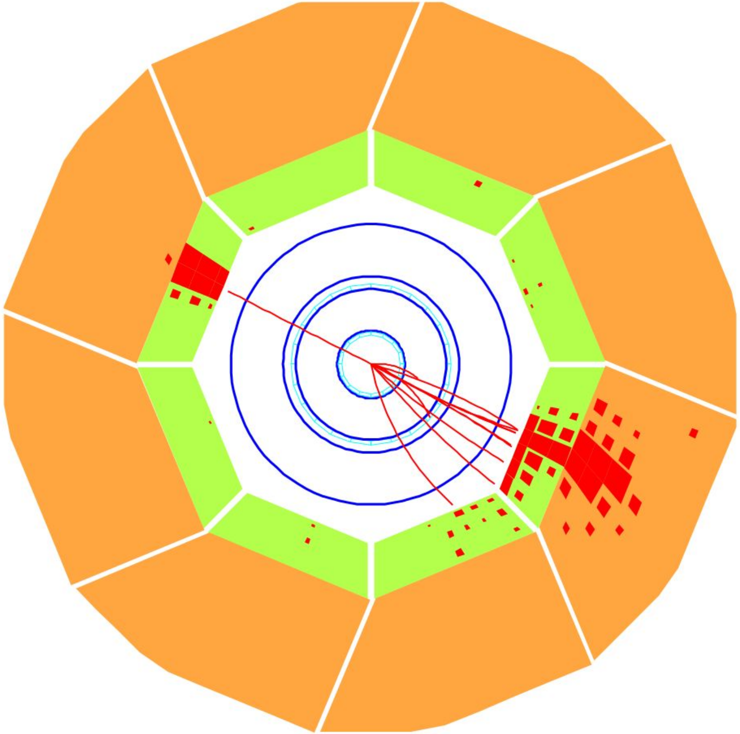
Machine learning-assisted measurement of multi-differential lepton-jet correlations in deep-inelastic scattering with the H1 detector

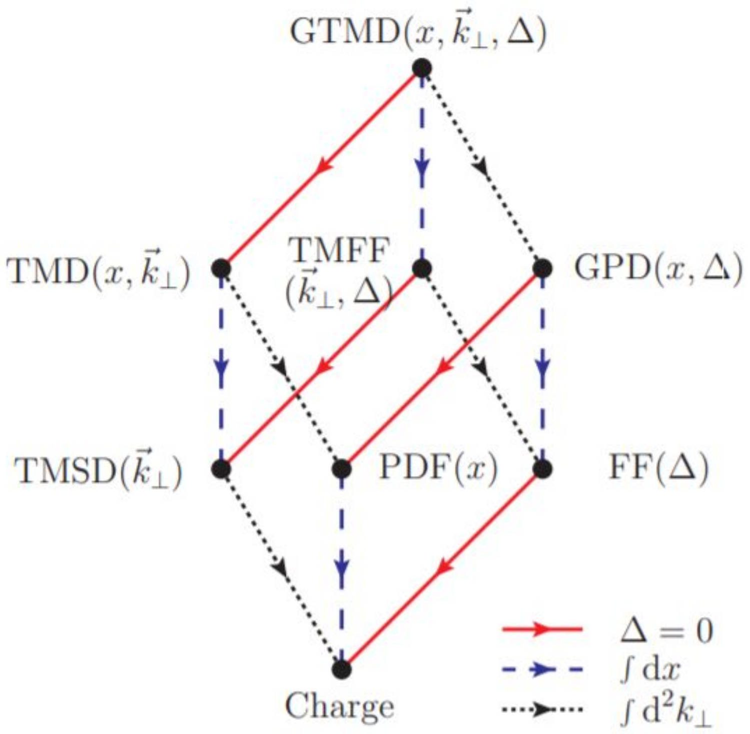
Miguel Arratia

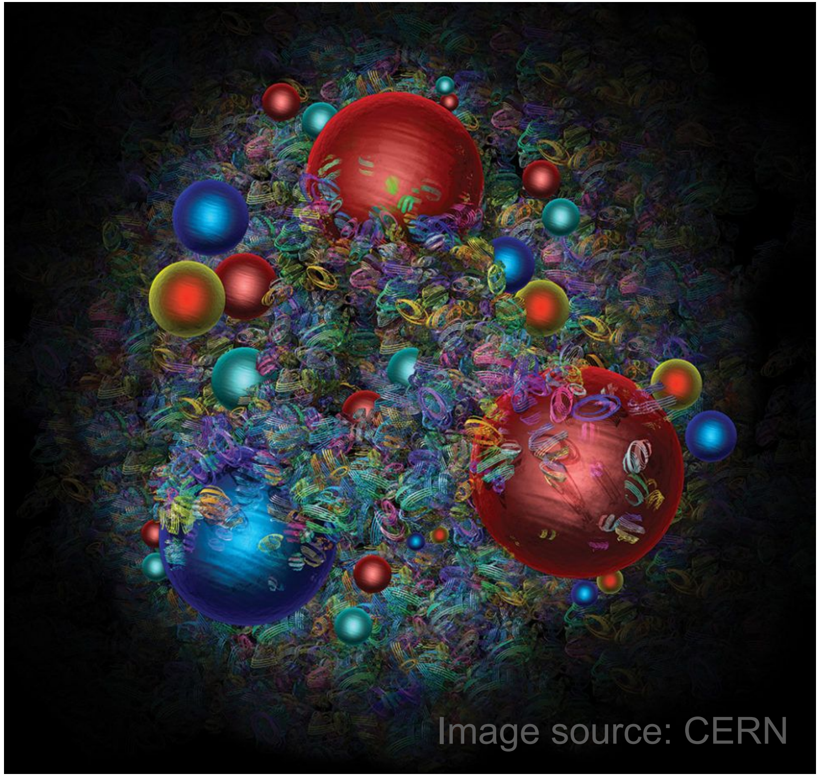
UC RIVERSIDE



14th Conference on the Intersection of Particle & Nuclear Physics, Lake Buena Vista, FL, Sep 3 2022

Towards a quantum tomography of the proton (and nuclei)

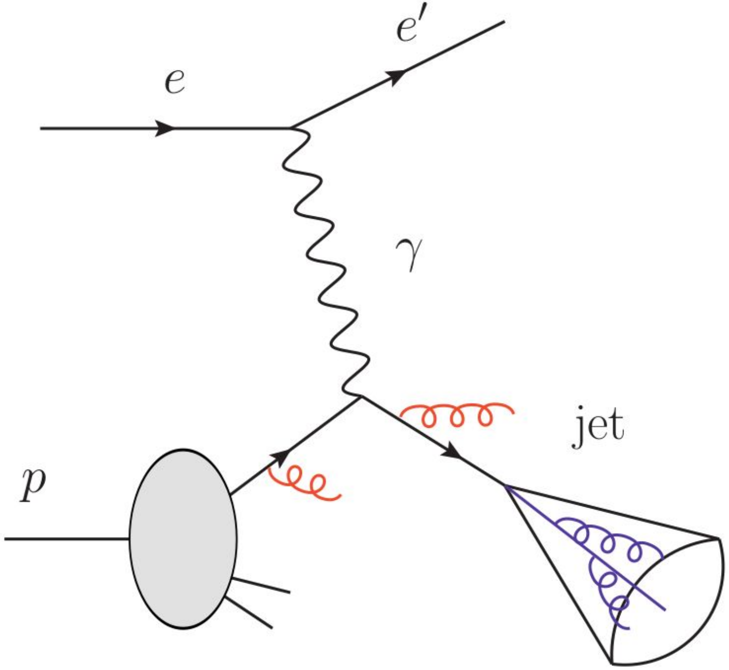


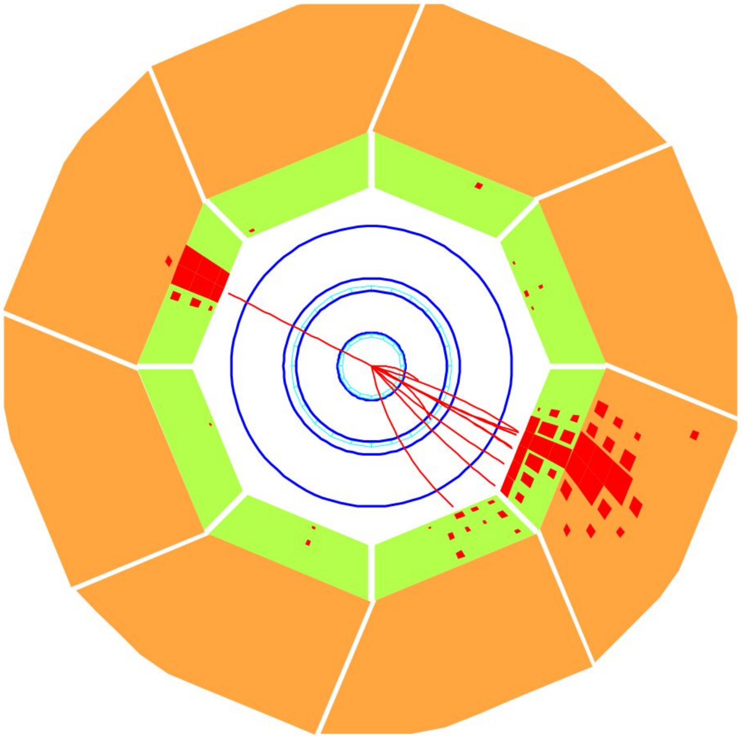


A new channel to probe for quark TMDs and evolution

Liu et al. PRL. 122, 192003 (2019)
Gutierrez et al. PRL. 121, 162001 (2018)

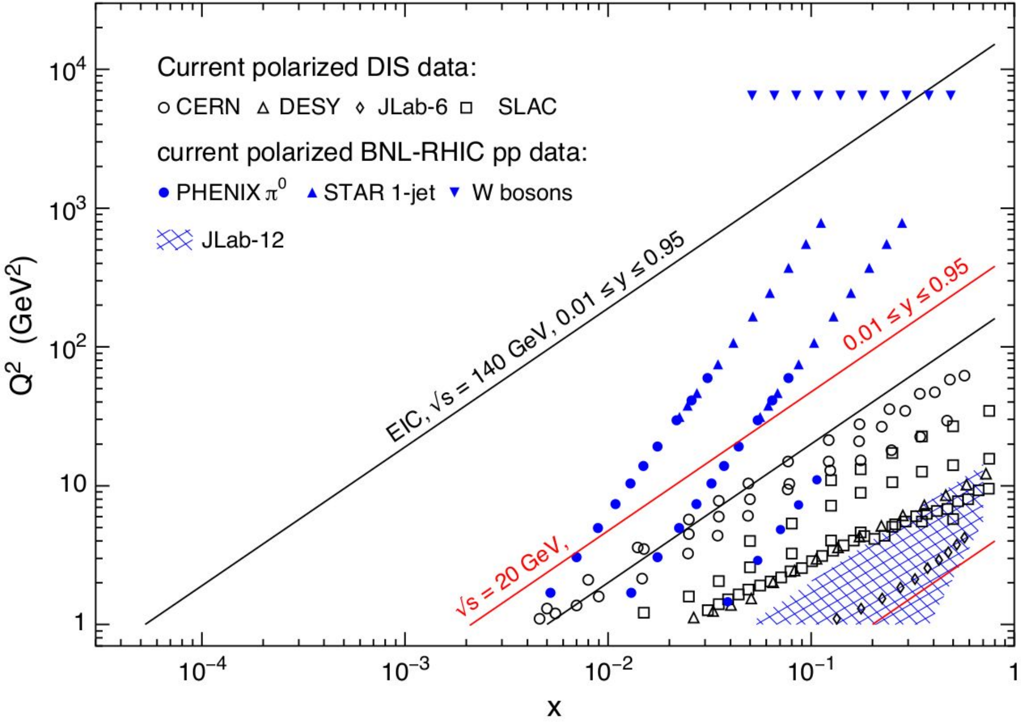
$$q_T = |\vec{k}_{l\perp} + \vec{p}^{\,j}_{\perp}|$$





