Limits for the central production of $\Theta^+$ and $\Xi^{-}$ pentaquarks in 920 GeV pA collisions

I. Abt, M. Adams, M. Agari, H. Albrecht, A. Aleksandrov, V. Amaral, A. Amorim, S. J. Aplin, V. Aushev, Y. Bagaturia, V. Balagura, M. Bargiotti, O. Barsukova, J. Bastos, J. Batista, C. Bauer, Th. S. Bauer, A. Belkov, Ar. Belkov, I. Belotelov, A. Bertin, B. Bobchenko, M. Böcker, A. Bogatyrev, G. Bohm, M. Bräuer, M. Brünsma, M. Bruschi, P. Buchholz, T. Buran, J. Carvalho, P. Conde, C. Cruse, M. Dam, K. M. Danielsen, M. Danilov, S. De Castro, H. Deppe, X. Dong, H. B. Dreis, V. Egorytchev, K. Ehret, F. Eisele, D. Emeliyanov, S. Essenov, L. Fabbi, P. Faccioli, M. Feuerstack-Raible, J. Flanner, B. Fominyykh, M. Funcke, Ll. Garrido, B. Giaobbe, Gläß, D. Goloubkov, Y. Golubkov, A. Golutvin, I. Golutvin, I. Gorbounov, A. Gorisık, Gouthchitine, D. C. Goulart, S. Gradl, W. Gradl, F. Grimaldi, Y. Guiltsky, J. D. Hansen, J. M. Heinemann, W. Hofmann, T. Hott, W. Hulsbergen, U. Husemann, O. Igonkina, T. Jagla, C. Jiang, H. Kapitza, S. Karabekyan, N. Karpenko, S. Keller, J. Kessler, F. Khasanov, Y. Kiryushin, K. T. Knöpfle, H. Kolanoski, S. Korpita, C. Krauss, P. Kreuzer, P. Križan, D. Krücker, S. Kupper, K. Kvaratskhelidze, A. Lanyov, K. Lau, B. Lewendel, T. Löhse, B. Lomonosov, R. Männner, S. Masciocchi, I. Massa, I. Matchikhilian, G. Medin, M. Medinnis, M. Mevius, A. Michetti, Y. Mikhailov, R. Mizuk, R. Muresan, M. zur Nedden, M. Negodaev, M. Nörenberg, S. Nowak, M. T. Núñez Pardo de Vera, M. Ouchrif, F. Ould-Saada, C. Padilla, P. Peralta, R. Pernack, R. Pestonik, M. Piccinini, M. A. Pleier, M. Poli, V. Popov, A. Pose, D. Pose, I. Rostovtseva, I. Rostovtseva, V. Rybnikov, F. Sánchez, A. Sbrizzi, M. Schmelling, B. Schmid, A. Schreiner, H. Schröder, A. J. Schwartz, A. S. Schwarzmüller, B. Schwinger, N. Semprini-Cesari, S. Shuvalov, L. Silva, K. Smirnov, L. Söözer, S. Sollun, A. Somov, S. Somov, Spengler, R. Spiglet, A. Spiridonov, A. Stanovnik, M. Starić, C. Stegmann, H. S. Subramania, M. Symalla, I. Tikhonirov, M. Titov, I. Tsakov, U. Uwer, C. van Eldik, Yu. Vassiliev, M. Villa, A. Vitale, I. Vukotic, H. Wahlberg, A. H. Walenta, M. Walter, J. J. Wang, D. Wegener, O. Werthenbach, H. Wolters, R. Wurth, A. Wurz, Yu. Zaitsev, M. Zavertyaev, G. Zech, T. Zeuner, A. Zhelezov, Z. Zheng, R. Zimmermann, T. Živko, and A. Zoccoli (HERA-B Collaboration)

