Forward Jets with the CAL

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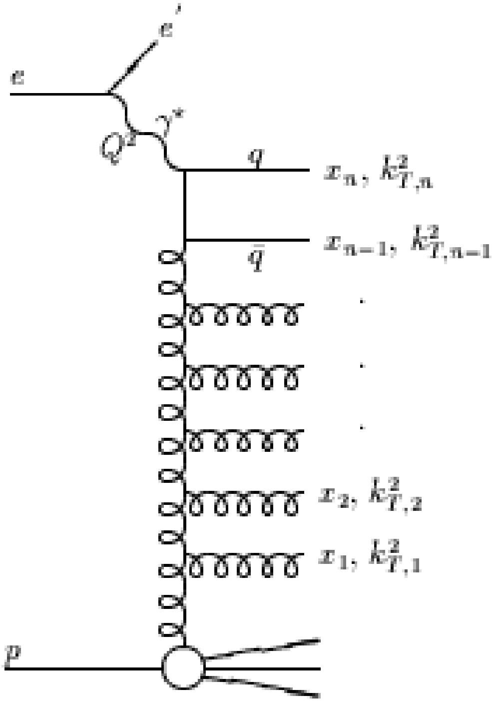
ZEUS Collaboration Meeting



- Motivation
- Event Selection
- Monte Carlo Programs
- Forward Jet Measurements
- Summary and Plans

Parton Evolution Schemes

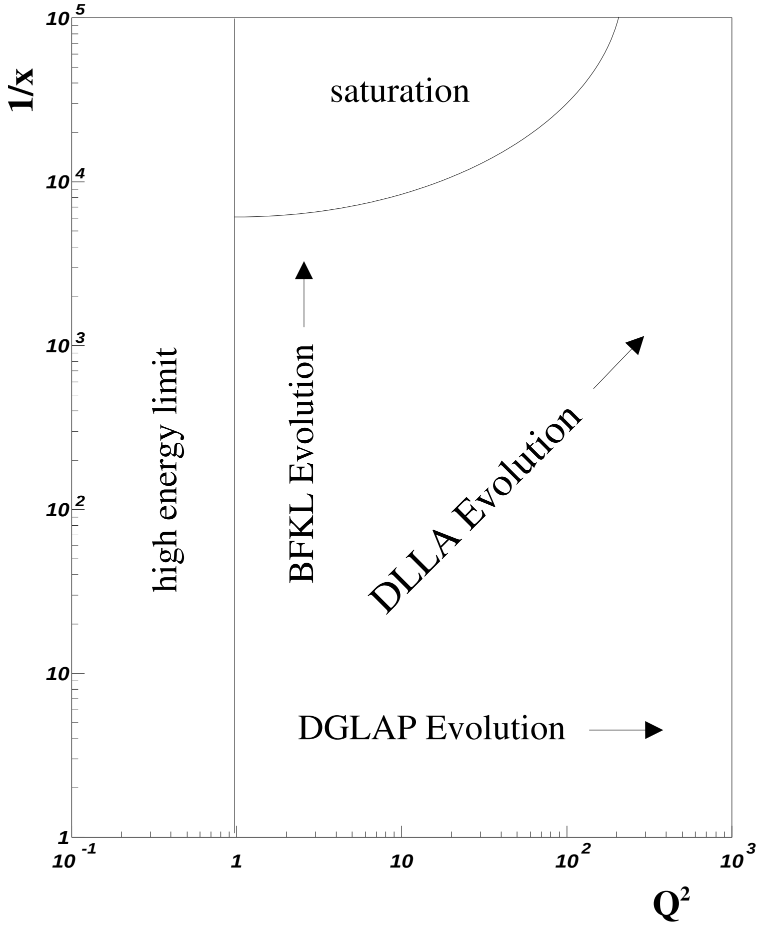
Perturbative expansion of parton evolution equations:

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

(can't be calculated explicitly to all orders)

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

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



As terms small in x contribute strongly to BFKL resummation scheme, BFKL evolution may become important at the lowest x values HERA can measure.

Gluon Ladder

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

DGLAP:

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

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

$\Rightarrow$ forward fadeout

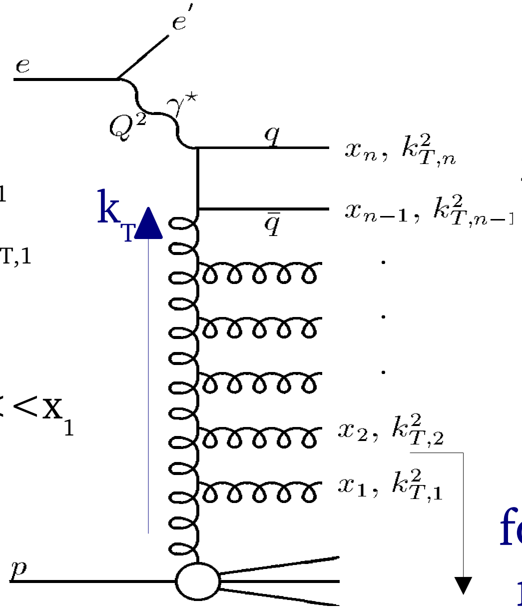
BFKL :

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

no k_T ordering

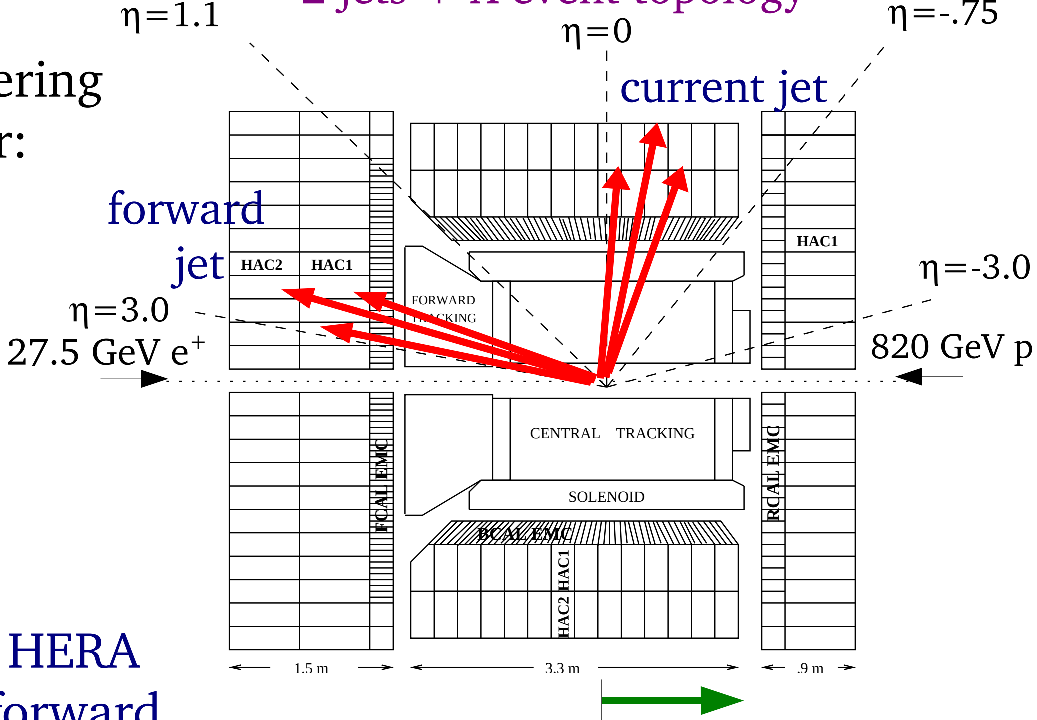
$\Rightarrow$ eta democracy

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



HERA forward region

2 jets + X event topology



hadronic angle

$\gamma_h > 90^o$

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

BFKL $\Rightarrow$ additional hadrons from high transverse momentum forward partons, above the DGLAP prediction.

