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

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April 20 2012

- Background
  - Physics Questions
  - FMS History
- FMS Event Topology; Event Selection
- **Cross Ratio** method vs. **$A(\phi)=A_N \cos(\phi)$** method
- Explore high statistics A_N for Run 11
  - P_T dependence for fixed X_F
  - Dependence on event topology

FMS History

- Proposed (BNL, LBL Space Science, Texas AM, Penn State)
- Run 8: FMS Online   dAu, pp (Transverse)
  - Calibration/Trigger problems.
- Conflicts over Management Of FMS
  - Little data in 2009
- Reorganized for Run 11; change of players (+UCLA, +new BNL)
  - ~25 pb-1 of pp (250 x 250 GeV) with transverse polarization (this presentation)

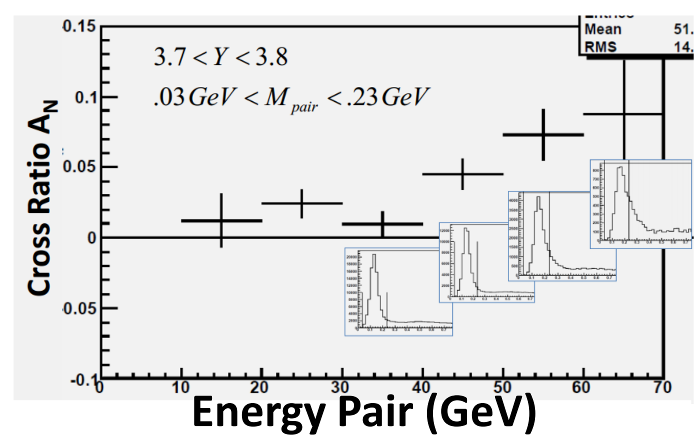
Current: Run 12

PP (100x100 GeV) with transverse and longitudinal polarization

FMS operated very successfully, <u>thanks </u>to huge effort from

Mriganka Mondal
Yu Xi Pan
Chris Dilks
and Stephen Trentelange and many others

Nearly Real Time Star Data analysis   Run 12 (S. Heppelmann)
First look at about 20% of the runs taken between Friday Feb 17 and Tuesday Feb 21, 2012.
(Assume 60% polarization of Blue Beam)



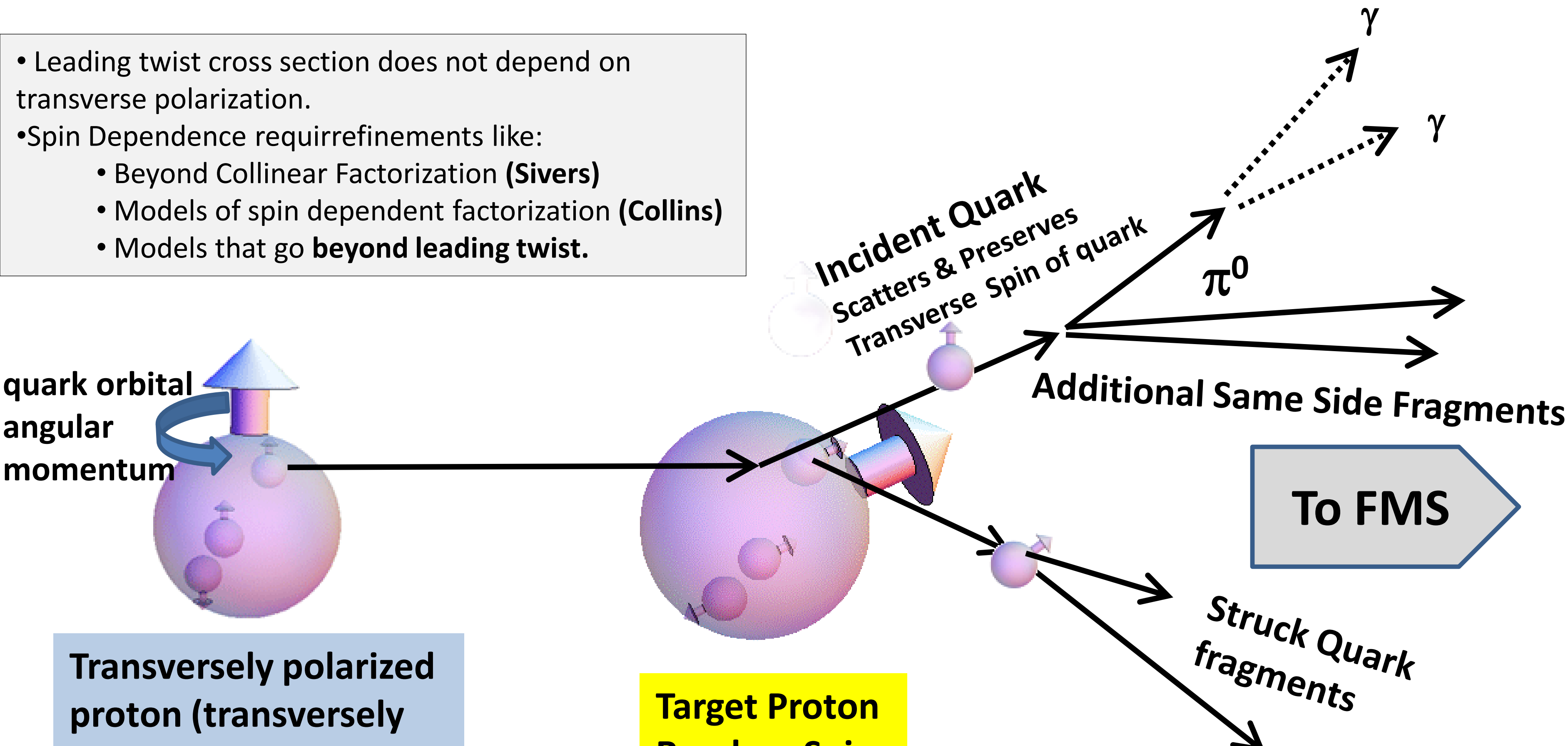
Proton Forward Scattering at High PT
QCD Perspective

PQCD (Leading Twist):

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

- Does good job of predicting the "> 90% " of the cross section that does not depend on spin.

