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Exclusive ρ^0 Production in Deep-Inelastic Scattering Events at HERA

H1 Collaboration

Abstract

The production of exclusive ρ^0 mesons in deep-inelastic scattering events at HERA is studied with the H1 detector. The data used in this analysis correspond to 2.9 pb^{-1}. We observe two-prong events with a reconstructed mass in the ρ^0 resonance region. Cross sections are derived as function of W and Q^2. The main production characteristics are studied.

1 Introduction

The elastic production of ρ mesons can be studied at the HERA collider both with quasi-real photons ($Q^2 \to 0$) and with virtual photons ($Q^2 >$ several GeV^2). In the latter regime, production characteristics and comparison with lower energy data [1] [2] [3] are expected to provide information on the nature of diffractive interactions and possibly on the gluon density in the proton; in particular, several models based on non-perturbative [4] or perturbative [5] [6] QCD calculations have recently been proposed.

2 Event selection

This analysis is based on an integrated luminosity of 2.9 pb^{-1} accumulated by H1 in 1994, the colliding particles being 27.5 GeV positrons and 820 GeV protons. Its main goal is the study of the exclusive channel

$$e^+ + p \to e^+ + \rho^0 + p \;\; ; \;\; \rho^0 \to \pi^+ + \pi^-, \tag{1}$$

where the intermediate photon is highly virtual ("deep-inelastic scattering").

The events selected in the H1 detector [7] thus contain only a positron and two opposite charge pion candidates, originating from a vertex situated in the nominal e^+p interaction region. The scattered proton remains in the beam pipe and is not detected because of the small momentum transfer to the target in diffractive interactions.

The positron is identified as an electromagnetic cluster of energy larger than 12 GeV, reconstructed in the backward electromagnetic calorimeter and associated with a hit in the proportional chamber located in front of it. The backward direction is defined as that of the incident electron beam, the forward direction is that of the proton beam. Cuts are applied on hit and cluster positions in order to provide high trigger efficiency and a good quality measurement, which results in the selection of events with $Q^2 > 7$ GeV^2. The Q^2 is minus the square of the 4-momentum transfer from the electron to the hadrons. The pion candidates are required to be emitted in the central region of the H1 tracker, with polar angles $25° < \theta < 155°$, and with a momentum component transverse to the beam direction larger than 0.1 GeV/c. The difference between the total (ρ + e) energy and longitudinal momentum, $(E - p_z)$, is required to be larger than 45 GeV, in order to minimise radiative corrections.

Elastic ρ events can be contaminated by energy clusters not associated with the pion candidates, mainly resulting from background interactions which are not related to the e^+p collision and from backgrounds in the liquid argon calorimeter. Only events with less than 1 GeV energy deposited in the argon calorimeter inside an angle of 6° around the proton beam direction are used. The presence of additional clusters is parametrised by the variable E_{max}, defined as the energy of the most energetic cluster not associated with a track. The E_{max} distribution (Fig. 1) shows a peak at small values, attributed mostly to diffractive events, and a bump at higher energies; these two contributions cross around 0.5 GeV.

The sample of events containing an electron and two pion candidates consists in fact of two contributions : "elastic" ρ production, defined by reaction (1), and events where the proton is diffractively excited into a system of mass M_X, which subsequently dissociates. With the H1 detector, it is possible to identify part of these "proton dissociation" events, when particles from the diffractively excited system reach the detector components situated in the very forward region [8]. These events are tagged by the presence of at least 2 pairs of hits in the forward muon detector, or at least one hit in the proton tagger (an array of scintillators placed 24 m. downstream of the interaction point). In the present stage of the analysis, these events are used on a statistical basis for estimating the proton dissociation background to the elastic ρ signal.

3 Signal extraction

The ρ production event kinematics are defined by three independent variables, e.g. Q^2, W, the (ρ p) invariant mass, and t, the square of the 4-momentum transfer to the scattered proton. For elastic events, these variables are best reconstructed using the positron and ρ meson polar angles and the ρ momentum. The kinematical variables for all the selected events are computed under the asumption that they are due to elastic ρ production.

