Analyzing Powers for Forward $p_{\uparrow}+p \rightarrow \pi^0+X$ at STAR

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Indiana University Cyclotron Facility

SPIN 2002 Parallel Session

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Brookhaven National Laboratory

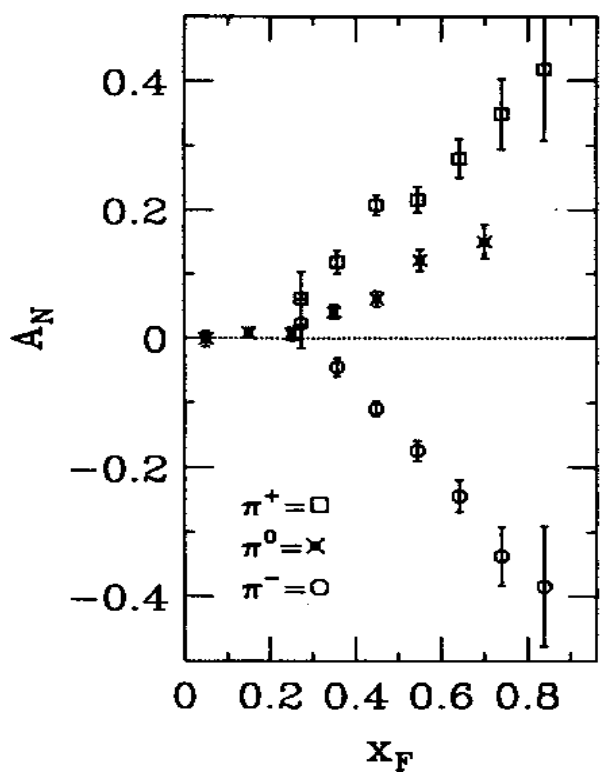
Motivation

Spin asymmetries in π^0 production: $p_{\uparrow} + p \rightarrow \pi + X$

Non-zero A_N measured in E704 at Fermilab at sqrt(s)=20 GeV, p_T=0.5-2.0 GeV/c:

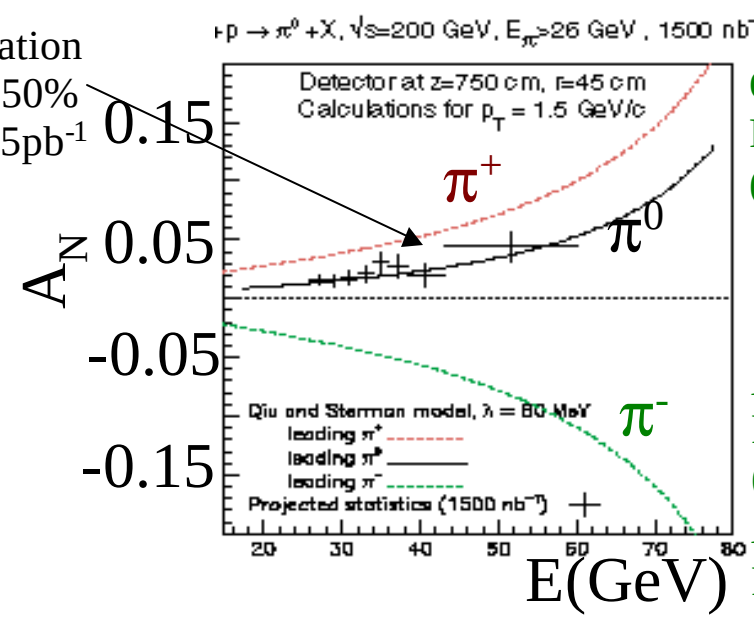
$$A_N=(\sigma_{up}(x_F)-\sigma_{dn}(x_F))/(\sigma_{up}(x_F)+\sigma_{dn}(x_F))$$

Predictions by different theorists expect non-zero A_N values, attributed to different dynamics, to persist at RHIC energies: sqrt(s)=200 GeV...



π^0 - D.L. Adams, et al., Phys. Lett. B261(1991)201.
$\pi^{+/-}$ - D.L. Adams, et al., Phys. Lett. B264(1991)462.

Simulation w/P_b=50% and 1.5pb^{-1}



Qiu and Sterman, Phys. Rev. D59 (1998) 014004.

See also:

Anselmino, et al., Phys. Lett. B442 (1998) 470.; Anselmino, et al., PRD 60 (1999) 054027.

...Non-zero analyzing power expected to persist up to RHIC collision energies...

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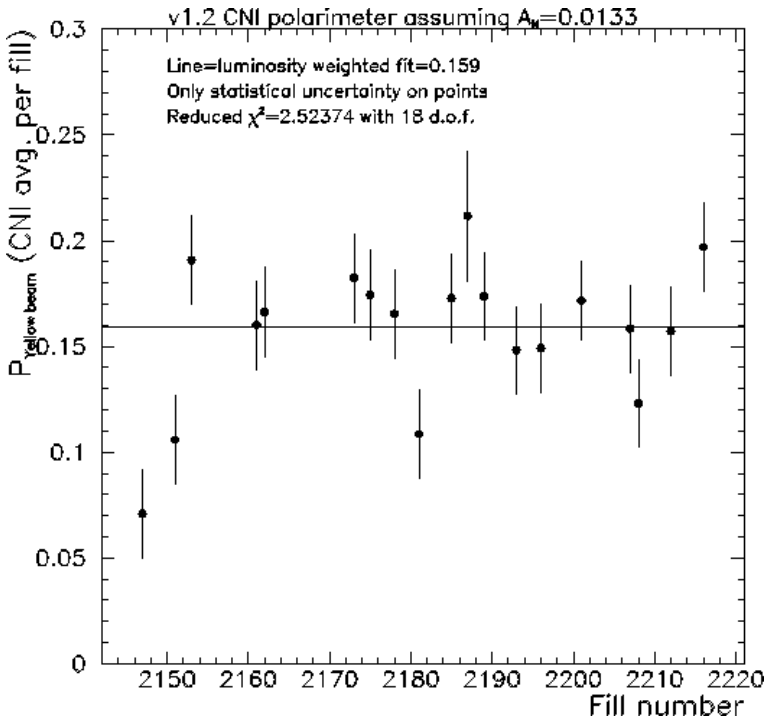
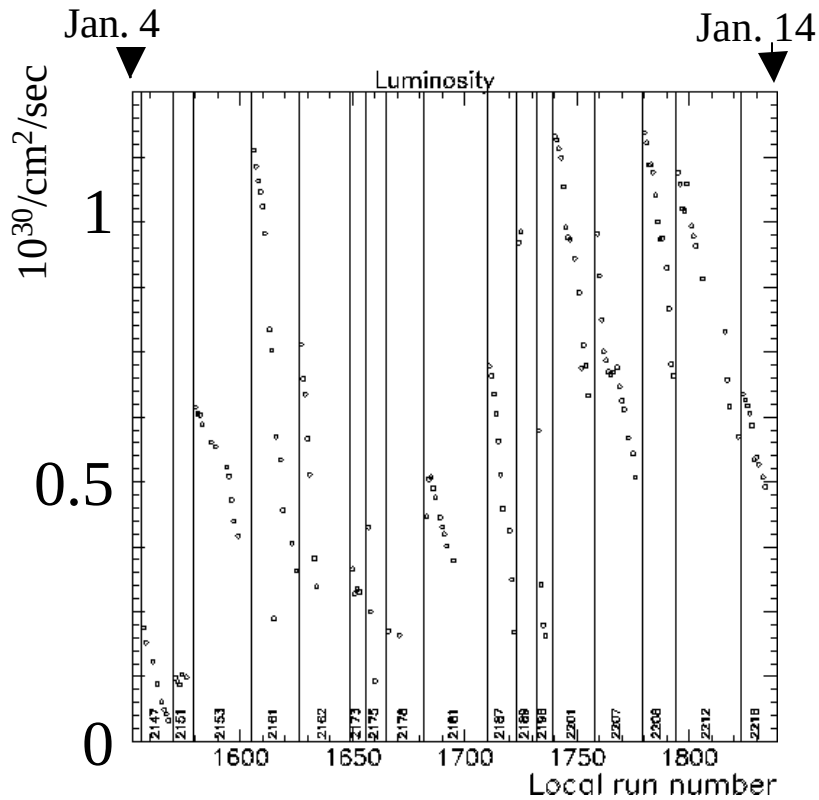
Polarized protons at RHIC

...Data collected at STAR during the first polarized proton run at RHIC in January 2002... At injection, ~47 spin-flips from source to STAR Interaction Region

First collisions of polarized protons ever seen in a collider...





