Jets in CC DIS for 3D imaging

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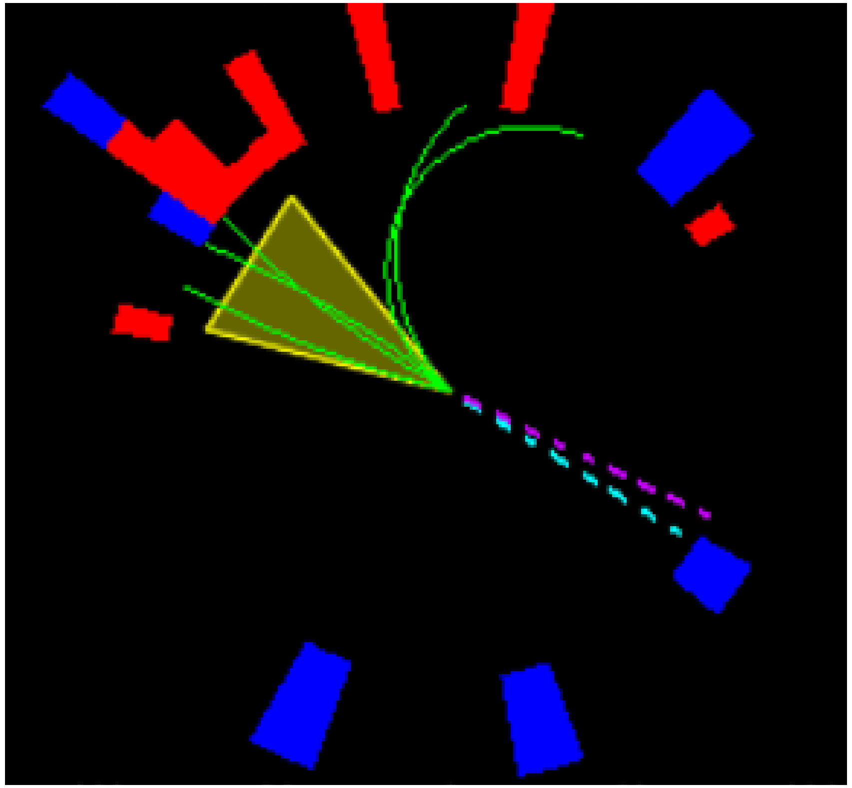
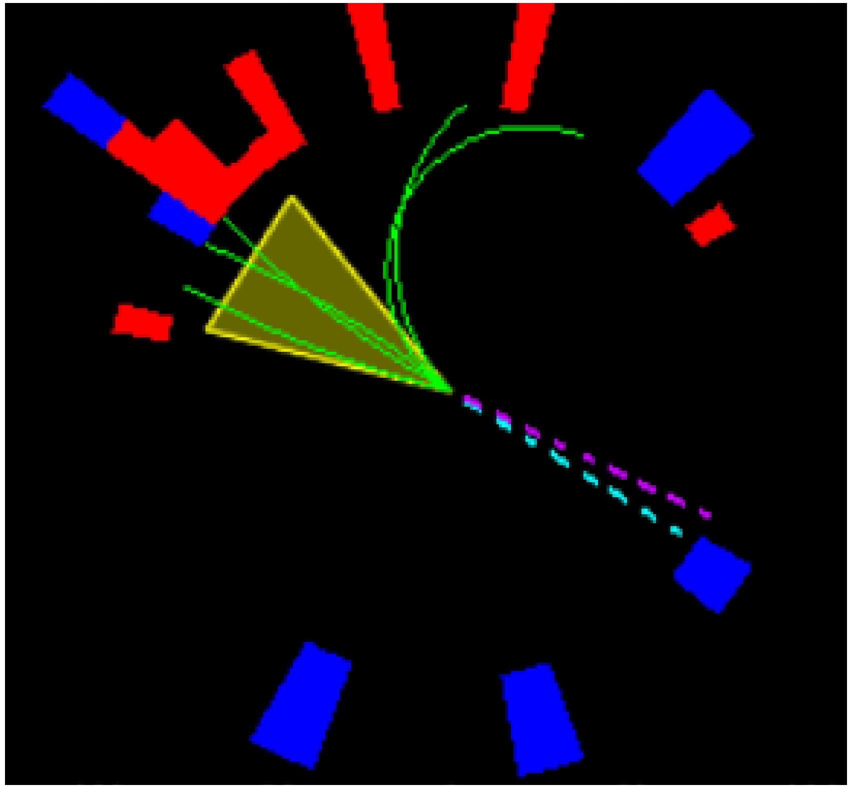


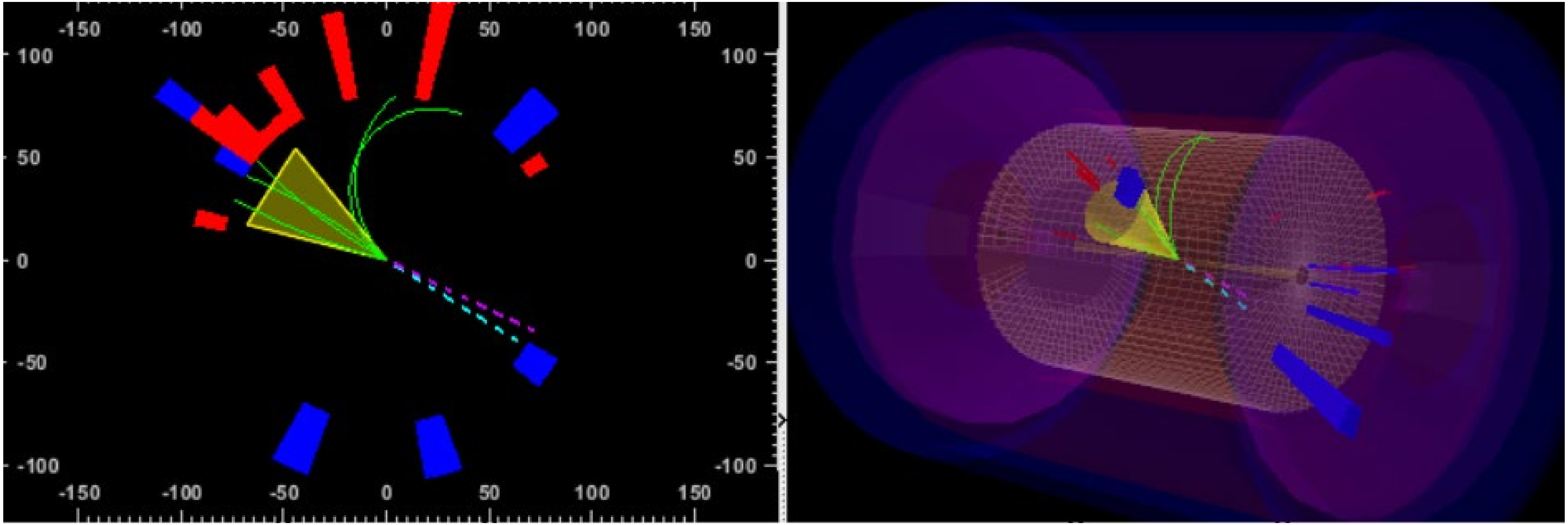
Electroweak and BSM physics at the EIC, May 2020

Outline

- What?
- Why?
- How?
- Looking forward

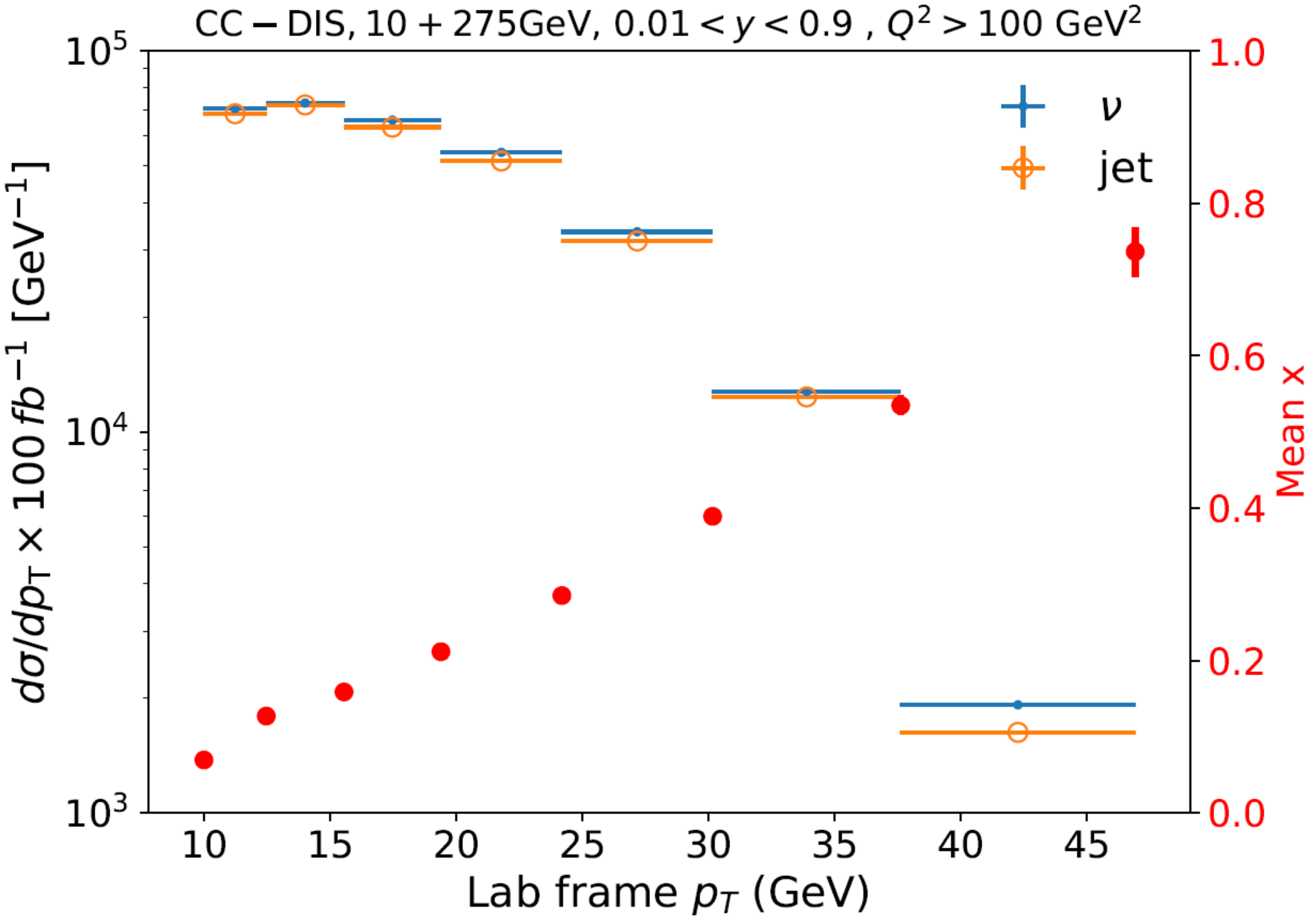


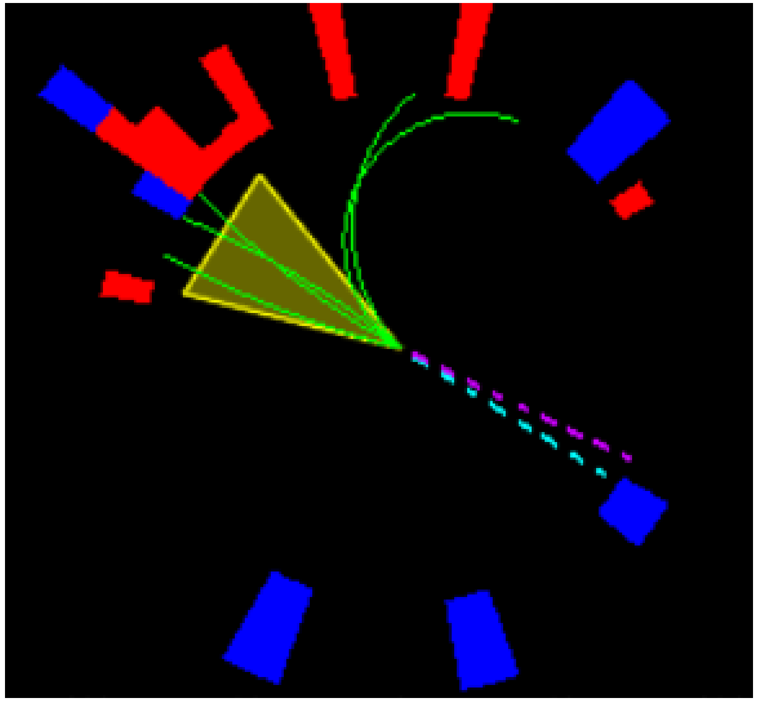
Charged-current DIS at the EIC



Delphes fast simulation of an EIC detector and Pythia8 charged-current DIS event

Jet cross-section (anti-kT, R=1.0)

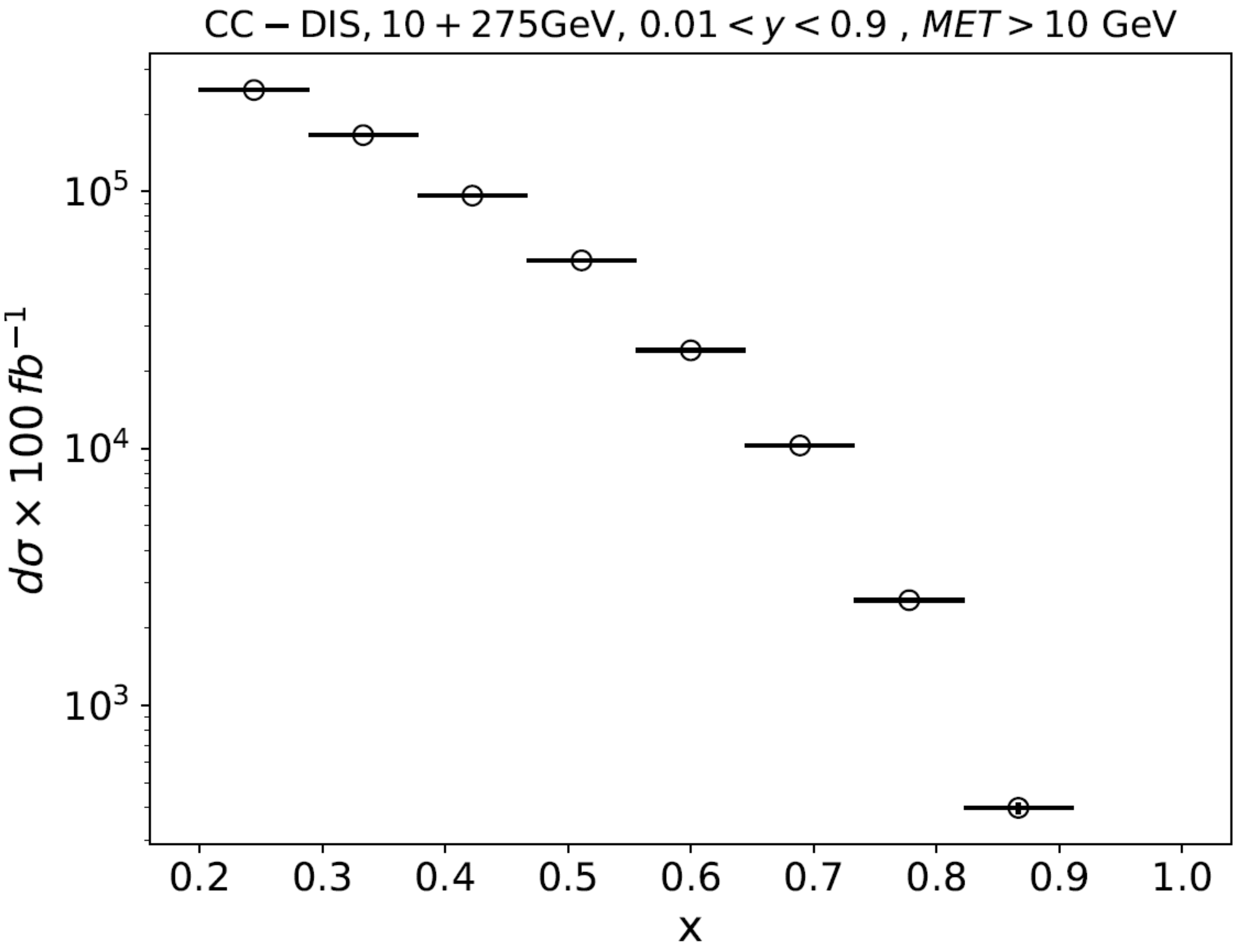


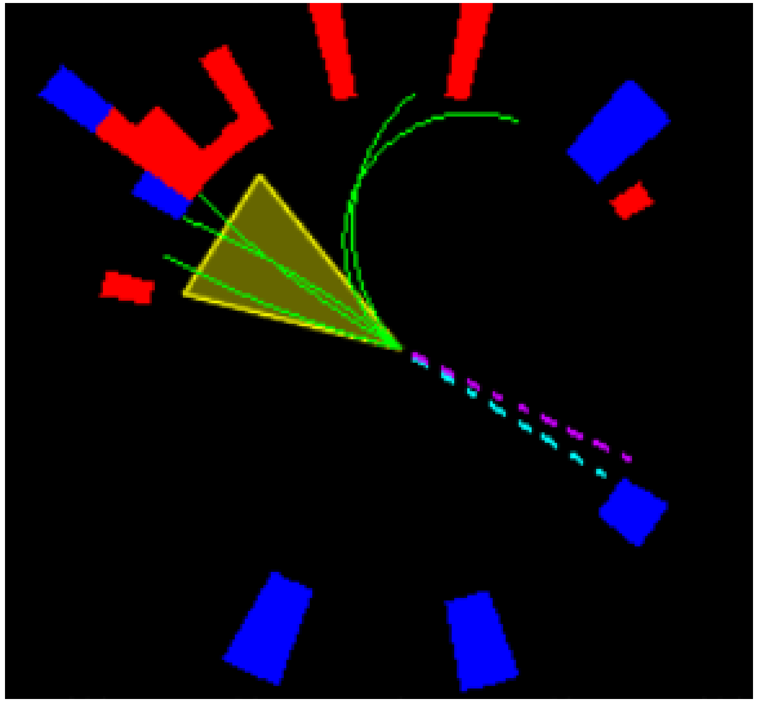


What can we do with CC DIS at EIC?

