Search for Odderon induced contributions to exclusive Meson Photoproduction at HERA*

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Abstract

Odderon induced contributions to exclusive photoproduction of π°, $f_2(1270)$ and $a_2(1320)$ have been searched for at HERA, using the multiphoton decays of these mesons. No indication for such contributions was found, in a kinematic region defined by the average photon-proton centre-of-mass energy $\langle W \rangle = 200 - 215$ GeV, photon virtualities $Q^2 < 0.01$ GeV^2 and 0.02 GeV$^2 < |t| < 0.3$ GeV^2, where t is the squared momentum transfer at the proton vertex. The measured upper limits for the cross sections, $\sigma(\gamma p \xrightarrow{\mathbb{O}} \pi^\circ N^*) < 39$ nb, $\sigma(\gamma p \xrightarrow{\mathbb{O}} f_2(1270)X) < 16$ nb and $\sigma(\gamma p \xrightarrow{\mathbb{O}} a_2(1320)X) < 96$ nb, all at 95 % CL, are lower than the predictions by a theoretical model. Exclusive photoproduction of ω and $\omega\pi^\circ$, in the 3γ and 5γ decay modes, is observed with the expected cross sections.

1 Introduction

The discussion about the possible contribution of an odd-under-crossing amplitude in high energy hadron-hadron scattering goes back to the early 1970's. The seminal papers[1, 2] established the Odderon[1] as the $C = P = -1$ partner of the Pomeron trajectory, with an intercept $\alpha_{\mathbb{O}}(0) \approx 1$. In the Regge picture the presence of the Odderon amplitude would lead to a difference in the total cross sections for hh and $\bar{h}h$ scattering at high energies, and thus to a violation of Pomeranchuk's theorem[3]. This and other predictions based on the differences in cross sections of hh and $\bar{h}h$ scattering could however not be satisfactorally tested, due to the scarcity of precise measurements at high energies. Indeed, global fits (see e.g. [4]) of the available hh and $\bar{h}h$ data seemed to establish the conventional Regge picture, with the high energy scattering dominated by exchange of the $C = P = +1$ Pomeron, and with the odd amplitudes dominated by (Reggeon) trajectories with intercepts $\alpha_{\mathbb{R}}(0) \approx 1/2$; Reggeon exchange then contributes only at low scattering energies.

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[1] Odd-under-crossing-Pomeron[2].

In the parton picture, the quantum numbers of the Pomeron and Odderon make it natural to view their exchange as exchange of 2 and 3 gluons, respectively. With the development of perturbative QCD (pQCD) the interest in the Odderon has in recent years intensified, since in the investigations of multigluon compound states, exact solutions to the Odderon equations have been found[5]. pQCD based predictions, for exclusive reactions specific to Odderon exchange, like $\sigma(\gamma p \xrightarrow{\mathbb{O}} \eta_c p) = 50$ pb at $Q^2 = 0$[6], as well as for several asymmetry effects due to the interference of Pomeron and Odderon exchange[7], now pose a challenge to experiments at HERA and elsewhere.

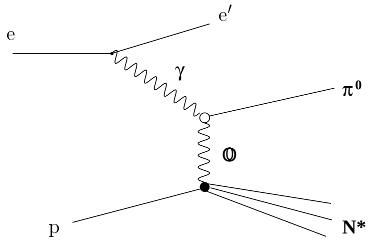

Figure 1: Diagram for exclusive π° photoproduction, via Odderon-photon fusion. The proton is excited into an $I = 1/2$ isobar.

Exclusive photoproduction and electroproduction of pseudoscalar and tensor mesons via Odderon-photon fusion are reactions where Pomeron exchange cannot contribute, and their detection and measurement would therefore be a clear proof of the existence of the Odderon. Such reactions are accessible at the ep collider HERA. The corresponding diagram is shown in Fig. 1, for the particular case of exclusive π° photoproduction,

$$ep \xrightarrow{\mathbb{O}} e\pi^\circ N^*. \tag{1}$$

The cross section of process (1) has been calculated by E.R. Berger et al.[8] and is of special interest to the HERA experiments, since the predicted cross section is sizable and within reach of experimental confirmation. The calculation is based on non-perturbative QCD, applying functional methods[9] in the framework of the "Model of the Stochastic Vacuum" (MSV)[10]. In the model the proton is viewed as a diquark-quark system in transverse space; through symmetry arguments the suppression of Odderon exchange in the elastic case (as well as in pp and $\bar{p}p$ scattering) can be explained. This suppression is not present when the proton is excited into an N^* state with negative parity. Thus the predicted cross section is $\sigma(\gamma p \xrightarrow{\mathbb{O}} \pi^\circ N^*) = 294$ nb at $W_{\gamma p} = 20$ GeV. Using the relation $\sigma = \sigma_\circ (W_{\gamma p}^2/20^2)^{\alpha_{\mathbb{O}}(0)-1}$, the same[2] large cross section is predicted for HERA energies, $\langle W_{\gamma p} \rangle = 200 - 215$ GeV.

