THE ZEUS EXPERIMENT AT HERA.

Proposal 760

Bristol, Glasgow, Imperial College London, University College London, Oxford, Rutherford Appleton Laboratory

in collaboration with
Argonne, Bologna, Bonn, Brookhaven, Calabria, Columbia, DESY, DESY-Zeuthen, Florence, Frascati, Freiburg, Hamburg, Iowa, Jülich, Krakow, Louisiana, Madison (Wisconsin), Madrid, Manitoba, McGill, Moscow, NIKHEF, Ohio, Padova, Pennsylvania, Rome, Santa Cruz, Seoul, Siegen, Tel Aviv, Tokyo, Tokyo Metropolitan Univ., Torino, Toronto, Virginia, Warsaw, Weizmann Inst., Yokohama, York (Ontario).

Introduction

During 1995 HERA ran with 174 colliding bunches of 820 GeV protons and 27.5 GeV positrons. Approximately 6 pb^{-1} of usable data were accumulated by the ZEUS experiment, roughly twice as much as in 1994. Major contributions to the improved performance were the achievement of higher proton currents and the extended running period in 1995. As in most of 1994, it was decided to run HERA mainly with positrons, since these give a much longer beam lifetime than that obtained using electrons. It is believed that the replacement of some of the vacuum pumps should make an electron beam viable for the 1997 running.

The ZEUS detector as a whole continued to function well. The increase in luminosity made it necessary to employ more stringent triggers than in previous years – in particular, making much tighter use of the tracking information – and the collaboration is beginning to have to be more selective on the physics data that it is able to record on tape. Analysis of the 1993 data is now essentially complete, that of the 1994 data is well progressed, and first results are appearing from the 1995 running.

Hardware developments.

The ZEUS apparatus was improved in a number of ways for the 1995 running. These particularly assist the coverage in the region of the beamline.

1. An improved version of the beampipe calorimeter (BPC) has been in operation, following the group's experience with the 1994 prototype. The full planned azimuthal coverage is now obtained, so as to maximise the acceptance for electrons that tag virtual photons in a Q^2 range 0.1–0.7 GeV^2. In conjunction with this, the two halves of the central column of cells in the rear uranium calorimeter (RCAL) have each been moved 5 cm towards the beamline to improve the Q^2 coverage of the RCAL.
2. Scintillator arrays have been installed in front of the forward and rear calorimeters to act as presampler devices which improve the energy measurement of forward jets and scattered beam leptons. An extension of this system to the barrel calorimeter is planned.
3. The Leading Proton Spectrometer is now fully installed and instrumented. A trigger involving this device was brought into operation to enhance the measurement of diffractive processes.
4. Readout of the forward and rear trackers and the transition radiation detector is now complete, and information from these detectors can be incorporated into the track measurements. Progress is continuing on the analysis of the TRD signals.

CTD performance.

The Central Tracking Detector, together with its associated readout and trigger electronics, has been the major contribution made by the UK groups to the ZEUS detector, and it remains our joint task to operate it effectively and obtain the optimum results from it. In data taking the CTD has performed very reliably, with less than 2% of dead channels and little contribution to the experimental running downtime. No signs of aging are apparent. A much improved data quality monitoring system has been of great assistance.

At the offline level, a number of detailed improvements to the corrections have enabled the (r, ϕ) resolution to be brought down to the 190 μm level. Such a value is close to reasonable expectations, but we shall continue to seek further improvement. Much progress has been made on the extraction of dE/dx (ionisation density) measurements, which are now being used to assist particle identification in a number of physics analyses. Both the previous and present ZEUS tracking coordinators are ZEUS-UK members.

Trigger and running.

ZEUS operates a three-level trigger, of which the first level is a hardware-based system whose principal aim is to reduce backgrounds from processes that do not come from the interaction point. Information from the CTD makes an important contribution to this, by means of dedicated pipelined processor cards which enable (r, z) information from track segments in the first drift chamber superlayer to be incorporated into the trigger. This system gives fast recognition of the point of origin of tracks, and is currently used by 28 of the 33 active first level triggers. It is to be extended and improved by using information from superlayers 3 and 5, by means of the so-called CP3 and CP5 cards. These are now installed and read out, and work is taking place to integrate the information into the trigger system for the 1996 running.

The second level trigger applies software cuts to clean the event sample further and identify certain classes of physics event. The CTD component to this has been in operation since 1994, and enables detailed information on the tracking and vertexing to to be used in the event selection. It is used by five of the six physics filters at this level. At the third trigger level, all the event information is available, and many different types of physics selection can be made using software algorithms similar to those used offline. All the physics analysis groups contribute here.

