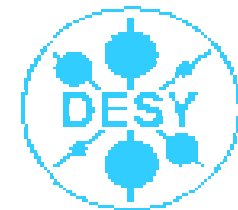# Hadronic Final States and QCD

JET CROSS SECTIONS AND α_s IN NC DIS AT ZEUS

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MOTIVATION + OUTLINE

¶ **Jets in NC DIS** (at high $Q^2 > 125$ GeV^2)

$$\sigma = \sum_{n} \alpha_S^n \cdot \sum_{a=q,\bar{q},g} f_{a/p} \otimes \hat{\sigma}_a^{(n)}$$

– General tests of pQCD (factorisation, perturbative expansion, PDF universality).
– High-precision measurements of strong coupling α_S.
– Valuable input to NLO QCD fits of the parton distributions.

¶ **News since DIS06 in Tsukuba**

– New data: First HERA-2 jet measurements available
  → dijets measurement in combined HERA-1+2 data set (210 pb^{-1}).
– New measurements in old data
  → dependence of inclusive jet cross section on jet radius, α_S extraction.
– HERA has finished high-energy running
  → Working on combined analyses of all data sets.

¶ **Outline**

– Data and MC samples, selections, theory predictions, uncertainties
– Inclusive-jet measurements and dependence on the jet radius,
– Dijet measurements,
– Measurements of α_S at ZEUS.

SAMPLES AND SELECTIONS

¶ **Samples and Theory**
- inclusive jets: 1998-2000 $e\pm$ (81.7 pb^{-1}).
- dijets: plus 2004/05 $e-$ (+127.6 pb^{-1}=209.3pb^{-1}).
- ARIADNE and LEPTO MC samples
- Theory: NLO QCD (DISENT), CTEQ6M PDFs.

¶ **Typical event selection**
- $|cos\gamma_{had}|<0.65$
- $Q^2 > 125$ GeV^2 dijets: $Q^2 < 5000$ GeV^2 → no Z^0.
- long.-inv. k_T cluster algo (inclusive mode) in Breit frame.
- $E_{T,jet} > 8$ GeV   dijets: $E_{T,jet1(2)} > 12(8)$ GeV.
- $-2 < \eta_{jet,Breit} < 1.5$

¶ **Uncertainties**
- statistical: HERA-1: at most ~8% for highest E_T, Q^2 bins, HERA-2: 1-5%.
- systematics dominated by jet energy scale (±1-3%) → typically 5-10%. Next important: model uncertainty in acceptance correction.
- theoretical: scale variations (higher order effects): typically 5-20%; other sources (α_S, PDFs, factorisation scale, hadronisation) mostly negligible.
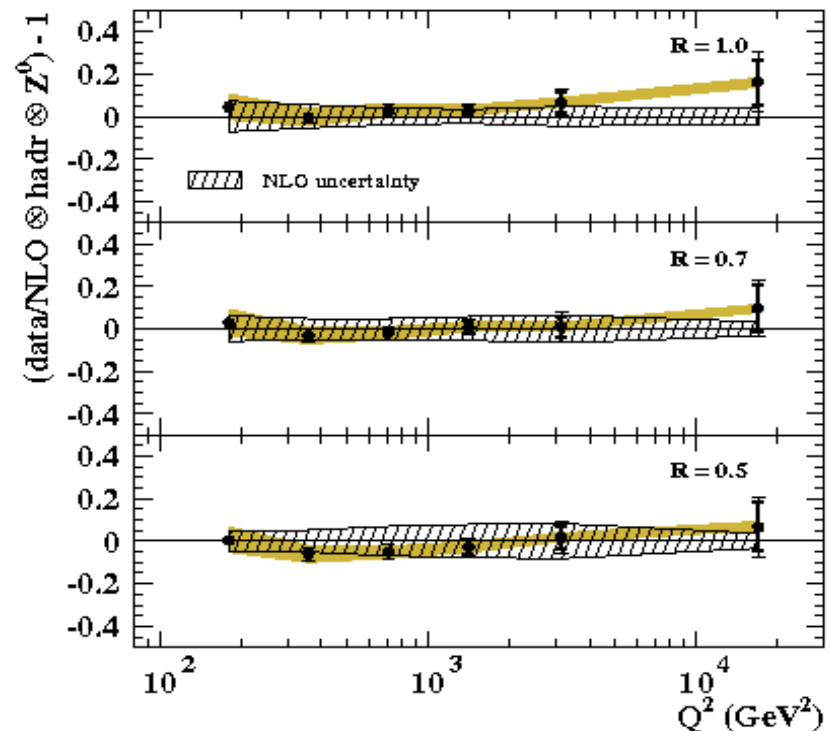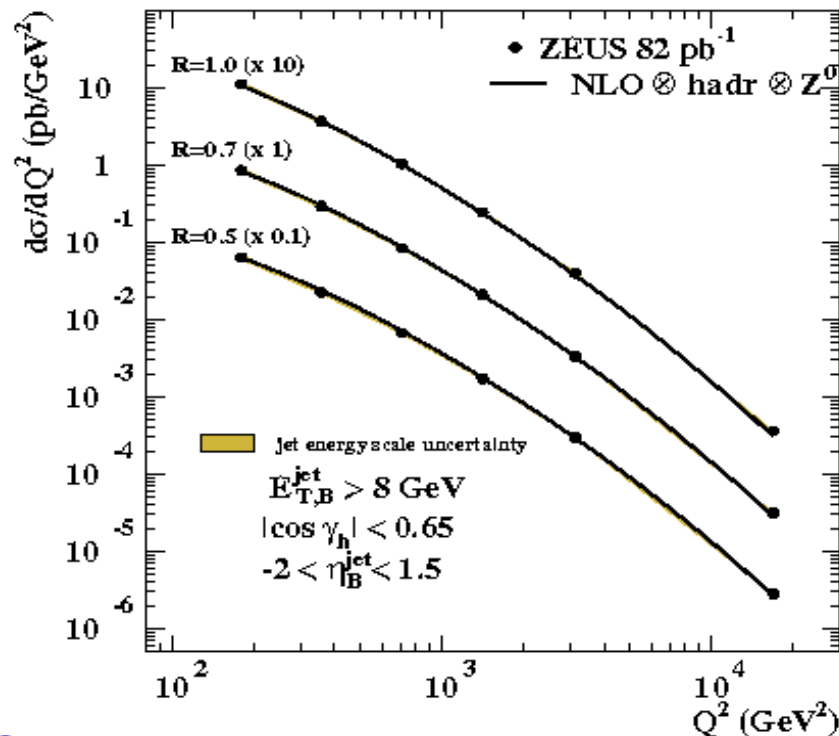

