Phenomenology Of The Proton Structure Function F_2 At Low Q^2

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- Introduction
- Overview of the data sets
- Presentation of final ZEUS 96/97 F_2 data
- Slopes of F_2
- Summary & Outlook

Introduction

- The results shown in this talk are part of an ongoing analysis of the phenomenology of the proton structure function data.

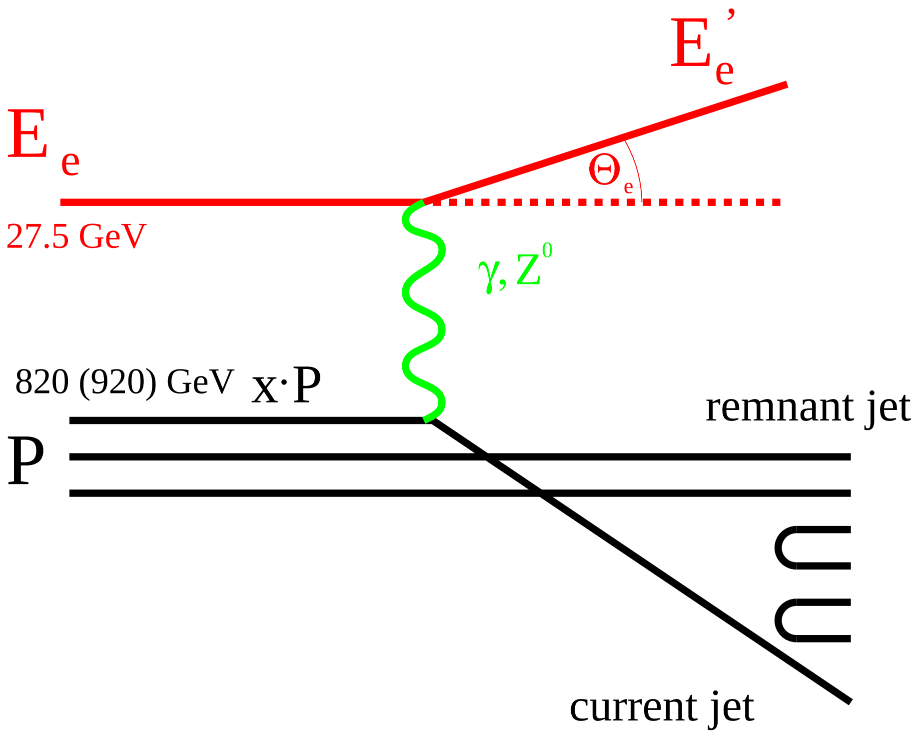
- This includes the behaviour of the proton structure function F_2, diffractive data from HERA and the extrapolation of the measured cross-sections to $Q^2 = 0$ GeV^2

- This talk concentrates on slopes of the proton structure function F_2, studied over a large kinematic range

- Special attention is given to the transition region between photoproduction and the regime of perturbative QCD

- ZEUS & fixed-target data used

Kinematics of NC e^+P scattering at HERA



Q^2	$= -q^2 = -(k-k')^2$	squared 4-momentum transfer;
x	$= \frac{Q^2}{2p\cdot q}$	fractional parton momentum $(0 \leq x \leq 1)$
y	$= \frac{p\cdot q}{p\cdot k}$	fractional energy transfer $(0 \leq y \leq 1)$
W^2	$= (q+p)^2 \simeq \frac{Q^2}{x}(1-x)$	$\gamma^* P$ CMS energy^2 energy;
s	$= (k+p)^2 \simeq 4E_e E_P$	e^+P CMS energy^2 $(\sqrt{s} \sim 300(318)$ GeV)

$\boxed{Q^2 \simeq x \cdot y \cdot s}$ $\Rightarrow$ 2 independent variables

Cross Sections & Structure Functions

Differential NC e^+P cross section for 1-photon exchange

$$\frac{d\sigma^{NC}_{e^\pm p}}{dx\, dQ^2} = \frac{2\pi\alpha^2}{x\, Q^4} Y_+ \left[F_2 - \frac{y^2}{Y_+} F_L \mp \frac{Y_-}{Y_+} xF_3 \right] = \Gamma \left[\sigma_T^{\gamma^* p} + \epsilon\, \sigma_L^{\gamma^* p} \right],$$

where:

$$\begin{aligned} Y_\pm &= 1 \pm (1-y)^2 \\ \Gamma &= \alpha Y_+/(2\pi Q^2 y) (\text{virtual photon flux}) \\ \epsilon &= 2(1-y)/Y_+ (\text{photon polarisation}) \end{aligned}$$

Total $\gamma^* p$ cross-section:

$$\sigma_{tot}^{\gamma^* p} = \sigma_T^{\gamma^* p} + \sigma_L^{\gamma^* p} = \frac{4\pi^2\alpha}{Q^4} \frac{4M^2x^2 + Q^2}{1-x} F_2.$$

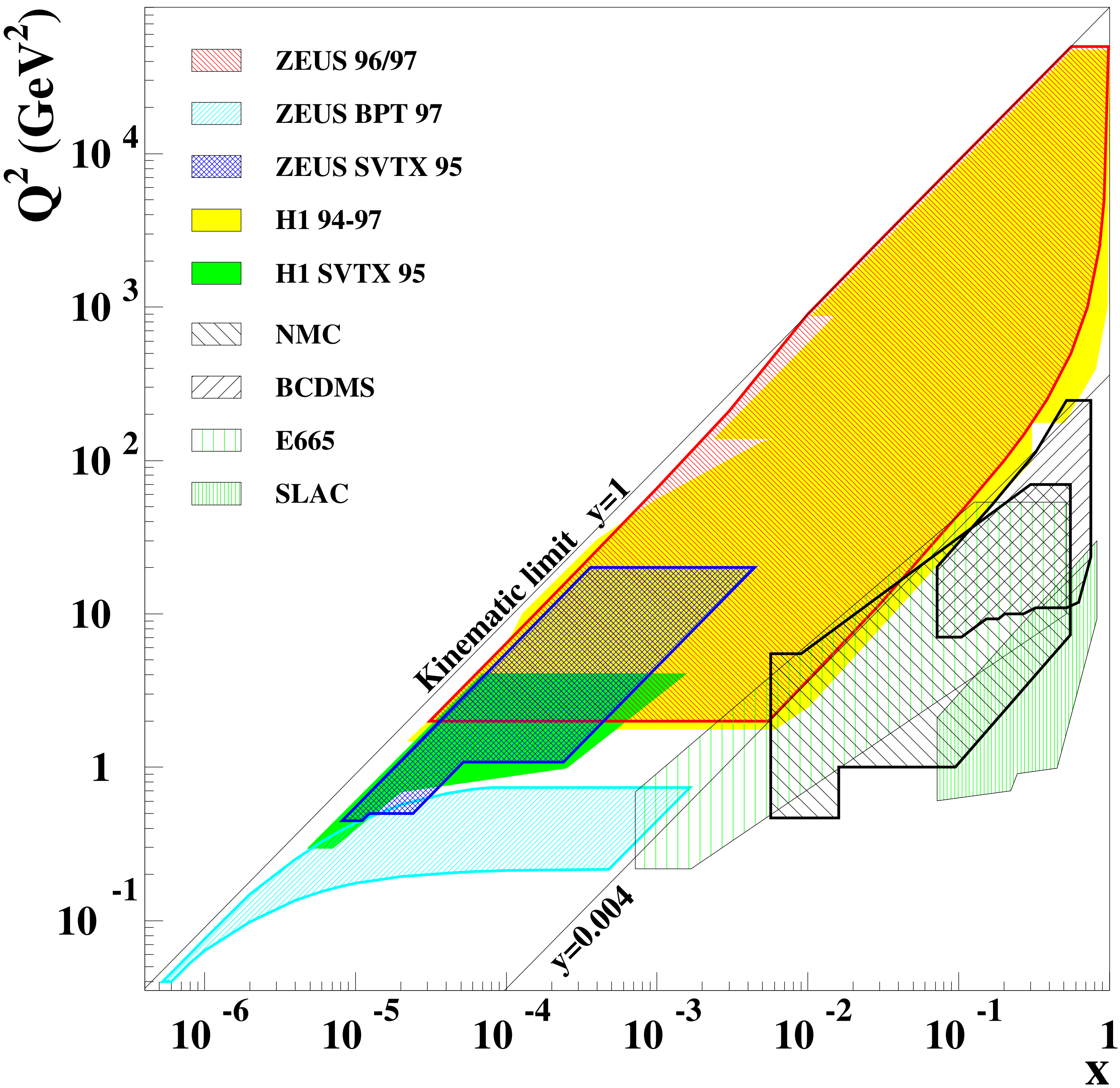
$$F_2 = F_2^{em}(1+\delta_Z);$$

At low Q^2:

- Z^0 exchange negligible: $F_2 \rightarrow F_2^{em}$

$$\sigma_{tot}^{\gamma^* p} = \sigma_T^{\gamma^* p} + \sigma_L^{\gamma^* p} \approx \frac{4\pi^2\alpha}{Q^2} F_2$$