No measurements of A_N(CNI) at 100 GeV.... We assume A_N(CNI)=0.013 at 100 GeV.... $\langle P_{beam} \rangle$=16% in first part of Jan.

Typical data rate ~300 Hz
Integrated luminosity reported here ~ 0.2 pb^{-1}

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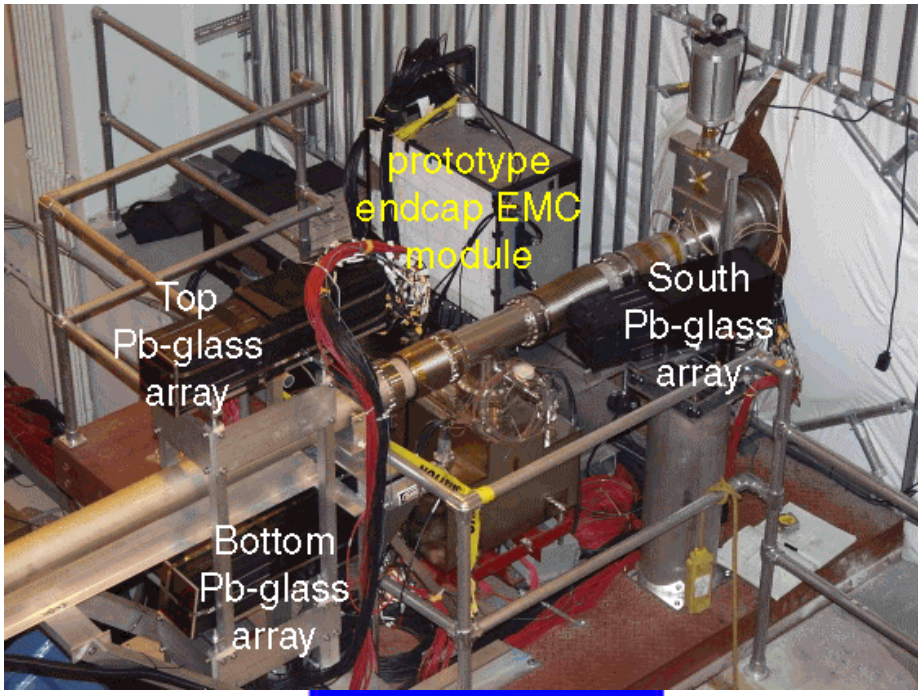
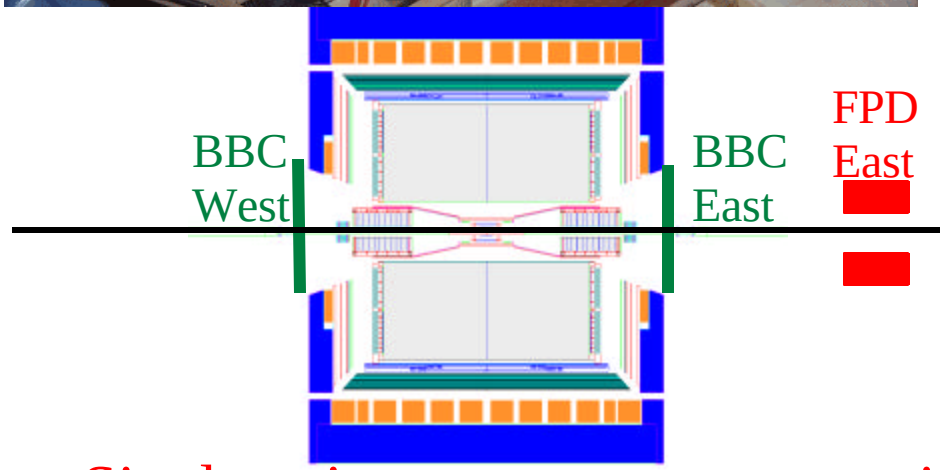
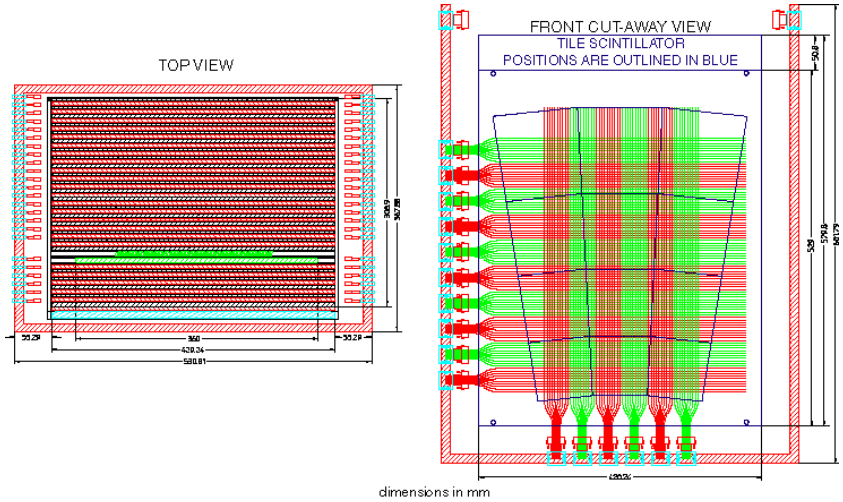
Forward π^0 Detector (FPD) at STAR

Located east of STAR detector at z=750cm:





- Pb-glass detectors provided by IHEP-Protvino
- prototype Endcap EMC module (pEEMC)



π^0 identification with pEEMC:

24 layer Pb-scintillator sampling calorimeter (segmented into 12 towers)

2 orthogonal planes of finely segmented triangular scintillator strips (Shower-Maximum Detector, or SMD)

2 Preshower layers

Single-spin transverse asymmetries at STAR from four single arm experiments utilizing different technology...

Measurement Details

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FPD Trigger = ~20 GeV electron equivalent deposited in any arm together with BBC E.W coincidence

Both proton beams polarized—spin sort by polarization direction of one beam only, averaging over other—$x_F>0$

$$A_N = \frac{+/-1}{P_{beam}} \frac{N_{up} - R\,N_{down}}{N_{up} + R\,N_{down}}$$

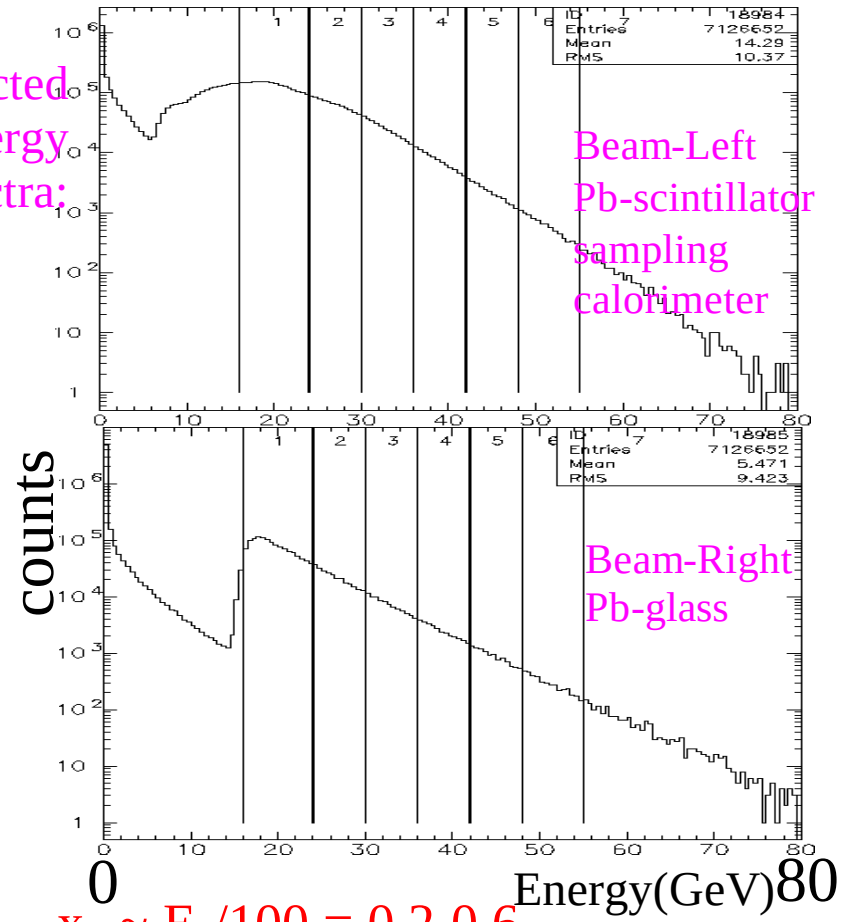
$N_{up(down)}$ = number of counts with beam polarized up (down)

$$R = \frac{Lumi_{up} * Livetime_{up}}{Lumi_{down} * Livetime_{down}}$$

= spin-dependent yield normalization ratio

P_{beam} = beam polarization

Uncorrected energy spectra:



