HEP2003 Europhysics Conference in Aachen, Germany

Studies of Dijets Production in ep Interactions at HERA

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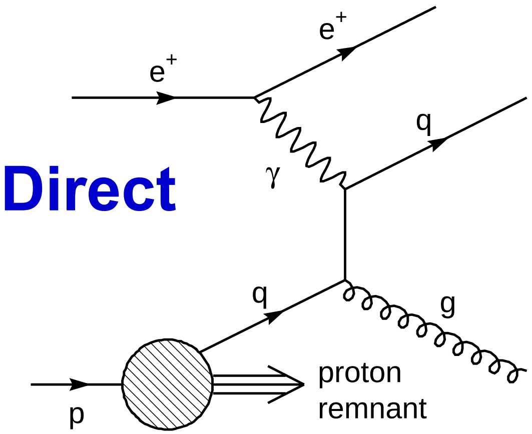
On behalf of the H1 & ZEUS Collaborations

Dijet Production at HERA

Photoproduction

$E_T^2 >> Q^2 \sim 0$

Direct

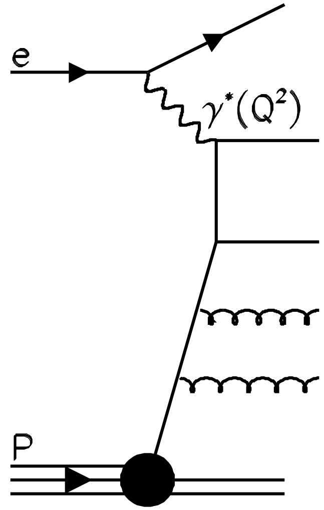


Deep Inelastic Scattering

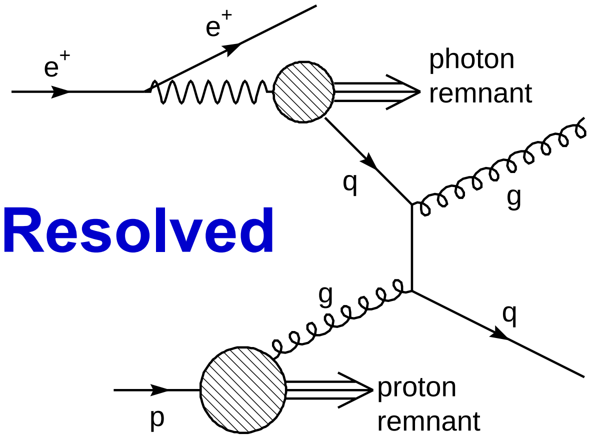
Low Q^2

$E_T^2 > Q^2 > 0$

$Q^2 >> m_p^2$



Resolved



x_γ: Fraction of γ momentum involved in collision

$x_\gamma < 0.75$: Resolved contribution enhanced

x_p: Fraction of P momentum involved in hard interaction

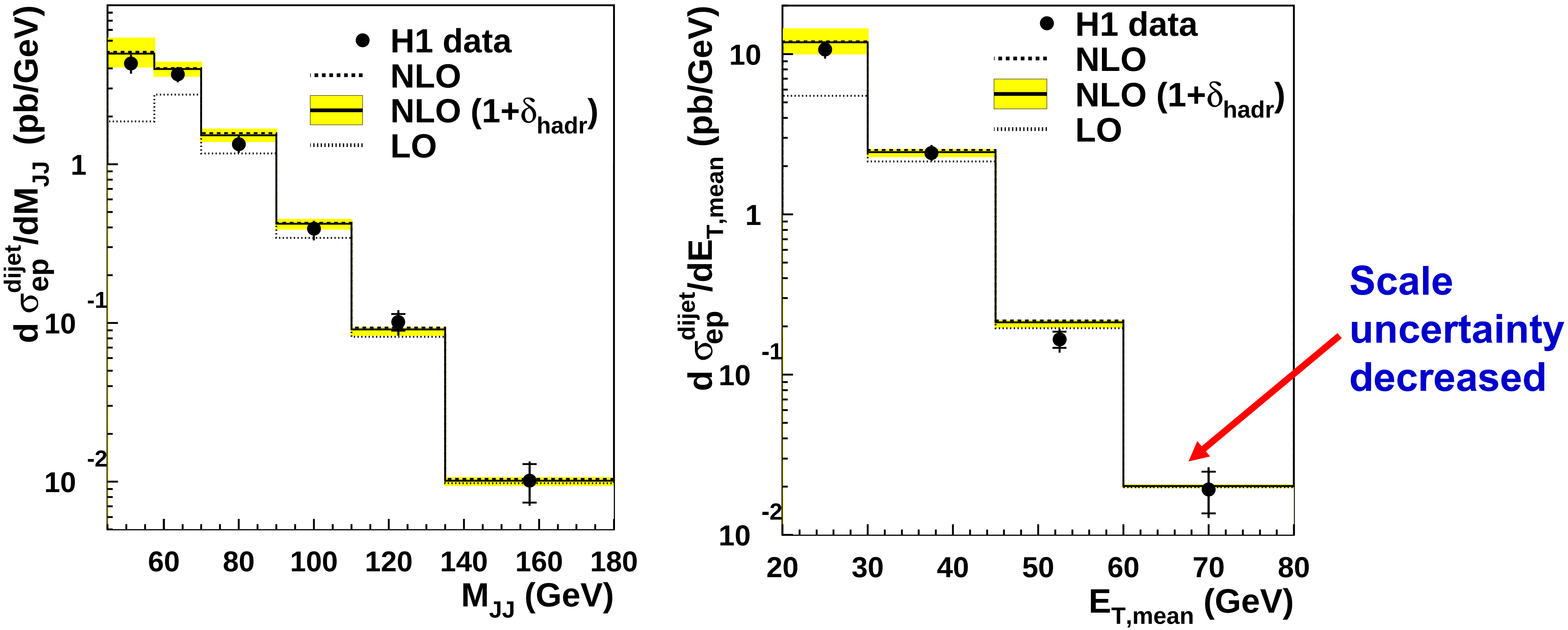
$$x_\gamma^{OBS} = \frac{\sum_{jets} E_T e^{-\eta}}{2yE_e}$$

: Fraction of γ momentum involved in the production of dijet system (Experimental estimation of x_γ)

Why Dijet

- ✓ At HERA, partons of the proton probe directly the quark and gluon density of the photon
  - A test of both proton PDFs and photon PDFs
  - Resolution scale of the probe is directly related to the transverse energy of the jets
- ✓ As photon's virtuality increases, it will begin to lack the time to develop a complex hadronic structure
  - Dijet events very sensitive to (virtual) photon structures and used to explore low Q^2 transition region
- ✓ Provide an ideal laboratory for Multijet study
  - Ratio of Trijet/Dijet cross section directly proportional to $O(\alpha_s)$

Dijet Cross Sections in Photoproduction – H1 Collaboration

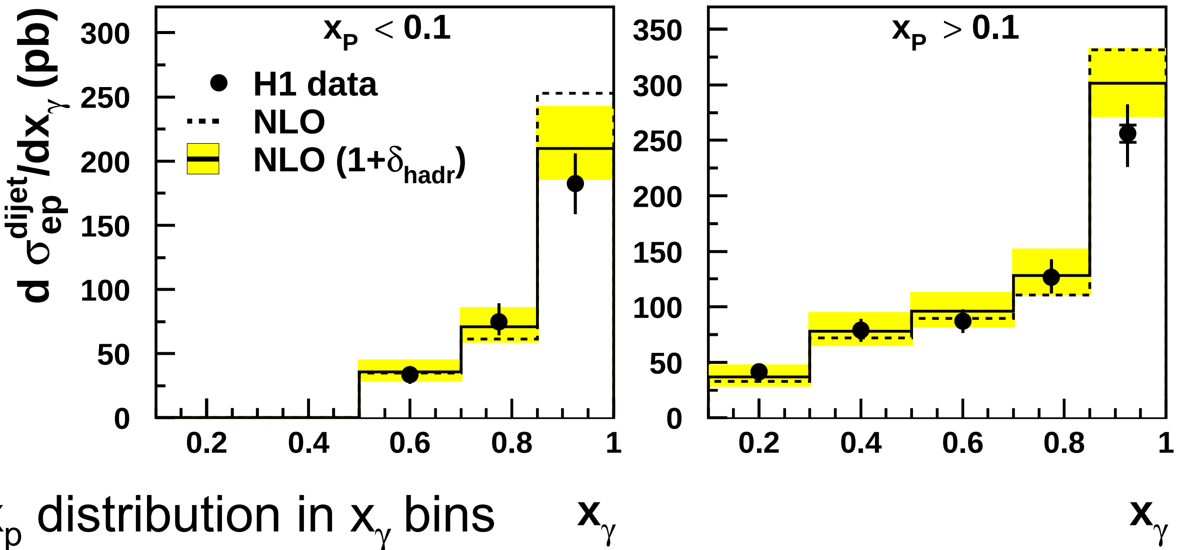


$Q^2 < 1$ GeV^2
$0.1 < y < 0.9$
$E_{T,max}$=Max($E_{T,1}$, $E_{T,2}$) > 25 GeV
$E_{T,second}$ > 15 GeV
$-0.5 < \eta_i < 2.5$

