Multijet Production at Low X_{Bj} and Forward Jet Production in DIS

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Parton dynamics

Perturbative expansion of parton evolution equations $\sim \Sigma_{mn} A_{mn} \ln(Q^2)^m \ln(1/x)^n$

Cannot be explicitly calculated to all orders

1. Fixed order calculations

2. Approximations ⇨ resumming certain infinit subsets of terms according to the phase space region

- **DGLAP, collinear factorisation:** $\sum (\alpha_s \ln Q^2)^n$

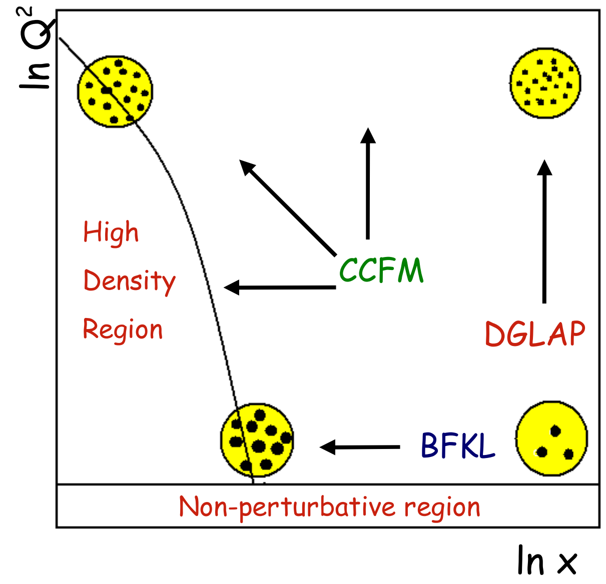
  Ordering in x, ***strong ordering in k_T***

- **BFKL, k_T factorisation** : $\sum (\alpha_s \ln (1/x))^n$

  Strong ordering in x, ***no k_T ordering***

- **CCFM, k_T factorisation**: resum $\ln Q^2$ and $\ln (1/x)$

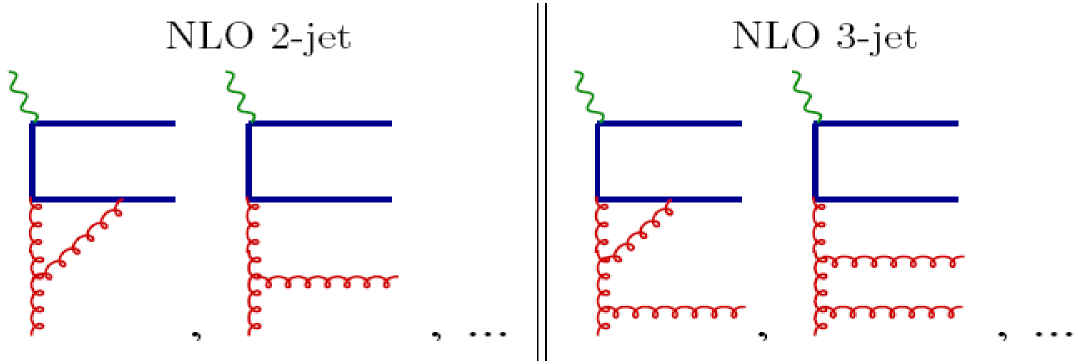
  Angular ordering ⇨ ***k_T non-ordered at small x_{Bj}***



If HERA's x_{BJ} are small enough to reveal deficiency of DGLAP?

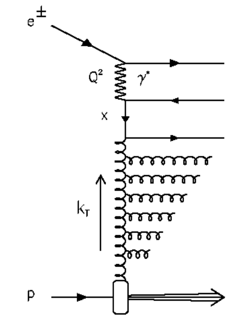
QCD Calculations

NLOJET++: **Fixed order QCD partonic cross section, on mass shell ME + DGLAP , (collinear factorisation)**



- **Terms of up to $O(\alpha_s^2)$ ($O(\alpha_s^3)$) for dijet (trijet) calculations**
- **One-loop corrections for virtual particles**
- **Correction for 3rd (4th) parton in final state (soft/collinear gluon emissions)**
- **$O(\alpha_s^3)$ calculations possible for dijets for certain jet phase space region**
- **No fragmentation, hadronization corrections from MC**