$x_F \sim E_\pi/100 = 0.2\text{-}0.6$

$p_T \sim E_\pi/\cosh(\eta) = 1\text{-}4$ GeV/c

η=3.4-4.0; sqrt(s)=200 GeV

π^0 signal extraction

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$$M_{\gamma\gamma} = E_{tot}\,\mathrm{sqrt}(1-z_\gamma^2)\,\sin(\phi_{\gamma\gamma}/2)$$
$$\sim E_{tower}\,\mathrm{sqrt}(1-z_\gamma^2)\,d_{\gamma\gamma}/2z_{vertex}$$

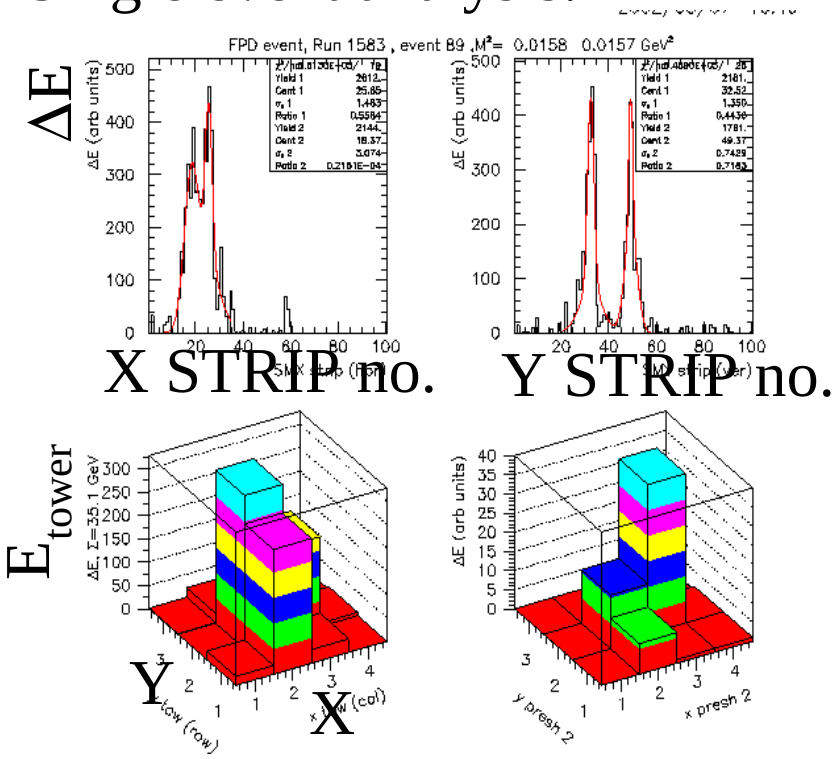
E_{tot}=sum over towers ($\delta E/E$=17%/sqrt(E))

γ separation from centroid separation of two peaks

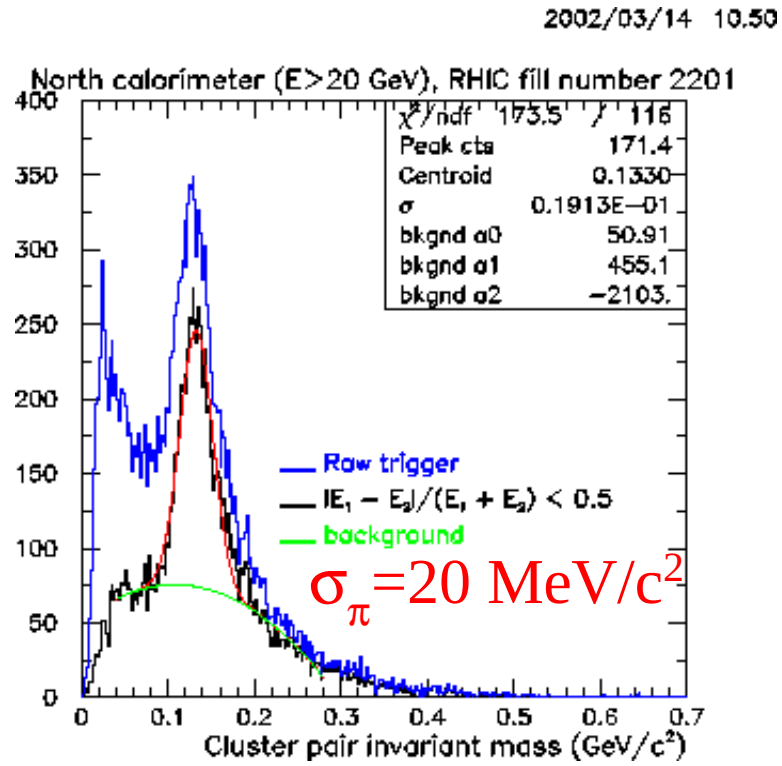
z_γ=|E1-E2|/(E1+E2) from relative yield in two peaks in SMD profile distribution ($\delta E/E$=30%/sqrt(E))

z_{vertex} = collision vertex

Single event analysis:



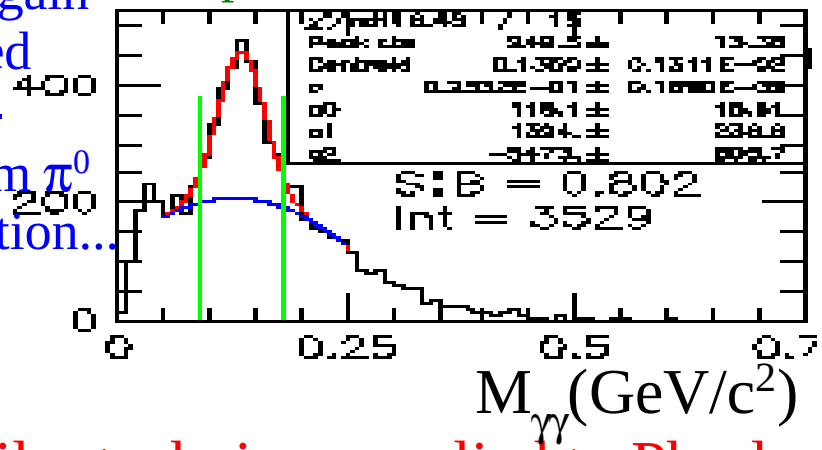
Results in π^0 peak:



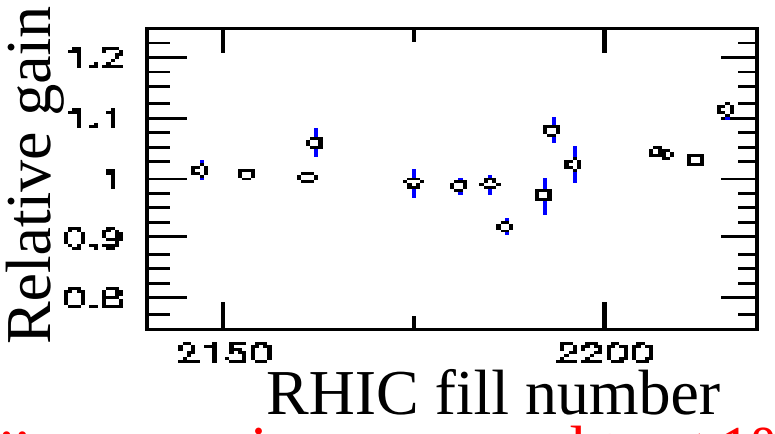
Gain Calibration/Correlation with Collision Vertex