HERA delivered
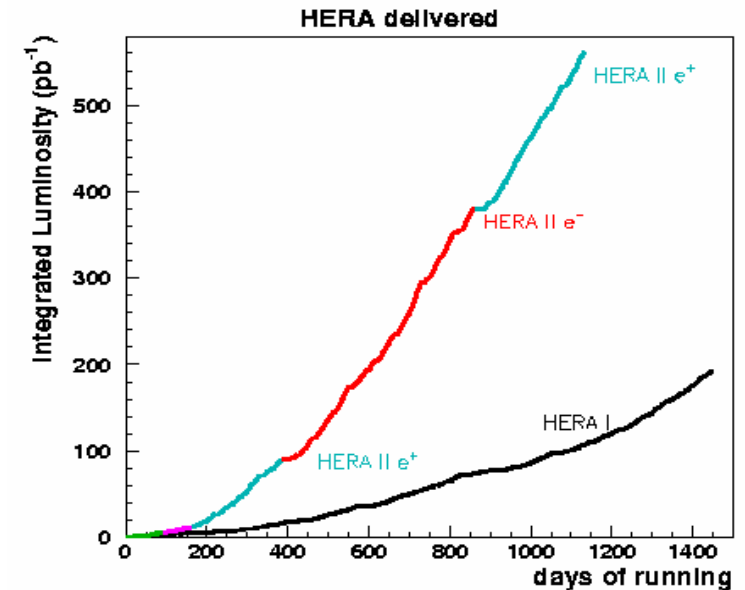
INCLUSIVE JETS AND JET RADIUS (HERA-1)

¶ Inclusive jet cross-section for $E_T > 8$ GeV

– ~20k events in HERA-1 sample. Here: $d\sigma/dQ^2$
– for various 'jet radii': R_0=0.5, 0.7, 1.0 (def.)
  → reliability of theory? Heavy flavour decays?

$$d_i = E_{T,i}^2 \cdot R_0^2 \qquad d_{ij} = \min\left(E_{T,i}^2, E_{T,j}^2\right) \cdot R_{ij}^2$$
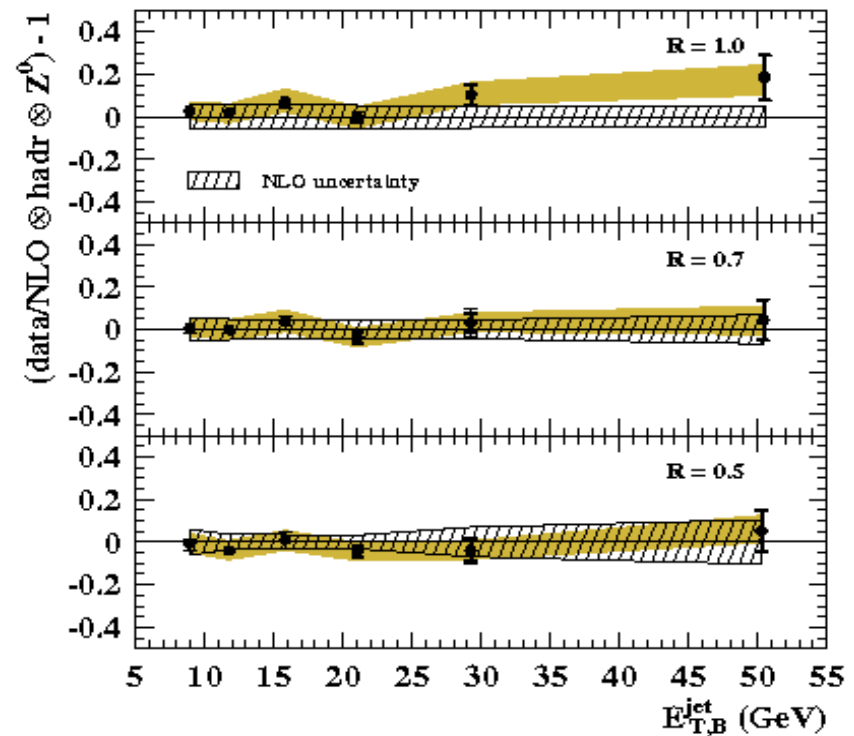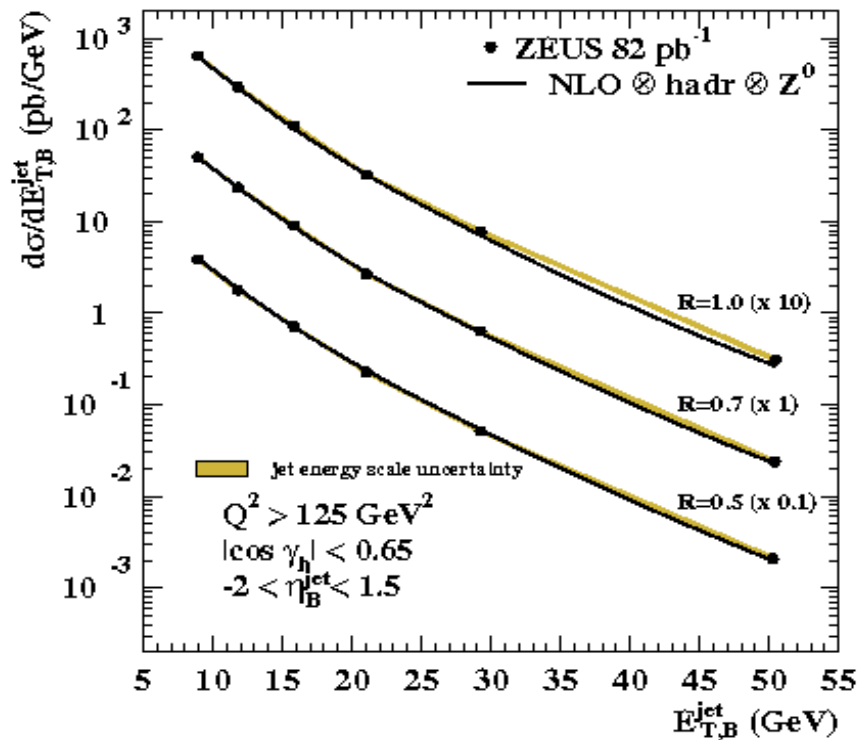

¶ Conclusion:

– Good description of all data by NLO QCD (for both $\mu_R=E_T$ and Q^2).
– R=1, $Q^2 > 500$ GeV²: Used for extraction of $\alpha_S(M_Z)$ (later).

