Slides mostly from J. Hessler

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Measurement of the 1-jettiness event shape observable and first observation of Empty Hemisphere Events

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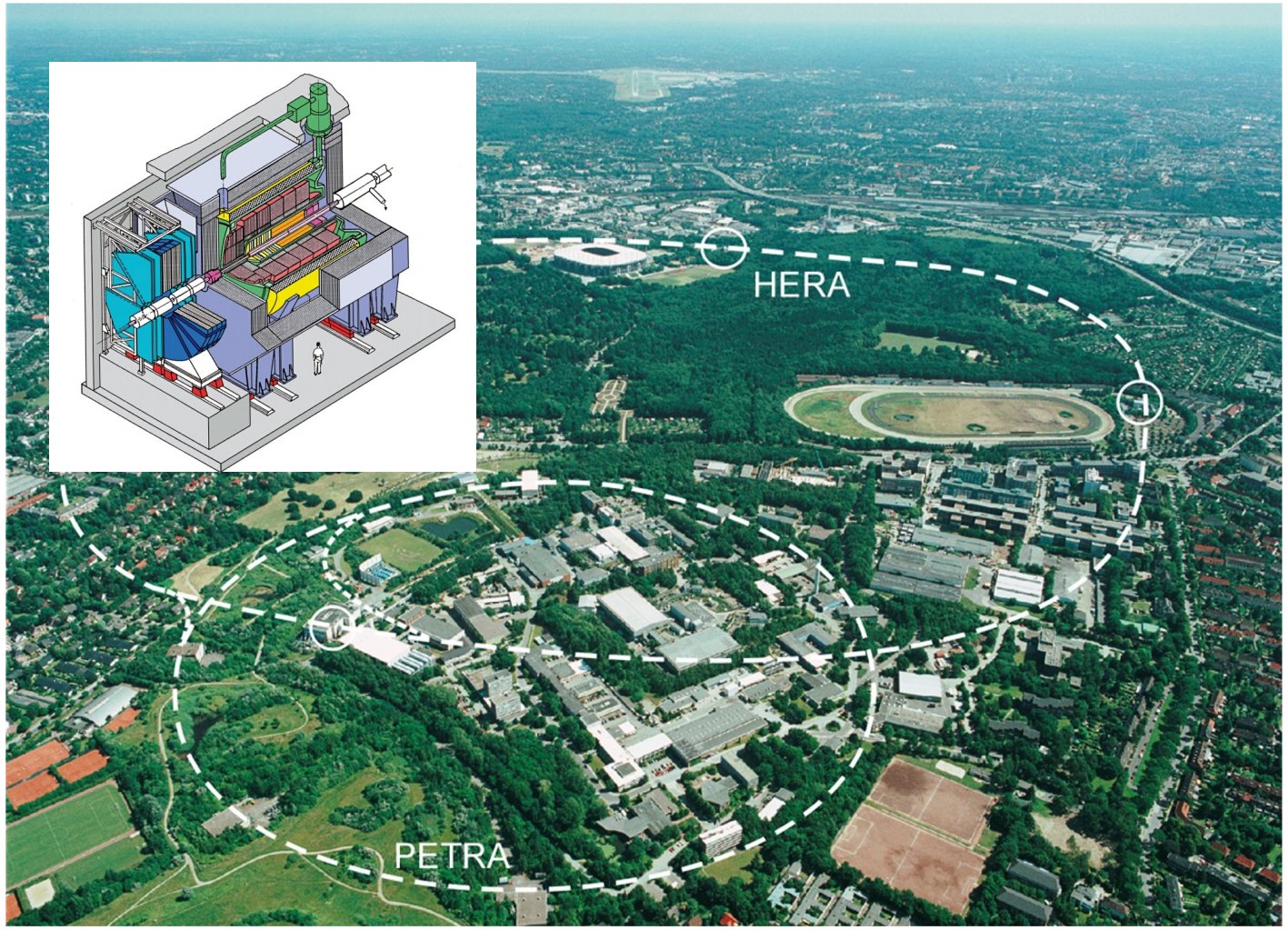
BNL/SBU

Final H1 results published:

1. arXiv:2403.10109v1
2. arXiv:2403.08982

DIS 2025, Cape Town, SA

The H1 experiment



- 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 → $\sqrt{s}$ = 319 GeV
- Asymmetric design with trackers, calorimeter, solenoid, muon-chambers, forward & backward detectors
- Particles are reconstructed using a particle flow algorithm → Combining cluster and track information without double-counting of energy