Absolute gain determined tower-by-tower from π^0 peak position...

pEEMC tower 3:



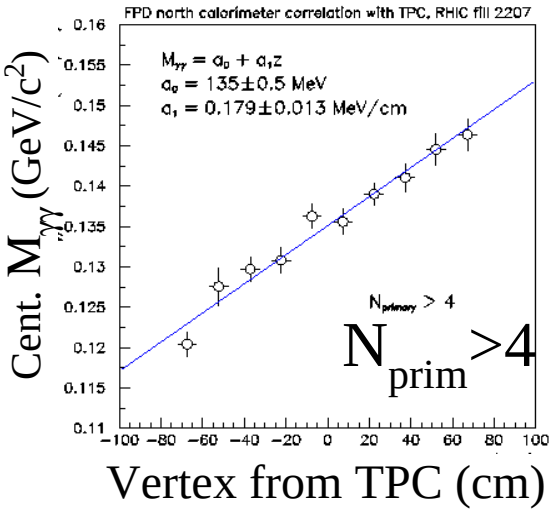
Determined for each fill to compensate for gain drifts...

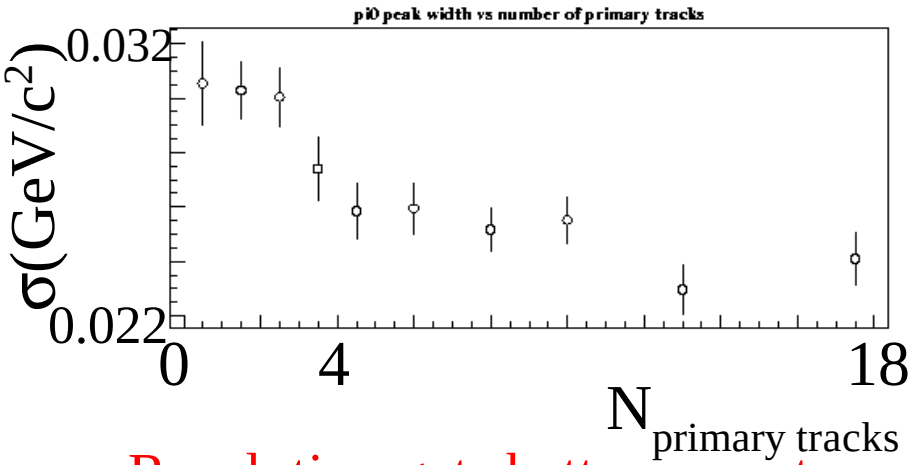


...Similar technique applied to Pb-glass...

...gains measured to < 1%

Expected geometric correlation of reconstructed π^0 mass with zvertex:





Resolution gets better as vertex becomes more well defined...

...observed π^0 mesons come from p+p collisions...

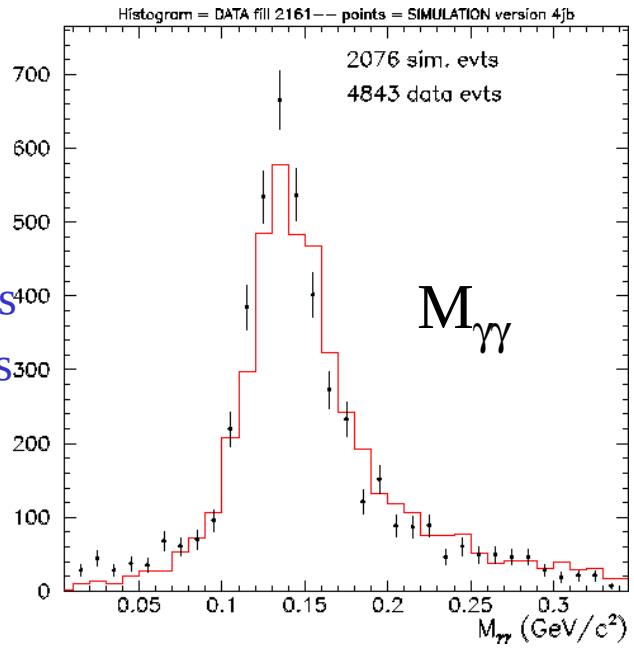
Simulation of pEEMC in STAR

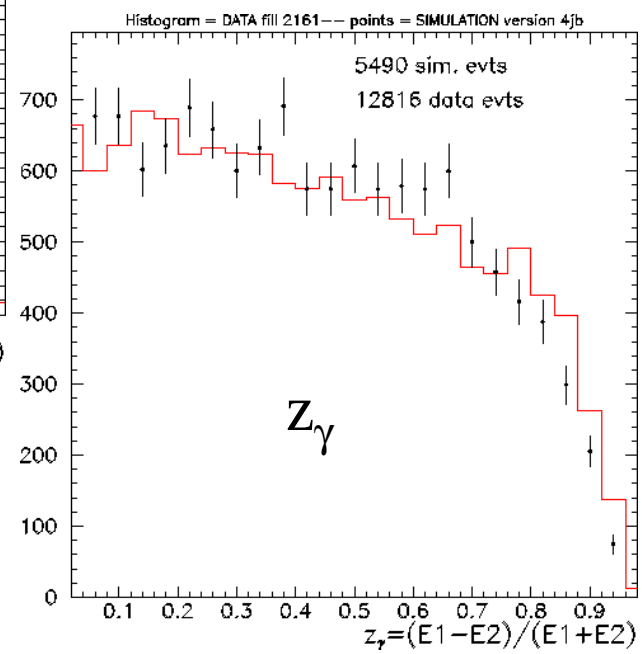
Scheme:

Events generated with PYTHIA (min bias)
Events stored if >25 GeV pointing to "box"
Full PYTHIA record included with events
GEANT simulation of pEEMC
Reconstruct using algorithm applied to data

Cuts applied:

E_{tow}>31 GeV
13 < SMD-Y centroid < 90 strips
12 < SMD-X centroid < 48 strips
SMD-X or SMD-Y > 1 peak
z_γ<0.3





Histogram = data
Points = simulation norm. to data

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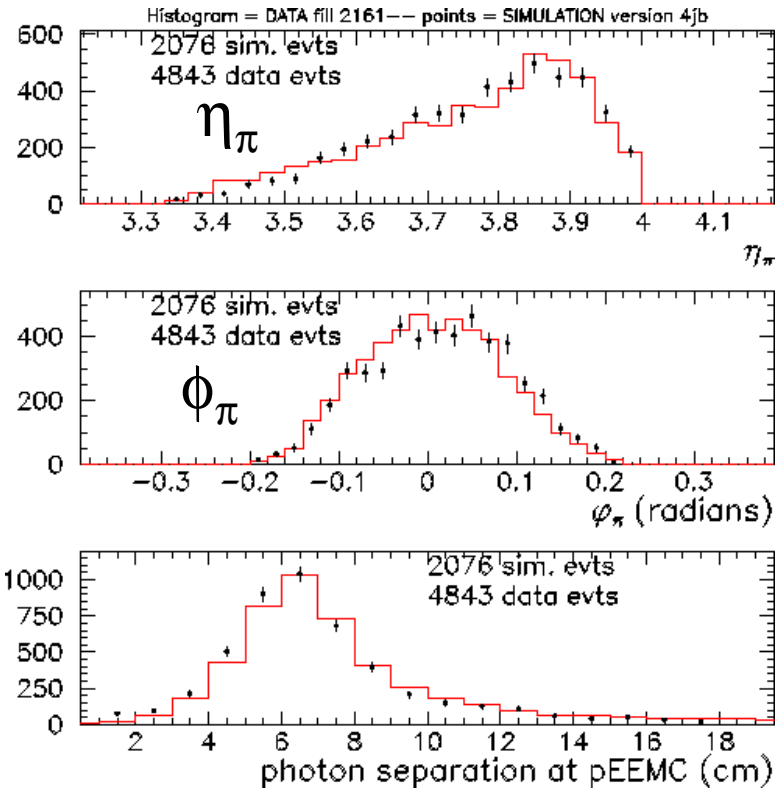
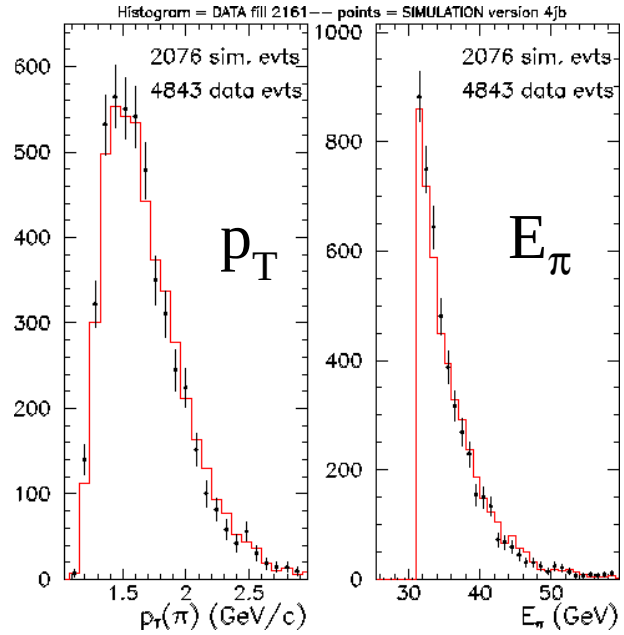
Simulation of pEEMC (cont.)