INCLUSIVE JETS AND JET RADIUS (HERA-1)

¶ Inclusive jet cross-section for $E_T > 8$ GeV

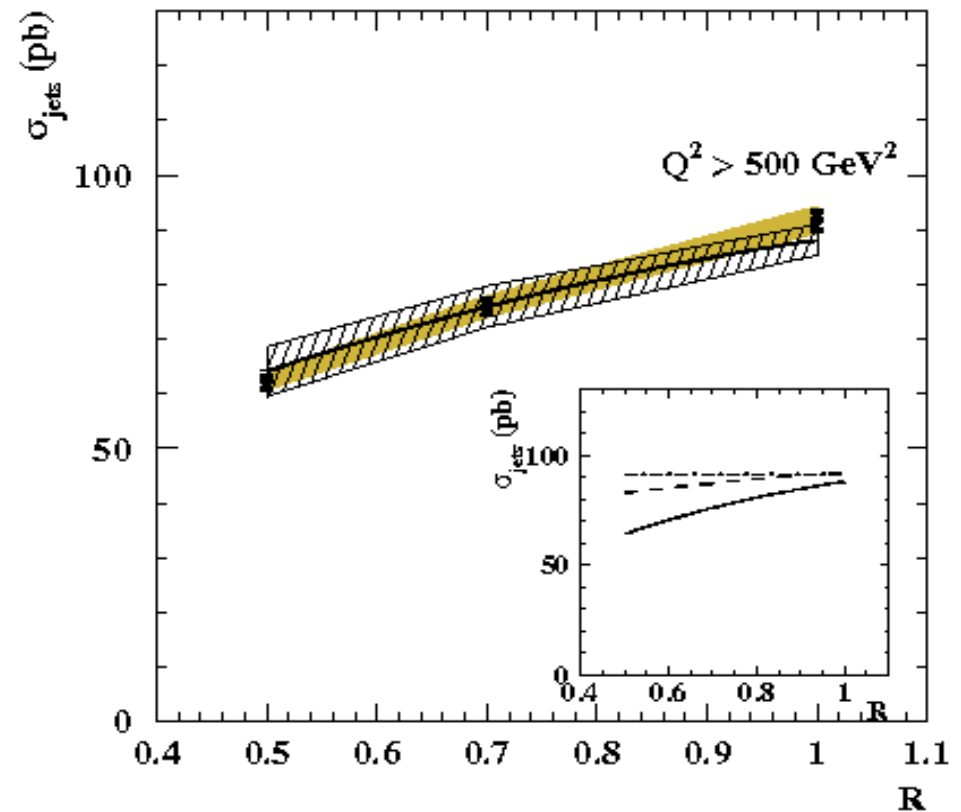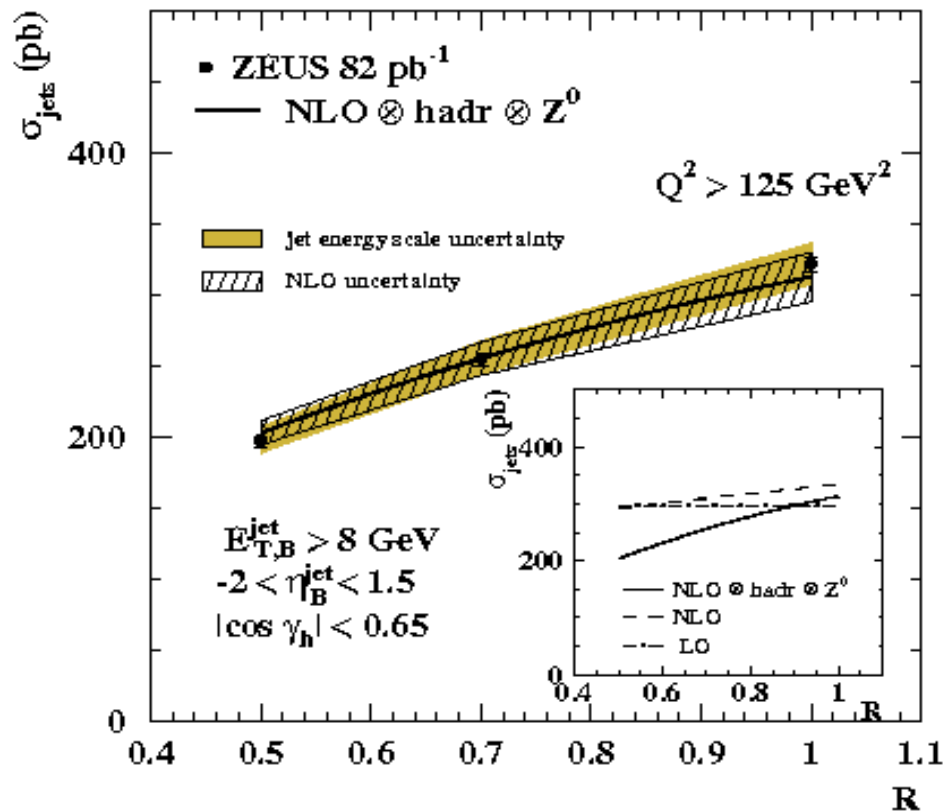– Here: $d\sigma/dE_T$ for R=0.5, 0.7, 1.0.

¶ Conclusion

– good description by NLO QCD
– R=1: data used for demonstration of running of α_S (later).
– For lower (higher) R: larger hadronisation (NLO) errors

INCLUSIVE JETS AND JET RADIUS (HERA-1)

¶ Integrated incl. jet cross section as function of parameter R
  – For R=0.5, 0.7, 1.0 (default) and two lower Q^2 boundaries: 125 / 500 GeV^2.

