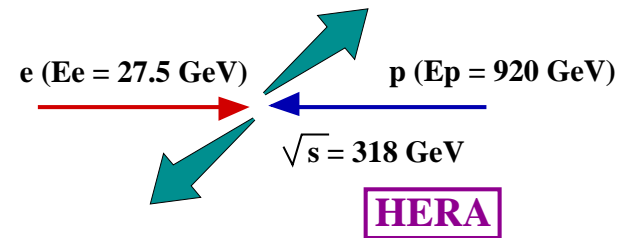


Jet measurements and determinations of α_s at HERA

Marcos Jiménez

Universidad Autónoma de Madrid

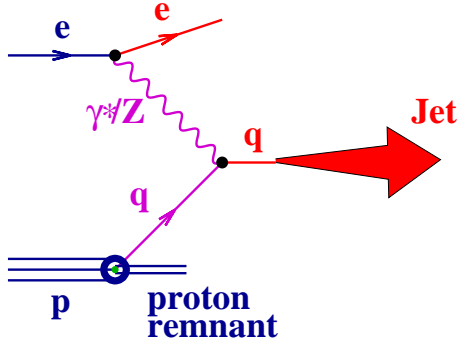


On behalf of H1 and ZEUS collaborations

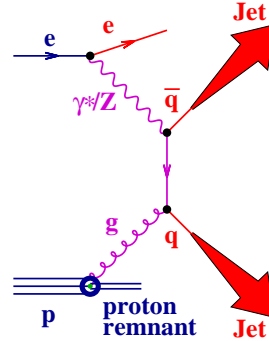
DIS cross section

- The production of jets in DIS at HERA provides a testing ground for pQCD
- Up to LO in α_s , these are the diagrams that contribute to the jet production cross section in DIS ($Q^2 \gg \Lambda_{QCD}^2$):

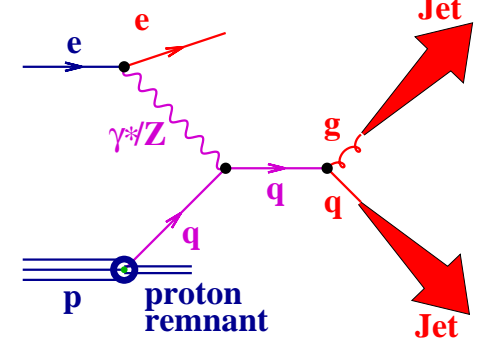
BORN CONTRIBUTION



BOSON-GLUON FUSION



QCD COMPTON

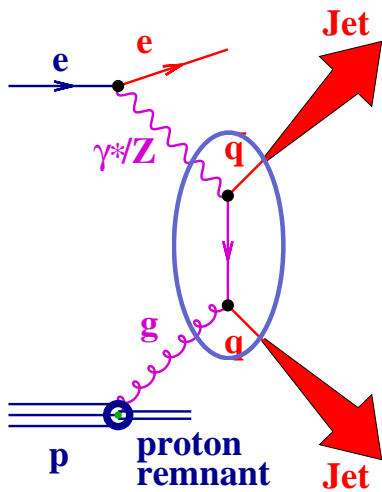


- The cross section in pQCD is given by:

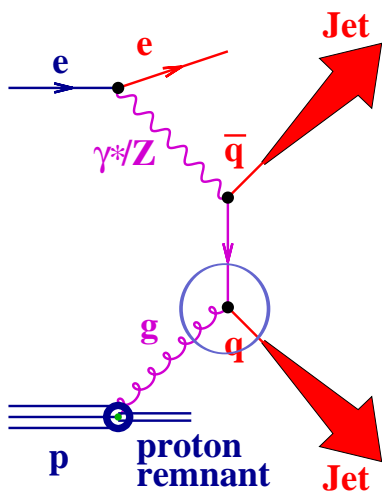
$$d\sigma_{\text{jet}} = \sum_{a=q,\bar{q},g} \int dx f_a(x, \mu_F) d\hat{\sigma}_a(x, \alpha_s(\mu_R), \mu_R, \mu_F)$$

- f_a are the experimentally determined parton distribution functions
→ long-distance structure of the interaction
- $d\hat{\sigma}_a$ is the subprocess cross section, calculable in pQCD
→ short-distance structure of the interaction

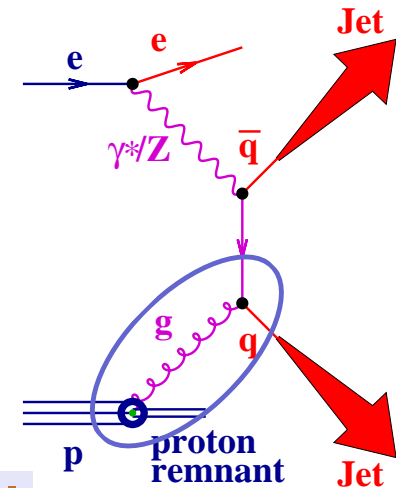
Motivation and Outline



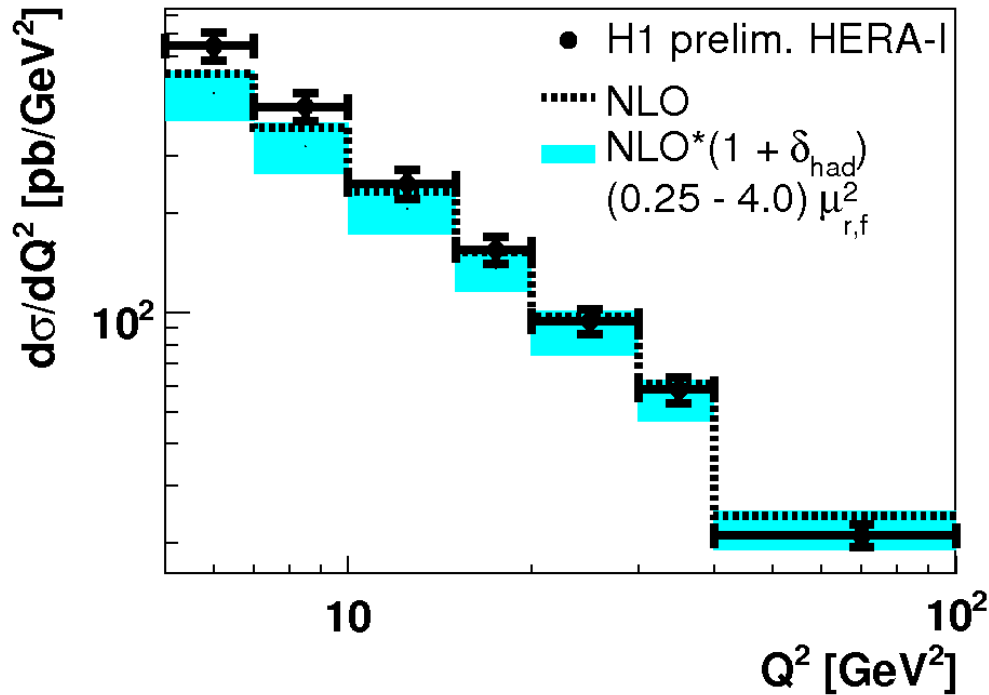
- In regions where the PDFs are well constrained
 - Low Q^2 region provides **high statistics**
 - test general aspects of pQCD
 - High Q^2 region has **smaller theoretical uncertainties**
 - study jet algorithm



- In regions where the PDFs are not as well constrained
 - e.g. Gluon PDF at mid-to-high x
 - Jet cross sections **help constrain gluon pPDF**
- Variables that allow smallest theoretical and experimental uncertainties
 - Inclusive-jet cross sections at high Q^2
 - extraction of α_s **with high precision**
 - test scale-dependence of α_s



INCLUSIVE JET PRODUCTION AT LOW Q^2 DIS (H1)



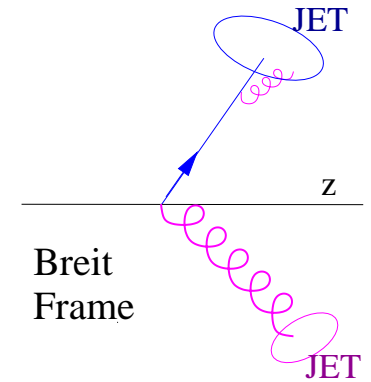
- **Motivation: how low in Q^2 and E_T is pQCD at NLO reliable?**

- **Kinematic region:**

- $5 < Q^2 < 100 \text{ GeV}^2$

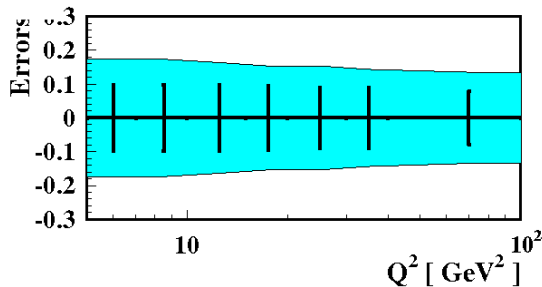
- $E_{T,B}^{\text{jet}} > 5 \text{ GeV}$

