Recent Results from HERA

Jörg Gayler*
DESY, Hamburg

May 26, 1998

Abstract

Results of the HERA experiments HERMES, H1 and ZEUS obtained in 1997 are presented. They cover recent measurements on the proton structure function F_2, the extraction of the gluon density, which is compared with open charm production, diffractive scattering and results on the proton spin structure. We further give an update on the NC events at very high Q^2 and report on an observation of events with an isolated lepton and missing p_t.

1 Introduction

This talk [1] covers a selection of results obtained in 1997 at the e^+p collider HERA by the experiments H1 and ZEUS in deep inelastic scattering (DIS) and photo-production and by the experiment HERMES on the scattering of polarized e^+ on polarized protons.

HERA is in a unique position to explore ep interactions, extending the range of momentum transfer Q^2 and of $1/x_{Bjorken}$ in DIS by about 2 orders of magnitude compared to previous fixed target experiments. This allows for detailed QCD analyses of hard scattering processes as well as for searches for unknown phenomena at the highest energies. On the other side HERA offers the opportunity to study in detail the transition into kinematic regions where perturbative methods fail and where the data can be described by phenomenological models only up to now. This is in particular the transition from DIS to photoproduction ($Q^2 \approx 0$), where the QCD based DGLAP evolution equations [1], which successfully describe the structure function F_2 in DIS are no longer applicable, but where phenomenological models based on Regge theory [2] allow to relate the energy dependence of $\sigma_{\gamma p}^{tot}$ to soft hadronic interactions.

Similarly, the observation of the hadronic final states allows on the one hand for tests of perturbative QCD (pQCD), e. g. the determination of the strong coupling constant α_s from multi-jet production, but also for the study of diffractive scattering which, in terms of Regge phenomenology, is dominated at the high HERA energies by pomeron exchange. HERA data help to understand the partonic structure of these t-channel exchange phenomena, and it is

*DESY, Notkestr.85, D-22603 Hamburg, electronic mail: joerg.gayler@desy.de
[1]Invited talk given at the workshop WHEPP-5, Pune, India, January 1998.

tempting to bridge to pQCD by analysing such data in terms of quark and gluon densities of the exchanged object [3].

The present talk covers only a part of the available new results. The results on the proton structure presented in section 2 include the latest F_2 measurements leading to a new determination of the gluon density in the proton, which then is compared directly with a determination of the gluon density from open charm production. The F_2 results at lowest Q^2 are compared with various phenomenological models. These results of H1 and ZEUS on proton structure functions are complemented by the measurements of HERMES on the nucleon spin structure. After a discussion of diffraction in DIS in section 3, the status of the observations of events at very high Q^2 is presented (section 4), followed by the observation of events which are characterized by an isolated lepton at high p_t and substantial missing momentum (section 5).

2 Proton Structure Functions

2.1 Structure function F2 and the gluon density

The measurement of proton structure functions has always been one of the main tasks of HERA since the start of data taking in 1992. It was observed in the previous years that the structure function F_2 rises at HERA energies strongly versus small Bjorken x, which can be interpreted as being due to an increasing gluon density. The data taken up to 1994 [4] had been shown to be consistent with pQCD, in particular with the DGLAP evolution equations. The new data taken in 1995 to 97 allow to extend the kinematic range and to test pQCD with improved precision.

The structure function F_2 is related to the measured differential cross section by:

$$\frac{d^2\sigma^{l^\pm N}}{dx dQ^2} = \frac{2\pi\alpha^2}{Q^4 x}\left[(1+(1-y)^2)F_2(x,Q^2) - y^2 F_L(x,Q^2) \mp (1-(1-y)^2)xF_3(x,Q^2)\right] \quad . \qquad (1)$$

Here Q^2 is the squared momentum transfer from the lepton l to the nucleon N, x is the Bjorken scaling variable, s the center of mass energy squared of the collision and y is the inelasticity given by $y = Q^2/xs$. For Q^2 well below the mass squared of the Z^0 boson, the parity violating structure function F_3 can be neglected. The contribution of the longitudinal structure function F_L gets only important at large y, typically $y \gtrsim 0.5$.

The new results on the structure function F_2 from the H1 and ZEUS Collaborations cover the range of momentum transfers $0.11 < Q^2 < 5000$ GeV^2. The data at the low Q^2 end can be compared to phenomenological models (see below). Both collaborations performed QCD analyses of their data in the range $1.5 < Q^2 < 5000$ GeV^2. Here parametrized parton distributions are assumed at some Q_0^2, the parameters of which are determined by fitting the DGLAP based evolution to the F_2-data at the available Q^2 values. The evolution equations are applied in next to leading order (NLO) for three light quark flavours adding the charm contribution as calculated in NLO from the boson gluon fusion process [5]. ZEUS used a starting scale of $Q_0^2 = 7$ GeV^2, H1 chose for the present analysis [6] $Q_0^2 = 1$ GeV^2. The valence quark densities at large x were constrained by including data from the muon scattering experiments NMC [7] (H1 and ZEUS fits) and BCDMS [8] (H1 fit only).

The gluon densities from these fits [6,9] are shown in Fig. 1 at $Q^2 = 20$ GeV^2. Both analyses, which agree very well, show a strong rise of the gluon density versus small x, however less steep than predicted by the GRV94-HO [10] parametrization, but in agreement with MRSR1 [11] and CTEQ4M [12].] The result of the NMC-experiment [13], which is limited to larger x, is shown for comparison.

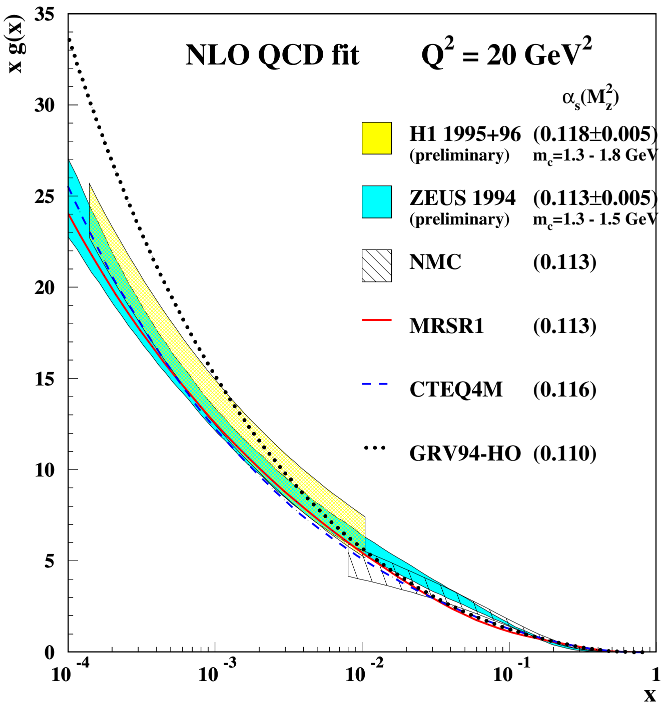

Figure 1: Gluon distributions at $Q^2 = 20$ GeV^2 from the HERA NLO QCD fits to structure function data. The error bands include the statistical and systematic errors. The gluon distribution from a QCD fit to NMC data is also shown at higher x. The MRSR1, CTEQ4M and GRV94-HO parameterizations are shown for comparison.

