14^{th} - 18^{th} **April 2004**

Dijets in DIS and Photoproduction

DIS 2004 - Štrbské Pleso, High Tatras, Slovakia

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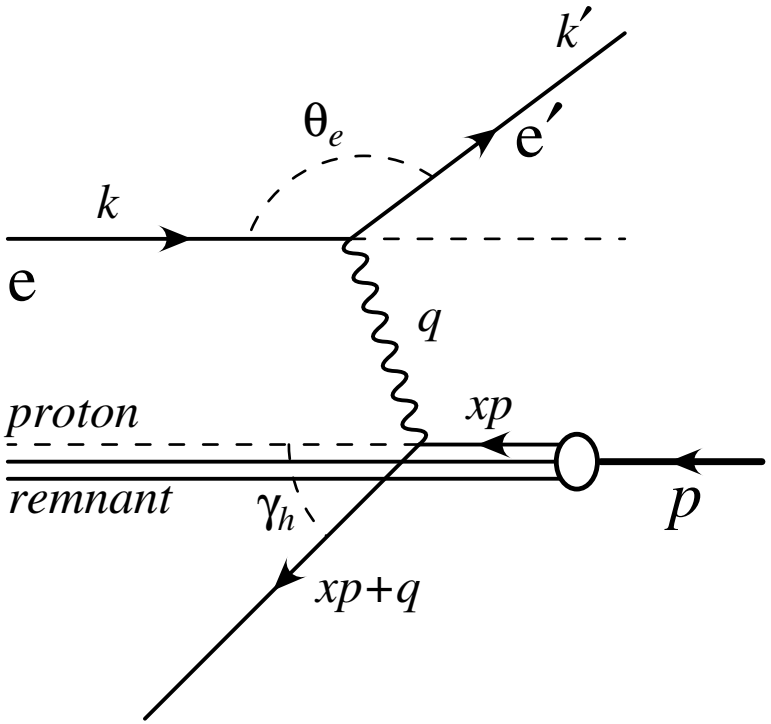
Introduction

- HERA kinematics.
- Virtual Photon structure.
- Dijet production.
- Event selection.
- Theoretical predictions.
- Results.
- Summary.

HERA Kinematics

▷ **HERA collides 27.5 GeV $e^{\pm}$ with 820 GeV protons**

$$\rightarrow \sqrt{s} = 300 \text{ GeV}$$



$$ep \rightarrow e'X$$

Q^2 photon virtuality

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

x fraction of proton's momentum carried by struck parton

$$x \equiv \frac{Q^2}{2p.q}$$

y inelasticity

$$y \equiv \frac{q.p}{k.p}$$

Virtual Photon Structure

- **Photon wave function has two components:**

  $\rightarrow |\gamma\rangle = |DIRECT\rangle + |RESOLVED\rangle$

  $\rightarrow |RESOLVED\rangle = |ANOMALOUS\rangle + |VDM\rangle$

  - ▷ **Anomalous from photon fluctuating into** $\mathrm{q\overline{q}}$ **pair:** $\gamma \rightarrow \mathrm{q\overline{q}}$**.**

    $\rightarrow \sim \log(\mu^2/\mathrm{Q}^2)$

  - ▷ **VDM from QCD emission in colour field of the** $\mathrm{q\overline{q}}$ **pair:** $\gamma \rightarrow \mathrm{q\overline{q}} \rightarrow V$**.**

    $\rightarrow \sim \mathrm{Q}^{-4}$

- **Experimentally differentiate between the two using** x_γ^{OBS}**:**

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

$x_\gamma^{\mathrm{OBS}} < 0.75 \rightarrow$ **"Resolved Enhanced"**

$x_\gamma^{\mathrm{OBS}} > 0.75 \rightarrow$ **"Direct Enhanced"**

Dijet Production

- **Opportunity to investigate wide range of interesting physics:**
  - ▷ Q^2 **evolution of "resolved" photon contribution to jet cross section?**

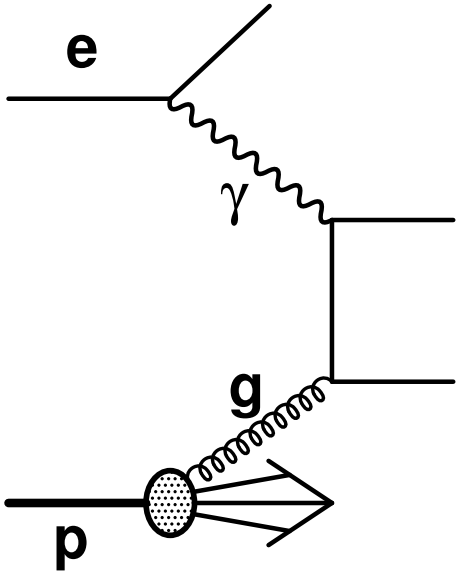
$$R = \frac{\sigma(x_\gamma^{\mathrm{OBS}}<0.75)}{\sigma(x_\gamma^{\mathrm{OBS}}>0.75)}$$

