



This talk covers 4 preliminary results from H1:

- [H1Prelim-21-032](#): 1-jettiness
- [H1Prelimi-22-033](#): groomed event shapes
- [H1Prelim-22-032](#): jet substructure using correlation between leading and sub-leading charged particles
- [H1Prelimi-22-034](#): jet substructure using Machine Learning technique



Introduction

H1 was a general purpose detector at the unique electron-proton collider HERA, operated over 15 years until 2007



Neutral and charged current Deep Inelastic Scattering (DIS) processes are the dominant processes



Their cross sections have been the primary source for constraining proton's PDFs (Parton Distribution Functions)

Preserved data and modernised analysis codes ([EPJC Web Conf 251 \(2021\) 03004](#)) have been actively used in recent years as a testing ground for a future Electron Ion Collider (EIC)

Common Features of the Presented Analyses

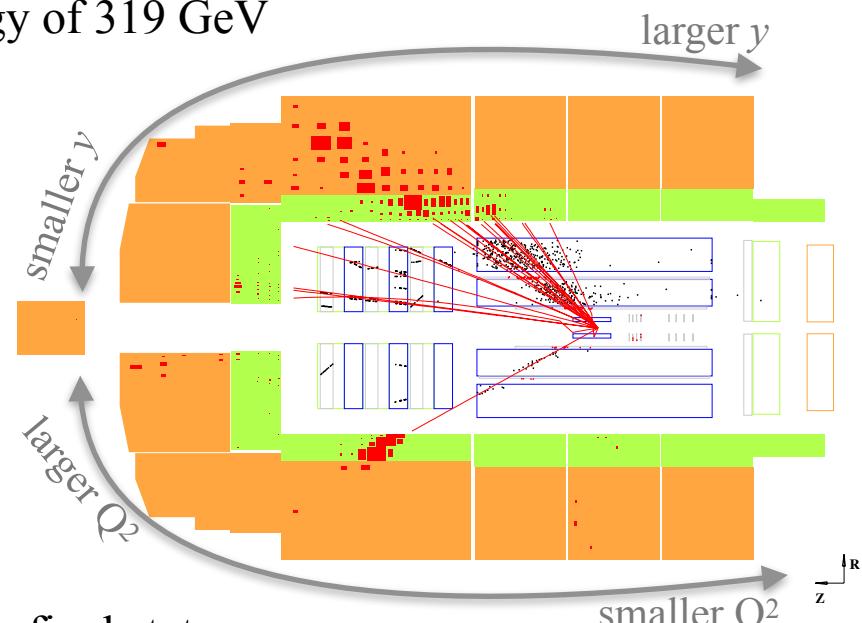
All are based on data samples taken in 2003-2007 corresponding to an integrated luminosity of $\sim 350 \text{ pb}^{-1}$ at a center-of-mass energy of 319 GeV

Kinematic regions:

$$Q^2 > 150 \text{ GeV}^2$$

$$y: 0.2-0.7$$

Q^2 being the boson's momentum transfer q squared,
 y being the inelasticity



Event shape variables use (selected) NC inclusive final states

Jet substructure studies are of course based on jets

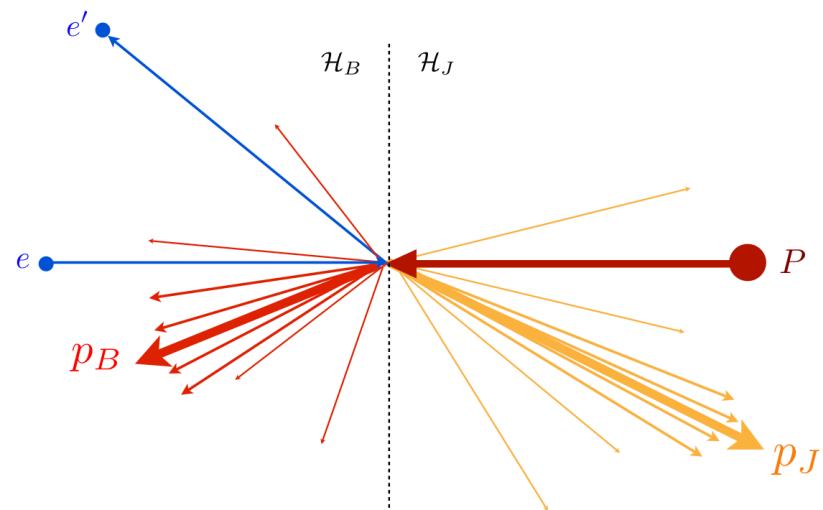
1-Jettiness Event Shape Variable

The general N-jettiness τ_N for $N+N_B$ was introduced [here](#) where N is the number of jets in the final state and N_B is the number of initial-state beam directions (for DIS $N_B=1$)

