Measurement of 1-Jettiness in the Breit Frame at High Q^2

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Center for Frontiers in Nuclear Science

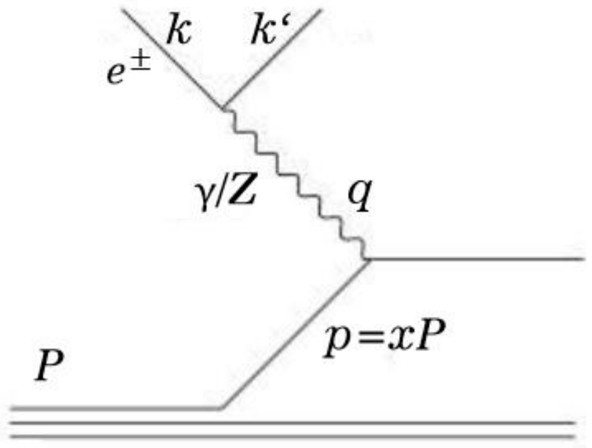
Neutral-Current DIS

- Electron-Proton Scattering
  - Kinematic variables:
    - Exchanged boson virtuality - Q^2
    - Inelasticity - y
    - Bjorken x – $x_{Bj.}$

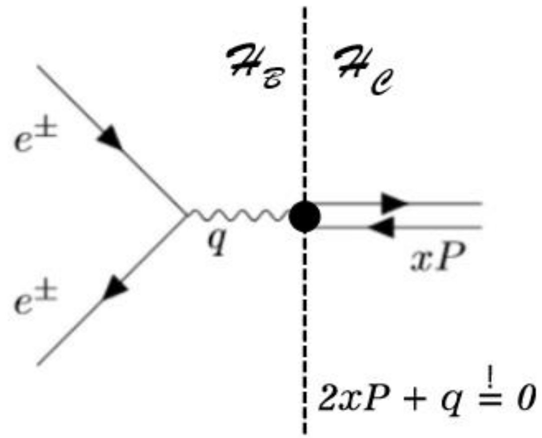
$$Q^2 = -q^2 = -(k - k')^2$$

$$y = \frac{p \cdot q}{p \cdot k}$$

$$x = -\frac{q^2}{2P \cdot q} = \frac{Q^2}{2P \cdot q}$$



- Breit Frame
  - Defined as the frame where $2x_{Bj.}P + q = 0$
    - Event is divided into two hemispheres: “beam” or ”remnant” or ”target” hemisphere and “current” hemisphere
  - Exchanged boson collides with struck parton and reverses the parton’s momentum



Beam Hemisphere: Proton remnant continues at η = ∞

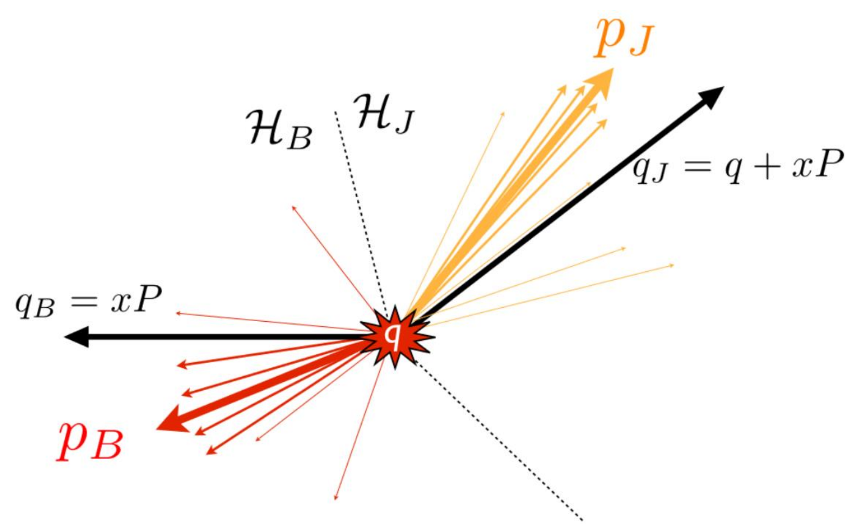
Current Hemisphere: Struck parton continues at η = -∞

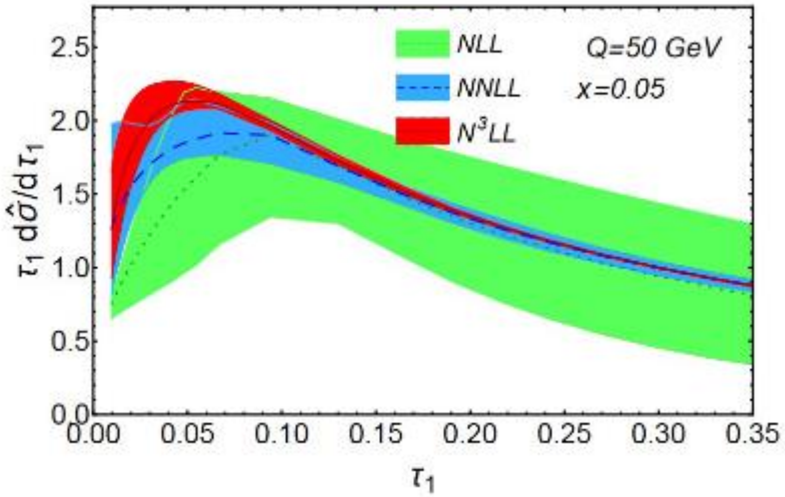
1-Jettiness Event Shape

- Sum of four-vector dot product of final state particles with struck-parton axis or beam axis

$$\tau_1 \equiv \frac{2}{Q^2} \sum_{i \in X} \min\{q_B \cdot p_i, q_J \cdot p_i\}$$

  - IR-safe and free from non-global logarithms
  - Sensitive to α_s and PDFs





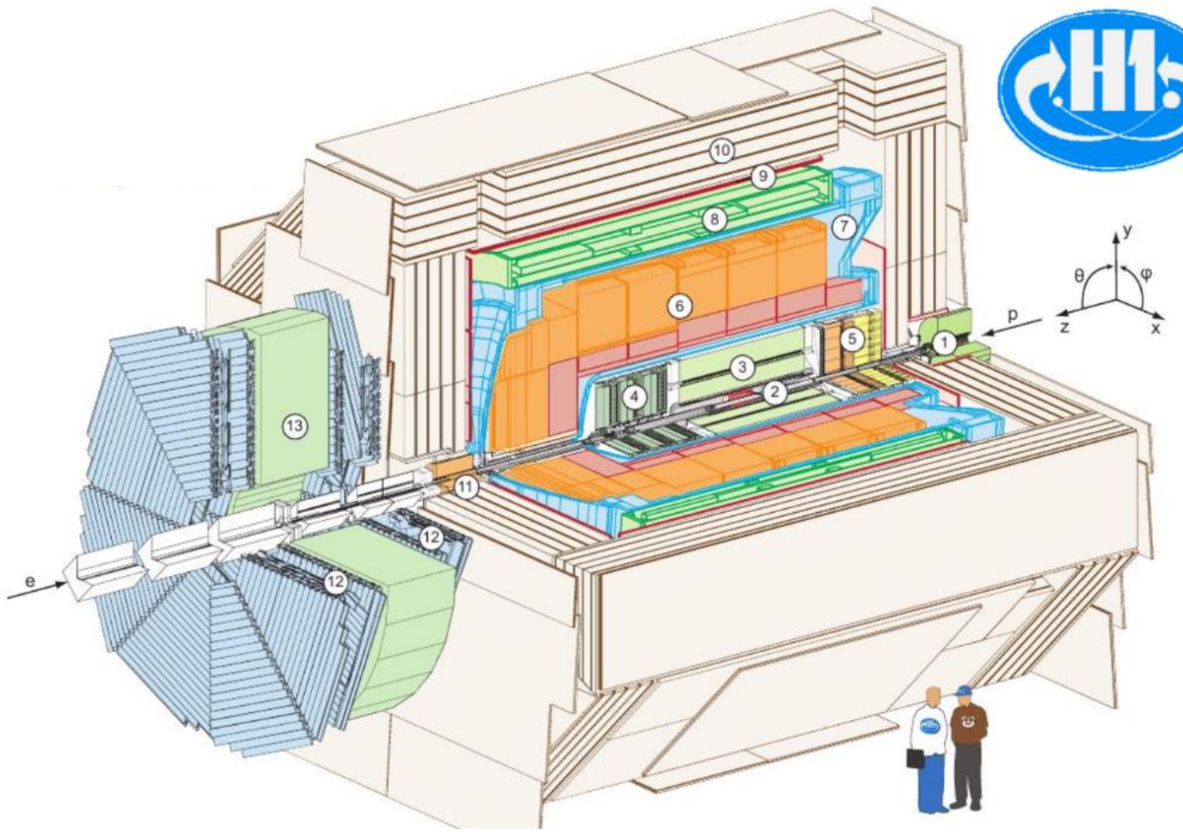
Kang, Lee, Stewart, [PoS DIS2015 (2015) 142]