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

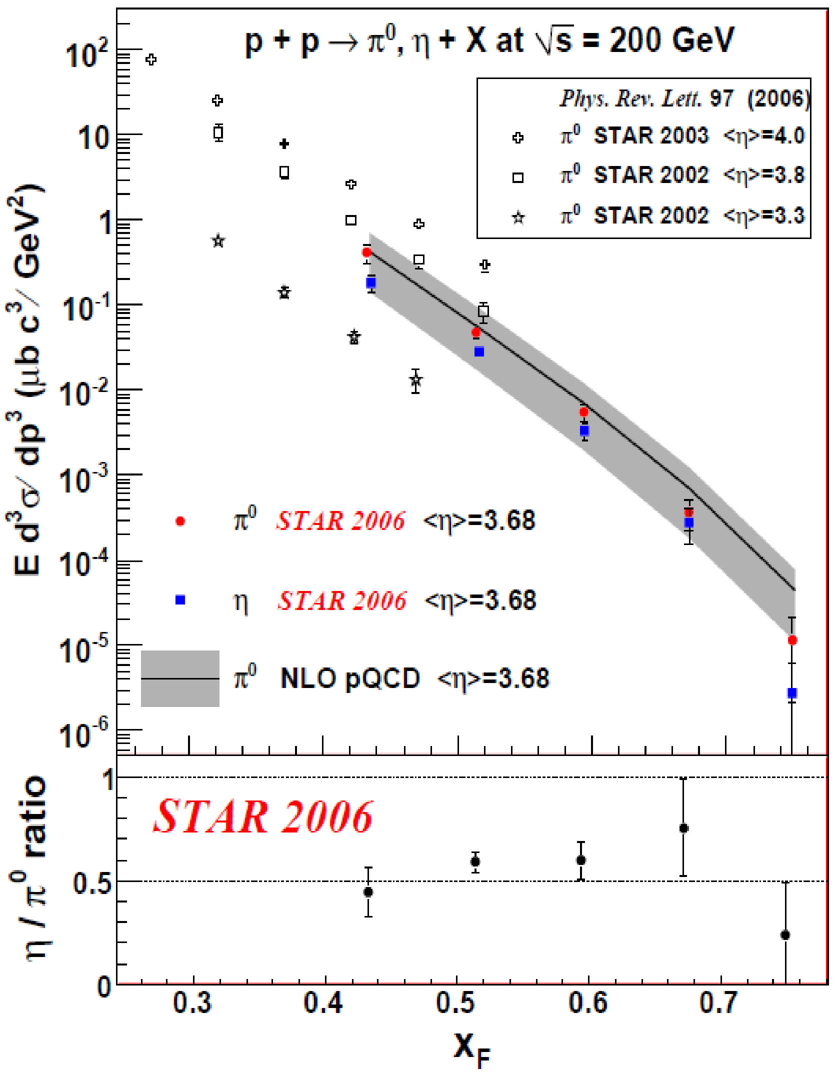


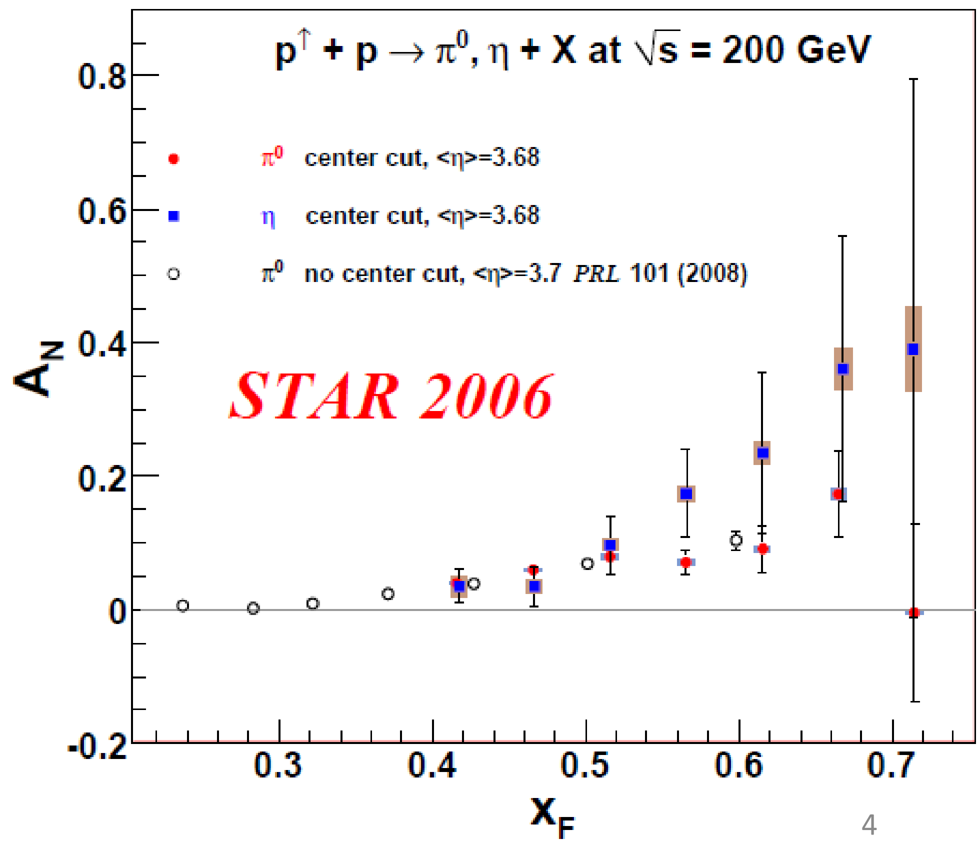
Transversely polarized proton (transversely polarized quark)
Blue Beam

Target Proton
Random Spin
Yellow Beam

New paper on η/π^0 at $X_F>0.5$

- 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 $X_F > 0.55$





- 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.**

Sivers Model: 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!

Collins Model: 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!

Transverse momentum **increases/decreases** with transverse **spin up/down**

A toy model for proton Cross Section

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

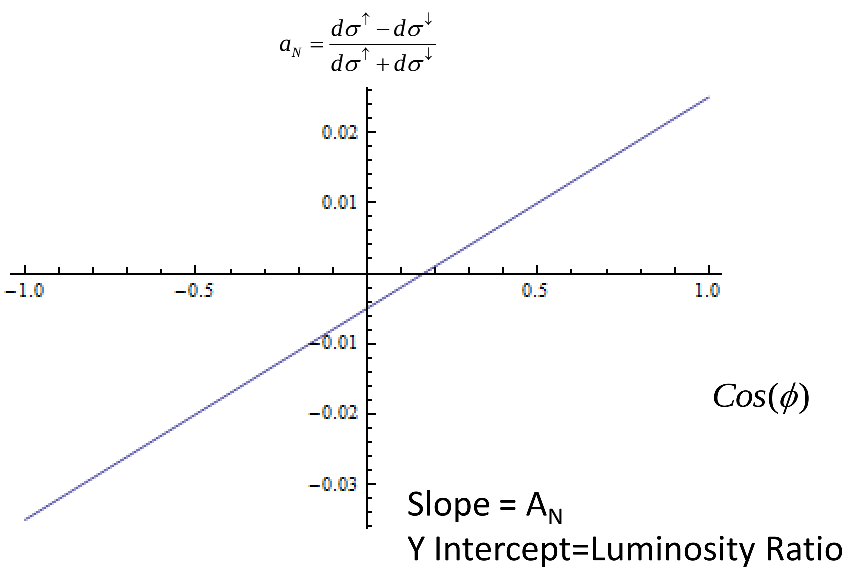
$$A_N \sim \frac{\sigma(p_T+k_T)-\sigma(p_T-k_T)}{2\sigma(p_T)} \sim \frac{6k_T}{p_T} \sim \frac{1}{p_T}$$

Similar transverse momentum dependence **for higher twist.**

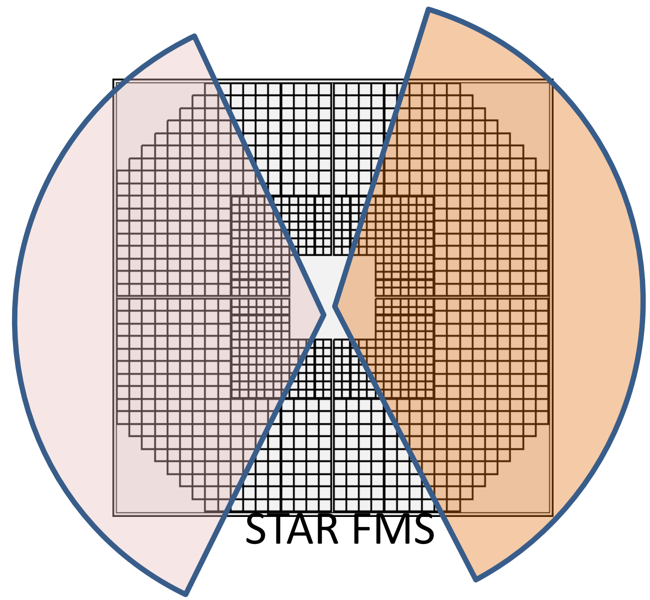
Cross Ratio Transverse Asymmetry
vs
A(ϕ) observation

Method 1:
Cross Ratio:

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



Left(N): Cos(ϕ)<-0.5



Right(S): Cos(ϕ)>0.5

$$a_N(\phi) = a_0 + A_N \cos(\phi)$$

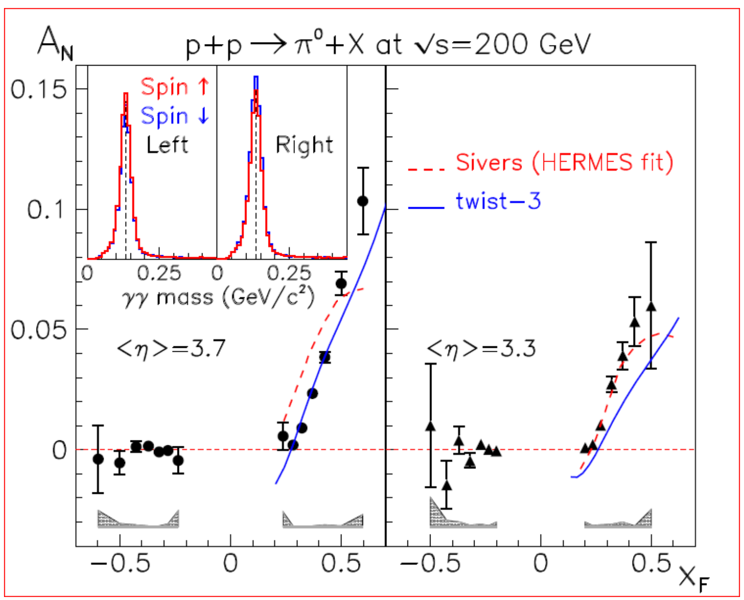
Method 2:

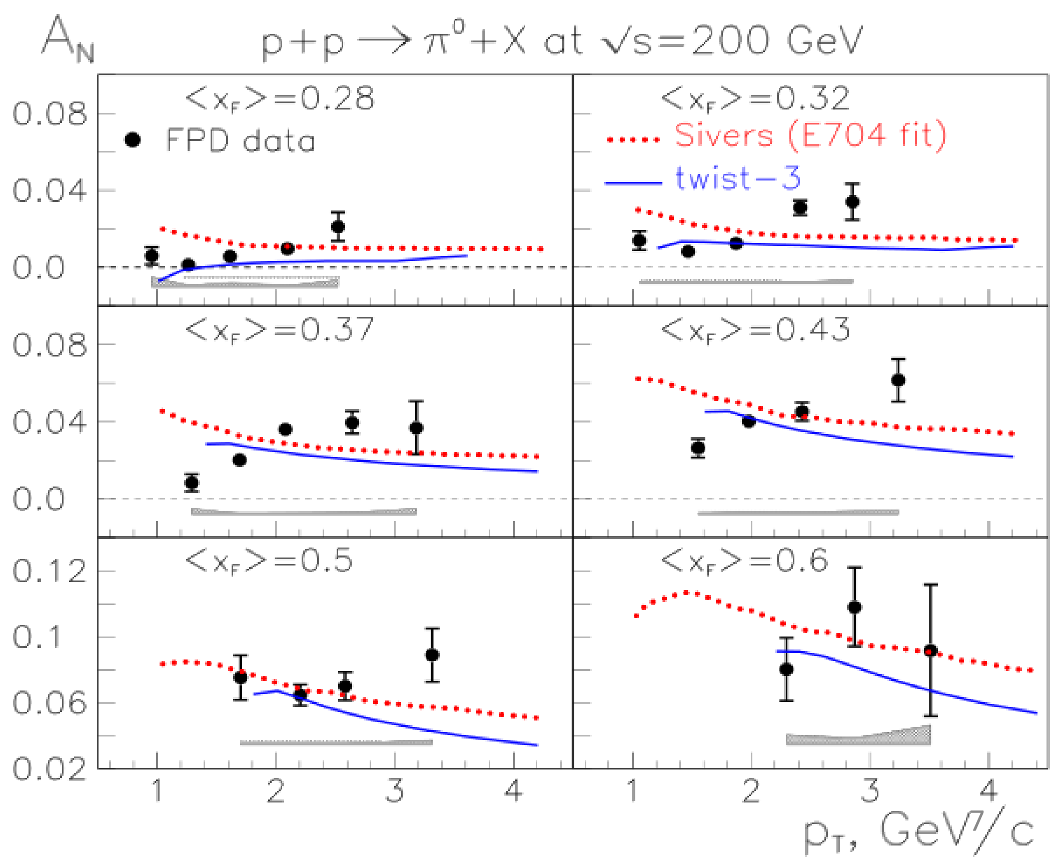
Fix a_0 for full data set for many small data subsets ….. One parameter fit for A_N

Advantage: Every fitted value of A_N comes with error and chi^2.

