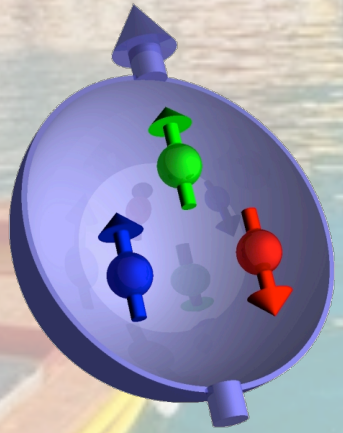
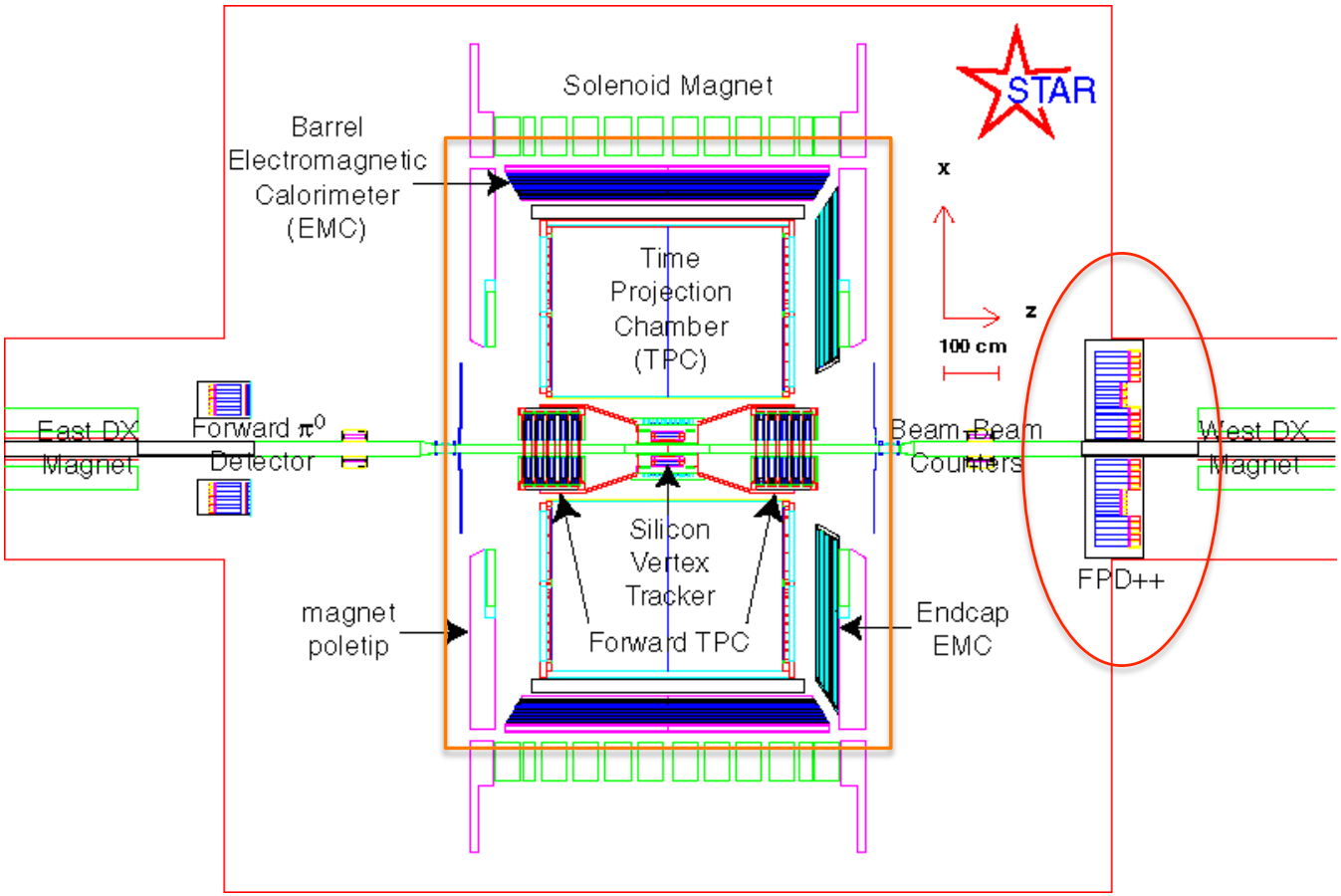
STAR results and perspectives on transverse spin asymmetries



Nikola Poljak for the STAR collaboration
University of Zagreb
Transversity 2011, Veli Losinj, Croatia
31.8.2011.

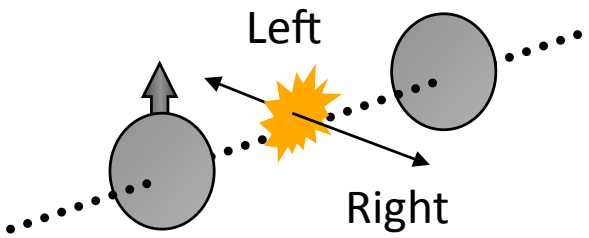
Done at RHIC – STAR 2006 configuration



Run6
East FPD West FPD++
$\sqrt{s}$=200 GeV
P_{beam} ~ 60%
$L_{int} = 6.8 pb^{-1}$
η = -3.7/3.3
-1 < η < 1

FOM (P^2L) in Run 6 is ~50 times larger than from all the previous STAR runs

Transverse Single Spin Asymmetries



$$A_N = \frac{1}{P}\frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$

A_N difference in cross-section between particles produced to the left and right

Theory Expectation:

Small asymmetries at high energies

(Kane, Pumplin, Repko, PRL 41, 1689–1692 (1978))

$$A_N \propto \frac{m_q}{p_T}$$

A_N O(10^{-4}) Theory

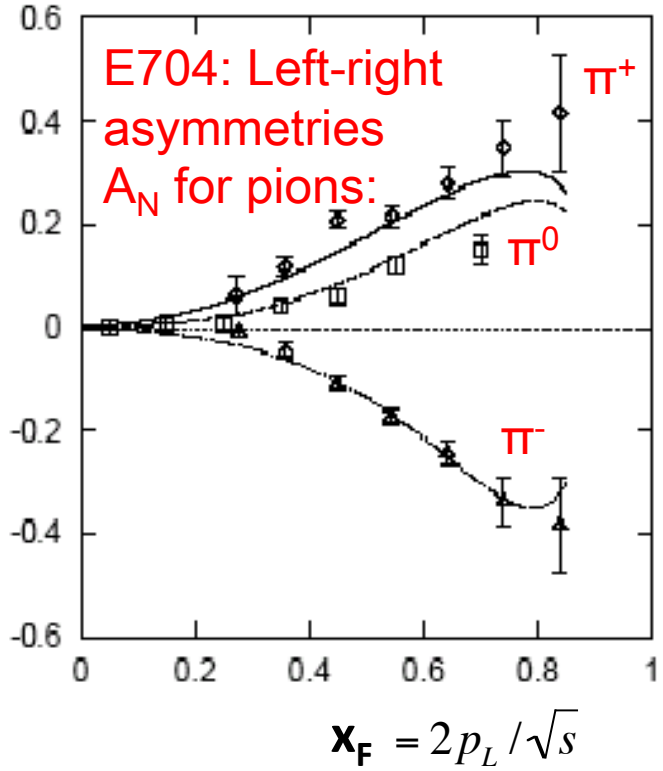
Experiment:

(E704, Fermi National Laboratory
Phys. Lett. B 261 (201) Phys. Lett. B 264 (462))

$$pp^{\uparrow} \rightarrow \pi + X$$

$$\sqrt{s} = 20\,\mathrm{GeV}$$

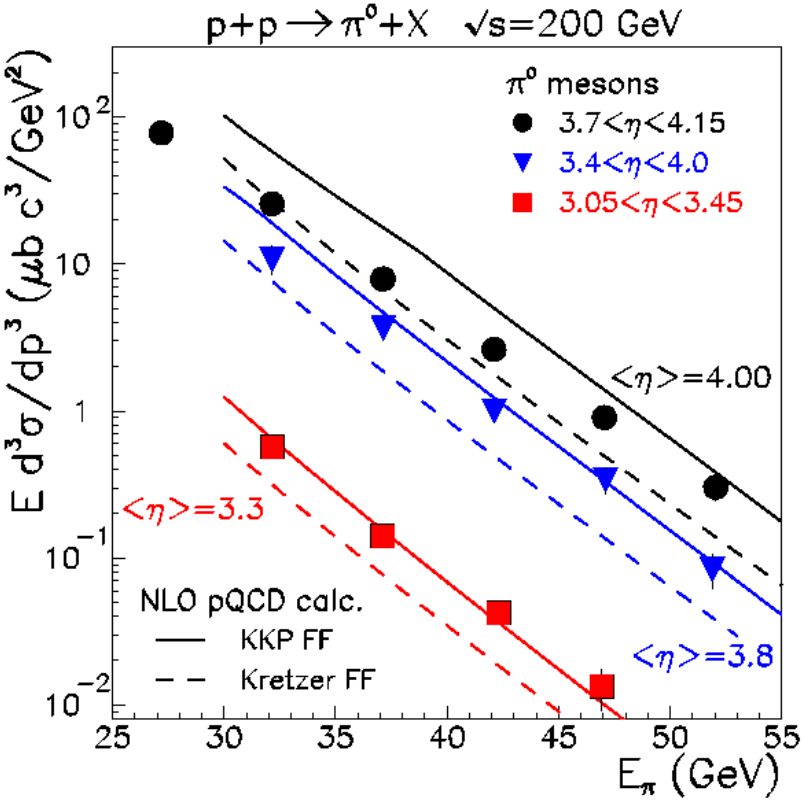
A_N O(10^{-1}) Measured



Published measurements - A_N

PRL 97, 152302 (2006)

nucl-ex/0602011



At this energy the cross-section is consistent with NLO pQCD (run2 + run3) and included in global fits on fragmentation functions
Phys.Rev. D75: 114010, 2007

