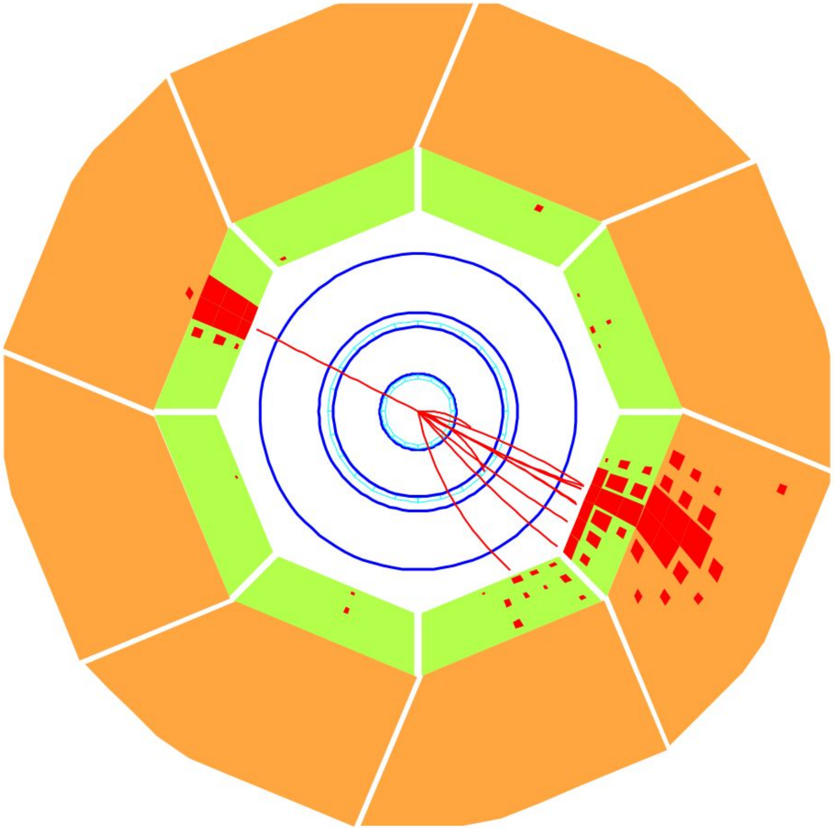
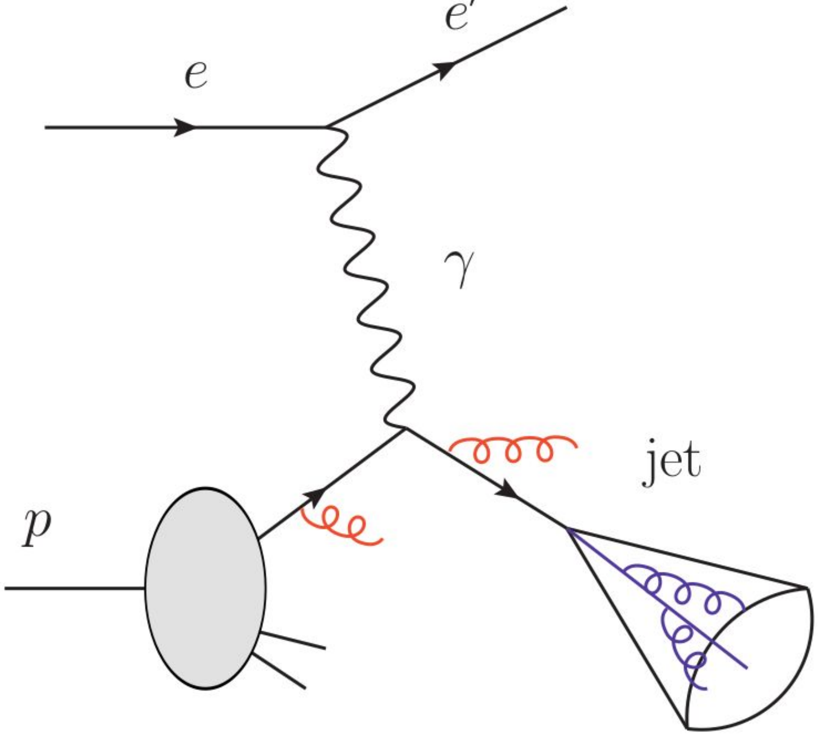
Jet tomography in DIS today and tomorrow

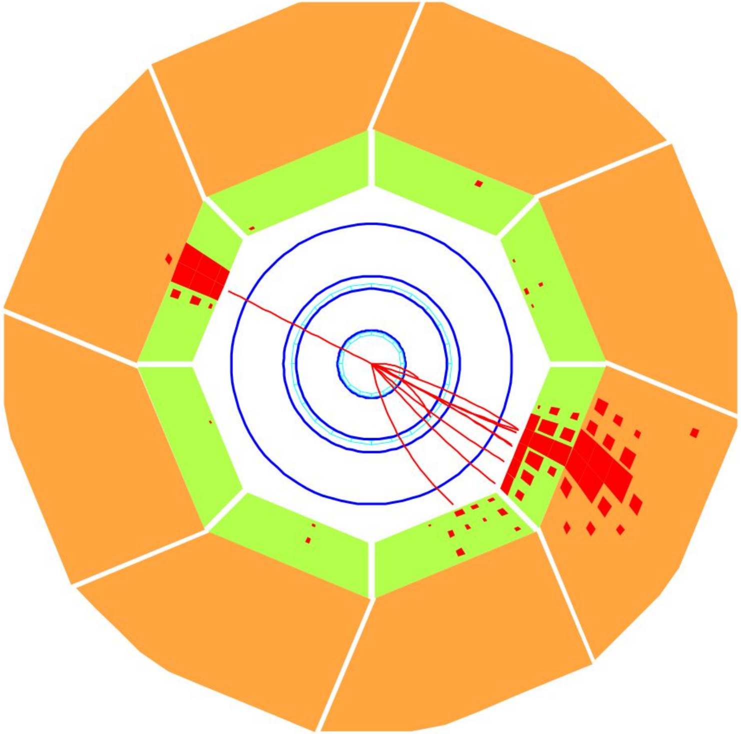
Miguel Arratia



DIS Born-level configuration

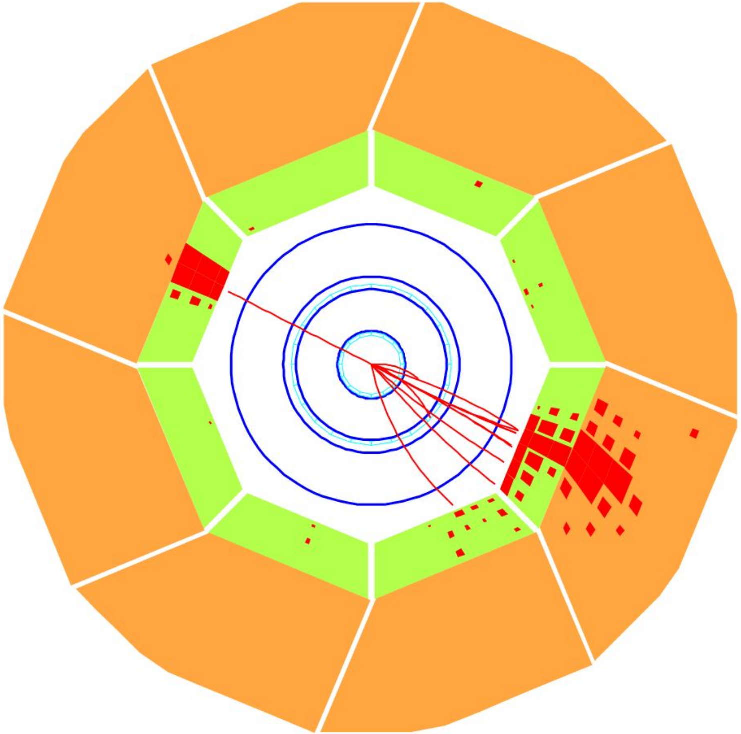
$$\gamma^* q \rightarrow q$$





A new channel to probe for quark transverse-momentum distributions (TMDs) and evolution

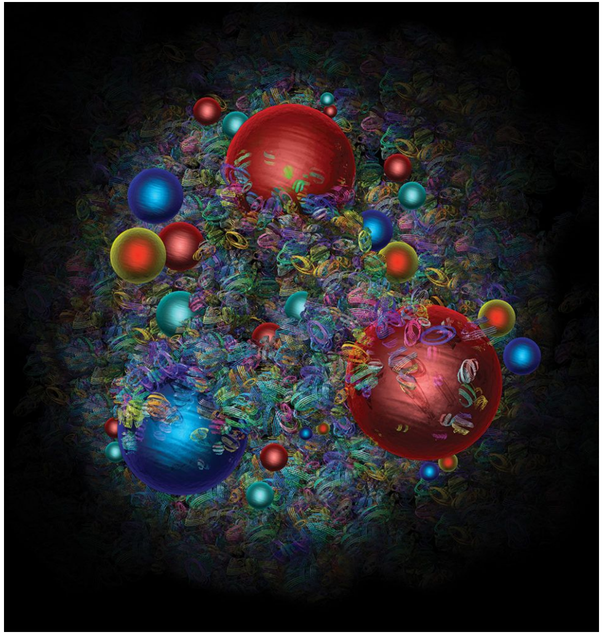
Liu et al. PRL. 122, 192003, Gutierrez et al. PRL. 121, 162001



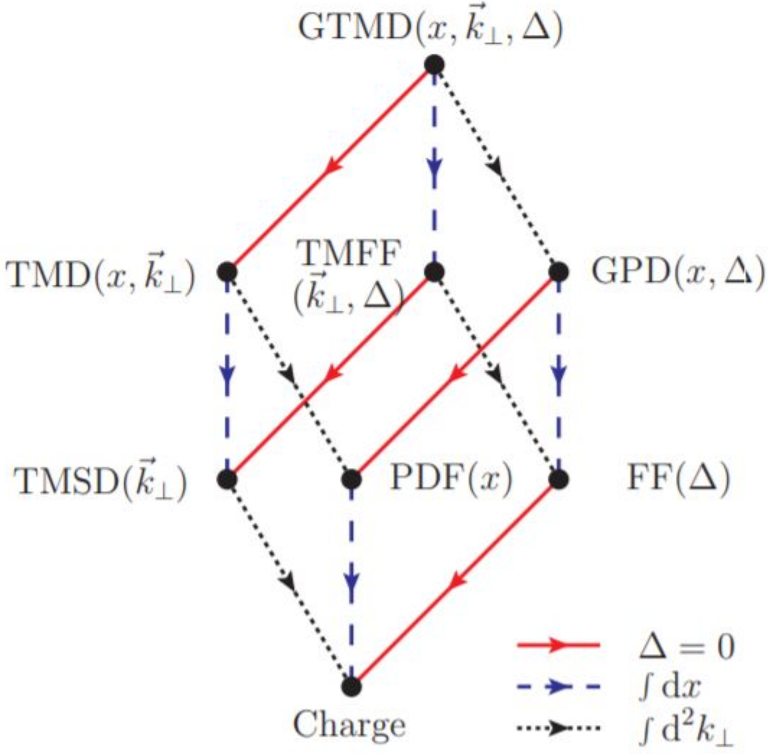
"The advantage of the lepton-jet correlation as compared to the standard SIDIS processes is that it ***does not involve TMD fragmentation functions."***

Ideally, a complete "quantum tomography" of the proton involves:

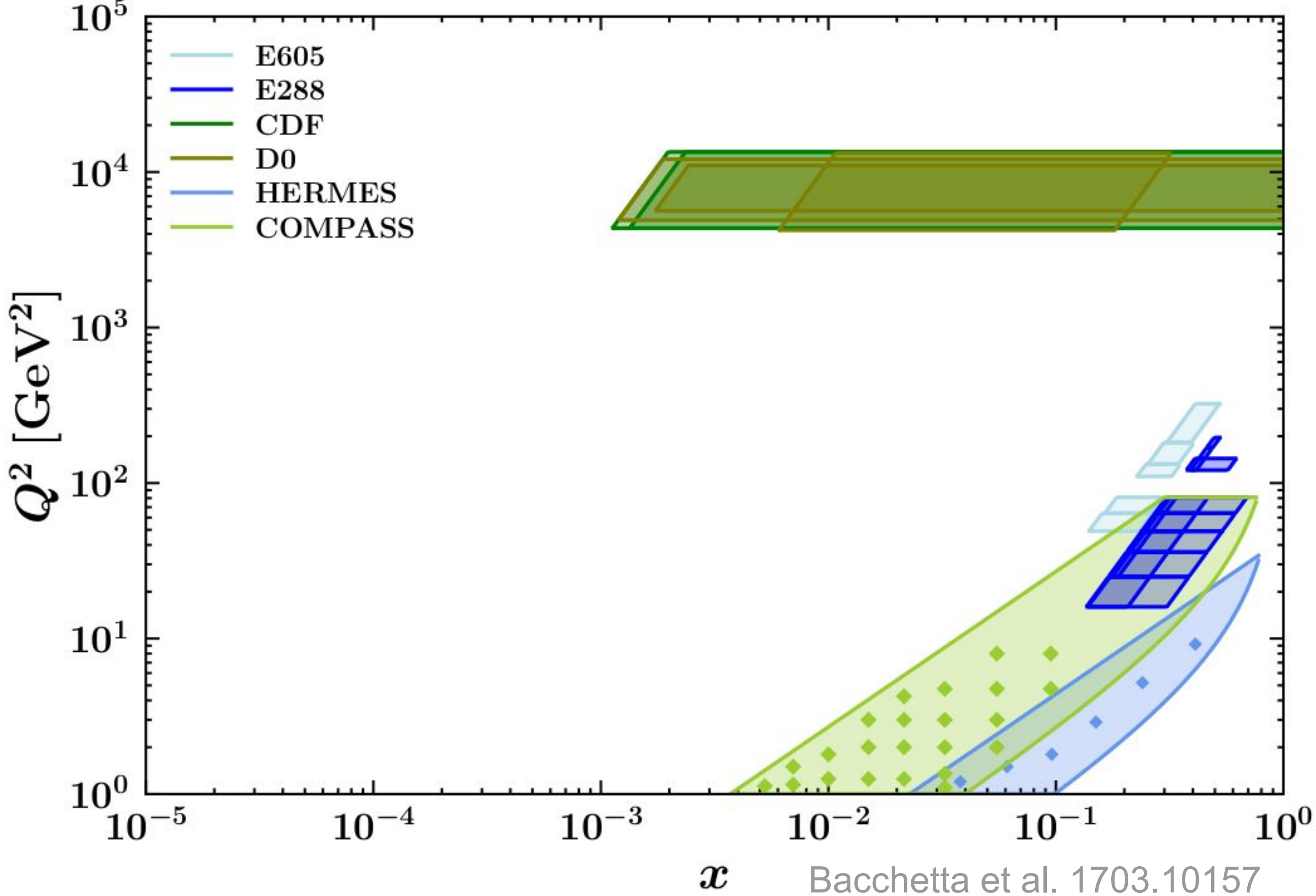
$$W(x,p) = \int \psi^*(x - \eta/2)\psi(x + \eta/2)e^{ip\eta}d\eta \ ,$$



Difficult, so attempt to measure "projections" of the quantum-phase density



Existing TMD data

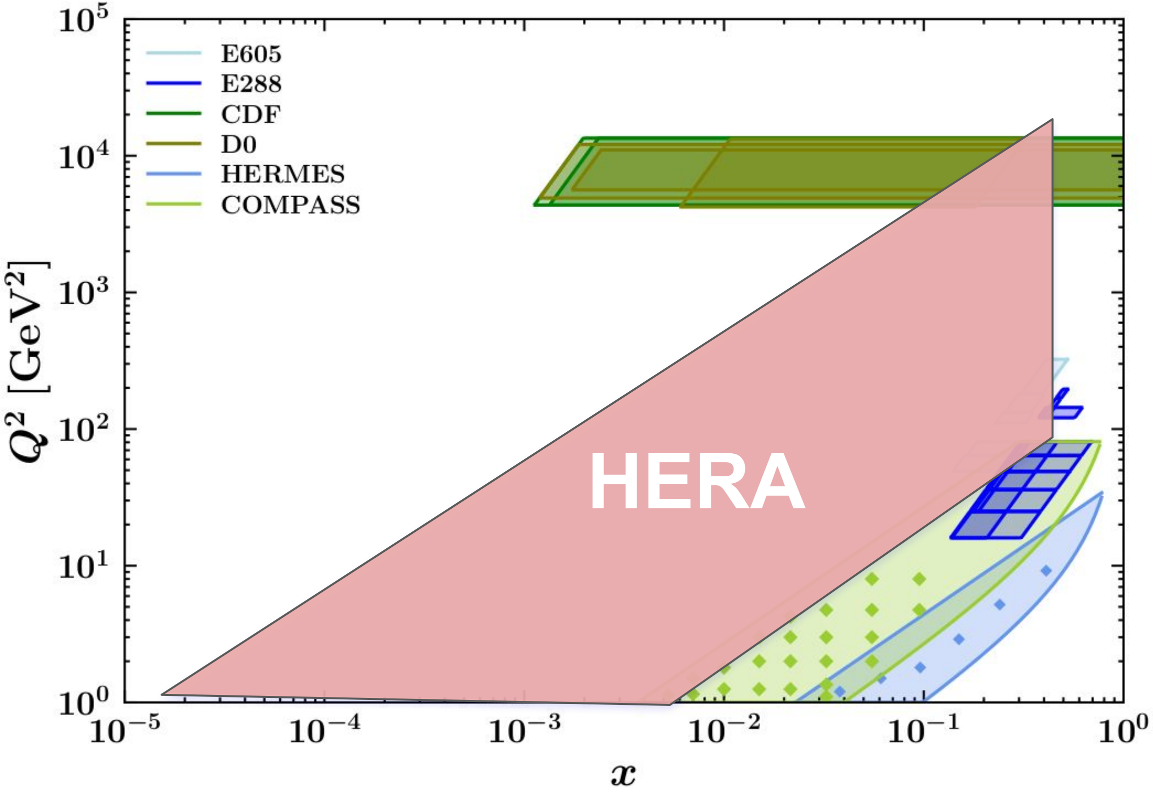


Bacchetta et al. 1703.10157

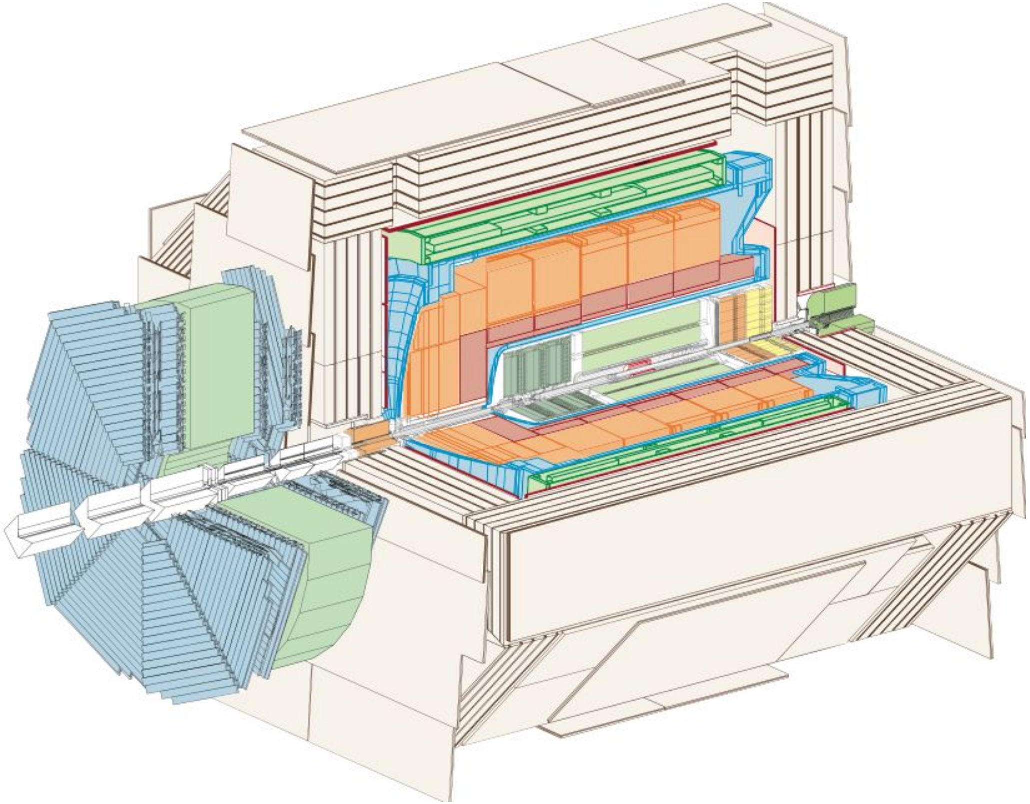
Constraining TMD evolution with HERA data

Bridging DIS from fixed-target exp. and high Q2 Drell-Yan at colliders.

