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

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31st International Workshop on Deep Inelastic Scattering

Technische Universität München,
Max-Planck-Institut für Physik

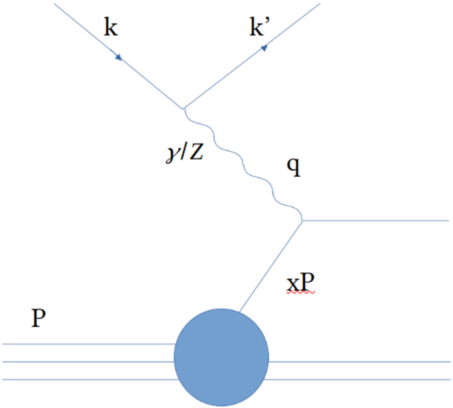
9.4.2024

Neutral current deep-inelastic scattering

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

Kinematic variables

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



The 1-jettiness event shape observable - Definition

1-jettiness τ_1^b

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

- Axes: Incoming parton and (q+xP)
- Infrared safe and free of non-global logs
- Sensitive to α_s and parton shower models
- Measurement can be used for MC tuning

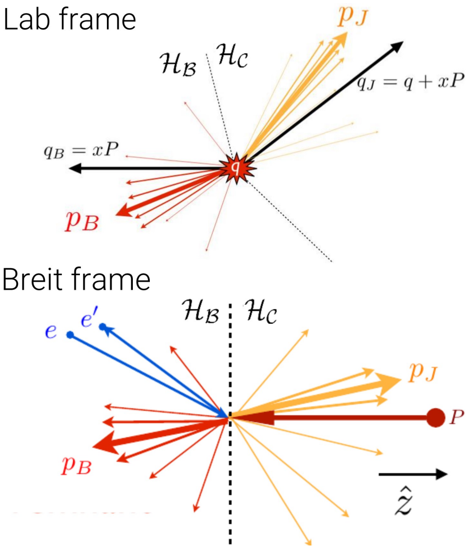
Equivalent expressions

- Using momentum conservation

$$\tau_1^b = 1 - 2 \sum_{i \in HFS} \max\{0, \frac{q \cdot p_i}{q \cdot q}\}$$

- DIS thrust

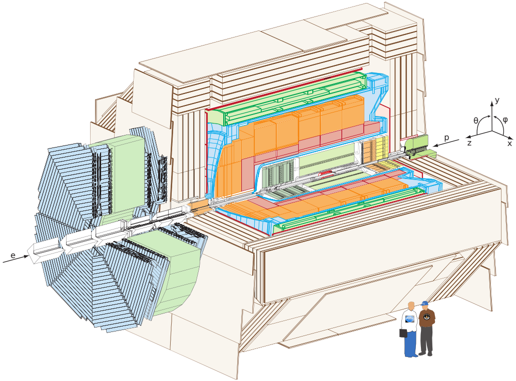
$$\tau_1^b = 1 - \frac{2}{Q} \sum_{i \in H_C} P_{z,i}^{Breit}$$



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

The H1 detector

- Data were taken from 2003 to 2007 (HERA-2)
- Electron ($L = 159.6\ \text{pb}^{-1}$) and positron ($L = 192.0\ \text{pb}^{-1}$) runs
- $E_e = 27.6$ GeV, $E_p = 920$ GeV $\rightarrow \sqrt{s} = 319$ GeV

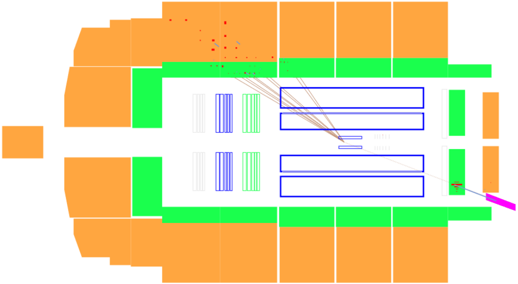


- Asymmetric design with trackers, calorimeter, solenoid, muon-chambers, forward & backward detectors
- Particles are reconstructed using a particle flow algorithm $\rightarrow$ Combining cluster and track information without double-counting of energy

