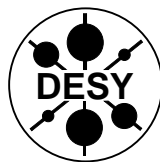


QCD at small x at HERA

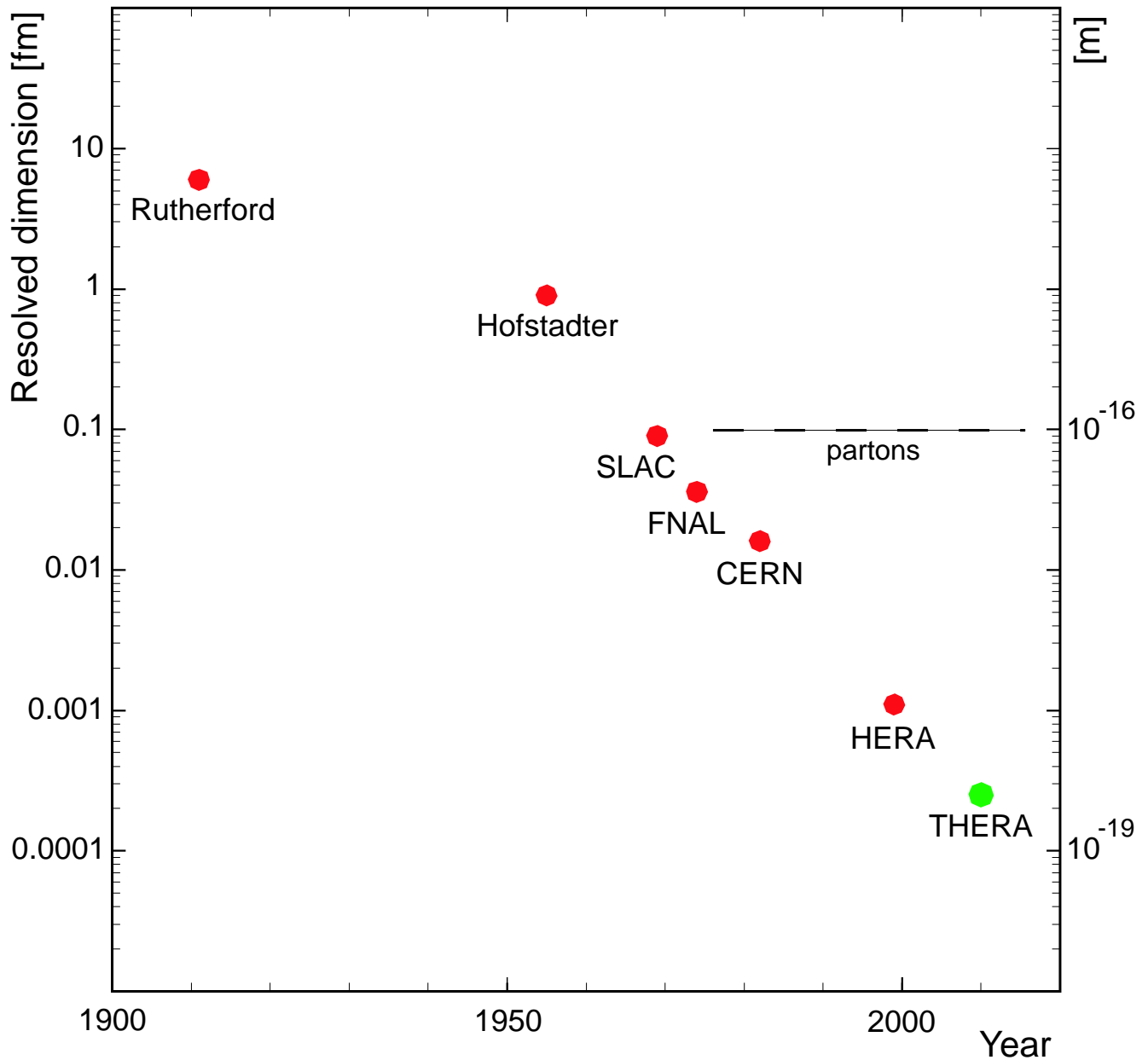
Stefan Schlenstedt (Columbia Univ, DESY Zeuthen)

Outline

- ▷ Introduction
- ▷ The structure function F_2 at medium Q^2
- ▷ Gluon density and charm in the proton
- ▷ The longitudinal structure function F_L
- ▷ Looking for non-DGLAP QCD effects
- ▷ Summary and outlook

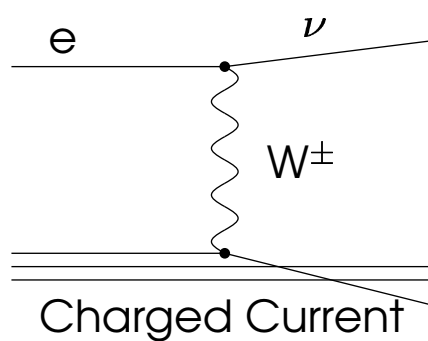
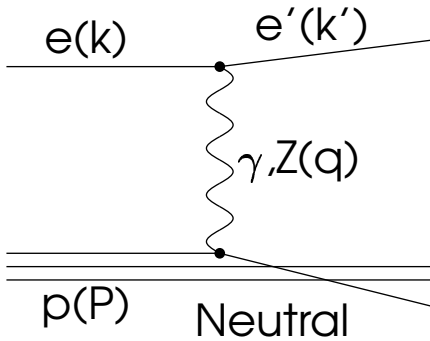


Resolving the Structure of Matter



using Deep Inelastic Scattering experiments

Deep Inelastic Scattering

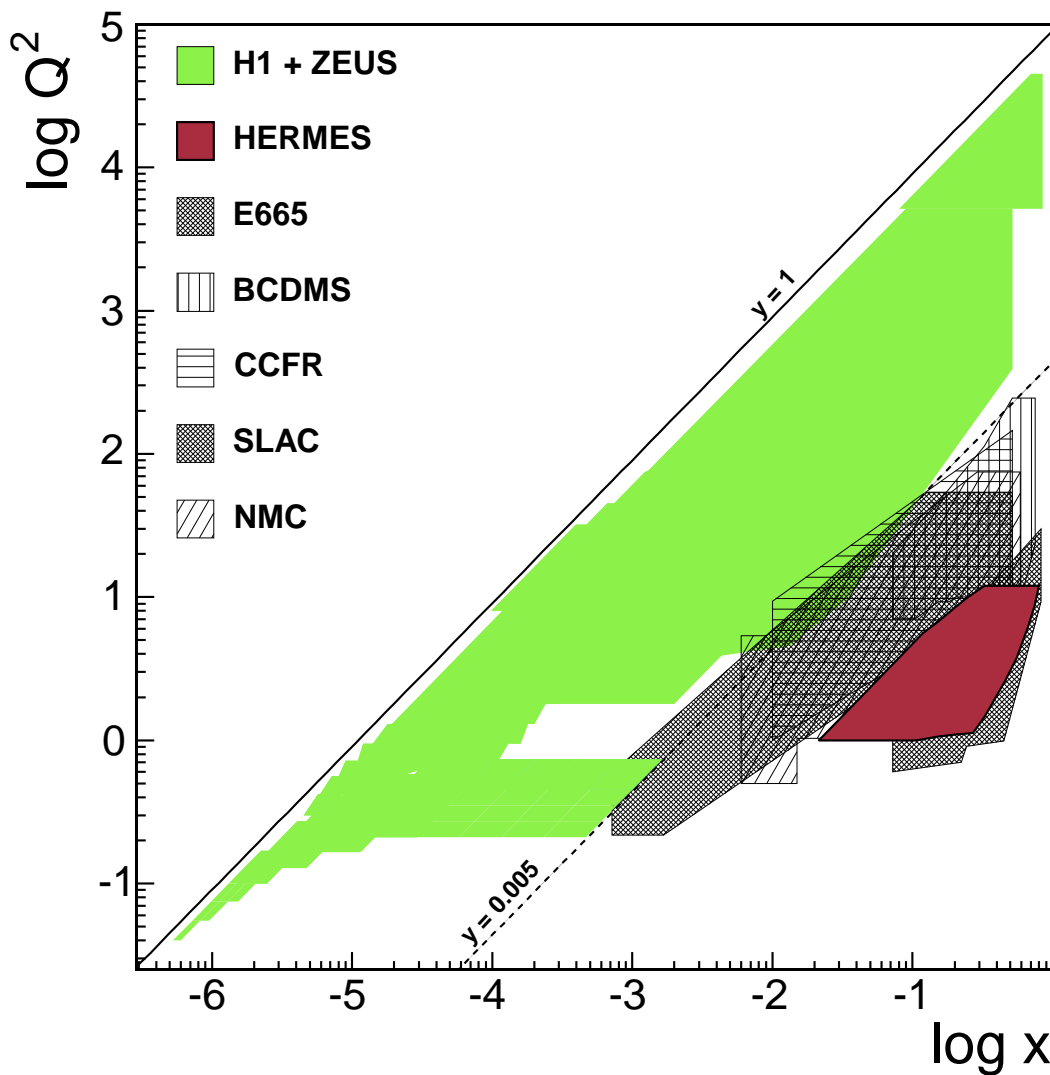


$$s = (k + P)^2$$

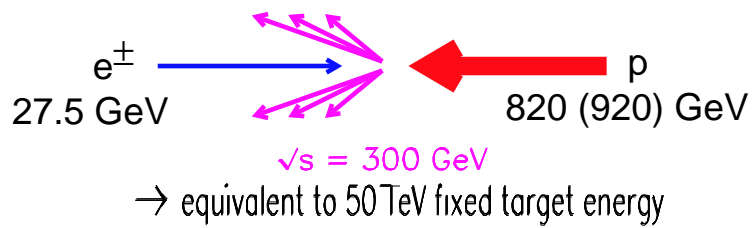
$$Q^2 = -q^2$$

$$x = Q^2 / (2Pq)$$

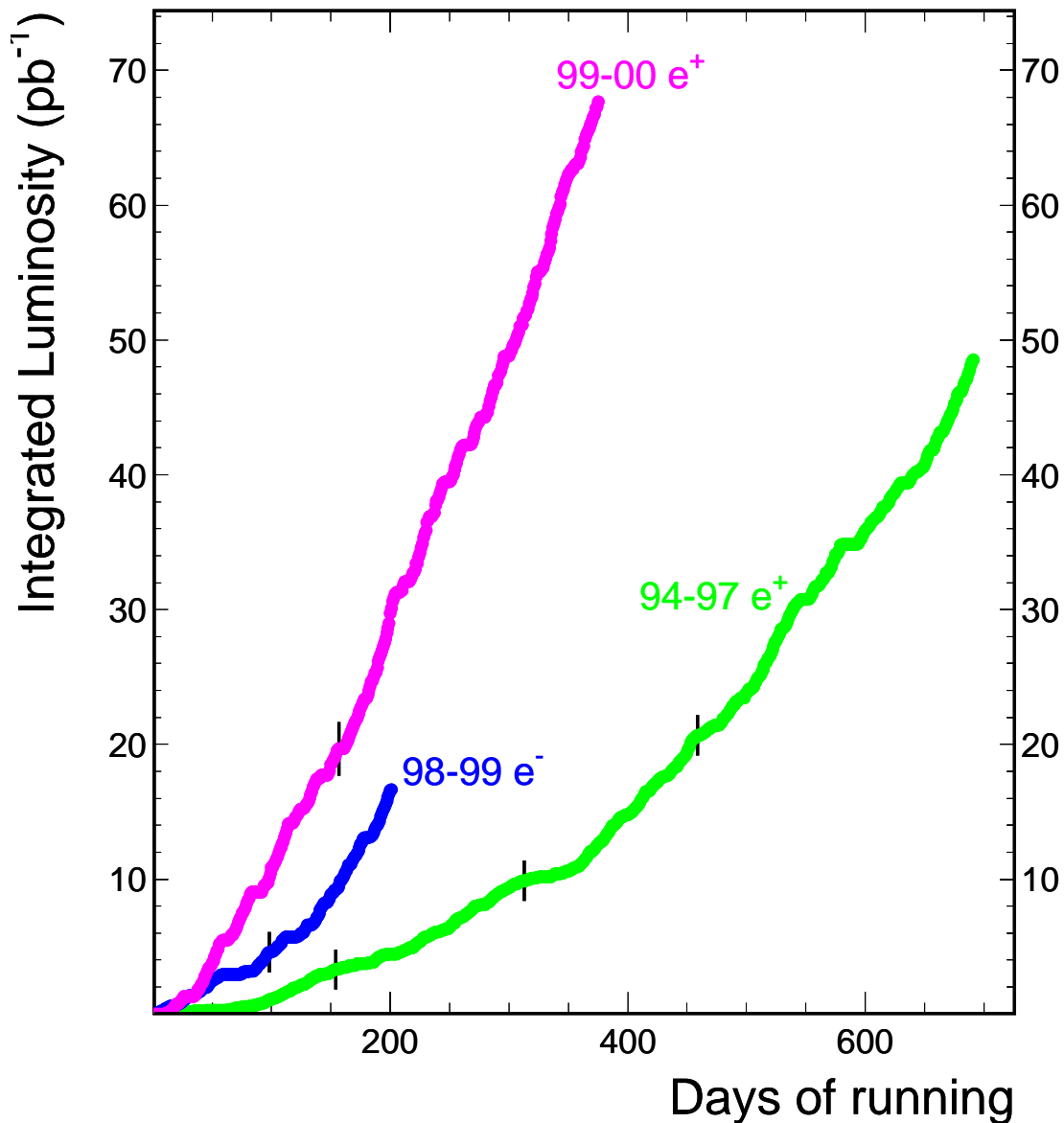
$$Q^2 = xys, W^2 = ys$$



HERA → Physics Luminosity



Physics Luminosity 1994 – 2000



Electron nucleon scattering

Elastic Mott (1929): spinless, structureless, heavy target

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{4E^2 \sin^4 \frac{\theta}{2}} \left[\cos^2 \frac{\theta}{2} \right]$$