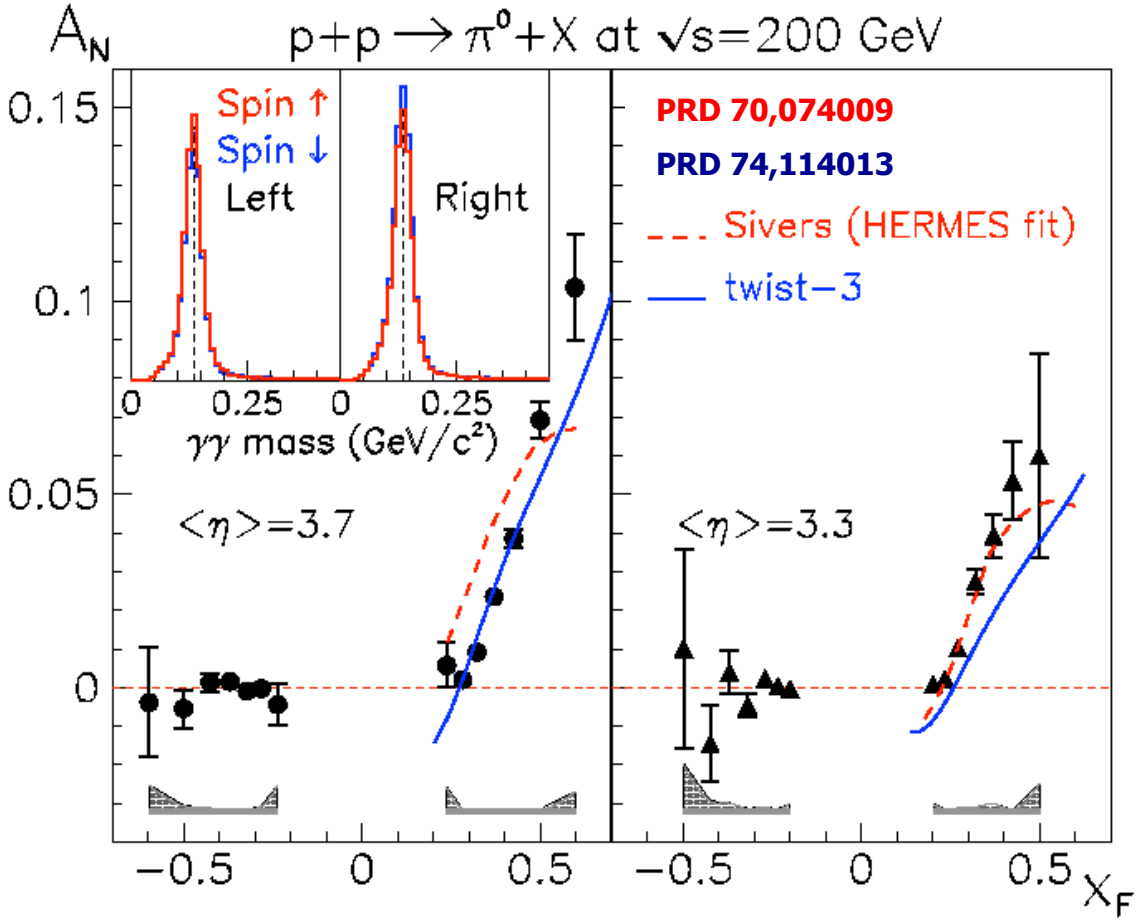
Polarized pp collisions:

- large rapidity production probes asymmetric partonic collisions (high x quark + low x gluon)
- describe pp particle production using NLO pQCD, relying on universal distribution and fragmentation functions
- can study quark transversity distributions

Published measurements - A_N

RUN6 : PRL 101 (222001)

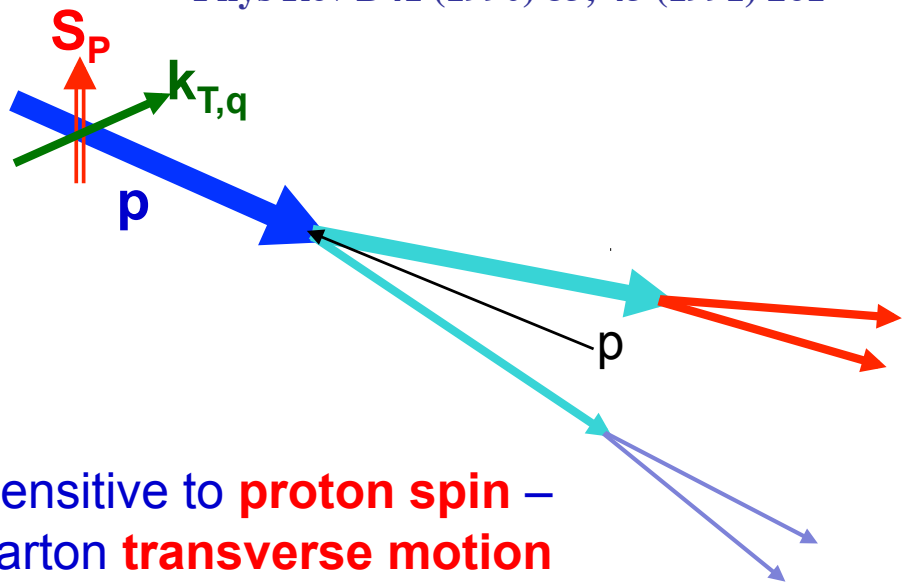
- Large transverse single-spin asymmetries at large x_F
- x_F dependence matches Sivers effect expectations qualitatively (under current study by theory)
- Obtained with the FPD and FPD++ modules



Separating Sivers and Collins effects

Sivers mechanism: asymmetry in the forward jet or γ production

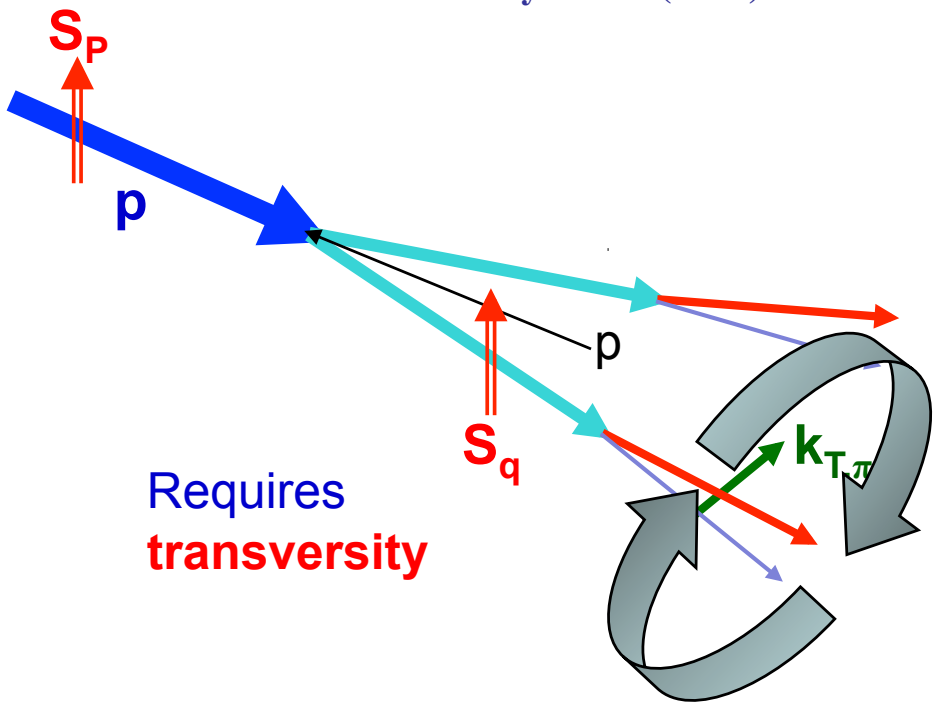
Phys Rev D41 (1990) 83; 43 (1991) 261



Sensitive to **proton spin** – parton **transverse motion** correlations

Collins mechanism: asymmetry in the forward jet fragmentation

Nucl Phys B396 (1993) 161



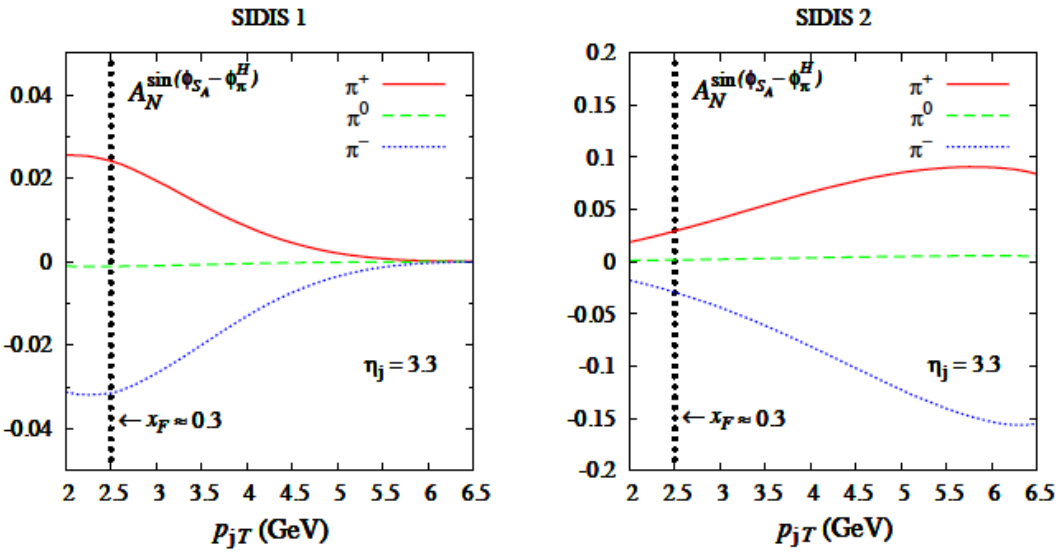
Requires **transversity**

To discriminate between the two effects we need to go beyond inclusive π^0 detection to **jet-like events** and measure the π^0 asymmetry as a function of the azimuthal angle aroud the jet-event axis

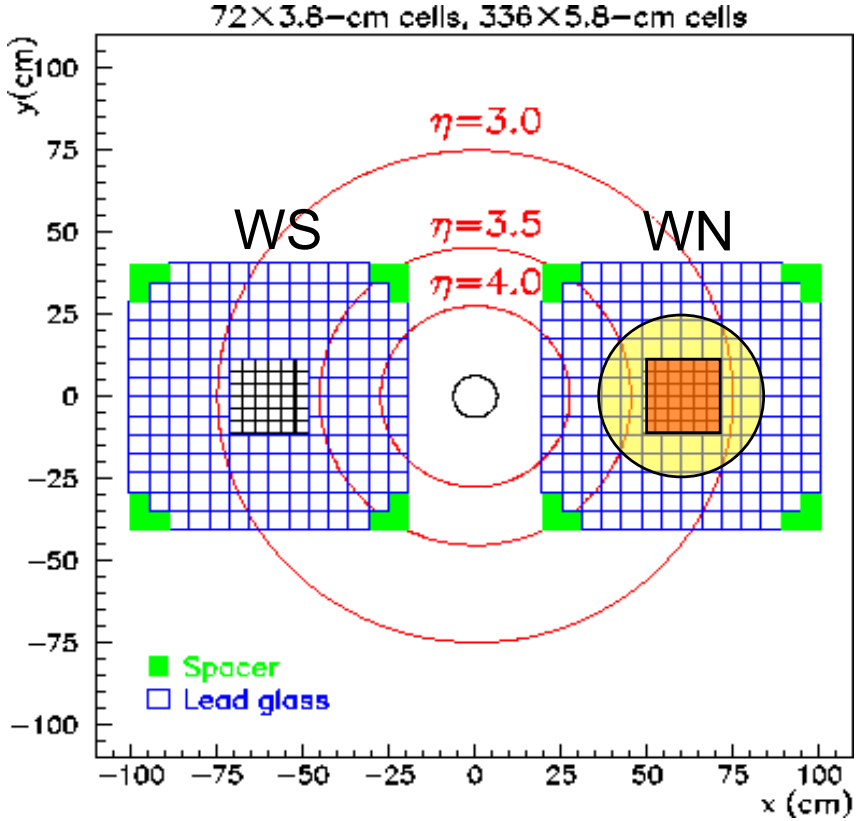
Motivation and idea

Phys.Rev.D83:034021,2011

The estimated quark Collins asymmetry for $p^{\uparrow} p \rightarrow jet + \pi + X$ process at $\sqrt{s} = 200GeV$ for 2 different quark transversity distributions



