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High Energy Electron–Proton Physics at HERA

Report to the UK PPARC
Particle Physics Experiments Selection Panel

March 1998

H1 COLLABORATION PROPOSAL 750

The Universities of Birmingham, Glasgow, Lancaster, Liverpool, and Manchester, Queen Mary and Westfield College, University of London, and Rutherford Appleton Laboratory

with

RWTH Aachen (I and III Inst.), Humboldt Univ. Berlin, Universities of Brussels, Cracow, California (Davis), and Dortmund, CEA Saclay, DESY–Hamburg, DESY–Zeuthen, Universities of Hamburg (I and II Inst.) and Heidelberg, MPI Heidelberg, Universities of Kiel, Kosice, and Lund, CPPM-Marseille, ITEP Moscow, LPI Moscow, MPI Munich, LAL Orsay, Ecole Polytechnique, Universities of Paris VI, Paris VII, Prague, and Rome, PSI-Villigen, University of Wuppertal, ETH Zürich and University of Zürich

1 Introduction and Overview

In 1996 the positron–proton collider HERA commenced operation in May, and from July delivered positron–proton (e^+p) luminosity for physics to H1 and ZEUS and polarized e^+ beams for HERMES. The fourth HERA experiment, HERA–B, also began first tests in this year. With four competing experiments, and complicated background conditions, HERA nevertheless performed very well and H1 accumulated $\sim 9\,\mathrm{pb}^{-1}$ of good quality data during the 1996 run. The recently completed 1997 run was the most successful so far. The machine began operation in May and ran efficiently with very few breaks until October 1997. The $\sim 25\,\mathrm{pb}^{-1}$ of data delivered to H1 surpasses that delivered in all previous years combined.

H1 took advantage of the good performance of HERA by achieving a steadily improving overall data taking efficiency, averaging 70% in 1996 and 80% in 1997. New detector components took data for the first time including:

- the central silicon tracking detector, to enhance charge particle measurement and enable tagging of charm or bottom quarks by detecting secondary vertices
- the backward silicon tracking detector, to improve the resolution on the angle of the scattered electron in deep-inelastic scattering and enable identification of electrons at very low energies
- a proton spectrometer, to measure protons scattered very close to the proton beam
- an additional electron tagger, to detect positrons scattered at low angles to extend the energy range over which photoproduction measurements can be made.

The successful operation of these new components alongside the established H1 detector will enable new and higher precision measurements to be made with the current and future data.

During 1996 – 1997 data taking, all of the H1 detector components which were designed and built by the UK groups, or for which they have some responsibility, were operational. These include the superconducting solenoid (RAL), the forward track detector (RAL, Glasgow, Lancaster, Liverpool, Manchester), the H1 central data acquisition system (RAL), the H1 central trigger control (RAL), the forward muon detector (Manchester) and its trigger (RAL, Birmingham, QMW), the backward calorimeters (SPACAL) timing system (RAL, Birmingham, QMW), the forward ToF scintillators (Manchester, QMW) and the data acquisition system of the silicon trackers (RAL).

The "Centipede Network Processing" system has been written to allow a master processor at one laboratory to run software on H1 processors at other sites in the UK with minimal human intervention. It is now operational at all H1-UK sites and at a number of German sites, and it plays an important role in data Monte Carlo simulation and reconstruction.

Notable H1 results during 1996 and 1997 include:

- observation of an excess in the number of events observed at high Q^2 above the standard model prediction,
- observation of a number of events containing a high P_T isolated lepton and large missing transverse momentum,
- exclusion limits for supersymmetric particle production in the minimal supersymmetric model,
- a first determination of the proton structure function F_L,

- new measurements of the proton structure function F_2 across the range $0.35 < Q^2 < 5000$ GeV^2,
- a first measurement of the charm contribution to F_2 at low x, and a determination of the gluon density in the proton from deep inelastic charm production,
- factorisation breaking and violations of scale invariance in deep–inelastic diffraction and,
- a measurement of jet production at low Q^2 enabling an examination of the structure of the virtual photon.

This document is organised as follows: sections 2 to 6 focus on analysis work carried out by H1–UK groups; section 7 describes the detector developments that were the responsibility of the H1–UK groups.

It is planned to increase the luminosity delivered by HERA by a factor of about 5 in the year 2000. A supplementary document details a proposal to upgrade the H1 Forward Track Detector (FTD) to take advantage of the physics opportunities presented by very large luminosities.

2 Deep–inelastic Scattering at High Q^2

The deep-inelastic scattering (DIS) cross section and extraction of the proton structure functions are experimental measurements from which the structure of hadrons can be understood and with which tests of Quantum Chromodynamics (QCD), the theory of the strong interactions, can be made. Such measurements are usually made as a function of two variables x and Q^2. The Bjorken scaling variable x is the fraction of the proton's momentum carried by the quark that interacts with the electron. The variable Q^2 is the square of the 4-momentum carried by the object exchanged (photon, Z^0 or W boson) between the electron and proton. The higher the Q^2 of the process the higher is the resolution with which the structure of the proton is probed.

Measurements of the proton structure functions at H1 have continued to investigate the low momentum components of the proton with ever greater precision [1]. These measurements probe the hitherto inaccessible low x region of proton structure. The sharp fall in the DIS cross section with Q^2, however, makes the precision of measurements at larger Q^2 strongly dependent on the amount of data collected. The large increase in the integrated luminosity delivered by the HERA machine in recent years has not only improved the precision of high Q^2 measurements, but has also greatly extended the Q^2 range across which DIS may be investigated. Two examples of analyses of the high Q^2 data involving UK physicists are described below.

2.1 Proton Structure Function F_2

A measurement has been made of the cross section for inclusive neutral current ($ep \to eX$) scattering, using data taken in the years 1995–1997 [2]. From this the proton structure function, F_2, was evaluated over the range $133 < Q^2 < 5000$ GeV^2. The F_2, shown in figure 1 is seen to rise steeply with decreasing x, with a slope that increases as Q^2 increases. This is in line with expectations of an increasing parton density at lower x as Q^2 increases caused by the enhanced resolution of low momentum Bremsstrahlung processes at higher Q^2 as the size of the virtual photon probe decreases.

Superimposed on the data in figure 1 is a prediction from perturbative QCD using parton distributions of the proton obtained from fits to H1 and fixed target data measured at lower values of Q^2 than those presented here [1]. It can be seen that the QCD prediction is in excellent agreement with the data throughout the range of the measurement. There is no evidence within the present experimental uncertainties for any deviation from standard model expectations for photon virtualities up to 5000 GeV^2.

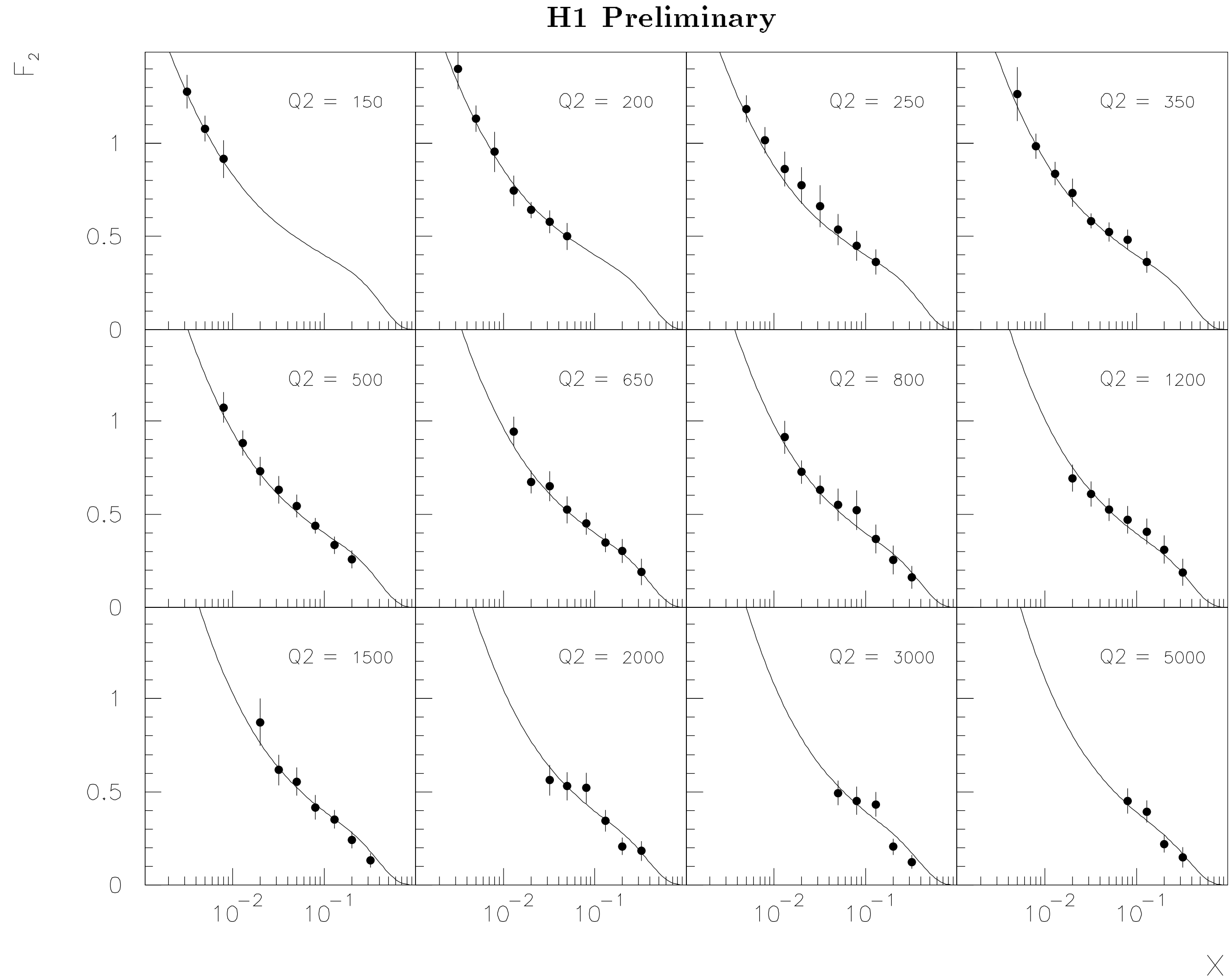

Figure 1: The proton structure function F_2, plotted as a function of x for various Q^2. Also shown is the prediction of a QCD fit to data taken at lower Q^2.

2.2 Deep–inelastic Scattering at Very High Q^2

At very high Q^2 the deep inelastic neutral current (photon or Z^0 exchange, $ep \to eX$) and charge current ($W^\pm$ exchange, $ep \to \nu X$) cross sections are sensitive to possible extensions of the standard model that are not fully explored at other experiments. Deviations of the cross section from the standard model may arise from a number of effects including resonance production of a new particle, quark or lepton substructure or a contact interaction arising from the virtual exchange of a very massive particle [3, 4].

H1 has made a comparison of the number of events observed in the data for the years 1994–1997 with the number expected from the standard model [5, 6]. As can be seen in figure 2 for values of $Q^2 < 15000$ GeV^2 there is excellent agreement between the data and the standard model expectation in both neutral and charge current scattering. For $Q^2 > 15000$ GeV^2, however, more events are seen in data than are expected from from the standard model. For neutral current scattering 18 events are observed compared with 8.0 expected from the standard model.

The probability that the events observed are due to a chance upward fluctuation of the standard model is 0.34%. The excess in charged current scattering is of less statistical significance with 6 events observed compared with a standard model expectation of 2.92, corresponding to a standard model fluctuation probability of 14%.

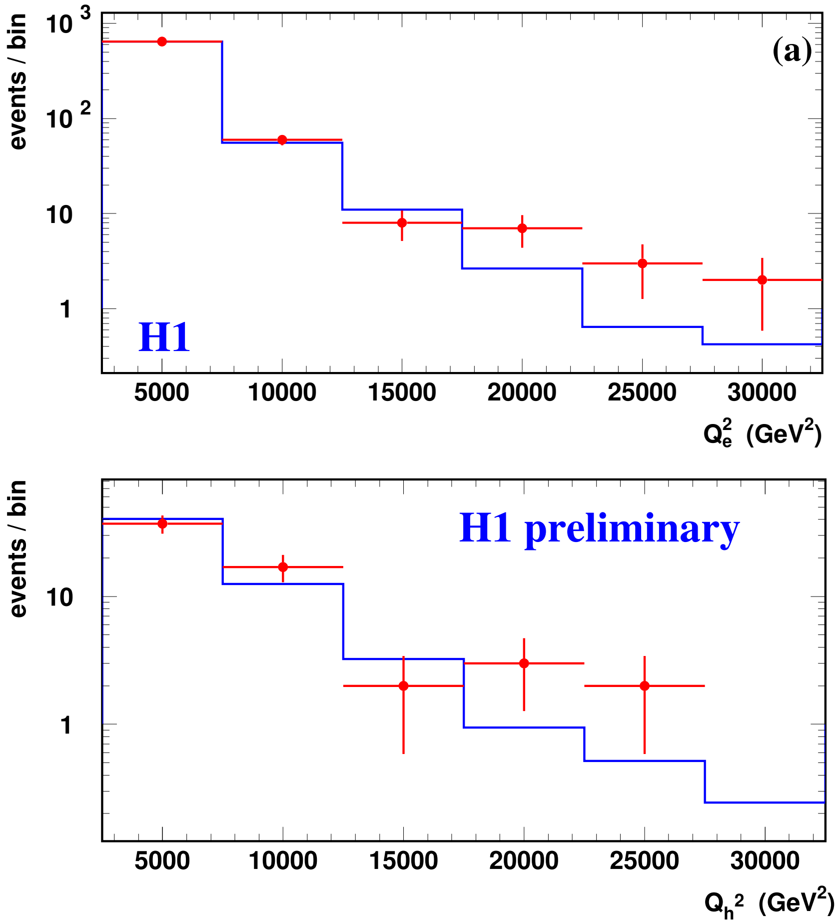

Figure 2: Comparison of the number of observed neutral current events (filled circles) to the expection of the standard model (histogram) for (a) neutral current and (b) charge current events.

