Update on systematics of jet cross sections

ZEUS meeting

Florian Lorkowski

Deutsches Elektronen-Synchrotron DESY

ZEUS

March 24, 2021

Goal of analysis

- Precision measurement of inclusive jet cross sections in DIS
- No ZEUS paper from HERA-II on this subject yet
- This talk: show systematic uncertainties

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

Phase space[1]

$$150\,\text{GeV}^2 < Q^2 < 15\,000\,\text{GeV}^2$$
$$0.2 < y < 0.7$$
$$7\,\text{GeV} < p_{\perp,\text{breit}} < 50\,\text{GeV}$$
$$-1 < \eta_{\text{lab}} < 2.5$$

Q^2 binning: $150 - 200 - 270 - 400 - 5000 - 15000\,\text{GeV}^2$
$p_{\perp,\text{breit}}$ binning: $7 - 11 - 18 - 30 - 50\,\text{GeV}$

[1] From now on, call transverse momentum of jets $p_\perp$, rather then $E_\perp$

Data

- ~~03p~~ (trigger simulation incorrect; very low luminosity)
- ~~04p (up to run 50500)~~ (trigger simulation not ideal; lose $\sim$ 8% statistics)
- 04p (starting at run 50500)
- 05e, 06e
- 06p, 07p

$\Rightarrow$ Total luminosity: 344 pb^{-1} (189 pb^{-1} e^-p; 155 pb^{-1} e^+p)

MC[1]

- Signal: `ariadne_high_Q2_NC_{0304p,05e,06e,0607p}`
- Signal: `mps_high_Q2_NC_{0304p,05e,06e,fixlst_0607p}` (for model variation)
- Background: `PHP_HER_{dir,res}_4D_{0304p,05e,06e,0607p}`

[1] 0304p run periods are have a cut on `SimRun`, to match the runperiod in the data

Phase space

- $Q^2_{\text{da}} \in [150, 15000]\,\text{GeV}^2$
- $0.2 < y_{\text{da}} < 0.7$

DIS selection

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

Quality flags/triggers

- `EVTAKE` $\in \{1, 2\}$
- Several triggers[1] **new**

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] FLT: 28, 30, 36, 39, 40, 41, 43, 44, 46, 47, 50; SLT: SPP1, EXO{1,2,3}, DIS7; TLT: DIS3
[2] no other EM electron with $\rho > 0.001$, $\Delta\phi > 3$, $p_{\perp,1}/p_{\perp,2} > 0.8$ 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

DIS corrections[1]

- Longitudinal structure function reweighting
- ~~Electron energy resolution correction~~ (not consistent[2])
- Vertex position reweighting
- Track matching efficiency reweighting
- Track veto efficiency reweighting
- Polarisation (not yet implemented)
- Absolute electron calibration (detector level → truth level)

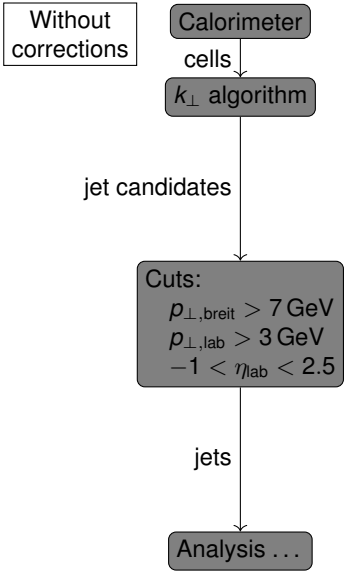
Jet corrections[1]

- Relative jet calibration (MC detector level → data)
- Absolute jet calibration (detector level → truth level)
- Jet reweighting (MC → data) **new**

All detector corrections are taken as the average of Ariadne and Lepto (factors are similar; combination improves statistics) **new**

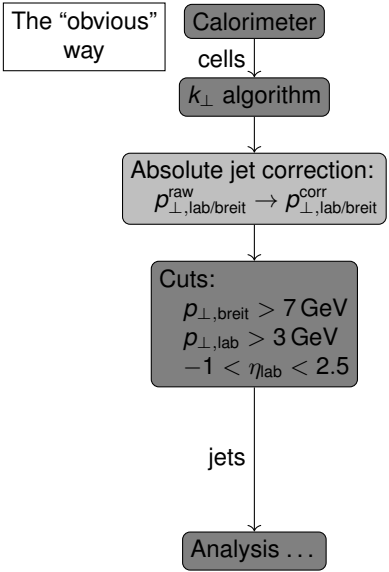
[1] See talk from 2020-09-15 for details
[2] Correction factors derived using Ariadne differ from the ones derived using Lepto

