

# Measuring spin asymmetries with jet correlations and substructure

Felix Ringer

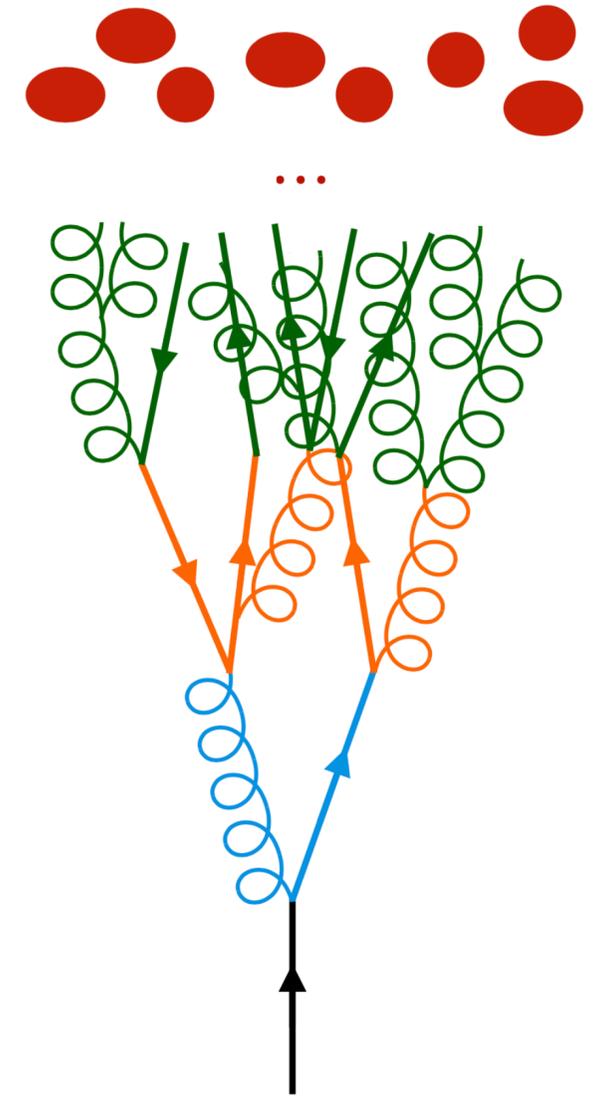
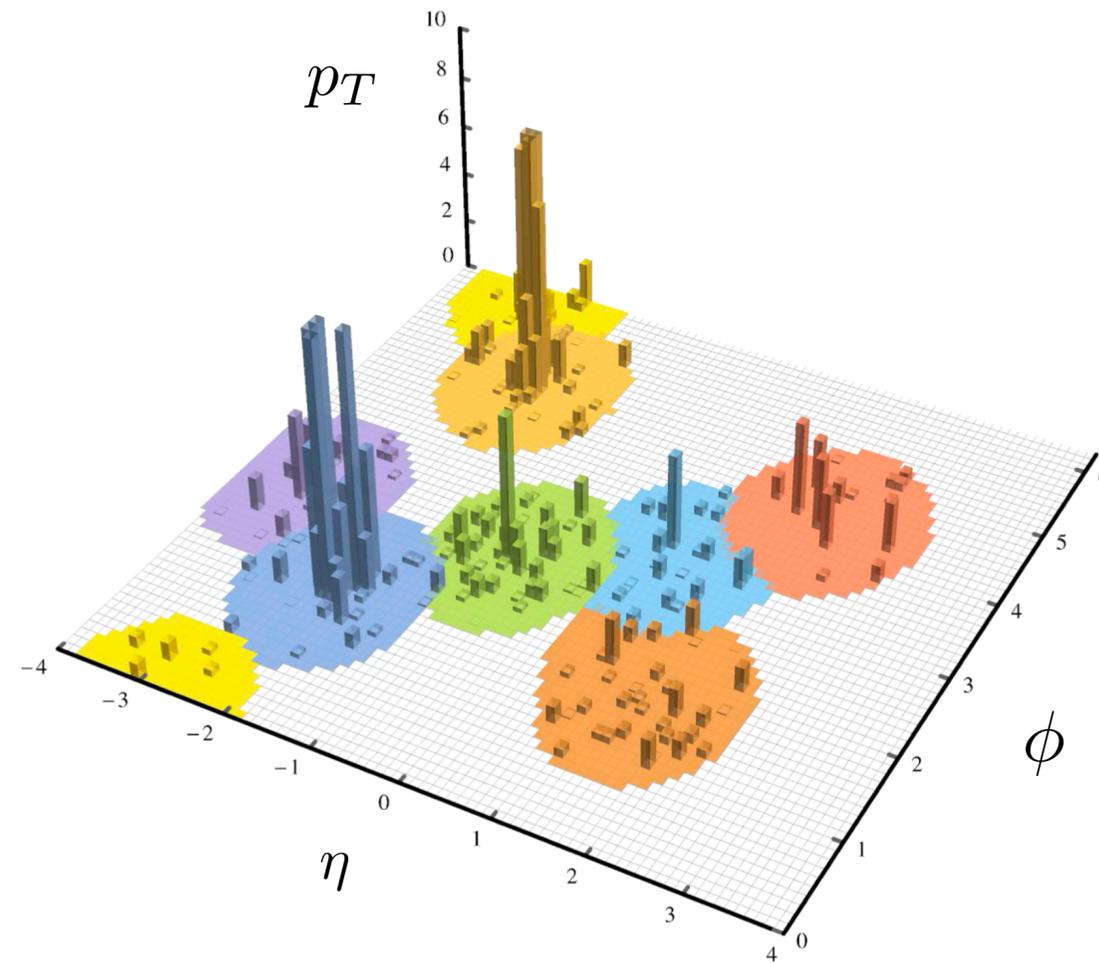
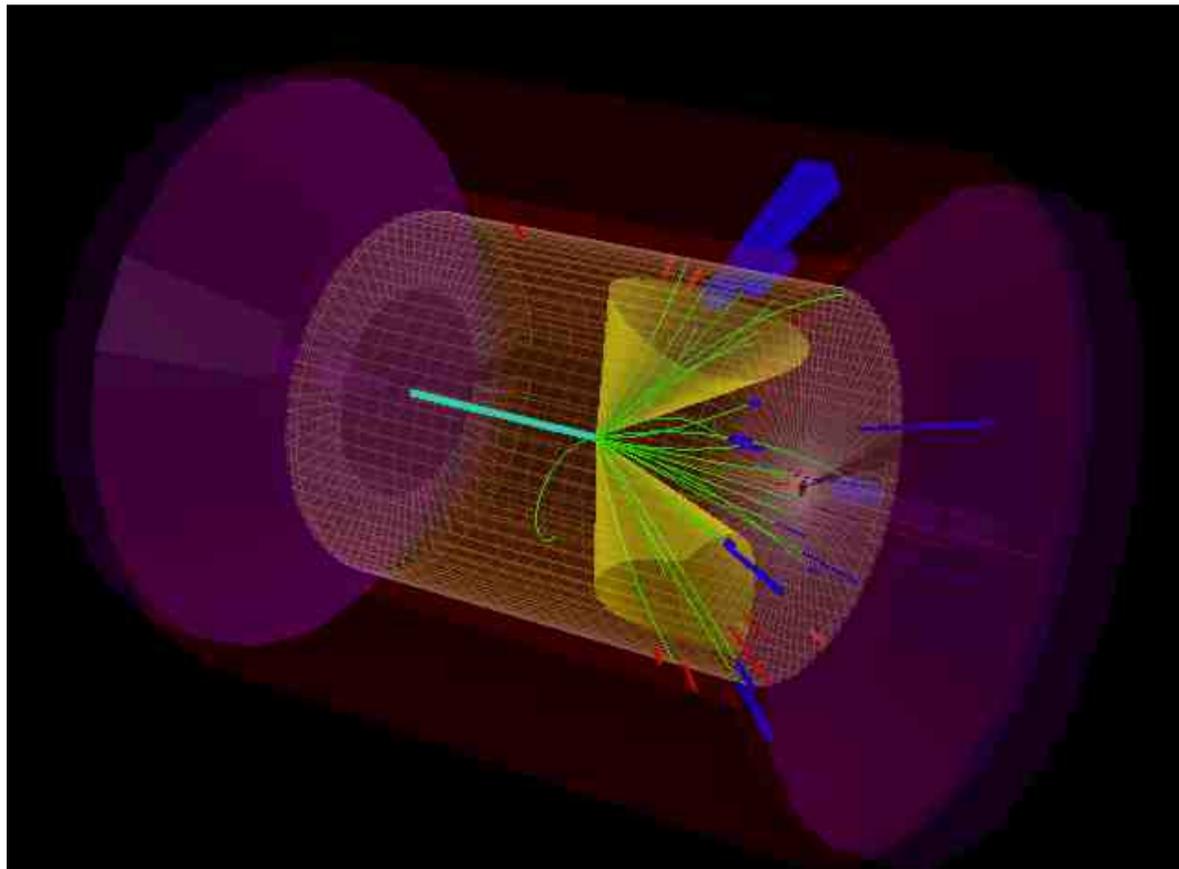
YITP, Stony Brook University

