Azimuthal Single-Spin Asymmetries of Charged Pions in Jets in $\sqrt{s}$ = 200 GeV $p^{\uparrow}p$ Collisions at STAR

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For the STAR Collaboration

SPIN 2014 – Beijing, China
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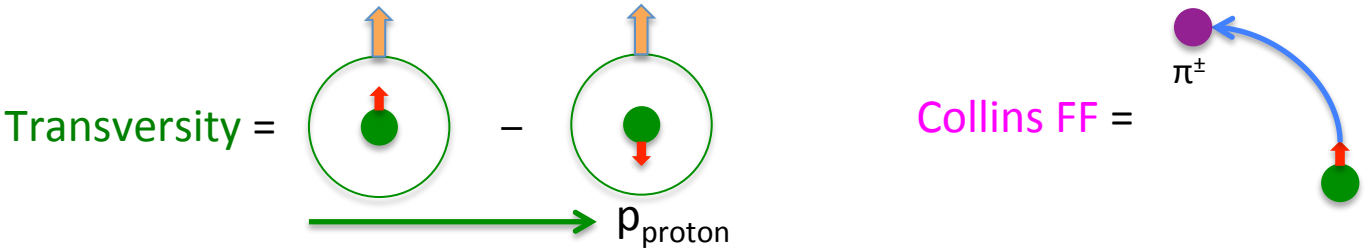
Using Jets as a Tool to Access Transversity in $p^{\uparrow}$+p Collisions

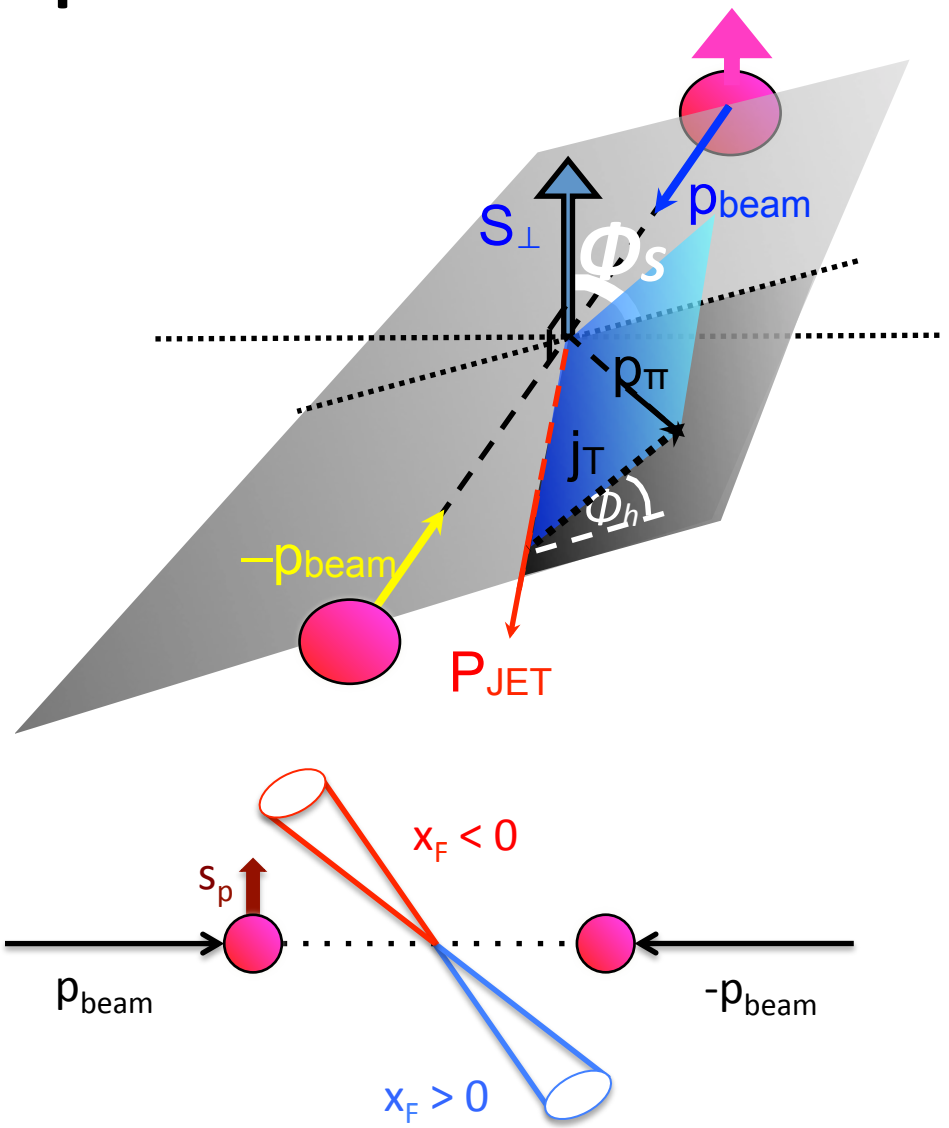


$$A_{UT}^{\pi^{\pm}} \approx \frac{h_1^{q_1}\left(x_1,Q^2\right) f_{q_2}\left(x_2,Q^2\right)\hat{\sigma}_{UT}(\hat{s},\hat{t},\hat{u})\,\Delta D_{q_1}^{\pi^{\pm}}\left(z,j_T\right)}{f_{q_1}\left(x_1,Q^2\right) f_{q_2}\left(x_2,Q^2\right)\hat{\sigma}_{UU} D_{q_1}^{\pi^{\pm}}\left(z,j_T\right)}$$

- Single-spin asymmetries in hadronic collisions may help answer these questions
  - What is the size of the factorization breaking in the x region where we overlap with SIDIS?
  - How does transversity behave at high x?
  - What can we learn about the dynamics of proton-proton scattering, given that the above yields surprising results?

Single Spin $p^{\uparrow}p$ Collisions

- ϕ_S is defined as the angle between proton spin and reaction plane
- j_T defines particle transverse momentum in jet
- ϕ_H defines angle between jet particle transverse momentum and reaction plane
- $\phi_C = \phi_S - \phi_H$ (Collins Angle)



Single-Spin Asymmetries (SSA)

- There are multiple contributions to transverse single-spin asymmetries in the TMD framework
- STAR is sensitive to several modulations

Terms in Numerator of TMD SSA for qq scattering	English Names	Modulate
$\Delta^N f_{a/A\uparrow} \bullet f_{b/B} \bullet D_{\pi/q}$	Sivers•PDF•FF	$\sin\left(\varphi_{S_A}\right)$
$h_1^a \bullet \Delta^N f_{b\uparrow/B} \bullet D_{\pi/q}$	Transversity•Boer-Mulders•FF	$\sin\left(\varphi_{S_A}\right)$
$h_{1T}^{\perp a} \bullet \Delta^N f_{b\uparrow/B} \bullet D_{\pi/q}$	Pretzelocity•Boer-Mulders•FF	$\sin\left(\varphi_{S_A}\right)$
$h_1^a \bullet f_{b/B} \bullet \Delta D_{\pi/q\uparrow}$	Transversity•PDF •Collins	$\sin\left(\varphi_{S_A} - \varphi_\pi\right)$
$\Delta f_{a/A\uparrow}^N \bullet \Delta^N f_{b\uparrow/B} \bullet \Delta D_{\pi/q\uparrow}$	Sivers•Boer-Mulders•Collins	$\sin\left(\varphi_{S_A} - \varphi_\pi\right)$
$h_{1T}^{\perp a} \bullet f_{b/B} \bullet \Delta D_{\pi/q\uparrow}$	Pretzelocity•PDF•Collins	$\sin\left(\varphi_{S_A} + \varphi_\pi\right)$
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Phys. Rev. D 83 034021 (2011)

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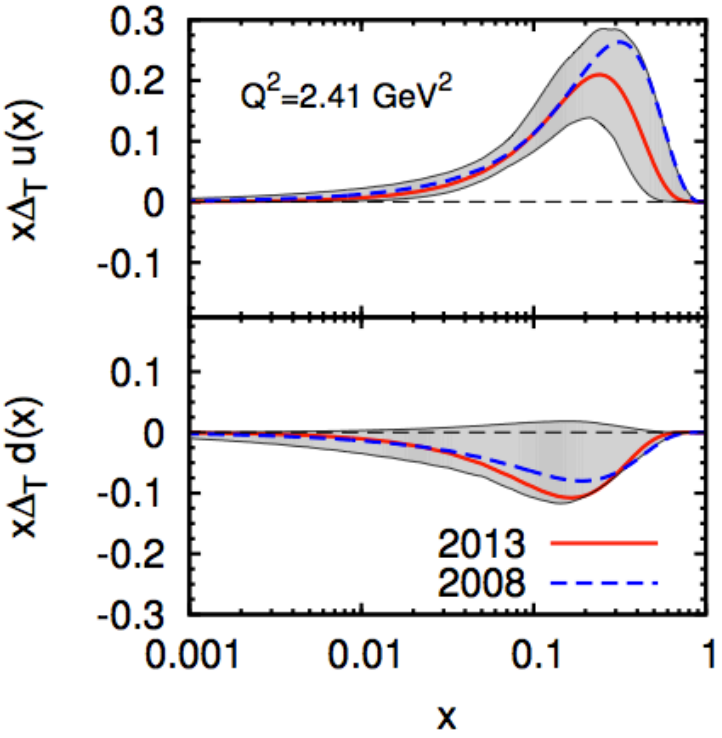
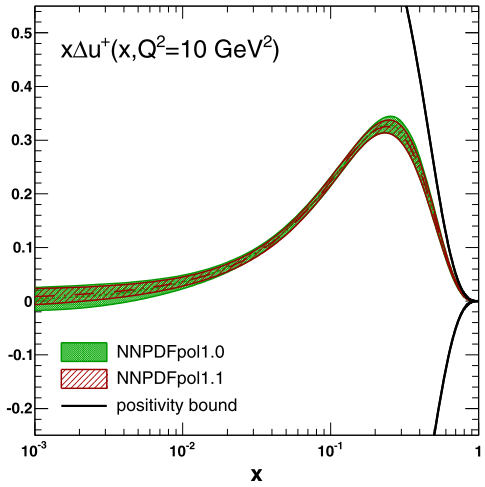
Phys. Rev. D 83 034021 (2011)

