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Search for Exotic Baryons in 800 GeV $pp \to p\Xi^{\pm}\pi^{\pm}X$

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We report the results of a high-statistics, sensitive search for narrow baryon resonances decaying to $\Xi^-\pi^-$, $\Xi^-\pi^+$, $\overline{\Xi}^+\pi^-$, and $\overline{\Xi}^+\pi^+$. The only resonances observed are the well known $\Xi^0(1530)$ and $\overline{\Xi}^0(1530)$. No evidence is found for a state near 1862 MeV, previously reported by NA49[11]. At the 95% confidence level, we find the upper limit for the production of a Gaussian enhancement with $\sigma = 7.6$ MeV in the $\Xi^-\pi^-$ effective mass spectrum to be 0.3% of the number of observed $\Xi^0(1530) \to \Xi^-\pi^+$. We find similarly restrictive upper limits for an enhancement at 1862 MeV in the $\Xi^-\pi^+$, $\overline{\Xi}^+\pi^-$, and $\overline{\Xi}^+\pi^+$ mass spectra.

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A number of different experiments have reported evidence for the existence of the Θ^+, a strangeness +1 baryon that decays to nK^+ or pK^0 [1][2][3][4][5][6][7][8]. The Θ^+ mass is reported to be approximately 1540 MeV and its width less than ~20 MeV. The Θ^+ has been interpreted as a pentaquark, consisting of two up quarks, two down quarks, and one anti-strange quark. If the pentaquark interpretation is correct, then a large number of similar states are expected[9]. Many of these states besides the Θ^+ have 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 ~ 50% greater than the width of the Θ^+[10]. Shortly after this prediction, NA49 reported evidence for a $\Xi^-\pi^-$ resonance produced in proton-proton interactions at $\sqrt{s} = 17.2$ GeV with a mass of 1862 MeV and width less than the detector resolution of 18 MeV FWHM[11]. NA49 also reported evidence for states with similar masses and widths decaying to $\Xi^-\pi^+$, $\overline{\Xi}^+\pi^-$, and $\overline{\Xi}^+\pi^+$.

However, the experimental case for the existence of pentaquarks is not yet compelling. Although the Θ^+ has been observed in a variety of different reactions, many experiments have failed to confirm its existence [12][13][14][15][16]. Futhermore, the HERA-B collaboration has reported that they do not observe an enhancement at 1862 MeV in $\Xi^-\pi^-$ produced near Feynman $x = 0$ in interactions of 920 GeV protons with a variety of nuclear targets[12]. A search in Σ^--nucleus collisions at 350 GeV by WA89[17] yielded only an upper limit on the production of a $\Xi^-\pi^-$ resonance. Similarly, the HERMES collaboration[18] searching in photoproduction, the ZEUS[19] collaboration searching in deep inelastic ep collisions, and the COMPASS collaboration[20] searching in deep inelastic μ^+N collisions were also only able to place limits on the production of this state.

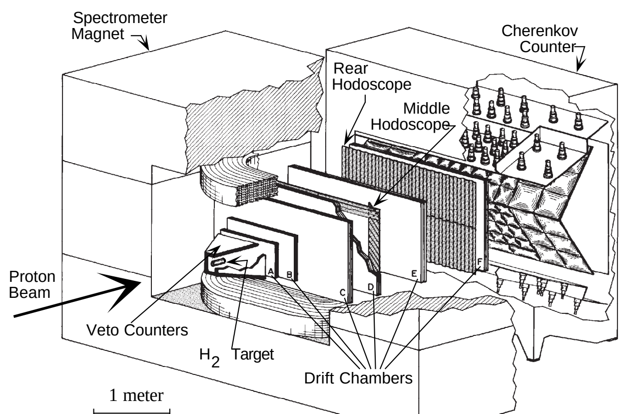

FIG. 1: *E690 Multiparticle Spectrometer.*

We have conducted a high-statistics, sensitive search for new resonances decaying to $\Xi^-\pi^-$, $\Xi^-\pi^+$, $\overline{\Xi}^+\pi^-$, and $\overline{\Xi}^+\pi^+$ using data collected in 1991 by Fermilab E690. The E690 apparatus consisted of an open-geometry multiparticle spectrometer (shown in Fig. 1) and a beam spectrometer. The multiparticle spectrometer was used to measure the target system (X) in reactions

$$pp \to p_{fast}X. \quad (1)$$

The beam spectrometer was used to measure the incident 800 GeV beam and scattered proton. A liquid hydrogen target was located just upstream of the multiparticle spectrometer. The multiparticle spectrometer included six mini-drift proportional wire chambers, each with four signal planes. Five of the wire chambers were located inside a large aperture dipole magnet, and the sixth chamber was located just downstream of the magnet. The magnet had a central field of ∼7 kG. The angular coverage was ±580 mrad in the horizontal (bend) direction and ±410 mrad in the vertical direction. The spaces between the wire chambers were filled with helium to reduce multiple scattering. Particle identification was provided by 102 time-of-flight scintillation counters and a 96-cell Freon-114 Cherenkov counter with a pion momentum threshold of 2.57 GeV.