- Equivalent definition follows from momentum conservation

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

  - Only particles in current hemisphere contribute – experimentally favorable

H1 at HERA



- HERA
  - World's only high energy electron-proton collider

$E_e = 27.6$ GeV, $E_p = 920$ GeV
$\rightarrow \sqrt{s} = 319$ GeV

- H1 Experiment
  - Hermetic detector with asymmetric design
    - Drift chamber + silicon tracking
    - High-resolution LAr calorimeter
    - Particles reconstructed with particle flow algorithm
  - Trigger on high-energy hadronic or EM LAr cluster
    - > 99% efficient for $y < 0.7$

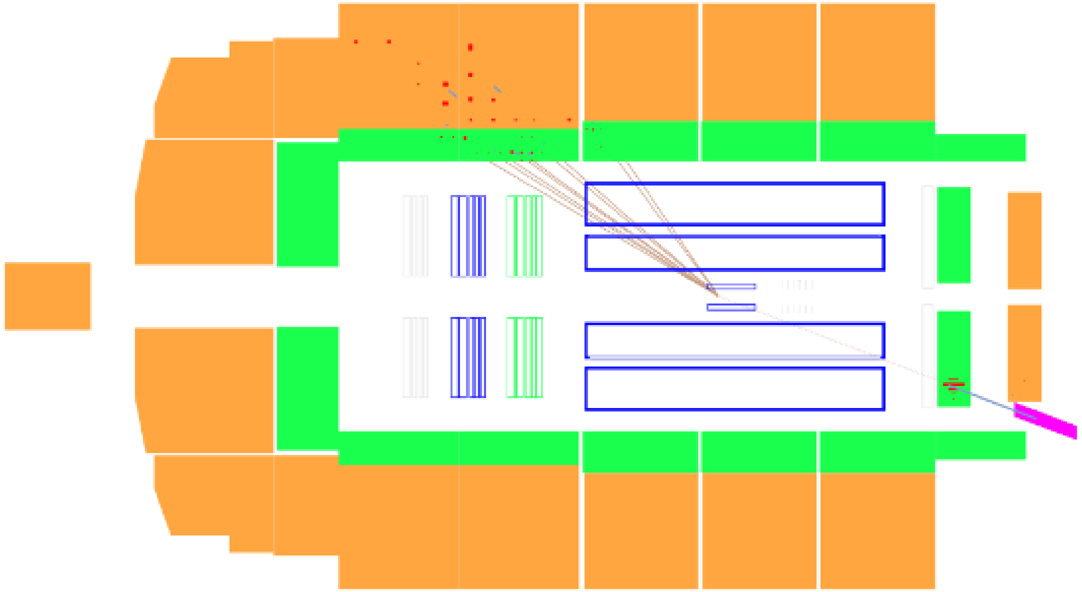
H1 LAr Calorimeter Specifications

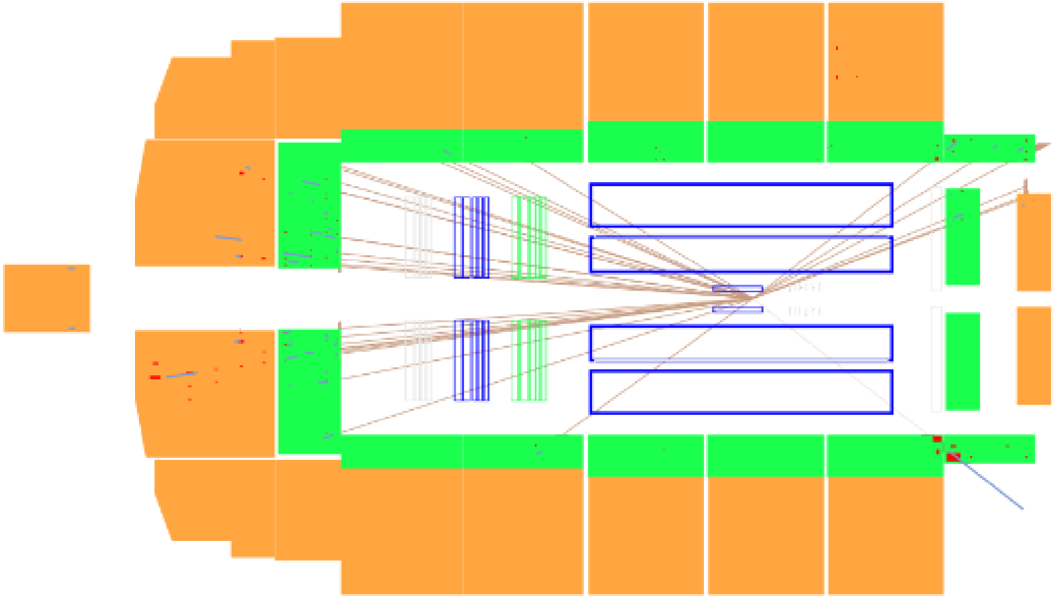
Electromagnetic part	Hadronic part
10 to 100 cm^2	50 to 2000 cm^2
20 to 30 X_0 (30784)	4.7 to 7 λ_{abs} (13568)
$\approx 11\%/\sqrt{E_e} \oplus 1\%$	$\approx 50\%/\sqrt{E_h} \oplus 2\%$

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



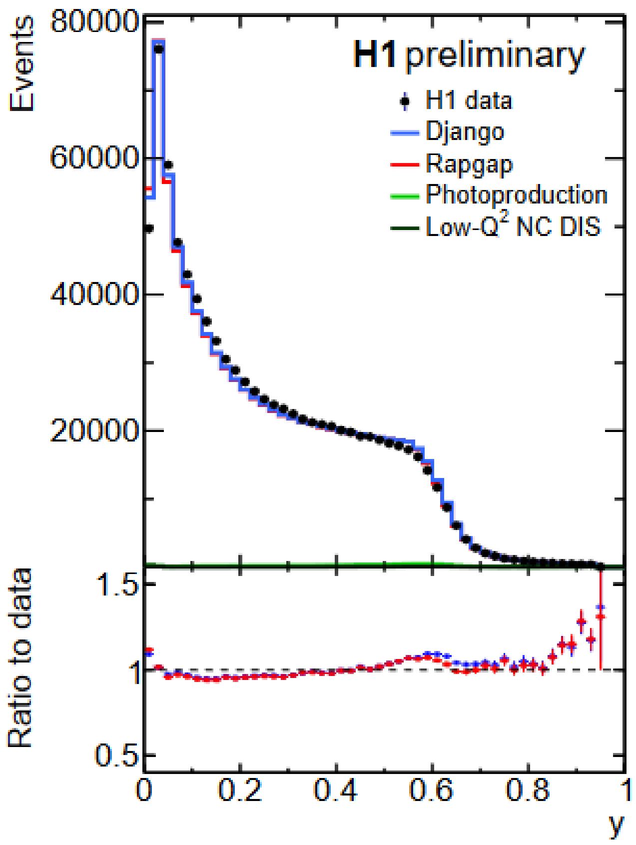


- DIS 1-jet configuration
- Most HFS particles collinear to scattered parton
  $\rightarrow$ Small τ_1^b

