PRL 97, 102001 (2006) PHYSICAL REVIEW LETTERS week ending 8 SEPTEMBER 2006

Search for Θ^{++} Pentaquarks in the Exclusive Reaction $\gamma p \rightarrow K^+ K^- p$

V. Kubarovsky,[1,2] M. Battaglieri,[3] R. De Vita,[3] J. Goett,[1] L. Guo,[2] G. S. Mutchler,[6] P. Stoler,[1] D. P. Weygand,[2]
P. Ambrozewicz,[16] M. Anghinolfi,[3] G. Asryan,[39] H. Avakian,[2] H. Bagdasaryan,[33] N. Baillie,[38] J. P. Ball,[9] N. A. Baltzell,[4]
V. Batourine,[27] I. Bedlinskiy,[24] M. Bellis,[1,5] N. Benmouna,[18] B. L. Berman,[18] A. S. Biselli,[5] S. Bouchigny,[22] S. Boiarinov,[2]
R. Bradford,[5] D. Branford,[15] W. J. Briscoe,[18] W. K. Brooks,[2] S. Bültmann,[33] V. D. Burkert,[2] C. Butuceanu,[38]
J. R. Calarco,[30] S. L. Careccia,[33] D. S. Carman,[32] S. Chen,[17] E. Clinton,[28] P. L. Cole,[20] P. Collins,[9] P. Coltharp,[17]
D. Crabb,[37] H. Crannell,[12] V. Crede,[17] J. P. Cummings,[1] R. De Masi,[13] D. Dale,[40] E. De Sanctis,[21] P. V. Degtyarenko,[2]
A. Deur,[2] K. V. Dharmawardane,[33] C. Djalali,[4] G. E. Dodge,[33] J. Donnelly,[19] D. Doughty,[14,2] M. Dugger,[9] O. P. Dzyubak,[4]
H. Egiyan,[2,*] K. S. Egiyan,[39] L. Elouadrhiri,[2] P. Eugenio,[17] G. Fedotov,[29] H. Funsten,[38] M. Y. Gabrielyan,[40] L. Gan,[41]
M. Garçon,[13] A. Gasparian,[42] G. Gavalian,[30,33] G. P. Gilfoyle,[34] K. L. Giovanetti,[25] F. X. Girod,[13] O. Glamazdin,[26]
J. T. Goetz,[10] E. Golovach,[29] A. Gonenc,[16] C. I. O. Gordon,[19] R. W. Gothe,[4] K. A. Griffioen,[38] M. Guidal,[22] N. Guler,[33]
V. Gyurjyan,[2] C. Hadjidakis,[22] K. Hafidi,[8] R. S. Hakobyan,[12] J. Hardie,[14,2] F. W. Hersman,[30] K. Hicks,[32] I. Hleiqawi,[32]
M. Holtrop,[30] C. E. Hyde-Wright,[33] Y. Ilieva,[18] D. G. Ireland,[19] B. S. Ishkhanov,[29] E. L. Isupov,[29] M. M. Ito,[2] D. Jenkins,[36]
H. S. Jo,[22] K. Joo,[7] H. G. Juengst,[18,†] J. D. Kellie,[19] M. Khandaker,[31] W. Kim,[27] A. Klein,[33] F. J. Klein,[12] A. V. Klimenko,[33]
M. Kossov,[24] L. H. Kramer,[16,2] J. Kuhn,[5] S. E. Kuhn,[33] S. V. Kuleshov,[24] J. Lachniet,[5,33] J. M. Laget,[13,2] J. Langheinrich,[4]
D. Lawrence,[28] T. Lee,[30] Ji Li,[1] K. Livingston,[19] H. Lu,[4] M. MacCormick,[22] N. Markov,[7] B. McKinnon,[19] B. A. Mecking,[2]
J. J. Melone,[19] M. D. Mestayer,[2] C. A. Meyer,[5] T. Mibe,[32] K. Mikhailov,[24] R. Minehart,[37] M. Mirazita,[21] R. Miskimen,[28]
V. Mochalov,[23] V. Mokeev,[29] L. Morand,[13] S. A. Morrow,[22,13] M. Moteabbed,[16] P. Nadel-Turonski,[18] I. Nakagawa,[43]
R. Nasseripour,[16,4] S. Niccolai,[22] G. Niculescu,[25] I. Niculescu,[25] B. B. Niczyporuk,[2] M. R. Niroula,[33] R. A. Niyazov,[2]
M. Nozar,[2] M. Osipenko,[3,29] A. I. Ostrovidov,[17] K. Park,[27] E. Pasyuk,[9] C. Paterson,[19] J. Pierce,[37] N. Pivnyuk,[24]
D. Pocanic,[37] O. Pogorelko,[24] S. Pozdniakov,[24] J. W. Price,[10,11] Y. Prok,[37,‡] D. Protopopescu,[19] B. A. Raue,[16,2]
G. Riccardi,[17] G. Ricco,[3] M. Ripani,[3] B. G. Ritchie,[9] F. Ronchetti,[21] G. Rosner,[19] P. Rossi,[21] F. Sabatié,[13] C. Salgado,[31]
J. P. Santoro,[12,2] V. Sapunenko,[2] R. A. Schumacher,[5] V. S. Serov,[24] Y. G. Sharabian,[2] N. V. Shvedunov,[29] E. S. Smith,[2]
L. C. Smith,[37] D. I. Sober,[12] A. Stavinsky,[24] S. S. Stepanyan,[27] S. Stepanyan,[2] B. E. Stokes,[17] I. I. Strakovsky,[18]
S. Strauch,[18,§] M. Taiuti,[3] D. J. Tedeschi,[4] A. Teymurazyan,[40] U. Thoma,[2,‖] A. Tkabladze,[18] S. Tkachenko,[33] L. Todor,[34]
C. Tur,[4] M. Ungaro,[7] M. F. Vineyard,[35] A. V. Vlassov,[24] L. B. Weinstein,[33] M. Williams,[5] E. Wolin,[2] M. H. Wood,[4,¶]
A. Yegneswaran,[2] L. Zana,[30] J. Zhang,[33] and B. Zhao[7]

