Jet-based measurement of Sivers and Collins asymmetries at the EIC

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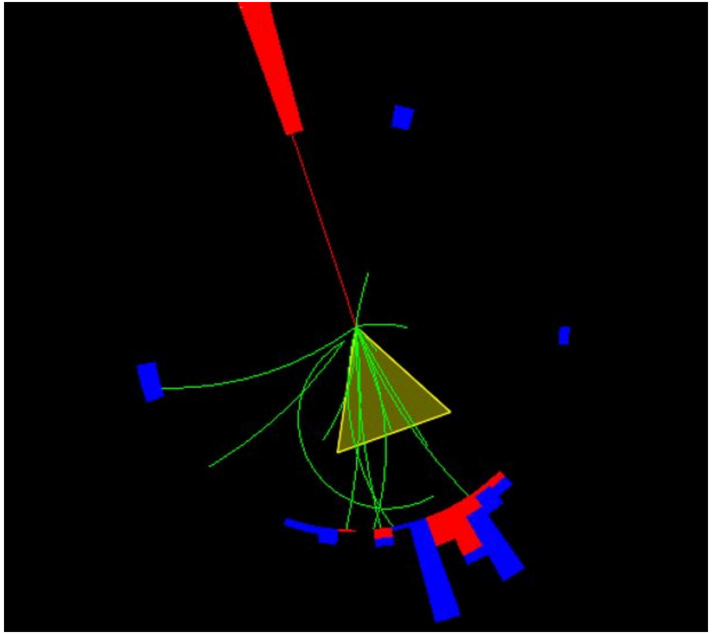
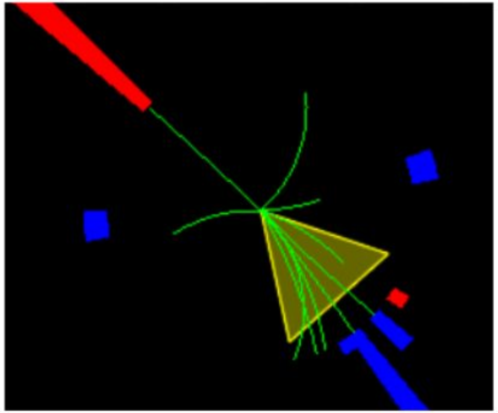
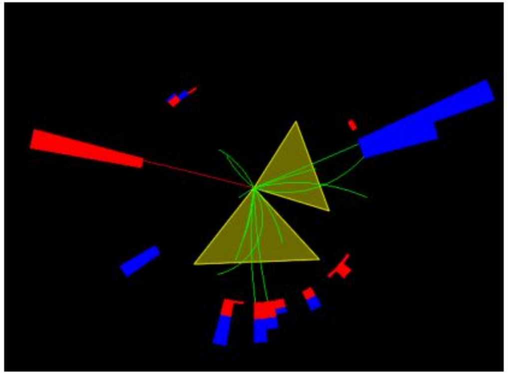
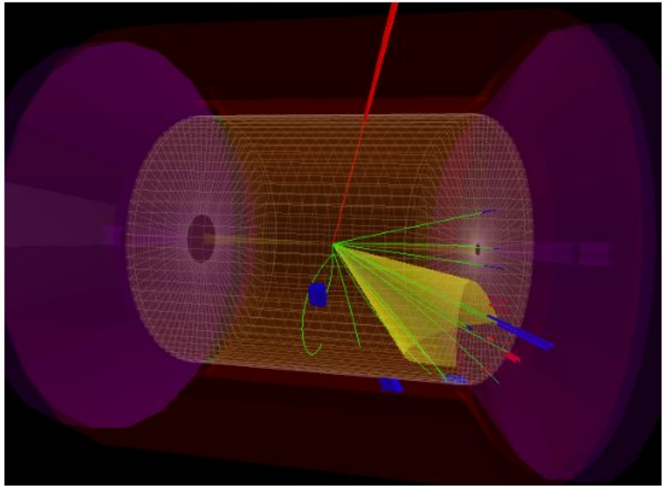
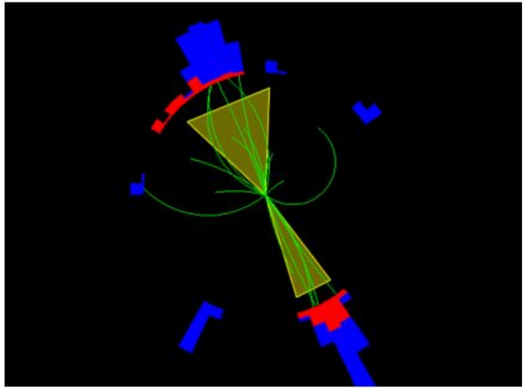


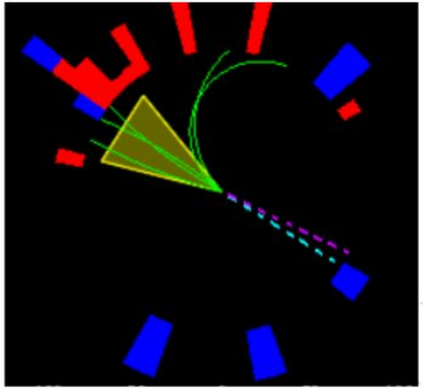
The EIC, a jet factory, will make the first jets in nuclear DIS and proton-polarized DIS