- $\mathcal{L} = 44 \text{ pb}^{-1}$

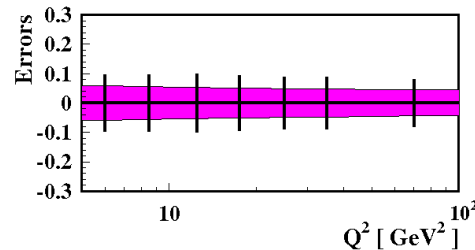


- k_T clustering algorithm in the Breit frame

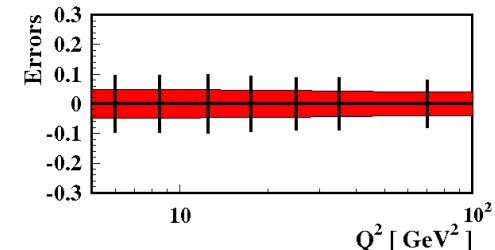
- **Discrepancies from pQCD observed at $Q^2 < 10 \text{ GeV}^2$ and $E_{T,B}^{\text{jet}} < 10 \text{ GeV}$**
- **Contributions to the uncertainty mean NNLO needed!**



unc from μ_r ($\sim 20\%$!)



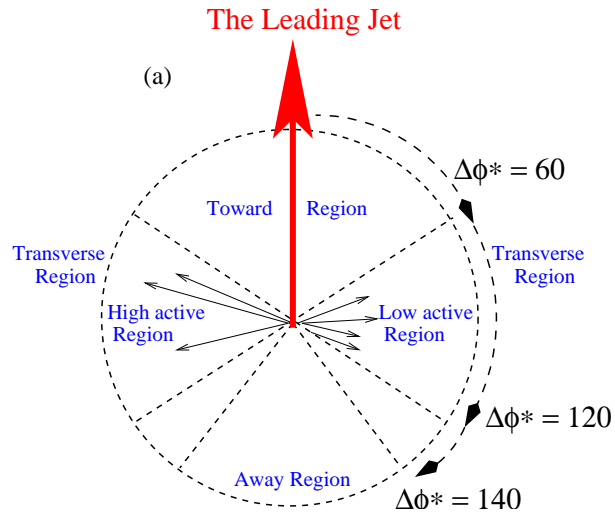
unc from PDFS



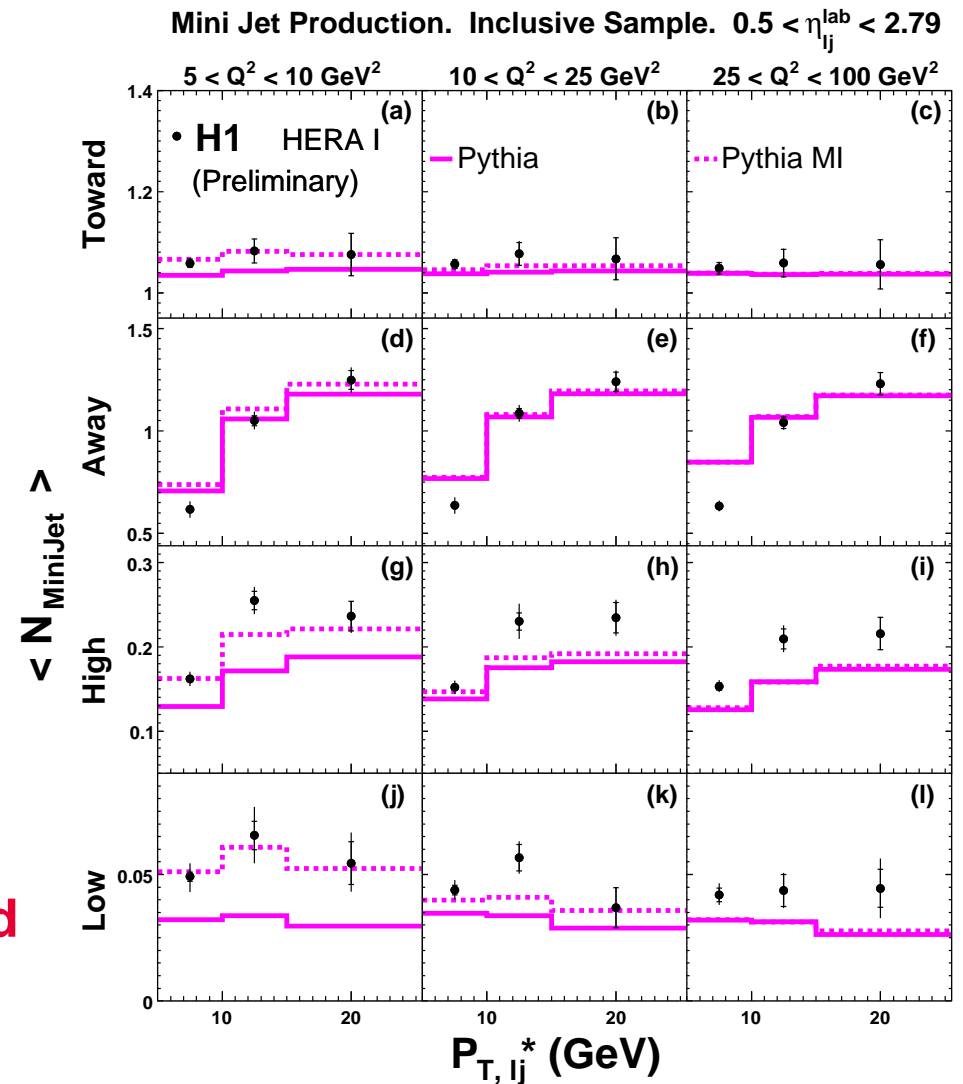
unc from $\alpha_s(M_Z)$

Mini-Jets in DIS (H1)

- An analysis has been made using minijets, low E_T jets ($E_T^{h.c.m} > 3 \text{ GeV}$)
- The idea is to study hadronic activity **in excess** to primary interaction in a well understood environment → **useful for LHC**

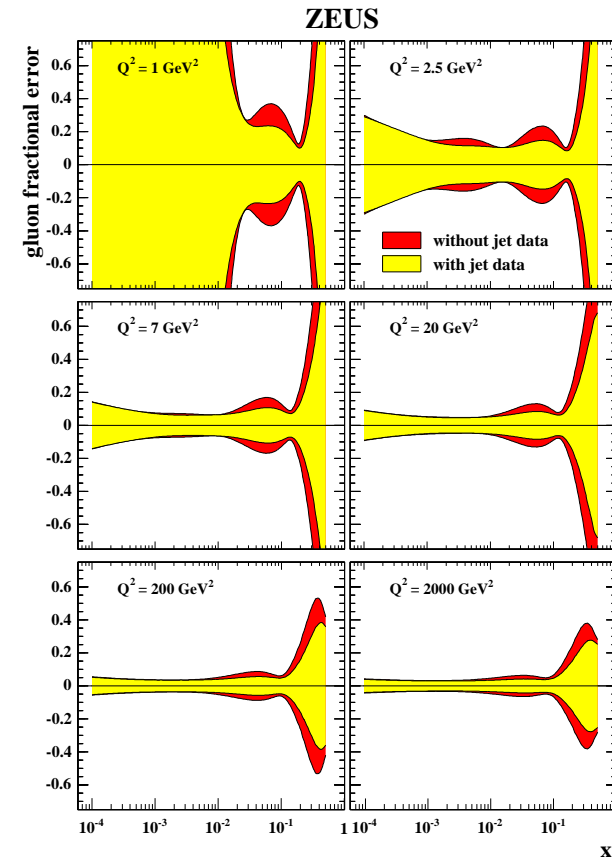
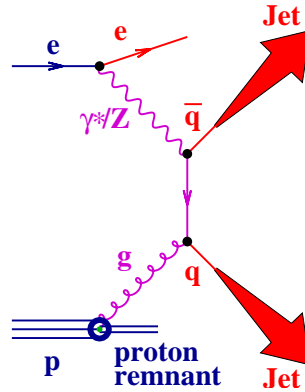
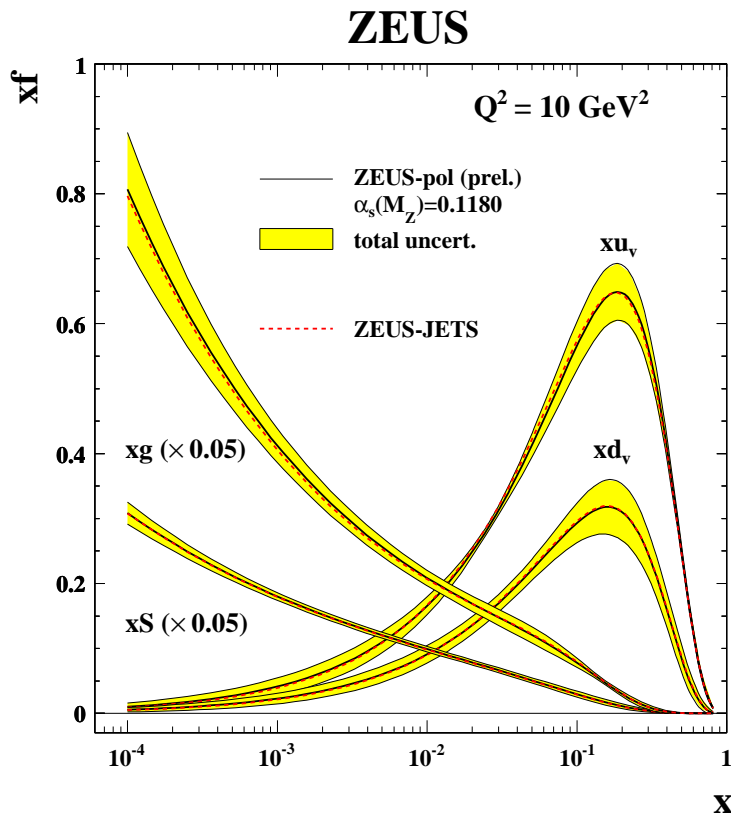


