Real Photon Structure

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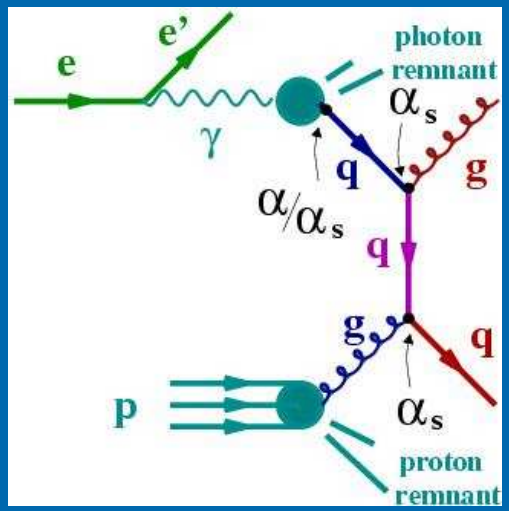
(on behalf of the ZEUS Collaboration)

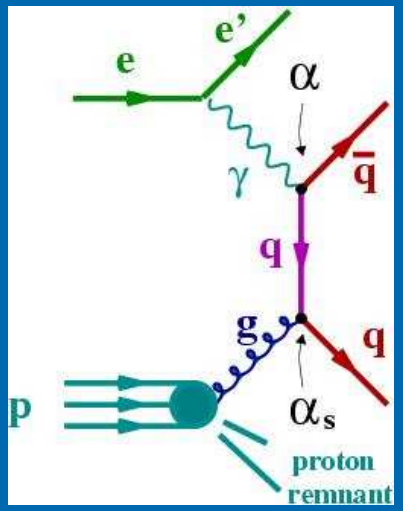
Dijet Photoproduction at HERA

At lowest order QCD, two hard scattering processes contribute to jet production:



RESOLVED PROCESSES

DIRECT PROCESSES



$$d\sigma_{\gamma p} = \sum_{ab} \int_{x_p} \int_{x_\gamma} dx_p dx_\gamma \, f_p(x_p, \mu^2) \, f_\gamma(x_\gamma, \mu^2) \, d\hat{\sigma}_{ab}(x_p, x_\gamma, \mu^2) \cdot (1 + \delta_{had})$$

Jet production cross section depends on:

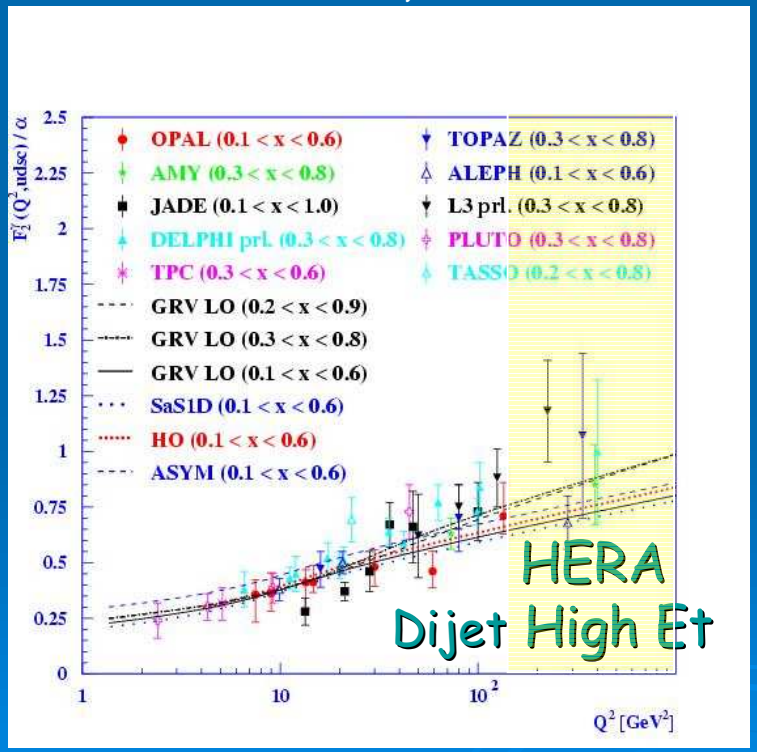
parton densities in the proton (experimentally constraint)

parton densities in the photon

subprocess cross section (matrix-elements: calculable)