Detector jet reconstruction



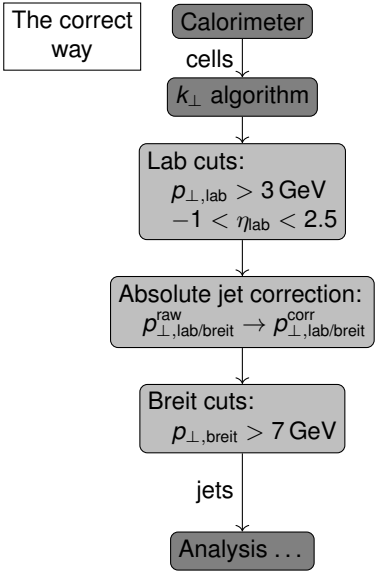
Detector jet reconstruction

- "Obviously," corrections should be applied before cuts
- E.g. a jet might be corrected
  $p_{\perp,\text{breit}} = 6.9\,\text{GeV} \rightarrow p_{\perp,\text{breit}} = 7.1\,\text{GeV}$,
  $\rightarrow$ this jet should be used in the analysis



Detector jet reconstruction

- "Obviously," corrections should be applied before cuts
- E.g. a jet might be corrected
  $p_{\perp,\text{breit}} = 6.9\,\text{GeV} \rightarrow p_{\perp,\text{breit}} = 7.1\,\text{GeV}$,
  $\rightarrow$ this jet should be used in the analysis
- **BUT:** the absolute jet scale correction especially increases the energy of low $p_\perp$ jets
- E.g. a jet might be corrected
  $p_{\perp,\text{lab}} = 0.5\,\text{GeV} \rightarrow p_{\perp,\text{lab}} = 3.1\,\text{GeV}$,
  $\rightarrow$ this jet should **NOT** be used in the analysis
- Consequences of incorrect order:
  - Many detector level-only jets (that do not really exist)
  - Low matching efficiency of gen to rec jets
  - Unfolding does not work as intended
  - Systematic uncertainties increased



Purpose of jet reweighting

- Detector simulation has been improved by previous corrections
- MC generator level does not describe data truth level exactly
  $\rightarrow$ data and MC disagree at detector level
  $\rightarrow$ acceptance estimated using MC will be incorrect
- Reweight MC at generator level such that data and MC agree at detector level
  $\rightarrow$ data and MC agree at generator level (since detector simulation is correct)
  $\Rightarrow$ bin-by-bin acceptance correction is applicable
- Alternative to reweighting: matrix unfolding (not in this talk)
  $\rightarrow$ Response matrix describes detector response without relying on correct generator level distributions (of the quantities in the response matrix)

Model uncertainty

- Both approaches do not work exactly, due to differences in other quantities at generator level
- Unfold data using Ariadne and Lepto MC separately; use their average as central value and their difference as systematic uncertainty

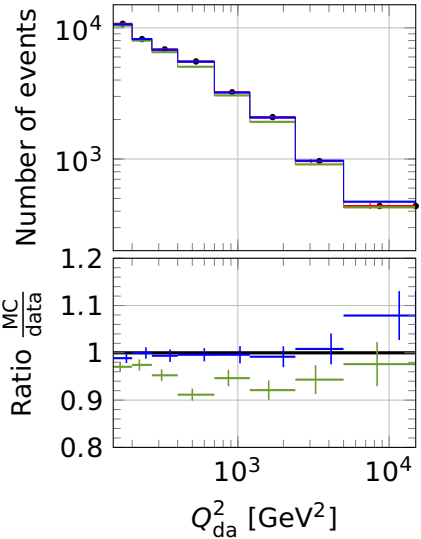
Usual approach to jet reweighting[1]

