Measurement of the 1-jettiness Event Shape Observable in Deep-inelastic Electron-Proton Scattering

Johannes Hessler

IMPRS Recruiting Workshop

Technische Universität München,
Max-Planck-Institut für Physik

Masterthesis: https://inspirehep.net/literature/2010833
H1 prelimiary report: https://www-h1.desy.de/psfiles/confpap/EPSHEP2021/H1prelim-21-032.pdf
PoS EPS-HEP: https://arxiv.org/abs/2111.11364

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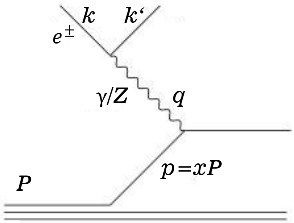
Neutral current deep-inelastic scattering

- Process $ep \to e'X$
- Electron or positron scattering

Kinematic variables

- Virtuality of exchanged boson Q^2
  $Q^2 = -q^2 = -(k - k')^2$
- Inelasticity, Bjorken-x and centre-of-mass energy
  $y = \frac{P \cdot q}{P \cdot k}$ $\quad Q^2 = x_{Bj} \cdot y \cdot s$



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1-jettiness

$$\tau_1^b = \frac{2}{Q^2} \sum_{i \in X} \min\{xP \cdot p_i, (q + xP) \cdot p_i\}$$

- Infrared safe and free of non-global logs
- Sensitive to strong coupling α_s and PDFs

Boost to Breit frame:

$\rightarrow$ **DIS thrust normalised to boson axis**

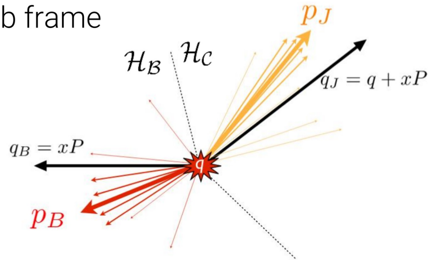
$$\tau_Q = 1 - \frac{2}{Q} \sum_{i \in \mathcal{H}_C} P_{z,i}^{Breit}$$

- Normalisation with $Q/2$ of the event
- Only particles in the current hemisphere contribute

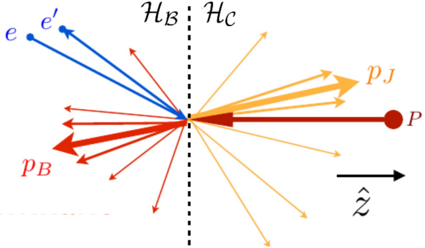
Equivalence follows from momentum conservation:

$$\tau_Q = \tau_1^b$$

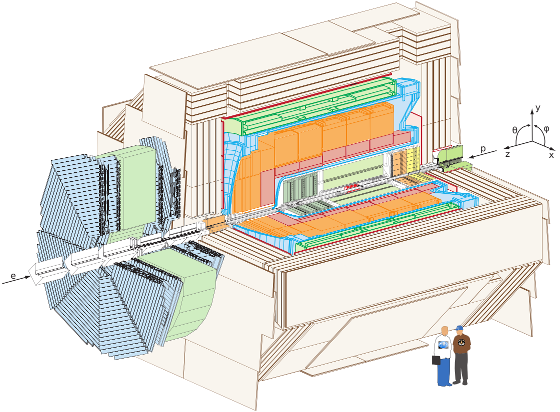
Lab frame



Breit frame



Kang, Lee, Stewart [Phys.Rev.D 88 (2013) 054004]



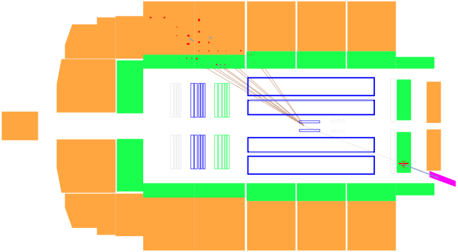
H1 'Multi-purpose' DIS detector

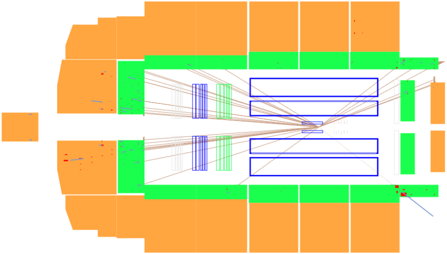
- Asymmetric design with trackers, calorimeter, solenoid, muon-chambers, forward & backward detectors
- Particles are reconstructed using a particle flow algorithm
  $\rightarrow$ Combining cluster and track information without double-counting of energy