1-jettiness event shape observable

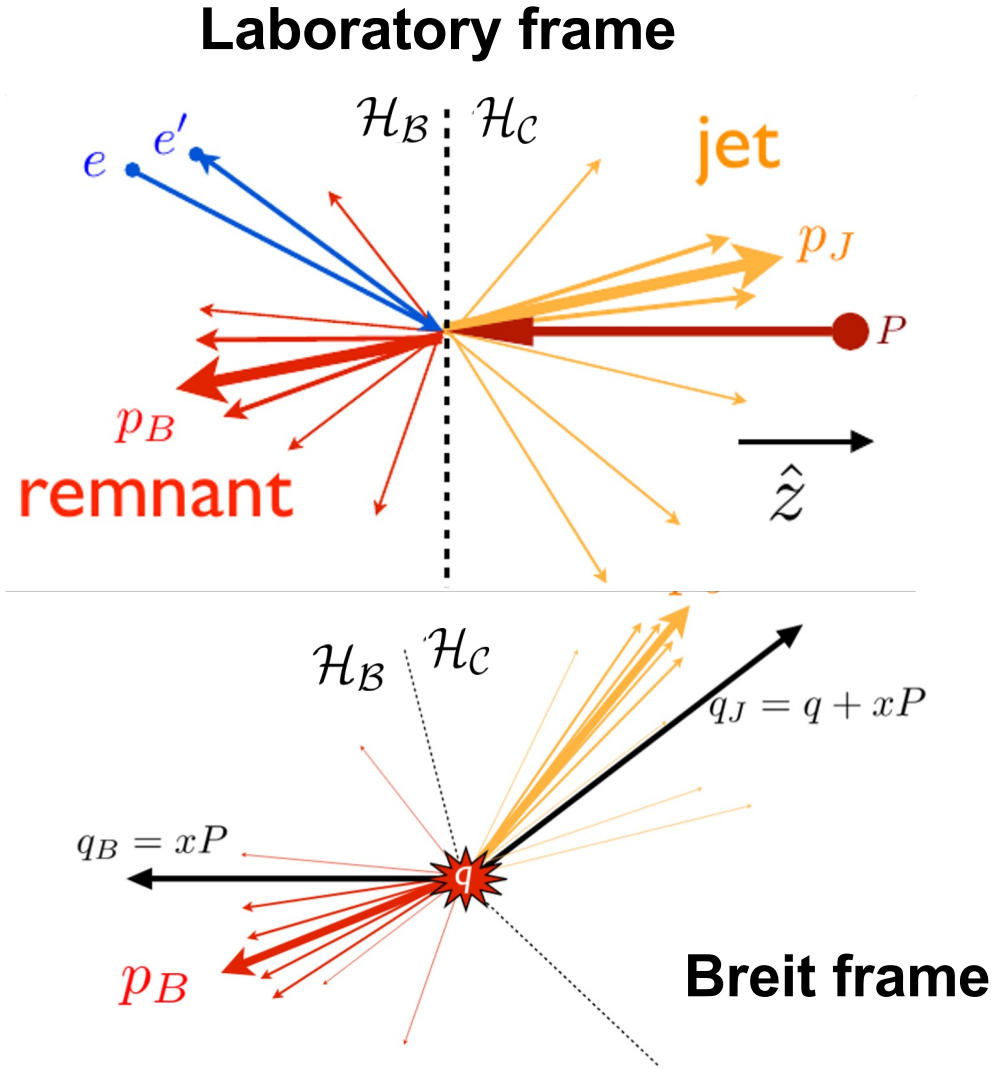
1-jettiness τ_1^b

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

- 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: DIS thrust

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



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

1-jettiness - Intuition

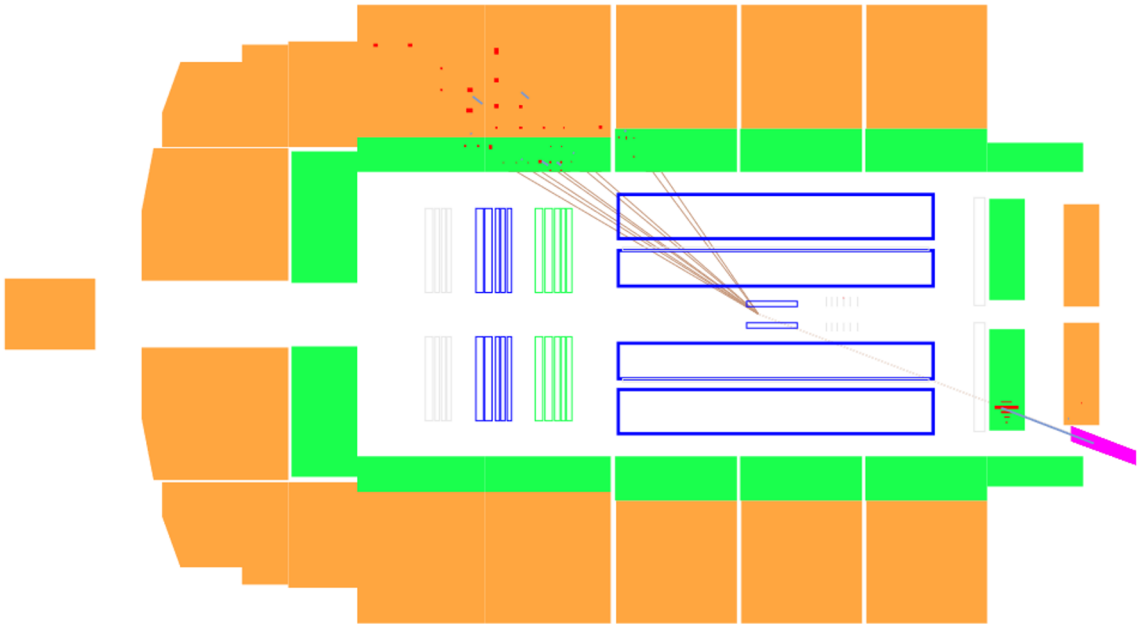
$$\tau_1^b = \frac{2}{Q^2} \sum_{i \in X} \min\{xP \cdot p_i, (q + xP) \cdot p_i\}$$

1-jettiness:

→ Defined for every NC DIS event

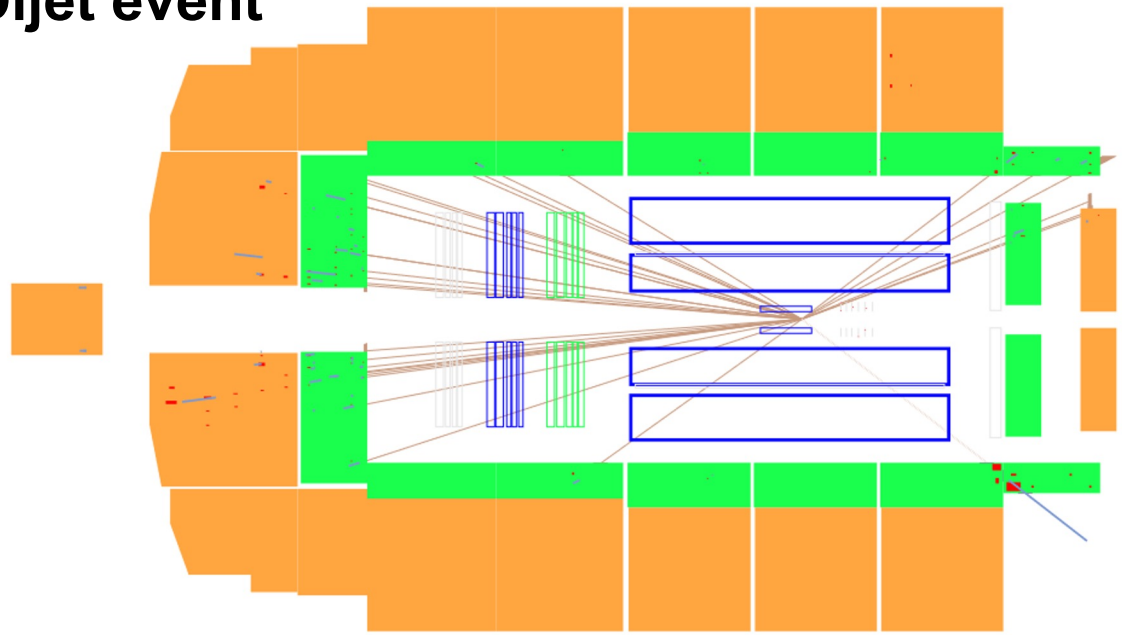
→ All particles can contribute, no jet clustering

DIS 1-jet event



HFS particles collinear to scattered parton
→ **Small τ_1^b**

Dijet event