1-jettiness τ_1 is a special case when $N=1$

$$\tau_1 = \frac{2}{Q^2} \sum_{i \in X} \min\{q_B \cdot p_i, q_J \cdot p_i\},$$

1-jettiness τ_1^b is yet another special case when $q_B = xP$ and $q_J = q + xP$ as defined [here](#) (x being the Bjorken variable, P being the initial proton beam momentum)



Global event shape variables have the advantage over jet-based variables that theoretical predictions can be performed to higher orders

The H1 1-jettiness is measured

- 1D in the full kinematic region $150 < Q^2 < 20\,000 \text{ GeV}^2$ and $0.2 < y < 0.7$
- 3D, namely 1D in each of 2D (Q^2, y) bins (9 bins in Q^2 and 4 bins for $0.1 < y < 0.9$)

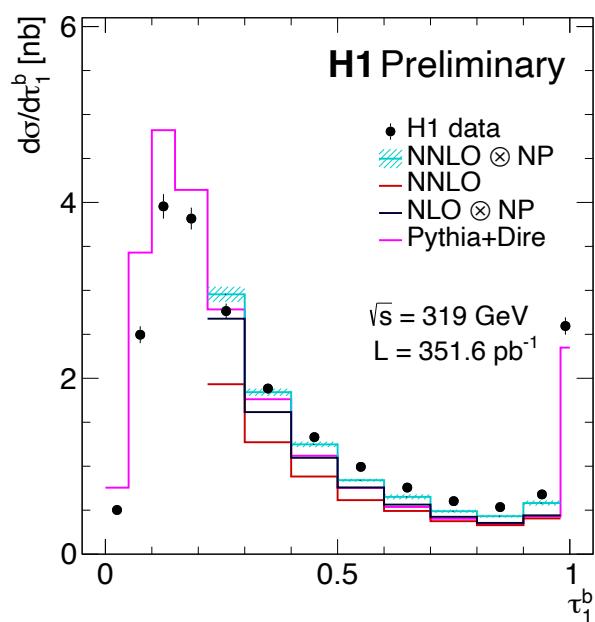
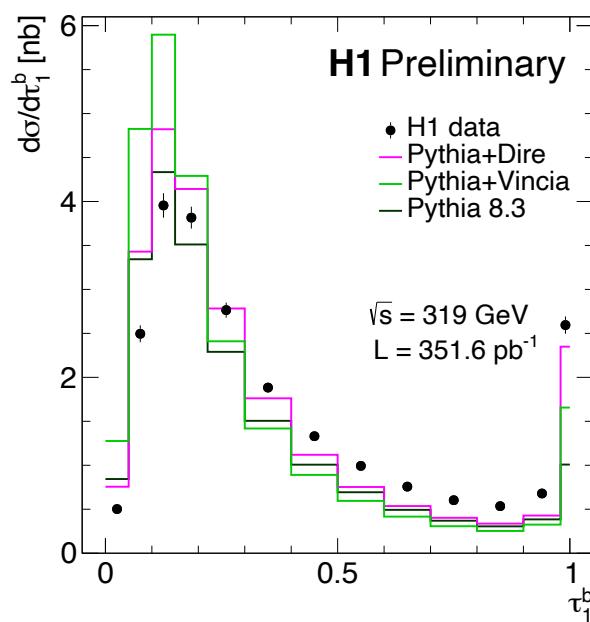
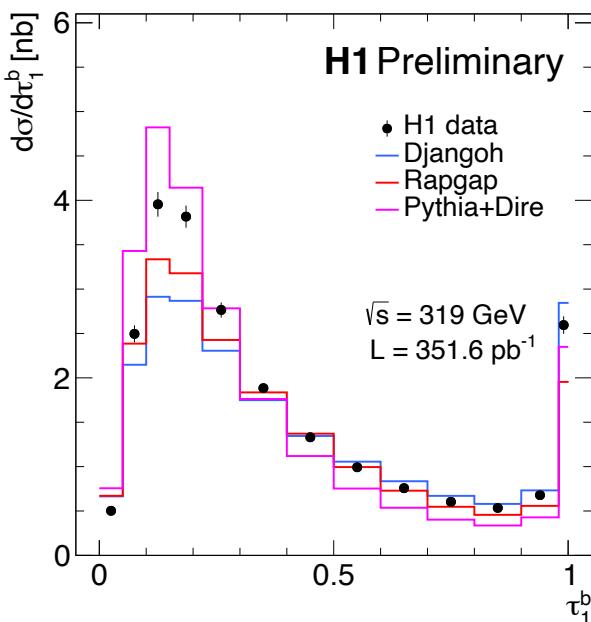
1st Measurements of (1D) 1-Jettiness

The measurements are compared with different event generators, parton shower models and perturbative predictions including non-perturbative (NP) corrections

The data and prediction differences show the potential to use these data to improve the event generators.