(The CLAS Collaboration)

[1]*Rensselaer Polytechnic Institute, Troy, New York 12180-3590, USA*
[2]*Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606, USA*
[3]*Istituto Nazionale di Fisica Nucleare, Sezione di Genova, and Dipartimento di Fisica, Universitá di Genova, 16146 Genova, Italy*
[4]*University of South Carolina, Columbia, South Carolina 29208, USA*
[5]*Carnegie Mellon University, Pittsburgh, Pennsylvania 15213, USA*
[6]*Rice University, Houston, Texas 77005-1892, USA*
[7]*University of Connecticut, Storrs, Connecticut 06269, USA*
[8]*Physics Division, Argonne National Laboratory, Argonne, Illinois 60439-4843, USA*
[9]*Arizona State University, Tempe, Arizona 85287-1504, USA*
[10]*University of California at Los Angeles, Los Angeles, California 90095-1547, USA*
[11]*California State University, Dominguez Hills, California 90747-0005, USA*
[12]*Catholic University of America, Washington, D.C. 20064, USA*
[13]*CEA-Saclay, Service de Physique Nucléaire, F91191 Gif-sur-Yvette, France*
[14]*Christopher Newport University, Newport News, Virginia 23606, USA*
[15]*Edinburgh University, Edinburgh EH9 3JZ, United Kingdom*
[16]*Florida International University, Miami, Florida 33199, USA*
[17]*Florida State University, Tallahassee, Florida 32306, USA*
[18]*The George Washington University, Washington, D.C. 20052, USA*
[19]*University of Glasgow, Glasgow G12 8QQ, United Kingdom*
[20]*Idaho State University, Pocatello, Idaho 83209, USA*
[21]*INFN, Laboratori Nazionali di Frascati, 00044 Frascati, Italy*
[22]*Institut de Physique Nucleaire ORSAY, Orsay, France*
[23]*Institute for High Energy Physics, Protvino, 142281, Russia*

0031-9007/06/97(10)/102001(5)