More and larger contributions to sum over HFS
→ **Larger τ_1^b**

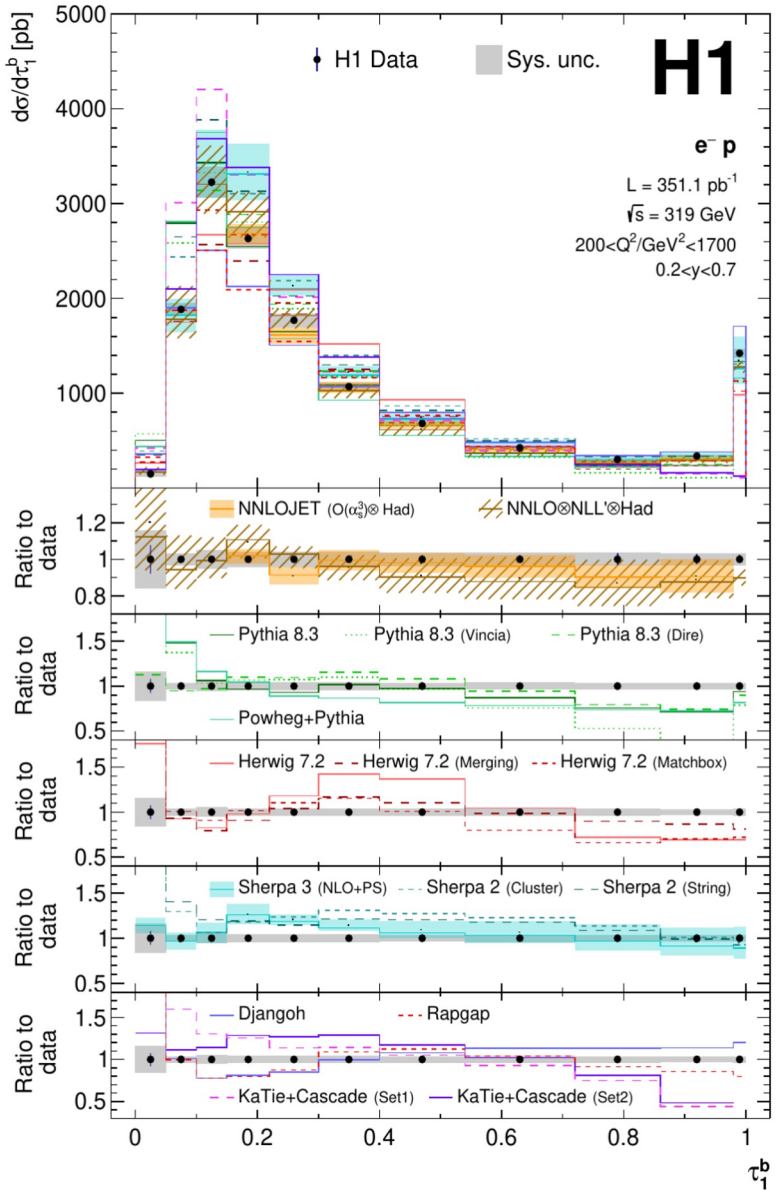
Single differential cross section

1-jettiness cross section

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

Comparison with MC models

- Compare data to 16 different models
- Cross sections are measured at high precision
- → None of the MC models works perfectly, now have precision data for tuning
- → Exact QCD predictions have sizable scale uncertainties and large hadronisation corrections



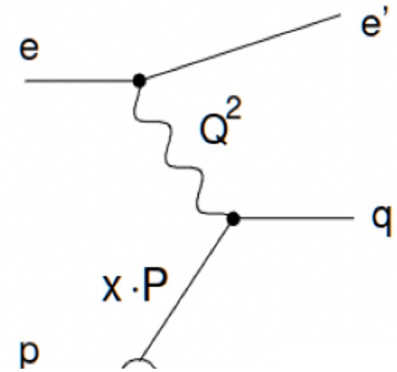
Triple differential cross section

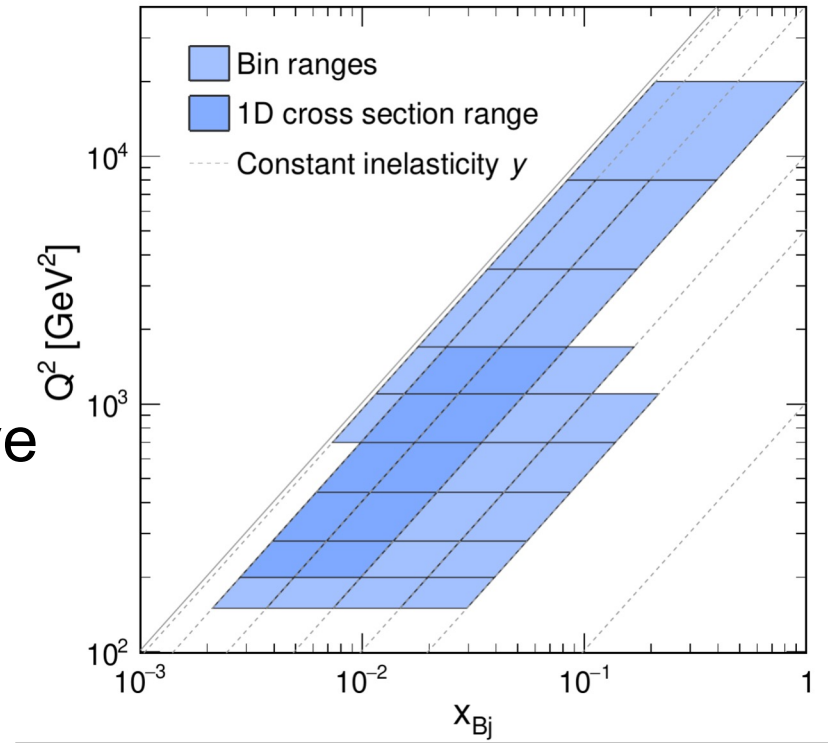
Large cross section and sizable data statistics
→ Triple-diff. cross sections as a function of