Transversity 2005 proc. (arXiv:hep-ex/0602012):
Resolve the origin of large transverse spin asymmetries in polarized pp reactions for forward pion production – use of a detector suitable for reconstruction of jet-like events



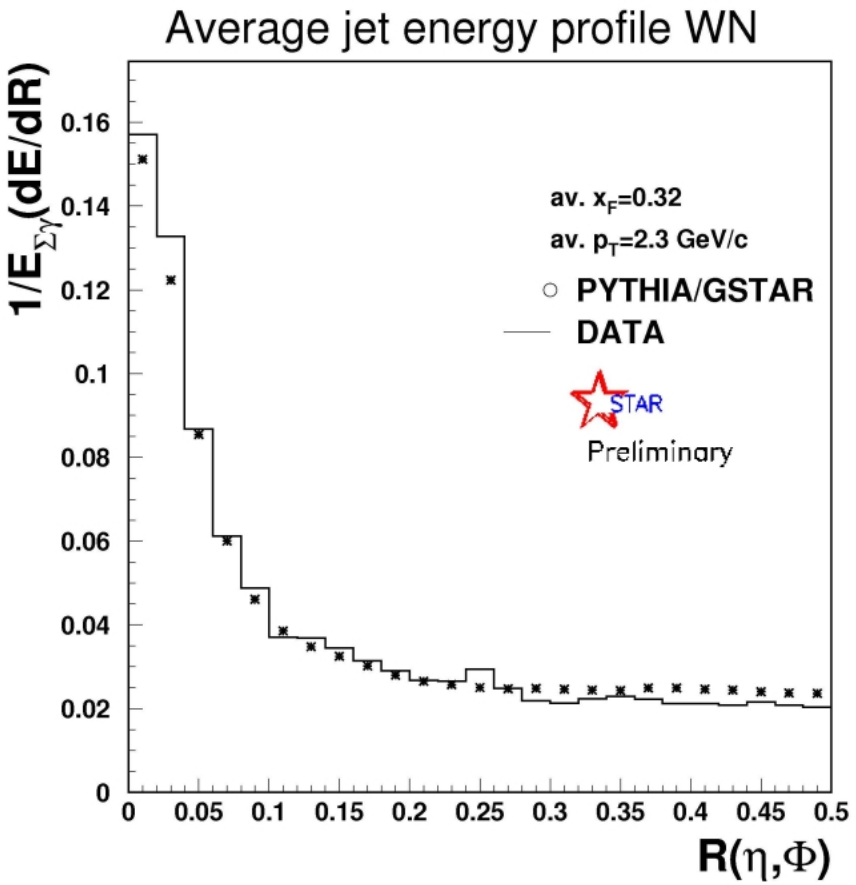
RUN-6; FPD++

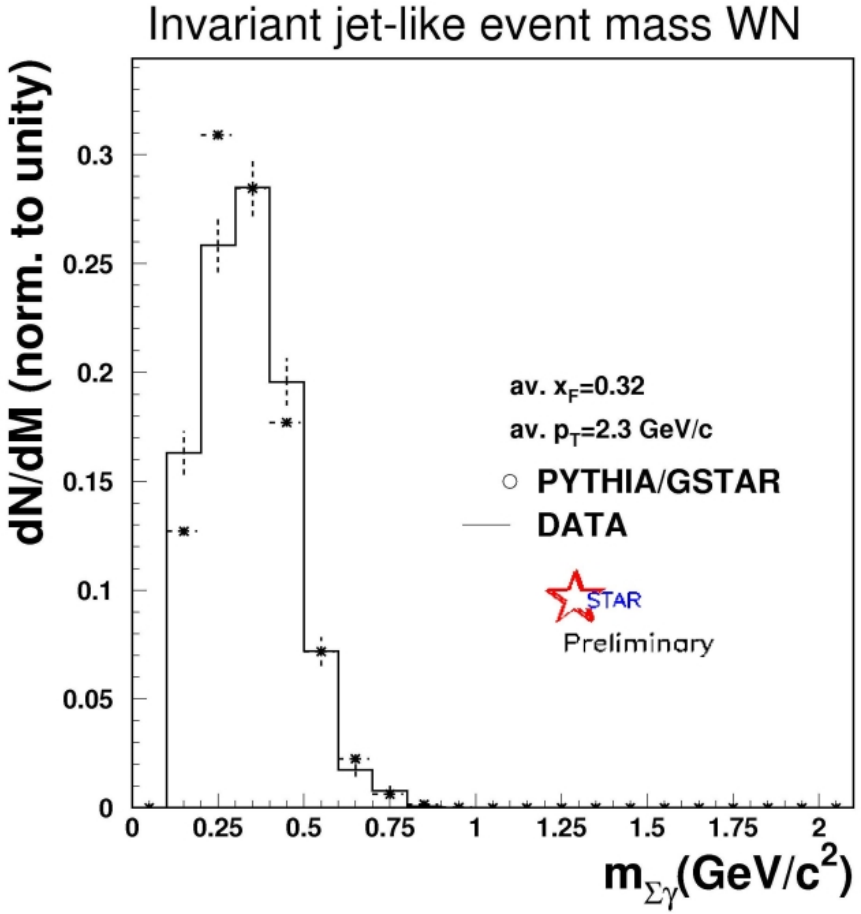
Summed module energy trigger

Modular EM detector with explicit azimuthal symmetry primarily sensitive to incoming γ, e^+ and e^-

Forward “jet-like” objects selection

Module energy sum with the following event requirements:
≥4 towers with E ≥ 0.4GeV, cell area weighted sum of towers ≥ 10 (w(small)=1, w(large =1.52), “jet-like” p_T ≥ 1.5 GeV/c , “jet-like” E ≥ 20 GeV , max. cone radius of 0.5 in the η-Φ space, 2 perimeter fiducial volume cut



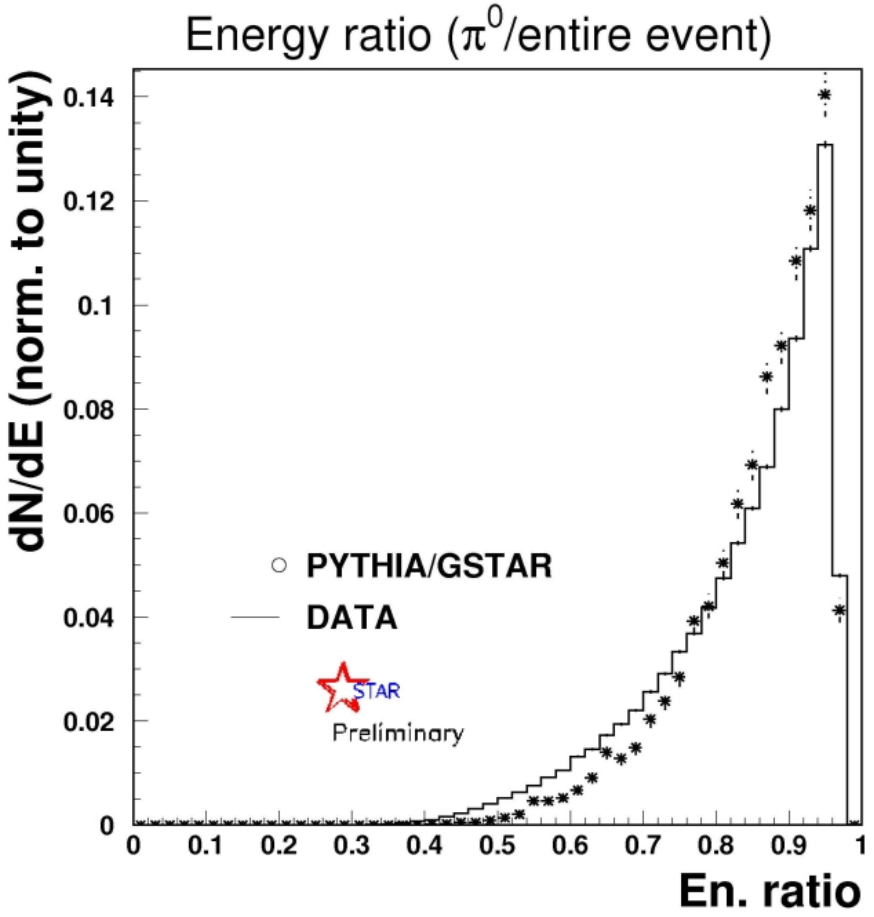


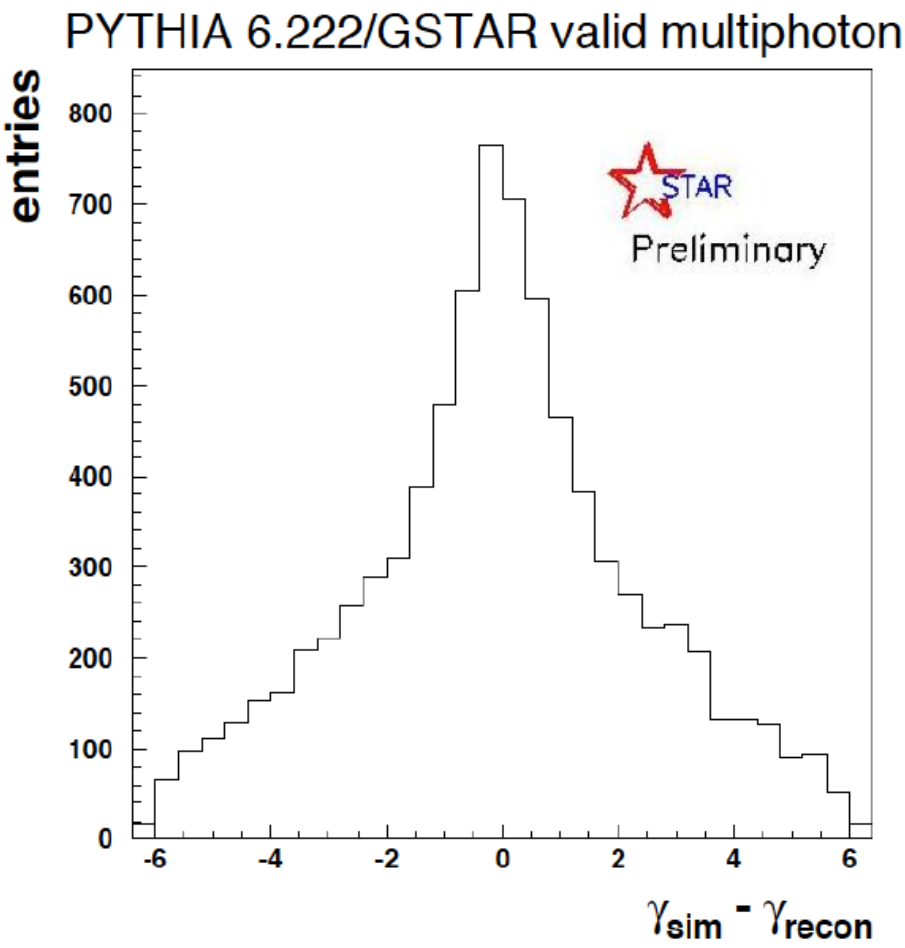
Simulations set up to mimic the data small cell module energy trigger

The agreement between data and simulations is very convincing and repeats itself over a variety of results and throughout the x_F range

Association analysis and event jettiness

Simulations show reasonable agreement with data. The neutral pion is well reconstructed and carries most of the energy of the event. What about the "jet-like" object?



