Search for $\Phi(1860)^{--}$ pentaquark state in photoproduction

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We searched for $\Phi(1862)^{--}$ pentaquark in photoproduction process in $\Xi^-\pi^-$ decay channel using CLAS. The invariant mass spectra of $\Lambda\pi^-\pi^-$ and $\Xi^-\pi^-$ systems do not indicate a statistically significant enhancement near mass $M = 1.860$ GeV. The statistical analysis of the sideband-subtracted mass spectrum yields an upper limit of 200 pb for the photoproduction cross section of $\Phi(1862)^{--}$ with a consecutive decay to $\Xi^-\pi^-$ system in the photon energy range 4.5 GeV $< E_\gamma <$ 5.5 GeV.

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During last five years there has been a number of experimental observations, including from CLAS, of a narrow exotic S=+1 baryon state at a mass of approximately 1.54 GeV. These observations, if true, would confirm the existence of the Θ^+, which is the predicted spin 1/2, isospin 0, member of the anti-decuplet of baryons within the Chiral Soliton Model [1]. The anti-decuplet contains three explicitly exotic states located at the apexes whose quantum numbers require a minimal quark content of four quarks and one anti-quark. These exotic states cannot be accommodated within the simple quark model which assumes all baryons are built out of 3 quarks. On the other hand, there has been a number of other high statistics experiments which tried to search for the Θ^+ signal but failed to observe any statistically significant enhancement near 1.54 GeV. The existence of the Θ^+ is still considered as an open question.

Besides the $\Theta^+(1540)$, the other exotic states have S=-2 and charge Q=-2 and Q=+1, which we will denote by Φ^{--} and Φ^+ respectively. These exotic cascade states have isospin 3/2. Two additional partners, denoted Φ^- and Φ^0, are also pentaquark states but are not explicitly exotic. The NA49 collaboration has reported evidence for the strangeness $S = -2$ pentaquark Φ^{--} and the Φ^0 at a mass of 1.862 GeV [2]. The states were reconstructed from their decay products using their decays into $\Phi^{--} \to \Xi^-\pi^-$ and $\Phi^0 \to \Xi^-\pi^+$. These observations are important for verifying the existence of the anti-decuplet of pentaquark, and require confirmation. We also note that many experiments [3–13], some of which represented a much larger statistical sample, have not been able to confirm this observation yet. In this paper we report our results on search for Φ^{--} state in the $\Phi^{--} \to \Xi^-\pi^-$ decay channel using the CLAS detector [14] located in Hall B at Jefferson Laboratory.

The main magnetic field of CLAS is provided by six superconducting coils, which produce an approximately toroidal field in the azimuthal direction around the beam axis. The gaps between the cryostats are instrumented with six identical detector packages, also referred to here as "sectors". Each sector consists of four start-counter (ST) paddles, [15] mainly used for triggering purposes, three regions of Drift Chambers (DC) [16] to determine the trajectories of the charged particles, Čerenkov Counters (CC) [17] for electron identification, Scintillator Counters (SC) [18] for charged particle identification using the Time-Of-Flight (TOF) method, and Electromagnetic Calorimeters (EC) [19] used for electron identification and detection of neutral particles. Hall B also houses a photon tagging system allowing for absolute normalization of the cross sections. The liquid-deuterium target was located 50 cm upstream of the center of the detector on the beam axis. The CLAS detector can provide $\frac{\delta p}{p} < 0.5\%$ momentum resolution, and $\approx 80\%$ of 4π solid-angle coverage. The efficiency of detection and reconstruction for stable charged particles in fiducial regions of CLAS is $\epsilon > 95\%$. The combined information from the tracking in the DC and the TOF systems allows us to reliably separate protons from positive pions for momenta up to 3 GeV.

The $\Lambda(1116)$ candidates were identified by considering every pair of negative and positive pairs with a hypothesis that these are the proton and the negative pion from a $\Lambda(1116)$ decay using timing information from the scintillator counters, and momentum and vertex information from tracking. Whenever a $\Lambda(1116)$ was found it was combined with other negative pions in the event to search for the ground state $\Xi(1321)^-$. After selecting the best $\Lambda\pi^-$ pair, putting a tight cut around Ξ^- mass an invariant mass of $\Lambda\pi^-\pi^-$ system was plotted, as shown in Fig. **??** No statistically significant enhancement is present in this spectrum near mass $M = 1.862$ GeV.