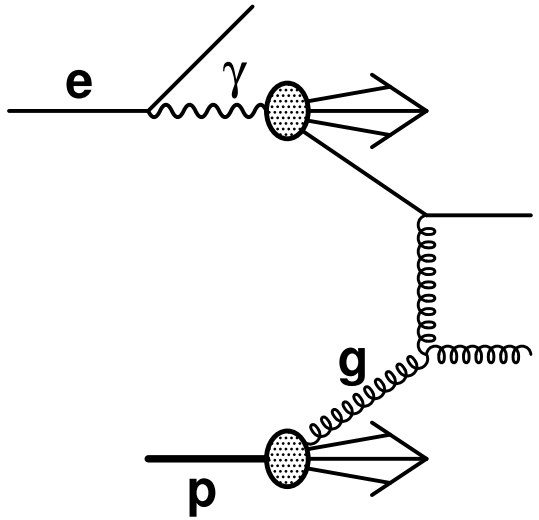
  - ▷ **Multiscale effects in transition from photoproduction to DIS?**

$\rightarrow$ Q, E_T,(m_q)**?**

  - ▷ **Theoretical uncertainties?**

$\rightarrow$ **Size of terms beyond NLO?**





Cross Section Definition.

1996-1997 data set 38.6 pb^{-1}.

Dijet cross sections defined in the photon-proton CMS with:

$$E_T^{jet1,2} > 7.5, 6.5 \text{ GeV}$$
$$-3.0 < \eta^{jet} < 0.0$$
$$0.2 < y < 0.55$$

Dijet cross sections measured:

$$d^2\sigma/dQ^2$$
$$d^2\sigma/dQ^2 dE_T^{jet1}$$
$$d^2\sigma/dQ^2 d\eta^F$$
$$R = \sigma(x_\gamma^{OBS} < 0.75)/\sigma(x_\gamma^{OBS} > 0.75)$$

$$49.0 < \overline{E_T}^2 < 85.0 \text{ GeV}^2$$
$$85.0 < \overline{E_T}^2 < 150.0 \text{ GeV}^2$$
$$150.0 < \overline{E_T}^2 < 700.0 \text{ GeV}^2$$

Q^2 Regions:

- $0.0 < Q^2 < 1.0 \text{ GeV}^2$
- $0.1 < Q^2 < 0.55 \text{ GeV}^2$
- $1.5 < Q^2 < 4.5 \text{ GeV}^2$
- $4.5 < Q^2 < 10.5 \text{ GeV}^2$
- $10.5 < Q^2 < 49.0 \text{ GeV}^2$
- $49.0 < Q^2 < 120.0 \text{ GeV}^2$
- $120.0 < Q^2 < 2000.0 \text{ GeV}^2$