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

Event Selection

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

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

Trigger Chain: FLT40,41,42,43,44; SLT DIS6; TLT DIS03,04; DST11,12,14

Phase Space Selections

Inclusive Sample:

- $Q^2 > 25$ GeV^2
- $y > 0.04$
- $E_{T,jet} > 6$ GeV
- $-1 < \eta_{jet} < 3$
- $E_{el} > 10$ GeV

QPM Suppressed Sample:

- $Q^2 > 25$ GeV
- $y > 0.04$
- $E_{T,jet} > 6$ GeV
- $0 < \eta_{jet} < 3$
- $\cos(\gamma_h) < 0$
- $E_{el} > 10$ GeV

BFKL Forward Jets Sample:

- $Q^2 > 25$ GeV^2
- $y > 0.04$
- $E_{T,jet} > 6$ GeV
- $0 < \eta_{jet} < 3$
- $\cos(\gamma_h) < 0$
- $E_{el} > 10$ GeV
- $0.5 < Q^2/E_{T,jet}^{\ 2} < 2$

effective $Q^2 > 18$ GeV

Detector Cuts:

$|Z_{vtx}| < 50$

$y_{el} < 0.95$; $y_{jb} > 0.04$

$38 < E-p_z < 65$

$p_T^{CAL} / \sqrt{E_T^{CAL}} < 3$

Sinistra $E_{el} > 10$ GeV

14x14 boxcut

electron isolation 0.1

jets are selected using k_T-inclusive algorithm in the laboratory frame

→ better reach to low x

→ better resolution in the forward

NLO

2 implementations of NLO calculation by DISENT

<u>Inclusive Jet (QPM) Phase Space (1)</u>

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

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

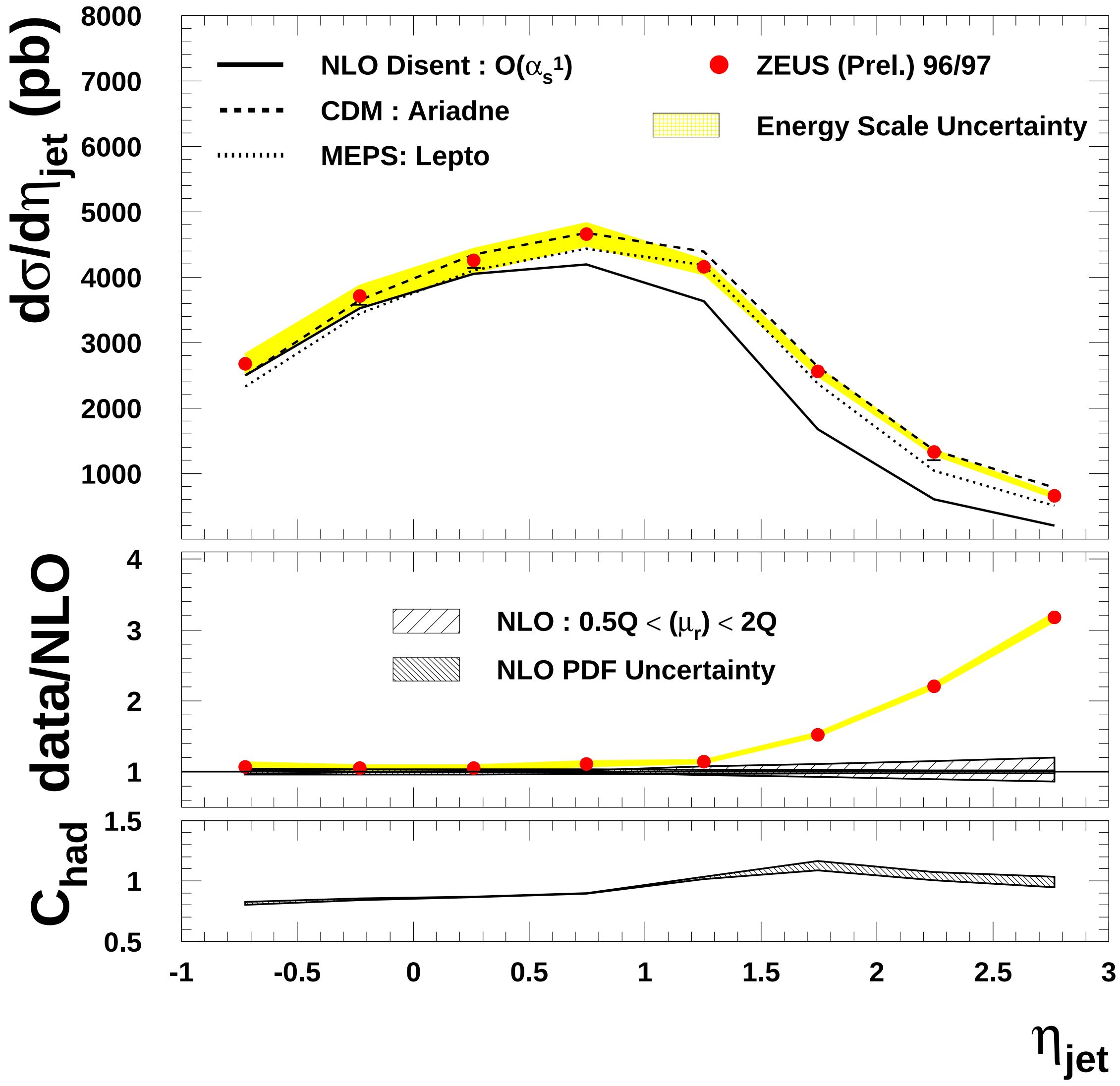
<u>QPM Suppressed Phase Spaces (2&3)</u>

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

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

- employs subtraction method
- $\mu_r = \mu_f = Q$
- estimated renormalisation scale uncertainty: $\frac{Q}{2} < \mu_r < 2Q$
- PDF : CTEQ6
- corrected from partons to hadrons using Ariadne (CDM MC)

Inclusive Jet Cross Section vs. η_{jet}



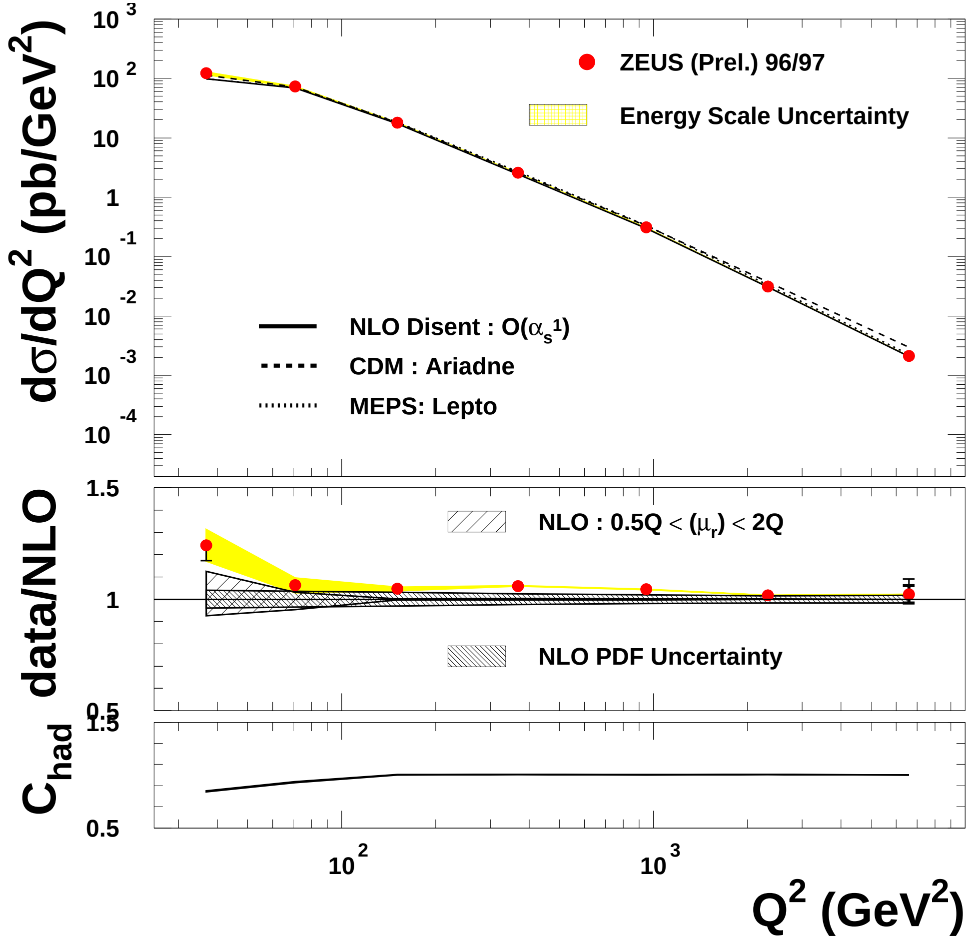
Cross section drops in forward region due to y-cut

