Photon Structure

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DIS2000, April 28th 2000

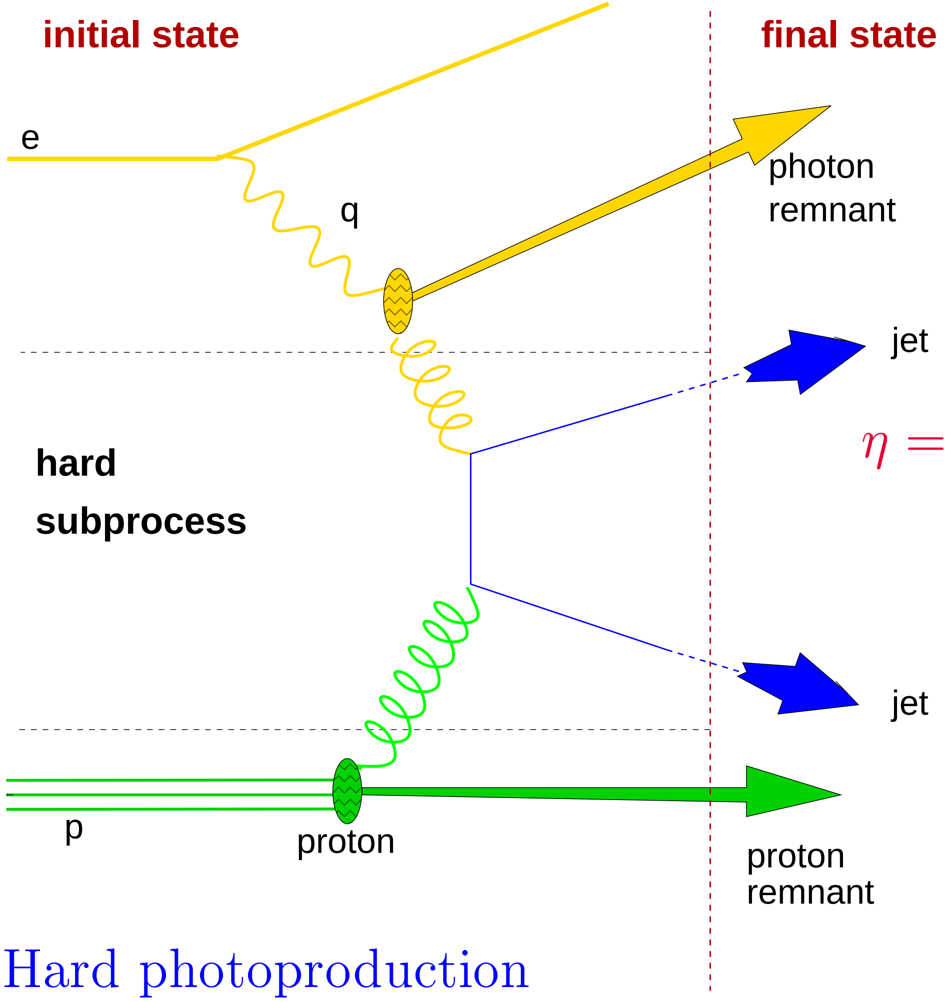
Overview

- hard photoproduction and photon structure
- recent results in real photon structure
- recent results in virtual photon structure
- conclusions

Hard photoproduction at HERA

HERA

- eP collider, cms energy $\sqrt{s} \approx 300$ GeV
- measurements made using ZEUS detector



$$\eta = -ln(tan\theta/2)$$
$$y = \frac{q.p}{e.p}$$
$$Q^2 = -q^2$$

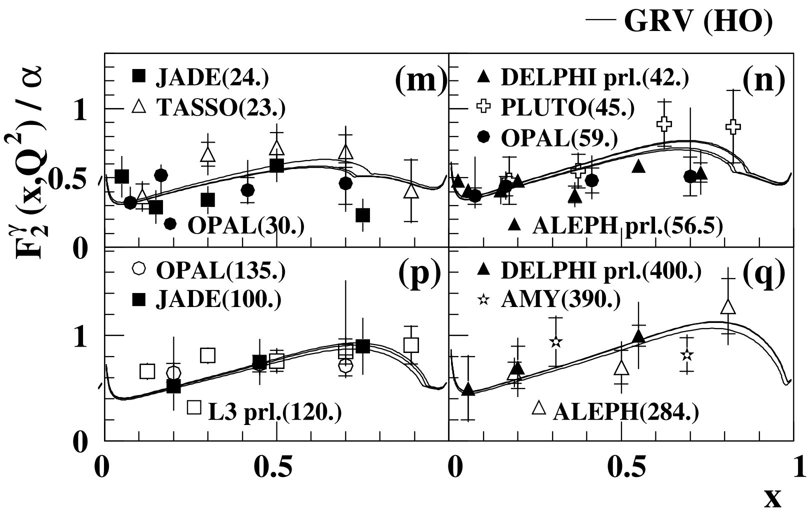
Hard photoproduction

- γ has low virtuality $\rightarrow$ long lived c.f. hard scatter
- dynamics of subprocess reconstructed using jets (k_T-clus algorithm) found in final state
- E_T of jets provide hard scale $\rightarrow$ perturbatively calculable for 2+ jets