STAR Published Run 6 (FPD √s =200GeV)

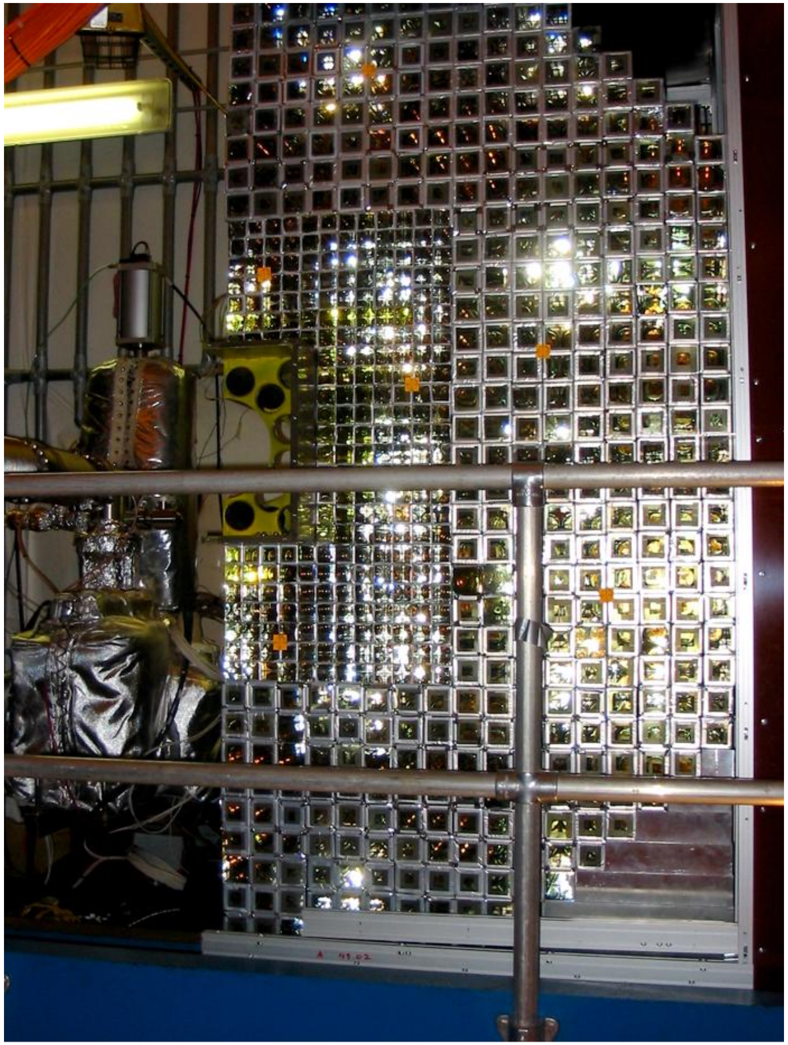
- Rising A_N with XF ($0<X_F<0.5$) from 0% to 5-10%
- No evidence of fall in A_N with increasing P_T.

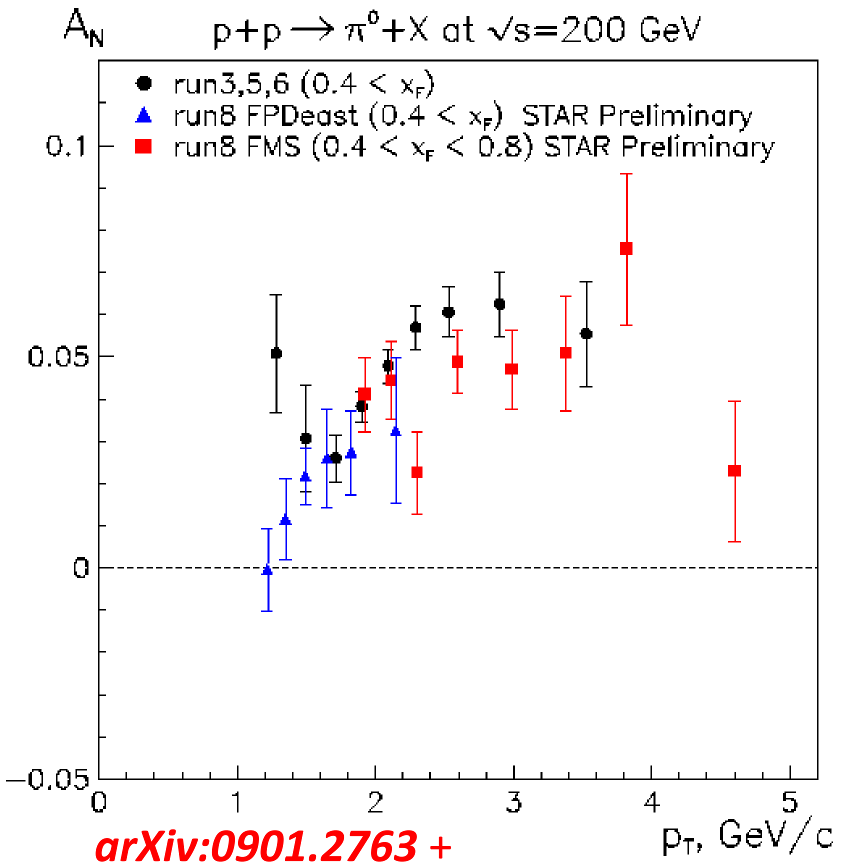




From FMS Run 8, STAR has Expanded Rapidity Coverage -1<Y<4.2

STAR Forward Meson Spectrometer
2.5 < Y < 4.0

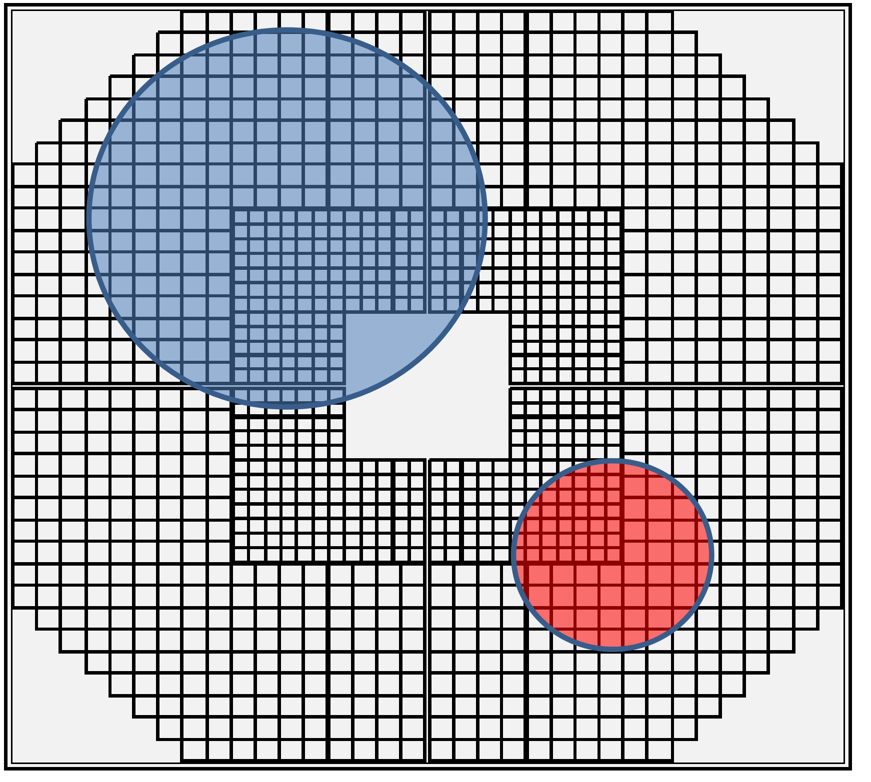




arXiv:0901.2763 +
A.Ogawa @CIPANP09

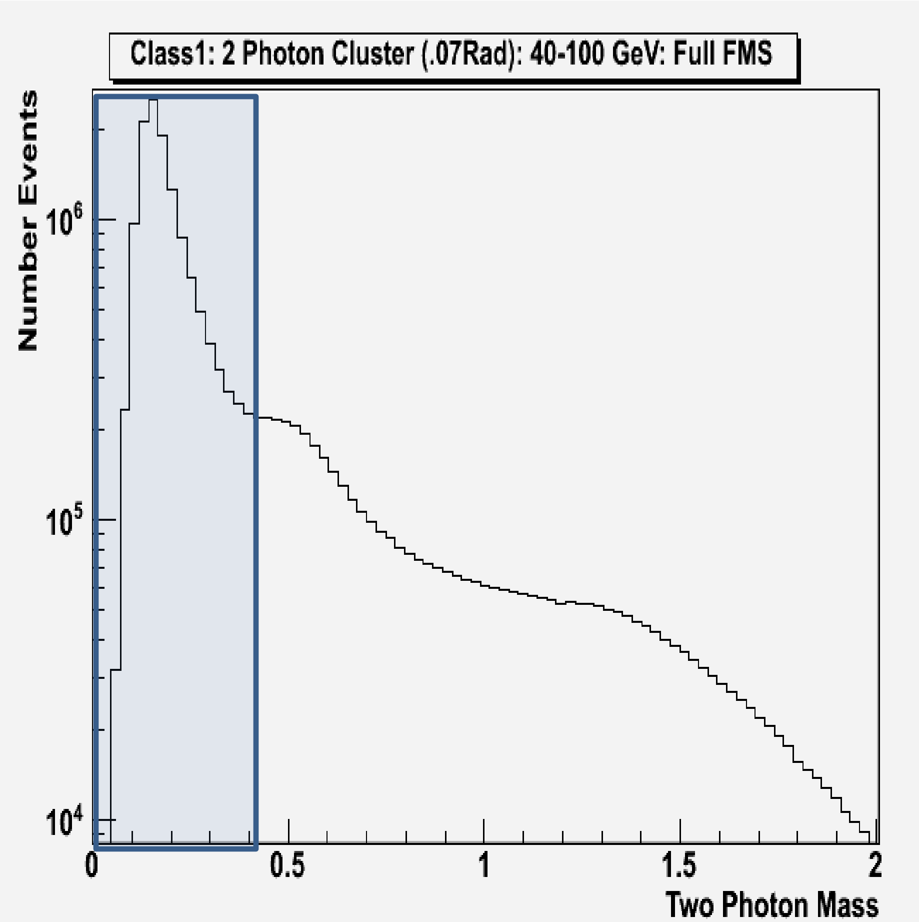
Event Selection:

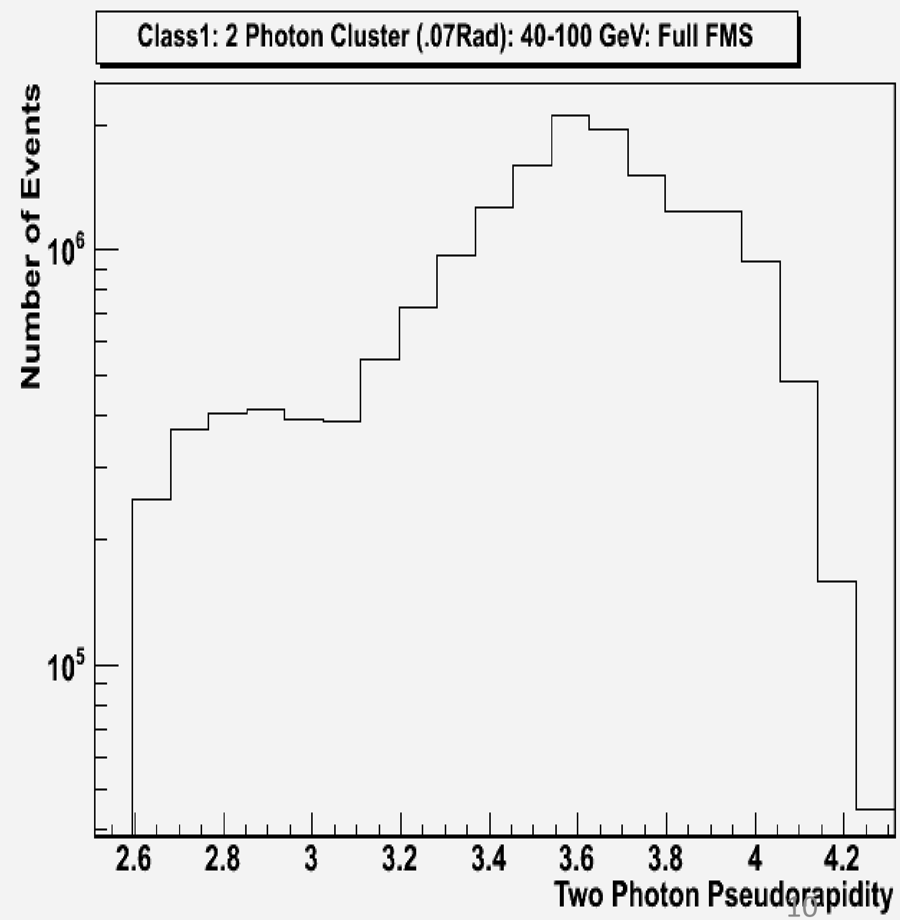
1. **<u>Analyze FMS for all photon</u>** candidates. (Showers that are fit successfully to photon hypothesis)
2. **<u>Find Clusters of EM energy</u>** grouping photon candidates that are within opening angle cone $\Delta\theta$ (relative to energy weighted center)
3. We consider 2 event classes {1,2,3,4}
   1. **$\Delta\theta$ =0.07** 2 Photon clusters, Pi0 Mass (inclusive)?
   2. **$\Delta\theta$ =0.03** 2 Photon clusters ,Pi0 Mass (inclusive)?



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
- 2.6 < Y < 4.1 (Full FMS Pseudo-rapidity)
- Selection of π^0 Peak



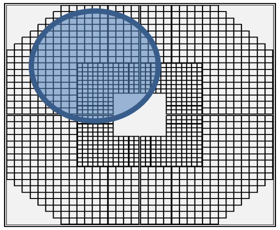


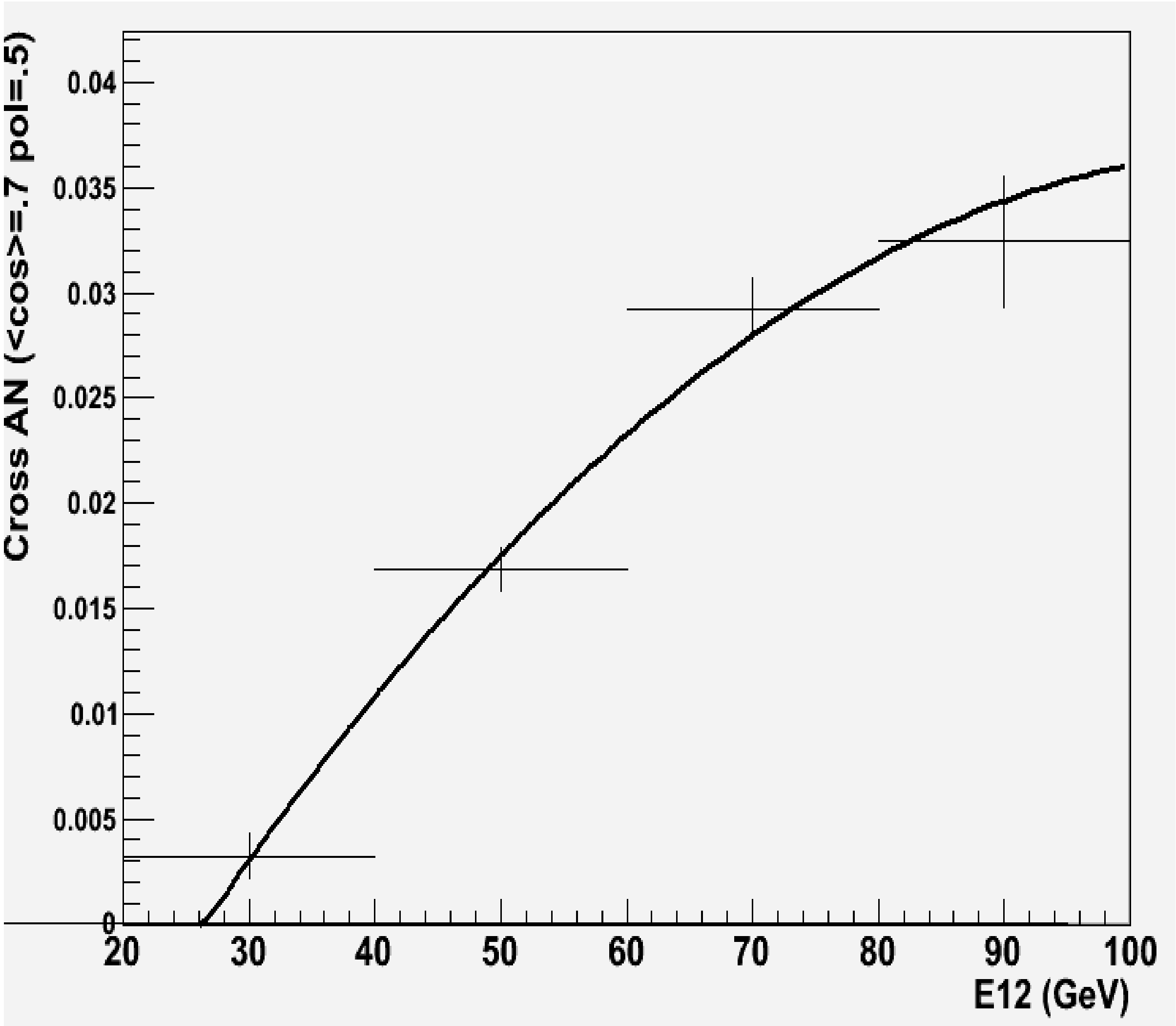
Cross Ratio Transverse Single Spin Asymmetry for Run 11

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

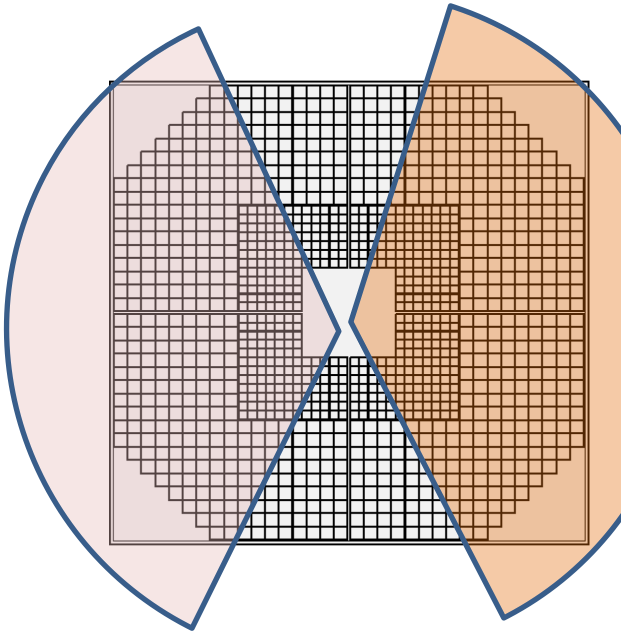
For Blue Beam (Forward)

Full FMS rapidity range.