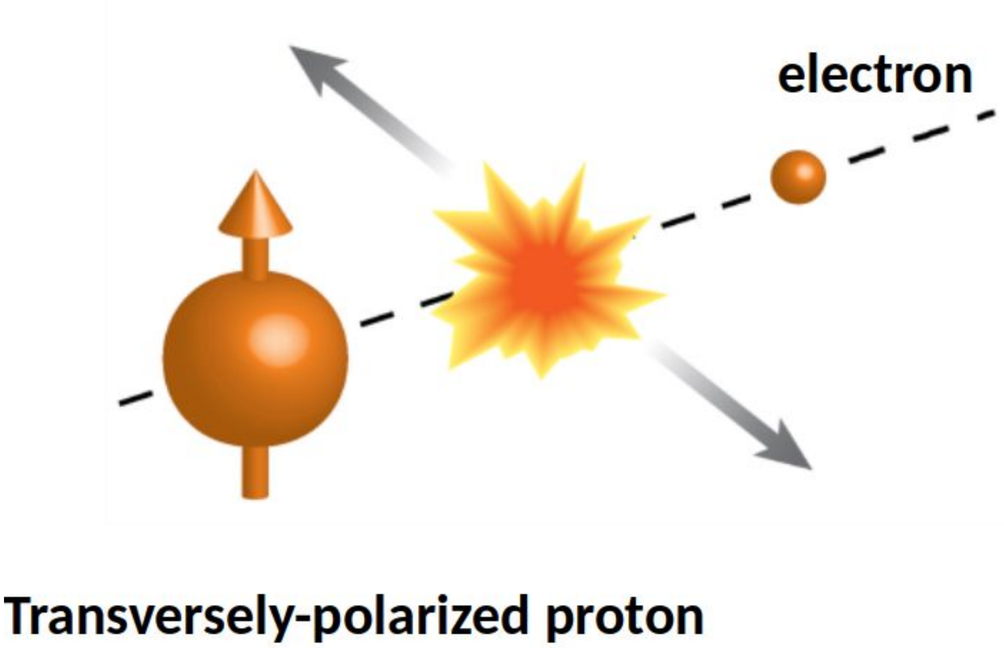


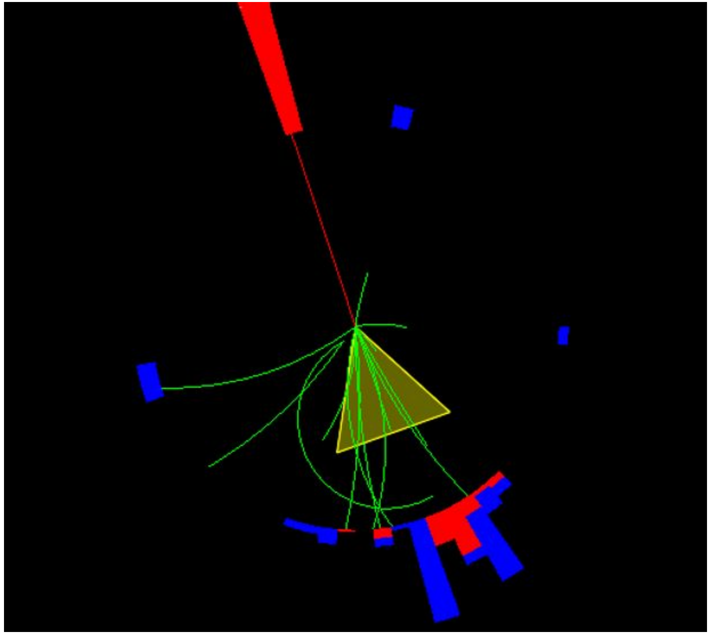






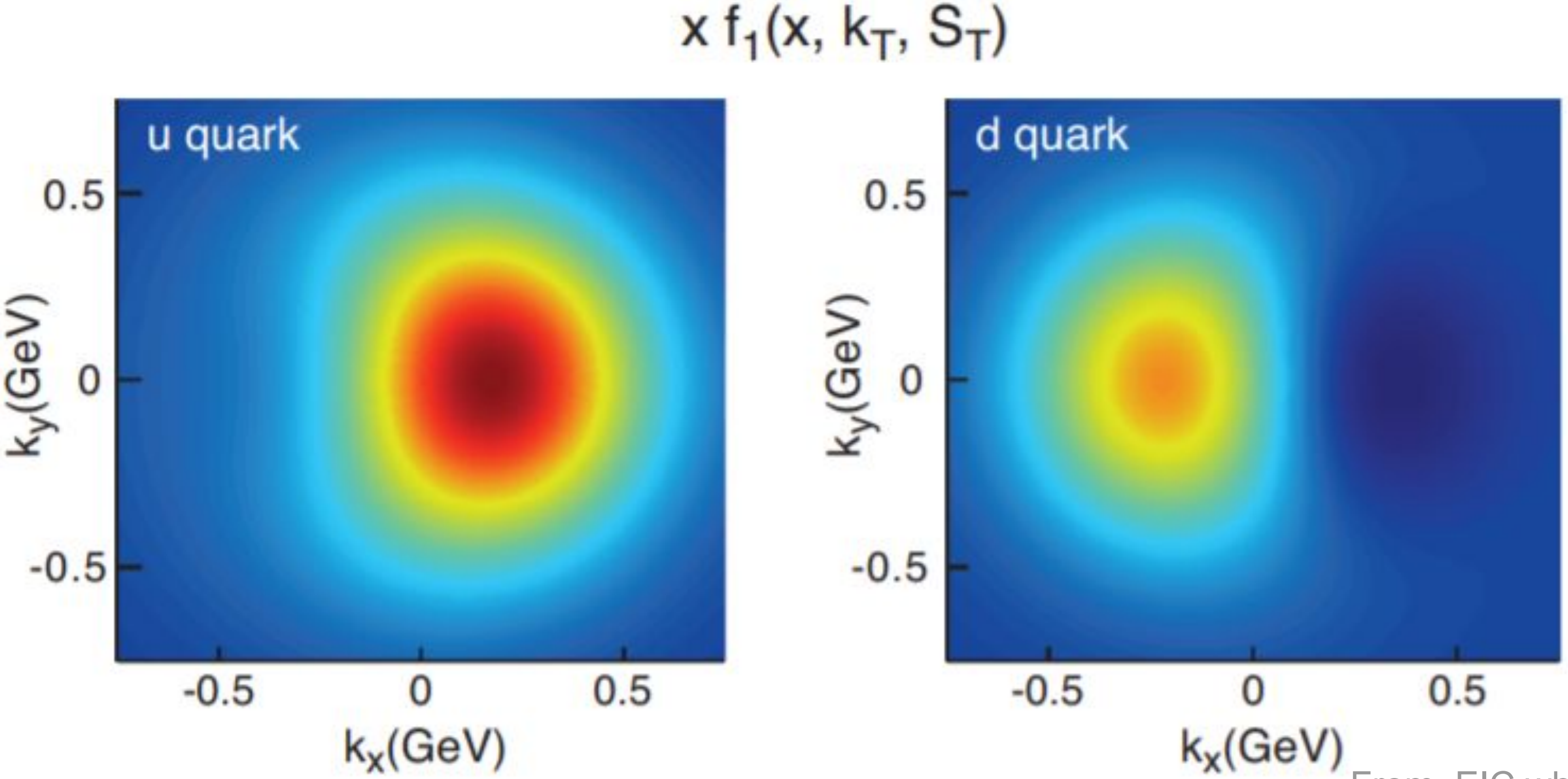
Spin-orbit correlations lead to azimuthal asymmetries





In fixed target experiments, this is studied measuring one hadron at the time (i.e. “SIDIS”)

The asymmetry strength reflects a correlation between proton spin and quark momentum, “Sivers function”

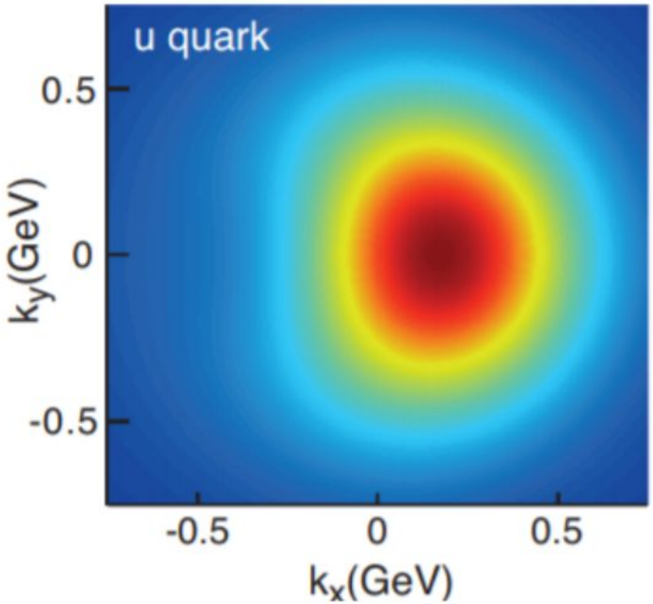


From EIC white paper

Fact: one gets a "blurred" image by measuring one hadron at the time

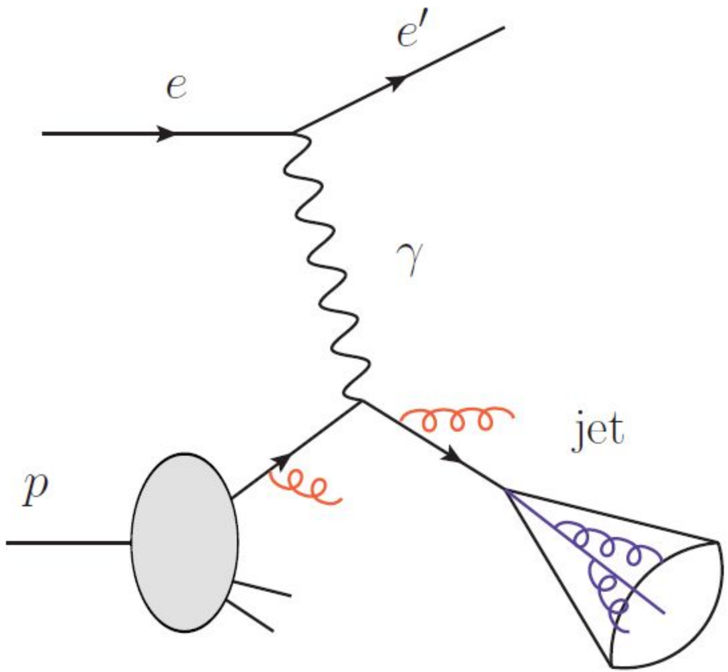
TMD PDF TMD FF

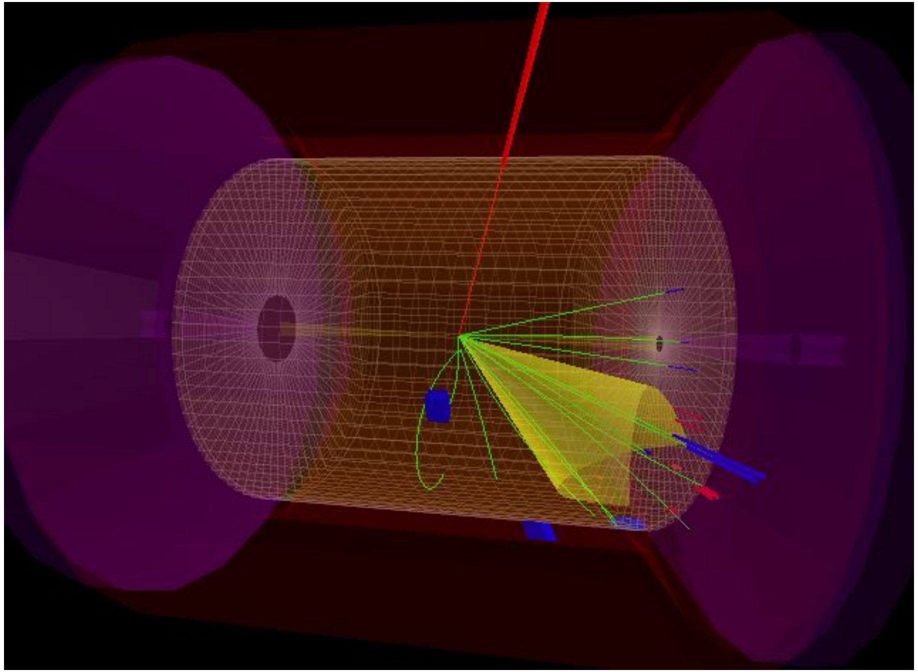
$$\int d^2\boldsymbol{k}_\perp\, d^2\boldsymbol{P}_\perp\, f_1^a(x,\boldsymbol{k}_\perp^2;Q^2)\, D_1^{a\to h}(z,\boldsymbol{P}_\perp^2;Q^2)\, \delta^{(2)}(z\boldsymbol{k}_\perp - \boldsymbol{P}_{hT} + \boldsymbol{P}_\perp)$$



Trying to constrain PDF and FF from SIDIS data leads to huge correlations.