More information on the form of the excess may be gleaned by examining the dependence on the other DIS variable x. The results shown in figure 3 for the neutral current events are presented in terms of the closely related variable $M = \sqrt{sx}$, where $s = 90528$ GeV^2 is the ep centre of mass energy. The excess is observed to be largest around $M \simeq 200$ GeV. A clustering of events around a single mass value is expected for resonance production of a new particle, although the present results are only suggestive.

The number of events observed at very high Q^2 is not yet high enough to conclude firmly whether there was a chance upward fluctuation of the standard model or else if the first signs of new physics have been seen. Whatever the outcome high Q^2 physics will remain an exciting testing ground for the standard model as the HERA machine continues to produce ever increasing luminosity in the years to come.

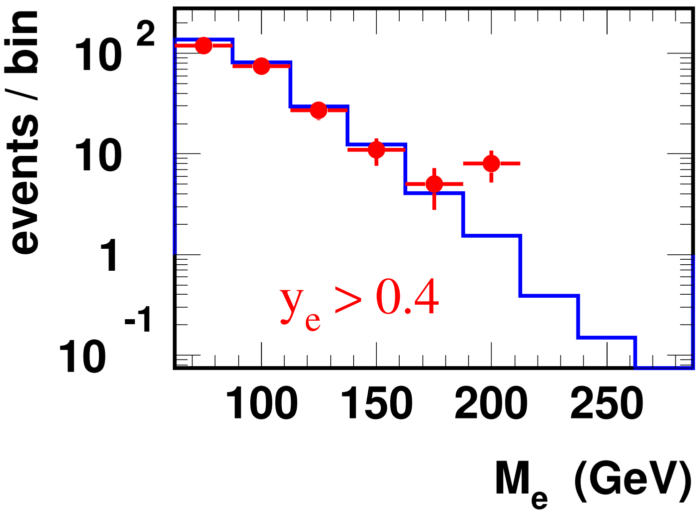

Figure 3: The distribution in $M = \sqrt{sx}$ for neutral current events with $y = Q^2/(sx) > 0.4$ observed in the data (filled circles) together with the expectation from the standard model (histogram).

3 Diffractive Scattering

Quantum chromodynamics, although well understood in its short range manifestation, is still far from complete for long range scattering processes. These long range interactions, though making up the bulk of the cross section in hadron-hadron and photon-hadron collisions, are not easily calculable within QCD. Such 'soft' interactions may, however, be described using the phenomenological Regge model, in which cross sections are built from a sum of distinct reggeon exchanges [7]. At high energies the dominant exchange is that of a pomeron ($I\!P$) [8]. Such pomeron exchange processes are known as diffractive.

HERA, being the only electron-hadron collider to reach the high energies where pomeron exchange becomes important, is in a unique position to study diffraction. Inclusive diffractive photoproduction processes can be compared to hadron-hadron scattering processes to test the universality of the pomeron. In diffractive DIS the pomeron is probed with a hard virtual photon, allowing a determination of its structure. It is hoped that measurements made at HERA will help towards a unification of diffraction and perturbative QCD within a complete theory of the strong force [9].

3.1 Diffractive Photoproduction Cross Sections

The cross section for the process $\gamma p \to XY$ has been measured at HERA where the systems X and Y are separated by a large interval in the rapidity distribution of final state particles [10]. Such a configuration is expected for processes involving the exchange of reggeons including the pomeron. The measurement has been made both for the process where the proton dominantly remains intact ($\gamma p \to Xp$) and for where the proton dissociates. The results for the elastic proton case are shown in figure 4 as a function of M_X, the invariant mass of the system X. Also shown are data taken at lower photon-proton centre of mass energy W by the E612 collaboration [11]. The data from both experiments are well described with a model based on

Regge theory. In this model pomeron exchange dominates the cross section at HERA energies although a subleading exchange identified with the ρ, a, ω or f mesons is needed to explain the fixed target data and the HERA data at higher M_X. In this fit the intercept of the pomeron is found to be $\alpha_{\mathbb{P}}(0) = 1.068 \pm 0.016$ (stat.) $\pm\, 0.022$ (syst.) $\pm\, 0.041$ (model) in good agreement to that found in other soft scattering processes [12, 13].

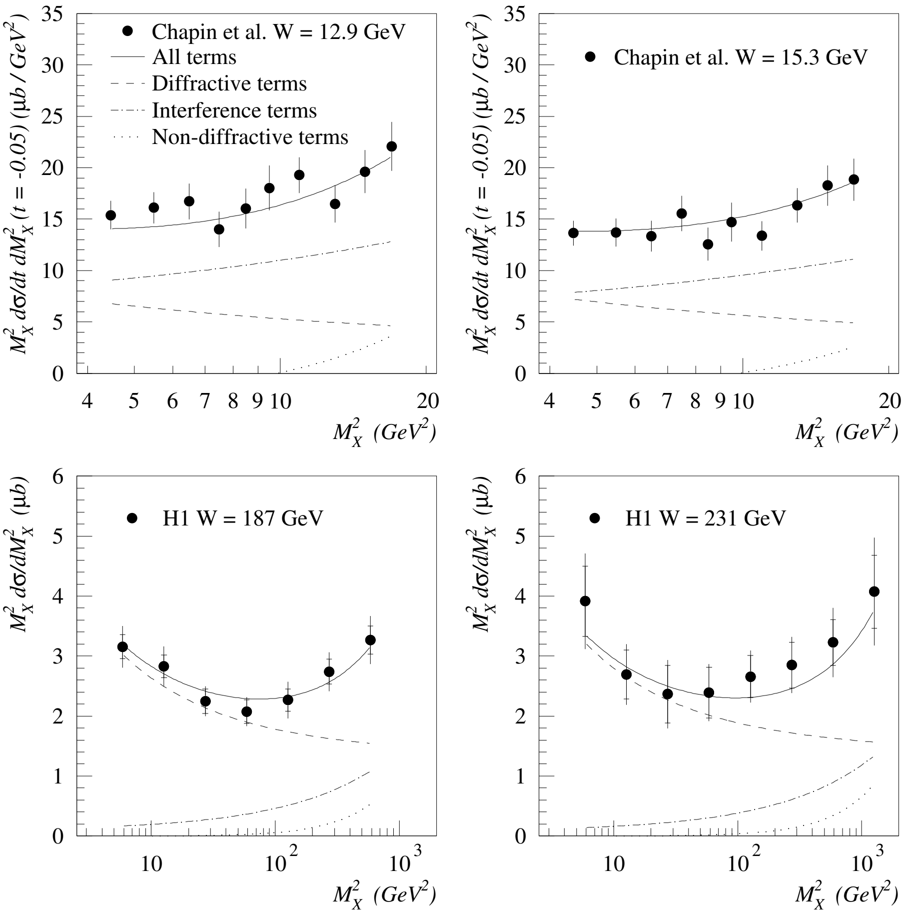

Figure 4: Measurements of the quantity $M_X^2\ \mathrm{d}\sigma/\mathrm{d}M_X^2$ for the process $\gamma p \to Xp$ by H1 and E612. Also shown is a Regge fit which includes pomeron exchange, subleading reggeon exchange and a term arising from interference between the exchanges.

3.2 Diffractive Structure Function $F_2^{D(3)}$

A measurement of cross section for the process $ep \to eXY$ has also been made in the DIS regime [14]. For this data the cross section is expressed as a differential structure function $F_2^{D(3)}$, defined in analogy to the proton structure function F_2, and is measured as a function of the kinematic variables Q^2, $x_{\mathbb{P}}$ and β. The variable $x_{\mathbb{P}}$ is the fraction of the proton's momentum carried by the pomeron and β is the fraction of the pomeron's momentum carried by the struck quark, which is resolved in the scattering.

$F_2^{D(3)}$ is shown in figure 5 as a function of $x_{\mathbb{P}}$ for two example β and Q^2 values. Also shown are the results of a Regge model fit of the $x_{\mathbb{P}}$ dependence of $F_2^{D(3)}$. Good agreement with the data is obtained if a subleading exchange is included along with a pomeron contribution. The intercept of the pomeron is measured to be $\alpha_{I\!P}(0) = 1.203 \pm 0.020(\text{stat.}) \pm 0.013(\text{sys.})^{+0.030}_{-0.035}(\text{model})$. This value is larger than that obtained in soft processes [12,13] including the measurement made in photoproduction. The intercept of the subleading trajectory agrees within errors with that expected for the degenerate ρ, a, ω and f trajectory.

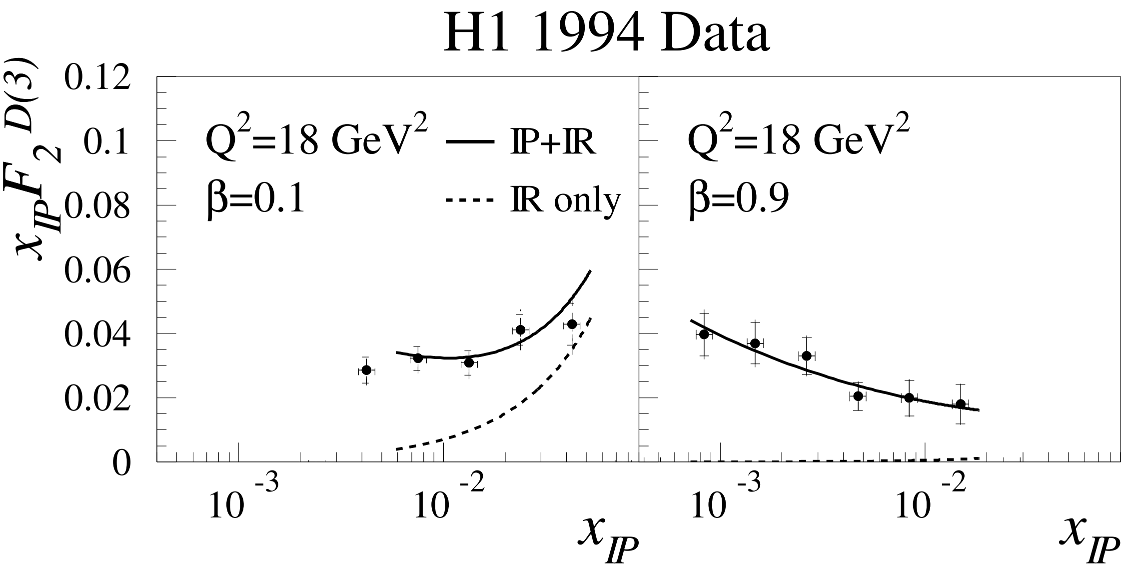

Figure 5: The quantity $x_{I\!P}F_2^{D(3)}$ shown at two example β, Q^2 values, plotted as a function of $x_{I\!P}$. Also shown are the results of the Regge fit to the data. The dashed curve is the contribution from the subleading reggeon exchange and the solid curve is the total contribution from subleading reggeon plus pomeron exchange.

The Regge fit is extended by fitting the β and Q^2 dependencies with a model based on perturbative QCD. Two different fits are performed, one in which the pomeron is assumed only to be composed of quarks at low Q^2 and a second in which at low Q^2 the pomeron is composed of quarks and gluons. The results of the QCD fits are shown in figure 6 together with the measured $F_2^{D(3)}$ at a fixed value of $x_{I\!P} = 0.003$. It can be seen that the quark only fit does not describe the change in $F_2^{D(3)}$ as a function of Q^2 whereas the fit with both quarks and gluons describes the data very well. In this fit it is found that between 80 and 90% of the momentum of the pomeron is carried by gluons.

The conclusion that the pomeron is a mainly gluonic object has also been drawn from diffractive hadronic final state measurements [15–18]. An example of this supporting evidence is shown in figure 7 which shows the energy flow in the hadronic final state measured in the Lorentz frame in which the diffractive exchange and the virtual photon meet head–on. If the proportion of the momentum of the diffractive exchange with which the virtual photon interacts is substantial, and if parton carrying this momentum proportion is of similar nature to the remnant, then this distribution is expected to be approximately symmetric, which it is. If this interacting momentum is in the form of one or more gluons, then substantial energy flow transverse to the head–on axis is expected, and this is found.