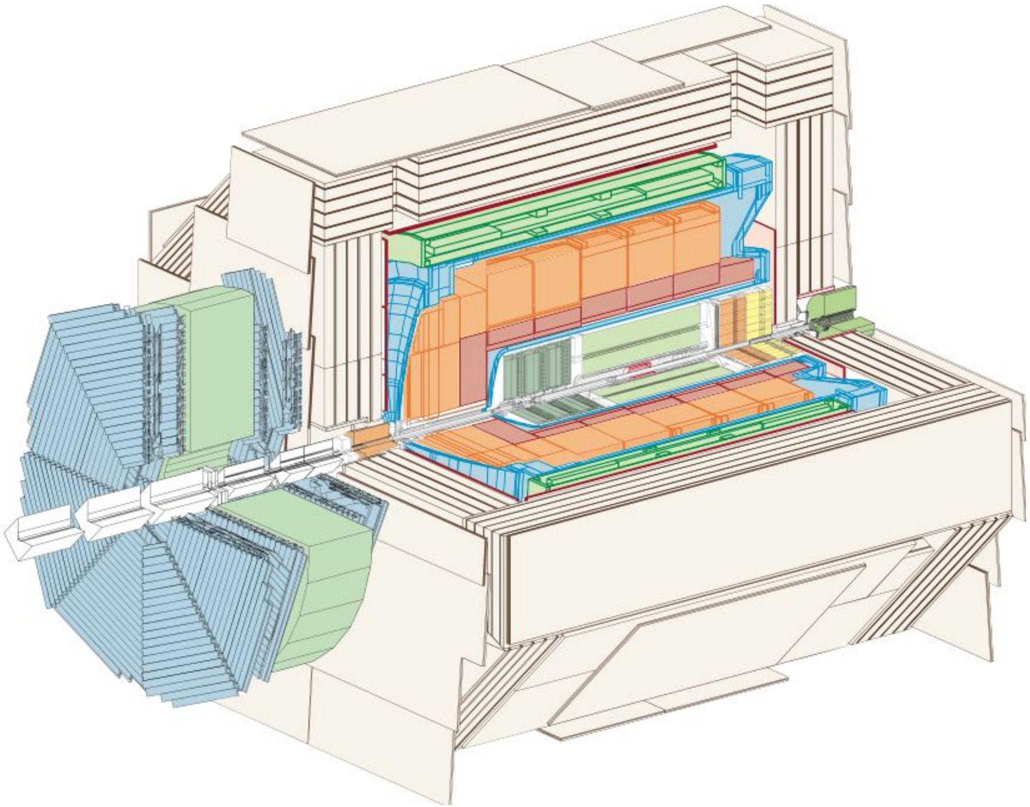
Constraining TMD evolution

H1 can bridge low Q2 DIS from fixed-target exp. and high Q2 Drell-Yan at colliders.
Fixing open issues of TMD factorization & universality



Unpolarized TMD DIS measurements
Important baseline for EIC

The H1 experiment at HERA

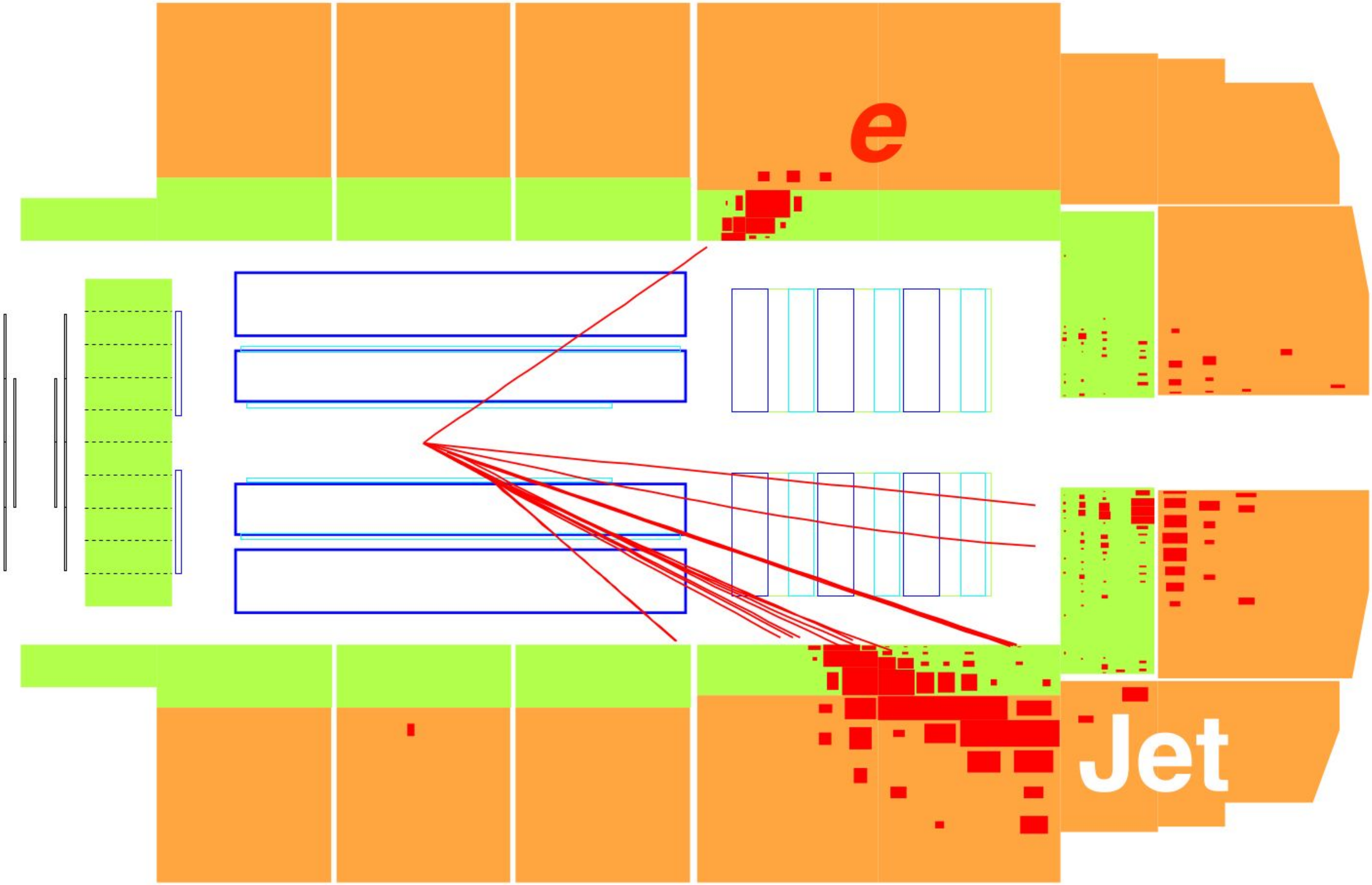


- Tracking system
(silicon tracker, jet chambers, proportional chambers)
- LAr calorimeter (em/had)
- Scintillating fiber calorimeter

