Jets as precision probes in Semi-Inclusive DIS events at the future Electron-Ion Collider

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Motivation :

To explore the potential Jet observables as a probe for the three-dimensional (3D) hadron structure encoded in transverse-momentum-dependent parton-distribution functions (TMD PDFs) and fragmentation functions (TMD FFs).

Outline

- Introduction
  - *Some of the Questions that the EIC will address*
- *Simulation (Pythia8)*
  - *Event Generation with Pythia8*
- *TMD PDFs and FFs*
  - *Quark Sivers Function*
  - *Collins Fragmentation Function*
  - *The projected statistical uncertainties*
- Conclusion

Introduction

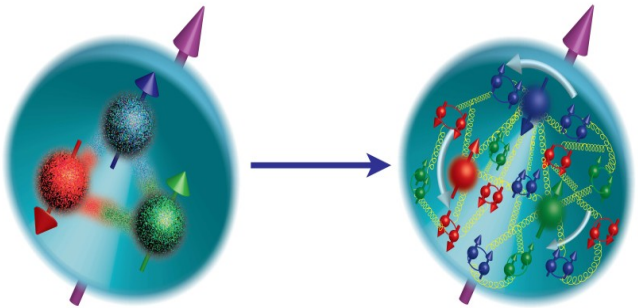


Figure 1.1: Evolution of our understanding of nucleon spin structure. **Left:** In the 1980s, a nucleon's spin was naively explained by the alignment of the spins of its constituent quarks. **Right:** In the current picture, valence quarks, sea quarks and gluons, and their possible orbital motion are expected to contribute to overall nucleon spin.

Nucleon Spin an its 3D Structure

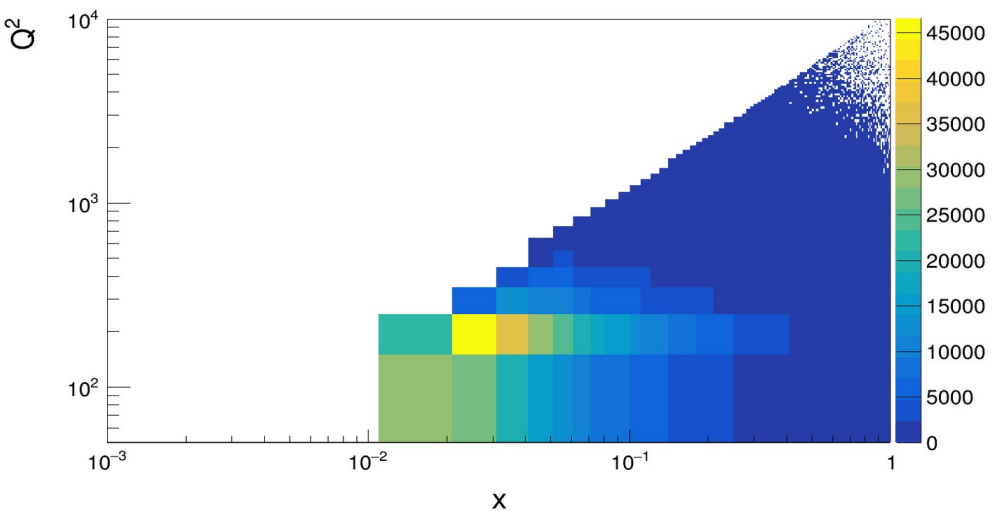
- The EIC is designed to yield much greater insight into the nucleon structure (Fig. 1.1, from left to right), by facilitating multi-dimensional maps of the distributions of partons in space, momentum (including momentum components transverse to the nucleon momentum), spin, and flavor. Whether a substantial "missing" portion of nucleon spin resides in the gluons.

- In this study we use Pythia8 simulation tool to explore the kinematic reach and Statistical precision required for the future EIC.