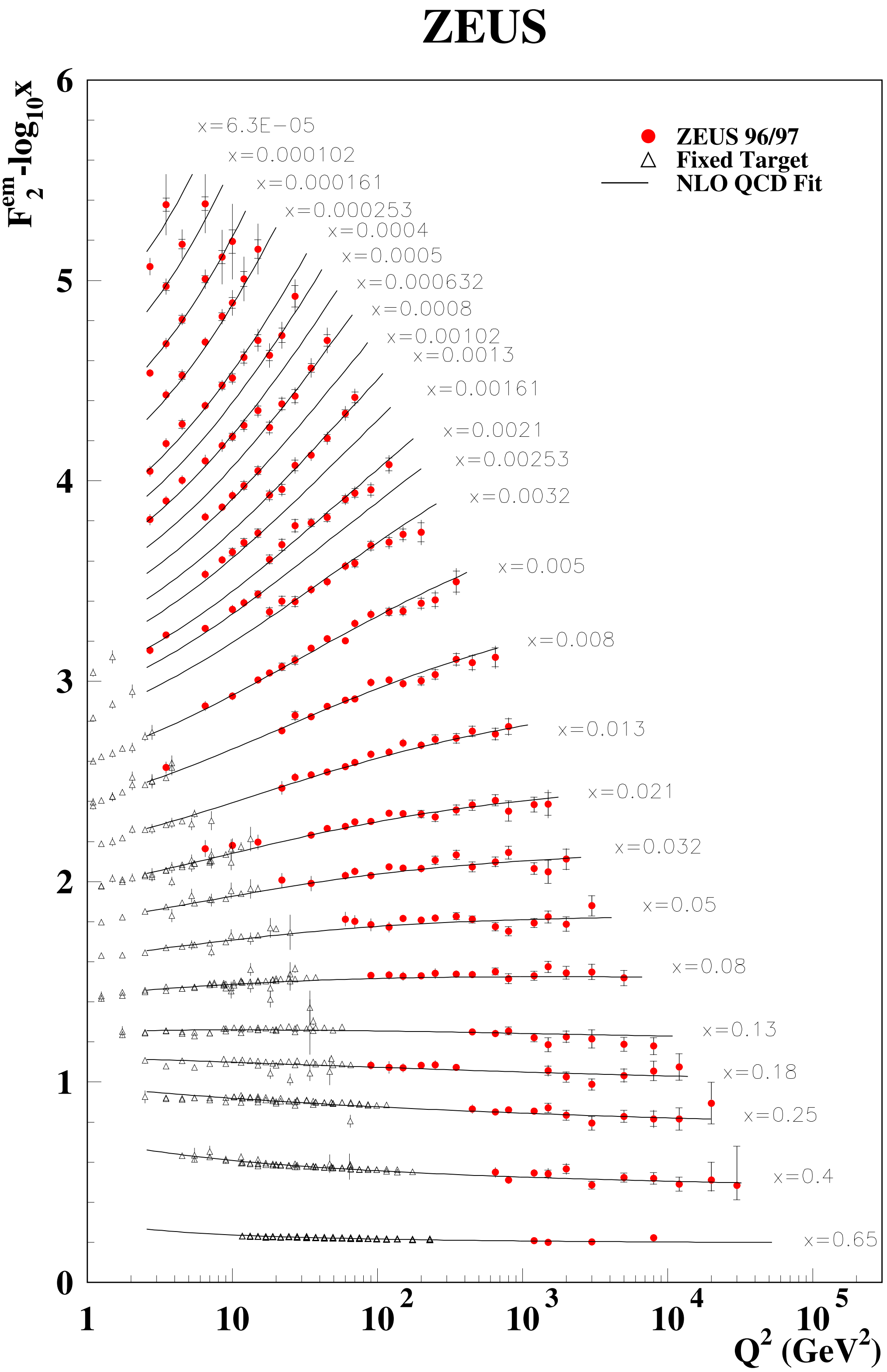
Experimental Range



- ZEUS (BPT97, SVTX95, 96/97) and fixed-targed data used

- ZEUS 96/97 data now final

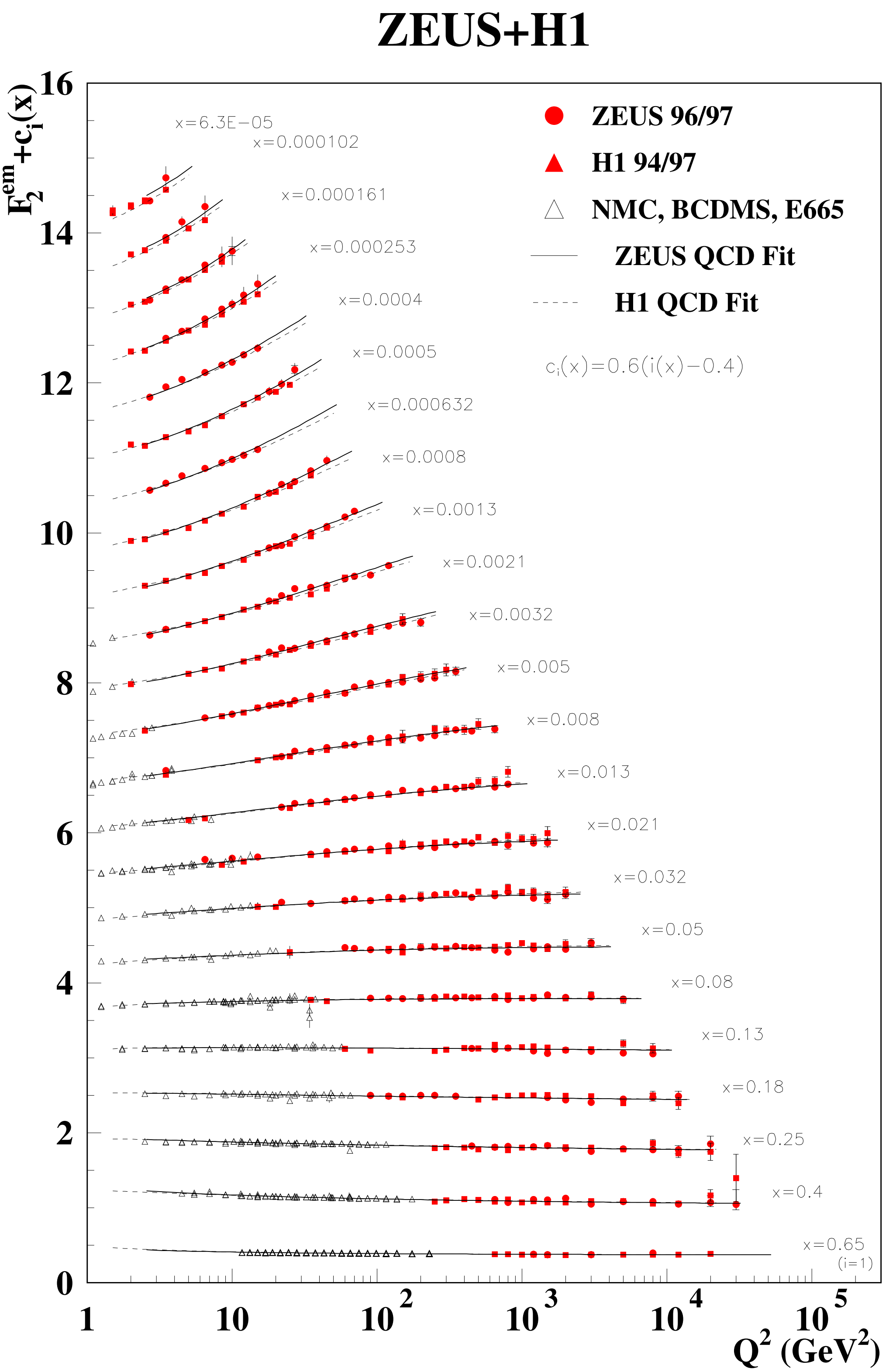
Final ZEUS 96/97 data



Improvements compared to ZEUS 94 data:

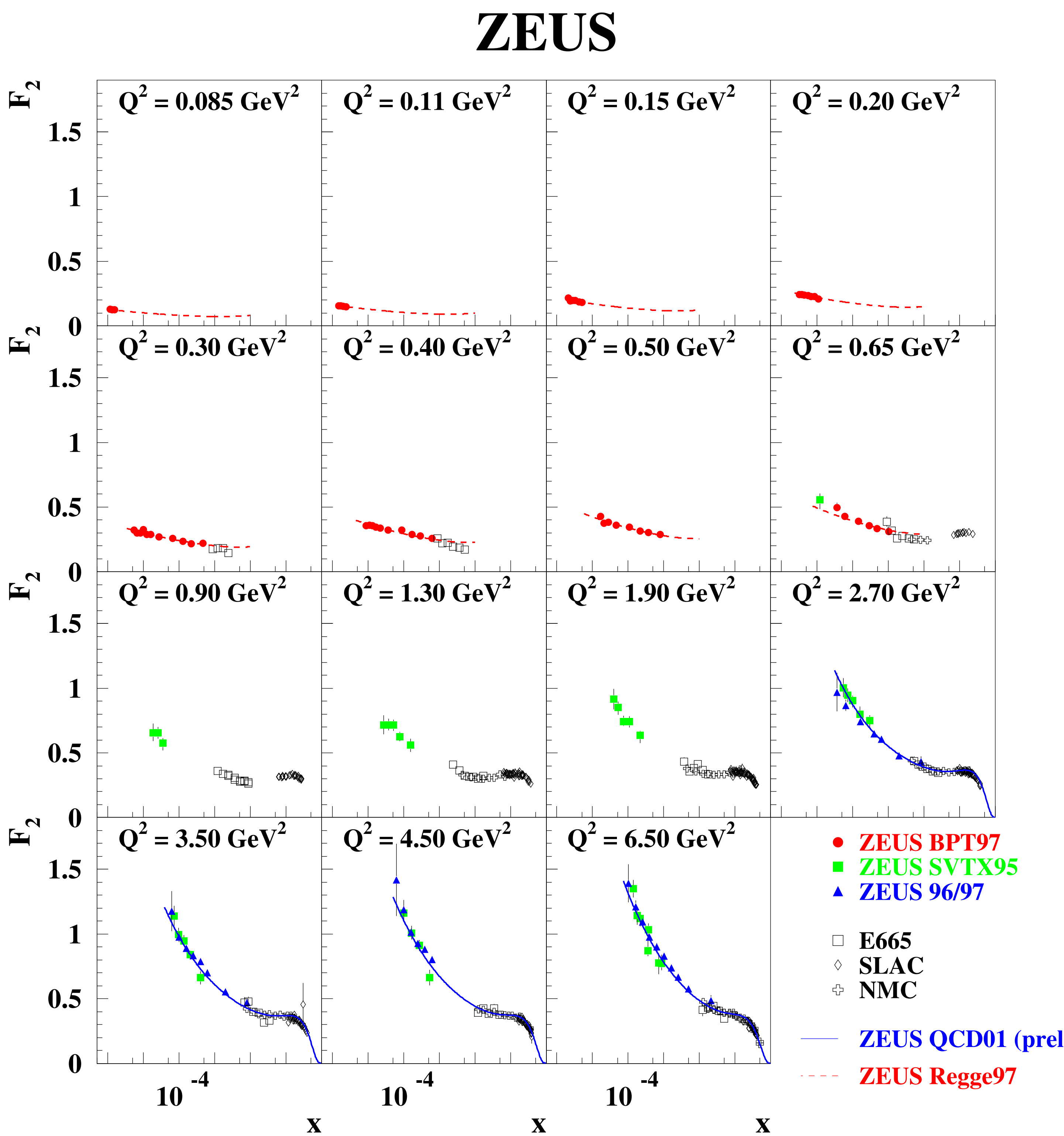
- Larger kinematic area covered
- Reduction of the systematic uncertainties