A programme of continued improvement to all three levels of the trigger will remain of paramount importance over the coming years if ZEUS is to exploit effectively the expected increases in HERA luminosity. The UK groups plan to maintain a central role in this essential activity.

ZEUS data taking has become an increasingly smooth operation, and the collaboration has decided to reduce the number of regular shift personnel required from four to three. The UK groups have continued to play a full part here, and have provided several of the designated shift leaders. We also provided one of the four ZEUS Run Coordinators for 1995.

Physics analysis.

During 1995 a large number of analyses were completed and published by the ZEUS collaboration. This has been made possible to a large extent by the ZARAH computing system and environment, which was designed and implemented by the collaboration. It is based on the rapid accessibility of events on disk storage, which together with an Ampex tape system and high CPU power provides an outstandingly versatile and fast data handling capability. The facilities at the ZEUS member institutions, including the UK groups, are now being increasingly exploited in conjunction with those at DESY to carry out Monte Carlo simulations. In this way the use of resources is maximised in performing the massive amounts of computation which the physics analyses demand.

In the following summary, we concentrate especially on those physics areas where the UK members of ZEUS have been particularly active. During 1994-95, the Deep Inelastic Scattering (DIS) analysis group was coordinated by a UK physicist, and ZEUS-UK also currently provide deputy coordinators for the Structure Function and the Hard Photoproduction analysis groups. From Autumn 1995, a UK physicist has been the collaboration's overall Physics Coordinator.

1. *Proton structure.* A major focus of activity has been the measurement of the structure function $F_2(x, Q^2)$ for Deep Inelastic Scattering off the proton. Measurements now reach down to x values well below 10^{-4}. The extended coverage was made possible by using events with initial state radiation, and also a special period of running of HERA with the interaction point moved 60 cm upstream to allow smaller $e^{\pm}$ scattering angles to be measured in ZEUS. Two important features are seen in the data. One is that F_2 continues to rise with decreasing x; the other is that this rise still occurs at Q^2 values as low as 1.5 GeV^2. The latter comes as a slight surprise as it contradicts Regge-based predictions at this Q^2 value, although perturbative QCD-based predictions are still able to describe the data.

   Fig. 2 shows the rise in the gluon density in the proton that is implied by the F_2 data. The F_2 values can alternatively be expressed as total $\gamma^* p$ cross sections (Fig. 1). Here it is apparent that quite a rapid transition in behaviour needs to occur in the region $Q^2 < 1.5$ GeV^2 if the curves for constant Q^2 values are not to cross. However there is no known theoretical argument that prohibits the latter. The intermediate region between quasi-real photons and $Q^2 = 1.5$ GeV^2 is thus of considerable interest for further study.

2. *Photon structure in the intermediate Q^2 region.* One contribution to our understanding of this region may come from the study of direct and resolved hard photoproduction, with particular reference to the behaviour of the resolved component. The newly installed BPC has enabled first measurements to be made in the range $0.1 < Q^2 < 0.55$ GeV^2. The expectation that the resolved component should fall with Q^2 is found to be fulfilled. The results, as presented at the 1995 Brussels conference, are shown in Fig. 3.

3. *Charm states in low Q^2 photoproduction.* Clear signals for D^* production have been found in inclusive photoproduction, and the total inclusive cross section has been measured at a mean centre of mass energy of 163 GeV. The results are substantially higher than those found at lower energies, but are well described by NLO QCD calculations with rising gluon distributions at low x in the proton, such as are obtained from the HERA F_2 data. Figs. 4 and 5 illustrate charm signals seen in the 1994 data with the help of the dE/dx measurements in the CTD. Cross sections have also been determined for elastic J/ψ photoproduction (Fig. 6). Here too, a substantial rise compared with lower energy experiments is found, leading to similar conclusions as with the D^* data, and again confirming the general picture of the proton which HERA is presenting to us.

4. *High Q^2 DIS.* At the opposite extreme, deep inelastic scattering at Q^2 values of $O(10^4)$ GeV^2 is sensitive to electroweak effects, and this was indeed one of the original prime motivations for constructing HERA. First measurements of neutral and charged current cross sections in this region have now been published. As shown in Fig. 7, agreement with the standard model is good. This provides a direct confirmation of the unification of the electromagnetic and weak forces, which should be further reinforced with the use of beam polarisation and high statistics data from both electron and positron beams.