Explore the high-x frontier

For a fixed Q2, the EIC probes a factor of 10 larger x than HERA

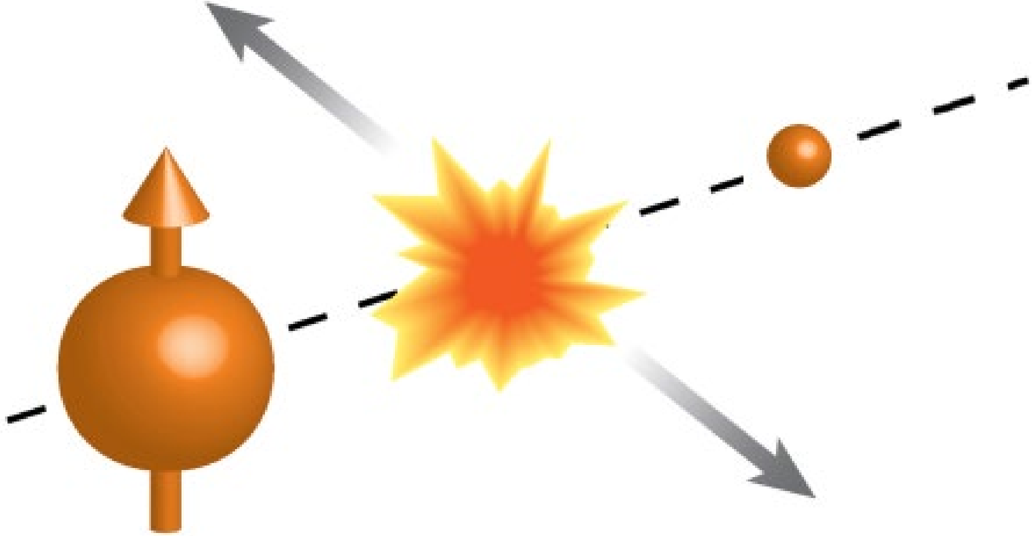


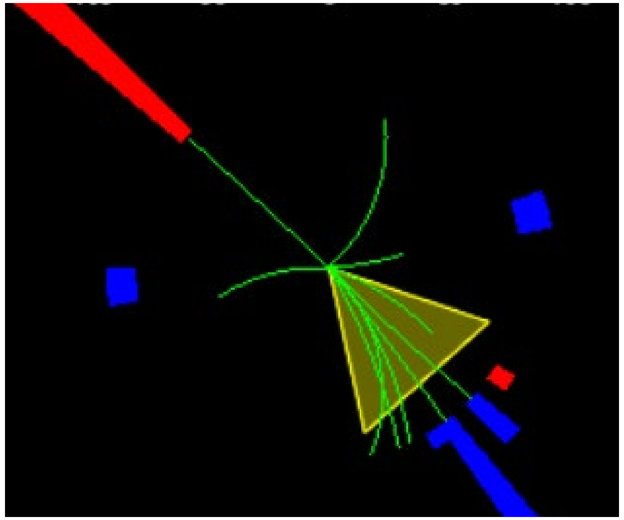


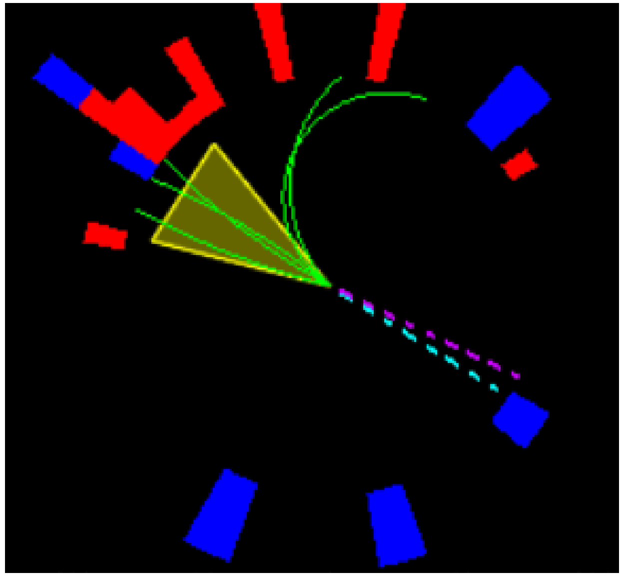
Improving on what H1 & ZEUS did

Doing what H1& ZEUS did not

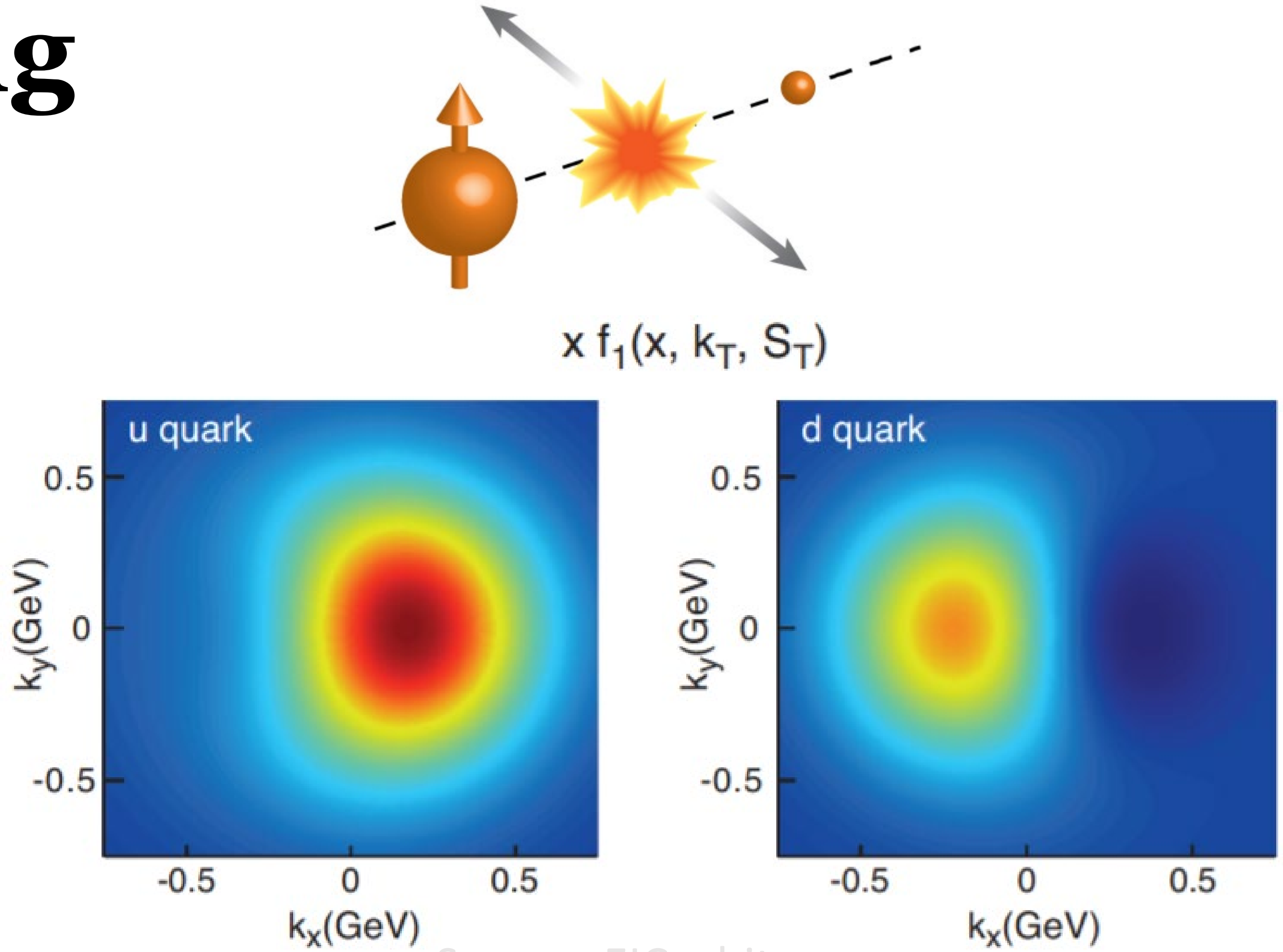
e.g TMD/spin physics







Jet for 3D-imaging

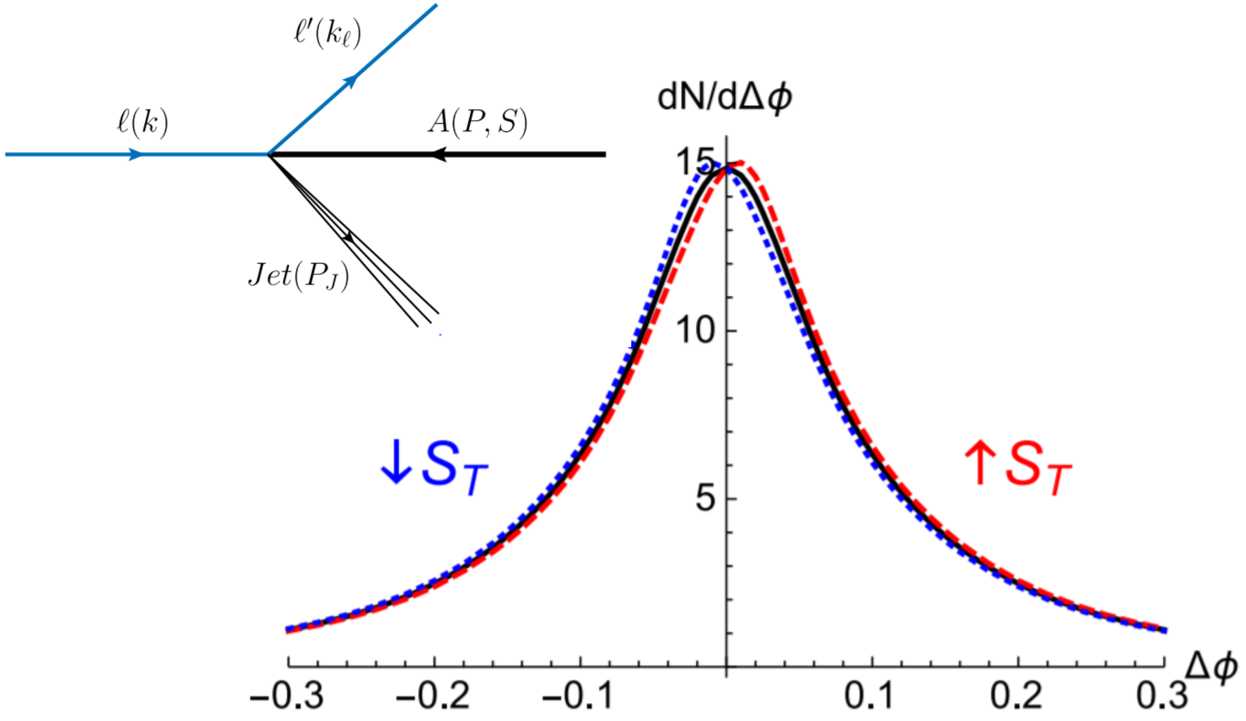


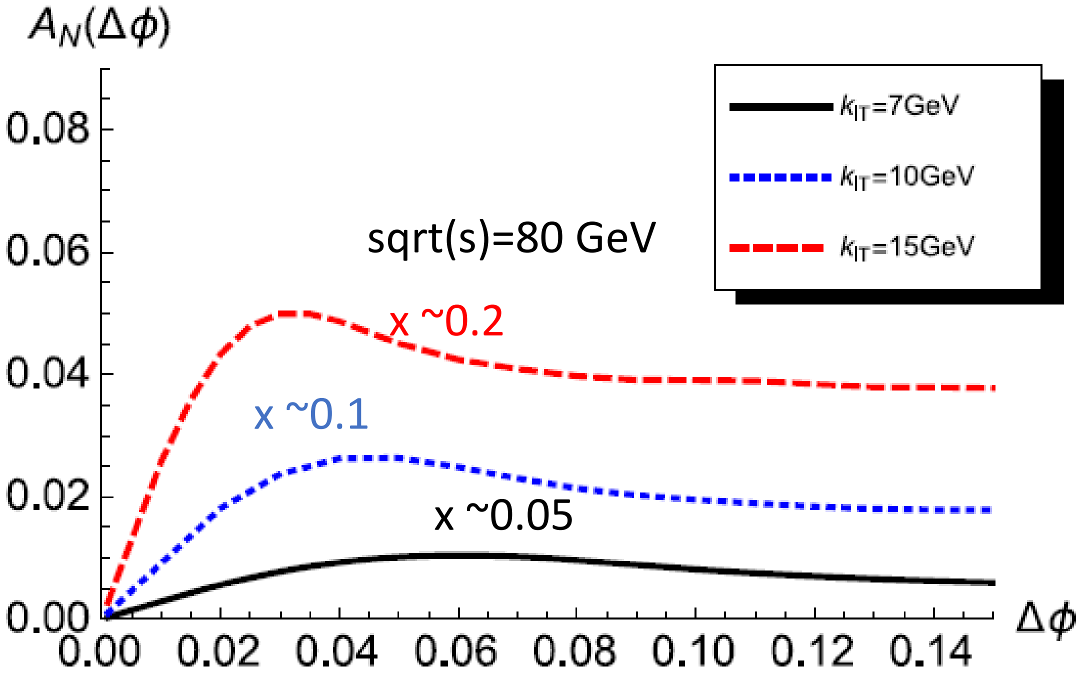
- DIS jets are a novel tool for 3D imaging
- Complementary and more direct way for EIC flagship measurements
- Potential for unique jet program, unlike any previous collider or fixed-target experiment

Source: EIC white paper

Quark Sivers effect with Jets

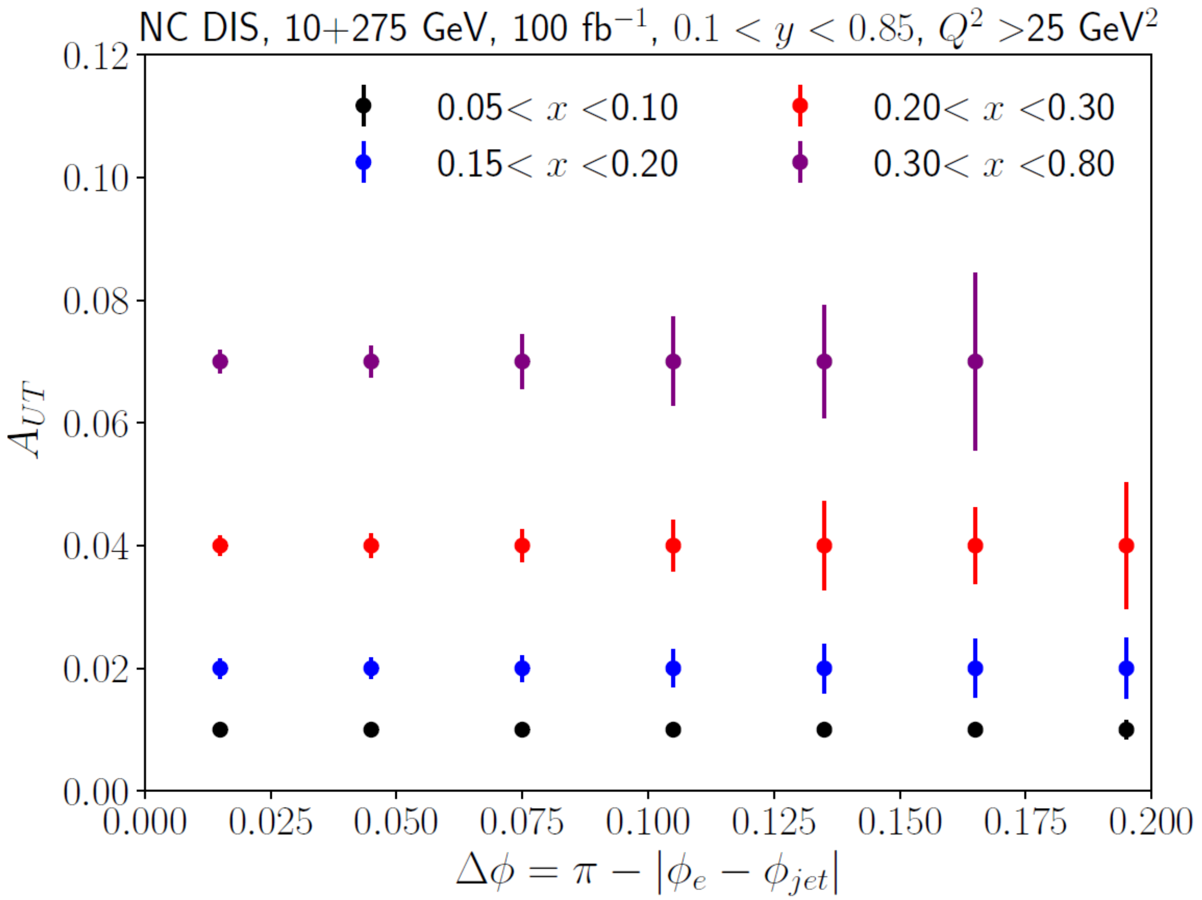
Liu, Ringer, Vogelsang, Yuan, PRL 122 192003 (2019)

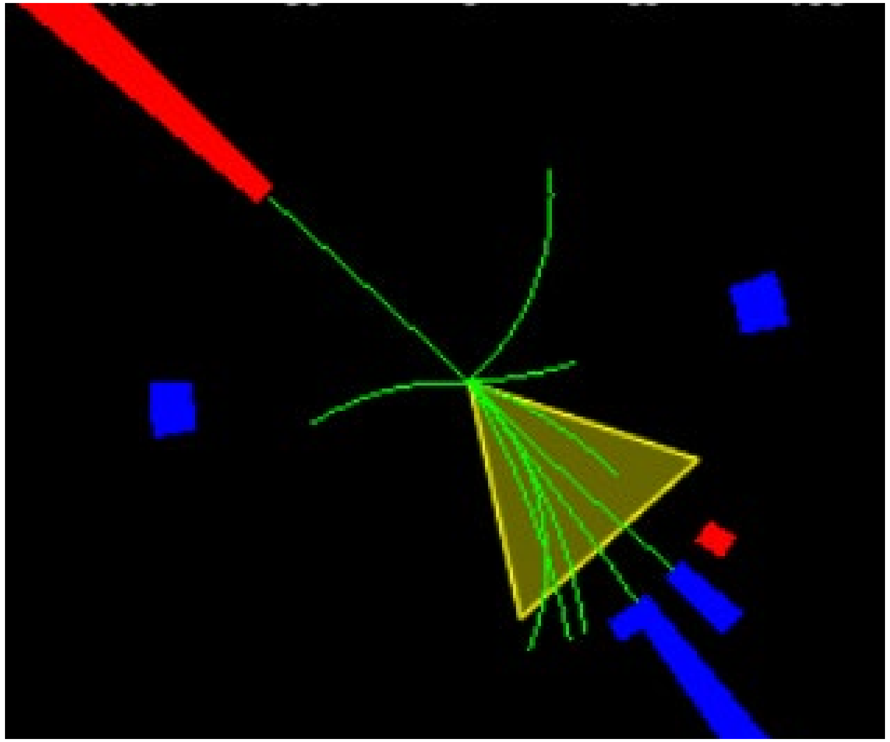




"The advantage of the lepton-jet correlation as compared to the standard SIDIS processes is that it does not involve TMD fragmentation functions."