In photoproduction events at HERA the quasi-real photon can act as a hadronic object, described in terms of parton distribution functions, and a hard scatter can take place between a parton in the photon and a parton in the proton. At sufficiently high momentum transfers, this will result in the formation of jets. In the majority of such events, the hard scattering is

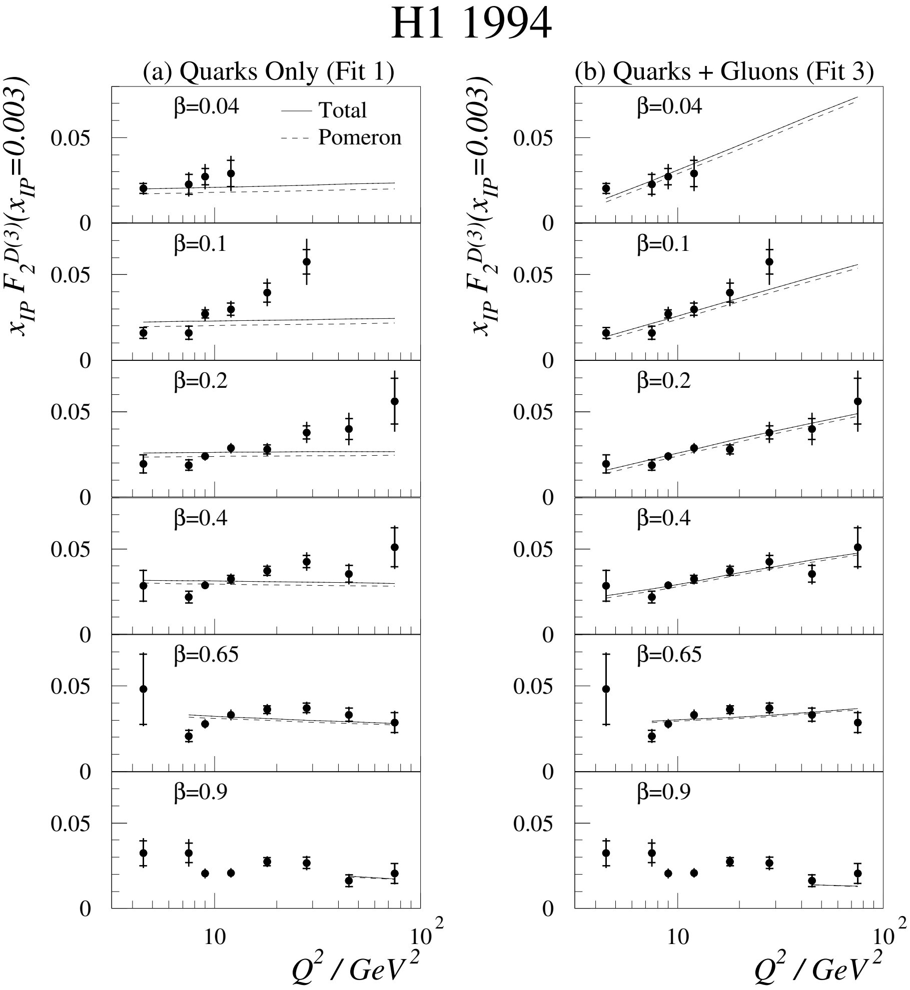

Figure 6: The quantity $x_{\mathbb{P}} F_2^{D(3)}$ shown at fixed $x_{\mathbb{P}}$ as a function of Q^2 for various values of β. Also shown are the results of QCD fits to the data. In (a) only quarks are assumed to contribute at low Q^2 and in (b) both quarks and gluons contribute at all Q^2. In both fits the dashed curve is the contribution from pomeron exchange and the solid curve is the total contribution from subleading reggeon plus pomeron exchange.

mediated by a quark or a gluon, such that the outgoing partons are connected by colour strings both to the corresponding remnants and to each other. These colour connections result in observable hadronic activity in the rapidity interval between the two final state jets. However if a strongly interacting colour singlet object is exchanged in the hard process, there are no colour connections between the outgoing partons. At the hadron level, an absence of energy flow is then expected in the rapidity region between the jets.

The 'gap fraction', $f(\Delta\eta)$, is defined as the proportion of events containing two or more high E_T jets for which there is a gap in rapidity between the two highest E_T jets as a function of the jet - jet separation $\Delta\eta$ [19]. For processes involving the exchange of objects with net colour, $f(\Delta\eta)$ is expected to decrease exponentially with increasing $\Delta\eta$. If colour singlet exchange also plays a role, the gap fraction is expected to level off at some value of $\Delta\eta$.

The gap fraction, corrected to the case in which there is no hadron in the rapidity region between the jets with energy greater than 400 MeV, is shown in figure 8. Also shown is the prediction from standard photoproduction (direct and resolved contributions) using the HERWIG Monte Carlo event generator. Within the errors the data are well described without

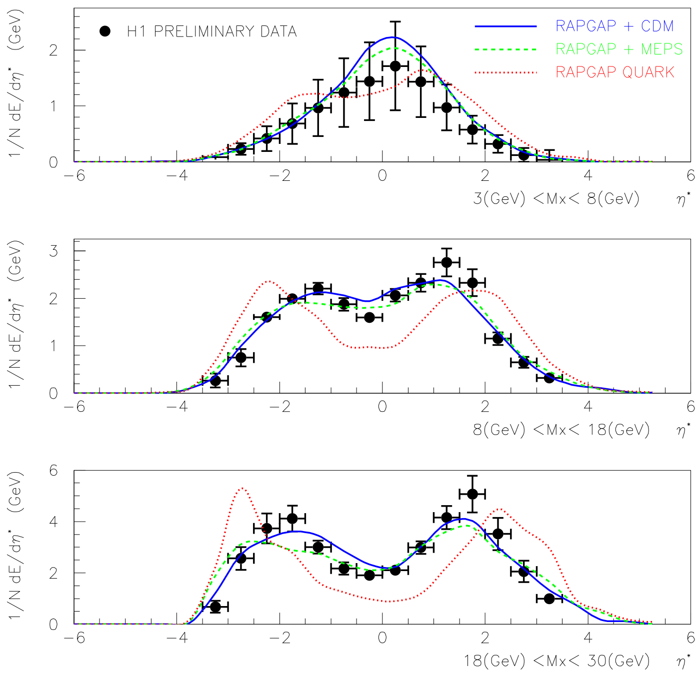

Figure 7: Hadronic energy flow $1/N \cdot \mathrm{d}N/\mathrm{d}\eta^*$ as a function of pseudo–rapidity η^* in the centre of mass frame of the virtual photon–diffractive exchange; the superimposed curves (RAPGAP+MEPS and RAPGAP+CDM) assume that diffractive exchange is dominated by gluons with two different hypotheses for parton fragmentation; the curve labelled RAPGAP QUARK assumes that the partonic structure of diffractive exchange is predominantly the exchange of quarks.

any colour singlet exchange contribution throughout the region $2.0 < \Delta\eta < 3.5$, whereas an excess of events with a rapidity gap between the jets is observed for $3.5 < \Delta\eta < 4.0$. Integrated over this latter interval, the measured value of $f(\Delta\eta)$ lies more than two standard deviations above the prediction of the simulation without a colour singlet exchange contribution.

4 The Hadronic Final State at HERA

The hadronic final state at HERA is an ideal testing ground for many features of perturbative QCD. Scaling violations can be observed, which are sensitive to the strong coupling constant α_s, obtained from the study of particle fragmentation functions. By the identification of jets and high transverse momentum particles hard partonic sub-processes can be tagged and thus information on the structure of the proton and photon extracted.

Furthermore, non-perturbative QCD effects such as Bose Einstein correlations between like charge bosons and the production of low transverse momentum strange particles can also be studied with the hadronic final state over a wide kinematic range available at HERA.

4.1 Inclusive particle spectra in γp and DIS

Studies of the hadronic final states of photoproduction and DIS interactions have been made with inclusively produced charged [20] and strange particles [21]. Figure 9 shows the corrected transverse momentum distribution $(1/N)\mathrm{d}^2n/\mathrm{d}p_T^*\mathrm{d}\eta^*$ of charged particles inclusively produced in non-diffractive low Q^2 DIS ($\langle Q^2\rangle$=23 GeV^2) and photoproduction interactions ($Q^2 \approx 0$ GeV^2) at a common mean hadronic centre of mass energy, $\langle W\rangle$=190 GeV. Here, p_T^* and η^* denote

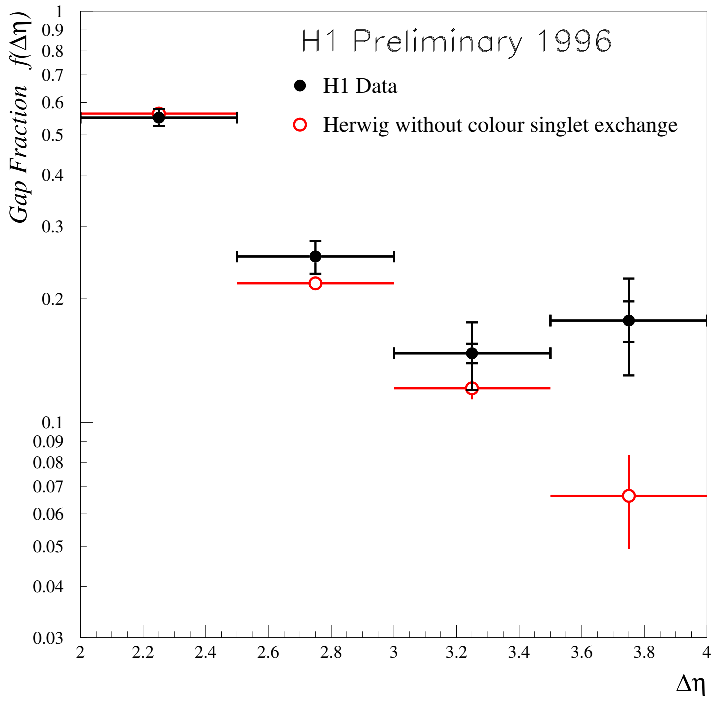

Figure 8: The corrected gap fraction $f(\Delta\eta)$. H1 data are solid points. The prediction of the HERWIG simulation without a colour singlet exchange component is shown as the open points.

the transverse momentum and pseudorapidity respectively in the photon-proton centre of mass system where the photon is taken to be aligned with the $+z^*$ direction. The measurement is presented in the following intervals of η^*: $-0.5 < \eta^* < 0.5$, $0.5 < \eta^* < 1.5$ and $1.5 < \eta^* < 2.5$ and the error bars correspond to the quadratic sum of the statistical and systematic errors. The larger errors in the range $-0.5 < \eta^* < 0.5$ are due to increasing use of the FTD. This is discussed in more detail in the accompanying proposal to upgrade the FTD. The charged particle transverse momentum spectra in DIS is seen to be significantly harder than γp for the larger values of rapidity although they are seen to converge towards the most central rapidity interval $-0.5 < y < 0.5$. These results support the picture of the rapidity distributions of inclusively produced hadrons in ep scattering as consisting of a photon fragmentation region depending on Q^2 and a central region spanning the proton and photon fragmentation regions which, given the short range nature of the strong force, depends only on W [26].

Also shown are the predictions of various QCD-based Monte Carlo calculations. The γp model PHOJET describes the data adequately over the entire phase space region considered in this analysis. The DIS models LEPTO [27] and the Colour Dipole Model (CDM) [28] both predict excellently the p_T distributions at high η^* although LEPTO becomes increasingly unable to describe the charged particle rate in the highest p_T bins as η^* decreases. This observation is consistent with those of an earlier study in which UK physicists also participated, now published [22], of the charged particle transverse momentum spectra in DIS only for different regions of x and Q^2.

A more sensitive discriminant to the underlying parton dynamics between DIS and γp is

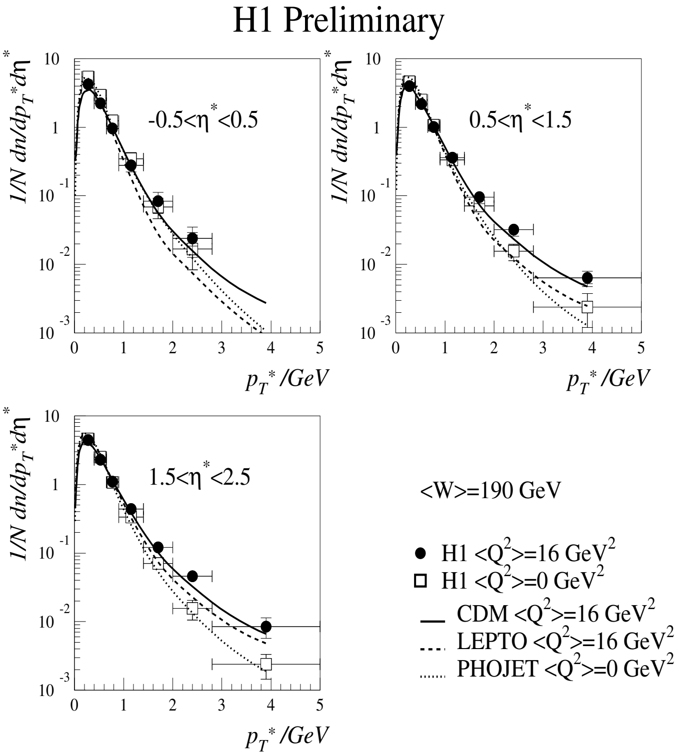

Figure 9: The inclusive charged particle distribution $(1/N)\mathrm{d}^2n/\mathrm{d}p_T^*\mathrm{d}\eta^*$ in the pseudorapidity intervals: $-0.5 < \eta^* < 0.5$, $0.5 < \eta^* < 1.5$ and $1.5 < \eta^* < 2.5$ in photoproduction and DIS. A comparison is made to the predictions of the CDM, LEPTO and PHOJET.

that of the flavour composition of the hadronic final state. Strange particle production at high p_T is a useful "foot-print" of charm and gluon partonic processes whereas at low p_T, strangeness production proceeds dominantly via the non-perturbative hadronization process and an environmental and therefore Q^2 independence would be expected. Figure 10 shows the rapidity and transverse momentum distributions in the hadronic centre of mass system for non-diffractively produced K^0s at $\langle Q^2\rangle$=23 GeV^2 and $\langle Q^2\rangle \approx 0$ GeV^2 [20] and at an average hadronic centre of mass energy, $\langle W\rangle$=200 GeV. The K^0 measurements, despite their lower statistical significance, show a behaviour consistent with the charged particles and show no large changes with Q^2 over any of the phase space exploited here.

Strangeness production in DIS is sensitive to novel QCD phenomena, for example instantons [24, 25]. One of the striking features of instanton associated events is the democratic production of all kinematically allowed flavours, leading to an enhanced strangeness production rate. Measurements of the K^0 yield as a function of pseudo–rapidity η have been converted in an upper limit on the cross section for instanton production of 0.9 nb (95% confidence) [23].