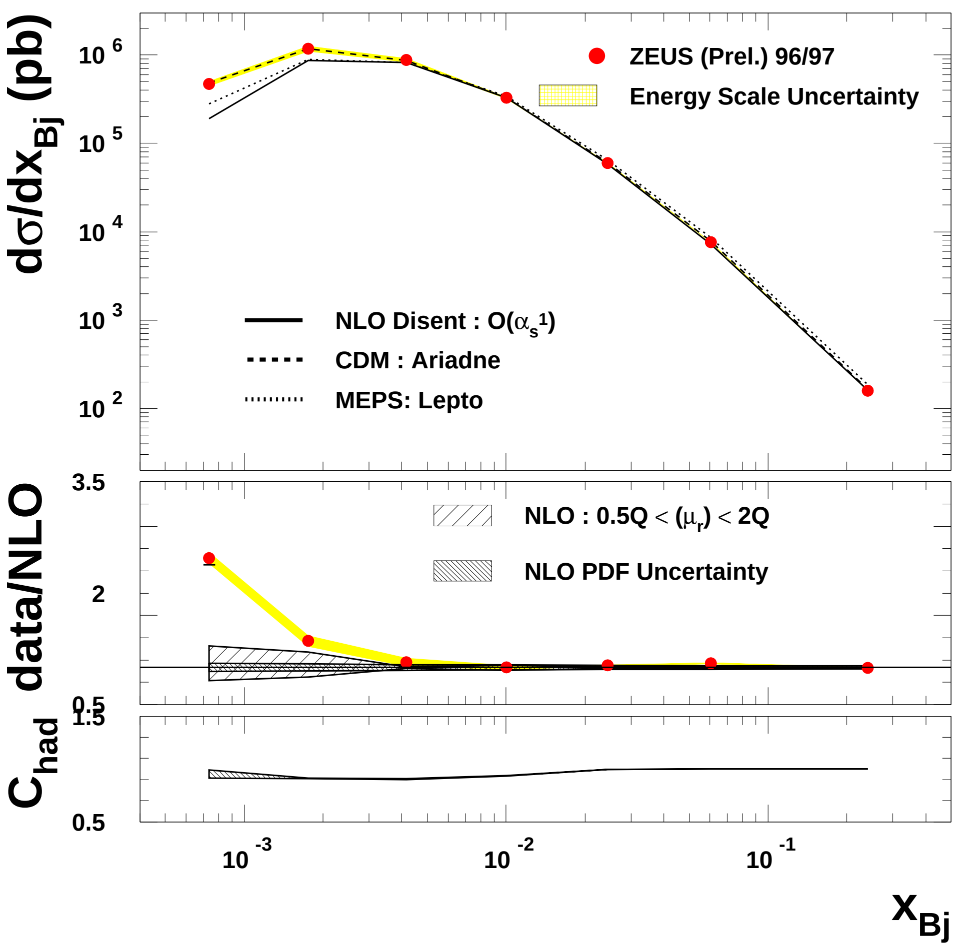
- Significant discrepancy with NLO at high η,
- Ariadne (BFKL-like LO MC) can describe the data
- Lepto (DGLAP-like LO MC) gives fairly good description

Cross section dominated by QPM events - should be well understood! NLO is $O(\alpha_s)$

BFKL?
Parton shower missing from NLO?

Inclusive Jet Cross Section vs. Q^2, x

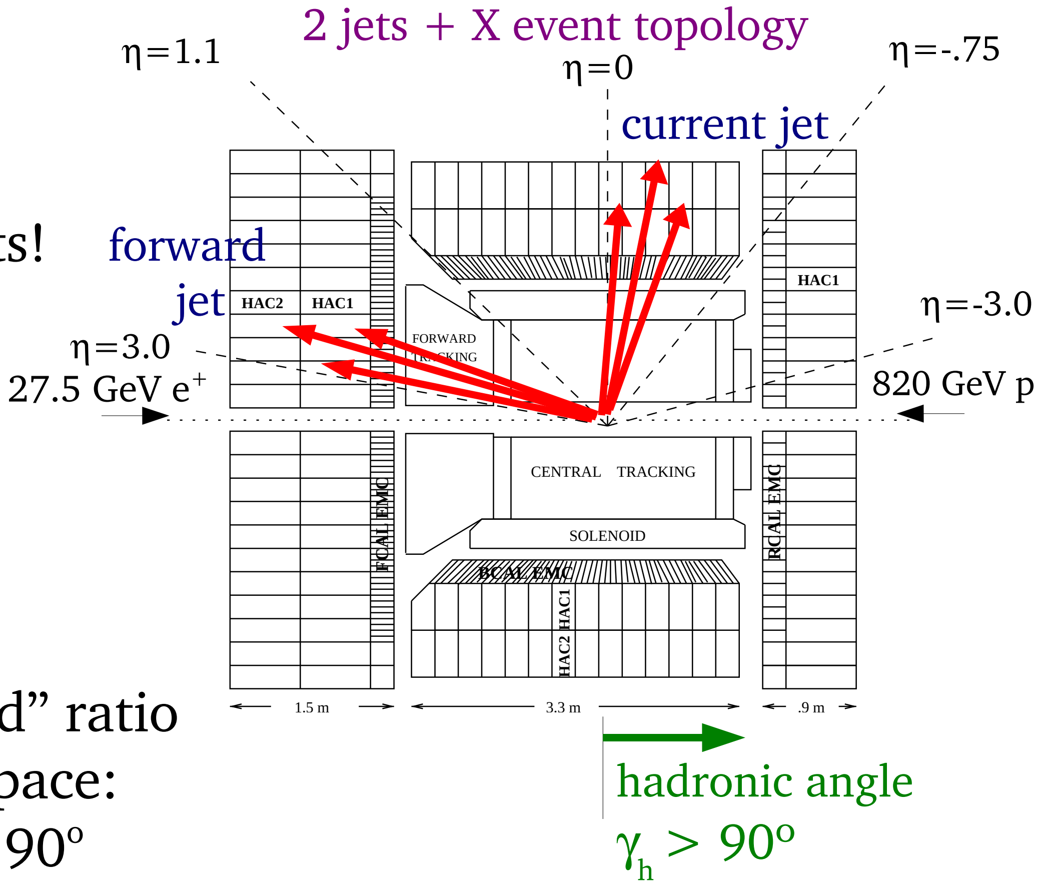




Discrepancy between data and NLO localized in lowest x_{Bj} and Q^2 bins, regions where BFKL may be important

Event Topology: Isolating the Signal

Remember that our signal events are Boson-Gluon Fusion and QCDC events with high-E_T forward going jets!



In QPM events, only 1 jet =>
hadronic angle = jet angle

To enhance our "signal-to-background" ratio (reject QPM), we restrict our phase space:

- events must have hadronic angle > 90°
- jet η must be in forward half of detector

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

Reselection of Phase Space

Inclusive Jet Phase Space

- $Q^2 > 25\ \mathrm{GeV}^2$
- $y > 0.04$
- $E_{el} > 10\ \mathrm{GeV}$
- $E_{T,jet} > 6\ \mathrm{GeV}$
- $-1 < \eta_{jet} < 3$

to suppress QPM →

"QPM Suppressed" Phase Space

- $Q^2 > 25\ \mathrm{GeV}^2$
- $y > 0.04$
- $E_{el} > 10\ \mathrm{GeV}$
- $E_{T,jet} > 6\ \mathrm{GeV}$
- $0 < \eta_{jet} < 3$
- $\cos(\gamma_{had}) < 0$

Disent Calculations:

with hadronic angle requirement

$LO = O(\alpha_s^{\,0}) = QPM \rightarrow QPM = 0 \text{ for } \eta > 0 \rightarrow LO = O(\alpha_s^{\,1}) = BGF + QCDC$

$NLO = QPM + \text{corrections} \rightarrow BGF + QCDC \text{ for } \eta > 0 \rightarrow NLO = O(\alpha_s^{\,2}) = BGF + QCDC$

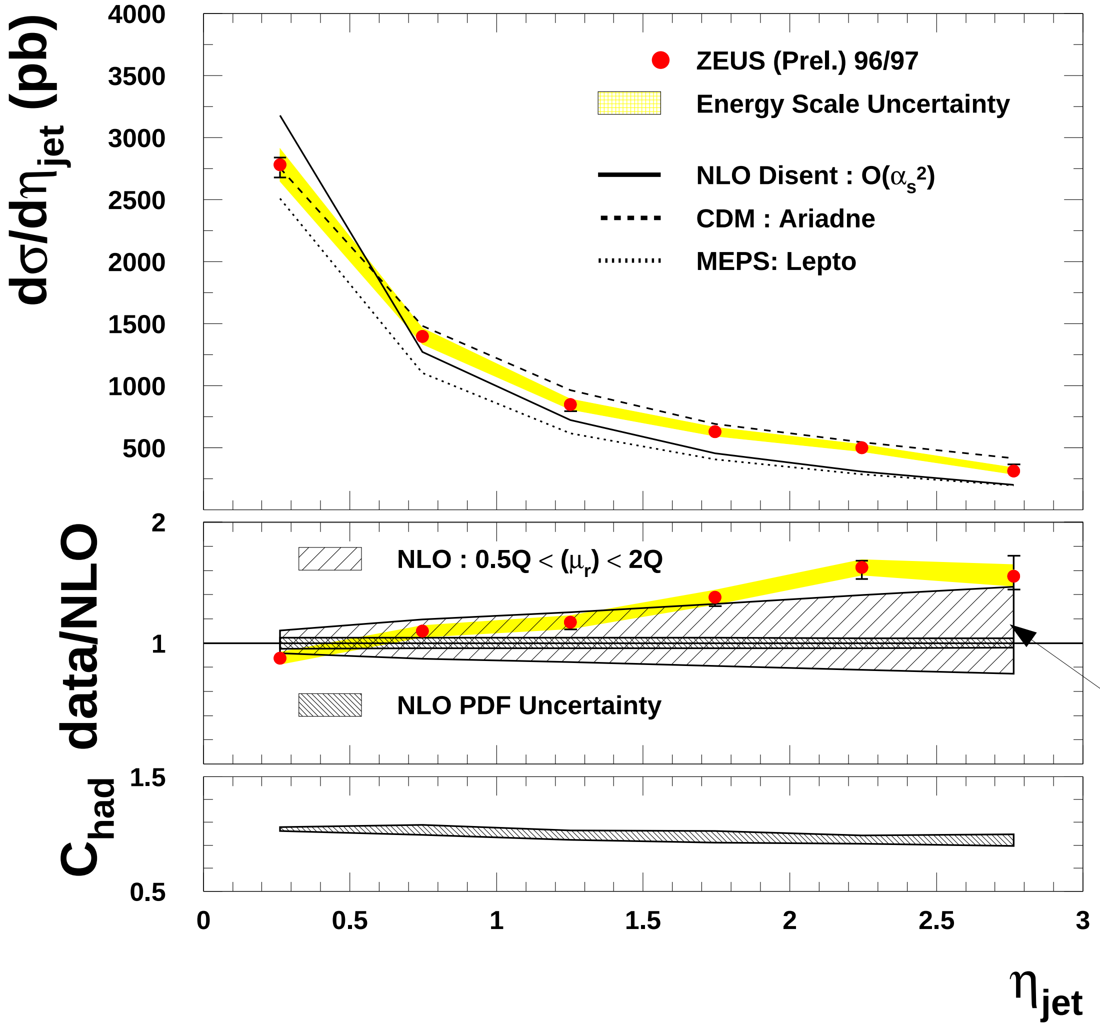
+ corrections

Just 1 order in the series of α_s

2 orders in the series of α_s

2 orders in the series of α_s

Inclusive Jet Cross Section vs. η_{jet} for "QPM Suppressed" Phase Space



For our signal events, agreement with NLO within errors.