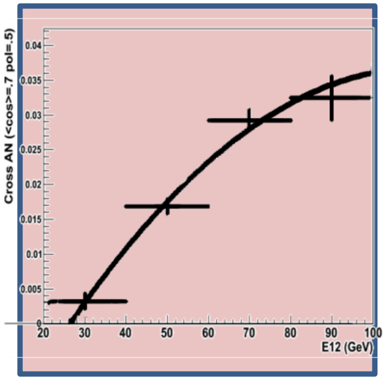


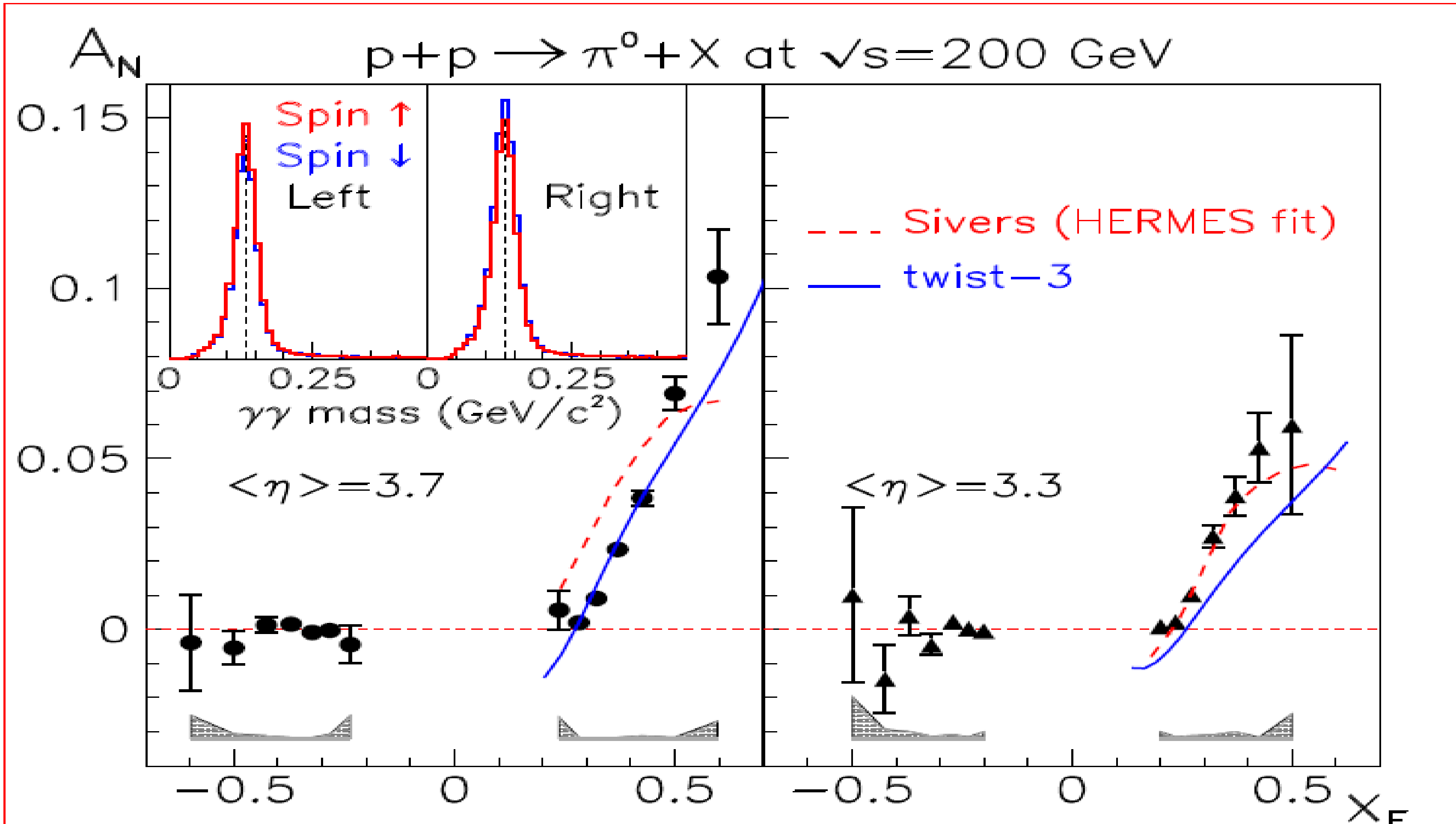
Left: Cos(ϕ)<-0.5



Left: Cos(ϕ)>0.5

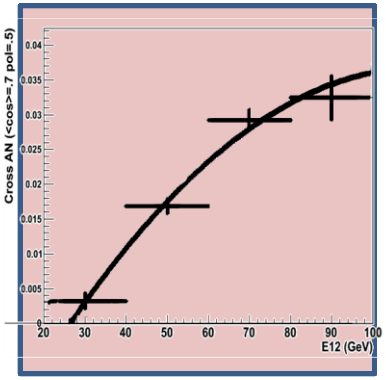
Compare New √s=500 GeV Run 11 Full FMS Data on right with **Run 6 published data below.**

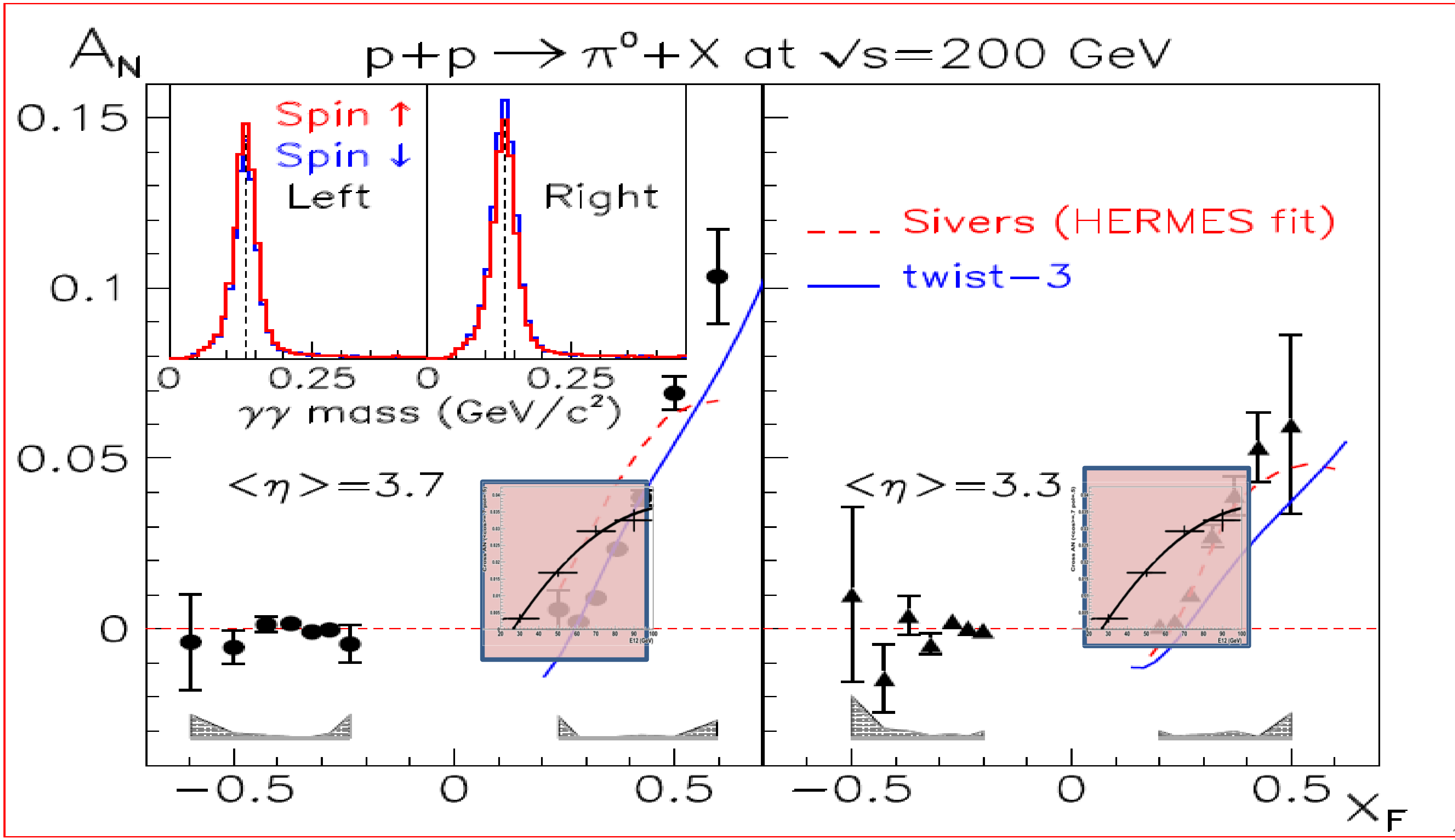


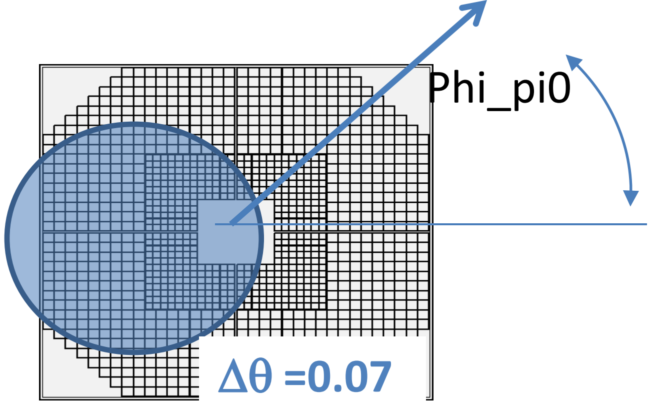


Compare **new √s=500 GeV Run 11** Full FMS Data on right with **Run 6 √s=200** published data below.