- Virtuality $Q^2 = -(p_e - p_{e'})^2$
- Inelasticity $y = (P \cdot q)/(P \cdot p_e)$
- 1-jettiness 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





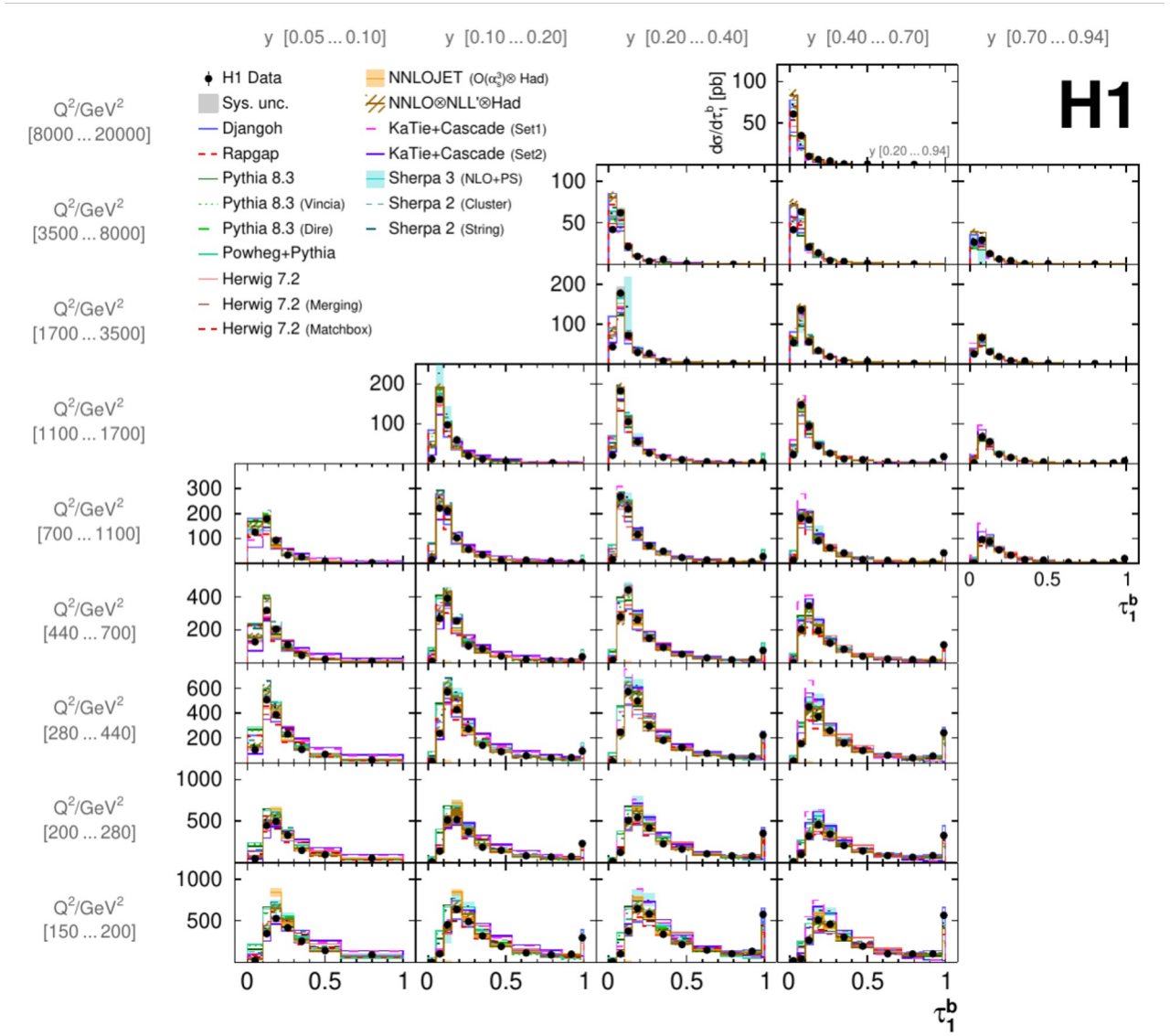
Triple differential cross section

Study change in shape of the distribution

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

Reasonable description by vario models

→ Study ratio to data for better comparison



Triple differential cross section

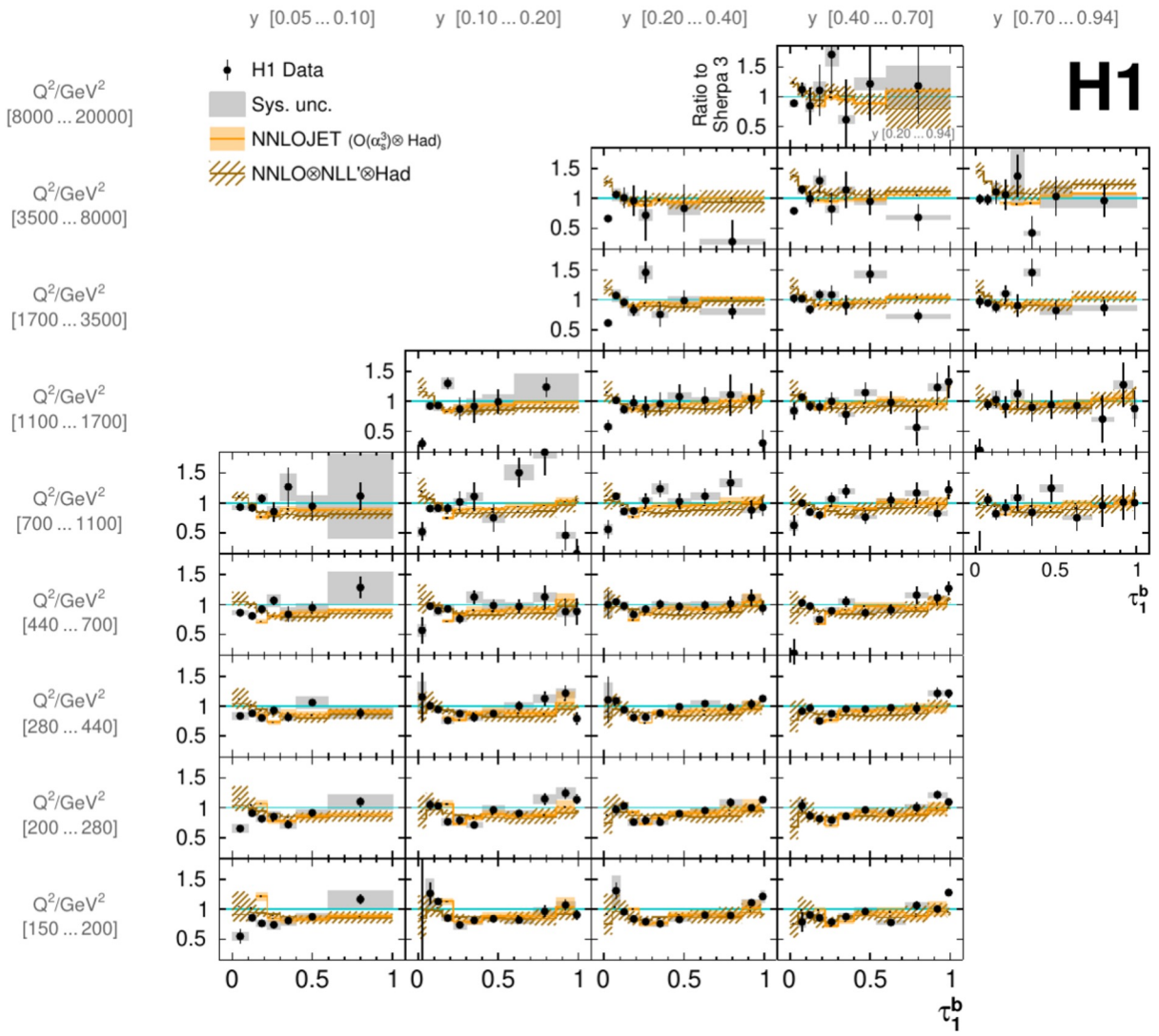
Uncertainties

- 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

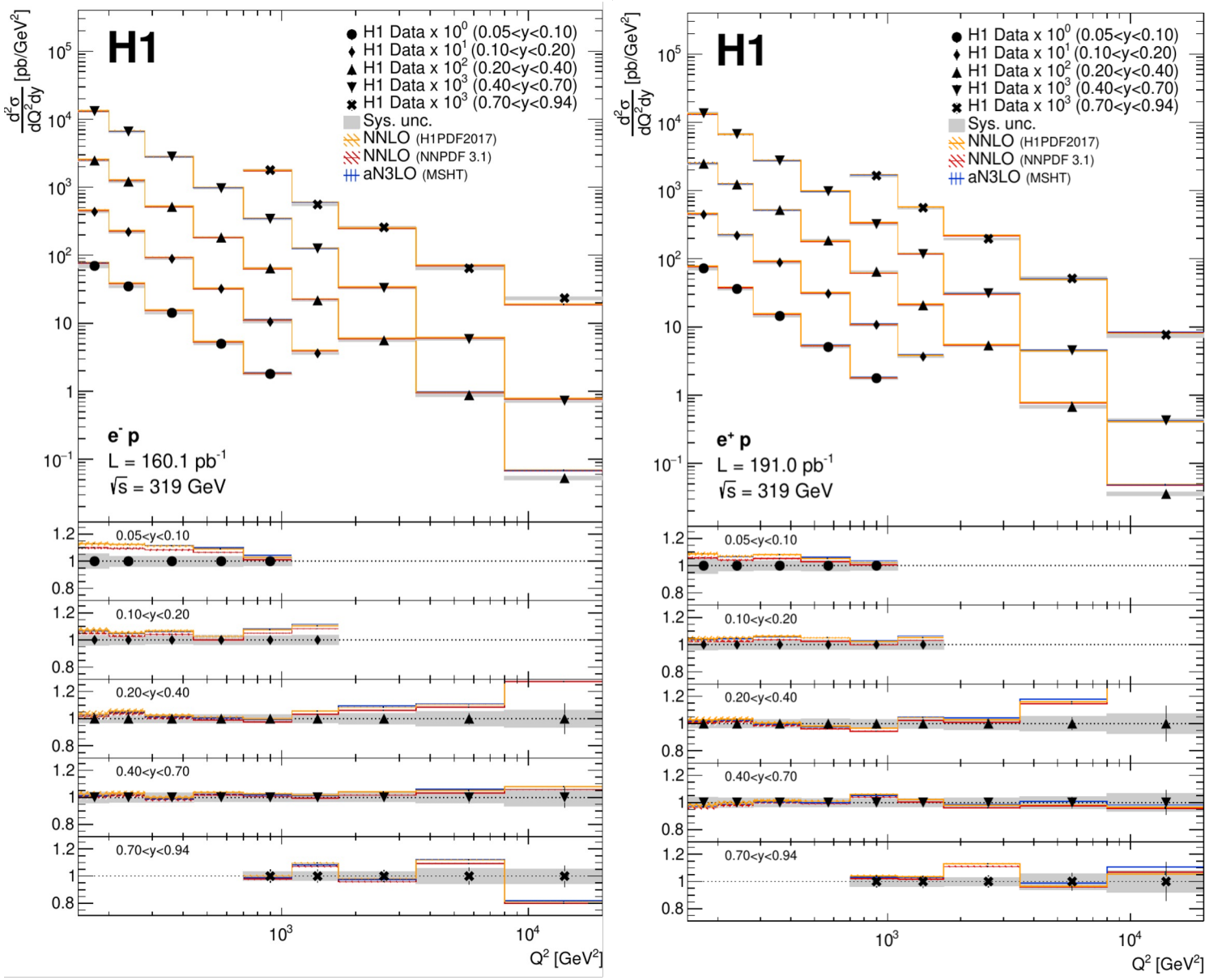


Double differential cross section

Integrate over τ_1^b distribution
→ Inclusive DIS cross section

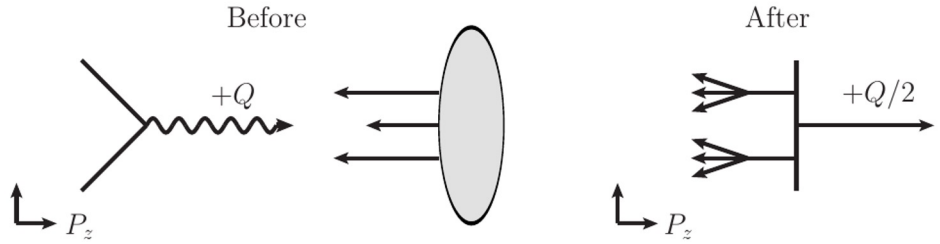
- Cross sections for e^-p and e^+p collisions
- Compare the data to fixed order calculations at NNLO and approximate N3LO accuracy
- → Excellent agreement between data and predictions