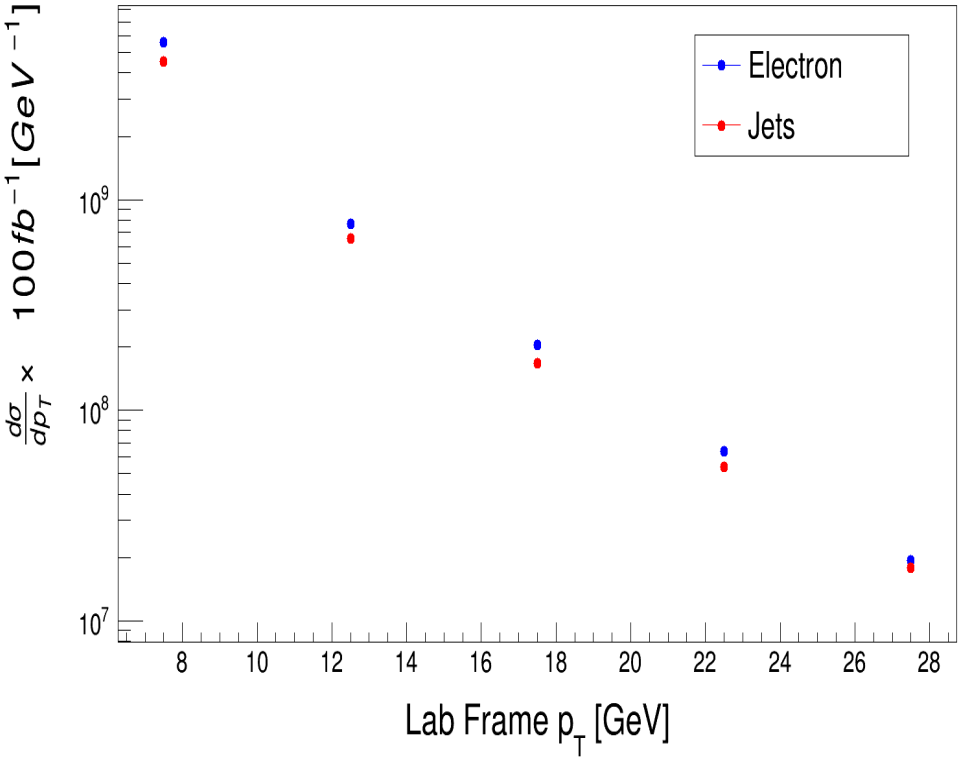
Simulation

- We use Pythia8 to generate neutral-current SIDIS events in unpolarized electron-proton collisons.
- We disabled QED shower initiated by leptons.
- The energies of the electron and proton to 18 GeV and 275 GeV, respectively. center-of-mass energy of s = √105 GeV,
- 10^7 events generated
- Events selected with $Q^2 > 25\ GeV^2$ and $0.1 < y < 0.85$
- We chose the Laboratory frame
- Jets are formed by implementing the the Fastjet 3.3 package with anti-kT algorithm.
- The Jet cone radius R = 1