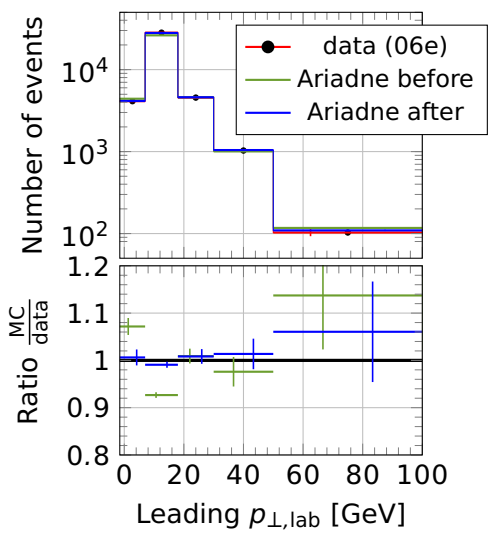
- Consider Q^2 and/or $p_\perp$ of leading lab jet at detector level
- Fit (complex) function to ratio $\frac{\text{data}}{\text{MC}}$
- Use fitted function to reweight events at generator level
- Iterate until detector level distributions agree

Method used here

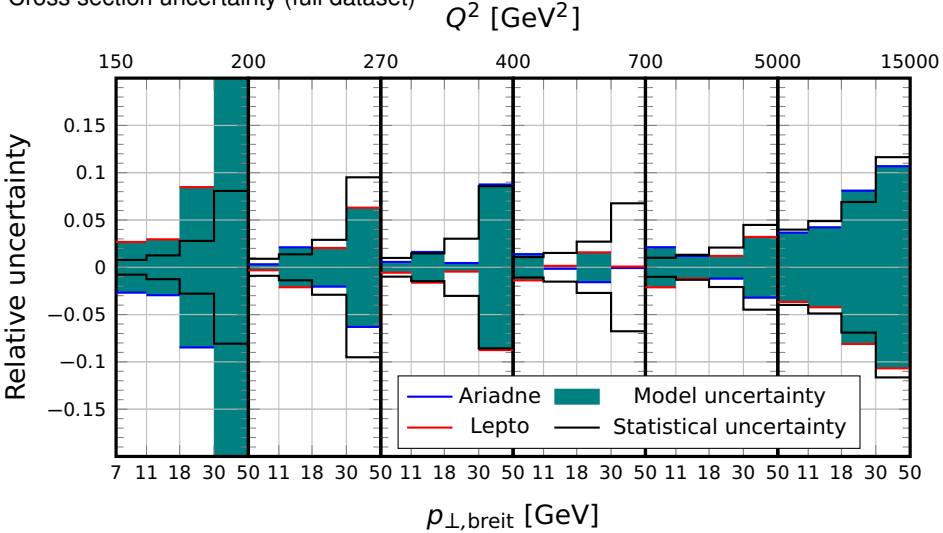
- Reweight in bins Q^2 and $p_\perp$ of leading lab jet
- Apply four iterations
  $\Rightarrow$ very good agreement at detector level (see next slide)

[1] See e.g. PhD theses of J.Behr or I.Makarenko





Cross section uncertainty (full dataset)



Go to per-jet reweighting

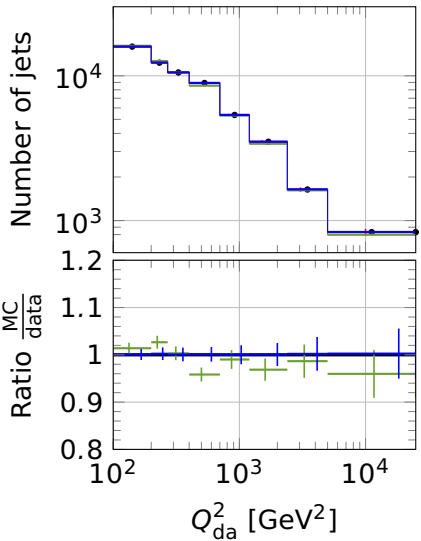
Problem with usual approach

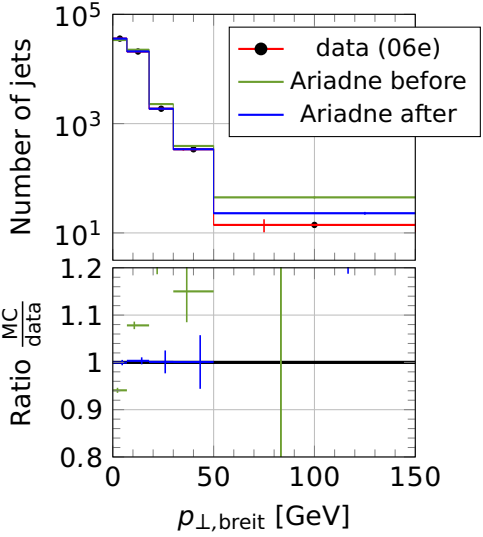
- Only leading jet is reweighted to match
- If jet correlations are not described by MC, subleading jets will still be incorrect

