Charged Current Cross Section Measurement at HERA

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Summary

Today, the proton is seen as a dynamic system with three valence quarks and a sea of quarks and antiquarks that radiate gluons and gluons that split into quark-antiquark pairs or two gluons. These processes are described by the theory of the strong force, the quantum chromo dynamics, QCD. By deep inelastic scattering of leptons on protons information about the structure of the proton can be acquired. Two types of deep inelastic processes can be distinghuished: neutral current scattering and charged current scattering. In neutral current deep inelastic scattering processes $e^{\pm}p \rightarrow e^{\pm}X$, a photon or a neutral weak boson, Z^0 particle, is exchanged between the incoming electron and a (anti)quark in the proton. The cross section of this process gives information about the contributions of all quarks and antiquarks in the proton, and can therefore be used as a direct measurement of the structure of the proton. In charged current deep inelastic scattering a charged weak boson, a W^+ or W^- particle, is exchanged between the incoming electron and one of the (anti)quarks in the proton. In this scattering process the electron (positron) changes into a neutrino (antineutrino). Due to the charge of the W boson only particular combinations of quarks and antiquarks participate in the interaction. Hence, the charged current deep inelastic process reveals information about specific quark and antiquark distributions in the proton: in $e^-p \rightarrow \nu X$ only positively charged (anti)quarks contribute to the charged current cross section and in $e^+p \rightarrow \nu X$ only negatively charged (anti)quarks contribute to it.

In this thesis the measurement is described of the cross sections of the charged current deep inelastic scattering processes $e^-p \rightarrow \nu X$ and $e^+p \rightarrow \nu X$ for $Q^2 > 200\,\mathrm{GeV}^2$ and at a centre-of-mass energy of 318 GeV. The cross sections are measured using the ZEUS detector. ZEUS is a detector at the particle accelerator HERA, an accelerator with colliding beams of electrons [1] and protons, at the DESY institute in Hamburg. The measurement of the e^-p charged current cross section is based on a data sample of $16.4\,\mathrm{pb}^{-1}$ and the e^+p charged current cross section measurement is based on a data sample of $60.9\,\mathrm{pb}^{-1}$. To

[1] Electron can be read as positron, unless otherwise stated.

build a sample of charged current interactions, one must select interactions with a neutrino in the final state. Since the neutrino will escape the detector undetected, a large measured missing transverse momentum is characteristic for these events, a property that is used on-line to identify them. But after applying this selection criteria, the vast majority of the selected events was not a charged current interaction. Background events from various sources, some of them with much larger cross sections than the cross section of the charged current interaction, had to be removed from the data sample. Special selection criteria were developed to remove the serious background of photoproduction and neutral current interactions. Although these interactions should not have missing transverse momentum, particles can escape undetected due to e.g. fluctuations in the energy measurement. Also non-*ep* interactions formed a considerable background. Beam-gas interactions, interactions with residual gas molecules in the beampipe, can have an imbalance in measured transverse momentum, because a lot of energy escapes through the beampipe. The selection criteria designed to remove these events were based on the quality of the reconstruction of the tracks and the vertex. Muons travelling parallel to the beam and cosmic muons which caused an imbalance in missing transverse momentum were removed by a, especially for this analysis developed, computer program, which identified halo and cosmic muons by searching for characteristic patterns caused by muons traversing the detector. After all selection criteria were applied the remaining events were subjected to a visual scan by eye which removed a few cosmic muon and halo muon events. More than a million e^-p and e^+p charged current candidate events were selected by the detector. The final data sample used for the measurements of the cross sections consisted of 627 e^-p and 1456 e^+p events.

The estimated contamination of *ep* background events is smaller than 2% over the full kinematic range; only at $Q^2 < 400\,\mathrm{GeV}$ the background is higher, about 10%; this is mainly due to photoproduction events.

To perform a precise measurement of the cross section it is necessary to measure the kinematic variables as precisely as possible. The kinematic variables were reconstructed using the energy, measured by the CAL, and the vertex, determined from the CTD information. Corrections were necessary since, due to detector effects, large differences can occur between the measured values of the kinematic variables and the real values. The presented reconstruction method contains energy corrections for noise in the CAL, clustering of the energy deposits in the CAL cells and corrections for energy loss of particles in inactive material in the detector. A new correction, a correction on the reconstructed vertex position was developed using the timing information of the CAL. All these corrections allowed a bias-free determination of the kinematic variables.

Measurements are presented of the single differential cross sections $\mathrm{d}\sigma/\mathrm{d}Q^2$, $\mathrm{d}\sigma/\mathrm{d}x$, $\mathrm{d}\sigma/\mathrm{d}y$ and the reduced double differential cross section $\tilde{\sigma}$ for both e^+p and e^-p interactions. The precision of the measured cross sections is dominated by the statistical error. To determine the systematic uncertainty many possible sources of systematic uncertainties were studied in great detail. The largest contribution to the systematic uncertainty appeared to come from the energy scale of the calorimeter and the simulation of the QCD cascade (MEPS versus Ariadne). The results for e^-p show a large improvement compared to formerly published results based on only $0.82\,\mathrm{pb}^{-1}$. For the first time it was possible to measure the e^-p cross sections in bins of x and Q^2 and to measure the reduced cross section. For the results for e^+p the statistical errors reduced considerably compared to earlier published results.

The final results are compared with the latest theoretical predictions using the most recent parametrizations of the parton distribution functions by the CTEQ, MRST and ZEUS collaborations. The parametrizations are extracted from fits to neutral current data from various experiments (the charged current data of HERA are not included in the fits). Over the whole measured kinematic range all predictions agree well with the measured cross sections. The obtained precision of the measurement allows plotting the reduced double differential cross sections for both e^+p and e^-p as function of $(1-y)^2$ in bins of x and reveals the helicity structure of charged current interactions in accordance with predictions of the Standard Model.

The work of this thesis has greatly improved the understanding of the systematic uncertainties and has shown what the experimental limits on the precision of these cross section measurements are. In the near future HERA will, after a luminosity upgrade, produce a much larger number of charged current events which will reduce the statistical error considerably, especially in the interesting region of high-Q^2 and high-x. This larger sample can be used to improve the precision of the measured cross sections, which will be an important contribution to the parameterisation of the parton density distributions.