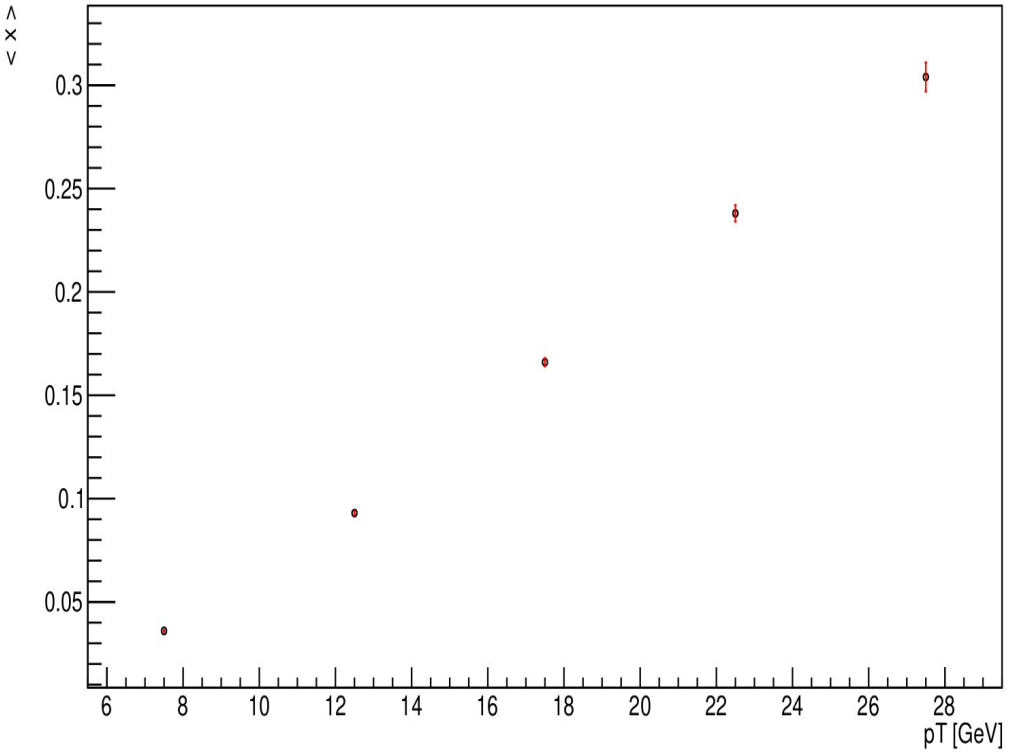
- Partons' total helicity contribution to the proton spin is very sensitive to their minimum momentum fraction x.
- EIC aims to provide an enhanced range to investigate quarks and gluons with small momentum fraction (x) and analyze their properties over a wide range of momentum transfers Q^2



Event Generation with Pythia8

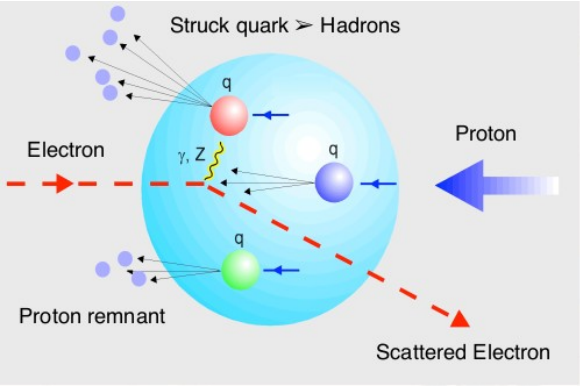


- Differential Cross-section measurements over the entire pT range.
- The error bars are smaller than the marker size.



- The red error bars represent the standard deviation of the < x > for each electron pT interval.
- The sea-quark-dominated region is probed with jets at pT ≈ 7 GeV and x ≈ 0.05
- The valence region, with pT ∼ 15 GeV and the x > 0.1
- x > 0.3, unconstrained region probed with pT > 25 GeV.

Transverse Momentum Dependent Parton Distribution Functions and Fragmentation Functions (TMD PDFs and FFs)



- The 3D parton structure of hadrons in momentum space is encoded in transverse momentum dependent parton distributions (TMDs). f(x, k_T)

- Jet observables can probe the three-dimensional (3D) hadron structure encoded in transverse-momentum-dependent parton-distribution functions (TMD PDFs) and fragmentation functions (TMD FFs)

✔ Sivers Quark Function

- In this study we measured the transverse single-spin asymmetry in electron-jet correlations, also known as the left-right asymmetry.

Sivers asymmetry is sensitive to transverse momentum imbalance:

$q_T = |p_T^e + p_T^{jet}|$

$$A_{UT} = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}},$$

✔ Collins Function

- Collins function describes the correlation between the transverse momentum of a quark and the transverse momentum of the produced hadron-in-jet.