Fixing open issues of TMD factorization & universality



The H1 experiment at HERA



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

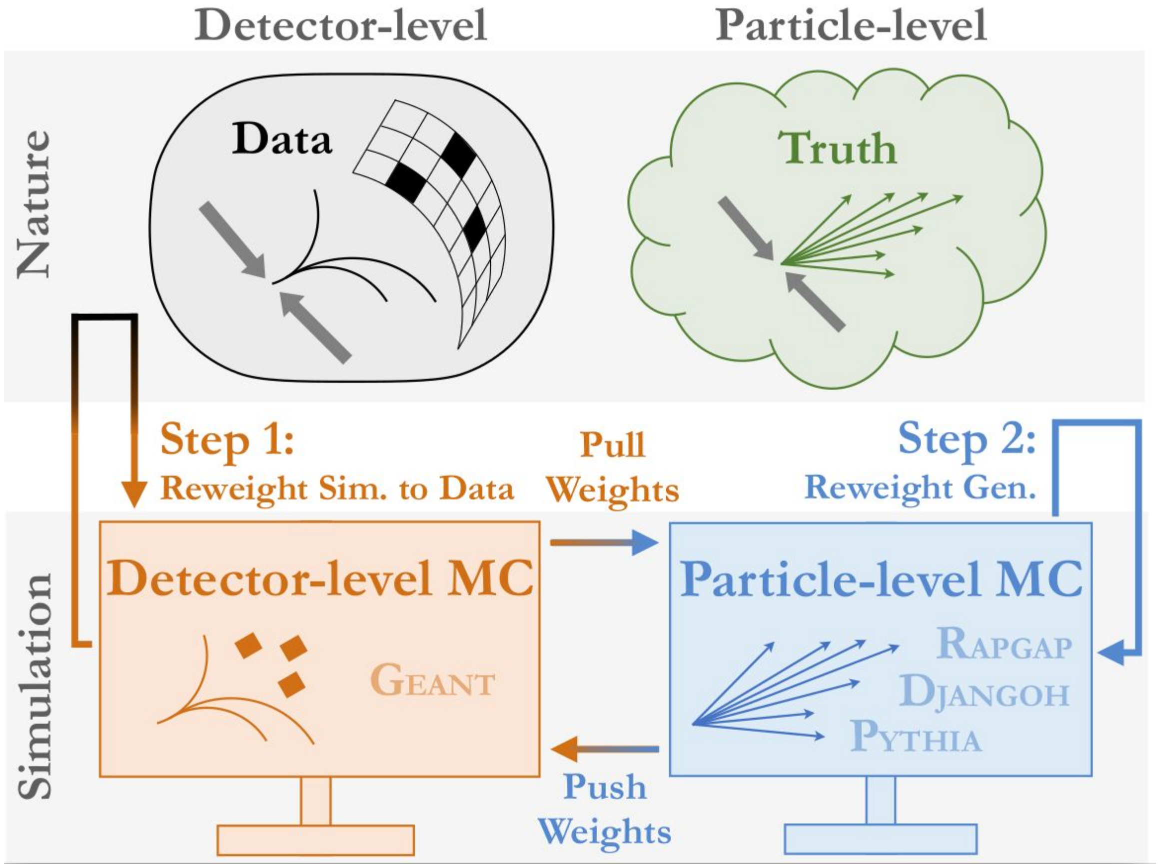
Both combined using an energy flow algorithm

1% Jet energy scale

0.5-1% lepton energy scale

Unfolding with Omnifold (via machine-learning).

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



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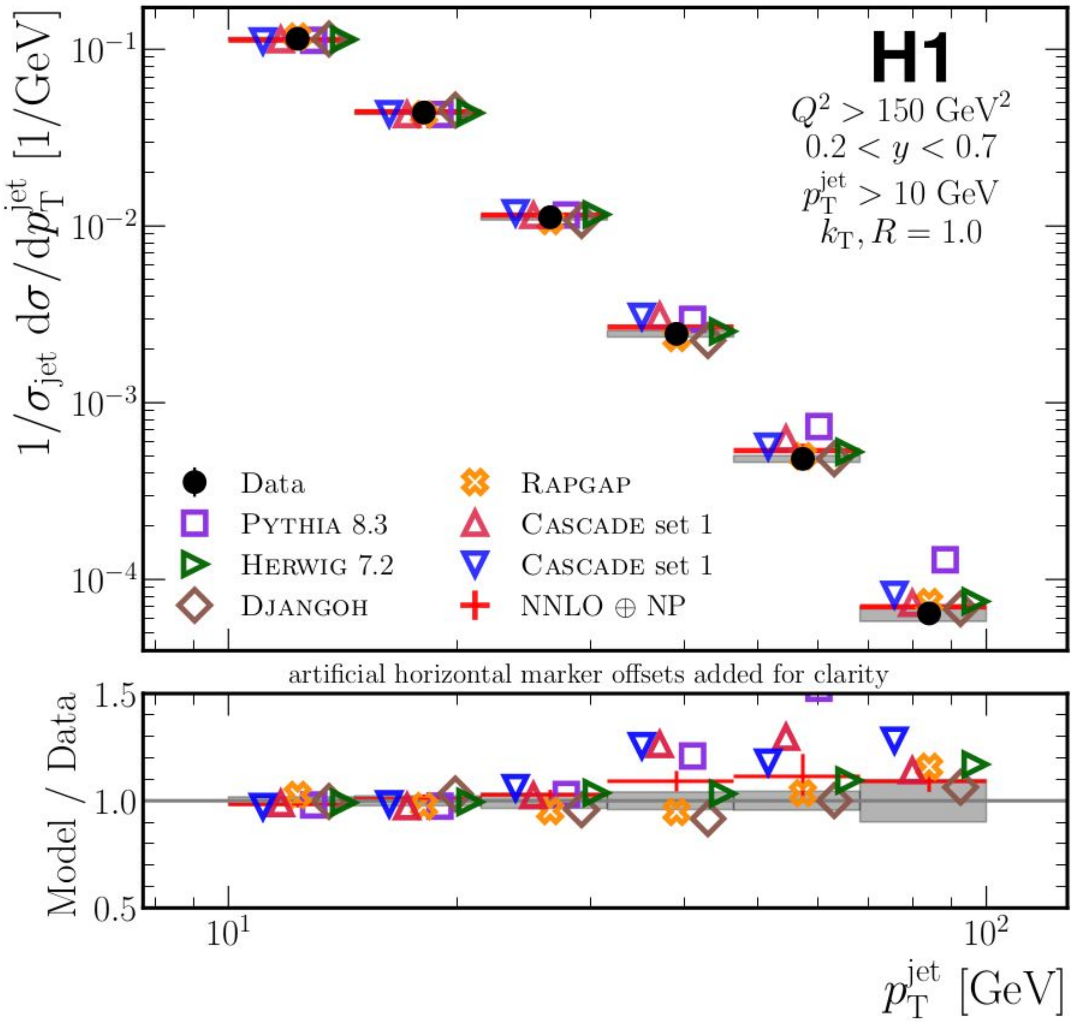
Measurement of Lepton-Jet Correlation in Deep-Inelastic Scattering with the H1 Detector Using Machine Learning for Unfolding

V. Andreev *et al.* (H1 Collaboration)

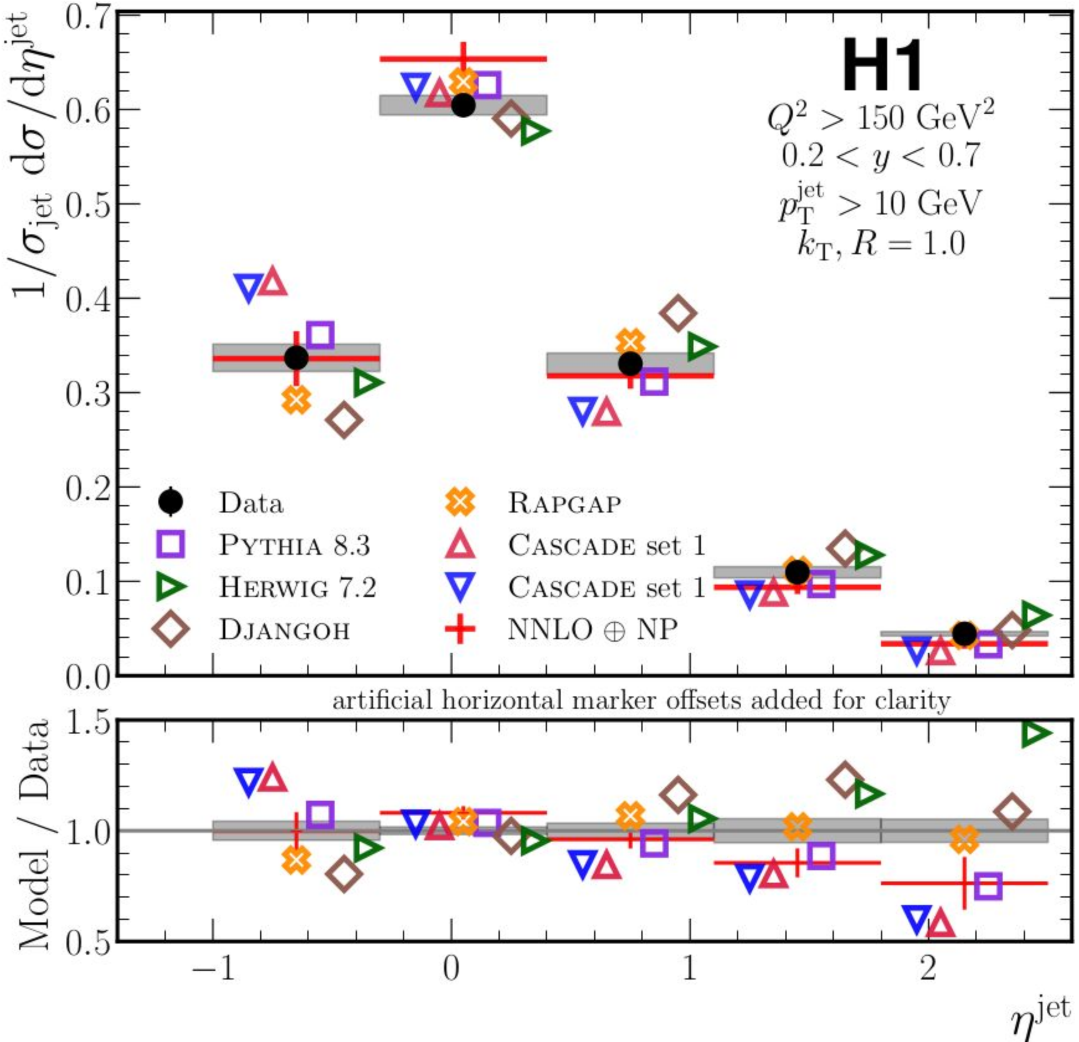
Phys. Rev. Lett. **128**, 132002 – Published 31 March 2022

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

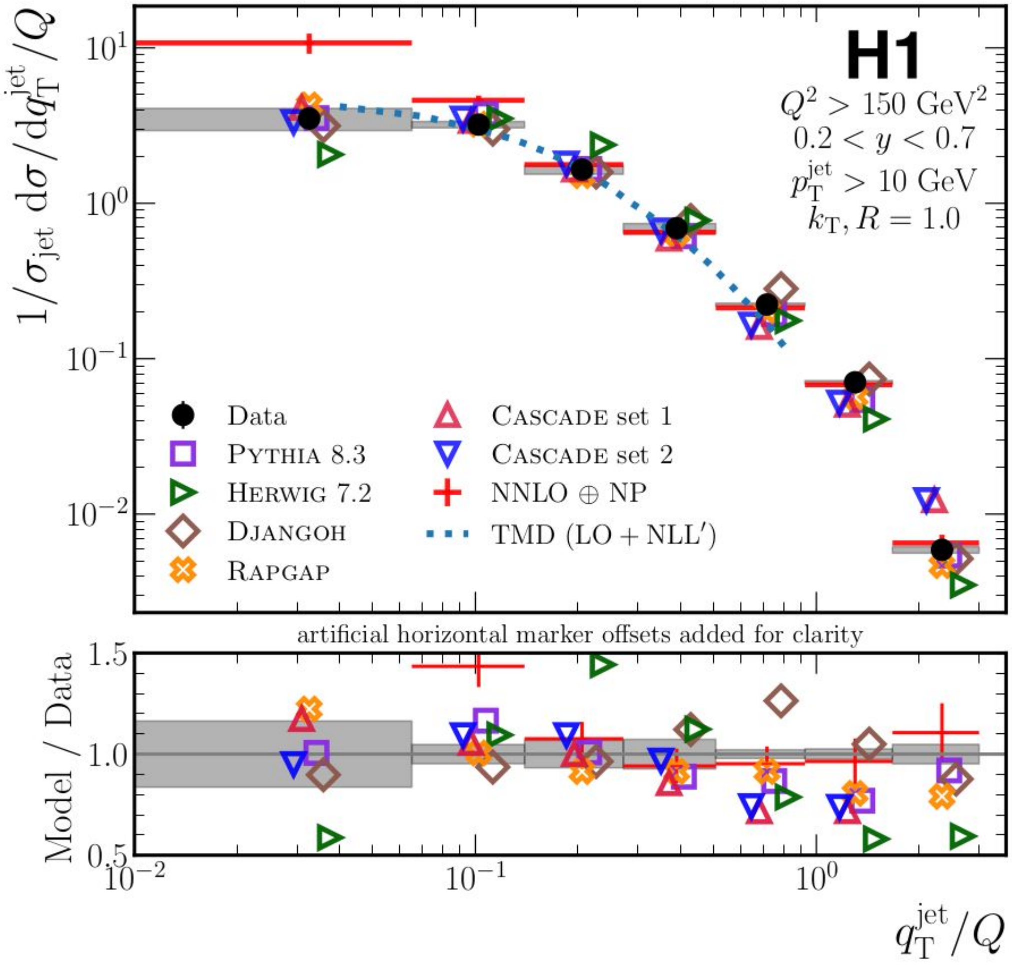


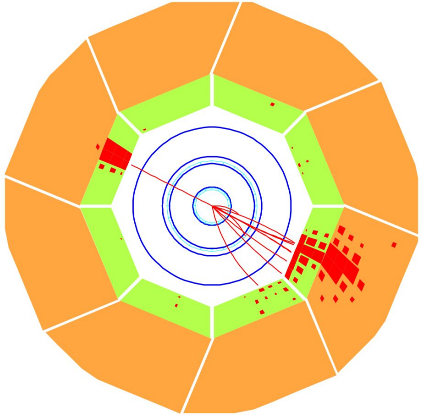
Jet pseudorapidity

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

Well described by Rapgap

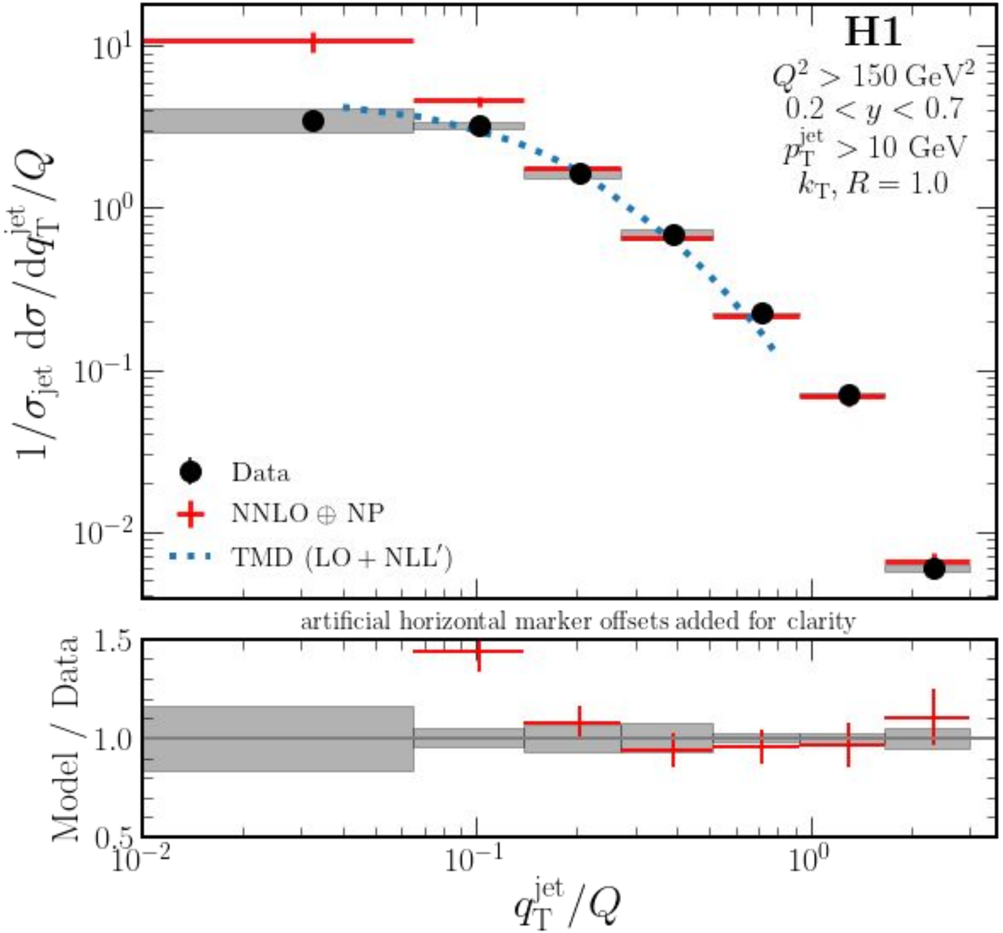
Lepton-jet momentum imbalance $q_T = |\vec{p}_T^{\,e} + \vec{p}_T^{\,\text{jet}}|$





