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Jet cross sections in NC DIS and measurement of α_s at HERA

- Introduction
- NC DIS Jet production
- NLO pQCD vs. measurements
- α_s & its scale dependence
- Summary & Outlook

The strong coupling constant: α_s

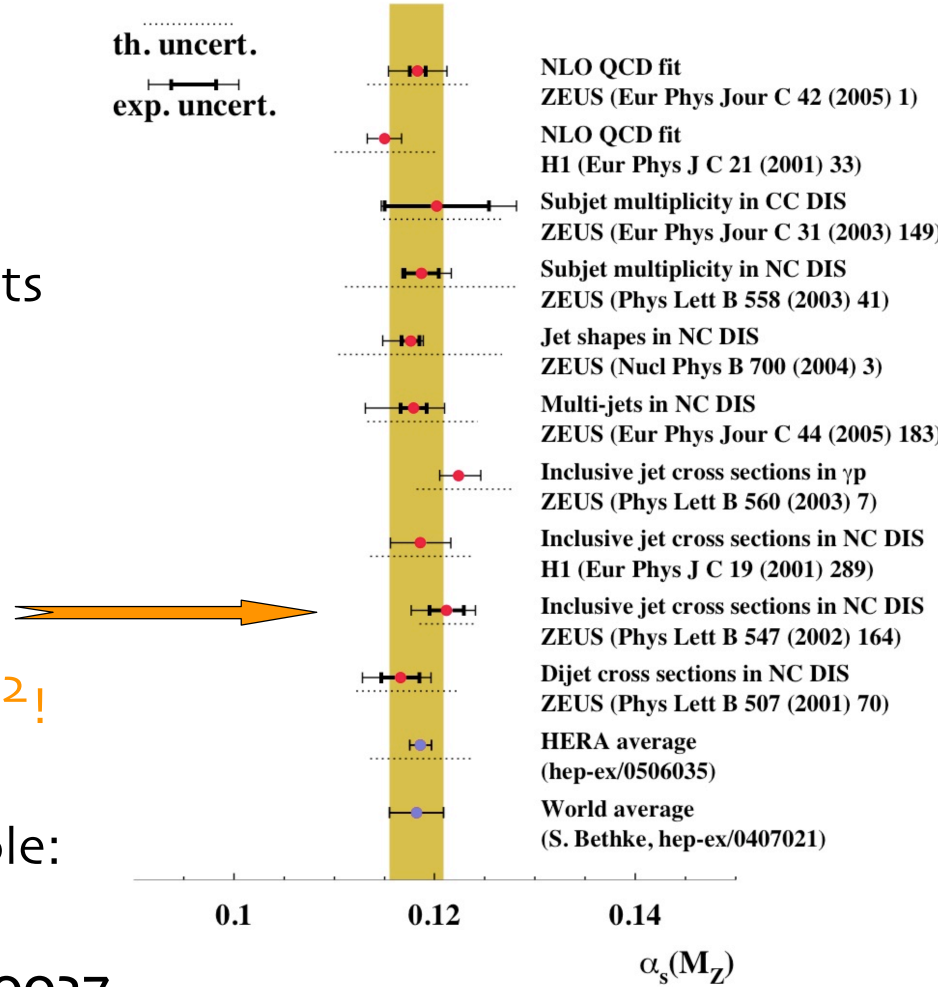
α_s is fundamental parameter of QCD

--> must be determined from experiment!

For precise determination:

- many measurements
- diverse phenomena
  - HERA: - internal structure of jets
    - structure functions
    - event shapes
    - jet cross sections

Inclusive jets yield smallest theoretical uncertainty at high Q^2!



$\alpha_s(M_Z)$ measurements compatible:

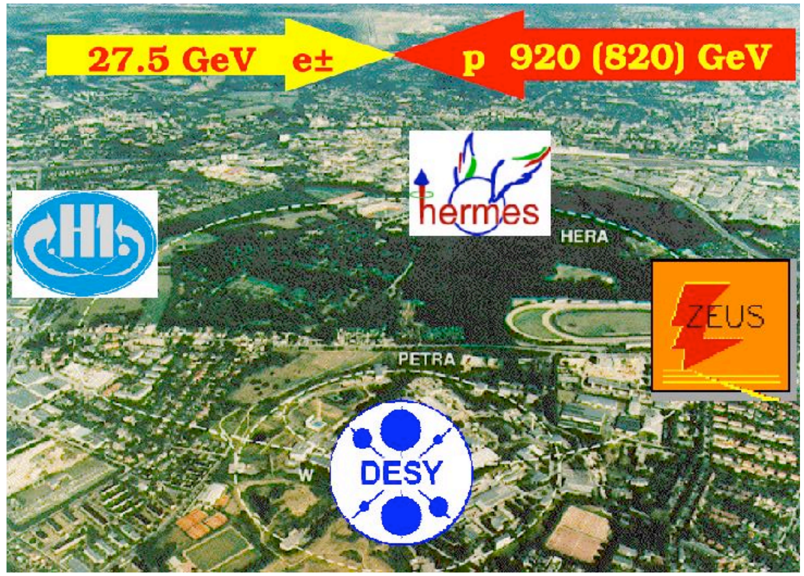
- amongst themselves
- with world average: **0.1182 ± 0.0027**

HERA: H1 and ZEUS experiments

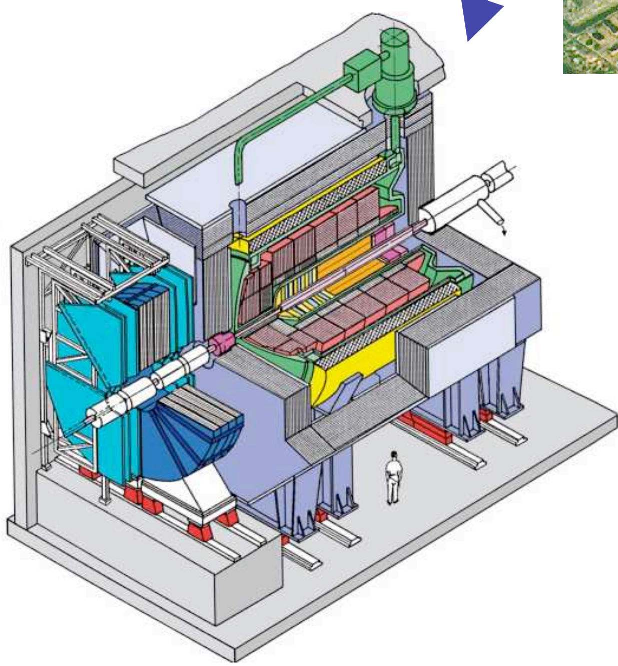
HERA: $e^{\pm}p$ -> e'X

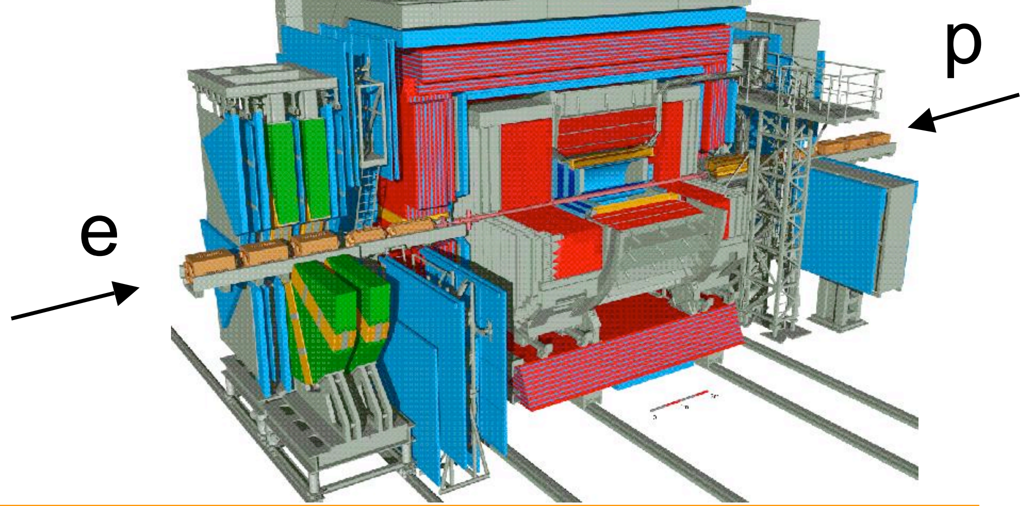
$e^{\pm}p$ cm energy after(before) 1998:

$\sqrt{S}$ =318(300) GeV

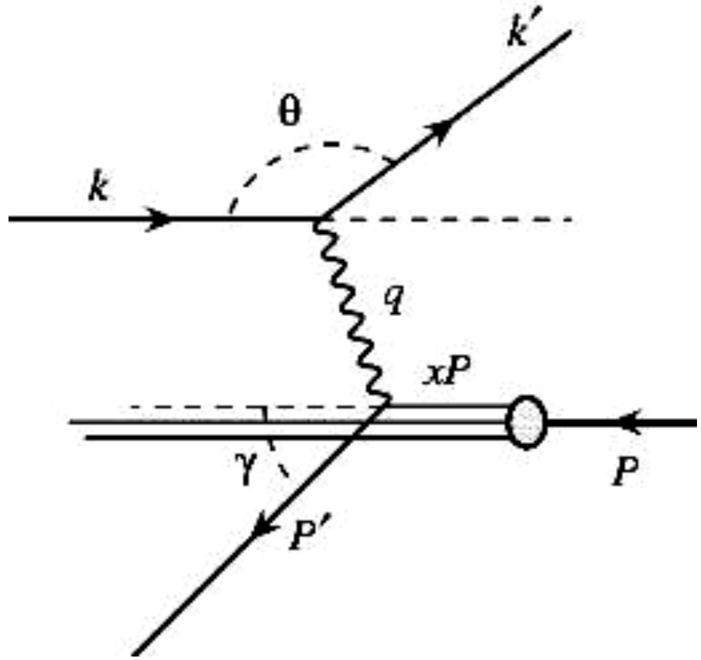


DESY (Hamburg, Germany)





Deep Inelastic Scattering at HERA



Charged current: exchange of $W^{\pm}$

Neutral current: exchange of γ or Z^0

$$Q^2 = -q^2 = -(k - k')^2$$

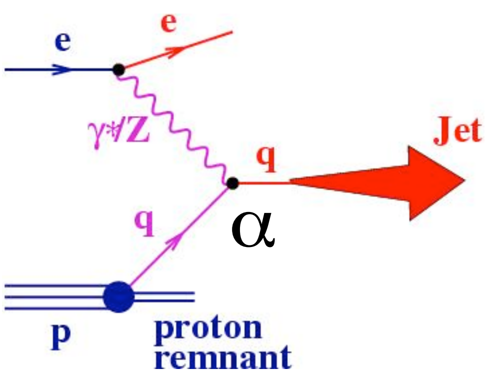
$$x = \frac{Q^2}{2p \cdot q} \qquad y = \frac{p \cdot q}{p \cdot k}$$

$$s = (p + k)^2 \qquad Q^2 = x \cdot y \cdot s$$

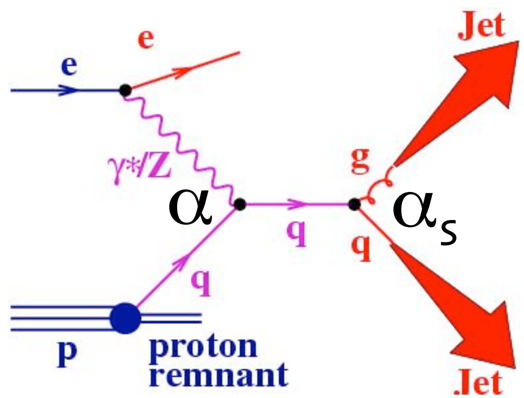
- Q^2 is the probing power
- x is the Bjorken scaling variable
- y is the inelasticity

Jets in NC DIS at HERA

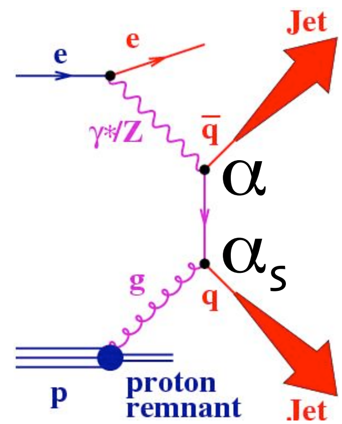
Jet production in NC DIS ($Q^2 >> \Lambda^2_{QCD}$)
- at $O(\alpha_s)$, three diagrams contribute to jet production cross section



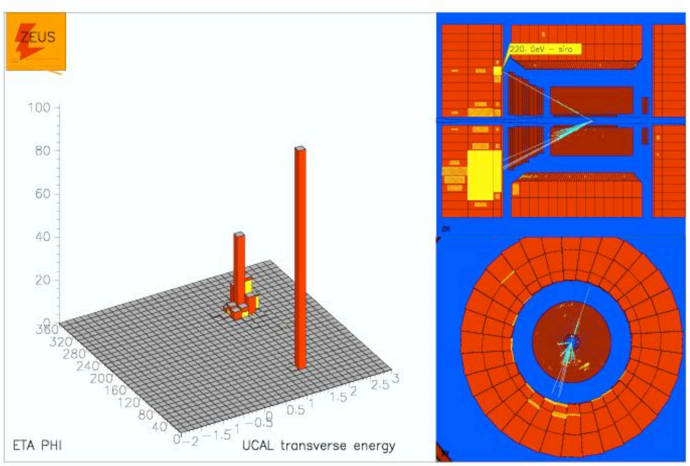
QPM $O(\alpha)$

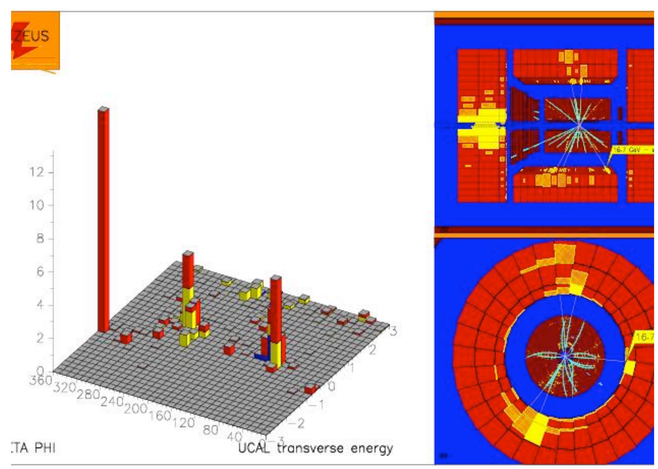


QCD Compton $O(\alpha\alpha_s)$



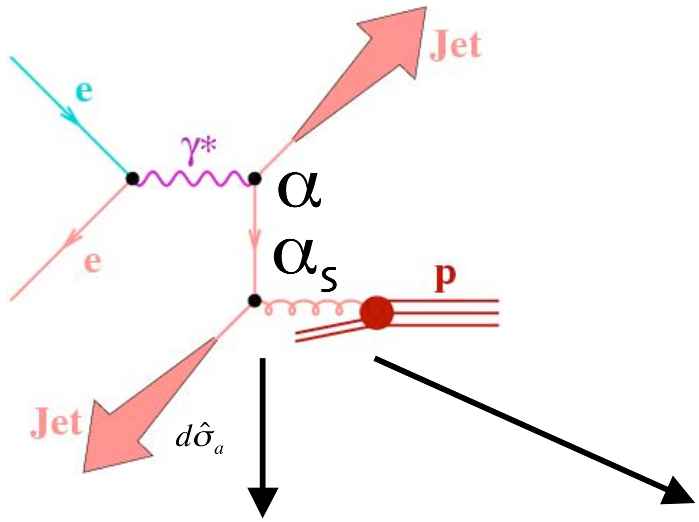
BGF $O(\alpha\alpha_s)$





Jets cross sections in NC DIS

Cross section for ep -> e + jet +jet + X at high Q^2:



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

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

-> hard process (short-distance structure of interaction)

f_a are the experimentally determined Parton Distributions Functions

-> proton structure (long-distance structure of interaction)

Allows test of color dynamics, determination of α_s, test of proton PDFs

NLO Calculations of jet cross sections

Differential cross sections were calculated at $O(\alpha_s^2)$ by ZEUS (H1) with DISENT (NLOJET++). Ingredients needed for pQCD calculation:

- assume value of $\alpha_s(M_Z)$: 0.1175 (0.118) (α_s is calculated at 2 loops)
- assume parametrizations for proton PDFs:
  MRST99 set (CTEQ5M1)
- choose hard scale:
  Renormalization scale $\mu_R = E_{T,B}$ of jet
  Factorization scale $\mu_F = Q$
- correct calculations for hadronization effects (calculations are for jets of partons and measurements are done at hadron level)

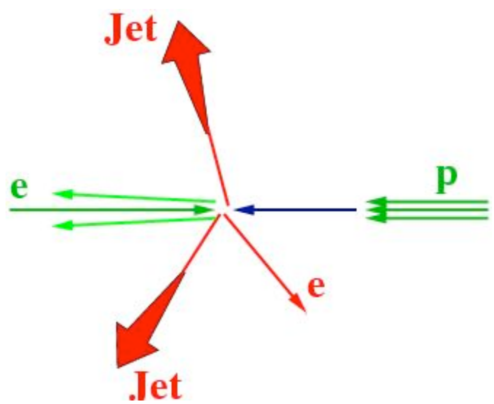
Contributions to the theoretical uncertainty:

- on value of $\alpha_s(M_Z)$: **0.1182 ± 0.0027**
- on parametrizations of proton PDFs: w/40 sets of CTEQ6
- terms beyond NLO: variation of μ_R by factors of 2 & 1/2 (μ_F by 4 & 1/4)
- from hadronization corrections: use different LO QCD MCs

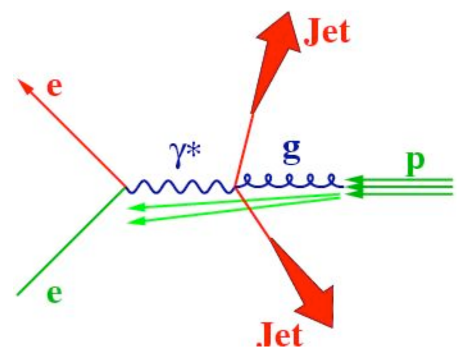
Jet search: The Breit Frame

Breit frame -> natural frame to measure NC DIS jet xs:
- suppression of QPM contribution (final state quark: negligible E_T)
- suppression of beam remnant jet (negligible E_T)
- lowest order non-trivial contributions: $\gamma^* g \to q\bar{q}$ and $\gamma^* g \to qg$

Lab frame



Breit frame



Jets are reconstructed in Breit frame using a K_t-cluster algorithm:
- invariant under longitudinal boosts
- xs predicted are infrared and collinear safe

$$d_{ij} = \min(E_T^{\,i}, E_T^{\,j})^2 \times (d\eta_{ij}^2 + d\varphi_{ij}^2)$$

Measurements of $d\sigma/dE_{T,B}$(jet): ZEUS

$d\sigma/dE_{T,B}$(jet) measurement vs. NLO prediction

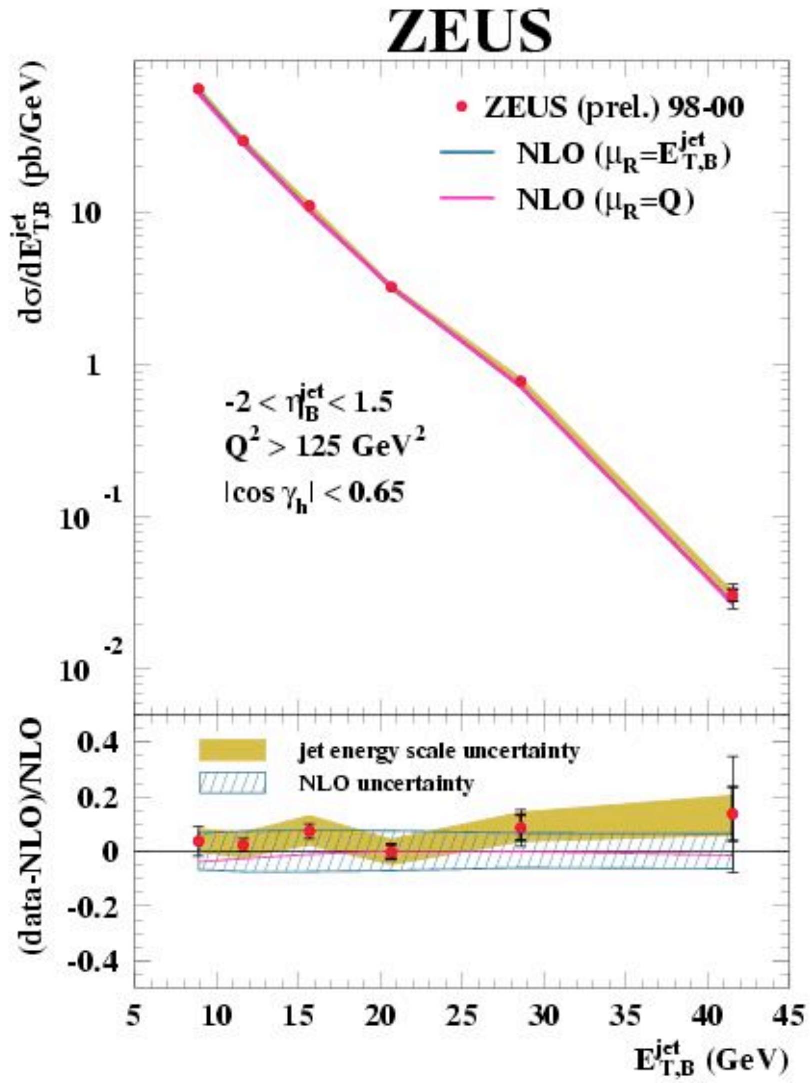
Data:

98-00 → $\mathcal{L}$ = 81.7 pb^{-1}

$Q^2 > 125\ GeV^2$

$E_{T,B}^{jet} > 8$ GeV

$-2 < \eta^{jet}_B < 1.5$



Measured inclusive jet cross sections are well described by predictions.

