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Jets and α_S measurements at HERA

Armen Bunyatyan

representing the H1 and ZEUS Collaborations

Outline:

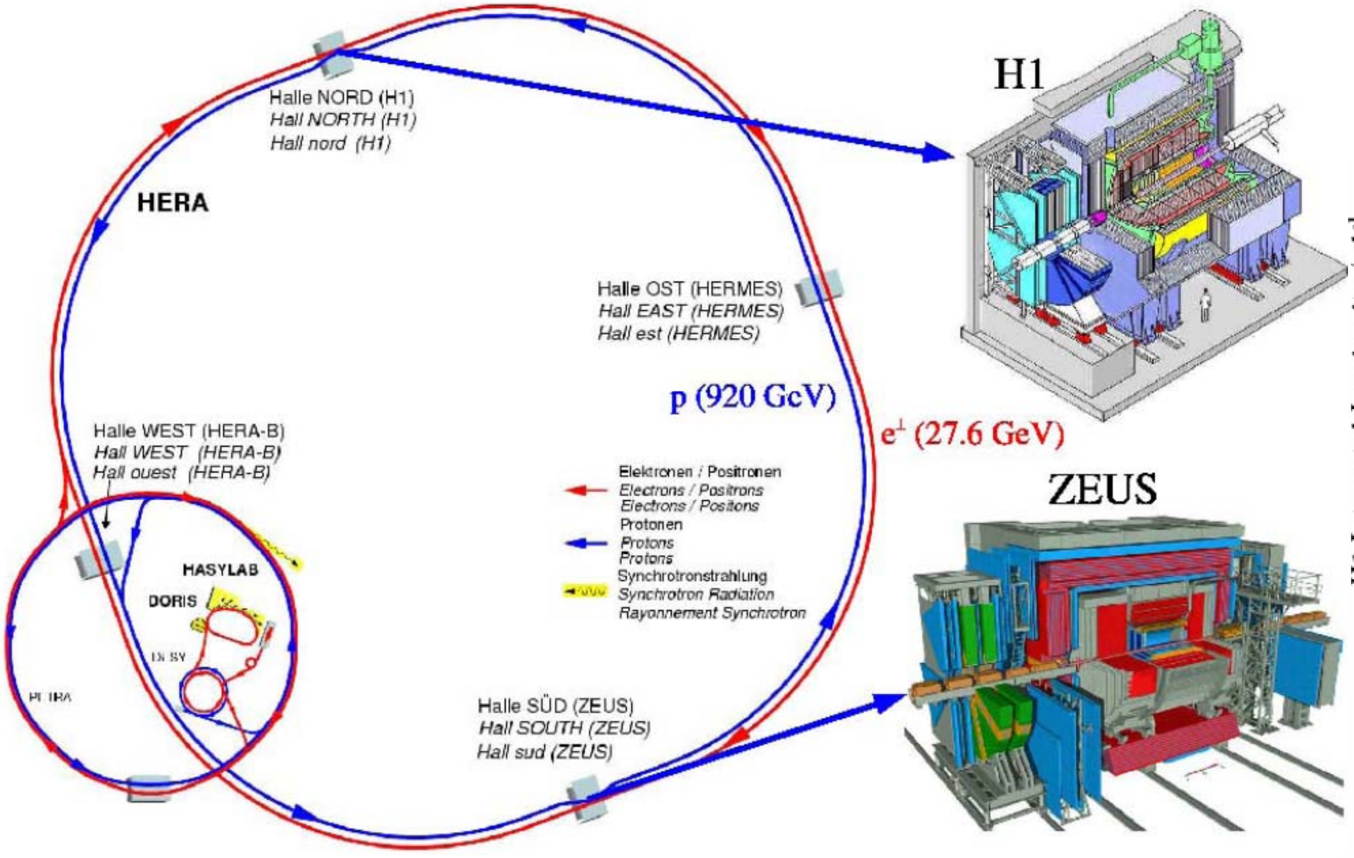
- High E_t Jets in Photoproduction
- Jet production at low and high Q^2 NC DIS
- Extraction of strong coupling α_S
- Jets in Charged Current DIS

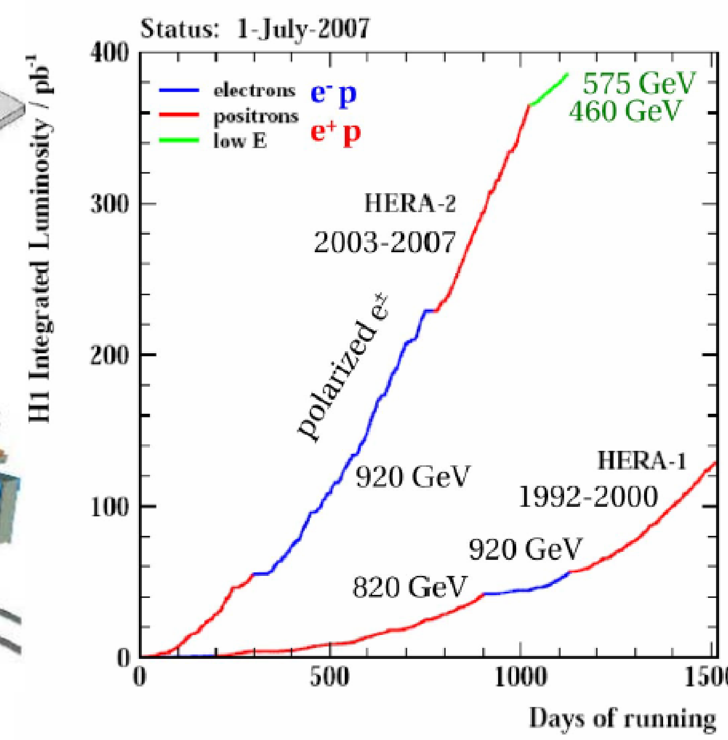
HERA

The world's only electron/positron-proton collider at DESY, Hamburg

E_e = 27.6 GeV E_p = 920 GeV (also 820, 460 and 575 GeV)

(total centre-of-mass energy of collision up to $\sqrt{s} \approx$ 320 GeV)





Two colliding experiments: H1 and ZEUS

HERA-1: 1992 – 2000

HERA-2: 2003 - 2007

total lumi: 0.5 fb^{-1} per experiment

Jet production in NC DIS and photoproduction at HERA

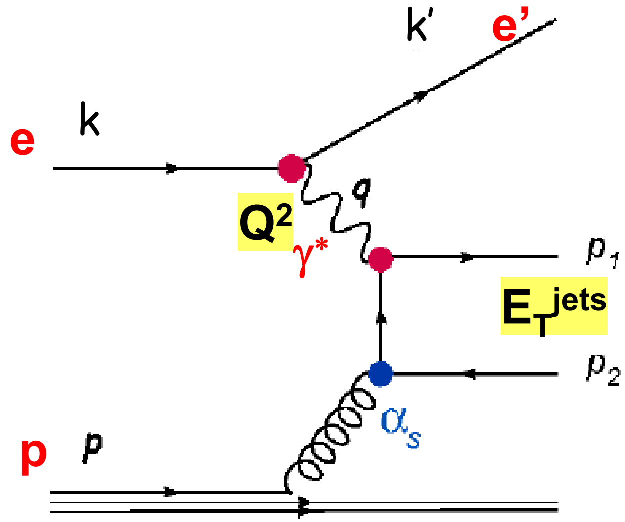
Deep Inelastic Scattering (DIS) ➔ Q^2> few GeV^2

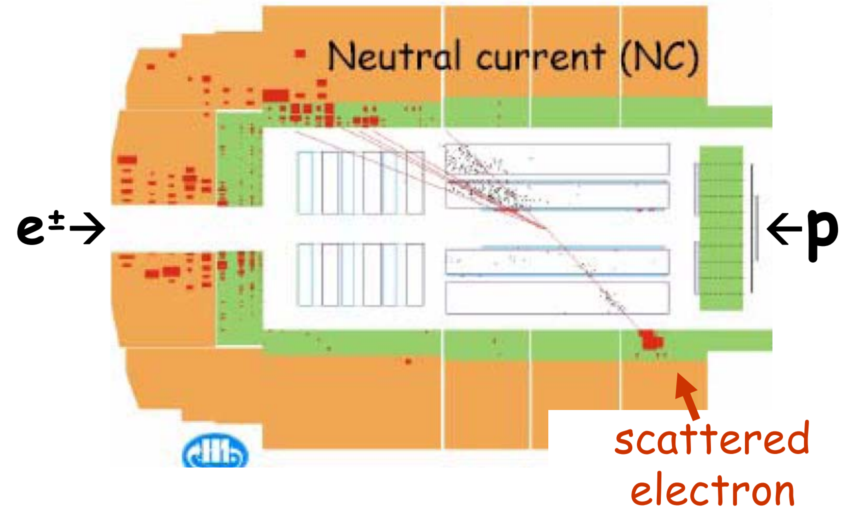
two hard scales provided by Q^2 and E_T^{jet}

$Q^2=-(k-k')^2$
virtuality of exchanged boson

$x=Q^2/2p\cdot q$
fraction of proton momentum carried by struck quark

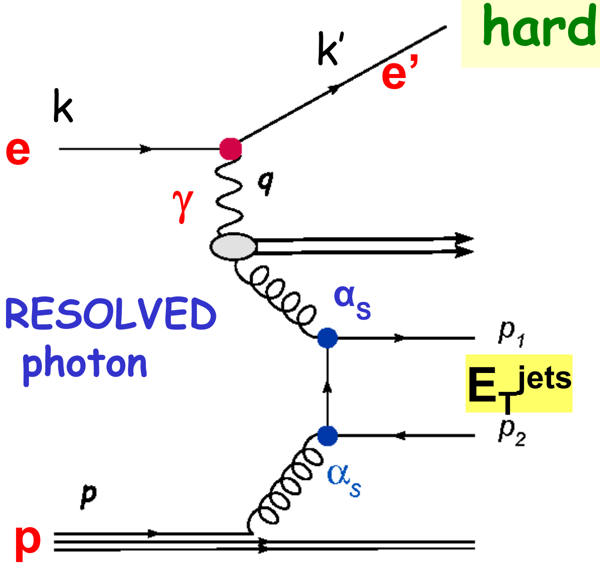
$y=p\cdot q/p\cdot k$
inelasticity variable