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

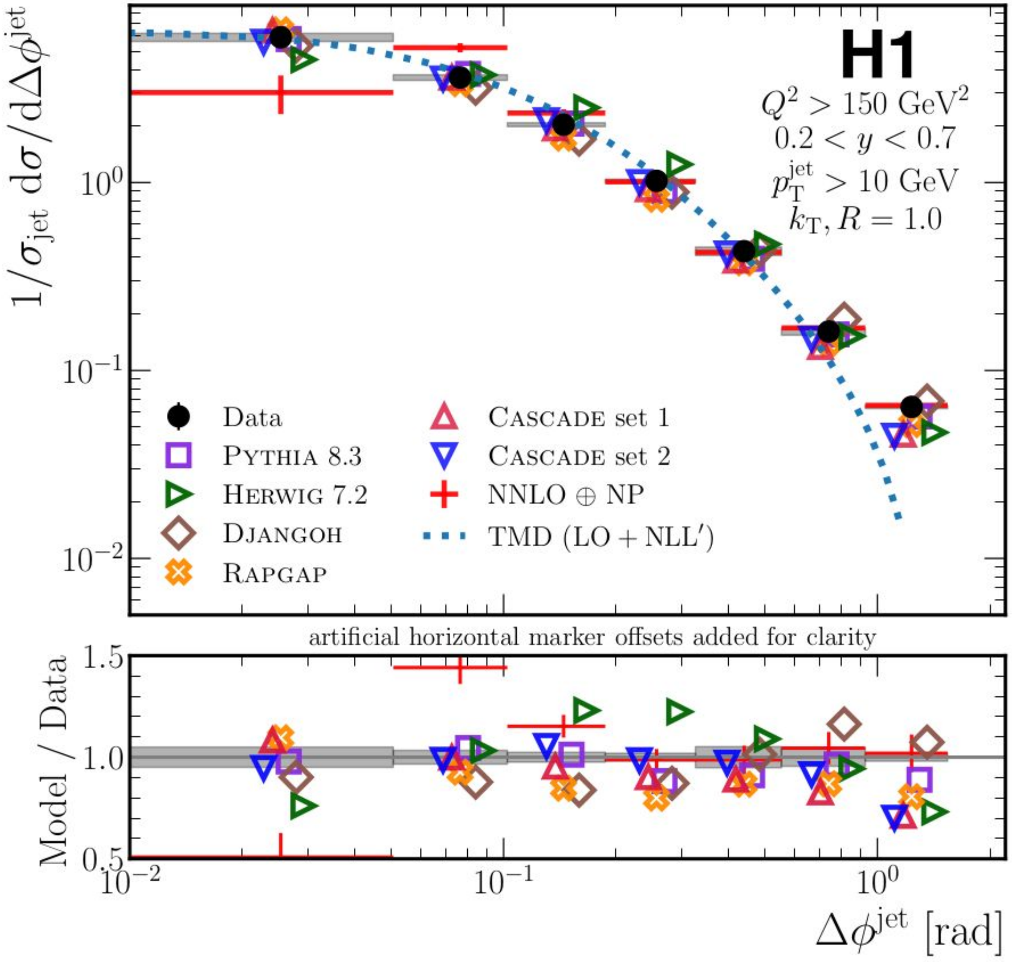


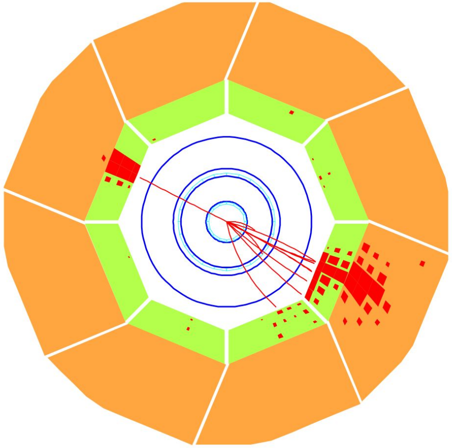
Textbook example of "matching" between collinear and TMD frameworks

First time seen in DIS!

(not seen in fixed-target DIS)

Lepton-jet azimuthal correlations



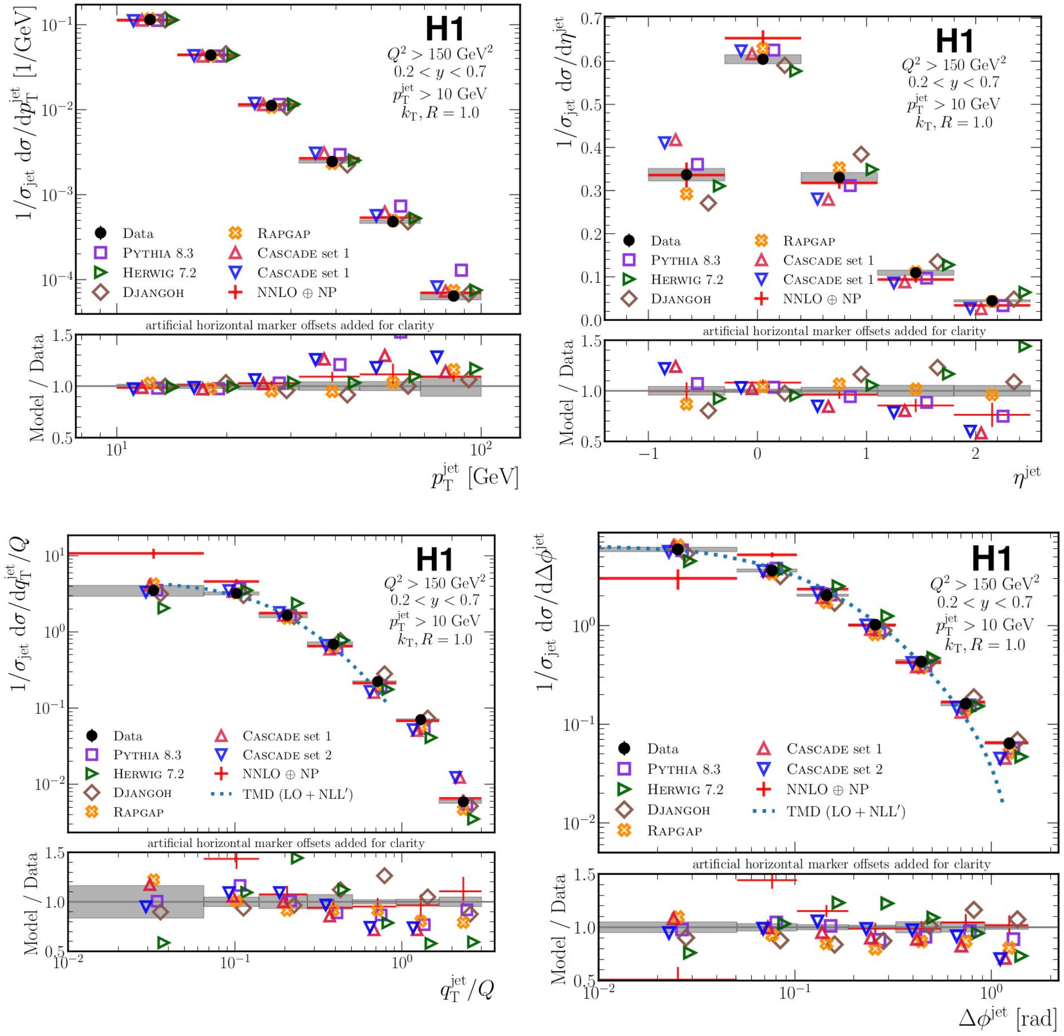


TMD calculation does a great job at low qT; collinear calculation does a great job at large qT.

Large overlap between collinear and TMD frameworks

Omnifold allowed us to do a simultaneous, unbinned “unfolding”

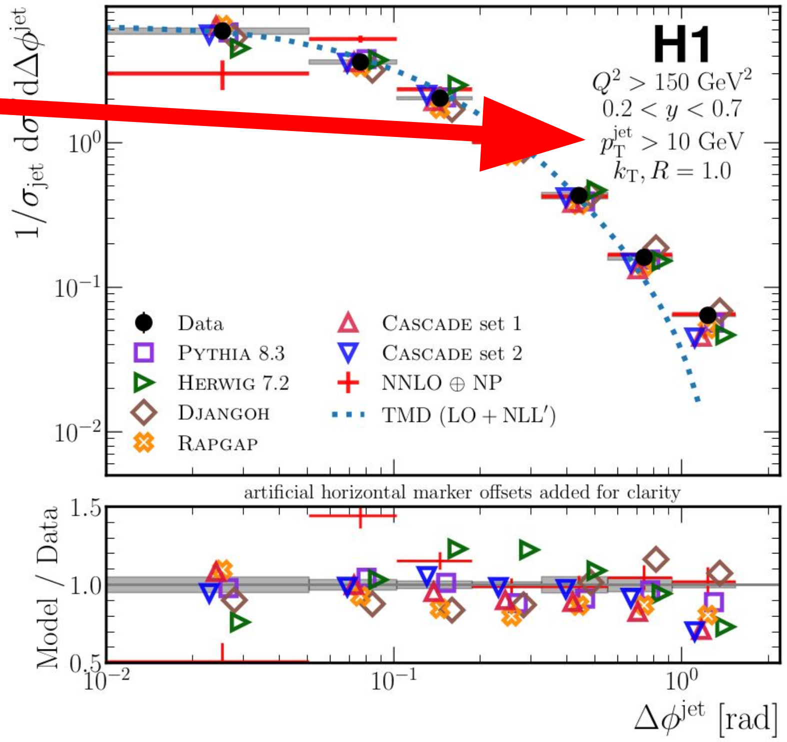
First-ever measurement that uses <u>machine-learning</u> to correct for detector effects.



“But the jets at EIC will be too low energy to be interesting”

Said most people commenting jets @ EIC

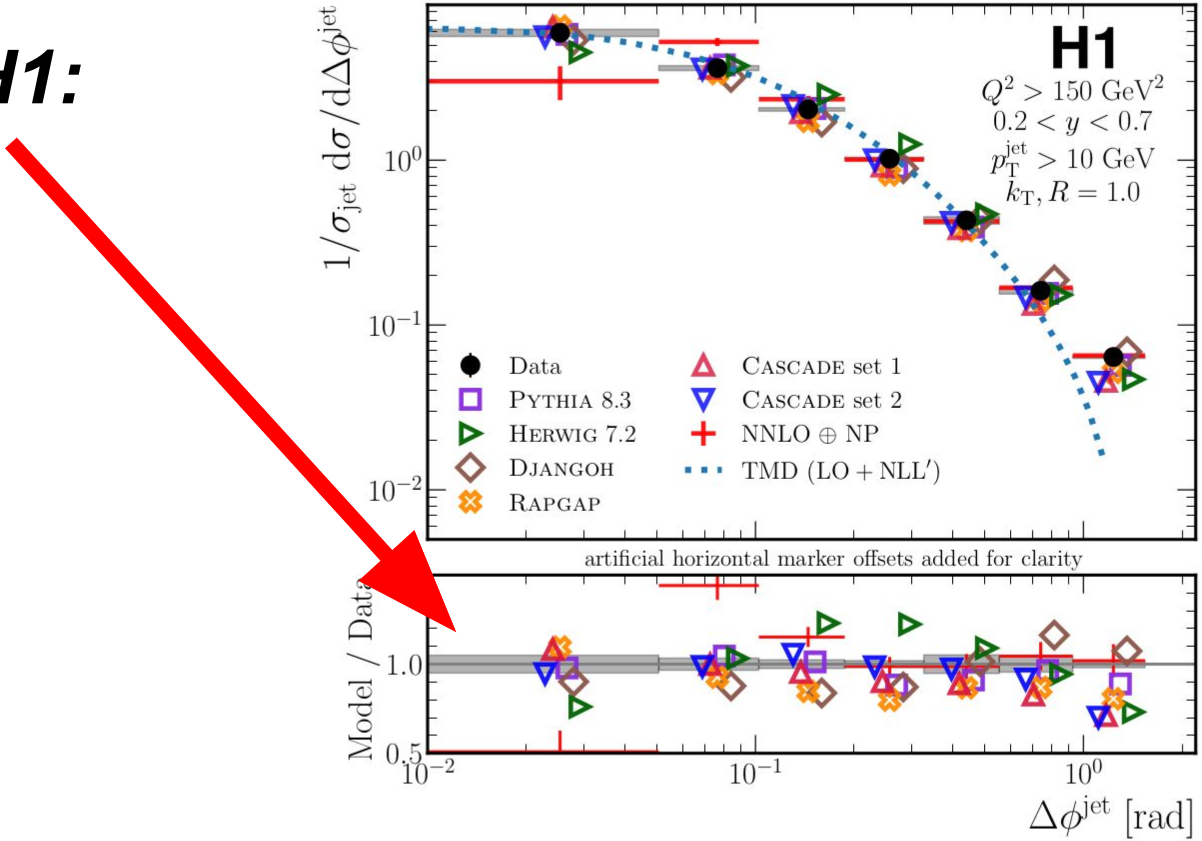
H1:



“But the uncertainties at low energy would be too large”

Said most people commenting jets @ EIC

H1:



“But you cannot do jet substructure with low-energy jets”

Said most people commenting jets @ EIC

H1:

H1prelim-22-034	**Jet Substructure at high Q**2 using machine learning**

H1prelim-22-032	**Charge asymmetry Jet substructure in DIS**

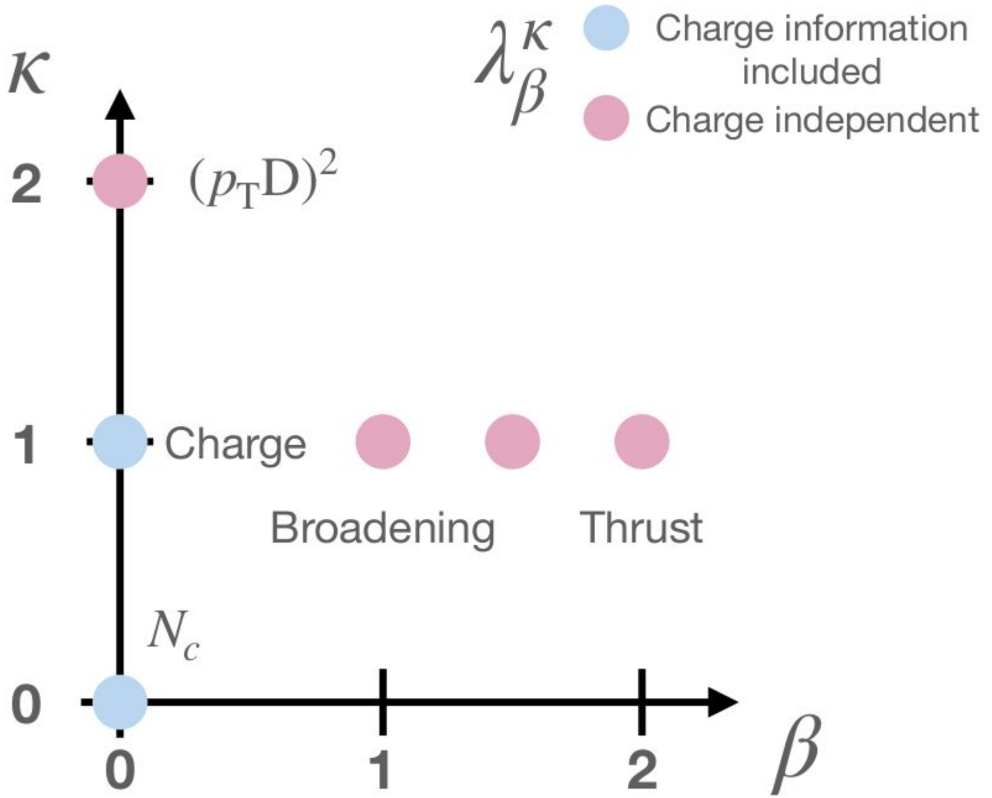
https://www-h1.desy.de/publications/H1preliminary.short_list.htm

Jet substructure observables with machine learning

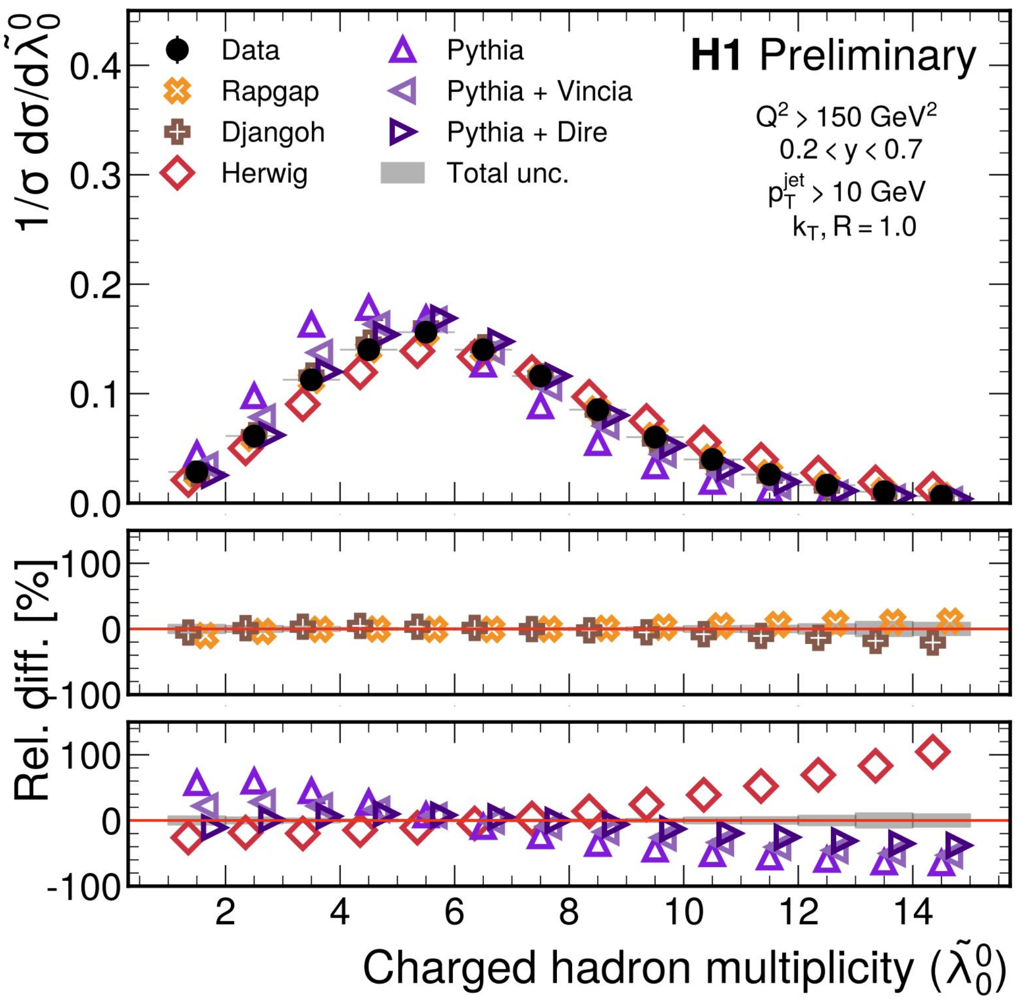
https://www-h1.desy.de/h1/www/publications/htmlsplit/H1prelim-22-034.long.html