4.2 QCD Studies in the Breit Frame at HERA

The construction of the hadronic final state resulting from a partonic scattering process can be viewed as factorising into the hard scattering process itself followed by partonic radiation and hadronization. For large energy scales, the running coupling constant is small and hard scattering cross sections can be calculated reliably using perturbative QCD. However, the hadronization process involves mass scales of the order of Λ_{QCD}. At these scales, the run-

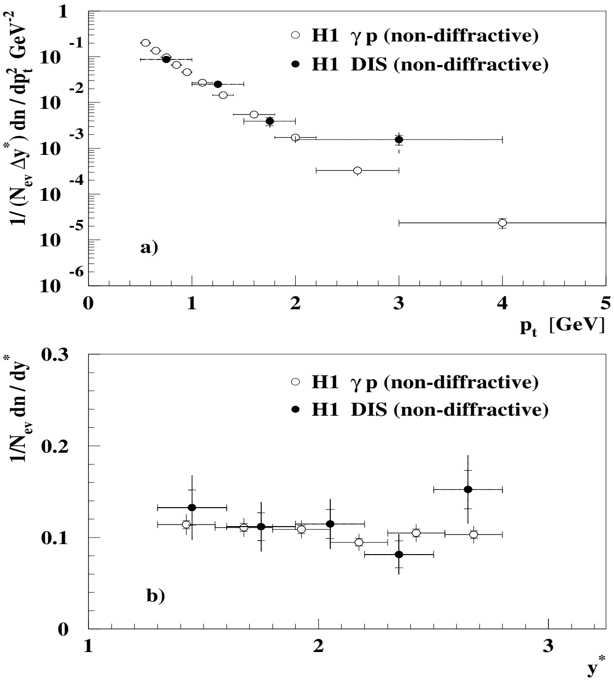

Figure 10: The inclusive K^0 distributions $(1/N)\mathrm{d}n/\mathrm{d}p_T^2\mathrm{d}y^*$ (a) and $(1/N)\mathrm{d}n/\mathrm{d}y^*$ (b) in the rapidity intervals $1.3 < y^* < 2.8$ in non-diffractive photoproduction and DIS.

ning coupling constant is large and the perturbative picture breaks down. The fragmentation of partons into hadrons must therefore be described by means of a phenomenological model. Recently, progress has been made in understanding this process within the framework of the Modified Leading Logarithmic Approximation (MLLA) complemented with the assumption of Local Parton Hadron Duality (LPHD).

Studies at HERA [31–34], using data taken in 1993 and 1994, have demonstrated that in ep interactions charged particle production in the current hemisphere of the Breit frame is very similar to a single hemisphere of an e^+e^- collision when Q, the magnitude of the four momentum transfer, is taken to be equivalent to the centre of mass energy, $\sqrt{s_{ee}}$ (figure 12).

These studies have focused on the energy dependence of the moments of the fragmentation function $D(\ln(1/x_p))$, where $x_p = 2p/Q$ is the fraction of the initial parton momentum ($Q/2$ in the Quark Parton Model) taken by the final state charged hadrons.

The improved statistics of the 1994 data have allowed the measurement of the fragmentation functions to be extended [35]. A study of the Q dependence of the inclusive charged particle distribution $(1/N)\mathrm{d}n^{+-}/\mathrm{d}x_p$ in intervals of x_p as shown in figure 11 shows a clear scaling violation. Due to the greater phase space available for QCD radiation at higher Q the rate in the lowest interval of x_p shows a strong rise of charged particle rate with Q with this rise becoming less pronounced as x_p increases until a small decrease is observed at the largest measured interval of x_p. Also shown are the predictions of the Leading Order QCD Monte Carlo DJANGO which give an adequate description of the DIS data. The observation of scaling violations in a single experiment should allow a measurement of the strong coupling constant at HERA. However, in order to yield a result whose error is competitive with the world average, more statistics are required.

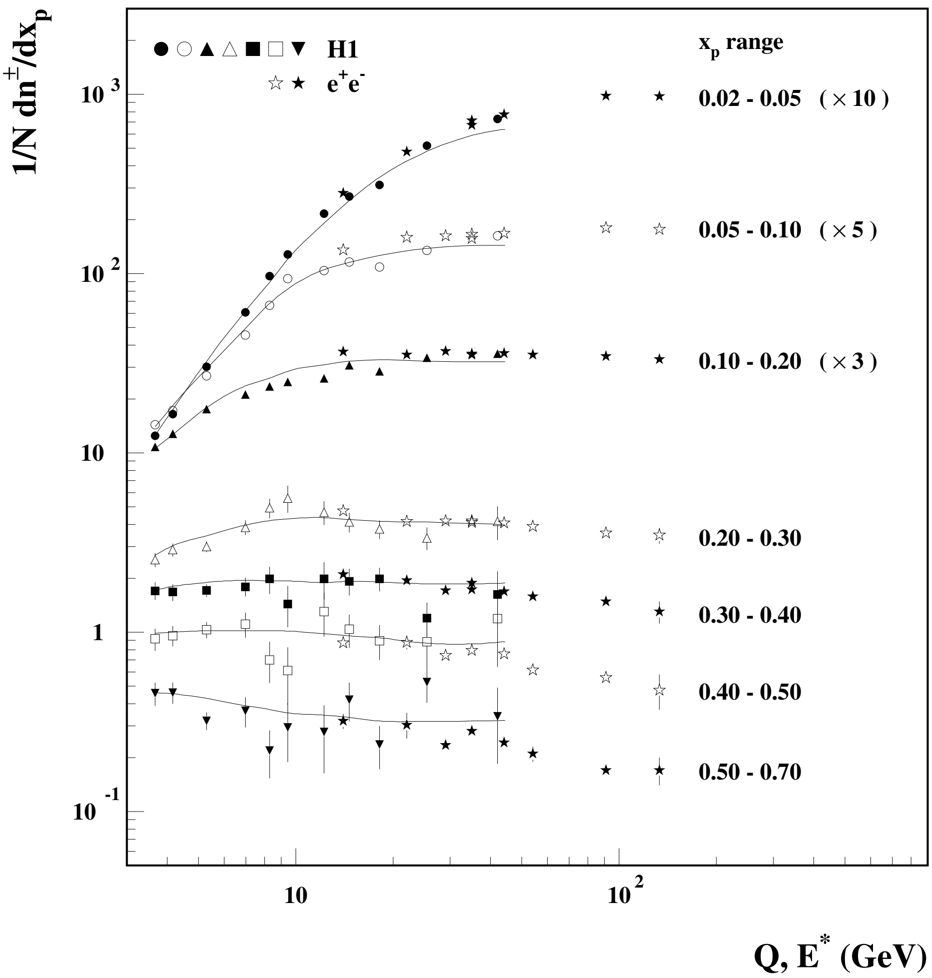

Figure 11: The inclusive charged particle distribution $(1/N)\mathrm{d}n^{+-}/\mathrm{d}x_p$, shown for different intervals of x_p as a function of Q and compared with e^+e^- data at equivalent centre-of-mass energies, E^*. The solid lines are the predictions of the DJANGO Monte Carlo.

The invariant energy spectrum $(E/N)\mathrm{d}n/\mathrm{d}^3p$ has been investigated for the first time in DIS [36]. Perturbative QCD based on the MLLA and LPHD predicts that the production rate of very low momentum particles should be approximately independent of the energy of the parent parton. Evidence for this scaling behaviour in which the distributions move toward a common limit as the particle energy become small $(E \to 0)$ can be seen in figure 13.

4.3 Bose-Einstein Correlations in DIS

An analysis has been performed of two-particle correlations in invariant mass for low Q^2 diffractive and non-diffractive DIS [39]. The observed enhancement of like-sign correlations at low invariant mass may be related to the dimensions of the hadronic source, r, as expected from Bose-Einstein interference in the production amplitudes for identical boson pairs. No difference between the data-samples was observed, with the non-diffractive data yielding $r = 0.54 \pm 0.03 \pm 0.03$ fm. The quantity r was found to increase with increasing particle density,

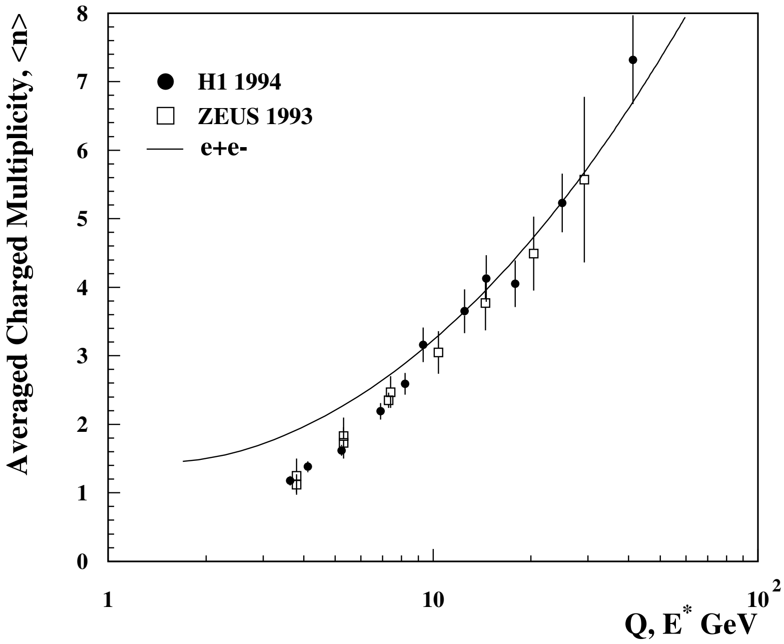

Figure 12: The average multiplicity of charged hadrons as a function of Q for the H1 and ZEUS experiments together with a representation (solid line) of the equivalent multiplicity from e^+e^- annihilations as a function of the centre of mass energy, E^*.

though systematic uncertainties reduce the significance. Nevertheless, the trend is consistent with that observed in hadron-hadron collisions. Figure 14 shows the dependence of r on $\langle \mathrm{d}n/\mathrm{d}\eta \rangle$ compared to hadron-hadron data at a centre of mass energy of 1.8 TeV [40](E735), and 630 GeV [41] (UA1).

5 Virtual Photon Structure at HERA

In leading order two processes contribute to the production of high transverse momentum (p_t) jets in photoproduction: "direct" processes, where the photon couples to a parton in the proton, and "resolved" processes, in which the photon fluctuates into a system of partons, one of which interacts with a parton from the proton. By studying such processes it is possible to extract the partonic content of a real photon at the scale at which the photon is probed (p_t^2) [37]. In contrast, it is usual to consider that the only contribution to jet production in deep inelastic scattering is from direct interactions with the partons in the proton probed by a structureless photon of virtuality Q^2. However, if high p_t jets are produced with p_t^2 much larger than Q^2, the jet production rate may be interpreted in terms of the partonic structure of the virtual photon. Parton densities within the virtual photon are expected to be suppressed with increasing Q^2 until direct processes dominate for $Q^2 \gtrsim p_t^2$.

The inclusive jet cross-section has been measured by H1 in the kinematic range $0.3 < y < 0.6$ and $0 < Q^2 < 49$ GeV^2 using data taken in 1994 and 1995 [38]. It was found that QCD inspired models which include only direct processes are unable to describe the data in the region where $p_t^2 >> Q^2$, where the structure in the virtual photon can be resolved. Models which include a resolved component of the photon suppressed with increasing Q^2 are in good agreement with the data. This can be seen in figure 15 which shows the inclusive $\gamma^* p$ jet cross section as a function of Q^2 in bins of jet transverse momentum, E_t, compared to a series of models which

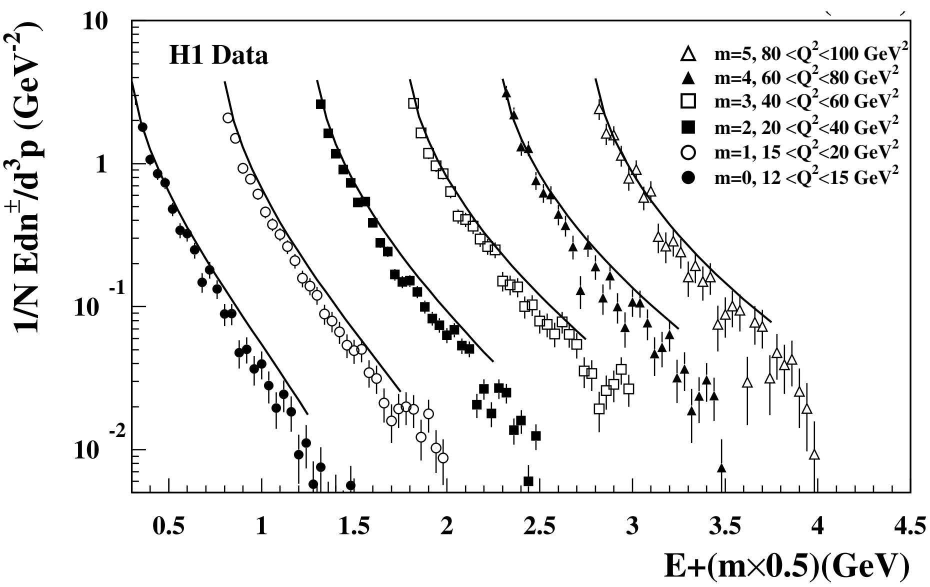

Figure 13: The invariant charged particle energy spectra at different momentum transfers, Q and plotted as a function of particle energy, E. For clarity the data at different Q^2 are plotted with a regular incremental spacing of 0.5 GeV on the abscissa. The solid lines are the predictions of MLLA + LPHD.

include a partonic structure of the virtual photon. In addition, it was found that many of the events at low Q^2 contain a photon remnant, as expected in resolved photon processes.

