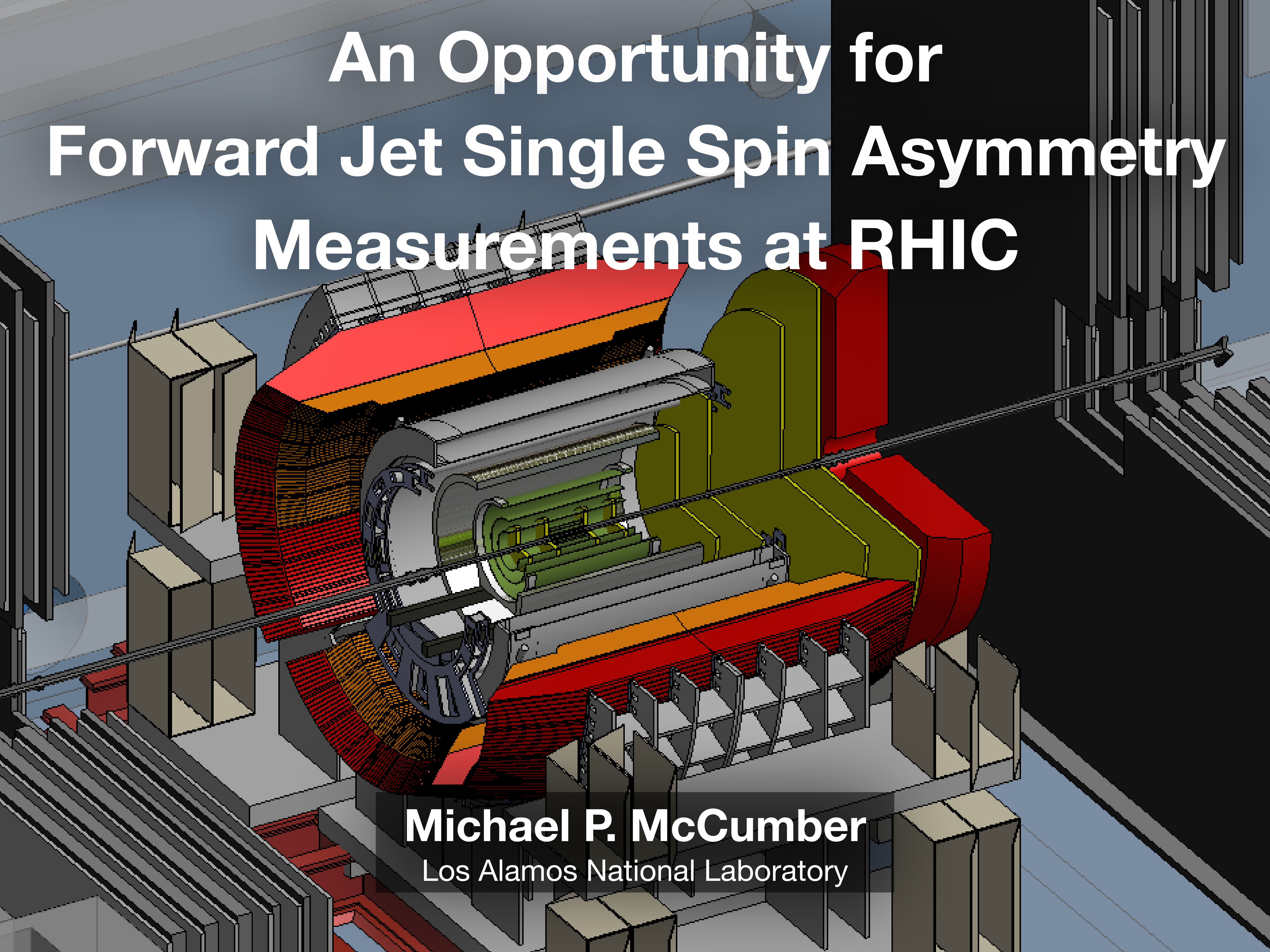
An Opportunity for Forward Jet Single Spin Asymmetry Measurements at RHIC



Michael P. McCumber
Los Alamos National Laboratory

Overview

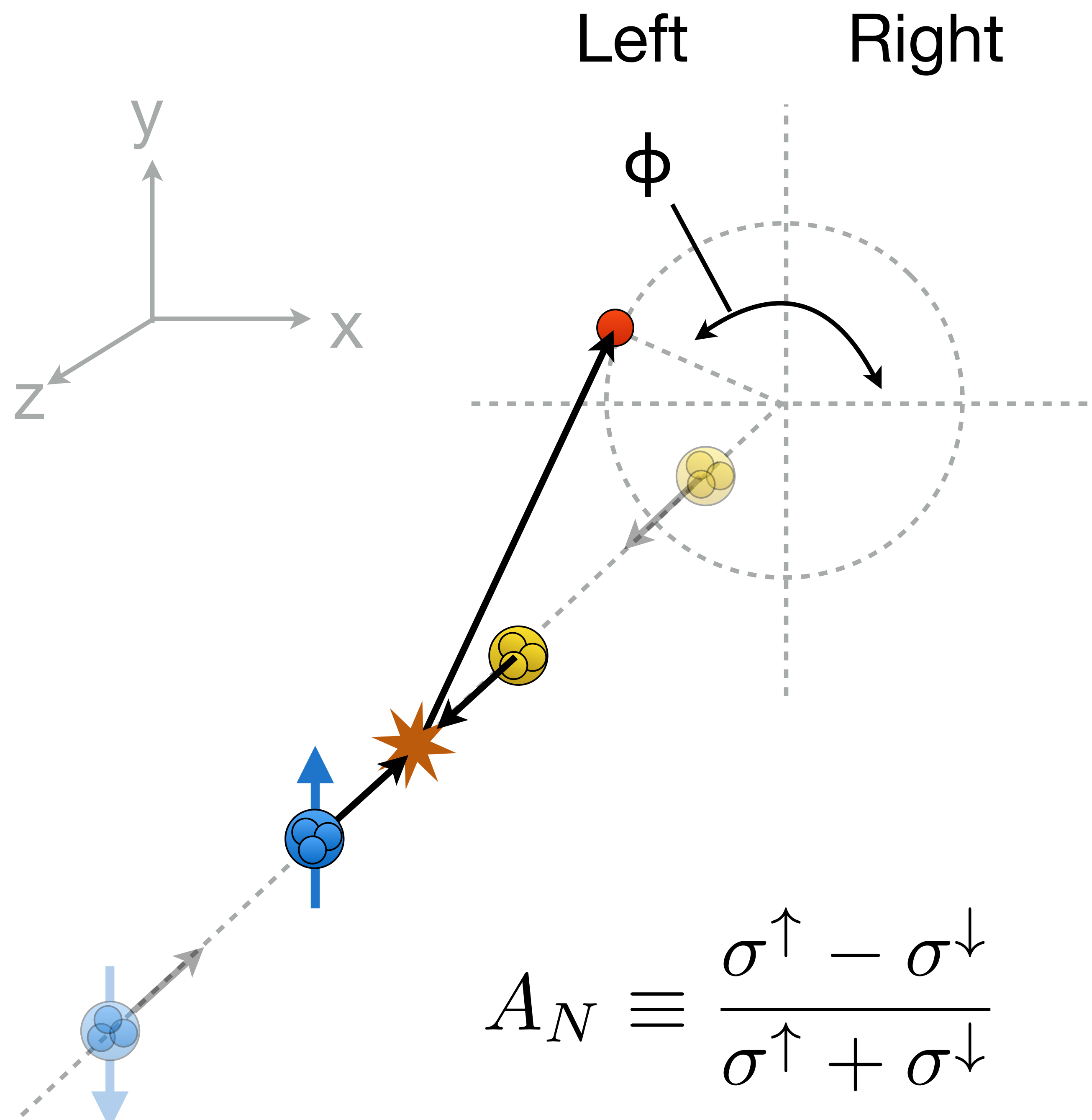
1. Forward jet left-right asymmetries in $p^{\uparrow}$+p are actually sensitive to valence quarks' Sivers-type distribution

2. The gauge invariance requirement of QCD results in the **"process dependence behavior"** of Sivers-type distribution that **can be witnessed by jet measurements**

3. A_NDY's jet A_N measurement (**small asymmetries**) is understood as an almost exact **cancellation between up and down quark** Sivers-type effect.

4. Forward detector upgrades at RHIC have an opportunity to clearly verify "Sivers-type distribution process dependency" by selecting **"tagged-jet events" to enhance up or down quark contributions** and apply different selection criteria, which leads to opposite predicted behaviors of jet A_N according to different types of theories

Transverse Single Spin Asymmetry



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

TSSA measured via particle production relative to proton spin direction, i.e.:

$$N(\phi) = N_0[1 + P A_N \cos\phi]$$

where P is the polarization

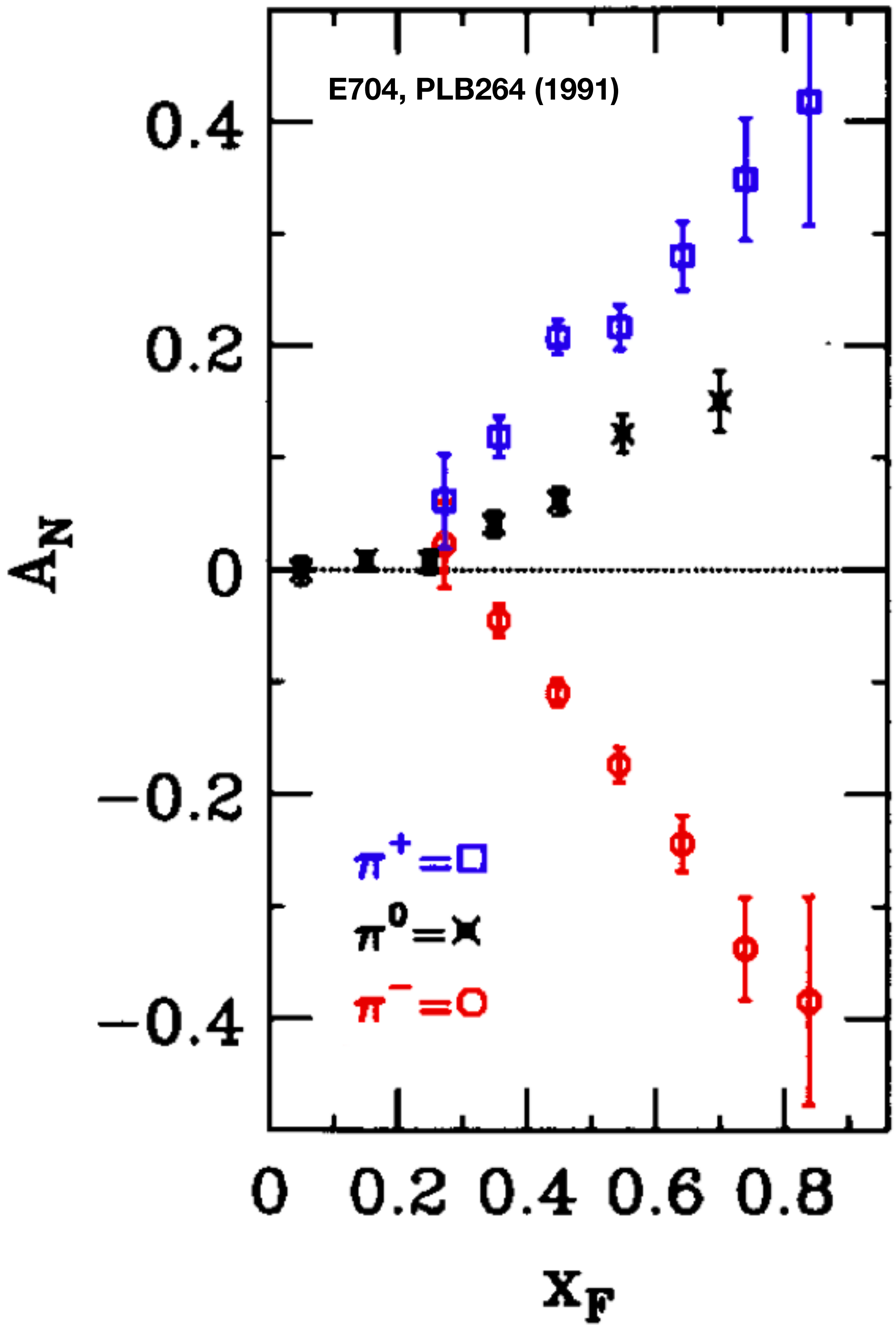
Theoretical expectations via collinear pQCD:

$$A_N \approx \frac{m_q \alpha_s}{p_T}$$

$$A_N\big|_{p_T=2GeV/c} \approx 10^{-3}$$

Only small asymmetries predicted

Experimental Observations



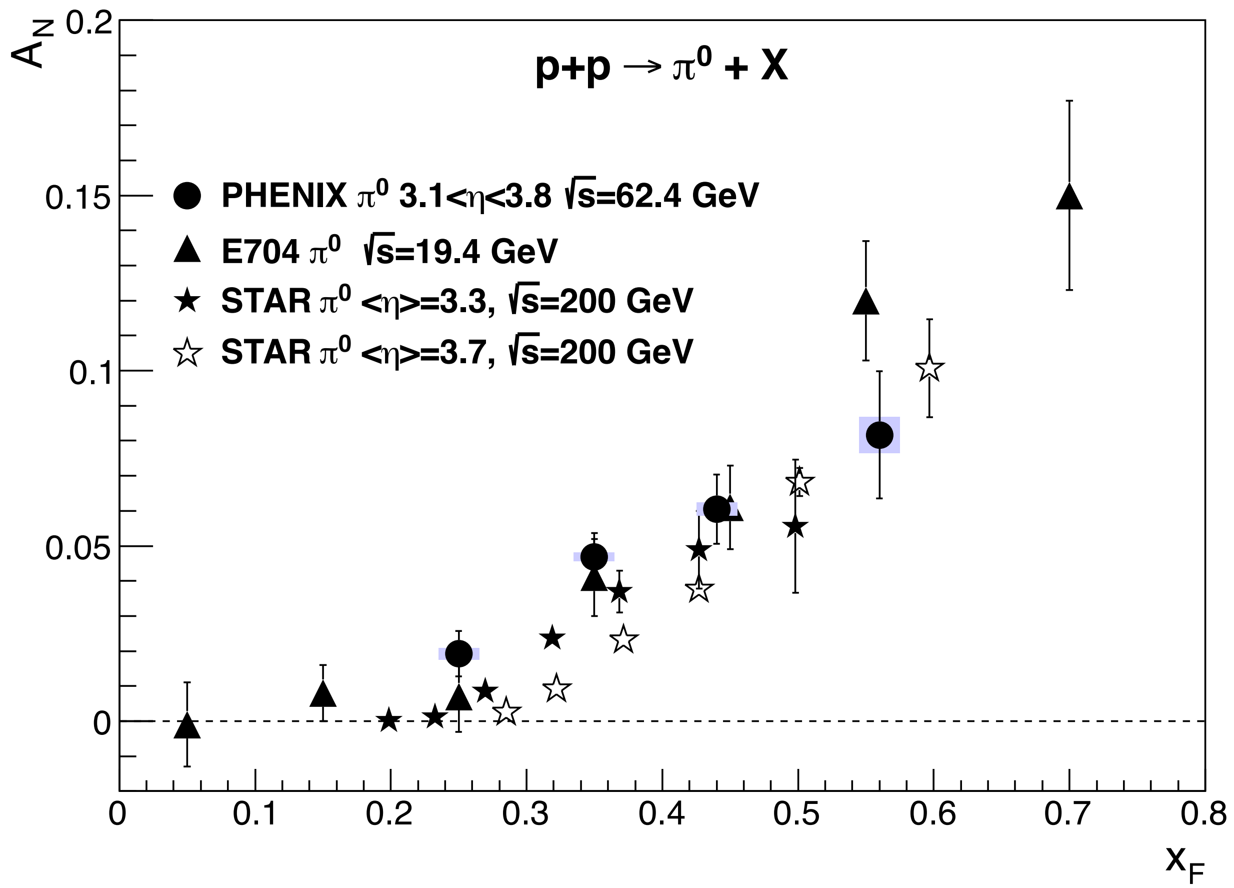
E704 measured A_N of a polarized proton on fixed target and discovered **large A_N values at large x_F**