Rosenbluth (1950): proton with mass, spin and magn. moment
matrix element contains Dirac and Pauli form factors - rewrite:

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{4E^2 \sin^4 \frac{\theta}{2}} \left[\cos^2 \frac{\theta}{2} a(q^2) - \frac{q^2}{2M^2} \sin^2 \frac{\theta}{2} c(q^2) \right]$$

Deep inelastic scattering: QCD with EW exchange

$$\frac{d^2\sigma}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4} [Y_+ F_2(x, Q^2) \mp Y_- xF_3(x, Q^2) - y^2 F_L(x, Q^2)]$$

In QCD parton model $F_{2,3}$ sum over couplings \times quark momentum distributions in the proton

$$F_2 = \frac{1}{2} \sum_f x q_f^+ [(V_f^L)^2 + (V_f^R)^2 + (A_f^L)^2 + (A_f^R)^2]$$

$$xF_3 = \sum_f x q_f^- [V_f^L A_f^L - V_f^R A_f^R]$$

where $x q_f^\pm = x(q_f(x, Q^2) \pm \bar{q}_f(x, Q^2))$ and xq_f ($x\bar{q}_f$) are the quark (anti-quark) momentum distributions.

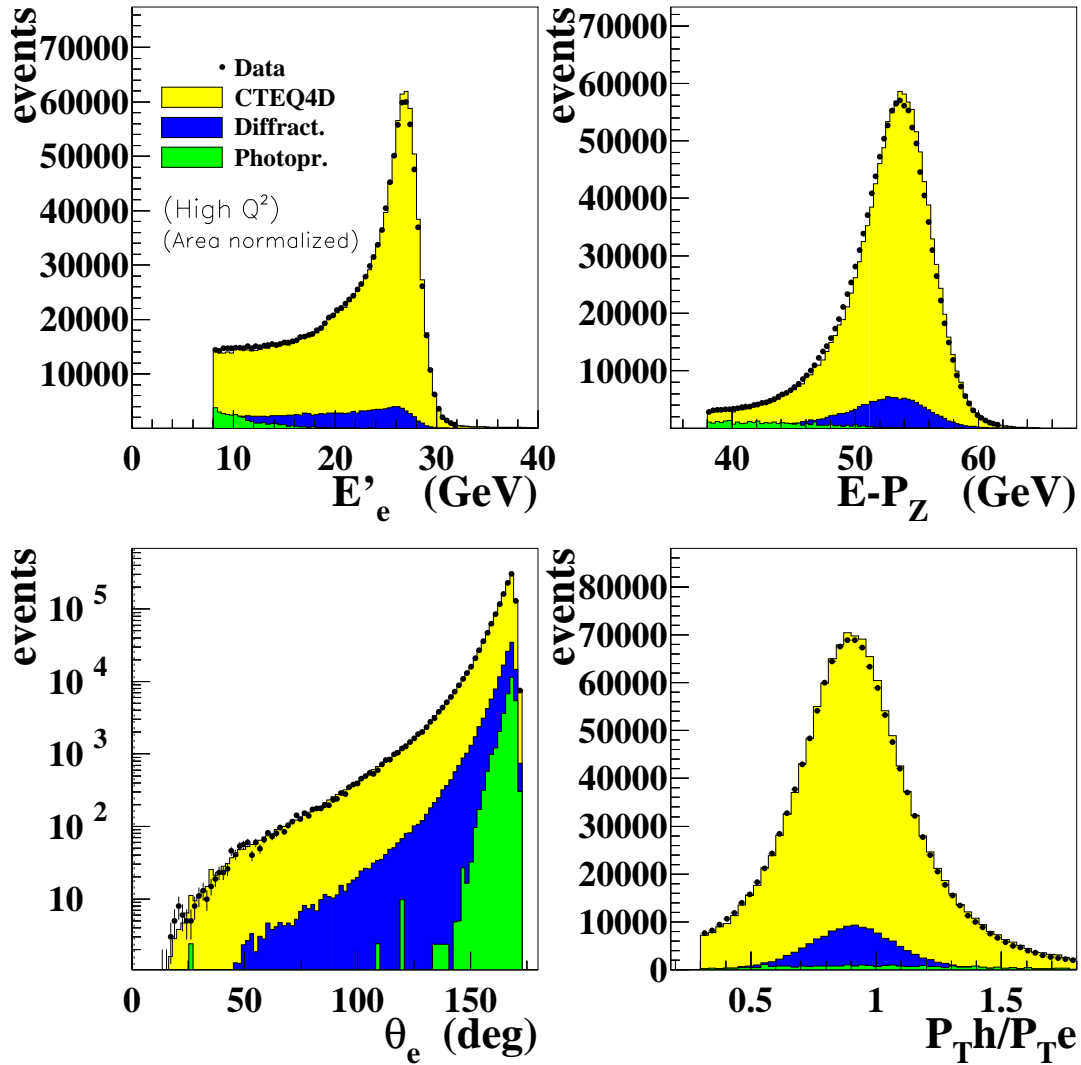
Coupling

$$V_f^{L,R} = e_f - (v_e \pm a_e) v_f \chi_z(Q^2),$$

$$A_f^{L,R} = - (v_e \pm a_e) a_f \chi_z(Q^2)$$

Reconstruct E and θ

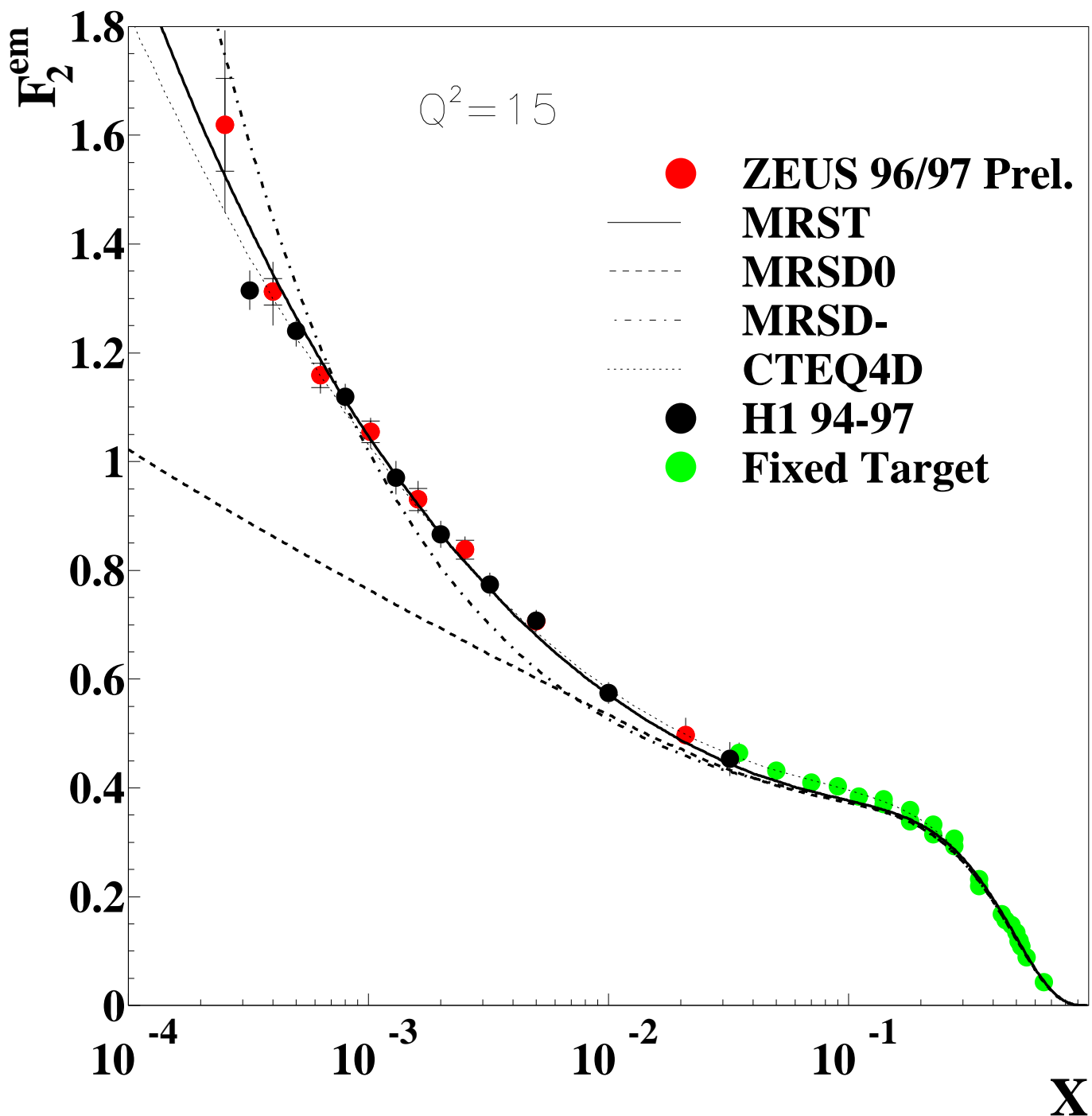
ZEUS Preliminary 1996-97



and reconstruct Q^2 and x_{bj}

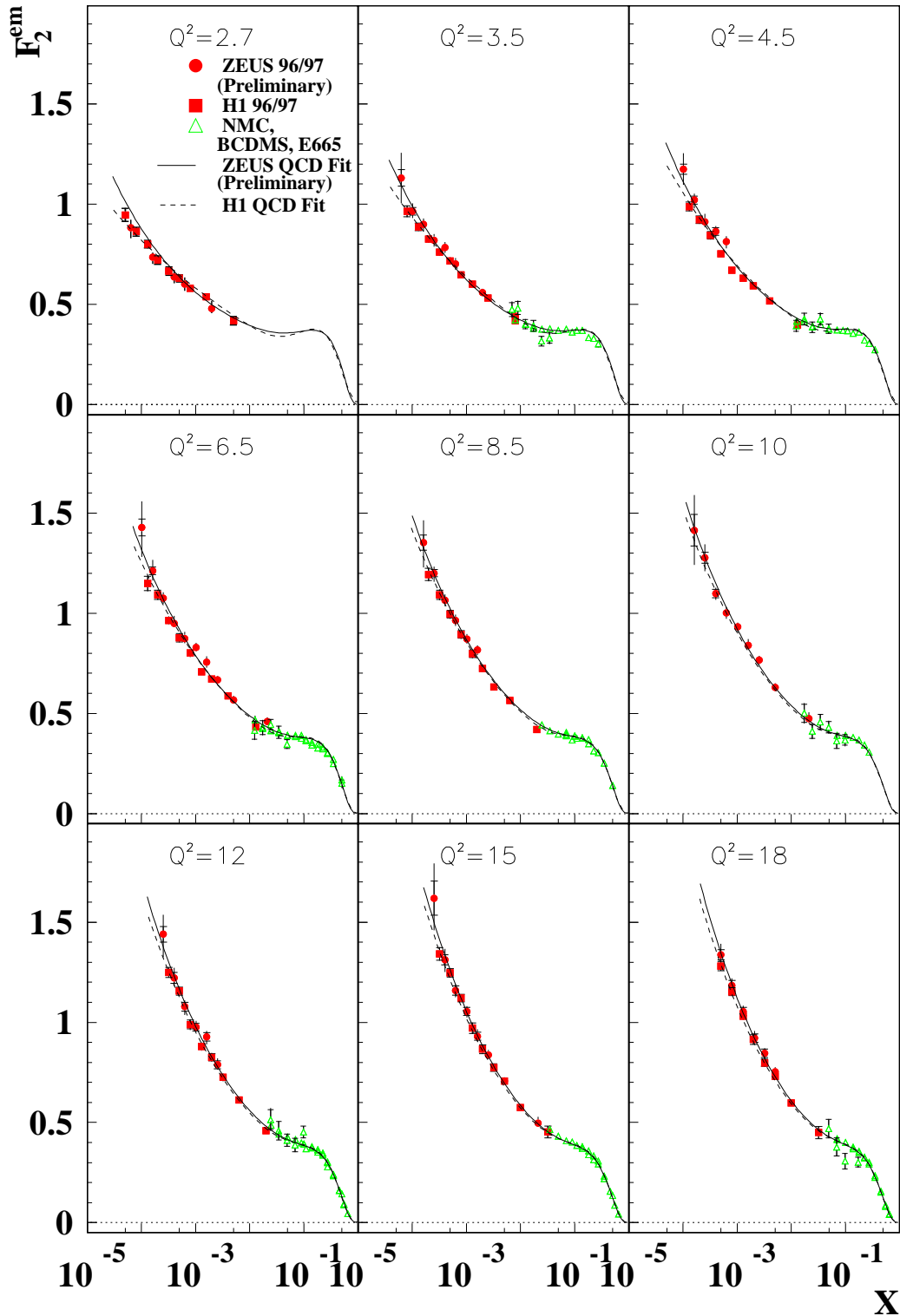
after background subtraction $\Rightarrow d^2\sigma/dxdQ^2$