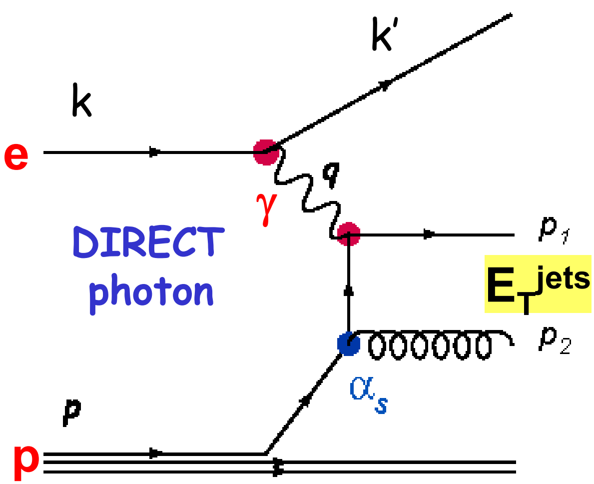


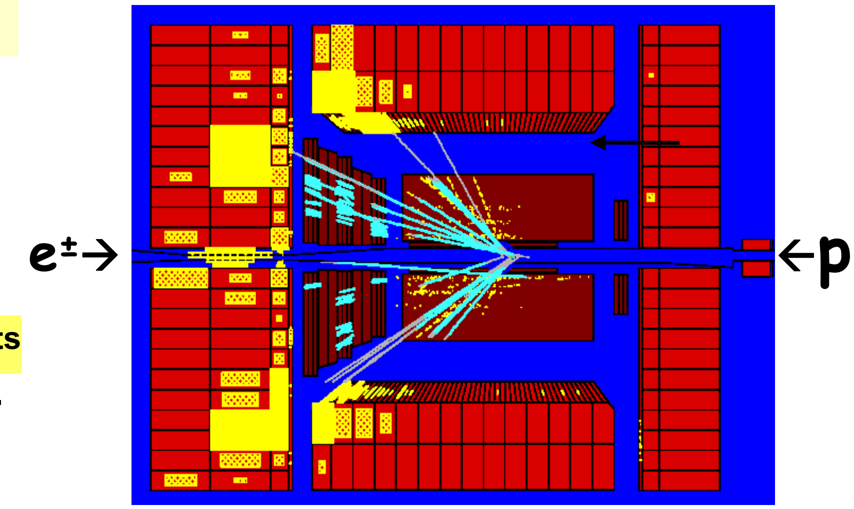


Photoproduction ➔ Q^2 ~ 0

hard scale provided by E_T^{jet}







Physics with Jets at HERA

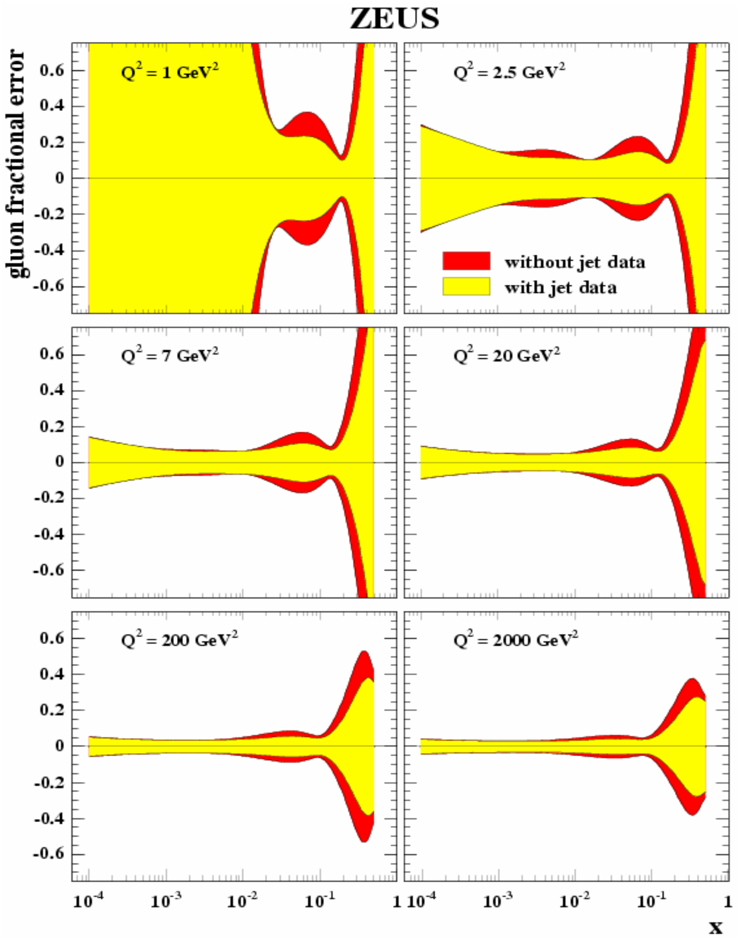
- **Measurements of jets in DIS and photoproduction provide a powerful ground for precision QCD test**

- **Jets are directly sensitive to gluons: $\sigma \sim \alpha_s \cdot g(x)$**

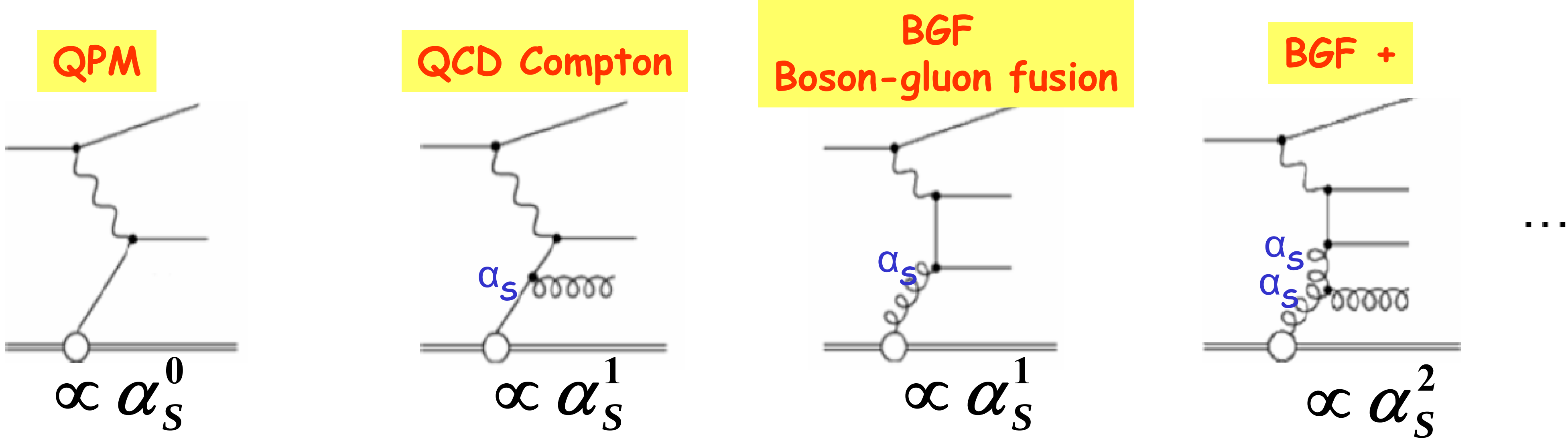
→ extract strong coupling α_s with high precision
→ help to improve constraining gluon density

HERA-1 data in inclusive DIS and dijet photoproduction already successfully used to constrain high-x gluon PDF ➡

Wealth of new jet data from HERA available to provide further constrains on gluon PDF at medium and high x



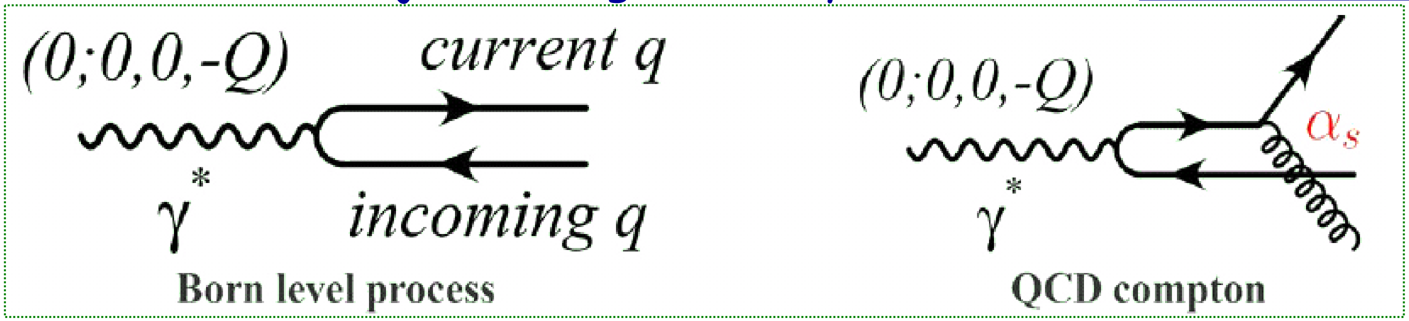
Jet production processes, sensitivity to strong coupling α_s



Number of jets is proportional to power of α_s

To study pQCD in jet production in DIS, jet finding is usually done in the **Breit frame**

→proton and virtual photon collide head-on



- Born level contribution is suppressed → struck quark bounces off from the photon, produced jets have no E_T
- lowest order contribution $O(\alpha_S)$ → two high E_T jets, well separated from p-remnant
- longitudinally invariant k_T jet-algorithm in the Breit frame → collinear and infrared safe

High-E_T dijets in photoproduction

Phys.Rev.D76,072011(2007)

