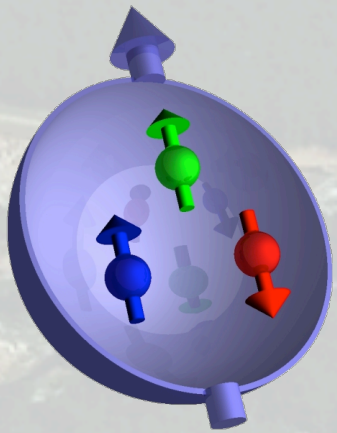
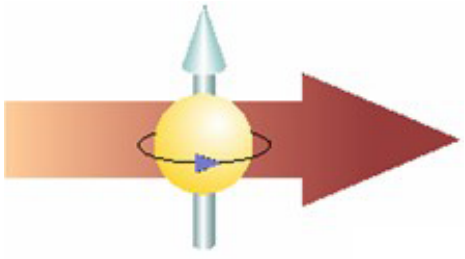
Forward jet-like event spin-dependent properties in polarized p+p collisions at $\sqrt{s}$ = 200 GeV



Nikola Poljak for the STAR collaboration
University of Zagreb
28.7.2011.

Proton transverse spin decomposition



For a proton with transverse spin vector $\vec{s}_T$

PRD 70 (2004) 114001

$$\frac{1}{2} = \frac{1}{2}\sum_{q,\bar{q}}\int dx \Delta_T q^a(x) + \sum_{q,\bar{q},G}\left\langle L_{\vec{S}_T}\right\rangle^a$$

Sivers DF

Collins FF from Belle

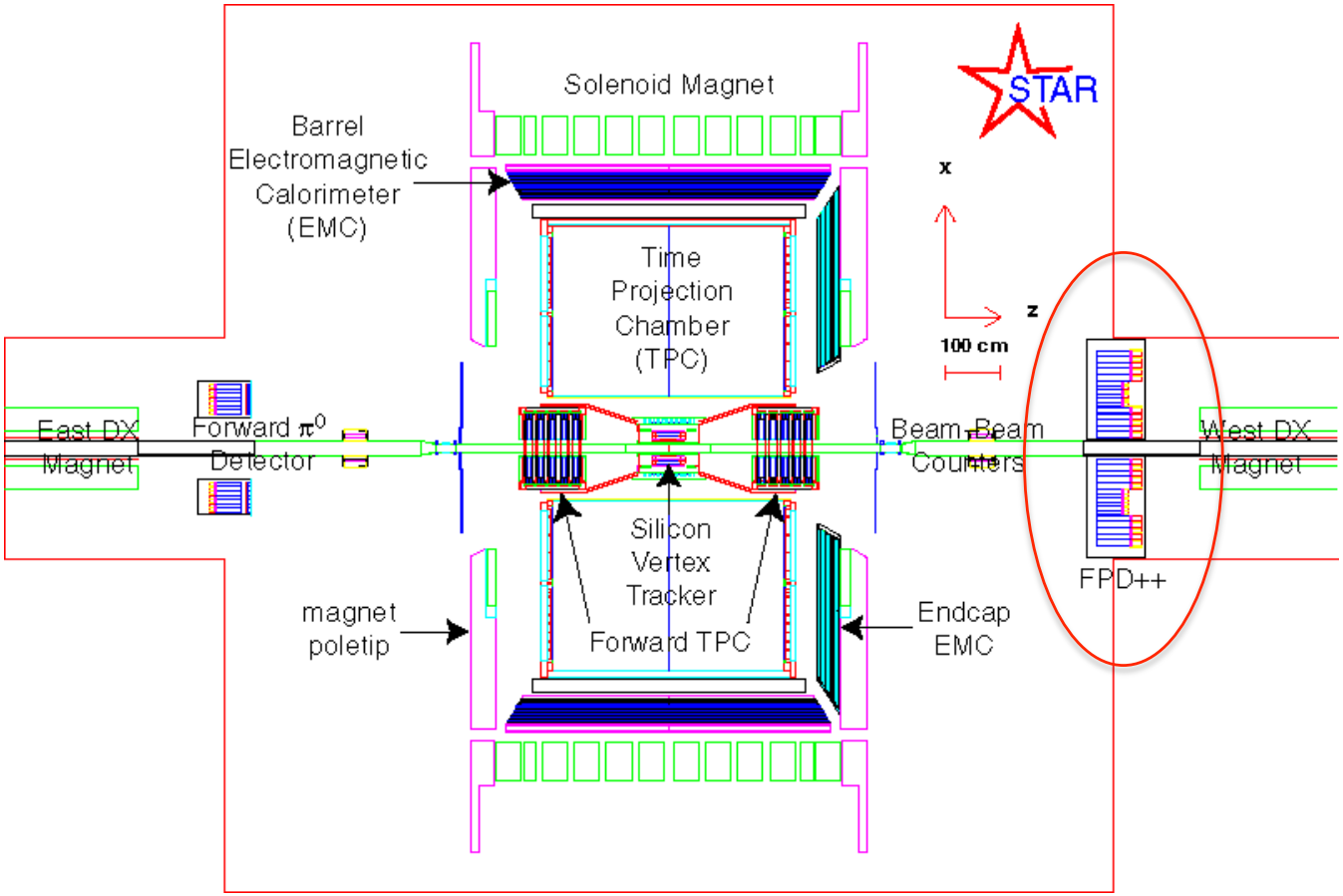
SI-DIS & RHIC Spin

$L_{\vec{S}_T}$ component of partonic orbital angular momentum *L* along $\vec{s}_T$

$\Delta_T q^a(x)$ quark transversity distribution in the nucleon

Understanding the origin of proton spin helps to understand its structure.

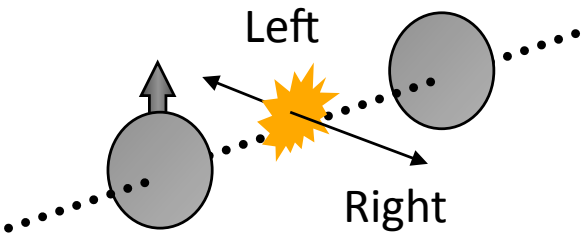
Done at RHIC – STAR 2006 configuration



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

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:

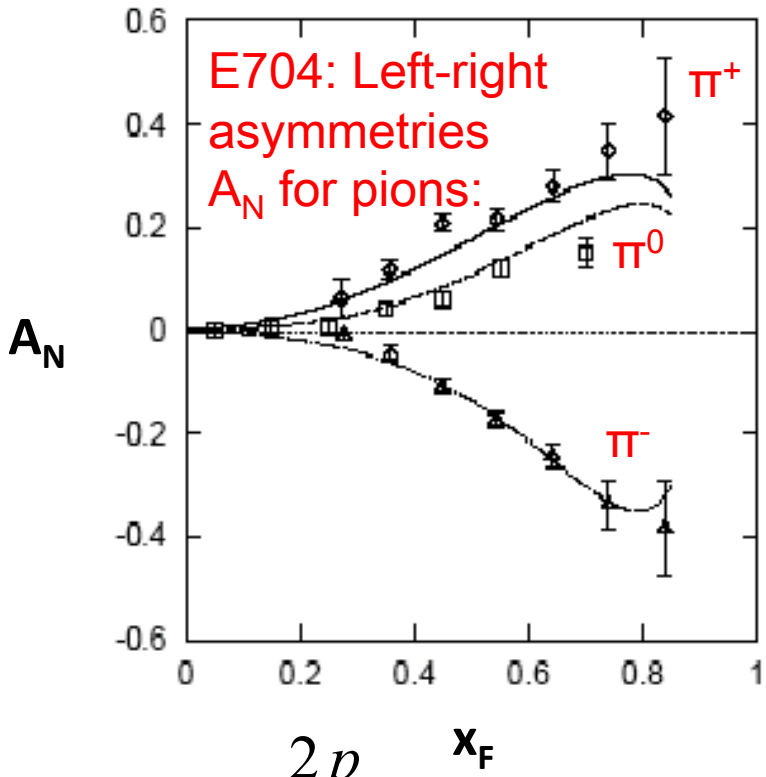
(E704, Fermi National Laboratory

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

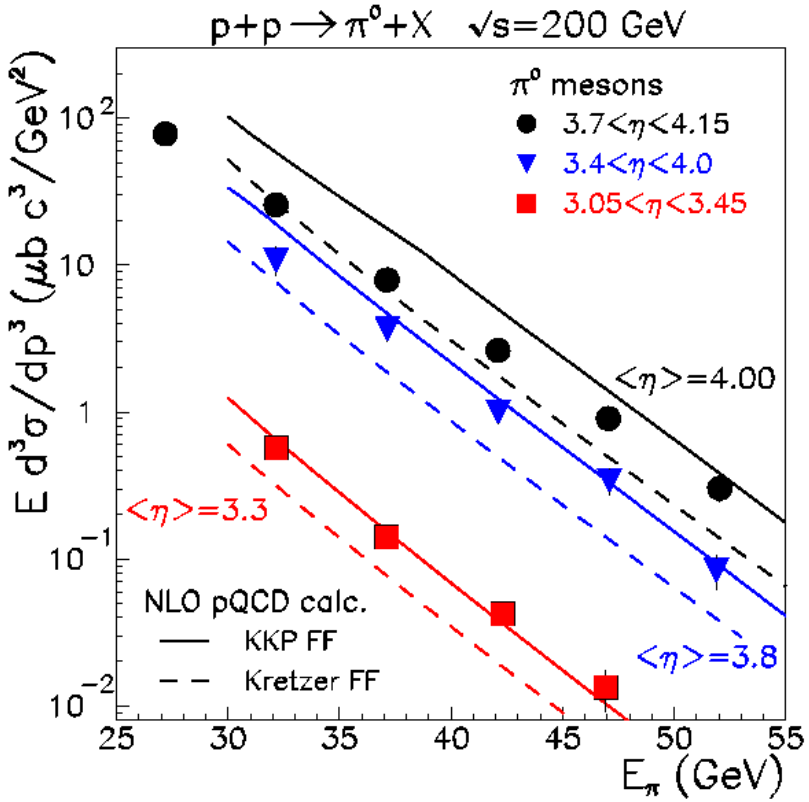


$$x_F = \frac{2p_L}{\sqrt{s}}$$

Published precision measurements - A_N

PRL 97, 152302 (2006)

