IL NUOVO CIMENTO Vol. 29 C, N. 3 Maggio-Giugno 2006
DOI 10.1393/ncc/i2005-10233-y

Search for Θ^+ production in the $\gamma d \to \Lambda K^+ n$ reaction

M. Mirazita
for the CLAS Collaboration
INFN, Laboratori Nazionali di Frascati - Frascati (Rome), Italy

(ricevuto il 20 Dicembre 2005; approvato il 13 Marzo 2006; pubblicato online il 9 Giugno 2006)

Summary. — The study of the Θ^+ production in photoreactions is one of the main topics of the experimental program of the CLAS Collaboration. Among the various possible reaction channels, one of the most interesting one is the reaction $\gamma d \to \Lambda K^+ n$, because, having only one kaon in the final state, there are no background contributions from mesonic resonances, and also the number of possible baryonic resonances are very limited. Here the preliminary results of the data collected in 2004 at CLAS will be shown. The final state is identified by detecting in CLAS the proton and pion coming from the Λ and the kaon, while the neutron is detected via missing mass.

PACS `12.39.Mk` – Glueball and nonstandard multi-quark/gluon states.
PACS `13.60.Rj` – Baryon production.
PACS `13.60.-r` – Photon and charged-lepton interactions with hadrons.
PACS `14.20.Jn` – Hyperons.

1. – Introduction

The existence of non qqq baryons was proposed since the beginning of the QCD and the quark model of the hadrons. However, the studies performed in the '70s did not give any conclusive result, essentially due to their limited accuracy. The interest in the pentaquark search was recently renewed by the the prediction within the chiral soliton model [1] of a $S = +1$ baryon with a mass of 1530 MeV and width of less than 15 MeV. Thus, if it exists, its detection should be relatively simple in the modern experimental detectors. After the first announcement by the LEPS Collaboration at Spring8 [2] in 2003, many other experiments [3-12] reported evidence for a new exotic baryon with strangeness $S = +1$ and valence quark structure $udud\bar{s}$. The observation of other pentaquark states belonging to the Θ^+ anti-decuplet were then also reported [13,14] and finally the H1 Collaboration observed the first candidate of an anti-charmed pentaquark [15]. On the other hand, other high-energy experiments did not found any evidence for pentaquarks [16-29], thus suggesting that, if pentaquarks exist, their production mechanism is, in some case, strongly suppressed in an *exotic* way. All the experimental evidences, both positive and negative, were obtained from the analysis of data previously collected for other purposes, involving many reaction channels and very different kinematic conditions, thus not allowing a direct comparison of the results among them.

To definitively clarify the situation, a second generation of dedicated photoproduction experiments, optimized for the pentaquark search, was undertaken at Jefferson Lab. These experiments have been done with different targets and cover the few GeV energy region, where most of the positive results have been obtained, each collecting at least one order of magnitude more data than any of the previous measurements.

In Hall B, the *g10* experiment had as first aim to confirm (or refute), with high statistical precision, the published result in the $\gamma d \to pK^- K^+ n$ reaction channel [4]. Real photons with energy between 0.8 and 3.6 GeV was sent to a liquid-deuterium target. Data were taken at two settings of the CLAS main torus field, a high field setting ($I = 3375$ A) as in the published data, and a low field setting ($I = 2250$ A) to increase the acceptance for negative particles in the forward direction. At each setting, a total luminosity of 25 pb^{-1} was collected. The Θ^+ production in the *g10* data is searched in various reaction channels, namely

- $\gamma d \to \Theta^+ K^- p$ with the decay $\Theta^+ \to K^+ n$ (the published one);
- $\gamma d \to \Theta^+ K^- p$ with the decay $\Theta^+ \to K^0 p$;
- quasi-free $\gamma n \to \Theta^+ K^-$ with the decay $\Theta^+ \to K^+ n$ (the LEPS analysis);
- $\gamma d \to \Theta^+ \Lambda$ with the $\Lambda \to \pi^- p$ decay and both Θ^+ decays.