The collider era will bring another tool: jets

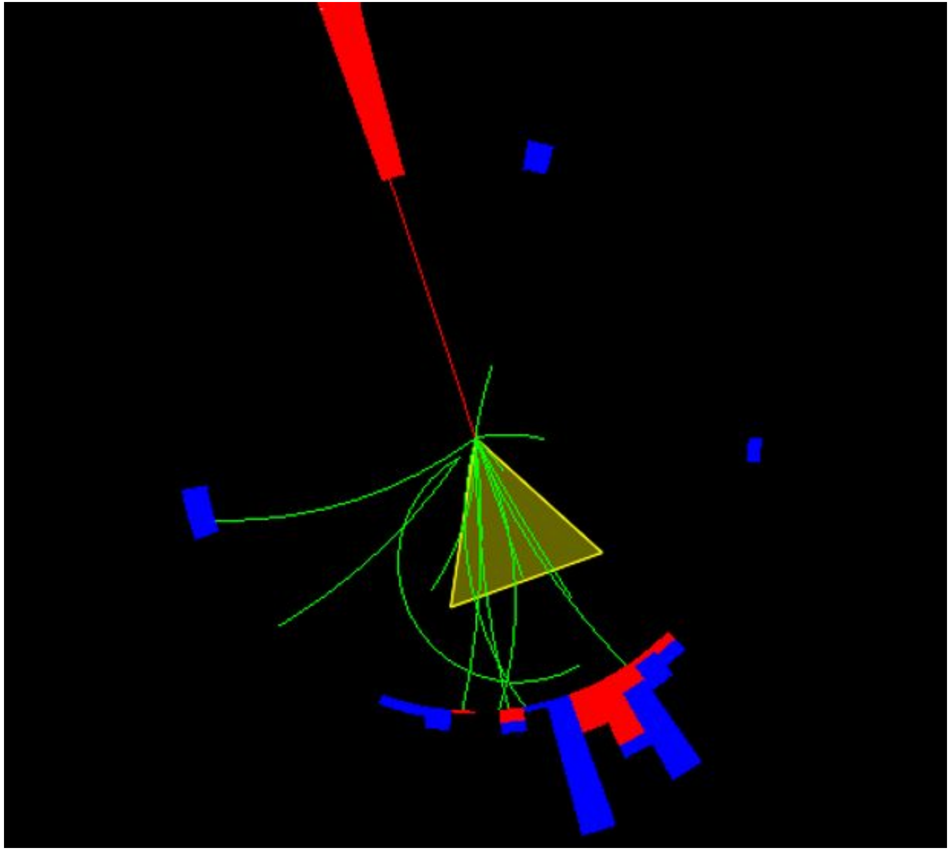




Delphes fast simulation of an EIC detector and Pythia8 neutral-current DIS event

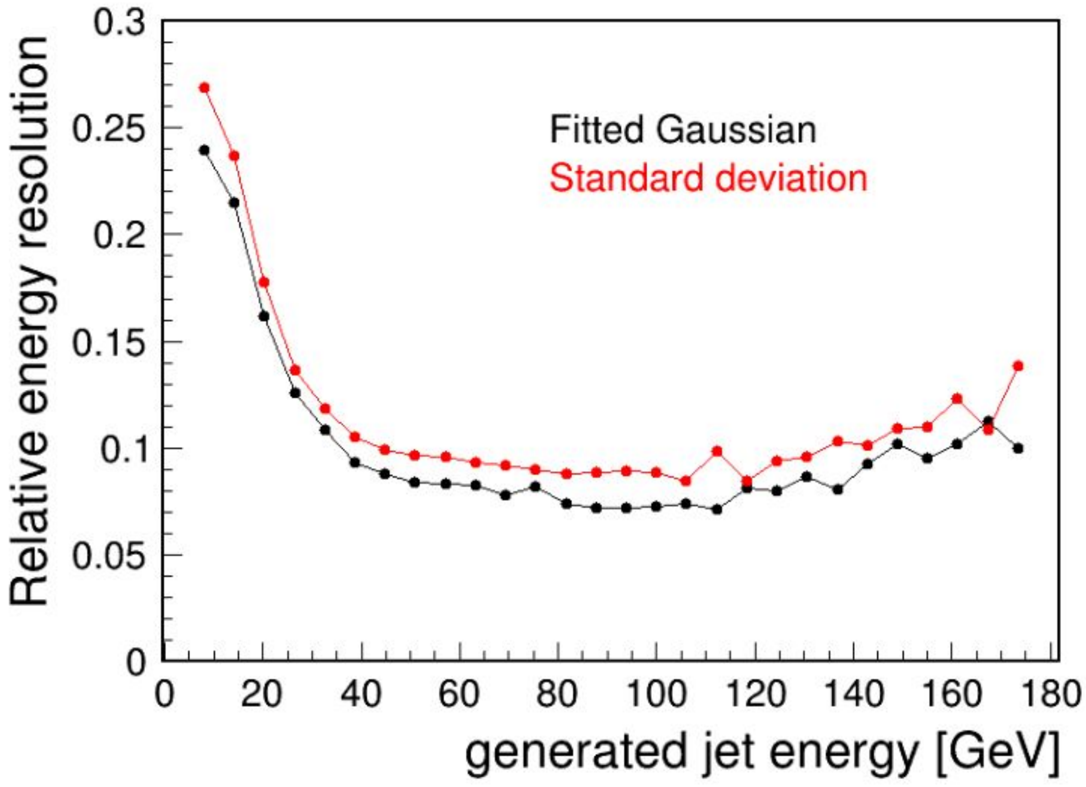
A new channel to probe for quark TMDs and evolution

Liu et al. PRL. 122, 192003, Gutierrez et al. PRL. 121, 162001

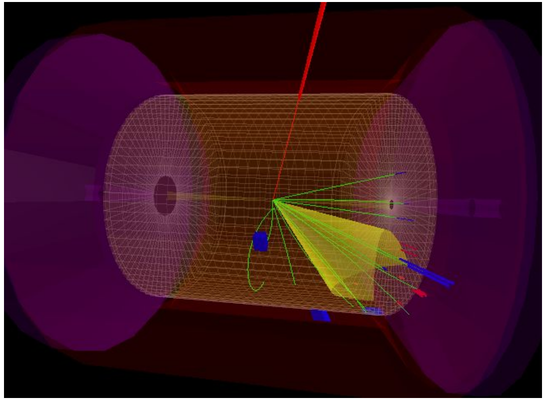


"The advantage of the lepton-jet correlation as compared to the standard SIDIS processes is that it does not involve TMD fragmentation functions."

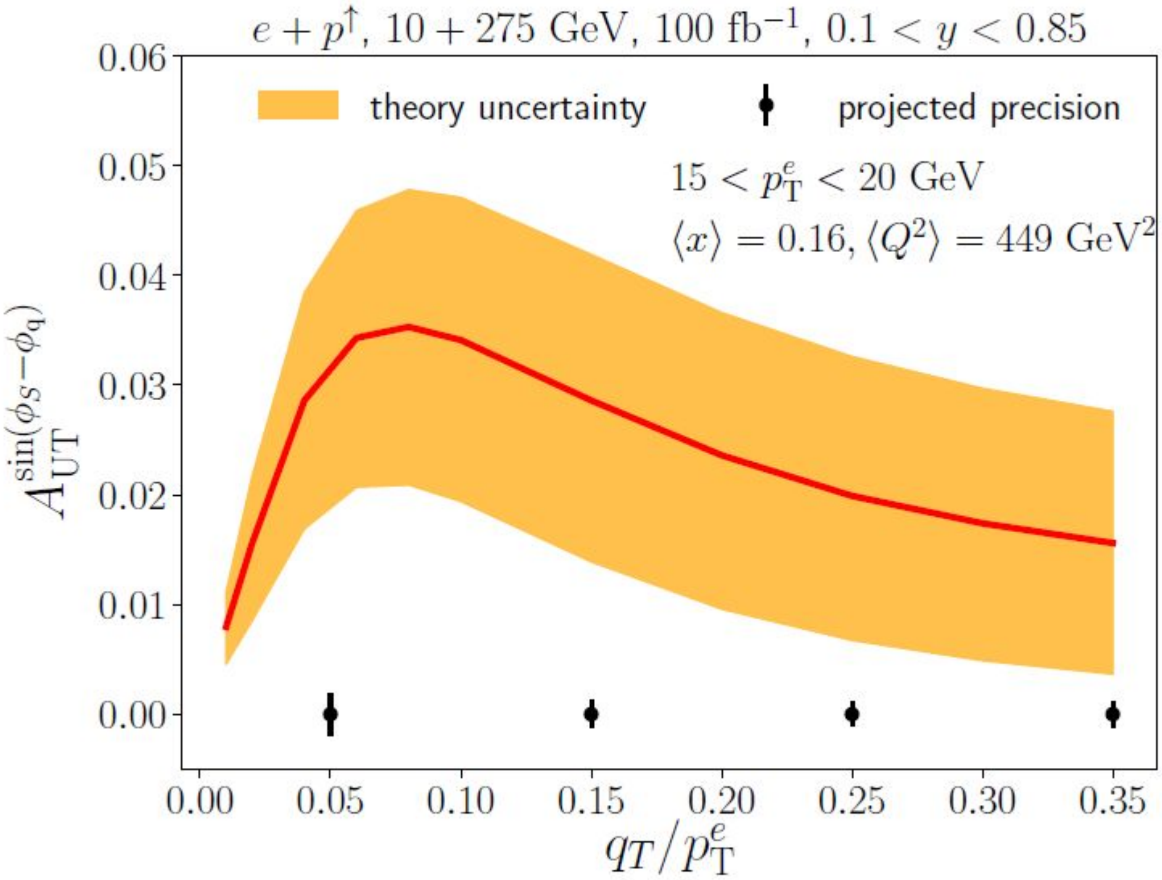
Expected performance (with energy flow algorithm)



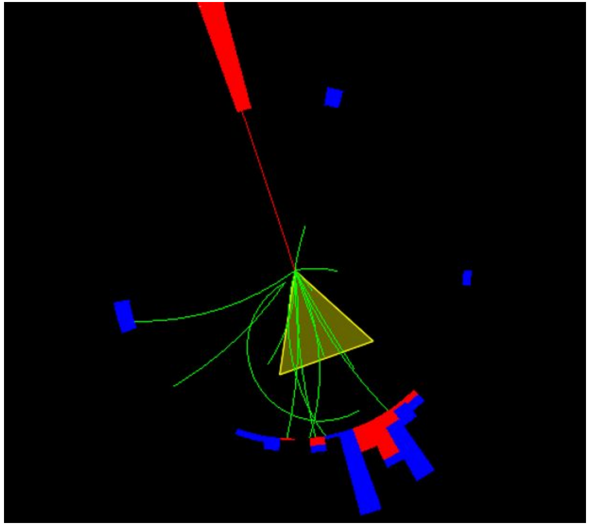
Using Delphes fast-sim with EIC Yellow report parameters