6 Production of Charm

The study of the production of charm quarks in positron-proton collisions provides the opportunity, in particular, to make precision tests of QCD and to determine the gluon content of the proton. Owing to the mass of charm quarks ($m_c \approx 1.5$ GeV), interactions in which they are produced are characterised by small transverse distances and so can be described using perturbative QCD calculations, even for small-angle scattering of the positron and for final states of small transverse momenta. In addition, the lack of charm in the proton results in particular production mechanisms: inelastic production of $c\bar{c}$ pairs by photon-gluon fusion, and diffractive production of $c\bar{c}$ vector mesons by pomeron exchange. In the former case, cross-sections are directly proportional the gluon density in the proton, in the latter case cross-sections are postulated to be proportional to the square of the gluon density in the proton.

Although charm is produced copiously at HERA, the total positron-proton cross-section is of the order of 1μb, the present tagging efficiencies at H1 are only around 10^{-4} so that presently studied data samples typically consist of a few hundred events. The charm tagging efficiencies of many future analyses will be substantially improved by use of the new central silicon tracker.

6.1 J/ψ Photoproduction

The largest cross section is for the elastic photoproduction of J/ψ ($\gamma p \to J/\psi p$). Measurements by H1 have now reached a precision where the W^2 dependence of the total cross section shows a clear rise with increasing W^2 in excess of that expected for soft diffractive processes [45]. The observation of a rise $\propto (W^2)^{\sim 0.3}$ demonstrates unambiguously that the $I\!P$ is harder in such

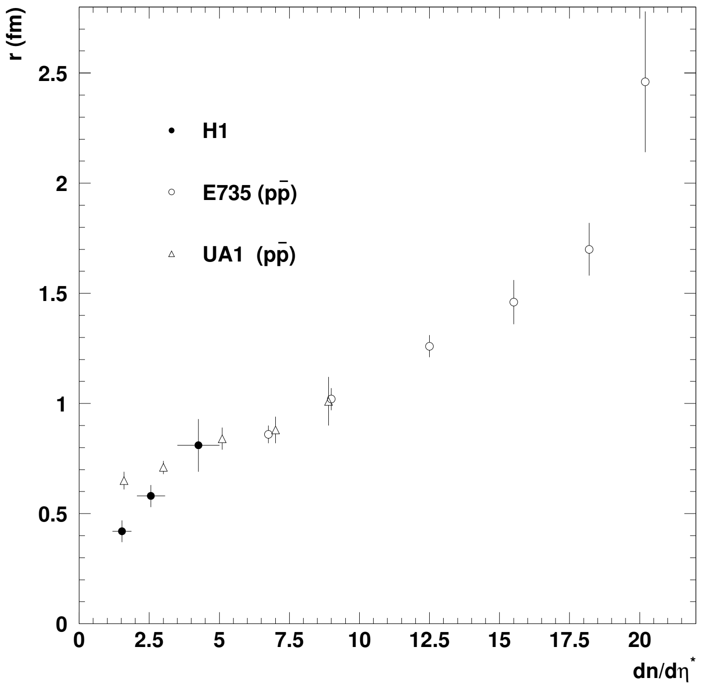

Figure 14: The radius parameter r versus charged particle density. The full circles are from this analysis, the open circles (triangles) are from $p\bar{p}$ collisions at a centre of mass energy of 1.8 TeV and 630 GeV.

heavy quark production than in inclusive real photoproduction processes (see section 3 above). The charm quark mass provides naturally a "hard scale", much as does Q^2 in inclusive virtual photon diffractive processes (section 3).

A further extension of the W^2 range of the J/ψ elastic photoproduction cross section to lower values is possible using the H1 Forward Muon Detector (FMD). Figure 16 shows mass distributions for elastic $\mu^+\mu^-$ events with tracks in both the H1 FTD and FMD. Clear J/Ψ signals are reconstructed in both detectors.

Below, two studies of charmonium production by UK physicists which have yielded results in the last year are introduced.

6.2 Vector Mesons with Large Momentum Transfer

It is possible to test perturbative QCD (pQCD) using vector meson production at HERA. Such a process involves the exchange of a 'hard' pomeron which can be described in terms of perturbative QCD as a gluon ladder. These calculations require the use of the BFKL evolution equations and are only reliable when $|t|$ (the square of the 4–momentum transfer) is large. QCD calculations for vector meson production with proton dissociation using this 'hard' pQCD pomeron have already been made [42, 43]. The only free parameter in these calculations is the value of the strong coupling constant, α_s, but once this is fixed the model can predict the cross-section and also the t and $W_{\gamma p}$ dependence. This model is applicable for all vector mesons but is restricted to the region of $|t| > 1\,\mathrm{GeV}^2$.

Analysis of the H1 data for vector meson production at large $|t|$ has consisted, so far, of looking at J/ψ production [44]. The J/ψ is tagged using its decay to two muons and events where the proton dissociates are identified by requiring activity in the forward detectors of H1.

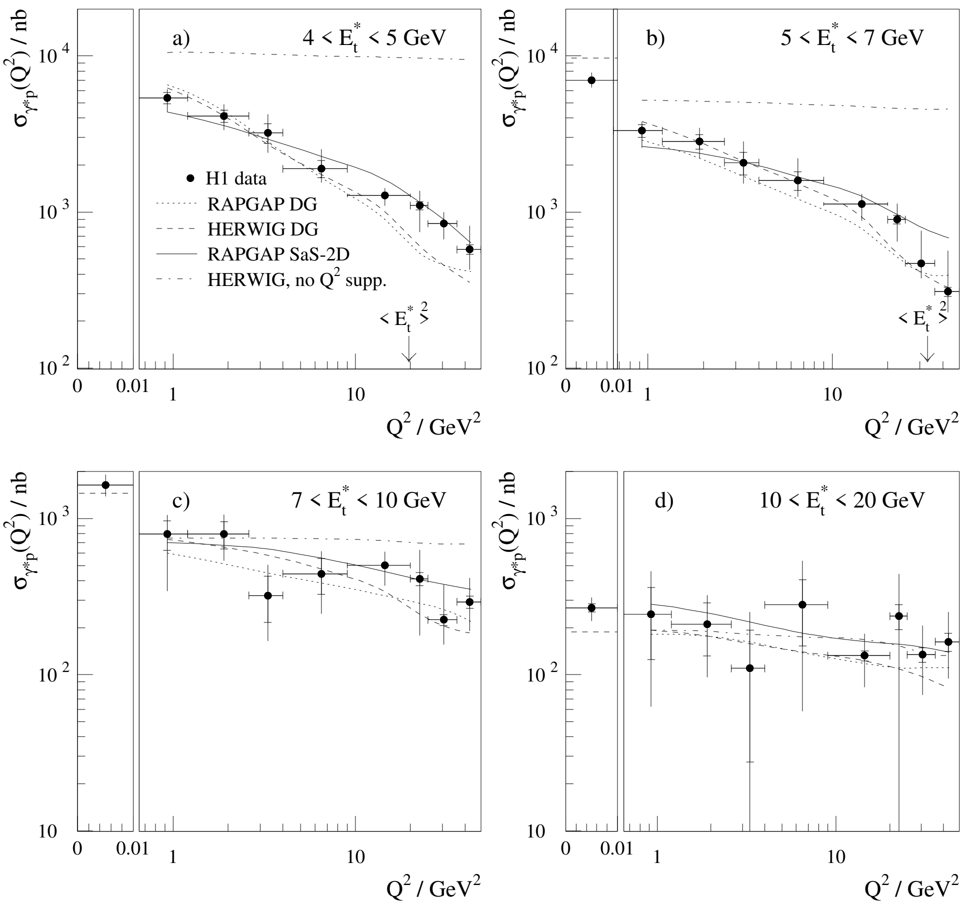

Figure 15: The inclusive $\gamma^* p$ jet cross-section $\sigma_{\gamma^* p}(Q^2)$. The data are compared to a series of models including a partonic structure of the virtual photon (dashed line, dotted line, solid line). The dotted-dashed line shows the predicted cross-section with no Q^2 dependence of the photon parton densities.

For the kinematic region $30 < W_{\gamma p} < 150\,\mathrm{GeV}$ and $|t| > 1\,\mathrm{GeV}^2$ the cross-section for J/ψ with proton dissociation has been measured to be $4.1 \pm 0.3|_{\mathrm{stat}} \pm 0.6|_{\mathrm{syst}}$ nb and this is used to extract a preferred value of α_s for the pQCD model. Additionally the differential cross-sections $\mathrm{d}\sigma/\mathrm{d}p_t^2$ and $\mathrm{d}\sigma/\mathrm{d}W_{\gamma p}$ have also been determined and are shown in figures 17(a) and 17(b) respectively. The pQCD model is found to give good agreement with the data which suggests that the 'hard' pomeron is well described by pQCD using BFKL formalism. The result will become even more significance once higher order corrections to the BFKL formalism are available, thus facilitating more precise comparison between data and theory.

6.3 Photo-production of $\psi(2S)$ Mesons

The charmonium state $\psi(2S)$ is identified via its decays to e^+e^- or $\mu^+\mu^-$, or to $J/\psi\pi^+\pi^-$ where the J/ψ subsequently decays to e^+e^- or $\mu^+\mu^-$. In figure 18(a) the di-lepton mass distribution is shown, with a fit which yields a signal of 50 ± 12 $\psi(2S)$ mesons. Additionally, 27 $\psi(2S)$ events

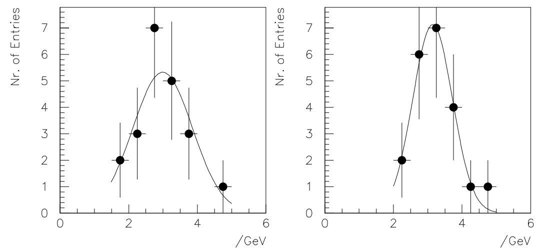

Figure 16: The $\mu^+\mu^-$ effective mass plots for quasi-elastic events with both muons traversing both the FTD and FMD. On the left the reconstructed mass from the FTD measurements and on the right from the FMD measurements

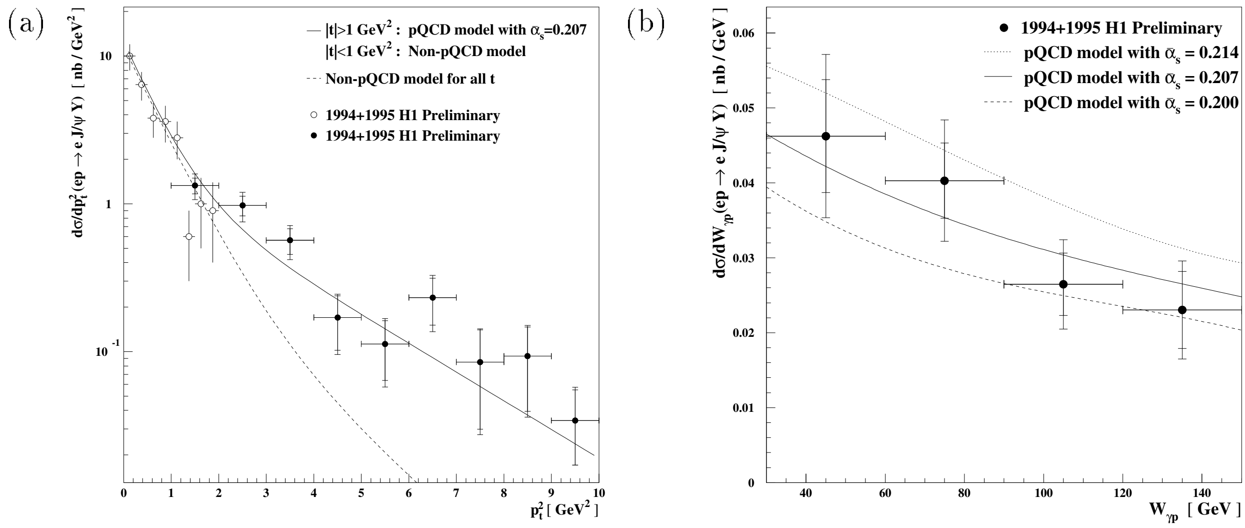

Figure 17: The differential cross-sections (a) $\mathrm{d}\sigma/\mathrm{d}p_t^2$ and (b) $\mathrm{d}\sigma/\mathrm{d}W_{\gamma p}$ for J/ψ production with proton dissociation. A pQCD model using BFKL formalism is found to give good agreement with the H1 data.

with negligible background are identified by the decays via J/ψ. The quasi-elastic ($z > 0.95$, where the elasticity $z \equiv E_{\psi(2S)}/E_\gamma$ in the proton rest frame) photo-production cross-section for $\psi(2S)$ at a photon-proton centre-of-mass energy of 80 GeV is measured to be [52]

$$\sigma\left[\gamma p \to \psi(2S)Y\right] = [17.9 \pm 2.8(\mathrm{stat}) \pm 2.7(\mathrm{syst}) \pm 1.4(\mathrm{BR})]\ \mathrm{nb},$$

where BR denotes the uncertainty due to the branching ratios. The ratio of the $\psi(2S)$ with respect to the J/ψ cross-section is

$$\frac{\sigma\left[\gamma p \to \psi(2S)Y\right]}{\sigma\left[\gamma p \to J/\psi Y\right]} = 0.150 \pm 0.027(\mathrm{stat}) \pm 0.018(\mathrm{syst}) \pm 0.011(\mathrm{BR}).$$

In figure 18(b) this ratio is shown together with results from fixed target experiments at lower photon-proton centre-of-mass energies, W. It is evident that the ratio is not strongly dependent on W; the $\psi(2S)$ cross-section rises steeply with W as has already been observed by the H1 collaboration to be the case for J/ψ [53].