[24]*Institute of Theoretical and Experimental Physics, Moscow, 117259, Russia*
[25]*James Madison University, Harrisonburg, Virginia 22807, USA*
[26]*Kharkov Institute of Physics and Technology, Kharkov 61108, Ukraine*
[27]*Kyungpook National University, Daegu 702-701, Republic of Korea*
[28]*University of Massachusetts, Amherst, Massachusetts 01003, USA*
[29]*Moscow State University, General Nuclear Physics Institute, 119899 Moscow, Russia*
[30]*University of New Hampshire, Durham, New Hampshire 03824-3568, USA*
[31]*Norfolk State University, Norfolk, Virginia 23504, USA*
[32]*Ohio University, Athens, Ohio 45701, USA*
[33]*Old Dominion University, Norfolk, Virginia 23529, USA*
[34]*University of Richmond, Richmond, Virginia 23173, USA*
[35]*Union College, Schenectady, New York 12308, USA*
[36]*Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061-0435, USA*
[37]*University of Virginia, Charlottesville, Virginia 22901, USA*
[38]*College of William and Mary, Williamsburg, Virginia 23187-8795, USA*
[39]*Yerevan Physics Institute, 375036 Yerevan, Armenia*
[40]*University of Kentucky, Lexington, Kentucky 40506, USA*
[41]*University of North Carolina, Wilmington, North Carolina 28403, USA*
[42]*North Carolina Agricultural and Technical State University, Greensboro, North Carolina 27455, USA*
[43]*The Institute of Physical and Chemical Research, RIKEN, Wako, Saitama 351-0198, Japan*

(Received 28 April 2006; published 7 September 2006)

The reaction $\gamma p \to pK^+K^-$ was studied at Jefferson Lab with photon energies from 1.8 to 3.8 GeV using a tagged photon beam. The goal was to search for a Θ^{++} pentaquark, a narrow, doubly charged baryon state having strangeness $S = +1$ and isospin $I = 1$, in the pK^+ invariant mass spectrum. No statistically significant evidence of a Θ^{++} was found. Upper limits on the total and differential cross section for the reaction $\gamma p \to K^-\Theta^{++}$ were obtained in the mass range from 1.5 to 2.0 GeV/c^2, with an upper limit for a narrow resonance with a mass $M_{\Theta^{++}} = 1.54$ GeV/c^2 of about 0.15 nb, 95% *C.L.*. This result places a stringent upper limit on the Θ^{++} width $\Gamma_{\Theta^{++}} < 0.1$ MeV/c^2.

DOI: 10.1103/PhysRevLett.97.102001 PACS numbers: 13.60.Rj, 13.40.−f

Since the first reports of possible observations of Θ^+ pentaquarks, there has been a great deal of speculation about its isospin structure [1–9]. If it were an isovector ($I = 1$), one might expect to observe its isospin partners, in particular Θ^0 and Θ^{++}. On the experimental side, the existence of a Θ^{++} has not been resolved. Gibbs [10], analyzing K^+p total cross sections [11,12], finds no evidence for an isovector resonance. In other experiments involving electromagnetic probes, CLAS [13,14], ZEUS [15], SAPHIR [16], and HERMES [17] reported that no statistically significant Θ^{++} decaying to pK^+ were observed, even though each reported positive observations for candidate Θ^+ peaks. On the other hand, a recent report by the STAR collaboration [18] finds a positive signal for a candidate Θ^{++}.

All previous experiments suffered from low statistics and did not report any quantitative limits on either the production cross section or width of the Θ^{++} baryon. The Θ^{++} and Θ^+ would be expected to have similar widths if they belong to an isovector triplet. Evaluations of the Θ^+ width from existing data is consistent with a width in the range 0.6–1 MeV/c^2 [19–22]. Even a Θ^+ width as small as 1 MeV/c^2 is a challenge for any theoretical model [2,23,24]. This Letter reports the result of a high statistics experiment, which yields about $1 \times 10^6 \Lambda(1520)$s, in search of the production of the Θ^{++} state in the reaction $\gamma p \to K^-\Theta^{++}$, with $\Theta^{++} \to pK^+$. The upper limit of the cross section is obtained, from which a quantitative estimate of the upper limit of the width an order of magnitude smaller than 1 MeV is made. This makes it likely that if the $\Theta^+(1540)$ exists, it is an isosinglet. In addition, the experiment searched for other members of the expected 27 multiplet in a wide mass range, with negative results.