Here, we present the preliminary results of the study of the last reaction. The presence of the Λ hyperon in the final state, with its weak decay into the πN channel, makes this channel particularly interesting, because the mesonic resonances cannot contribute at all to the final state. Thus, if a peak is found in the observed invariant mass of the KN system, it cannot be attributed to possible kinematic reflection of some mesonic resonance, as has been proposed [30] to explain the CLAS published result [4]. In addition, very few baryonic resonances can contribute, allowing a relatively simple estimation of the background contribution to the reaction.

2. – Final-state selection

The search for the production of the $\gamma d \to \Theta^+ \Lambda$ reaction in the *g10* data has been performed independently by three different groups, which found results in agreement among each other. The small differences (less than 10%) between the different analyses are mainly due to the different particle identification cuts used, but the physics results, *i.e.* the mass distributions of the KN system, are not affected by these differences. Both Θ^+ decays have been studied, leading to the two possible final states, $p\pi^- K^+ n$ and $p\pi^- \pi^+ \pi^- p$. In the first case, the three charged particles are detected with CLAS, while the neutron is identified with missing mass cuts. In the second case, several different exclusive topologies can be examined, depending on how many of the five final charged particles were detected in CLAS. In the following, only the topology with all five particles detected will by analyzed.

2˙1. *The* $p\pi^- K^+ (n)$ *final state.* – The missing mass of the $\gamma d \to p\pi^- K^+ X$ reaction and the invariant mass of the $\pi^- p$ system for the low field data are shown in fig. 1 for the low field data. Cuts on these distributions have been applied in order to select exclusive

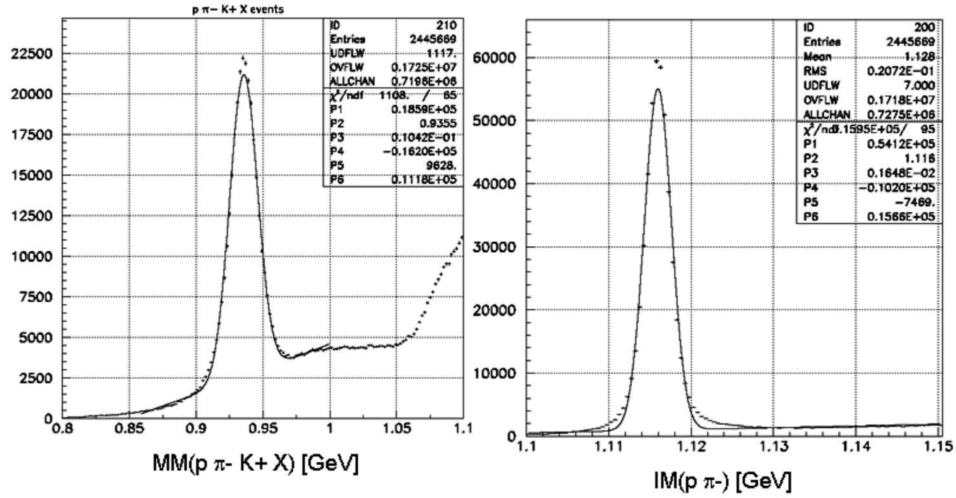

Fig. 1. – Missing mass (left plot) and invariant mass of $p\pi^-$ in $\gamma d \to p\pi^- K^+ X$ events. Data of low torus field setting.

$\Lambda K^+ n$ events, respectively a 2σ and a 3σ cut around the peak of the missing neutron and of the Λ. Very similar results in terms of mass resolutions have been obtained for the high field data, but with a factor almost 5 lower statistic due to the lower acceptance for negative particles.

