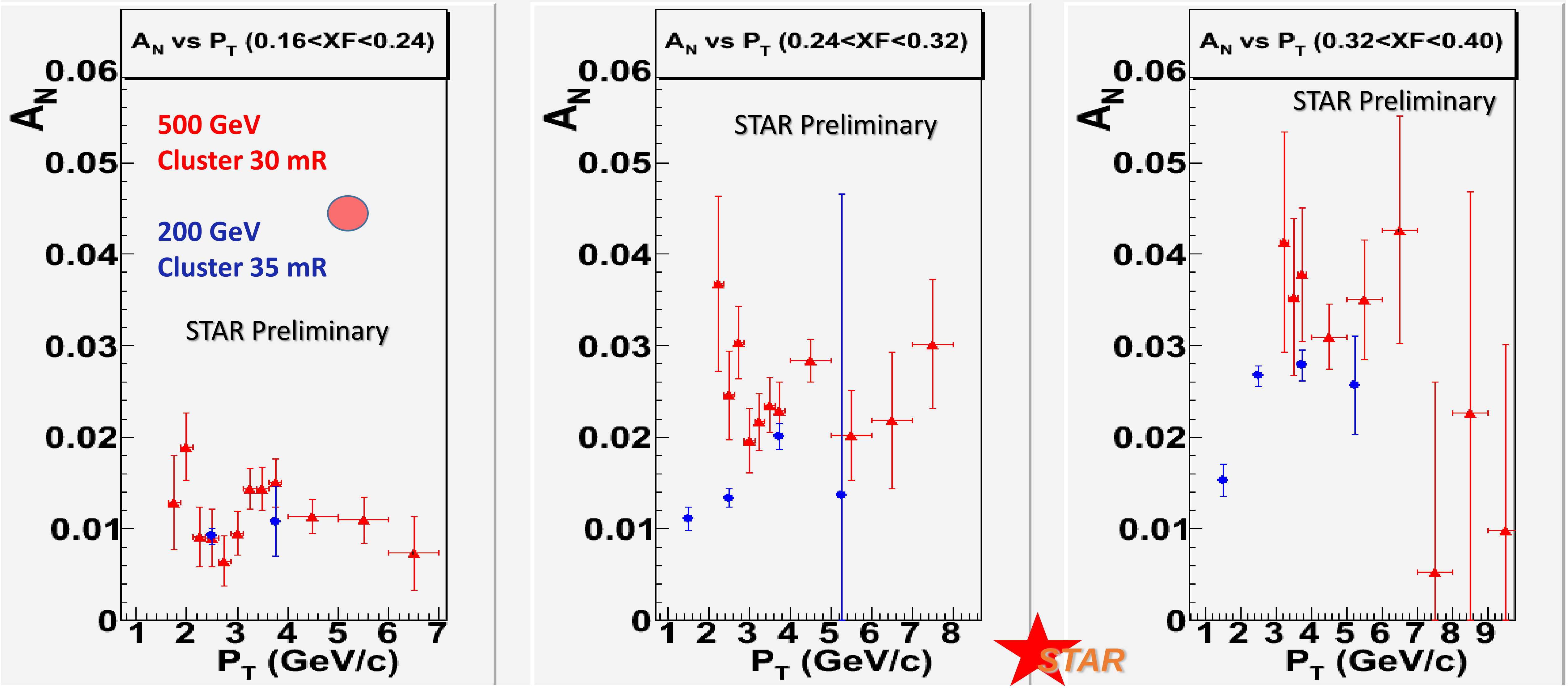


Examples of Run 12 Mass Distributions:
35<E<55GeV, four pseudo-rapidity (η) regions.



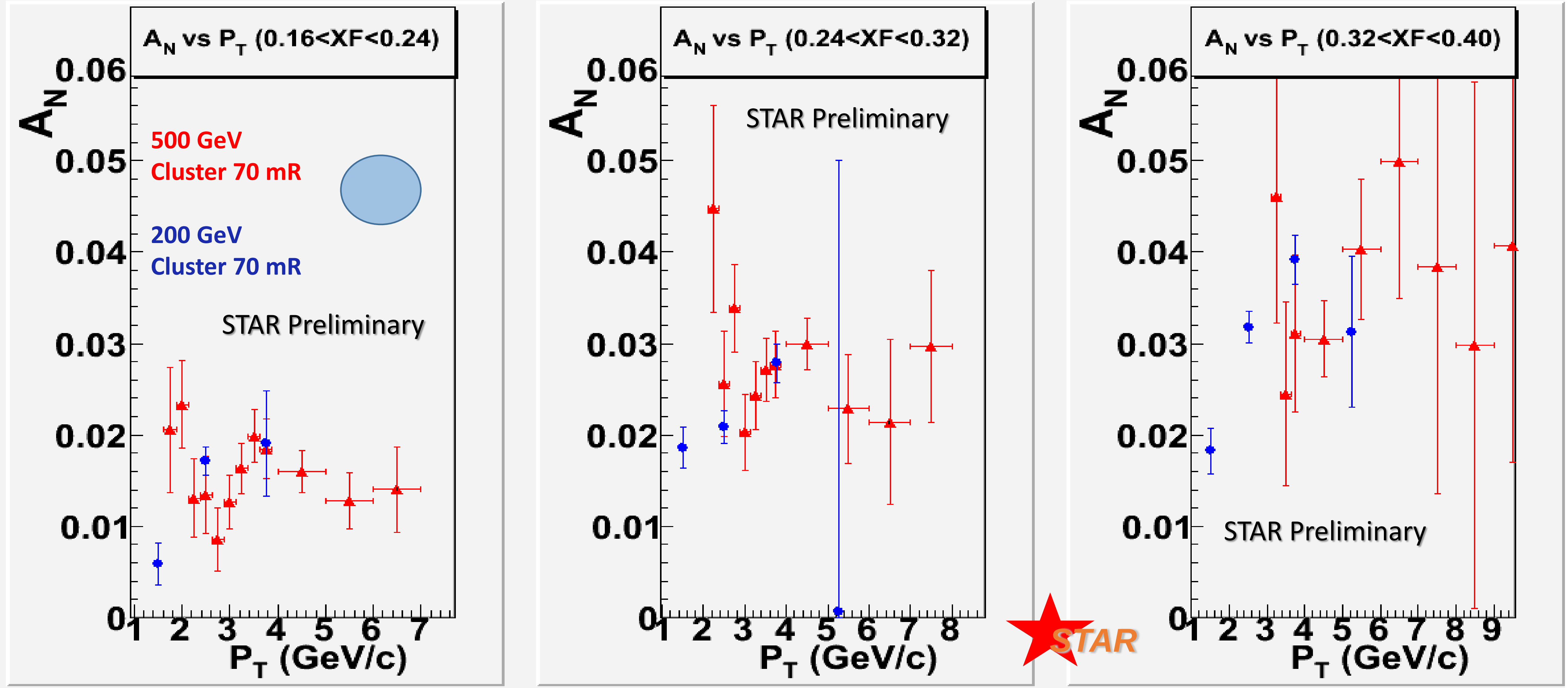
Compare p_T Dependence of A_N at 200 and 500 GeV.