Sketch taken from R. Kogler [DESY-THESIS-2011-003 (2010)]

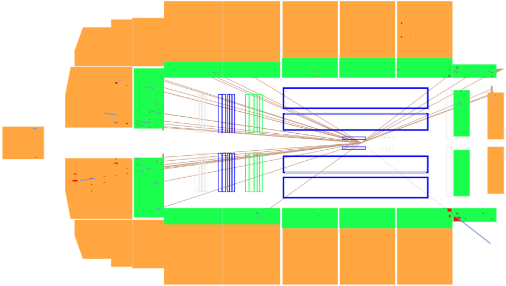
1-jettiness: $\tau_1^b = \frac{2}{Q^2} \sum_{i \in HFS} \min\{xP \cdot p_i, (q + xP) \cdot p_i\}$

Visualisation of the 1-jettiness with event displays



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

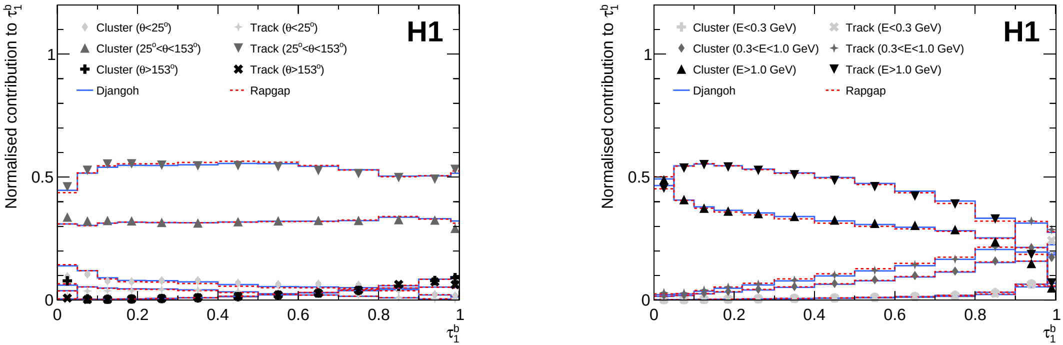
→ **1-jettiness defined for every DIS event**
→ **All particles can contribute, no jet clustering!**



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

DIS thrust - a 4π observable

- All particle candidates in all DIS events contribute $\left(\tau_1^b = 1 - \frac{2}{Q}\sum_{i\in\mathcal{H}_\mathcal{C}} P_{z,i}^{Breit}\right)$
- Normalised contribution to τ_1^b for different ranges in polar angle ϑ and energy



- Mainly tracks and clusters in the central part of the detector contribute $(25^\circ < \vartheta < 153^\circ)$
- Mainly particles with high energy contribute ($E > 1$ GeV)

  $\Rightarrow$ Well measured particles dominate in τ_1^b

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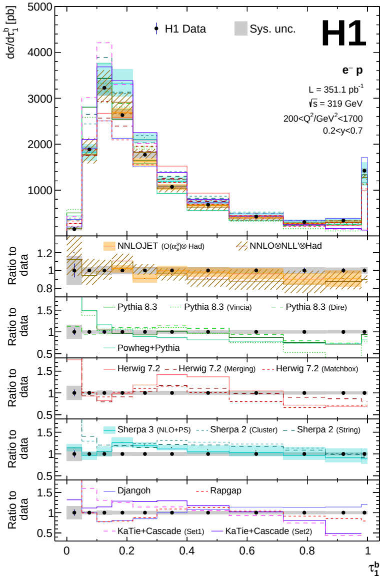
1-jettiness cross section

- Data unfolded using TUnfold
- Correct for QED radiation and electro-weak effects
- Resulting cross section reported for $e^- p$ and $e^+ p$ collisions

