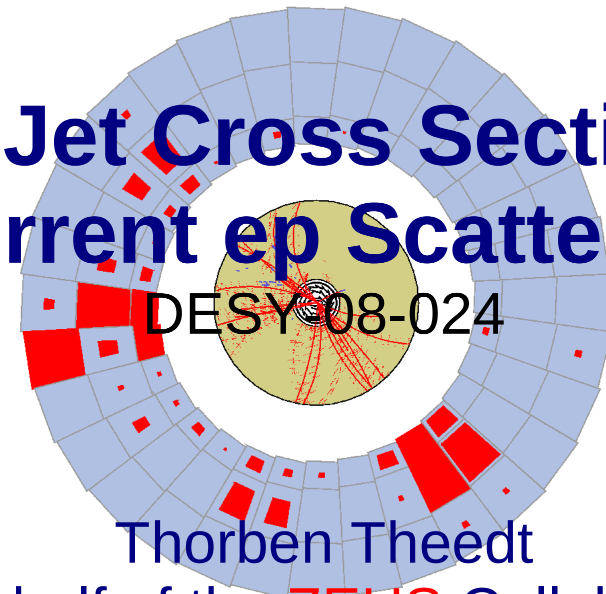
Multi-Jet Cross Sections in Charged Current ep Scattering at HERA



DESY-08-024

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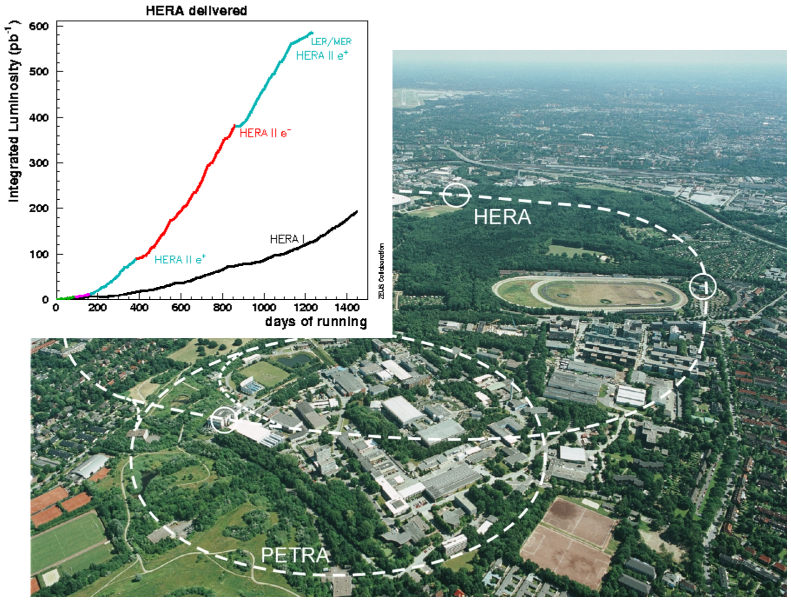
on Behalf of the ZEUS Collaboration

Outline

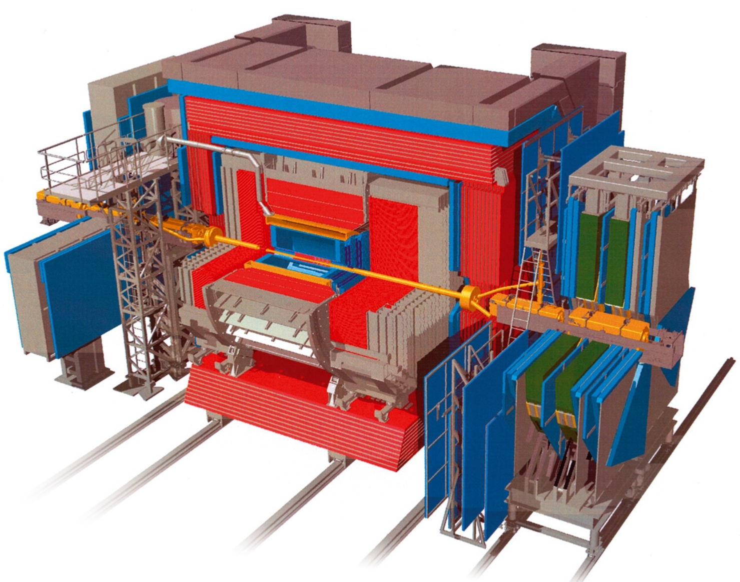
- **Experimental setup**
- **Physics at HERA**
  - DIS events in HERA
  - Charged current DIS: Why are we interested in multi-jets in CC DIS?
- **Measurement**
  - Data selection and jet reconstruction
  - Systematic uncertainties
- **Fixed order QCD calculation**
  - Determination of theoretical errors
- **Results**
  - Polarized inclusive-jet cross sections
  - Unpolarized inclusive-jet cross sections
  - Dijet cross sections
  - Three-jet cross sections

Experimental Setup



HERA

- E_e = 27.5 GeV , E_p = 920 GeV
- $\sqrt{s}$ = 318 GeV
- HERA 1 (93-00) L= 143 pb^{-1}
- HERA 2 (02-07) L= 358 pb^{-1}
  longitudinally-polarized electron beam



ZEUS: Multipurpose detector

Central Tracking Detector

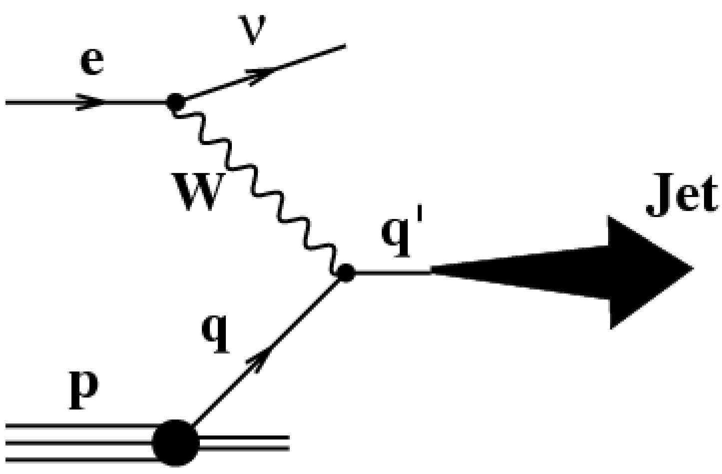
- Drift chamber
- Polar angle $15^{o}<\Theta<164^{o}$

Uranium -Calorimeter

- Covers 99.7% of solid angle
- $\frac{\sigma(E)}{E} = \frac{0.18(0.35)}{\sqrt{E}}$ for electrons (hadrons)

DIS at HERA

QPM process:



Kinematic variables:

- Q^2 ... virtuality of the exchanged boson
- x_{Bj}...fraction of proton momentum carried by struck quark
- y...inelasticity, energy transfer from electron into hard scattering process

$$Q^2 = x_{Bj}\, y\, s$$

Charged current DIS:

- No electron in the final state
- Signature: large missing p_T and large E_T
- Kinematic variables are calculated from hadronic final state

Jacquet-Blondel method

$$y_{jb} = \frac{\sum_i (E_i - p_{zi})}{2E_e} \qquad Q^2_{jb} = \frac{(\sum_i p_{xi})^2 + (\sum_i p_{yi})^2}{1 - y_{jb}} \qquad x_{jb} = \frac{Q^2_{jb}}{s\, y_{jb}}$$

