

Pentaquark searches at the $BABAR$ experiment *

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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^- annihilations 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. Additionally the decay $\Theta_5(1540)^+ \rightarrow pK_S^0$ has been searched for in events that correspond to interactions of both electrons and hadrons with the inner-most material of the $BABAR$ detector, but then again, no evidence for such a process is found as a result of this analysis. The exclusive search of the Θ^{*++} pentaquark in the B meson decay $B^+ \rightarrow \bar{p}\Theta^{*++}$ where $\Theta^{*++} \rightarrow pK^+$, 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 $2.00 \text{ GeV}/c^2$ and thus the corresponding upper limits at the 90% confidence level has been set on the product of the branching fractions (BF's) $BF(B^+ \rightarrow \bar{p}\Theta^{*++}) \times BF(\Theta^{*++} \rightarrow pK^+)$ at the 10^{-7} level.

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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. Alternatively a number of experiments that observe either large samples of strange baryons with mass similar to that of the $\Theta(1540)^+$ [e.g., $\Lambda(1520) \rightarrow pK^-$] 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 data analyses here presented are of great interest since they involve high statistics and high resolution searches which encompass different production processes. On the one hand, the *BABAR* experiment has measured the upper limits for the production of pentaquark states in e^+e^- annihilations as well as studied the electro- and hadron-production of the pentaquark state $\Theta(1540)^+$ in the material of the inner part of the *BABAR* detector. On the other hand, it has carried out exclusive searches for pentaquarks in the decay of B mesons, in particular it has measured the upper limit of the product of $BF(B^+ \rightarrow \bar{p}\Theta^{*++}) \times BF(\Theta^{*++} \rightarrow pK^+)$.

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^- annihilations

The search for inclusive production of pentaquark states is performed in $e^+e^- \rightarrow PX$ 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_S^0 decay mode, where $K_S^0 \rightarrow \pi^+\pi^-$. A sample of K_S^0 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_S^0 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 $2285 \text{ MeV}/c^2$ (with a mass resolution of $6 \text{ MeV}/c^2$) containing 98,000 entries

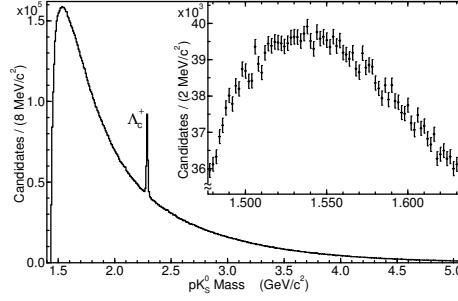


Figure 1: Figure 1. Distribution of the pK_S^0 invariant mass for the combinations satisfying the criteria described in the text. The data are plotted for the full kinematically allowed pK_S^0 mass range and, in the inset, with statistical uncertainties and a suppressed zero on the vertical axis, for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

originating from $\Lambda_c \rightarrow pK_S^0$ decays. This null result for a $\Theta(1540)^+$ mass of $1540 \text{ MeV}/c^2$ 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 $\Gamma = 1 \text{ MeV}$ (for a narrow $\Theta(1540)^+$) and $\Gamma = 8 \text{ MeV}$ (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 $e^+e^- \rightarrow \text{hadrons}$ event, and then compared to the production rates of known baryons, assuming $\text{BF}(\Theta(1540)^+ \rightarrow pK_S^0) = 25\%$. The measured upper limit values of 5.0×10^{-5} ($\Gamma = 1 \text{ MeV}$) and 11×10^{-5} ($\Gamma = 8 \text{ MeV}$) 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 $\Xi^- \rightarrow \Lambda(1115)\pi^-$ and $\Lambda(1115) \rightarrow p\pi^-$, 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 $\Gamma = 1 \text{ MeV}/c^2$ (narrow) and $\Gamma = 18 \text{ MeV}/c^2$ (best upper limit) to determine the 95% confidence level upper limit of the production rate in e^+e^- interactions. The results of $0.74 \times 10^{-5}/\text{event}$ (for the narrow width) and of $1.1 \times 10^{-5}/\text{event}$ 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 $\sim 230 \text{ fb}^{-1}$ 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

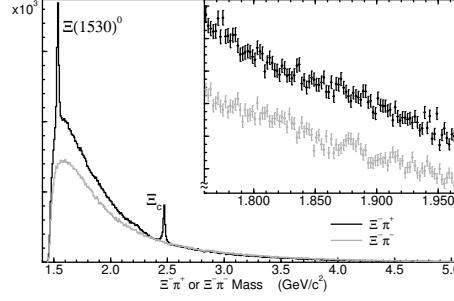


Figure 2: Figure 2. Invariant mass distributions of $\Xi^-\pi^+$ (black) and $\Xi^-\pi^-$ (grey) for combinations satisfying the criteria described in the text. The data are plotted for the full kinematically allowed $\Xi^-\pi^\pm$ range and, in the inset, with statistical uncertainties and a suppressed 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 corresponding 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 $\Upsilon(4S)$ resonance [15]. After the observation of the decay (charge conjugation implied hereafter) $B^+ \rightarrow p\bar{p}K^+$ [16][17], it has been suggested that this decay might include events of the form $B^+ \rightarrow \Theta^{*++}\bar{p}$ 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 $1.43 - 1.70 \text{ GeV}/c^2$ in the pK^+ invariant mass and have width of $37 - 80 \text{ MeV}$ [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 $B^+ \rightarrow p\bar{p}K^+$ 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 $BF(B^+ \rightarrow \bar{p}\Theta^{*++}) \times BF(\Theta^{*++} \rightarrow pK^+)$, is found to be 0.5×10^{-7} for the range

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

6. Conclusions

A search 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.

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