HEP 2007
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High Energy Physics
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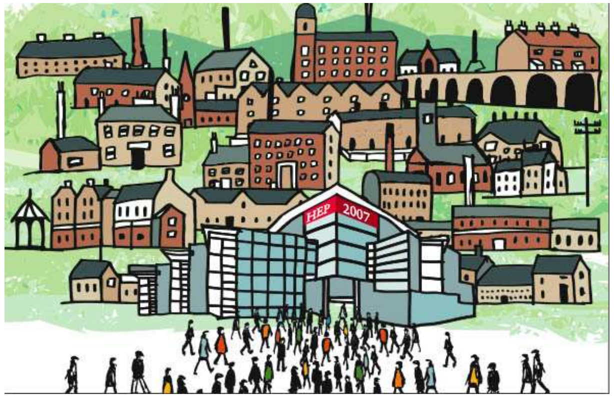

Precision measurements of α_s at HERA

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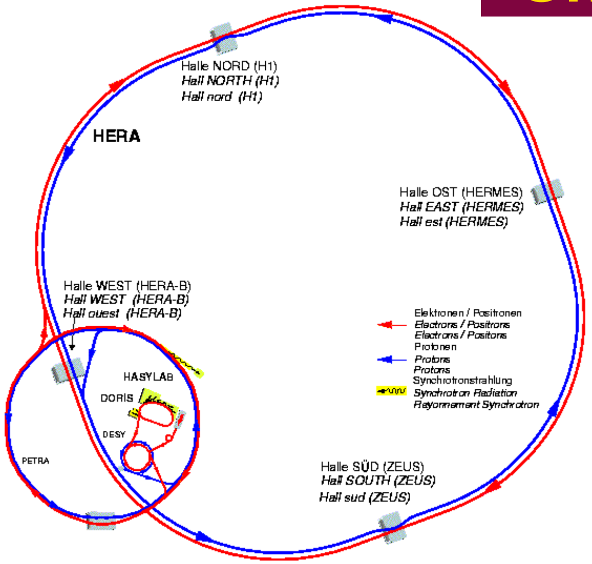
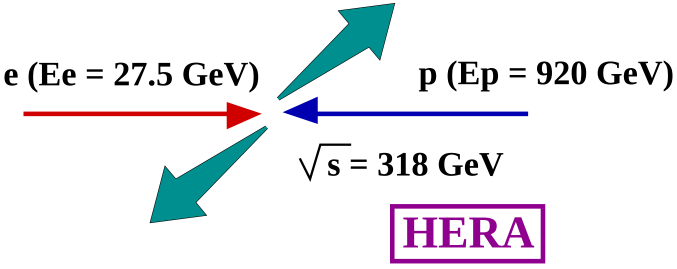
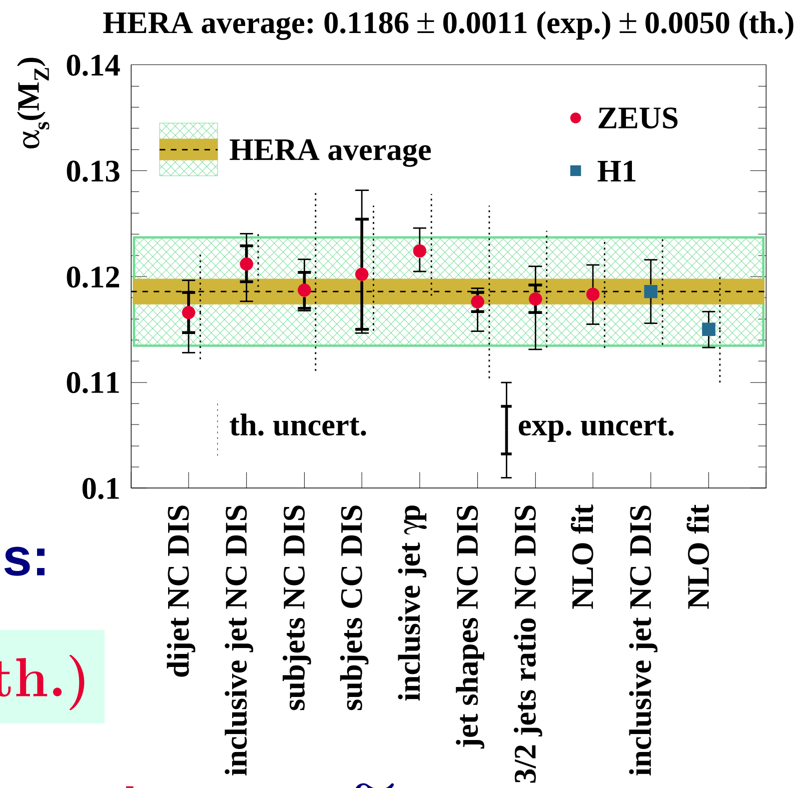


HERA α_s Working Group
H1 and ZEUS
Collaborations



The strong coupling constant α_s

- The strong coupling constant, α_s, is one of the fundamental parameters of QCD
- However, its value is not predicted by the theory and must be determined from experiment
- The success of perturbative QCD lies on precise and consistent determinations of α_s from diverse phenomena (eg τ decays, event shapes, Z decays ...)



- There is a wealth of precise determinations of α_s at HERA from a variety of observables (jets, structure functions, jet substructure...)
- The $\alpha_s(M_Z)$ values are in good agreement with each other and with the world average
- HERA average obtained from these determinations:

$$\rightarrow \overline{\alpha_s(M_Z)} = 0.1186 \pm 0.0011\ (\text{exp.}) \pm 0.0050\ (\text{th.})$$

experimental uncertainty: $\sim 0.9\%$; theoretical uncertainty: $\sim 4\%$

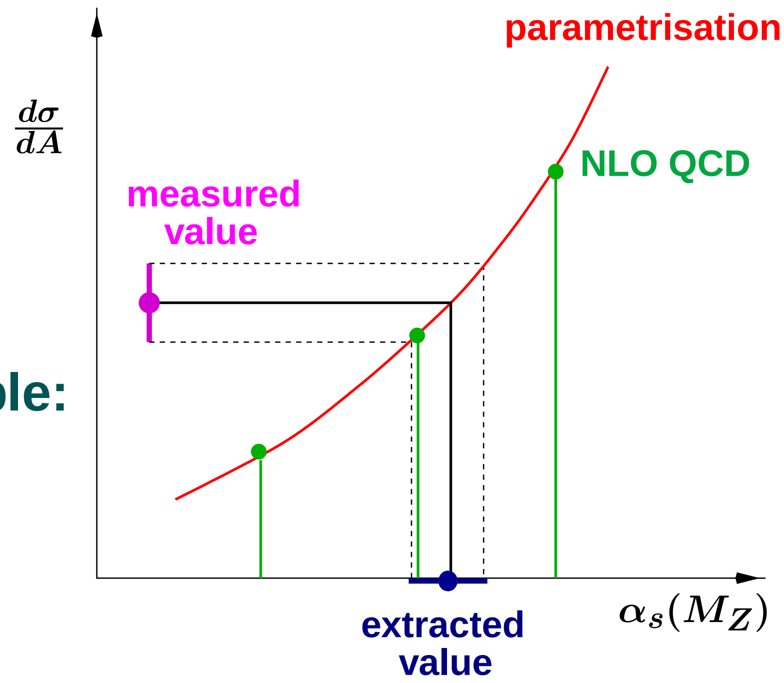
C Glasman, hep-ex/0506035

The method to determine α_s from jet observables

- The procedure to determine α_s from jet observables used by ZEUS is based on the α_s dependence of the pQCD calculations, taking into account the correlation with the PDFs:
  - perform NLO calculations using different sets of proton PDFs
  - use as input in each calculation the value of $\alpha_s(M_Z)$ assumed in each PDF set
  - parametrise the α_s dependence of the observable:

$$A(\alpha_s(M_Z)) = A_i^i\,\alpha_s(M_Z) + A_2^i\,\alpha_s(M_Z)^2$$

  - determine $\alpha_s(M_Z)$ from the measured value using the NLO parametrisation



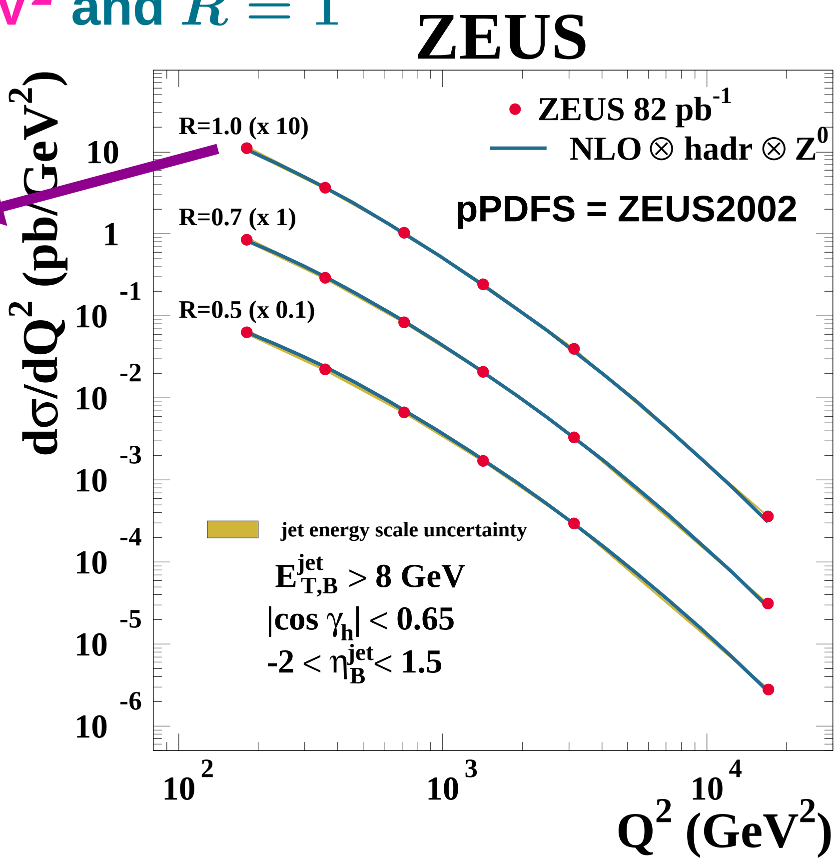
- This procedure handles correctly the complete α_s-dependence of the NLO calculations (explicit dependence in the partonic cross section and implicit dependence from the PDFs) in the fit, while preserving the correlation between α_s and the PDFs
- Similar method used by H1

$\alpha_s(M_Z)$ from jet cross sections

Inclusive-jet cross section in NC DIS

- From the measured $d\sigma/dQ^2$ for $Q^2 > 500$ GeV^2 and $R = 1$ a value of $\alpha_s(M_Z)$ has been extracted:

$$\alpha_s(M_Z) = 0.1207 \pm 0.0014\ (\text{stat.})\ {}^{+0.0035}_{-0.0033}\ (\text{exp.})\ {}^{+0.0022}_{-0.0023}\ (\text{th.})$$



- Experimental uncertainties:
  - $\longrightarrow$ dominated by jet energy scale uncertainty:

$$\Delta\alpha_s/\alpha_s = \pm 2\%$$

- Theoretical uncertainties:
  - $\longrightarrow$ terms beyond NLO: $\Delta\alpha_s/\alpha_s = \pm 1.5\%$
  - $\longrightarrow$ uncertainties from pPDFs: $\Delta\alpha_s/\alpha_s = \pm 0.7\%$
  - $\longrightarrow$ hadronisation corrections: $\Delta\alpha_s/\alpha_s = \pm 0.8\%$
  - $\longrightarrow$ μ_F uncertainty: negligible

$\longrightarrow$ $\alpha_s(M_Z)$ from inclusive jet cross sections in the Breit frame: very precise determination at HERA (total uncertainty: $\sim 3.6\%$; theoretical uncertainty: $\sim 1.9\%$)