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

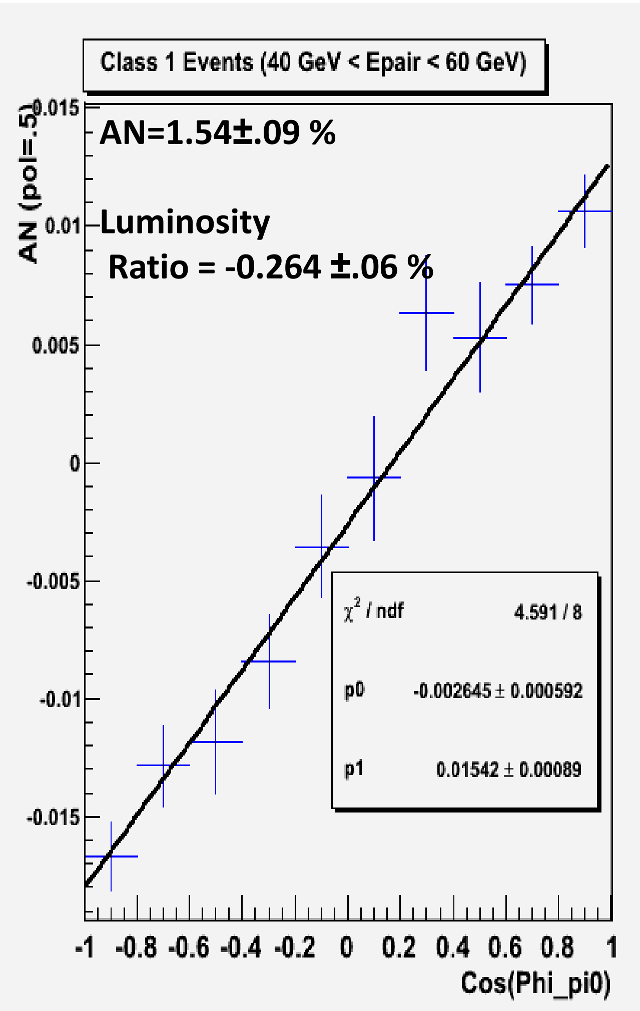


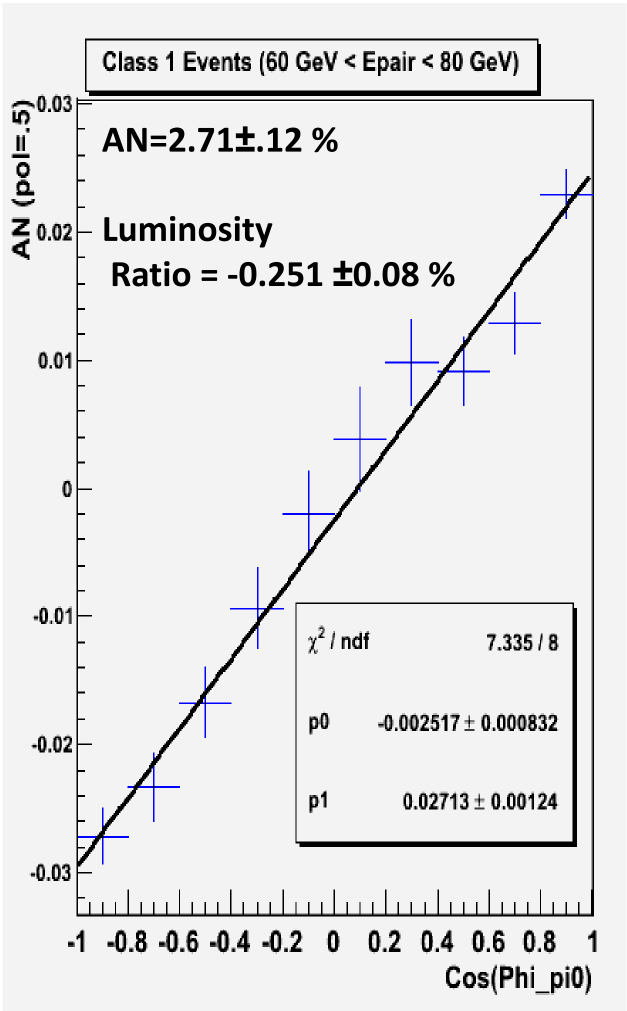


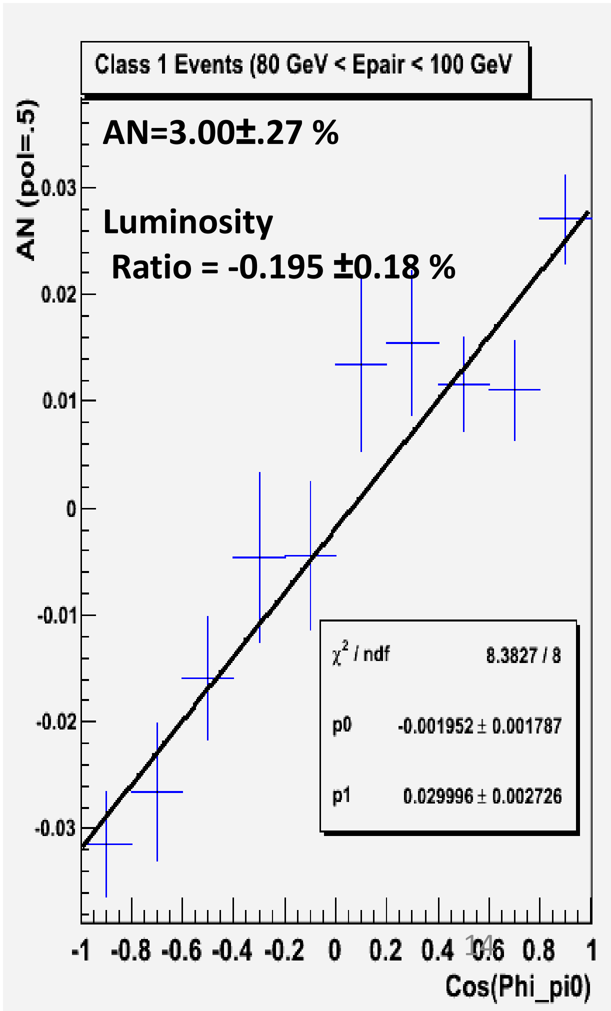


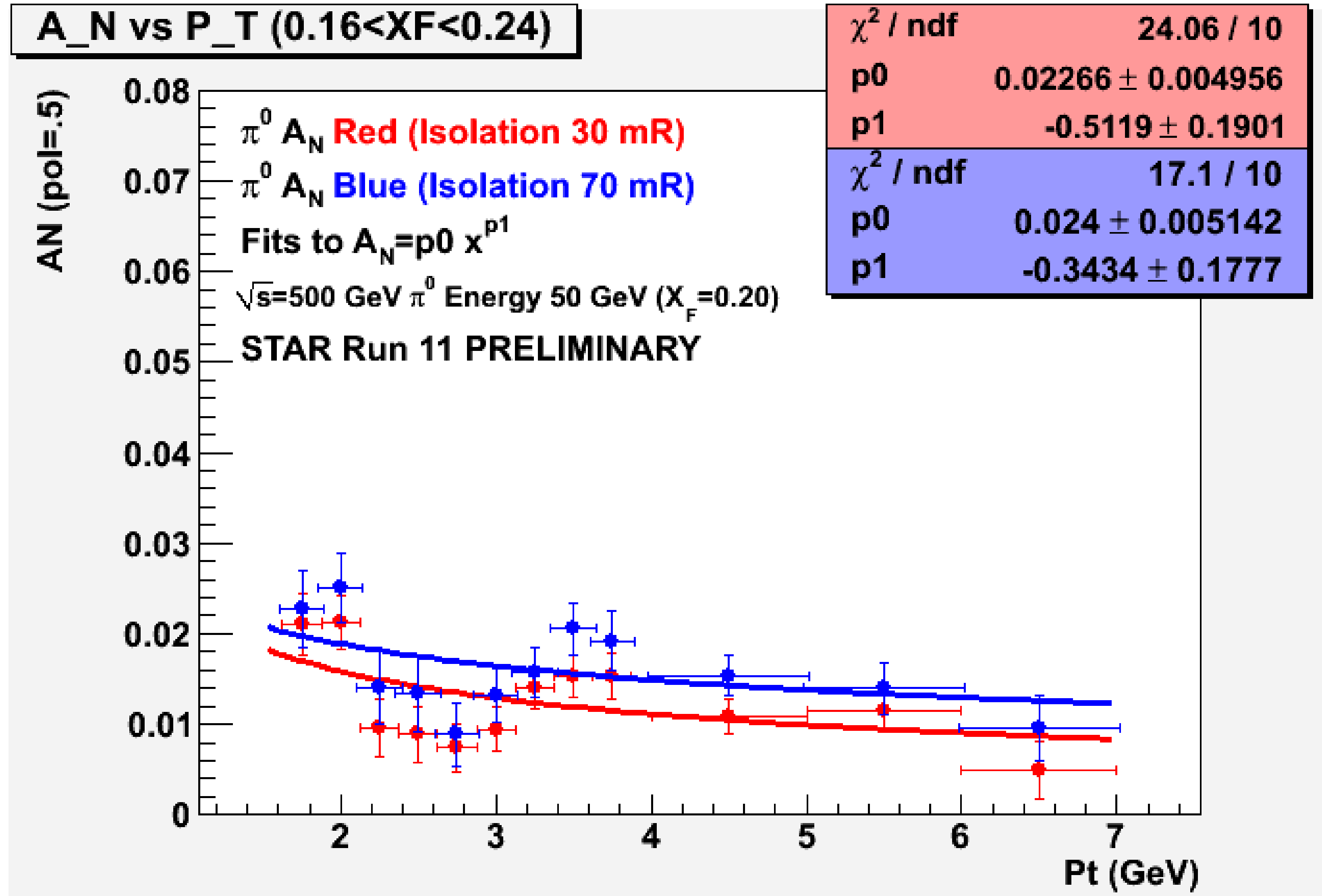
Blue Beam AN

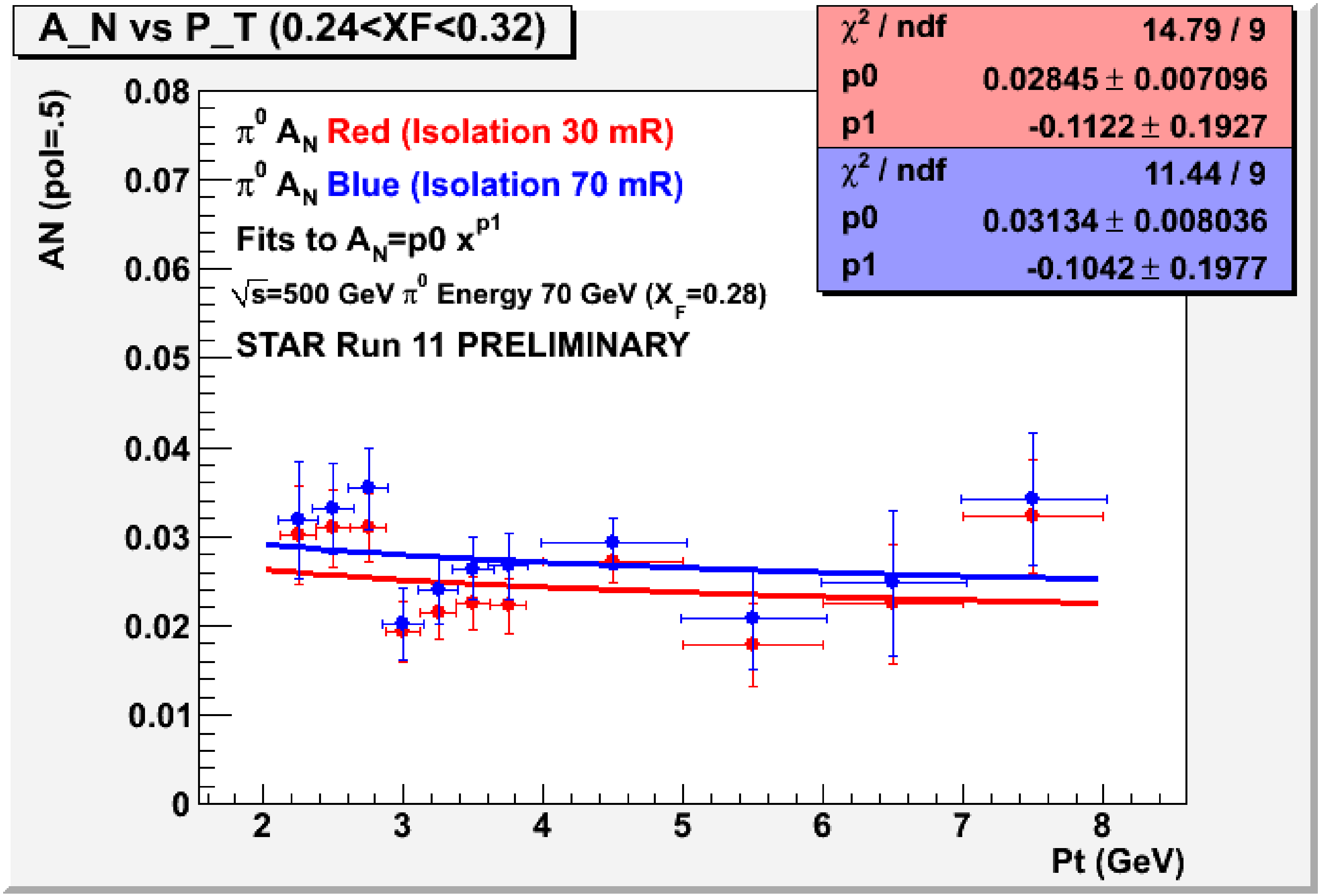
As and alternative to Cross Ratio, the raw asymmetry
Can be plotted as a function of Cos(Phi)
(with polarization axis at Phi=pi/2)
Slope =AN
Intercept = Luminosity Ratio for data set
