# High $E_T$ Photoproduction and the Photon Structure

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On behalf of the H1 and ZEUS Collaborations

- Introduction.
- Virtual Photon Structure.
- High $E_T$ Photoproduction.
  - Tests of pQCD.
  - Knowledge of the Photon Structure.

# Introduction: Basic Mission Statements

**Virtual Photon Structure (covered by S. Maxfield in previous talk):**

- Here consider "transition region" at low $Q^2$.

**High $E_T$ Real Photoproduction:**

- Test of pQCD calculations.
- Access the structure of the photon.
- Both become more reliable with the 'elimination' of soft-physics at high $E_T$.
- Luminosity allowing us to make precise measurements at high $E_T$.

# Introduction: What to measure?

**Tests of pQCD:**

- **Measure $E_T^{\text{jet}}$, $M_{jj}$ and $|cos\theta^*|$ cross-sections.**
- **Do we see any resonances or deviations from the theory?**

**Photon Structure:**

- **Measure cross-sections with sensitivity to photon structure, e.g. $\eta^{\text{jet}}$ and $x_\gamma^{\text{obs}} = (E_T^{\text{jet1}} \text{e}^{-\eta_1^{\text{jet}}} + E_T^{\text{jet2}} \text{e}^{-\eta_2^{\text{jet}}})/2yE_e$.**
- **(Obviously) try and minimise errors for use of data in global fits.**
- **Investigate regions where hadronisation corrections are small.**
- **$\gamma P$ data currently *not* used in fits for the photon PDF:**
  - **Sensitive to the gluon in the photon.**
  - **Sensitive to the quark in the photon at high $x_\gamma$.**

# Virtual Photon Structure

**Investigate the transition region between the real and the virtual photon.**

**Extension down to "almost real" photon (DESY 00-017, accepted by PLB).**

**For** $134 < W_{\gamma P} < 223$ **GeV, ranges in** $Q^2$**:**

$Q^2 \approx 0$ **GeV$^2$,** $0.1 < Q^2 < 0.55$ **GeV$^2$** $1.5 < Q^2 < 4.5$ **GeV$^2$**

**Low** $E_T^{\text{jet}}$**:**

$E_T^{\text{jet}} > 5.5$ **GeV**

$1.125 < \eta^{\text{jet}} < 2.2$

**High** $E_T^{\text{jet}}$**:**

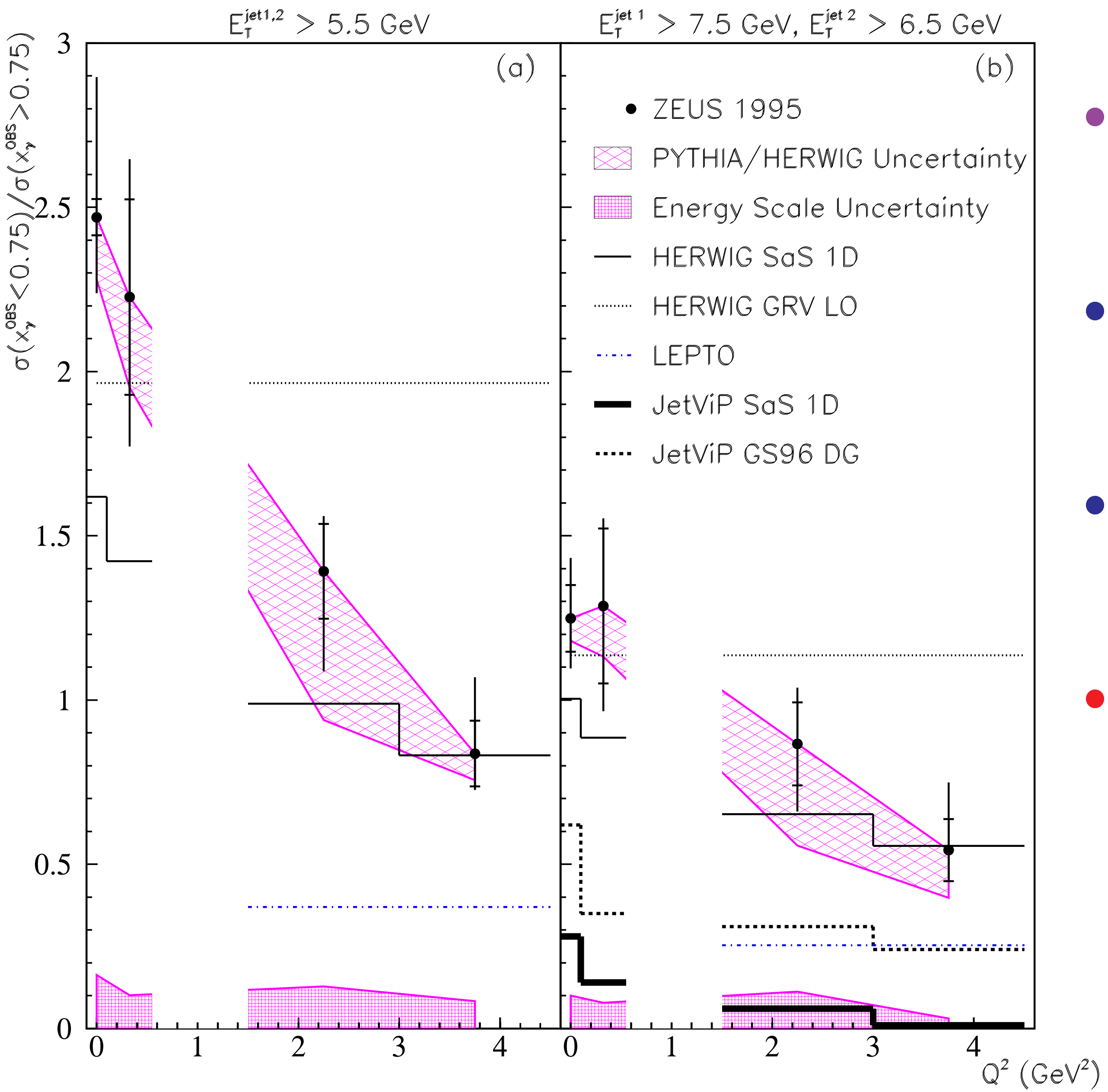
$E_T^{\text{jet1,2}} > 7.5, 6.5$ **GeV**