Transversity 2022, Pavia 05/26/22



SIMONS  
FOUNDATION

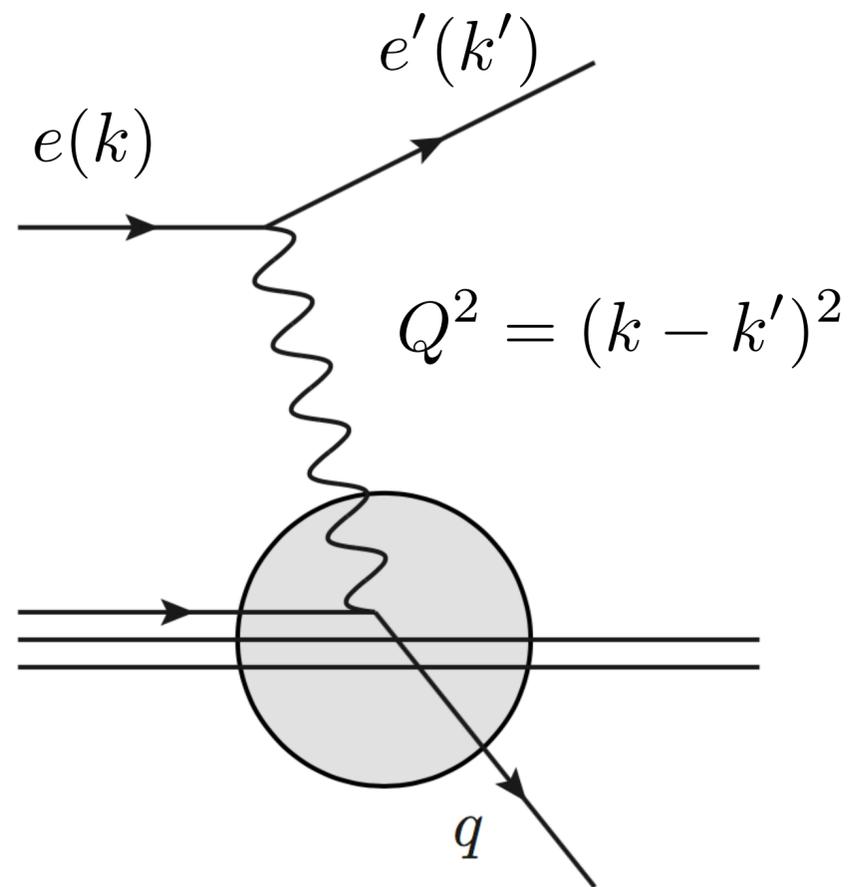
# Jet physics at collider experiments



see talks by Feng Yuan, Ignazio Scimemi

# Jet physics at low energies

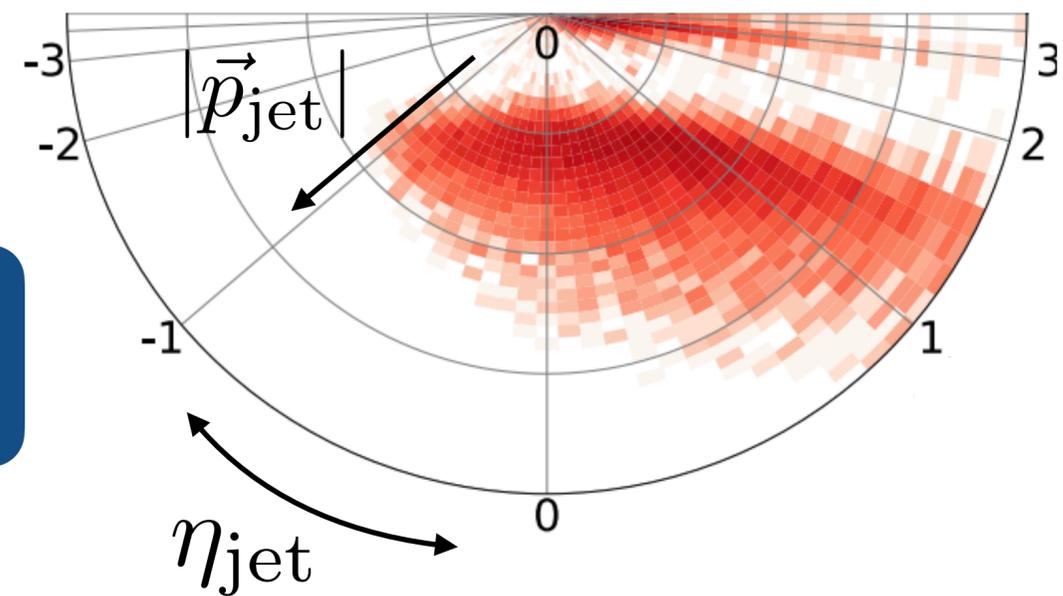
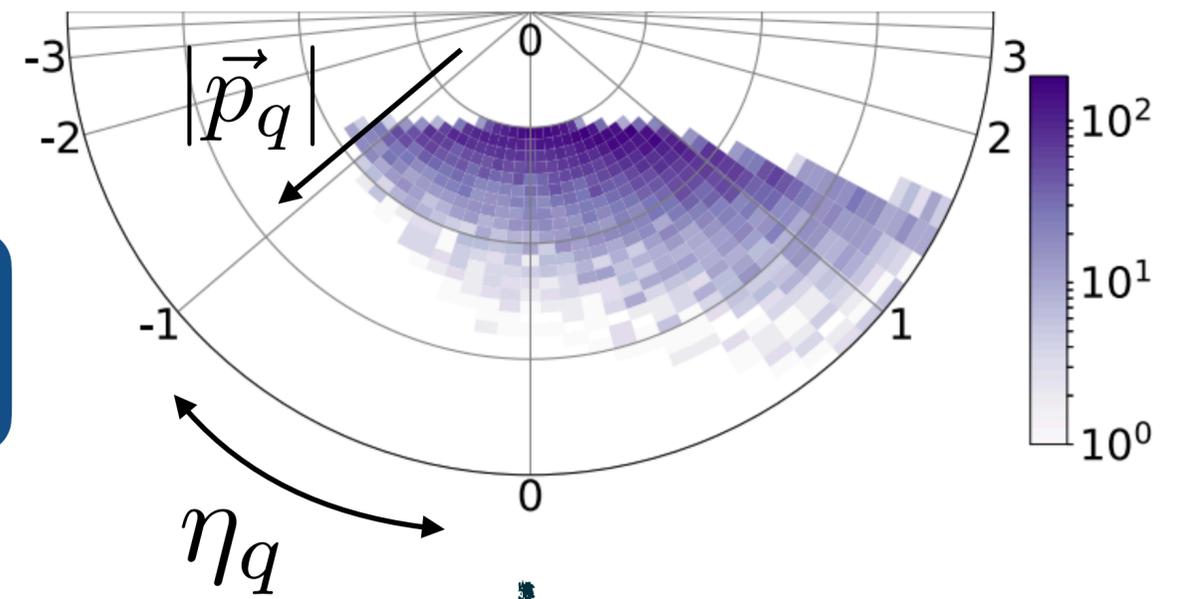
EIC kinematics



Arratia, Jacak, FR, Song '19

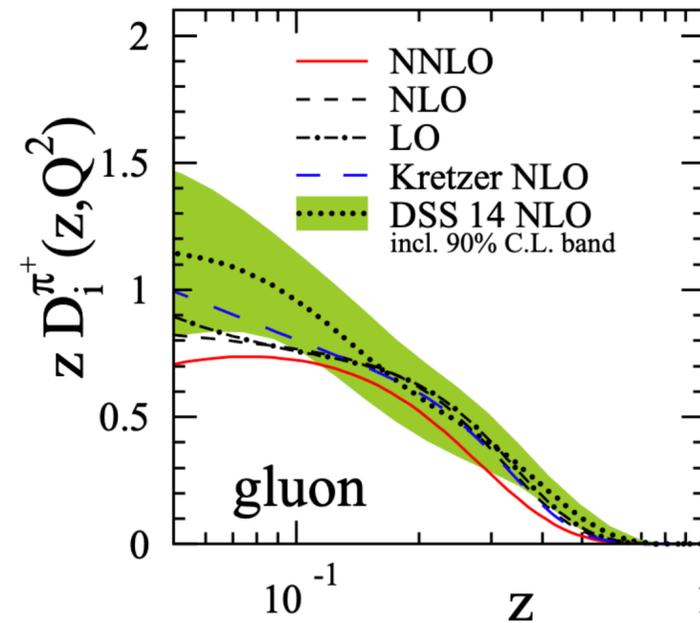
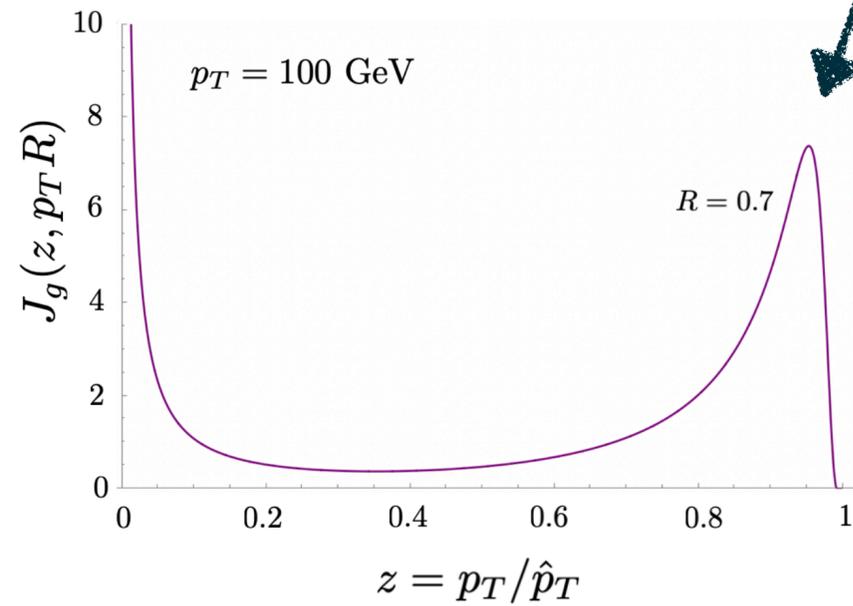
Struck quark

Jets



EIC kin

$e(k)$



- Very direct access to parton level kinematics
- Experimental and theoretical challenges

