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

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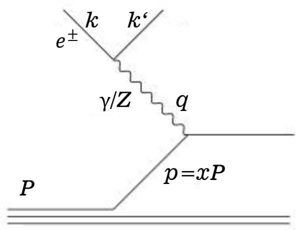
Neutral current deep-inelastic scattering

- Process $ep \rightarrow e'X$
- 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

  $y = \frac{P \cdot q}{P \cdot k} \qquad Q^2 = x_{Bj} \cdot y \cdot s$



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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 strong coupling α_s

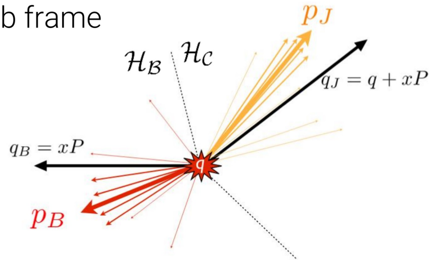
Equivalent expressions

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

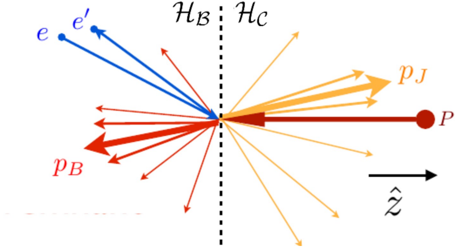
$$\tau_1^b = 1 - \frac{2}{Q} \sum_{i \in HFS} \min\{0, \frac{\Delta}{2}(E_i + P_{z,i}) - p_i \cdot k'\}$$

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

Lab frame

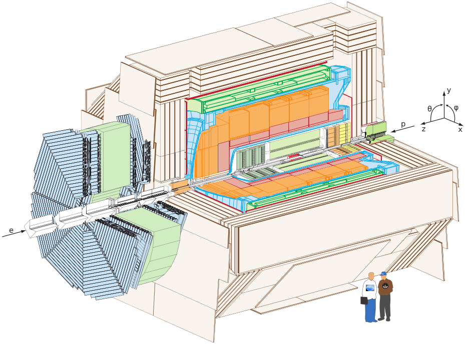


Breit frame



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

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



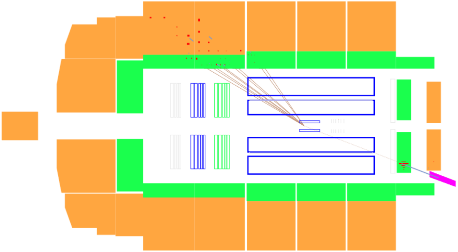
- Asymmetric design with trackers, calorimeter, solenoid, muon-chambers, forward & backward detectors
- Particles are reconstructed using a particle flow algorithm
  $\rightarrow$ Combining cluster and track information without double-counting of energy

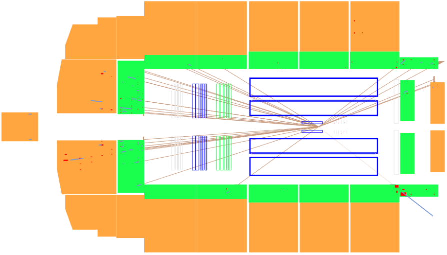
Sketch taken from R. Kogler [DESY-THESIS-2011-003 (2010)]

1-jettiness

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

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

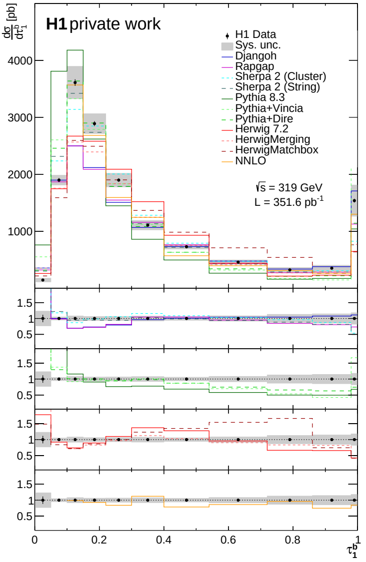
Single differential cross section

1-jettiness cross section

- Data unfolded using TUnfold
- Correct for QED radiation and electro-weak effects
- Resulting cross section reported for $e^- p$ collisions
- Correct for binning effects in τ_1^b