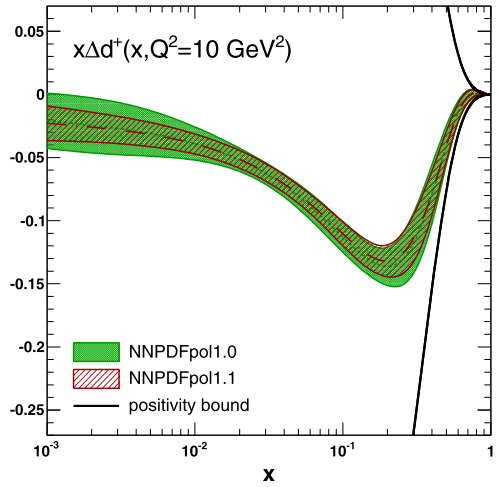
Knowledge of Transversity

- Distribution is chiral odd, accessibility limited in inclusive lepton scattering
- Transversity much less constrained than it's helicity counterpart



Phys. Rev. D **87** 094019 (2013)

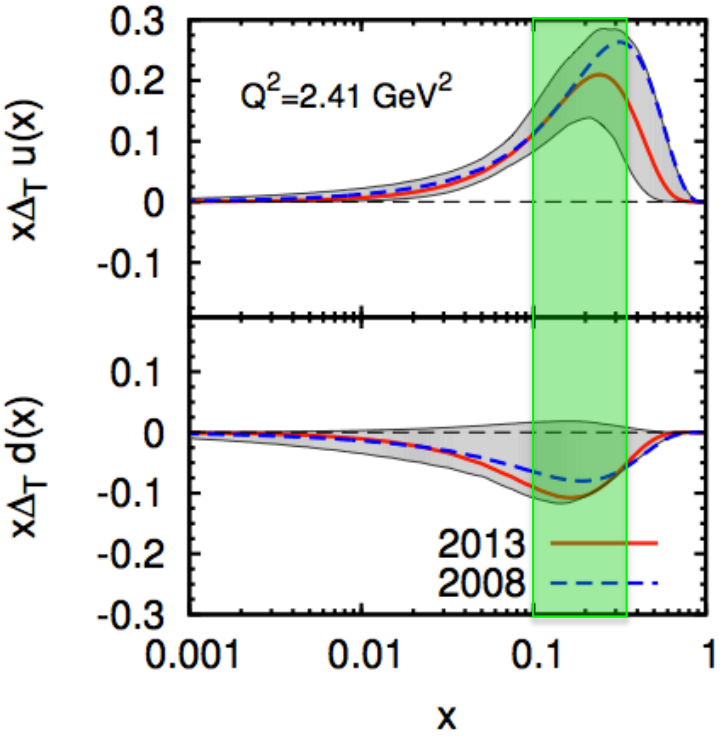


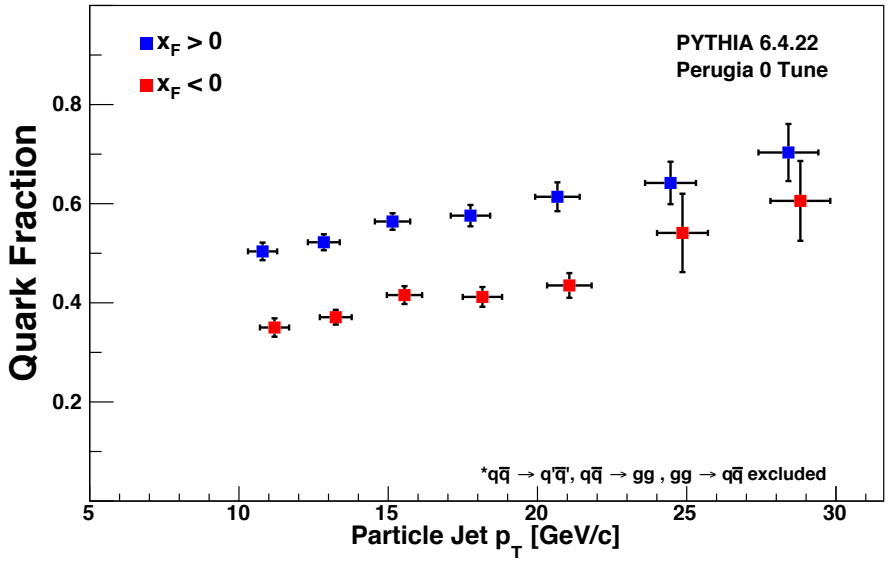


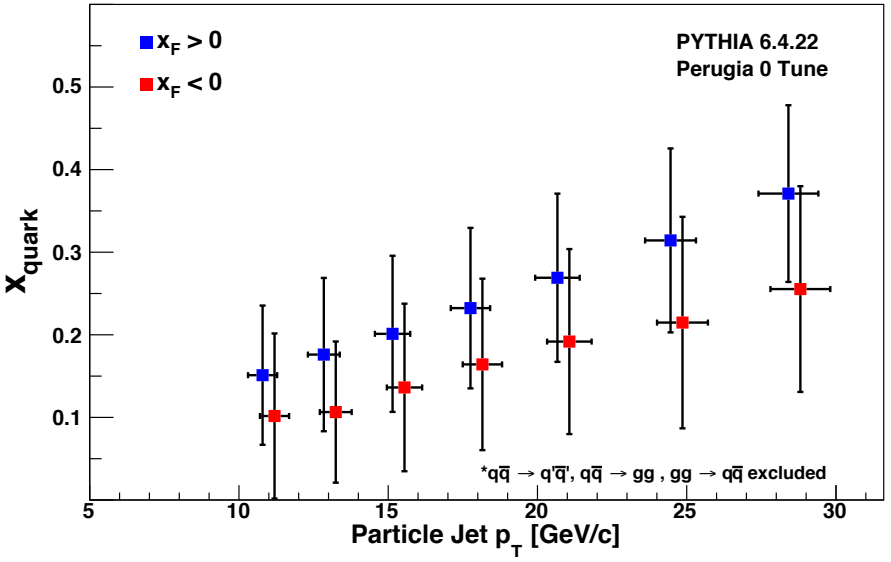
Nuclear Physics B, Vol 887 (2014)

STAR Kinematic Coverage

- Analysis of forward and backward scattered jets yields access to a broad range of momentum fractions



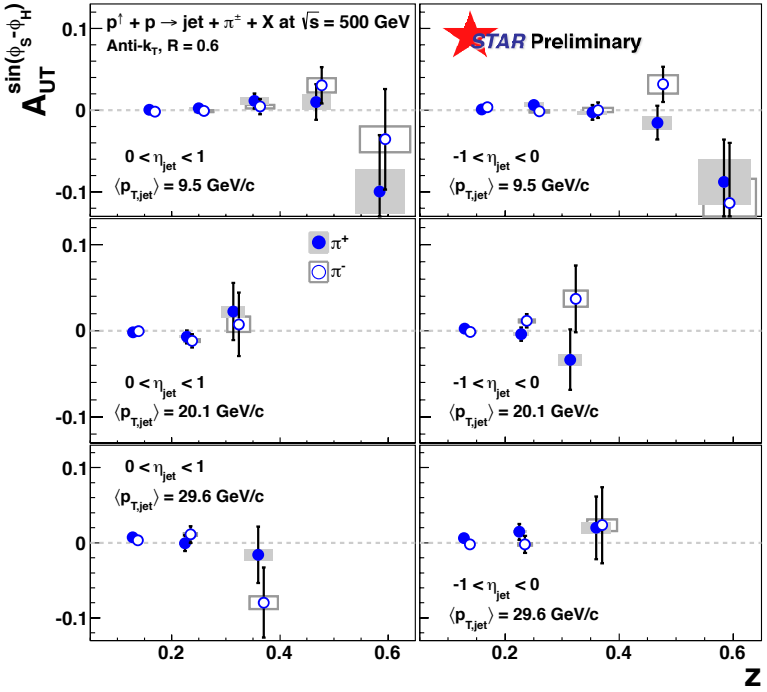




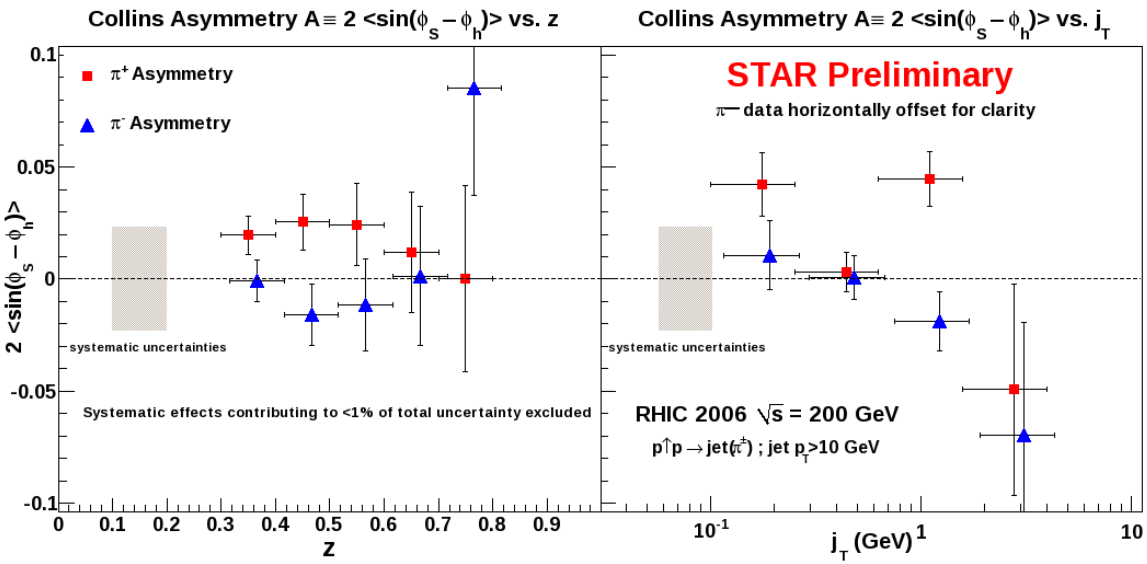
Phys. Rev. D **87** 094019 (2013)