Experimental uncertainties on xs:
- jet energy scale (~5 %)

Theoretical uncertainties on xs:
- terms beyond NLO (~5%)
- assumed value of α_s (4%)
- uncertainties on PDFs (3%)

Measurements of $d^2\sigma/dE_T dQ^2$: H1

$d^2\sigma/dE_T dQ^2$ measurement vs. NLO prediction

Data:

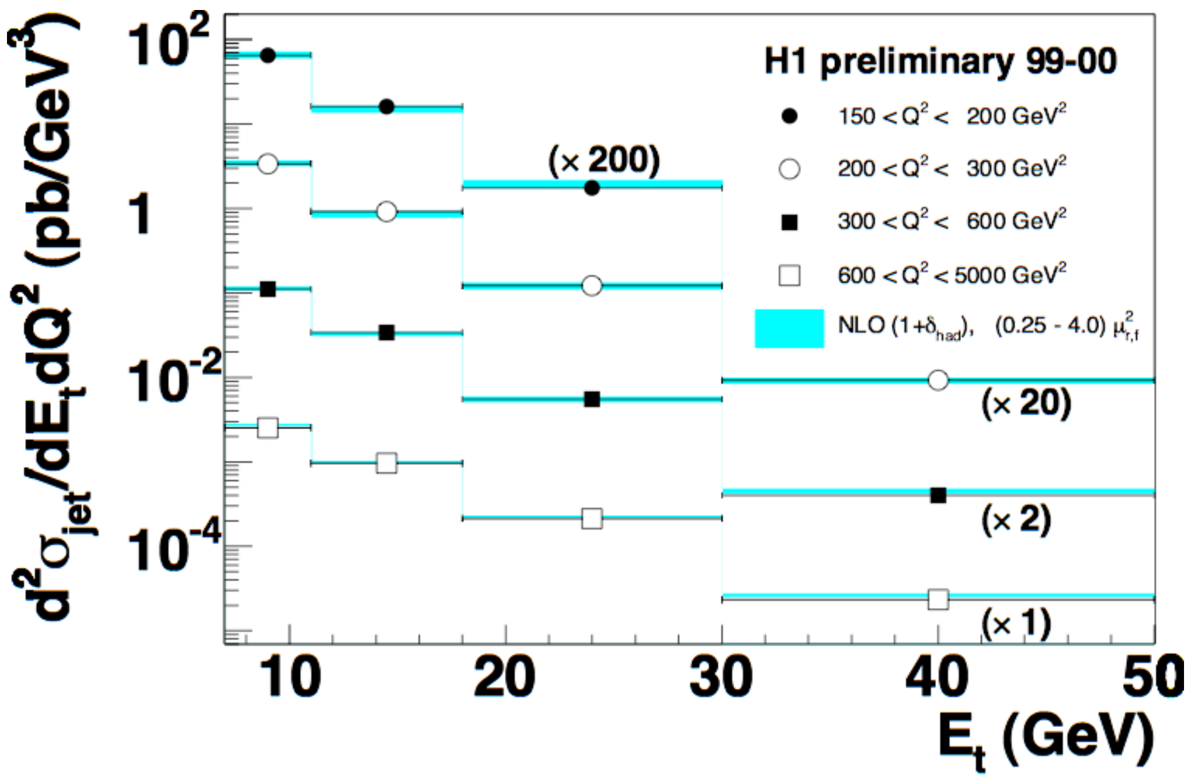
99-00 → $\mathcal{L}$ = 61.25 pb^{-1}

Kinematic region:

$150 < Q^2 < 5000$ GeV^2

$E_T^{jet} > 7$ GeV

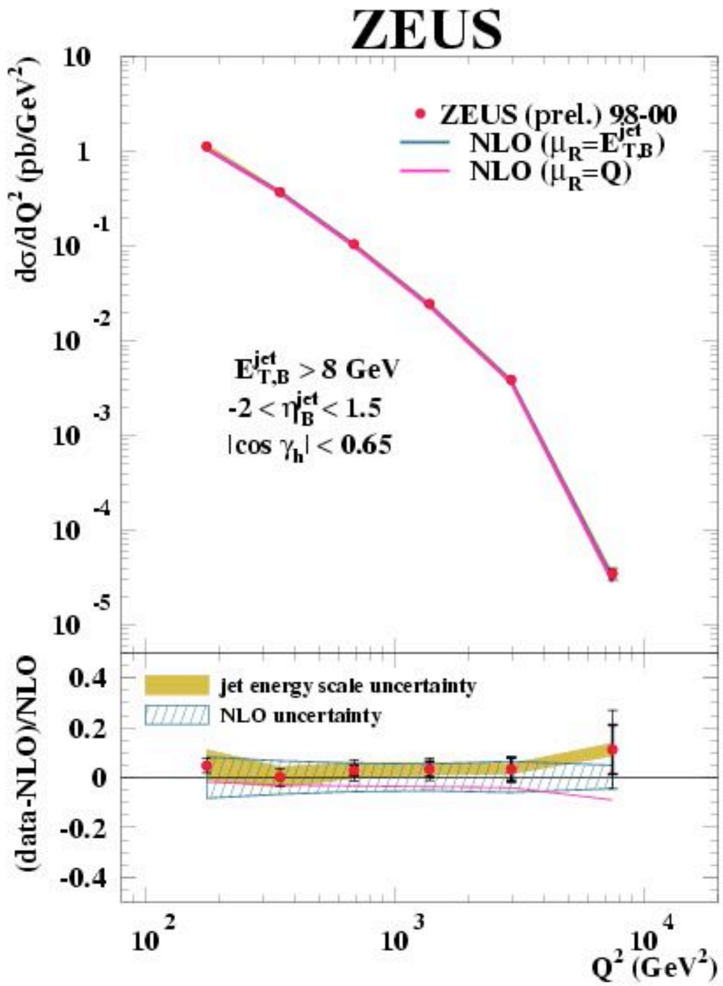
$-1 < \eta^{lab} < 2.5$

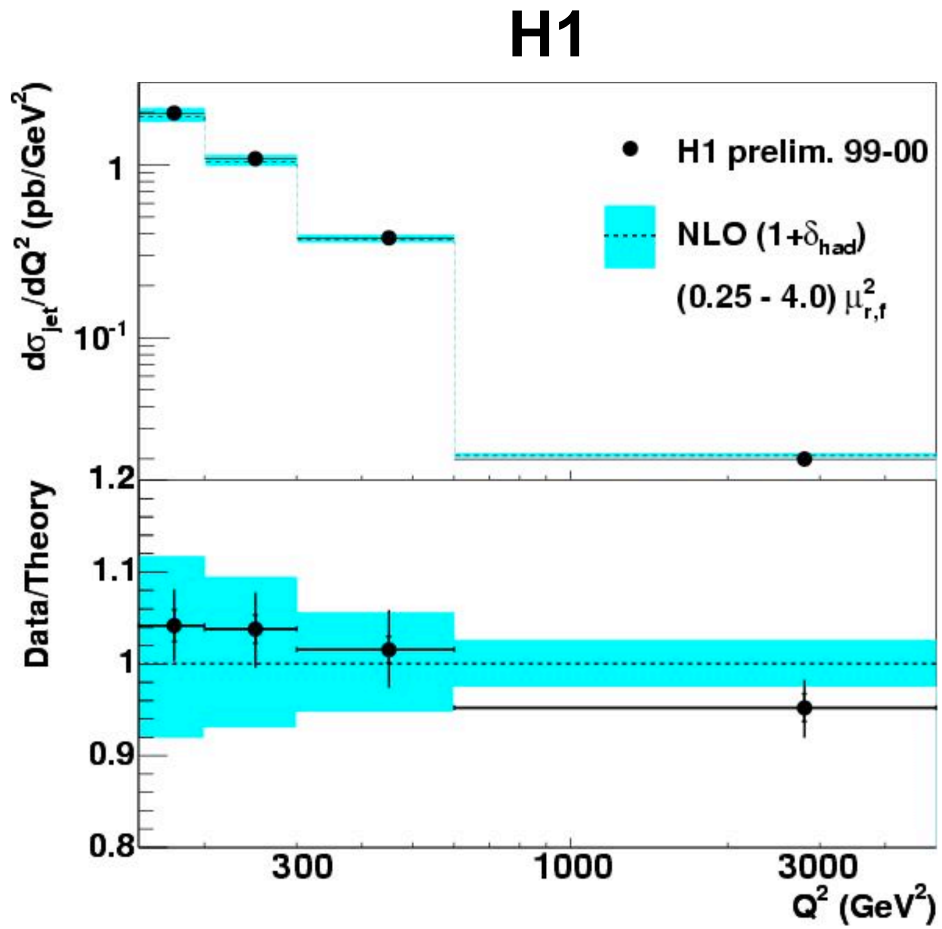


Measured inclusive jet cross sections are well described by predictions.