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

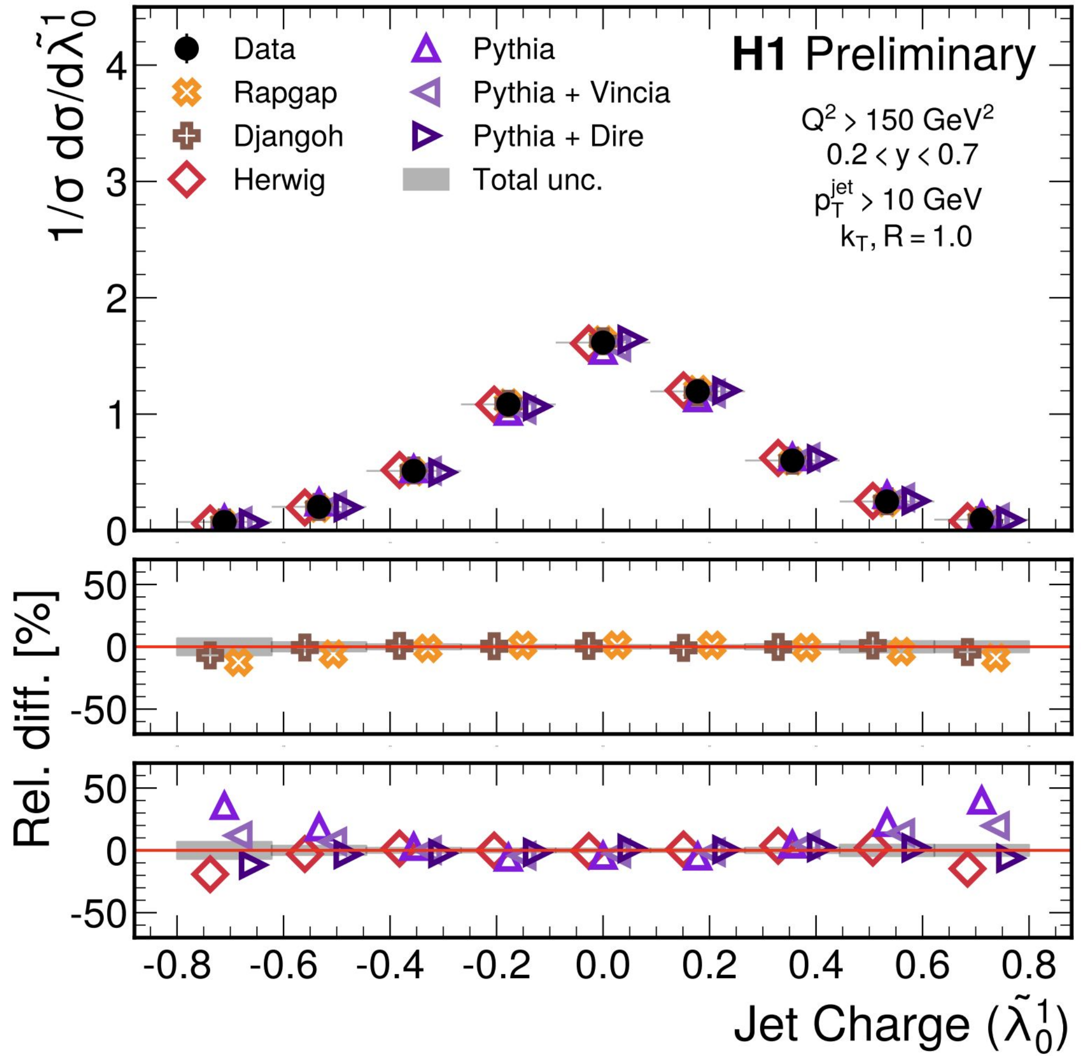
$$\tilde{\lambda}_0^\kappa = Q_\kappa = \sum_{i \in \text{jet}} q_i \times z_i^\kappa .$$



Charged hadron Multiplicity

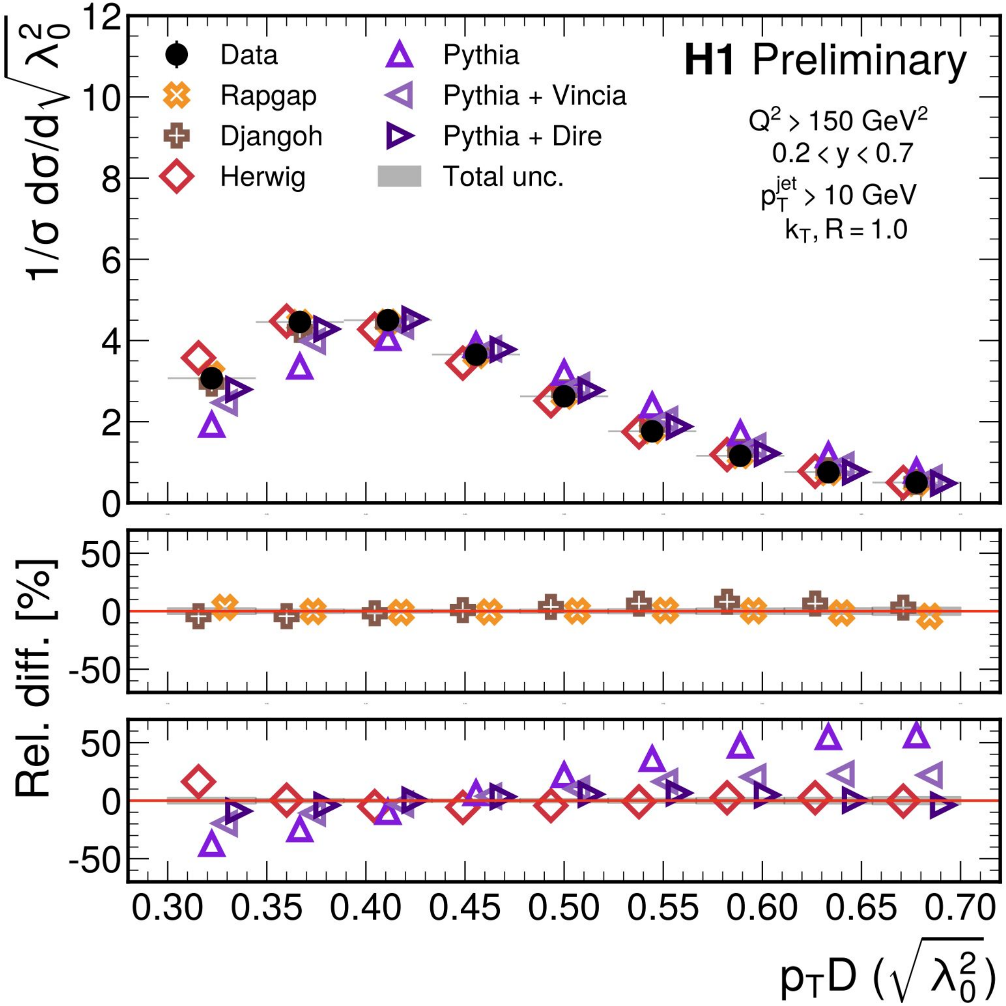


Jet charge



H1 Preliminary
Data
Rapgap
Djangoh
Herwig
Pythia
Pythia + Vincia
Pythia + Dire
Total unc.
$Q^2 > 150$ GeV^2
$0.2 < y < 0.7$
$p_T^{jet} > 10$ GeV
k_T, R = 1.0
$1/\sigma\ d\sigma/d\tilde{\lambda}_0^1$
Rel. diff. [%]
Jet Charge ($\tilde{\lambda}_0^1$)

Dispersion



H1 Preliminary
Data
Rapgap
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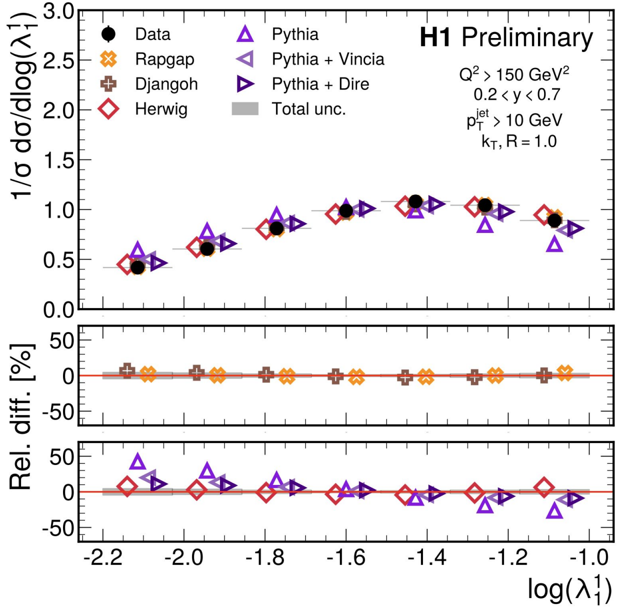
Pythia
Pythia + Vincia
Pythia + Dire
Total unc.
Q² > 150 GeV²
0.2 < y < 0.7
p_T^jet > 10 GeV
k_T, R = 1.0
1/σ dσ/d√λ₀²
Rel. diff. [%]
p_T D (√λ₀²)
0.30
0.35
0.40
0.45
0.50
0.55
0.60
0.65
0.70

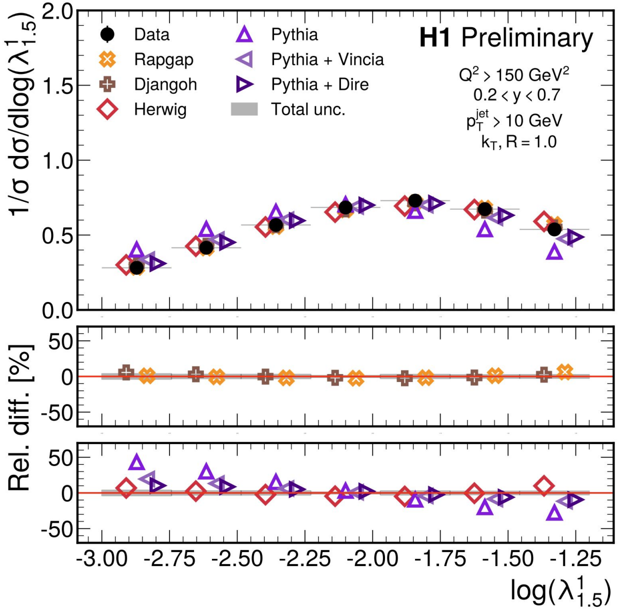
Angularities

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

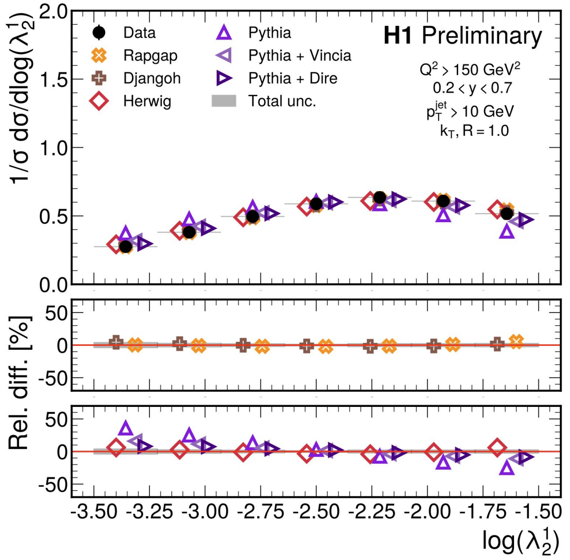
(1, 1)



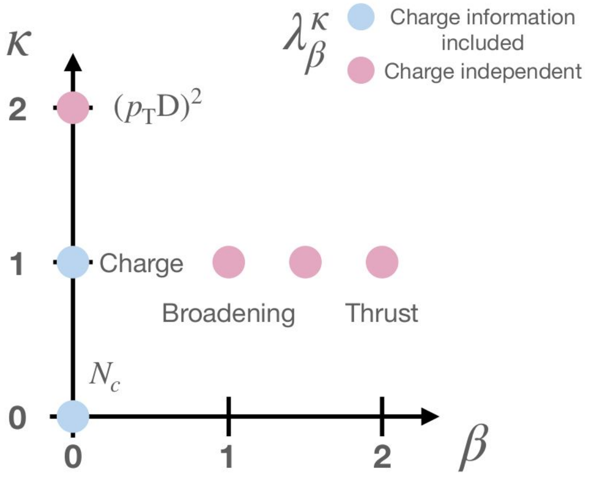
(1, 1.5)

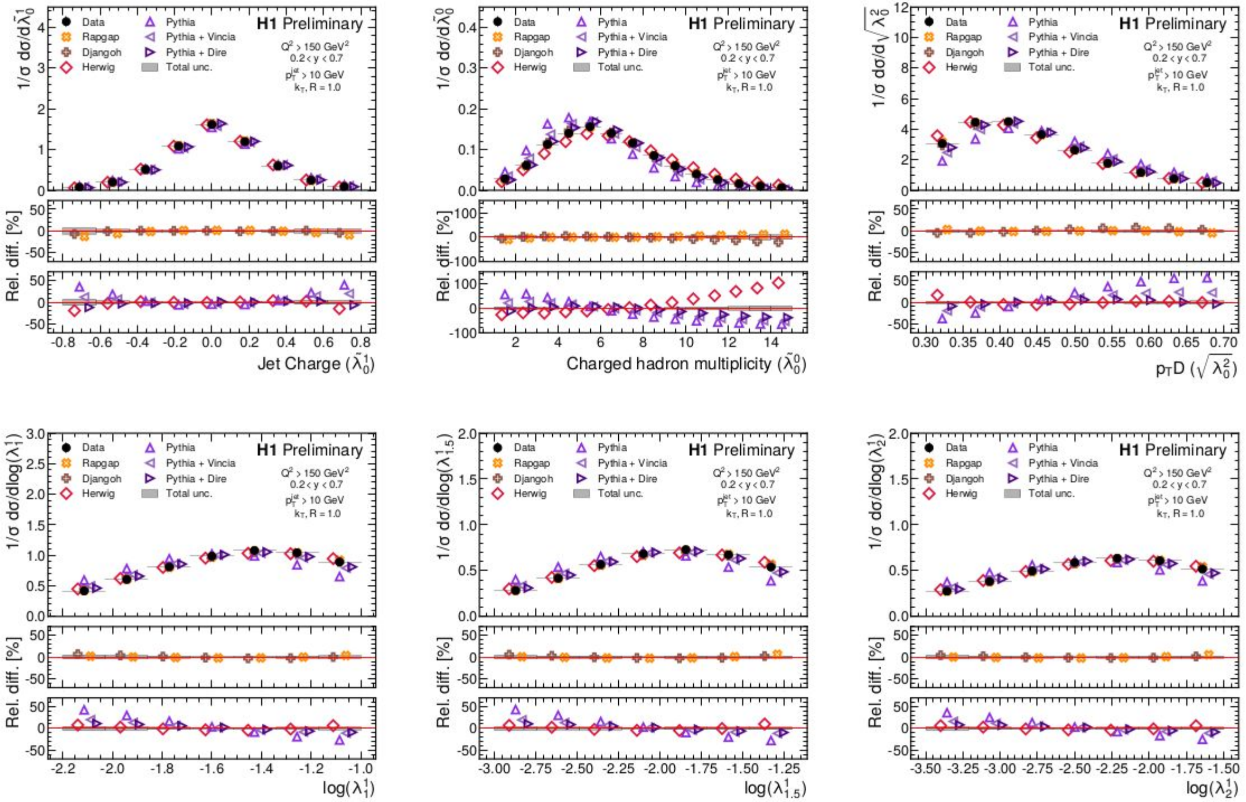


(1, 2)

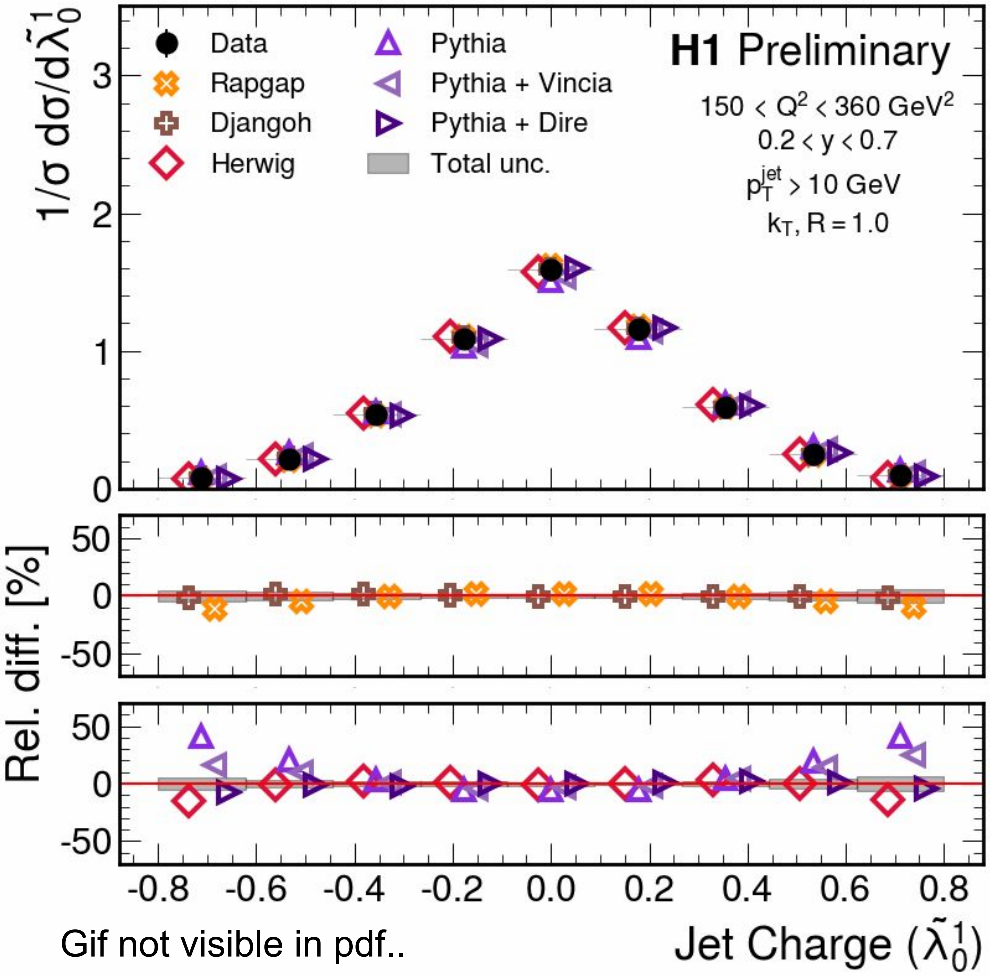


All of them unfolded simultaneously!!!