Projection for Lepton-jet Sivers asymmetry



$$q_T = |\vec{p}_T^{\,e} + \vec{p}_T^{\,\mathrm{jet}}|$$

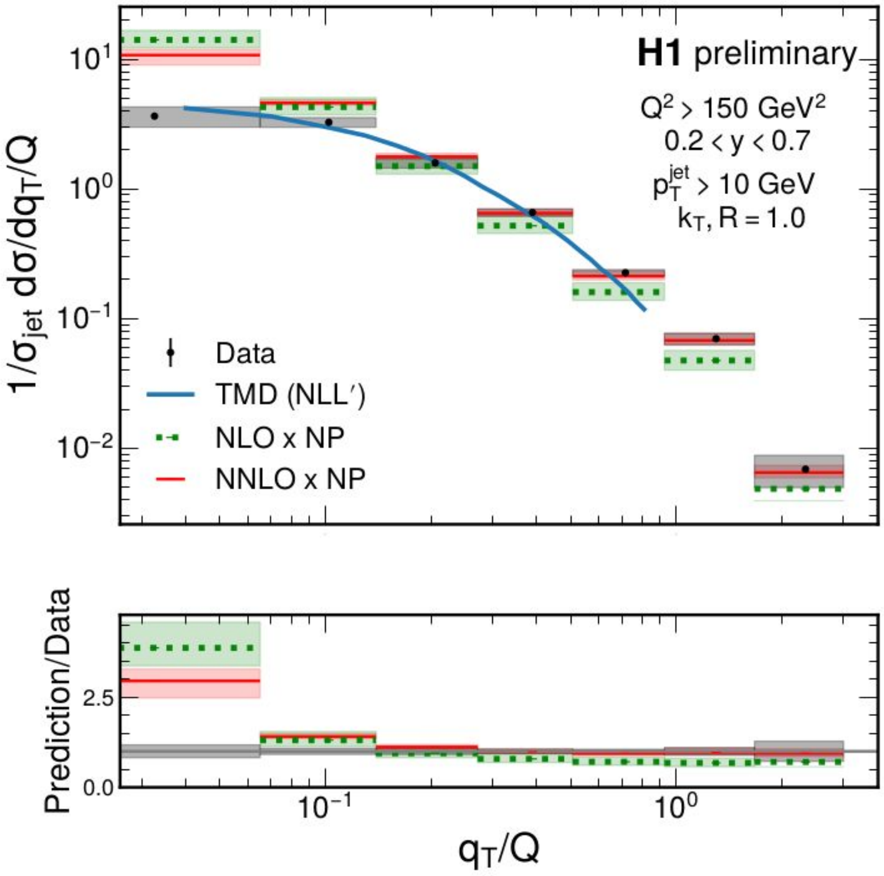


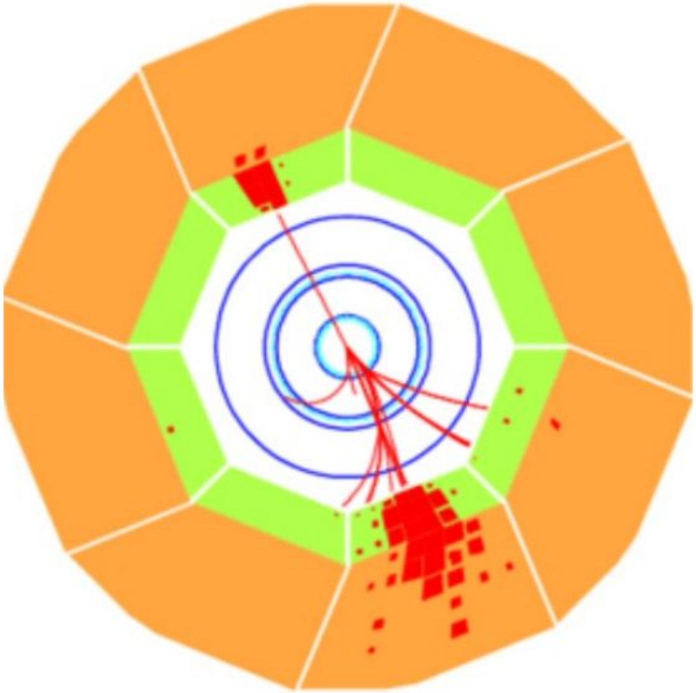
Prediction & projection in
Arratia et al. PRD 102, 074015 (2020
Based on formalism in
Liu et al. PRL. 122, 192003

Can the momentum imbalance be measured well enough?

(Spoiler alert) Yes. See my talk on Thursday for more details on H1 analysis

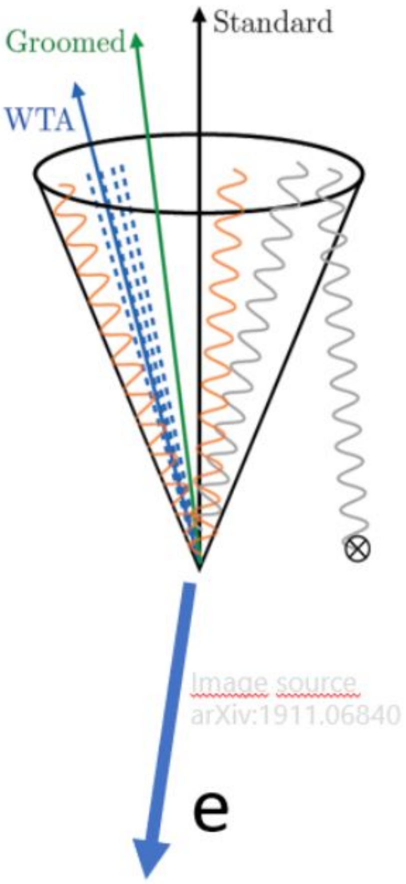
https://www-h1.desy.de/h1/www/publications/htmlsplit/H1prelim-21-031.long.html

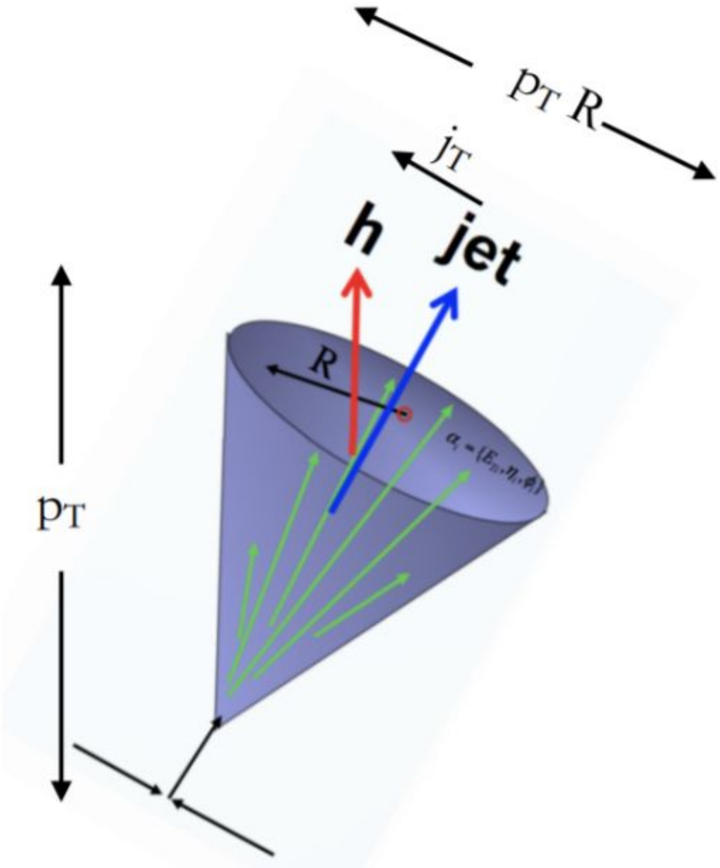


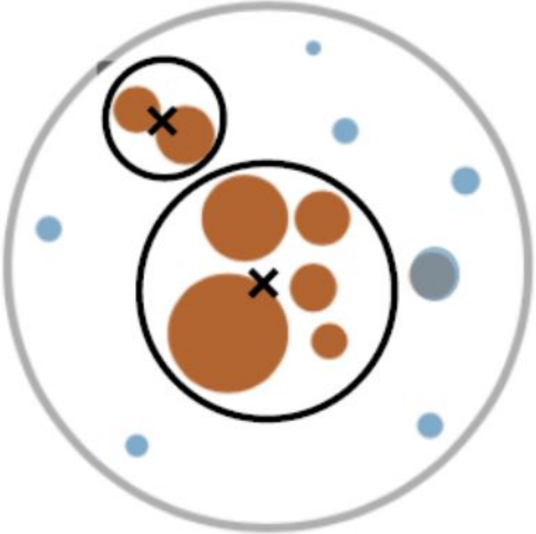


$$q_T = |\vec{p}_T^{\,e} + \vec{p}_T^{\,jet}|$$

Jets have rich substructure, which encodes rich dynamics



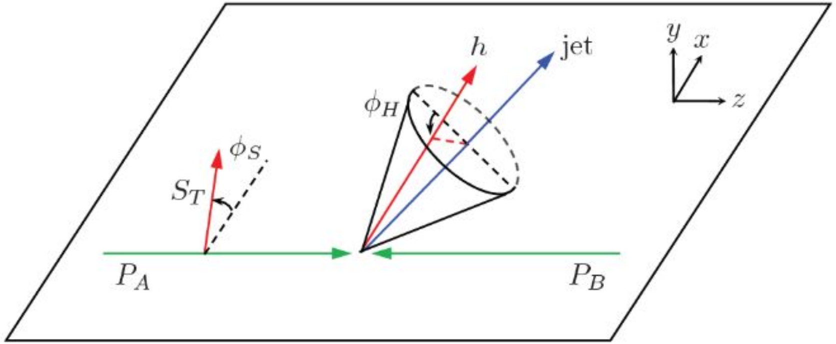




Transversity with jets

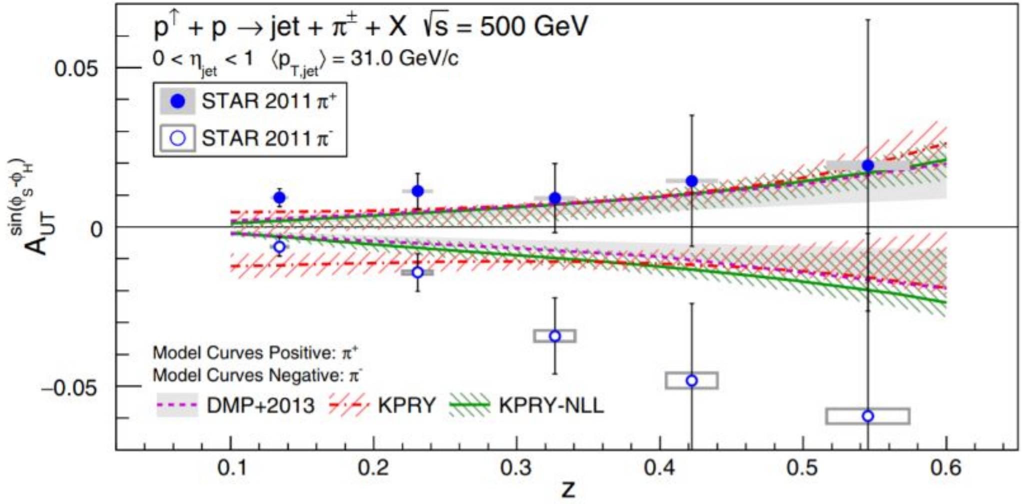
distribution of transversely polarized quarks inside a transversely polarized nucleon

