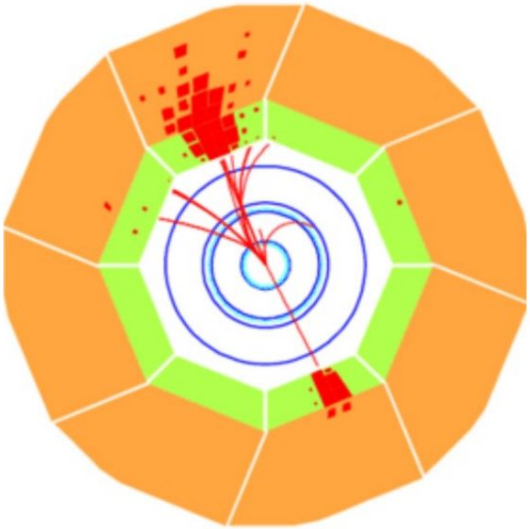
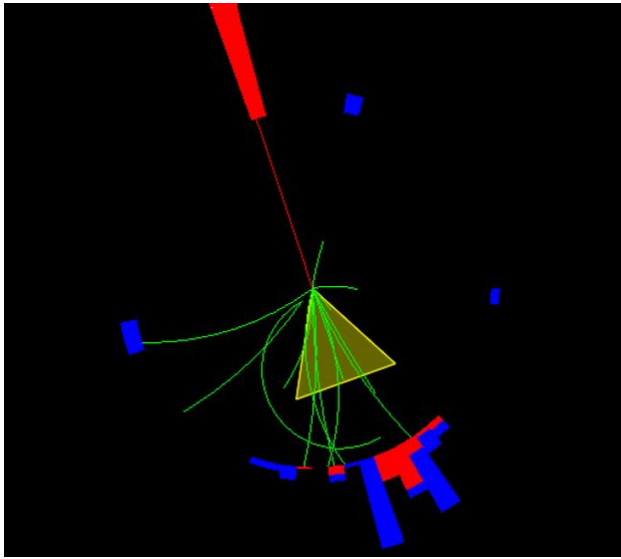
Projections of jet measurements at the EIC and recent HERA results



Miguel Arratia

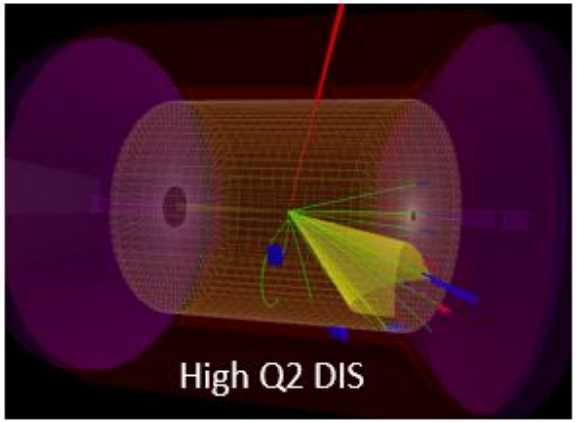
UC RIVERSIDE

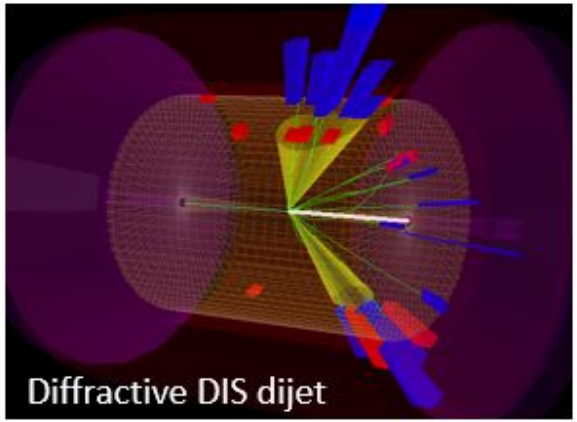
Jefferson Lab

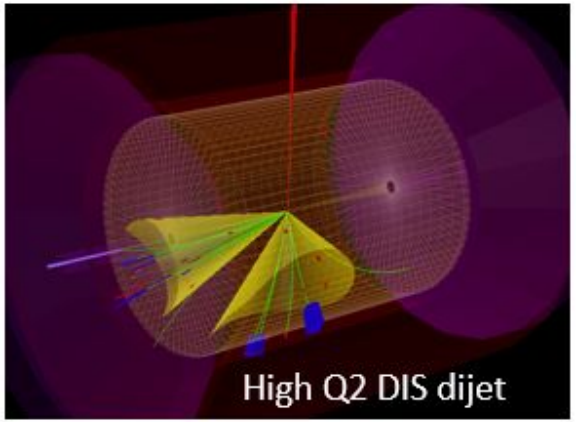


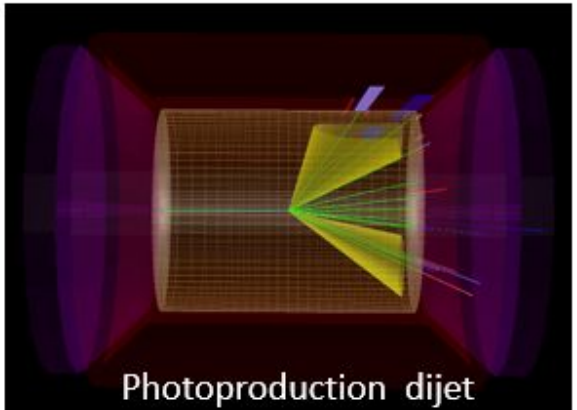
QCD Evolution Workshop 2021, May 21

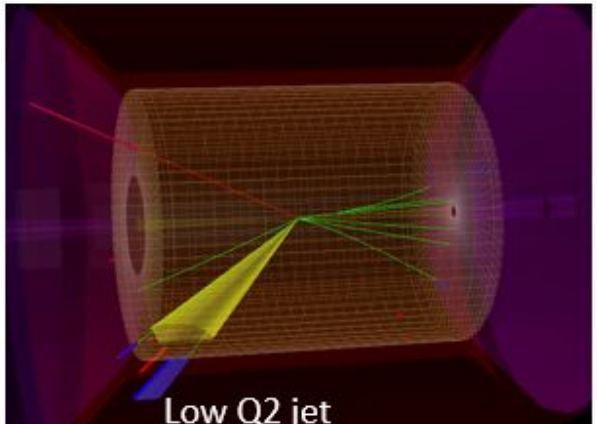
The EIC, a jet factory, will make the first jets in nuclear DIS and proton-polarized DIS

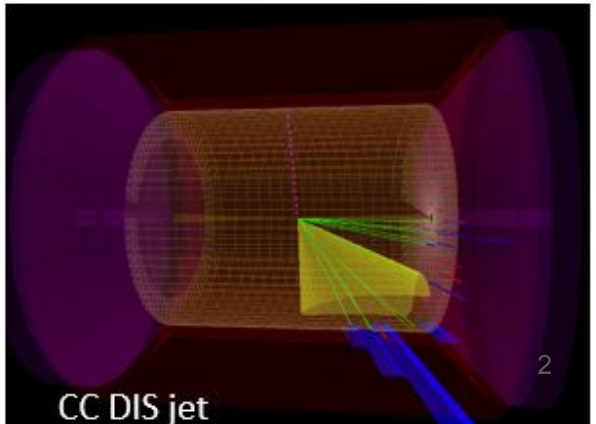






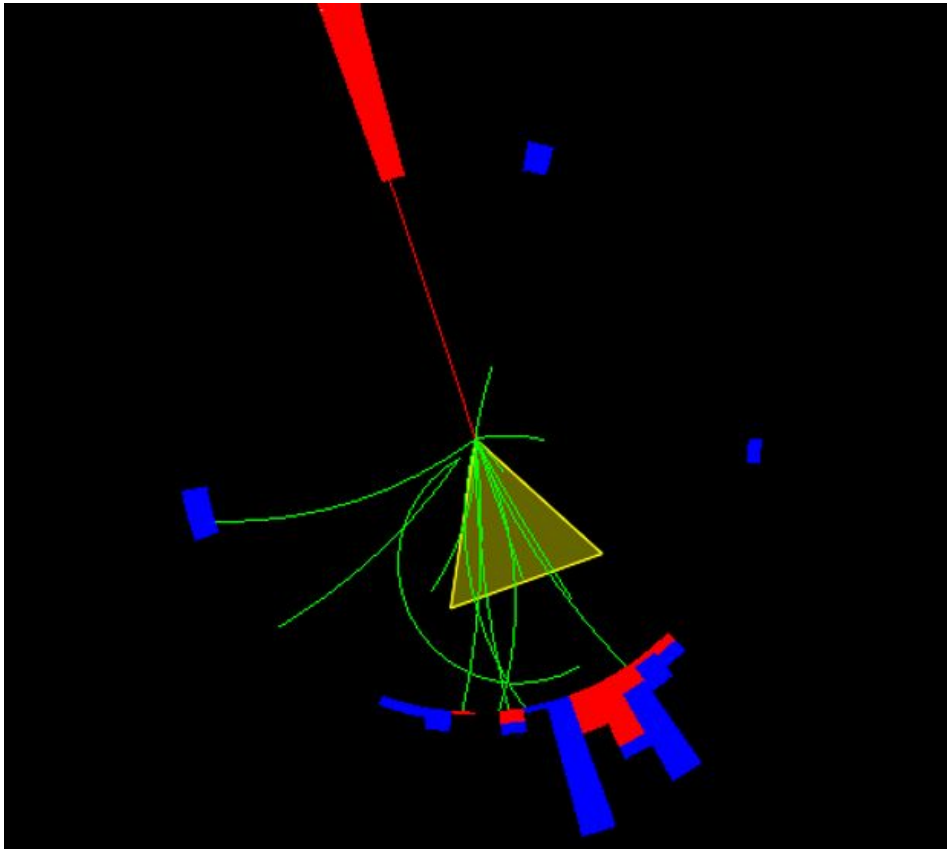






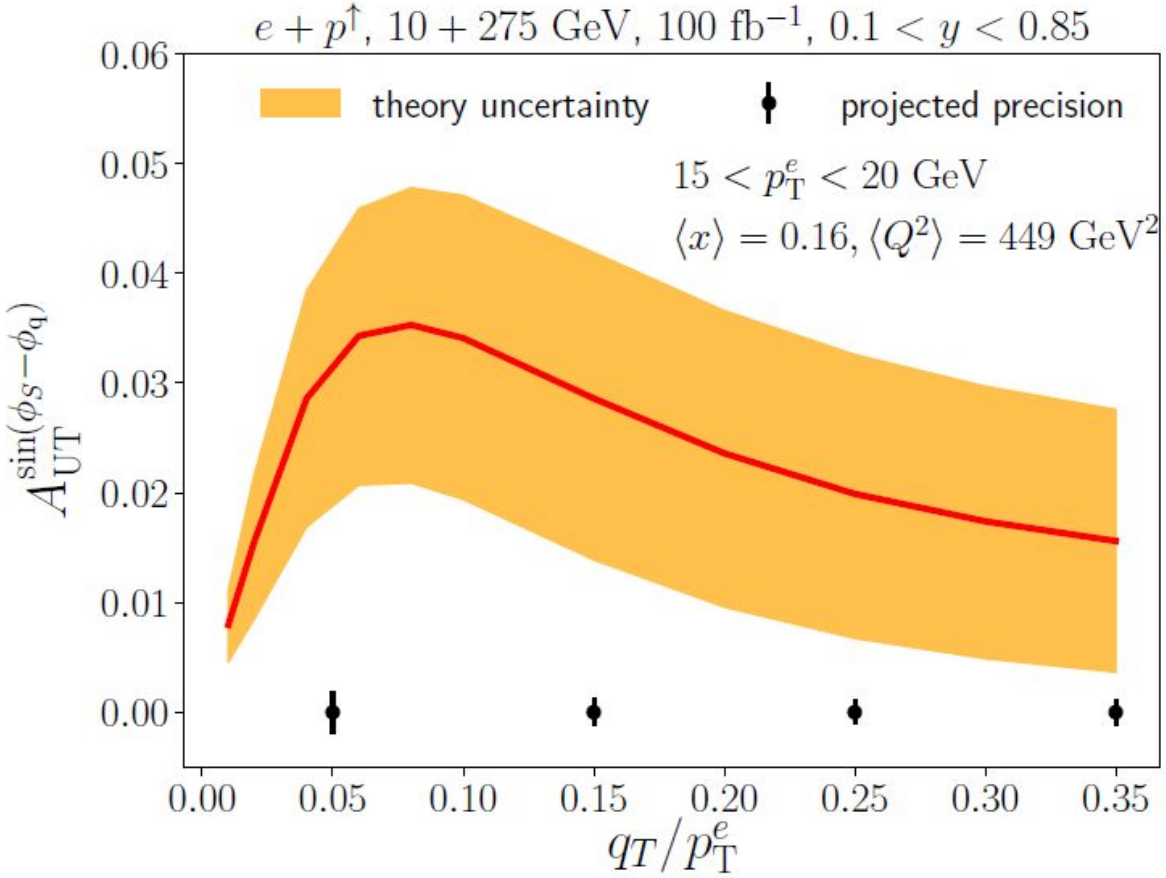
A new channel to probe for quark TMDs and evolution

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

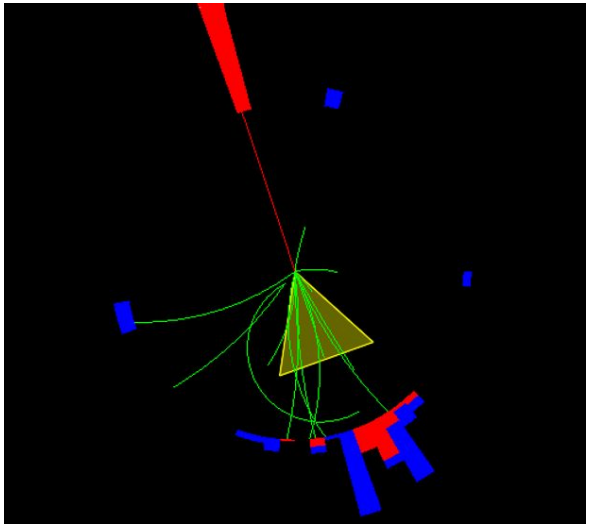


“The advantage of the lepton-jet correlation as compared to the standard SIDIS processes is that it does not involve TMD fragmentation functions.”

