Search for an exotic S = −2, Q = −2 baryon resonance at a mass near 1862 MeV in quasi-real photoproduction

Hadronic matter was known until recently to exist only in two states: mesons, which contain a quark and an antiquark, and baryons, which comprise three quarks (or antiquarks), even though Quantum Chromodynamics (QCD), the theory that describes the strong interaction, allows for states with more than three quarks. After 30 year of searching, several experiments have recently claimed evidence for particles containing five quarks, since called pentaquarks.

First evidence came from the Laser Electron Photon experiment at SPring-8 (LEPS) collaboration in Spring 2003: a particle with a mass of about 1540 MeV was observed in an experiment in which high-energy gamma rays were scattered off neutrons in a carbon nucleus. Both, the mass of the particle and the width of the particle peak (less than 25 MeV) were in agreement with a recent theoretical model by Dmitri Diakonov, Victor Petrov and Maxim Polyakov of the Petersburg Nuclear Physics Institute, that predicted the existence of narrow baryon resonances. Further evidence emerged from a series of experiments, covering a broad energy range with different beam and target configurations, where narrow peaks in the pK^0 or nK^+ invariant mass spectra near 1530 MeV were observed. In most cases, the observed widths of these peaks were limited by the experimental resolution of these experiments.

Meanwhile, experimental evidence for a second exotic pentaquark state, which was also predicted in Diakonov's model, came from the reported observation of a $S = -2$, $Q = -2$ baryon resonance in proton-proton collisions at the CERN Super Proton Synchroton. A narrow peak at a mass of about 1862 MeV in the $\Xi^-\pi^-$ invariant mass spectrum was proposed as a candidate for the predicted exotic $\Xi^{--}_{3/2}$ baryon with $S = -2$, $I = 3/2$, and a quark content of $ddss\overline{u}$. A candidate for the $\Xi^0_{3/2}$ member of the same isospin quartet was identified by a peak observed at the same mass in the $\Xi^-\pi^+$ invariant mass spectrum. However, this result has not been confirmed by any other experiment so far.

In addition, besides a large number of reports that have shown evidence in support of a Θ^+ particle, a comparable number of experiments have failed to observe a signal. This has recently raised some doubts about the existence of pentaquark states, and it has been hypothesized that experimental artefacts could be responsible for the observed positive signals. At present, many further searches for the Θ^+ and the Ξ^{--} are underway for which no final results are available yet. The general experimental situation is therefore quite unsettled.

The HERMES collaboration at the DESY laboratory in Hamburg reported first evidence for a Θ^+ in a high-energy experiment last year. In this experiment high-energy positrons, which are accelerated and stored in the HERA electron-proton collider, were scattered off a deuterium target. The reaction products were detected and analysed in a spectrometer that surrounds the interaction point of the experiment in the forward region. A narrow peak at 1528 MeV has been observed in the invariant mass distribution of inclusive pK^0 events. The reliability of the result was tested by a detailed Monte Carlo simulation, and cross-checked by a novel technique to estimate the combinatorial background by combining kaons and protons belonging to different scattering events.

The HERMES collaboration has now performed a search for the Ξ^{--} resonance, by analyzing the decay $\Xi^{--} \to \Xi^-\pi^- \to \Lambda\pi^-\pi^- \to p\pi^-\pi^-\pi^-$. The background contribution to the 4-track invariant mass spectra was best estimated by combining Ξ^- and π^- belonging to different scattering events. Although clear signals for the Λ and Ξ^- were found, no evidence of a Ξ^{--} pentaquark was found in the mass range around 1860 MeV (see Fig. 1). In the corresponding $\Xi^0 \rightarrow p\pi^-\pi^-\pi^+$ neutral channel, the well established $\Xi^0(1530)$ was clearly identified, but again no signal was found around 1860 MeV. The HERMES experiment is among only two experiments, together with the ZEUS experiment at the HERA collider, that have seen evidence for the Θ^+ but not for the Ξ^{--}.

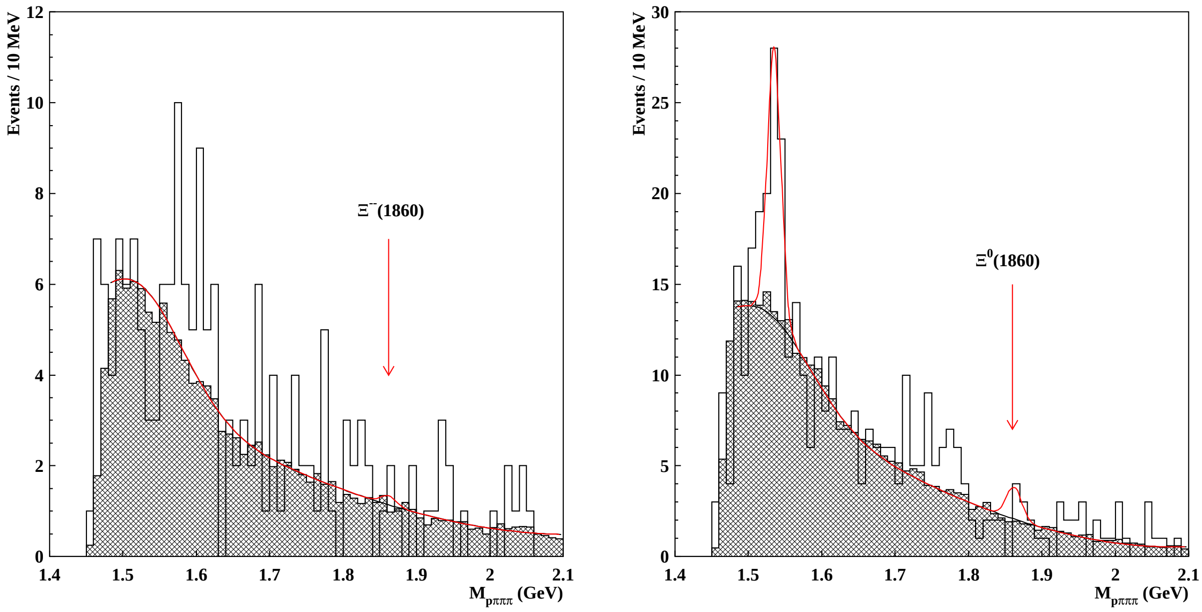

Figure 1: *Invariant mass distribution of the $p\pi^-\pi^-\pi^-$ system (left panel), and of the $p\pi^-\pi^-\pi^+$ system (right panel). The mixed-event background is represented by the gray shaded histogram, and the fitted curve describes the signal and background contributions the the spectra. The arrows show the hypothetical $\Xi^{--}_{3/2}$ and $\Xi^{0}_{3/2}$ masses, respectively.*

The HERMES measurement has allowed to put an upper limit on the photoproduction cross section times branching fraction of the heavy exotic state. The acceptance times efficiency of the spectrometer was estimated by a Monte Carlo simulation where the initial kinematic distributions of the Ξ^{--} (Ξ^0) was assumed to be similar to the one for the Λ hyperon as observed at HERMES, and the decay angle distribution was assumed to be isotropic. The extracted upper limits were 3.4 nb for Ξ^{--} and 7.7 nb for Ξ^0. The cross section for the $\Xi^0(1530)$ was measured to be between 8.7 and 24 nb, due to the unknown production kinematics. The upper limit of the cross section ratio of $\Xi^{--} \rightarrow \Xi^-\pi^-$ to $\Xi^0(1530)$ was derived to be between 0.10 and 0.39.