Cross check validates τ_1^b measurement

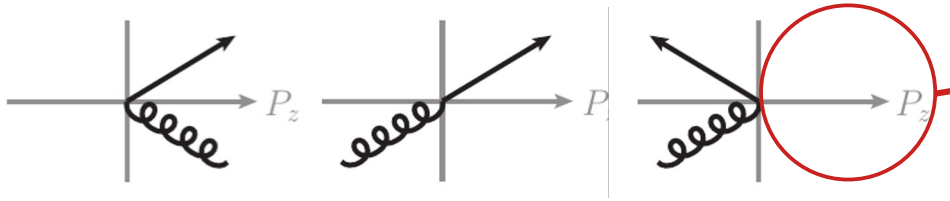


Breit frame in LO and NLO

Leading order parton model

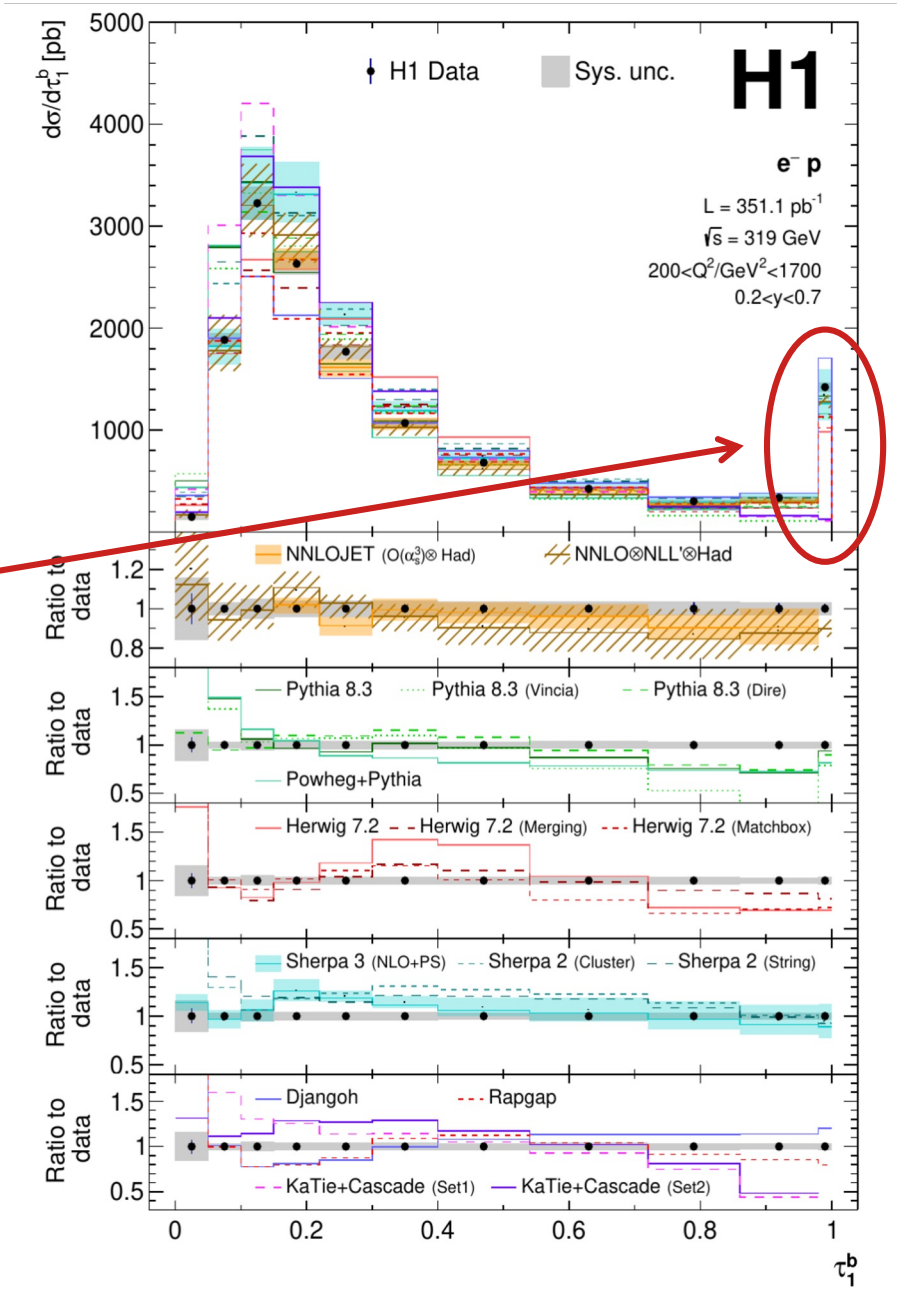


Next-to-leading order in QCD

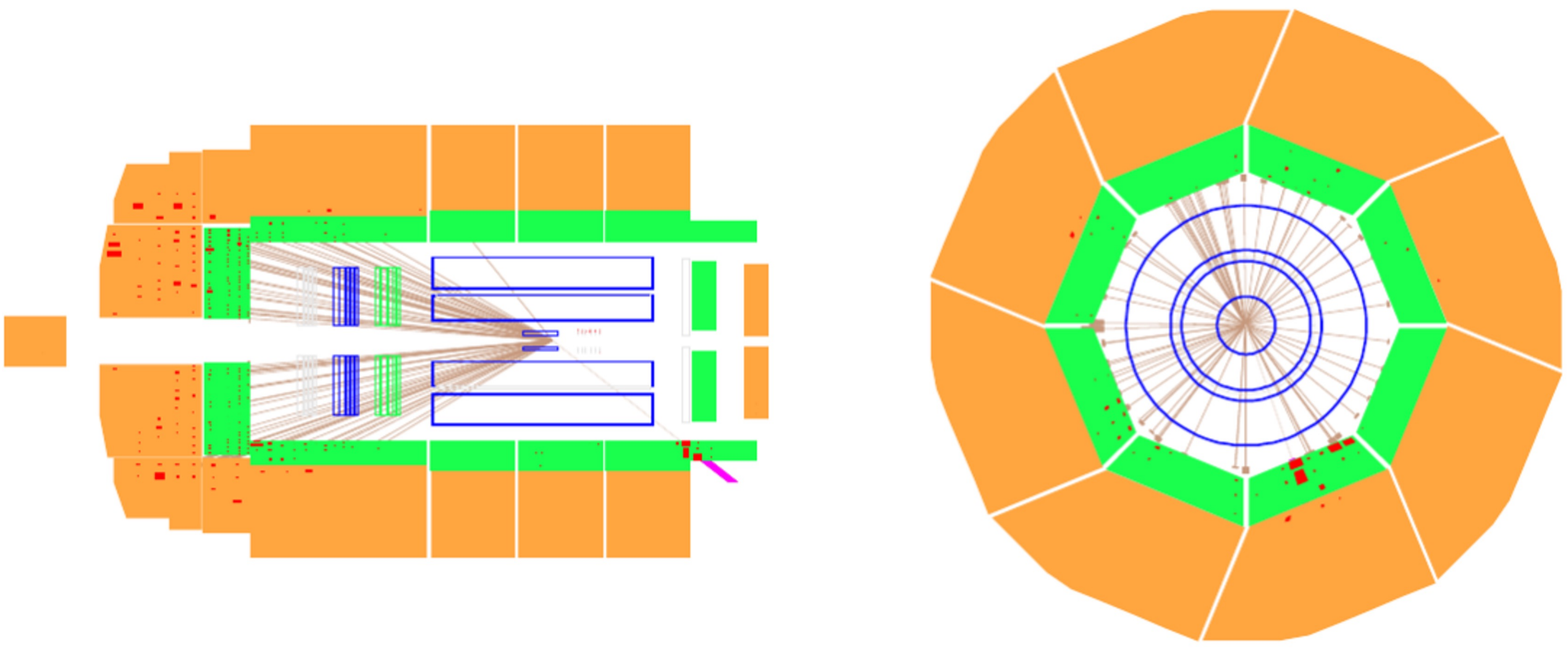


- Empty (current) hemisphere events (EHE) appearing at NLO
- Predicted already in 1979 (link)