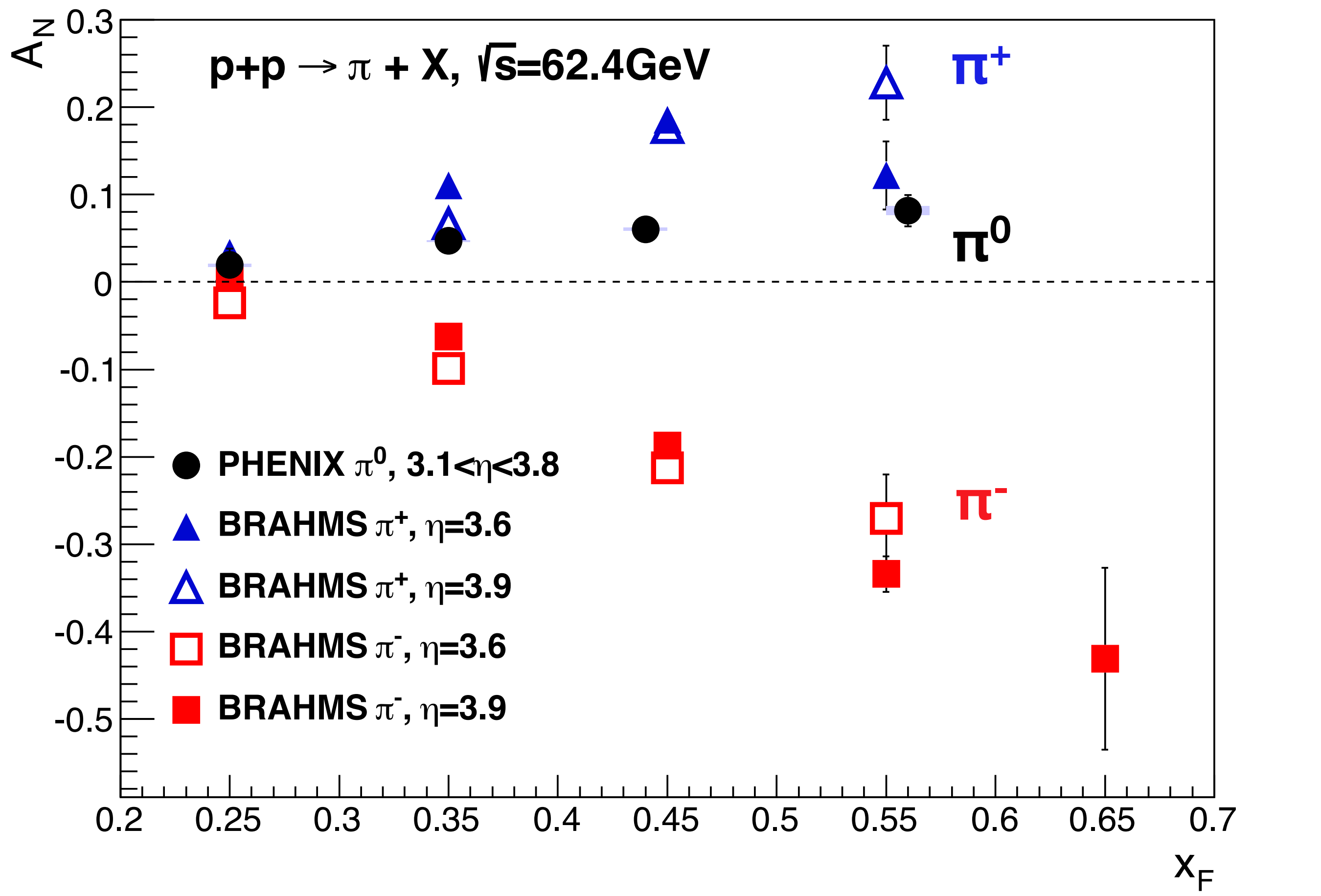
Large **positive values for π^+**
Smaller positive values for π^0
Large **negative values for π^-**

Indicative of a valence quark effect

Positive effect from up-quark
Negative effect from down-quark

Existing RHIC Measurements



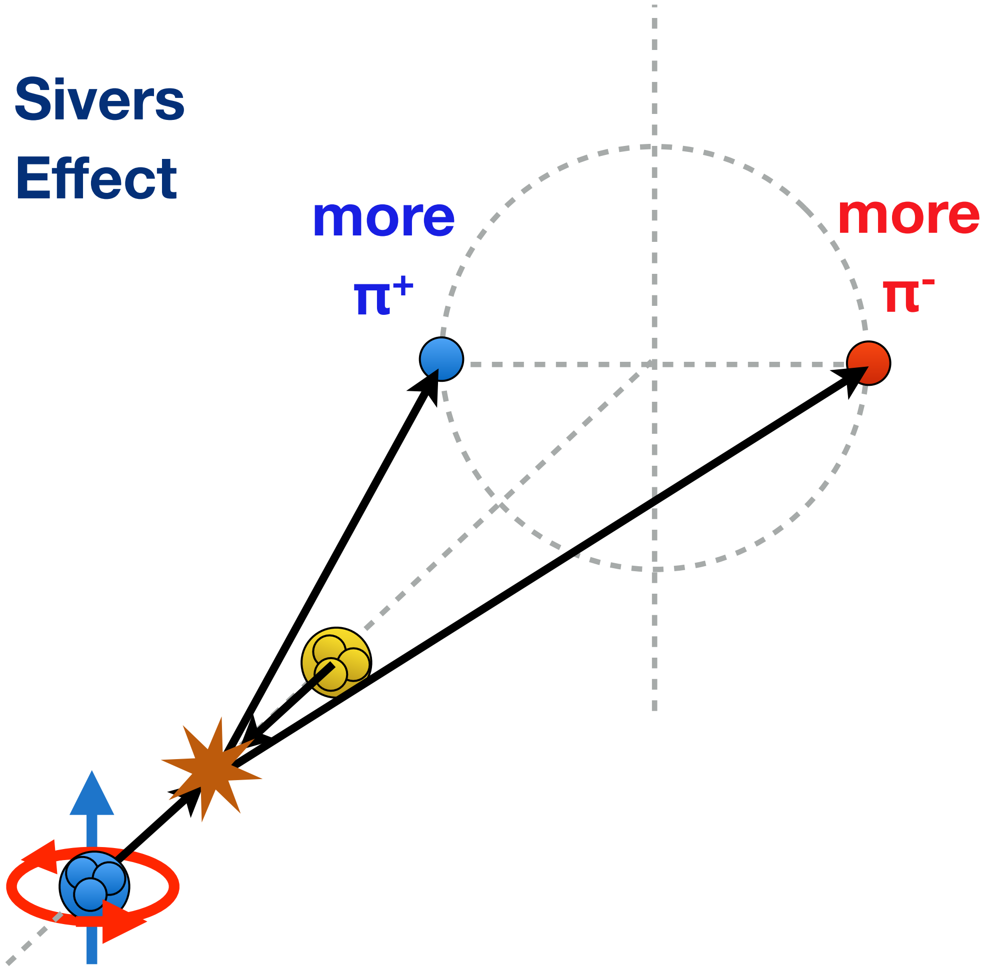


PHENIX and STAR have measured similar large π^0 asymmetries in the forward direction at RHIC energies of 62.4-200 GeV

BRAHMS has also measured large transverse asymmetries of the charged pions at 62.4 GeV

Large forward TSSA are accessible at RHIC energies

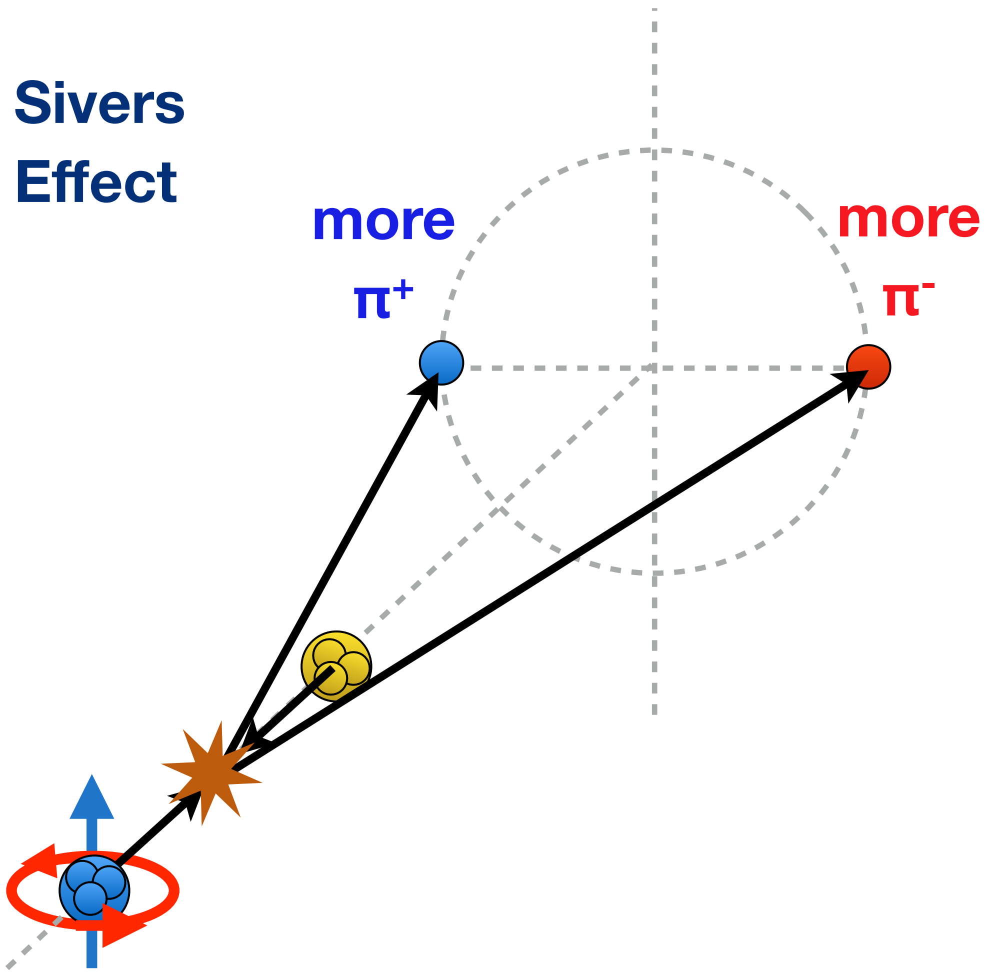
Physical Explanations



Transverse momentum dependence incorporated directly into **proton structure function**

$$\propto \bar{f}_{1T}^{\perp q}(x, k_\perp^2) \times D_q^h(z)$$

Physical Explanations



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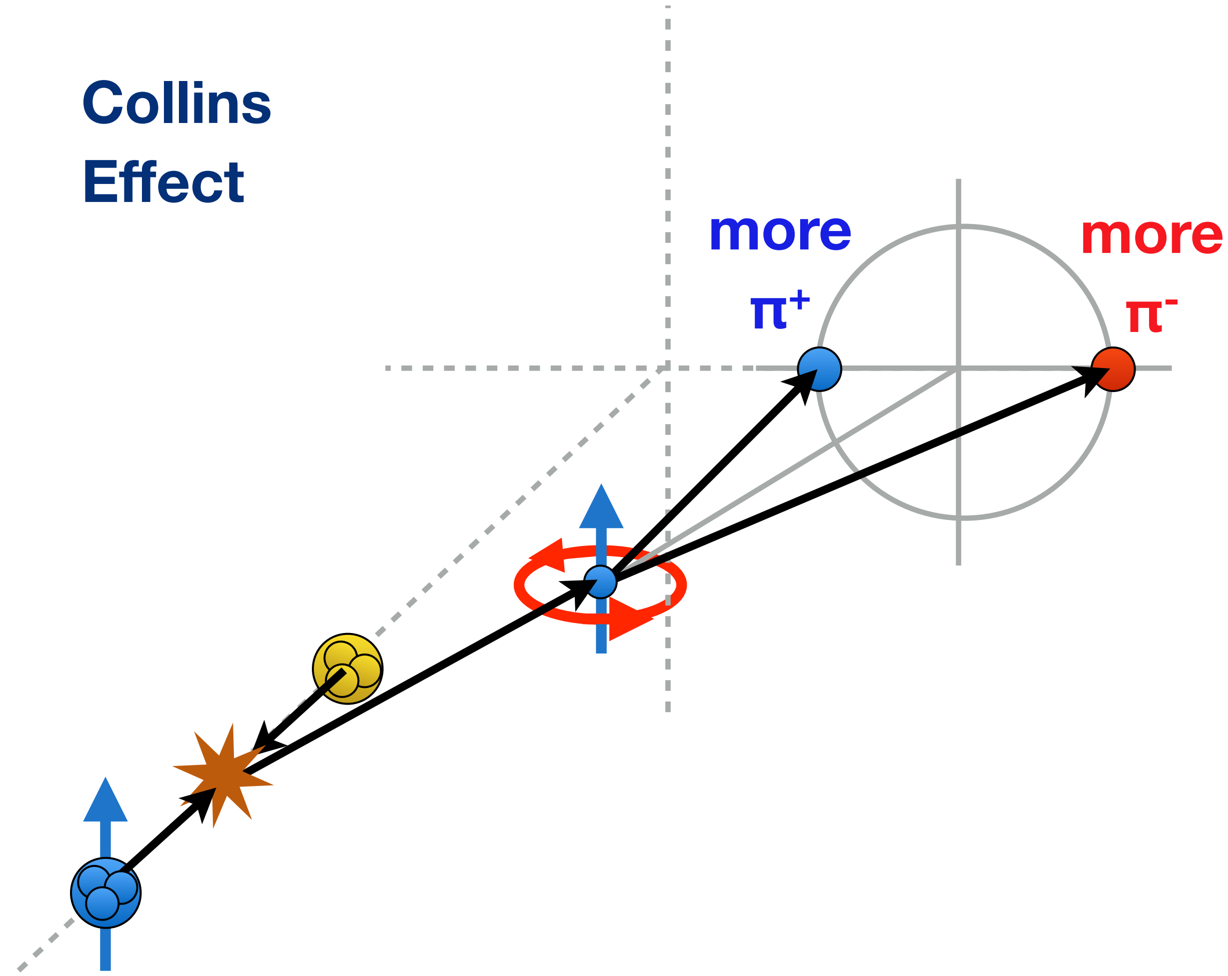


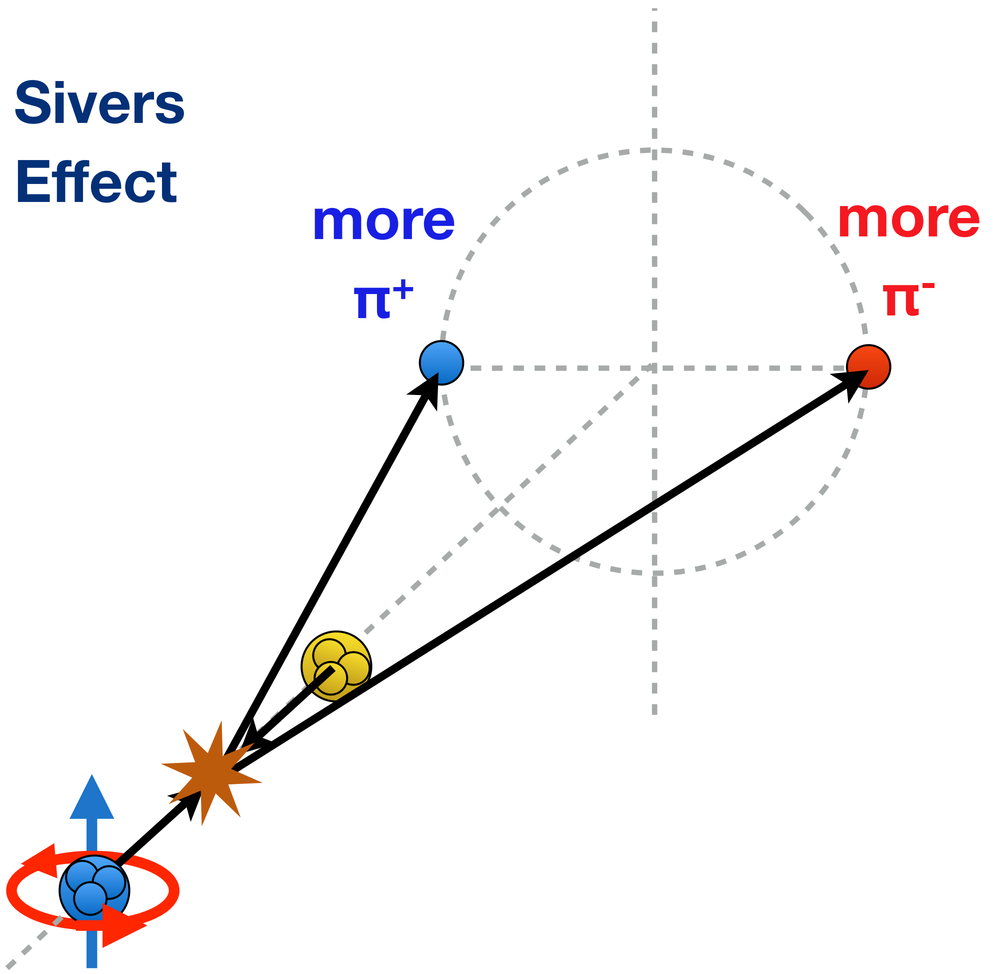
Correlation between proton and quark spin + polarized quark **fragmentation function**

$$\propto \delta q(x) \times H_{1}^{\perp}(z_2, \bar{k}_{\perp}^{2})$$

Source separation can be achieved by full reconstruction of the jet fragmentation

Physical Explanations

Sivers Effect



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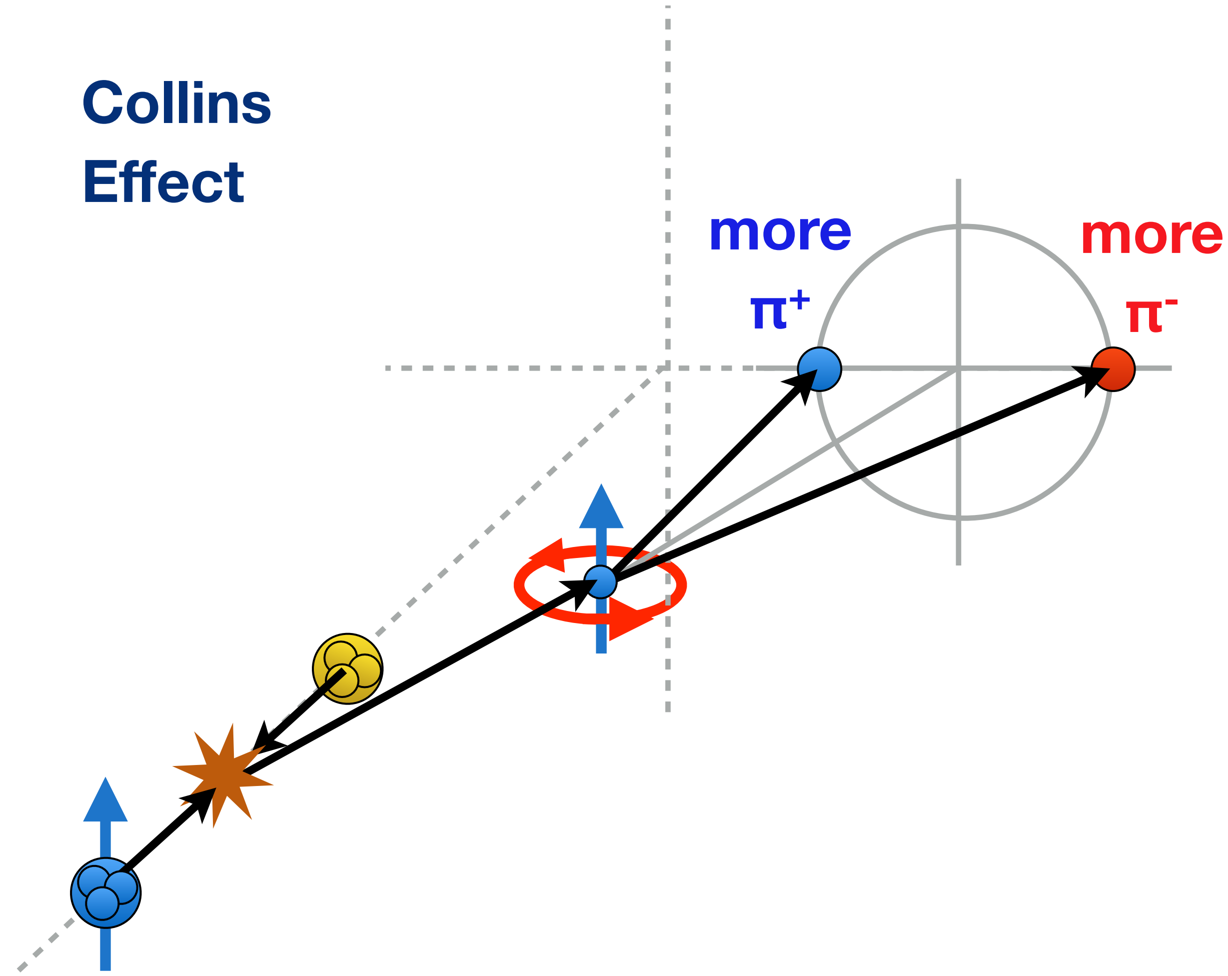
Collins Effect