Final ZEUS 96/97 data



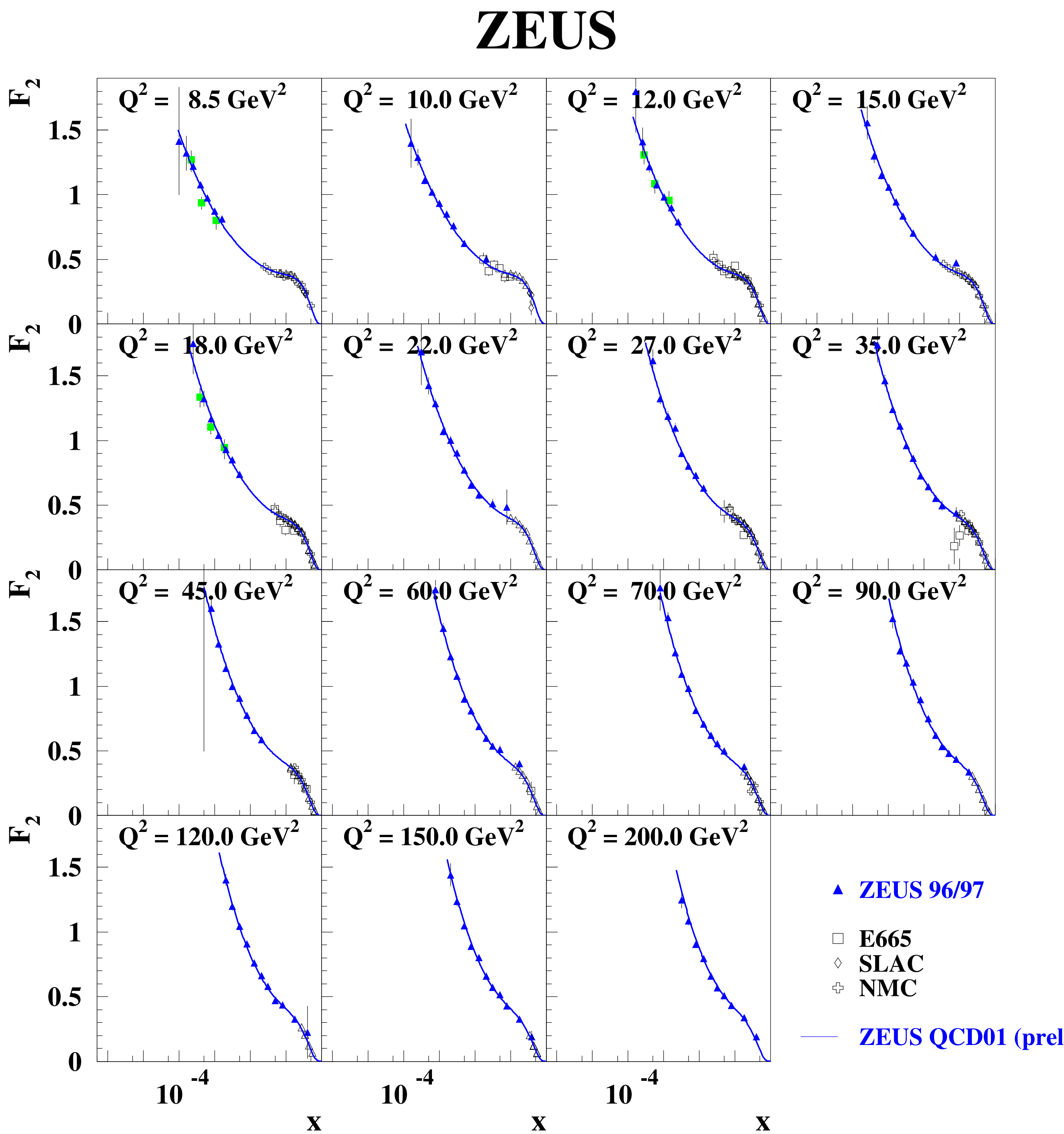
- Agreement between ZEUS & H1
- Tables will be availiable soon

Overview: F_2 vs. x, Q^2 fixed (1)



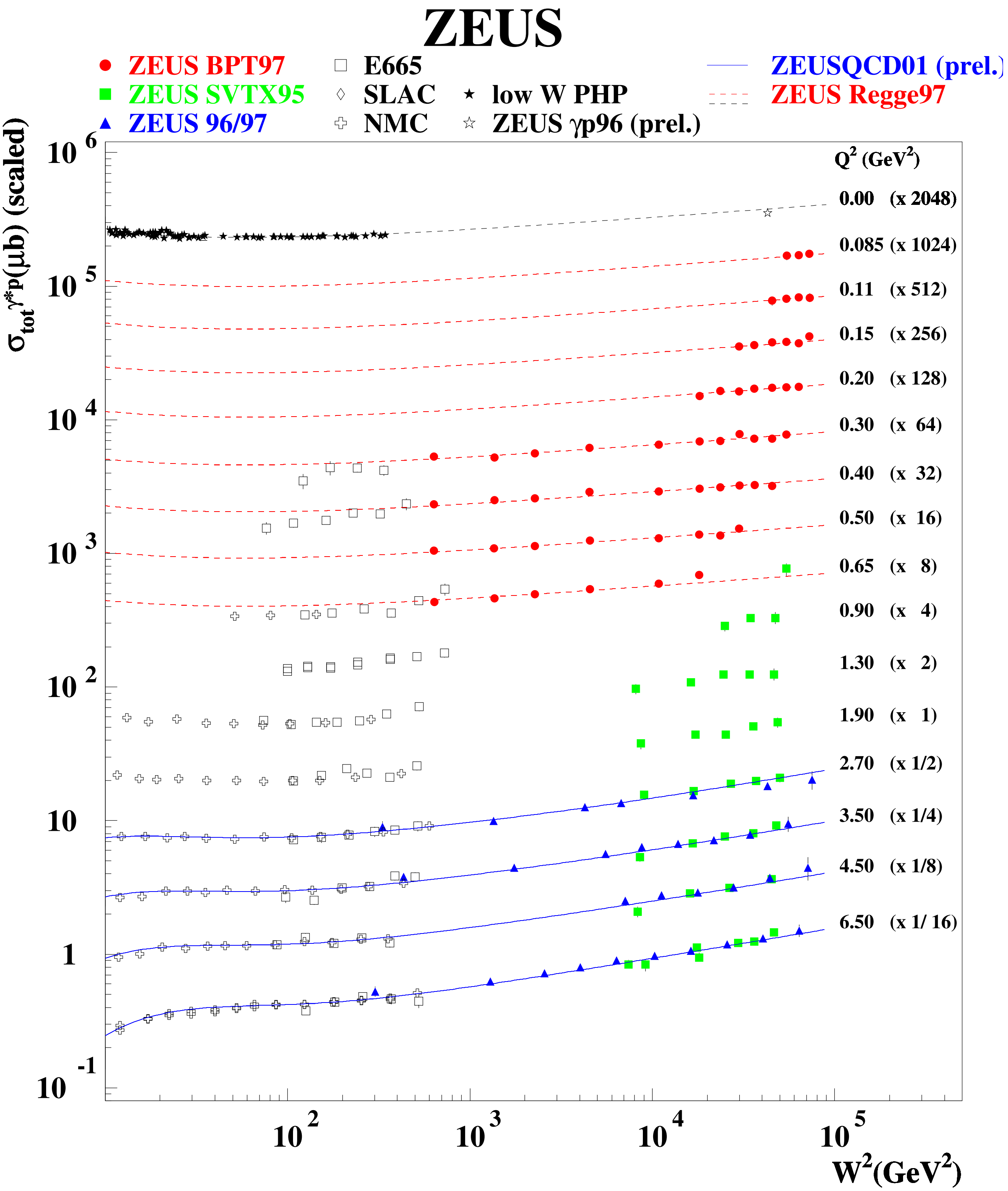
- ZEUS REGGE97: GVDM/REGGE fit (Q^2_{Max}=0.65 GeV^2)
- ZEUS QCD01: NLO QCD FIT (Q^2_{Min}=2.5 GeV^2)
  (see talk by K. Nagano on Sunday 15h)
- ZEUS QCD01 & ZEUS REGGE97 are shown only in the fitted Q^2 range