The above results on the gluon density in the proton are deduced from the scaling violations in inclusive ep scattering. Open charm production is related directly to this density via the boson gluon fusion process. Both H1 and ZEUS could show that the measured cross sections for open charm production are consistent with NLO calculations of charm production [14] using the gluon density in the proton as determined from the F_2 data.

An attempt by H1 to unfold the gluon density from open charm production led to the result [15] shown in Fig. 2. It shows agreement of the two entirely different methods, within the still substantial errors.

New data on F_2 at high Q^2 up to 5000 GeV^2 have recently been presented by the H1 Collaboration [16]. These results are remarkably well described by QCD expectation as demonstrated in Fig. 3, in which the data are compared with a QCD analysis as described above. For this comparison, however, only data with $Q^2 < 120$ GeV^2 are used as input to the QCD-fit.

Possible deviations at highest Q^2 values are discussed in section 4.

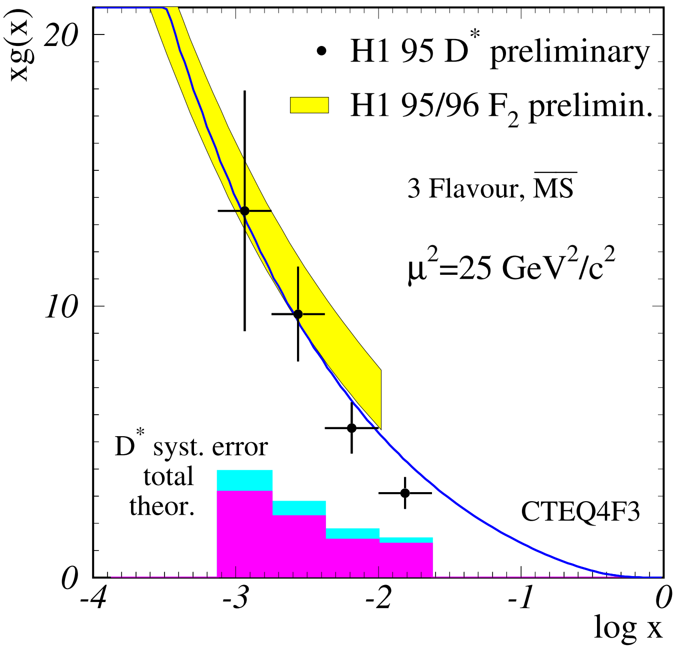

Figure 2: Gluon distribution determined from open charm production (theoretical and total systematical error as dark and shaded bands along abscissa), compared to the CTEQ4F3 parametrization and to the result of the H1 QCD analysis of inclusive F_2 data (light shaded band).

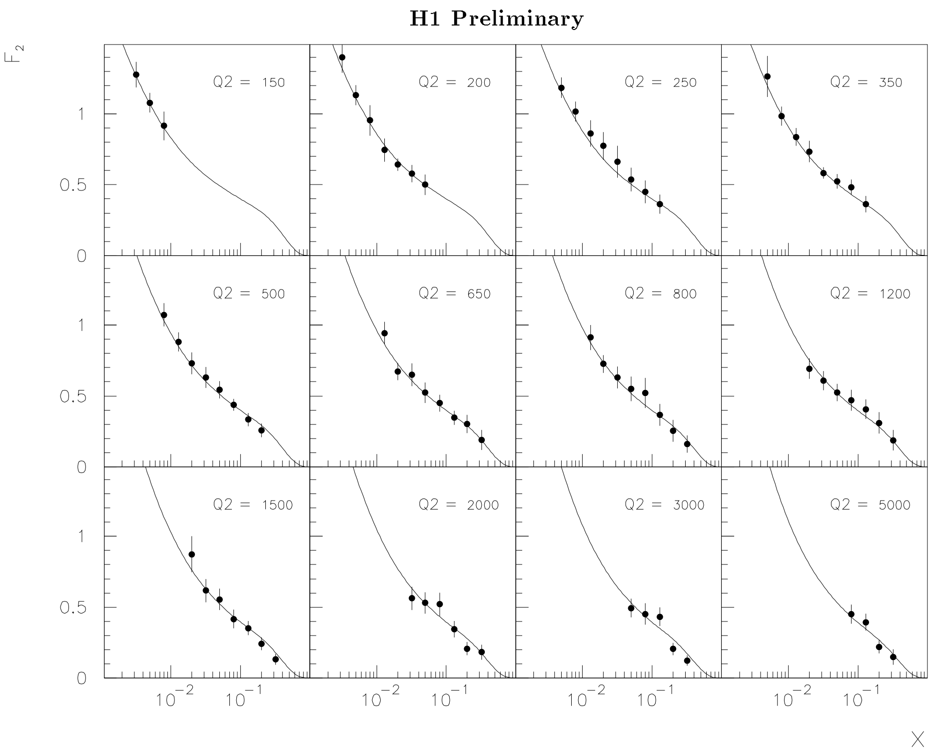

Figure 3: Preliminary results on F_2 from H1 in the range $Q^2 = 150$ to 5000 GeV^2. The curves represent the NLO QCD fit to the H1 data (1994 to 1996) at low Q^2 (≤ 120 GeV^2) and to NMC and BCDMS data.

At the other end, at lowest Q^2, improved detectors and a special run in 1995 with a shifted position of the beam interaction point allowed for measurements with very small e^+- scattering angles, and therefore for detailed studies of the transition to photo-production ($Q^2 = 0$). The results of H1 [17] and ZEUS [18] together with those of the muon scattering experiment E665 [19] are compared in Fig. 4 with various phenomenological models.

