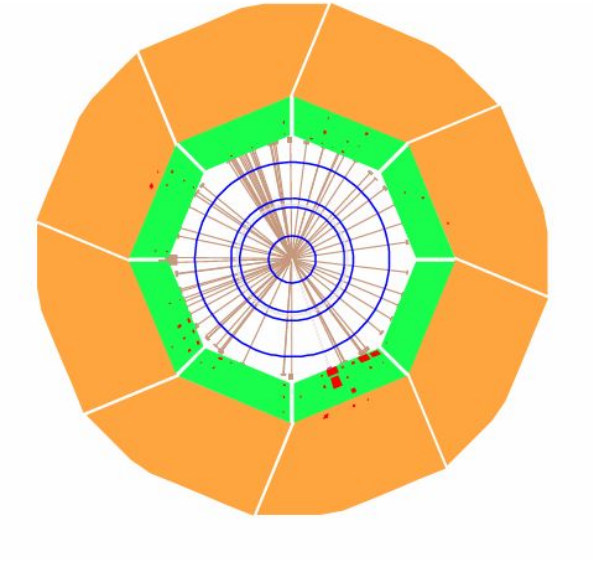


Measurement of groomed event shape observables in deep-inelastic electron-proton scattering at HERA

+ Observation and differential cross section measurement of neutral current DIS events with an empty hemisphere in the Breit frame

Miguel Arratia,
on behalf of the H1 Collaboration

DIS 2025 at Cape Town, South Africa, March 25th 2025

Eur. Phys. J. C (2024) 84:720
https://doi.org/10.1140/epjc/s10052-024-13003-1

THE EUROPEAN PHYSICAL JOURNAL C

Letter

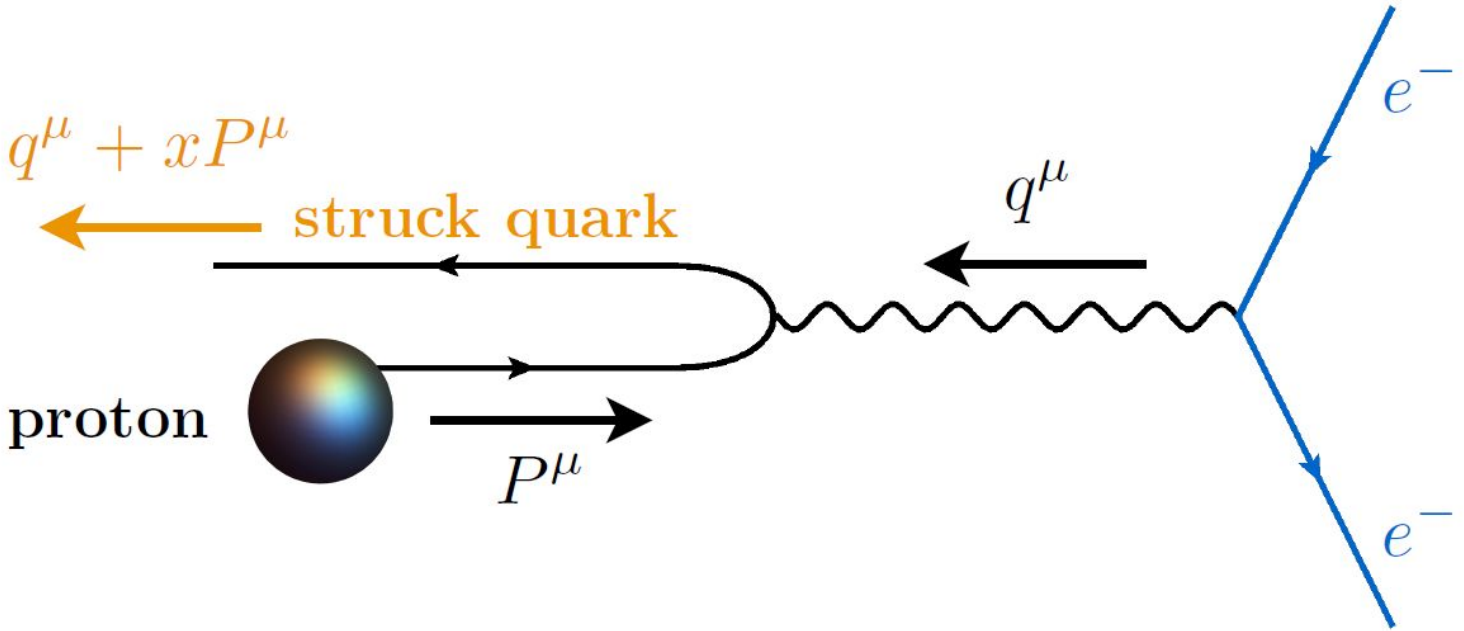
Observation and differential cross section measurement of neutral current DIS events with an empty hemisphere in the Breit frame

H1 Collaboration*

DIS in Breit Frame:

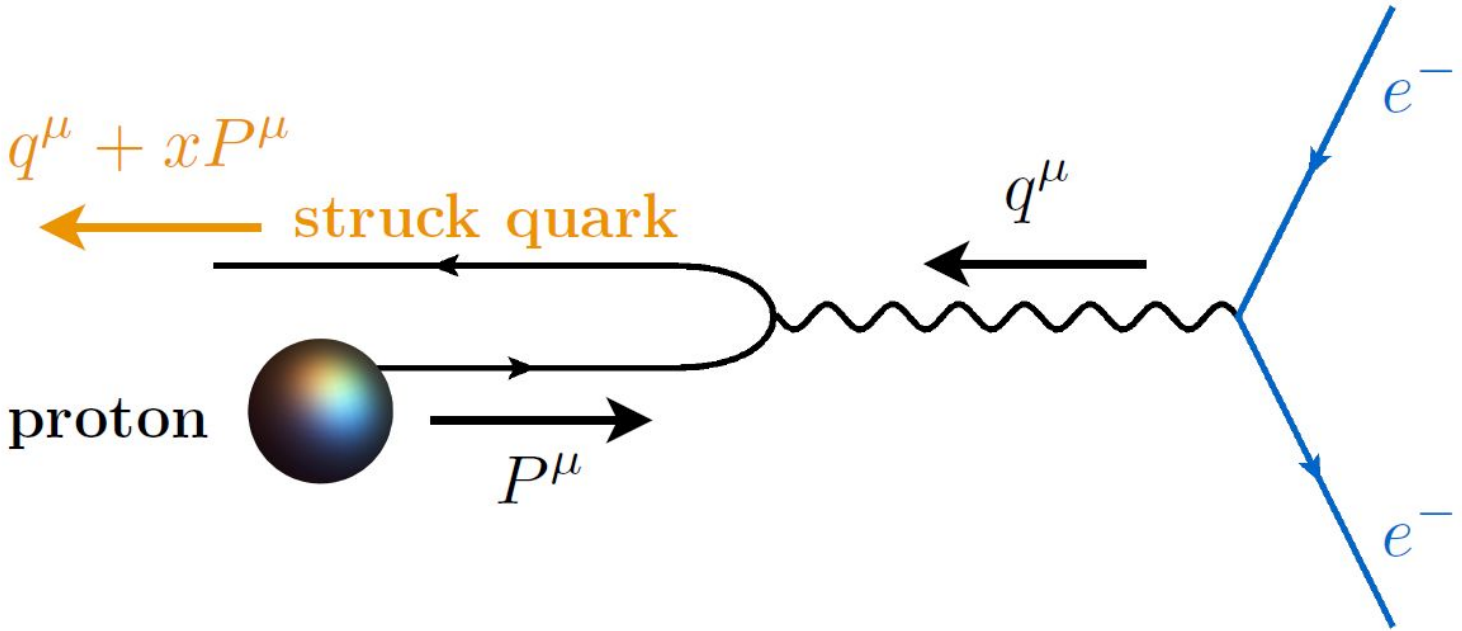
Born-level has a struck-quark backscattering