Projection for Lepton-jet Sivers asymmetry



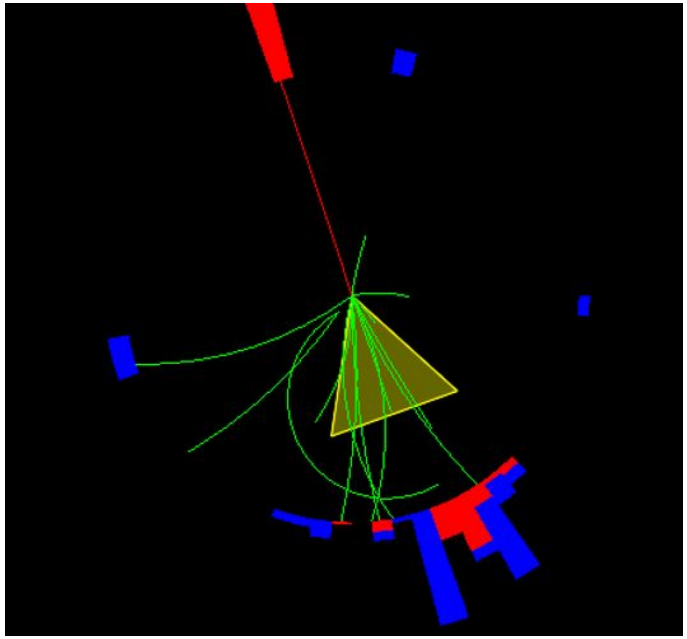
$$q_T = |\vec{p}_T^{\,e} + \vec{p}_T^{\,\mathrm{jet}}|$$



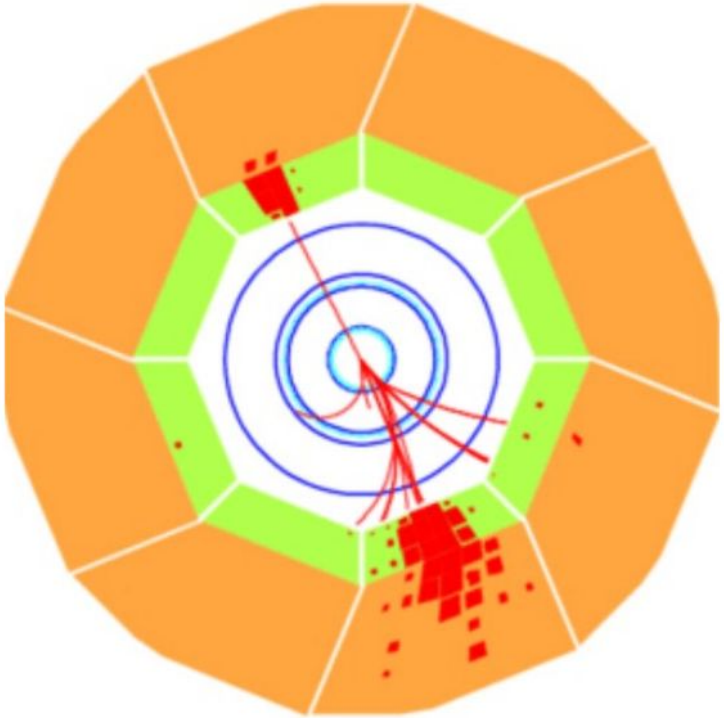
Prediction & projection in
Arratia et al. PRD 102, 074015 (2020
Based on formalism in
Liu et al. PRL. 122, 192003

We can actually explore feasibility of these measurements and test the TMD calculations with the unpolarized data taken at HERA

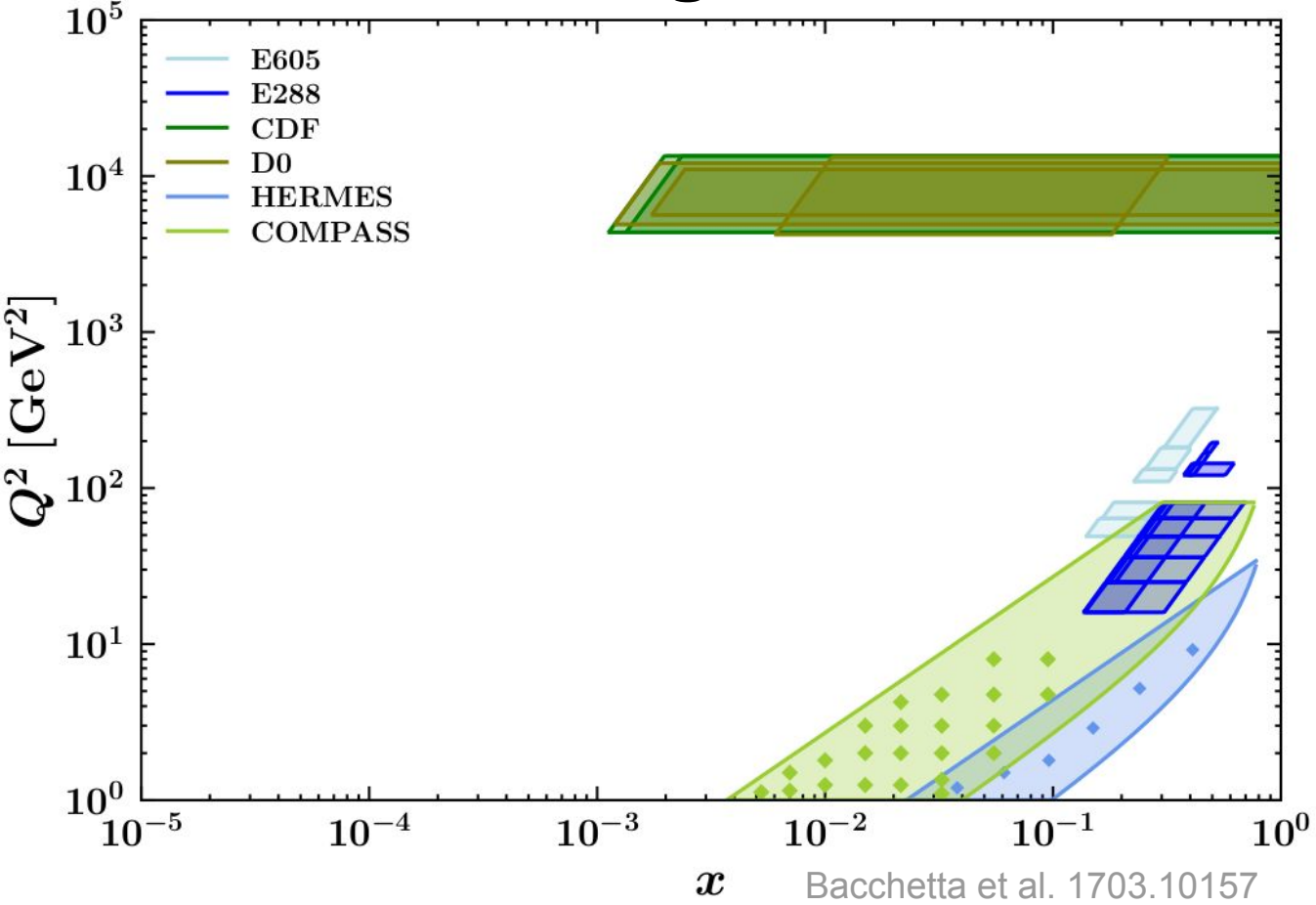
EIC



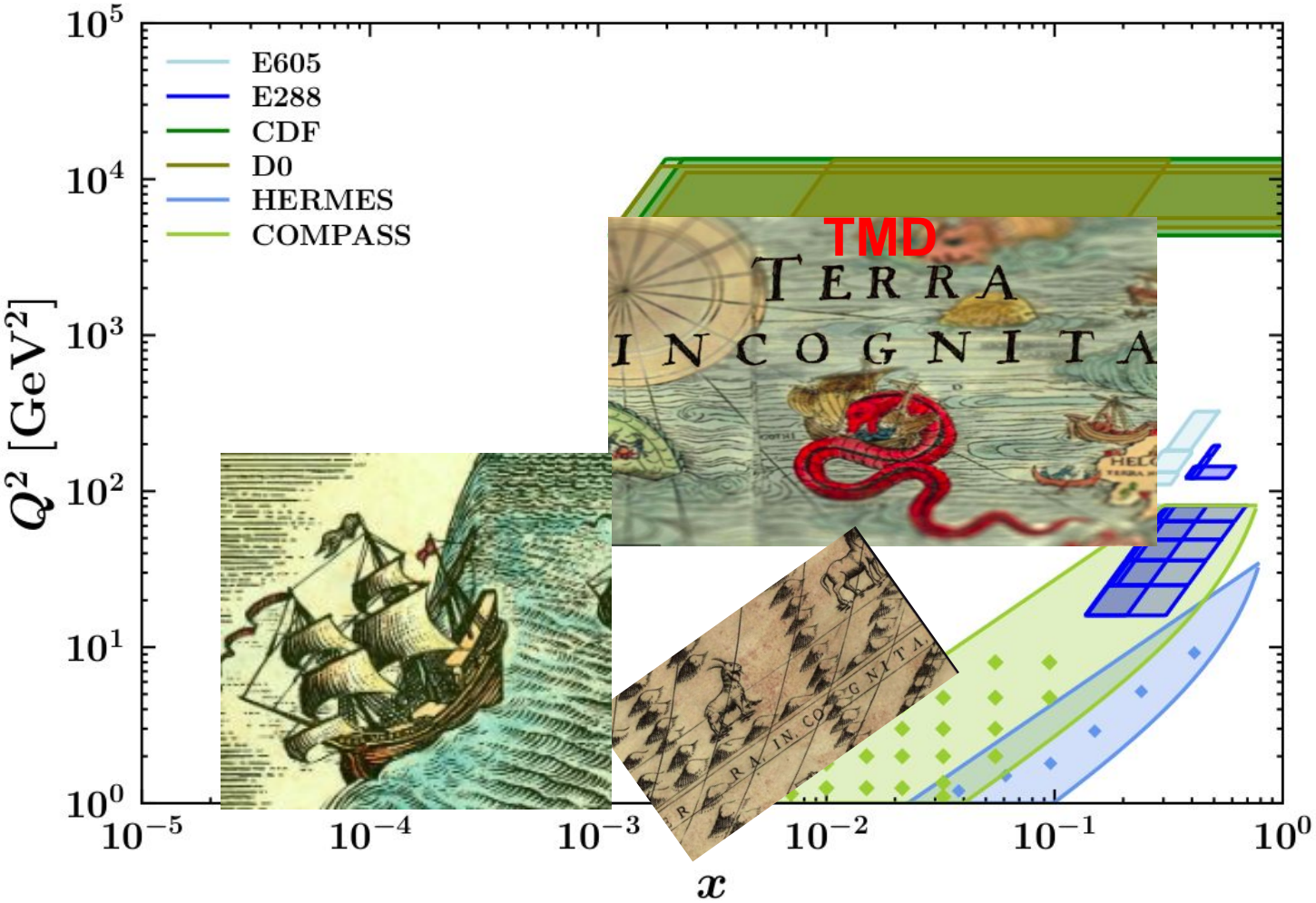
H1@HERA



Existing TMD data



Bacchetta et al. 1703.10157


E605
E288
CDF
D0
HERMES
COMPASS
TMD
TERRA
INCOGNITA
10^5
10^4
10^3
10^2
10^1
10^0
Q^2 [GeV^2]
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^0
x

Constraining TMD evolution with HERA data

Bridging DIS from fixed-target exp. and high Q2 Drell-Yan at colliders.
Fixing open issues of TMD factorization & universality

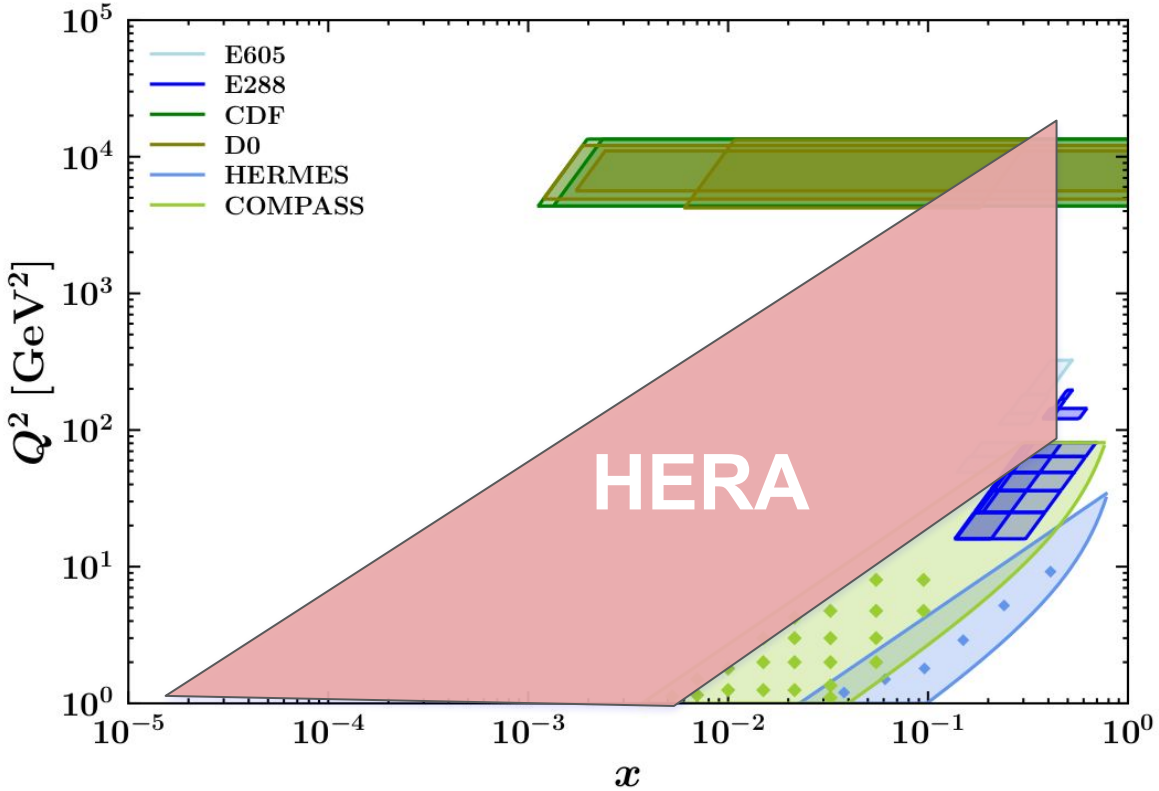
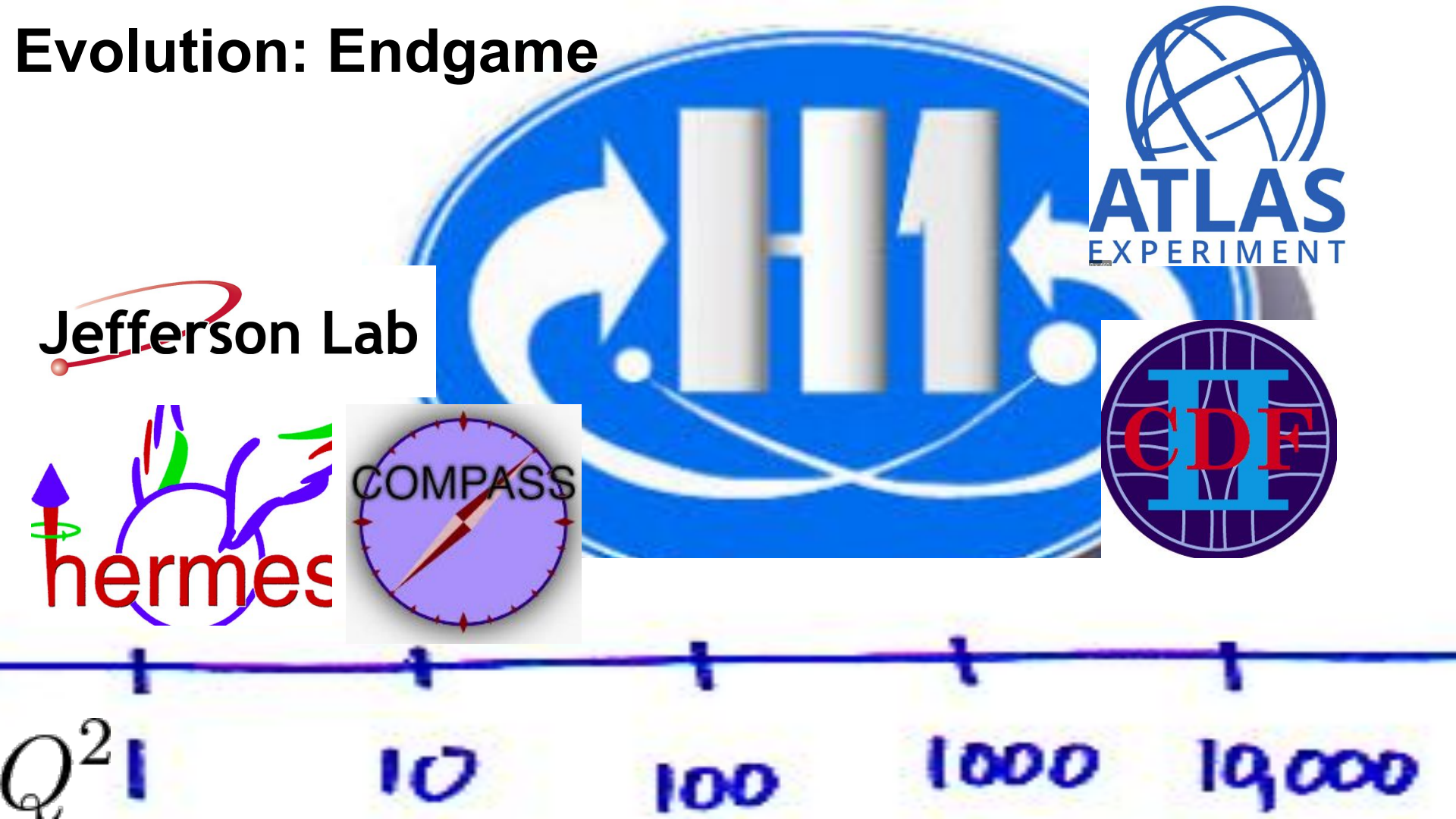