Fig. 2a shows the two pion candidate mass $M_{\pi\pi}$ for all the selected events (2296 events). A ρ peak appears over a background mostly concentrated at a lower mass. This background is strongly reduced when an E_{max} cut is applied to the data (see Fig. 2b, for $E_{max} < 1$ GeV).

On the other hand, diffractive production is characterized by a steeply falling t-distribution. For the events in the ρ peak with $(0.6 < M_{\pi\pi} < 1.0)$ GeV/c^2, it is indeed observed that the t-distribution is well described as the sum of two exponentials, attributed respectively to the diffractive ρ signal and a flatter background (Fig. 2c is for events with no E_{max} cut, and Fig. 2d for events with $E_{max} < 1$ GeV).

Varying the E_{max} cut between 0.5 and 1.5 GeV, and correcting for the loss of diffractive events with higher E_{max}-values, provides a stable total diffractive signal of $(380 \pm 25(stat) \pm 25(syst))$ events.

The mass distribution for the events with $E_{max} < 1$ GeV and $|t| < 1$ GeV^2 is shown on Fig. 3. It is well fitted by a Breit-Wigner distribution over a constant background, with a peak value of 750 MeV/c^2 and a width of 150 MeV/c^2, in good agreement with the PDG values. No skewing factor is needed to describe the ρ shape.

A clean sample of diffractive ρ events is thus selected with the cuts $E_{max} < 1$ GeV, $|t| < 1$ GeV^2 and $(0.6 < M_{\pi\pi} < 1.0)$ GeV/c^2 (392 event). The cross section for reaction (1) is extracted from this sample for $(7 < Q^2 < 25)$ GeV^2 and $(50 < W < 120)$ GeV/c^2 (256 events). Several correction factors are applied, to take into account detector acceptance and efficiencies, smearing and selection effects (in particular the electron selection criteria, and the $E - p_z$ and $M_{\pi\pi}$ cuts). These corrections are obtained directly from the data, and from a Monte-Carlo simulation describing in detail the H1 detector, based on the vector meson dominance model (VDM) [1] [9]. The W cut was designed in order to have a very small correction ($< 1\%$) for the central tracker acceptance, since this acceptance depends on the *a priori* unknown W dependence of the signal.

An important correction is due to the presence of diffractive events with proton dissociation. The rate of dissociative to elastic events is not known in the Q^2 range of this experiment. An advantage of the H1 experiment, already mentioned before, is that it is possible to use the forward muon detectors and the proton tagger to estimate this correction. In the final sample, 24 % of the selected events give a signal in these forward detectors and are thus tagged as due to proton dissociation. This result has to be corrected for the loss of elastic events due to the use of these detectors, and for the efficiency in tagging proton dissociation events. This is achieved using Monte Carlo simulations of elastic and proton dissociation ρ production (with a $1/\mathrm{M}_\mathrm{X}^2$ dependence of the cross section) [9]. For the present analysis, the proton dissociation contribution is subtracted uniformly, applying to the measured numbers of events a constant factor of (0.74 ± 0.08); the error takes into account the present uncertainties on the forward detector efficiencies and backgrounds, and the uncertainty on the details of the dissociation production and decay. It should be noted that this factor does not provide a measurement of the inelastic to elastic ρ meson production rate, since part of the dissociative events was already removed by the cut on the energy deposited in the forward part of the liquid argon calorimeter. Furthermore, the effect of possible differences in the |t|-slope distributions should be taken into account (see below). The average correction factor for losses and backgrounds is finally (1.33 ± 0.24).

4 Cross section and production characteristics

The total (transverse + longitudinal) cross section for elastic ρ meson production by virtual photons is estimated using the relation

$$\sigma(\gamma^* p \to \rho^0 p) = \Gamma^{-1} \, \frac{d^2\sigma(ep \to e\rho^0 p)}{dy dQ^2}, \tag{2}$$

where Γ^{-1} is a flux factor given, for small values of the Bjorken y variable, by

$$\Gamma^{-1} \simeq \frac{\pi \ y \ \mathrm{Q}^2}{\alpha \ (1-y)}. \tag{3}$$

Fig. 4 and 5 show, respectively, the $\sigma(\gamma^* p \to \rho^0 p)$ cross section as a function of Q^2 and as a function of W, in the latter case compared to the NMC [3] and the ZEUS [10] results.

