Jets and QCD in gamma-P reactions

Sascha Caron, I. Phys. Institut, RWTH Aachen

EPS HEP 2001, 13.7.2001

on behalf of the H1 and ZEUS Collaborations at HERA

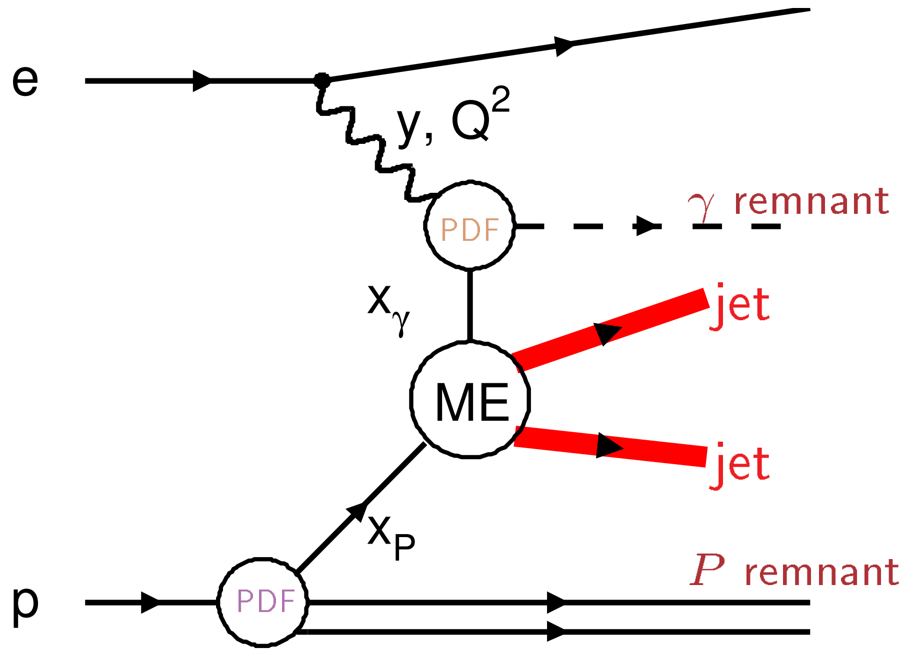
Topics:

- What can be studied?
- Production mechanism
- Discussion of the measured data
- What do we expect in the future?

What can be studied?

- Photon and Proton PDF in γP at high scales E_T (up to $6000\mathrm{GeV}^2$) and high x
  $\rightarrow$ Additional and complementary information to DIS , $p\overline{p}$ and e^+e^- data
- The structure of virtual photons from DIS eP data?
- Everything perturbative QCD or some unexpected physics in γP?

Production mechanism of Jets in γP



- $\mathbf{Q^2}$ photon virtuality
- $\mathbf{y}$ fraction of electron momentum carried by the photon
- $\mathbf{x_P}$ momentum fraction carried by partons out of the proton
- $\mathbf{x_\gamma}$ momentum fraction carried by partons out of the photon.

DIRECT: $\Rightarrow x_\gamma \approx 1$
RESOLVED: $\Rightarrow x_\gamma < 1$

- θ^* angle of the 2-jet system in 2-Jet CMS

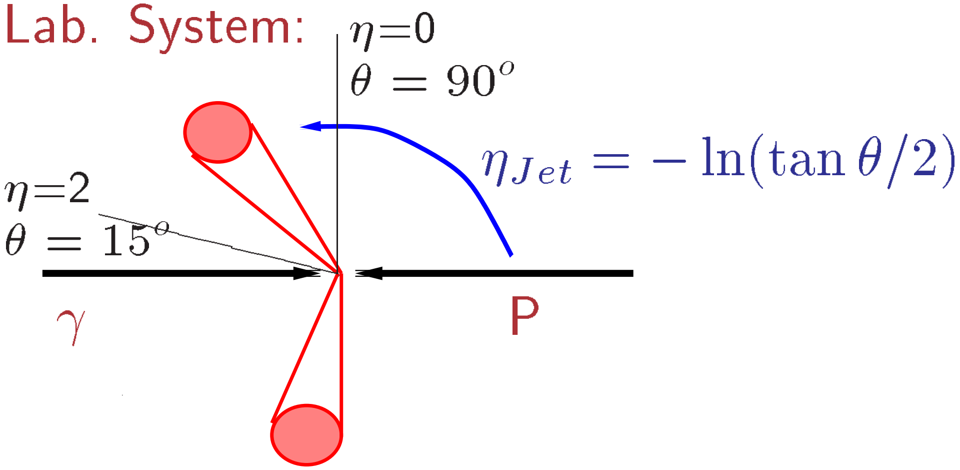
ME : $\gamma q \rightarrow qg$, $\gamma g \rightarrow q\bar{q}$
$qq \rightarrow qq, ,qq \rightarrow gg, qg \rightarrow qg \ldots$

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

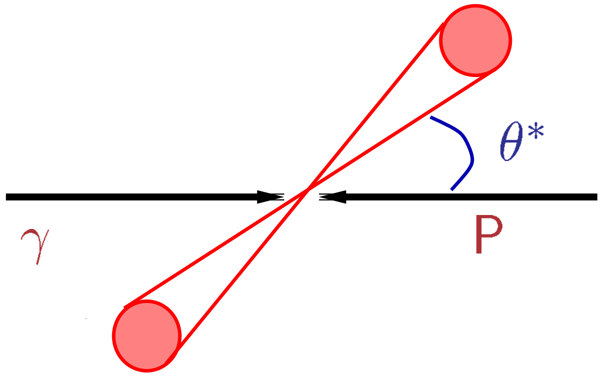
$$\boxed{\frac{d\sigma_{eP}}{dQ^2} = \gamma\text{-flux}(y, Q^2) \otimes \gamma\text{-PDF}(x_\gamma, Q^2, \mu) \otimes P\text{-PDF}(x_P, \mu) \otimes d\sigma_{ij}(\theta^*, Q^2, \mu)}$$