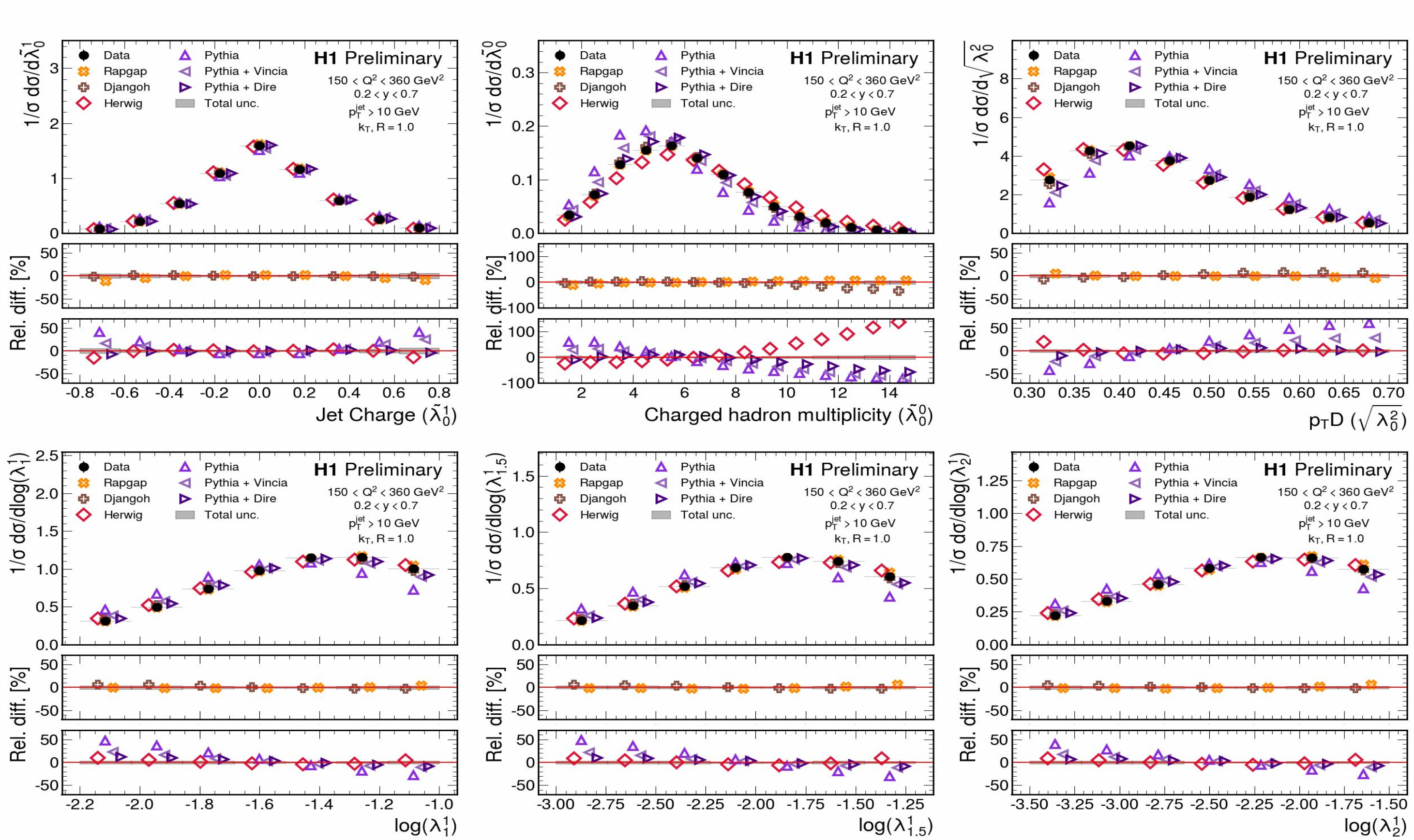


Differentially in Q2

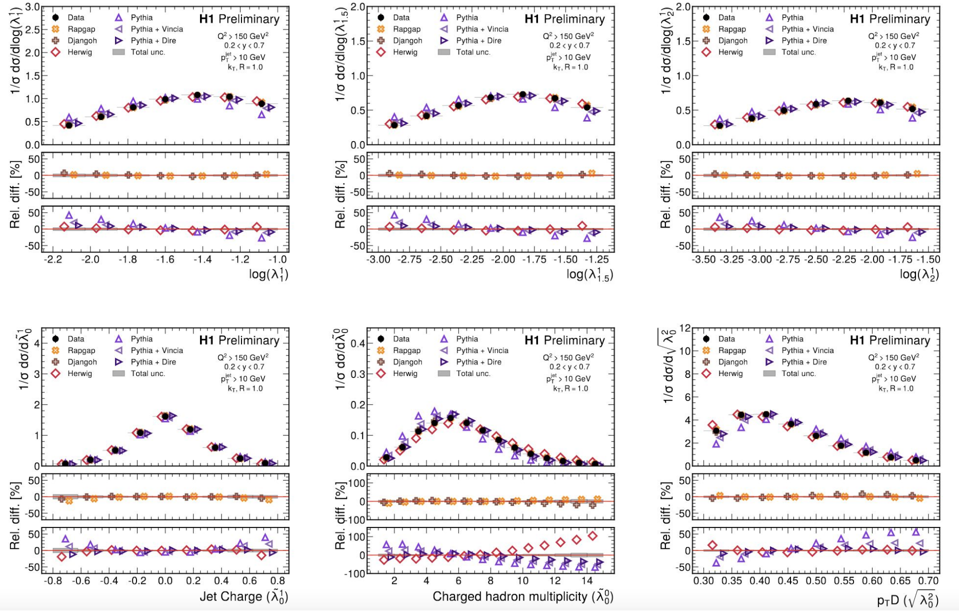


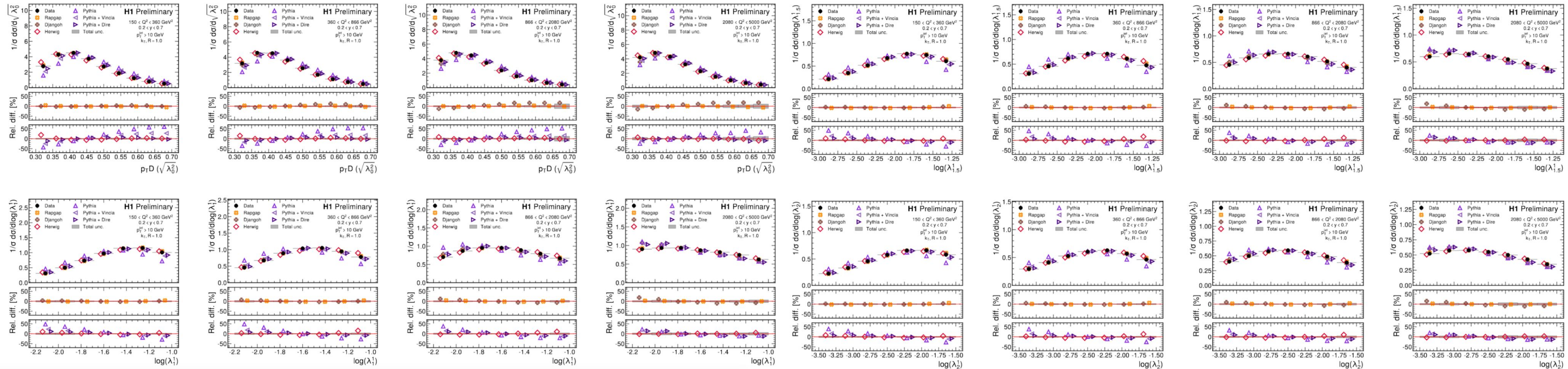
Gif not visible in pdf..

All of them unfolded simultaneously!!!
& differentially in Q2



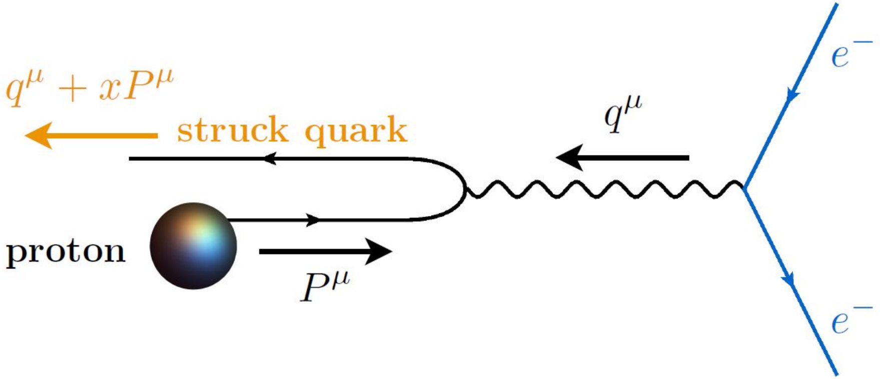
All unfolded simultaneously!





New methods needed to study Jet in Breit Frame

Like Centauro algorithm Phys. Rev. D 104, 034005 (2021)



$$d_{ij} = (\bar{\eta}_i - \bar{\eta}_j)^2 + 2\bar{\eta}_i\bar{\eta}_j(1 - \cos(\phi_i - \phi_j))$$

$$\bar{\eta}_i \equiv - \frac{2Q}{\bar{n} \cdot q} \frac{p_i^\perp}{n \cdot p_i}$$

fastjet.hepforge.org/contrib/contents/1.049.html

- fastjet.fr
- fastjet-contrib
- contrib list
- contrib svn

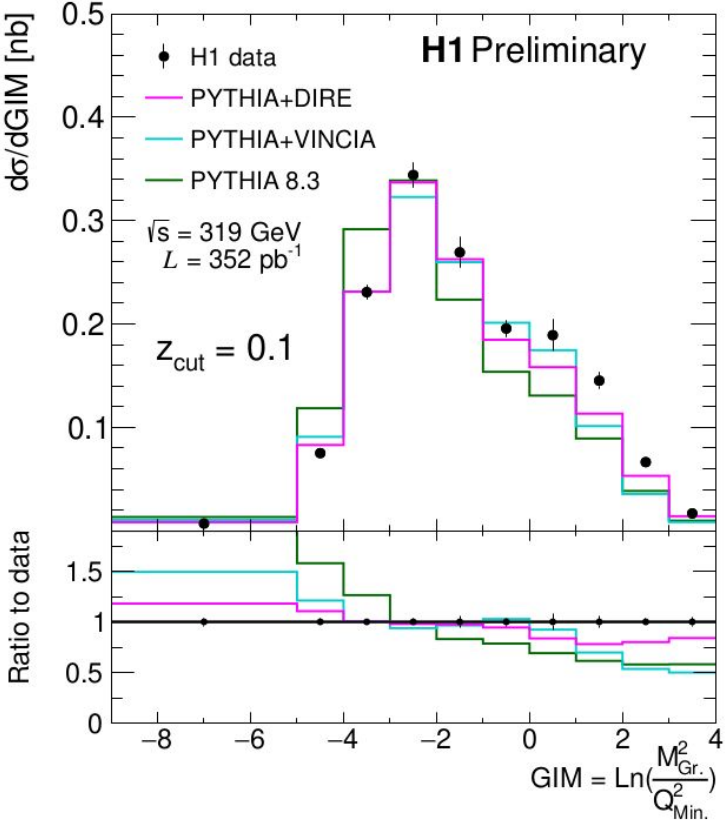
Version 1.049 of FastJet Contrib is distributed with the following packages

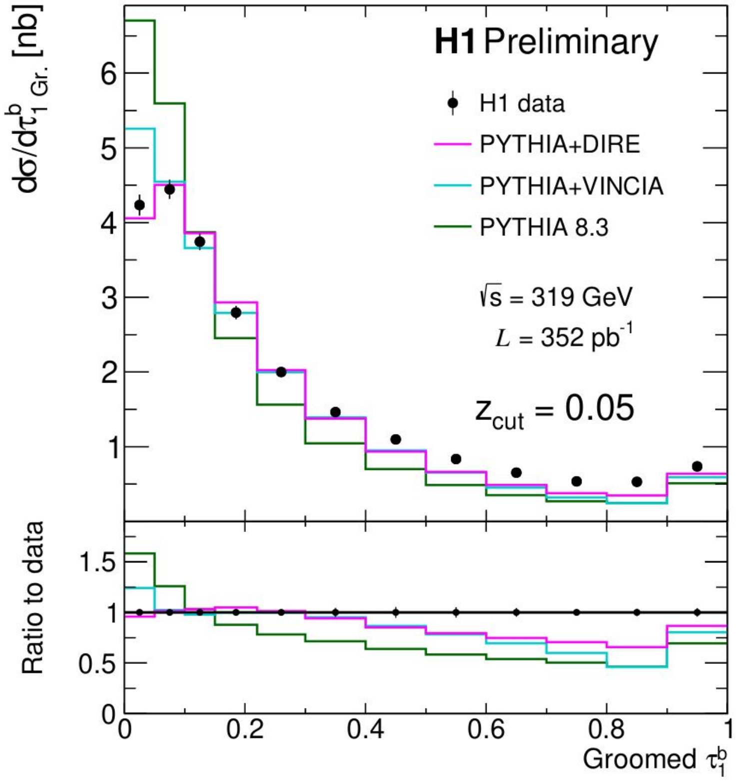
Package	Version	Release date	Information
Centauro	1.0.0	2020-08-04	README NEWS
ClusteringVetoPlugin	1.0.0	2015-05-04	README NEWS
ConstituentSubtractor	1.4.5	2020-02-23	README NEWS
EnergyCorrelator	1.3.1	2018-02-10	README NEWS

Easy to use for your EIC studies

Event shapes with grooming using Centauro metric

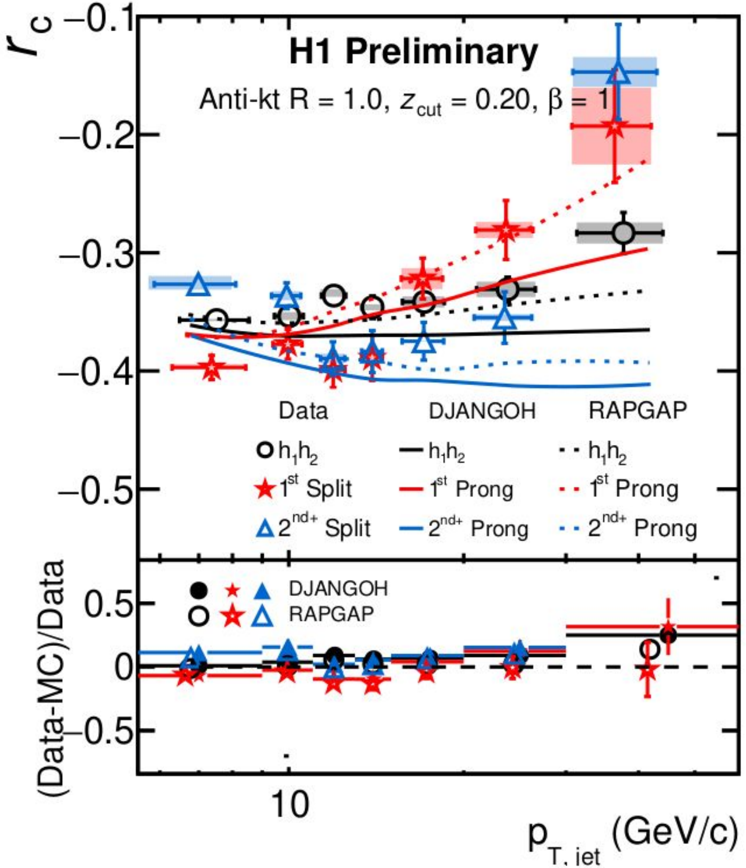
https://www-h1.desy.de/h1/www/publications/htmlsplit/H1prelim-22-033.long.html

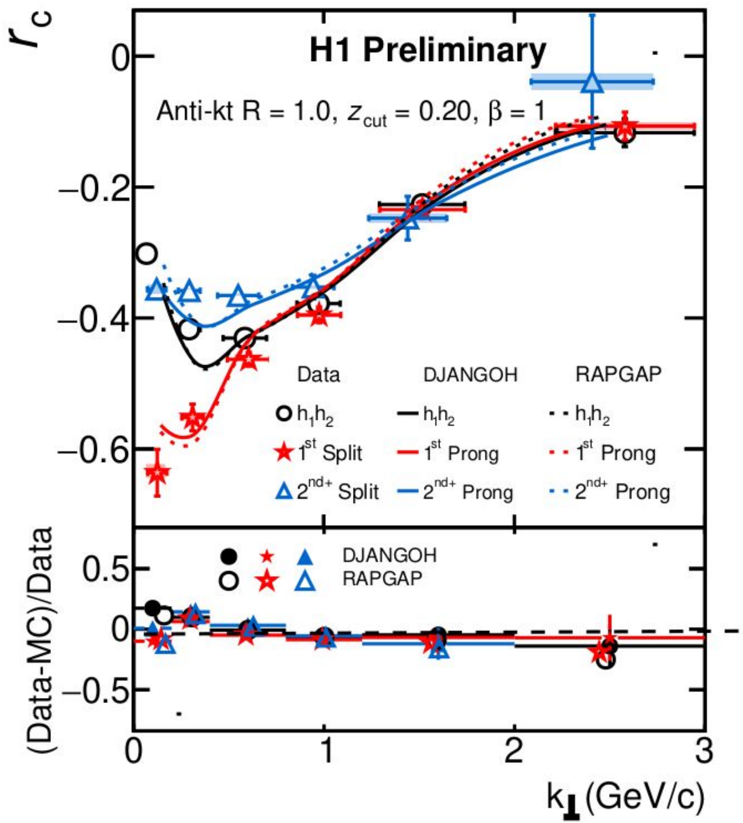




Charge-asymmetryjet substructure

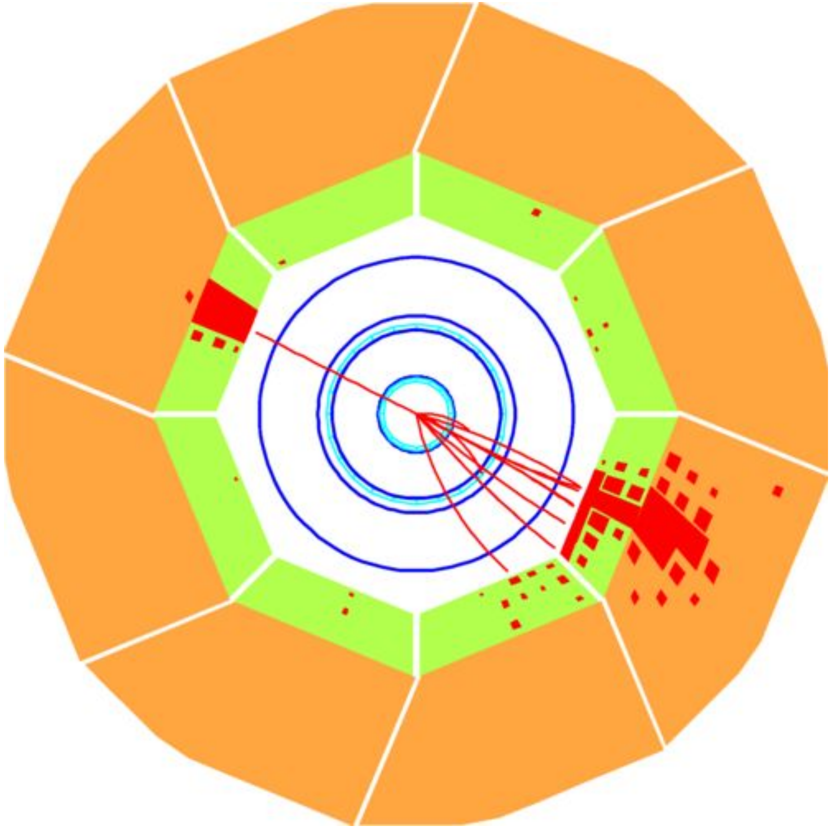
https://www-h1.desy.de/h1/www/publications/htmlsplit/H1prelim-22-032.long.html