Both combined using an energy flow algorithm

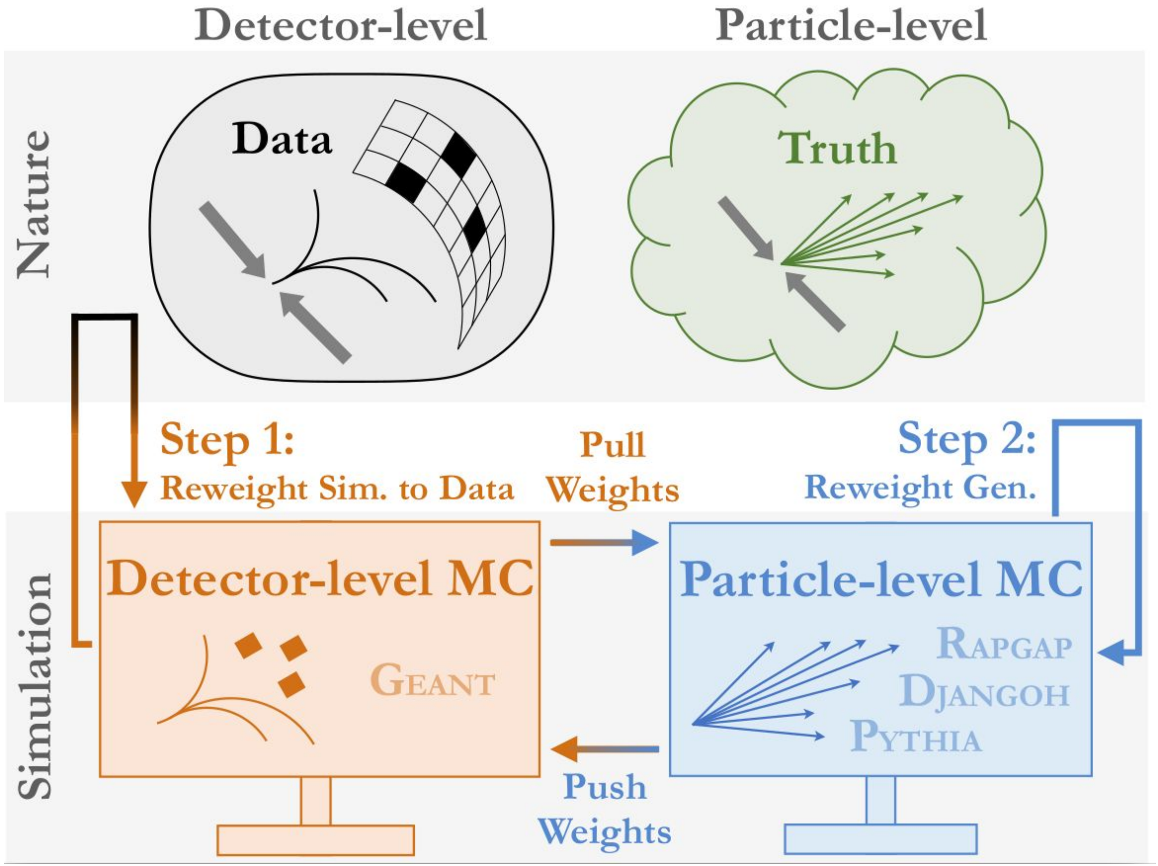
1% Jet energy scale

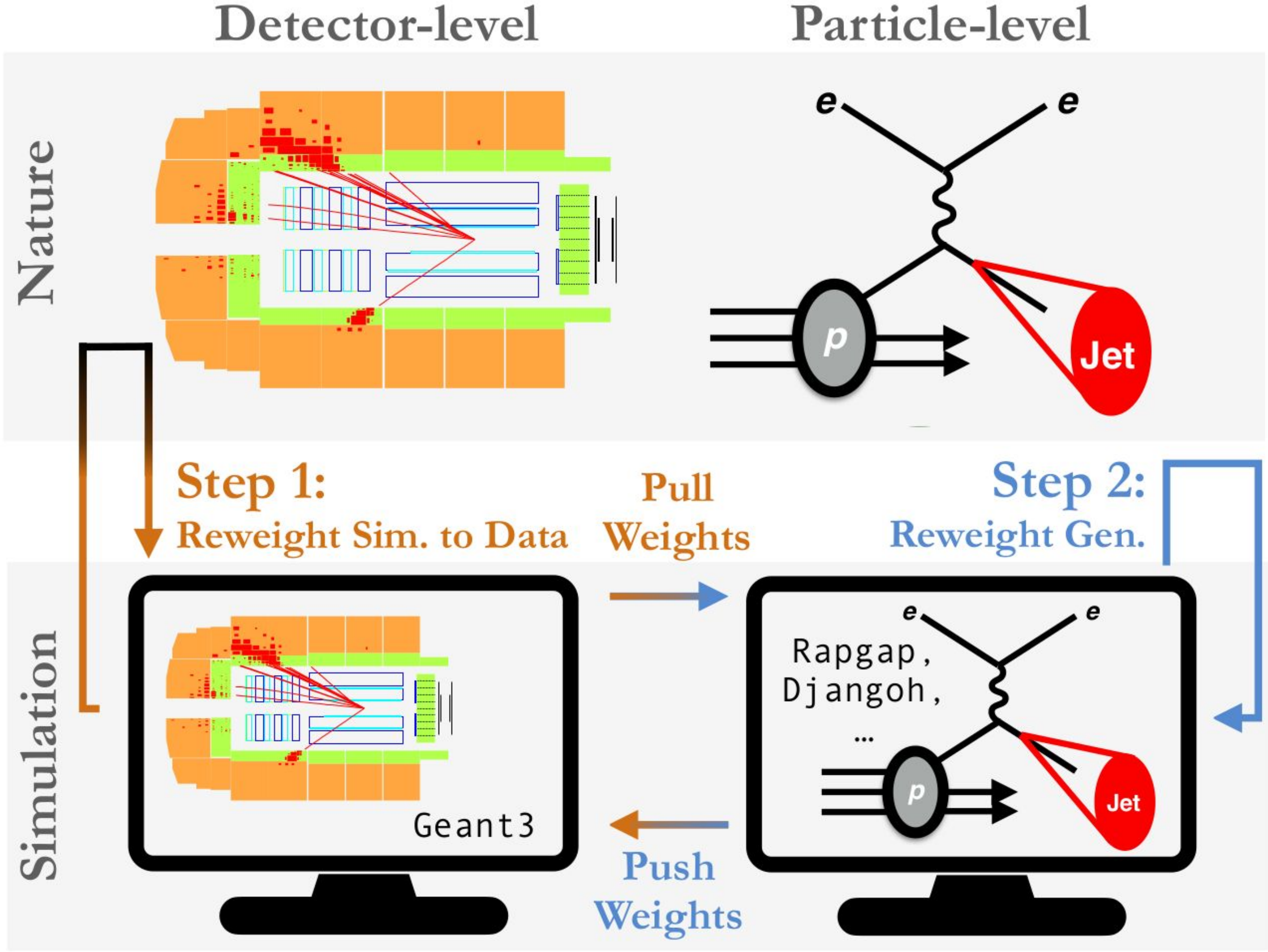
0.5-1% lepton energy scale


e
Jet

Unfolding with Omnifold (via machine-learning).

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




Detector-level
Particle-level
Nature
e
e
p
Jet
Step 1:
Reweight Sim. to Data
Pull
Weights
Step 2:
Reweight Gen.
Simulation
Geant3
Rapgap,
Djangoh,
...
e
e
p
Jet
Push
Weights


PHYSICAL REVIEW LETTERS

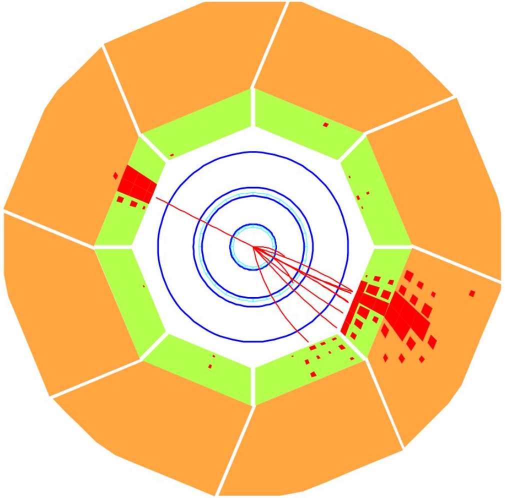
Highlights Recent Accepted Collections Authors Referees Search Press About Staff

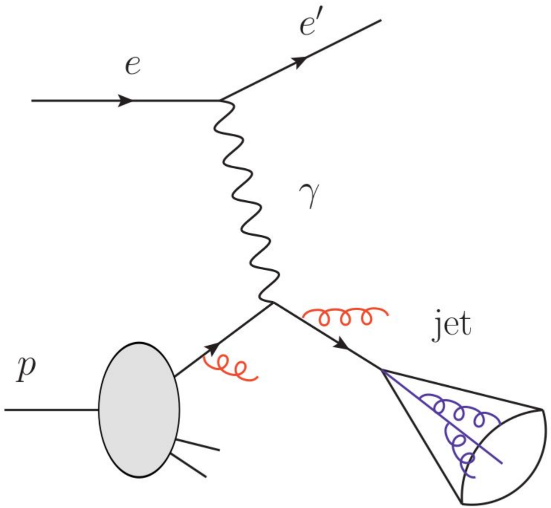
Open Access

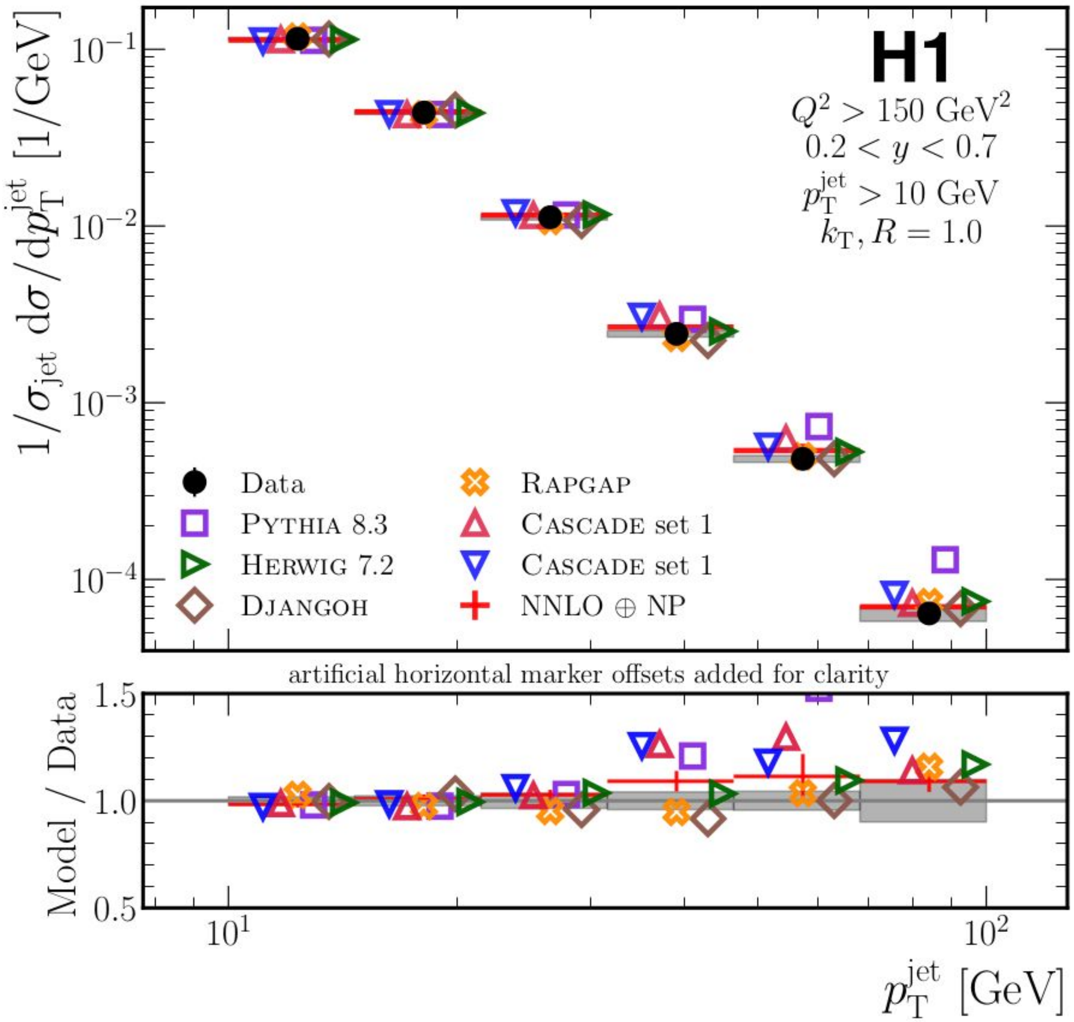
Measurement of Lepton-Jet Correlation in Deep-Inelastic Scattering with the H1 Detector Using Machine Learning for Unfolding

V. Andreev *et al.* (H1 Collaboration)
Phys. Rev. Lett. **128**, 132002 – Published 31 March 2022

Article | References | No Citing Articles | Supplemental Material | PDF | HTML | Export Citation