Previous STAR Results and Theory

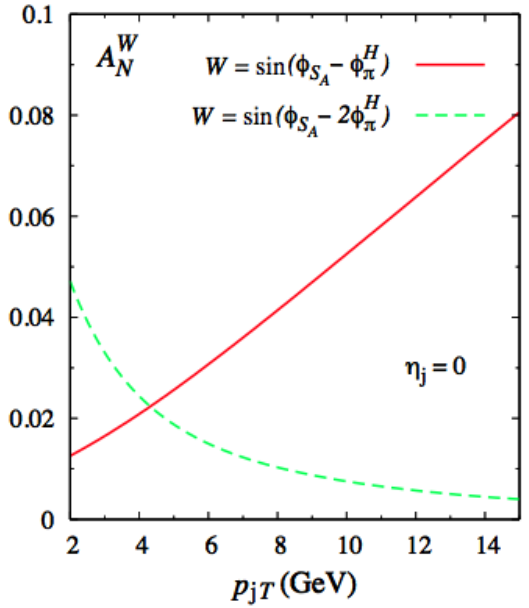
- √s = 500 GeV asymmetries consistent with zero
- Non-zero Collins asymmetries predicted at midrapidity for 200 GeV proton collisions
- Hints of significant statistical differences in asymmetries for the two charges found in previous 2006 Collins measurement at STAR
  - Systematic errors are very large



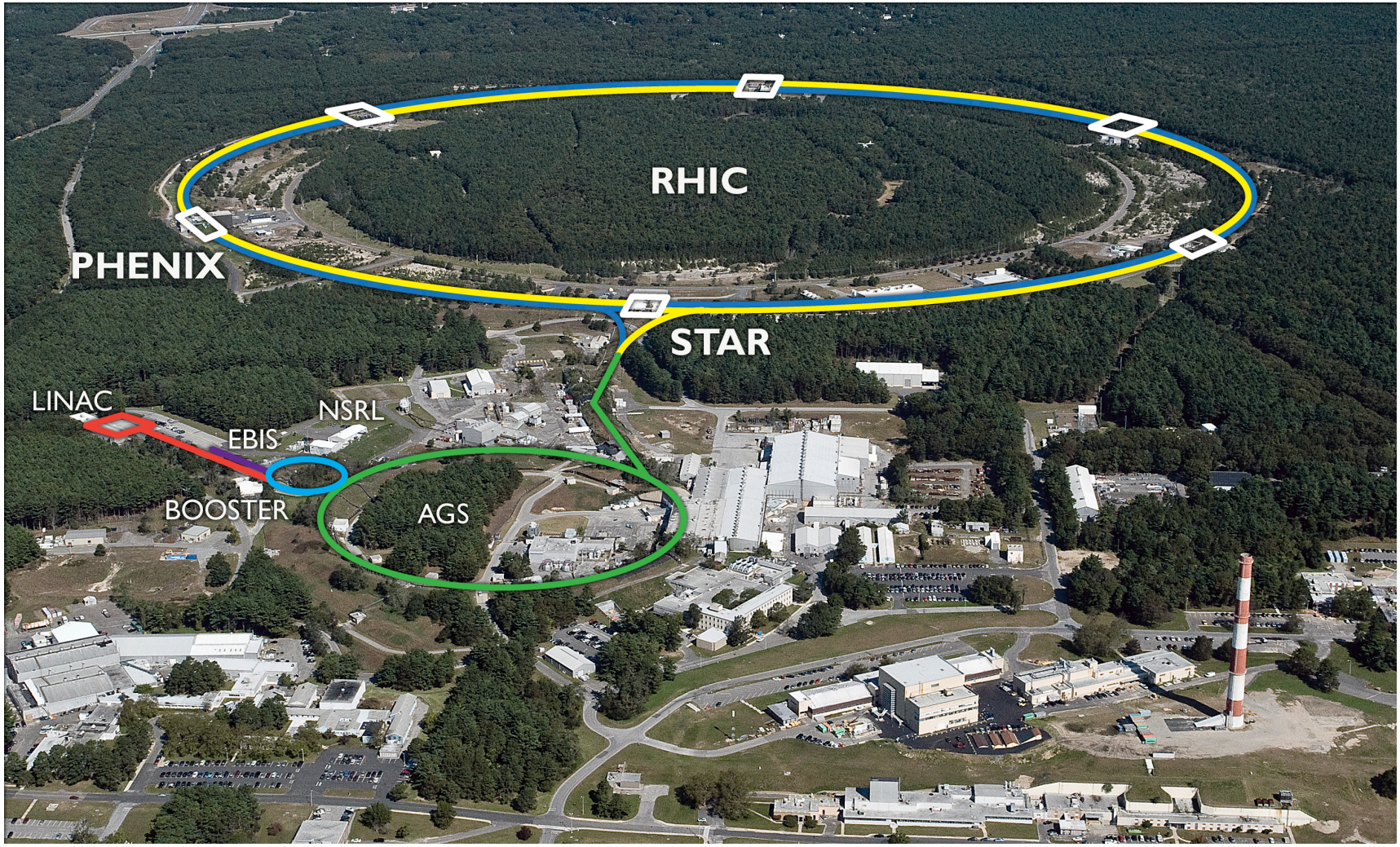
Phys. Rev. D 83 034021 (2011)



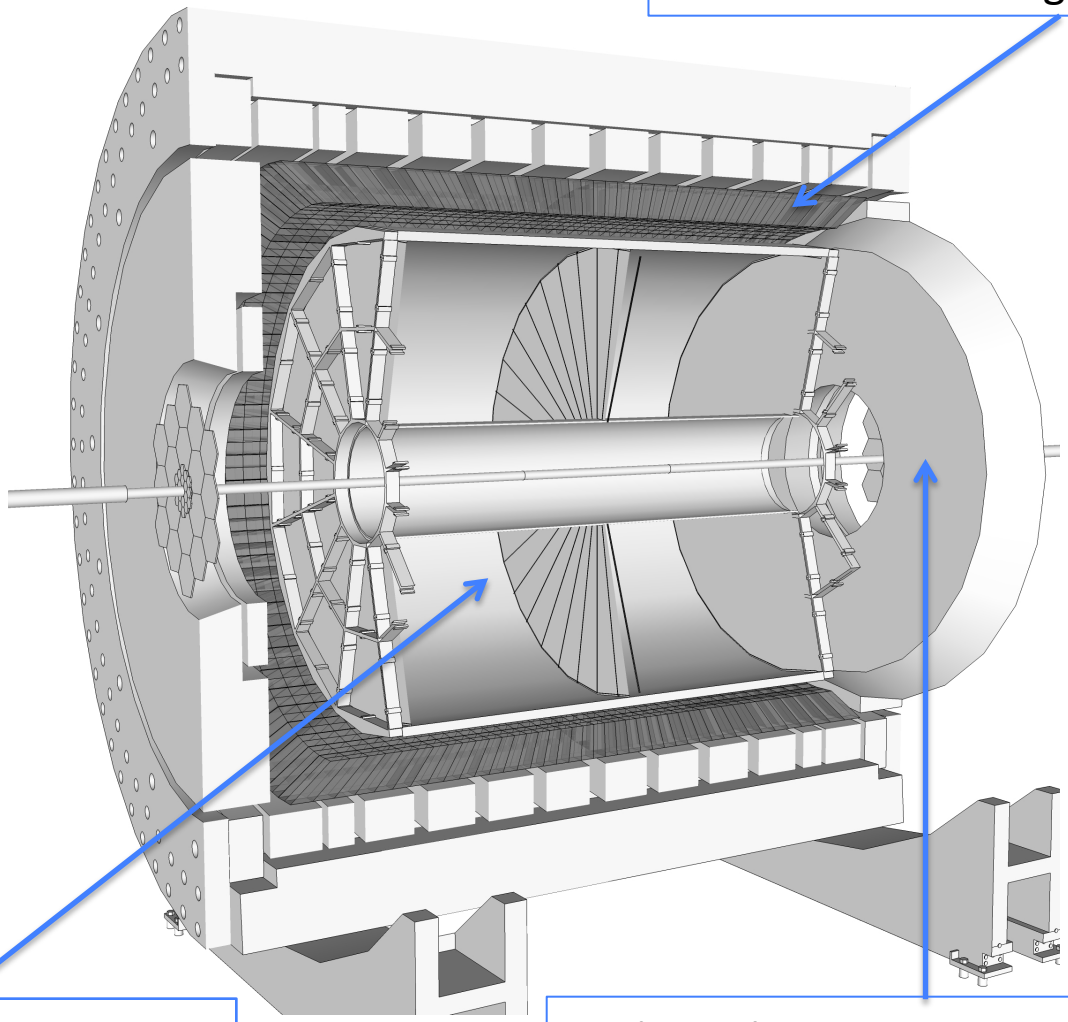
AIP Conf. Proc. 1441, 233 (2012)