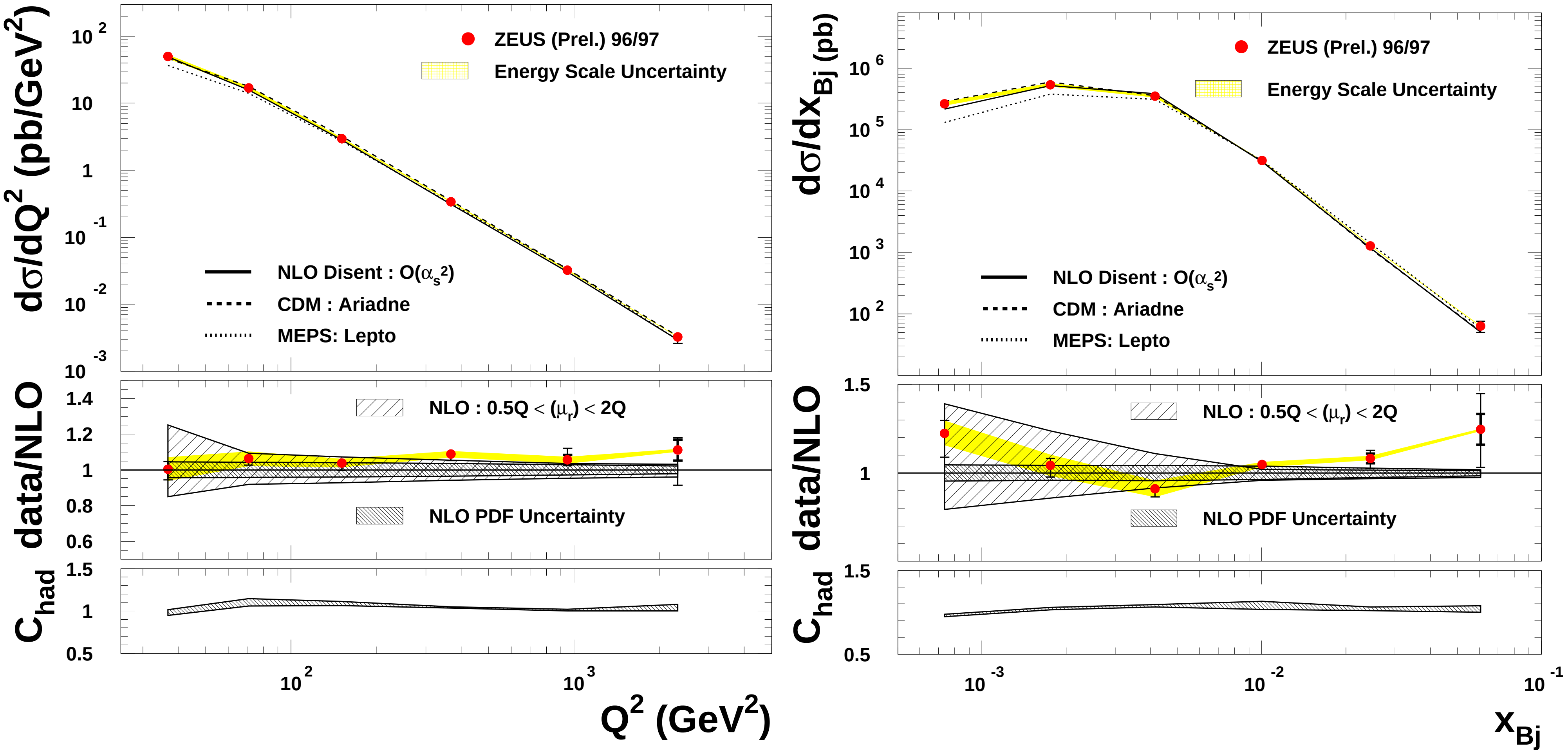
NLO now includes terms $O(\alpha_s^2)$

Ariadne gives good description of data

Lepto gives fair description of data

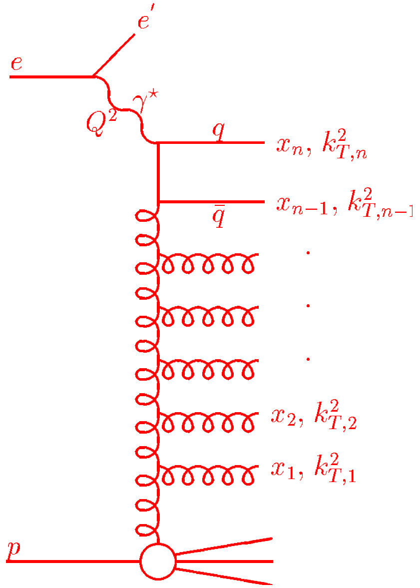
Renormalization scale uncertainty grows in the forward region

Inclusive Jet Cross Section vs. Q^2,x for QPM Suppressed Phase Space



NLO based on DGLAP agrees with data within errrors.

BFKL Phase Space



Further restrictive phase space suggested by Mueller, Navalet

limitation on $Q^2/E^2_{T,jet}$ suppresses events exhibiting DGLAP evolution

$$Q^2 \sim E^2_{T\ ,\ jet}$$

Inclusive Sample:

- $Q^2 > 25$ GeV
- $y > 0.04$
- $E_{el} > 10$ GeV
- $E_{T,jet} > 6$ GeV
- $-1 < \eta_{jet} < 3$

QPM Suppressed Sample:

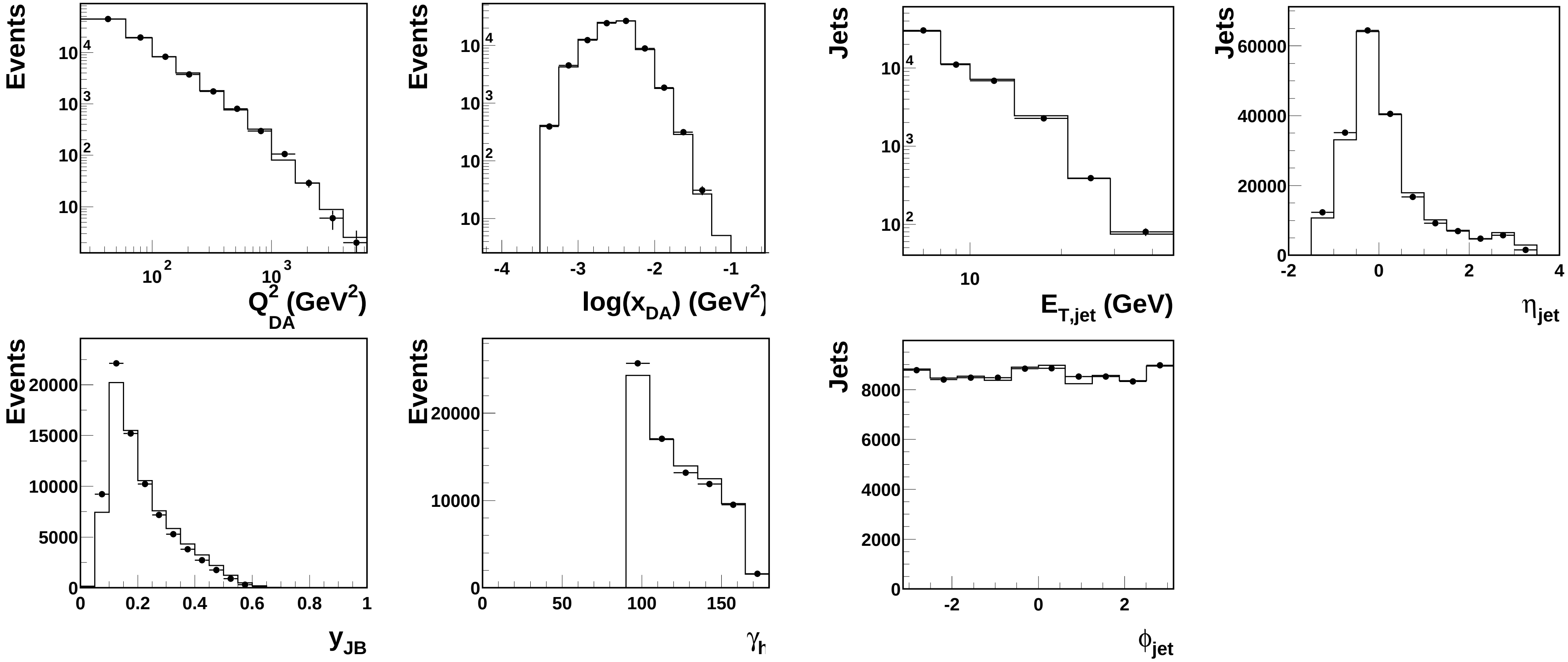
- $Q^2 > 25$ GeV
- $y > 0.04$
- $E_{el} > 10$ GeV
- $E_{T,jet} > 6$ GeV
- $0 < \eta_{jet} < 3$
- $\cos(\gamma_h) < 0$