Proton structure function F_2 - 1996-97



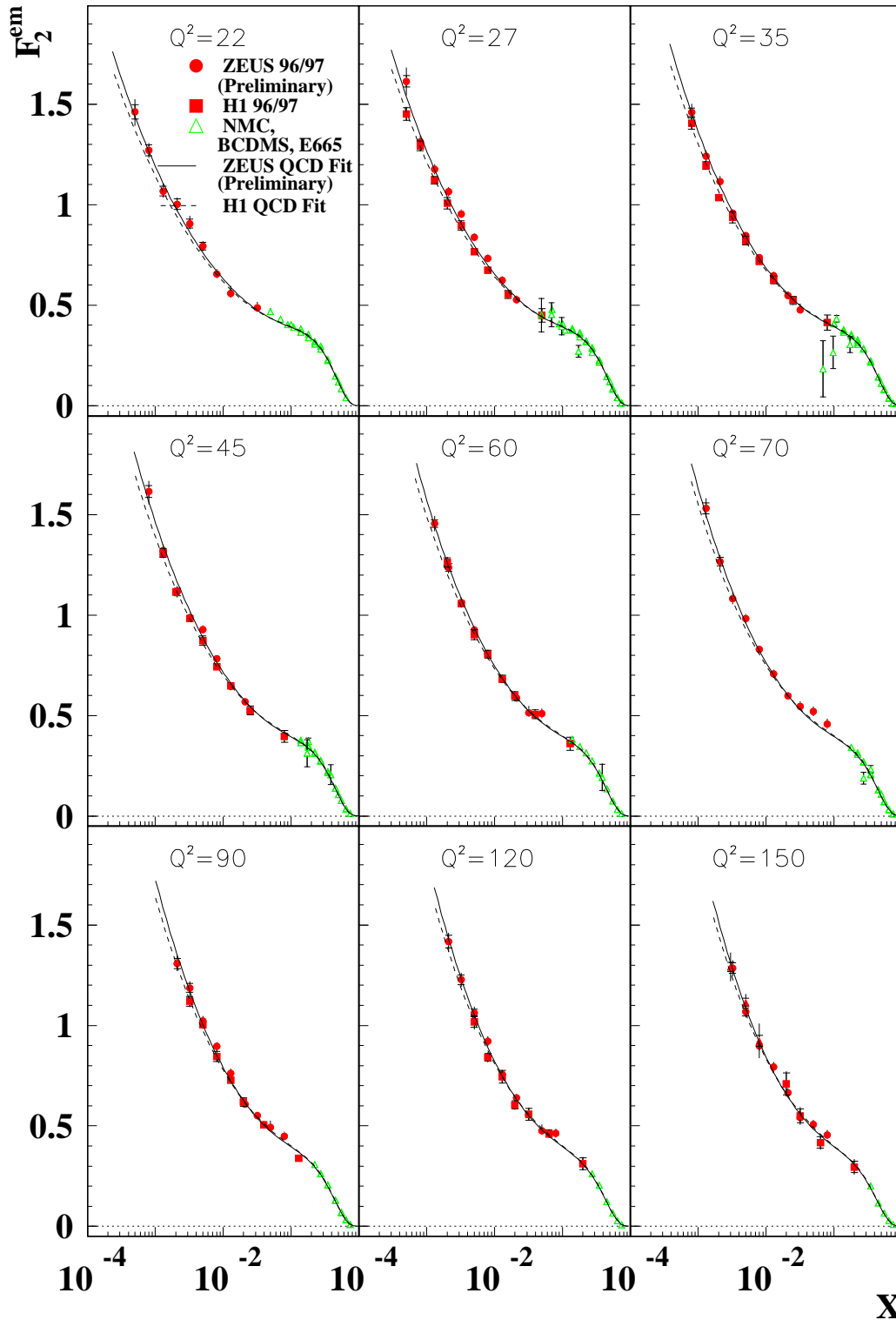
Proton Structure Function F_2

ZEUS+H1 96/97

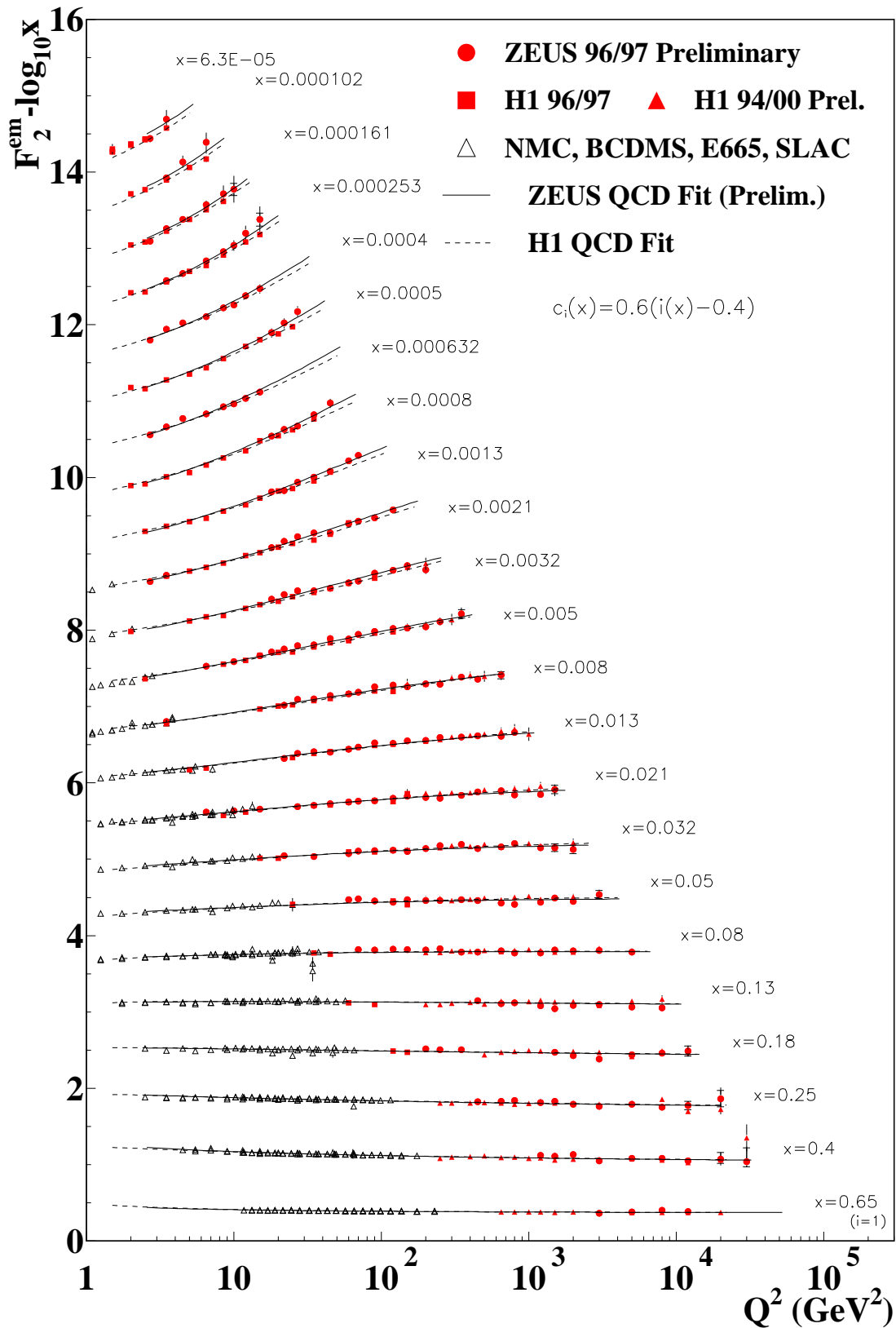


Proton Structure Function F_2

ZEUS+H1 96/97

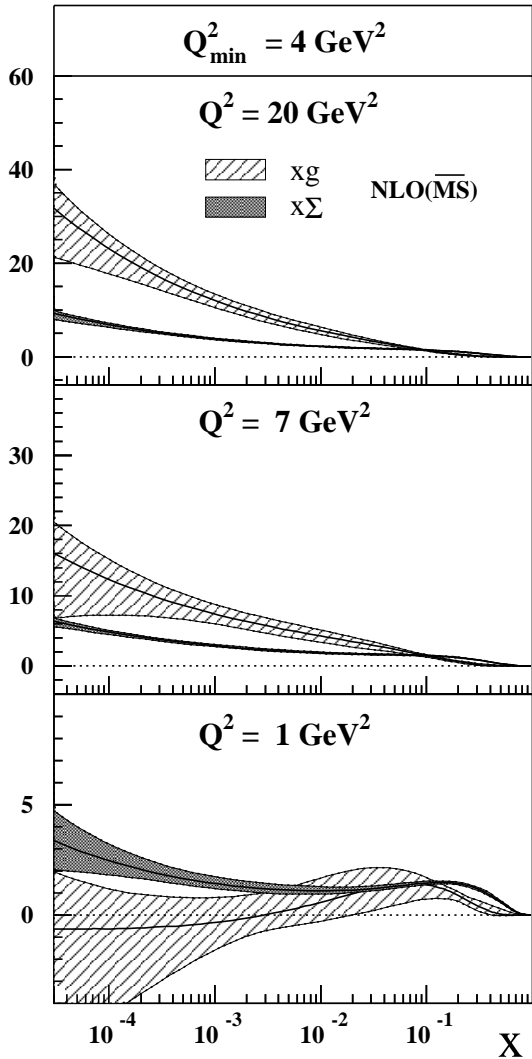


F₂ scaling violation

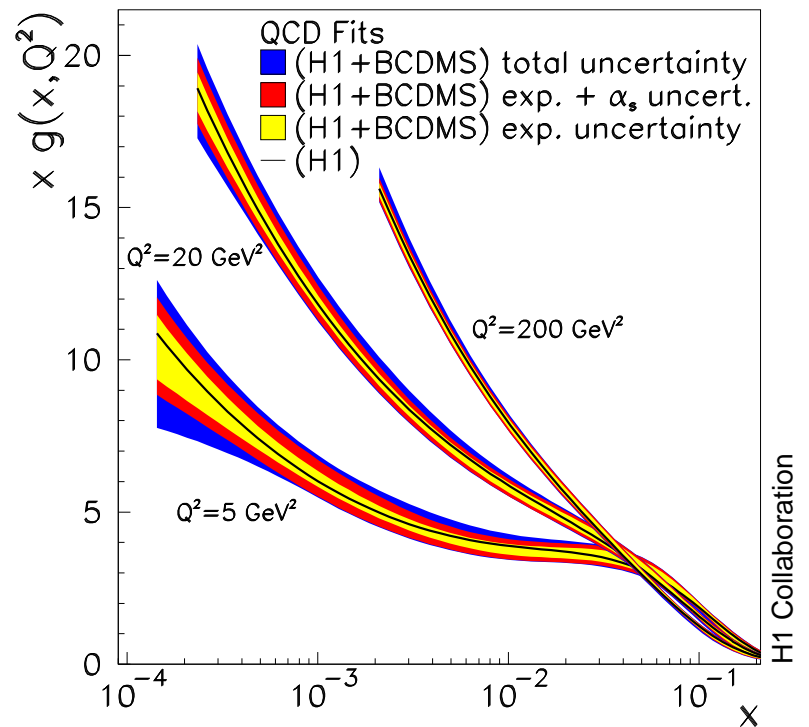


Analysis of F_2 : $xg(x)$ and singlet

ZEUS 1995

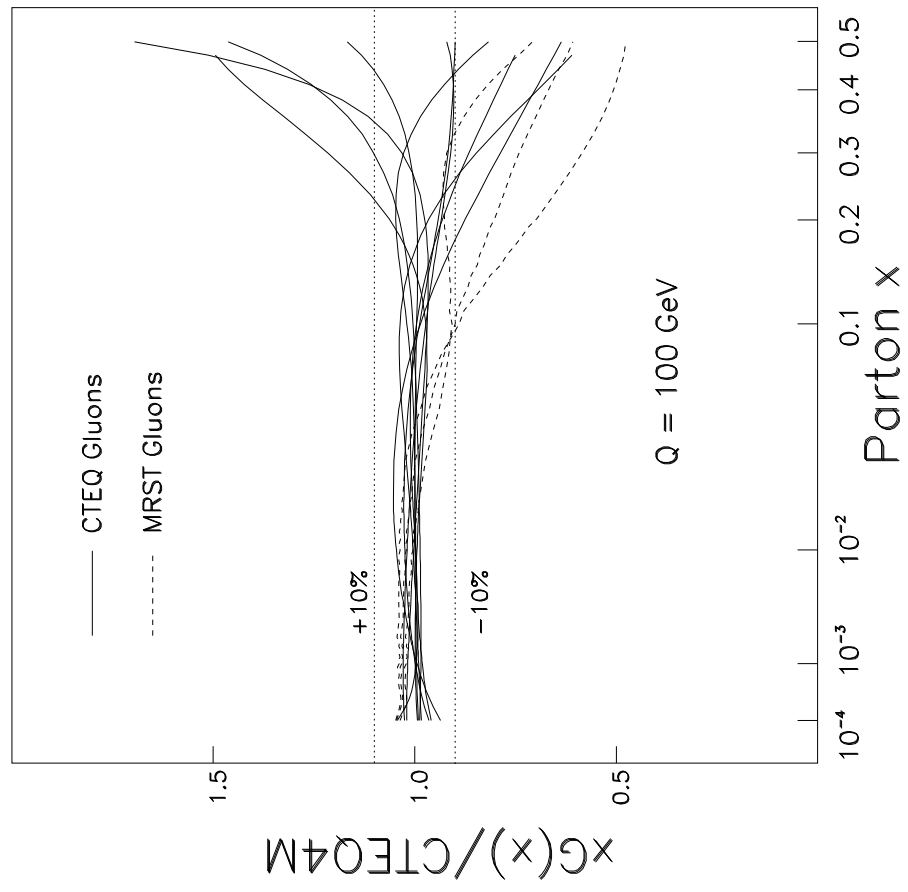