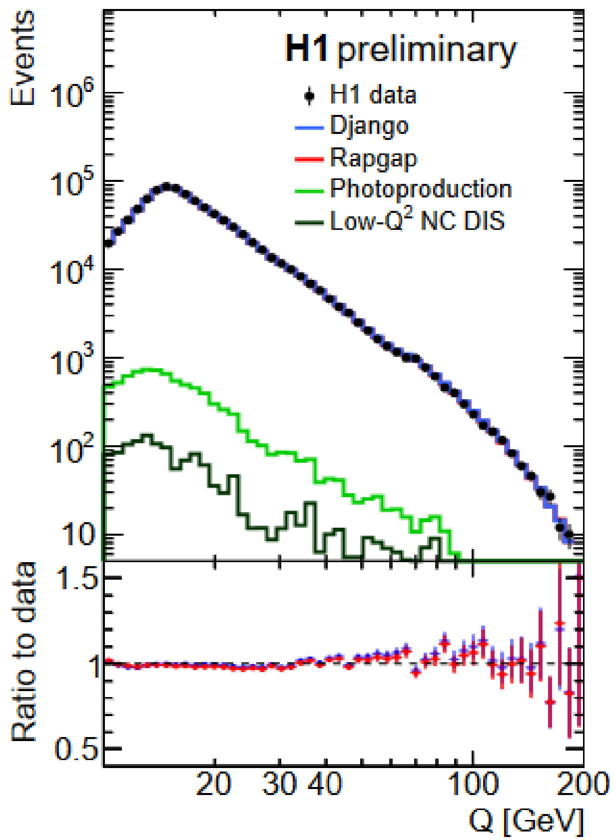
- Dijet event
- More and larger contributions to the sum over the HFS
  $\rightarrow$ Large τ_1^b

Inclusive DIS

- HERA-II data
  - $Q^2 > 150$ GeV^2, $0.2 < y < 0.7$
  - 351.7 pb^{-1} collected
- Rapgap (ME+PS) and Djangoh (CDM) used as “signal” generators
  - Both are full DIS generators
- Small backgrounds
  - Photoproduction, Low-Q NC DIS are largest sources
- DIS kinematics reconstructed with IΣ method
  - Independent of QED ISR



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



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

- Fully inclusive observable – all events contribute
  - All particles in current hemisphere contribute to sum →
  - Normalized contributions to τ_Q spectrum
    - 0 Degrees → proton-going direction, 180 degrees → electron-going direction

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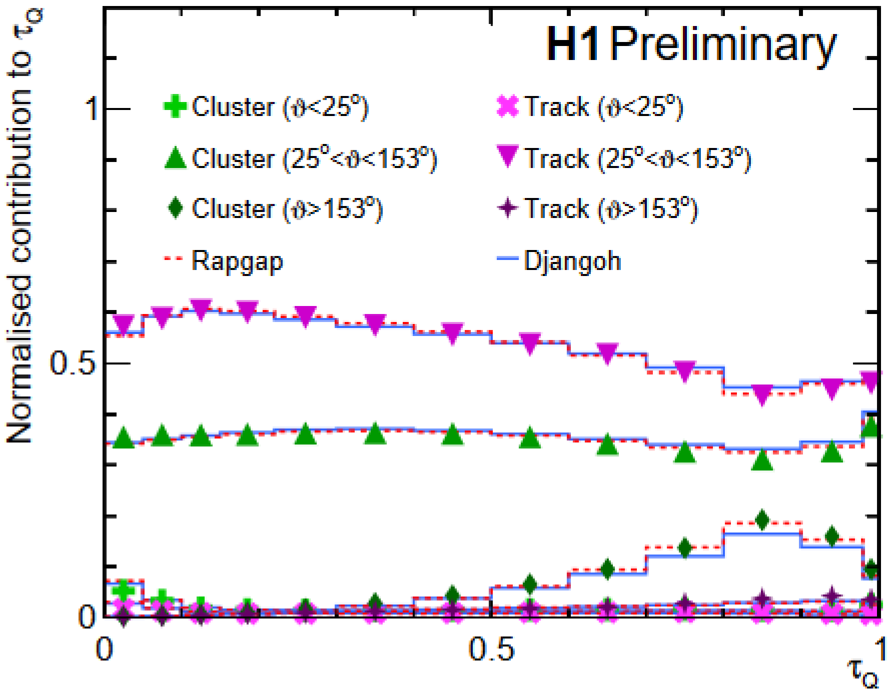
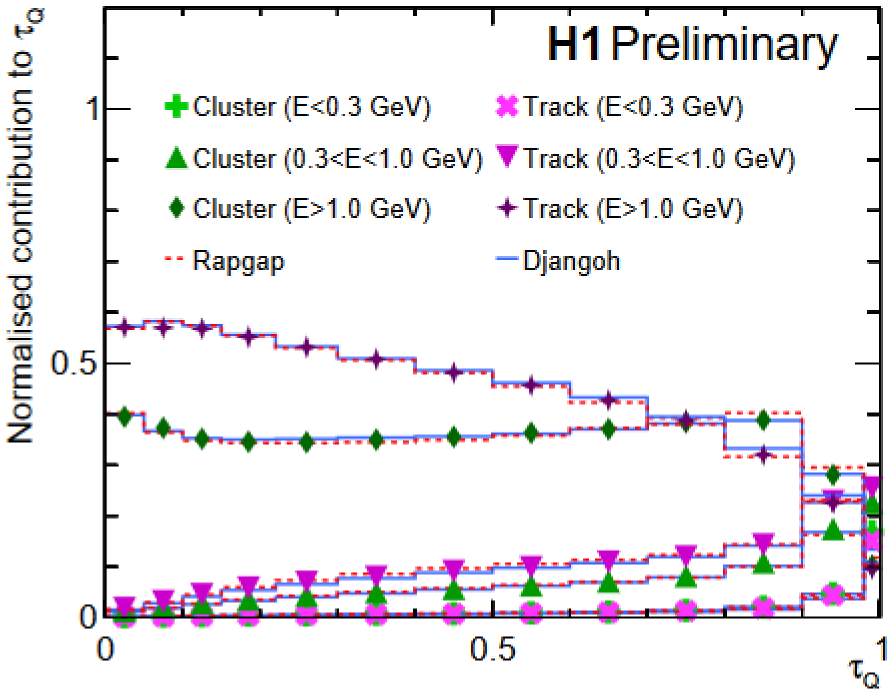
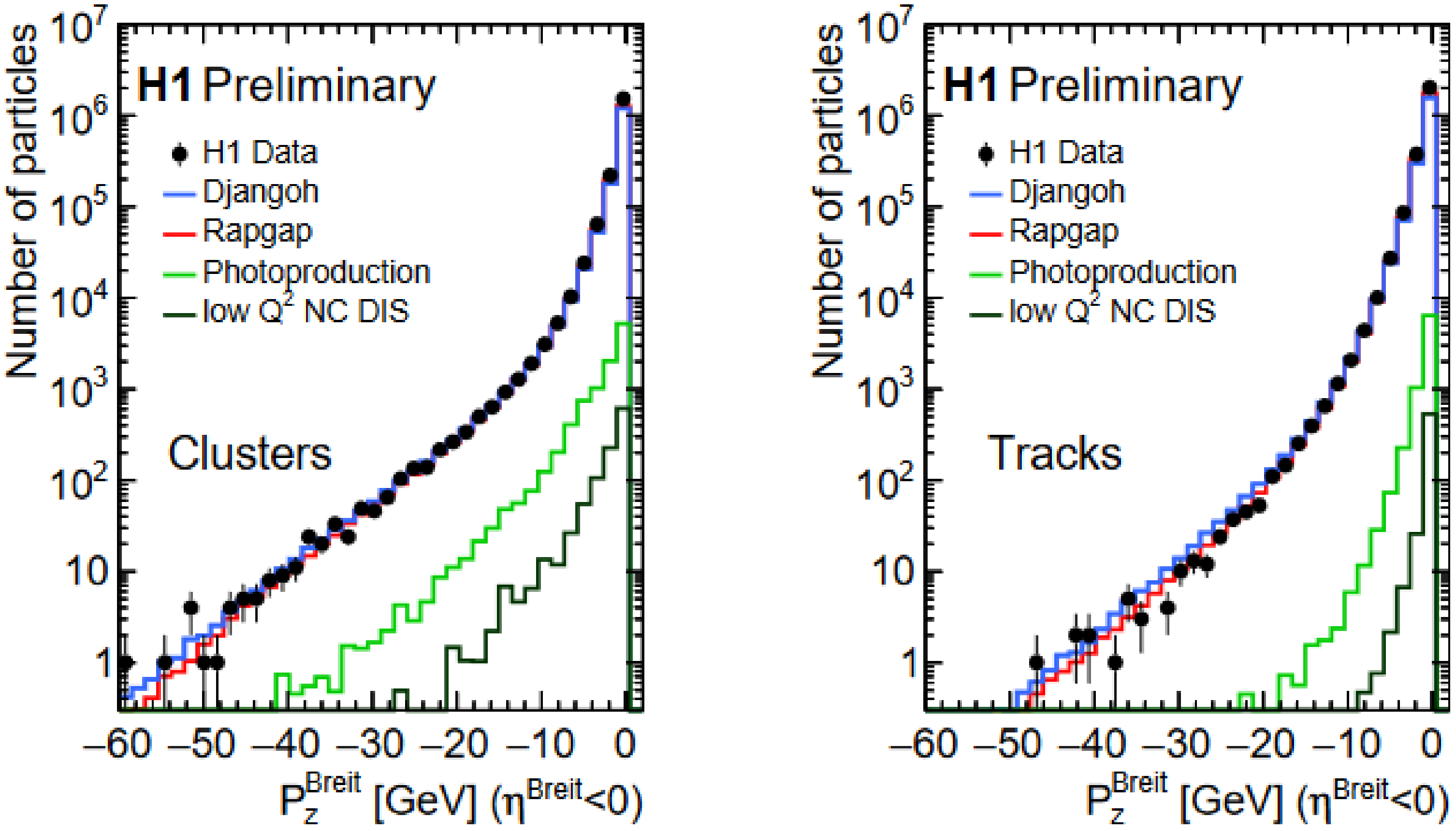