Current hemisphere is defined as struck-quark direction



Empty current events

Rare configurations where NOTHING shows up to the left

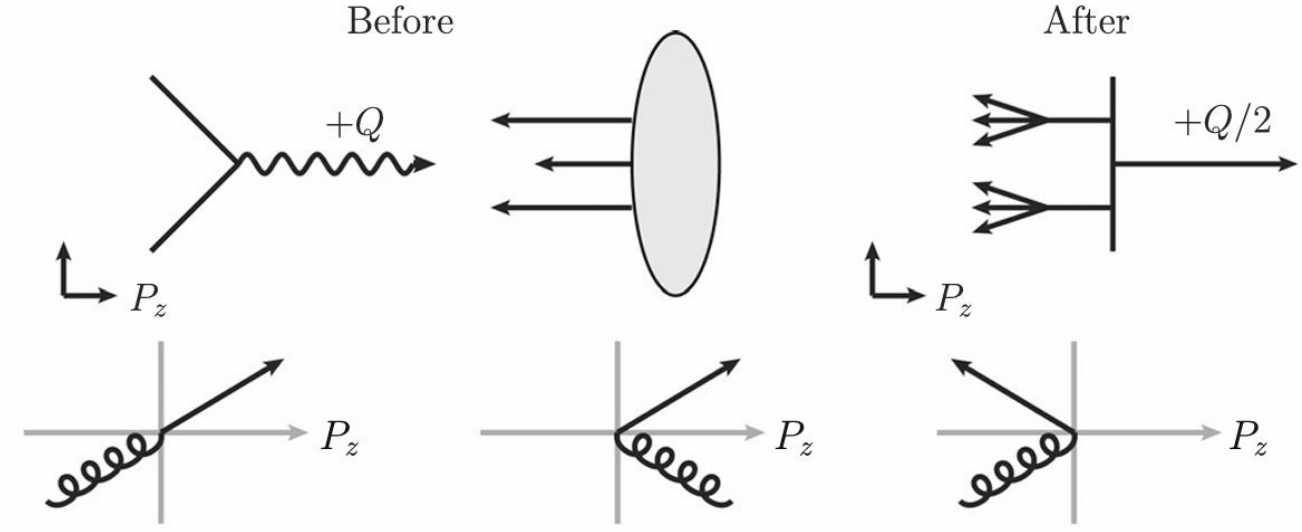


What might induce empty-current events in DIS?

Qualitatively, this topology can be explained by an off-shell parton with energy fraction x > xBj

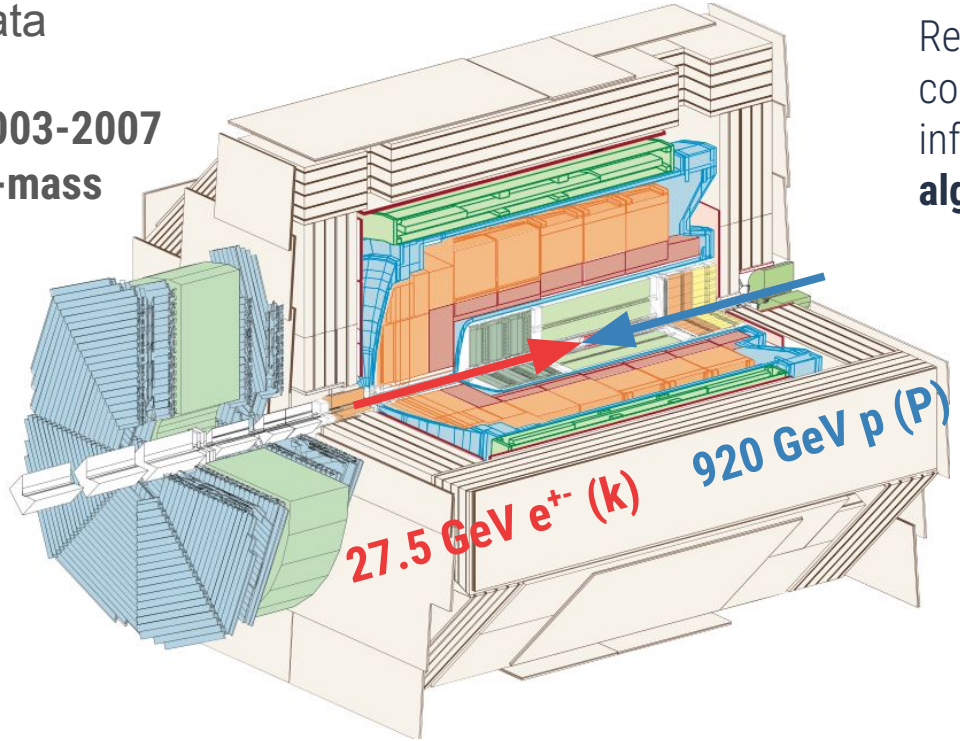
Higher-order QCD processes & non-perturbative effects

Breit frame and the partonic center-of-mass frame deviate from each other.