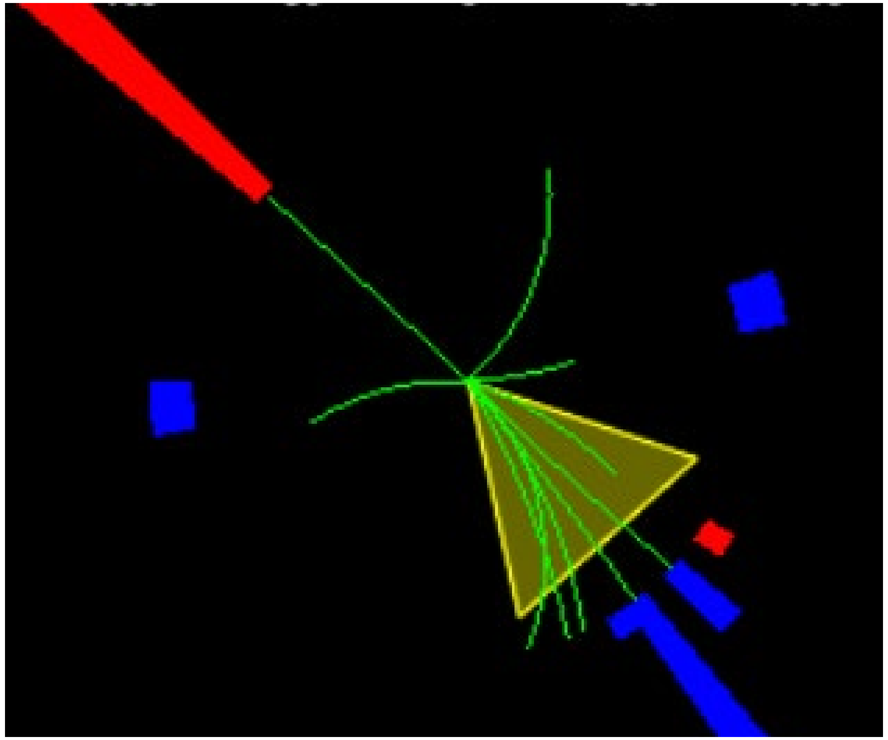
Quark Sivers effect with electron-jet correlations



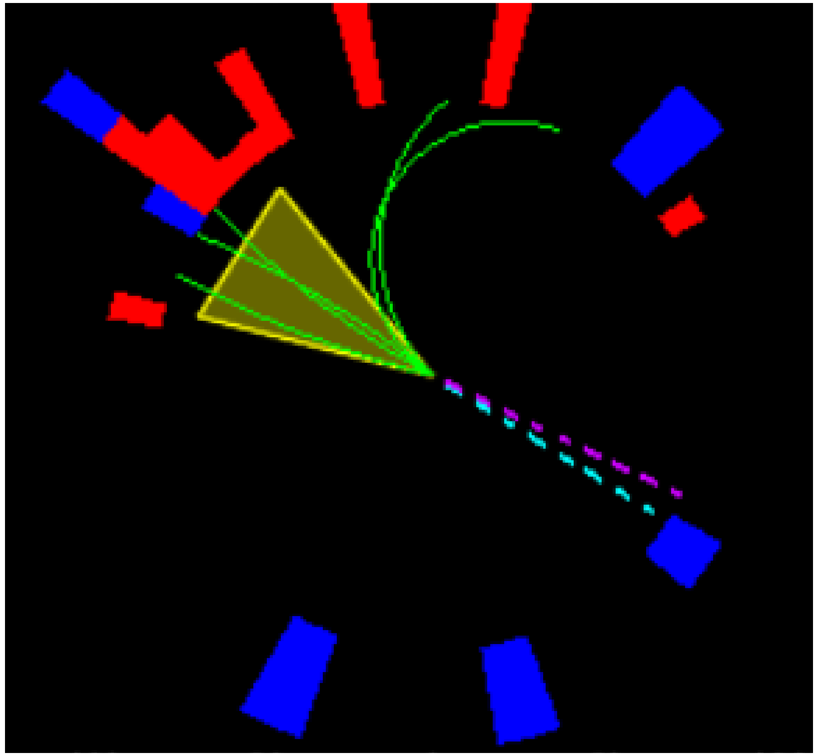


70% polarization, 50% overall efficiency.

My crazy idea: replace electron with neutrino!

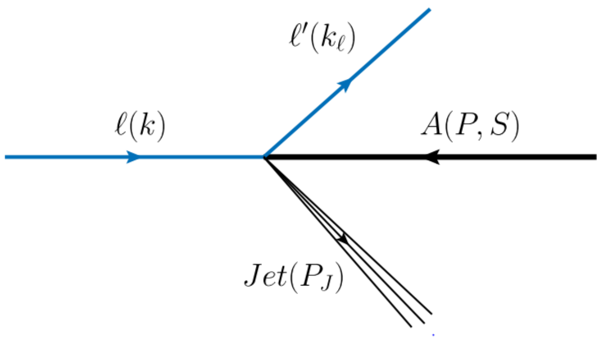


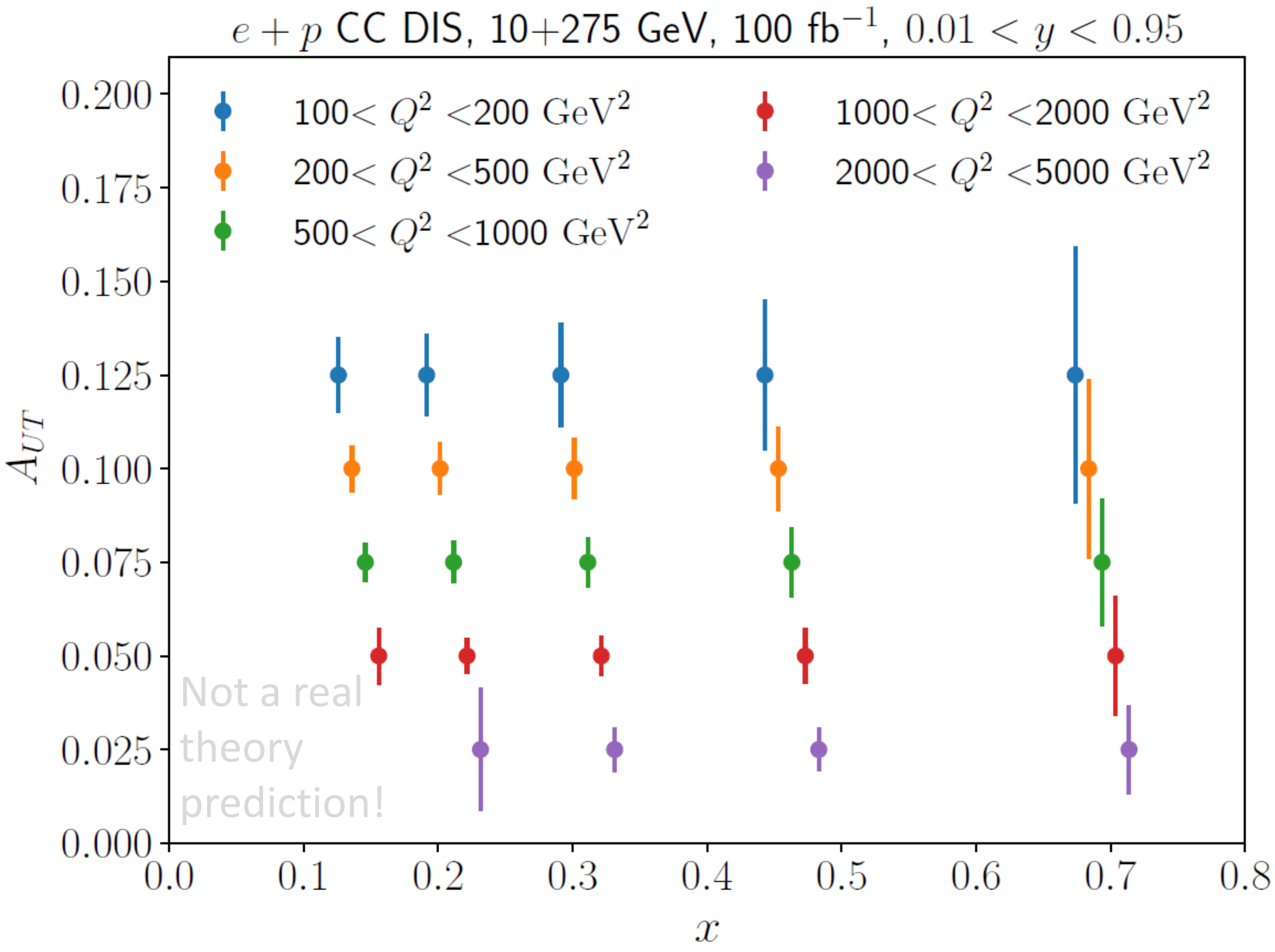
Novel channel for quark Sivers and quark transversity



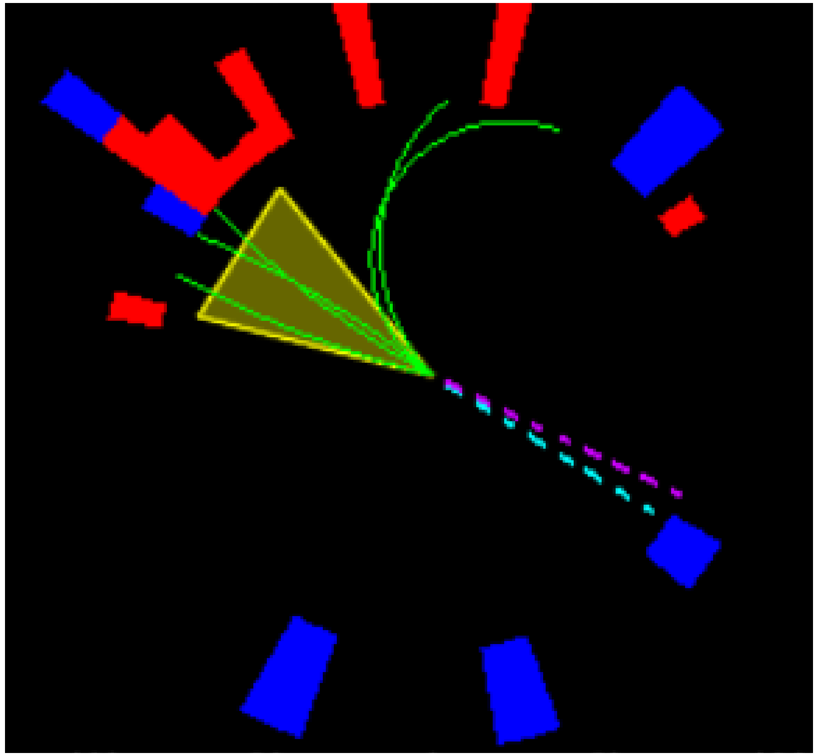
Same as left, but with flavor sensitivity.
u-quarks for electron, d-quark for positron

u-quark Sivers with neutrino-jet correlations



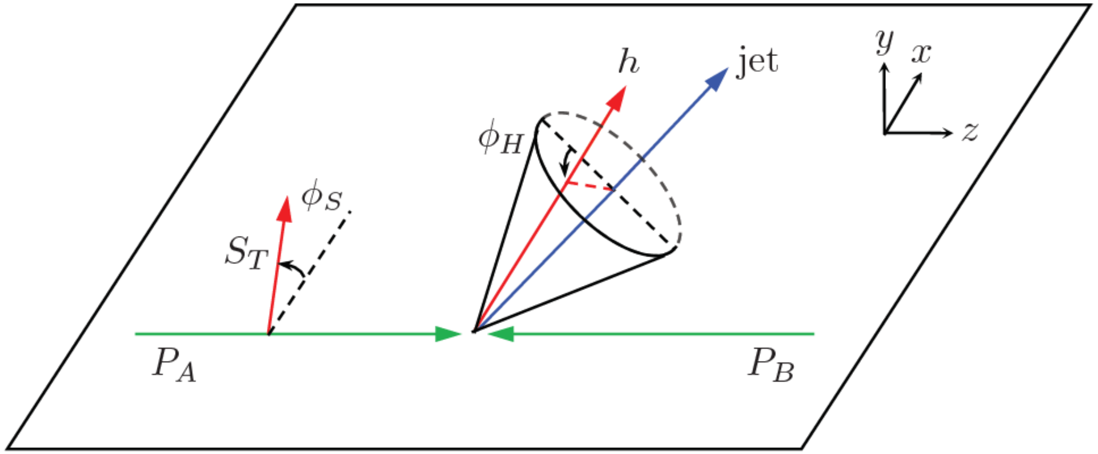


70% polarization, 50% overall efficiency.



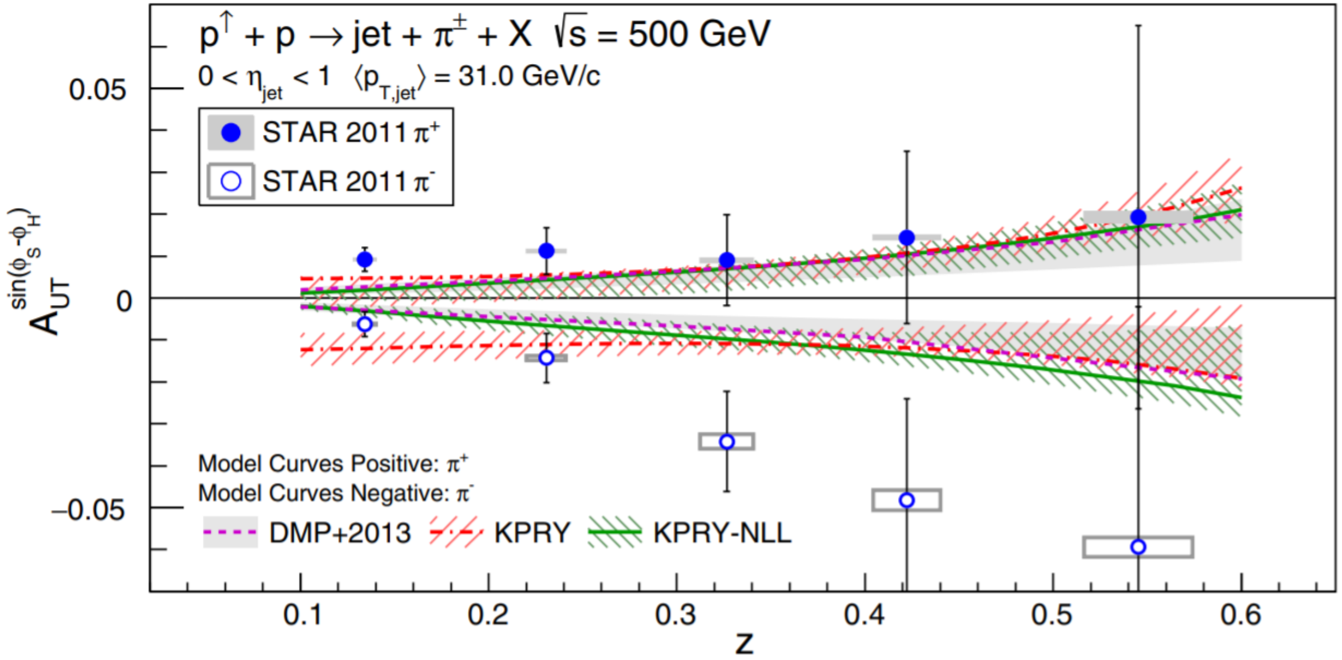
Transversity with jets

distribution of transversely polarized quarks inside a transversely polarized nucleon



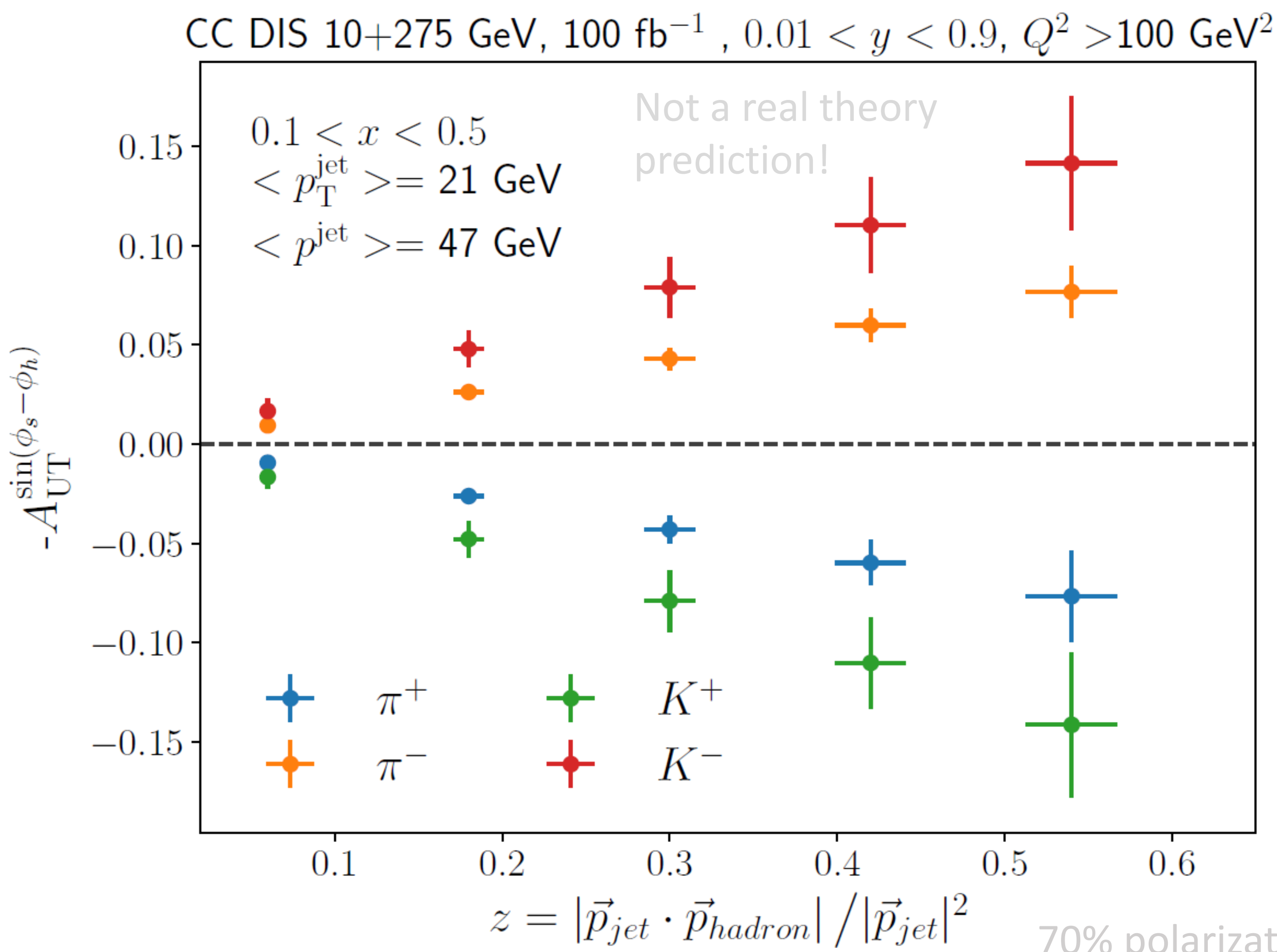
"Collins azimuthal asymmetries of hadron production inside jets",
Phys. Lett. B 774, 635 (2017), Kang et al.