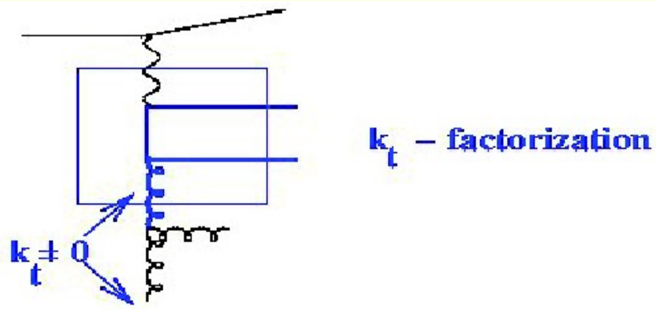
MC Models



LEPTO: **LO ME on mass shell + PS in DGLAP**

→ ***Strong ordering in k_T***

CASCADE: **LO off mass shell ME + PS based on k_T factorized CCFM evolution**



transverse momentum of emitted gluon $k_\perp > k_\perp^{cut}$

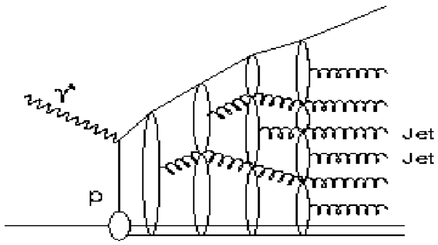
uPDF set1 : $k_\perp^{cut}$ = 1.33 GeV

uPDF set2 : $k_\perp^{cut}$ = 1.18 GeV

non-singular term in splitting function

At small x_{Bj} ***no ordering in k_T***

ARIADNE: **implementation of Color Dipole Model (CDM)**



→ **Independently radiating dipoles formed by emitted gluons**

→

→ ***Random walk in k_T*** **like in BFKL**

Dijets&trijets without forward jet

Event & Jet selection

1998 – 2000 ZEUS $e^{\pm}p$ data, 82 pb^{-1}

Low – x_{Bj} DIS selection

$$10^{-4} < x_{Bj} < 10^{-2}$$

$$10 < Q^2 < 100\ GeV^2$$

$$0.1 < y < 0.6$$

Dijet/trijet selection