NLO calculation with LO hadronization corrections (parton $\rightarrow$ hadron) describes data up to the highest masses and transverse energy

Dijet Cross Sections in Photoproduction – H1 Collaboration

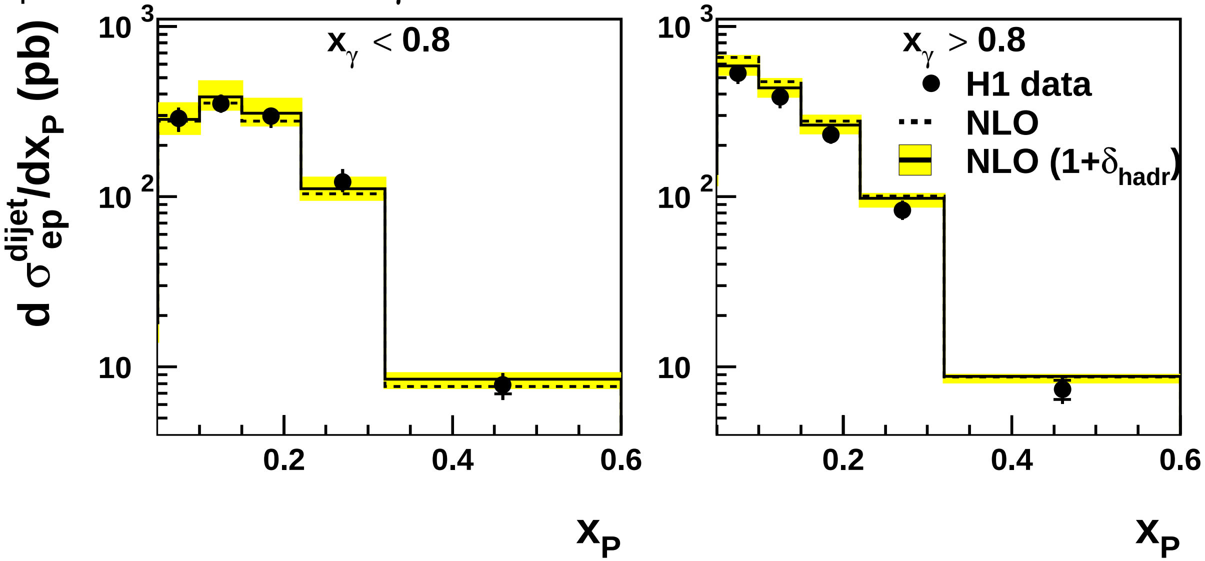
x_γ distribution in x_p bins



NLO QCD predictions agree well with data in a wide kinematics range, even at highest x_p (higher scale)

→ **Power of both proton and photon PDFs**

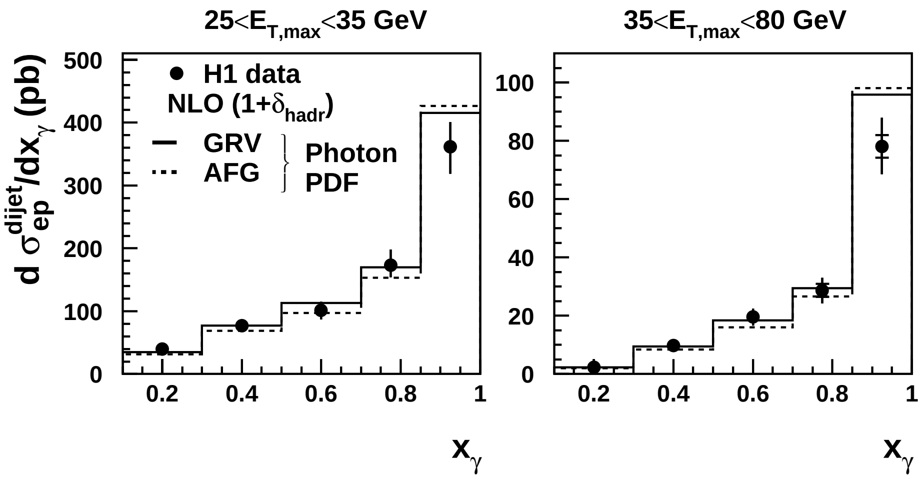
x_p distribution in x_γ bins

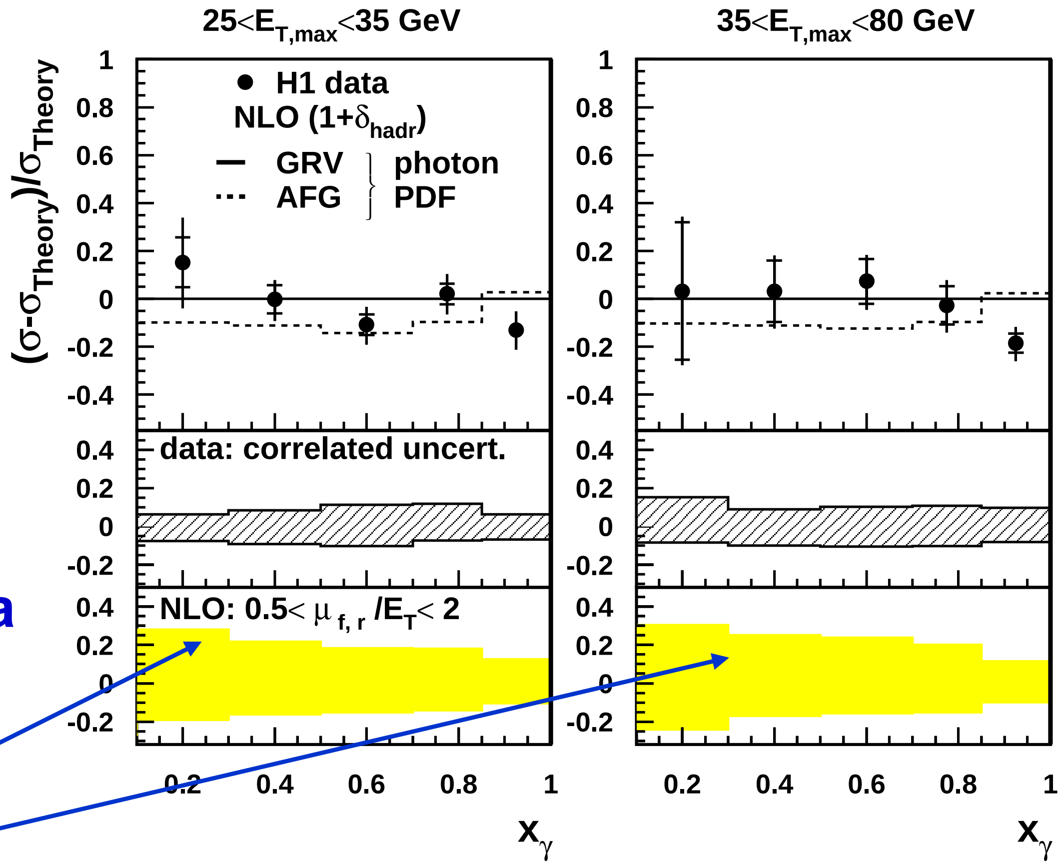


Photon PDF used (GRV) from different process (e^+e^-) and mostly at lower scales

→ **Universal PDFs**

Dijet Cross Sections in Photoproduction – H1 Collaboration





NLO predictions describes data well and vary only slightly with photon PDFs (GRV, AFG)