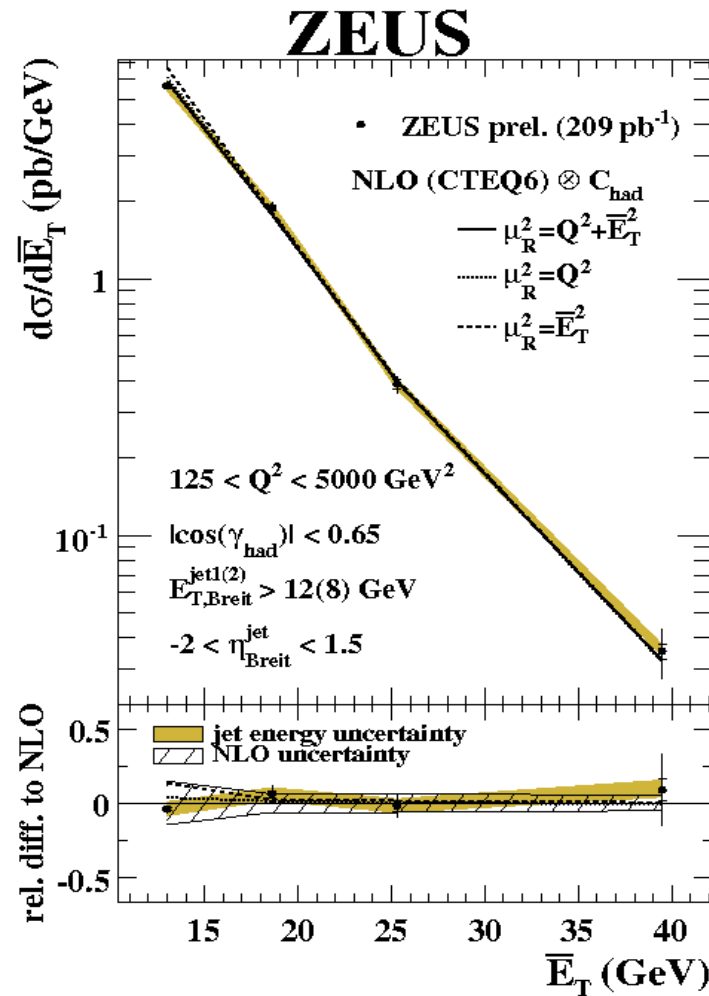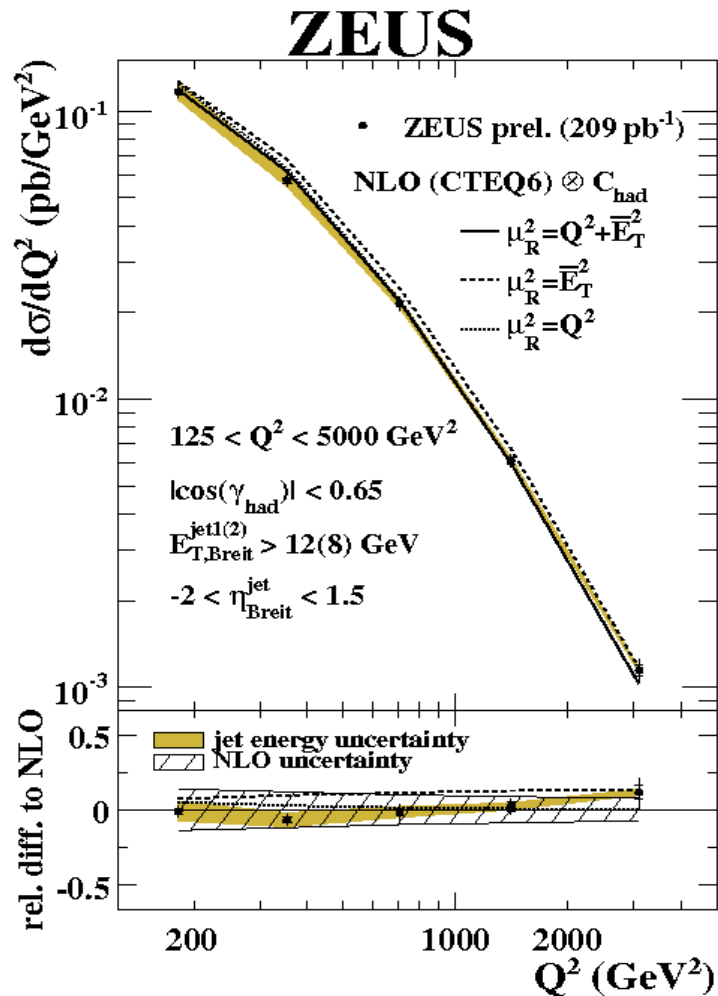¶ Conclusion
  – at LO σ_{jet} flat in R (1 parton!), 'NLO' $O(\alpha_S^2)$ is lowest-order for R-dependence.
  – linear increase of σ_{jet} with R (more energy → more easily above threshold).