This is measured with “Hadron-in-jet” azimuthal asymmetries:

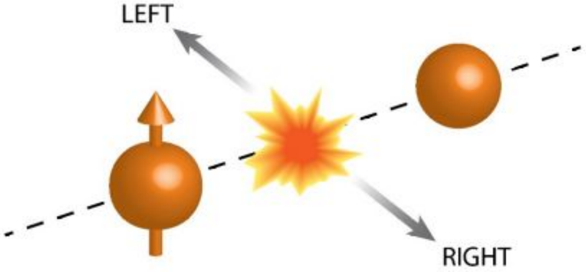


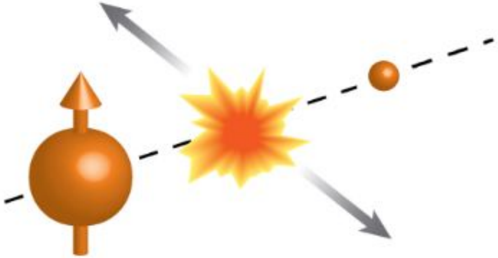
Phys. Lett. B 774, 635 (2017), Kang et al.
Phys.Rev.D77:074019 (2008) Yuan.

Measured at the RHIC proton-collider
STAR Collaboration, Phys. Rev. D 97, 032004 (2018)



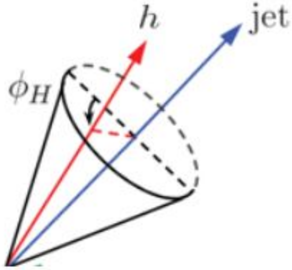
Complementarity

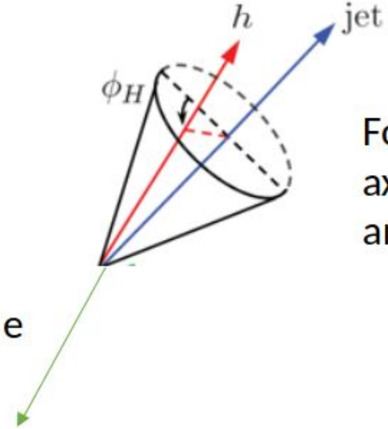




pp at RHIC

ep at EIC



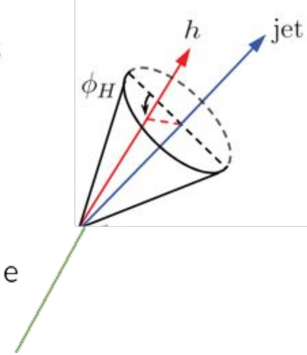


For DIS we will have 2 axes (virtual photon and jet).

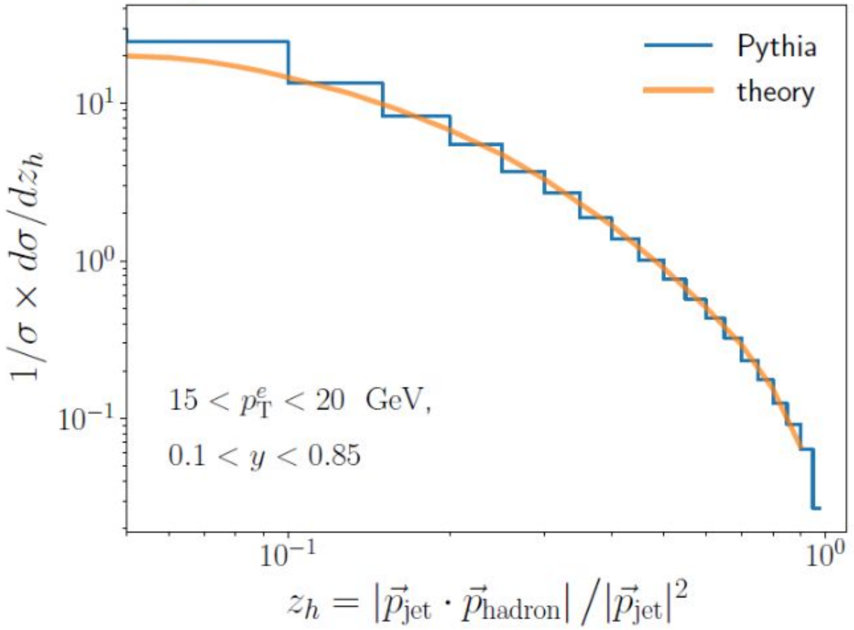
Extended to DIS:

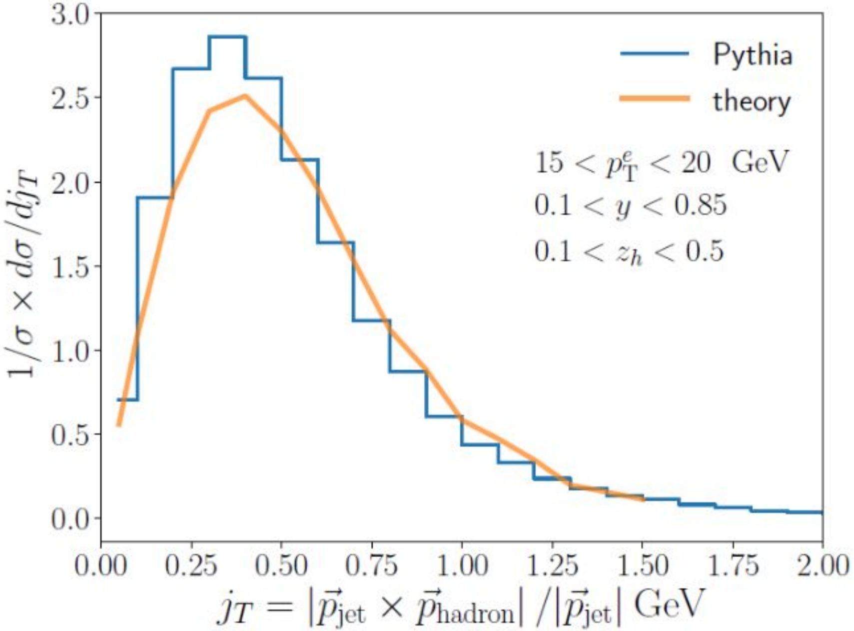
The unpolarized structure function F_{UU}^{h} for hadron in-jet production is given by

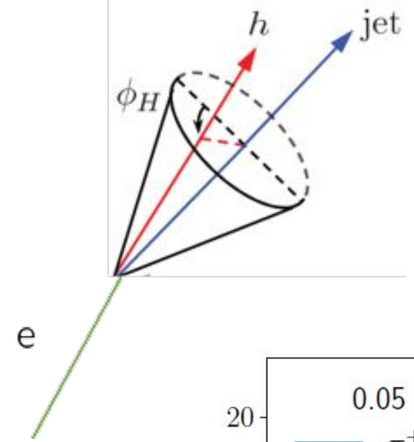
$$F_{UU}^{h} = \sigma_0 \, H_q(Q,\mu) \sum_q e_q^2 \, \mathcal{G}_q^h(z_h, \vec{j}_T, p_T^{\rm jet} R, \mu) \times \int \frac{d^2\vec{b}_T}{(2\pi)^2} \, e^{i\vec{q}_T\cdot\vec{b}_T} \, f_q^{\rm TMD}(x, \vec{b}_T, \mu) \, S_q(\vec{b}_T, y_{\rm jet}, R, \mu) \, .$$