The distribution of A_N vs. p_T, comparing the same X_F. The **200 GeV (blue circles)** and **500 GeV (red triangles)** represent A_N measurements based on two photon clusters selected with 30 mR cluster at 500 GeV and 35 mR at 200 GeV. The 200 GeV two photon mass is **|M12-0.135|<.12 GeV.** The other cut is **z<0.7**.

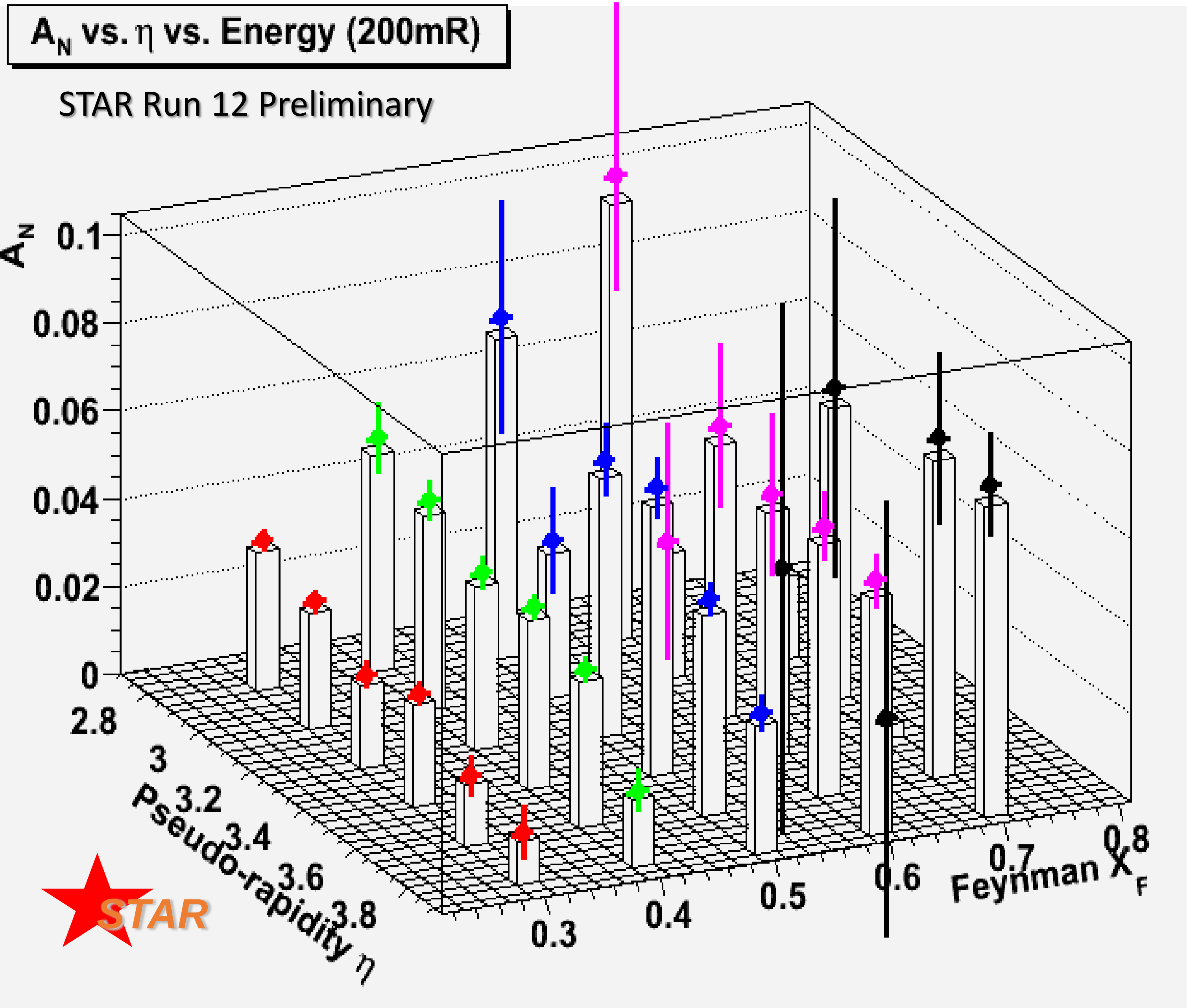


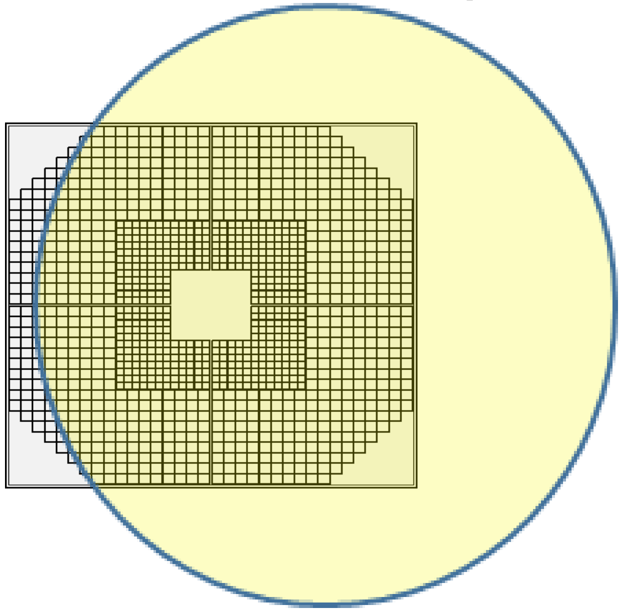
Compare p_T Dependence of A_N at 200 and 500 GeV.

The distribution of A_N vs. p_T, comparing different center of mass energy for the same X_F. The **200 GeV (blue circles)** and **500 GeV (red stars)** represent A_N measurements based on two photon 70 mR (bottom) cluster angles. The 70 mR cluster angle. The 200 GeV two photon mass is selected to be **|M12-0.135|<.12 GeV.** The other cut is **z<0.7**.



Run 12: $p^{\uparrow} p \rightarrow \pi^0$ $\sqrt{s}$= 200 GeV A_N as a Function of Energy and Pseudo-rapidity (η)