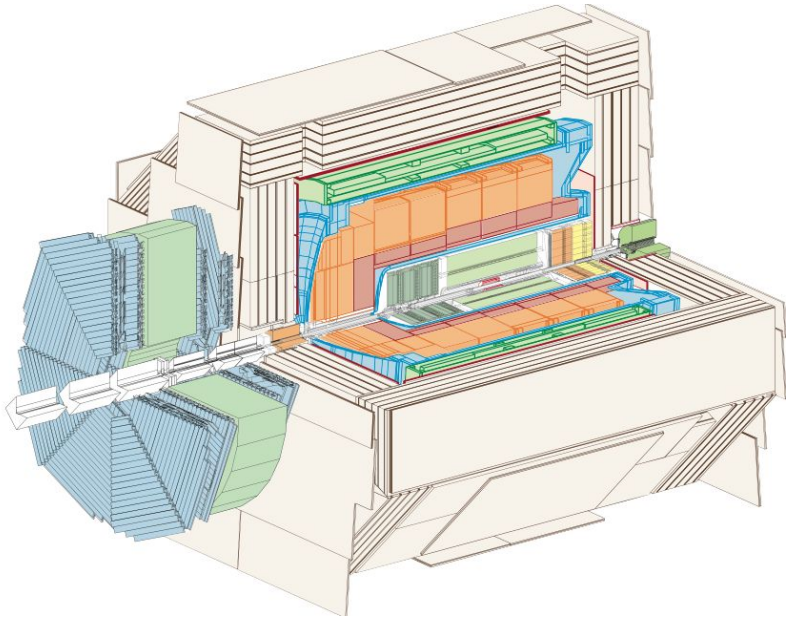
Fig adapted from rom Alessandro's slides

Evolution: Endgame



New, preliminary H1 results

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



H1prelim-21-031
April 5, 2021

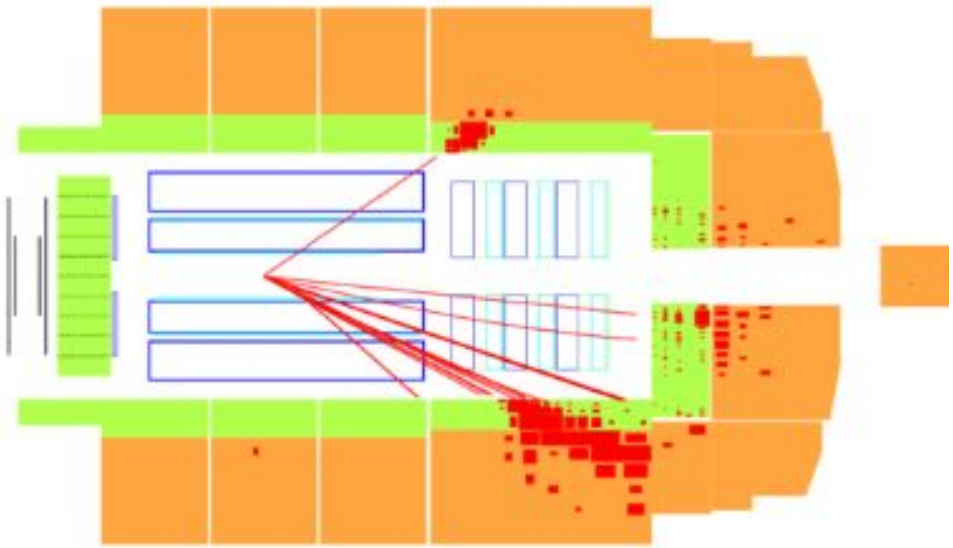
Measurement of lepton-jet correlations in high Q^2 neutral-current DIS with the H1 detector at HERA

The H1 Collaboration

Abstract

A measurement of jet production in high Q^2 neutral-current DIS events close to the Born-level configuration $\gamma^* q \to q$ (Born kinematics) is presented. This cross section is measured deferentially as

Accurate and precise jet and lepton measurements



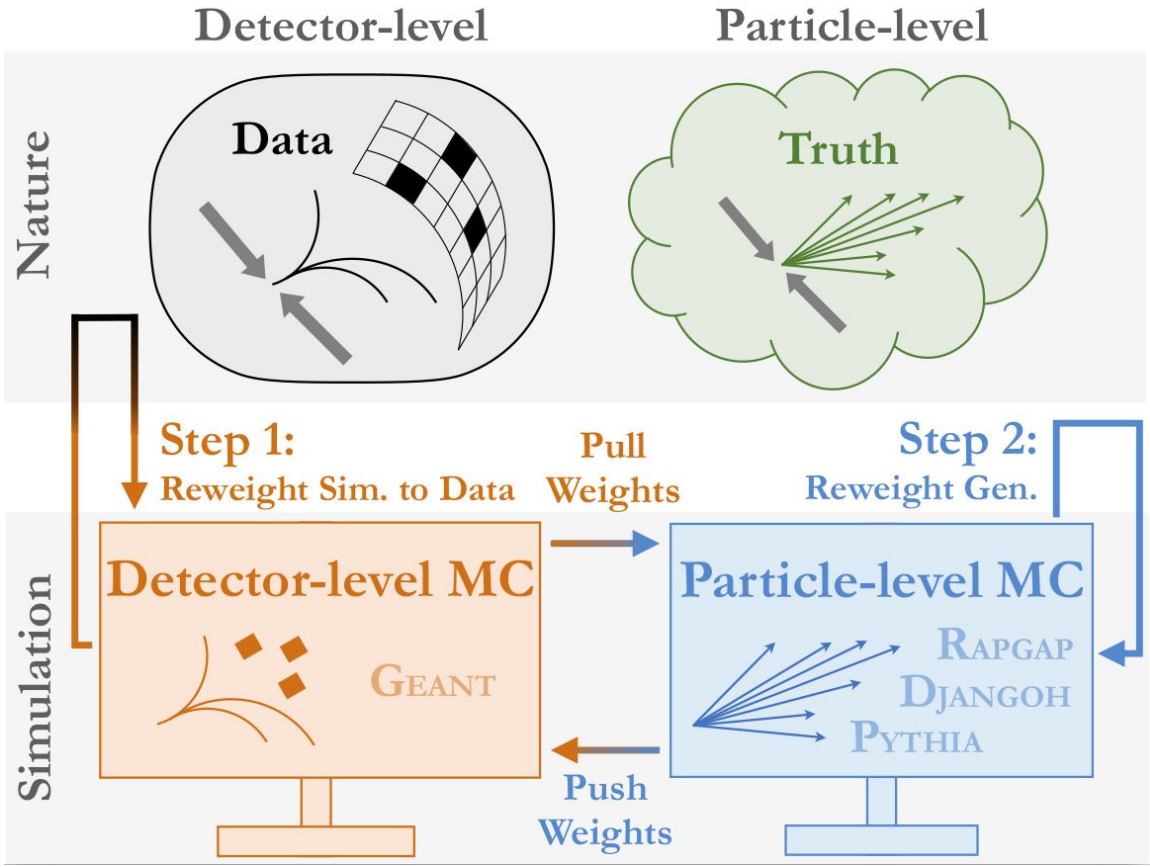
Neural-net based in-situ jet calibration for data and MC.

1% Jet energy scale

0.5-1% lepton energy scale

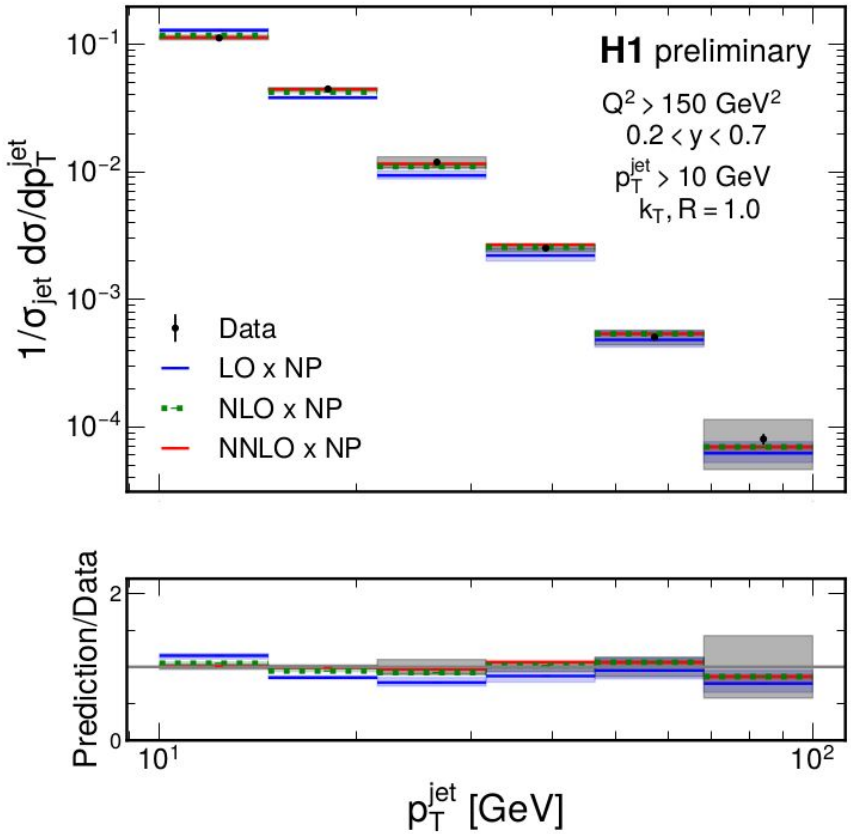
Unfolding with Omnifold (via machine-learning).

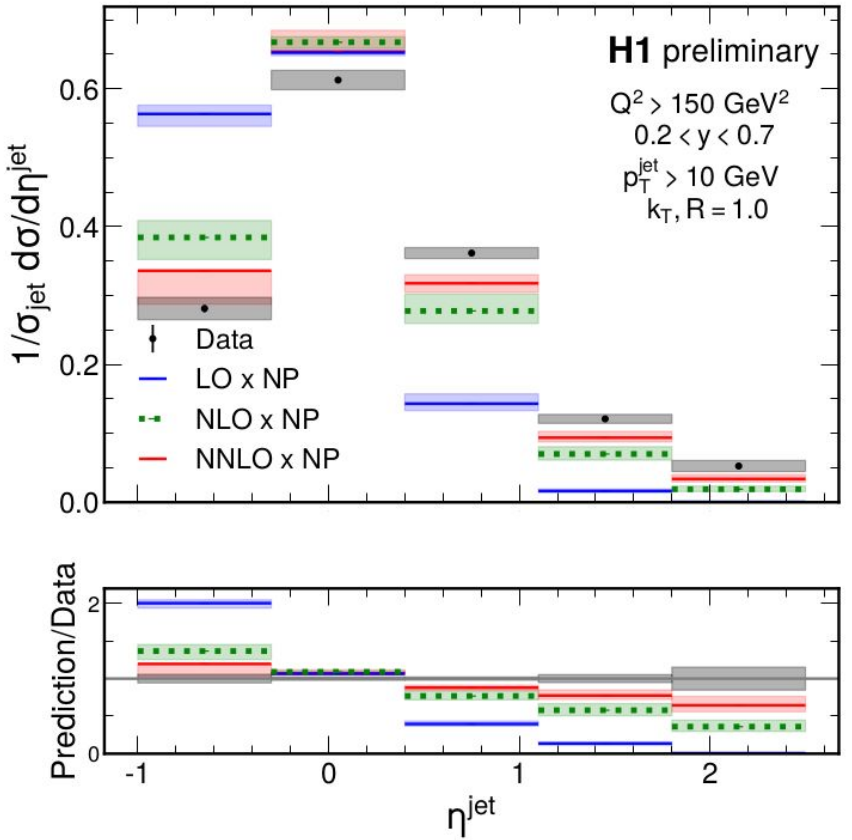
Andreassen et al. PRL **124**, 182001 (2020)



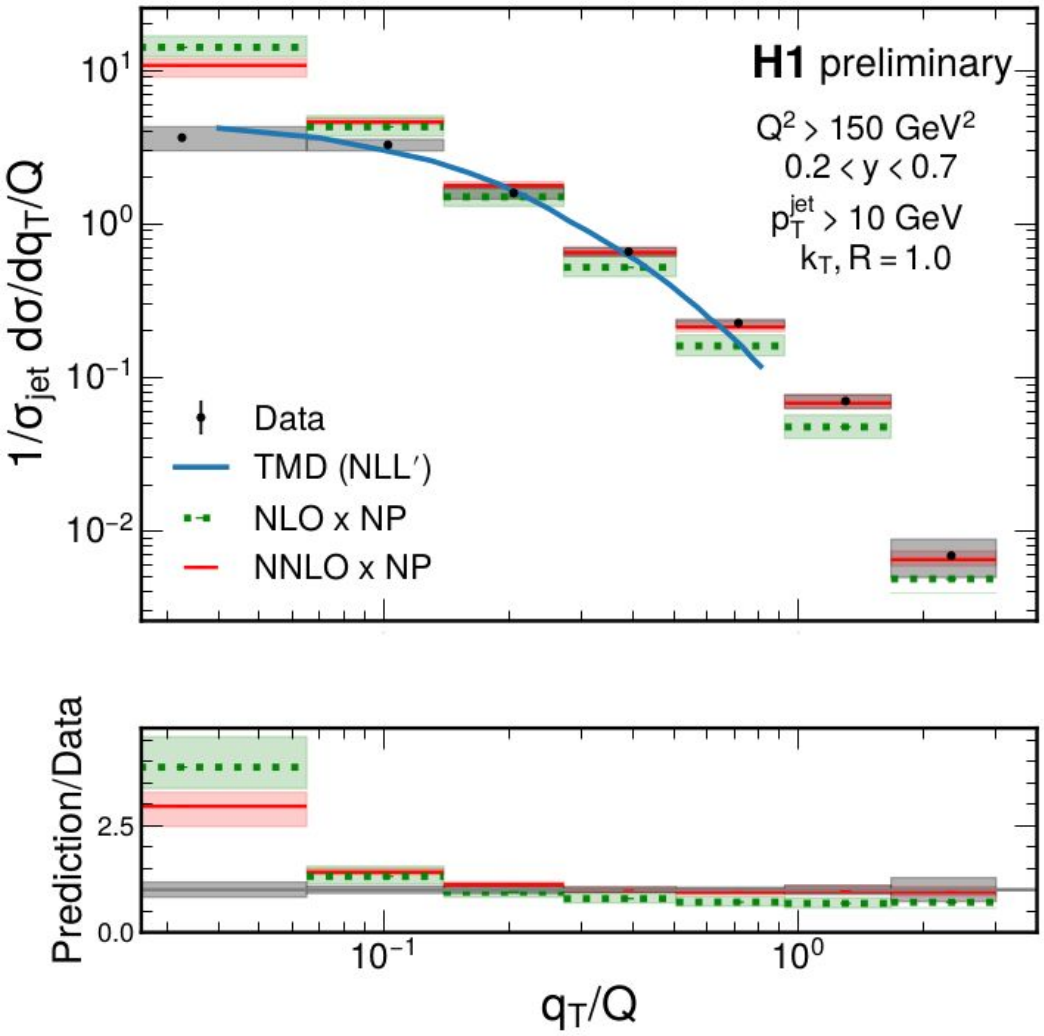
The H1 analysis that I am presenting is the **first-ever** measurement that uses machine learning to correct for detector effects.

