# Current Status of Transverse Spin at STAR

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Brookhaven National Laboratory
DIS 2010
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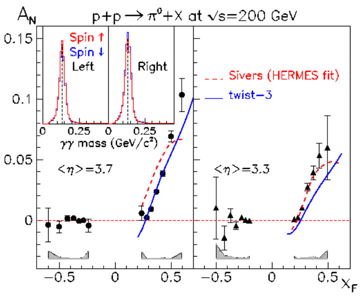
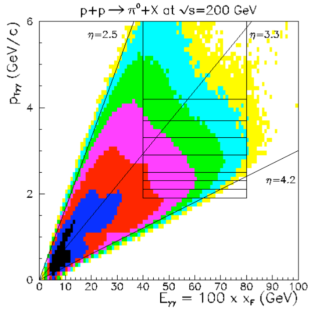
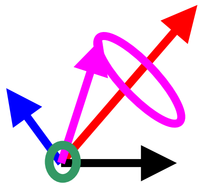
# Outline

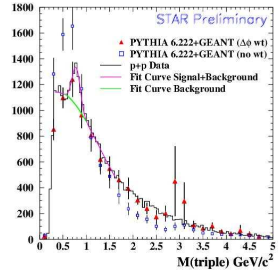
## Summary of forward results



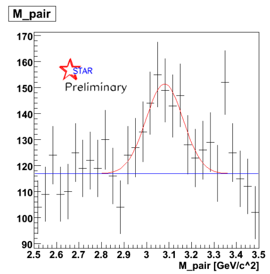




## Update of ongoing analyses



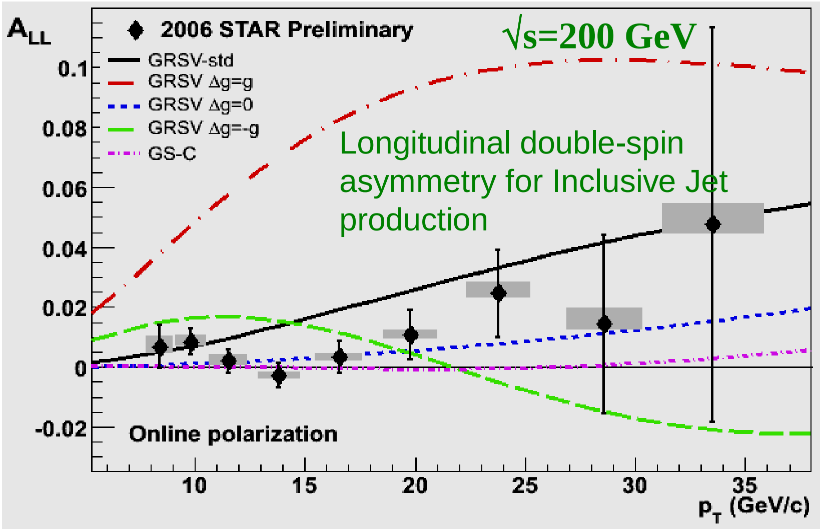



## Outlook



# Colliding-Beam Spin Physics: Only at RHIC

## Longitudinal Spin program at STAR




Strong constraint on the size of $\Delta$g from RHIC data for 0.05<x<0.2.

STAR data contributes strongly to global fits as in D. deFlorian et al., PRL 101 072001, 2008.

Run 9 ran polarized protons at $\sqrt{s}$=500 GeV for the first time. W spin program was described in other talks.

## Transverse Spin program at STAR

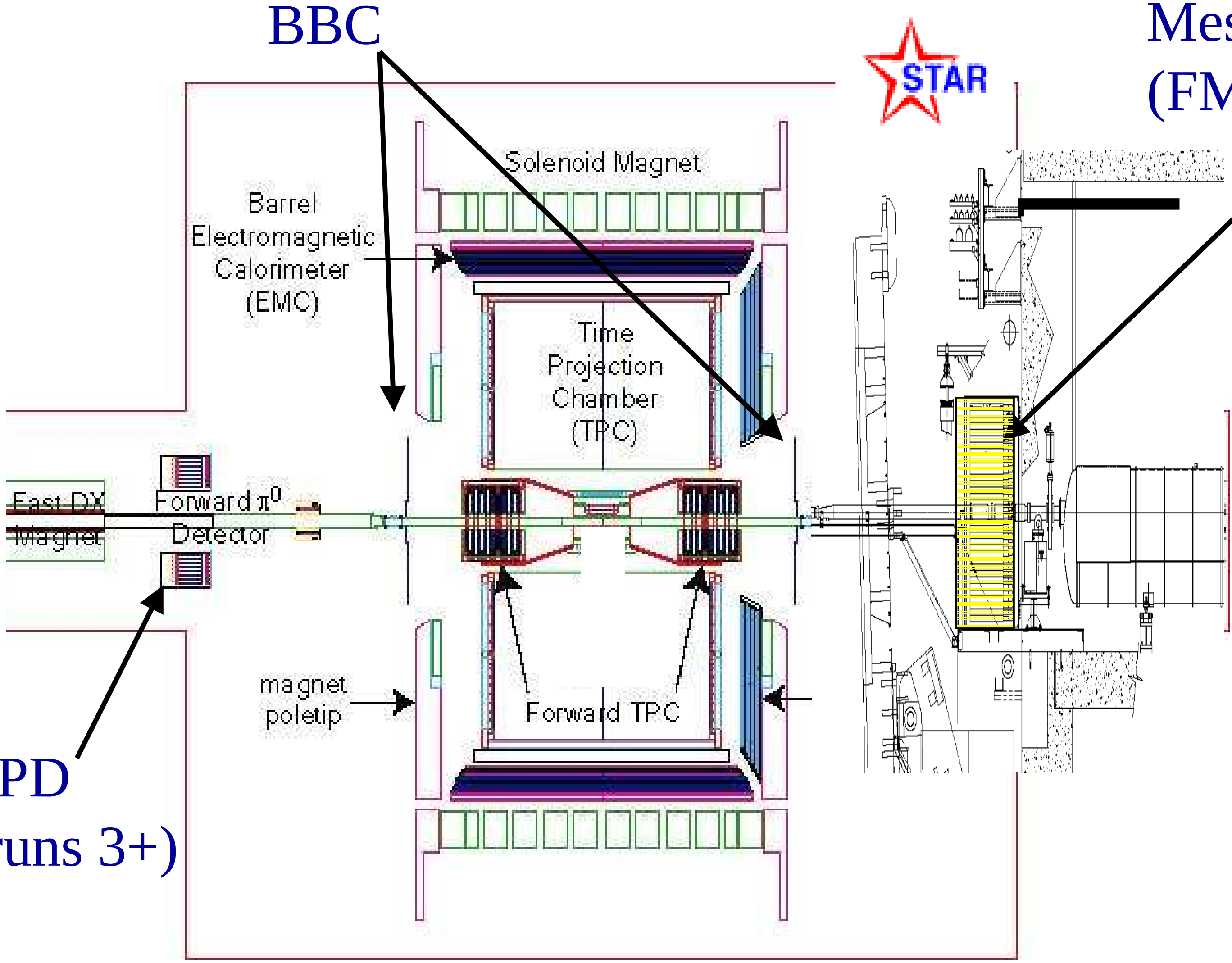
Large asymmetries are observed in the forward region.

New forward detector has allowed higher kinematic reach and extensions beyond inclusive $\pi^0$ data.

# STAR Detector

BBC

Run 8+: Forward Meson Spectrometer (FMS)




FPD (runs 3+)

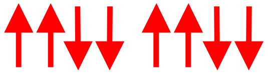
Stack of 1264 lead glass cells, roughly 18 $X_0$ in z.

Located at far West side of Hall, at the opening to RHIC tunnel. Faces blue beam.

7.5 meters from interaction point.

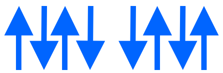
# Bunch-by-bunch polarization from colliding beams at STAR

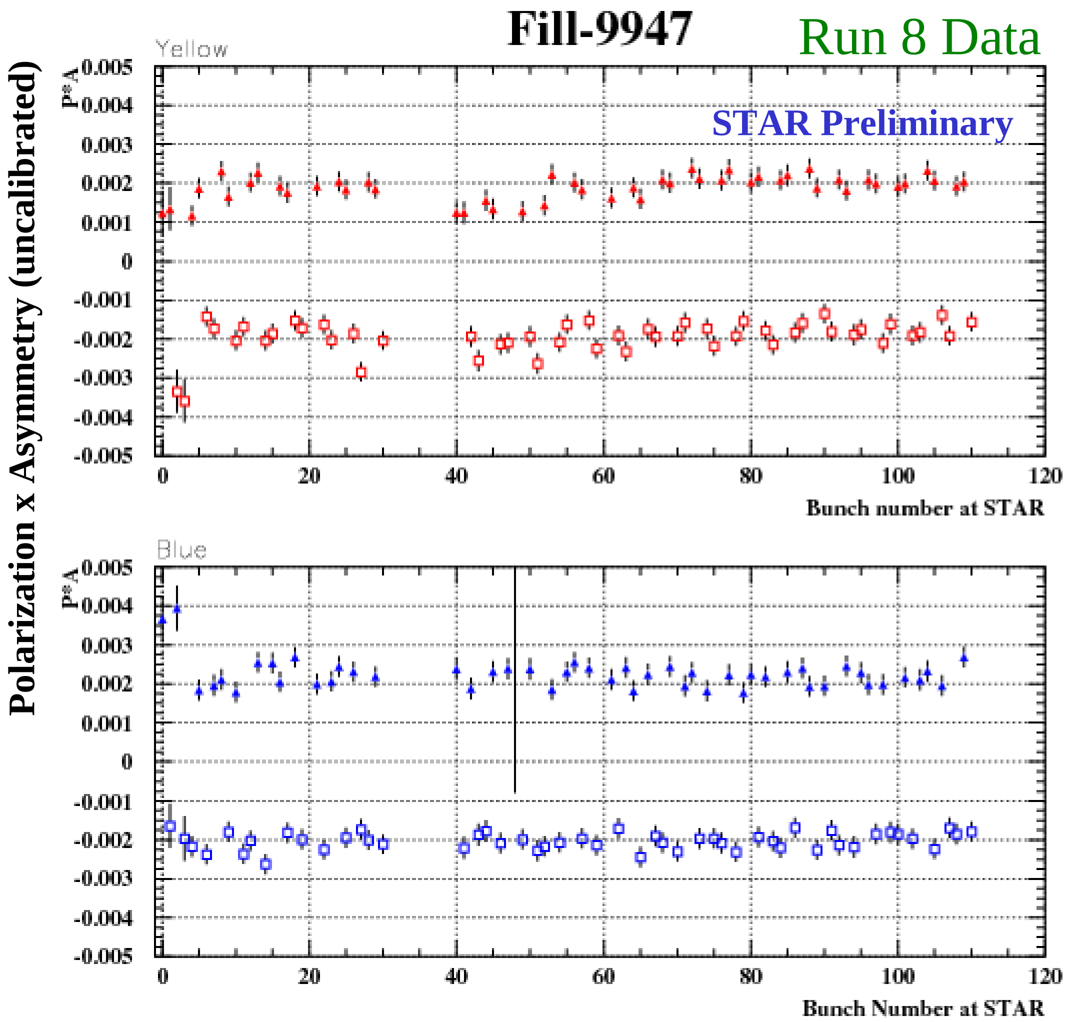
Yellow
(east BBC)