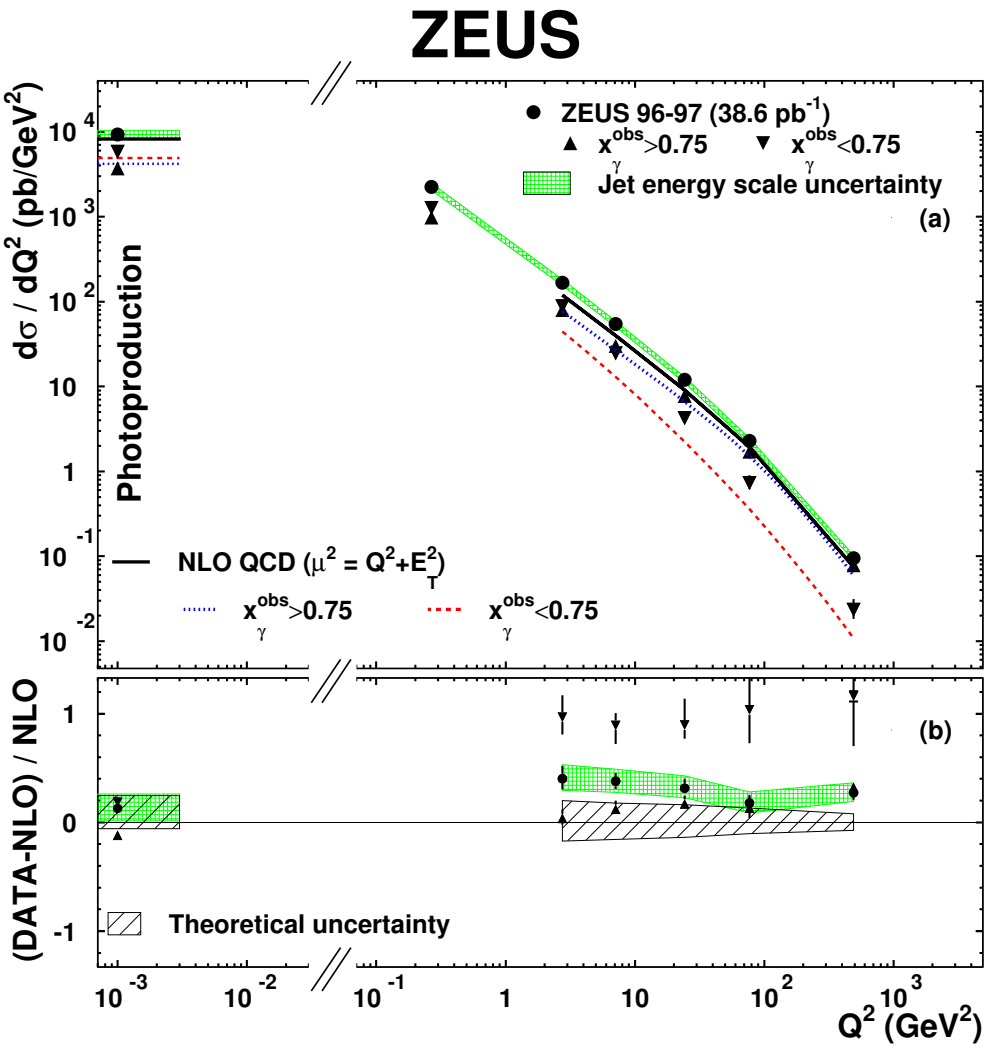
$$\overline{E_T}^2 = \left(\frac{E_T^{jet1} + E_T^{jet2}}{2}\right)^2$$

Theoretical Predictions.

- **Photoproduction NLO calculation performed using Frixione-Ridolfi (FR).**
  - ▷ **CTEQ5M1 proton PDF**
  - ▷ **GRV photon PDF**
  - ▷ $\mu_{\mathrm{F}}^2 = \mu_{\mathrm{R}}^2 = \mathrm{E}_{\mathrm{T}}^2$
- **DIS NLO calculations performed with DISASTER++ (DISENT)**
  - ▷ **Point-like processes only** $\rightarrow$ **CTEQ5M1 proton PDF**
  - ▷ $\mu_{\mathrm{F}}^2 = \mu_{\mathrm{R}}^2 = \mathrm{Q}^2$ **+** $\mathrm{E}_{\mathrm{T}}^2$ **and** $\mu_{\mathrm{F}}^2 = \mu_{\mathrm{R}}^2 = \mathrm{Q}^2$
- **Theoretical uncertainties estimated:**
  - ▷ **Terms beyond NLO** $\rightarrow$ **varying** μ **by factors 2 and 0.5** $(7 - 20\%)$
  - ▷ **Hadronisation corrections** $(2 - 3\%)$