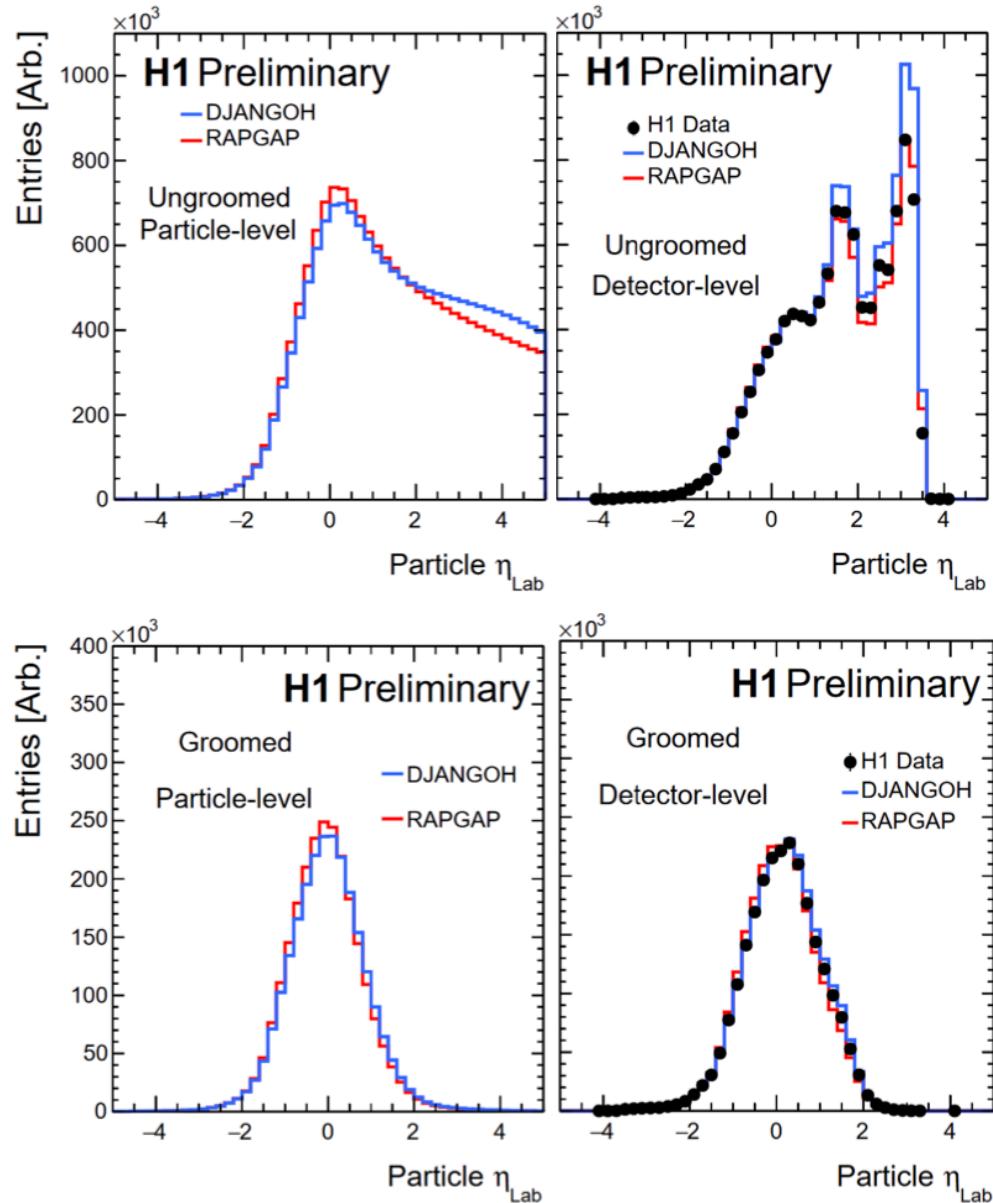
The data are also sensitive to α_s , hadronisation and resummation effects and PDFs

