QCD results at HERA

Aspen 2008 Winter Conference

"Revealing the Nature of Electroweak Symmetry Breaking"

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On behalf of the H1 and ZEUS collaborations

The HERA physics, on nucleon structure and the QCD

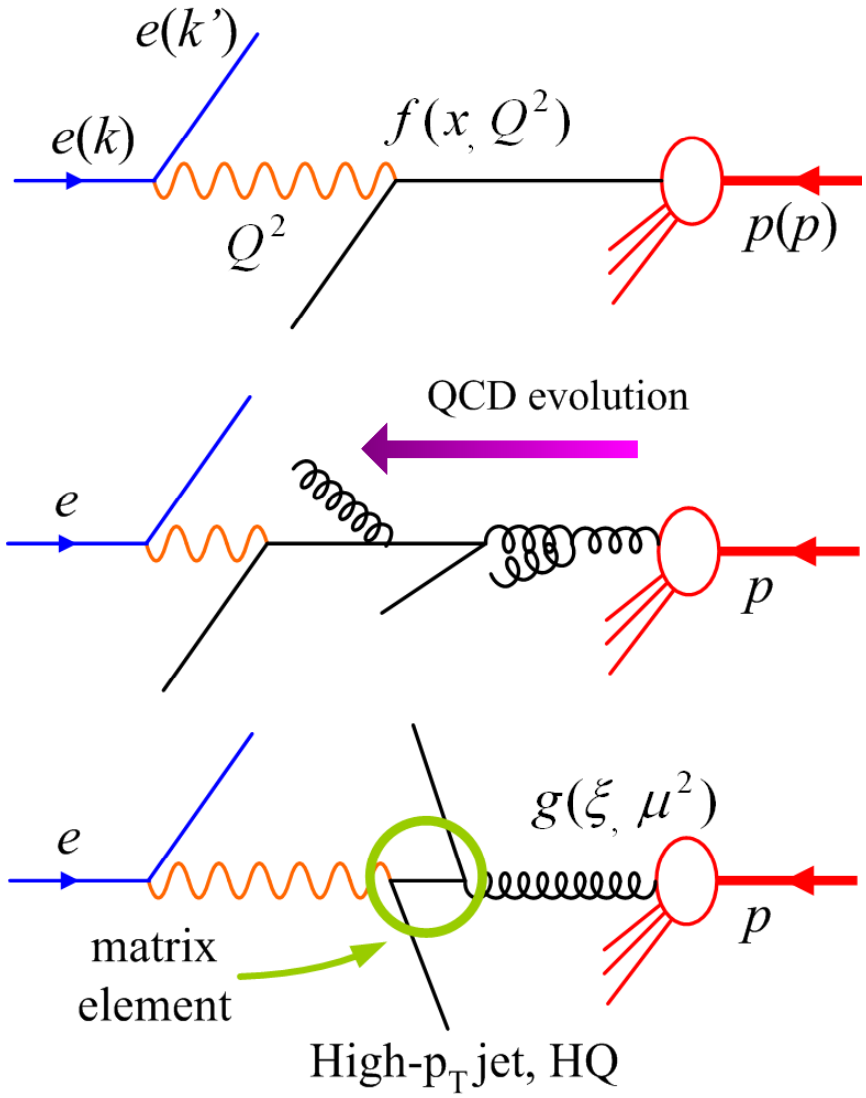
- cross section $\approx F_2$
  $\propto$ quark charge density

$$\frac{d\sigma}{dxdQ^2} = \frac{4\pi\alpha^2}{xQ^4}\left[Y_+ F_2(x,Q^2) - y^2 F_L(x,Q^2)\right]$$

$$Q^2 = -q^2 = -(k-k')^2,\ x = \frac{Q^2}{2p\cdot q},\quad y = \frac{p\cdot q}{p\cdot k}$$

- Gluon from scaling violation
  - DGLAP analysis

- jets, HQ: direct sensitivity to
  - gluon density
  - QCD dynamics



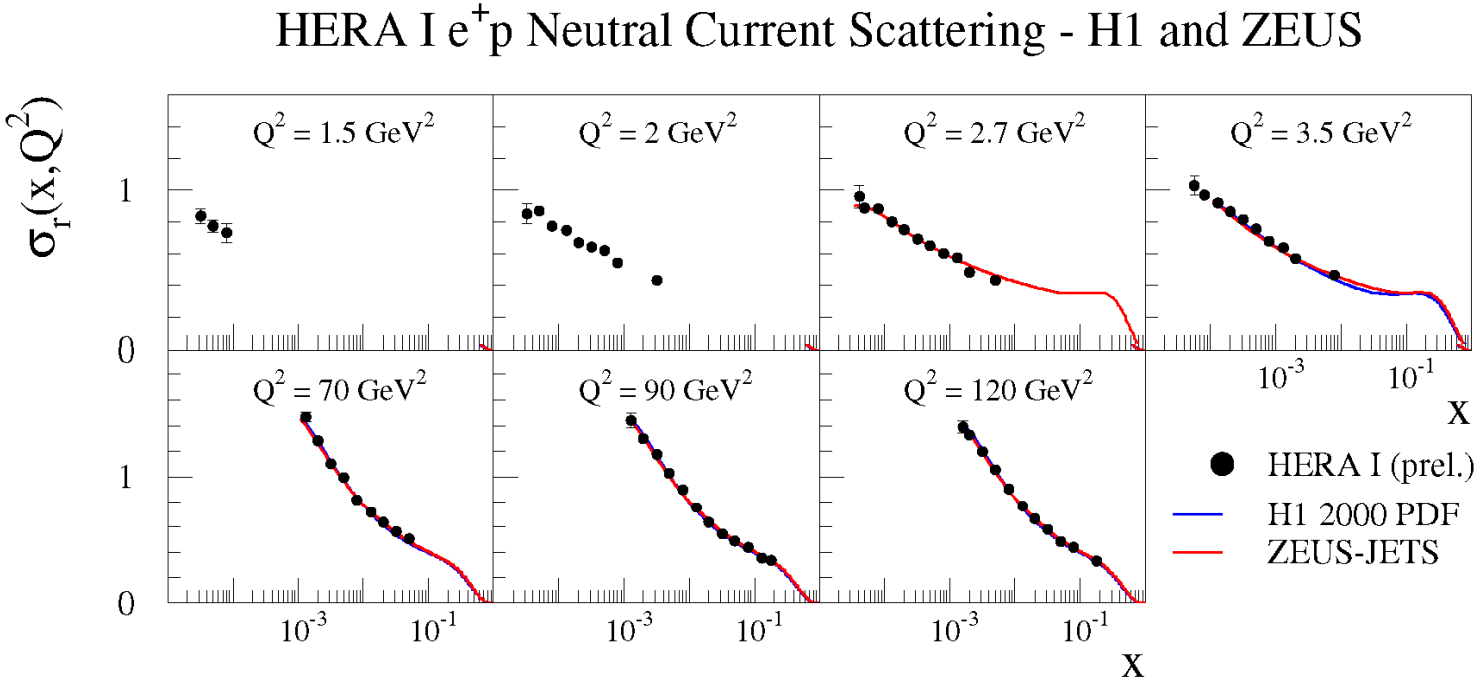
Main questions to HERA QCD study

- Gluon densities from the DGLAP analysis is indirect.
  Can we trust DGLAP and the extracted gluon densities?
- Is the NLO pQCD theory good enough to explain the hadronic final state of the *ep* collisions?
  - These questions are also relevant to the LHC environment

- This talk reviews
  - Low-Q^2 NC cross sections and the pdfs
  - Jet and HQ cross sections
  - α_s determination
  - DIS cross section at high-y and F_L

  Many are combined results of H1 and ZEUS

New: H1+ZEUS combined NC cross sections



Objective 1: gain in precision

Objective 2: understanding the systematic error of each measurement through the difference (cross-calibration!)