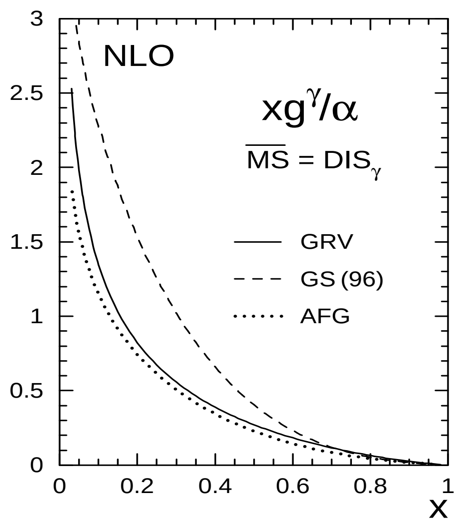
Real ($Q^2 \approx 0$) and Virtual ($Q^2 > 0$) photon structure is probed by hard dijet system when $E_T^2 >> Q^2$

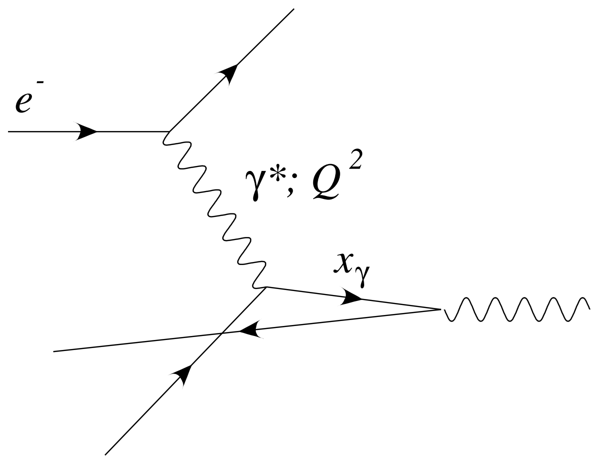
Photon structure at e^+e^-

- Photon parton distribution functions derived from fits to F_2^γ measurements in γ-DIS
- At high x_γ experimental uncertainties are large $\rightarrow$ F_2^γ not strongly constrained by data



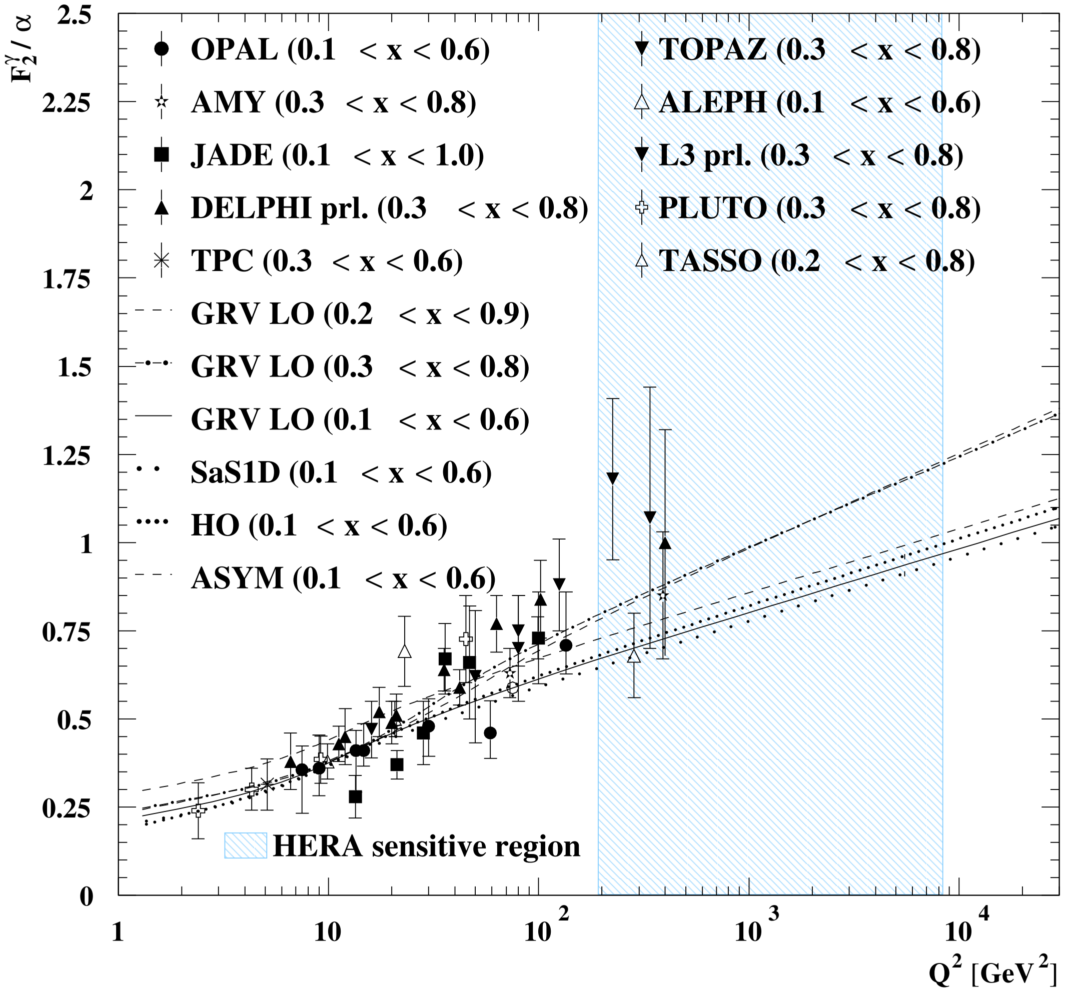
- At LO, γ-DIS only sensitive to quark densities in photon