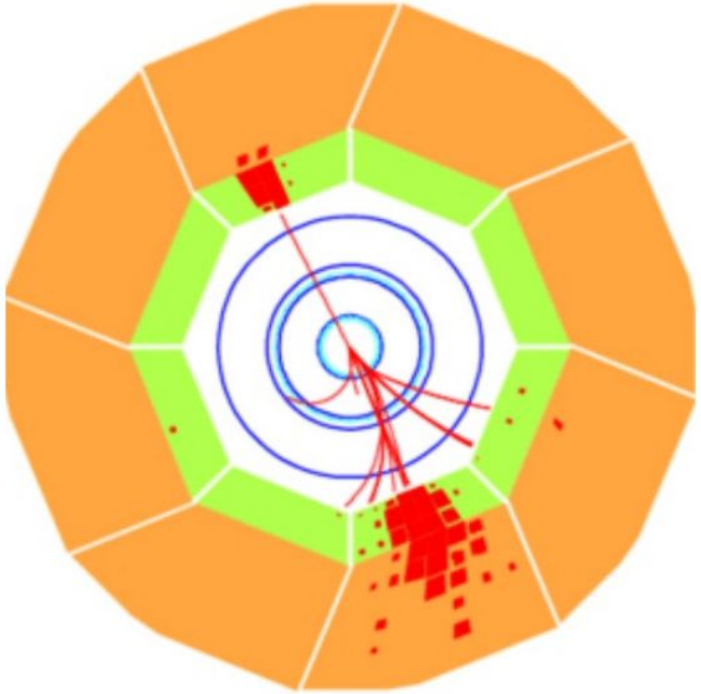
Jet transverse momentum and pseudorapidity





- Well described, quick convergence
- Hints at need of NNNLO





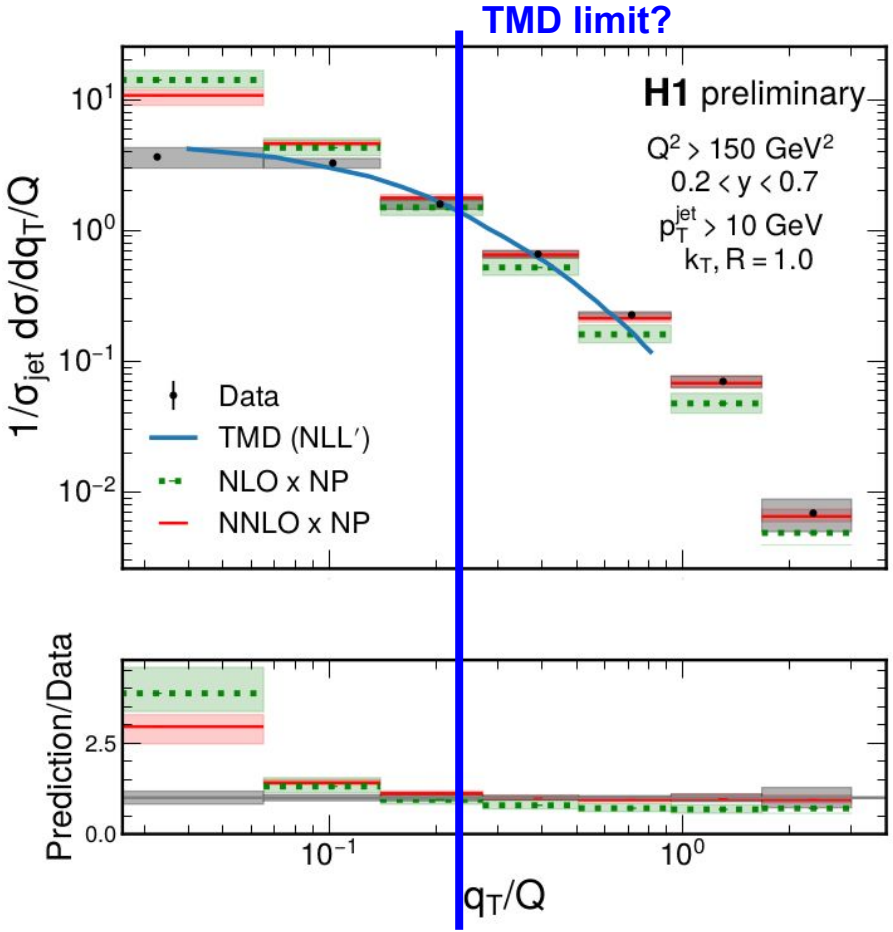
$$q_T = |\vec{p}_T^{\,e} + \vec{p}_T^{\,\mathrm{jet}}|$$

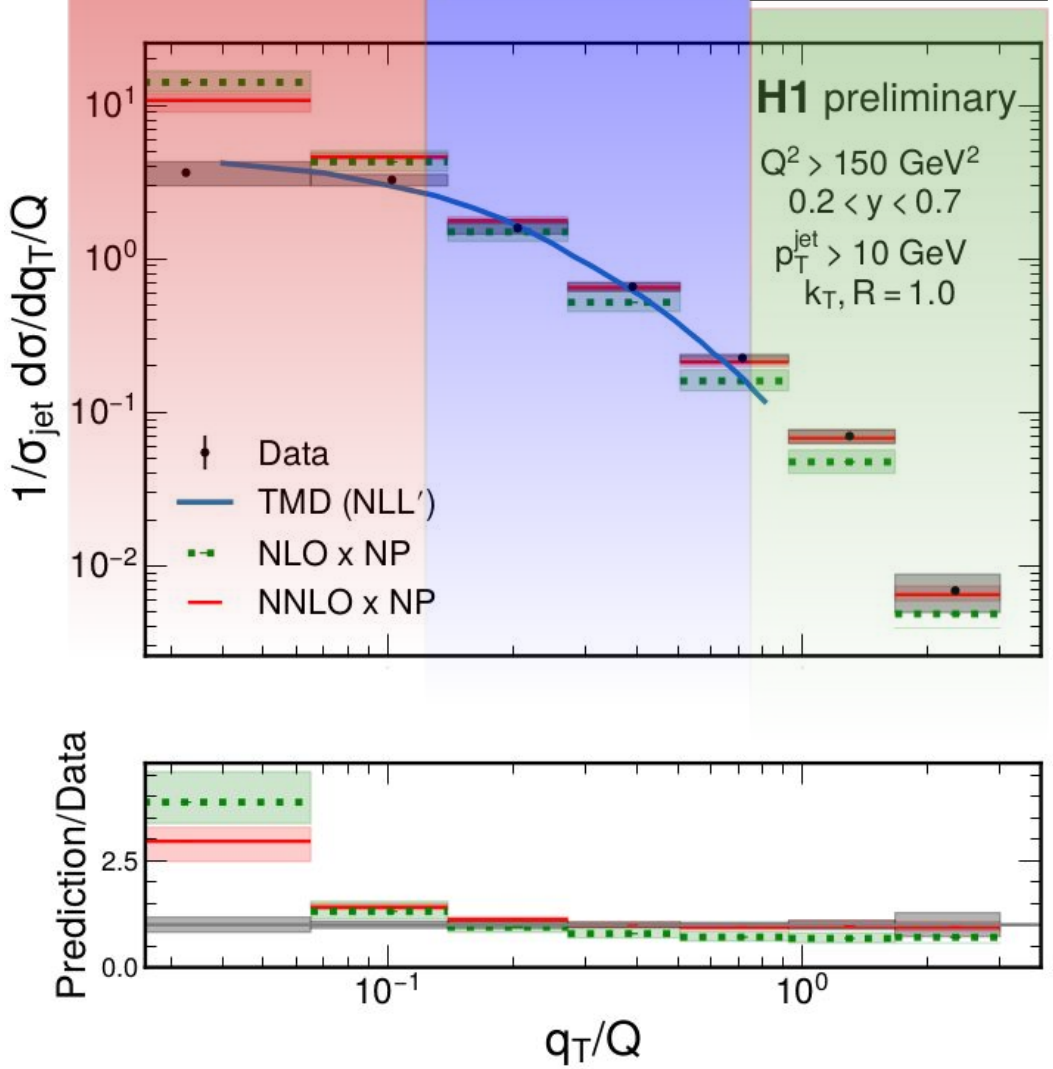
Calculations: Kang, Yuan, de Florian et al.

TMD calculation, without free parameters, describes data over wide kinematic range

$$\frac{d^5\sigma(\ell p \to \ell' J)}{dy_\ell d^2k_{\ell\perp} d^2q_\perp} = \sigma_0 \int d^2k_\perp d^2\lambda_\perp x f_q(x, k_\perp, \zeta_c, \mu_F) \times H_{\mathrm{TMD}}(Q, \mu_F) S_J(\lambda_\perp, \mu_F) \times \delta^{(2)}(q_\perp - k_\perp - \lambda_\perp).$$

- TMD PDFs and soft factors extracted from low Q2 DIS and DY data. Sun et al. arXiv:1406.3073
- Recently tested in Echeverria et al. JHEP 01 (2021) 126
- pQCD calculations from Borsa et al. PRL. 125, 082001 (2020)



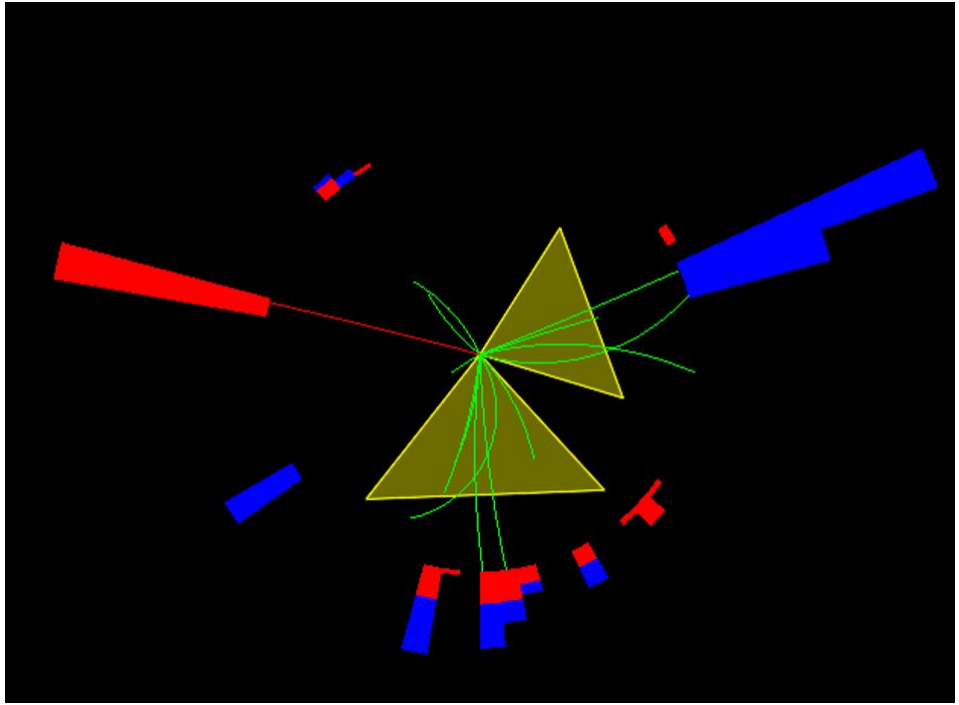


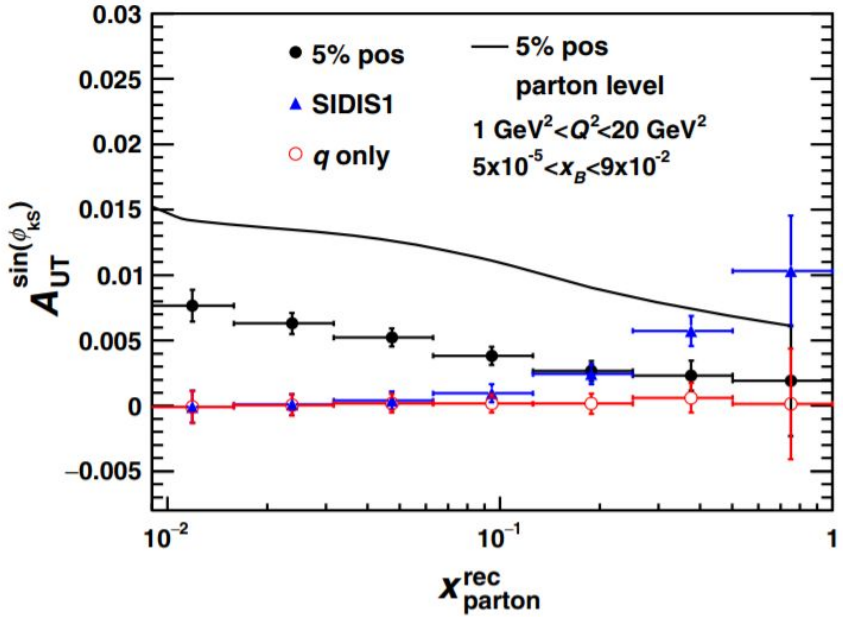
Textbook example of matching?

First time seen in DIS!

“Di-jet channel is the most promising way to constrain the magnitude of the Gluon Sivers function”

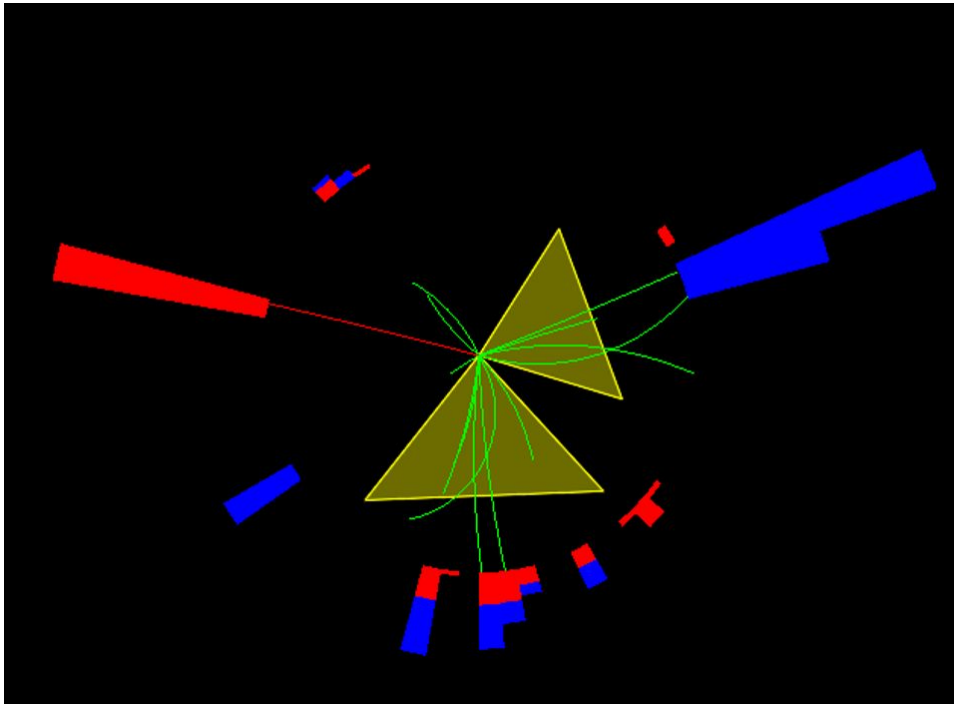
L. Zheng et al. Phys. Rev. D 98, 034011 (2018)

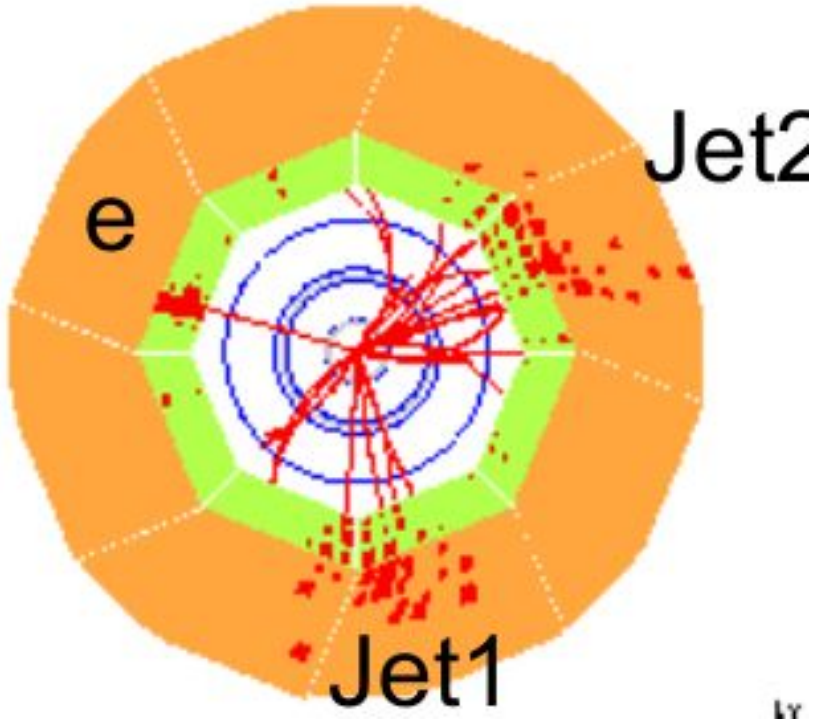




There is a ton of recent work on this topic...