DIJETS IN HERA-1 + HERA-2

¶ Update wrt DIS06: 128 pb⁻¹ from 04/05 (factor 2.5 increase)
- comparison to NLO QCD with various scale choices μ_R.
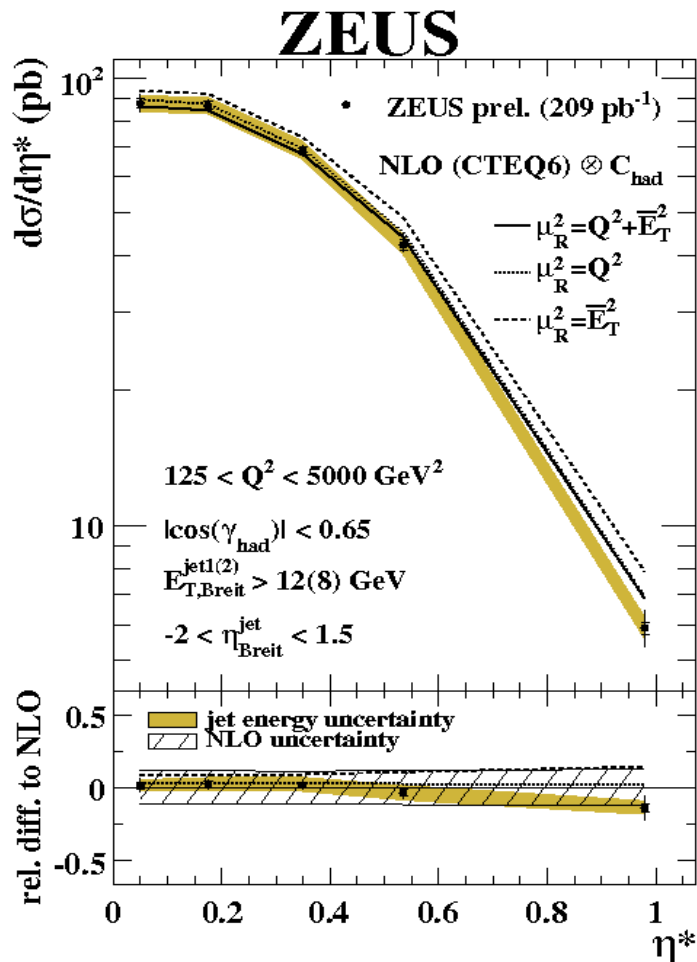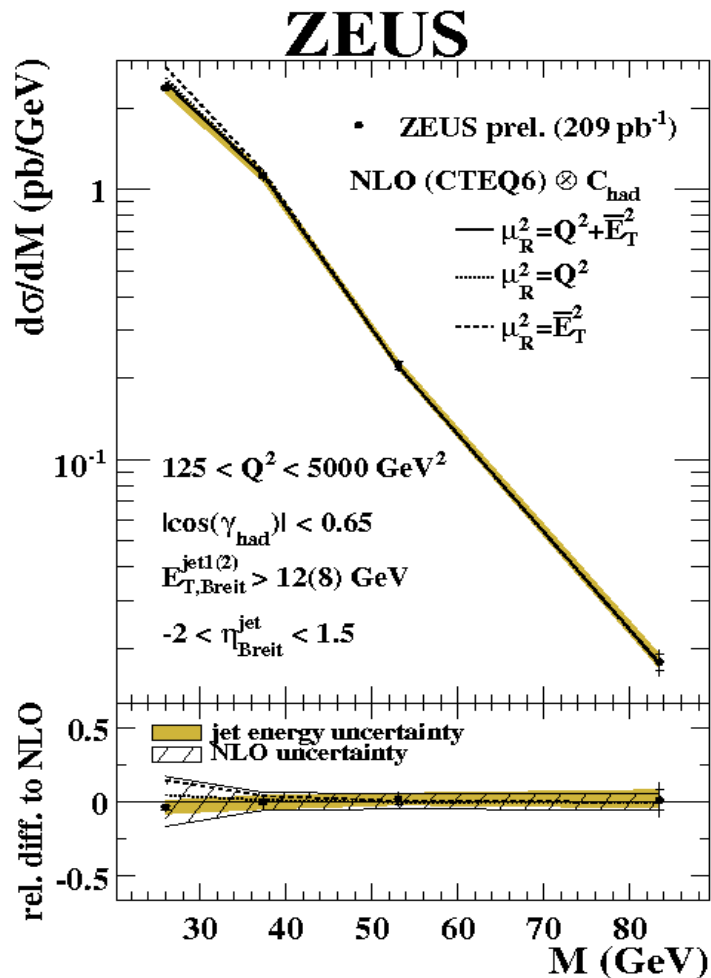- First ZEUS jets analysis in HERA-2 data. Here: $d\sigma/dQ^2$ and $d\sigma/dE_{T,mean}$

¶ Conclusion
- Good description of data by NLO.
- Data dominated by theo. errors.
- syst. errors: jet scale and model.

DIJETS IN HERA-1 + HERA-2

¶ $d\sigma/dM_{jj}$ and $d\sigma/d\eta*$.
- $\eta*=0.5\cdot(\eta_1+\eta_2)$: sensitive to matrix element

¶ Conclusion
- Good description of data by NLO.
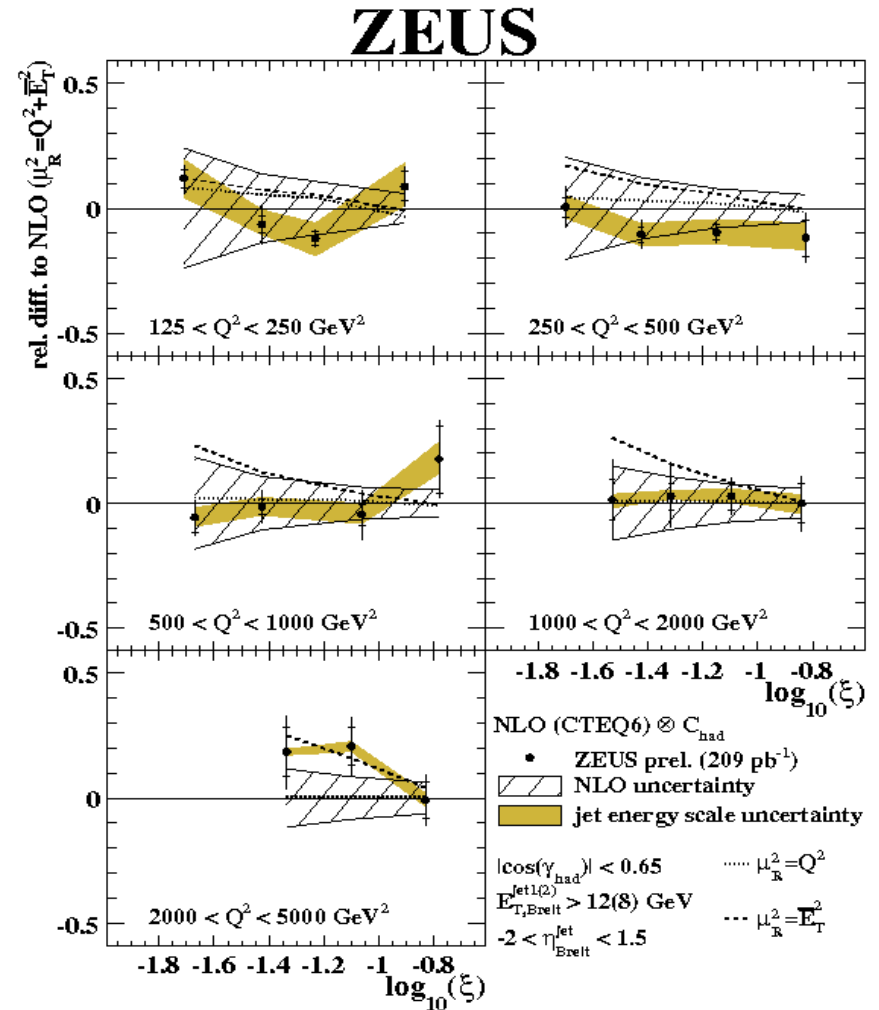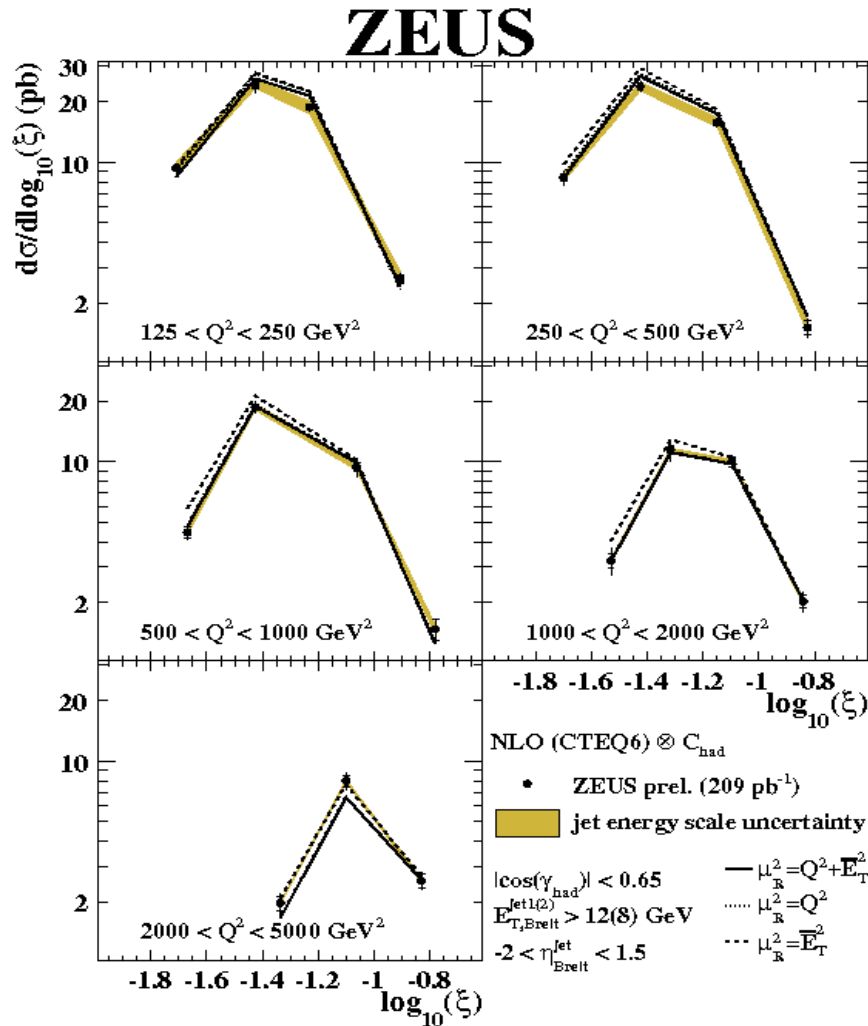- Data dominated by theo. errors.