Arratia, Kang, Prokudin, Finger, Phys. Rev. D **102**, 074015

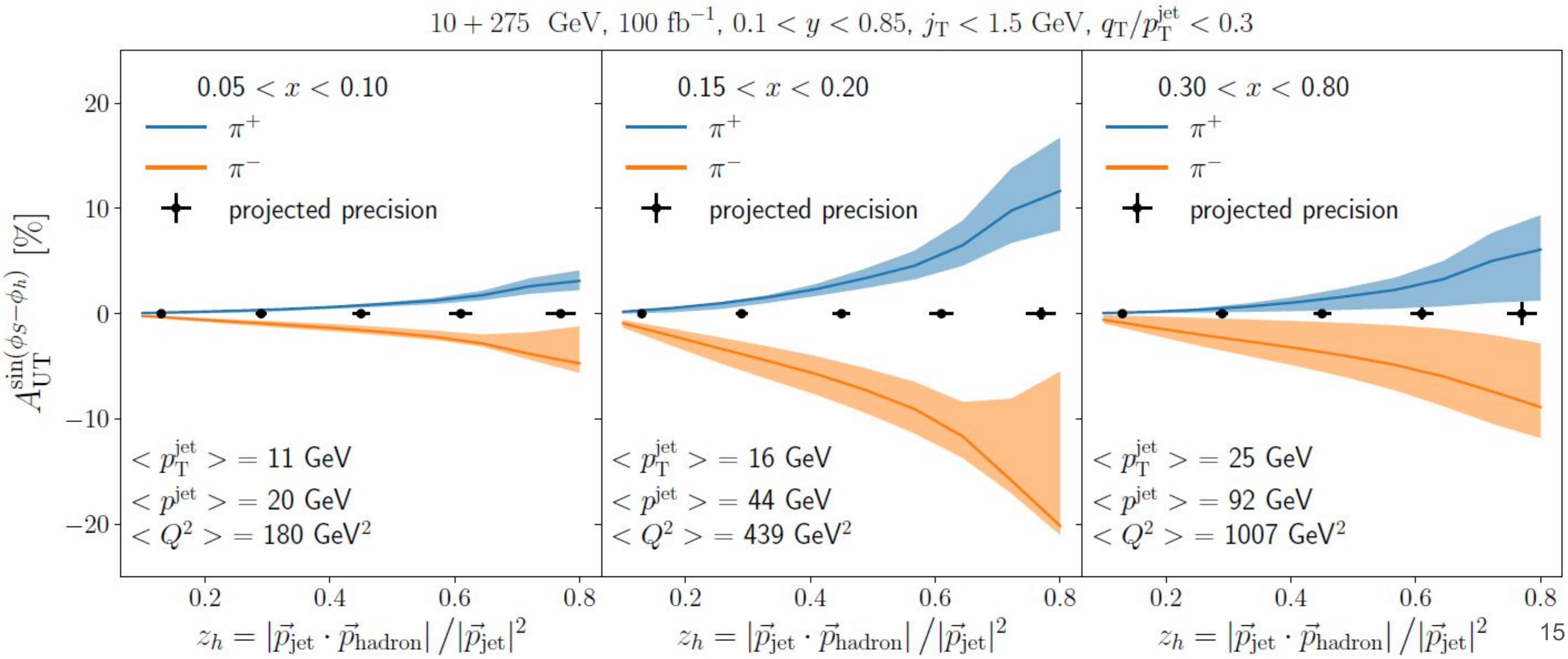




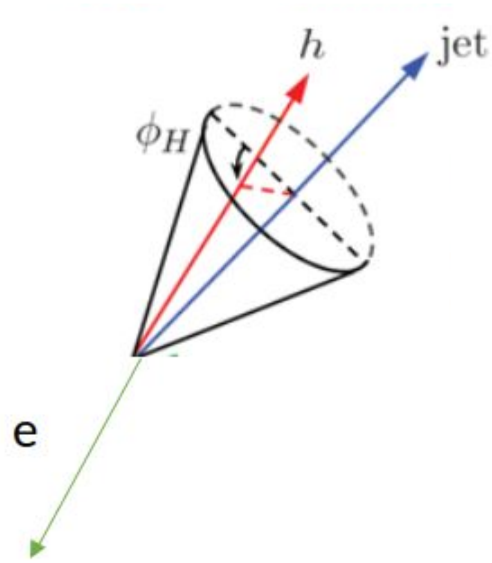


Hadron-in-jet Collins asymmetry at EIC

PRD 102, 074015 (2020)



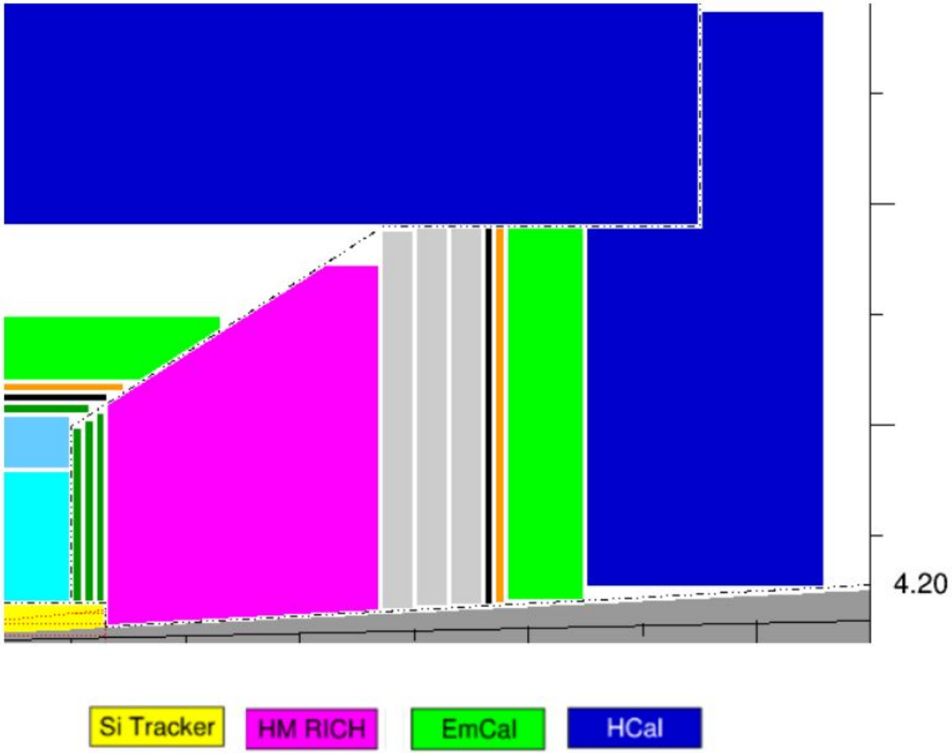
We need to do unfolding in many dimensions



- These will be highly differential measurements (more than SIDIS). **How do we unfold in 8 or more dimensions?**

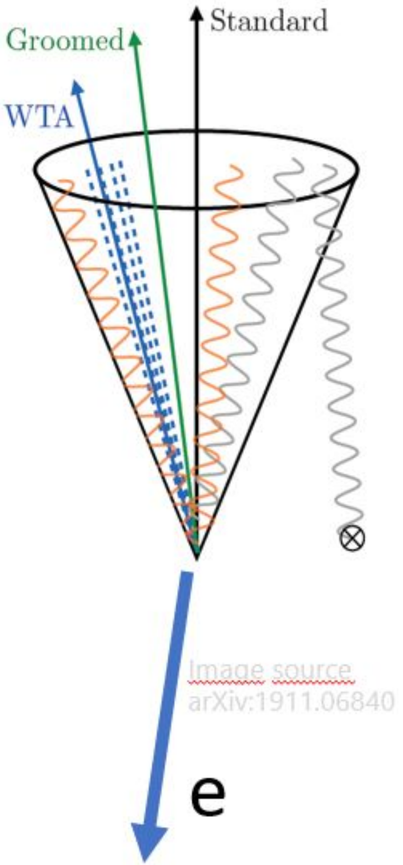
- **Machine-learning techniques** can help! (see my talk on Thursday for a demo)

Potential for unprecedented jet measurements



Combined with EIC high luminosity and polarization, this combination will enable unique **jet substructure measurements**

Jet substructure, the key to novel TMD studies



Recent example:
“T-odd jets” (last week on arXiv:2104.03328)

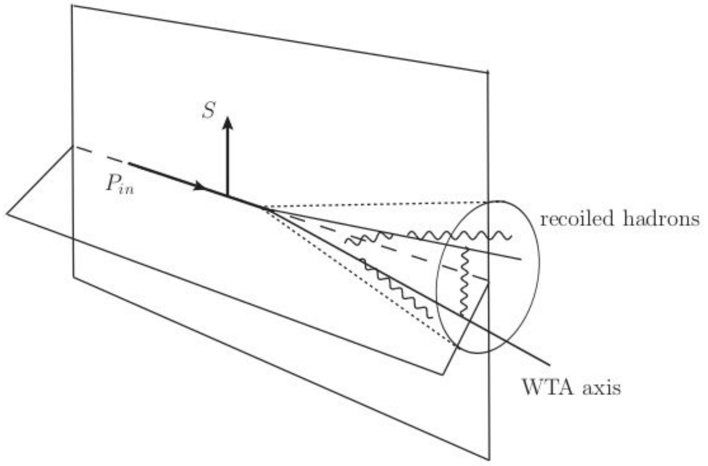


FIG. 1. Origin of the jet T-odd contributions. The WTA jet axis lies outside the plane by the spin S and P_{in}, to allow for the asymmetry due to the quantum correlation between parton's spin and its hadronization about the plane.

- **Grooming**

  Gutierrez et al. JHEP 08 (2019) 161 . Makris et al. JHEP 07 (2018) 167

- **Jet axes**

  Cal et al. JHEP 04 (2020) 211,
  Niell et al. JHEP04 (2017)020
  Liu et al. arXiv: 2104.03328

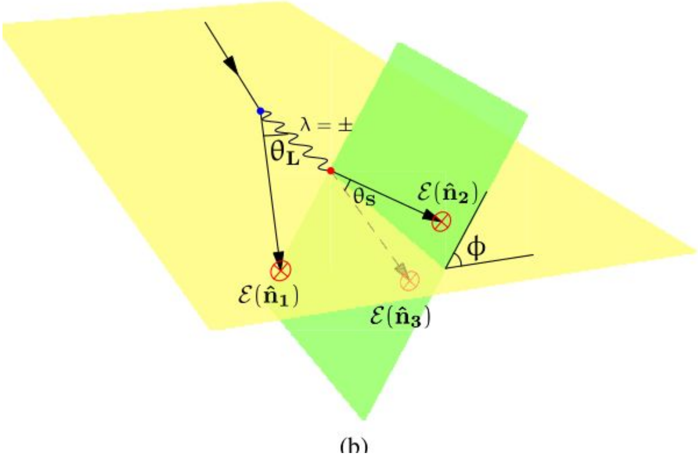
- **Declustering?**

Spin effects in jet fragmentation

Renewed theory thrust, new observables.
Just a matter of time before EIC-specific developments

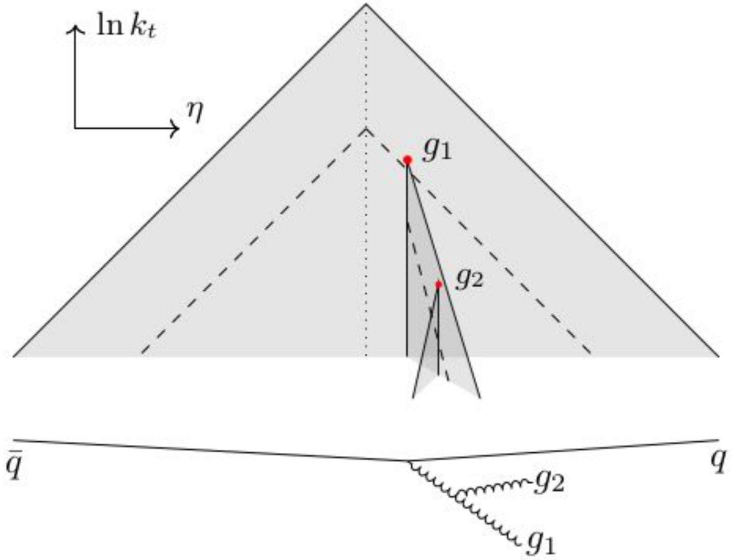
Energy correlators

Phys. Rev. Lett. **126**, 112003



Lund-Plane analysis

arXiv:2103.16526



Provide ways to explore smoothly transition to non-perturbative regime
Potentially new ways to address EIC science ??