NIKHEF, 1009 DB Amsterdam, The Netherlands
Department ECM, Faculty of Physics, University of Barcelona, E-08028 Barcelona, Spain
Institute for High Energy Physics, Beijing 100039, P.R. China
Institute of Engineering Physics, Tsinghua University, Beijing 100084, P.R. China
Institut für Physik, Humboldt-Universität zu Berlin, D-12489 Berlin, Germany
Dipartimento di Fisica dell’ Università di Bologna and INFN Sezione di Bologna, I-40126 Bologna, Italy
Department of Physics, University of Cincinnati, Cincinnati, Ohio 45221, USA
LIP Coimbra, P-3004-516 Coimbra, Portugal
Niels Bohr Institutet, DK 2100 Copenhagen, Denmark
Institut für Physik, Universität Dortmund, D-44227 Dortmund, Germany
Joint Institute for Nuclear Research Dubna, 141980 Dubna, Moscow region, Russia
DESY, D-22603 Hamburg, Germany
Max-Planck-Institut für Kernphysik, D-69117 Heidelberg, Germany
Physikalisches Institut, Universität Heidelberg, D-69120 Heidelberg, Germany
Department of Physics, University of Houston, Houston, TX 77204, USA
Institute for Nuclear Research, Ukrainian Academy of Science, 03680 Kiev, Ukraine
J. Stefan Institute, 1001 Ljubljana, Slovenia
University of Ljubljana, 1014 Ljubljana, Slovenia
University of California, Los Angeles, CA 90024, USA
Lehrstuhl für Informatik V, Universität Mannheim, D-68131 Mannheim, Germany
University of Maribor, 2000 Maribor, Slovenia
Institute of Theoretical and Experimental Physics, 117259 Moscow, Russia
Max-Planck-Institut für Physik, Werner-Heisenberg-Institut, D-80805 München, Germany
Dept. of Physics, University of Oslo, N-0316 Oslo, Norway
Fachbereich Physik, Universität Rostock, D-18051 Rostock, Germany
Fachbereich Physik, Universität Siegen, D-57068 Siegen, Germany
Institute for Nuclear Research, INRNE-BAS, Sofia, Bulgaria
Universiteit Utrecht/NIKHEF, 3584 CB Utrecht, The Netherlands
Recent experimental evidence suggests not only that pentaquarks (PQs), i.e. baryons with at least five constituent quarks, exist but that their production in high energy collisions is common. After the possible discovery of the Θ⁺ PQ (uudds) at 1540 MeV/c² in the γn→K⁺K⁻n process on carbon [1], more than 10 experiments using incident beams of photons, electrons, kaons, protons or (anti-)neutrinos have observed resonances within ±20 MeV/c² of this mass in either the nK⁺ [2] or the pK⁰ [3,4,5] decay channels; the measured widths have all been consistent with the experimental resolutions ranging from 20 MeV/c² to 2 MeV/c² [6]. The Θ⁺ interpretation is based on a prediction of the chiral soliton model (CSM) according to which the Θ⁺ is expected to have a mass of 1530 MeV/c², a width of less than 15 MeV/c², and to decay into the KN channel. In both the CSM and the correlated quark model [7], the Θ⁺ is a member of an antidecuplet with two further exotic isospin 3/2 states of S = −2, the Ξ⁻(ddssū) and the Σ₃/₂ (uussd). In pp collisions at √s ≈ 18 GeV, narrow candidate resonances for both the Ξ⁻ and its neutral isospin partner have been found in the Ξ⁻π⁻ and Ξ⁺π⁺ final states at the mass of 1862 MeV/c² [8]. Theoretically, PQs are not restricted to the strange sector, and experimental evidence for an anti-charmed PQ, Θ⁰_c (uuddc), with a mass of 3.1 GeV/c² has recently been reported [9]. In this context also earlier already ‘forgotten’ c ¯ c PQ candidates [10] have been recalled [11].

On the other hand, criticism addressed to some of the reported PQ signals includes the problem of kinematic reflections [12], of spurious states [13], and of low statistics [14]. Other puzzles include the surprisingly narrow width of the Θ⁺ [15], the large and systematic spread of measured Θ⁺ masses, and the non-observation of the Θ⁰_c in an equivalent experiment [16]. Hence, for establishing the existence and character of the new resonances, high statistics mass spectra are needed as well as measurements of spin, parity, width and cross sections. In addition, considering the results of high statistics studies which have found neither the Θ⁺ signal in ψ(2S) and J/ψ hadronic decays [17] nor the Ξ⁻ signal in Σ⁻⁰-induced reactions on nuclear targets [18], the need for a thorough understanding of the PQ production mechanism has been emphasized [19]. Benchmarks for PQ production exist based on statistical hadronization models; they typically predict particle ratios such as Θ⁺/Λ(1520) to be very heavy ion [15, 20, 21, 22, 23] and pp [22, 24, 25] collisions. Taking advantage of a large data sample with good mass resolution (see Table I) HERA-B can contribute significantly to many of these topics. The simultaneous study of Θ⁺→pK⁰ [26] and Ξ⁻→Ξ⁻π⁻→Λπ⁻π⁻ decays in proton-nucleus collisions at √s = 41.6 GeV allows a test of these theoretical predictions and a comparison with earlier experimental results including the possible first confirmation of the Ξ⁻ signal.