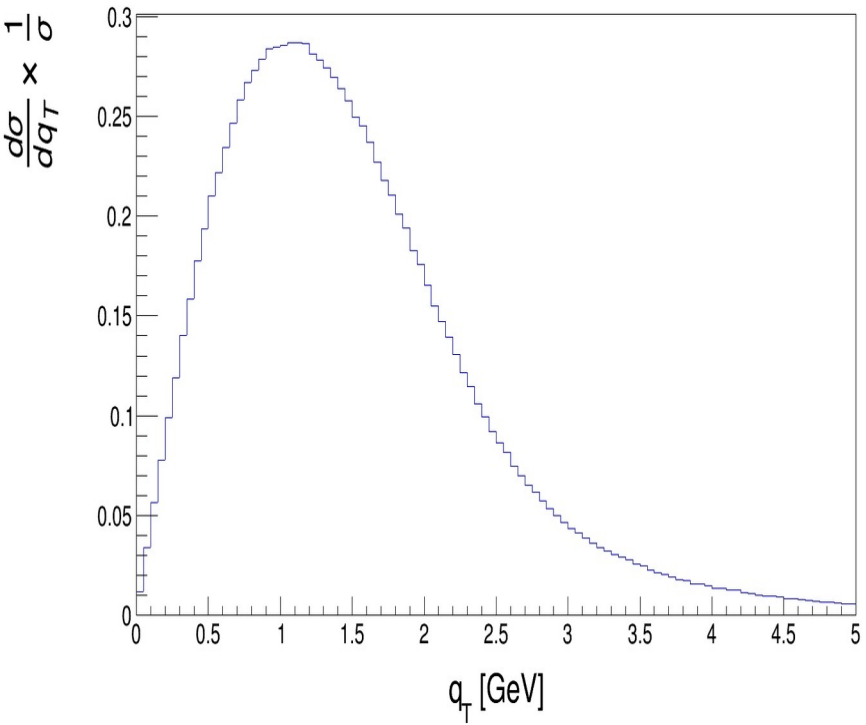
- Hadron-in-jet Collins asymmetries as a function of z_h (longitudinal momentum fraction).