World data on F_2^γ

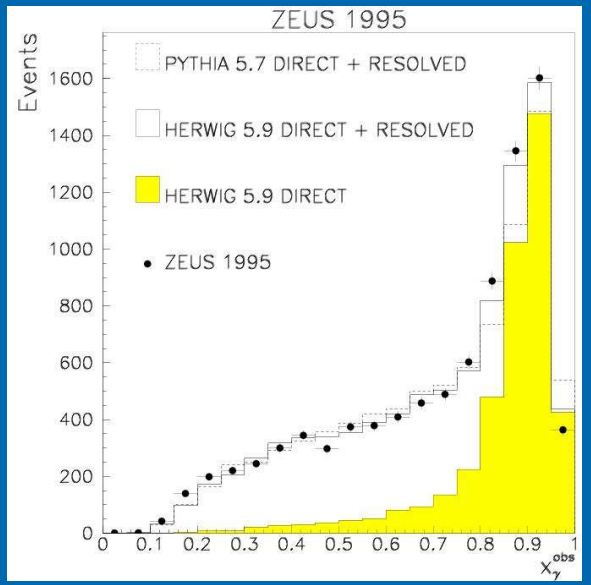
- Information on quark densities from F_2^γ in e^+e^- at low scales
- Photon's gluon density poorly constraint (for all x_γ)
- Photon's quark density not well constraint for $x_\gamma > 0.5$



- At HERA the photon structure can be probed at higher scales than at LEP
- Jet photoproduction is sensitive (LO) to the gluon density in the photon (γ-DIS only sensitive to quark content)
  - the gluon content of the photon dominates cross section at low x_γ
  - sensitive to quark (and gluon) up to very high x_γ

Photon Structure at HERA

- **Observables whose distributions are sensitive to the photon structure:**
  - the fraction of the photon's energy participating in the production of the dijet system x_γ^{obs}
  - the jets pseudorapidities η^{jet} are sensitive to the momentum distributions of the incoming partons. In the LAB frame: at low x_γ^{obs} the dijet system is boosted more forward (proton direction) than at high x_γ^{obs}



$$x_\gamma^{obs} = \frac{\sum_{i=1}^{2} E_T^{jet_i} e^{-\eta^{jet_i}}}{2E_\gamma}$$

- **Several NLO QCD calculations are available** (phase-space slicing, subtraction method)

  choice of scales: $\mu_R = \mu_F = E_T^{jet} \quad (Q^2 \approx 0)$

Photon Structure at HERA

To provide precise measurements that can be used to constrain the photon parton densities several difficulties have to be overcome:

- Jet algorithms and jet selections for which accurate (at least NLO) pQCD predictions can be performed
  - inclusive k_T -algorithm
  - asymmetric cuts on E_T^{jet1} and E_T^{jet2}
- Suppression of non-perturbative effects (underlying events and fragmentation) and good knowledge of the proton parton densities

→ high E_T dijets

High Et dijets Cross-Sections

Cross-section:

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

$$0.2 < y < 0.85, \quad 134 < W_{\gamma p} < 277\,\mathrm{GeV}$$

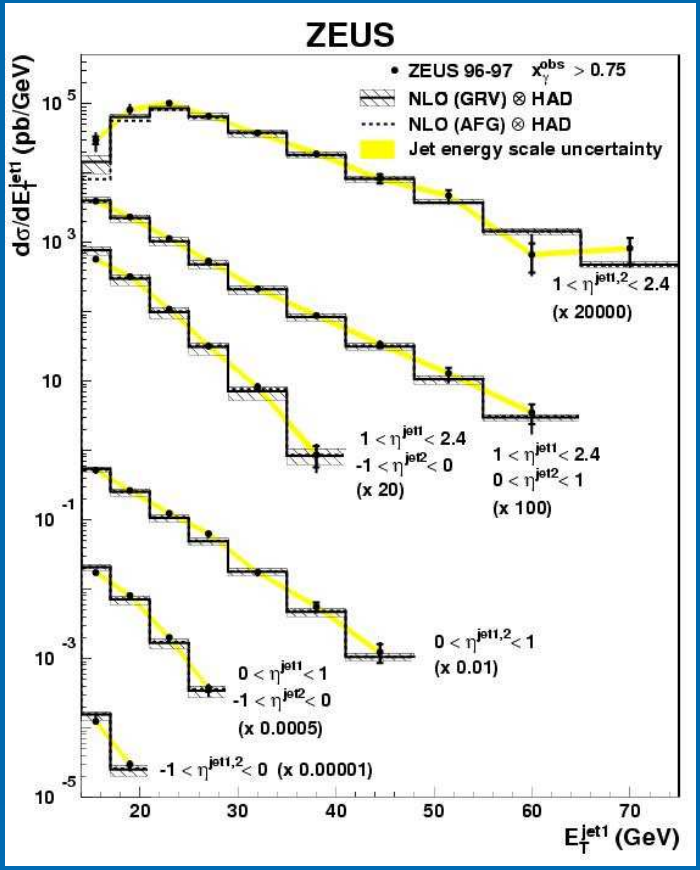
$$E_T^{jet_1}(\mathrm{Lab}) > 14\,\mathrm{GeV}, \; E_T^{jet_2}(\mathrm{Lab}) > 11\,\mathrm{GeV}$$