Improved approach to jet reweighting

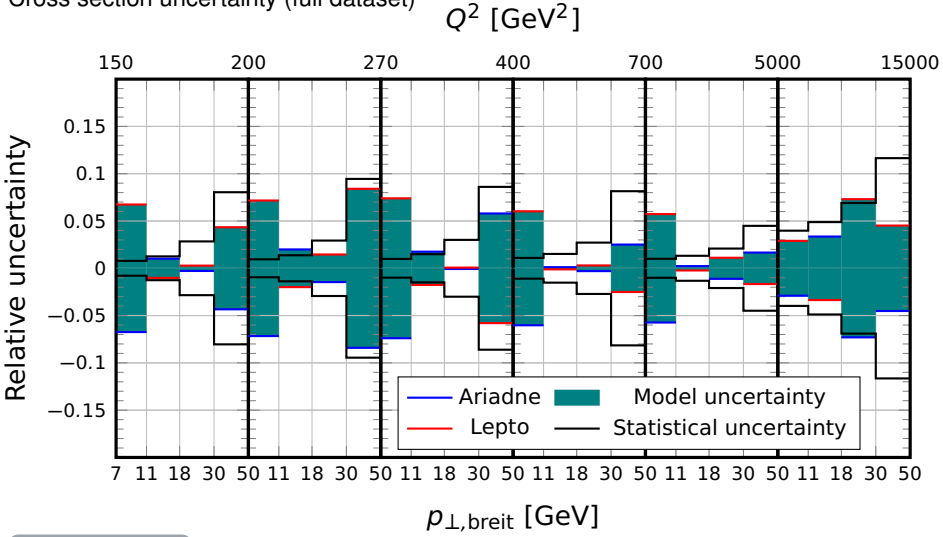
- Matching efficiency for generator level jets to detector level jets is $> 97\%$
  $\rightarrow$ per-jet reweighting is feasible
- Consider Q^2 and $p_{\perp,\text{breit}}$ **of each jet** at detector level[1]
- Determine two-dimensional correction factors from ratio $\frac{\text{data}}{\text{MC}}$
- Use correction factors to reweight **each jet** at generator level (before cuts)
- Match detector level jets to generator level jets and copy weights
  (remaining $< 3\%$ of detector level jets are not weighed)
- Apply four iterations
  $\Rightarrow$ inclusive jet distributions agree very well (see next slide), also double-differentially (see appendix), except for overflow bin $p_{\perp,\text{breit}} > 50\,\text{GeV}$

[1] First to $p_\perp$-bins have been merged for reweighting





Cross section uncertainty (full dataset)