$$N_{photons} = 2\,(in\ cone)$$

$$E_1 > 6\ GeV\ \&\&E_2 > 6\,GeV$$

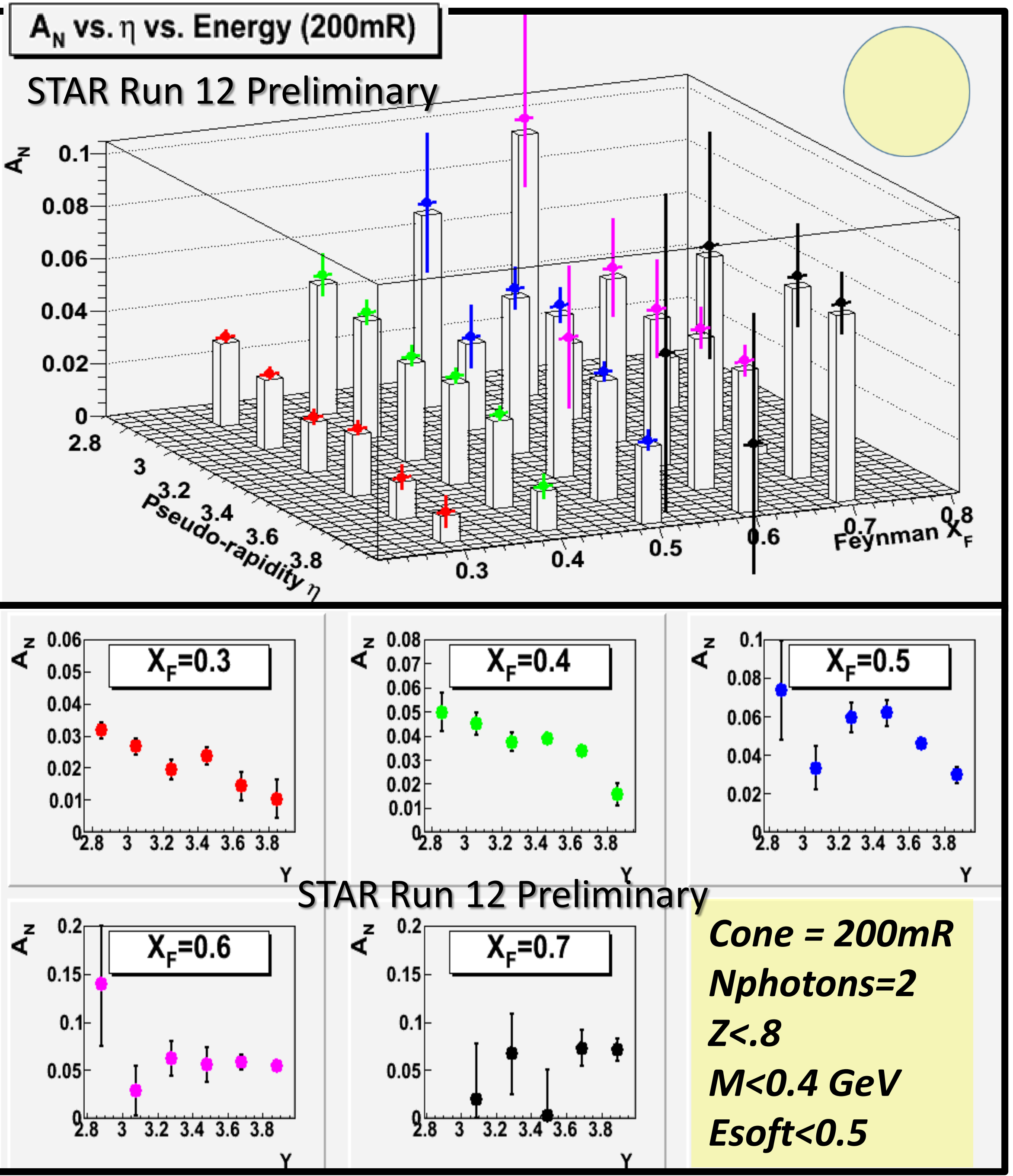
$$Z = \left|\frac{E_2 - E_1}{E_2 + E_1}\right| < 0.7$$

$$M_{1,2} < 0.4\,GeV$$

$$E_{soft} < 0.5\,GeV$$

$$Cone: 200mR$$

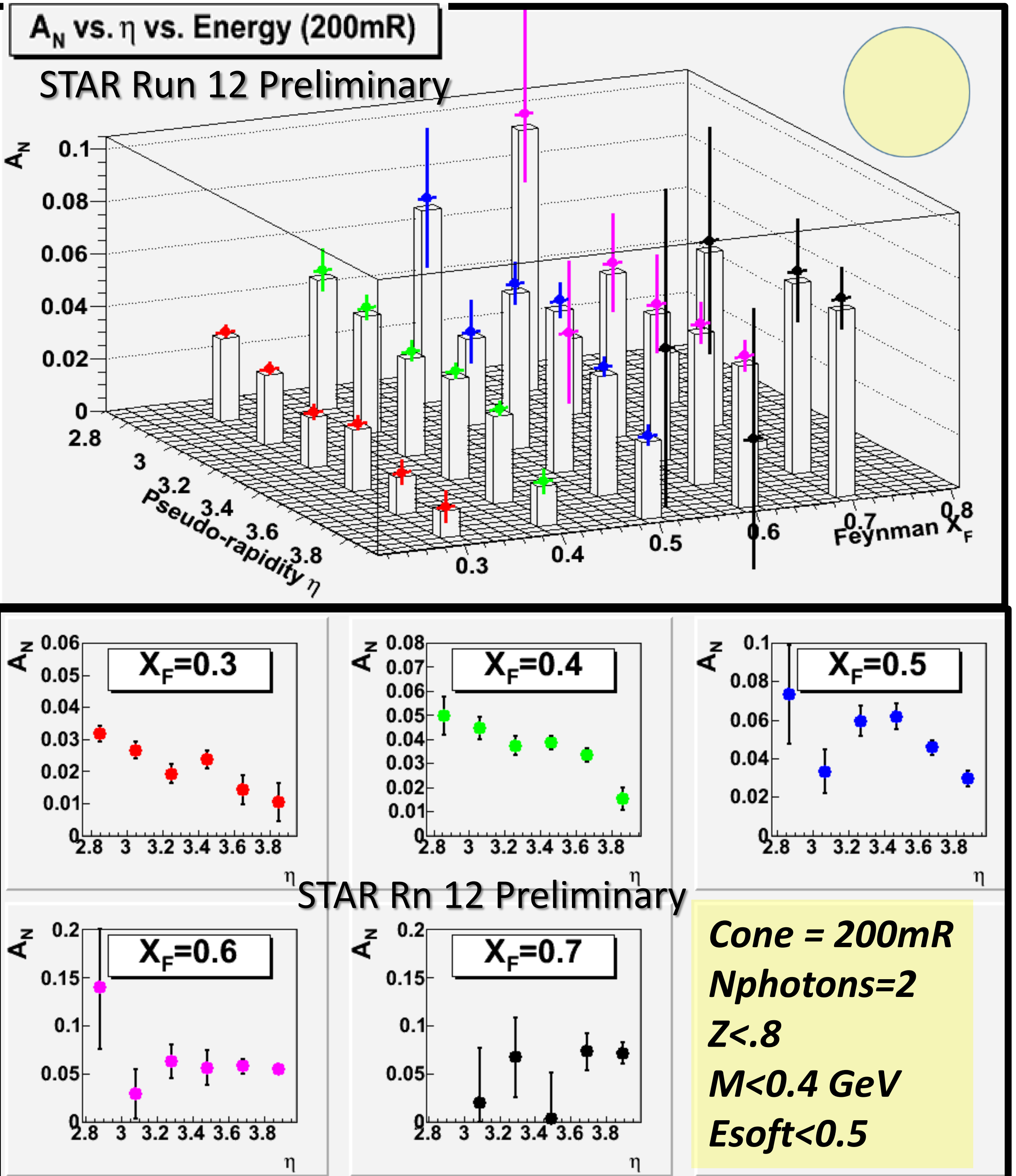
Run 12: $p^{\uparrow} p \rightarrow \pi^0$ $\sqrt{s}$= 200 GeV A_N as a Function of Energy and Pseudo-rapidity (η)



