Proton and Photon Structure at HERA

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Outline:

- Introduction
- Proton Structure: F_2^p, NLO Fits, gluon density
- Photon Structure: F_2^g, charm content, PDFs
- QCD results and a_s

Why Structure Functions ?

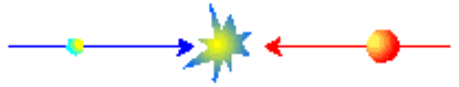
Understanding of the Hadronic Structures
(i.e. momentum distributions, quark flavor contents…),
also through the quantum fluctuations of the photon

Test the Standard Model in the electroweak
and strong interactions sectors
(e.g excellent measures of α_S)

Constraints and important knowledge
for new machines like LHC

HERA

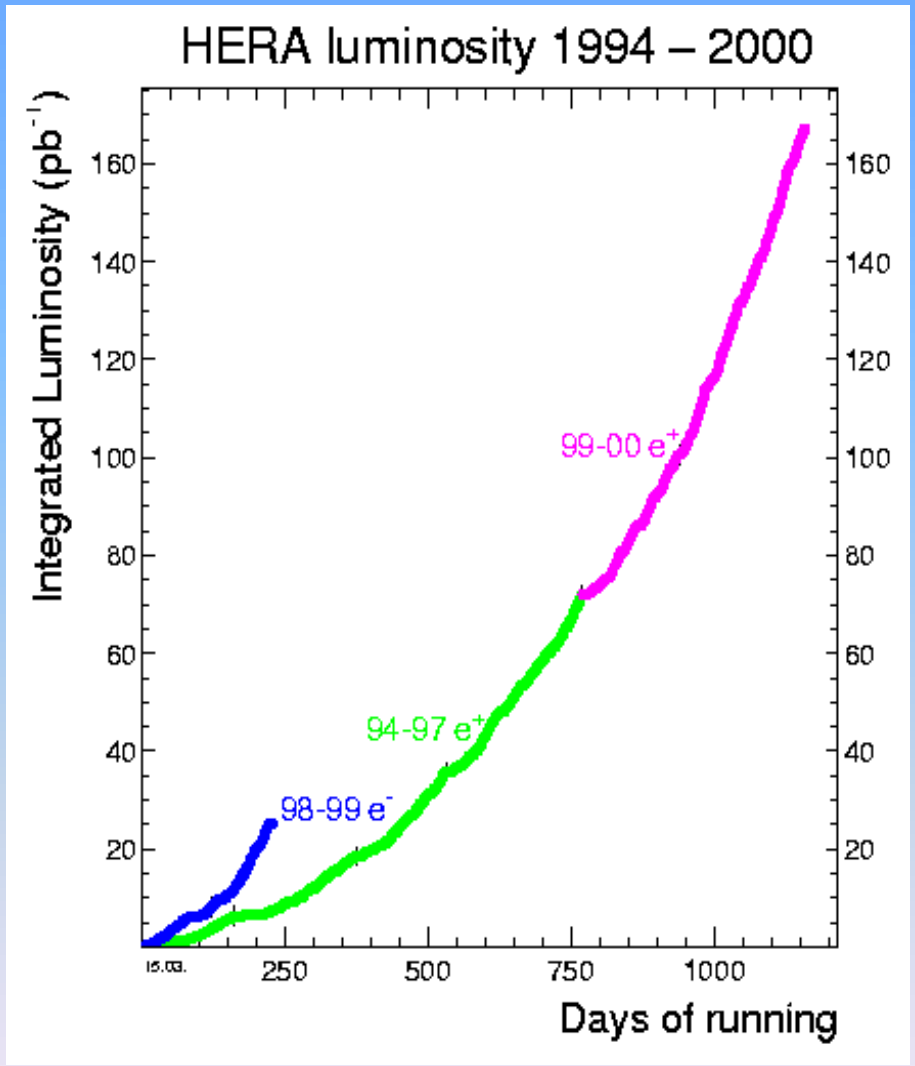
Electron	Proton
27.5 GeV	920 GeV



Positron	Proton
27.5 GeV	820 GeV

- *The* Proton Structure *machine*

e^+p: 1994-2000 and e^-p: 1994-1999



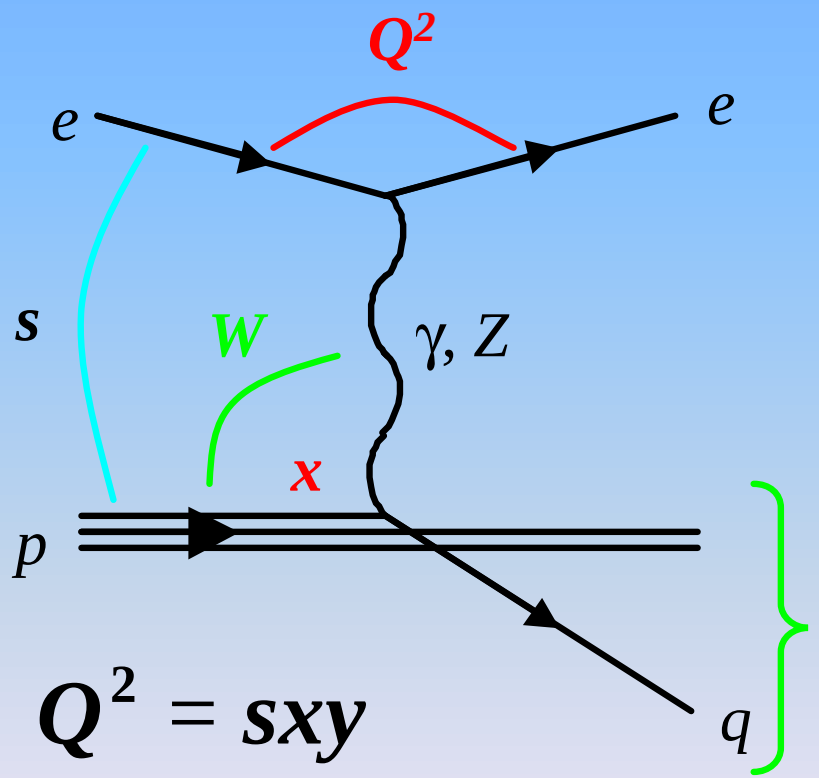
Luminosity Analyzed:

	Luminosity (pb^{-1})	
	H1	ZEUS
e^-P	16	16
e^+P	100	110

HERA kinematics

- *s:* e-p (c.m. energy)^2
- $Q^2 = -q^2$*:* 4-momentum transfer squared, "size" of the probe (g)
- *y:* energy transferred from lepton to g
- *x:* fraction of proton momentum carried by quark = $Q^2/2p.q$
- *W:* γ-p c.m. energy

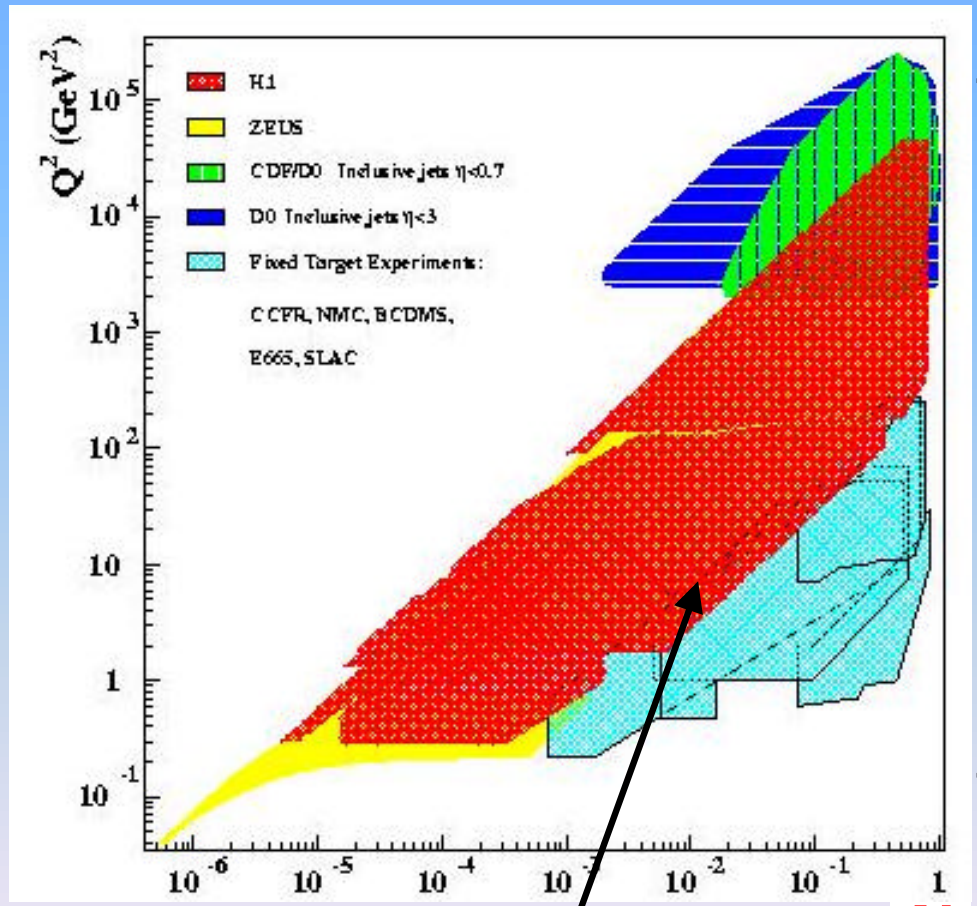
$\sqrt{s} = 300 - 318$ GeV



Kinematics Plane:

- For $Q^2 \sim 1\ GeV^2$: the transition from photoproduction ($Q^2 \sim 0$) to DIS
- For $Q^2 > 1\text{-}2\ GeV^2$: pQCD region
- For $Q^2 > 10^4\ GeV^2$: EW sector, overlap with Tevatron data, probes distances to ~ 1/1000th of proton size

New HERA (H1 and ZEUS) measurements have about a 3% precision (syst.)

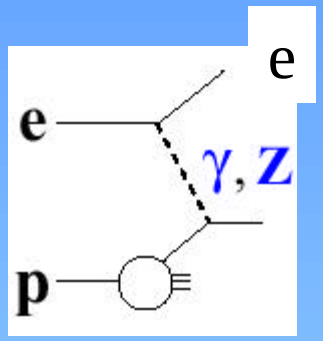


~ am

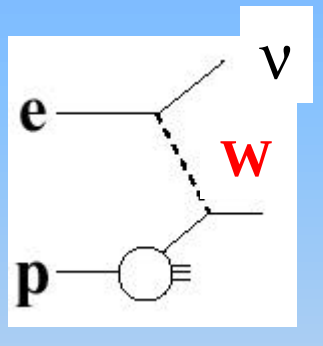
Resolution scale

~ fm

HERA: Neutral and Charged **Currents**



$$\frac{d^2\sigma_{NC}}{dQ^2\,dx} \sim \alpha^2 \frac{1}{Q^4} \frac{1}{x}\Phi_{NC}(x,Q^2)$$



$$\frac{d^2\sigma_{CC}}{dQ^2\,dx} \sim G_F^2 \left(\frac{M_W^2}{M_W^2+Q^2}\right)^2 \frac{1}{x}\Phi_{CC}(x,Q^2)$$

coupling constants

propagators

Spin dependencies, quark flavors

(and Z contributions for NC)

Neutral cross section

$$\frac{d\sigma^2_{e^\pm p}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}(Y_+ F_2 - y^2 F_L \mp Y_- xF_3)$$

$$F_2^{NC} = x \sum_{Quarks} A_f(Q^2)[q(x,Q^2) + \bar{q}(x,Q^2)]$$

$$Y_\pm \equiv 1 \pm (1-y)^2$$

Photon, Z couples to all quark flavours

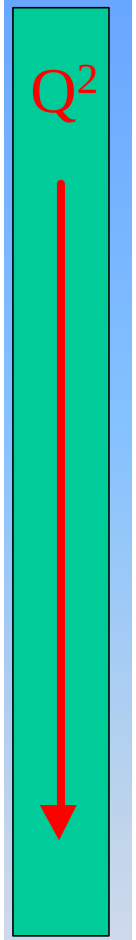
F_L is the longitudinal Structure Function $\propto$ gluon density

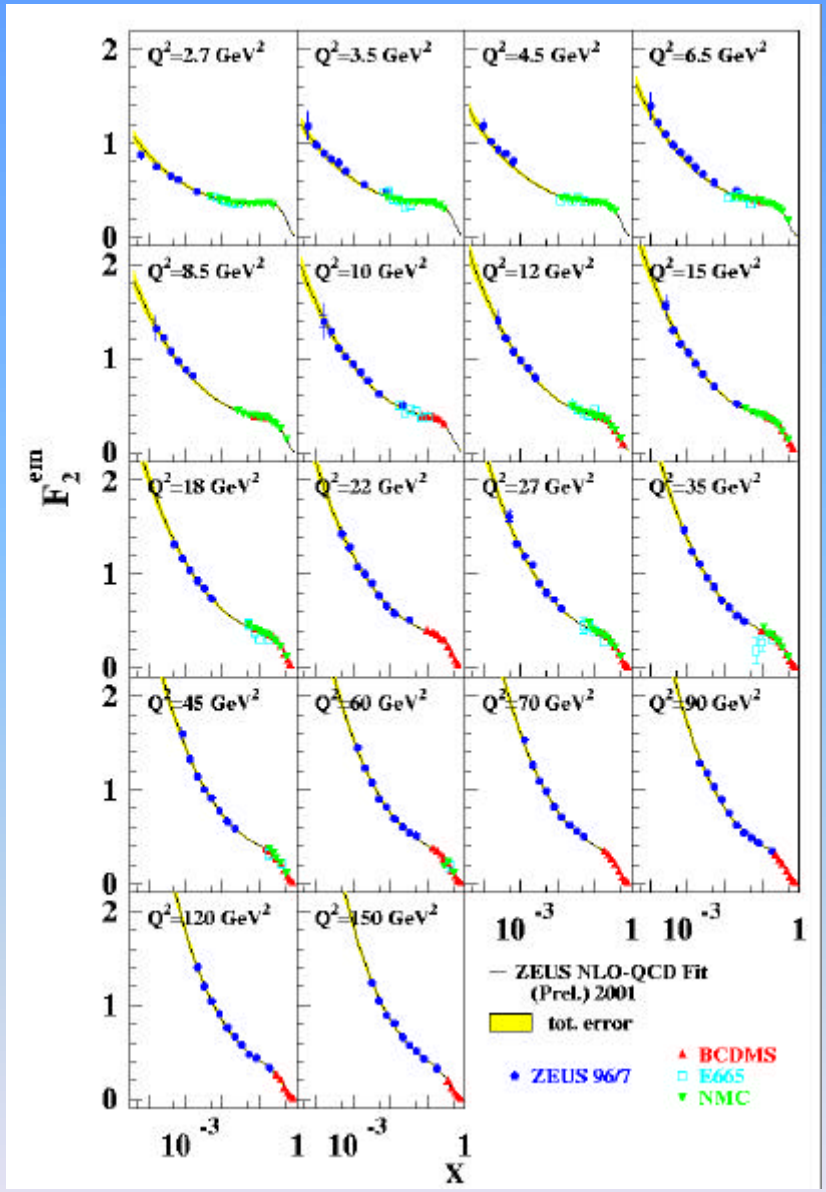
important only at high y

$$xF_3^{NC} = x \sum_{Quarks} B_f(Q^2)[q(x,Q^2) - \bar{q}(x,Q^2)]$$

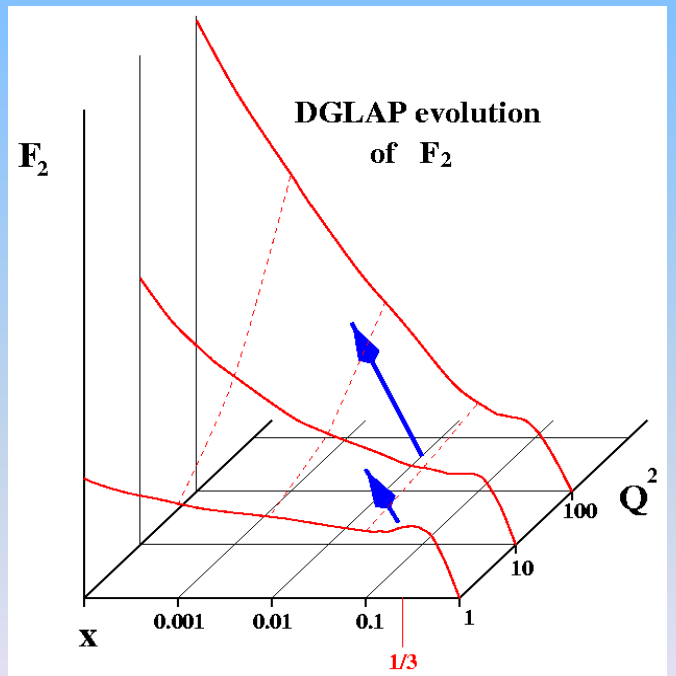
xF_3 is the parity violating term – sensitive to valence quarks and is only significant at $Q^2 \sim M_Z^2$

