

## Exclusive $\rho^0$ meson photoproduction with a leading neutron at HERA

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**Abstract.** A first measurement is presented of exclusive photoproduction of  $\rho^0$  mesons associated with leading neutrons at HERA. The data were taken with the H1 detector in the years 2006 and 2007 at a centre-of-mass energy of  $\sqrt{s} = 319$  GeV and correspond to an integrated luminosity of  $1.16 \text{ pb}^{-1}$ . The  $\rho^0$  mesons with transverse momenta  $p_T < 1$  GeV are reconstructed from their decays to charged pions, while leading neutrons carrying a large fraction of the incoming proton momentum,  $x_L > 0.35$ , are detected in the Forward Neutron Calorimeter. The phase space of the measurement is defined by the photon virtuality  $Q^2 < 2 \text{ GeV}^2$ , the total energy of the photon-proton system  $20 < W_{\gamma p} < 100$  GeV and the polar angle of the leading neutron  $\theta_n < 0.75$  mrad. The cross section of the reaction  $\gamma p \rightarrow \rho^0 n \pi^+$  is measured as a function of several variables. The data are interpreted in terms of a double peripheral process, involving pion exchange at the proton vertex followed by elastic photoproduction of a  $\rho^0$  meson on the virtual pion. In the framework of one-pion-exchange dominance the elastic cross section of photon-pion scattering,  $\sigma^{el}(\gamma \pi^+ \rightarrow \rho^0 \pi^+)$ , is extracted. The value of this cross section indicates significant absorptive corrections for the exclusive reaction  $\gamma p \rightarrow \rho^0 n \pi^+$ .

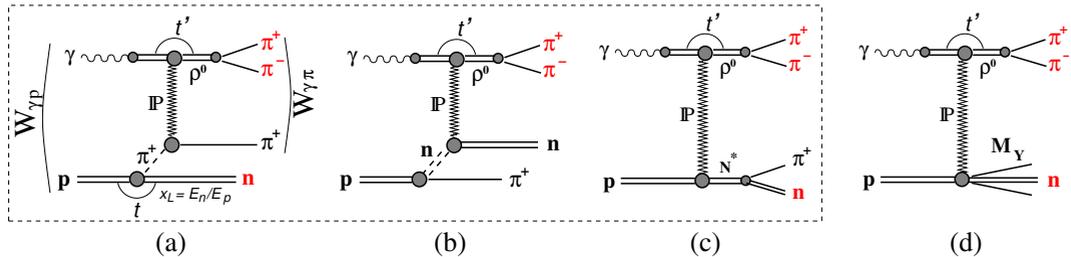
### 1 Introduction

The H1 experiment at HERA has measured exclusive photoproduction of  $\rho^0$  mesons associated with leading neutrons,  $\gamma p \rightarrow \rho^0 n \pi^+$ , with the aim to extract for the first time experimentally, the elastic  $\gamma \pi$  cross section. Here, for the  $\rho$  meson photoproduction at a soft scale, Regge phenomenology is most appropriate to describe the reaction. In the Regge framework the process is explained by the diagram shown in Fig. 1a which involves an exchange of two Regge trajectories in a process  $2 \rightarrow 3$ , known as Double Peripheral Process (DPP). In this picture the pion exchange at the proton vertex is followed by elastic scattering of this pion on the virtual photon emitted from the beam electron,  $\gamma \pi^+ \rightarrow \rho^0 \pi^+$ . The successful description of experimental data in similar reactions at lower energies has shown that in addition to the pion exchange (Fig. 1a) two further contributions (Fig. 1a, 1b) have to be included and interference between the graphs a,b, and c in Fig. 1 plays an important role [1].

The data sample corresponds to an integrated luminosity of  $1.16 \text{ pb}^{-1}$  and was collected at  $\sqrt{s_{ep}} = 319$  GeV using a special low multiplicity trigger. Exclusive events are selected containing two oppositely charged pions from the  $\rho^0$  decay, the leading neutron and nothing else above noise

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level in the detector. The pion from the proton vertex is emitted under very small angle with respect to the proton beam and escapes detection.



**Figure 1.** Generic diagrams for processes contributing to exclusive photoproduction of  $\rho^0$  mesons associated with leading neutrons at HERA. The signal corresponds to the Drell-Hiida-Deck model graphs for the pion exchange (a), neutron exchange (b) and direct pole (c). Background from diffractive  $\rho^0$  production with proton dissociation (d). The  $N^*$  in (c) denotes both resonant (via  $N^+$ ) and possible non-resonant  $n + \pi^+$  production.

Signal events (Fig. 1a) are modelled by the Monte Carlo generator POMPYT [2], in which the virtual pion is produced at the proton vertex according to one of the available pion flux parametrisations and then the quasi-elastic scattering process,  $\gamma\pi^+ \rightarrow \rho^0\pi^+$ , is generated. Diffractive  $\rho^0$  production with proton dissociation into a system containing a neutron (Fig. 1d) contributes as background to the DPP and is modelled by the DIFFVM generator [3]. This background is subtracted from the data and its fraction in the final data sample is estimated to be  $0.34 \pm 0.05$ . More details of the analysis can be found in [4].