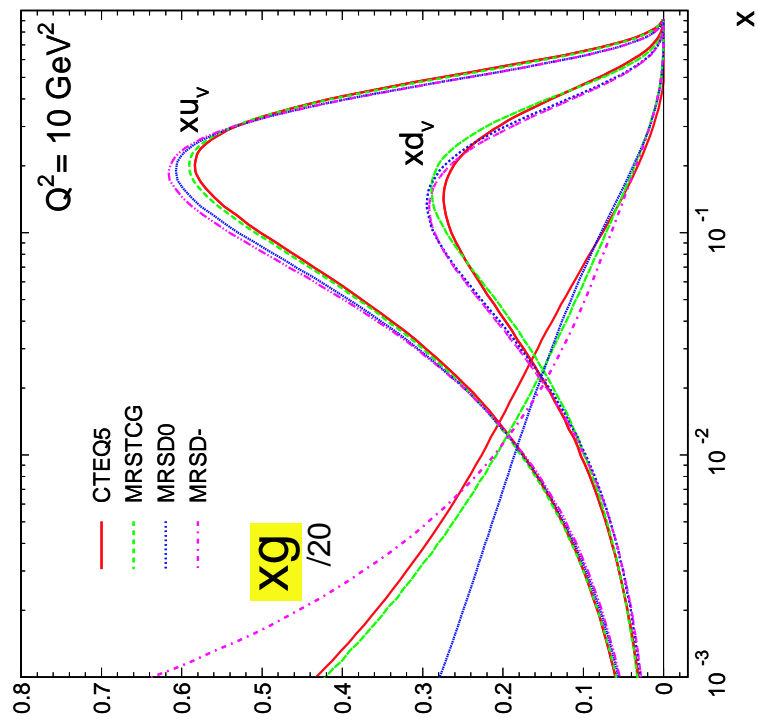


Fit to F_2 with input scale Q_0^2
 $xg(x) = A_g x^{\delta_g} (1-x)^{\eta_g} (1 + \gamma_g x)$
 with QCDNUM: NLO in $\overline{\text{MS}}$ scheme



QCD is able to describe F_2 data to $Q^2 \geq 1 \text{ GeV}^2$
 (where $\alpha_s \simeq 0.46$)

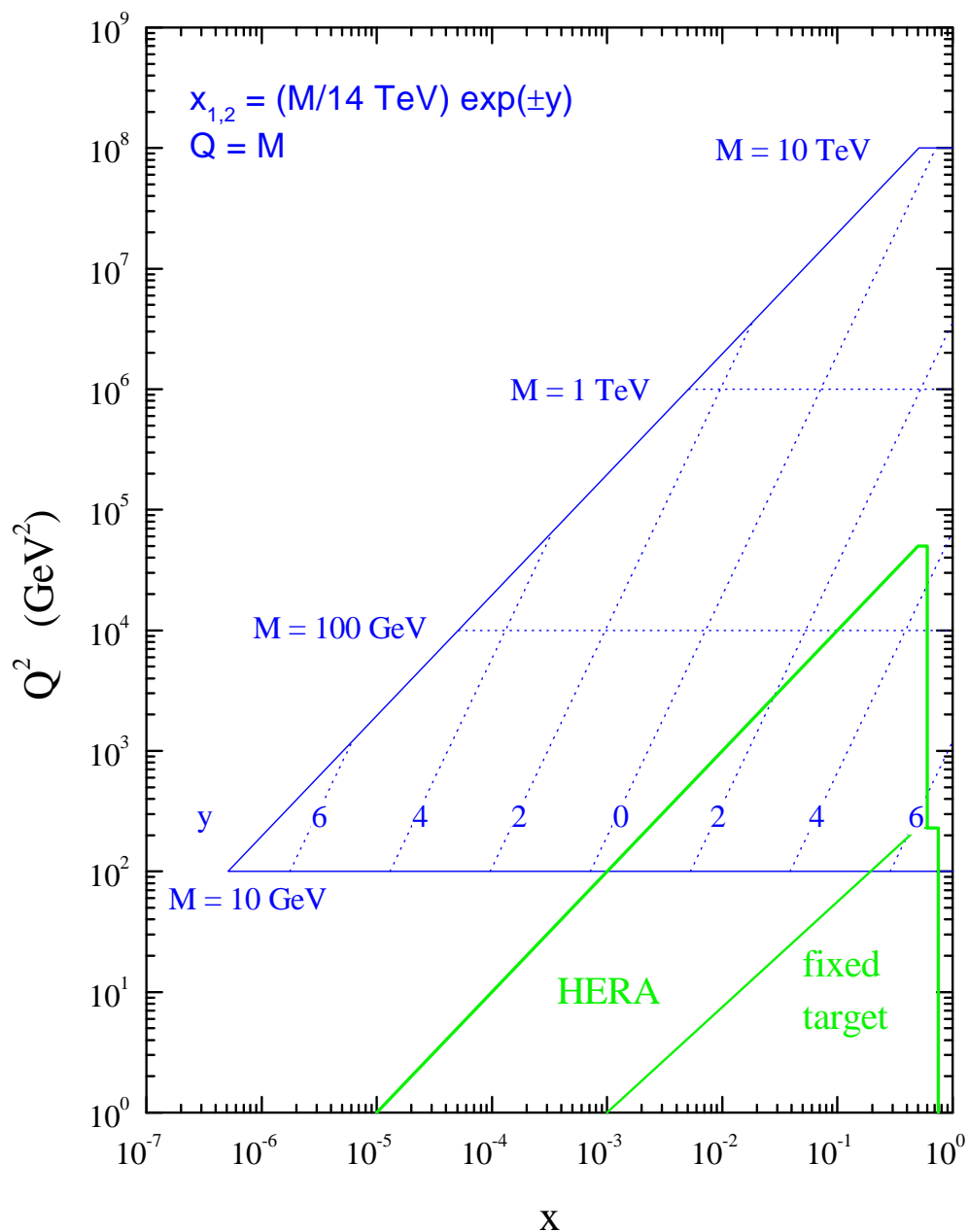
What have we learned about the quarks and gluons?