Structure Function:



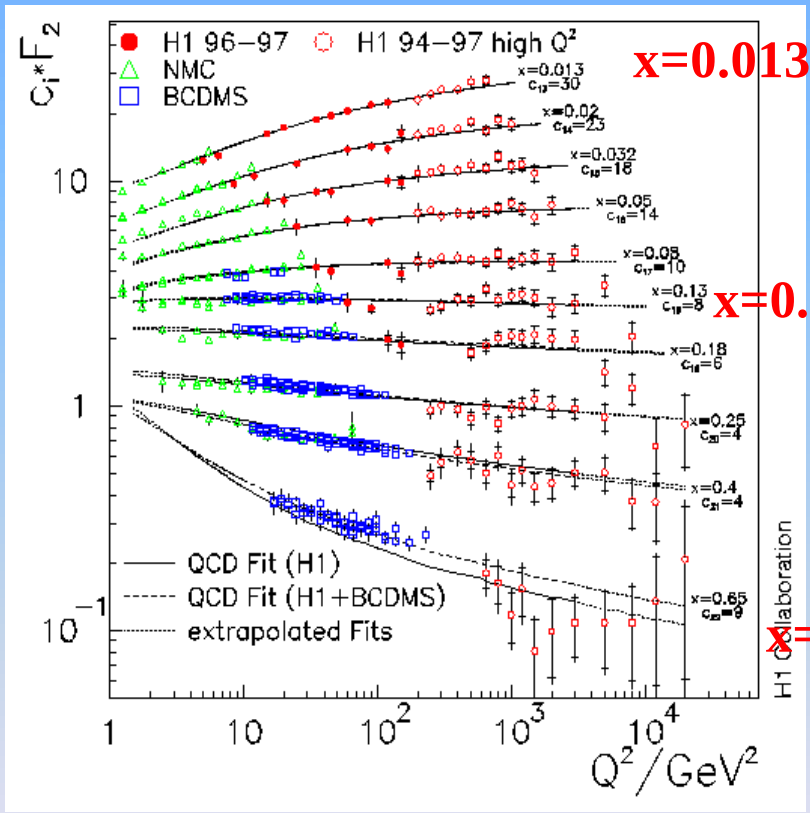


Strong rise of F_2 towards low x

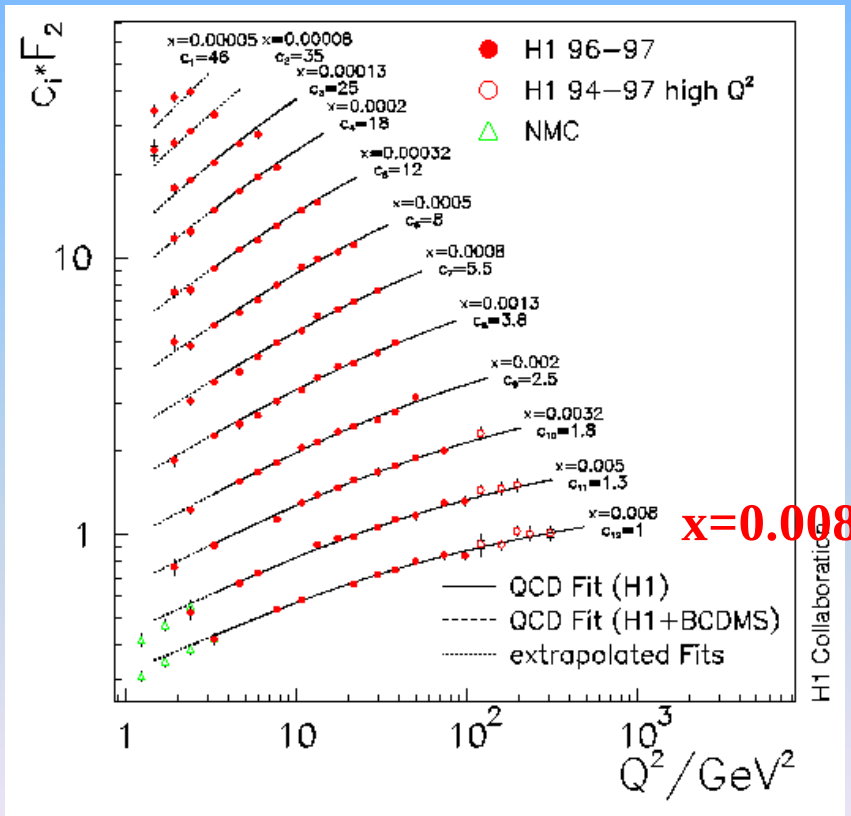


Structure functions: Scaling violations

Nice matching with fixed target data

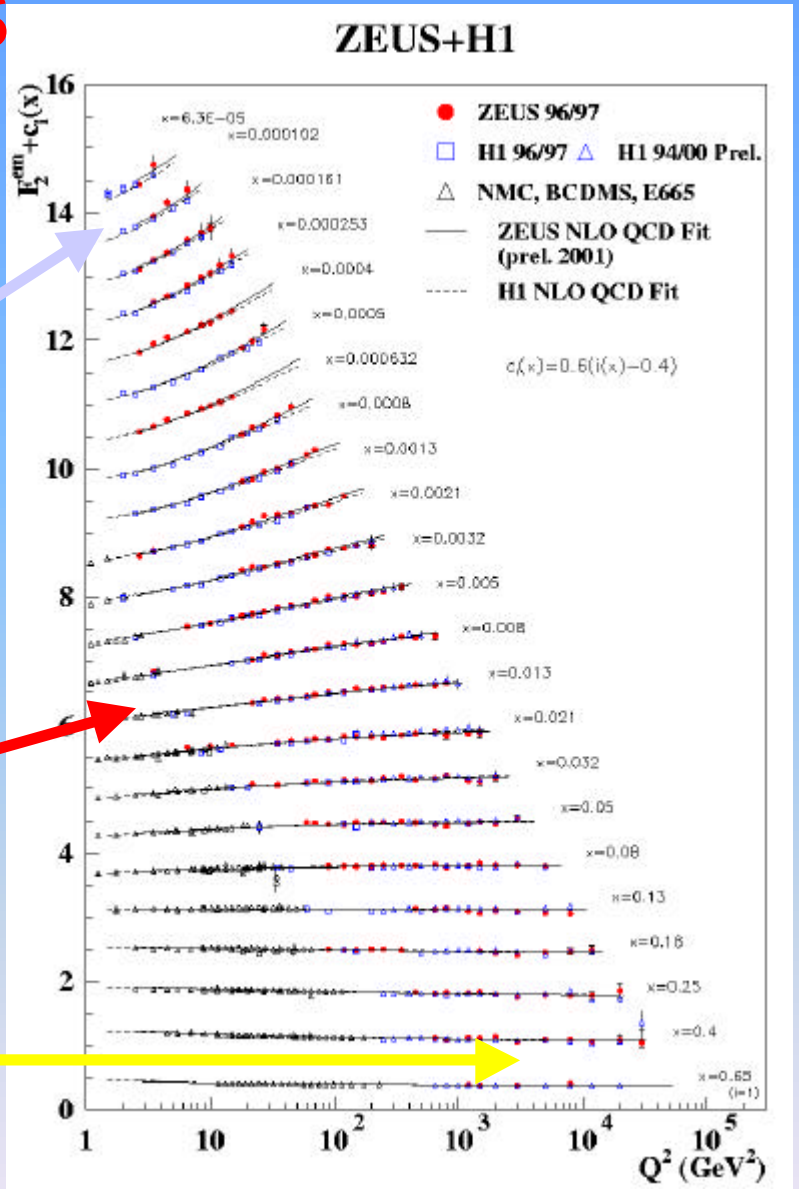


while due to gluon radiation:



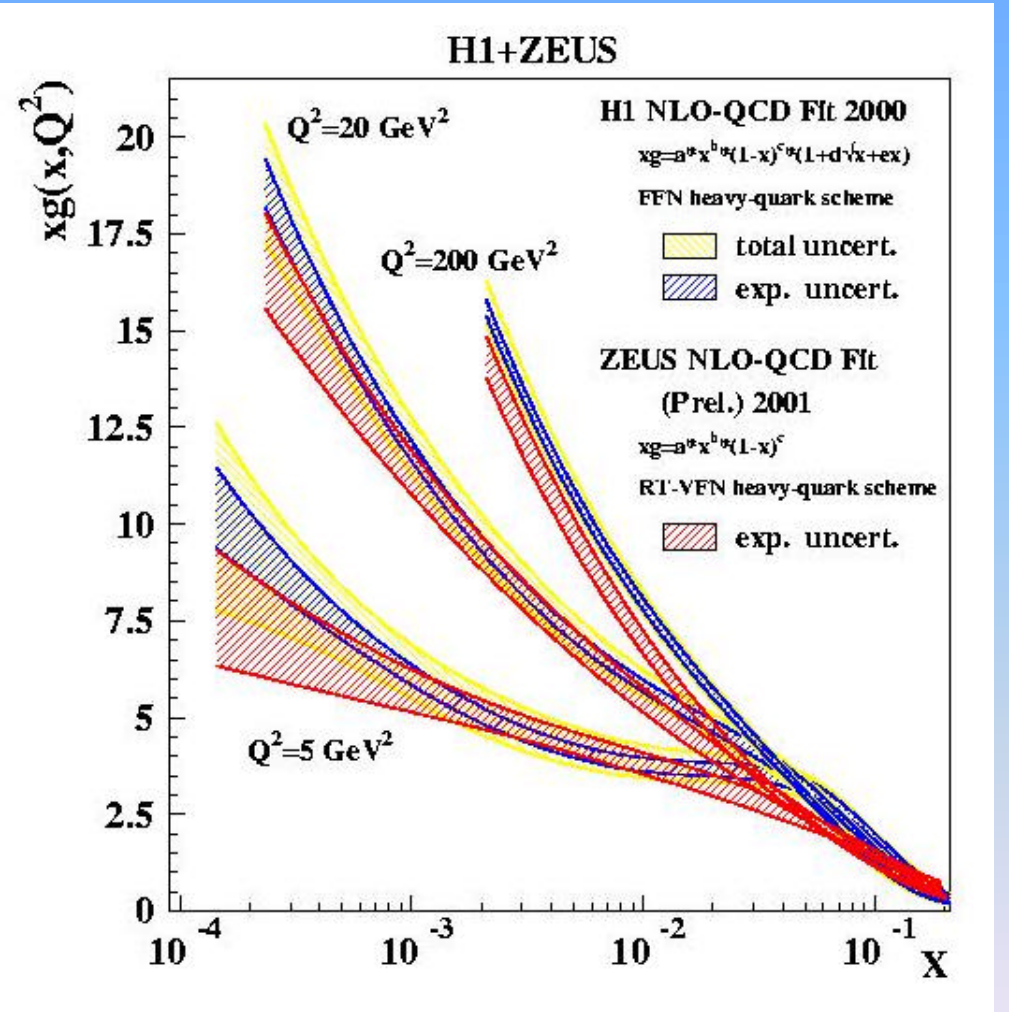
HERA NLO QCD fits

- Are the data described by DGLAP QCD?
- Determine the PDFs (q,g) and $a_S(M_Z^2)$
- The ZEUS and H1 data and fits show some differences at small *x*
- But they generally agree very well
- Limited statistics at large Q^2



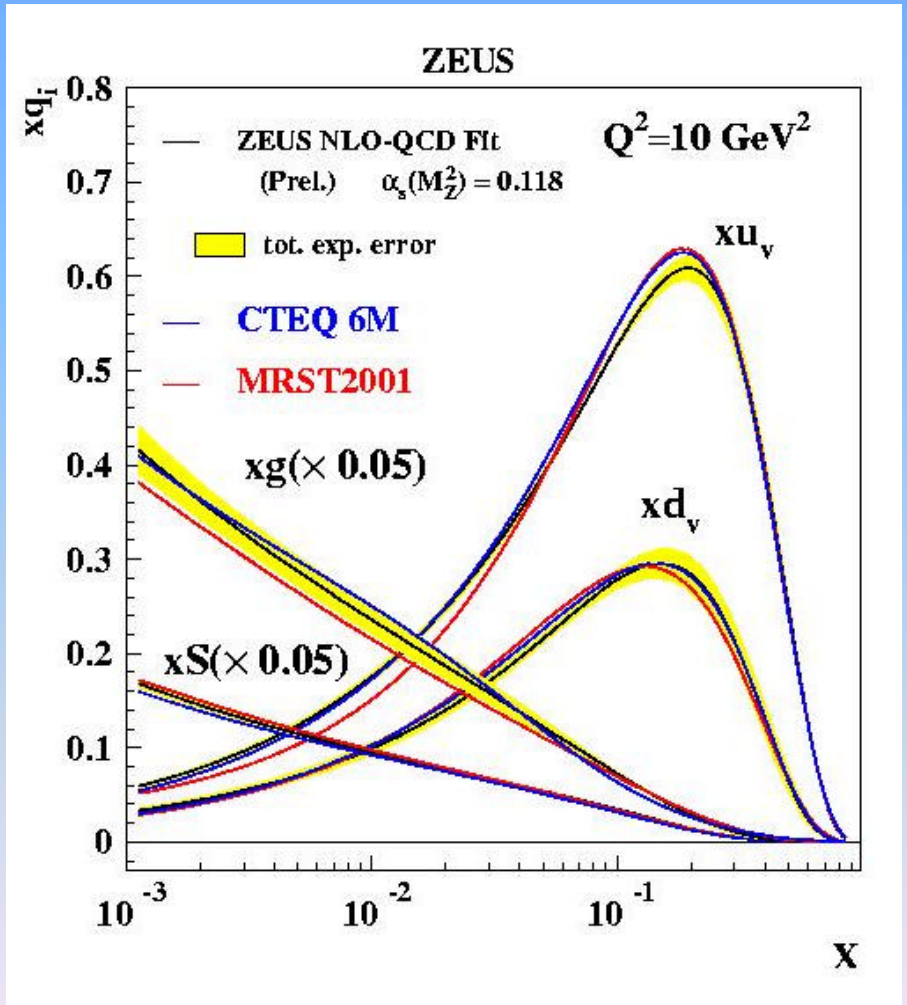
H1 and ZEUS Gluon Density

- See the evolution of **gluon density** as a function of Q^2
- Comparing the **H1** and **ZEUS** distributions
- Some **differences** observed, probably due to:
  - heavy flavour scheme
  - *xg(x)* parameterisation
- a_s **correlation** in the error on *xg(x)*



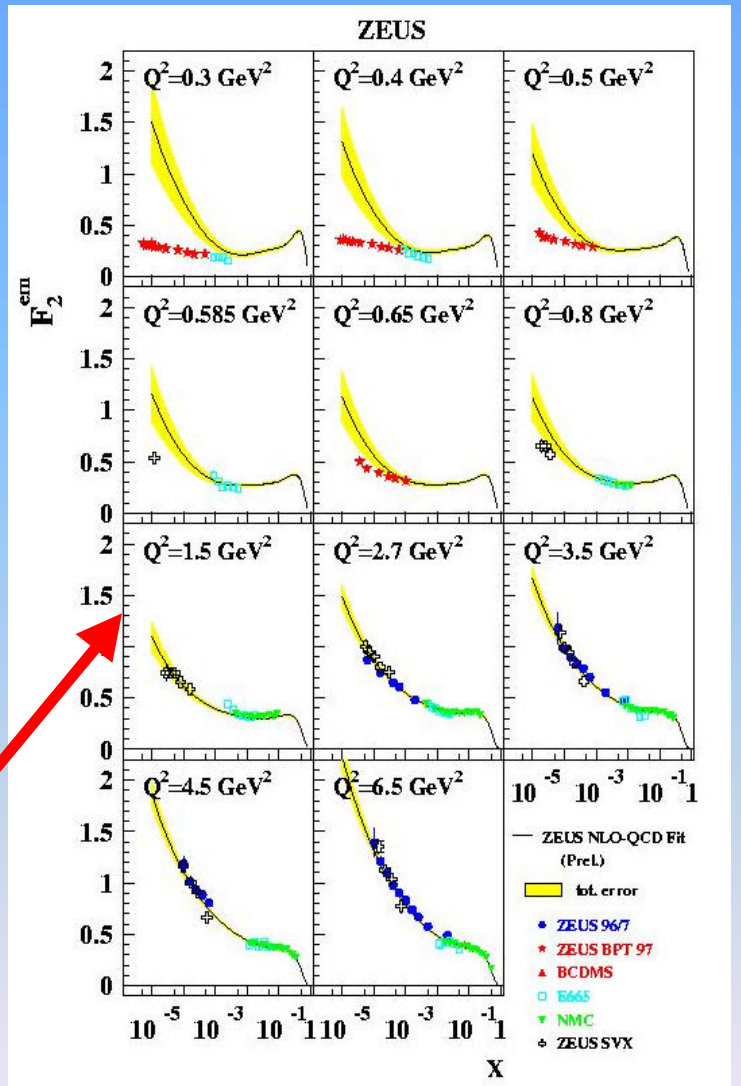
Compare CTEQ6, MRST2001 and ZEUS

- General agreement between all three
- within the uncertainties of the fitted PDFs