In a model of elastic charmonium production which considers the $c\bar{c}$ quark pair as a colour dipole which interacts with the proton via two-gluon exchange, a predicted ratio of 0.17 is obtained [54], in good agreement with the experimentally measured value above. According to this model, charmonium production cross-sections are sensitive to the radial wave-functions of the charmonium states. The node in the $2S$ wave-function results in a suppression of its production with respect to the $1S$ state J/ψ. The confirmation of this suppression by the H1

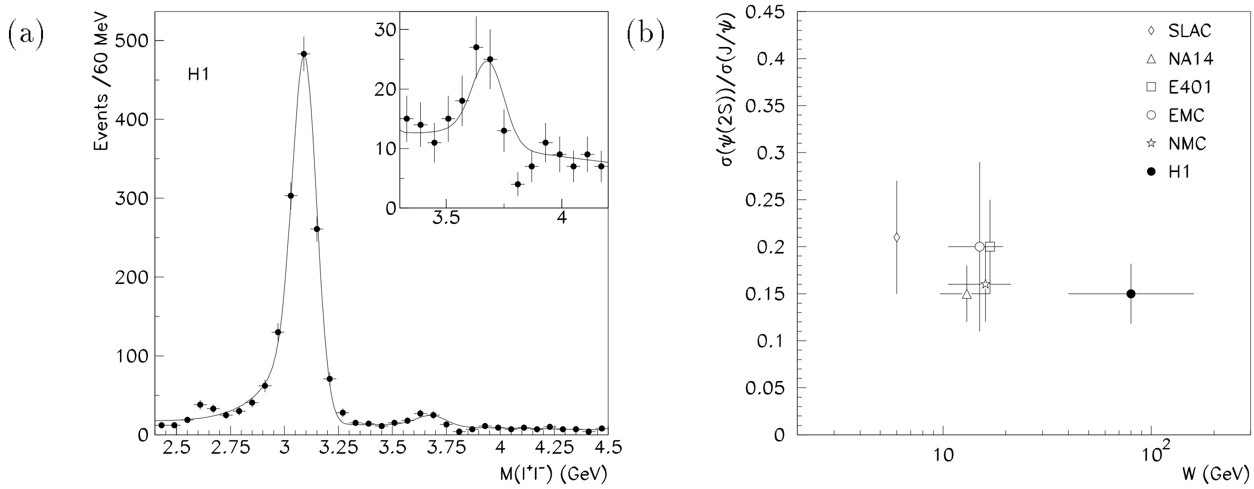

Figure 18: (a) Invariant mass distribution for lepton (muon or electron) pairs, with a fit showing the resonances corresponding to the J/ψ meson and the $\psi(2S)$ meson (insert); (b) The ratio of the cross-sections for $\psi(2S)$ and J/ψ photo-production on nucleons as a function of photon-proton centre-of-mass energy, W. The results from the present analysis are shown together with those from earlier fixed target experiments [47–51]. The ratios from the fixed target experiments have been corrected using the latest decay branching ratios.

measurement provides an important insight into the mechanism of the elastic production of vector mesons at HERA.

6.4 Open Charm Production in Hard Diffraction

A very important measurement in heavy flavour production at HERA is the cross section for open charm production in deep–inelastic diffraction. If the interpretation of diffractive exchange (section 3) in terms of a large gluon exchange contribution is correct, then open charm production by virtual photon–gluon fusion is expected to be substantial.

In figure 19 is shown the distribution of the invariant mass combination $M(K^{\pm}\pi^{\mp}\pi^{\mp}_{slow}) - M(K^{\pm}\pi^{\mp})_{D^0}$ in which a clear enhancement is seen corresponding to inclusive production of $D^{*\mp}$ in deep–inelastic diffraction. The superimposed curve shows the expectation from a calculation in which the $D^{*\mp}$ production is attributed to virtual photon–gluon fusion and the partonic structure of diffractive exchange is taken from the measurements and QCD analysis of the diffractive structure function $F_2^{D(3)}$ (section 3).

The charm production cross section is extracted to be

$$\sigma(ep \to eD^{*+}XY) = 380^{+150}_{-120}\,(\mathrm{stat.})^{+140}_{-110}\,(\mathrm{syst.})\,\mathrm{pb}$$

for the kinematic range $10 \le Q^2 \le 100\,\mathrm{GeV}^2$, $0.06 \le y \le 0.6$, $x_{\mathbb{P}} < 0.05$, $M_Y < 1.6\,\mathrm{GeV}$, $\eta(D^*) < 1.25$, and $p_T(D^*) > 1.5\,\mathrm{GeV}$. It is in agreement with the gluon interpretation extracted from the QCD analysis of the diffractive structure function $F_2^{D(3)}$ (section 3), for which the value 200 pb is expected. In an interpretation in which diffractive exchange is taken to be flavour singlet quark–antiquark exchange, a value less than 10 pb is expected [46].

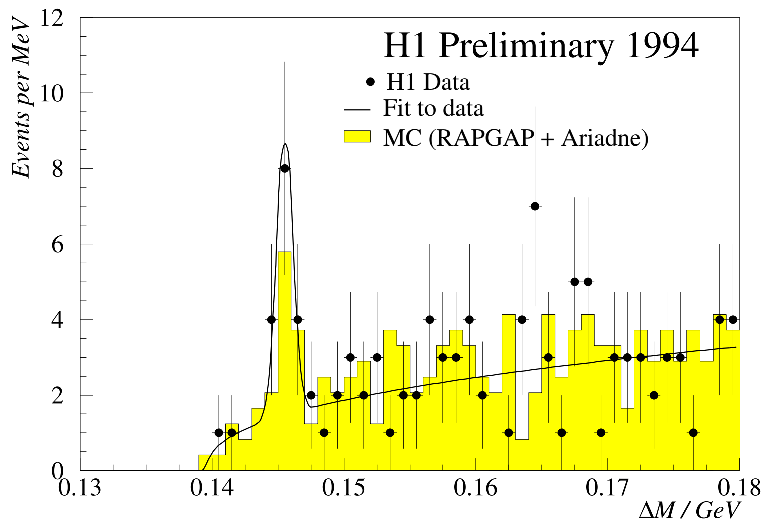

Figure 19: Spectrum of the invariant mass combination $M(K^{\pm}\pi^{\mp}\pi^{\mp}_{slow}) - M(K^{\pm}\pi^{\mp})_{D^0}$ in which a clear enhancement is seen corresponding to inclusive production of $D^{*\mp}$ in deep–inelastic diffraction.

7 Detector Developments

All the components described below remain the responsiblity of the UK groups. Each detector requires the continuous attention of dedicated physicists, either resident at DESY or from the UK remotely via computer link. UK groups have also been centrally involved in the design and commissioning of either the detector or readout electronics and software for all of these components.

7.1 Data Acquisition and Silicon Tracker Readout

During 1996 and 1997, the data acquisition and readout systems, for which RAL are responsible, continued to operate and perform reliably. These systems have been described extensively in previous annual reports. The VMEbus standard provides the architectural framework using fibre-optics to interconnect over 100 electronics crates containing the necessary analogue to digital componentry and several hundred microprocessing elements. Over the last two years, the introduction of the PCI standard has considerably enhanced the system potential which, together with the latest PowerPC technology, has resulted in ever more compact solutions performing at increased data throughput rates. The readout for the Central Silicon Tracker was designed, built and commissioned, with a full complement of system software, on schedule, in under a year and ready for the 1996 data taking.

7.2 Backward Calorimeter Timing (SPACAL)

Since installation and commissioning in 1995, the timing electronics has functioned reliably and well. UK physicists have also been involved in the design and testing of new trigger conditions for low Q^2 neutral current interactions in which the scattered electron enters the SPACAL. Despite the increase in the proton current and inevitable associated background, the good timing and the innovative use of the first, second and fourth level triggers have enabled special very low energy electron events to be triggered.

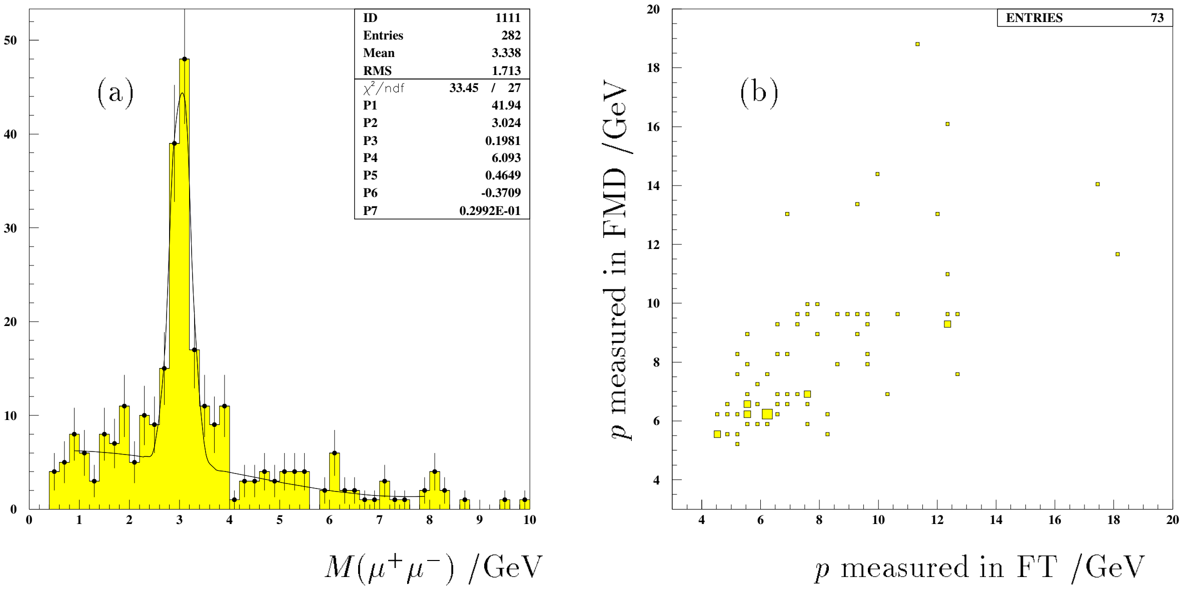

Figure 20: a) Di-muon mass distribution, where at least one of the muons is identified in the forward direction; b) momentum correlation between forward muon detector and forward track detector for $J/\psi \rightarrow \mu^+\mu^-$ candidates.

7.3 Forward Track Detector

Throughout 1996 and 1997 the FTD has functioned reliably. A new readout system for the Forward and Central Track Detectors and the Forward Muon Detector which enabled the hit finding algorithm to be performed on–line was fully commissioned in 1996. As a consequence the H1 data taking purity has been improved, by reducing the online processing time.

A proposal to upgrade the FTD to take advantage of the new physics opportunities presented by the imminent luminosity upgrade of the HERA collider is presented in a supplementary document.

7.4 Forward Muon Detector and Trigger

The forward muon detector (FMD) comprises three double layers of drift chambers on either side of a 1.8 Tm iron toroid magnet, and serves to identify and measure the momentum of muons with momentum greater than about 5 GeV and with polar angle between about 4 and 17^o with respect to the incoming proton direction. Associated with it is the forward muon trigger (FMT) which uses signals from the FMD and is able to find muon tracks at the first level trigger stage (L1). Improvements in the programming of the trigger processors of the FMT for 1995 resulted in an improvement in the efficiency for tracks found in the FMD of 80%.

It has also been found possible to use the FMD and FMT to identify events in which there is a rapidity gap adjacent to the proton by rejecting events in which activity is found in the detector resulting from the dissociation of the proton. In particular, the FMT has been configured to recognise such proton dissociation events at L1.

Both detector and trigger were designed and built in the UK and the maintenance, operation and monitoring are provided by UK physicists resident at DESY. Operation has been stable 1996 and 1997, and with the increased integrated luminosity collected during this period it has been possible to study J/ψ meson production using events triggered by the FMT in which muons are identified in the FMD. Here, the FMD is used in partnership with the FTD which provides the link to the primary event vertex and a complementary momentum measurement (figure 20). The ability to study J/ψ mesons, where the decay muons are found in the forward region of H1, is important because it gives access to the low W range of phase space. This study is also valuable for all physics analyses in which tracks are present in the FTD and FMD, not just those at low W.

7.5 Distributed Processing

During the period from January to April 1997 a third of the H1 data (1.3T Byte in total) were reprocessed using the central computing facilities at RAL and the results exported back to DESY. This operation considerably reduced delays in the release of many H1 analyses based on the latest data.

Throught the period 1996 to 1997 the Centipede system for Monte Carlo processing has continued to run extremely sucessfully. The system has been in operation in the UK since 1995, making use of the central bact systems at RAL and spare computing capacity in the Universities, such as workstations out of office hours. Since May 1997 the system has averaged 0.7 million Monte Carlo events per month in the UK alone, peaking at over 1.3 million events in October. It has also been installed on the H1 workgroup servers at DESY and is in the process of being installed in Marseille.

8 Requests to the Particle Physics Experiments Selection Panel

8.1 Continuation of the H1 Physics Program

This document has outlined the rich, productive and diverse range of ep physics being studied by UK physicists working on the H1 experiment at DESY. We request continuing PPARC support for this program in the form of adequate funds for Travel and Subsistence, and for the Maintenance and Operation of UK built detector components. Based on the experience of the funding made available in FYs 96-98, in which commuting to DESY had to be cut by 30% and a number of initiatives were either delayed or postponed for purely financial reasons, we request an increase in real terms of 30% on present funding.

The future of ep physics at HERA with H1 is laid out in the paper "ep Physics beyond 1999" [55] where it is clearly stated that the physics program will extend to at least 2005 and that HERA will be upgraded to provide 5 times the present luminosity. In order to continue and to extend the present physics program, by taking full advantage of this HERA upgrade, we also make a "Proposal to Upgrade the H1 Forward Track Detector" for which we request funding as detailed in the accompanying document.

