Measurement of the Proton Structure Function F_2 and of the Total Photon-Proton Cross Section $\sigma_{\rm tot}^{\gamma^* p}$ at Very Low Q^2 and Very Low x

Christoph Amelung[a] * (ZEUS Collaboration)

[a]Physikalisches Institut der Universität Bonn, Nußallee 12, D-53115 Bonn, Germany

The proton structure function F_2 has been measured in the range $0.045\,\mathrm{GeV}^2 < Q^2 < 0.65\,\mathrm{GeV}^2$ and $6{\cdot}10^{-7} < x < 1{\cdot}10^{-3}$ using $3.9\,\mathrm{pb}^{-1}$ of $ep \to eX$ reactions recorded with the ZEUS detector in 1997. The analysis is based on data from the Beam Pipe Calorimeter (BPC) and the Beam Pipe Tracker (BPT). Compared to our previous analysis, the BPT permits improved background suppression and better control of systematic uncertainties, allowing the extension of the kinematic region of the measurement towards lower Q^2 as well as higher and lower y. Significant improvements have also been achieved in the simulation of the hadronic final state via a mixture of samples of non-diffractive and diffractive Monte Carlo events, generated by the programs DJANGO and RAPGAP.

1. INTRODUCTION

Since the first measurement from ZEUS [1] using 1995 data, the proton structure function F_2 at low Q^2 has continued to generate a lot of interest. Various groups, among them ZEUS [2], used the data to study the transition between photoproduction and deep inelastic scattering, others obtained improved parameterizations of F_2 [3, 4].

At this workshop, a new measurement of F_2 is presented in the range $0.045\,\mathrm{GeV}^2 < Q^2 < 0.65\,\mathrm{GeV}^2$ and $6 \cdot 10^{-7} < x < 1 \cdot 10^{-3}$, where x denotes the Bjorken scaling variable; $-Q^2$ is the four-momentum transfer squared. One also defines y, the relative energy transfer to the proton in its rest frame, and W, the photon-proton center-of-mass energy. The data were taken with special detector components and triggers during six weeks in 1997, yielding an integrated luminosity of $3.9\,\mathrm{pb}^{-1}$. The new analysis covers a larger kinematic region and has a higher precision than the previous one [1].

2. ANALYSIS

2.1. Scattered positron reconstruction

The scattered positron is reconstructed in the Beam Pipe Calorimeter (BPC) and Beam Pipe Tracker (BPT) of the ZEUS detector. The BPC has been installed in 1995 and was used for the previous measurement of F_2 at low Q^2. In 1997, the BPT was installed in front of the BPC.

The BPC is a small calorimeter that detects positrons with a scattering angle of 1–2° w.r.t. the positron beam direction. Its energy resolution is $\sigma_E = 0.17 \cdot \sqrt{E}$. The energy scale is known to $\pm 0.3\%$, the non-linearity is less than $\pm 1\%$ at 4 GeV. The shower position in the BPC is reconstructed with a resolution of $500\,\mu$m at 27.5 GeV.

The BPT consists of two silicon microstrip detectors. A track is reconstructed as the straight line through two hits in the BPT, providing the positron scattering angle, its impact point on the BPC and the event vertex. The uncertainty of the absolute BPT position is less than $\pm 200\,\mu$m. The tracking efficiency is known to $\pm 1.5\%$.

2.2. Kinematic reconstruction

The event kinematics are reconstructed with the electron method, i.e. from positron variables only, for $y > 0.08$, where it gives the best resolution. For $y < 0.08$, the $e\Sigma$ method [5] is used, which improves the y reconstruction by combining positron and hadronic final state variables.

2.3. Physics simulation

DJANGOH 1.1 [6] and RAPGAP 2.06 [7] are used to simulate non-diffractive respectively diffractive events. The samples are mixed in a proportion determined from the data. This is expected to give the best possible description of the hadronic final state, which is crucial at high y and low Q^2, where the fraction of diffractive events

*Supported by a grant from the Bundesministerium für Wissenschaft und Forschung in Germany.