DIJETS IN HERA-1 + HERA-2

¶ Double-differential: $d\sigma/d\log_{10}\xi$ in different Q^2 bins.
– sensitivity to proton PDFs: scale and momentum fraction!
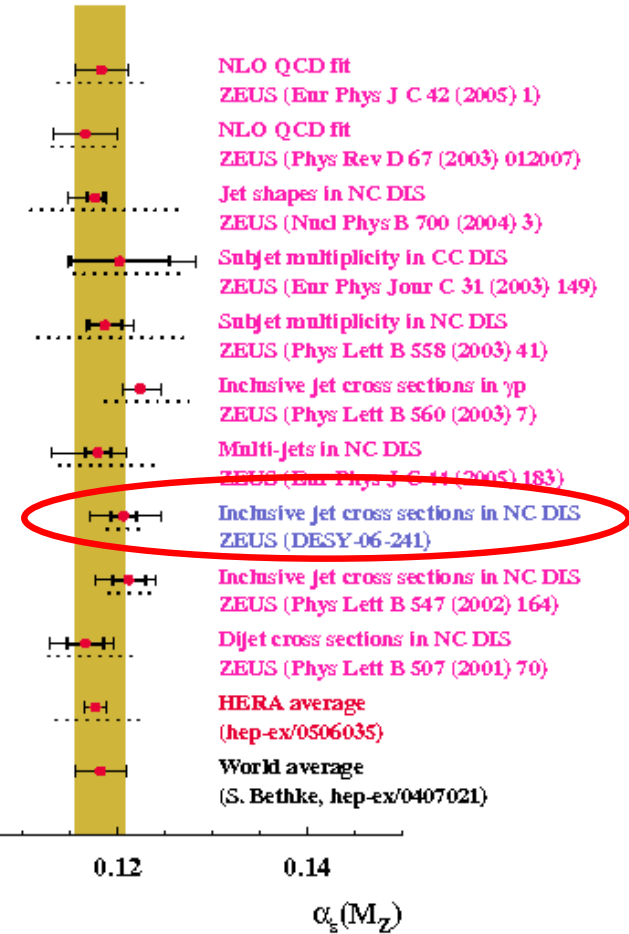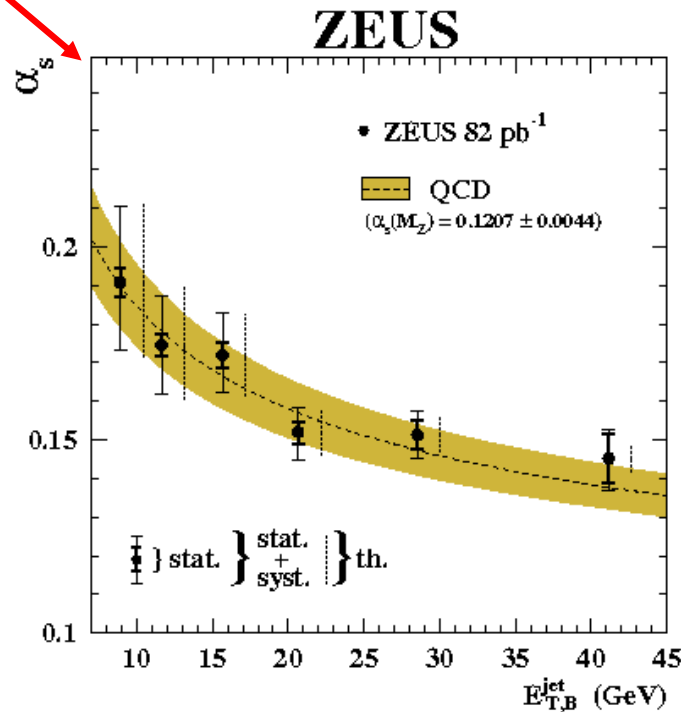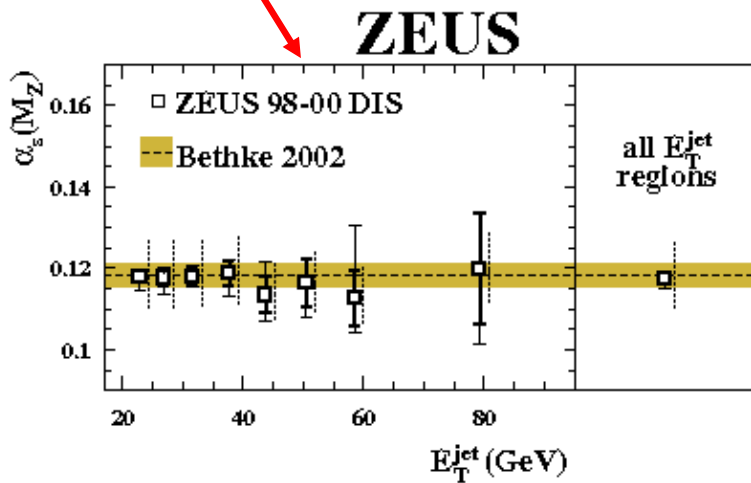– Reasonable description by NLO QCD (note various scales μ_R).