The experiment was performed at the Jefferson Lab—CLAS facility. Details of the design and operation of the CLAS spectrometer and its components may be found in Ref. [25] and references within. Reference [26] discusses the experimental setup used in the present study in greater detail. An energy tagged bremsstrahlung beam produced by a continuous 60 nA electron beam of energy $E_0 = 4.02$ GeV, impinging on a gold radiator of thickness 8×10^{-5} radiation lengths, yielded incident photons in the energy range 1.8 to 3.8 GeV. The photon energy for each event was determined by means of a tagger placed upstream of the CLAS spectrometer. The photon energy resolution was approximately $0.1\% \times E_0$. The reaction target consisted of liquid hydrogen contained in a cylindrical mylar cell of length 40 cm.

Charged particles were detected by the CLAS spectrometer. Particle tracking utilized multiwire drift chambers and a toroidal magnetic field. Particle identification was primarily obtained by comparing the particle momentum with that calculated from the track length and flight time between scintillator detectors around the target and scintillator detectors surrounding the CLAS spectrometer. The CLAS momentum resolution is of the order of 0.5–1% (σ) depending on the kinematics. The detector's geometrical acceptance for positively charged particles in the relevant kinematic region is about 40%, and several times smaller for low energy negative hadrons, which can be lost at forward angles because they are bent out of the acceptance by the toroidal field. For example, the number of $\Lambda(1520)$ obtained by the reconstruction of pK^- events is almost an order of magnitude smaller than the number reconstructed from the missing mass of K^+ when the K^- is not required to be detected. Coincidences between the photon tagger and two charged particles in the CLAS detector triggered the recording of the events. The interaction time between of the incoming photon with the target was measured by the start counter [27], consisting of a set of 24 2.2 mm thick plastic scintillators surrounding the hydrogen cell. An integrated luminosity of 70 pb^{-1} was accumulated in 50 days of data taking.

The putative reaction $\gamma p \to K^-\Theta^{++} \to K^-K^+p$ was studied in two ways. In Case 1, three final state hadrons, p, K^-, and K^+, were detected, and the missing mass of the pK^+ was constructed to check the quality of the particle identification. It was found that the K^- peak dominates the pK^+ missing mass spectrum with very small background, indicating that nearly all the events are in the exclusive 3-body final state. In Case 2, only a pK^+ pair were required, and the K^- was identified by missing mass reconstruction. The background is somewhat higher than in Case 1, but the statistics in the exclusive pK^-K^+ final state are almost an order of magnitude greater.

Figure 1 shows the invariant masses of the K^+K^- and pK^- pairs for the events, in which only proton and K^+ were detected by CLAS. The K^- momentum was calculated from the missing momentum of the pK^+ pair and its energy as $E_{K^-} = \sqrt{P^2_{\text{missing}} + M^2_{K^-}}$. The ϕ peak is clearly seen at the top of Fig. 1. The lower panel displays the pK^- invariant mass spectrum. The most notable feature in the spectrum is the prominent peak due to the $\Lambda(1520)$. There are nearly 1×10^6 events corresponding to the $\Lambda(1520)$ peak for Case 2 and an order of magnitude fewer in Case 1. In addition to greater statistics, Case 2 has the advantage that the undetected K^- can be emitted at any value of $\cos\theta_{\text{CM}}$, where θ_{CM} is the angle between the electron beam direction and pK^+ system in the center-of-mass system, so that the acceptance is significant in the entire range of $\cos\theta_{\text{CM}}$, from -1 to $+1$, and t-channel processes are not suppressed. On the other hand, in Case 1, the acceptance in $\cos\theta_{\text{CM}}$ for detecting the K^-s becomes smaller near $\cos\theta_{\text{CM}} = -1$, so that t-channel processes are suppressed. The trade-off for selection of Case 2 is that the additional background due to pion contamination is significantly greater than for Case 1.

In all further analysis, cuts were applied in the pK^- and K^+K^- mass spectra to eliminate the contribution of the $\Lambda(1520)$ and $\phi(1020)$, respectively, (indicated in Fig. 1 by vertical arrows).