$$E_{T,HCM}^{jet1} > 7\ GeV$$

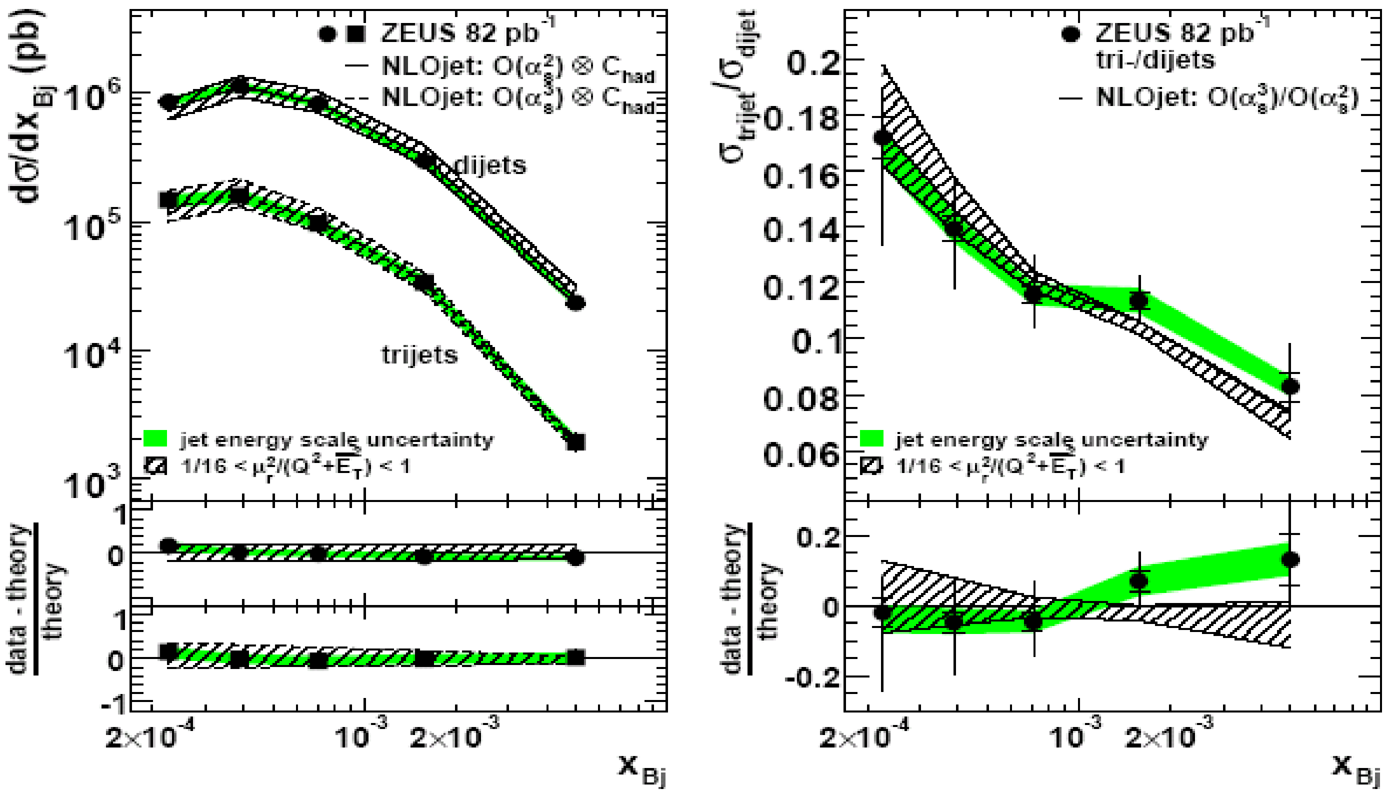
$$E_{T,HCM}^{jet2(,3)} > 5\ GeV$$

$$-1 < \eta_{LAB}^{jet1,2(,3)} < 2.5$$

Jets reconstructed with K_T algorithm in inclusive mode

Dijets & trijets vs. x_{Bj}

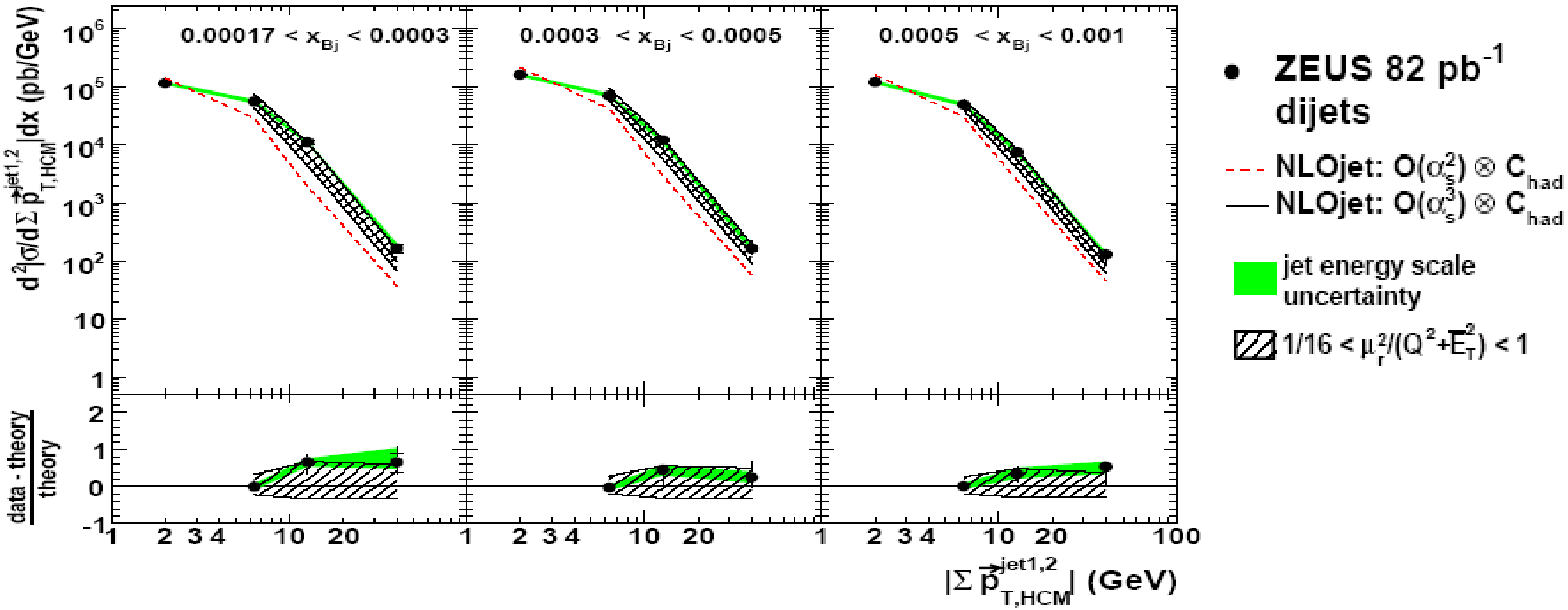
NLOjet++ compared with data on inclusive cross-sections (left) and ratios of trijet to dijet cross-sections (right)



- **Dijets and trijets are described by NLO.**
- **For cross section ratios theoretical uncertainties mainly canceled, within these smaller uncertainties agreement is again satisfactory**

P_T correlations for dijets

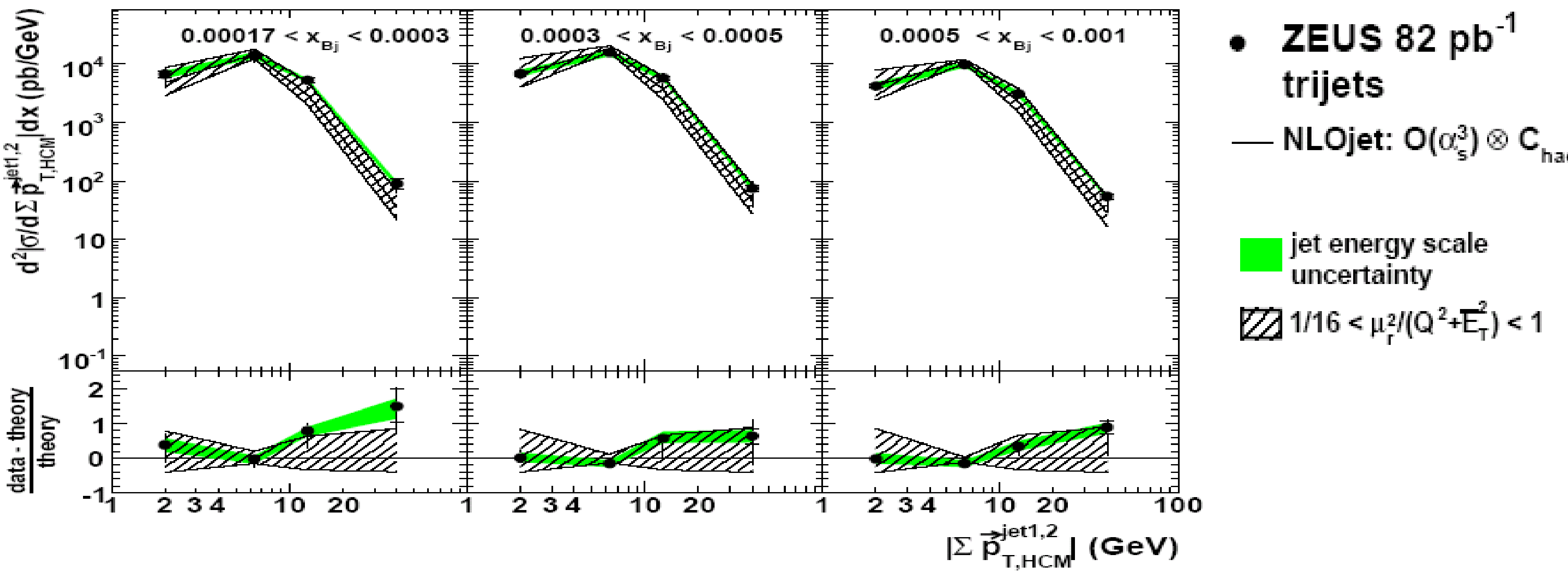
Inclusive distributions are of insufficient resolving power, try correlations.
First, abs. value of vector sum of p_T of two jets, NLOjet vs data
Without gluon radiation two jets are correlated, back to back in HCMS: $|\Sigma p_T| = 0$