Photon structure at HERA

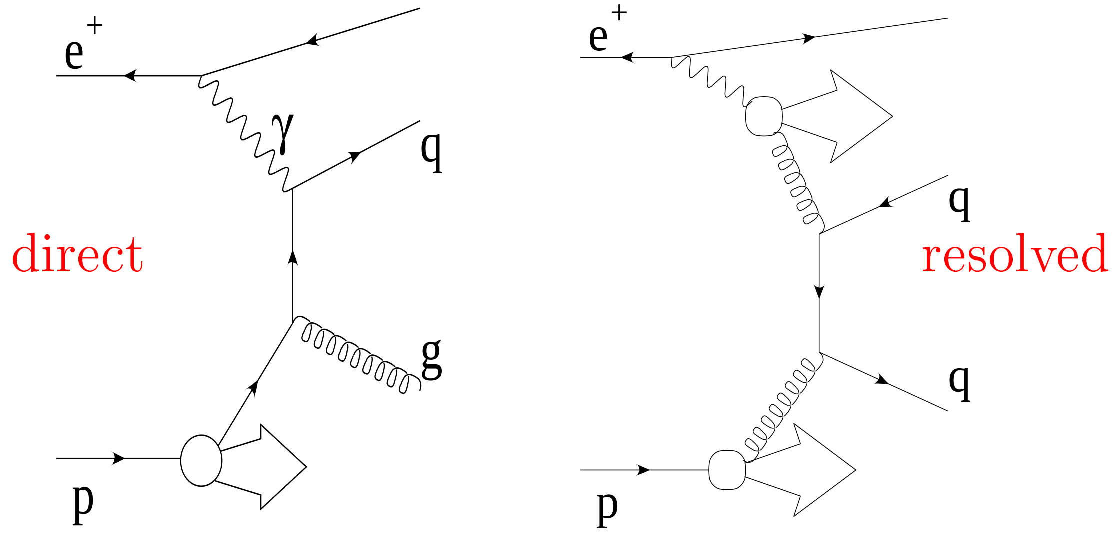
- jet photoproduction is sensitive to gluon density in photon at leading order
- gluon content of photon dominates cross-section at low x_γ
- sensitive to quark (and gluon) densities up to very high x_γ



At HERA we can probe the photon structure at higher scales than at LEP (or anywhere else!).

Dijet photoproduction

LO dijet photoproduction:



Resolved cross-section

$$d\sigma_{\gamma p\to cd} = \sum_{ab} \int_{x_p} \int_{x_\gamma} f_{p\to b}(x_p, \mu^2) f_{\gamma\to a}(x_\gamma, \mu^2) \mathcal{M}_{ab\to cd}$$

$\mu^2 \Longrightarrow$ scale $\to (E_T^{jet})^2$

$\mathcal{M}_{ab\to cd} \Longrightarrow$ perturbatively calculable

$f_{p\to b} \Longrightarrow$ experimentally constrained

$f_{\gamma\to a} \Longrightarrow$ photon structure

x_γ^{OBS} is defined in QCD at all orders:

$$x_\gamma^{OBS} = \frac{E_T^{jet1} e^{-\eta^{jet1}} + E_T^{jet2} e^{-\eta^{jet2}}}{2E_\gamma}$$

Real γ: High $\mathrm{E_T}$ dijets

Analysis motivation

- Test of pQCD calculations
- High $\mathrm{E_T}$ dijets give information on the photon structure in a kinematic region where soft physics is suppressed
- At HERA, we can probe the photon structure at higher scales, and with greater sensitivity to gluon content of photon than anywhere else.

