ZEUS Forward Jets in DIS

Sabine Lammers
University of Wisconsin
on behalf of the ZEUS Collaboration
DIS03
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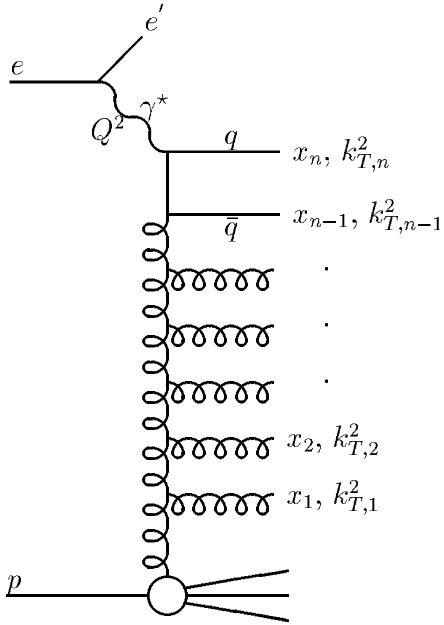


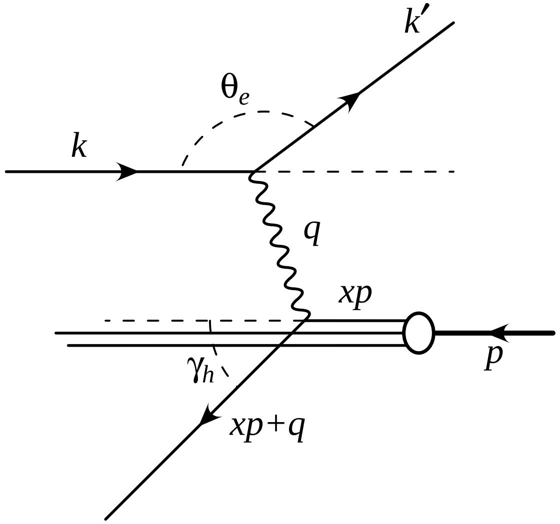
- Theoretical motivation
- NLO successes: F_2 and dijets
- Inclusive Jets
- Conclusions

Deep Inelastic Scattering at HERA

HERA is an electron-proton collider operating at center-of-mass energy $\sqrt{s} \approx 300\, GeV$

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

$$x_{Bj} = \frac{Q^2}{2p \cdot q}$$ fraction of proton's momentum carried by the struck parton



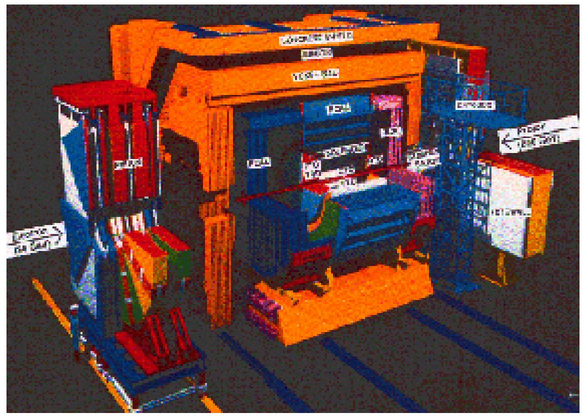
$$y_{Bj} = \frac{p \cdot q}{p \cdot k}$$ fraction of electron's energy transferred to the proton in the proton's rest frame

$$Q^2 = s\, x\, y$$

DIS cross section is an incoherent sum of electron-parton scattering, weighted by parton distribution probabilities.

Proton structure function is a weighted sum of the of the quark densities:

$$F_2(x, Q^2) = \sum_{quarks} A_q(Q^2) \cdot (x\, q(x, Q^2) + x\, \bar{q}(x, Q^2))$$

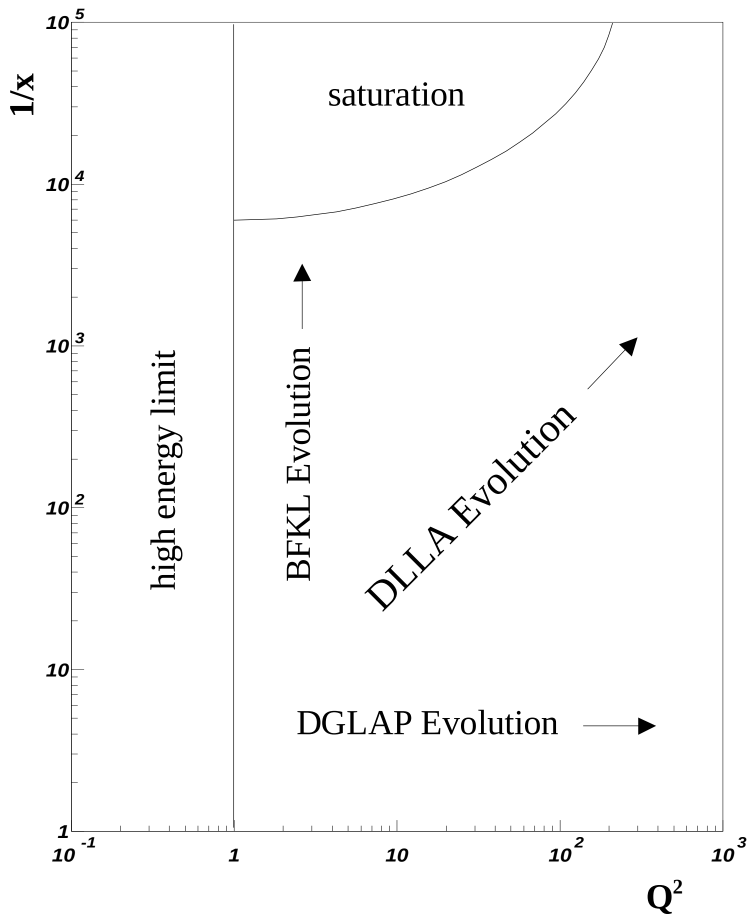


Parton Evolution Schemes

Perturbative expansion of parton evolution equations:

$$\sim A_{mn} (\ln Q^2)^m (\ln \frac{1}{x})^n$$

(can't be calculated)