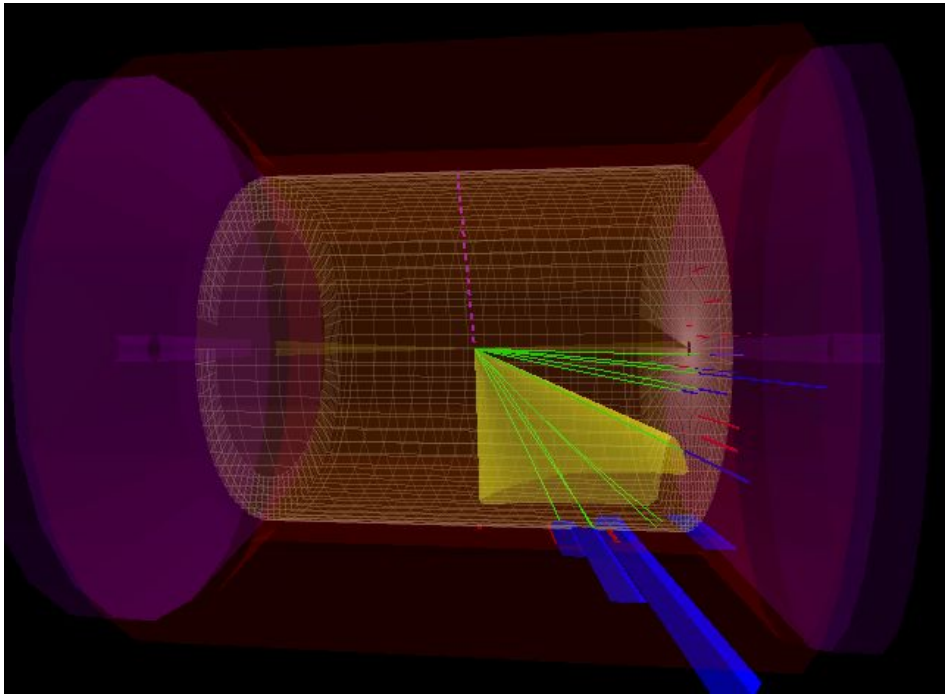
Gluon TMDs, low-x reach

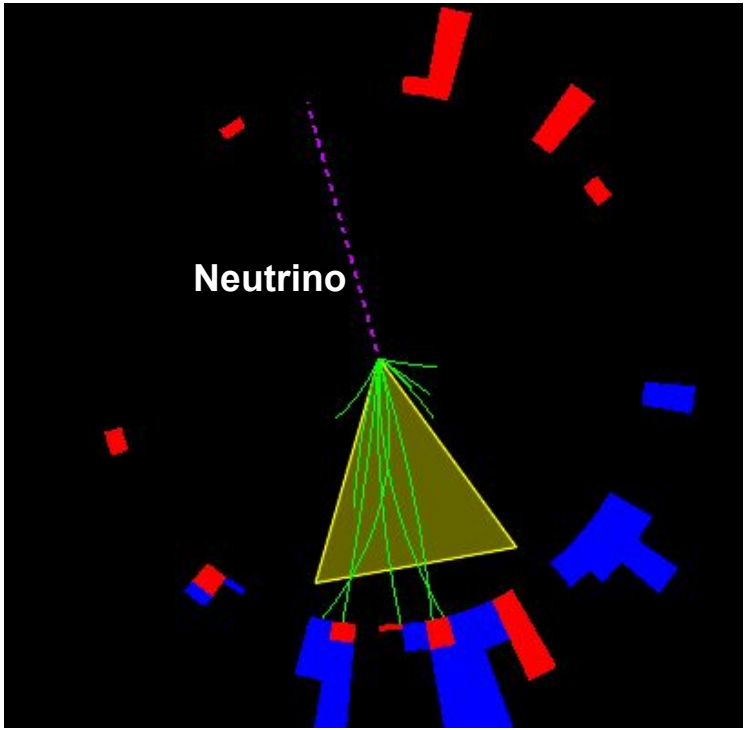




Stay tuned for dijet qT measurements with H1...

Charged-current DIS.
Neutrino-jet correlations for TMDs?

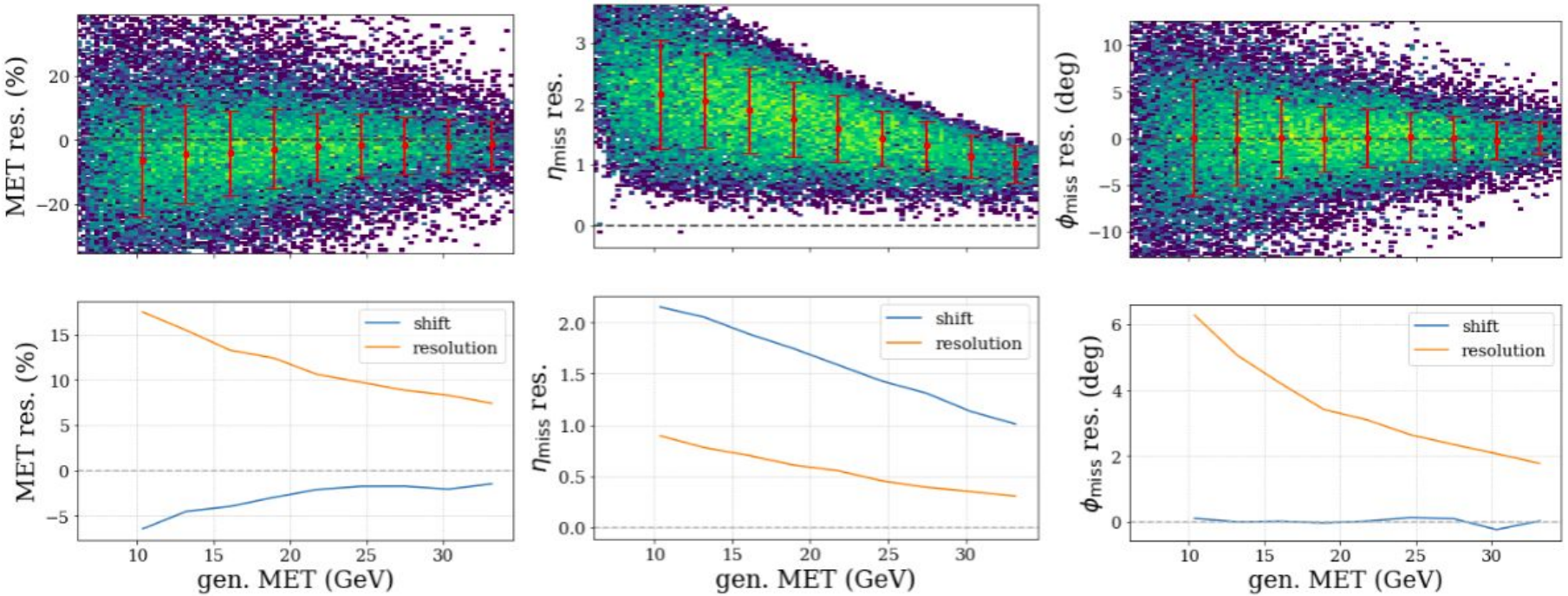


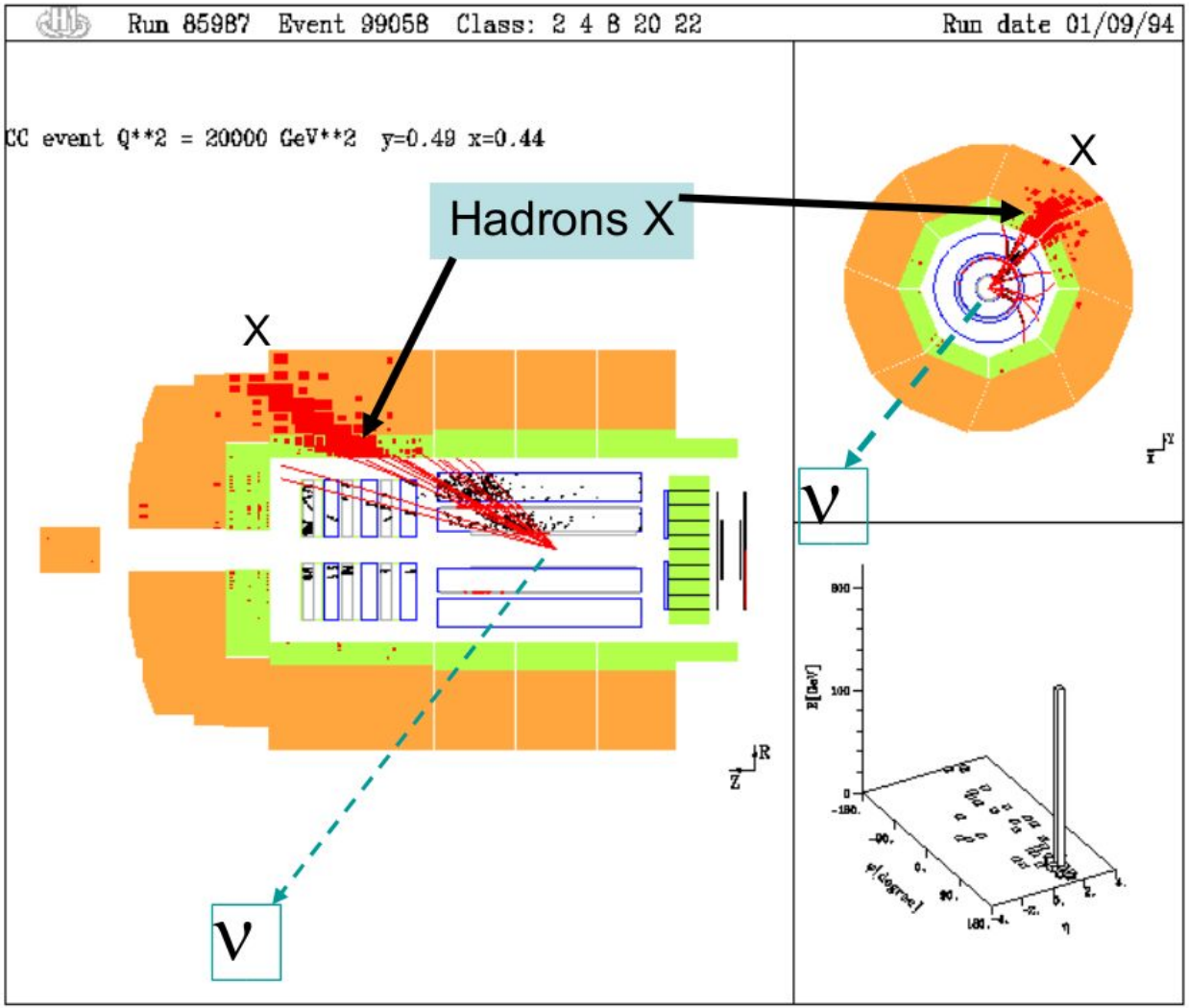


Slides presented by Sebouh Paul in APS April mtg

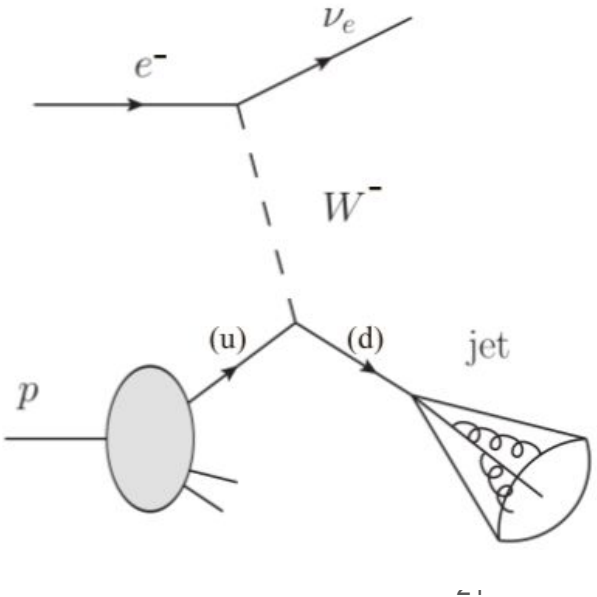
Missing energy recons. performance: MET, ϕ, η resolutions

- missing transverse energy (MET): neutrino four-momentum determined using conservation of momentum.

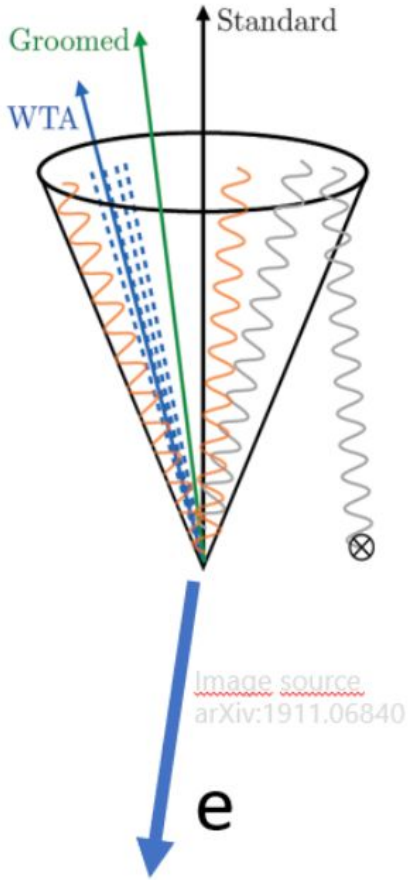


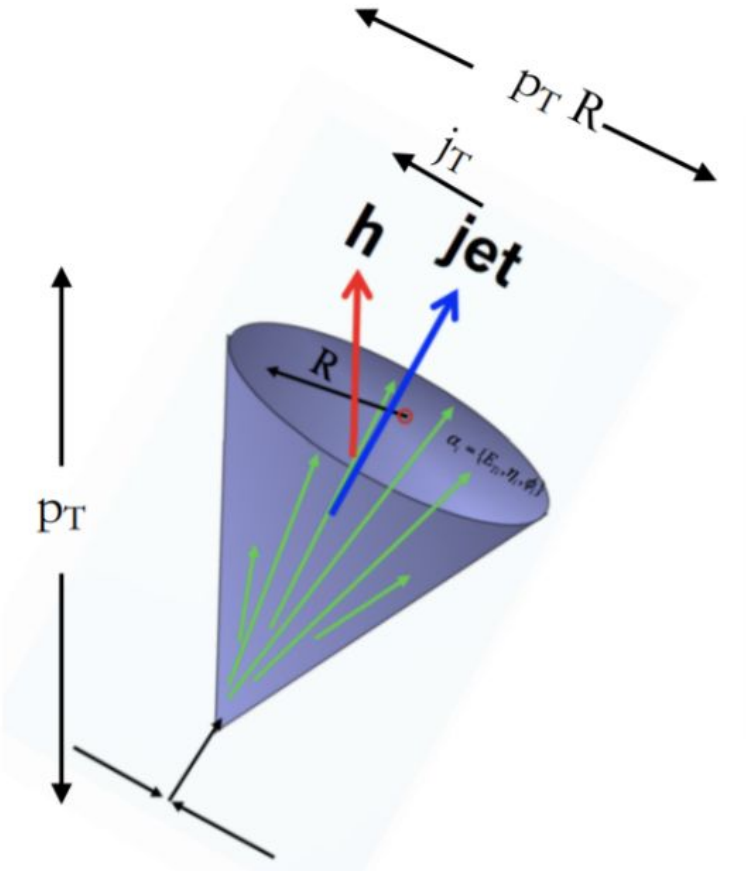


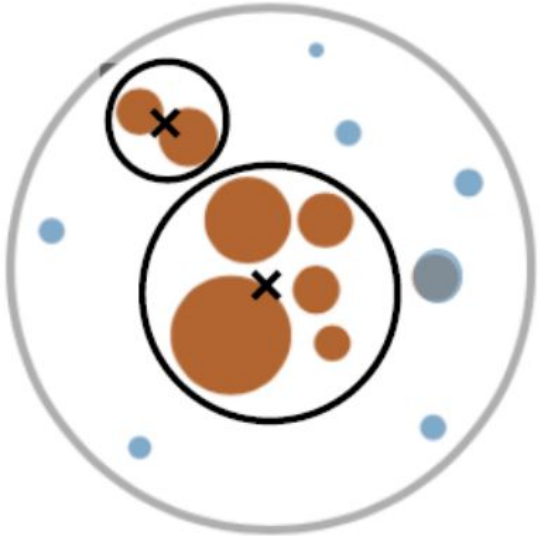
TMDs with neutrino-jet correlations at HERA?
Both electron and positron data available, so both u quark and d-quark