HERA-B is a fixed target experiment at the 920 GeV proton storage ring of DESY. It is a forward magnetic spectrometer with a large acceptance centered at mid-rapidity (y_{cm} ≈ 0), featuring a high-resolution vertexing and tracking system and excellent particle identification [27]. The present study is based on a sample of 2·10^9 minimum bias events which were recorded at √s = 41.6 GeV using carbon (C), titanium (Ti) and tungsten (W) wire targets during the 2002/03 run pe-

---

**TABLE I: Statistics and experimental resolutions σ of the relevant signals (charge-conjugate modes indicated by c.c.).**

| Signal | C target | all targets | σ/(MeV/c²) |
|--------|----------|-------------|------------|
| K⁰⁺     | 2.2M     | 4.9M        | 4.9        |
| Λ [c.c.] | 440k [210k] | 1.1M [520k] | 1.6        |
| Λ(1520) [c.c.] | 1.3k [760] | 3.5k [2.1k] | 2.3        |
| Ξ⁻ [c.c.] | 4.7k [3.4k] | 12k [8.2k] | 2.6        |
| Ξ(1530)⁰ [c.c.] | 610 [380] | 1.4k [940] | 2.9        |
period. For this analysis the information from the silicon vertex detector, the main tracking system, the ring-imaging Cherenkov counter (RICH), and the electromagnetic calorimeter (ECAL) was used.

With standard techniques described in [26], signals from \( K_0^0 \rightarrow \pi^+\pi^- \), \( \Lambda \rightarrow p\pi^- \) and \( \bar{\Lambda} \rightarrow \bar{p}\pi^+ \) decays are identified above a small background without particle identification (PID) requirements. Similar clean signals from \( \Xi^- \rightarrow \Lambda\pi^- \) and c.c. decays (Fig. 1a) are obtained by requesting the \( \Lambda\pi^- \) vertex to be at least 2.5 cm downstream of the target and the event to exhibit a cascade topology: a further downstream \( \Lambda \) vertex and the \( \Xi^- \) pointing back to the target wire (impact parameter \( b < 1 \text{ mm} \)). Table II summarizes the statistics of these signals, together with their measured mass resolutions \( \sigma \). These resolutions are about 20% larger than those of the Monte Carlo (MC) simulation, while all mass values agree within \( <1 \text{ MeV}/c^2 \) with the nominal masses. For all particle selections, invariant masses are required to be within \( \pm3\sigma \) of the respective nominal mass.

For the search for \( \Theta^+ \rightarrow pK_0^{*}\) decays, events with at least one reconstructed primary vertex were selected. The proton PID was provided by the RICH. The cut in proton likelihood of > 0.95 implies a misidentification probability of less than 1% in the selected momentum range from 22 to 55 GeV/c. [27]. The \( \Lambda \) and \( \bar{\Lambda} \) contaminations [13] were removed [26] in the \( K_0^0 \) sample. The invariant mass spectrum of the \( pK_0^{*} \) pairs is shown in Fig. 2a) for the p+C data. The solid line represents the background determined from event mixing after normalization to the data. The spectrum exhibits a smooth shape in the mass region from 1.45 to 1.7 GeV/c^2. Using the prescription of ref. [28], we have calculated from these data upper limits at 95% confidence level, UL(95%), for the inclusive production cross section of a narrow resonance at mid-rapidity, \( B\cdot\sigma/\text{dy}|_{y=0} \), (Fig. 2a)); the \( y_{cm} \) interval is \( \pm0.3 \). The data have been fitted with a Gaussian plus a background of fixed shape. The mean of the Gaussian was varied in steps of 1 MeV/c^2 but fixed in the fit; its width was fixed to the MC prediction multiplied by 1.2 and increased from 2.6 to 6.1 MeV/c^2 over the considered range. At the \( \Theta^+ \) mass, the width was 3.9 MeV/c^2. The reconstruction efficiencies have been determined by MC simulations assuming a flat rapidity distribution and a \( p_T^2 \) distribution proportional to \( \exp(-B \cdot p_T^2) \) with \( B = 2.1 \text{(GeV/c)}^{-2} \). Assuming an atomic mass dependence of \( \Lambda^{0.7} \) for the production cross section, the UL(95%) of \( B\cdot\sigma/\text{dy} \) varies from 3 to 22 \( \mu\text{b}/\text{nucleon} \) (N) for a \( \Theta^+ \) mass between 1521 and 1555 MeV/c^2. A systematic error of 14% was taken into account. For the \( \Theta^+ \) mass of 1530 MeV/c^2 (about the average of the mass values observed in the \( pK_0^{*} \) final state [10]), our limit is \( B\cdot\sigma/\text{dy} < 3.7 \mu\text{b}/\text{N} \). The ULs from all target data are within \( \pm30\% \) of these values.