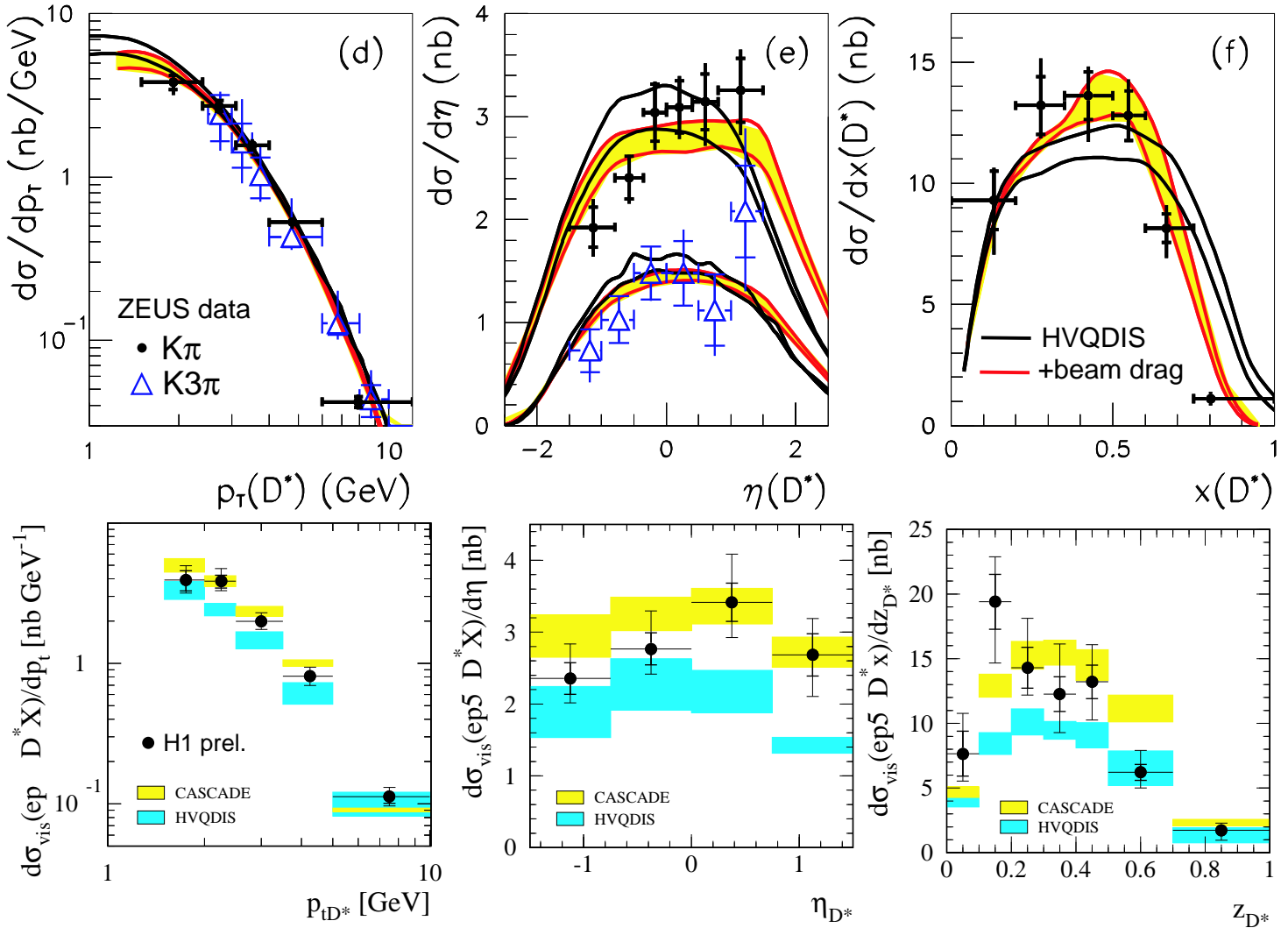
Why is it important?

Implications for future QCD studies
Understanding of the QCD vacuum
and

LHC parton kinematics

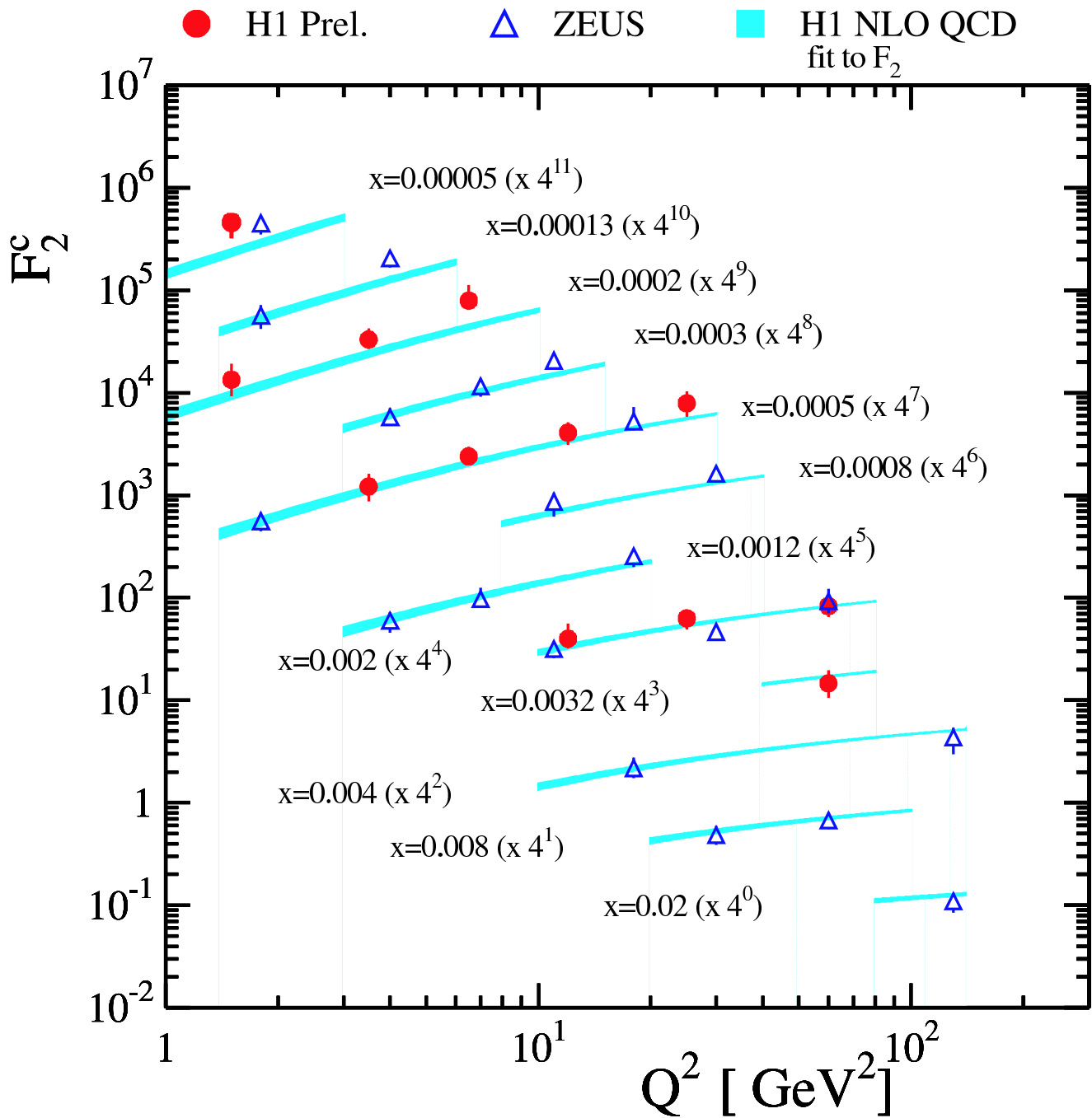


Charm contribution to F_2 from D^*



Measure $D^{*\pm}$ in DIS (gluon dominated) in 2 decay modes
 Determine the cross sections in DIS and D^* variables
 Relate the extrapolated double differential cross section to $F_2^{c\bar{c}}$
 Issues: Fragmentation, "beam drag" and/or DGLAP \rightarrow CCFM

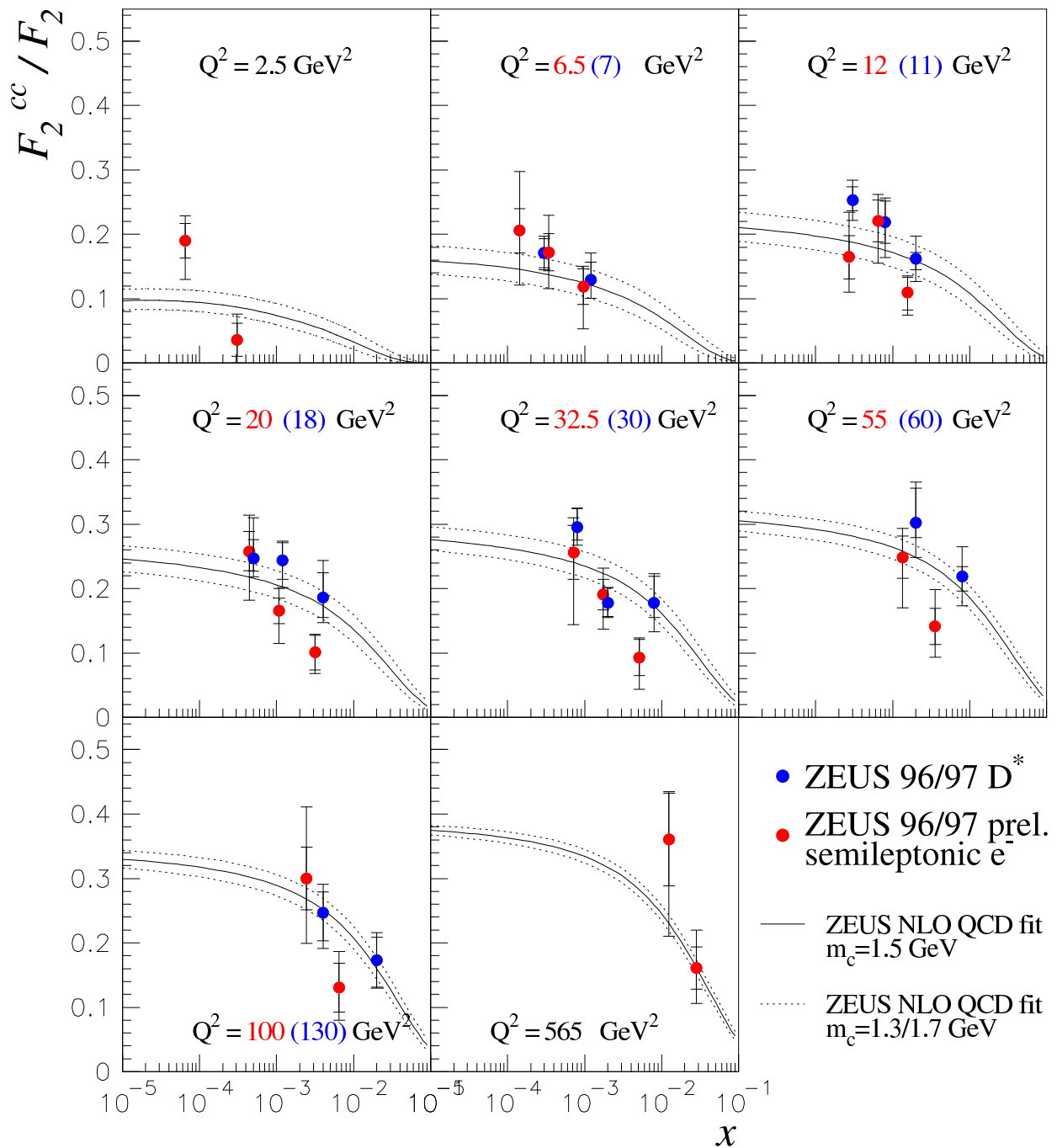
Charm contribution to F_2



test of QCD: $F_2 \rightarrow x g(x), xg \otimes BGF \rightarrow F_2^{c\bar{c}}$
 relate to "directly" measured $F_2^{c\bar{c}}$ from σ^{D^*}