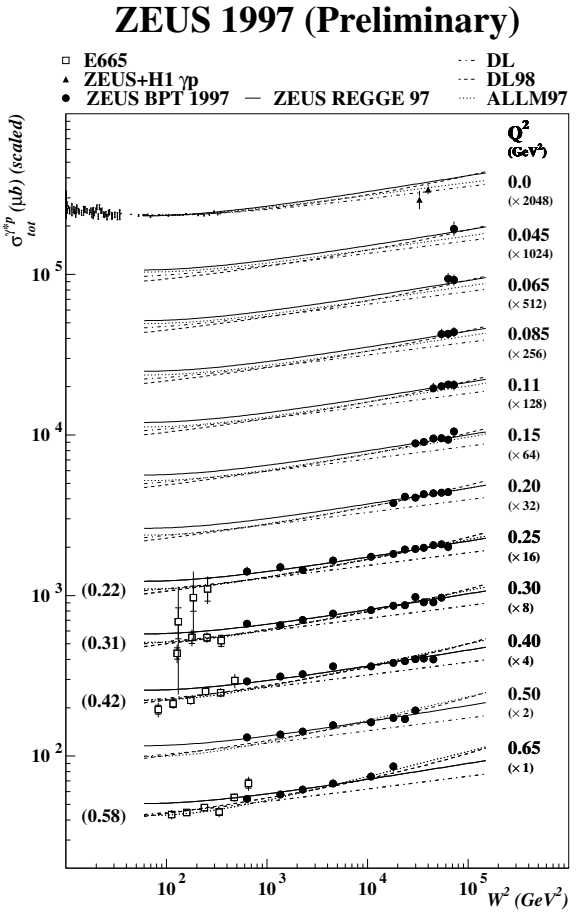

Figure 1. $\sigma_{\rm tot}^{\gamma^* p}$ versus W^2 in bins of Q^2, compared to E665 results and $\sigma_{\rm tot}^{\gamma p}$ from ZEUS and H1.

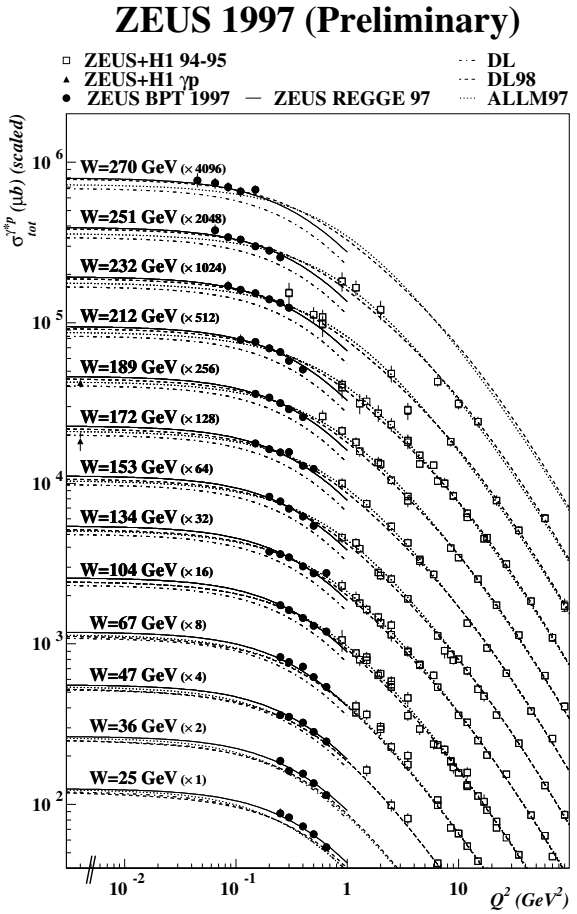

Figure 2. $\sigma_{\rm tot}^{\gamma^* p}$ versus Q^2 in bins of W, compared to other measurements from ZEUS and H1.

rejected by trigger or offline cuts is significantly different from non-diffractive events.

2.4. Event selection

The event selection is based predominantly on the requirement of a well reconstructed positron in BPC and BPT. The analysis covers a kinematic region between $0.045\,\mathrm{GeV}^2 < Q^2 < 0.65\,\mathrm{GeV}^2$ and $6 \cdot 10^{-7} < x < 1 \cdot 10^{-3}$, corresponding to $25\,\mathrm{GeV} < W < 270\,\mathrm{GeV}$ or $0.007 < y < 0.8$. Measuring at high y was made possible by the use of the BPT, which serves to suppress background at low scattered positron energies.

3. RESULTS

3.1. Determination of F_2 and $\sigma_{\rm tot}^{\gamma^* p}$

F_2 is extracted using an iterated bin-to-bin unfolding method and converted into a total cross section via $\sigma_{\rm tot}^{\gamma^* p} = 4\pi^2\alpha/Q^2 \cdot F_2$. The measured cross section depends also weakly on F_L, which is taken from the BKS model [8], yielding an effect of at most 3%. The results are shown in figs. 1 and 2. In the region of this analysis, the cross section becomes nearly flat as a function of Q^2.

The data are displayed together with two fits (ALLM97 [3], DL98 [4]) that have already included the 1995 measurement, as well as with the older DL [9] curve. While DL98 gives the best description at high W, it undershoots the data

at low W. DL seems to describe the shape better over the whole W range. ALLM97 underestimates the cross section at low Q^2 by 10–15%. The best description of the data is given by the ZEUS REGGE 97 fit presented in section 3.3.