NLO scale uncertainties dominate! (vary $0.5 < \mu_{f,\,r} / E_T < 2$)

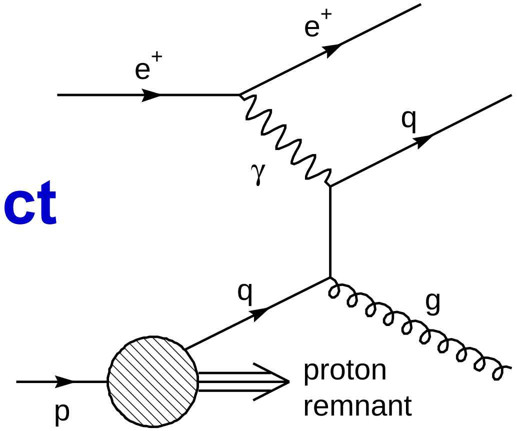
NLO predictions shows agreement with data within uncertainties
→ Useful to future constrain the existing photon PDFs

Dijet Cross Sections at low Q^2
H1 Collaboration

DGLAP

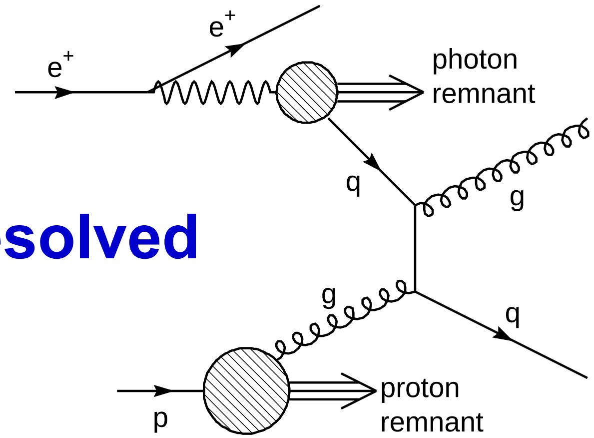
CCFM

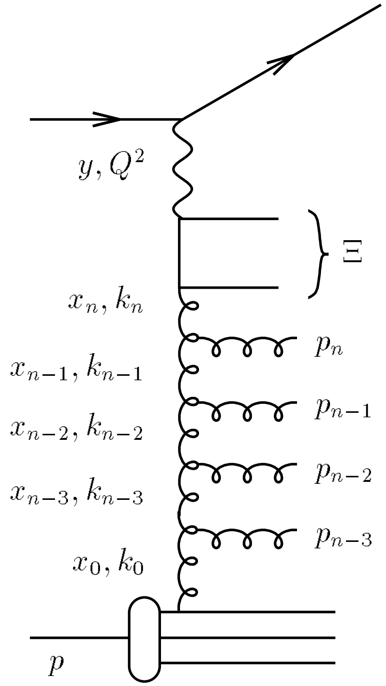
Direct



alternate approach

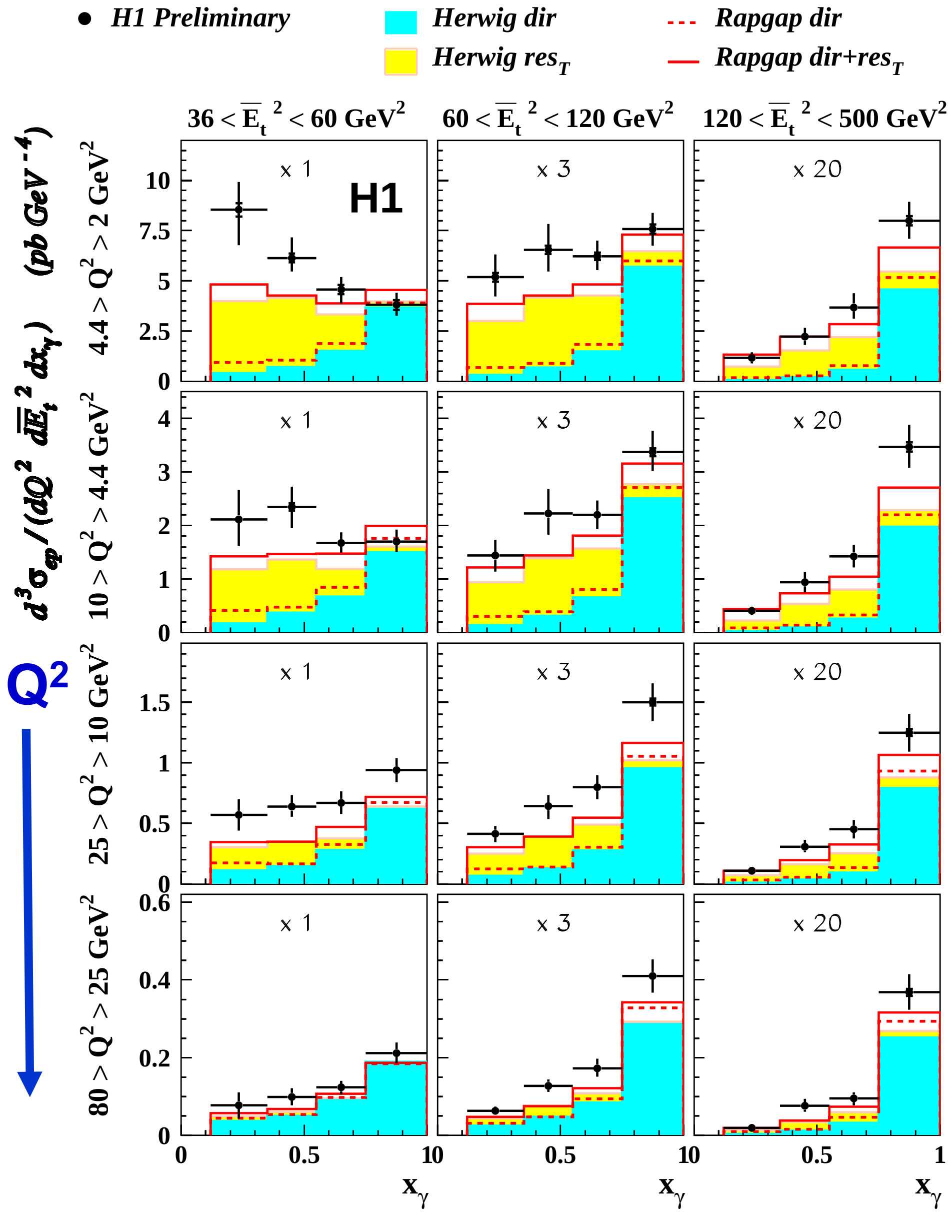
Resolved





CASCADE MC based on CCFM evolution: K_T unordered gluon emission and no concept of photon structure

Dijet Cross Sections at low Q^2
H1 Collaboration



$2\ \text{GeV}^2 < Q^2 < 80\ \text{GeV}^2$
$0.1 < y < 0.85$
$E_T^{jet1,2} \geq 5$ GeV
$E_{T,mean}$ ($\overline{E}_T$) > 6 GeV
$-2.5 < \eta^{jet1,2} < 0$