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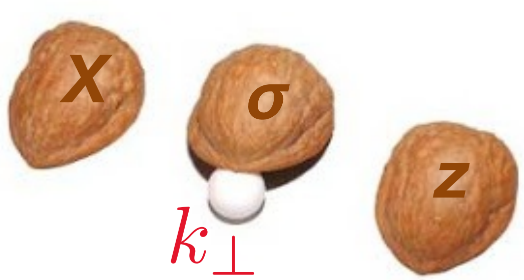


Higher-twist approach has parallels to above effects:

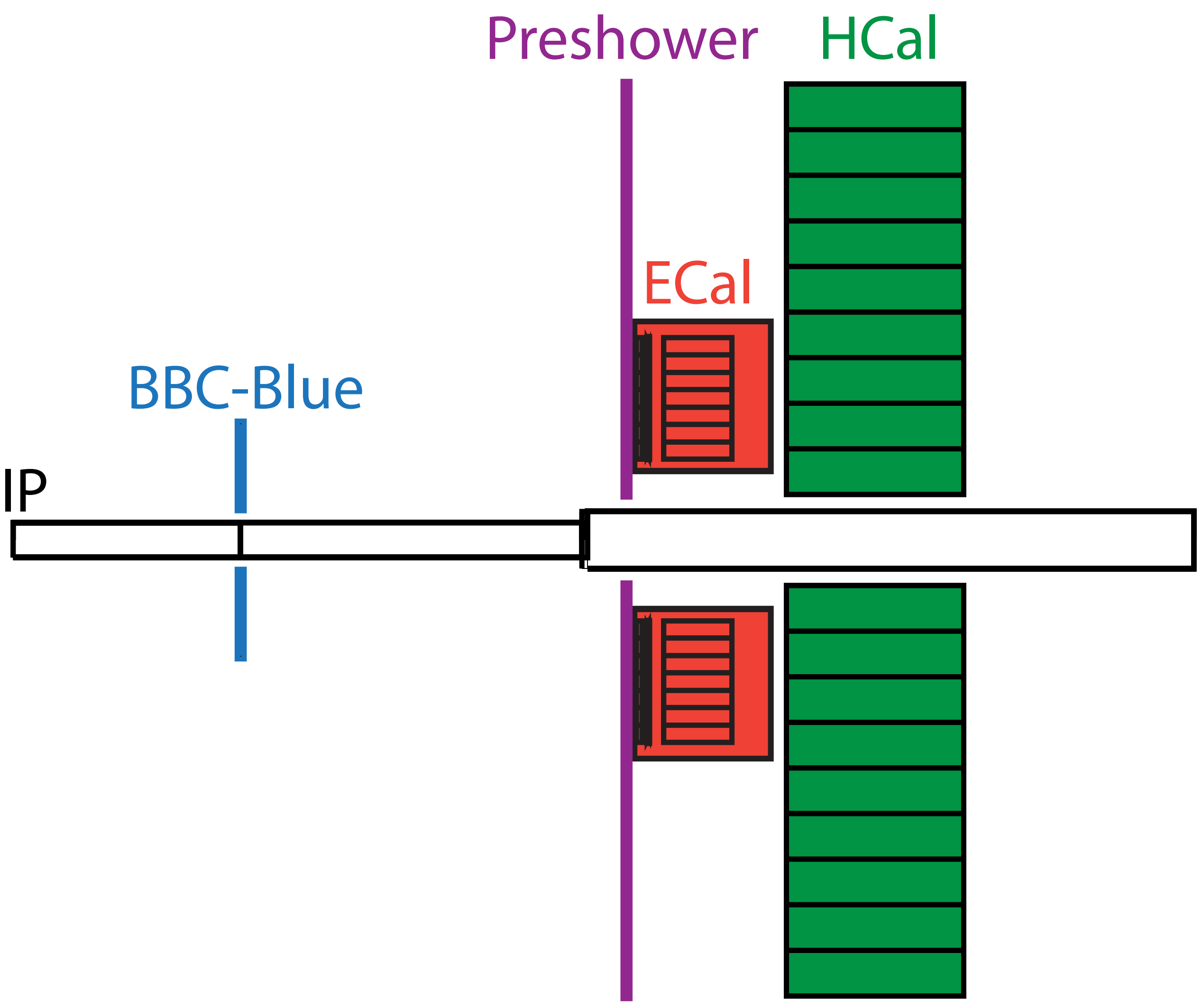
additional terms incorporated into extended pQCD calculation, different structure func.

predicts $A_N \sim 1/p_T$ at $p_T >>$ few GeV/c, in contrast to Collins

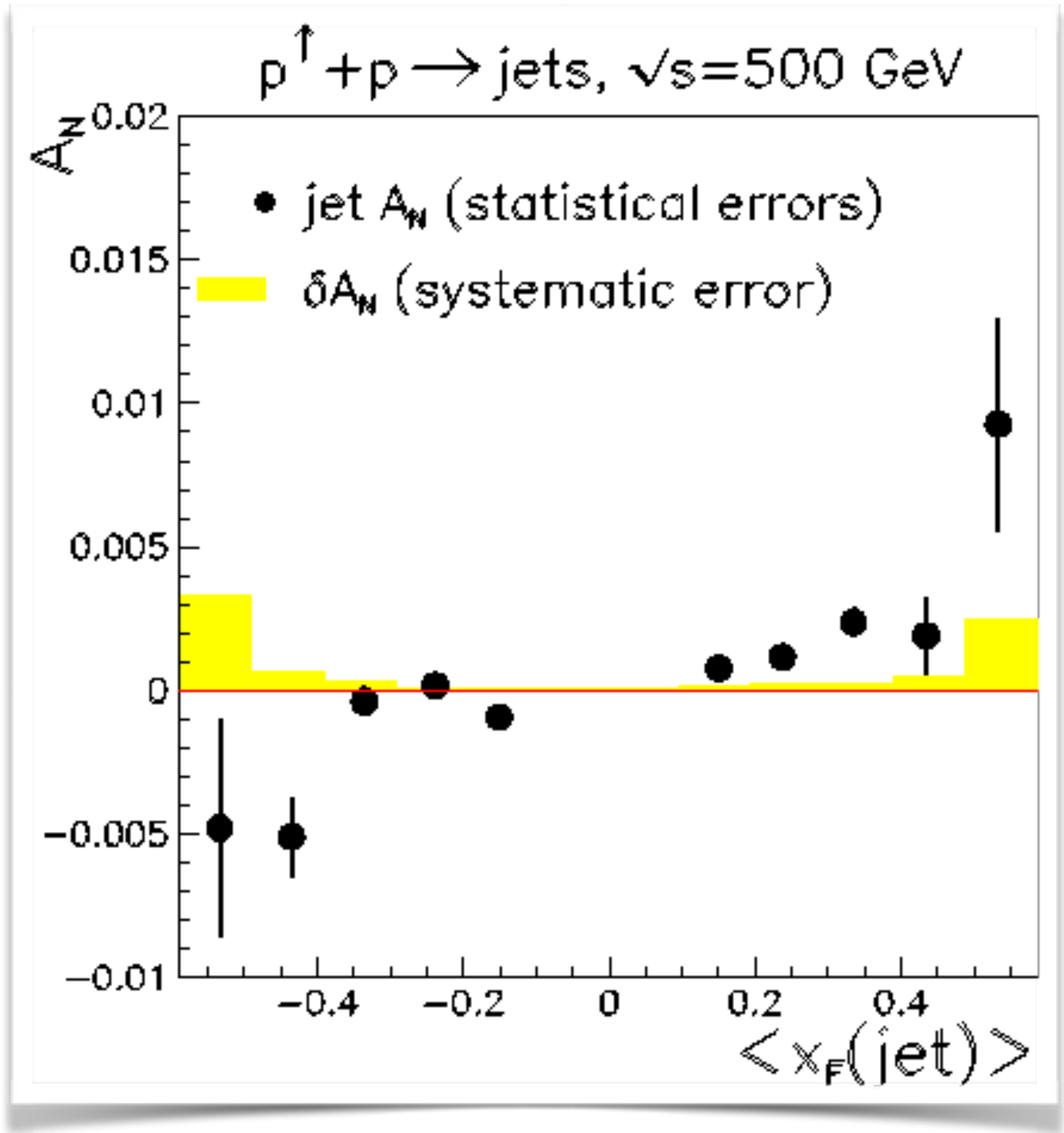
and so **requires high statistics large p_T measurements (aka inclusive 'jets')**

A_NDY Measurements

IP2/AnDY-Run11



A_N at $x_F > 0$ is "small and positive" ~ A_NDY, arXiv:1304.1454

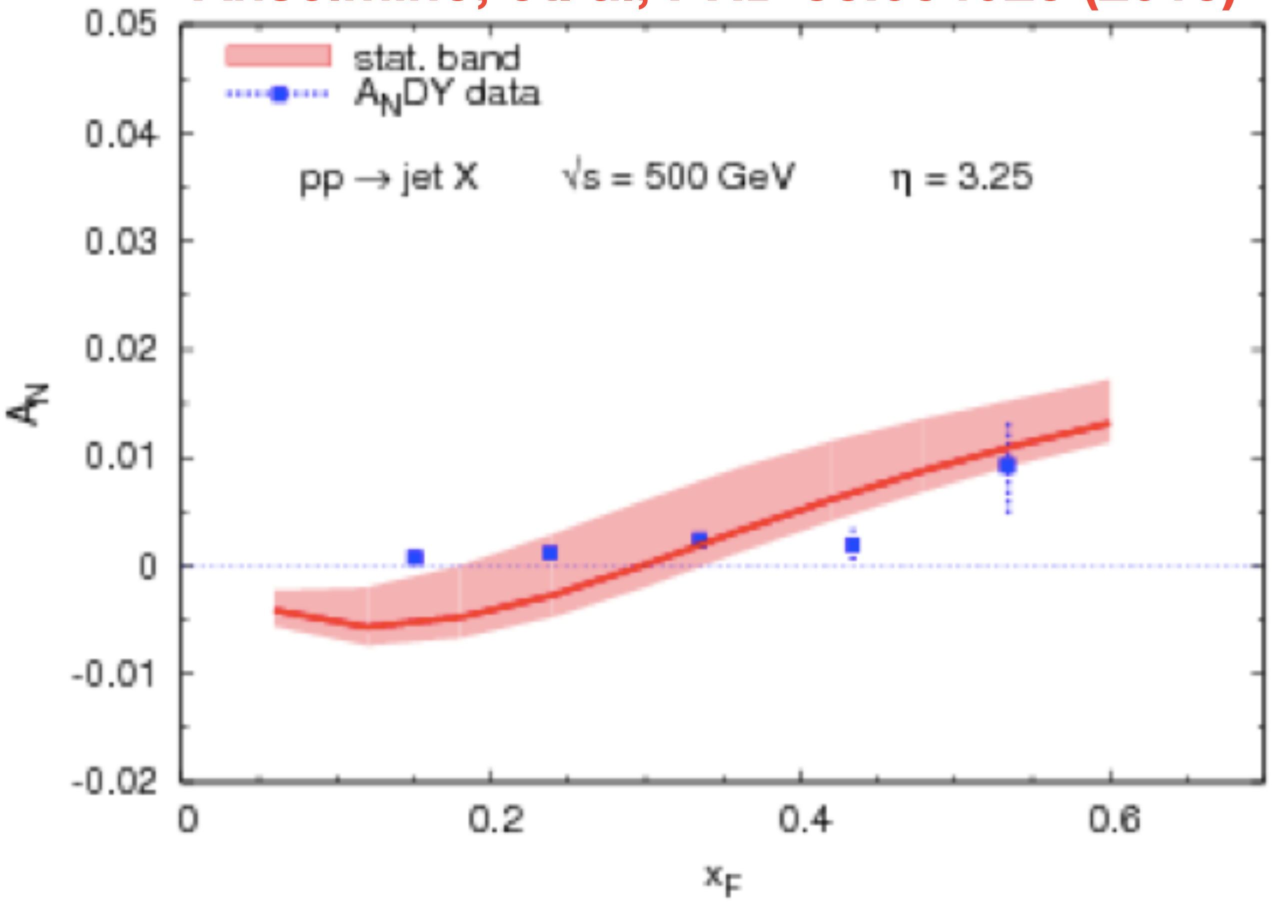


Forward HCAL for calorimetric jet reconstructions:

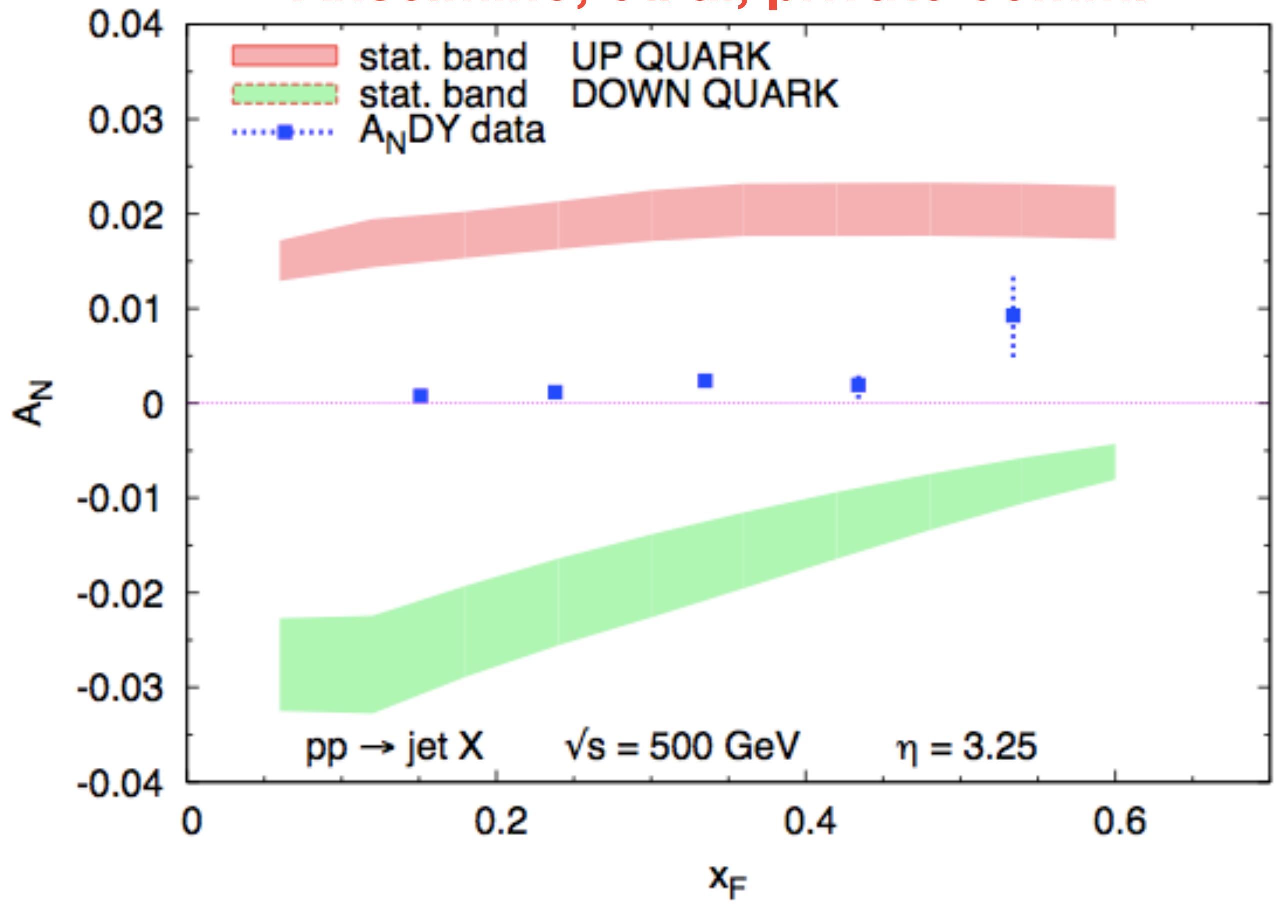
η_{jet} = 3.00-3.50

A_NDY Interpretation

Anselmino, et. al, PRD 88:054023 (2013)



Anselmino, et. al, private comm.