Angular variables:



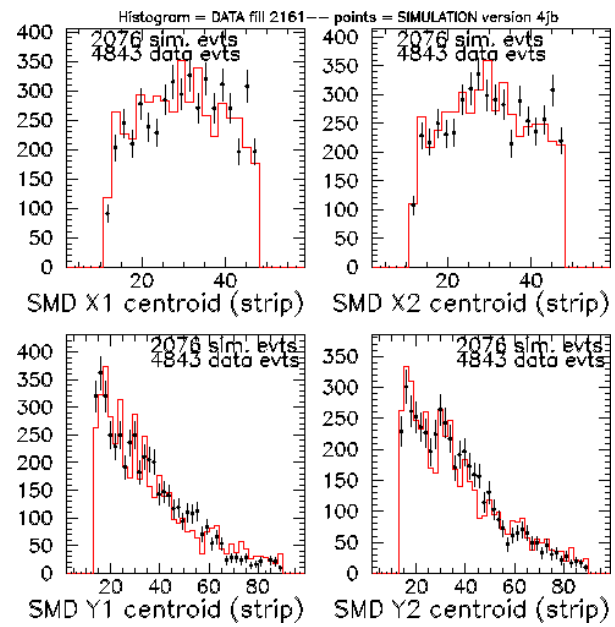
Photon separation at pEEMC



Single photon positions:

vertical

horizontal



PYTHIA+GEANT simulation describes data---p^0 mesons and background from collisions...

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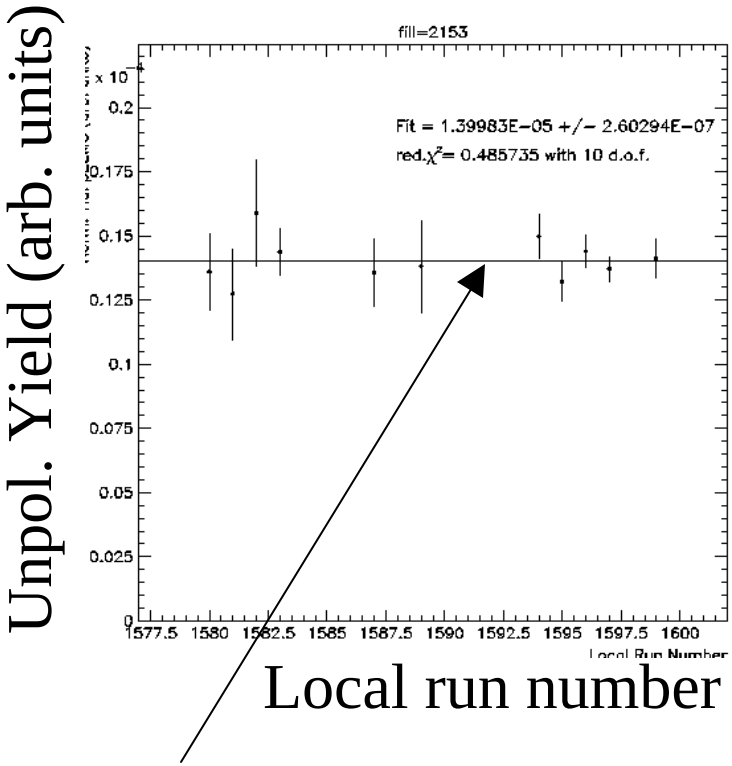
Unpolarized Yield Stability

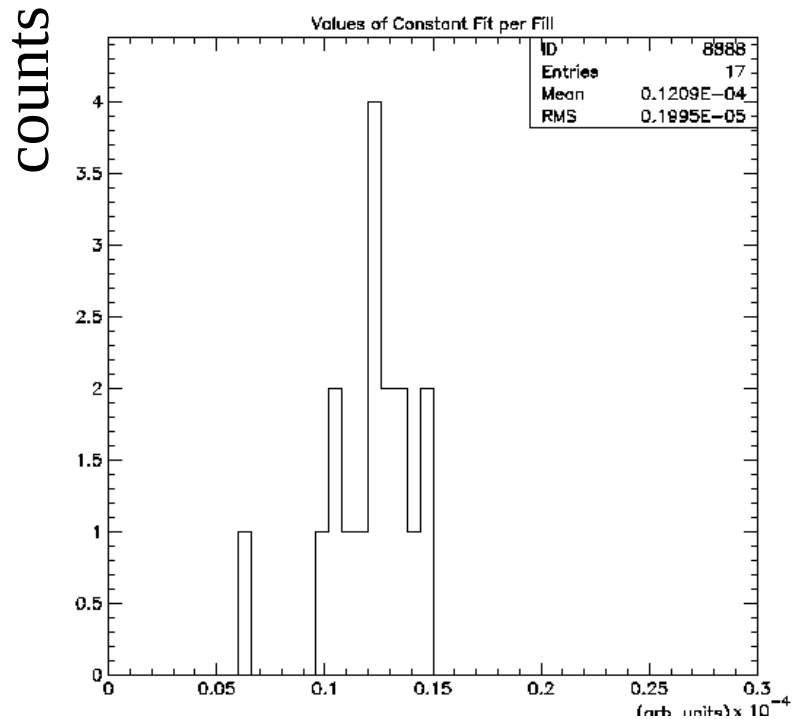
Correct raw yield by BBC coincidence rate and live time...

For fill 2153:



...fit a constant value to the normalized yield...

Plot value of constant fit for each fill to get the following distribution:



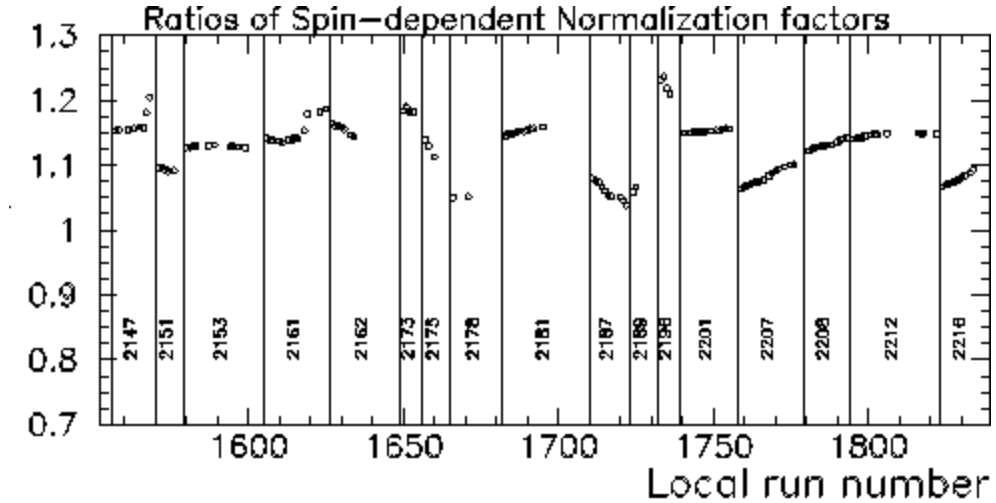
π^0 yield stable to RMS/mean ~15%

...Cross-sections coming soon...

