First look at jet cross sections

ZEUS Meeting

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Deutsches Elektronen-Synchrotron DESY

ZEUS

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First look at jet cross sections
Florian Lorkowski
2020-11-24

Overview
Goal
Datasets
DIS cuts
Jet cuts
Corrections
Jet plots
Bin-to-bin unfolding
Matrix unfolding
Outlook

Goal of analysis

- Precision measurement of inclusive jet cross sections in DIS
- No ZEUS paper from HERA-II on this subject yet
- This talk: compare cross sections to corresponding H1 paper[1]

Cross section definition

- Reconstruct jets using $k_\perp$ algorithm and weighted $p_\perp$-scheme (massless jets)
- Hadron level jets
- Corrected for higher order QED effects
- Not corrected for EW effects
- Weighted average of e^-p and e^+p cross sections with ratio $\approx 5:6$[1] (for now)

Phase space

- $150\,\mathrm{GeV}^2 < Q^2 < 15\,000\,\mathrm{GeV}^2$
- $0.2 < y < 0.7$
- $7\,\mathrm{GeV} < E_{\perp,\mathrm{breit}} < 50\,\mathrm{GeV}$
- $-1 < \eta_{\mathrm{lab}} < 2.5$
- Measure double differentially in Q^2 and $E_{\perp,\mathrm{breit}}$

[1] H1 Collaboration, *Measurement of Multijet Production in ep Collisions at High Q^2 and Determination of the Strong Coupling α_s*, 2014, arXiv:1406.4709

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Datasets

- Data: `03p`, `04p`, `05e`, `06e`, `06p`, `07p`
  - Total luminosity: $372\,\mathrm{pb}^{-1}$
  - e^-p luminosity: $189\,\mathrm{pb}^{-1}$
  - e^+p luminosity: $183\,\mathrm{pb}^{-1}$
- DIS MC: `ariadne_high_Q2_NC_{0304p,05e,06e,0607p}`

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Overview
DIS cuts

Phase space

- $Q^2_{\text{da}} \in [125, 20000]\,\text{GeV}^2$
- $0.2 < y_{\text{da}} < 0.7$

DIS selection

- At least one EM electron with $p > 0.001$
- $E_{\text{el}} > 10\,\text{GeV}$
- $E - p_z \in [38, 65]\,\text{GeV}$
- El. isolation: `Enin` < 10 %

Quality flags/triggers

- `EVTAKE` $\in \{1, 2\}$
- Triggers to be decided[1]

Background removal

- $|z_{\text{vertex}}| < 30\,\text{cm}$
- $\sqrt{\chi^2_{\text{vertex}}} < 10$
- $\frac{p_\perp}{\sqrt{E_\perp}} < 2.5\sqrt{\text{GeV}}$

MC deficiencies

- Reject QED compton[2]

Tracking

- If $0.3 < \theta_{\text{el}} < 2.85$: Electron has track with:
  - $p > 3\,\text{GeV}$
  - DCA $< 10\,\text{cm}$
- At least one well defined[3] vertex track

Detector effects

- Super crack[4]
- RCAL chimney[5]
- RCAL radius[6]

[1] So far: FLT: 28, 30, 36, 39, 40, 41, 43, 44, 46, 47, 50; SLT: SPP1, EXO{1,2,3}, DIS{1,4,7,9}; TLT: DIS3
[2] no other EM electron with $p > 0.001$, $\Delta\phi > 3$, $p_{\perp,1}/p_{\perp,2} > 0.8$ and no more than 3 GeV additional CAL energy
[3] $p_\perp > 0.2\,\text{GeV}$ and passes through at least three superlayers
[4] z_{el} not in $[-140, -98.5]$ cm or $[164, 200]$ cm
[5] not ($-12\,\text{cm} < x < 10\,\text{cm}$ and $y > 80\,\text{cm}$) for RCAL electrons
[6] $r < 175\,\text{cm}$ for RCAL electrons

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Jet reconstruction[1]

- Reconstruct jets from CAL cells, rejecting the EM electron
- Cluster jets in Breit frame (defined using DA electron)
- Reconstruct massless jets

Jet cuts[2]

- Reject events where any jet with $E_{\perp,\text{breit}} > 5\,\text{GeV}$ is closer than $\Delta R = 1$ to electron
- Reject events where any jet with $E_{\perp,\text{breit}} > 5\,\text{GeV}$ has $\eta_{\text{lab}} < -1$
- $E_{\perp,\text{lab}} > 3\,\text{GeV}$
- Cut to phase space (see slide 1)