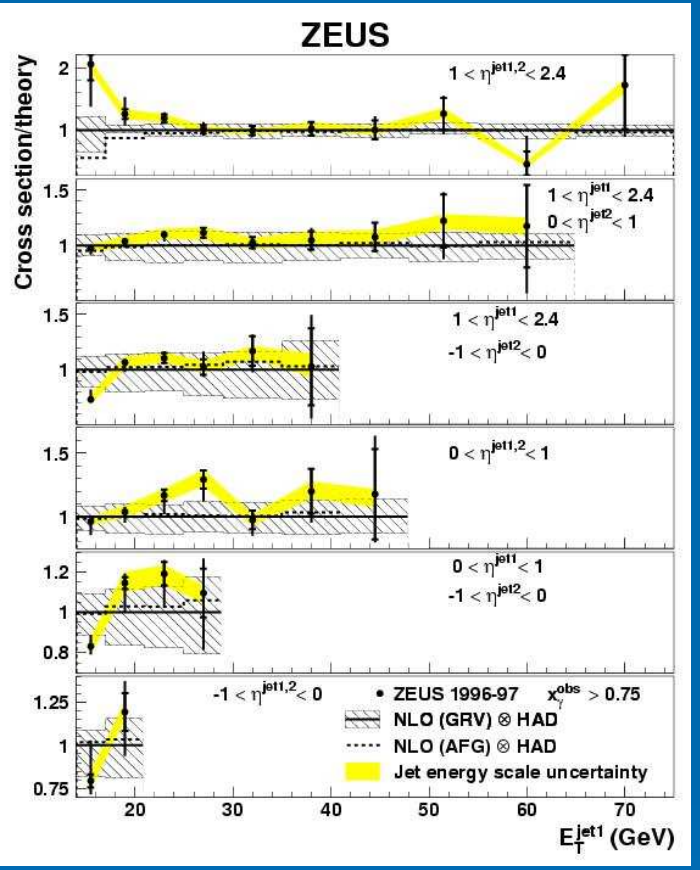
$$-1 < \eta^{\mathrm{jet}_{1,2}}(\mathrm{Lab}) < 2.4$$

→ Kinematic region where soft physics is suppressed

- Photon structure:
  - high scales
  - sensitivity to both the quark and the gluon densities in the photon
- Test of pQCD calculations:
  - dynamics of resolved and direct processes (the dijet angular distribution is sensitive to the spin of the exchanged particle)

Results: cross sections in E_T^{jet1}



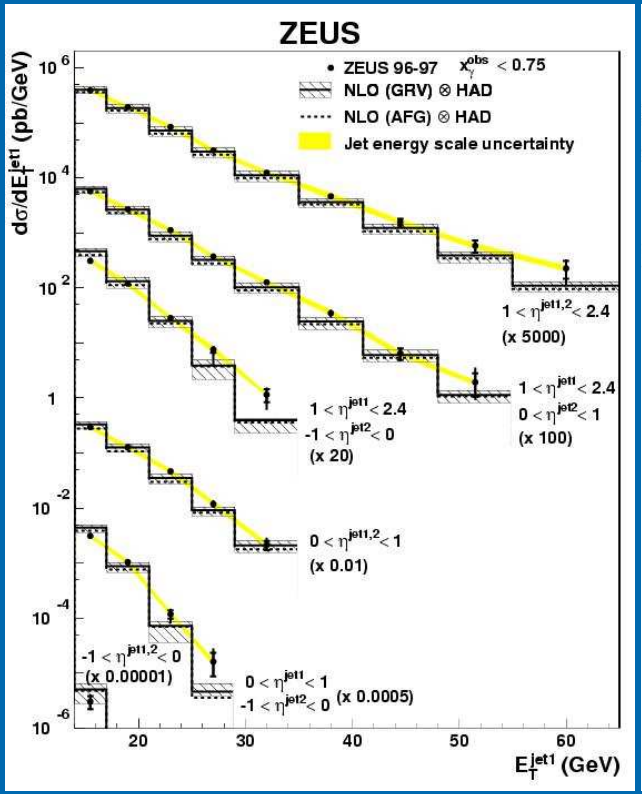


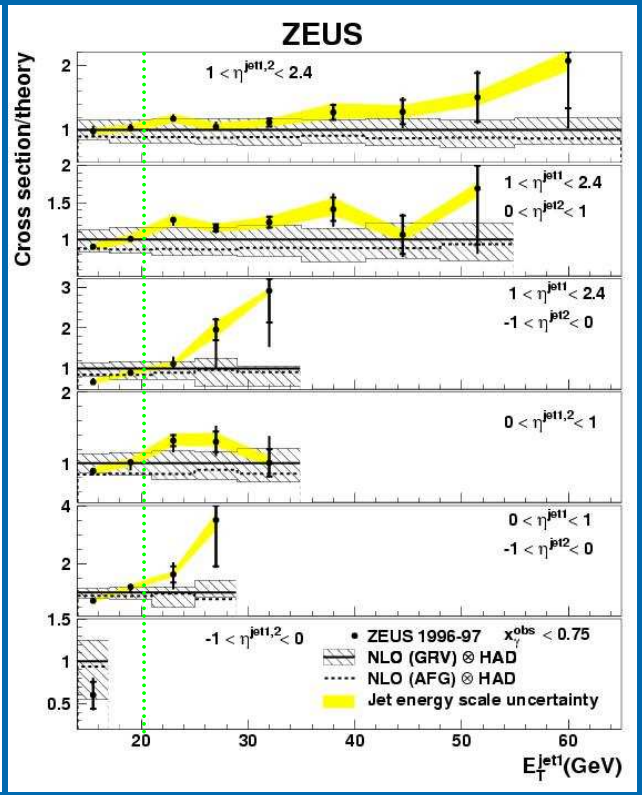
NLO:
Frixione & Ridolfi
(subtraction meth.)
proton PDF:
CTEQ-5M1
photon PDF:
GRV-HO,
AFG-HO

