PROCEEDINGS OF SCIENCE

Pentaquark searches at the BABAR experiment *

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SLAC–PUB–11392

A review of the results in the inclusive and exclusive searches for pentaquark states obtained from the analysis of the data recorded at the *BABAR* experiment at the Stanford Linear Accelerator Center PEP-II B-Factory, is presented. Inclusive searches for the strange pentaquark states $\Theta_5(1540)^+$, $\Xi_5(1860)^{--}$ and $\Xi_5(1860)^0$ have been performed in a dataset of e^+e^- anihilations corresponding to 123.4 fb^{-1} of integrated luminosity. No evidence is found and therefore the corresponding 95% confidence level upper limits on the $\Theta_5(1540)^+$ and $\Xi_5(1860)^{--}$ production rate are set, being well below ordinary baryon rates.
Additionally the decay $\Theta_5(1540)^+ \to pK^0_S$ has been searched for in events that correspond to interactions of both electrons and hadrons with the inner-most material of the *BABAR* detector. No evidence for such a process is found as a result of this analysis even though it is quite similar to the data analysis of some experiments which have claimed signals, especially HERMES [7], but with much higher statistics.
The exclusive search of the Θ^{*++} pentaquark in the the B meson decay $B^+ \to \bar{p}\Theta^{*++}$ where $\Theta^{*++} \to pK^+$, has been carried out in a dataset of 210 fb^{-1}. The results show no evidence for such a pentaquark in the mass range from 1.43 to 2.00 GeV/c^2 and thus the corresponding upper limits at the 90% confidence level has been set on the product of the branching fractions (BF's) $BF(B^+ \to \bar{p}\Theta^{*++}) \times BF(\Theta^{*++} \to pK^+)$ at the 10^{-7} level.

International Europhysics Conference on High Energy Physics
July 21st - 27th 2005
Lisboa, Portugal

*Work supported by the Department of Energy contract DE-AC02-76SF00515.
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PoS(HEP2005)085

1. Introduction

Lately different experiments have claimed observations [1]-[11] of narrow baryonic resonances with exotic quantum numbers which, if interpreted in terms of quark bound states, would require a minimum of five quarks, denoted as $\Theta(1540)^+$ ($uudd\bar{s}$), $\Xi_5(1860)^{--}$ ($ddss\bar{u}$) and its corresponding partner $\Xi_5(1860)^0$ with non-exotic quantum numbers. However a number of experiments that observe either large samples of strange baryons with mass similar to that of the $\Theta(1540)^+$ [*e.g.*, $\Lambda(1520) \to pK^-$] see no evidence for the $\Theta(1540)^+$ [12]; or large samples of non-exotic Ξ^- baryon do not observe the $\Xi_5(1860)^{--}$ resonance neither the $\Xi_5(1860)^0$ state [12].

Sometimes the comparison of the different experimental results is complicated since they have different production mechanisms and energy ranges. Therefore the results from the *BABAR* experiment presented here are of great interest since they involve high statistics and high resolution searches which encompass different production processes: Stringent upper limits have been set on inclusive $\Theta(1540)^+$ and $\Xi_5(1860)^{--}$ production in both e^+e^- annihilations into hadrons and $\Upsilon(4S)$ decays; a search for electro- and hadro-production of the pentaquark state $\Theta(1540)^+$ in the material of the inner part of the *BABAR* detector has been carried out, as well as several exclusive searches for pentaquarks production in the decay of B mesons, such as $B^+ \to p\bar{p}K^+$, where the upper limit of the product of $BF(B^+ \to \bar{p}\Theta^{*++}) \times BF(\Theta^{*++} \to pK^+)$ has been set.

2. The *BABAR* detector

The *BABAR* experiment is taking data at the SLAC PEP-II e^+e^- collider at a centre-of-mass energy of 10.58 GeV. The *BABAR* detector is described in detail elsewhere [13]. Charged particle track parameters are measured by a five-layer double-sided silicon vertex tracker and a 40-layer drift chamber located in a 1.5-T magnetic field. Charged particle identification is achieved with an internally reflecting ring imaging Cherenkov detector (DIRC) and from the average dE/dx energy loss measured in the tracking devices. Photons and neutral pions are detected with an electromagnetic calorimeter consisting of 6580 CsI(Tl) crystals. An instrumented flux return provides muon and long-lived hadron identification.