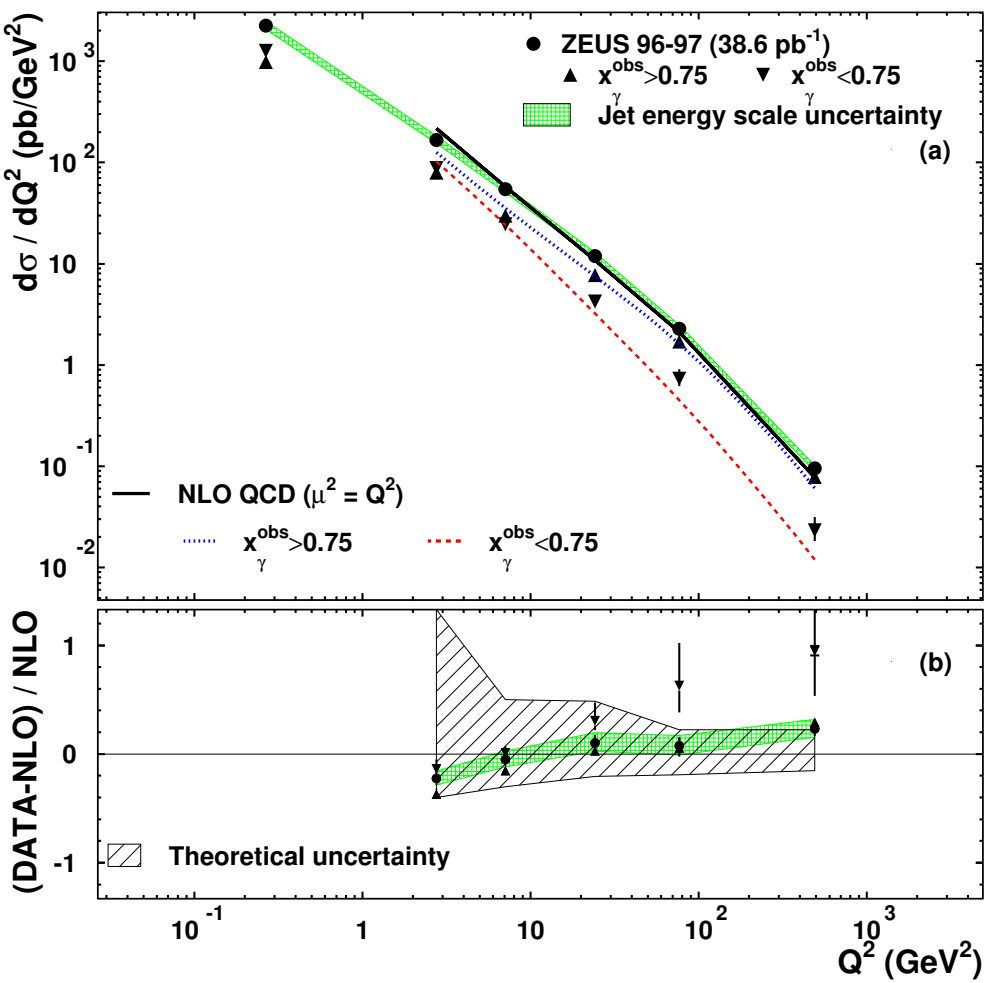
  $\rightarrow$ **HERWIG/PYTHIA** $(\mathrm{Q}^2 < 1.0\ \mathrm{GeV}^2)$**, LEPTO/ARIADNE** $(\mathrm{Q}^2 > 1.5\ \mathrm{GeV}^2)$
  - ▷ **Proton and photon PDFs** $\rightarrow$ **using MRST and AFG** (5%)

Results - $\mathrm{d}\sigma/d\mathrm{Q}^2$.