DGLAP resummation: $\sum (\alpha_s \ln Q^2)^n$

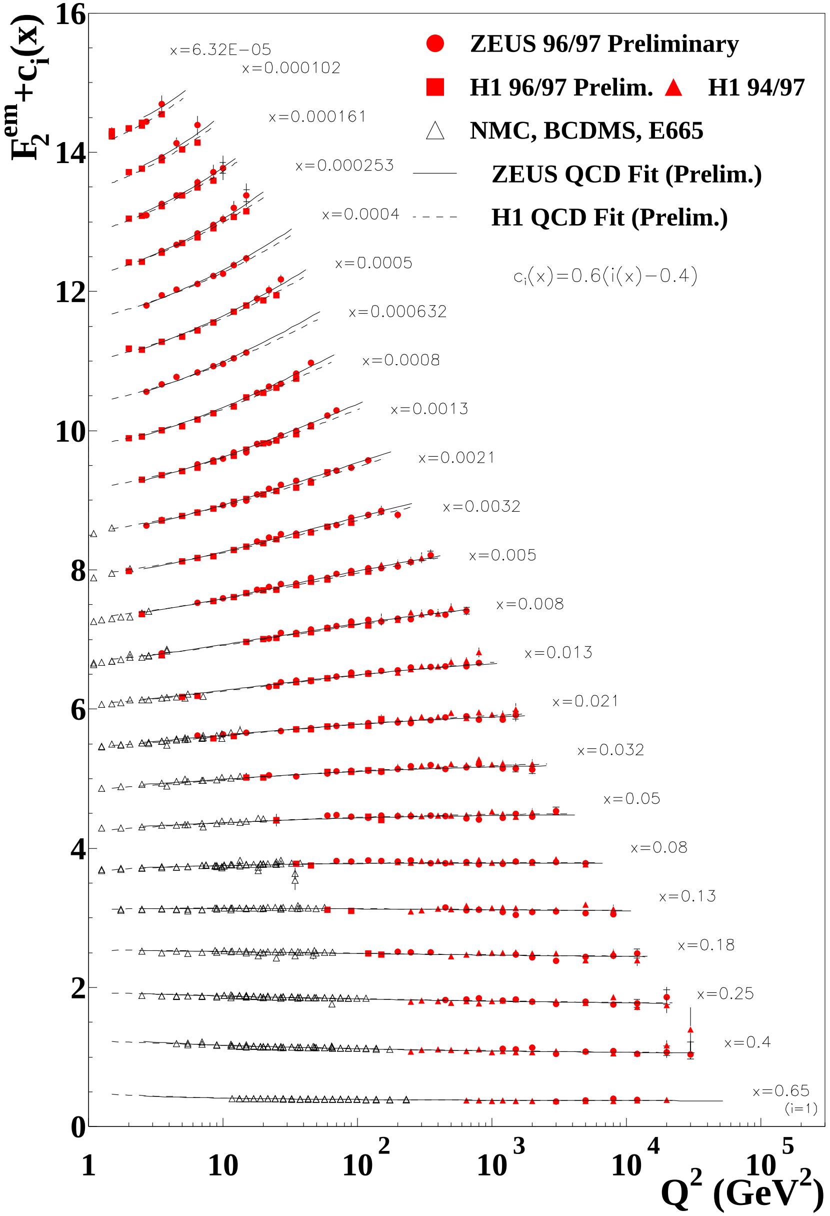
BFKL resummation: $\sum (\alpha_s \ln \frac{1}{x})^n$

QCD alone cannot predict parton densities!
(only evolution of those densities)

Experimental input is needed to determine proton pdf's

- necessary for testing accuracy of QCD description of proton
- proton pdf's important in calculation of hard processes in, e.g. p-p scattering