$1.125 < \eta^{\text{jet}} < 1.875$

**Compare to LO Photoproduction and DIS models and NLO calculation.**

**NB. All measurements use the longitudinally invariant** $k_T$ **algorithm.**

# Virtual Photon Results




- **"Resolved" component suppressed with increasing $Q^2$.**
- **Non-perturbative effects at low-$x_\gamma^{\rm obs}$?**
- **Interesting to goto higher $E_T$ and higher $Q^2$ in the future.**
- **None of the LO models, or NLO calculations give a good description of the data.**

# High $E_T$ Photoproduction and the Photon Structure

**New results from both H1 (36 pb$^{-1}$) and ZEUS (38 pb$^{-1}$).**

**H1 Measurement:**

$$Q^2 < 4 \ \textbf{GeV}^2$$

$$y < 0.9$$

$$-0.5 < \eta^{\text{jet}} < 2.5$$

**At least two jets:**

$$E_T^{\text{jet1,2}} > 25, 15 \ \textbf{GeV}$$

**At least three jets:**

$$E_T^{\text{jet1,2,3}} > 25, 15, 10 \ \textbf{GeV}$$

**ZEUS Measurement:**

$$Q^2 < 1 \ \textbf{GeV}^2$$

$$0.2 < y < 0.85$$

$$-1 < \eta^{\text{jet}} < 2$$

**At least two jets:**

$$E_T^{\text{jet1,2}} > 14, 11 \ \textbf{GeV}$$

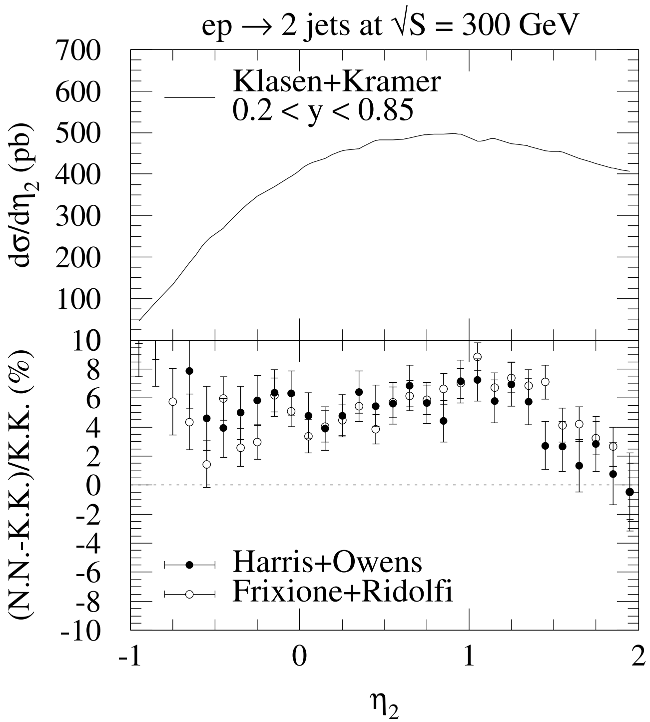
**Investigate for different $\eta^{\text{jet}}$ and $E_T^{\text{jet1}}$ regions**

# Testing pQCD: Theoretical calculations

- Frixione and Ridolfi, NPB 507 (1997) 315, NPB 507 (1997) 295.
  Subtraction method

- Harris and Owens, PRD 57 (1998) 5555, PRD 56 (1997) 4007.
  Phase space slicing method ($\delta_s, \delta_c$).