1-jettiness

$$\tau_1^b = \frac{2}{Q^2} \sum_{i \in X} \min\{xP \cdot p_i, (q + xP) \cdot p_i\}$$

Visualisation of the 1-jettiness with event displays





- DIS 1-jet configuration
- Most HFS particles collinear to scattered parton
  $\rightarrow$ Small τ_1^b

- Dijet event
- More and larger contributions to the sum over the HFS
  $\rightarrow$ Large τ_1^b

DIS thrust - a 4π observable

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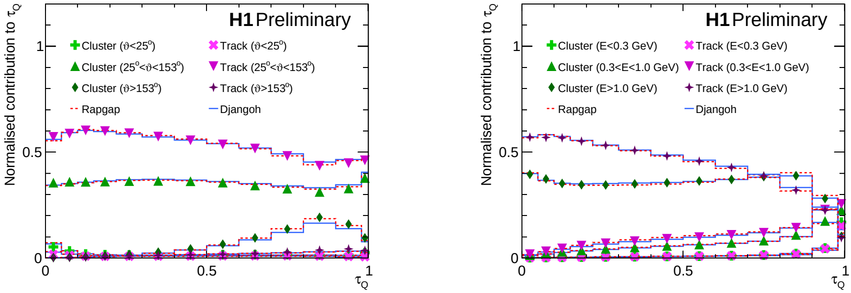
- All particle candidates in all DIS events contribute $\left(\tau_Q = 1 - \frac{2}{Q}\sum_{i\in\mathcal{H}_\mathcal{C}} P^{Breit}_{z,i}\right)$
- Normalised contribution to τ_Q for different ranges in polar angle ϑ and energy



- Mainly tracks and clusters in the central part of the detector contribute ($25° < \vartheta < 153°$)
- Mainly particles with high energy contribute ($E > 1$ GeV)
  $\Rightarrow$ Well measured particles dominate in τ_Q

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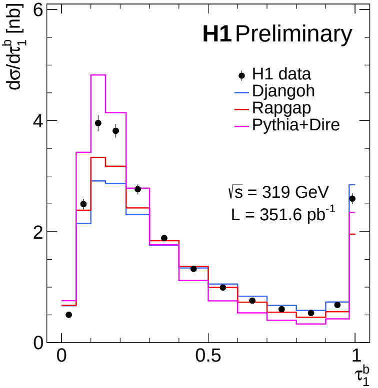
Measure τ_Q but present cross sections as a function of τ_1^b

1-jettiness cross section

$$\left(\frac{d\sigma}{d\tau_1^b}\right)_i = \frac{N_{data,i} - N_{bkgd,i}}{\Delta_i \cdot L} \cdot c_{\text{QED,i}} \cdot c_{\text{unfold,i}}$$

- Unfolded using bin-by-bin method c_{unfold}
- Corrected for QED radiative effects c_{QED}
- Divide by τ_1^b-bin width Δ_i
- Integrated luminosity $L = 351\ \text{pb}^{-1}$



Comparison with MC models

- Djangoh 1.4: Colour-dipole-model
- Rapgap 3.1: ME + parton shower
- Pythia 8.3 + Dire parton shower

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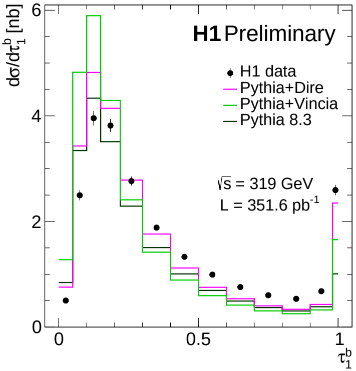
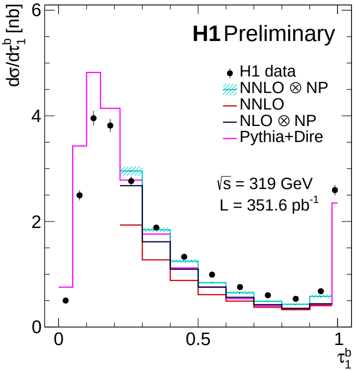
Comparison with parton shower models

