The structure of real photons at HERA

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representing H1 and ZEUS Collaborations

- Photoproduction at HERA
- High E_T jets:
  - Single inclusive cross sections
  - Dijet cross sections
- Conclusions

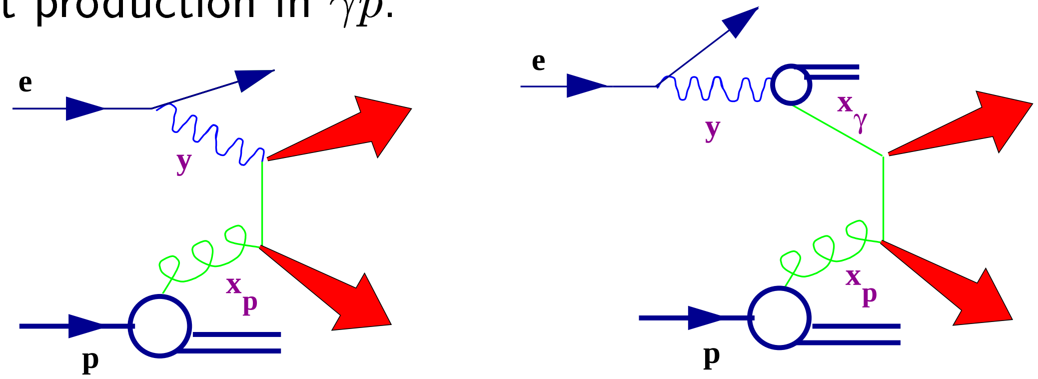
PHOTON 2001
Ascona, September 2 – 7, 2001

Photoproduction at HERA

e^+ (27.6 GeV) → ← p (820 GeV)

$\sqrt{s} = 300$ GeV

Jet production in γp:



DIRECT ($x_\gamma = 1$) RESOLVED ($x_\gamma < 1$)

σ_{ep} is convolution of partonic cross sections and PDFs:

$$\boxed{\frac{d\sigma_{ep}}{dQ^2} = \gamma_{flux}(y, Q^2) \otimes PDF_\gamma(x_\gamma, Q^2, \mu) \otimes PDF_p(x_p, \mu) \otimes d\sigma_{ij}(\theta^*, Q^2, \mu)}$$

- Q^2 - virtuality of γ^* and y - inelasticity
- E_T, η - transverse momentum and pseudorapidity of jets
- θ^* angle of dijet system in 2–jet CMS
- $\mu \rightarrow E_T$ is the hard scale

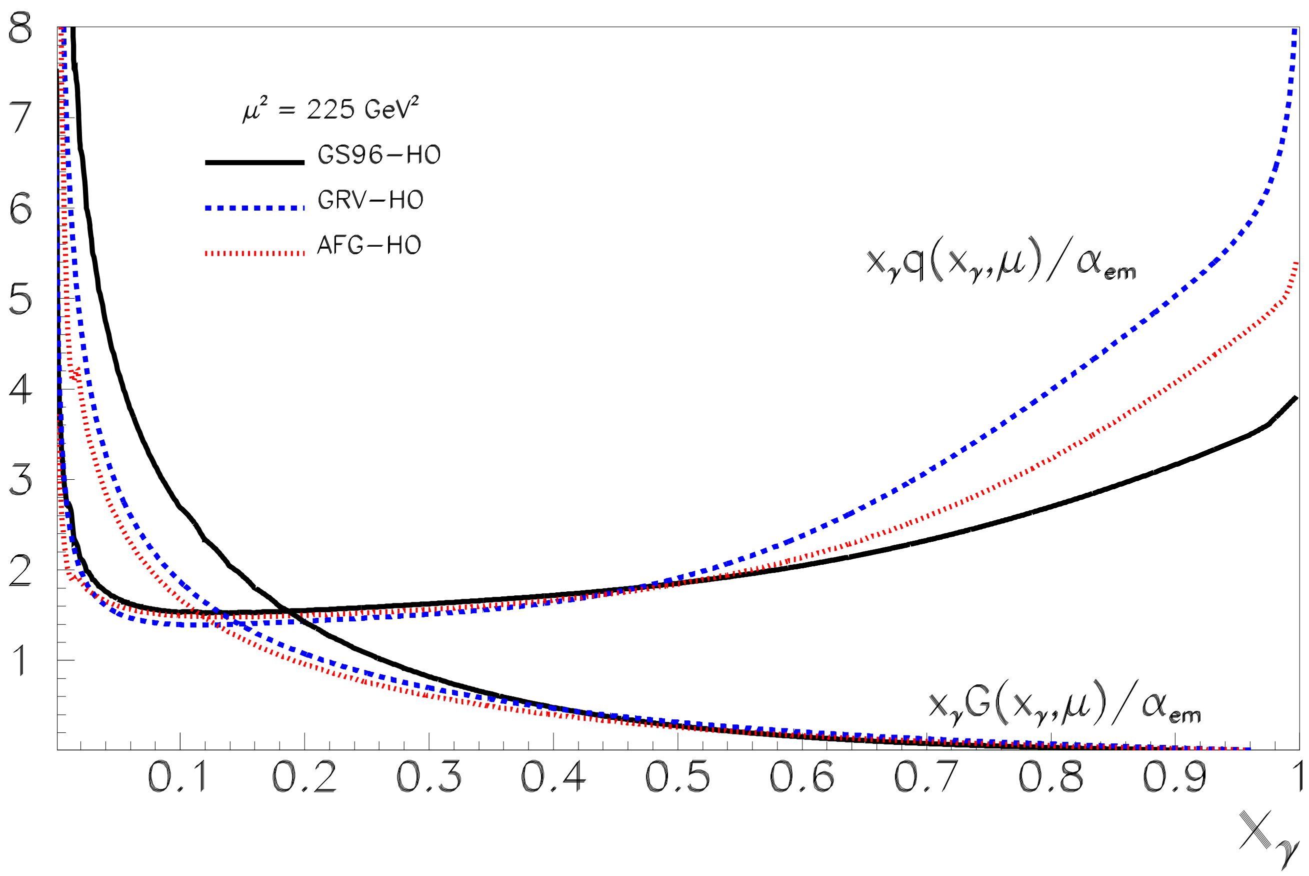
Photon structure at HERA

- $x_\gamma(x_p)$ - fraction of γ^*'s (proton's) momentum in hard subprocess

$$\boldsymbol{x_\gamma = \frac{\sum_{jets} E_{T,i} e^{-\eta_i}}{2yE_e}} \quad \text{or} \quad \boldsymbol{\frac{\sum_{jets}(E_i - p_{z,i})}{\sum_{had}(E_h - p_{z,h})}}$$

$$x_p = \frac{\sum_{jets} E_{T,i} e^{\eta_i}}{2E_p}$$

How different are photon structure functions?



