Measurement of 1-jettiness in deep-inelastic *ep* scattering at HERA

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Neutral current deep-inelastic scattering

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

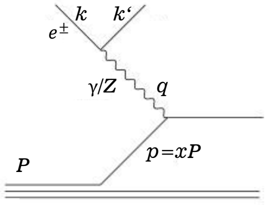
Kinematic variables

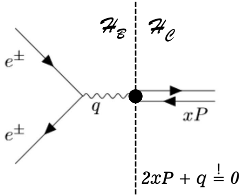
- Virtuality of exchanged boson Q^2
  $Q^2 = -q^2 = -(k - k')^2$
- Inelasticity, Bjorken-x and centre-of-mass energy

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

Breit frame

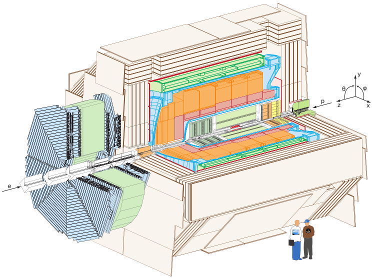
- Exchanged boson completely space-like
- Collides head-on with parton (brick-wall frame)





The H1 detector

- Integrated luminosity $L = 351.6\ \mathrm{pb}^{-1}$
- Electron and positron 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
- Trigger requires high-energetic cluster in LAr calorimenter
- Particles are reconstructed using a particle flow algorithm
  $\rightarrow$ Combining cluster and track information without double-counting of energy

The 1-jettiness event shape observable

1-jettiness

- Axes incoming parton and $q + xP$:

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

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

DIS thrust normalised to boson axis

- Normalisation with $Q/2$ of the event:

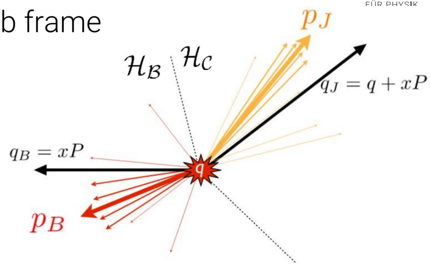
$$\tau_Q = 1 - \frac{2}{Q} \sum_{i \in \mathcal{H}_\mathcal{C}} P_{z,i}^{Breit}$$

- Only particles in the current hemisphere contribute

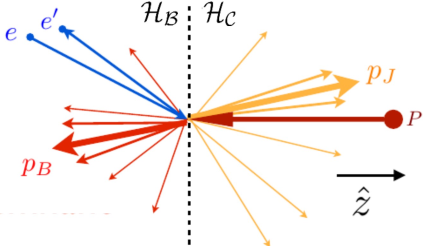
Equivalence follows from momentum conservation:

$$\tau_Q = \tau_1^b$$

Lab frame



Breit frame



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

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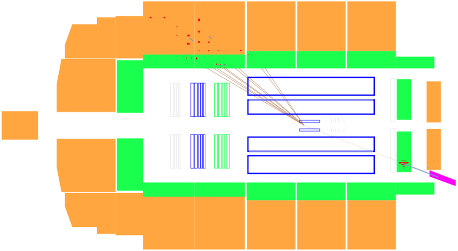
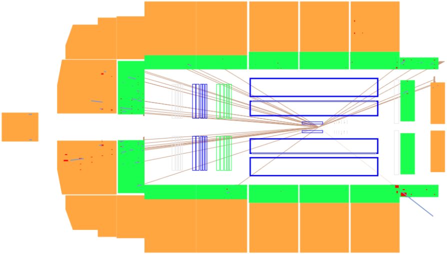
1-jettiness

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

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

HERA-II data

- High-Q^2 region: $Q^2 > 150$ GeV^2
- Luminosity: $L = 351$ pb^{-1}

Signal Monte Carlo models

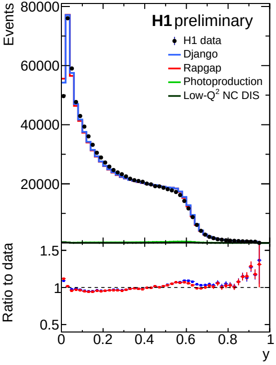
- Rapgap (ME + PS)
- Djangoh (CDM)

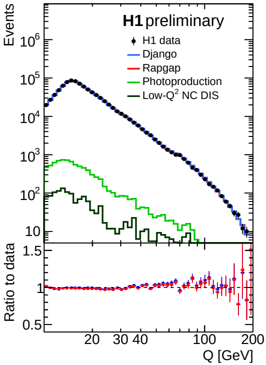
Little background in incl. DIS

- Photoproduction
- Low-Q^2 NC DIS
- Other sources are negligible (QEDC, CC DIS, di-lepton production)