Modest jet A_N values are believed to **require a large cancellation** between contributions of up and down quark jets

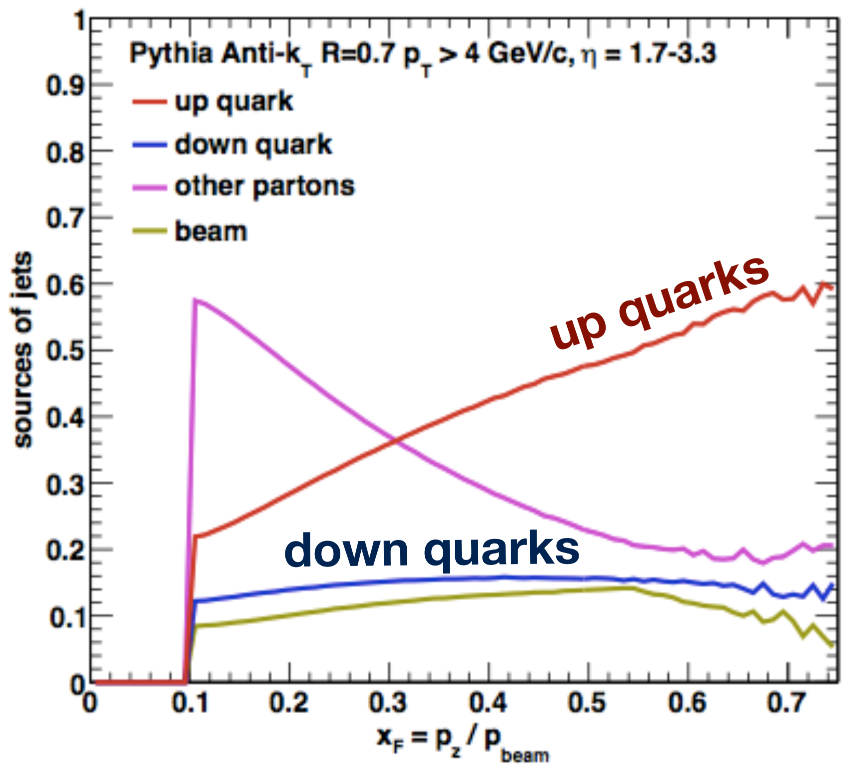
With charged particle tracking and large acceptance, **we will be able to separate these sources**

Changing the Mix

The Idea: cut on electromagnetic charge within the jet

Most Primitive Approach: cut on leading charge, z > 0.5

all jets



natural admixture
of jet sources

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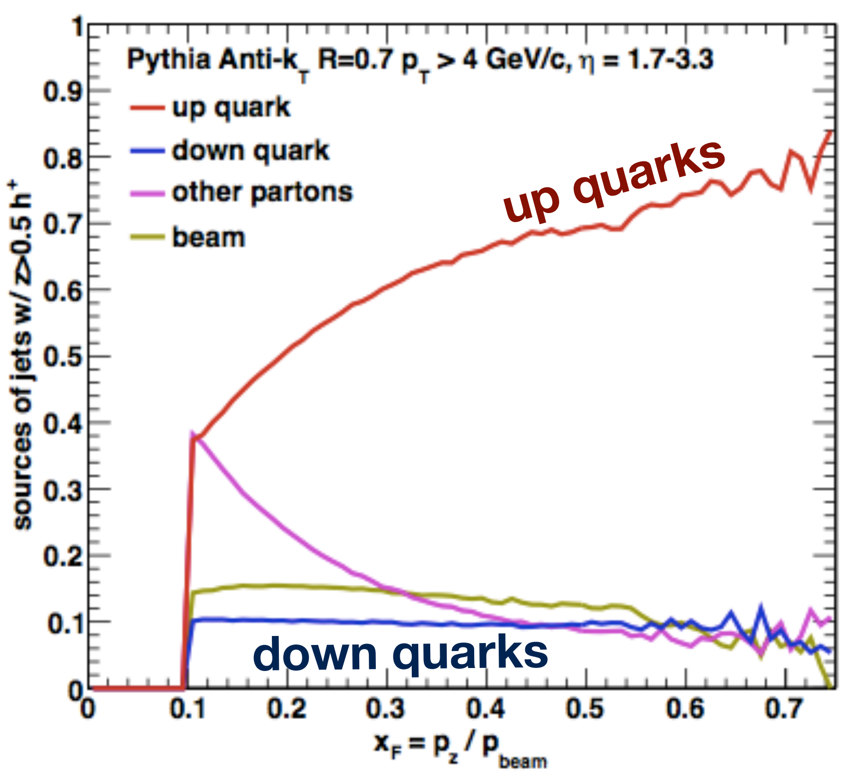
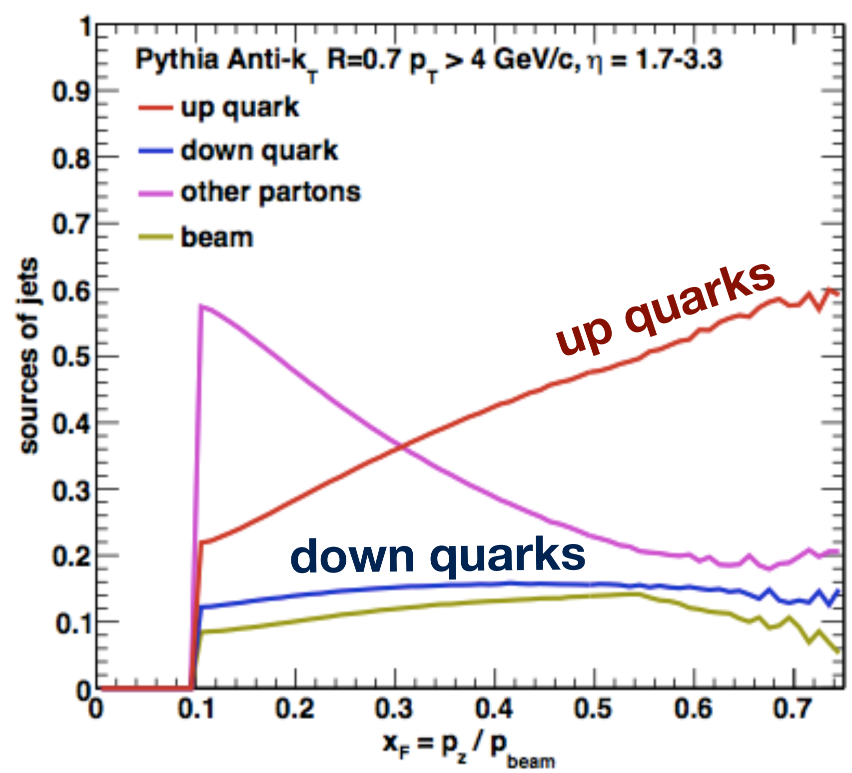
leading positive charge ← **all jets**





largely clean extraction of up quark jets

natural admixture of jet sources

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The Idea: cut on electromagnetic charge within the jet

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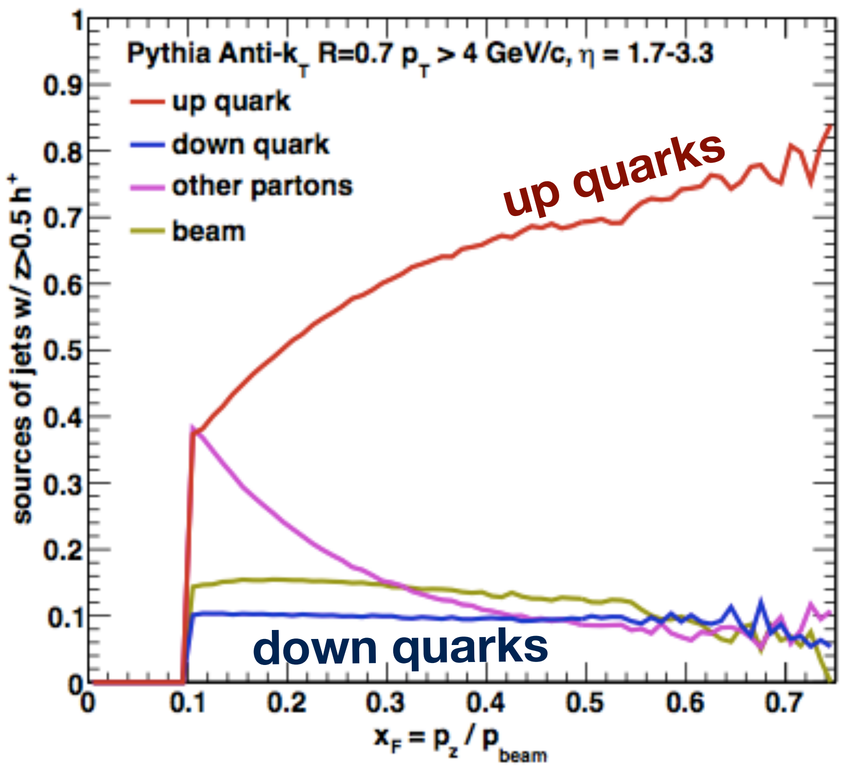
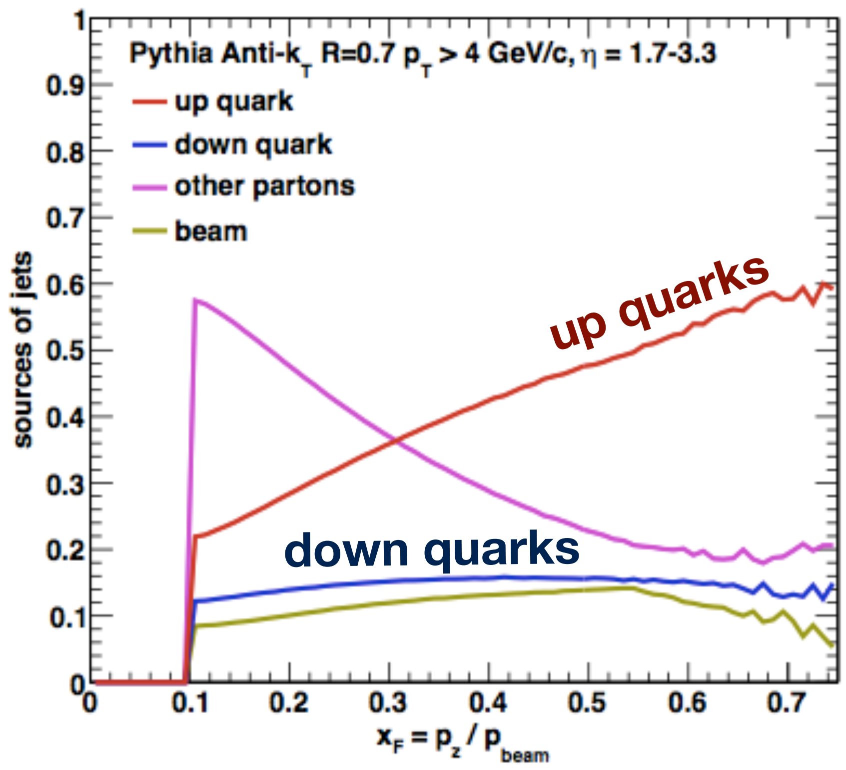
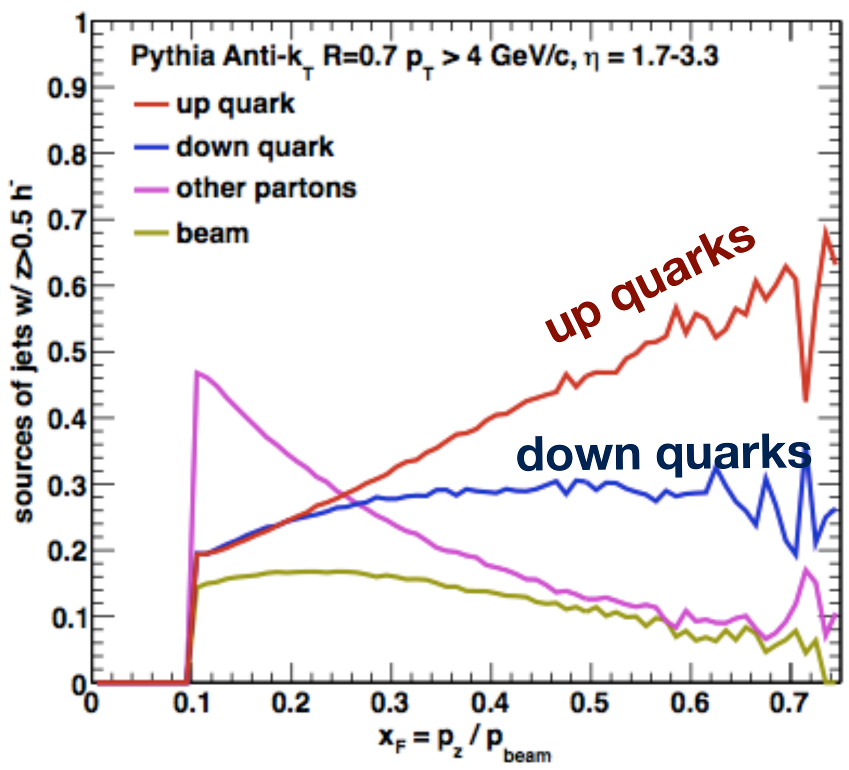
leading positive charge ← **all jets** → **leading negative charge**