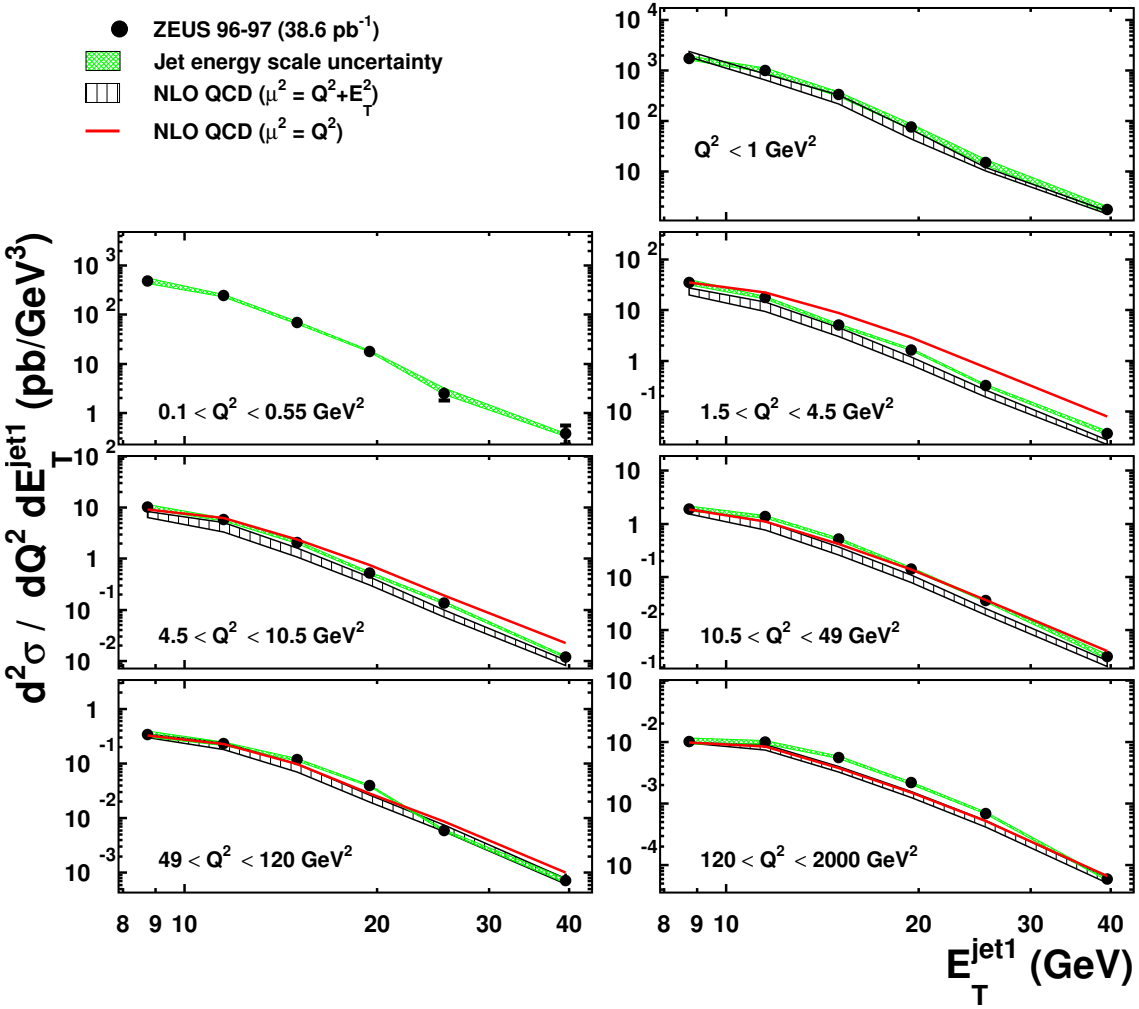
- Cross section $\mathrm{d}\sigma/d\mathrm{Q}^2$ measured.
- Data fall more than five orders of magnitude.
- $x_\gamma^{\mathrm{OBS}} < 0.75$ falls more rapidly than $x_\gamma^{\mathrm{OBS}} > 0.75$.
- NLO photoproduction prediction (FR)
  - ▷ describes the data well.
- NLO DIS prediction (DISASTER++)
  - ▷ Underestimates total cross sections by $\sim 30\%$.
  - ▷ Describes shape well.
  - ▷ Dramatically underestimates the $x_\gamma^{\mathrm{OBS}} < 0.75$.

Results - $d\sigma/dQ^2$.