$z_h = |p_{jet} \cdot p_{hadron}| / |p_{jet}^2|$

Normalized Distributions

0.1 < y <0.85

18 x 275 GeV

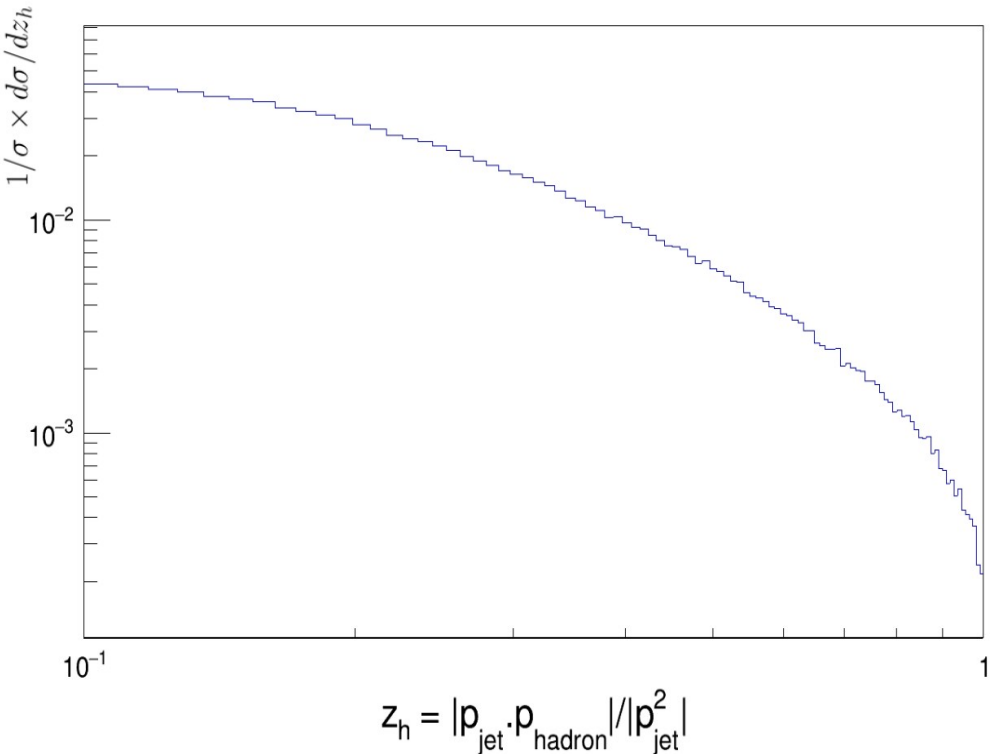


- Normalized differential cross section distribution