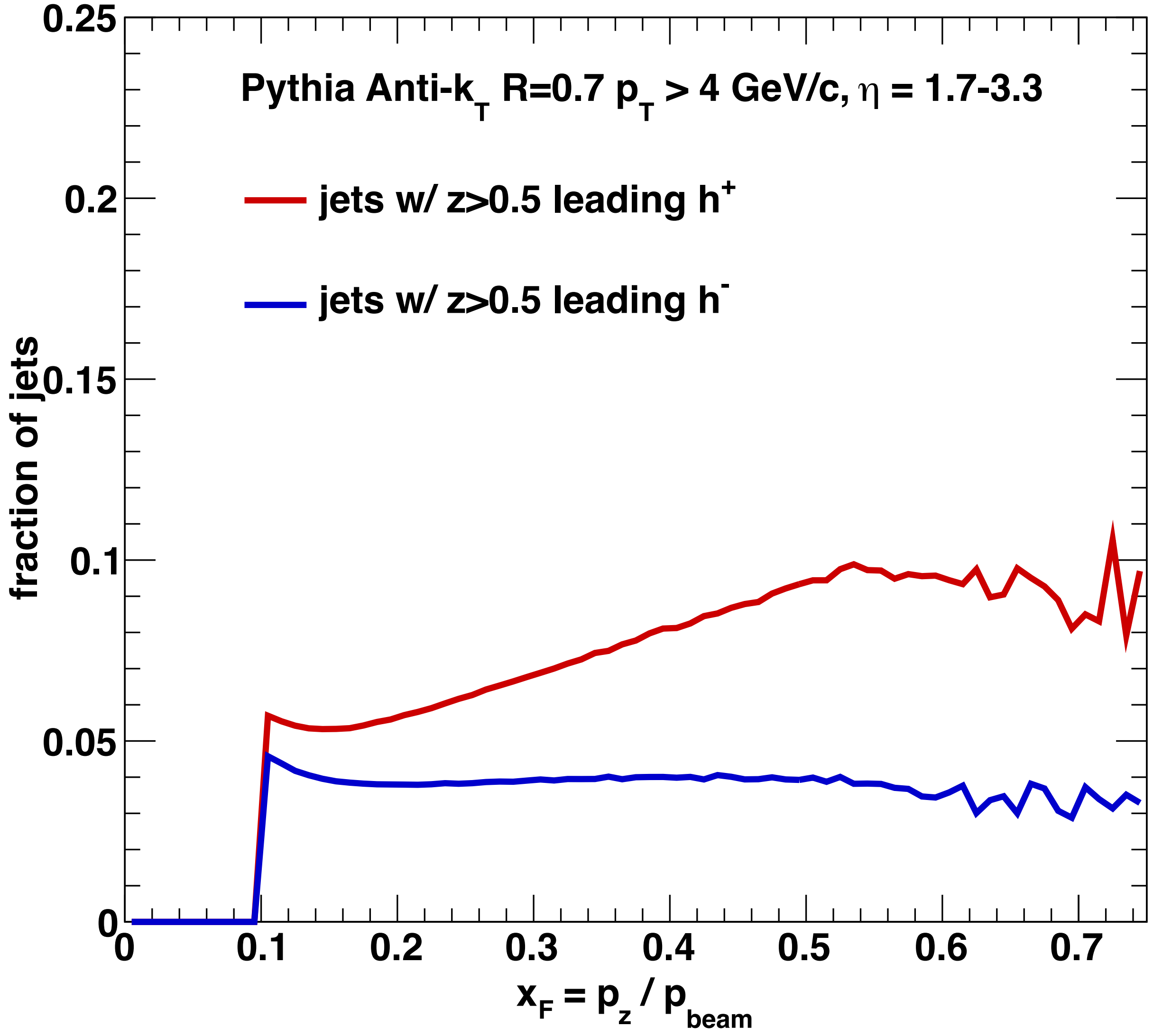


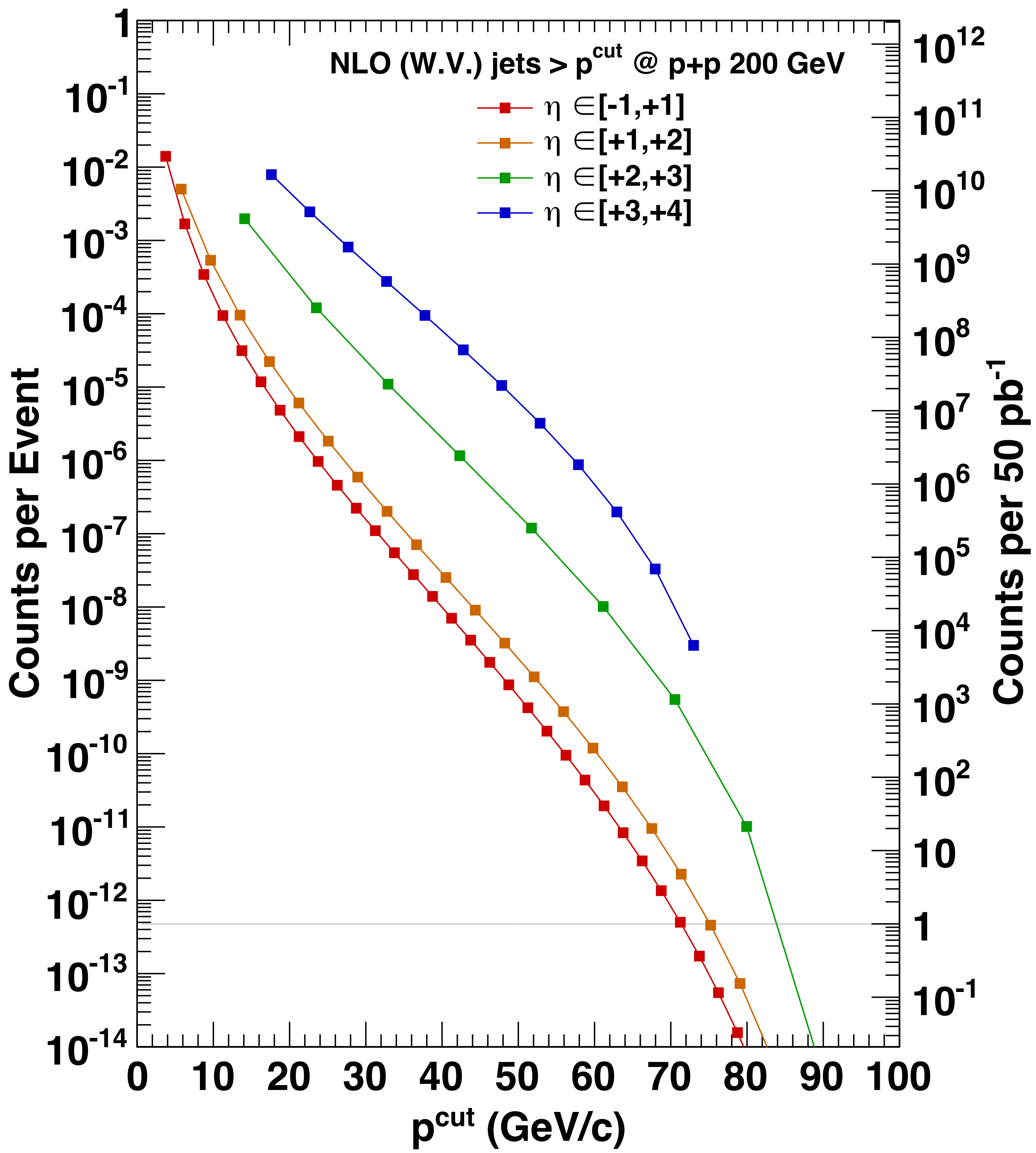
largely clean extraction of up quark jets

natural admixture of jet sources

enrichment of down quark jets

Charge Sign Selection





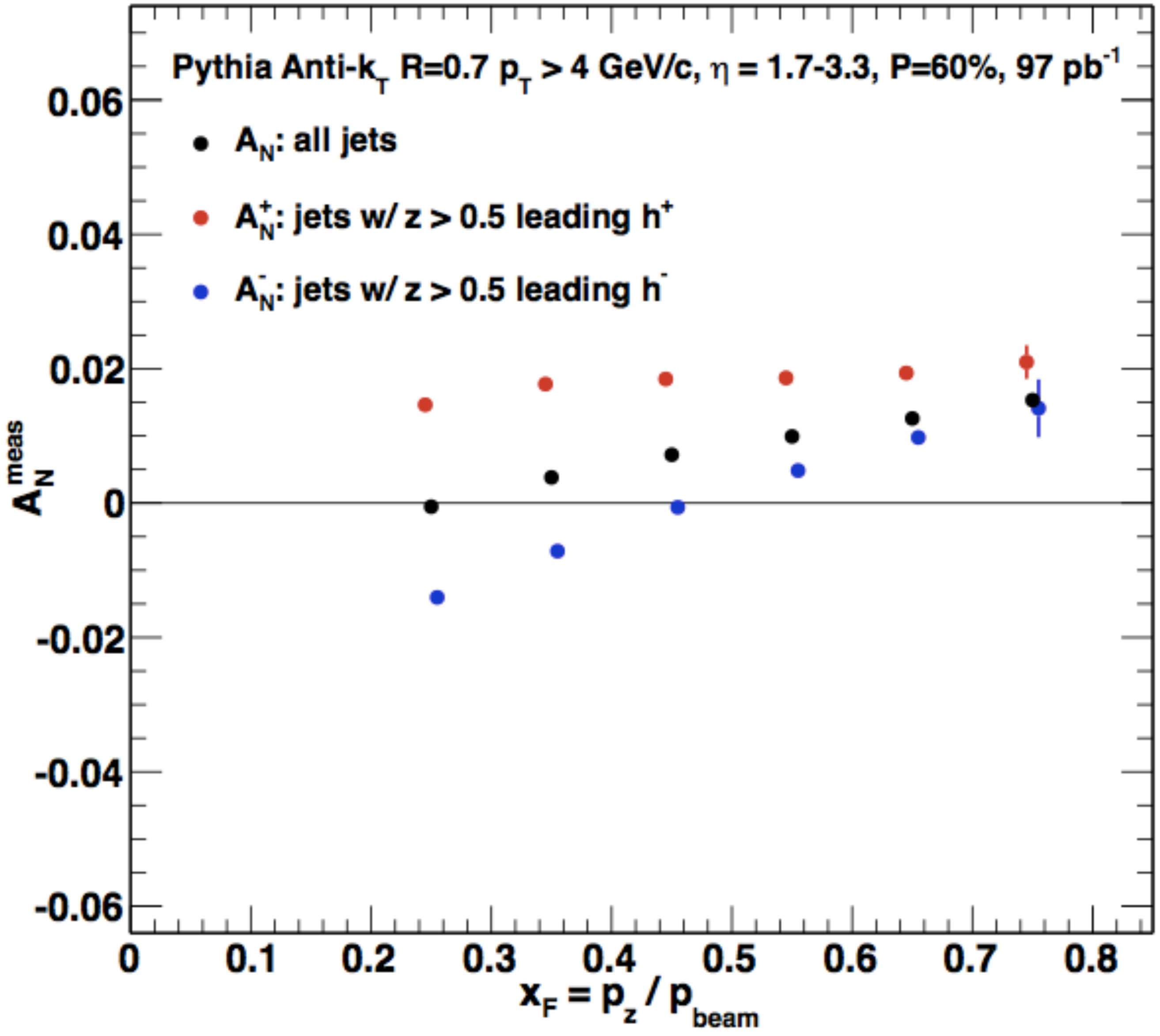
leading charge sign occurs in 10-14% of jets

fewer negative charge sign jets

however… copious jet production will allow a reach up to x_F ~ 0.7 with these cuts

Example Up & Down A_N Extraction

measured A_N
with leading charge sign jets



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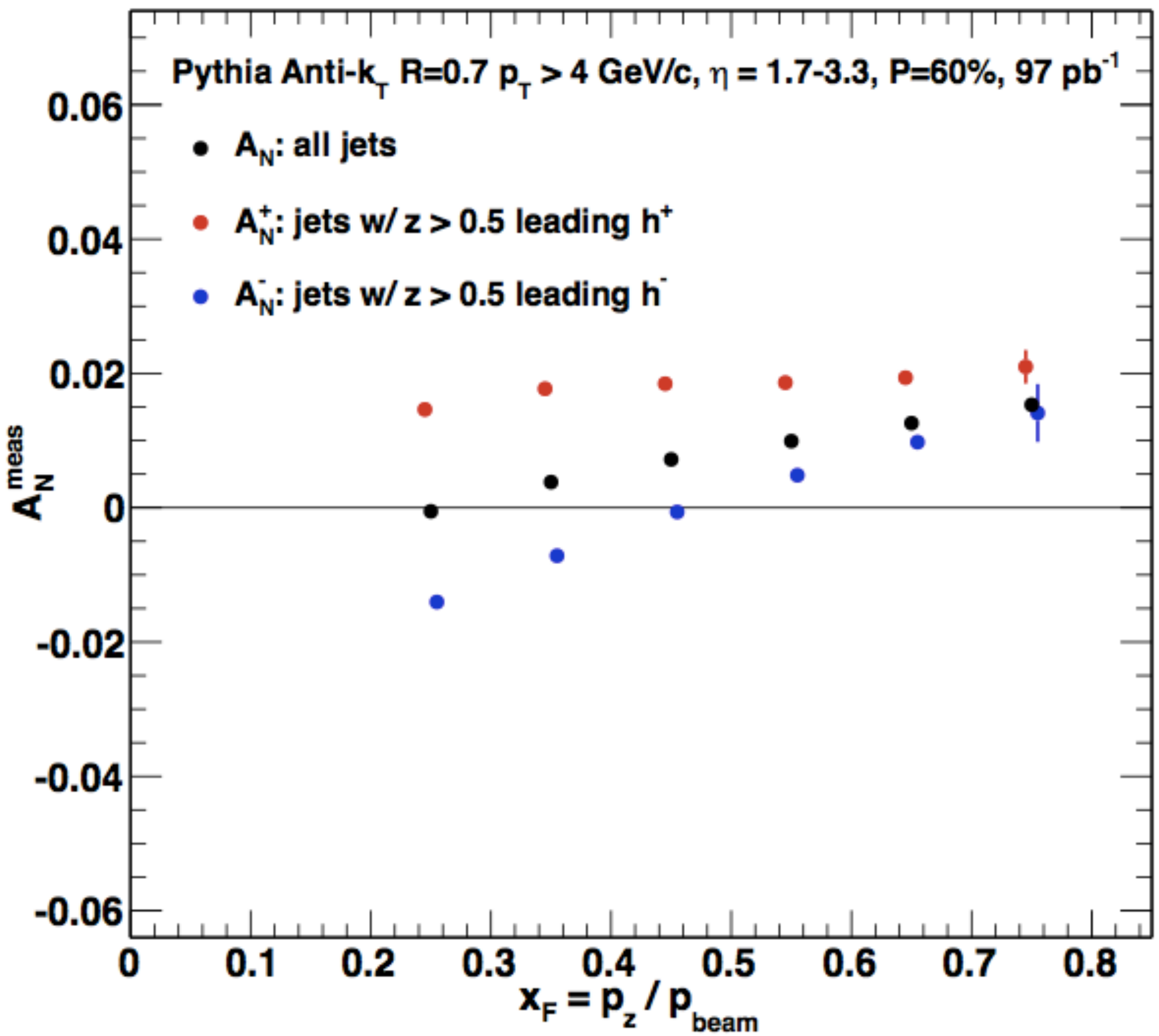
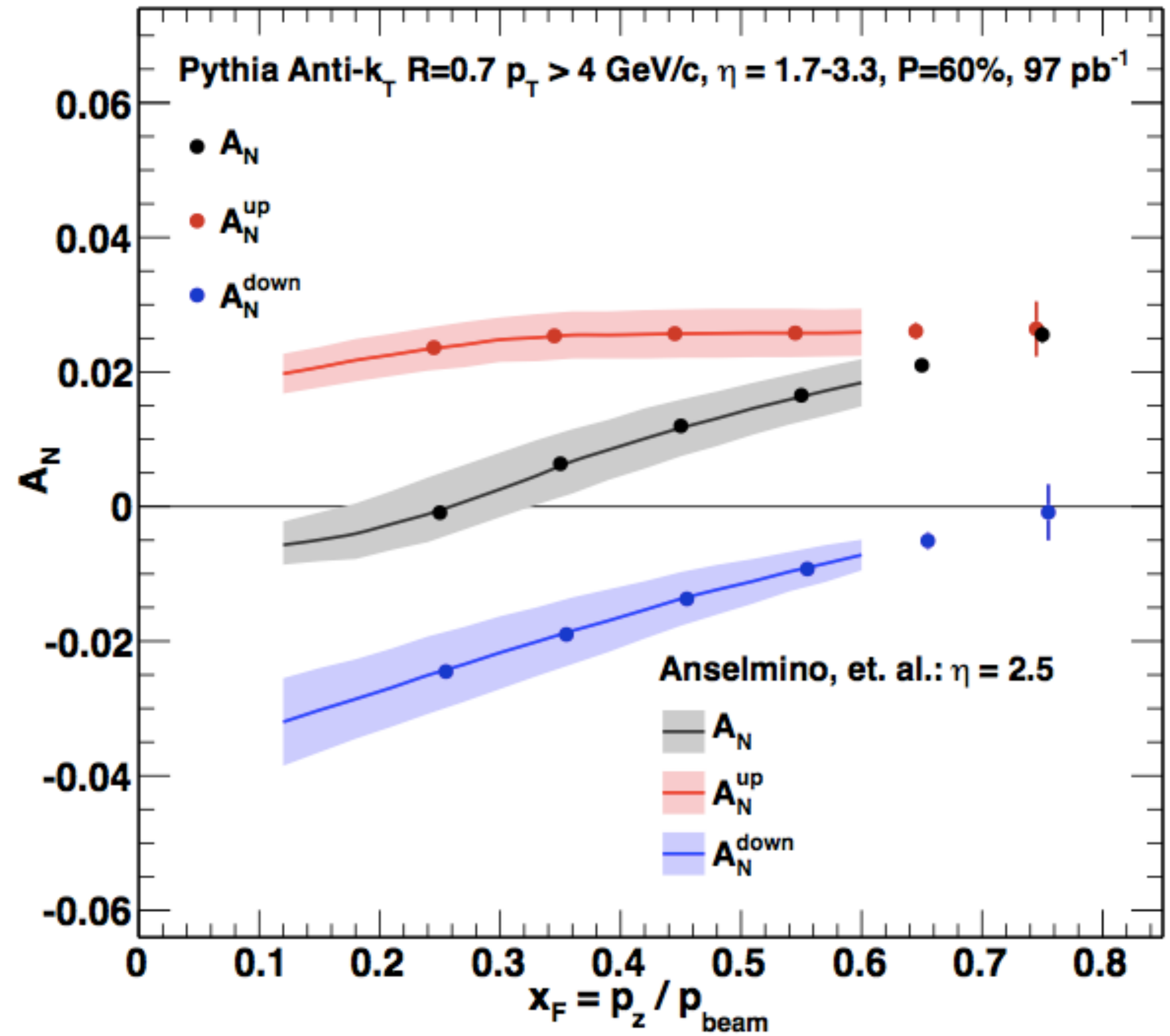
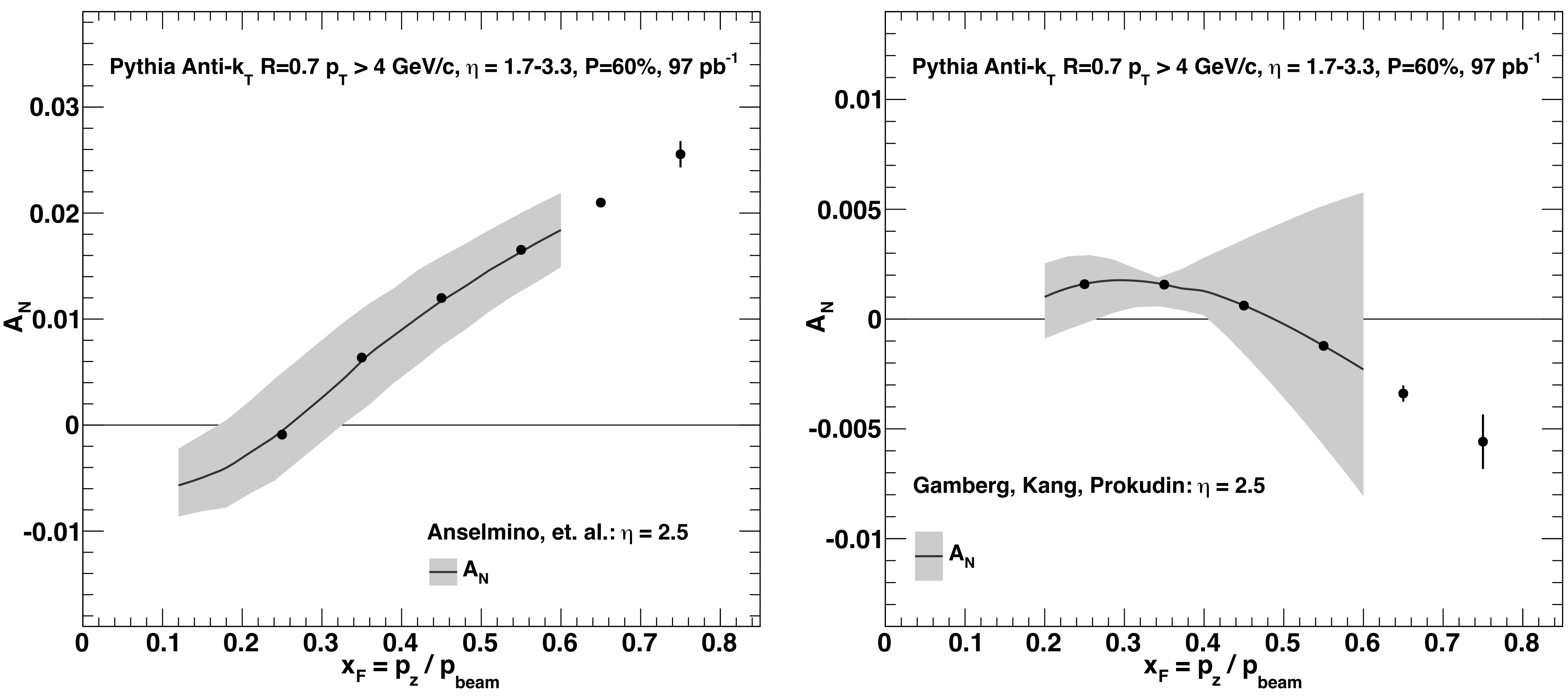