$x_\gamma > 0.75$

- **Overall reasonable description of the data**
  - Dominant theoretical uncertainty: scale dependence of the calculations (about 10-20)%
  - Dominant experimental uncertainty: energy scale of the jets and jets cuts (about 5% on the cross section)

Results: cross sections in E_T^{jet1}





NLO:
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(subtraction method)
proton PDF:
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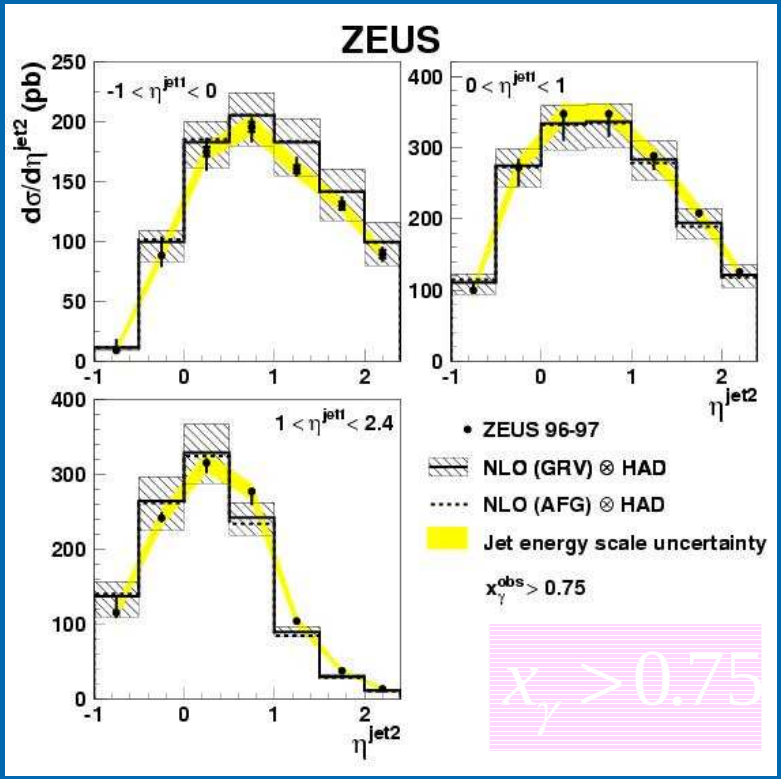
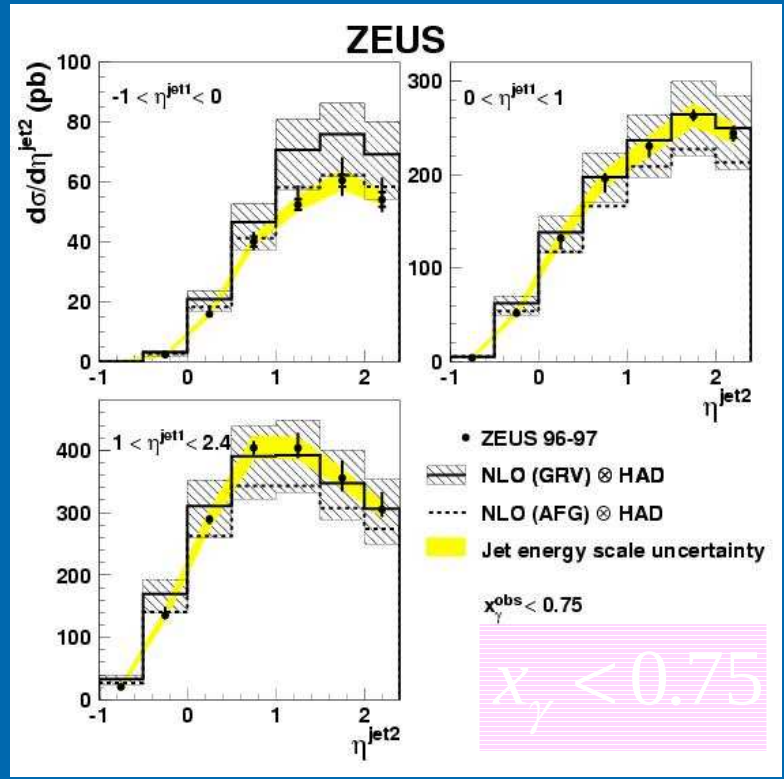
photon PDF:
GRV-HO,
AFG-HO