The 3D measurements show the peak at ~ 0.15 shifts to lower value as Q^2 increases while the peak at ~ 1 corresponding to no activity in the current hemisphere in the Breit frame reduces with Q^2

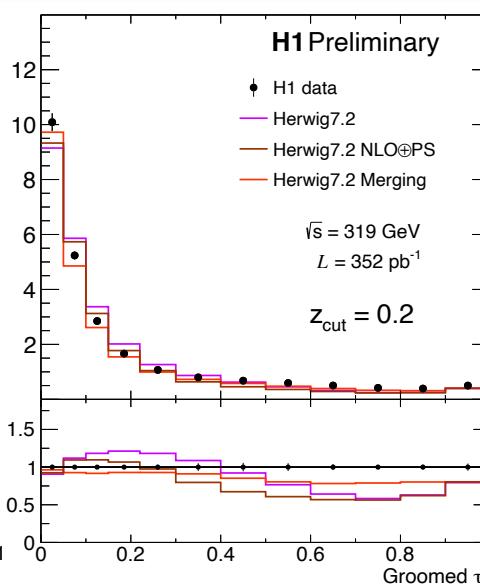
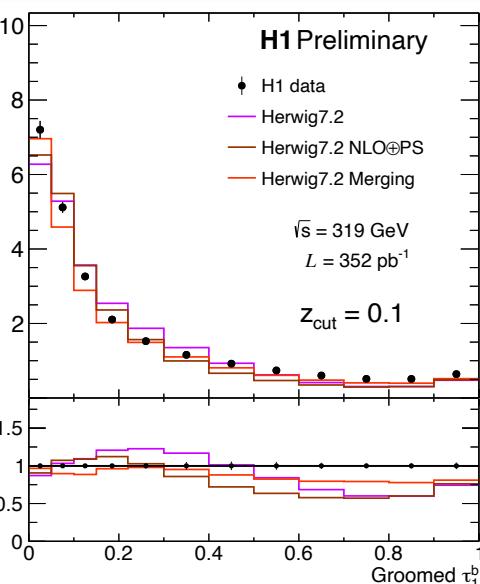
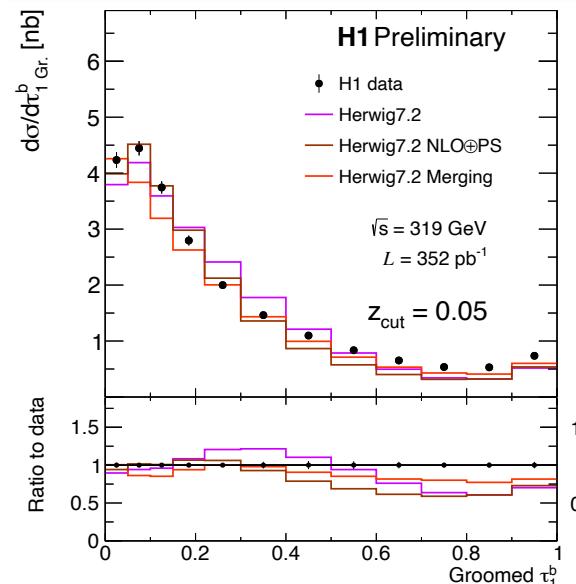


Groomed Event Shape Variables

- Cluster all particles in an event into a clustering tree with Centauro jet algorithm ([PRD 104 \(2021\) 034005](#)) (1st application in DIS)
- Iteratively decluster the tree in the order it was clustered, and compare $z_i = P \cdot p_i / P \cdot q$ of the branches at each step
- If $\min(z_i, z_j) / (z_i + z_j) < z_{\text{cut}}$ (grooming condition), the branch with smaller z_i is removed and the remaining branch is subdivided
- The procedure continues until the grooming condition is met
- Grooming allows to groom away QCD ISR, beam remnant, wide-angle, soft radiation to leave effectively only fragments of struck parton