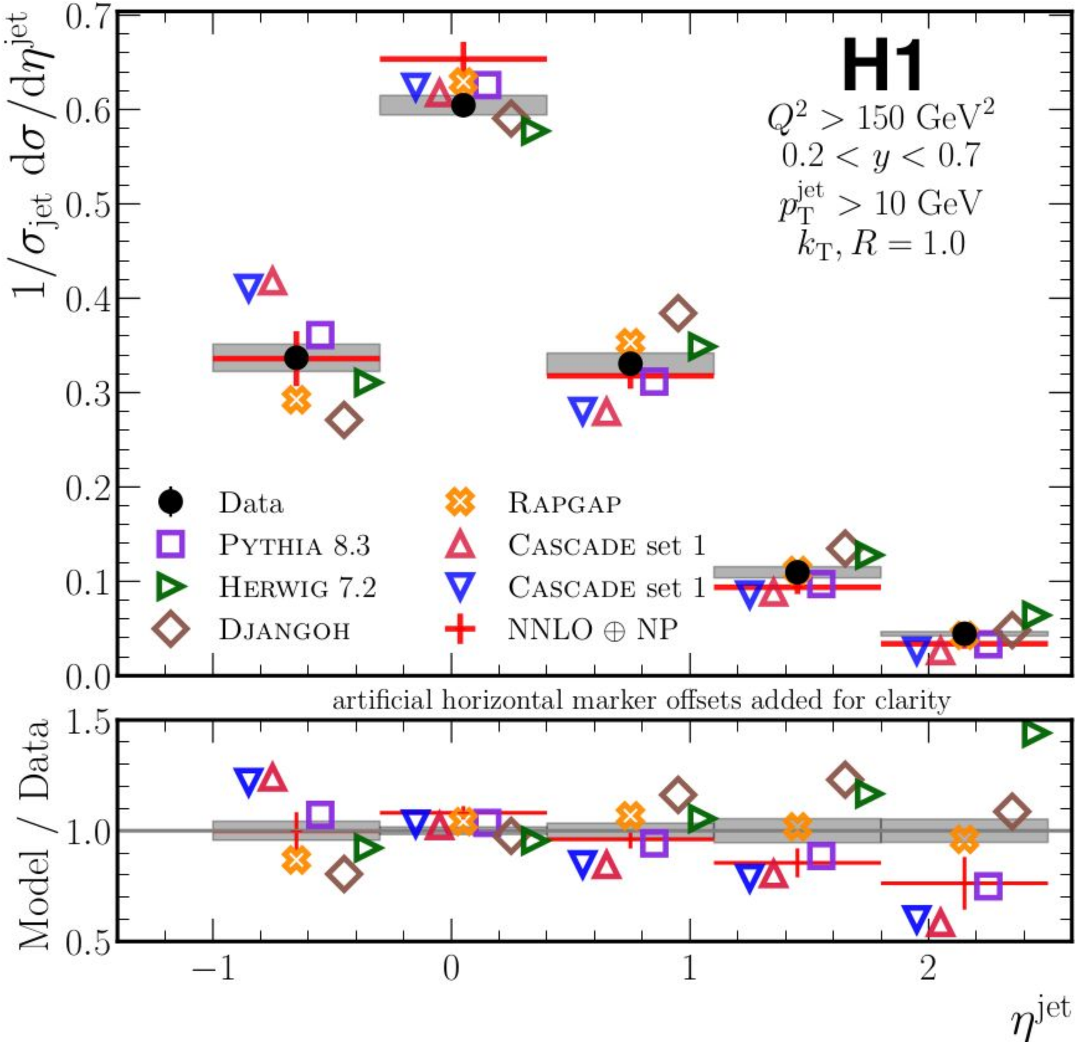






Jet transverse momentum

Well described by NNLO calculation, and some MCs like Herwig and Djangoh

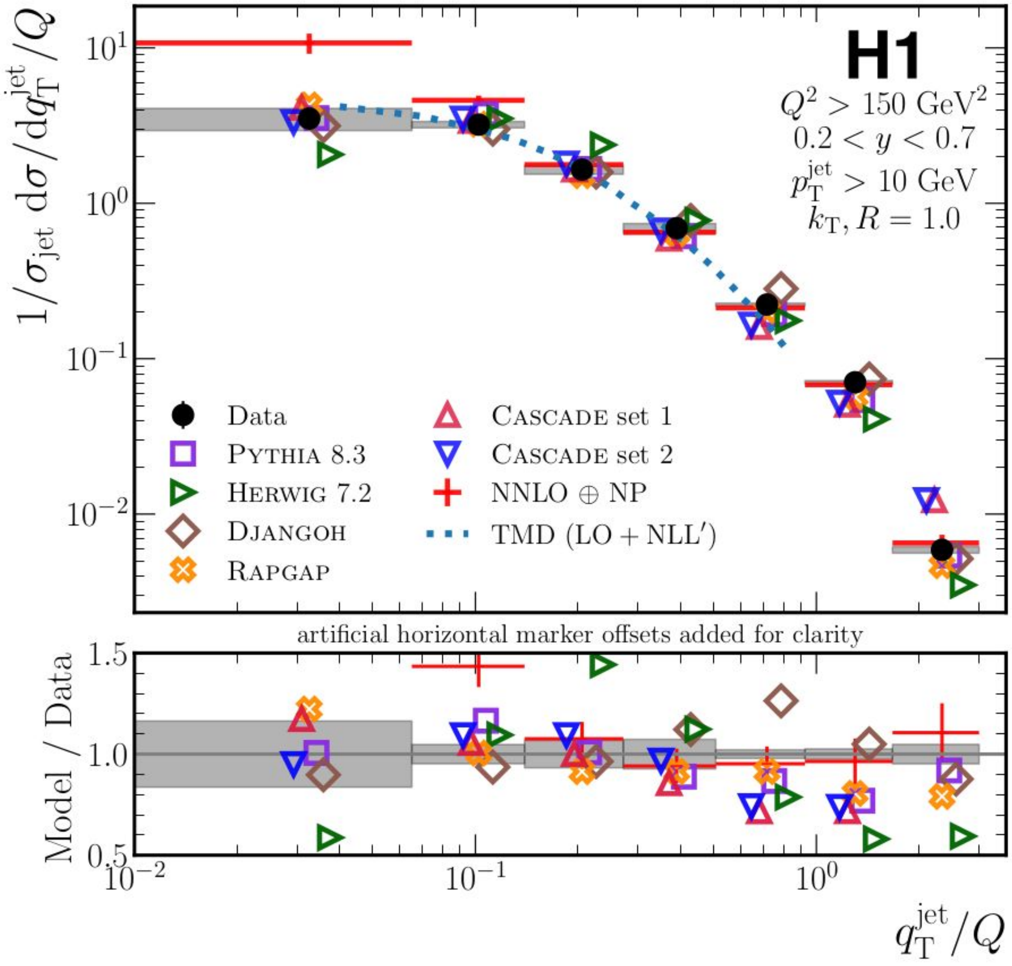


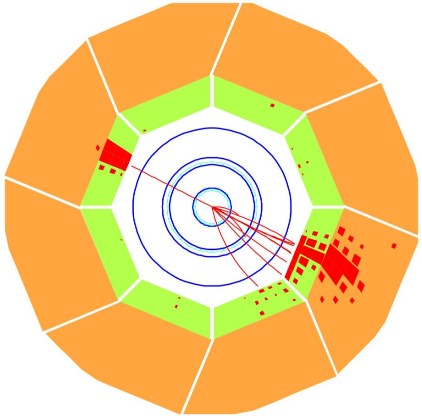
Jet pseudorapidity

Not well described at large pseudorapidity by NNLO, missing higher-order terms.

Well described by Rapgap

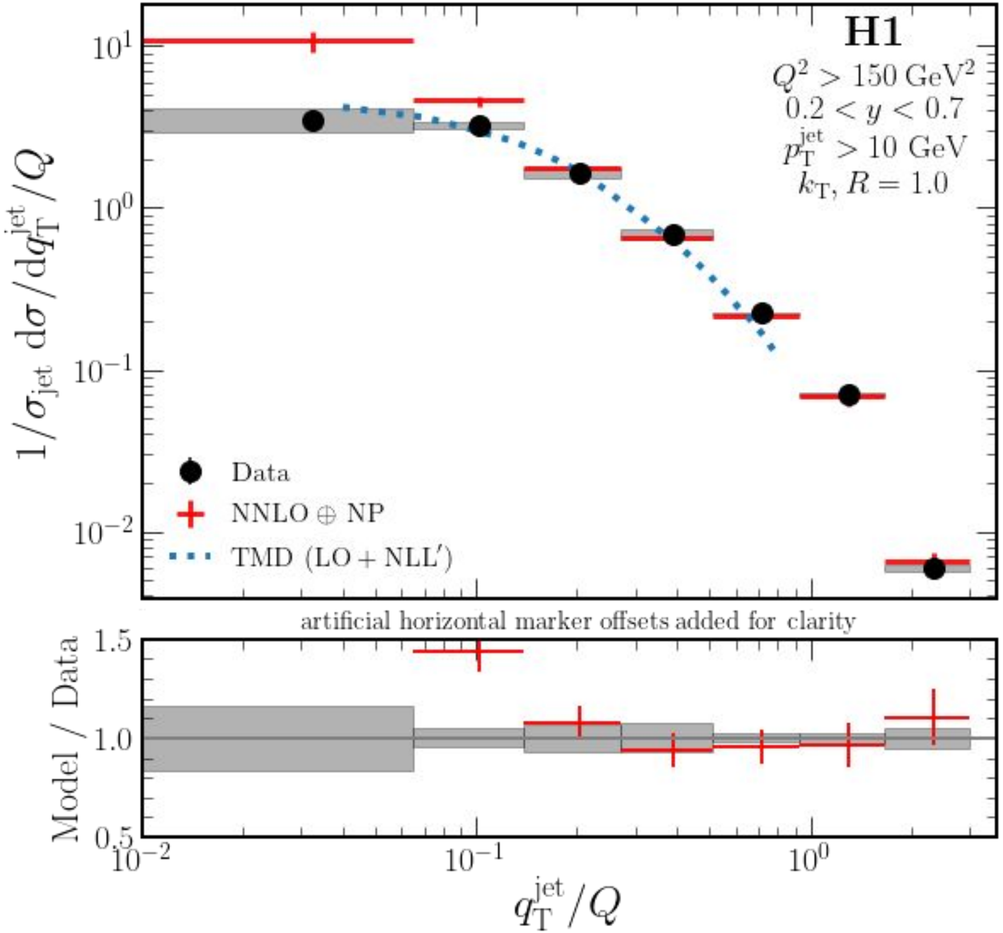
Lepton-jet momentum imbalance $q_T = |\vec{p}_T^{\,e} + \vec{p}_T^{\,\text{jet}}|$





TMD calculation does a great job at low qT; collinear calculation does a great job at large qT.

Large overlap between collinear and TMD frameworks

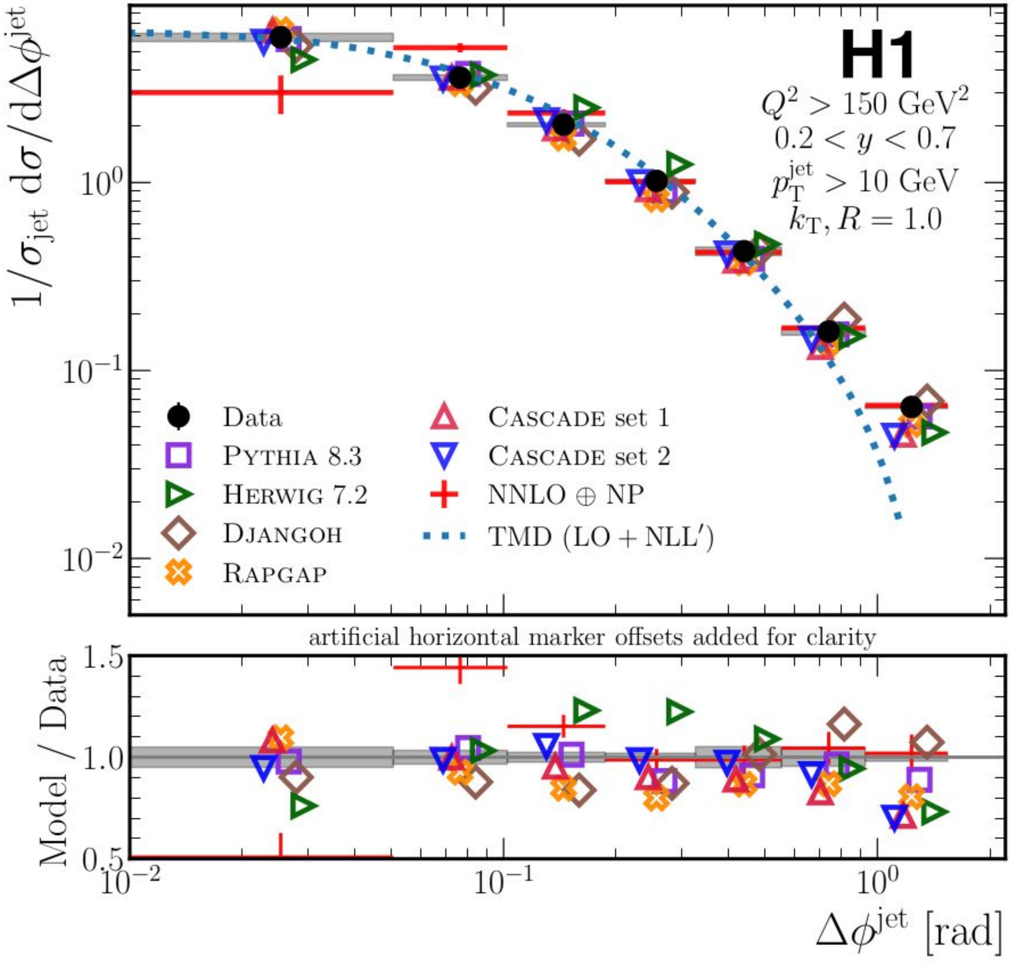


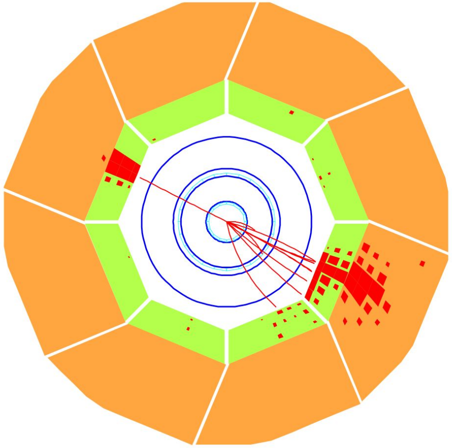
Textbook example of "matching" between collinear and TMD frameworks

First time seen in DIS!