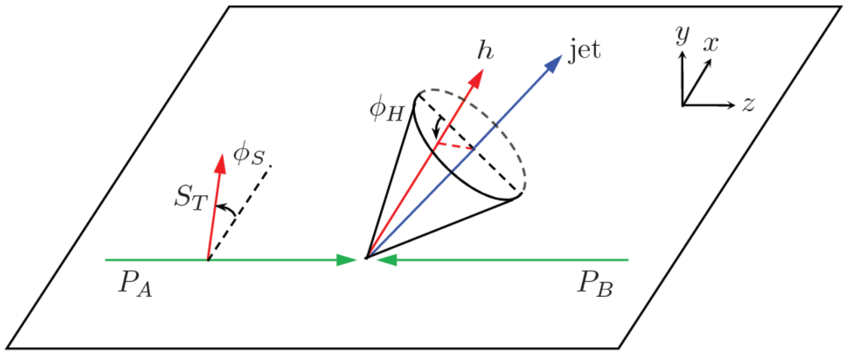
STAR Collaboration, Phys. Rev. D 97, 032004 (2018)



- Jet measurement crucial to factorize initial and final state TMD effects.
- At EIC, we'll have much better precision & kinematic control.
  Tests of TMD evolution & universality.

u-quark Transversity in charged-current DIS



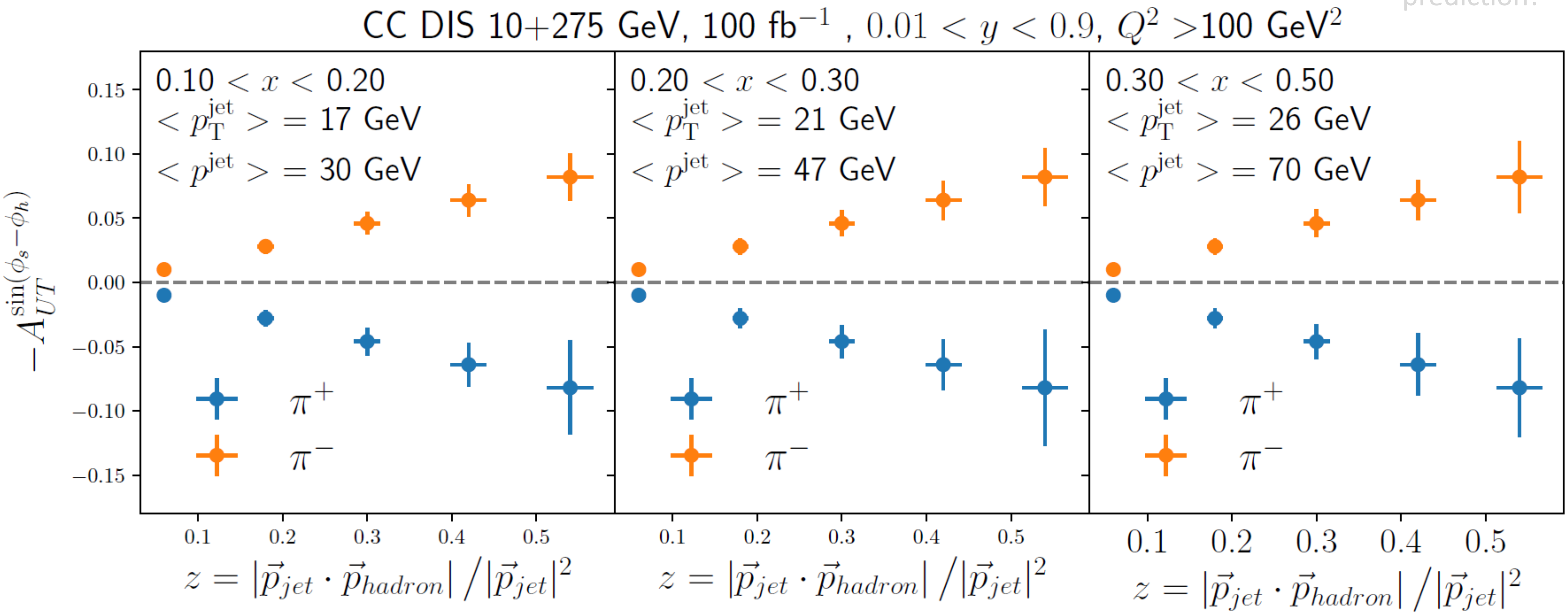


- Decent statistics, specially for pions.
- Flavor specific (u-quark for electrons; d-quark for positrons)
- Non-cancellation of u/d transversity will lead to larger asymmetries.

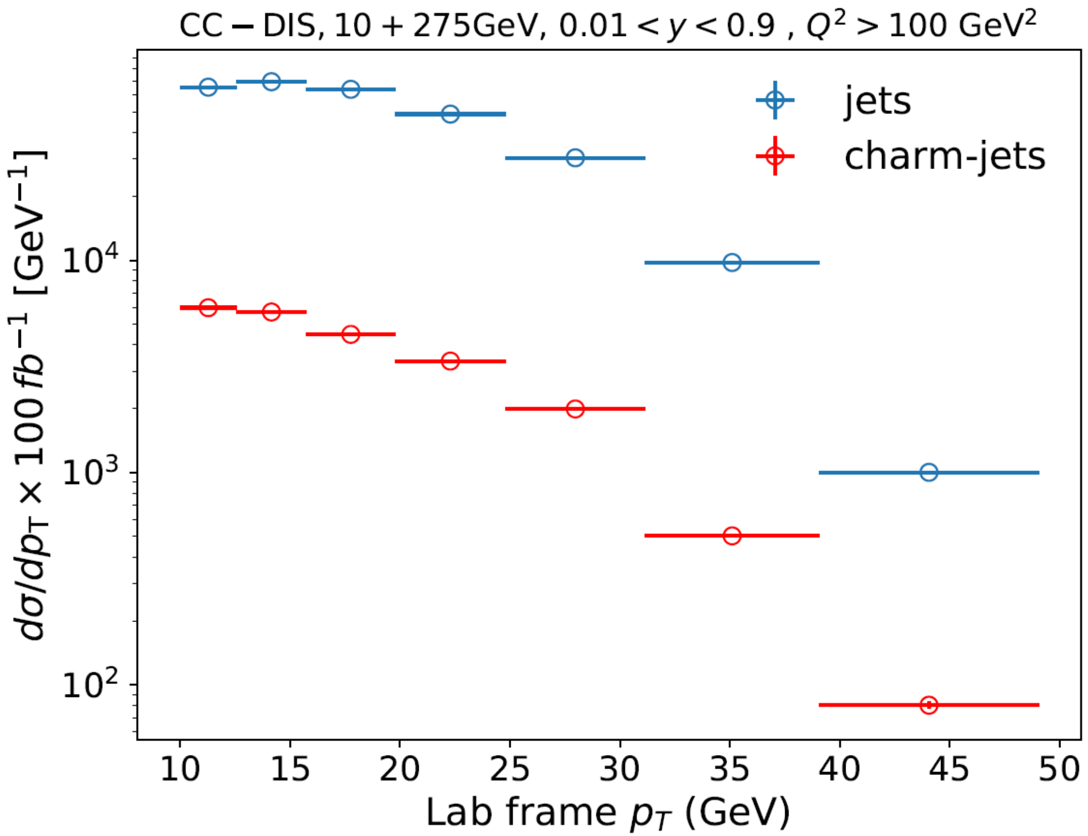
70% polarization, 50% overall efficiency.

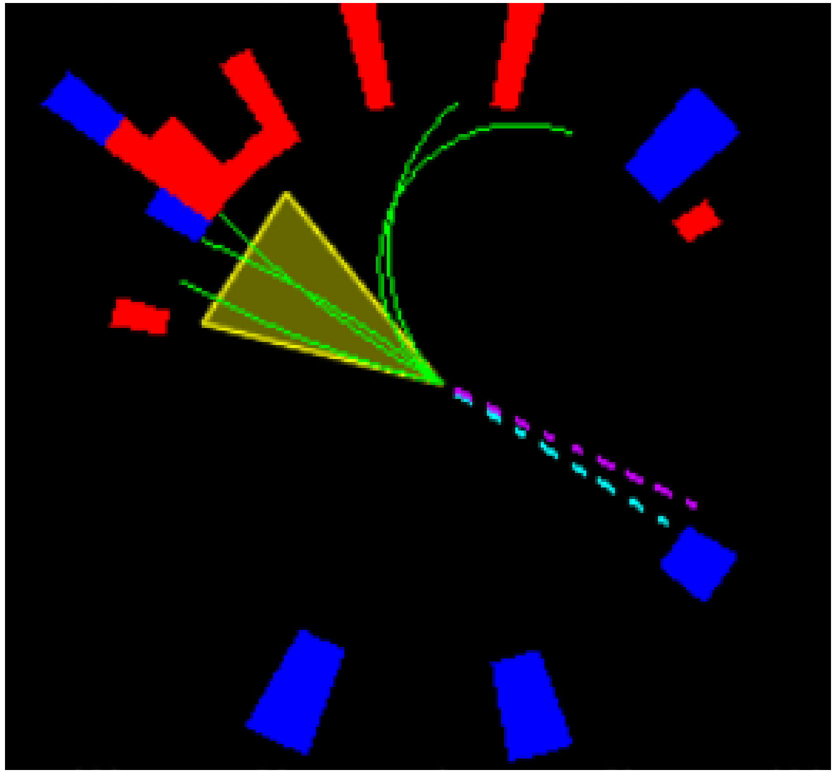
u-quark Transversity

Not a real theory prediction!



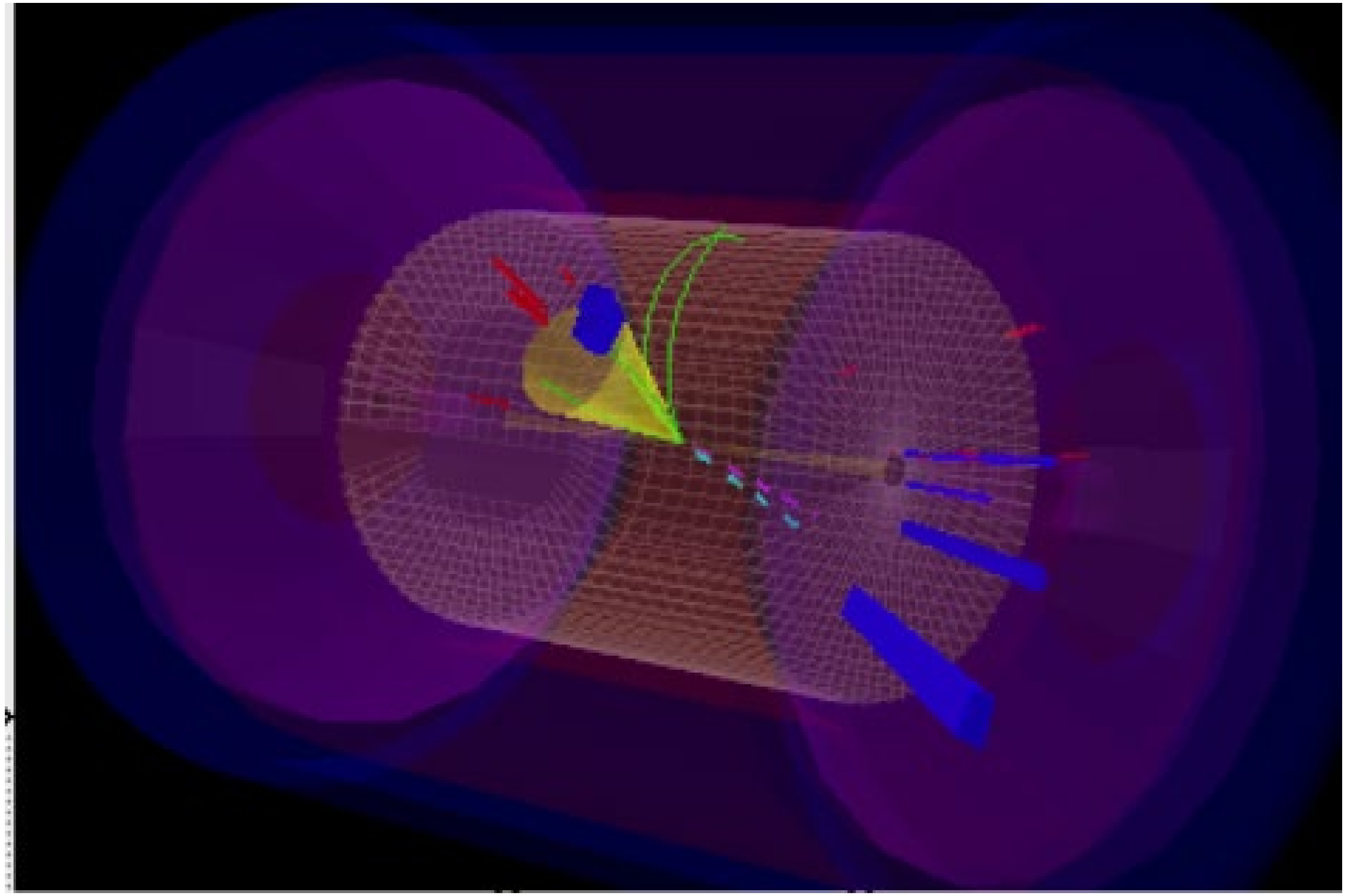
Tag charm-jets to cleanly access **strange quark**



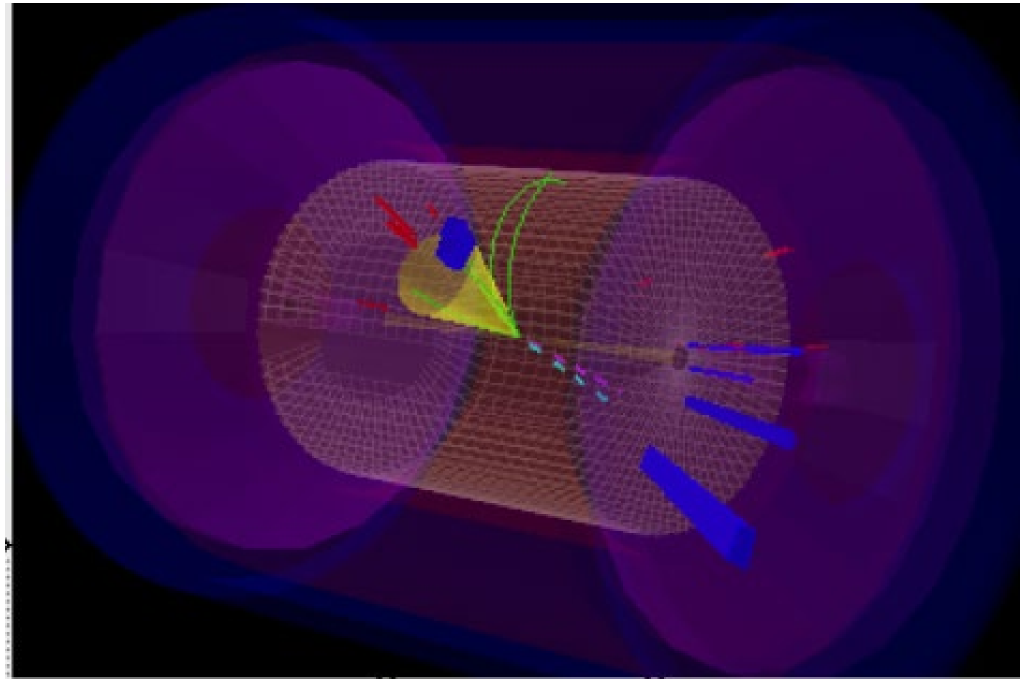


- ZEUS data JHEP 05 (2019) 201 of ~0.3 fb-1 yielded a proof of concept, but with very large errors
- EIC trackers will dwarfed the HERA ones, plus much higher lumi makes this promising for both collinear and TMD physics

What do we need?
A hermetic detector



"a hermetic detector (also called a 4π detector) is a particle detector designed to observe ***all possible decay products*** *of an interaction between subatomic particles in a collider by* ***covering as large an area*** *around the interaction point as possible and incorporating multiple types of sub-detectors"* Wikipedia