The striking feature of the ZEUS and H1 high energy data, when compared to the NMC results, is the large increase in the cross section for similar Q^2-values as shown in Fig. 5. This contrasts with the slow increase with W of the ρ photoproduction ($\mathrm{Q}^2 \to 0$) cross section [11]. Calculations based on soft pomeron and non-perturbative two-gluon exchange [4] predict a slow cross section increase. On the other hand, several recent studies of vector meson production based on perturbative QCD predict a rapid cross section increase with W [5]. This is the case in particular for the calculation of [6], which relates the elastic ρ production cross section to the gluon distribution in the proton, known to increase steeply at small values of the Bjorken x variable, i.e. for large W [12].

The Q^2-dependence of the cross section for diffractive ρ production by virtual photons is found to be well described by a $\mathrm{Q}^{-2\mathrm{n}}$ power law, with an effective (preliminary) value for n of 2.4 ± 0.4. The error includes statistical and systematic uncertainties.

The study of the angular distribution of the ρ decay pions shows that the ρ mesons are mostly longitudinally polarised, as expected in most theoretical models.

The value of the forward diffractive slope extracted from the $|t|$-dependence of the ρ production cross section is of particular interest (see e.g. [13]). In photoproduction, the slope value is found to be around $-10\ \mathrm{GeV}^{-2}$, whereas the NMC experiment measures a slope value of $(-4.6 \pm 0.8)\ \mathrm{GeV}^{-2}$ for the Q^2 interval 6-25 GeV^2 [3]. For the present analysis, a (preliminary) value of $(-4.2 \pm 0.7(stat.) \pm 1.0(syst.))\ \mathrm{GeV}^{-2}$ is measured. However, it is important to stress that the proton dissociation background has presently only been subtracted statistically. Indeed, it is known [14] that double dissociation has a smaller slope than single diffraction (about half of it). There are indications from a preliminary analysis of the present data, that the value of the $|t|$-slope could be increased by as much as 50 % when only the ρ events giving no signal in the forward detectors are selected, i.e. for a cleaner sample of elastic events. Thus quoted values of the diffractive slope are to be taken with care when the inelastic background is not subtracted on an event by event basis.

5 Conclusions

In conclusion, the production of exclusive ρ^0 mesons for Q^2-values $> 7\ \mathrm{GeV}^2$ and for $(80 < W < 150)\ \mathrm{GeV/c}^2$ has been studied at HERA with the H1 detector. The $(\gamma^* p \rightarrow \rho^0 p)$ cross section was measured in function of Q^2 and W, showing an important increase compared to lower energy data. The Q^2-distribution is well fitted by a $Q^{-4.8\pm0.8}$ law (preliminary). The measured value of the diffractive slope is $b = (-4.2 \pm 0.7 \pm 1.0)\ \mathrm{GeV}^{-2}$(preliminary); however, it should be noted that the present sample contains a contribution of double dissociation events, statistically subtracted for cross section measurement, and that the slope value may significantly increase when only elastic events are kept.

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References

[1] T.H. Bauer et al., Rev. Mod. Phys. 50 (1978) 261.

[2] W.D. Shambroom et al., Phys. Rev. D26 (1982) 1;
J.J. Aubert et al., EMC Coll., Phys. Lett. B161 (1985) 203;
J. Ashman et al., EMC Coll., Z. Phys. C39 (1988) 169.

[3] M. Arneodo et al., NMC Coll., Nucl. Phys. B429 (1994) 503.

[4] A. Donnachie and P.V. Landshoff, Phys. Lett. B185 (1987) 403;
A. Donnachie and P.V. Landshoff, Nucl. Phys. B311 (1989) 509;
J.R. Cudell, Nucl. Phys. B336 (1990) 1;
A. Donnachie and P.V. Landshoff, Phys. Lett. B348 (1995) 213.