- Inclusive and Dijet samples compared to RAPGAP, ARIADNE, PYTHIA (MI), HERWIG (SUE)
- **General agreement, but MI/SUE needed especially in 'low active region'**



Jet measurements for QCD global fits

- As a result of including jet cross sections, the gluon PDF uncertainty was reduced



- Gluon PDFs dominate in low x region

- Jet data has large effect on the gluon PDF uncertainty in mid-to-high x region

INCLUSIVE JETS AND DIJETS IN NC DIS AT HIGH Q^2 (ZEUS)

- Measurements of $d\sigma/dE_{T,B}^{jet}$ in different regions of Q^2

- Kinematic region defined by:

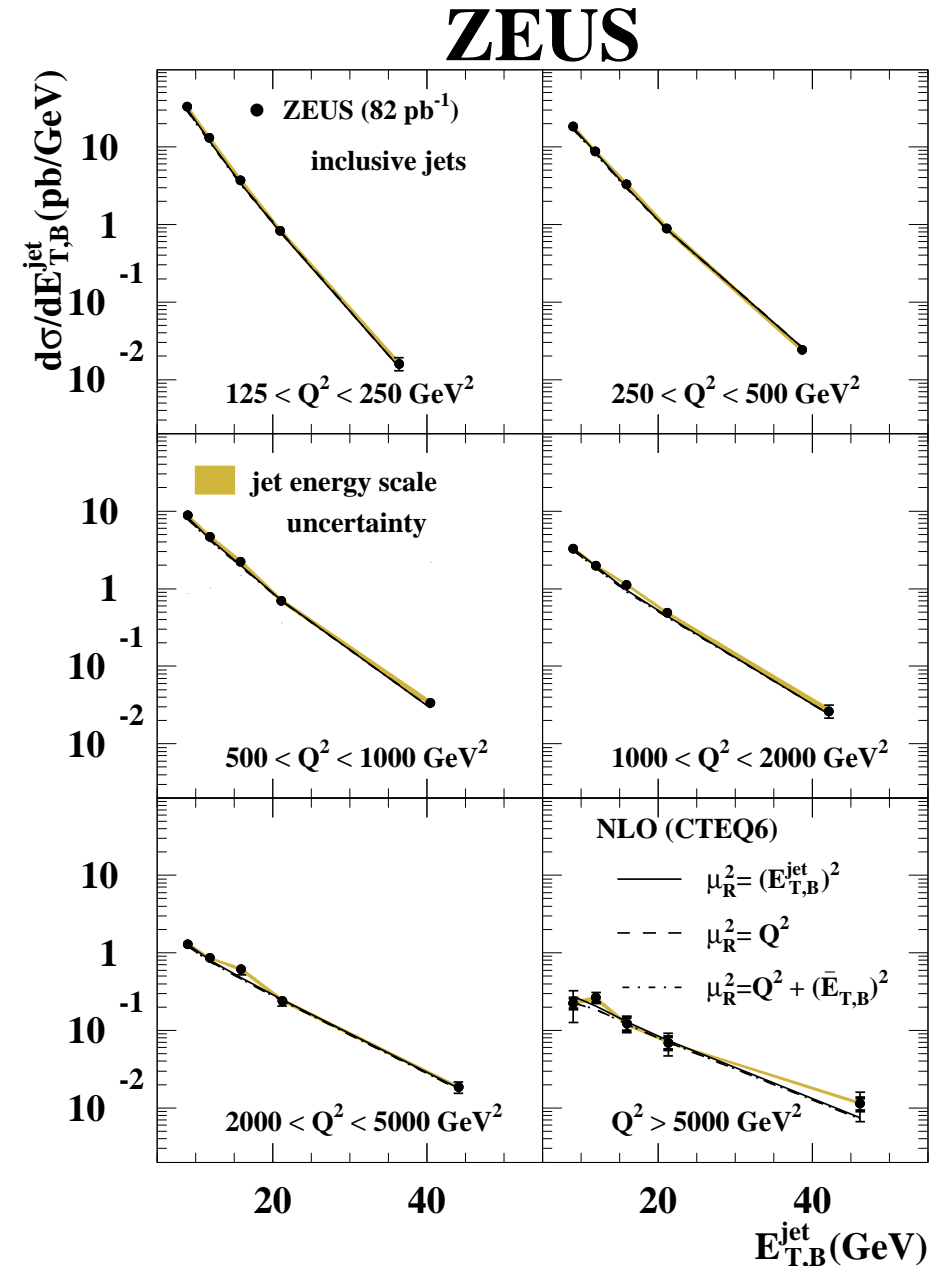
- $E_{T,B}^{jet} > 8 \text{ GeV}$
- $|\cos\gamma_h| < 0.65$
- $Q^2 > 125 \text{ GeV}^2$