Jets with almost real photons at HERA

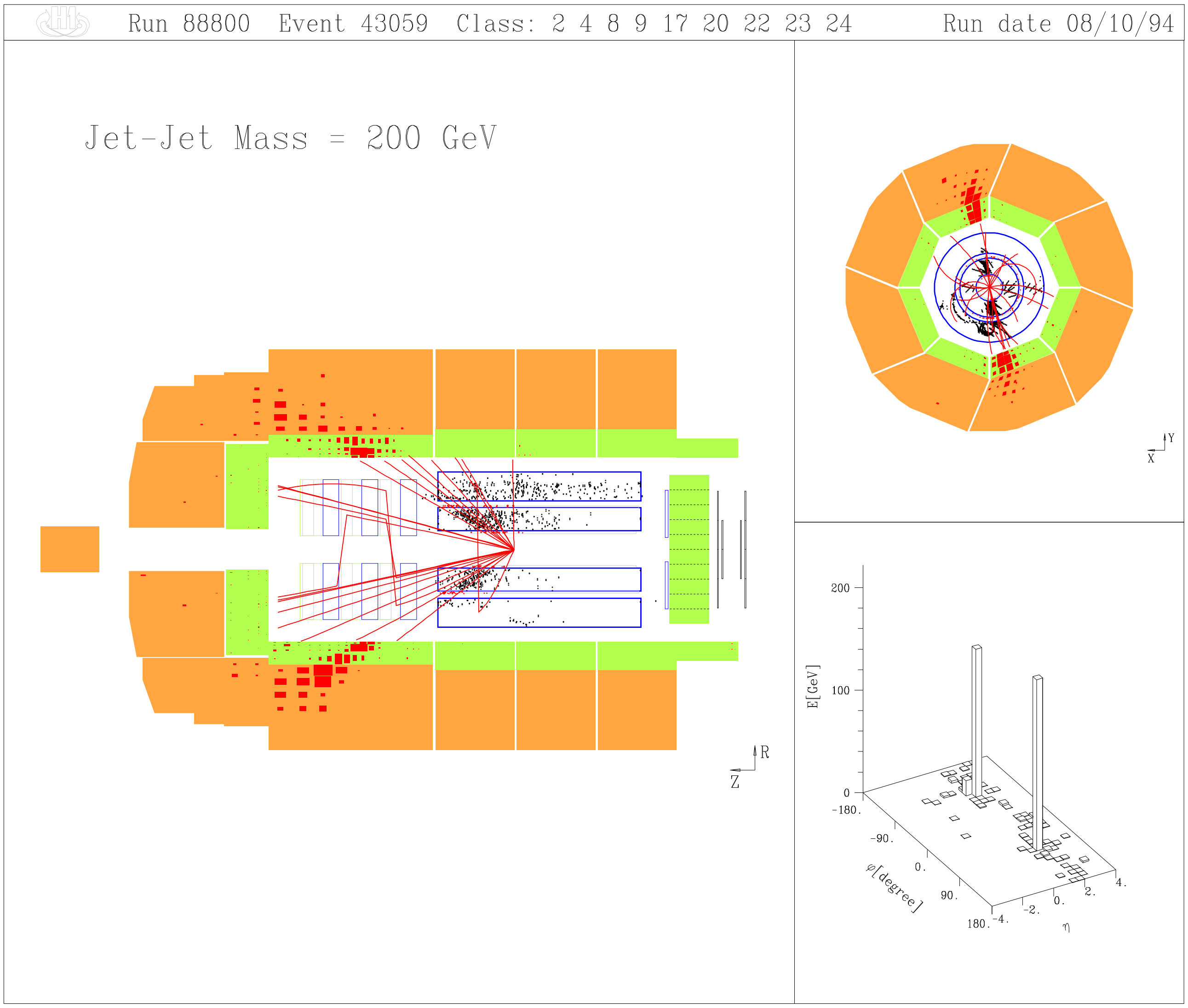
Why study high E_T jets?

- test of perturbative QCD
- access the quark and gluonic structure of the photon
- test of photon PDF's at the highest scales (up to 80 GeV)
- test the gluonic structure of proton at high x_p

Experimentally easier than low E_T jets

- influence of the soft underlying event is reduced
- fragmentation/hadronization effects small
- hard scale $\rightarrow$ reliable pQCD predictions at NLO