2 Monte Carlo Simulation

A characteristic feature of the MSV calculation is the t dependence of the cross section, shown as $d\sigma/dp_T$ in Fig. 2 (p_T is the transverse momentum of the produced π°, and $|t| \sim p_T^2$ is a good approximation in photoproduction). As seen, the cross section is large in the region of experimental acceptance,

[2]In [8] $\alpha_{\mathbb{O}}(0) = 1.15$ is estimated, leading to an even larger predicted cross section at HERA energies. The use of $\alpha_{\mathbb{O}}(0) = 1$ is however strongly recommended[11].

$0.02 < |t| < 0.3$ GeV^2, in contrast to the case of the $\gamma\gamma$ reaction.

In order to simulate events of the Odderon exchange reaction (1), the Monte Carlo simulation program DIFFVM[12] was modified to include this characteristic t dependence. Further modifications concern the inclusion of the N^* states N(1520), N(1535), N(1650) and N(1700); 42% of their decays result in a leading neutron.

Trivial background was simulated using the PYTHIA program[13]. Such background is expected from several diffractive processes with incompletely reconstructed final states, like exclusive vector meson production ($\gamma p \to \omega N^*$, $\omega \to \gamma\pi^\circ$; $\gamma p \to \rho^\circ N^*$, $\rho^\circ \to \gamma\pi^\circ$) or inclusive π° production, $\gamma p \to \pi^\circ X N^*$. Exclusive π° production via $\gamma\gamma$ interactions (Primakoff effect) or Reggeon (ω) exchange, $\gamma p \xrightarrow{\omega} \pi^\circ N^*$, is negligible.

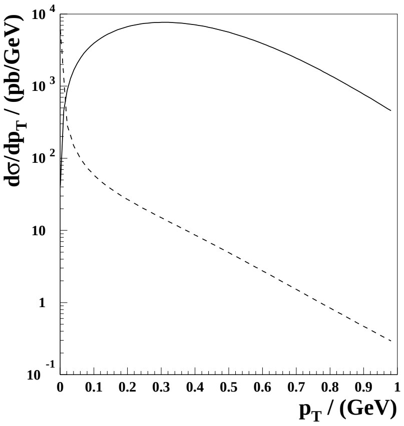

Figure 2: The π° transverse momentum distribution for Odderon exchange (solid line), compared to the corresponding distribution for photon exchange (dashed line).

3 Experimental procedure

A comprehensive description of the H1 detector is given in [14]. The detector components of importance for the present analysis are given by the simple experimental signature of process (1): The two photons from the π° decay are detected in the backward[3] electromagnetic calorimeters of H1, the SpaCal[15] and the VLQ[16], while the scattered electron is detected in the Electron Tagger, located 33 m upstream of the interaction point. The N^* is identified through those decays in which a leading neutron is produced. The latter is detected in the Forward Neutron Calorimeter (FNC), located 108 m downstream of the interaction point. The other major components of H1, namely the tracking chambers and the liquid argon calorimeter, were only used for the veto conditions, in the selection of exclusive events of process (1).

The data used in this analysis correspond to an integrated luminosity of 30.6 pb^{-1} and were obtained during the data taking period 1999-2000. The e and p beam energies were 27.5 and 920 GeV, respectively. The trigger was given by a combination of energy signals in the involved calorimeters, namely VLQ, FNC and Electron tagger. For further details of the experimental setup and the event selection, see [17].

[3] The z-axis of the H1 coordinate system coincides with the HERA beamline, the proton beam direction defining the positive direction.