▲ Expected spin up
☐ Expected spin down

Blue
(west BBC)





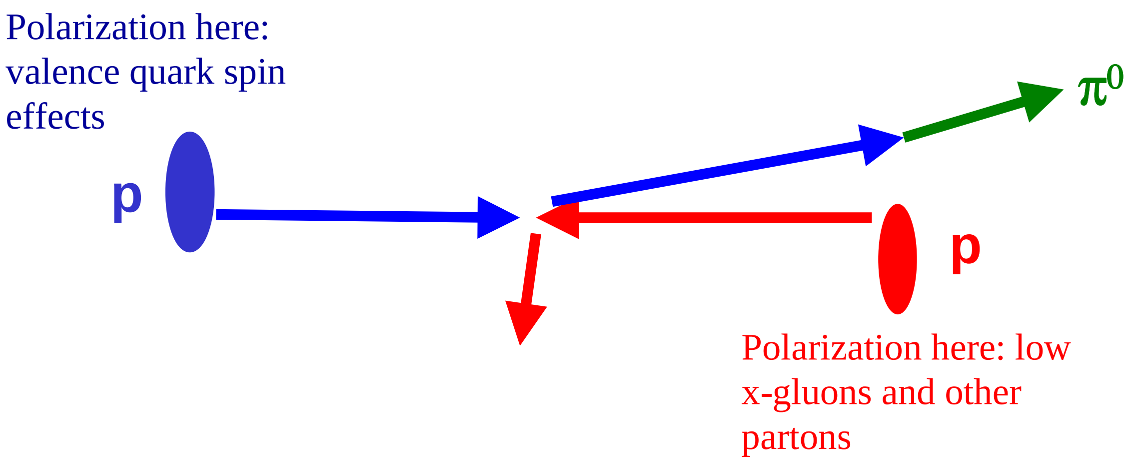

~3.5 σ (statistical) measurement of polarization per bunch per hour

Statistical uncertainties only

See also J. Kiryluk (STAR) ArXiv:hep-ex/0501072v1, 28 Jan 2005

# Why high $x_F$ at a Collider?

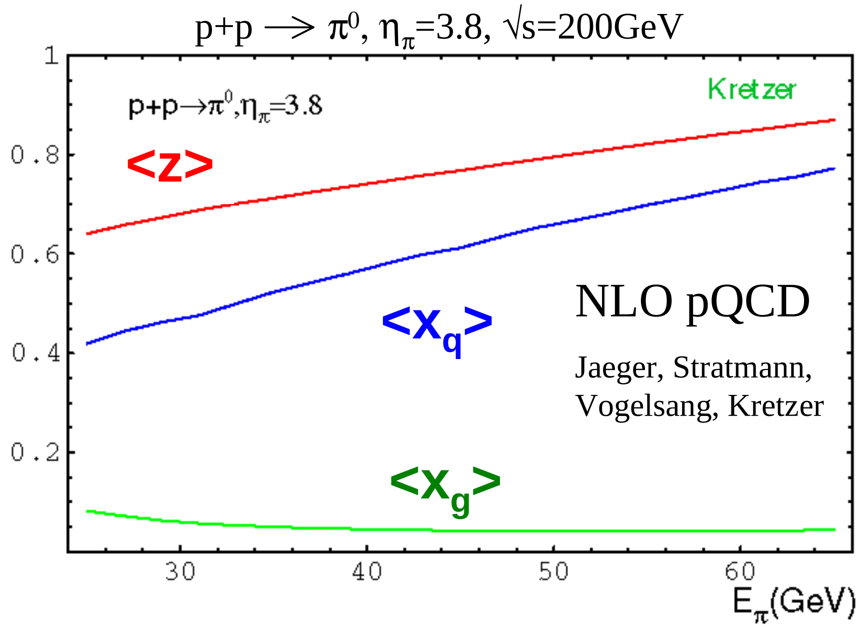
## High rapidity π's ($\eta_\pi$~4) from asymmetric partonic collisions




Mostly high-x valence quark on low-x gluon

**($0.3 < x_q < 0.7$, $0.001 < x_g < 0.1$)**

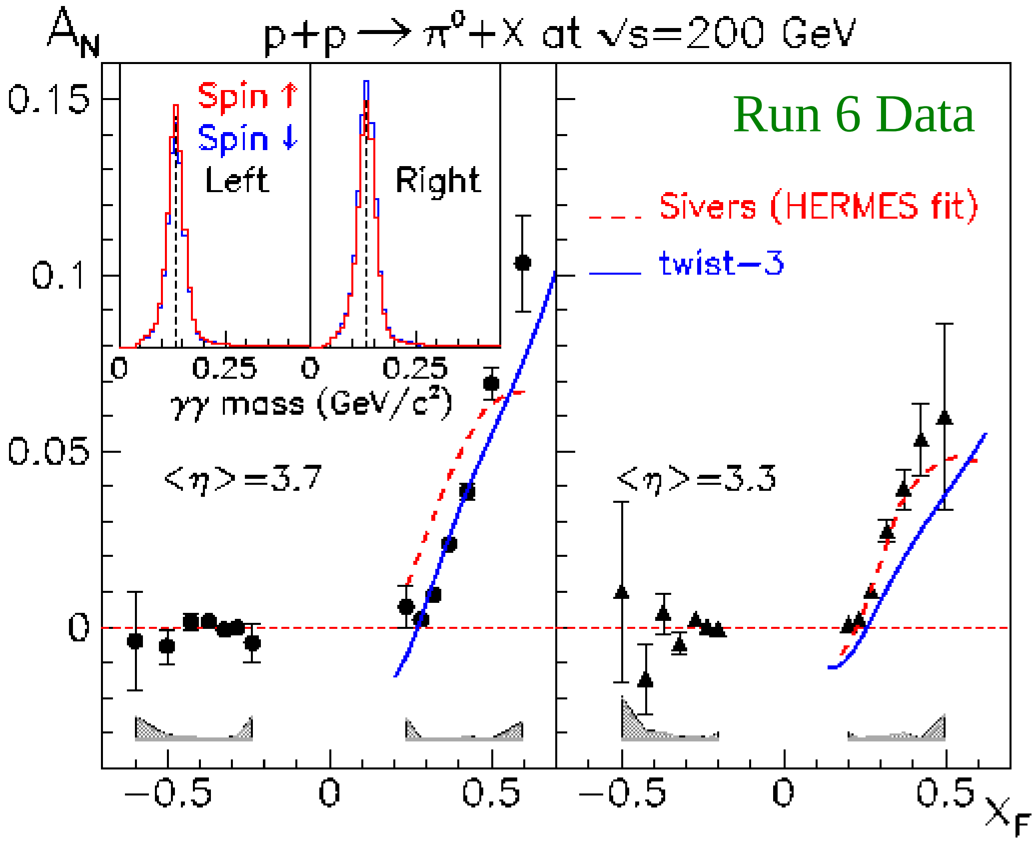
Fragmentation z nearly constant and high
0.7 ~ 0.8



# Run 3, 5, and 6 asymmetry data from FPD: Theory can predict $x_F$ dependence based on Sivers function fits to $\pi^+/\pi^-$ asymmetries…

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

$d\sigma^{\uparrow(\downarrow)}$=differential cross section when proton has spin up (down).




L=6.8 pb$^{-1}$
Yellow beam polarization = 56±2.6 %

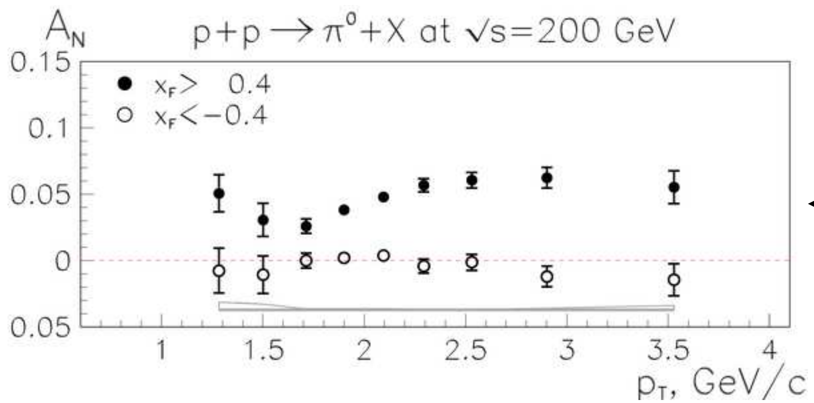
Data: B.I. Abelev et al. (STAR), PRL **101** (2008) 222001

Theory (red): M. Boglione, U. D'Alesio, F. Murgia [arXiv:hep-ph/0712.4240]

Theory (blue): C. Kouvaris, J. Qiu, W. Vogelsang, F. Yuan, PRD **74** (2006) 114013