Charged Current Events in DIS

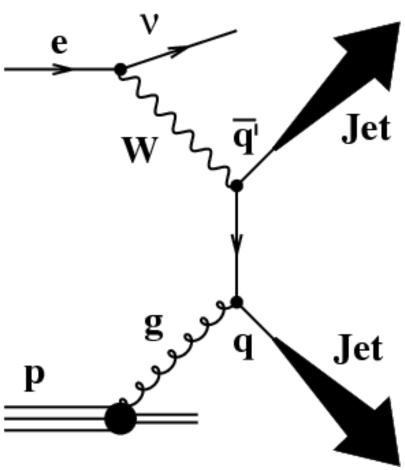
CC DIS cross section in QPM:

$$\frac{d^2\sigma_{CC}^{e^- p}}{dx\,dQ^2} = \frac{G_F^2}{2\pi}\frac{M_W^4}{(M_W^2+Q^2)^2}\sum_{i=1}^{2}[u_i(x,Q^2)+(1-y)^2\bar{d}_i(x,Q^2)] \times (1-P_{e^-})$$ electron

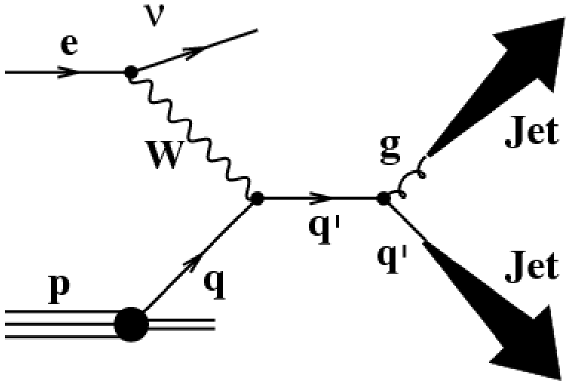
$$\frac{d^2\sigma_{CC}^{e^+ p}}{dx\,dQ^2} = \frac{G_F^2}{2\pi}\frac{M_W^4}{(M_W^2+Q^2)^2}\sum_{i=1}^{2}[\bar{u}_i(x,Q^2)+(1-y)^2 d_i(x,Q^2)] \times (1+P_{e^+})$$ positron

Sensitive to M_W and to u-type and d-type quark (anti-quark) densities, polarization

Higher order processes O(α_s):



Boson(W) -gluon fusion process



QCD -Compton process

Sensitive to α_s
and
gluon density

Data Selection and Jet Reconstruction

Data:
ZEUS 2004-2007 L = 358 pb^{-1}
polarized electron and positron data

electron: L = 180.0 pb^{-1} → 106.4 pb^{-1} (P = -0.27*) ; 73.6 pb^{-1} (P = +0.29*)

positron: L = 178.5 pb^{-1} → 76.5 pb^{-1} (P = -0.37*) ; 102.1 pb^{-1} (P = +0.32*)

*** luminosity weighted average**

Phase Space: $Q^2 > 200$ GeV^2 and $y < 0.9$

Jet reconstruction: k_T cluster algorithm in longitudinally invariant mode in LAB frame

incl. jet sample: $-1 < \eta^{jet} < 2.5$ and $E_T^{jet} > 14$ GeV , (10611 events)
dijet sample: $-1 < \eta^{jet} < 2.5$ and $E_T^{jet1(jet2)} > 14\ (5)$ GeV , (1581 events)
three-jet sample: $-1 < \eta^{jet} < 2.5$ and $E_T^{jet1(jet2)(jet3)} > 14\ (5)(5)$ GeV , (139 events)

Systematic Uncertainties

Acceptance correction:

- bin-by-bin method
- ARIADNE MC using CDM for QCD cascade

Systematic uncertainties:

Systematic	Variation	Error (incl, dijet, trijet)
Jet energy scale	± 1% E_T < 75 GeV ± 2% E_T > 75 GeV	0.5%, 2%, 4%
Energy scale CAL	± 1% $p_{T,miss}$ < 75 GeV +3(-1)% $p_{T,miss}$ > 75 GeV	0.2%, 0.3%, 0.4%
Parton shower model	CDM / MEPS	0.7%, 7%, 6%
Cut on missing pT	± 1 GeV	0.2%, 0.1%, < 0.1%
Cut on Z_{VTX}	± 11cm	2%, 2%, 2%
Trigger	additional jet E_T > 8 GeV	Negligible

- Experimental uncertainties dominated by statistical uncertainty (1.5% ,4%, 15%)
- Exception: incl. jet cross sections at high E_T and high Q^2 where uncertainty from modeling of QCD cascades is large

Fixed-Order QCD Calculations

Fixed-order QCD calculation

- MEPJET: employs phase-space slicing method, calculations in $\overline{\text{MS}}$ scheme
- $O(\alpha_s^2)$: NLO for incl. jet and dijets, LO for three-jets
- Number of flavours: 5
- $\mu_R = \mu_f = Q$, M_W = 80.40 GeV, M_Z = 91.188 GeV, $\alpha_s(MZ)$ = 0.118 (two loop accuracy)
- PDFs: ZEUS-S parametrisation (CTEQ6 / MRST2001)
- Calculated cross sections corrected for hadronisation with bin-by-bin method

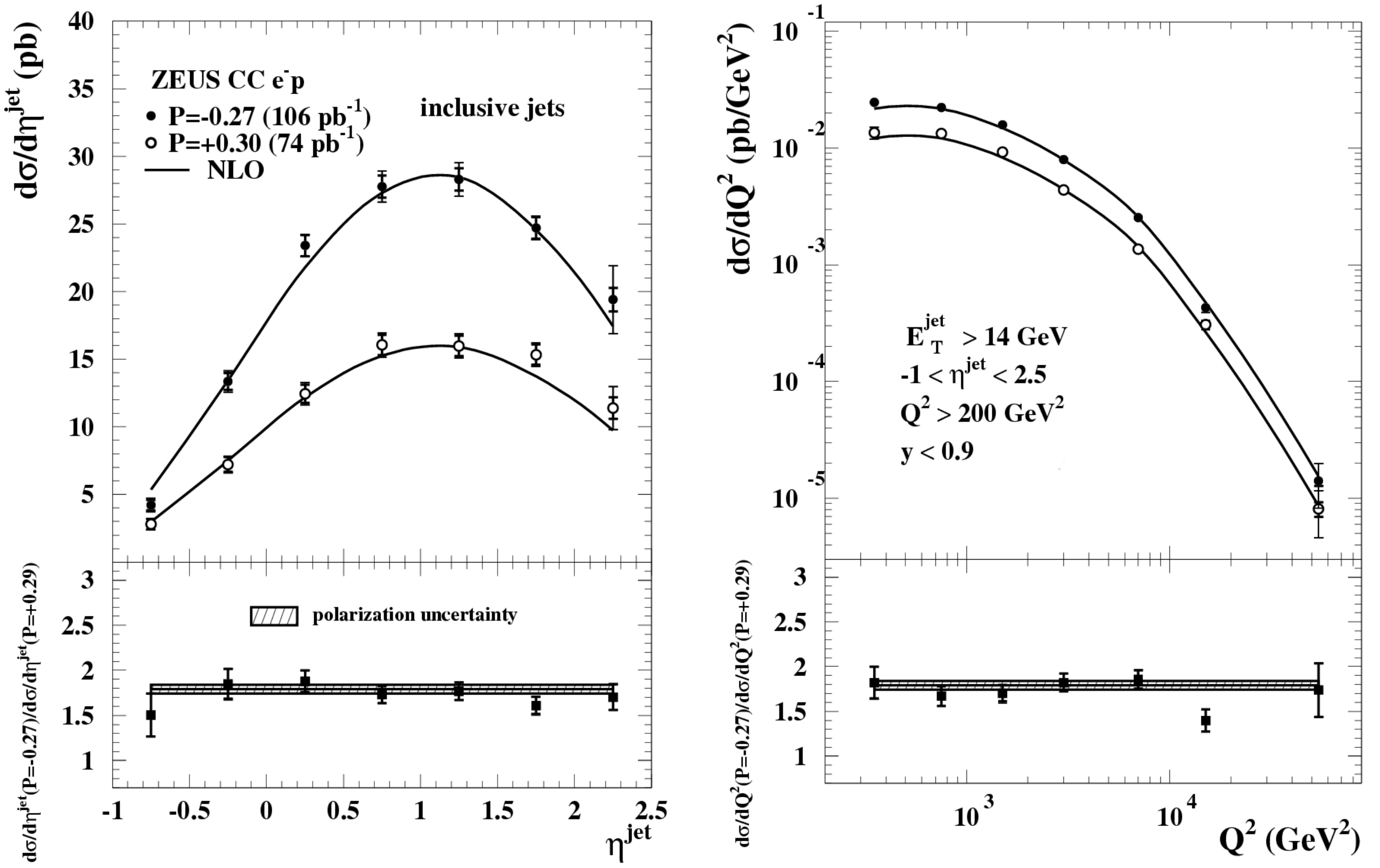
Theoretical uncertainties:

Systematic	Variation	Error (incl, dijet, trijet)
Higher orders	$\mu_R = Q/2$, $\mu_R = 2Q$	< 2%, <5%, 30%
Uncertainty on PDFs	22 additional sets from ZEUS-S	< 4%, <5%, - - - (10%, 15% , - - -)*
Uncertainty on α_s	Two additional sets of PDFs	< 1% ,<1%, - - -
QCD cascade	CDM / MEPS	< 1% ,<1%, - - -
Factorisation scale	$\mu_F = Q/2$, $\mu_F = 2Q$	Negligible

* in high-Q^2, high-E_T and high-x region

- For inclusive-jet and dijet cross sections dominated by uncertainty on PDFs

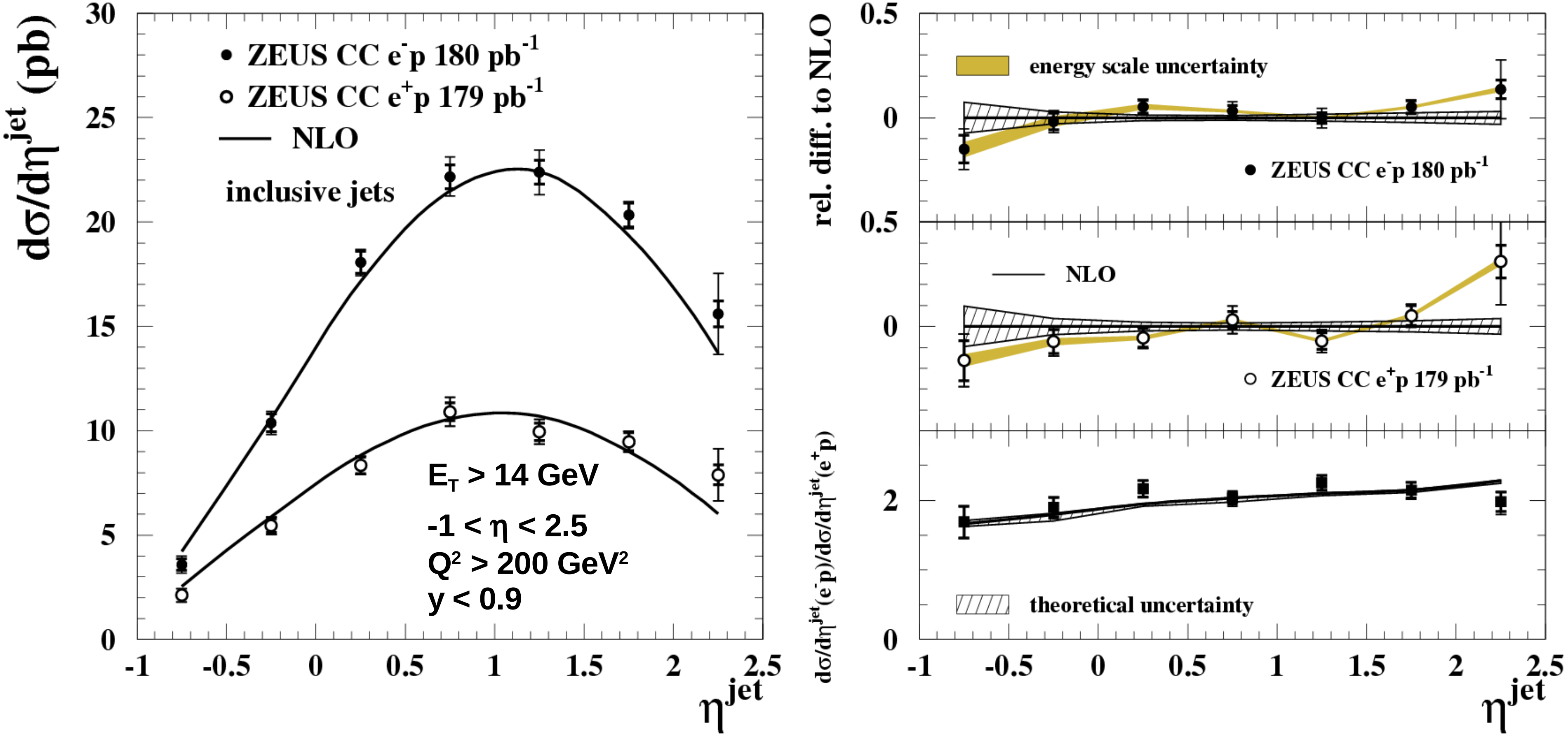
Polarized Inclusive-Jet Cross Sections



$$\frac{(1-P_{e^-}^{\text{neg}})}{(1-P_{e^-}^{\text{pos}})}=\frac{(1+0.27)}{(1-0.3)}=1.79$$

