Jet production in *ep* collisions

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(on behalf of the H1 and ZEUS Collaborations)

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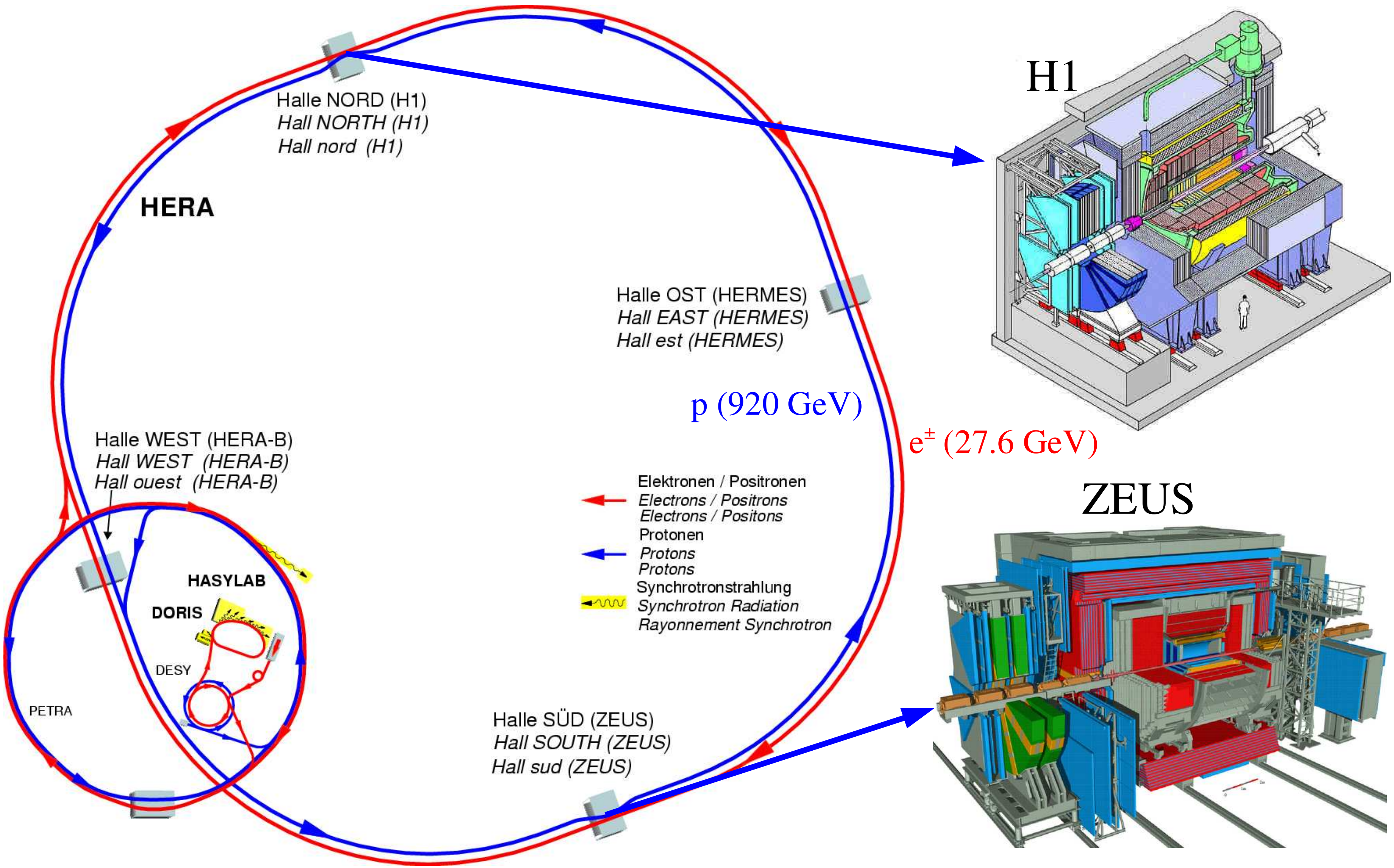
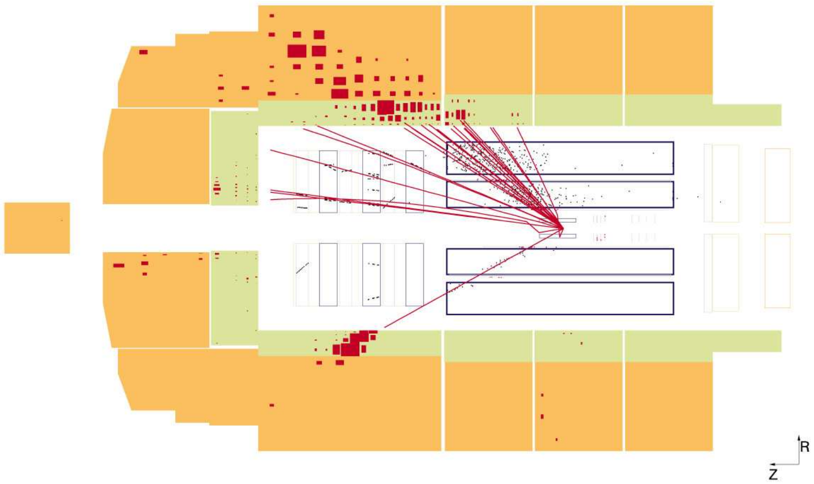
Outline:

- Introduction
- Inclusive jet photoproduction
- Dijet electroproduction
- Inclusve jet electroproduction

HERA, H1 and ZEUS



Jet finding algorithms



Clustering of final state objects (tracks, energy deposits) into few jets:

→ "longitudinal invariant $k_\perp$" algorithm

- infrared and collinear safe
- minimally sensitive to fragmentation and underlying event effects

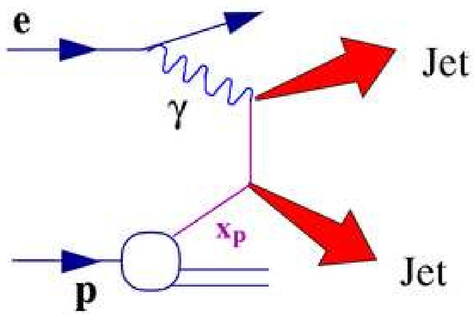
Correction from parton to hadron level:

