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Resonance Production in Multi-Photon Final States in Positron-Proton Scattering at HERA

H1 Collaboration

Abstract

Studies are made of the exclusive photoproduction of charge conjugation $C = \pm 1$ mesons at a γp center-of-mass energy $\langle W \rangle \approx 200$ GeV. The production of $I^G J^{PC} = 0^- 1^{--}$ $\omega(782)$ is observed by means of its $\pi^0\gamma$ decay. A search for exclusively produced C=+1 resonances is made. The exclusive production of the $I^G J^{PC} = 0^- 0^{-+}$ π^0, η and $\eta'(958)$ have been searched for using their two photon decay modes with the intention of elucidating any $C = -1$ component in diffractive exchange, that is any evidence for the "odderon", the $C = -1$ partner of the leading diffractive effective trajectory, the pomeron. Signals of the $I^G J^{PC} = 1^- 0^{++}$ $a_0(980)$ and $I^G J^{PC} = 1^- 2^{++}$ $a_2(1320)$ mesons are obtained in the $\eta\pi^0$ decay mode, and are tested for compatibility with exclusive production.

Abstract 382
Parallel Sessions 1,2,3,4
Plenary Sessions 1,2,3

1 Introduction

Properties of soft hadron-hadron interactions at high energies are known to be well described by Regge theory provided that the exchange of a trajectory with the quantum numbers of the vacuum and an intercept $\alpha(t=0) \approx 1$ and C parity $+1$ (called "Pomeron" – $I\!P$) is introduced. However, no direct evidence has been found at high energies (where subleading trajectories do no longer contribute) for an exchange with $\alpha(t=0) \approx 1$ but with $C=-1$ (called "Odderon" – $I\!O$). Contributions from an Odderon trajectory can be investigated e.g. when comparing antiproton-proton with proton-proton scattering.

At HERA the existence of an Odderon trajectory could result, as suggested by Schäfer, Nachtmann, and Mankiewicz [1], in the production of pseudoscalar mesons with $C=+1$ in addition to their production via the two photon fusion process. Figure 1 shows the two processes, taking as an example the η_c meson. The cross section in case of the η_c however is expected to be smaller than 10 pb. Thus Schäfer et al. suggest to measure the cross section ratio for exclusive production of η's and η''s, since a larger cross section is expected and in their model, the sensitivity to the Odderon induced process differs for η and η'. Assuming the coupling to the meson for photon-Odderon fusion to be proportional to the product of the electric charge and the baryon number of the quarks composing the meson, the η' – being dominantly the singlet state with respect to flavour $SU(3)$ – gets only a small contribution, whereas the η – dominantly the octet state – gets a large contribution.

2 Detector Performance

The data used were taken in 1996 with the H1 detector at HERA (27.5 GeV positrons on 820 GeV protons) and amount to an integrated luminosity of about 5 pb^{-1}. They are based on a trigger demanding a signal in the positron calorimeter of the H1 luminosity system and a localized energy deposit in the backward calorimeter (SPACAL) of more than 1.5 GeV. This corresponds to a kinematic range of $0.3 < y < 0.7$ and $Q^2 < 0.01\mathrm{GeV}^2/c^2$.

The lead/scintillating fibre calorimeter SPACAL [2] has a sampling term of $7\%/\sqrt{E/\mathrm{GeV}}$ and, due to its fine granularity, a position resolution of about 5 mm at 1 GeV. Together with the low energy threshold (≈ 100 MeV) this allows for a precise measurement of mesons decaying into multi-photon final states, e.g. of the π^0 and the η mesons in their 2γ decay mode, as shown in Figure 2. Here the invariant mass spectra of inclusively produced photon pairs are shown, yielding clear signals of π^0 (a) and η (b) mesons. The signal of the π^0 meson has been used for a calibration of the SPACAL in the photon energy range of 0.1 to 1.5 GeV to correct for energy losses. The central values of the Gaussian fit – after this correction – amount to 136 MeV/c^2 for π^0 and 535 MeV/c^2 for η. The measured width of the invariant mass distribution is $\sigma \approx 13$ MeV/c^2 for π^0 and $\sigma \approx 31$ MeV/c^2 for η, demonstrating the good performance of the detector. No inclusive signal of $\eta' \to \gamma\gamma$ has been found.