2·2. *The $p\pi^-\pi^+\pi^-p$ final state.* – First, we select exclusive events by cutting on the missing mass square of $\gamma d \to p\pi^-\pi^+\pi^- pX$ between -0.01 and $0.005\ \mathrm{GeV}^2$. The combinatorial background due to the possible combination of pions and protons to reconstruct the initial Λ and K^0 can be effectively reduced by looking at scatter plots of $M(\pi^+\pi^-)$ *vs.* $M(p\pi^-)$, as shown in fig. 2 for the low field data. The reconstructed Λ (K^0) mass with the approximate cut $0.48 < M(K^0) < 0.52$ GeV ($1.11 < M(\Lambda) < 1.12$ GeV) is shown in the upper (lower) plot of fig. 3. A clear signal over a small background is found. The final sample of $\Lambda K^0 p$ events is selected by applying 3σ cuts around these peaks. Also for this channel, similar results have been found with the high field data, with a factor of about 8 lower statistic (there are two negative particles detected).

3. – Results

After the PID cuts described, we ended with a sample of ΛKN events in which we can look for the Θ^+ production by studying the mass of the KN system. The main background contribution comes from ΛK production on a quasi-free nucleon, with the other nucleon in the deuteron target acting just as a spectator. This background can be very effectively reduced by cutting on the momentum of the nucleon well above the Fermi momentum. In the $\Lambda K^+ n$ topology, we required $P > 0.2$ GeV/c for the missing neutron momentum, while in the $\Lambda K^0 p$ topology a cut on the proton momentum of the order of 0.25–0.30 GeV/c (depending on the angle and on the torus field) is automatically set by the CLAS acceptance.

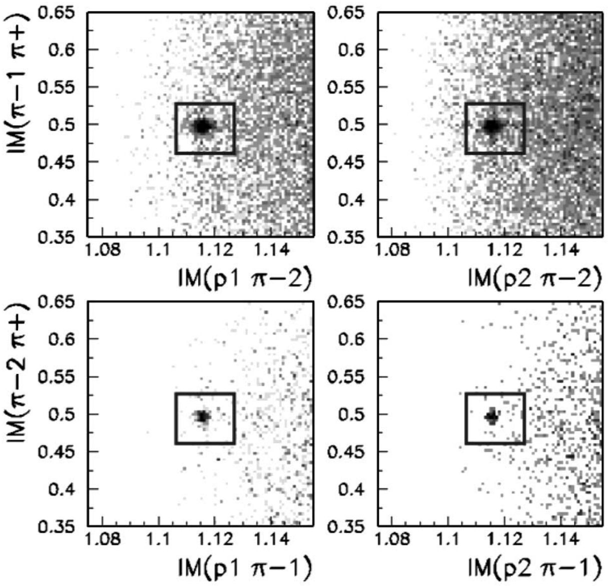

Fig. 2. – Invariant $\pi^+\pi^-$ mass *vs.* the invariant $p\pi^-$ mass for the four possible ways to reconstruct K^0 and Λ in $\gamma d \to p\pi^- p\pi^+\pi^-$ events. The boxes represent approximate cuts to select K^0 and Λ. Data of the low field setting.

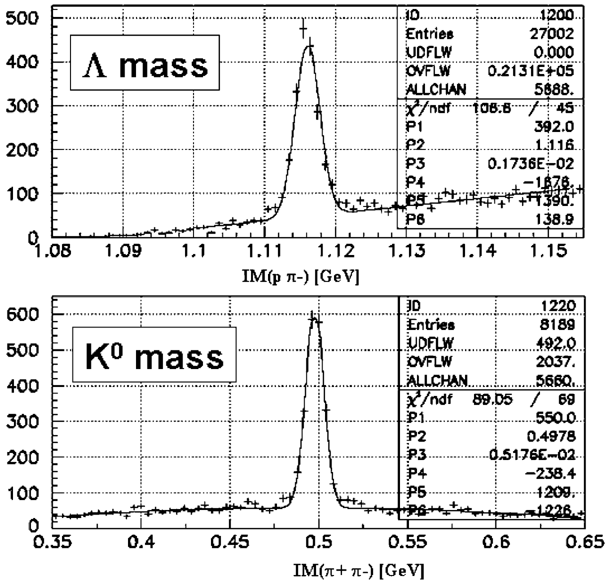

Fig. 3. – Reconstruction of K^0 and Λ particles in $\gamma d \to p\pi^- p\pi^+\pi^-$ events. Data of low torus field setting.