BFKL Jets Sample:

- $Q^2 > 25$ GeV
- $y > 0.04$
- $E_{el} > 10$ GeV
- $E_{T,jet} > 6$ GeV
- $0 < \eta_{jet} < 3$
- $\cos(\gamma_h) < 0$
- $0.5 < Q^2/E_{T,jet}^{\ 2} < 2$

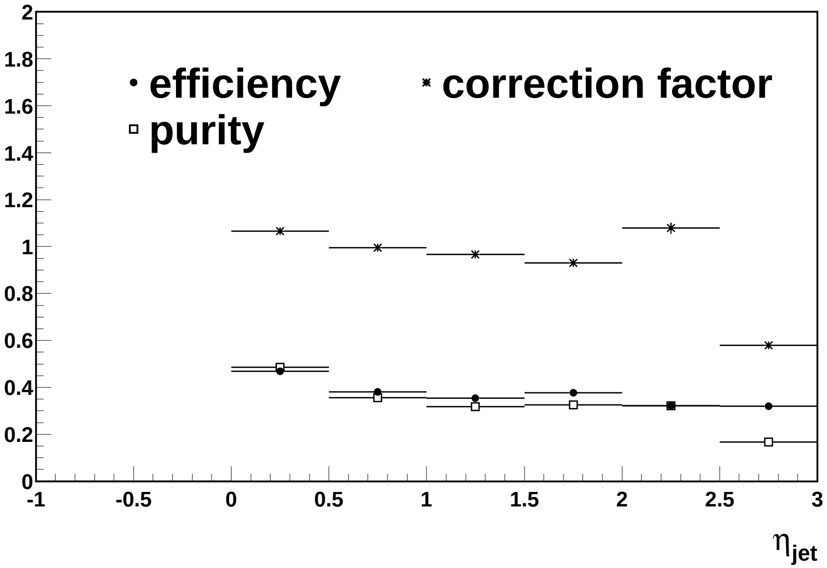
BFKL Phase Space – Data/MC Comparison

CDM (Ariadne) describes data well.

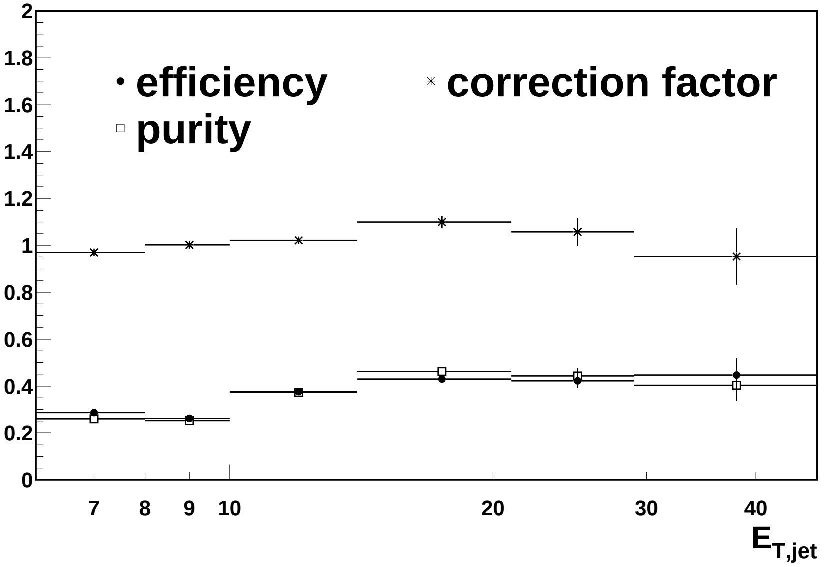


plots are area normalized

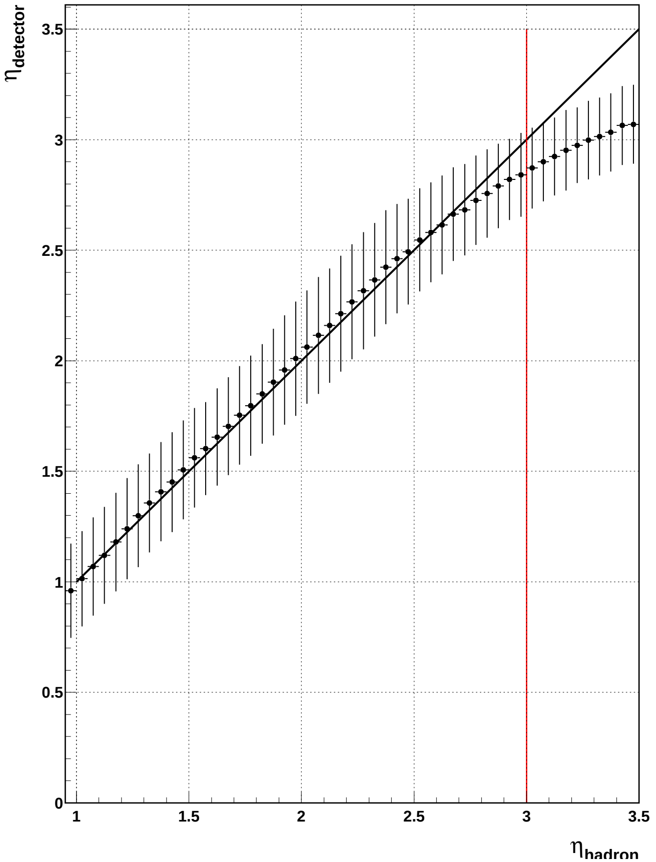
BFKL Phase Space – Efficiencies, Purities



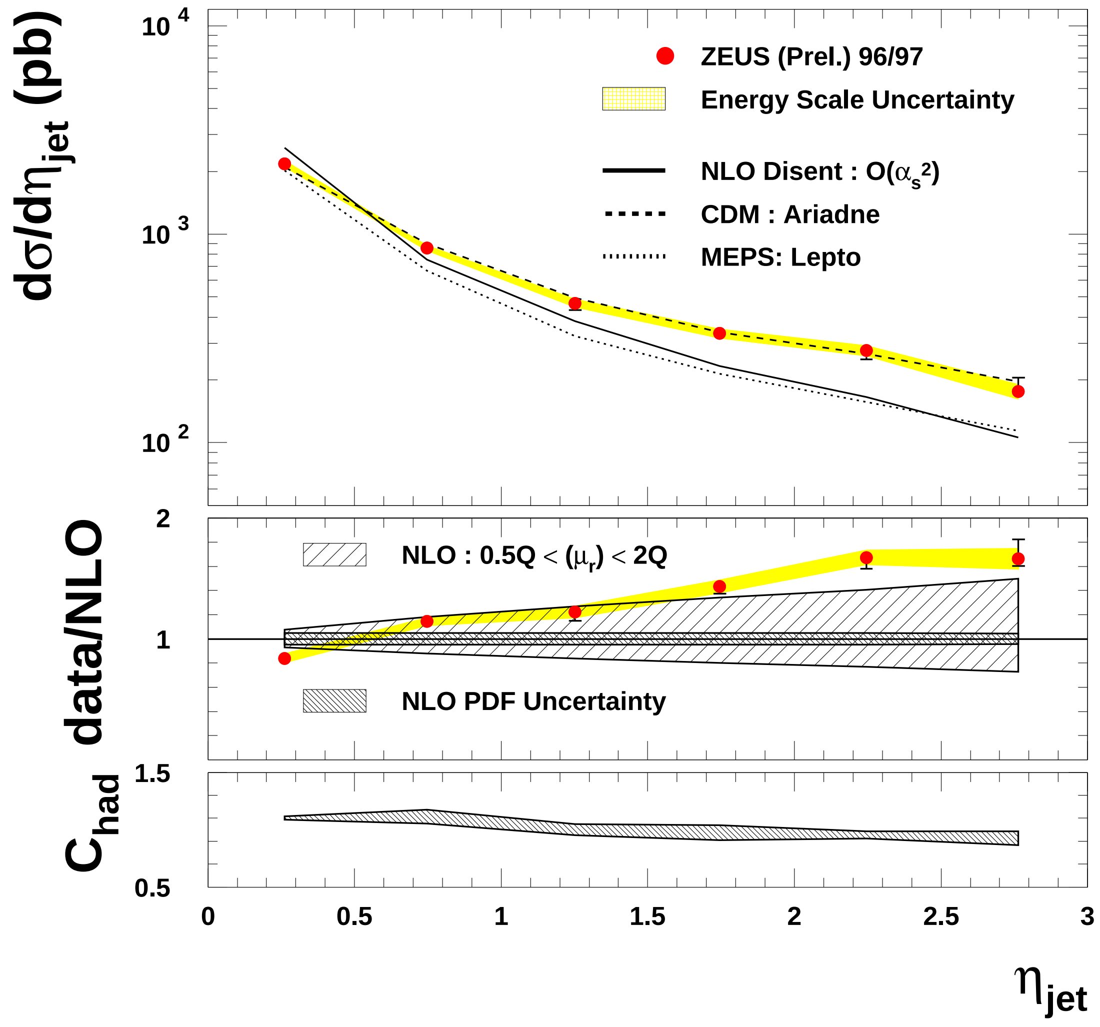
Efficiencies, purities reasonable.
Low purity in highest eta bin



