ASPECTS OF THE HERA II PHYSICS PROGRAMME

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A short account of the physics highlights of HERA I illustrates the trends towards precision measurements and outlines the scope of the upgraded high luminosity collider HERA II. Considerable hardware upgrades have been introduced during the recent HERA shutdown 2000/1 and their benefits for the physics at HERA II are briefly outlined. The examples concentrate on the H1 experiment while similar aspects have been considered for ZEUS [1].

1 Introduction

Primary goal of the high luminosity upgrade of HERA is to provide increased sensitivity for hard scale processes in *ep*-scattering with cross sections well below the $1\,\mathrm{pb}^{-1}$ level. Both neutral and charged current processes decrease quickly with momentum transfer - asymptotically like Q^{-4} and even faster due to the exhausted valence quark distribution. In a similar manner the photo production cross section with a large E_T scale is suppressed $\propto E_T^{-4}$. Experimentally such processes are easily recognized and simply await the envisaged luminosity of $1\,\mathrm{fb}^{-1}$ to be delivered. Subtleties are involved in selecting rare *low scale* processes from the overwhelming background of known reactions. Examples are heavy quark production and diffractive processes. Consequently major aspects of the upgrade specifically address these questions.

2 The lesson from HERA I - the Quest for Precision in QCD

The first round of upgrades of the H1 experiment in 1995 concentrated on extending the measurement capabilities for electrons scattered under small angles, in the so called *backward* direction. At the time the SPACAL calorimeter [2] fronted with the backward drift chamber (BDC) [3] were introduced. The first components of silicon detectors in the backward (BST) and central (CST) [3] direction followed suite. Such longstanding investments pay off with sufficient statistics now available - an example is shown in figure 1 - an extraction [4] of the longitudinal structure function F_L which has been made possible by detecting electrons down to energies of 2 GeV and down to scattering angles as small as 1.5°. The BST here is pivotal in determining the background of γp processes at large y by explicitly measuring wrong sign

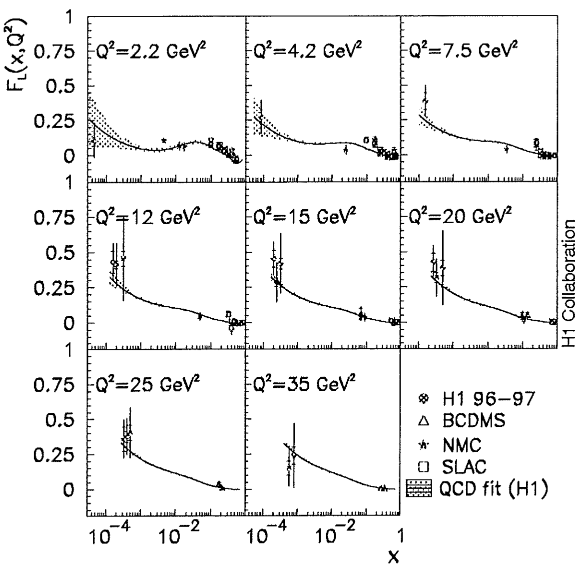

Figure 1. The longitudinal structure function F_L as derived from a comparison of the cross section measured with the extrapolation of F_2 into the region of large y (from published data of ref. [4]

charge contributions. The measurement of F_L to date is based on extrapolations of F_2 into the region of large y.

Such genuine detection capabilities will likewise be required in the high luminosity phase of HERA II where F_L will be measured free of assumptions on F_2 by varying the beam energy of the protons down to 400 GeV or less. The measurements will provide further constraints for tests of QCD since in lowest order $xg(x) \propto \partial F_L/\partial \log Q^2$ and higher twists are expected to contribute more prominently than for F_2.

2.1 Perturbative QCD

To date the technology to extract the parton distributions and the strength of the strong coupling constant has been developed to large sophistication [4–6]. The precision of the structure function measurements has been improved [4] to 1-3% at small Q^2 and x. Perturbative calculations in NLO QCD provide

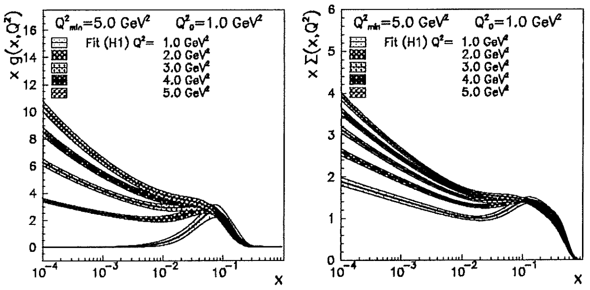

Figure 2. The parton distribution functions extracted from an analysis of structure function data of [4].

the means to extract the gluon and singlet parton distributions. An example of the current status is seen in figure 2. From these distributions it is evident that at small Q^2 the gluon becomes "valence-like" and thus exchanges its role with the sea quarks as the driving element for the increase of the steep rise of F_2 at small x. The value of α_s extracted using lepton proton scattering data alone is found to be $\alpha_s = 0.1150 \pm 0.0017 \pm 0.001$ with an additional scale uncertainty of 0.0050. It is expected that the latter uncertainty will be reduced once higher order calculations become available which is not inconceivable [7]. Already now the precision of extractions from inclusive measurements is well compatible with that of the world average of α_s [8].