Comparison with MC models

- First bin overestimated by predictions
- Good description of the data
  $\rightarrow$ Data can be used to test parton shower models

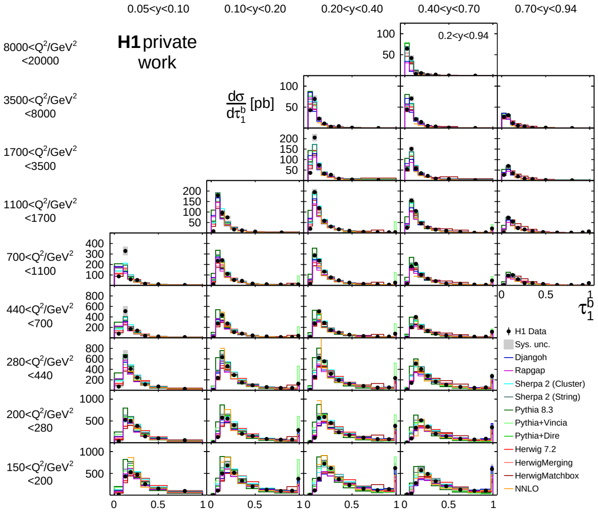


Large cross section and sizeable data

→ Triple-diff. cross sections as a function of Q^2, y, τ_1^b

3D cross sections

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



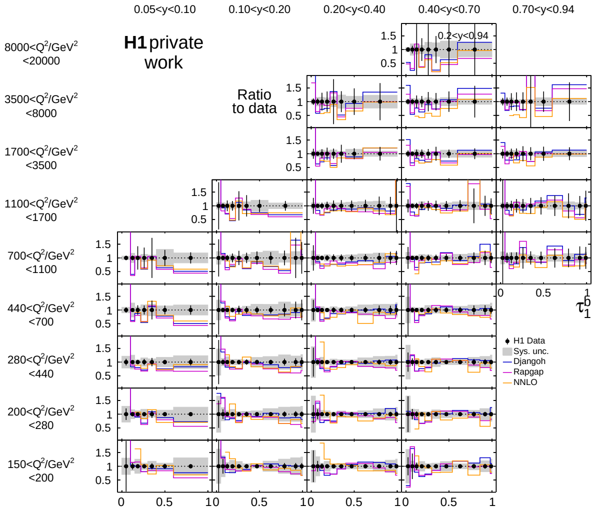
Triple differential cross sections

Ratio to data

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

$\rightarrow$ **Good discription by Rapgap and Djangoh**

$\rightarrow$ **Fixed order calculations provide reasonable description in region of validity**



Double differential cross section

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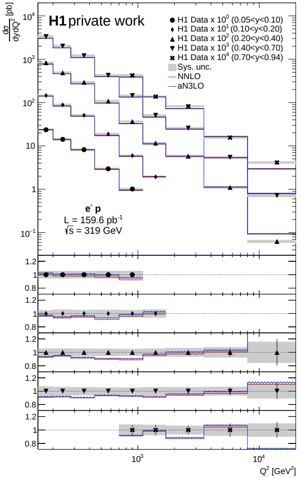
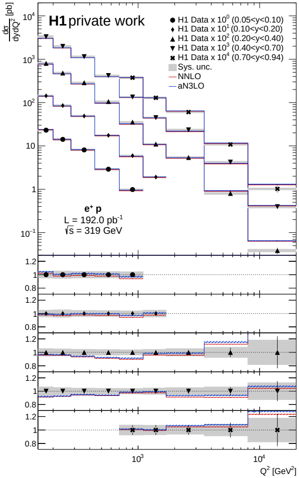
Integrating over τ_1^b results in the inclusive DIS cross section

