

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

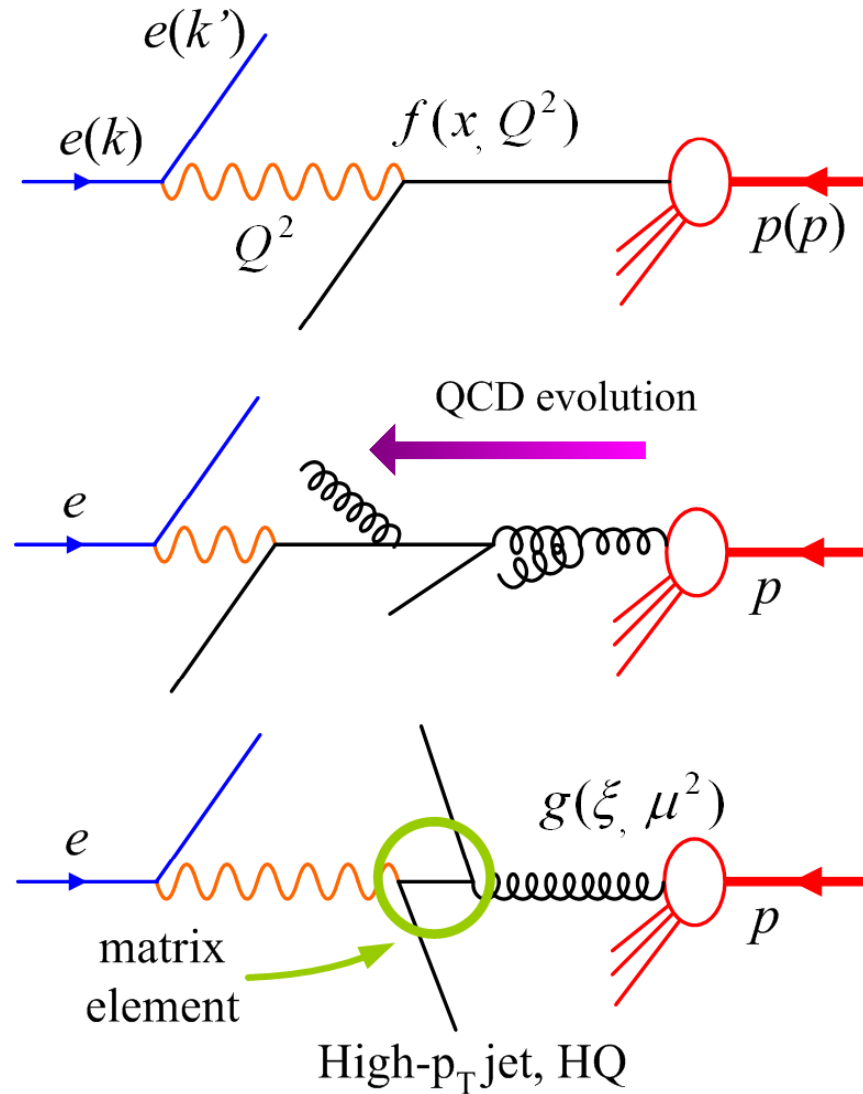
The HERA physics, on nucleon structure and the QCD

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

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

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

- Gluon from scaling violation
 - DGLAP analysis
- jets, HQ: direct sensitivity to
 - gluon density
 - QCD dynamics