Relativistic Heavy Ion Collider

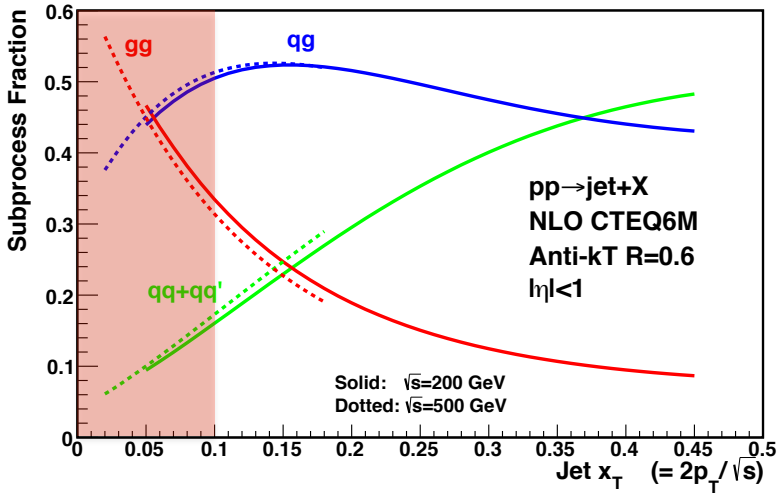


Solenoidal Tracker At RHIC



2012 Data and Cuts

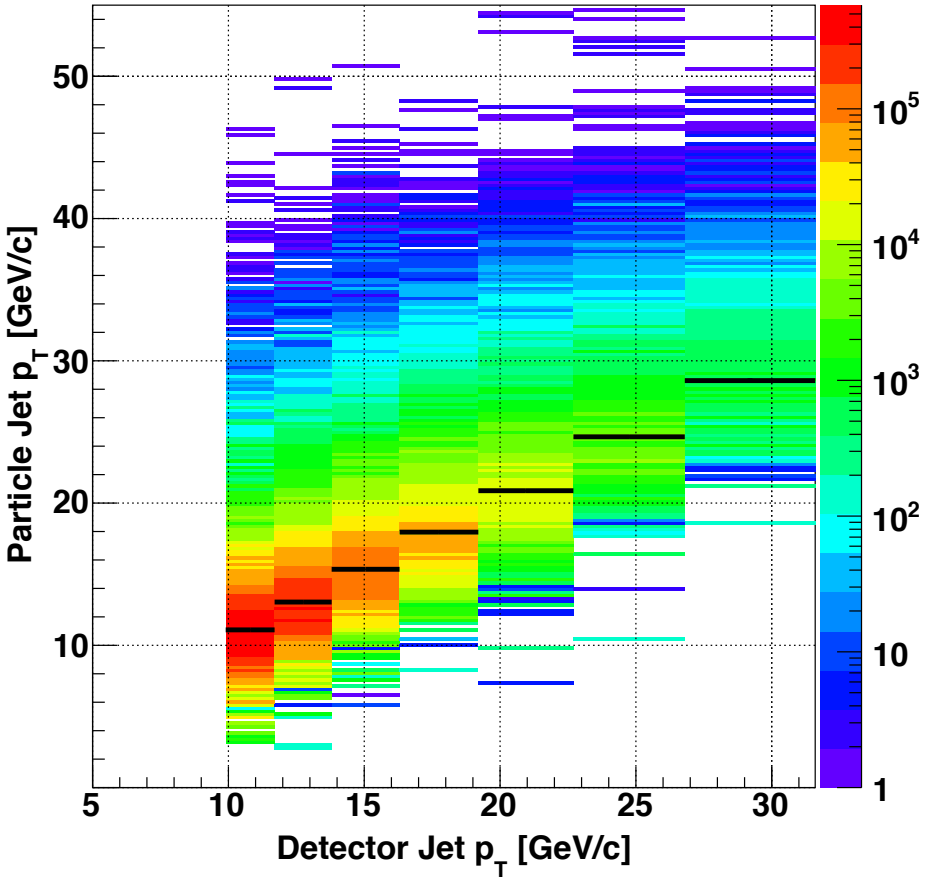
- 20 pb^{-1} transversely polarized proton collisions at √s = 200 GeV
  - Factor of 10 larger dataset than in 2006
- Average event weighted polarization: 63%
  - Increase from 58% in 2006 result
- Anti-k_T (R = 0.6) jet reconstruction
- Jet p_T > 10 GeV/c (x_T > 0.1) reduces gluon contamination
- $|\eta_{jet}| < 1$



Phys. Rev. D 86, 094009 (2012)

Systematic Uncertainties

- Use PYTHIA+GEANT to simulate STAR response to QCD processes
  - Embed detector response into zero-bias data
- Correct z, p_T, and j_T to particle level
- Simulation used to estimate systematic errors
  - Pion mis-identification
  - φ_c reconstruction errors
  - Trigger bias
  - Other transverse spin dependent modulations of the cross section

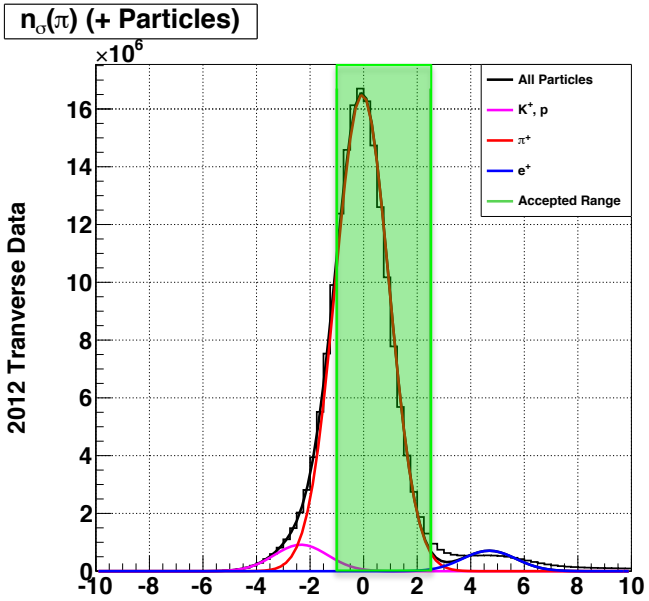


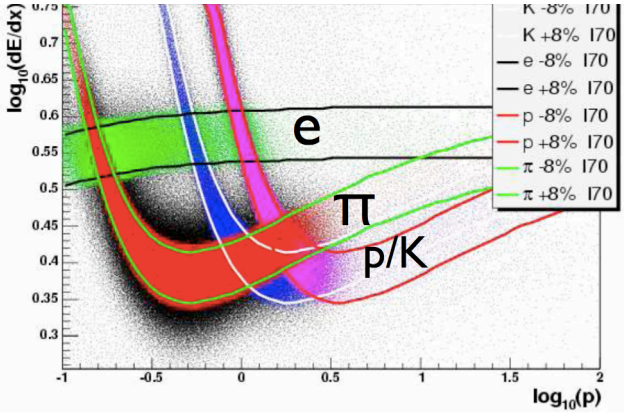
Identifying Charged Pions

- Pions identified from TPC track dE/dx
- Use $-1 < n_\sigma(\pi) < 2.5$ cut to identify pions in jets

$$n_\sigma(\pi) = \frac{1}{\sigma_{\exp}} \ln\left(\frac{dE/dx_{obs}}{dE/dx_{\pi,calc}}\right)$$

- Kaons, protons, and electrons contaminate the pion sample
- This contamination is p_T independent and contributes less than 3% to the overall systematic uncertainty