Proton structure function $F_2(x,Q^2)$

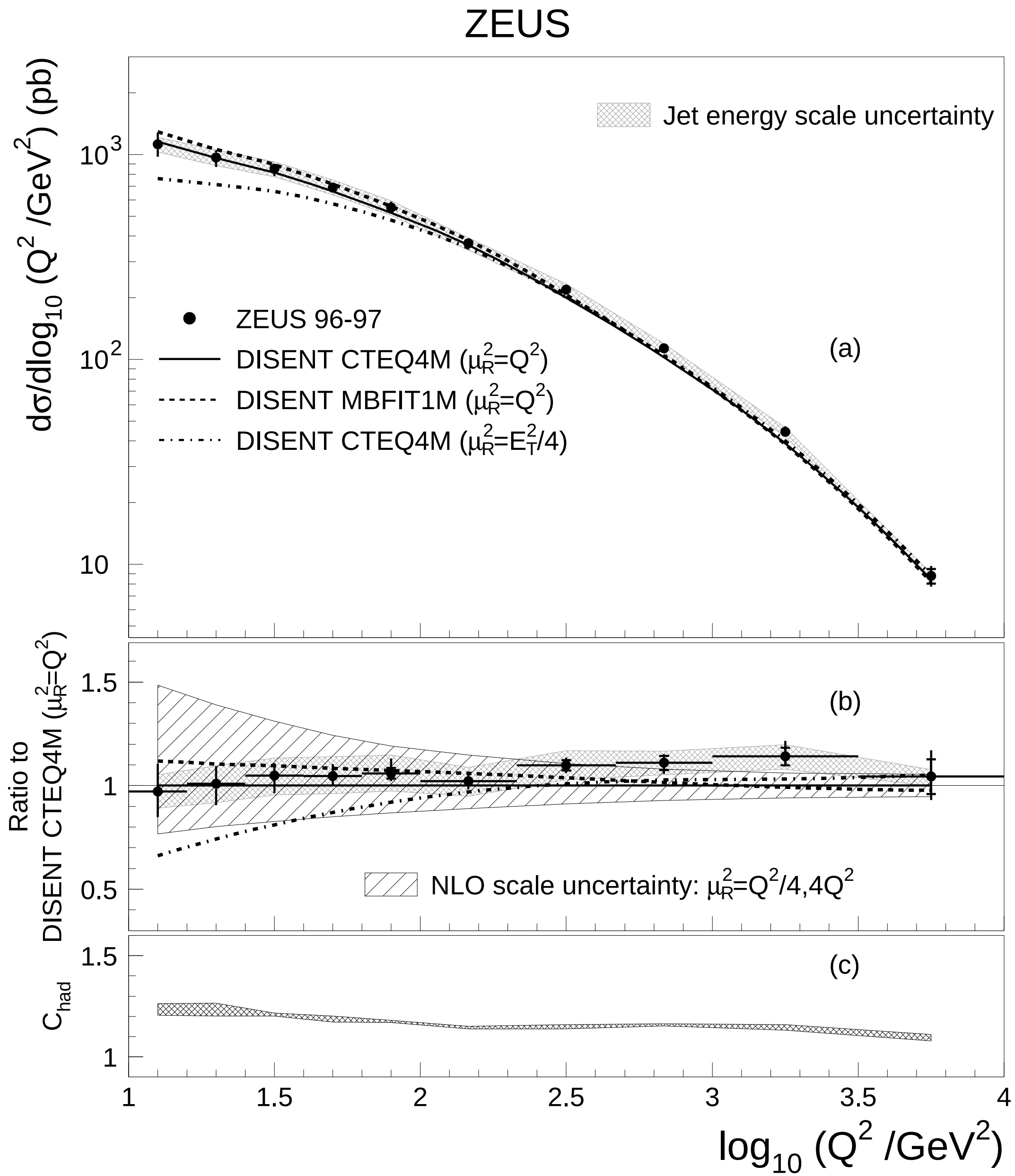


F_2 measured by counting events with an scattered electron at a certain x_{Bj} and Q^2 (fully inclusive measurement)

HERA structure function data perfectly described by parton densities that evolve according to DGLAP equations at next-to-leading order.

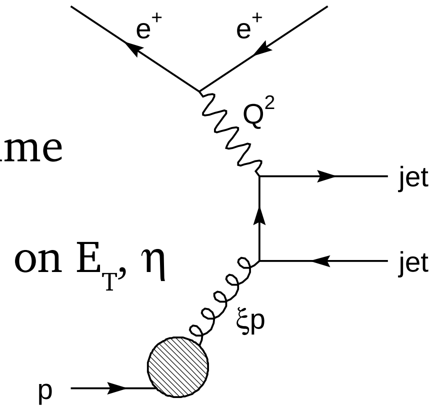
$$6.3 \times 10^{-5} < x_{Bj} < 0.65$$
$$1 < Q^2 < 25000 \text{ GeV}^2$$

Probing the Hadronic Final State: Dijets



Dijets: Boson-gluon fusion and QCD compton diagrams

Jets found
- in Breit frame
- with tight constraints on E_T, η



Proton pdf's extracted from F_2 are used for calculation of dijet production $\rightarrow$ tests universality of proton pdf's

NLO QCD interfaced with pdf's can also describe the dijet data over a large range of Q^2.

Event Signatures: BFKL vs DGLAP

DGLAP and BFKL formalism based on ordering of partons emitted along the parton ladder:

DGLAP:

$x = x_n < x_{n-1} < \ldots < x_1$

$Q^2 = k^2_{T,n} >> \ldots >> k^2_{T,1}$

⇒ forward fadeout

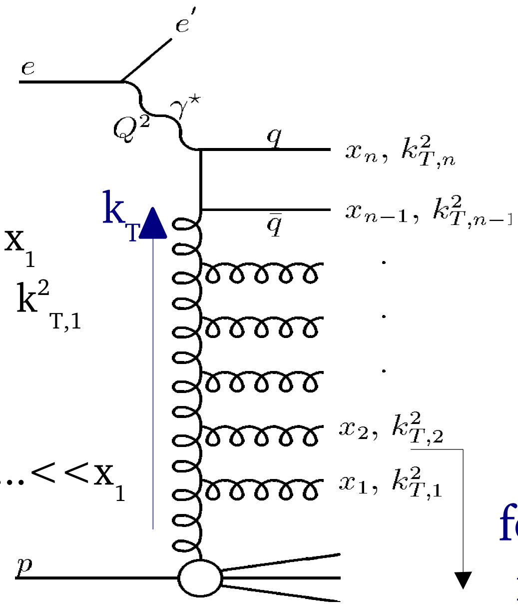
BFKL :

$x = x_n << x_{n-1} << \ldots << x_1$

no k_T ordering

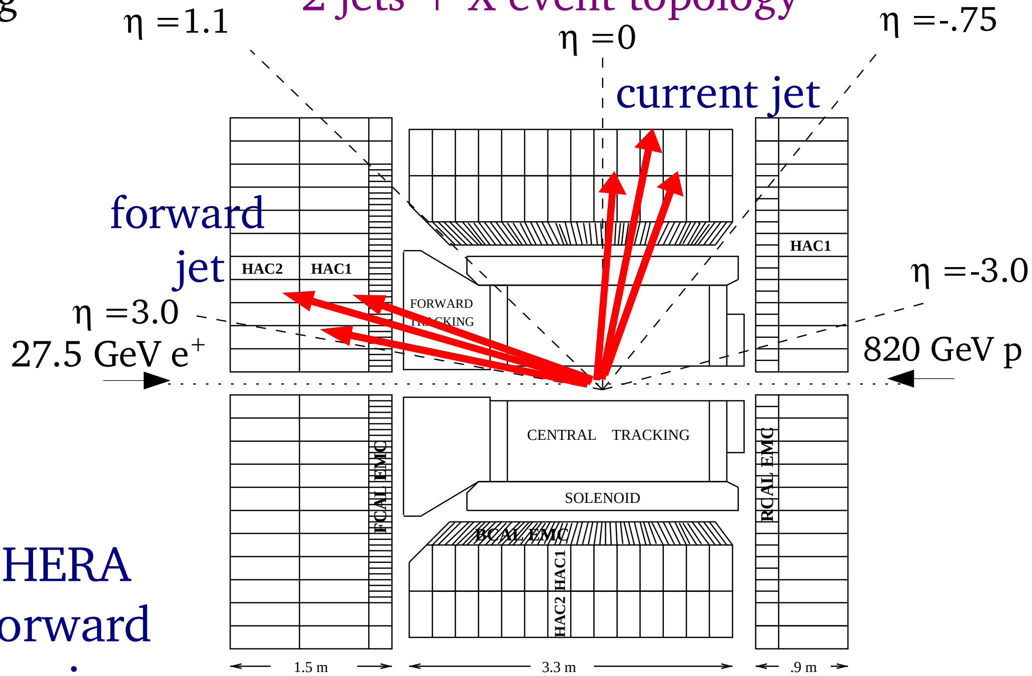
⇒ η democracy

$$\eta = -\ln\left(\tan\frac{\theta}{2}\right)$$



HERA forward region

2 jets + X event topology



hadronic angle $\gamma_h > 90^o$

$$\cos\gamma_h = \frac{(\sum p_x)^2 + (\sum p_y)^2 - (\sum E - p_z)^2}{(\sum p_x)^2 + (\sum p_y)^2 + (\sum E - p_z)^2}$$