Luminosity ratio for all **~- 0.25 ±.05 %**



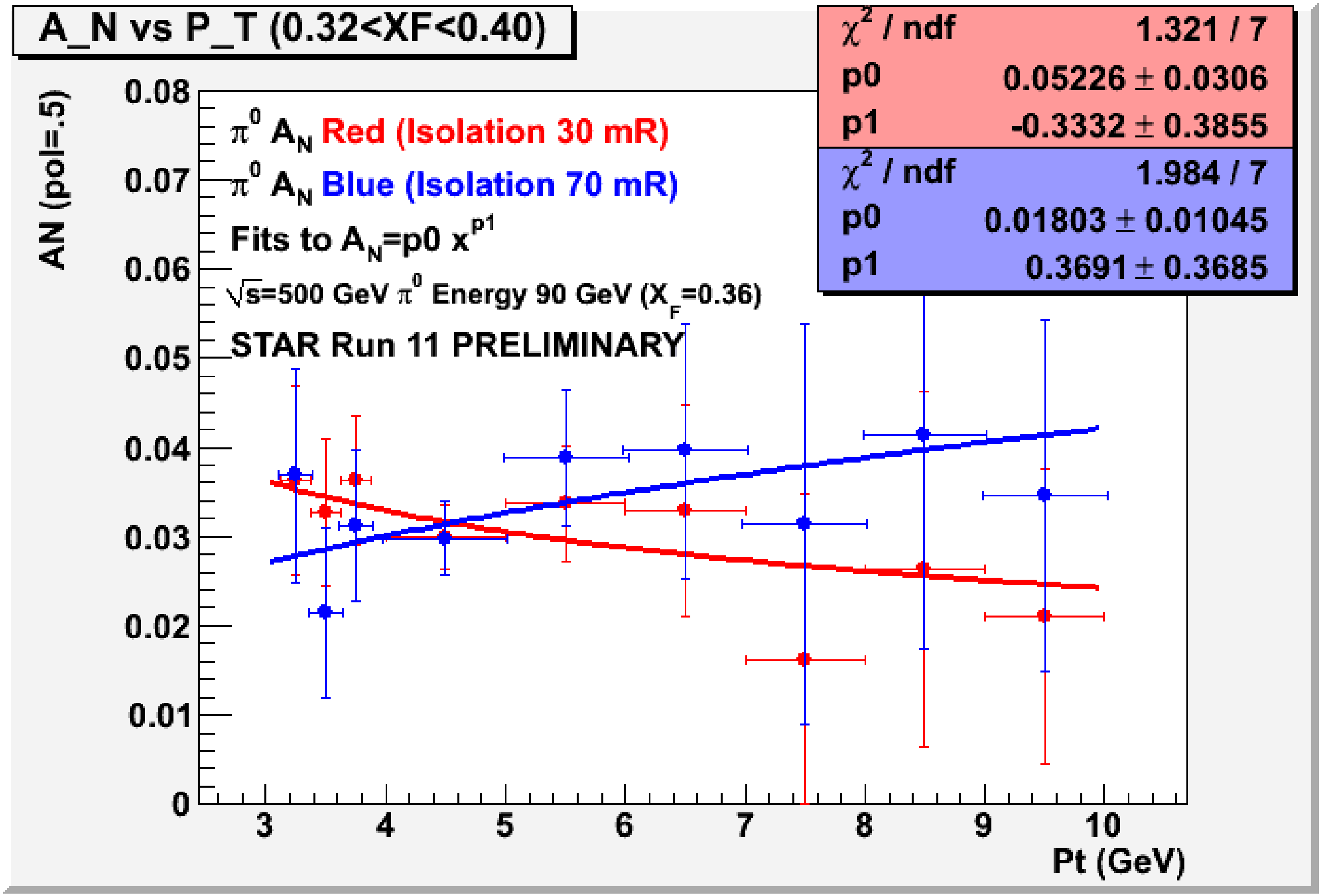





A_N vs P_T (0.16<XF<0.24)
χ² / ndf 24.06 / 10
p0 0.02266 ± 0.004956
p1 -0.5119 ± 0.1901
χ² / ndf 17.1 / 10
p0 0.024 ± 0.005142
p1 -0.3434 ± 0.1777
π⁰ A_N Red (Isolation 30 mR)
π⁰ A_N Blue (Isolation 70 mR)
Fits to A_N=p0 x^p1
√s=500 GeV π⁰ Energy 50 GeV (X_F=0.20)
STAR Run 11 PRELIMINARY
AN (pol=.5)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
2
3
4
5
6
7
Pt (GeV)