Cross-section

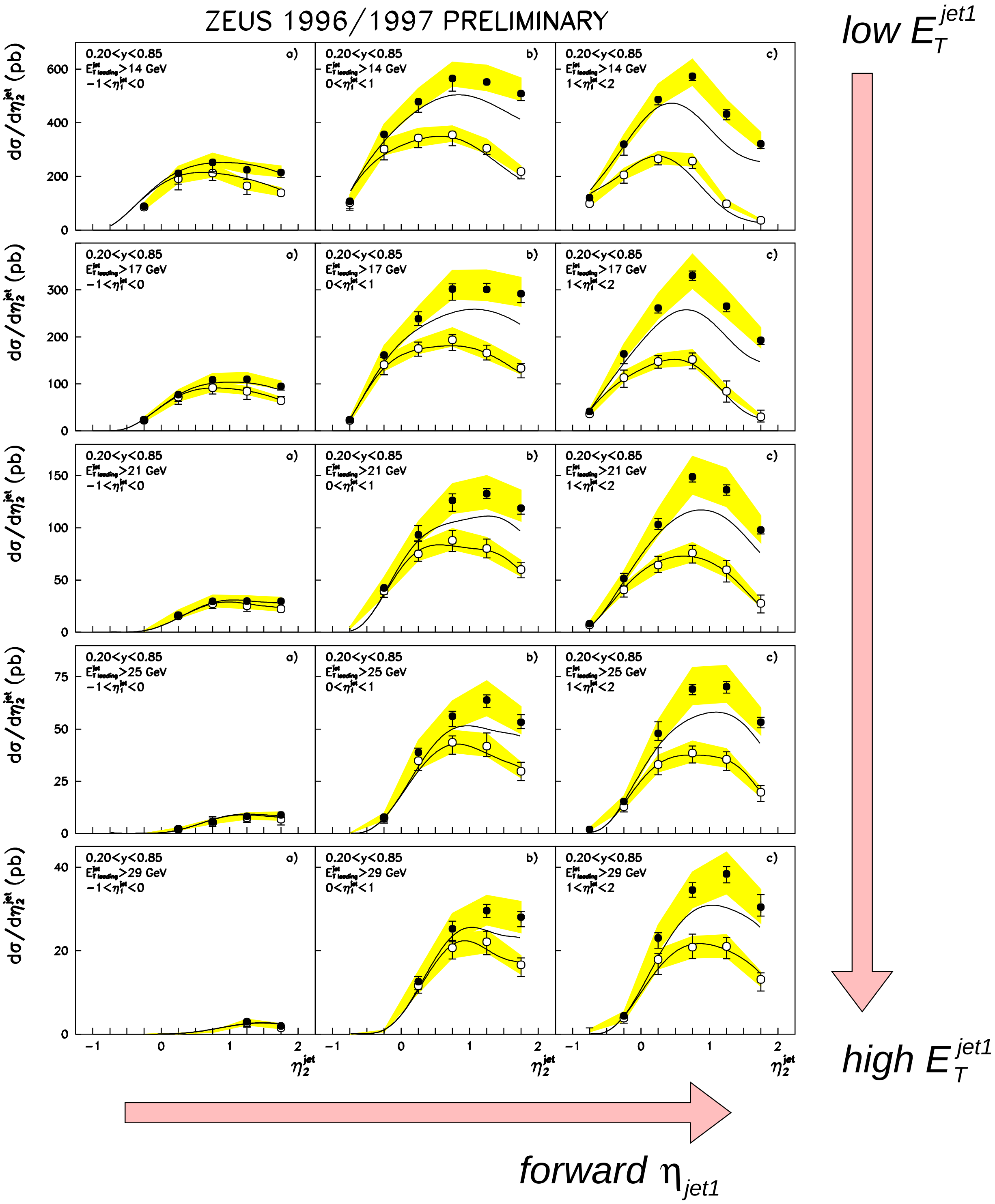
$$Q^2 < 1\mathrm{GeV}^2$$

$$0.2 < y < 0.85$$

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

$$-1 < \eta^{jet1,2} < 2$$

Results: η^{jet} cross section

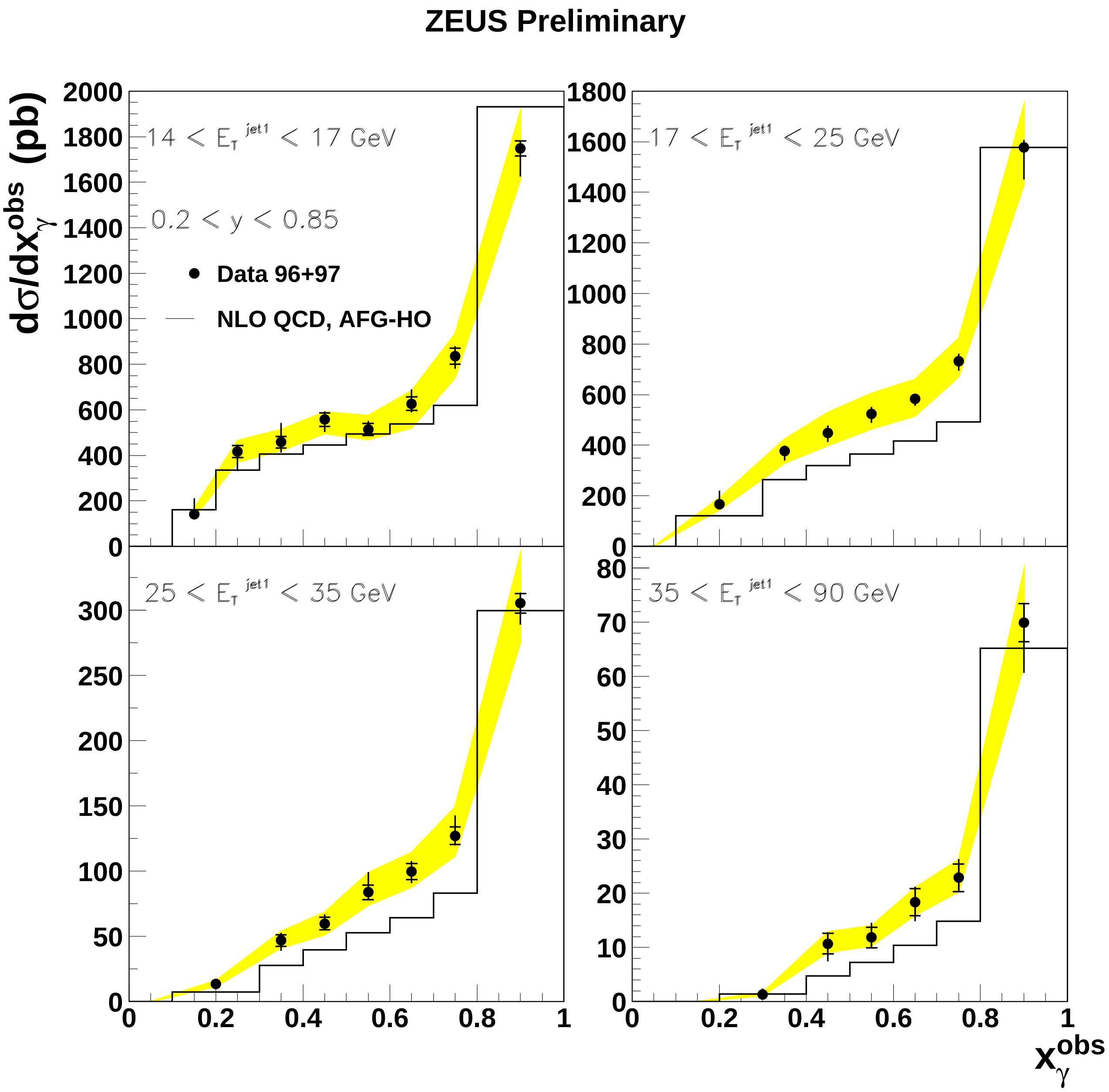


- NLO describes data points for $x_\gamma^{obs} > 0.75$ (lower curve)
- NLO falls short of data for full x_γ^{obs} range
- Discrepancy is largest in forward region, and persists up to high E_T^{jet1}

