Exotic baryon searches in 800 GeV/c \( pp \rightarrow pX \)


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Abstract. We report the results of the search for the pentaquark candidates \( \Theta(1540) \) and \( \Xi(1862) \) using data from Fermilab experiment E690 in the reaction \( pp \rightarrow pX \) at 800 GeV/c. We find no evidence for narrow baryon resonances near 1862 MeV decaying to \( \Xi\pi \). Also, we find no evidence of a narrow resonance near 1540 MeV decaying to \( pK^0 \).

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A number of different experiments have reported evidence for the existence of the \( \Theta^+ \), a strangeness +1 baryon that decays to \( nK^+ \) or \( pK^0 \) [1]. The \( \Theta^+ \) mass is reported to be approximately 1540 MeV and its width less than \( \sim 20 \) MeV. The \( \Theta^+ \) has been interpreted as a pentaquark. If this interpretation is correct, then a large number of similar states are expected[2], many of them, besides the \( \Theta^+ \), having quantum numbers not possible for baryons composed only of three quarks. One such state is a charge -2, strangeness +2 baryon expected to decay to \( \Xi^-\pi^- \). In 2003, Wilczek and Jaffe predicted that this state should have a mass of approximately 1750 MeV and should be narrow, with a width only \( \sim 50\% \) greater than the width of the \( \Theta^+ \)[3]. Shortly after this prediction, NA49 reported evidence for a \( \Xi^-\pi^- \) resonance produced in \( pp \) interactions at \( \sqrt{s} = 17.2 \) GeV with a mass of 1862 MeV and width less than the detector resolution of 18 MeV FWHM[4]. NA49 also reported evidence for states with similar masses and widths decaying to \( \Xi^-\pi^+, \Xi^+\pi^- \), and \( \Xi^+\pi^+ \). However, the experimental case for the existence of pentaquarks is not yet compelling, since many experiments have failed to confirm the existence of the \( \Theta^+ \) [5, 6], and other have only reported upper limits for the production of a state at 1862 MeV decaying to \( \Xi\pi \) [5, 7].

Here we report the results of the search for the pentaquark candidates \( \Theta(1540) \) and \( \Xi(1862) \) using more than 4.3 billion events collected by the E690 Collaboration during Fermilab 1991 fixed target run. The E690 apparatus consisted of an open-geometry multiparticle spectrometer and a beam spectrometer. The multiparticle spectrometer was used to measure the target system \( (X) \) in reactions \( pp \rightarrow p_{f_a}X \). The E690 apparatus has been described elsewhere[8].

Events were recorded using a trigger that imposed two event selection requirements: (a) an interaction in the target region, indicated by signals from one or more time-
of-flight scintillation counters, and (b) a scattered beam particle, detected by counters outside of the beam spot in the forward beam spectrometer. Event reconstruction was performed for the entire data sample. The primary (interaction) vertex was constrained to lie on an incoming beam-track trajectory. For events in which evidence of a “vee” or “cascade” decay was found, the tracks were refit with the constraint that each daughter vertex “point back” to its parent, and the daughter was then “assigned” to the parent. Mass constrained fits were not performed.

For this analysis we selected events, first, for the inclusive reaction

\[ pp \rightarrow p_{fast} \Xi^\pm \pi^\mp X, \ \Xi \rightarrow \Lambda \pi \]

and, second, for the exclusive reaction

\[ pp \rightarrow p_{slow} K^- \pi^+ p_{fast} \]