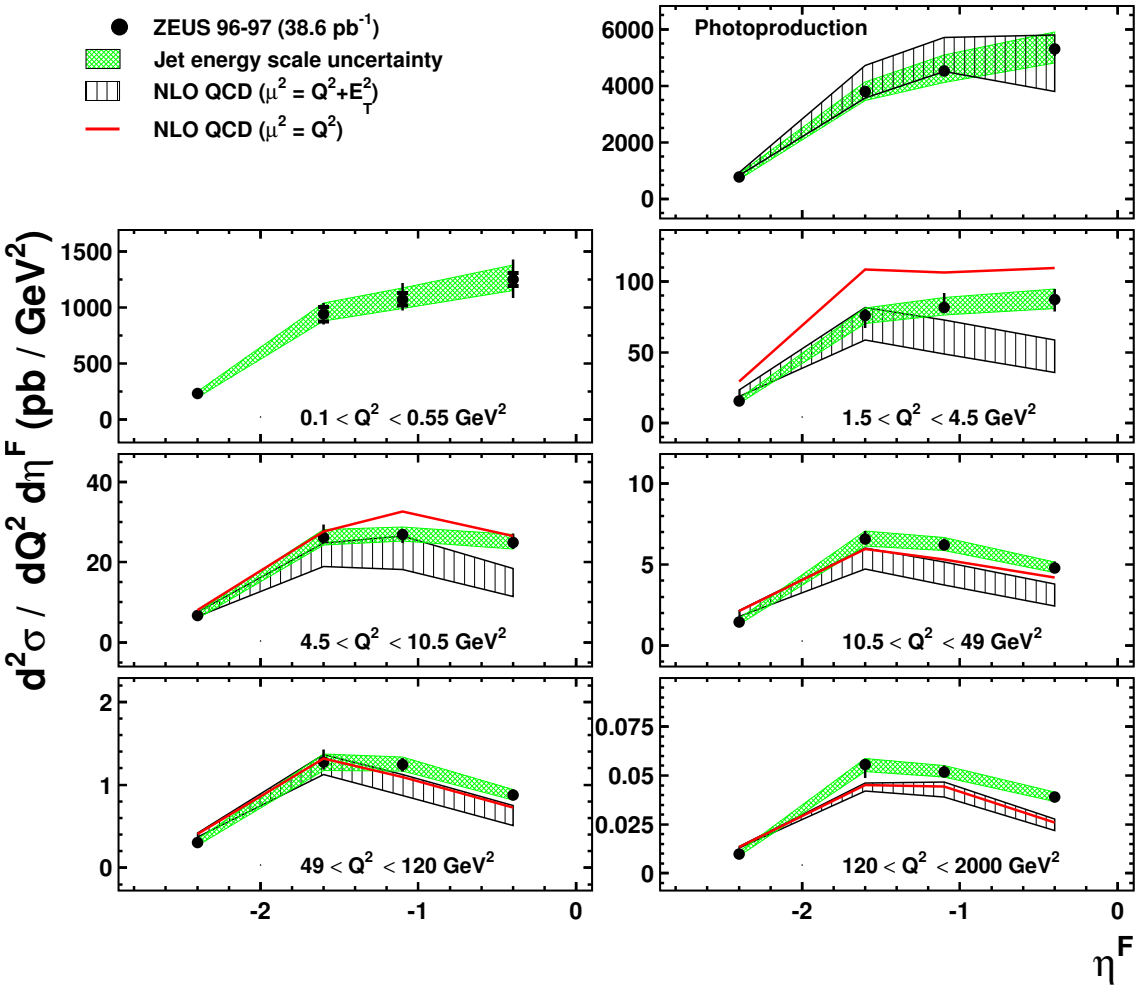
- Comparison to NLO prediction of DISASTER++ with $\mu_F^2 = \mu_R^2 = Q^2$.
- Theoretical uncertainties large at low Q^2.
  - $\rightarrow$ Validity of scale?
  - $\rightarrow$ Multiscale effects?
- Total cross sections described within uncertainties.
- Discrepancy at $x_\gamma^{OBS} < 0.75$ (both plots)
  - $\rightarrow$ Photon structure effects up to $Q^2 \sim 500\ GeV^2$?

Results - $d^2\sigma/dQ^2dE_T^{jet1}$.



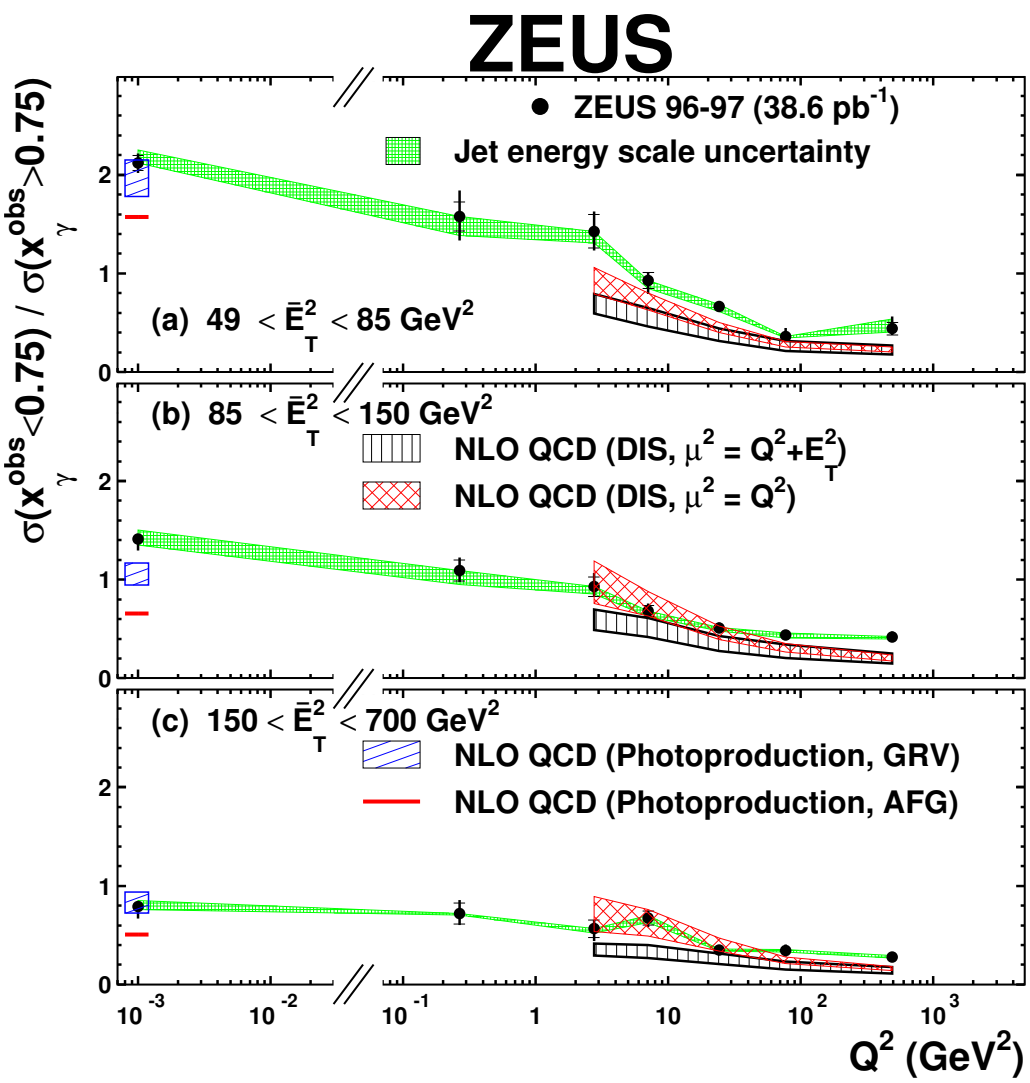
- $d^2\sigma/dQ^2dE_T^{jet1}$ **vs** E_T^{jet1}.
- **Cross sections fall less rapidly with increasing** Q^2.
- **NLO photoproduction:**
  - ▷ **Describes data well.**
- **NLO DIS** $(\mu^2 = Q^2 + E_T^2)$**:**
  - ▷ **Describes high and low** E_T^{jet1}.
  - ▷ **Lies below the data at "medium"** E_T^{jet1}.
- $\mu^2 = Q^2$ **describes data within large uncertainties (not shown).**