[1] See talk from 2020-05-15 for more details on jet reconstruction
[2] Cut values taken from J. Behr and I. Makarenko

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DIS corrections[1]

- Longitudinal structure function reweighting
- Electron energy resolution correction
- Vertex position reweighting
- Track matching efficiency reweighting
- Track veto efficiency reweighting

Energy scale calibrations[1]

- Absolute electron calibration (detector level $\rightarrow$ truth level)
- Relative jet calibration (MC detector level $\rightarrow$ data)
- Absolute jet calibration (detector level $\rightarrow$ truth level)

[1] See talk from 2020-09-15 for details

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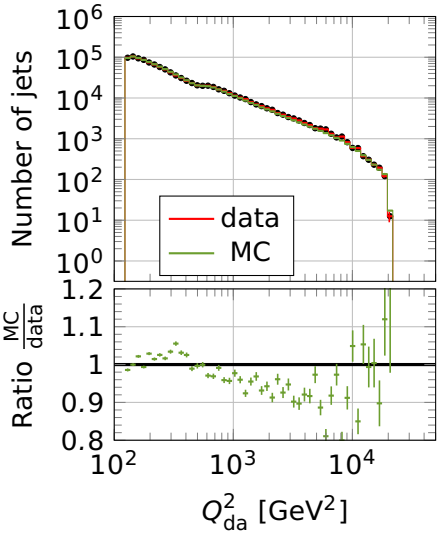
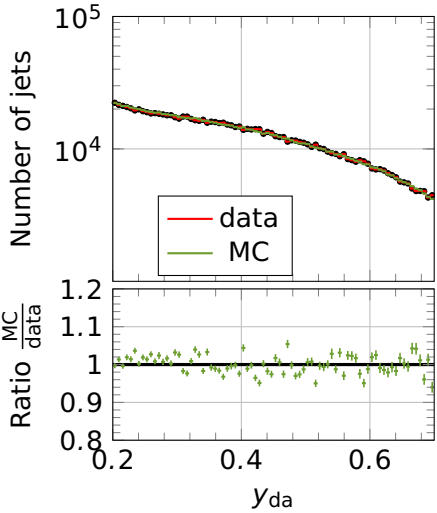
Jet plots
DIS quantities





Jet plots
Lab frame

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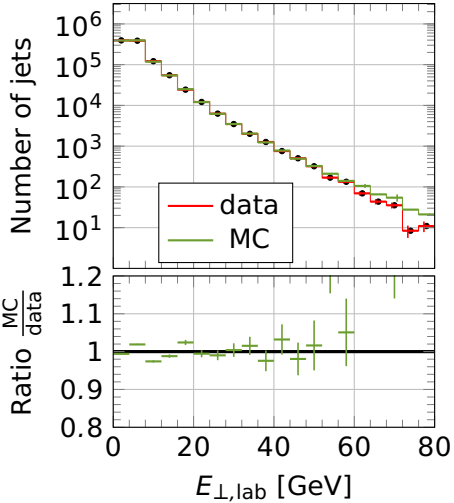