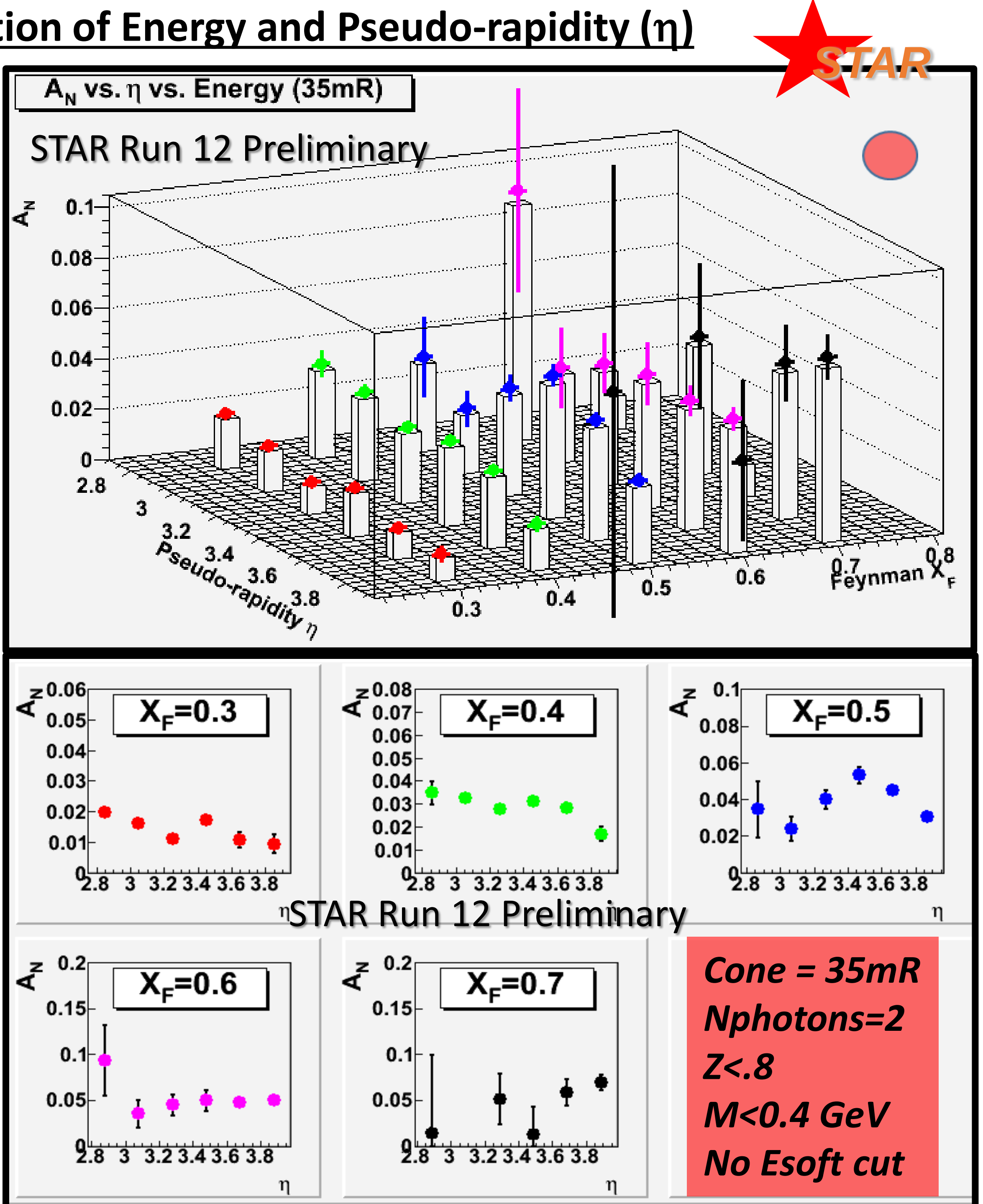
Cone = 200mR
Nphotons=2
Z<.8
M<0.4 GeV
Esoft<0.5

A_N vs. η vs. Energy (200mR)

Run 12: $p^{\uparrow} p \rightarrow \pi^0$ $\sqrt{s} = 200$ GeV A_N as a Function of Energy and Pseudo-rapidity (η)



Cone = 200mR
Nphotons=2
Z<.8
M<0.4 GeV
Esoft<0.5



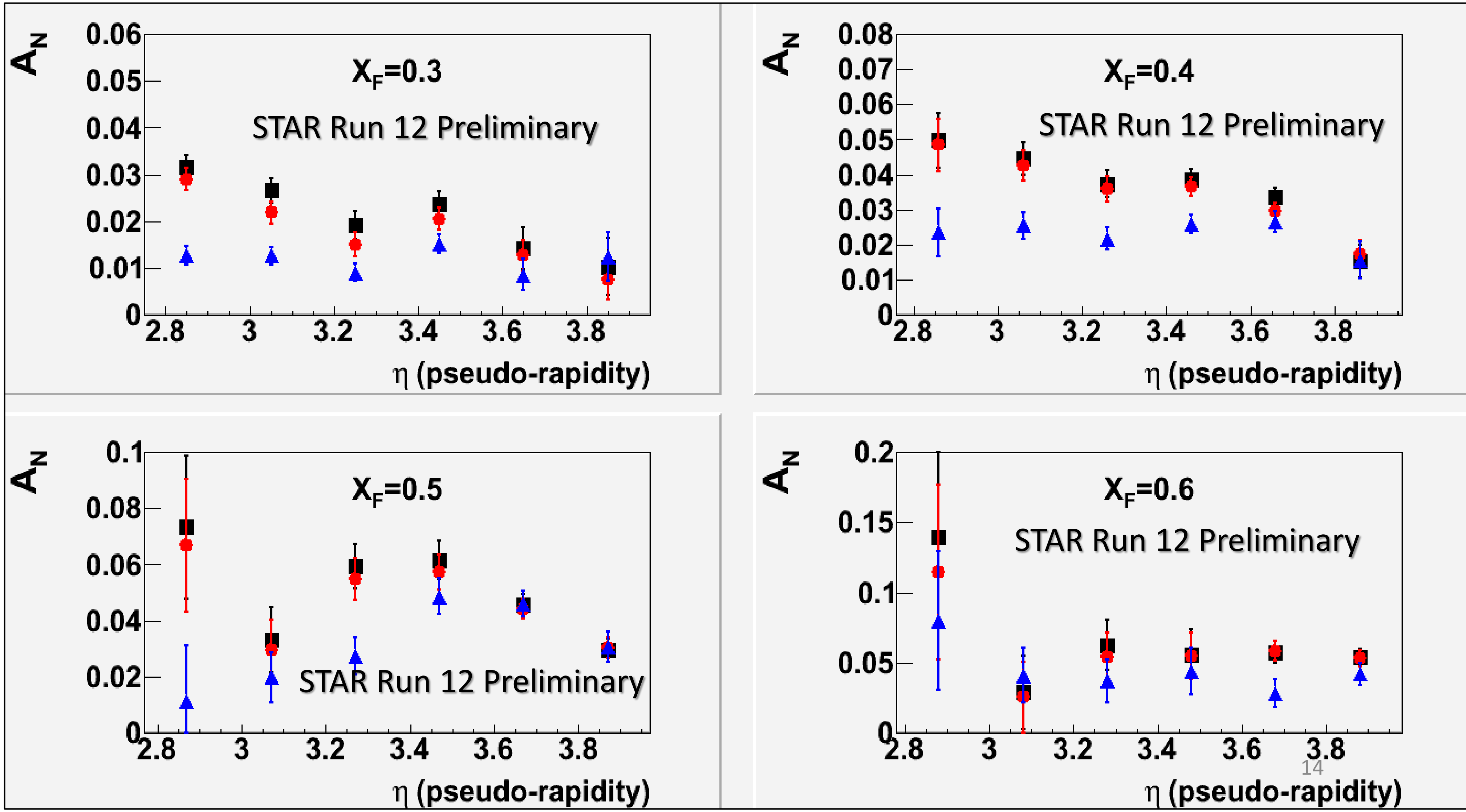
Cone = 35mR
Nphotons=2
Z<.8
M<0.4 GeV
No Esoft cut