3 Search for Exclusive Meson Production

The acceptance of the positron calorimeter of the luminosity system ($0.3 < y < 0.7$) restricts the meson energy in the laboratory frame to lie between 8 and 20 GeV and kinematically forces the production of the meson in the backward direction (positron beam). The selected events consist of the scattered positron (being tagged in the luminosity system), two photons within the angular acceptance of the SPACAL, and an elastically scattered proton which escapes detection

in the main detector. To ensure no losses in the backward direction, a cut on the variable [1] $(E-p_z c)_{e\gamma\gamma} > 50$ GeV is applied, as calculated from the scattered positron and the two photons, to exclude events with inclusive meson production.

Requiring in addition a reconstructed vertex, i.e. is at least one charged track in the detector, results in the invariant mass spectrum of photon pairs as shown in Figure 3 (a). Clear signals of the π^0 and the η mesons are observed, no indication for a signal of the η' meson is found. At about 800 MeV/c^2 a "bump" is observed, which will be discussed below.

By requiring no charged particles to be found in the central detector – thus selecting events without a reconstructed vertex, compatible with exclusive meson production – leads to the invariant mass spectrum of photon pairs as shown in Figure 3 (b). No signal of exclusively produced η and η' mesons is observed, nor of π^0. However, the resonance-like structure at an invariant mass of about 800 MeV/c^2 has become more pronounced. This is interpreted as being due to elastic photoproduction of ω mesons and their subsequent decays into the $\gamma\pi^0$ final state, where only two out of the three photons are detected.

Figure 4 (a) shows the invariant mass spectra of γ-π^0 pairs (i.e. events with three photons out of which two form a π^0), after applying a mass constrained fit to the reconstructed π^0. A clear signal of the ω meson is observed, confirming the contribution from ω mesons to the two photon invariant mass spectrum. These data will be used to measure the photoproduction cross section for ω mesons at high values of W ($140 < W < 250$ GeV).

The non-observation of η mesons is compatible with the expectation from a pure two photon fusion process, given the small acceptance of the detector. This excludes a large contribution from Odderon induced processes with cross sections substantially larger than the two photon fusion cross section. The magnitude of the observed ω signal supports these findings, since the acceptance is expected to be similar and the cross section for ω photoproduction due to Pomeron exchange is two to three orders of magnitude larger than the one for η mesons due to two photon fusion. In the case of the η' the small branching ratio of 2.12% further reduces the expected number of events by about one order of magnitude.

Figure 4 (b) shows the invariant mass spectra of η-π^0 pairs, where for both mesons a mass constrained fit has been applied. A signal of the $a_0(980)$ meson is observed. With tightened cuts, an indication of the $a_2(1320)$ is found. These mesons can also be used to search for Odderon induced processes at HERA.

4 Conclusions

In conclusion, a first search for contributions from Odderon induced production of $C = +1$ mesons at HERA has been performed. No signal for exclusive production of π^0, η and η' mesons has been obtained with the available statistics. The capability of the H1 detector to perform such a search and to study ω production at large W ($140 < W < 250$ GeV) has been demonstrated, utilizing the new backward calorimeter which allows the detection of resonances decaying into multi-photon final states.

[1] The proton beam direction defines the $+z$-axis, leading to the expected value of twice the positron beam energy for $(E - p_z c)_{e\gamma\gamma}$, where E is the energy and p_z the longitudinal momentum along the z-axis.

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References

[1] A. Schäfer, L. Mankiewicz, O. Nachtmann, *Diffractive η_c, η, η', J/ψ and ψ' Production in Electron-Proton Collisions at HERA Energies*, Proc. of the Workshop on Physics at HERA, Hamburg 1991, eds. W. Buchmüller and G. Ingelman, vol. 1, 243.

[2] H1 SPACAL Group (R.D. Appuhn, et al.), *Nucl. Instrum. Methods* A **374**, 149 (1996).