Measurement philosophy: Identify BGF type events with a hard forward jet while remaining as inclusive as possible in order to make a good comparison with NLO.

First proposed by Mueller, Navalet

A requirement on the hadronic angle (current jet) allows the exploration of lower x_{Bj}

Event Selection

Data Set: ZEUS 96/97 ($\sim$38.6 pb^{-1})

Monte Carlo: Detector acceptance estimated with LO Color Dipole Model (CDM) implemented with Ariadne, using CTEQ4M PDFs

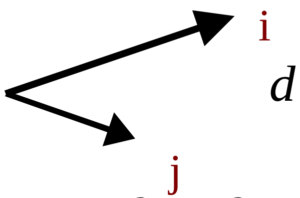
Phase space selection:

- $Q^2 > 25$ GeV
- $y > 0.04$
- $E_{T,jet} > 6$ GeV
- $-1 < \eta_{jet} < 3$ $\quad \eta = -\ln(\tan\frac{\theta}{2})$

DIS selection made by requesting high-energy positron in the final state with additional cuts applied to reject background.

Jets are selected in the lab frame using the longitudinally invariant k_T-cluster algorithm:

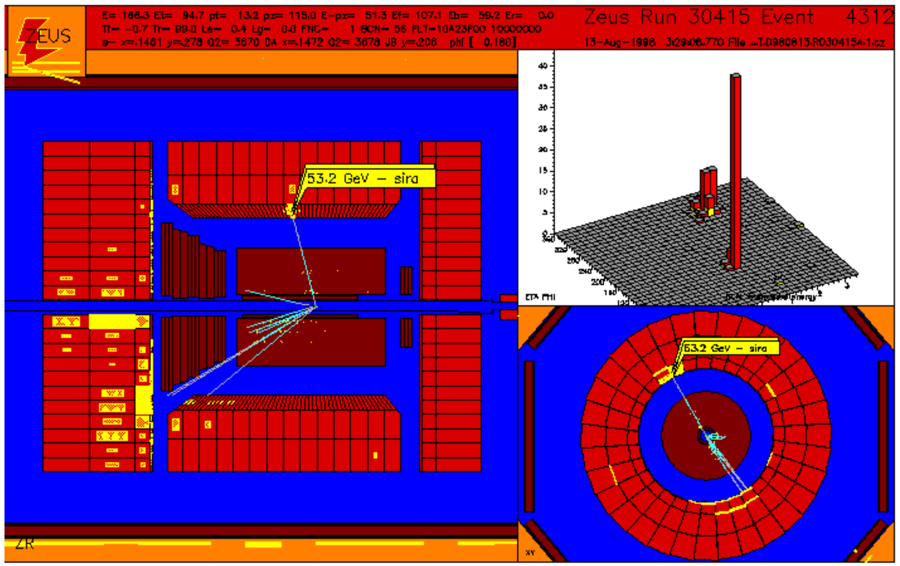
Catani et.al.; Ellis & Soper



$$d_i = E_{T,i}^2$$

$$d_{i,j} = min(E_{T,i}^{2}, E_{T,j}^{2})[\Delta\eta^2 + \Delta\phi^2]$$

Combine particles i and j into a jet if $d_{i,j}$ is smaller of $\{d_i, d_{i,j}\}$.



Leading Order Monte Carlos

- Parton Distribution Function → CTEQ4M
- LO QCD Matrix Elements → hard subprocess
- Parton Showering } model-dependent
- Hadronisation

LEPTO

- Parton showering a la DGLAP
- Lund String Model

ARIADNE

- Parton showering with CDM
  (Color Dipole Model: BFKL-like)
- Lund String Model