See M Gouzevitch's talk

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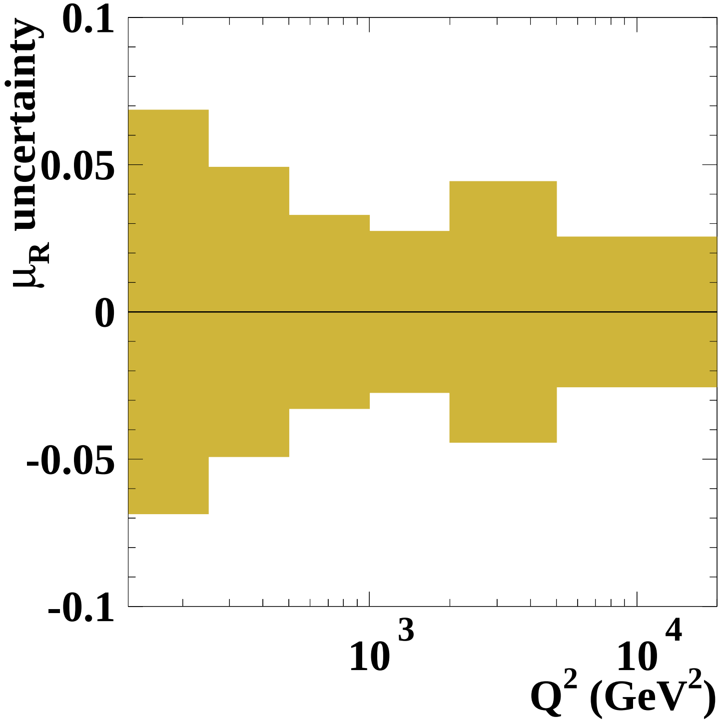
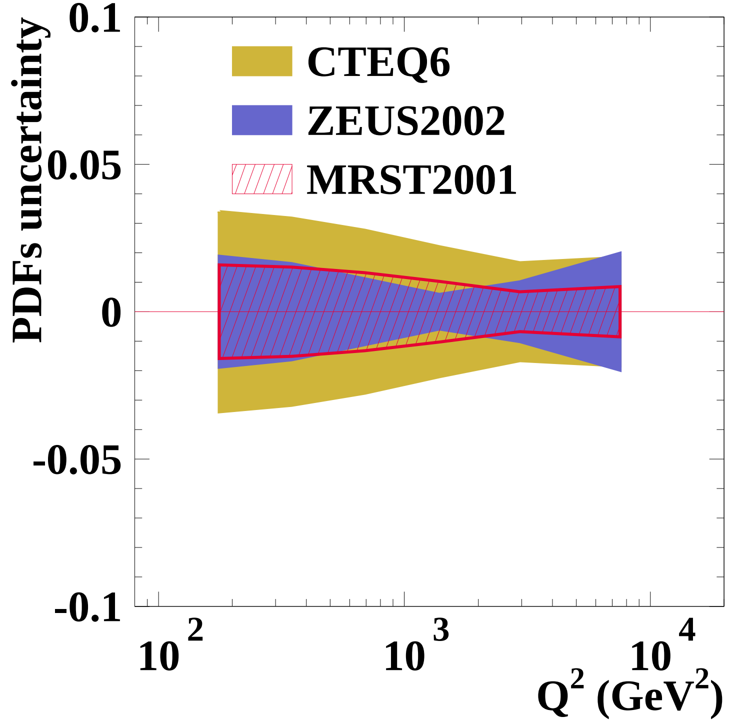
Theoretical uncertainties on $\alpha_s(M_Z)$



$\longrightarrow$ Uncertainty of inclusive-jet cross section from terms beyond NLO as a function of Q^2 estimated by varying μ_R by factors 2 and 0.5

- PDF uncertainty of inclusive-jet cross section as a function of Q^2 for various PDF sets $\longrightarrow$



- PDF uncertainty on $\alpha_s(M_Z)$:

ZEUS2002-RT $\longrightarrow \pm 0.7\%$

MRST-2001 $\longrightarrow \pm 0.7\%$

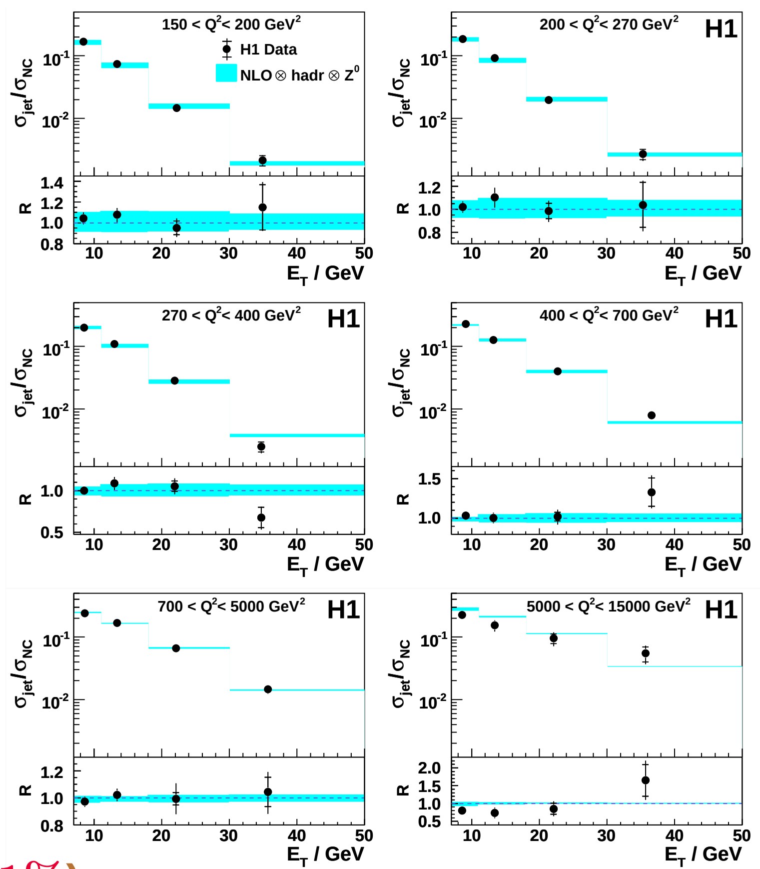
CTEQ6 $\longrightarrow \pm 1.6\%$

$\alpha_s(M_Z)$ from jet cross sections

Normalised inclusive-jet cross section in NC DIS

- From the measured normalised $1/\sigma_{\rm NC}\ d^2\sigma_{\rm jets}/dE^{\rm jet}_{T,{\rm B}}dQ^2$ for $150 < Q^2 < 15000$ GeV^2 a value of $\alpha_s(M_Z)$ has been extracted:

Normalised Inclusive Jet Cross Section



$$\alpha_s(M_Z) = 0.1193 \pm 0.0014\ ({\rm exp.})^{+0.0049}_{-0.0034}\ ({\rm th.})$$

- Experimental uncertainties:
  - $\longrightarrow$ dominated by jet energy scale uncertainty and model dependence
- Theoretical uncertainties: pPDFS = CTEQ6.5
  - $\longrightarrow$ terms beyond NLO: dominant
  - $\longrightarrow$ uncertainties from pPDFs: small
  - $\longrightarrow$ uncertainties from μ_F: small
  - $\longrightarrow$ hadronisation corrections: negligible

$\longrightarrow$ $\alpha_s(M_Z)$ from normalised inclusive jet cross sections: very precise determination at HERA (total uncertainty: $\sim 4.3\%$; experimental uncertainty: $\sim 1.1\%$)

See M Gouzevitch's talk H1 Collab, DESY 07-073

$\alpha_s(M_Z)$ from jet cross sections

- $\alpha_s(M_Z)$ from the measured $d^2\sigma_{\rm jets}/dE^{\rm jet}_{T,{\rm B}}dQ^2$ for $150 < Q^2 < 15000$ GeV^2:

$$\alpha_s(M_Z) = 0.1179 \pm 0.0024\,({\rm exp.})^{+0.0052}_{-0.0032}\,({\rm th.}) \pm 0.0028\,({\rm pdf})$$

$\longrightarrow$ experimental, theoretical and PDFs uncertainties go up

$\alpha_s(M_Z)$ from the normalised $1/\sigma_{\rm NC}\; d^2\sigma_{\rm jets}/dE^{\rm jet}_{T,{\rm B}}dQ^2$ for $150 < Q^2 < 15000$ GeV^2:

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

- $\alpha_s(M_Z)$ from the measured normalised $1/\sigma_{\rm NC}\; d^2\sigma_{\rm jets}/dE^{\rm jet}_{T,{\rm B}}dQ^2$ for $700 < Q^2 < 5000$ GeV^2:

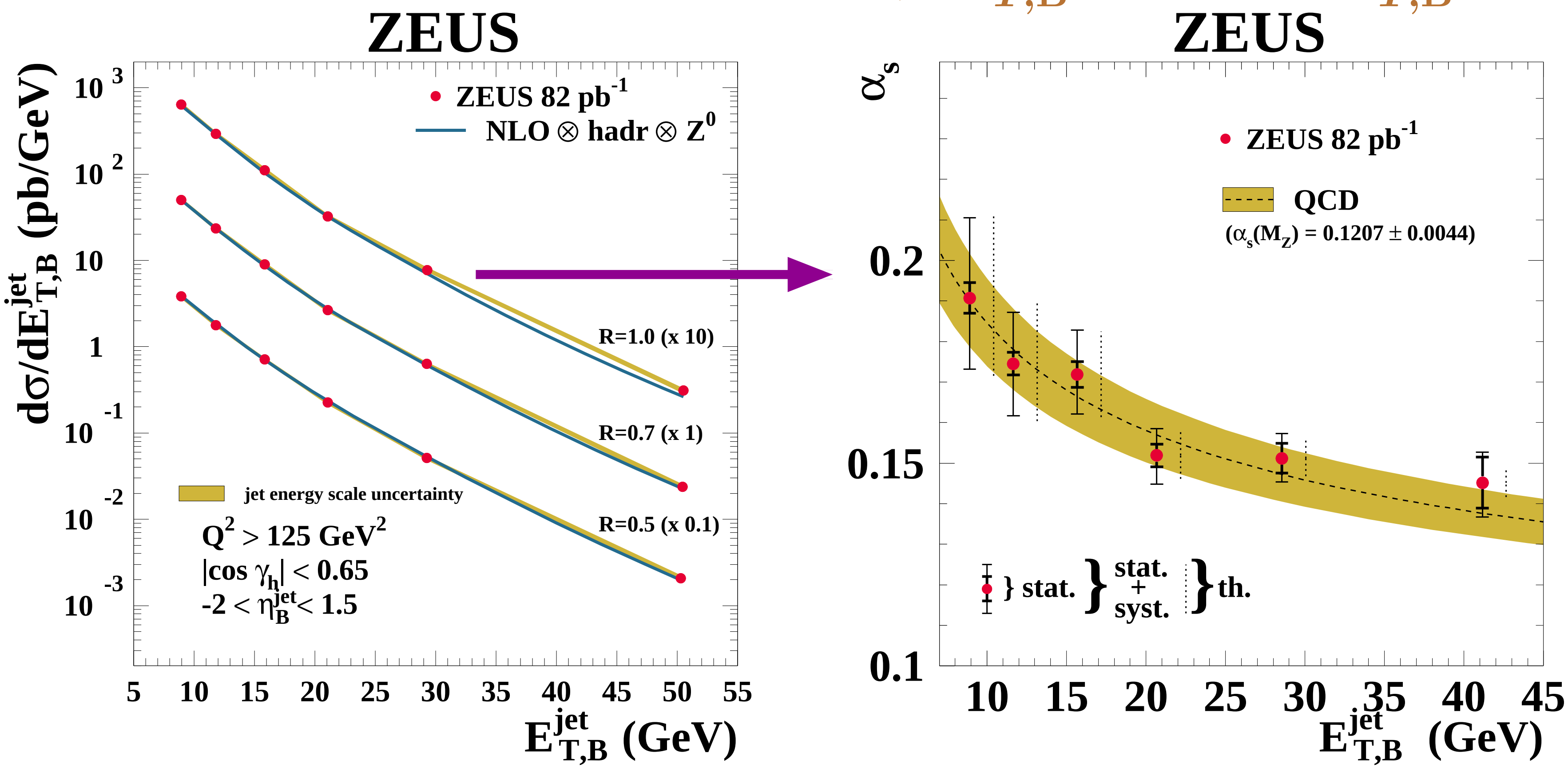
$$\alpha_s(M_Z) = 0.1171 \pm 0.0023\,({\rm exp.})^{+0.0032}_{-0.0010}\,({\rm th.}) \pm 0.0010\,({\rm pdf})$$

$\longrightarrow$ experimental uncertainty goes up, theoretical and PDFs uncertainties go down

Test of the energy-scale dependence of α_s

Inclusive-jet cross section in NC DIS

- The QCD prediction for the energy-scale dependence of the coupling was tested by determining α_s from the measured $d\sigma/dE_{T,\mathrm{B}}^{\mathrm{jet}}$ at different $E_{T,\mathrm{B}}^{\mathrm{jet}}$ values:



→ The results are in good agreement with the predicted running of α_s over a large range in $E_{T,\mathrm{B}}^{\mathrm{jet}}$

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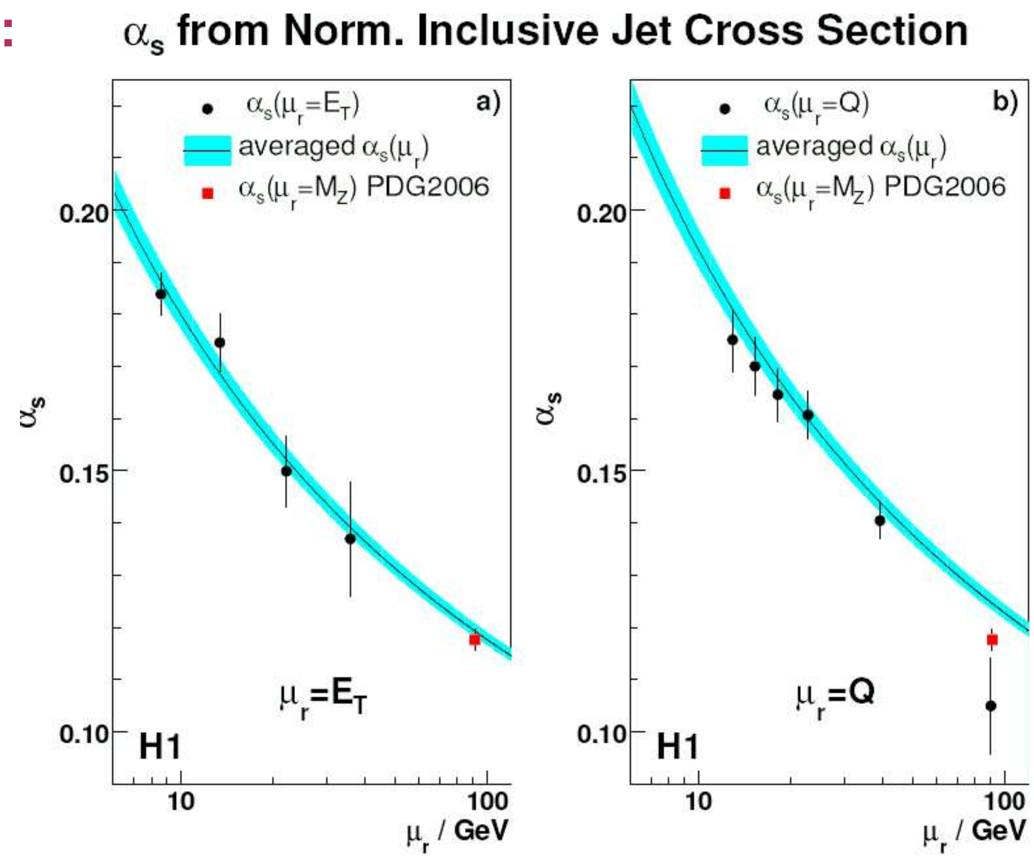
Test of the energy-scale dependence of α_s