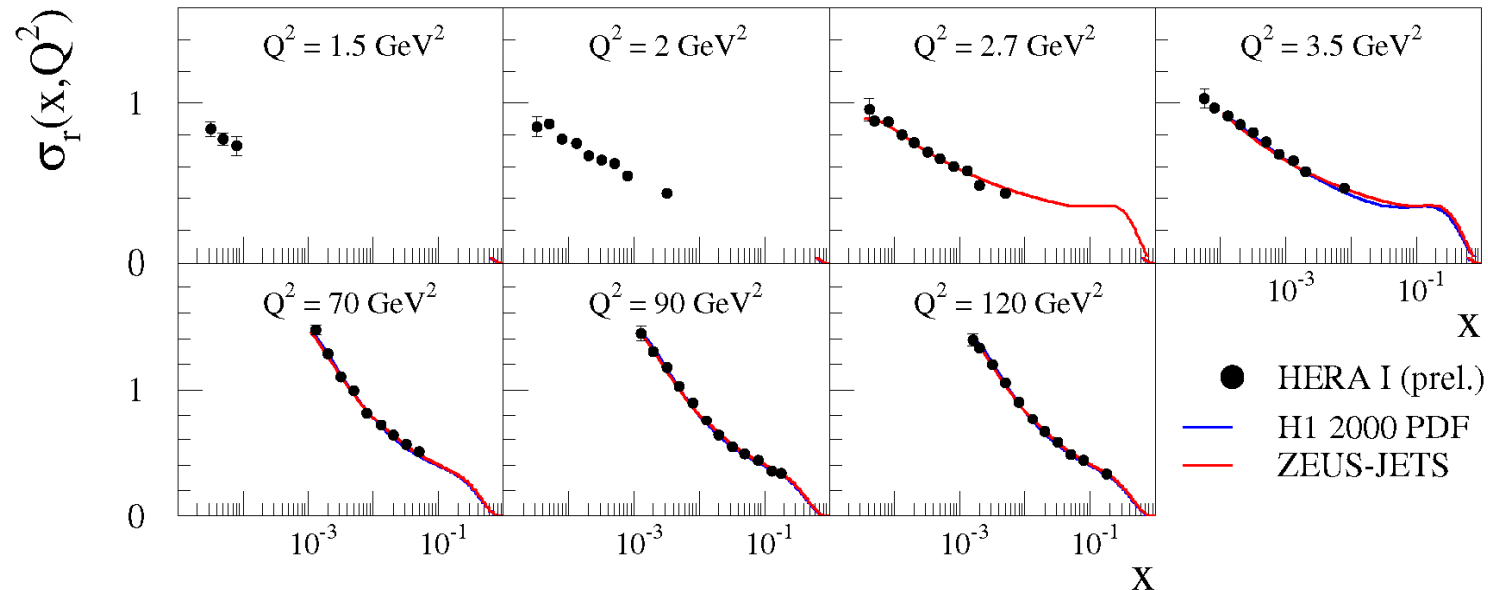
Main questions to HERA QCD study

- 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

HERA I e^+p Neutral Current Scattering - H1 and ZEUS



Objective 1: gain in precision

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

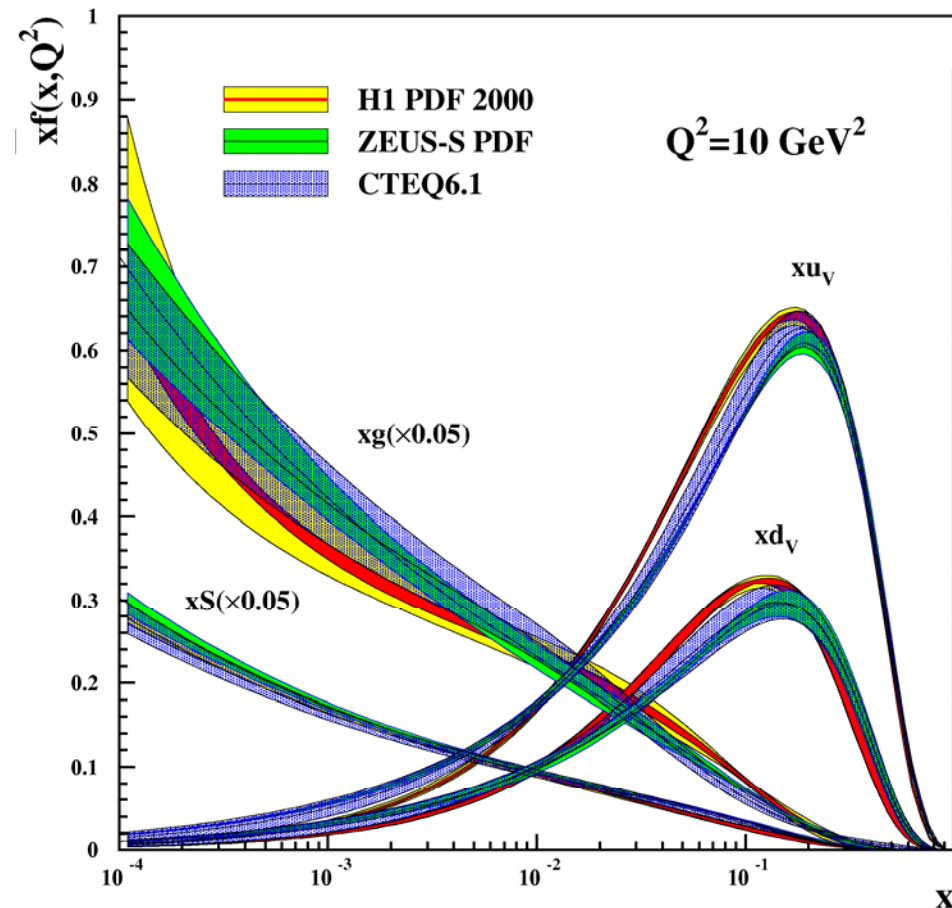
- QCD explains data towards very low Q^2 (down to 2.7 GeV^2)
- No large difference between H1 and ZEUS on F_2

Extracted pdfs from the HERA data

- Gluon densities through the QCD fit

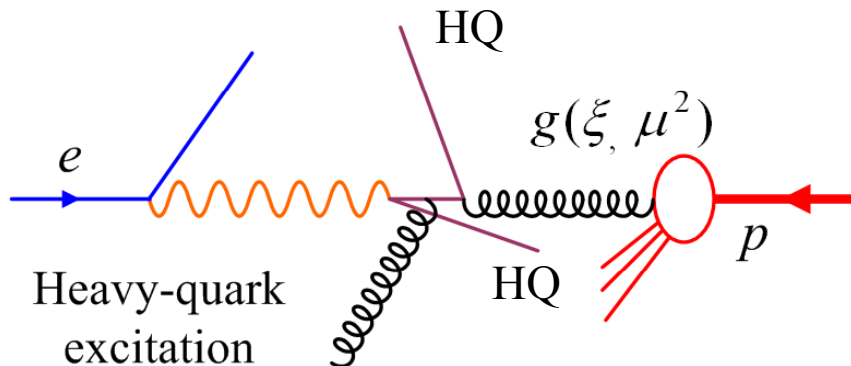
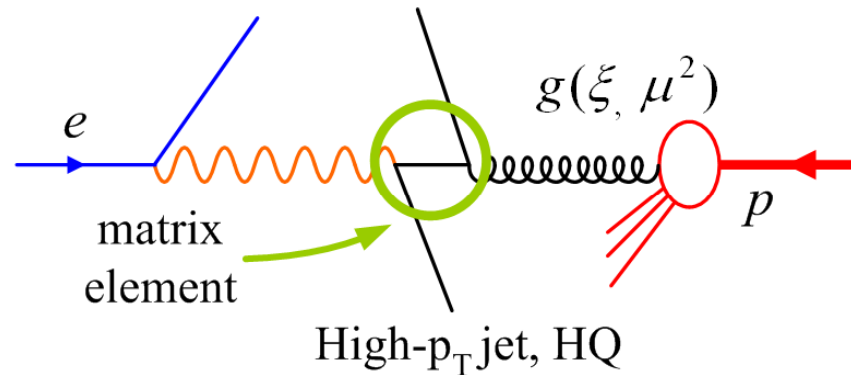
$$g(x) \propto \frac{d}{d \ln Q^2} F_2(x, Q^2)$$

- Precision at $x < 10^{-2}$
 - 10% at $Q^2 = 10 \text{ GeV}^2$
 - < 5% for $Q^2 > 200 \text{ GeV}^2$
- More direct method to cross-check →

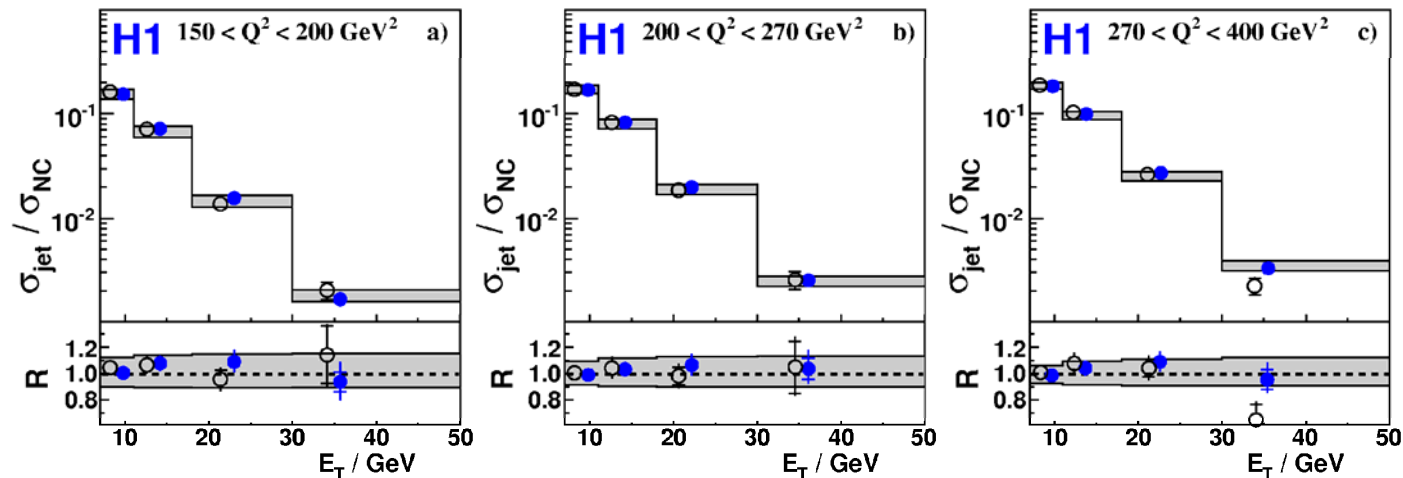
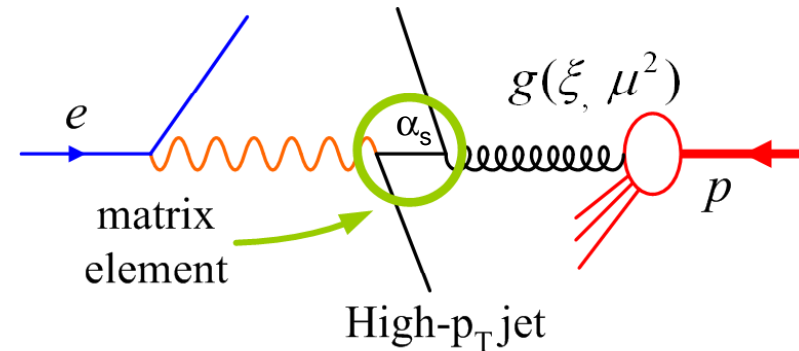