Charm contribution to F_2 cont'd

ZEUS Preliminary 1996-97



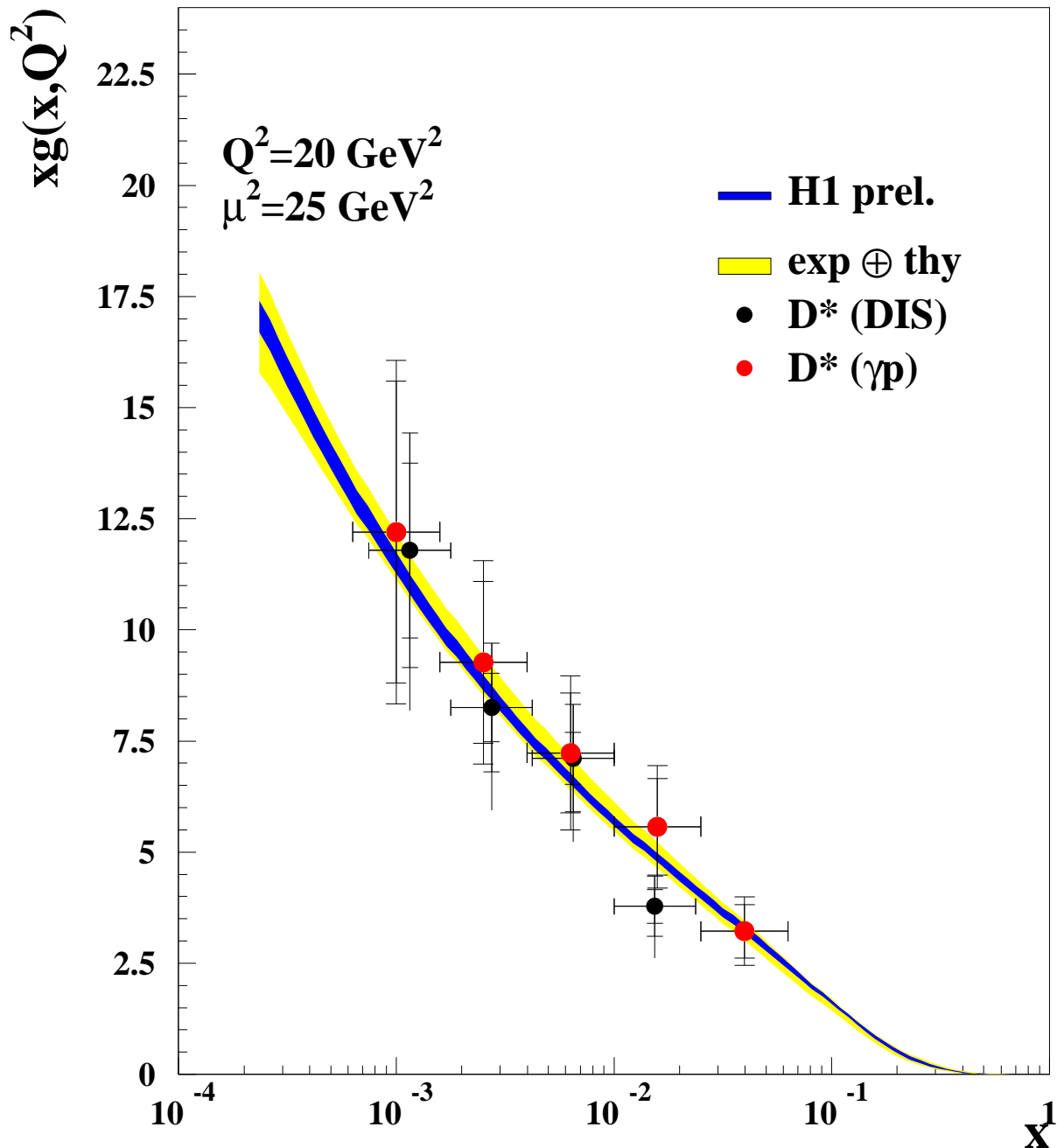
▷ F_2^{cc} rises faster than F_2 (glue dominated)

▷ $F_2^{cc} \approx 25\% F_2$ at low x , high Q^2

Charm contribution to F_2 contd'

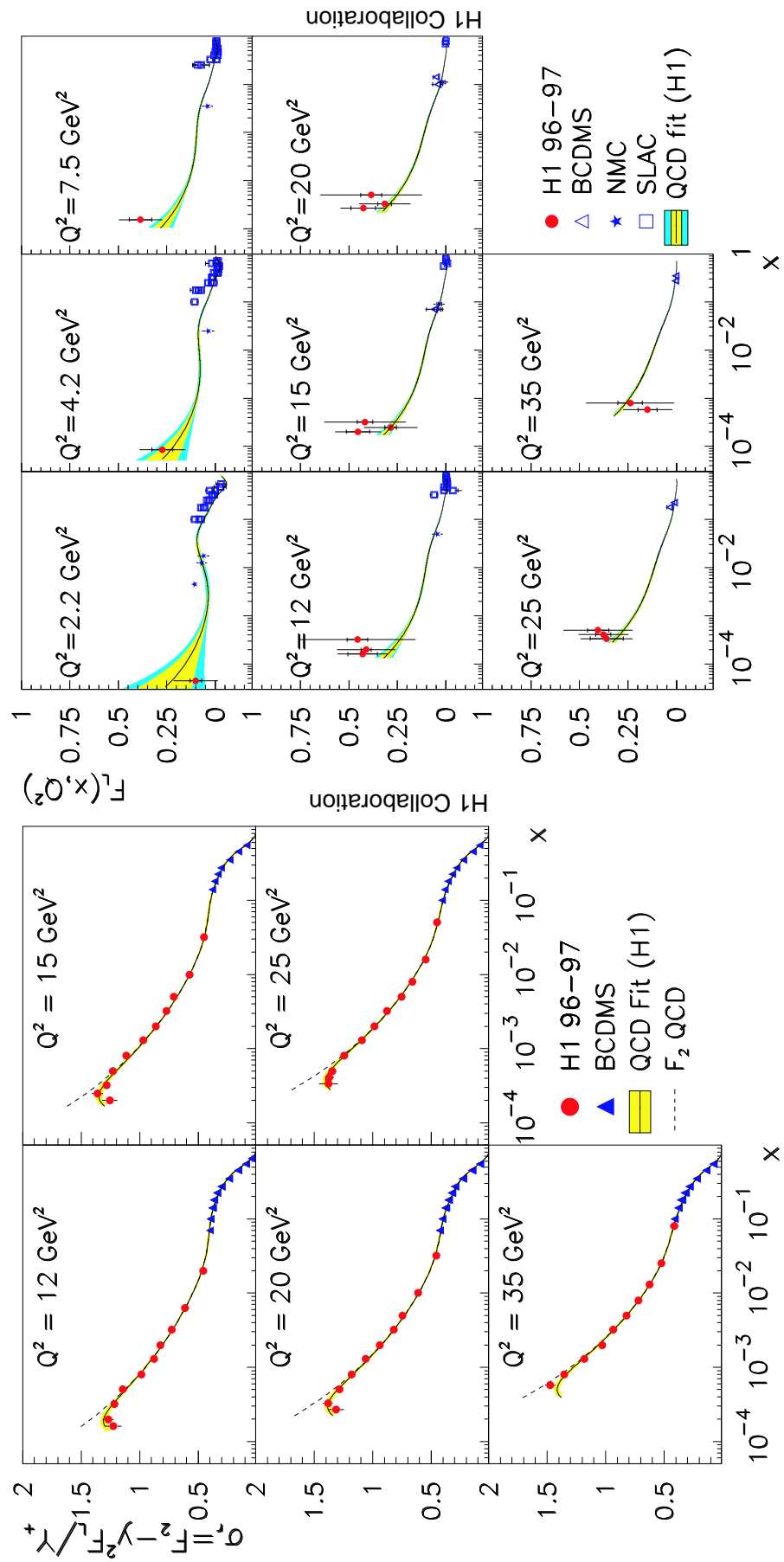
- ▷ "direct" x_g -unfolding of $x_g g(x_g)$ from D^*