Normalised inclusive-jet cross section in NC DIS

- The QCD prediction for the energy-scale dependence of the coupling was tested by determining α_s from the measured normalised cross sections at different $E_{T,\mathrm{B}}^{\mathrm{jet}}$ and Q values:



→ The results are in good agreement with the predicted running of α_s over a large range in $E_{T,\mathrm{B}}^{\mathrm{jet}}$ and Q

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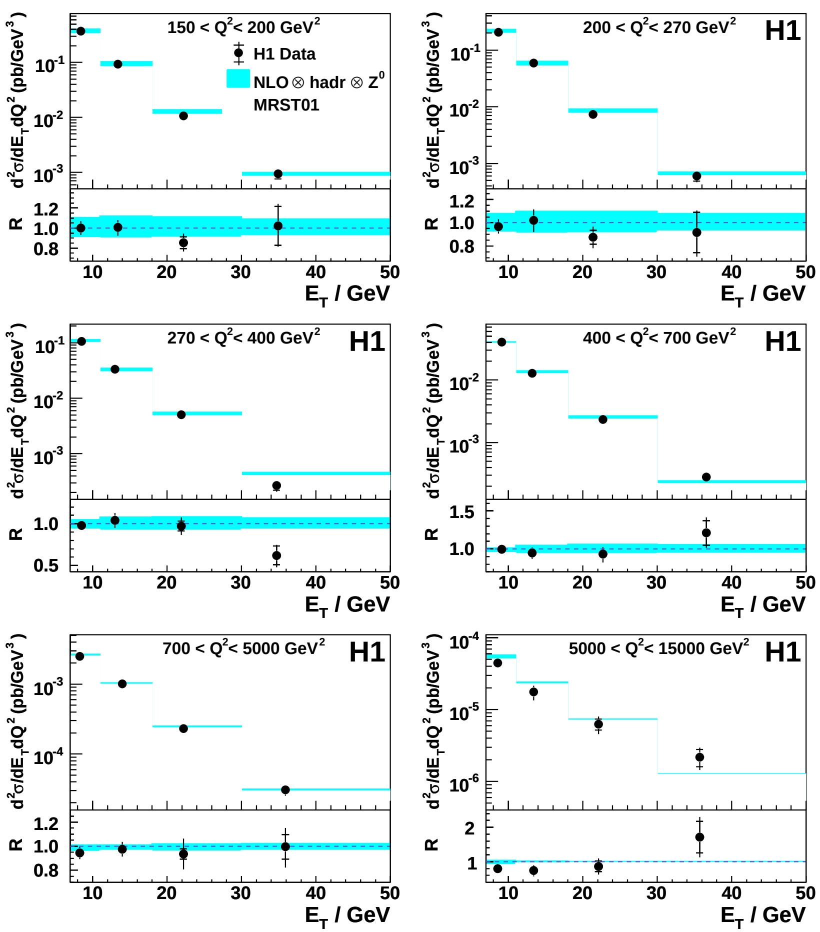
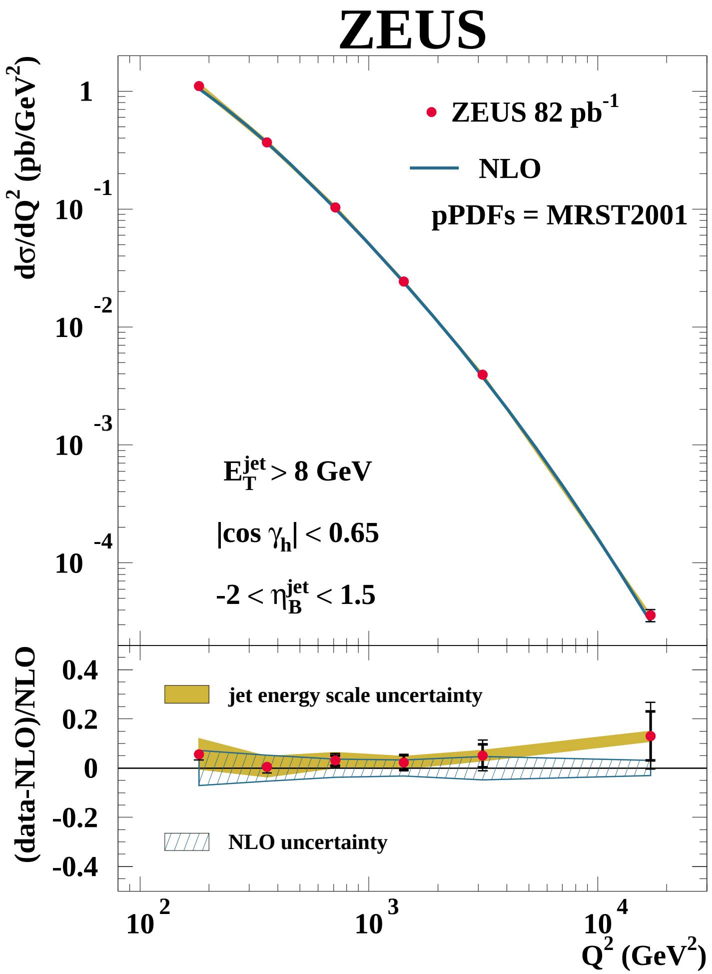
New HERA $\alpha_s(M_Z)$ combination

- **New $\alpha_s(M_Z)$ combination from inclusive-jet cross sections in NC DIS**
  - make a simultaneous fit to ZEUS and H1 data sets which yield the most precise $\alpha_s(M_Z)$ values (instead of combining $\alpha_s(M_Z)$ values)

