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FUTURE HIGH Q^2 DEEP INELASTIC SCATTERING AT HERA

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The luminosity of the electron-proton collider, HERA, will be increased by a factor of five during the long shutdown starting September 2000. At the same time longitudinal lepton beam polarisation will be provided for the collider experiments H1 and ZEUS. These far reaching upgrades to the machine will be matched by upgrades to the detectors. The result will be a unique facility for the study of the structure of the proton and the nature of the strong and electroweak interactions. The physics potential of the upgraded accelerator is discussed here.

1 Introduction

The electron-proton collider HERA started operation in the summer of 1992. The proton beam energy was 820 GeV while the electron beam energy was 26.7 GeV and was later raised to 27.5 GeV. In the years 1992-1997 H1 and ZEUS each collected a luminosity of $\sim$1 pb^{-1} using electron beams and $\sim$50 pb^{-1} using positron beams. These data have extended the kinematic range covered by deep inelastic scattering, DIS, measurements by two orders of magnitude in both Q^2, the four-momentum transfer squared, and x, the fraction of the proton four-momentum carried by the struck quark. These data have been used to dertermine the proton structure function, make measurements which test the electroweak Standard Model, SM, and the theory of the strong interactions, QCD, in both neutral current, NC, and charged current, CC, DIS. Jet analyses in DIS and photoproduction have been used to address fundamental issues in QCD. The observation of diffraction in DIS has led to a careful investigation of the transition from the kinematic region in which perturbative QCD is valid to the region where phenomenological models based on Regge theory must be applied (see for example [1] and [2] and references therein).

During the running period August 1998 to April 1999 $\sim$20 pb^{-1} of e^-p data were delivered with a proton beam energy of 920 GeV. HERA is now delivering e^+p collisions with a proton beam energy of 920 GeV. By the end of running in September 2000 H1 and ZEUS will each have an e^+p data set of $\sim$ 100 pb^{-1}. The data collected by H1 and ZEUS will be used to study the

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dependence of the NC and CC DIS cross sections on the charge of the lepton beam.

The HERA experiments will continue to take data until September 2000 when a long, 9 month, shutdown is scheduled. The shutdown will be used to upgrade the HERA accelerator and the collider detectors. The HERA luminosity will be increased by a factor of five and longitudinal lepton beam polarisation ($\sim$ 70%) will be provided for ZEUS and H1. Over a six year running period it is anticipated that a total luminosity of 1000 pb^{-1} will be delivered [3]. The physics motivation for this major upgrade programme is discussed in detail in reference [4].

2 Physics at HERA after the Upgrade

Following the HERA upgrade the proton will be probed using each of the four possible combinations of lepton beam charge and polarisation. The combination of high luminosity and polarisation will lead to a rich and diverse programme of measurements which can only be sketched below using a few examples.

2.1 Proton Structure

The large data volume will allow $F_2^{\rm NC}$ to be extracted with an accuracy of $\sim$3% over the kinematic range $2\times 10^{-5} < x < 0.7$ and $2\times 10^{-5} < Q^2 < 5\times 10^4\,{\rm GeV}^2$ [5]. If QCD evolution codes which go beyond next to leading order become available and a careful study of the dependence of the systematic errors on the kinematic variables is made it will be possible to determine $\alpha_{\rm S}$ from the scaling violations of $F_2^{\rm NC}$ with a precision of ≤ 0.003. The gluon distribution will also be determined from such a fit with a precision of $\sim$ 3% for $x = 10^{-4}$ and $Q^2 = 20\,{\rm GeV}^2$.

The combination of high luminosity and high charm tagging efficiency transforms the measurement of the charm contribution to $F_2^{\rm NC}, F_2^{cc}$ [6]. The precision will be sufficient to allow a detailed study of the charm production cross section to be made. The lifetime tag provided by the silicon micro-vertex detector allows the tagging of b-quarks and the determination of the ratio of the beauty contribution to $F_2^{\rm NC}$, F_2^{bb}, to F_2^{cc}.