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2. "A Measurement and QCD Analysis of the Proton Structure Function $F2(x, Q2)$ at HERA", DESY-96-39, Nucl.Phys. **B470** (1996) 3.

3. "Measurement of the Q^2 dependence of the Charged and Neutral Current Cross Sections in *ep* Scattering at HERA", DESY-96-46, Phys.Lett. **B379** (1996) 319.

4. "Photoproduction of D^* Mesons in Electron-Proton Collisions at HERA", DESY-96-55, Nucl. Phys. **B472** (1996) 32.

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11. "Inclusive D^0 and $D^{+/-}$ Production in Deep-Inelastic ep Scattering at HERA", DESY-96-138, Z. Phys. C72(1996) 593.

12. "Charged Particle Multiplicities in Deep-Inelastic Scattering at HERA", DESY-96-160, Z. Phys. C72(1996) 573.

13. "Search for Excited Fermions with the H1 Detector", DESY-96-163, Nucl. Phys. B483 (1997) 44.

14. "Measurement of Charged Particle Transverse Momentum Spectra in Deep Inelastic Scattering", DESY-96-215, Nucl. Phys. B485 (1997) 3.

15. "Scale Influence on the Energy Dependence of Photon-Proton Cross Sections", DESY-96-22, Phys. Lett. B392 (1997) 234.

16. "Determination of the Longitudinal Proton Structure Function $F_L(x, Q^2)$ at Low x", DESY-96-236, Phys. Lett. 393B (1997) 452.

17. "Diffractive Dissociation in Photoproduction at HERA", DESY-97-009, Z. Phys. C74 (1997) 221.

18. "Observation of Events at Very High Q^2 in ep Collisions at HERA", DESY-97-024, Z. Phys. C74 (1997) 191.

19. "A Measurement of the Proton Structure Function $F_2(x, Q^2)$ at low x and low Q^2 at HERA", DESY-97-042, Nucl. Phys. B497 (1997) 3.

20. "Bose-Einstein Correlations in Deep Inelastic ep Scattering at HERA", DESY-97-075, Z. Phys. C75 (1997) 437.

21. "Proton Dissociative ρ and Elastic ϕ Electroproduction at HERA", DESY-97-082, Z. Phys. C75 (1997) 607.

22. "Photoproduction of K^0 and Λ at HERA and a Comparison with Deep Inelastic Scattering", DESY-97-095, Z. Phys. C76 (1997) 213.

23. "Measurement of Event Shape Variables in Deep Inelastic ep Scattering", DESY-97-098, Phys. Lett. B406 (1997) 256.

24. "Evolution of ep Fragmentation and Multiplicity Distributions in the Breit Frame", DESY-97-108, Nucl. Phys. B504 (1997) 3.

25. "Inclusive Measurement of Diffractive Deep-Inelastic ep Scattering", DESY-97-158, accepted for publication in Z. Phys. C.

26. "Measurement of the Inclusive Di-Jet Cross Section in Photoproduction and Determination of an Effective Parton Distribution in the Photon", DESY-97-164, submitted to Z. Phys. C.

27. "Low Q^2 Jet Production at HERA and Virtual Photon Structure", DESY-97-179, submitted to Phys. Lett. B.

28. "Thrust Jet Analysis of Deep-Inelastic Large-Rapidity-Gap Events", DESY-97-210, submitted to Z. Phys. C.

29. "The H1 silicon tracker data acquisition system", W.J.Haynes et al., Accepted for publication in Nucl. Instr. and Methods A. Ref. NIMA-11663.

30. "Photo-production of $\psi(2S)$ Mesons at HERA", DESY-97-228,submitted to Phys. Lett. B.

Theses: 3/96 to 3/98

All Ph. D theses which are concerned with ep physics at H1 and which have been submitted in the period March 1996 to March 1998 are listed below.

1. D Kant, "A Study of the Fragmentation of Quarks in $e-p$ Collisions at HERA using the H1 Detector", PhD, University of London, March 1996 and RAL-TH-96-008 (March 1996).

2. D Milstead, "The Production of Neutral Strange Particles in Deep–Inelastic scattering events at HERA and a Search for Instantons", PhD, University of Liverpool, July 1996.

3. J. Lomas, "High Q2 diffractive physics at HERA", Ph. D thesis, University of Manchester, December 1996.

4. T. Nicholls, "A Measurement of the Diffractive Proton Structure Function at HERA", Ph. D thesis, University of Birmingham, April 1997, RAL-TH–97–013.

5. V. Hudgson, "Measurement of the Cross section for the Quasi-elastic Photoproduction of $\psi(2S)$ at HERA", Ph. D thesis, University of Birmingham, April 1997.

6. E. Rizvi, "Bose-Einstein Correlations in Diffractive and Non-diffractive Deep Inelastic Scattering at HERA.", Ph. D thesis, University of London, June 1997.

7. B. Waugh, "Charm production in diffractive deep inelastic scattering at HERA", University of Manchester, June 1997.

8. P. Dixon, "A study of the Fragmentation of Quarks in ep Collisions at HERA", Ph. D thesis, University of Lancaster, July 1997.

9. C. Cormack, "Measurements of hadron production in Deep Inelastic Diffractive Scattering", Ph. D thesis, University of Liverpool, September 1997.

H1 Conference Presentations: 3/96 to 3/98

Conference presentations (from March 1996) by members of the H1–UK groups which are concerned with all aspects of H1 physics and operation are listed below. They include "write-ups" of talks before March 1996 which were published since March 1996.

1. J P Phillips, "Diffraction in Deep–Inelastic Scattering at H1", in Proc. 6th Recontre de Blois, Château de Blois, 1994, ed J-F Mathiot and J Trân Thanh Vân, Edition Frontiere, **ISBN 2-86332-179-X**.
2. J B Dainton, "Deep–Inelastic Physics at the HERA Collider with the H1 Experiment", in Proc. of Colloque sur les Interactions Profondement Inelastiques, Paris, 1995, p. 37, ed. J-F Laporte et Y Sirois, Ecole Polytechnique, **ISBN 2-7302-0341-4**.
3. J P Phillips, "Rapidity Gap Events at HERA and the Structure of the Pomeron", in Proc. of Colloque sur les Interactions Profondement Inelastiques, Paris, 1995, p. 359, ed. J-F Laporte et Y Sirois, Ecole Polytechnique, **ISBN 2-7302-0341-4**.
4. D Kant, "The Fragmentation of Quarks in DIS and Strangeness in Photoproduction in ep Collisions at HERA", in Proc. Photon95, Sheffield, 1995, p. 153, ed. D J Miller, S L Cartwright, V Khoze, World Scientific, **ISBN 9810224737**.
5. A Mehta, "Comparison of Diffractive and Non–diffractive Deep–Inelastic Scattering", in Proc. Photon95, Sheffield, 1995, p. 313, ed. D J Miller, S L Cartwright, V Khoze, World Scientific, **ISBN 9810224737**.
6. T Greenshaw, "Pomeron Structure" in the Proc. of the 6th Int. Conf. on Hadron Spectroscopy, Manchester, July 1995, editors M.C. Birse, G.D.Lafferty and J.A McGovern, World Scientific, **ISBN 981-02-2468-0**.
7. S Burke "First Measurement of $F_2^{D(3)}$ in Deep–Inelastic Scattering at HERA and its Relation to F_2", in Proc. International Europhysics Conference on High Energy Physics, Brussels, July 1995, p. 509, ed. J Lemonne, C Vander Velde, F Verbeure, World Scientific, **ISBN 981-02-2702-7**.
8. R Martin "A Comparison of Diffractive and Non–Diffractive Deep–Inelastic Scattering", in Proc. International Europhysics Conference on High Energy Physics, Brussels, July 1995, p. 560, ed. J Lemonne, C Vander Velde, F Verbeure, World Scientific, **ISBN 981-02-2702-7**.
9. S J Maxfield "Measuring the Structure of the Photon at HERA", Proc. of the XXVth International Symposium on Multiparticle Dynamics, Stara Lesna, Slovakia, 12-16th September 1995, p. 133, ed. D. Bruncko, L. Šándor and J. Urbán, World Scientific **ISBN 981-02-2478-8**.
10. G Thompson, "Hadronic Final States in Deep Inelastic Scattering", J. Phys. **G22** (1996) 759.
11. S J Maxfield, "Some Aspects of Photoproduction at HERA", J. Phys. **G22** (1996) 787.
12. J R Forshaw, H Abramowicz and J P Phillips, "Diffractive Physics at HERA: introduction", J. Phys. **G22** (1996) 907.

13. H Abramowicz and J B Dainton, "On the energy dependence of the deep–inelastic diffractive cross section", J. Phys. **G22** (1996) 911.

14. K Golec–Biernat and J P Phillips, "QCD: Quantum Chromodynamic Diffraction", J. Phys. **G22** (1996) 911..

15. W von Schlippe, "Recent Results from the H1 Experiment at HERA", invited talk at the 30th Winter School of the St.Petersburg Nuclear Physics Institute, January 1996.

16. A Mehta, "Deep–Inelastic Diffraction", in Proc. of Topical Conference on Hard Diffractive Processes, February 18-23 1996, Eilat, Israel, p. 710, ed. A Levy, Tel Aviv University.

17. T Greenshaw "QCD at HERA", invited talk at the Institute of Physics Conference, Imperial College of Science, Technology and Medicine, London, 10-12th April 1996.

18. V Hudgson, "Measurement of the $\psi(2S)$ Photoproduction Cross section at HERA", Institute of Physics Conference, Imperial College of Science, Technology and Medicine, London, 10-12th April 1996.

19. T R Ebert, "Jets at Low Q^2 and Virtual Photon Structure", invited talk at the International Workshop on Deep-Inelastic Scattering and Related Phenomena, Rome, Italy, April 1996, to be published in the proceedings.

20. S J Maxfield "Summary of Working Group 2: Photoproduction", invited plenary talk at the International Workshop on Deep Inelastic Scattering and Related Phenomena", Roma, Italy, 15-19 April 1996, to be published in the proceedings.

21. P Newman, "Inclusive Measurements of Diffraction in Deep-Inelastic Scattering and Photoproduction at HERA", invited talk at the International Workshop on Deep-Inelastic Scattering and Related Phenomena, Rome, Italy, April 1996, DESY **96-162**, to be published in the proceedings.

22. C Cormack, "Energy Flow and Thrust Jets In Diffractive DIS", Meeting on Low-x Physics, June 1996, Durham.

23. J P Phillips, "Hard Diffraction", invited talk at the parallel session "Low-x and Soft Physics", International Conference on High Energy Physics ICHEP'96, Warsaw, Poland.

24. C Hilton, "Production of Charm at HERA", invited talk at the parallel session "Heavy Flavour Physics", International Conference on High Energy Physics ICHEP'96, Warsaw, Poland.

25. G Thompson, "An Introduction to HERA Physics", invited talk at the XVI International Symposium on Multiparticle Dynamics, Faro, Portugal, September 1996, to be published in proceedings.

26. P Biddulph, "Hard diffraction in H1", invited talk at the Workshop on Low-x Physics and Related Phenomena, Argonne National Laboratory, Illinois, September 1996.

27. M Gibbs, T Greenshaw, D Milstead, A Ringwald, F Schrempp, "Search Strategies for Instanton–induced processes at HERA", in Proc. of the Workshop on Future Physics at HERA, p. 509, ed. G Ingelman, A De Roeck, R Klanner, DESY.

28. H Abramowicz, T Doeker, L Ianotti, S Kananov, A Levy, L West, "Future Aspects of vector Meson Production at HERA", in Proc. of the Workshop on Future Physics at HERA, p. 509, ed. G Ingelman, A De Roeck, R Klanner, DESY.

29. A Mehta, J P Phillips, B Waugh, "Future Diffractive Structure Function Measurements at HERA", in Proc. of the Workshop on Future Physics at HERA, p. 704, ed. G Ingelman, A De Roeck, R Klanner, DESY.

30. L West, "Hard Diffraction at HERA", invited talk at the XI Topical Workshop on Proton-Antiproton Collider Physics, Abano (Padova), Italy, May 1996, to be published in proceedings.

31. C. Hilton, "Production of Charm at HERA", in Proc. 28th International Conference on High Energy Physics, Warsaw, July 1996, p.930, ed. Z Ajduk, A K Wroblewski, World Scientific ISBN 981-02-3985-8.

32. J.P. Phillips, "Diffractive Hard Interactions in Electron Proton Collisions", in Proc. 28th International Conference on High Energy Physics, Warsaw, July 1996, p.623, ed. Z Ajduk, A K Wroblewski, World Scientific ISBN 981-02-3985-8.

33. P. Newman, "Inclusive Measurements of Diffraction in Deep-Inelastic Scattering and Photoproduction", in Proc. 4 International Workshop on Deep-Inelastic Scattering and Related Phenomena, Rome, April 1996, p.331, ed. G. D'Agostini, Negro, World Scientific.

34. J.B. Dainton, "Low x physics at HERA", Aspen Winter Conference on Particle Physics, Aspen, January 1997

35. L West, "Heavy Quark Production at HERA", invited talk at the XXXII Rencontres de Moriond: QCD and High Energy Hadronic Interactions, Les Arcs, March 1997.

36. J.P. Sutton, "Vector Meson Production", invited talk at the XXXII Rencontres de Moriond: QCD and High Energy Hadronic Interactions, Les Arcs, March 1997.

37. J.B. Dainton, "Latest Experimental Results from H1", invited talk at IOP conference of Particle Physics and the Early Universe, April 1997.

38. T. Ebert, "Low Q^2 Jet Production and Virtual Photon Structure at HERA", talk given at IOP conference of Particle Physics and the Early Universe, April 1997.