Reconstruction

- Use the IΣ method → Independent of electron ISR



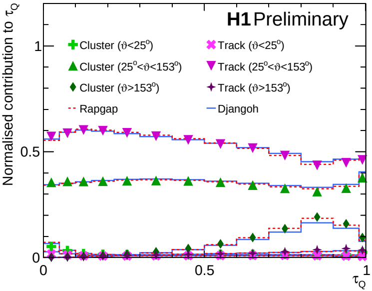


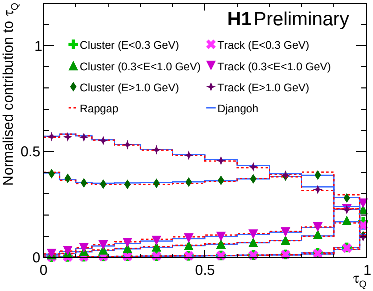
$$y = y_\Sigma = \frac{\Sigma}{\Sigma + E_{e'}(1 - \cos\vartheta_{e'})}$$

$$Q^2 = Q^2_\Sigma = \frac{E^2_{e'} \sin\vartheta_{e'}}{1 - y_\Sigma}$$

DIS thrust - a 4π observable

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





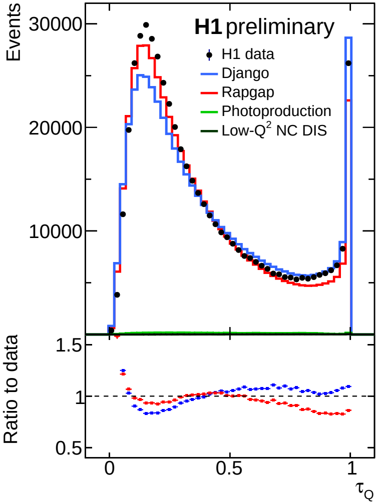
- Mainly tracks and clusters in the central part of the detector contribute $(25^\circ < \vartheta < 153^\circ)$
- Mainly particles with high energy contribute ($E > 1$ GeV)
  $\Rightarrow$ Well measured particles dominate in τ_Q

DIS thrust

- $\tau_Q \to 0$: DIS 1-jet events
- $\tau_Q \to 1$: Dijet events
- $\tau_Q = 1$: Dijet event, both jets in beam hemisphere

MC models

- Harder spectrum in Django (more dijet events) $\to$ Agrees with previous measurements
- Reasonable agreement between data and MC $\to$ Full τ_Q range measurable



Single differential cross section

- Unfolded using bin-by-bin method
- Corrected for electron QED radiative effects
- Divide by τ_1^b-bin width

Comparison with MC models

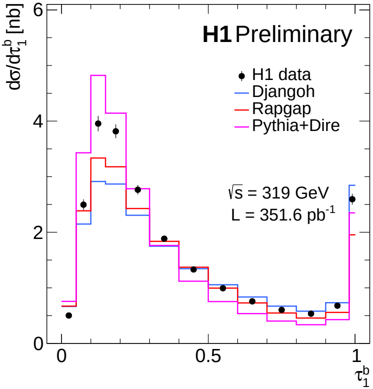
- Djangoh 1.4: Colour-dipole-model
- Rapgap 3.1: ME + parton shower
- Pythia 8.3 + Dire

Dire Parton Shower

- Dipole-like shower
- Inclusive NLO DGLAP corrections to the shower evolution are included

Phase space

- $150 < Q^2 < 20.000$ GeV^2
- $0.2 < y < 0.7$



Peak region (resummation region)

- Not well described by the models

Tail region (fixed order region)