$x_\gamma < 0.75$

- Data generally well describe although a difference in shape is seen (predictions above the data for low E_T and below the data at high E_T)
- Predictions with AFG-HO uniformly about 15% below GRV-HO

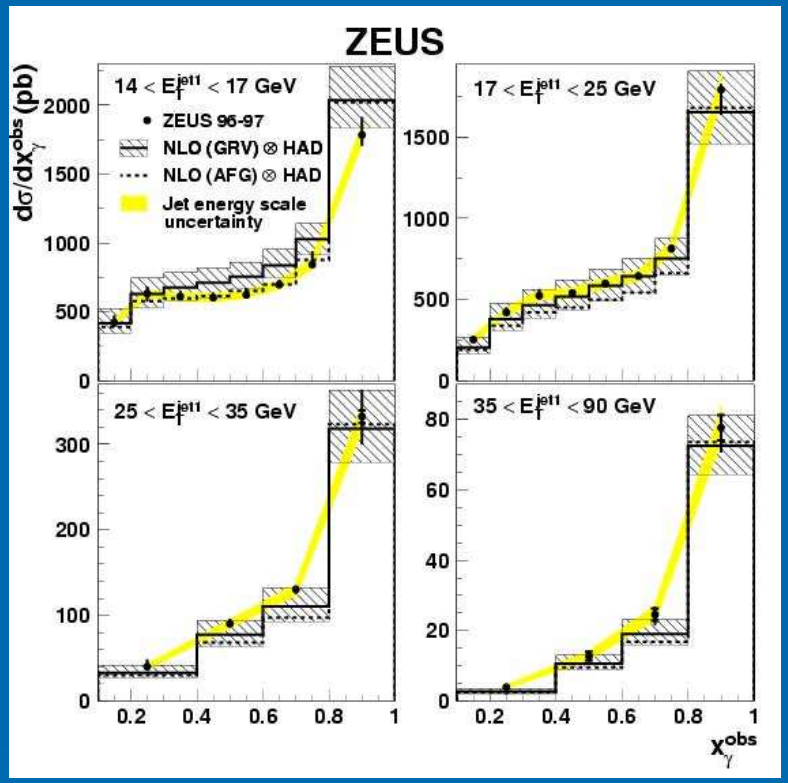
Results: cross sections in $\eta_T^{jet_2}$

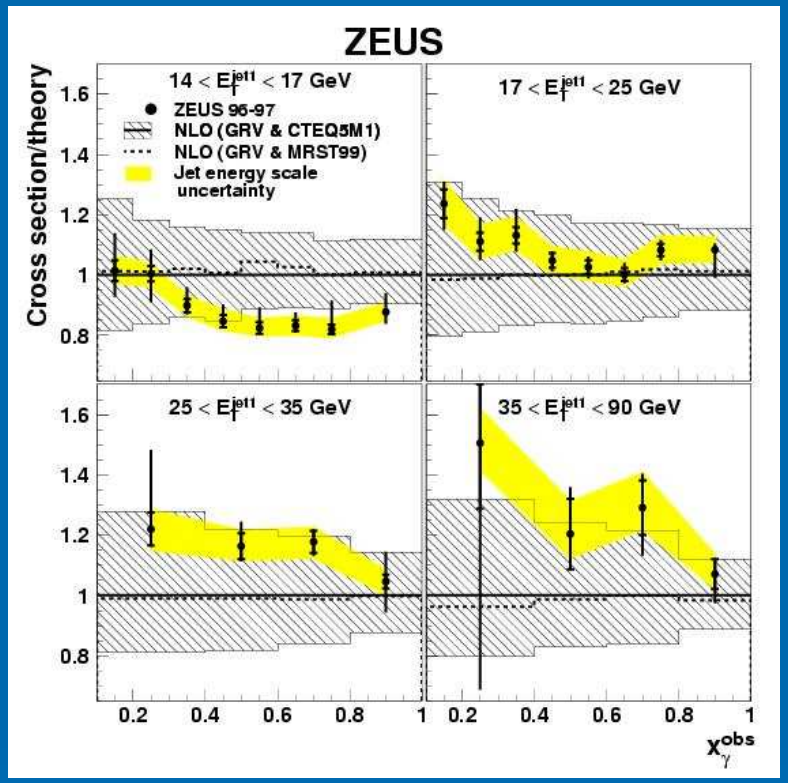




- Good description of the data except for
  $-1 < \eta^{jet_1} < 0$ and $x_\gamma < 0.75$
- AFG-HO about (10-15)% below GRV-HO
- Parametrisation of the photon PDFS inadequate?