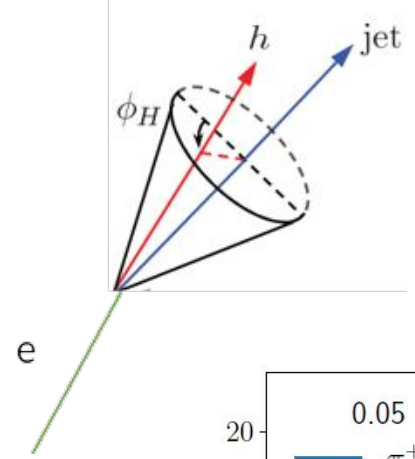


Jets have rich substructure, which encodes TMD effects









Hadron-in-jet Collins asymmetry at EIC

PRD 102, 074015 (2020)

$10 + 275$ GeV, 100 fb^{-1}, $0.1 < y < 0.85$, $j_T < 1.5$ GeV, $q_T/p_T^{jet} < 0.3$

$0.05 < x < 0.10$ | $0.15 < x < 0.20$ | $0.30 < x < 0.80$

π^+, π^-, projected precision

$A_{UT}^{\sin(\phi_S - \phi_h)}$ [%]

$< p_T^{jet} > = 11$ GeV, $< p^{jet} > = 20$ GeV, $< Q^2 > = 180$ GeV^2

$< p_T^{jet} > = 16$ GeV, $< p^{jet} > = 44$ GeV, $< Q^2 > = 439$ GeV^2

$< p_T^{jet} > = 25$ GeV, $< p^{jet} > = 92$ GeV, $< Q^2 > = 1007$ GeV^2

$z_h = |\vec{p}_{jet} \cdot \vec{p}_{hadron}| / |\vec{p}_{jet}|^2$

Jet substructure, the key to novel TMD studies

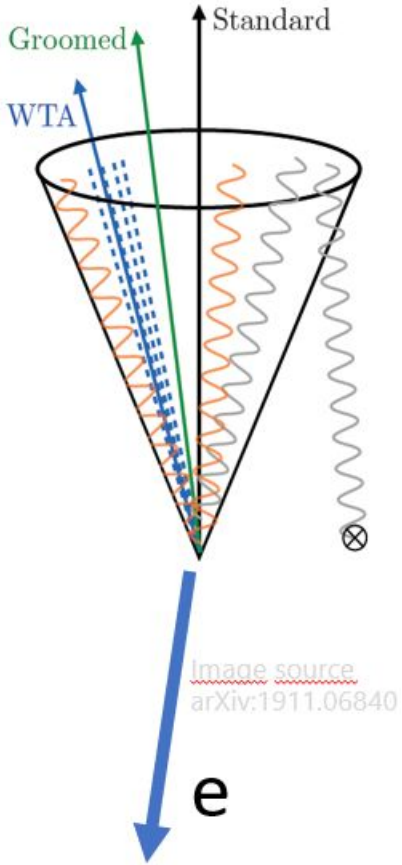


Image source
arXiv:1911.06840

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

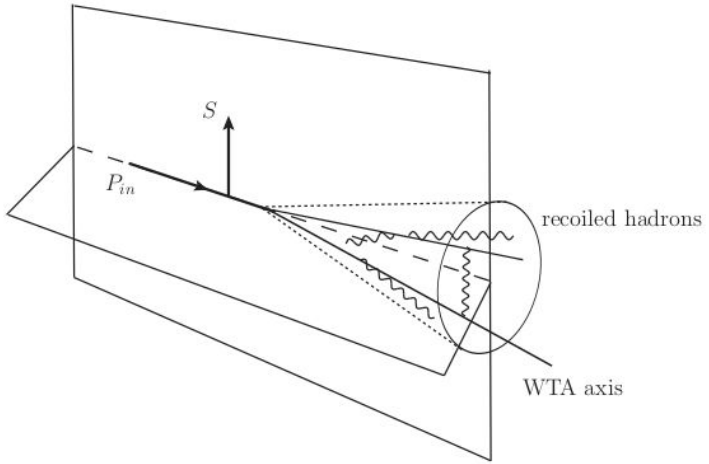


FIG. 1. Origin of the jet T-odd contributions. The WTA jet axis lies outside the plane by the spin S and P_{in}, to allow for the asymmetry due to the quantum correlation between parton's spin and its hadronization about the plane.

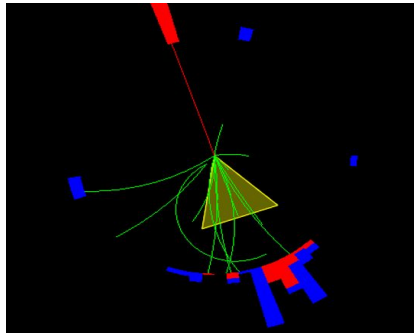
- **Grooming**

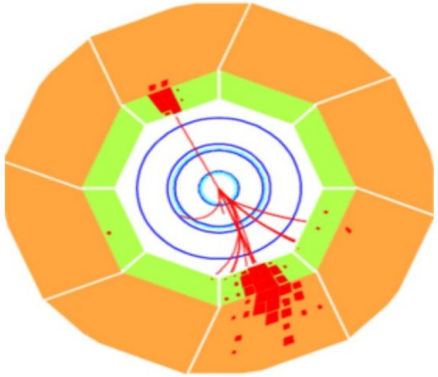
  Gutierrez et al. JHEP 08 (2019) 161 . Makris et al. JHEP 07 (2018) 167
- **Jet axes**

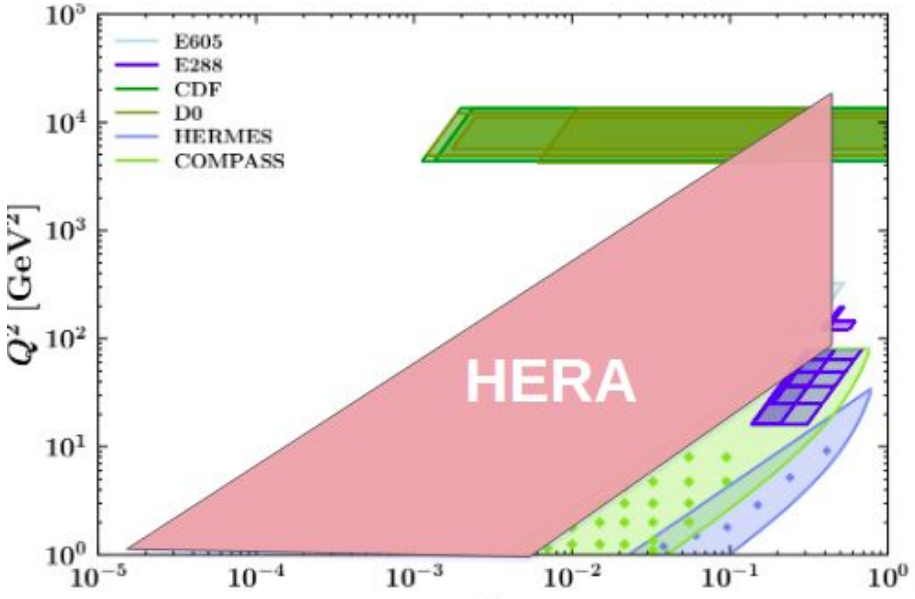
  Cal et al. JHEP 04 (2020) 211, Niell et al. JHEP04 (2017)020 Liu et al. arXiv: 2104.03328
- **Declustering?**

Summary

- Feasibility studies show large potential for future lepton-jet Sivers and hadron-in-jet Collins measurements at the EIC.
- A new EIC pathfinder program with HERA data will allow us to test feasibility studies and TMD framework.
- Lepton-jet @ HERA agrees well with TMD calculation, reveals large overlap with fixed-order calculations. Constraints TMD evolution, and “matching”.
- The future of QCD evolution studies is bright. I look forward to see you in person for the next workshop!

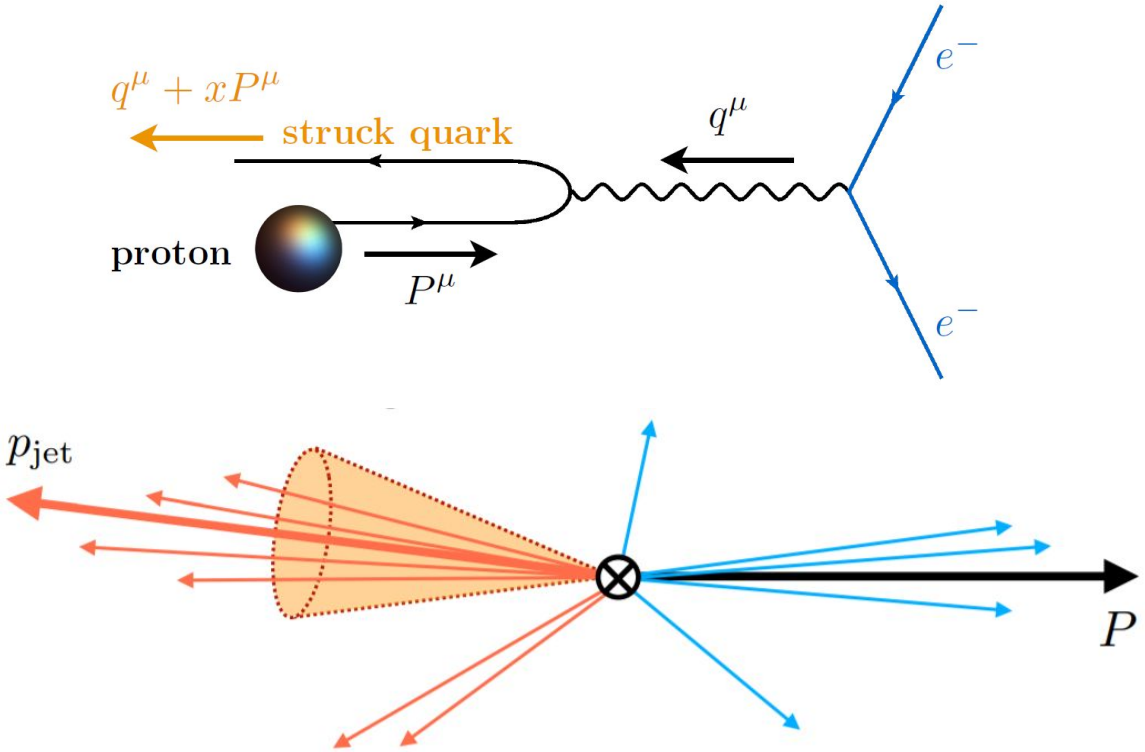


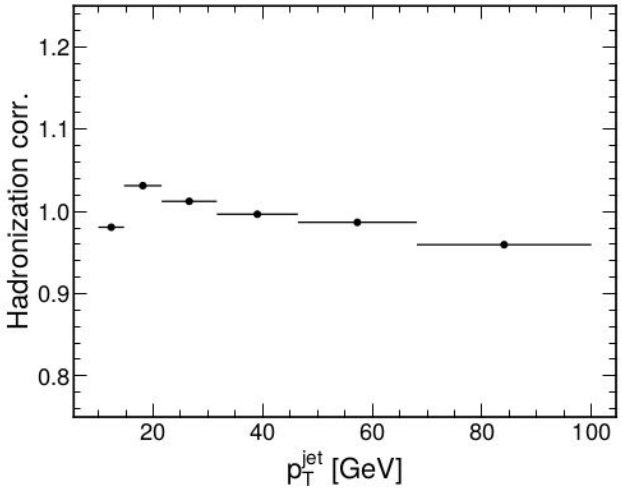


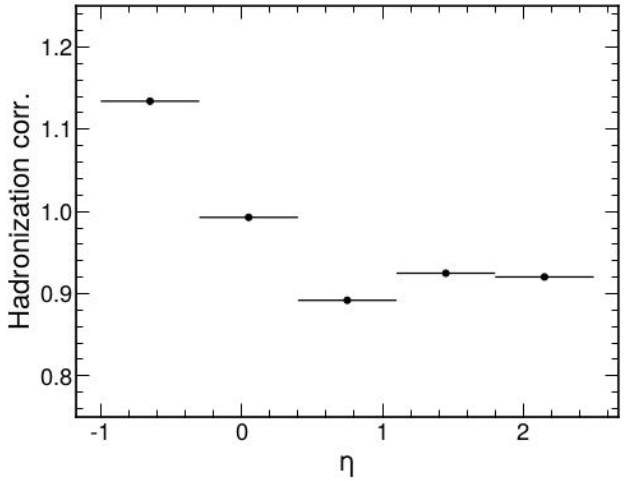


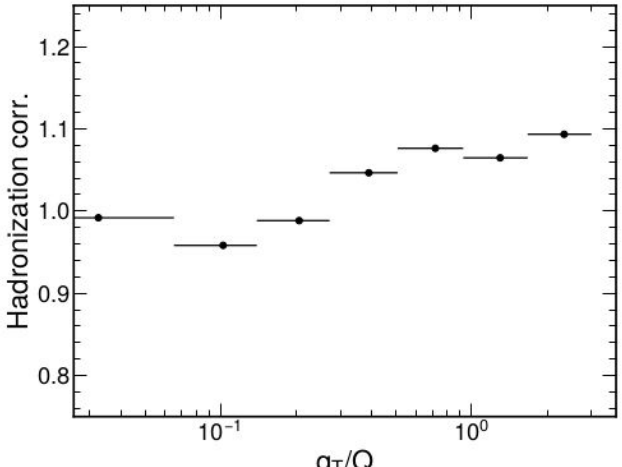
Backup

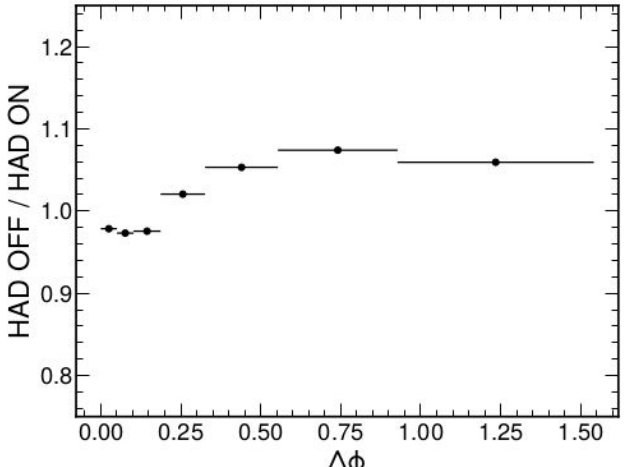
These studies also possible in Breit frame (in complete analogy to SIDIS), but requires dedicated jet algorithms, like Centauro