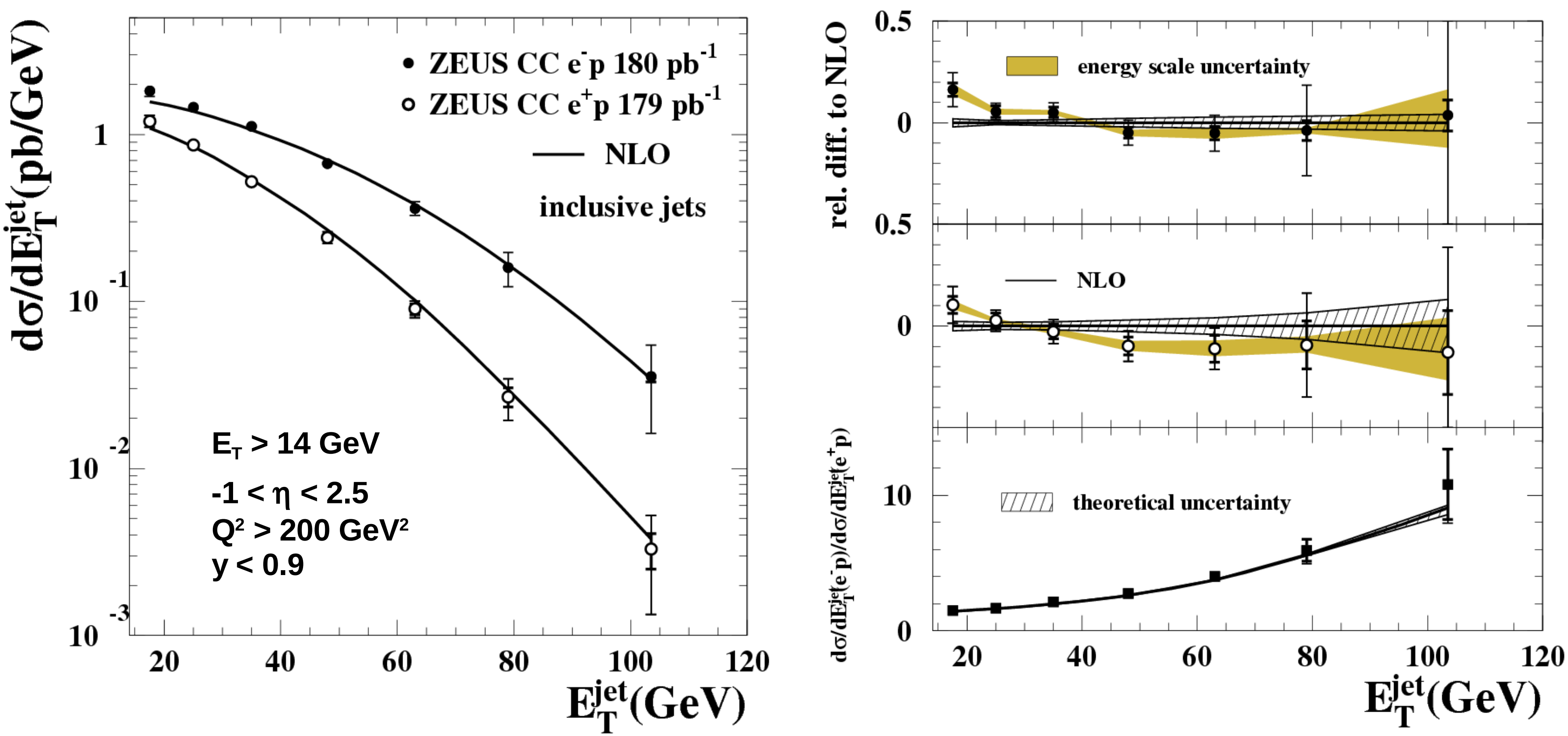
- Good agreement between data and NLO calculation (3 orders of magnitude for Q^2)
- Ratio between negatively and positively polarized cross sections in good agreement with measured polarizations

Unpolarized Inclusive-Jet Cross Section dσ/dη



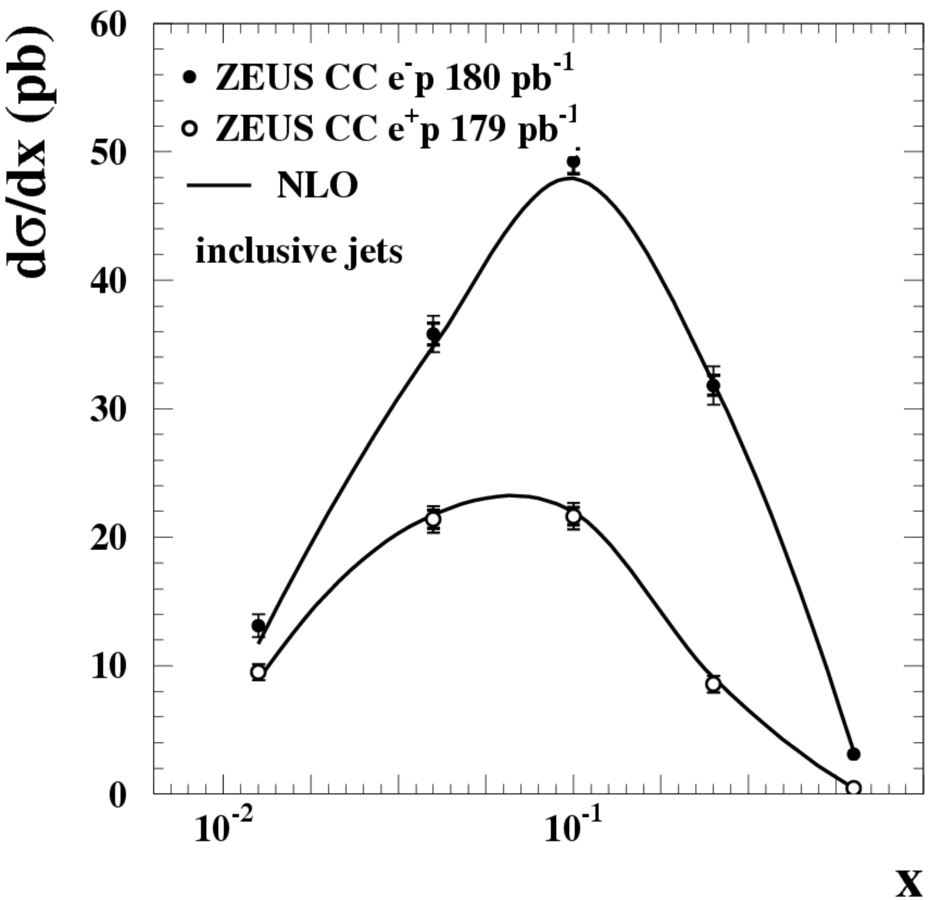
- Reasonable description by the NLO calculation
- Ratio between electron and positron data is ~2 over whole eta range, well described by NLO calculation
- Electron (positron) data probing u-type (d-type) quark density

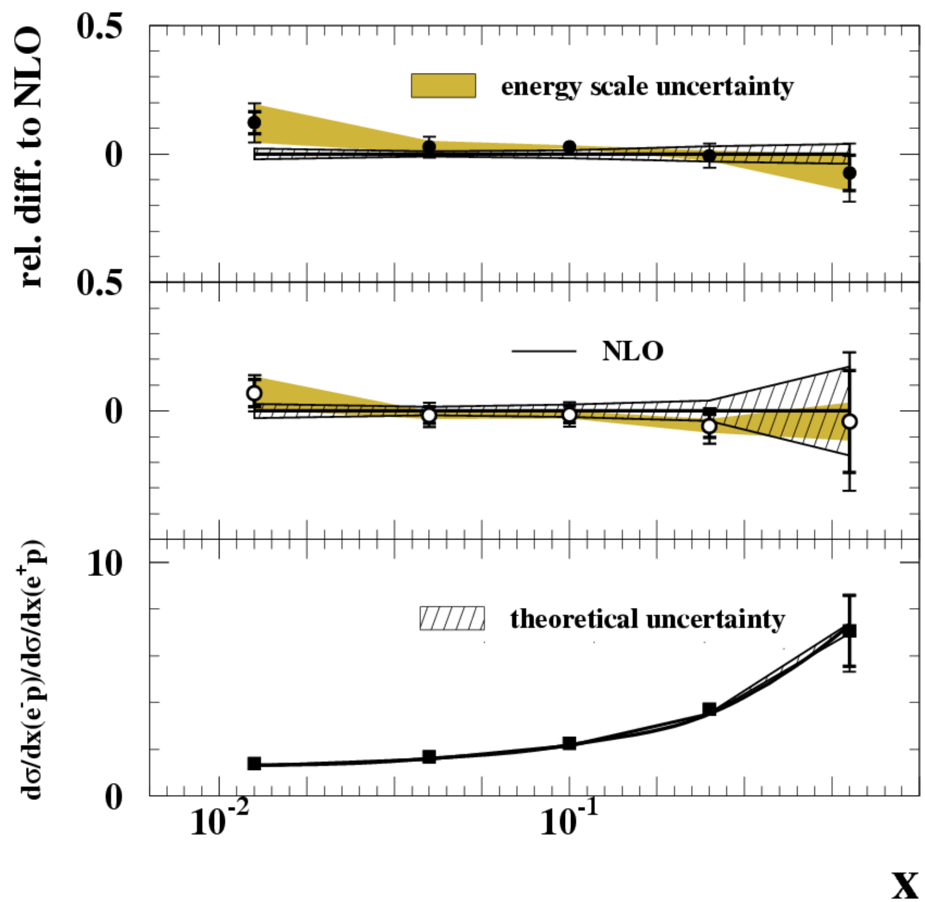
Unpolarized Inclusive-Jet Cross Section $d\sigma/dE_T$



