PROCEEDINGS

International Europhysics Conference on HEP

Investigation of Pomeron- and Odderon Induced Photoproduction of Mesons Decaying to Pure Multiphoton Final States at HERA

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Abstract: Cross section measurements made with the H1 detector at HERA are reported for the reactions $\gamma p \to \omega p$ and $\gamma p \to \omega \pi^0 X$, and on searches for the reactions $\gamma p \to \pi^0 N^*$, $\gamma p \to f_2(1270)X$, and $\gamma p \to a_2^0(1320)X$, where N^* denotes an excited nucleon state. The average photon - proton centre-of-mass energy at HERA were $\langle W \rangle = 200$ GeV and 215 GeV. Cross sections for the Pomeron - mediated reactions were determined in agreement with previous measurements and theoretical expectations. Processes mediated by Odderon - photon fusion could not be observed; upper limits on cross sections are below predictions from a non-perturbative QCD model.

1. Introduction

The Pomeranchuk trajectory ("Pomeron", $I\!P$) was introduced, in the framework of Regge theory, in order to explain the high energy behaviour of hadron-hadron scattering. A conjecture by Pomeranchuk, known as the Pomeranchuk theorem [1], states that, in the limit of very large energies, the difference between particle-particle and particle-antiparticle total cross sections vanishes.

The Pomeranchuk theorem might, however, be violated by means of an additional "odd under crossing" trajectory which contributes with different signs to particle-particle and particle-antiparticle total cross sections, and thus leads to a finite difference in these cross sections at high energies [2]. No effects of this trajectory named "Odderon" ($I\!O$) have been experimentally observed so far.

This paper reports on cross section measurements for the reactions $\gamma p \to \omega p$ and $\gamma p \to \omega \pi^0 X$, and on searches for the reactions $\gamma p \to \pi^0 N^*$, $\gamma p \to f_2(1270)X$, and

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†Supported by the Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie, Germany, under contract number 7HD27P.

$\gamma p \rightarrow a_2^0(1320)X$ in the photoproduction regime, illustrated in Fig. 1 in a generic graph. N^* denotes an $(I = 1/2)$ - nucleonic state. The former two processes are mediated by Pomeron exchange and have been observed before [3], the latter three are believed to proceed via photon - Odderon fusion and have not been observed so far.

Only meson decays to net multiphoton final states are considered. Vector- and axial vector - mesons, with an odd number of final state photons, carry odd C - parity ($I\!\!P$ exchange), while pseudoscalar and tensor mesons, with an even number of final state photons, carry even C - parity ($O\!\!\!/$ exchange).

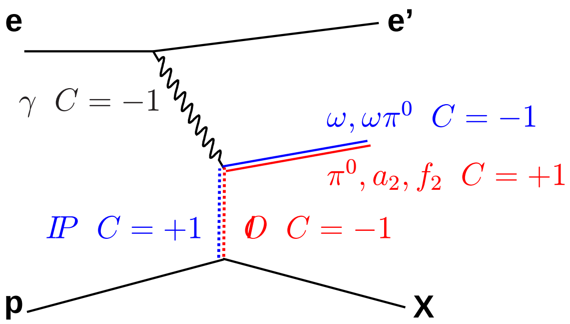

Figure 1: Generic diagram illustrating photon - Pomeron and photon - Odderon induced exclusive processes.

Vector meson production can be well described by phenomenological models [5]. For quantitative predictions of Odderon induced processes a model in the framework of non-perturbative QCD, the Stochastic Vacuum Model (SVM) [7], is used and applied to high energy scattering by functional methods [8] in which the proton is treated as a quark-diquark system in transverse space. At HERA, a sizeable Odderon contribution to single pseudoscalar or tensor meson photoproduction is expected if simultaneously the proton is excited into an $(I = 1/2)$ – nucleonic state with negative parity [6].

2. Event Selection

The analysis with an exclusive π^0 in the final state is based on data taken in 1999 and 2000 where electrons of 27.56 GeV were collided with protons of 920 GeV. The data samples for the remaining analyses were collected during the 1996 run period with a proton beam energy of 820 GeV. The data correspond to integrated luminosities of 30.6 pb^{-1} and 4.5 pb^{-1}, respectively. Photoproduction events with $Q^2 < 0.01$ GeV^2 and $0.3 < y < 0.7$ were selected by measuring the almost undeflected electron in a low-angle electron detector 33 m downstream from the interaction point.

The number of final state photons varies between two and five. Since in photoproduction the quasi-elastically produced mesons take over the incoming photon's energy and momentum, the decay products are detected in the "backward" region of the detector, i.e. in the electron beam direction. At H1 [9], part of this region is covered by two electromagnetic calorimeters, the SpaCal [10] and the VLQ [11].