Jets at high E_T in γP

Lab. System:



Center of mass:



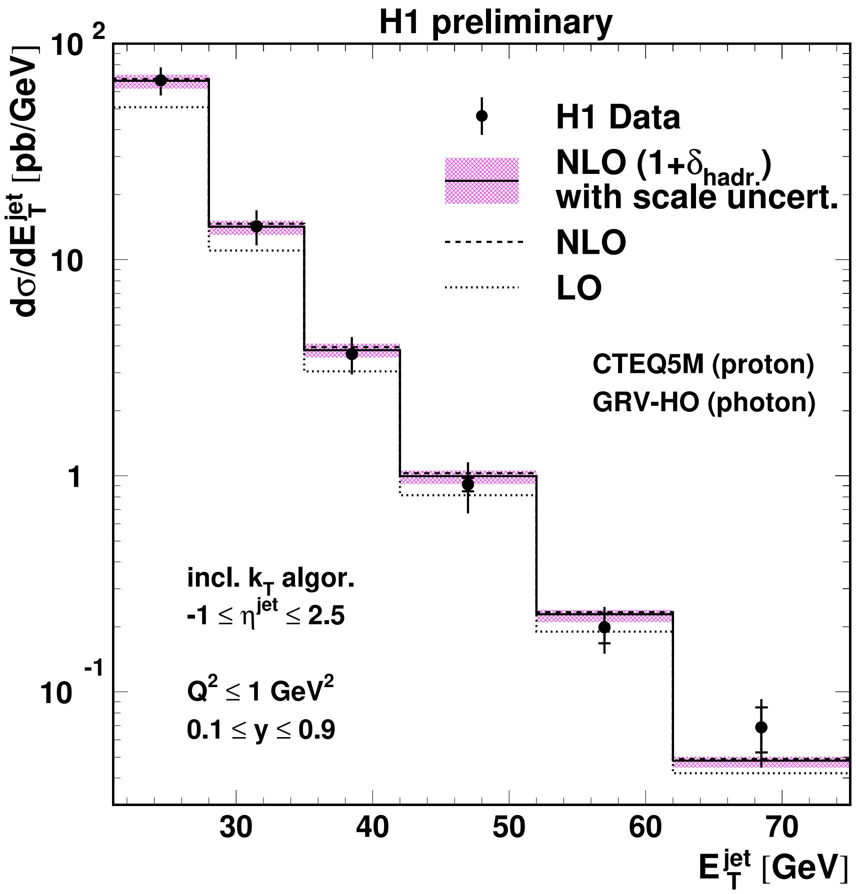
- $\overline{\eta}$ related to $x_\gamma \approx 1/y * e^{-\overline{\eta}} * E_T$ and $x_P \approx e^{\overline{\eta}} * E_T$
- $\Delta\eta \rightarrow \theta^*$
- $E_T \rightarrow$ hard scale μ

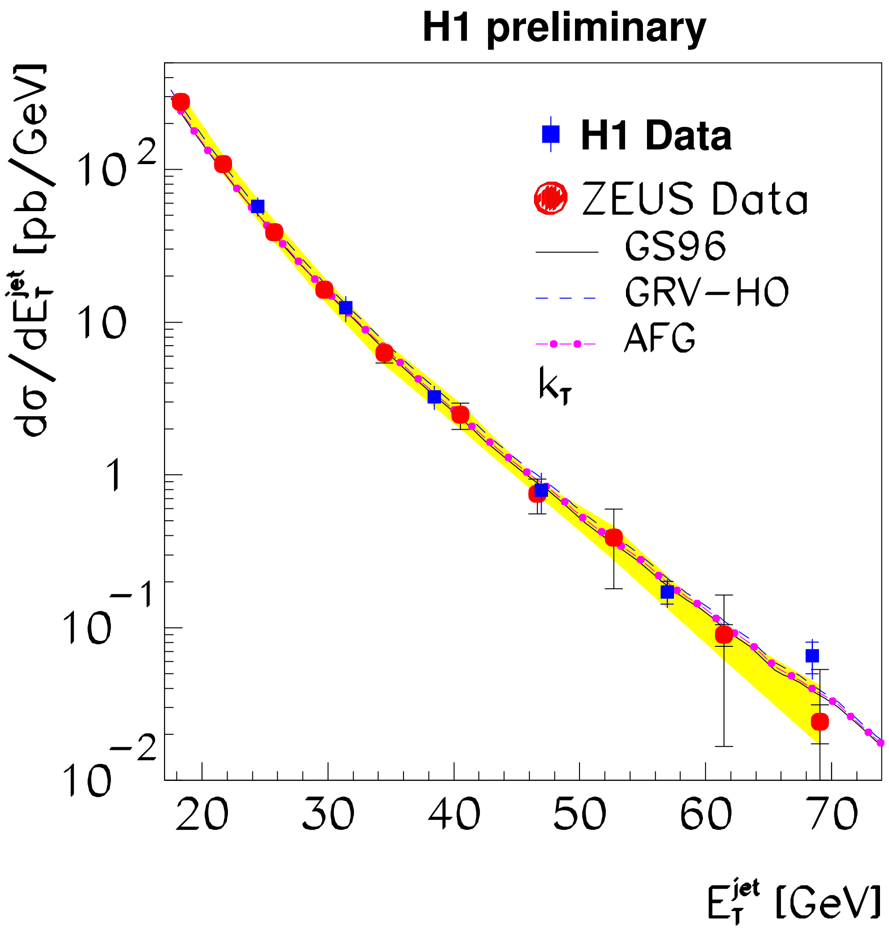
High E_T jets (found with inv. $k_\perp$ jetalgorithm):