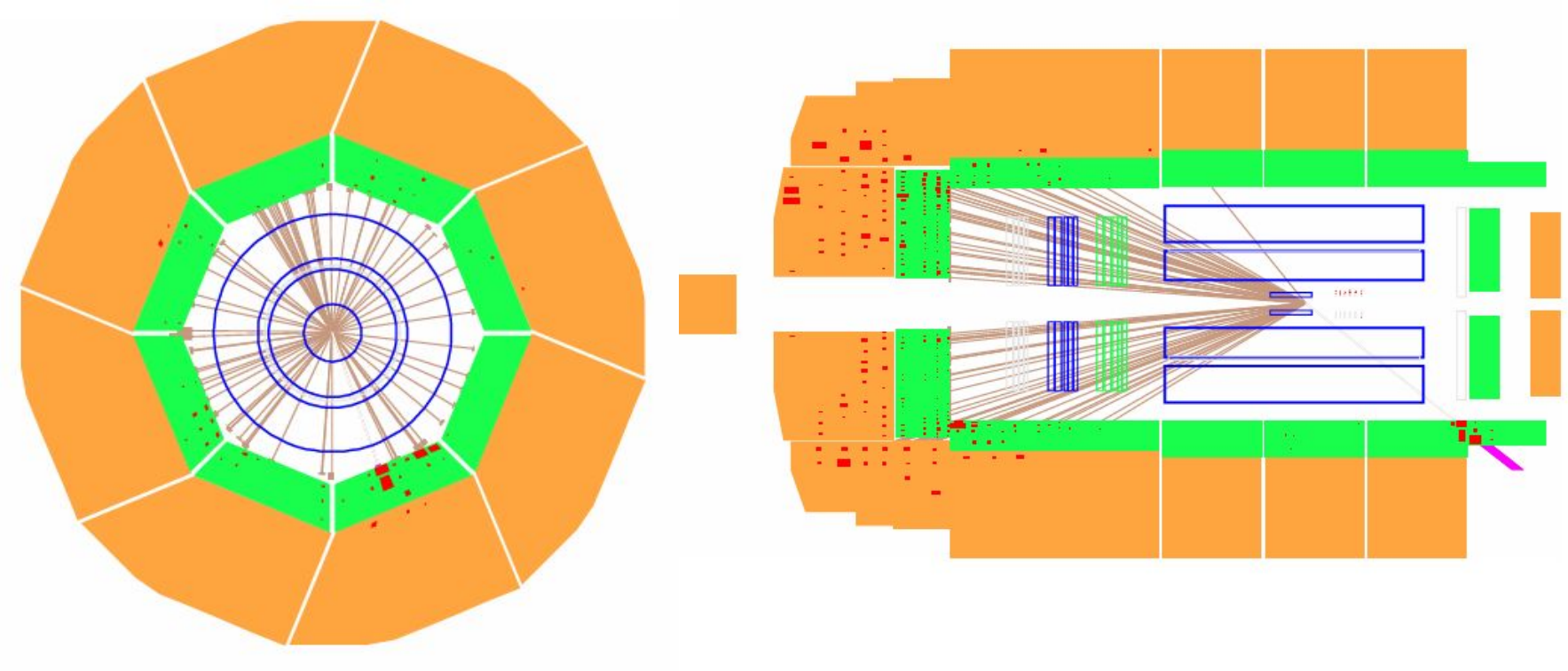
Experimental setup

Using **351 pb^{-1}** of data collected by the **H1 Experiment** during **2003-2007** at **318 GeV center-of-mass energy**



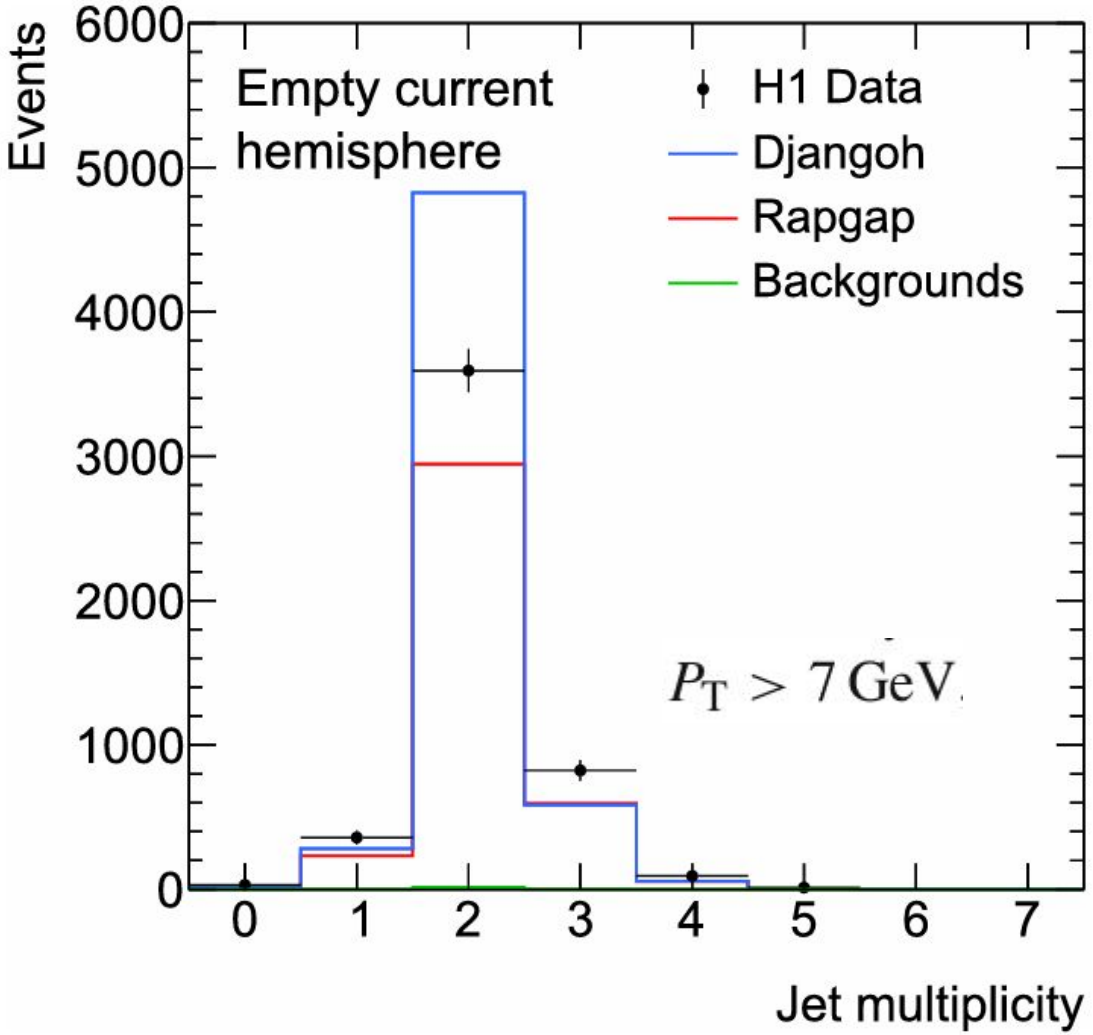
Reconstructed hadrons using combined detector information: **energy flow algorithm**

Example of Empty-current event



Jet multiplicity in Empty-current events

Event have high-pT jets, just not going in the struck-quark direction



Fraction of empty-current events

$$r := \frac{n_{(E_C=0)}}{n_{(E_C>0)} + n_{(E_C=0)}} \cdot c_{\mathrm{QED}} = \frac{\sigma_{(E_C=0)}}{\sigma_{(\mathrm{NC\ DIS})}},$$