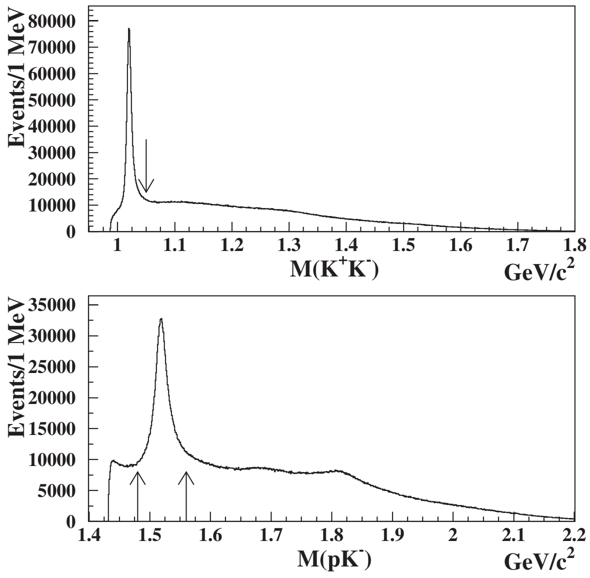

FIG. 1. Upper panel: The K^+K^- invariant mass spectrum. The ϕ meson is clearly seen. Lower panel: The pK^- invariant mass spectrum. The most notable structure is the $\Lambda(1520)$ peak. Events due to the $\Lambda(1520)$ and $\phi(1020)$ were removed from further analysis by cuts indicated by vertical arrows. The distributions are for events in which only the p and K^+ are required to be detected.

The pK^+ mass spectra after all cuts were applied are shown for Case 1 and Case 2, in the upper and lower panels of Fig. 2. In neither case is there any visual evidence for any narrow structures which could be interpreted as due to a Θ^{++}. The insets show expanded views in the region where one might expect a Θ^{++} partner of an isovector Θ^+ located near $M = 1.54$ GeV$/c^2$. The pK^+ mass resolution $\sigma(M_{\Theta^{++}})$ varies as a function of the mass from 2 MeV$/c^2$ at $M_{\Theta^{++}} = 1.5$ GeV$/c^2$, up to 5.5 MeV$/c^2$ at $M_{\Theta^{++}} = 2.0$ GeV$/c^2$.

As for the $\Lambda(1520)$, the acceptance of the undetected K^- is significant at all center-of-mass angles. Thus, invariant mass spectra for pK^+ pairs were also obtained for discrete intervals of the center-of-mass angles of the emitted K^- (or pK^+ pairs) covering the entire angular range. No indication of a Θ^{++} peak is observed in any angular region.

Since no positive signal was observed, upper limits for the cross sections were determined for Case 2. Case 2 was chosen rather that Case 1 since there are no gaps in the acceptance, and statistics are much higher. Two methods were employed. In the first (Method 1), a Gaussian peak corresponding to $N_{\Theta^{++}}$ and a polynomial background were fit to the pK^+ spectrum for an assumed Θ^{++} mass, $M_{\Theta^{++}}$. Then a Feldman-Cousins [28] algorithm was applied to the number under the fit peak and background in a $\pm 3\sigma$ interval to obtain an upper limit of Θ^{++} events ($N^{95\%}_{\Theta^{++}}$) at the 95% confidence level ($C.L.$). This was repeated as a function of $M_{\Theta^{++}}$. In the second method (Method 2), the

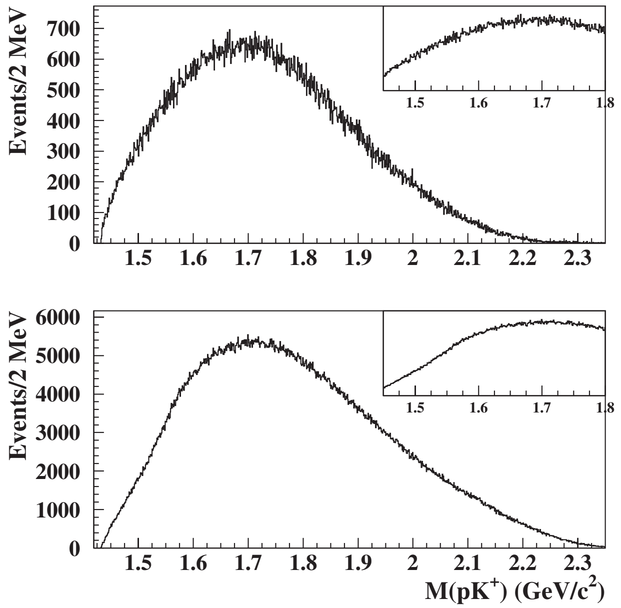

FIG. 2. The pK^+ invariant mass spectra obtained after all cuts were applied, including the removal of the $\Lambda(1520)$ and $\phi(1020)$ events. Upper panel: Case 1 in which all three final state particles, p, K^+, and K^-, were detected. Lower panel: Case 2, in which only the p and K^+ are required to be detected and the K^- is identified by missing mass cuts. The inset in each panel is a detail in the region near the reported Θ^+ mass where one might expect a peak due to the Θ^{++}. In both cases the spectra appear featureless.