E_T^{jet1}>20 GeV, E_T^{jet2}>15 GeV

$x_\gamma^{obs}=(E_T^{jet1}e^{-\eta 1}+E_T^{jet1}e^{-\eta 1})/2yE_e$

resolved enriched sample: $x_\gamma^{obs} < 0.75$

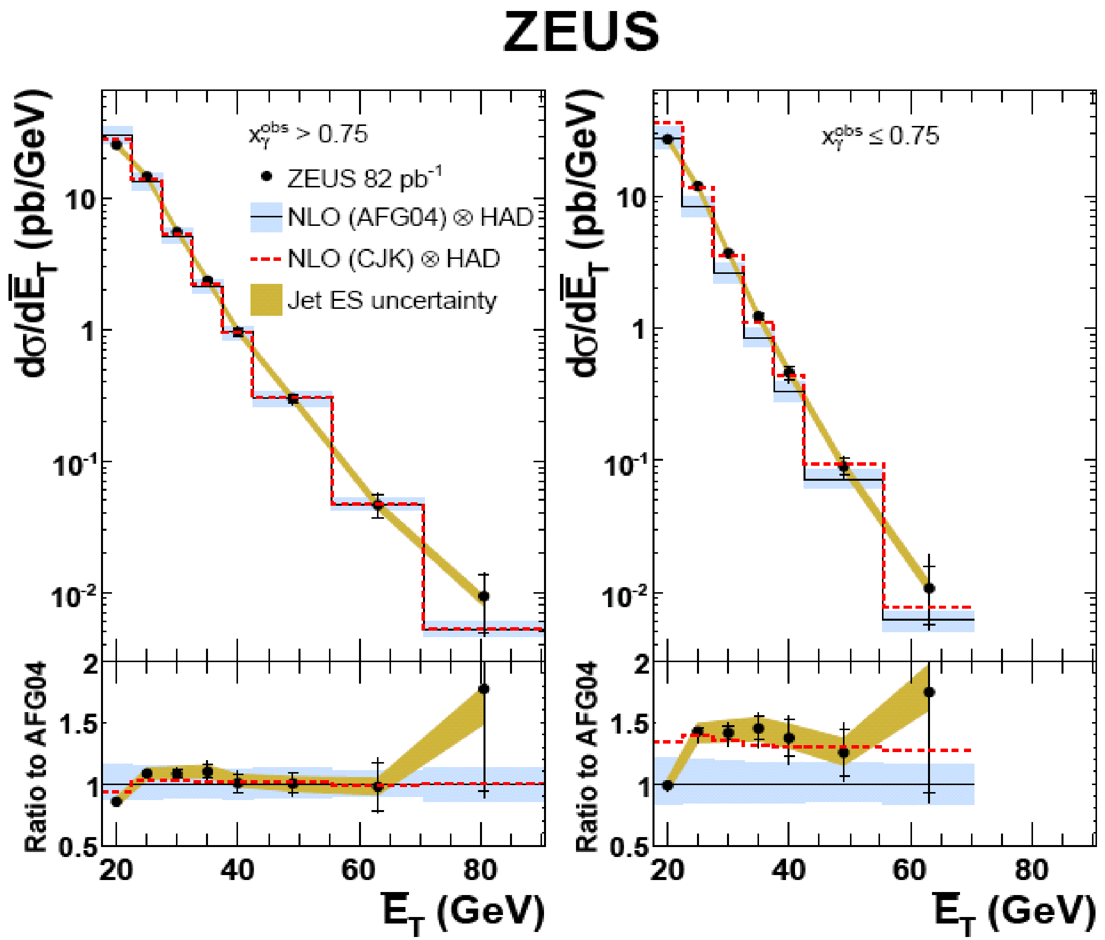
direct enriched sample: $x_\gamma^{obs} > 0.75$

Accurate measurement: experimental uncertainty ~ 5÷10% on cross sections, dominated by hadronic energy calibration

Well described by NLO QCD calculation (Frixione,Ridolfi)

jet cross sections in photoproduction sensitive to the photon gluon PDF

For x_γ^{obs}<0.75 photon PDF differ by up to 40% → can constrain photon PDF



direct enriched   resolved enriched

$\bar{E}_T=(E_T^{jet1}+E_T^{jet2})/2$

Inclusive jets in photoproduction

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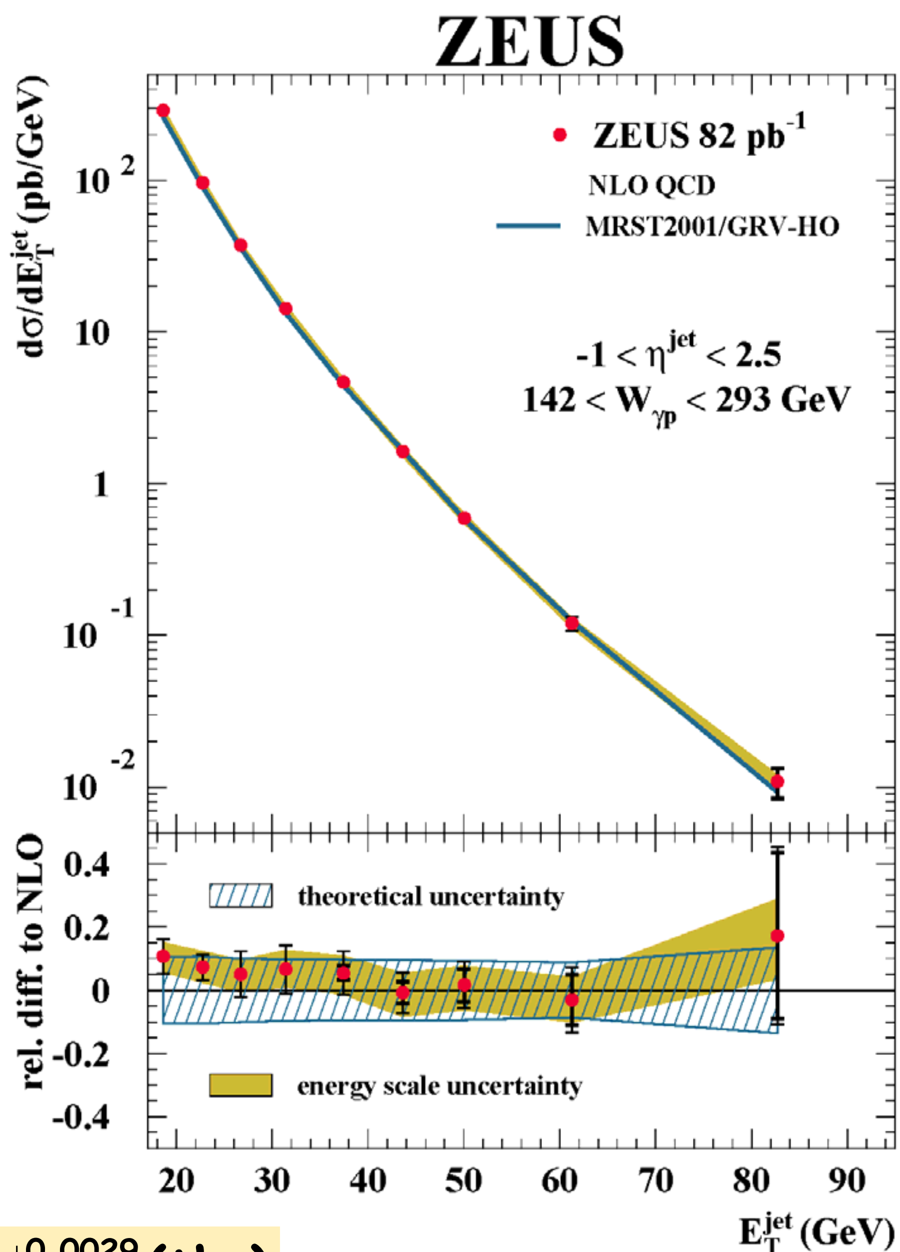
Well described by NLO QCD calculations (Klasen,Kleinwort,Kramer): PDFs: proton MRST2001, photon- GRV-HO; $\mu_r,\mu_f=E_T^{jet}$



α_s extraction:

Theoretical uncertainties :

-Terms beyond NLO:
no strict theory prescription how to estimate their size;
prescription used to provide an estimate:
μ_r, μ_f variation by factors 0.5 and 2

- PDFs uncertainties : < 1%

-hadronisation (HERWIG and PYTHIA) : <0.5%

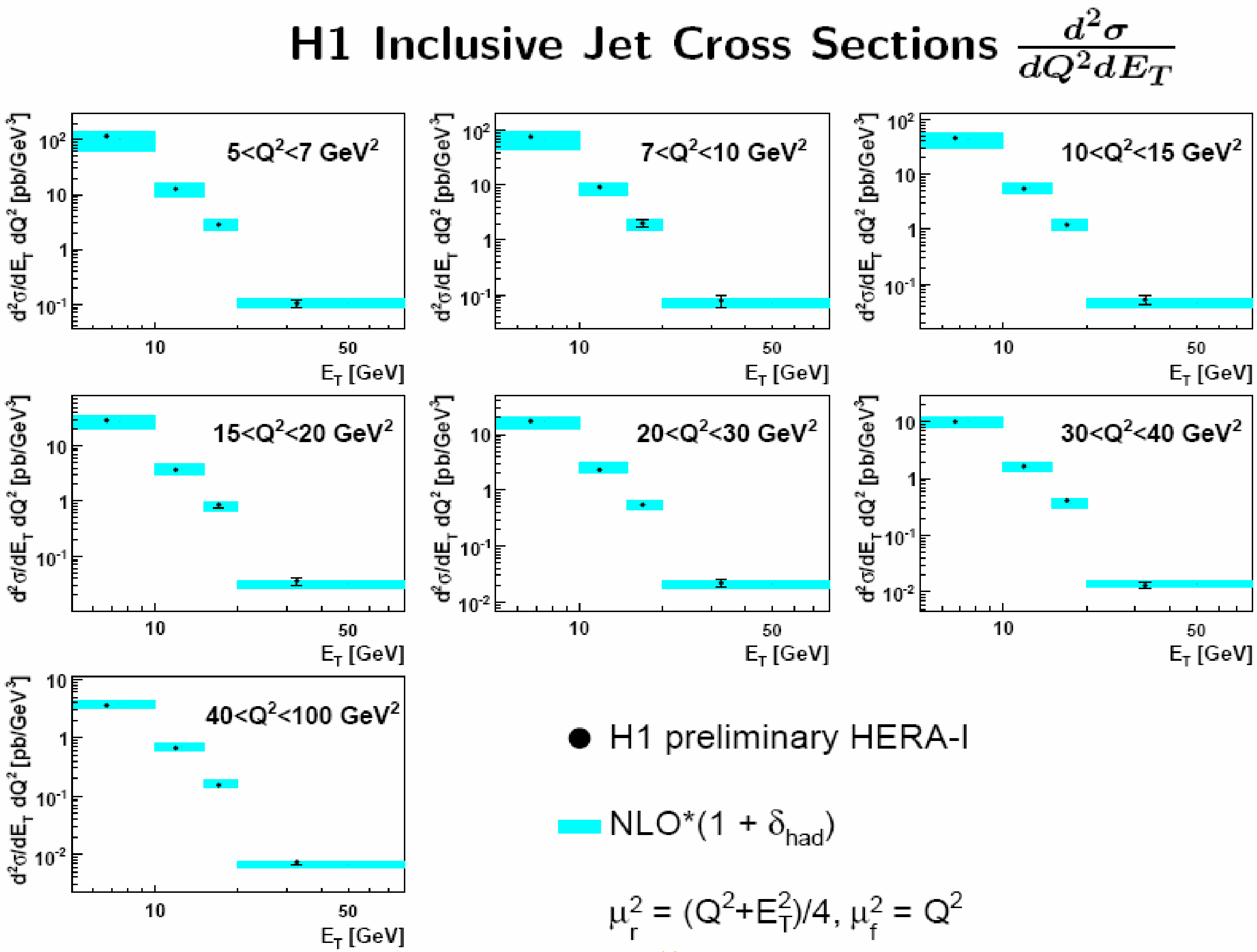
- 1.8% experim. and 3.1% total errors

$$\alpha_s(M_Z) = 0.1223 \pm 0.0001(stat.)^{+0.0023}_{-0.0021}(exp.)^{+0.0029}_{-0.0030}(th.)$$

(ZEUS-prel-08-008)