- Peak region has strong dependence on different parton showers
- No PS model provides a fully satisfactory description
- 'Pythia default' underestimates $\tau = 1$

$\gamma p \rightarrow$2 jets+X NNLO prediction form NNLOJET

- NP corrections from Pythia 8.3 (sizeable)
- NNLO provides a reasonable description of fixed-order region
- NNLO improves over NLO

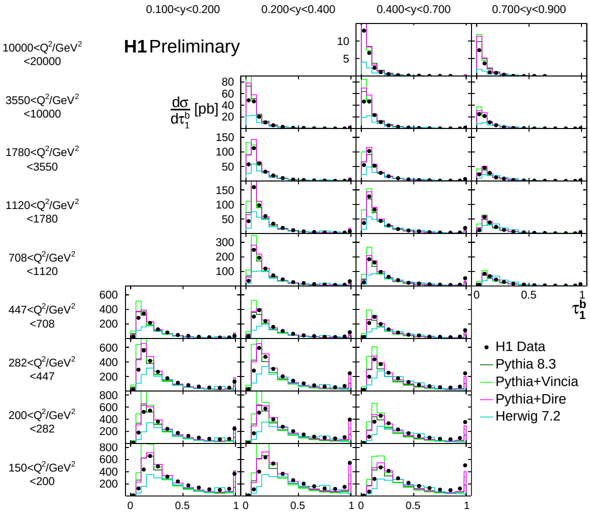




Large cross section and sizeable data
→ Triple-diff. cross sections as a function of Q^2, y, τ

3D cross sections

- increasing Q^2
  → Peak moves to lower τ
  → Tail region lowers
- Increasing y
  → $\tau = 1$ becomes enhanced



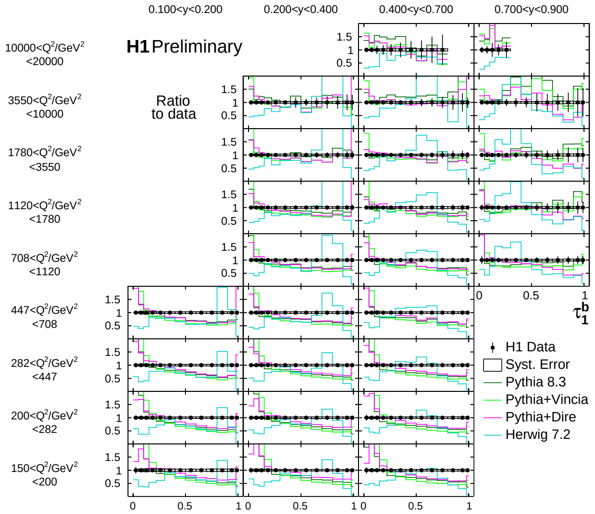
Triple differential cross sections

Ratio to data

- Stat. uncertainties of a few to $O(10\%)$
- Syst. uncertainties are in the range of 5%