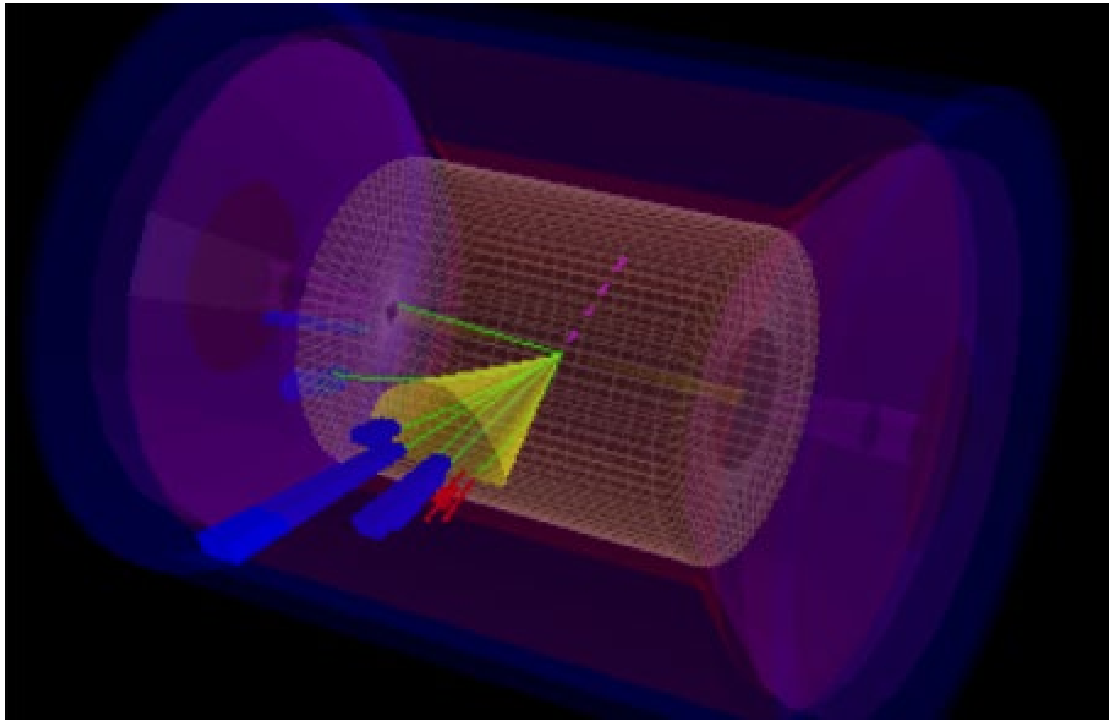
EIC detector in Delphes

https://github.com/miguelignacio/delphes_EIC/blob/master/delphes_card_EIC.tcl

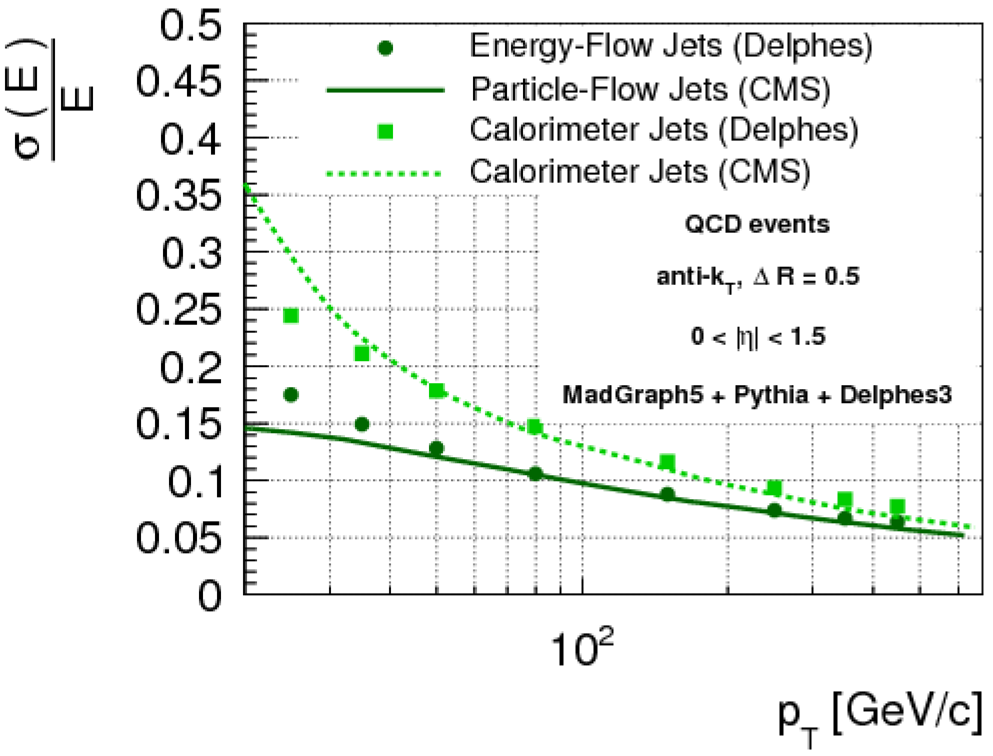
Tracking resolution, EMCAL resolution and HCAL resolution as in EIC detector handbook.

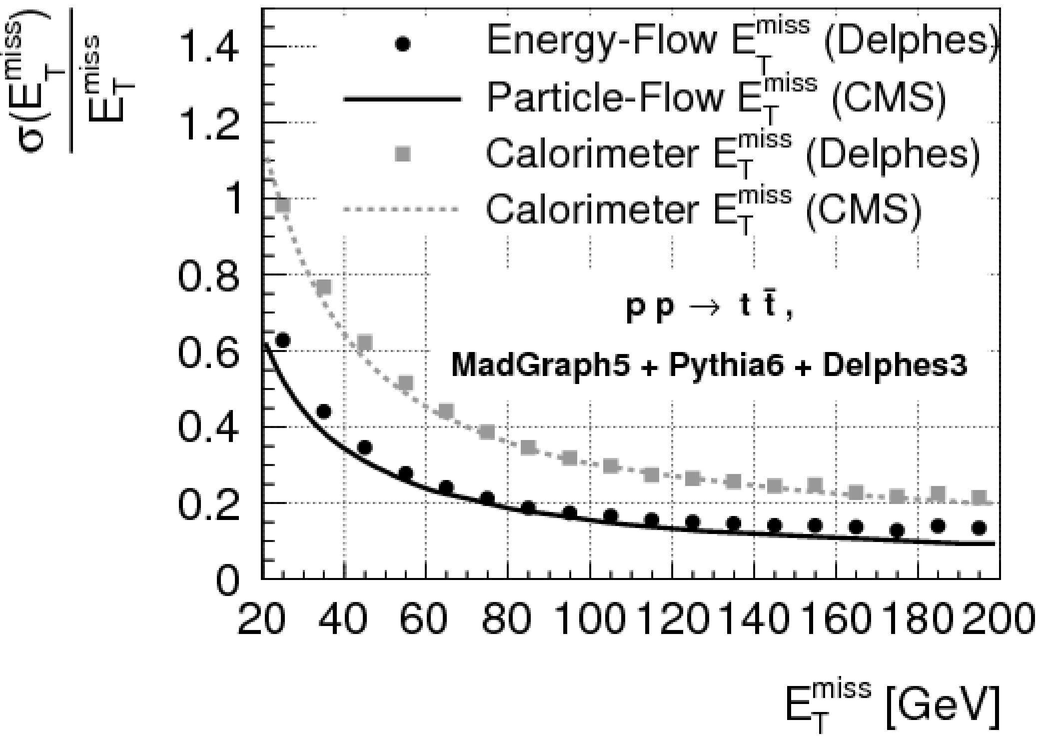
In addition:

- B=1.5 T, R=0.80 m, L = 1 m
- EMCAL granularity (dphi x deta):
  0.02 x 0.02 for |eta|<3.5
- HCAL granularity (dphi x deta):
  0.1 x 0.1 for |eta|<1.0
  0.025 x 0.025 for 1.0 |eta|<4.0
  (10x10 cm2 at 3.6 m)
- HCAL resolution:
  100%/sqrt(E) + 10% in barrel (0.0—1.0)
  50%/sqrt(E) + 10% in encap (1.0—4.0)
- Tracking threshold 100 MeV pT;
  EMCAL threshold of 200 MeV; (noise ~ 30 MeV per tower)
  HCAL threshold of 500 MeV; (noise ~100 MeV per tower)
- No PID yet, but it can be included (LHCb is in Delphes).
  Need parametrization of efficiency and mis-identification matrix



Jet/Met performance in Delphes vs full-sim of CMS

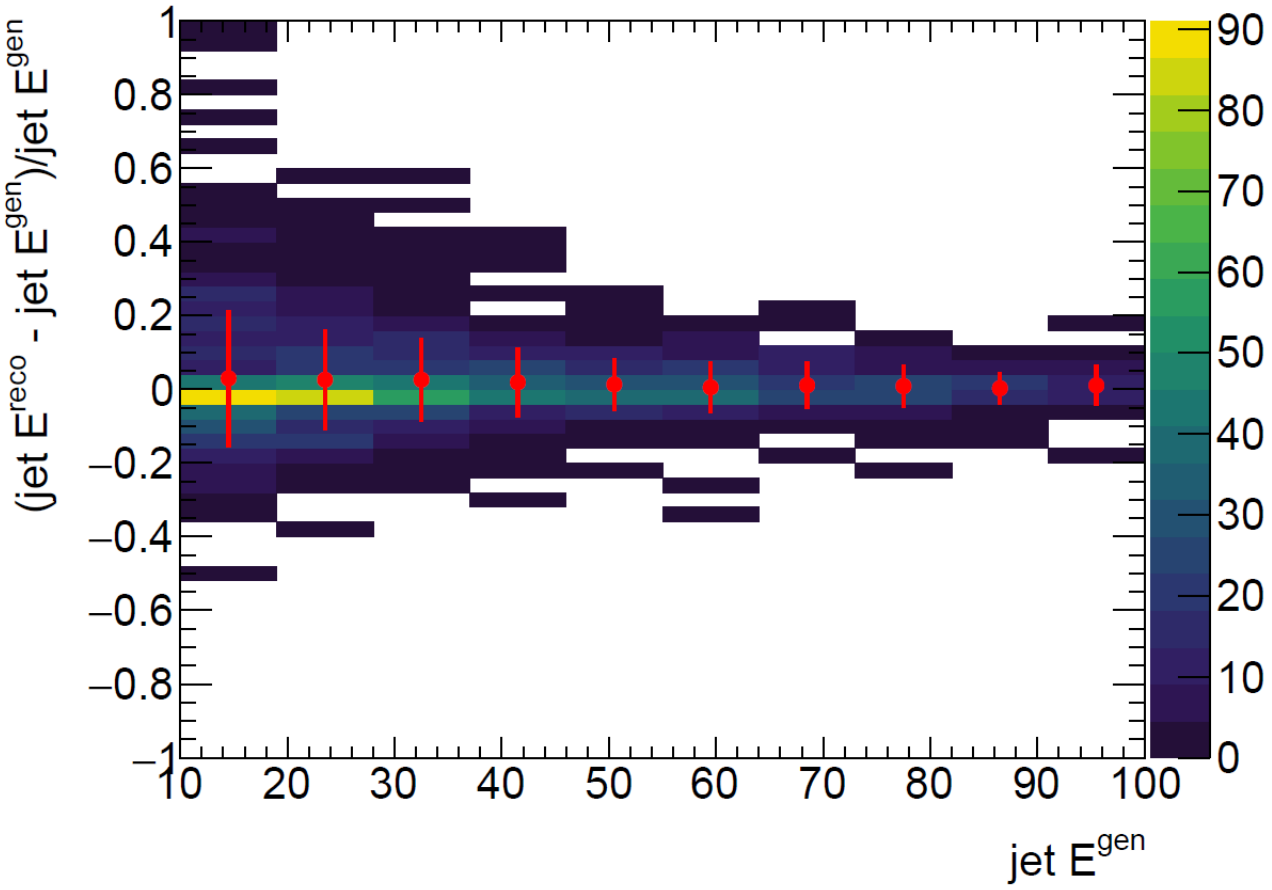


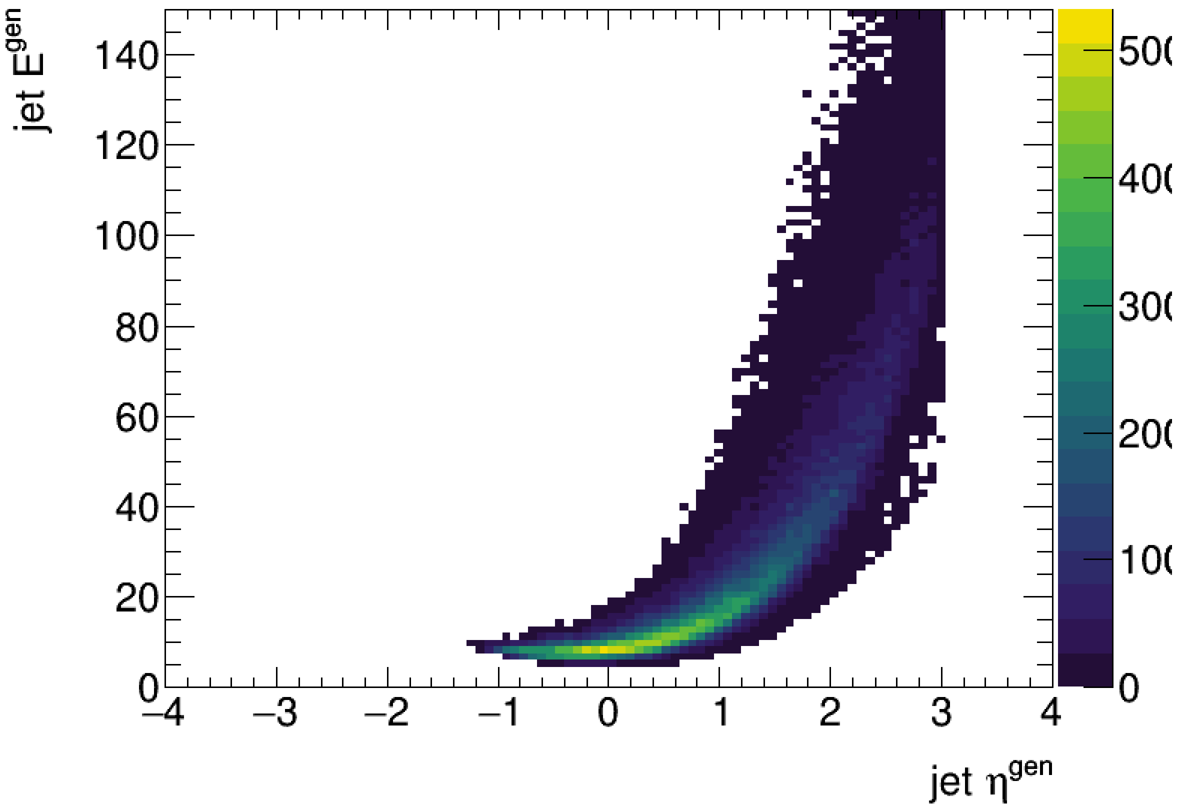


This is **not** by construction, it emerges from tracking and calorimetry resolution and granularity, as well as implementation of “particle flow”