Approximately 4.3 billion events were recorded using a trigger that imposed two event selection requirements. The trigger required:

1. An interaction in the target region, indicated by signals from one or more time-of-flight scintillation counters.

2. 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. Events without an identified primary vertex were not processed further. 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. The following decay types were searched for: $\gamma \to e^+e^-$, $K^0_s \to \pi^+\pi^-$, $\Lambda \to p\pi^-$, $\overline{\Lambda} \to \overline{p}\pi^+$, $\Xi^- \to \Lambda\pi^-$, $\overline{\Xi}^+ \to \overline{\Lambda}\pi^+$, $\Omega^- \to \Lambda K^-$, $\overline{\Omega}^+ \to \overline{\Lambda}K^+$, $K^+ \to \pi^+\pi^+\pi^-$, and $K^- \to \pi^-\pi^-\pi^+$. Any remaining vertices were assumed to be caused by secondary interactions or interactions of spectator beam particles.

For this analysis, events were selected if they had a candidate Ξ^- or $\overline{\Xi}^+$ decay. The sample contains just over 500,000 unambiguously identified Ξ^-'s and approximately 34,500 Ξ^- candidates that may be interpreted as Ω^- if the negative track is assumed to be a K^- rather than a π^-. Of these, approximately 513,000 are assigned to the primary vertex. The sample contains just over 160,000 unambiguously identified $\overline{\Xi}^+$ candidates and approximately 9,600 ambiguous $\overline{\Xi}^+/\overline{\Omega}^+$ candidates. Of these, approximately 153,700 are assigned to a primary vertex. The effective mass spectra of the Ξ^- and $\overline{\Xi}^+$ candidates assigned to a primary vertex are shown in Fig. 2. There is slightly more background for the $\overline{\Xi}^+$ distribution compared to the Ξ^- distribution. The effective mass spectra of the Λ and $\overline{\Lambda}$ candidates contained in the Ξ candidates are also shown in Fig. 2.

$\Xi\pi$ mass distributions were computed by pairing each Ξ candidate that was assigned to a primary vertex with every charged track (assumed to be a pion) assigned to

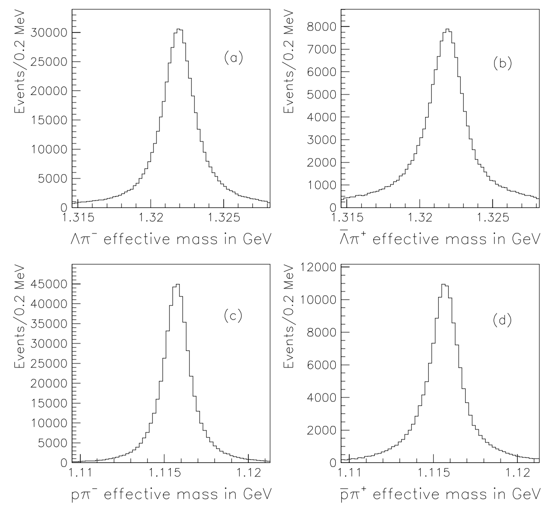

FIG. 2: *Hyperon effective mass spectra in events used for this analysis: a)Ξ^-, b)$\overline{\Xi}^+$, c)Λ from Ξ^- decay, and d)$\overline{\Lambda}$ from $\overline{\Xi}^+$ decay. The full width at half maximum is* 1.8 *MeV for the* Λ *and* $\overline{\Lambda}$ *and* 2.6 *MeV for the* Ξ^- *and* $\overline{\Xi}^+$.