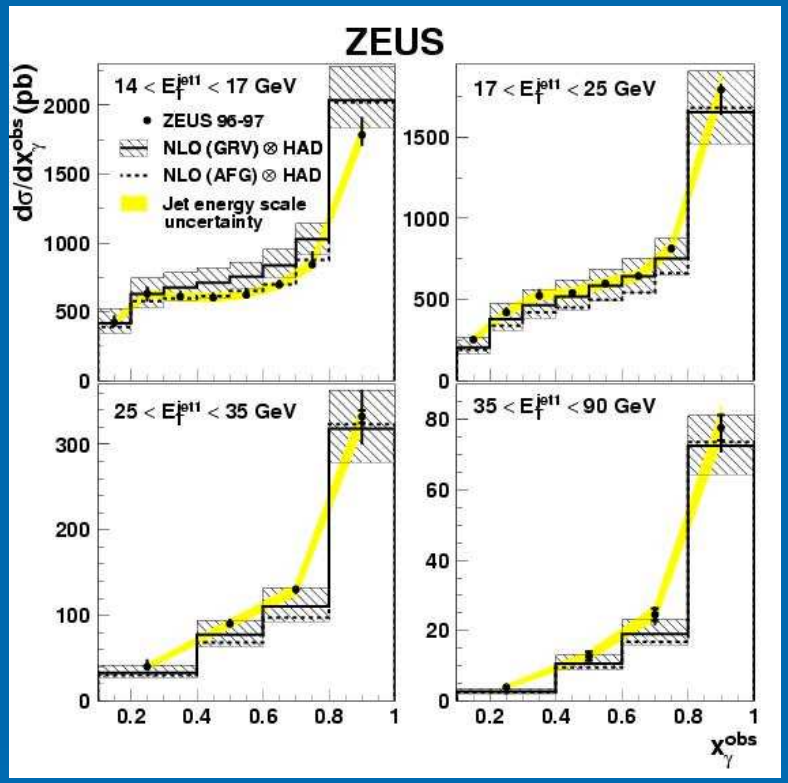
Results: cross sections in x_γ^{obs} compared to GRV

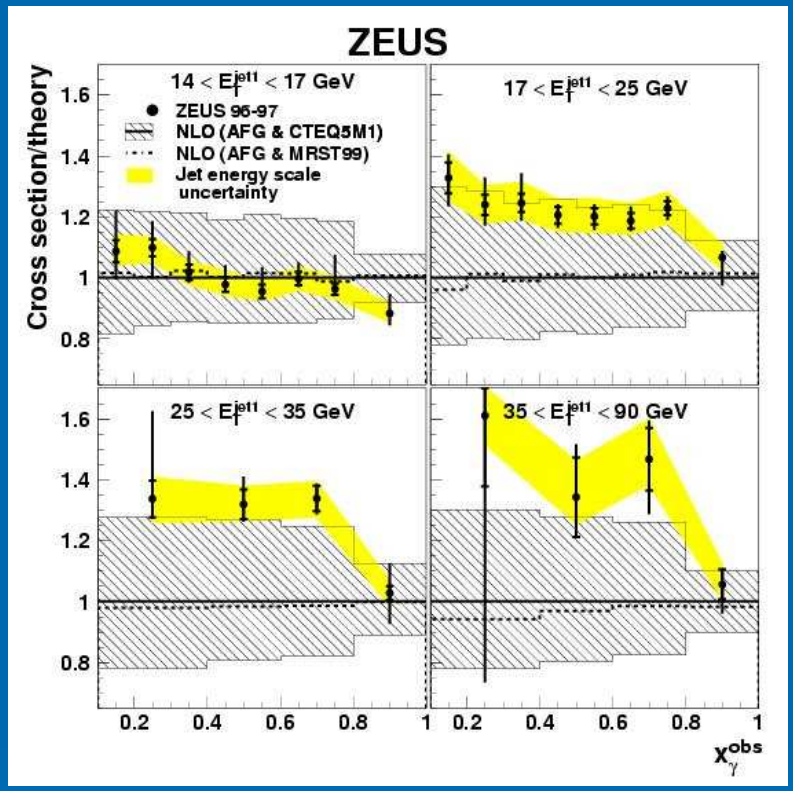




- Predictions significantly above the data in the lowest E_T bin for $0.5<x_\gamma^{obs}<0.8$ but increasingly below the data for E_T >17 GeV
- Differences between CTEQ5M1 and MRST99 < 5%
- Parametrisation of the photon PDFs inadequate?