nucl-ex/0602011

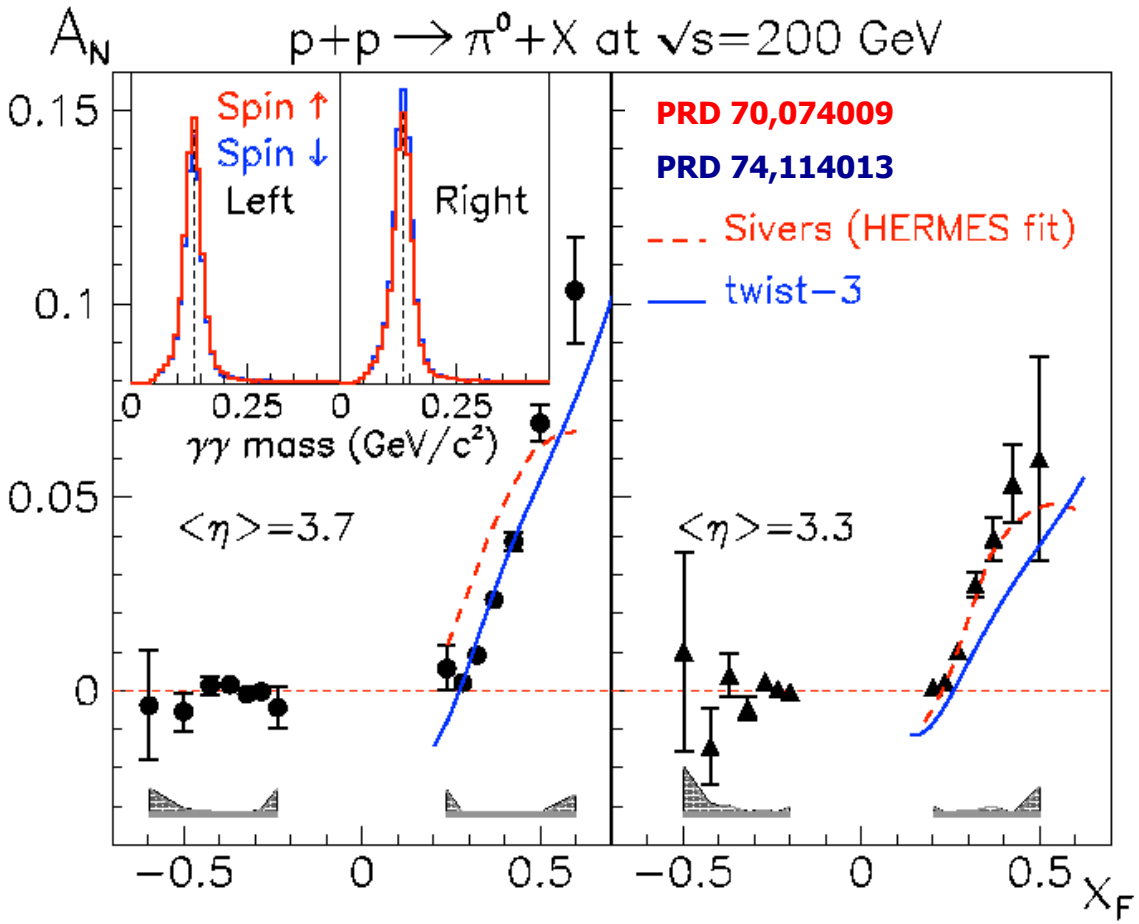


At this energy the cross-section is consistent with NLO pQCD (run2 + run3) and included in global fits on fragmentation functions
Phys.Rev. D75: 114010, 2007

Published precision measurements - A_N

RUN6 : PRL 101 (222001)

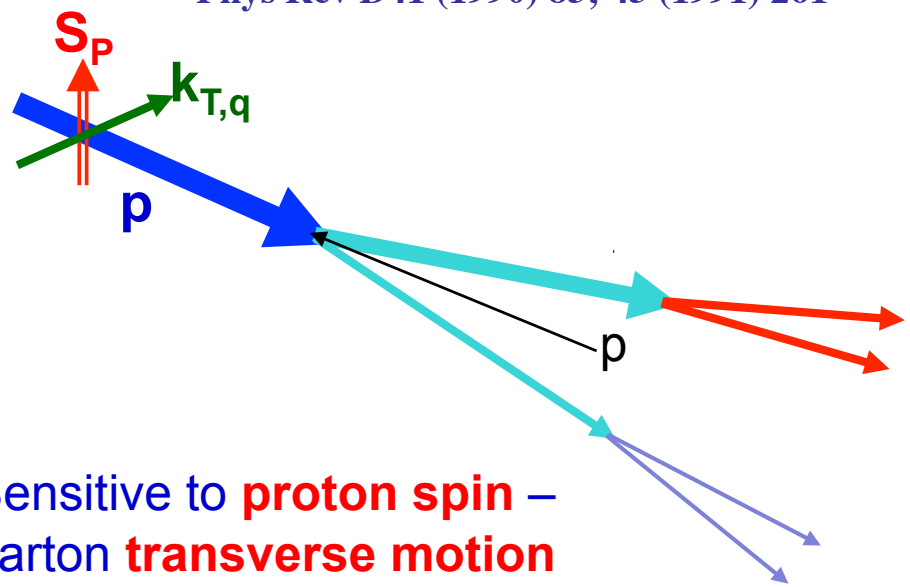
- Large transverse single-spin asymmetries at large x_F
- x_F dependence matches Sivers effect expectations qualitatively (under current study by theory)
- Obtained with the FPD and FPD++ modules