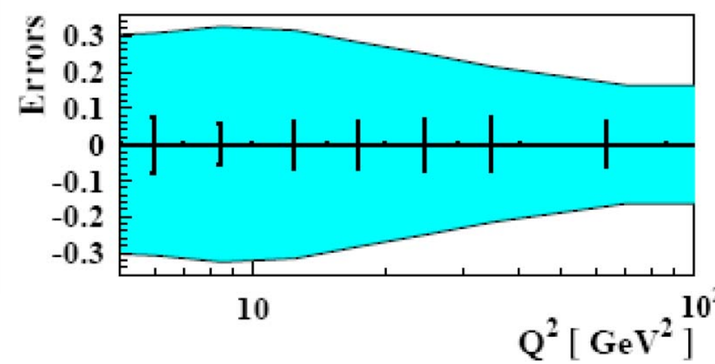
Inclusive jet production at low Q^2 DIS ($5<Q^2<100$ GeV^2)

H1prelim-08-032



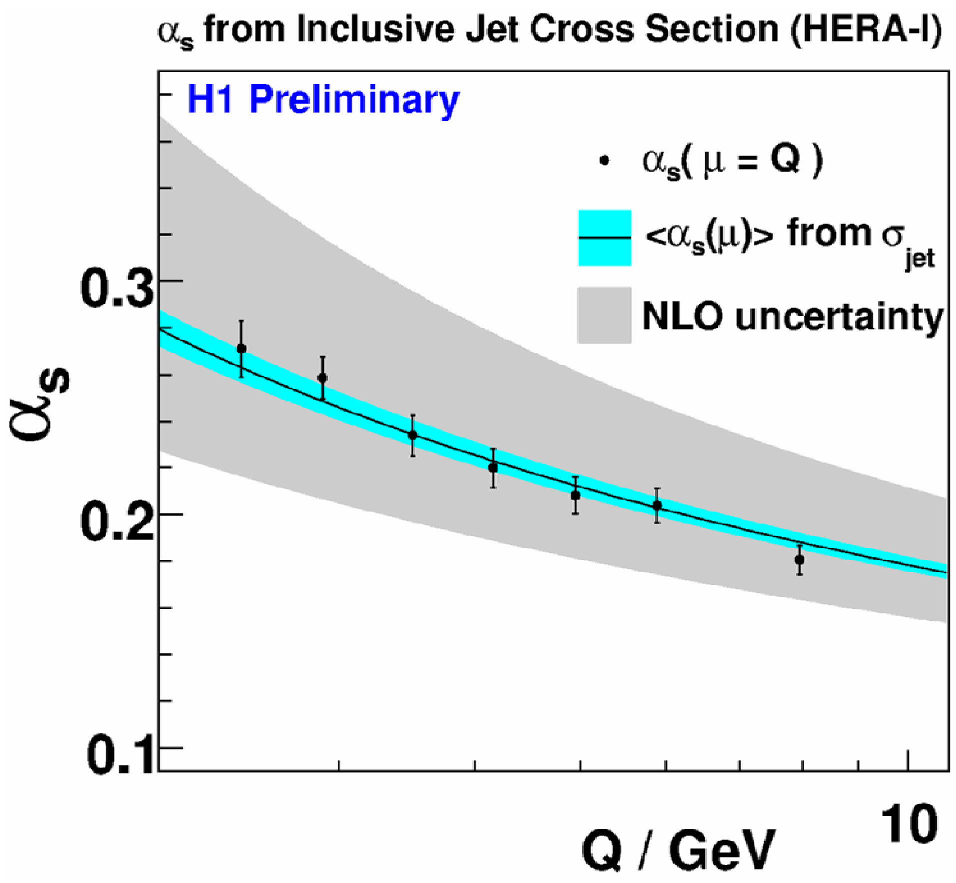
- Accurate measurement well described by QCD NLO: experimental uncertainty ~ 5-10 % on cross sections

- However small predictive power of NLO calculations : Missing orders uncertainty ~ 15-30% on cross sections dominates over experimental and other uncertainties



relative contribution of experimental and NLO scale uncertainties

α_s from low Q^2 DIS jets $(5<Q^2<100\ GeV^2)$



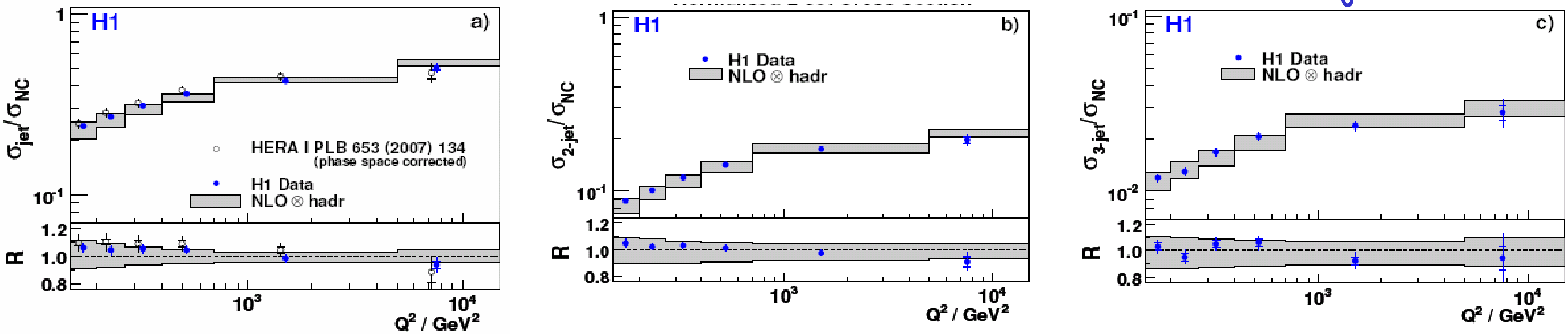
H1prelim-08-032

$$\alpha_s(M_Z) = 0.1186 \pm 0.0014\,(exp.)^{+0.0132}_{-0.0101}\,(scale) \pm 0.0021(PDF)$$

Jet multiplicities in DIS- normalised cross sections ($150<Q^2<15000$ GeV^2)

DESY-09-032

inclusive jets | 2-jets | 3-jets



$P_T^{\text{jet}} > 7$ GeV, $-0.8 < \eta_{\text{jet}} < 2.0$

$P_T^{\text{jet1, jet2}} > 5$ GeV, $M_{12} > 16$ GeV, $-0.8 < \eta_{\text{jet}} < 2.0$

$P_T^{\text{jet1, jet2, jet3}} > 5$ GeV, $M_{12} > 16$ GeV, $-0.8 < \eta_{\text{jet}} < 2.0$

- Data sample 1999-2007: 395 pb^{-1}

- exp. errors reduced by normalising to the total DIS NC cross section :

experimental uncertainty ~3% on cross sections

Uncertainty dominated by hadronic energy calibration known within 1.5% :

→ ~2% effect on cross sections

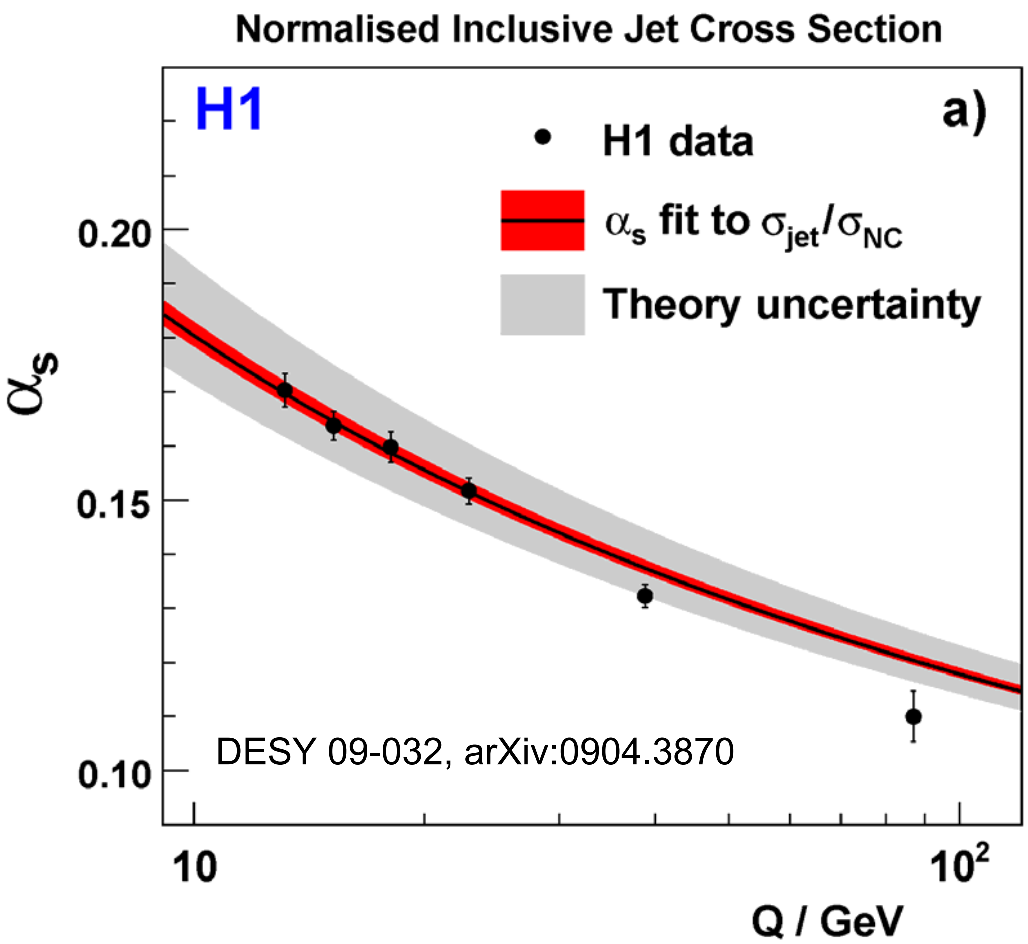
- Jet multiplicity increases with Q^2 and well described by NLO QCD

$$\mu_r = \sqrt{Q^2 + P_T^2/2};\ \mu_f = Q$$

PDF = CTEQ6.5 M

α_s from normalised jet cross sections in DIS ($150<Q^2<15000$ GeV^2)