- $\mathcal{L} = 82 \text{ pb}^{-1}$

- Uncertainty in the data dominated by jet energy scale

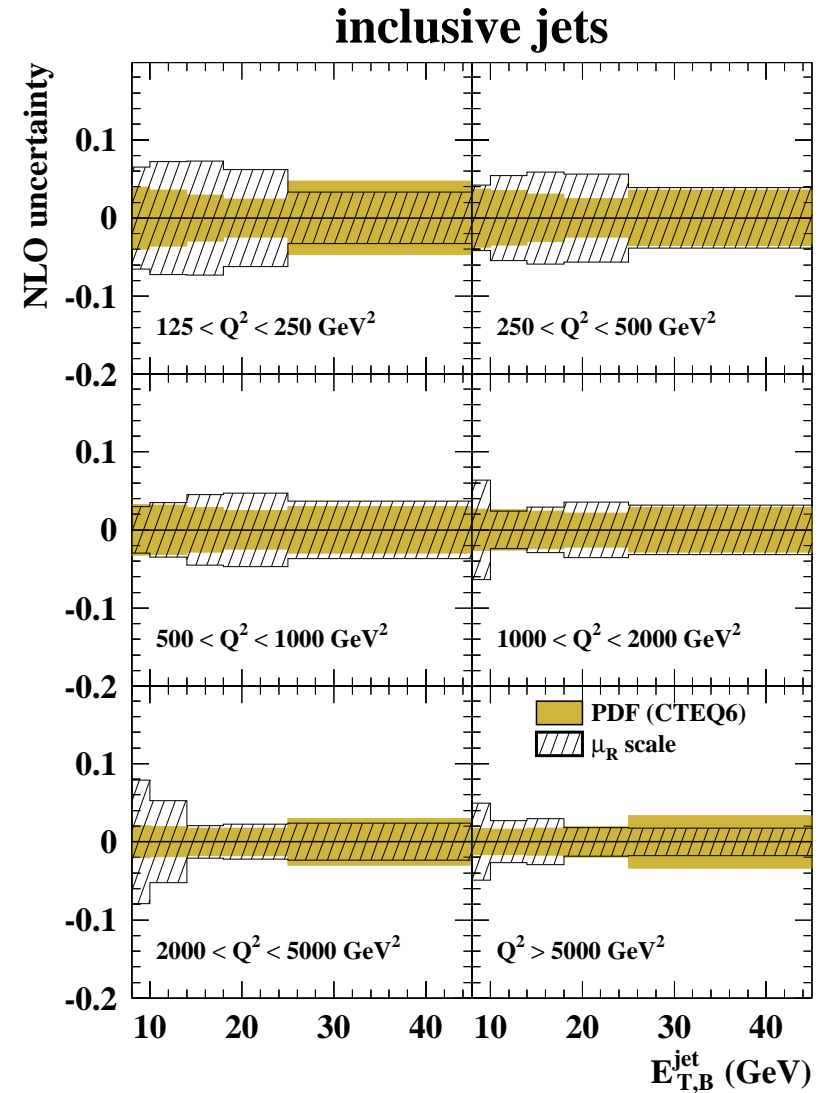
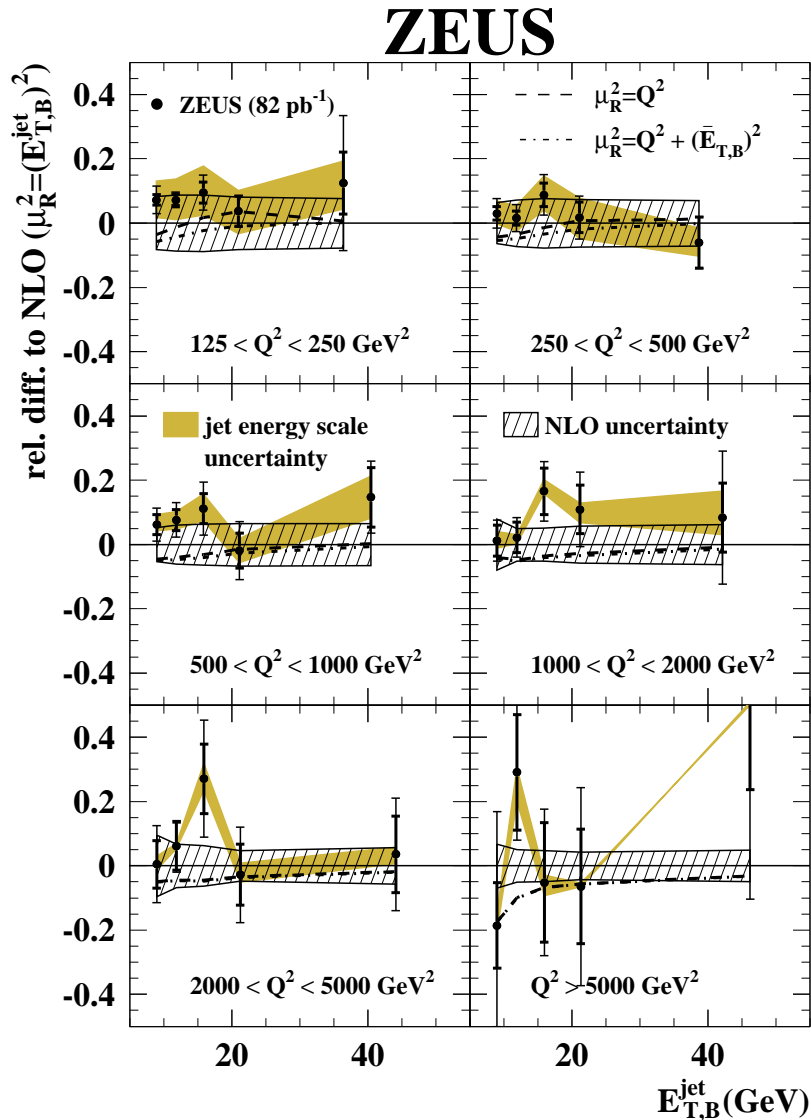
- E-scale unc. $\pm 1\%$ for $E_{T,L}^{jet} > 10 \text{ GeV}$
- E-scale unc. in cross sections $\pm 5\%$

- The dependence of $E_{T,B}^{jet}$ with Q^2 becomes **less steep** as Q^2 increases



INCLUSIVE JETS AND DIJETS IN NC DIS AT HIGH Q^2 (ZEUS)

- Comparison of $d\sigma/dE_{T,B}^{jet}$ in regions of Q^2 with NLO predictions
- PDF unc contribute most → data can help constrain PDFs in global fits



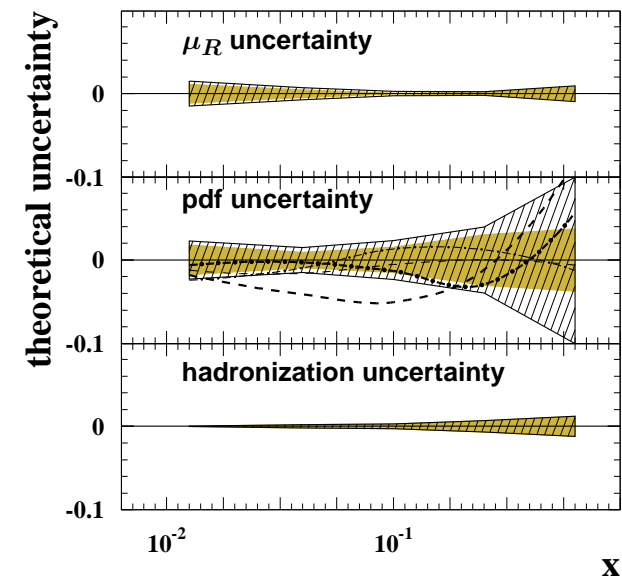
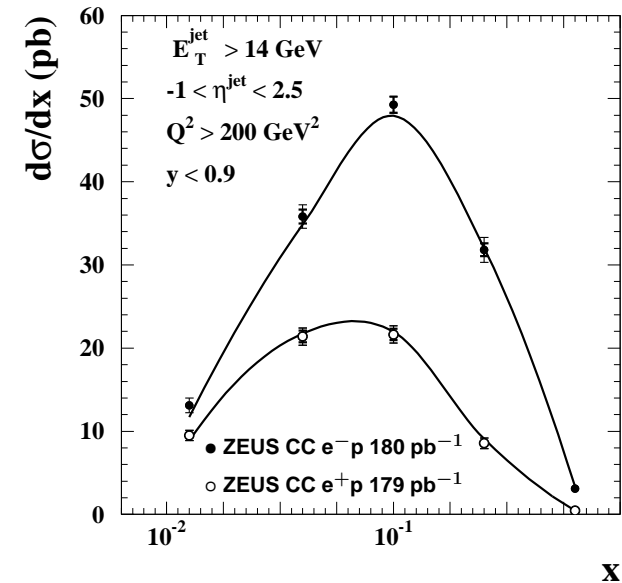
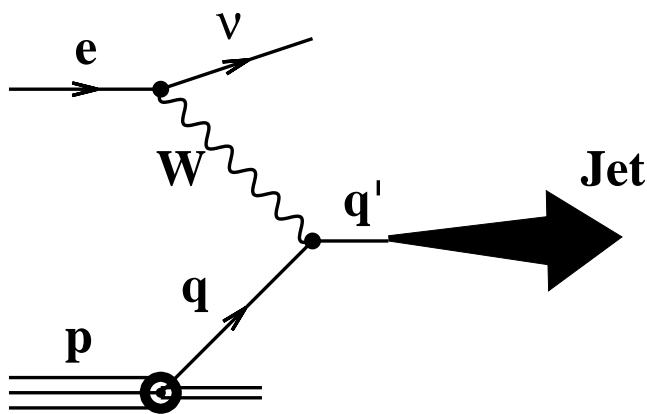
Inclusive jets in charged current DIS with HERA II data (ZEUS)

- Measurements of polarized and unpolarized differential cross sections with HERA II

$$\rightarrow \mathcal{L} = 360 \text{ pb}^{-1}$$

- Good agreement found with SM over a wide range of Q^2 for $\frac{d\sigma}{dx_{Bj}}$, $\frac{d\sigma}{dQ^2}$, $\frac{d\sigma}{dE_T}$, and $\frac{d\sigma}{d\eta}$

- CC is sensitive to proton flavour content
 \rightarrow can help constrain further u, d PDF's



Determinations of $\alpha_s(M_Z)$ (H1)

- Inclusive-jet cross sections at high Q^2 have small theoretical and experimental uncertainties