Results: $x_\gamma^{\rm obs}$ cross section

NLO - Frixione & Ridolfi.
proton pdf. : CTEQ-4M, photon pdf : AFG-HO

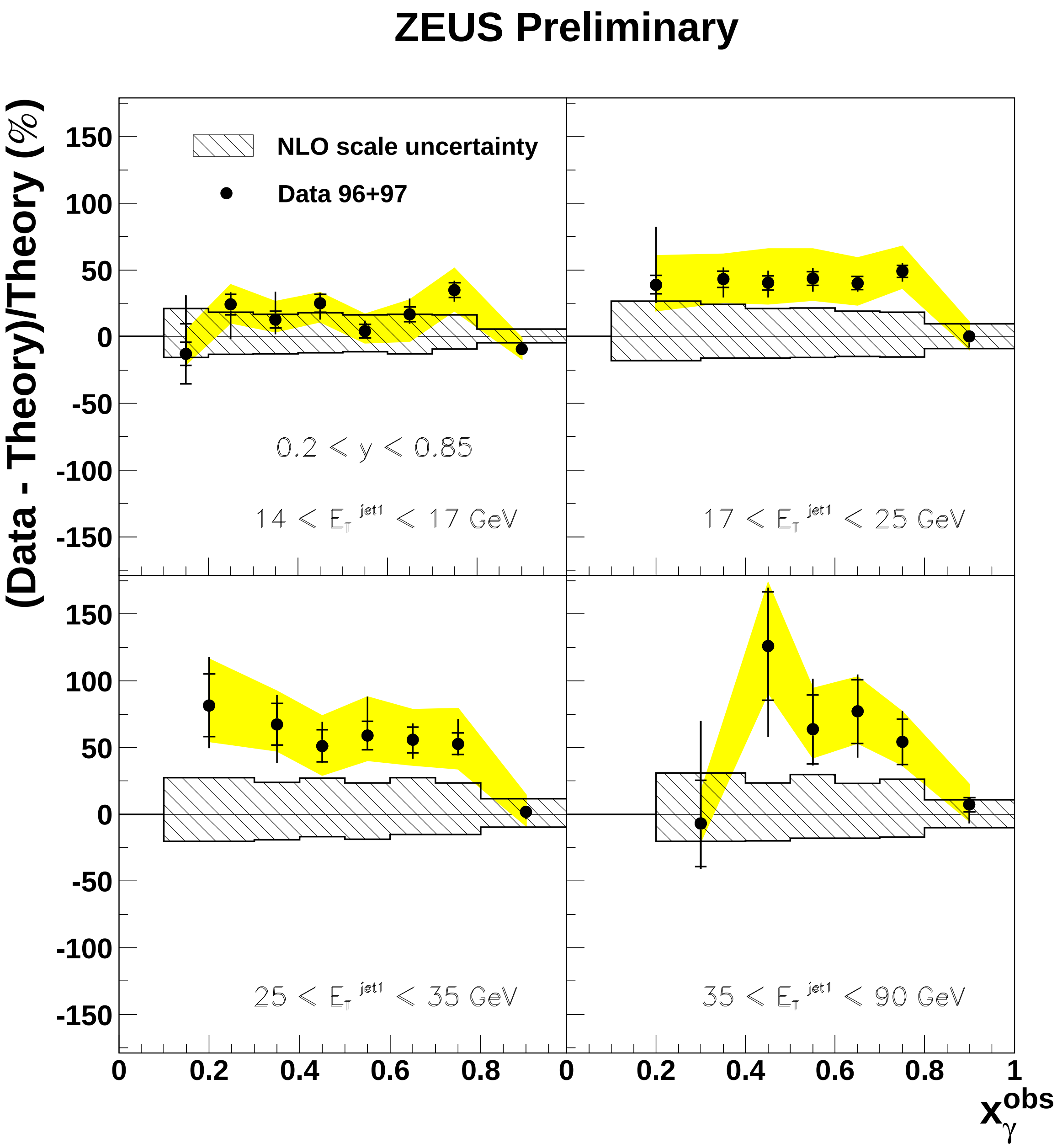
AFG from LEP data with $\mu^2 \lesssim 100\mathrm{GeV}^2$, but in this analysis $\mu^2 > 200\mathrm{GeV}^2$



- NLO describes data reasonably well for $x_\gamma^{obs} > 0.8$
- Data higher than NLO for $x_\gamma^{obs} < 0.8$.