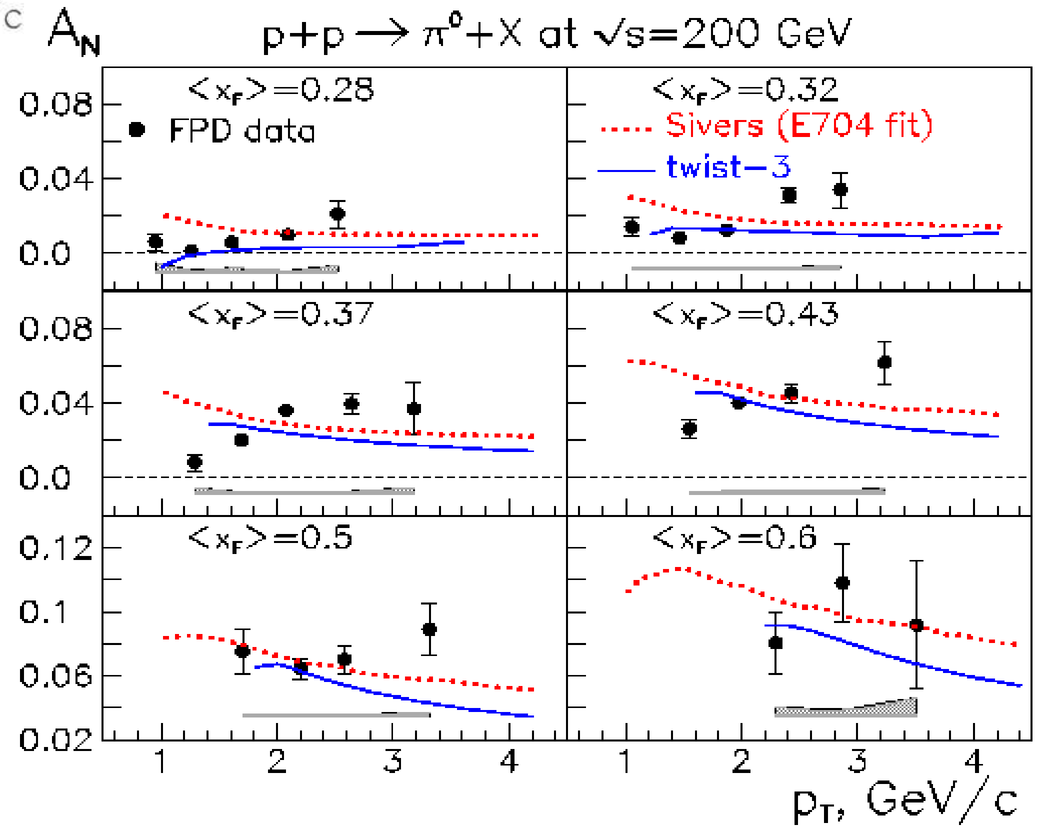
# …but rising $P_T$ dependence is not predicted by the same fits

B.I. Abelev et al. (STAR)
PRL **101** (2008) 222001




← $x_F$>0.4

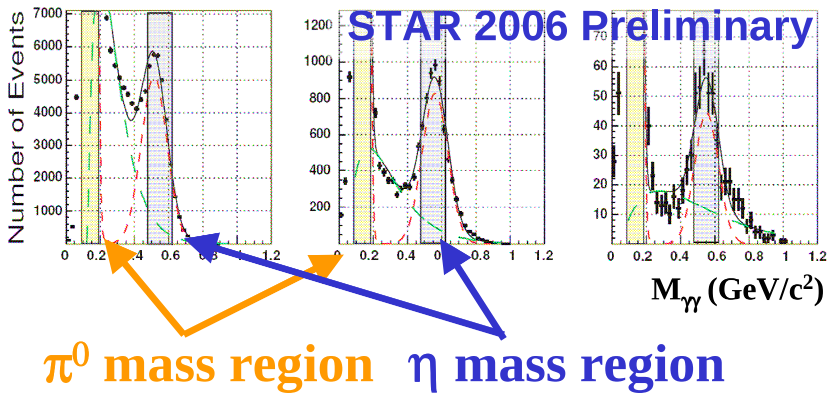
Data broken out in $x_F$ bins →



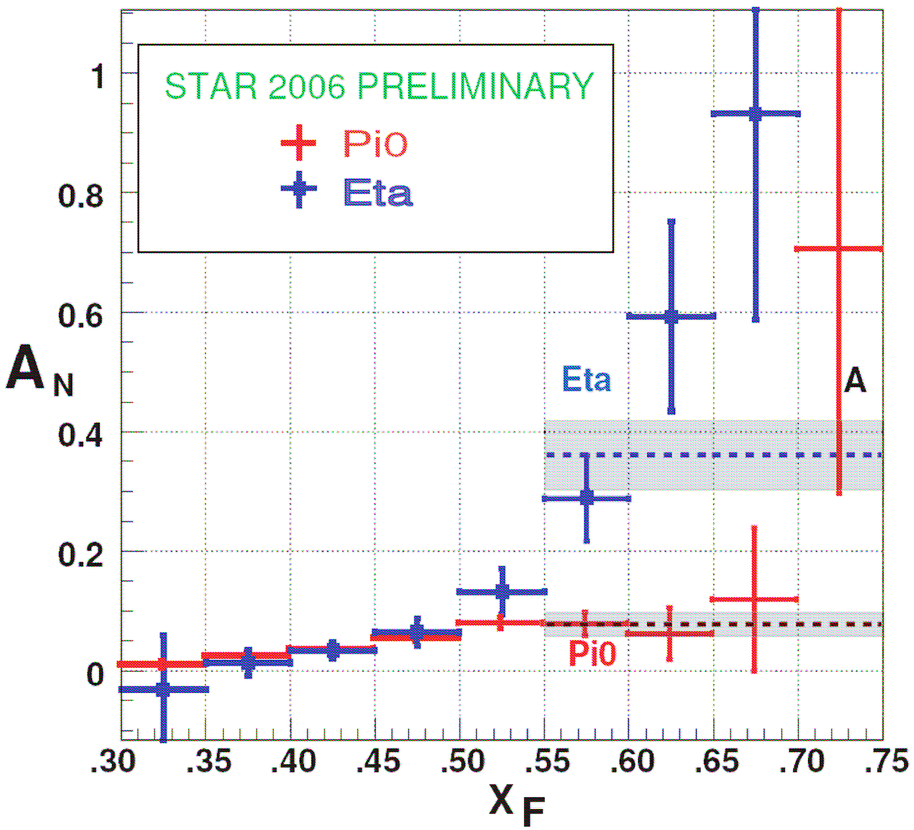
# Heavier mesons also accessible at high $X_F$

## Di-photons in FPD with E(pair)>40 GeV (Run 6)

$M_{\gamma\gamma}$ in energy bins

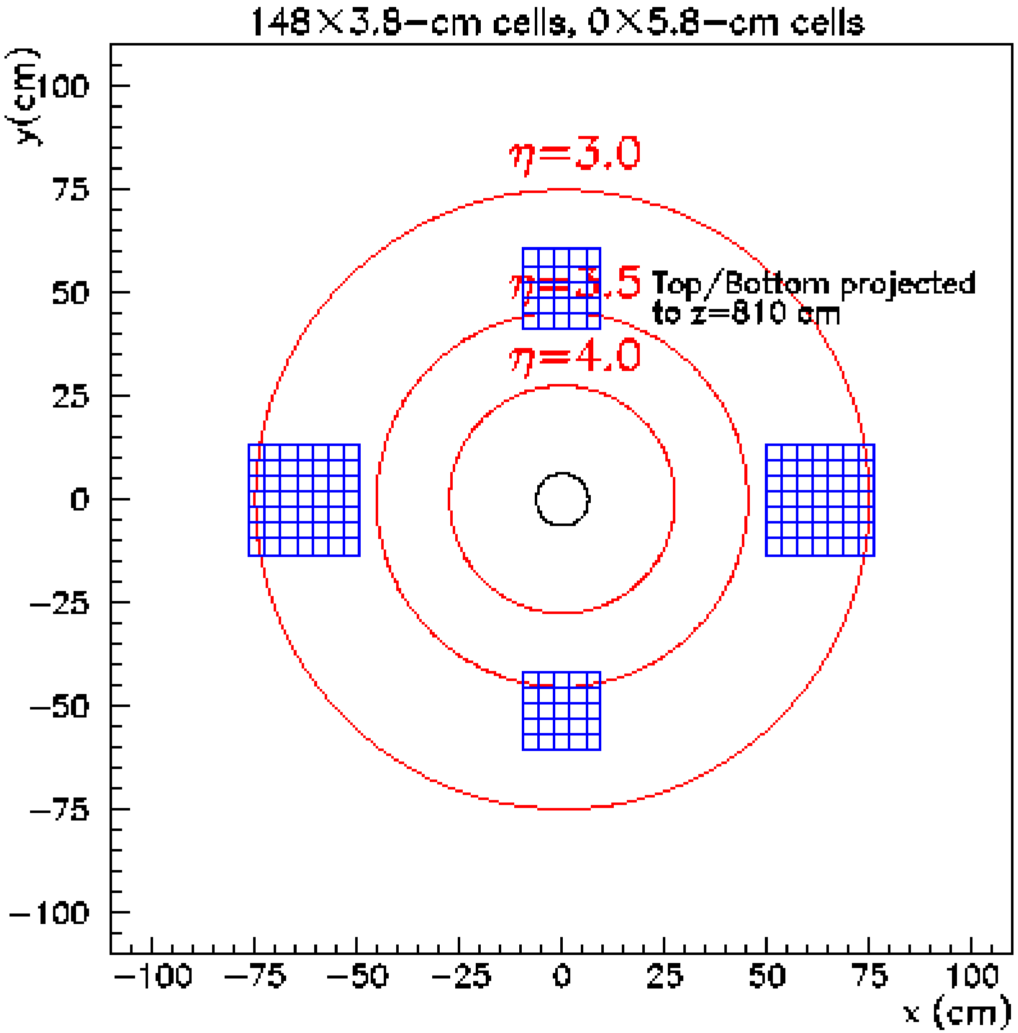



Single Spin Asymmetry




See Steve Heppelmann, for the STAR Collaboration, ArXiv:0905.2840(2009)