- **Calculations at $O(\alpha_s^2)$ are much below data**
- **Difference is largest for smallest x_{BJ}**
- **Addition of $O(\alpha_s^3)$ leads to agreement with data (within theoretical uncertainty, which is large)**

P_T correlations for trijets

Abs. value of vector sum of p_T of two highest E_T jets, NLOjet vs data

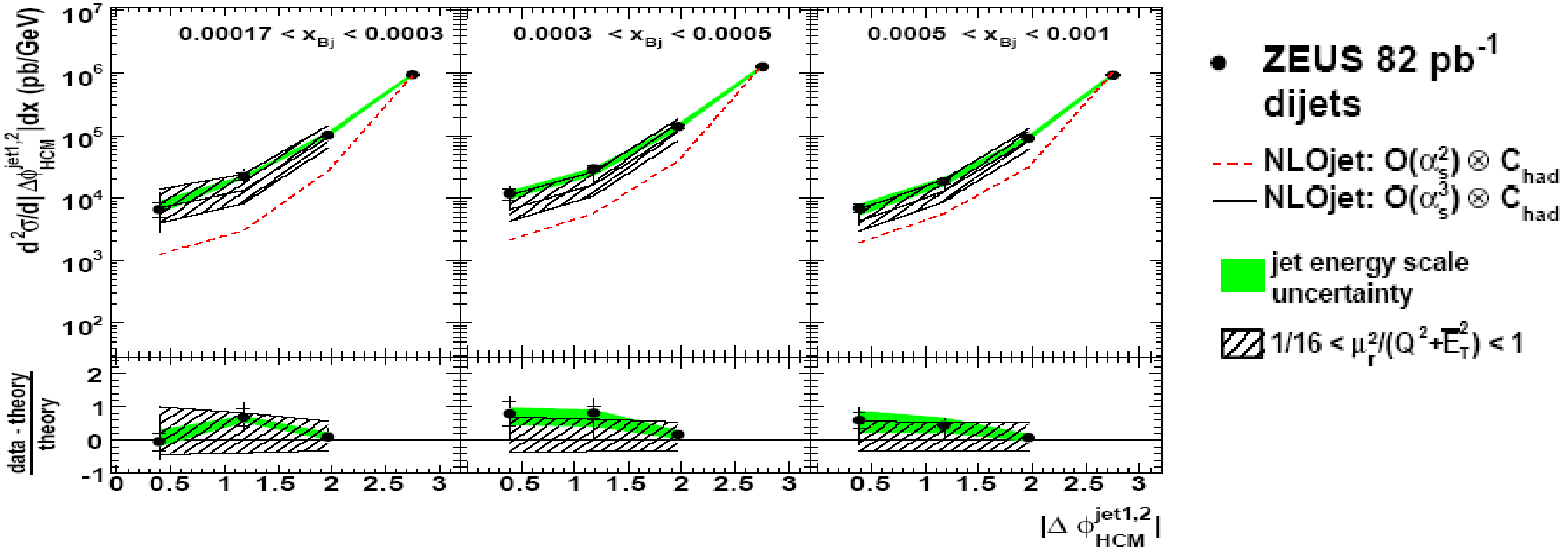


Calculations agree with data within theoretical uncertainty

ϕ correlations for dijets

Separation in azimuthal angle ϕ of two jets, NLOjet vs data

$|\Delta\phi| = \pi$ without gluon radiation



- **NLOjet calculations at $O(\alpha_s^2)$ are much below data**
- **Difference seemingly increases with decrease of x_{Bj}, reaching almost one order of magnitude for smallest x_{BJ} and most decorrelated jets**
- **Addition of $O(\alpha_s^3)$ leads to agreement with data**