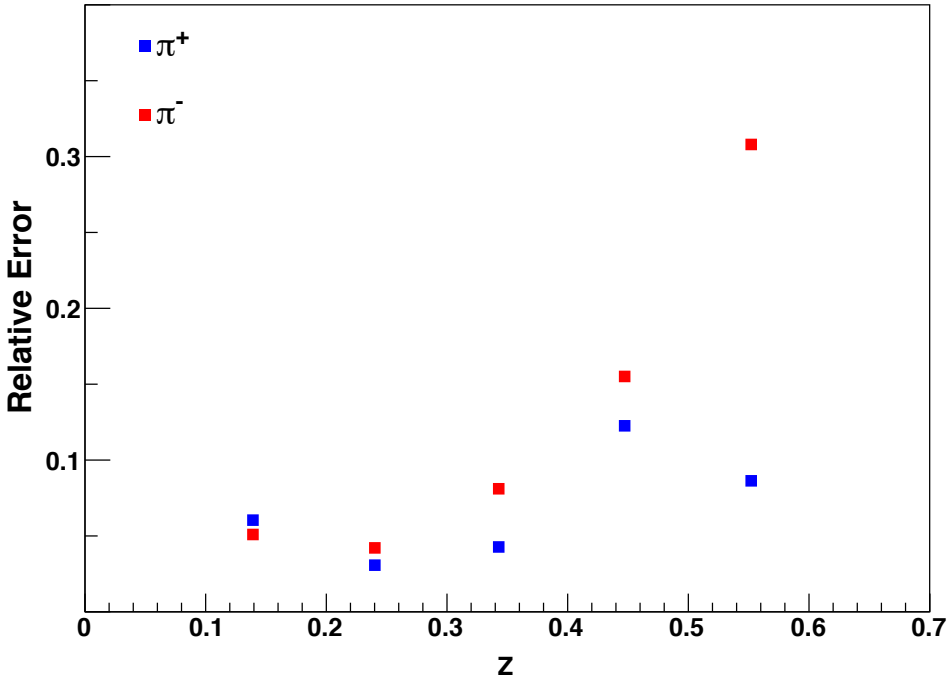




Nucl.Instrum.Meth. A558:419-429,2006

φ_c Reconstruction Bias

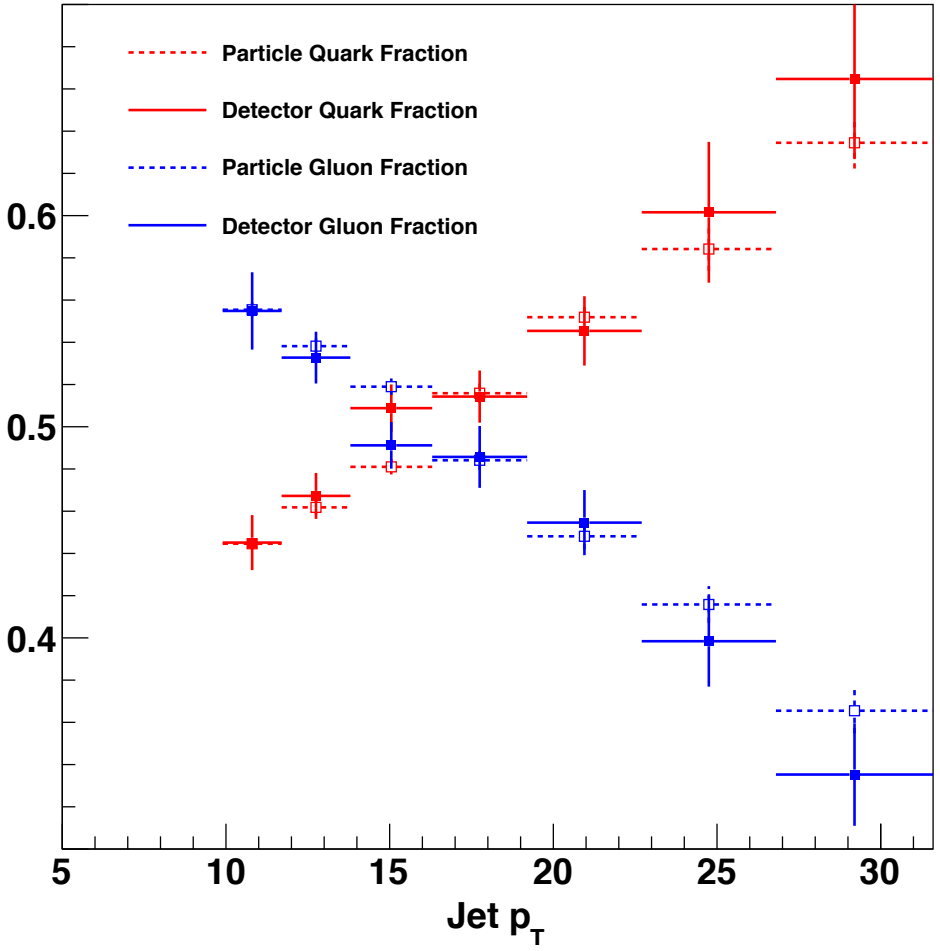
- Detector resolution and incorrect reconstruction of φ_c will decrease measured asymmetry
- Seed simulation with an asymmetry weight extracted from data
- Repeat analysis at detector and particle levels of simulation, and extract asymmetry
- Relative error gives estimate of φ_c resolution and reconstruction errors



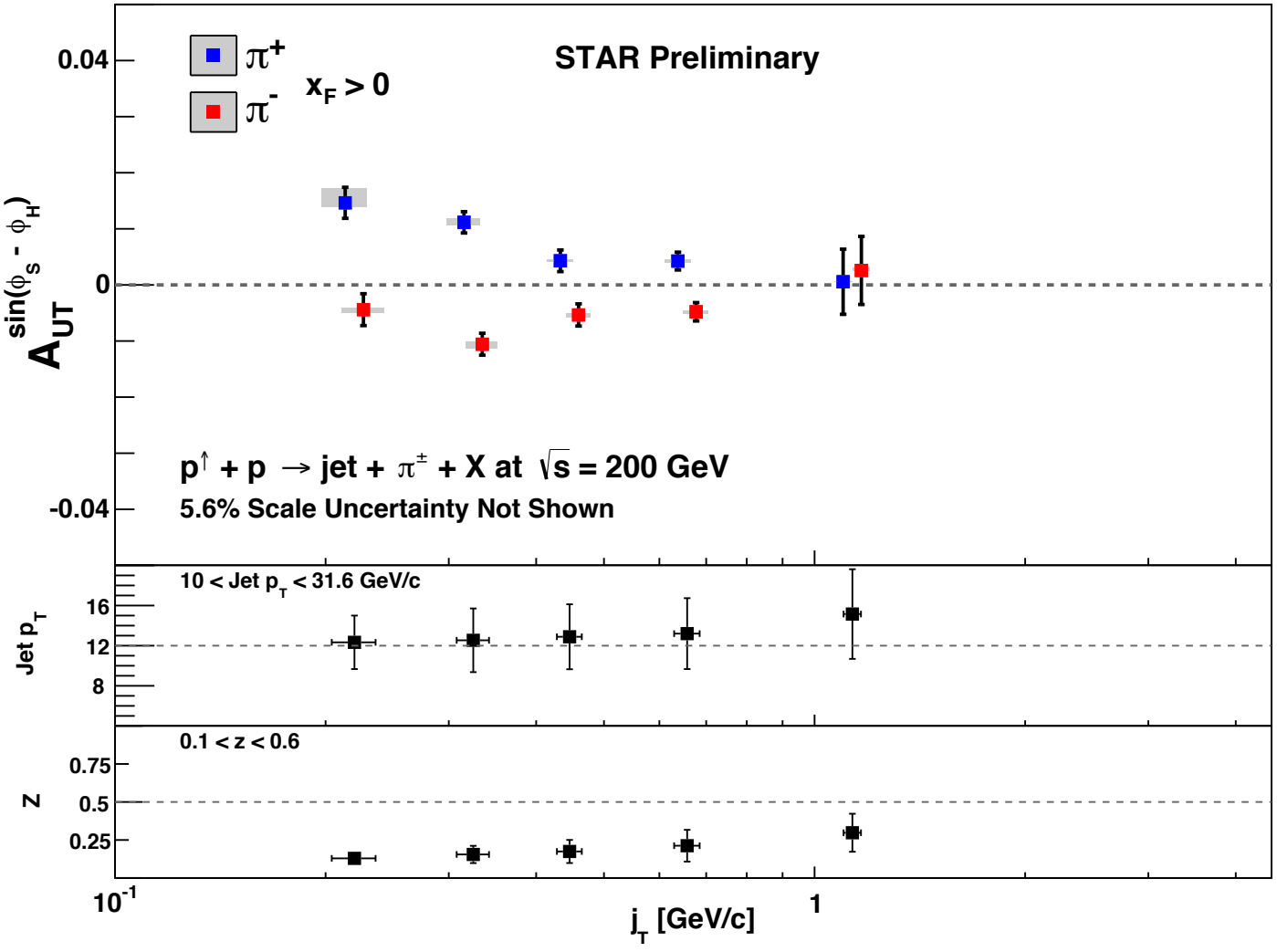
$$Error = \frac{A_{UT}^{Particle} - A_{UT}^{Detector}}{A_{UT}^{Detector}}$$

Trigger Bias

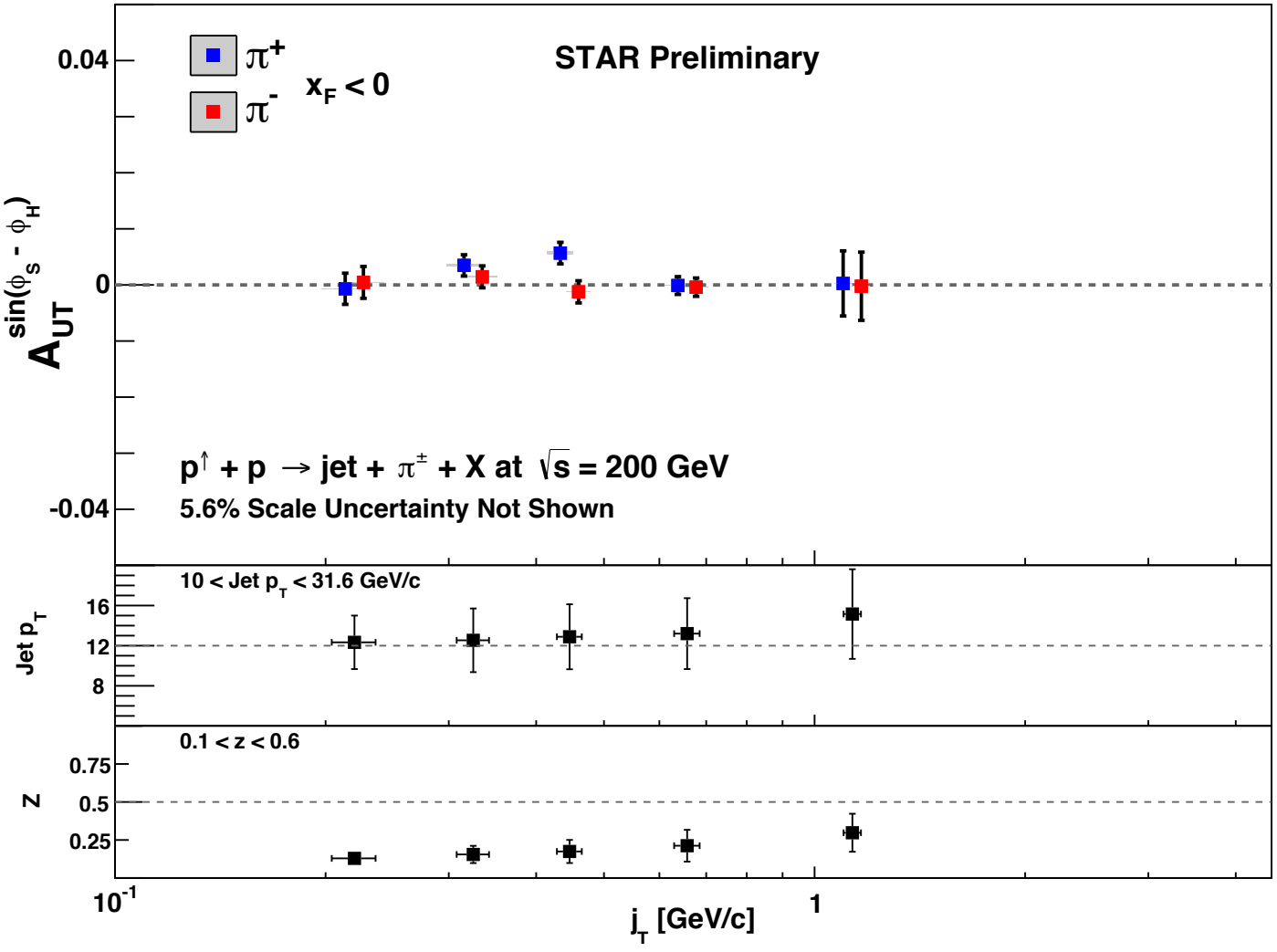
- Trigger used to collect this data is biased towards quark jets
- Increased quark contributions will enhance measured asymmetry
- Contributes 5% to overall systematic uncertainty