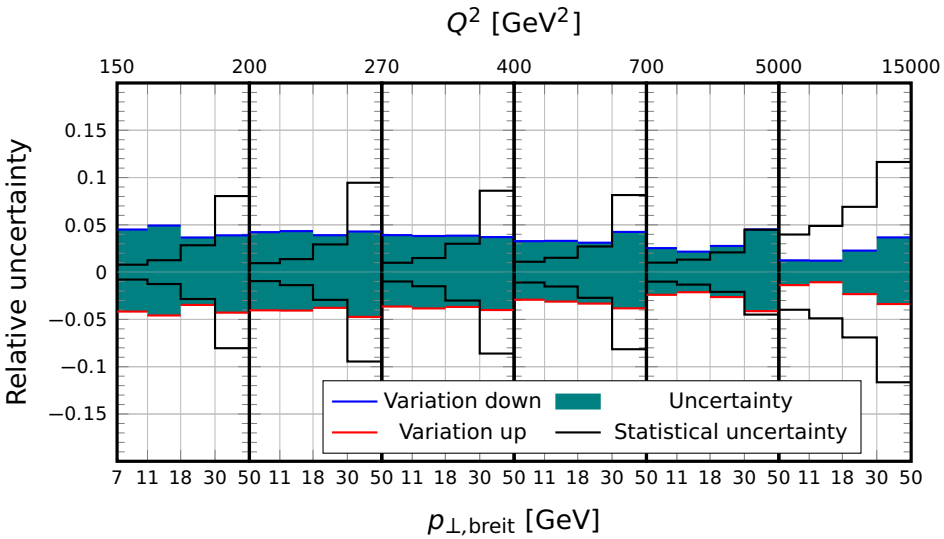
Go to per-event reweighting

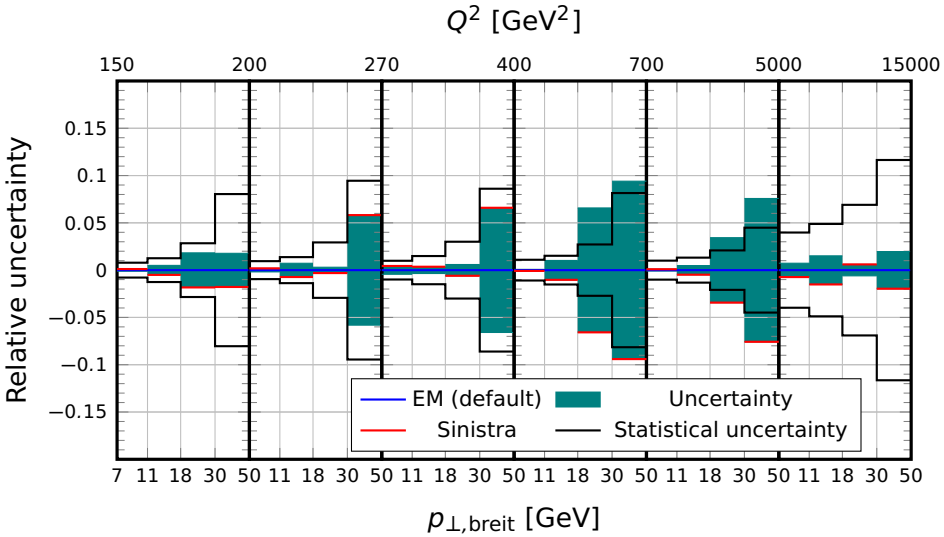
Major sources

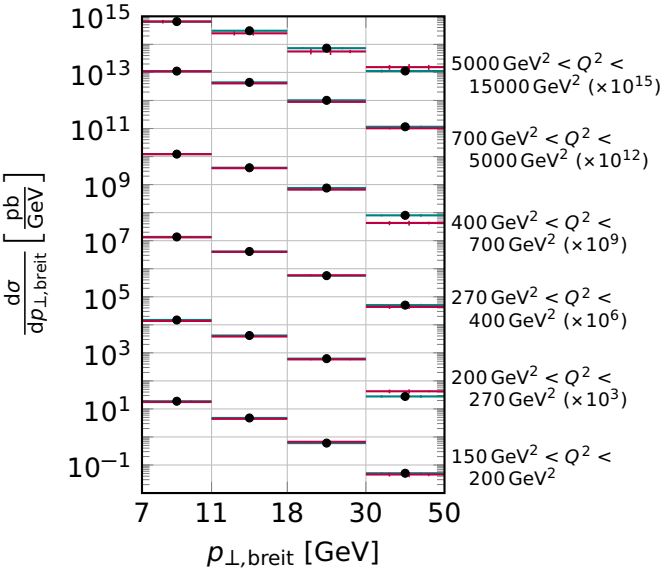
- Jet energy scale
  change energies of jets by $\pm 1\%$
  ($\pm 3\%$ if $p_{\perp,\text{lab}} < 10\,\text{GeV}$)
- Electron identification
  use Sinistra instead of EM

Minor sources (see appendix)

- Electron energy scale
- Cut values:
  - $p_{\perp,\text{lab}}$
  - E_{el}
  - $E - p_z$
  - $p_\perp / \sqrt{E_\perp}$
  - z_{vertex}
  - Electron track distance of closest approaches
- PHP background
- Trigger efficiency correction
- Vertex position reweighting
- Polarisation (not yet implemented)