DESY-09-032



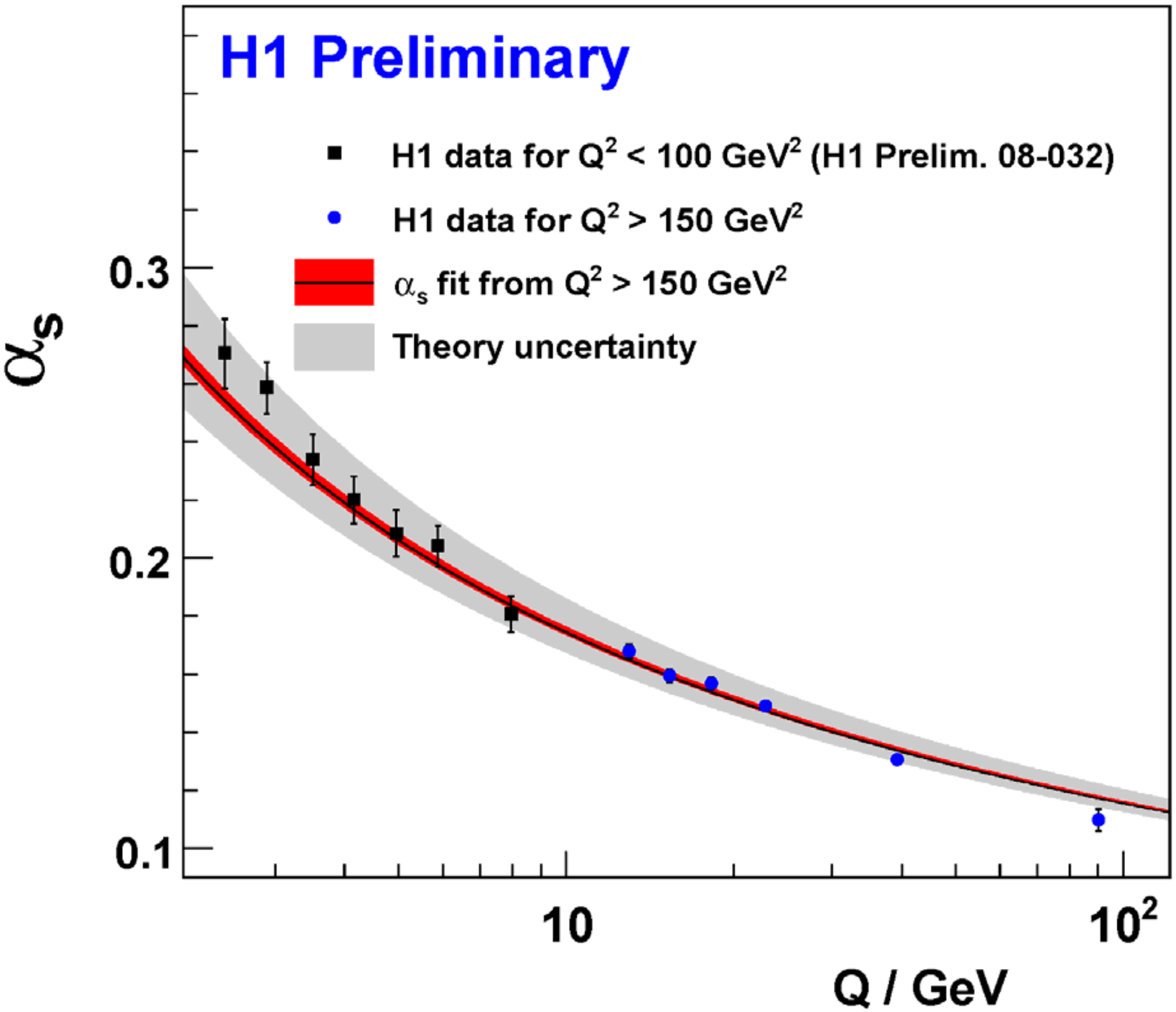
- $\alpha_s(M_Z)$ determined from the fits to jet multiplicities for inclusive and dijets as a function of Q^2 and E_T^{jet} and as a function of Q^2 for trijets

- each of them separately gives consistent values

- Result of simultaneous fit :

  0.6% exp.error, 3.6% total error

$$\alpha_s(M_Z) = 0.1168 \pm 0.0007\,(exp.)^{+0.0046}_{-0.0030}\,(th.) \pm 0.0016(PDF)$$



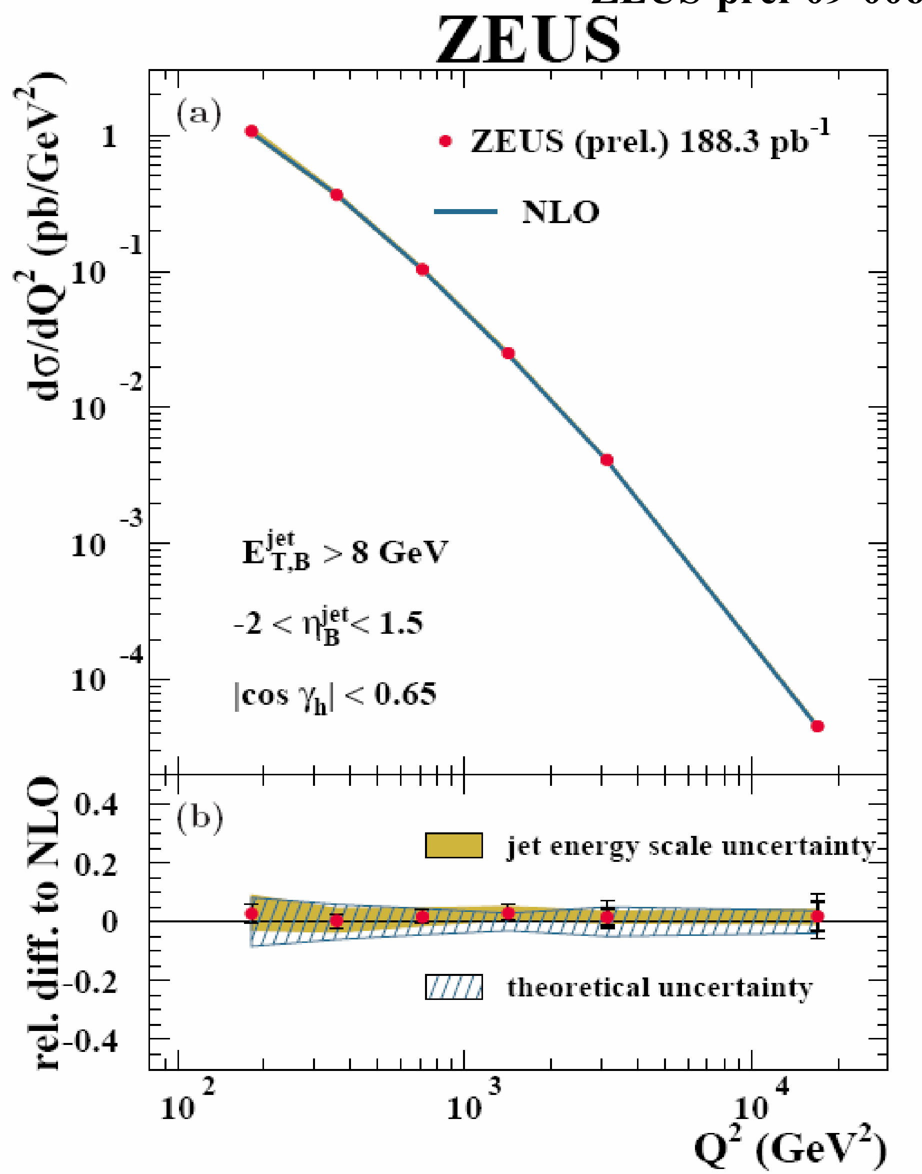
- NLO and α_S extrapolated from high Q^2 (>150 GeV^2) to low Q^2 (<100 GeV^2)
- α_S from low Q^2 added to high Q^2 curve.
  Striking agreement between low and high Q^2
  Low Q^2 data lie within the theory uncertainty of the high Q^2 fit

α_S running is verified over two orders of magnitude in Q

Inclusive jet cross sections at high Q^2 DIS (Q^2>125 GeV^2)

- new prel. measurement of the incl. jet cross section in NC DIS from HERA-2
- Very good description of data by NLO QCD (DISENT) using ZEUS_S PDF $\mu_r=\mu_f=E_T^{jet}$, over many orders of magnitude in the cross sections
- hadronic energy scale uncertainty <1.9% is dominant exp.uncertainty
- for cross sections the theoretical uncertainty dominates over experimental