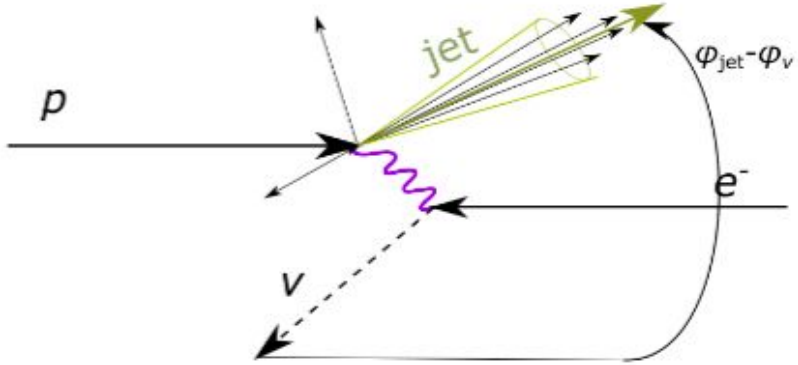

Hadronization corr.
1.2
1.1
1.0
0.9
0.8
20
40
60
80
100
p_T^{jet} [GeV]


Hadronization corr.
1.2
1.1
1.0
0.9
0.8
-1
0
1
2
η

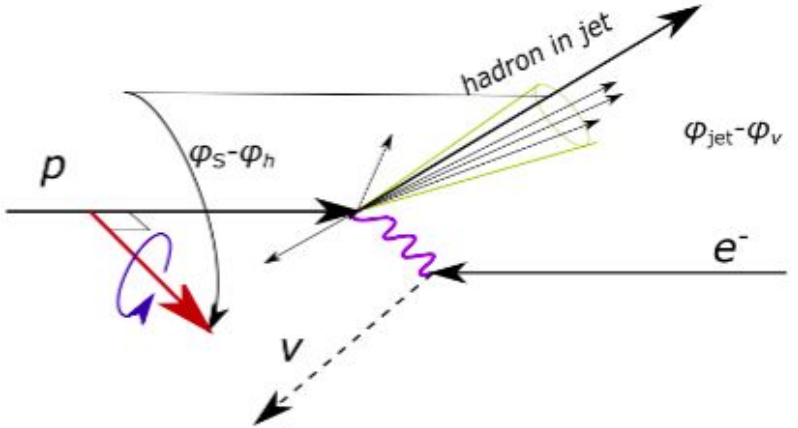

Hadronization corr.
1.2
1.1
1.0
0.9
0.8
10^{-1}
10^{0}
q_T/Q


HAD OFF / HAD ON
1.2
1.1
1.0
0.9
0.8
0.00
0.25
0.50
0.75
1.00
1.25
1.50
Δφ

Might be feasible...



Neutrino-jet momentum imbalance

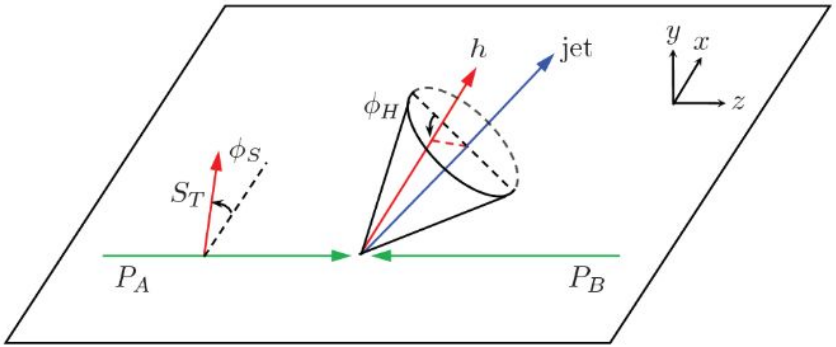


Neutrino-tagged hadron-in-jet

Transversity with jets

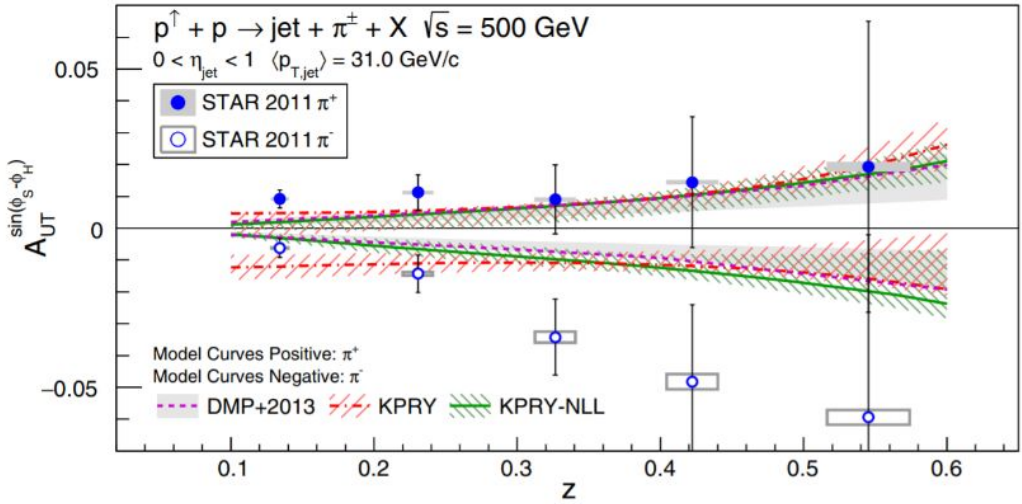
distribution of transversely polarized quarks inside a transversely polarized nucleon

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

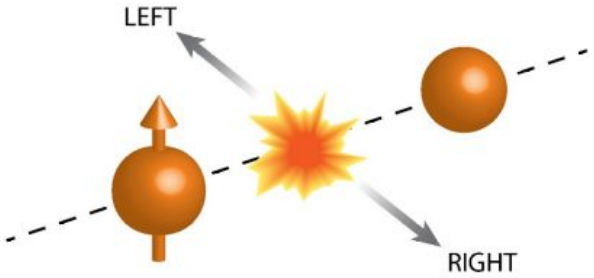


Phys. Lett. B 774, 635 (2017), Kang et al.
Phys.Rev.D77:074019 (2008) Yuan.

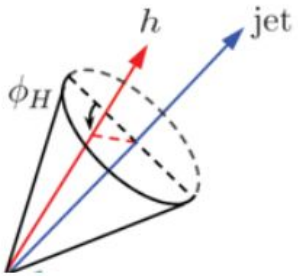
Measured at the RHIC proton-collider
STAR Collaboration, Phys. Rev. D 97, 032004 (2018)

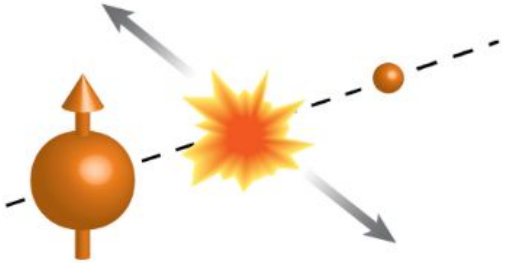


Complementarity

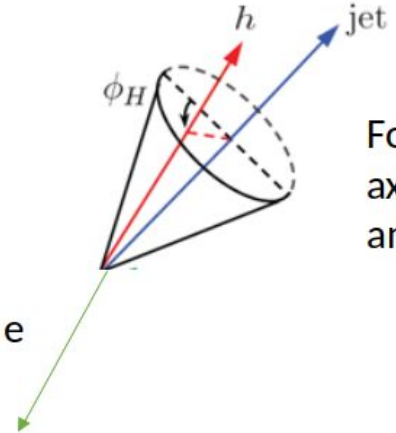


pp at RHIC





ep at EIC



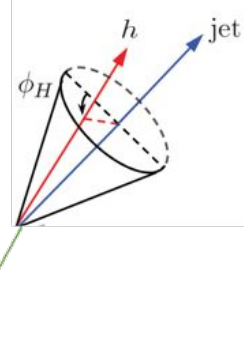
For DIS we will have 2 axes (virtual photon and jet).

Extended to DIS:

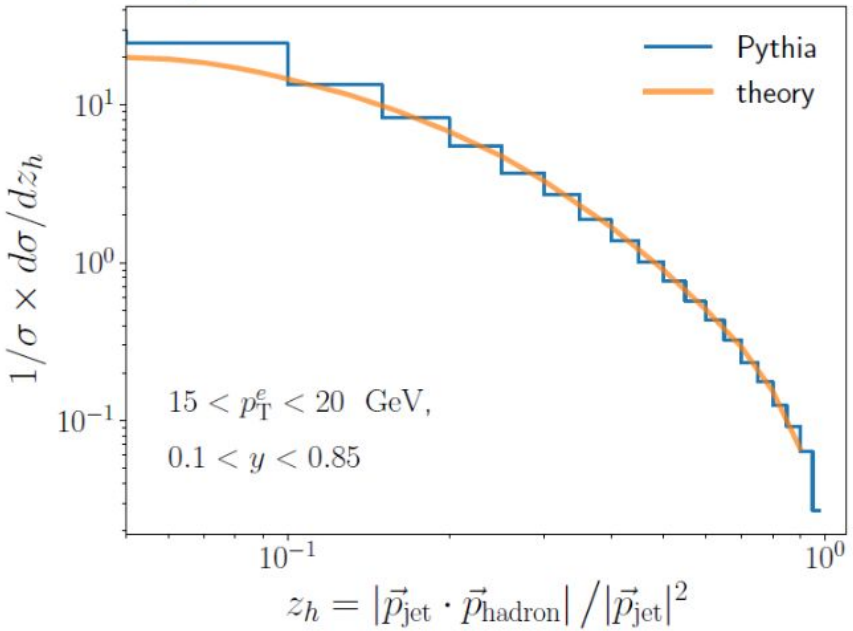
The unpolarized structure function F_{UU}^h for hadron in-jet production is given by

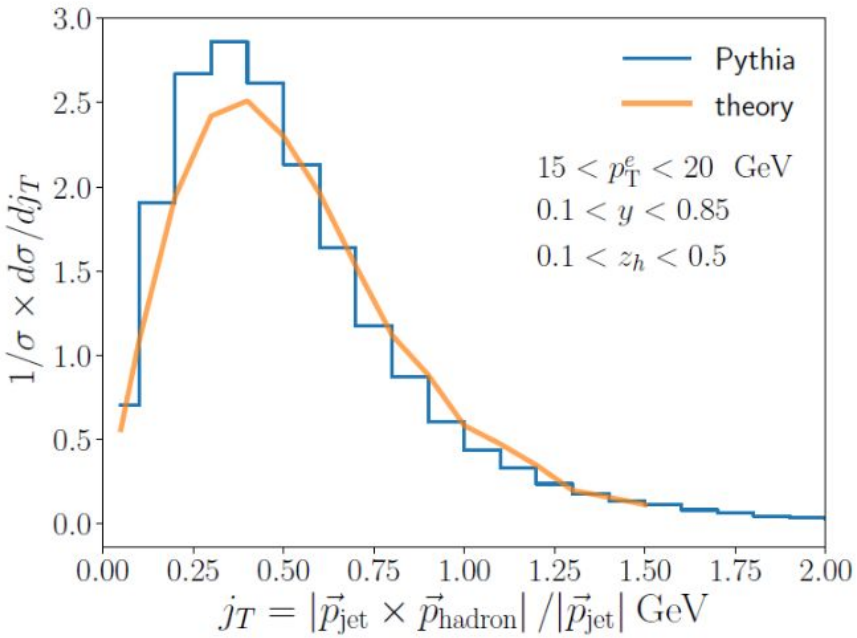
$$F_{UU}^h = \sigma_0 \, H_q(Q,\mu) \sum_q e_q^2 \, \mathcal{G}_q^h(z_h, \vec{j}_T, p_T^{\rm jet} R, \mu)$$

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



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





Motivation

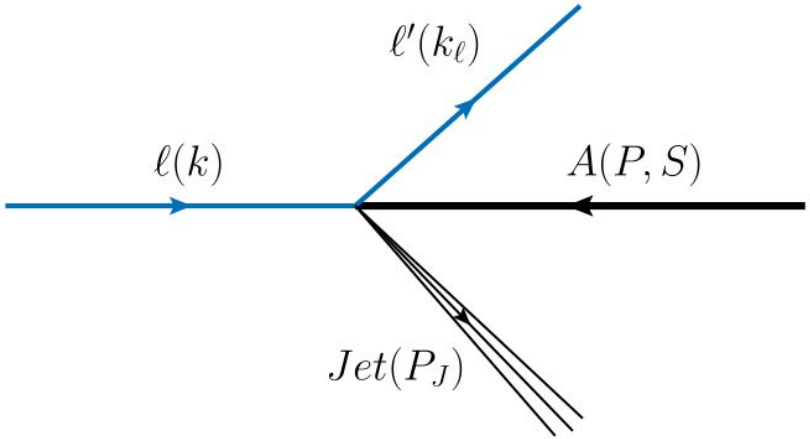
Lepton-jet imbalance $q_T = |\vec{k}_{l\perp} + \vec{p}^{\,j}_{\perp}|$

In Born-level configuration

Probes quark TMD PDFs

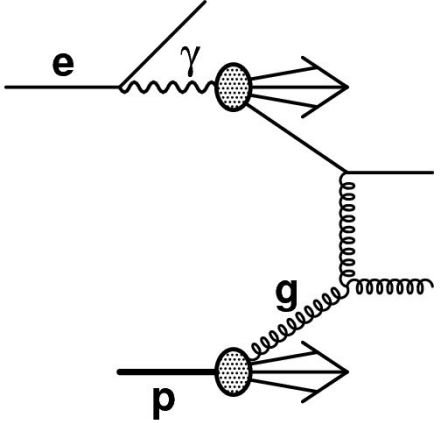
Liu et al. PRL. 122, 192003 (2019)

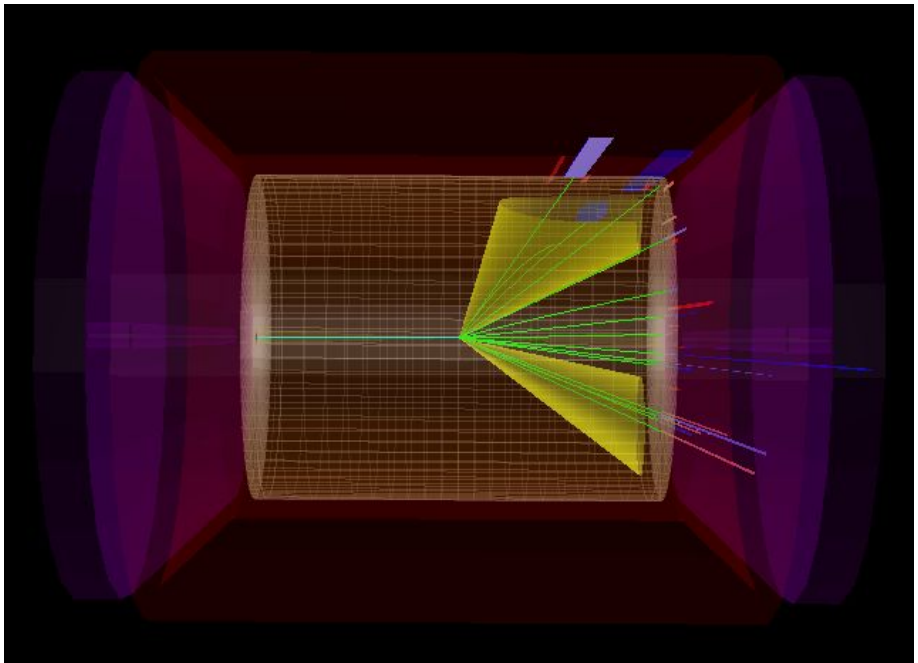
Gutierrez et al. PRL. 121, 162001 (2019)