5. *Determination of α_s.* A measurement of the strong coupling constant α_s has been made from DIS events containing two high-p_T jets. The necessary NLO calculations at the parton level require that the JADE jet definition scheme be applied to the data. On this basis, the observed jet rates can be fitted to extract α_s, which is found to decrease with

Q^2 in agreement with expectations (Fig. 8). Expressed at the Z^0 mass, our result is: $\alpha_s = 0.117 \pm 0.005\ (stat)\ ^{+0.004}_{-0.005}\ (sys_{exp})\ \pm 0.007\ (sys_{theory})$; this value is consistent with other determinations, and the already competitive errors should be significantly improved with further development of this approach.

6. *Properties of final states in DIS.* At a range of Q^2 values above 10 GeV^2, the collaboration have published a study of inclusive particle distributions in the Breit frame, where direct comparisons can be made with e^+e^- annihilation data (Fig. 9). No significant differences are suggested at this global level. An analysis has also been made of inclusive K^0 cross sections in DIS final states; the K^0s are expected to be observed mainly as products of hadronisation in the struck parton jet, so that the measurements test our detailed understanding of this process. Here, fewer K^0s are found than expected from predictions based mainly on the parameterisation of e^+e^- data. These are clearly topics which merit more detailed investigation. A study of K^0s in hard photoproduction is well advanced.

7. *Diffractive processes.* The collaboration have continued to place much effort in investigating processes whose energy flow displays a large rapidity gap. Three types of such process have been studied: diffractive processes in DIS and in low-Q^2 hard photoproduction, and processes with a centrally occurring rapidity gap. Present data have not yet resolved the debate as to whether or not the processes in these kinematic regimes are fundamentally similar, in particular whether a common "pomeron" is involved. In DIS, the diffractive structure function is found to show no variation with Q^2 or with the fraction of the proton momentum taken by the diffractively exchanged object, thus respectively displaying scaling and factorisation. The errors are at present substantial, however, and although a particle-like pomeron is supported, there is also consistency with other models. From the DIS studies it is apparent that such an object must have a quark substructure, while the low-Q^2 results confirm that if the same pomeron is involved, it must in addition contain gluons. Centrally occurring rapidity gaps have also given first evidence for "colour singlet exchange" in hard photoproduction, providing yet another perspective on this area.

8. *Other topics.* In hard photoproduction ZEUS have also published further studies of jet properties, in particular those of dijet events, where the direct component gives information on the gluon content of the proton while the resolved is also sensitive to the photon structure. Other measurements in this area have included inclusive jet cross sections, and angular distributions of the scattered partons in their centre of mass system.

   Searches for exotic states also continue. They have so far proved unsuccessful but not unfruitful, since accounting for the candidate events which are found demands an increasingly rigorous understanding of lepton and jet physics in ZEUS.

HERA still remains a unique instrument for the study of lepton-hadron interactions at the highest energies, and its potential is only gradually becoming realised. We expect higher luminosities for some years yet, and eventually polarised electron and positron beams. It is evident that the results so far have opened up many interesting questions which future running should help to solve. The ZEUS collaboration thus looks forward to a very healthy future, with a continuing rich diversity of physics.

Publications.

1. *Measurement of total and partial photon proton cross sections at 180 GeV center of mass energy.* M Derrick et al., Z. Phys. C63 (1994) pp391-408.

2. *Comparison of energy flows in Deep Inelastic Scattering with and without a Large Rapidity Gap.* M Derrick et al., Phys. Lett. B338 (1994) pp483-496.