Results: x_γ^{obs}

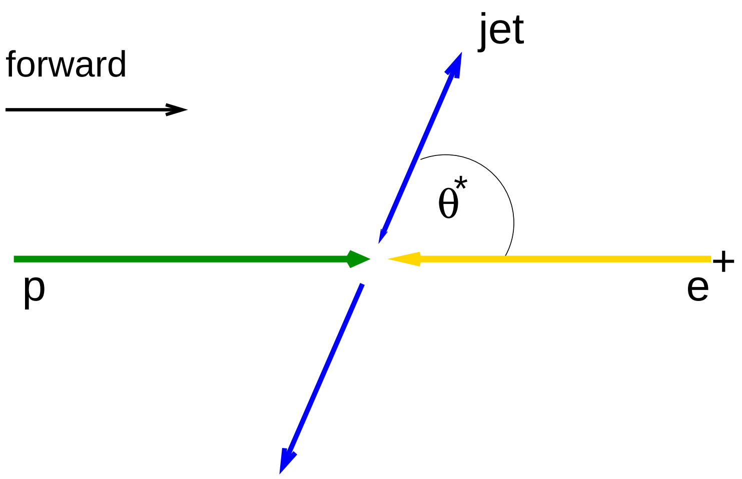
- For $x_\gamma^{\mathrm{obs}} < 0.8$ normalisation is off by 20 - 80 %, increasing with $\mathrm{E_T^{jet}}$.
- Increasing shape with $\mathrm{E_T^{jet}}$.



$\Longrightarrow$ Need new parametrisation of photon structure function?

Dijet angular distributions: $\cos\theta^*$

$$\cos\theta^* = \tanh\frac{(\eta^{jet1} - \eta^{jet2})}{2}$$



- both jets have same energy and θ^* in cms $\rightarrow$ measure $|\cos\theta^*|$ only
- $|\cos\theta^*|$ is sensitive to spin of propagator

$\sigma \sim (1 - |\cos\theta^*|)^{-2}$ spin1, gluon prop.

$\sigma \sim (1 - |\cos\theta^*|)^{-1}$ spin 1/2, quark prop.

$\rightarrow$Expect resolved cross-section to rise more steeply than direct

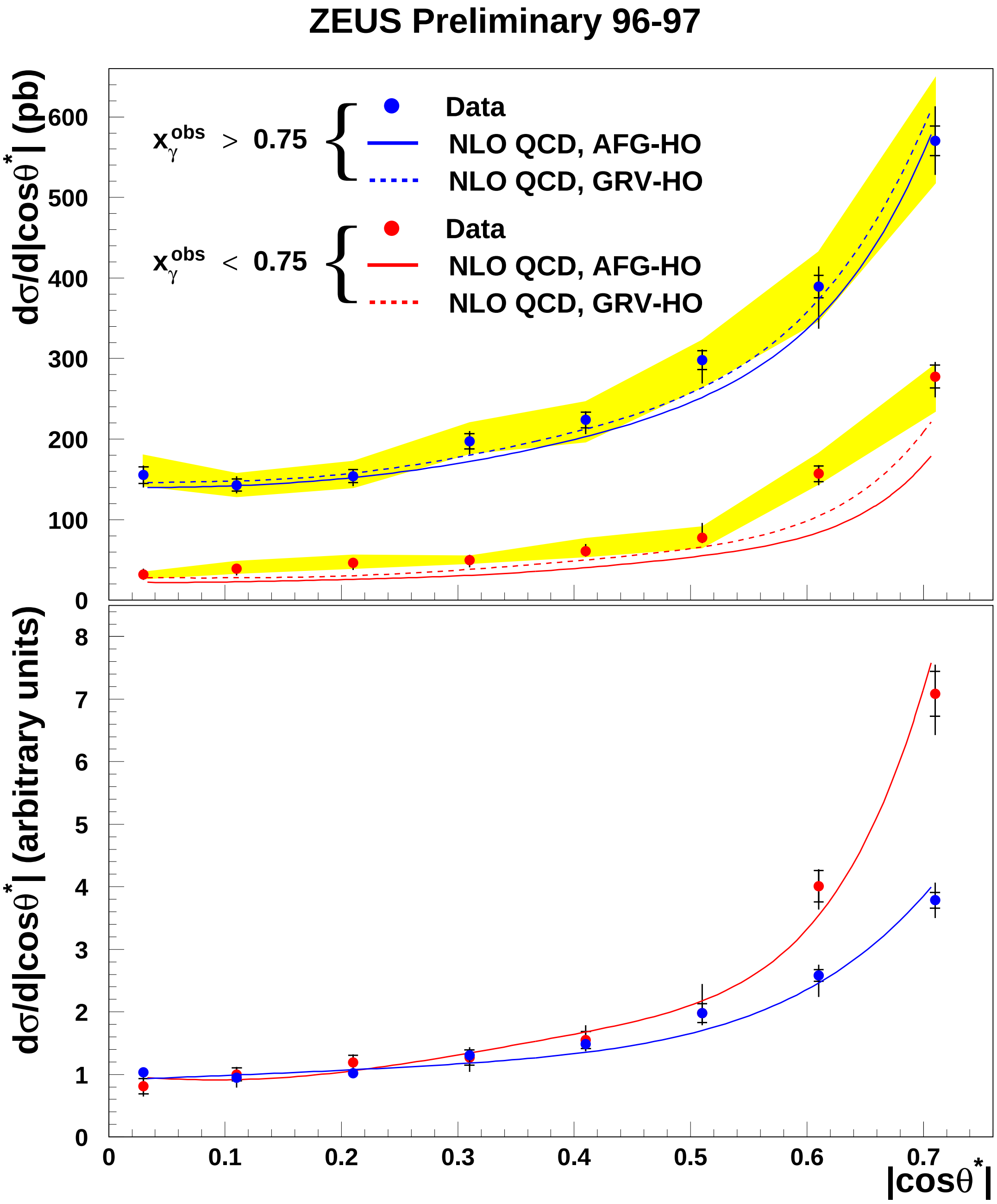
Cross-section(in addition)

$$M_{jj} > 39\mathrm{GeV}^2$$

$$0 < \bar{\eta} < 1$$

$$|cos\theta^*| < 0.76$$

Results : $\cos\theta^*$



- Much larger excess in data over NLO for 'resolved' processes than 'direct'
- Shape described well by NLO for both x_γ^{obs} regions
- $\rightarrow$ Only a normalisation difference between NLO and data at low x_γ