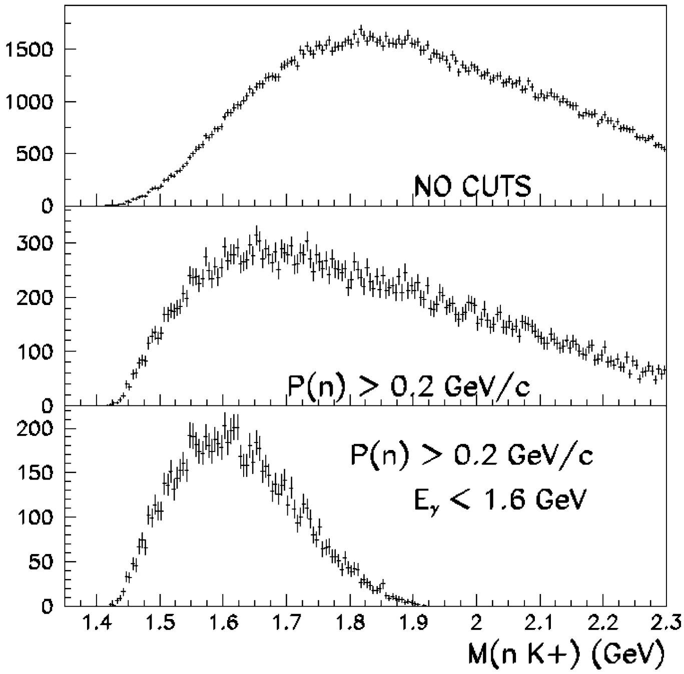

Fig. 4. – Mass of the K^+n system in $\gamma d \rightarrow \Lambda K^+ n$ events: without any additional cut (upper plot), after spectator neutron cut (middle plot), after the additional cut for low photon energy (lower plot). Data for low torus field setting.

3·1. *The* $p\pi^-K^+(n)$ *final state.* – The mass of the K^+n system is shown in the upper plot of fig. 4 as computed from all the $\gamma d \rightarrow \Lambda K^+ n$ events, while the middle plot of the figure shows the mass distribution after the neutron momentum cut $P_n > 0.2$ GeV/c. As can be seen, these mass distributions are smooth in all the measured range and no structures are evident, in particular in the region around $M \approx 1.54$ GeV, where the Θ^+ signal was expected. Several further kinematical cuts have been tried in order to increase the ratio between the possible Θ^+ signal and the background, in particular following ref. [31]. In this paper, a t-channel mechanism for the Θ^+ production is proposed, in which the cross-section is strongly peaked close to the physical threshold and the Λ is produced in the forward direction. The lower plot of fig. 4 shows the mass distribution for photon energy below 1.6 GeV, but no signal comes out from the background. Various other angular cuts have been also tried, corresponding either to forward Λ production (as in Guzey's calculation) or to forward Θ production, but we did not find any peak appearing.