- Kleinwort, Klasen and Kramer, EPJC direct 1 (1998) 1, ZPC 76 (1997) 67.
  Phase space slicing method ($y_{\mathrm{cut}}$)



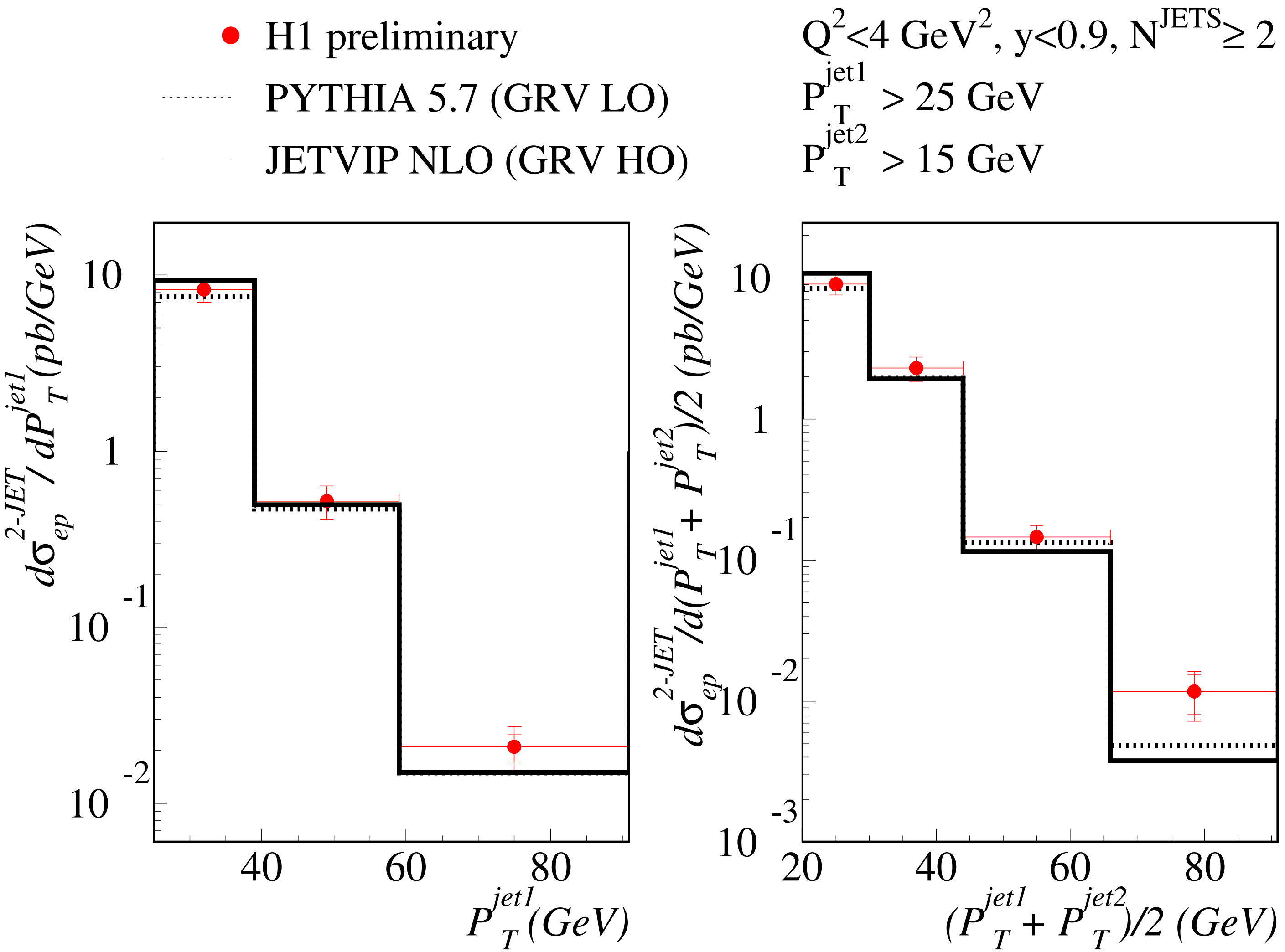

Calculations shown to be consistent to within 5 – 10 % (Harris, Klasen and Vossebeld, HERA MC proceedings, hep-ph/9905348)

- Aurenche et al., “Future Physics at HERA” (1996) 570. Phase space slicing method.

- JetViP: Kramer and Pötter, EPJC 5 (1998) 665, Pötter, EPJC 5 (1999) 1, CPC 119 (1999) 4.