- Central, high momentum particles dominate the contribution
  - These are well-measured by the H1 detector

τ_Q Measurement

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

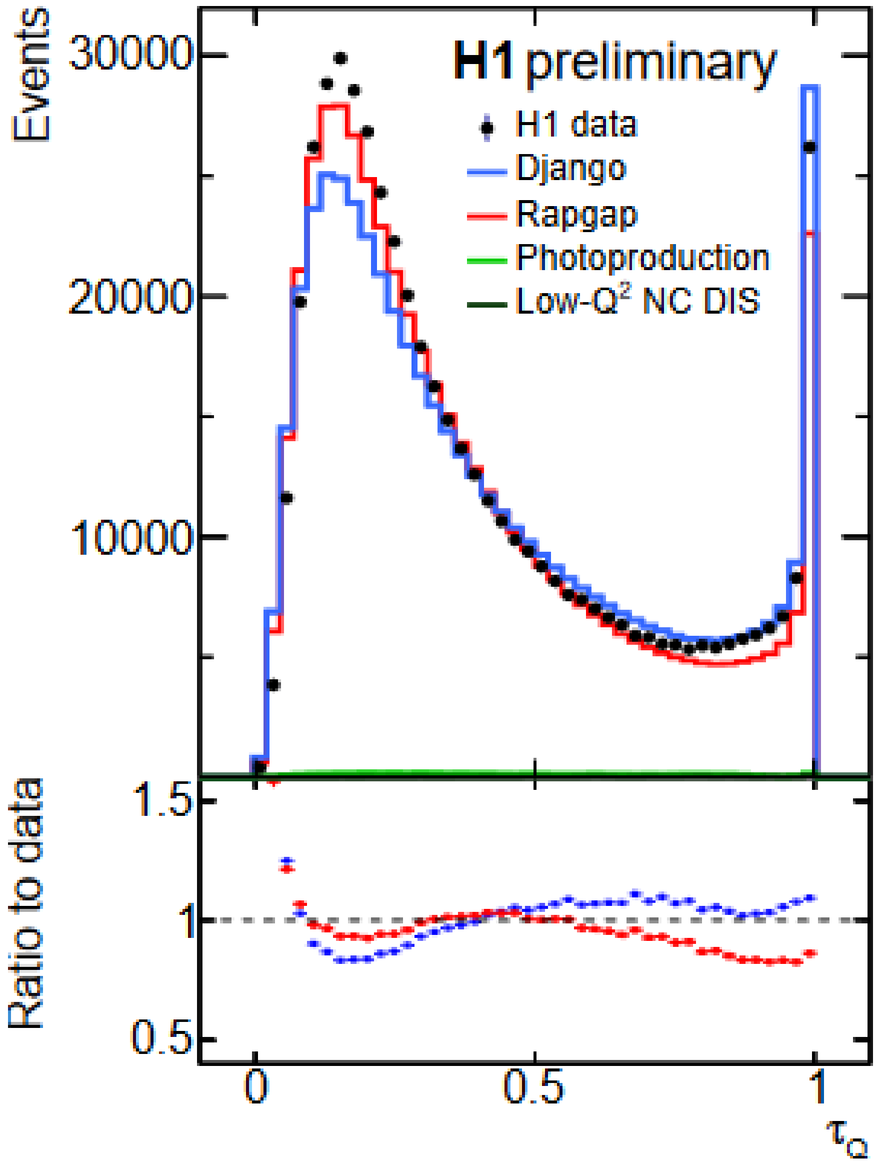


- Current hemisphere longitudinal momentum is well modelled by H1 detector-level simulation

τ_Q Measurement

- $\tau_Q \to 0$ = DIS 1-jet event (Born-level)
- $\tau_Q \to 1$ = DIS dijet event
- $\tau_Q \to 1$ = Dijet event with both jets in beam hemisphere

- Simulation provides reasonable description of data over full range of τ_Q
  - Observable can clearly resolve differences in MC models