H1 96-97

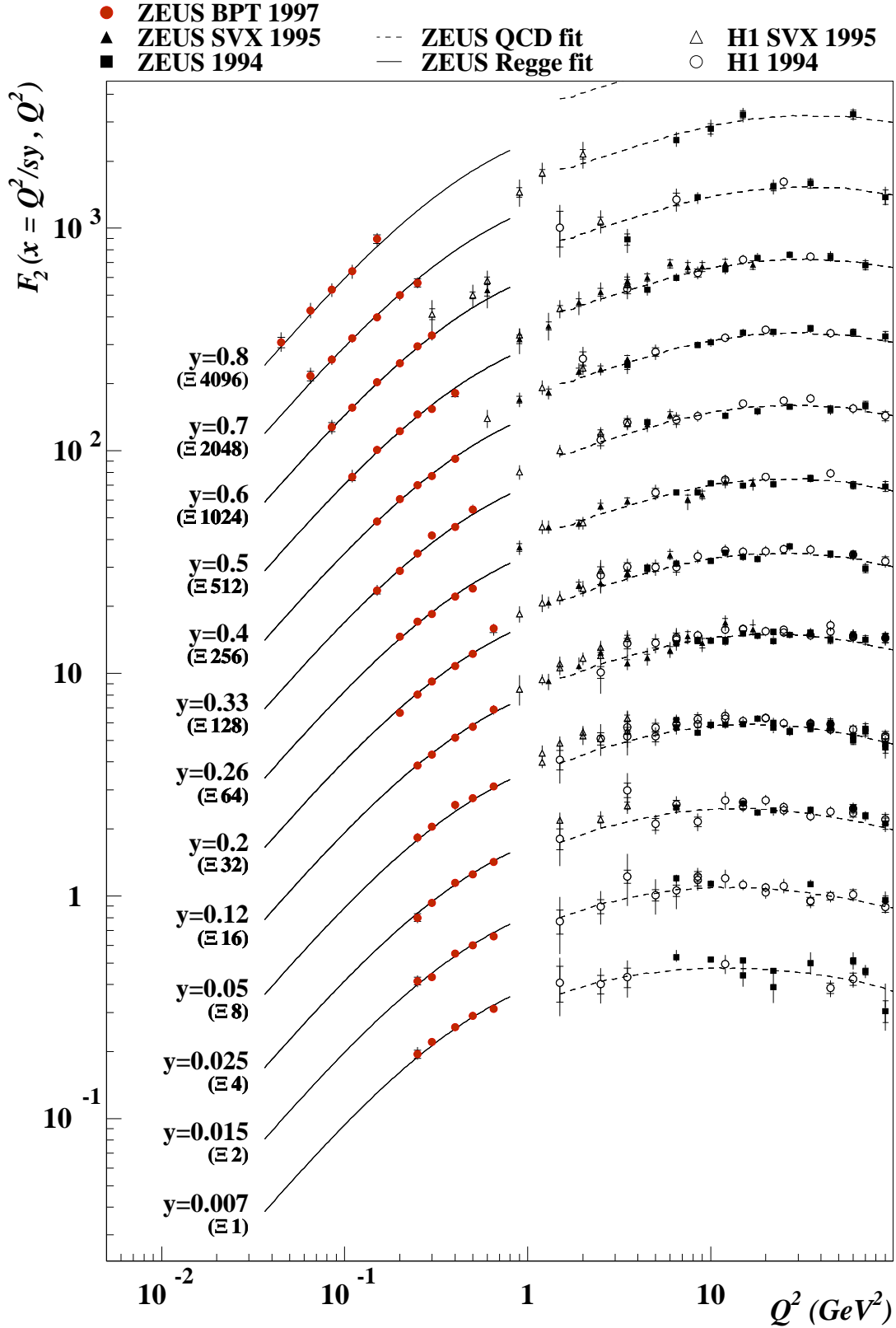


F_L : the longitudinal structure function

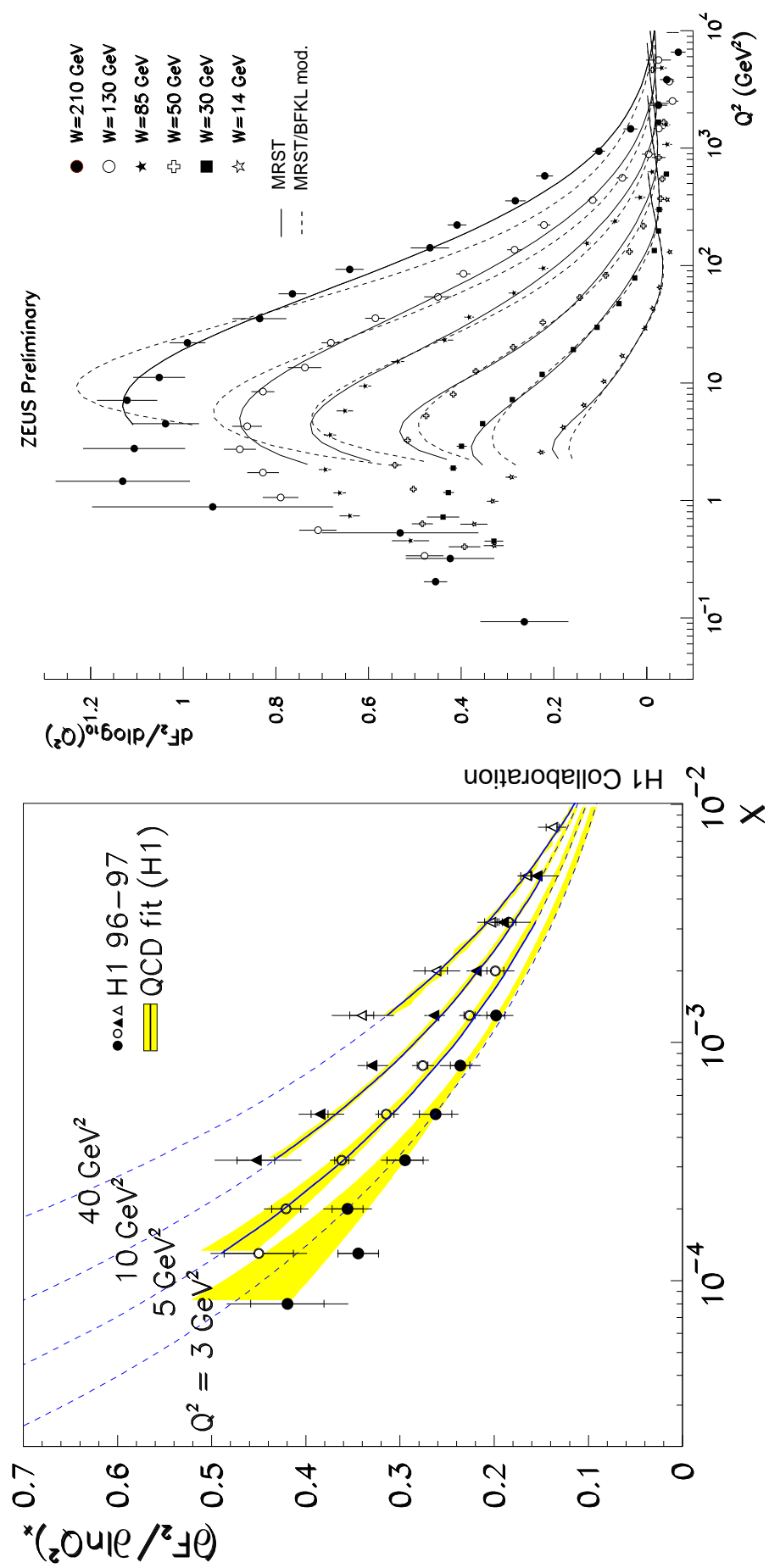
Very low x physics - deeply connected to the gluon density



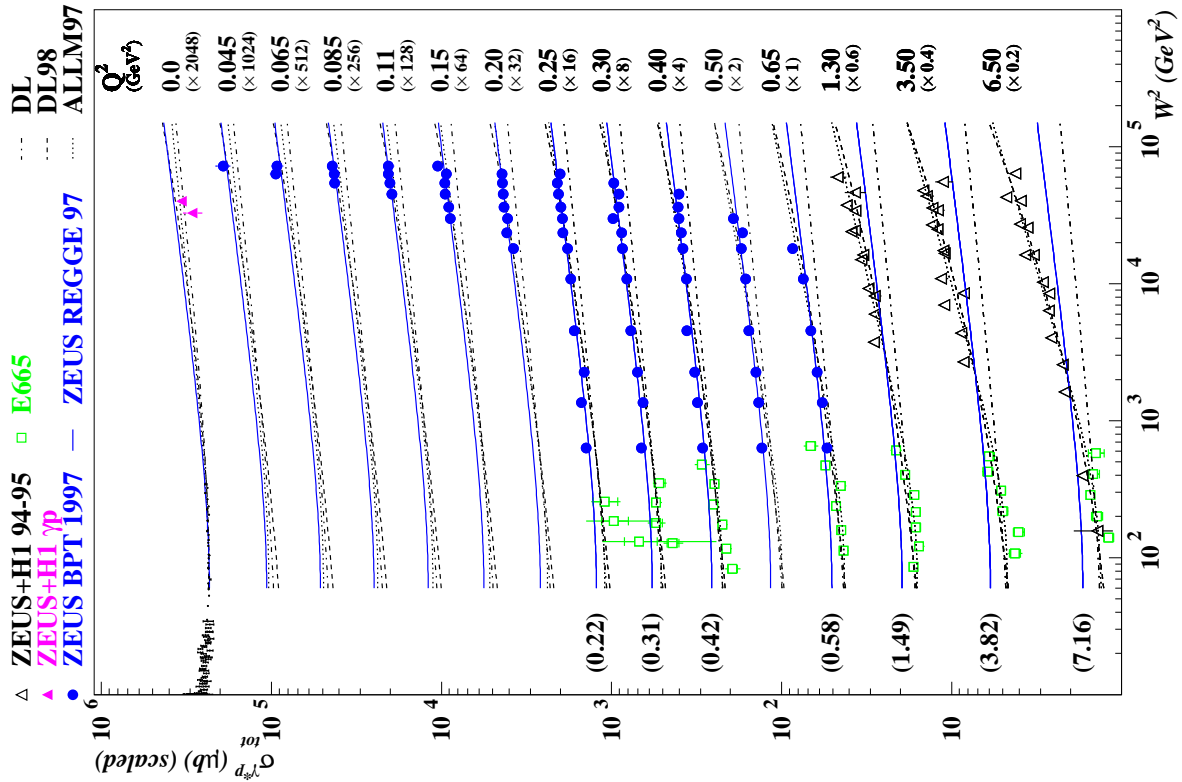
Transition from DIS to very low Q^2



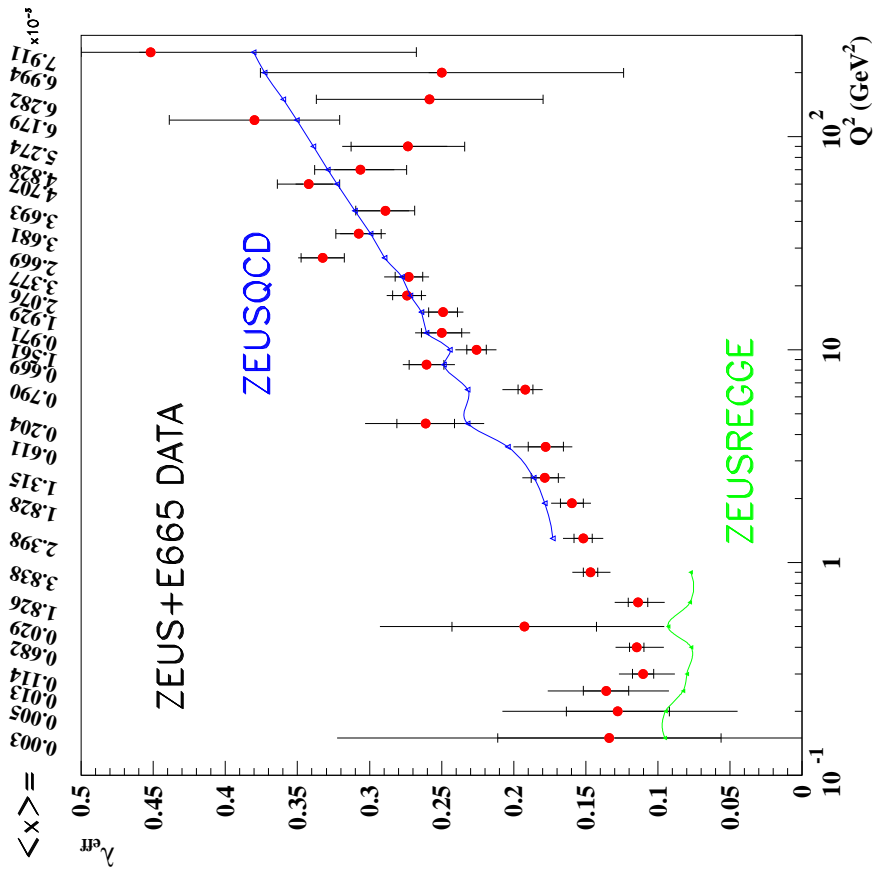
What can we learn from derivatives?



Cross section behaviour vs Q^2

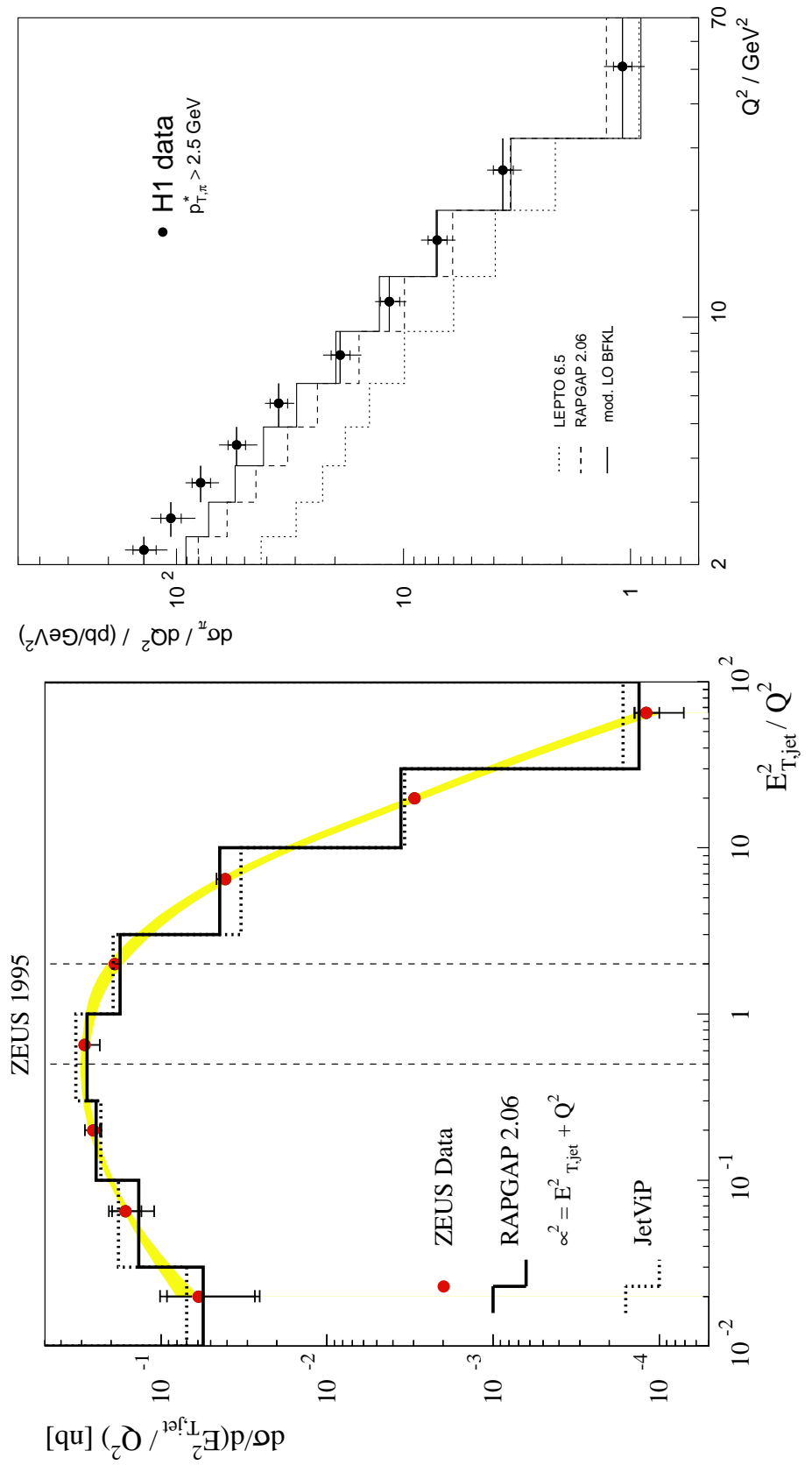


Model prediction:
VDM+QCD, ALLM, saturation...