NLO Calculations

2 implementations of NLO calculation by DISENT

<u>Inclusive Jet (QPM) Phase Space</u>

$$d\sigma_{LO} = A_0$$

$$d\sigma_{NLO} = A_1 + B_1 \alpha_s^1$$

<u>QPM Suppressed (Dijet) Phase Space</u>

$$d\sigma_{LO} = C_1 \alpha_s^1$$

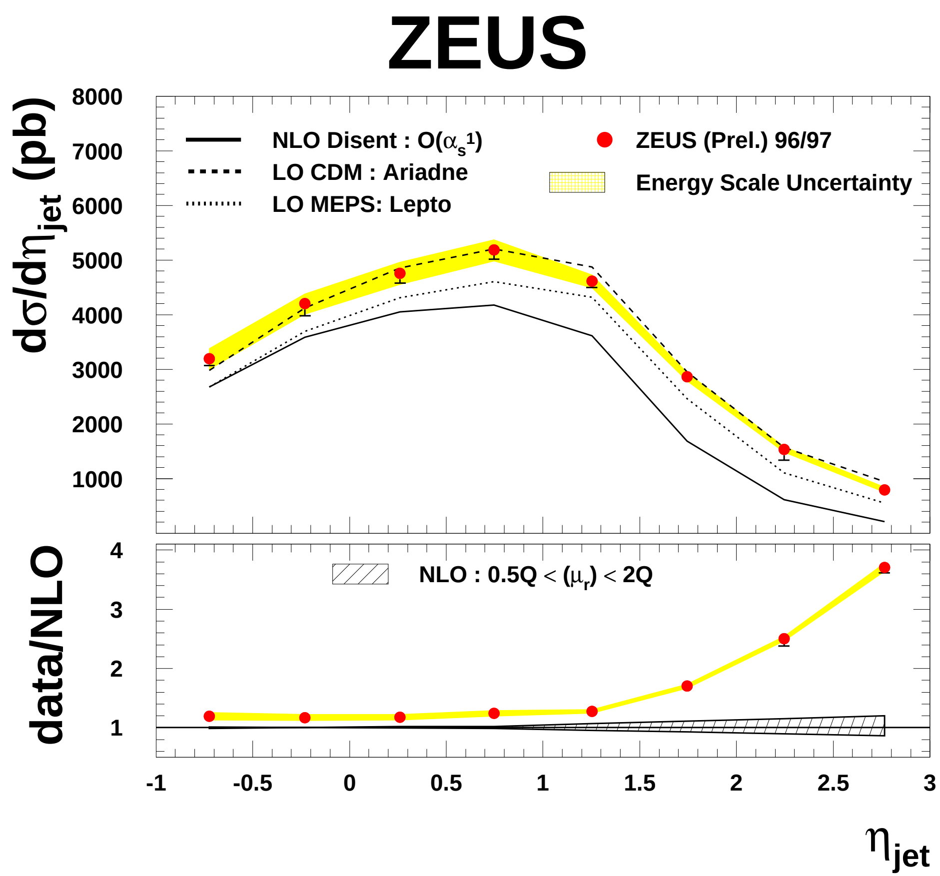
$$d\sigma_{NLO} = C_2 \alpha_s^1 + D_2 \alpha_s^2$$

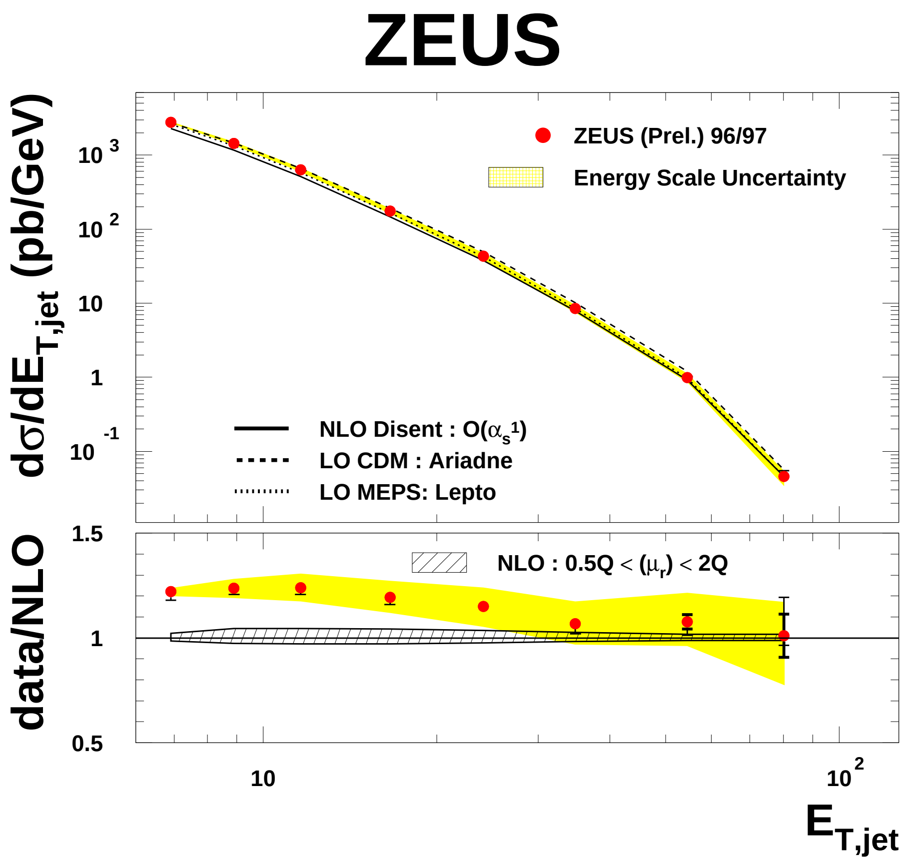
- employs subtraction method
- $\mu_r = \mu_f = Q$
- estimated renormalisation scale uncertainty: $\frac{Q}{2} < \mu_r < 2Q$
- PDF : MRST99
- corrected from partons to hadrons using Ariadne (CDM MC)

Measurement of hadronic cross sections for **inclusive** jet production: $d\sigma/d\eta_{jet}$, $d\sigma/dE_{T,jet}$

DISENT implementation of NLO calculation
LO = $O(\alpha_s^0)$; NLO = $O(\alpha_s^1)$
MRST99 PDF's