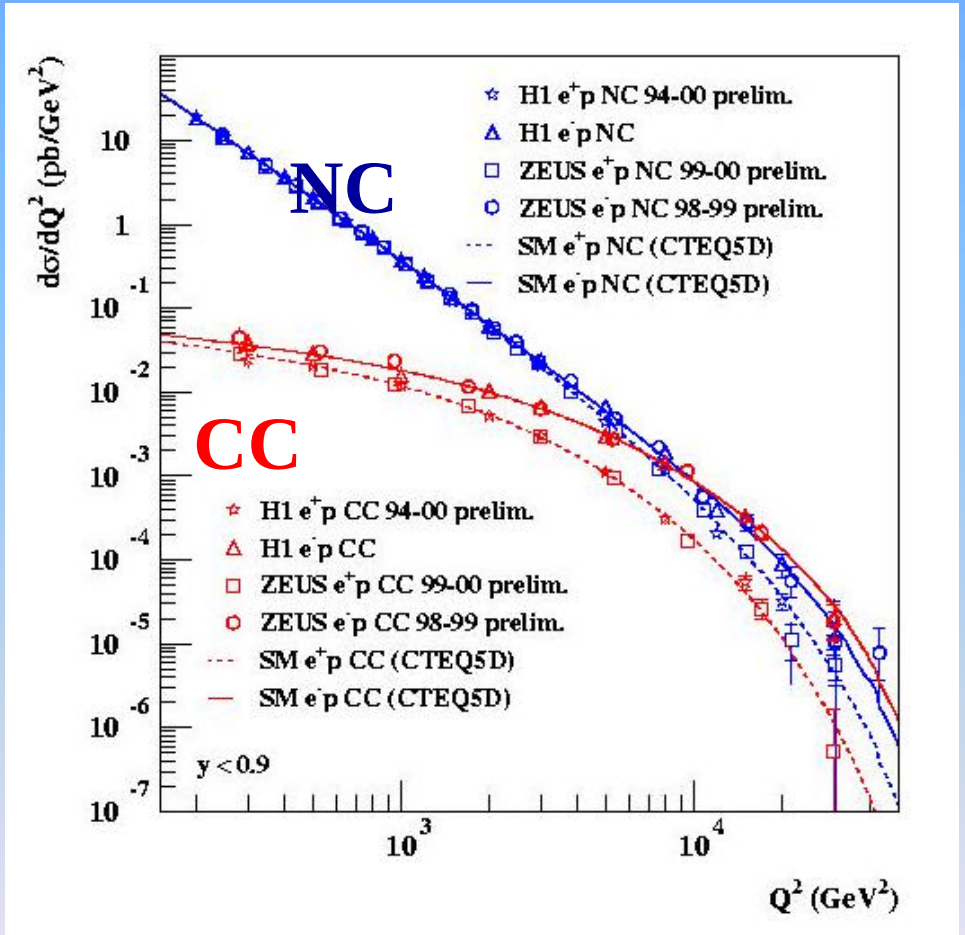
Range of validity of DGLAP fit?

- ZEUS fits to data with $Q^2 > 2.5$ GeV^2
- Then extrapolate back to lower Q^2
- The fit does not describe the data – when using the existing parameterizations – below ~1.5 GeV^2



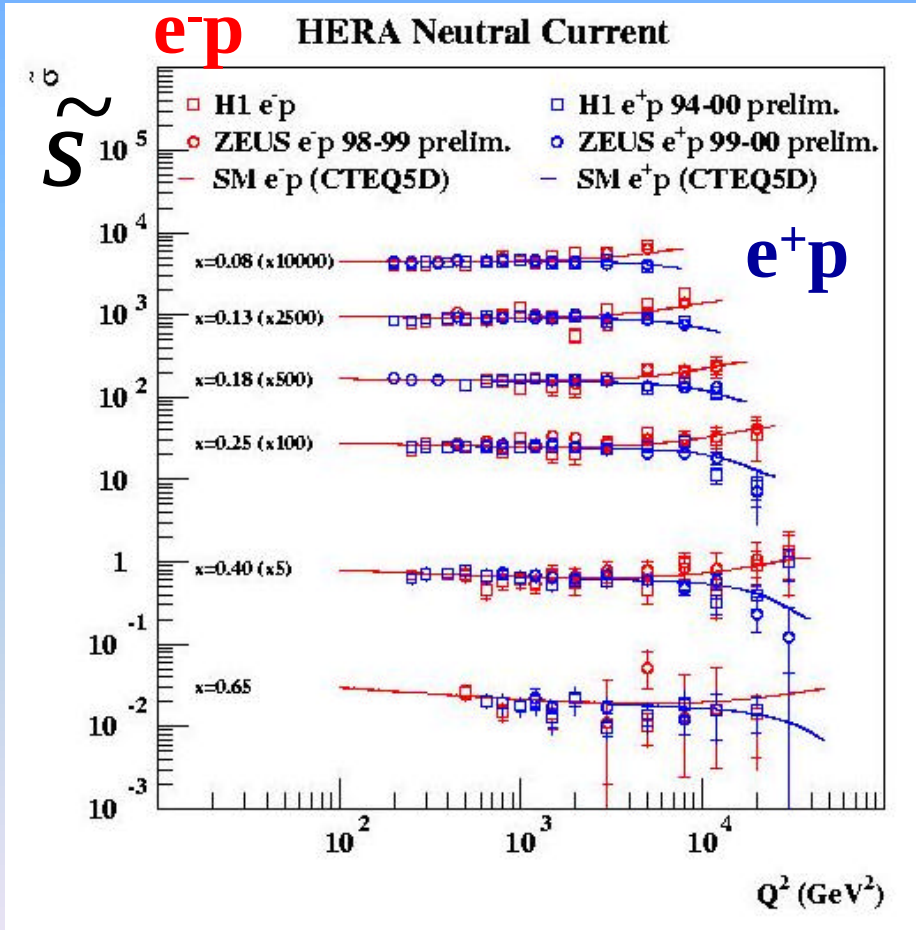
High Q^2: Neutral and Charged Current

- Clearly see effect of W/Z exchange in cross sections at high Q^2
- Standard Model shows good agreement over 6 orders of magnitude
- QCD + EW effects completely explain data
- These cross sections are sensitive to individual quark flavors