## 2 Results

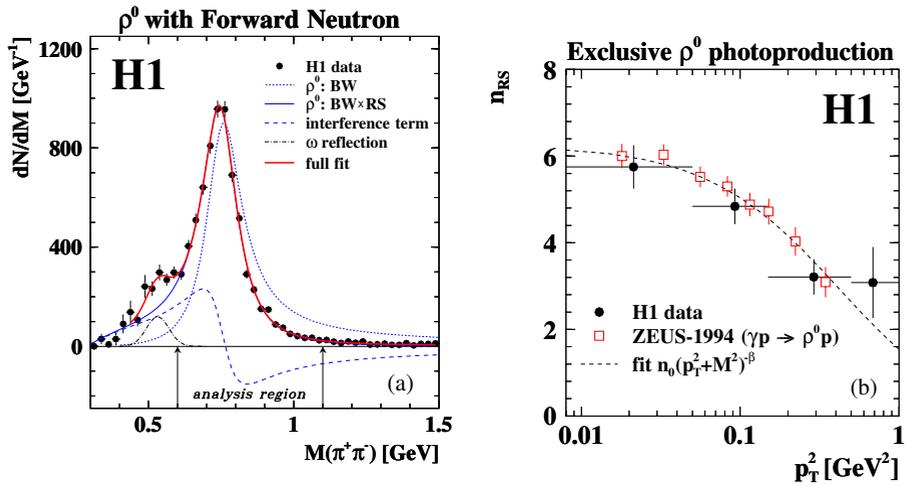
Fig. 2a shows the invariant mass distribution of two charged pions corrected for the mass dependent detector efficiency. The shape of the  $\rho^0$  mass deviates from a pure Breit-Wigner resonance and its distortion due to the interference between the resonant and non-resonant  $\pi\pi$  production (dashed curve in Fig. 2a) is characterised by the Ross-Stodolsky skewing parameter  $n_{RS}$ . The dependence of  $n_{RS}$  on  $p_T^2$  of the  $\pi\pi$  system measured in this analysis, as shown in Fig. 2b, is in agreement with results for elastic photoproduction of  $\rho^0$  mesons,  $\gamma p \rightarrow \rho^0 p$ , obtained previously by the ZEUS Collaboration.

The measured cross section of the exclusive reaction  $ep \rightarrow e\rho^0 n\pi^+$  is converted into the  $\gamma p$  cross section using the effective photon flux of the Vector Dominance model [5]. The integrated  $\gamma p$  cross section in the kinematic range  $20 < W_{\gamma p} < 100$  GeV,  $0.35 < x_L < 0.95$  and  $\theta_n < 0.75$  mrad is determined with 2% statistical and 14.6% systematic precision:

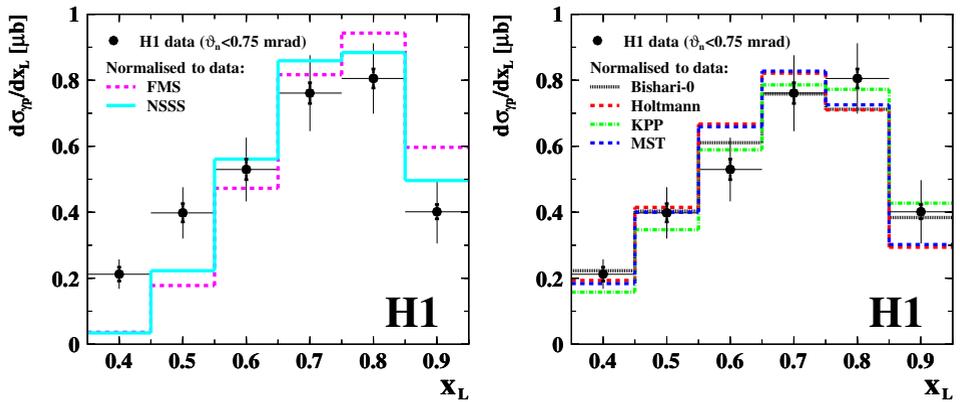
$$\sigma(\gamma p \rightarrow \rho^0 n\pi^+) = (310 \pm 6_{\text{stat}} \pm 45_{\text{sys}}) \text{ nb}. \quad (1)$$

The differential cross section  $d\sigma_{\gamma p}/dx_L$  compared to the predictions based on different models for the pion flux is shown in Fig. 3. The shape of the  $x_L$  distribution is well reproduced by most of the pion flux parametrisations (Fig. 3 right). However, some models can be ruled out even on the basis of a shape comparison alone (Fig 3 left). References to pion flux models can be found in [4].

The energy dependence of the reaction  $\gamma p \rightarrow \rho^0 n\pi^+$  is presented in Fig. 4 (left). The cross section drops with  $W_{\gamma p}$  in contrast to the POMPYT MC expectation, where the energy dependence is driven by Pomeron exchange alone. A Regge motivated power law fit to the data,  $\sigma_{\gamma p}(W_{\gamma p}) \propto W_{\gamma p}^{\delta}$ , yields  $\delta = -0.26 \pm 0.06_{\text{stat}} \pm 0.07_{\text{sys}}$ .