- fragmentation: partons from the hard scatter fragment into hadrons
- underlying events: photon and proton remnants partons may produce secondary scatter

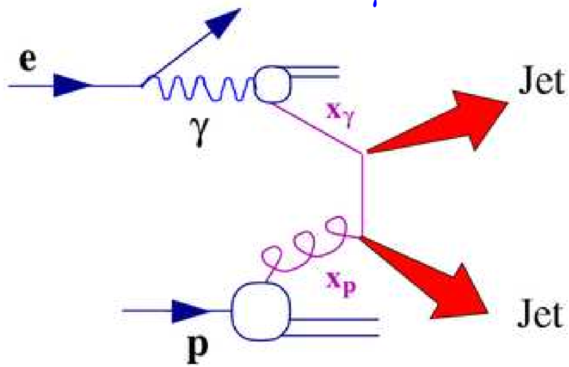
→ correction factors obtained from LO Monte Carlo models with parton showers

QCD calculations

Direct ($x_\gamma \sim 1$)



Resolved ($x_\gamma < 1$)



$$\sigma^{direct}_{ep \to e + N\ jets + X} = f_{\gamma/e} \otimes f_{i/p} \otimes \hat{\sigma}_{\gamma i \to N\ jets}$$

$$\sigma^{resolved}_{ep \to e + N\ jets + X} = f_{\gamma/e} \otimes f_{j/\gamma} \otimes f_{i/p} \otimes \hat{\sigma}_{i j \to N\ jets}$$

Resolved/direct processes:

- resolved γ's are useful in photoproduction as well as in DIS when $Q^2 \ll E_T^2$
- distinction can only clearly be made in LO
- use x_γ to separate resolved and direct enhanced samples

$$x_\gamma = \frac{\sum_{jets} E_T^{jet} e^{-\eta^{jet}}}{2 E_\gamma}$$

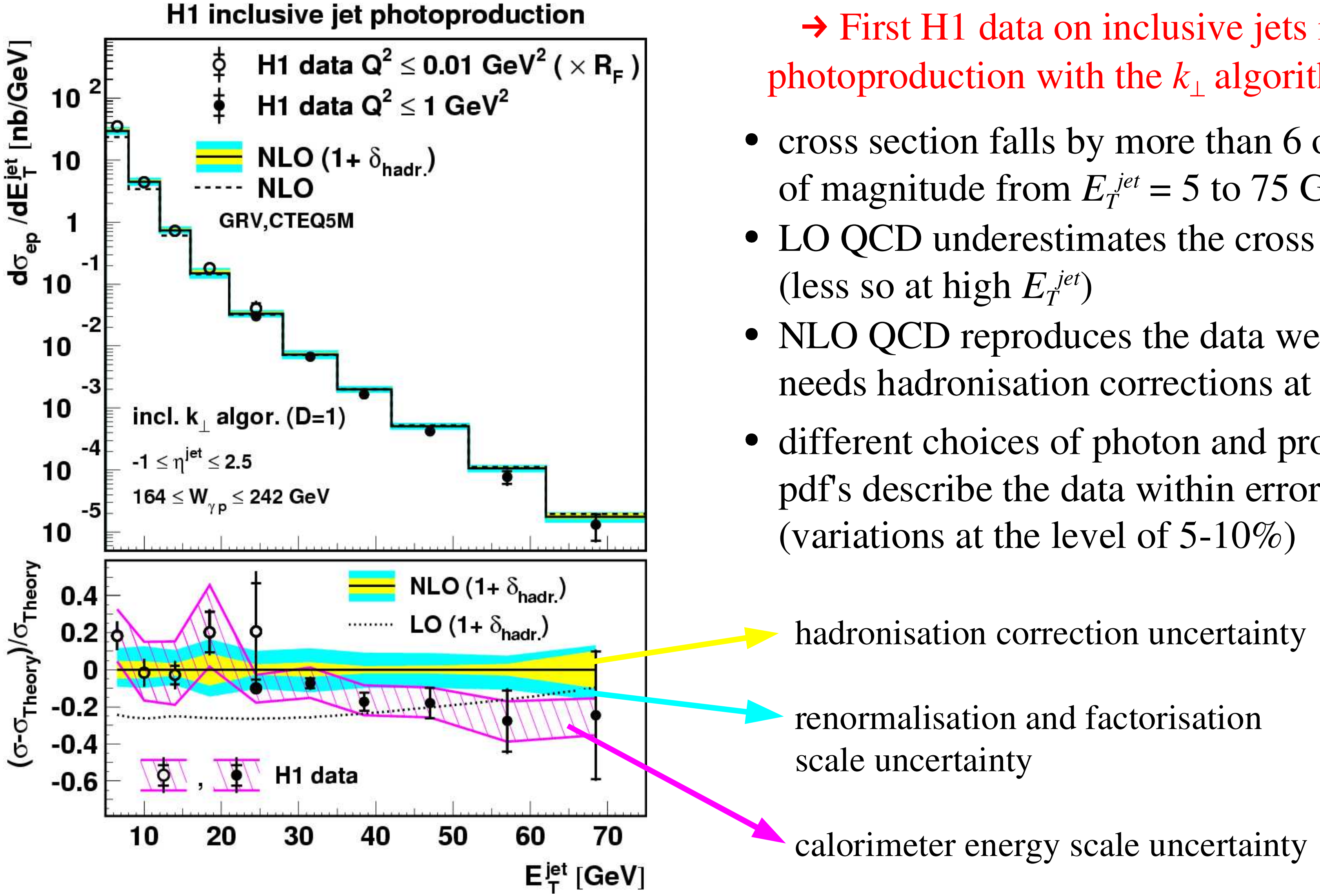
QCD calculations:

- renormalisation and factorisation scales in *f*-factors lead to some uncertainty
- different NLO calculation differ in their treatment of infrared and collinear divergences

➔ Jet production provides a means of testing:

- NLO matrix elements
- photon and proton pdf's

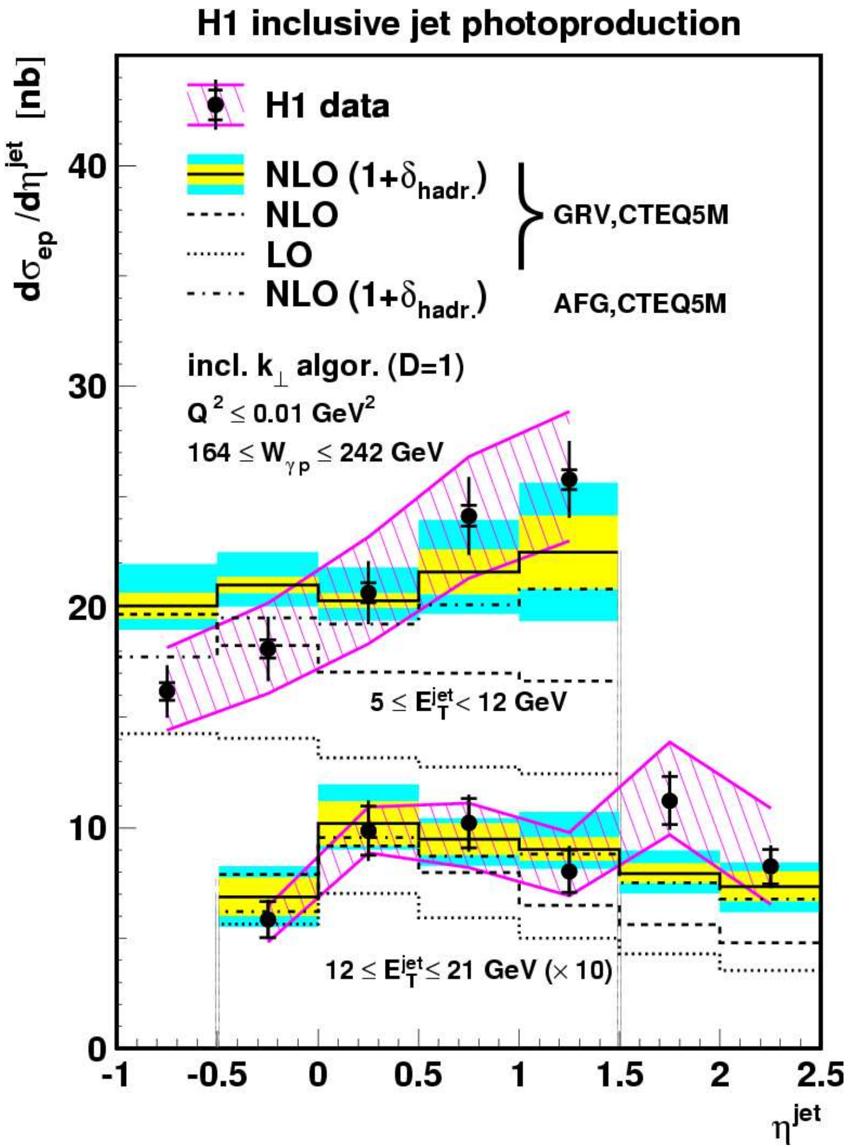
Jet photoproduction: E^T_{jet}



→ First H1 data on inclusive jets in photoproduction with the $k_\perp$ algorithm!

- cross section falls by more than 6 orders of magnitude from E_T^{jet} = 5 to 75 GeV
- LO QCD underestimates the cross section (less so at high E_T^{jet})
- NLO QCD reproduces the data well, but needs hadronisation corrections at low E_T
- different choices of photon and proton pdf's describe the data within errors (variations at the level of 5-10%)