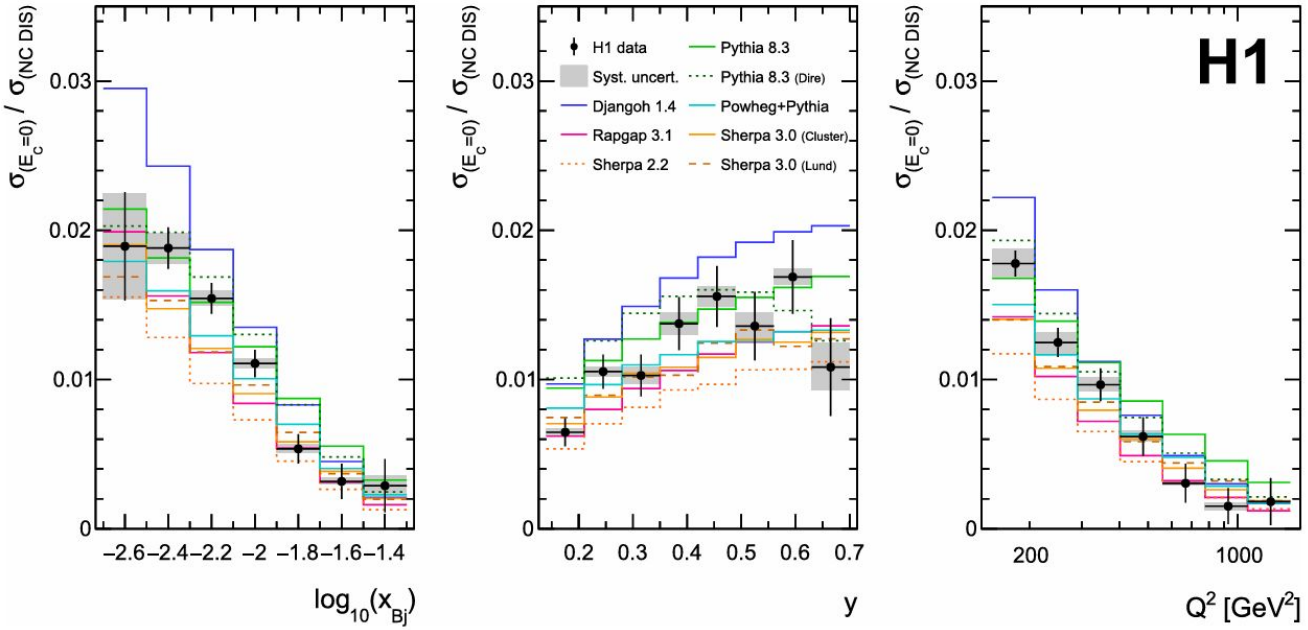
Bin-migrations corrected with unfolding.

QED corrections corrected with multiplicative factor (HERACLES)

Table 1 Comparison of the fraction r of empty current hemisphere events in NC DIS with various predictions in the analyzed phase space $150 < Q^2 < 1500\,\mathrm{GeV}^2$ and $0.14 < y < 0.7$

	r	δr
Data	0.0112	$\pm 3.9\%_{\mathrm{stat}}$
		$\pm 4.5\%_{\mathrm{syst}}$
		$\pm 1.6\%_{\mathrm{mod}}$
Djangoh 1.4	0.0150	$\pm 0.1\%_{\mathrm{stat}}$
Rapgap 3.1	0.0096	$\pm 0.1\%_{\mathrm{stat}}$
Pythia 8.3	0.0127	$\pm 0.1\%_{\mathrm{stat}}$
Pythia 8.3 (Dire)	0.0120	$\pm 0.1\%_{\mathrm{stat}}$
Powheg+Pythia	0.0107	$\pm 0.1\%_{\mathrm{stat}}$
Sherpa 3.0 (Cluster)	0.0100	$\pm 0.1\%_{\mathrm{stat}}$
Sherpa 3.0 (Lund)	0.0101	$\pm 0.3\%_{\mathrm{stat}}$
Sherpa 2.2	0.00818	$\pm 0.5\%_{\mathrm{stat}}$

Differential measurement of fraction of empty-current events



The phase space for Born-level two-parton topology enabling the events of interest decreases with Q2 and xBj

Great discriminating power for state-of-the art DIS Monte Carlo generators, parton showers

Eur. Phys. J. C (2024) 84:718
https://doi.org/10.1140/epjc/s10052-024-12987-0

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

Measurement of groomed event shape observables in deep-inelastic electron-proton scattering at HERA

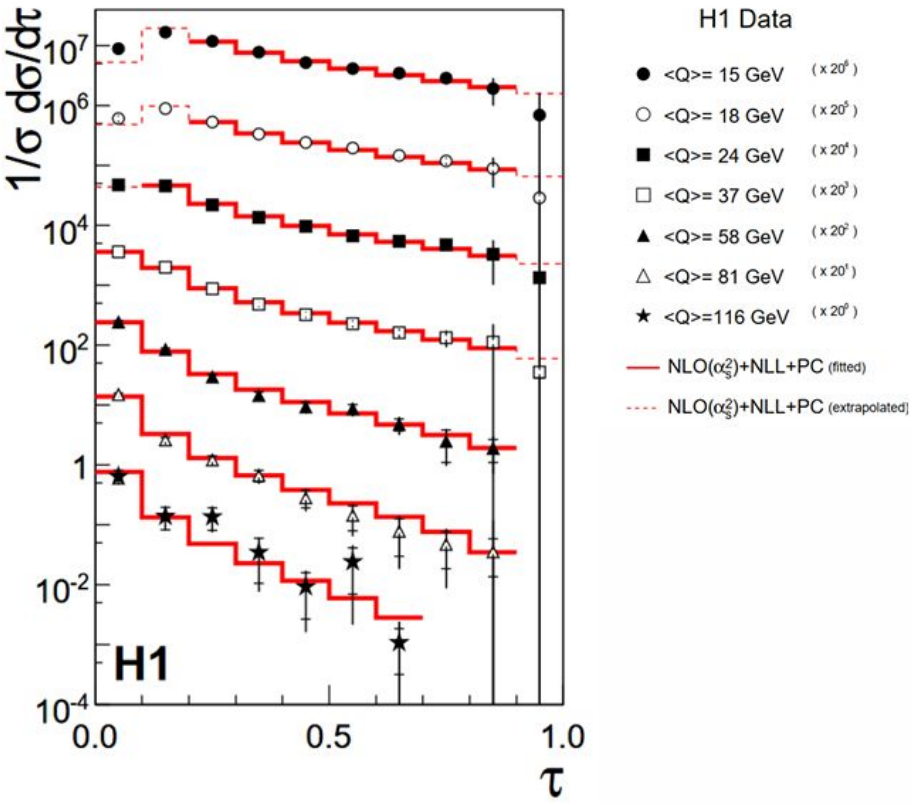
H1 Collaboration[⋆,a]

Event shapes

$$\tau = 1 - T \quad \text{with} \quad T = \frac{\sum_h |\vec{p}_{z,h}|}{\sum_h |\vec{p}_h|}$$

Traditional observable, sensitive to QCD across all scales, calculable with pQCD / SCET

Several prior studies in ep (e.g. see right)