3. *Measurement of the proton structure function F_2 from the 1993 HERA Data.* M Derrick et al., Z. Phys. C65 (1995) pp379-398.
4. *A Search for excited fermions in electron-proton Collisions at HERA.* M Derrick et al., Z. Phys. C65 (1995) pp627-647.
5. *Inclusive jet differential cross sections in photoproduction at HERA.* M Derrick et al., Phys. Lett. B342 (1995) pp417-432.
6. *Extraction of the gluon density of the proton at small x.* M Derrick et al., Phys. Lett. B345 (1995) pp576-588.
7. *Observation of hard scattering in photoproduction events with a large rapidity gap at HERA.* M Derrick et al., Phys. Lett. B346 (1995) pp399-414.
8. *Dijet cross sections in photoproduction at HERA.* M Derrick et al., Phys. Lett. B348 (1995) pp665-680.
9. *Study of $D^*(2010)^{\pm}$ production in ep collisions at HERA.* M Derrick et al., Phys. Lett. B349 (1995) pp225-237.
10. *Measurement of charged and neutral current ep deep inelastic scattering cross sections at high Q^2.* M Derrick et al., Phys. Rev. Lett. 75 (1995) pp1006-1011.
11. *Measurement of the cross section for the reaction $\gamma p \rightarrow J/\psi p$ with the ZEUS detector at HERA.* M Derrick et al., Phys. Lett. B350 (1995) pp120-134.
12. *Jet production in high Q^2 deep-inelastic ep scattering at HERA.* M Derrick et al., Z. Phys. C67 (1995) pp81-92.
13. *Measurement of multiplicity and momentum spectra in the current fragmentation region of the Breit frame at HERA.* M Derrick et al., Z. Phys. C67 (1995) pp93-107.
14. *Inclusive transverse momentum distributions of charged particles in diffractive and non–diffractive photoproduction at HERA.* M Derrick et al., Z. Phys. C67 (1995) pp227-237.
15. *Study of the photon remnant in resolved photoproduction at HERA.* M Derrick et al., Phys. Lett. B354 (1995) pp163-177.
16. *Diffractive hard photoproduction at HERA and evidence for the gluon content of the pomeron.* M Derrick et al., Phys. Lett. B356 (1995) pp129-146.
17. *Exclusive ρ^0 production in Deep Inelastic electron-proton scattering at HERA.* M Derrick et al., Phys. Lett. B356 (1995) pp601-616.
18. *Measurement of the diffractive structure function in Deep Inelastic Scattering at HERA.* M Derrick et al., accepted by Z. Phys. C.
19. *Neutral strange particle production in Deep Inelastic Scattering at HERA.* M Derrick et al., Z. Phys. C68 (1995) pp29-42.
20. *Measurement of α_s from Jet Rates in Deep Inelastic Scattering at HERA.* M Derrick et al., DESY–95–182, accepted by Phys. Lett. B.
21. *Optimization of the pulse arrival time determination in the ZEUS central tracking detector FADC system.* D.G. Cussans and H.F. Heath, NIM A 362 (1995) pp277-282.
22. *A Measurement of the proton structure function $F_2(x, Q^2)$ at low x and a determination of the low-x gluon distribution.* M Lancaster in proc. XXVII International Conference on High Energy Physics, Glasgow (ed. P J Bussey, I G Knowles), IOP (1995) pp641-644.
23. *Proton structure functions and diffraction in Deep Inelastic Scattering at HERA.* A Prinias in proc. XXIV International Symposium on Multiparticle Dynamics, Vietro sul Mare, (ed. A Giovanni, S Lupia, R Ugoccioni), World Scientific (1995) pp503-516.

Ph.D Theses.

1. A F Byrne (Oxford) *An initial study of diffractive physics in ep collisions at HERA and performance of the tracking trigger for the ZEUS experiment.*
2. C Catterall (UCL) *Measurement of charged particles from the hadronic final state of electron proton deep inelastic scattering at a centre of mass energy of 296 GeV.*
3. S George (Bristol) *SDC trigger studies and measurement of* $\sigma(K^0)$ *in DIS.*
4. P Kaziewicz (UCL) *Energy flows in deep inelastic scattering at HERA.*
5. J O'Mara (Bristol) *NLO QCD fit to ZEUS and NMC DIS data.*
6. A Prinias (IC) *Measurement of the proton structure function* F_2 *using the ZEUS detector.*

The thesis by V. Jamieson *(Measurement of scaled momentum distributions in the Breit Frame at HERA)*, shared a prize with two others for the best experimental Ph.D. theses submitted in 1994 on work done at DESY.

Talks on ZEUS and ZEUS-related physics given at International Conferences.