Run 12 ($\sqrt{s}$ =200 GeV pp): Compare A_N for π^0 three different selection criterion

1) Isolation cone 200mR && 2 photon clusters (photonE>6 GeV) && Esoft<0.5 GeV. (Least Jet like)
2) Isolation cone 35mR && 2 photon clusters (photonE>6 GeV) && Esoft<0.5 GeV (More Jet like)
3) Isolation cone 35mR && 2 photon clusters (photonE>6 GeV) && Esoft>0.5 GeV. (Most Jet like)

Large A_N for (X_F<0.60) and small pseudo-rapidity is associated with Isolated pions.

Smaller A_N when evidence for jet fragmentation is seen.

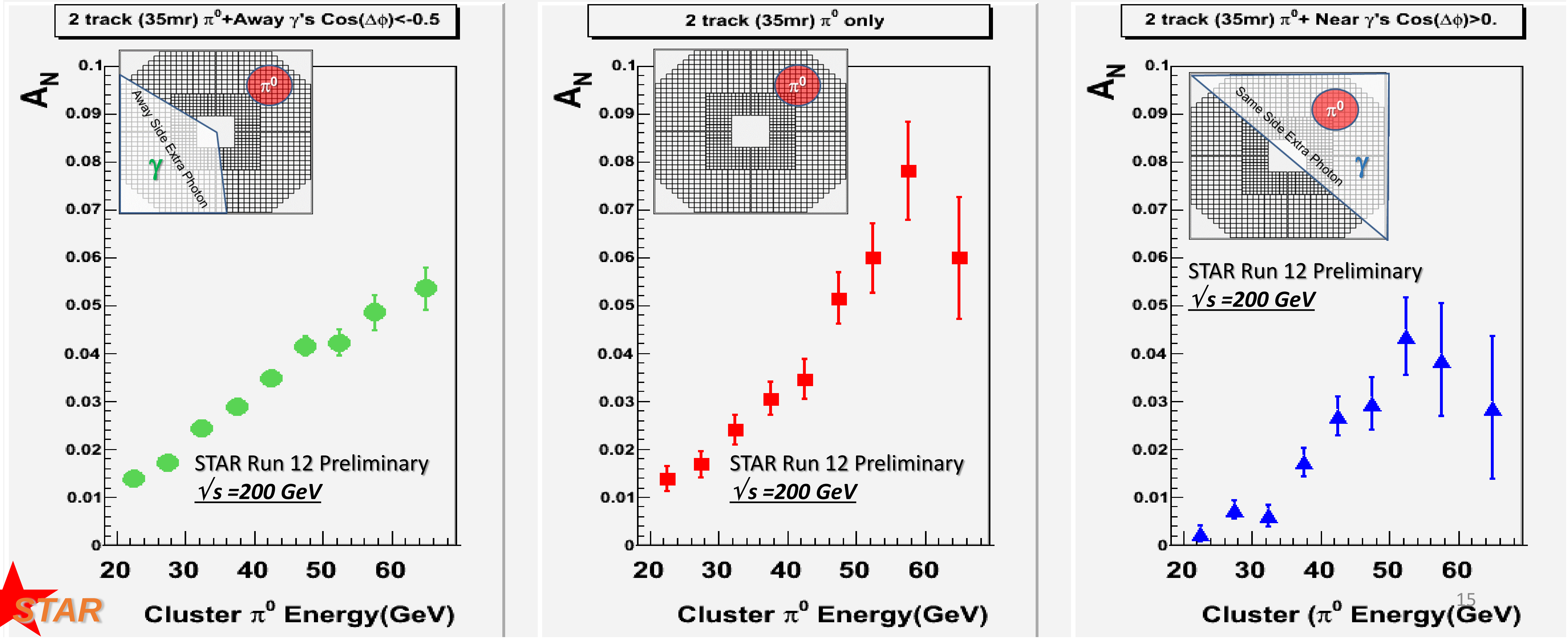


This plot compares three non-overlapping sets of events, all of which involve a **2 photon π^0 cluster** selected with the **35mR cone** size. The plots show energy dependence averaged over pseudo-rapidity bins. The 2 photons in the cone satisfy a π^0 mass cut **|M12-.135|<.08**.

Green triangles: Additional photons away from the cluster, have average azimuthal angle $\cos(\phi_{away}-\phi) < -0.5$