pK^+ spectrum was fit with a polynomial, excluding the region of $M_{\Theta^{++}}$. For each $M_{\Theta^{++}}$, the $N_{\Theta^{++}}$ was obtained as the difference between the polynomial and the total number of events within a $\pm 3\sigma$ interval around $M_{\Theta^{++}}$. Again, this was analyzed with the Feldman-Cousins [28] algorithm. The cross section upper limit at the 95% level was then obtained from

$$\sigma^{95\%}_{\Theta^{++}} = \frac{N^{95\%}_{\Theta^{++}}}{L(M_{\Theta^{++}})\epsilon(M_{\Theta^{++}})\mathrm{BR}(\Theta^{++} \to pK^+)},$$

where $L(M_{\Theta^{++}})$ is the integrated luminosity for photons in the energy range from threshold for a given mass to 3.8 GeV, $\epsilon(M_{\Theta^{++}})$ is the pK^+ acceptance, and $\mathrm{BR}(\Theta^{++} \to pK^+)$ is the branching ratio for $\Theta^{++} \to pK^+$, which is assumed to equal 1 for an isovector Θ^{++}.

This procedure was repeated as a function of $M_{\Theta^{++}}$ and as a function of $\cos\theta_{\mathrm{CM}}$ at $M_{\Theta^{++}} = 1.54\ \mathrm{GeV}/c^2$. The upper limits obtained in Method 1 and Method 2 were found to be consistent. Since the mass resolution $\sigma(M_{\Theta^{++}})$ varies approximately linearly, increasing with $M_{\Theta^{++}}$, the variation in $\sigma(M_{\Theta^{++}})$ and the acceptance $\epsilon(M_{\Theta^{++}})$ as a function of $M_{\Theta^{++}}$ were taken into account in determining the cross section upper limit $\sigma^{95\%}_{\Theta^{++}}$. The CLAS acceptance, $\epsilon(M_{\Theta^{++}})$ for the detection of the Θ^{++}, was obtained by means of a detailed Monte Carlo simulation. The simulation assumed t-channel dominance in which the K^- is mainly produced at forward angles in the center-of-mass system. Assuming that the properties of the t-channel K^- would be similar to that of the K^+ in $\Lambda(1520)$ production, the energy dependence and the t-slope were taken from the experimental $\Lambda(1520)$ photoproduction reaction. The Monte Carlo study showed that the acceptance was almost flat over the full range of $\cos\theta_{\mathrm{CM}}$. Thus, even for extremely different event generators, t-channel, and u-channel Θ^{++} photoproduction, the calculated acceptances differ by less than 10%. The u-exchange distribution was generated the same way as t-channel exchange except that the center-of-mass angles of the K^- and Θ^{++} were interchanged. The result of the simulation is that the CLAS acceptance with all the applied analysis cuts varied from 6% at $M_{\Theta^{++}} = 1.5\ \mathrm{GeV}/c^2$, up to 16% at $M_{\Theta^{++}} = 2.0\ \mathrm{GeV}/c^2$.

The estimated systematic errors in acceptance were combined with those of the detector inefficiencies, photon flux normalization, and Θ^{++} mass resolution to give an overall estimated 15% systematic error in the resulting upper limit. This error was not included in the estimation of the upper limit.

The resulting upper limit of the scans in $M_{\Theta^{++}}$ and $\cos\theta_{\mathrm{CM}}$ for Case 2 using Method 1 is shown in Fig. 3. For both methods, we find the average upper limit in the mass region where an isospin partner of a Θ^+ is expected, near 1.54 GeV/c^2, at approximately 0.15 nb, and not much different for masses from 1.5 to 2.0 GeV/c^2, the range of photon energies accessed in this experiment.