→ extraction of $\alpha_s(M_Z)$

- Normalized cross section

In a given bin: $\frac{\#jets}{\#events}$

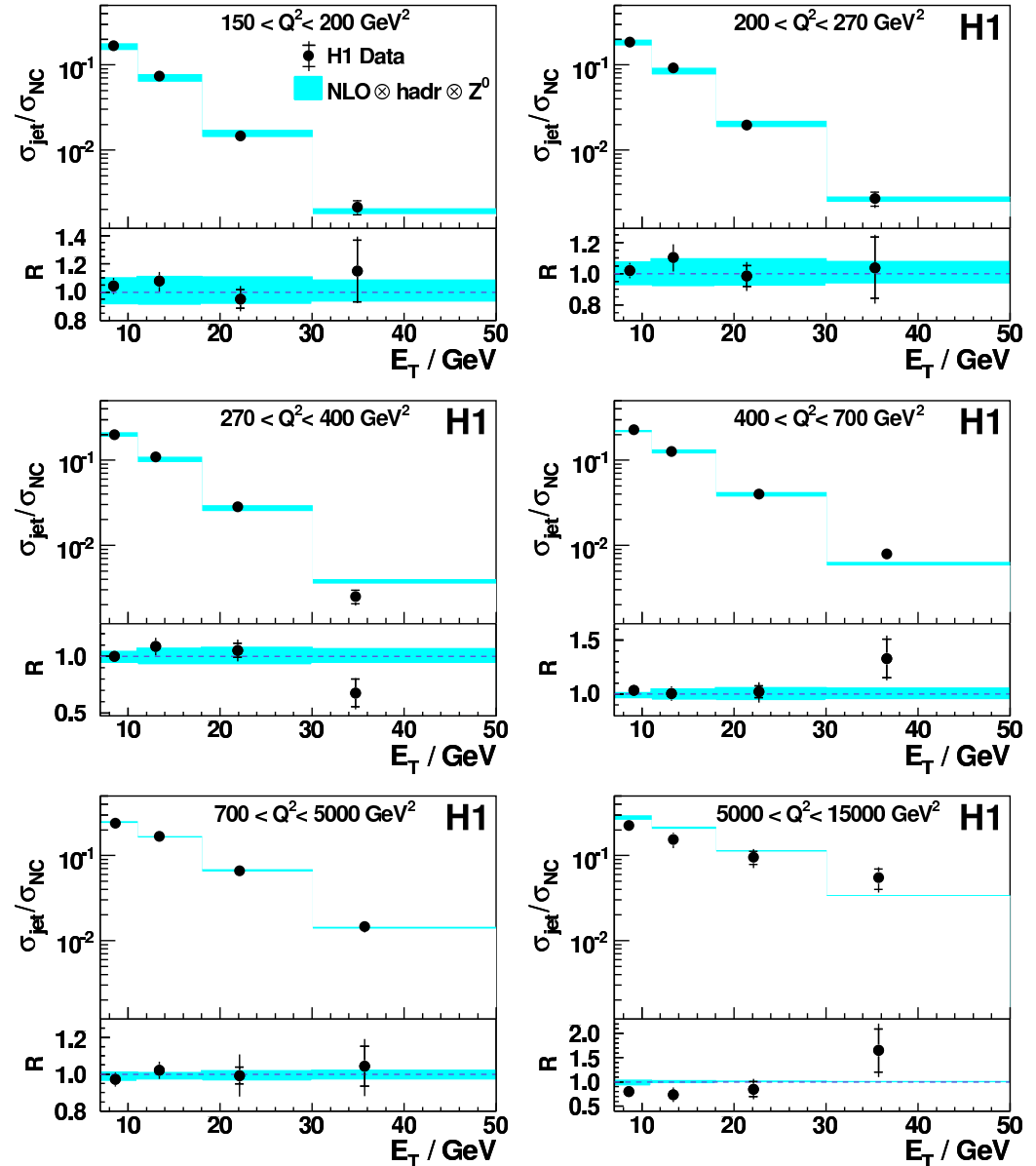
- Kinematic region defined by:

- $E_{T,B}^{jet} > 7 \text{ GeV}$
- $0.2 < y < 0.7$
- $Q^2 > 150 \text{ GeV}^2$
- $\mathcal{L} = 65 \text{ pb}^{-1}$

- NLO ingredients:

- $\alpha_s(M_Z) = 0.118$
- PDF = CTEQ6.5M
- $\mu_R = E_{T,B}^{jet}$ of each jet
- $\mu_F = Q$

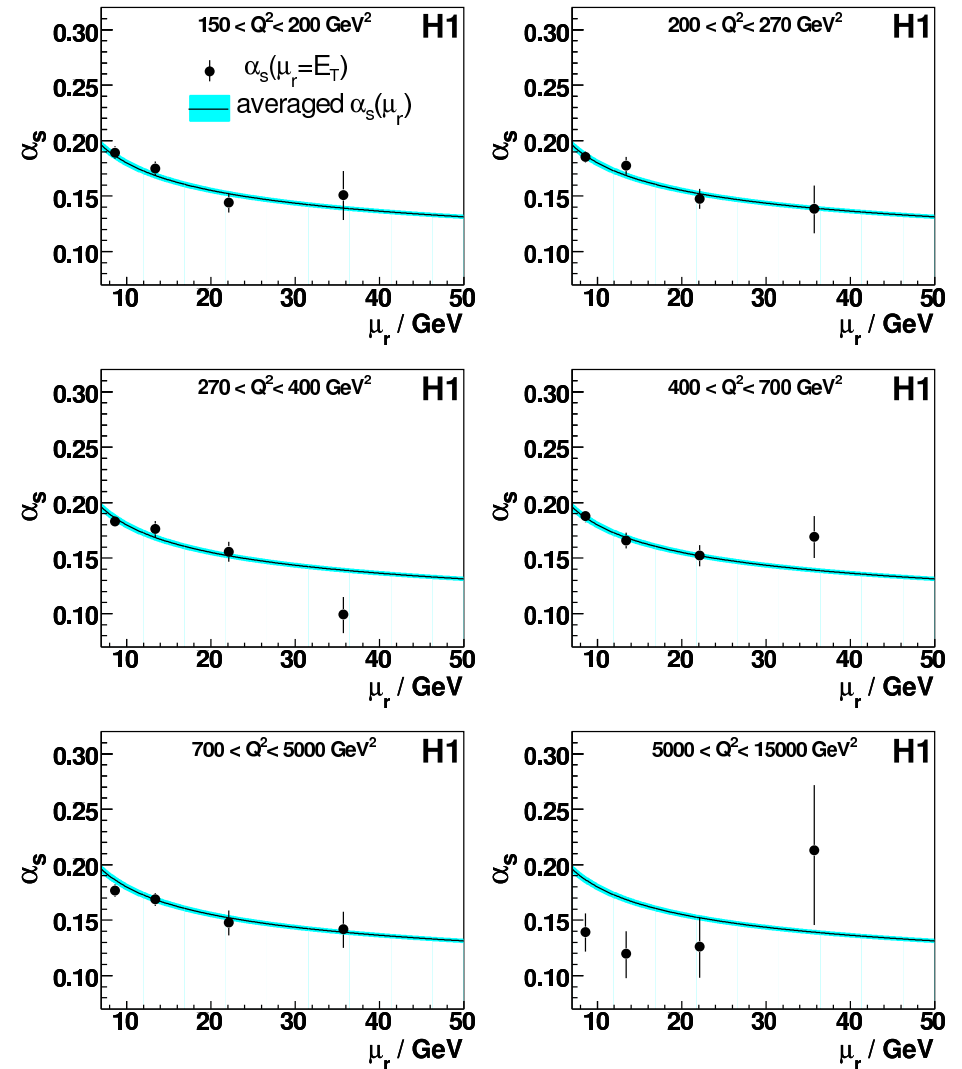
Normalised Inclusive Jet Cross Section



Determinations of $\alpha_s(E_{T,B}^{\text{jet}})$ (H1)

α_s from Norm. Inclusive Jet Cross Section

- The running of α_s has been tested in different regions of Q^2 using the normalized $d\sigma/dE_{T,B}^{\text{jet}}$
 - In normalized cross sections
 - PDF uncertainties largely cancel
 - LUMI uncertainty cancels completely
 - The 24 measurements were combined to yield a precise value of $\alpha_s(M_Z)$
- Total uncertainty → $\pm 4.3\%$