(not seen in fixed-target DIS)

Lepton-jet azimuthal correlations



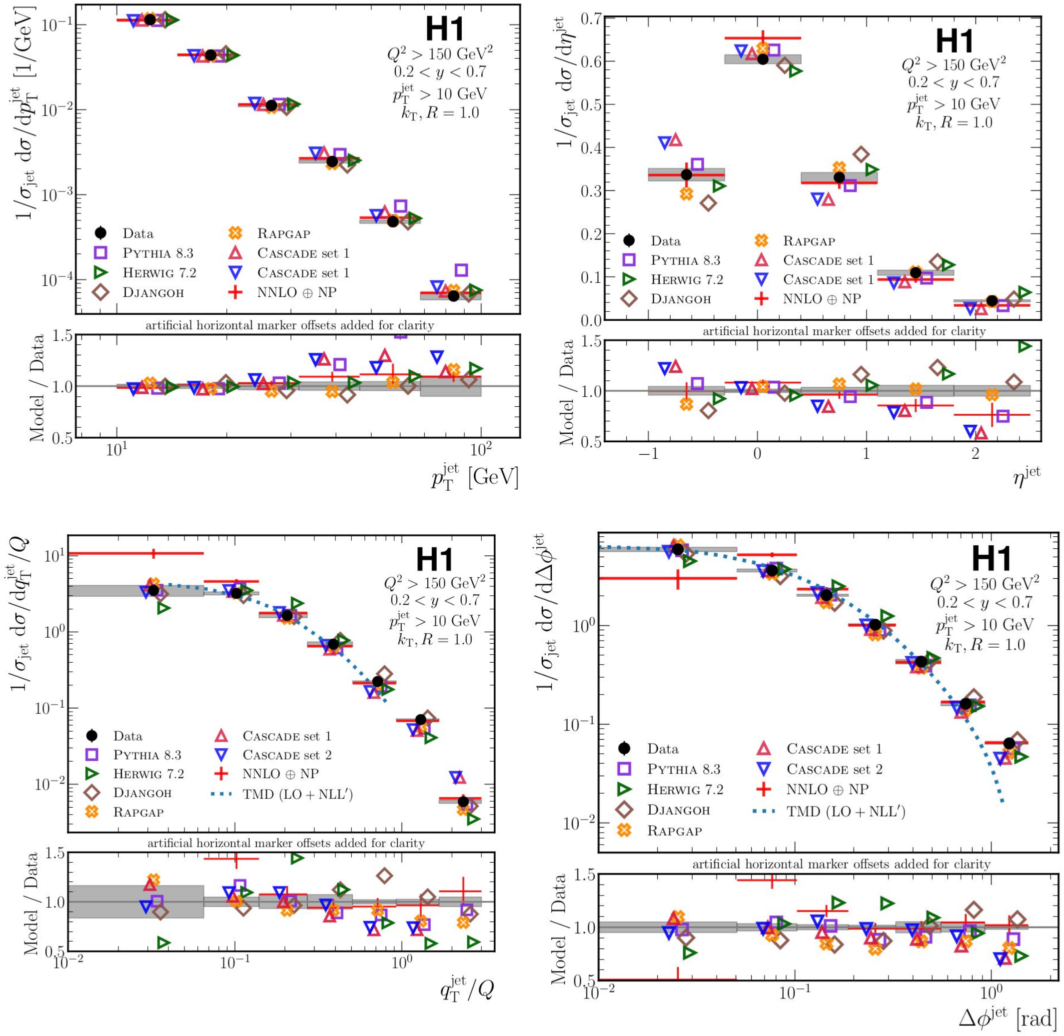


TMD calculation does a great job at low qT; collinear calculation does a great job at large qT.

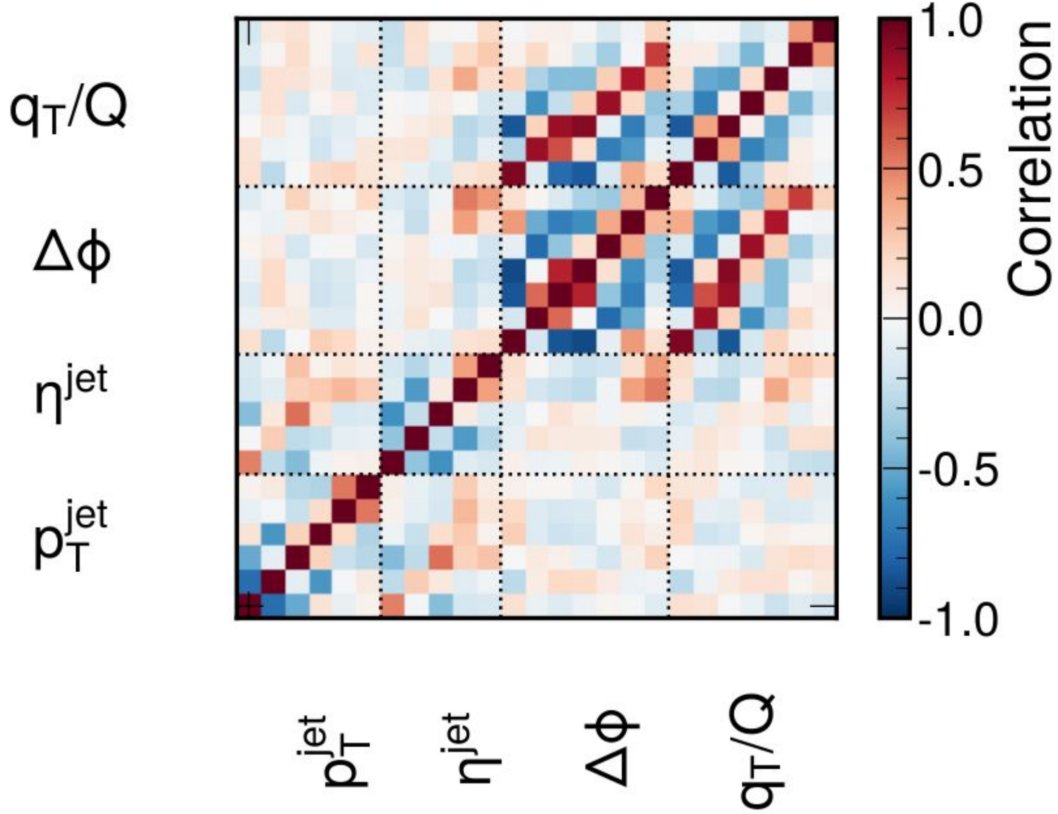
Large overlap between collinear and TMD frameworks

Omnifold allowed us to do a simultaneous, unbinned "unfolding"

First-ever measurement that uses machine-learning to correct for detector effects.

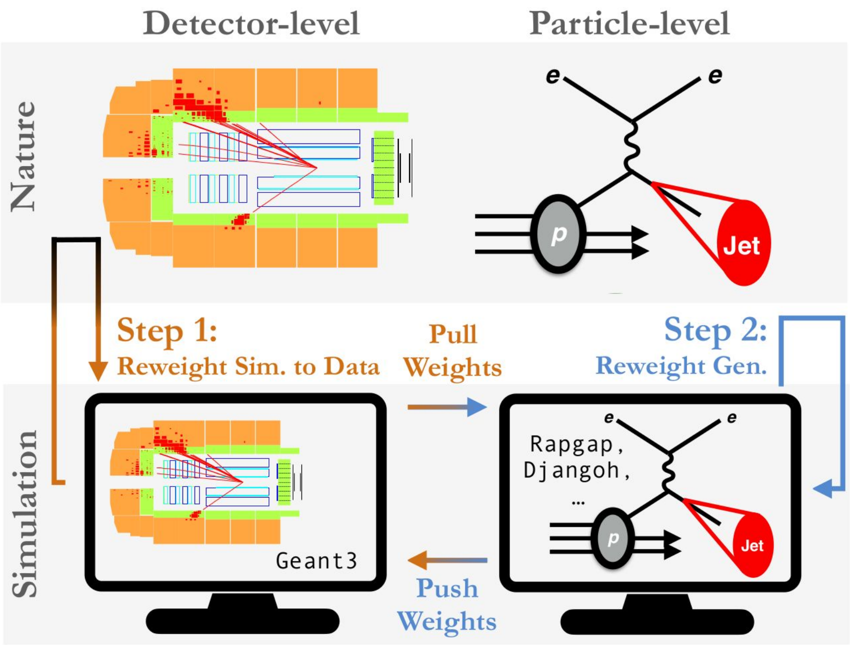


Simultaneous unfolding → Correlations

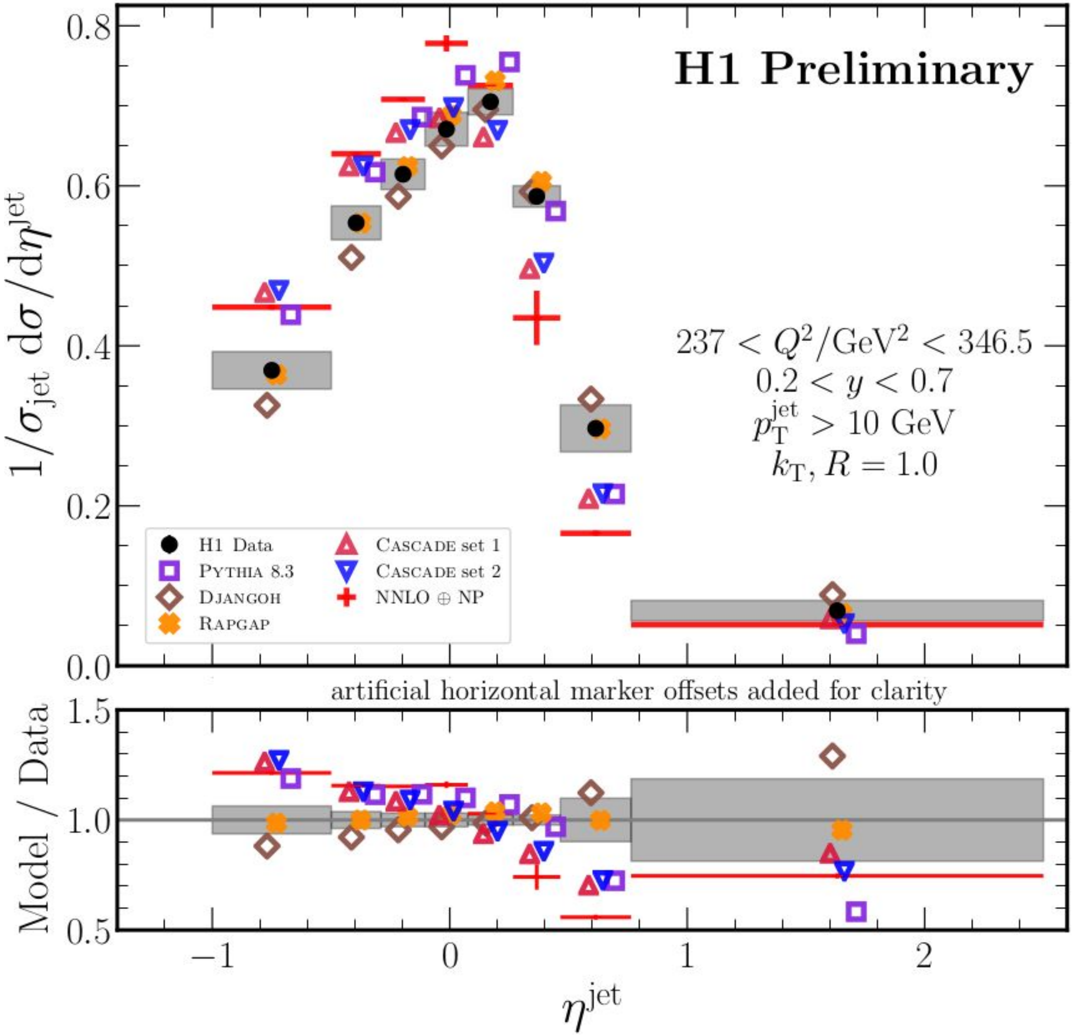


“This measurement also represents a ***milestone in the use of ML techniques for experimental physics,*** *as it provides the first example of ML-assisted unfolding,.... This opens up the possibility for high dimensional explorations of nucleon structure with H1 data and beyond”*

