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Charged Current Cross Section Measurement at HERA

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Introduction

The twentieth century has truly been a glorious time for physics. At the turn of the century two major breakthroughs in the understanding of physics were made. In 1900 Max Planck introduced the theory of quantum physics [1], which was the basis for the development of quantum mechanics. Around the same time Einstein also formulated his theory of relativity [2]. Experimentally, physics was dominated by the investigation of radioactivity. And in 1909 Rutherford provided the start of particle physics as we know it today by, for the first time, using a particle beam to investigate matter. He and his collaborators Geiger and Marsden allowed a beam of α-particles to hit a target composed of a gold foil. Analysis of the scattering angle distribution showed that the atom was not a uniformly filled object, but in fact contained a charged nucleus which had a radius of less than a $1/10000^{\text{th}}$ of the radius of the atom [3]. The atom was mostly void! This experiment inspired Niels Bohr to formulate his model of the atom [4]: A highly positively charged nucleus with electrons orbiting around. The discovery of the neutron in nuclear fission [5] prompted the idea that the nucleus was built up of protons and neutrons held together by a new force, the nuclear force or strong interaction.

Many years and significant world events passed, until in the 50's technology had advanced sufficiently to allow the first particle accelerators to be built. Using a beam of electrons McAllister and Hofstadter managed to measure the shape of the proton, the so called form factor [6]. This experiment showed that the proton was an extended object, unlike the electron which even today behaves like a point-like particle.

The year 1969 saw the first deep inelastic scattering, DIS, experiment. Here the word deep indicates that the energies were so high as to probe the proton structure with a resolution of a fraction of the radius of the proton. The word inelastic indicates that the proton breaks up and other particles are produced. The experiment took electrons that had been accelerated to 7 GeV and brought them into collision with a hydrogen target. In the same way as the Rutherford experiment showed a small hard structure in the atom, this experiment showed that the proton was not an extended object with uniform charged density, but an object composed of point-like charged particles [7]. Feynman immediately explained the results with a model where the proton was built up of point-like particles and antiparticles, named partons. These partons were later identified with the quarks, Gell-Mann had introduced several years before to explain the increasing number of particles found in particle beam experiments [8].

Quarks have never been observed as free particles and this among other things was incorporated in the gauge theory of strong interactions, quantum chromo dynamics, QCD. The mediators of the strong force are the gluons. This helped explain why in the deep inelastic scattering experiments it was observed that only half of the momentum of the proton was carried by the charged quarks. Evidence for the existence of the gluon was obtained in 1979 when in e^-e^+ scattering events were observed with three distinct jets of particles: a quark, an antiquark and a gluon jet [9].

So far we have concentrated on the electromagnetic interaction between charged particles such as electrons with quarks and the strong interaction between quarks. There is however a third interaction, the weak interaction. This interaction mediates for instance nuclear β-decay. In 1932 Fermi was the first to attempt an explanation of this phenomenon [10]. He described this by the transition of a neutron into a proton an electron and a massless neutral particle for which the name neutrino was coined. This theory was at first very successful, but ran into some difficulty. The interaction did not conserve parity: an interaction viewed in a mirror does not occur in nature, whereas the original does. Lee and Yang suggested that this might be the case by studying the mathematics of the theory [11]. The experimental evidence for parity violation was given by Wu by studying angular asymmetries in the β-decay of polarised ^{60}Co nuclei [12]. To incorporate parity violation in the Fermi model, Glashow, Salam and Weinberg combined the electromagnetic and weak interaction in the electroweak theory [13]. The mediators of the weak force are the neutral Z^0 and the charged $W^\pm$ particles. Due to the high mass of these particles, $M_Z \approx 91\,\text{GeV}$ and the $M_W \approx 80\,\text{GeV}$, it took till 1983 that they were discovered by the CERN $p\bar{p}$ collider experiments [14]. Today, the electroweak theory together with quantum chromo dynamics form the Standard Model, SM, in particle physics.

The first electron/positron-proton collider in the world, HERA, built at the DESY institute in Hamburg, became operational in 1992 and collides electrons/positrons of 27.5 GeV with protons of 920 GeV. It provides an unprecedented resolution for probing the structure of the proton down to $1/1000^{\text{th}}$ of its radius. The work presented in this thesis has been performed with the

ZEUS detector, one of the colliding beam experiments situated at HERA. The high energy particle beams of HERA allow the exploration of a significant extension of the kinematic phase space in deep inelastic scattering and provide a very clean way of measuring the structure of the proton. With the ZEUS detector, the structure of the proton can be determined from the neutral current DIS cross section measurements. In this case the exchanged particle in the ep interaction is a photon or a Z^0 and all quark and antiquark flavours in the proton contribute to the cross section. In this thesis another measurement, which provides information about the structure of the proton, is described: the measurement of the charged current DIS cross section. In ep charged current DIS the exchanged particle is a $W^{\pm}$ boson providing an excellent way of obtaining information about specific quark and antiquark distributions in the proton. Measuring the cross section at low-x and high-Q^2, where x is the fraction of the proton momentum carried by the struck quark and Q^2 the momentum transferred to the quark from the incoming lepton, provides a very strong test of QCD. At high-x and high-Q^2 in e^-p scattering it gives a direct measurement of the u valence quark distribution and in e^+p scattering a direct measurement of the d valence quark distribution in the proton. Furthermore, according to the electroweak theory, the W boson only couples to left-handed fermions and right-handed antifermions and this can be verified very nicely with the measurement of the charged current deep inelastic scattering cross section.

This thesis is organised as follows. In chapter 1, the theoretical framework of deep inelastic scattering and QCD is given. The experimental set-up, both the accelerator and detector, is described in chapter 2. Detector simulation, needed for a precise measurement, is described in chapter 3. The reconstruction of the measured quantities and their corrections are explained in chapter 4. In chapter 5 the on-line and off-line selection of charged current events is described in great detail. In chapter 6 it is described how the charged current cross sections are determined together with an analysis of the uncertainties on the measurements. Finally, the results of the cross section measurements and a discussion of the results are given in chapter 7.