- Values of E_T^{jet} of more than 100 GeV accessible with present statistic
- Fall-off of two (three) orders of magnitude in electron (positron) sample
- Reasonable description of shape and normalization

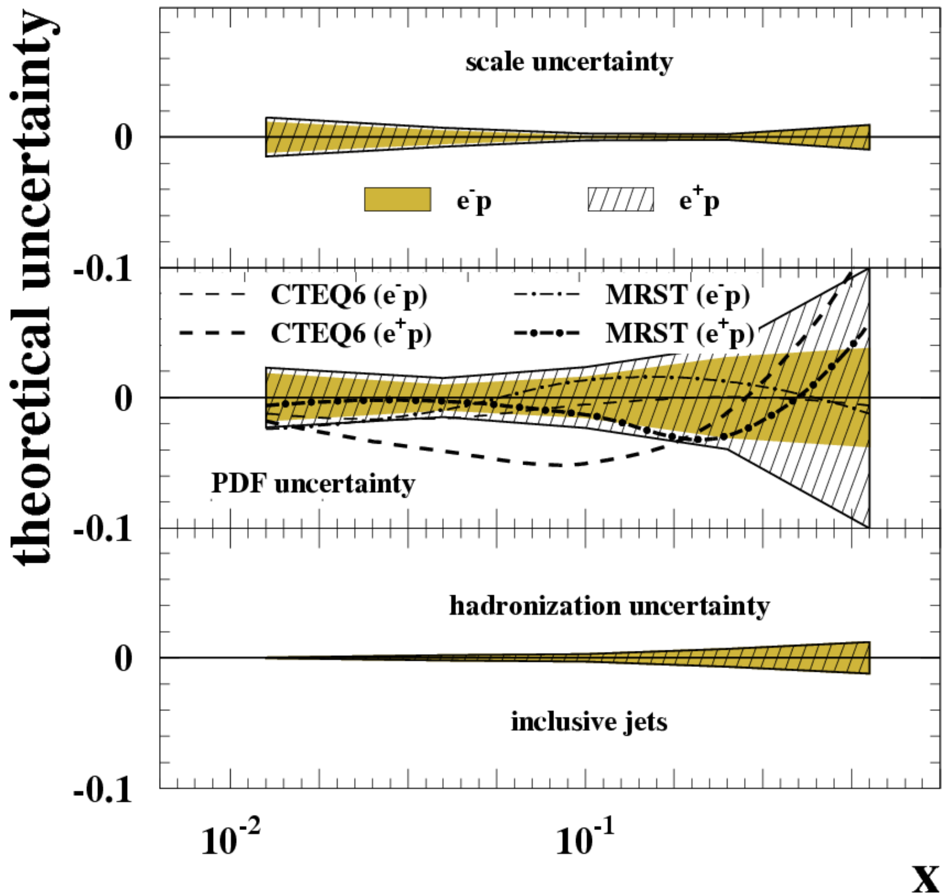
Unpolarized Inclusive-Jet Cross Section dσ/dx

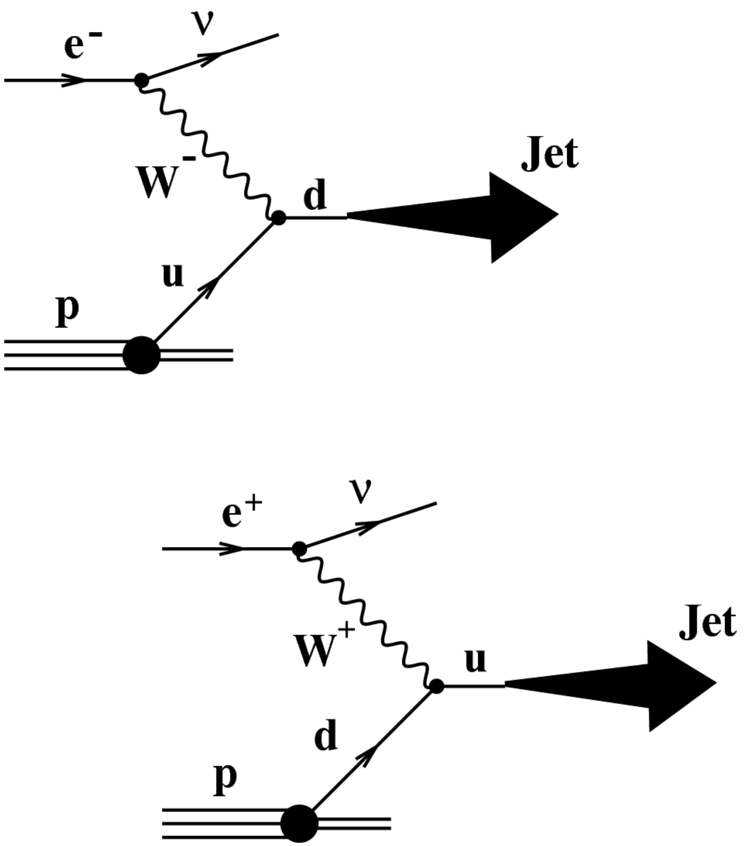




- The values in x accessible by the data are within the range $0.013 < x < 0.63$
- Reasonable description by NLO calculation
- At high x large theoretical uncertainty especially for positron data

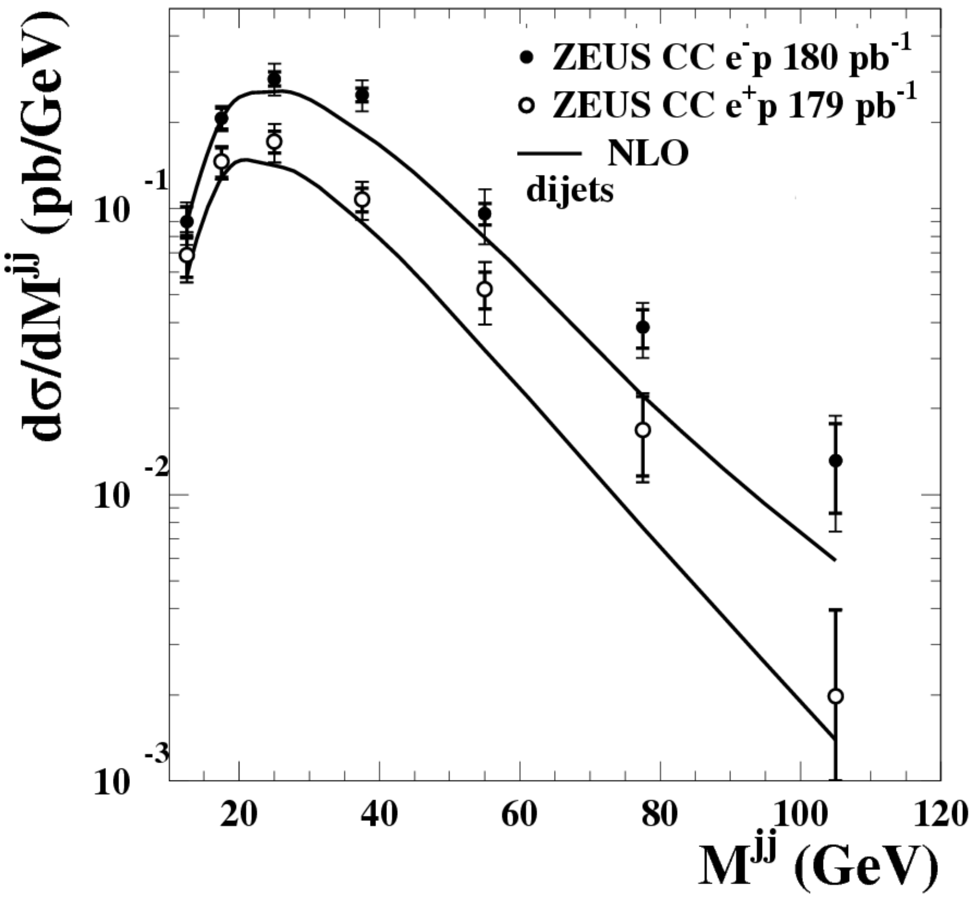
Inclusive-Jet Cross Sections: Theoretical Uncertainties