[5] M.G. Ryskin, Z. Phys. C57 (1993) 89;
J. Nemchick et al., Phys. Lett. B341 (1994) 228;
B.Z. Kopeliovich et al., Phys. Lett. B324 (1994) 469.
H. Abramowicz, L. Frankfurt and M. STrikman, DESY 95-047 (1995)

[6] S.J. Brodsky et al., Phys. Rev. D50 (1994) 3134.

[7] I.Abt et al., H1 Coll., DESY 93-103 (1993).

[8] I.Abt et al., H1 Coll., Phys. Lett. B348 (1995) 681;
A. Mehta, PhD Thesis, Manchester Univ., unpubl. (1995).

[9] B. List, Diploma Thesis, Techn. Univ. Berlin, unpubl. (1993).

[10] M. Derrick et al., ZEUS Coll., DESY 95-133 (1995).

[11] M. Derrick et al., ZEUS Coll., DESY 95-143 (1995)
S.Aid et al., H1 Coll., "Elastic Photoproduction of ρ^0 Mesons in H1 at HERA", to be publ.

[12] S.Aid et al., H1 Coll., DESY 95-081 (1995)
S.Aid et al., H1 Coll., DESY 95-086 (1995)

[13] J.R. Forshaw and M.G. Ryskin, DESY 94-192 (1994).

[14] K. Goulianos, Phys. Rep. 101 (1983) 169;
P. Amaudruz et al., NMC Coll., Z. Phys. C54 (1992) 239.

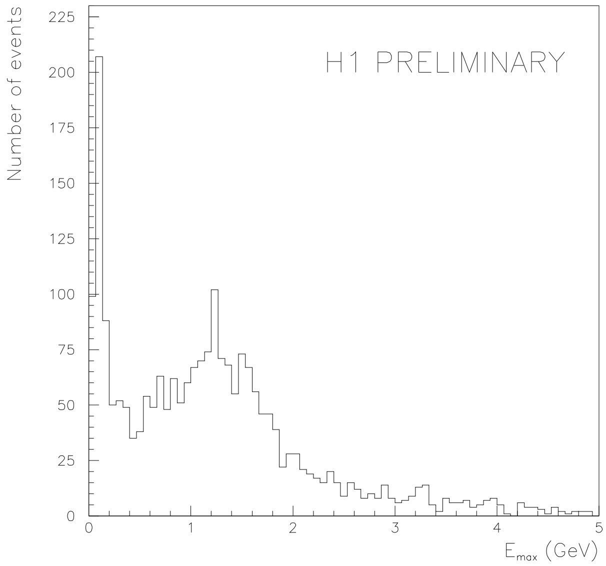

Fig. 1 : Distribution of E_{max}, the energy of the most energetic cluster in the liquid argon calorimeter, not associated with a ρ decay pion candidate track (all selected events).