$1/\text{jet}$

# Outline

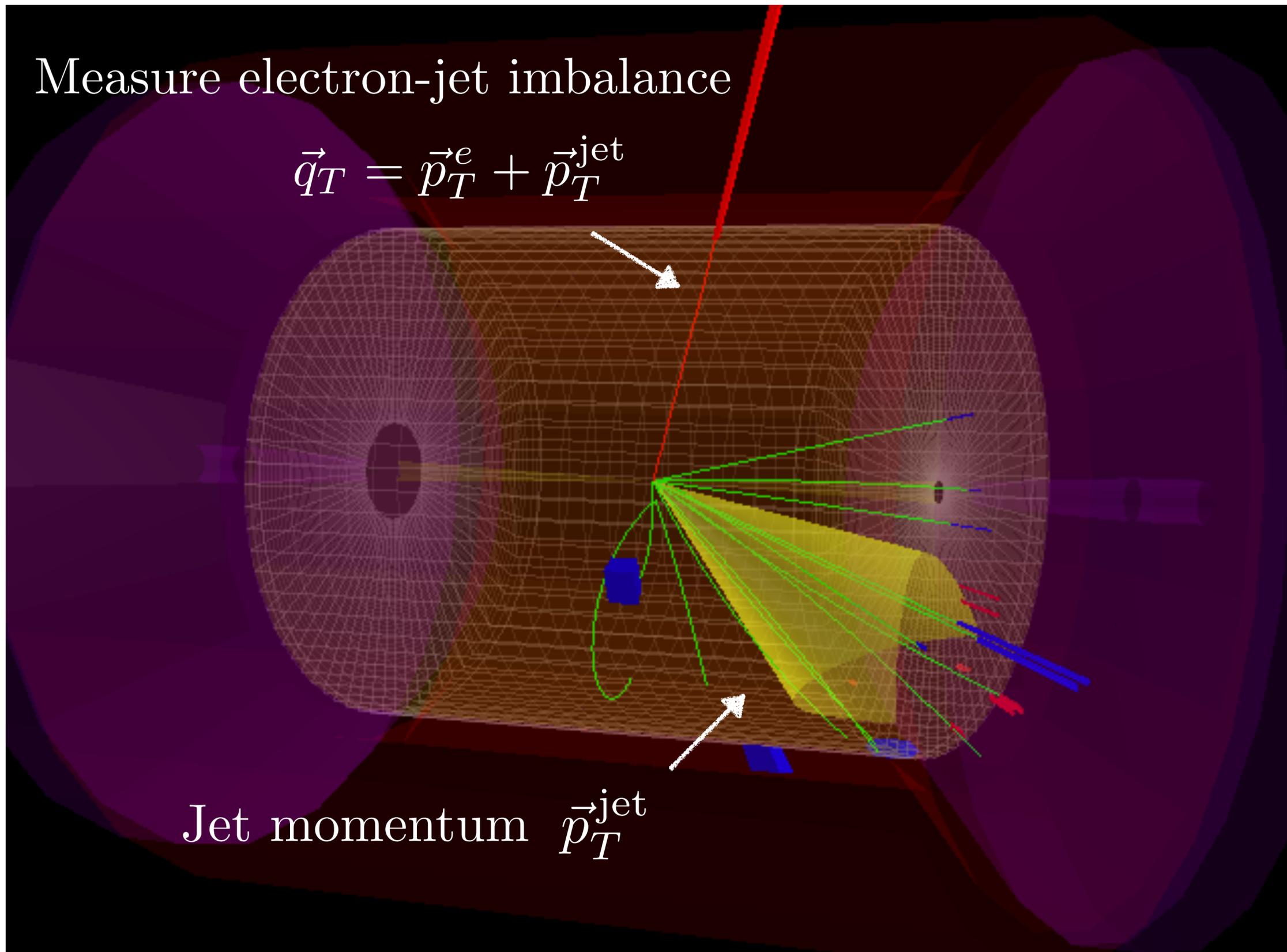
Jet correlations

Jet substructure

Flavor dependence

# Measure electron-jet imbalance

$$\vec{q}_T = \vec{p}_T^e + \vec{p}_T^{\text{jet}}$$



Jet momentum  $\vec{p}_T^{\text{jet}}$

# Electron-jet correlations

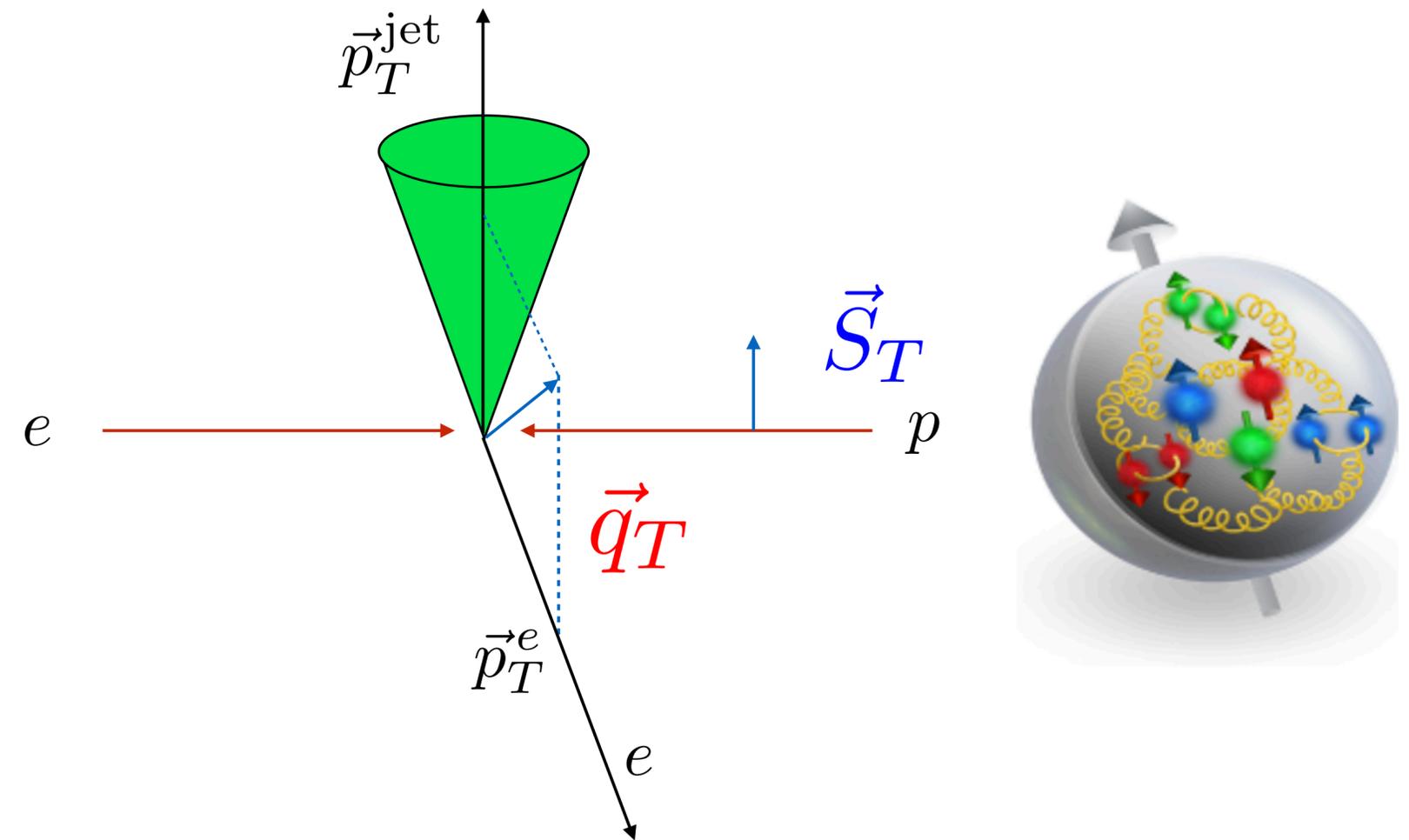
Liu, FR, Vogelsang, Yuan '18, '20

- Electron-jet imbalance at the EIC

$$\vec{q}_T = \vec{p}_T^e + \vec{p}_T^{\text{jet}}$$

- Sensitivity to Transverse Momentum Dependent (TMD) PDFs but no TMD FF
- Laboratory frame
- Factorization structure

$$F_{UU} = \sigma_0 H_q(Q, \mu) \sum_q e_q^2 J_q(p_T^{\text{jet}} R, \mu) \times \int \frac{d^2 \vec{b}_T}{(2\pi)^2} e^{i\vec{q}_T \cdot \vec{b}_T} f_q^{\text{TMD}}(x, \vec{b}_T, \mu) S_q(\vec{b}_T, y_{\text{jet}}, R, \mu)$$