Inclusive Jet Cross Section





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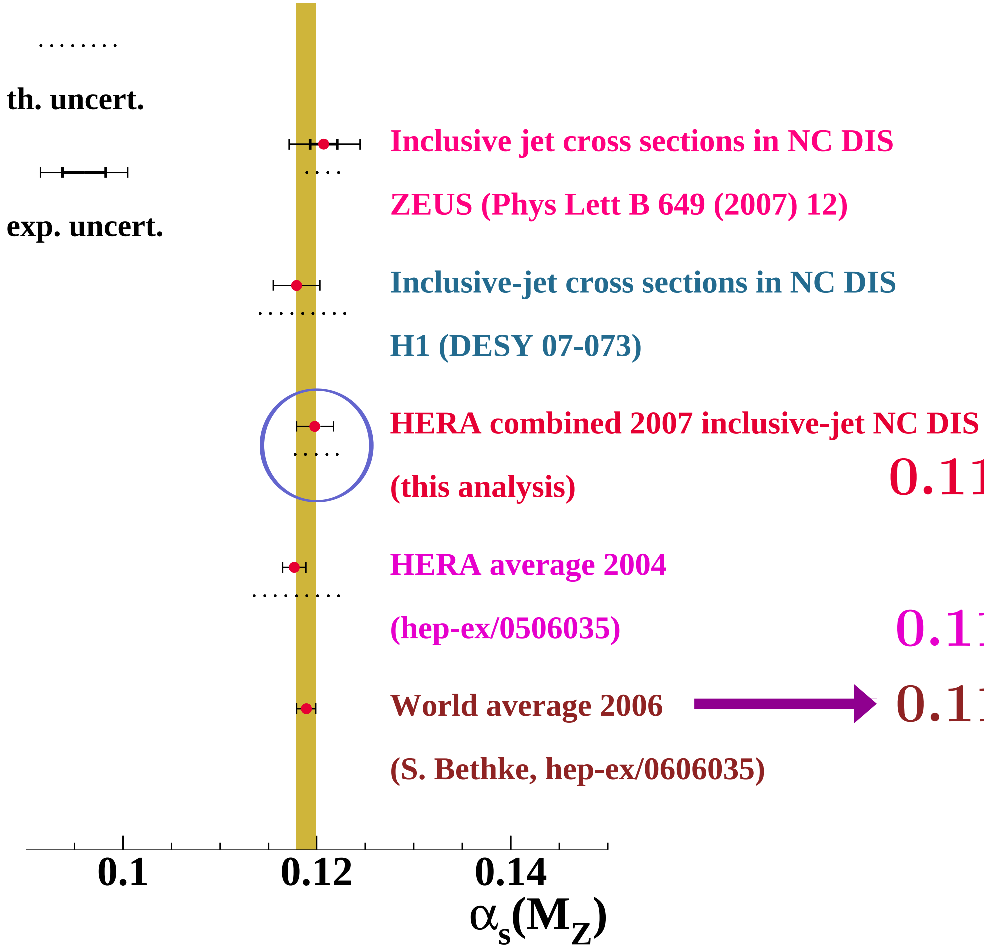
New HERA $\alpha_s(M_Z)$ combination

- **Fit to 30 measurements of inclusive-jet cross sections in NC DIS:**
  - $\longrightarrow$ **24 H1 data points from double-differential cross section** ($150 < Q^2 < 15000$ GeV^2)
  - $\longrightarrow$ **6 ZEUS data points from single-differential Q^2 cross section** ($125 < Q^2 < 10^5$ GeV^2)
- **NLO QCD calculations:**
  - $\longrightarrow$ **differential cross sections were calculated at NLO ($\mathcal{O}(\alpha_s^2)$) with:**
    - – **pPDFs: MRST2001 sets**
    - – **renormalisation scale: $\mu_R = E_{T,\mathrm{B}}^{\mathrm{jet}}$ of each jet**
    - – **factorisation scale: $\mu_F = Q$**
- **Experimental uncertainties on combined $\alpha_s(M_Z)$:**
  - $\longrightarrow$ **0.0019 (obtained using Hessian method; fit sources of systematic uncertainties, eg energy scale, luminosity, model dependence)**
- **Theoretical uncertainties on combined $\alpha_s(M_Z)$:**
  - $\longrightarrow$ **terms beyond NLO: 0.0021 (using Jones et al method, JHEP 122003007)**
  - $\longrightarrow$ **factorisation scale: 0.0010 (obtained by varying μ_F by factors 2 and 0.5 in the calculations)**
  - $\longrightarrow$ **pPDFs: 0.0010 (obtained by using 30 sets of MRST2001)**
  - $\longrightarrow$ **hadronisation: 0.0004 (obtained from different parton-shower models)**

HERA combined 2007 $\alpha_s(M_Z)$ value

- **HERA combined 2007 $\alpha_s(M_Z)$ value:**

$$\alpha_s(M_Z) = 0.1198 \pm 0.0019\ (\text{exp.}) \pm 0.0026\ (\text{th.})$$



Measurements consistent with each other and the world average

HERA combined 2007:

$0.1198 \pm 0.0019(\text{exp}) \pm 0.0026(\text{th})$ **(2.7%)**

HERA average 2004:

$0.1186 \pm 0.0011(\text{exp}) \pm 0.0050(\text{th})$ **(4.3%)**

World average 2006 → 0.1189 ± 0.0010 **(0.8%)**

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Test of the energy-scale dependence of α_s

- The QCD prediction for the energy-scale dependence of the coupling was tested by determining α_s at different scales

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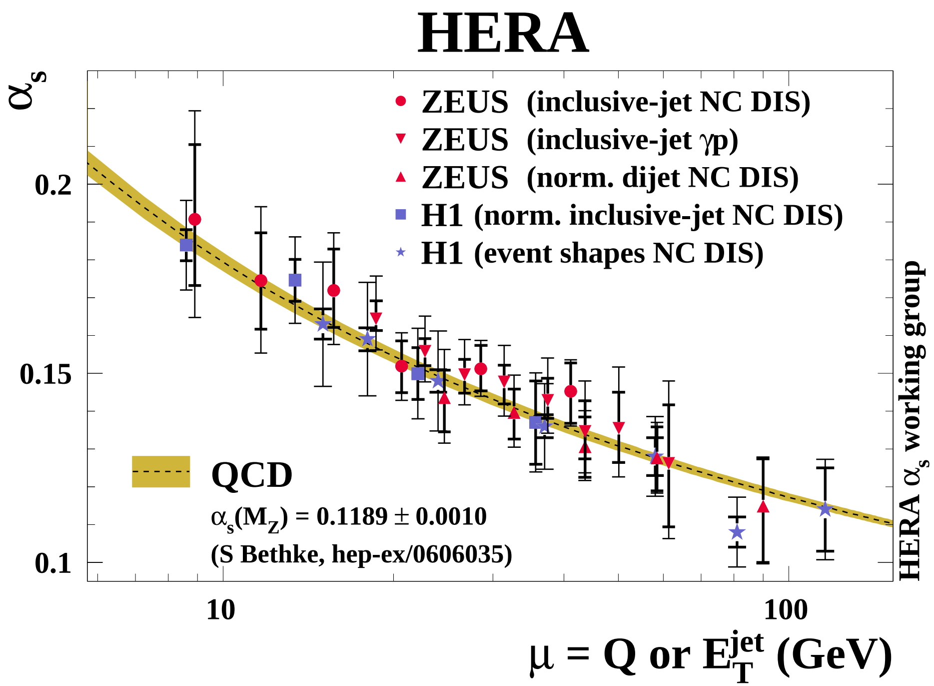