It is reassuring that the same quantity can be extracted consistently from jet data where 2- or 3-jets produced [9, 10] in deeply inelastic *ep*-scattering require the contribution of higher order terms to the scattering process and yield very similar values of α_s. Figure 3 depicts the three jet measurement extracted from the H1 data. The importance of recently made available [12] higher order calculations is evident at small scales. Such cross sections can be used to further constrain the value of α_s in the future.

2.2 Diffraction

QCD in all but the simplest final state configurations is not easily exposing itself to particularly constraining quantitative tests. The process of diffraction

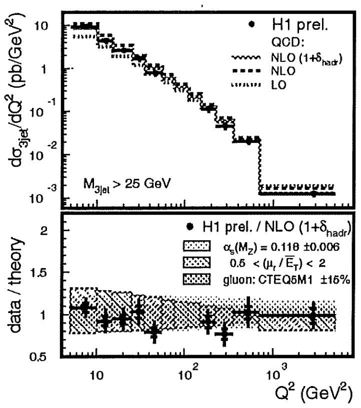

Figure 3. The 3-jet cross section measured in deeply inelastic scattering.

has been seen to persist even in hard scattering processes at the largest Q^2 for a considerable fraction of ep interactions. While at first sight surprising seeing a proton survive the extraction of a large mass system, in the language of QCD it must be identified with a colour singlet exchange. The precise mechanism for this exchange, which in lowest order perturbative QCD involves at least two gluons, is much less understood. Exclusive precision data will be required to provide more experimental information and possibly help shed light on the understanding of the scattering process. Recently some 2-jet data reconstructed in events with a large rapidity gap and thus indicative of the colourless exchange have become available [13]. Such exclusive processes distinguish between various models, cf. figure 4. More conclusive data will become available with the introduction of the VFPS, cf. section 3.3.

2.3 Exploration of the Kinematic Limit

With a total integrated luminosity of 1 fb^{-1} to be made available in polarized electron and positron interactions major progress can be achieved in pinning down the electroweak couplings of the u and d-quark as is documented in [11]. Q^2 comparable to M_Z^2 or M_W^2 are a prerequisite.

H1 has seen a class of events exhibiting an explicit hard scale which in their rate are presently hard to reconcile with a production mechanism in the Standard model. 10 events with an isolated lepton and a missing trans-

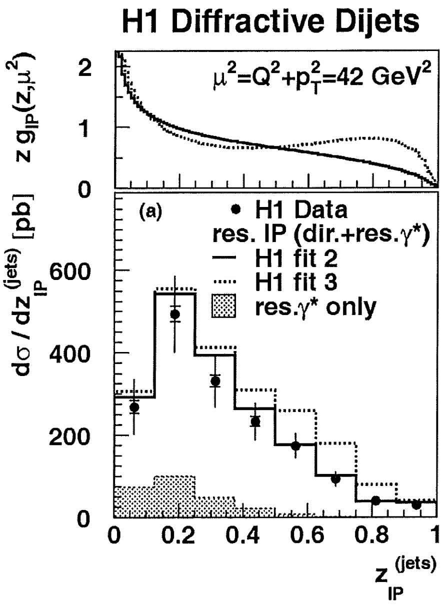

Figure 4. The cross section for production of diffractive 2-jets. The top insert displays two gluon distributions extracted from the inclusive cross section at fixed scale.

verse momentum exceeding 25 GeV have been reconstructed [14] while only 2.8 events are expected from an integrated luminosity exceeding 100 pb^{-1}. The dominant production mechanism for these events is believed to be W-production which makes up for most of the indicated background rate. Evidently considerably more luminosity is required to settle the nature of this class of events.

3 Short Overview of the H1 Upgrades

3.1 Modifications of the Forward Direction

Final state electrons in processes at high Q^2 are scattered back into the forward proton direction with an energy of a few hundred GeV, so that showering in the detector material becomes an issue. H1 has augmented the recognition of charged particles tracks by installing a planar Forward Silicon Tracker (FST) surrounding the beampipe (Aluminum/Beryllium alloy) and by increas-