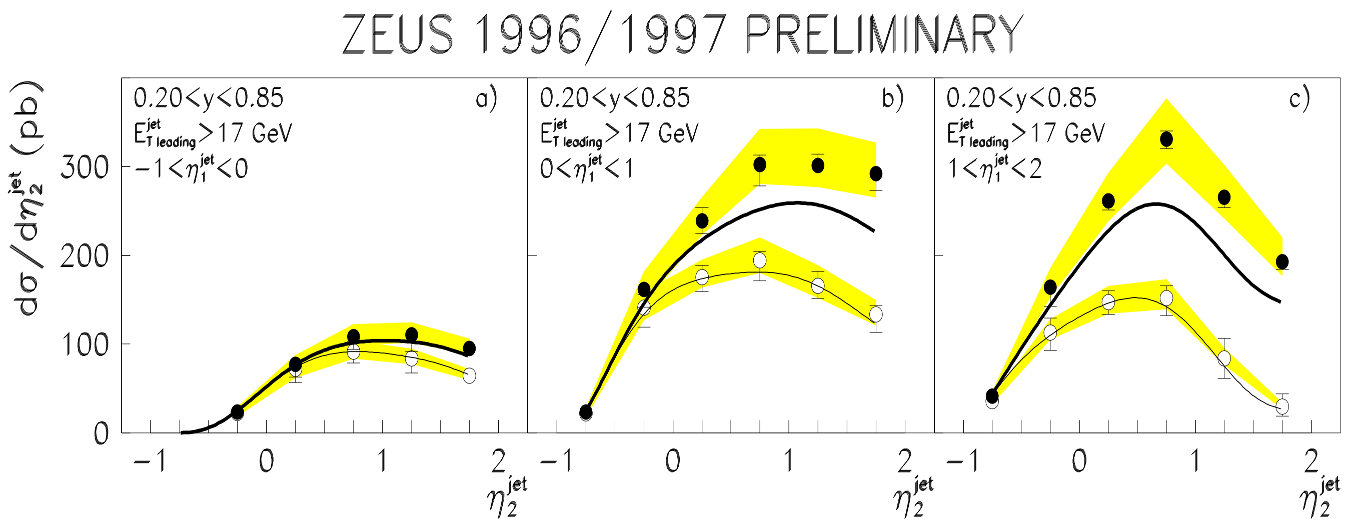
Shown to be consistent with Klasen et al. (Pötter, hep-ph/9911221)

# Two jet production at high $E_T^{\text{jet}}$

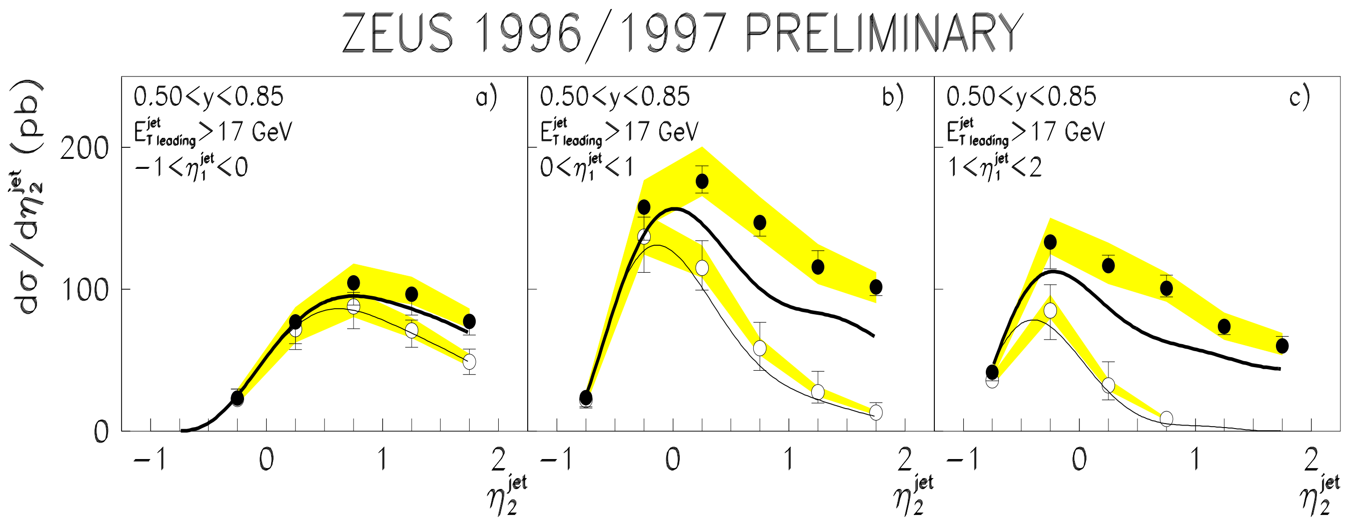



- **Cross section falls by three orders of magnitude, up to 90 GeV.**
- **Normalisation and shape described by predictions.**
- **No obvious deviations seen.**

# Regions sensitive to the Photon Structure?




- **Data at high-$x_\gamma^{obs}$ is well described by NLO.**
- **For all-$x_\gamma^{obs}$ data is above at forward $\eta_2^{jet}$.**