Separating Sivers and Collins effects

Sivers mechanism: asymmetry in the forward jet or γ production

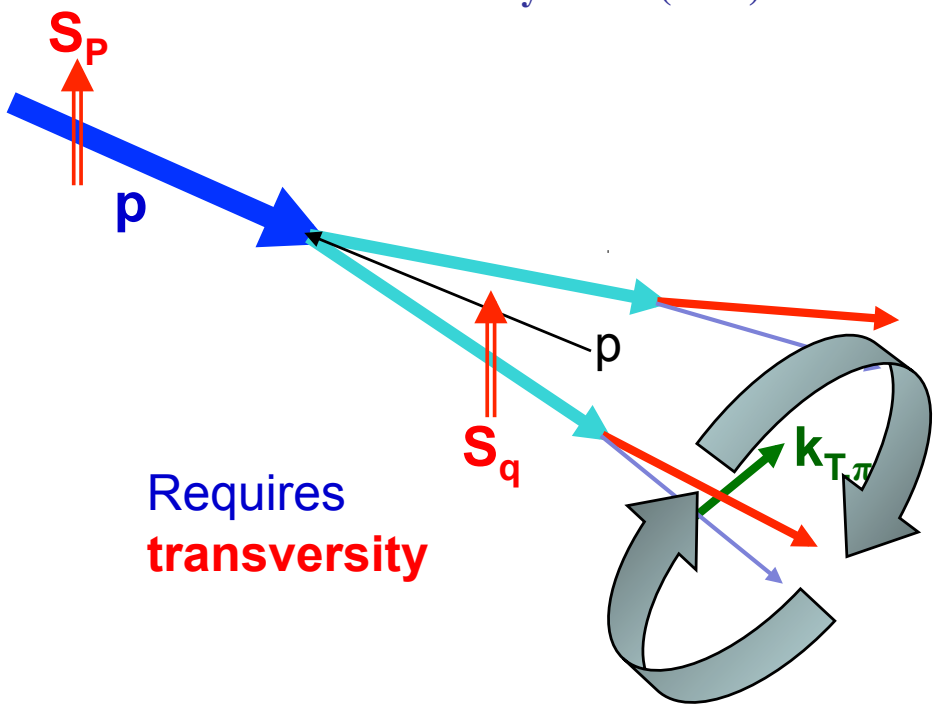
Phys Rev D41 (1990) 83; 43 (1991) 261



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

Collins mechanism: asymmetry in the forward jet fragmentation

Nucl Phys B396 (1993) 161



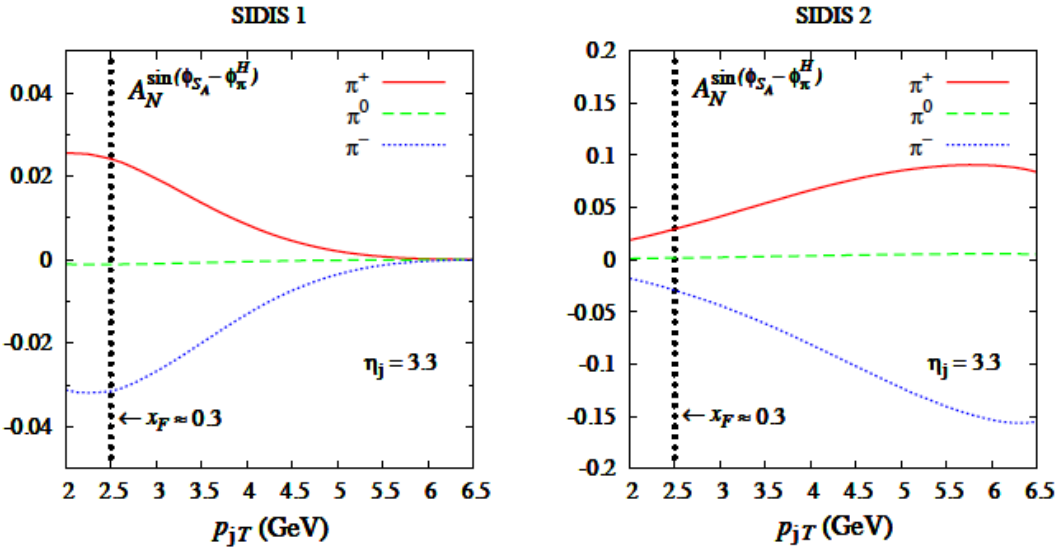
Requires **transversity**

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

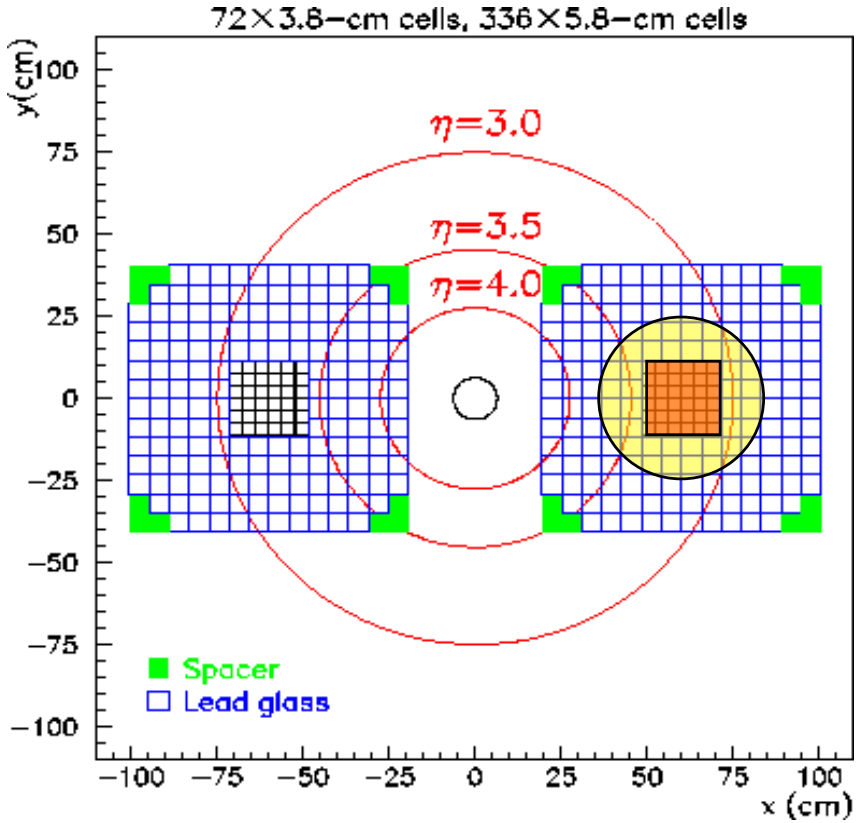
Motivation and idea

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 detector with explicit azimuthal symmetry

Detector calibration

Small cells:
Calibration done on hardware level
(cell-by-cell)
energy and time-dependent corrections

Calibration is known at the level of 2%

Event selection done with:

minbias condition

summed energy threshold

$(25/15\ GeV\ \ for\ the\ East/West\ \ FPD)$

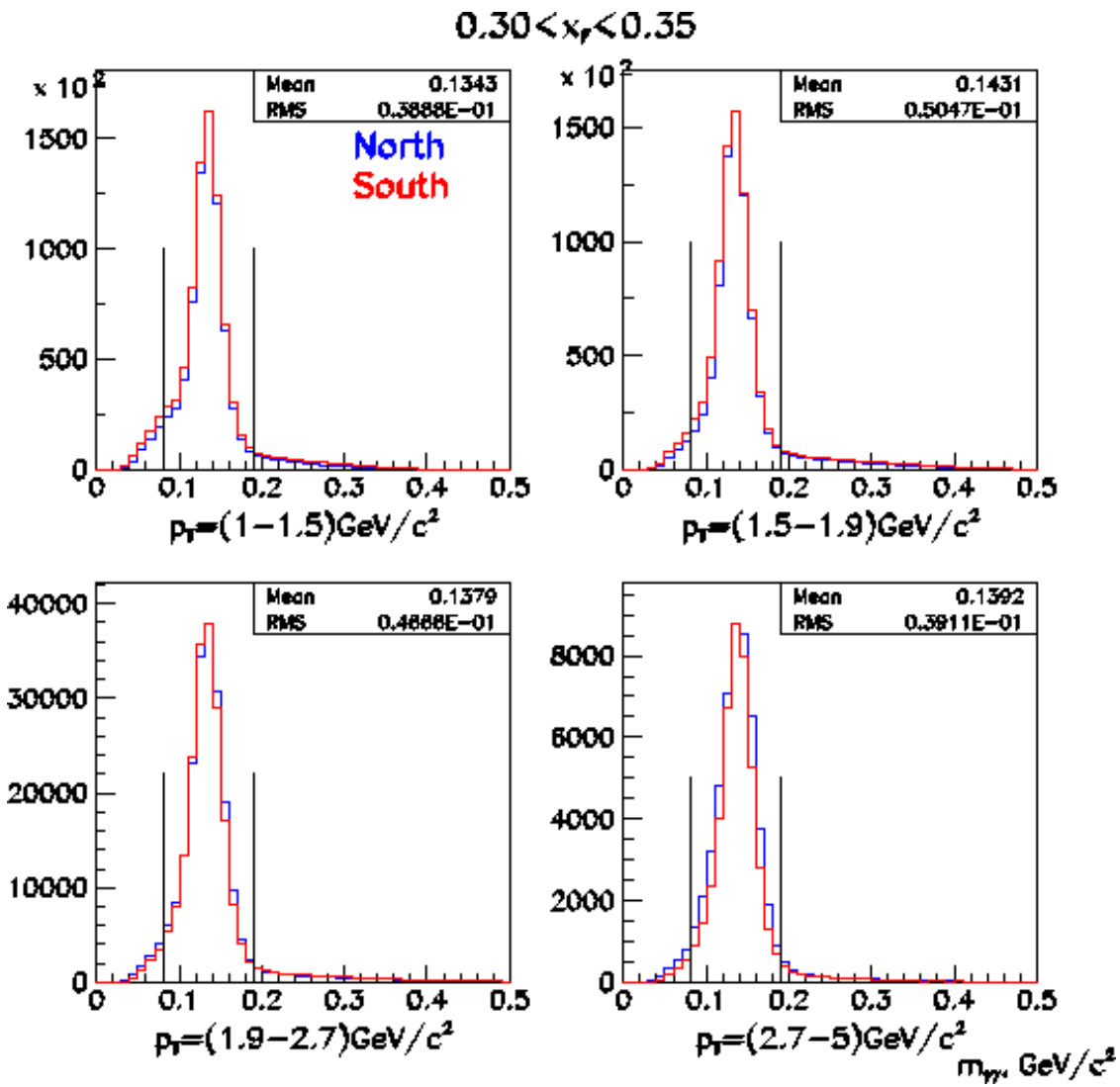
$N_\gamma = 2$

$z_{\gamma\gamma} = |E_{\gamma 1} - E_{\gamma 2}|/(E_{\gamma 1} + E_{\gamma 2}) < 0.7$