# FMS provides nearly 20x the coverage of previous forward detectors at STAR




Run 5 FPD

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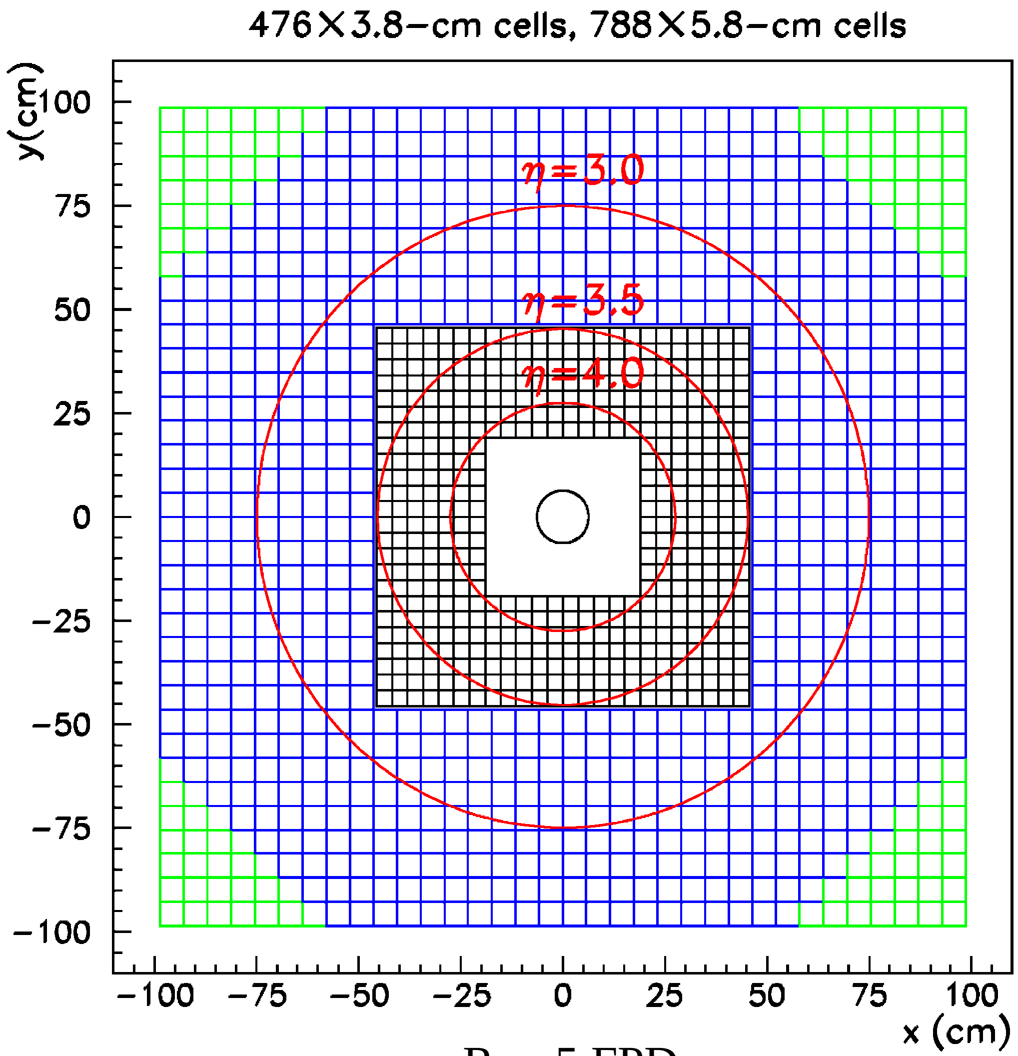


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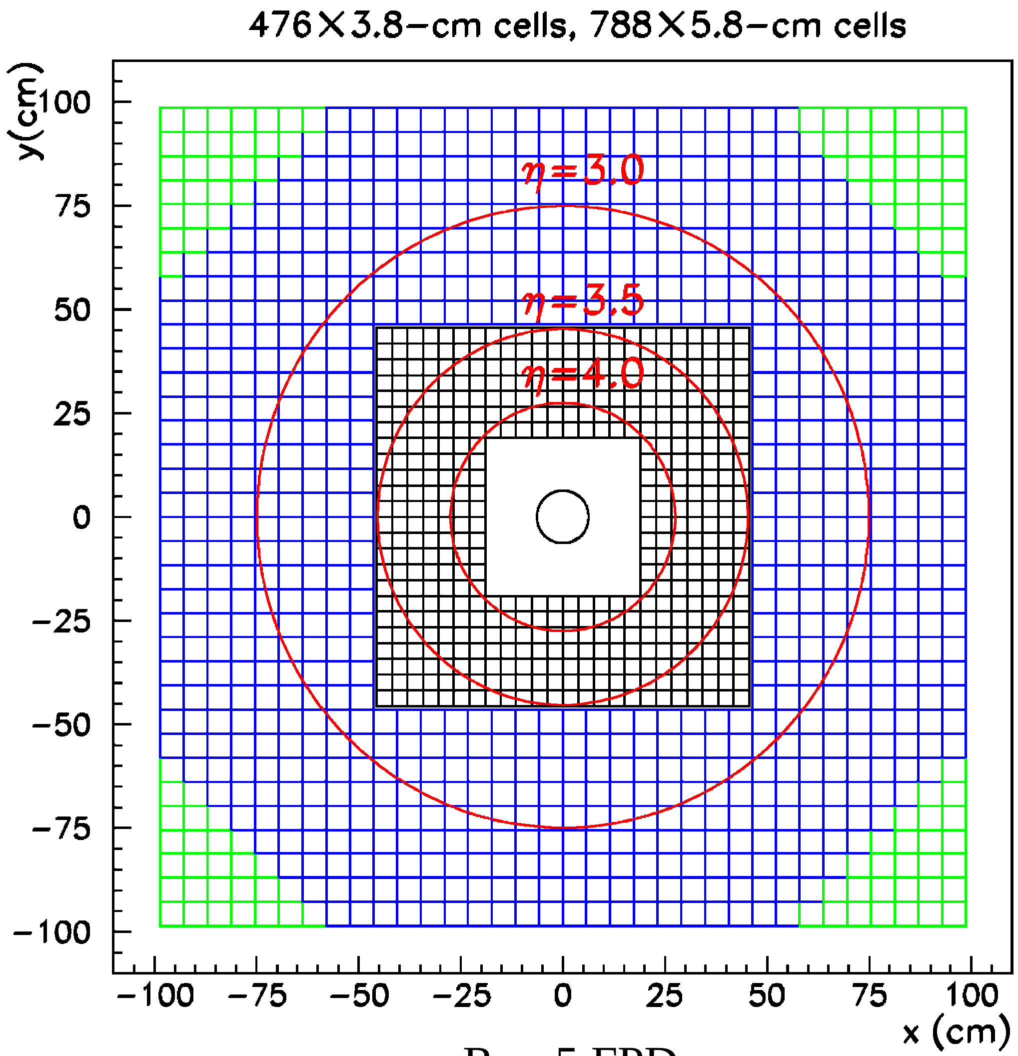
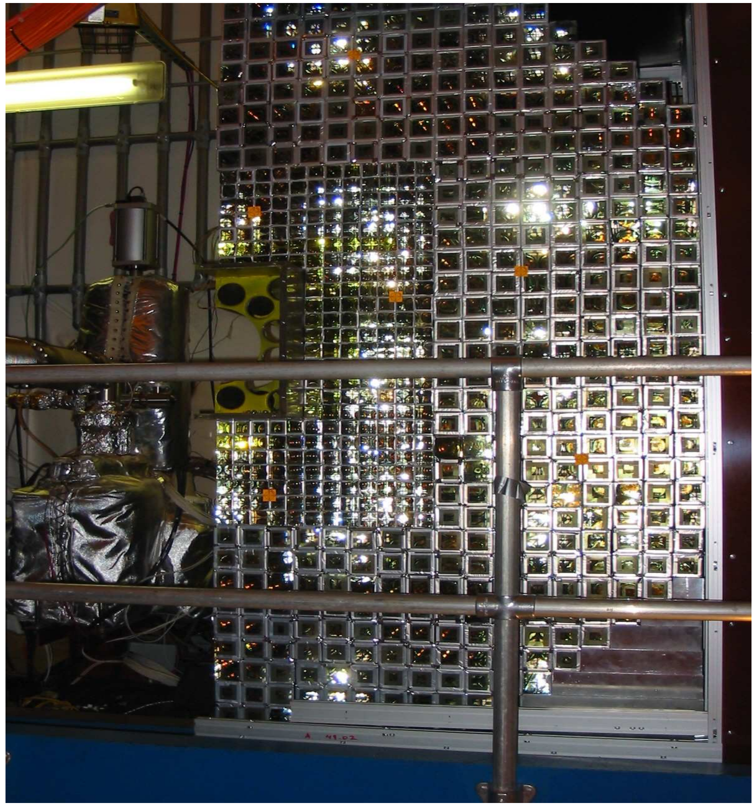