One additional gluon is not enough, at least two are needed

Event & Jet selection

Kinematic range

98-00 Data, L ≅ 82 pb^{-1}

$20 < Q^2 < 100$ GeV^2

$0.0004 < x_{Bj} < 0.005$

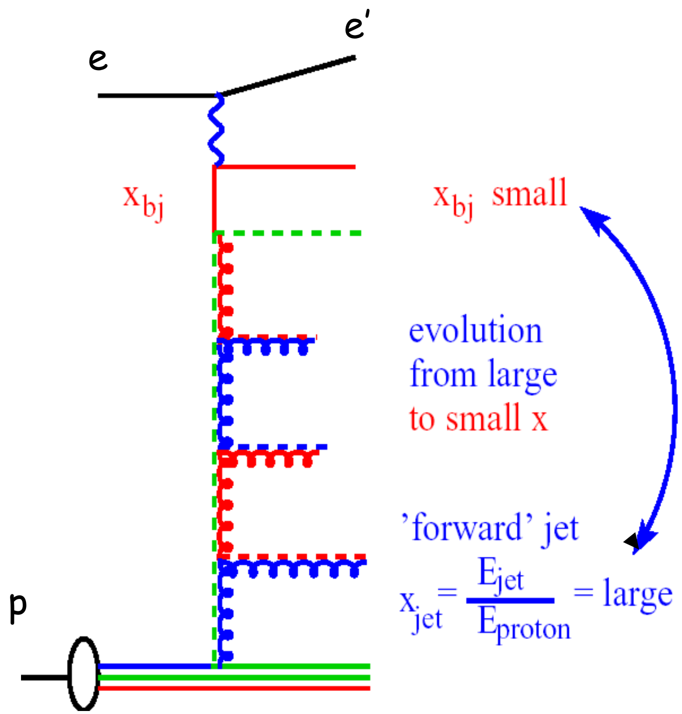
$0.04 < y < 0.7$

Forward Jet selection

Inclusive K_T algorithm

$E_t^{jet} > 5$ GeV

$2 < \eta^{jet} < 4.3$



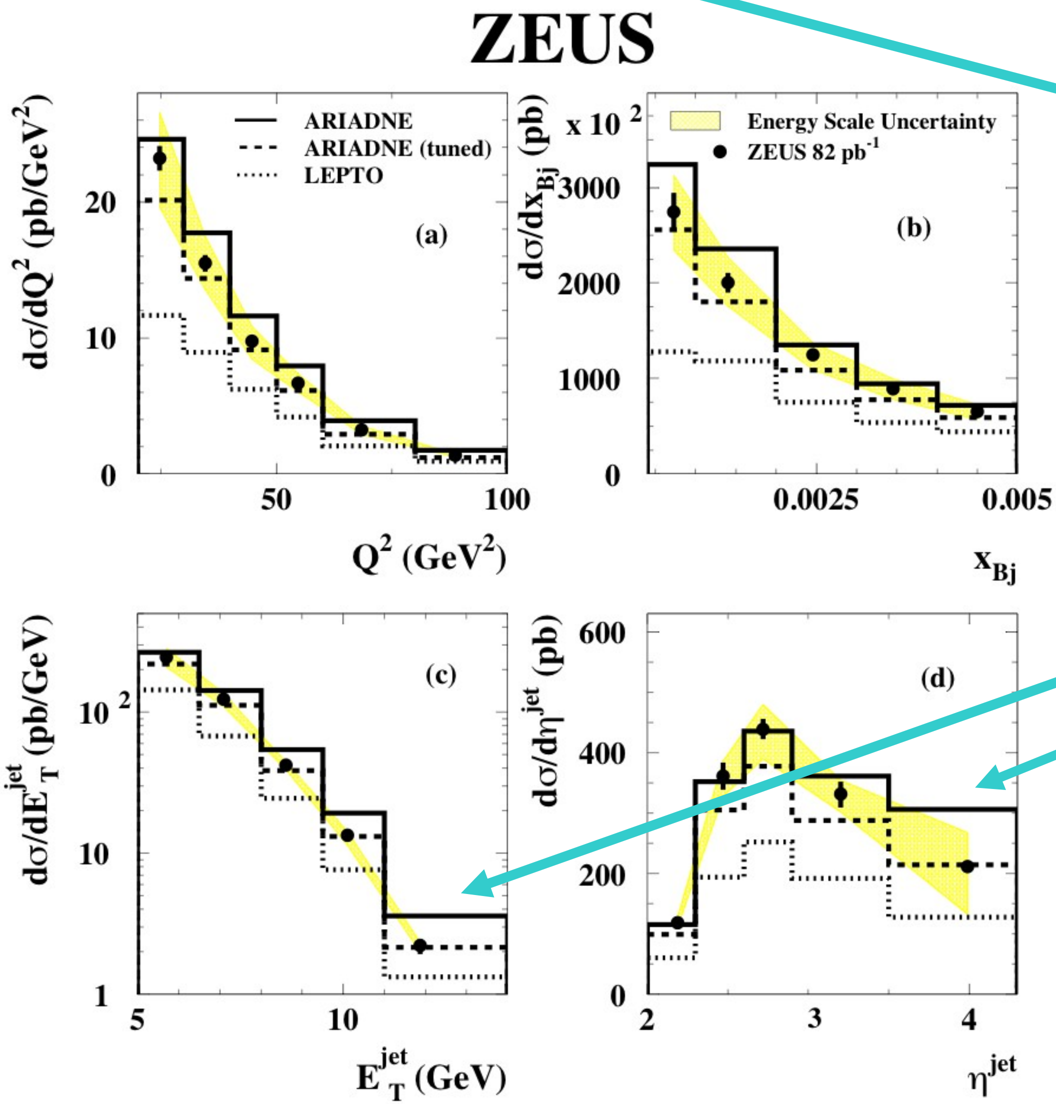
1.4 unit more forward than before

$0.5 < (E_t^{jet})^2/Q^2 < 2$ → $(E_t^{jet})^2 \sim Q^2$ suppresses DGLAP evolution