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



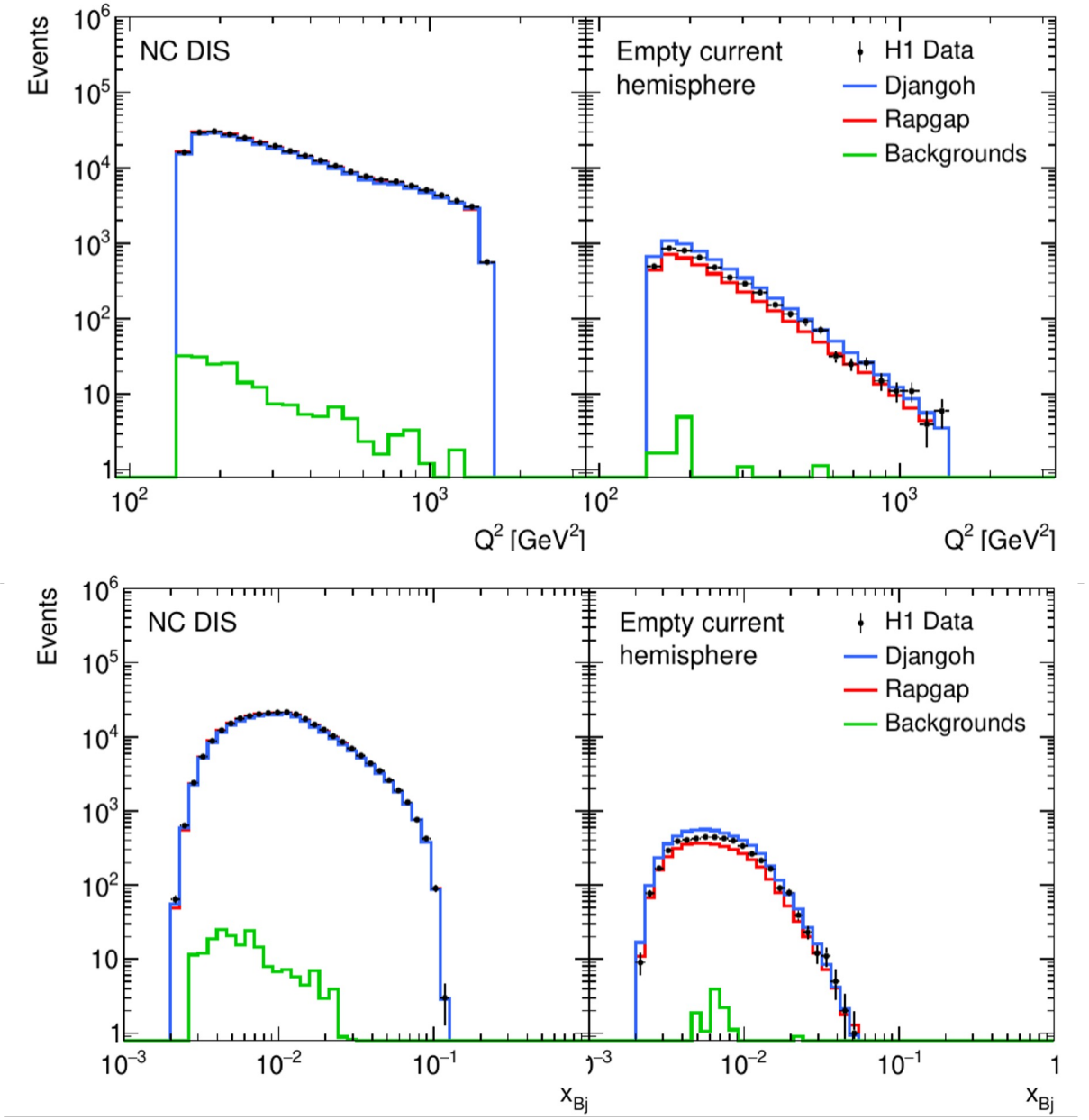
Example of an *Empty Hemisphere Event*



→Characteristic signatures with high particle multiplicity in forward region

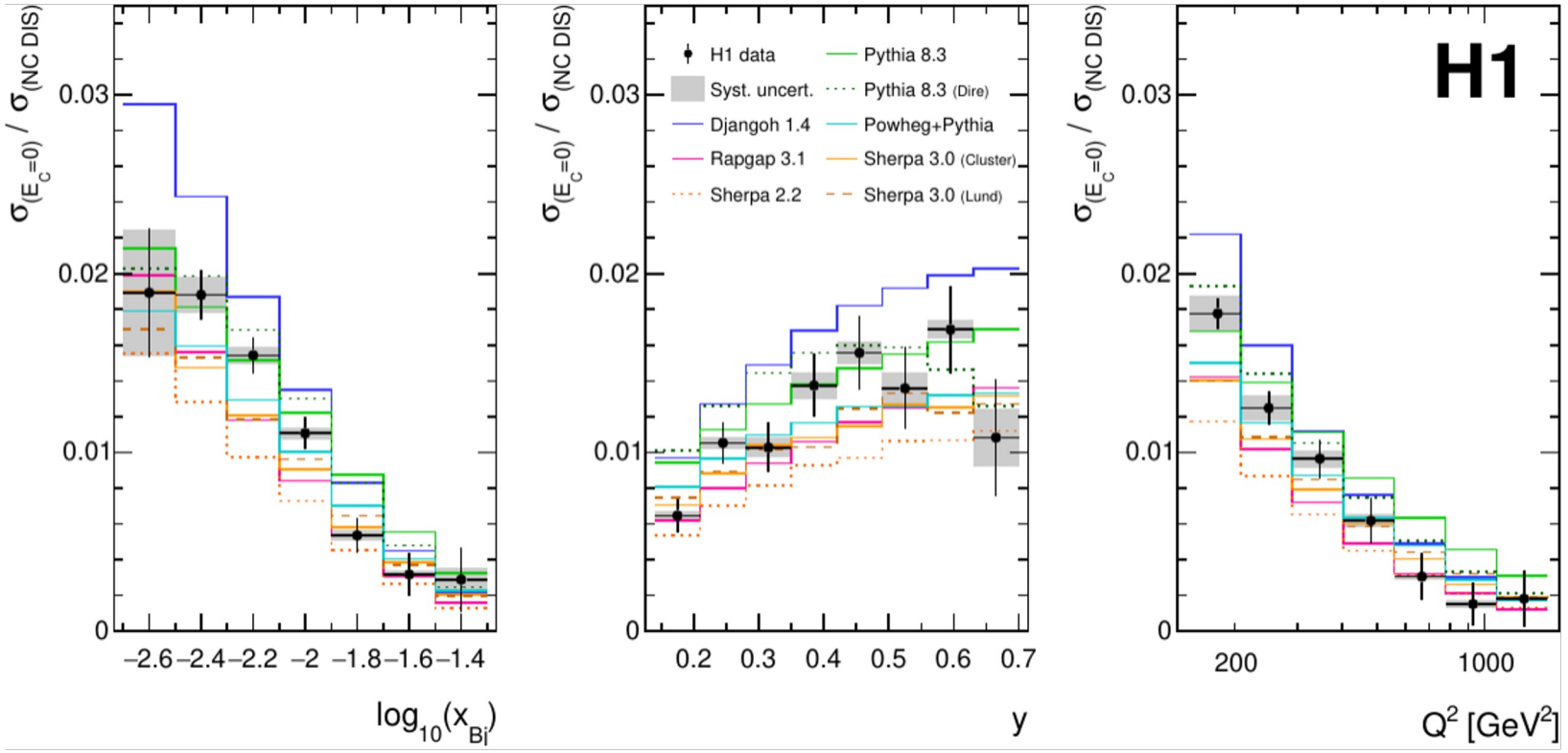
Inclusive DIS events and *Empty Hemisphere Events*

- Comparison of inclusive NC DIS events and EHEs
- More EHEs predicted in Djangoh compared to Rapgap
- Tiny background contribution
- Fraction of EHEs ~ 1%
- EHEs only occuring at low x_{Bj}



Inclusive and differential fraction

- Fraction of *Empty Hemisphere Events*:
  r = 0.0112±6.2%
- MC predictions envelope the data
- First observation of *Empty Hemisphere Events*



	r	δr
Data	0.0112	$\pm 3.9\,\%_{\text{stat}}$ $\pm 4.5\,\%_{\text{syst}}$ $\pm 1.6\,\%_{\text{mod}}$
Djangoh 1.4	0.0150	$\pm 0.1\,\%_{\text{stat}}$
Rapgap 3.1	0.0096	$\pm 0.1\,\%_{\text{stat}}$
Pythia 8.3	0.0127	$\pm 0.1\,\%_{\text{stat}}$
Pythia 8.3 (Dire)	0.0120	$\pm 0.1\,\%_{\text{stat}}$
Powheg+Pythia	0.0107	$\pm 0.1\,\%_{\text{stat}}$
Sherpa 3.0 (Cluster)	0.0100	$\pm 0.1\,\%_{\text{stat}}$
Sherpa 3.0 (Lund)	0.0101	$\pm 0.3\,\%_{\text{stat}}$
Sherpa 2.2	0.00818	$\pm 0.5\,\%_{\text{stat}}$

Table 1 Comparison of the fraction r of empty current hemisphere events in NC DIS with various predictions in the analyzed phase space $150 < Q^2 < 1500\,\text{GeV}^2$ and $0.14 < y < 0.7$.

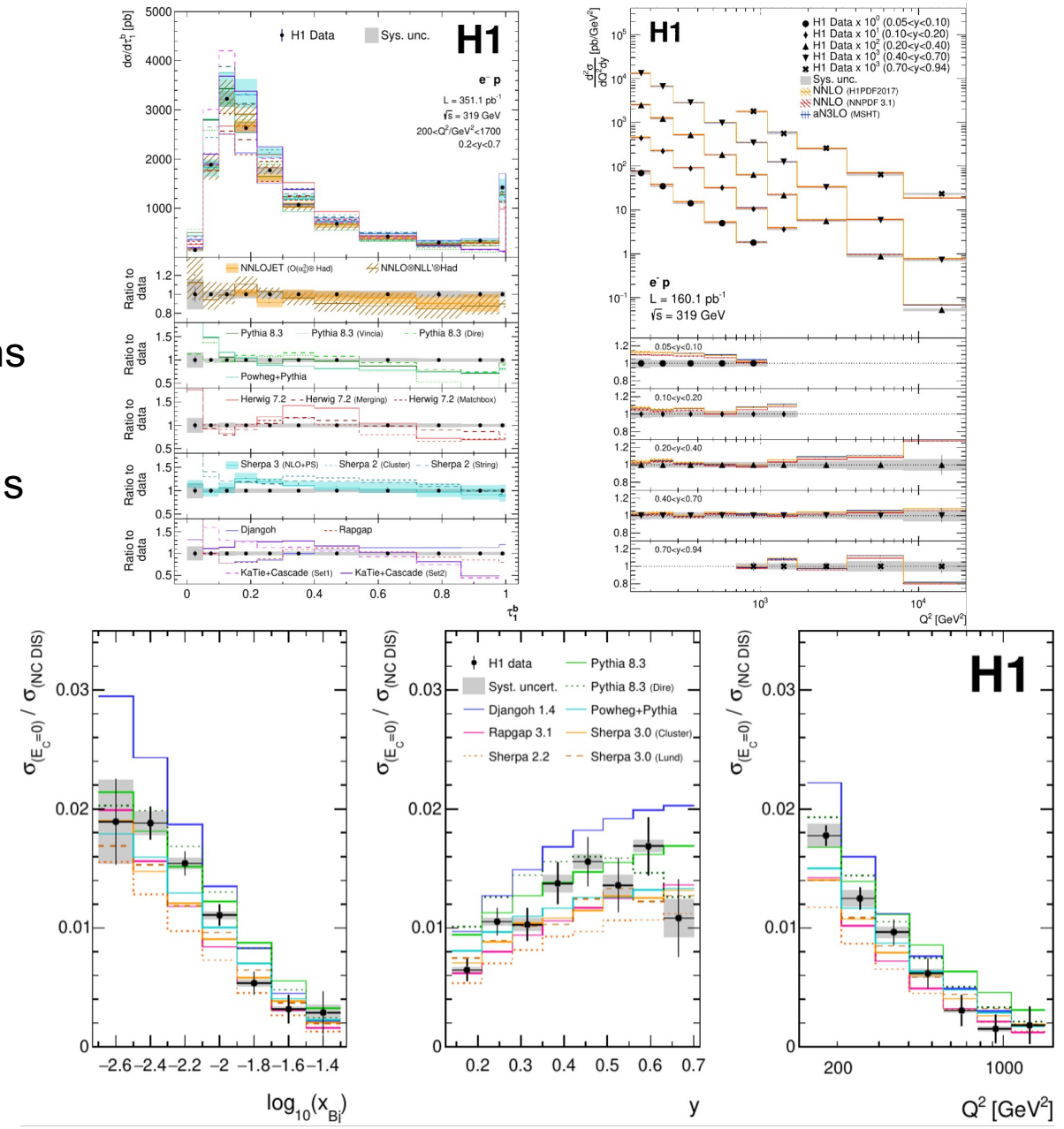
Summary

A **first measurement** of the 1-jettiness event shape observable in NC DIS:

- 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

First observation of Empty Hemisphere Events in DIS:

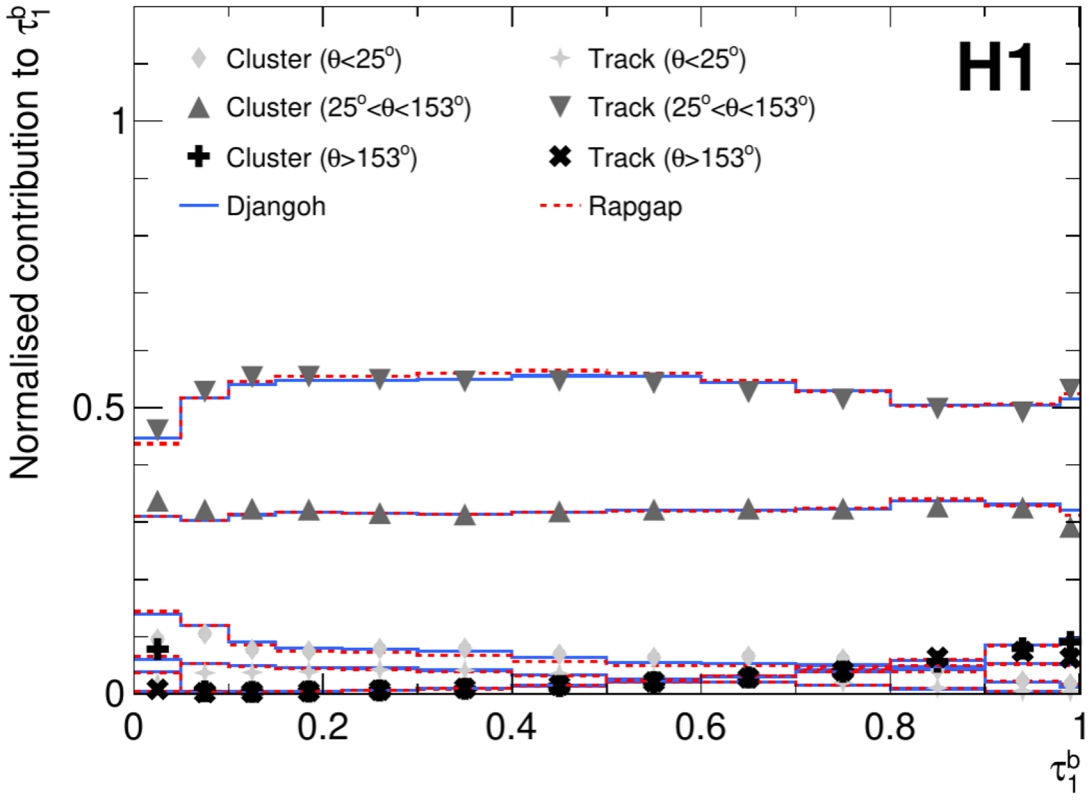
- Inclusive and differential results as a function of x_{Bj}, y and Q^2
- Help improve and validate parton shower and hadronisation models

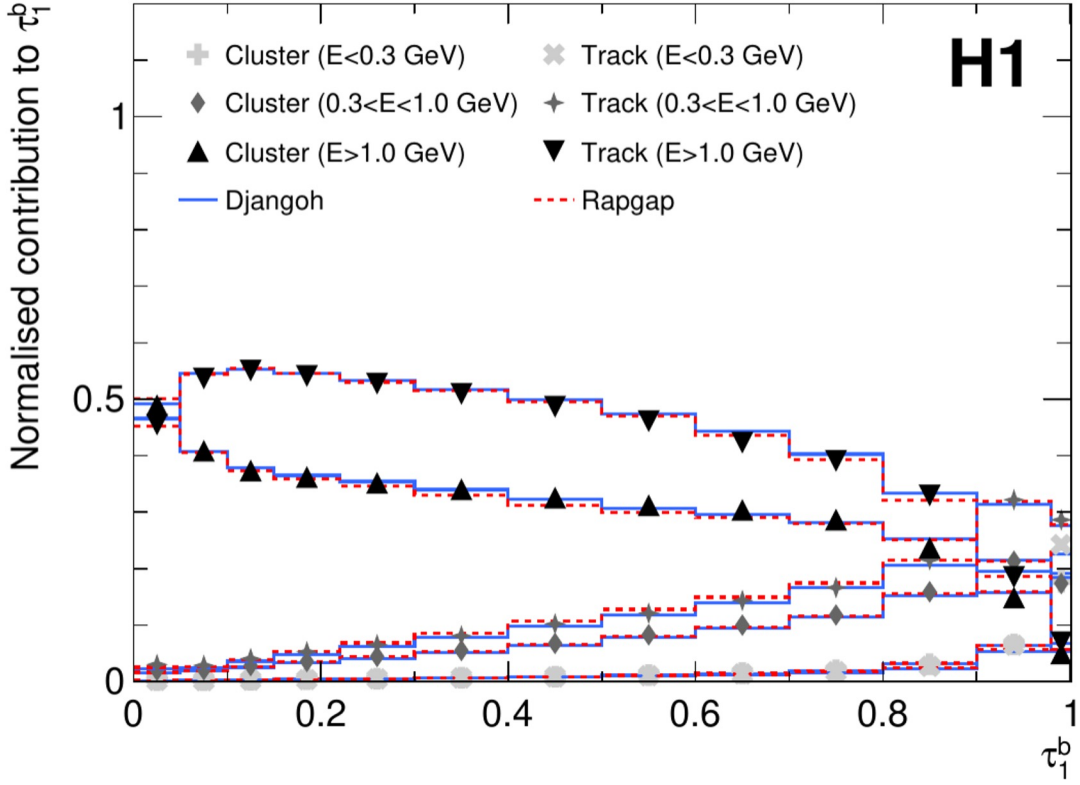


Backup

DIS thrust – 4π observable

- All particle candidates in all DIS events contribute
- Normalized contributions to tau1b for different ranges in polar angle and energy:





- Mainly tracks and clusters with high energy in the central part of the detector contribute
- → Well measured particles dominate in tau1b