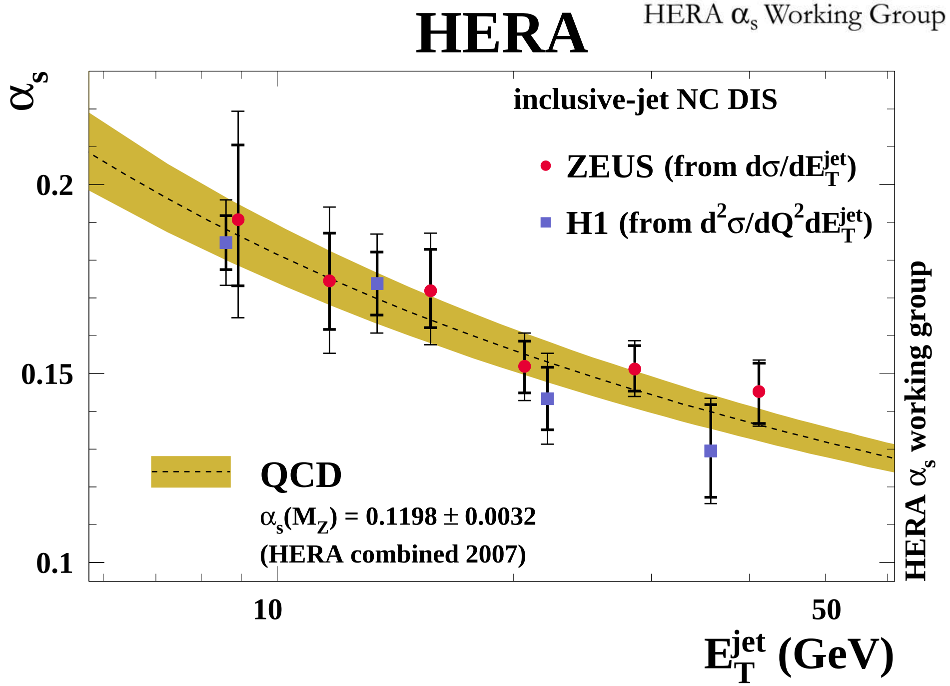

→ The results are in good agreement with the predicted running of α_s over a large range in the scale

→ **Observation of the running of α_s from HERA data alone**

Test of the energy-scale dependence of α_s

- **Comparison of HERA results with other experiments:**

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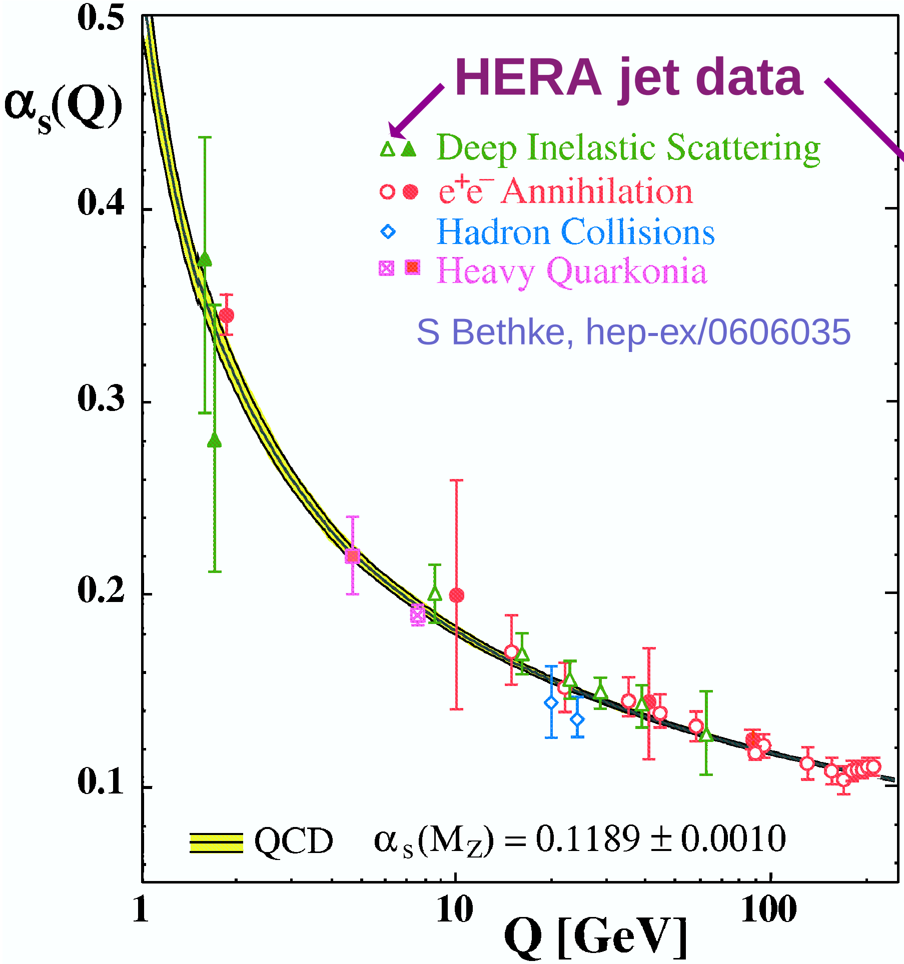
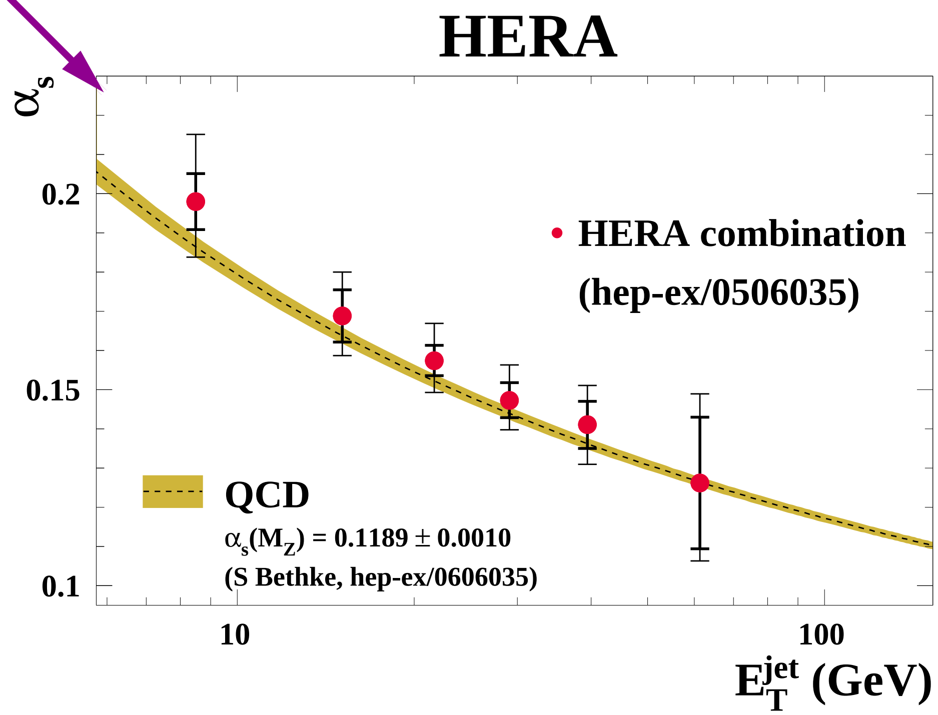