Comparison with MC models

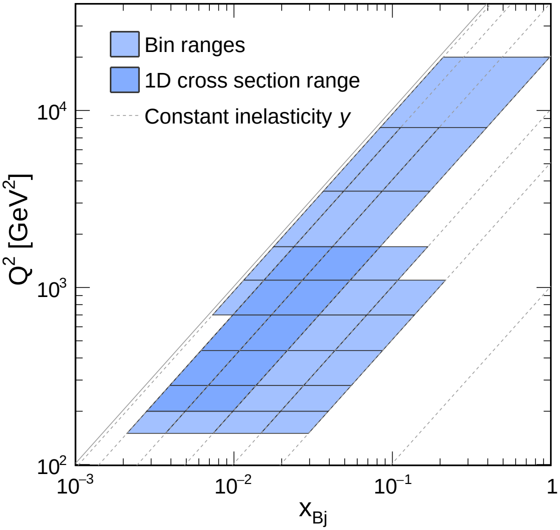
- Compare data to 15 different models
- $\delta-$distribution at $\tau_1^b = 1$
  $\rightarrow$ Events with empty current hemisphere
  $\rightarrow$ Dedicated talk by Zhiqing
- Cross sections are measured at high precision
  $\rightarrow$ None of the MC models works perfectly, now have precision data for tuning
  $\rightarrow$ Exact QCD predictions have sizeable scale uncertainties and large hadronization corrections



Large cross section and sizeable data
→ Triple-diff. cross sections as a function of Q^2, y, τ_1^b

Triple differential measurement

- Investigate change in shape of the distribution
- Integral over the τ_1^b distribution results in inclusive DIS cross section



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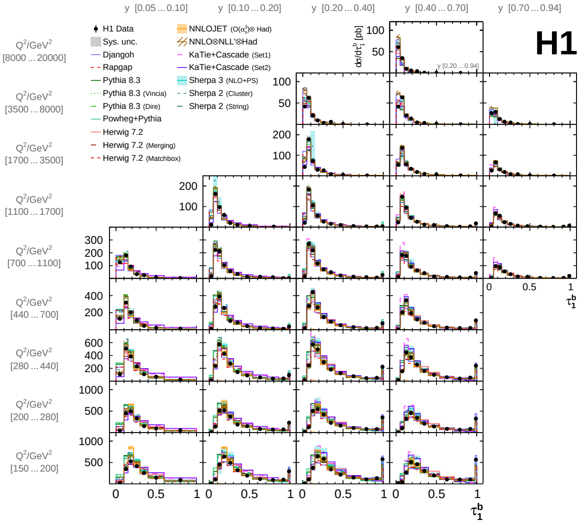
3D cross sections

- increasing Q^2
  $\rightarrow$ Peak moves to lower τ
  $\rightarrow$ Tail region lowers
- Increasing y
  $\rightarrow$ $\tau = 1$ becomes enhanced
- Reasonable description by various models
  $\rightarrow$ Study ratio to data for better comparison

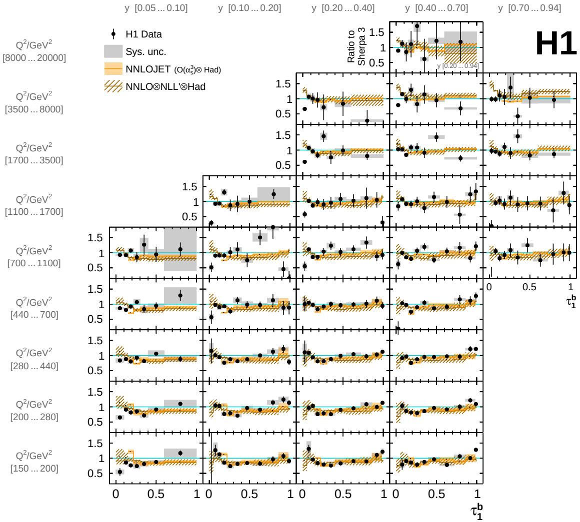


Uncertainties

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

MC comparison

- Ratio to Sherpa 3
- Fixed order calculations provide satisfactory description in region of validity
- Comparison to other MC predictions included in backup