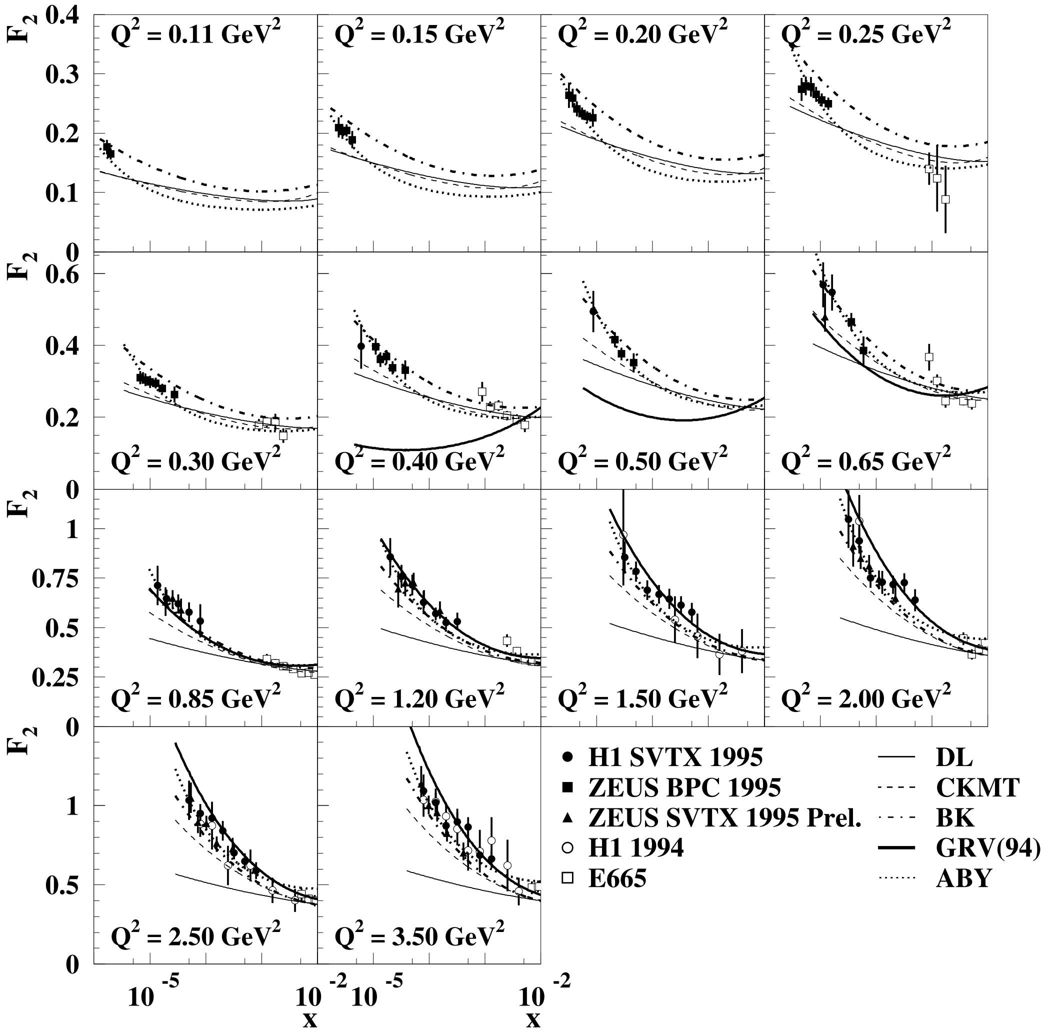

Figure 4: F_2 from H1 and ZEUS at low x in the range $Q^2 = 0.11$ to 3.5 GeV^2 together with fixed target results from E665 and model calculations.

The pQCD approach of GRV [10] describes the data reasonably well for $Q^2 \geq 0.85$ GeV^2. It assumes valence like parton distributions at a very low starting scale of $Q_0^2 = 0.34$ GeV^2 which then are successfully evolved to higher Q^2. It is obvious from Fig. 4, that the assumed parton distributions do not describe the data at low $Q^2 \approx Q_0^2$.

Transcribing the Regge phenomenology of soft hadronic interactions (soft pomeron approach of Donnachie and Landshoff [20]) fails to reproduce the strong rise versus small x with increasing Q^2. This can be improved by allowing the pomeron intercept to increase with Q^2 (CKMT parametrization [21]). Further models which combine Generalized Vector Meson Dominance (GVMD) with pQCD concepts [22] or which try to apply pQCD evolution to lowest momentum transfers [23] describe the data quite well.

2.2 HERMES results on proton spin structure

Recent experiments on polarized lepton-nucleon scattering at SLAC, CERN and now also at DESY concentrated on precise determinations of the first moment of the spin structure function $g_1(x, Q^2)$, where the difference on proton and neutron targets are related by the famous Bjorken sum rule [24] to the axial vector coupling constants g_A and g_V. The function $g_1(x, Q^2)$ is obtained from the asymmetry in polarized $\vec{\gamma}^* \vec{N}$ scattering with parallel and anti-parallel spins. In the quark parton model (QPM) it is given by the simple relation

$$g_1(x) \quad = \sum_{f=u,d,s,\ldots} e_f^2 (q_f^+(x) - q_f^-(x)), \tag{2}$$

where $q_f^{\pm}(x)$ is the probability to find a quark of flavour f and momentum fraction x with spin parallel or anti-parallel to the nucleon's spin and e_f is the quark's charge.

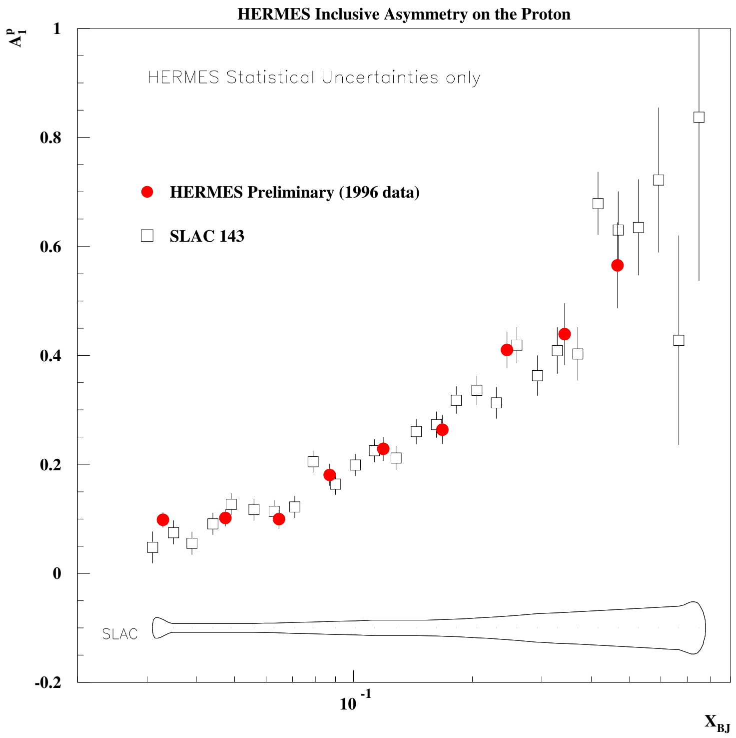

Figure 5: Results on the γ^*-proton spin asymmetry from HERMES and SLAC as function of x_{Bj}.