fiducial volume cut $(0.5\ cell)$

$0.08 < m_{\gamma\gamma} < 0.19\ GeV/c^2$

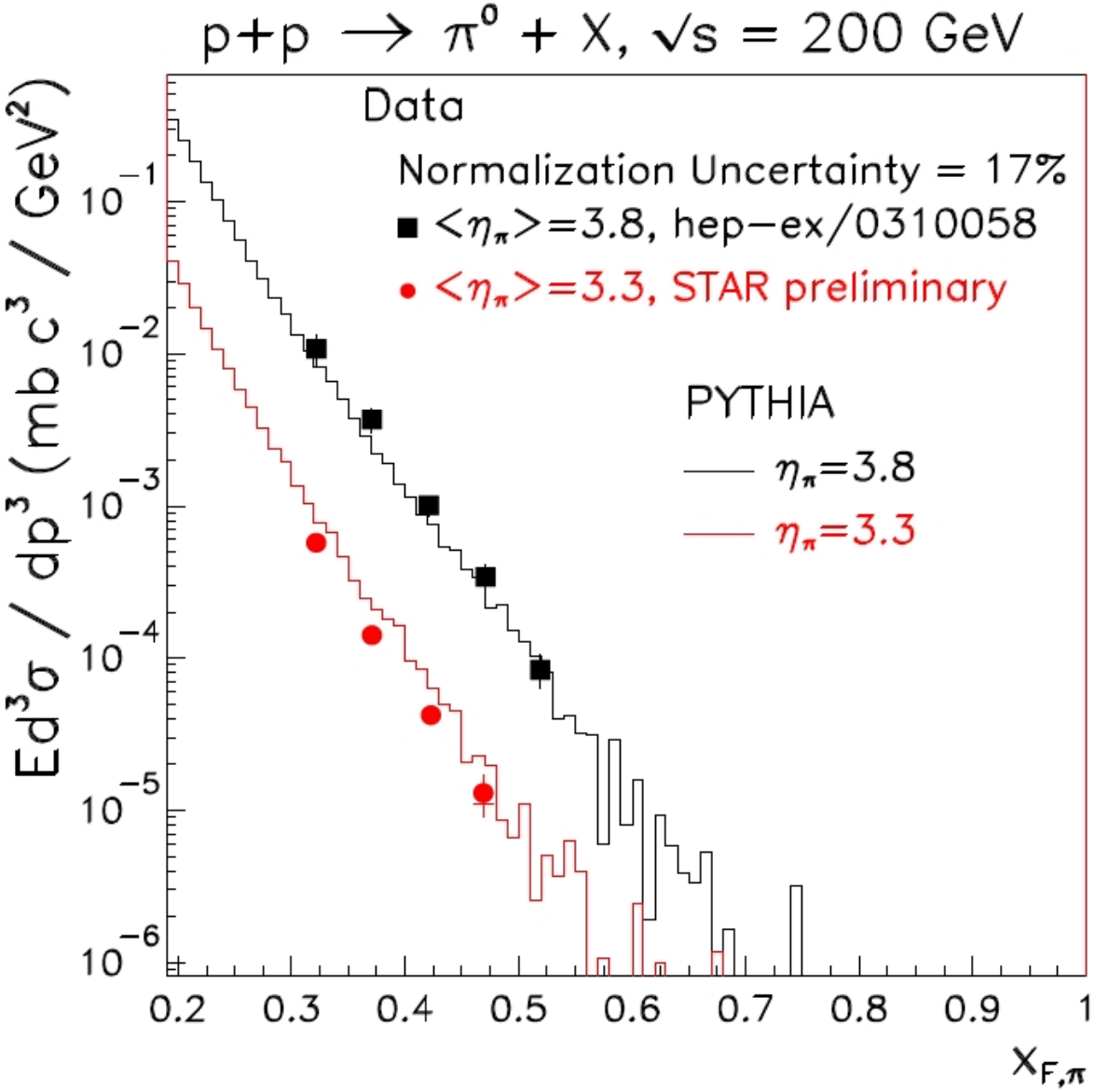
Large cells:
Energy deposition slope calibration before the procedure outlined here due to the detector trigger



Simulation sample

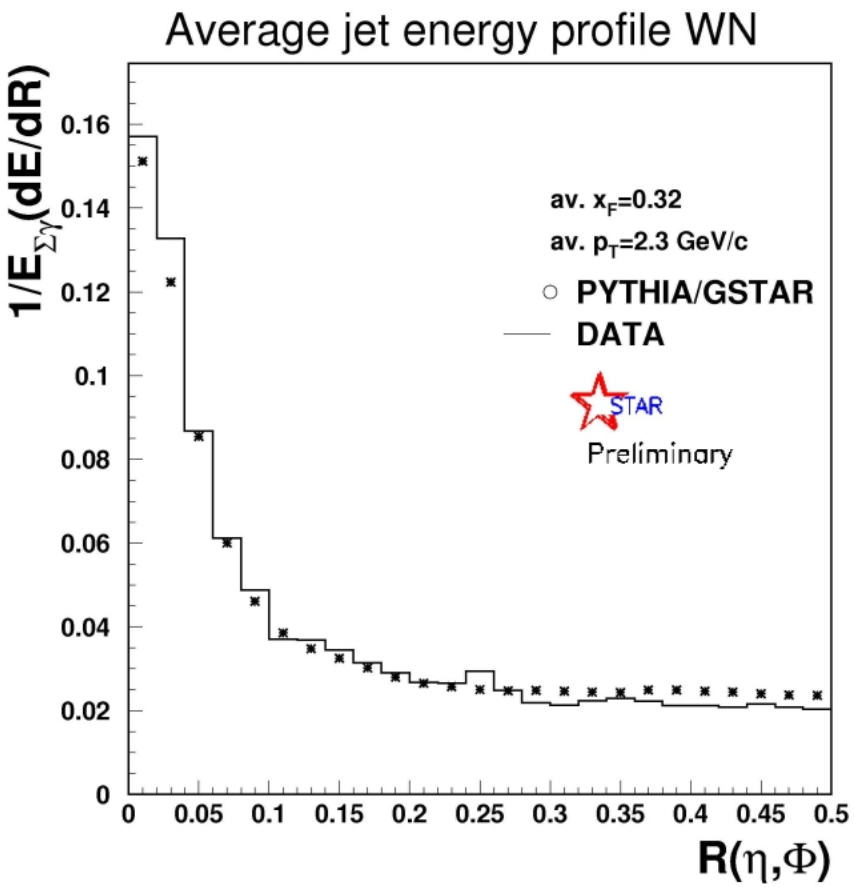
- Full PYTHIA/GEANT simulations
- Energy deposition computed by GEANT is ''digitized''
- Pseudodata is run through the exact same algorithms as the data
- Used PYTHIA 6.222 that predates tunings related to "underlying event" for midrapidity Tevatron data. These tunings impact forward production at RHIC energies
- Cross sections in PYTHIA/data agree well