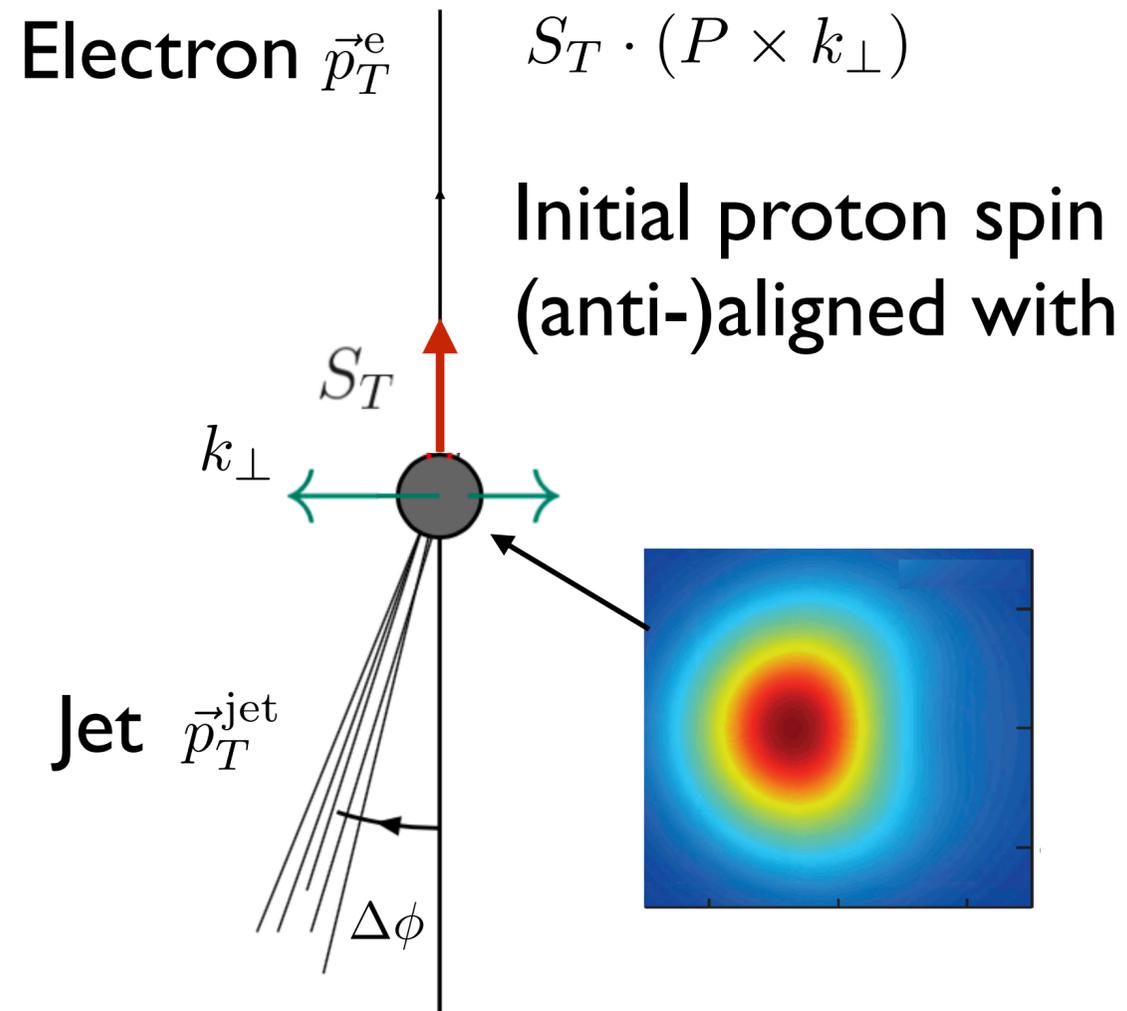
see also Boer, Vogelsang '05

Gutierrez-Reyes, Scimemi, Waalewijn, Zoppi '18, '19

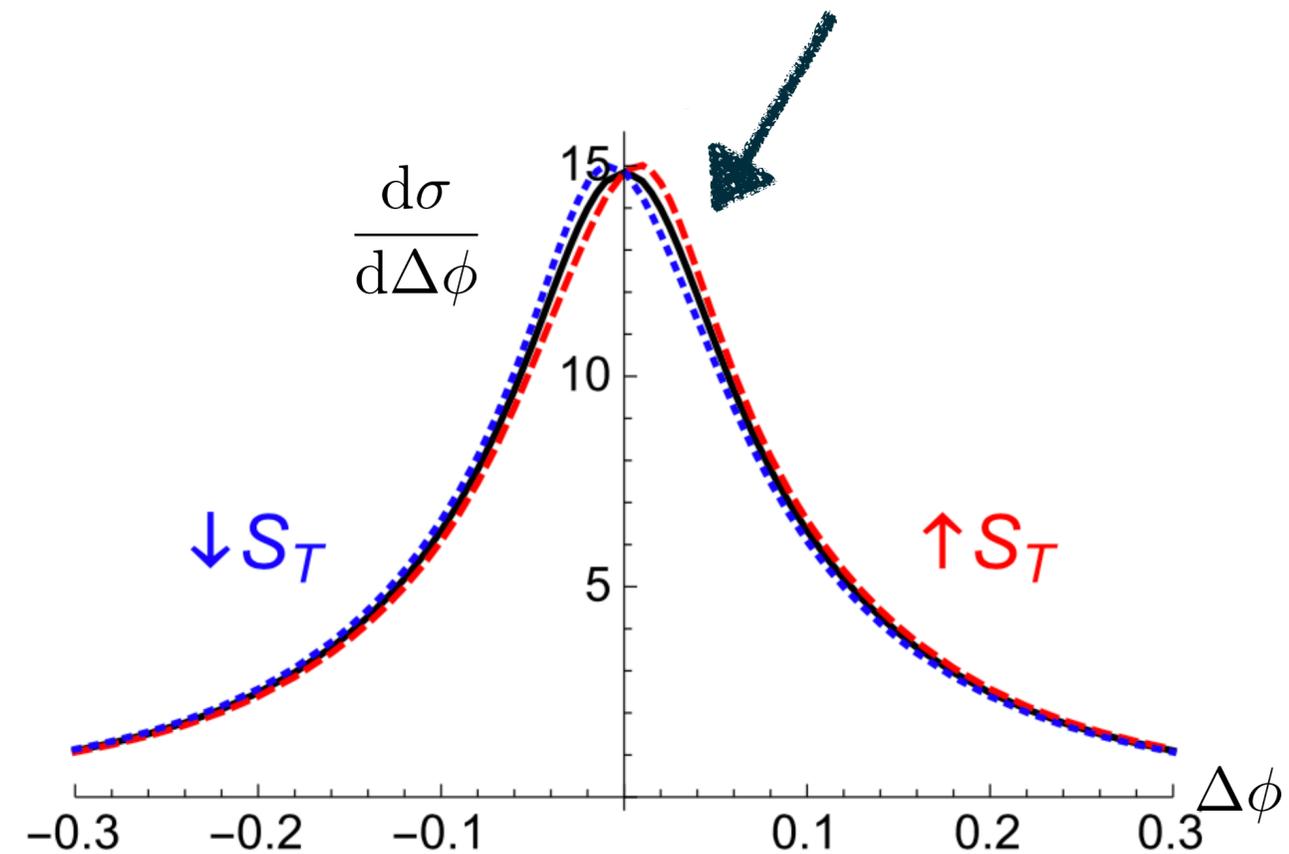
# Electron-jet correlations

Liu, FR, Vogelsang, Yuan '18, '20  
Arratia, Kang, Prokudin, FR'20

- Electron-jet imbalance at the EIC



Small shift depending on the spin orientation

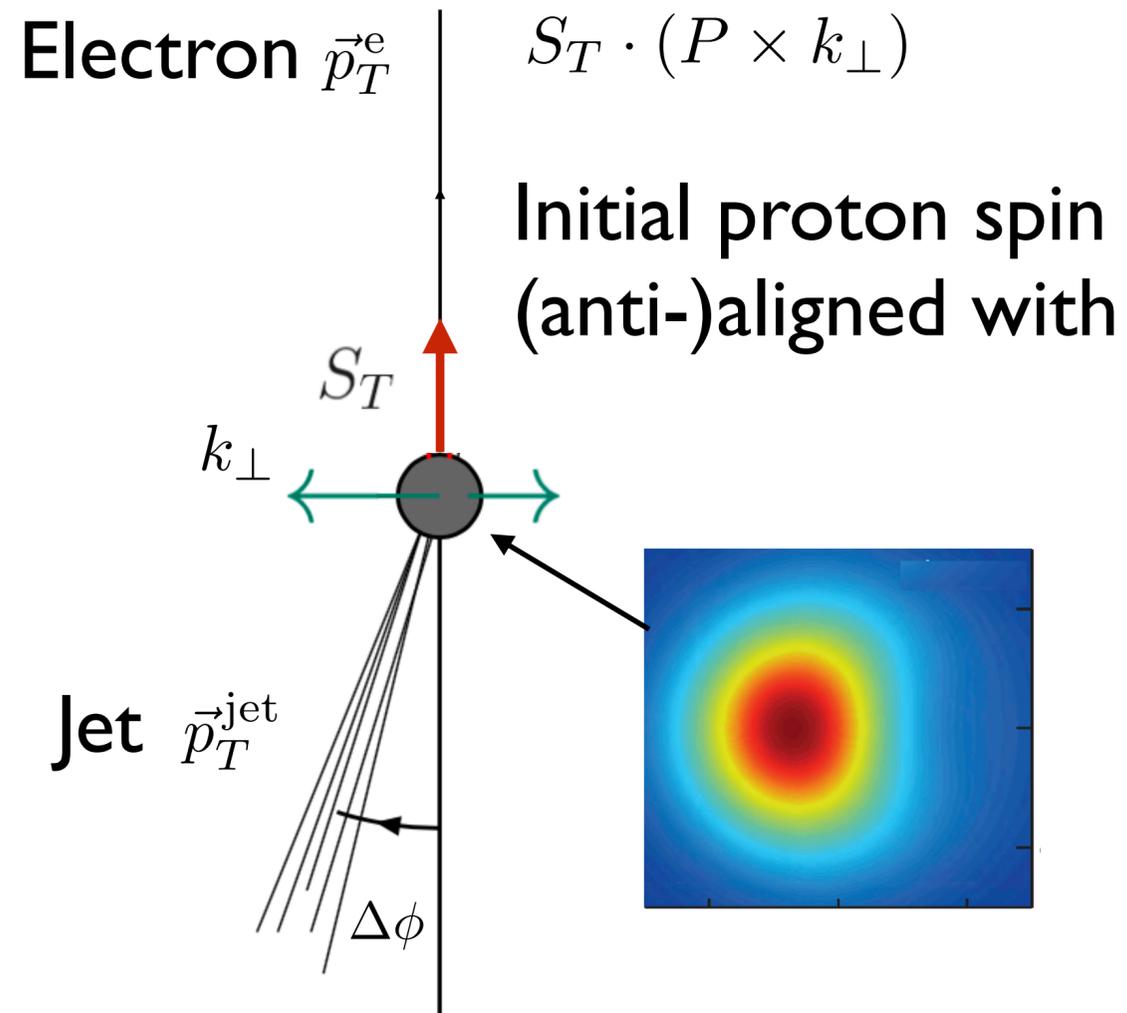


- Sivers function but no TMD fragmentation

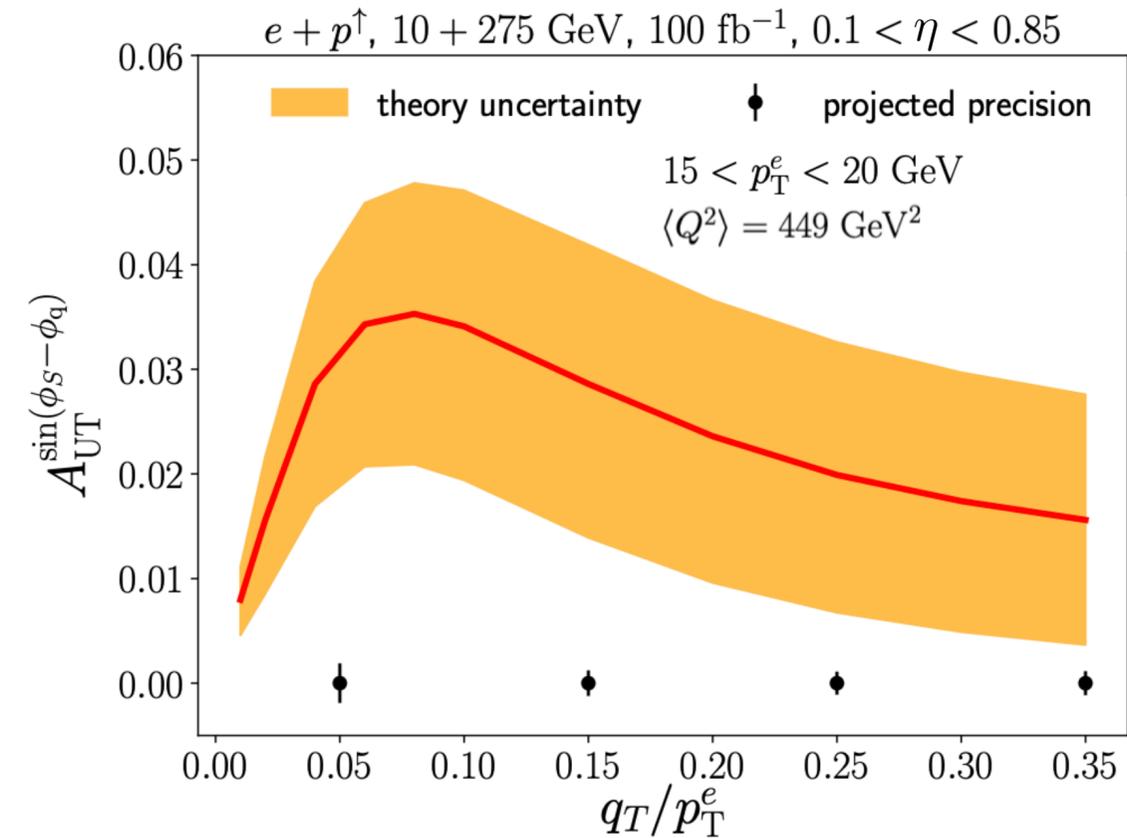
Sivers '90

# Electron-jet correlations

- Electron-jet imbalance at the EIC



- Predictions for the EIC



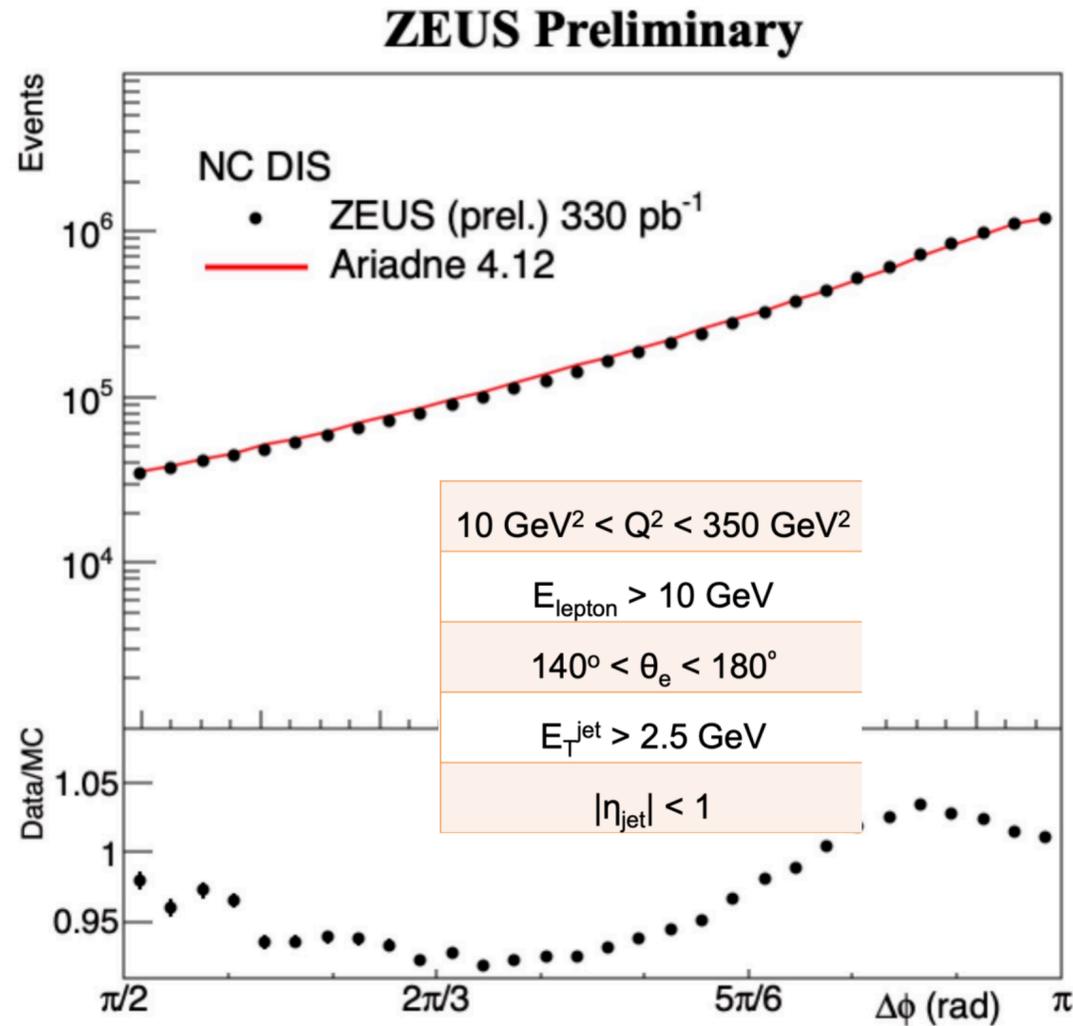
- Sivers function but no TMD fragmentation