MEASUREMENTS OF α_s AT ZEUS

¶ From various input data (see also talk by C. Glasman)

– Inclusive jets in NC DIS
– NC DIS di- and multi-jets
– Photoproduction (di)jets
– NLO QCD fits.
– Jet shapes

$$\text{new}: \quad \alpha_s(M_Z) = 0.1207 \pm 0.0014(stat)\,{}^{+0.0035}_{-0.0033}(exp)\,{}^{+0.0022}_{-0.0023}(theo)$$

ZEUS

- ● ZEUS 82 pb^{-1}
- ▨ QCD

$(\alpha_s(M_Z) = 0.1207 \pm 0.0044)$

$E^{jet}_{T,B}$ (GeV)

α_s

} stat. } stat. + syst. } th.

ZEUS

□ ZEUS 98-00 DIS
▨ Bethke 2002

all E^{jet}_T regions

$\alpha_s(M_Z)$

E^{jet}_T (GeV)

NLO QCD fit
ZEUS (Eur Phys J C 42 (2005) 1)

NLO QCD fit
ZEUS (Phys Rev D 67 (2003) 012007)

Jet shapes in NC DIS
ZEUS (Nucl Phys B 700 (2004) 3)

Subjet multiplicity in CC DIS
ZEUS (Eur Phys Jour C 31 (2003) 149)

Subjet multiplicity in NC DIS
ZEUS (Phys Lett B 558 (2003) 41)

Inclusive jet cross sections in γp
ZEUS (Phys Lett B 560 (2003) 7)

Multi-jets in NC DIS
ZEUS (Eur Phys J C 44 (2005) 183)

Inclusive jet cross sections in NC DIS
ZEUS (DESY-06-241)

Inclusive jet cross sections in NC DIS
ZEUS (Phys Lett B 547 (2002) 164)

Dijet cross sections in NC DIS
ZEUS (Phys Lett B 507 (2001) 70)

HERA average
(hep-ex/0506035)

World average
(S. Bethke, hep-ex/0407021)

$\alpha_s(M_Z)$

¶ Conclusion:

– Uncertainties of single measurements of order of 3-4%.
– Good agreement between measurements, clear demonstration of running α_s.
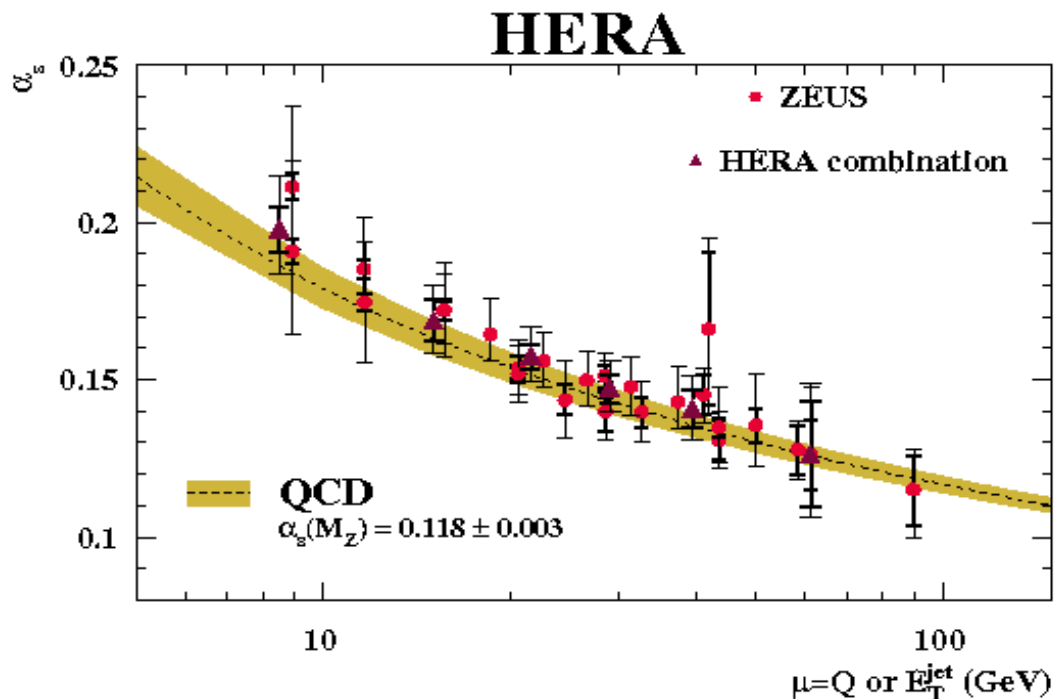
DIS MEASUREMENTS OF α_S AT ZEUS

¶ Combination of ZEUS and H1 data.

- excellent level of agreement between experiments
- large number of data points over large scale range.
- Combined HERA value (C. Glasman, hep-ex/0506035):

$$\alpha_s(M_z) = 0.1186 \pm 0.0011(\exp) \pm 0.0050(theo)$$

¶ Summary: Running of α_S (including new inclusive-jet measurement)

¶ Data sets in HERA average
- ZEUS inclusive jets in PHP
  → PLB 560 (2003) 7
- ZEUS inclusive jets in DIS
  → PLB 547 (2002) 164
- H1 inclusive jets in DIS
  → EPJ C19 (2001) 289

SUMMARY AND OUTLOOK

¶ **Jets in NC DIS** (at high $Q^2 > 125$ GeV^2)
- NLO QCD gives good description of jet cross sections.
- Measurements are dominated by their theoretical uncertainties
  (variation of scale μ_R by factors of 2 or use of different scale choices).