In order to set an upper limit for the photoproduction cross sections the procedure was slightly modified. Instead of selecting the best $\Lambda\pi^-$ all $\Lambda\pi^-$ pairs were considered to eliminated the ragged background underneath the cascade peak to utilize sideband subtraction method. The mass spectrum of $\Xi^-\pi^-$ after the side-band subtraction is shown in Fig. ??. Again, this spectrum does not indicate an enhancement near mass $M = 1.862$ GeV. In order to relate the experimental yields to cross sections, acceptance correction factors were calculated using the Monte-Carlo method. The GEANT-based detector simulation package GSIM incorporated the survey geometry of CLAS, realistic drift chamber and timing resolutions along with missing wires and malfunctioning photomultiplier tubes. Because CLAS is a complicated detector covering almost 4π of solid angle, it is virtually impossible to separate the efficiency calculations from the geometrical acceptance calculations. In this work the term acceptance correction refers to a combined correction factor due to the geometry of the detector and the inefficiencies of the detection and reconstruction. It is defined as the ratio of the number of reconstructed Monte-Carlo events to the number of simulated events in a given bin. Because the acceptance uncertainty due to the possible production mechanism is the largest uncertainty in the absolute cross sections, we used four different distributions to evaluate the acceptance and its uncertainty for inclusive $\Xi^-\pi^-$ photoproduction. This study showed that the uncertainty in the acceptance uncertainty of CLAS for this reaction is on the order of $\sim 25\%$.

In order to obtain an upper limit on the photoproduction cross section we developed a procedure based on the method described in Ref. [20]. This procedure allows to factor-in the uncertainties in the background determination and the acceptance correction into the determination of the upper limits at a given confidence level. We scanned each bin in the sideband-subtracted mass spectrum in Fig. ?? considering the center of each bin as a mean value of a Gaussian with a fixed width of $\sigma_G = 7$ MeV. Then the points in the neighborhood of the bin were fitted to a polynomial plus the Gaussian to estimate the shape of the background. The total number of "signal" events are estmeted as the excess over the background summed within a window of 20 MeV around the center of a bin. The upper limit of the photoproduction cross section for the process $\gamma d \to \Phi^{--}X \to \Xi^-\pi^-X$ versus invariant mass of $\Xi^-\pi^-$ system is shown in Fig. 1. In the mass range near $M = 1.862$ GeV where the NA49 collaboration observed an enhancement we estimate the upper limit of ~ 200 pb. This is an order of magnitude improvement over the previous limit set by the HERMES collaboration in a nearly-real photoproduction experiment [4].

In conclusion, for the first time we searched for $\Phi(1862)^{--}$ pentaquark state in real photoproduction. We do not observe any statistically significant enhancement near invariant mass $M = 1.862$ GeV. Our estimate for the photoproduction cross section in the photon energy range 4.5 GeV $< E_\gamma <$ 5.5 GeV with consecutive decay $\Phi^{--} \to \Xi^-\pi^-$ is ~ 200 pb.

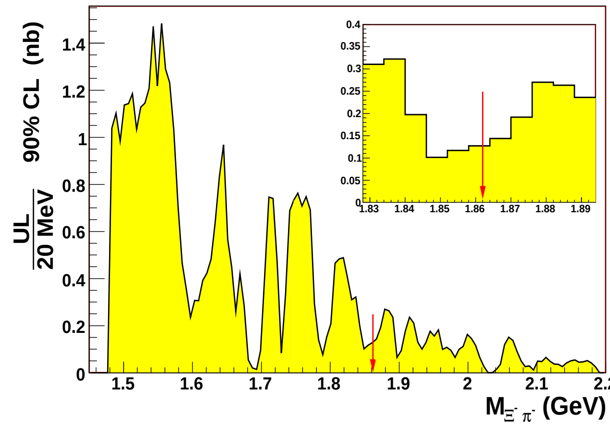

FIG. 1: Upper limits for the photoproduction cross section in 20 MeV window at 90% confidence level versus the mass of $\Xi^-\pi^-$ system. The red arrow shows where the position of the enhancement from the NA49 experiment.

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