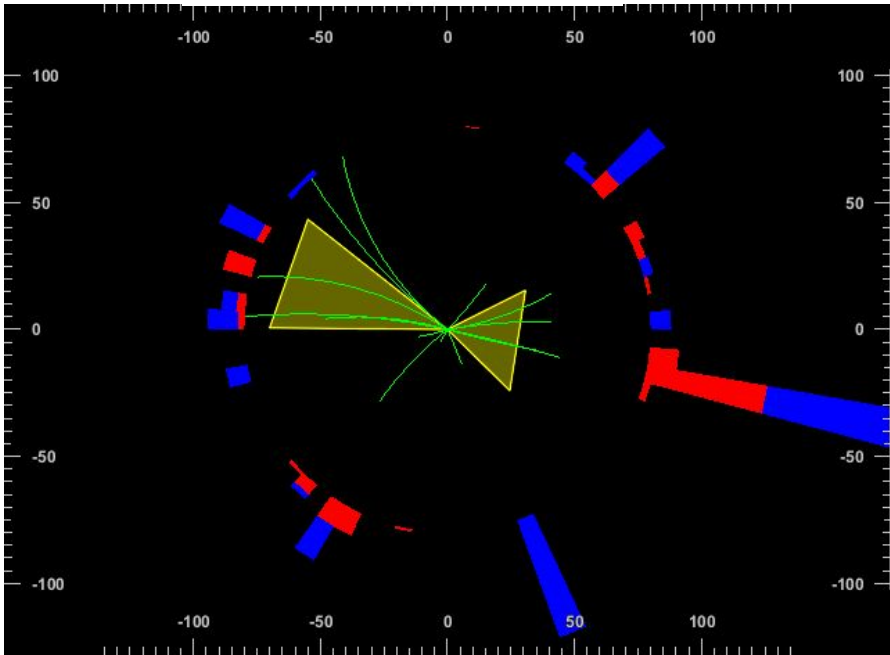


$$\frac{d^5\sigma(\ell p \to \ell' J)}{dy_\ell d^2k_{\ell\perp} d^2q_\perp} = \sigma_0 \int d^2k_\perp d^2\lambda_\perp x f_q(x, k_\perp, \zeta_c, \mu_F)$$
$$\times H_{\mathrm{TMD}}(Q, \mu_F) S_J(\lambda_\perp, \mu_F)$$
$$\times \delta^{(2)}(q_\perp - k_\perp - \lambda_\perp).$$

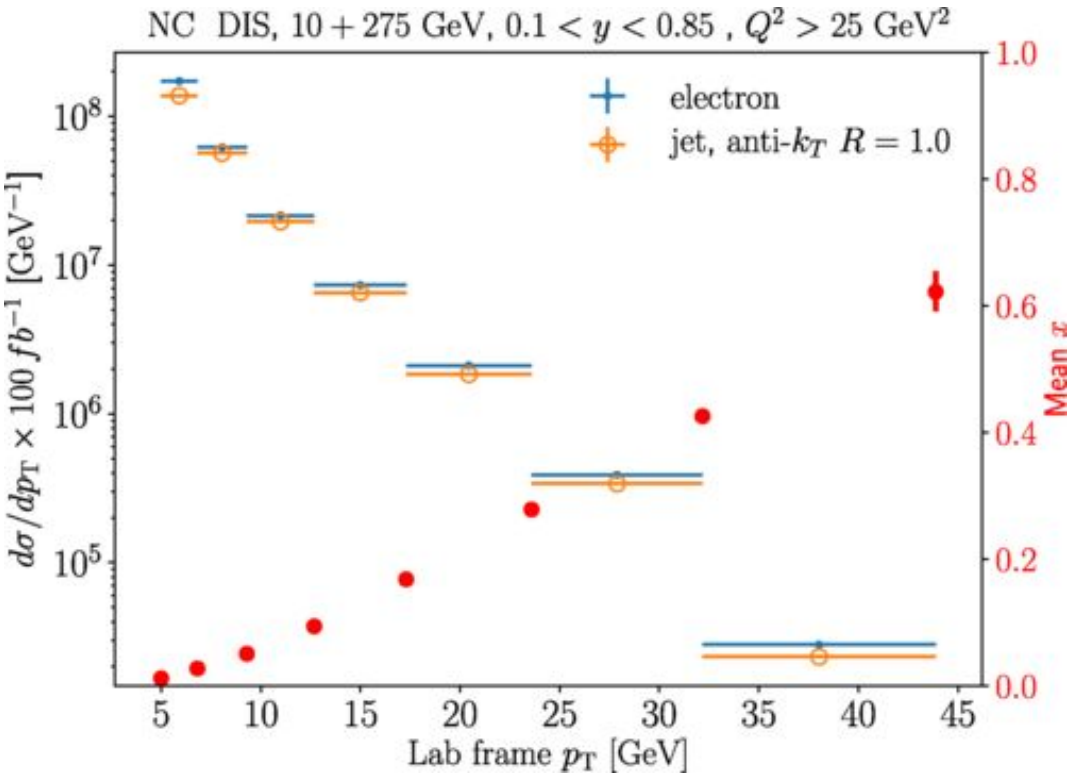
Dijets in photoproduction can probe the photon TMD structure





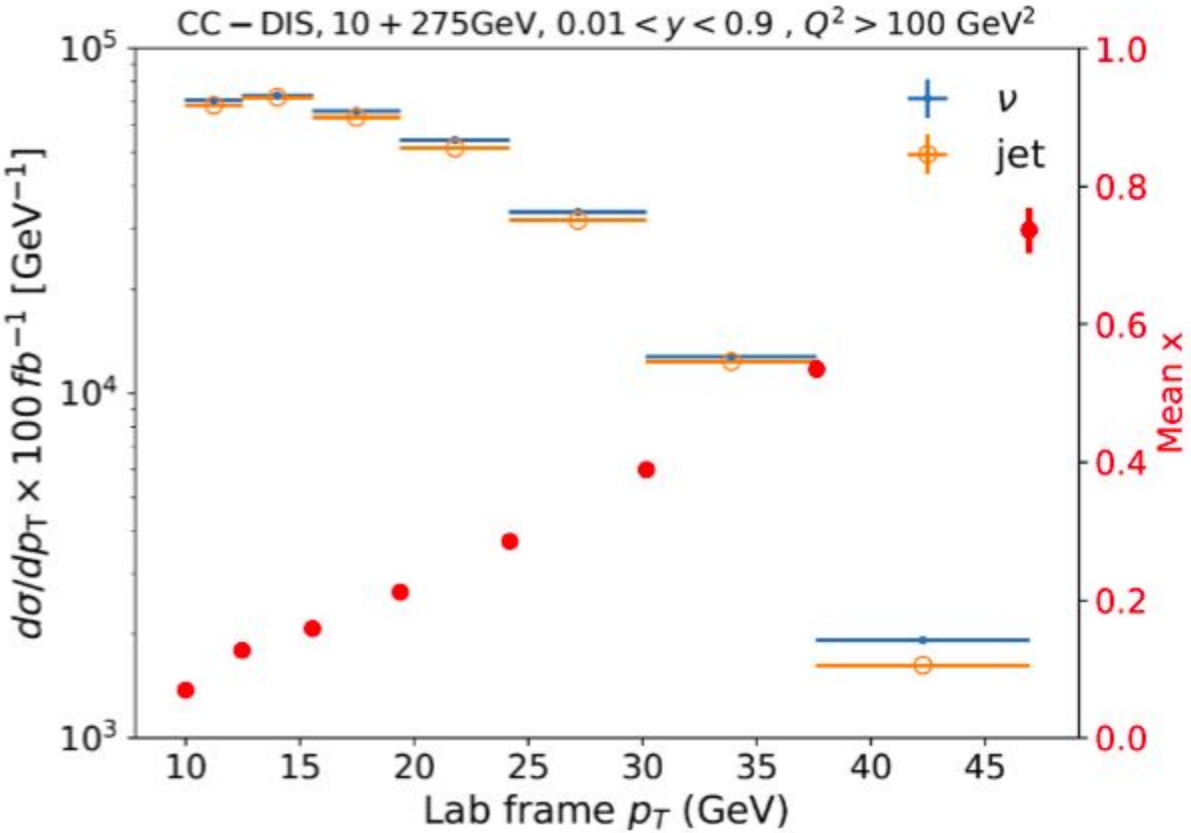


Expected rate, x coverage (@100 GeV)

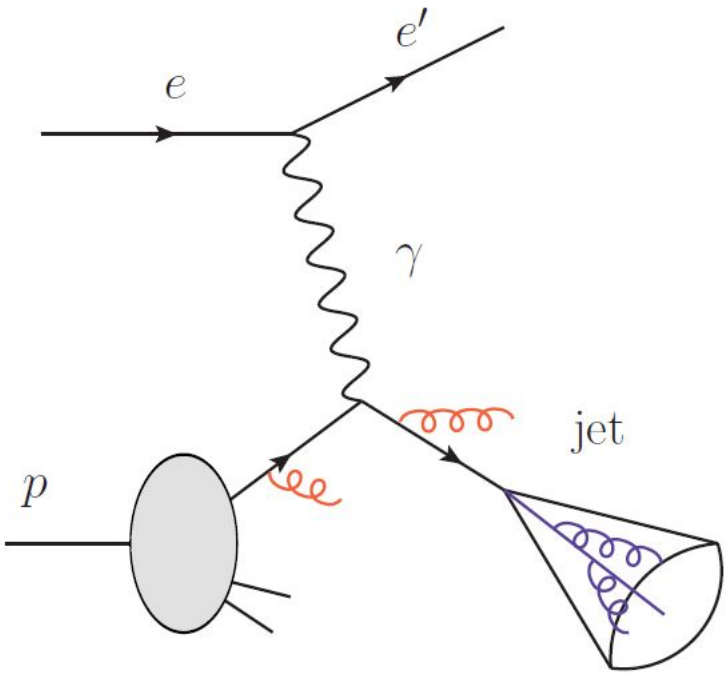


Unique opportunity to measure high-x at high Q2 (complementing fixed-target experiments)

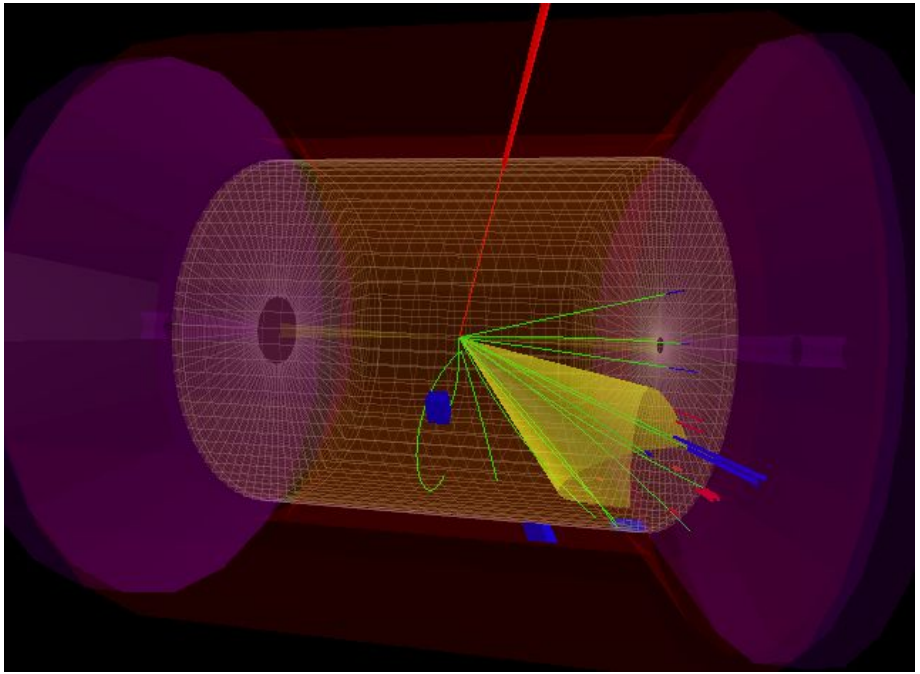
-> Nail down TMD evolution


CC − DIS, 10 + 275GeV, 0.01 < y < 0.9 , Q² > 100 GeV²
ν
jet
dσ/dp_T × 100 fb⁻¹ [GeV⁻¹]
Mean x
Lab frame p_T (GeV)
10⁵
10⁴
10³
10
15
20
25
30
35
40
45
1.0
0.8
0.6
0.4
0.2
0.0

Jets in neutral-current deep-inelastic scattering

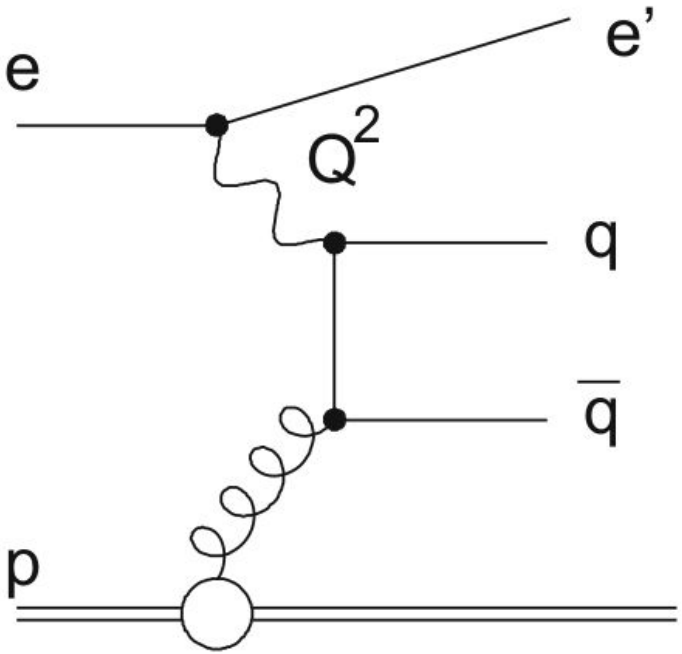


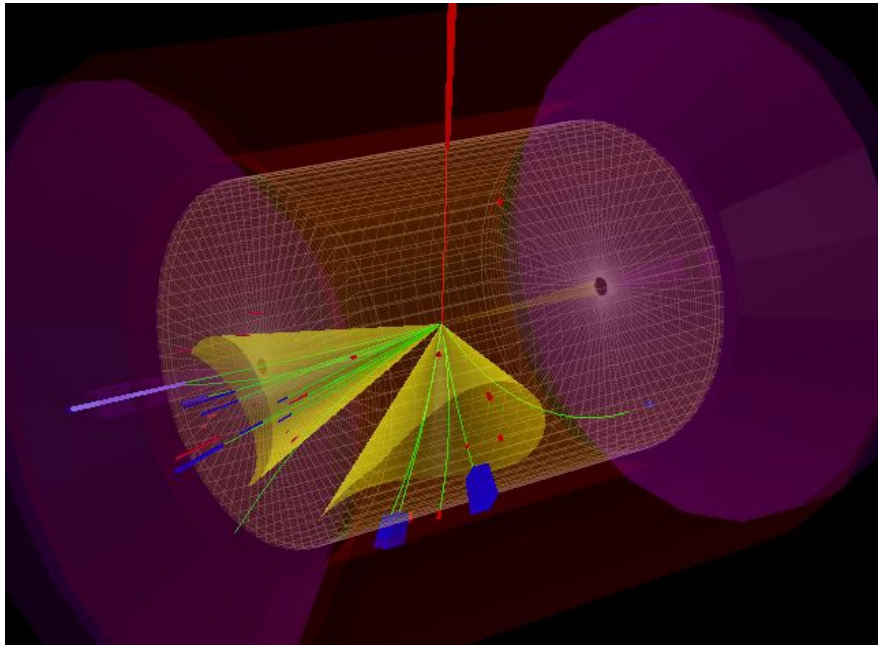
Theory



Experiment (simulated)

Dijet events probe the gluon TMD distributions





Qualitatively the same results for azimuthal angle correlation