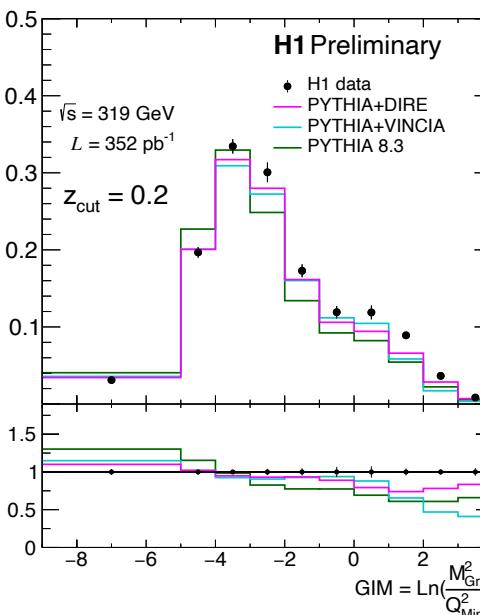
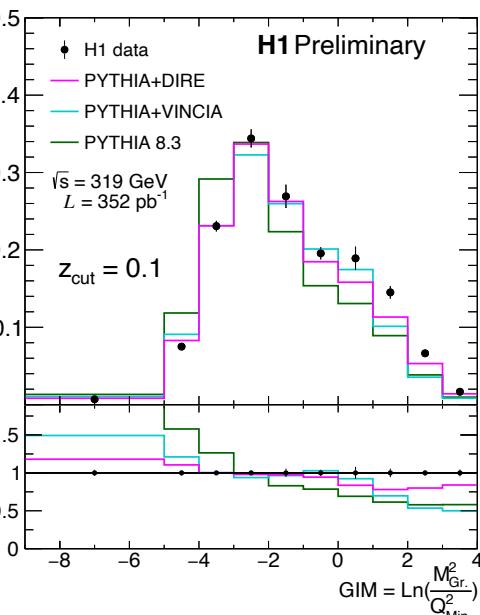
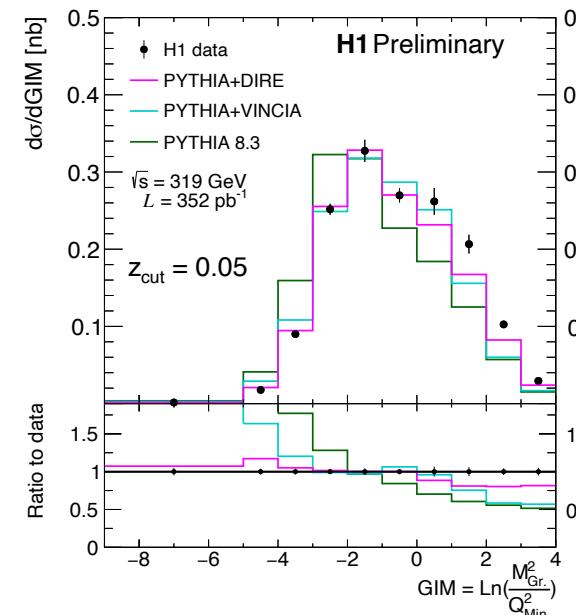


1st Measurements of Groomed Event Shape Variables



Groomed τ_1^b

The evolution vs.
zcut is measured
and compared
with different
generators,
parton shower
models and
analytic Soft
Collinear
Effective Theory
(SCET)

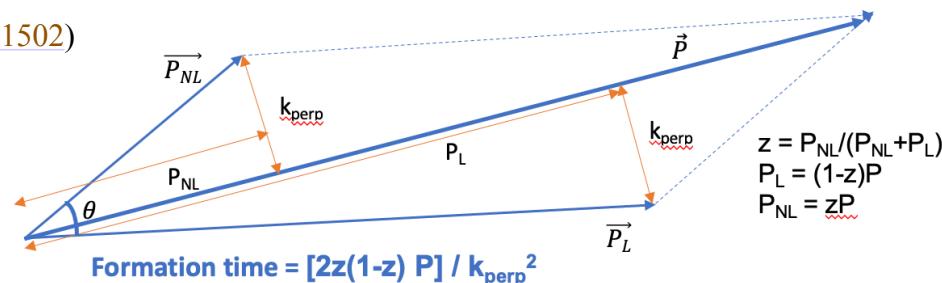


Groomed
invariant Mass
(GIM)
Same
measurements
and comparison
performed

Use Leading Particles in a Jet to Probe Hadronisation & Jet Substructure

Define charge correlation ratio ([PRD 105 \(2022\) L051502](#))

$$r_c(X) = \frac{\frac{d\sigma_{h_1 h_2}}{dX} - \frac{d\sigma_{h_1 \bar{h}_2}}{dX}}{\frac{d\sigma_{h_1 h_2}}{dX} + \frac{d\sigma_{h_1 \bar{h}_2}}{dX}}$$