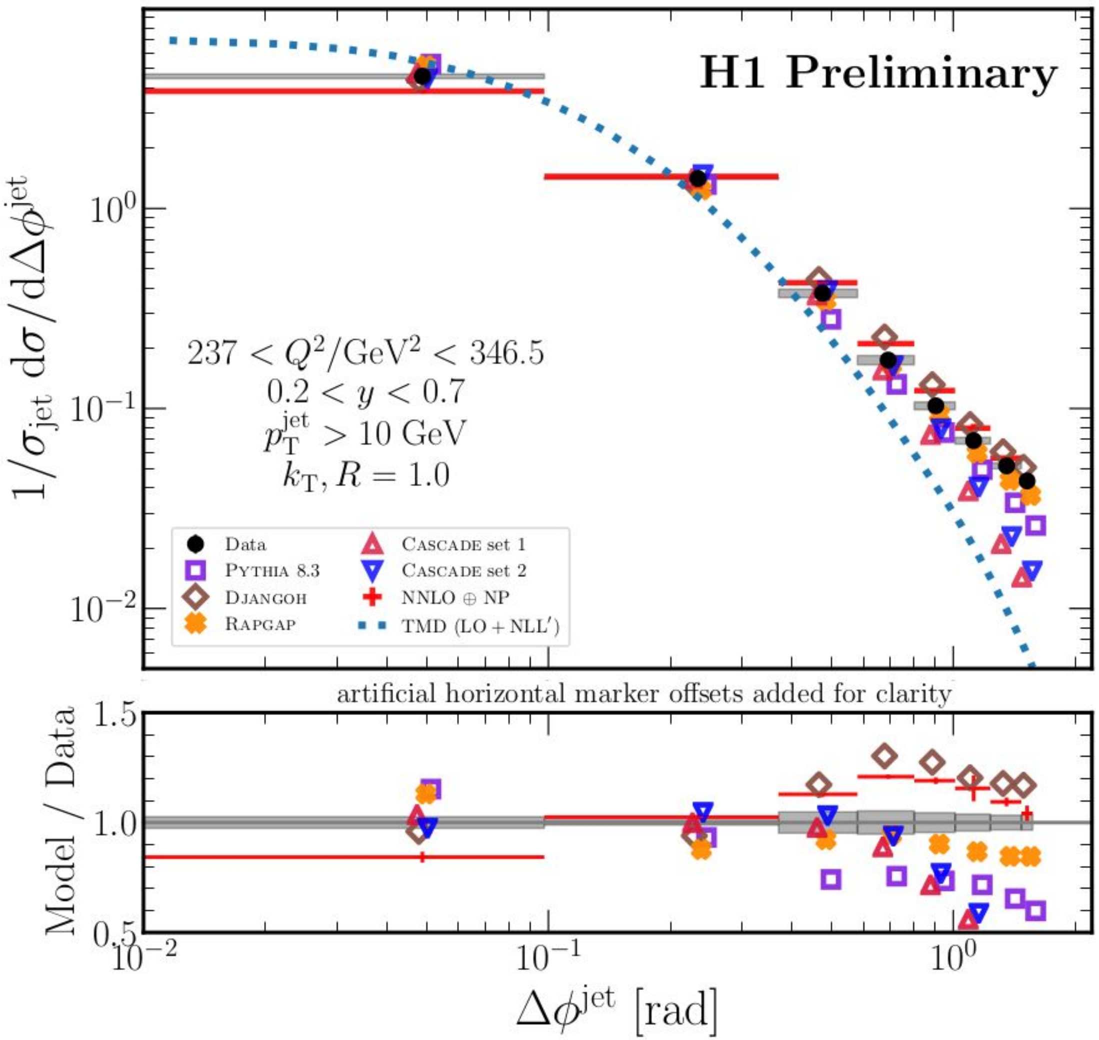
Phys. Rev. Lett. **128**, 132002



Jet pseudorapidity in slice of Q2.



Lepton-jet azimuthal correlation in slice of Q2.

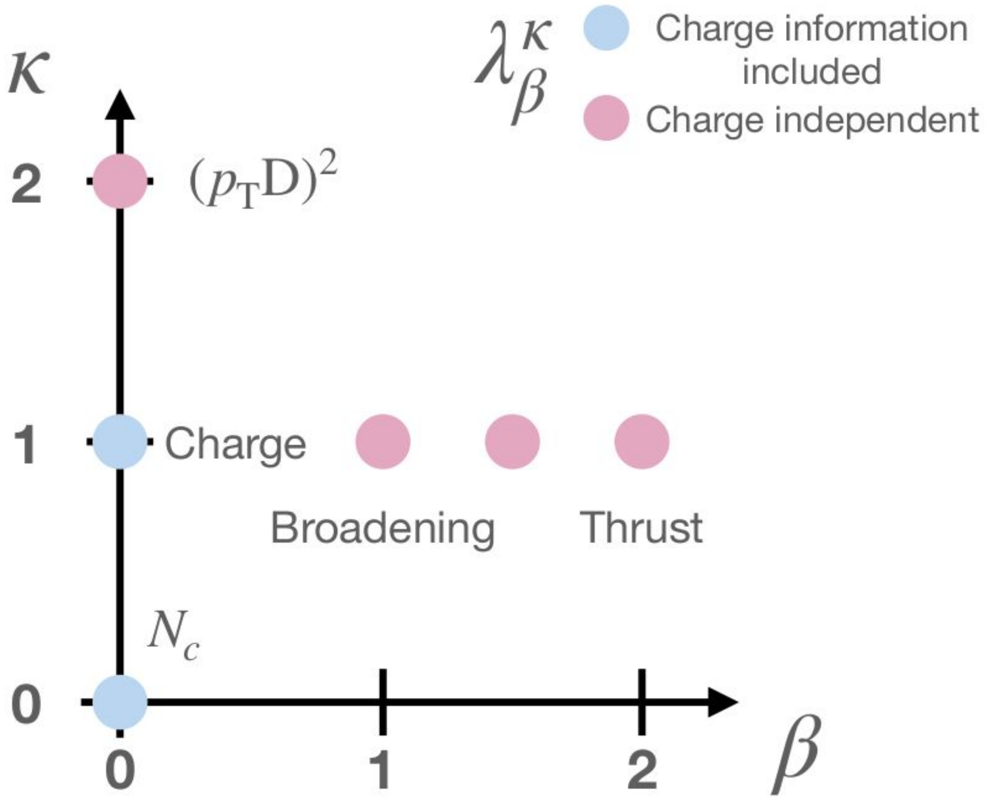


Jet substructure observables with machine learning

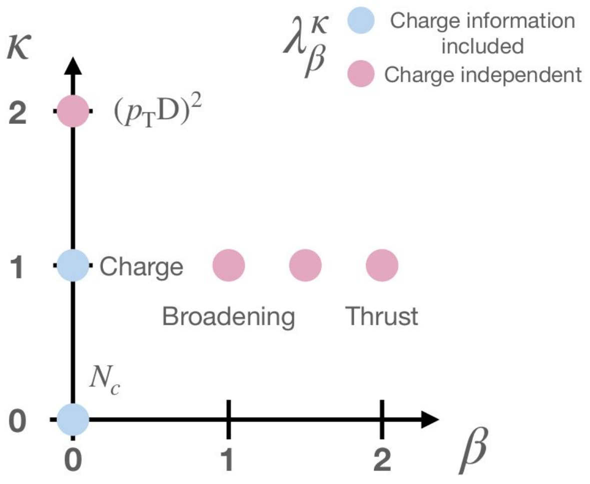
https://www-h1.desy.de/h1/www/publications/htmlsplit/H1prelim-22-034.long.html

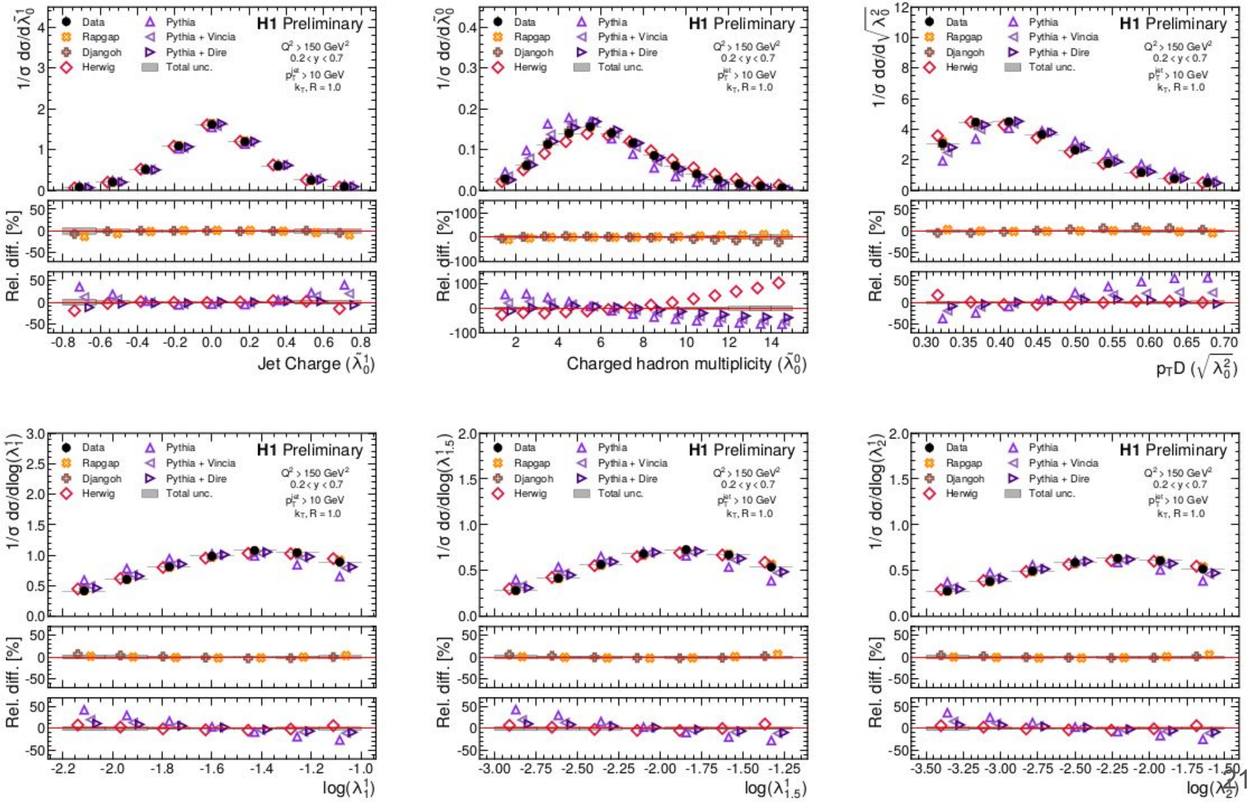
$$\lambda_\beta^\kappa = \sum_{i \in \text{jet}} z_i^\kappa \left(\frac{R_i}{R_0} \right)^\beta$$

$$\tilde{\lambda}_0^\kappa = Q_\kappa = \sum_{i \in \text{jet}} q_i \times z_i^\kappa .$$