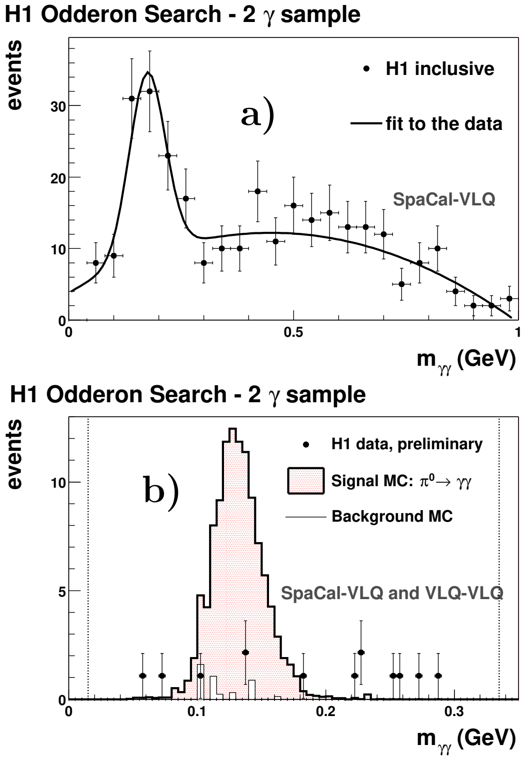

Figure 3: Two photon inv. mass. a) Inclusive two photon event sample with one photon detected in VLQ and one in SpaCal. The curve shows the fitted sum of a Gaussian and a polynomial background term. b) Final exclusive two photon event sample. One photon is detected in VLQ, the other either in SpaCal or in VLQ. Also shown are the expectations from model (hatched histogram) and background (white histogram). Vertical lines indicate the mass region for π° candidates.

In the first step of the analysis events with exactly two "good" photons are selected, where "good" photons are defined as electromagnetic clusters with energy above certain thresholds, with cluster shapes compatible with the photon hypothesis, and with positions within the fiducial volumes of the calorimeters, avoiding energy loss from shower leakage. At least one photon had to be detected in the VLQ (trigger condition). This selection defines an *inclusive* event sample, for which the mass of the two photons is shown in Fig. 3a, for the topology VLQ-SpaCal photons.

A clear π° signal is seen in Fig. 3a. Since the events are not yet subjected to an *exclusive* selection, this signal can be taken as proof that π°'s indeed can be detected. In order to arrive at a sample of exclusive events, corresponding to reaction (1), further selection cuts are applied: No charged track activity is allowed in the event, and the longitudinal energy balance $E - p_z$ must be satisfied by the energies of the scattered electron and the two photons: $49 < (E - p_z)_{e'\gamma\gamma} < 60$ GeV (the longitudinal energy balance of all particles produced at the electron vertex is expected to sum up to twice the incident electron energy).

The invariant mass distribution of the two photons in the final two photon event sample, after all selection cuts, is shown if Fig. 3b. Only a few events pass all cuts, and there is no indication of a π° signal; altogether 13 events are observed in the generous π° window, indicated by the dotted lines. These few events are consistent with the background expectation from PYTHIA, namely 4 events. In contrast, the expectation from the MSV model is 110 events.

An upper limit for the cross section of reaction (1) can be derived from the data, using the prescription of [18]. This preliminary upper limit,

$$\sigma(\gamma p \xrightarrow{\mathbb{O}} \pi^\circ N^*) < 39 \text{ nb} \quad (95\%\ \text{CL}),$$

has to be compared with the predicted value of 200 nb at HERA energies; the latter value is clearly incompatible with the observation even when considering the warning given in [8], "uncertainty at least a factor 2".

4 Discussion

The upper limit for the cross section of the reaction $ep \xrightarrow{\mathbb{O}} e\pi^\circ N^*$ is a factor 5 below the model prediction. Can this non-observation be understood? Possible explanations are:

1. The energy dependence of the cross section is different from the assumed one, implying that the Odderon intercept is considerably smaller than unity. Indeed, predictions for the Odderon intercept in the literature span a wide range. The H1 non-observation result can also be interpreted as an upper limit on the intercept, $\alpha_{\mathbb{O}}(0) < 0.65$. Such a low value is rather in the range of standard Reggeon intercepts, incompatible with the expectation for the "classical" Odderon.

2. The coupling $\gamma\mathbb{O}\pi^\circ$ is much smaller than assumed in [8]. This could be due to the Goldstone Boson nature of the π°[19]. More reliable predictions for Odderon induced exclusive meson production can then be expected for heavier mesons, like the tensor mesons $f_2(1270)$ and $a_2(1320)$. Predictions for such cross sections have also been made within the MSV framework[20, 11] and their experimental investigation by the H1 collaboration[21, 22] is described below.