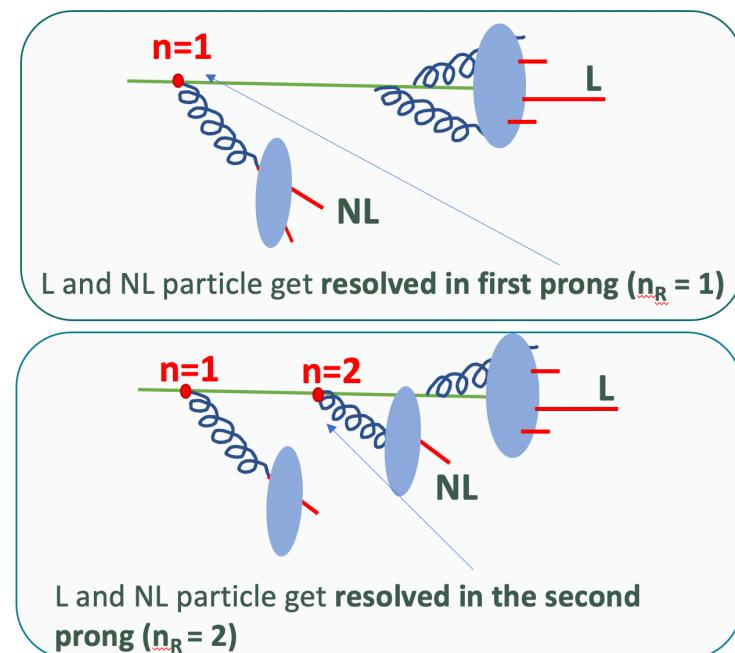
between leading (L) and next to leading (NL) hadrons in a jet (reconstructed with anti- kt $R_0=1$)
The variables X measured here are: formation time (t_{form}), k_{perp} , $p_{\text{T,jet}}$

Use Recursive Soft Drop ([JHEP 06 \(2018\) 093](#))

$$z_{12} = \frac{\min(p_{\text{T},1}, p_{\text{T},2})}{p_{\text{T},1} + p_{\text{T},2}} > z_{\text{cut}} \left(\frac{\Delta R_{12}}{R_0} \right)^\beta$$

to define $n=1, 2$ (Split or Prong)

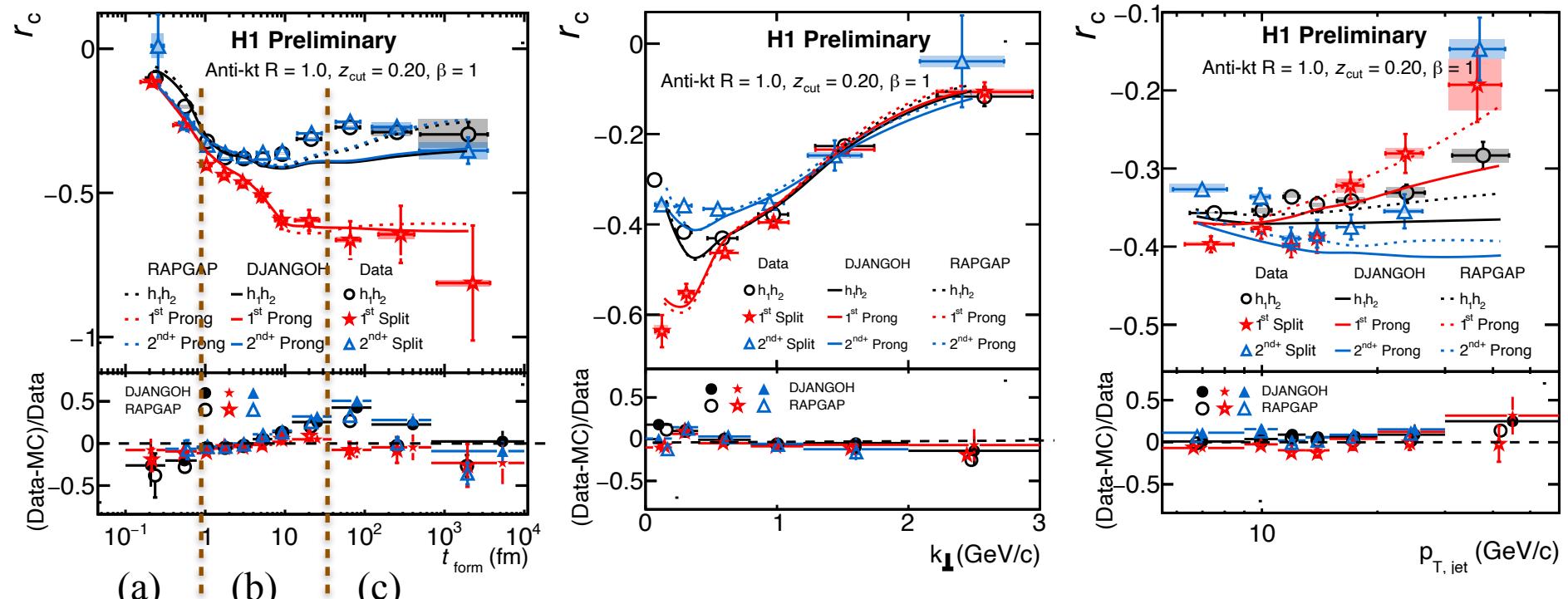
This analysis uses $z_{\text{cut}}=0.2$ and $\beta=1$