Measurements of dσ/dQ^2

dσ/dQ^2 measurement vs. NLO prediction





Data are well described by NLO predictions.
The theoretical uncertainties are higher at low Q^2.

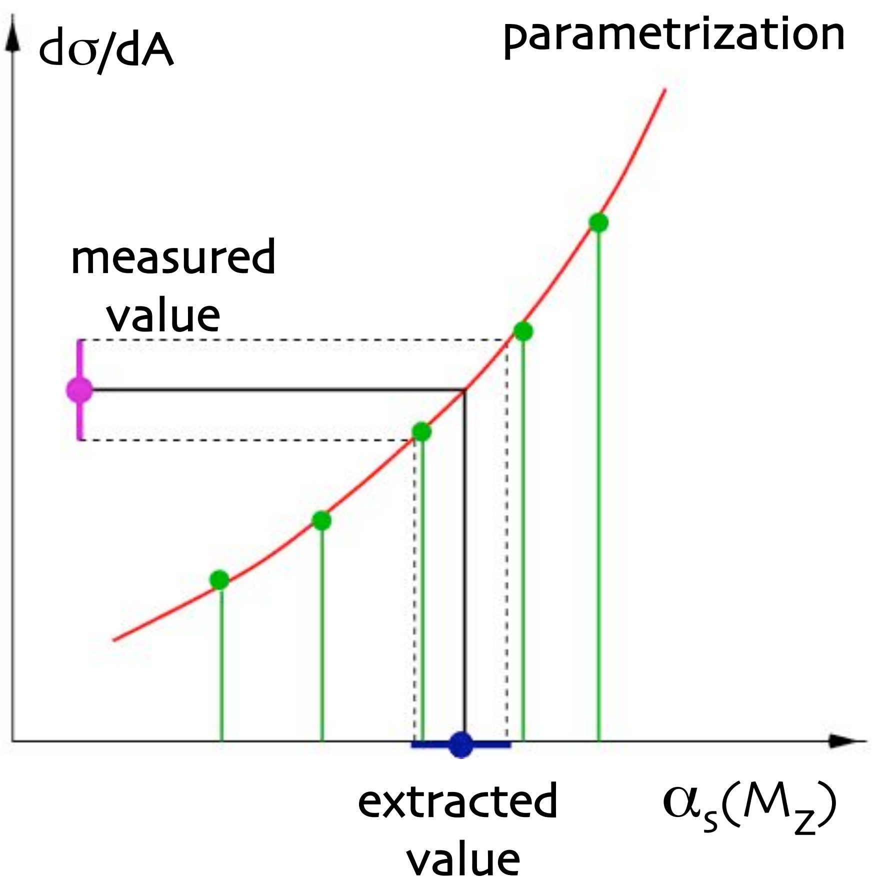
Extraction of $\alpha_s(M_Z)$

α_s determination:

1. perform NLO calculations for different values of $\alpha_s(M_Z)$

   (values of α_s used correspond to those used in the different PDF sets available)

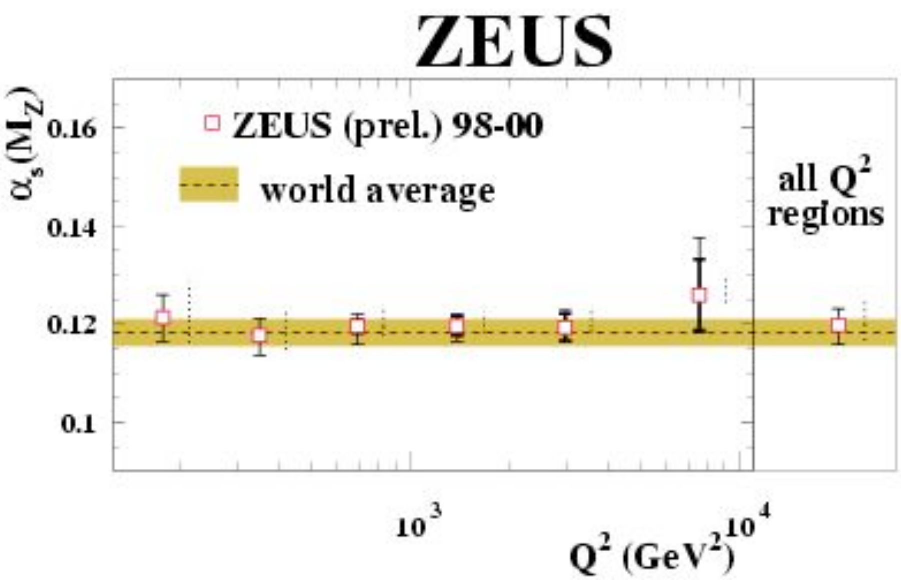
2. parametrize α_s dependence of observable ($d\sigma/dQ^2$ or $d\sigma/dE_{T,B}$(jet)) according to:

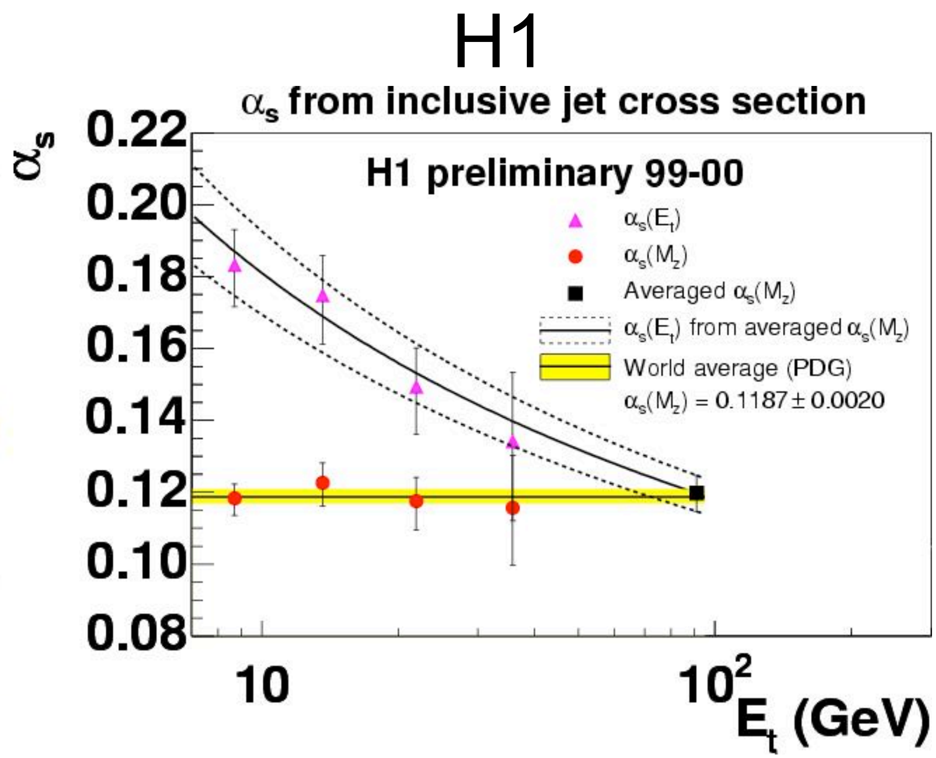


$$[d\sigma/dA(\alpha_s(M_Z))] = A_1^i \alpha_s(M_Z) + A_2^i \alpha_s^2(M_Z)$$

Measurement of $\alpha_s(M_Z)$

Values of α_s have been determined from the measured $d\sigma/dE_{T,B}$(jet) and $d\sigma/dQ^2$ cross sections:



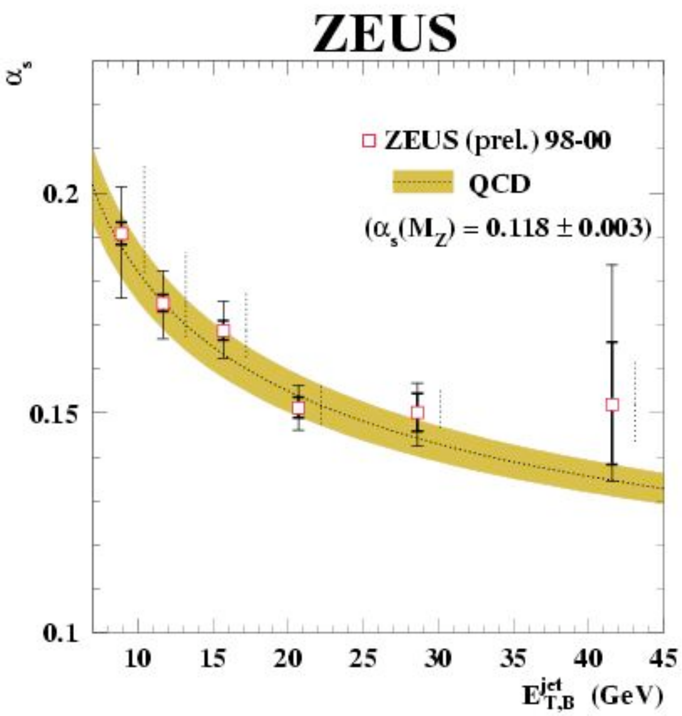


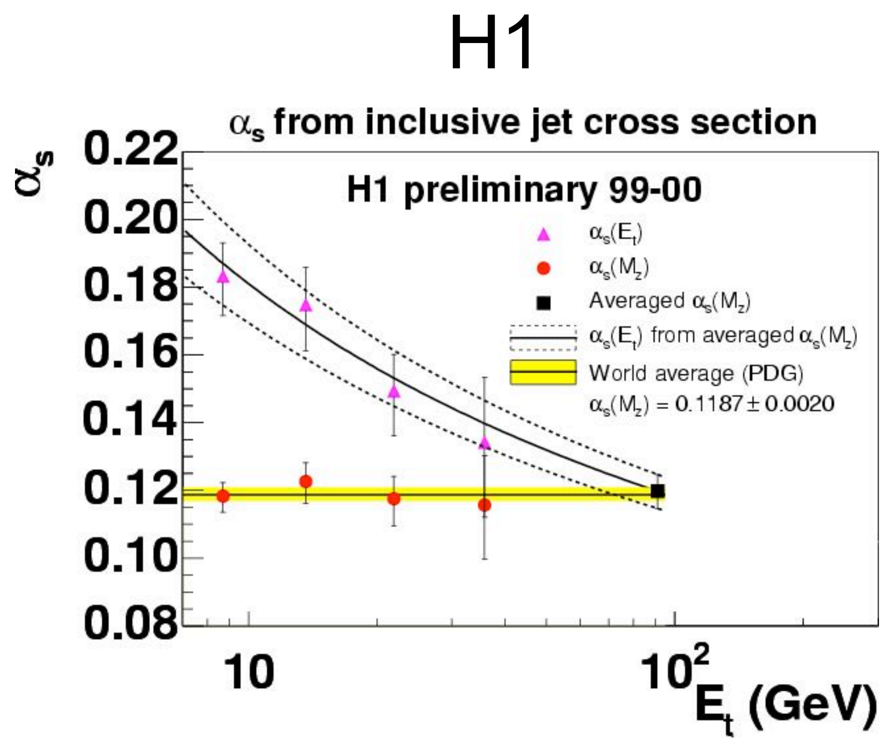
ZEUS: $Q^2 > 500$ GeV^2: $\alpha_s(M_Z) = 0.1196 \pm 0.0006(\text{stat.})^{+0.0019}_{-0.0025}(\text{exp.})^{+0.0029}_{-0.0017}(\text{th.})$

H1: All E_T regions: $\alpha_s(M_Z) = 0.1197 \pm 0.0016(\text{exp.})^{+0.0046}_{-0.0048}(\text{th.})$

$\alpha_s(M_Z)$ and energy scale dependence

The measured $d\sigma/dE_{T,B}$(jet) and $d\sigma/dQ^2$ have been used to test the energy-scale dependence of α_s:

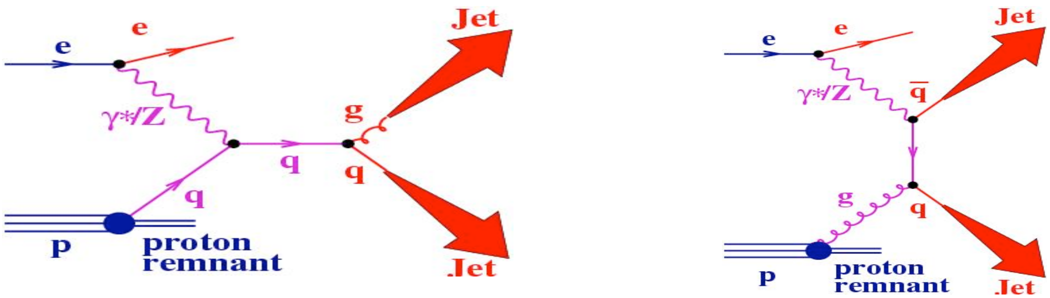




Measurement is in good agreement with the QCD predictions over a large range in Q and E_T.