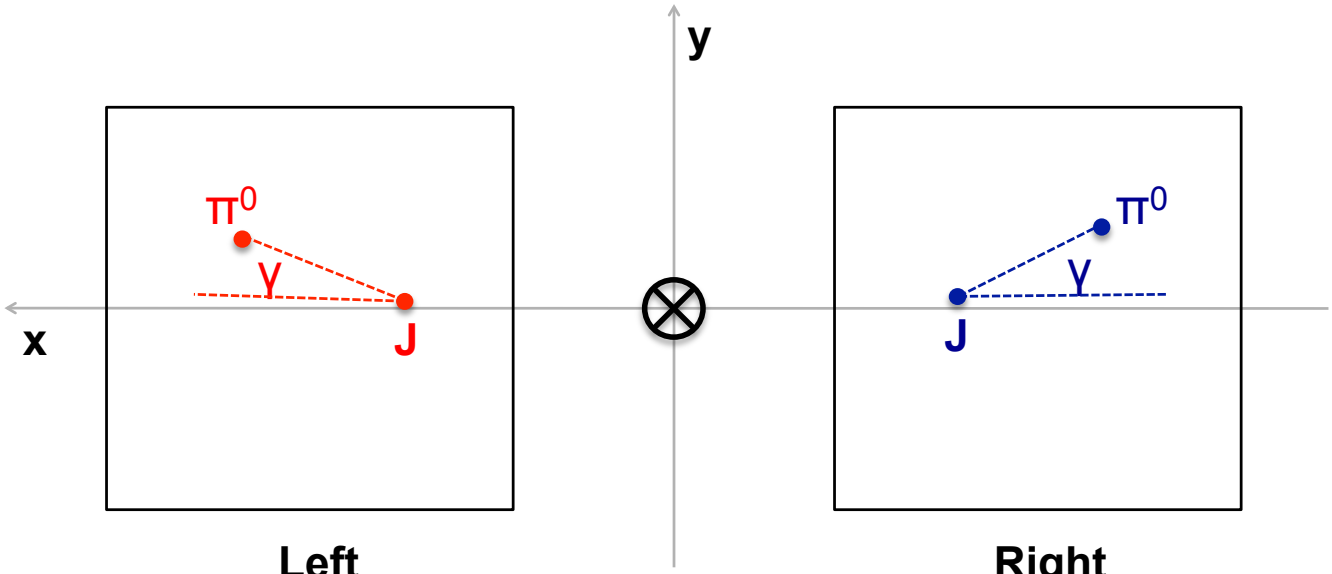


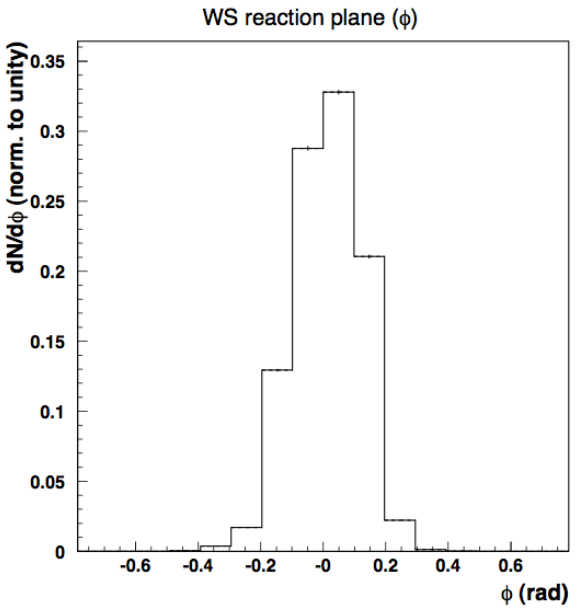
"jet-like" objects reconstructed from simulation are found to be associated with a hard-scattered or a radiated parton. The "jet-object" axis agrees well with the direction of the parton. On average, there are 2.5 fragmenting mesons per one object, making them reasonably "jetty".

γ and asymmetry definition

• γ is the angle in the x-y plane from the jet-like impact point to the neutral pion impact point. γ is defined **mirror symmetrically (CW-CCW)** for the left and right modules

$$A_N f(\gamma) = \frac{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} - \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} + \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}$$

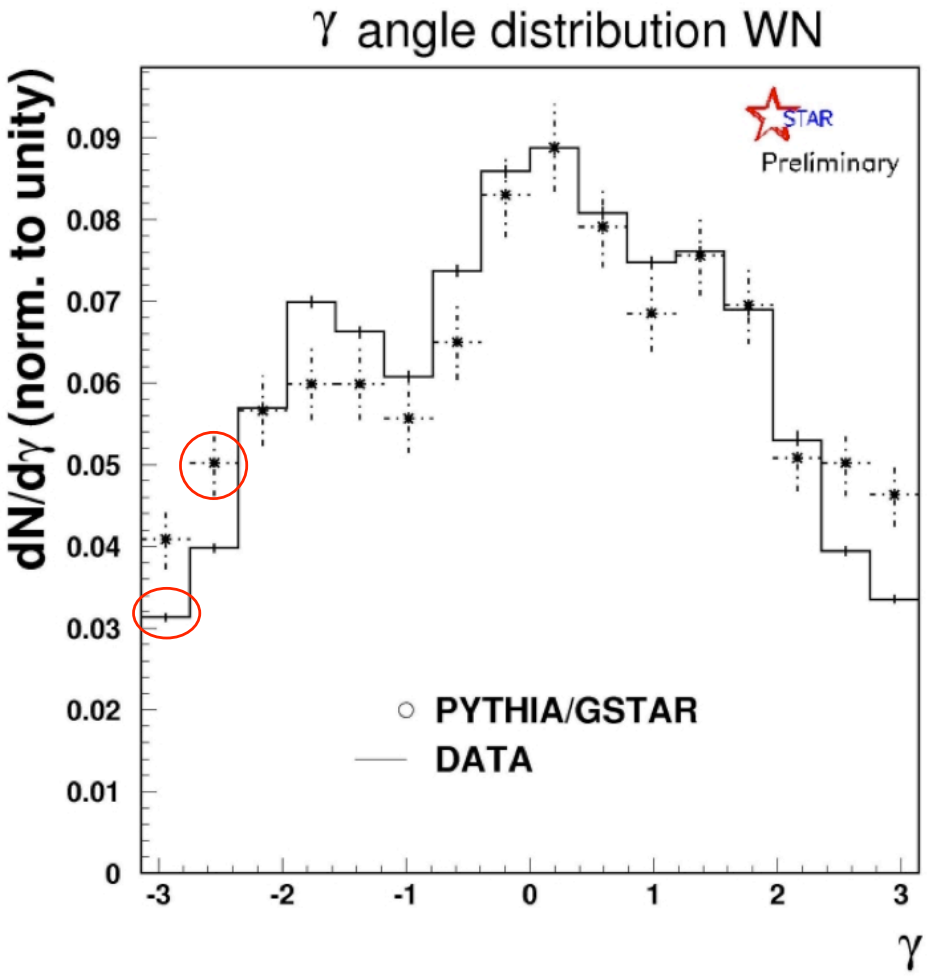


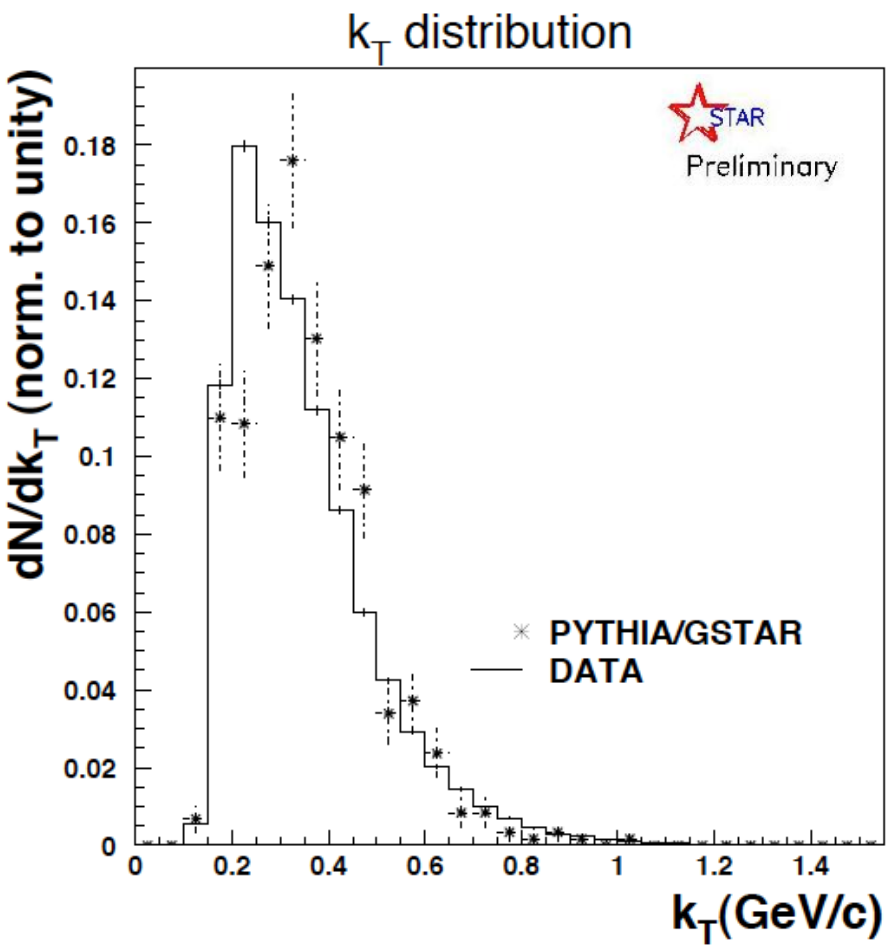


By forming the geometric mean in each term, the detector effects are minimized. For the Sivers effect, the asymmetry does not depend on the cos(γ) bin. The slope of the asymmetry as a function of cos(γ) is a signal of the Collins effect.