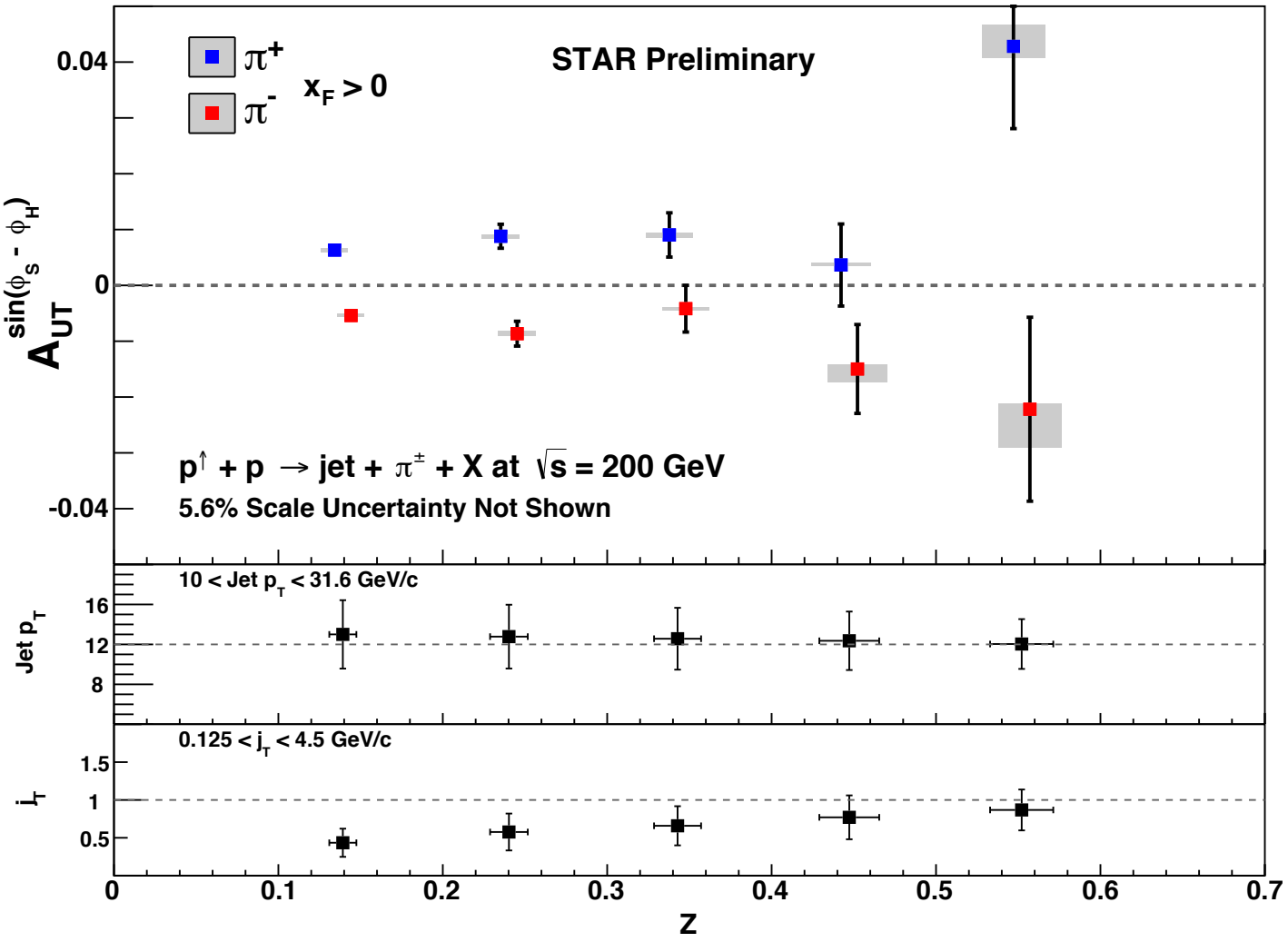
A_{UT} vs. j_T for $x_F > 0$



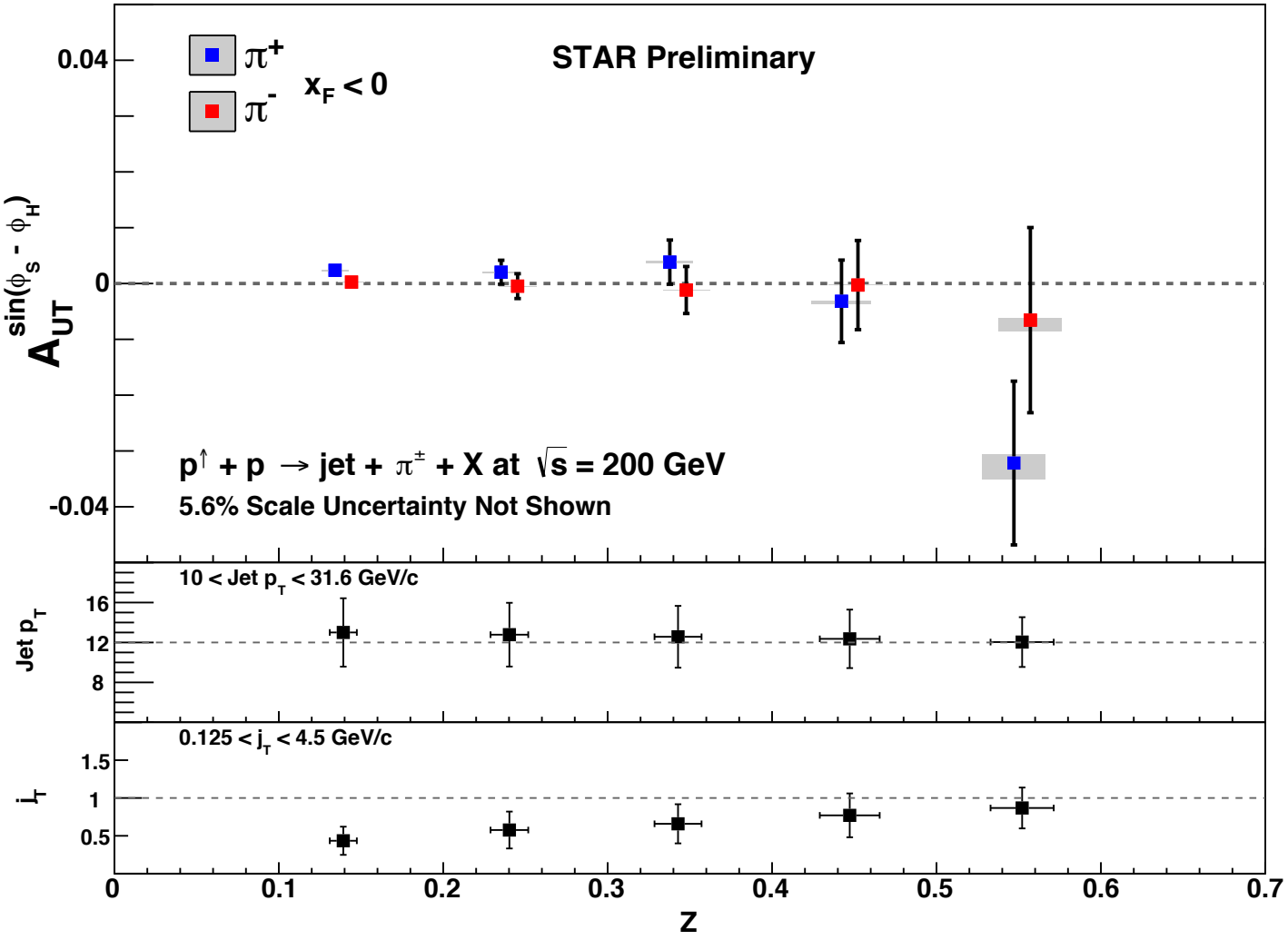
A_{UT} vs. j_T for $x_F < 0$



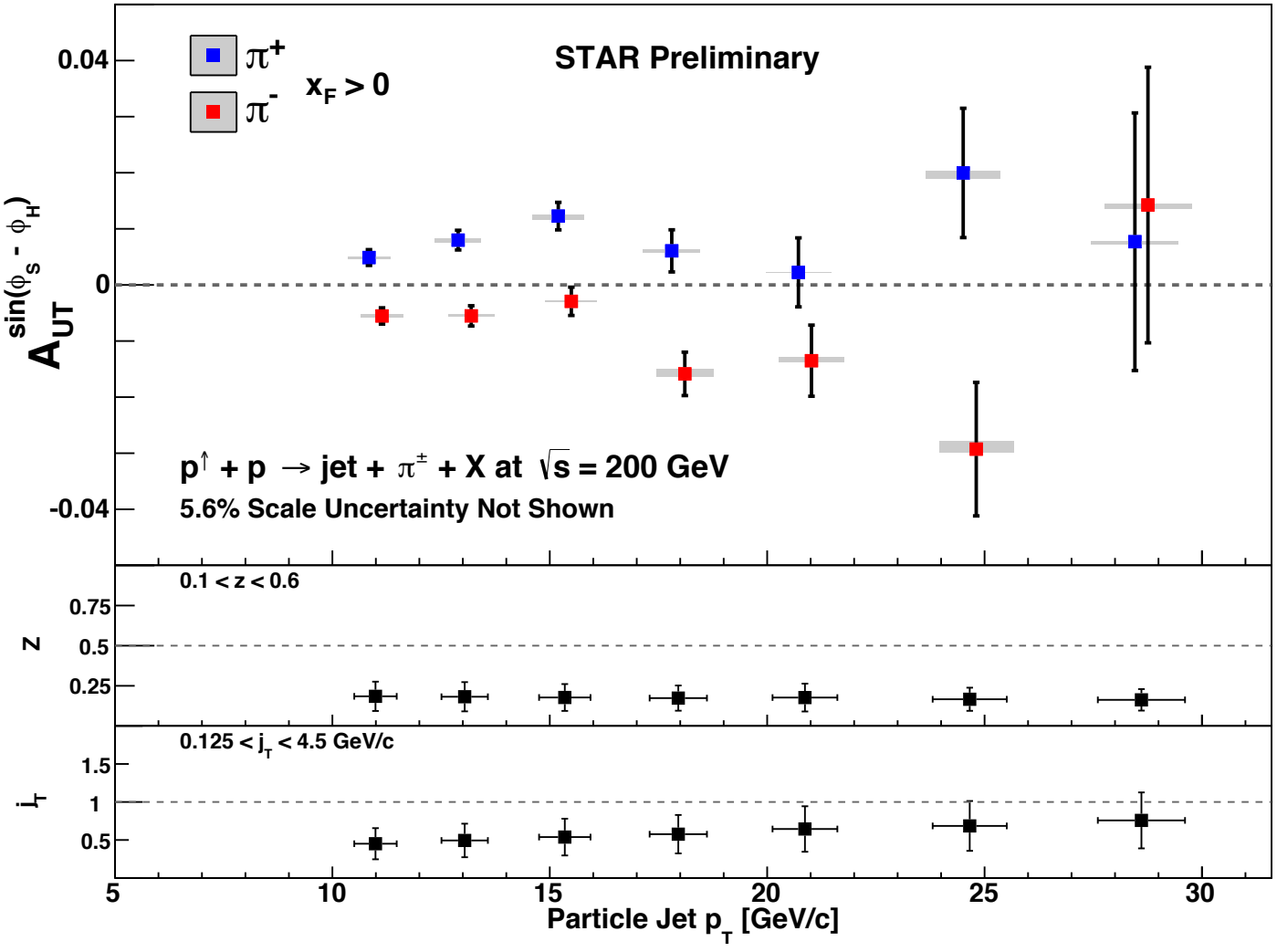