1. N Brook, *Energy flow, forward jets (ZEUS),* DIS Workshop, Cambridge 1995.
2. P Bussey, *A comparison of prompt photon processes and two jet processes in hard photoproduction,* Photon '95, Sheffield.
3. R Cashmore, *Prospects for very high luminosity at HERA,* DIS '95, Paris, and Zeuthen Meeting on Spin Physics at HERA, 1995.
4. R Devenish, *Recent results on proton structure,* DESY Theory Workshop 1995.
5. A Doyle, *Diffraction (ZEUS),* DIS Workshop, Cambridge 1995.
6. A Doyle, *Diffraction at HERA: Experimental Perspective,* Durham workshop on proton, photon and pomeron structure, 1995.
7. I Fleck, *Measurement of* F_2 *of the proton in ZEUS data and extraction of the gluon density at small* x*,* Photon '95, Sheffield.
8. B Foster, *Recent results from ZEUS,* DIS '95, Paris.
9. M Lancaster, *A measurement of the proton structure function* F_2 *in DIS at low* x *and low* Q^2*,* DIS '95, Paris.
10. M Lancaster, *Proton structure at HERA:* F_2*, QCD fits and Beyond,* Durham workshop on proton, photon and pomeron structure, 1995.
11. L Lindemann, *Latest ZEUS results on* F_2*,* DIS Workshop, Cambridge 1995.
12. V Noyes, *Results from the searches for new particles at HERA,* XVth Workshop on Weak Interactions and Neutrinos, Talloires.
13. H Uijterwaal, *The ZEUS central tracking detector second level trigger,* CHEP95, Brazil.
14. M Utley, *Direct and resolved photoproduction at HERA with virtual and quasi-real photons,* EPS Conference on High Energy Physics, Brussels 1995.
15. R Walczak, *W and Z boson production at HERA,* International Symposium on Vector Boson Self Interactions. Los Angeles, 1995.
16. A Whitfield, *Vector mesons in Deep Inelastic Scattering at HERA,* DIS '95, Paris.
17. A Whitfield, *Photo- and Electroproduction of Vector Mesons (ZEUS),* DIS Workshop, Cambridge 1995.
18. R Yoshida, *Deep Inelastic Scattering at HERA: Recent results from H1 and ZEUS,* Rencontres de Phys. de la Vallée d'Aosta, La Thuile.