Direct or Resolved: LO

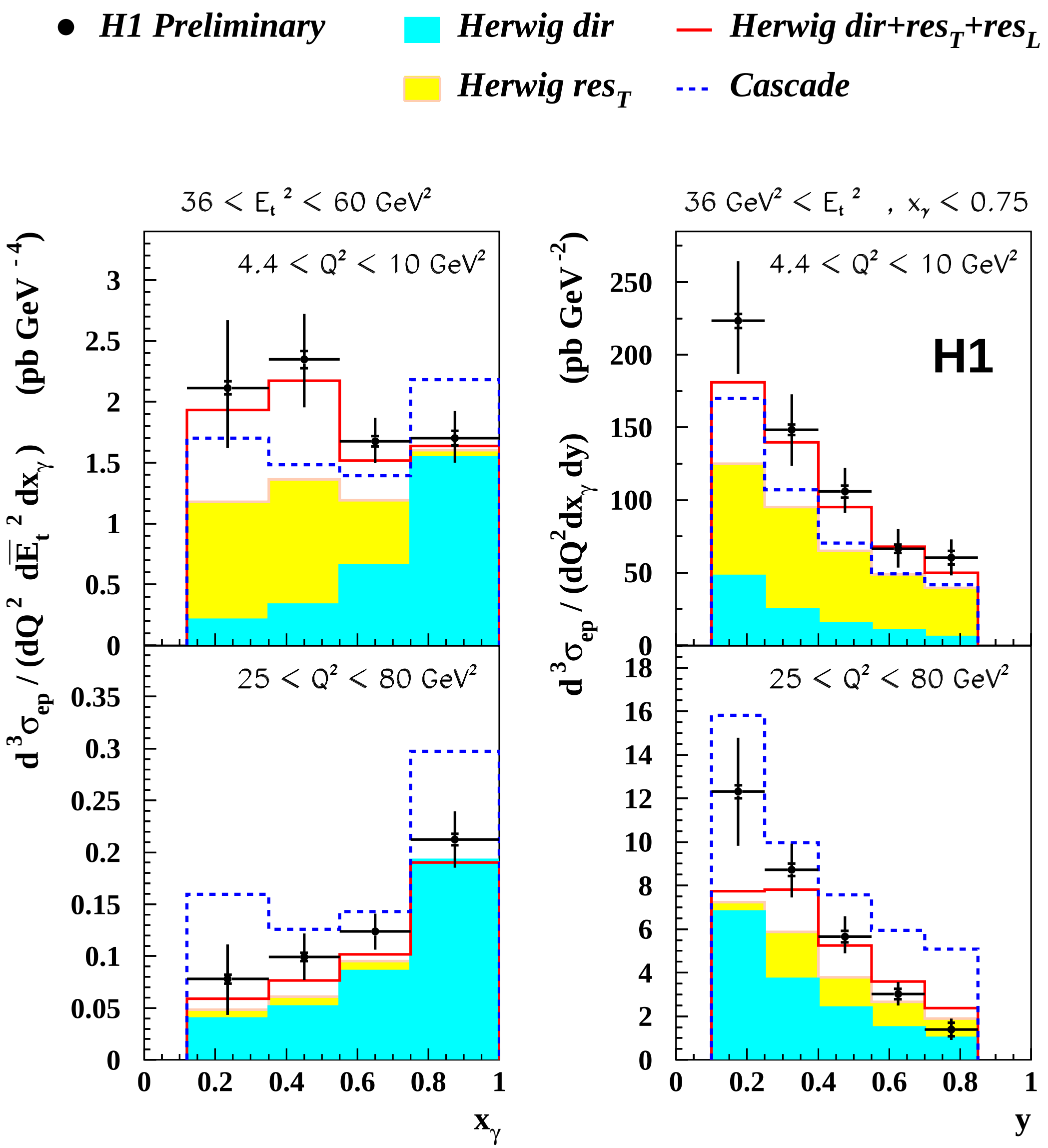
$Q^2 > \overline{E}_T^{\,2}$: Resolved process not needed

$Q^2 < \overline{E}_T^{\,2}$: Direct-only process not enough to describe the data, resolved contribution needed

⇓

Ratio $\overline{E}_T^{\,2}/Q^2$ governs the relevance of resolved photon contribution rather than Q^2 itself