For reaction (1), events were selected if they had a candidate \( \Xi^- \) or \( \Xi^+ \) decay. The sample contains approximately 513,000 \( \Xi^- \)'s and 153,700 \( \Xi^+ \)'s assigned to a primary vertex. The effective mass spectra of the \( \Xi^- \) and \( \Xi^+ \) candidates are shown in Fig. 1, together with the effective mass spectra of the corresponding \( \Lambda \) and \( \bar{\Lambda} \) candidates. \( \Xi \pi \) mass distributions were computed by pairing each \( \Xi \) candidate with every charged track (assumed to be a pion) assigned to the same primary vertex. Direct particle identification was not used in this analysis. The effective mass distributions for the four charge combinations are also shown in Fig. 1. The \( \Xi^- \pi^+ \) and \( \Xi^+ \pi^- \) mass distributions contain prominent \( \Xi^0(1530) \) and \( \bar{\Xi}^0(1530) \) resonances. None of the four effective mass distributions contains any other obvious resonance.
The plots in Fig. 1 clearly show that if a narrow pentaquark with mass 1862 MeV decaying to $\Xi\pi$ exists, then its production is highly suppressed with respect to the production of $\Xi^0(1530)$ and $\Xi^-B_4(1530)$ in these data. In order to quantify this conclusion, we computed 95% confidence level upper limits[9] for Gaussian signals with mass = 1862 MeV and $\sigma$=7.6 MeV (the NA49 mass resolution). We estimated the yield of $\Xi^0(1530)$ and $\Xi^0(1530)$ by fitting the $\Xi^-\pi^+$ and $\Xi^+\pi^-$ effective mass distributions to the sum of a background function and a signal consisting of a relativistic ($L = 1$) Breit-Wigner function convoluted with a Gaussian with $\sigma = 2.5$ MeV. The Gaussian smearing term represents the spectrometer mass resolution for effective mass close to 1530 MeV. The form of the background function was $F(M) = (M - M_T)^\alpha e^{\beta(M - M_T)}$, where $M_T$ is the $\Xi\pi$ threshold mass of 1.46 GeV$^2$ and $\alpha$ and $\beta$ are fit parameters [10]. The results of the fits are shown in Fig. 2. The obtained yields were $93728 \pm 422 \Xi^0(1530)$ events, and $22211 \pm 219 \Xi^0(1530)$ events (statistical errors only.) The upper limits computed for a Gaussian enhancement at 1862 MeV with $\sigma = 7.6$ MeV are given in Table 1.

### TABLE 1. 95% confidence level upper limits for a signal at 1862 MeV. Each limit is also expressed as a fraction of the $\Xi^0(1530)$ or the $\Xi^-B_4(1530)$ yield, for baryon and antibaryon modes.

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>Limit on Gaussian signal (events)</th>
<th>Decay Mode</th>
<th>Limit on Gaussian signal (events)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Xi^-\pi^+$</td>
<td>1020 (1.1%)</td>
<td>$\Xi^+\pi^-$</td>
<td>310 (0.3%)</td>
</tr>
<tr>
<td>$\Xi^-\pi^-$</td>
<td>290 (1.3%)</td>
<td>$\Xi^-\pi^+$</td>
<td>288 (1.3%)</td>
</tr>
</tbody>
</table>
Events in the exclusive reaction (2) where selected to satisfy the required topology by imposing energy and momentum conservation. Due to the low multiplicity in this reaction, combinatorics are very limited. In the selection process we imposed a loose cut on the conservation of longitudinal momentum (5 GeV/c), but we applied tight cuts on the overall $p_T^2$ ($p_T^2 < 0.002$ GeV$^2$/c$^2$) and $E - p_T$ ($-0.2 < E - p_T < 0.15$ GeV.) We also required that these cuts eliminated events consistent with topology of $p_{slow} K^+ p_{fast}$, which would not give the adequate strangeness for $\Theta^+$ decays. The energy momentum conservation cuts are depicted in Fig.3 (left panel.) 68,050 events were selected with these cuts. Of these, only 6% had two solutions per event, corresponding to $\pi^+ / p_{slow}$ ambiguity. As it is shown in Fig.3 (right panel), many well known resonances can be seen in these events.

In Fig.4 we compare the $pK^0_s$ and $pK^-$ invariant mass distributions. The $pK^-$ effective mass shows about 5000 $\Lambda(1520)$ events above background, with a FWHM of about 14 MeV. However, there is no indication of any exotic resonance structure in the $pK^0_s$ effective mass distribution below 1.7 GeV/c$^2$. The Monte Carlo $pK^0_s$ mass resolution ($\sigma$) at 1540 MeV is 1.5 MeV. The estimated yield of a narrow $pK^0_s$ resonance at 1540 MeV is less than 25 events (95% CL.)

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FIGURE 4. $pK_s$ and $pK^-$ invariant mass distributions below 1.7 GeV/$c^2$ for events in reaction (2).

REFERENCES


2. See, for example, D. Strottman, Phys. Rev. D20 (1979) 748.