Summary

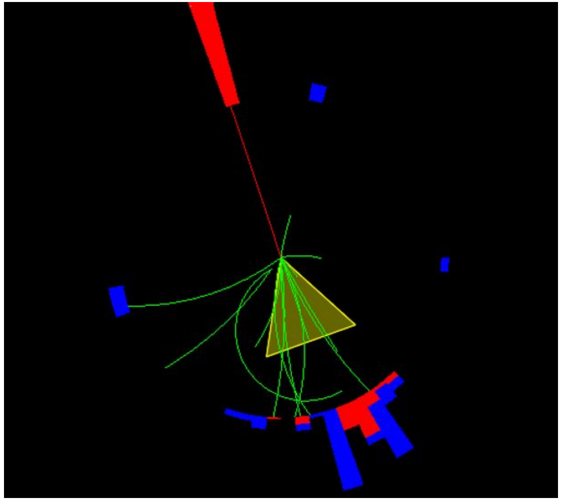
- Jets can help us address key EIC science goals, including 3D imaging measurements

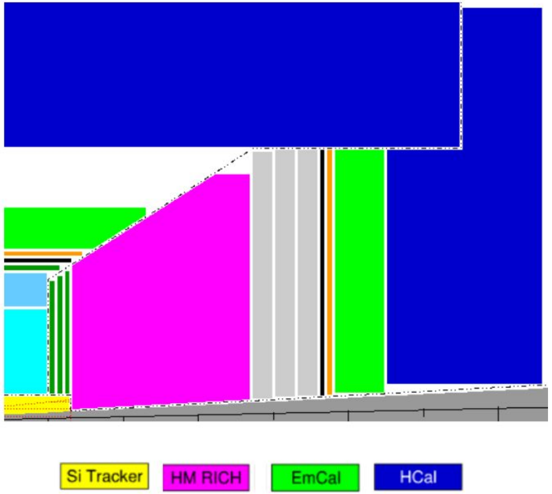
- Jet substructure could open up new class of TMD studies. *"Jet tomography of the proton/nuclei"*

- EIC jet studies will exploit unprecedented combination of Tracking, PID, full calorimetry and beam polarization.

- Theory demands highly dimensional measurements. Unfolding is a challenge that can be addressed with machine learning

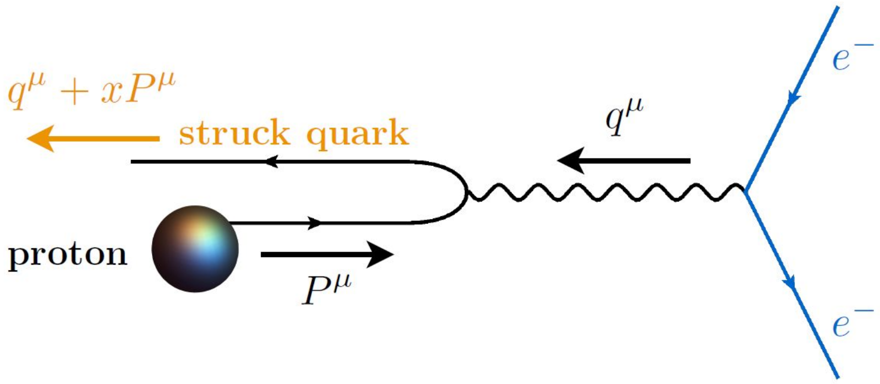
- Given the recent theory developments, HERA data provides a great opportunity for a *"EIC pathfinder"* program

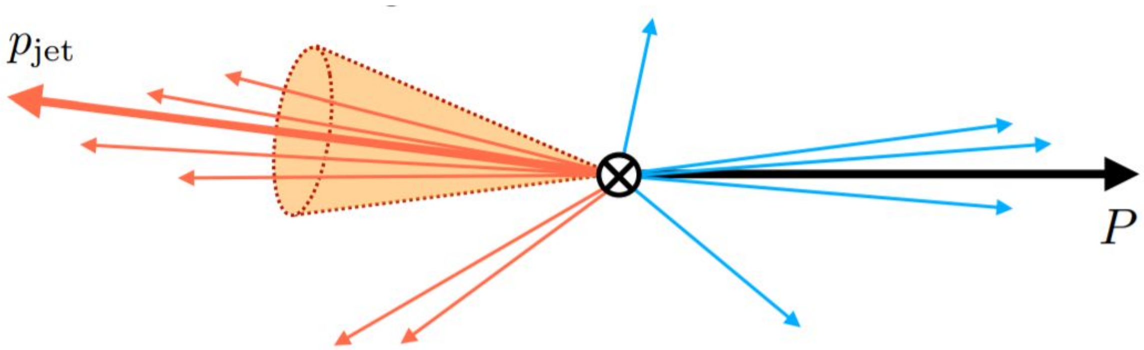




Backup

These studies also possible in Breit frame (in complete analogy to SIDIS), but requires dedicated jet algorithms, like Centauro





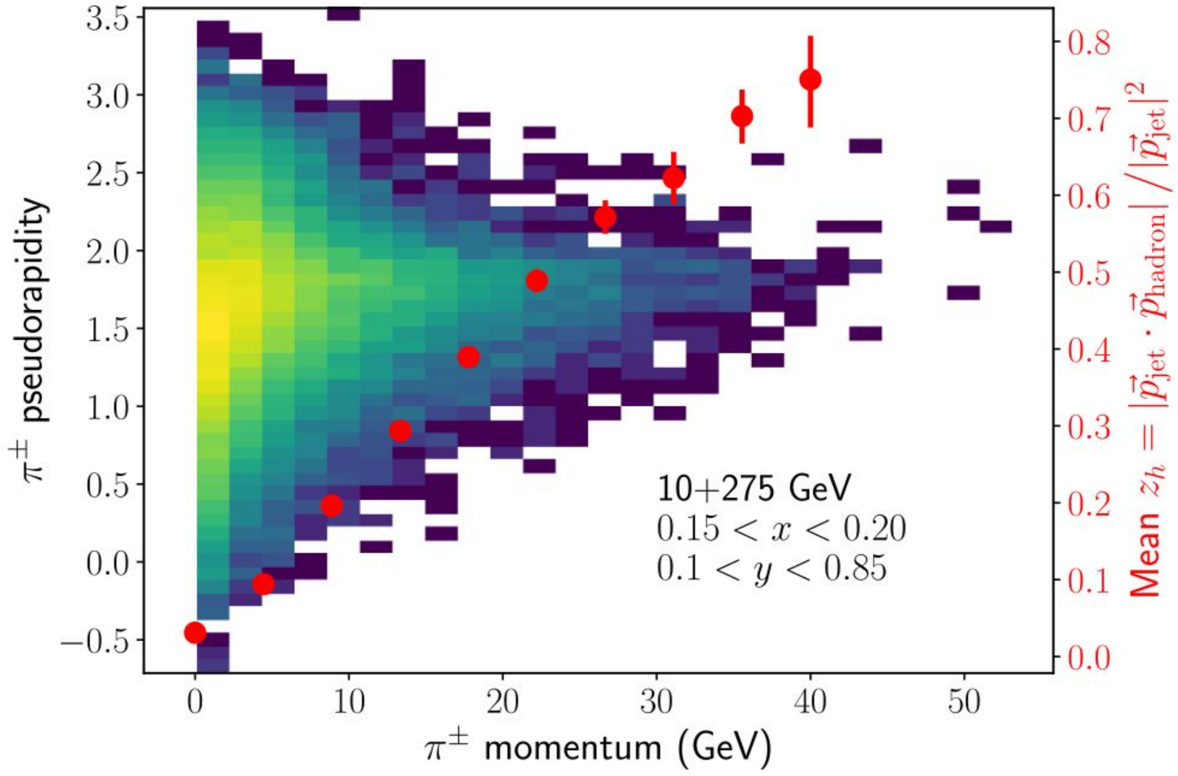
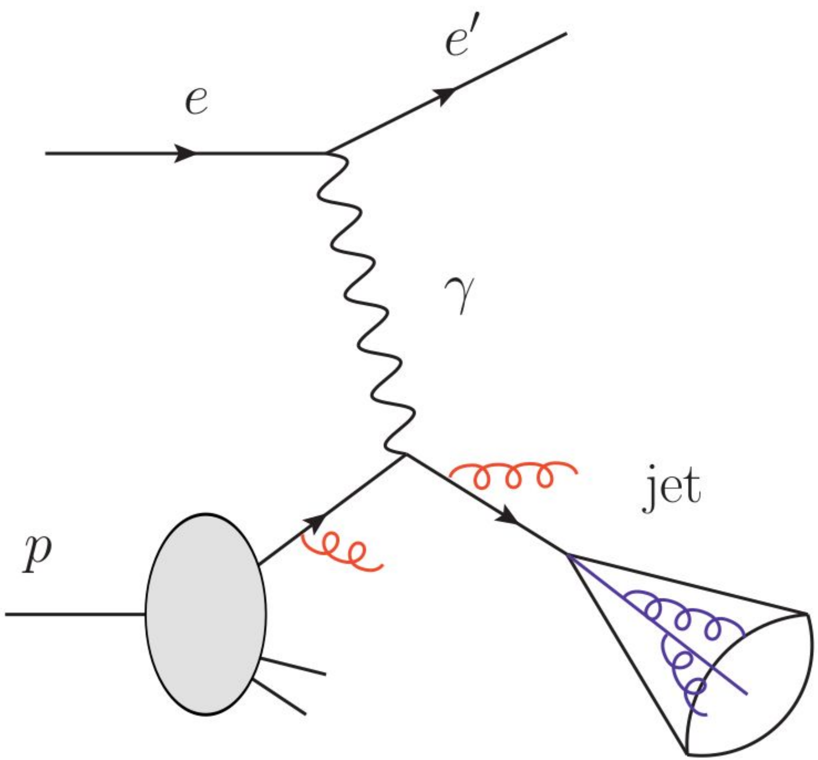
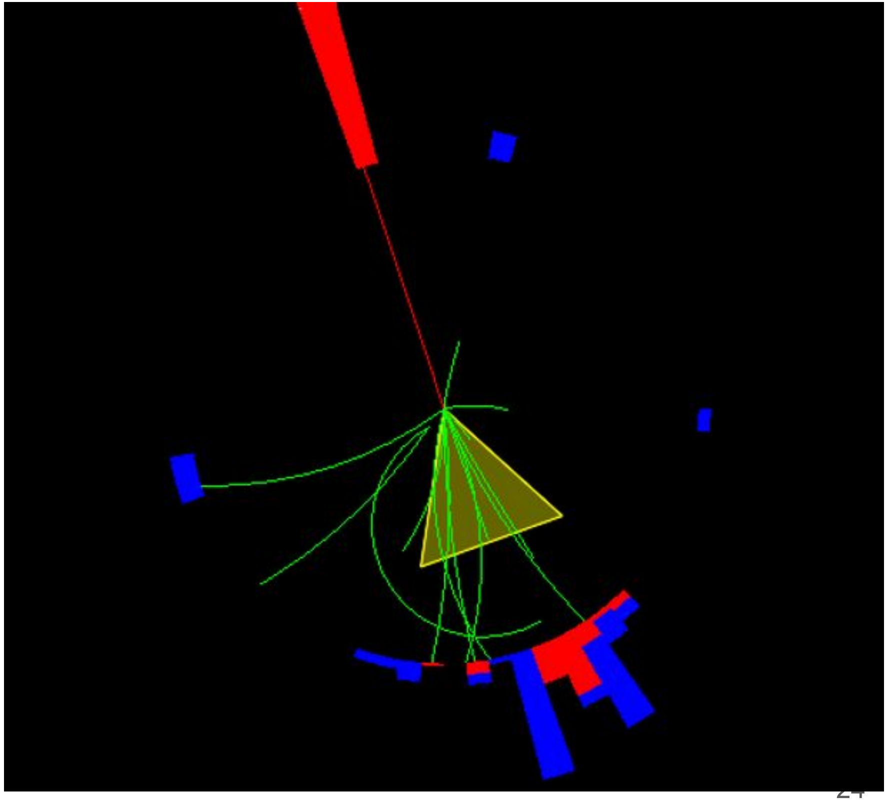