Centauro

Jet algorithm with asymmetric clustering distance measure

Here Centauro is used to produce a clustering tree for the full event

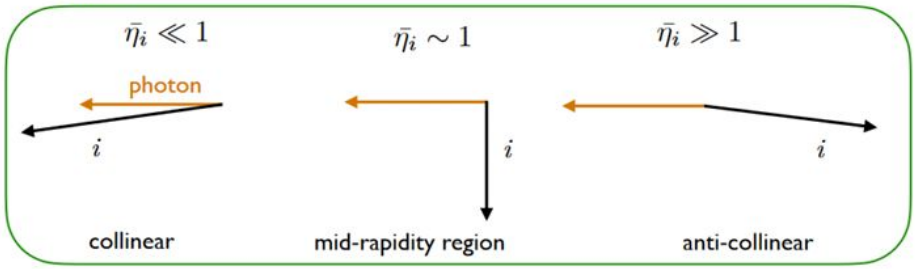
Definition:

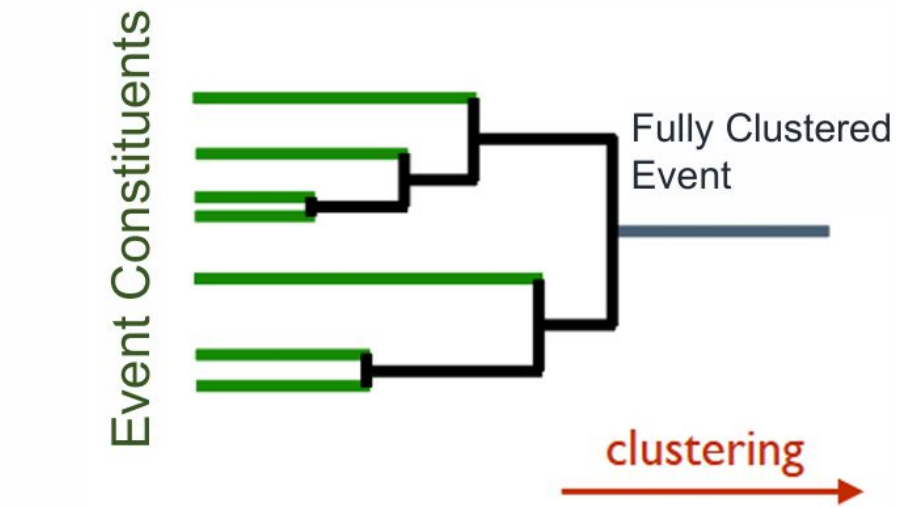
$$d_{ij} = (\bar{\eta}_i - \bar{\eta}_j)^2 + 2\bar{\eta}_i\bar{\eta}_j(1 - \cos(\phi_i - \phi_j))$$

Breit frame

$$\bar{\eta}_i = 2\sqrt{1 + \frac{q \cdot p_i}{x_B P \cdot p_i}} \xrightarrow[\text{frame}]{\text{Breit}} \frac{2p_i^{\perp}}{p_i^{+}}$$

Limits:





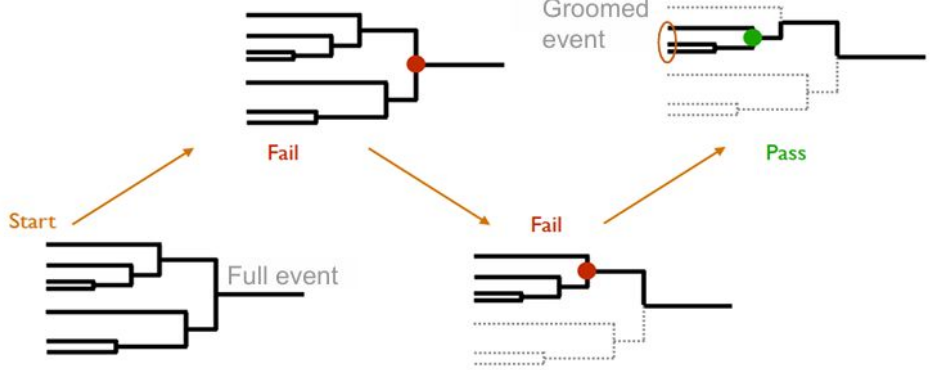
Asymmetric jet clustering in deep-inelastic scattering:
Arratia et al. Phys.Rev.D 104 (2021) 3, 034005

Event grooming

Whole event is clustered into one “Cantauro jet”

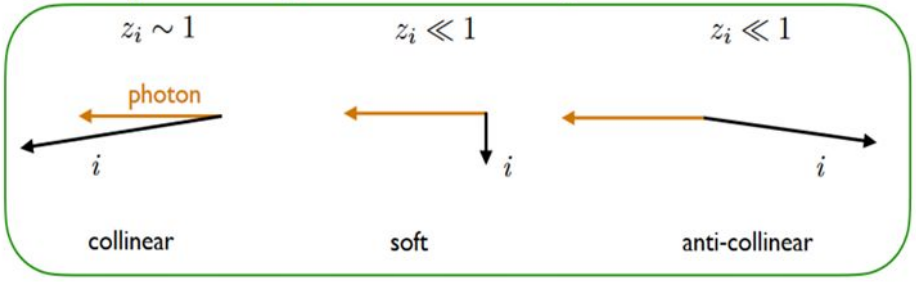
Iteratively de-cluster until grooming condition is passed

Groomed events are similar to groomed jets!



$$z_i = \frac{P \cdot p_i}{P \cdot q} \xrightarrow[\text{frame}]{\text{Breit}} z_i = n \cdot p_i / Q = p_i^+ / Q \,.$$

Limits (geometric interpretation in the Breit frame)



$$\frac{\min(p_{t1}, p_{t2})}{p_{t1} + p_{t2}} > z_{\text{cut}} \quad \Rightarrow \quad \frac{\min(z_i, z_j)}{z_i + z_j} > z_{\text{cut}}$$

p+p Soft Drop condition

DIS grooming condition

See Y. Makris Phys. Rev. D 103, 054005 (2021)