Jet photoproduction: η_{jet}

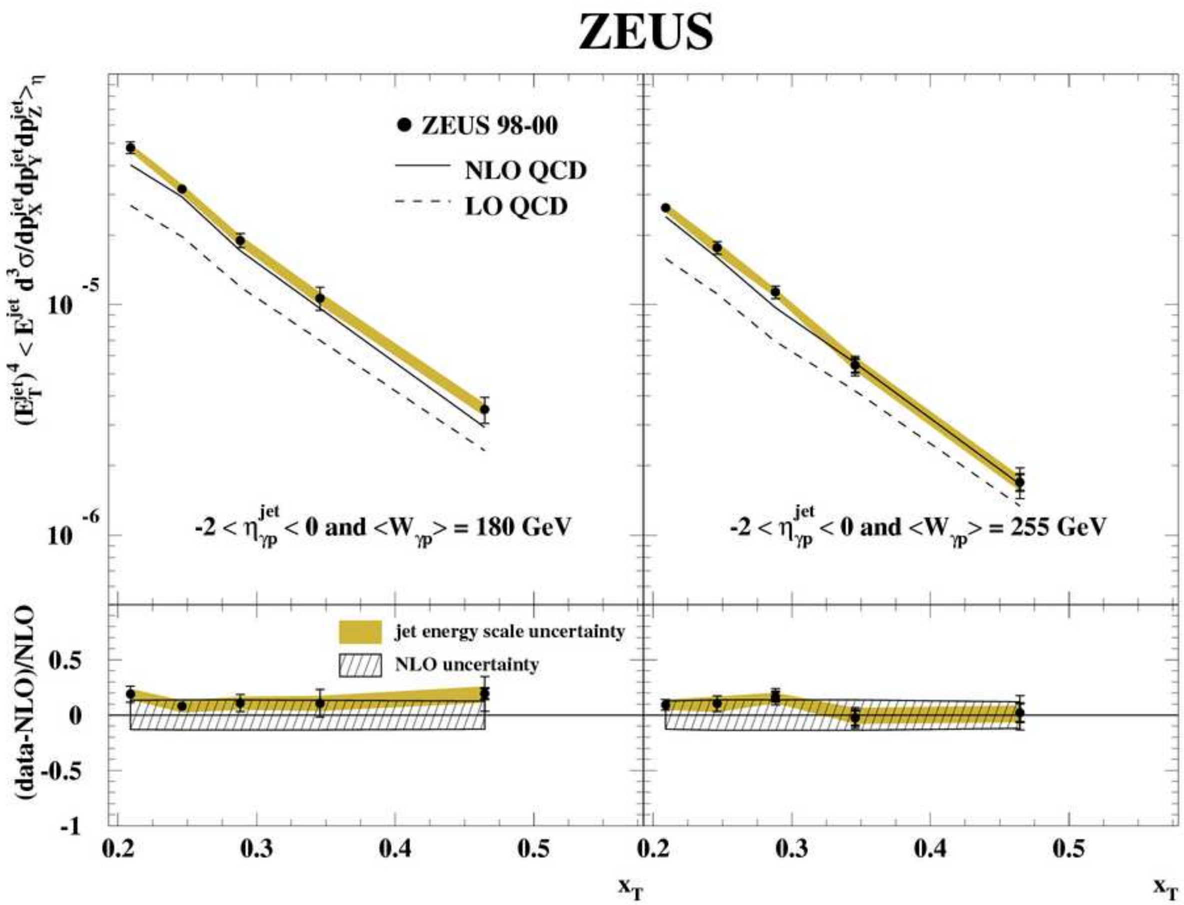


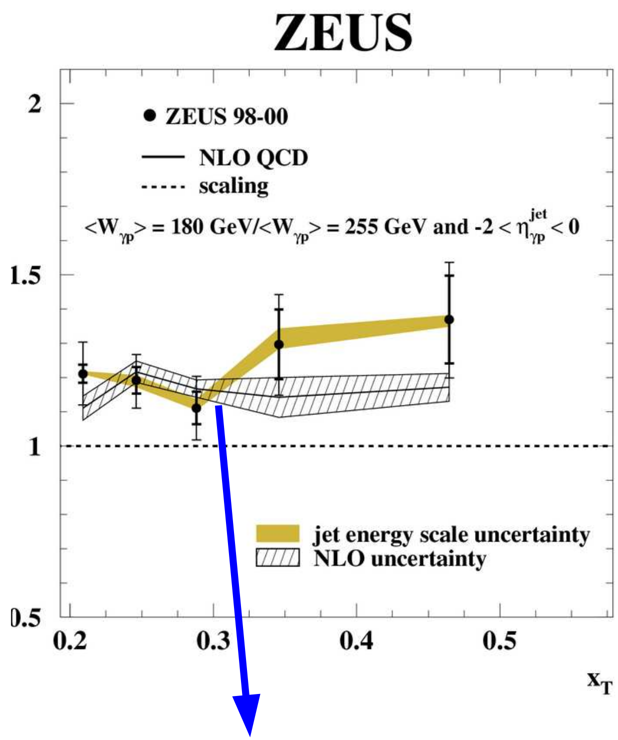
- hadronisation corrections increase towards proton remnant
- for $E_T^{jet} > 12$ GeV the data are well described by NLO predictions
- η_{jet} distribution at low E_T^{jet} seems to indicate a faster rise in data than according to NLO QCD

→ possible problems:

- failure of LO MC to describe hadronisation
- inadequacy of photon pdf
- higher order corrections required

Jet photoproduction: scaling





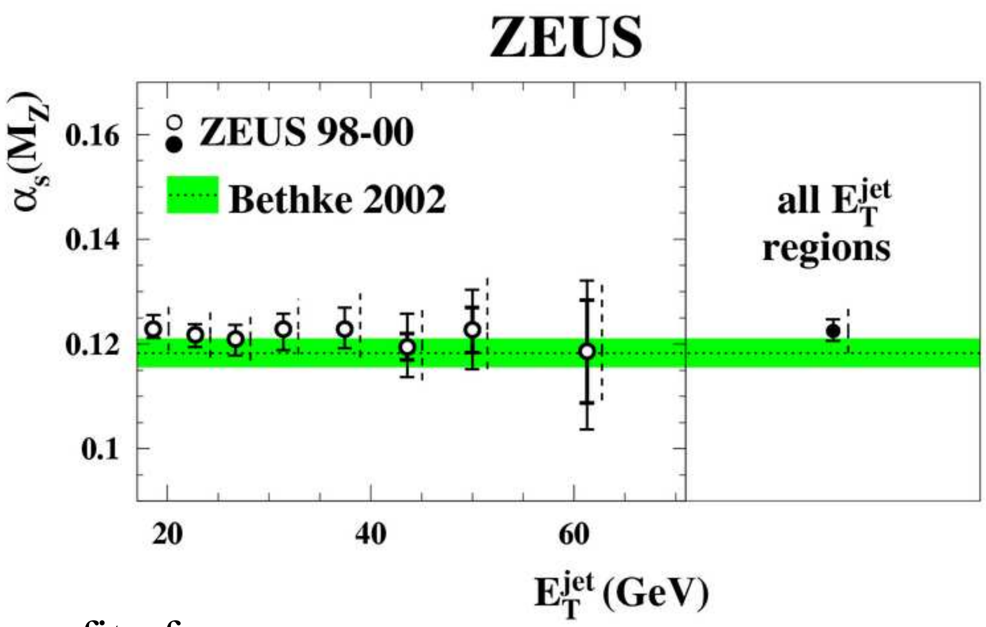
deviation from unity!