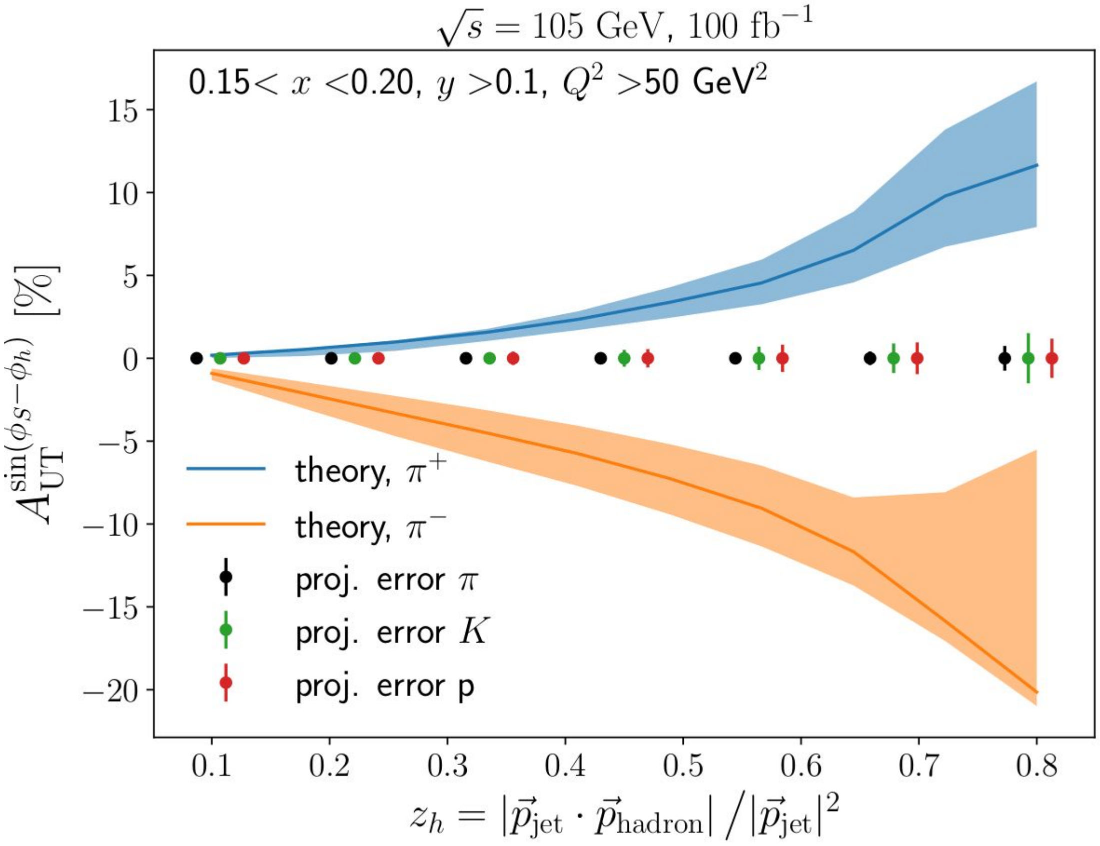
FIG. 11. Pseudorapidity and momentum distribution for charged pions in jets with $p_T > 5$ GeV. The average longitudinal momentum fraction of the hadron with respect to the jet axis is shown by the red dots.

DIS Born-level configuration $\gamma^* q \to q$

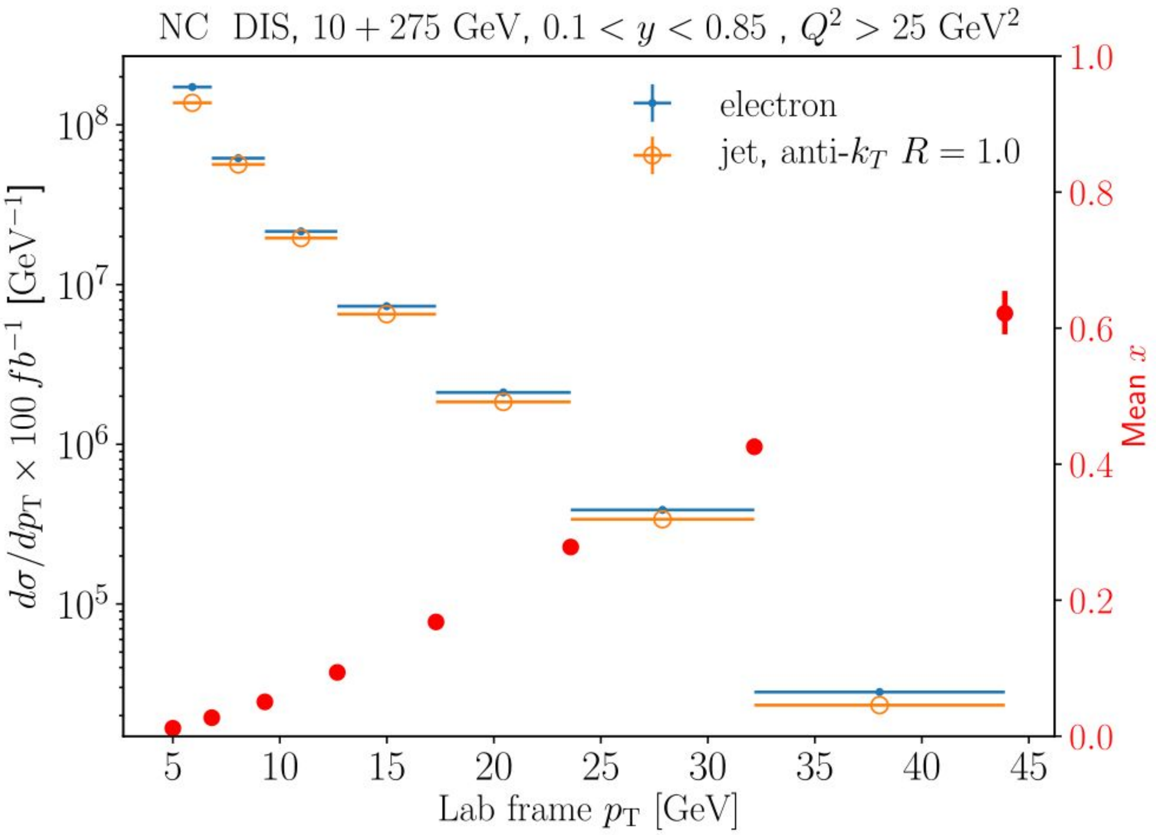




Great potential for Kaon measurements (requires high purity)
"Sea transversity"



Expected rate, x coverage (@100 GeV)



Unique opportunity to measure high-x at high Q2 (complementing fixed-target experiments)

-> Nail down TMD evolution