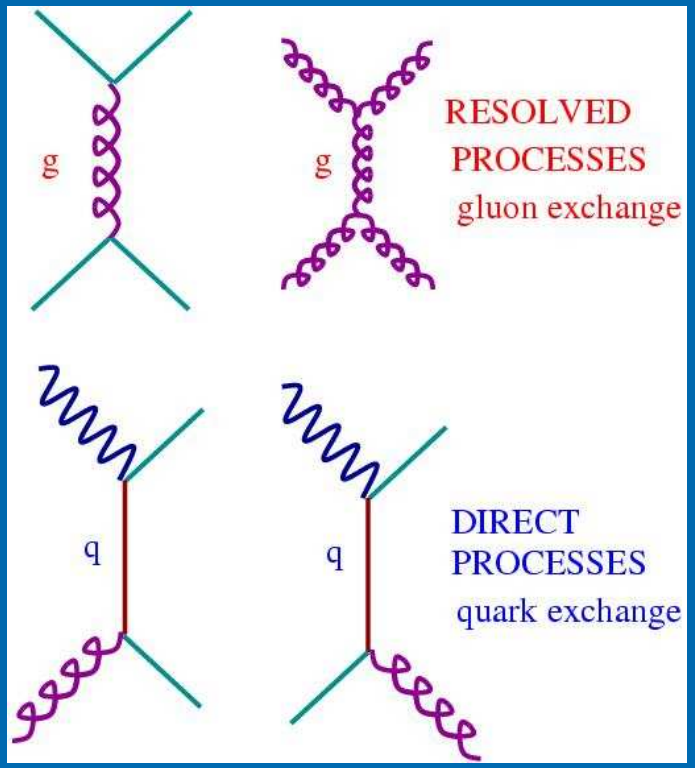
Results: cross sections in x_γ^{obs} compared to AFG





- Predictions using AFG-HO similar in shape to GRV-HO but (10-15)% lower ➔ now the predictions are below the data for the higher Et bins for $x_\gamma < 0.8$
- Parametrisation of the photon PDFs inadequate?

Probing the matrix elements



- The dynamics of dijet production has been investigated by studying the variable

$$\cos\theta^* \equiv \tanh\left(\frac{\eta^{jet_1} - \eta^{jet_2}}{2}\right)$$

  - For two-to-two parton scattering θ^* coincides with the scattering angle in the dijet CMS
- QCD predicts different dijet angular distributions for resolved and direct:

Resolved: $\frac{d\sigma}{d|\cos\theta^*|} \sim \frac{1}{(1-|\cos\theta^*|)^2}$

Direct: $\frac{d\sigma}{d|\cos\theta^*|} \sim \frac{1}{(1-|\cos\theta^*|)}$

$$\frac{d\sigma}{d|\cos\theta^*|}$$

steeper for resolved at high $\cos\theta^*$

Probing the matrix elements

- Measurements of $d\sigma/d|\cos\theta^*|$ in the region:

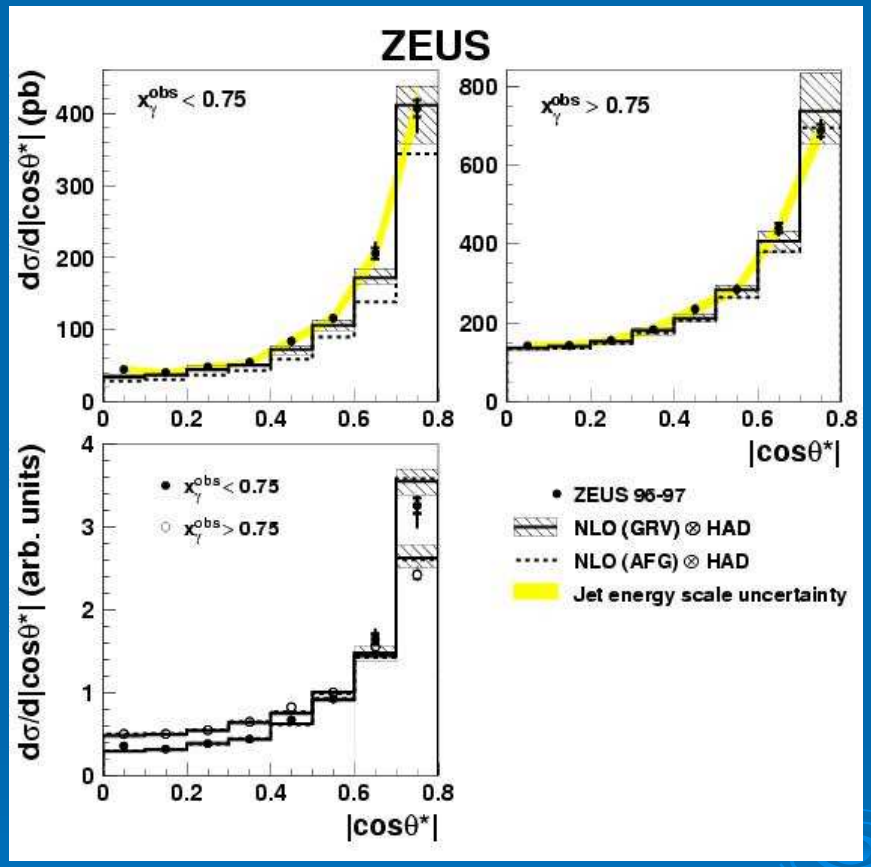
$$|\cos\theta^*| < 0.8, \quad M_{jj} > 42\ \text{GeV}$$

(to avoid bias due Et requirements)

$$0.1 < \overline{\eta} < 1.3$$

(to have uniform acceptance in $|\cos\theta^*|$)

- High-x_γ^{obs} : NLO QCD describes shape and normalisation of the cross section
- Low-x_γ^{obs} : NLO QCD describes the shape but not the normalisation of the data
- Dynamics OK! Parametrisation inadequate?