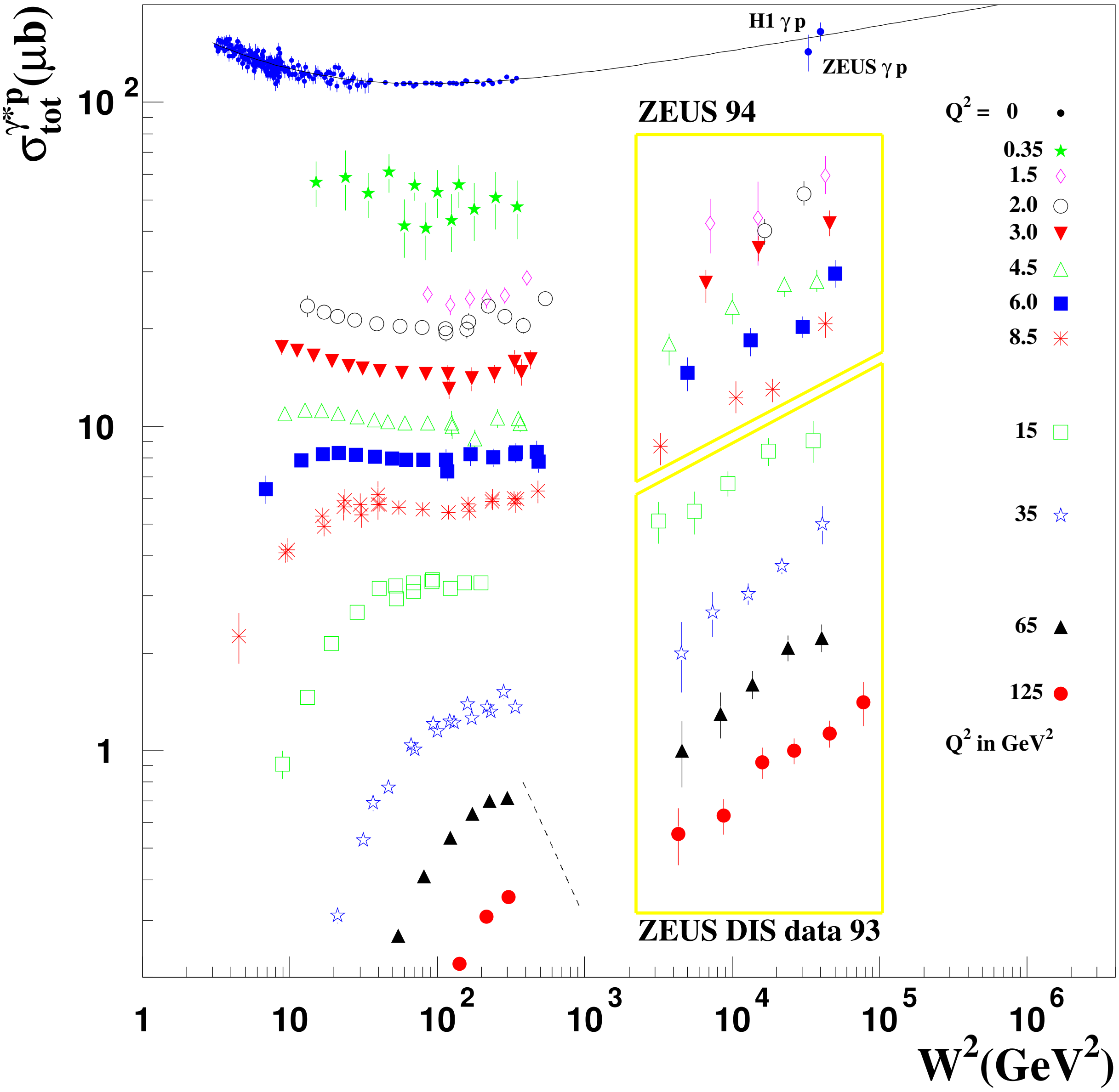

Figure 1: Total $\gamma^* p$ cross sections for photons of varying degrees of virtuality as a function of $\gamma^* p$ centre of mass energy W squared. It can be seen that at high W^2, the trend of each set of $Q^2 > 0$ points with W^2 is a much steeper rise than for the "real" photoproduction data parameterised by the top curve.

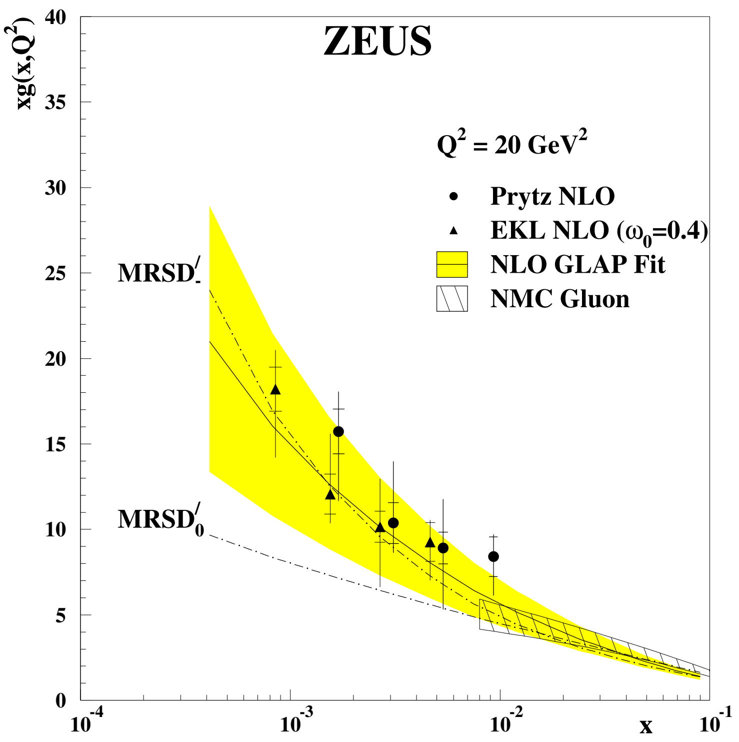

Figure 2: Gluon density in the proton, as extracted using methods of Prytz and EKL and compared with the MRSD$-'$ and MRSD0$'$ global fits [6].