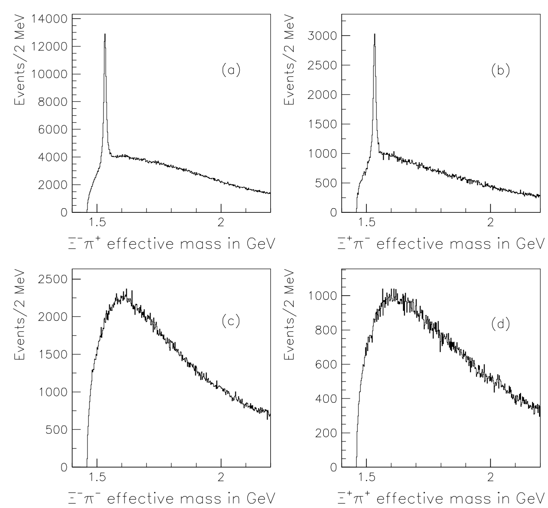

FIG. 3: *Effective mass spectra for: a)$\Xi^-\pi^+$, b)$\overline{\Xi}^+\pi^-$, c)$\Xi^-\pi^-$, and d)$\overline{\Xi}^+\pi^+$.*

the same primary vertex. Direct particle identification was not used in this analysis because a significant fraction of the tracks had momentum too high to provide good time-of-flight particle identification and too low to allow Cherenkov identification. The effective mass distributions for the four charge combinations are shown in Fig. 3. The $\Xi^-\pi^+$ and $\overline{\Xi}^+\pi^-$ mass distributions contain prominent $\Xi^0(1530)$ and $\overline{\Xi}^0(1530)$ resonances. None of the four effective mass distributions contains any other

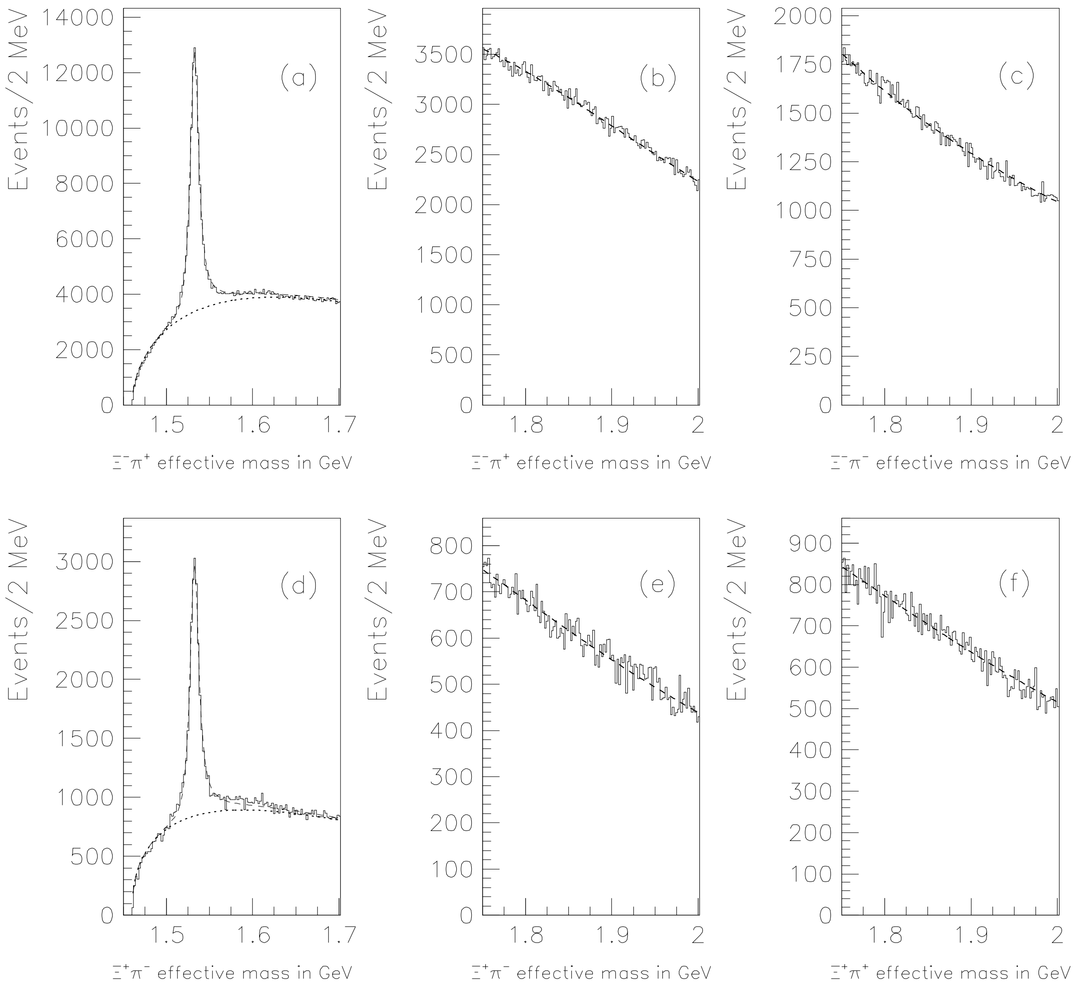

FIG. 4: *Fits to the $\Xi\pi$ effective mass spectra: a) and d) show the region near 1530 MeV. The superimposed curves show the background function and the sum of the background and a relativistic Breit-Wigner resonance, as described in the text. b), c), e), and f) show the region near 1862 MeV. The superimposed curves consist of the background function only.*

obvious resonance.