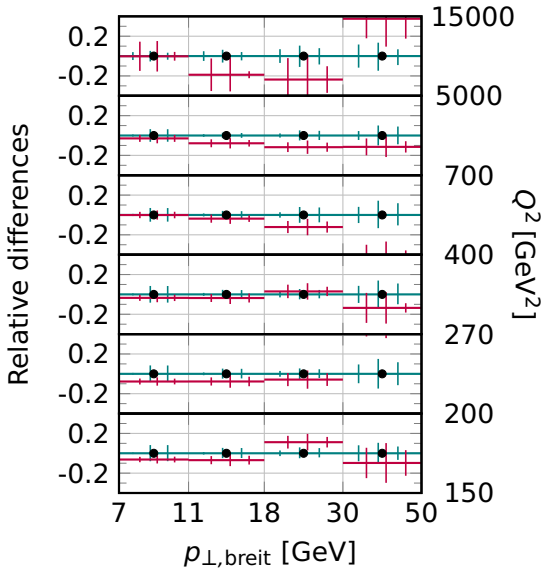
data
H1 data

Data
- HERA-II, 344 pb^{-1}
- Not corrected for QED effects

H1[†]
- HERA-II, 351 pb^{-1}
- Corrected for QED effects

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

[†] H1 Collaboration, 2014, arXiv:1406.4709



data
H1 data

Data
- HERA-II, 344 pb^{-1}
- Not corrected for QED effects

H1[†]
- HERA-II, 351 pb^{-1}
- Corrected for QED effects

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

[†] H1 Collaboration, 2014, arXiv:1406.4709

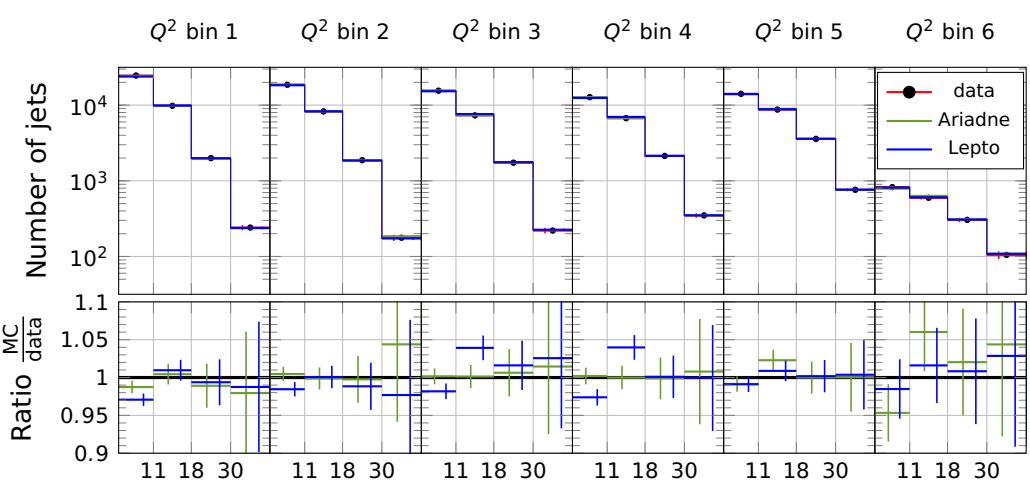
Summary

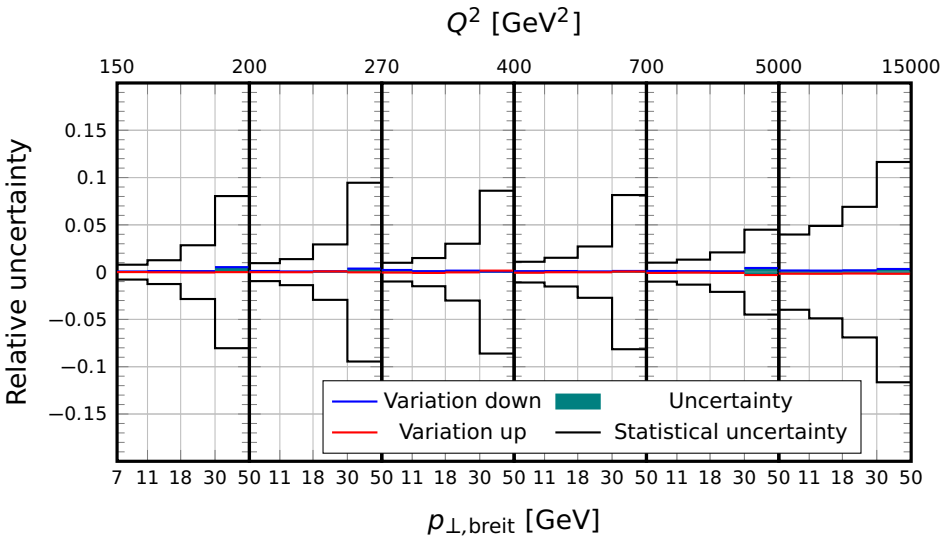
- Systematic uncertainties have been evaluated
- Per-jet reweighting reduces model uncertainty