Obtaining gluon densities using high- p_T partons in hadronic final state

- 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

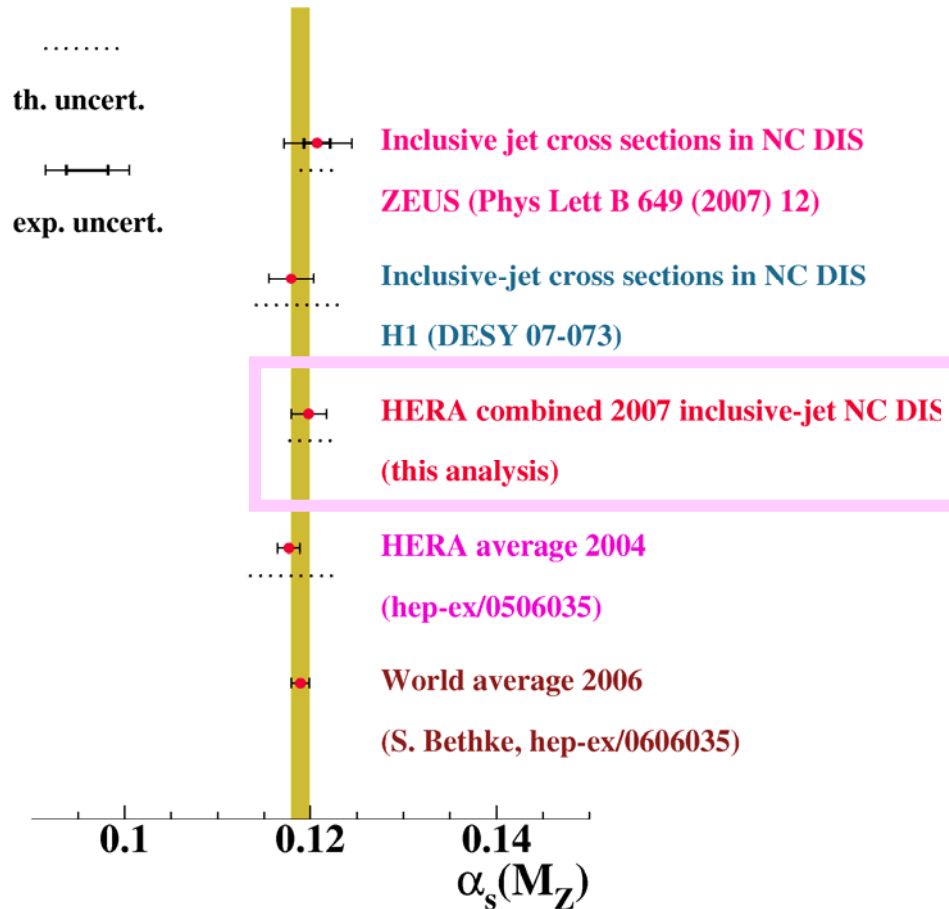


Jets in high- Q^2 DIS

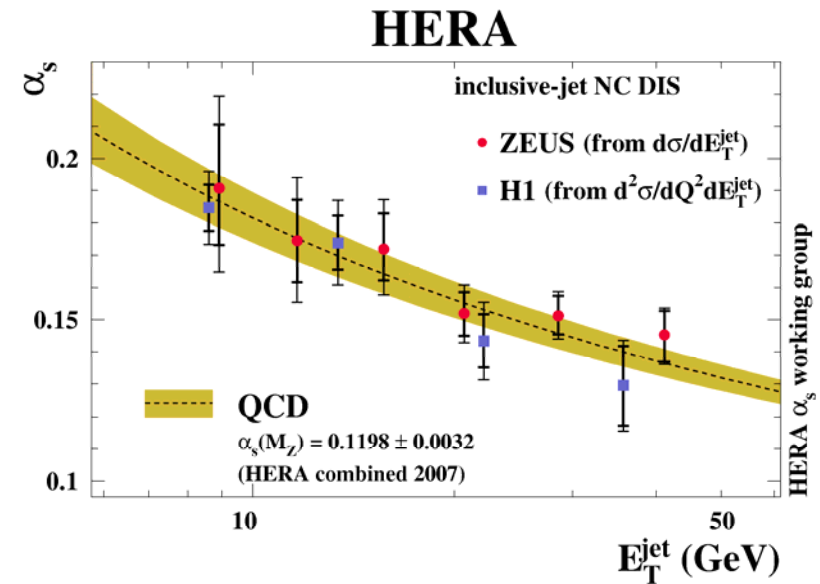


- Inclusive and dijet cross sections well described by NLO for $Q^2 > 100 \text{ GeV}^2$: ready to be used for QCD studies
 - α_s
 - QCD fit for parton densities