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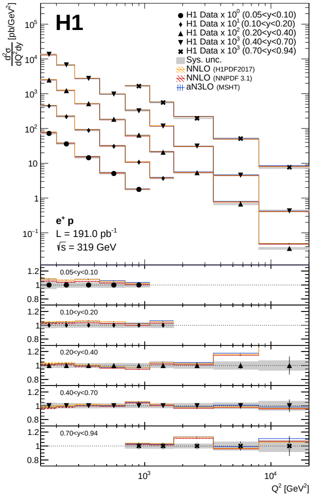
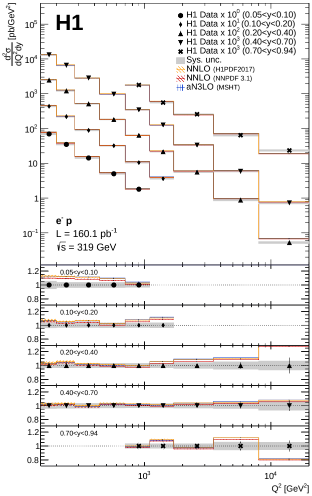
Integrate over τ_1^b distribution
$\rightarrow$ Inclusive DIS cross section

- Cross sections for e^-p and e^+p collisions
- Compare the data to fixed order calculations at NNLO and approximate N3LO accuracy
  $\rightarrow$ Excellent agreement between data and predictions
- Cross check validates τ_1^b measurement





Summary

A first measurement of the 1-jettiness event shape observable in NC DIS was presented

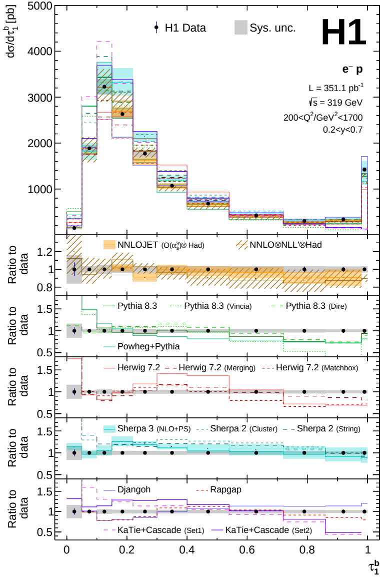
- Defined for every NC DIS event
- Every particle candidate can contribute

Cross section measurement

- Presented single differential cross sections and in bins of y and Q^2
- Reasonable description of the data by multiple models
- Integrating over τ_1^b results in DIS cross section

Full publication available at arXiv:2403.10109v1

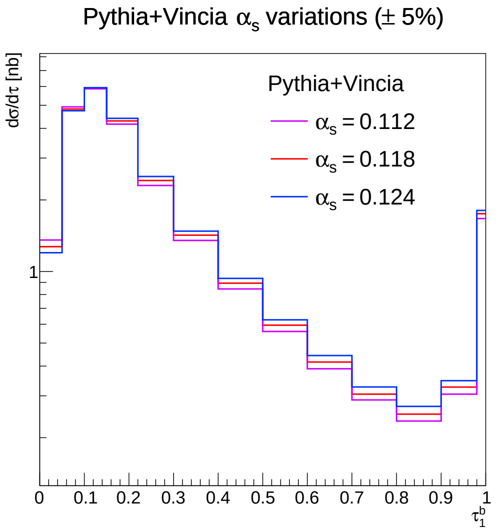
More H1 event shape results in Henry's talk