of the transverse momentum imbalance qT for jets

0.1 < y <0.85

18 x 275 GeV

$q_T / p_{jetT} < 0.3$



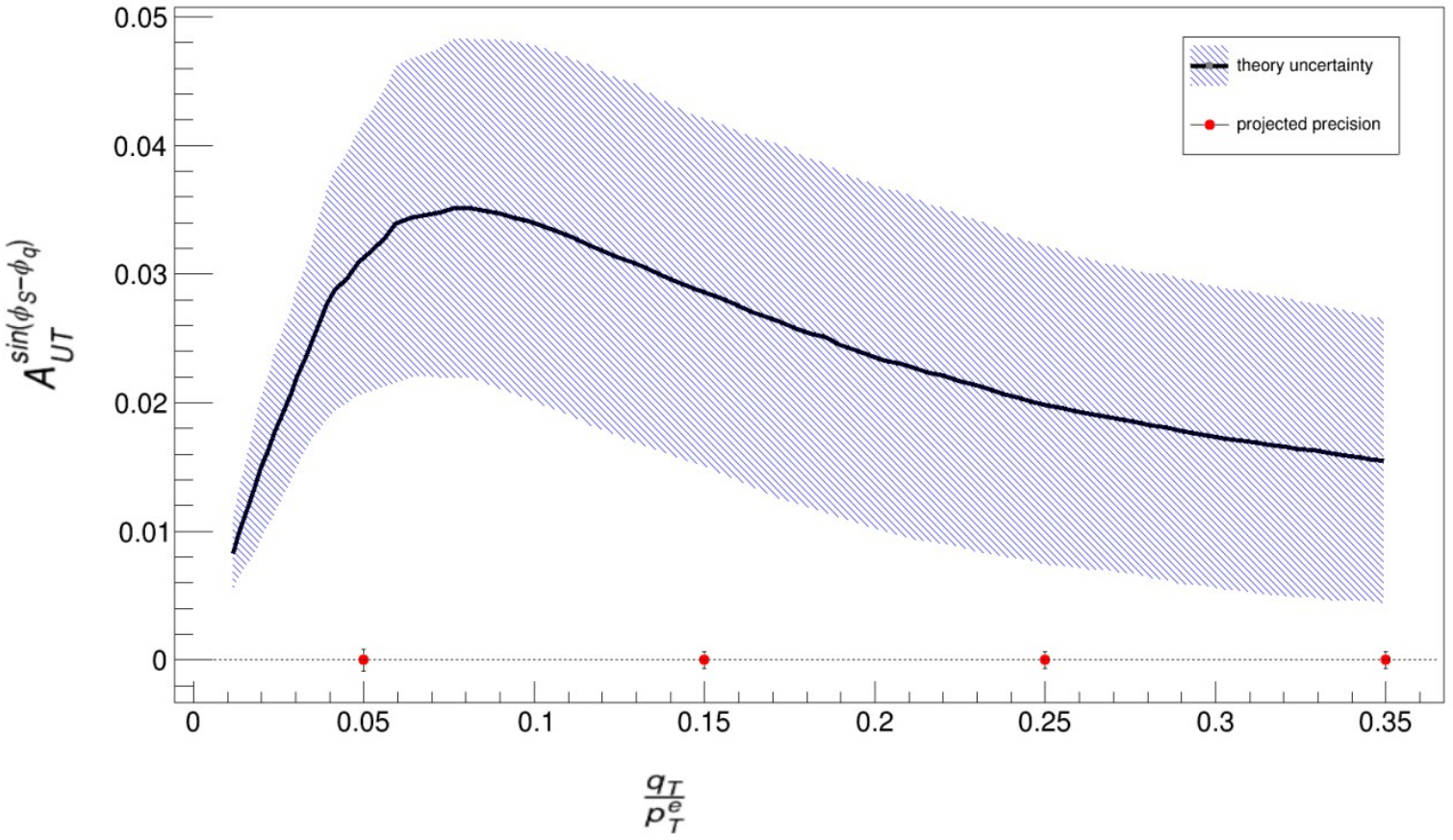
- Hadron-in-jet distributions as a function of z_h