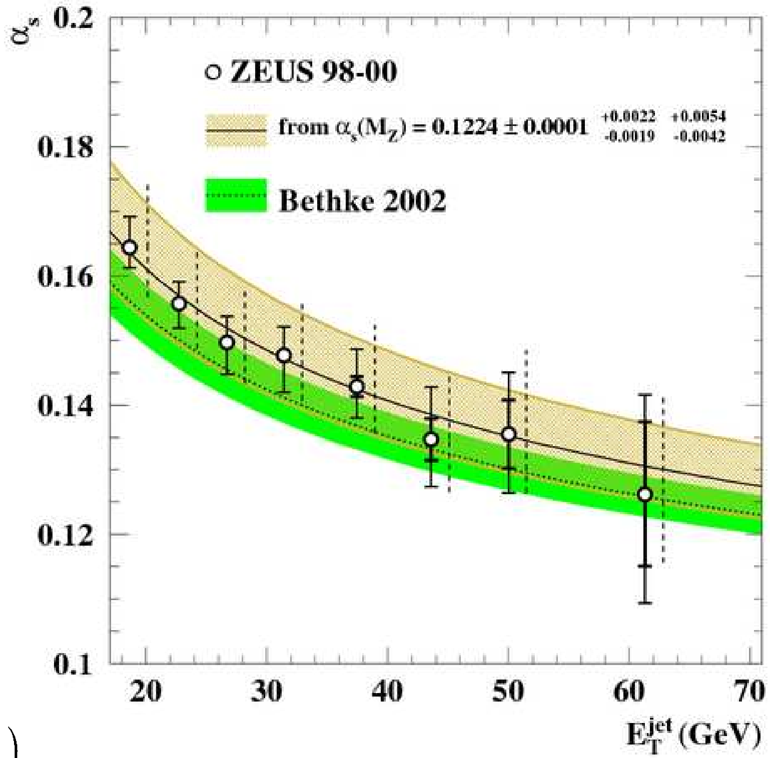
Parton Model: scaled σ_{jet} as function of $x_T = 2E_T^{jet}/W$ is energy-independent

QCD: scaling violations occur due to structure function evolution + running of α_S

→ first observation of scaling violations in ep jet photoproduction

Jet photoproduction: α_S extraction





- fit of

$$[\mathrm{d}\sigma/\mathrm{d}E_T^{jet}(\alpha_S(\mu))]_i = C_1^i \alpha_S(\mu) + C_2^i \alpha_S^2(\mu)$$

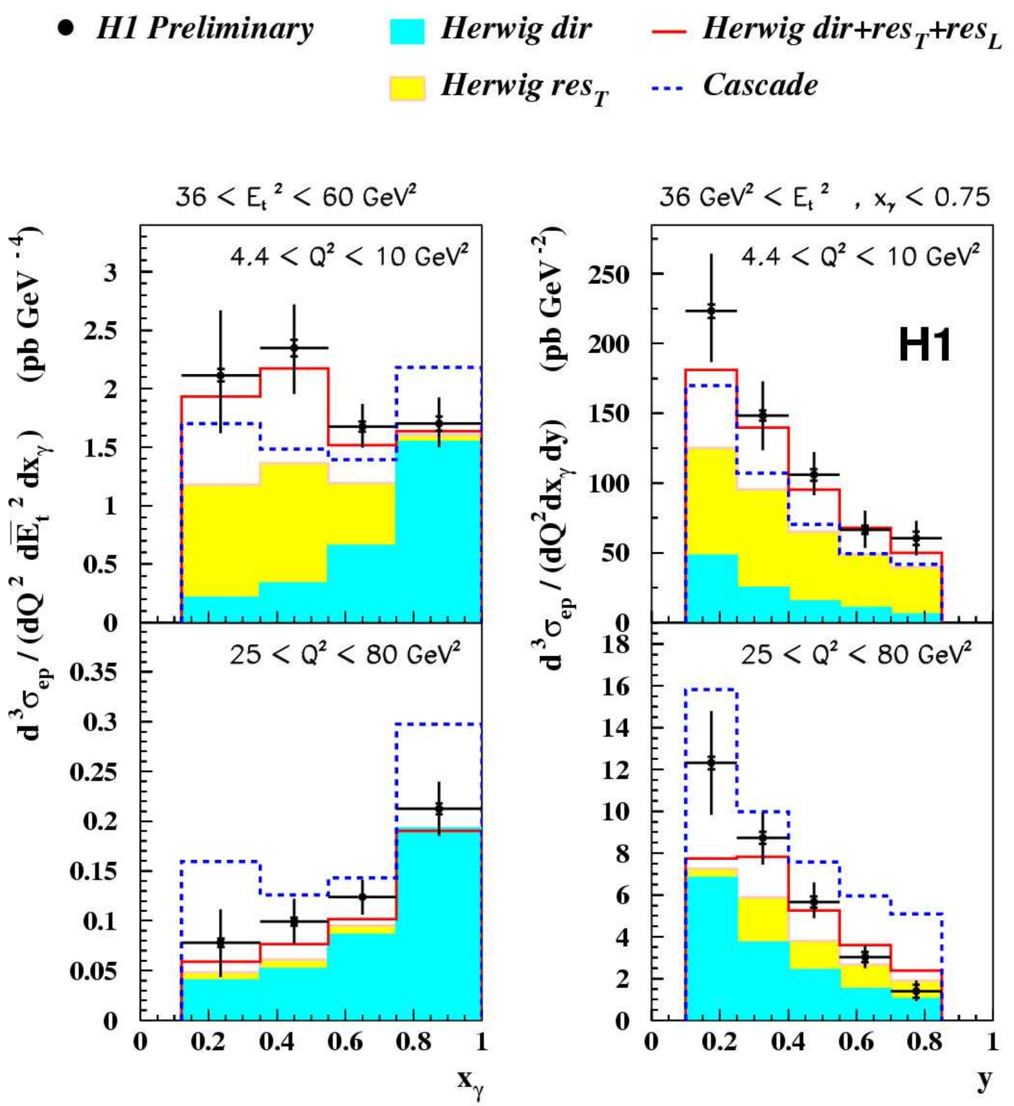
with C_1^i and C_2^i constants obtained from NLO QCD calculations

- fit of energy-scale dependence of measured $\alpha_S(E_T^{jet})$ to renormalisation group equation

$$\alpha_S(M_Z) = 0.1224 \pm 0.0001\,(\text{stat.})^{+0.0022}_{-0.0019}(\text{exp.})^{+0.0054}_{-0.0042}(\text{th.})$$

➔ competitive α_S value is consistent with the current world average of 0.1183 ± 0.0027