Structure of virtual photons

- Photons at high Q^2 commonly considered to be point-like and structureless (i.e. as a probe of proton structure in DIS)
- Photons at $Q^2 \approx 0$ have been shown to have partonic structure (i.e. $e^+e^-\gamma$ DIS and jet photoproduction at HERA)

  $\rightarrow$ Measure photon structure dependence on Q^2 in transition region between real and virtual photon using dijet events in eP scattering at HERA

  [DESY 00-17, accepted by PLB]

Cross section

$$0.2 < y < 0.55$$

Low $\mathrm{E_T}$ region:	High $\mathrm{E_T}$ region:
$\mathrm{E_T^{jet1,2}} > 5.5$ GeV	$\mathrm{E_T^{jet1}} > 7.5$ GeV
	$\mathrm{E_T^{jet2}} > 6.5$ GeV
$-1.125 < \eta^{\mathrm{jet}} < 2.2$	$-1.125 < \eta^{\mathrm{jet}} < 1.875$

Three ranges of Q^2 :

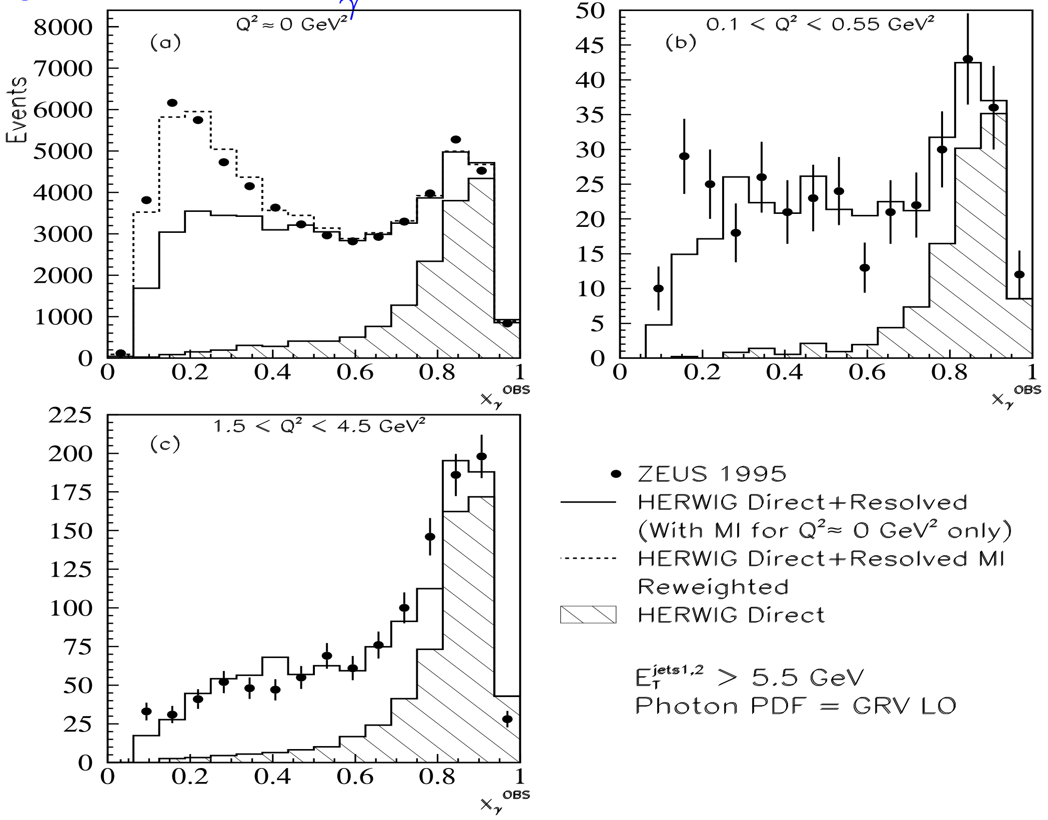
$$Q^2 \approx 0 \text{ GeV}^2$$

$$0.1 < Q^2 < 0.55 \text{ GeV}^2,$$

$$1.5 < Q^2 < 4.5 \text{ GeV}^2$$

Virtual photon structure: results

Uncorrected x_γ^{obs} distribution

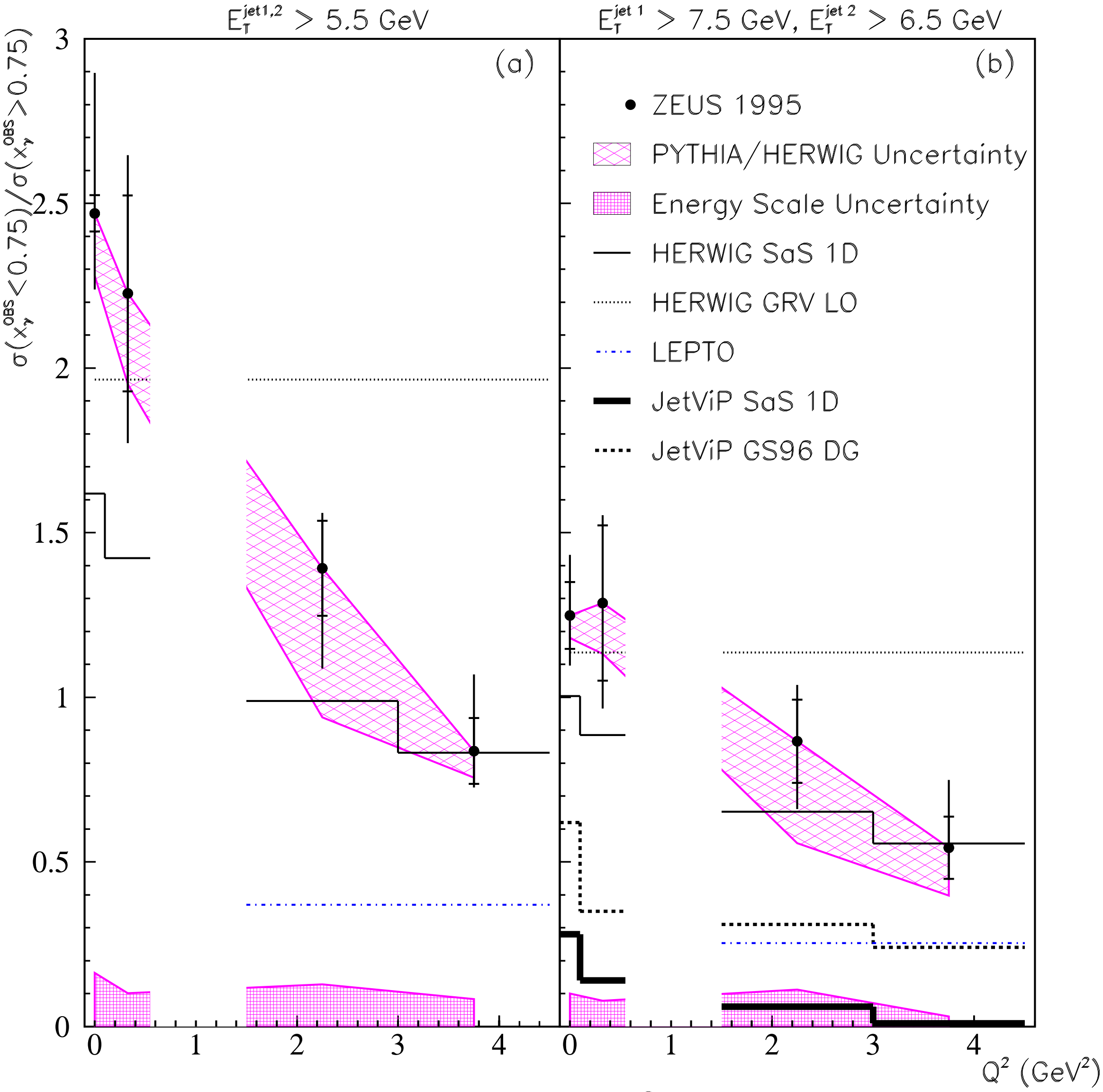


- Need significant LO resolved γ component in HERWIG to describe data in all 3 Q^2 regions
  $\rightarrow$ dijet distribution sensitive to photon structure up to $Q^2 \sim 4.5\text{GeV}^2$

Data is compared with:

HERWIG	SaS 1D	resolved (anom. and VMD) dependence on Q^2 is modelled
	GRV	valid for real photons, no suppression of resolved with Q^2
LEPTO		low x_γ^{obs} component comes purely fom parton shower contribution to LO-DIR

Virtual photon structure: Results