Dijet Cross Sections at low Q^2
H1 Collaboration

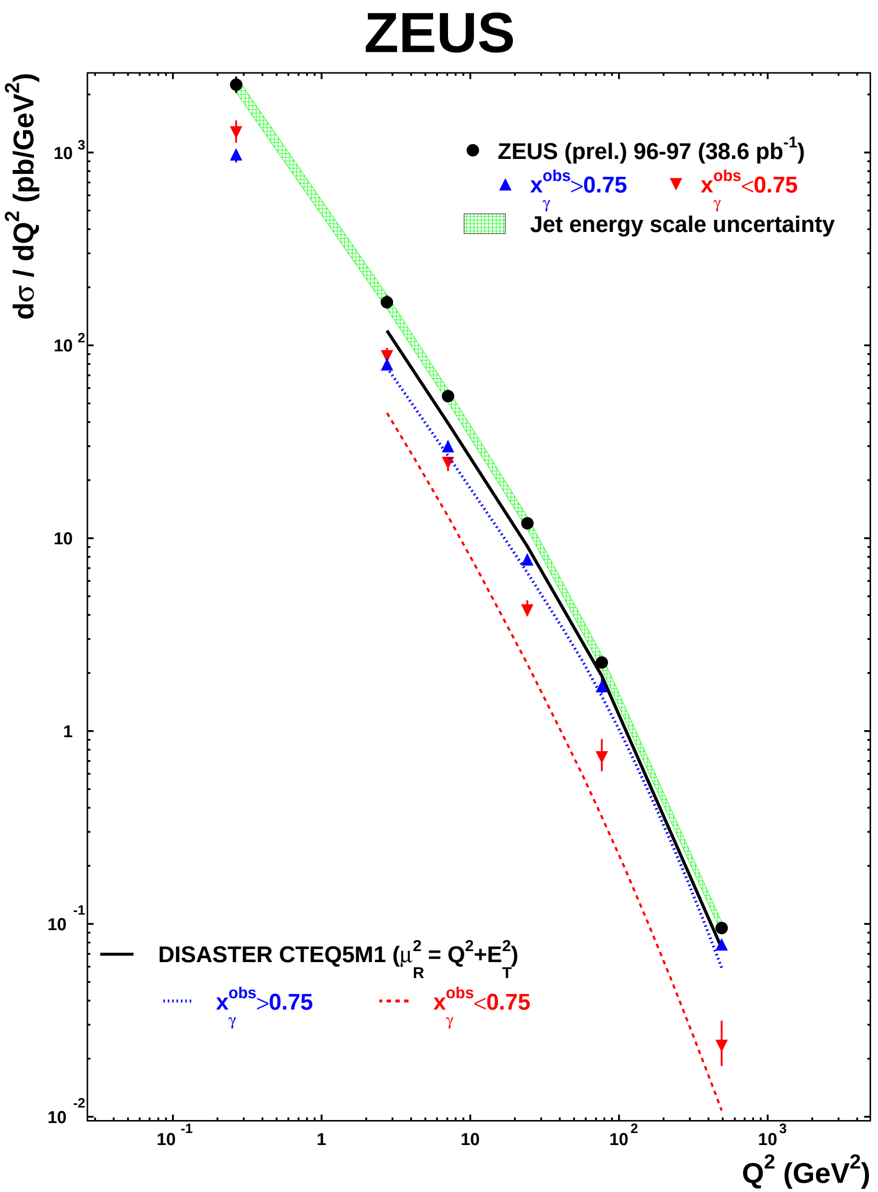


With resolved γ^*_L added, discrepancy at low x_γ and low y becomes smaller

HERWIG dir + resγ^*_T + resγ^*_L: best agreement with data

CASCADE describes data reasonably but not perfectly

The Q^2 dependence of dijet production – Zeus Collaboration



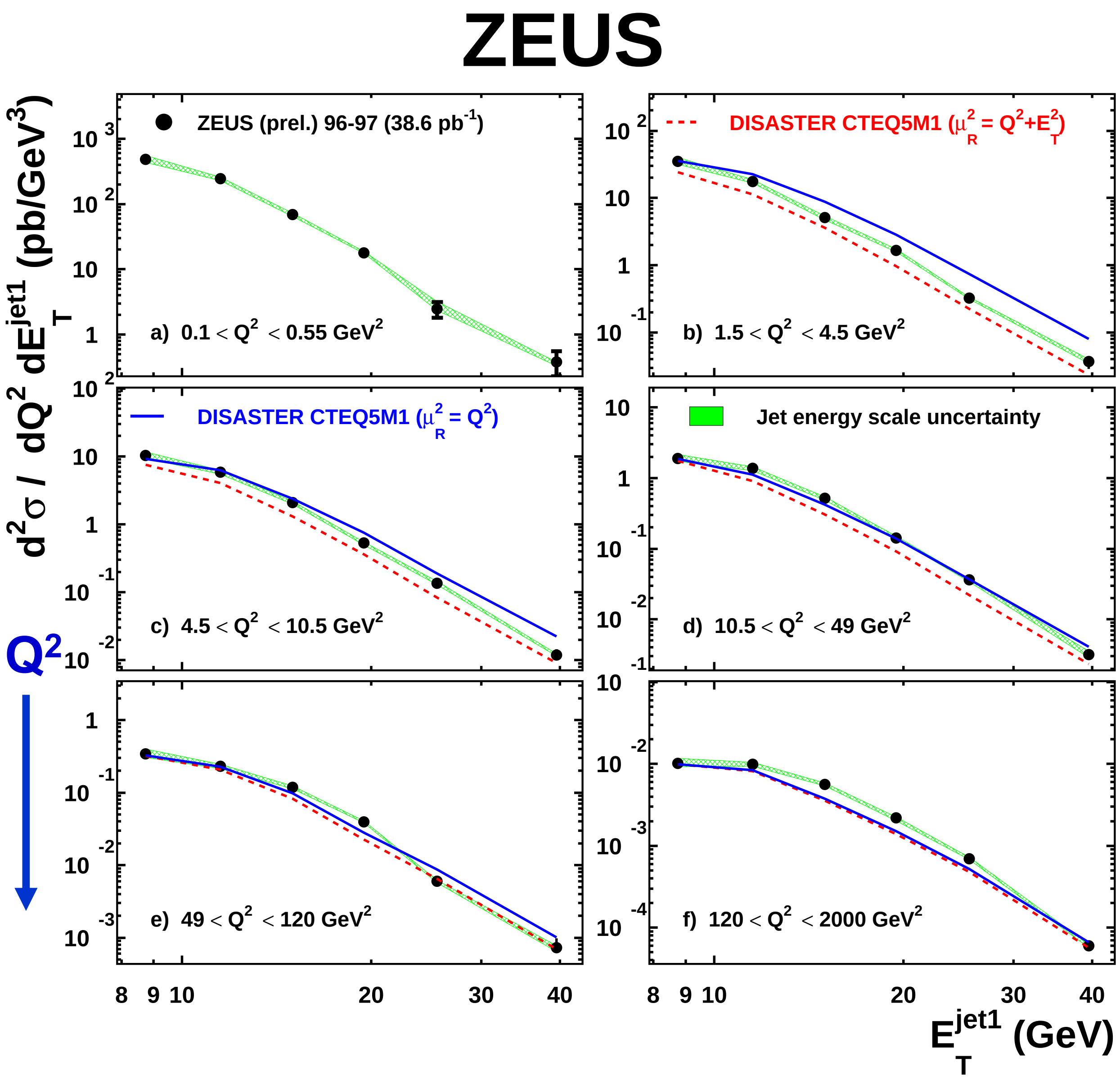
Direct or Resolved: NLO

DISASATER NLO calculation contains no hadronic photon structure

Renormalization scale $\mu_R^2 = Q^2 + E_T^2$: DISASTER NLO tends to lie below the data

For $x_\gamma^{OBS} > 0.75$ data is well described, discrepancy mainly with $x_\gamma^{OBS} < 0.75$

The Q^2 dependence of dijet production – Zeus Collaboration

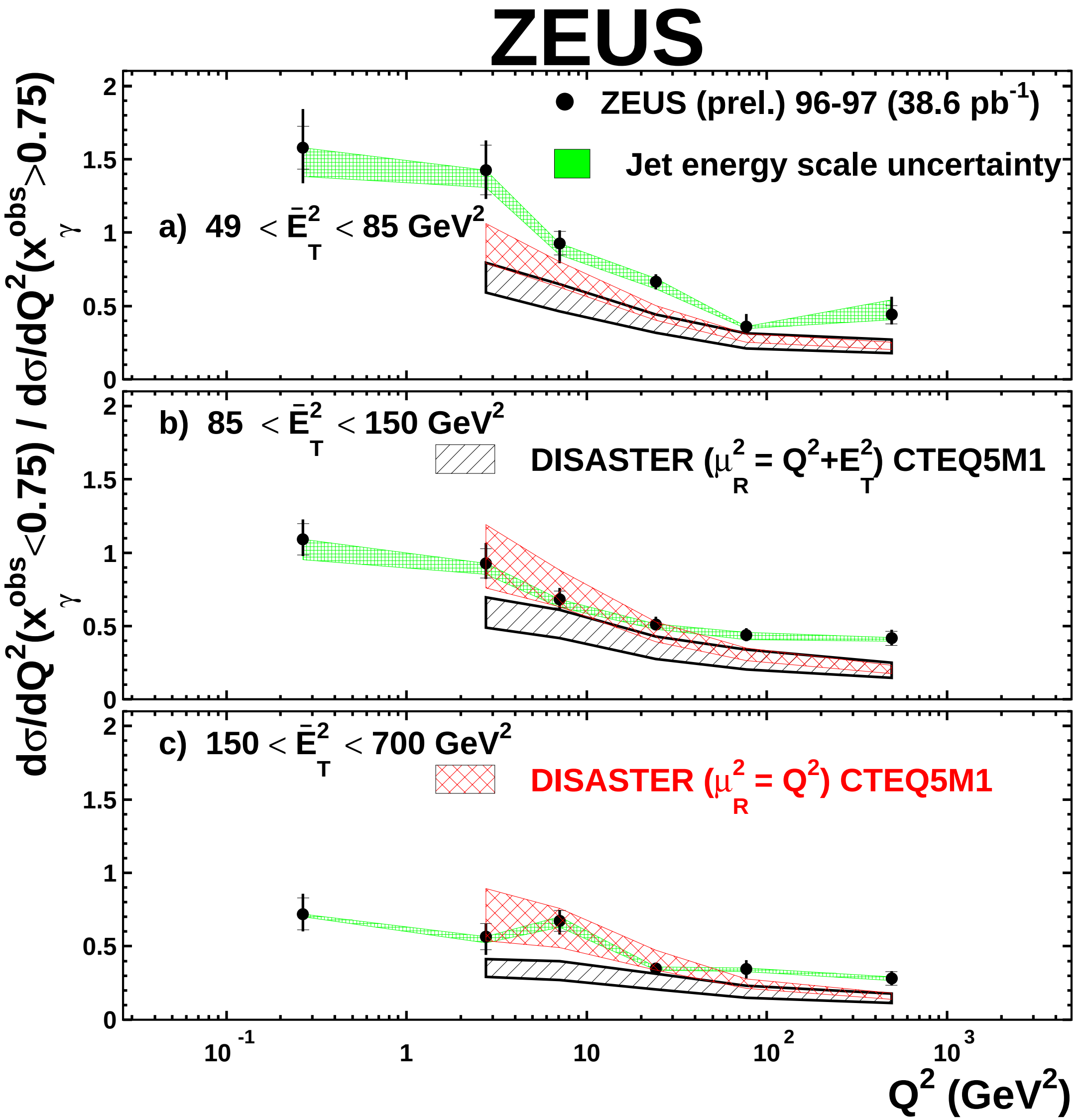


Two hard QCD scales, $\mu_R{}^2 = Q^2 + \overline{E}_T{}^2$ and $\mu_R{}^2 = Q^2$

$\mu_R{}^2 = Q^2$ raises DISASTER NLO prediction

Increasing Q^2: two scales give similar results

The Q^2 dependence of dijet production – Zeus Collaboration



Some experimental and theoretical uncertainties cancel in:

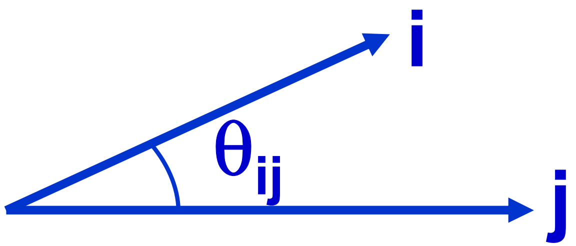
$$R = \frac{\frac{d\sigma}{dQ^2}(x_\gamma^{OBS} < 0.75)}{\frac{d\sigma}{dQ^2}(x_\gamma^{OBS} > 0.75)}$$

Data falls with Q^2, $\overline{E}_T^2$: resolved effects suppressed as photon virtuality increases

DISASTER NLO describes data except for low $\overline{E}_T^2$ and Q^2
→ compatible with the idea that resolved photon contribution needed for scale as high as $Q^2 \sim 10$ GeV^2

Dijet Electroproduction at Small Jet Separation - H1 Collaboration

NLO QCD calculations accurately describe dijet production in DIS?