- QCD explains data towards very low Q^2 (down to 2.7 GeV^2)
- No large difference between H1 and ZEUS on F_2

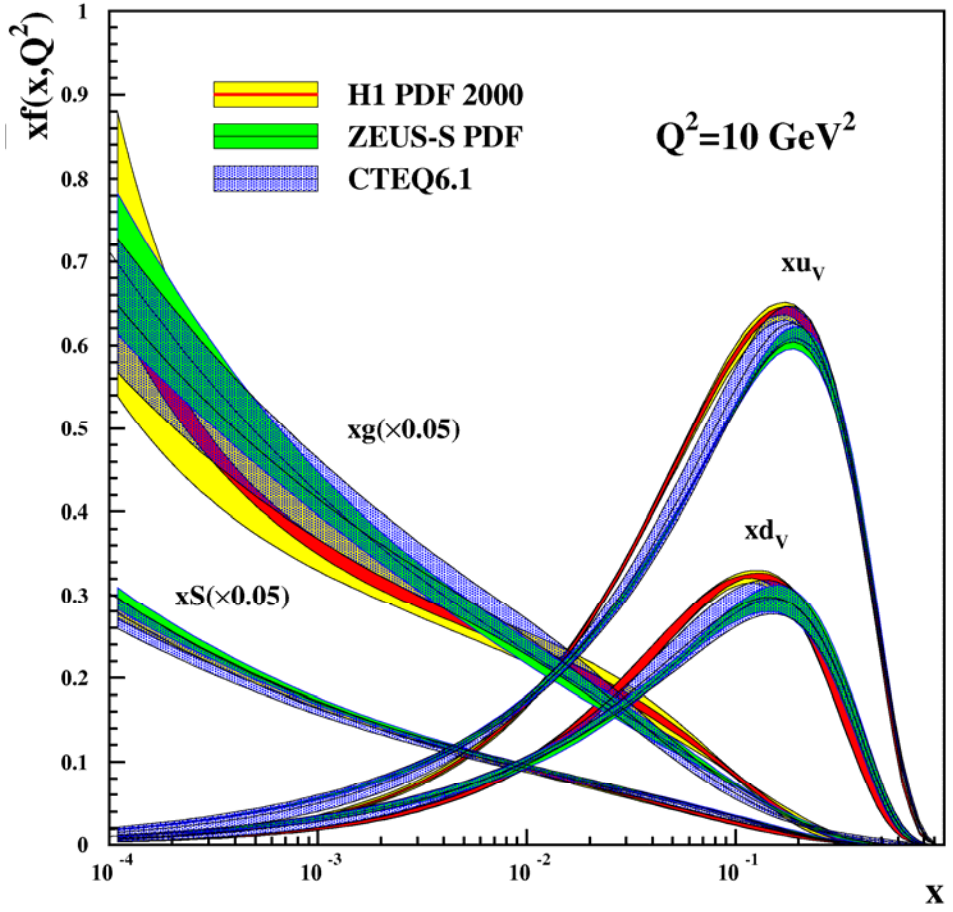
Extracted pdfs from the HERA data

- Gluon densities through the QCD fit

$$g(x) \propto \frac{d}{d \ln Q^2} F_2(x, Q^2)$$

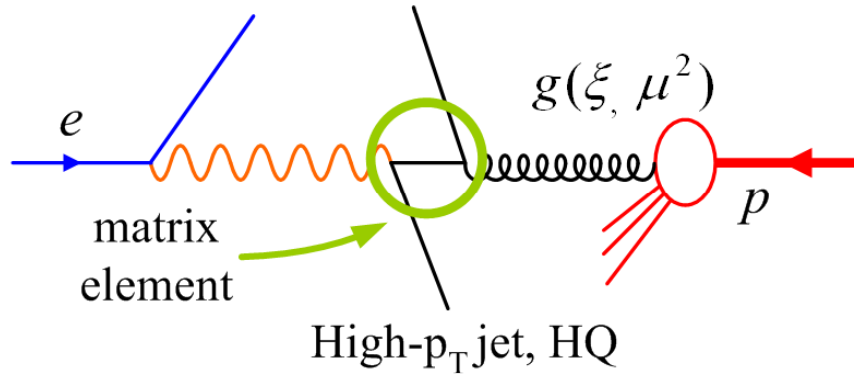
- Precision at $x < 10^{-2}$
  - 10% at $Q^2 = 10$ GeV^2
  - < 5% for $Q^2 > 200$ GeV^2

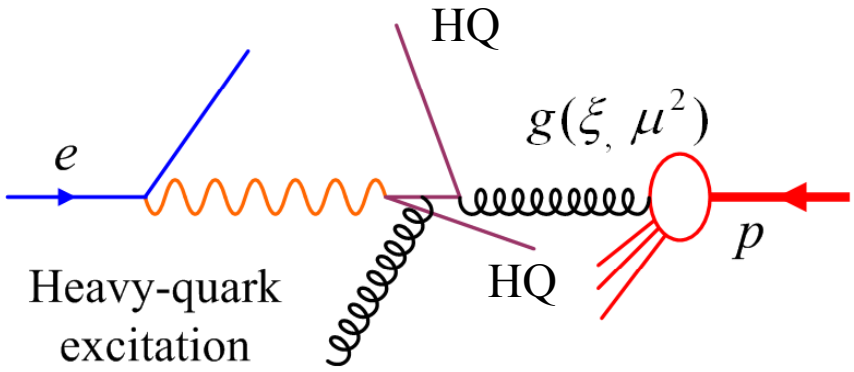
- More direct method to cross-check →



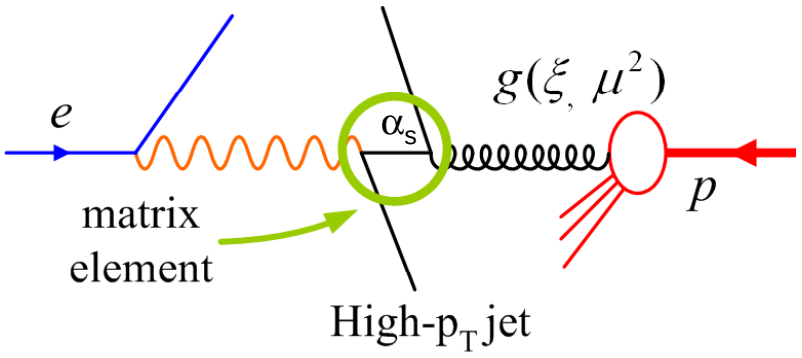
Obtaining gluon densities using high-p_T partons in hadronic final state