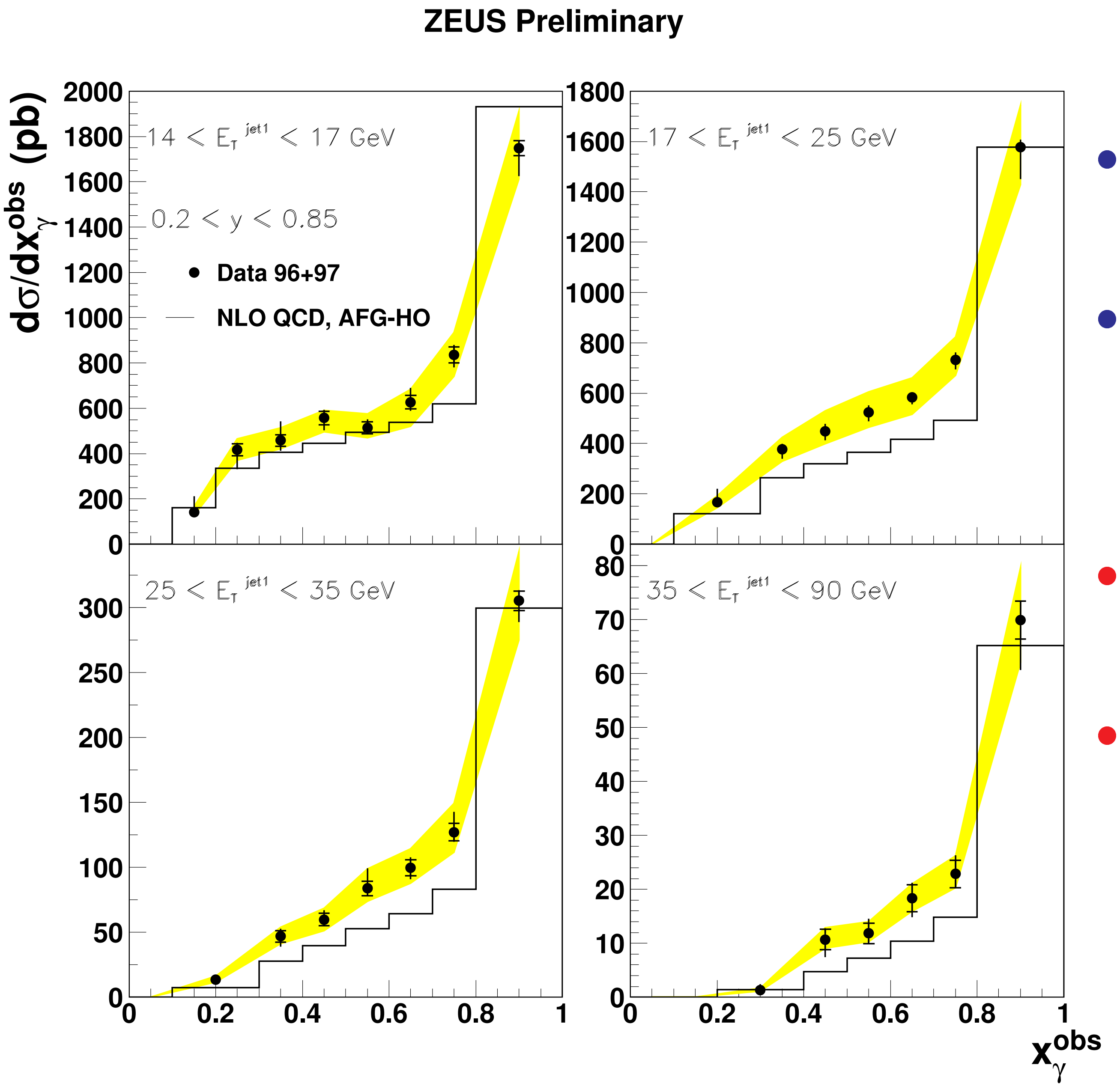



**High $y \Rightarrow$ low $x_\gamma^{obs}$:**

- **Increased sensitivity to photon structure.**
- **Discrepancy larger.**

**Investigate further...**

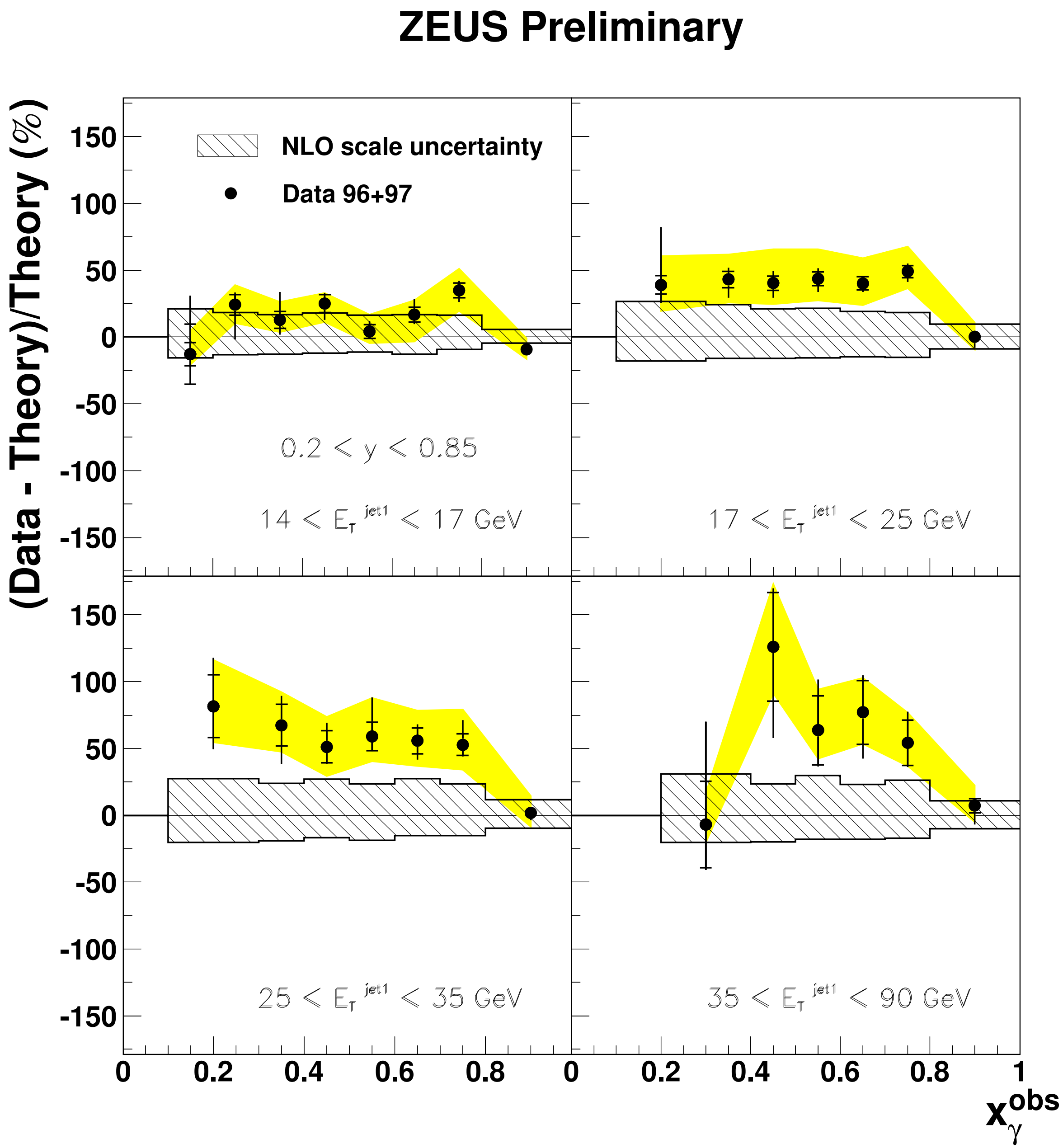
# Cross-sections in $x_\gamma^{\text{obs}}$




- **Data clearly above NLO at low-$x_\gamma^{\text{obs}}$.**