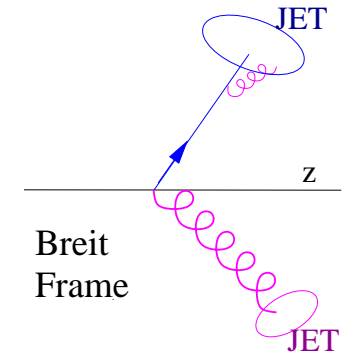
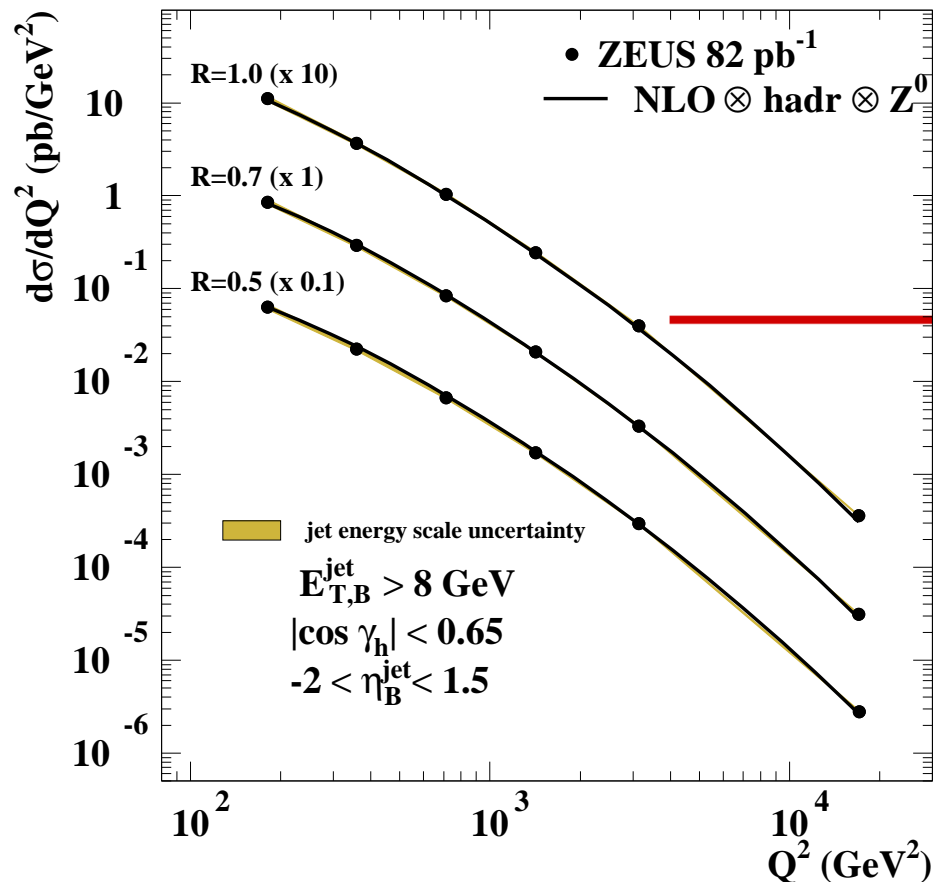
$$\rightarrow \alpha_s(M_Z) = 0.1193 \pm 0.0014(\text{exp.})_{-0.0030}^{+0.0047}(\text{th.}) \pm 0.0016(\text{pdf})$$

- For $Q^2 > 700 \text{ GeV}^2 \rightarrow \alpha_s(M_Z) = 0.1171 \pm 0.0023(\text{exp.})_{-0.0010}^{+0.0032}(\text{th.}) \pm 0.0010(\text{pdf})$ (lower theo. unc.)

Determinations of $\alpha_s(M_Z)$ and jet-radius dependence (ZEUS)

- Inclusive jet cross sections at high Q^2 used to study jet algorithm

→ DIS provides a well understood environment to study jet production dependence on R → LHC particle searches



- k_T clustering algorithm in the Breit frame

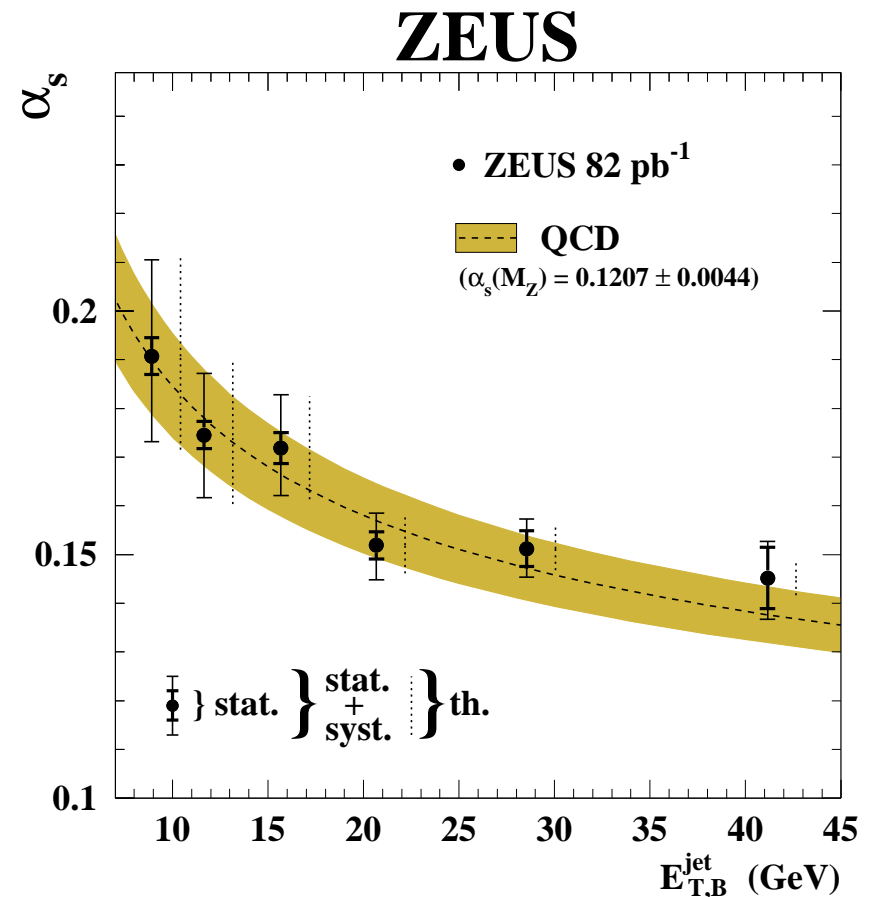
→ **R=1 used to extract $\alpha_s(M_Z)$**
 (R parameter also called 'd' in the literature)

- **Small theo unc ($\mu_R < \pm 7\%$)**
- **Exp unc dominated by energy scale ($< \pm 5\%$)**

Determinations of $\alpha_s(E_{T,B}^{\text{jet}})$ (ZEUS)

- The measured cross sections $d\sigma/dQ^2$ and $d\sigma/dE_{T,B}^{\text{jet}}$ were used to obtain **precise** determinations of $\alpha_s(M_Z)$
- The region $Q^2 > 500 \text{ GeV}^2$ yielded the value with the **smallest uncertainty**:
 - $\alpha_s(M_Z) = 0.1207 \pm 0.0014(\text{stat.})_{-0.0033}^{+0.0035}(\text{exp.})_{-0.0023}^{+0.0022}(\text{th.})$
 - **Total uncertainty $\pm 3.7\%$**

- The measured $d\sigma/dE_{T,B}^{\text{jet}}$ have been used to test the energy-scale dependence of α_s
- The running of α_s as predicted by pQCD is in agreement with the data
- **Asymptotic freedom of QCD!**



Combined HERA determination of $\alpha_s(M_Z)$ (H1, ZEUS)

- A simultaneous fit to H1 and ZEUS data yields most precise $\alpha_s(M_Z)$ so far
- 24 H1 data points from $\frac{d\sigma}{dQ^2 E_T}$ ($150 < Q^2 < 15000$) GeV²

- 6 ZEUS data points from $\frac{d\sigma}{dQ^2}$ ($125 < Q^2 < 10^5$)

- NLO QCD calculations

- pPDFs: MRST2001 sets

- $\mu_r = E_{T,B}^{jet}$, $\mu_F = Q$

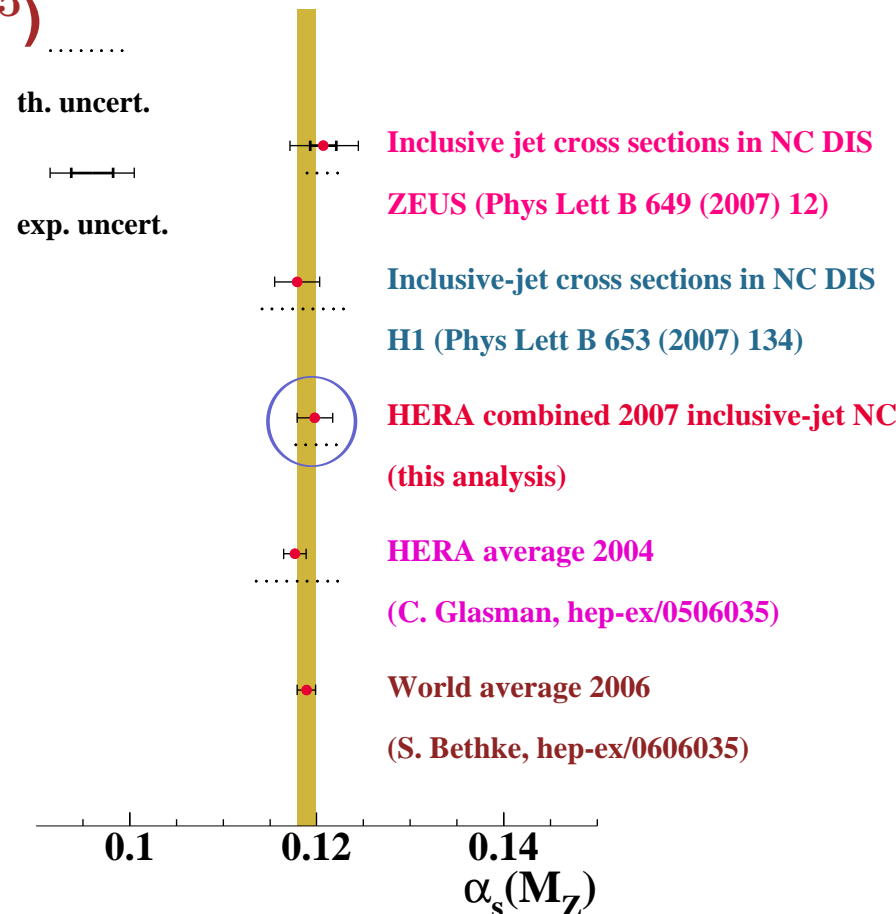
- Experimental uncertainties on $\alpha_s(M_Z)$