Photoproduction dijet event in H1 experiment



z – direction

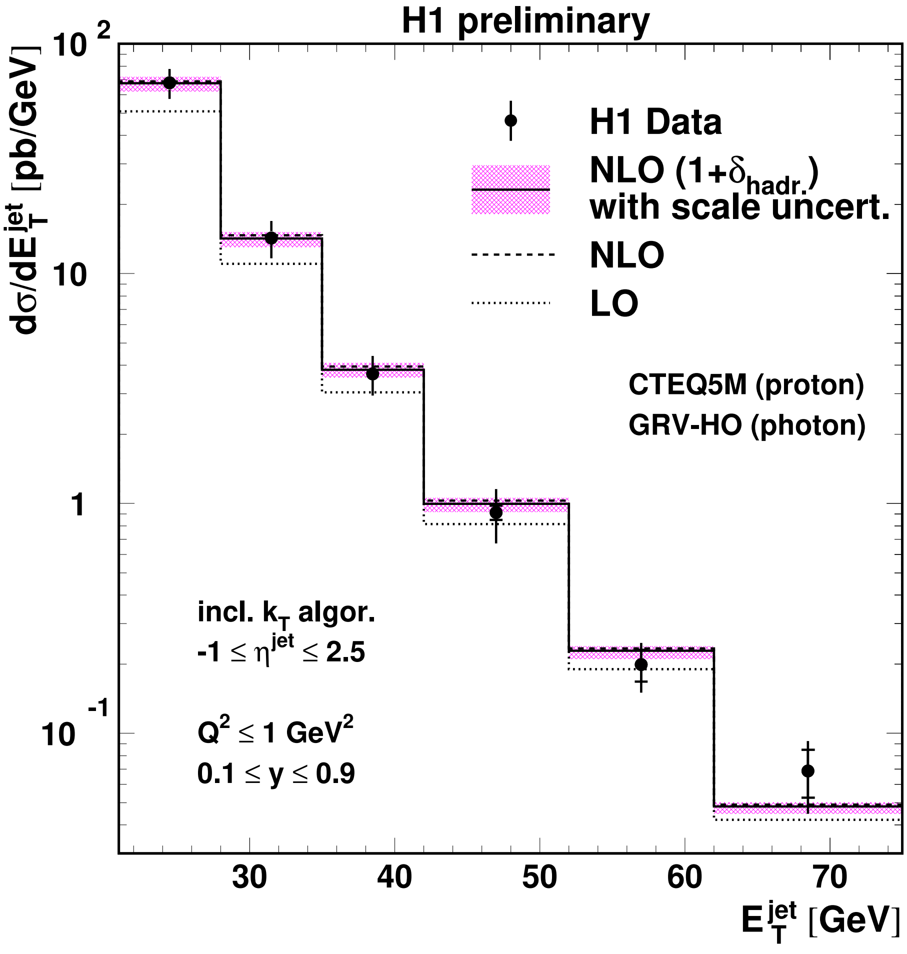
Single Inclusive High E_T Jet Cross Section

H1, 1996–97 (L=24 pb^{-1}),
$Q^2 < 1GeV^2$, 95 < $W_{\gamma p}$ < 285 GeV

k_T longitudinal inv. cluster algorithm in LAB
$E_T^{jet} > 21$ GeV, -1< η^{jet} <2.5

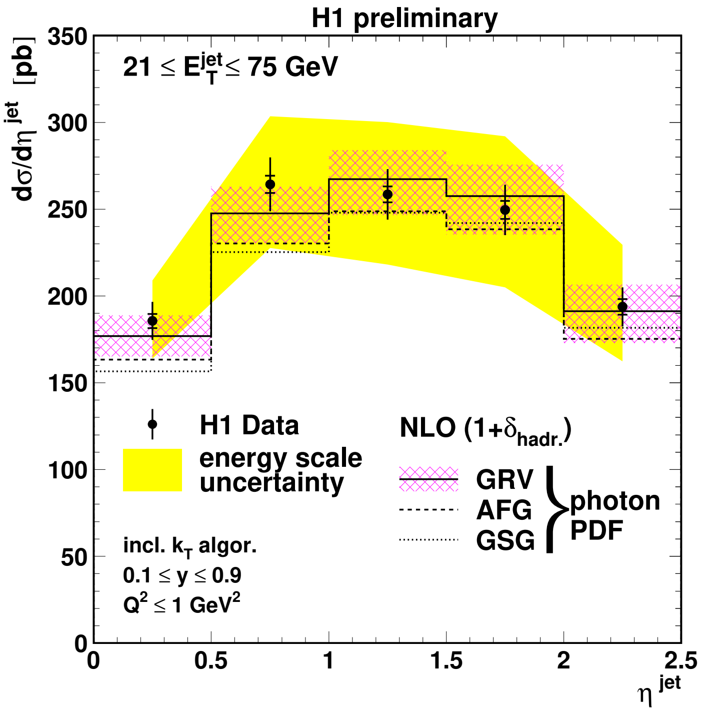
NLO QCD calculation → Frixione,Ridolfi,Nucl.Phys. B507 (1997),315

Renormalization/factorization scales (varied by factor 2 up and down):
$\mu_r = \mu_f = 1/2\Sigma E_T^{parton}$