Figures

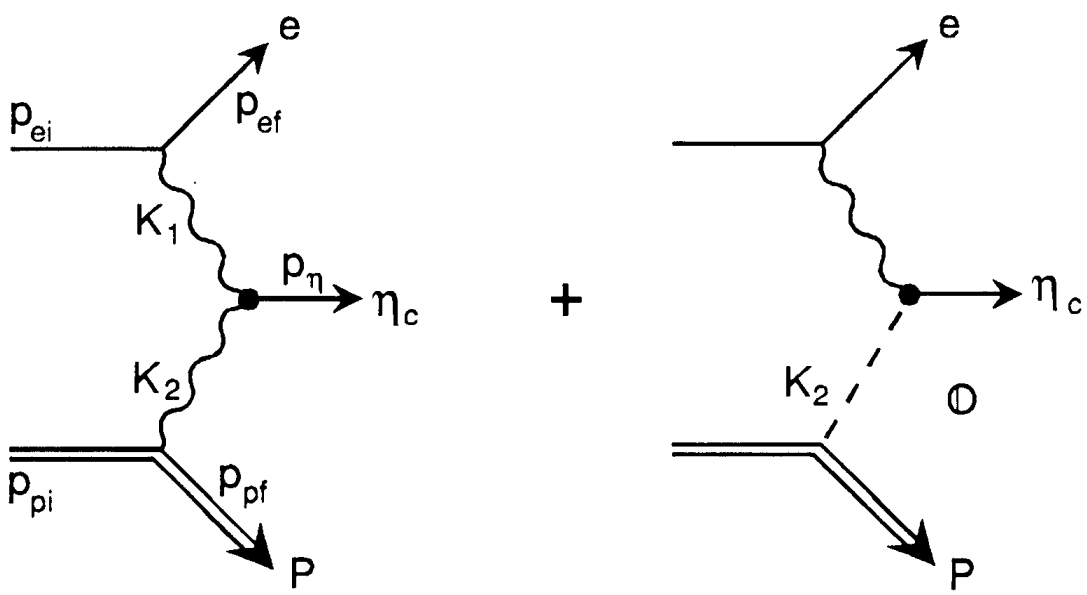

Figure 1: Processes contributing to the exclusive production of $C = +1$ mesons at HERA (taken from ref. [1]): photon-photon fusion (left part) and photon-Odderon fusion (right part).

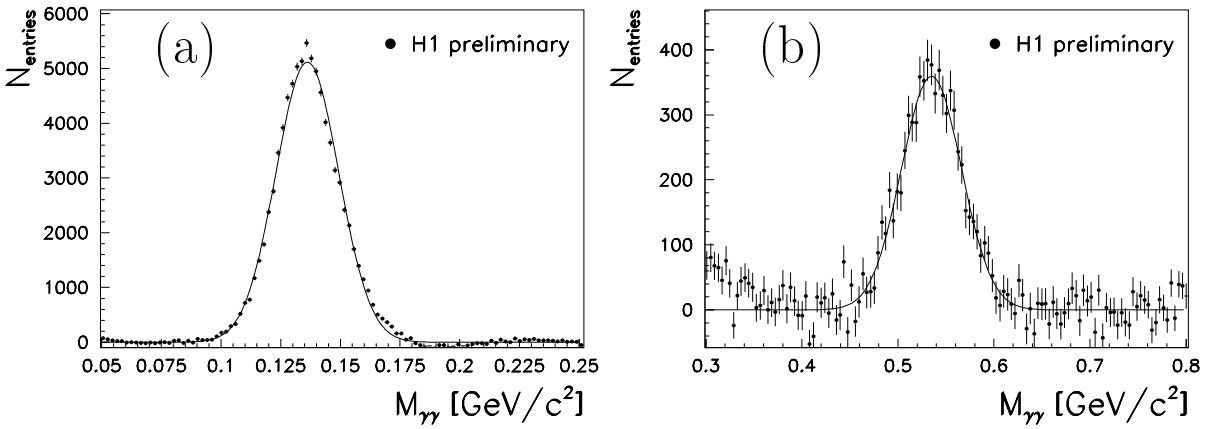

Figure 2: Invariant mass spectra of inclusively produced γ-γ pairs (after background subtraction): in the π^0 mass region (a), with a minimal energy for each photon of at least 1 GeV, and in the η mass region (b), with a minimal energy for each photon of at least 1.5 GeV.