Overview: F_2 vs. x, Q^2 fixed (2)



- Data is well-decribed by ZEUS QCD01 fit
- The rise of F_2 for $x \to 0$ is increasing with Q^2
- Hard to see $\to$ look at the slope $dF_2/dln(1/x)$

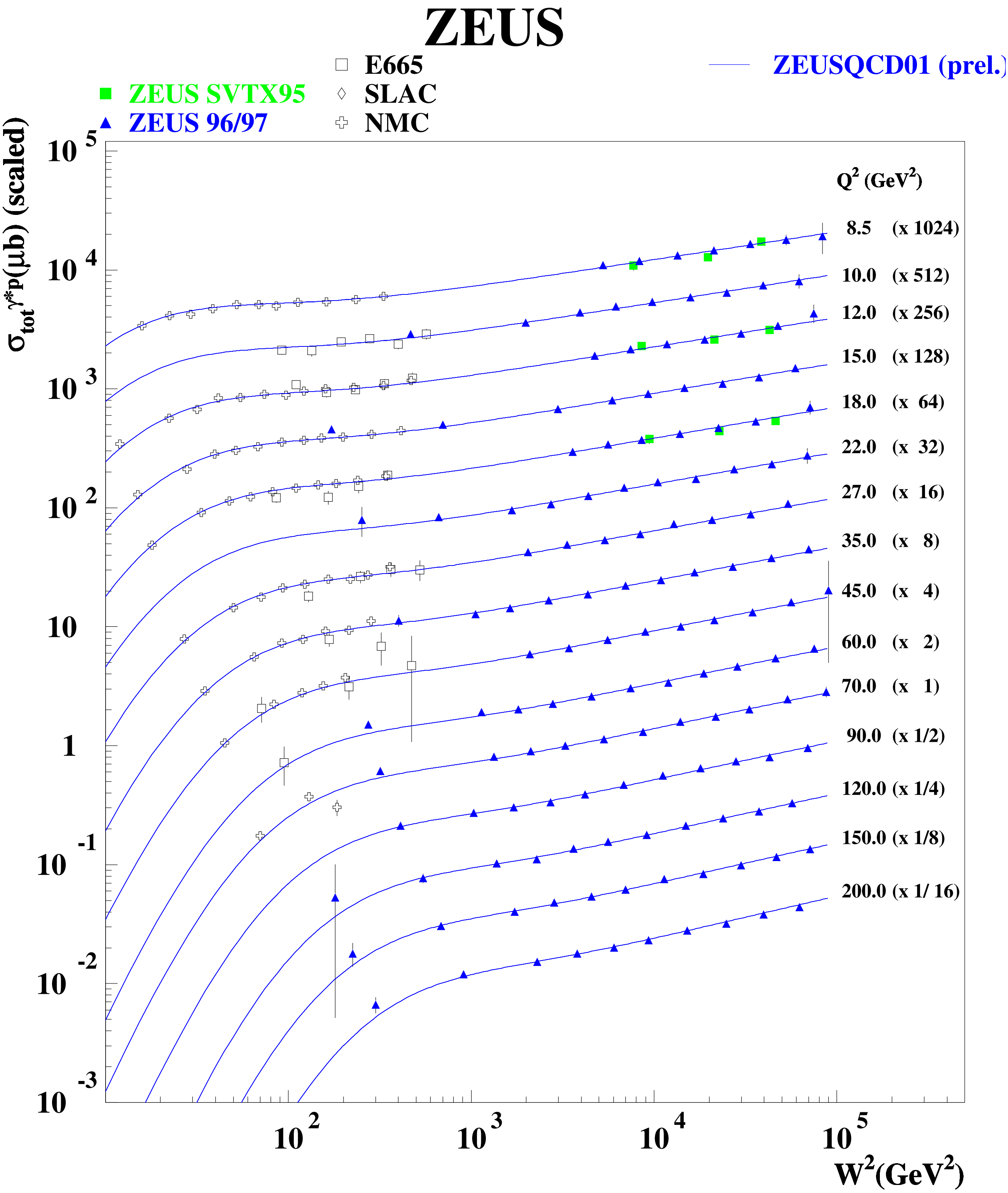
Overview: $\sigma_{tot}^{\gamma^* p}$ vs. W^2 at fixed Q^2 (1)



- Note: $\sigma_{tot}^{\gamma^* p} \approx \frac{4\pi^2\alpha}{Q^2} F_2$

- Rise of $\sigma_{tot}^{\gamma^* p}$ with W^2 increases with Q^2

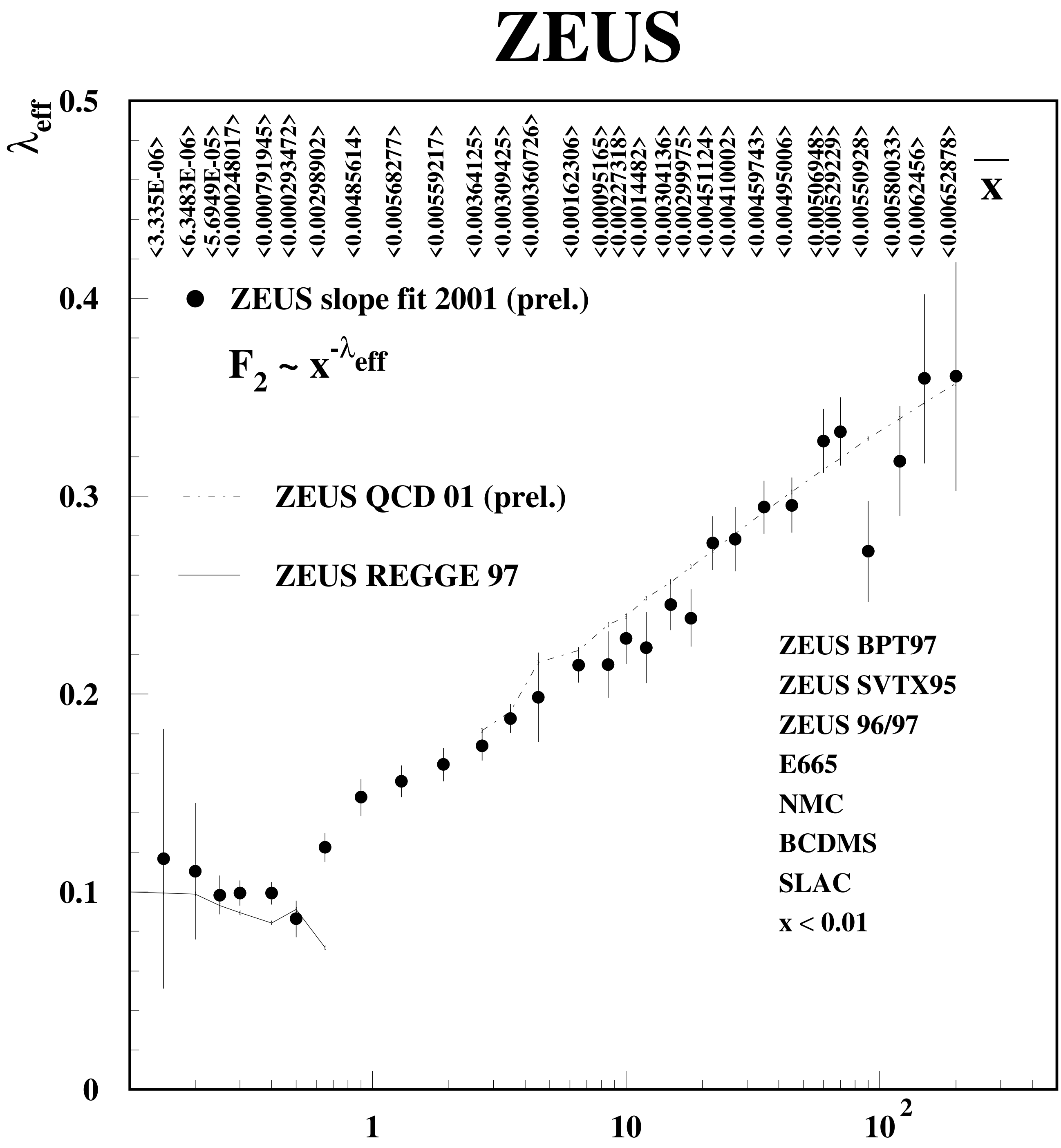
Overview: $\sigma_{tot}^{\gamma^* p}$ vs. W^2 at fixed Q^2 (2)



- Rise of $\sigma_{tot}^{\gamma^* p}$ with W^2 increases with Q^2
- Hard to see $\rightarrow$ look at the slope $dF_2/dln(1/x)$

Slopes: $dF_2/dln(1/x) = \lambda_{eff}$ (1)

- For $x << 1$, $\sigma_{tot}^{\gamma^* p} \sim (W^2)^{\alpha_{I\!P}-1} \rightarrow F_2 \sim x^{-\lambda_{eff}}$
- Fit $F_2(x, Q^2) = C(Q^2) \cdot x^{-\lambda_{eff}}$ in bins of Q^2



- Rise of F_2 for $x \rightarrow 0$ agrees with pQCD even at $Q^2 \approx 2.5$ GeV^2
- For $Q^2 < 0.6$ GeV^2 $\lambda_{eff} \sim 0.1$. consistent with Regge prediction
- Accuracy improved due to ZEUS BPT97 & 96/97