extracted quark A_N against model inputs

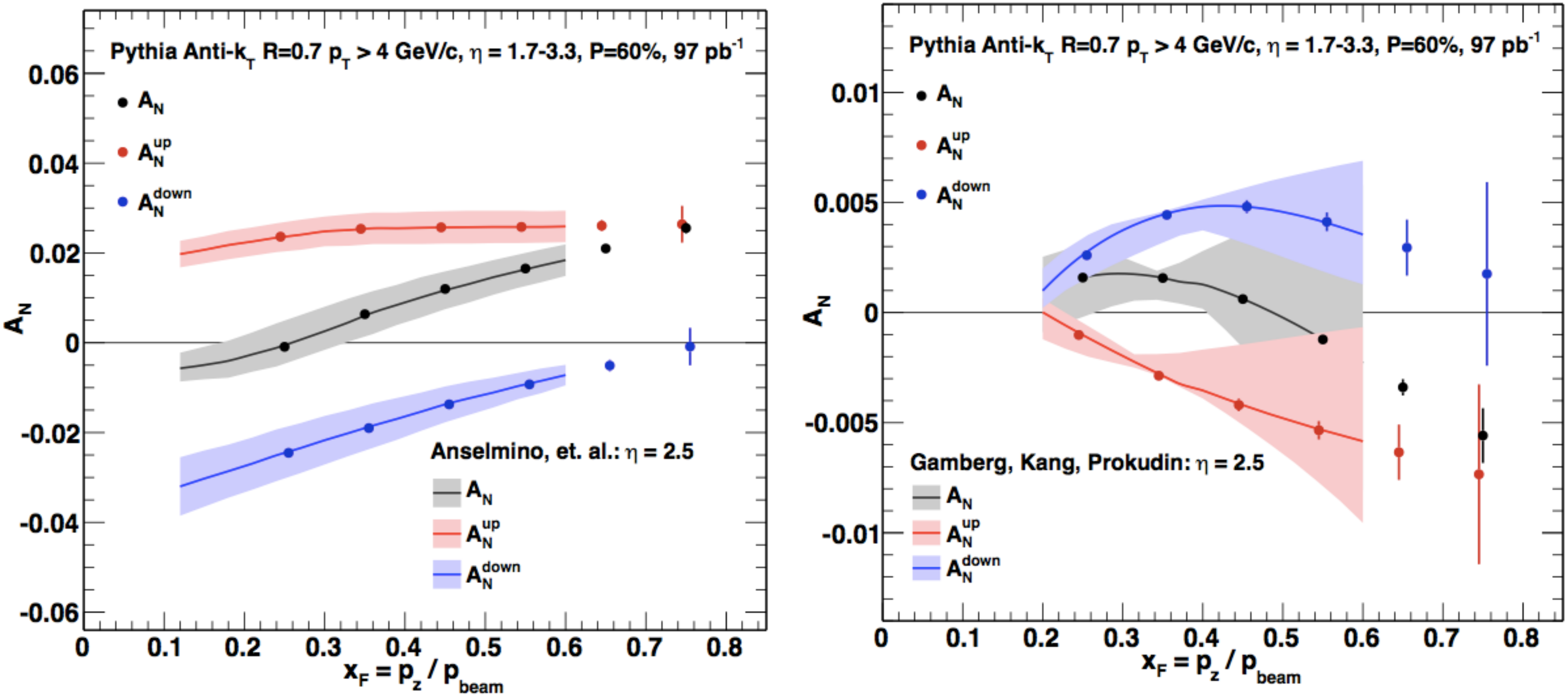


Different Models, Different Expectations



new kinematic window (beam energy, pseudorapidity) will give a different set of results than was found at A_NDY and framework results diverge away from this experimental constraint

Different Models, Different Expectations II

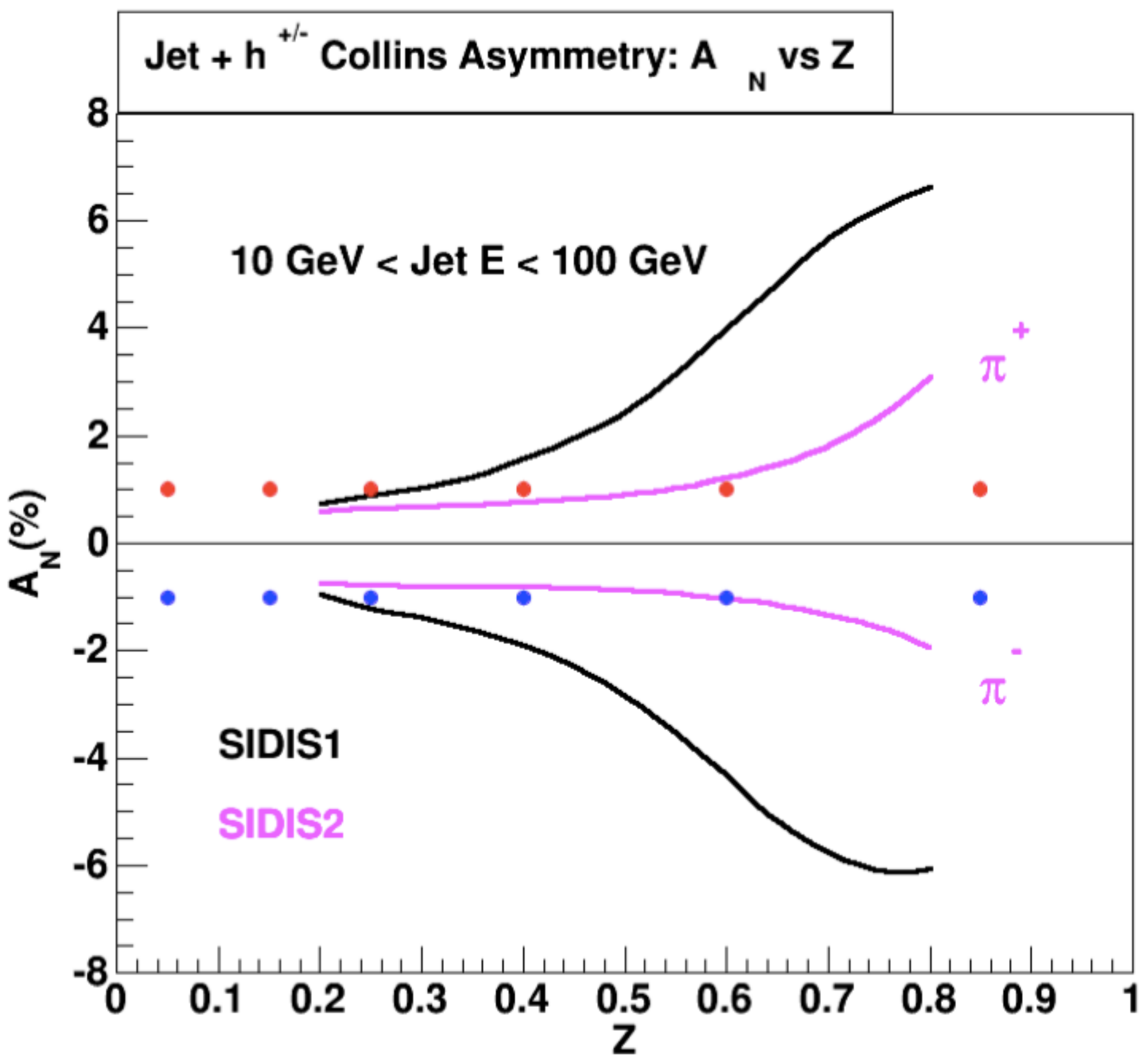


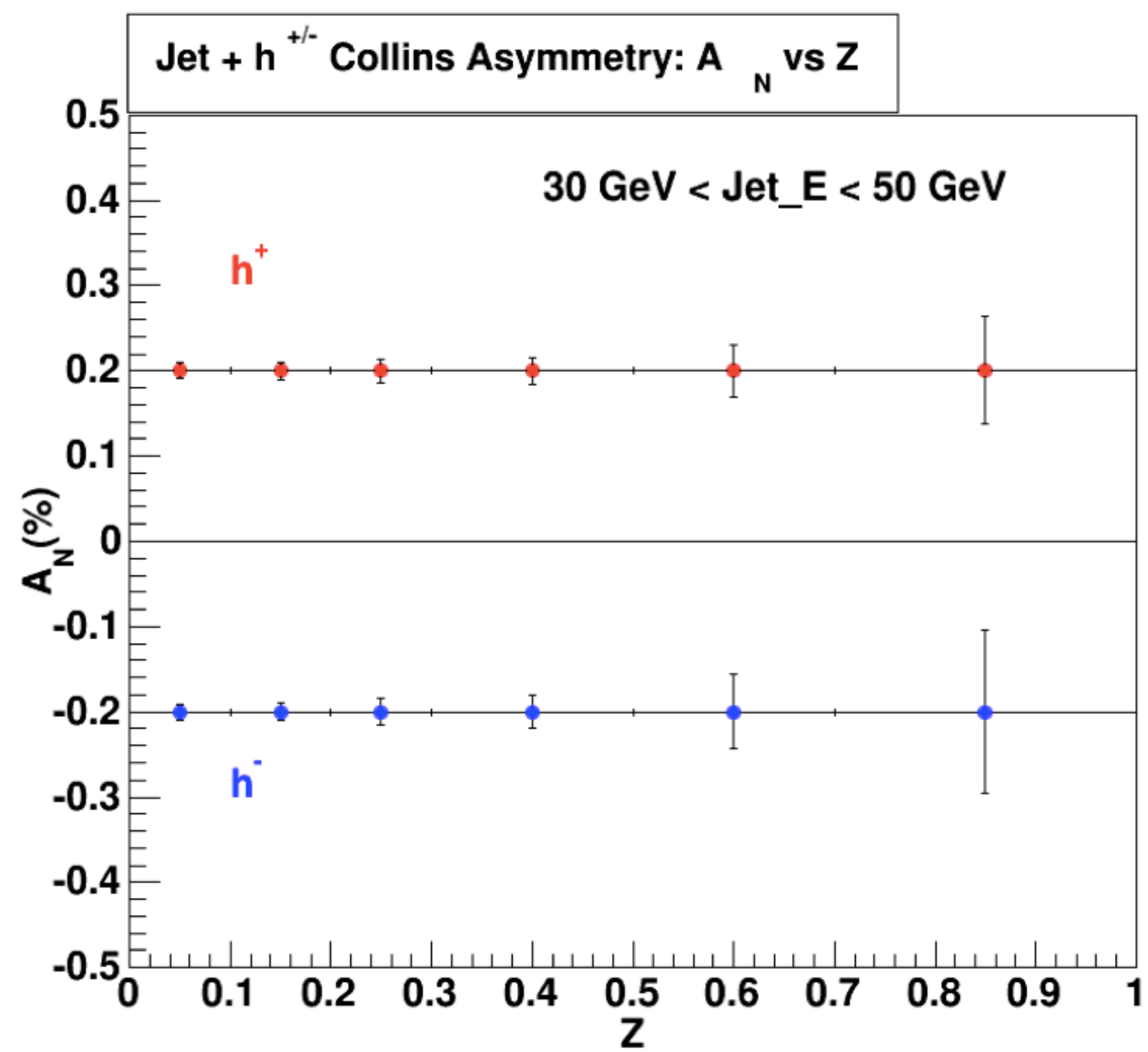
opportunity to distinguish between leading process-dependent models at very large x_F

similar physics goal as direct photon and DY

Jet Substructure

Simultaneous measurements of…

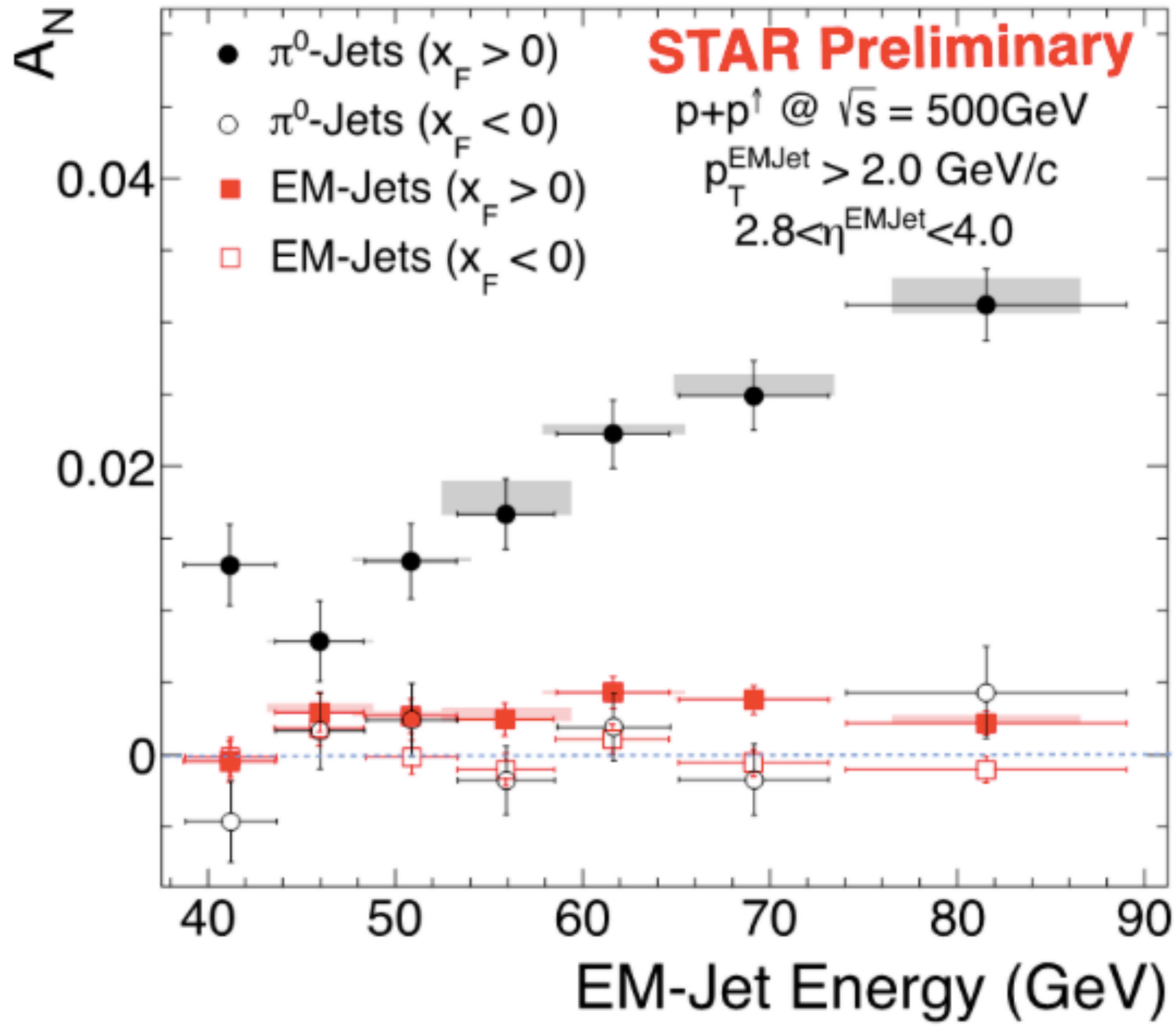




Direct access to
Collins physics within the jet

High statistics at
large jet energies

STAR Forward Calorimetry

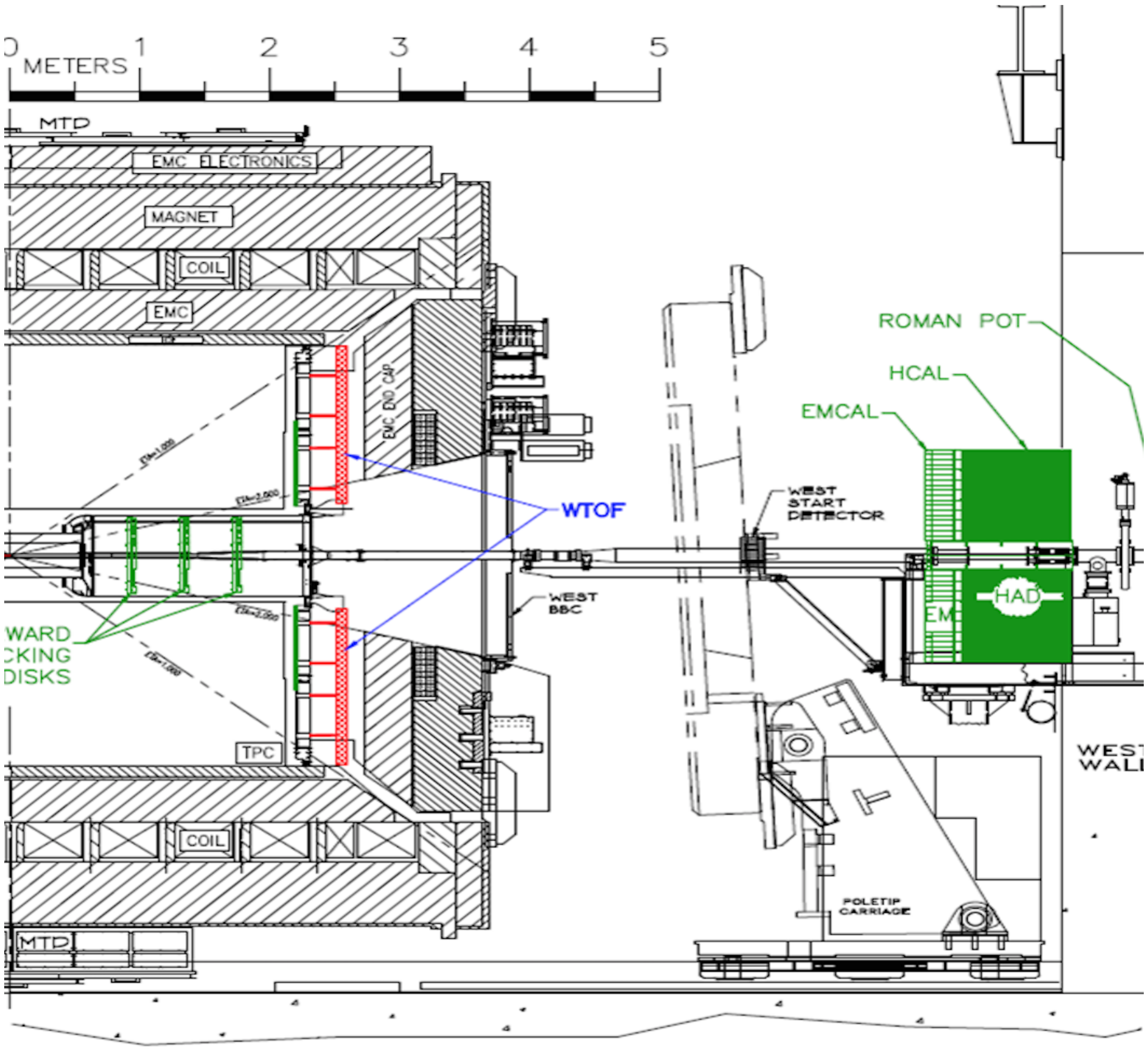


Forward EMCal has allowed STAR to begin a forward jet program.