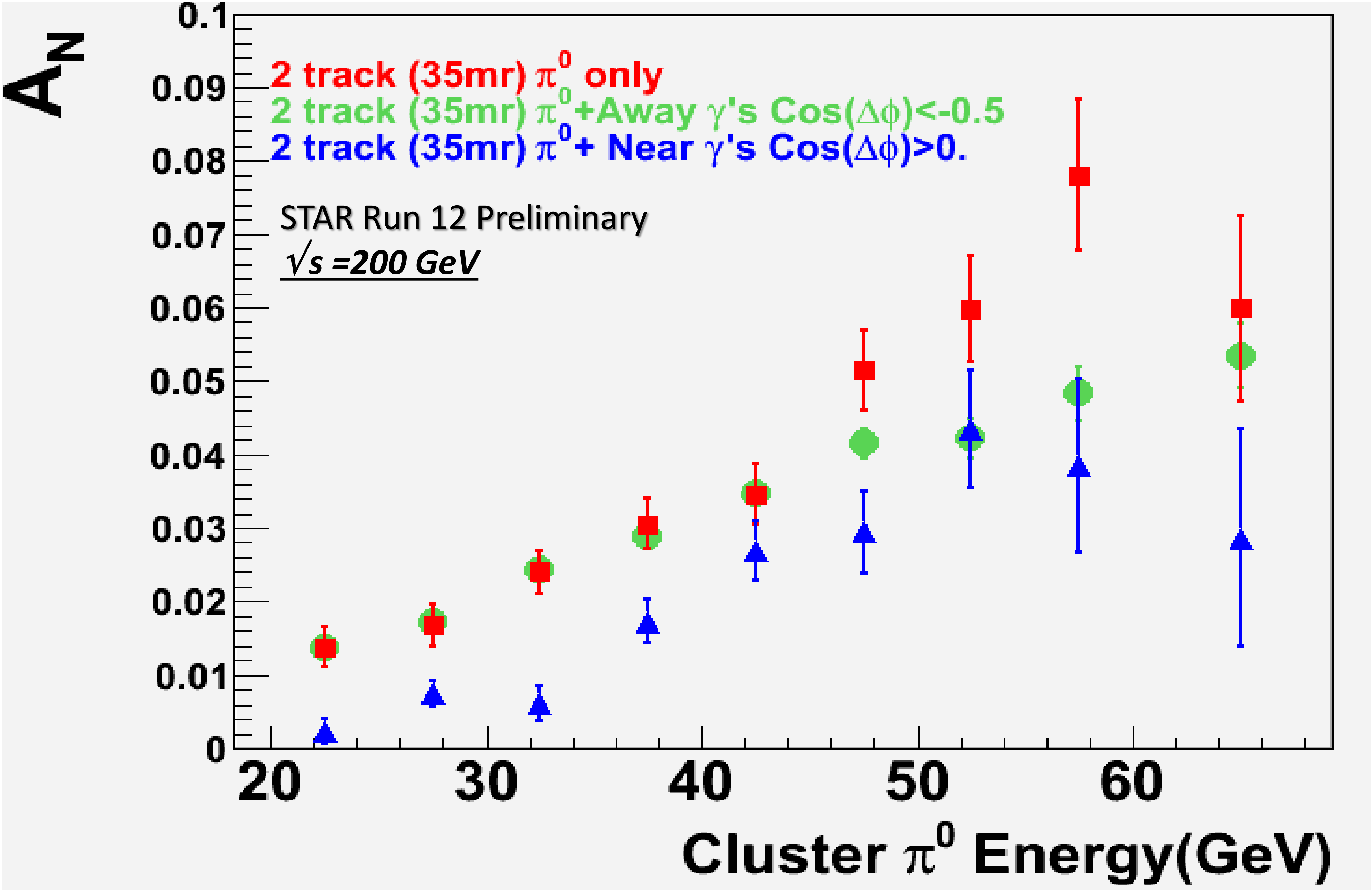
Red squares: No additional photons

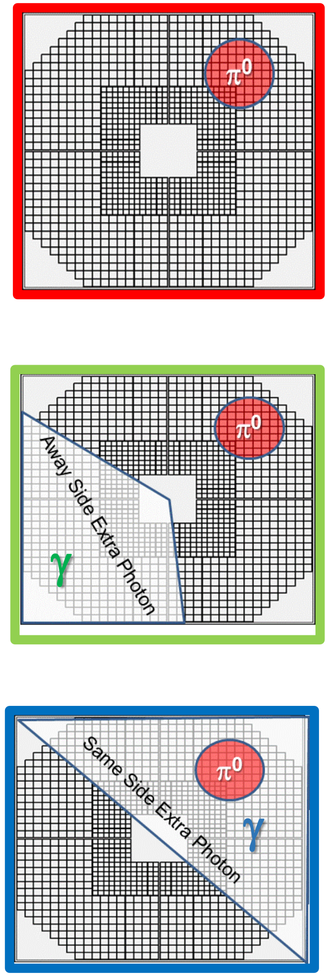
Blue circles: Additional photons near the cluster, have average azimuthal angle $\cos(\phi_{away}-\phi) > 0$.



A_N vs. Energy, averaged over pseudo-rapidity.

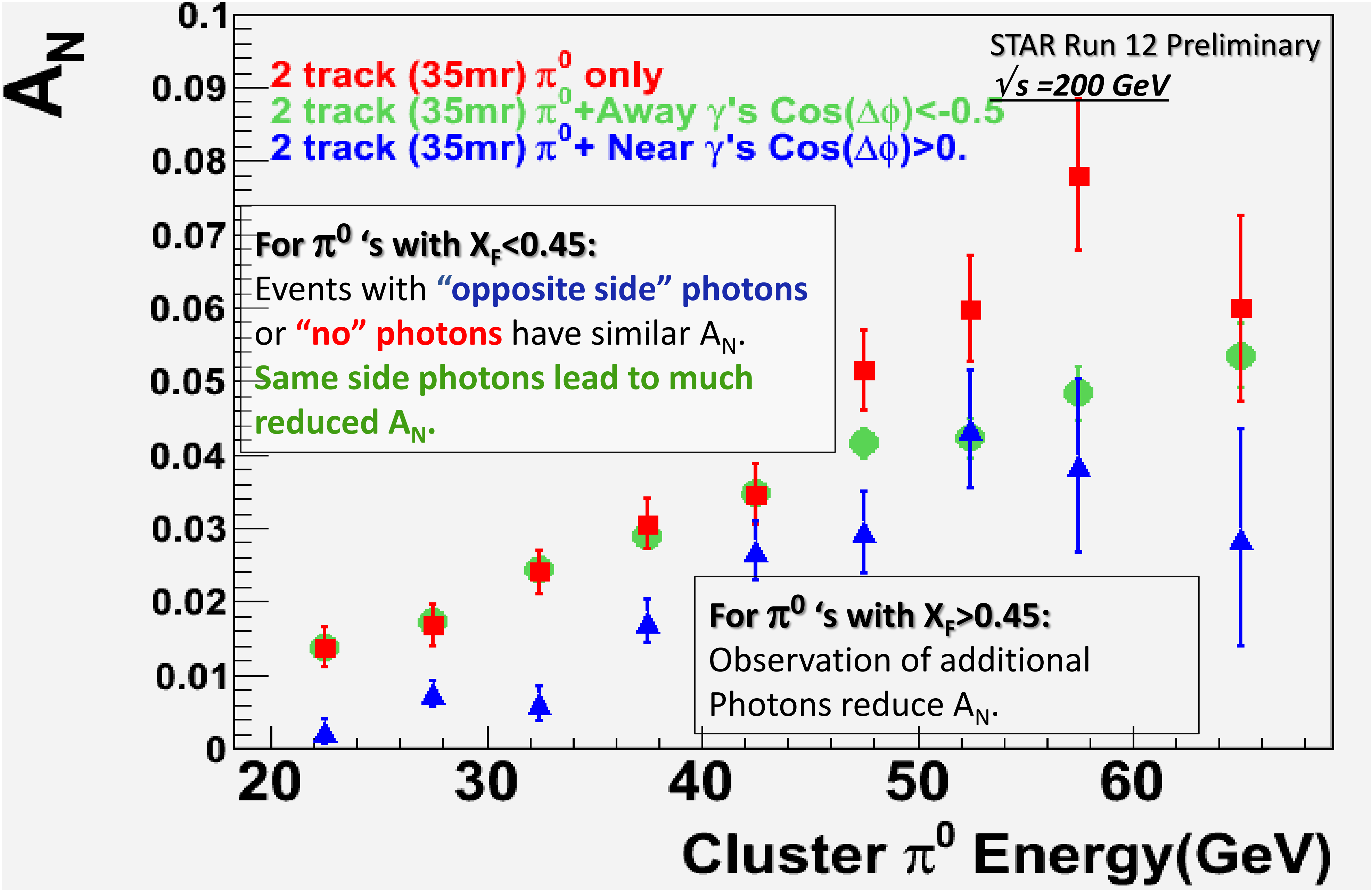
Compare 3 selection criterion based on photon energy outside the cone (all with 35mR cone and no soft E cut)