Modified Durham algorithm:

$$k_{Tij}^{2} = 2min\{E_i^{2}, E_j^{2}\}(1-cos\theta_{ij})$$

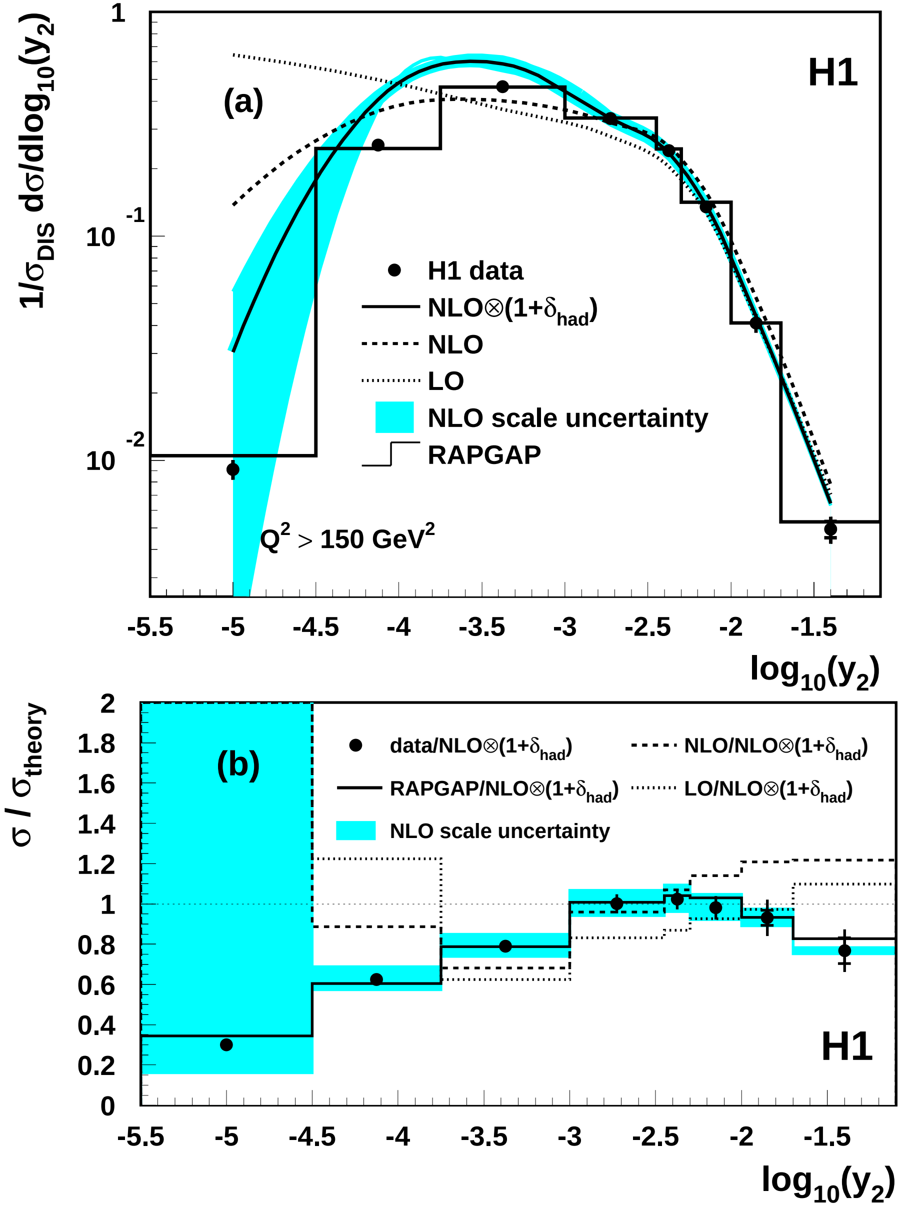
i, j: any of the two final dijet or remnant jet

M: invariant mass of all objects of jet algorithm

$$y_2 = \frac{\min\limits_{i,j,i\neq j} k_{Tij}^{2}}{M^2}$$

Large jet distances correspond to large y_2

Dijet Electroproduction at Small Jet Separation - H1 Collaboration



$150\ \mathrm{GeV}^2 < Q^2$

$0.1 < y < 0.7$

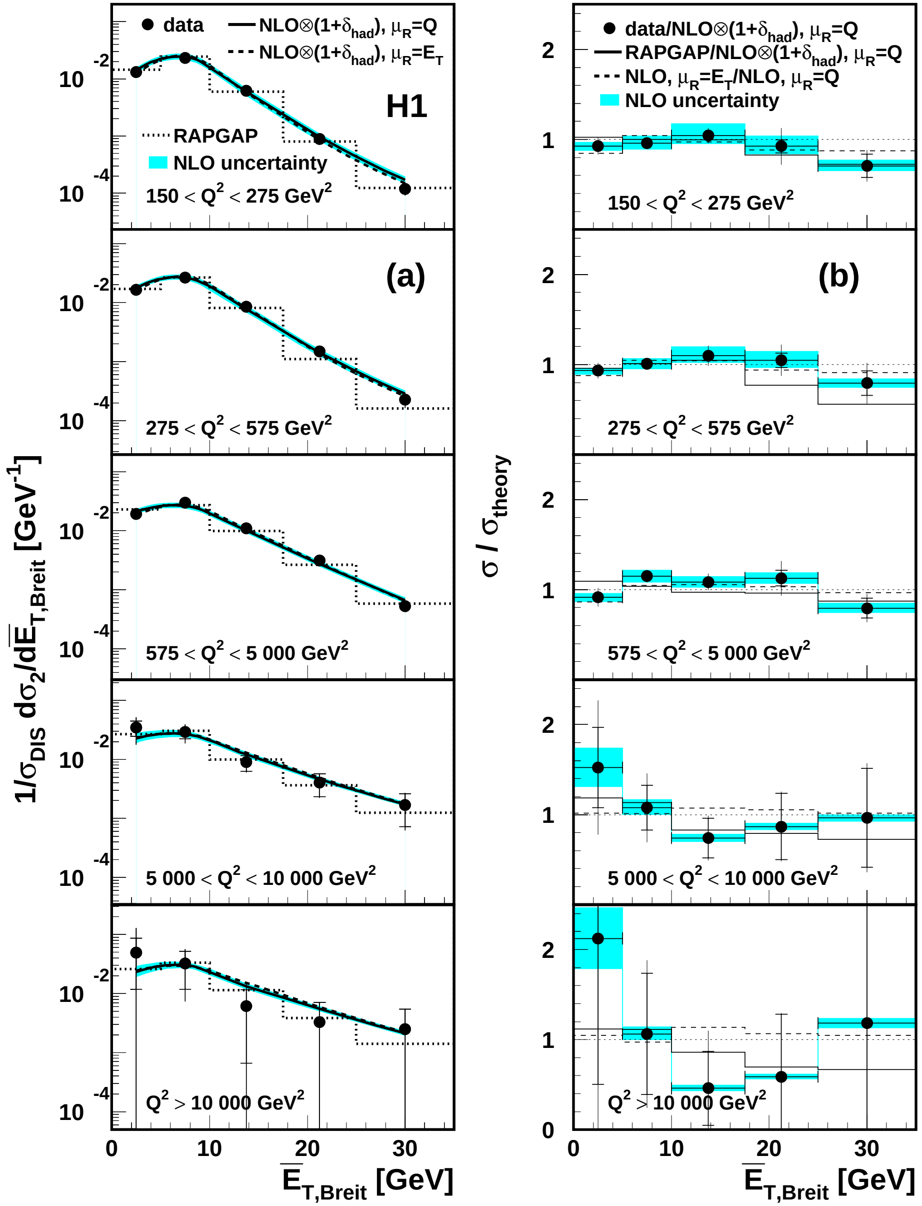
$150^\circ < \theta_e$

$10^\circ < \theta_{jet} < 140^\circ$

Good description of data for $y_2 > 0.001$

RAPGAP describes data over full range
→Combination of parton showers and Lund String hadronization accurately models multi-parton emissions