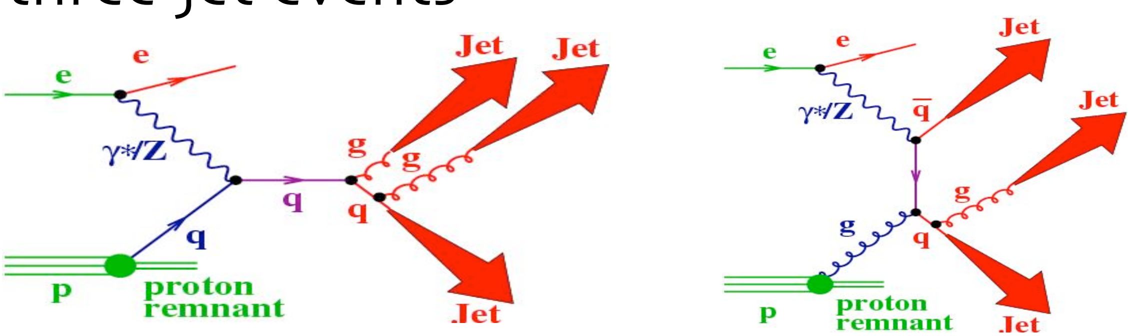
Multijet production in NC DIS at HERA

one- and two-jet events



$O(\alpha_s)$

three-jet events

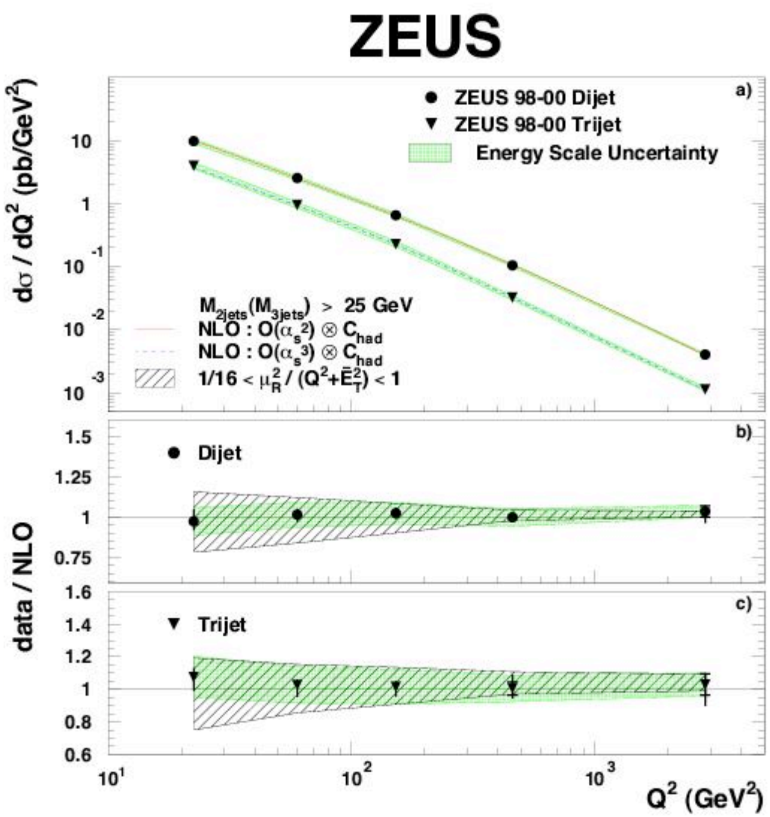


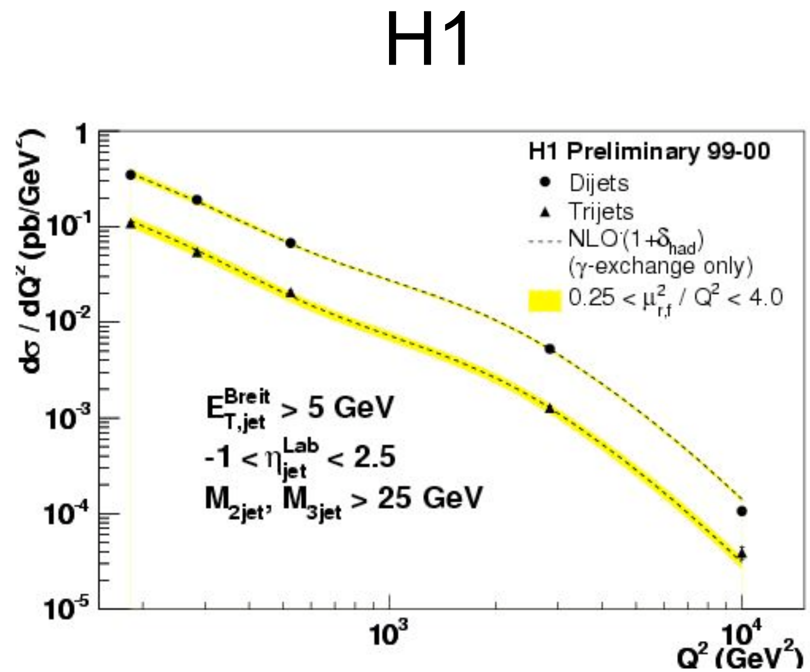
$O(\alpha_s^2)$

Three jet events are processes in which:
- gluon is radiated in final state
- splitting of a gluon in to a $q\bar{q}$ pair

These events provide direct tests of pQCD beyond LO: $\sigma_{3jets} \propto O(\alpha_s^2)$

Dijet and trijet cross sections in NC DIS





M_{2jet}, M_{3jet} > 25 Gev

10 < Q^2 < 5000 GeV^2 150 < Q^2 < 15000 GeV^2

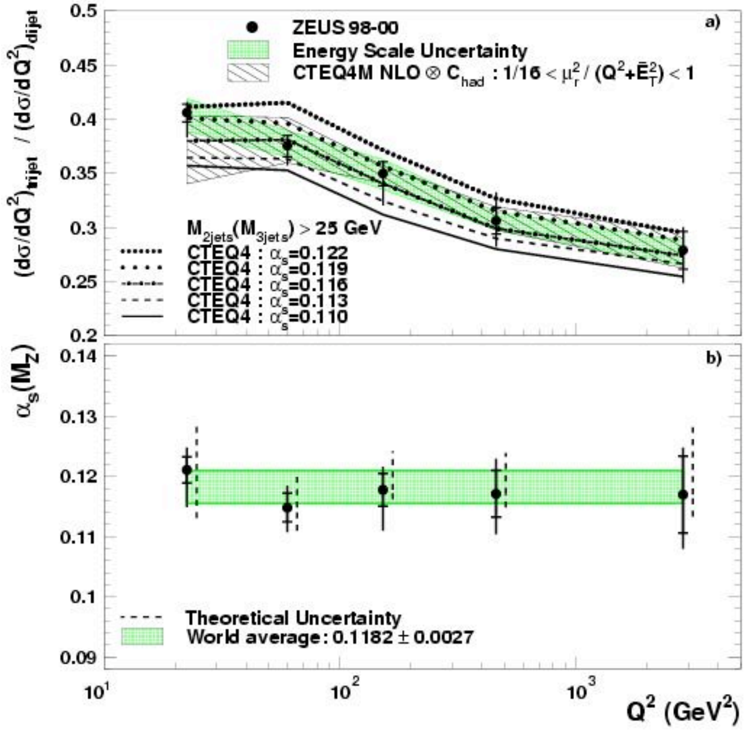
Measured dijet and trijet cross sections
are well described by NLO predictions.

$\alpha_s(M_Z)$ from multijet cross sections

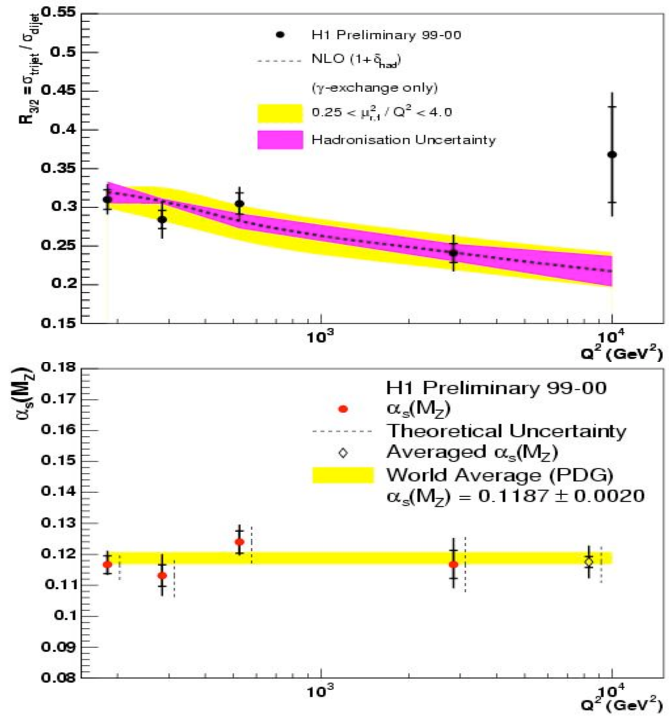
Ratio: experimental and theoretical uncertainties cancel out in the ratio

---> more accurate test of color dynamics

ZEUS



H1



$\alpha_s(M_Z)=0.1179 \pm 0.0013(\text{stat.})^{+0.0028}_{-0.0046}(\text{exp.})^{+0.0064}_{-0.0046}(\text{th.})$ $\alpha_s(M_Z)=0.1175 \pm 0.0017(\text{stat.}) \pm 0050(\text{exp.})^{+0.0054}_{-0.0068}(\text{th.})$

Ratio yields precise measurements at LOW Q^2.