Characteristics of the spin-averaged results

- γ is well reconstructed as confirmed by association analysis
- the component of the pion momentum perpendicular to the jet-like object axis (k_T) was found in data and simulations

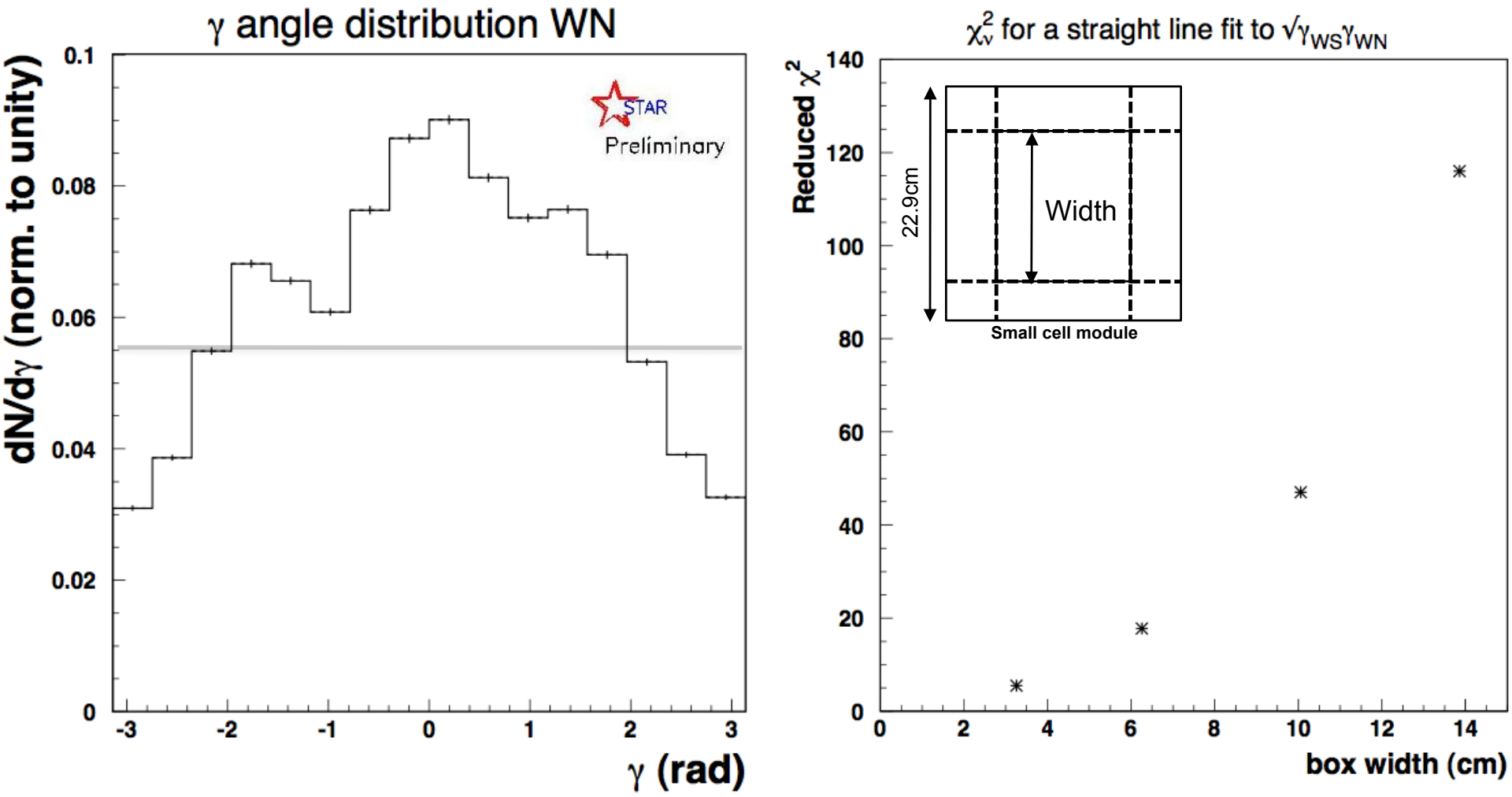




The jet-like γ distributions show agreement in data and simulations. The magnitude of k_T is in the domain of TMD fragmentation.

Why isn't the γ distribution uniform?

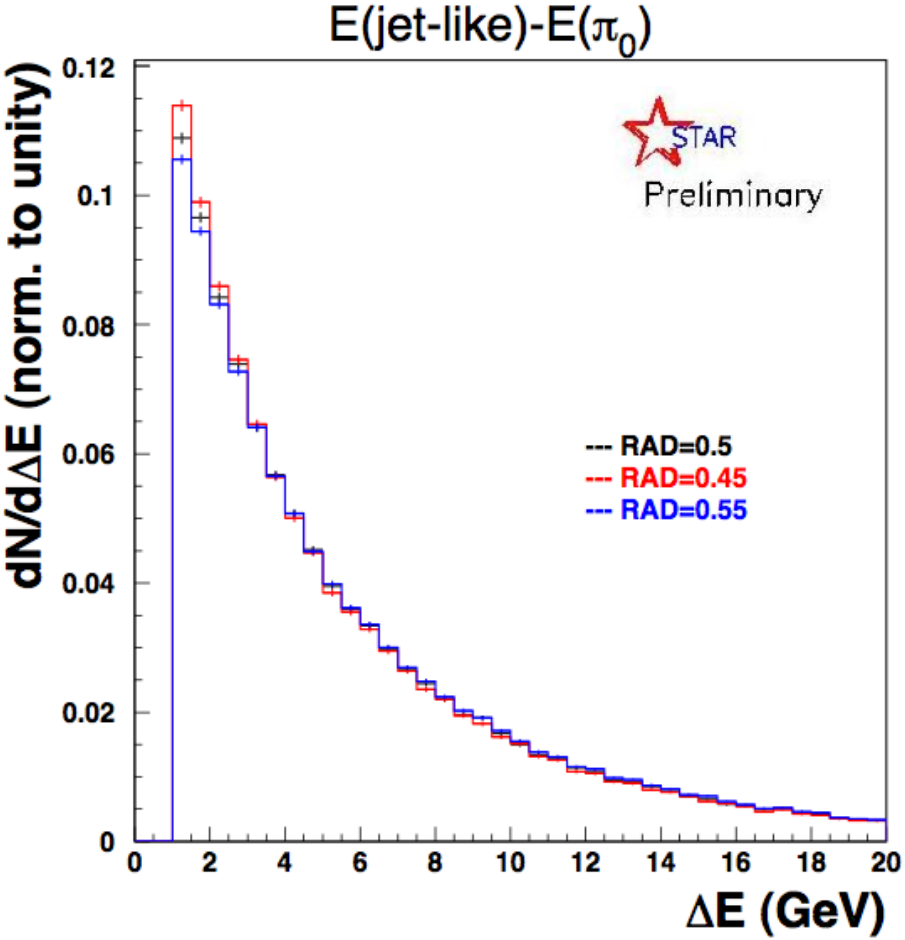
• peaking in γ is an acceptance effect – a combination of falling p_T jet-like object cross section and limited pion acceptance prefers angles γ close to 0

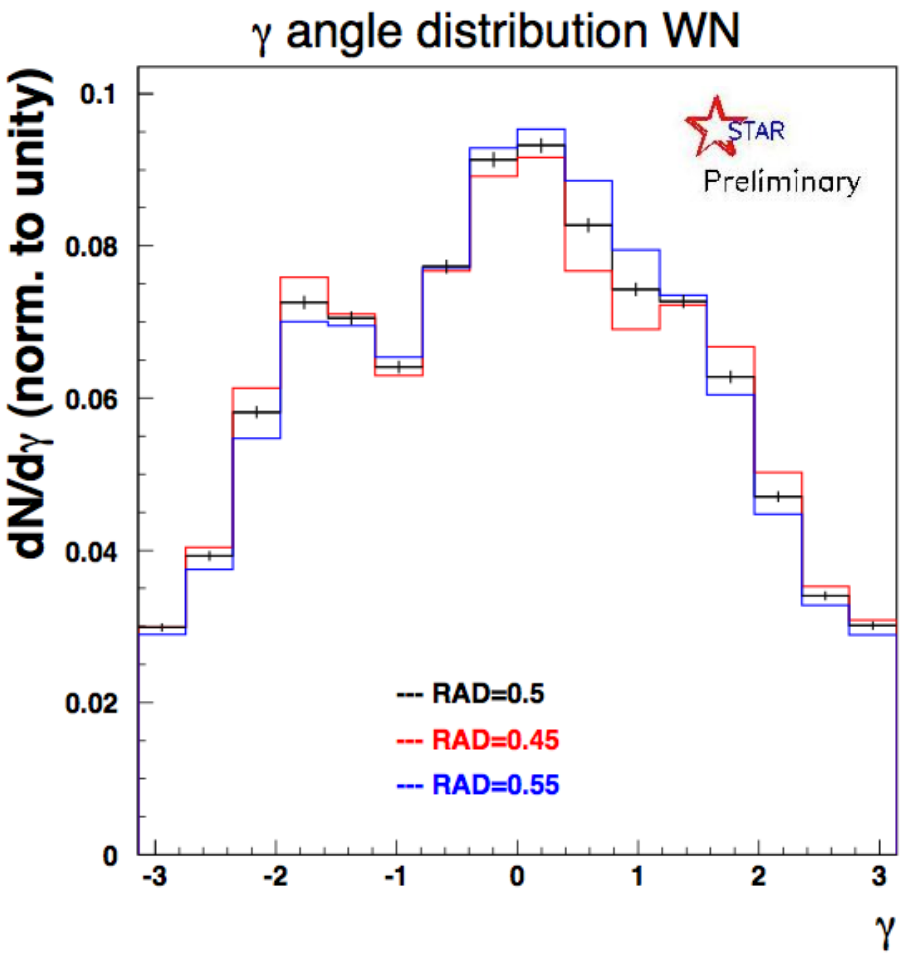


By restricting the jet-like object axis closer to the detector center, the distribution expectedly flattens.