3·2. *The* $p\pi^-\pi^+\pi^-p$ *final state.* – The invariant mass of the K^0p system in the $\gamma d \rightarrow \Lambda K^0 p$ events is shown in the upper plot of fig. 5 (note that the CLAS acceptance automatically selects high momentum protons). Since 5 charged particles have been detected in CLAS, for this topology the total statistic collected is much lower than for the $p\pi^-K^+(n)$ final state. Also in this case, no structures above the smooth background have been found. Again, we tried several kinematic cuts to improve the possible signal with respect to the background (for example, the lower plot of fig. 5 shows the

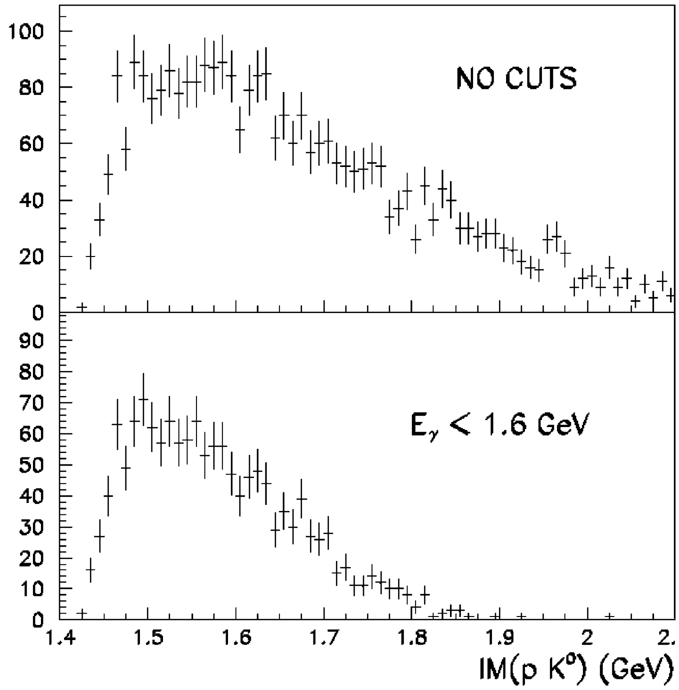

Fig. 5. – Invariant mass of the K^0p system in all $\gamma d \to \Lambda p K^0$ events (upper plot) and after cut for low photon energy (lower plot). Data for low torus field.

$M(K^0p)$ for photon energy below 1.6 GeV) but in none of the obtained mass distributions significant structures have been found.

3˙3. *Monte Carlo background studies.* – As mentioned, the ΛNK final state is relatively free by contributions from mesonic and baryonic resonances. This fact allows a relatively simple treatment of the background with Monte Carlo simulations. To this aim, in the event generator code for real photon interactions with nucleons and nuclei developed in [32] five new reaction channels on free nucleon with kaons in the final state have been added. The code allows to correctly take into account the Fermi motion of the nucleons inside the deuteron nucleus. A simple mechanism to describe the final-state re-scattering of the spectator nucleon has also been implemented. The generated events are sent to the package simulating the CLAS response and then analyzed with the same code used for the analysis of the real data. Preliminary results are in good agreement with the measured $M(K^+n)$ distributions in the ΛK^+n final state.

3˙4. *Cross-section estimate.* – Since we did not find any Θ^+ signal in our mass distributions, we can only derive upper limits on the cross-section of Θ^+ production. Thus, we need an estimate of the CLAS acceptance for $\Lambda\Theta^+$ events in the various topologies we detected. For this, we generated $\Lambda\Theta^+$ events by using two different, in some sense opposite, models. The first one is pure two-body phase space and the second one is given by the t-channel production of [31] in which the Λ is forward produced. Since CLAS has limited acceptance for forward-going negative particles, we expect that the two calculations produce really different total acceptances. Their difference can be assumed as systematic uncertainty in the upper limit calculation due to the model dependence. Calculations are still in progress and will be published soon.

4. – Conclusion

The high-statistic *g10* experiment has been performed by the CLAS Collaboration in order to extensively study the possible existence of the Θ^+ pentaquark. Among the different reaction mechanisms studied, we presented here the preliminary results on the $\gamma d \to \Lambda\Theta^+$ search. In both the final states considered here, no evidence for Θ^+ production has been found, neither using the minimal selection cuts, nor by applying all the kinematical cuts described above in order to increase a possible signal with respect to the background. The preliminary results of the Monte Carlo calculations show that the measured $M(K^+n)$ distributions of fig. 4 are in agreement with the quasi-free ΛK^+ production on proton. Other topologies for the $\Theta^+ \to pK^0$ decay are under analysis, in which some of the final particles are detected by missing mass. Adding these topologies will increase the total statistics by a factor bigger than 10 with respect to the plots of fig. 5, but we did not expect substantial changes in our results.