α_s from jets



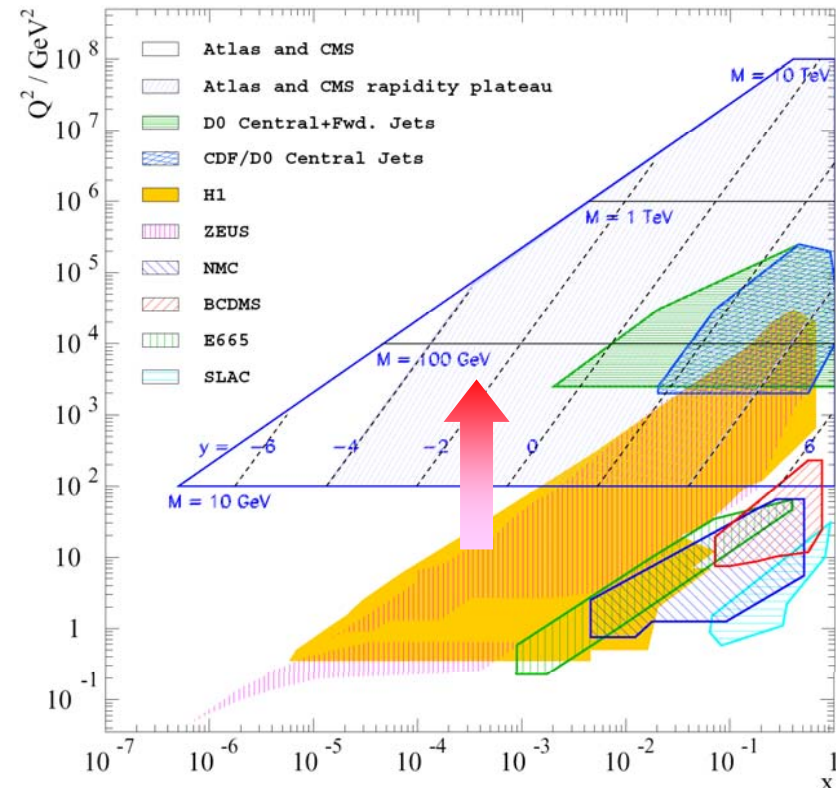
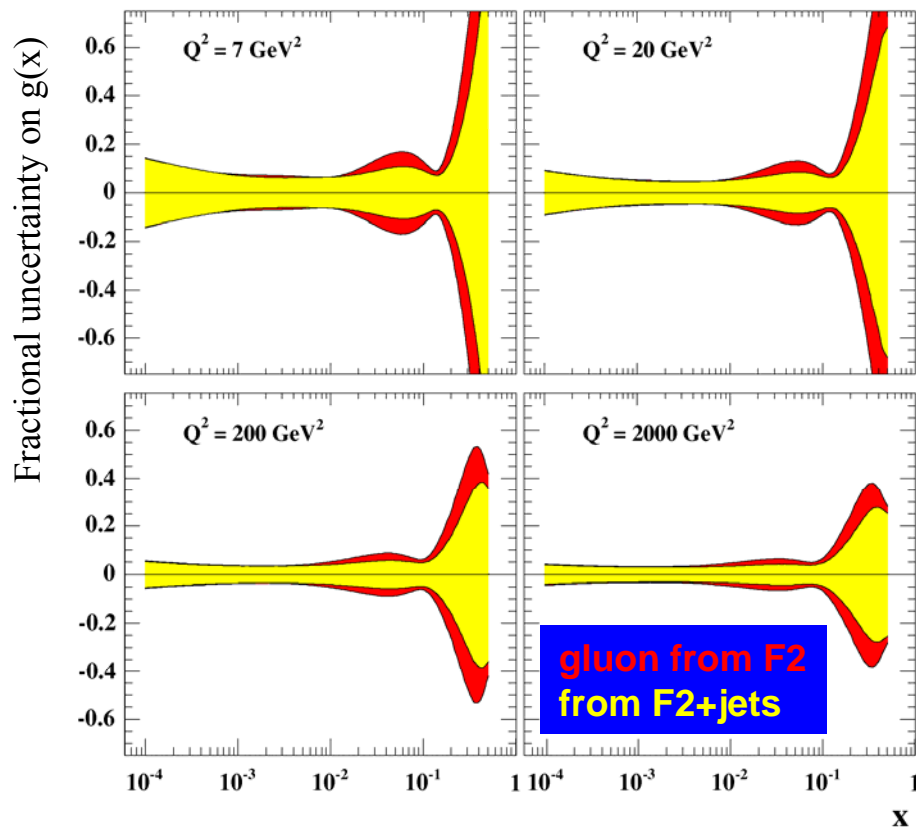
$$\alpha_s(m_Z) = 0.1198 \pm 0.0019(\text{exp.}) \pm 0.0026(\text{th.})$$



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

Very competitive measurement

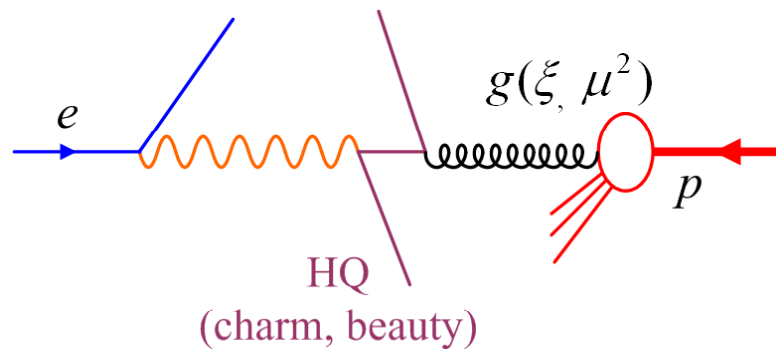
Determining gluons using jet data



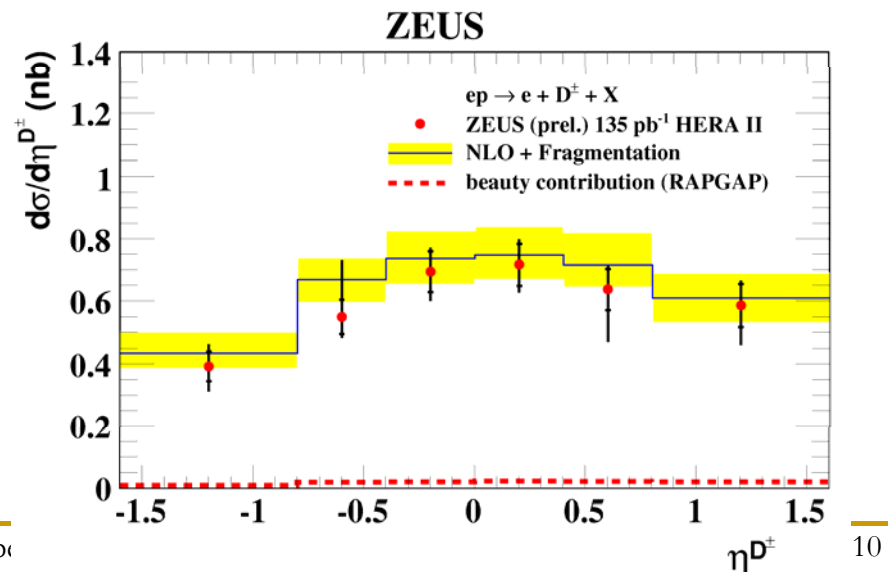
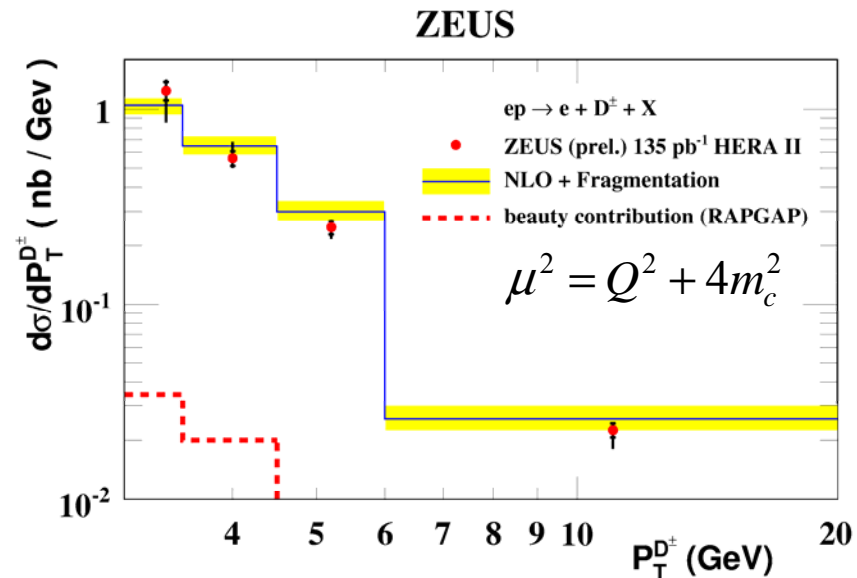
HERA PDF: right x range for LHC
Extrapolation in Q^2