HERMES contributes to such measurements, and the results [26] on the proton asymmetry $A_1^p \approx g_1^p(x)/F_1^p(x)$ agree beautifully with those obtained at SLAC [25] as shown in Fig. 5.

However the main contributions of HERMES are to be expected from semi-inclusive measurements, where the additional detection of forward hadronic final state particles gives more direct information on the contribution of the various quark flavours to the nucleon spin. The spin asymmetry of the $\pi^+ - \pi^-$ difference can be related (QPM) to the spin contributions Δu_v and Δd_v of the valence u and d quarks respectively:

$$A_\pi = \frac{N_{\uparrow\uparrow}^{\pi^+-\pi^-} - N_{\uparrow\downarrow}^{\pi^+-\pi^-}}{N_{\uparrow\uparrow}^{\pi^+-\pi^-} + N_{\uparrow\downarrow}^{\pi^+-\pi^-}} \quad \Rightarrow \quad A_\pi^p = \frac{4\Delta u_v(x) - \Delta d_v(x)}{4u_v(x) - d_v(x)} \tag{3}$$

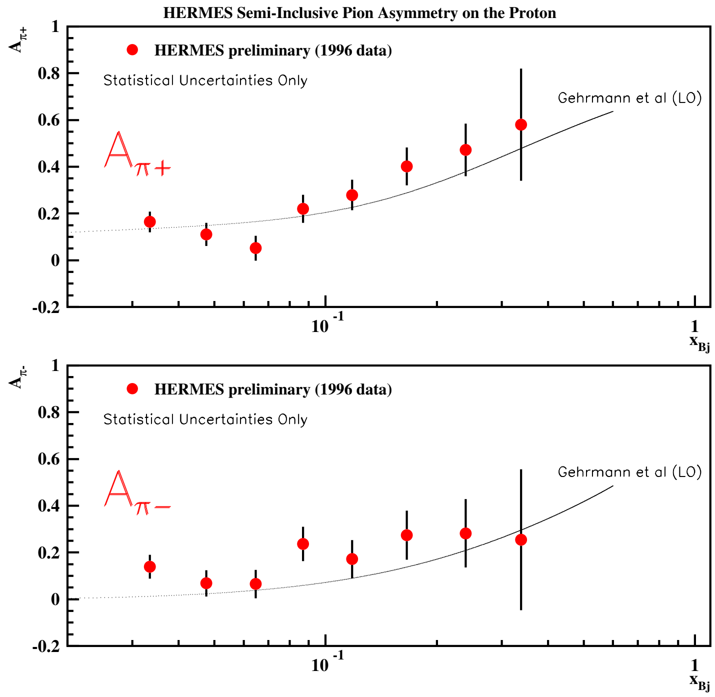

Figure 6: γ^*-proton spin asymmetry in forward π production as function of x_{Bj}. The curves are from a parametization of polarized and unpolarized structure function data.

Fig. 6 shows preliminary results on the π-asymmetry in polarized e^+p scattering together with the prediction of parton density functions [27] derived from polarized and unpolarized structure function data. Using also d or He^3 targets for measurements on the neutron allows to disentangle the u_v and d_v contributions. Particle identification will be further improved in the HERMES experiment by a replacement of the present gas Cerenkov detector by a RICH detector. This will allow to measure directly the strange sea polarization which is believed to play a crucial role in the violation of the Ellis-Jaffe sumrule [28]. (For a recent review see ref. [26]).

3 Diffraction in DIS

The typical experimental signature of diffractive scattering events at HERA is the observation of a rapidity gap in the hadronic final state as an indication of the exchange of a colourless object (see Fig. 7).

Such data are analysed in DIS in terms of the kinematic quantities

$$x_{I\!P} \simeq \frac{Q^2 + M_X^2}{Q^2 + W^2} \qquad \beta \simeq \frac{Q^2}{Q^2 + M_X^2} \quad , \tag{4}$$

where $x_{I\!P}$ can be interpreted as the momentum fraction of the proton carried by the exchanged object and $\beta = x/x_{I\!P}$ as the fraction of the momentum of the exchanged object which is carried by the parton interacting with the virtual photon. In these expressions W is the invariant mass of the final state hadronic system. From the systems X and Y, which are separated by the

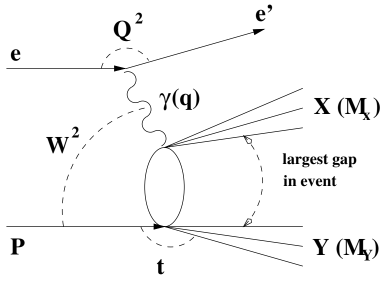

Figure 7: Schematic of a DIS scattering event $ep \to eXY$.

rapidity gap (cf. Fig. 7), X is measured in the main detector and Y stays either unseen in the beam pipe and is experimentally constrained to be small ($M_X \lesssim$ 1.6 GeV, e.g. in case of H1), or Y is detected as a high momentum proton (some of the presented ZEUS data).

A diffractive structure function $F_2^{D(4)}$ is derived from the measured cross section using the relation

$$\frac{d^4\sigma(ep \to e'XY)}{d\beta\, dQ^2\, dx_{\mathbb{P}}\, dt} = \frac{4\,\pi\,\alpha^2}{\beta\, Q^4}(1 - y + \frac{y^2}{2})\, F_2^{D(4)}\,(\,x_{\mathbb{P}},\, \beta,\, t,\, Q^2) \quad , \tag{5}$$

or, if the momentum transfer t is not explicitly measured, the data are presented as $F_2^{D(3)}\,(x_{\mathbb{P}},\, \beta,\, Q^2)$ after integration over the accepted t range (e.g. $|\,t\,| \lesssim$ 1 GeV^2 for H1).

H1 recently parametrized $F_2^{D(3)}$, measured in the kinematic range $4.5 < Q^2 < 75$ GeV^2, $0.04 < \beta < 0.9$ and $3 \cdot 10^{-4} < x_{\mathbb{P}} < 0.05$, in the frame of a Regge model in terms of a pomeron trajectory and an effective subleading meson trajectory [29]. The latter contribution gets important at low β and high $x_{\mathbb{P}}$. This is illustrated in Fig.8 which gives examples of the data and the fit at low and high β at $Q^2 = 18$ GeV^2.

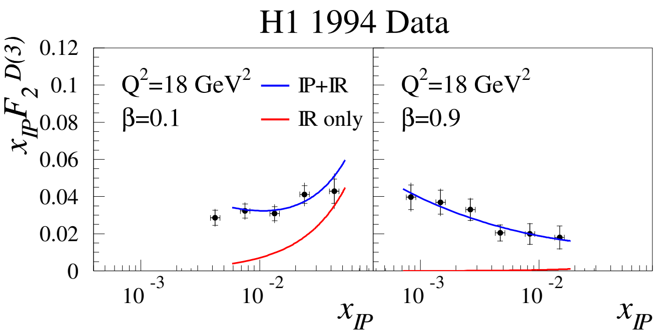

Figure 8: Examples of $x_{\mathbb{P}} F_2^{D(3)}$ for low and high β at $Q^2 = 18$ GeV^2 as function of $x_{\mathbb{P}}$. Curves: Sum of Pomeron and Reggeon exchange (solid line) and the latter only (broken).