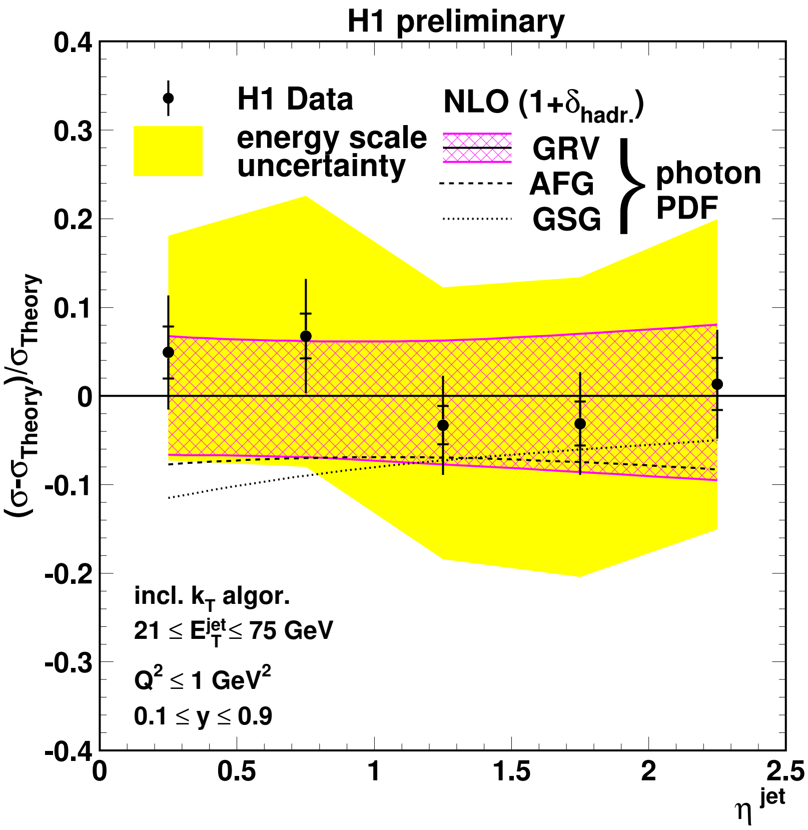


→ Inclusive jet data compatible with NLO QCD

Single Inclusive High E_T Jet Cross Section

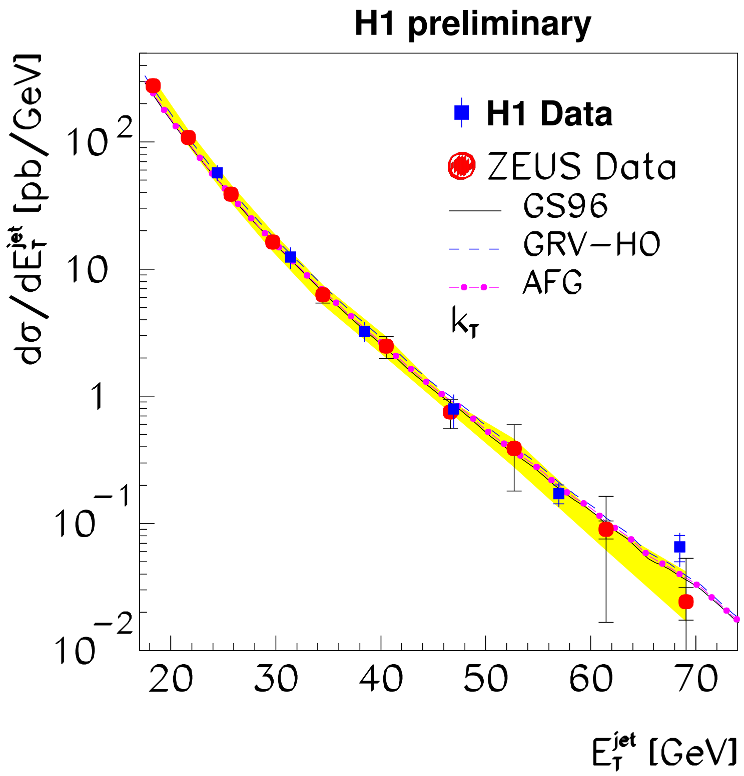


GRV–HO photon PDF → good description of the data

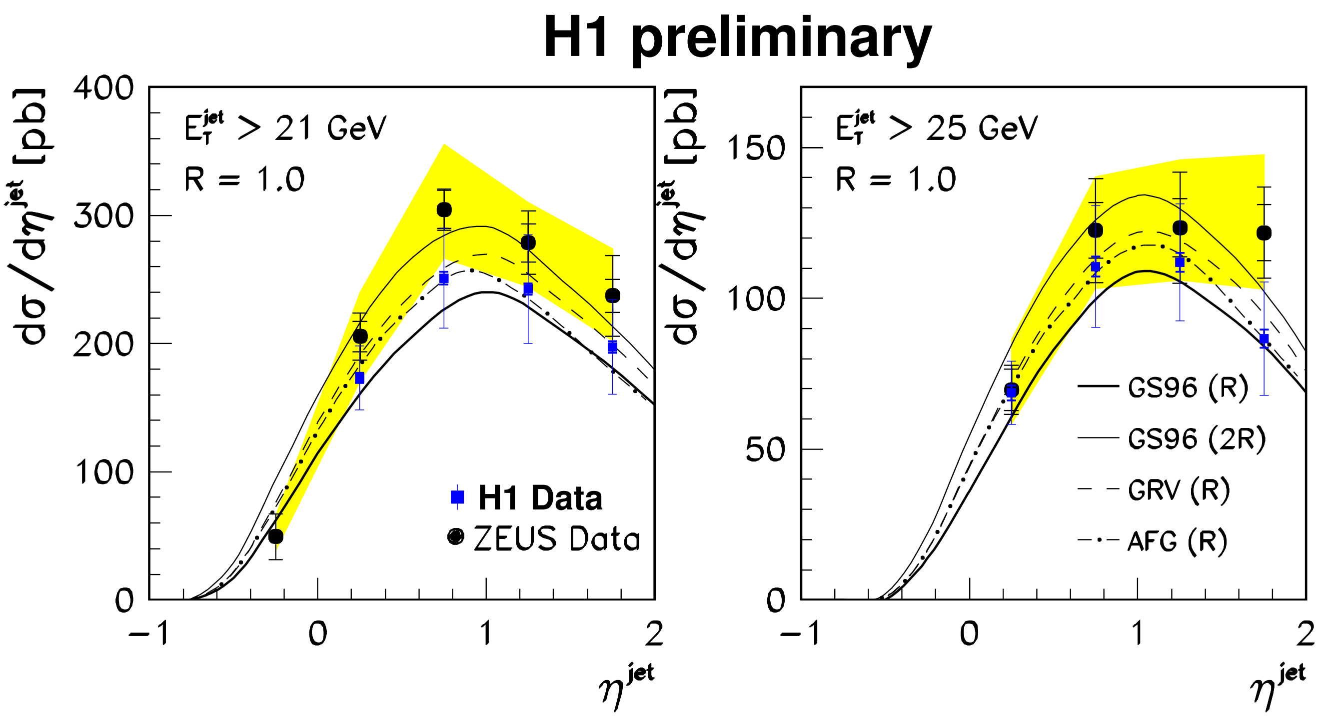


Comparison of H1 and ZEUS results

ZEUS preliminary data:



ZEUS data:



→ H1 and ZEUS data compatible.

Dijet Cross Sections in Photoproduction

ZEUS, 1996–97, (L=38 pb^{-1})