- high x_γ, x_P
- small nonperturbative effects

- perturbative QCD:
  (NLO by Frixione/Rudolfi (Substraction method) Harris/Owen, Klasen/Kramer, Aurenche et al. (phase space slicing))

Inclusive jets at high E_T in γP

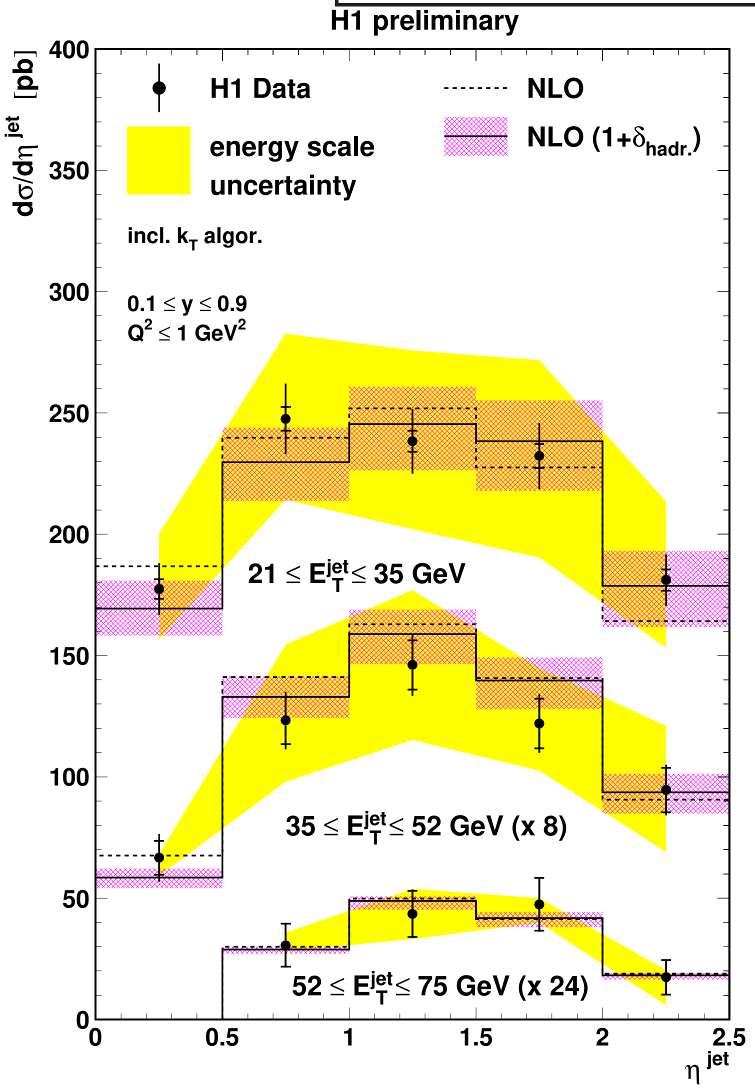


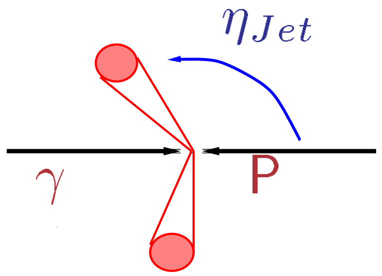


⇒ Inclusive jet data compatible with NLO pQCD

⇒ H1 and ZEUS data compatible

Inclusive jets at high E_T in γP





Inclusive jet production: $d\sigma/d\eta$

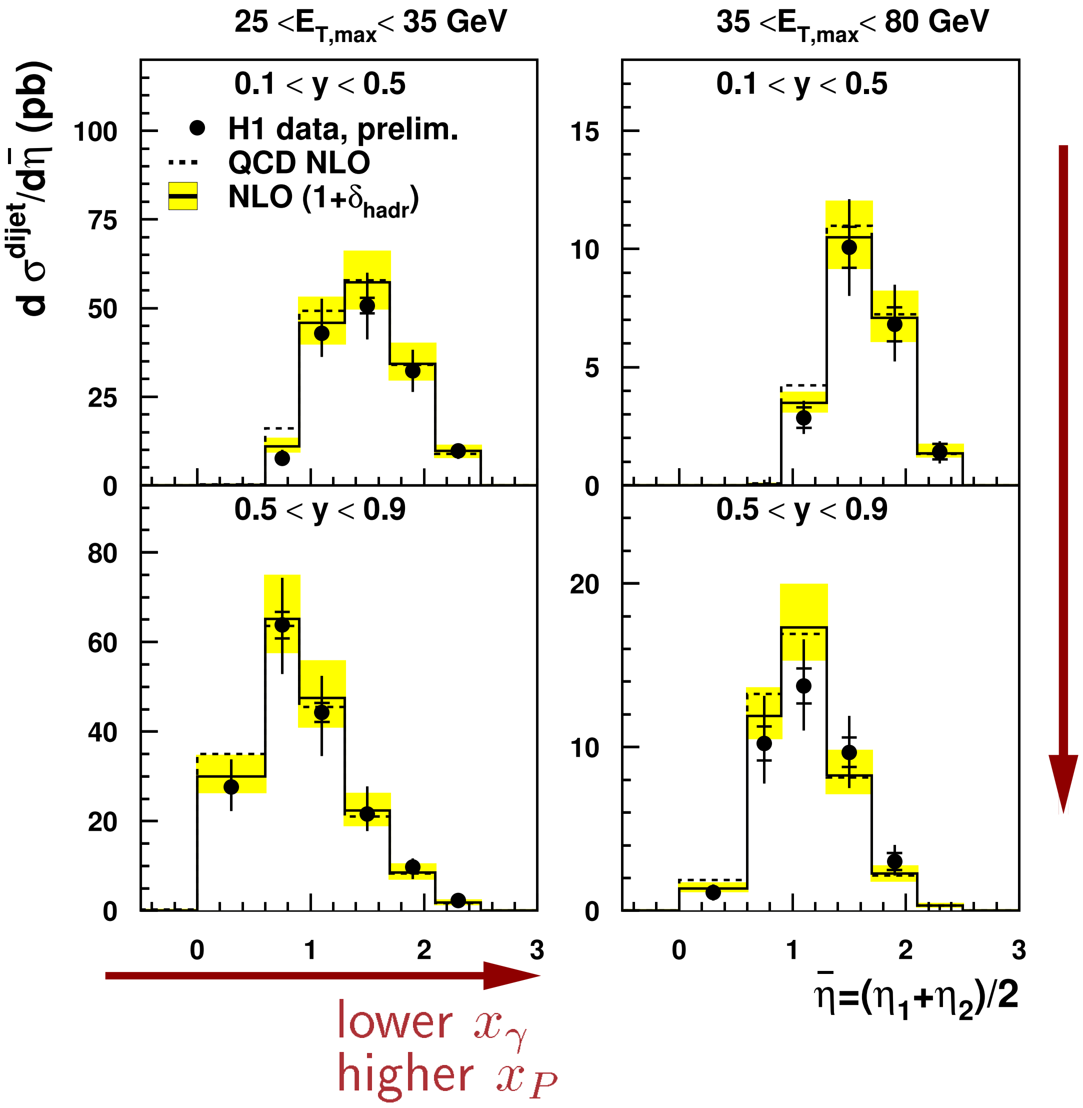
$\rightarrow$ PDF sensitivity

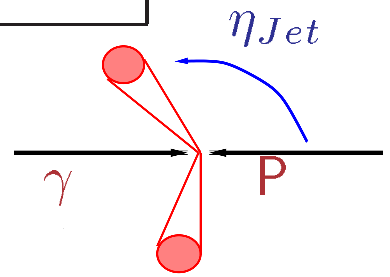
- Hadronization effects small