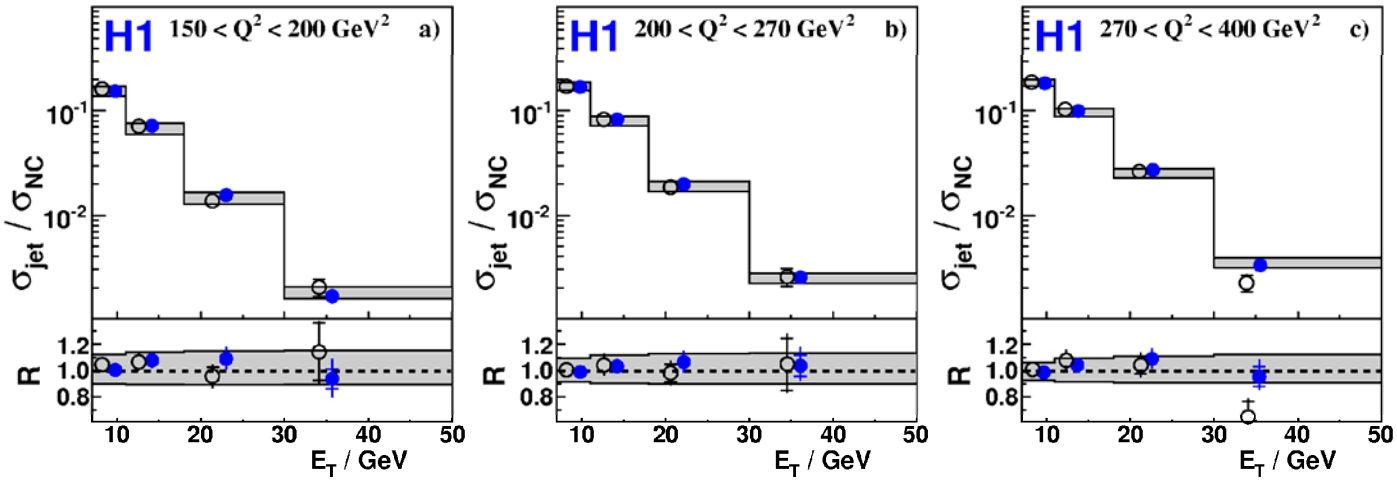
- High-p_T jets and HQs: mostly produced by gluons in the initial state
- Higher-order processes may change the cross sections significantly
- The theory should describe the data, if we use hadronic final state data for extracting gluons





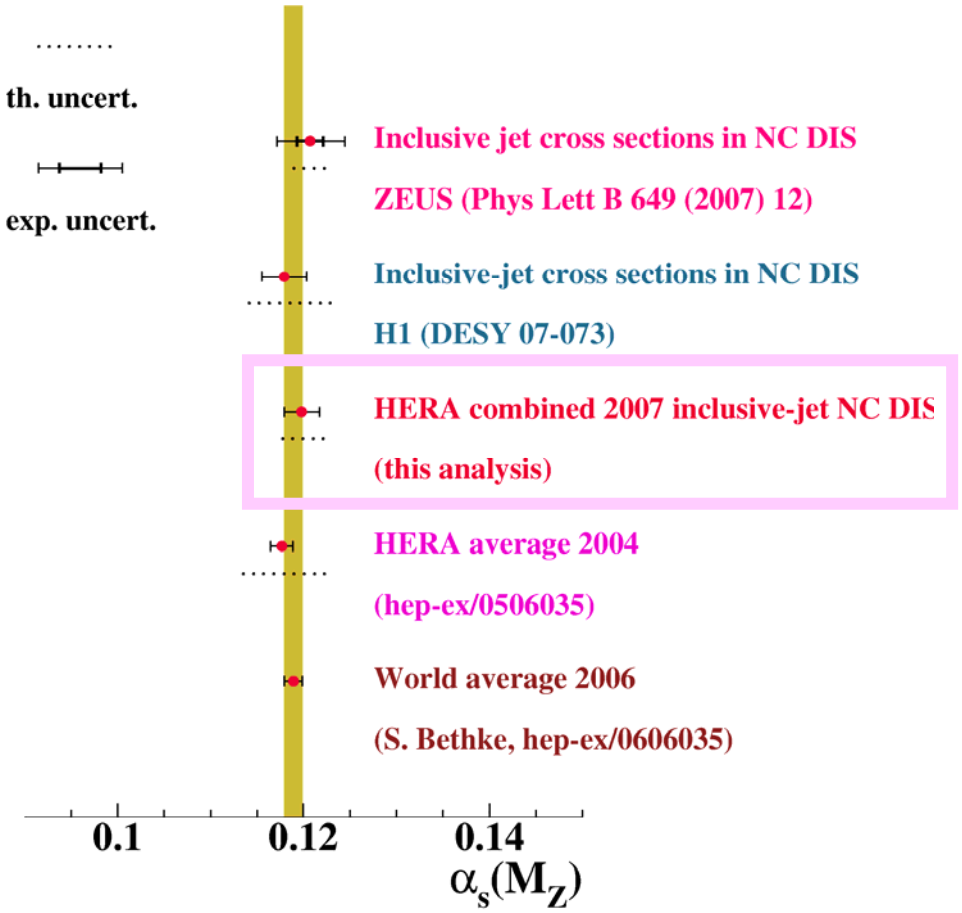
Jets in high-Q^2 DIS

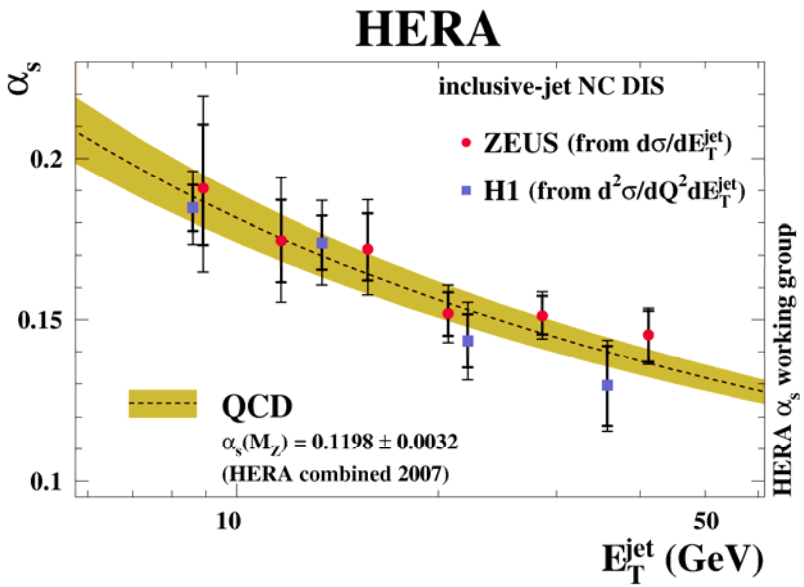




- Inclusive and dijet cross sections well described by NLO for $Q^2 > 100$ GeV^2: ready to be used for QCD studies
  - α_s
  - QCD fit for parton densities