Run 5 FPD

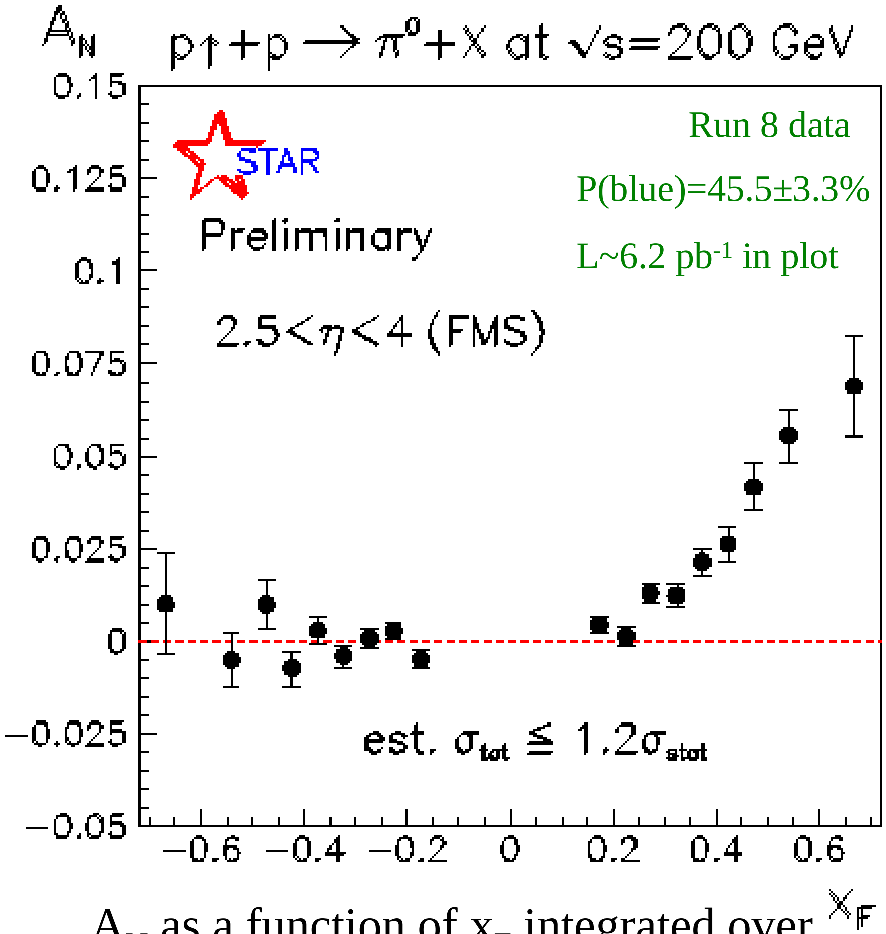
North-half, view from the hall



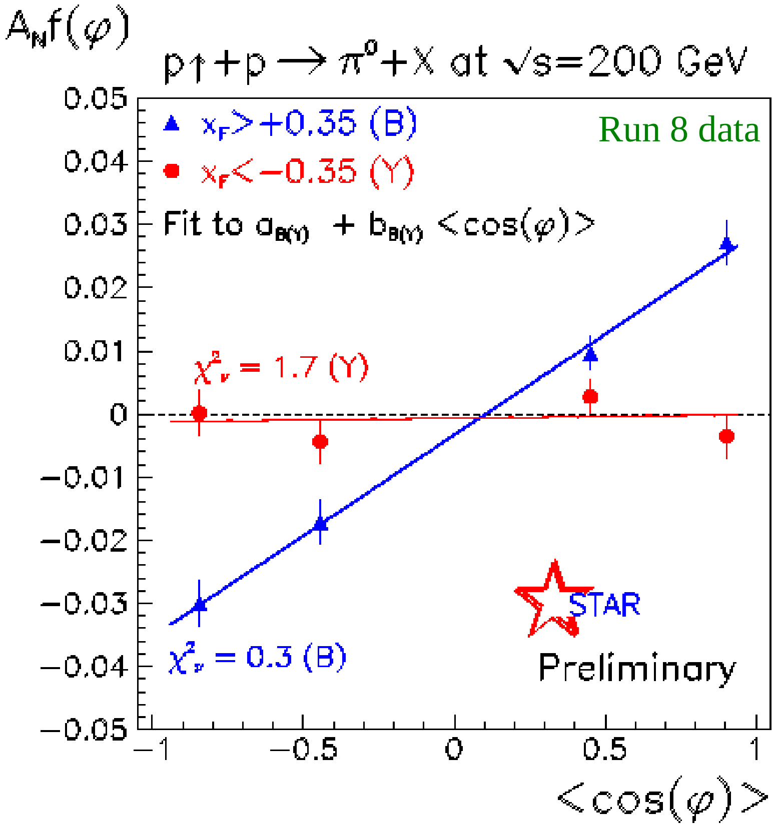
Nearly contiguous coverage for $2.5<\eta<4.0$.

FMS newly commissioned for Run 8

# FMS Acceptance allows azimuthal dependence to be measured and extends data to higher $X_F$...




$A_N$ as a function of $x_F$ integrated over the FMS acceptance.

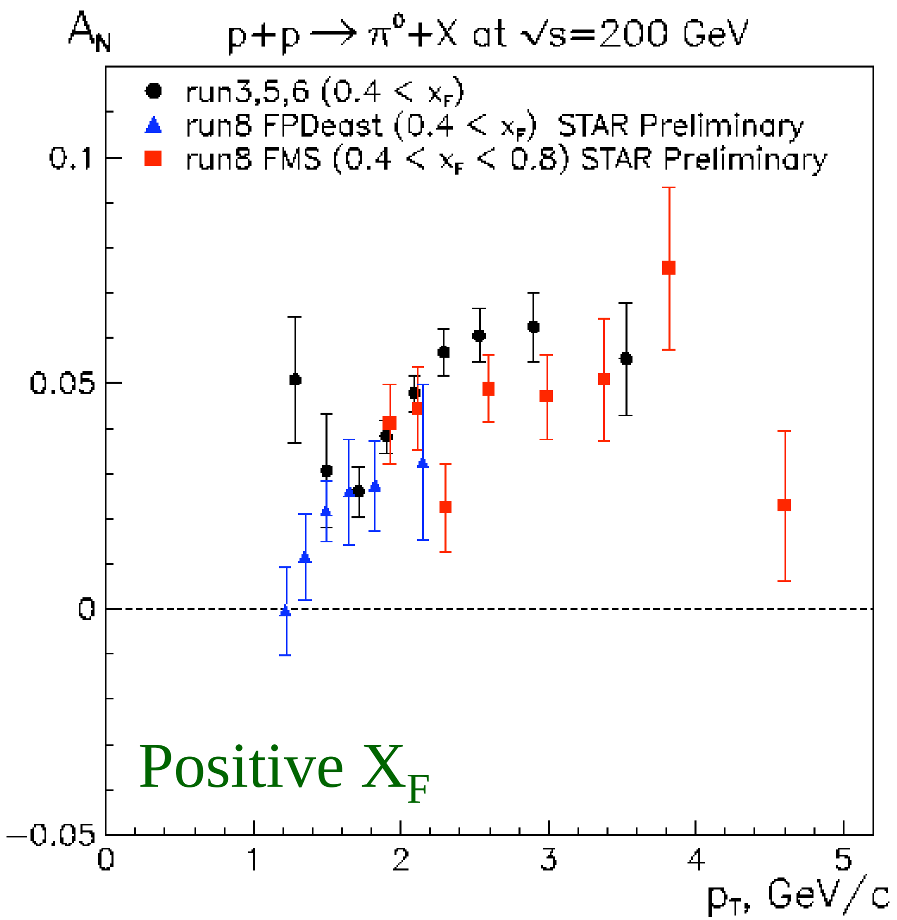


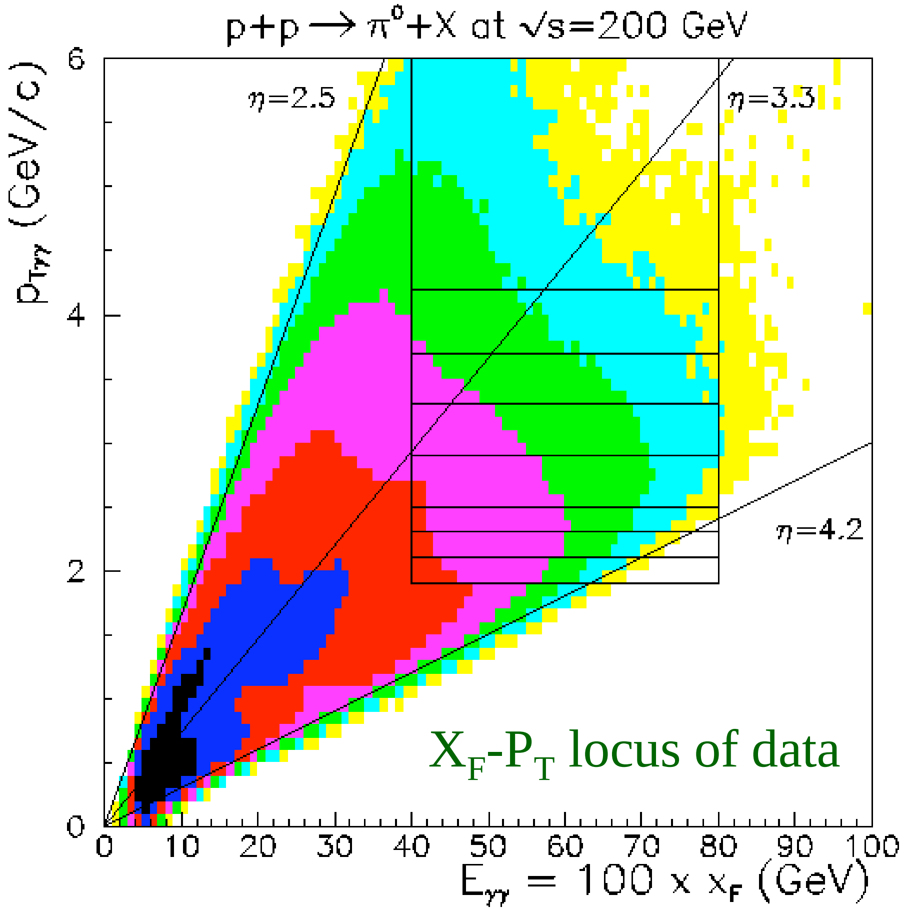

$A_N$ versus <cos φ> for positive (blue beam) and negative (yellow beam) $X_F$

Plots from Nikola Poljak, for STAR collaboration, "Spin-dependent Forward Particle Correlations in p+p Collisions at √s = 200 GeV," hep-ex/0901.2828, to be published as Spin 2008 conference proceedings.

Important confirmation of previous data

# …and higher $P_T$




J.Drachenberg, Spin 2008, arXiv:0901.2763

Akio Ogawa, CIPANP 2009

Indications that $A_N$ persists to $P_T \gtrsim 4$ GeV/c.