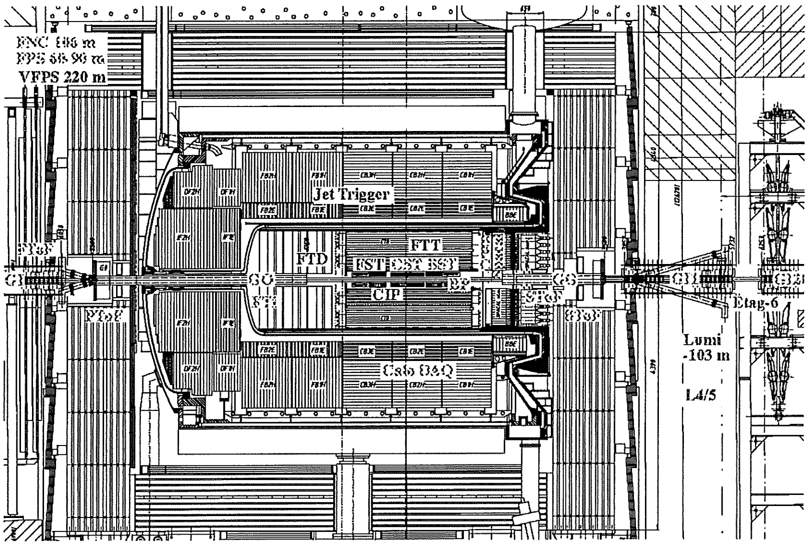

Figure 5. Overview of the components of the upgrade 2000/1 of the H1 detector. The components denoted in blue are genuine upgrades, those in red were necessitated by the strong focusing magnets in the experiment. The components in green underwent modifications.

ing the number of layers in the Forward Tracking Detector (FTD) replacing the existing transition radiation detector. There is hence larger redundancy in track recognition and reconstruction.

3.2 Improvements of the Trigger System

The luminosity increase is accomplished by strong focusing inside the experimental apparatus. The extra bending generates synchrotron radiation that has to be fanned out into a specific absorber. Residual components may increase the noise levels. The Central Inner Proportional chamber CIP has been replaced [15] by a five layer chamber with pointing geometry to the interaction point. The selectivity of events without inherent large scale can only be accomplished with more sophisticated trigger systems. The Fast Track trigger FTT [16] will employ a three level decision process to derive invariant mass combinations such as $\Delta m = m_{K\pi\pi} - m_{K\pi}$ to enrich the selectivity for *heavy quark* events while maintaining low rates overall. The central silicon detector CST will thus be used in the reconstruction of these events. The calorimeter

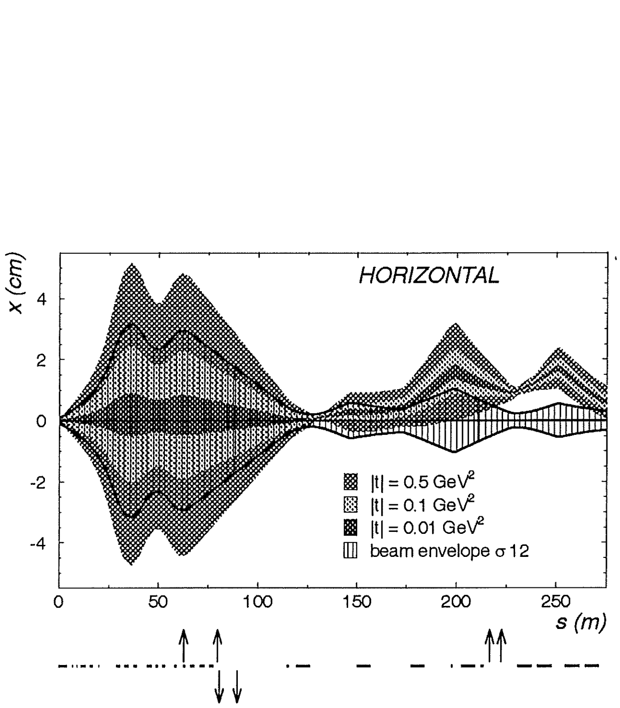

Figure 6. The p-beam 12σ envelope from the detector at (0,0) displayed more than 250 m in proton direction. The arrows between 60 and 100 m indicate the positions of the existing FPS stations. The planned VFPS station is depicted by the arrows around 220 m. Scattered protons, shown for three values of t at fixed $x_{I\!P} = 0.01$, are deflected away from the beam line such that a detector registers protons with high efficiency. The horizontal "ladder" indicates the position of the machine magnets along the beams line.

jet trigger [17] will select individual regions of interest of comparatively small energy deposits and thus complement the charged particles information.

3.3 Very Forward Proton Spectrometer

Given the physics potential of further diffractive studies at a high luminosity HERA H1 is undertaking an extension of the forward tagging facilities [18]. For the first time the proton will be tagged in Roman pots inserted into the beam pipe at around 220 m from the interaction point. At this point the proton beam has undergone the first bending in the dipole fields which can be put to use as spectrometer magnets. The beam envelopes are shown together with the envelopes of a deflected beam at small t. The operation necessitates the installation of a bypass for the cryogenics support lines planned for the shutdown 2002/3. For $x_{I\!P} < 0.04$ the detector will have high efficiency for $|t| < 0.5\,\mathrm{GeV}^2$. The t-resolution is inevitably moderate ($\approx 0.2\,\mathrm{GeV}^2$), largely determined by the beam divergence in the high luminosity optics. The measurements will thus be complemented by information from the main detector.

4 Conclusion

The major upgrade of the H1 detector since 1995 has just been completed. With high luminosity becoming available improved detection and reconstruction techniques have been implemented to select rare processes both at hard and soft scales. H1 is thus well poised to explore the physics at shortest distances, to resolve the puzzle of isolated lepton events and to measure precisely the deeply inelastic scattering process including its diffractive component.

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