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

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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

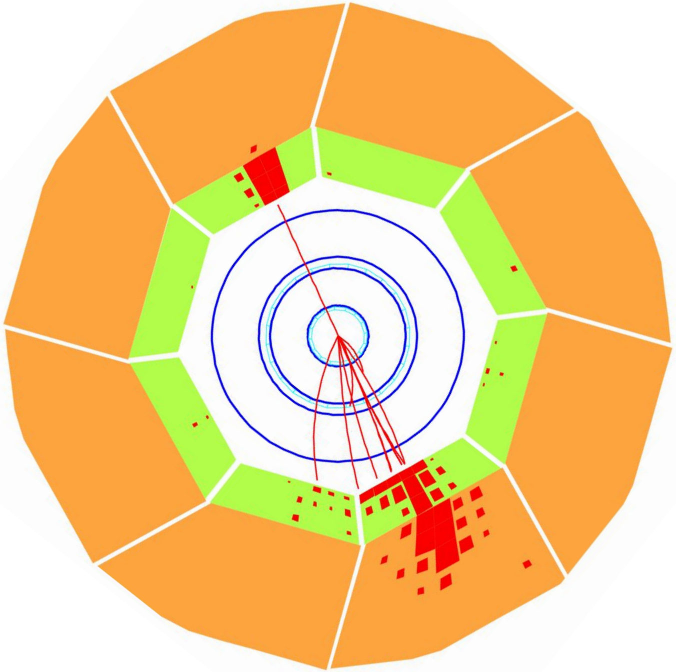
Stay tuned.
Just the beginning of a new & rich jet program

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

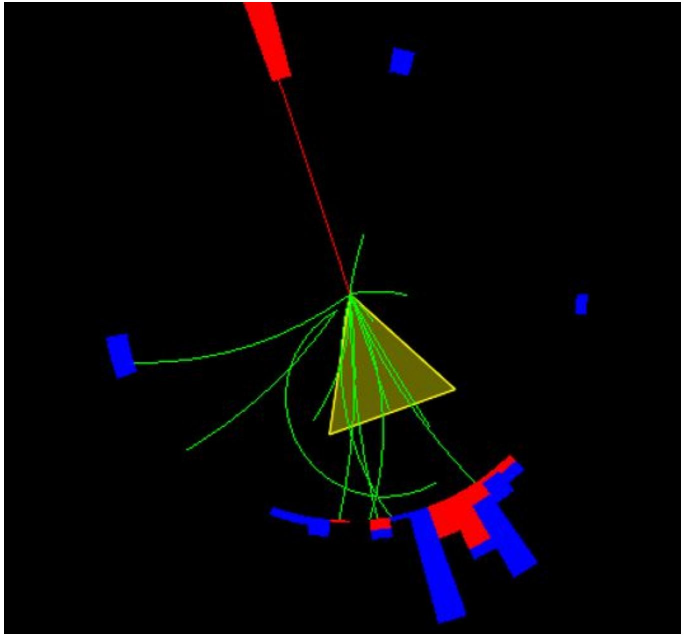
H1 team at DIS22 in Santiago de Compostela

H1 had 5 contributed talks showing new jet-related results!

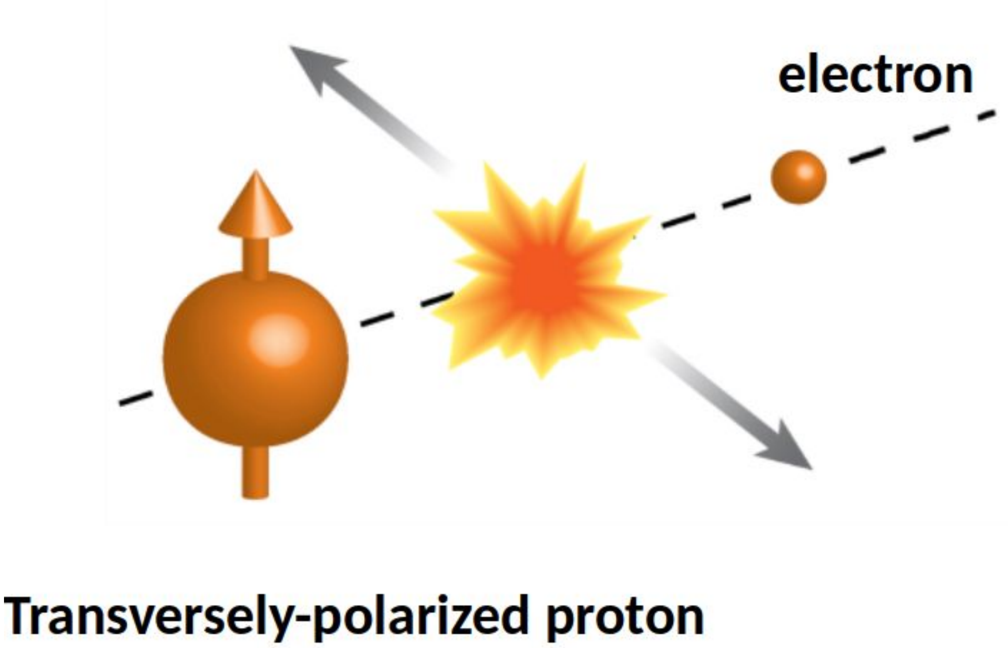
H1@HERA

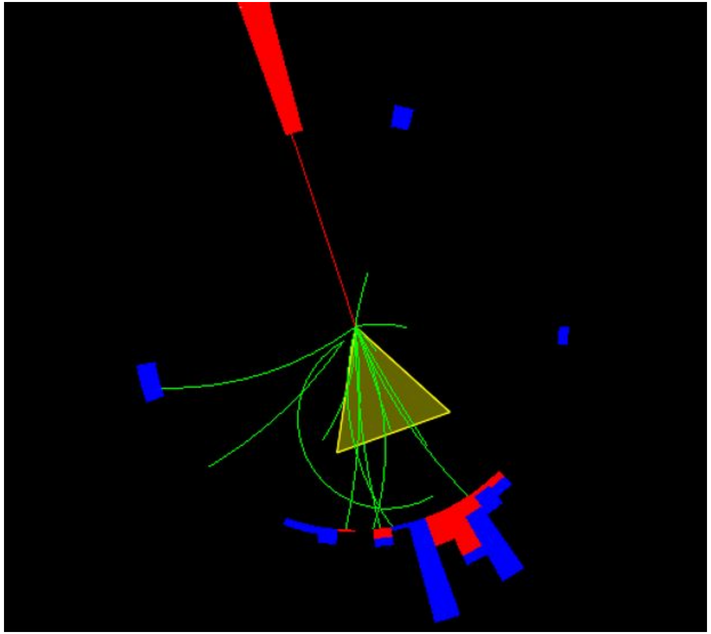


EIC

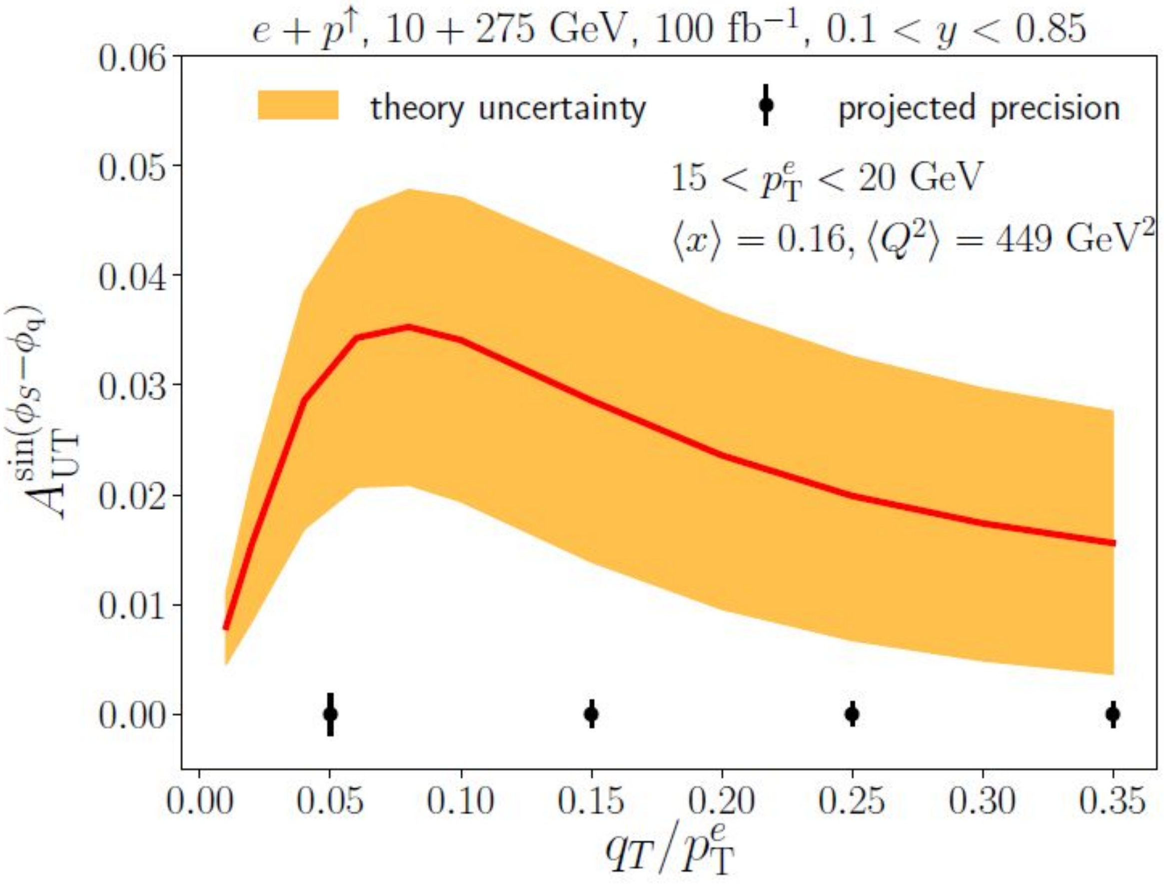


Spin-orbit correlations lead to azimuthal asymmetries

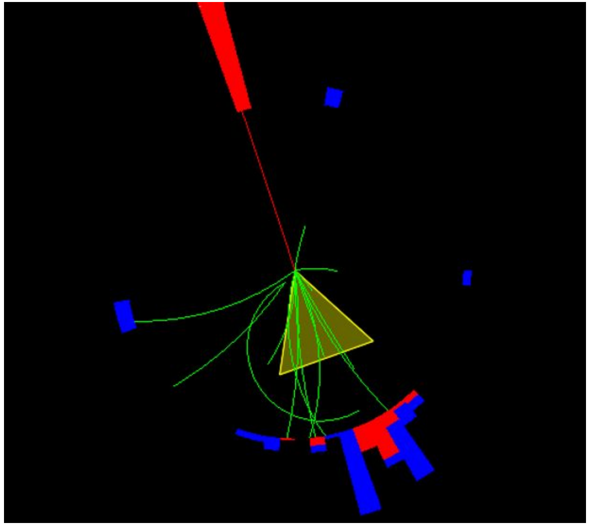




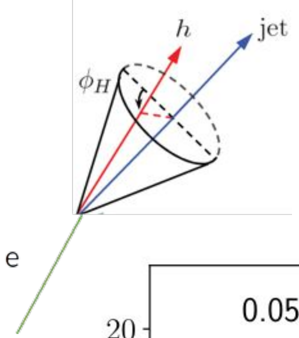
Projection for Lepton-jet Sivers asymmetry



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

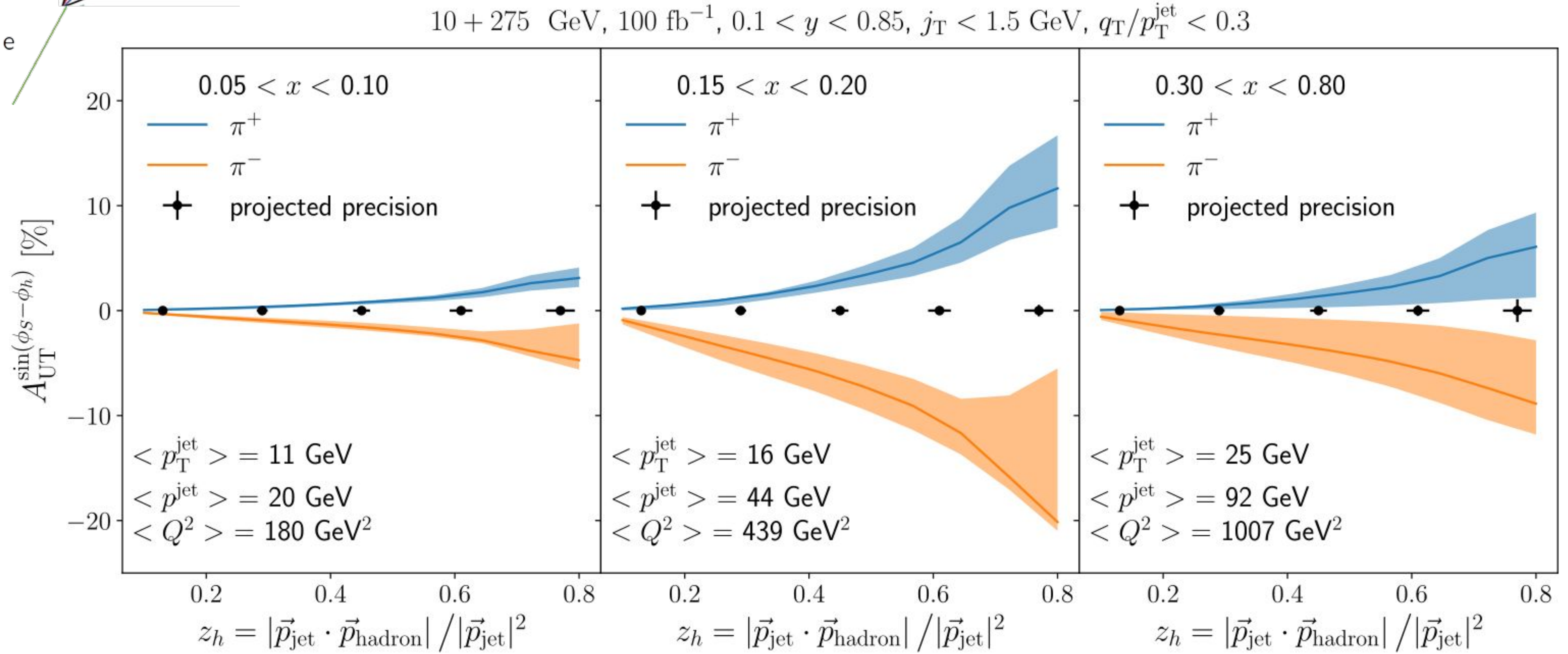


Prediction & projection in PRD 102, 074015 (2020)
Based on formalism in Liu et al. PRL. 122, 192003



Hadron-in-jet Collins asymmetry at EIC

PRD 102, 074015 (2020)



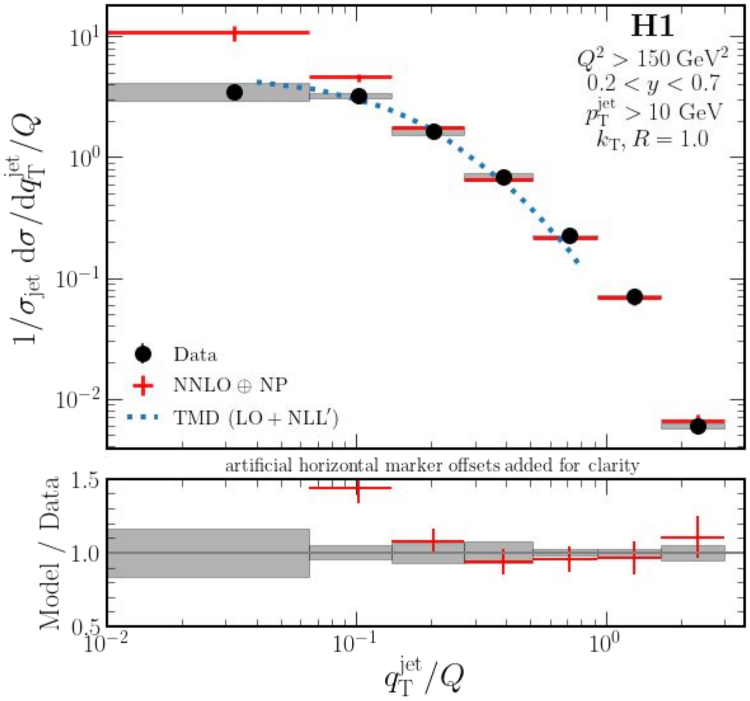
Summary

- New 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)

- This is the first measurement in a series of studies that aim at creating a **pathfinder program for the future EIC**