Intercepts at $t = 0$ of $\alpha_{\mathbb{P}}(0) = 1.203 \pm 0.020(\text{stat.}) \pm 0.013(\text{sys.})^{+0.030}_{-0.035}(\text{model})$ for the pomeron trajectory and $\alpha_{\mathbb{R}}(0) \approx 0.5$ for the subleading trajectory are obtained in the fit. This result on $\alpha_{\mathbb{P}}(0)$ in diffractive DIS is above the value of ≈ 1.08, which is expected from soft hadronic interactions [30] and which fits photo-production ($Q^2 = 0$).

Also the ZEUS Collaboration found in DIS [31] values of the pomeron intercept around 1.2 ($\alpha_{\mathbb{P}}(0) = 1.16 \pm 0.01 \pm 0.02$ [32]), taking experimentally a somewhat different approach, where the diffractive contribution is identified as the excess of events at small M_X above the exponential fall-off expected from the non-diffractive contribution with decreasing $\ln M_X^2$.

Detecting the leading proton in a spectrometer ZEUS studied diffractive events for the reaction $ep \to Xp$ (Y is a proton in Fig. 7) [33] and measured the slope of the t-dependence $d\sigma/dt \sim e^{-b|t|}$ to $b = 7.2 \pm 1.1(\text{stat.})^{+0.7}_{-0.9}(\text{syst.})$ GeV^{-2} supporting assumptions made for the inclusive analyses. This led further to results on $F_2^{D(4)}$ which are shown in Fig. 9. The consistency observed by integration over t [33] gives further experimental support to the analyses of $F_2^{D(3)}$.

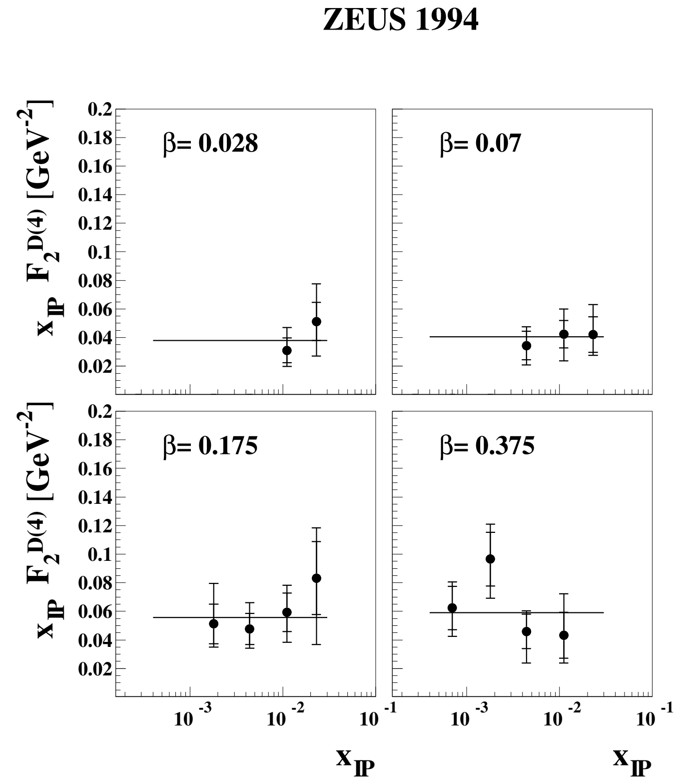

Figure 9: $x_{I\!P} F_2^{D(4)}(x_{I\!P}, \beta, t, Q^2)$ plotted as function of $x_{I\!P}$ in 4 bins of β at $< Q^2 >= 8$ GeV^2 and $< t >= 0.17$ GeV^2. The solid line is the result of a fit $F_2^{D(4)} \sim (1/x_{I\!P})^a$ yielding $a = 1$.

On the basis of the above $F_2^{D(3)}$ analysis, the H1-Collaboration went one step further and described, in the spirit of Ingelman and Schlein [3], the exchanged pomeron in terms of parton distributions which follow QCD evolution governed by the DGLAP equations. The results strongly favour the notion of a large gluon content of the exchanged object. This is visible in Fig. 10, which shows that only by including gluons the data are well described by the fit. Indeed in the prefered solution about 90% of the momentum of the exchanged object are carried by gluons at $Q^2 = 4.5$ GeV^2.

4 NC Events at Very High Q^2

The H1 and ZEUS Collaborations reported recently on an excess of events beyond standard model expectation at very high Q^2 and x. These reports [34] were based on data taken in

1994 to 1996 with luminosities of 14.2 pb^{-1} and 20.1 pb^{-1} for H1 and ZEUS respectively. The unexpected findings were in case of H1 12 NC events with $Q^2 > 15000$ GeV^2 with an expectation of only 4.71 ± 0.76. In particular an accumulation of 7 events in a mass window of 25 GeV around $M = 200$ GeV and $y > 0.4$, where only 0.95 ± 0.18 were expected, was suggestive for new physics. Here $M = \sqrt{xs}$ corresponds to the invariant mass of the incident lepton and the interacting parton; the mass window corresponds to $0.39 < x < 0.50$. ZEUS had observed 2 events with $Q^2 > 35000$ GeV^2 expecting only 0.145 ± 0.013 and 4 events with $x > 0.55$, $y > 0.25$, with an expectation of 0.91 ± 0.08.