Systematics studies of the model

- Systematic studies of the model were done by changing the model parameters by 10% both on data as well as simulations
- Results here given for data when changing maximal radius of the event cone

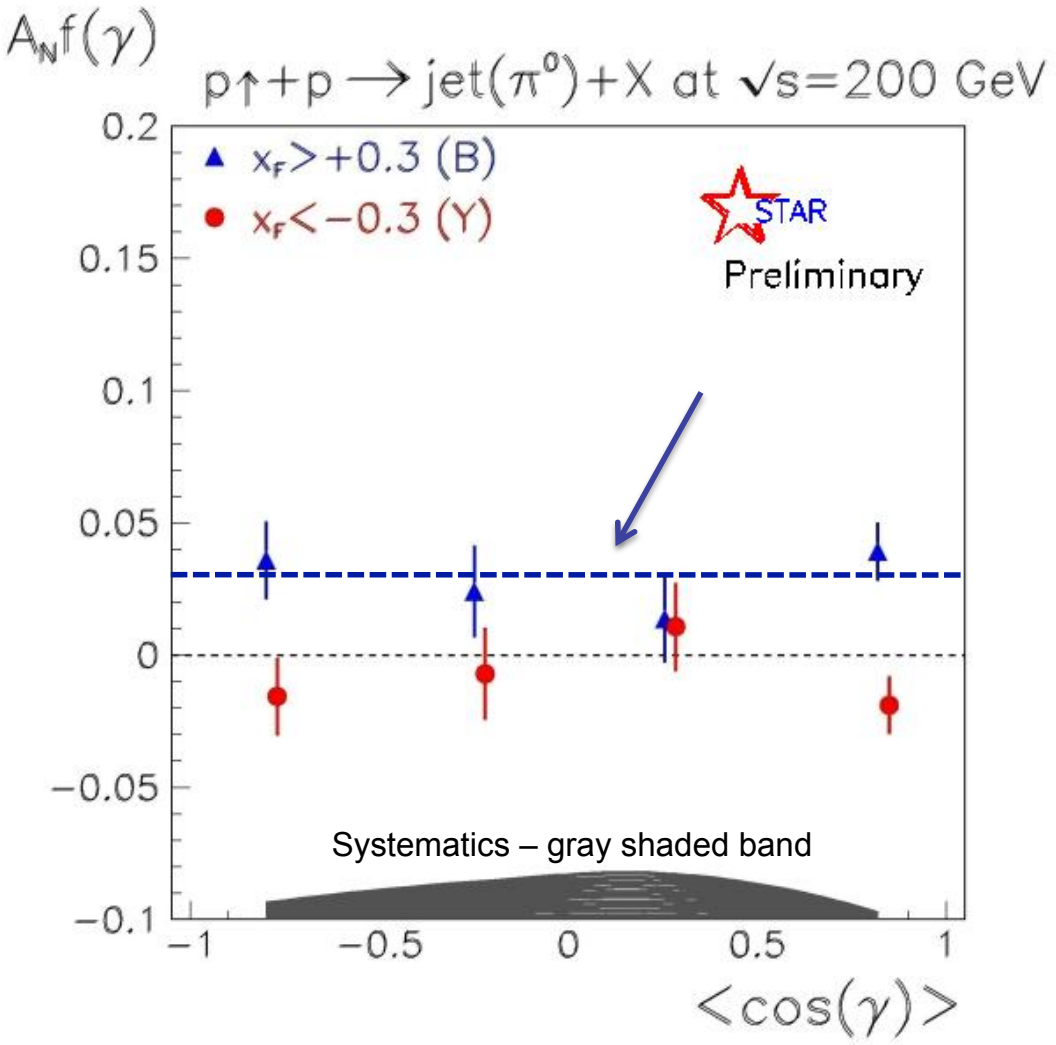




The results show that no special point in the parameter space has been selected and the systematic effects are small. The data follow the same trends as the simulations.

Forward results - asymmetry

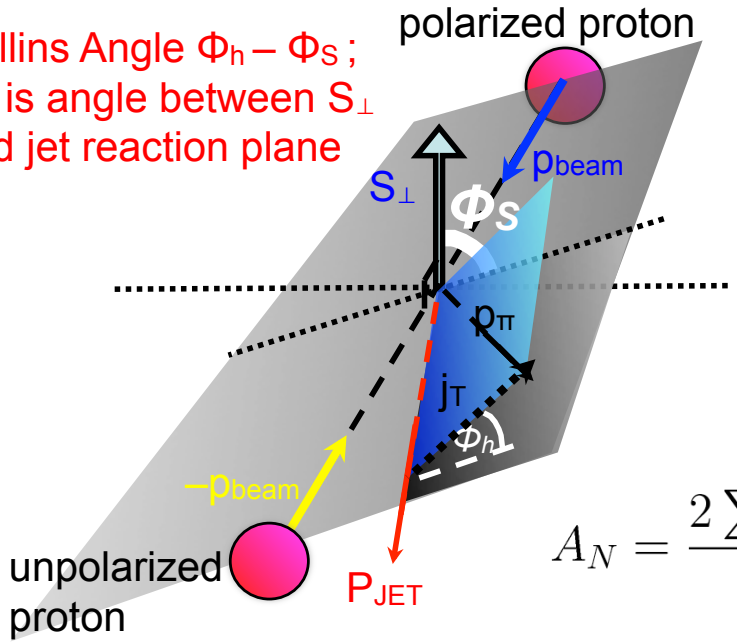
- The pion asymmetry for the events was calculated in bins in the cosine of the jet-like γ angle
- The negative x_F asymmetry is consistent with zero
- The $x_F>0$ asymmetry is greater than zero in all bins (av. 0.031±0.014), but doesn't show a dependence on cos(γ)



The "jet-like" events $x_F>0$ asymmetry is positive, but doesn't show any Collins effect contributions.

Mid-rapidity jet reconstruction

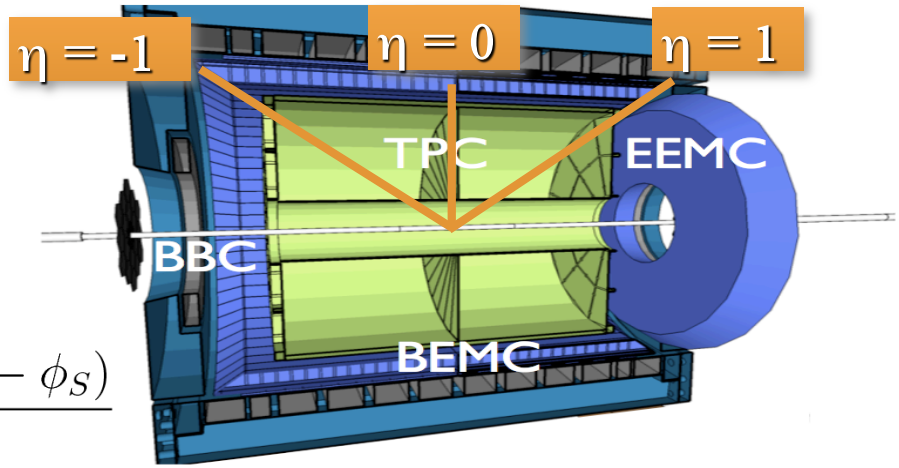
Collins Angle $\Phi_h - \Phi_S$; Φ_S is angle between $S_\perp$ and jet reaction plane



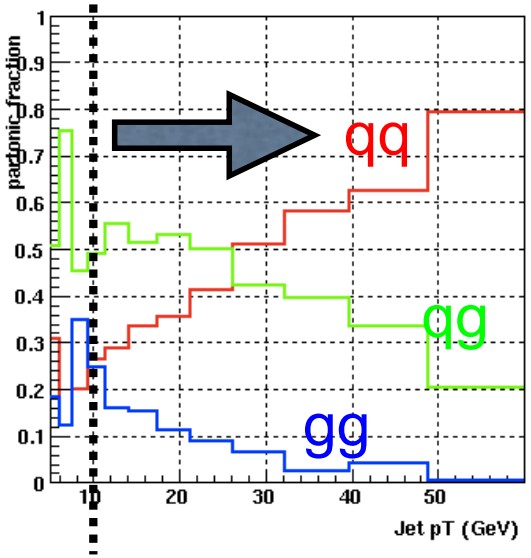
PRL 100 032003 (2008)

$$d\sigma \approx d\sigma^{UU}[1 + A_N \sin(\phi_h - \phi_S)]$$

$$A_N = \frac{2\sum_N \sin(\phi_h - \phi_S)}{p_{beam} N}$$

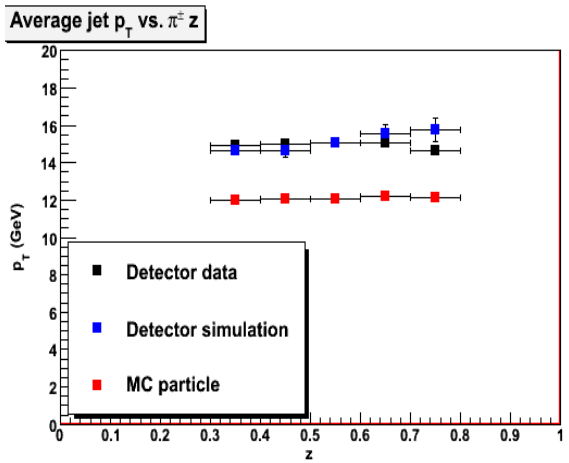


STAR simulation at √s = 200 GeV

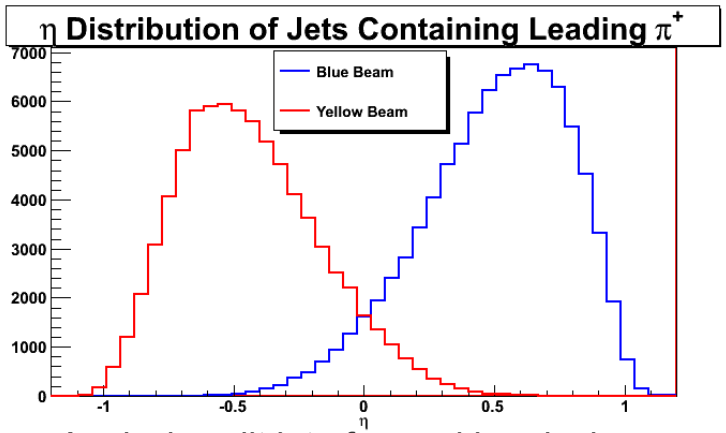


Jet Patch trigger collects data; reconstructs with Midpoint Cone Algorithm ($\Delta R < 0.7$)