A photon in the SpaCal or the VLQ is defined as a cluster with an energy larger than 90 MeV or 2 GeV, respectively. The study of the exclusive π^0 requires either that one photon be reconstructed in the SpaCal and the other one in the VLQ, or that two photons be reconstructed in the same VLQ module. The remaining analyses make only use of photons in the SpaCal with energies larger than 100 MeV. The number of photon candidates reconstructed have to equal the number of final state photons expected, and for final states with π^0's and η's, appropriate mass restrictions have to be obeyed.

In the π^0 data sample the presence of an intermediate excited nucleonic state N^* is verified by detecting a high energy decay neutron in the forward neutron calorimeter. In the case of the tensor mesons, no experimental distinction between elastic and proton - dissociative production is made in the analysis presented here. The same holds for $(\omega\pi^0)$ production. In the case of ω production a condition designed to suppress inelastic reactions is imposed.

To ensure exclusive production of a π^0, no further cluster in the above calorimeters or any charged particle in the track detectors, from which an interaction vertex can be reconstructed, is allowed. The variable $\sum_i (E - P_z)_i$, where i runs over all particles in the final state takes a value equal to twice the electron beam energy if no particles escape undetected. A cut of 49 GeV $< \sum_{i=e',\gamma,\gamma}(E-P_z)_i <$ 60 GeV serves to reject non-exclusive or radiative events. For the 1996 data, the lower limit is 50 GeV.

3. Monte Carlo Models

The simulation programs used are PYTHIA [13] and DIFFVM [14]. The original DIFFVM event generator produces exclusive vector mesons as the ω by Pomeron exchange based on the Vector Meson Dominance model. This generator has been extended to the exclusive production of the $b_1(1235)$ meson which decays dominantly into $\omega\pi^0$ [4] as well as to include Odderon exchange according to the SVM with a single π^0, $f_2(1270)$, or $a_2^0(1320)$ in the final state, with t-distributions for the signal processes as calculated in [6] and assuming an Odderon intercept $\alpha_{\mathbb{O}}(0) = 1$. The extended event generator is called OPIUM[1] [15].

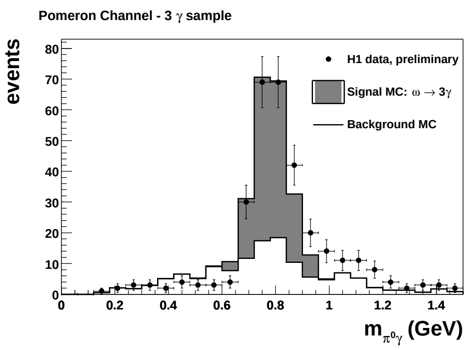

Figure 2: Three photon sample: π^0 - γ invariant mass.

PYTHIA, a universal tool for describing γp interactions, is used to simulate all backgrounds contributing to exclusive meson production. These are mainly inclusive events with low multiplicity. Contributions from Regge exchange (ω-trajectory) or $\gamma\gamma$ fusion ("Primakoff effect"), leading to elastic single pseudoscalar and tensor meson production, are negligible.

4. Results

Figure 2 shows the $\pi^0\gamma$ invariant mass distribution in the 3-photon sample from which a cross section was determined as

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

In Fig. 3 the $\omega\pi^0$ invariant mass distribution in the 5-photon sample is shown. The absolute normalization of the resonant b_1 contribution to the $\omega\pi^0$ final state has been taken from

[1] An acronym for "Odderon and Pomeron Induced Unified Meson maker"

the OPIUM generator which was adjusted to fit the observed data. The non-resonant contribution is taken from the PYTHIA prediction. The conclusion is that there is substantial $\omega\pi^0$ diffractive photoproduction which might well proceed via dominant resonant $b_1(1235)$ production. The corresponding cross section is

$$\sigma(\gamma p \to \omega\pi^0 X) = (980 \pm 200 \text{ (stat)} \pm 200 \text{ (syst)}) \text{ nb}.$$