Further search strategies were tried including i) a cut...
on the track multiplicity of the event (Fig. 2) which would otherwise peak at \( \approx 13 \), ii) the request of a tagging particle such as a \( \Lambda \), \( \Sigma \) or \( K^- \) in the event, or iii) both conditions (Fig. 2). None yielded a statistically significant structure in \( \Theta^+ \) mass region. Also, the effect of lowering the cut on the RICH proton likelihood and the corresponding increase of the proton momentum acceptance has been systematically studied without yielding a \( \Theta^+ \) signal. On the other hand, as shown in Fig. 2, when the same proton PID requirement used to produce Fig. 2 is applied to \( pK^- \) candidates, a strong \( \Lambda(1520) \) signal results, further demonstrating the capabilities of the RICH. The cut in the \( K^- \) likelihood of > 0.95 implies a selection of kaon momenta from 12 to 55 GeV/c. With the same cut on the \( K^0_S \) momenta, and assuming a branching ratio of \( \mathcal{B}(\Theta^+ \to pK^0_S) = 0.25 \), the UL(95%) of the particle ratio \( \Theta^+(1530)/\Lambda(1520) \) at \( y_{cm} \approx 0 \) is 2.7%.

Both doubly-charged and neutral \( \Xi_{3/2} \) PQ candidates as well as their anti-particles have been searched for in the \( \Xi \pi \) channels. The pion candidates were required to originate from the primary vertex. The background was further reduced by weak cuts on the PIDs from the ECAL and RICH which eliminated all the tracks with a positive electron, proton, or kaon PID. The histograms of Fig. 3 show the resulting \( \Xi \pi \) invariant mass spectra obtained from the C target data. The smooth lines are the background estimates from event-mixing normalized to the data. In the neutral channels the \( \Xi(1530)^0 \) resonance shows up as a prominent signal of \( \approx 10^3 \) events (see Table I). The observed width (\( \approx 9.5 \) MeV/c^2) of the \( \Xi(1530)^0 \) agrees with MC simulations which imply an experimental resolution of 2.9 MeV/c^2. None of these mass spectra shows evidence for the narrow, less than 18 MeV/c^2 (FWHM) wide PQ candidates at 1862 MeV/c^2 reported by the NA49 collaboration \(^8\) nor for any other narrow state at masses between 1.6 and 2.3 GeV/c^2. Fig. 3(b) shows the sum of the four spectra of Fig. 3(a) after background subtraction and can be compared directly to Fig. 3 of ref. \(^8\). The corresponding ULs(95%) of the production cross sections \( Bd\sigma/dy \big|_{y=0} \) per carbon nucleus at mid-rapidity (Fig. 3) have been obtained in the same way as described above for the \( pK^0_S \) channel; here the \( y_{cm} \)-interval is \( \pm 0.7 \). The experimental resolution increases from 2.9 to 10.6 MeV/c^2 in the considered mass range, and is 6.6 MeV/c^2 at 1862 MeV/c^2. At this \( \Xi^- \pi^+ \) mass, the UL(95%) of \( Bd\sigma/dy \) is 2.5 \( \mu b/N \); the corresponding limits in the \( \Xi^- \pi^+ \pi^0 \) and \( \Xi^+ \pi^- \) channels are 2.3, 0.85, and 3.1 \( \mu b/N \). With an \( \Lambda \) dependence, the ULs from all targets are 2.7, 3.2, 0.94, and 3.1 \( \mu b/N \), respectively.