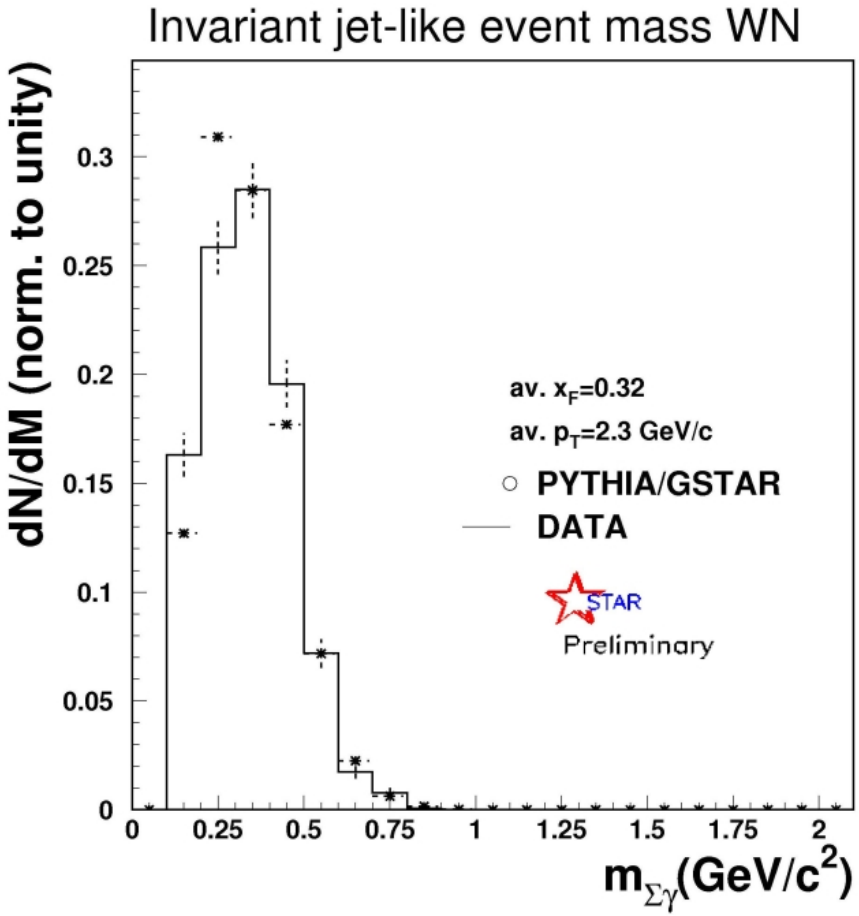
arXiv:hep-ex/0403012



“jet-like” events selection and results

≥4 towers with E ≥ 0.4GeV, 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



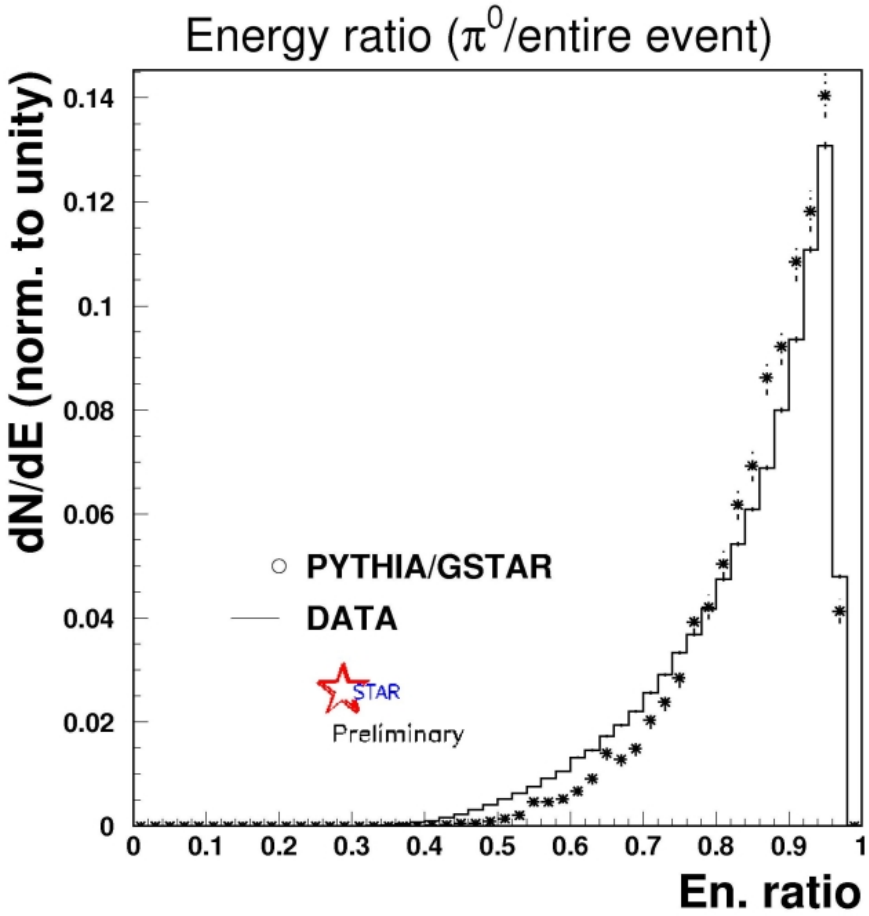


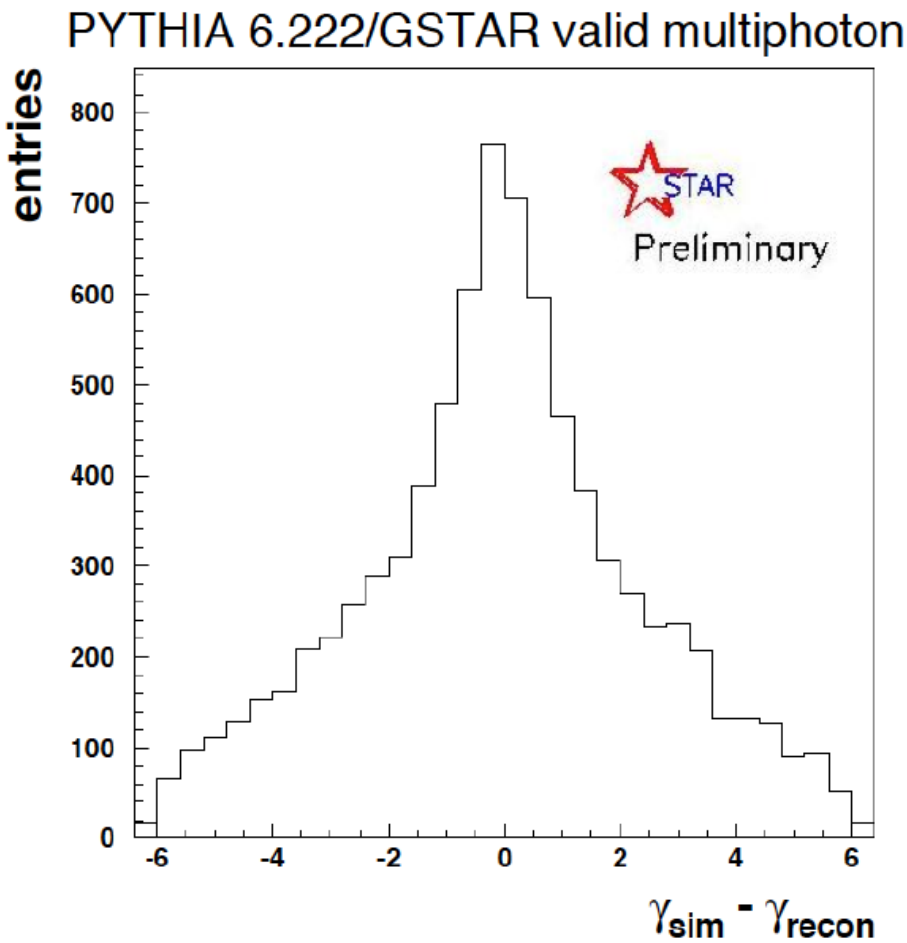
Simulations set up to mimic the data small cell module energy trigger

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" event?



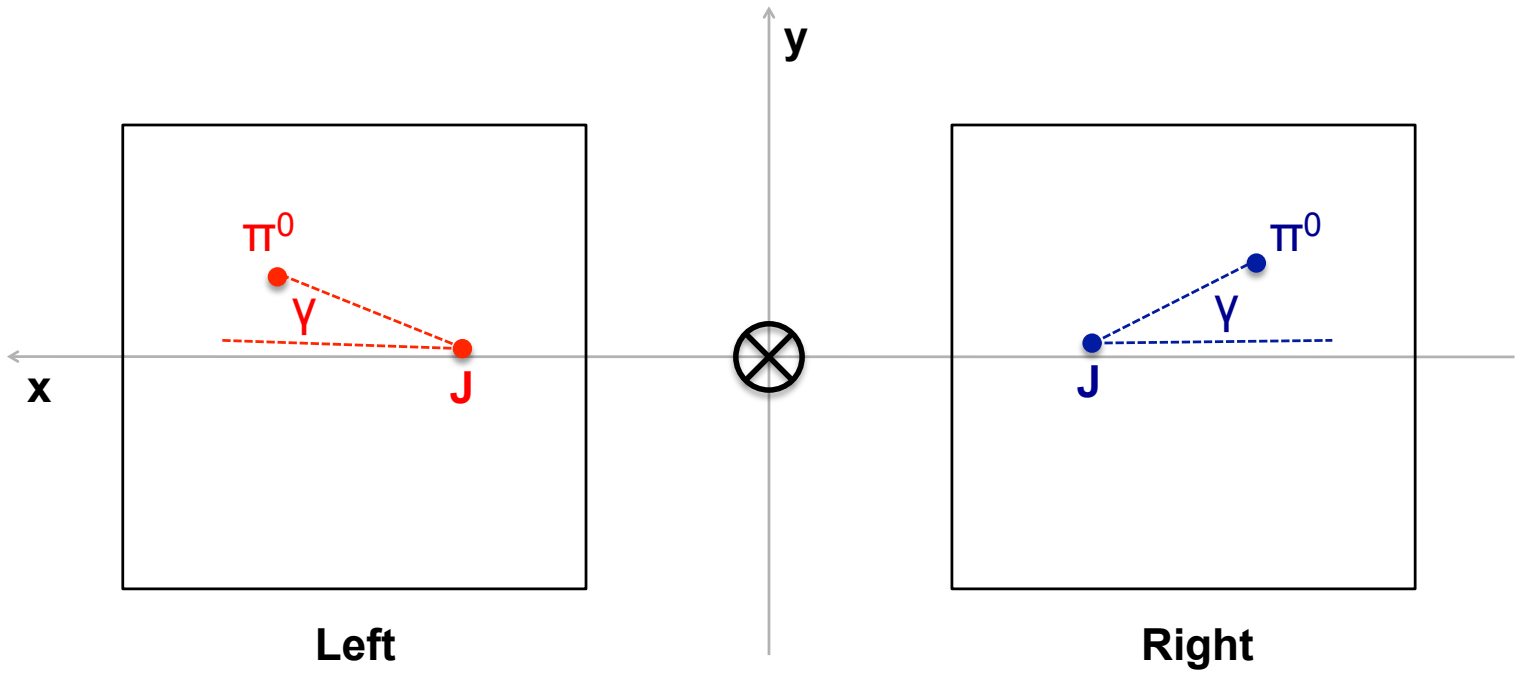


"jet-like" events reconstructed from simulation are found to be associated with a hard-scattered or a radiated parton. The "jet-event" axis agrees well with the direction of the parton. On average, there are 2.5 fragmenting mesons per one event, making them reasonably "jetty".