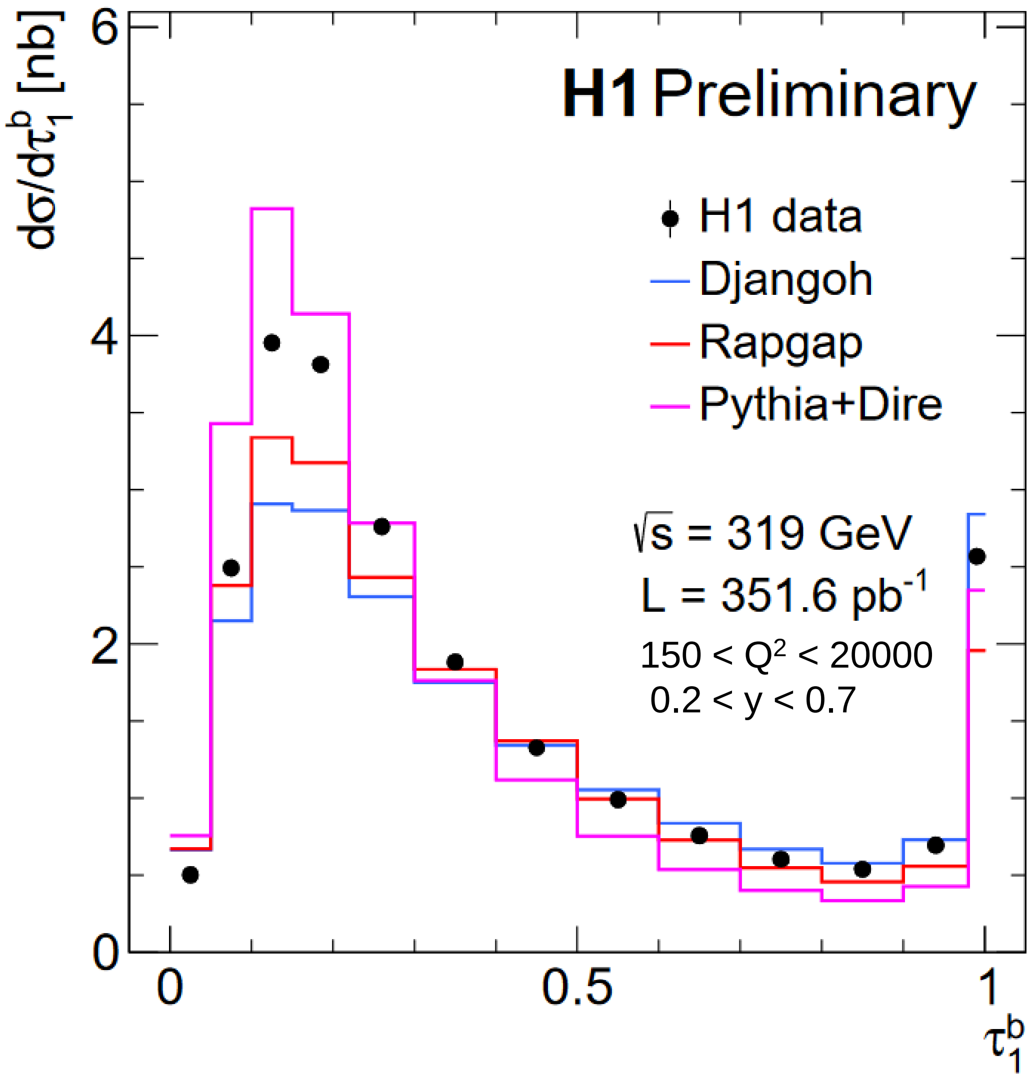
Single Differential Cross-Section

- Corrected for detector and QED effects bin-by-bin

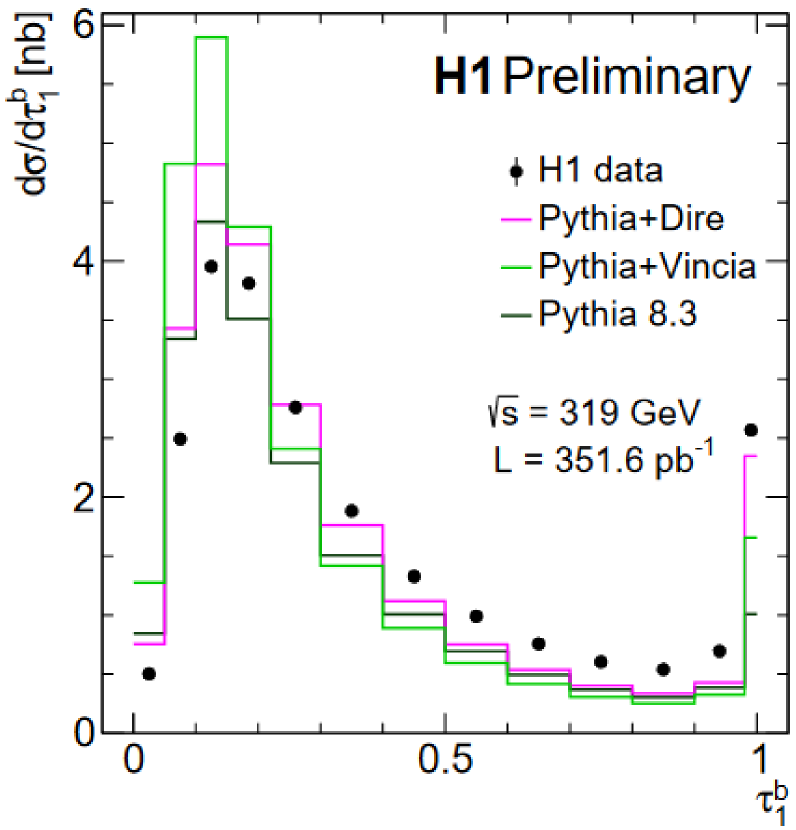
$$\sigma = \frac{N_{\text{data}} - N_{\text{Bkg}}}{L \cdot \Delta_\tau} \cdot c_{\text{unfold}} \cdot c_{\text{QED}}$$

L = Luminosity
Δ_τ = Bin width

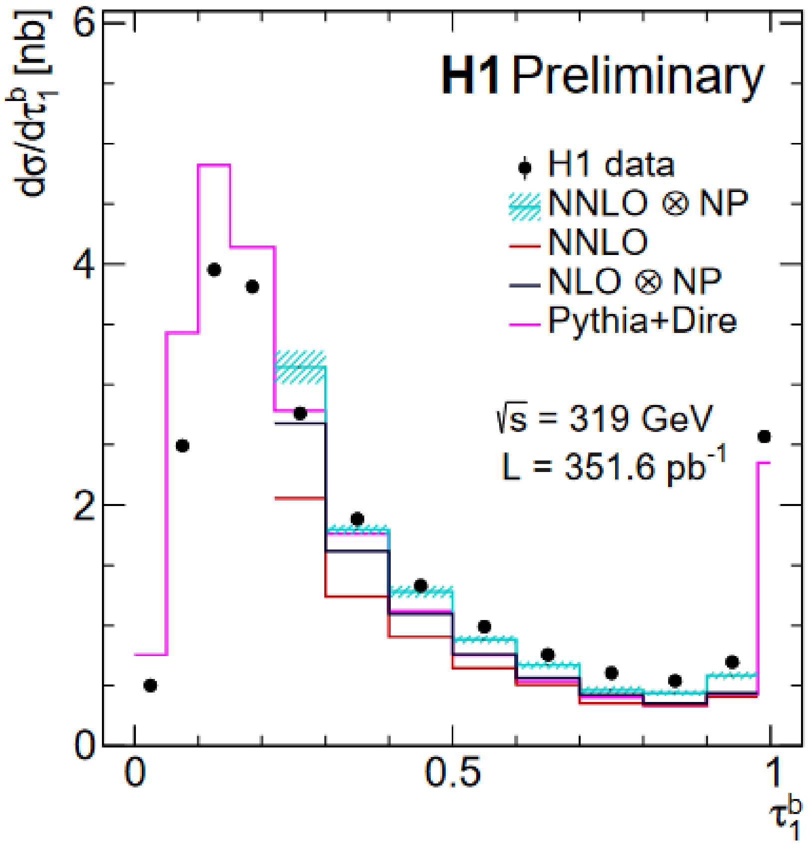
- Peak (resummation) region $\tau_Q \to 0$ poorly described by all models
  - Rapgap/Djangoh underestimate, Pythia+Dire overestimates
- Tail (fixed-order) region $\tau_Q \to 1$
  - Rapgap and Djangoh do well, Pythia+Dire underestimates



- Parton shower model comparison
  - Peak region highly sensitive to different showering
  - No fully satisfactory description



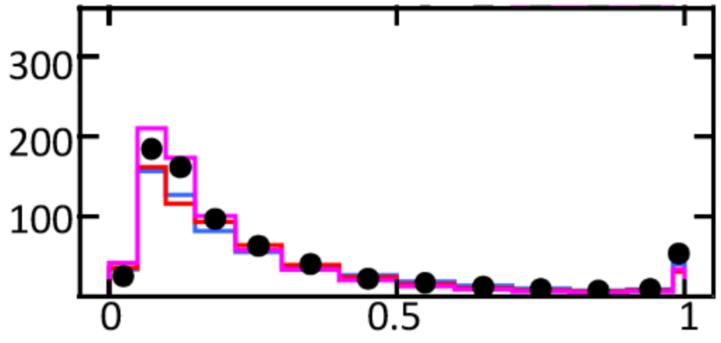
- $e + p \rightarrow 2\,Jets + X$ Prediction from NNLOJET
  - NP corrections from Pythia8.3
    - NP corrections large at low τ_1^b
  - NNLO provides good description of tail region, improves over NLO