Sivers '90

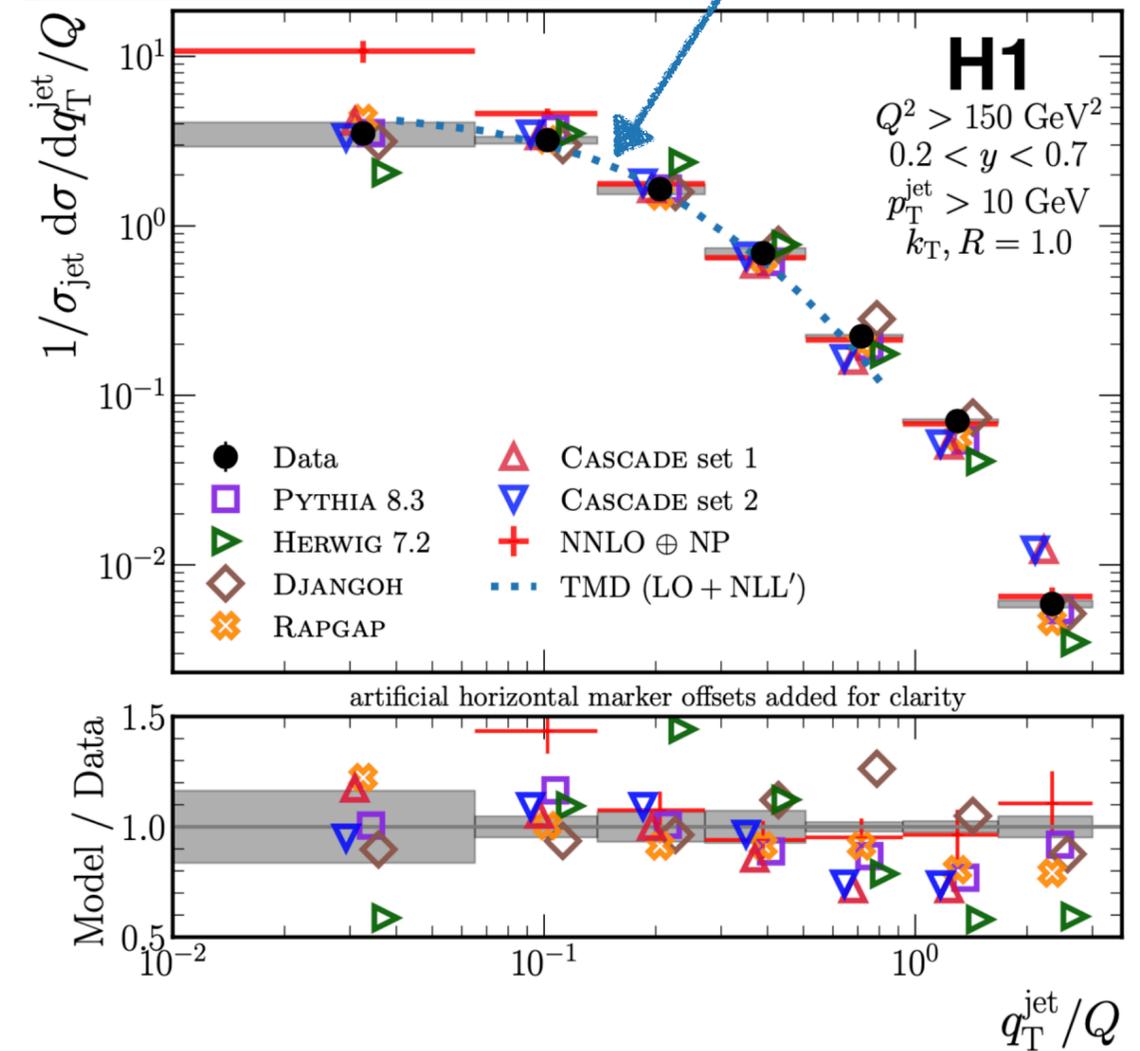
Liu, FR, Vogelsang, Yuan '18, '20  
Arratia, Kang, Prokudin, FR'20

# Results from HERA

TMD resummed result



ZEUS, Amilkar Quintero, EIC meeting



H1, PRL 128 (2022) 13, 132002

# Outline

Jet correlations

Jet substructure

Flavor dependence

# Transversity & Collins

Yuan '08

Liu, FR, Vogelsang, Yuan '18

Kang, Prokudin, FR, Yuan '17

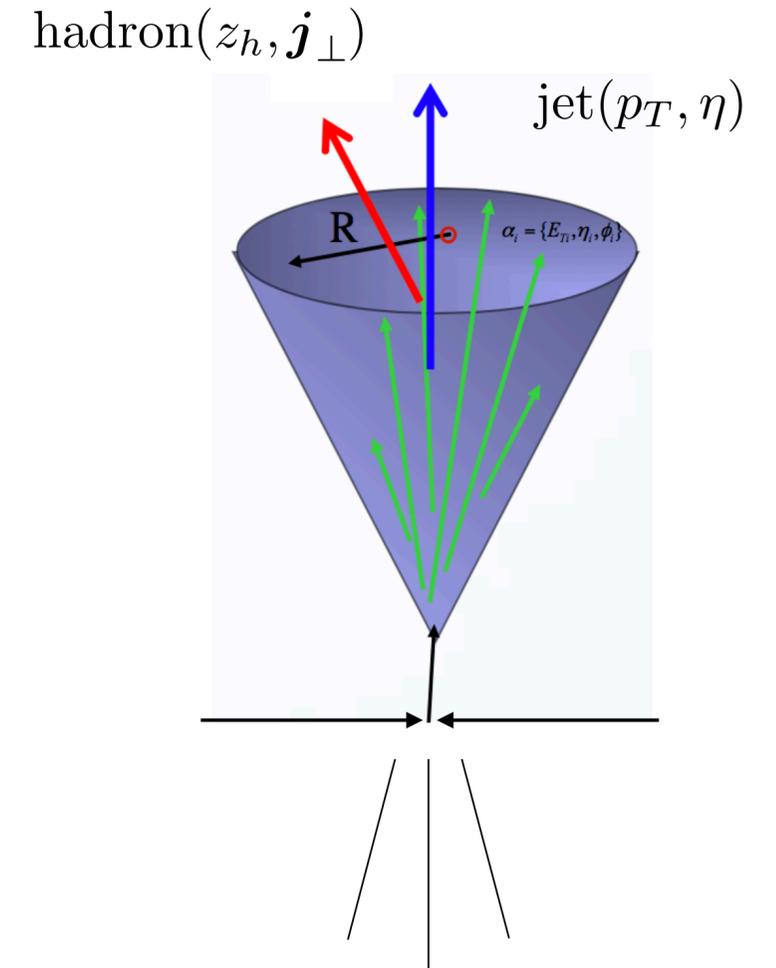
Arratia, Kang, Prokudin, FR '20

- Measure hadrons inside a jet relative the jet axis
- Azimuthal transverse spin asymmetries
- Independent handle on transversity and the Collins TMD FF  $H_1^{\perp q}(z_h, \vec{j}_T)$
- Factorization structure at NLL'

$$F_{UU}^h = \sigma_0 H_q(Q, \mu) \sum_q e_q^2 \int \frac{d^2 \vec{b}'_T}{(2\pi)^2} e^{i \vec{j}_T \cdot \vec{b}'_T / z_h} D_{h/q}^{\text{TMD}}(z_h, \vec{b}'_T, p_T^{\text{jet}} R)$$

$$\times \int \frac{d^2 \vec{b}_T}{(2\pi)^2} e^{i \vec{q}_T \cdot \vec{b}_T} f_q^{\text{TMD}}(x, \vec{b}_T, \mu) S_q(\vec{b}_T, y_{\text{jet}}, R, \mu) + \mathcal{O}(R^2)$$