Data corrected for ISR/FSR effects

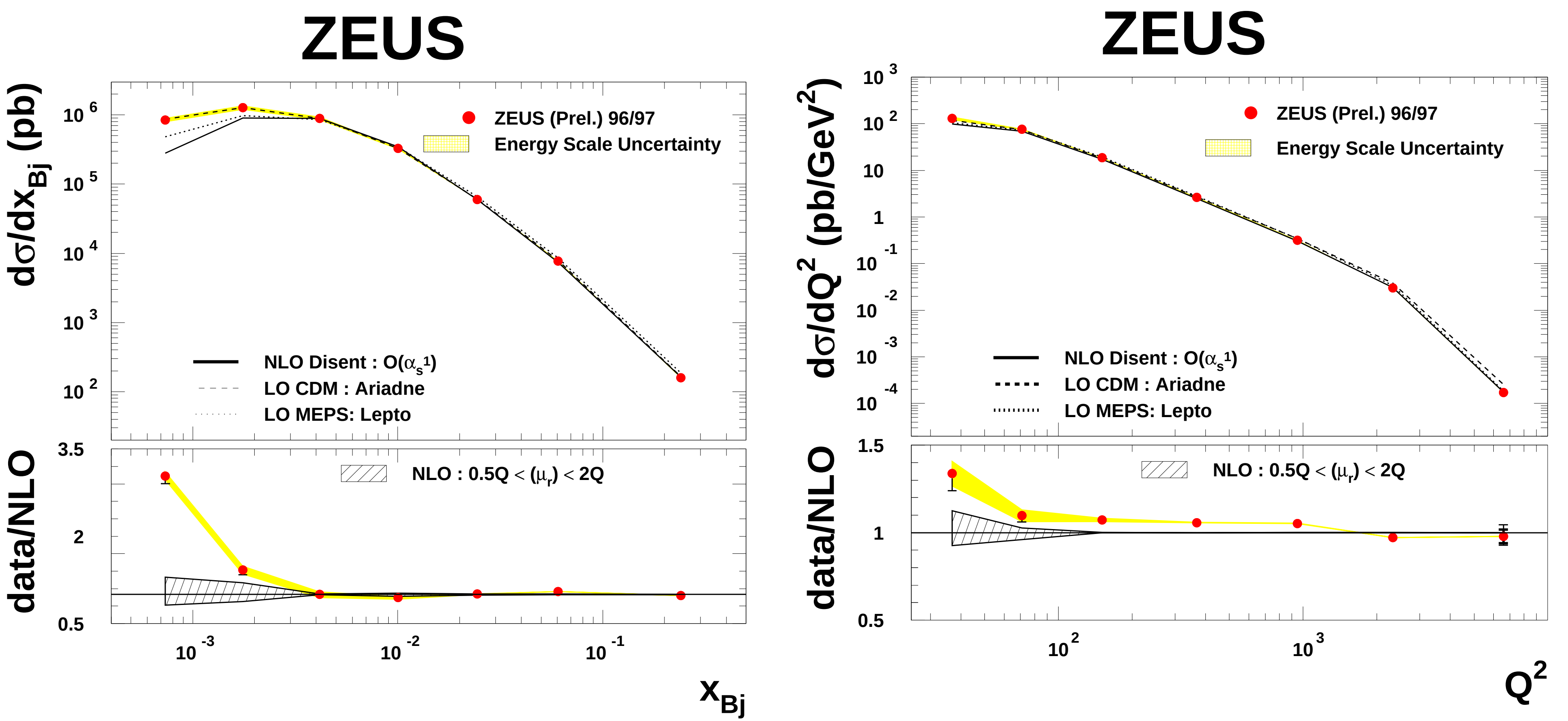




Cross sections dominated by
Quark Parton Model (QPM) events

Differential cross sections in kinematic quantities:
$d\sigma / d x_{Bj}$, $d\sigma / dQ^2$

Large discrepancy in the forward and central regions of the detector are localized in the smallest x_{Bj} values.



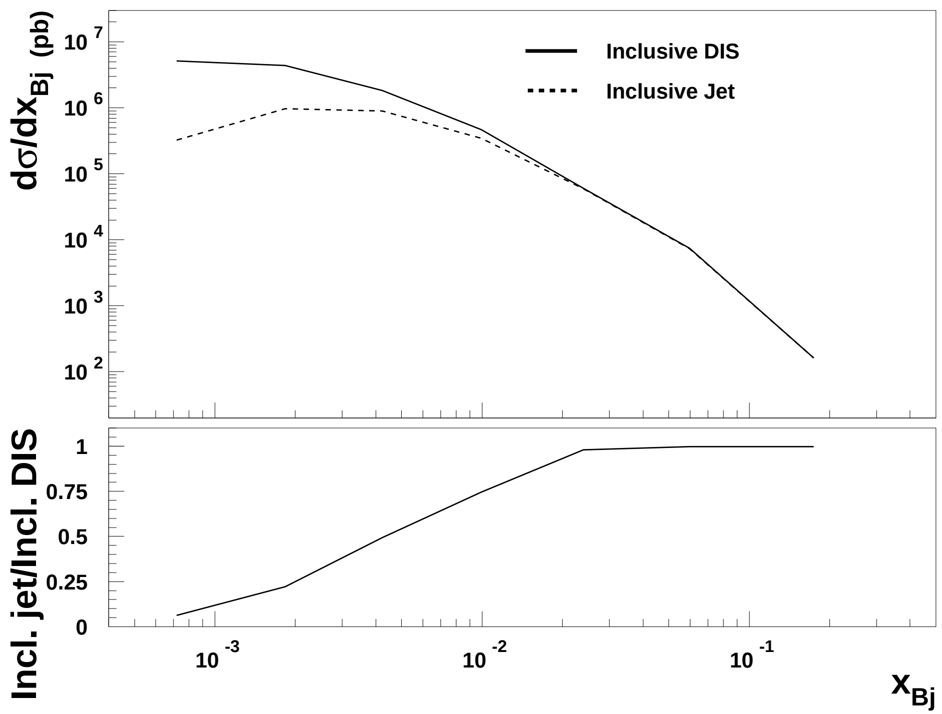
Comparison with totally inclusive cross section

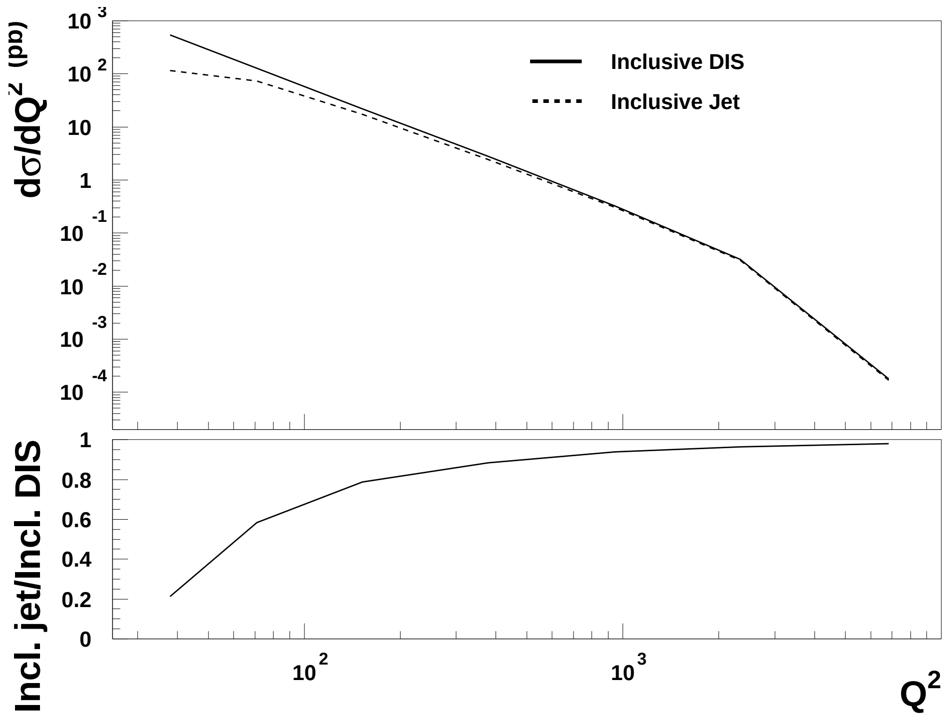
Inclusive jet phase space

- $Q^2 > 25\ \text{GeV}^2$
- $y > 0.04$
- $E_{T,jet} > 6$ GeV
- $-1 < \eta_{jet} < 3$