The plots in Fig. 3 clearly show that if a narrow pentaquark decaying to $\Xi\pi$ exists, then its production is highly suppressed with respect to the production of $\Xi^0(1530)$ and $\overline{\Xi}^0(1530)$ in these data. In particular, the data contain no evidence for the existence of a pentaquark with mass 1862 MeV in any of the four final states being studied. In order to quantify this conclusion, we computed 95% confidence level upper limits[21] for Gaussian signals with mass = 1862 MeV and σ=7.6 MeV (the NA49 mass resolution).

For comparison, we estimated the yield of $\Xi^0(1530)$ and $\overline{\Xi}^0(1530)$. We fit the $\Xi^-\pi^+$ and $\overline{\Xi}^+\pi^-$ effective mass distributions between threshold and 2200 MeV. The mass distributions were fit to the sum of a background function and a signal consisting of a relativistic ($L = 1$) Breit-Wigner function[22] 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. It was set so that the fit value of the widths of the $\Xi^0(1530)$ and $\overline{\Xi}^0(1530)$ approximately agreed with the values listed by the Particle Data Group. The inferred mass resolution of 2.5 MeV is consistent with the observed width of other particles, such as Ξ^- and Λ^0. 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 α and β are fit parameters. This background function was also used in reference[23].

The results of the fits to the $\Xi^-\pi^+$ and $\overline{\Xi}^+\pi^-$ effective mass distributions are shown in Fig. 4 and summarized in Table I [24]. The doubly charged $\Xi^-\pi^-$ and $\overline{\Xi}^+\pi^+$ effective mass distributions were fit satisfactorily using only the background function described above. The upper limits computed for a Gaussian enhancement at 1862 MeV with $\sigma = 7.6$ MeV are given in Table II.

TABLE I: $\Xi^0(1530)$ *and* $\overline{\Xi}^0(1530)$ *fit results. The errors shown are statistical errors only.*

Decay Mode	$\Xi^-\pi^+$	$\overline{\Xi}^+\pi^-$
χ^2/dof	683/364	443/364
Fit Mass (MeV)	1532.73 ± 0.03	1532.65 ± 0.06
Fit Width (MeV)	8.96 ± 0.06	9.41 ± 0.01
Yield	93728 ± 422	22211 ± 219

TABLE II: 95% *confidence level upper limits for a signal at 1862 MeV. Each limit is also expressed as a fraction of the* $\Xi^0(1530)$ *yield (for baryon modes) or the* $\overline{\Xi}^0(1530)$ *yield (for antibaryon modes).*

Decay Mode	Limit on Gaussian signal (events) (Mass = 1862 MeV, $\sigma = 7.6$ MeV)
$\Xi^-\pi^+$	1020 (1.1%)
$\Xi^-\pi^-$	310 (0.3%)
$\overline{\Xi}^+\pi^-$	290 (1.3%)
$\overline{\Xi}^+\pi^+$	288 (1.3%)

In summary, we have performed a study of inclusive $\Xi^\pm\pi^\pm$ production in beam diffraction reactions of the type $pp \rightarrow p_{fast}X$ with an 800 GeV proton beam and a liquid hydrogen target. Strong signals are observed for both the $\Xi^0(1530)$ and the $\overline{\Xi}^0(1530)$. No other peak is observed in any of the four $\Xi\pi$ effective mass distributions. If a Gaussian line shape with $\sigma = 7.6$ MeV is assumed, the number of $\Xi^-\pi^-$ produced at 1862 MeV is less than 0.3% of the observed number of $\Xi^0(1530) \rightarrow \Xi^-\pi^+$. The limit for the $\Xi^-\pi^+$ final state is 1.1% of the $\Xi^0(1530)$ yield. The limits for the $\overline{\Xi}^+\pi^-$ and $\overline{\Xi}^+\pi^+$ final states are 1.3% of the observed number of $\overline{\Xi}^0(1530) \rightarrow \overline{\Xi}^+\pi^-$. No evidence is found for a state near 1862 MeV.

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