Since no positive results have been found, the CLAS Collaboration will produce an upper limit on the production cross-section of $\gamma d \to \Lambda\Theta^+$. The Monte Carlo calculation of the CLAS acceptance is underway. We expect a factor of ≈ 2 of systematic uncertainty in our results due to model dependence in the CLAS acceptance calculation.

REFERENCES

[1] Diakonv D., Petrov V. and Poliakov M., *Z. Phys. A*, **359** (1997) 305.
[2] Nakano T. *et al.*, *Phys. Rev. Lett.*, **91** (2003) 012002.
[3] Barmin V. V. *et al.*, *Phys. Atom. Mol.*, **66** (2003) 1715.
[4] Stepanyan S. *et al.*, *Phys. Rev. Lett.*, **91** (2003) 252001.
[5] Barth J. *et al.*, *Phys. Lett. B*, **572** (2003) 127.
[6] Asratyan A. E. *et al.*, *Phys. Atom. Nucl.*, **67** (2004) 682.
[7] Koubarovsky V. *et al.*, *Phys. Rev. Lett.*, **92** (2004) 032001.
[8] Airapetian A. *et al.*, *Phys. Lett. B*, **585** (2004) 213.
[9] Chekanov S. *et al.*, *Phys. Lett. B*, **591** (2004) 7-22.
[10] Abdel-Barv M. *et al.*, *Phys. Lett. B*, **595** (2004) 127.
[11] Aleev A. *et al.*, *Phys. Atom. Nucl.*, **68** (2005) 974.
[12] Aslanyan P. Z. *et al.*, *Nucl. Phys. A*, **755** (2005) 375.
[13] Alt C. *et al.*, *Phys. Rev. Lett.*, **92** (2004) 042003.
[14] Kabana S., *Acta Phys. Hung. A*, **24** (2005) 321.
[15] Aktas A. *et al.*, *Phys. Lett. B*, **588** (2004) 17.
[16] Bai J. Z. *et al.*, *Phys. Rev. D*, **70** (2004) 012004.
[17] Abe K. *et al.*, hep-ex0409010.
[18] Aubert B. *et al.*, hep-ex0408064.
[19] Knopffe K. T. *et al.*, *J. Phys. G*, **30** (2004) S1363.
[20] Pinkerton C. *et al.*, *J. Phys. G*, **30** (2004) S1201.
[21] Napolitano J., Cummings J. and Witkowski M., hep-ex0412031.
[22] Antipov Y. M.. *et al.*, *Eur. Phys. J. A*, **21** (2004) 455.
[23] Stenson K. *et al.*, *Int. J. Mod. Phys. A*, **20** (2005) 3745.
[24] Longo M. J. *et al.*, *Phys. Rev. D*, **70** (2004) 111101R.
[25] Christian D. C. *et al.*, *Phys. Rev. Lett.*, **95** (2005) 152001.
[26] Barate R. *et al.*, *Phys. Lett. B*, **599** (2004) 1.
[27] Adamovich M. I. *et al.*, *Phys. Rev. C*, **72** (2005) 055201.

[28] Armstrong S. R., hep-ex04111080.
[29] Gerchtein E. A. *et al.*, *Int. J. Mod. Phys. A*, **20** (2005) 3742.
[30] Dzierba A. *et al.*, *Phys. Rev. D*, **69** (2004) 051901.
[31] Guzey V., *Phys. Rev. C*, **69** (2004) 065203.
[32] Iljinov A. S. *et al.*, *Nucl. Phys. A*, **616** (1997) 575.