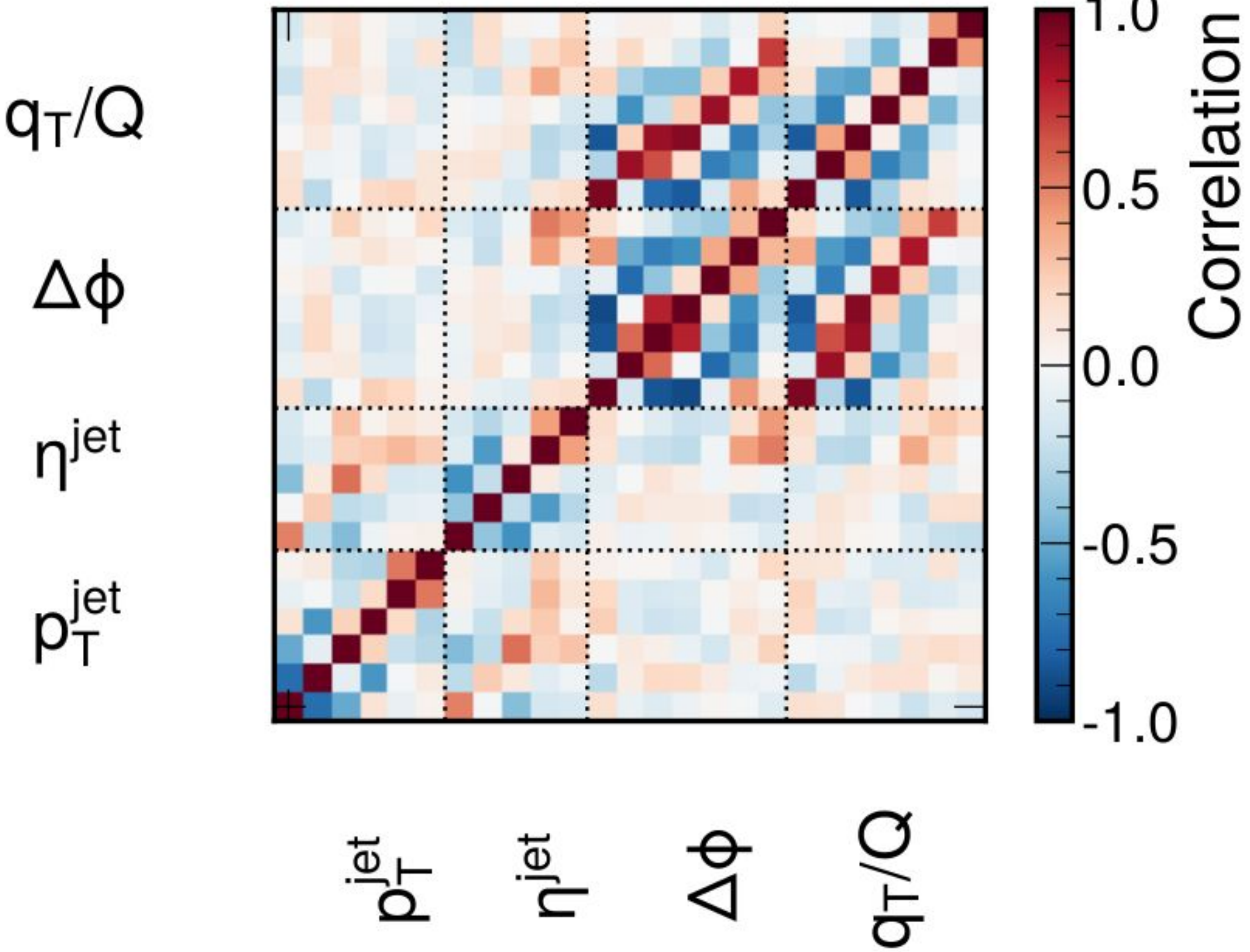


backup

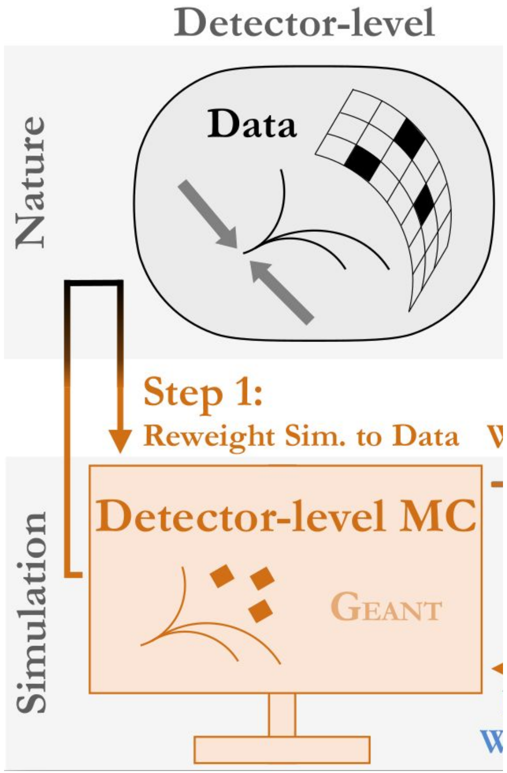
Correlation matrix

- Simultaneous Unfolding of these observables

- Unbinned (binned here for reference)

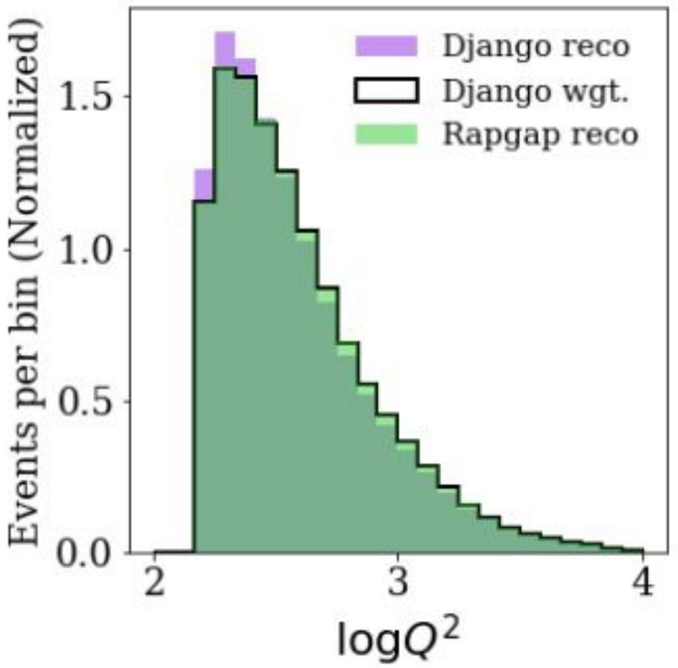


Reweighting the reco-level distributions

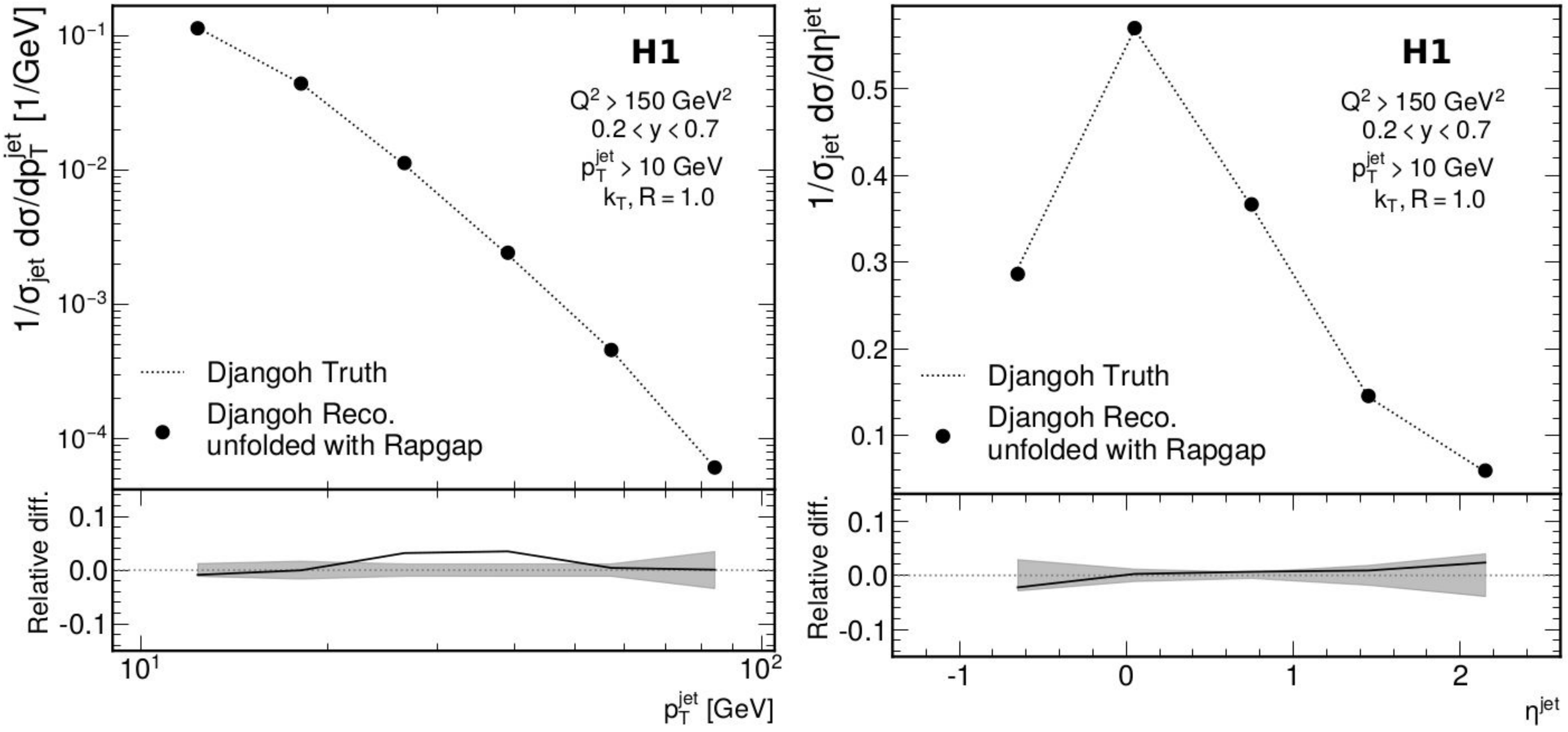


We use simple fully connected networks with a few hidden layers.

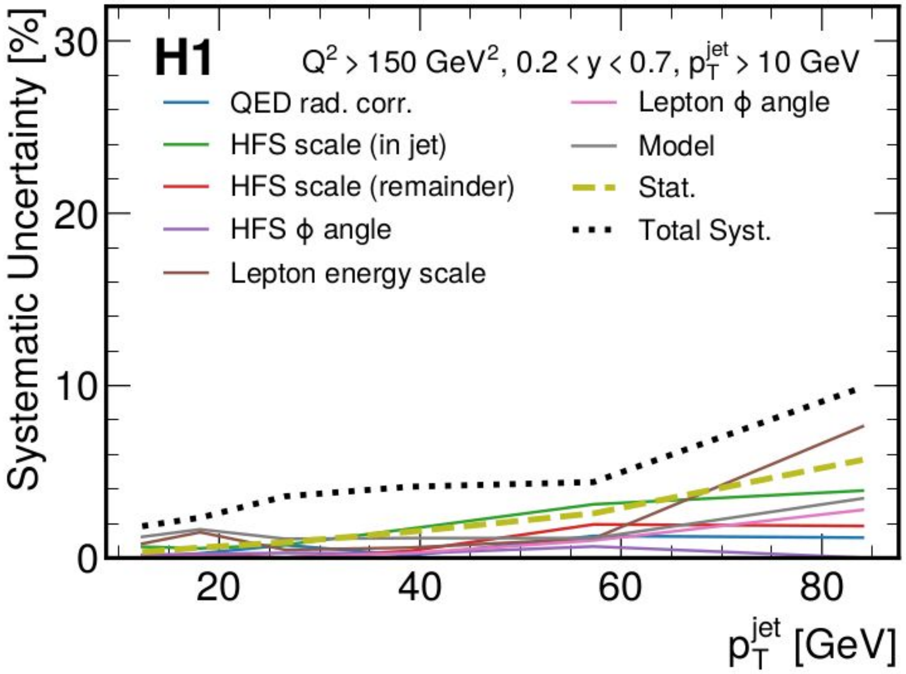
The distribution is binned for illustration, but the reweighting is unbinned.

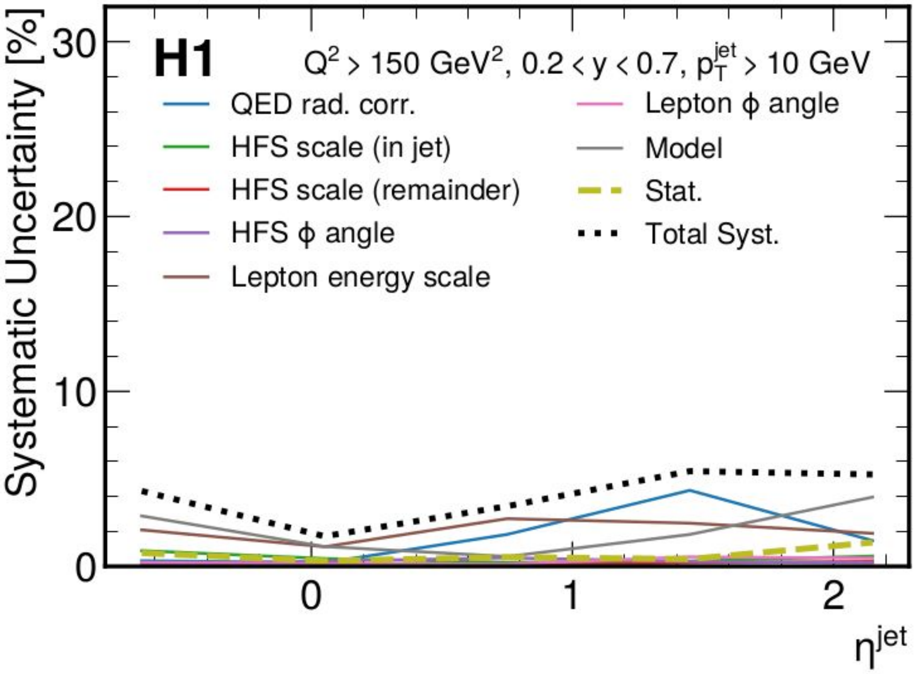


Closure tests (Pseudo Data: Django, Response: Rapgap)