5 Photoproduction of $f_2(1270)$ and $a_2(1320)$

In order to study the exclusive photoproduction of the tensor mesons $f_2(1270)$ and $a_2(1320)$, their decays into four photons were utilized: $ep \to ef_2(1270)X$, $f_2 \to 2\pi^\circ$ and $ep \to ea_2(1320)X$, $a_2 \to \pi^\circ\eta$. The data set used in this analysis

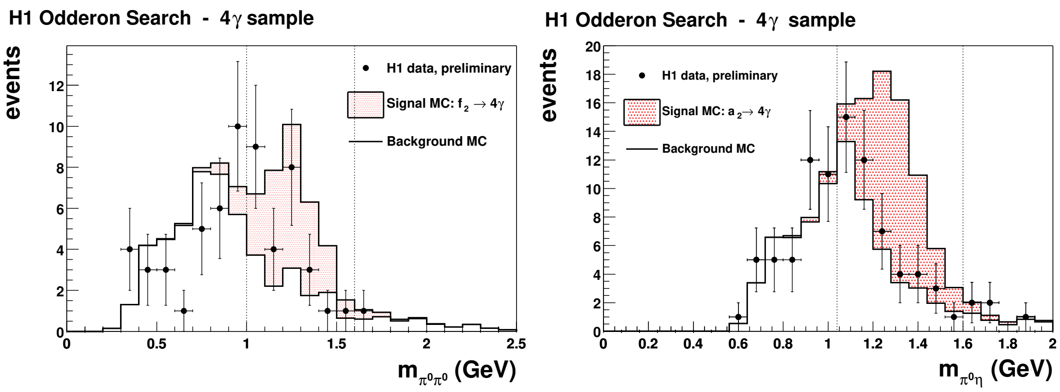

Figure 4: Four photon invariant mass, for $\pi^\circ\pi^\circ$ and $\pi^\circ\eta$ event candidates. Also shown are the expectations from model (hatched histograms) and background (white histograms). Vertical lines indicate the f_2 and a_2 mass bands, used for the upper limits derivation.

was obtained in 1996 and corresponds to 4.5 pb^{-1}. In contrast to the previous analysis, the four photons were all detected in the SpaCal, and the trigger was based on a combination of energy deposits in the electron tagger and the SpaCal, without special requirements on a detected neutron. The average

CMS energy is $\langle W_{\gamma p}\rangle = 200$ GeV, corresponding to the lower proton beam energy in this data taking period, 820 GeV.
Exclusive events with exactly four good photons were selected, satisfying the restrictions of longitudinal energy balance and no charged track activity. The two photon mass distribution, with 6 entries per event, has a clear π° peak. However, the recoil mass spectrum, obtained for the remaining two photons for each π° candidate, has only a weak π° signal, and no η signal. Selecting nevertheless those events with two photon combinations in massbands corresponding to $\pi^\circ\pi^\circ$ and $\pi^\circ\eta$ final states, the four photon mass distributions in Fig. 4 are obtained. They agree well with the expected, trivial background, as given by PYTHIA. Since no signals of f_2 or a_2 are seen in Fig. 4, preliminary upper limits for the cross sections are derived, again using [18]:

$$\sigma(\gamma p \xrightarrow{\mathbb{O}} f_2(1270)X) < 16 \text{ nb} \quad \text{and} \quad \sigma(\gamma p \xrightarrow{\mathbb{O}} a_2(1320)X) < 96 \text{ nb}.$$

These limits, both at 95 % CL, can be compared with the model predictions[20, 11], 21 and 190 nb, respectively.

6 Exclusive photoproduction of ω and $\omega\pi^\circ$

Multiphoton final states induced by Odderon exchange have C-parity +1 and thus even number of photons. In contrast, final states induced by Pomeron exchange have C-parity −1 and consequently an odd number of photons. Exclusive final states of three and five photons were therefore studied, searching for exclusive vector meson production, a process which is conventionally described by Pomeron exchange. The same data set was used as in case of the four photon final state investigation described above.

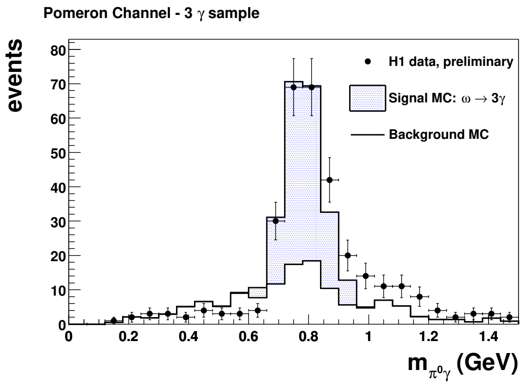

Figure 5: Three photon invariant mass, for $\gamma\pi^\circ$ event candidates. Model prediction and expected background (hatched and white histograms) are also shown.