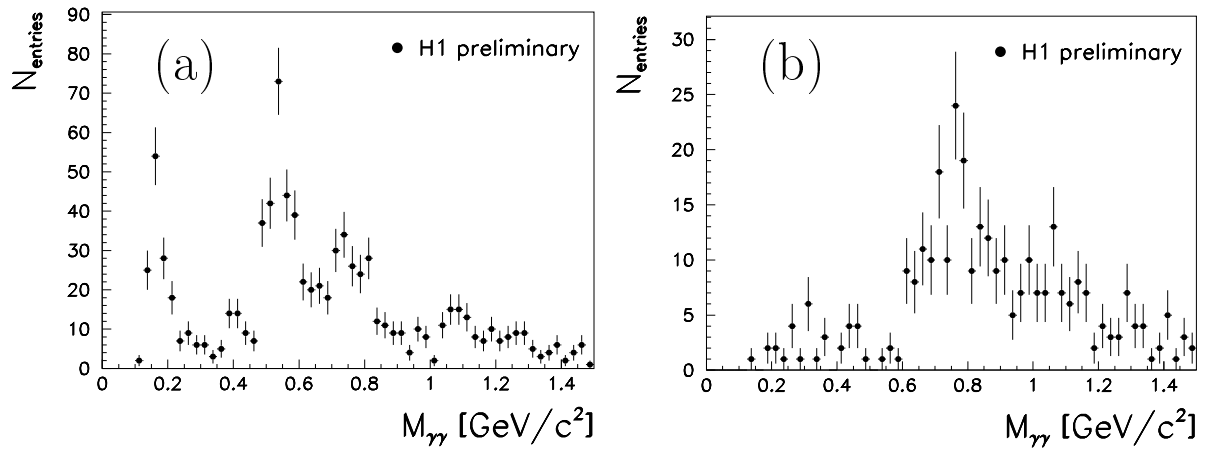

Figure 3: Invariant mass spectrum of candidates for photon pairs, where each photon has an energy of at least 0.7 GeV and $(E - p_z c)_{e\gamma\gamma} > 50$ GeV is required: (a) events with a vertex, (b) events without a vertex.

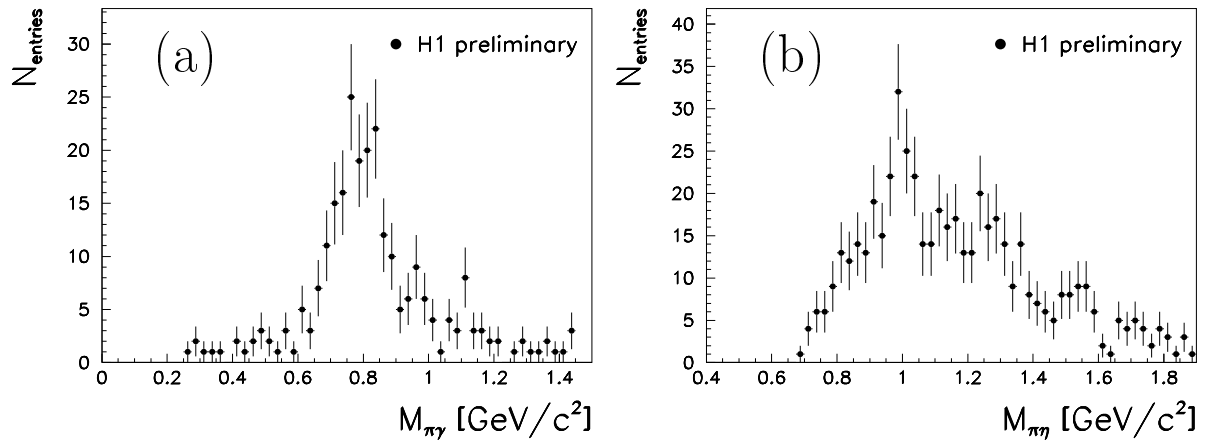

Figure 4: (a): Invariant mass spectrum of candidates for exclusively produced γ-π^0 pairs in the ω mass region (photon energy $E > 0.8$ GeV and $(E - p_z c)_{e\pi^0\gamma} > 49$ GeV).
(b): Invariant mass spectrum of candidates for exclusively produced η-π^0 pairs (photon energy $E > 1$ GeV and $(E - p_z c)_{e\eta\pi^0} > 49$ GeV).