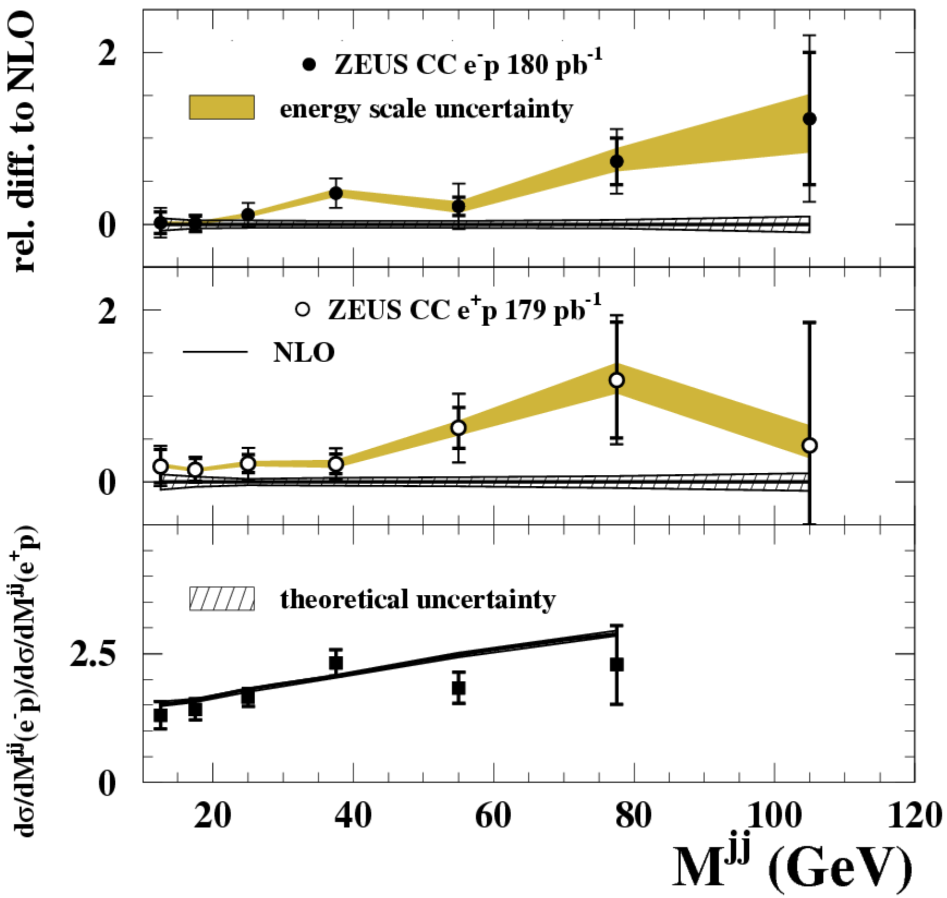




- Theoretical uncertainties dominated by uncertainty on proton PDFs
- Largest uncertainty for positron data at high x: large uncertainty on d-quark density
- Other theoretical uncertainties are small and well under control
- Cross sections have the potential to constrain flavour content of the proton at high *x*

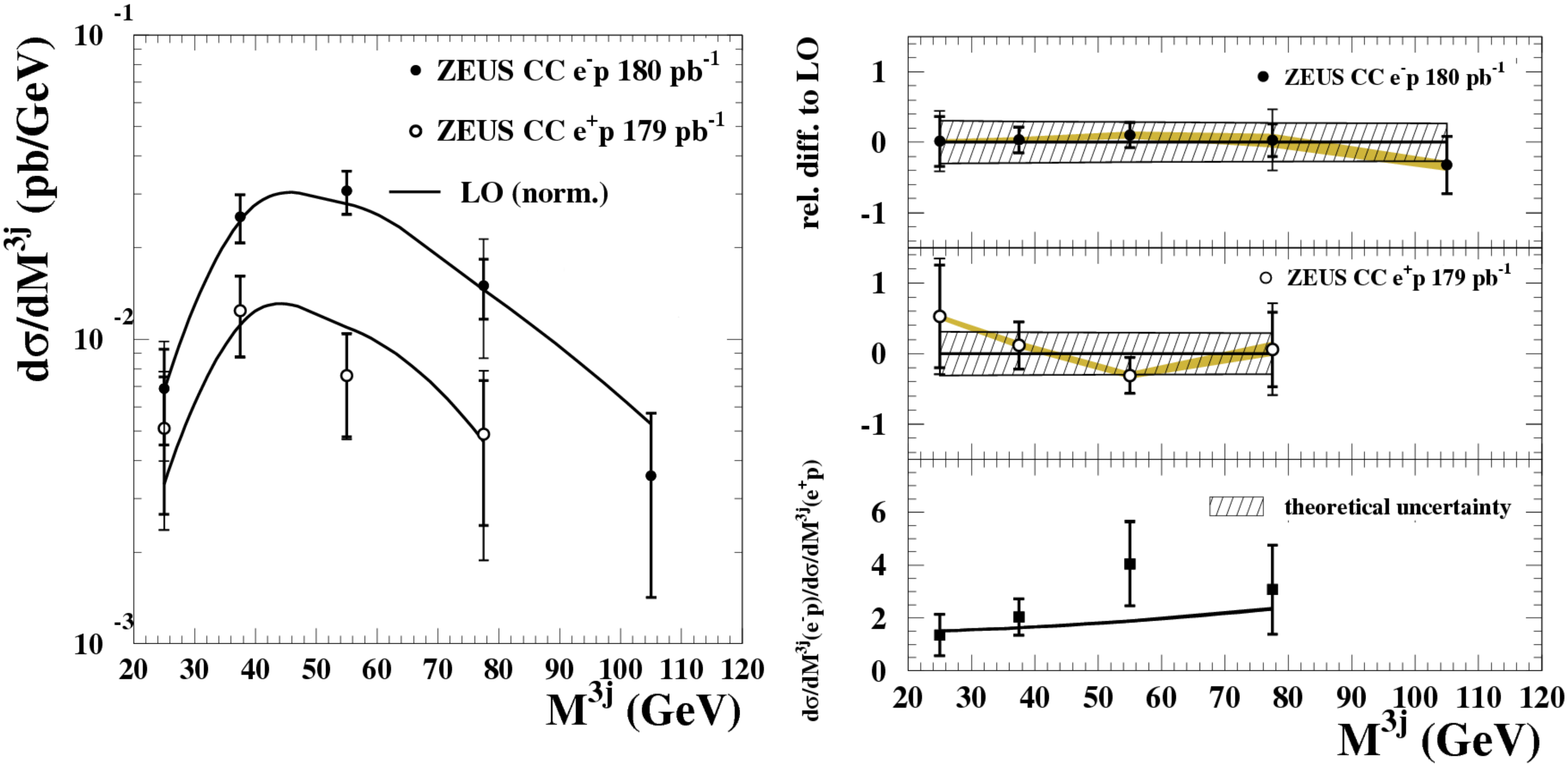
Unpolarized Dijet Cross Section dσ/dM^{jj}