$\longrightarrow$ **HERA determinations consistent with other experiments**

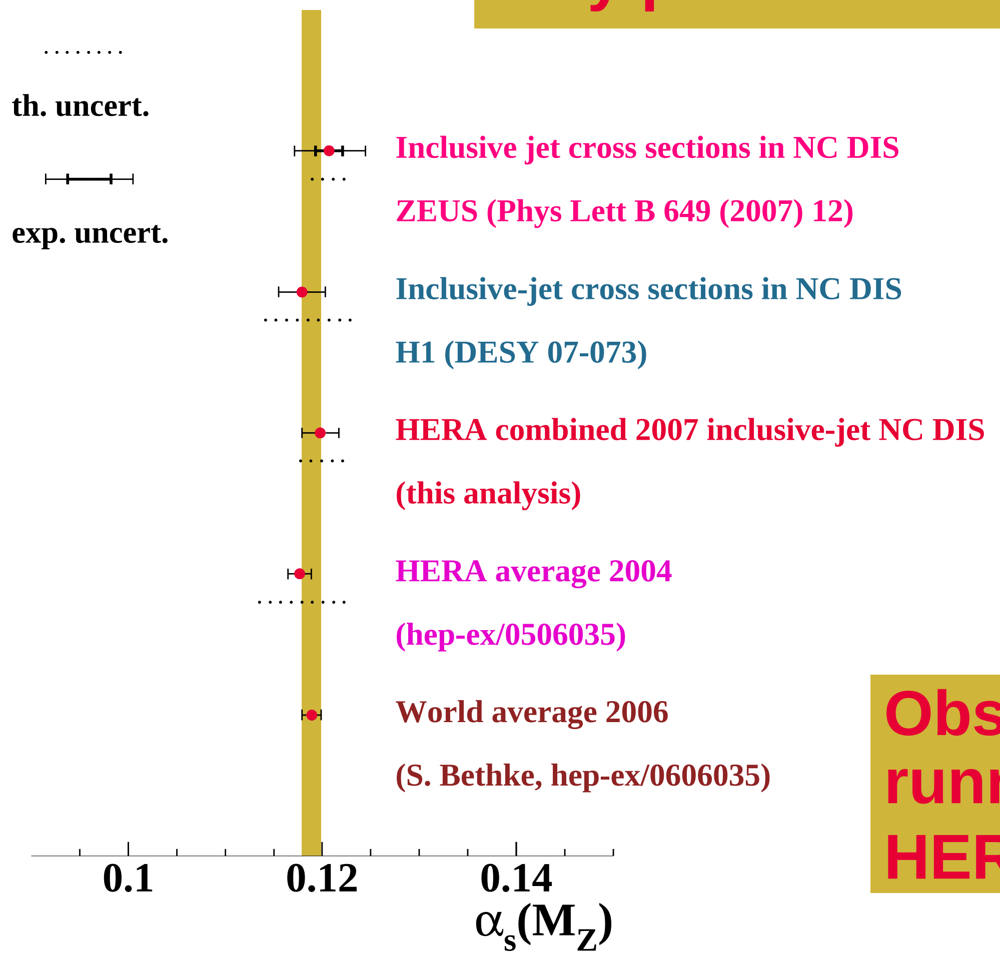
$\longrightarrow$ **Uncertainties of HERA determinations very competitive**

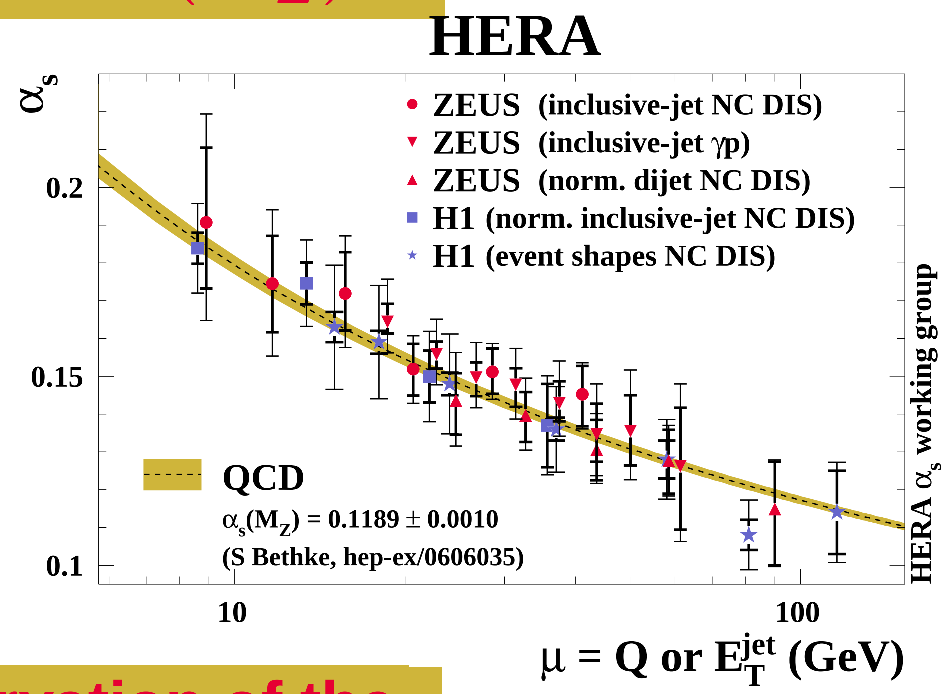
Summary

- **HERA combined 2007 $\alpha_s(M_Z)$ value:**

$$\alpha_s(M_Z) = 0.1198 \pm 0.0019\ (\text{exp.}) \pm 0.0026\ (\text{th.})$$

Very precise value of $\alpha_s(M_Z)$!!!





Observation of the running of α_s from HERA data alone !!!

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Back-up slides

Experimental uncertainties