- 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

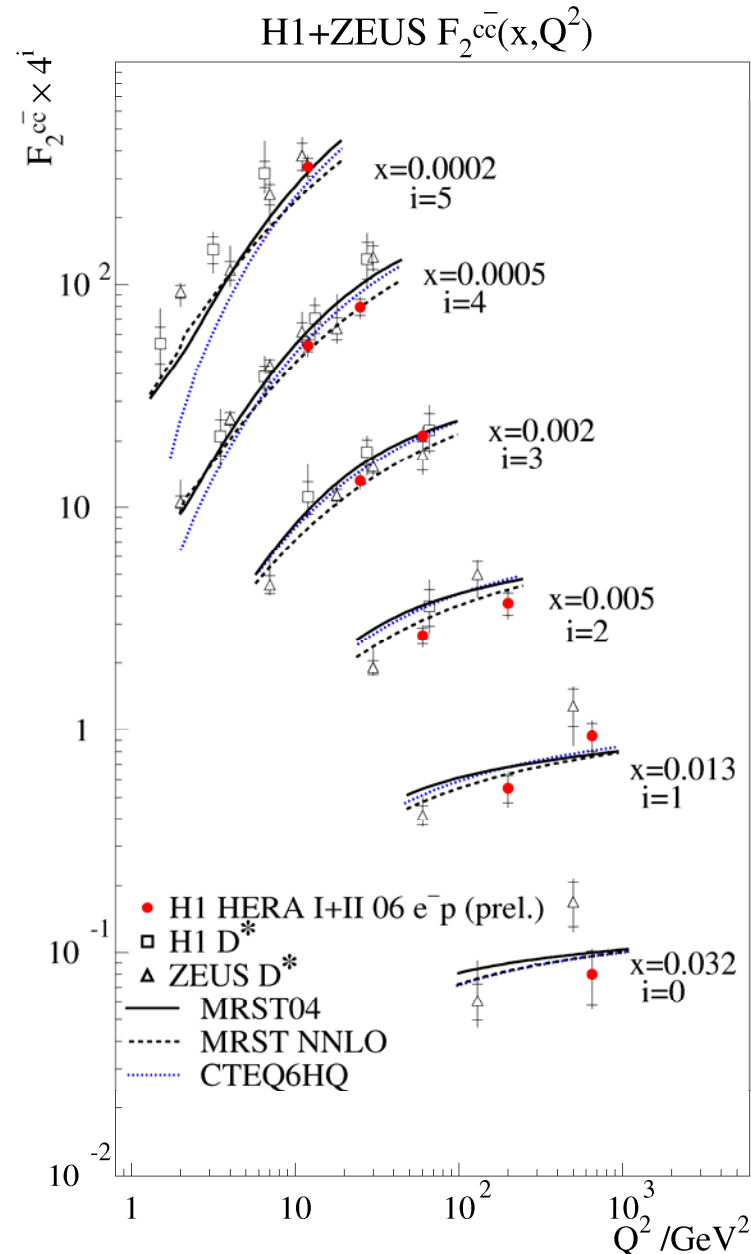


- Quark pair production – dominated by Boson-gluon fusion process
 - High sensitivity to gluons
- Multi-scale process (Q^2 , $p_T(\text{HQ})$, m_{HQ})
- Charm production (right): Description by NLO: $\sim \text{OK}$