- Reasonable description of ratio between e^-p and e^+p cross sections by the NLO but:
- NLO does not give an adequate description in shape and normalization
- Jet cross sections in NC DIS calculated with MEPJET differ by 5-8% from results of other NLO programs but for CC no alternative to MEPJET
- New implementations of theory needed to use CC dijet cross sections in PDF fits

Unpolarized Three-Jet Cross Section $d\sigma/dM^{3j}$



- First measurement of three-jet events in CC DIS ep collisions
- QCD calculations are LO and can not predict the normalization
- QCD predictions are scaled to reproduce the integrated three-jet cross sections
- Scaled LO calculations give a good description of the shape

Summary

Polarized and unpolarized multi-jet cross sections have been measured in charged current $e^{\pm}$ p DIS using 0.36 fb^{-1} of HERA II data

Polarized incl.-jet cross sections have been measured differentially in η^{jet}, E_t^{jet}, Q^2, *and* x

- Cross sections are in good agreement with SM predictions
- Ratios of differential cross sections for neg. and pos. longitudinally- polarized lepton beams are well described by the predictions

Inclusive-jet cross sections have been measured differentially in η^{jet}, E_T^{jet}, Q^2 and x

- NLO QCD predictions give a good description of the measured cross sections
- Ratio of cross sections for e^-p and e^+p collision is well described
- Theoretical uncertainties are dominated by contribution from PDFs
- Cross sections have the potential to constrain flavor content of the proton at high x

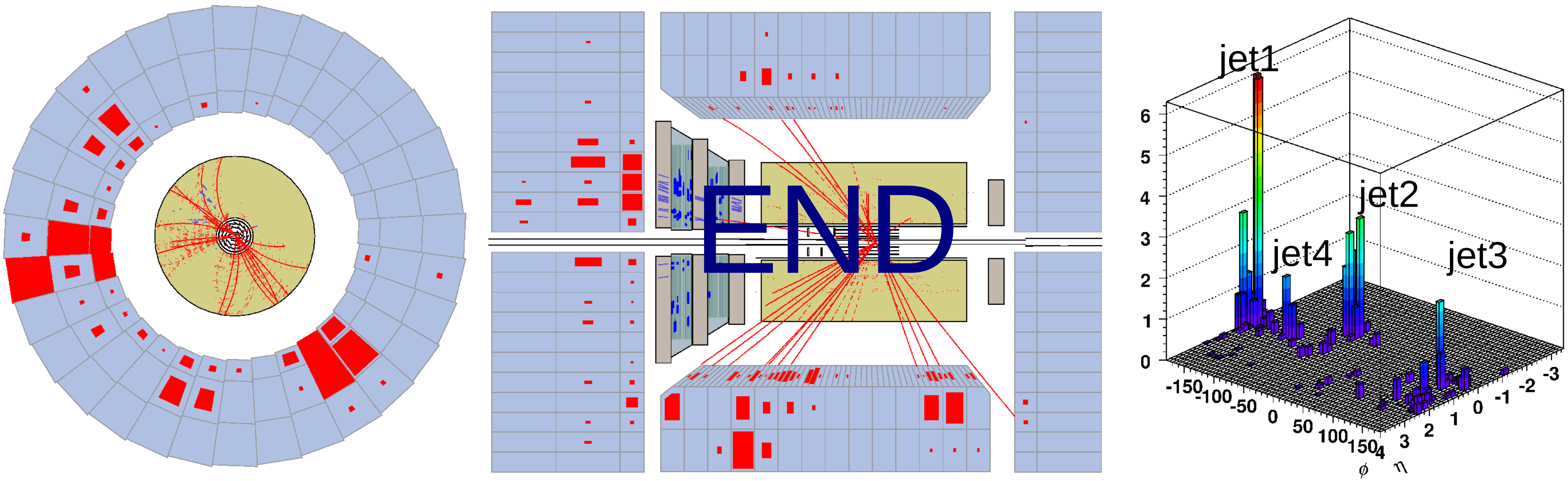
Summary

Dijet cross sections have been measured differentially in $\overline{\eta}$, $\overline{E}_T^{jet}$, M^{jj}, and Q^2

- NLO calculation by MEPJET provides poor description of shape and normalization
- Improved implementations of theory are crucially needed to use dijet cross sections in QCD fits to constrain the proton PDFs

Three-jet cross sections have been measured differentially in $\overline{\eta}$, $\overline{E}_T^{jet}$, M^{3j}, and Q^2

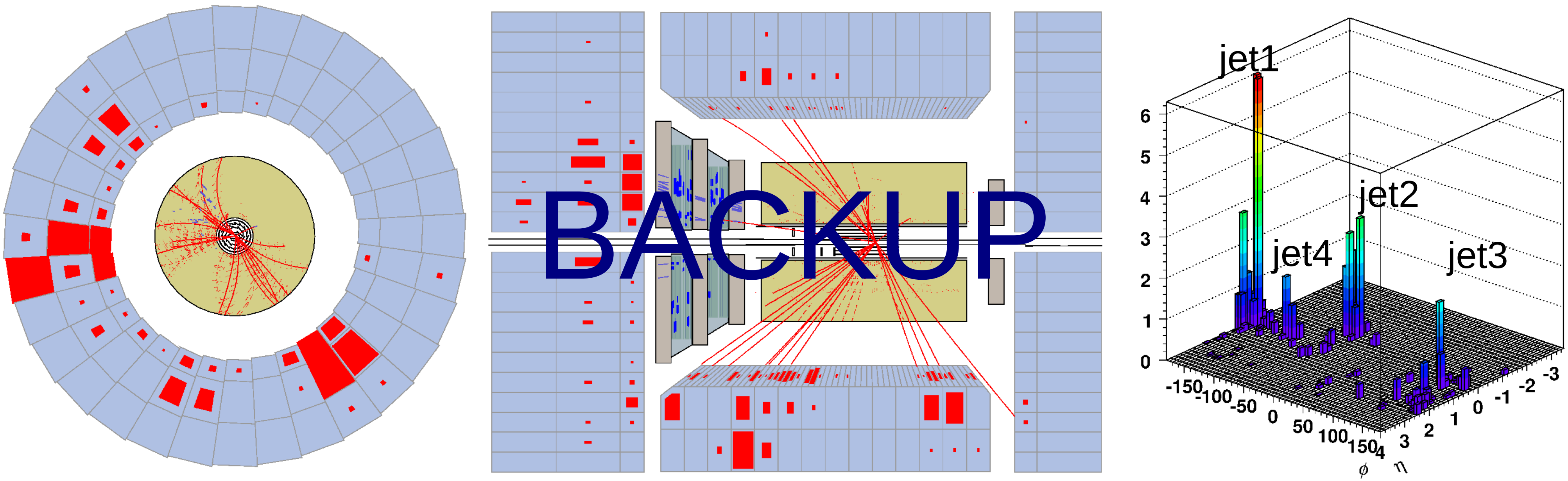
- First measurement of three-jet cross sections in CC ep DIS
- LO QCD calculation by MEPJET gives good description of shape
- 11 three-jet candidates do have 4^{th} jet with $E_T > 5$ GeV