Summary

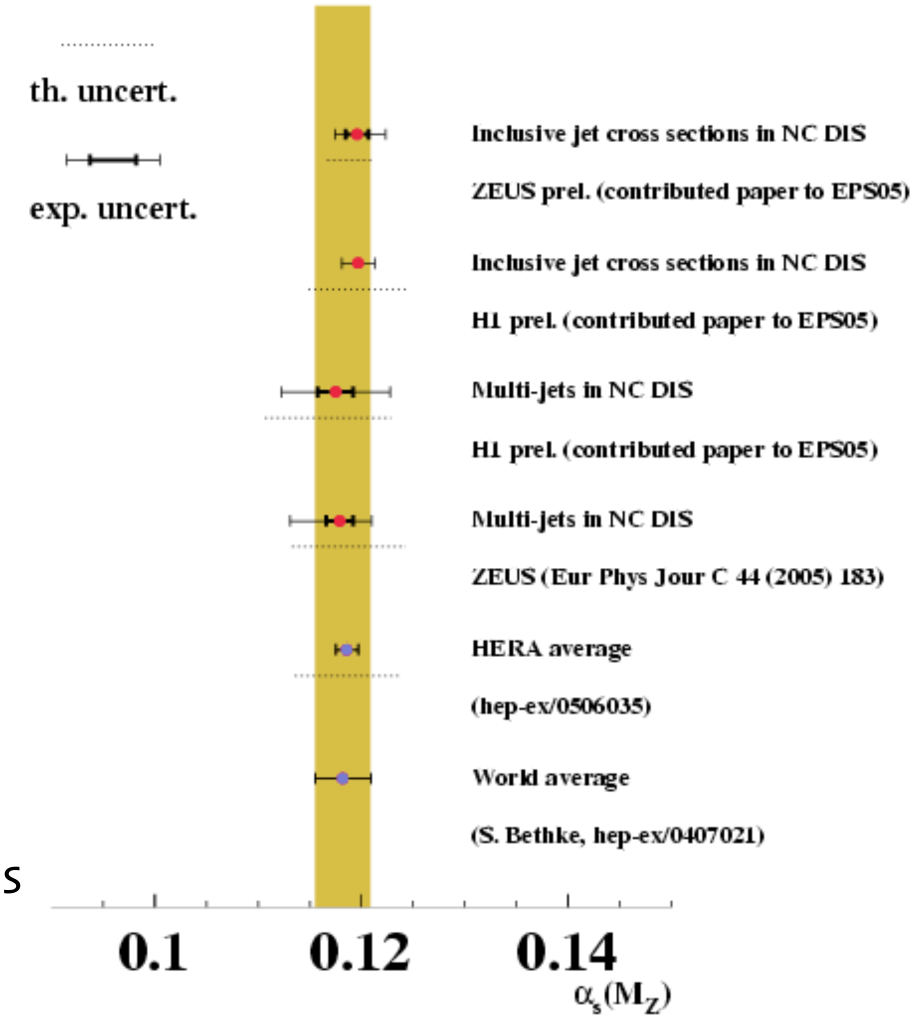
HERA is a unique machine for testing QCD:

Precise measurements of α_s have been made. The measurements agree:

- with one another
- with the world average:
  0.1182 ± 0.0027
- with the HERA average:
  0.1186 ± 0.0011(exp) ± 0.0050(th)

However, limited by theoretical uncertainties at lower Q^2

The energy-scale dependence of α_s has been tested -> in agreement with the running of α_s as predicted by QCD



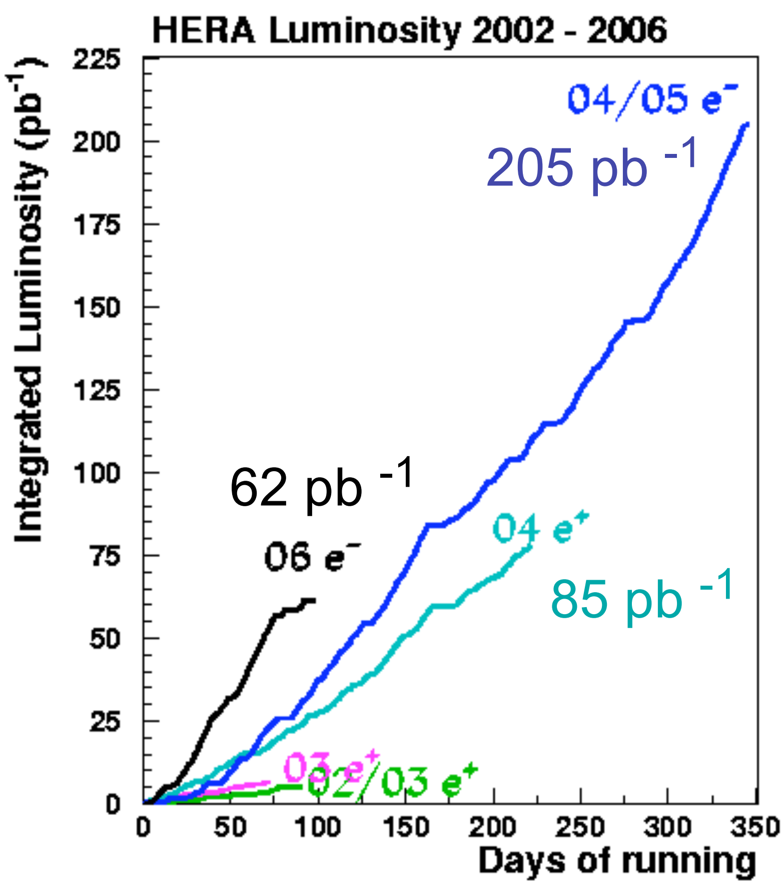
Outlook

Analyses presented here
use HERA I luminosity

HERA II phase:

- Luminosity delivered > 350 pb^{-1}

- higher statistics allow (even) more precise measurements
  ---> especially at higher Q^2/E_T where the theoretical uncertainties are smaller.



Bkp: Measurements of $\alpha_s(M_Z)$

$\alpha_s(M_Z)$ values:

- determined from $d\sigma/dE_{T,B}$(jet) and $d\sigma/dQ^2$ cross sections
- combined fits to single $\alpha_s(M_Z)$ value

ZEUS

- for all $E_{T,B}$ (jet) regions:

$$\alpha_s(M_Z) = 0.1201 \pm 0.0006(\text{stat.})^{+0.0033}_{-0.0038}(\text{exp.})^{+0.0049}_{-0.0032}(\text{th.})$$

- for all Q^2 regions:

$$\alpha_s(M_Z) = 0.1198 \pm 0.0006(\text{stat.})^{+0.0034}_{-0.0039}(\text{exp.})^{+0.0049}_{-0.0033}(\text{th.})$$

- for $Q^2 > 500$ GeV^2 (smallest uncertainties):

$$\alpha_s(M_Z) = 0.1196 \pm 0.0006(\text{stat.})^{+0.0019}_{-0.0025}(\text{exp.})^{+0.0029}_{-0.0017}(\text{th.})$$

H1

- for all E_T regions:

$$\alpha_s(M_Z) = 0.1197 \pm 0.0016(\text{exp.})^{+0.0046}_{-0.0048}(\text{th.})$$