Jet performance

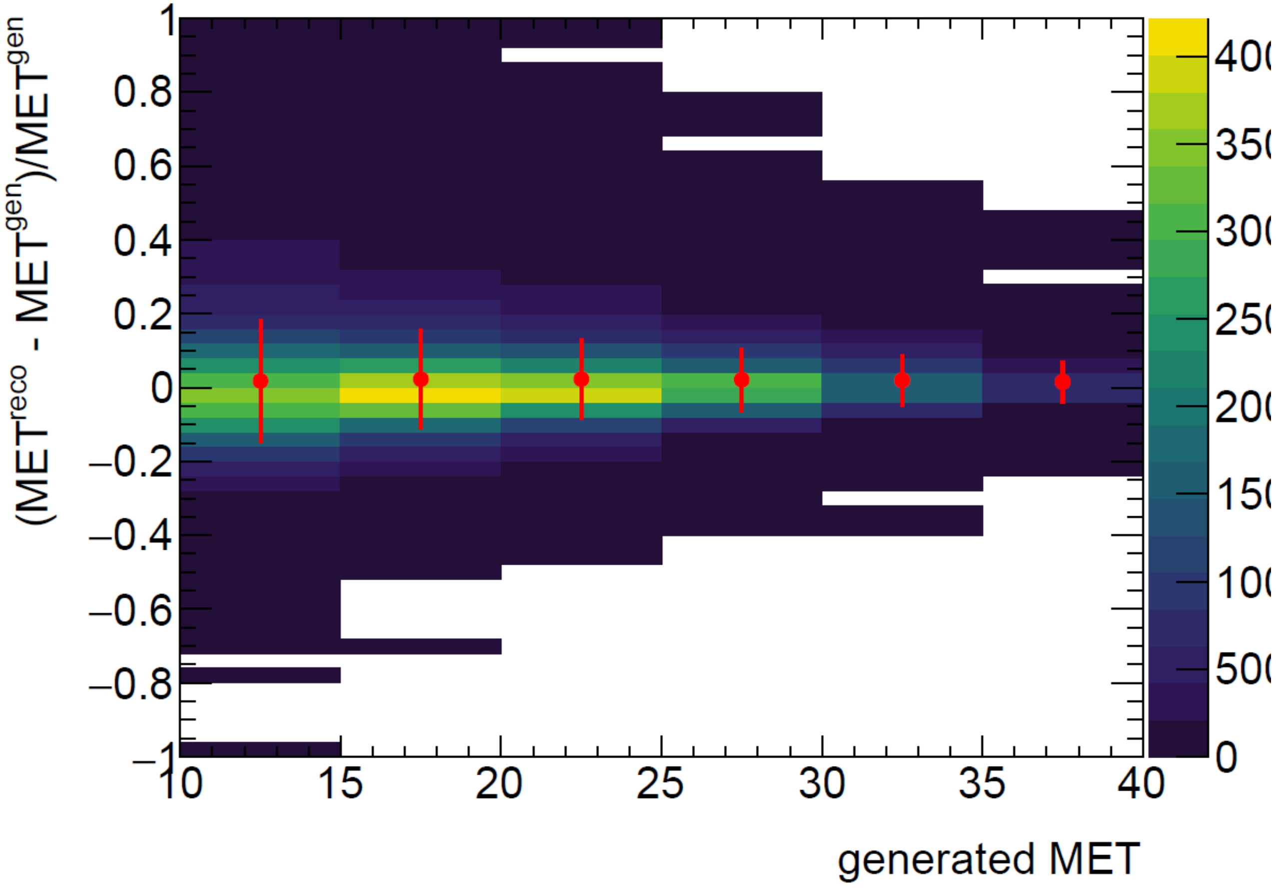
anti-kT R=1.0, particle-flow

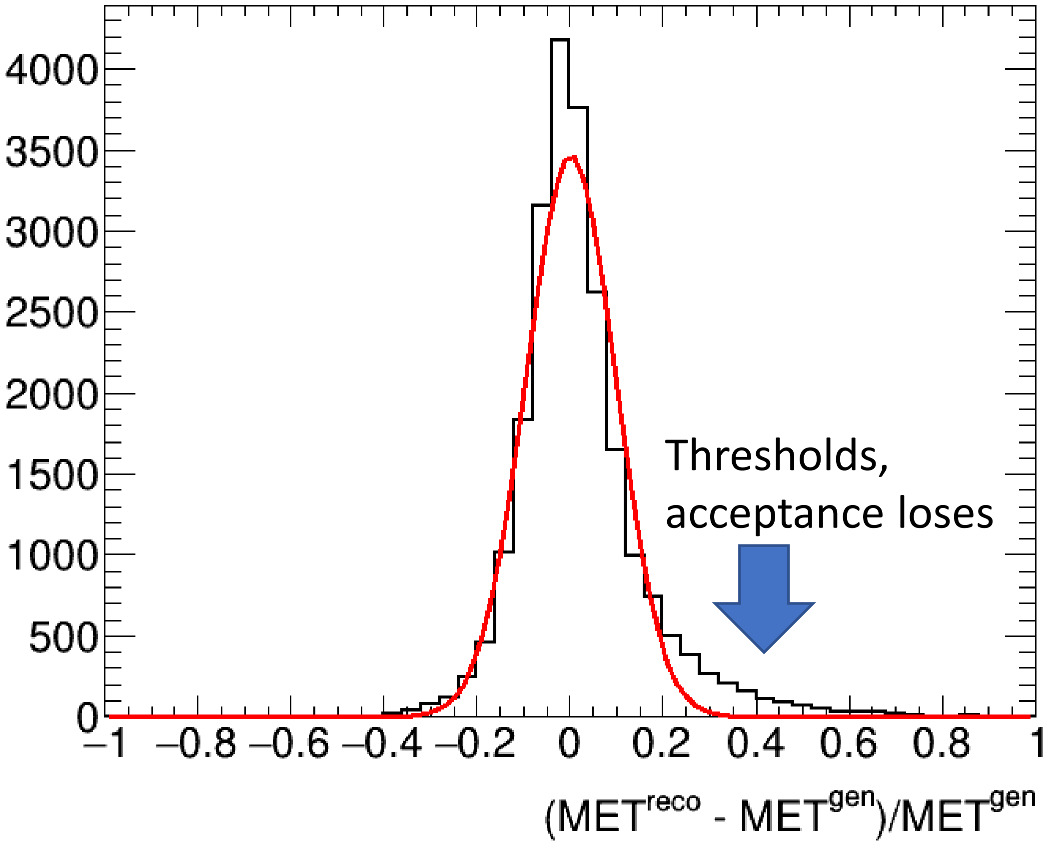




~20% at 10 GeV, ~10% at 50 GeV

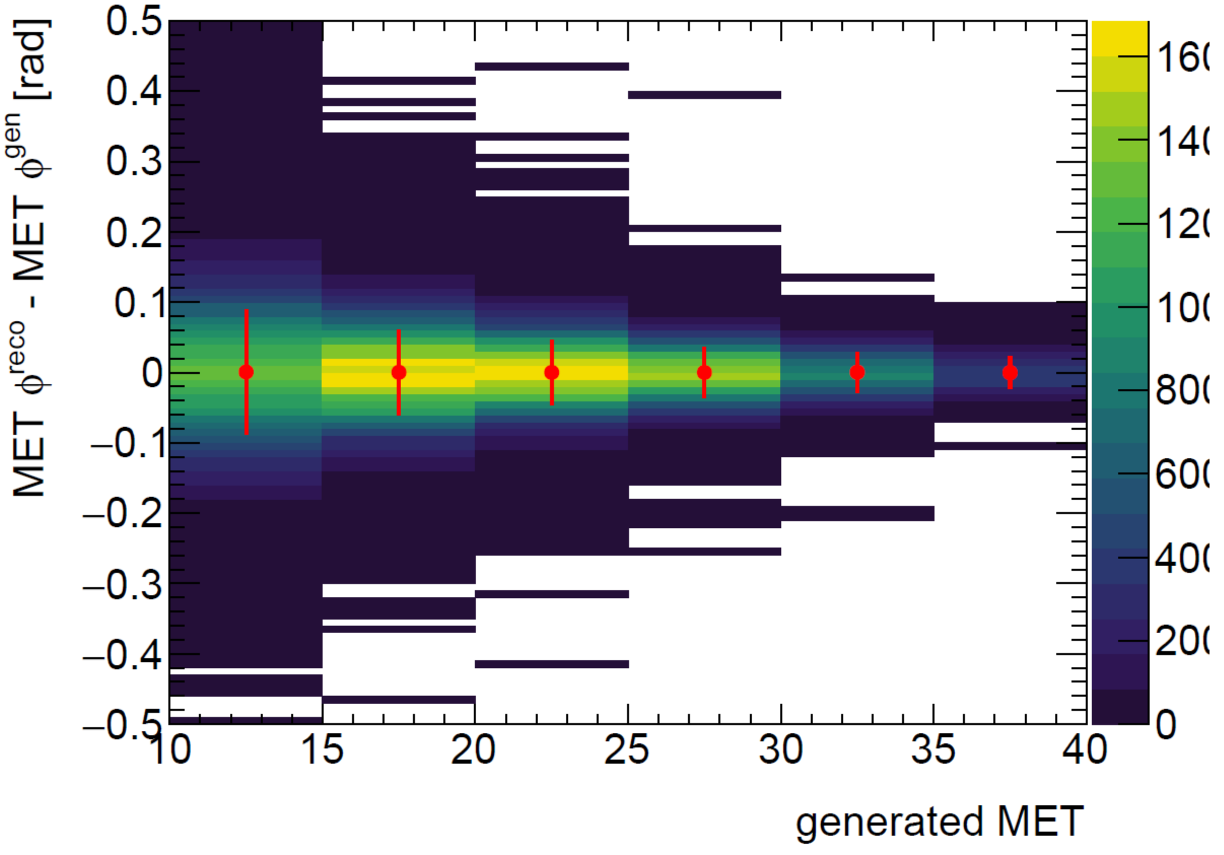
Neutrino pT

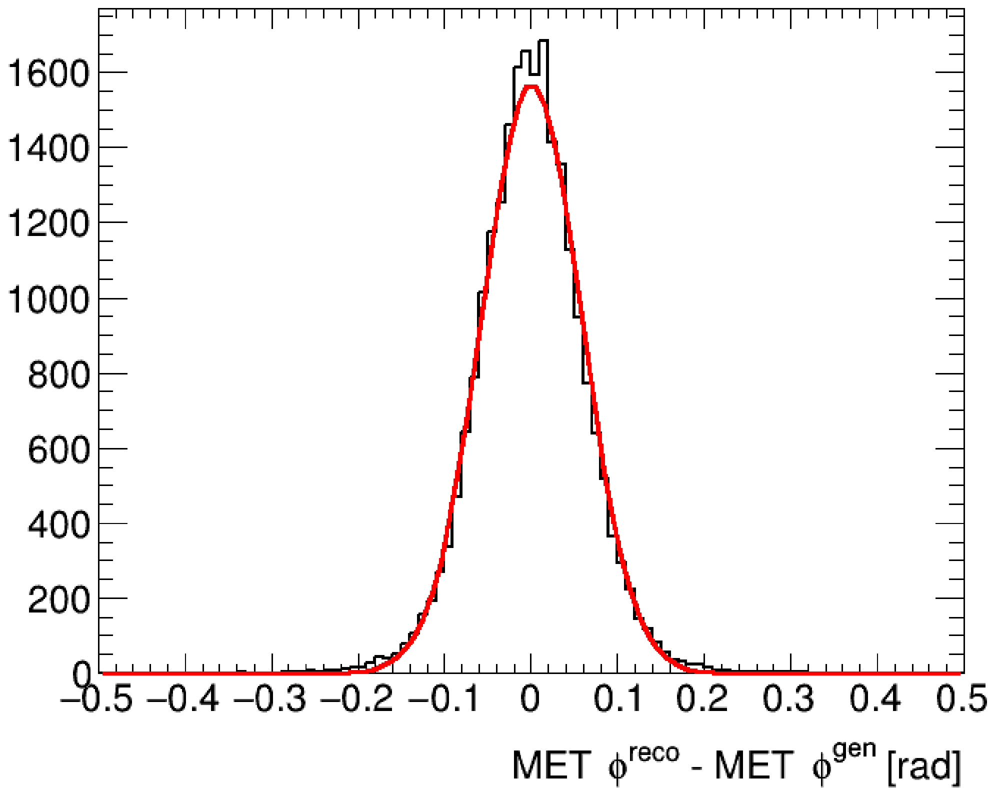




~20% at 10 GeV , ~10% at 25 GeV, but non-Gaussian response

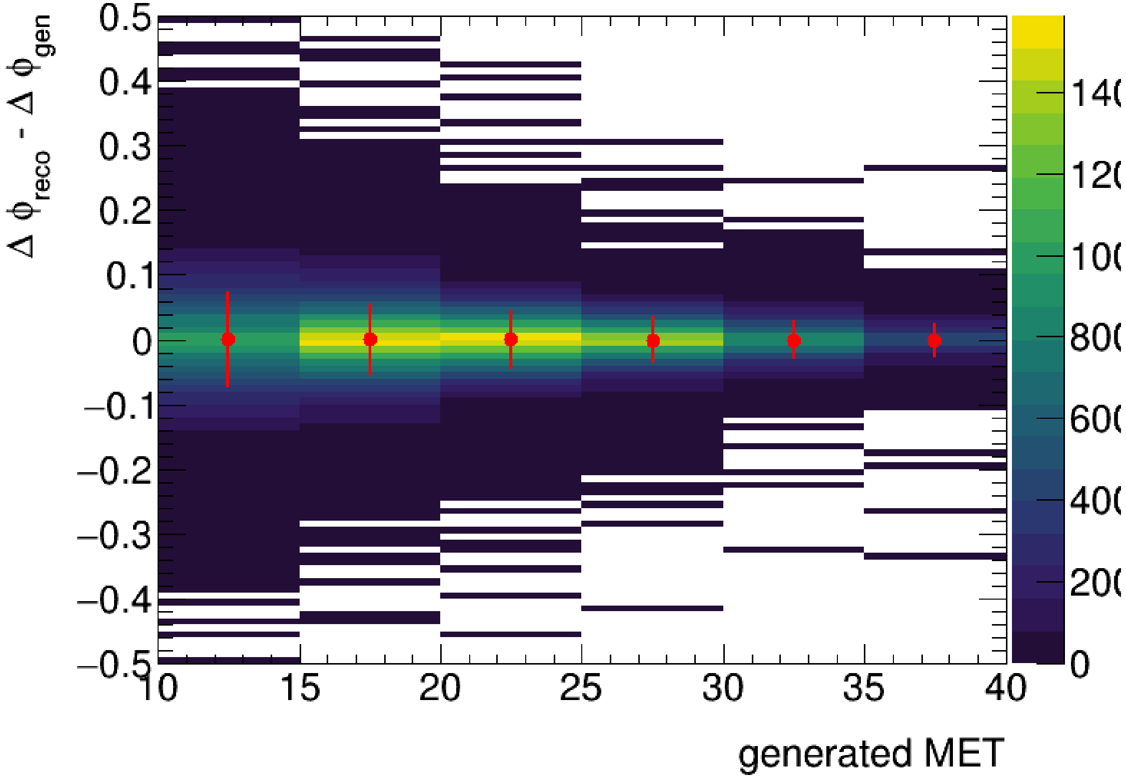
Neutrino azimuthal angle

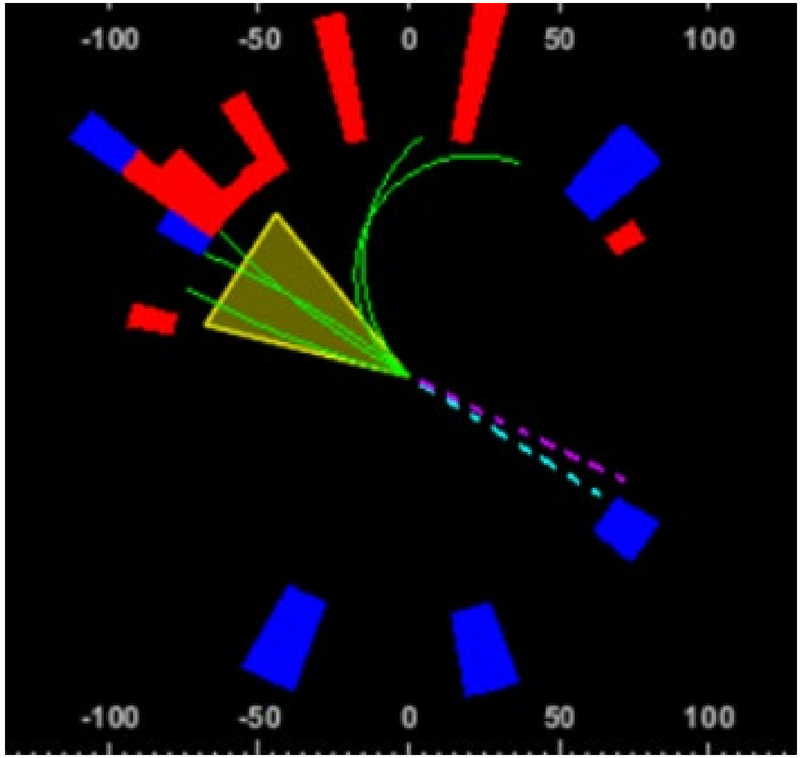




~ 0.10 rad at 10 GeV, ~0.05 rad at 30 GeV

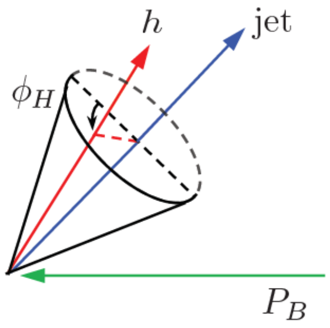
Resolution for Neutrino-jet opening angle

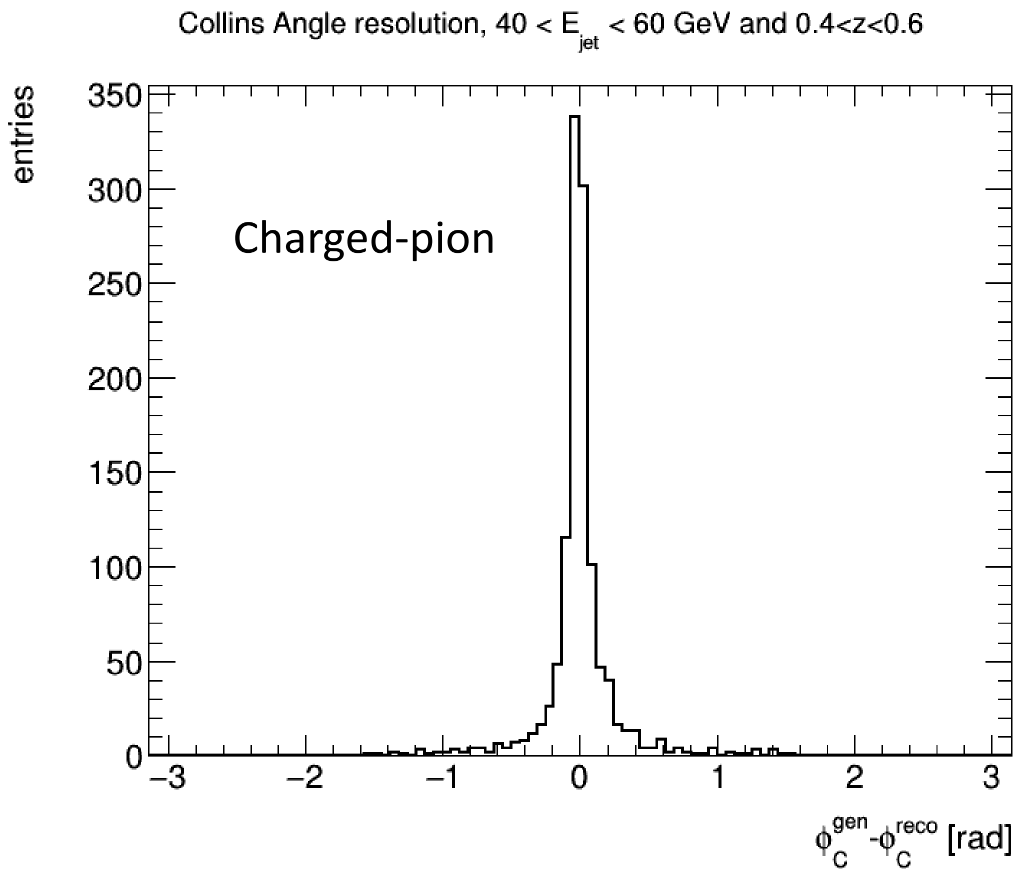


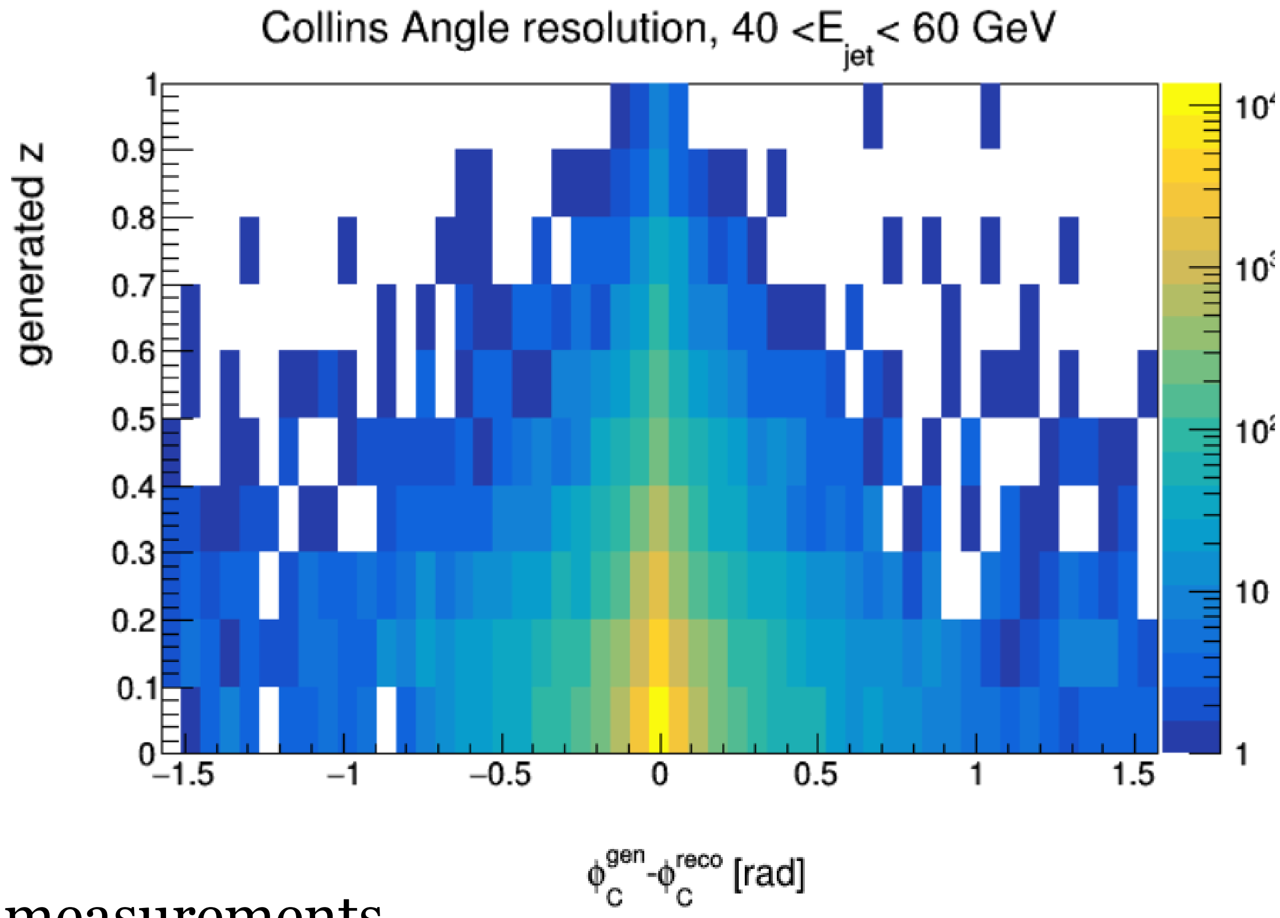


Dominated by MET resolution, ~0.1 rad RMS.
Feasibility studies still ongoing but looking promising!
(comparable RMS to dijet at RHIC Phys. Rev. Lett. **99**, 142003)