- 0.0019 (obtained using Hessian method)

- Theoretical uncertainties on $\alpha_s(M_Z)$

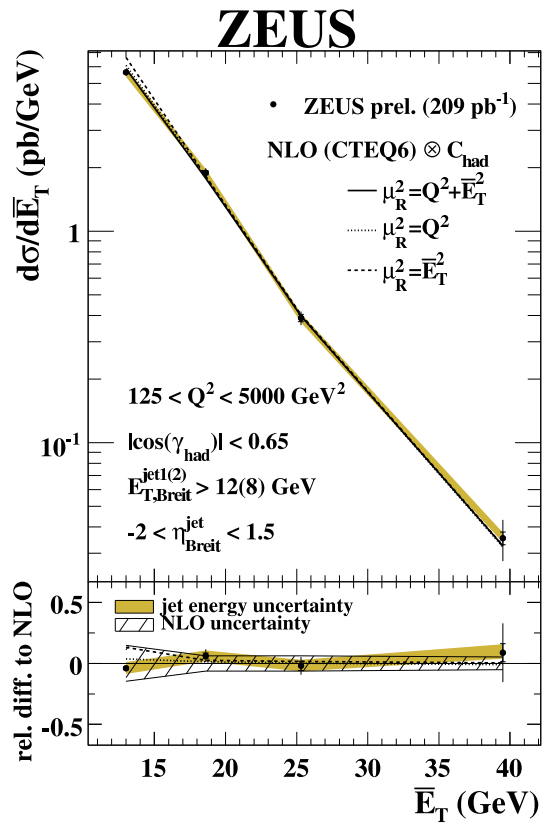
- terms beyond NLO: 0.0021 (using Jones, et al method JHEP 122003007)

COMBINED HERA $\alpha_s(M_Z)$ DETERMINATION



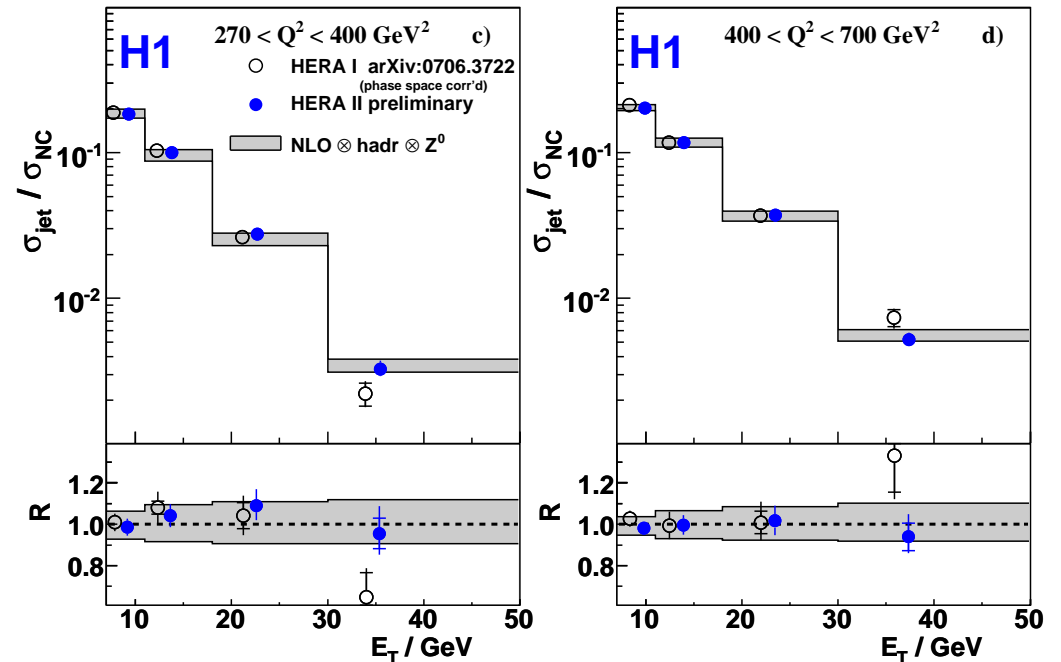
→ $\alpha_s(M_Z) = 0.1198 \pm 0.0019(\text{exp}) \pm 0.0026(\text{th}) \rightarrow (2.7\%)$

NEW HERA II MEASUREMENTS EMERGING (H1, ZEUS)



← **Measurements of dijet cross sections in NC DIS ($\mathcal{L} = 209 \text{ pb}^{-1}$)**

Measurements of inclusive jets in NC DIS ($\mathcal{L} = 320 \text{ pb}^{-1}$) →



Summary

- Jet production in DIS at HERA provides a good testing ground for QCD studies

→ New tests of pQCD predictions have been made

- Jet production at low Q^2 , hadronic activity using minijets.
- Study of the **R dependence** of inclusive-jet cross sections

→ New input for the determination of the proton PDFs

- Dijet and inclusive-jet cross sections will help constrain gluon PDF in mid-to-high x region

→ New results with HERA II data → more lumi!