$x_{jet} > 0.036$ → $x_{jet} = E_{jet}/E_{proton} >> x_{Bj}$ enhances BFKL evolution

Inclusive Forward Jets

LEPTO & ARIADNE vs data

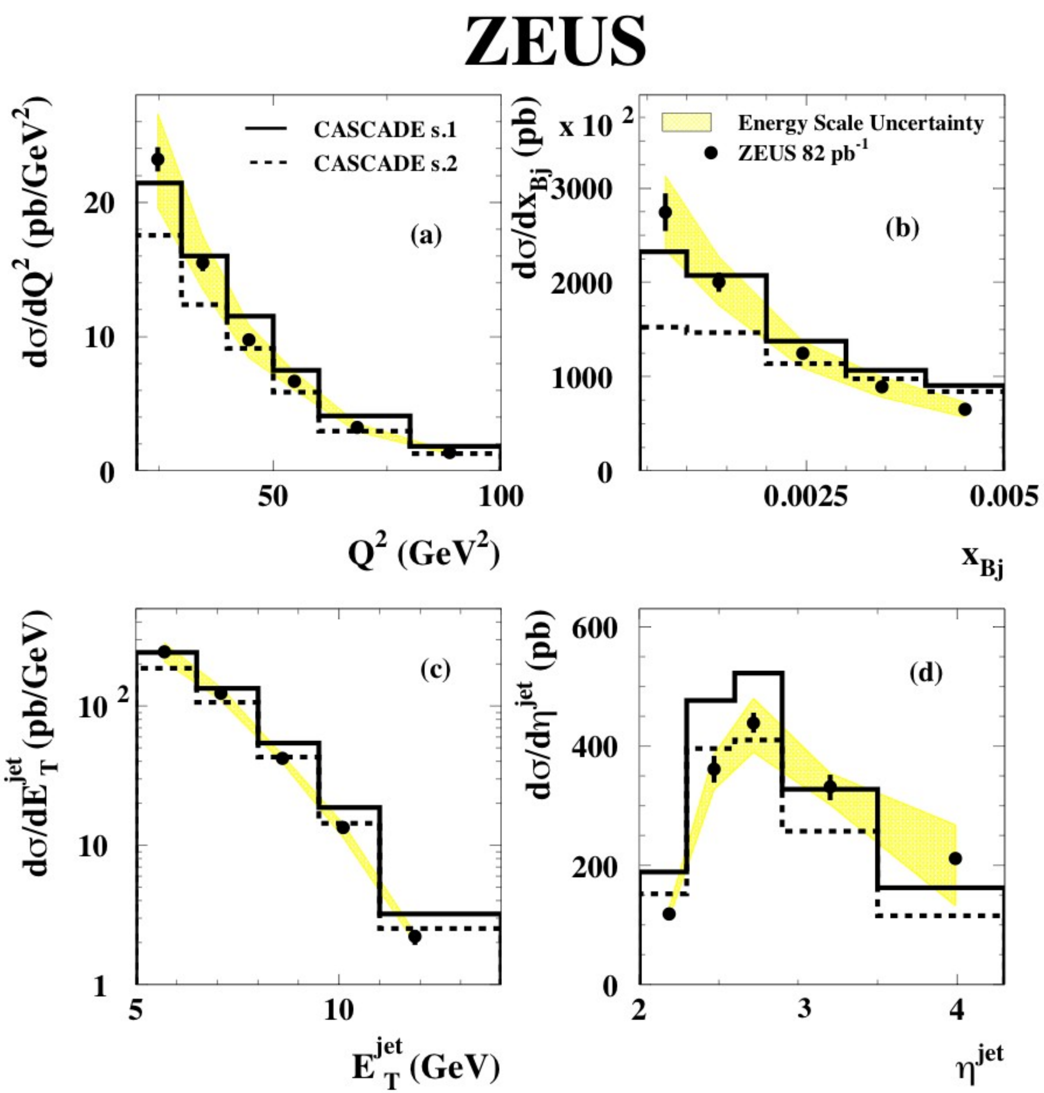


Two versions, with default tuning ("default") and retuned by H1 ("tuned")

- Lepto doesn't suffice
- Ariadne "default " overestimates high E_t^{jet}, overestimates high η^{jet} (proton remnant)
- Ariadne "tuned" is good