Results - $d^2\sigma/dQ^2d\eta^F$.



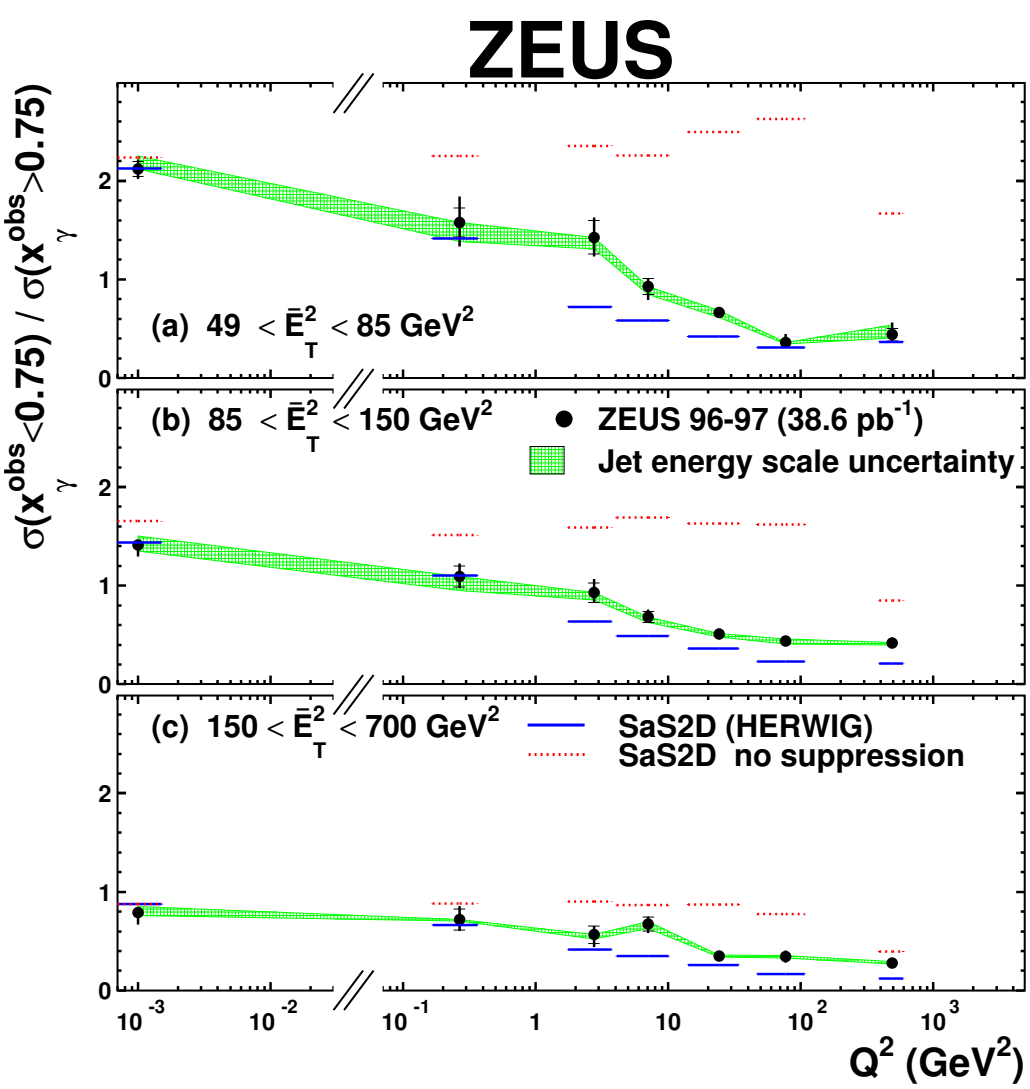
- $d^2\sigma/dQ^2d\eta^F$ **vs** η^F.
  - **Sensitive to resolved photon in the forward direction** $(\eta^F \to 0)$.
- **Cross sections exhibit turnover at** $\eta^F > -1.5$ **as** Q^2 **increases.**
- **NLO photoproduction:**
  - **Describes data well.**
- **NLO DIS** $(\mu^2 = Q^2 + E_T^2)$**:**
  - **Underestimates cross section in the forward region.**
- $\mu^2 = Q^2$ **describes data within large uncertainties (not shown).**