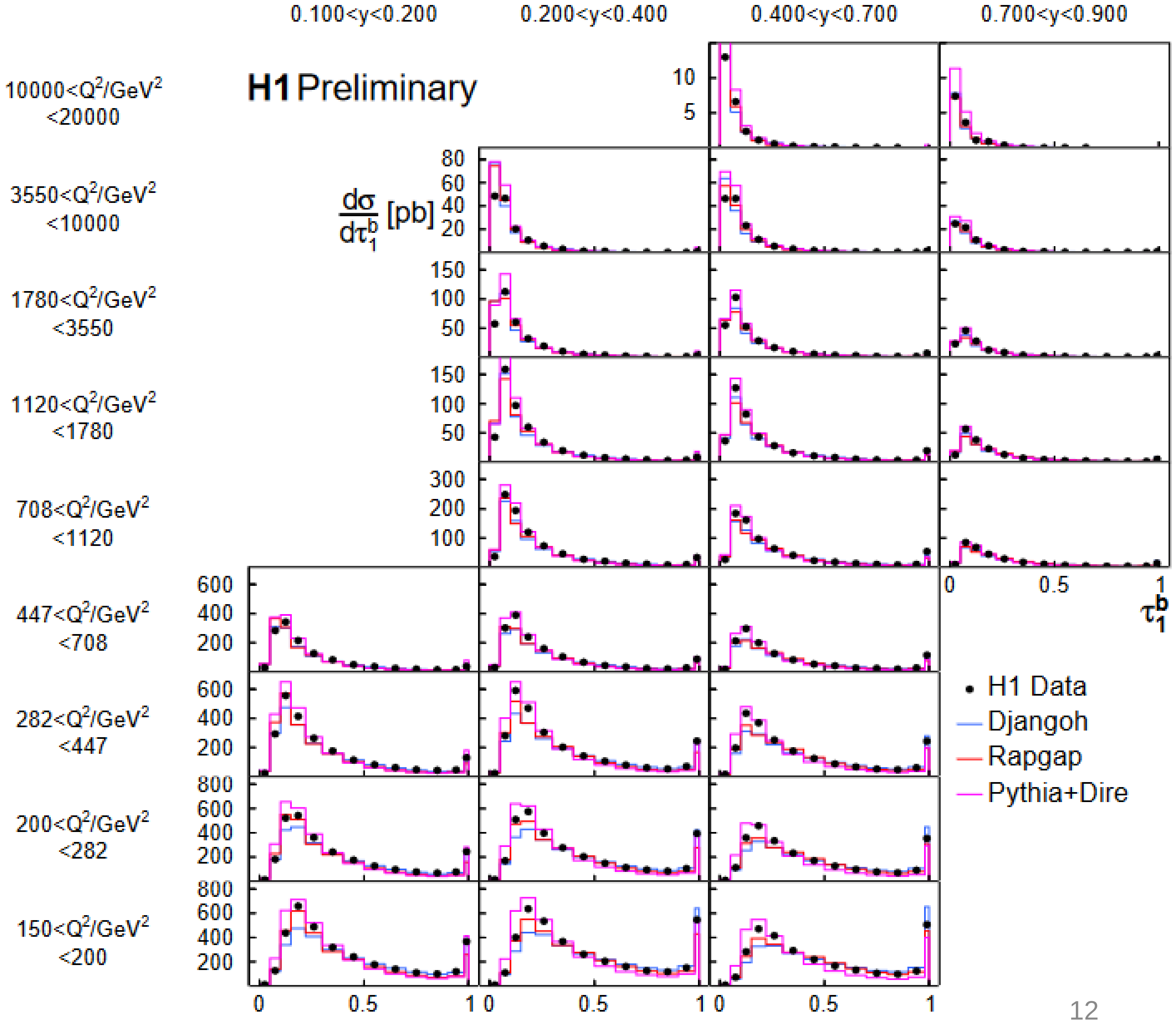


Triple-Differential Cross-Section

- With increasing Q:
  - Total cross-section decreases
  - Tail region decreases
  - Peak moves to lower τ
    - At higher momentum transfer, jets are more collimated
- With increasing y:
  - τ = 1 is enhanced

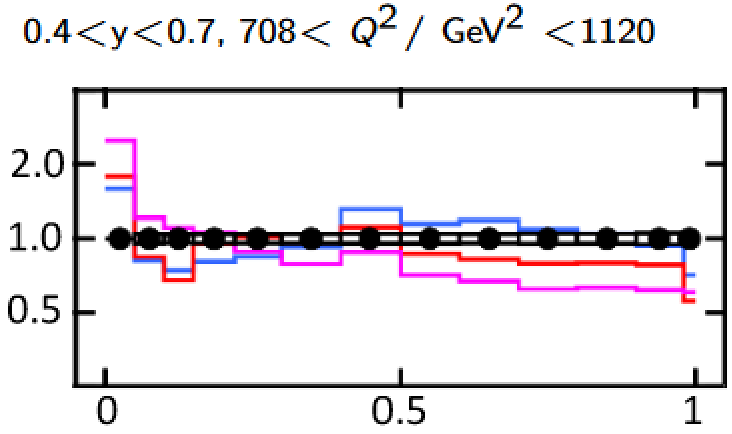
$0.4 < y < 0.7,\ 708 < Q^2 / \mathrm{GeV}^2 < 1120$

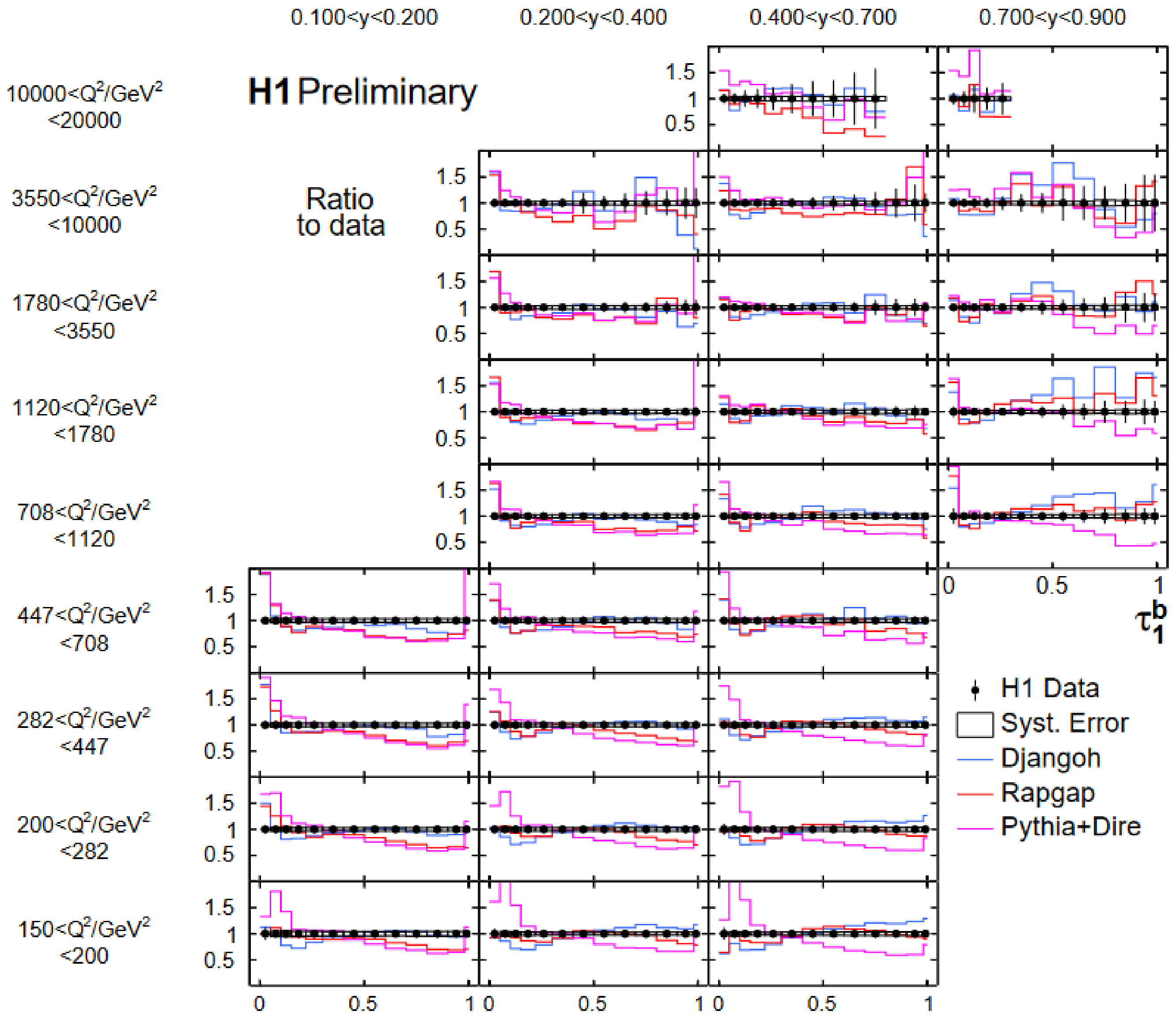




Triple-Differential Cross-Section

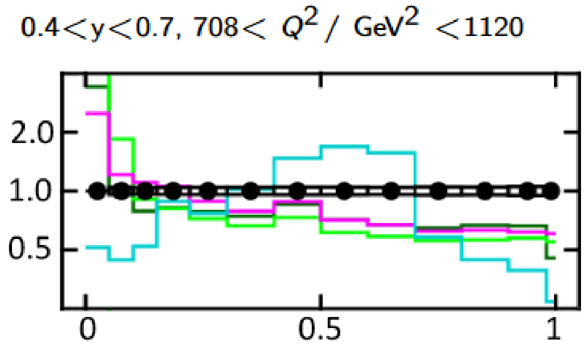
- Ratios to data
- Stat. uncertainties range from a few % to a few 10s of %
- Sys. uncertainties around 5%
- Djangoh and Rapgap perform reasonably well over full phase space
- Pythia+Dire too large in peak region

