# INVESTIGATION OF POMERON- AND ODDERON INDUCED PHOTOPRODUCTION OF MESONS DECAYING TO PURE MULTIPHOTON FINAL STATES AT HERA* **

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In this contribution the first search at HERA for Odderon induced reactions is presented and contrasted with cross section measurements for Pomeron induced processes. The searches are performed in the channels $\gamma p \to \pi^0 N^*$, $\gamma p \to f_2(1270)X$ and $\gamma p \to a_2 X$, where $N^*$ denotes an excited nucleon state. The rates found are compatible with the background alone, and the upper limits derived therefrom are confronted with the expectations of a specific non-perturbative QCD model. In contrast, to these findings the cross sections for the Pomeron mediated processes — $\gamma p \to \omega p$ and $\gamma p \to \omega \pi^0 X$ — were found to be in perfect agreement with earlier measurements and the expectations from Regge theory with soft Pomeron exchange. The mean $\gamma p$ centre-of-mass energies were $\langle W \rangle = 200\,\mathrm{GeV}$ and 215 GeV, respectively.

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## 1. Introduction

This contribution reports on a search for Odderon [1] induced processes and limits on the cross sections derived for the reactions $\gamma p \to \pi^0 N^*$, $\gamma p \to f_2 X$ and $\gamma p \to a_2 X$, as well as on measurements of the Pomeron [2] mediated processes $\gamma p \to \omega p$ and $\gamma p \to \omega \pi^0 X$, in the photoproduction regime ($Q^2 < 0.01\,\mathrm{GeV}^2$) at HERA. The outgoing baryonic system is in

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general not observed and thus denoted by $X$, in case of elastic processes the proton stays intact and is therefore denoted by $p$, and if a neutron was detected in the Forward Neutron Calorimeter, it is assumed that this neutron stems from the decay of an $I = 1/2$ nucleonic state and the final state baryon is denoted by $N^*$. The Pomeron ($\mathbb{P}$) — the Regge-trajectory [3] that is thought to dominate the hadronic cross section at high energies — exchanges only vacuum quantum numbers and in particular it is *even* under crossing *i.e.* has $C$-parity of $+1$. Its hypothetical partner that is *odd* under crossing *i.e.* $C = -1$, called the Odderon ($\mathbb{O}$), has not been observed yet.

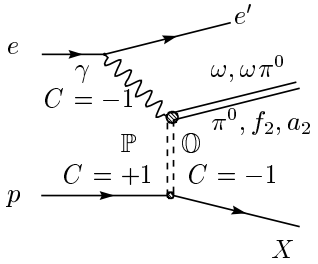


Fig. 1. Generic graph illustrating $\gamma p$ interactions via Pomeron- and Odderon exchange, respectively.

The respective processes leading to the above final states are sketched schematically in Fig. 1. Only purely photonic final states of the mesons are analysed, since together with the $C$-parity of the incoming photon the number of final state photons uniquely determines the $C$-parity of the exchanged trajectory, viz. an even number of final states photons can only be produced if odd $C$-parity ($\mathbb{O}$) is exchanged from the proton side, and vice versa an odd number of final state photons can only produced by a $C$ even ($\mathbb{P}$) exchange.

Vector meson photoproduction can be well described in the framework of the Vector Meson Dominance (VMD) model combined with Regge phenomenology [4].

In order to describe the Odderon induced production of the $\pi^0$, the $f_2$ and the $a_2^0$ a genuine non-perturbative QCD model is applied, namely the Stochastic Vacuum Model [5,6] (SVM). In this model the proton is treated as quark-diquark system and the photon as a quark-antiquark colour dipole. Both are convoluted with appropriate wavefunctions of the initial and final states, respectively.

## 2. Event selection

The analyses are based on data samples taken in the years 1996 ($\omega$, $\omega\pi^0$, $f_2$ and $a_2^0$), 1999 and 2000 (both for the exclusive $\pi^0$). The integrated luminosities are 4.5 pb$^{-1}$ for 1996 and 30.6 pb$^{-1}$ for the years 1999 and 2000 combined, respectively.

Electrons of 27.6 GeV were brought to collision with protons of 820 GeV[1]. Photoproduction events were selected by demanding the scattered electron to be detected under very low angles in a small angle Electron Detector (ET) 33 m downstream the electron beam, resulting in a limited phase-space of $Q^2 < 0.01\,\mathrm{GeV}^2$ and $0.3 < y < 0.7$.