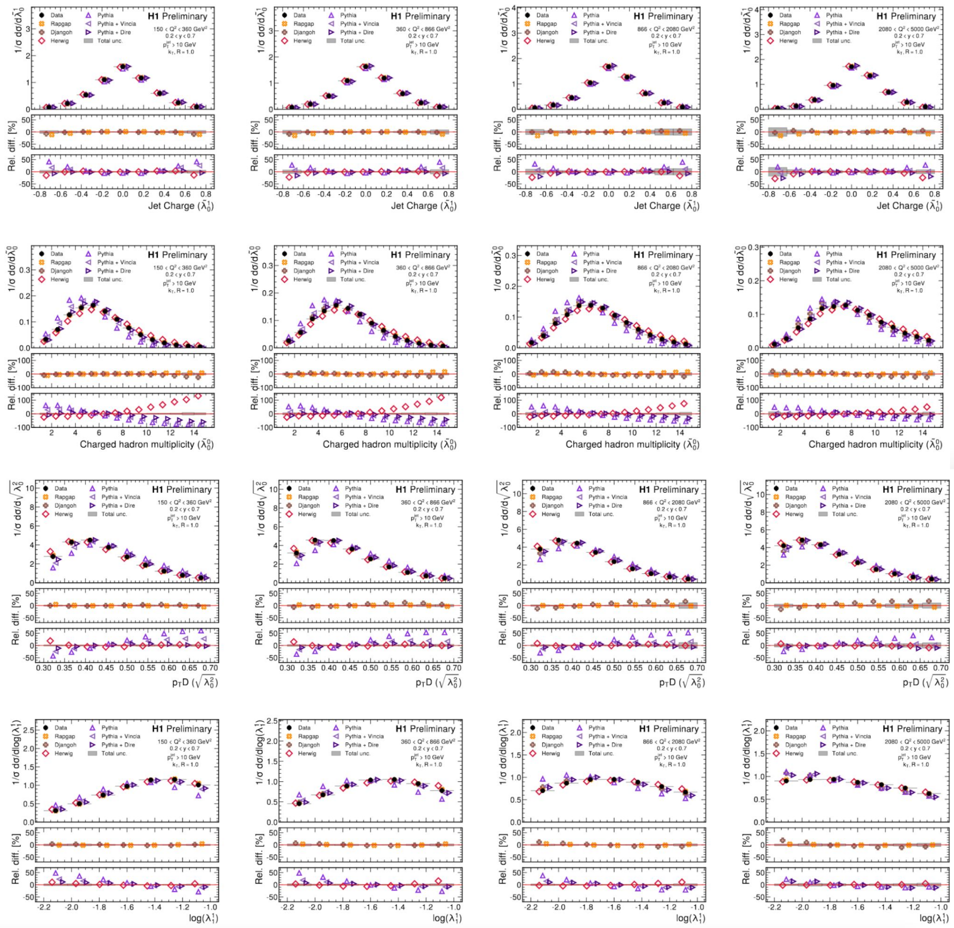


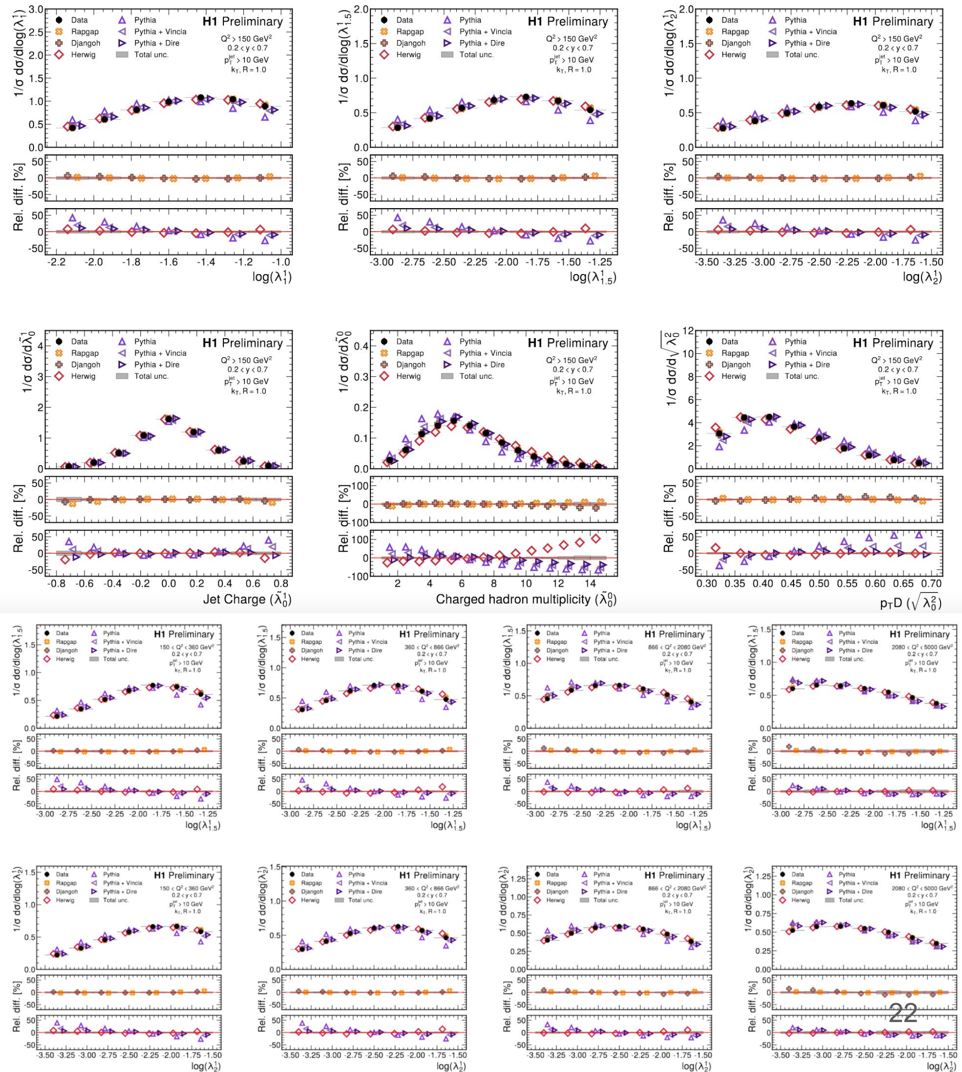
All of them unfolded simultaneously!!!





All unfolded simultaneously!

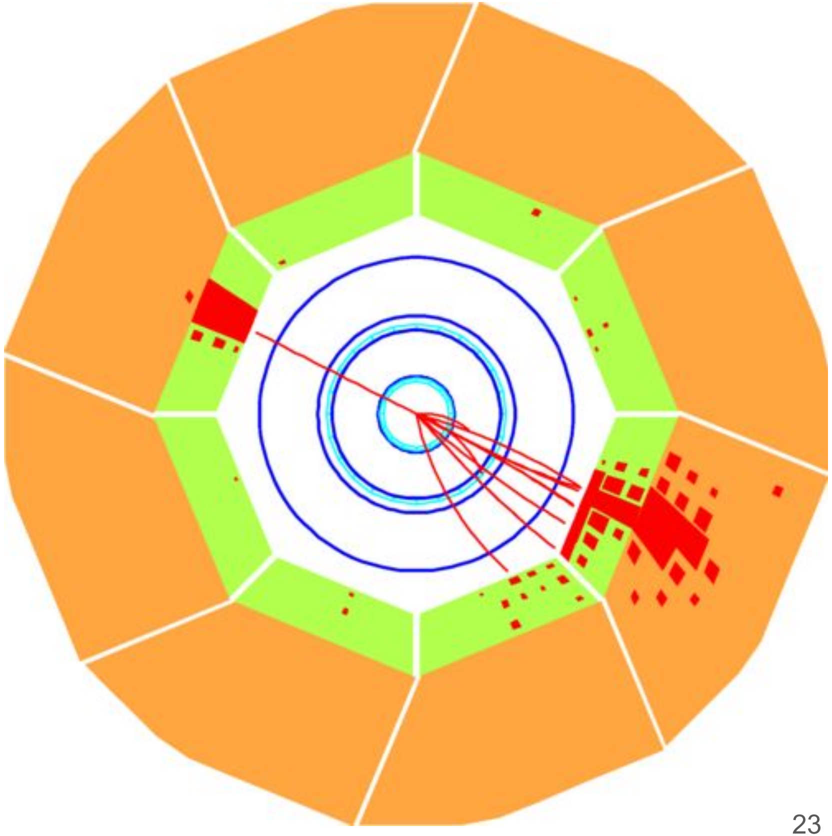




The road towards EIC during this decade

Every jet-related observable in ep collisions **can and will be measured** with H1 data

The ultimate "reference" for future polarized ep and eA data at EIC



PHYSICAL REVIEW LETTERS

Highlights Recent Accepted Collections Authors Referees Search Press About Staff

Open Access

Measurement of Lepton-Jet Correlation in Deep-Inelastic Scattering with the H1 Detector Using Machine Learning for Unfolding

V. Andreev *et al.* (H1 Collaboration)
Phys. Rev. Lett. **128**, 132002 – Published 31 March 2022

Article | References | No Citing Articles | Supplemental Material | PDF | HTML | Export Citation

H1prelim-22-034	Jet Substructure at high Q**2 using machine learning Document H1 Info **Figures:** (1) (2a) (2b) (2c) (2d) (2e) (2f) (3a) (3b) (3c) (3d) (3e) (3f) (3g) (3h) (3i) (3j) (3k) (3l) (3m) (3n) (3o) (3p) (3q) (3r) (5k) (5l) (5m) (5n) (5o) (5p) (5q) (5r) (5s) (5t) (5u) (5v) (5w) (5x) (use mouse for preview)
H1prelim-22-033	Groomed event shaps in high Q**2 DIS Document H1 Info **Figures:** (5a) (5b) (5c) (5d) (5e) (5f) (5g) (5h) (5i) (5j) (5k) (5l) (6a) (6b) (6c) (6d) (6e) (6f) (7a) (7b) (7c) (7d) (7e) (7f) (7g)
H1prelim-22-032	Charge asymmetry Jet substructure in DIS Document H1 Info **Figures:** (1) (2) (3a) (3b) (3c) (4a) (4b) (5a) (5b) (6) (7) (9) (10) (11) (12) (13) (14) (use mouse for preview)
H1prelim-21-032	Measurement of 1-jettiness in the Breit Frame at high Q^2 Document H1 Info

Stay tuned.
Just the beginning of a new & rich jet program

https://www-h1.desy.de/publications/H1preliminary.short_list.html

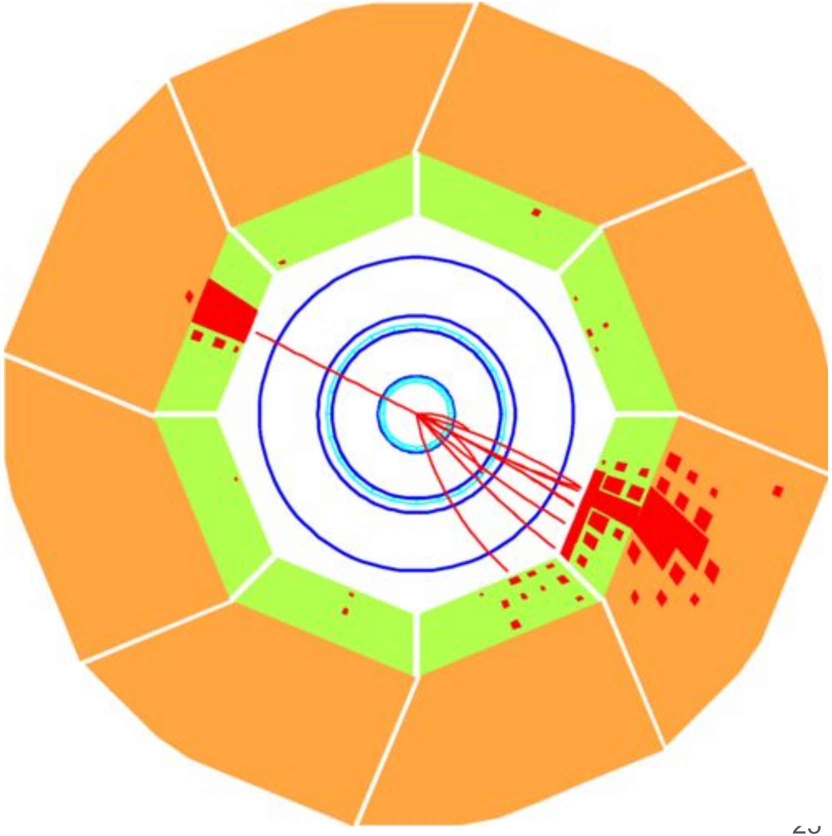
Summary

- We report a measurement of lepton jet momentum and azimuthal imbalance in DIS, which provide **a new way to constrain TMD PDFs and their evolution**

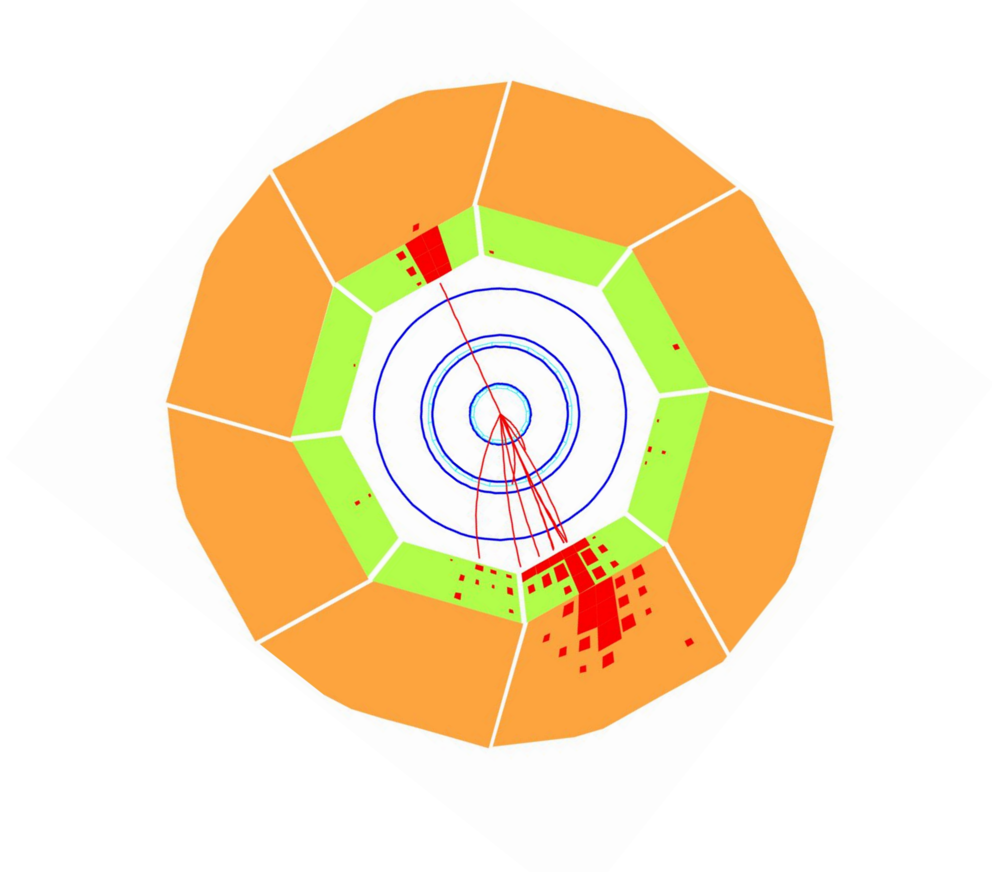
- Pure TMD calculation does a great job at low qT;
  Pure collinear calculation does a great job at large qT.
  Large overlap. Data can **constrain matching between TMD and collinear frameworks**