- Hadronic energy scale uncert.: $\pm 4\% \rightarrow \pm 20\%$
- NLO uncert. (scale varied 0.5 to 2) $\rightarrow \pm 10\%$

$\Rightarrow$ Inclusive jet data compatible with NLO pQCD

(Glück Reya Vogt (GRV) photon, CTEQ5M Proton)

Dijets at high E_T in γP





Dijet production: $d\sigma/d\overline{\eta}$

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- Hadronic energy scale uncert.: $\pm 4\% \rightarrow \pm 20\%$
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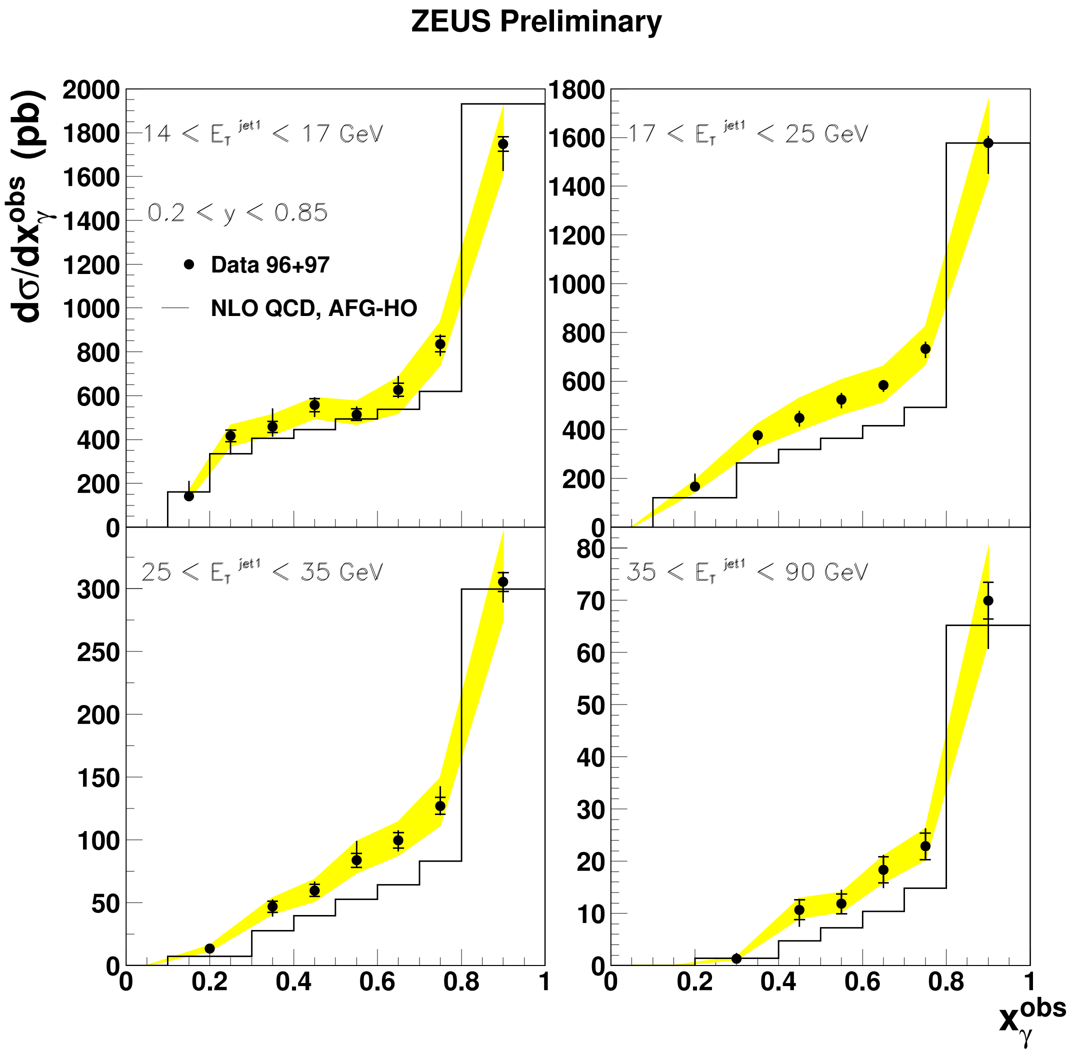
$\Rightarrow$ Dijet $d\sigma/d\overline{\eta}$ compatible with NLO pQCD GRV photon, CTEQ5M Proton