Depending on the meson analysed the number of photons in the final state varies from two to five: $\pi^0 \to \gamma\gamma$, $\omega \to \pi^0\gamma \to 3\gamma$, $f_2 \to \pi^0\pi^0 \to 4\gamma$, $a_2^0 \to \pi^0\eta \to 4\gamma$, and $\omega\pi^0 \to (\pi^0\gamma)\pi^0 \to 5\gamma$, respectively. These photons are detected in the backward calorimeter(s) of the H1-detector [7], since the mesons are produced with only little transverse momentum but large and negative longitudinal momentum as the initial quasi-real photon is emitted nearly parallel to the incident electron with energies of $\sim 8 - 20\,\mathrm{GeV}$. For 1996 the analyses were restricted to the SpaCal [8] only and for the exclusive $\pi^0$-measurement of the years 1999 and 2000 the VLQ-calorimeter [9] and the Forward Neutron Calorimeter (FNC) [10] were included additionally.

To ensure that the events selected were indeed exclusive a variant of energy-momentum conservation was utilised, viz. $50(49)\,\mathrm{GeV} < \Sigma < 60\,\mathrm{GeV}$, where $\Sigma := \sum_i E^{(i)} - p_z^{(i)}$, and the sum runs over all photons the SpaCal, the VLQ and the scattered electron. The number in brackets refers to the exclusive pion analysis. If $\Sigma$ is found to be equal (within the resolution) twice the beam energy of 55 GeV the whole final state is detected.

For the mesons decaying via $\pi^0$'s and $\eta$'s appropriate mass windows for the respective $\gamma\gamma$-masses of 40 MeV and 100 MeV around the their nominal values of 135 MeV and 547 MeV, were chosen, according to the resolution of the SpaCal, except for the exclusive pion, where the window was determined by means of the width of *inclusive* pions, namely $15\,\mathrm{MeV} < m_{\gamma\gamma} < 335\,\mathrm{MeV}$.

For the $\omega$ it was further required that the interaction occurred elastically by imposing cuts limiting the mass of possible proton-excitations to less than 1.6 GeV, in contrast to the exclusive $\pi^0$ were it was explicitely demanded that the proton was excited into a state ($N^*$) decaying into a leading neutron, which was detected in the forward neutron calorimeter. For the remaining analyses no constraints on the outgoing baryonic final state were imposed.

## 3. Monte Carlo models

In order to describe the processes under study DIFFVM [12] and a derivative of this generator called OPIUM [13][2] were used. In addition to the processes based on Pomeron exchange combined with VMD as implemented in DIFFVM, OPIUM is capable to generate pseudoscalar and tensor mesons as described in [6]. The background consisting of inclusive $\gamma p$-interactions and mesons decaying via charged pions, was studied using PYTHIA [11].

[1] For the years 1999 and 2000 the proton energy was 920 GeV.

[2] OPIUM is an acronym for *Odderon, Pomeron Induced Unified Meson Maker.*

## 4. Results

Fig. 2 shows the invariant mass spectra of the $\pi^0$-, $f_2$- and $a_2^0$-searches, respectively. Since the distributions observed are compatible with the background alone, 95% confidence level limits on the cross sections are given. The predictions of the SVM are give in brackets for comparison.

$$\begin{aligned} \sigma_{\rm acc}(\gamma p \to \pi^0 N^*) &< 39\,{\rm nb} \quad (200\,{\rm nb})\,, \\ \sigma(\gamma p \to f_2 X) &< 16\,{\rm nb} \quad (21\,{\rm nb})\,, \\ \sigma(\gamma p \to a_2^0 X) &< 96\,{\rm nb} \quad (190\,{\rm nb})\,. \end{aligned} \tag{1}$$

The top part of Fig. 3 shows the invariant $\pi^0\gamma$-mass spectrum from which a cross section for elastic $\omega$-photoproduction of

$$\sigma(\gamma p \to \omega p) = (1.3 \pm 0.2({\rm stat}) \pm 0.2({\rm syst}))\,\mu{\rm b}$$

was derived. This result is in nice agreement with expectations from the VDM combined with Regge extrapolations.