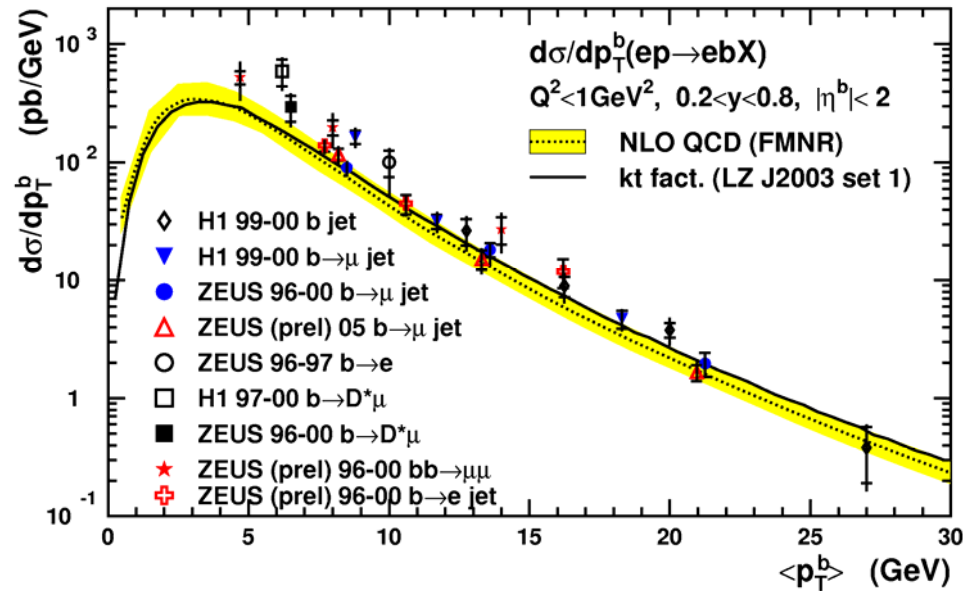


F_2^{cc} : Charm contribution to the DIS cross section

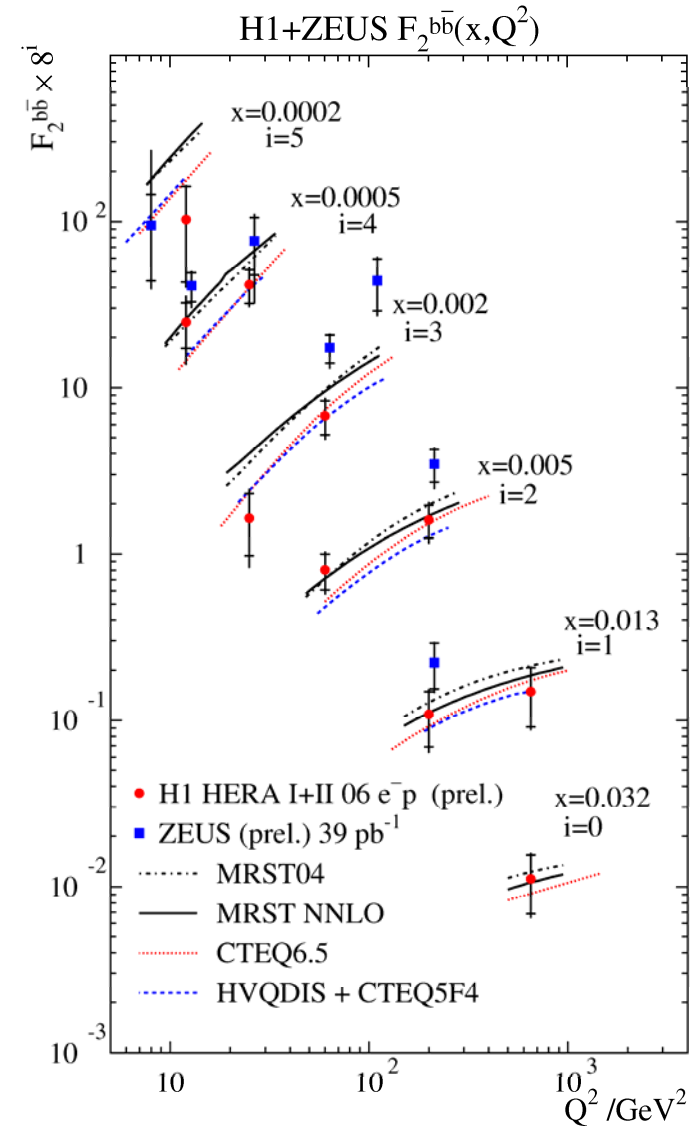
- Description fairly good
 - Give us a confidence that gluon from the QCD fit is trustful
- F_2^{cc} is not yet included in the QCD fit for the gluon pdf
 - Theoretical treatment in the QCD fit is non-trivial
- More HERA-II data to be analysed, to give insight to models, pdfs



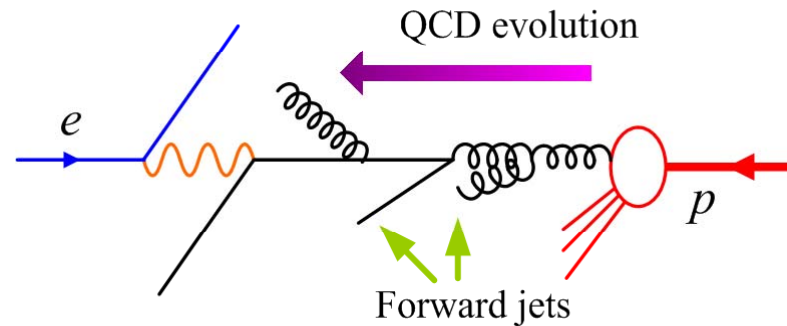
Beauty in photoproduction and DIS



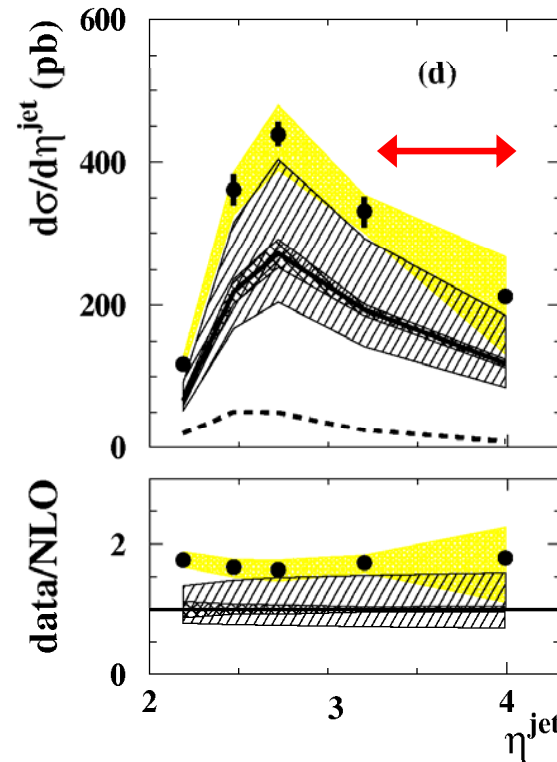
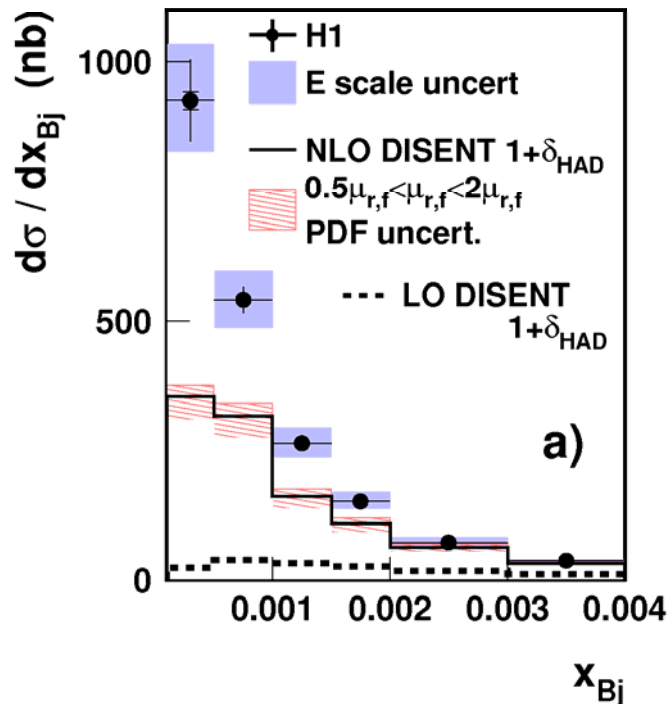
- Photoproduction: some excess at low- p_T ?
 Yet to see if the NLO is good enough
- DIS: large variety between models
 - HERA-II data to be analysed, for precision



Forward jet: checking DGLAP, NLO



H1 forward jet data



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

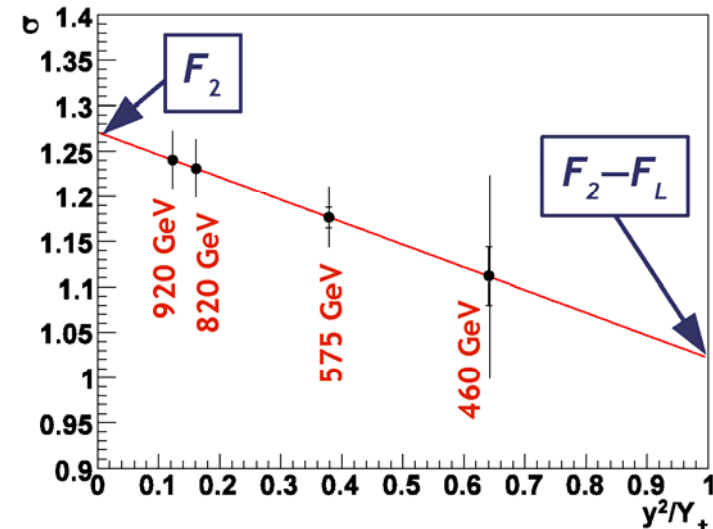
$$\frac{d\sigma}{dx dQ^2} = \frac{4\pi\alpha^2}{xQ^4} \left[Y_+ F_2(x, Q^2) - y^2 \underline{F_L(x, Q^2)} \right]$$