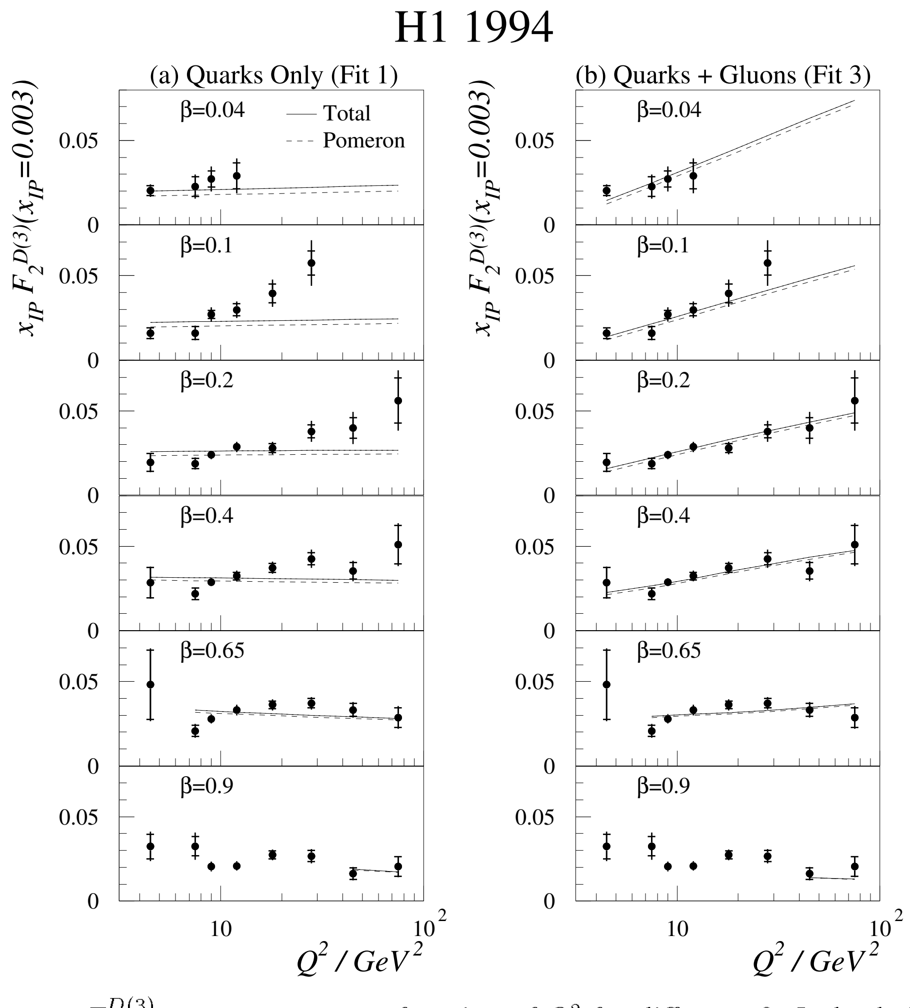

Figure 10: $x_{\mathbb{P}} F_2^{D(3)}$ at $x_{\mathbb{P}} = 0.003$ as function of Q^2 for different β. In both (a) and (b) the same data are shown which are compared with QCD fits, for which in (a) only quarks contribute to the pomeron structure at $Q^2 = 3$ GeV^2, whereas in (b) quarks and gluons contribute. The solid lines represent $x_{\mathbb{P}} F_2^{D(3)}$, whilst the dotted lines show the contribution from the pomeron only.

After the successful 1997 run, leading to luminosities of 37.0 pb^{-1} and 46.6 pb^{-1} for H1 and ZEUS respectively for the years 1994 to 1997 together, the Q^2 distributions for all data (Figs. 11 and 12) show less excess over the standard model expectations than the previous data alone. [2]

In terms of numbers of events: H1 now observes in total for $Q^2 > 15000$ GeV^2 22 events

[2] The presented preliminary numbers including the full year 1997 were available since 13th March 98 only [35].

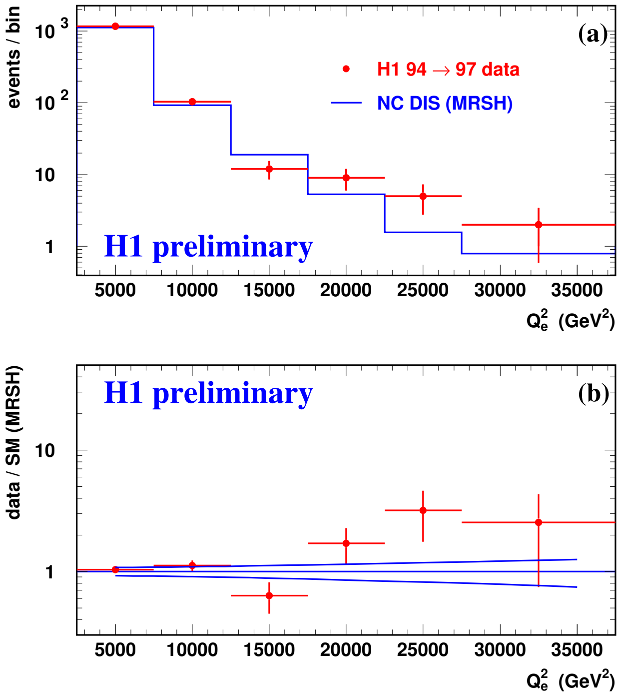

Figure 11: (a) Q^2 distribution for the selected e^+p NC DIS candidates and for the NC DIS expectation (histogram). (b) ratio of the expected and observed number of events. The lines above and below unity specify the $\pm 1\sigma$ levels of the NC DIS expectation.

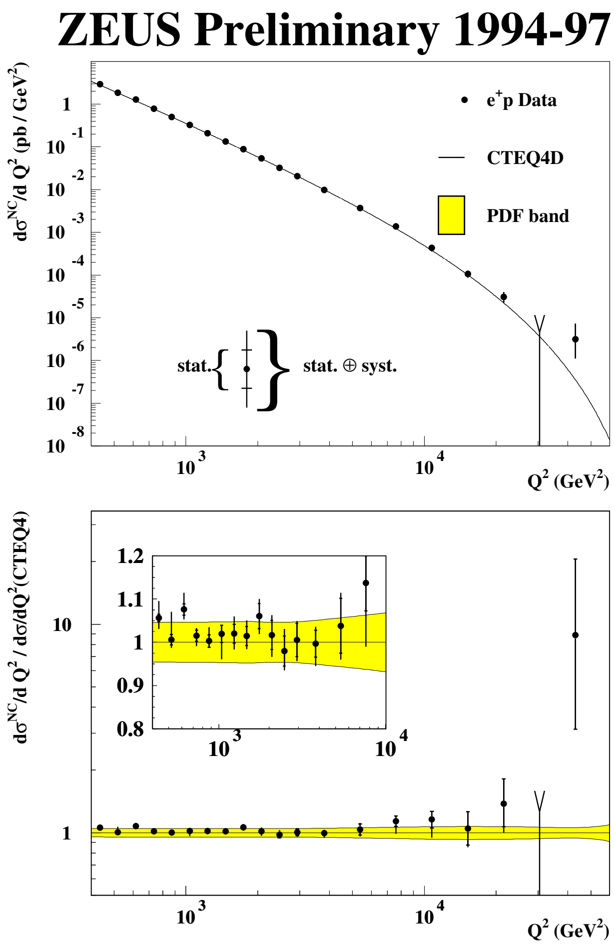

Figure 12: $d\sigma/dQ^2$ for NC e^+p DIS and expectation (solid line), and ratio (lower graph).

expecting 14.7 ± 2.1, and in the mass window of 25 GeV around $M = 200$ GeV there are now 8 events whilst 3.01 ± 0.54 are expected. ZEUS reports no new events for $Q^2 > 35000$ GeV^2, and the two older events are now to be compared with an expectation of 0.29 ± 0.02 events.