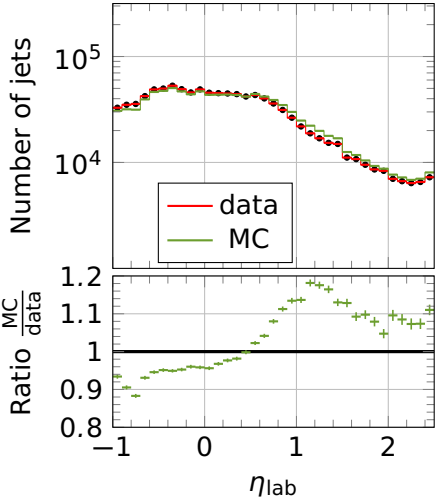

Jet plots
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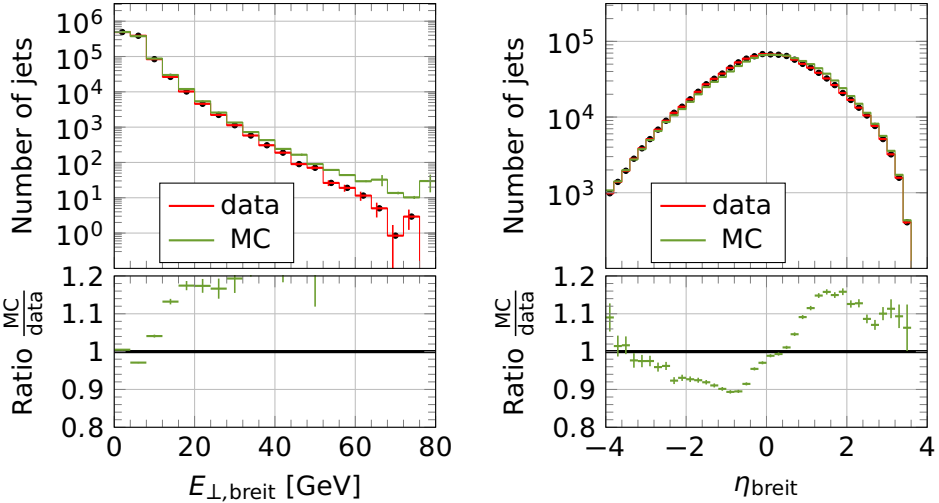


Bin-to-bin unfolding
Definition

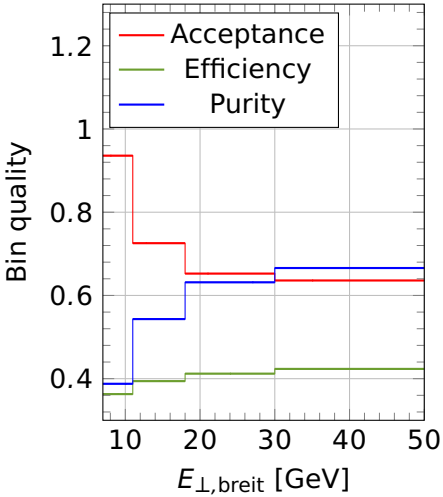
- Count number of jets in each bin (in Q^2, y, $E_{\perp,\text{breit}}$, η_{lab}) in data, MC reconstructed level and MC generator level
- $\text{Unfolded} = \text{Data} \cdot \frac{\text{MC gen}}{\text{MC rec}}$
- Bins do not influence each other
- Important criteria for bin quality:

$$\text{Acceptance} = \frac{N_{\text{rec}}}{N_{\text{gen}}}$$

$$\text{Efficiency} = \frac{N_{\text{gen\&rec}}}{N_{\text{gen}}}$$

$$\text{Purity} = \frac{N_{\text{gen\&rec}}}{N_{\text{rec}}}$$

where N_{gen} and N_{rec} are the number of jets generated/reconstructed in the bin and $N_{\text{gen\&rec}}$ is the number of jets generated and reconstructed in the same bin



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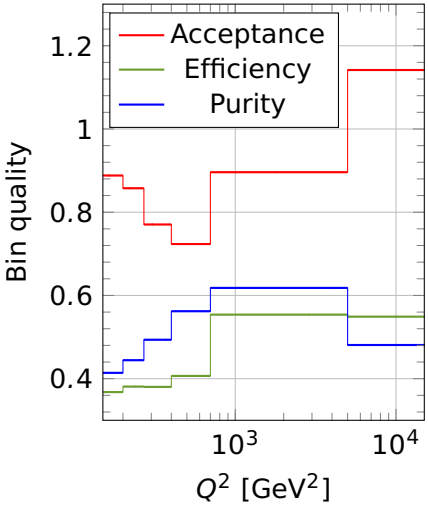

Bin-to-bin unfolding
Cross sections

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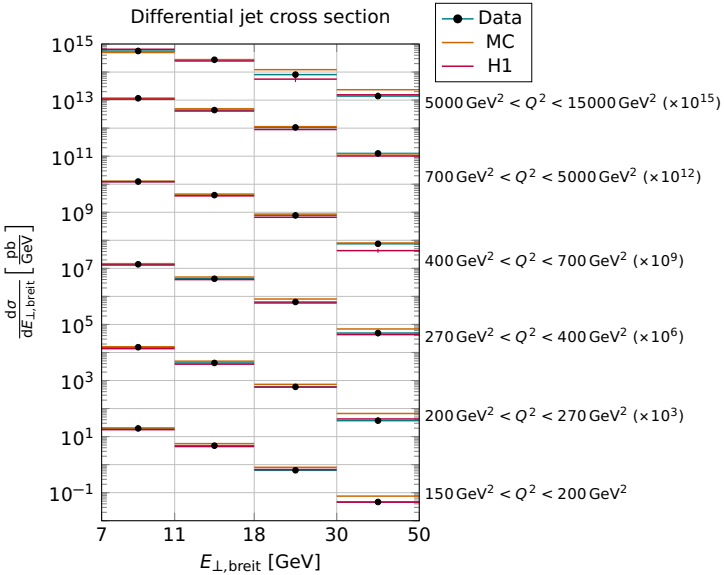

