Deep inelastic scattering off hydrogen and deuterium

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1. INTRODUCTION

When considering very small scales, hadronic matter consists of partons, more specifically quarks and gluons. Clusters of quarks and gluons form the proton and neutron, the constituents of the atomic nucleus. The proton and neutron each consist of three valence quarks and a large number of relatively low momentum quark-anti-quark pairs (the so-called sea quarks), which are held together by the exchange of gluons between the quarks. These gluons are the mediators of the strong force, which is described by Quantum ChromoDynamics (QCD).

When studying the structure of the proton with particles of high energy (larger than 10 GeV) very small length scales are probed: 10^{-16} to 10^{-17}m. At these distance scales the dynamics of the quarks correspond to that of almost free particles, a phenomenon referred to as asymptotic freedom. Because the interactions are relatively weak, QCD can be treated in a perturbative manner (pQCD). At larger distance scales the interactions become considerably stronger and perturbative techniques cease to be applicable. In this non-perturbative domain of QCD, correlations between quarks and gluons emerge and give rise to bound states, i.e. the hadrons.

In order to obtain information on such partonic correlations, we need to carry out precision high energy scattering experiments at somewhat larger distance scales, which correspond to low to intermediate Q^2 values, where the transferred four-momentum squared, Q^2, determines the distance scales probed. When Q^2 is larger the scales probed are smaller.

The experimental tool of choice to study partons and their correlations is Deep Inelastic Scattering (DIS), which corresponds to scattering a lepton off a parton in the nucleon. Partonic correlations are manifest in DIS because additional gluons are exchanged in the scattering process. In the theoretical framework used to describe DIS processes diagrams involving additional gluons are known as higher twist contributions. By carrying out high precision lepton scattering experiments on hydrogen and deuterium one can search for experimental evidence of such higher-twist effects.

The experimental data used to search for such higher-twist effects have been obtained in the HERa MEasurement of Spin (HERMES) experiment, which is based at the Deutsches Elektronen SYnchrotron (DESY) and designed to clarify the spin structure of the nucleon. As the HERMES spectrometer system is optimised to measure cross-section ratios we searched for possible differences in higher twist effects between the proton and the deuteron. In the framework of this thesis, we focus on two specific kinematic regions where possible deviations are most likely to become visible. The differences between the quark distributions in the proton and neutron are most prominent at high x (high fractional momentum of the quark in the nucleon) where valence quarks dominate the quark distribution. Therefore, in this domain one can search for differences between the u and d quark distributions that are possibly related to higher twist effects. To perform these studies one has to investigate the behaviour of the cross-section ratio of deuterium over hydrogen as a function of Q^2. By combining the present data with those of previous measurements, collected a t higher Q^2, one can search with better accuracy for differences between the data and the pQCD calculations, that do not include higher-twist effects.

At low x one can investigate whether higher twist effects can be identified that can be associated with differences in the sea quark distributions of the proton and the deuteron. The search for possible higher-twist effects is performed by measuring the ratio of the longitudinal to transverse DIS cross sections, $R = \sigma_L/\sigma_T$. At high Q^2 values the DIS cross section is purely transverse, leading to $R = 0$, which is also observed experimentally [1], [2]. Deviations from $R = 0$ have been observed on the proton at low Q^2 and low x. These deviations are associated with higher twist effects. The sensitivity for higher twist effects increases at low Q^2, since they are expected to scale with a factor $1/Q^{2n}$ [3], where $n = 1, 2$ stands for the order of twist. The data presented in this thesis are used to investigate whether R^d differs from R^p, which could be indicative of higher-twist effects that are different in hydrogen with respect to deuterium at low x.

To achieve these goals, high statistics DIS data on unpolarised proton and deuteron targets have been collected at HERMES. As compared to earlier high statistics DIS experiments, such as those reported by the New Muon Collaboration (NMC) at the Centre Européenne pour la Recherche Nucléaire (CERN) [1], the average Q^2 is lower. In some cases the data are combined with these NMC data. The resulting large coverage in Q^2 is essential in searching for higher twist effects.

One of the difficulties encountered when trying to extract neutron DIS data from the difference between data collected on proton and deuteron targets is represented by nuclear effects that possibly affect the deuteron data. As a result possible higher-twist effects that are different in the deuteron as compared to the proton, cam either be due to proton-neutron differences or be of nuclear origin. In order to determine 'neutron' data, these nuclear effects need to be accounted for, which is difficult as they cannot be determined unambiguously. A cleaner method to obtain information on DIS neutron data is provided by tagging experiments, where the events occurring on the neutron can be positively identified by detecting the low momentum spectator proton simultaneously. So far, this method has only been explored with low statistics in neutrino-induced experiments on heavy nuclei [4].

In the second part of this thesis the construction and operation of a prototype silicon recoil-detector is described. It was used to perform a first direct tagging measurement of DIS events on the neutron in electron scattering on the deuteron. In practice the observation of a DIS event in the HERMES spectrometer was used to trigger the readout of the recoil detector. The purpose of the prototype detector was to demonstrate the feasibility of operating a silicon recoil-detector very close to an electron scattering target. Using the prototype it has been investigated whether it is indeed possible to tag DIS events on the neutron in deuterium. For that reason it had to be demonstrated that the spectator protons have a momentum distribution which is very close to the momentum distribution as measured in quasi-elastic electron scattering on the deuteron. If the tagging technique has thus been validated, it can be investigated whether the tagged DIS data on the neutron are similar or different from those derived from inclusive measurements, where only the scattered electron is detected. In addition it can be studied whether the neutron to proton DIS cross-section ratio is dependent on the initial momentum of the nucleon in deuterium. This is of interest since a nucleon momentum dependence of the DIS cross section could be at the origin of the EMC-effect [5]. The EMC-effect is the observed nuclear mass dependence of deep inelastic scattering. It is noted that the recoil detector studies presented in this thesis are exploratory because of the rather low statistics obtained. In the future these first results can be improved significantly after the installation of a large recoil detector at HERMES, which is currently under development [6].

The outline of this thesis is as follows. The necessary theoretical background is introduced in chapter 2. The HERMES detector system used in the experiments is briefly described in chapter 3, mainly focusing on the parts crucial for analyses of the type presented in this thesis. The analysis of precise σ^d/σ^p data is the topic of chapter 4 in which the behaviour of the longitudinal and transverse components of the cross section ratio in the deuteron is compared to that in the proton. Also, the results of our search for higher twist effects at low and high x are presented. In chapter 5 the prototype silicon recoil-detector (known as the silicon test counter) is described and first physics results are presented on the nucleon momentum distribution in deuterium obtained in DIS. Also, a first attempt is presented to study the origin of the EMC-effect through the extraction of the structure-function ratio of the tagged neutron data and the proton data. The final part of the thesis contains a summary of the results obtained.