Evidence for a narrow baryon state with \(|S| = 1\) at the HERMES experiment

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A narrow baryon state has been found in the channel \(pK_0^+ \rightarrow p\pi^+\pi^-\) of quasi-real photoproduction on a deuterium target at the HERMES experiment. Its mass is \(1528 \pm 2.6 \pm 2.1\) MeV and its width is somewhat larger than the experimental resolution of \(4.3-6.2\) MeV. This state may be interpreted as the predicted \(S=-1\) exotic \(\Theta^+\) pentaquark baryon. No signal for a hypothetical \(\Theta^{++}\) baryon was observed, indicating that the \(\Theta^+\) is an isoscalar particle.

**Keywords:** Glueball and nonstandard multi-quark/gluon states; Photon and charged-lepton interactions with hadrons; Baryon production; Baryon.

1. Introduction

Until recently, all known hadrons could be described as compound system of two or three quarks. Although models in early days of quantum chromodynamics \(^2\) predicted already the existence of particles with quantum numbers that could only be explained in terms of more than three quarks, such state were not observed experimentally.

In Quark Soliton model the two lowest rotational states form the well-known baryon octet and decuplet. By the study of next rotational state, in 1997 Diakonov, Petrov and Polyakov \(^3\) treated the known \(N(1710)\) resonance as a member of anti-decuplet and derived a mass of \(1530\) MeV and a width less than \(15\) MeV for an exotic baryon, which is named the \(\Theta^+\). The quark configuration of this state corresponds to \(uudds\) and its decay modes are \(\Theta^+ \rightarrow pK_0^+\) or \(nK^+\). However, measurements of \(K^+\) scattering on proton and deuteron \(^4\) showed no evidence for this strange resonance. First evidence for this exotic baryon resonance came from the observation of a narrow resonance at \(1540 \pm 10\)MeV in the \(K^-\) missing mass spectrum for the \(\gamma n \rightarrow K^+K^-\) reaction on \(^{12}\)C \(^5\). Recently, such a resonance has also been observed at HERMES \(^1\).

2. Experiment

At HERMES \(^6\) a 27.5 GeV positron beam is scattered off a deuteron gas target. The particularly decay channel \(\Theta^+ \rightarrow pK_0^+ \rightarrow p\pi^+\pi^-\) has been investigated in photoproduction. Events have been selected which contained at least three hadron tracks,
two opposite charged pions and proton. The momentum range has been restricted
to 1-15 GeV/c for pions and 4-9 GeV/c for protons. According to simulations these
constraints make possible cross contamination negligible. The cuts included in these
analyses are aimed to improve the statistics of the $K_S^0$ peak and suppress its back-
ground. There are no constraints to improve explicitly the significance of the peak in
final $M_{\pi^+\pi^-}$ spectrum. The cuts are as follows: the minimum approach between
$\pi^+$ and $\pi^-$ is smaller than 1 cm, the distance between the production and the $K_S^0$
decay vertices is greater than 7 cm, the minimum approach between proton and
$K_0^0$ reconstructed track is smaller than 6 mm, the distance of the production vertex
from the beam axis is smaller than 4 mm in radial direction and smaller than 18 cm
in longitudinal direction. Those $K_S^0$ candidates are selected for which the invariant
mass $M_{\pi^+\pi^-}$ is within 2$\sigma$ the nominal $K_S^0$ mass, where $\sigma = 6$ MeV is the apparent
width of the $K_S^0$ peak observed in this experiment. To avoid a possible contami-
nation from the $\Lambda(1116)$ hyperon, the events which have an invariant mass $M_{\pi^+\pi^-}$
equal to the $\Lambda(1116)$ mass within 2$\sigma$ have been rejected.

The resulting spectrum of the invariant mass of the $p\pi^+\pi^-$ system is displayed in
Fig. 1. The sum of a third-order polynomial and a gaussian is used for an unbinned
fit of the histogram.

In order to understand the background two different models were explored. Events calculated by the PYTHIA6 simulation of non-resonant background were
used in the first model. An assumption that background is formed by uncorrelated
$K_S^0$ and proton 4-momenta were used for the second one. This background was
calculated by combining tracks from different events. Both these models are consistent
with each other and are shown in Fig. 1 (right plot) as shaded and fine binned
histograms respectively.
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![Graph]

Fig. 2. Spectra of invariant mass $M_{pK^+}$ (top) and $M_{pK^-}$ (bottom). A clear peak from the $\Lambda(1520)$ is seen in $M_{pK^-}$ distribution. However, distribution of $M_{pK^+}$ shows no peak structure of hypothetical $\Theta^{++}$.

The background as simulated by the PYTHIA6 was fitted by a polynomial. In order to fit a shape of the final invariant mass spectrum, the gaussians of six known $\Sigma^{*+}$ resonances were included (dotted curves) and parameters of gaussian for the peak of interests. This fit reproduce very well entire spectrum (solid line).

There are theoretical models\(^7\) which claim that the observed resonance is an isotensor. In this case a double charge isopartner has to exist and its decay mode is $\Theta^{++} \rightarrow pK^+$. We investigated in our analyses the existence of this state. Although the invariant mass spectrum of the system $pK^-$ show a clear peak of the $\Lambda(1520)$ there is no evidence of a peak structure in the system $pK^+$. From this fact we conclude that observed resonance is very likely an isosinglet.

3. Conclusion

In quasi-real photoproduction on a deuterium target a narrow resonance was observed with a mass $1528 \pm 2.6{\text{(stat)}} \pm 2.1{\text{(syst)}}$ MeV. Depending on the background model, the naive statistical significance of the peak is 4-6 standard deviations. This state may be interpreted as the $\Theta^+$ exotic baryon. Due to absence of signal of isotensor partner of $\Theta$ this state is very likely an isosinglet.

References