ZEUS-prel-09-006

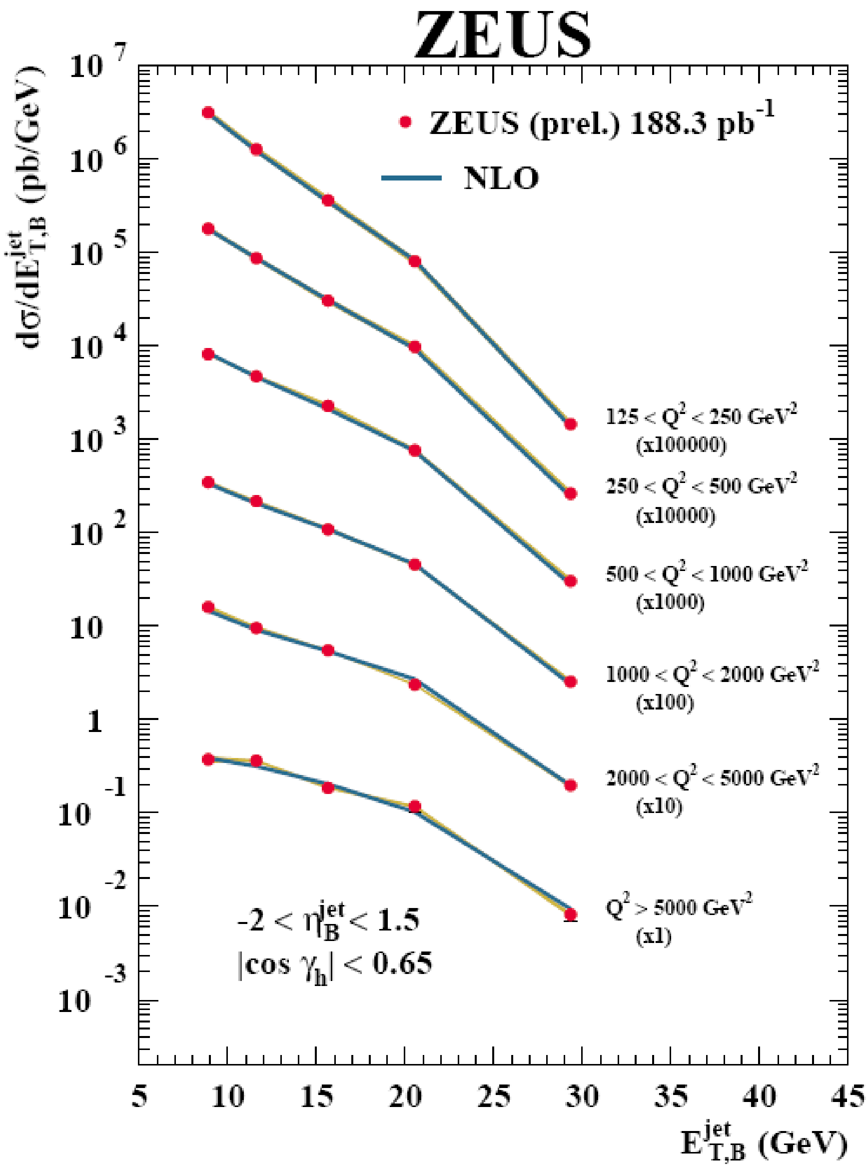


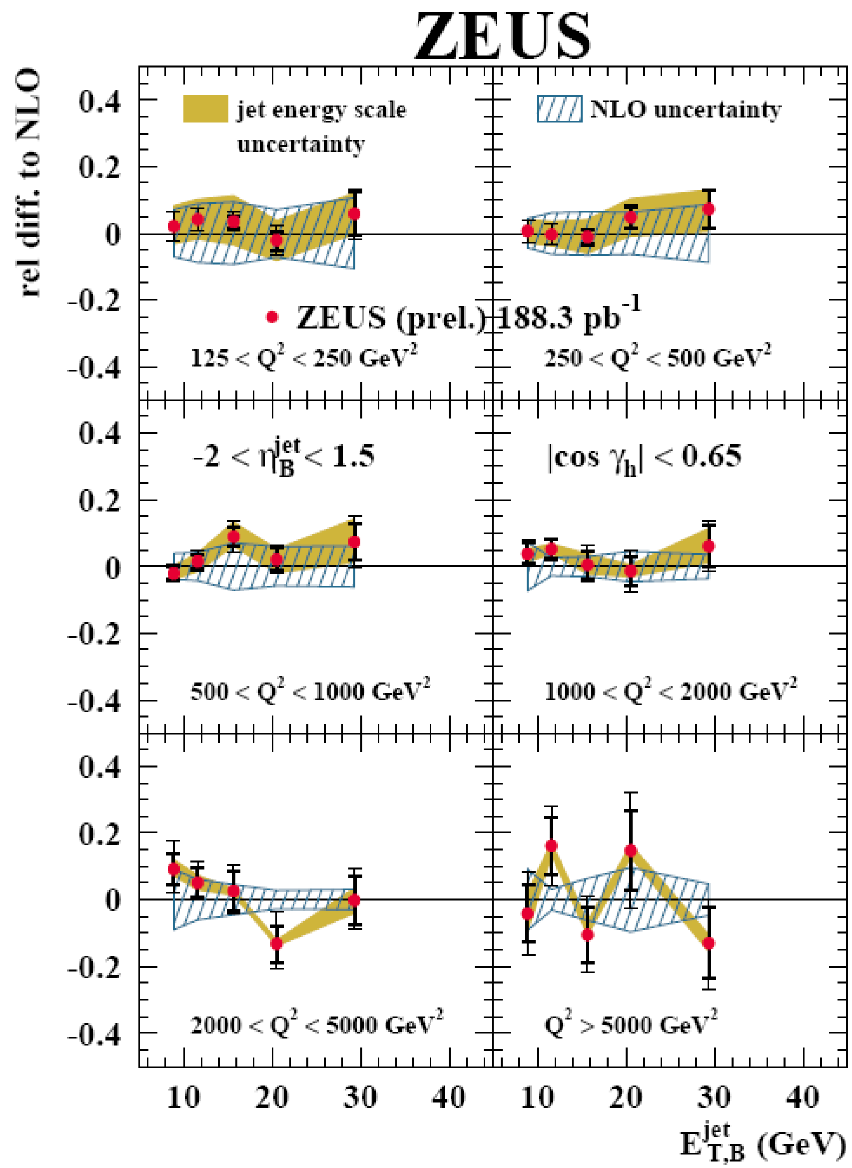
- **extract α_s:**
exploit high Q^2 region (Q^2>500 GeV^2) to reduce theory uncertainty;

2.9% stat+exp.; 3.5% total error

$$\alpha_s(M_Z) = 0.1192 \pm 0.0009(\text{stat.})^{+0.0035}_{-0.0032}(\text{exp.})^{+0.0020}_{-0.0021}(\text{th.})$$

Inclusive jet cross sections at high Q^2 DIS (Q^2>125 GeV^2)



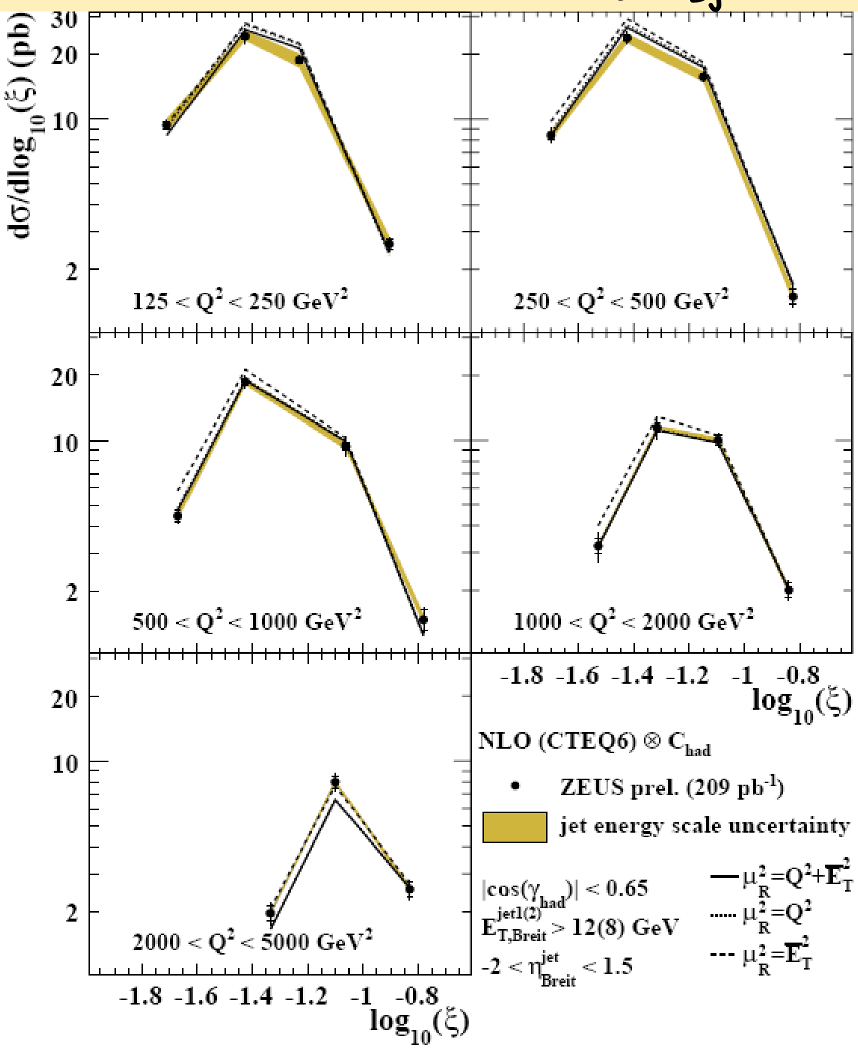


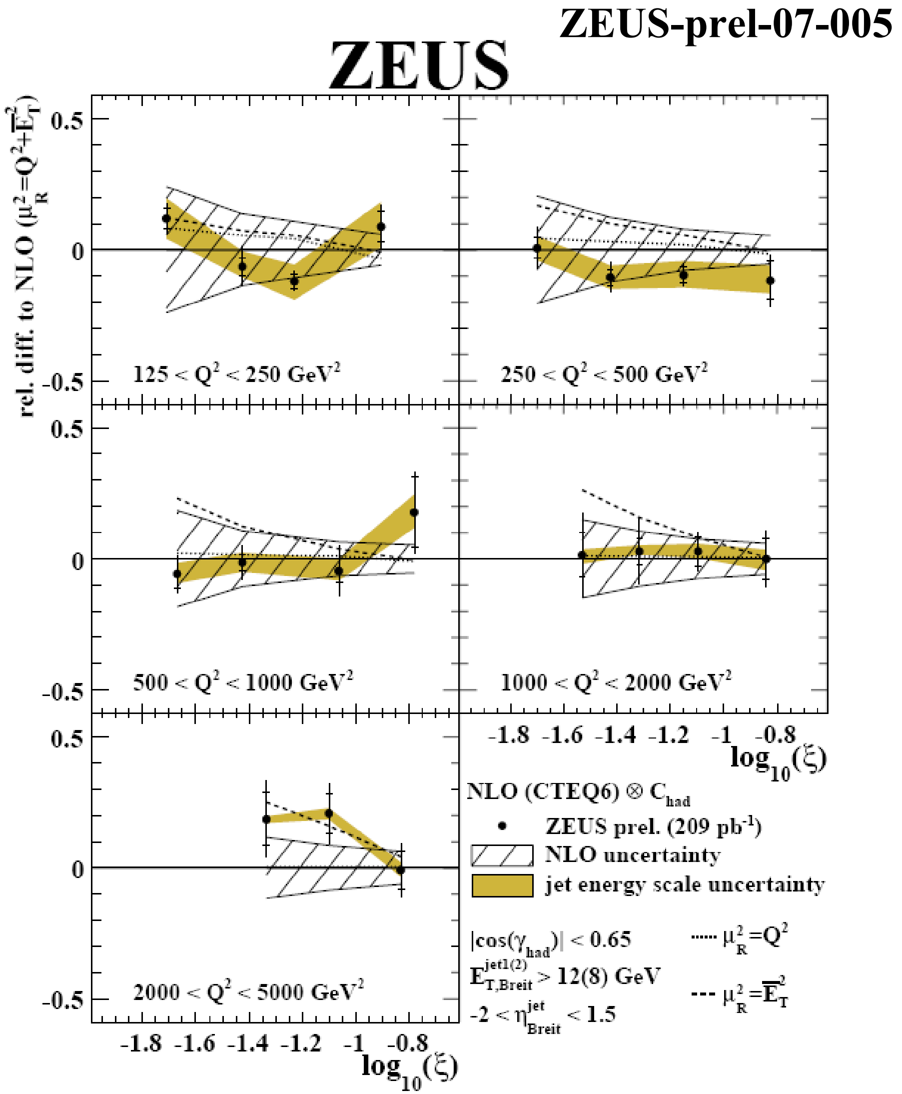
Double differential inclusive jet cross sections as function of E_T^{jet} and Q^2

→**good description of all data by NLO QCD**

Dijet cross sections at high Q^2 DIS ($125<Q^2<5000$ GeV^2)

parton momentum fraction $\xi = x_{Bj} * (1 + M_{jj}^2/Q^2)$





$E_T^{jet1(2)} > 12$ (8) GeV

Sensitive to gluon PDF

Differential 2-jet cross sections in different variables well described by NLO QCD . Theoretical uncertainties dominate.