1st Measurements of Charge Correlation Ratio

r_c measured as functions of t_{form} , k_{perp} , $p_{\text{T,jet}}$ in three different cases:

- Leading charged hadrons in a jet
- Subjets at the 1st split for the resolved prong
- Subjets at the 2nd and further splits for the resolved prongs



- (a): Perturbative region
(b): transition region
(c): non-perturbative region

The measurements are compared with two generators
Fairly good agreement between data and MCs observed

Substructure using Machine Learning Technique

Extend generalized jet angularities ([JHEP 11 \(2014\) 129](#))

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

to include hadron's electric quark info in a jet

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

six observables are defined:

Jet charge: λ_0^1

Charged hadron multiplicity λ_0^0

Momentum dispersion $p_T D = \sqrt{\lambda_0^2}$

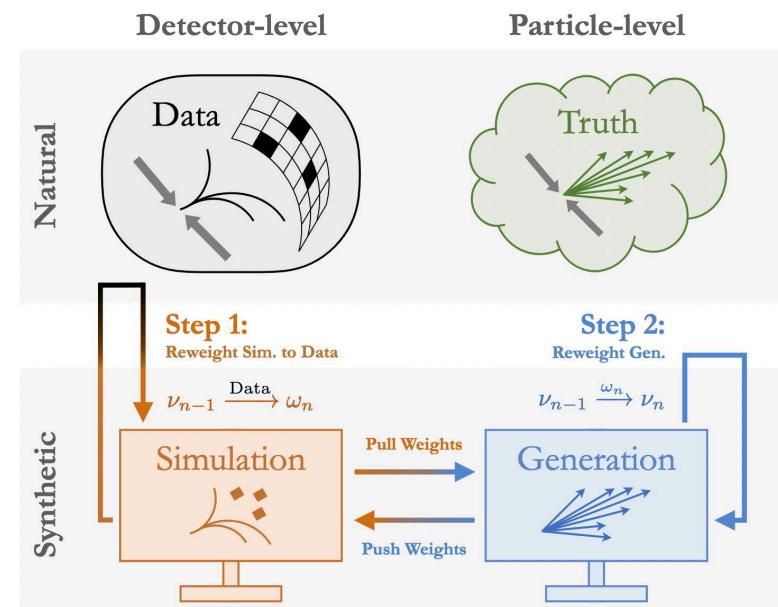
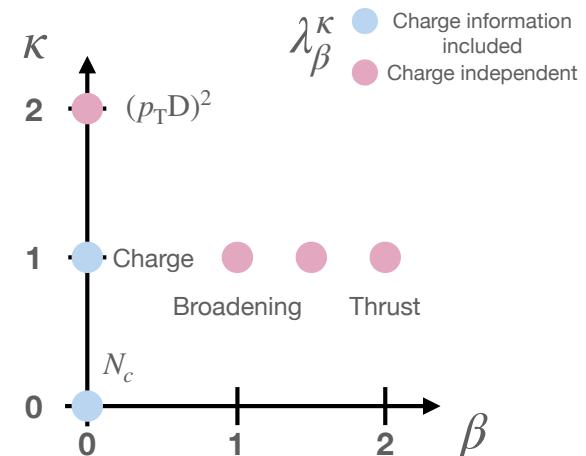
Jet broadening: λ_1^1