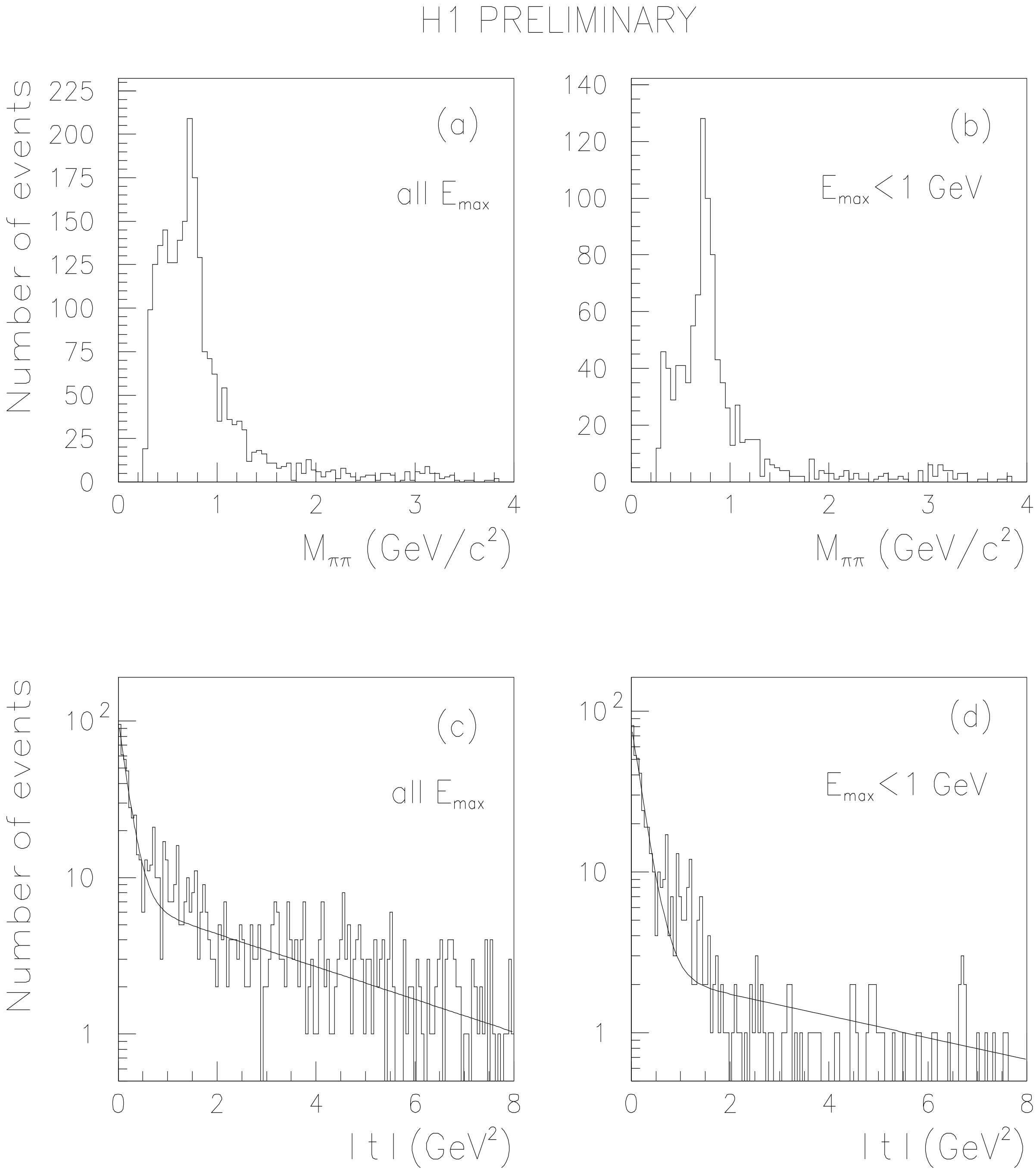

Fig. 2 : Distribution of the invariant mass $M_{\pi\pi}$ of ρ decay pion candidates : (a) all selected events, (b) events with $E_{max} < 1$ GeV; $|t|$-distribution for events with $(0.6 < M_{\pi\pi} < 1.0)$ GeV/c^2 : (c) all selected events, (d) events with $E_{max} < 1$ GeV.