- arXiv:hep-ex/0005012



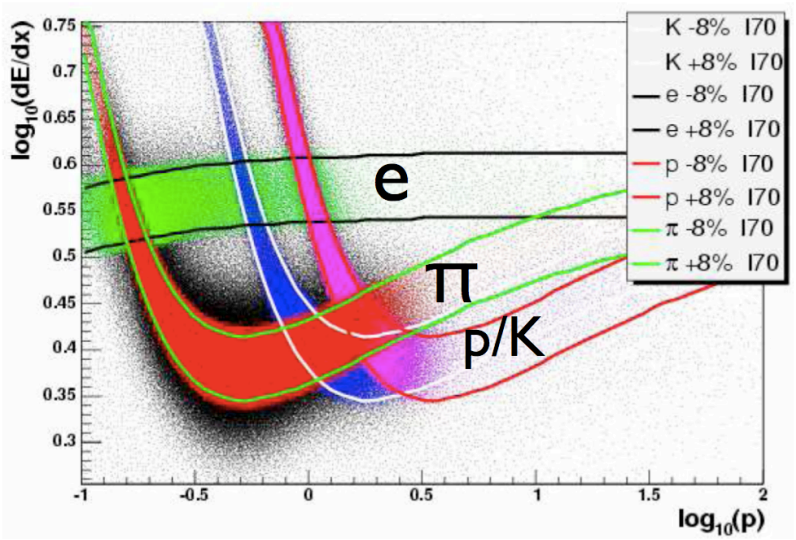
10 GeV p_T cut reduces gluon contribution



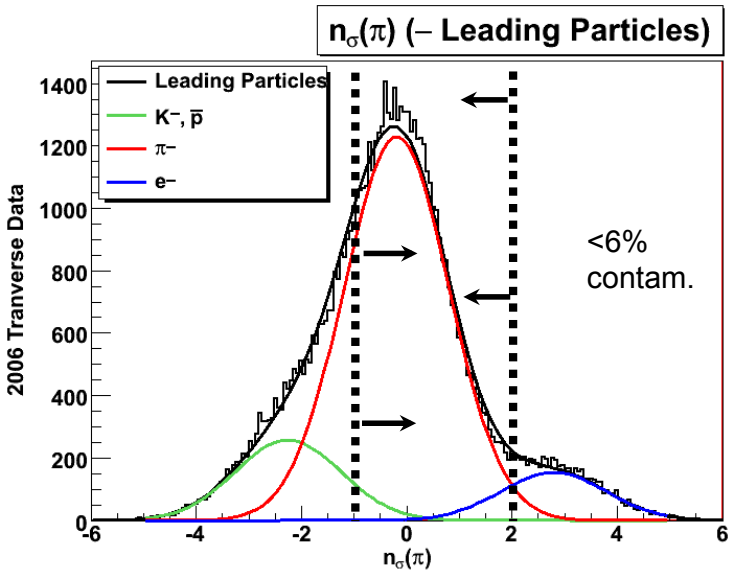
Analysis split into forward hemispheres to maximize partonic spin transfer

$\pi^{\pm}$ identification and preliminary results

TPC dE/dx isolates charged pions

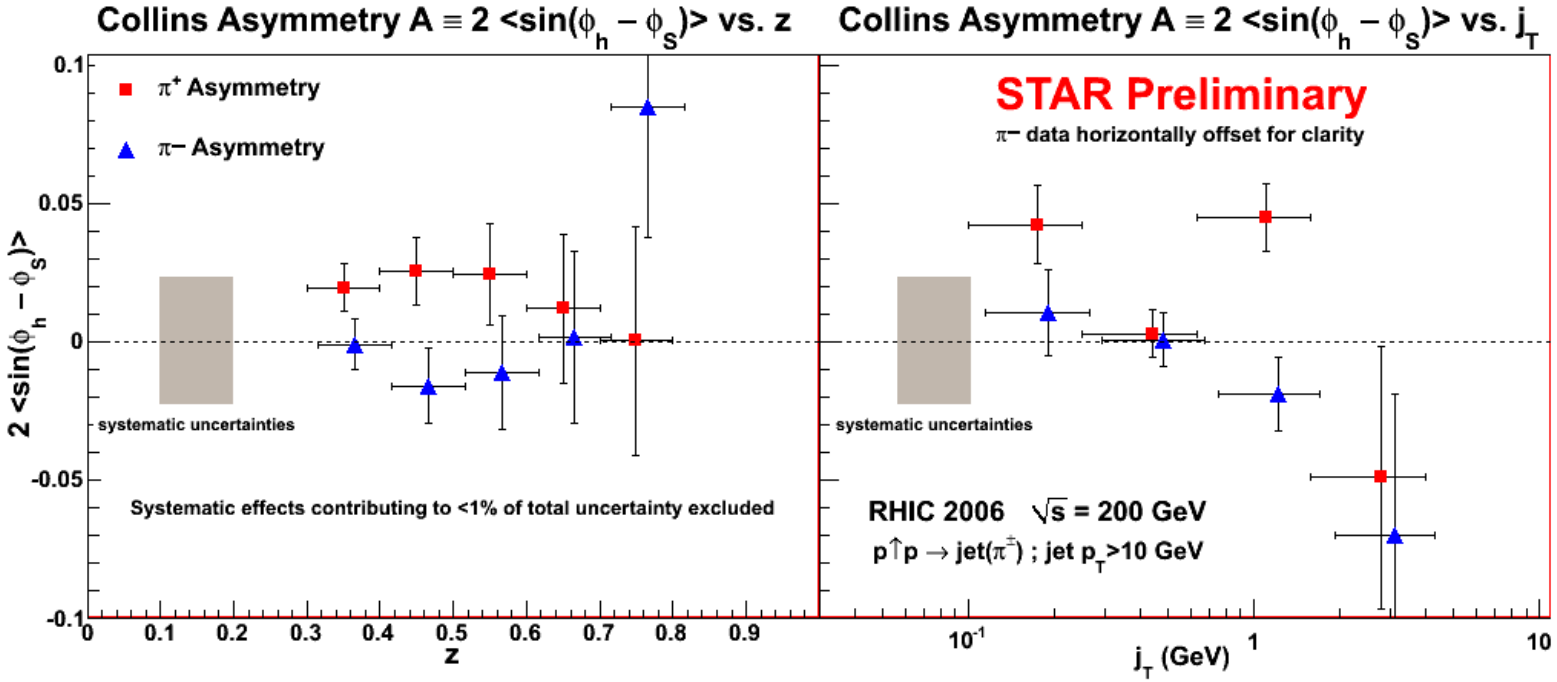


Nucl.Instrum.Meth.A558:419-429,2006



-1 < $n_\sigma(\pi)$ < 2 cut removes contamination

- Require $\pi^{\pm}$ to be leading particle in jet
- At z (p_π/p_{jet}) >0.3 sample is nearly inclusive (90% of pions are leading)



- Systematic uncertainty limit given by ΔA ≡ A(detector) – A(MonteCarlo)
- Results tentatively show asymmetries with opposite signs for opposite charge

Conclusions

Forward rapidity

• Data shows agreement with the simulated sample of events for the jet-like event sample

• The events have been shown to be “jetty”

• The jet-like γ angle was found and compares well in data/simulations. The magnitude of k_T is in domain of TMD fragmentation

• The systematics of the jet-like object model have been explored and no special point in the parameter space was selected

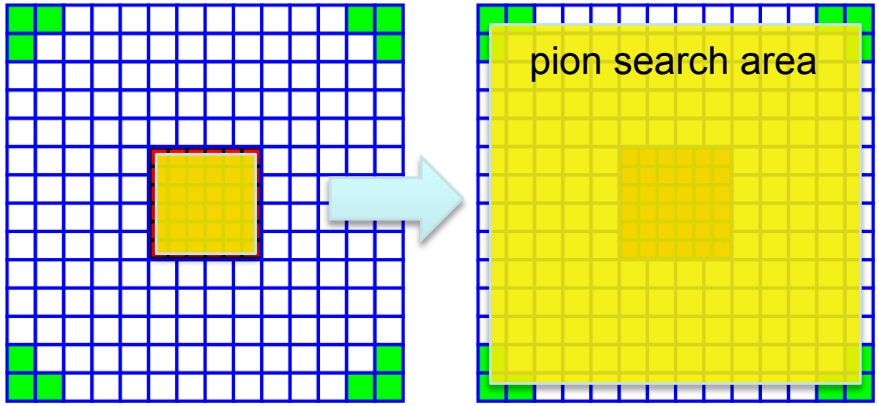
• The calculated positive x_F asymmetry is greater than zero (av. of 0.031, as in the published RUN6 result) and doesn’t show any Collins contributions

Mid-rapidity

• Jet reconstruction selects mostly quark jets. At z>0.3 the sample is nearly inclusive (90 % of pions are leading)

• The asymmetries, although limited at low (high) z by systematic (statistical) errors, flip sign for oppositely charged pions

Outlook



Forward rapidity

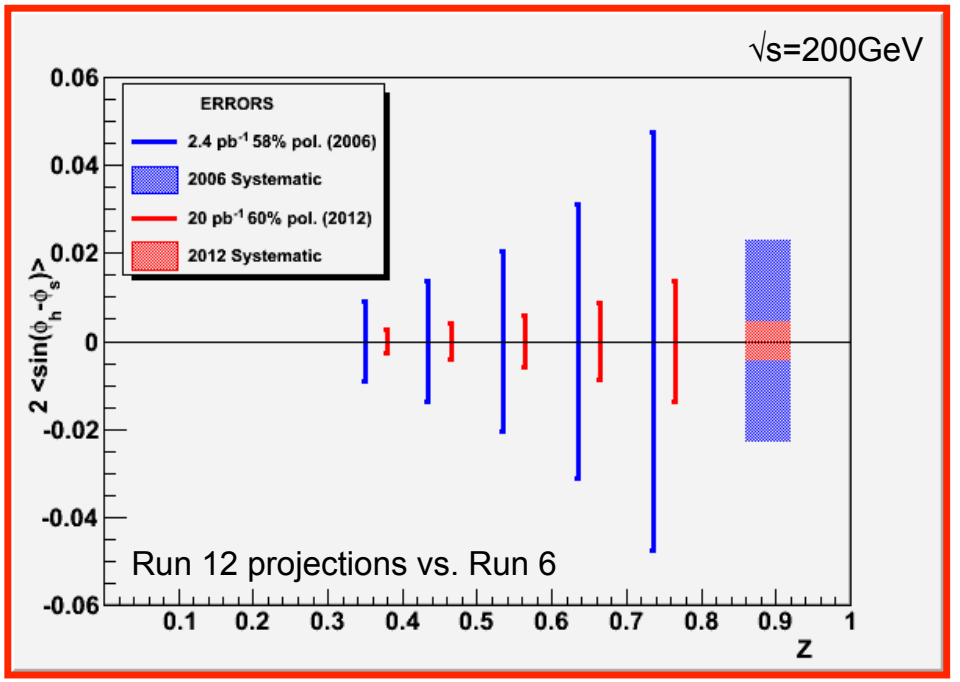
• Open up the neutral pion acceptance from small cells to entire calorimeter module, thereby increasing statistics and further addressing the gamma distribution shape