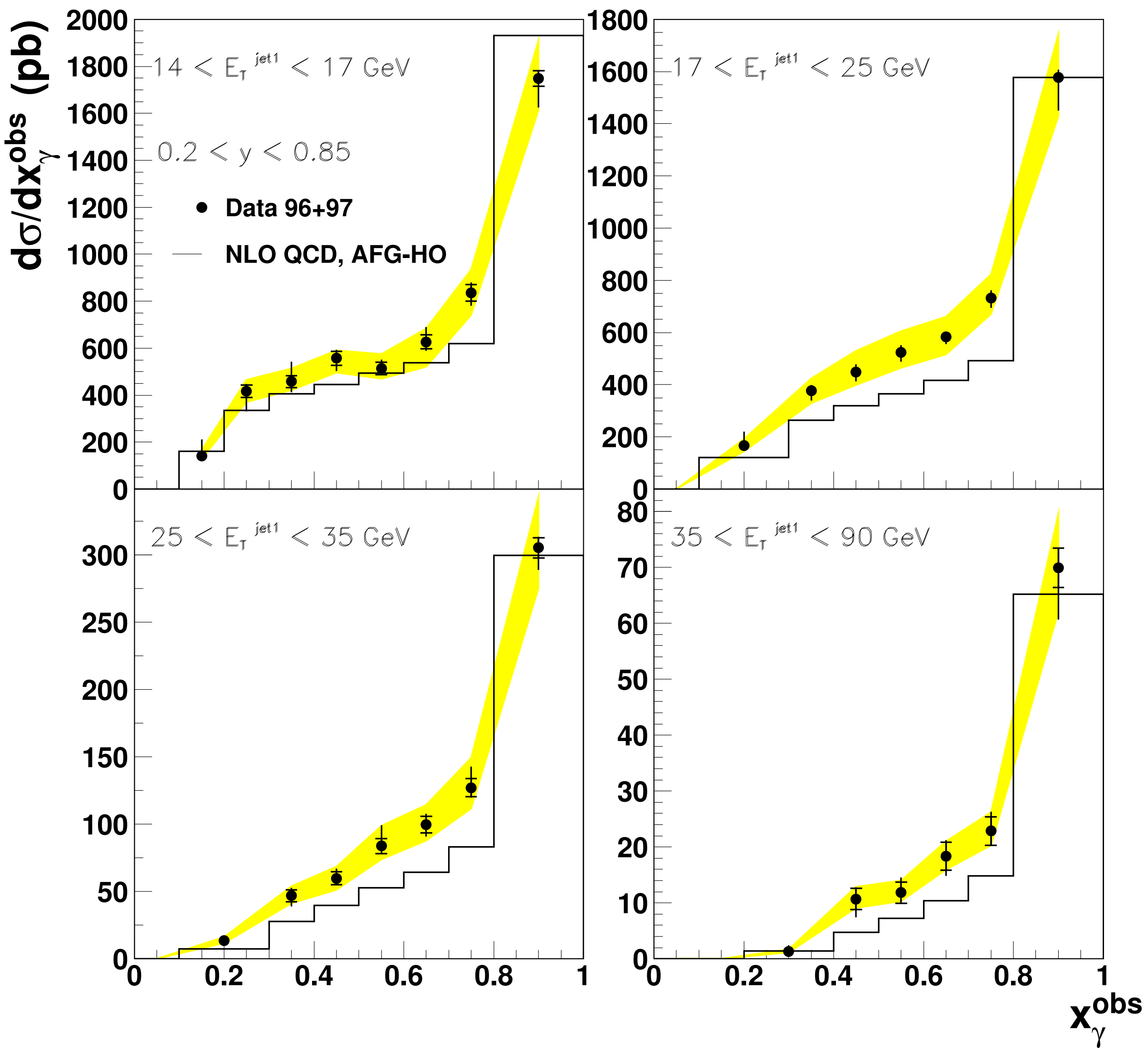
k_T cluster algorithm in LAB, $Q^2 < 1 GeV^2$, 0.2< y < 0.85

$E_{T,1}^{jet}$ > 14 GeV, $E_{T,2}^{jet}$ > 11 GeV, -1< η^{jet} <2

proton PDF : CTEQ4M

hadronization corrections ~ 10–15% → not shown

ZEUS Preliminary



Dijet Cross Sections in Photoproduction

- ZEUS data well described by NLO for high x_γ
- for $x_\gamma < 0.75$ data ABOVE NLO
- difference is larger for larger E_T
- modification of the photon structure function????

Access to Hard Scattering

E_T and $\Delta\eta$ are invariant under long. boost and give access to kinematics in the parton–parton CMS!!!

$$\Delta\eta = \eta_1 - \eta_2 \qquad \cos\theta^* = |tanh(\Delta\eta/2)|$$

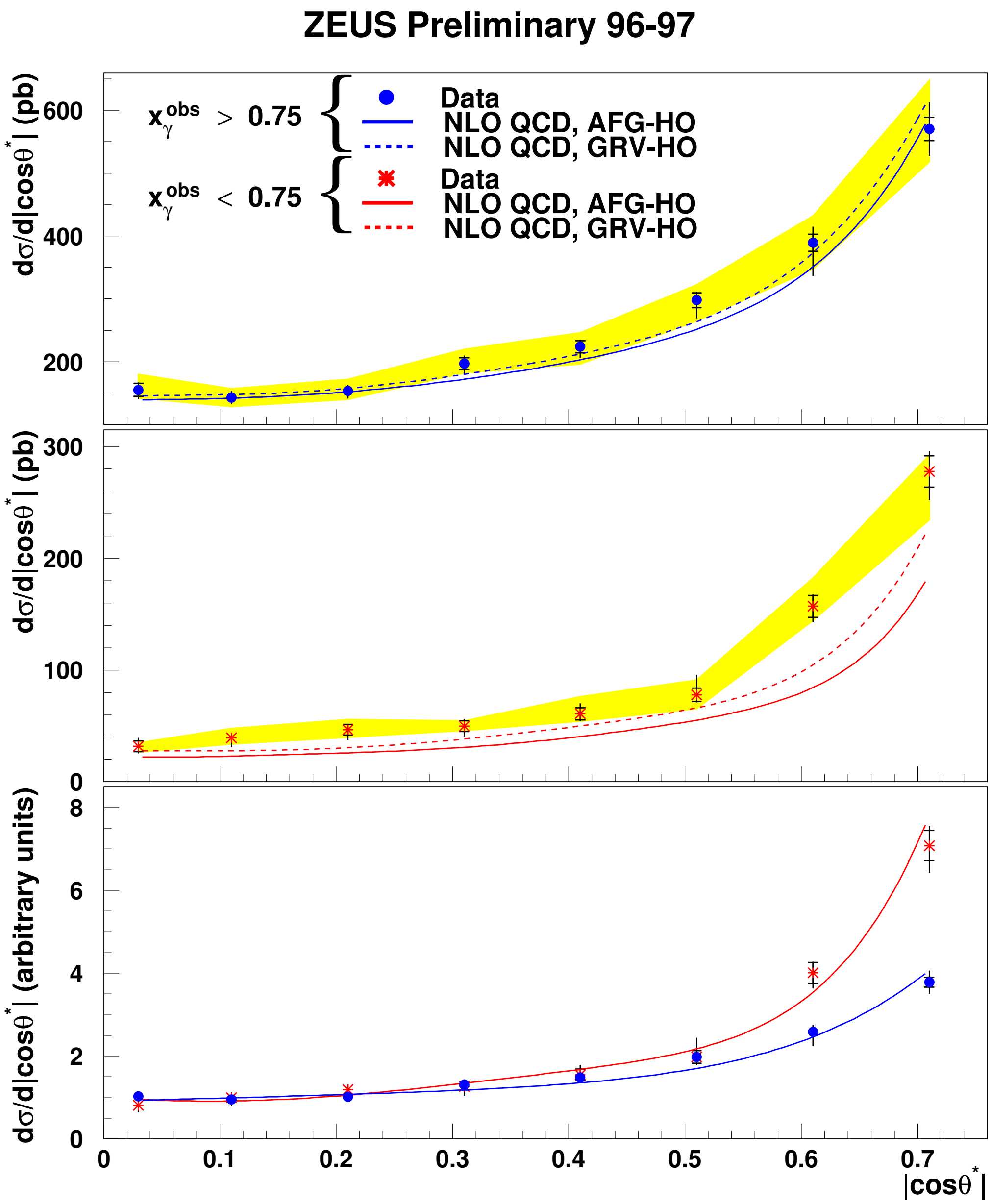
Test of the parton–parton dynamics:

direct: $\mathrm{ME} \sim (1 - cos\theta^*)^{-1} \leftarrow$ propagator is q

resolved: $\mathrm{ME} \sim (1 - cos\theta^*)^{-2} \leftarrow$ propagator is g

Distribution of $d\sigma/dcos\theta^*$

*



- after normalization to two first bins → (fig.c)) shapes described by NLO
- Indication for inadequate parametrisation of the photon parton–density function?

Dijet Cross Sections in Photoproduction

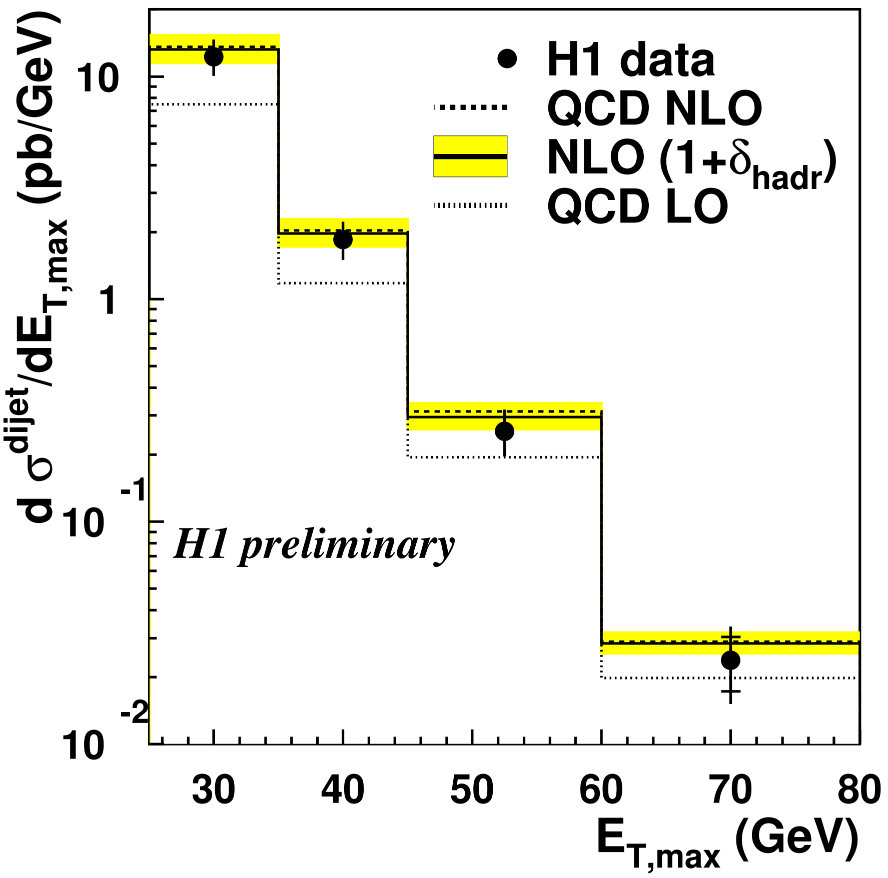
H1

1995–97 (L=34.9 pb^{-1})
$Q^2 < 1GeV^2$, $95 < W_{\gamma p} < 285$ GeV