Results - Ratio.



- Photon structure effects even at high Q^2 or $\overline{E_T}^2$?
  - $R = \frac{\sigma(x_\gamma^{OBS}<0.75)}{\sigma(x_\gamma^{OBS}>0.75)}$ vs Q^2 & $\overline{E_T}^2$.
- Low x_γ^{OBS} component suppressed:
  - at low Q^2 as $\overline{E_T}^2$ increases.
  - at low $\overline{E_T}^2$ as Q^2 increases.
- NLO photoproduction:
  - GRV photon PDF in reasonable agreement.
  - AFG photon PDF below the data.
- NLO DIS:
  - Below the data.

Results - Ratio.



- Ratio compared to LO prediction of HERWIG.
  - ▷ SaS2D photon PDF.
  - ▷ Includes $0.1 < Q^2 < 0.55\,\mathrm{GeV}^2$.
    $\rightarrow$ Not covered by current NLO.
- Predictions with Q^2 suppression:
  - ▷ Qualitative description of data.
- Without Q^2 suppression:
  - ▷ Relatively constant with increasing Q^2.

Summary.

- Dijet cross sections differential in Q^2, $\mathrm{E}_{\mathrm{T}}^{\mathrm{jet1}}$ and η^{F} measured for a wide range of photon virtualities $0.0 < \mathrm{Q}^2 < 2000\ \mathrm{GeV}^2$.
- Ratio of cross sections $\sigma(x_\gamma^{\mathrm{OBS}} < 0.75)/\sigma(x_\gamma^{\mathrm{OBS}} > 0.75)$ as function of Q^2 and $\overline{\mathrm{E}_{\mathrm{T}}}^2$ measured.
- Ratio qualitatively described by LO MC models + parton showers when applying a virtual photon PDF suppressed with increasing Q^2.
- Photoproduction cross sections and ratio are well described by NLO models.
- NLO calculations of the ratio which do not implement a virtual photon PDF (i.e in DIS) lie below the data.
- NLO calculations underestimate the measured cross sections, $\mathrm{d}^2\sigma/d\mathrm{Q}^2\mathrm{d}\eta^{\mathrm{F}}$, in the forward region, particularly at high Q^2.

Summary.

- **Discrepancies between data and NLO seen in regions where effect of photon structure is expected.**
- **These data suggest a significant contribution from photon structure effects for scales as high as $\mathrm{Q}^2 \sim 500\ \mathrm{GeV}^2$ and $85 < \overline{\mathrm{E_T}}^2 < 150\ \mathrm{GeV}$.**
- **Data have the potential to significantly constrain future parameterisations of the virtual photon PDFs.**
  - $\rightarrow$ **Include data in future fits.**
- **Large theoretical uncertainties particularly at low Q^2.**
  - $\rightarrow$ **Improved higher order calculations are needed.**
  - $\rightarrow$ **Calculations covering region $0.1 < \mathrm{Q}^2 < 0.55\ \mathrm{GeV}^2$ needed.**