39. C. Cormack, " Energy Flow and the Structure of the Pomeron in Deep-Inelastic Scattering at HERA", talk given at IOP conference of Particle Physics and the Early Universe, April 1997.

40. A. Mehta, "Measurement of the Diffractive Structure Function at HERA", talk given at IOP conference of Particle Physics and the Early Universe, April 1997.

41. M. Anderson, "Elastic J/ψ in Photoproduction at HERA", talk given at IOP conference of Particle Physics and the Early Universe, April 1997.

42. T. Holtom, "Charged Particle Transverse Momentum Spectra at H1", talk given at IOP conference of Particle Physics and the Early Universe, April 1997.

43. T. Ebert, "Inclusive Jet Production and Virtual Photon Structure", invited talk at Workshop on Deep Inelastic Scattering and QCD (DIS97), Chicago, April 1997.

44. P. Newman, "Diffractive Photoproduction in H1", invited talk at Workshop on Deep Inelastic Scattering and QCD DIS97, Chicago, April 1997.

45. P. Newman, "Colour Singlet Exchange in *ep* Interactions", invited talk at Workshop on Deep Inelastic Scattering and QCD (DIS97) Chicago, April, 1997.

46. C. Cormack, "Energy Flow, Thrust, Charm and the Structure of the Pomeron", invited talk at Workshop on Deep Inelastic Scattering and QCD (DIS97), Chicago, April 1997.

47. W.J. Haynes "Silicon Tracker Data Acquisition", in Proc. Sixth LeCroy Int. Conf. Electronics for Particle Physics, New York, May 1997, p25.

48. D. Milstead, "High p_t charged particles and strangeness photoproduction and comparison with DIS at HERA", invited talk at International Conference on the Structure and the Interactions of the Photon (PHOTON97), Egmond aan Zee, May 1997.

49. T. Ebert, "Results on Hard Diffraction from H1", invited talk at International Conference on the Structure and the Interactions of the Photon (PHOTON97), Egmond aan Zee, May 1997.

50. L. West, "Charm Production at HERA", invited talk at the UK HEP Heavy Flavour Forum, Abingdon, June 1997.

51. C. Cormack "Energy Flow, Event Shapes Charm and the structure of the Pomeron" invited talk given at the Madrid Workshop for Low-x Physics Madrid, June 1997.

52. C. Cormack "Non-diffractive and Diffractive Real and Virtual Photoproduction of Hadrons and Jets", invited talk given at the International Europhysics Conference on High Energy Physics (HEP 97), Jerusalem, August 1997.

53. A. Mehta "Diffractive Structure Function measurements", invited talk given at the International Europhysics Conference on High Energy Physics (HEP 97), Jerusalem, August 1997.

54. D. Kant, "QCD Studies in the Breit Frame at HERA", invited talk given at the XXVII International Symposium on Multiparticle Dynamics, Frascati, September 1997.

55. L. West, "Diffractive Heavy Flavour Production at HERA", invited talk at LAFEX Int. School on High Energy Physic, Rio de Janeiro, February 1998.

56. B. Cox, "Rapidity Gaps Between Di-jets at HERA", invited talk at LAFEX Int. School on High Energy Physic, Rio de Janeiro, February 1998.

H1 Conference Submissions: 3/96 to 3/98

The following papers were submitted by the H1 collaboration to the International Conference on High Energy Physics ICHEP'96, Warsaw, Poland.

1. "Elastic ρ' Electroproduction at High Q^2", pa01-088.

2. "A Measurement of the Production of $D^{*\pm}$ Mesons in Deep–InelasticDiffractive Interactions at HERA", pa02-060.

3. “A Measurement and QCD Analysis of the Diffractive Structure Function $F_2^{D(3)}$, pa02-061.
4. “Leading Neutron Production in Deep-Inelastic ep Scattering at HERA” pa02-063.
5. “Elastic Electroproduction of ϕ Mesons at large Q^2 at HERA”, pa02-064.
6. “Measurement at HERA of the Cross Section for the Electroproduction at large Q^2 of ρ Mesons with Proton Dissociation”, pa02-065.
7. “Elastic Electroproduction of ρ and J/ψ Mesons at large Q^2 at HERA”, pa02-066.
8. “The Mass Dependence of Inclusive Diffractive Photoproduction at HERA”, pa02-067.
9. “Thrust Jet Analysis of Deep–Inelastic Large Rapidity Gap Events at HERA”, pa02-068.
10. “A Determination of the Longitudinal Proton Structure Function $F_L(x, Q^2)$ at HERA”, pa02-069.
11. “A Measurement of the Proton Structure Function $F_2(x, Q^2)$ at low x and low Q^2 at HERA”, pa02-070.
12. “Multiplicity Distributions and Fragmentation functions in Deep-Inelastic ep Scattering in the Breit Frame of Reference”, pa02-072.
13. “Properties of Transverse Energy Production in Deep-Inelastic Scattering”, pa02-073.
14. “Strangeness Production in Deep-Inelastic Positron-Proton Scattering at HERA”, pa02-074.
15. “Charged Particle Multiplicities in Deep-Inelastic Scattering at HERA”, pa02-075.
16. “Measurement of Charged Particle Transverse Momentum Spectra in Deep-Inelastic Scattering at HERA”, pa02-076.
17. “Event Shape Variables in Deep-Inelastic Scattering”, pa02-077.
18. “Charged Current Differential Cross-sections for e^-p and e^+p interactions at very high Q^2, pa02-078.
19. “Scale Dependence of the Energy Behaviour of Photon-Proton Cross Sections”, pa02-079.
20. “Measurement of the Di-Jet Cross Section in γp Collisions at HERA and Extraction of the Effective Parton Distribution in the Photon”, pa02-080.
21. “Diffractive and Non-diffractive Photo-production of J/ψ at HERA”, pa02-085.
22. “Photo-production of ψ(2S) Mesons at HERA”, pa02-086.
23. “Photoproduction of D^* Mesons in ep Collisions at HERA”, pa02-088.
24. “Inclusive D^0 and $D^{*\pm}$ Production in Deep-Inelastic ep Scattering at HERA”, pa02-089.
25. “Polarisation Study of High Q^2 Elastic ρ Meson Production at HERA”, pa03-048.
26. “Forward Jet Production at HERA”, pa03-049.

27. "A Search for Squarks of R_p-violating SUSY at HERA", pa07-082.

28. "Search for Excited Fermions with the H1 Detector", pa07-083.

29. "A Search for Leptoquarks at HERA", pa07-084.

30. "A Search for Selectrons and Squarks at HERA", pa07-086.

31. "The H1 Forward Proton Spectrometer", pa17-025.

32. "Luminosity Measurement in the H1 Experiment at HERA", pa17-026.

The following papers were submitted by the H1 collaboration to the International Europhysics Conference on High Energy Physics (HEP 97), Jerusalem.

1. Abstract 242: "Elastic Production of J/ψ Mesons in Photoproduction and at High Q^2 at HERA."

2. Abstract 243: "Photo-production of ψ(2S) Mesons at HERA."

3. Abstract 244: "A New Method of Determining the Proton Gluon Density from Jet Rates in Deep-Inelastic Scattering."

4. Abstract 246: "Determination of α_S from Jet Rates in Deep–Inelastic Scattering."

5. Abstract 247: "Di-jet Rates in Deep-Inelastic Scattering at HERA."

6. Abstract 249: "Bose-Einstein Correlations in Deep–Inelastic *ep* Scattering at HERA."

7. Abstract 250: "Multiplicity Structure of Hadronic Final States in Diffractive Deep–Inelastic Scattering at HERA."

8. Abstract 251: "Evolution of *ep* Fragmentation and Multiplicity Distributions in the Breit Frame."

9. Abstract 253: "Measurement of Event Shape Variables in Deep Inelastic *ep* Scattering."

10. Abstract 255: "Forward π^0 Production at HERA."

11. Abstract 260: "A Measurement of the Inclusive Deep-Inelastic *ep* Scattering Cross Section at Low Q^2 at HERA."

12. Abstract 262: "A Measurement of the Proton Structure Function $F_2(x, Q^2)$ at High Q^2 at HERA."

13. Abstract 263: "Measurements of the Differential Neutral and Charged Current Cross Sections at HERA."

14. Abstract 265: "Measurement of Isolated Photons with High Transverse Energy in Photoproduction at HERA."

15. Abstract 269: "Photoproduction of K^0 and Λ at HERA and a Comparison with Deep–Inelastic Scattering."

16. Abstract 270: "Gluon Density in the Photon Extracted Using High pT Charged Particles in Photoproduction at HERA."

17. Abstract 273: "Low-Q^2 Jet Production and Virtual Photon Structure at HERA."
18. Abstract 274: "Production of J/ψ Mesons with large $|t|$ at HERA."
19. Abstract 275: "Determination of the Gluon Density in the Proton from Deep Inelastic ep Charm Production using NLO QCD."
20. Abstract 276: "Photoproduction of D^* Mesons in ep Collisions at HERA."
21. Abstract 280: "The Evolution of Inclusive Charged Particle Spectra with Q^2 in ep Interactions at HERA."
22. Abstract 377: "A Measurement of the Diffractive Structure Function $F_2^{D(3)}$ for Q^2 between 1 and 65 GeV^2."
23. Abstract 378: "Leading Neutron Production in Deep–Inelastic Scattering at HERA."
24. Abstract 379: "Measurement of Leading Proton Production in Deep–Inelastic Scattering at HERA."
25. Abstract 380: "Rapidity Gaps between Jets in Photoproduction at HERA."
26. Abstract 381: "Elastic Electroproduction of ρ and ϕ Mesons at Intermediate Q^2 at HERA."
27. Abstract 382: "Resonances in Multi–Photon Final States in Positron–Proton Scattering at HERA."
28. Abstract 708: "Observation of Events with a High Energy Isolated Lepton and Missing Transverse Momentum at HERA."
29. "Measurement of the Diffractive Structure Function at Low Q^2."
30. "Flux Factor Factorisation Breaking in p_t^{thrust} in Diffractive Deep-inelastic ep Scattering."

9 H1–UK Manpower: 3/96 to 3/98

Manpower which has contributed to the on–going H1 physics programme is listed below for each H1–UK institute.

1. **University of Birmingham**
   J. Dowell, J. Garvey, K. Hewitt, V. Hudgson, I. Kenyon, P. Newman, T. Nicholls, P. Sutton, P. Thompson, L. West.
2. **University of Glasgow**
   I. O. Skillicorn
3. **University of Lancaster**
   S. Burke, A.B. Clegg, C. Davis, P. Dixon, R.C.W. Henderson, L. Johnson, D. Newton, T. Sloan.
4. **University of Liverpool**
   S. Cocks, C. Cormack, J.B. Dainton, T. McMahon (née Ebert), E. Gabathuler, T. Greenshaw, T. Holtom, S.J. Maxfield, S.J. McMahon, D. Milstead, J.M. Morton, G.D. Patel, J.P. Phillips, A. Burrage, M. Jones.

5. **University of Manchester**
M. Anderson, P. Biddulph, P. Bispham, D.P. Brown, J.M. Foster, C.D. Hilton, M. Ibbotson, J.W. Lomas, R. Marshall, D. Mercer, K. Stephens, B. Waugh.

6. **Queen Mary and Westfield College, University of London**
K.T. Donovan, E.F. Eisenhandler, R.K. Griffiths, P.I.P. Kalmus, D. Kant, M.J.P.I. Landon, B. Morgan, D. Newman–Coburn, E. Rizvi, W. von Schlippe, G. Thompson.

7. **CCRL Rutherford Appleton Laboratory**
D. Clarke, D.G. Cussans, J. Coughlan, W.J. Haynes, D.L. Hill, A. Mehta, J.V. Morris, D.P.C. Sankey.

10 H1–UK Physicists with General Responsibilities

The following have held positions of central responsibility for H1 during the period March 1996 to March 1998.

1. P. Biddulph (University of Manchester): H1 Technical Coordinator.
2. S. Burke (University of Lancaster): H1 FTD Software Convenor, H1 Reconstruction Coordinator (from 12/95).
3. D. Cussans (RAL): H1 Physics Monte Carlo Simulation Coordinator (to 12/96).
4. D. Clarke (RAL): H1 Forward Track Detector Coordinator.
5. J.B. Dainton (University of Liverpool): physics co–ordinator (to 8/97), Spokesman (from 8/97).
6. T. Greenshaw (University of Liverpool): co–convenor – H1 Physics Working Group "Flow and Spectra Group Phenomena", Project Co-ordinator for the $8m$ Tagger.
7. W.J. Haynes (RAL): H1 Central DAQ Coordinator.
8. C. Hilton (University of Manchester): convenor – H1 Forward Muon Detector (to 4/97), co–convenor "Heavy Flavour Group" (from 4/97).
9. D. Milstead (University of Liverpool): co-convenor – H1 Physics Working Group "Flow and Spectra Working Group".
10. D. Newton (University of Lancaster): Magnetic Field Map.
11. P. Newman (University of Birmingham): co–convenor – H1 Physics Working Group "Diffractive Phenomena" (from 8/97).
12. J.P. Phillips (University of Liverpool): Co–convenor – H1 Physics Working Group "Diffractive Phenomena" (to 8/97).
13. D. Sankey (RAL): H1 QT coordinator.
14. B. Waugh (University of Manchester): H1 Forward Muon Detector Coordinator (from 4/97).
15. L. West (University of Birmingham): H1 PHAN coordinator (from 11/97).

In addition to the above, UK physicists have taken their share of responsibilities as H1 Run Co-ordinators during data taking. H1–UK physicists are regularly asked to be collaboration referees for putative H1 publications concerned with the work of others. During the period of this report, J.B. Dainton, G. Thompson and T. Sloan have served as members of the H1 Executive Committee, elected, ex officio, or both.