Table II lists our ULs(95%) of various relative yields for the \( \Theta^+ \) and \( \Xi^- \). Reference states for the \( \Theta^+ \) are the \( \Lambda \) and the \( \Lambda(1520) \), and for the \( \Xi^- \), the \( \Xi^- \) and the \( \Xi(1530)^0 \). The \( \Theta^+ \) and \( \Xi^- \) widths are assumed to be equal to our experimental mass resolution and their momentum distributions are assumed to be the same as those of the reference states. Table II lists also predictions of various statistical hadronization models for the respective ratios. We note that these ratios show no significant variation between \( 17 < \sqrt{s} < 40 \) GeV, nor is there a significant difference between predictions for pp and AA collisions. We find our UL for \( \Theta^+/\Lambda(1520) < 2.7\% \) to be more than one order of magnitude lower than the model predictions. Also, the UL of \( \Theta^+/\Lambda < 0.92\% \) is lower than all predictions including the model which uses the Gribov-Regge approach for describing the \( \Theta^+ \) production and its \( \sqrt{s} \) dependence in pp collisions \(^{25}\). Our UL of the \( \Xi^-/\Xi^- \) yield ratio is
 TABLE II: Our 95% CL upper limits on the relative yields of $\Theta^+(1530)$ and $\Xi^{-+}(1862)$ FPs at $y_{cn} \approx 0$ and predictions for pp and AA collisions. For a $\Theta^+$ mass of 1540 MeV/c$^2$, the quoted values have to be multiplied by $4\pi$.

| Reaction | $\sqrt{s} [\text{GeV}]$ | $\sigma^+_{\Lambda}$ | $\sigma^+_{\Xi(1520)}$ | $\sigma^+_{\Xi(1530)}$ | $\Xi^{-+}_{\Xi(1530)}$ | $\Xi^{-+}_{\Xi(1530)}$ | Ref. |
|----------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|-----|
| pA, $y=0$ | 42 | -0.92 | 2.7 | 3/B | 4/B | | |
| pp, $y=0$ | 18 | 2.3 | | | | | |
| pp | 20/40 | 6.3/5.0 | 2.5/3.6 | | | | |
| pp | 17 | 4.7 | 57 | | | | |
| AA | 20 | 3-10 | 50-200 | 0.4-1 | | | |
| AA | 40 | 3-7 | 44-140 | 0.4-1 | | | |

Compatible with the model predictions. No theoretical value is yet available for the $\Xi^{-+}/\Xi(1530)^0$ ratio, but our UL of $\leq 4\%$ should be compared with the value from the NA49 experiment which, however, is not explicitly quoted in the original paper, which reports only the number of $38 \Xi^{-+}$ events. According to ref. 21, the number of $\Xi(1530)^0$ events is about 150 leading to a yield ratio $\Xi^{-+}/\Xi(1530)$ in contradiction to our UL unless the relative efficiencies for $\Xi(1530)^0$ and $\Xi^{-+}$ of NA49 (unpublished) differ markedly from those of HERA-B.

In conclusion, spanning no evidence for narrow $\Theta^+$ and $\Xi^{-+}$ signals, we have set UL(95%) for the central production cross sections of resonances in the $pK^0_S$ and $\Xi^-\pi^+$ final states with widths less than our experimental resolution of $\approx 5 \text{ MeV/c}^2$. For the $\Theta^+(1530)$ and the $\Xi^{-+}(1862)$ the respective ULs of $B(\sigma/dy)_{y=pA=0}$ are 3.7 and $2.5 \mu b/N$. For the $\Theta^+$ candidate observed in pA collisions at $\sqrt{s} = 11.5$ GeV, the total cross section for $x_F \geq 0$ was estimated to be $30 \mu b/N[4]$. A decrease of the central $\Theta^+$ production with increasing $\sqrt{s}$ could be understood if the $\Theta^+$ is produced by disintegration of forward/backward peaked remnants $[25]$. On the other hand, our UL(95%) for $\Theta^+/\Lambda(1520) < 2.7\%$ is significantly lower than statistical hadronization predictions which yield a ratio of $> 0.5$ in agreement with experiments in which the $\Theta^+$ candidate and $\Lambda(1520)$ showed similar yields $[31]$. Our UL(95%) of $B(\Xi^{-+}/\Xi^-) < 3\%$ is not low enough to contradict the theoretical predictions. It is, however, inconsistent with the previously-published $[8]$ observation of the $\Xi^{-+}(1862)$ at mid-rapidity which is based on a data sample of lower statistics (1.6k v. 12k $\Xi^{-+}$) and comparable mass resolution (7.6 v. 6.6 MeV/c$^2$).