Statistical Errors of Sivers and Collins Functions

- Estimated statistical uncertainties of the asymmetry measurements assuming an integrated luminosity of 100 fb^{-1} and an average proton-beam polarization of 70% to follow the EIC specifications.
- The projected uncertainties on the raw asymmetry are obtained after including the beam polarizations, nucleon effective polarization and the effective dilution factor.
- The statistical uncertainties for single spin asymmetries (single-spin asymmetries, requiring only one beam—typically the hadron beam—to be polarized) are estimated with ($\delta A = 1/P\sqrt{N_{raw}}$)
- P is beam polarization and N_{raw} is the yield number which measures counts summing over the two spin states , it is only proportional to the unpolarized cross section.
- Additional factor √2 is introduced to mimic the increase of uncertainties due to the azimuthal angular separation of Collins and Sivers asymmetry. ($\delta A = \sqrt{2}/P\sqrt{N_{raw}}$)

Projected Statistical Uncertainties

Quark Sivers Function



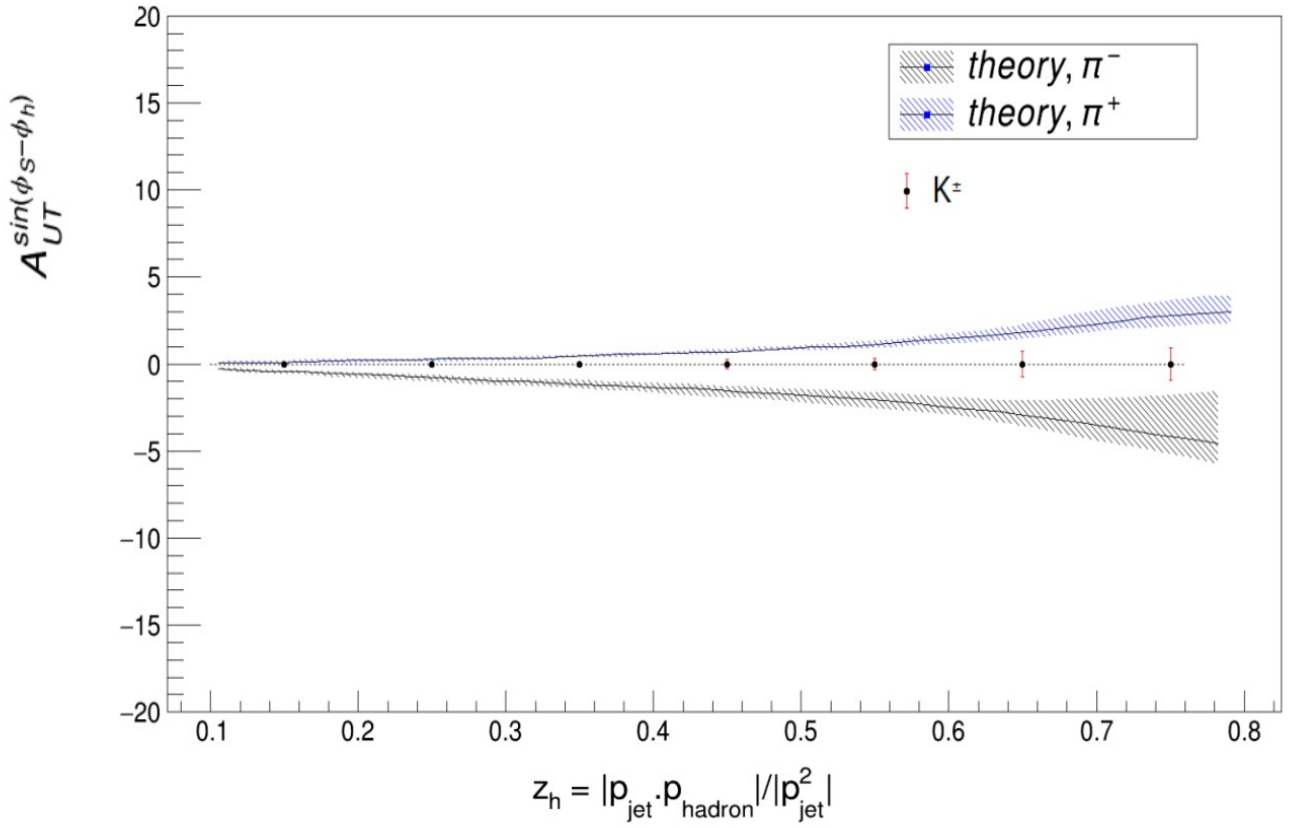
Collins Asymmetries

Statistical uncertainties for the z_h distribution for the $K^{\pm}$ in-jet Collins asymmetries