Dijet Electroproduction at Small Jet Separation - H1 Collaboration



Take y_2 > 0.001 sample:
1/3 of the selected DIS events

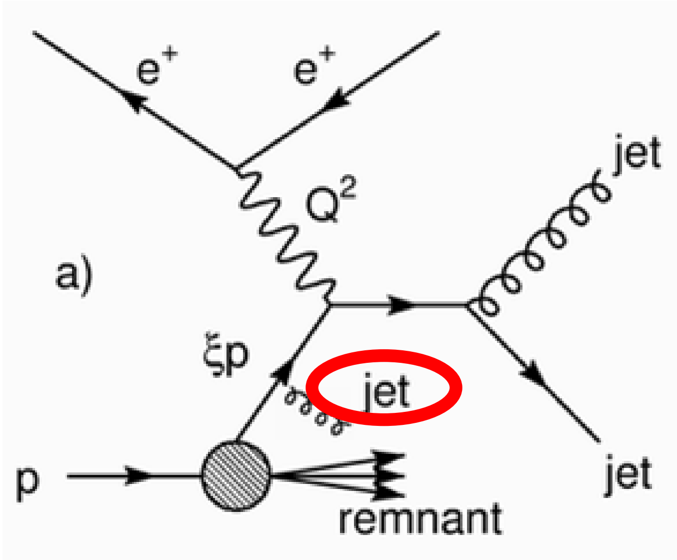
Two choices of renormalization scale: μ_R=Q and μ_R=$\overline{E}_{T\ Breit}$
Small difference in NLO predictions

NLO describes $\overline{E}_{T\ Breit}$ distribution well, including region $\overline{E}_{T\ Breit}$ < 5 GeV
RAPGAP also describes data well

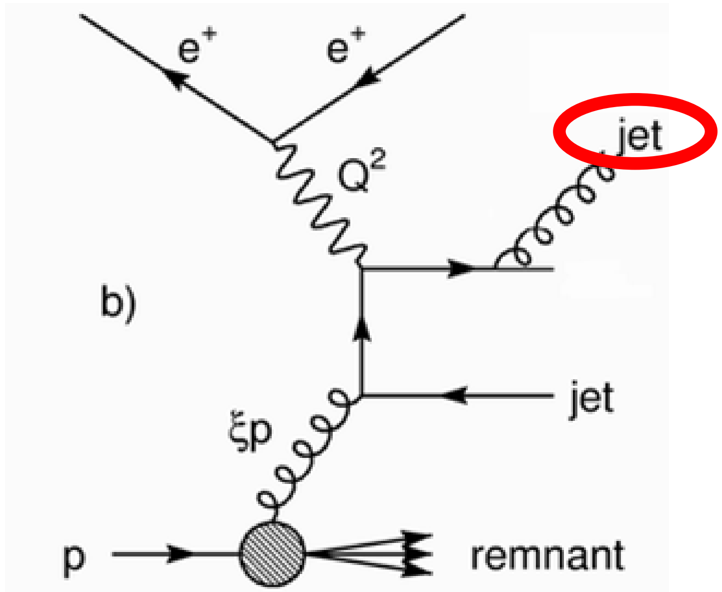
Multijet Production in DIS
Zeus Collaboration

- **Add a gluon radiation to dijet or split a gluon to $q\bar{q}$**

  $\rightarrow$ Direct test of QCD



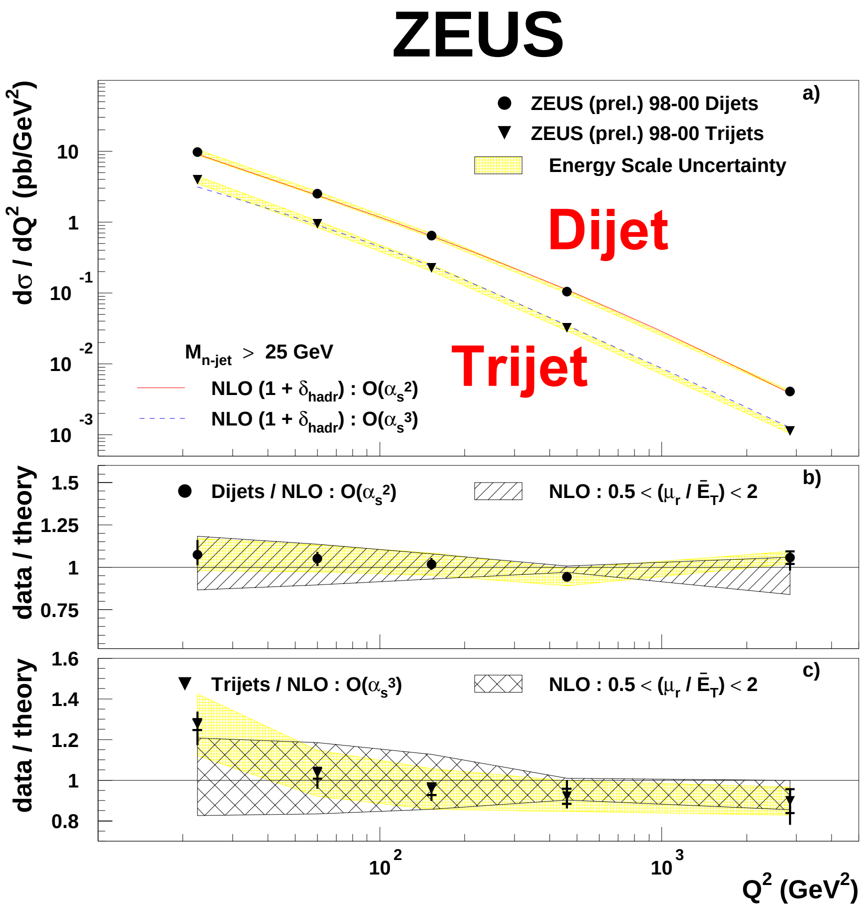
- **In the ratio $\sigma_{trijet}/\sigma_{dijet} = O(\alpha_s)$, cancellation of some experimental and theoretical uncertainties.**