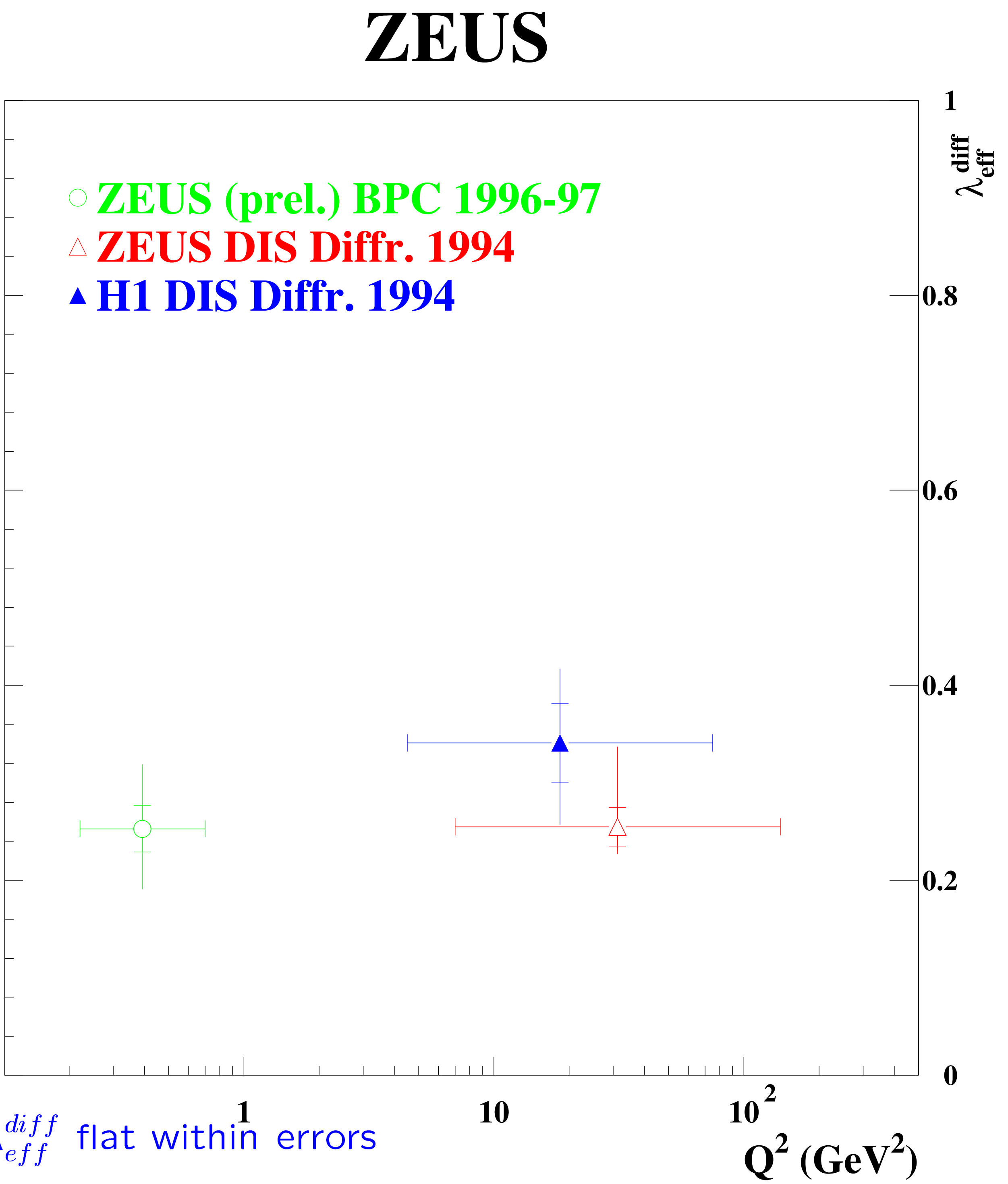
Slopes: $dF_2/dln(1/x) = \lambda_{eff}$ (2)

- Compare λ_{eff} with results from VM production
- Define λ_{eff}^{VM}: $\sigma_{\gamma^* p \to VMp} \sim (x_{VM})^{-\lambda_{eff}^{VM}} = \left(\frac{Q^2+M^2}{W^2}\right)^{-\lambda_{eff}^{VM}}$

- λ_{eff}^{VM} scales with $M^2 + Q^2$ not Q^2
- Naive expectation: $\lambda_{eff}^{VM} \approx 2\lambda_{eff}$ (2-gluon-exchange)
- Approx. true for $M^2 + Q^2 >= 7$ GeV^2

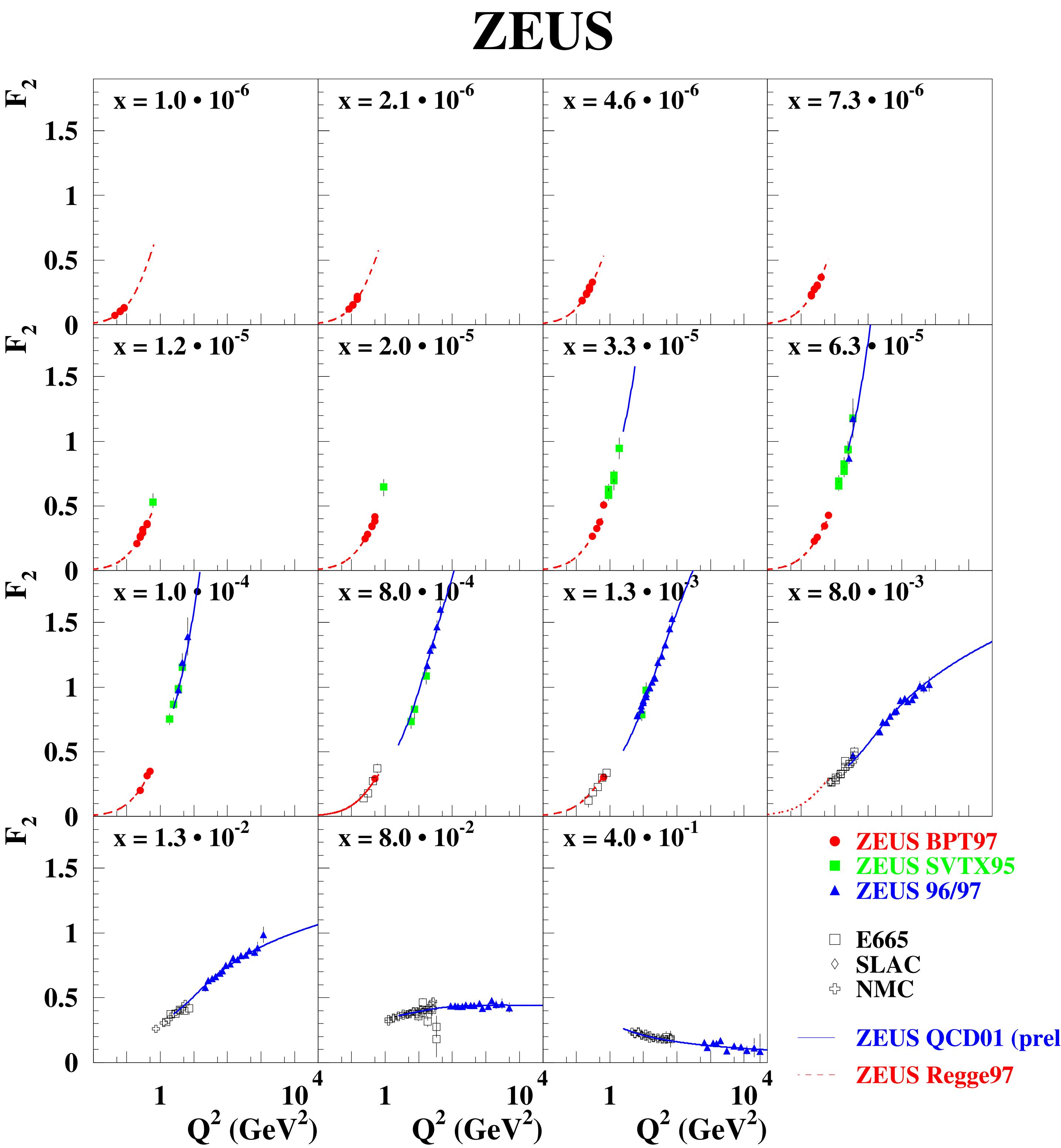
Slopes: $dF_2/dln(1/x) = \lambda_{eff}$ (3)

- Compare λ_{eff} with slope from σ_{tot}^{diff}
- Identical Q^2-dependency of λ_{eff}^{VM} and λ_{eff}^{diff}?