k_T cluster algorithm in LAB

$E_{T,1}^{jet} > 25$ GeV, $E_{T,2}^{jet} > 15$ GeV, -0.5< η^{jet} <2.5

proton PDF : CTEQ5M photon PDF : GRV,GSG,AFG



0.1< x_γ <1.
0.05< x_p <0.6

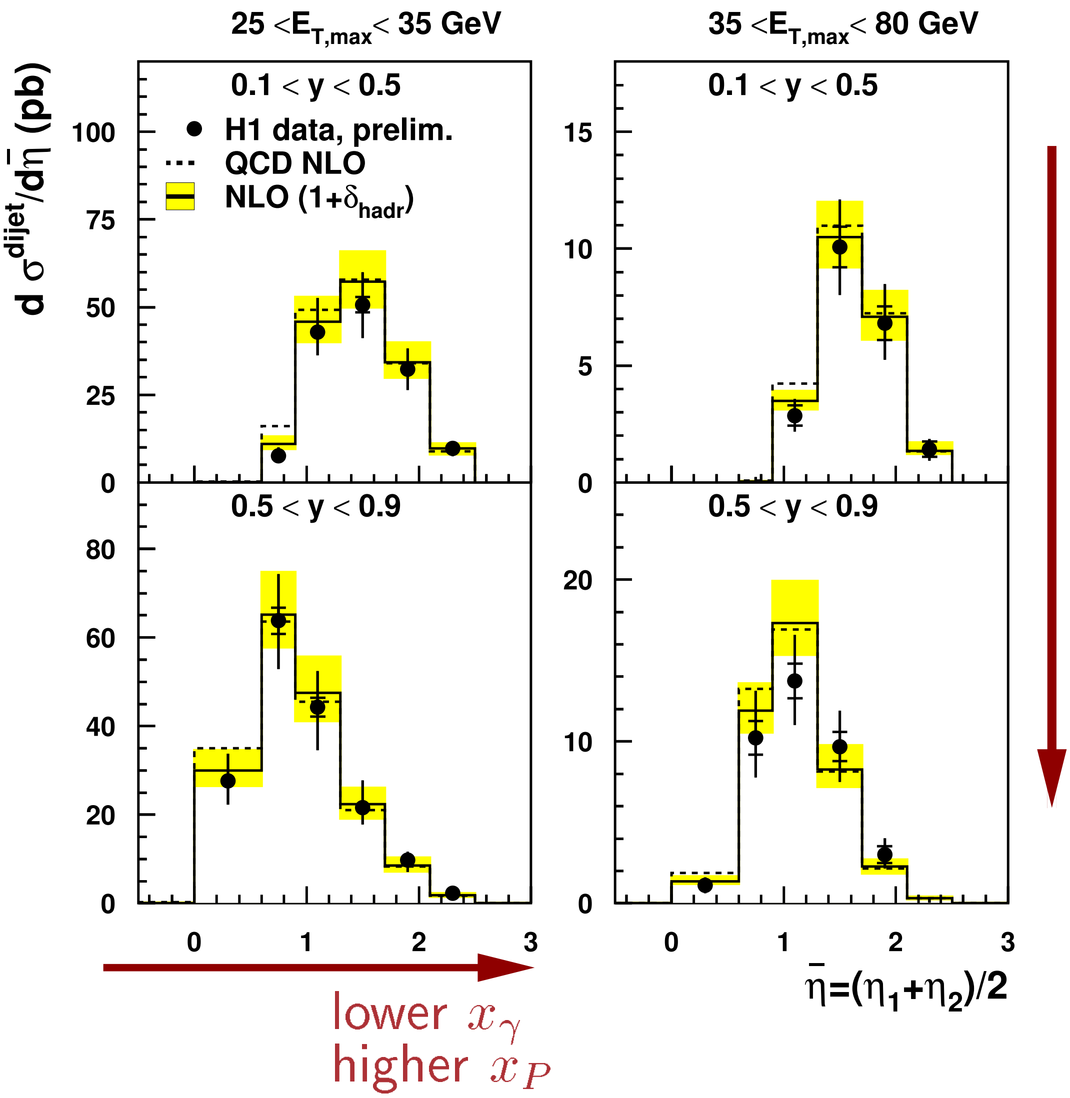
→ Dijet data compatible with NLO QCD up to $E_{T,max} = 80$ GeV

Dijet Cross Sections in Photoproduction

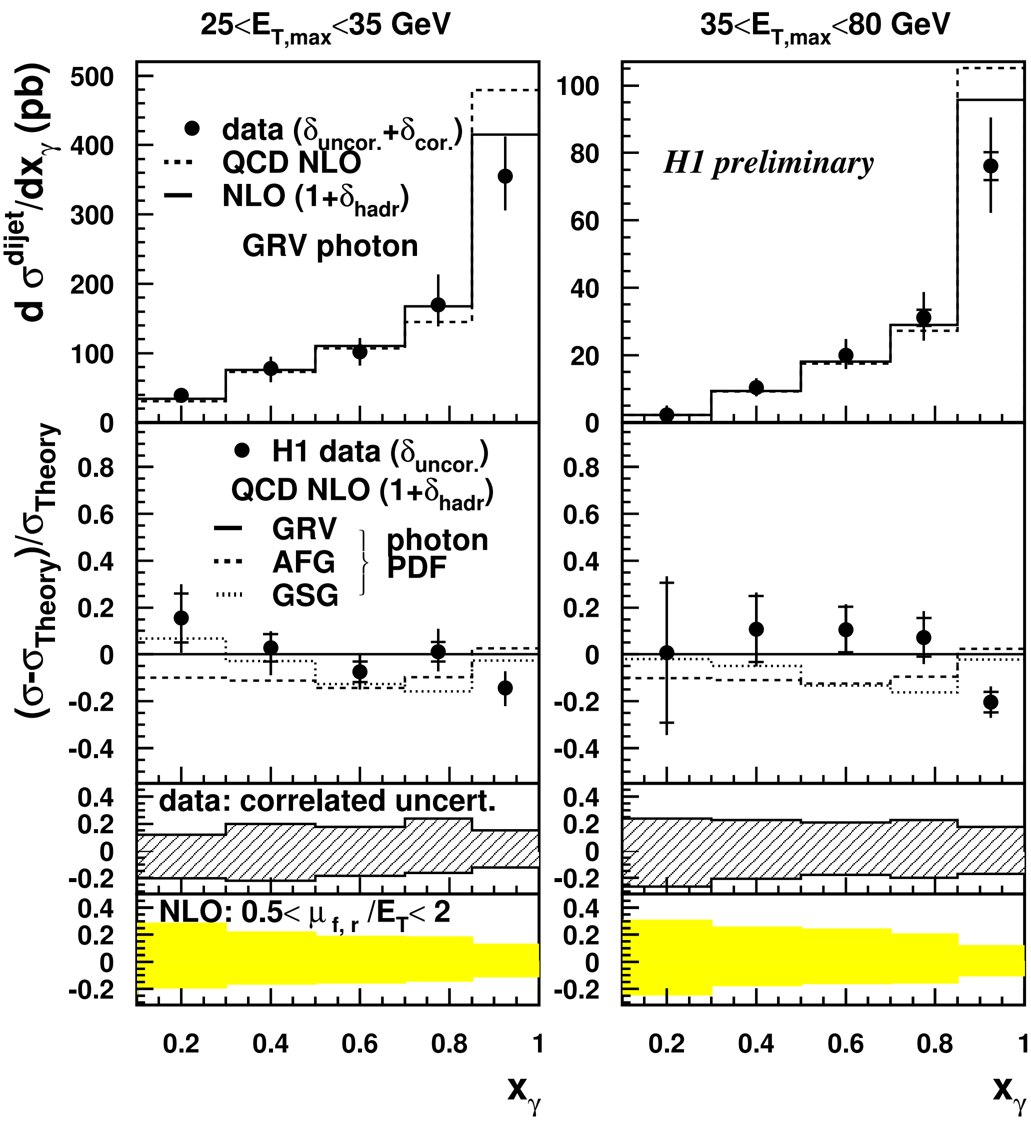
- hadronic scale uncert.:$\pm 4\% \rightarrow \pm 20\%$
- NLO uncert. (scale varied from 0.5 to 2) $\rightarrow \pm$ 20%