Spin-dependent normalizations

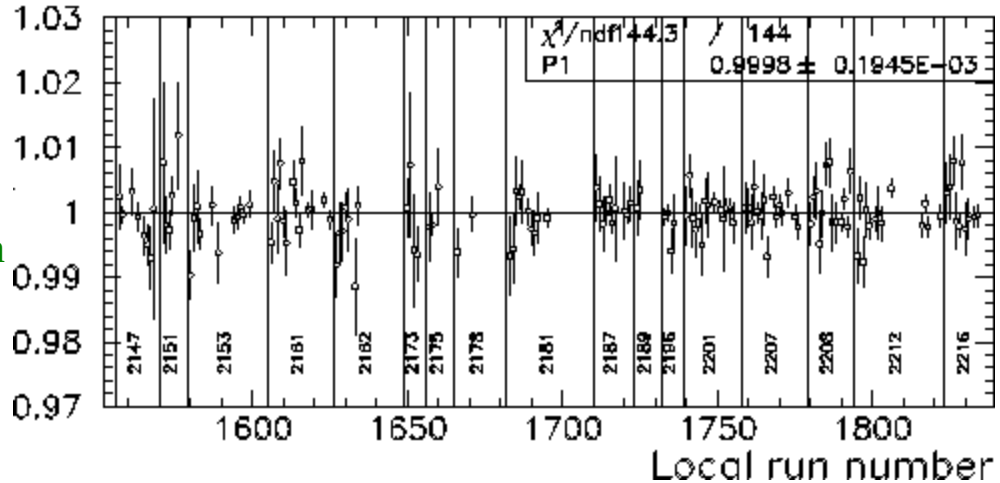
- 55 beam crossings of varying polarization and specific luminosity occurs every 213ns
- Relative luminosity normalization performed with Beam-Beam Counters (BBC) at STAR… (For details please see talk later in session by J. Kiryluk)

$$\frac{\text{Lumi}_{up}}{\text{Lumi}_{down}}$$



← Correction on the order of ~1.15...

$$\frac{\text{Livetime}_{up}}{\text{Livetime}_{down}}$$



← Relative livetime correction stable and consistent with 1.000

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Pi-zero Asymmetries

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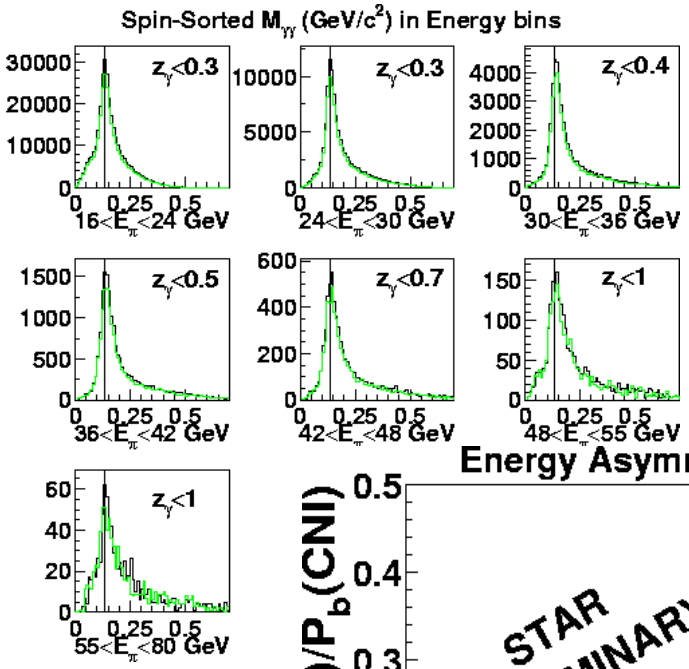
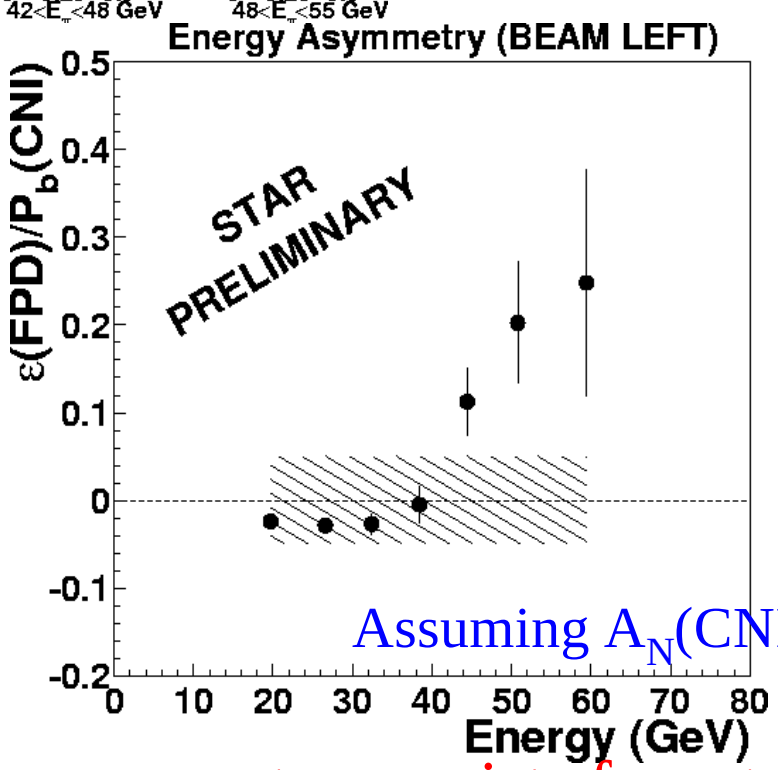
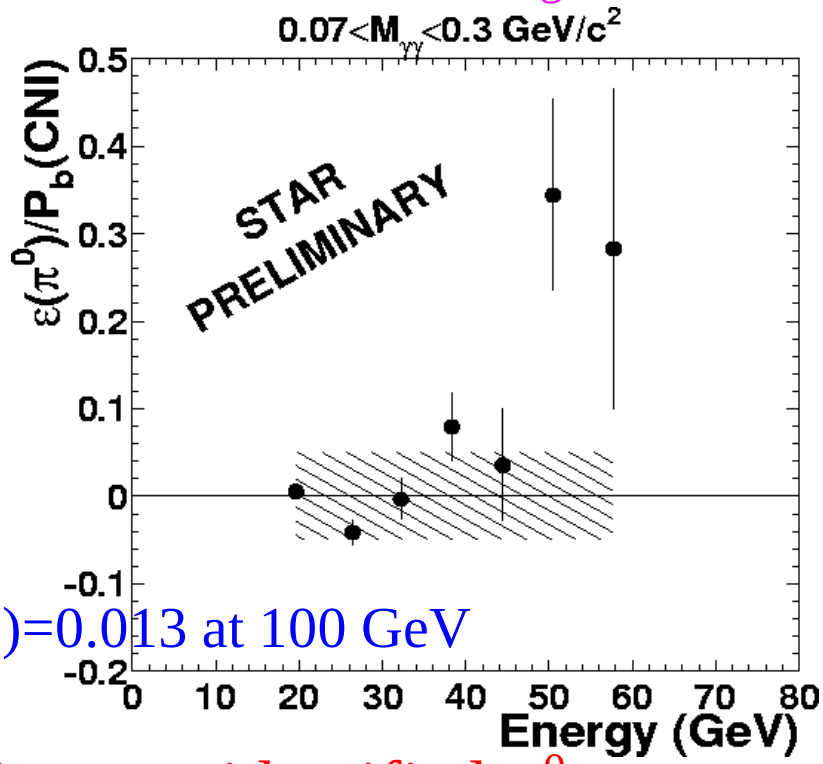
Spin sorted $M_{\gamma\gamma}$ spectra: Green = spin down, Black = spin up



...No evidence of spin or energy dependent gain shifts...