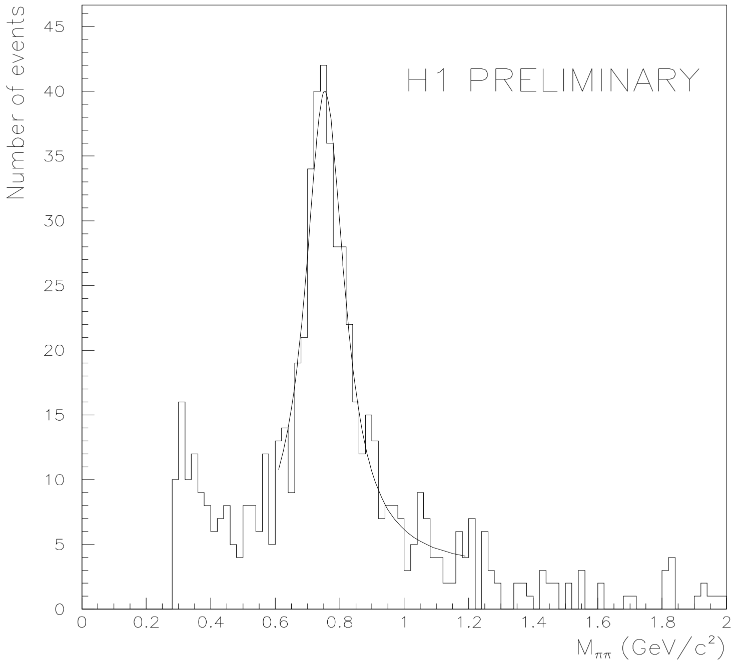

Fig. 3 : Distribution of the $M_{\pi\pi}$ mass for the events with $E_{\mathbf{max}} < 1$ GeV and $|t| < 1$ GeV^2 ; superimposed is the result of the fit to a Breit-Wigner distribution over a smooth background.

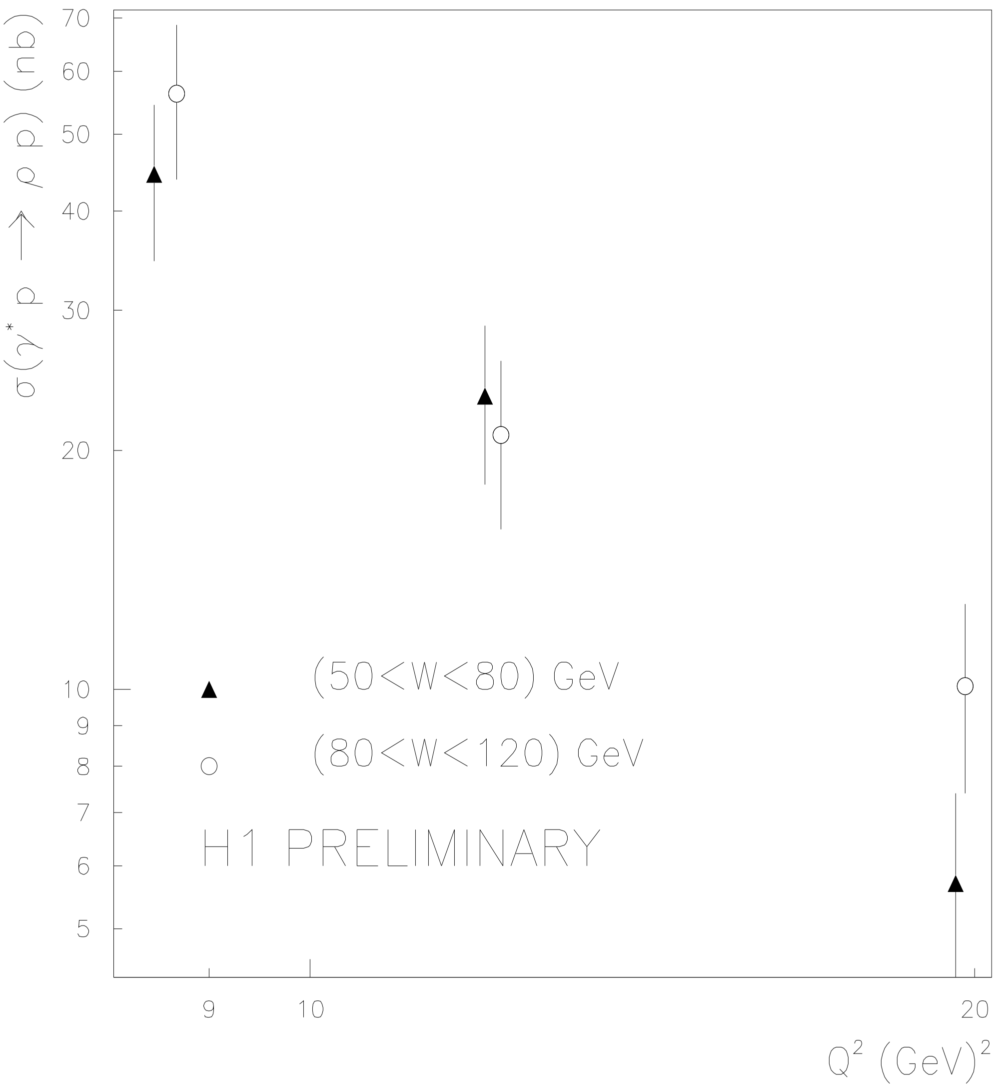

Fig. 4 : $(\gamma^{*}p \rightarrow \rho^{0}p)$ cross section in function of Q^2 for two W-intervals.