- **First-ever measurement that uses machine-learning to correct for detector effects.** (using Omnifold method)

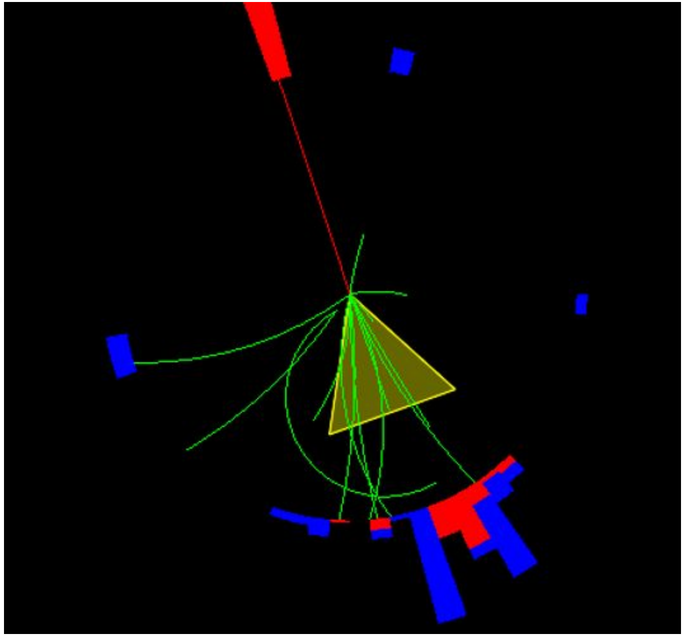
- These results are the beginning of a decade-long **pathfinder program for the future EIC**



H1@HERA

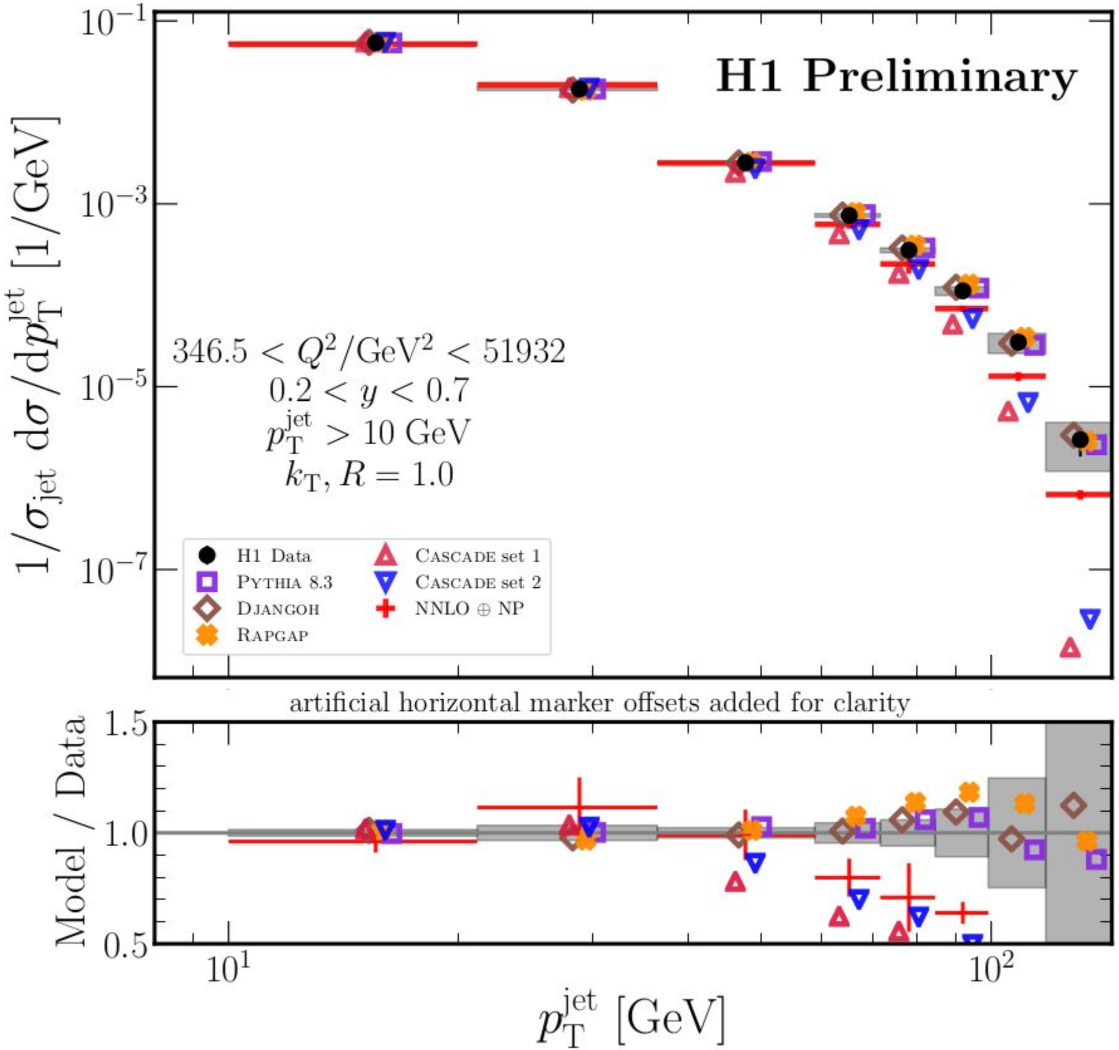


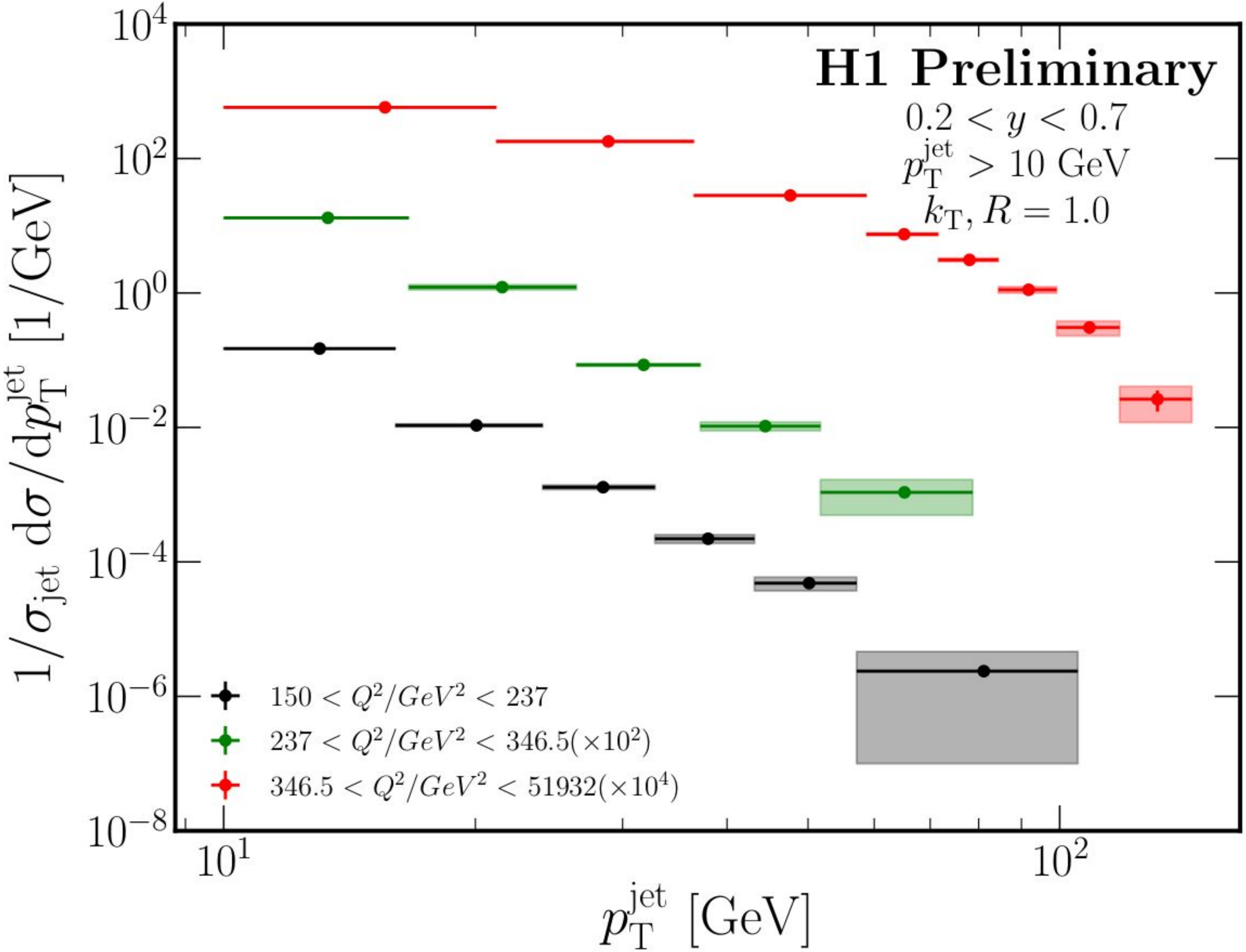
EIC



Backup

Jet transverse momentum in slice of Q2.



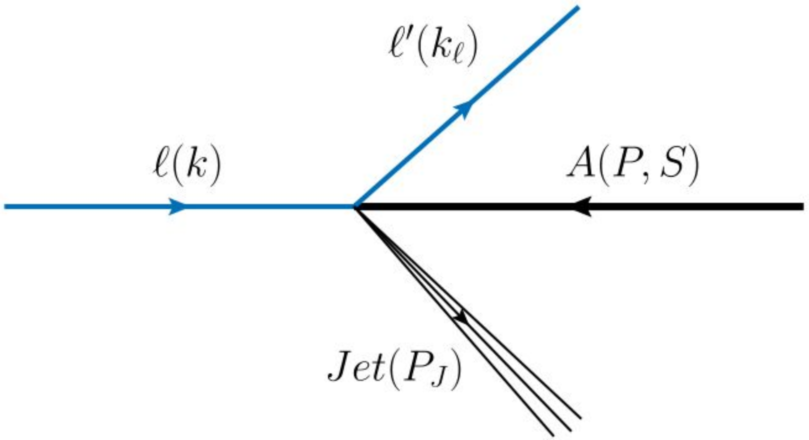

H1 Preliminary
$0.2 < y < 0.7$
$p_T^{jet} > 10$ GeV
$k_T, R = 1.0$
$1/\sigma_{jet}\, d\sigma/dp_T^{jet}$ [1/GeV]
p_T^{jet} [GeV]
$150 < Q^2/GeV^2 < 237$
$237 < Q^2/GeV^2 < 346.5 (\times 10^2)$
$346.5 < Q^2/GeV^2 < 51932 (\times 10^4)$
10^4
10^2
10^0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^1
10^2

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)

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