Fully inclusive DIS phase space

- $Q^2 > 25\ \text{GeV}^2$
- $y > 0.04$





Introducing a hard cut-off in the jet E_T significantly limits the phase space

$\Rightarrow$ inclusive jet cross section does not dominate "F_2" at low x_{Bj} and Q^2

Redefinition of phase space

Inclusive Jet Phase Space

- $Q^2 > 25$ GeV
- $y > 0.04$
- $E_{T,jet} > 6$ GeV
- $-1 < \eta_{jet} < 3$

to suppress QPM →

"Dijet" Phase Space

- $Q^2 > 25$ GeV
- $y > 0.04$
- $E_{T,jet} > 6$ GeV
- $0 < \eta_{jet} < 3$
- $\cos(\gamma_{had}) < 0.0$

Disent Calculations:

$LO = O(\alpha_s^0) = QPM$ →

$NLO = QPM + corrections$ →

with hadronic angle requirement

$QPM = 0$ for $\eta > 0$ →

$BGF + QCDC$ for $\eta > 0$ →

Just 1 order in the series of α_s

Disent Calculations:

$LO = O(\alpha_s^1) = BGF + QCDC$

$NLO = O(\alpha_s^2) = BGF + QCDC + corrections$

2 orders in the series of α_s

2 orders in the series of α_s

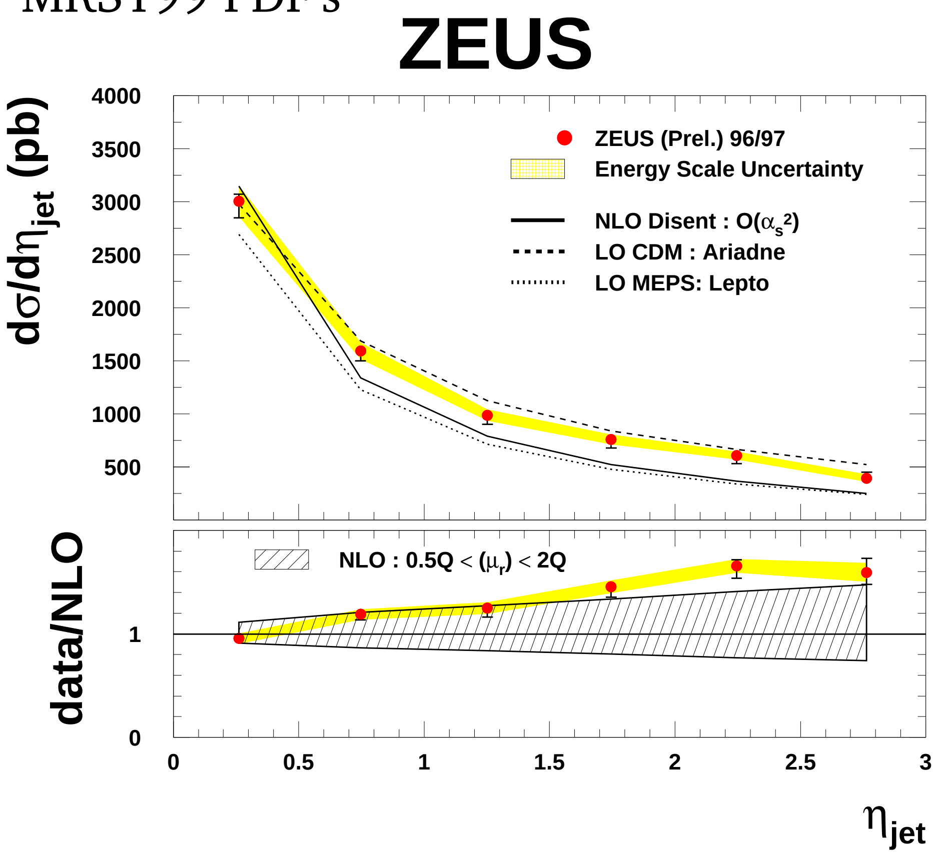
Measurement of $d\sigma/d\eta_{jet}$, $d\sigma/dE_{T,jet}$ for inclusive jets with $\cos\gamma_h < 0$