An intermediate value: $\lambda_{1.5}^1$

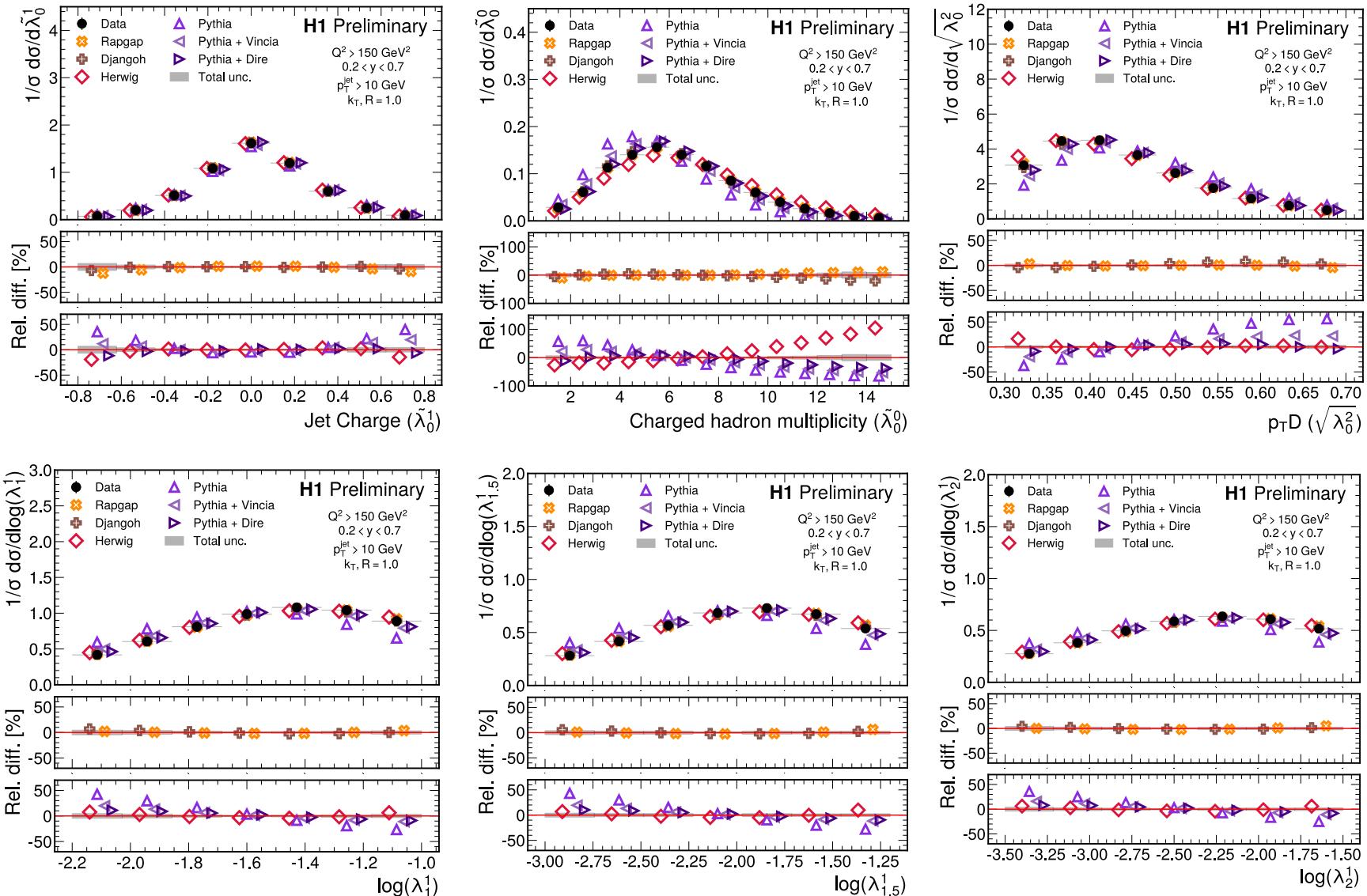
Jet thrust: λ_2^1

All observables are then unfolded simultaneously by using reconstructed particles inside jets as inputs without binning to a graph neural network, using the machine learning-based method

Omnifold ([PRL 124 \(2020\) 182001](#))



Measurements of the Six Observables



Differential measurements in four Q^2 bins between 150 and 5000 GeV^2 are also available

Summary

Preserved H1 data have been exploited with new ideas, person-powers, and modern analysis techniques

Four new preliminary measurements have been presented

These measurements are sensitive to α_s , PDFs, TMD, hadronisation, resummation effects, and useful for improving event generators, parton shower models, better understanding of hadronisation dynamics, stimulating theory community to provide improved or higher order predictions

➤ see e.g. “Phenomenology of Jet Angularities at NLO+NLL’ accuracy” by
Daniel Reichelt ([link](#))