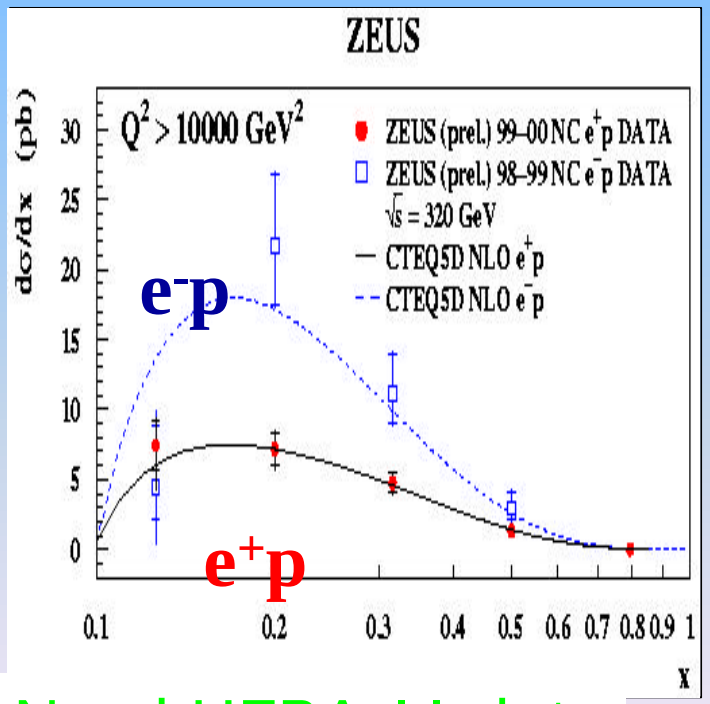


High Q^2 NC "reduced cross sections"

$$\tilde{s}_{NC} \equiv \frac{1}{Y_+}\frac{xQ^4}{2pa^2}\frac{d^2s}{dx\,dQ^2}$$

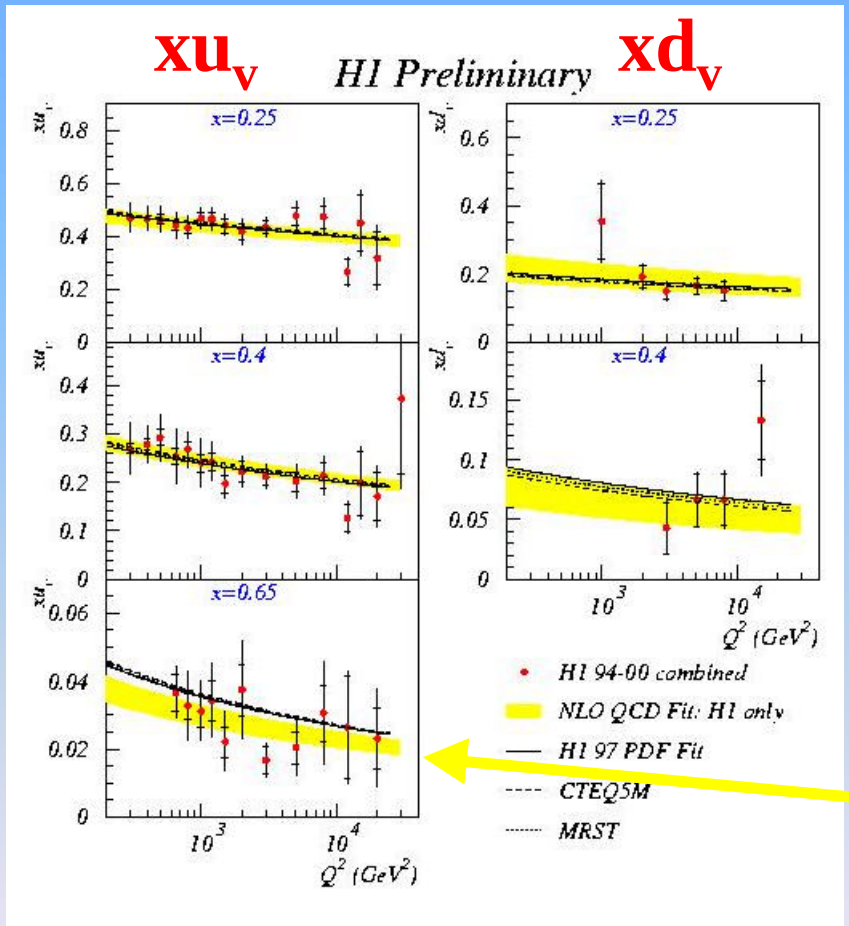


- ***e*** $^-$***p*** **has *CONSTRUCTIVE***
  g **-** ***Z*** **interference**
- ***e*** $^+$***p*** **has *DESTRUCTIVE***
  g **-** ***Z*** **interference**



Need HERA II data

Determination of valence quark densities



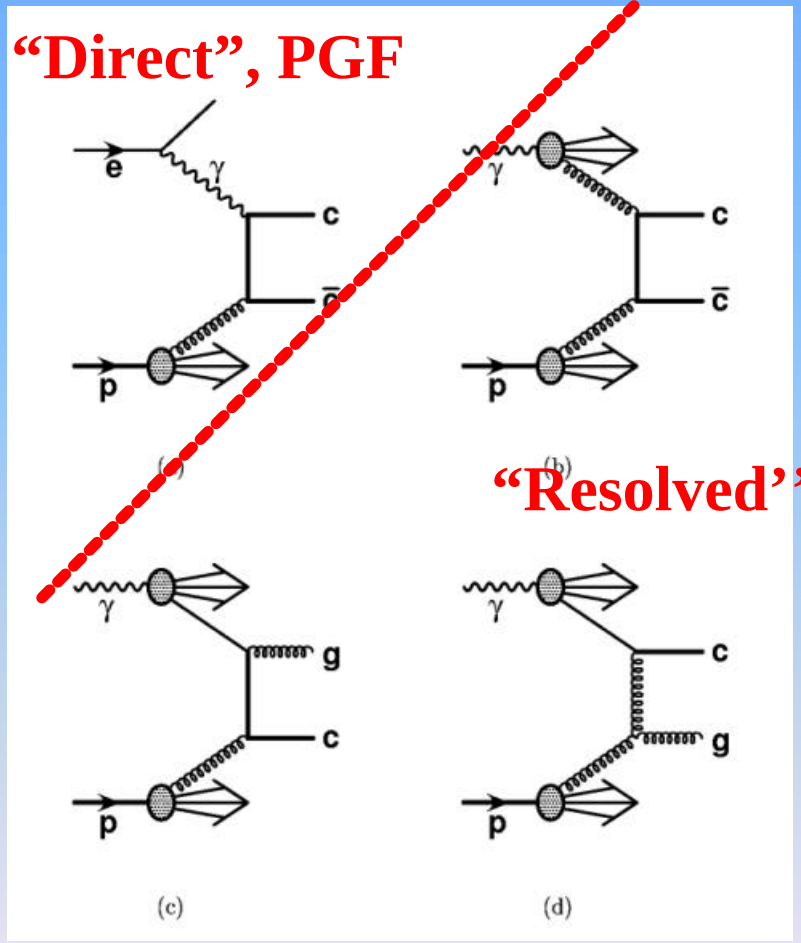
- Both H1 and ZEUS are able to determine the valence quark densities using only HERA data (both medium and high Q^2 data)
- Precision ~10-20%
- u_v at high x is ~17% lower than that found with fixed target data (result from H1)

Photon Structure Function

- Dijet production from LO "resolved" processes in quasi-real photoproduction at HERA
- **Look** at the angle between the jet-jet axis and the beam in the dijet rest frame, i.e. cos θ*:

cosq*=tanh[(h_1-h_2)/2]

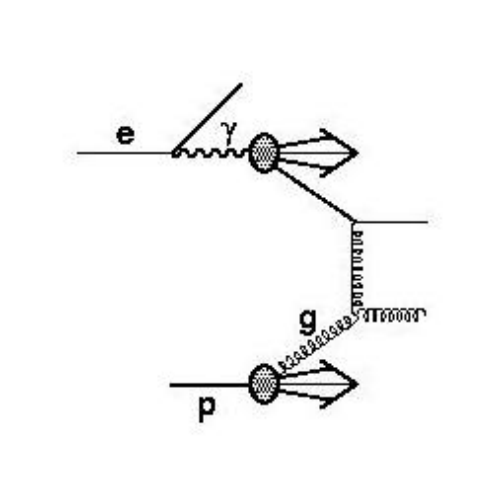
$$x_g^{obs} = \frac{E_T^{jet1} e^{-h^{jet1}} + E_T^{jet2} e^{-h^{jet2}}}{2yE_e}$$