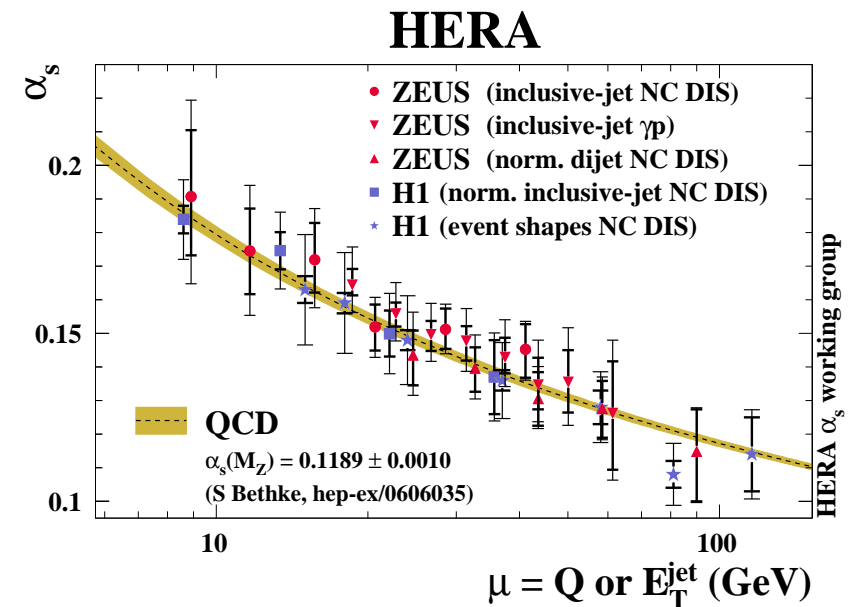
- CC DIS, Dijets and inclusive-jets

→ Improved $\alpha_s(M_Z)$ by H1 and ZEUS

- H1 → reduced experimental error
- ZEUS → reduced theoretical error

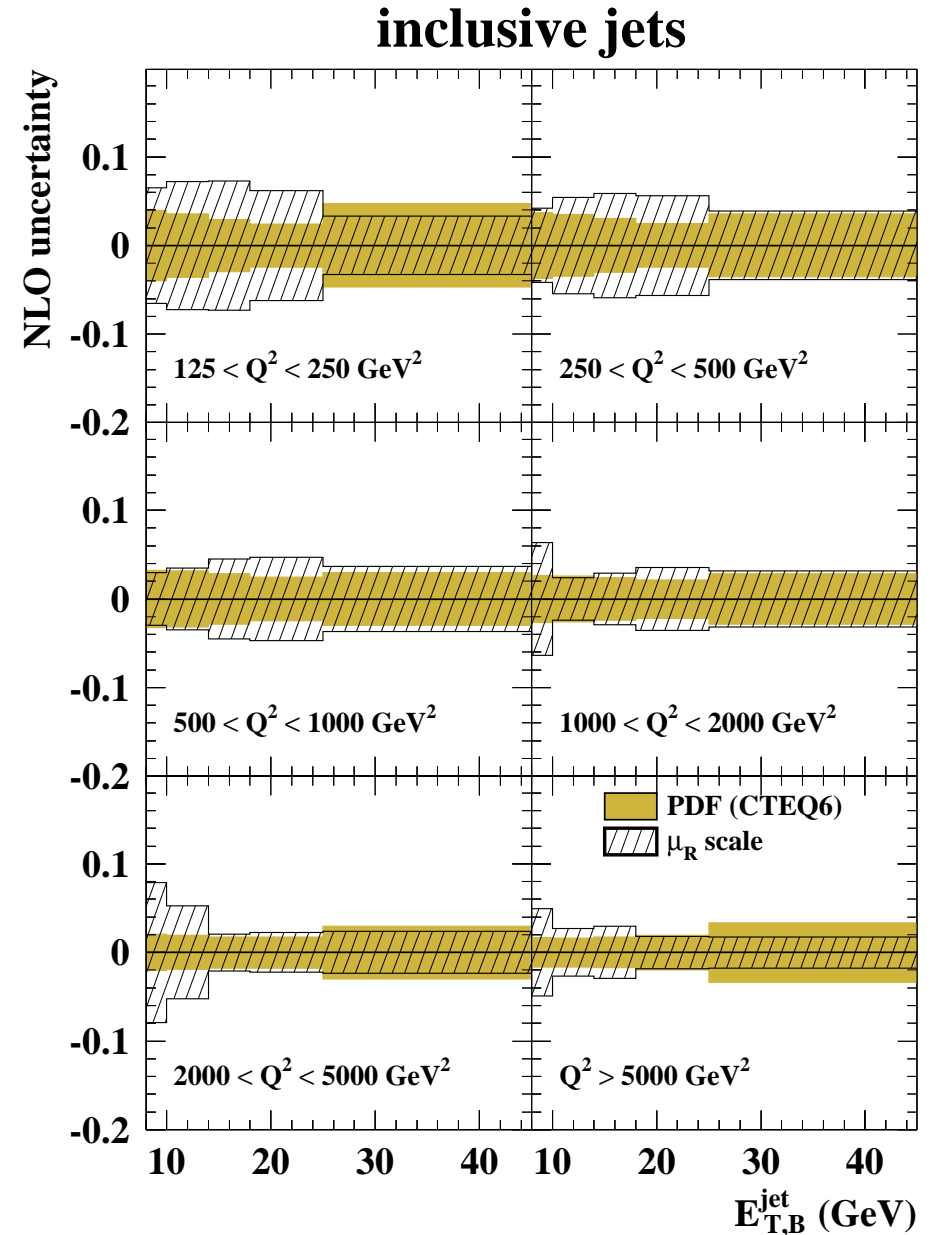
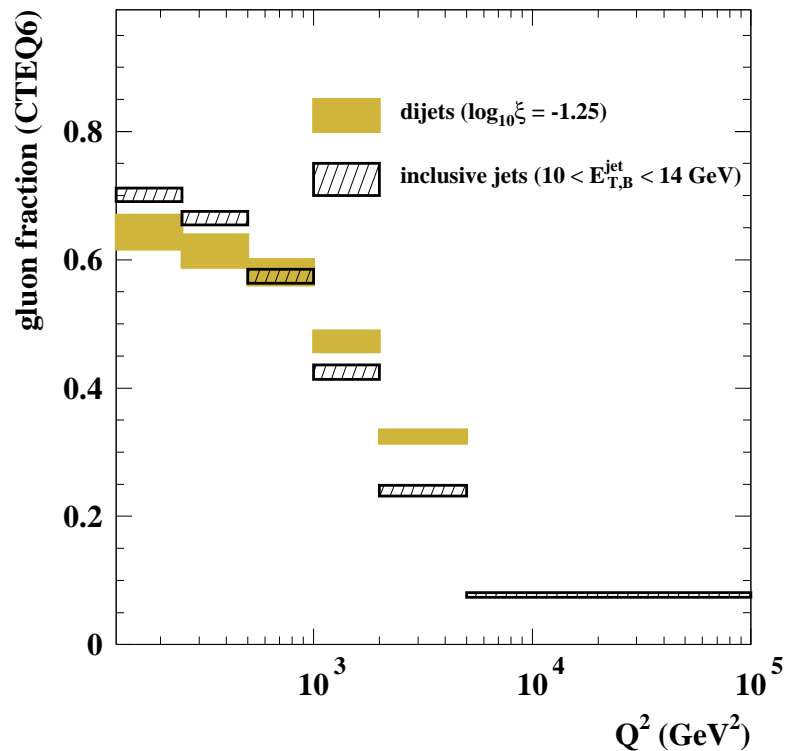
Combined value of α_s for HERA

→ $\alpha_s(M_Z) = 0.1198 \pm 0.0019(\text{exp}) \pm 0.0026(\text{th}) \rightarrow (2.7\%)$



BACK-UP SLIDE - PDF vs μ_R uncertainties in inclusive jets

- The uncertainty from that in the PDFs is large in comparison to the precision of the inclusive-jet and dijet measurements → will constrain gluon PDF further
- There is a substantial contribution from gluon initiated events to the dijet and inclusive-jet cross section



BACK-UP SLIDE - Extraction of $\alpha_s(M_Z)$ (ZEUS method)

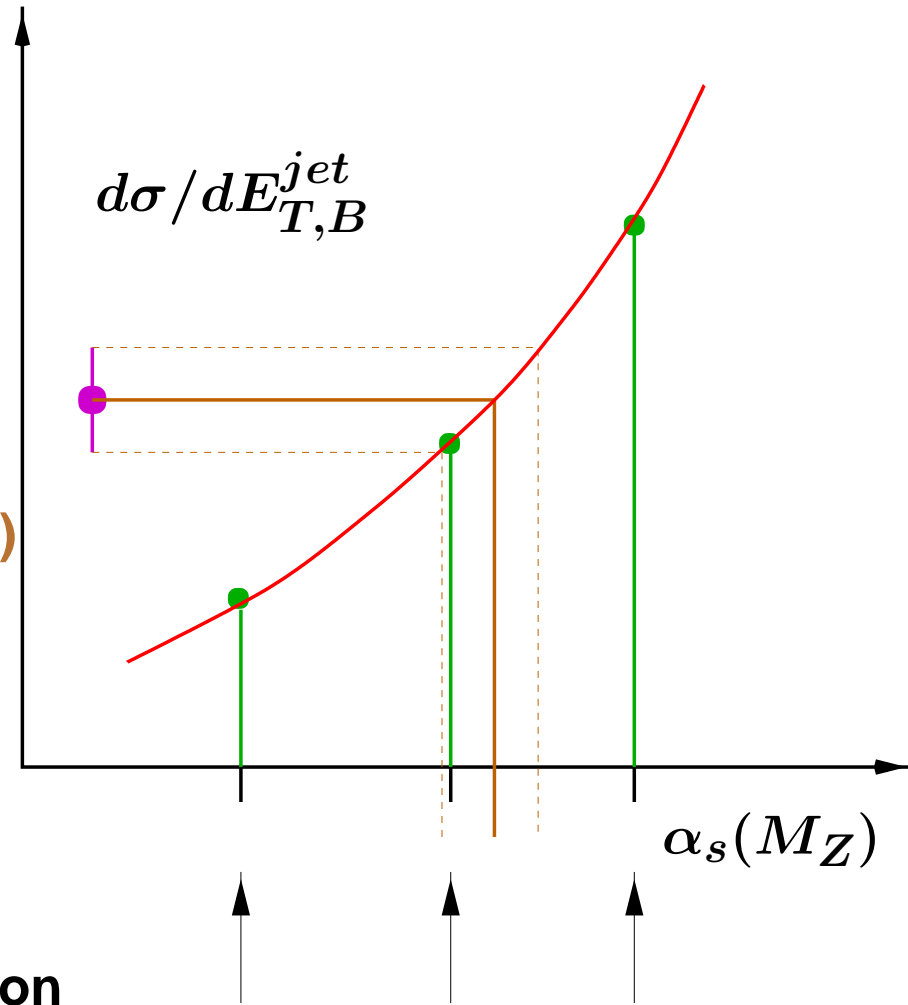
- Method for the determination of $\alpha_s(M_Z)$:

- An NLO cross section is calculated assuming different values of $\alpha_s(M_Z)$ in the PDFs

- Dependence of cross section (e.g. $d\sigma/dE_{T,B}^{jet}$) on $\alpha_s(M_Z)$ is parametrised according to:

$$[d\sigma/dE_{T,B}^{jet}(\alpha_s(M_Z))] = A_1^i \alpha_s(M_Z) + A_2^i \alpha_s^2(M_Z)$$

- $\alpha_s(M_Z)$ value given by measured cross section



NLO calculations with different $\alpha_s(M_Z)$