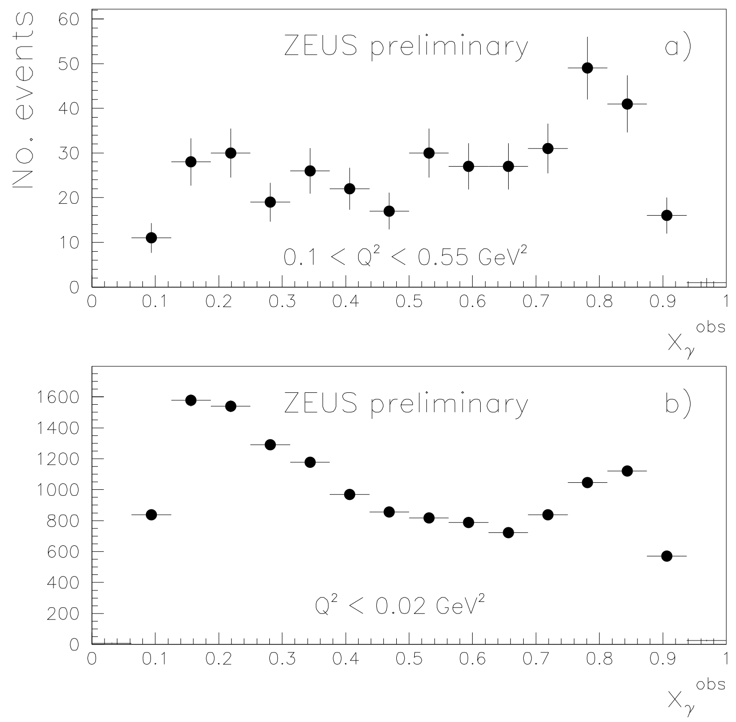

Figure 3: Distributions of x_γ for hard photoproduction as measured using dijet events for (a) $0.15 < Q^2 < 0.55\,\mathrm{GeV}^2$, (b) $Q^2 \approx 0$. The resolved component (i.e. for $x_\gamma < 0.7$) is proportionately much reduced in (a) compared to (b).

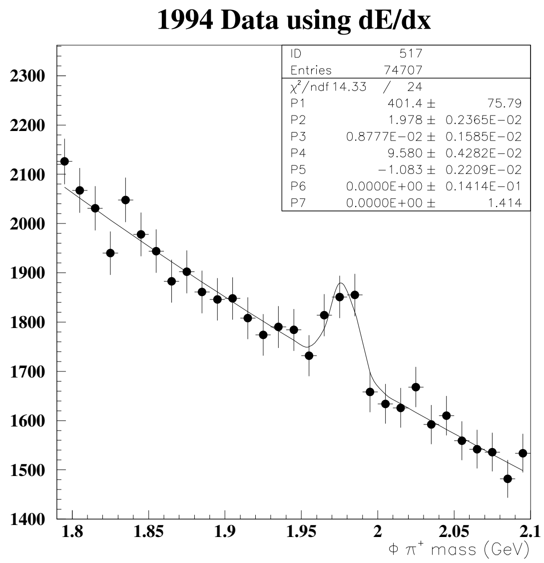

Figure 4: D_S signal in $\phi\pi^+$ decay mode in low Q^2 photoproduction.

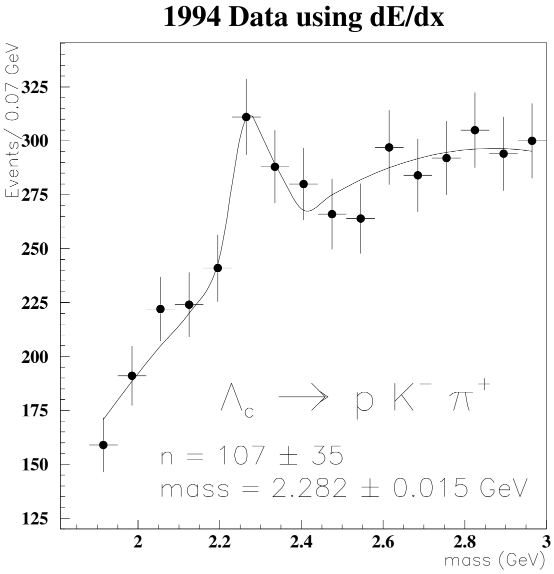

Figure 5: Λ_c signal in $pK^-\pi^+$ channel.

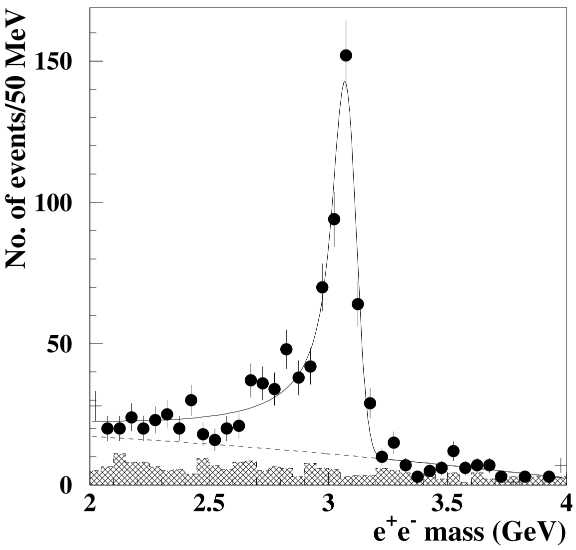

Figure 6: Elastically produced J/ψ signal in e^+e^- decay channel.