• Explore biases in k_T determination

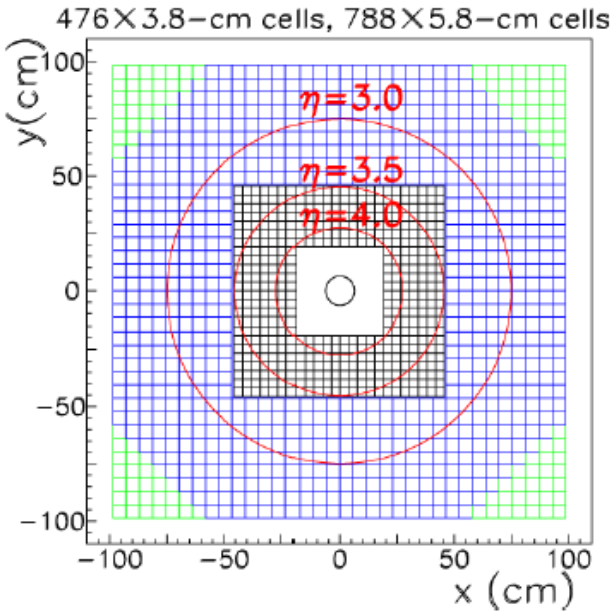
Mid-rapidity

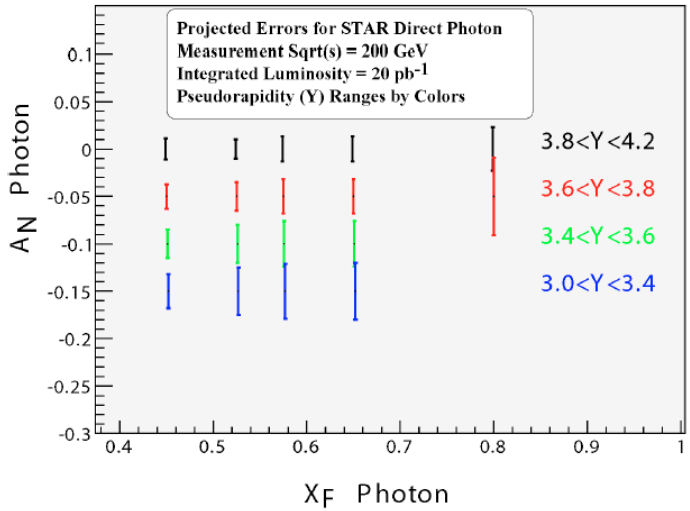
• Improve uncertainties with inclusion of additional simulation statistics and new analysis methods

• Look at data taken in 2012 – decrease systematics and increase statistics



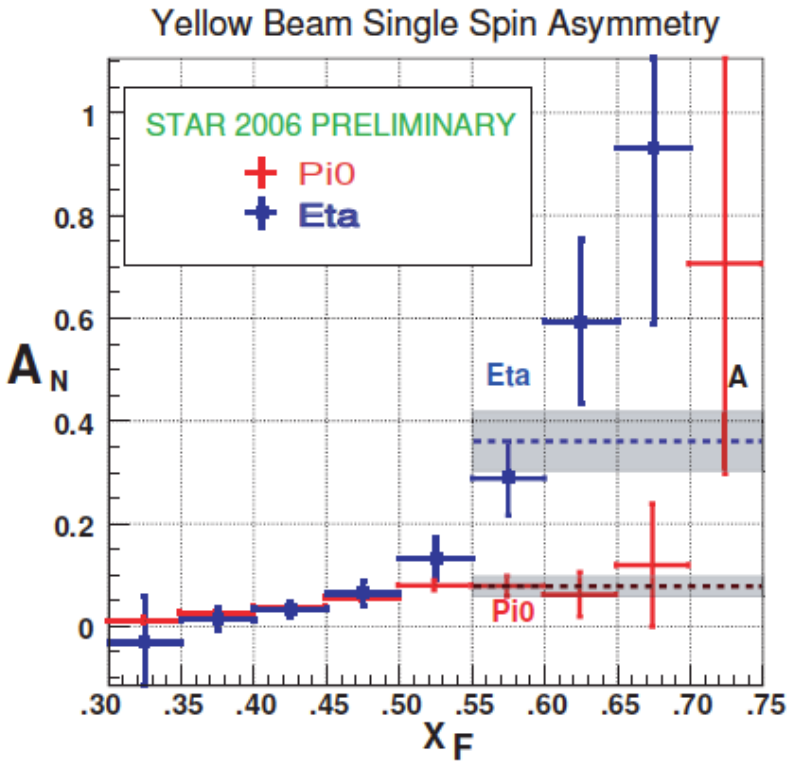
Thank you!





FMS

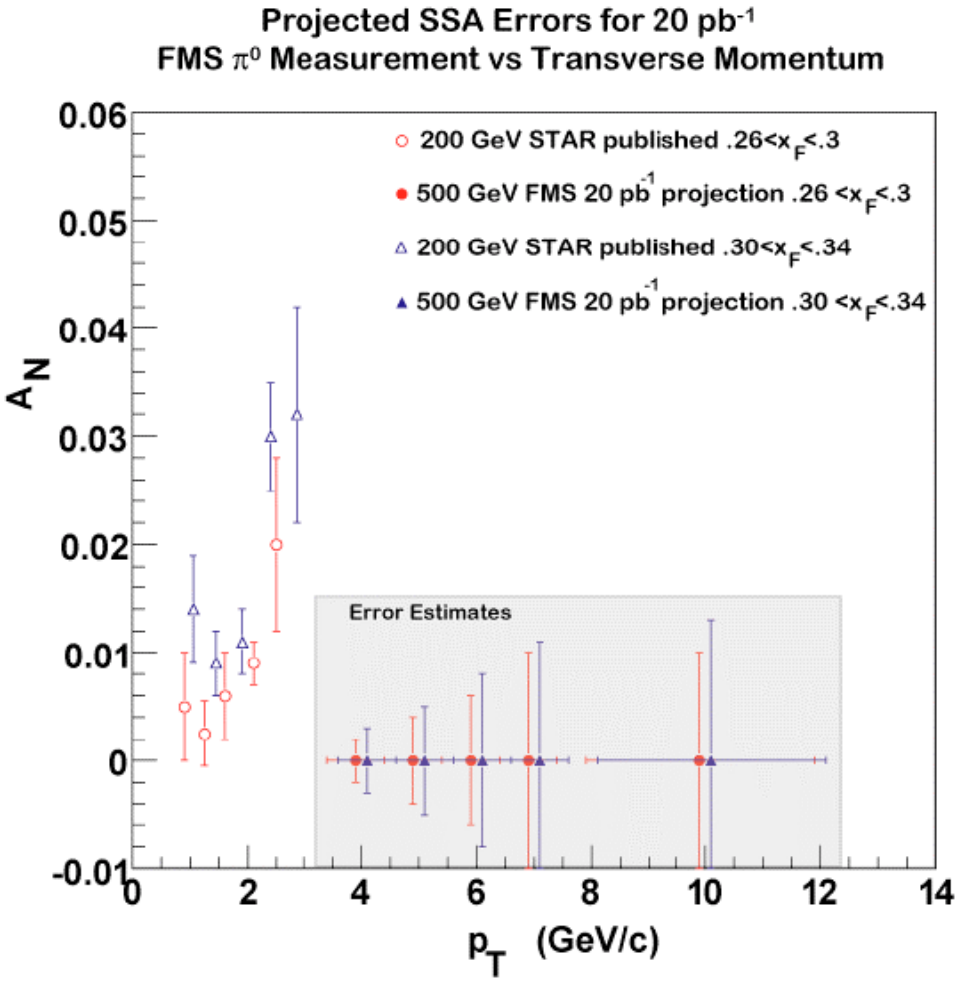
- Ongoing and future work on neutral pions, eta mesons and single gammas

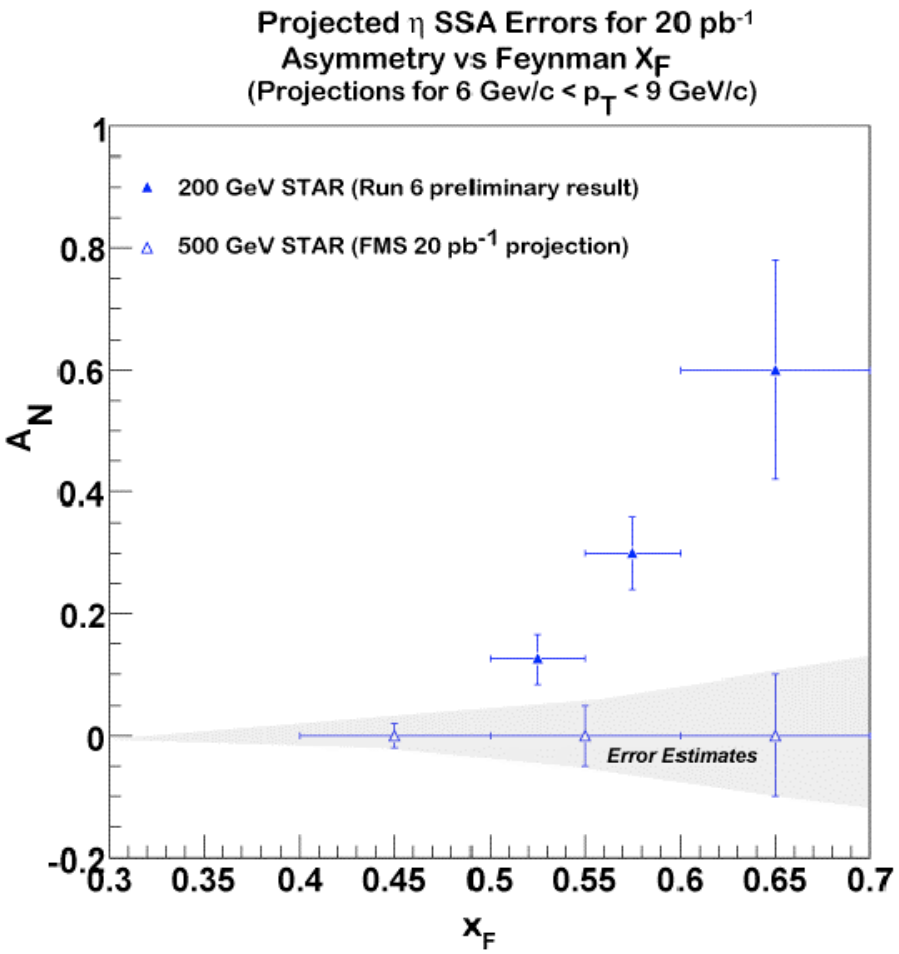


Eta analysis (FPD 2006)

- measurement of asymmetry as a function of x_F
- determination of eta cross section and the ration of eta/pion cross sections

2011 500GeV projections - FMS





- projected 20 pb^{-1} at 60% polarization; measured 22 pb^{-1} at 50% polarization
- measure transverse spin asymmetries and their scaling properties in x_F, p_T and $\sqrt{s}$
- look at pions and eta mesons