- The only inclusive DIS cross section directly connected to gluons

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

- 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

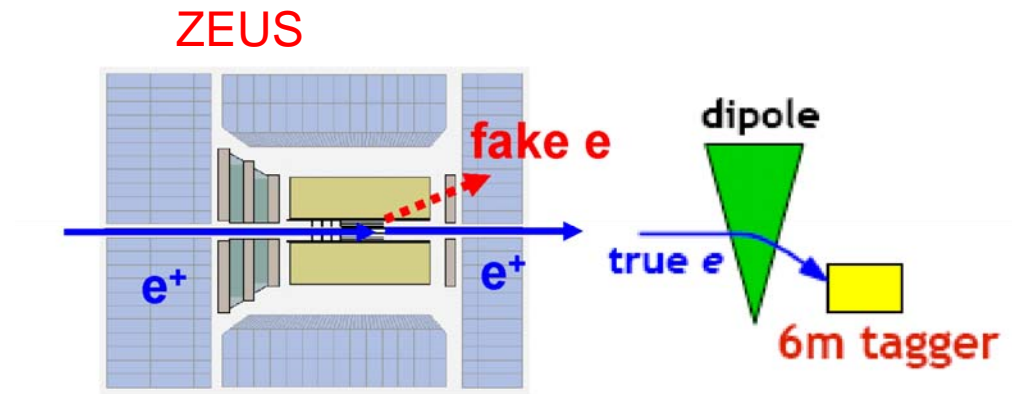
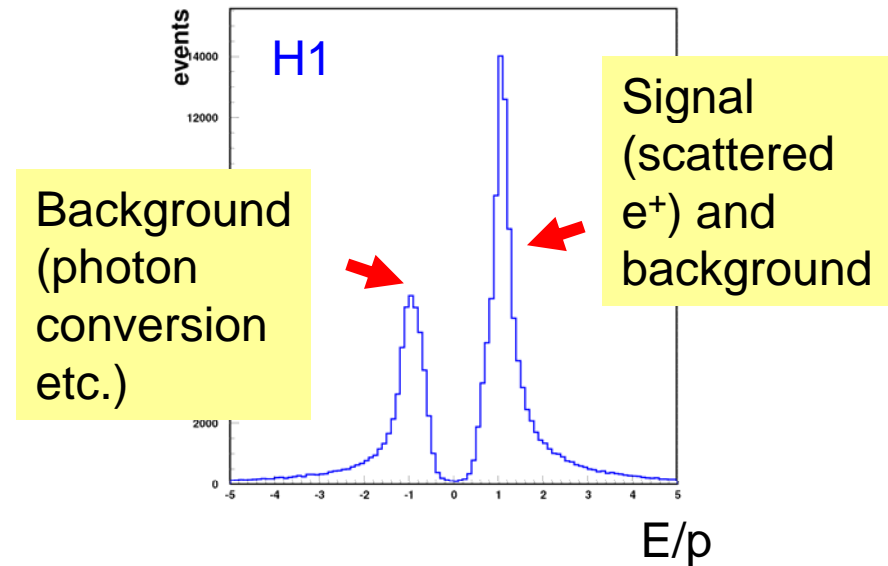
- Data with low CM energy taken in spring 2007
 - 14 pb^{-1} @ $E_p = 460 \text{ GeV}$
 - 7 pb^{-1} @ $E_p = 575 \text{ GeV}$



Points: simulation of ZEUS
with projected precision

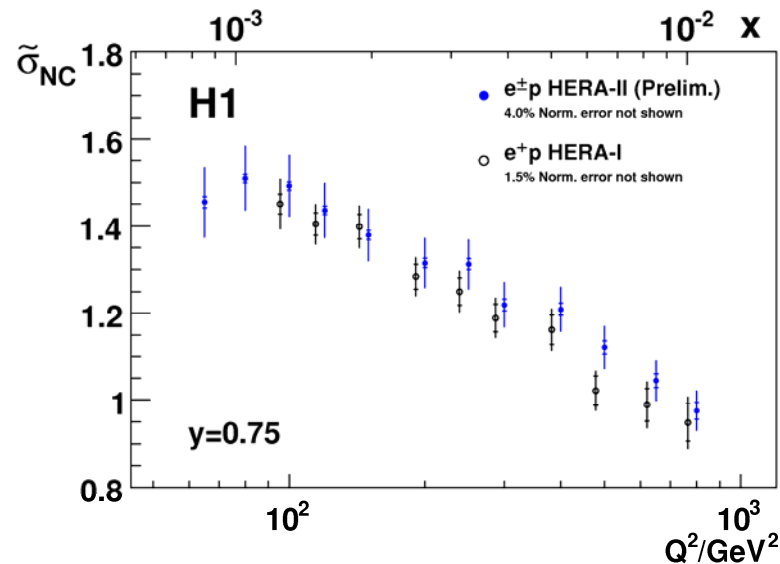
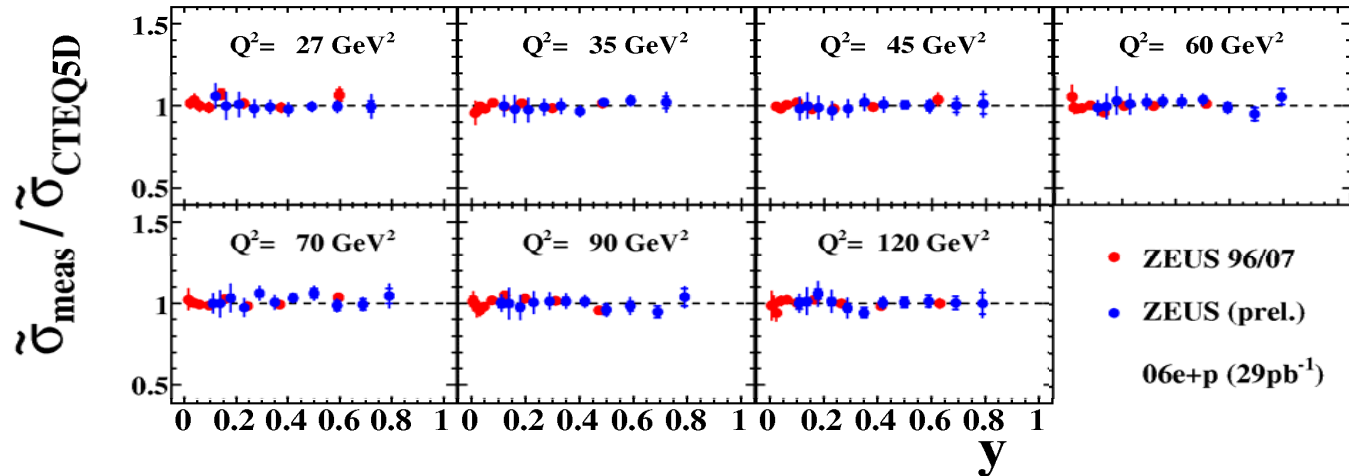
Technical issues in measuring F_L