¶ **News since DIS06 in Tsukuba**
- First HERA-2 jet measurements (dijets), combined with HERA-1 (210 pb^{-1})
- jet-radius-dependent measurement of inclusive jet cross sections
- strong coupling from inclusive jets $d\sigma/dQ^2$ with R=1 and $Q^2 > 500$ GeV^2:

$$\alpha_s(M_z) = 0.1207 \pm 0.0014\,(stat)\,^{+0.0035}_{-0.0033}\,(\exp)\,^{+0.0022}_{-0.0023}\,(theo)$$
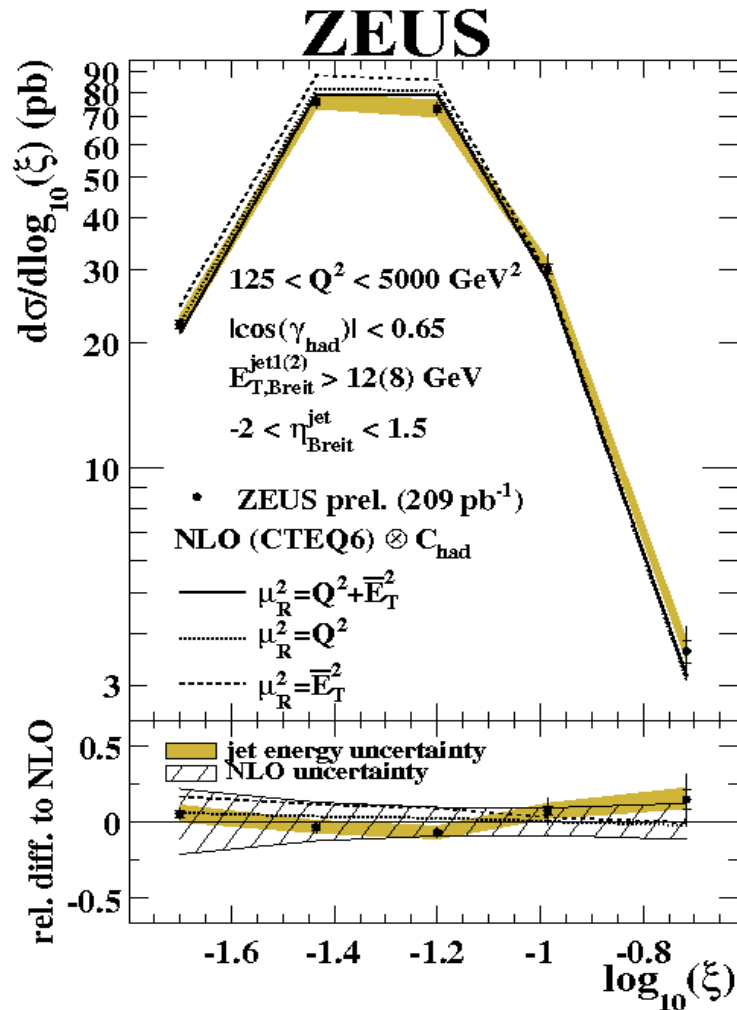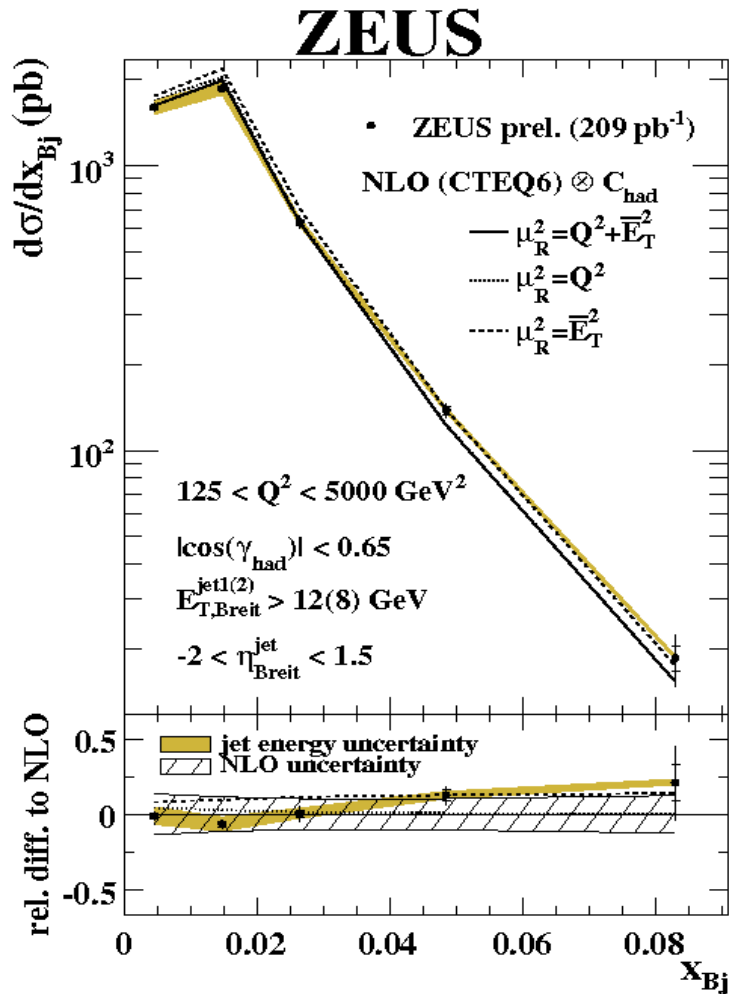
¶ **Future**
- Make use of full HERA-1+2 statistics (500 pb^{-1})
- Produce final HERA answer: strong coupling from jets in DIS!
- Refine jet input to QCD fits → improvement of PDFs?

DIJETS IN HERA-1 + HERA-2

¶ $d\sigma/dx_{Bj}$ and $d\sigma/d\log_{10}\xi$.
– $\xi=x_{Bj}\cdot(1+M^2/Q^2)$

¶ Conclusion
– Good description of data by NLO.
– Data dominated by theo. errors.