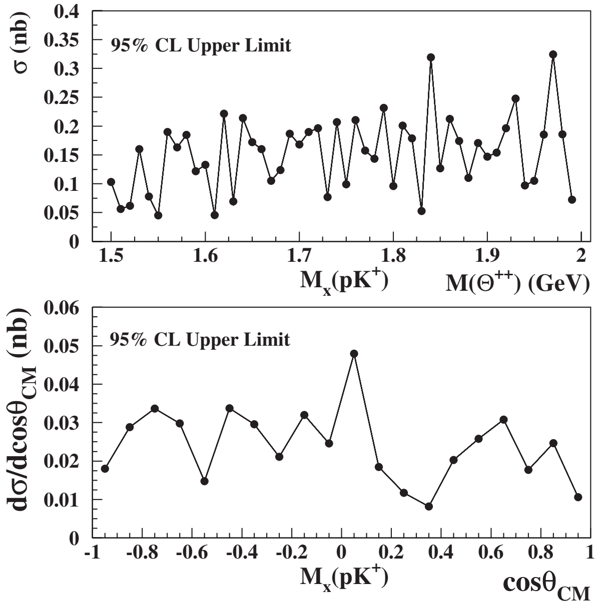

FIG. 3. Upper panel: The calculated upper limit on the cross section at 95% confidence level vs $M_{\Theta^{++}}$, using the Feldman-Cousins approach, as discussed in the text, for Case 2 in which the K^- was not required to be detected. The upper limit at 95% *C.L.* at $M_{\Theta^{++}}$ near 1.54 GeV/c^2 is estimated to be approximately 0.15 nb. Lower panel: The upper limit as a function of $\cos\theta_{\mathrm{CM}}$ at $M_{\Theta^{++}} = 1.54\ \mathrm{GeV}/c^2$. The systematic uncertainty in the magnitude of the upper limit is estimated at 15%.

The upper limit of the ratio $\Theta^{++}/\Lambda(1520)$ was also obtained from the data. The average cross section for $\Lambda(1520)$ photoproduction was calculated from the number of $\Lambda(1520)$ events in a manner similar to that described for $\sigma^{95\%}_{\Theta^{++}}$ above. The result is $\sigma_{\Theta^{++}}/\sigma_{\Lambda(1520)} < 2.3 \times 10^{-4}$ at 95% *C.L.* averaged over the photon energy range of this experiment.

The Θ^{++} production cross section may be directly connected with the Θ^{++} width $\sigma_{\Theta^{++}} \sim \Gamma_{\Theta^{++}}$ (see, for example, Ref. [5]). Such a small cross section implies a very narrow resonance width. However, an upper limit on the width would be highly model dependent, differing by as much as an order of magnitude for existing approaches [5,29–32]. For example, for an isovector pentaquark of $J^P = 1/2^+$, the upper limit on the width implied by the present result for the Regge approach [29] would be $\Gamma_{\Theta^{++}} < 0.1$ MeV$/c^2$, while for the effective Lagrangian approach [5] ,$\Gamma_{\Theta^{++}} < 0.01$ MeV$/c^2$.

In conclusion, the present experiment finds no evidence of the formation of a doubly charged pentaquark in the exclusive channel $\gamma p \rightarrow K^- \Theta^{++} \rightarrow K^- K^+ p$. An upper limit on the cross section was obtained over a mass range from 1.5 to 2.0 GeV$/c^2$, with a value of about 0.15 nb at 95% *C.L.* near 1.54 GeV$/c^2$ where a Θ^{++} isovector partner of the Θ^+ might be expected. A conservative estimate of the upper limit on the width is $\Gamma_{\Theta^{++}} < 0.1$ MeV$/c^2$. The comparison of this limit with the evaluation from existing data of the Θ^+ width ($\sim$1 MeV$/c^2$) makes it likely that the Θ^+ baryon (if it exists) has no isotopic partner and thus is an isovector singlet state. Although the present experiment does put very strong limits on the mechanisms which would be required to produce an isovector pentaquark, we point out that it does not access a reaction in which a pentaquark may be produced in association with an additional pion, as in Ref. [14].