Dijets at high E_T in γP



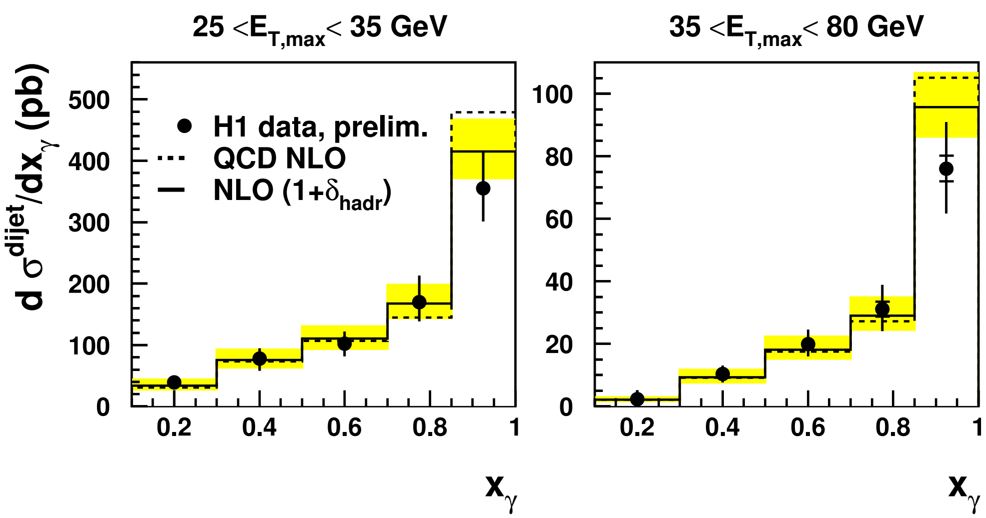
Dijet data: $d\sigma/dx_\gamma$

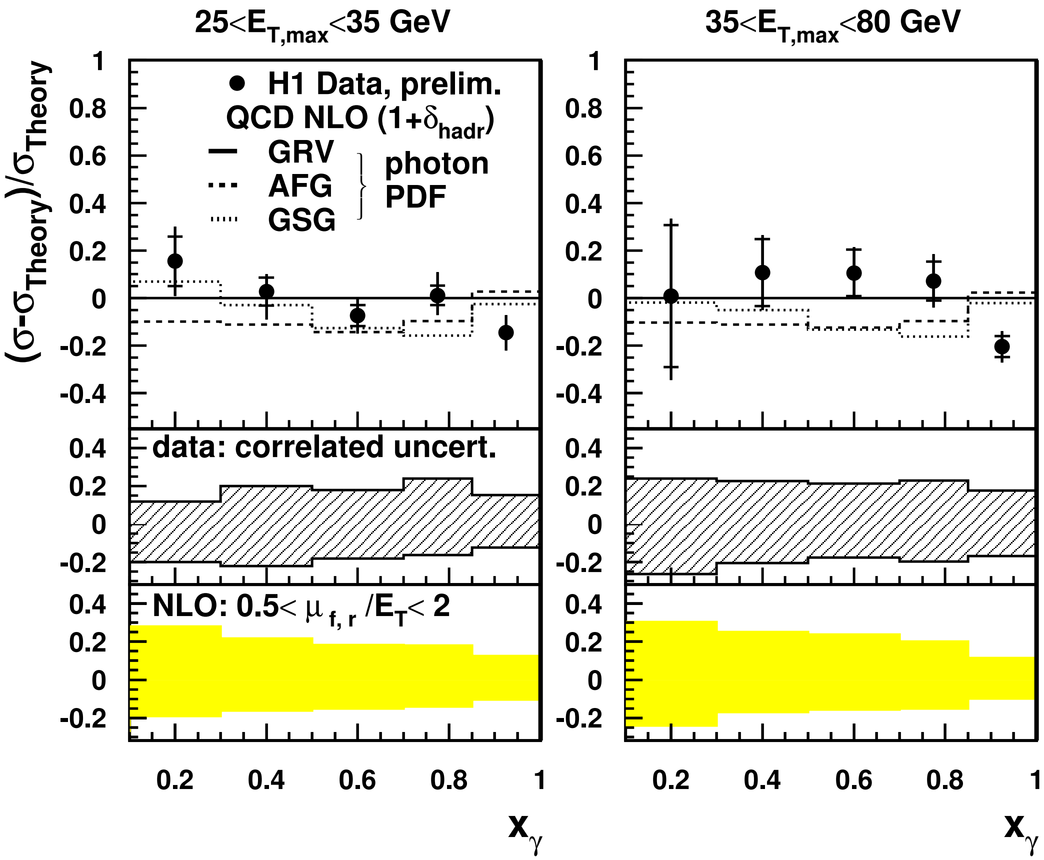
$$x_\gamma = \frac{1}{2E_e y}(E_{T,1}e^{-\eta_1} + E_{T,2}e^{-\eta_2})$$

Data higher than NLO pQCD with AFG and CTEQ4M at $x_\gamma < 0.8$ at $E_T > 25$ GeV
$\rightarrow$ Need for new photon PDF?