- ratio falls steeply with Q^2 → suppression of 'resolved' photon component with Q^2
- HERWIG + SaS best describe high Q^2 data
- HERWIG + GRV best describe low Q^2 data
- LEPTO significantly below data → low x_γ^{obs} contributions from parton shower effects alone (no photon structure) are insufficient to describe ratio
- NLO pQCD JetViP calculations lie well below data

All models and calculations compared with data fail to describe x_γ^{obs} distribution for full Q^2 range

Conclusions

Virtual photon structure

Dijet cross section has been measured in three separate Q^2 regions

- $\sigma(x_\gamma^{\rm obs} < 0.75)/\sigma(x_\gamma^{\rm obs} > 0.75)$ falls rapidly with Q^2
  $\rightarrow$ suppression of 'resolved' photon with Q^2
- low $x_\gamma^{\rm obs}$ component exists up to at least $Q^2 = 4.5$ GeV^2
- none of the models or calculations considered describe the data for full kinematic region

Real photon structure

New measurements illustrate the already observed deficiences in the photon structure description in terms of x_γ^{obs} and $\mathrm{E_T^{jet}}$.

They show:

- Data above NLO for $x_\gamma^{obs} < 0.8$
- This discrepancy increases with $\mathrm{E_T^{jet}}$.
- Shape of discrepancy increases with $\mathrm{E_T^{jet}}$.
- Shape of cosθ^* distribution for $x_\gamma^{obs} < 0.75$ described well by NLO, however normalisation is not:

$\rightarrow$ Time to take advantage of HERA data (higher scales, more sensitive to gluon in photon) to make new parametrisation of photon structure