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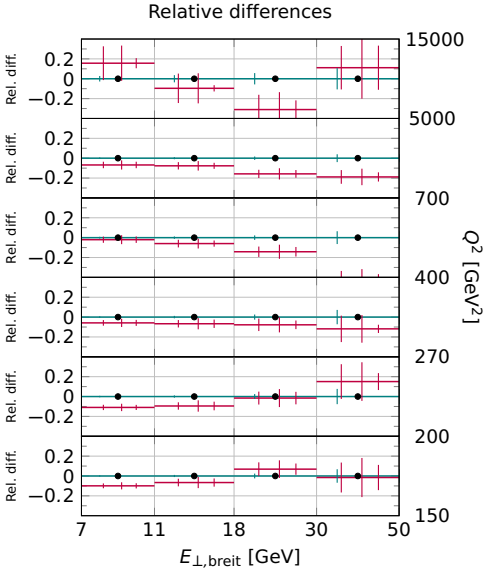
Cross sections



Data:
ZEUS, HERA-II, 372 pb^{-1}
Not corrected for QED effects

H1:
HERA-II, 351 pb^{-1}
Corrected for QED effects
arXiv:1406.4709

Uncertainties:
- Left: statistical
- Right: systematic
- Center: total

Go to matrix unfolding: ➔

Matrix unfolding
Definition

- Draw response matrix in MC: reconstructed vs generated quantity (allows to derive detector level distribution from truth level distribution)
- Unfolding algorithm tries to find truth level distribution, such that derived detector level distribution matches data as closely as possible
- Bins do influence each other
- Use package TUnfold[1]

Advantages over bin-to-bin unfolding

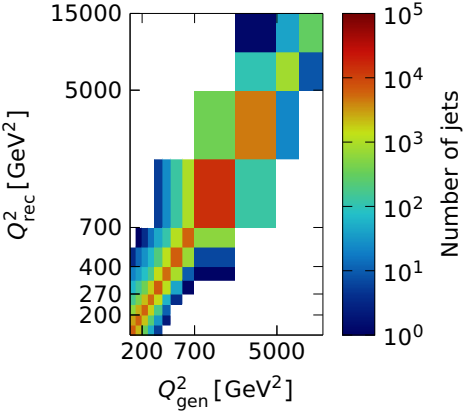
- More reliable uncertainty estimates
- Reduced dependency on MC model
- Better treatment of large migrations

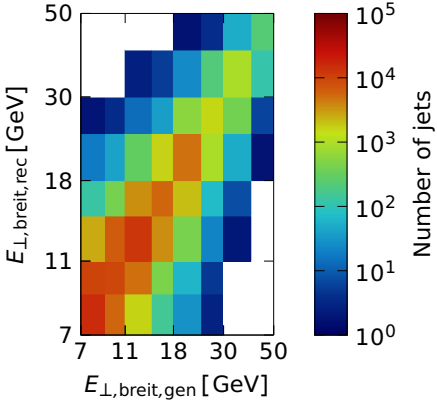
Disadvantages

- Conceptually more complex/difficult to reason about
- Need more MC statistics
- Detector and generator level jets need to be matched

[1] Stefan Schmidt, *TUnfold: an algorithm for correcting migration effects in high energy physics*, 2012, arXiv:1205.6201

Matrix unfolding
Definition

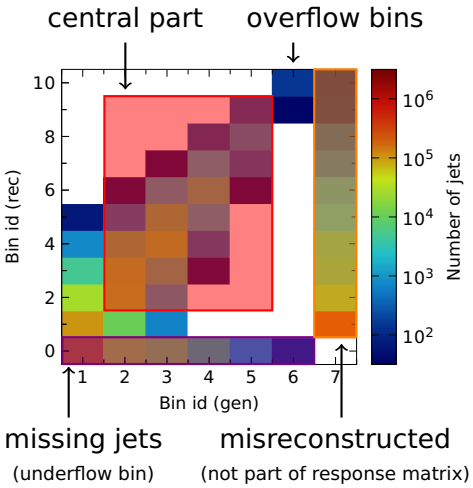




$\Rightarrow$ migrations in $E_{\perp,\mathrm{breit}}$ are much larger than in Q^2 $\Rightarrow$ use matrix unfolding only for $E_{\perp,\mathrm{breit}}$