AFG: P. Aurenche, J.P. Guillet and M. Fontannaz

Dijets at high E_T in γP





Dijet data: $d\sigma/dx_\gamma$ $\Rightarrow$ All Photon PDFs describe data (CTEQ5M Proton)

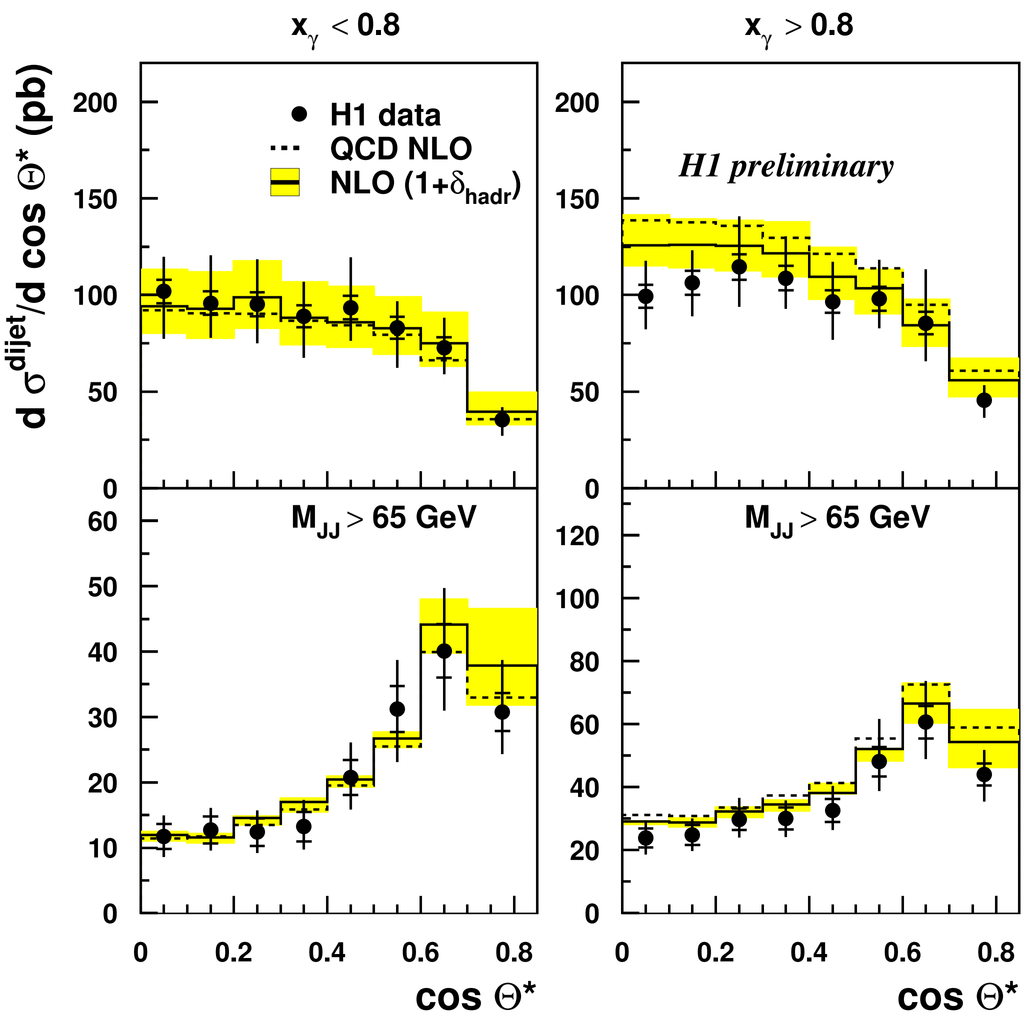
exp. uncertainty $\approx$ theor. uncertainty

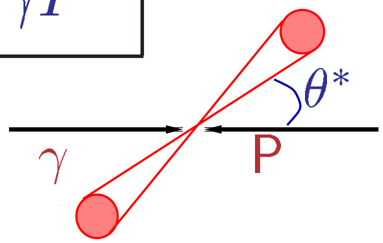
Difference to ZEUS result due to :

Hadronization corrections, different photon and Proton PDFs, data,?

- GSG: L.E. Gordon, J.K. Storrow

Dijets at high E_T in γP





Dijet data: $d\sigma/d\cos\theta^*$

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

$\rightarrow$ sensitive to $ME \times PS$

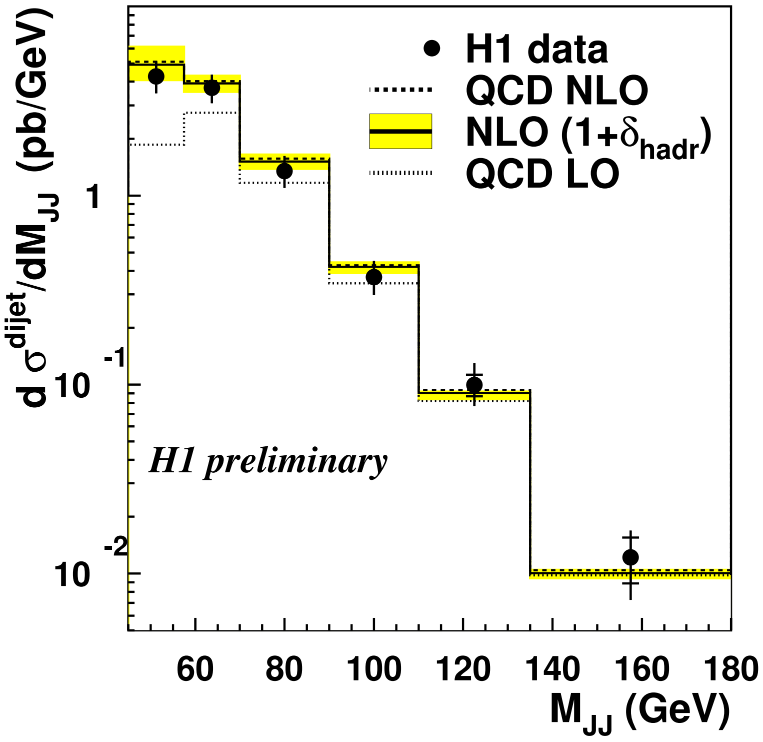
direct: $ME \sim (1 - \cos\theta^*)^{-1}$