→ **Pythia description improves with increasing Q^2**

→ **HERWIG DIS cross section too low**

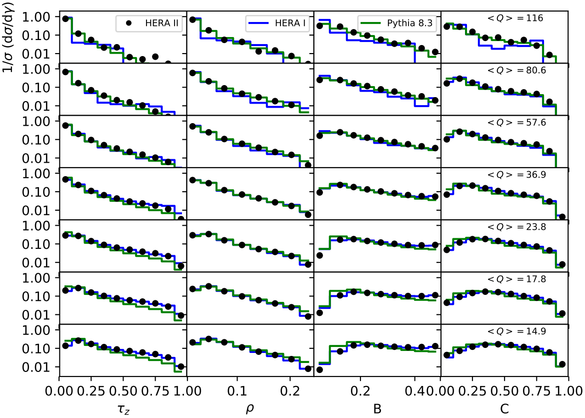


Classical event shapes

- Measured at HERA-I by H1 and ZEUS
- No public measurement in HERA-II

Definitions of observables

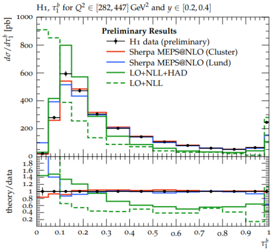
- z-Thrust
$$\tau_z = 1 - \frac{\sum_{h\in\mathcal{H}_c} |p_{z,h}|}{\sum_{h\in\mathcal{H}_c} |\vec{p}_h|}$$
- Jet broadening
$$B = \frac{\sum_{h\in\mathcal{H}_c} |p_{t,h}|}{2\sum_{h\in\mathcal{H}_c} |\vec{p}_h|}$$
- Jet mass
$$\rho = \frac{(\sum_{h\in\mathcal{H}_c} |p_h|)^2 - (\sum_{h\in\mathcal{H}_c} \vec{p_h})^2}{(2\sum_{h\in\mathcal{H}_c} |\vec{p}_h|)^2}$$
- C-parameter
$$C = \frac{1}{2}\cdot\frac{3\sum_{h,h'\in\mathcal{H}_c} |\vec{p_h}||\vec{p_{h'}}| \sin^2\vartheta_{hh'}}{(\sum_{h\in\mathcal{H}_c} |\vec{p}_h|)^2}$$



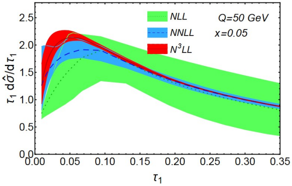
Only particles in the current hemisphere contribute
→ Introduce cut to ensure infrared safety $E_c = \sum_h E_h > Q/10$

Summary and outlook

- A first measurement of the 1-jettiness event shape observable in NC DIS was presented
- 1-jettiness is equivalent to DIS thrust normalised with $Q/2$
  $\rightarrow$ Defined for every NC DIS event
- Reasonable description of the data by various models
- New predictions to be confronted with the data (N^3LL, SHERPA 3, ...)



Reichelt, Phenomenology of Jet Angularities at NLO+NLL' accuracy, Jet physics from LHC/RHIC to EIC, https://indico.bnl.gov/event/14375/contributions/65419/



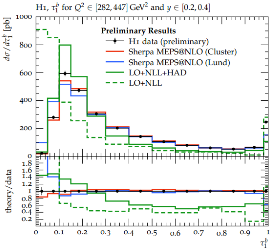
Kang, Lee, Stewart, [PoS DIS2015 (2015) 142]

Summary

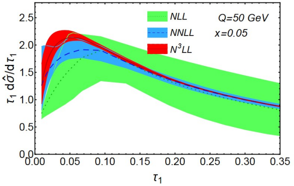
My contributions to the analysis

- Wrote large parts of the analysis code (cross checks, QED corrections, unfolding, plotting)
- Studied different definition of the observable and different reconstruction methods
- Determined systematic uncertainties
- Achieved a 'preliminary' approval from the H1 collaboration
- Presented the results at DPG and EPSHEP21 conference

Code is now also used by other collaborators



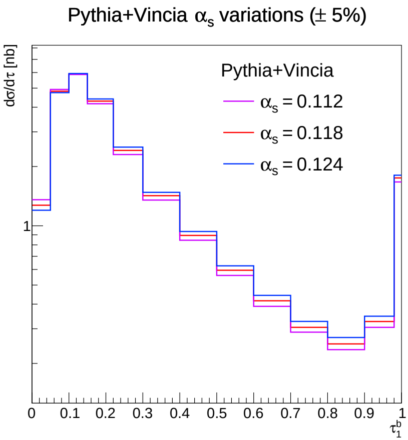
Reichelt, Phenomenology of Jet Angularities at NLO+NLL' accuracy, Jet physics from LHC/RHIC to EIC, https://indico.bnl.gov/event/14375/contributions/65419/



Kang, Lee, Stewart, [PoS DIS2015 (2015) 142]