With constraints on energy sharing in SMD to reduce combinatoric background:



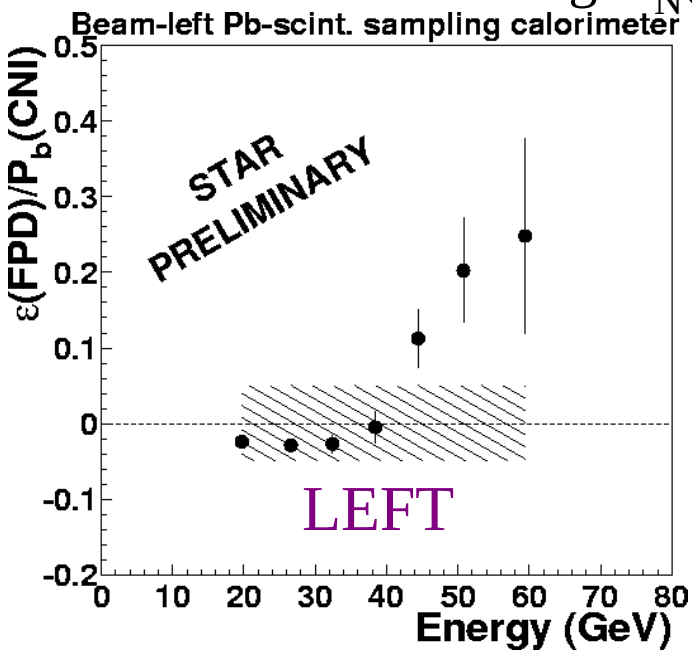


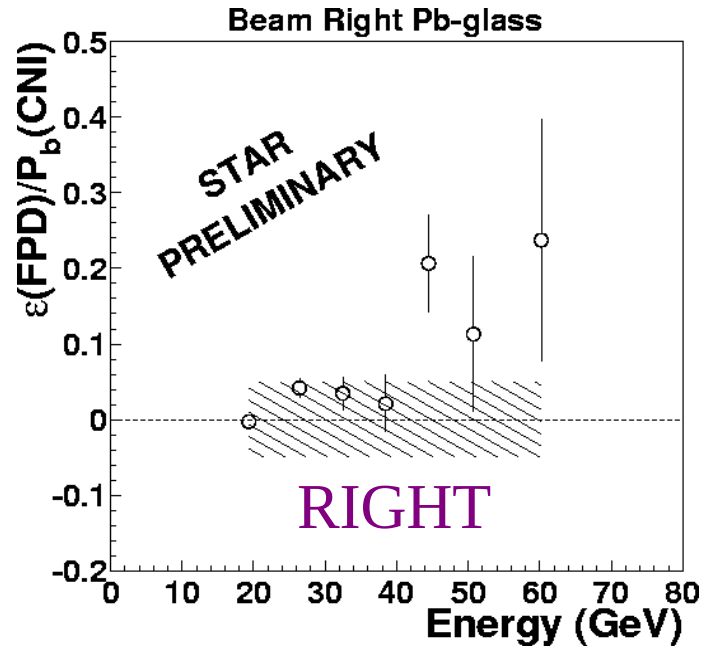
Assuming A_N(CNI)=0.013 at 100 GeV

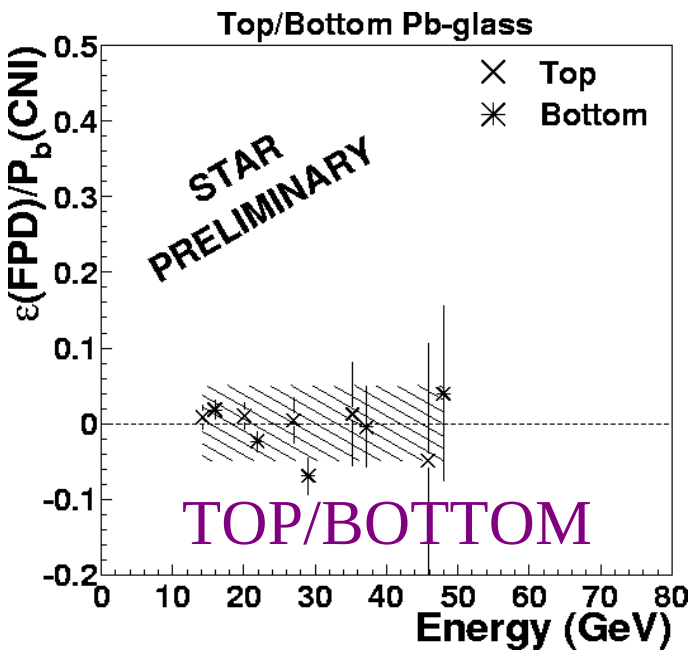
Increasing asymmetry persists from trigger to identified π^0 mesons...

Spin asymmetries from four arms

Assuming A_N(CNI)=0.013 at 100 GeV







With vertical polarization, expect:

- Left = Right
- Top = Bottom = 0

Conclusions:

- Left = Right
- Top = Bottom = 0
- Left/Right increasing

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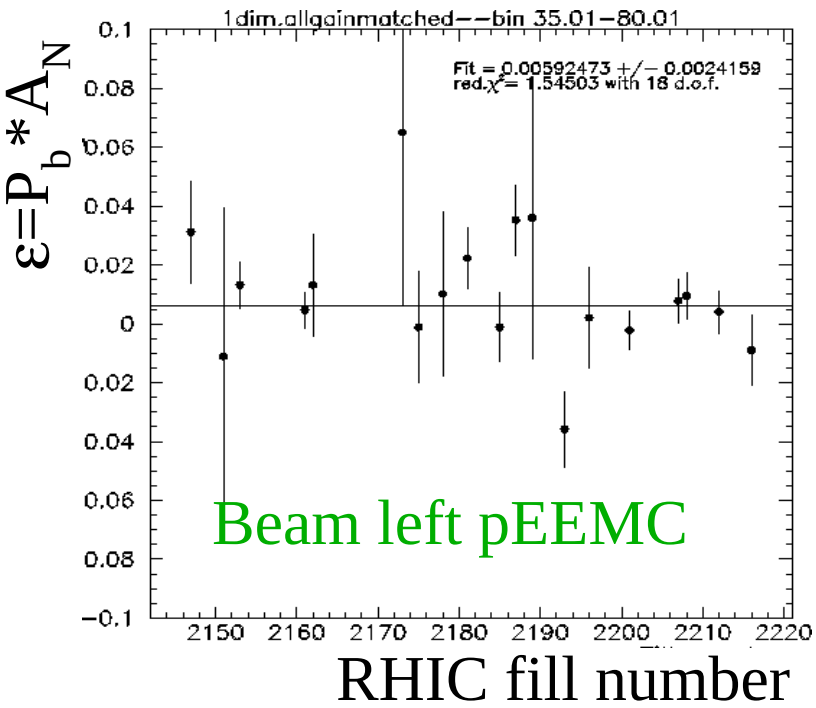
Estimate of Systematic Uncertainty

Fill dependence of trigger asymmetry:



Effect	Estimate
Left-Right difference	0.027
Background in Lumi	0.012
Non π^0 fraction in trigger	0.029
Abort gap/spin selection	0.000
Top/Bottom diff. from 0	0.002
Beam left time dep.	0.023
Sum in quadrature	0.05