A_{UT} vs. z for $x_F > 0$



A_{UT} vs. z for $x_F < 0$



A_{UT} vs. p_T for $x_F > 0$



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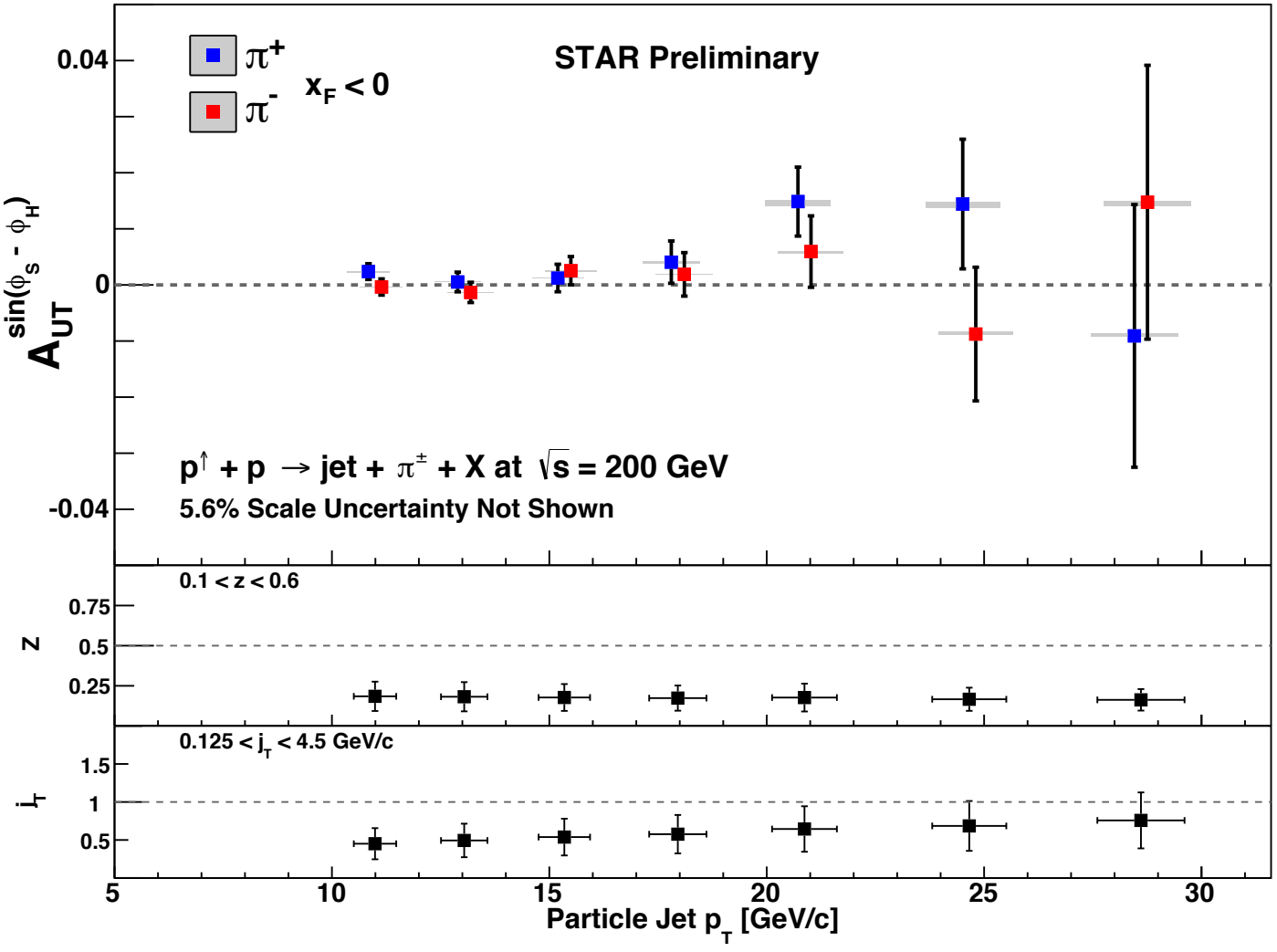