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

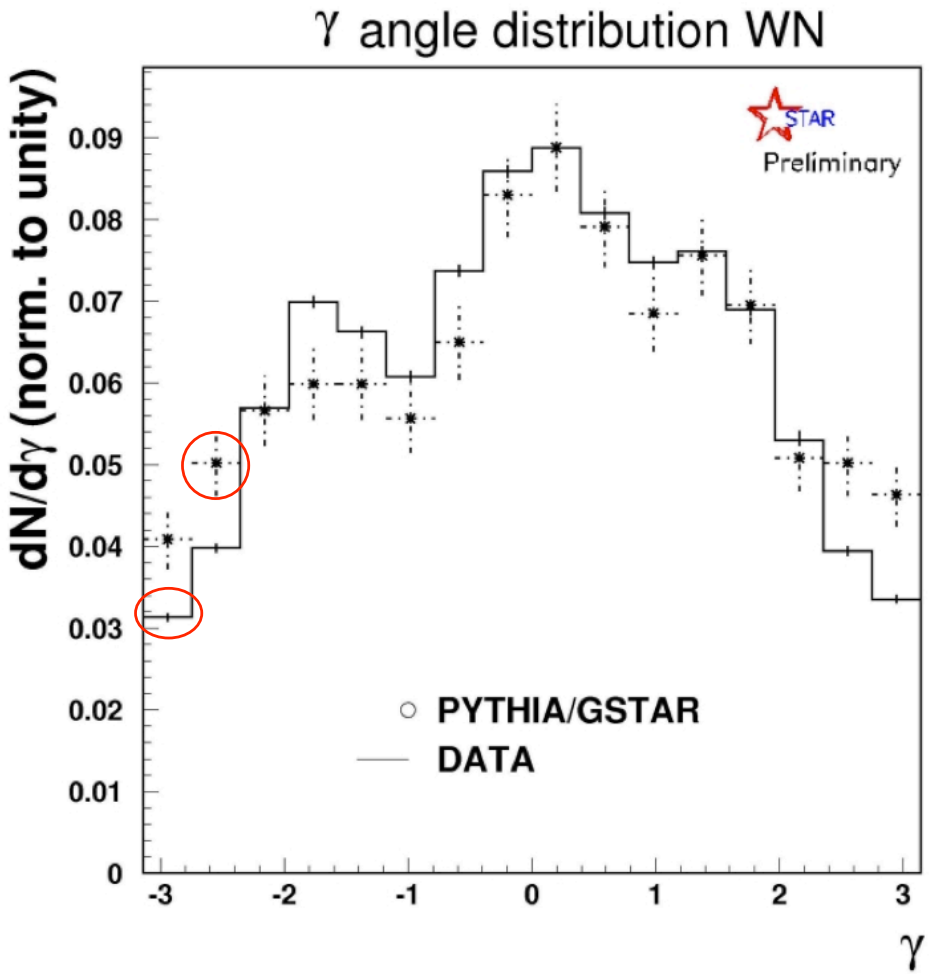
$$A_N f(\gamma) = \frac{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} - \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} + \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}$$

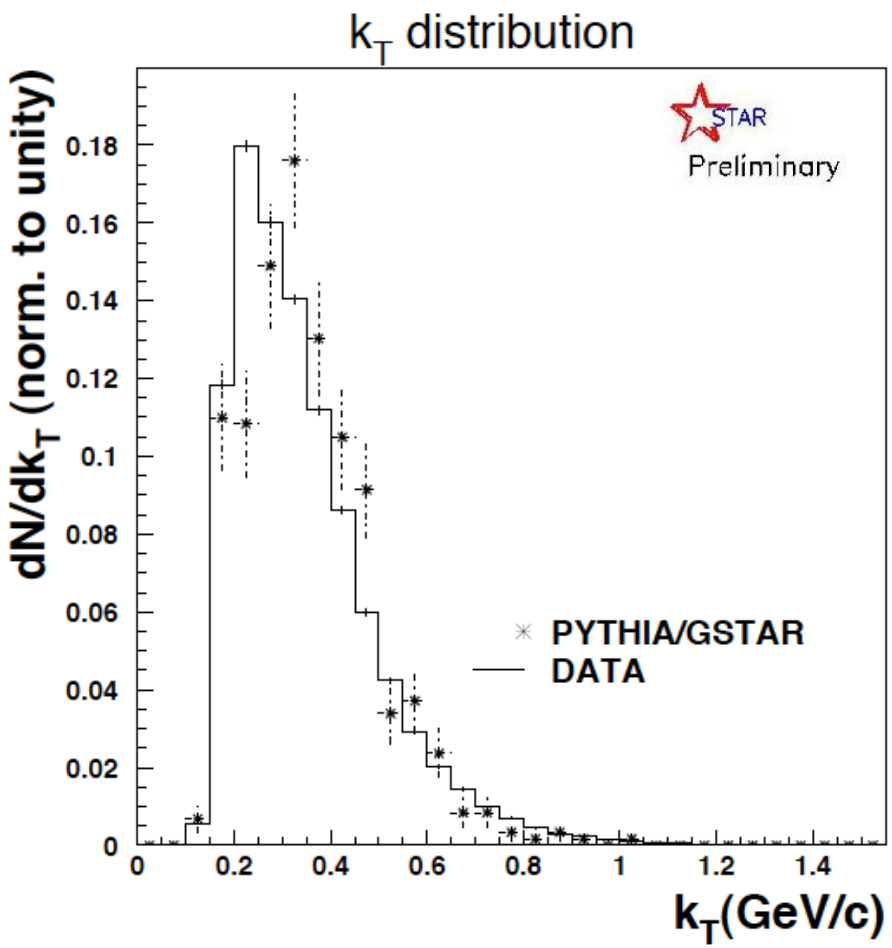


By forming the geometric mean in each term, the detector effects are minimized. For the Sivers effect, the asymmetry does not depend on the cos(γ) bin. The slope of the asymmetry as a function of cos(γ) is a signal of the Collins effect.

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 event axis (k_T) was found in data and simulations