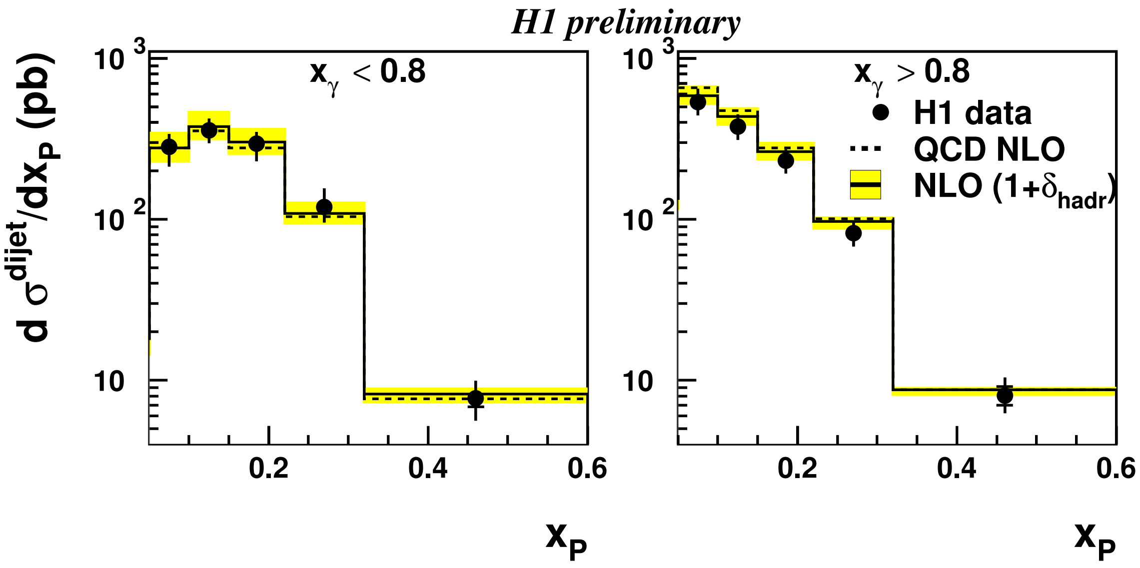
resolved: $ME \sim (1 - \cos\theta^*)^{-2}$

- low x_γ: well described
- high x_γ: NLO slightly overshoots the data
- high M_{JJ}: dramatical change of shape

$\Rightarrow$ Described by NLO pQCD

Dijets at high E_T in γP





Dijet data: $d\sigma/dx_P$ → sensitive to Proton PDF

$x_P < 0.1$:

$<5\%$ difference between CTEQ5M and MRST (g↓,g↑

$x_P > 0.1$:

$10-15\%$ difference between CTEQ5M and MRST (g↓,g↑

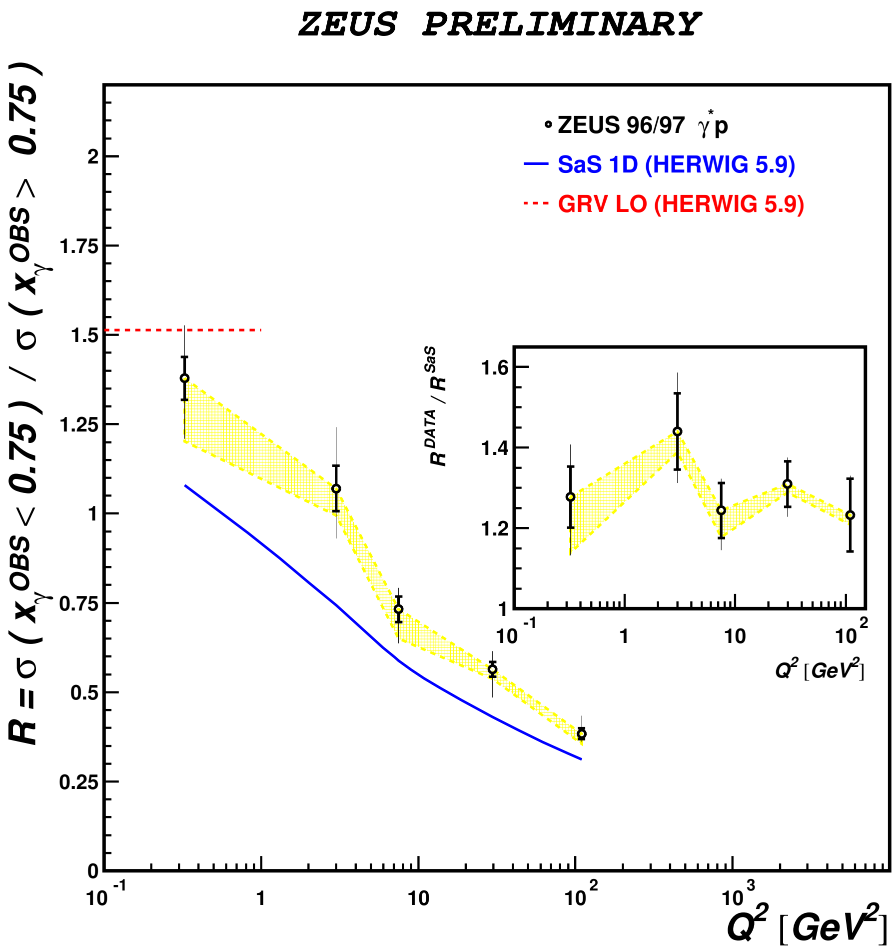
data and NLO scale uncertainty dominant effect