- Initial & final state TMDs are independent



# Transversity & Collins

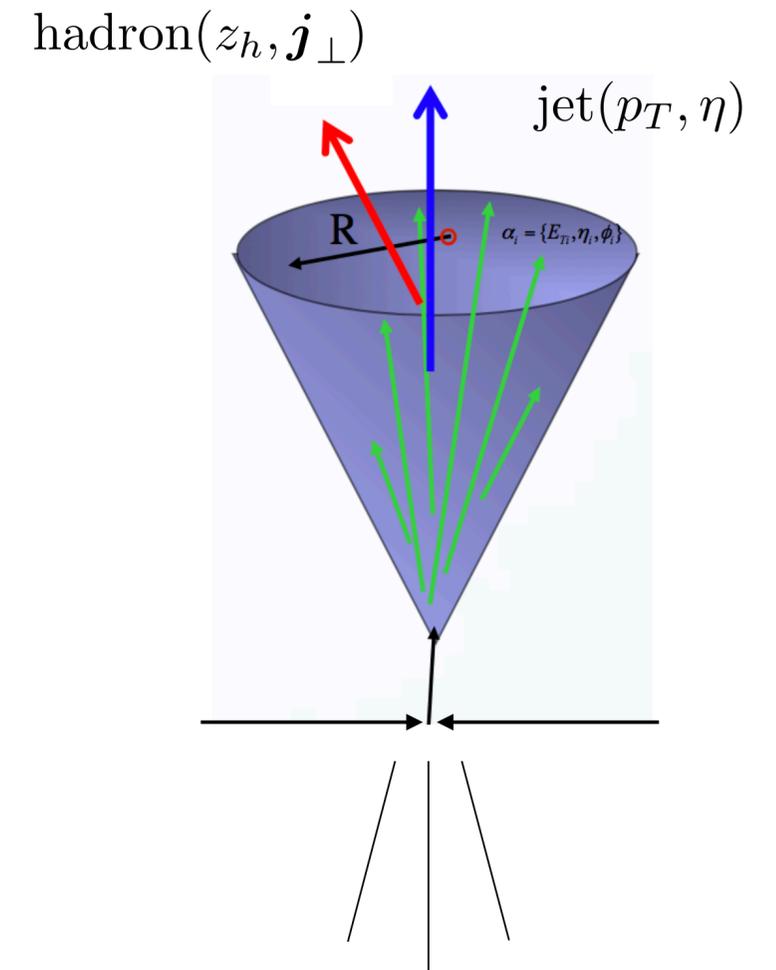
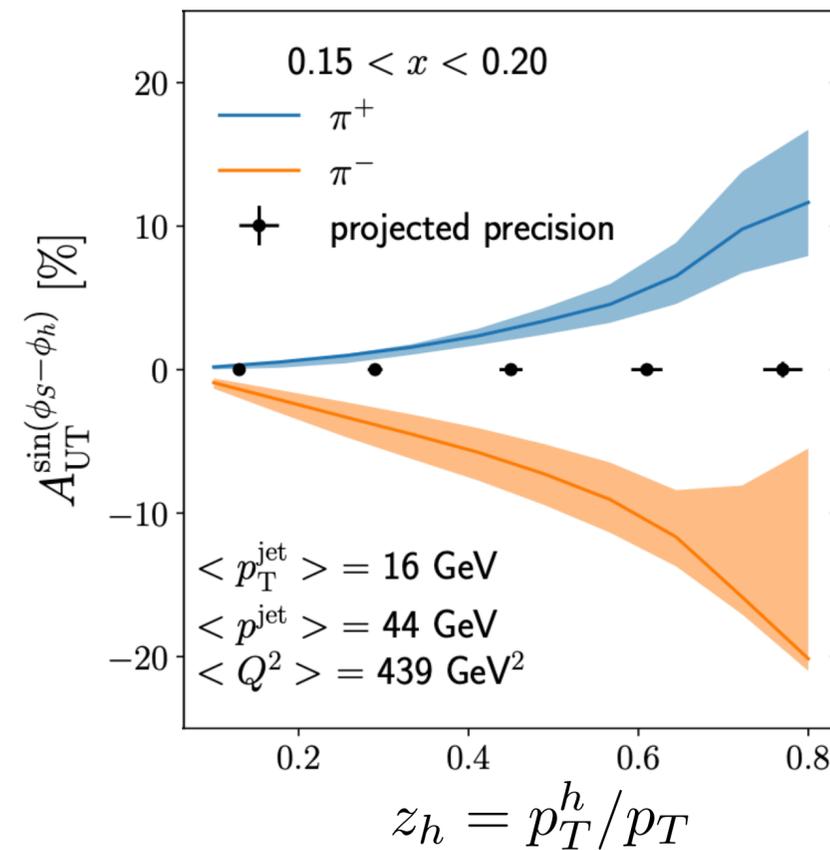
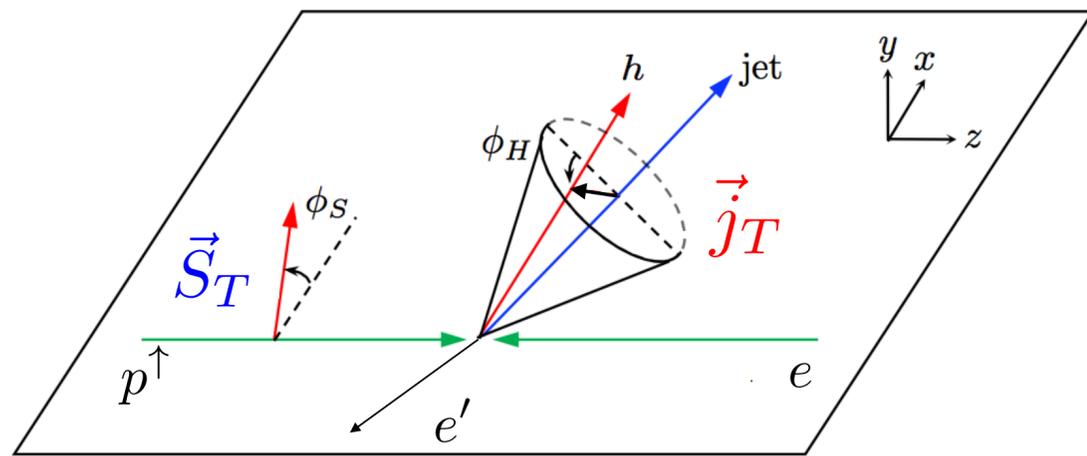
Yuan '08

Liu, FR, Vogelsang, Yuan '18

Kang, Prokudin, FR, Yuan '17

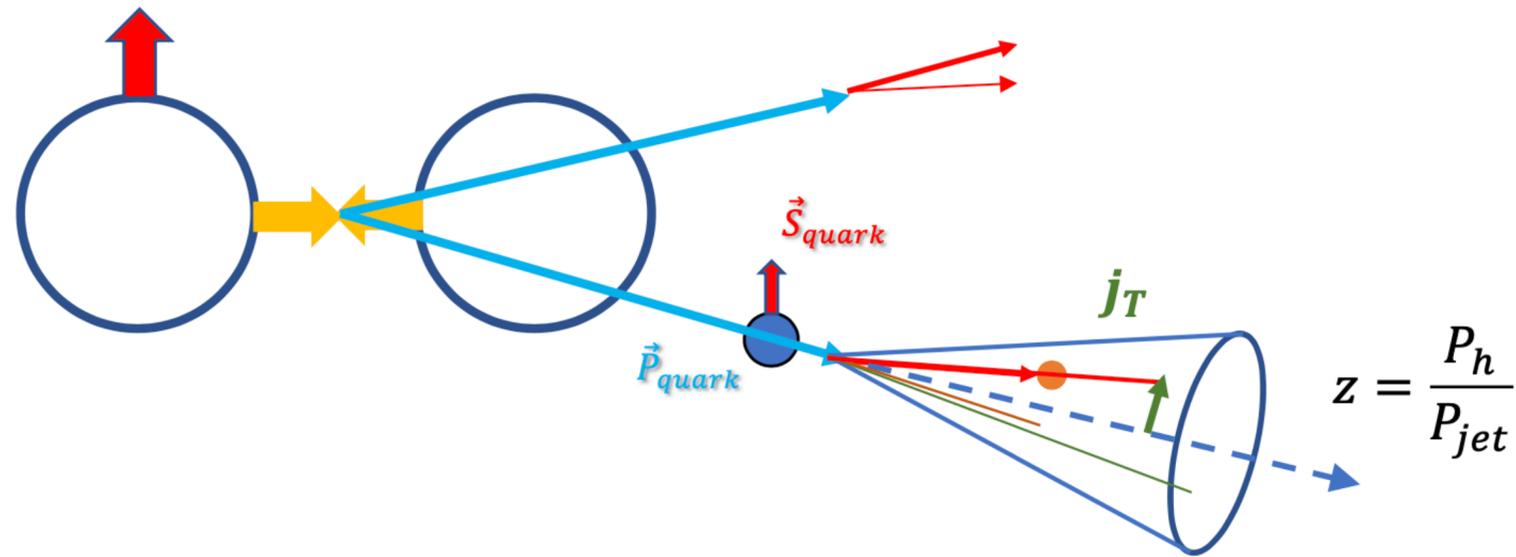
Arratia, Kang, Prokudin, FR '20

- Measure hadrons inside a jet relative the jet axis
- Azimuthal transverse spin asymmetries
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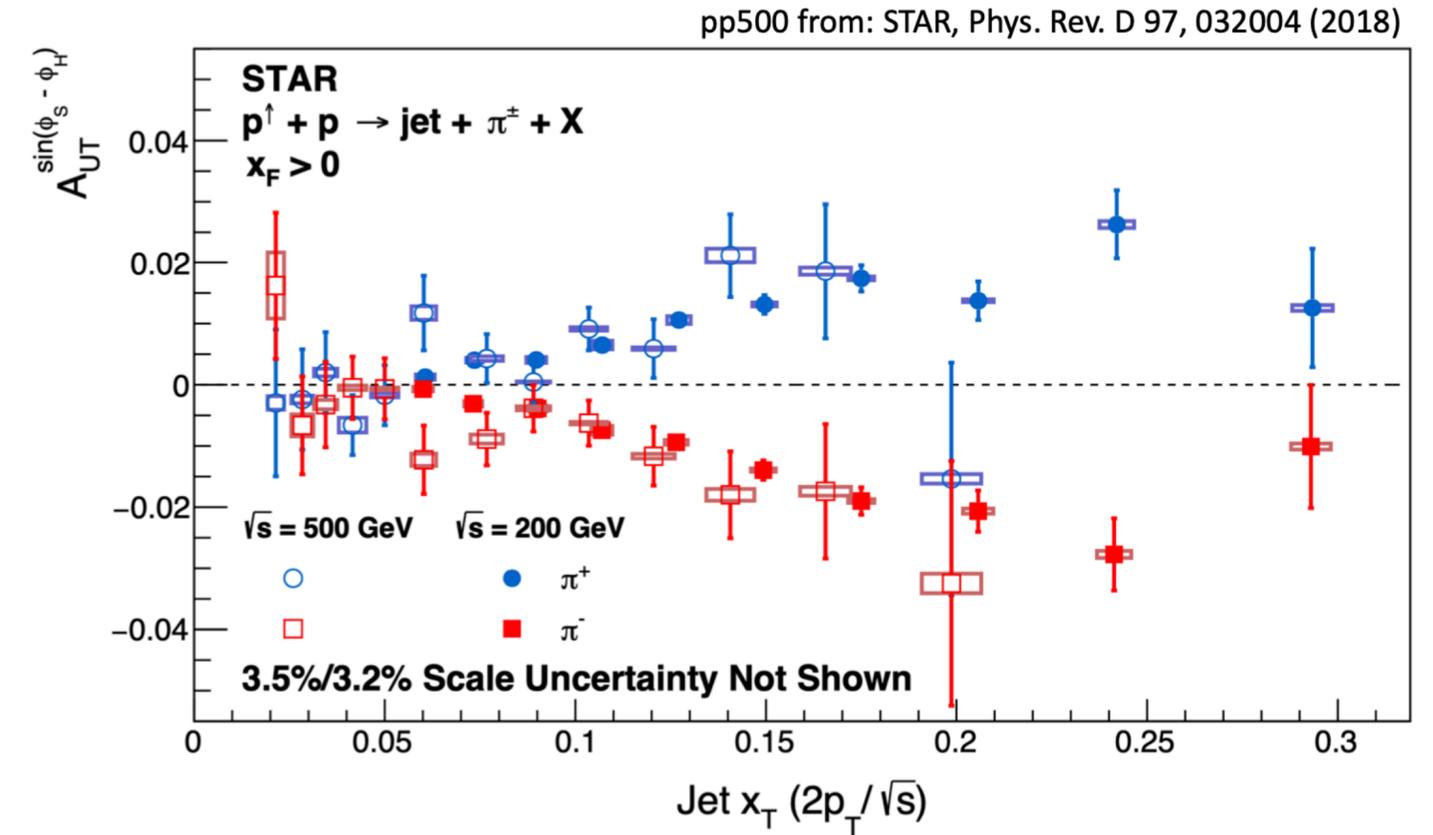