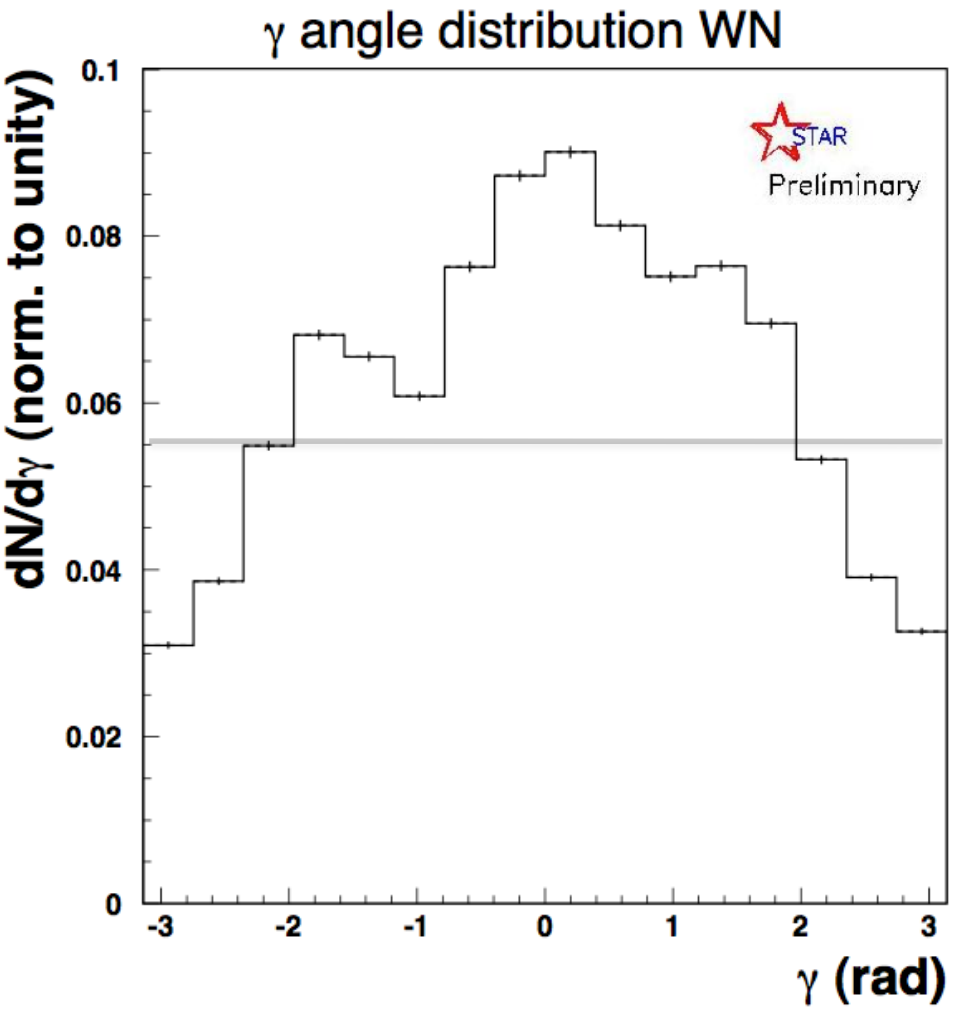


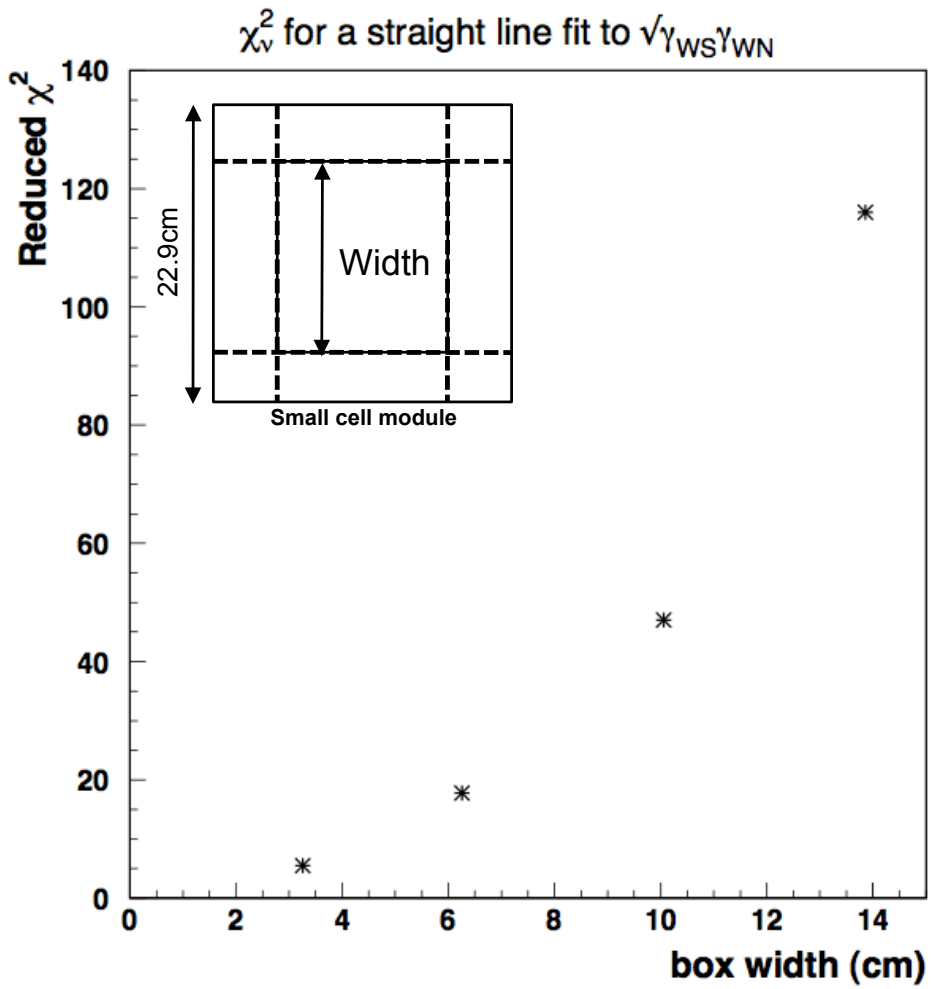


The jet-like γ distributions show agreement in data and simulations. The magnitude of k_T is in the domain of TMD fragmentation.

Why isn't the γ distribution uniform?

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

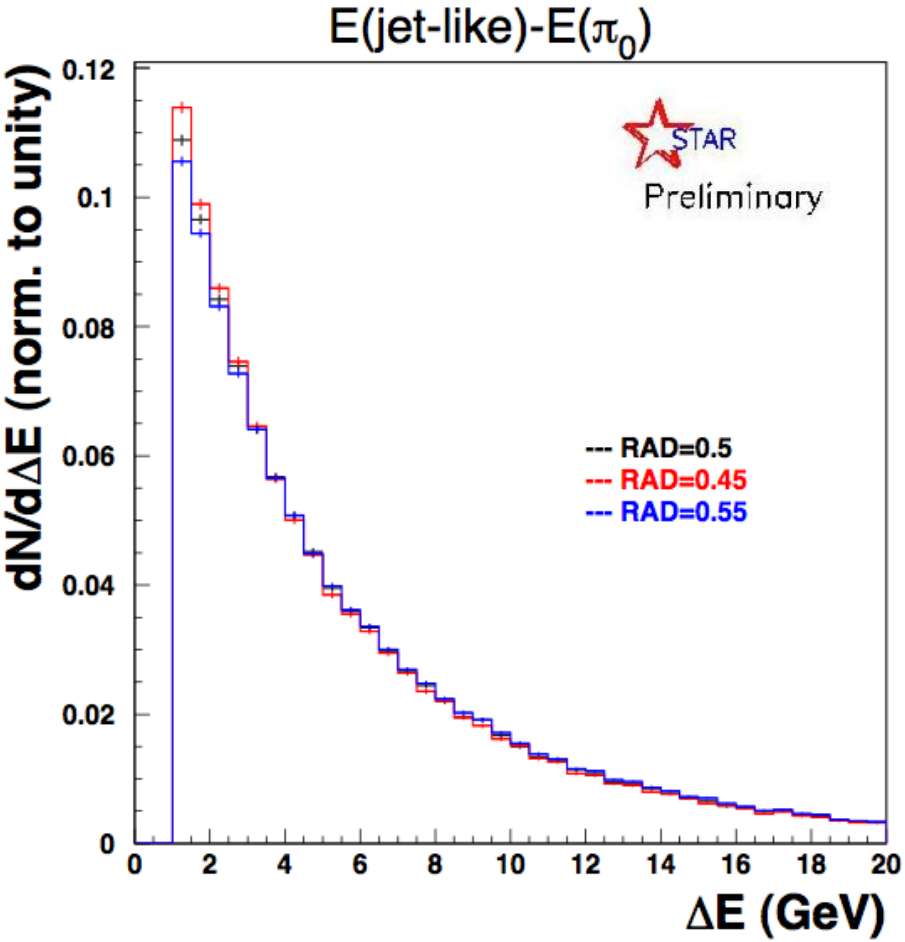


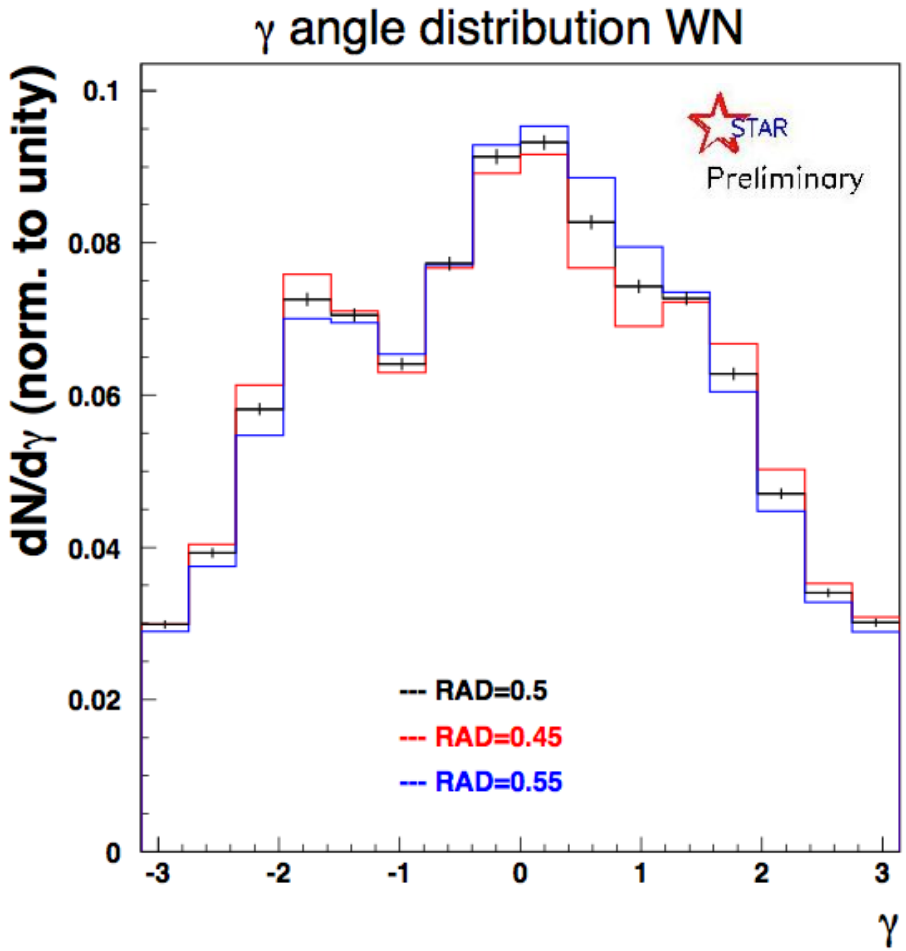


By restricting the jet-like event axis closer to the detector center, the distribution expectedly flattens.