αs from jets



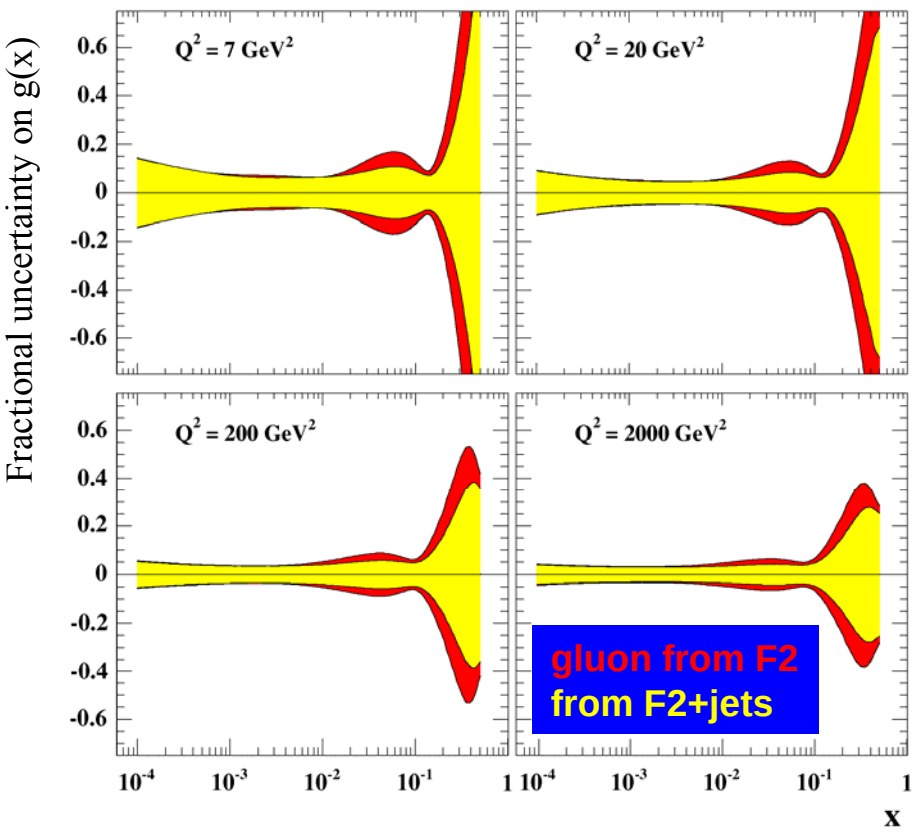


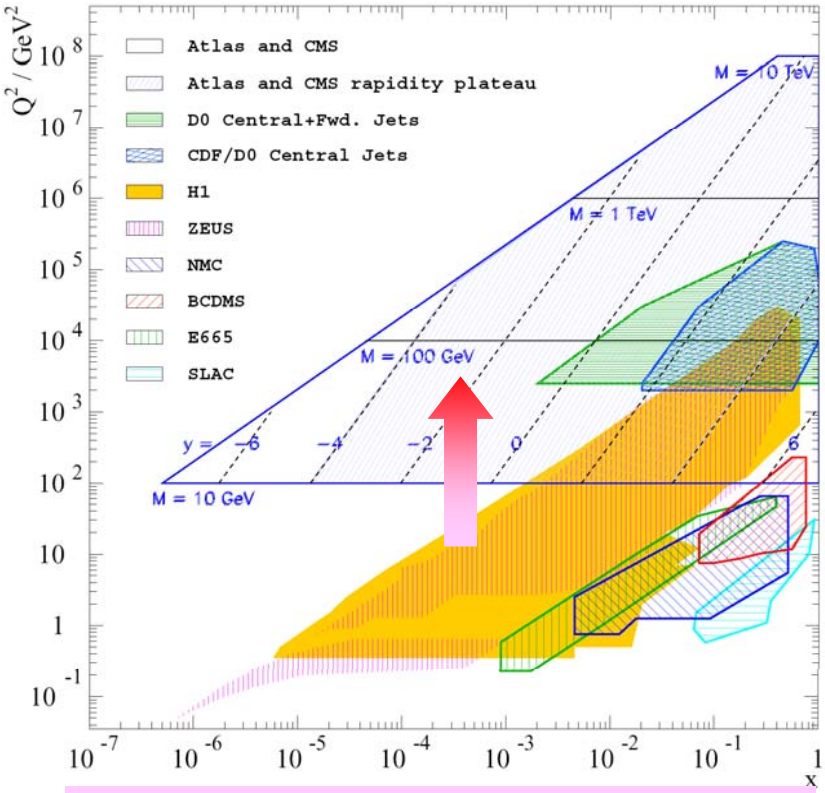
- **First combined H1+ZEUS α_s** using high-Q^2 inclusive jet
- Running from HERA data alone
- Experimental error small

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

Very competitive measurement

Determining gluons using jet data

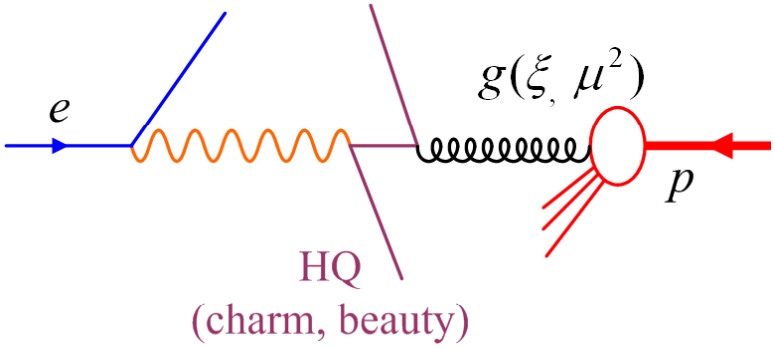




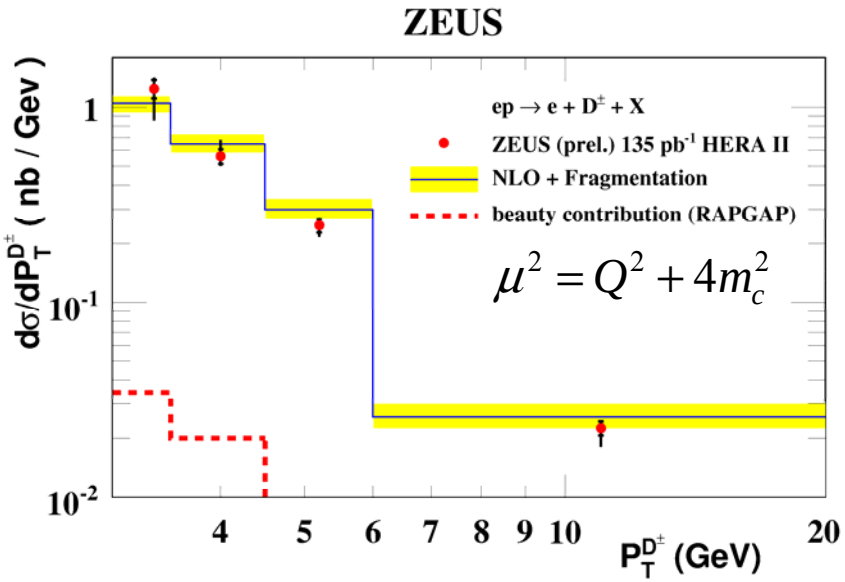
HERA PDF: right x range for LHC
Extrapolation in Q^2

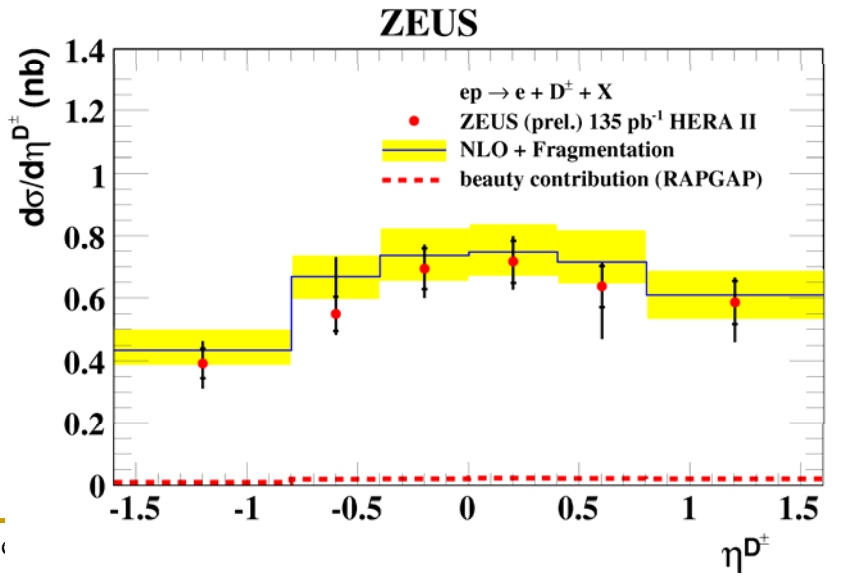
- Jet data improves gluon densities
- uncertainty still large at high-x = forward / backward at the LHC
  - HERA-II data, Tevatron high-E_T jets, LHC high-E_T and forward jets …