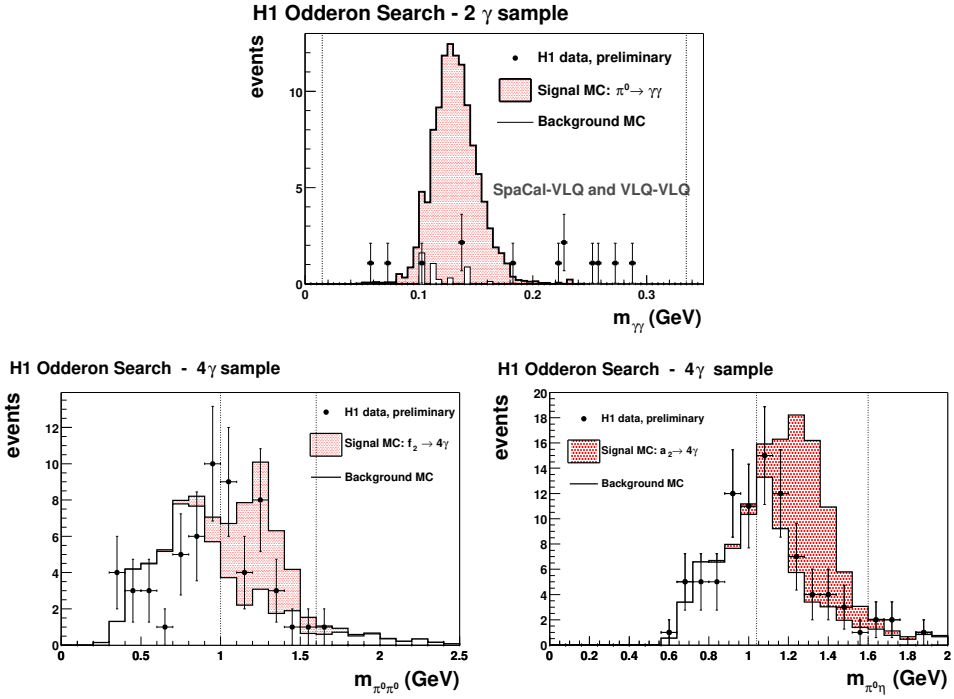


Fig. 2. The topmost part shows the invariant mass of exclusive $\gamma\gamma$-pairs, the lower left part shows the invariant $\pi^0\pi^0$-mass and in the lower right the mass of $\pi^0\eta$-pairs is shown.

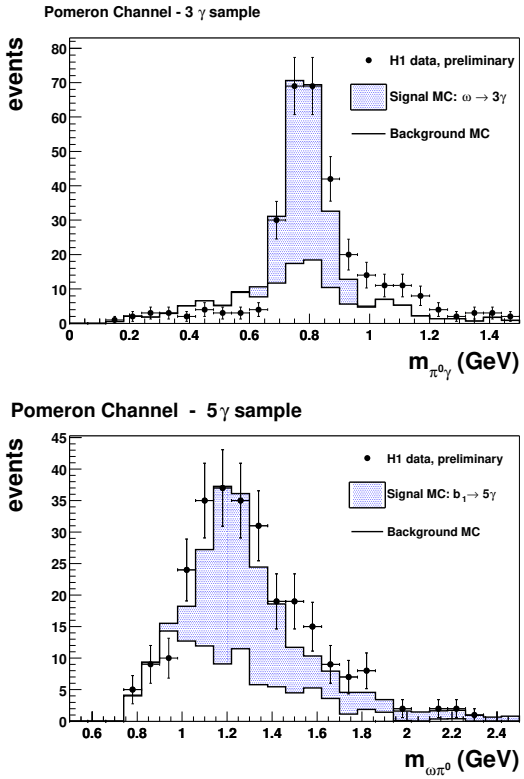


Fig. 3. Three (top) and five (bottom) photon invariant mass spectra, made up of $\pi^0\gamma$- for the $\omega$ and $\omega\pi^0$ final states.

In addition the diffractive slope $b$, characterising the differential cross section $\mathrm{d}\sigma/\mathrm{d}|t|$ by an exponential function $\propto \exp(-b|t|)$, was extracted: $b = (10.2 \pm 1.1(\mathrm{stat}) \pm 2.0(\mathrm{syst})\,\mathrm{GeV}^{-2}$ which is in gross accordance with other measurements. The bottom part of the figure shows the invariant mass of exclusive $\omega\pi^0$-pairs for which a cross section of

$$\sigma(\gamma p \to \omega\pi^0 X) = (1.0 \pm 0.2(\mathrm{stat}) \pm 0.2(\mathrm{syst}))\,\mu\mathrm{b}$$

was found. This result matches the expectation of resonant $b_1$ photoproduction, as shown by the filled histogram, although due to the lack of a spin parity analysis, it cannot be firmly stated that the observed signal indeed stems from the decay $b_1 \to \omega\pi^0$. Subtracting a non-resonant contribution of $\sim 0.2$ $\mu$b as taken from PYTHIA, one arrives at a cross section for resonant $\omega\pi^0$ photoproduction of $\sim 0.8$ $\mu$b, that can be compared to a Regge extrapolation of low energy measurements of $b_1$-mesons that yields an expectation of 0.7 $\mu$b.

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