18 x 275 GeV

0.1 < y <0.85

0.05 < x < 0.1

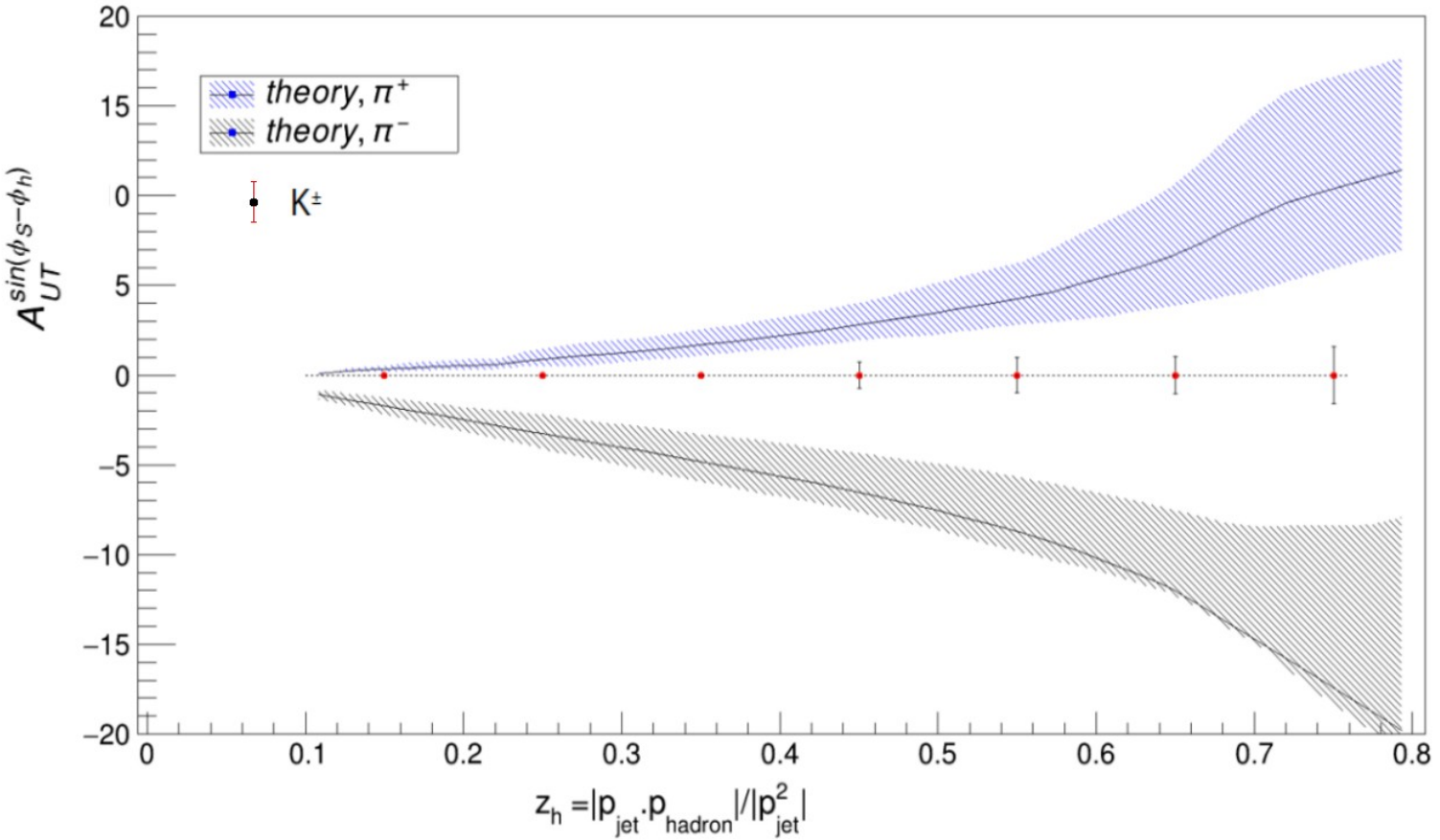


Collins Asymmetries

18 x 275 GeV

0.1 < y <0.85

0.15 < x < 0.20



Conclusion

- Jet-based TMD measurements in neutral -current DIS events could provide a channel for future EIC.
- Hadron-in-jet measurements and electron-jet azimuthal correlations at the future Electron-Ion Collider (EIC) might directly probe the three-dimensional (3D) structure of hadrons.

Thank you for your attention …

Backup

References

1) Paper : Jet-based measurements of Sivers and Collins asymmetries at the future Electron-Ion Collider
Authors: Miguel Arratia, Zhong-Bo Kang, Alexei Prokudin, Felix Ringer

2) White Paper:

Semi-inclusive Deep Inelastic Scattering

Semi-inclusive hadron production in deep inelastic scattering (SIDIS) provides a powerful probe of the transverse momentum dependent (TMD) quark distributions of nucleons. Common kinematic variables have been described in the DIS section (see the Sidebar on page 18). In SIDIS, the kinematics of the final state hadrons can be specified as follows

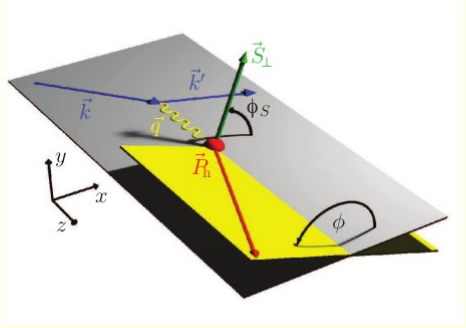


Figure 2.11: Semi-inclusive hadron production in DIS processes: $e + N \to e' + h + X$, in the target rest frame. $\boldsymbol{P}_{hT}$ and $\boldsymbol{S}_\perp$ are the transverse components of $\boldsymbol{P}_h$ and $\boldsymbol{S}$ with respect to the virtual photon momentum $\boldsymbol{q} = \boldsymbol{k} - \boldsymbol{k'}$.

$\boldsymbol{\phi_h}$, $\boldsymbol{\phi_s}$ Azimuthal angles of the final state hadron and the transverse polarization vector of the nucleon with respect to the lepton plane.

$\boldsymbol{P_{hT}}$ Transverse momentum of the final state hadron with respect to the virtual photon in the center-of-mass of the virtual photon and the nucleon.

$\boldsymbol{z} = P_h \cdot P/q \cdot P$ gives the momentum fraction of the final state hadron with respect to the virtual photon.