3. Inclusive search in e^+e^- anihilations

The search for inclusive production of pentaquark states is performed in $e^+e^- \to PX$ reactions with any final state X recoiling against the pentaquark candidate P. The analysis is based on 123 fb^{-1} of data recorded at or slightly below the $\Upsilon(4S)$ resonance [14]. In particular the states $\Theta(1540)^+$, $\Xi_5(1860)^{--}$ and $\Xi_5(1860)^0$ are considered here. The $\Theta(1540)^+$ state is reconstructed in the pK^0_S decay mode, where $K^0_S \to \pi^+\pi^-$. A sample of K^0_S candidates is obtained from all pairs of oppositely-charged tracks identified as pions, that are consistent with having a common origin near the interaction point. The p and $\bar{p}$ candidates are identified by using dE/dx information measured with the tracking system, and the Cherenkov angle θ_c determined with the DIRC sub-detector [13]. The distribution of the pK^0_S invariant-mass, as seen in in Fig. 1, shows no enhancement in the mass region where the pentaquark state $\Theta(1540)^+$ was reported (inset in Fig. 1), but a strong, narrow peak is visible at 2285 MeV/c^2 (with a mass resolution of 6 MeV/c^2) containing 98,000 entries

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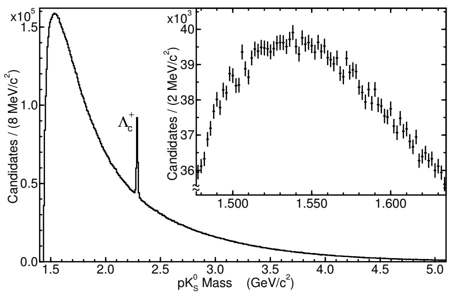

Figure 1: Distribution of the pK_S^0 invariant mass for the combinations satisfying the criteria described in the text. The data are plotted for the full kinematically allowed pK_S^0 mass range and, in the inset, with statistical uncertainties and a suppressed zero on the vertical axis, for the mass range in which the $\Theta(1540)^+$ has been reported.

originating from $\Lambda_c \to pK_S^0$ decays. This null result for a $\Theta(1540)^+$ mass of 1540 MeV/c^2 is quantified by fitting a convolution of a Gaussian and a P-wave Breit-Wigner as the signal lineshape and a background polynomial to the invariant-mass distributions. Since the intrinsic width of the $\Theta(1540)^+$ has not been measured so far, width values of Γ = 1 MeV (for a narrow $\Theta(1540)^+$) and Γ = 8 MeV (best upper limit) are used, and the results quoted for each assumed width. The upper limit, at 95% confidence level, are determined for the number of produced pentaquarks per $e^+e^- \to hadrons$ event, and then compared to the production rates of known baryons, assuming BF($\Theta(1540)^+ \to pK_S^0$)= 25%. The measured upper limit values of 5.0 $\times$ 10^{-5} (Γ = 1 MeV) and 11 $\times$ 10^{-5} (Γ = 8 MeV) are between 8 and 15 times lower than expected for conventional baryons.

The reported $\Xi_5(1860)^{--}$ and $\Xi_5(1860)^0$ states decaying into a Ξ^- and a charged pion, where the $\Xi^- \to \Lambda(1115)\pi^-$ and $\Lambda(1115) \to p\pi^-$, have also been searched for. The $\Lambda(1115)$ candidates are selected from all pairs of oppositely-charged tracks satisfying proton and pion identification requirements and that are consistent with a common origin. The invariant mass distributions for $\Xi^-\pi^-$ and for $\Xi^-\pi^+$ combinations are shown in Fig. 2. On the one hand, the $\Xi(1530)^0$ and $\Xi_c(2470)$ baryons are clearly seen in the $\Xi^-\pi^+$ invariant mass spectrum with 24,000 and 8,000 entries respectively, but no other structure is visible. On the other hand, there are no visible narrow structures in the $\Xi^-\pi^-$ mass spectrum. As before, we assume two different intrinsic widths of this pentaquark state, namely Γ = 1 MeV/c (narrow) and Γ = 18 MeV/c^2 (wide) to the determine the 95% confidence level upper limit of the production rate in e^+e^- interactions. The results of 0.74 $\times$ 10^{-5}/event (for the narrow width) and of 1.1 $\times$ 10^{-5}/event are between 4 and 6 times lower than those for conventional baryons.