# Results from RHIC

Ting Lin, DIS 2022



- Jet measurements can provide important constraints in global analyses



# Outline

Jet correlations

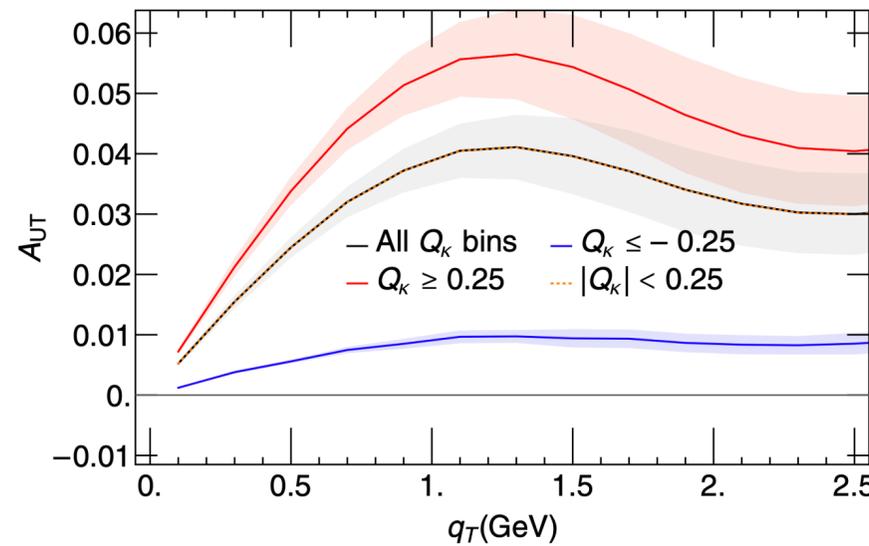
Jet substructure

Flavor dependence

# Quark flavor dependence

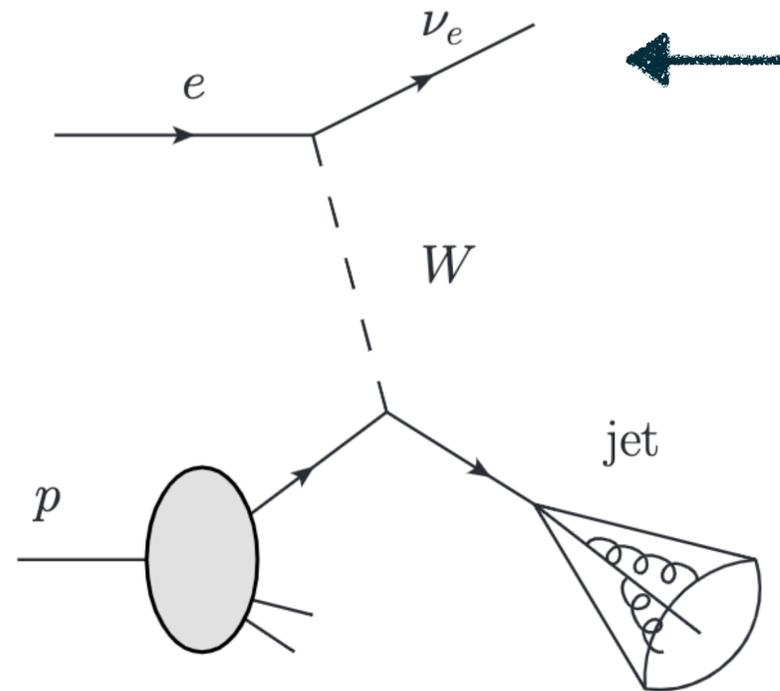
- Jet charge

$$Q_\kappa \equiv \sum_{h \in \text{jet}} z_h^\kappa Q_h$$



Waalewijn '12, RHIC  
Kang, Liu, Mantry, Shao '20

- Neutrino-jet correlations in charged current events



Measure missing  
transverse momentum  $\vec{p}_T^{\text{miss}}$

Arratia, Kang, Paul, Prokudin, FR, Zhao  
in preparation

- See e.g. inclusive DIS at HERA

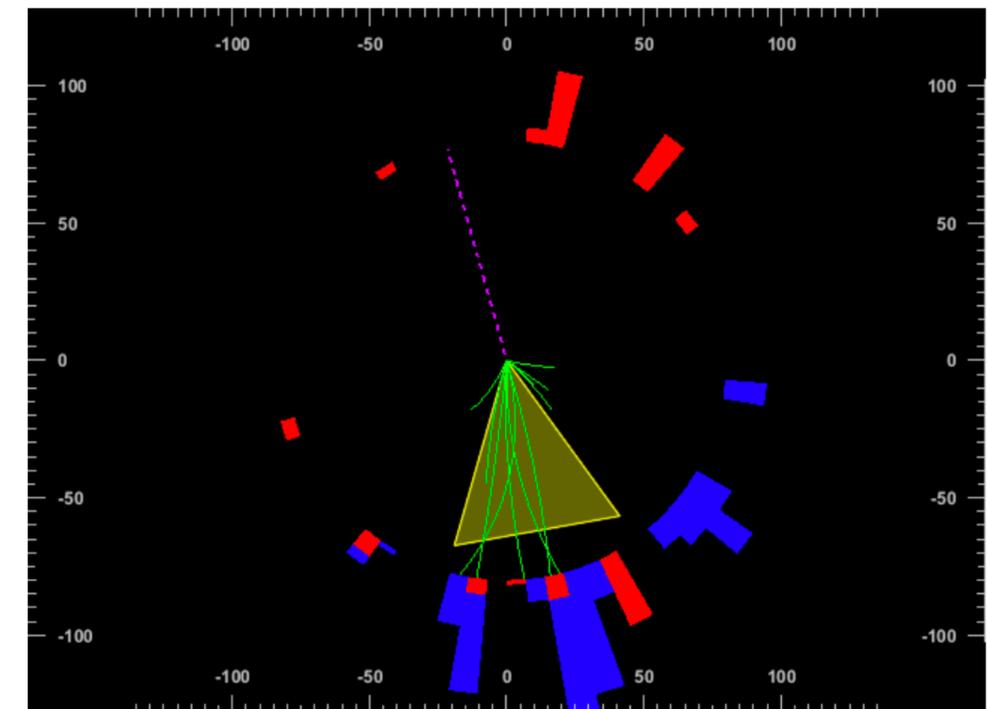
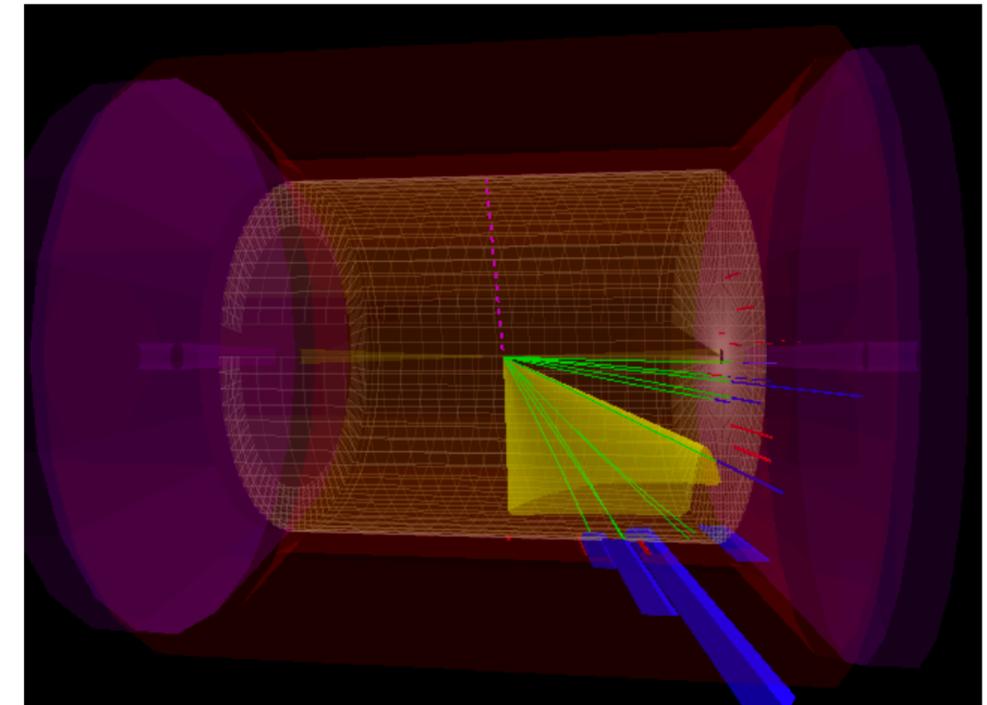
# Neutrino-jet correlations

- Lab instead of Breit frame: do not need full neutrino 3-momentum
- Measure Sivers for  $q_T = |\vec{p}_T^{\nu_e} + \vec{p}_T^{\text{jet}}| \sim 0$  and transversity + Collins

$$\mathcal{M}^{\text{LO}} = \left( \frac{ie}{\sqrt{2} \sin \theta_w} \right)^2 (\bar{\nu}_{eL} \gamma^\mu e_L) \frac{-i(g^{\mu\nu} - \frac{q^\mu q^\nu}{m_W^2})}{q^2 - m_W^2 + im_W \Gamma_W} (V_{ud} \bar{d}_L^i \gamma^\nu u_L^i)$$

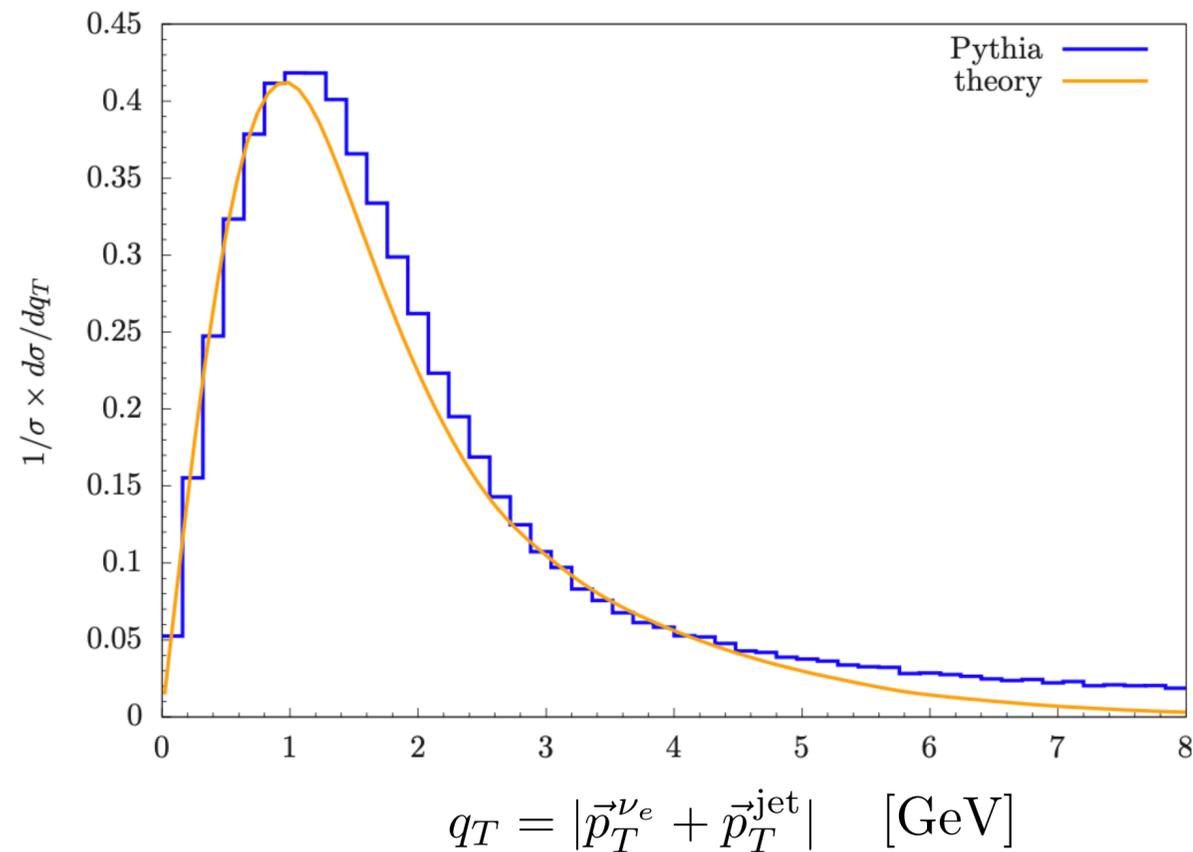
- Requires a sufficiently hermetic detector, here full azimuthal coverage and  $|\eta| < 4$