Inclusive Forward Jets

CASCADE vs data



Non singular term (in set 2) reduces cross section, but not improves agreement

Shape of all distributions disagrees with data

Shape is a problem

Trijet with a Forward Jet

Event & Jet selection

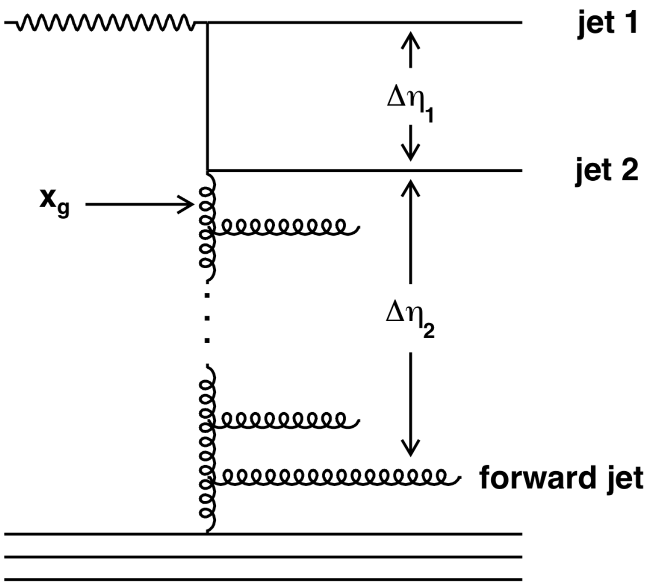
Kinematic range the same as for inclusive forward jets

Forward jet the same,

$0.5 < (E_t^{jet})^2/Q^2 < 2$ **constraint excluded**

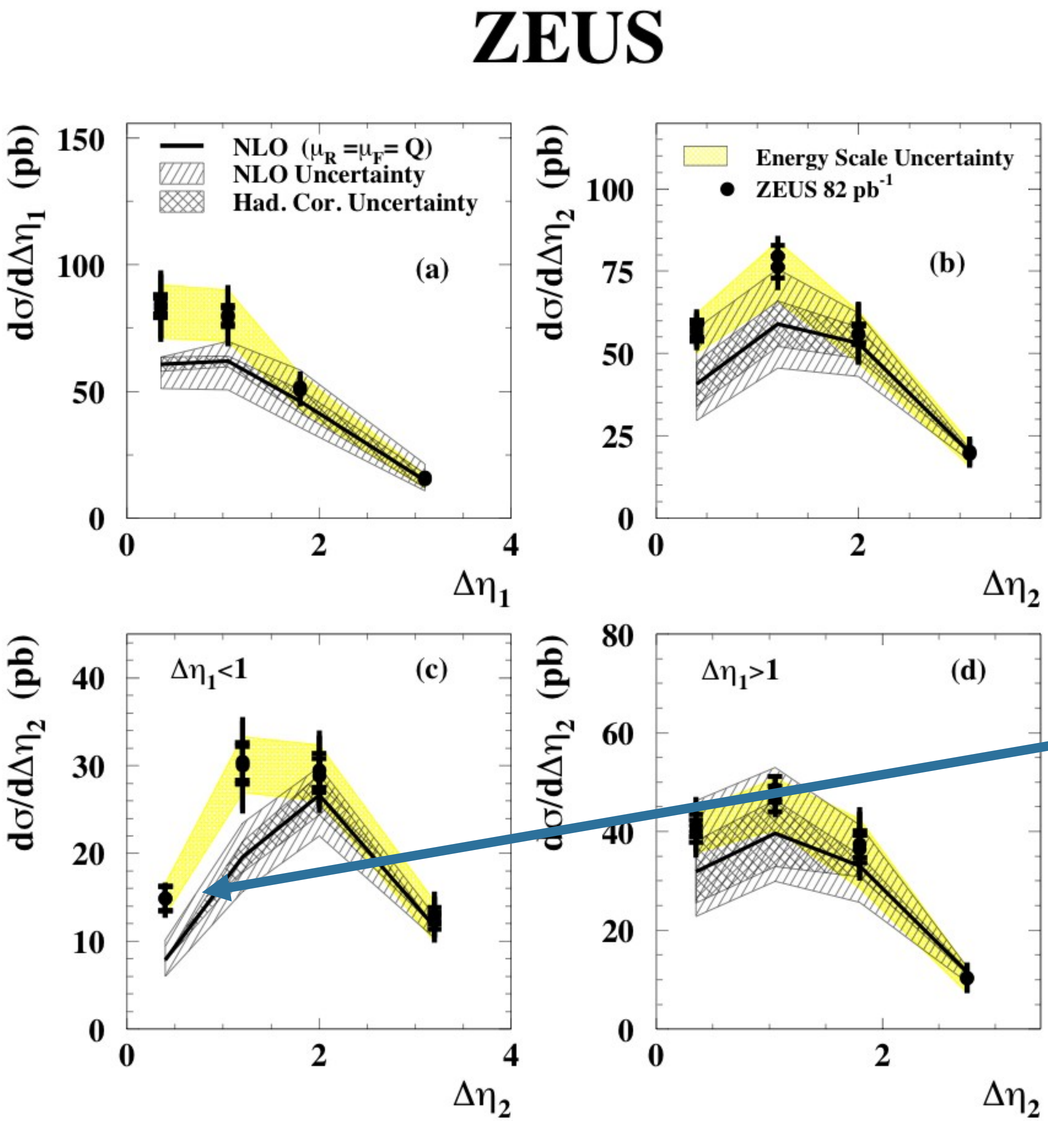
Two additional jets with $E_t^{jet} > 5$ GeV