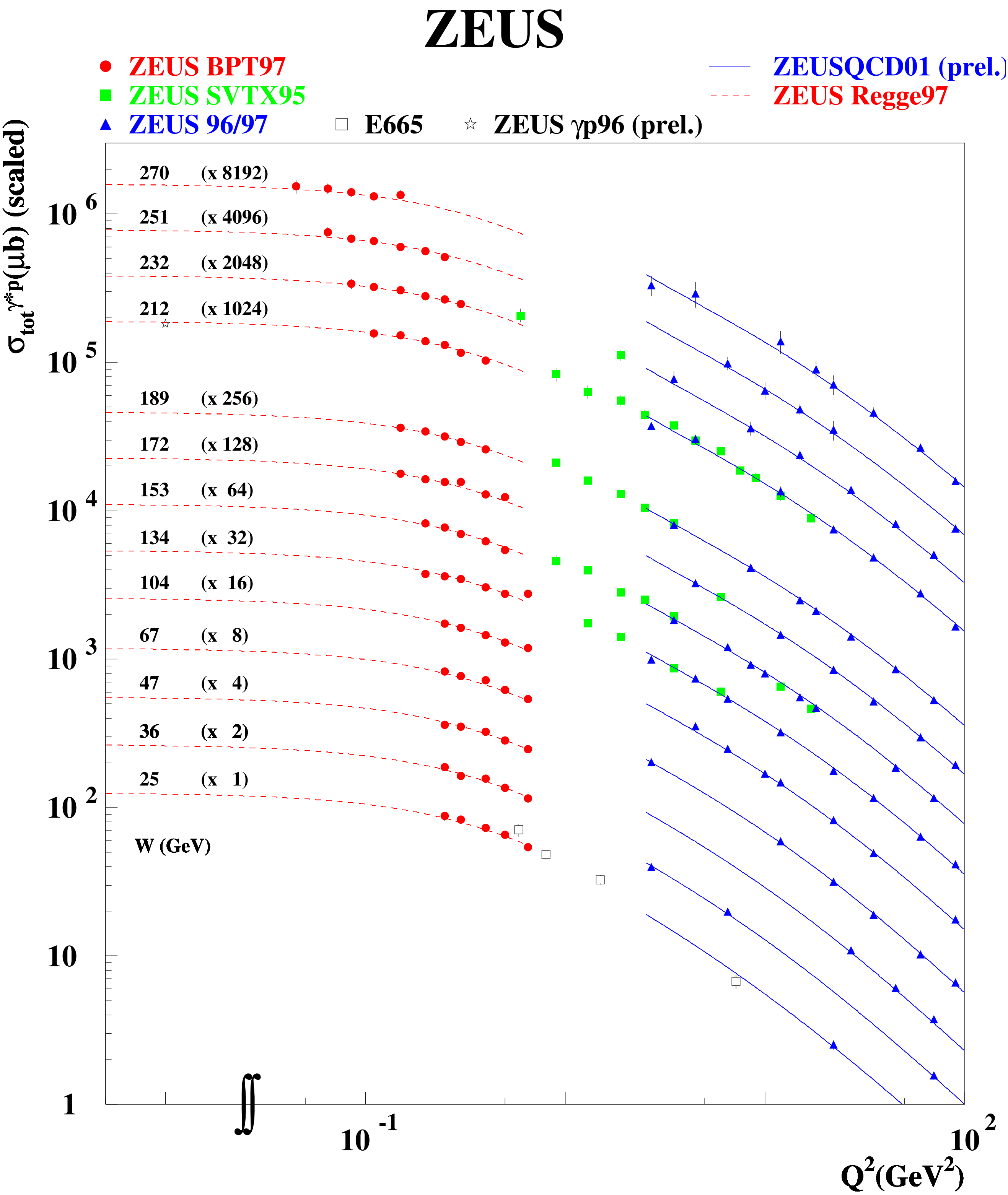
- λ_{eff}^{diff} flat within errors
- Different behaviour than λ_{eff}^{VM} and λ_{eff}
- How do we explain this?

Overview: F_2 vs. Q^2, x fixed



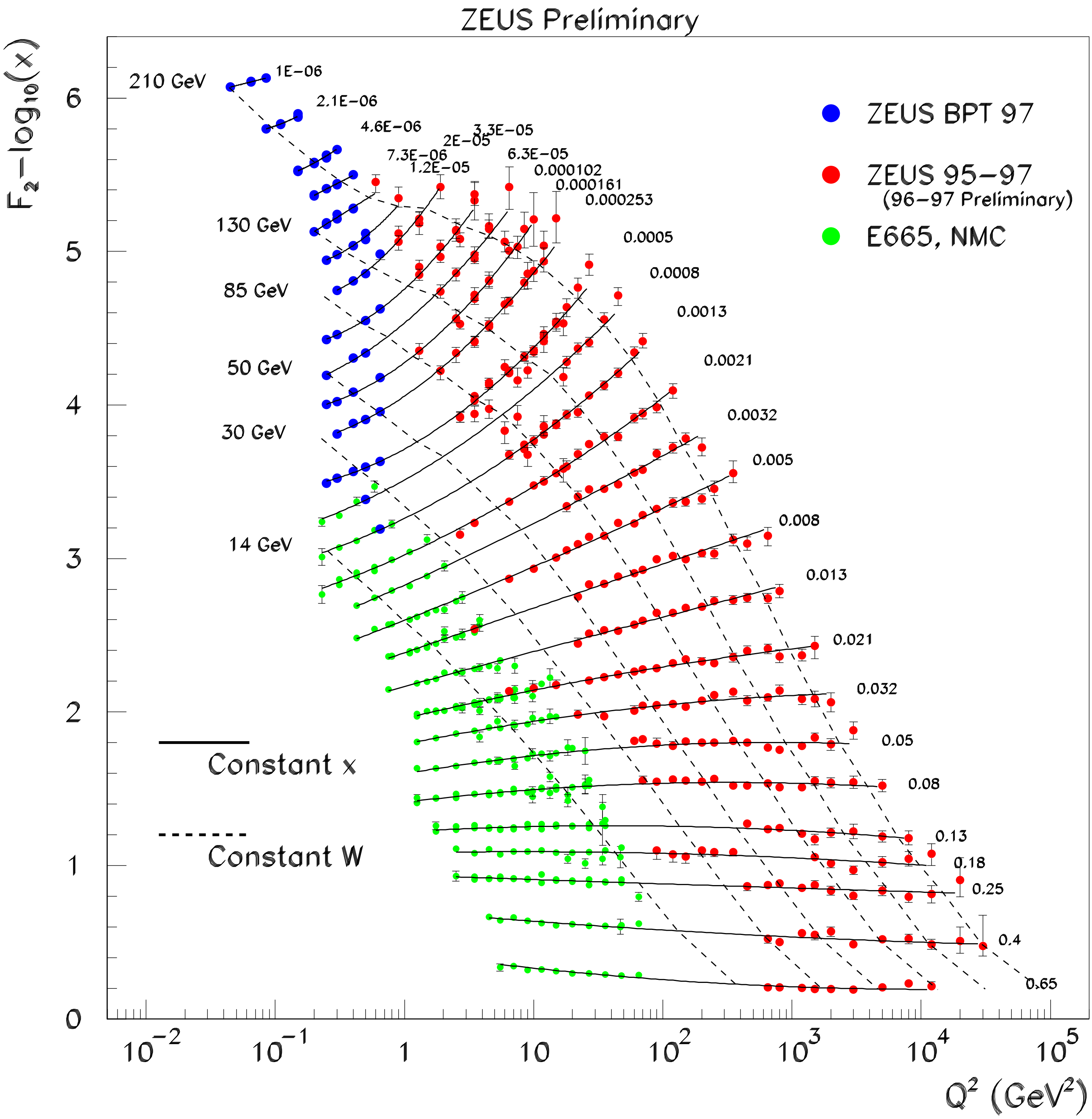
- ZEUS QCD01 & ZEUS REGGE97 describe data for $Q^2 > 2.5$ GeV^2 and $Q^2 < 1$ GeV^2
- Slope is decreasing with x
- Quantify this from the slope $dF_2/dlog(Q^2)$

Overview: $\sigma_{tot}^{\gamma^* p}$ vs. Q^2 at fixed W (1)



- ZEUS QCD01 & REGGE97 shown in fitted Q^2 range
- Is the slope changing?
- Quantify this from the slope $dF_2/dlog(Q^2)$

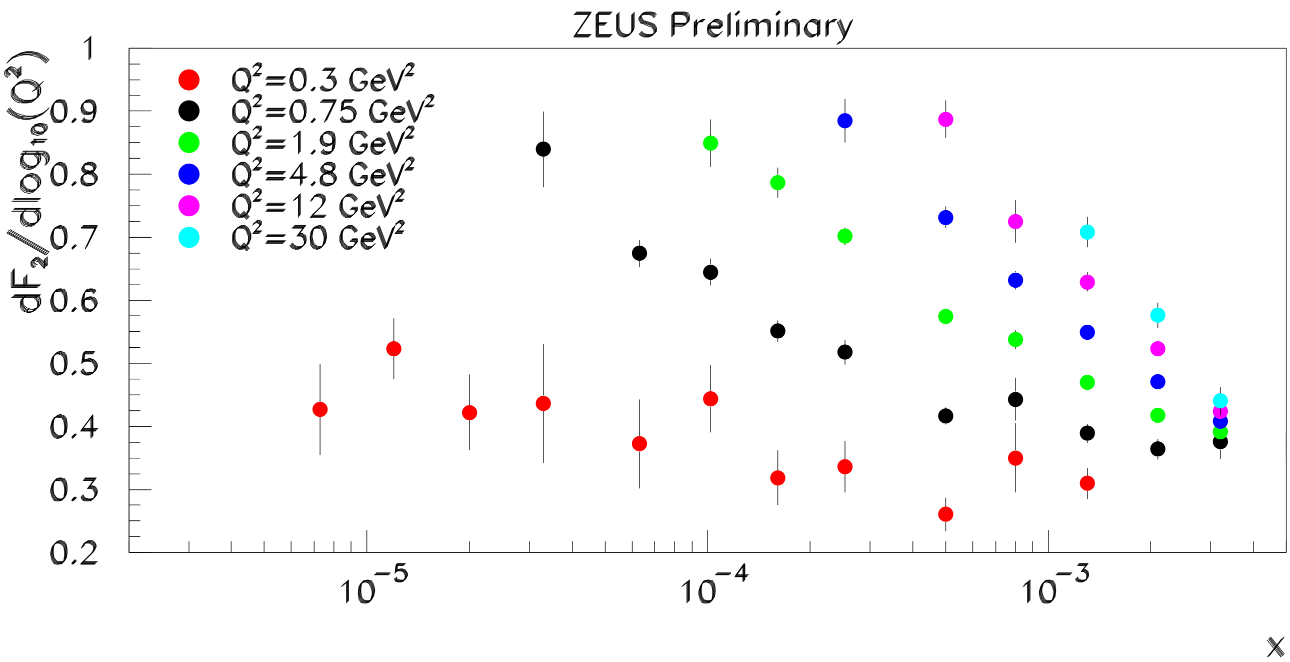
F_2-Slopes: $dF_2/dlog(Q^2)$ (1)