Matrix unfolding
Definition

- Cut on y, η_{lab} and a specific Q^2-bin
- Match detector to generator level jets:[1]
  - Successfull match:
    $\rightarrow$ Fill response matrix
  - Unmatched generator level jet:
    $\rightarrow$ Fill additional histogram for missing jets (inefficiencies)
  - Unmatched detector level jet:
    $\rightarrow$ Fill additional histogram for misreconstructed jets/events (migrated from outside phase space)
- Use twice as many bins at detector level, than at generator level (requirement of TUnfold)
- Missing jets become part of response matrix, as additional detector level bin



[1] According to $\Delta R < 0.9$, as was used by H1

Matrix unfolding
Definition

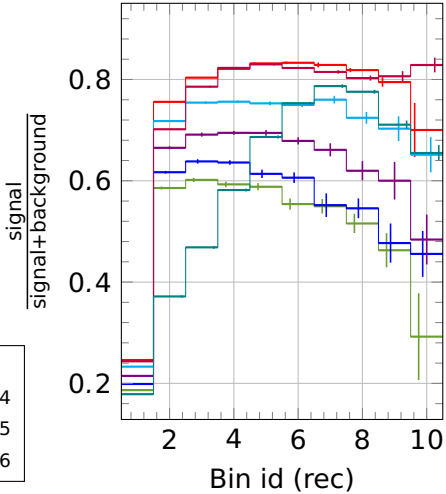
- Define background fraction b_i for each detector level bin i

$$b_i = \frac{\text{Matched jets in bin } i}{\text{Total jets in bin } i}$$

- Before unfolding, correct data for background

$$\text{data}_i \rightarrow \text{data}'_i = \text{data}_i \cdot b_i$$

- Misreconstructed jets are not part of the response matrix



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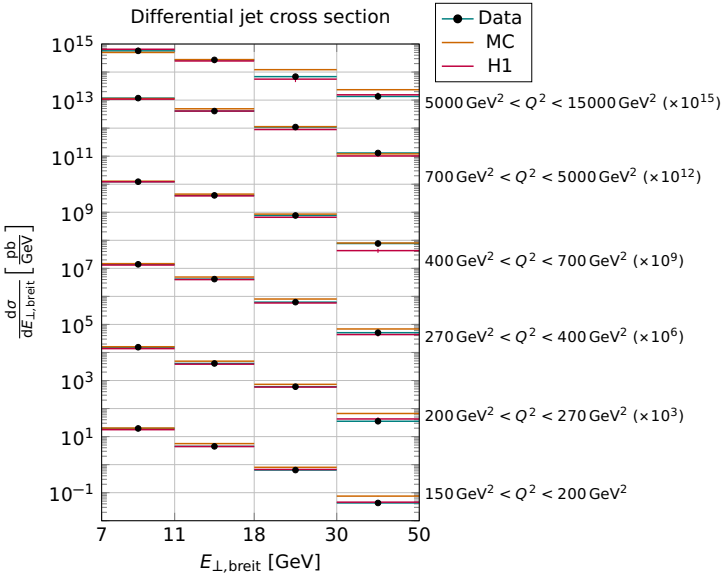

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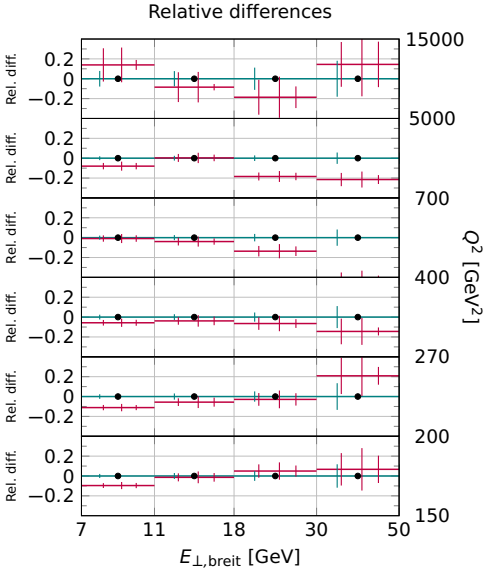

Data
H1

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Go to bin-to-bin unfolding: ↩

Outlook

Next steps

- Determine systematic uncertainties
- Determine missing corrections to compare to H1 and theory predictions

To determine corrections

- Need to estimate QED and EW corrections to cross section
- At HERA, this is usually done with HERACLES/DJANGOH
- Does anyone have the necessary configuration files?