A_N vs P_T (0.24<XF<0.32)
χ2 / ndf 14.79 / 9
p0 0.02845 ± 0.007096
p1 -0.1122 ± 0.1927
χ2 / ndf 11.44 / 9
p0 0.03134 ± 0.008036
p1 -0.1042 ± 0.1977
π0 AN Red (Isolation 30 mR)
π0 AN Blue (Isolation 70 mR)
Fits to AN=p0 x^p1
√s=500 GeV π0 Energy 70 GeV (XF=0.28)
STAR Run 11 PRELIMINARY
AN (pol=.5)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
2
3
4
5
6
7
8
Pt (GeV)


A_N vs P_T (0.32<XF<0.40)
AN (pol=.5)
π0 AN Red (Isolation 30 mR)
π0 AN Blue (Isolation 70 mR)
Fits to AN=p0 x^p1
√s=500 GeV π0 Energy 90 GeV (XF=0.36)
STAR Run 11 PRELIMINARY
χ2 / ndf 1.321 / 7
p0 0.05226 ± 0.0306
p1 -0.3332 ± 0.3855
χ2 / ndf 1.984 / 7
p0 0.01803 ± 0.01045
p1 0.3691 ± 0.3685
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
3
4
5
6
7
8
9
10
Pt (GeV)

Systematic Errors of ~ 10%

- Run 11 blue beam polarization 50% ± 5%

$$\frac{\Delta A_N}{A_N} < 0.1$$

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

$$\frac{\Delta A_N}{A_N} < 0.05$$

Conclusion

- A_N less dependent on P_T that models predict.
- A_N larger for isolated π^0 s.

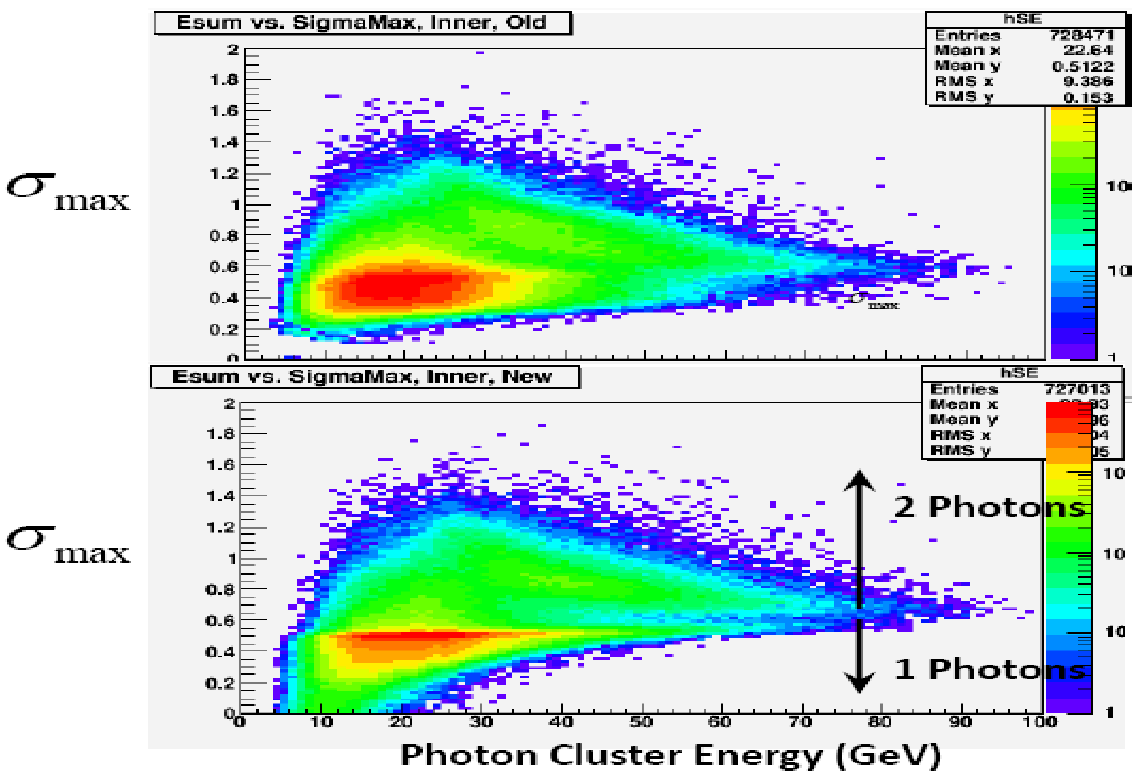
Extra

$$\Delta\sigma_x{}^2 = \frac{\sum\limits_{i\,(e_i>e_0)} (x_i - x_0)^2 \ln(e_i / e_0)}{\sum\limits_{i\,(e_i>e_0)} \ln(e_i / e_0)}$$

$$\Delta\sigma_x \Delta\sigma_y = \frac{\sum\limits_{i\,(e_i>e_0)} (x_i - x_0)(y_i - y_0) \ln(e_i / e_0)}{\sum\limits_{i\,(e_i>e_0)} \ln(e_i / e_0)}$$

Separation of single photon cluster from two photon cluster based upon distribution of shower energy along a preferred axis.

$$\sigma_{\max} \equiv Max\ Eigenvalue\ of \begin{bmatrix} \Delta\sigma_x{}^2 & \Delta\sigma_x\Delta\sigma_y \\ \Delta\sigma_y\Delta\sigma_x & \Delta\sigma_y{}^2 \end{bmatrix}$$



Old algorithm with
Energy weighted moments

Improved algorithm with
log energy weighted moments.

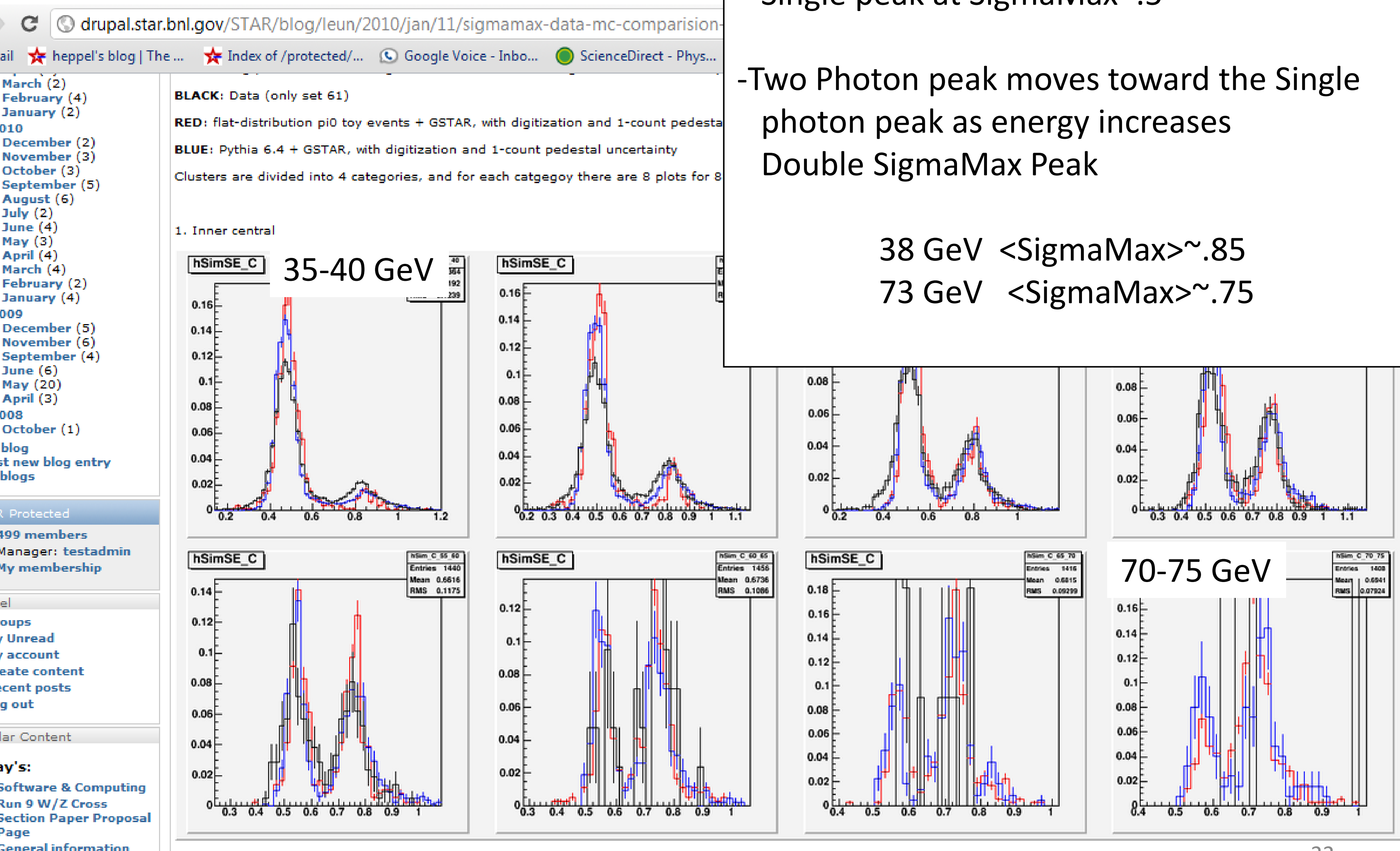
Provides clearer separation
Between π^0 and single photon.
Clusters up to ~80 GeV.

From Len's Analysis,

-Single Photon peak changes little with Energy
  Single peak at SigmaMax~.5

-Two Photon peak moves toward the Single photon peak as energy increases
  Double SigmaMax Peak

38 GeV <SigmaMax>~.85
73 GeV <SigmaMax>~.75



Run 11 distributions of SigmaMax as a indicator of single photon vs π^0 only slowly degrades with higher energy.