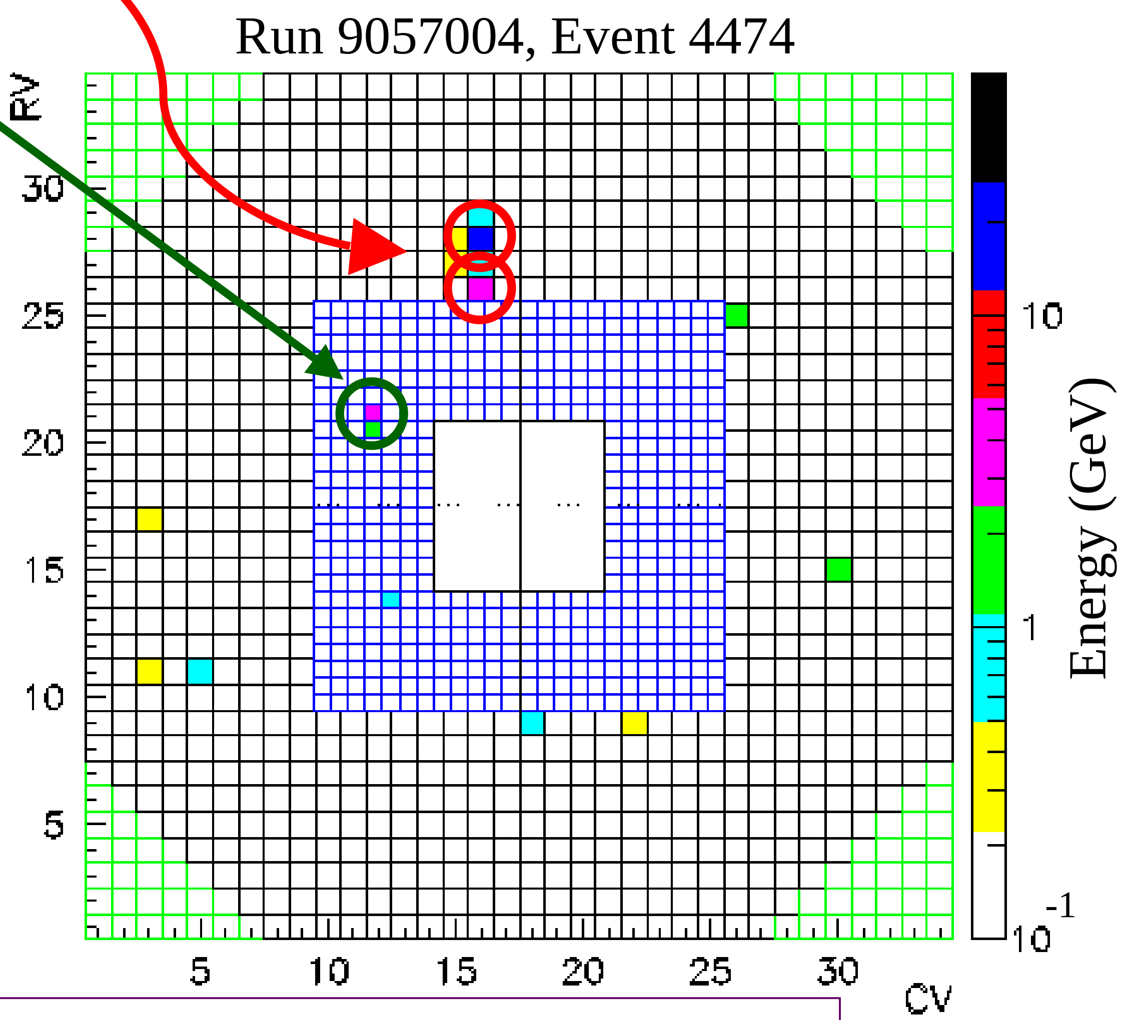
# Search for spin 1 ω signal in Run 8 data

## Candidate $\omega \rightarrow \pi^0 \gamma$

$E_\pi$=16.7+6.3=23.0 GeV
$E_\gamma$=7.5 GeV

$E_\omega$=30.5 GeV
$M_\omega$=0.754 GeV/$c^2$

Kinematic range for signal after all cuts (see below) is $E_\omega$ from 30 to ~ 60 GeV and $P_T$ from 2.5 to ~ 5 GeV/c.




**Motivation**: Artru String fragmentation model of the Collins effect predict that a spin-1 particle should have opposite asymmetry from a scalar particle (see Artru, ArXiv:1001.1061 (2010))

# High $P_T$ ω selection

See A. Gordon, Moriond 2009 Proc., arXiv:0906.2332



Look at all triplets of clusters with E>6 GeV. Apply fiducial cuts of 1/2 cell from all module boundaries.

Associate clusters with $\pi^0$ and γ:

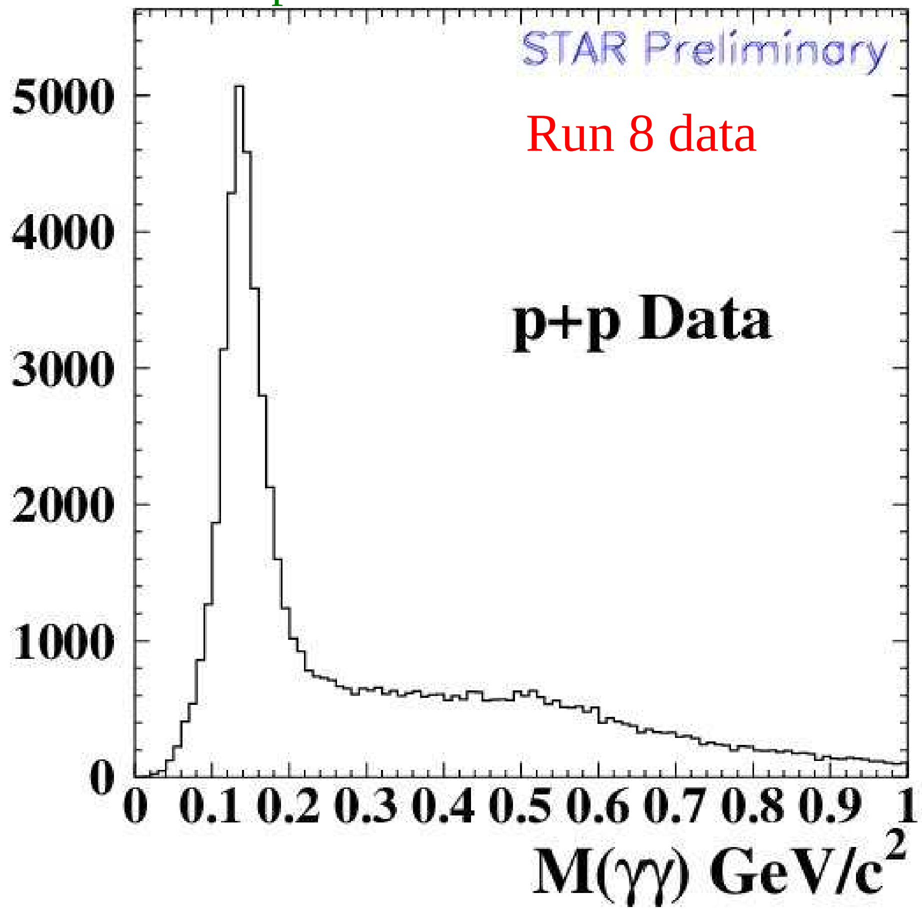
Choose $\pi^0$ to be pair with mass closest to 0.135 GeV/$c^2$. Simulation indicates that this gives correct association for nearly all events.

Require that $M(\pi^0)$ be within 0.1 GeV/$c^2$ of 0.135 GeV/$c^2$.

Kinematic cuts to reduce QCD background (real $\pi^0$ decays with a third EM-rich hadronic cluster in the FMS):

- $P_T$(triplet)>2.5 GeV/c
- E(triplet)>30 GeV
- $P_T$(photon cluster)>1.5 GeV/c
- $P_T(\pi^0)$>1 GeV/c.

Mass distribution of two clusters of the triplet associated with $\pi^0$.



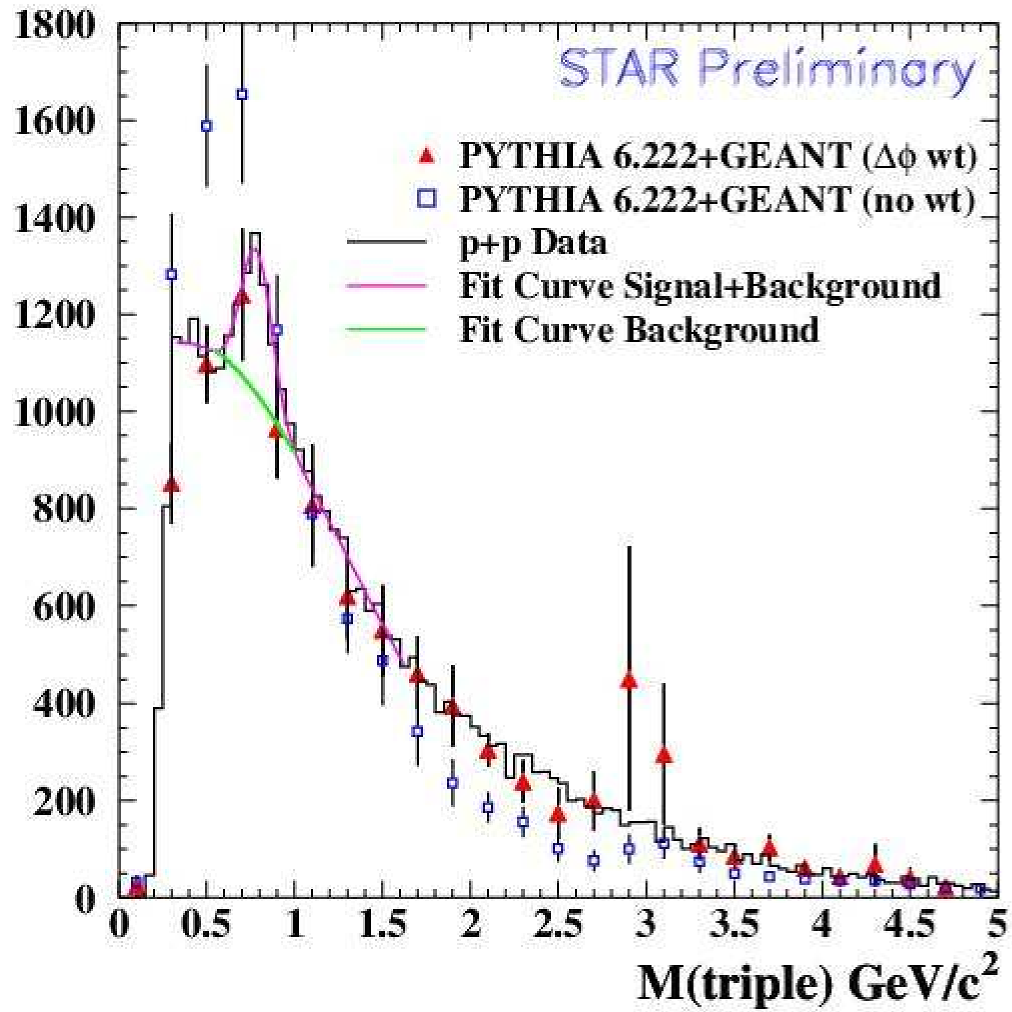
# Mass distribution of all triples

Fit is gaussian + cubic polynomial

$\mu$=0.784±0.008 GeV/c$^2$

$\sigma$=0.087±0.009 GeV/c$^2$

Scale=1339±135 Events

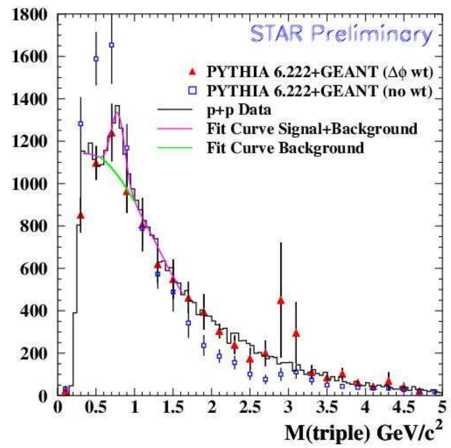



Significant (10$\sigma$) $\omega \to \pi^0 \gamma$ signal seen in the data.