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

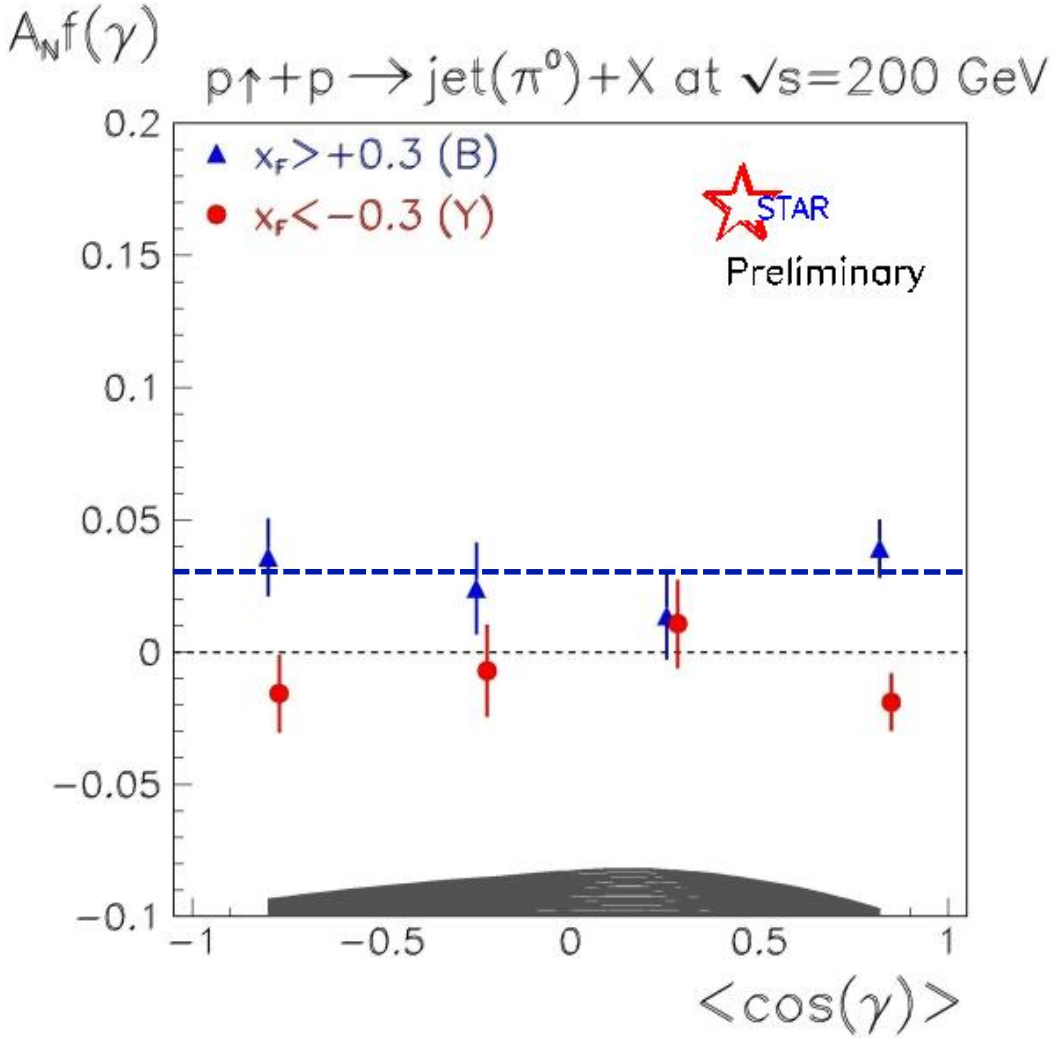




The results show that no special point in the parameter space has been selected and the systematic effects are small. The data follow the same trends as the simulations.

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.

Conclusions and outlook

- Data shows reasonable 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 event model have been explored and have shown 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
- open up acceptance for pions to large cells - increasing the statistics and further addressing the question of the gamma distribution shape
- pursue possible biases in k_T determination

BACKUP

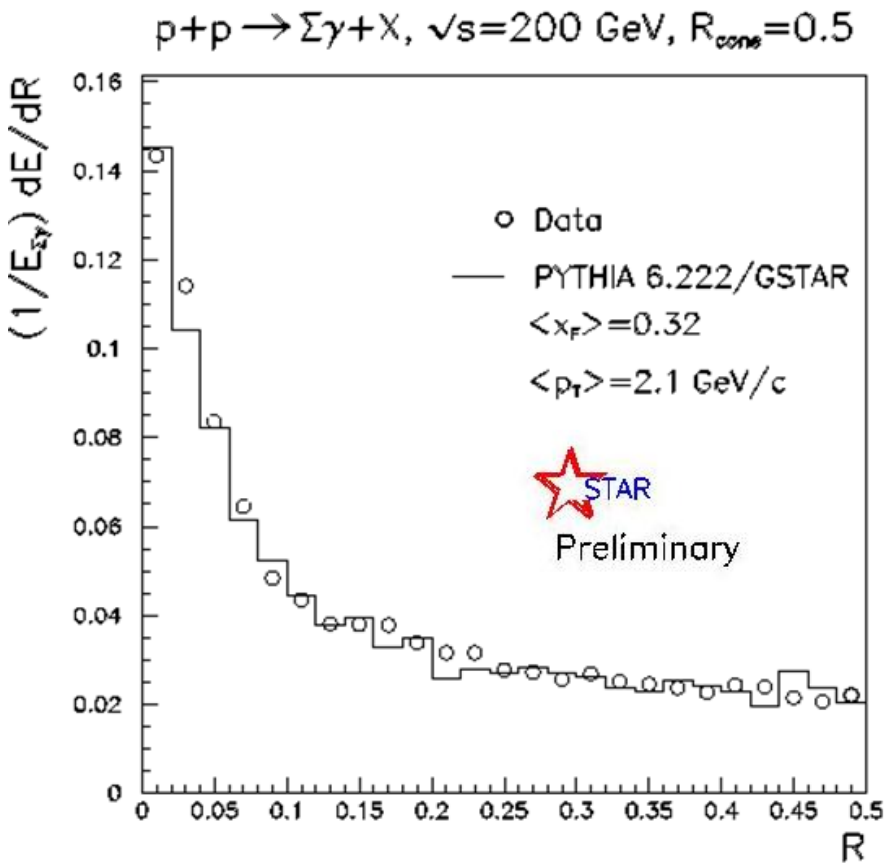
“jet-like” event measurements with the FMS

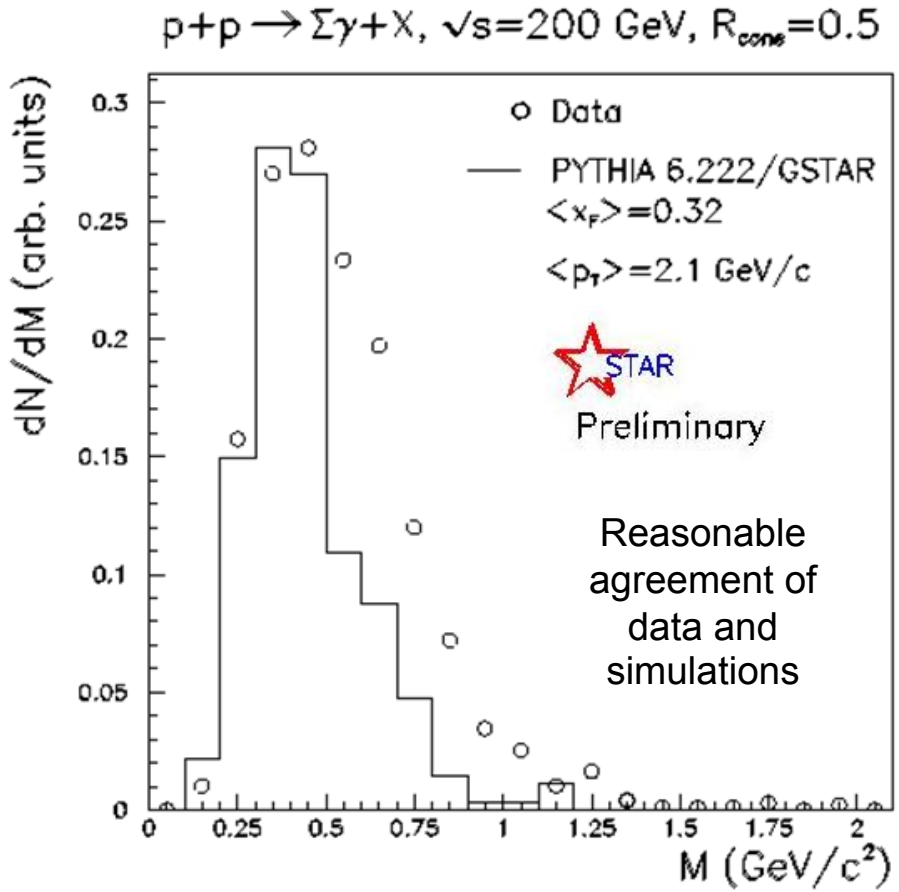
Obtained with the FMS; event selection done with:

- >15 cells with energy > 0.4GeV in the event (no single pions in the event sample)
- cone radius = 0.5 (eta-phi space)
- “Jet-like” p_T > 1 GeV/c ; x_F > 0.2
- 2 perimeter fiducial volume cut (small/large cells)

arXiV:0901.2828

N. Poljak for the STAR collaboration





Reasonable agreement of data and simulations