Jets in Charged current DIS ($Q^2>200\ GeV^2$)

$Q^2>200\ GeV^2$, $y<0.9$, $E_T^{jet}>14\ GeV$, Lumi=359pb^{-1} e^+p/e^-p data

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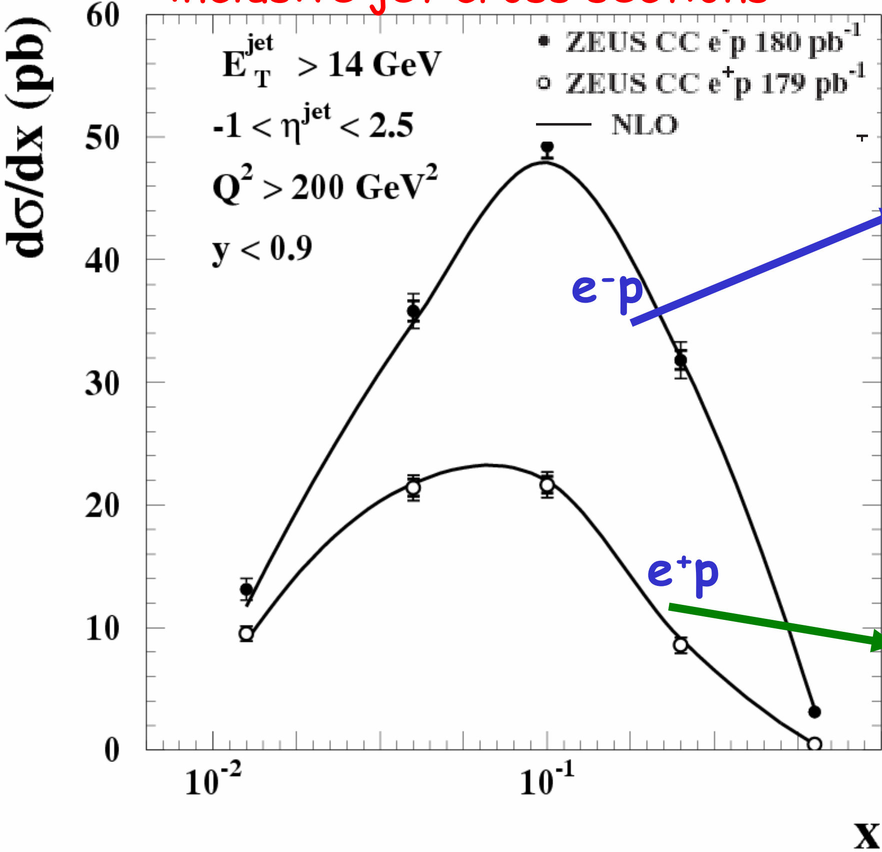
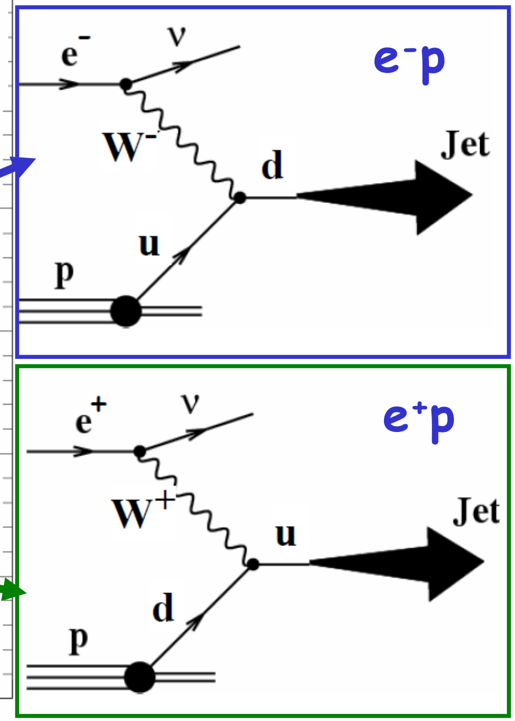
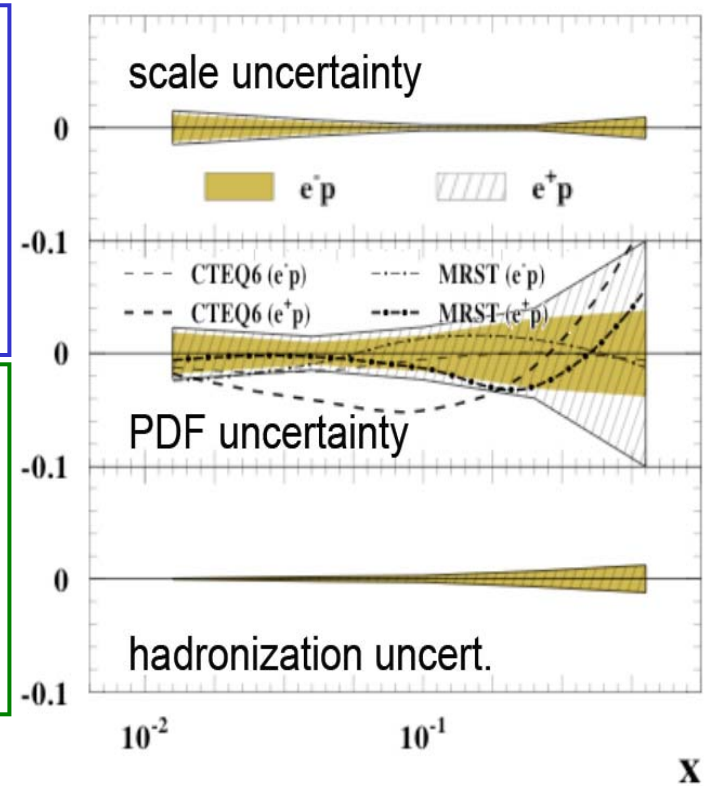
inclusive jet cross sections





theory uncertainty

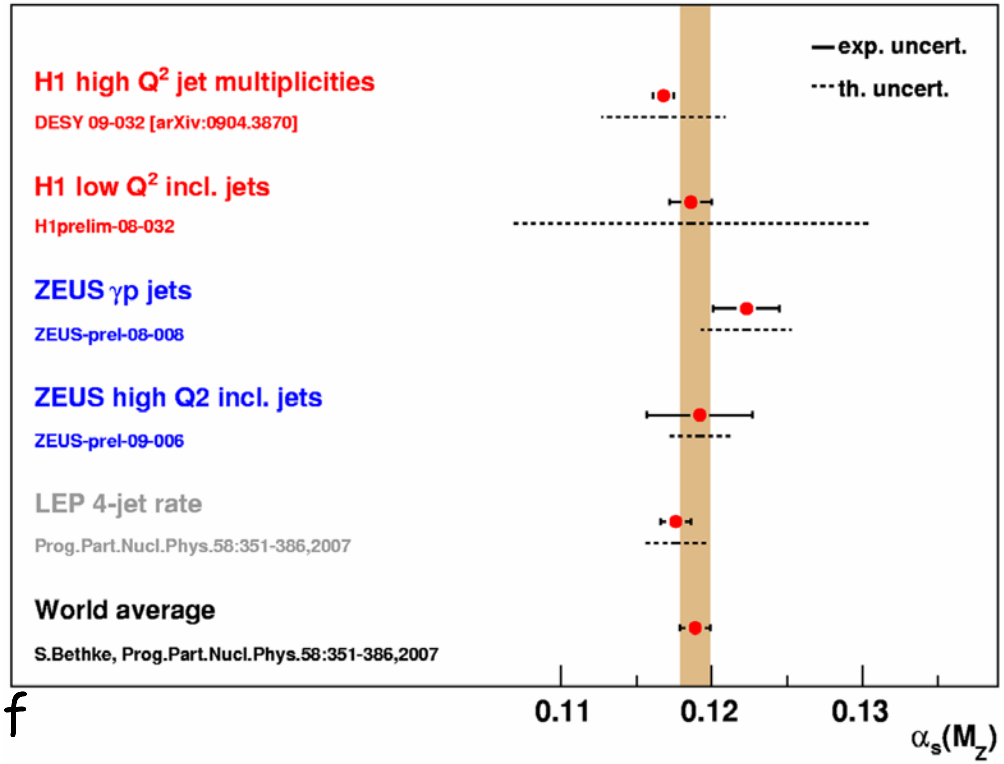


- $W^{-(+)}$ couples primarily to u(d)
- NLO QCD based on MEPJET with ZEUS PDF fit describes jet data reasonably well
- largest theory certainties from PDF for e+ at high x ➔ d-quark density
- ***CC DIS constrains flavour content at high x***

Summary

Wealth of high precision experimental measurements of cross-sections of inclusive and multi-jet production in photoproduction, low and high Q^2 NC DIS and CC DIS

- Data are, in general, well described by NLO QCD
- New precise and consistent $\alpha_S(M_Z)$ extraction in photoproduction and DIS
  - compatible with LEP and the world average
  - high experimental precision(0.6÷3%)



- Striking agreement between low and high Q^2 measurements
- α_s running is verified over two orders of magnitude in Q (5<Q<100 GeV)

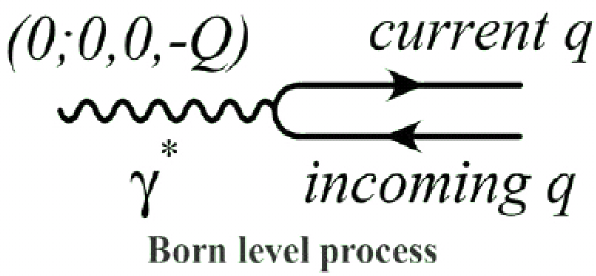
- The jet constrain gluon densities in the proton and the photon, jets in charged current DIS constrains flavour content at high x

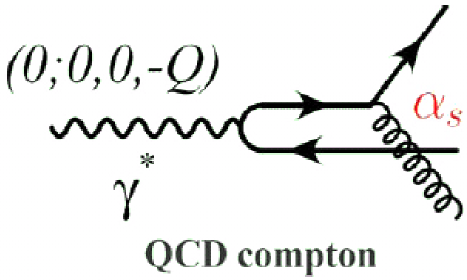
- Theory scale uncertainties dominate over the experimental ones; NNLO necessary to take full advantage of the data.