- **Differences maintained up to high $E_T^{\text{jet1}}$.**

- **Problem with QCD calculation for multi-jet events?**
- **Current (LEP-motivated) photon structure functions are inadequate?**

# How large is the discrepancy?




- **Differences up to** $50-60\%$**.**

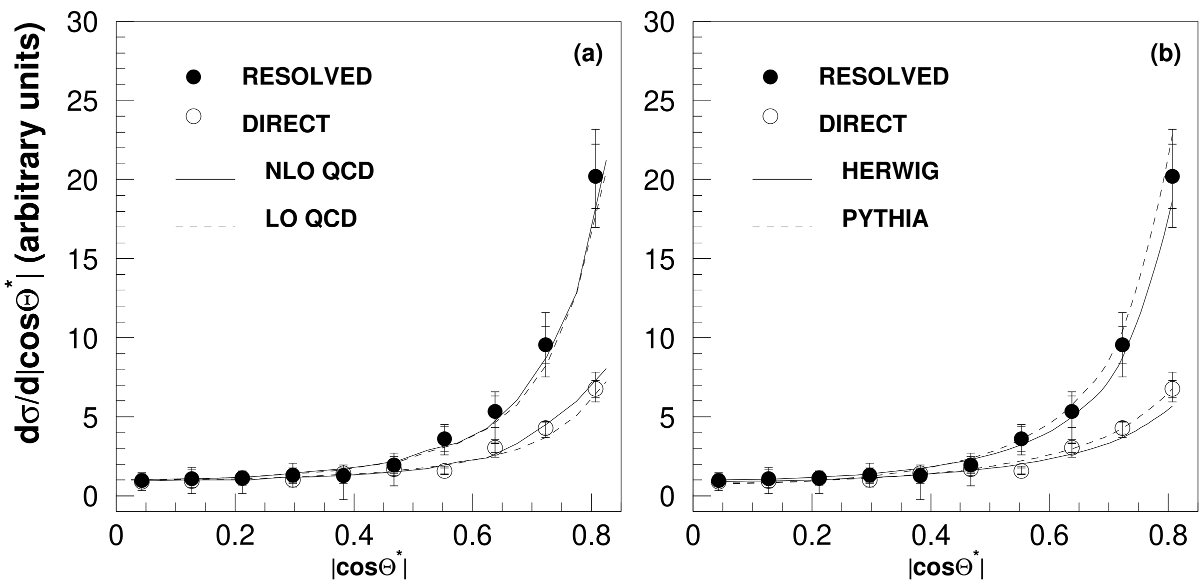
Photon structure:

- **Gluon content of the photon not well constrained at low-**$x_{\gamma}^{\rm obs}$**.**
- **Quark content of the photon not well constrained at high-**$x_{\gamma}^{\rm obs}$**.**
- **Scale** $E_T^2 \sim 200$ **GeV**$^2$**; larger than region for current photon PDF's.**

# Parton-parton Dynamics

**Angle, $\theta^*$ is that between the jet-jet axis and beam axis in the dijet centre-of-mass system.**

**ZEUS 1994**



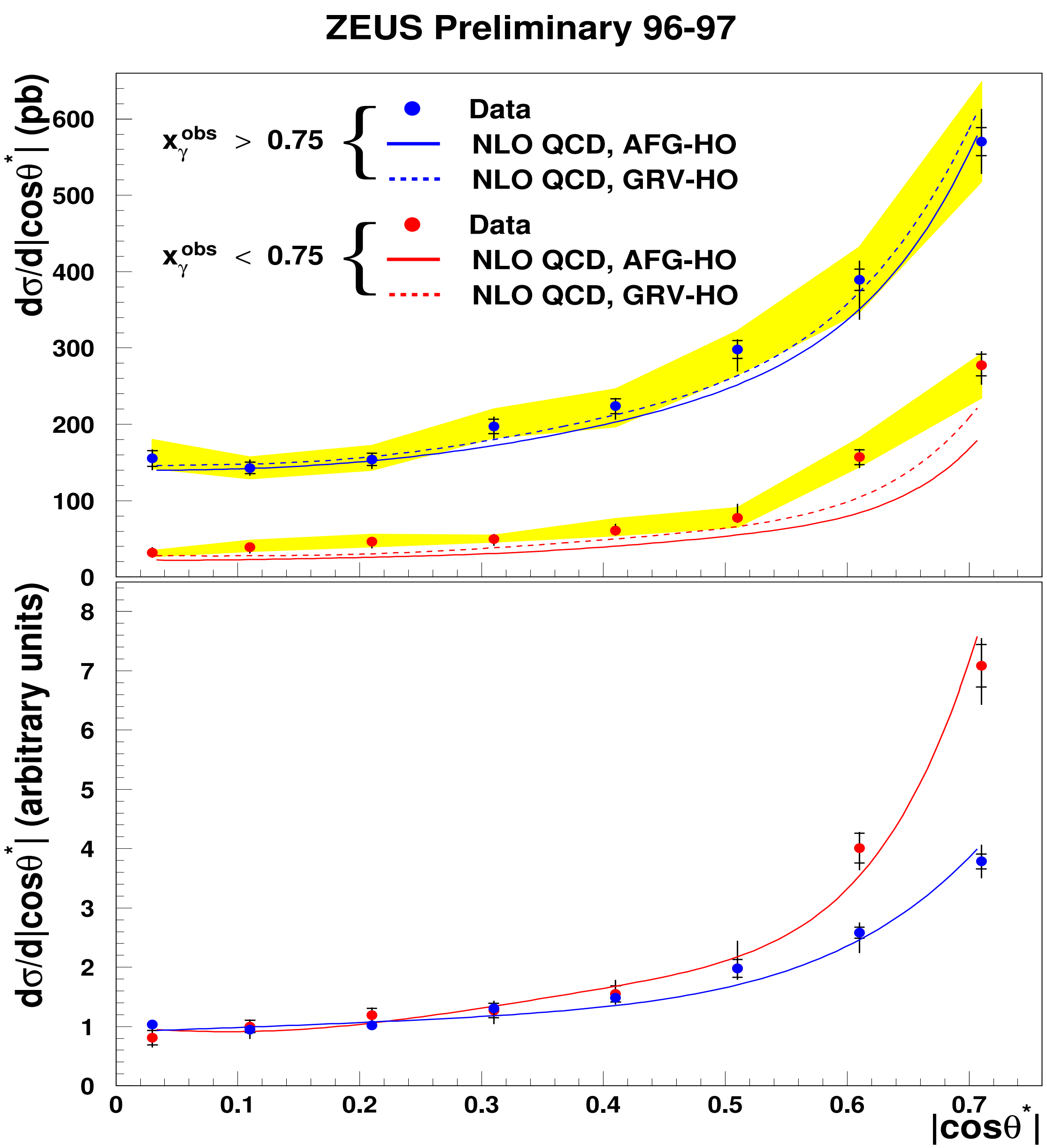

$E_T^{\text{jet}} > 6$ **GeV,** $M_{jj} > 23$ **GeV**

- **"Resolved" has spin-1 gluon propagator** $\propto (1 - |\cos\theta^*|)^{-2}$
- **"Direct" has spin-$\frac{1}{2}$ quark propagator** $\propto (1 - |\cos\theta^*|)^{-1}$

**Does this hold to high $E_T^{\text{jet}}$? Is the shape of the low-$x_\gamma^{\text{obs}}$ region described?**

# Dijet Angular Distribution

**For high $E_T$ analysis; $M_{jj} > 39$ GeV, $|\cos\theta^*| < 0.76$, $0 < (\eta_1^{\rm jet} + \eta_2^{\rm jet})/2 < 1$.**