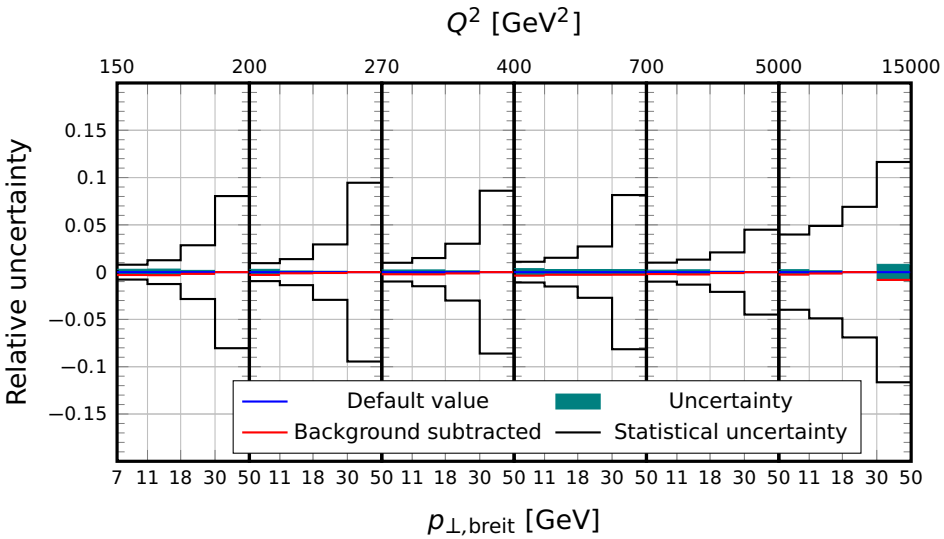
Outlook

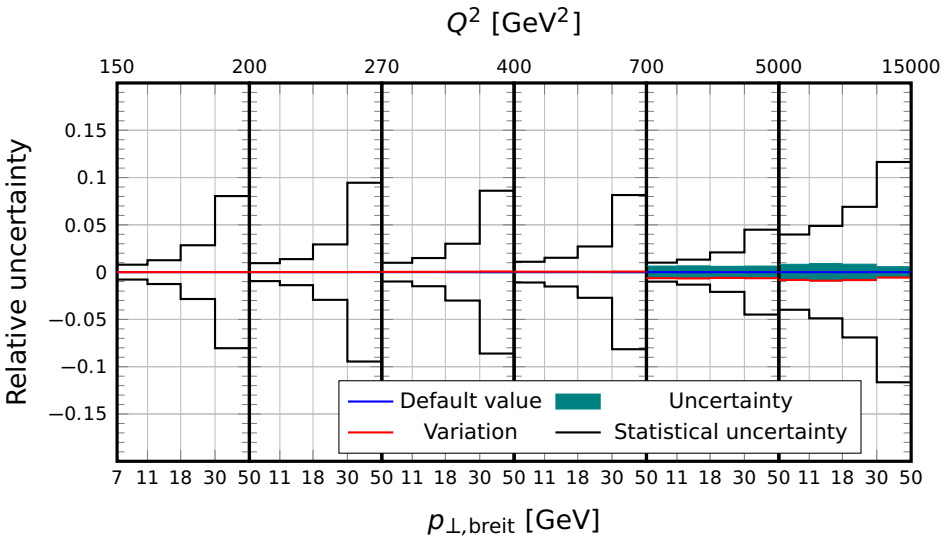
- Determine QED and EW corrections
- Compare to theory predictions
- Explore matrix unfolding of jet migrations
- Fit strong coupling constant