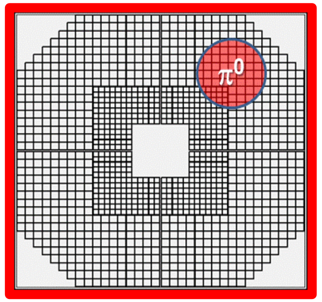


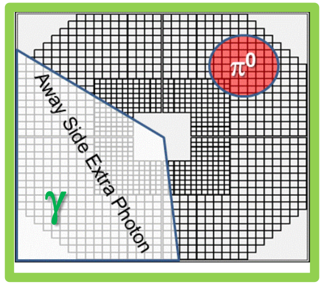


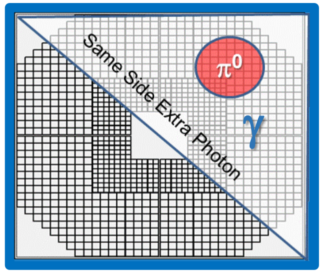
A_N vs. Energy, averaged over pseudo-rapidity.

Compare 3 selection criterion based on photon energy outside the cone (all with 35mR cone and no soft E cut)

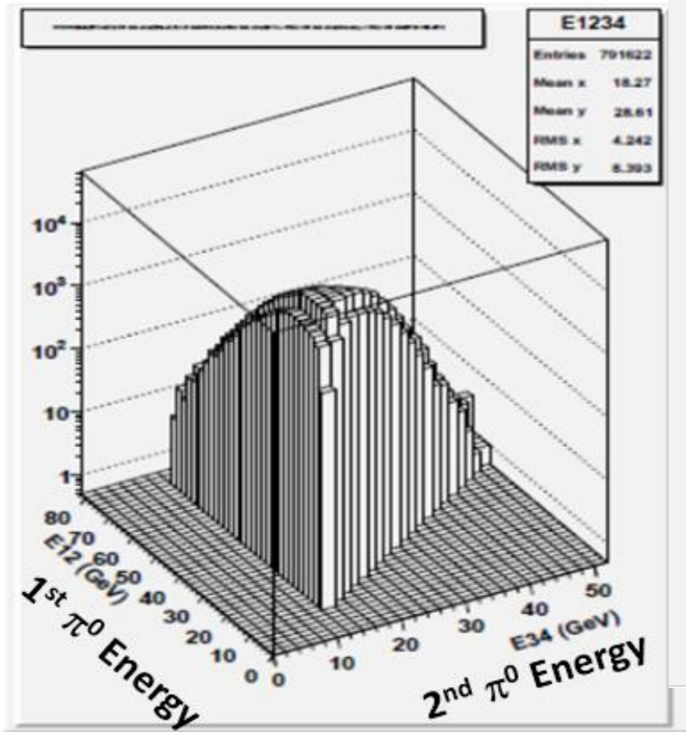


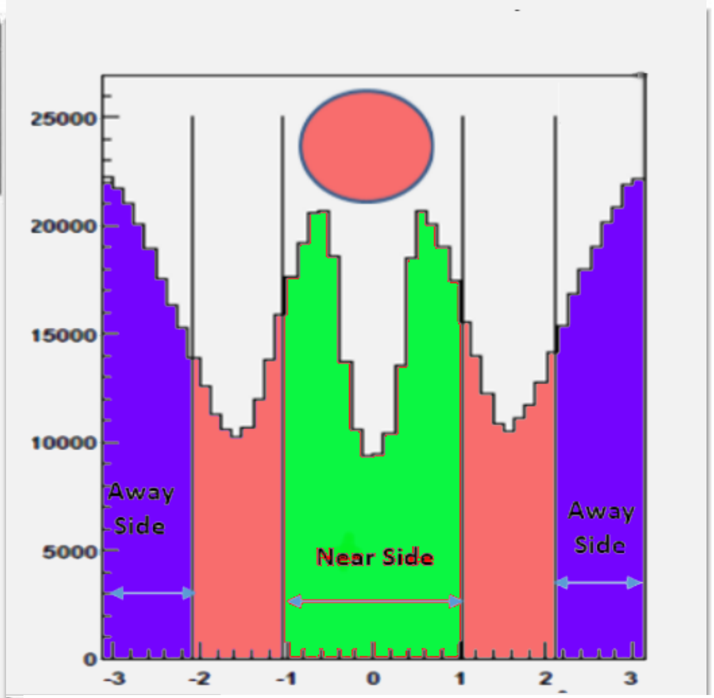






For pairs of π^0's, $\sqrt{s}$ =200 GeV





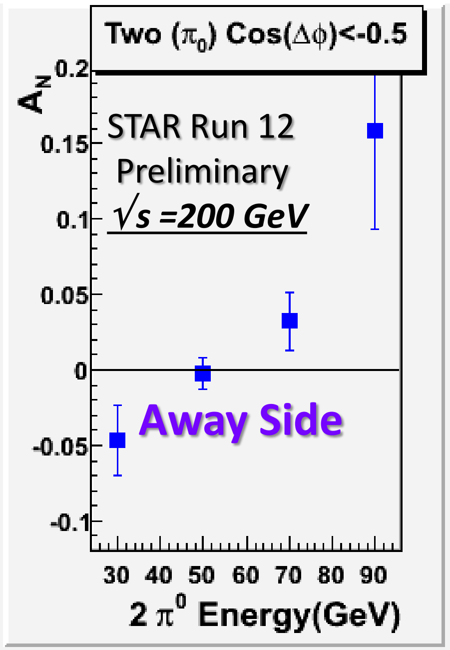
$$\Delta\phi = (\phi_{\pi^0} - \phi_{away\,\pi^0})$$