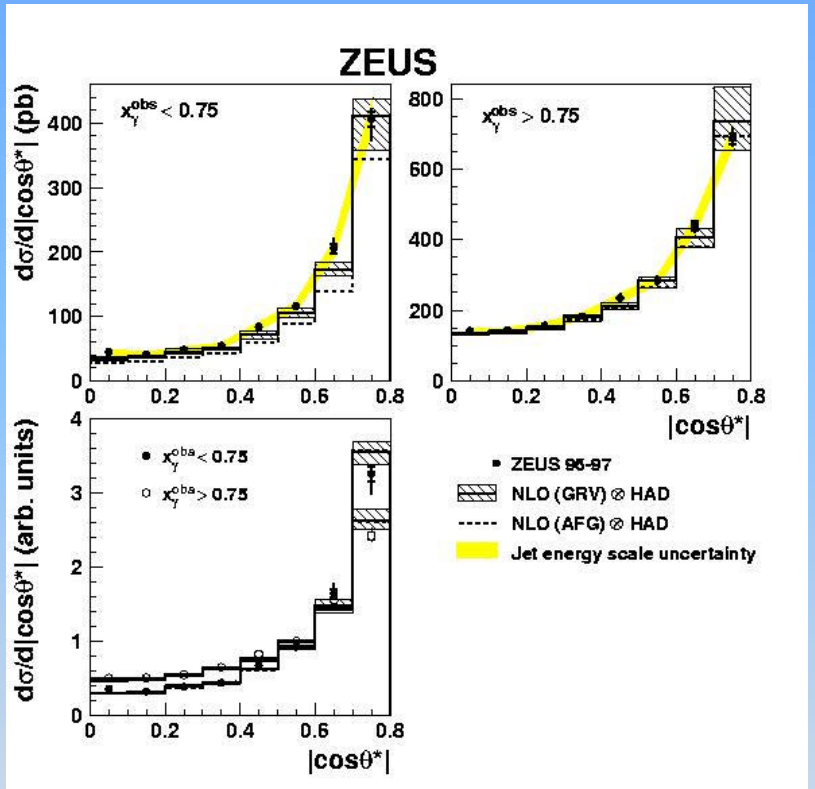


Photon structure from HERA

quark prop. $\alpha\ (1-|\cos\theta^*|)^{-1}$

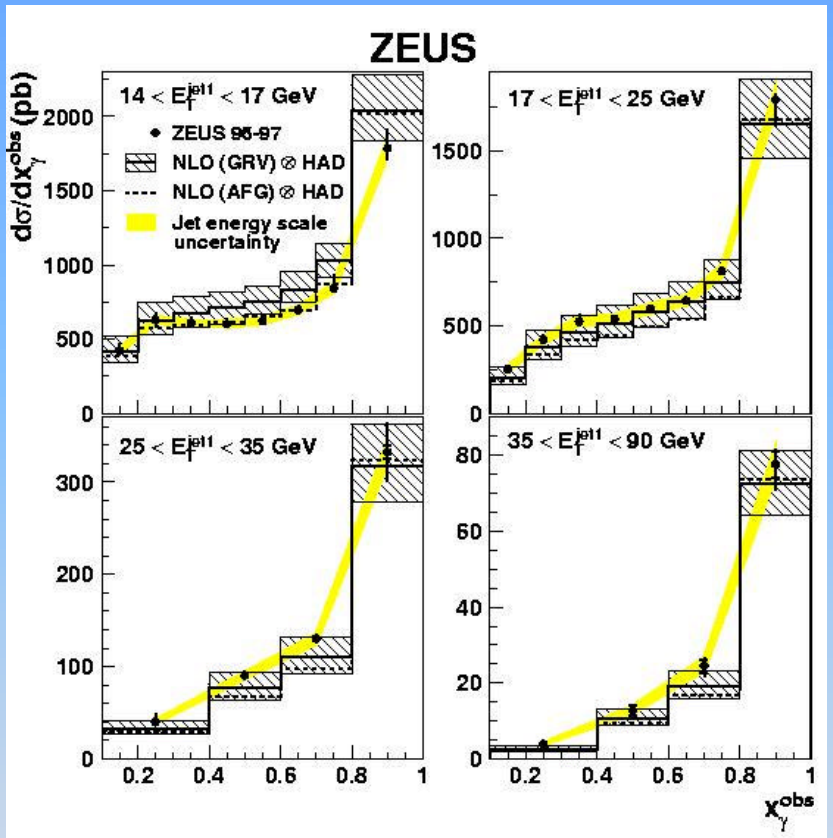
gluon prop. $\alpha\ (1-|\cos\theta^*|)^{-2}$



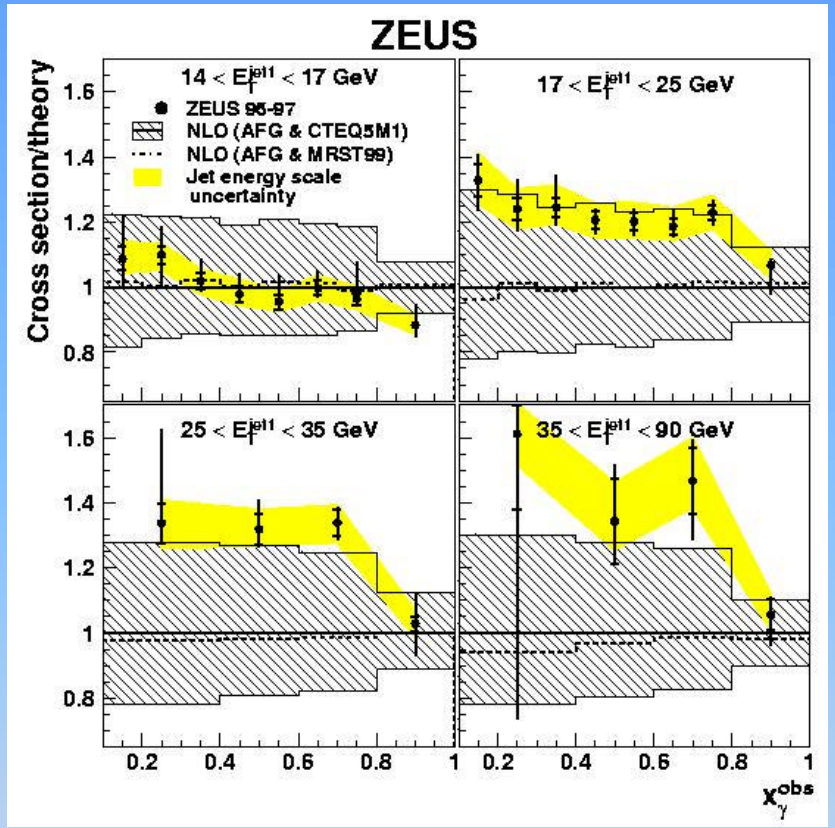


- **The agreement with the NLO calculations shows that the parton-parton dynamics are OK**

ZEUS data:

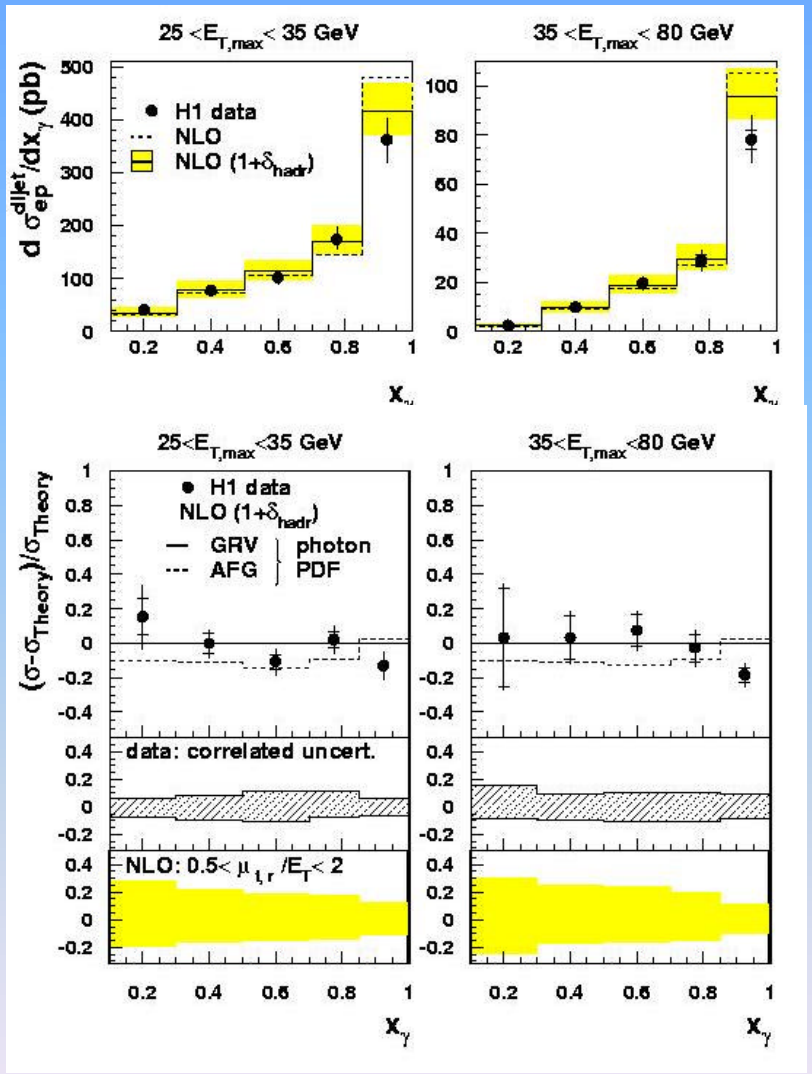


- High x_g data are well described by NLO



- Low x_g data are above NLO, more so at high E_T
- Suggests g PDFs are not quite correct ?