Can improve with eta correction



Inclusive Jet Cross Section vs η_{jet} for BFKL Phase Space



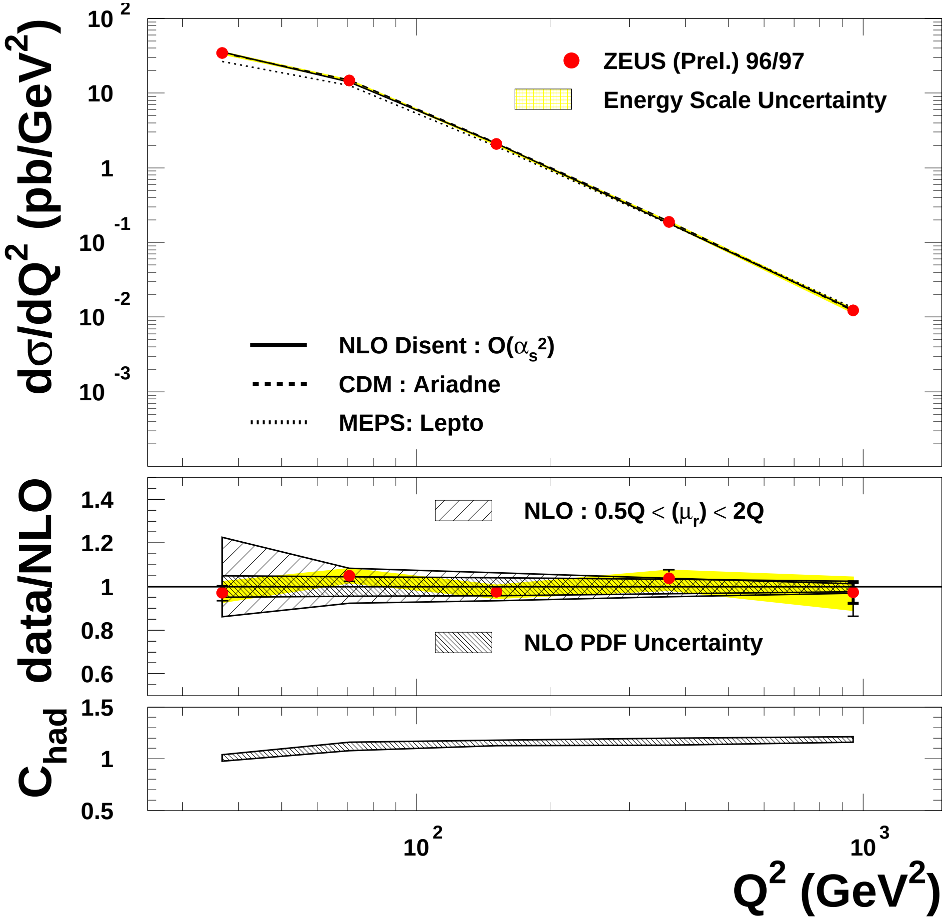
Data shows excess over NLO

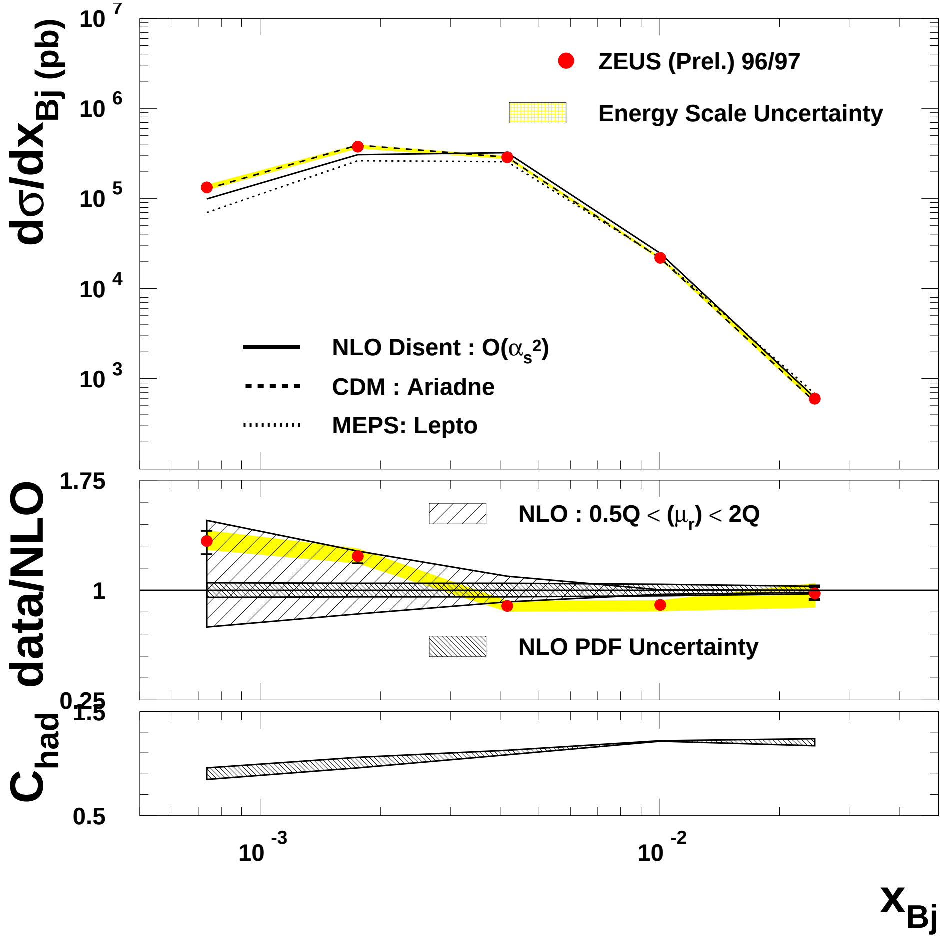
Large renormalization scale uncertainty persists

Ariadne (BFKL-like MC) gives excellent description of data over entire region

Lepto (DGLAP-like MC) cannot describe data

Inclusive Jet Cross Section vs Q^2,x for BFKL Phase Space





NLO Calculation can describe the data.

Summary

- Inclusive jet cross sections at $Q^2 > 25$ GeV^2 , $y > 0.04$ have been measured over the full rapidity acceptance region in three phase space regions

	NLO Calculation	Ariadne (BFKL-like MC)	Lepto (DGLAP-like MC)
Inclusive PS	cannot describe data in forward	good description	good description
QPM Suppressed PS	data above NLO; agreement w/in errors	good description	fair description
BFKL PS	data above NLO	excellent description	data above Lepto