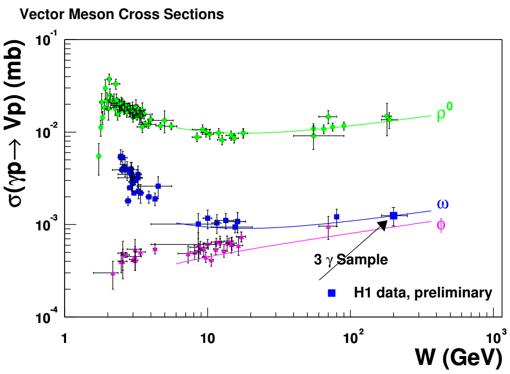

Figure 6: Synopsis of elastic vector meson photoproduction cross sections vs. $W_{\gamma p}$, from fixed target to HERA experiments.

In the exclusive three photon event sample, the two photon mass distribution, with 3 entries per event, shows a clear π° peak. The three photon mass distribution for events having at least one candidate for the $\gamma\pi^\circ$ final state is shown in Fig. 5. A prominent ω peak is seen, due to the decay $\omega \to \gamma\pi^\circ$. The corresponding[4] preliminary cross section is

$$\sigma(\gamma p \to \omega p) = (1.25 \pm 0.17 \pm 0.22)\ \mu\text{b},$$

which agrees very well with the expectation from other measurements, Fig. 6.

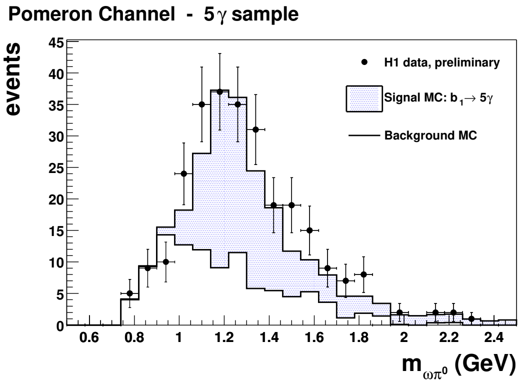

Figure 7: Five photon invariant mass for $\omega(\gamma\pi^\circ)\pi^\circ$ event candidates. Also shown are the model prediction (hatched histogram) and the expected background (white histogram).

Also the exclusive final state of five photons shows a prominent π° peak in the two photon mass distribution (10 entries per event). Many events are candidates for the final state $\gamma\pi^\circ\pi^\circ$ and the three photon mass recoiling against a π° candidate shows a clear ω peak. Selected events with mass combinations in the corresponding π° and ω mass bands have the five photon mass distribution in Fig. 7. The axial vector meson $b_1(1235) \to \omega\pi^\circ$, earlier observed in photoproduction at lower energies[23], is a candidate for the broad resonant structure observed above the PYTHIA background.

The preliminary cross section is

$$\sigma(\gamma p \to \omega\pi^\circ X) = (980 \pm 200 \pm 200)\ \text{nb},$$

with a background of 190 nb. The difference, i.e. the cross section which possibly may be attributed to exclusive resonant $\omega\pi^\circ$ production, is compatible with the cross section measured in [23] for $b_1(1235)$ photoproduction. Extrapolated to HERA energies[5], it is $\sigma(\gamma p \to b_1(1235)p) = (660 \pm 250)$ nb.

7 Summary

A search for exclusive photoproduction of π°, $f_2(1270)$ and $a_2(1320)$, induced by Odderon exchange, was performed using multi-photon final states. No signal was found. Upper limits for the cross sections are below the predictions of a model based on non-perturbative QCD.

Exclusive ω and $\omega\pi^\circ$ photoproduction is observed in three and five photon final states, at levels consistent with the expectations from Pomeron exchange and consistent with other observations of exclusive vector and axial vector meson photoproduction.

[4]Note that feed-down background from the exclusive photoproduction of $\omega\pi^\circ \to 5\gamma$ has been taken into account.

[5]The extrapolation followed [24] in analogy to the ordinary vector mesons with the $\gamma\mathbb{P}V$ coupling adapted to match the low energy data.

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