PYTHIA(6.222)+GEANT over-predicts low mass region and under-predicts high mass

$\Delta\phi(\pi^0,\gamma)$ weighting improves comparison

# Statistical power of current data




Use mass fits to generate random samples the same size as the data for signal and background.

For a given value of $A_N$, the probability of an ω going to the right is

$P_R = (P_{BEAM} A_N \langle\cos(\phi)\rangle + 1)/2$, where we assume the ω are distributed uniformly in ϕ so $\langle\cos(\phi)\rangle = 2/\pi$, and we use $P_{BEAM}=50\%$.

and

$P_L = 1 - P_R$

see next page

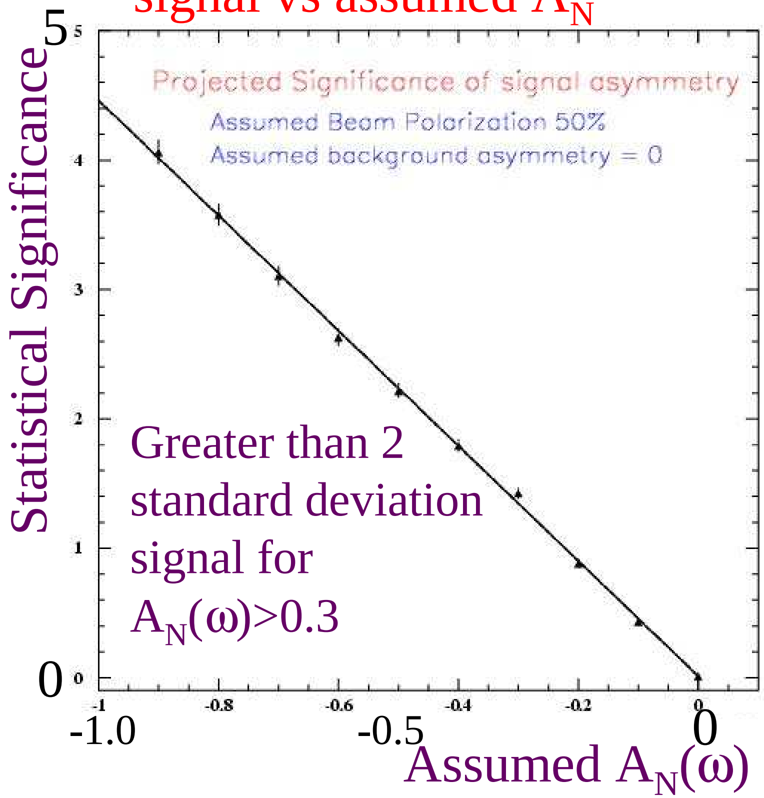
For a "background" event assume background asymmetry is 0 so $P_R=P_L=0.5$

For each set, calculate

$$\text{Raw asymmetry} = \frac{N(\text{left})-N(\text{right})}{N(\text{left})+N(\text{right})}$$

Repeat 1000 times for each value of $A_N$. The mean of raw asymmetry distribution divided by the RMS is then a measure of the ability to distinguish $A_N$ from 0.

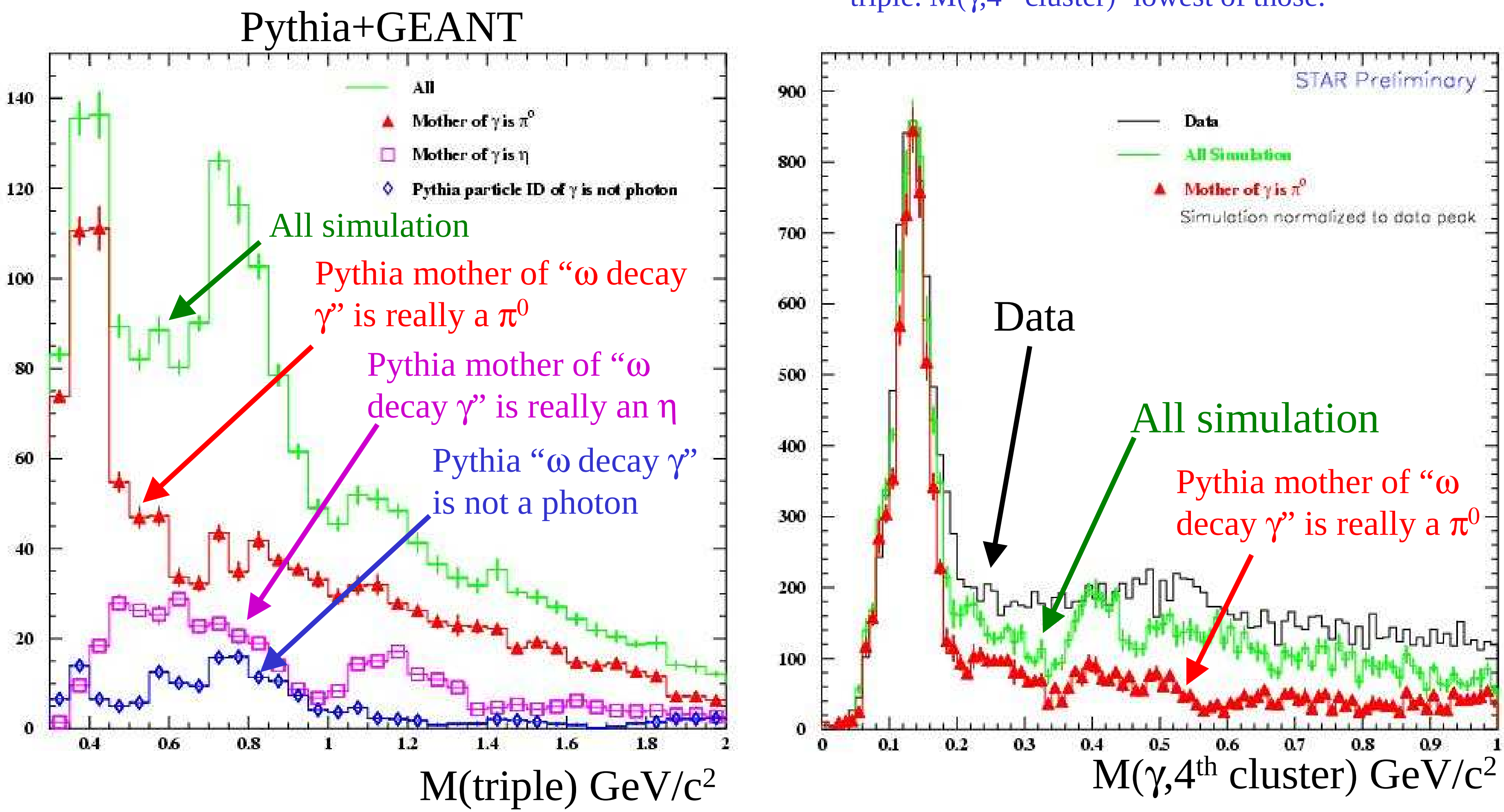
Projected Significance of signal vs assumed $A_N$



# Background breakdown from simulation

Backgrounds can have a non-zero asymmetry and need to be well understood.

To test background simulation calculate mass of the ω decay γ-cluster with all other clusters not in triple. M(γ,4th cluster)=lowest of those.



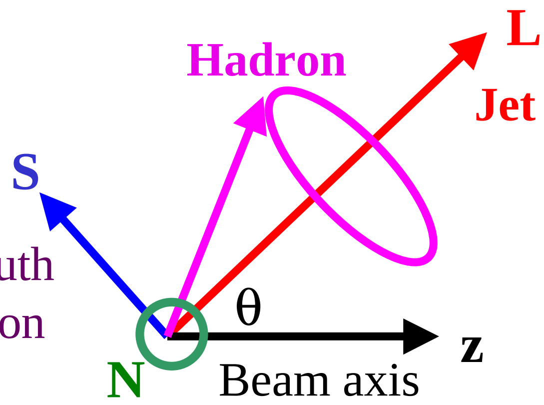

Is non-photon background underpredicted by simulation? Can other cuts reduce this background?

Plot dominated by $\pi^0\pi^0$ events, but tail is significantly underpredicted.

# Mid-rapidity jets to measure Collins Asymmetry

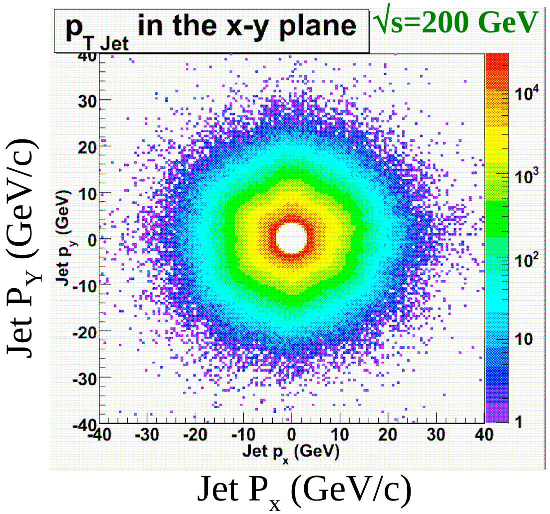
Collins effect predicts asymmetry around jet axis from transversity of initiating quark.

Higher $P_T$ jets have enhanced qq contributions.