The collaborating institutions wish to thank DESY for its support and kind hospitality. This work is supported by NSRC (Denmark); BMBF, DFG, and MPRA (Germany); INFN (Italy); FOM (The Netherlands); RC (Norway); POCTI (Portugal); MIST (No. SS1722.2003, Russia); MESS (Slovenia); CICYT (Spain); SNF (Switzerland); NAS and MES (Ukraine); DOE and NSF (U.S.A.);

[1] T. Nakano et al. (LEPS Coll.), Phys. Rev. Lett. 91, 012002 (2003).
[2] S. Stepanyan et al. (CLAS Coll.), Phys. Rev. Lett. 91, 252001 (2003); J. Barth et al. (SAPHIR Coll.), Phys. Lett. B572, 127 (2003); V. Kubarovsky et al. (CLAS Coll.), Phys. Rev. Lett. 92, 032001 (2004).
[3] V. V. Barniin et al. (DIANA Coll.), Yad. Fiz. 66, 1763 (2003); A. E. Asratyan et al. (ITEP Coll.), Yad. Fiz. 67, 704 (2004); A. Airapetian et al. (HERMES Coll.), Phys. Lett. B585, 213 (2004); M. Abdel-Bary et al. (COSY-TOF Coll.), hep-ex/0403011.
[4] P. Zh. Aslanyan, V. N. Emelyanenko, G. G. Rikhiketsky, hep-ex/0403044.
[5] A. Aleev et al. (SVD Coll.), hep-ex/0401024.
[6] S. Chekanov et al. (ZEUS Coll.), Phys. Lett. B591, 7 (2004).
[7] D. Diakonov, V. Petrov, M. V. Polyakov, Z. Physik A 359, 305 (1997).
[8] A. R. Dzierba et al. (WA89 Coll.), hep-ex/0405042.
[9] A. T. Dziewia et al., Phys. Rev. D69, 051901 (2004).
[10] M. Zavertyaev, hep-ph/0311250.
[11] J. MiHul, Cern Courier 44, No. 5, 50 (2004).
[12] A. R. Dzierba et al., Phys. Rev. D69, 051901 (2004).
[13] A. T. Dziewia et al., Phys. Rev. D69, 051901 (2004).
[14] M. Zavertyaev, hep-ph/0311250.
[15] H. G. Fischer, S. Wenig, hep-ex/0401014.
[16] R. N. Cahn, G. H. Trilling, Phys. Rev. D69, 011501 (2004).
[17] J. M. S. Close, hep-ph/0404075.
[18] J. Z. Bai et al. (BES Coll.), hep-ex/0407004.
[19] M. I. Adamovich et al. (WA89 Coll.), hep-ex/0405042.
[20] M. Karliner, H. Lipkin, hep-ph/0405092.
[21] J. Randrup, Phys. Rev. C68, 031903 (2003).
[22] J. Letessier et al., Phys. Rev. C68, 061901 (2004).
[23] F. Becattini et al., Phys. Rev. C69, 024905 (2004).
[24] F. M. Liu, H. Stöcker, K. Werner, hep-ph/0404156.
[25] M. Bleicher et al., hep-ph/0401049.
[26] K. Werner et al., J. Phys. G:30 S211 (2004).
[27] I. Abt et al. (HERA-B Coll.), Eur. J. Phys. C29 181-190 (2003) and refs. therein.
[28] I. Ariño et al., Nucl. Instr. Meth. A516, 445 (2004).
[29] G. J. Feldman, R. D. Cousins, Phys. Rev. D57, 3827 (1998).
[30] Spectra without angle cut show about 47 $\Xi^{-+}$ and 143 $\Xi(1530)^0$ events; K. Kadja, J. Phys. G:30 S1359 (2004).
[31] Yu.M. Antipov et al. (SPHINX Coll.), hep-ex/0407026.
[32] Upon completion of this paper, we learned that the SPHINX collaboration has searched for the $\Theta^+$ in exclusive proton-induced reactions on carbon at $\sqrt{s} = 11.5$ GeV studying four different final states of the $\Theta^+\bar{K}^0$ system. No evidence for a narrow PQ peak is found in any of the studied channels $[33]$. 