photon PDF: GRV proton PDF: CTEQ5M

Dijet $d\sigma/d\overline{\eta}$ data compatible with NLO



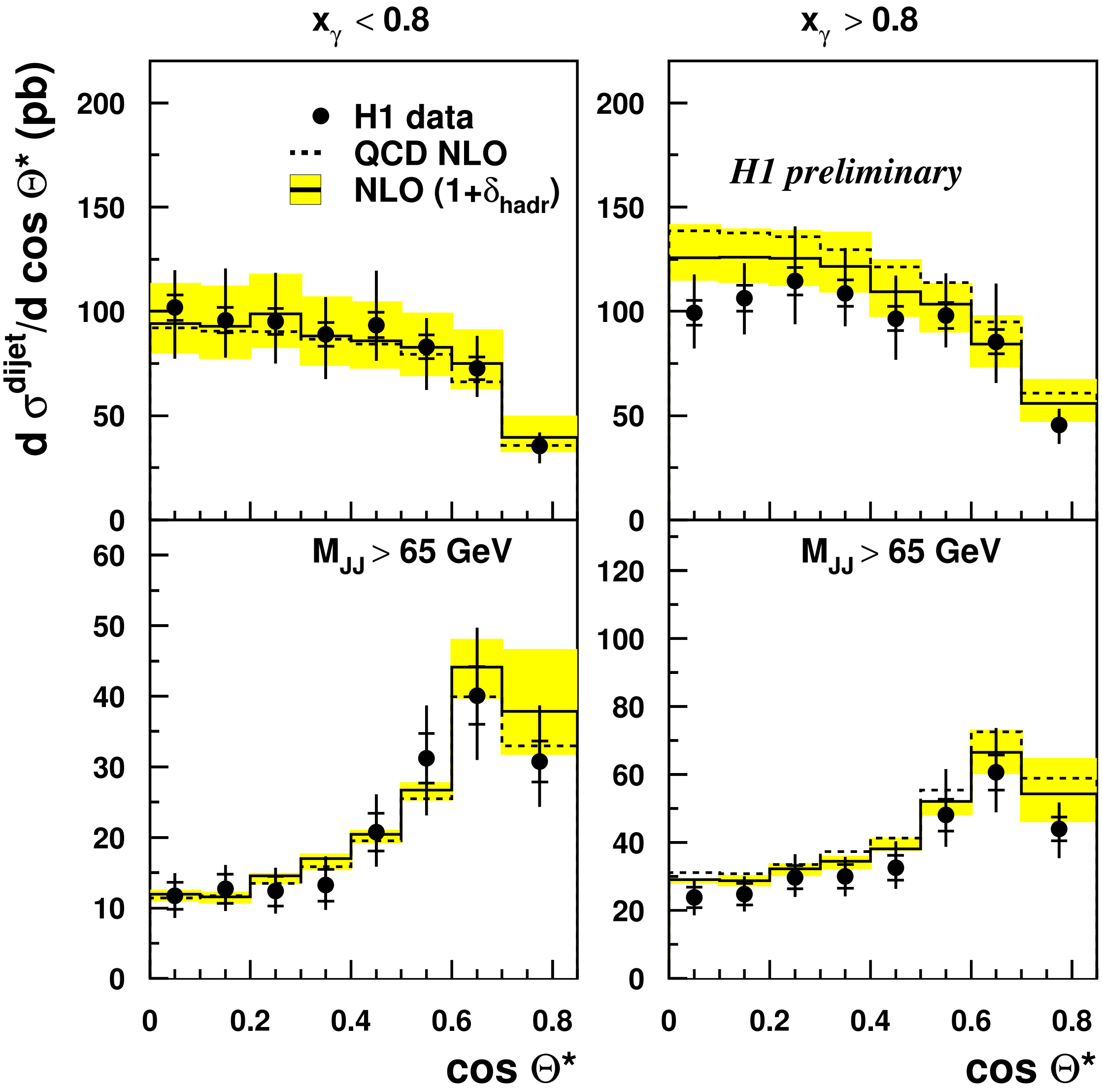
Dijet Cross Sections in Photoproduction



- All photon PDFs describe data (with CTEQ5M proton)
- Experimental uncertainty COMPARABLE with theor.uncertainty

Distribution of $d\sigma/dcos\theta^*$

$cos\theta^* = |tanh((\eta_1 - \eta_2)/2)|$



- low x_γ: well described
- high x_γ: NLO slightly higher than data

Discussion of H1 and ZEUS dijet results

H1 cuts	ZEUS cuts
$0.1 < y < 0.9$ k_T cluster alg. $E^{jet}_{T,1} > 25$ GeV,$E^{jet}_{T,2} > 15$ GeV -0.5< η^{jet} <2.5	$0.2 < y < 0.85$ k_T cluster alg. $E^{jet}_{T,1} > 14$ GeV,$E^{jet}_{T,2} > 11$ GeV -1< η^{jet} <2
$M_{JJ} > 65$ GeV	0< $\overline{\eta}$ <1 M_{JJ} >39 GeV
NLO calc.– Frixione,Ridolfi Λ_{QCD}=226 MeV 5 flavours hadronization corr.included proton PDF : CTEQ5M γ PDF: GRV,AFG,GSG	NLO calc.– Frixione,Ridolfi Λ_{QCD}=202 MeV 5 flavours hadronization corr.not included proton PDF : CTEQ4M γ PDF: GRV,AFG

Differencies in H1 and ZEUS results due to:

Different phase space? Different proton structure function? Hadronization corrections?

Quantitative comparisons between both experiments will be done...

Conclusions

- Jet observables in photoproduction measured at high E_T by H1 and ZEUS
- experimental uncertainties dominated by hadronic energy scale (work in progress)
- QCD interpretation of data often limited by theoretical uncertainties
- NLO QCD predictions using available photon PDF's describe the measured single inclusive high E_T jet production (H1).
- Different conclusions from H1 and ZEUS in dijet production
  - H1 data agree with NLO calculations with existing photon PDFS
  - ZEUS data do not agree with NLO – modification of photon PDFS?