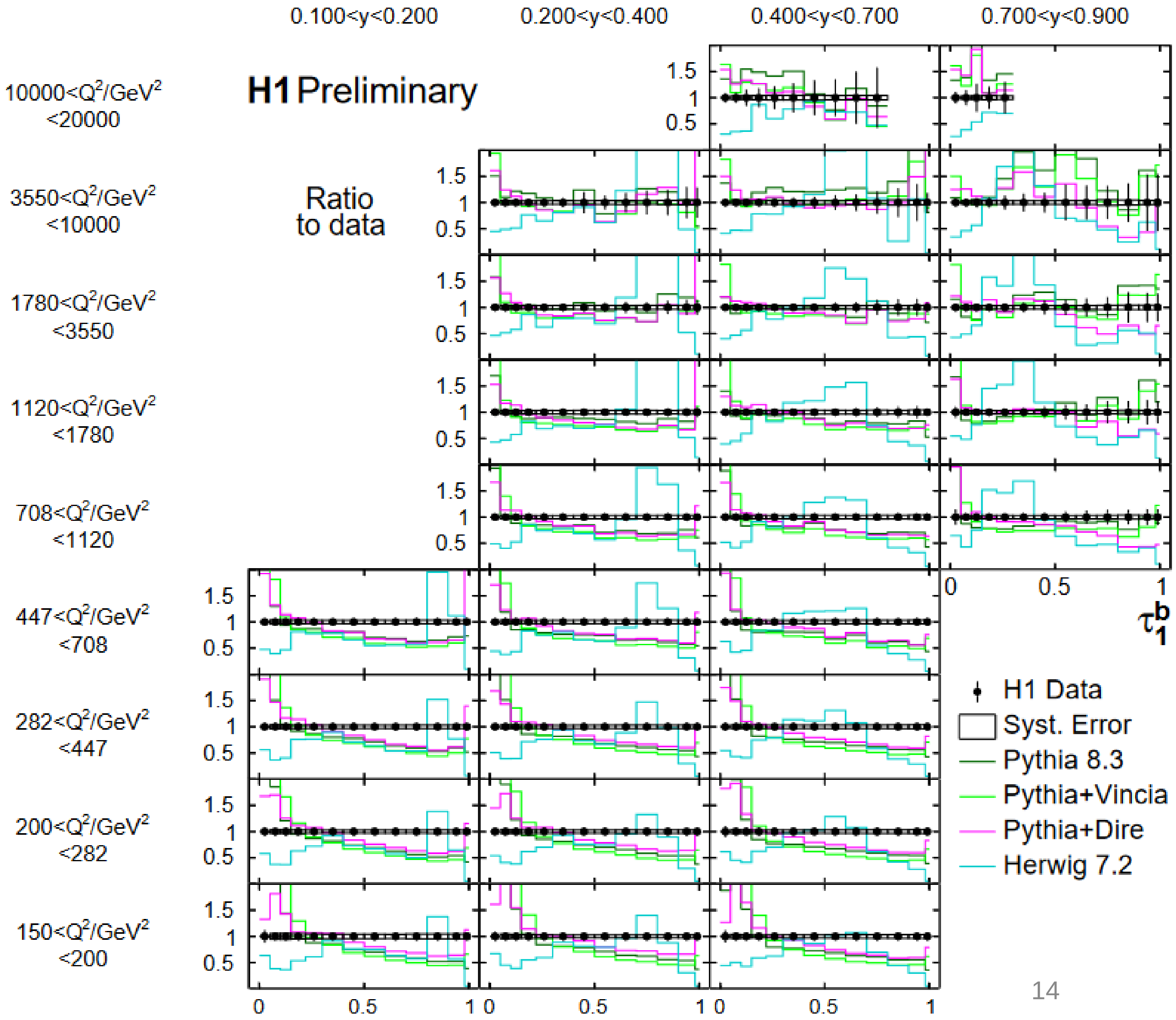




Triple-Differential Cross-Section

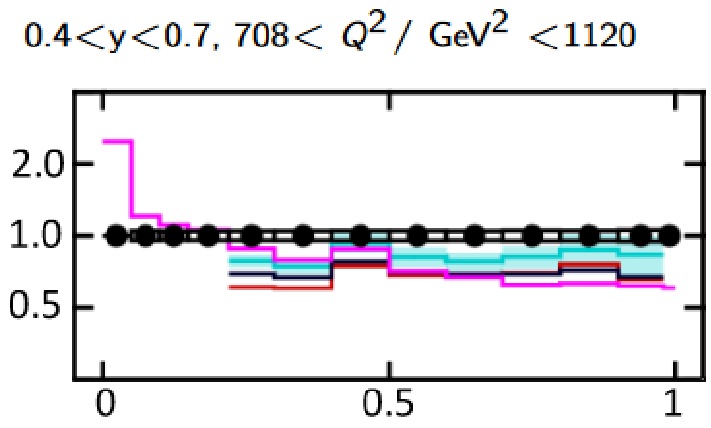
- Further model comparison
  - Pythia+Default shower
  - Pythia+Vincia
  - Herwig 7.2
- Herwig underestimates DIS cross-section
  - Bump structure visible at mid τ