Collins Angle resolution



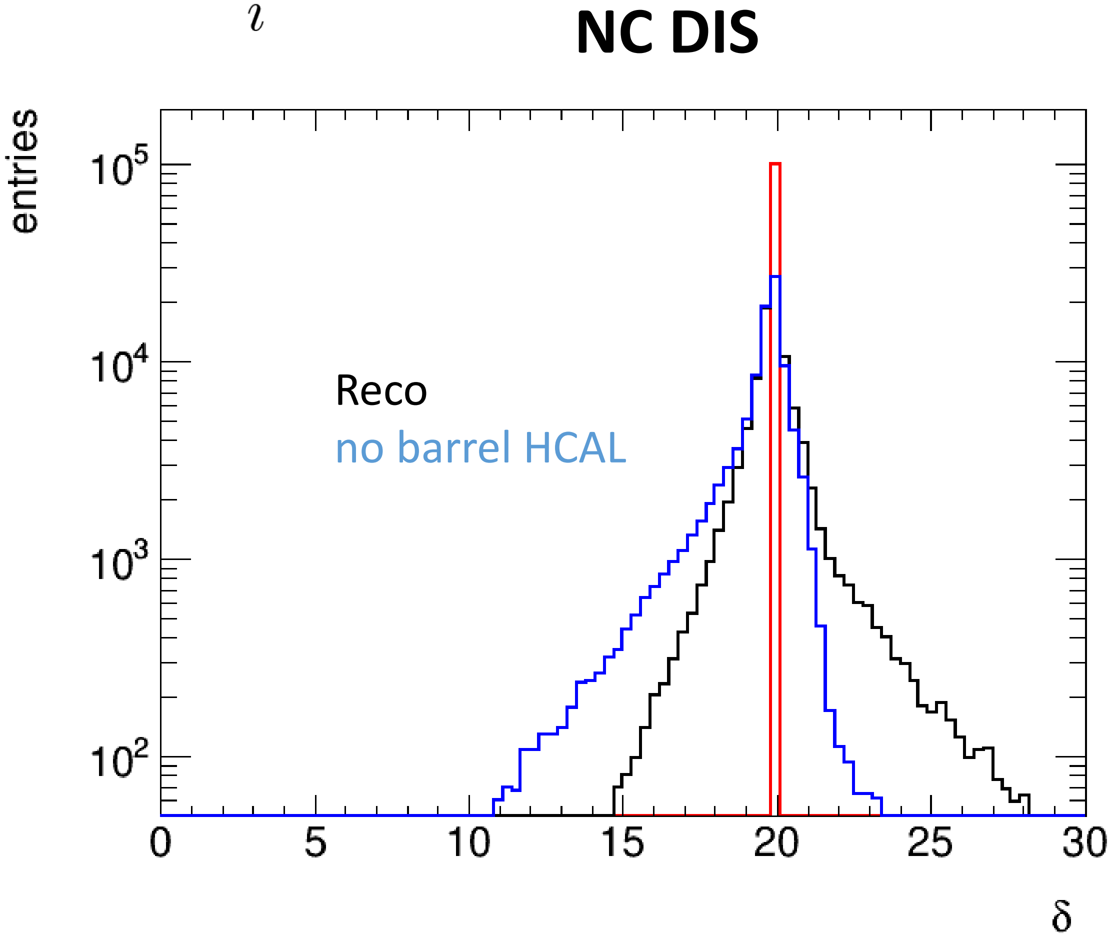


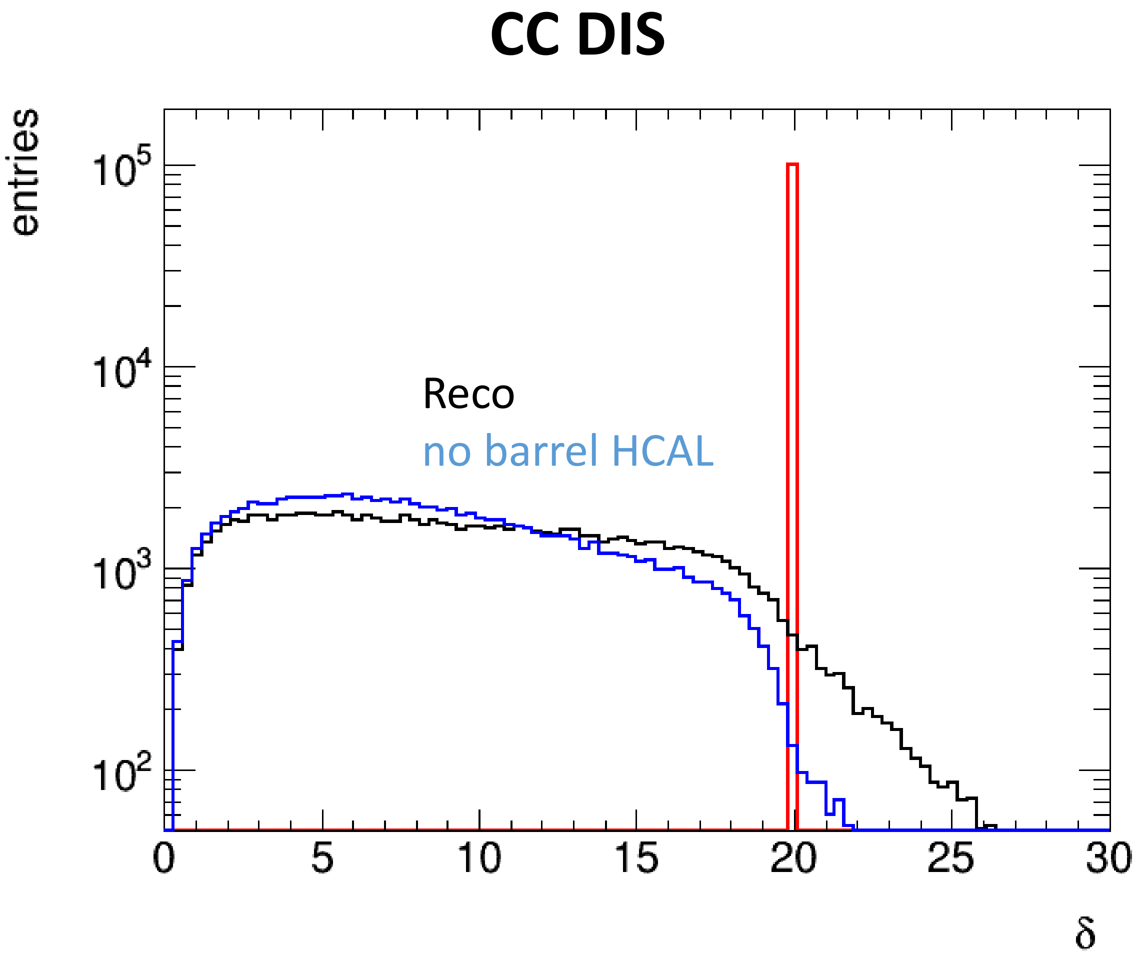


- Compares favorably to STAR measurements
- Calculation on how this propagates to “asymmetry dilution” ongoing

Background rejection to NC DIS:

$$\delta = \sum_i E_i(1 - \cos\theta_i)$$



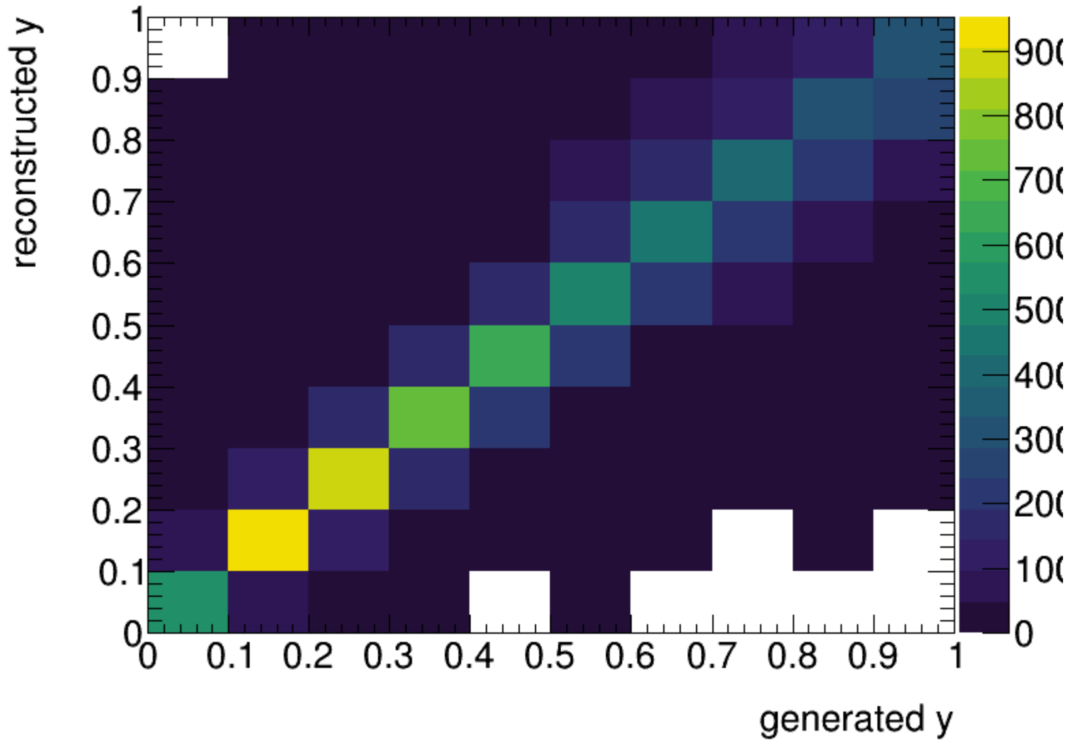


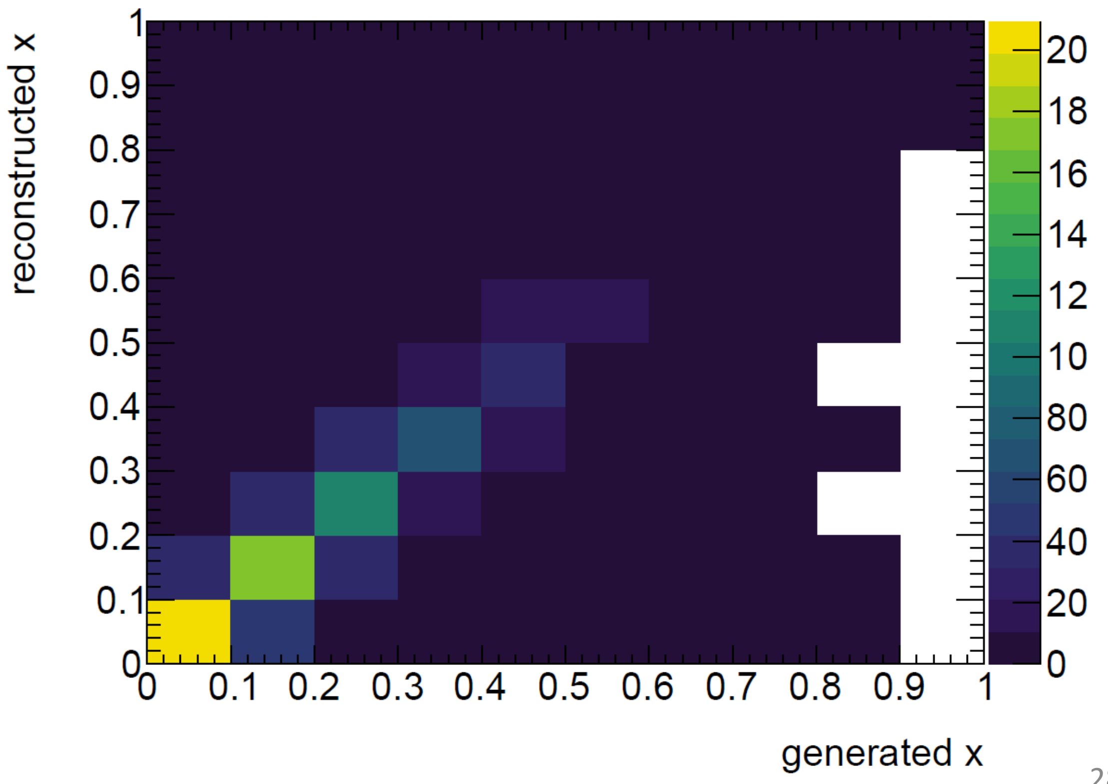
- If one misses track of electron but measures cluster (or viceversa), delta-cut useful to veto NC DIS.

Jacquet-Blondel performance

(which is very related to MET performance)

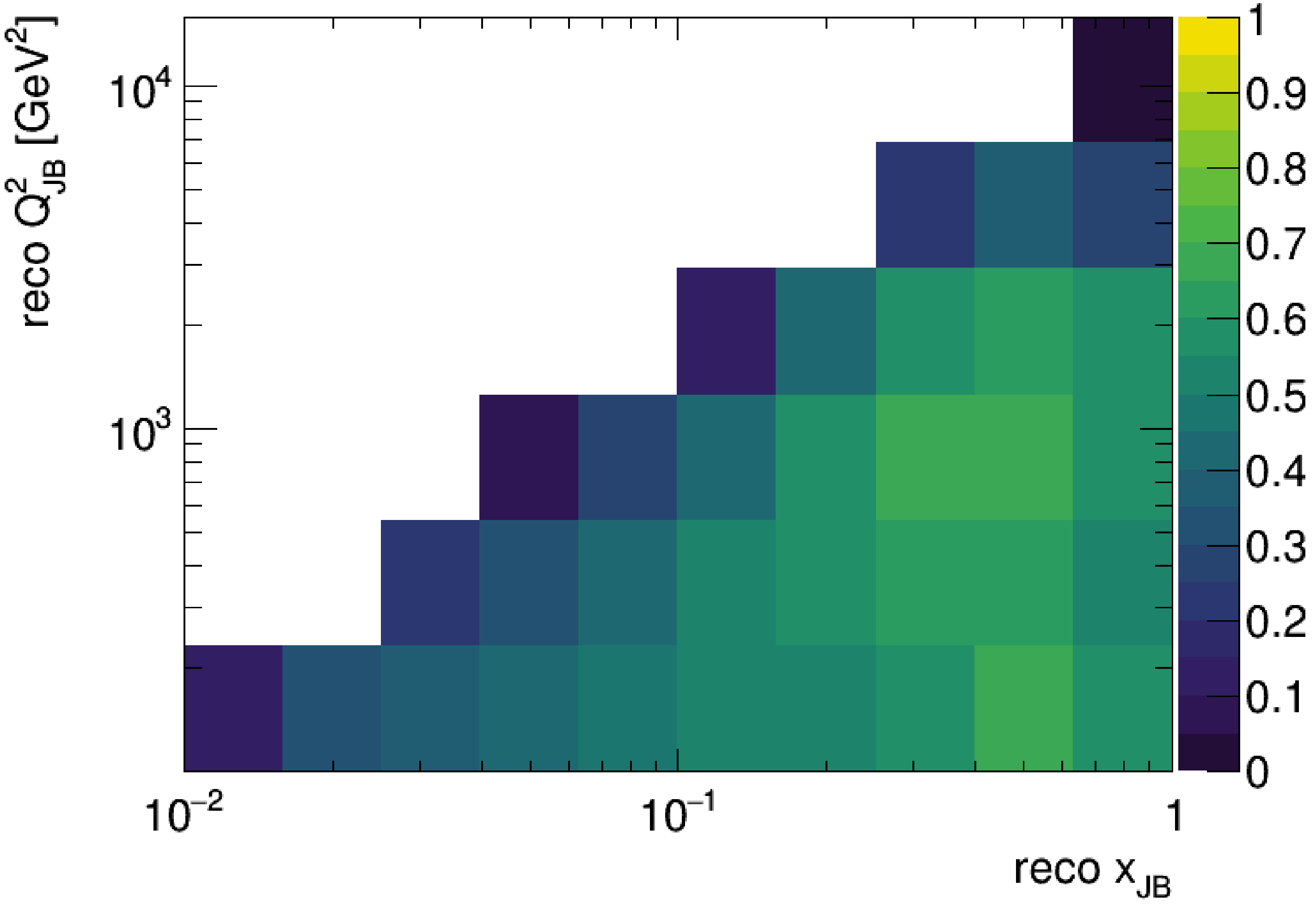
$$y_{\rm JB} = \frac{\sum_i (E_i - p_{Z,i})}{2\ E_e}, \qquad Q^2_{\rm JB} = \frac{(p_T^{\rm miss})^2}{1 - y_{\rm JB}} \qquad \text{and} \qquad x_{\rm JB} = \frac{Q^2_{\rm JB}}{s\ y_{\rm JB}},$$





Jacquet-Blondel Purity

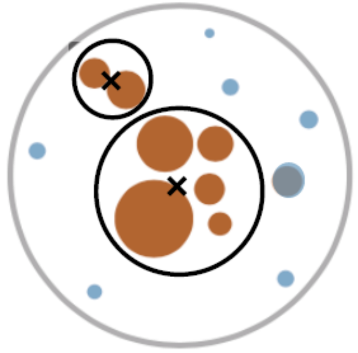
$$\text{purity} = (N_{gen} - N_{out})/(N_{gen} - N_{out} + N_{in})$$



- Reasonable purity reached at high-x and high Q2. (similar conclusion reached in Aschenauer et al. Phys. Rev. D 88, 114025 (2013))
- This is one figure of merit, but one should not forget to consider non-Gaussian tails in response…

Looking ahead

Jet substructure, the key to novel TMD studies



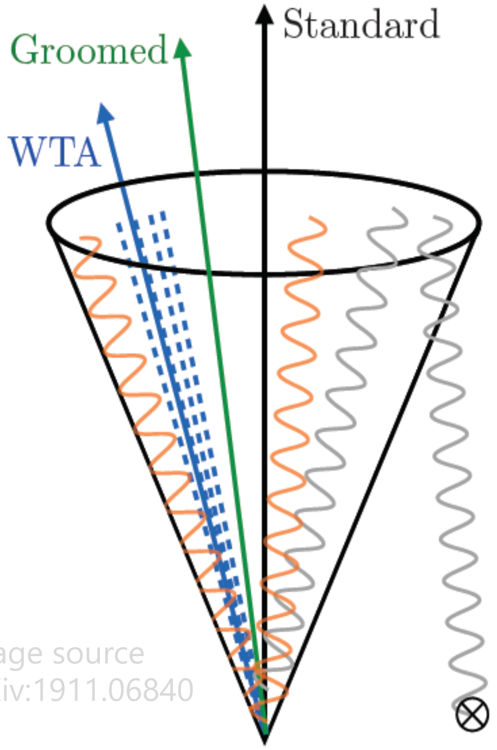


Image source arXiv:1911.06840

- Grooming: new tool to control hadronization for better access to TMD PDFs:
  Gutierrez-Reyes et al. *JHEP 08 (2019) 161 .*
  Makris et al. *JHEP 07 (2018) 167 .*
- "Jet axes" studies from LHC research will likely flourish at EIC to study TMD fragmentation, TMD evolution and more e.g. *Cal et al.* *arXiv:1911.06840 ,*
  Niell et al. *10.1007/JHEP04(2017)020*

By the time EIC comes online, we will be counting EIC jet papers by the hundreds.
Let's not miss the upcoming explosion in this field,
We need day-1 capabilities for a comprehensive jet program

yesterday on arXiv…

arXiv:2005.02398 (cross-list from hep-ph) [pdf, other]

Polarized jet fragmentation functions

Zhong-Bo Kang, Kyle Lee, Fanyi Zhao

Comments: 14 pages, 5 figures

Subjects: **High Energy Physics - Phenomenology (hep-ph)**; High Energy Physics - Experiment (hep-ex); Nuclear Experiment (nucl-ex); Nuclear Theory (nu

We develop the theoretical framework needed to study the distribution of hadrons with general polarization inside jets, with and without transve
in this paper, referred to as "polarized jet fragmentation functions", opens up new opportunities to study both collinear and transverse moment
framework, we study longitudinally polarized collinear Λ and transversely polarized TMD Λ production inside jets in both pp and ep collisions.
fragmentation functions with sizeable asymmetries predicted, in particular, at the future Electron-Ion Collider.