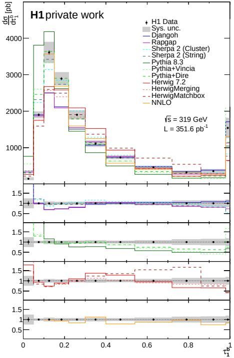


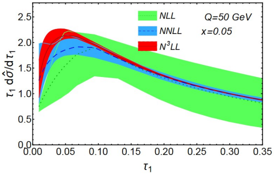


→ Cross sections for $e^- p$ and $e^+ p$ collisions
→ Compare the data to fixed order calculations at approximate N3LO and NNLO accuracy
→ Excellent agreement between data and predictions [Predictions from V. Bertone with Apfel++]

Summary and outlook

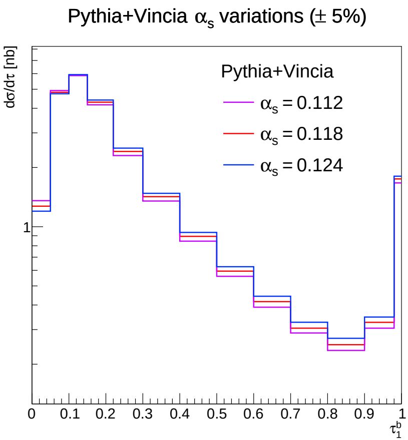
- A first measurement of the 1-jettiness event shape observable in NC DIS was presented
  → Defined for every NC DIS event
  → Presented single differential cross sections and in bins of y and Q^2
- Reasonable description of the data by multiple models
- New N^{3}LL predictions to be confronted with the data
- Aiming for publication this spring





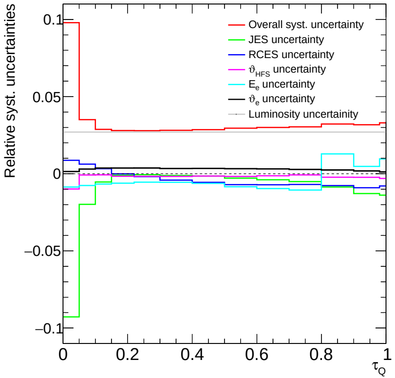
Kang, Lee, Stewart, [PoS DIS2015 (2015) 142]

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)

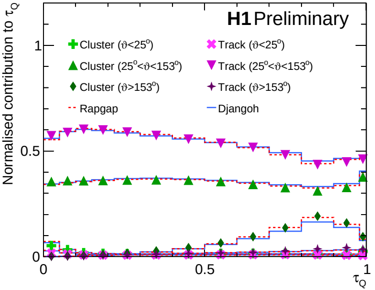
Systematical uncertainties

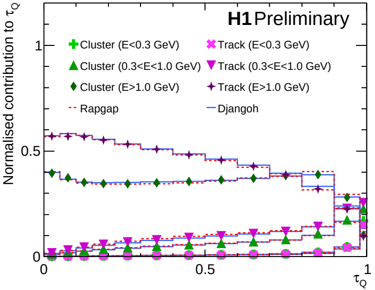


- Systematic uncertainties as a function of τ_Q
- Dominated by 2.7% luminosity uncertainty

DIS thrust - a 4π observable

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



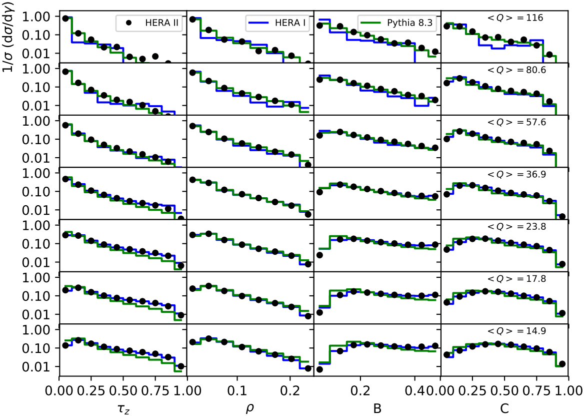


- Mainly tracks and clusters in the central part of the detector contribute ($25° < \vartheta < 153°$)
- Mainly particles with high energy contribute ($E > 1$ GeV)
  $\Rightarrow$ Well measured particles dominate in τ_Q

Classical event shape observables

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

$\rightarrow$ Introduce cut to ensure infrared safety $E_c = \sum_h E_h > Q/10$