Summary

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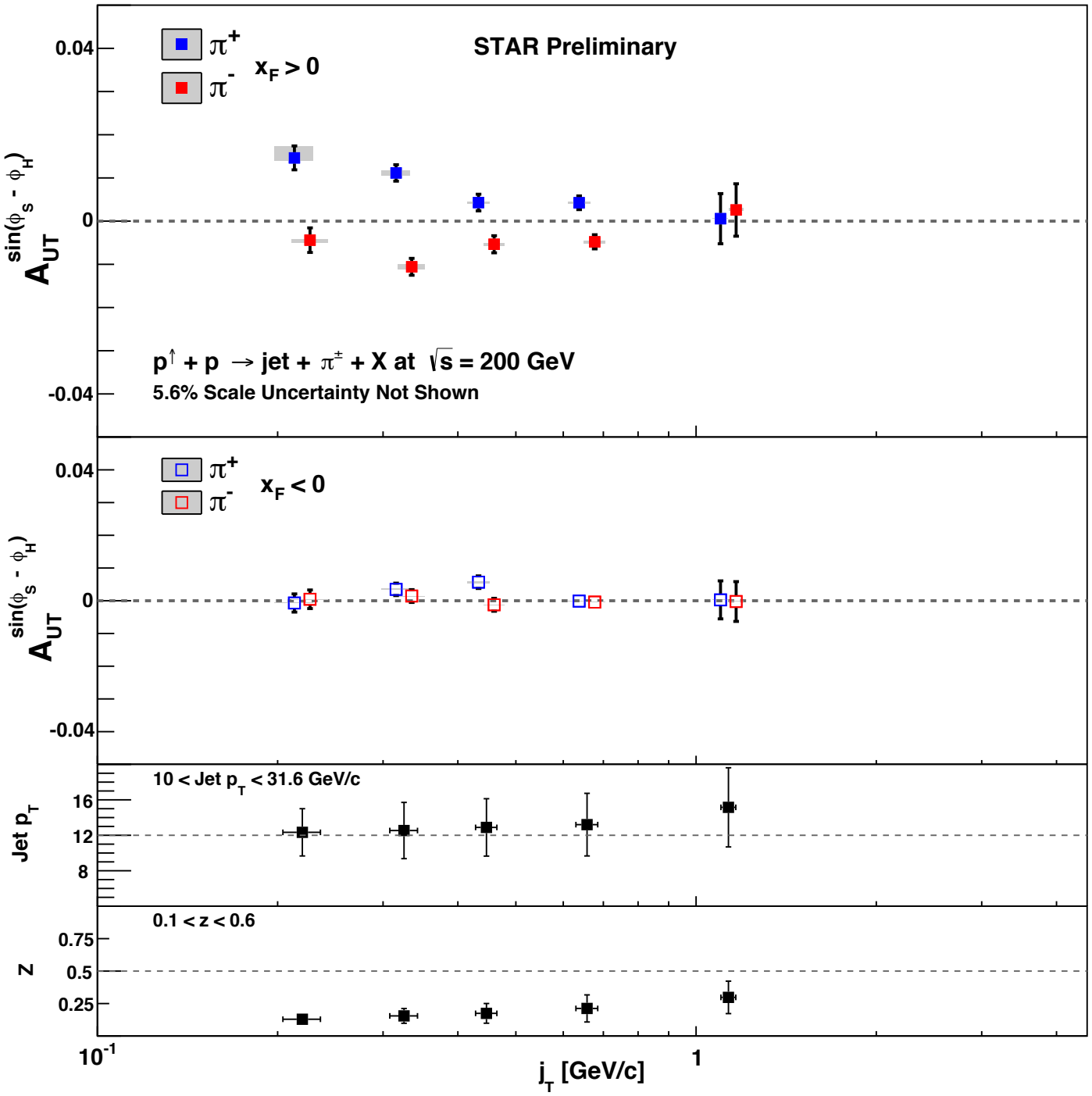
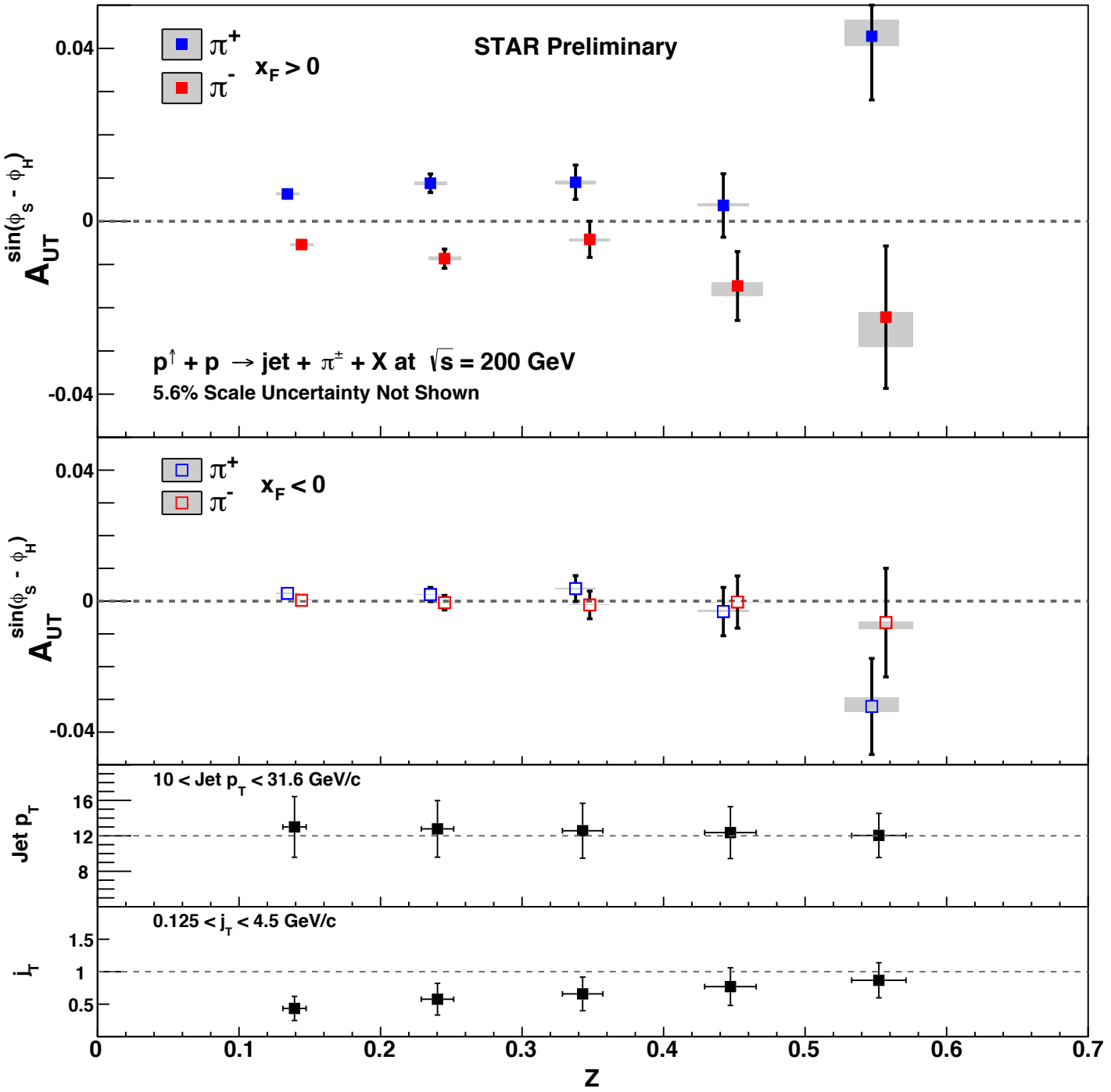
- During upcoming 2015 RHIC run, STAR expects to record twice the 2012 data set, allowing for more detailed multi-dimensional study of the Collins effect

Backup


STAR Preliminary
π^+
π^-
$x_F > 0$
$\sin(\phi_S - \phi_H)$ A_{UT}
0.04
0
-0.04
$p^\uparrow + p \rightarrow$ jet + $\pi^\pm$ + X at $\sqrt{s}$ = 200 GeV
5.6% Scale Uncertainty Not Shown
π^+
π^-
$x_F < 0$
$\sin(\phi_S - \phi_H)$ A_{UT}
0.04
0
-0.04
10 < Jet p_T < 31.6 GeV/c
Jet p_T
16
12
8
0.1 < z < 0.6
z
0.75
0.5
0.25
10^{-1}
1
j_T [GeV/c]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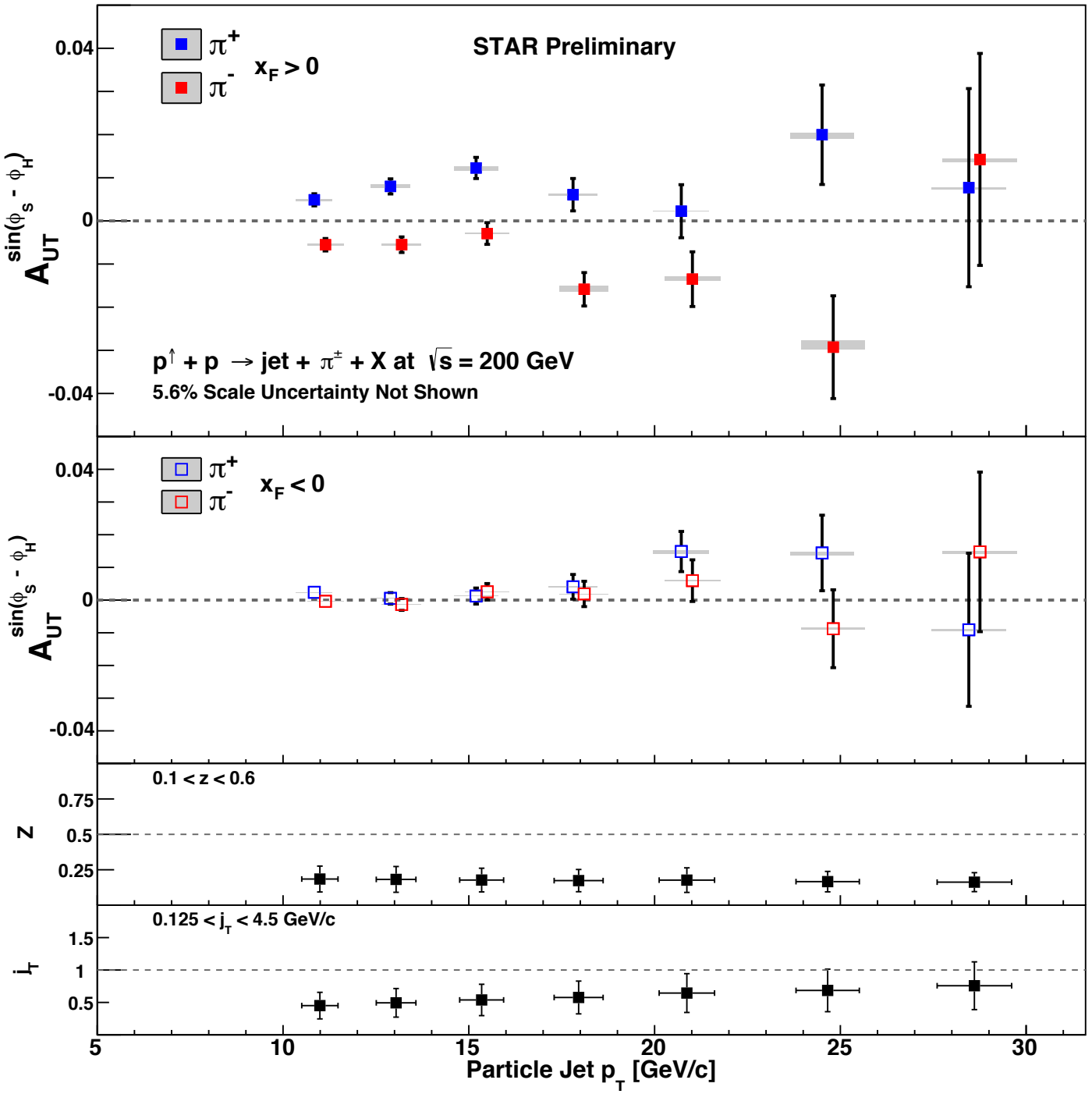
5.6% Scale Uncertainty Not Shown
$A_{UT}^{\sin(\phi_s - \phi_H)}$
$x_F < 0$
10 < Jet p_T < 31.6 GeV/c
Jet p_T
0.125 < j_T < 4.5 GeV/c
j_T
z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5.6% Scale Uncertainty Not Shown
sin(φs - φH) AUT
0.04
0
-0.04
π+
π-
xF < 0
0.1 < z < 0.6
z
0.75
0.5
0.25
0.125 < jT < 4.5 GeV/c
jT
1.5
1
0.5
5
10
15
20
25
30
Particle Jet pT [GeV/c]

Flavor Matching Fractions