Heavy flavour production in DIS



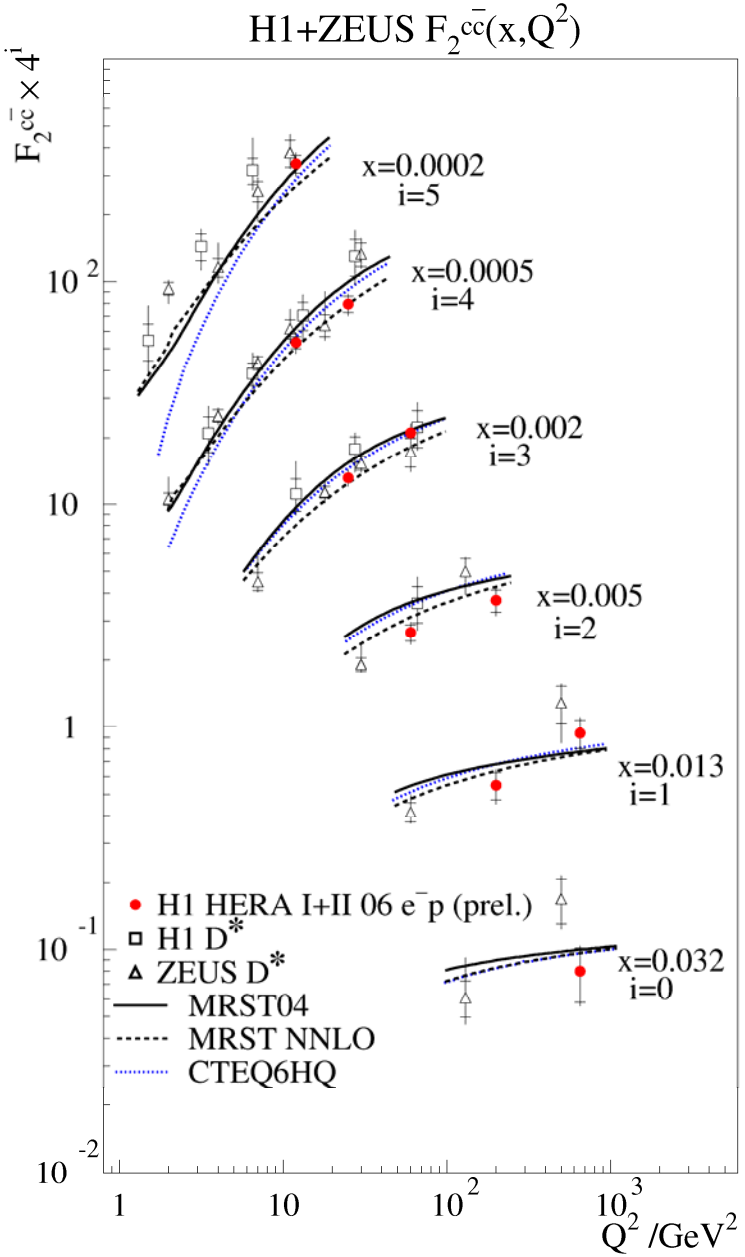
- Quark pair production – dominated by Boson-gluon fusion process
  - High sensitivity to gluons
- Multi-scale process (Q^2, p_T(HQ), m_{HQ})
- Charm production (right): Description by NLO: ~ OK



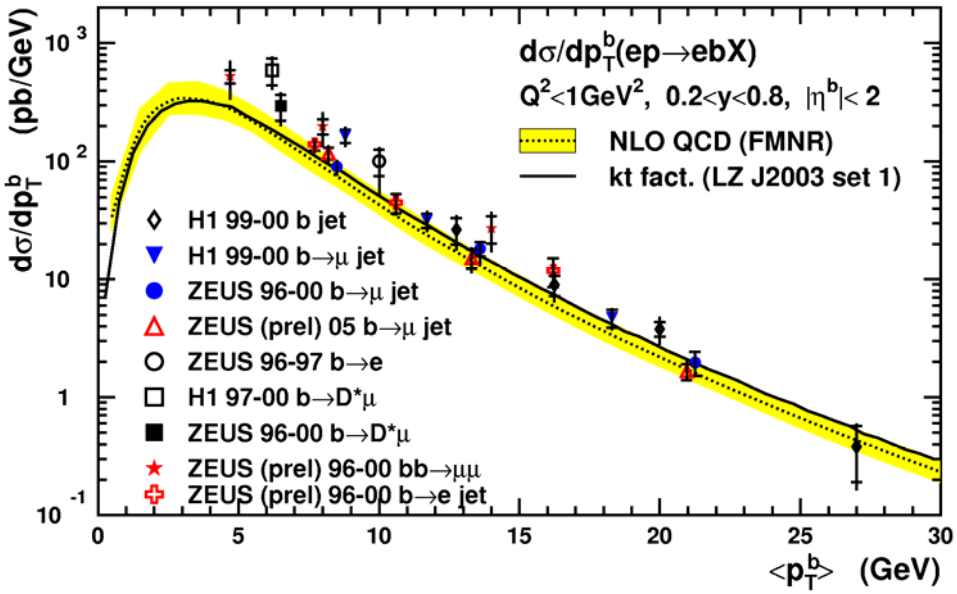


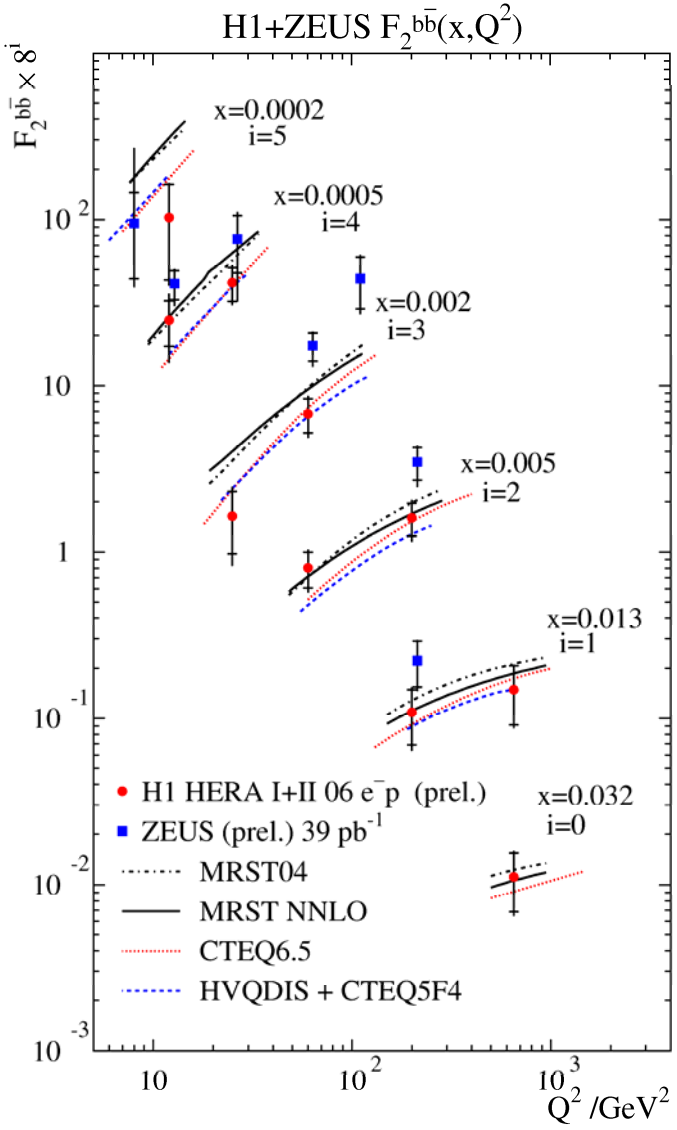
F_2^{cc}: Charm contribution to the DIS cross section