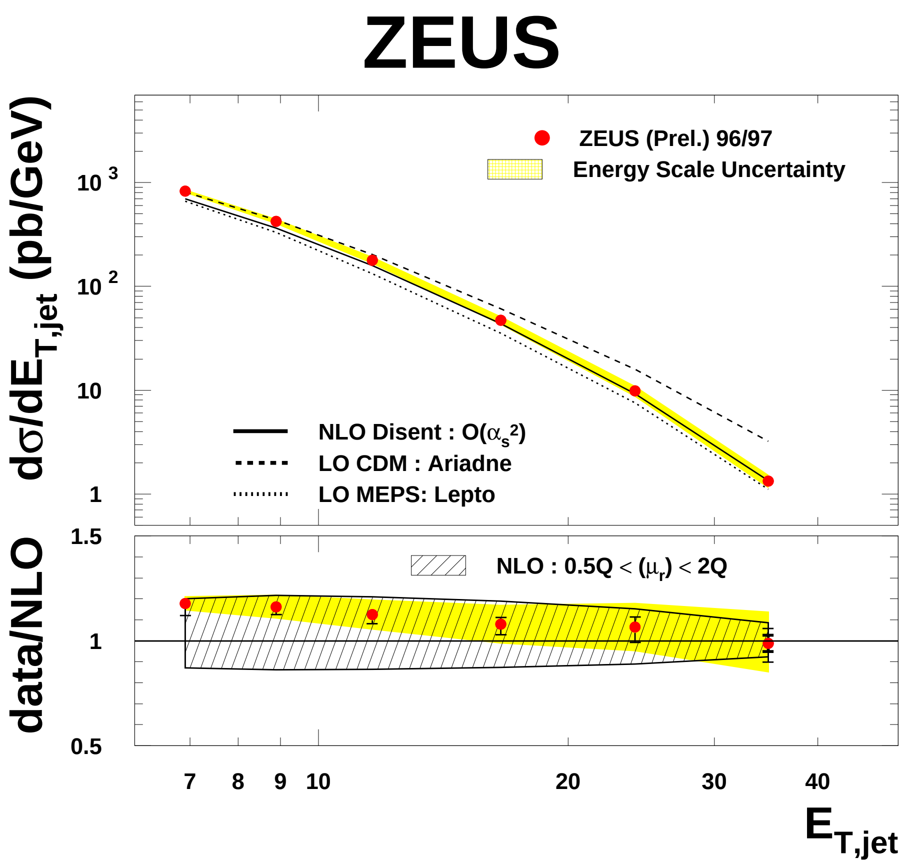
DISENT implementation of NLO calculation

LO = $O(\alpha_s^{\ 1})$; NLO = $O(\alpha_s^{\ 2})$

MRST99 PDF's

" Dijet" Phase Space

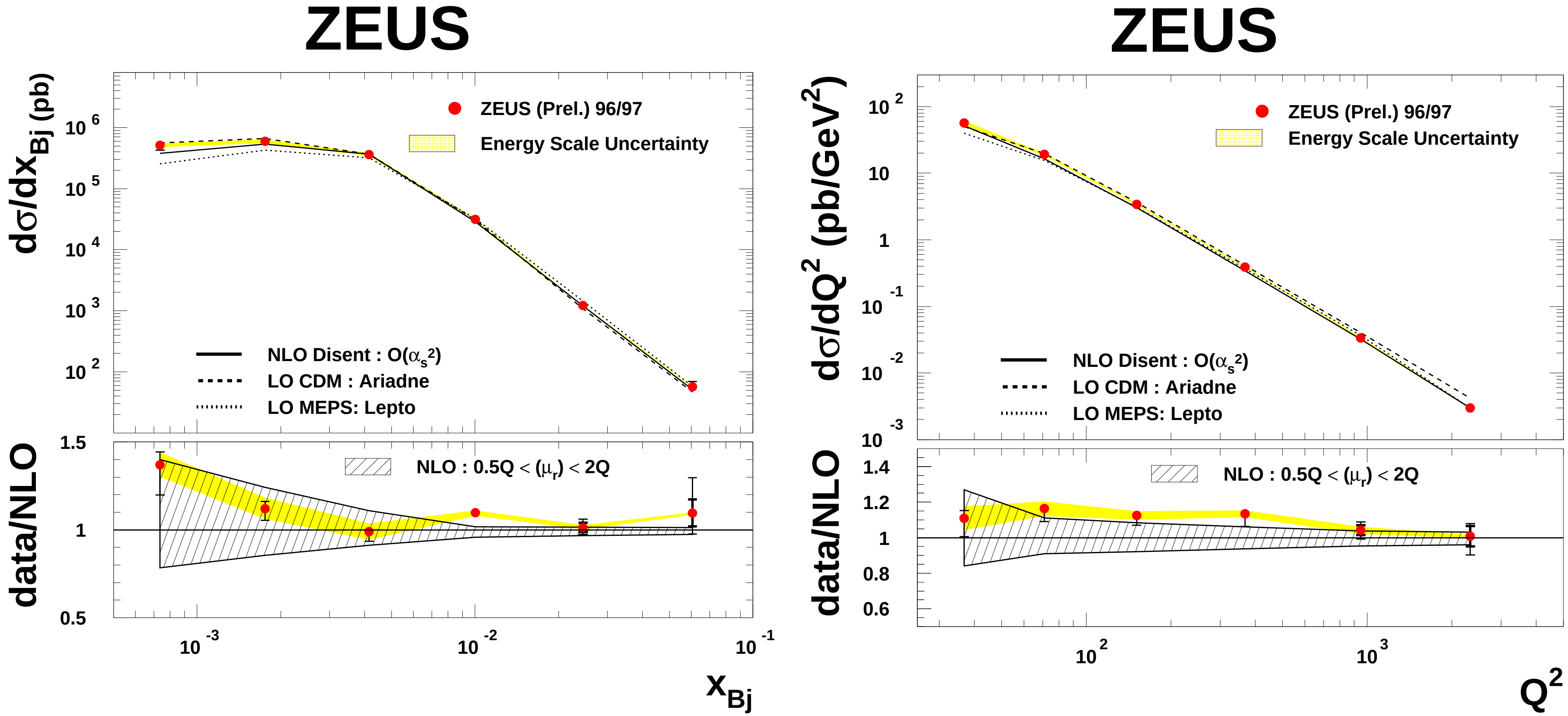




NLO agrees with data within larger renormalization scale uncertainty

Measurement of $d\sigma / dx_{Bj}$, $d\sigma / dQ^2$ with $\cos\gamma_h < 0$

" Dijet" Phase Space



NLO agrees with data

Large renormalization scale dependence => higher orders contribute!

Conclusions

Summary:

- Inclusive jet cross sections at $Q^2 > 25$ GeV^2 have been measured over the full rapidity acceptance region;
- NLO QCD fails to describe the inclusive jet rate in central and forward (proton direction) regions of the detector;
  - ➔ discrepancy between data and theory is localized in low x_{Bj} region

  Measurements have been made in a region $\cos\gamma_h < 0$ so as

  to suppress the contribution from the quark-parton-model process in the forward region;
  - ➔ NLO QCD calculations are consistent with the data albeit with still sizeable theoretical uncertainties;
  - ➔ a much better description of the measured inclusive jet rate at low x_{Bj} by the calculations is obtained
- Large renormalization scale uncertainty swamps any possible signal for BFKL in this region of phase space.