- Djangoh and Rapgap perform well
- Pythia+Dire underestimates the data

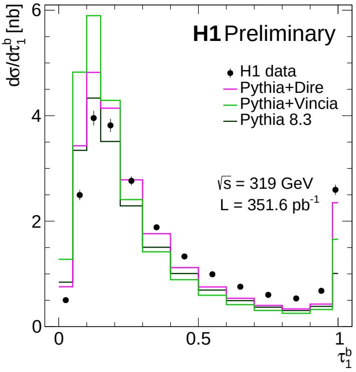
Single differential cross section

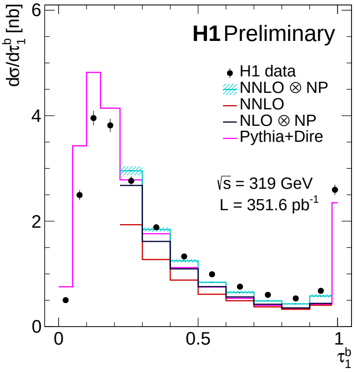
Comparison with parton shower models

- 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





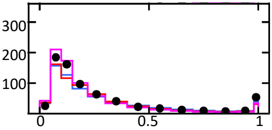
Large cross section and sizeable data

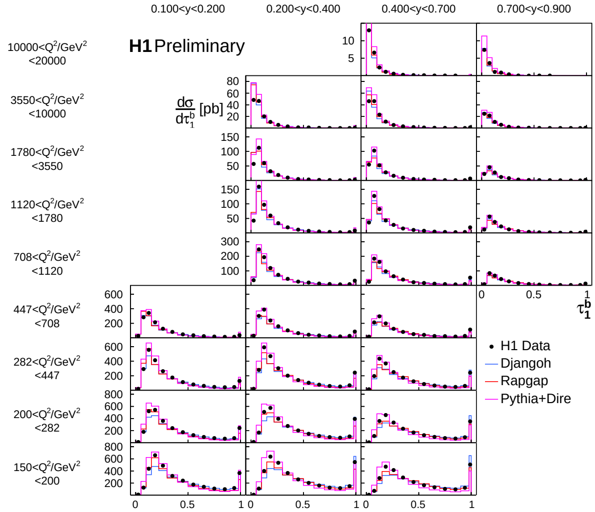
→ Triple-diff. cross sections as a function of Q^2, y, τ

3D cross sections

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

0.4 < y < 0.7, 708 < Q^2 / GeV^2 < 1120





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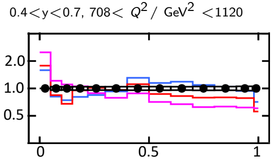
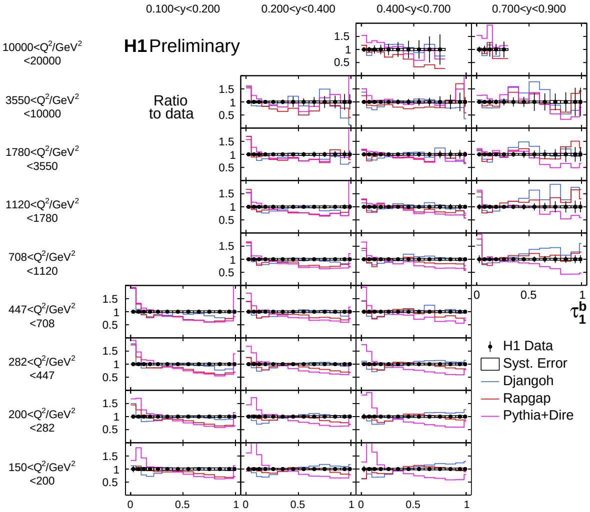
Ratio to data

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

$\rightarrow$ 'Classical' MC models perform reasonably well over entire phase space
$\rightarrow$ Pythia+Dire similar to Rapgap at low y, but too large at low τ





Triple differential cross sections

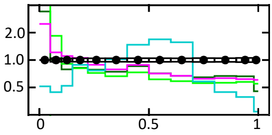
Comparison with further MC models

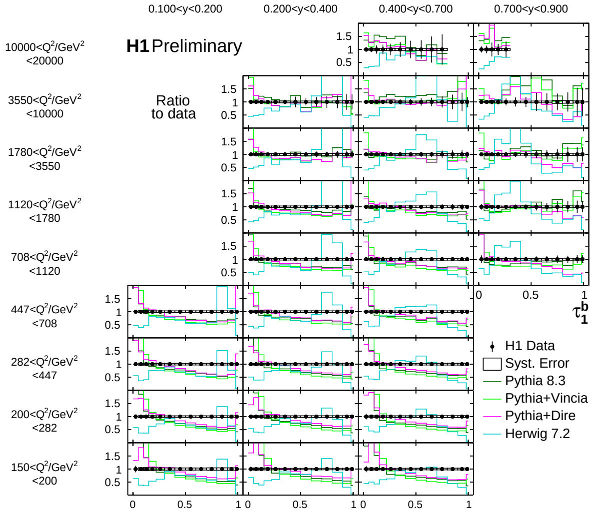
- Pythia+Vincia
- Pythia w/ default shower

Herwig 7.2

- Often similar to Pythia, but peak region too low (DIS cross section too low)
- Some structure at high τ