- Description fairly good
  - Give us a confidence that gluon from the QCD fit is trustful
- F_2^{cc} is not yet included in the QCD fit for the gluon pdf
  - Theoretical treatment in the QCD fit is non-trivial
- More HERA-II data to be analysed, to give insight to models, pdfs



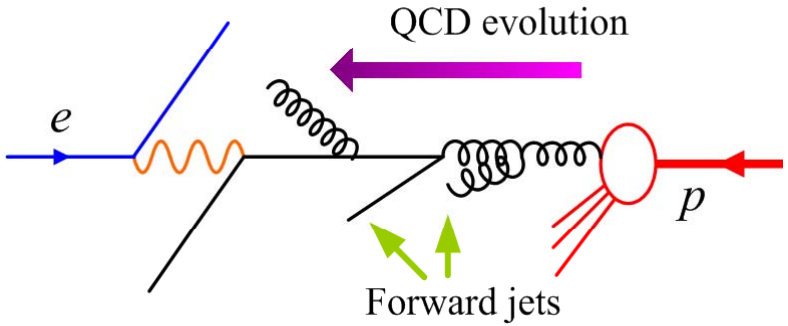
Beauty in photoproduction and DIS

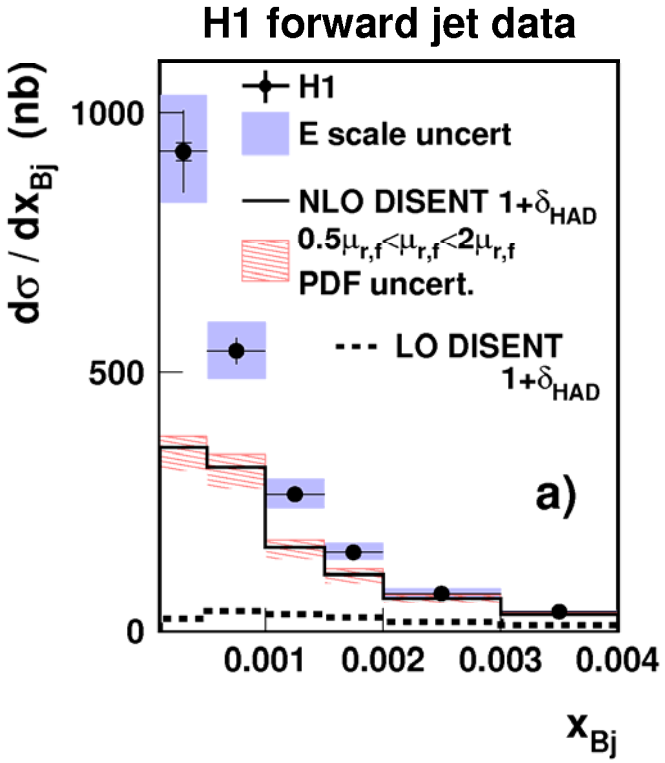


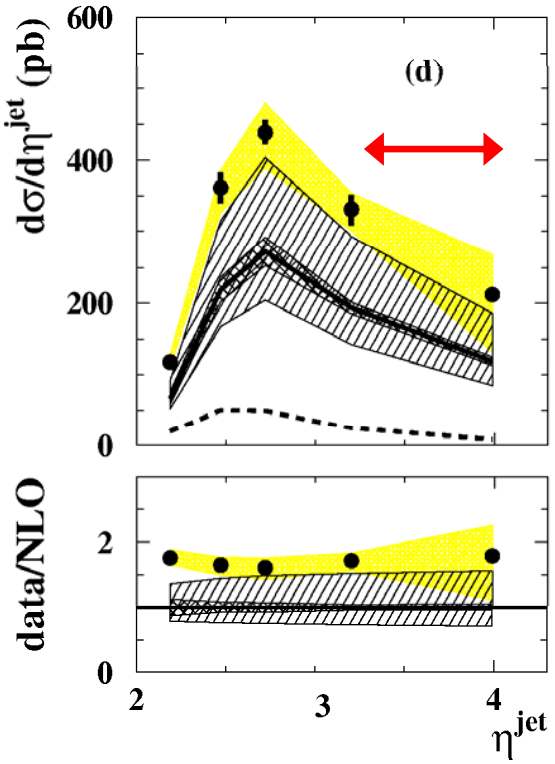


- Photoproduction: some excess at low-p_T?
  Yet to see if the NLO is good enough
- DIS: large variety between models
  - HERA-II data to be analysed, for precision

Forward jet: checking DGLAP, NLO







ZEUS data: very forward jet up to $\eta = 4.3$

- Parton production in the middle of the "ladder" : excess observed
- Dynamics beyond DGLAP? Just missing higher order?
  - In either case, a possible manifestation of a (minor) problem in the picture

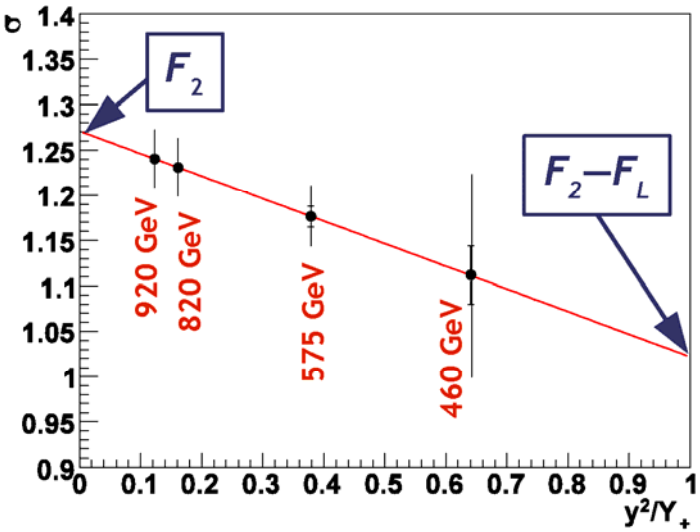
We are doing our best: F_L at HERA-II

$$\frac{d\sigma}{dxdQ^2} = \frac{4\pi\alpha^2}{xQ^4}\left[Y_+ F_2(x,Q^2) - y^2 F_L(x,Q^2)\right]$$

- The only inclusive DIS cross section directly connected to gluons

$$F_L = \frac{\alpha_S}{4\pi} x^2 \int_x^1 \frac{dz}{z^3}\left[\frac{16}{3}F_2 + 8\sum_q e_q^2\left(1-\frac{x}{z}\right) z g(z)\right]$$

- F_L is significant at high-y ($\propto y^2$)
  - Determined from the y-dependence of the cross section at the same (x,Q^2) points
    → Need data from different CM energy