4. Search for $\Theta(1540)^+$ in electro- and hadro-production

The majority of the positive evidence for exotic pentaquark states has been found in experiments based on photo-, electro- or hadro-production reactions on nuclear targets. The corresponding analysis performed by *BABAR*, based on $\sim$230 fb^{-1} of data, searches for the production of $\Theta(1540)^+$ from the interactions of secondary hadrons (tracks of every type) and beam halo electrons and positrons in the material of the inner part of the *BABAR* detector that lead to the inclusive

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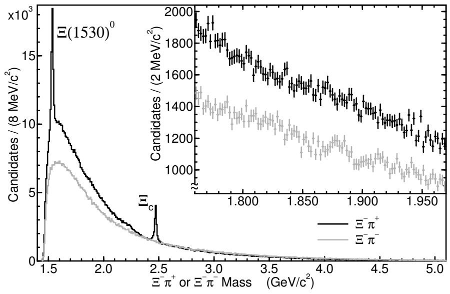

Figure 2: Invariant mass distributions of $\Xi^-\pi^+$(black) and $\Xi^-\pi^-$ (grey) for combinations satisfying the criteria described in the text. The data are plotted for the full kinematically allowed $\Xi^-\pi^\pm$ range and, in the inset, with statistical uncertainties and a suppressed zero on the vertical axis, for the mass range in which the $\Xi(1860)^{--}$ and the $\Xi(1860)^0$ have been reported.

production of pK_S^0 system. The reconstruction of pK_S^0 candidates is performed by identifying protons by their specific energy loss dE/dx measured by the tracking system. The K_S^0 candidates are selected from all pairs of oppositely-charged tracks, which have a maximum distance of closest approach (DOCA) of 3 mm, a minimum flight length of 2 mm, and a geometrical chi-squared fit probability $>$0.001. The candidate (p, K_S^0) vertices are selected by choosing the center of the connection line correponding to the distance of closest approach of the K_S^0 flight path to the proton track (required to be $<$ 3 mm), and this centre is required to be at a radius $<$ 2 cm, i.e. well-separated from the e^+e^- collision axis. The distribution of the (p, K_S^0) candidate vertices reproduces the beampipe and detector geometry to a high degree of accuracy, in clear support of the fact that these events result from interactions in the detector material. Nevertheless the inclusive pK_S^0 invariant-mass distribution, shows no evidence for the $\Theta(1540)^+$ pentaquark state.

If the same study is restricted to those regions which can be interpreted as corresponding to electro-production in the beampipe (mainly made of Be), again no $\Theta(1540)^+$ signal is seen.

5. Exclusive search for Θ^{*++}

The exclusive search for pentaquarks in the decay of B mesons has been carried out in Babar on a data sample of 210 fb^{-1} of integrated luminosity recorded at the Υ(4S) resonance [15]. After the observation of the decay (charge conjugation implied hereafter) $B^+ \to p\bar{p}K^+$ [16][17], it has been suggested that this decay might include events of the form $B^+ \to \Theta^{*++}\bar{p}$ where Θ^{*++} is an $I = 1, I_3 = 1$ pentaquark [18]. The Θ^{*++} would be a member of baryon 27-plet with quark content $uuud\bar{s}$. It had been predicted to lie in the region $1.43 - 1.70\,\mathrm{GeV/c^2}$ in the pK^+ invariant mass and have width of $37 - 80\,\mathrm{MeV}$ [19].