- 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

ZEUS

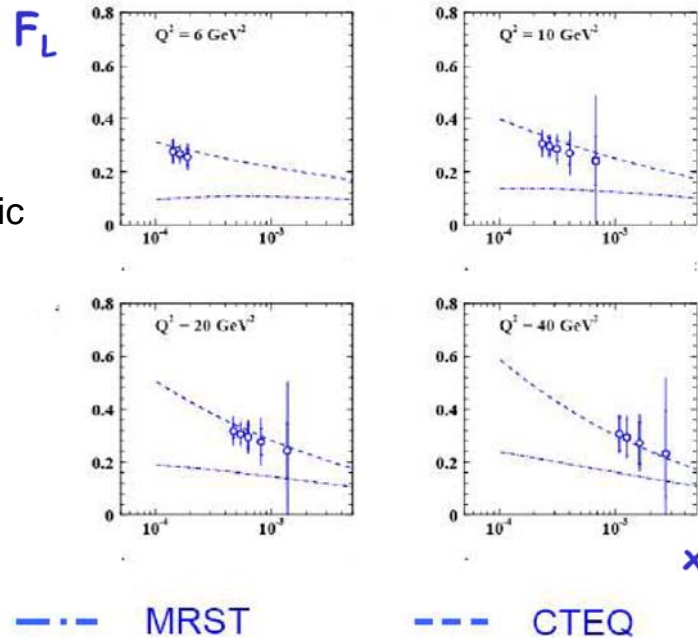


- Demonstrating the technical feasibility of F_L measurement
- Real F_L from HERA, hopefully in several months

F_L : projected uncertainty, theoretical prediction

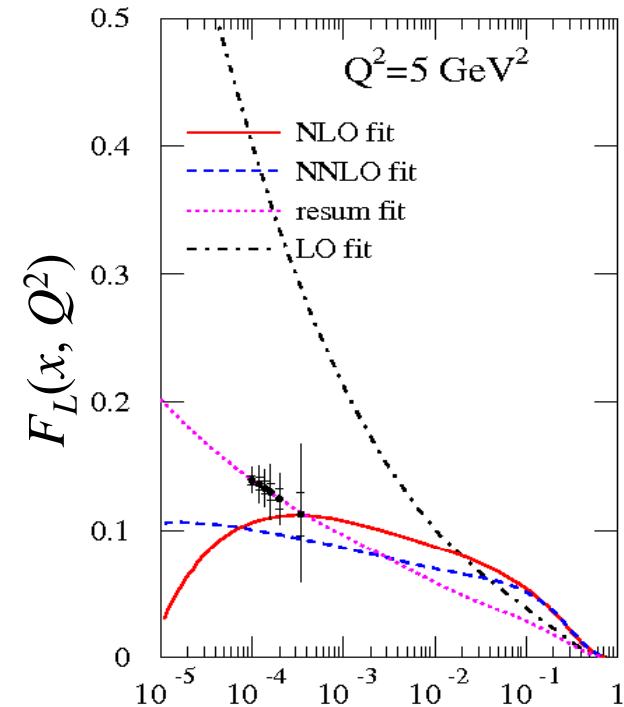
Simulation results

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



- 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

from proceedings
DIS2004 conf.
by Robert Thorne



overlaid: H1 simulation of
projected uncertainty in F_L

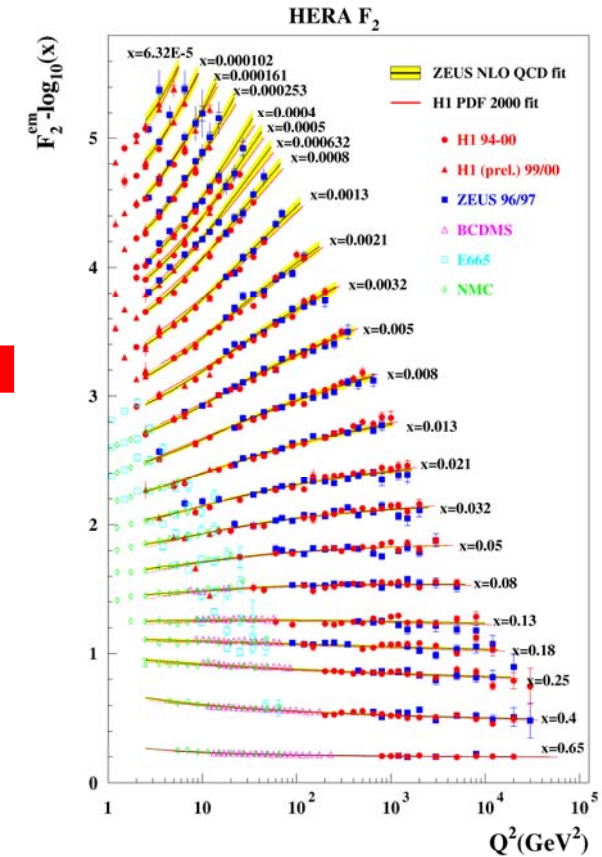
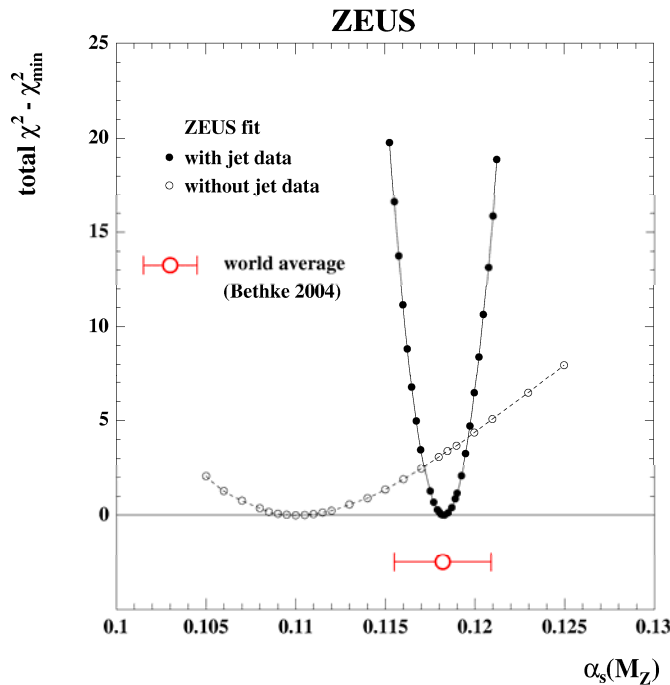
Conclusion

- 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