$\eta_{el} < \eta_{jet\ 1} < \eta_{jet\text{-}2} < \eta_{forward\text{-}jet}$



Trijet with a Forward Jet

NLOJET++ vs data

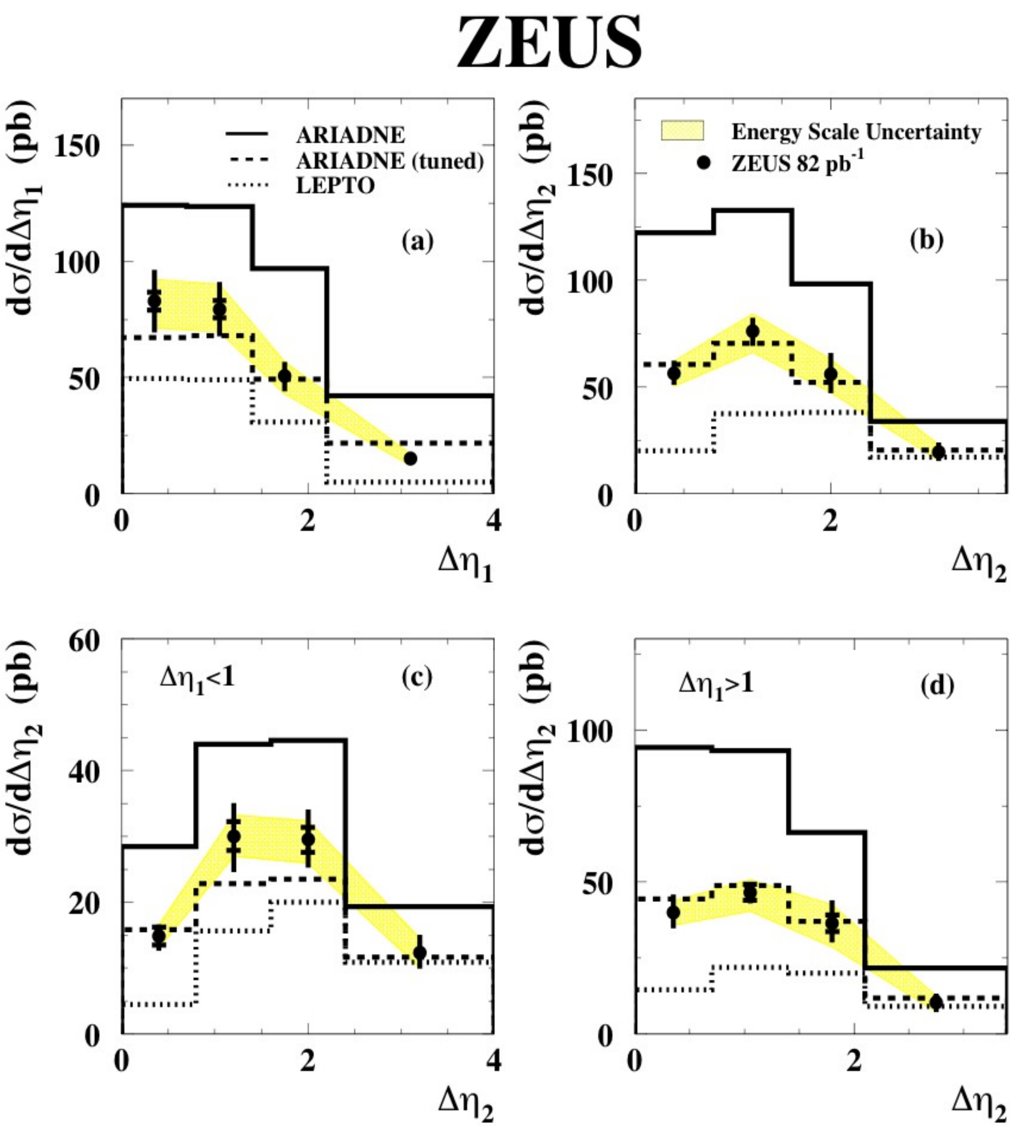


For NLOjet scales $\mu_R^2 = \mu_F^2 = Q^2$

Small $\Delta\eta_1$ and $\Delta\eta_2$ ➔ jets are most forward. At small x_{Bj} space is left for additional partons closer to the photon. NLOJET++ underpredicts many partons ➔ below data

Trijet with a Forward Jet

LEPTO & ARIADNE vs data



Lepto below data

Ariadne "default" pronouncedly above data –> too high multigluon emission rate

Ariadne "tuned" is fine

Summary & Conclusions

☎ ZEUS measured jets at small x_{Bj} in highly extended forward region

☎ Inclusive cross-sections of dijets and trijets without forward jets are satisfactorily described by collinear factorisation based NLO

☎ Correlations are more sensitive to parton dynamics, in particular they reveal failure of NLO for dijets, where only NNLO, i.e. $O(\alpha_s^3)$, suffices ⟹ four partons at HERA's lowest x_{BJ} are needed.

☎ Further insight provides addition to analysis of a forward jet, in particular η correlations for trijets with a forward jet reveal in certain phase space deficiency of $O(\alpha_s^3)$, here at least five partons are needed.

☎ Resummed DGLAP, realized by MC with LO matrix element and parton showers, LEPTO, yields about twice too low forward jet cross-sections.

☎ LO CCFM based MC, CASCADE, cannot fully describe data on forward jets, other sets of uPDF are to be tried (and/or more serious problems show up, i.e. lack of quarks).

☎ Only CDM (ARIADNE MC), featured by BFKL-like non-ordered in k_T parton cascade, is capable of successful description of the whole volume of data on forward jets. A problem could to be, nevertheless, that being based on phenomenology ARIADNE is too free in tuning.