Delphes

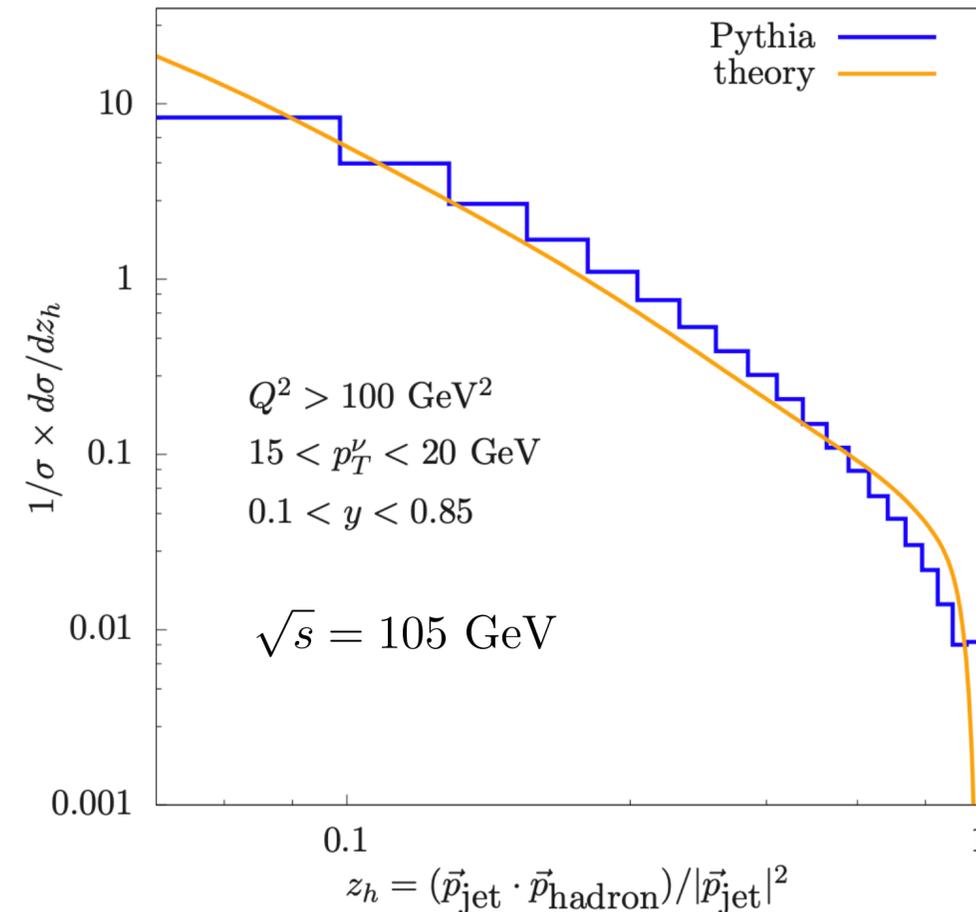


# Neutrino-jet correlations

- Comparison to Pythia, imbalance



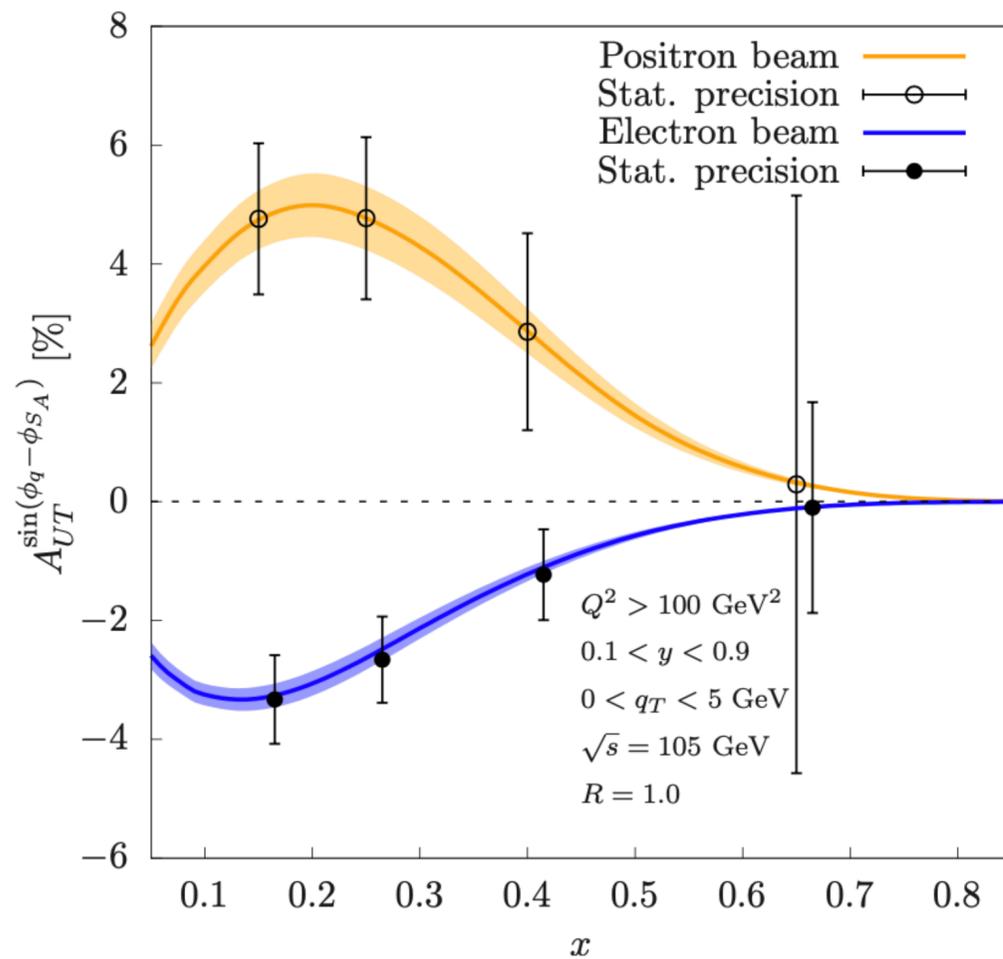
- In-jet hadron fragmentation spectrum



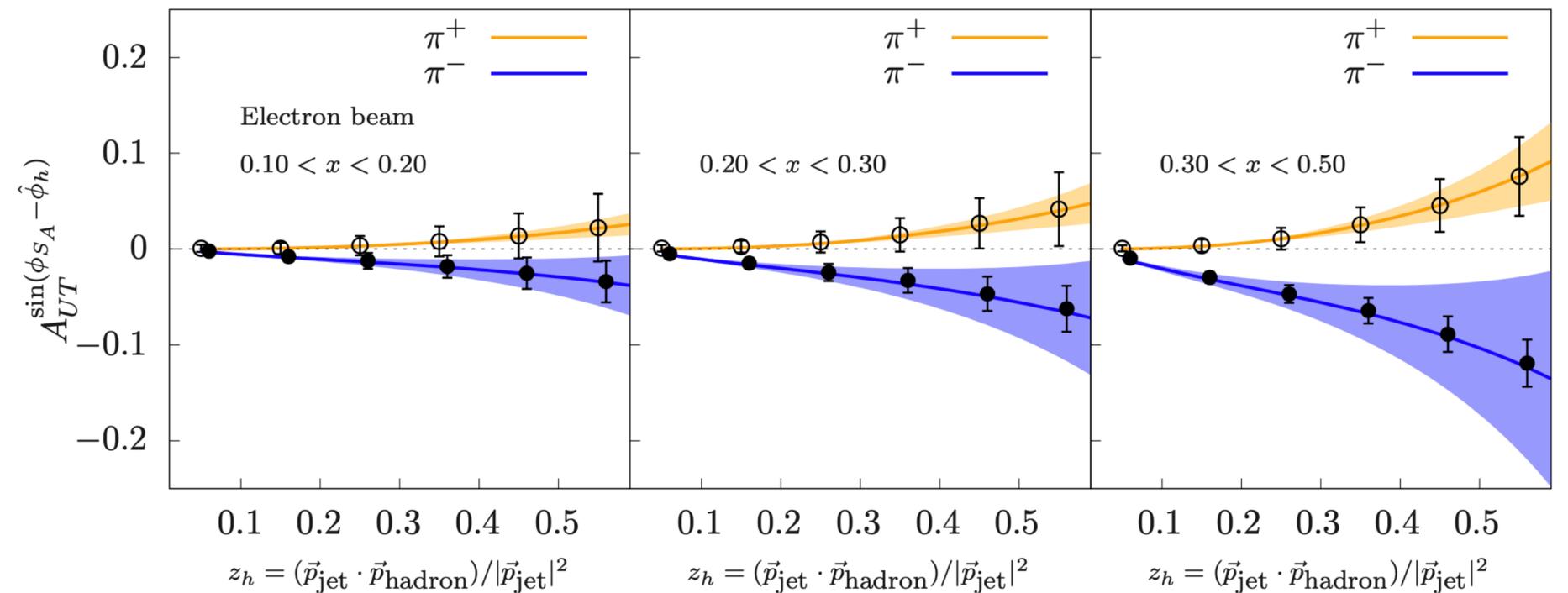
Arratia, Kang, Paul, Prokudin, FR, Zhao  
in preparation

# Neutrino-jet correlations

- Sivers asymmetry



- Transversity + Collins asymmetry



PRELIMINARY

Arratia, Kang, Paul, Prokudin, FR, Zhao  
in preparation

# Conclusions

- Jets are good proxies of parton level kinematics
- Correlations and substructure observables
- Experimental results from RHIC & HERA
- Constraints of non-perturbative distributions
- Studies for the future EIC