It is clear from the above numbers that the 1997 data alone do not support the excess observed previously. Only more luminosity will allow to clarify whether the unexpected large number of events at very high Q^2 is just a fluctuation or a glimpse of new physics.

5 Events with Isolated Leptons and Missing Transverse Momentum

In 1994 the H1 Collaboration reported [36] and speculated [37] on a remarkable event with an isolated muon with $p_t \approx 20$ GeV back to back in ϕ with an hadronic jet with $p_t \approx 40$ GeV implying missing p_t of order 20 GeV. Meanwhile more comparable events have been found in a systematic search based on the luminosity of 23.7 pb^{-1} [38]. The basic experimental conditions were a purely calorimetric measurement of missing transverse momentum, p_t^{calo}, above 25 GeV and an isolated track with $p_t > 10$ GeV. Note that muons contribute little to the measured p_t^{calo} and that therefore events with a high p_t muon satisfying the condition $p_t^{calo} > 25$ GeV may still be balanced in p_t.

In total 5 events were found which all have substantial missing p_t. The required isolated track turns out to be in all cases due to a lepton (μ in 4 events, e^- in one) with $p_t \gtrsim 20$ GeV. As an example the second observed muon event is shown in Fig. 13.

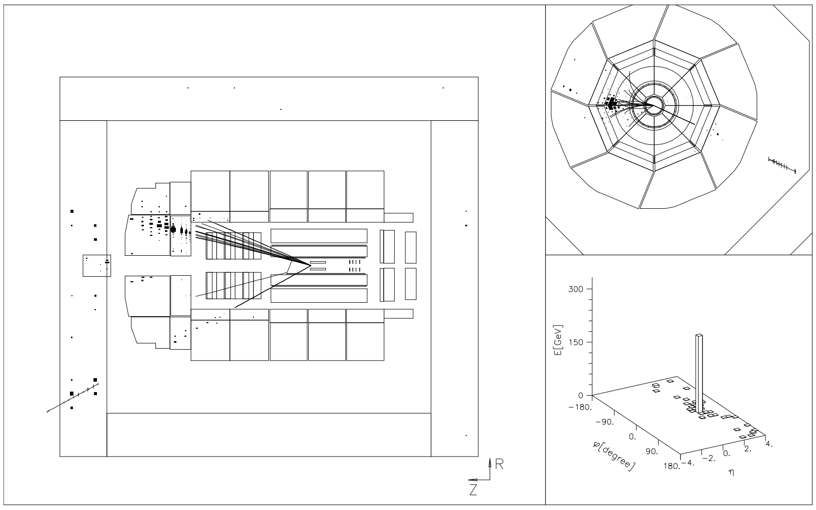

Figure 13: Event in the H1 detector with an isolated μ^+ with $p_t = 28.0^{+8.7}_{-5.4}$ GeV and an hadronic jet with $p_t = 67.4 \pm 5.4$ GeV. Left: side view, e^+ (27.5 GeV) from left, p (820 GeV) from right. Upper right: view along the beam. Lower right: calorimetric energy in $\eta - \phi$ plane.

The dominating known process for such events is production of W-bosons, where the observed missing p_t is produced by leptonic decay. For the H1 conditions 1.34 ± 0.20 e-events (of either charge) are expected from W-production in agreement with the observation of one event. However in case of the muons, the 4 observed events have to be compared with an expectation of only 0.41 ± 0.07. Other processes like photo-production of jets, heavy quarks, lepton pair production etc. contribute much less. If the observed events are interpreted as W-production with leptonic decay, the transverse mass $M_T^{\mu\nu}$ can be calculated. The distribution in the plane of hadronic p_t vs. $M_T^{\mu\nu}$ (Fig. 14) shows that the e^--event, but only 1 of the 4 muon events have kinematic properties typical for W-production.

The ZEUS Collaboration has performed a very similar search with the main cuts $E_e >$ 15 GeV, missing $p_t >$ 19 GeV in case of isolated $e^\pm$ and $p_t^\mu >$ 5 GeV, $p_t^{calo} >$ 18 GeV and missing $p_t >$ 18 GeV in case of isolated $\mu^\pm$. ZEUS[3] found on the basis of 46.6 pb^{-1} four e^+-events but zero muon events, well consistent with an expectation of $\sim$ 3.5 and $\sim$ 1.3 events respectively including background from non-W-production.

It will be very interesting to clarify with further data the origin of the observed events.

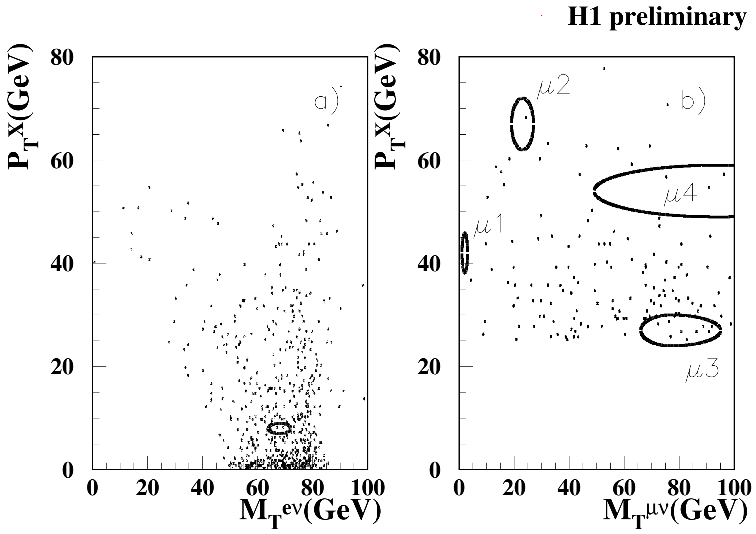

Figure 14: Distribution of isolated lepton events in hadronic p_t and transverse mass of the lepton and an assumed missing ν (a) electron channel, b) muon channel). The contours correspond to the 1σ uncertainty on the measured parameters of the 5 events. The points show the SM expectation for W-production for 500 times the data luminosity.

6 Summary

A selection of results of the HERA experiments HERMES, H1 and ZEUS obtained in 1997 has been presented.

In inclusive DIS new and more precise data are available in the range $0.11 < Q^2 < 5000$ GeV^2. All the range $Q^2 \gtrsim 1$ GeV^2 is well described by fits based on pQCD, which allow to

[3] The presented preliminary numbers including the full year 1997 were available since 3^{rd} February 98 only [39].

extract the gluon density in the proton at small x. Results on open charm production are consistent with the gluon density determined in inclusive DIS.