Backup

Jet reconstruction

Reconstructed in boson-proton collinear frame





Photoproduction – laboratory frame

DIS – Breit frame

Longitudinally invariant k_T algorithm

- Collinear and infrared safe
- Iterative clustering:

$$d_{i,j} = \min(P_{T,i}^2, P_{T,j}^2) \cdot R_{ij}$$

$$R_{ij} = (\eta_i - \eta_j)^2 + (\varphi_i - \varphi_j)^2$$

- p_T-weighted masseless recombination scheme

Resulting jets: Njets with $R_{ij} > R = 1$

Jet cross section dependence on Radius parameter R

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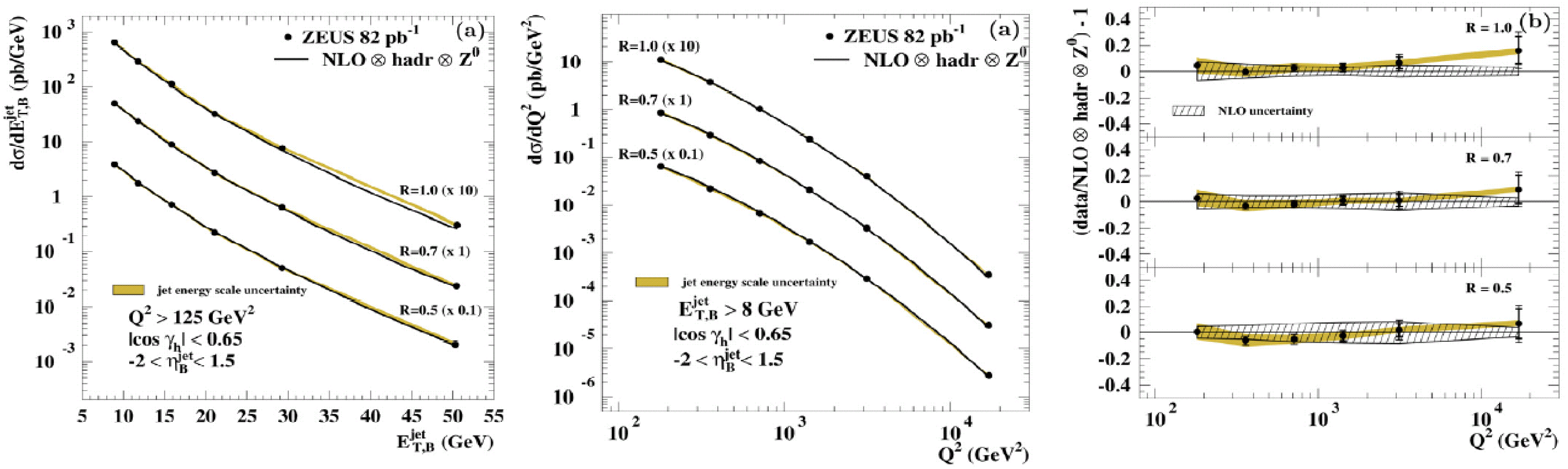
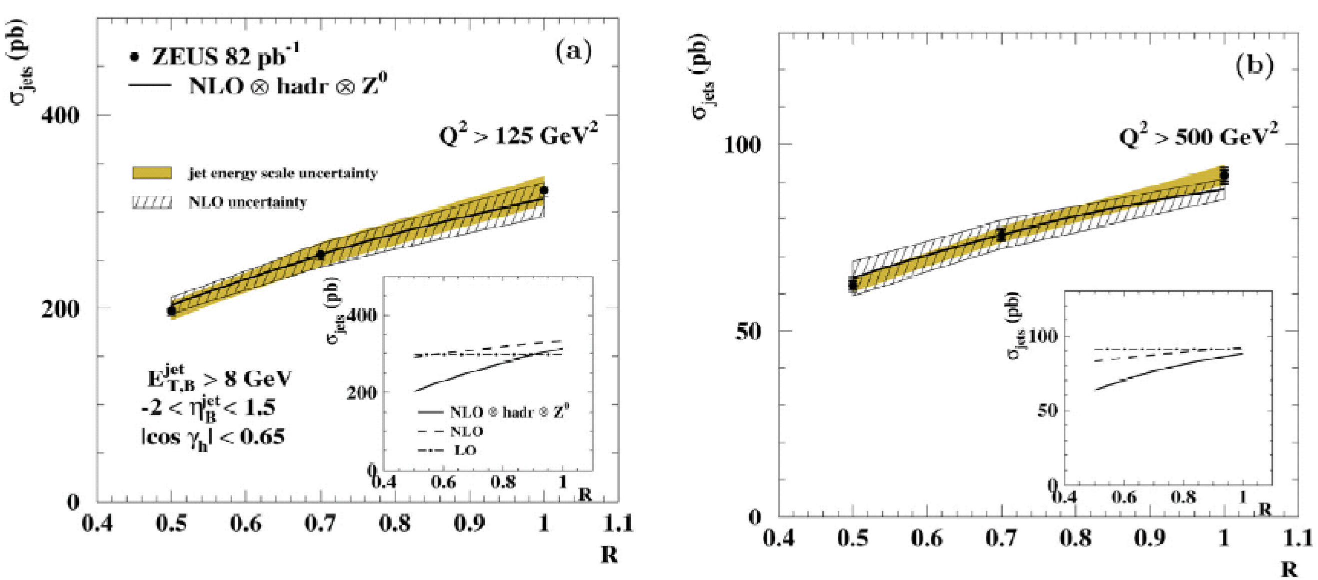


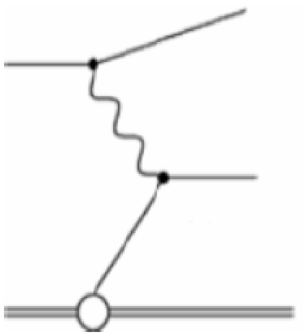
NLO describes well jet production for radius parameter down to R=0.5



Integrated cross section linearly depends vs R

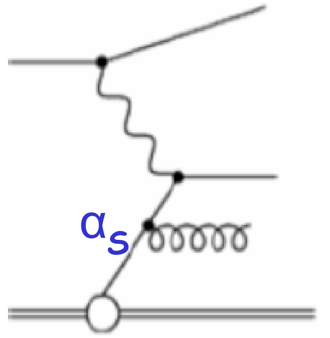
Jet production processes, sensitivity to strong coupling α_s

QPM



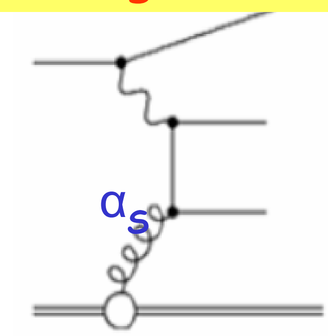
$\propto \alpha_s^0$

QCD Compton



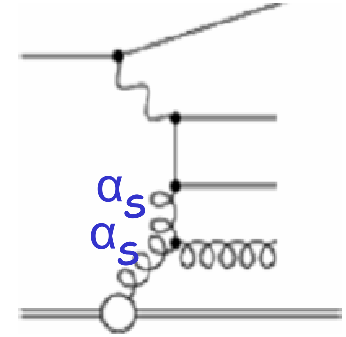
$\propto \alpha_s^1$

BGF
Boson-gluon fusion



$\propto \alpha_s^1$

BGF +



$\propto \alpha_s^2$

...

- Number of jets is proportional to power of α_s

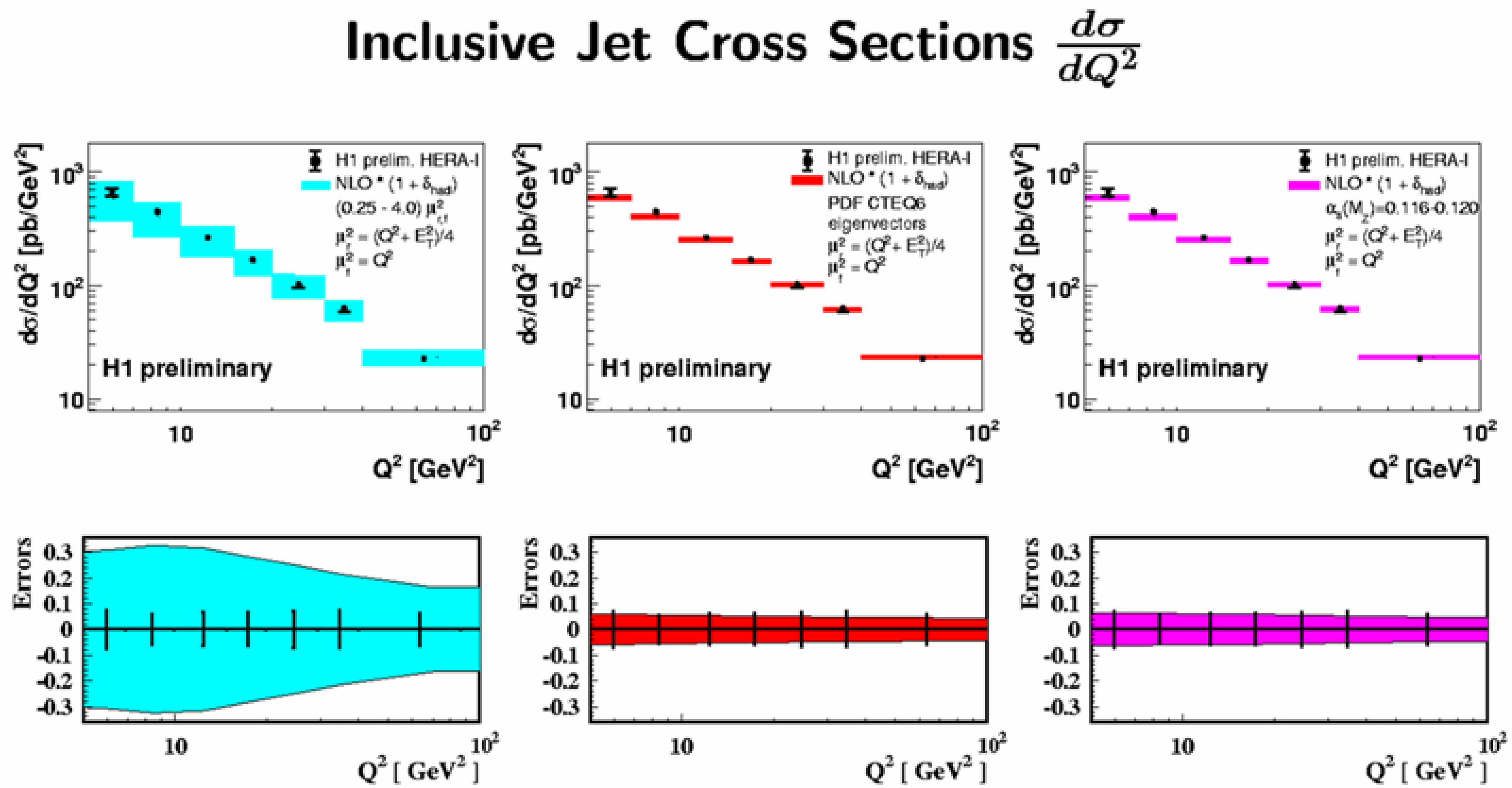
$$d\sigma_{njet} = \sum_{i=q,\bar{q},g} \int dx\, f_i(x, \mu_f)\, d\hat{\sigma}_i(x, \alpha_s^{njet-1}(\mu_r), \mu_r, \mu_f)$$

f_i are parton distribution functions

$d\hat{\sigma}_i$ is the subprocess cross section, calculable in pQCD

-jet cross sections sensitive to the proton gluon PDF

Inclusive jet production at low Q^2 DIS ($5<Q^2<100$ GeV^2)



μ_r, μ_f uncerainties

PDF uncerainties

α_s uncerainties

Scale uncertainty dominates over the experimental and other theoretical uncertainties