- Note: offset constant is $\log(x)$ i.e. no distortion
- Fit $F_2(Q^2) = A(x) + B(x) \cdot log(Q^2) + C(x) \cdot log(Q^2)^2$ for fixed x
- ZEUS (96/97, BPT 97, SVTX 95), E665 & NMC data used

F_2-**Slopes:**$dF_2/dlog(Q^2)$ **(2)**

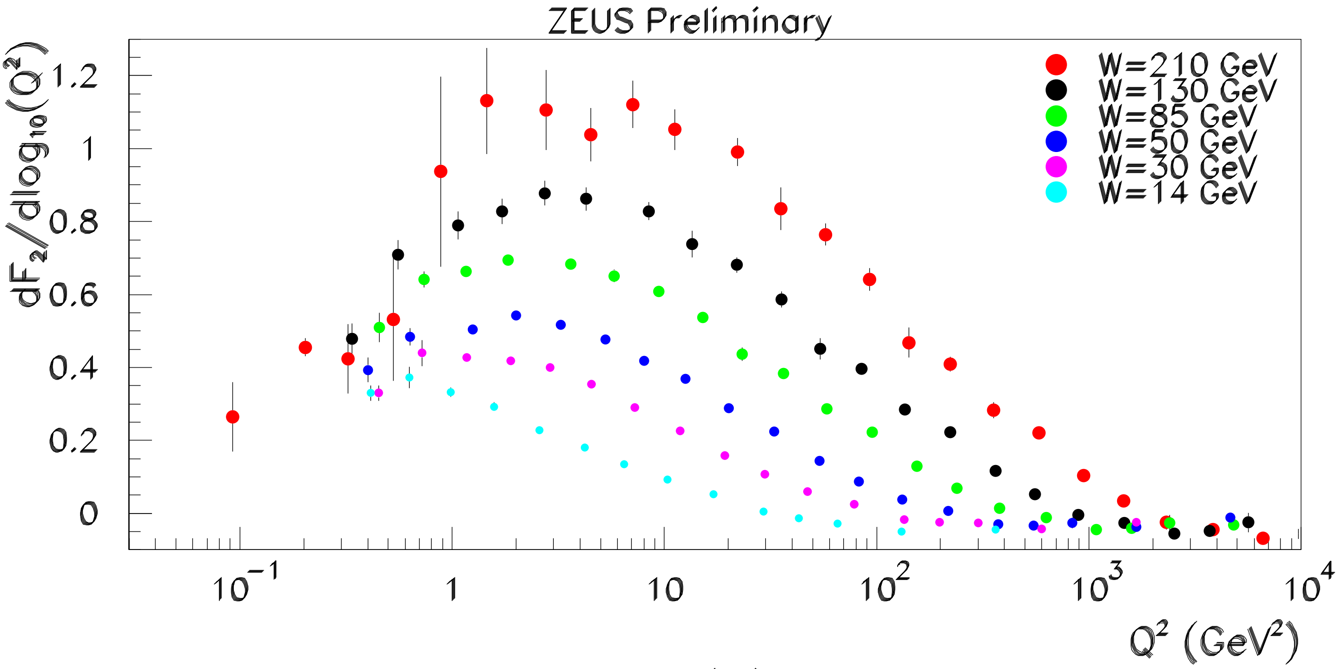
- How to make the transition region more visible: $\frac{dF_2}{dlogQ^2}|_x = B(x) + 2 \cdot C(x) \cdot log(Q^2)$ at fixed Q^2

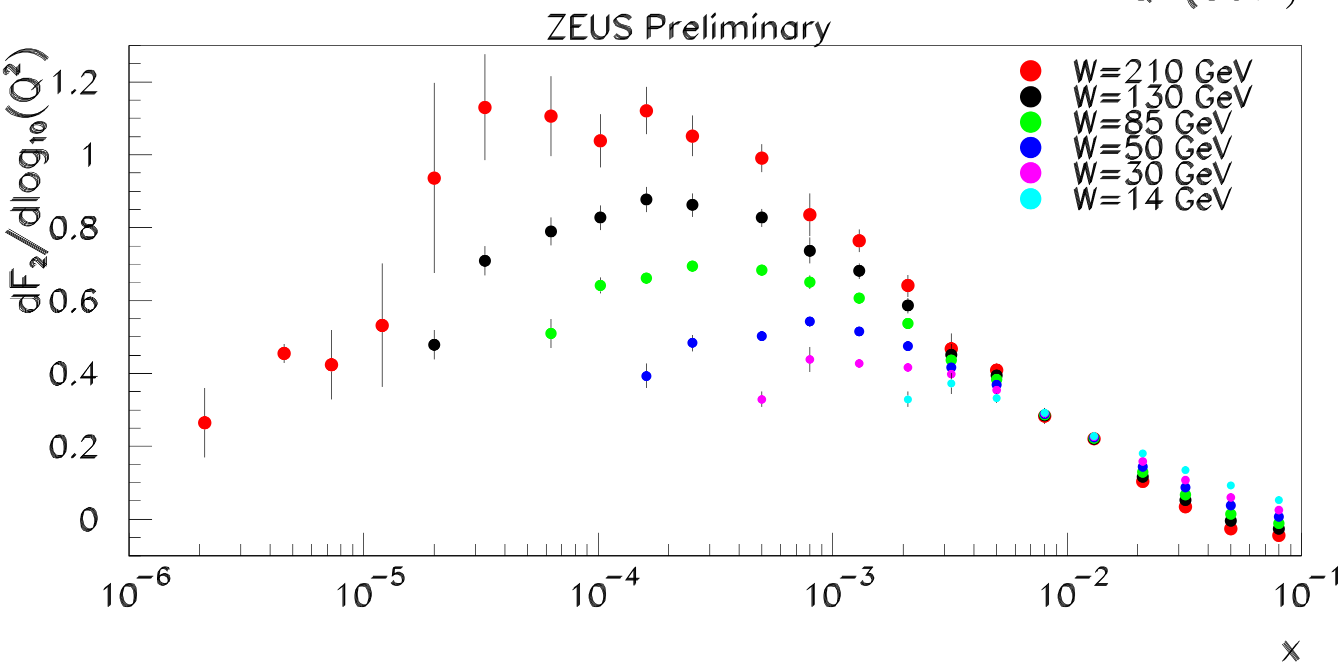


- $\frac{dF_2}{dlogQ^2}$ is increasing for $x \to 0$
- Increase of $\frac{dF_2}{dlogQ^2}$ is getting smaller for $Q^2 \to 0$ GeV^2
- Know from $F_2(x, Q^2)$ vs. x at fixed Q^2

F_2-**Slopes:** $dF_2/dlog(Q^2)$ **(3)**

- How to make the transition region more visible: $\frac{dF_2}{dlogQ^2}|_x = B(x) + 2 \cdot C(x) \cdot log(Q^2)$ at fixed W