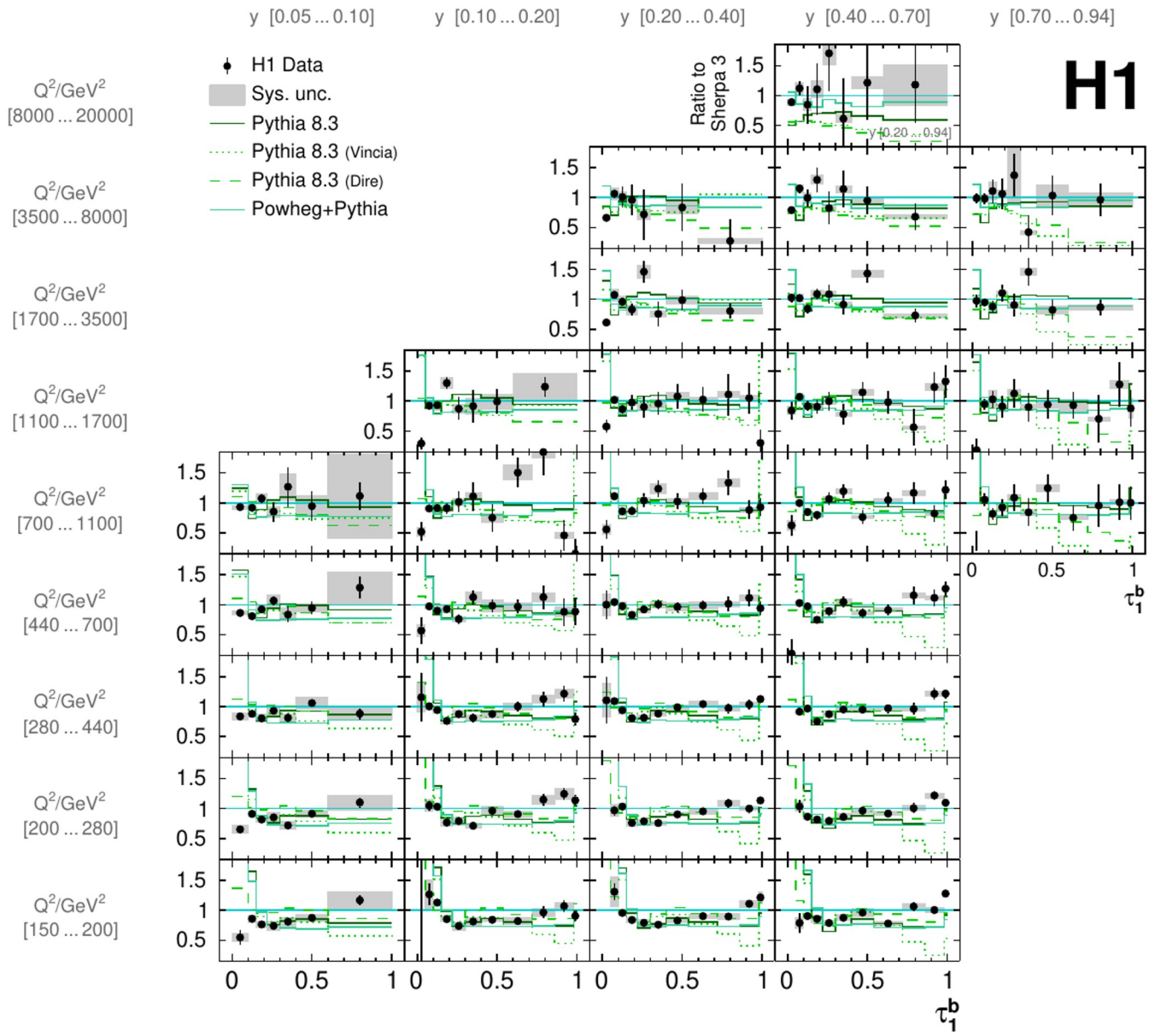
Triple differential cross section

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



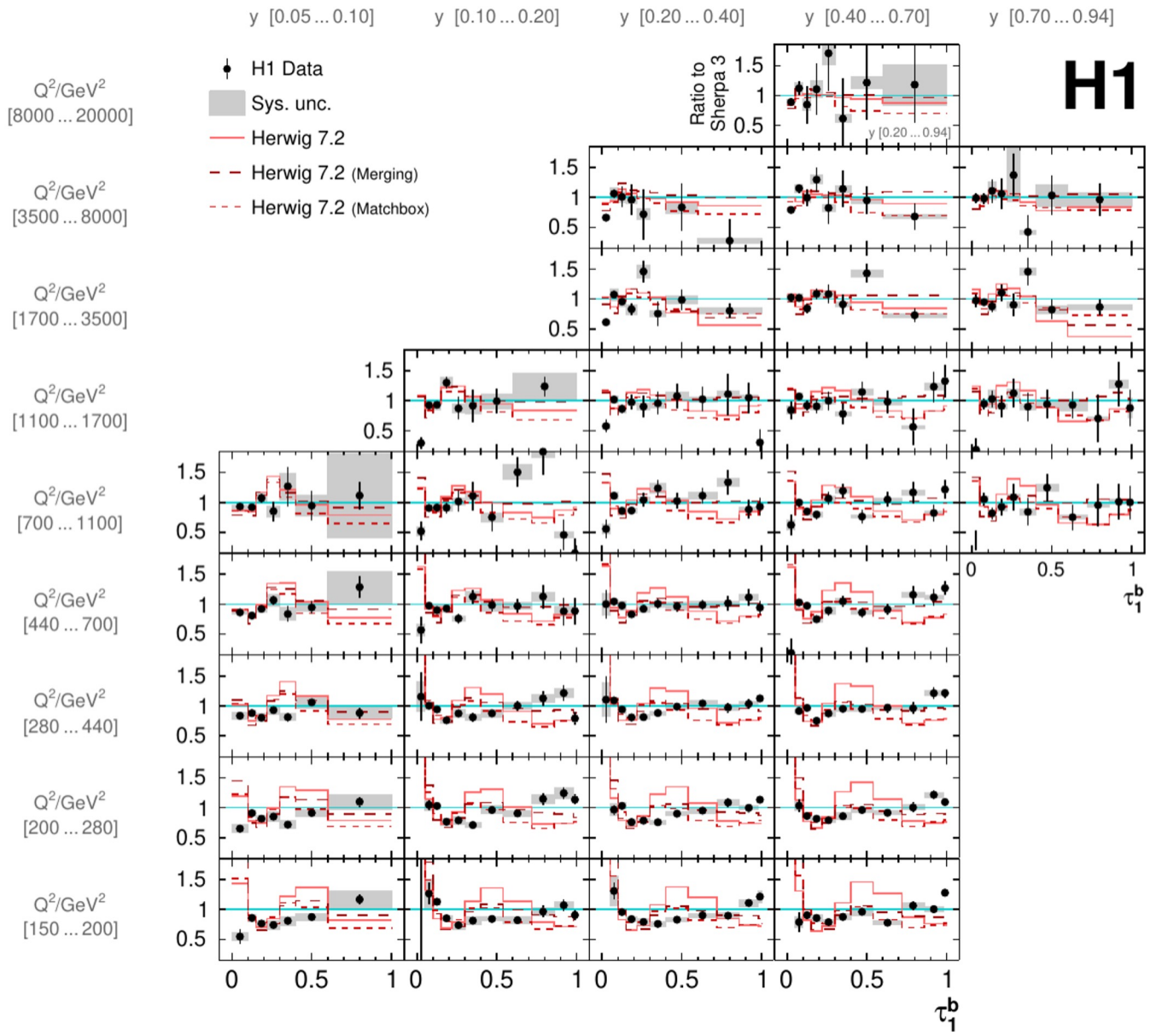
Triple differential cross section

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



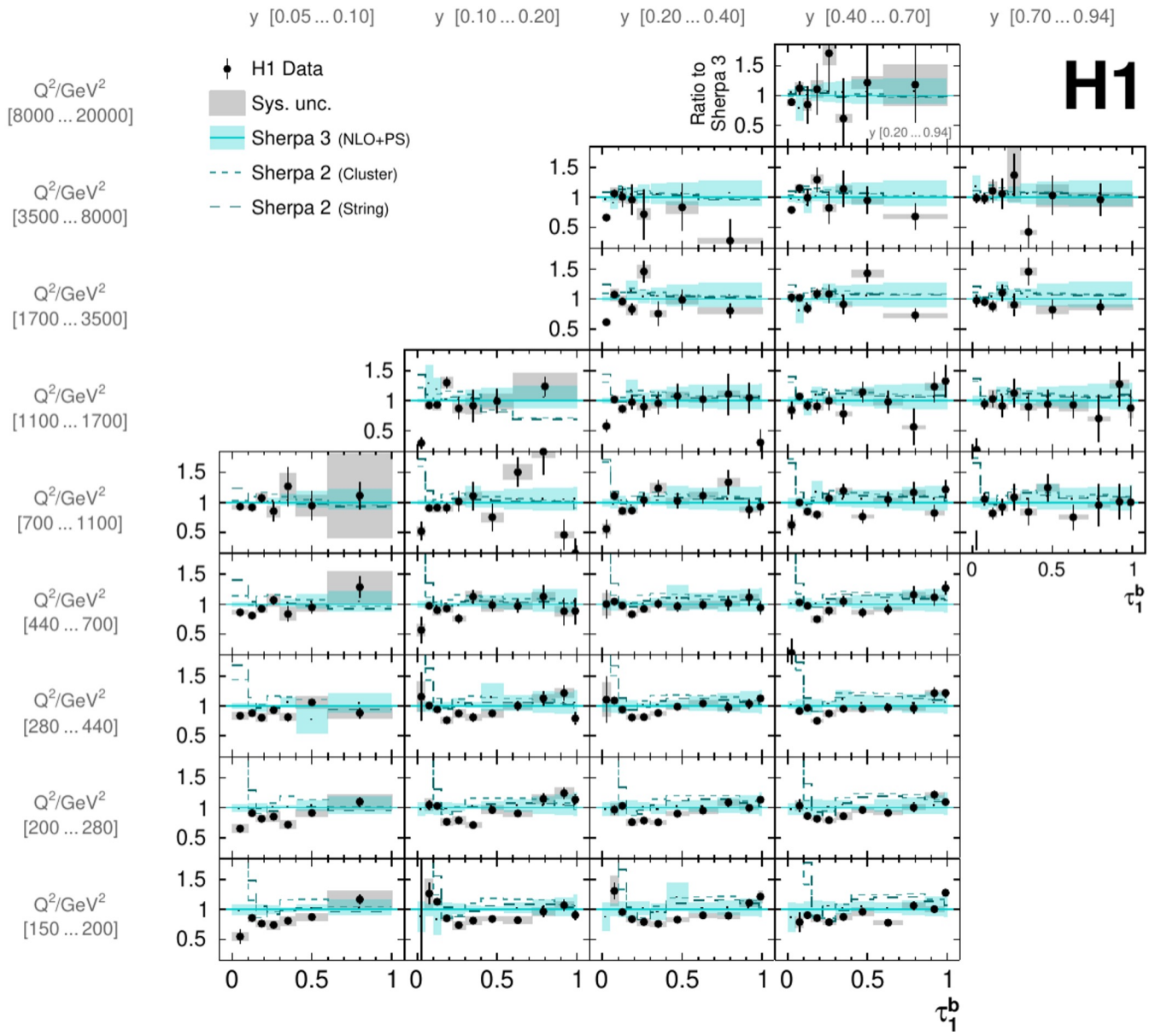
Triple differential cross section

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



Triple differential cross section

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