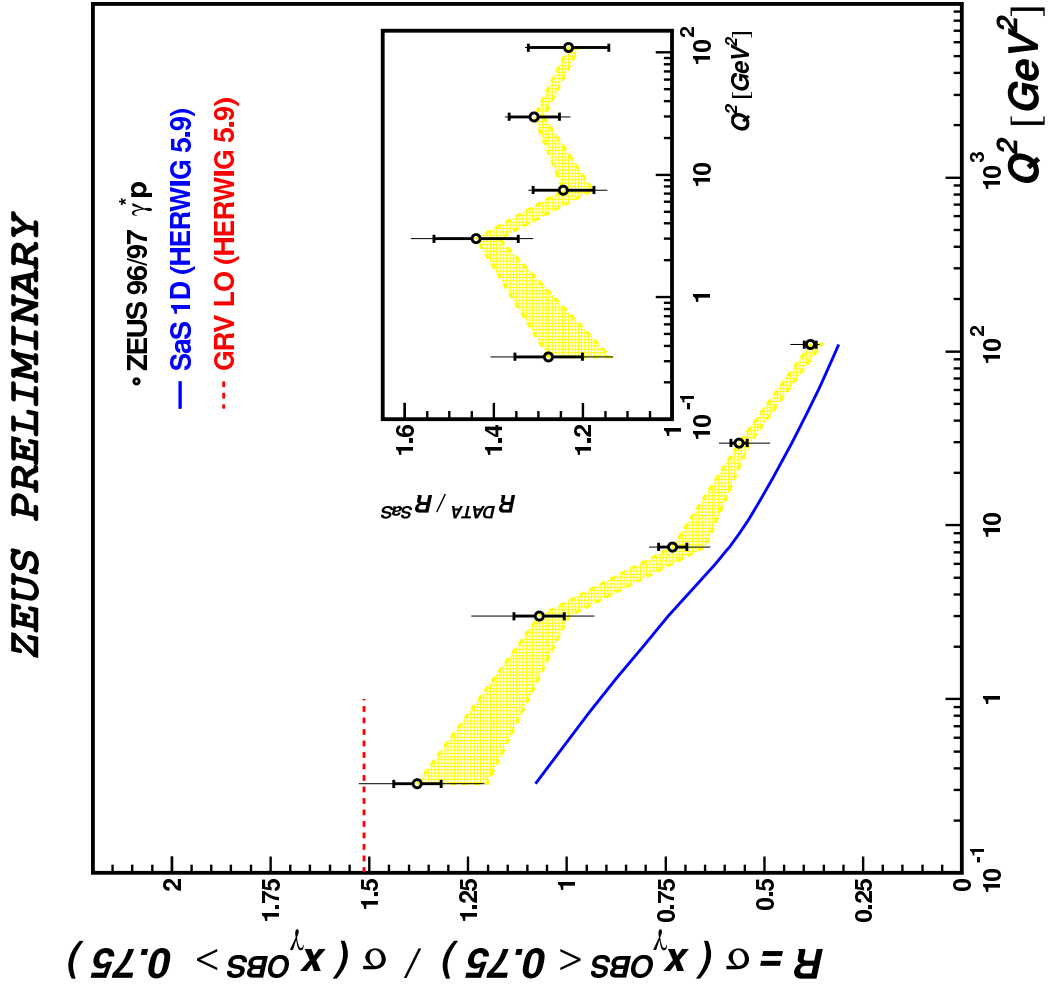
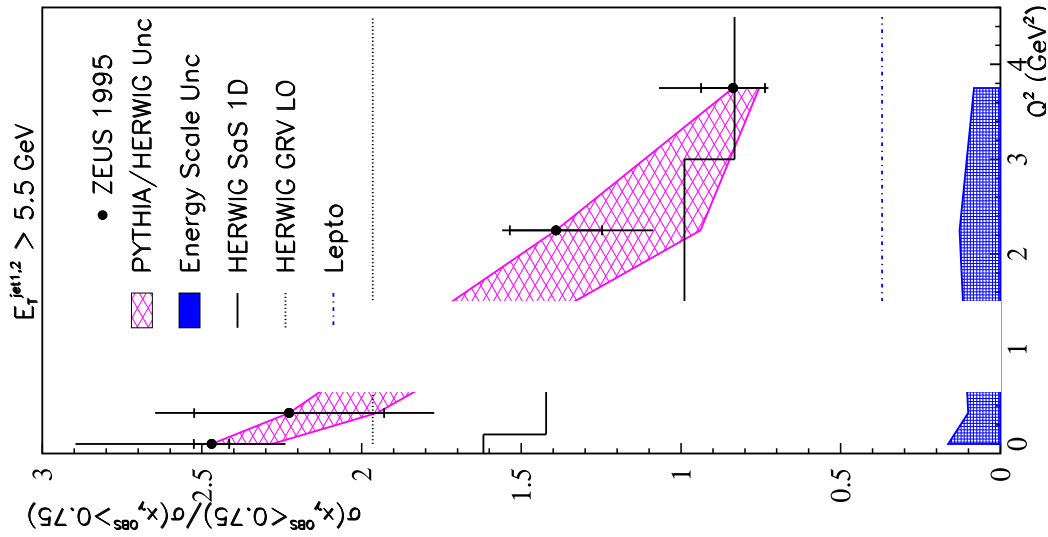


$d \ln F_2 / d \ln(1/x)$ at fixed Q^2 fit
 $F_2 \sim x^{-\lambda_{eff}}$

Looking for limitations of DGLAP?



Resolved photon component vs Q^2

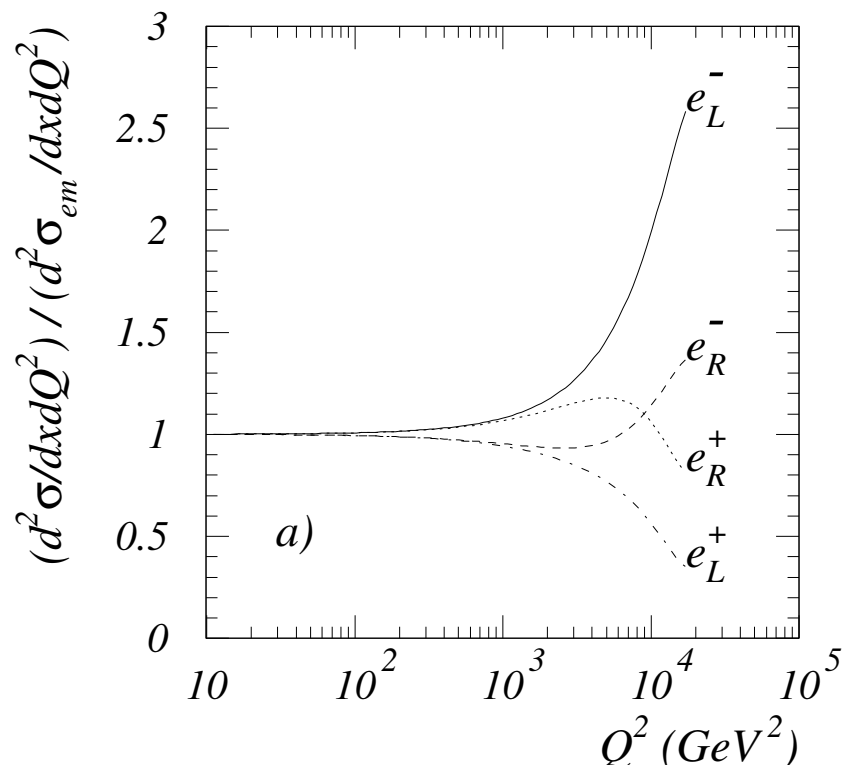


- Sizeable resolved component even at high Q^2
- No single model/ PDF describes the data
- NLO calculation (JETVIP) fails

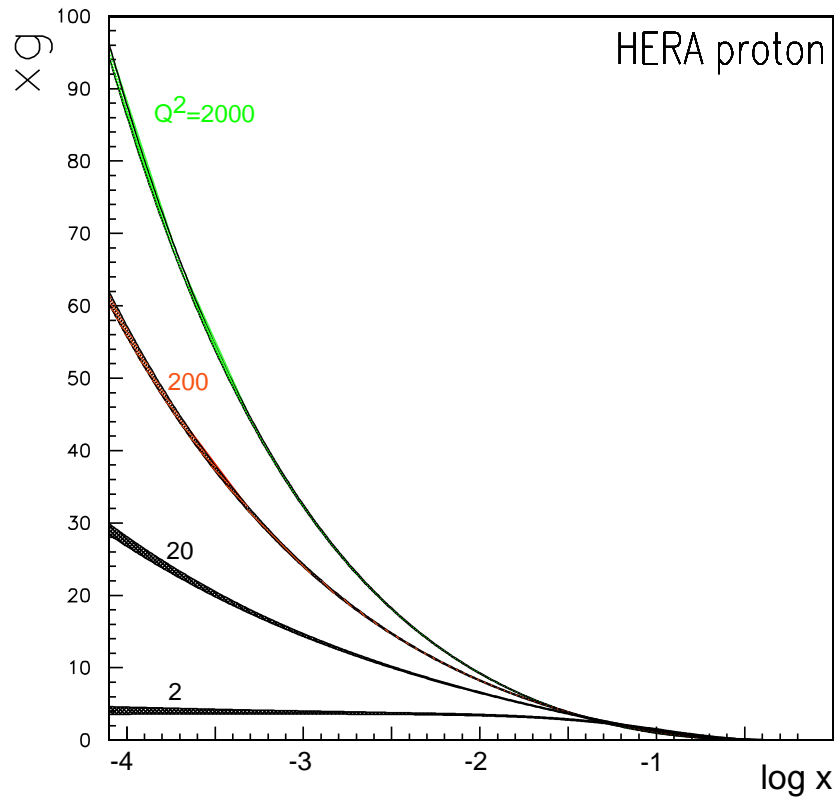
Summary and Outlook

- The HERA collider experiments H1 and ZEUS are working since 1992 and exploit and extend their detector(s) with better and better understanding
- The HERA program is rich: there are many other unique and competitive results of QCD, diffraction, heavy flavour physics, and photon structure, exotics...
- HERA physics reveals unique knowledge of the **proton** structure and the QCD at high parton densities

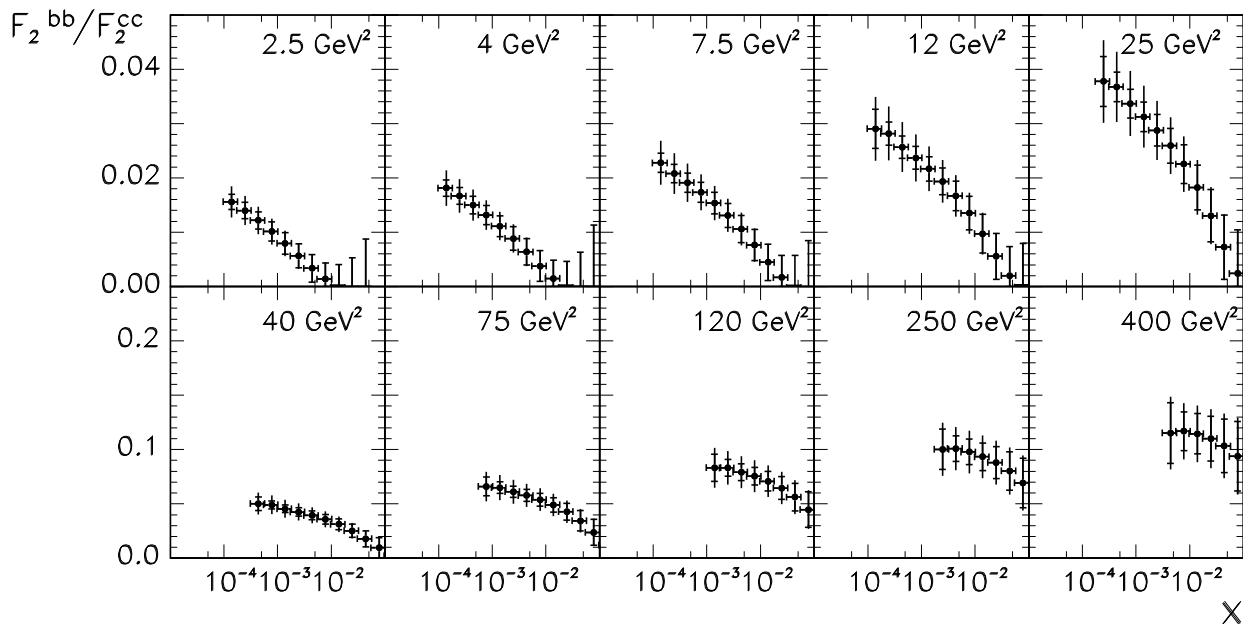
HERA's goal is to deliver 1 fb^{-1} with polarized electrons (positrons) starting 2001 mainly for high Q^2 physics



Post-upgrade physics: proton structure



Gluon density



Charm and beauty content of the proton