END
jet1
jet2
jet4
jet3
φ
η

Universität Hamburg

ZEUS

BACKUP



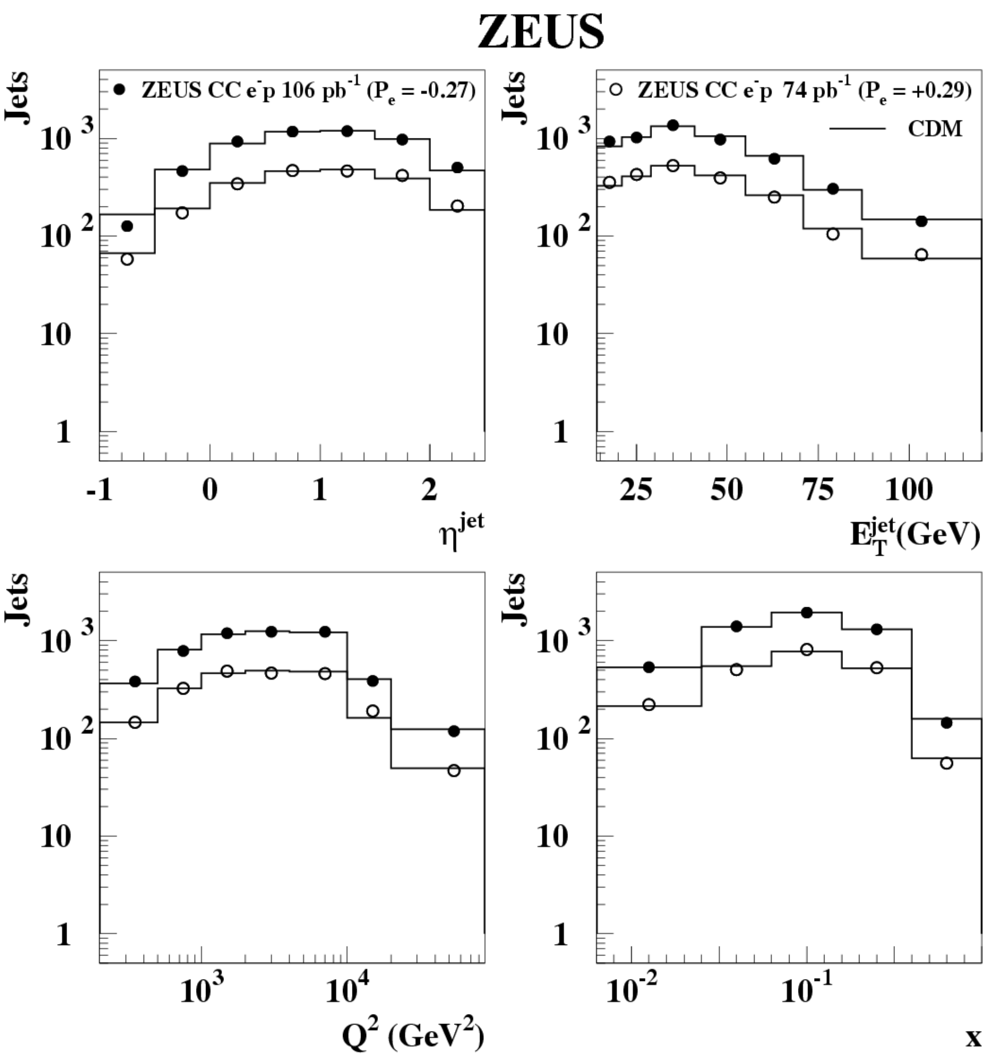
Data Selection

- $p_{T,miss}$ > 11 GeV
- $p_{T,miss} / E_T$ > 0.5: reject photoproduction and beam-gas background
- $-35 < Z_{VTX} < 33$ cm
- At least one track associated with the vertex: reject non ep background
- $\Delta\varphi < 1$ rad (difference between azimuth of net transverse momentum measured by tracks and azimuth measured by CAL): reject random coincidences of cosmic rays and ep interactions
- $\mathbf{p_{T,tracks} / p_{T,miss}}$ > 0.1: reject events with additional energy not related to ep events
- No electron candidate with E' >10 GeV: reject NC DIS
- E_{BHAC2} / E_{BCAL} > 0.5 for E_{BCAL} > 2GeV and

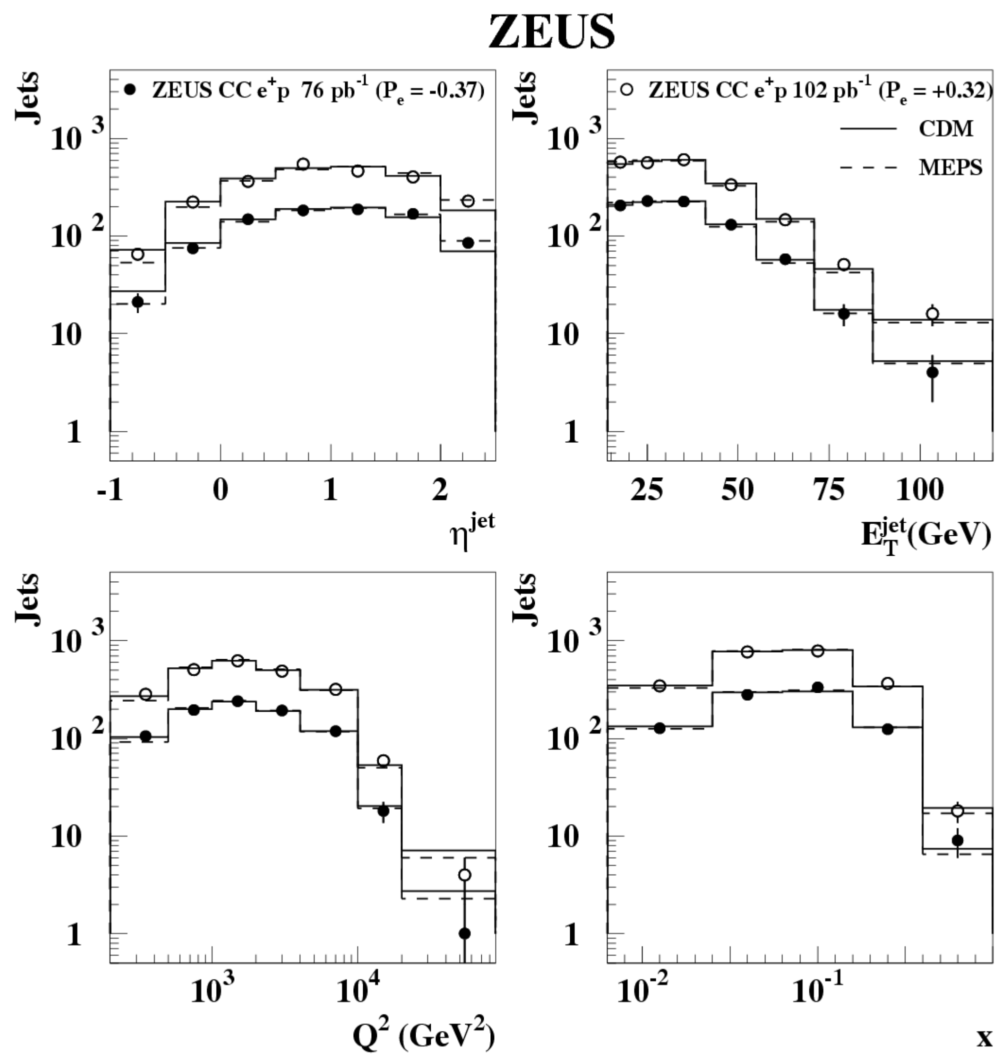
  E_{BHAC1} / E_{BCAL} >0.85 for E_{BCAL} > 8 GeV : reject beam related backgrounds
- No tracking requirement if highest E_T jet had an η>2, $p_{T,miss}$ cut raised to 20GeV
- Q^2 > 200 GeV
- y < 0.9: poor resolution for large values of y

Comparison between Data and MC

Polarized inclusive-jet electron data



Polarized inclusive-jet positron data



Comparison between Data MC

Unpolarized inclusive-jet electron and positron data