At low W, the analysis has reached kinematic overlap with E665. While at $Q^2 = 0.65\,\mathrm{GeV}^2$ the agreement is good, it deteriorates at lower Q^2.

3.2. Systematic uncertainties

Fifteen systematic checks were performed to study the stability of the results. The average statistical error is 2.6%, the average systematic error 3.3%. In most bins, the systematic error is similar to the statistical one. Only the two highest W bins are dominated by systematic effects, mostly due to the uncertainty of the fraction of diffractive events. The overall normalization uncertainty of $\pm 1.8\%$ is due to the luminosity measurement.

3.3. Phenomenological fits

With the precise F_2 data sample presented here, the GVDM and Regge-inspired fits as published in [2] have been repeated.

The first step is to make an assumption about the Q^2 dependence of the data in order to extrapolate them to $Q^2 = 0$, which is taken from the GVDM prediction on σ_T, giving $\sigma_{\mathrm{tot}}^{\gamma^* p}(W^2, Q^2) = m_0^2/(m_0^2 + Q^2) \cdot \sigma_{\mathrm{tot}}^{\gamma p}(W^2)$. Fitting instead both the σ_T and σ_L terms changes the extrapolated values only within their statistical errors.

In the second step, the W dependence of $\sigma_{\mathrm{tot}}^{\gamma p}(W^2)$ is explored. The extrapolations from the first step are compared to the direct photoproduction cross section measurements by ZEUS and H1 [10, 11] and to previous data from other experiments at lower W. This comparison is shown in fig. 3, together with Regge-type fits of the form $\sigma_{\mathrm{tot}}^{\gamma p}(W^2) = A_{I\!R} W^{2(\alpha_{I\!R}-1)} + A_{I\!P} W^{2(\alpha_{I\!P}-1)}$, and with the DL98 and ALLM97 parameterizations. The extrapolated cross sections are larger than the directly measured ones. Whether this is a feature of the assumed Q^2 dependence for the extrapolation or of the direct cross section measurements, remains to be resolved in the future.

The combination of the two fits is shown as ZEUS REGGE 97 in figs. 1 and 2.

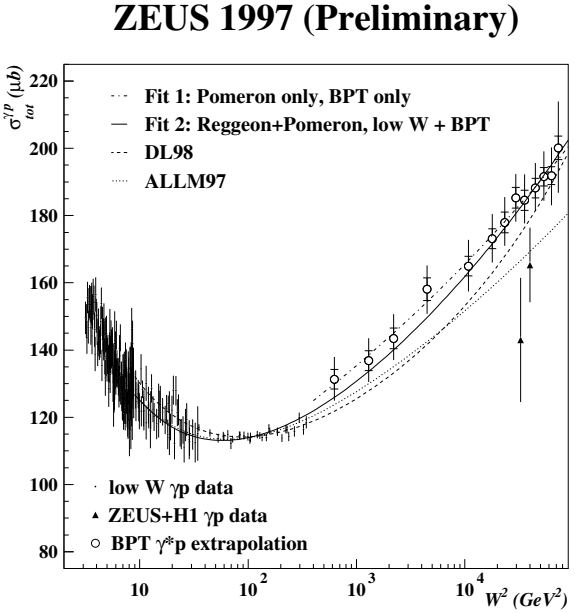

Figure 3. Extrapolated $\sigma_{\mathrm{tot}}^{\gamma p}$ versus W^2, compared to the two direct measurements from ZEUS and H1 and to data at lower energies.

4. CONCLUSIONS

The ZEUS collaboration has measured the proton structure function F_2 in the range $0.045\,\mathrm{GeV}^2 < Q^2 < 0.65\,\mathrm{GeV}^2$ and $6 \cdot 10^{-7} < x < 1 \cdot 10^{-3}$ with unprecedented precision. The data can be described and extrapolated by a simple GVDM and Regge inspired parameterization.

REFERENCES

1 ZEUS Coll., Phys. Lett. **B407** (1997) 432
2 ZEUS Coll., Eur. Phys. J. **C7** (1999) 609
3 H. Abramowicz and A. Levy, DESY 97-251
4 A. Donnachie and P.V. Landshoff, Phys. Lett. **B437** (1998) 408
5 U. Bassler and G. Bernardi, DESY 97-137
6 G.A. Schuler and H. Spiesberger, in Proc. Phys. at HERA (1991), Vol. 3, 1419
7 H. Jung, Comp. Phys. Comm. **86** (1995) 147
8 B. Badelek et al., Z. Phys. **C74** (1997) 297
9 A. Donnachie and P.V. Landshoff, Z. Phys. **C61** (1994) 139
10 ZEUS Coll., Z. Phys. **C63** (1994) 391
11 H1 Coll., Z. Phys. **C69** (1995) 27