Intriguing event activity preliminary results.

STAR Extension Concept

Tracking disks



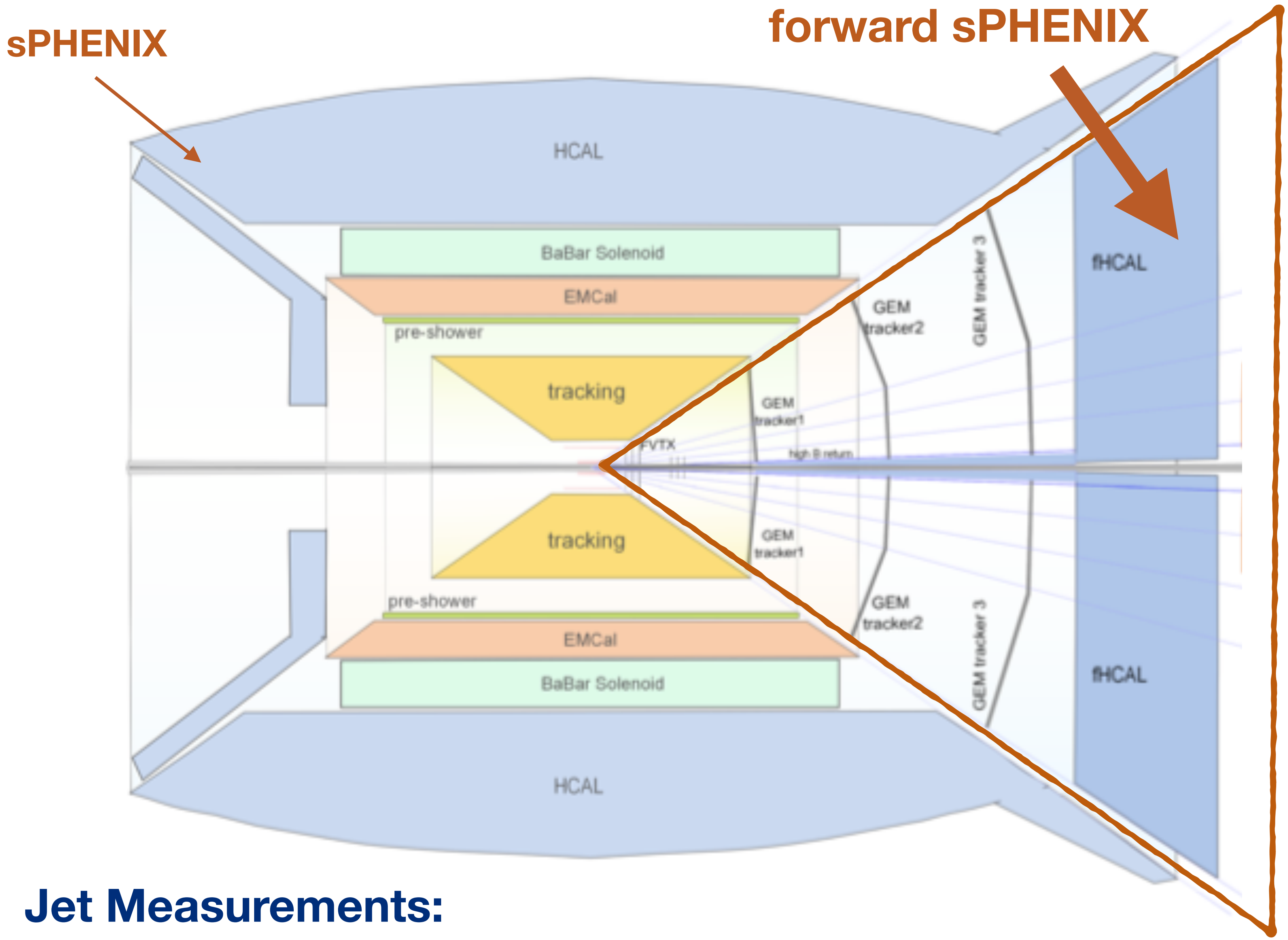
Forward EMCAL + HCAL

Roman pot

"detection capability for … jets and leading hadrons"
~ STAR

More: https://drupal.star.bnl.gov/STAR/starnotes/public/sn0605

sPHENIX Extension Concept



Jet Measurements:

(1) hadronic calorimeter
(2) GEM tracking
(3) field shaping piston
(4) Roman pots?

More: http://www.phenix.bnl.gov/phenix/WWW/publish/dave/sPHENIX/pp_pA_whitepaper.pdf

Summary

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2. The gauge invariance requirement of QCD results in the **"process dependence behavior"** of Sivers-type distribution that **can be witnessed by jet measurements**

3. A_NDY's jet A_N measurement (**small asymmetries**) is understood as an almost exact **cancellation between up and down quark** Sivers-type effect.

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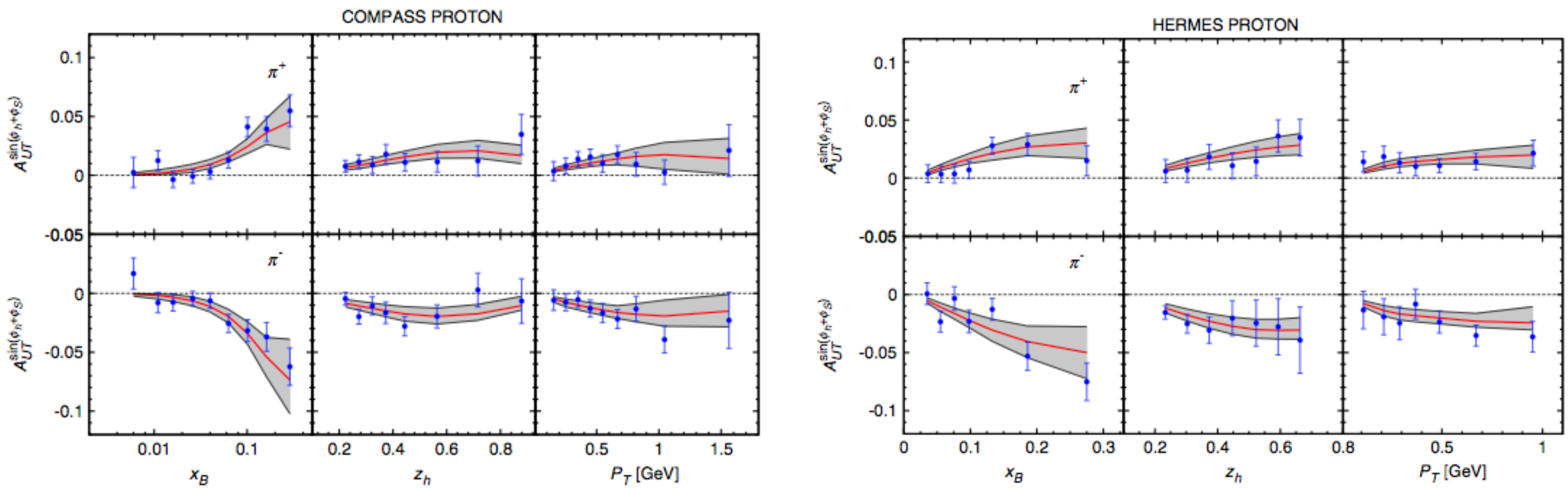
Extras

Attempts to Understand RHIC data

(1) Describe **SIDIS and e^+e^- data** with a combination of Sivers and Collins contributions

key issue: limited x_F coverage of existing data

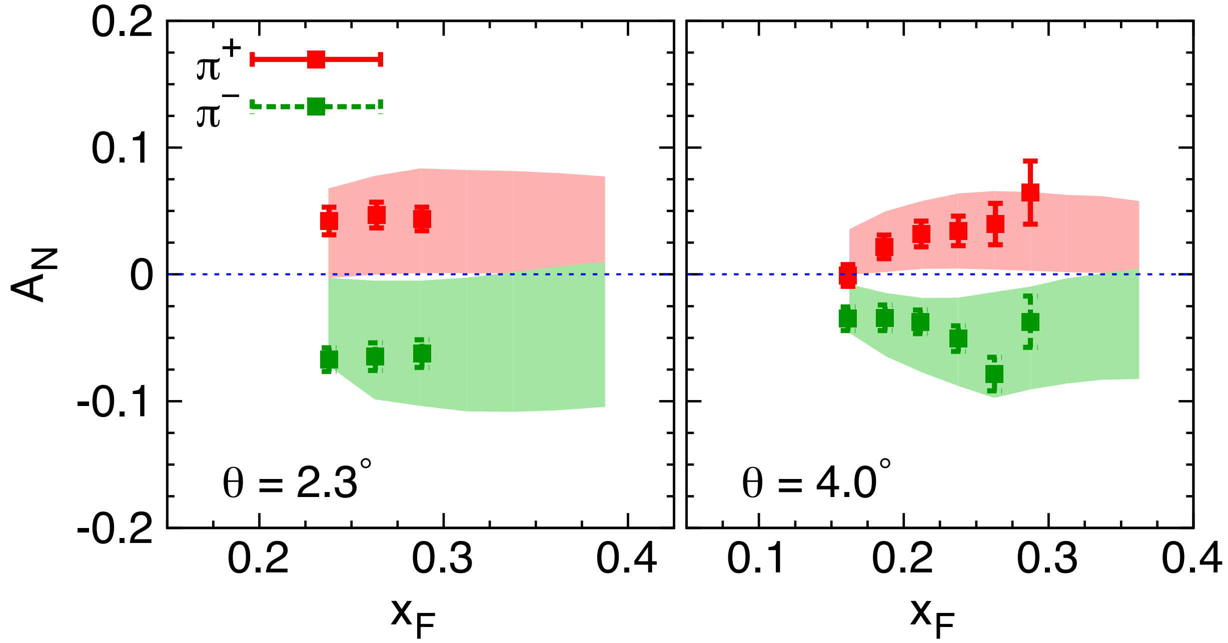


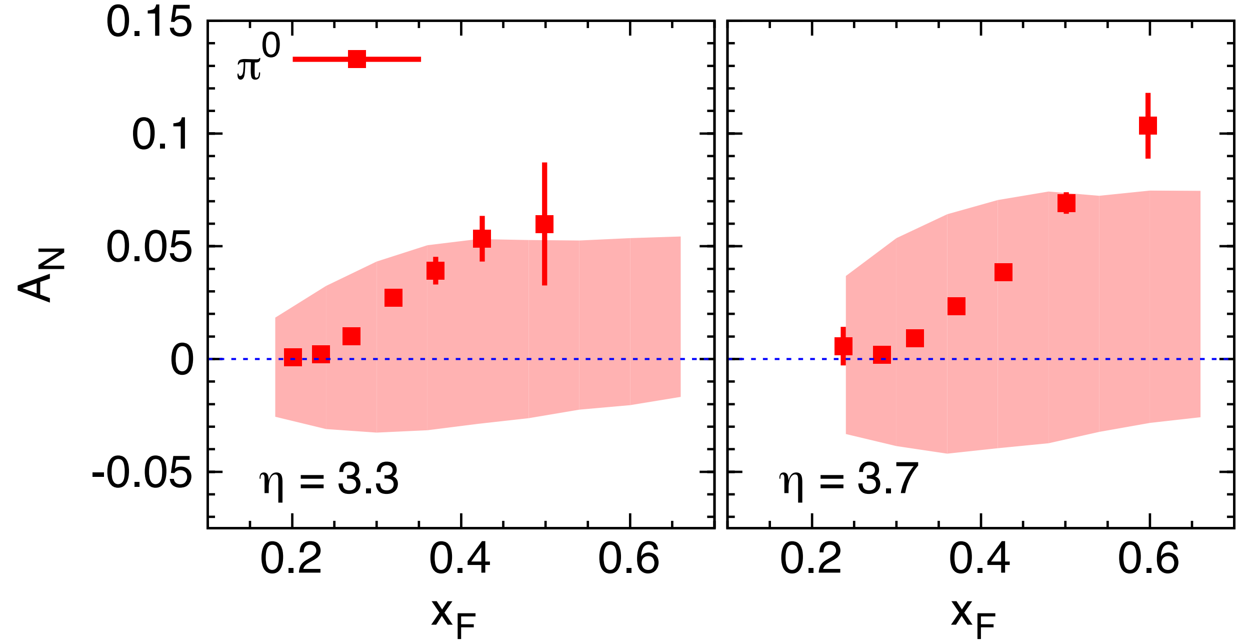
see: M. Anselmino, et al. Physical Review D **87**, 094019 (2013)

(2) **Extrapolate to larger x_F** and Q^2 for p+p collisions at RHIC

(3) **Make Sivers- and Collins-only projections** against the RHIC single particle data constrained by the SIDIS and e+e- data

Sivers-only RHIC Projections

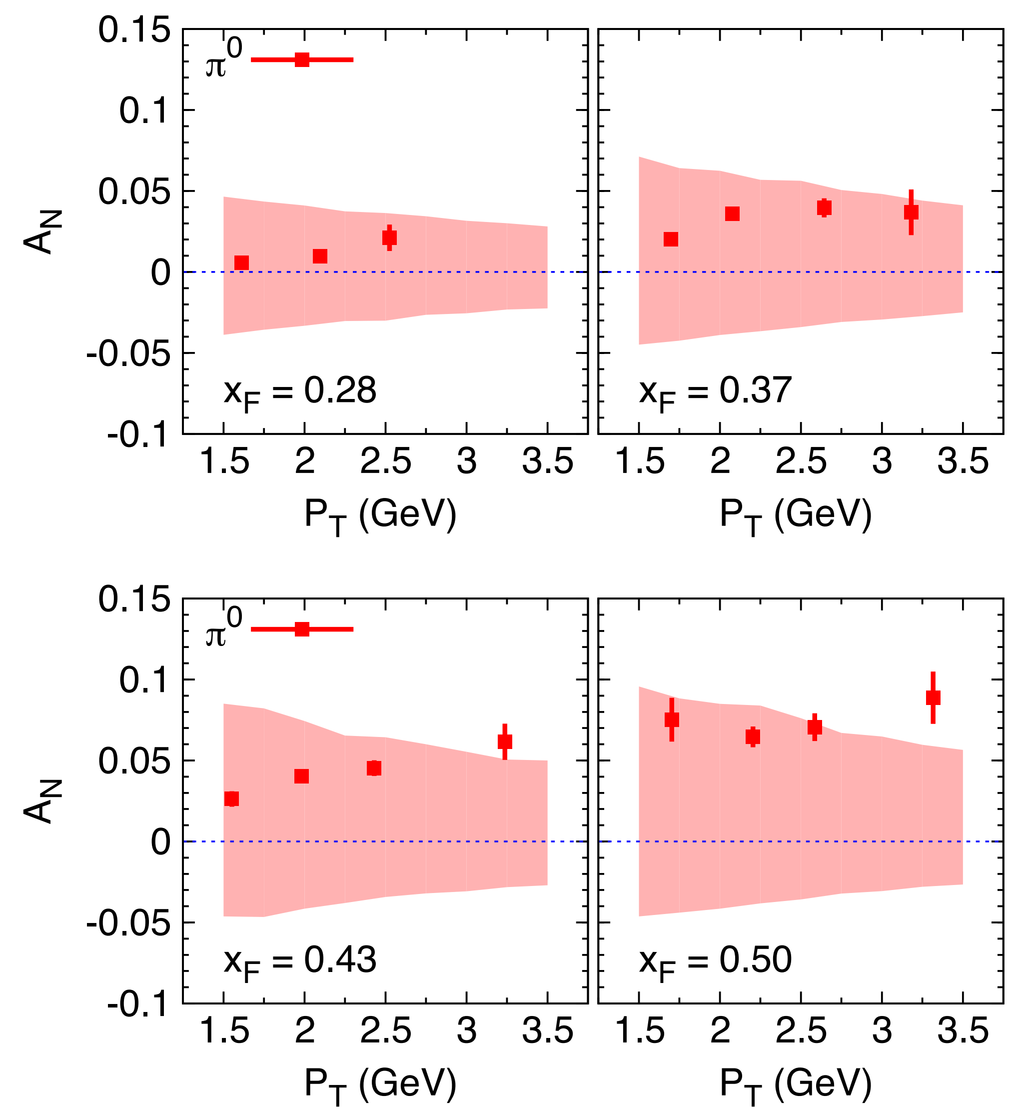




Sivers projections from SIDIS and e⁺e⁻ onto RHIC data have **large known and unknown theoretical uncertainties**