Backup

Sensitivity of τ_1^b to α_s

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



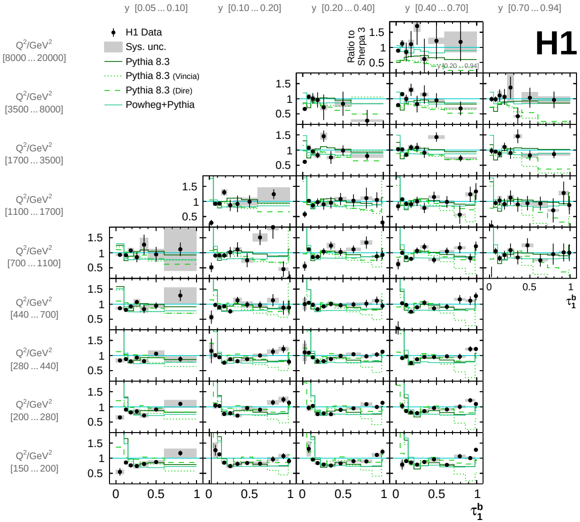
Triple differential cross sections

Comparison of data to

- Pythia 8.3
- Pythia 8.3 + Vincia Parton Shower
- Pyhtia 8.3 + Dire Parton Shower
- Powheg + Pythia

Ratio to Sherpa 3

- First bin overestimated by MC models
- Good agreement in peak region
- Smaller dependence on PS model at higher τ_1^b

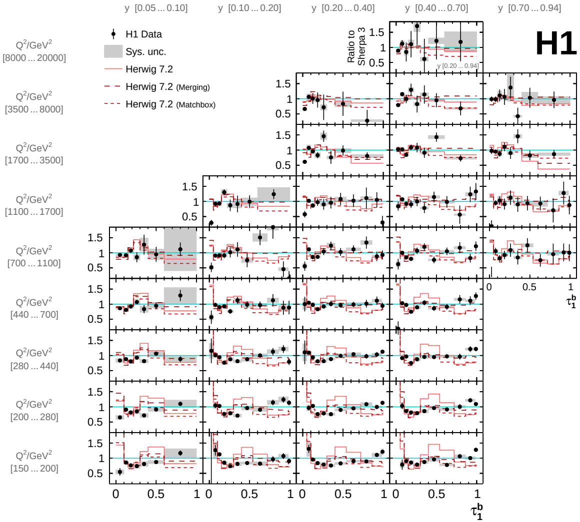


Comparison of data to

- Herwig 7.2
- Herwig 7.2 Merging
- Herwig 7.2 Matchbox

Ratio to Sherpa 3

- Overestimates data at medium τ_1^b and small Q^2



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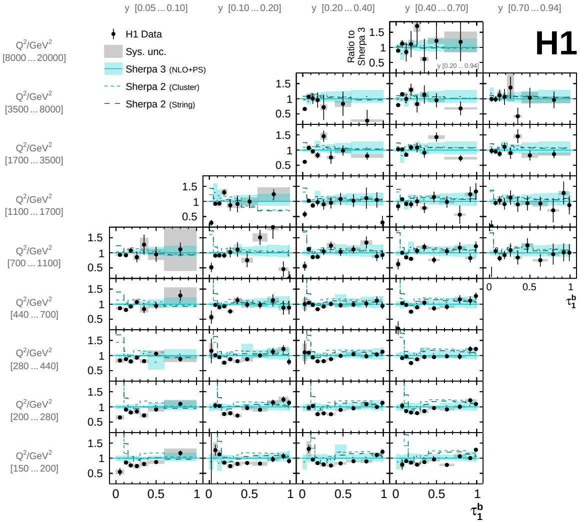
Comparison of data to

- Sherpa 3
- Sherpa 2 (Cluster)
- Sherpa 2 (String)

Ratio to Sherpa 3

- Best description by Sherpa 3
- Effect of different hadronization model is small



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Comparison of data to

- Djangoh
- Rapgap
- KaTie+Cascade (Set 1)
- KaTie+Cascade (Set 2)

Ratio to Sherpa 3

- Reasonable description of the data by Rapgap and Djangoh
- Good description of data at low τ_1^b by KaTie+Cascade but fail to describe tail region