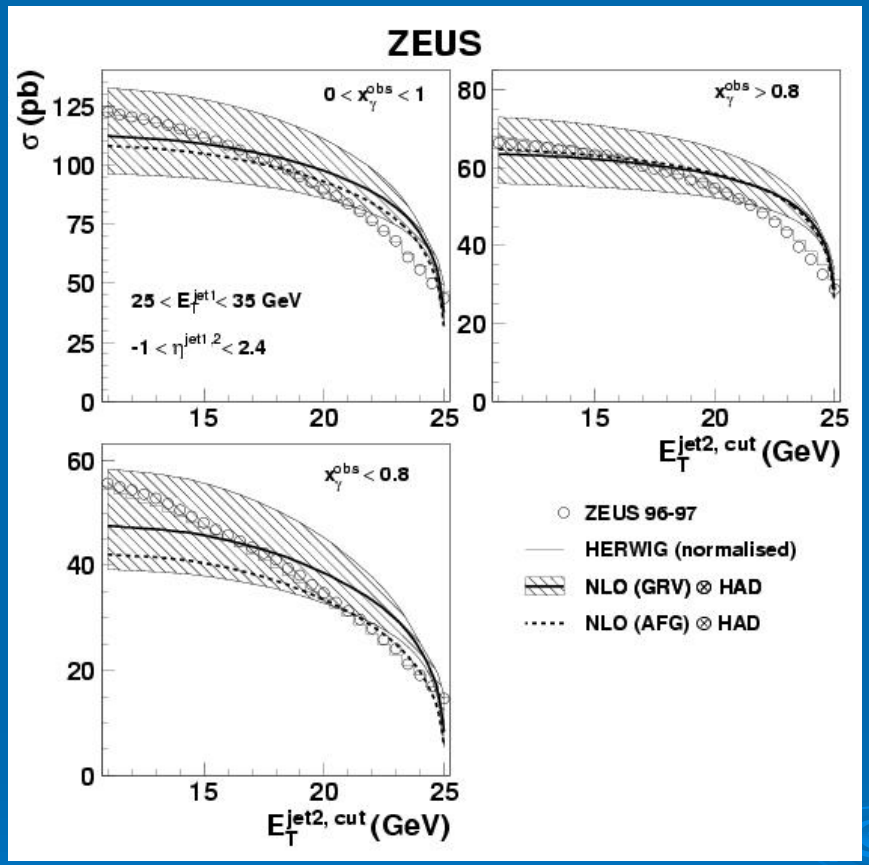
Data at low-x_γ^{obs} rise more rapidly at high $|\cos\theta^*|$ than at high-x_γ^{obs}

Dijet Photoproduction

(In)adequacy of the current parametristions of the photon PDFs?

Investigation of the differences by comparing with the same set of photon PDFs different cut on the second jet's E_t

- measured dependence not reproduce by NLO
- comparison data vs NLO depends on the cut value



Theoretical work on improving dijet (NNLO?, selection criteria?) is needed

Conclusions

- The dijet cross section in PHP has been measured in the kinematic region

$$Q^2 < 1\,\mathrm{GeV}^2,\ .2 < y < .85,\quad E_T^{jet_1}(\mathrm{Lab}) > 14\,\mathrm{GeV},$$
$$E_T^{jet_2}(\mathrm{Lab}) > 11\,\mathrm{GeV}, -1 < \eta^{\mathrm{jet}_{1,2}}(\mathrm{Lab}) < 2.4$$

- In the high-mass region defined by

$$|\cos\theta^*| < 0.8,\quad \mathrm{M}_{jj} > 42\,\mathrm{GeV},\quad 0.1 < \overline{\eta} < 1.3$$

the dijet angular distribution of the data is well reproduced by NLO → the dynamics of the short-distance process seems to be understood

- Over the wide region the measurements are compared with NLO using different photon's parametrisations
- The data show sensitivity to the photon's PDFs
- Neither the AFG-HO nor the GRV-HO, convoluted with the NLO matrix elements, fully describe all feature of the data

Conclusions cont.

- There is agreement with the theory at high x_γ and high E_T ➔ consistency check of the gluon distribution in the proton extracted from DIS
- The data at low x_γ significantly constrain the parton densities in the photon ➔ future parametrisations of the photon PDFs should take them into account
- These constraints would be made more stringent were improved higher-order or resummed calculations available