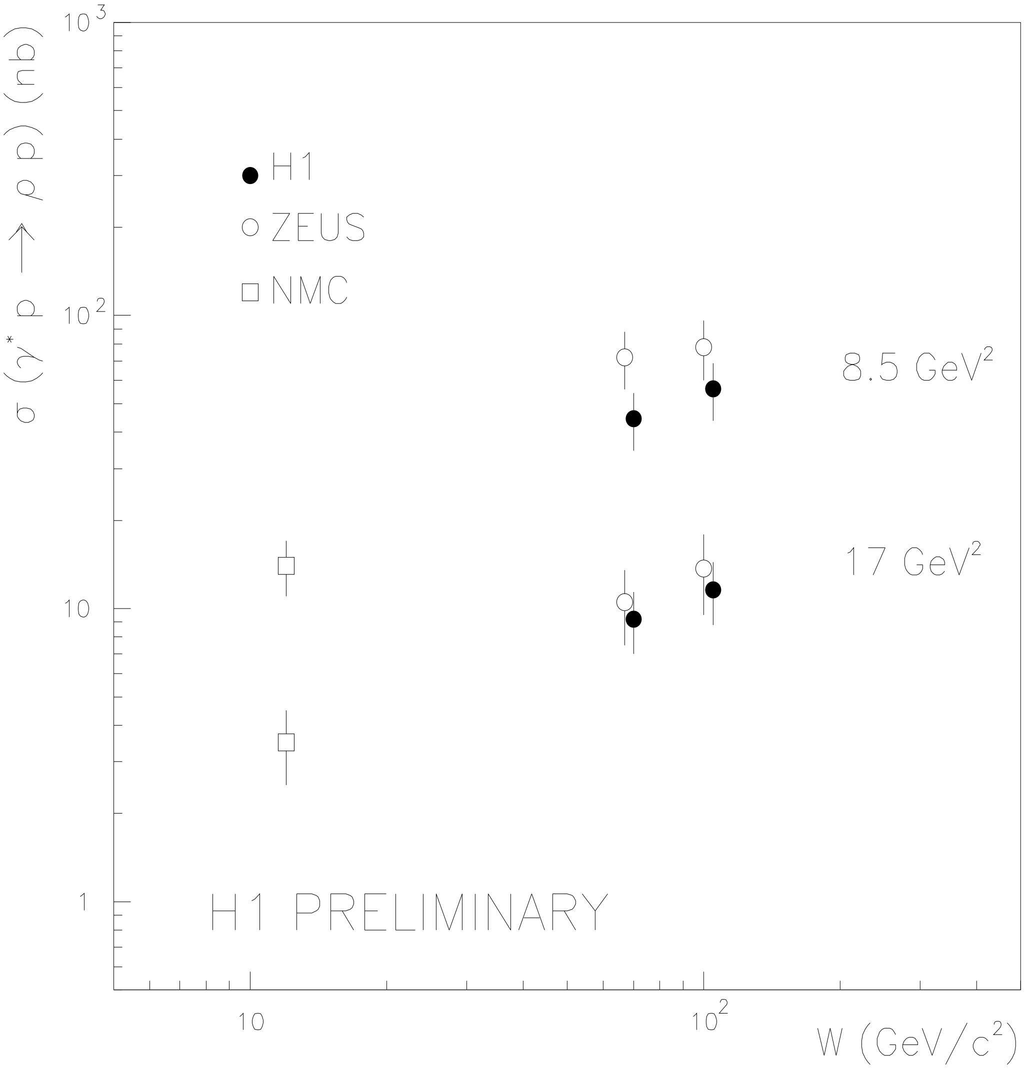

Fig. 5 : $(\gamma^* p \rightarrow \rho^0 p)$ cross section in function of W for two Q^2-values; the H1 results include statistical and systematic errors added in quadrature, the ZEUS results do not include a global systematic error of 31 %.