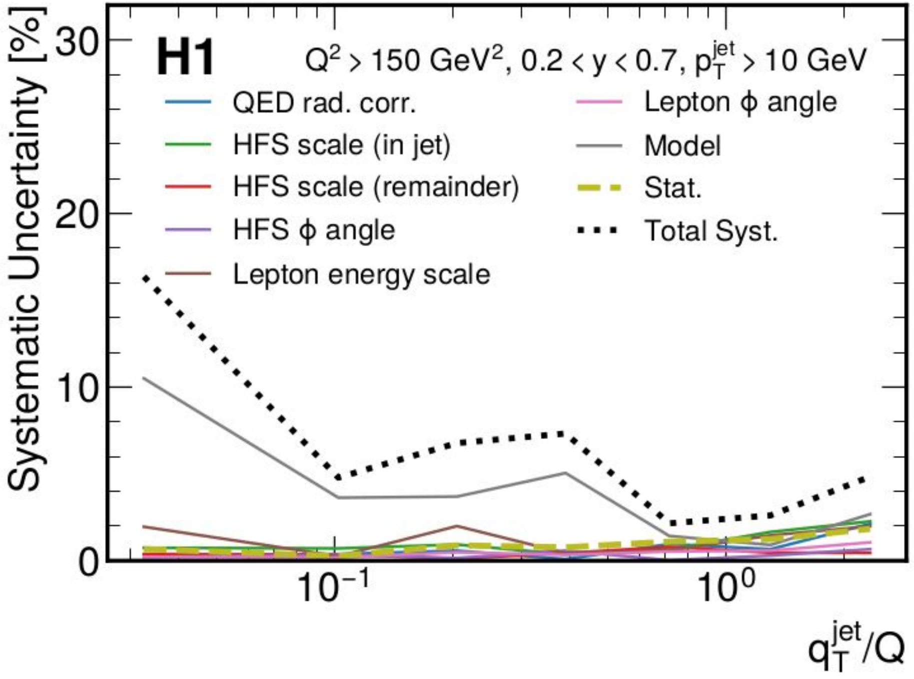


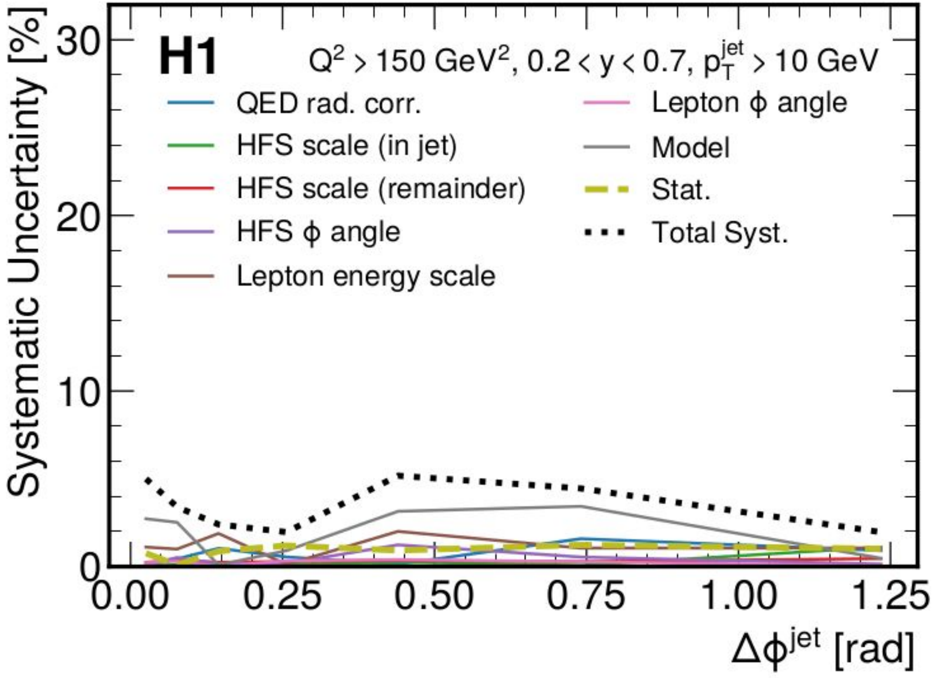
Systematic uncertainties



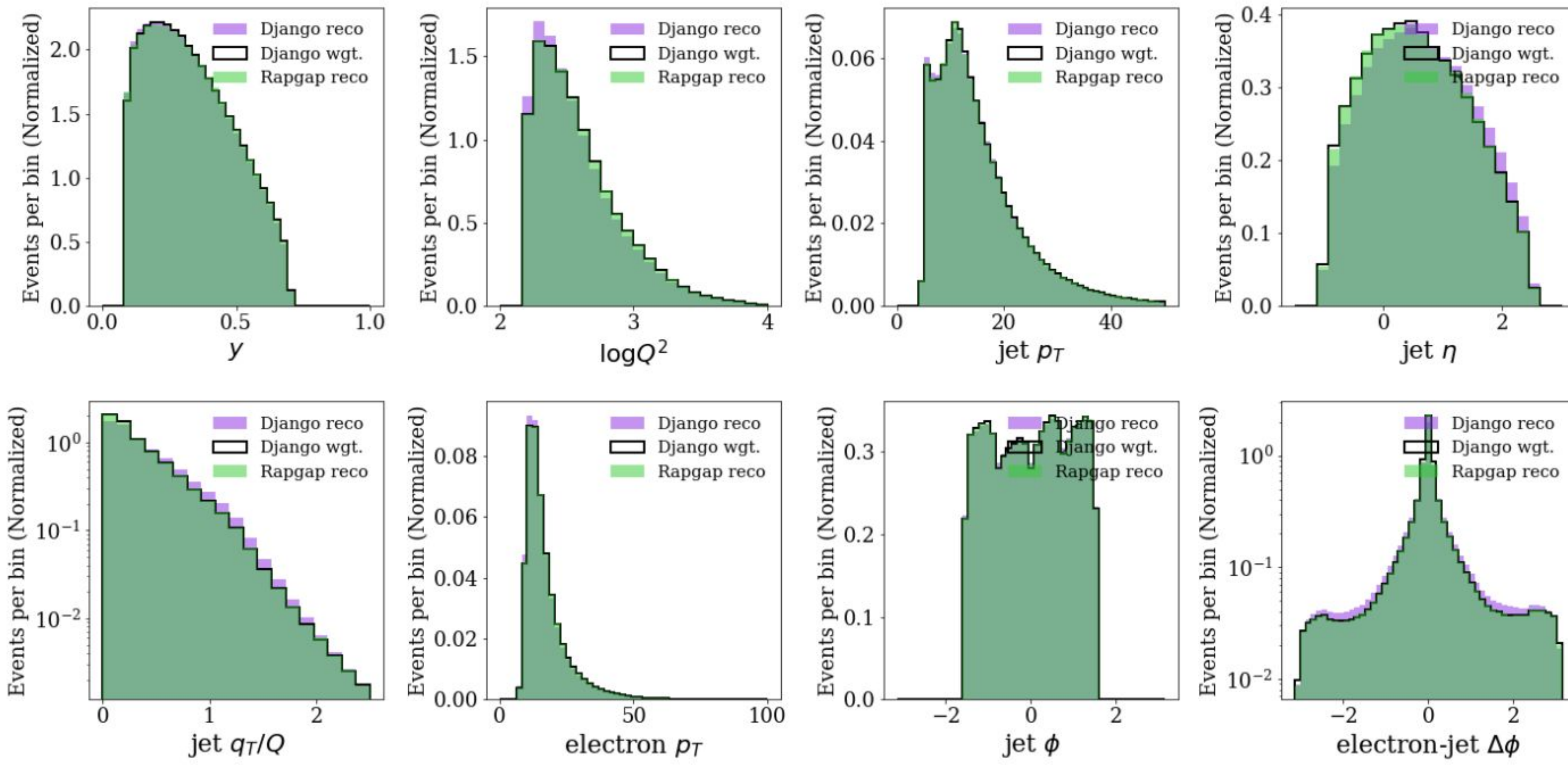


Systematic uncertainties

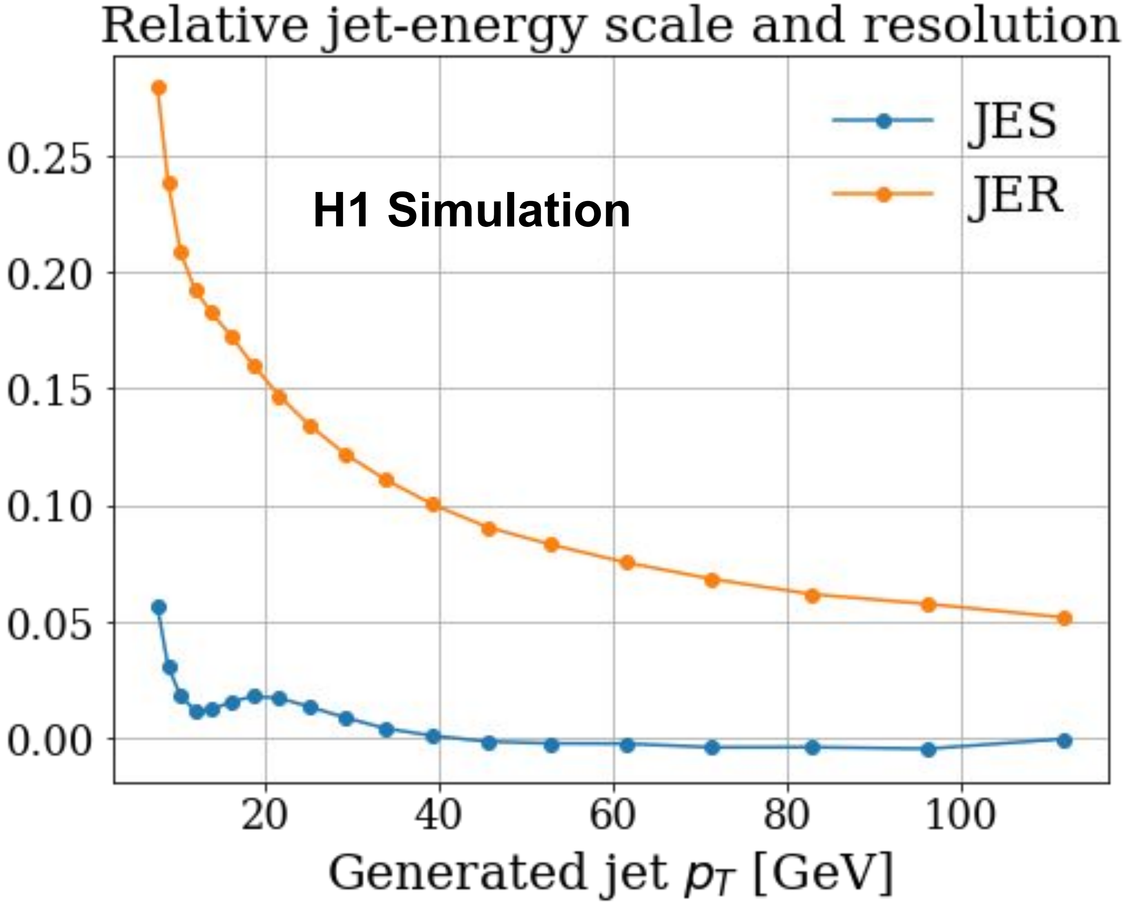




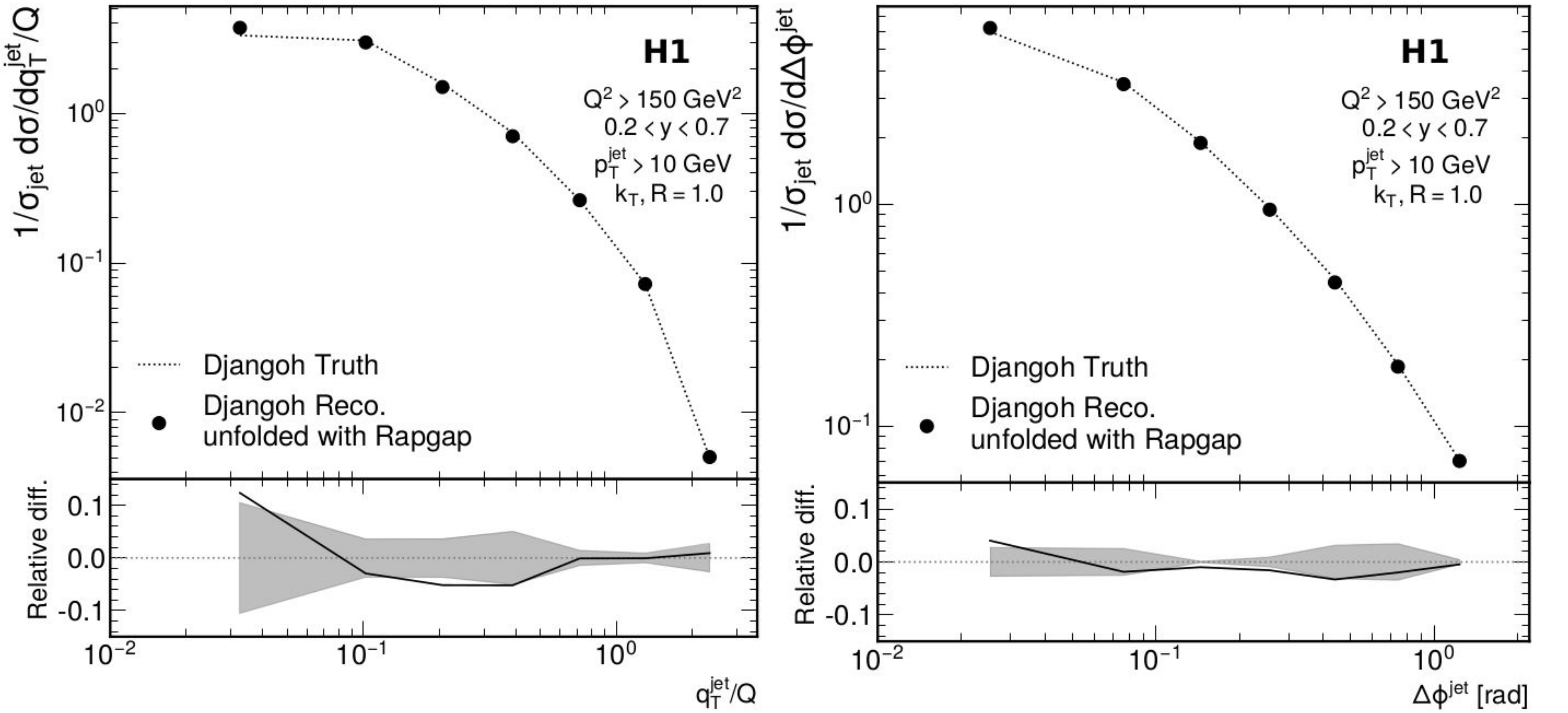
All these distributions are simultaneously reweighted



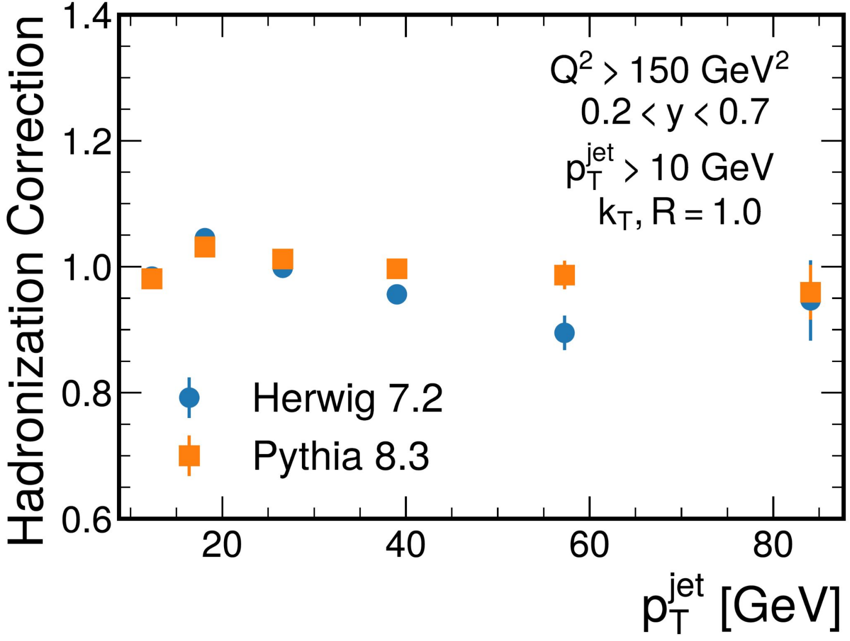
Jet performance
(energy flow reconstruction)

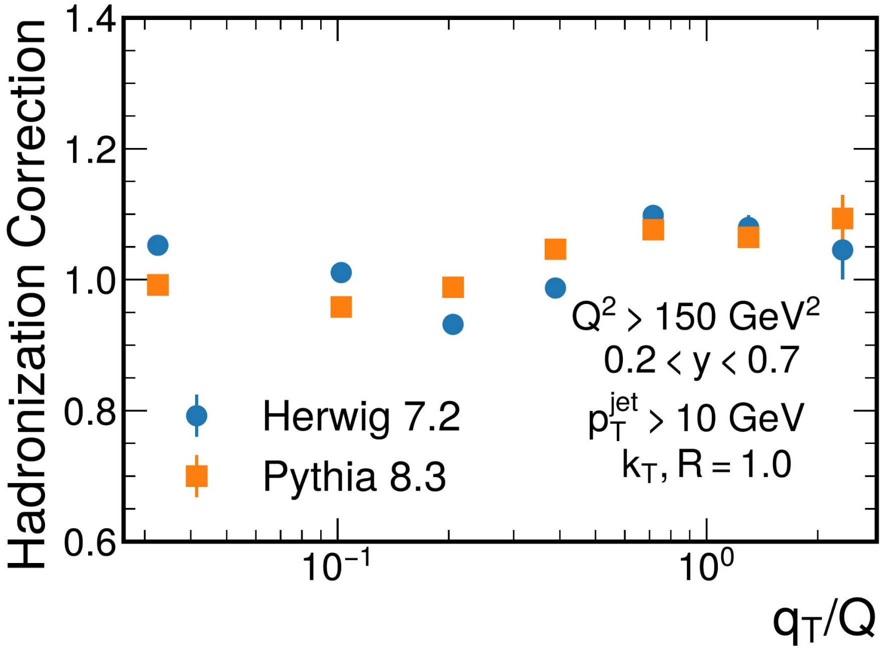


Closure tests (Pseudo Data: Django, Response: Rapgap)



Hadronization corrections (applied to NNLO calculation)





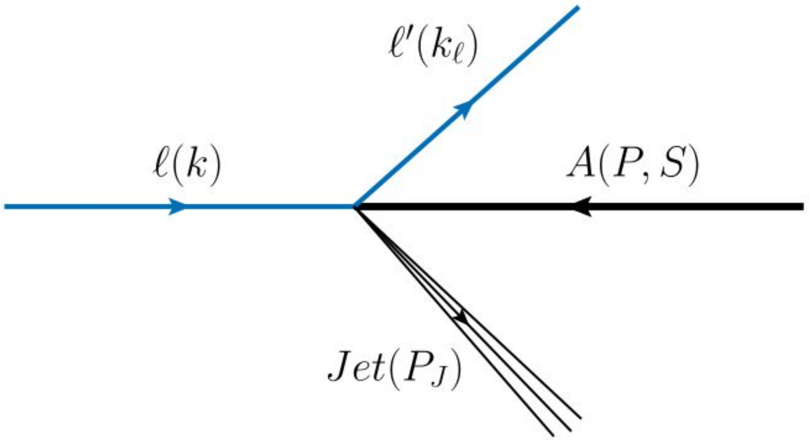
Small, and consistent with Pythia8 and Herwig despite different models of hadronization

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)

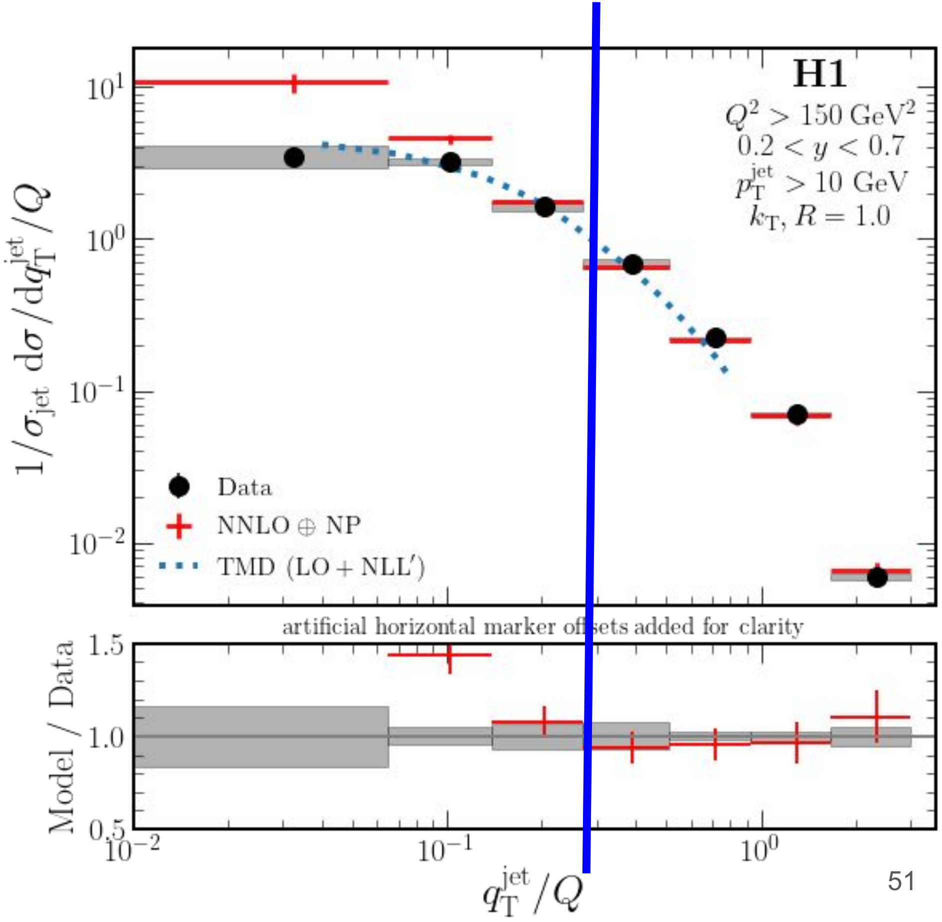


$$\frac{d^5\sigma(\ell p \to \ell' J)}{dy_\ell d^2k_{\ell\perp} d^2q_\perp} = \sigma_0 \int d^2k_\perp d^2\lambda_\perp x f_q(x, k_\perp, \zeta_c, \mu_F) \times H_{\rm TMD}(Q, \mu_F) S_J(\lambda_\perp, \mu_F) \times \delta^{(2)}(q_\perp - k_\perp - \lambda_\perp).$$

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 calculations by F. Yuan and Z. Kang, TMD PDFs and soft factors extracted from low Q2 DIS and DY data. Sun et al. arXiv:1406.3073



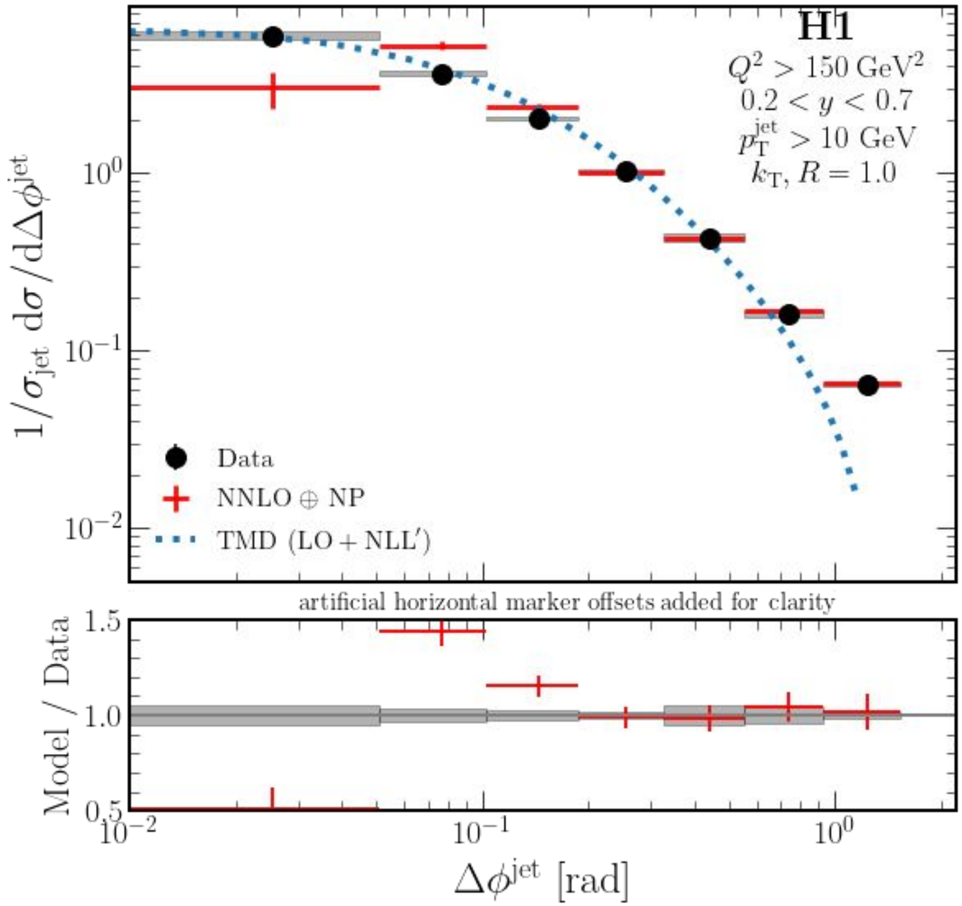
https://www-h1.desy.de/publications/H1preliminary.short_list.html

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 **Figures:** (1a) (1b) (2) (3a) (3b) (4) (5) (6) (7a) (7b) (8) (9) (10) (11) (12) (13) (use mouse for preview)

Stay tuned.

Just the beginning of a new, rich program in DIS

Azimuthal correlation



Textbook example of "matching" between collinear and TMD frameworks

First time seen in DIS!

(not seen in fixed-target DIS)