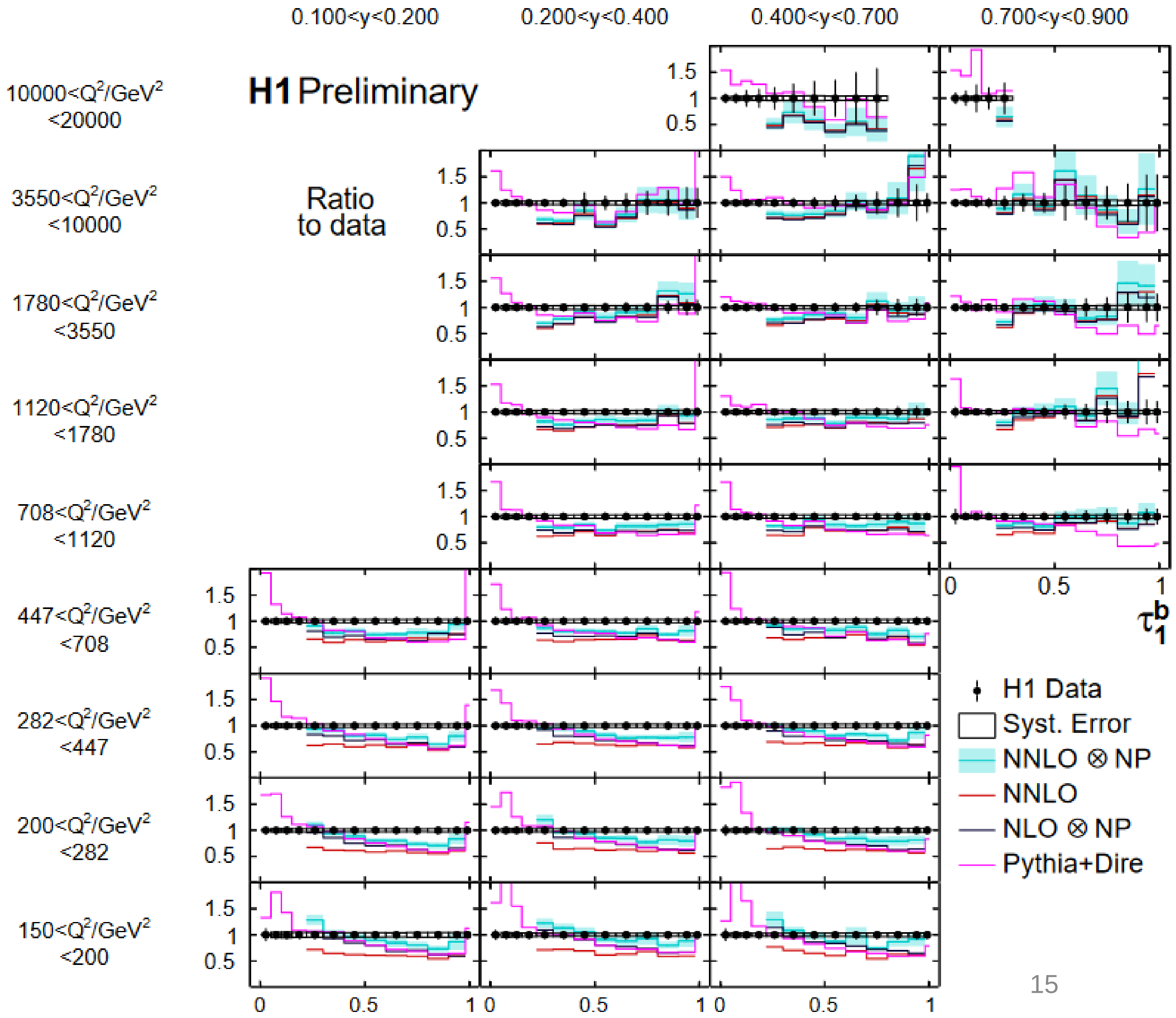




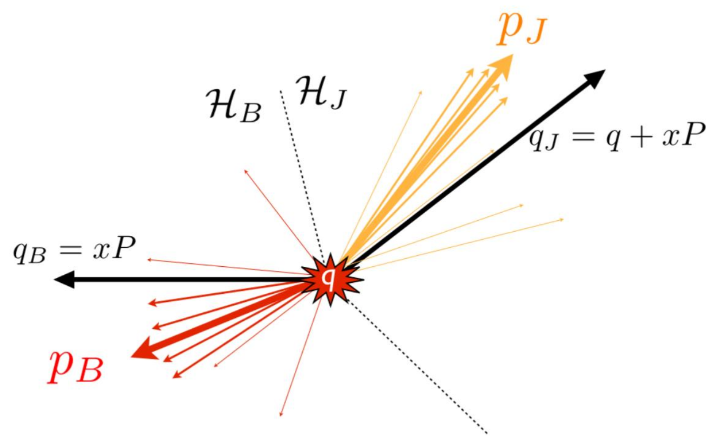
Triple-Differential Cross-Section

- NNLO QCD prediction for $ep \rightarrow 2\,Jets + X$
  - Reasonable description over full phase space
  - Scale uncertainties relatively small
  - NNLO improves over NLO
- NP corrections are sizable

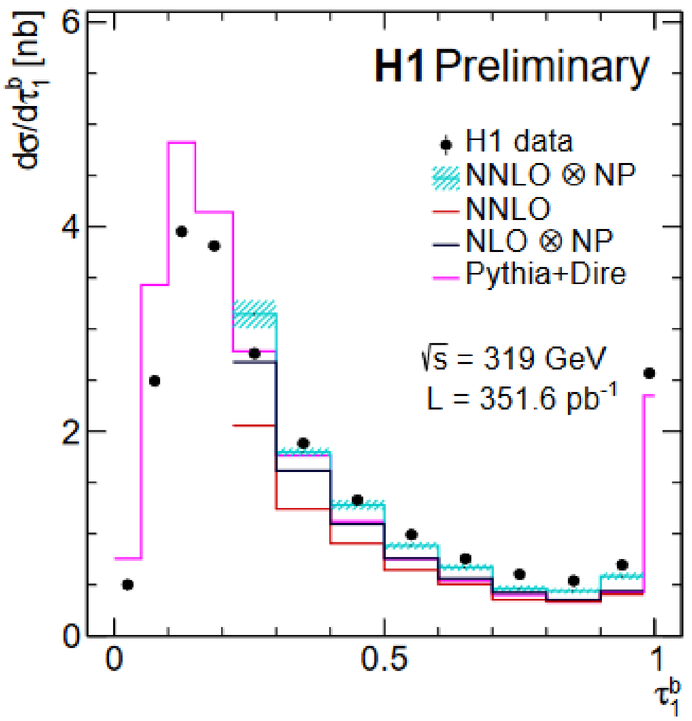




Conclusion + Outlook



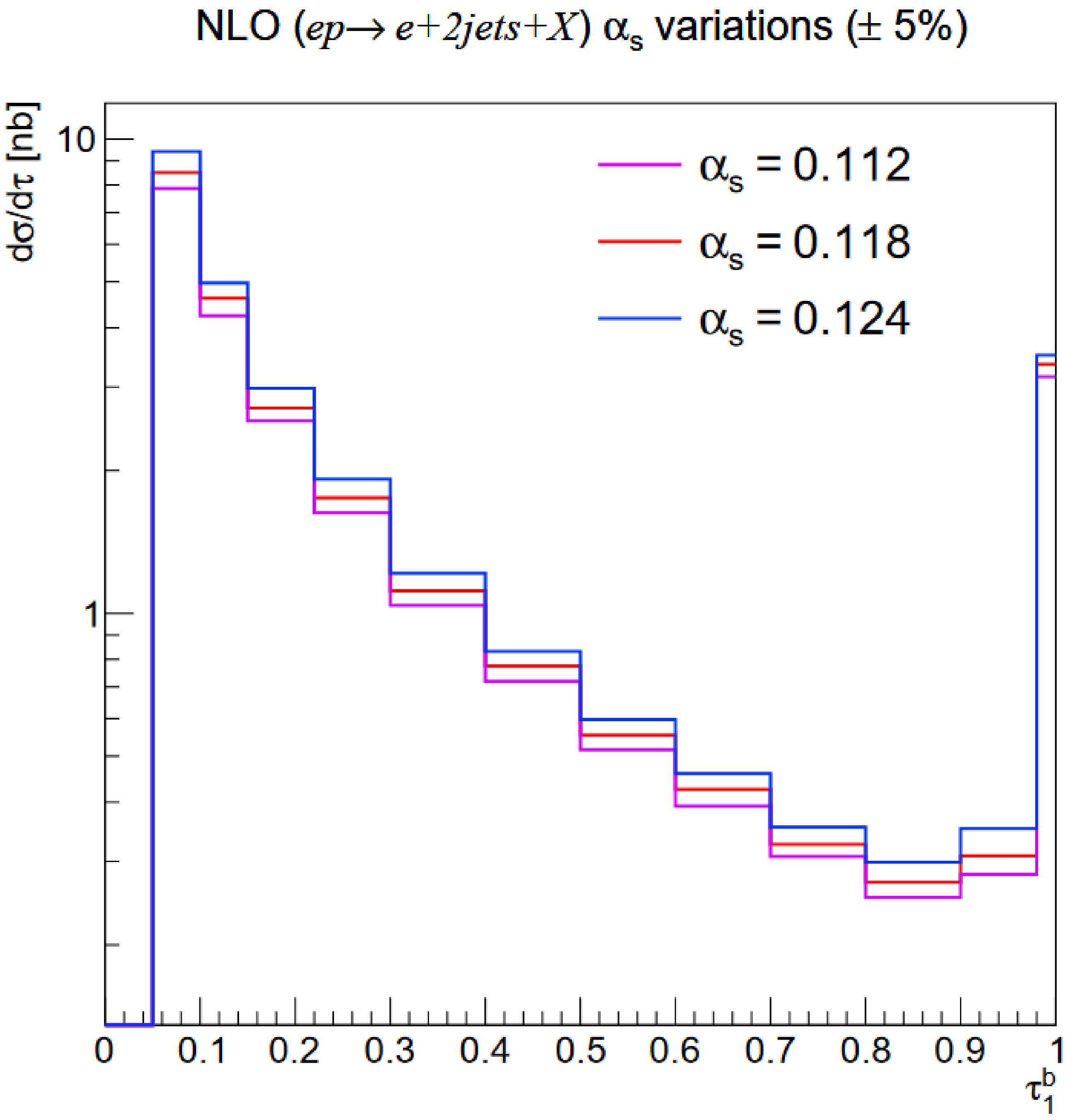
- First measurement of 1-Jettiness event shape in NC DIS
- Agrees reasonably well with pQCD predictions
  - Comparison with N^{3}LL and NNLO+PS pending
- Observable is highly sensitive to model parameters
  - No MC uniformly describes the data
  - Useful for improving DIS MC generators – Electron-Ion Collider coming soon!
- Sensitivity to α_s and PDFs to be explored in more detail, combined extraction should be possible
  - Promising measurement for EIC and other future e+p colliders



Any further questions? Email me at Henry.klest@stonybrook.edu

Backup

- 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



- 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)