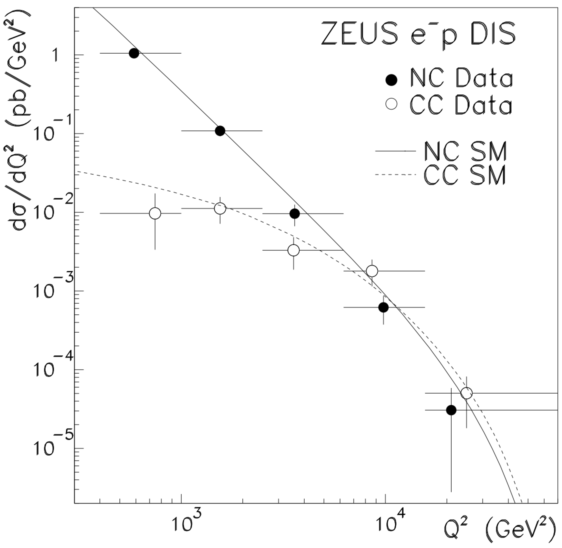

Figure 7: Cross sections for neutral and charged current e^-p scattering at very high Q^2, compared with Standard Model predictions [10].

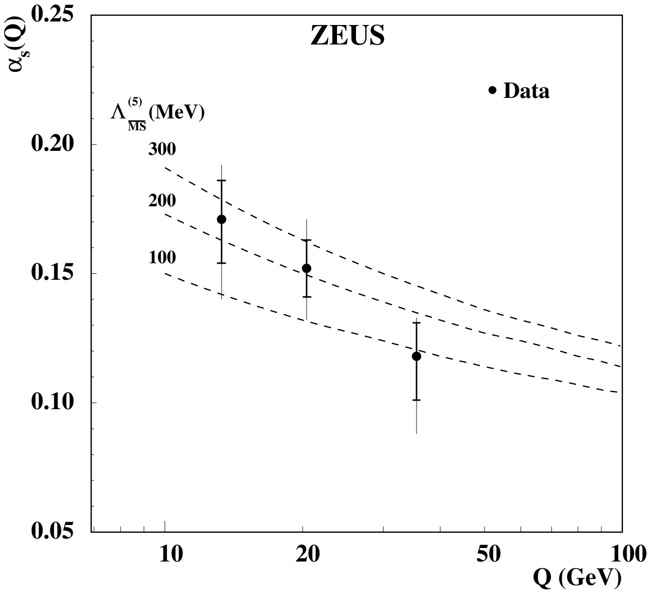

Figure 8: Measured values of α_s as a function of Q, together with predictions using different values of the QCD scale parameter Λ, as determined from the rate of two-jet events in DIS in the ZEUS 1994 data [20].

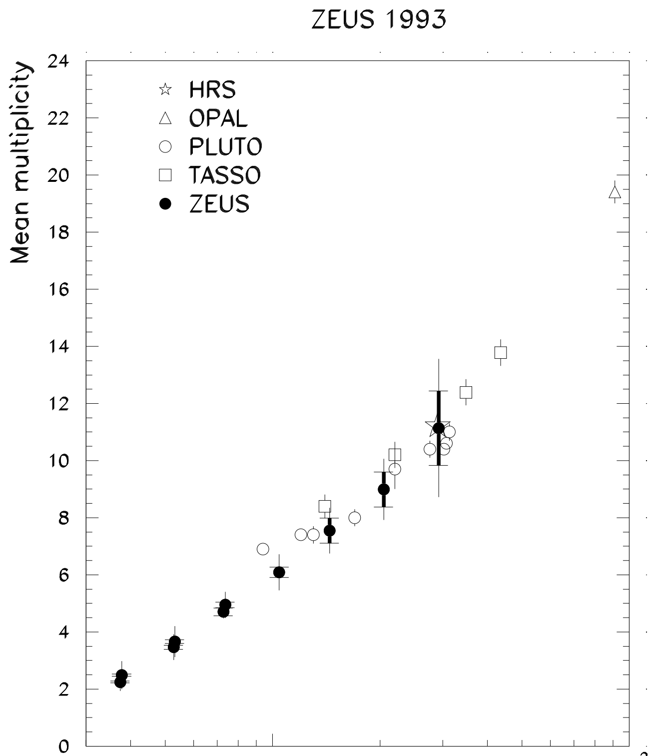

Figure 9: Charged hadron multiplicities in the current region of the Breit frame in ep scattering, scaled by a factor of two. These are compared with corresponding multiplicities in e^+e^- annihilation events on an equivalent energy scale [13], and demonstrate a similarity in quark hadronisation properties in the two classes of event.