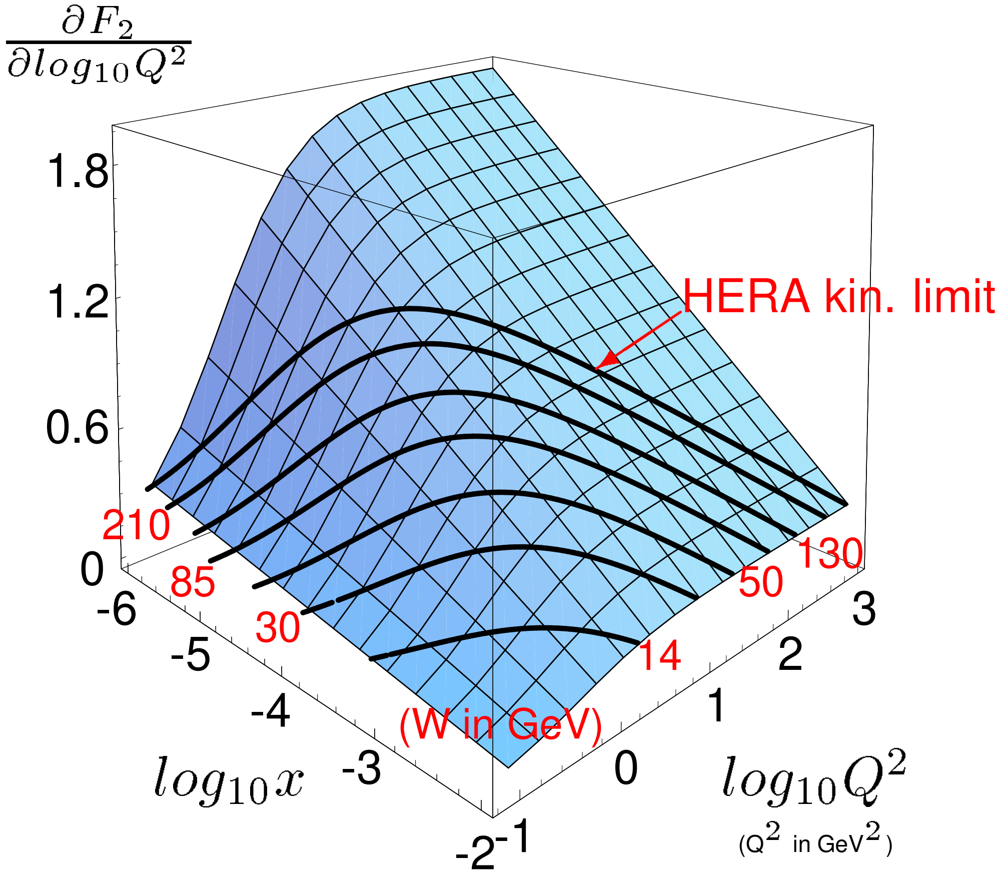


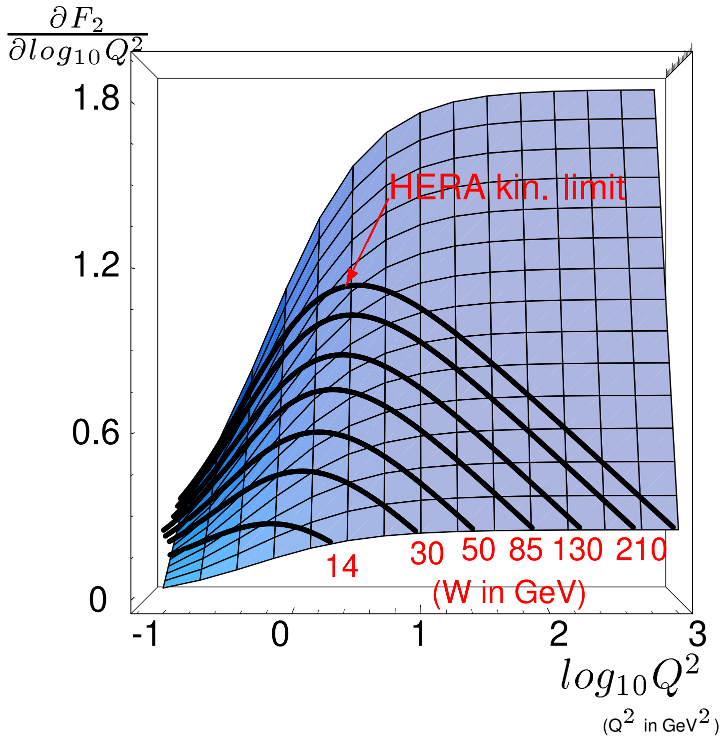
- Transition at Q^2 as high as 5 GeV^2?
- What does this shape mean?

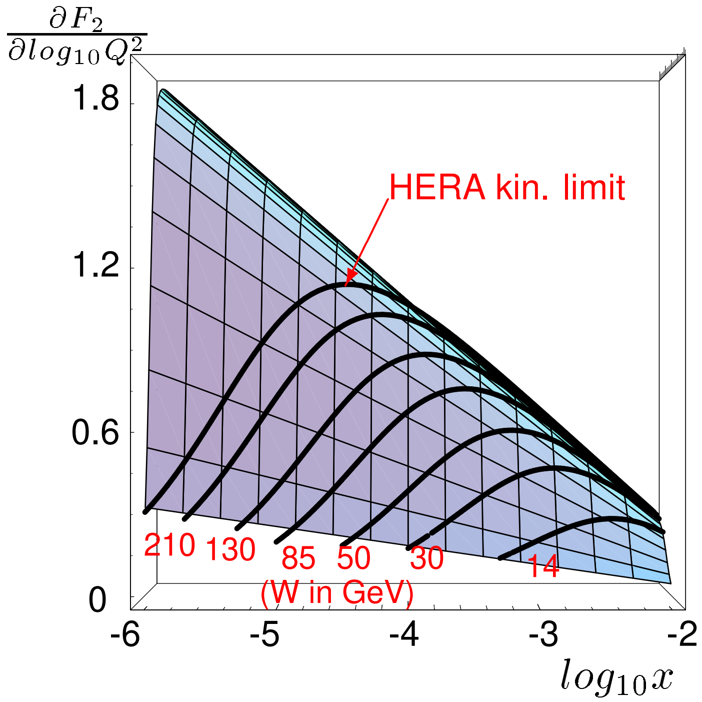
F_2-Slopes: $dF_2/dlog(Q^2)$ (4)

Toy model:

Qualitative Features of $\frac{dF_2}{dlogQ^2}$ in 2 Dimensions





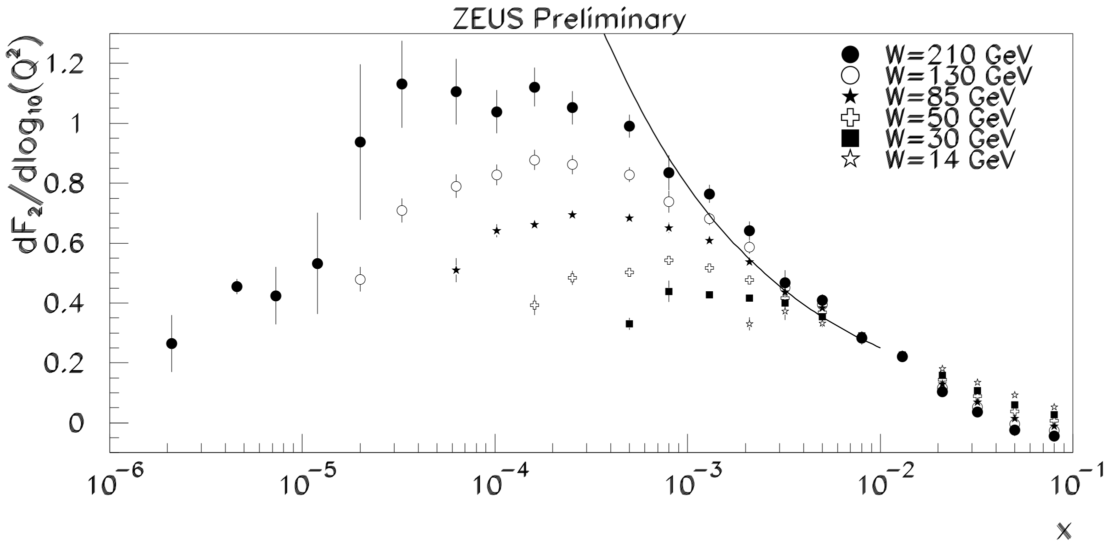


F_2-Slopes: $dF_2/dlog(Q^2)$ (5)

Naively, in the region where DGLAP applicable (Q^2 large):

$$dF_2/dlog(Q^2) \sim xg \sim x^{-\lambda}$$

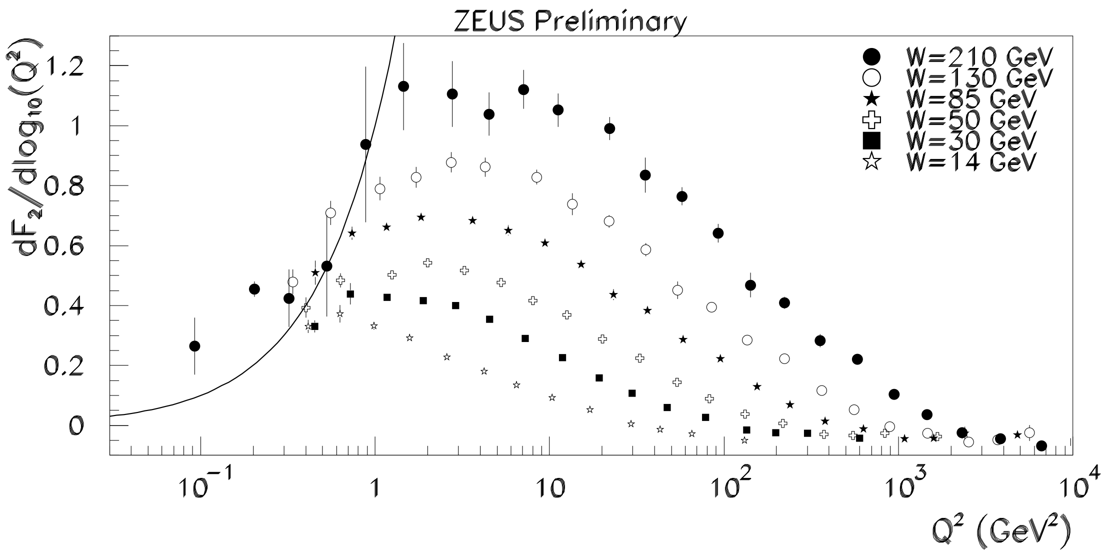
IF λ is a slow function of Q^2 and x
$\Rightarrow$ x, not Q^2, is the important variable in the right hand side.



In the low Q^2 region: $F_2 \sim Q^2\sigma_0$, i.e. vanishing like Q^2. Therefore:

$$dF_2/dlog(Q^2) \sim Q^2\sigma_0$$

$\Rightarrow$ Q^2, not x, is the important variable in the left hand side.



Summary & Outlook

Summary:

- The behaviour of F_2 was studied over a large kinematic range
- The slopes of F_2
  $dF_2/dln(1/x)$ at fixed Q^2 and
  $dF_2/dlog(Q^2)$ at fixed x
  were fitted using ZEUS and fixed-target data
- Results on $dF_2/dln(1/x)$ at low and high Q^2 improved due to ZEUS BPT97 & 9697 results
- $dF_2/dln(1/x)$ agrees with pQCD even at $Q^2 \approx 2.5$ GeV^2 and is consistent with Regge prediction for $Q^2 < 0.6$ GeV^2
- Both $dF_2/dlog(Q^2)$ & $dF_2/dln(1/x)$ important to study the transition between photoproduction and the regime of perturbative QCD
- Different behaviour of λ_{eff}, λ_{eff}^{diff} & λ_{eff}^{VM} not completly understood

Outlook:

- Improve treatment of systematic errors (see talk by K. Nagano on Sunday 15h)
- Update $dF_2/dlog(Q^2)$ analysis with final ZEUS 9697 and all fixed-targed data
- Closer look at diffractive data from HERA and the extrapolation of $\sigma_{tot}^{\gamma^* p}$ to $Q^2 = 0$ GeV^2.