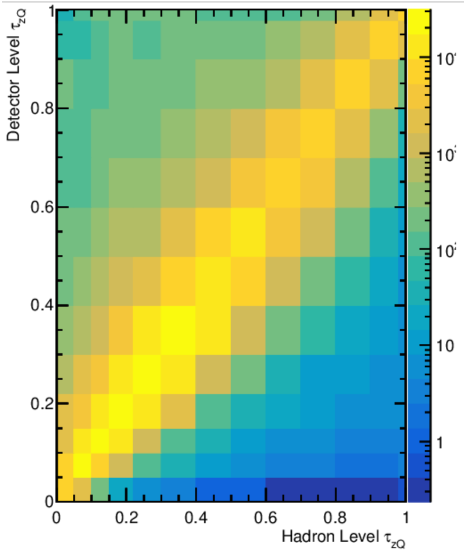
Backup

Sensitivity of τ_1^b to α_s

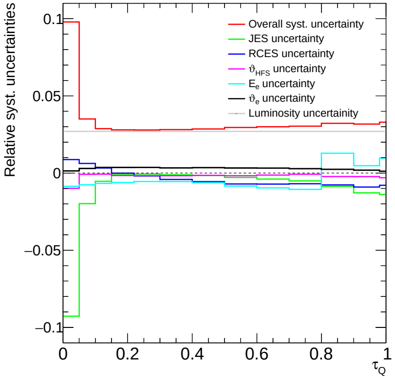


- Plot shows Pythia 8.3 + Vincia prediction for τ_1^b on particle level
  → High sensitivity in tail region
  → No sensitivity in peak region (Born level kinematics)

Migration matrix



Systematical uncertainties



- Systematic uncertainties as a function of τ_1^b
- Dominated by 2.7% luminosity uncertainty

Purity distribution

Purity defined as N_{stay}/N_{rec}

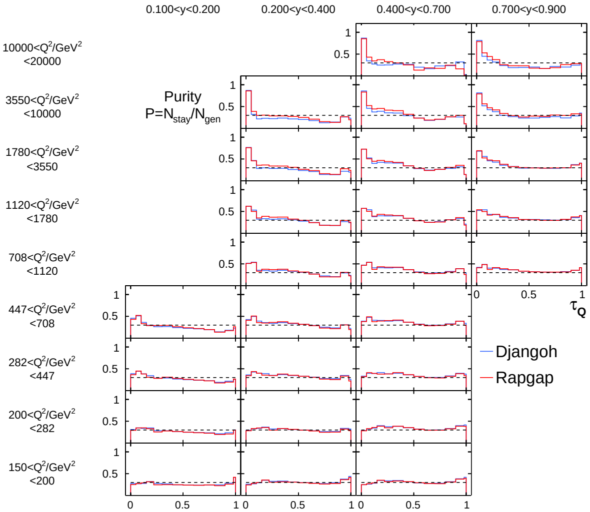
- N_{rec}: Events on detector level in one bin
- N_{stay}: Events that are reconstructed in the same bin they were generated

Purity

- Rapgap and Djangoh behave similarly
- Flat distribution in all y-Q^2 bins
- Purities $> 30\%$ in most bins

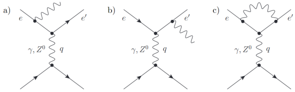
From different binnings and 2D migration matrices

- Purity mainly limited by bin-to-bin resolution effects
- Not an effect from limited detector acceptance



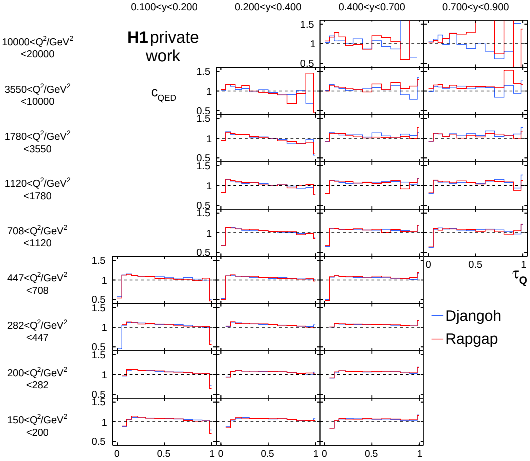
Correct for electron QED radiative effects

- Real emissions of photons (a,b)
- Vertex corrections (c)



- QED processes simulated with HERACLES
- Size of corrections depends on reconstruction method

→ Corrections around 10%
→ Large effect in the first bin



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NNLO pQCD ($ep \to$2 jets+X)

- Reasonable description in entire phase space
- Improved description with increasing Q^2
- Small scale uncertainties

$\to$ Altogether: NNLO improves over NLO but NP corrections are sizeable