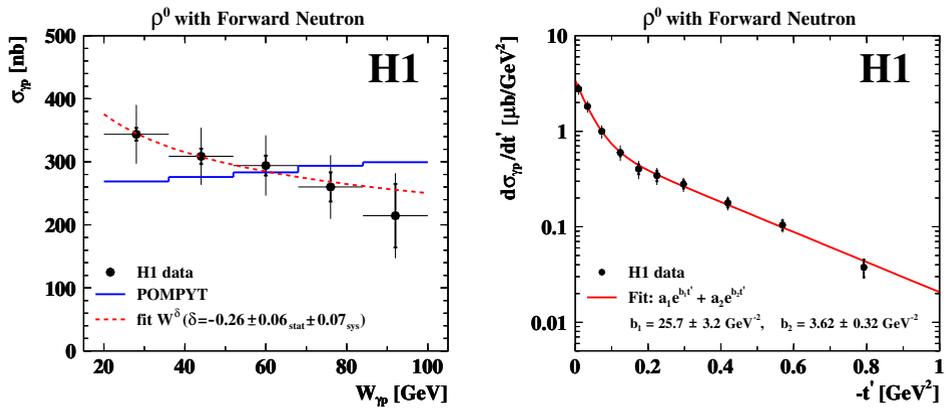


**Figure 2.** (a) Invariant mass distribution of two oppositely charged pions with  $p_T > 0.2$  GeV and polar angles within  $20^\circ < \theta < 160^\circ$ . (b) Ross-Stodolsky skewing parameter,  $n_{RS}$ , as a function of  $p_T^2$  of the  $\pi^+\pi^-$  system.



**Figure 3.** Differential cross section  $d\sigma_{\gamma p}/dx_L$  in the range  $20 < W_{\gamma p} < 100$  GeV compared to the predictions based on different models for the pion flux. The data points are shown with statistical (inner error bars) and total (outer error bars) uncertainties, excluding an overall normalisation error of 4.4%. All predictions are normalised to the data.

The cross section as a function of the four-momentum transfer squared of the  $\rho^0$  meson,  $t'$ , is shown in Fig. 4 (right). The  $t'$  distribution is fitted with the sum of two exponential functions with distinctly different slopes between the low- $t'$  and the high- $t'$  regions as expected for double peripheral processes. In a geometric picture, the large value of  $b_1$  suggests that for a significant part of the data  $\rho^0$  mesons are produced at large impact parameter values of order  $\langle r^2 \rangle = 2b_1 \cdot (\hbar c)^2 \approx 2\text{fm}^2 \approx (1.6R_p)^2$ . In this picture, photons find pions in a cloud which extends far beyond the proton radius. The small value of  $b_2$  corresponds to a target size of 0.5 fm.



**Figure 4.** (a) Cross section of the reaction  $\gamma p \rightarrow \rho^0 n \pi^+$  as a function of  $W_{\gamma p}$  compared to the prediction from the POMPYT MC program, which is normalised to the data. (b) Differential cross section  $d\sigma_{\gamma p}/dt'$  of  $\rho^0$  mesons.

At small momentum transfer squared at the proton vertex,  $t$ , the pion exchange diagram (Fig. 1a) dominates the photoproduction cross section for exclusive  $\rho^0$  production with a leading neutron. Thus the elastic photon-pion cross section is extracted from  $d\sigma_{\gamma p}/dx_L$  in the one-pion-exchange (OPE) approximation [6], using the pion flux parametrisation of the Holtmann model [7] compatible with the data. Using the pion flux integrated in  $x_L$  and  $p_{T,n}$ , the elastic  $\gamma\pi$  cross section is determined at an average energy  $\langle W_{\gamma\pi} \rangle \simeq 24 \text{ GeV}$ :

$$\sigma(\gamma\pi^+ \rightarrow \rho^0\pi^+) = (2.33 \pm 34(\text{exp})_{-0.40}^{+0.47}(\text{model}))\mu\text{b}. \quad (2)$$

The estimated cross section ratio for the elastic photoproduction of  $\rho^0$  mesons on the pion and on the proton,  $r_{el} = \sigma_{el}^{\gamma\pi}/\sigma_{el}^{\gamma p} = 0.25 \pm 0.06$ , indicates an absorption factor of  $K_{abs} = 0.44 \pm 0.11$  for the exclusive reaction  $\gamma p \rightarrow \rho^0 n \pi^+$ .

### 3 Summary

The photoproduction cross section for exclusive  $\rho^0$  production associated with a leading neutron is measured for the first time at HERA. Differential cross sections for the reaction  $\gamma p \rightarrow \rho^0 n \pi^+$  show behaviour typical for exclusive double peripheral exchange process. The elastic photon-pion cross section,  $\sigma(\gamma\pi^+ \rightarrow \rho^0\pi^+)$ , is extracted in the one-pion-exchange approximation. The value of this cross section indicates large absorptive corrections for the exclusive reaction  $\gamma p \rightarrow \rho^0 n \pi^+$ .

### References

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