> *"can only be considered as a phenomenological model for hadronic process"*

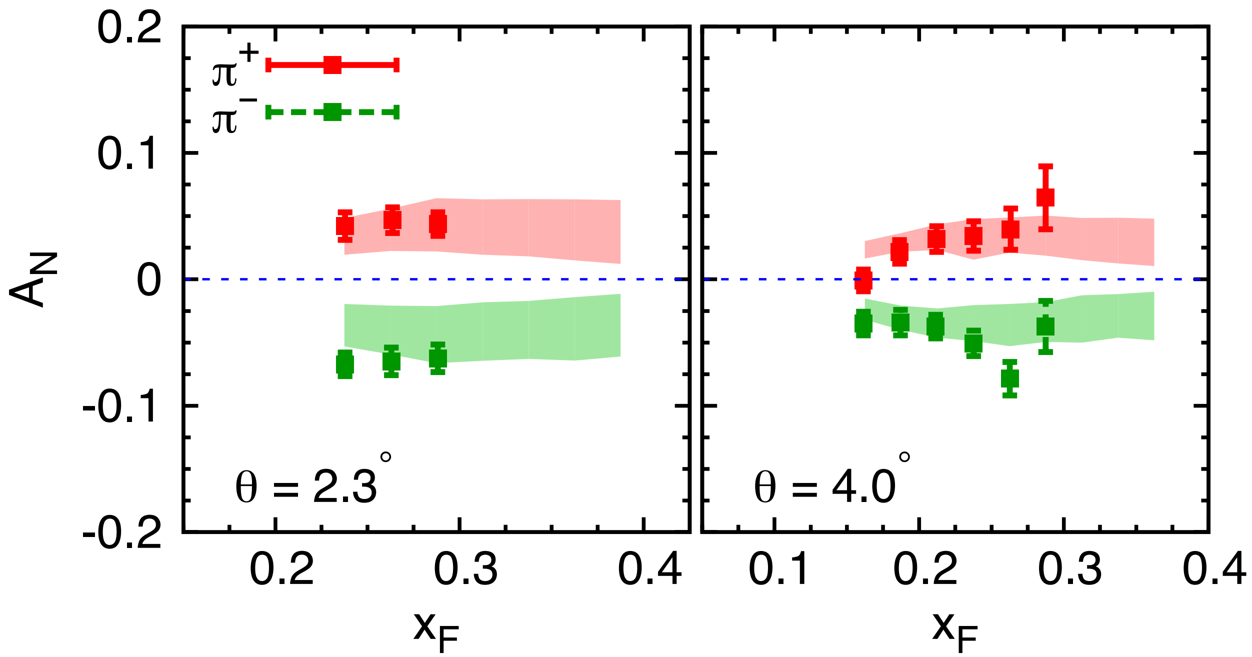
> *"the large x behavior of the Sivers function could not, and still cannot, be constrained by SIDIS data"*

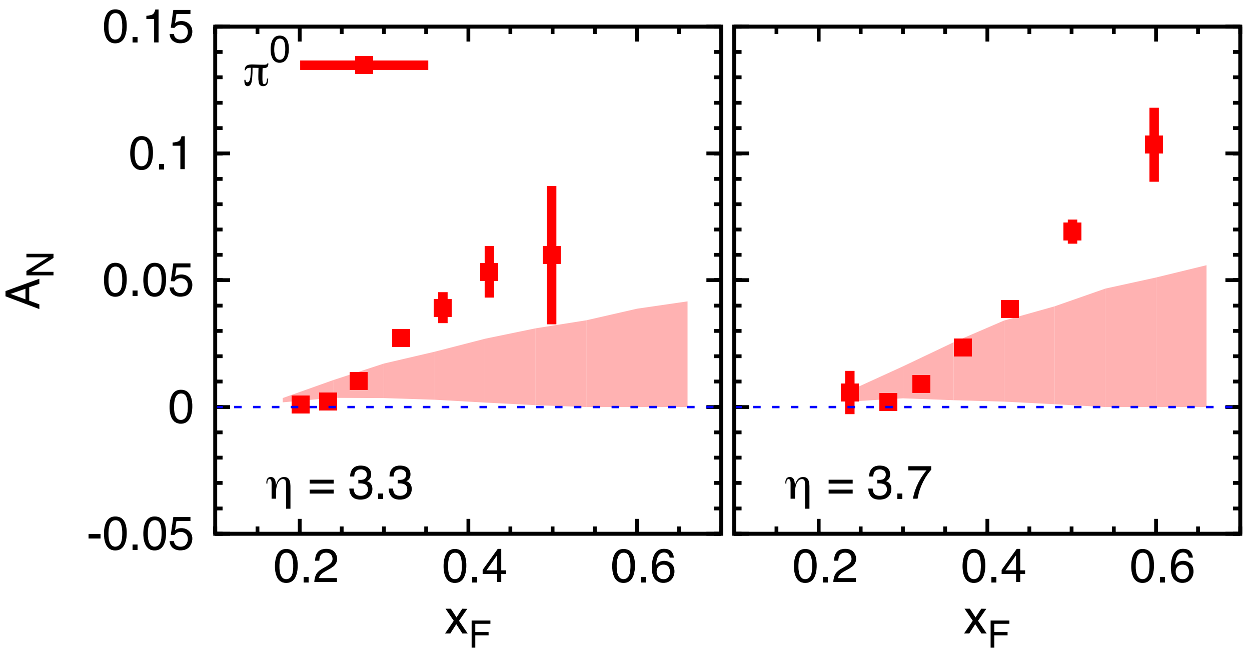


Settings can be found that describe all but the large p_T and large x_F extrema so **Sivers could explain most of the RHIC data**, but no stronger conclusions can be reached.

see: M. Anselmino, et al. Physical Review D **88**, 054023 (2013)

Collins-only RHIC Projections



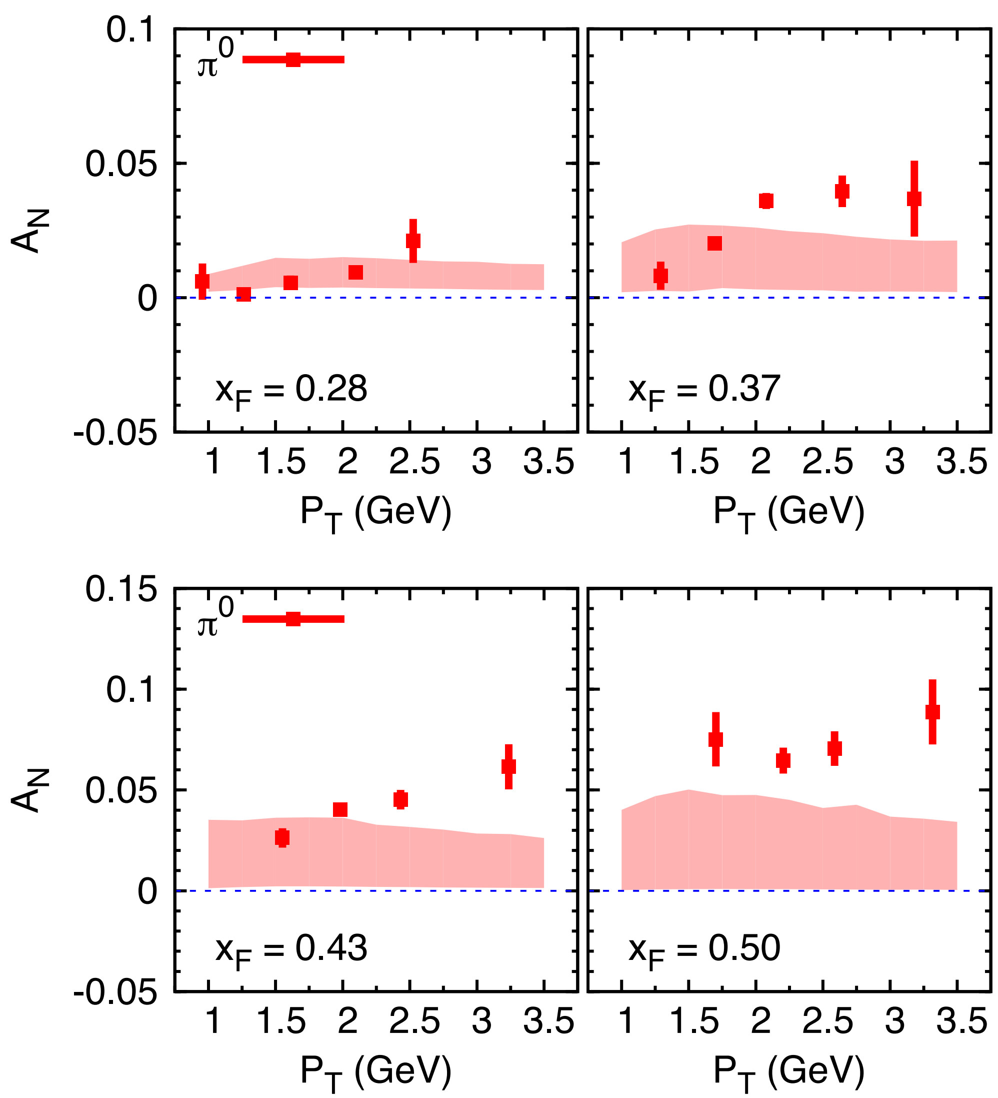


Collins projections from SIDIS and e^+e^- onto RHIC data also have **large known and unknown theoretical uncertainties**

Collins-only agreement worse at large xF and pT than for the Sivers-only projections.

Collins could contribute a significant portion of the asymmetries at RHIC

see: M. Anselmino, et al. Physical Review D **86**, 074032 (2012)



Take-away:

- **Fraction of contribution from Sivers vs Collins unknown at RHIC kinematics**
- **Validity of evolution method also not confirmed**

Sorting out Evolution

Theoretical Unknowns: TMD framework (e+p) and Twist-3 framework (p+p) are mutually exclusive due to a **“sign mismatch” problem.**

TMDs related to Twist-3 by the k_T-moment of the Sivers functions:

$$gT_{q,F}(x,x) = -\int d^2k_\perp \frac{|k_\perp|^2}{M} f_{1T}^{\perp q}(x,k_\perp^2)|_{SIDIS}$$

Three basic solutions to this problem…

(1) Assumed **k_T forms** have the incorrect large k_T dependence

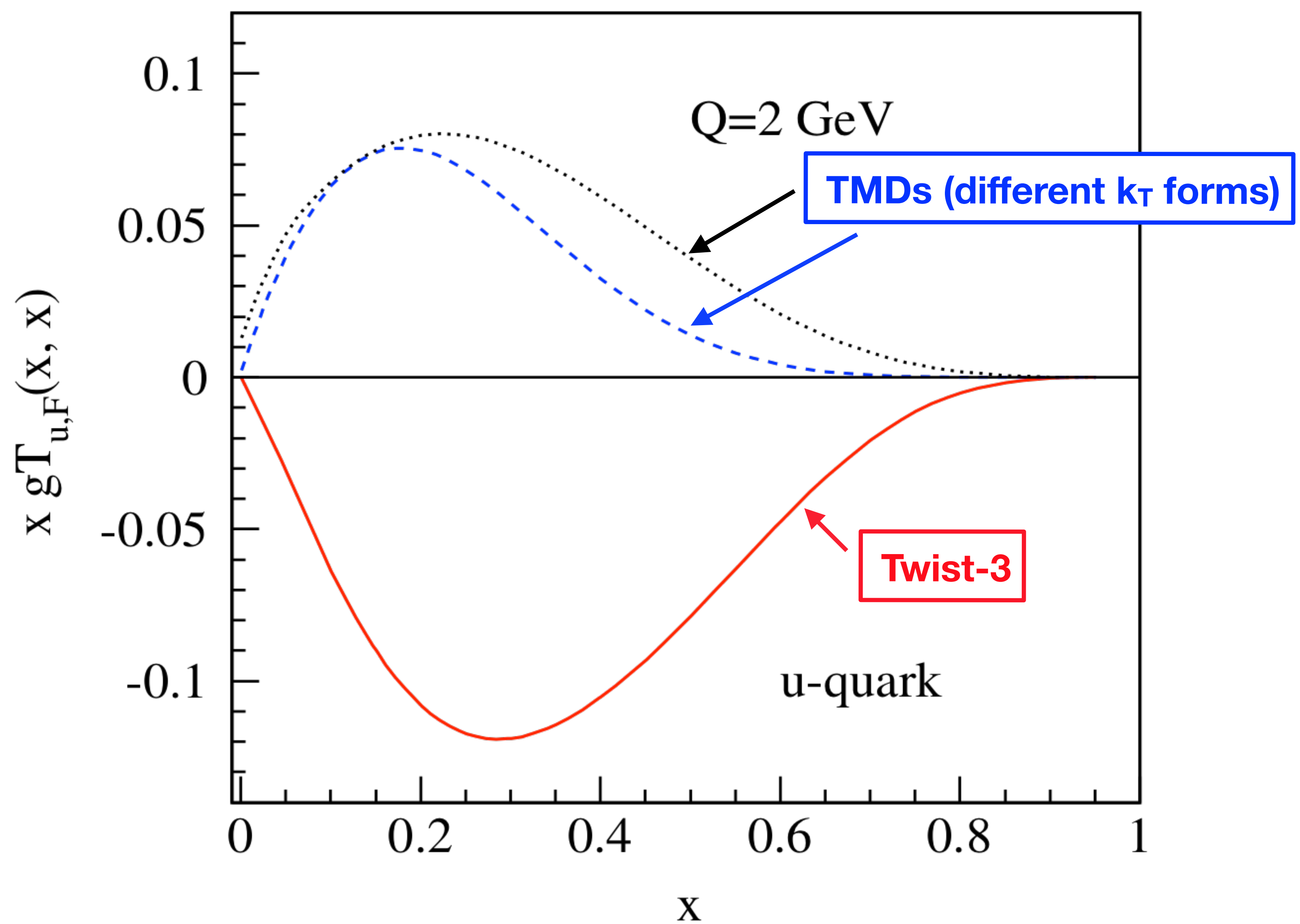
(2) **Rapid transition** in x

(3) **Collins contributions** to A_N are much more than assumed

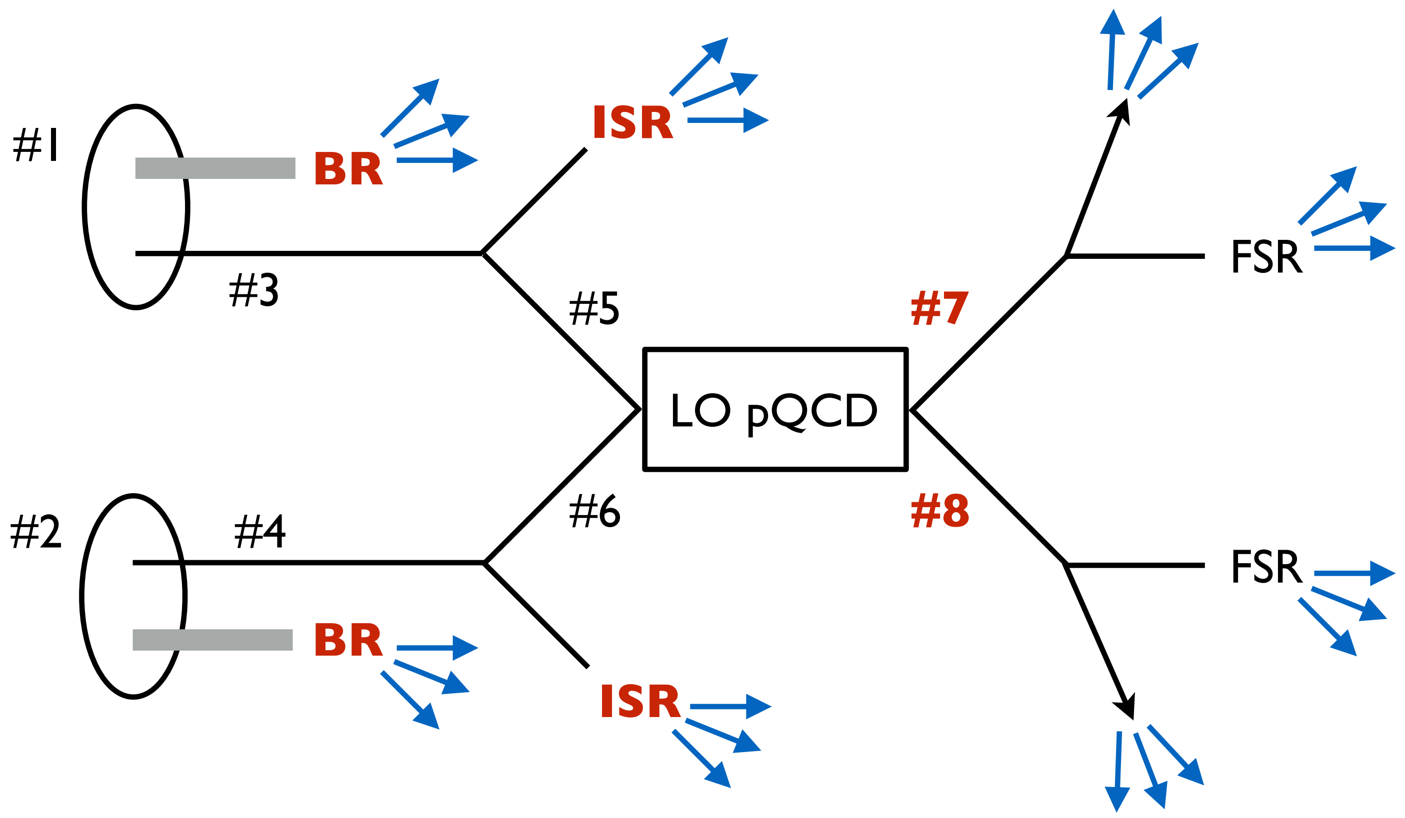
Resolution of this issue is a **NSAC Milestone**:

“Test unique QCD predictions for relations between single-transverse spin phenomena in p-p scattering and those observed in deep-inelastic scattering.”

see: Kang, et al. Physical Review D **83**, 094001 (2011)



Pythia Ancestry



Final state jets are assigned an origin by greatest truth energy contribution from sources labeled in **red.**