Conclusions and Plans

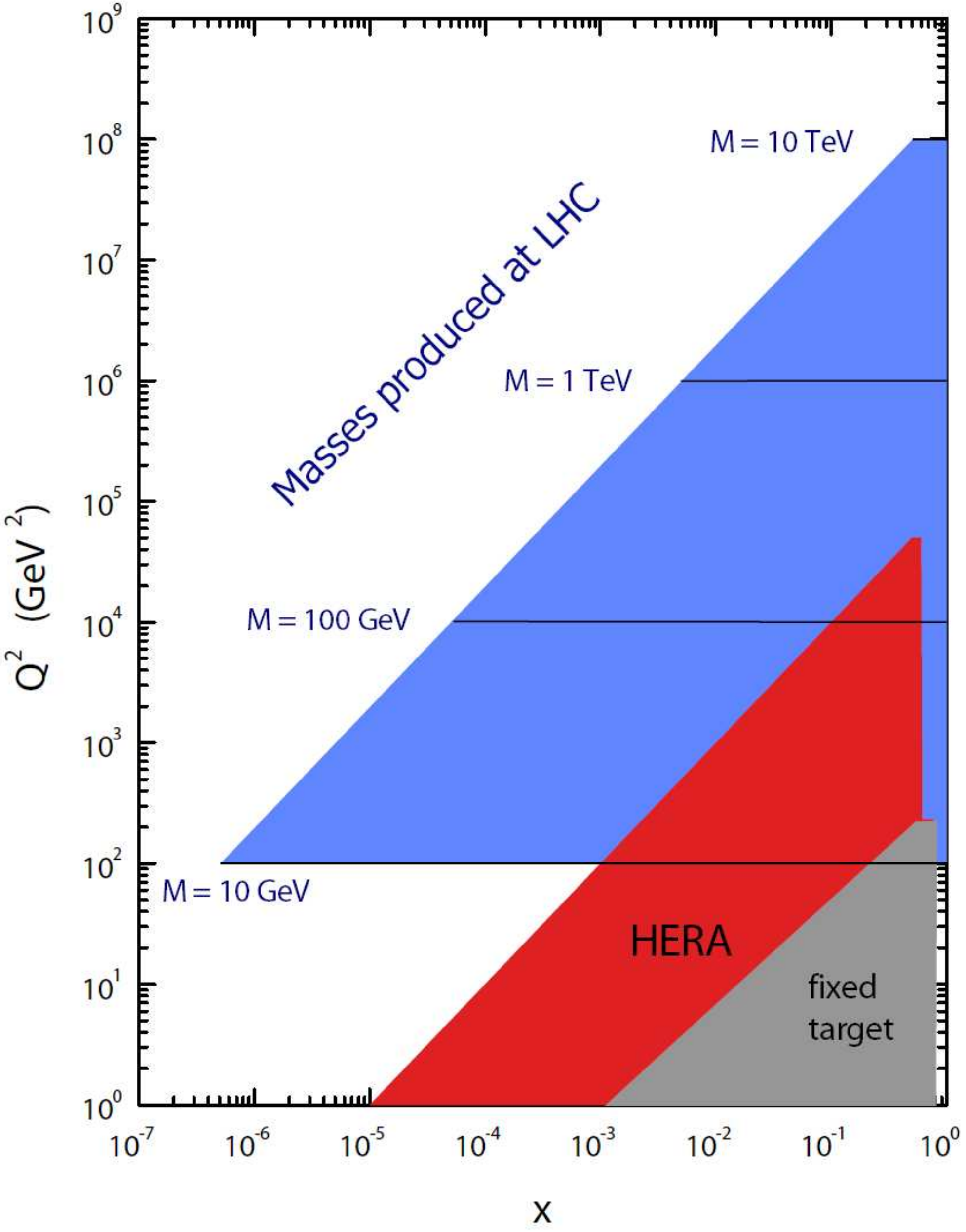
- Large renormalization scale uncertainty indicates higher order contributions are important for obtaining an accurate prediction from the theory.

A resummed NLO calculation, perhaps using the BFKL implementation, would be interesting to compare to the data, both for its cross section predictions and as a measure of the renormalization scale uncertainty in the low-x_{Bj} and high-η_{jet} region

Paper Publication:
- writing has begun
- SL leaves at end of April
- action items
  - cross sections in most forward region $2 < \eta < 3$
  - CASCADE prediction
  - fine tuning of systematics

End of Talk

HERA → LHC



HERA densities extrapolate into LHC region

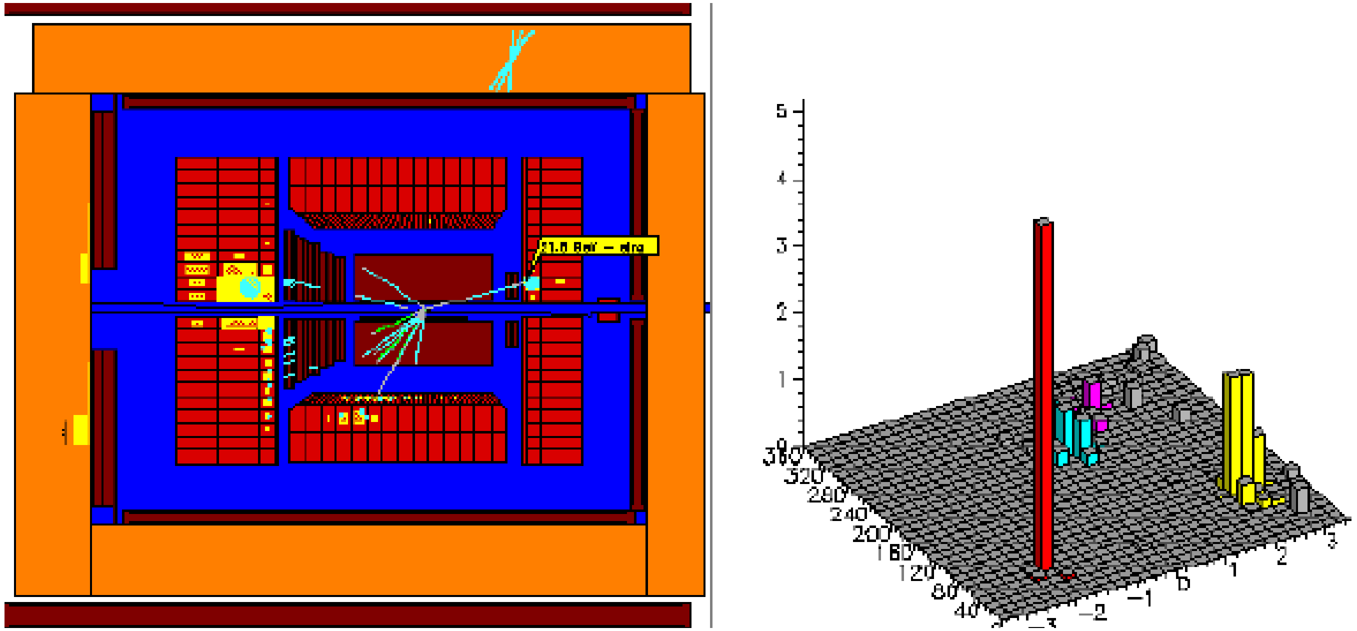
DGLAP parton densities,
QCD knowledge from HERA

↓

LHC measurements

HERA measurements crucial for understanding signal + background at LHC!

Dijet Event

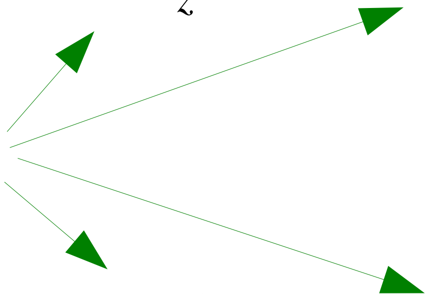


Looking for presence of strong forward jets accompanied by hadronic activity in central and/or rear parts of the detector

DGLAP Evolution Equations

Quark and gluon parton distribution functions (PDF's) are predicted at a certain x and Q^2, given an initial distribution at x_0 and Q_0^2.

$$\frac{dq_i(x,Q^2)}{d\,lnQ^2}=\frac{\alpha_s(Q^2)}{2\pi}\int_x^1\frac{dz}{z}[q_i(y,Q^2)P_{qq}(\frac{x}{z})+g(y,Q^2)P_{qg}(\frac{x}{z})]$$



splitting functions
-calculable by QCD

$$\frac{dg(x,Q^2)}{d\,lnQ^2}=\frac{\alpha_s(Q^2)}{2\pi}\int_x^1\frac{dz}{z}[\sum q_i(y,Q^2)P_{gq}(\frac{x}{z})+g(y,Q^2)P_{gg}(\frac{x}{z})]$$

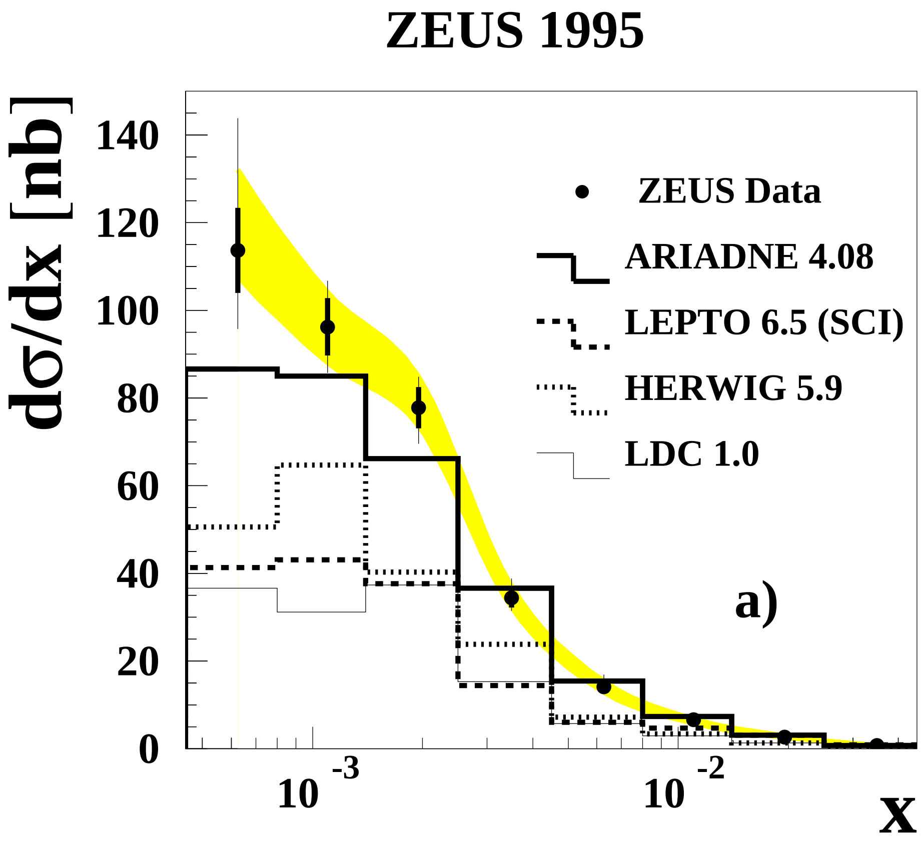
In the perturbation series calculation of the evolution of the PDF's with x and Q^2, there are terms proportional to $(\alpha_s \ln Q^2)^n$, $(\alpha_s \ln(1/x))^n$ and $(\alpha_s \ln Q^2 \ln(1/x))^n$