The exess over expectation at highest Q^2 reported previously by H1 and ZEUS is not confirmed by the 1997 data alone. However, full clarification will only be possible with larger data samples.

At low Q^2 in the transition region to photo-production ($Q^2 = 0$) the data can be compared with phenomenological models using concepts from vector dominance, Regge theory and QCD.

The HERMES experiment contributes to the understanding of the nucleon spin composition, especially by identified particles of the hadronic final states.

The measurements on inclusive diffractive scattering have been complimented by detection of leading protons. Analyses of DIS data in terms of Regge phenomenology yield intercepts of the pomeron trajectory of ≈ 1.2, which is larger than expected from soft hadronic interactions. Trying to describe the t-channel exchange in terms of parton distributions leads to a large gluonic content of the exchanged object.

Events with isolated leptons ($e^{\pm}, \mu^{\pm}$) at high p_t and missing tranverse momentum have been observed. Whereas the $e^{\pm}$ events are consistent with expectation, H1 observes 4 events with an isolated muon, where only about 0.5 are expected, mainly from W-production. ZEUS sees with a comparable selection no such muonic event in full agreement with expectation. The origin of these events will have to be clarified with further data.

Acknowledgements

I am grateful for the invitation to this stimulating workshop and to A. Caldwell, T. Doyle, M. Erdmann, E. Kinney and M. Tobien for useful comments to the manuscript.

References

[1] Yu.L. Dokshitzer, Sov. Phys. JETP **46** (1977) 641;
V.N. Gribov and L.N. Lipatov, Sov. J. Nucl. Phys. **15** (1972) 438 and 675;
G. Altarelli and G. Parisi, Nucl. Phys. B **126** (1977) 298.

[2] T. Regge, Nuov. Cim. **14** (1959) 951, ibid. **18** (1960) 947;
G. Chew, S. Frautschi, Phys. Rev. Lett. **7** (1961) 394;
G. Chew, S. Frautschi, S. Mandelstam, Phys. Rev. **126** (1962) 1202.

[3] G. Ingelman, P. Schlein, Phys. Lett. B **152** (1985) 256.

[4] H1 Collab., S. Aid *et al.*, Nucl. Phys. B **470** (1996) 3;
ZEUS Collab., M. Derrick *et al.*, Z. Phys. C **69** (1996) 607, Z. Phys. C **72** (1996) 399
H1 Collab., C. Adloff *et al.*, Phys. Lett. B **399** (1997) 452.

[5] E. Laenen *et al.*, Nucl. Phys. B **392** (1993) 162;
S. Riemersma *et al.*, Phys. Lett. B **347** (1995) 143

[6] H1 Collab., contributed paper 262 to HEP97, Jerusalem, August 1997.

[7] NMC, M. Arneodo *et al.* Nucl. Phys. B **483** (1997) 3.

[8] BCDMS Collab., A.C. Benvenuti *et al.*, Phys. Lett. B **223** (1989) 485; CERN-EP/89-06.

[9] M.A.J. Botje, Proc. 5th Workshop on Deep Inelastic Scattering and QCD (DIS 97), Chicago, April 1997, p. 375.

[10] M. Glück, E. Reya and A. Vogt, Z. Phys. C **67** (1995) 433; A. Vogt, Proc. 3rd Workshop on Deep Inelastic Scattering and QCD (DIS95), Paris (1995) 261.

[11] A. Martin, R. Roberts and W.J. Stirling, Phys. Lett. B **387** (1996) 419.

[12] H. Lai *et al.*, Phys. Rev. D **55** (1997) 1280.

[13] NMC, M. Arneodo *et al.*, Phys. Lett. B **309** (1993) 222.

[14] B.W. Harris and J. Smith, Nucl. Phys. B **452** (1995) 109; Phys. Lett. B **353** (1995) 535.

[15] H1 Collab., contributed paper 275 to HEP97, Jerusalem, August 1997.

[16] H1 Collab., contributed paper 262 to HEP97, Jerusalem, August 1997.

[17] H1 Collab., C. Adloff *et al.*, Nucl. Phys. B **497** (1997) 3.

[18] ZEUS Collab., J. Breitweg *et al.*, Phys. Lett. B **407** (1997) 432; B. Surrow, Proc. 5th Workshop on Deep Inelastic Scattering and QCD (DIS 97), Chicago, April 1997, p. 285.

[19] E665 Collab., M.R. Adams, *et al.*, Phys. Rev. D **54** (1996) 3006.

[20] A. Donnachie and P.V. Landshoff, Z. Phys. C **61** (1994) 139.

[21] A. Capella *et al.*, Phys. Lett. B **337** (1994) 358.

[22] B. Badelek and J. Kwiecinski, Phys. Lett. B **295** (1992) 263.

[23] K. Adel, F. Barreiro, and F.J. Yndurain, Nucl. Phys. B **495** (1997) 221.

[24] J.D. Bjorken, Phys. Rev. **148** (1966) 1467.

[25] K. Abe *et al.*,Phys. Rev. Lett. **74** (1995) 346; *ibid.* **75** (1995) 25.

[26] A. Brüll, Proc. 18^{th} Int. Symp. on Lepton-Photon Interactions, Hamburg, July 1997.

[27] T. Gehrmann and W.S. Stirling, Phys. Rev. D **53** (1996) 6100.

[28] J. Ellis and R.L. Jaffe, Phys. Rev. D **9** (1974) 1444; ibid. D **10** (1974) 1669.

[29] H1 Collab., C. Adloff *et al.*, Z. Phys. C **76** (1997) 613.

[30] H. Cheng, J.K. Walker, T.T. Wu, Phys. Lett. B **44** (1973) 97;
A. Donnachie and P. Landshoff, Nucl. Phys. B **244** (1984) 322; ibid. **267** (1985) 690.

[31] ZEUS Collab., contributed paper 638 to HEP97, Jerusalem, August 1997.

[32] H. Kowalski, Workshop on Diffractive Physics, Rio de Janeiro, Brazil, Feb. 1998.

[33] ZEUS Collab., J. Breitweg *et al.*, Eur. Phys. J. C **1** (1998) 81.

[34] H1 Collab., C. Adloff *et al.*, Z. Phys. C **74** (1997) 191;
ZEUS Collab., J. Breitweg *et al.*, Z. Phys. C **74** (1997) 207.

[35] G. Bernardi; A. Quadt, DESY Seminar, March 13, 1998.

[36] H1 Collab., T. Ahmed *et al.*, DESY preprint 94-248 (1994).

[37] H1 Collab., S. Aid *et al.*, Z. Phys. C **71** (1996) 211.

[38] H1 Collab., contributed paper 708 to HEP97, Jerusalem, August 1997.

[39] S. Schlenstedt, DESY PRC talk, Feb. 3, 1998.