Breit Frame Event Displays

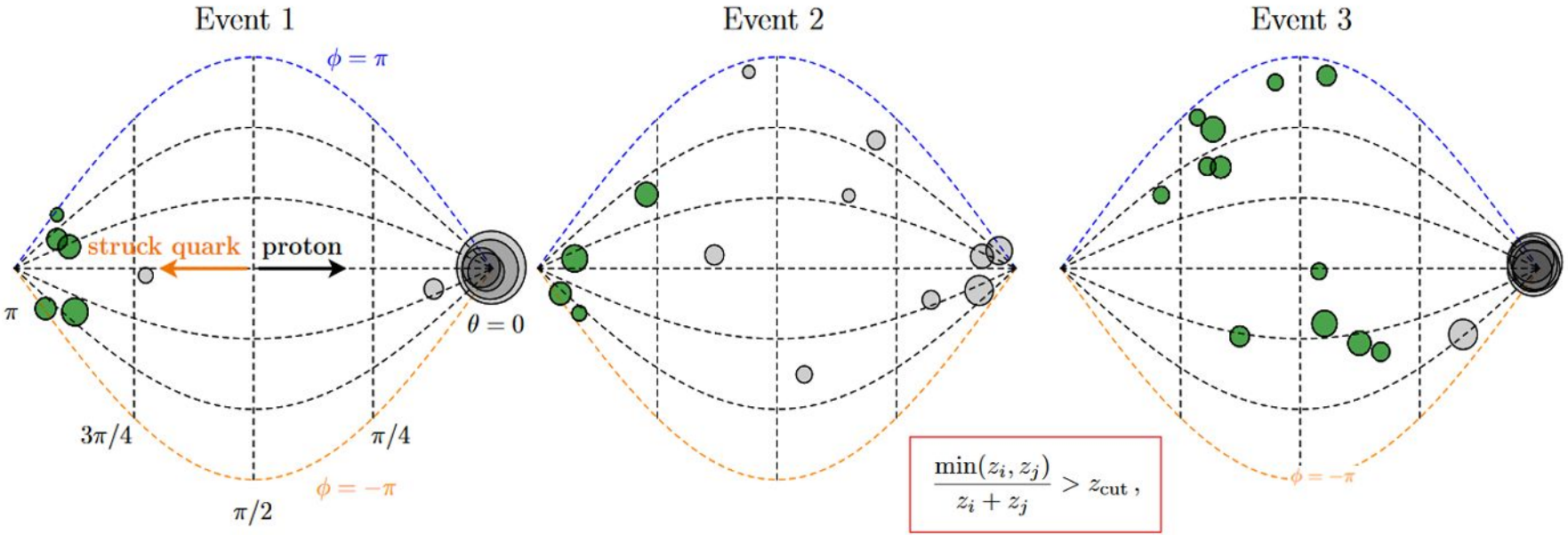


Figure 2. Visualization of three PYTHIA 8 events at $\sqrt{s} = 63$ GeV and $Q \sim 10$ GeV before and after grooming. The particles in this events are represented by disks on the unfolded sphere. Green disks represent particles that pass grooming where grayed-out particles are removed from the event by the grooming procedure. For the grooming parameter we use here $z_{\text{cut}} = 0.1$

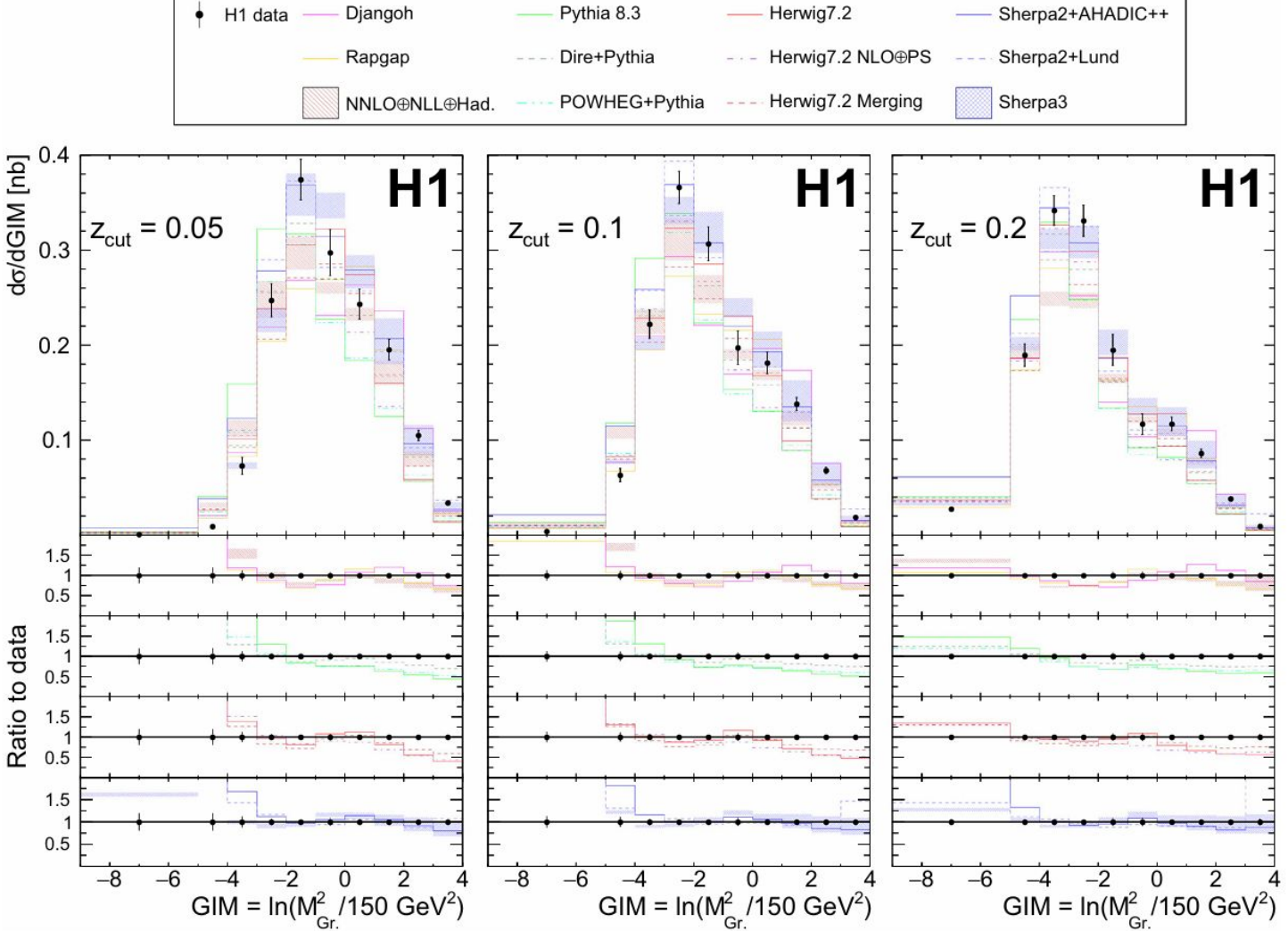
See Y. Makris Phys. Rev. D 103, 054005 (2021)