Preliminary systematic uncertainty: $\delta A_N = 0.05$

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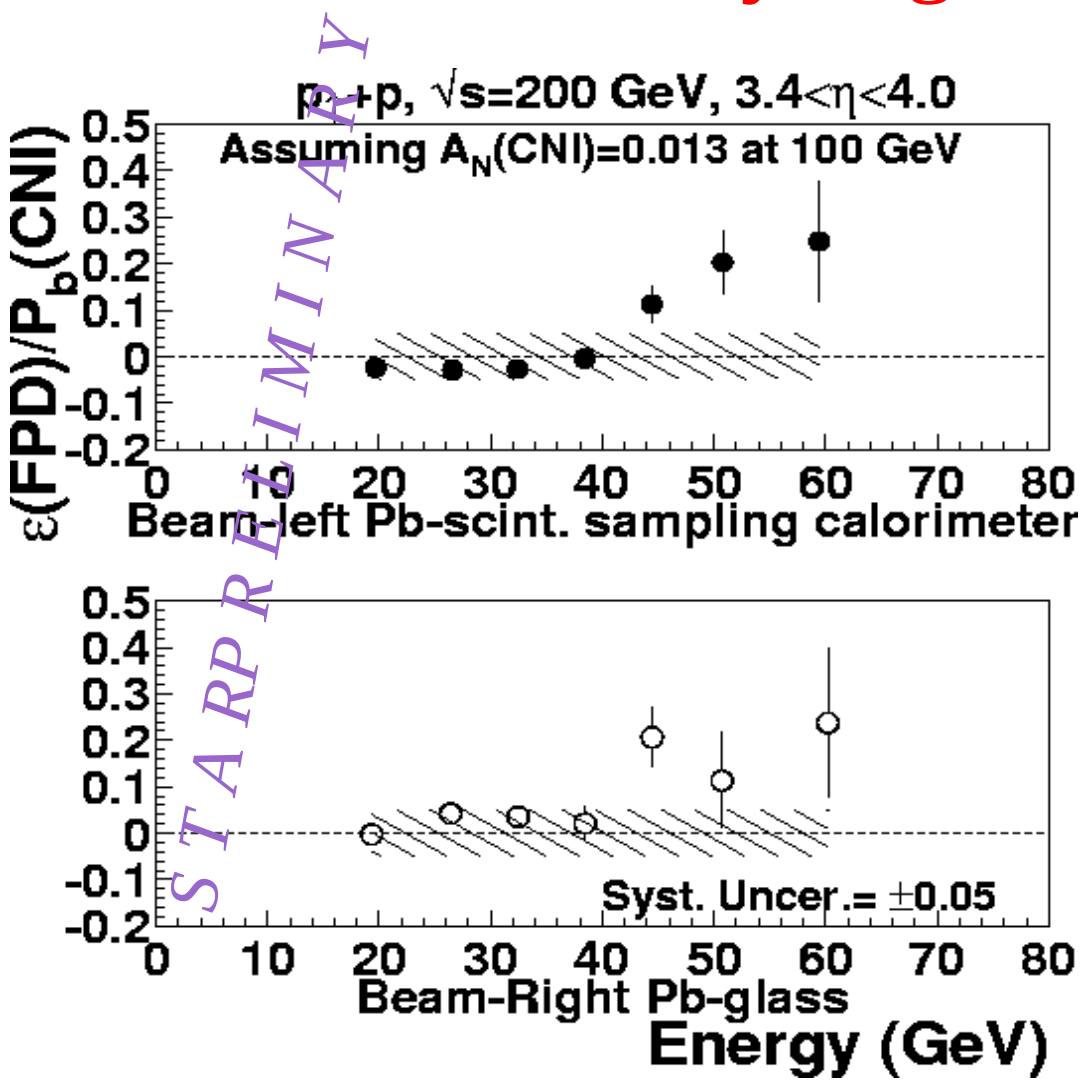
Forward π^0 Detector Analyzing Power at STAR



Signal dominated by π^0 mesons...

$1.1<p_T<2.5$ GeV/c for both detectors

- Trend of analyzing power to increase with energy is similar to E704

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Summary

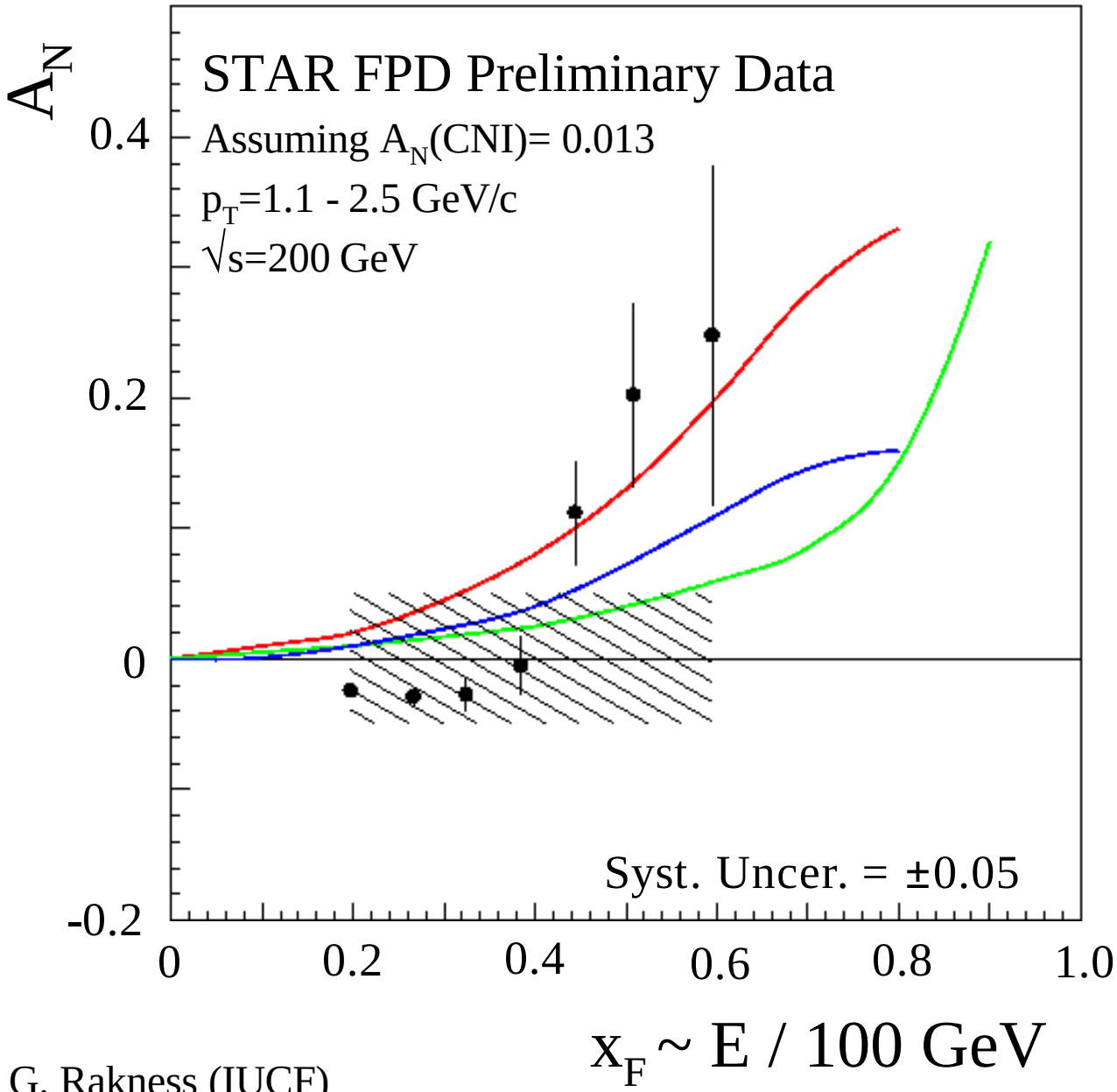
- Analyzing power measured for forward π^0 mesons at STAR during first year of RHIC polarized proton running

- Qualitatively similar to E704: A_N increases with energy
- What does this mean for the models?

To do:

- Refine estimate of systematic uncertainty
- π^0 total cross sections from 2002 data to compare with theoretical predictions
- Install improved Forward Pi-zero Detector for following years' runs (see next talk by A. Ogawa)

$$p_{\uparrow} + p \rightarrow \pi^0 + X$$



Theory predictions at p_T=1.5 GeV/c:

Collins effect
Anselmino, et al., private communication;
PRD 60 (1999) 054027.

Sivers effect
Anselmino, et al., private communication;
Phys. Lett. B442 (1998) 470.

Twist 3 effect
Qiu and Sterman, private communication;
PRD 59 (1998) 014004.