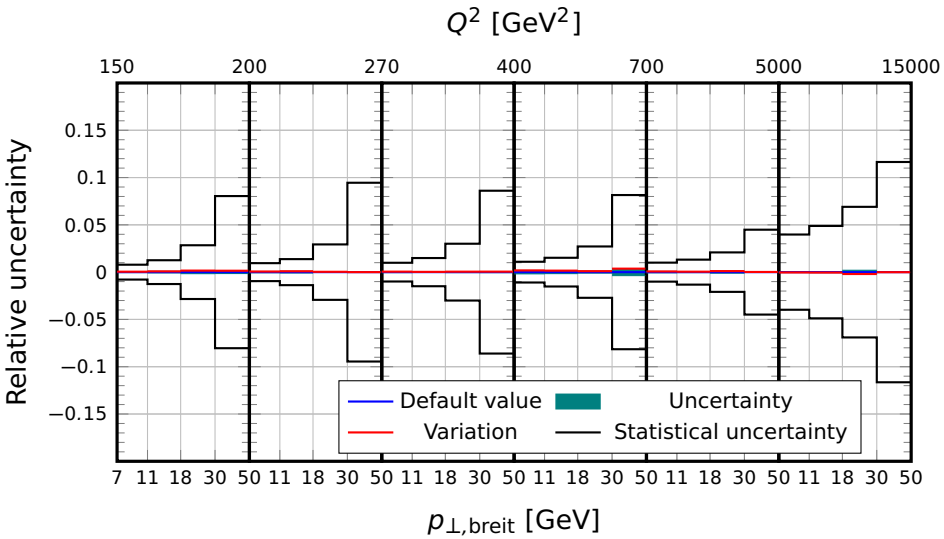
Jet control plots

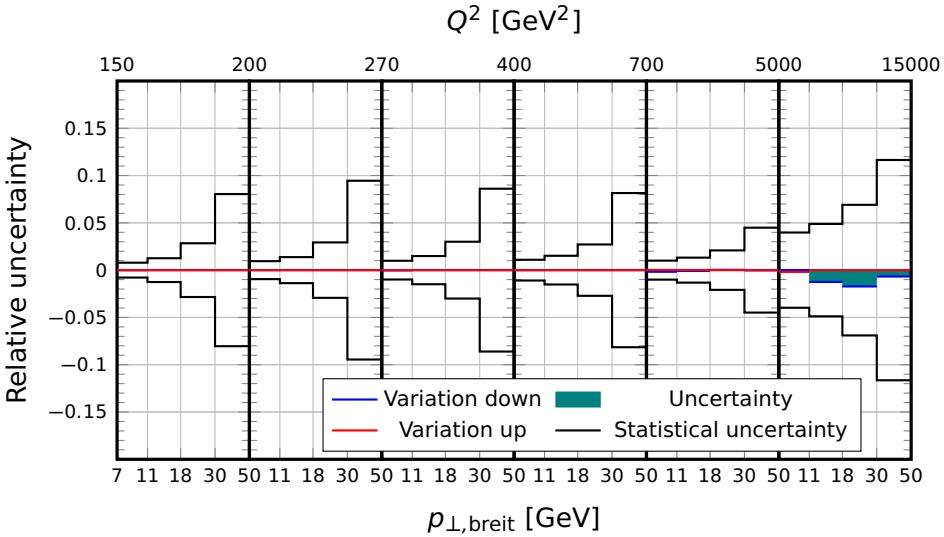


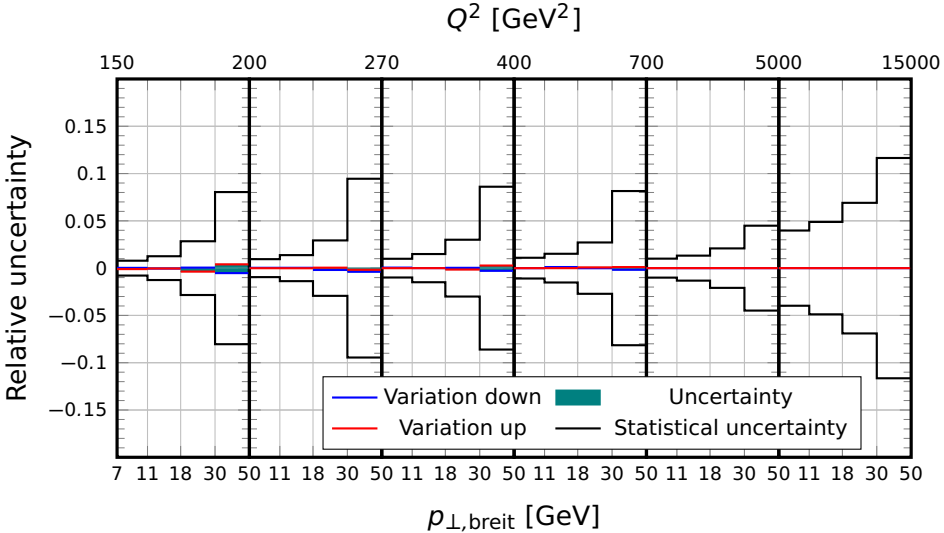












Uncertainties: cuts

$E - p_z$