Results

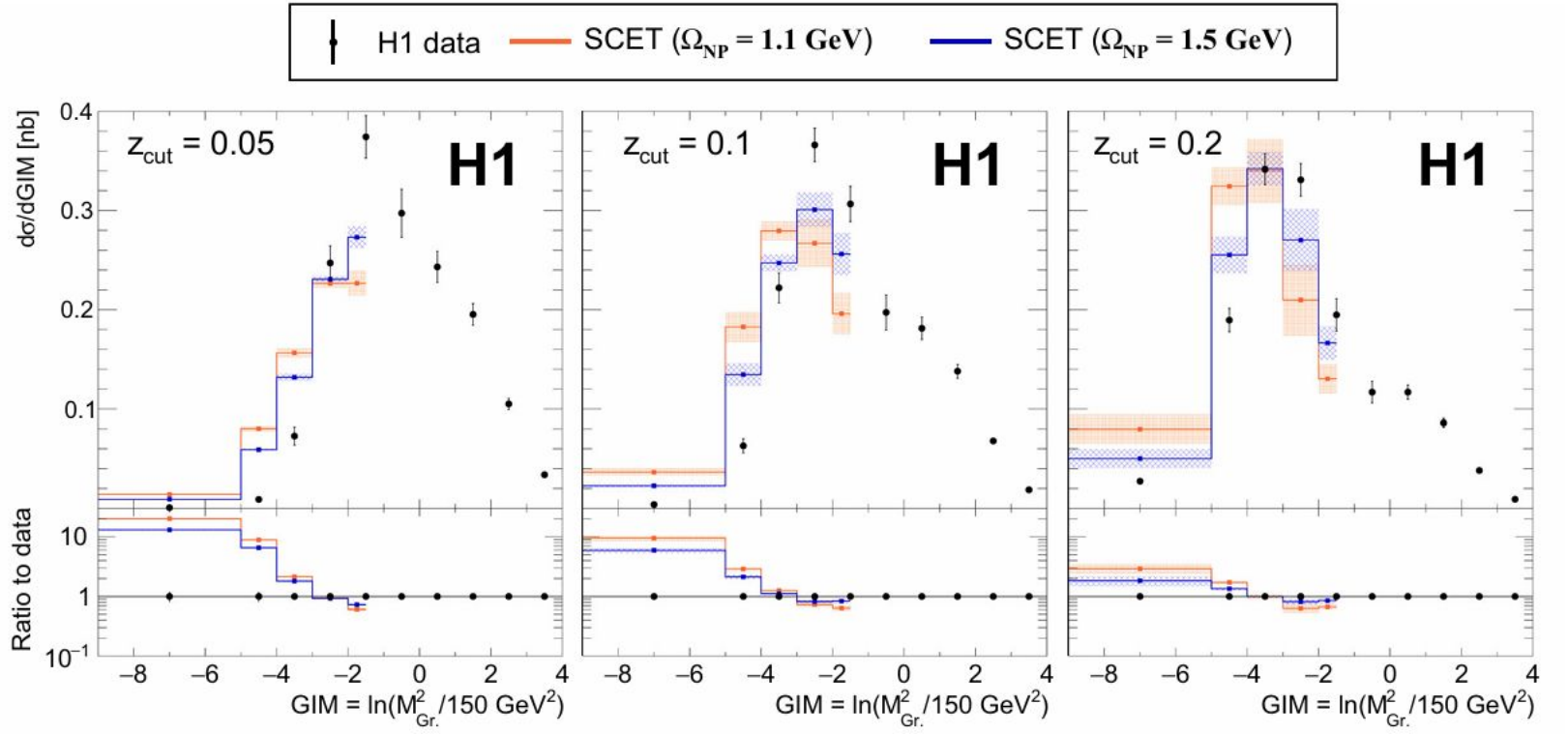
$$M^2_{\mathrm{Gr.}} = \left(\sum_{i \in \mathrm{groomed}(z_{\mathrm{cut}})} p_i \right)^2$$

Large values from Multijet events, hard splittings

Low values, from single-jet events, intra-jet evolution



Comparing to SCET. Sensitivity to non-perturbative parameter

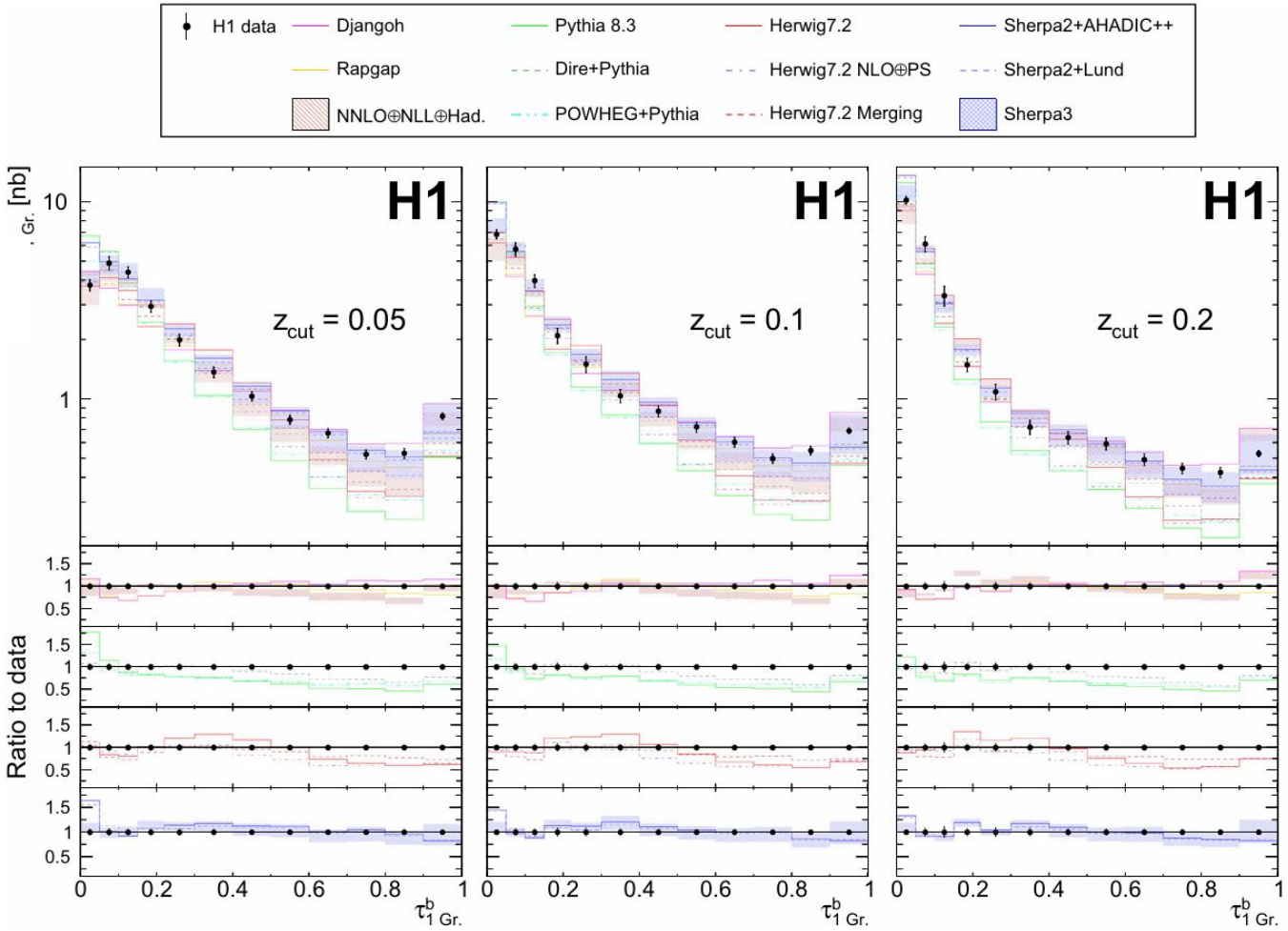


Results

$$\tau^{b}_{1,\mathrm{Gr.}} = \frac{2}{Q^2} \sum_{i \in \mathrm{groomed}(z_{\mathrm{cut}})} \min(q_B \cdot p_i, q_J \cdot p_i),$$