H1 data:

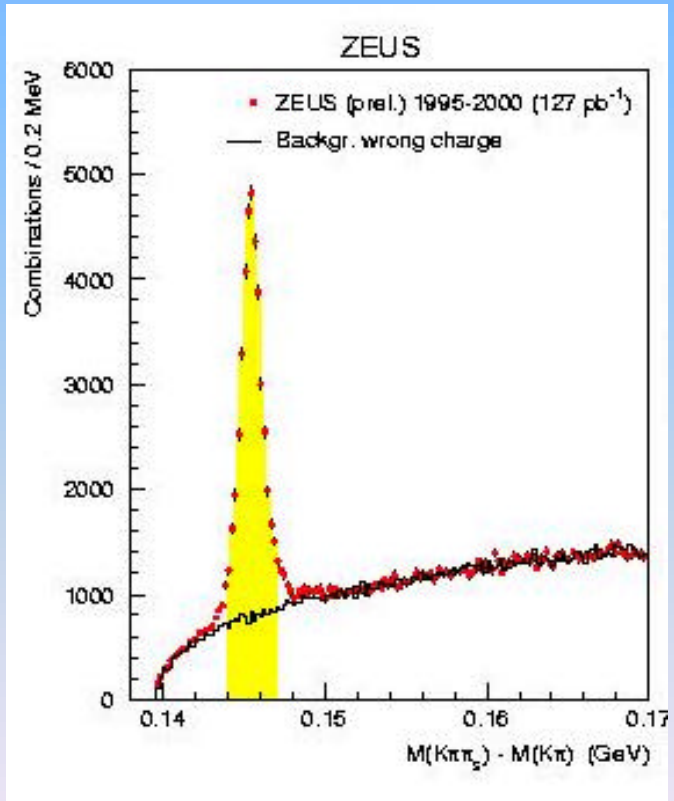


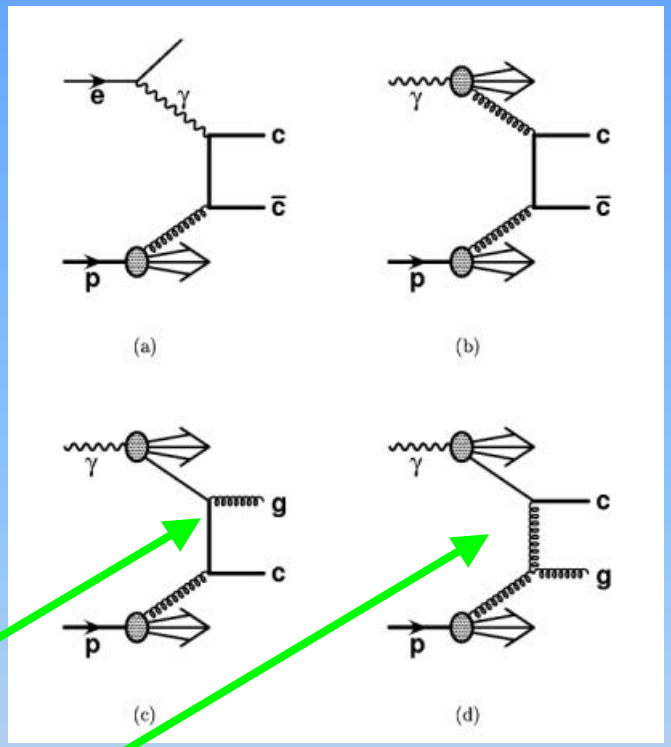
- High x_g data are slightly below NLO
- Low x_g data are in good agreement with NLO for both E_T ranges
- Suggests g PDFs are OK?
- The PDFs are determined at low scales; their evolution reproduce the data at high scales

D* in photoproduction

- D* sample is large; select dijets
- Look at the angle of the jet-jet axis and the beam in dijet

i.e. $|\cos q^*|$



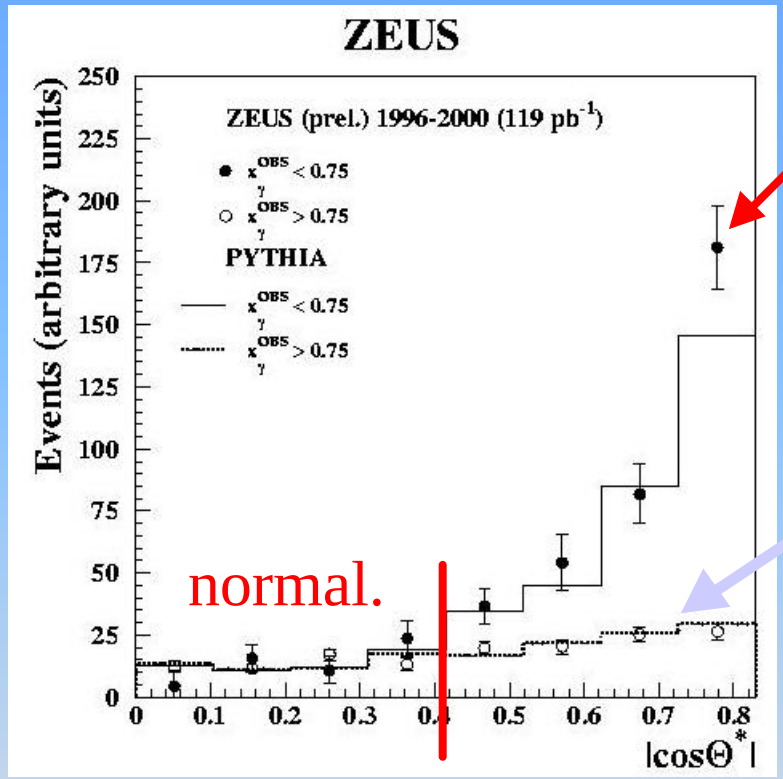


quark propagator a $(1-|\cos q^*|)^{-1}$

gluon propagator a $(1-|\cos q^*|)^{-2}$

→ hence the gluon has a steeper distribution in $|\cos q^*|$

D* in dijets: charm in the photon?

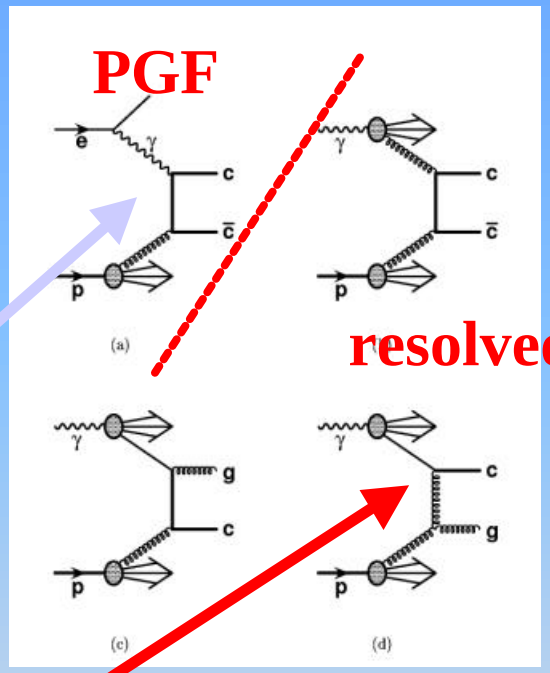


"resolved"

$X_g < 0.75$

"direct"

$X_g > 0.75$



The "resolved" distrib. is much steeper than "direct"

→ a gluon propagator

Suggests charm in photon

Summary

- Progress on proton structure:
  - a) Much effort on uncertainties
  - b) High Q^2 data needs HERA II
- Progress on photon structure
  - a) analysis in progress
  - b) Need new fits to HERA data?
- QCD
  - a) Theory uncertainties dominate α_S