$\Rightarrow \approx 35\%$ gluon induced at $x_P \approx 0.4$

$\Rightarrow$ Very interesting in future (50% g uncertainty)

Dijet data: $d\sigma/dM_{JJ}$ $\Rightarrow$ Good description up to $M_{JJ} \approx 160 GeV$

Transition from γP to DIS



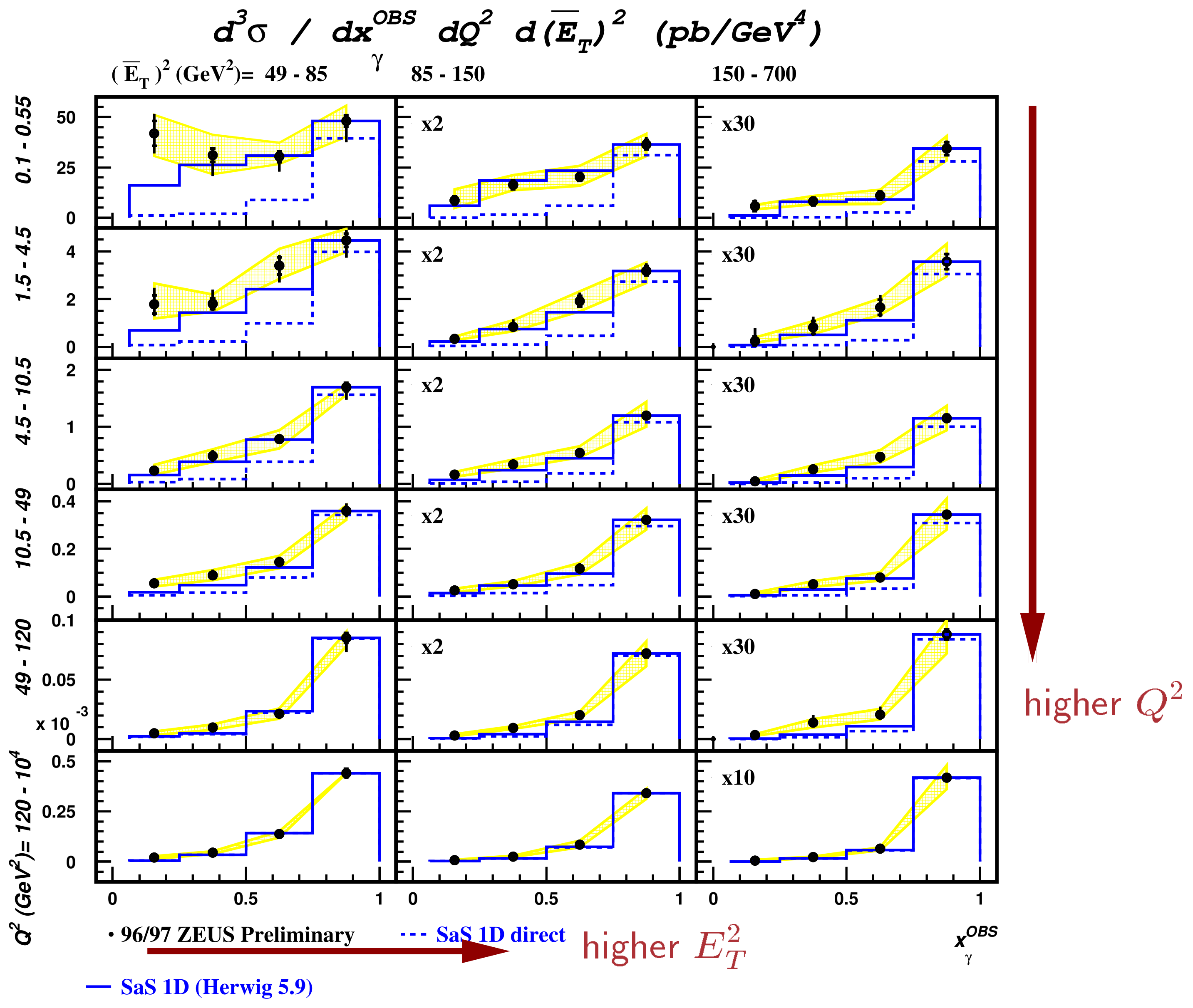
Dijet data with virtual photons:

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

Photon structure is suppressed with increasing Q^2.

$\Rightarrow$ SAS1D photon parameterization gives right suppression (but resolved part to small)

Dijets in deep inelastic scattering



Measurement of triple differential cross section $\Rightarrow$

$Q^2 < \overline{E_T^2}$: direct not enough to describe data

$Q^2 > \overline{E_T^2}$: data described by direct part

(Herwig scale to high x_γ bin)

Summary and Outlook

High E_T photo produced jets:

- Various jet observables measured at large x_P and x_γ
- exp. uncertainty $\approx$ theor. uncertainty
- NLO calculations and current PDF parameterizations are compatible with high E_T jet data (but still differences between H1 and ZEUS)
- Complementary and additional information of PDFs
- Future: H1 and ZEUS will reduce their hadronic energy scale uncertainty $\rightarrow$ very precise data
- Much more data to come ($30\times$) at high x_P ($\rightarrow$ P-PDF) and high x_γ ($\rightarrow$ γ-PDF)

Photon structure in DIS:

- Triple differential cross sections gives information of virtual photon structure
- Suppression of low x_γ part with increasing Q^2 (described by SAS1D)