Dijet production: virtual photon structure

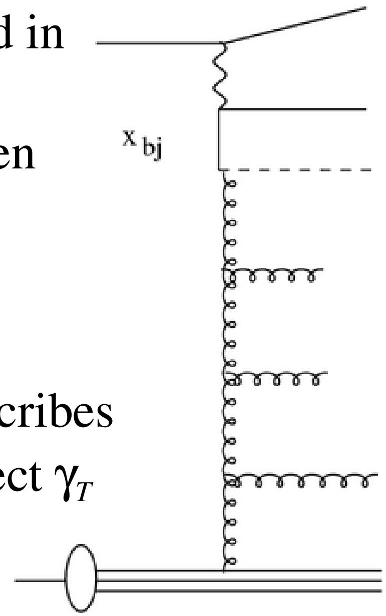


Resolved photons are in principle not obligatory for $Q^2 \gg \Lambda_{QCD}{}^2$

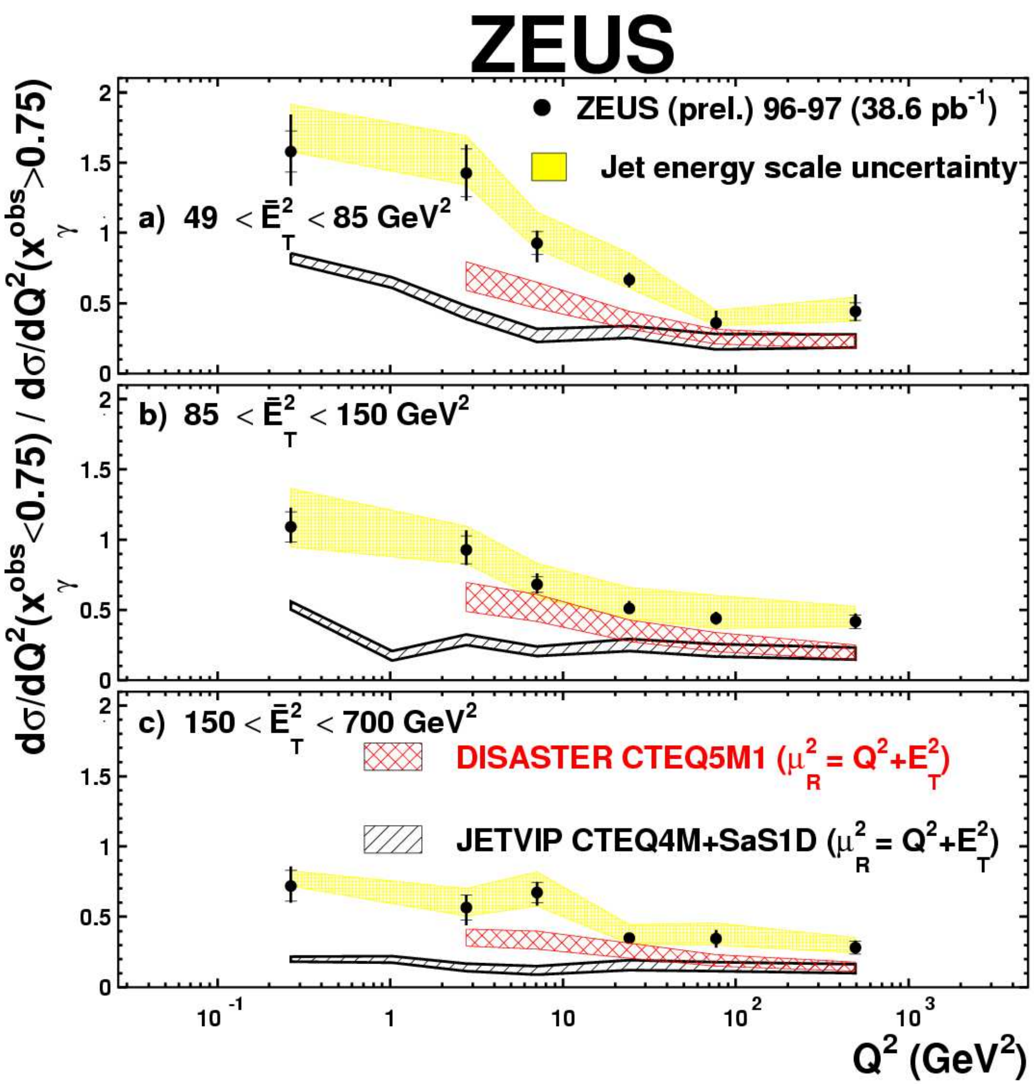
LO however does not describe the data
→ higher order effects are needed

Two approaches:

- HERWIG (DGLAP + resolved γ): γ_T as well as γ_L are needed; *y*-distribution should in principle allow to distinguish between both
- CASCADE (k_T unordered CCFM cascade): also describes data (includes direct γ_T and γ_L for all Q^2)



Dijet electroproduction: NLO models



Ratio of resolved to direct enhanced components:

$$R = \frac{\frac{d\sigma}{dQ^2}(x_\gamma^{obs} < 0.75)}{\frac{d\sigma}{dQ^2}(x_\gamma^{obs} > 0.75)}$$