The analysis is based on the selection of a proton, antiproton and a charged kaon to form a B candidate. The particle identification is based again on dE/dx information provided by the tracking system, as well as on the pattern of Cherenkov photons provided by the DIRC sub-detector. Once the sample of $B^+ \to p\bar{p}K^+$ events is selected, the pK^+ invariant mass spectrum is analysed, and there is no evidence of a narrow Θ^{*++} state. The corresponding 90% confidence level upper limit for the product $BF(B^+ \to \bar{p}\Theta^{*++}) \times BF(\Theta^{*++} \to pK^+)$, is found to be 0.5×10^{-7} for the range

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of 1.43 $<$ m(Θ^{*++}) $<$ 1.50 GeV/c^2, $< 0.9 \times 10^{-7}$ for 1.50 $<$ m(Θ^{*++}) $<$ 1.72 GeV/c^2, $< 1.2 \times 10^{-7}$ for 1.72 $<$ m(Θ^{*++}) $<$ 2.00 GeV/c^2.

6. Conclusions

Searches in several production mechanisms for the reported pentaquark states $\Theta(1540)^+$, $\Xi_5(1860)^{--}$ and $\Xi_5(1860)^0$ in e^+e^- annihilations has been performed at *BABAR*. Large signals for known baryon states have been found, but no excess is seen at the reported mass values for the pentaquark states. Also no appearance of the $\Theta(1540)^+$ state is found in the electro- and hadro-production events within the inner part of the *BABAR* detector. The exclusive search for the Θ^{*++} pentaquark production in the $B^+ \rightarrow p\bar{p}K^+$ decays shows no evidence for such a state.

References

[1] LEPS Collaboration, T. Nakano *et al.*, Phys. Rev. Lett. **9**1, 012002 (2003).

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

[3] CLAS Collaboration, S. Stepanyan *et al.*, Phys. Rev. Lett. **9**1, 252001 (2003).

[4] CLAS Collaboration, V. Kubarovsky *et al.*, Phys. Rev. Lett. **9**2, 032001 (2004). Erratum; ibid, 049902.

[5] DIANA Collaboration, V.V. Barmin *et al.*, Phys. Atom. Nucl. **6**6, 1715 (2003).

[6] SVD Collaboration, A. Aleev *et al.*, submitted to Yad. Fiz., hep-ex/0401024 (2004).

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

[8] A.E. Asratyan, A.G. Dolgolenko, and M.A. Kubantsev, Phys. Atom. Nucl. **6**7, 704 (2004).

[9] COSY-TOF Collaboration, M. Abdel-Bary *et al.*, Phys. Lett. **B** 595, 127 (2004).

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

[11] NA49 Collaboration, C. Alt *et al.*, Phys. Rev. Lett. **9**2, 042003 (2004).

[12] See, *e.g.* A. R. Dzierba, C. A. Meyer, and A. P Szczepaniak, hep-ex/0412077, and K. H. Hicks, Prog Part Nucl Phys **55**, 647 (2005), and references therein.

[13] B. Aubert *et al.*, *BABAR* Collaboration, Nucl. Instr. Meth. A**4**79,1-116 (2002).

[14] B. Aubert *et al.*, *BABAR* Collaboration, Phys. Rev. Lett. **9**5, 042002, 3-7 (2005).

[15] B. Aubert *et al.*, *BABAR* Collaboration, Phys. Rev. D 72, 051101 (2005).

[16] The Belle Collaboration, Phys. Rev. Lett. **8**8, 181803,(2002).

[17] T. Berger-Hryn'ova for *BABAR* Collaboration, IJMP A 20, 3749 (2005).

[18] J.L. Rosner, Phys. Rev. D **69**, 094014 (2004)

[19] J. Ellis, M. Karliner, M. Praszalowicz, JHEP **0405**, 002 (2004); B. Wu, B.Q. Ma, Phys. Rev. D **69**, 077501 (2004); H. Walliser, V.B. Kopeliovich, J. Exp. Theor. Phys. **97**, 433 (2003); D. Borisyuk, M. Faber, A. Kobushkin, Ukr. J. Phys. **49**, 944 (2004).