DGLAP = Dokshitzer, Gribov,
Lipatov, Altarelli, Parisi

DGLAP Approximation:

- sums terms $\alpha_s \ln Q^2$, ignores $\alpha_s \ln(1/x)$
- has limited applicability ---> $\alpha_s \ln(Q^2) \sim 1$ $\alpha_s \ln\frac{1}{x} \ll 1$

Previous ZEUS Measurement



Issues:

- all monte carlo models underestimate the data at low x
- LO monte carlo models are not consistent with each other

Improvements:

- new data set: 6x more statistics
- new calculation: NLO
- higher reach in η
- jet finding with k_T-algorithm

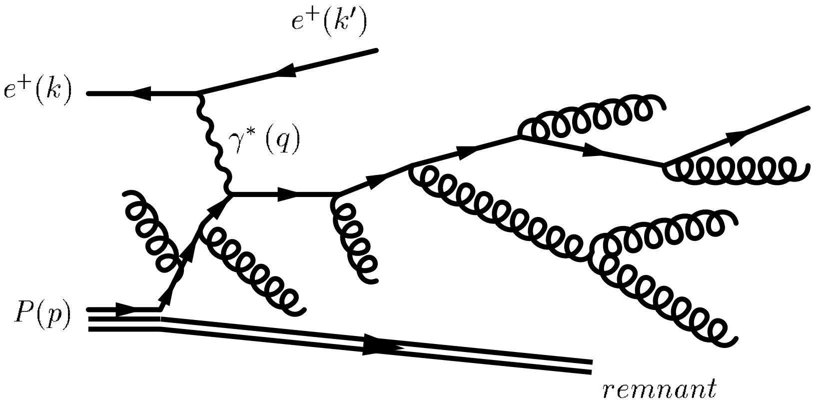
Monte Carlo

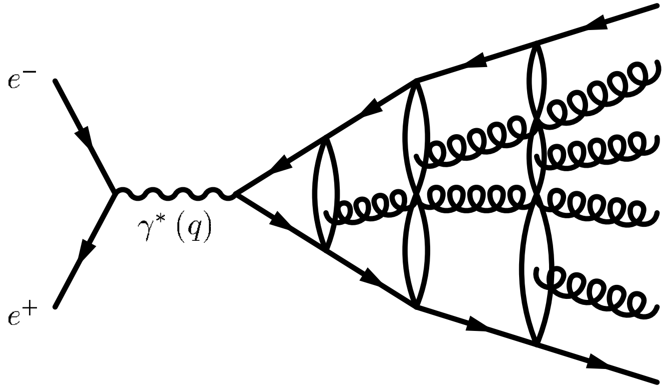
LEPTO:

- k_T-ordered parton shower - DGLAP
- Hadronization: Lund String Model

ARIADNE:

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





Lund String Model: Color string stretched across pairs of final state partons.
Energy stored in the string gives rise to hadrons.

Detector acceptance estimated with LO Color Dipole Model (CDM) implemented with Ariadne , which has the best description of data

Inclusive Jet Cross Sections vs. total Inclusive Cross Sections using DISENT

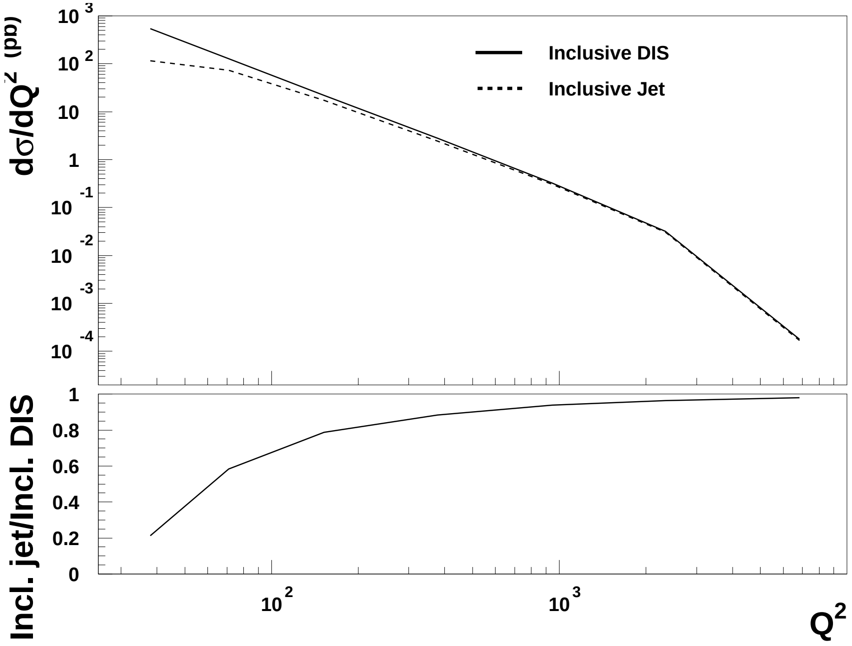
Inclusive jet phase space

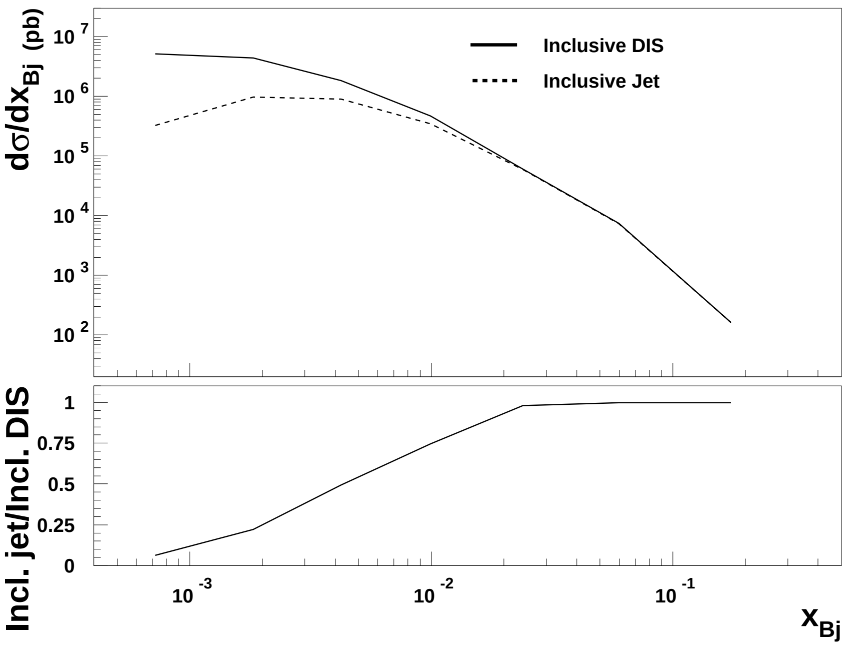
- $Q^2 > 25\ \mathrm{GeV}^2$
- $y > 0.04$
- $E_{T,\mathrm{jet}} > 6$ GeV
- $-1 < \eta_{\mathrm{jet}} < 3$

Fully inclusive DIS phase space

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

no jet selected!





A hard lower cut-off in the jet E_T significantly limits the phase space

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

Systematic Uncertainties

Systematic uncertainties arise from
- data measurement resolution
- poor description of data by MC at cut boundary
- model dependencies in MC

Systematic Checks	Typical/Maximal (in a bin) Variation
1. Lepto instead of Ariadne	6% / 15%
2.Calorimeter Energy Scale ±3%	5% / 23%
3. Jet Et cut variation ± 1GeV	2% / 13%
4. Jet η cut (forward) variation ± 0.2	1% / 5%
5. Electron energy cut variation ± 1 GeV	2% / 5%
6. Q^2 cut variation ± 2 GeV	1% / 3%
7. Vtx cut variation ± 10 cm.	1% / 2%
8. High E-pz cut variation ± 3 GeV	1% / 1%
9. Low E-pz cut variation ± 3 GeV	1% / 1%
10. Hadronic angle cut variation ± 0.1	3%/ 12%