"We expect our work will open new and exciting opportunities in the direction of studying spin-dependent hadron structures using hadrons inside jets."

First workshop for jets @ EIC:

Postponed due to Covid, we are planning reschedule

Motivation

As the realization of an Electron Ion Collider moves forward, efforts from the nuclear physics community continue to grow. In addition to the ongoing detector R&D efforts, plans for novel analysis topics must be demonstrated to aid in the detector designs, so that we can maximize the physics output of the EIC. This relies on input from both the experimental and theory communities. The aim of this workshop is to gather experts as well as those with a developing interest in the EIC so that theorists and experimentalists with experience measuring jets in a variety of hadronic collision systems can discuss the possible advantages and challenges of making measurements of jets in e+p and e+A collisions at the EIC.

In recent years, measurements at RHIC and LHC have demonstrated that reconstructed jets are a robust probe of QCD physics. Meanwhile, much progress has been made in understanding the usefulness of measuring jets at an EIC since the EIC white paper was written in 2011. However, one limiting factor in furthering these studies is

Just before the Berkeley YR meeting,

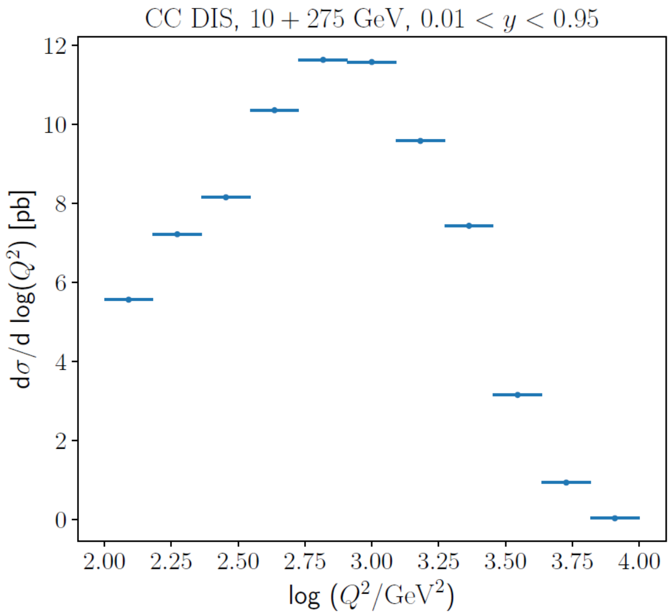
Topics:

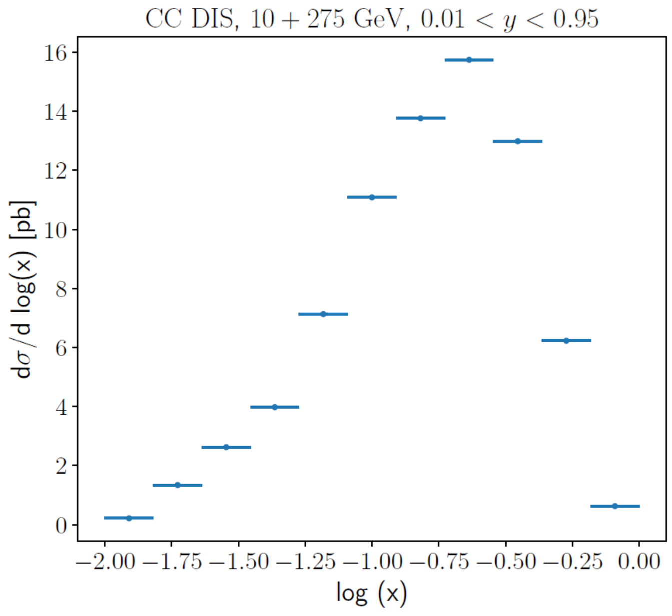
- Jet observables, advantages, and opportunities for EIC
- Novel observables via jet substructure
- TMD and SCET formalism for jets and substructure.
- 3D and 5D imaging with exclusive jets (GPDs and Wigner functions)
- Connections to Lattice QCD
- Detector requirements for the EIC

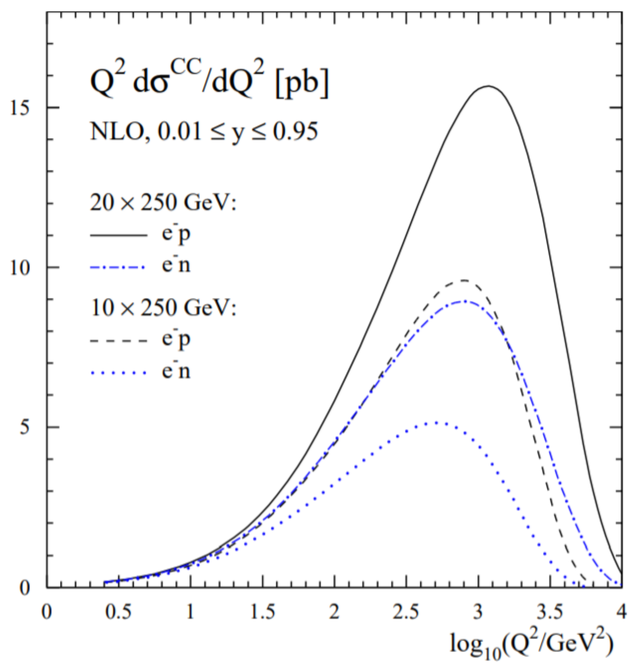
Summary

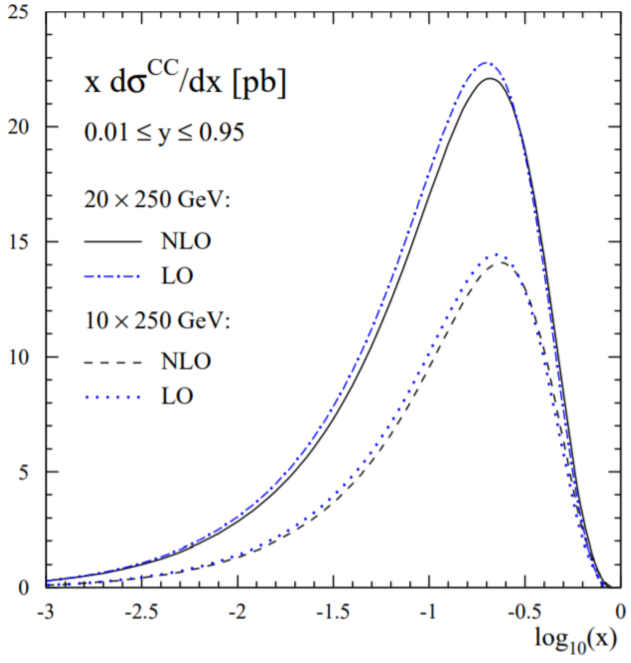
- Studies with jets at EIC will be unlike any previous collider (even HERA!). Key measurements include:
  - electron-jet correlations
  - neutrino-jet correlations
  - jet fragmentation
  - jet substructure
- Jets for 3D imaging is an excellent opportunity for the convergence of the collider and fixed-target community at the EIC.

Backup



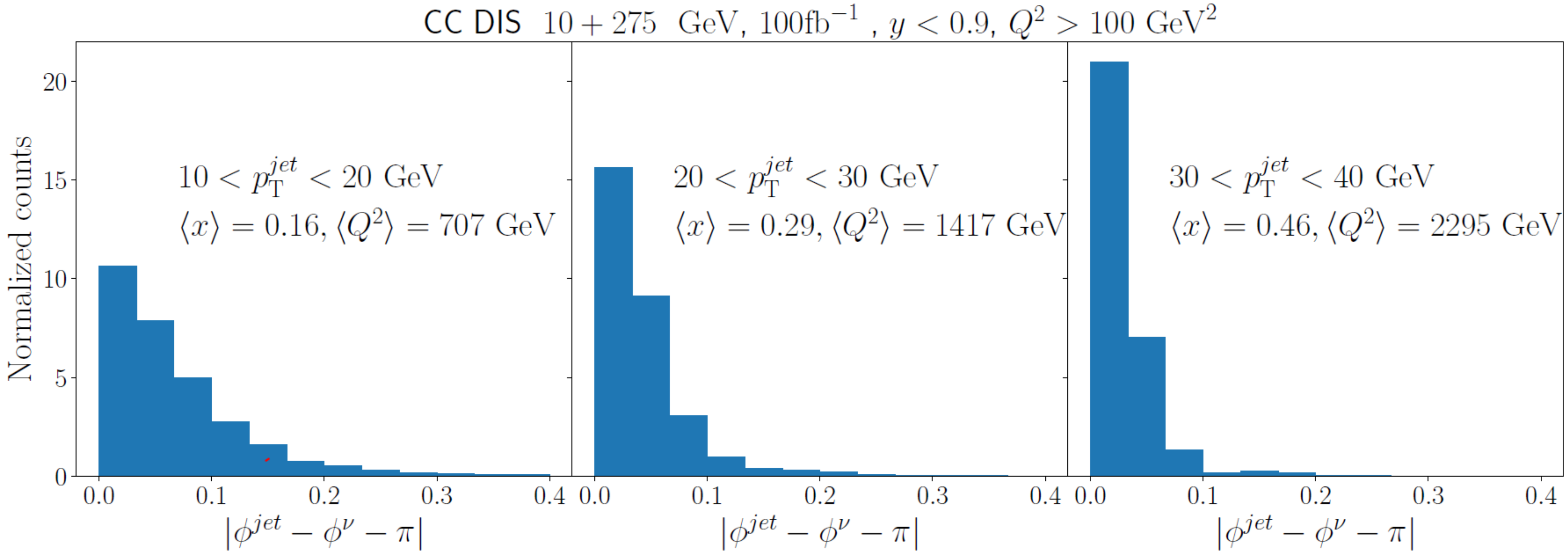






- Pythia (LO) very similar to calculations
- NLO effects are pretty small.
- Inclusive cross-section for Q2>100 GeV2 is 14.4 pb, or 1.4 M events in 100 fb-1.

Neutrino-jet correlation



Simulation parameters

- Pythia8, unpolarized e-p DIS,
  DIRE parton shower (angular ordered)
- $E^{proton} = 275$ GeV, $E^{electron} = 10$ GeV
- Event cuts:

For NC DIS: $0.1 < y < 0.85$, $Q^2 > 25$ GeV^2

For CC DIS: $0.01 < y < 0.90$, $Q^2 > 100$ GeV^2

- Jets are reconstructed with the anti-k_T algorithm with $R = 1.0$ using FastJet
- Particle cuts: $|\eta^{part}| < 4.5$, $p_T^{part} > 0.25$ GeV, ctau> 10mm exclude neutrinos and scattered electron.
- **No radiative corrections yet.**

We are using the lab frame, which is trivially related to the lepton-nucleon frame

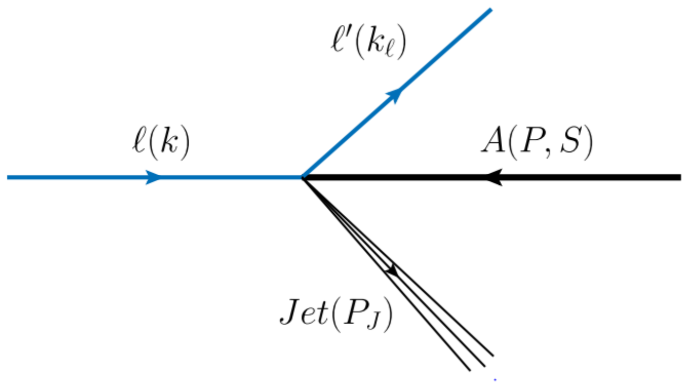
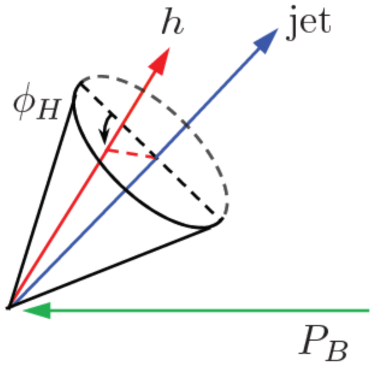


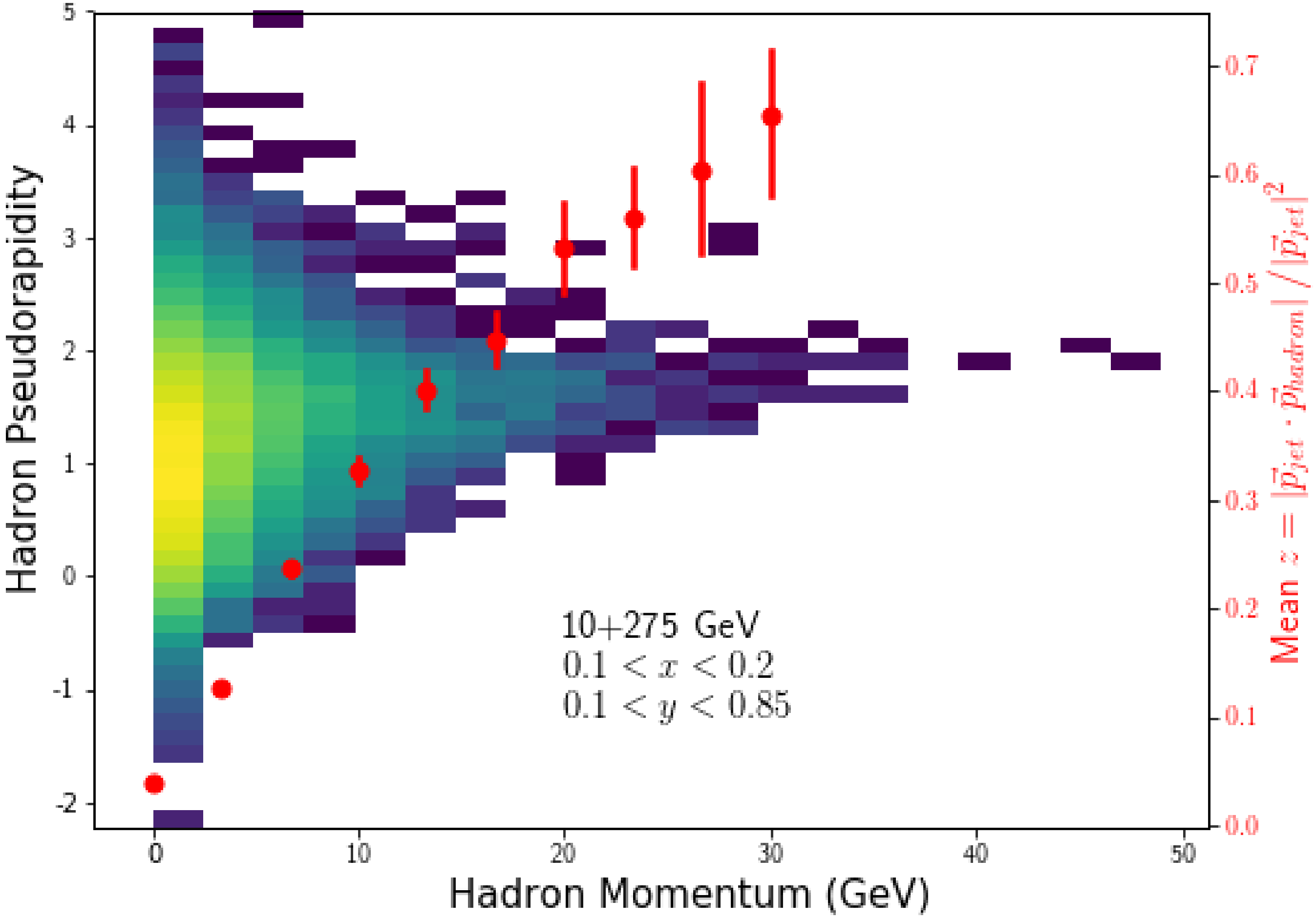
FIG. 1. Lepton-jet correlation for the tomography of the nucleon or nucleus at the EIC. *Liu et al. PRL 122 192003*

$$Q^2 = -\hat{t} = \sqrt{s}\, p_T^e\, e^{-y_e}$$

$$\hat{u} = \sqrt{s}\, x\, p_T^e\, e^{y_e}$$

PID requirements





- Charged pions separation from Kaons and protons up to ~30 GeV