Large values from Multijet events, hard splittings

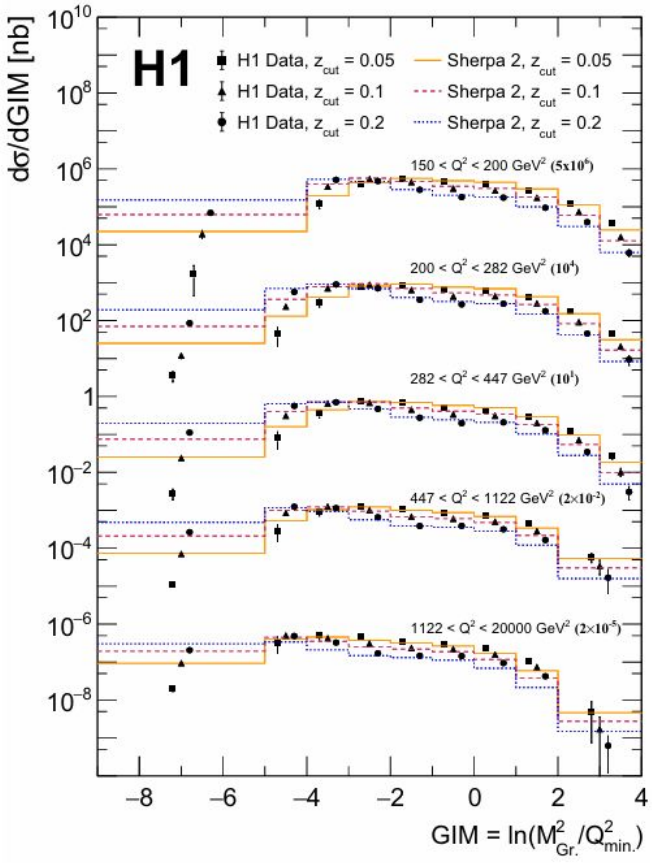
Low values, from single-jet events, intra-jet evolution

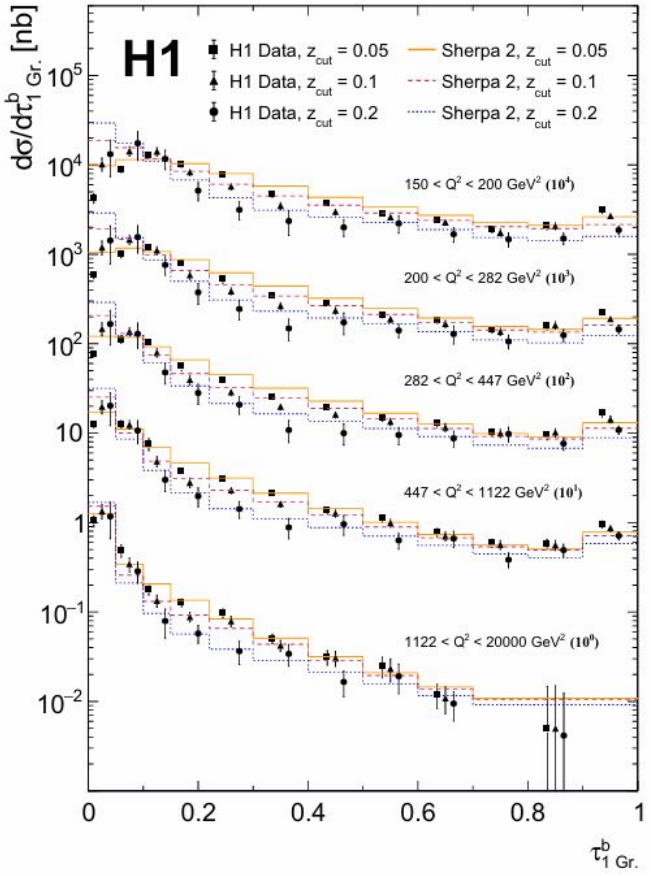


Multi Differential measurement of Centauro-groomed event shapes in DIS

New legacy event-shape measurement, great for challenging new generation of MC DIS generators, and SCET

(both needed for EIC!!!)

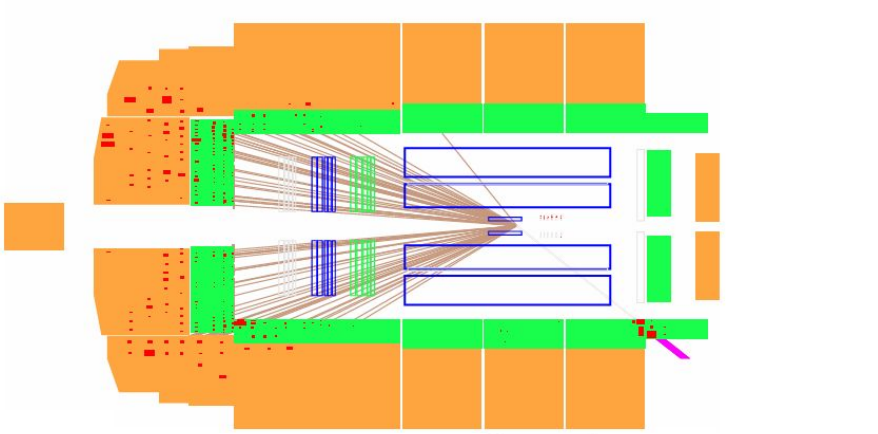


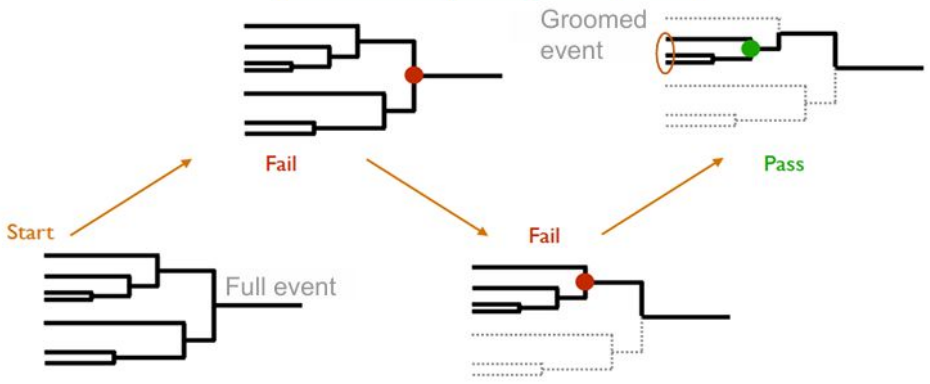


Summary

First direct observation of quite spectacular event topologies, which probe higher-order QCD and non-perturbative physics.

New measurement of event-shapes with grooming and Centauro metric, provide new ways to control non-perturbative effects for better, improved comparisons with pQCD and SCET!





$$z_i = \frac{P \cdot p_i}{P \cdot q} \xrightarrow[\text{frame}]{\text{Breit}} z_i = n \cdot p_i / Q = p_i^+ / Q \,.$$