0.4 < y < 0.7, 708 < Q^2 / GeV^2 < 1120





Triple differential cross sections

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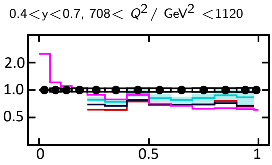
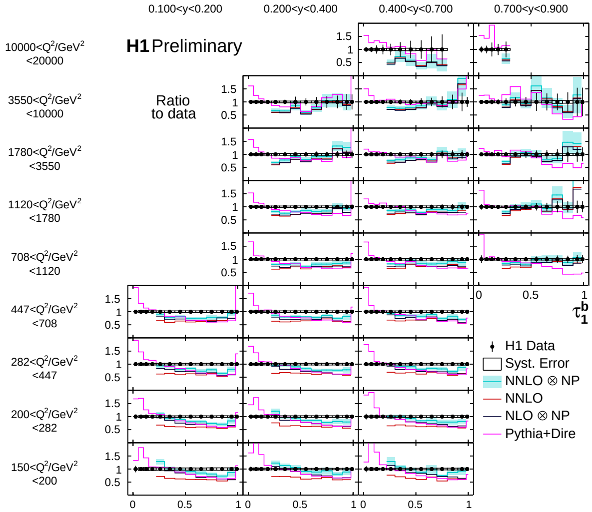
NNLO pQCD ($ep \to$2 jets+X)

- 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



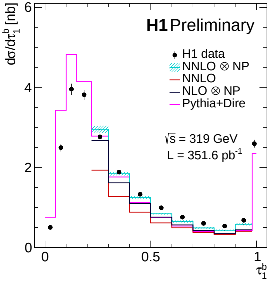


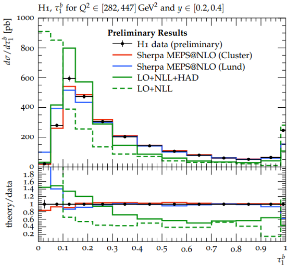
Summary and outlook

- A first measurement of the 1-jettiness event shape observable in NC DIS was presented
- 1-jettiness is equvalent to DIS thrust normalised with $Q/2$
- Classical Monte Carlo provides a good description of the data
- Modern Monte Carlo performs reasonably well
- NNLO fixed order predictions ($ep \to 2$ jets) provide good description in the region of validity, but hadronisation corrections are large
- H1prelim-21-032
  https://www-h1.desy.de/psfiles/confpap/EPSHEP2021/H1prelim-21-032.pdf

Outlook

- N3LL and NNLO+PS predictions need to be confronted with data
- Sensitivity to α_s and PDFs needs to be explored
- Data will become useful for improving (DIS) MC generators



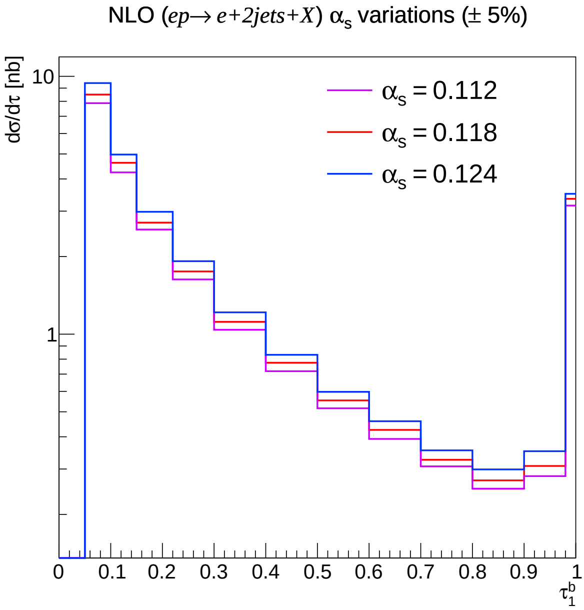


D. Reichelt @ Workshop: Jet Physics: From RHIC/LHC to EIC
https://indico.bnl.gov/event/14375/contributions/65419/attachments/41842/70086/JetsLCHtoEIC$_D$ Reichelt.pdf

Backup

Sensitivity to α_s

- Plot shows fixed order NLO calculation $ep \to e + 2jets$ for τ_1^b on PARTON LEVEL
- First bin is empty by definition
- Prediction scales linearly with strong coupling α_s



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- Plot shows Pythia 8.3 + Vincia prediction for τ_1^b on PARTICLE LEVEL
- Vary value of α_s in the simulation to test sensitivity
- High sensitivity in tail region
- No sensitivity in peak region (Born level kinematics)