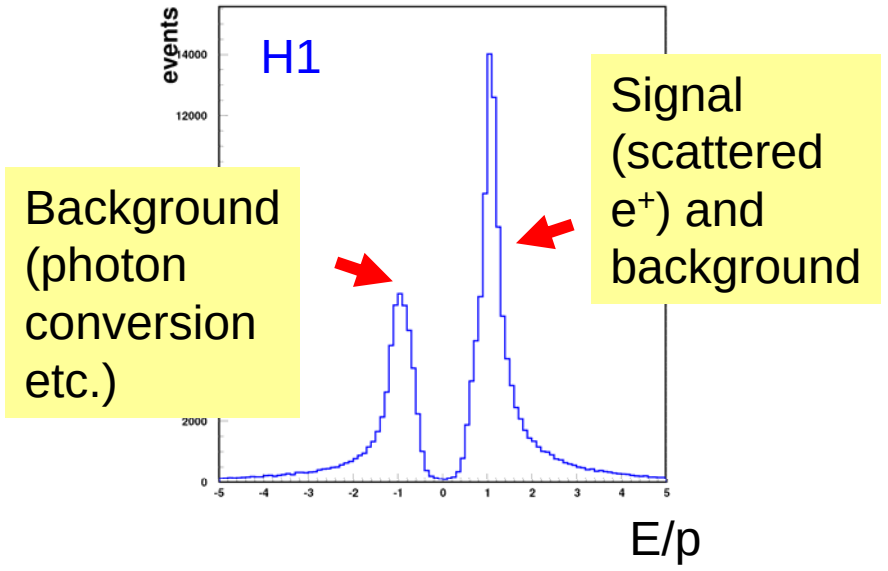


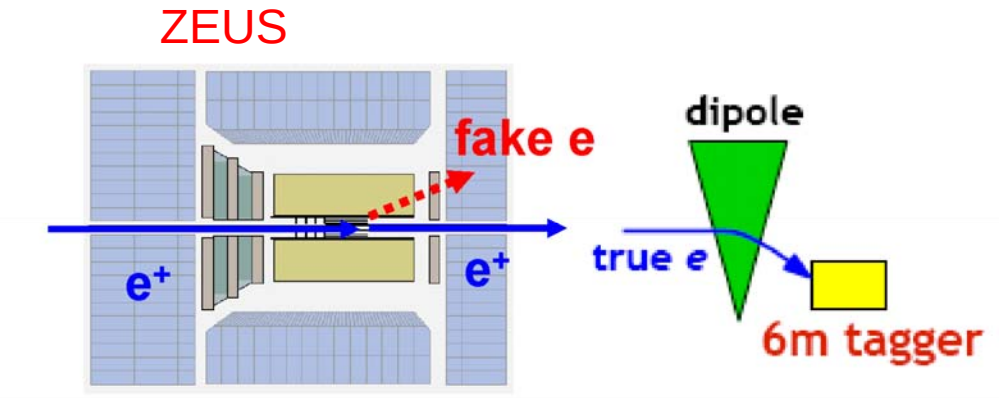
Points: simulation of ZEUS with projected precision

- Data with low CM energy taken in spring 2007
  - 14 pb^{-1} @ Ep = 460 GeV
  - 7 pb^{-1} @ Ep = 575 GeV

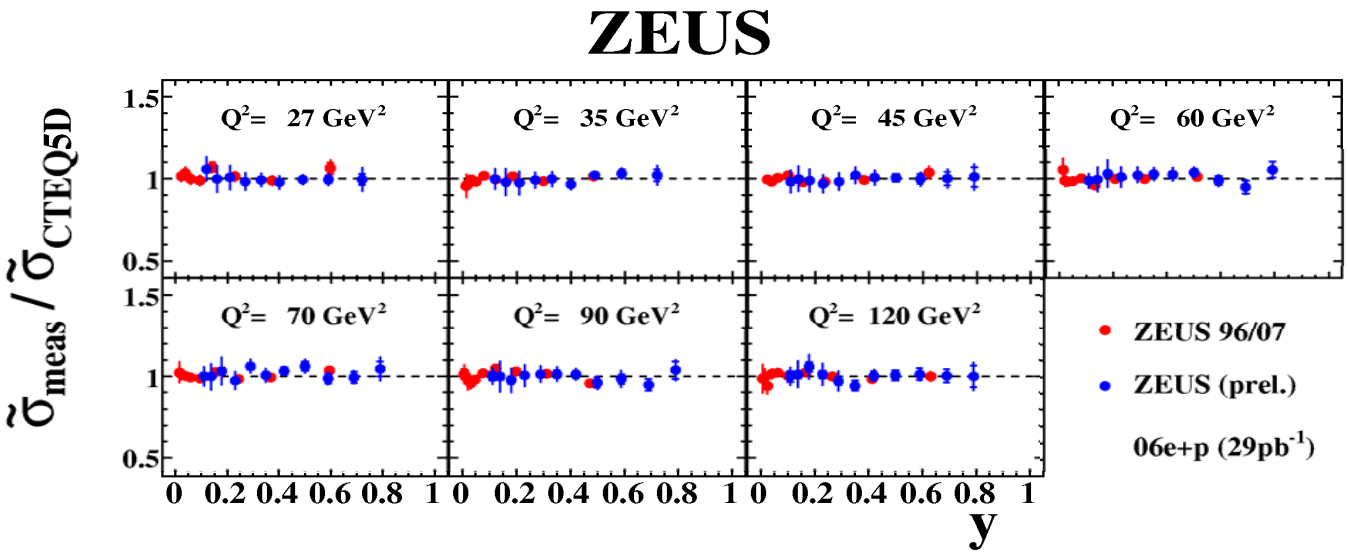
Technical issues in measuring F_L

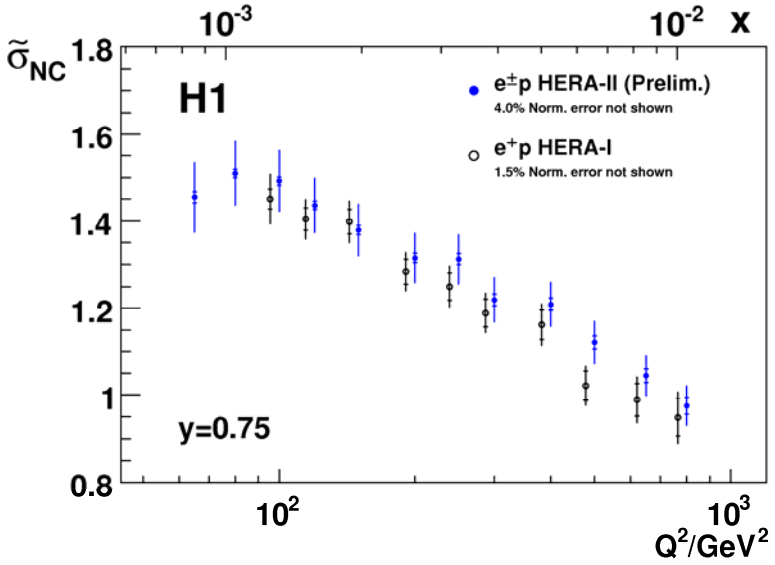
- High-y: energy of scattered electron is low
- Difficult to separate from photoproduction background
  - hadrons (especially photons from π^0) mimics scattered e
  - H1: charge asymmetry measured by BST
    (backward silicon tracker)
  - ZEUS: subtraction by tagged photoproduction sample