We would like to thank W. Roberts and Ya. I. Azimov for valuable communications. We would like to acknowledge the outstanding efforts of the staff of the Accelerator and the Physics Divisions at JLab that made this experiment possible. This work was supported in part by the Italian Istituto Nazionale di Fisica Nucleare, the French Centre National de la Recherche Scientifique and the Commissariat à l'Energie Atomique, the U.S. Department of Energy, the National Science Foundation, and the Korea Research Foundation. The Southeastern Universities Research Association (SURA) operates the Thomas Jefferson National Accelerator Facility for the United States Department of Energy under Contract No. DE-AC05-84ER40150.

---

[*] Current address: University of NH, Durham, NH 03824-3568, USA

[†] Present address: Old Dominion University, Norfolk, VA 23529, USA

[‡] Present address: MA Institute of Technology, Cambridge, MA 02139-4307, USA

[§] Present address: University of SC, Columbia, SC 29208, USA

[‖] Present address: Physikalisches Institut der Universität Gießen, 35392 Giessen, Germany

[¶] Present address: University of MA, Amherst, MA 01003, USA

[1] H. Walliser and V. B. Kopeliovich, Zh. Eksp. Teor. Fiz. **124**, 483 (2003) [JETP **97**, 433 (2003)].

[2] S. Capstick, P. R. Page, and W. Roberts, Phys. Lett. B **570**, 185 (2003).

[3] Bin Wu and Bo-Qiang Ma, Phys. Rev. D **69**, 077501 (2004).

[4] J. Ellis, M. Karliner, and M. Praszalowicz, J. High Energy Phys. 05 (2004) 002.

[5] W. Roberts, Phys. Rev. C **70**, 065201 (2004).

[6] V. B. Kopeliovich, Usp. Fiz. Nauk **174**, 323 (2004) [Phys. Usp. **47**, 309 (2004)].

[7] Shi-Lin Zhu, Phys. Rev. Lett. **91**, 232002 (2003).

[8] T. Nishikawa *et al.*, Phys. Rev. D **71**, 016001 (2005).

[9] Ya. I. Azimov *et al.*, Eur. Phys. J. A **26**, 79 (2005).

[10] W. R. Gibbs, Phys. Rev. C **70**, 045208 (2004).

[11] T. Bowen *et al.*, Phys. Rev. D **2**, 2599 (1970).

[12] A. S. Carroll *et al.*, Phys. Lett. B **45**, 531 (1973).

[13] H. G. Juengst (CLAS Collaboration), Nucl. Phys. A **754**, 265 (2005).

[14] V. Kubarovsky *et al.* (CLAS), Phys. Rev. Lett. **92**, 032001 (2004).

[15] S. Chekanov *et al.* (ZEUS), Phys. Lett. B **591**, 7 (2004).

[16] J. Barth *et al.* (SAPHIR Collaboration), Phys. Lett. B **572**, 127 (2003).

[17] A. Airapetian *et al.* (HERMES Collaboration), Phys. Lett. B **585**, 213 (2004).

[18] Huan Z. Huang (STAR Collaboration), Int. J. Mod. Phys. A **21**, 825 (2006), to appear in proceedings of International Conference on QCD and Hadron Physics at Beijing, China, June 16-20, 2005.

[19] R. A. Arndt, I. I. Strakovsky, and R. L. Workman, Phys. Rev. C **68**, 042201 (2003).

[20] R. N. Cahn and G. H. Trilling, Phys. Rev. D **69**, 011501 (2004).

[21] A. Sibirtsev *et al.*, Phys. Lett. B **599**, 230 (2004).

[22] K. Abe *et al.*, Phys. Lett. B **632**, 173 (2006).

[23] B. L. Ioffe and A. G. Oganesian, JETP Lett. **80**, 386 (2004).

[24] R. L. Jaffe and A. Jain, Phys. Rev. D **71**, 034012 (2005).

[25] B. A. Mecking *et al.* (CLAS Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **503**, 513 (2003).

[26] R. De Vita *et al.* (CLAS Collaboration), Phys. Rev. D **74**, 032001 (2006).

[27] Y. G. Sharabian *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **556**, 246 (2006).

[28] G. J. Feldman and R. D. Cousins, Phys. Rev. D **57**, 3873 (1998).

[29] H. Kwee *et al.*, Phys. Rev. D **72**, 054012 (2005).

[30] C. M. Ko and W. Liu, nucl-th/0410068.

[31] Y. Oh *et al.*, Phys. Rep. **423**, 49 (2006).

[32] S. Nam *et al.*, Phys. Lett. B **633**, 483 (2006).