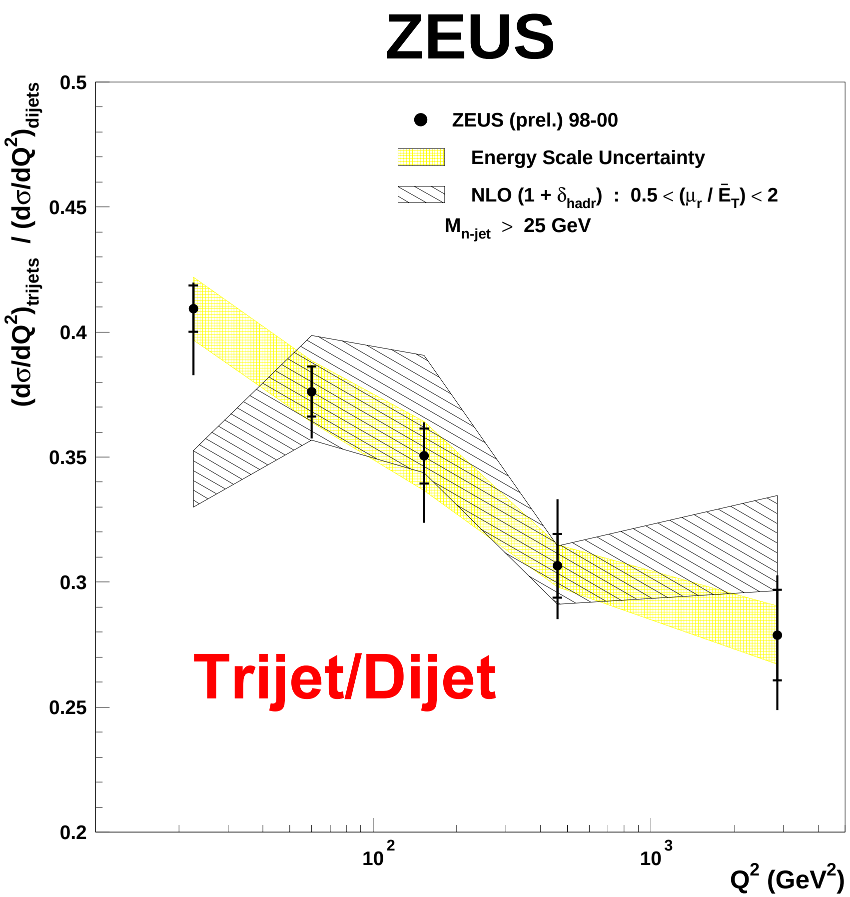


- **Measure α_s at a wide range of Q^2**

Multijet Production in DIS
Zeus Collaboration

Scale $\mu_r = \mu_f = \overline{E}_{T\,Breit}$





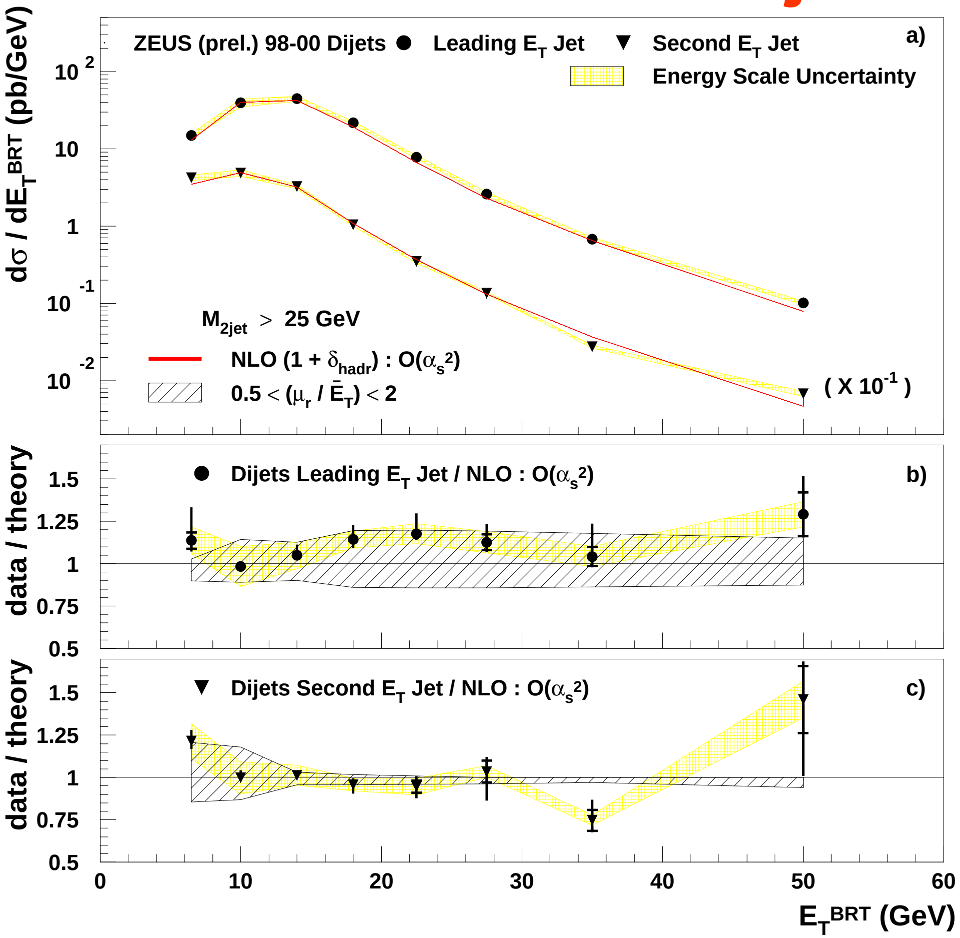
$R_{3/2} = \sigma_{trijet}/\sigma_{dijet}$

$10\ GeV^2 < Q^2 < 5000\ GeV^2$
$0.04 < y < 0.6$, $\cos\gamma_{had} < 0.7$
$E_{T\,Breit} > 5$ GeV, $-1 < \eta_{Lab} < 2.5$
invariant mass $M_{JJ} > 25$ GeV

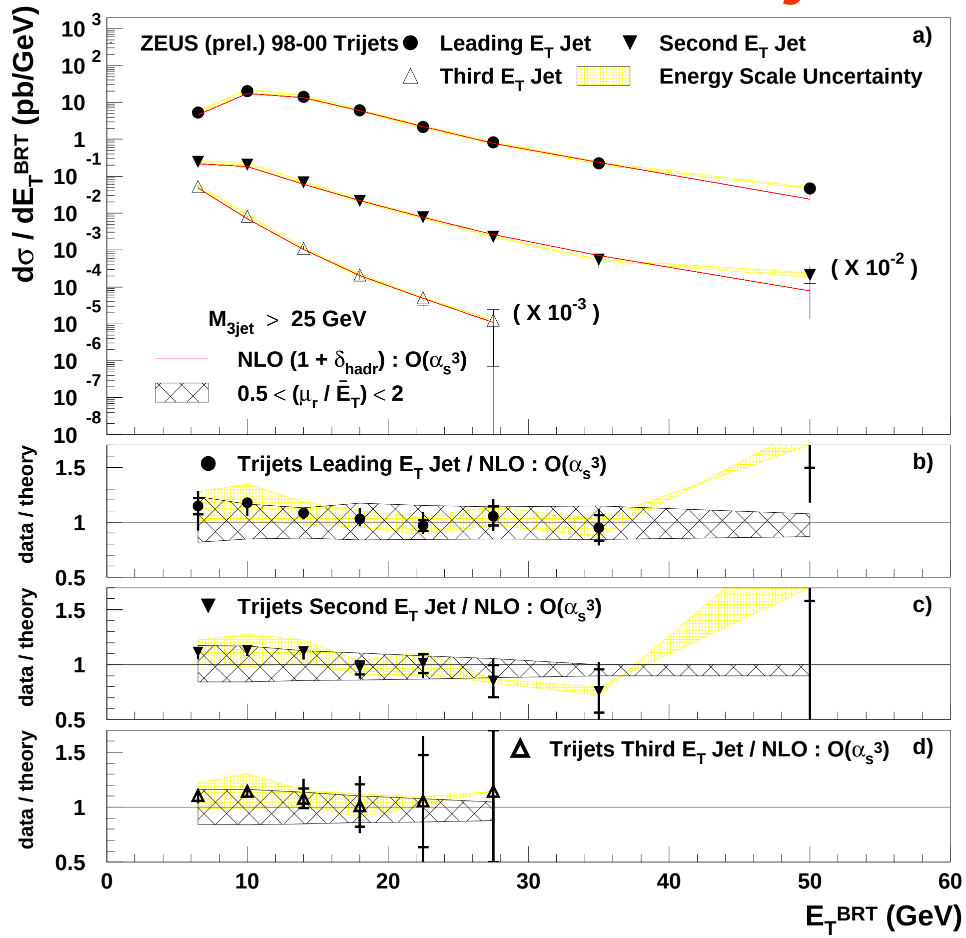
NLOJET describes both dijets & trijets well over 3 orders of magnitude
Cross section ratio describes data with substantially decreased uncertainties

Multijet Production in DIS
Zeus Collaboration

ZEUS Dijet



ZEUS Trijet



Jets ordered in $E_{T\ Breit}$

NLO describes data well

Summary and Outlook

✓ At HERA, precise measurements spanning a large of photon virtualities, including the transition region from photoproduction to the deep inelastic scattering, significantly constrain the parton densities in photon structure

✓ At high E_T theoretical uncertainties are small while at low Q^2 and low x_γ theoretical uncertainties dominate, theoretical developments needed