High-y cross sections @ nominal energy

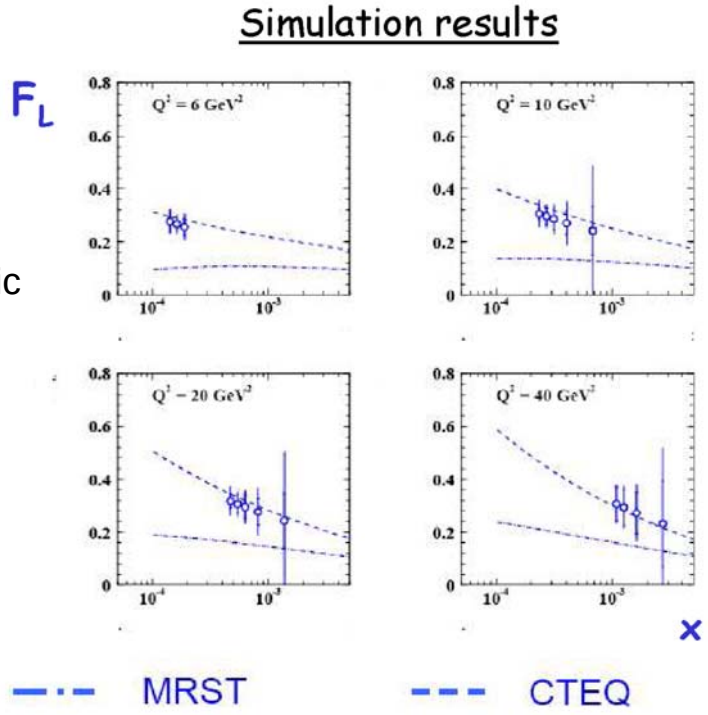




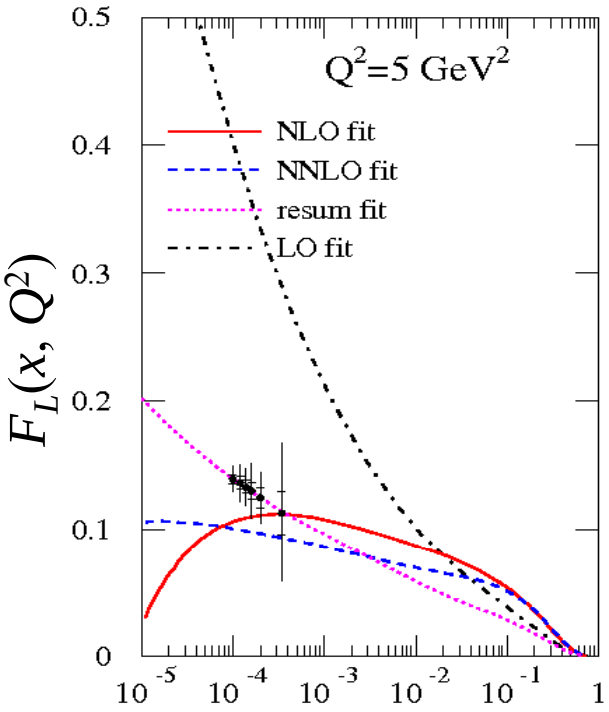
- Demonstrating the technical feasibility of F_L measurement
- Real F_L from HERA, hopefully in several months

F_L: projected uncertainty, theoretical prediction

from the talk
in EPS2007,
by N. Raicievic
(H1)



from proceedings
DIS2004 conf.
by Robert Thorne



overlaid: H1 simulation of projected uncertainty in F_L

- F_L gives an independent information on the low-x (low-Q^2) parton evolution
  - cross-check of gluons extracted from the DGLAP analysis
  - F_L shape also depending on the scheme of pQCD calculations

Conclusion

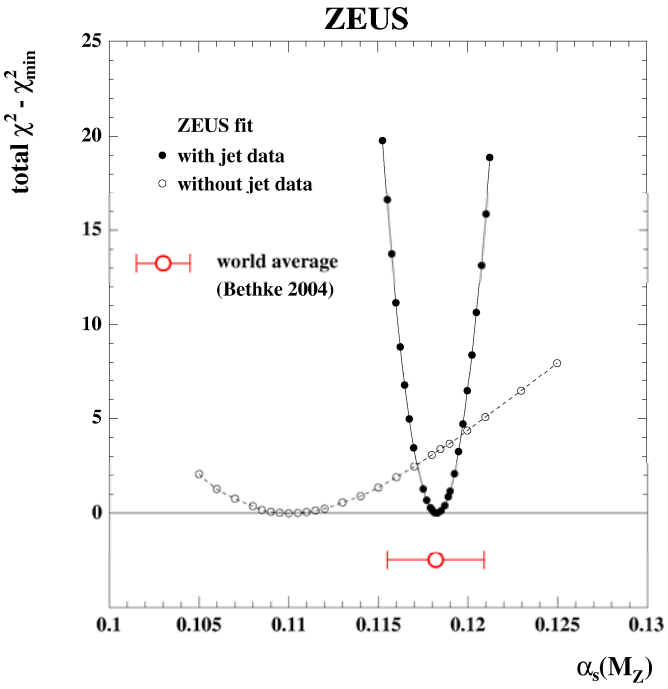
- HERA has shown that, processes at high Q^2 or high p_T:
  - The inclusive DIS cross sections
  - High-p_T jets and HQ production

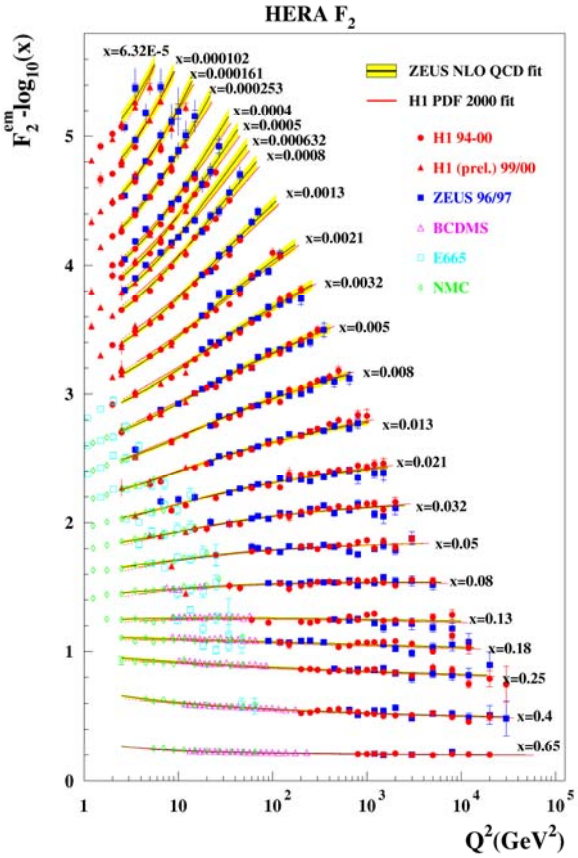
  … can be explained by DGLAP+NLO ME
  → we can trust PDFs from HERA to be used at the LHC

- Applicability of such a paradigm to
  - low-Q^2: appears to be OK (F_2 DIS)
  - low-E_T: sometimes shows deviation

- More insight on the low-Q^2 parton dynamics through F_L, to be presented from the HERA data

α_s from scaling violation





- α_s from the QCD fit
  - F2 + jet: consistent with the world average
  - F2 alone prefers to have lower α_s – like in the DIS data from fixed target
- Again an indication of the physics beyond DGLAP?

I did not cover …

- Spectroscopy results
- Scaling violation in fragmentation function
- Multi-parton phenomena
  - Multijet and multi-parton interactions in photoproduction and DIS
  - Diffractive cross section and QCD factorisation
  - Diffractive Upsilon production and pQCD model
- etc.

Data from lower E_T – prompt photon

- High-precision measurement with large statistics of HERA-II
- NLO seems not perfect
  - … tend to show excess at low-E_T, low-Q^2
- The NLO calculation are not perfect at low-E_T, low-Q^2