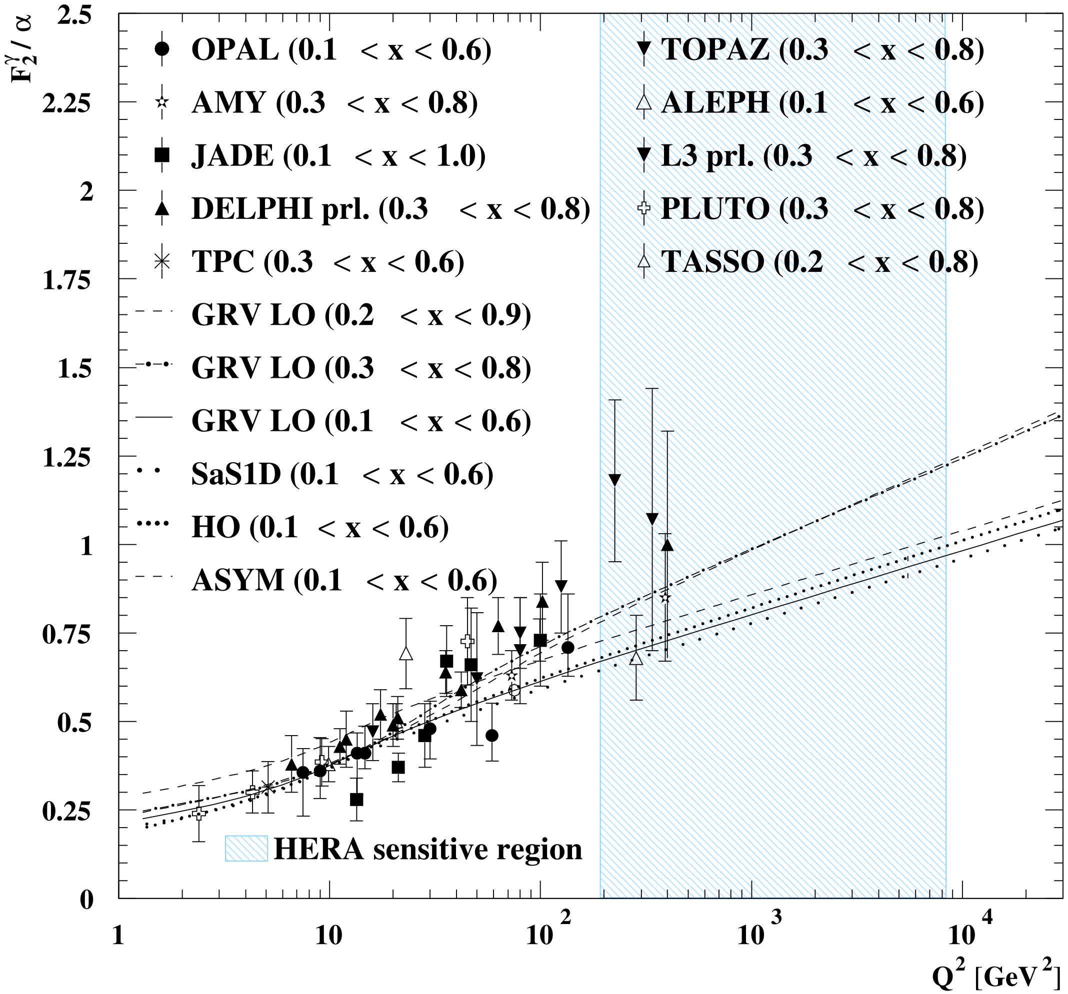



- As before, the cross-section for high-$x_\gamma^{\rm obs}$ is well described.
- The low-$x_\gamma^{\rm obs}$ region is poorly described in normalisaion.

- The low-$x_\gamma^{\rm obs}$ region rises faster than the high-$x_\gamma^{\rm obs}$region.
- The propagator for the two regions is different (also) at these higher masses.
- The shape of the low-$x_\gamma^{\rm obs}$ region is well described by the NLO prediction.

# Photon Structure Potential at HERA

**Why use HERA data in a global fit for the photon structure?**




From high $E_T^{\text{jet}}$ data:

- Extend to an order of magnitude higher in $Q^2(E_T^2)$.
- Overlap with region covered by LEP.
- Need new fits covering all of new LEP data.

**Need new fits incorporating HERA data.**

(Adapted from R. Nisius, hep-ex/9912049)

# Conclusions and Discussion

- **Both H1 and ZEUS have measured high $E_T$ photoproduction cross sections.**
- **They test pQCD calculations up to $E_T$ ~90 GeV.**
- **The data is well described by the predictions at high $E_T$.**
- **The calculations fall below the data at forward $\eta^{\mathrm{jet}}$ and low-$x_\gamma^{\mathrm{obs}}$.**
- **Indications are seen that the current photon PDF's are not adequate for the HERA data.**
- **Global fits should now be performed for the photon PDF** *including* **HERA data.**