In the quark parton model CC DIS is sensitive to specific quark flavours. The e^+p CC DIS cross section is sensitive to the d- and s-quark parton densities and the $\bar{u}$- and $\bar{c}$-anti-quark densities, while the e^-p CC DIS cross section is sensitive to the $u, c, \bar{d}$ and $\bar{s}$ parton density functions. With the large CC data sets expected following the upgrade it will be possible to use $e^{\pm}p$ CC data to determine the u- and d- quark densities. Further, by identifying charm in CC DIS it will be possible to determine the strange quark contribution to the proton structure function $F_2^{\rm NC}$ with an accuracy of between 15% and 30% [7].

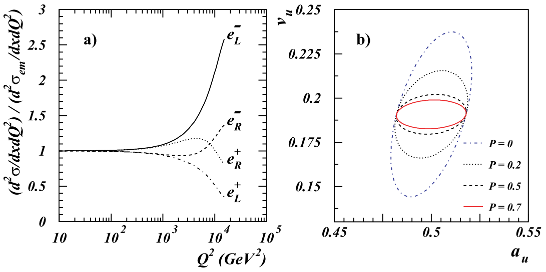

Figure 1: (a) Ratio of the NC DIS cross section to the cross section obtained when only single photon exchange is included as a function of Q^2 at $x = 0.2$. (b) Sensitivity of the errors on the u-quark coupling to the Z to the lepton beam polarisation P. One standard deviation contours are shown for fits in which the u-quark couplings are allowed to vary while the d-quark couplings are held fixed at their SM values [12].

2.2 Tests of the Electroweak Standard Model

The high luminosity provided by the upgrade will allow access to low cross section phenomena such as the production of real W-bosons. The SM cross section for the process $ep \to eWX$ is ~ 1 pb [8] which, combined with an acceptance of $\sim 30\%$, gives a sizeable data sample for a luminosity of 1000 pb^{-1}. The production of the W-boson at HERA is sensitive to the non-abelian coupling $WW\gamma$ [9]. The sensitivity of HERA to non-SM couplings is comparable to the sensitivities obtained at LEP and at the Tevatron and complementary in that at HERA is predominantly sensitive to the $WW\gamma$ vertex, independent of assumptions about the nature of the WWZ vertex.

The full potential of electroweak tests at HERA will be realised through measurements using polarised lepton beams [10]. Within the SM NC and CC DIS cross sections may be written in terms of α, M_W and m_t together with the mass of the Z boson, M_Z, and the mass of the Higgs boson, M_H. In order to test the consistency of the theory we may fix the values of α and M_Z to those obtained at LEP or elsewhere and use measurements of the NC and CC DIS cross sections to place constraints in the M_W, m_t plane for fixed values of M_H. The SM is consistent if the values of the parameters M_W and m_t obtained agree with the values determined in other experiments. Combining NC and CC data corresponding to a luminosity of 1000 pb^{-1}, recorded with a lepton beam polarisation of 70%, with a top mass measurement from the Tevatron with a precision of $\sim \pm 5$ GeV yields a measurement of M_W with an error of ~ 60 MeV [11].

The sensitivity of NC DIS to lepton beam polarisation is shown in figure 1(a). The figure shows the ratio of the full NC cross section to the cross section obtained in the single photon exchange approximation. The strong polarisation dependence of the NC cross section can be used to extract the NC couplings of the light quarks. In such an analysis the CC cross section may be used to reduce the sensitivity of the results to uncertainties in the PDFs [12]. The precision of the results obtained depends strongly on the degree of polarisation of the lepton beam as shown in figure 1(b). The figure shows the anticipated error on the vector and axial-vector couplings of the u-quark, v_u and a_u respectively, obtained in a fit in which v_u and a_u are allowed to vary while all other couplings are fixed at their SM values. With a luminosity of $250\,\mathrm{pb}^{-1}$ per charge, polarisation combination and taking the vector and axial-vector couplings of the u- and d-quarks as free parameters gives a precision of 13%, 6%, 17% and 17% for v_u, a_u, v_d and a_d respectively. By comparing these results with the NC couplings of the c- and b-quarks obtained at LEP a stringent test of the universality of the NC couplings of the quarks will be made.

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