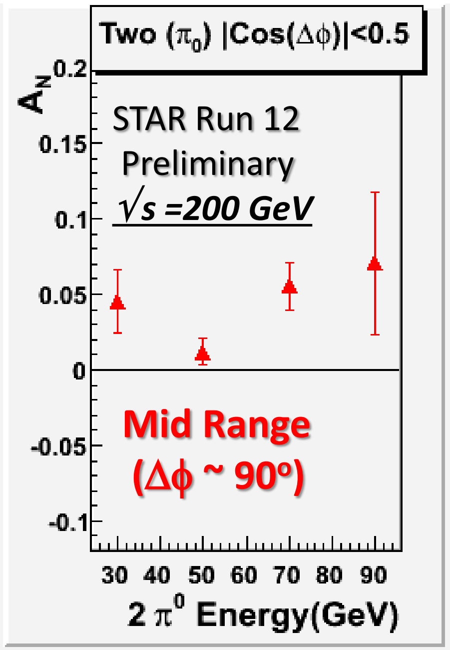
A_N vs π^0 pair energy: 35mR cone

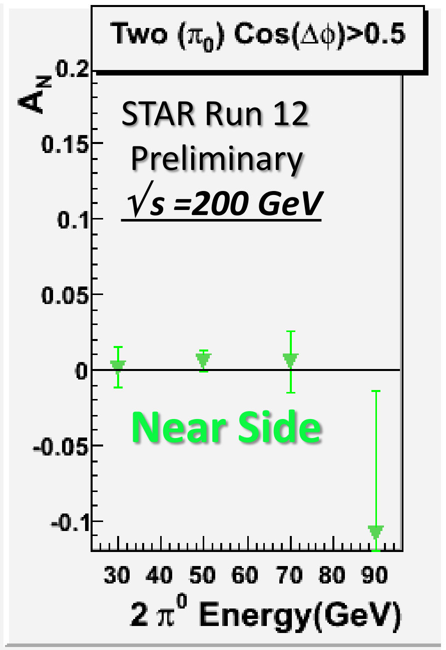
- with 2 photons cluster for 1st π^0
- with 2 additional photons outside the primary cluster satisfying π^0 mass
- Angle (for A_N calculation) from High energy π^0 (2nd π^0 energy >16 GeV)

and either

- **2nd pion on the Away Side**
- **2nd pion in Mid Range**
- **2nd pion on the Near Side**







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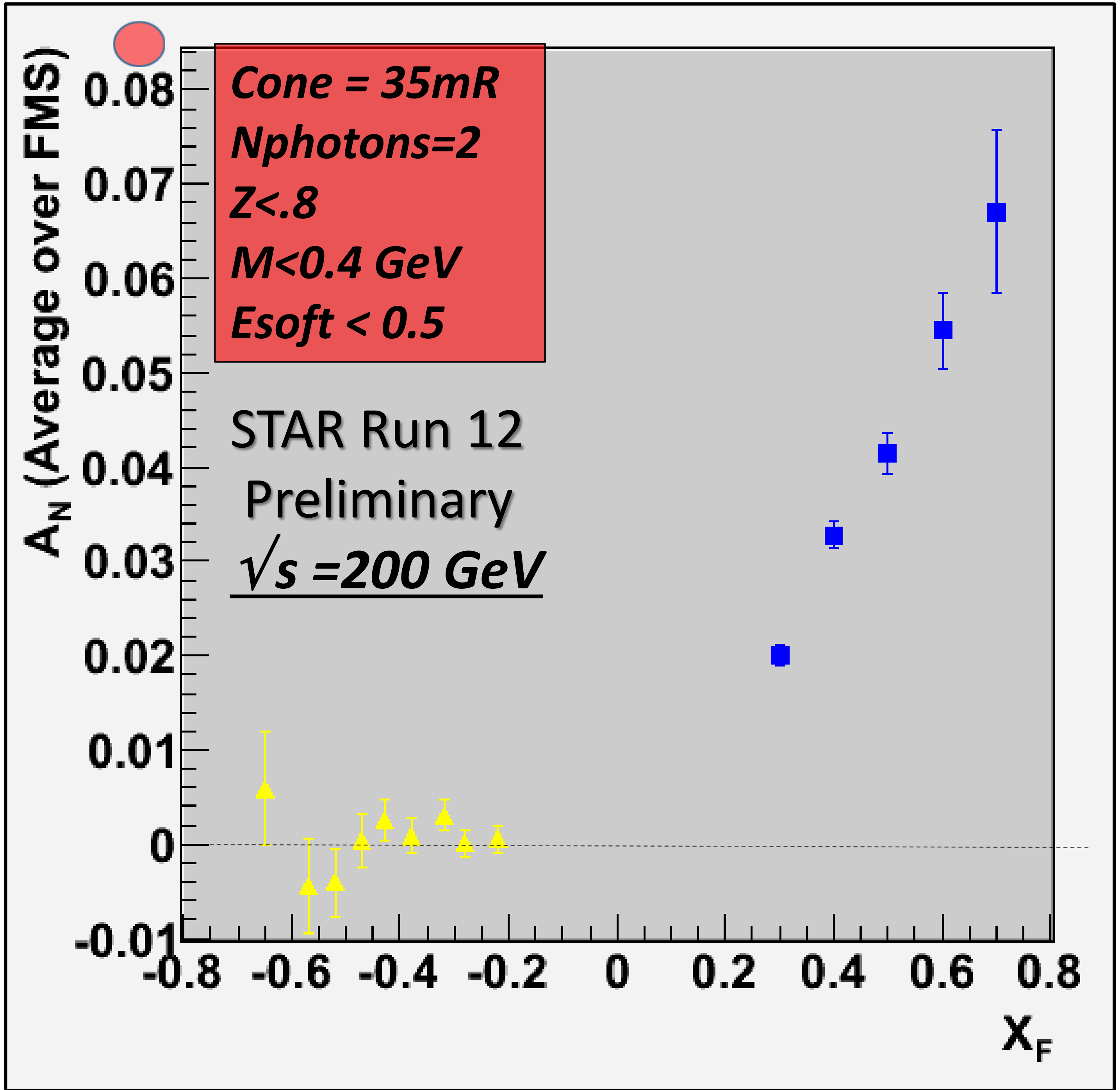
The FMS is illuminated by forward scattering
From the RHIC blue beam

and backward scattering from the yellow beam. No significant backward asymmetry is seen.



Systematic Errors

- Run 11 blue beam polarization 51.6% ±7%
- Run 12 blue beam polarization 60.7% ±7%

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

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

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

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

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

- 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

In $p^{\uparrow}p \rightarrow \pi^0 + X$ @$\sqrt{s}$=200 and 500GeV:

- A_N for forward π^0 production **does not fall with p_T,** as expected, even up to **p_T~10 GeV/c.**
- A_N as a function of p_T for forward π^0 production is compared **at $\sqrt{s}$=200 and 500 GeV** in the region of Feynman X, $0.16 < X_F < 0.4$ **The scale of the asymmetry is similar** but this depends greatly on details of how events are selected.
- From Run 12 data, at $\sqrt{s}$=200 Gev, for smaller X_F and largest p_T (smallest pseudo rapidity) selection **of isolated π^0** s results in **asymmetry 2 to 3 times greater than for selection of more "jet-like" π^0 s.**
- For an additional EM energy deposition "photons" outside the primary cone, the **asymmetry is smallest** if the additional energy is in the **same hemisphere as the π^0.**
- For **2 π^0 production**, the asymmetry is smaller when the lower energy π^0 is in the same hemisphere as the first π^0.
- **In summary: First seen at $\sqrt{s}$=500 GeV (Run 11) and now more clearly at $\sqrt{s}$=200 GeV (Run 12), *Isolated π^0s lead to larger A_N than more jet-like π^0s.***