This has to be compared with the sum of the non-resonant prediction by PYTHIA $\sigma_{\text{PYTHIA}}(\gamma\ p\ \to\ \omega\ \pi^0\ X)\ =\ 190$ nb and a cross section value measured for b_1 photoproduction at lower energies (8 GeV, [3]) which, after extrapolation to HERA energies reads $\sigma_{extrap}(\gamma p \to b_1 p) = (660 \pm 250)$ nb. The data distributions in the exclusive 2-photon and 4-photon samples are compatible with the background expectation which is shown in the figures 4 and 5. Converting the findings into numbers, one arrives, applying the prescriptions of [16], at upper limits of

$$\begin{aligned} \sigma_{\text{acc}}(\gamma p \xrightarrow{\mathbb{O}} \pi^0 N^*) &< 39\,\text{nb} \qquad (95\ \%\ \text{CL}) \\ \sigma(\gamma p \xrightarrow{\mathbb{O}} a_2 X) &< 96\,\text{nb} \qquad (95\ \%\ \text{CL}) \\ \sigma(\gamma p \xrightarrow{\mathbb{O}} f_2 X) &< 16\,\text{nb} \qquad (95\ \%\ \text{CL}) \end{aligned}$$

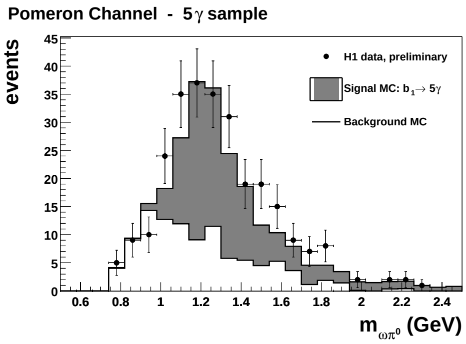

Figure 3: Five photon sample: ω - π^0 invariant mass.

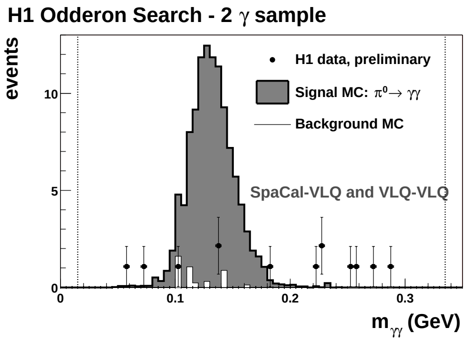

Figure 4: Two photon sample: γ - γ invariant mass.

to be compared with the SVM predictions for $\sigma_{\text{acc}}(\gamma p \xrightarrow{\mathbb{O}} \pi^0 N^*) = 200\,\text{nb}$, $\sigma(\gamma p \xrightarrow{\mathbb{O}} a_2 N^*) = 190\,\text{nb}$ and $\sigma(\gamma p \xrightarrow{\mathbb{O}} f_2 N^*) = 21\,\text{nb}$.

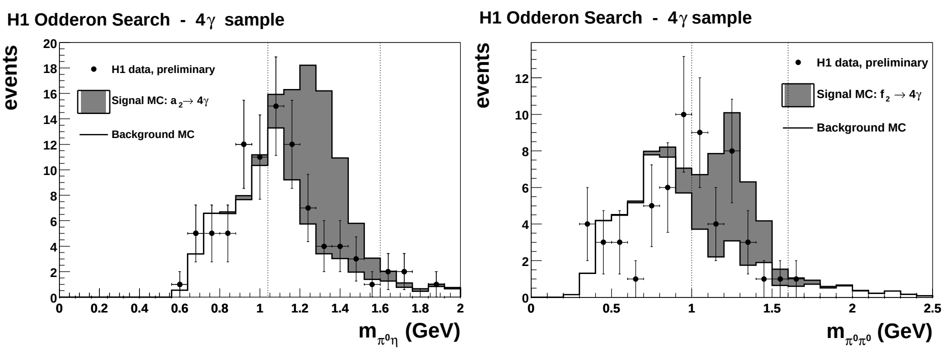

Figure 5: Four photon sample: η - π^0 and π^0 - π^0 invariant mass.

5. Conclusion

Our findings provide a rather clear picture. We have observed Pomeron induced reactions in complete agreement with previous measurements, expectations, and extrapolations from lower energy experiments, but: we see no trace of Odderon induced reactions as predicted by the Stochastic Vacuum Model (SVM). Possible explanations therefore include:

The energy dependence of the cross section is different from that assumed. This would imply that the Odderon intercept $\alpha_{\mathbb{O}}(0)$ is considerably smaller than one. A value of $\alpha_{\mathbb{O}}(0) < 0.65$ would be compatible with the π^0 cross section limit, but this would mean that the object exchanged is not a "genuine" Odderon for which $\alpha_{\mathbb{O}}(0) \approx 1$.

The absence of elastic π^0 production could be understood in that the coupling at the $\gamma\mathbb{O}\pi$-vertex is small due to the Goldstone Boson nature of the π^0 [17]. This explanation does, however, not hold in the case of the $f_2(1270)$ and the $a_2(1320)$.

The level of understanding of this sector of nonperturbative QCD is still unsatisfactory, and new theoretical ideas are needed.

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