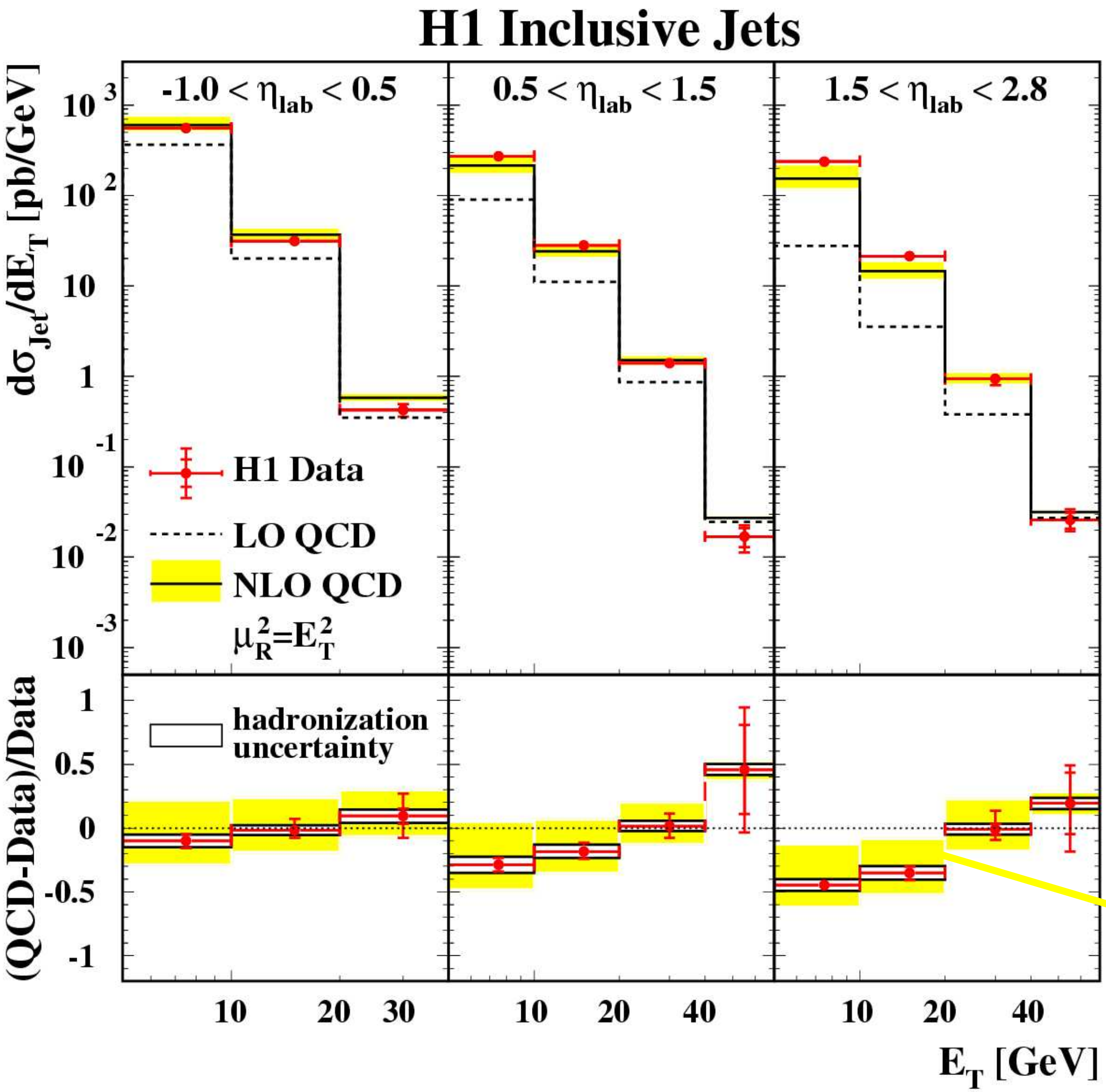
- R as function of Q^2 in bins of average E_T:

→ resolved contribution at low Q^2 is suppressed as E_T increases

- Comparison to NLO models:
  - DISASTER++ (pointlike γ)
  - JETVIP (dir.+res. γ)

→ neither really describes the data

Jet electroproduction: E_T^{jet}



$d\sigma_{jet}/dE_T$ distributions are well described by NLO (DISENT) calculations:

- in the backward region
- at all η_{lab} for $E_T > 20$GeV

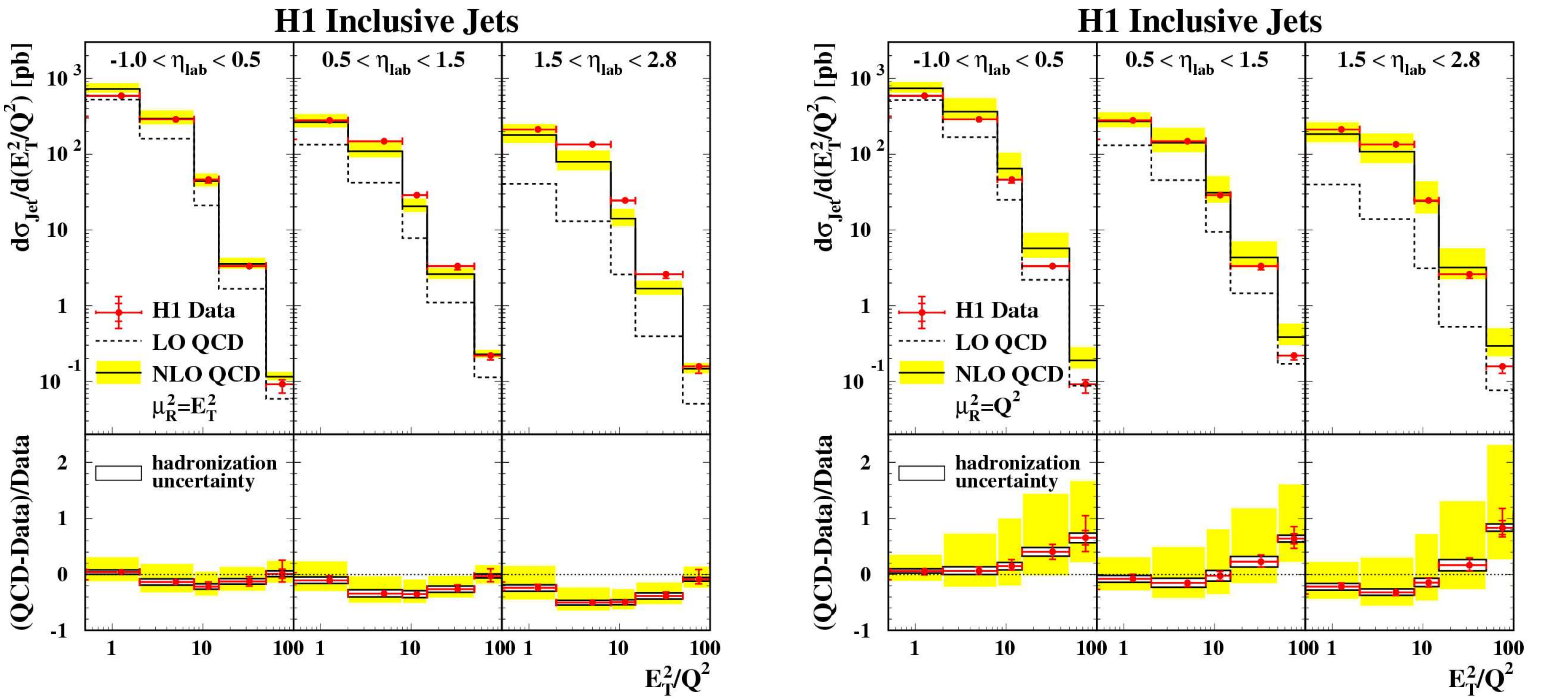
Deviations are however visible:

- in the forward (towards proton remnant) region when both E_T and Q^2 are small
- accompanied by large corrections between LO and NLO

➔ see talk by Stathes Paganis

renormalisation scale uncertainty

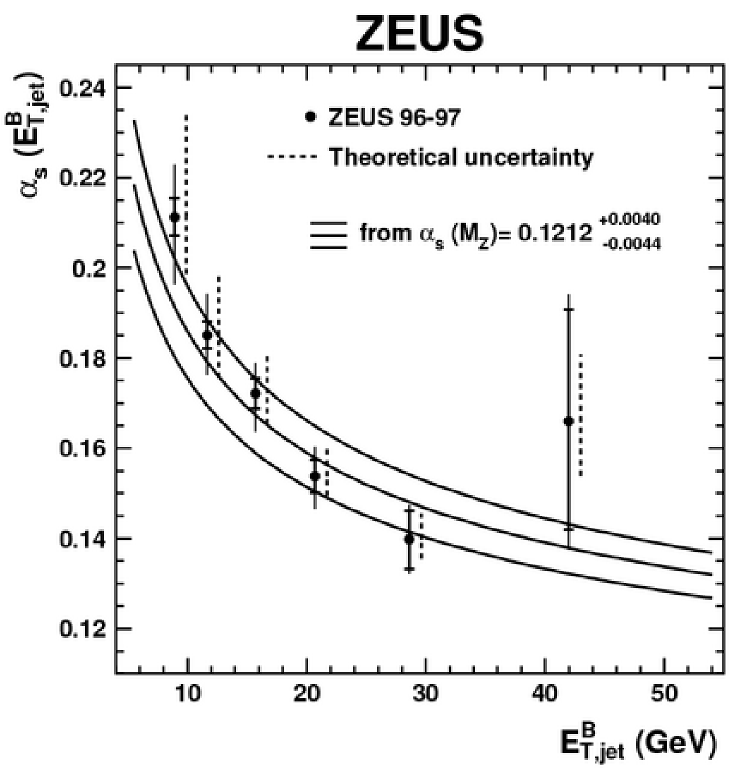
Jet electroproduction: scale dependence

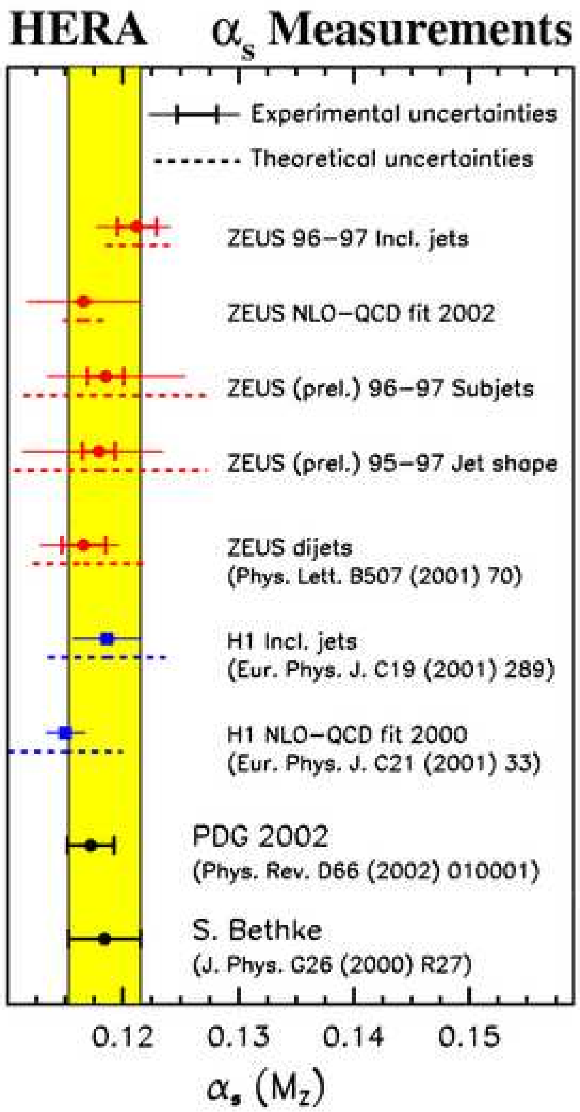


Study of interplay of possible scales in DIS jet events:

- $\mu_R^2 = E_T^2$ → discrepancies for forward η_{LAB} for $2 < E_T^2/Q^2 < 50$ where both scales are small
- $\mu_R^2 = Q^2$ → large deviations for $E_T^2/Q^2 > 50$ where Q^2 is small (this choice of scale leads to large scale uncertainties)

Jet electroproduction: α_s extraction





➜ Similar α_s extraction method as before, applied to $d\sigma/dQ^2$ for $Q^2 > 500$ GeV^2 yields:

$$\alpha_S(M_Z) = 0.1212 \pm 0.0017\,(\text{stat.})^{+0.0023}_{-0.0031}\,(\text{syst.})^{+0.0028}_{-0.0027}\,(\text{th.})$$

Summary

➔ H1 and ZEUS have measured jet photo- and electroproduction in a large kinematic range with cross sections ranging over 6 orders of magnitude

➔ competitive α_S values are obtained and are in agreement with the world average

➔ NLO calculations do a very good job in describing jet cross sections except in some areas:

- forward jets at low Q^2, $E_T{}^2$
- the ratio of direct to resolved enhanced components in dijet production

➔ new high precision data should be used in global fits of photon and proton pdf's