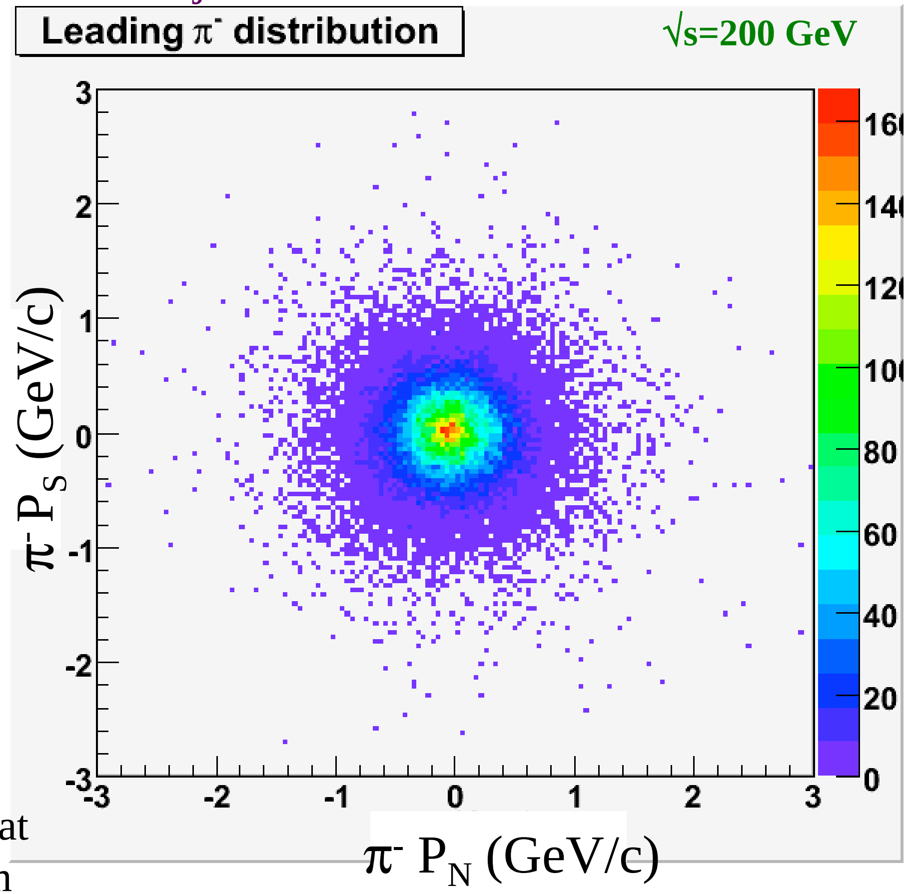



Calculate azimuth of leading hadron around jet axis

Use BEMC for neutral particles and TPC for charged particles to reconstruct jets.

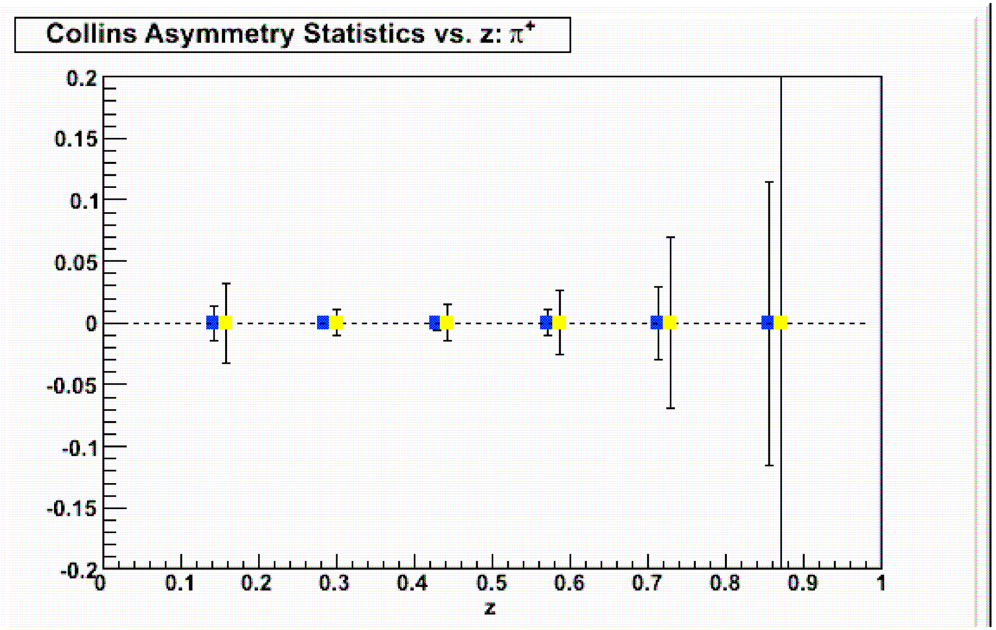



Full azimuthal coverage for jets




See Robert Fersch, Progress in High-$P_T$ Physics at RHIC, http://www.bnl.gov/riken/php/agenda.htm

# Mid-rapidity jet expected statistical uncertainties




(Jets in forward hemisphere of barrel calorimeter for each beam are analyzed. West side has less restrictive fiducial cut because of Endcap EM calorimeter.)

"Blue" beam polarized (Blue beam goes westward, toward Endcap calorimeter)

"Yellow" beam polarized (Yellow beam goes eastward)

Estimated expectation is asymmetry ~ 0.03

(using HERMES+COMPASS+Belle data for transversity and Collins fragmentation, see Anselmino et al, PRD 75, 054032 (2007))

# Conclusions

Large single spin asymmetries are observed in forward direction, for both inclusive $\pi^0$ and $\eta$ signals.

Run 8 measurements of $A_N$ have extended $P_T$ range for inclusive $\pi^0$s at high $X_F$ and also confirmed previous measurements.

An observed negative asymmetry for $\omega$ would be an exciting test of a theoretical understanding of the Collins effect (Artru, ArXiv:1001.1061 (2010)).

Work in progress:

$\omega \rightarrow \pi^0 \gamma$

Central Jets Collins effect

# Outlook

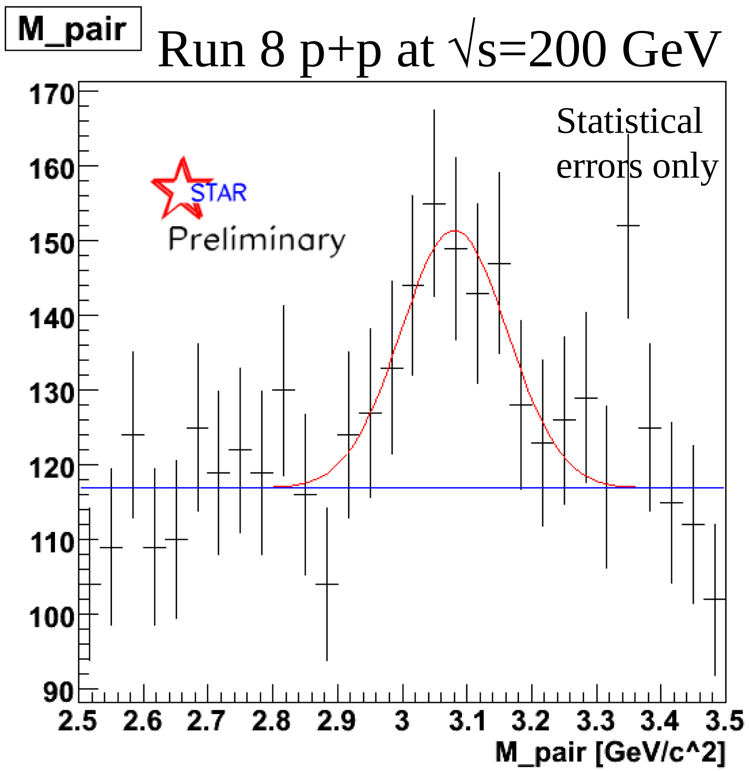
## STAR has reported observation of large $X_F$ $J/\psi \to e^+e^-$ production

All FMS cluster pairs are examined.

Isolation of R<0.5 for all clusters.

E(pair)>60 GeV and |E1-E2|/(E1+E2)<0.7

In addition a $P_T$>1 GeV/c cut is put on each cluster to reduce background near beampipe.




See Chris Perkins, ArXiv:0907.4396

Fit shown is gaussian + flat background

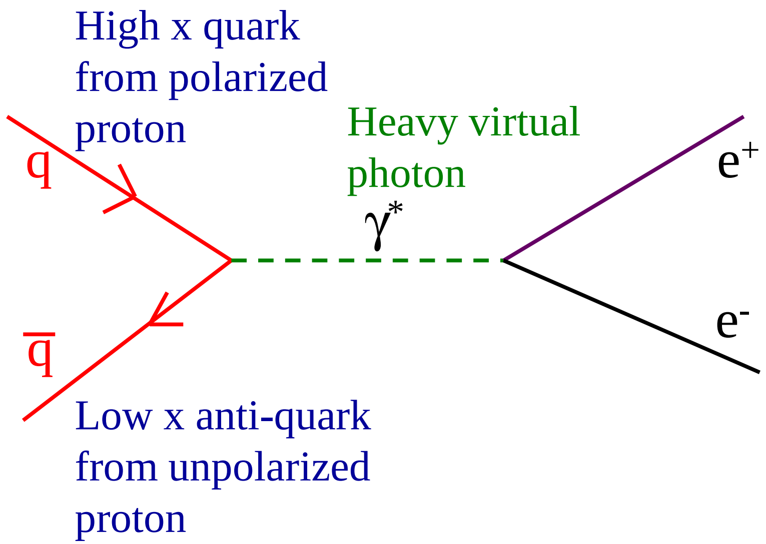
# Possible Near-term future transverse spin measurement: Drell-Yan between J/ψ and upsilon mass

Factorization theorems allow intercomparison of p+p and DIS data.

See
J. C. Collins, D. E. Soper, and G. Sterman, Nucl. Phys. B. **261**, 104 (1985); Nucl. Phys. B **308**, 833 (1988)

Sivers effect predicted to have opposite sign to SIDIS.

S. J. Brodsky, D. S. Hwang and I. Schmidt, Phys. Lett. B **530**, 99 (2002); Nucl. Phys. B **642**, 344 (2002);
J. C. Collins, Phys. Lett. B **536**, 43 (2002);
3) A. V. Belitsky, X. Ji and F. Yuan, Nucl. Phys. B **656**, 165 (2003);
4) D. Boer, P. J. Mulders and F. Pijlman, Nucl. Phys. B **667**, 201 (2003).
5) (HERMES collaboration) Phys. Rev. Lett 94, 012002 (2005)
6) (COMPASS collaboration), Nucl. Phys. B **765**, 31 (2007).




Requirements to measure Drell-Yan:

Discrimination of neutral EM clusters from charged to reduce $\pi^0$ backgrounds

Hadronic/EM discrimination to reduce all hadronic backgrounds

Do we need a charge sign measurement?

*End*