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EXOTIC CASCADES AT NA49*

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The results of resonance searches in $\Xi^-\pi^-$, $\Xi^-\pi^+$, $\overline{\Xi}^+\pi^-$ and $\overline{\Xi}^+\pi^+$ invariant mass spectra in proton-proton collisions at $\sqrt{s}$ =17.2 GeV are presented. A narrow state was observed in $\Xi^-\pi^-$ spectra with mass of 1.862 ± 0.002 GeV/c^2 and width below the detector resolution of about 0.018 GeV/c^2. This state is identified as a candidate for the hypothesized exotic Ξ_5^{--} baryon with $S=-2$, $I=3/2$ and a quark content of $(dsds\bar{u})$. $\Xi^-\pi^+$ and the corresponding antiparticle spectra show an indication of enhancements at the same mass. Very preliminary results of resonance search in $pK^0_{\rm S}$ channel show a resonant structure at 1.526 GeV/c^2.

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1. Introduction

The NA49 results of a search for the Ξ_5^{--} and Ξ_5^0 states and their antiparticles in proton–proton collisions at $\sqrt{s}=17.2$ GeV were published in the article [1]. In these proceedings we will address some issues that were not included in [1], and we will present some preliminary results of resonance search in $pK^0_{\rm S}$ channel.

2. The experiment

NA49 [2] is a fixed target, large acceptance hadron experiment at the CERN SPS. The central part of the detector are four large volume Time Projection Chambers (TPC) which provide precise tracking of charged particles and particle identification through a measurement of specific energy

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loss (dE/dx). After careful calibration, 3–6% dE/dx resolution was achieved depending on the reconstructed track length. Two of the TPCs (VTPC1 and VTPC2) are operated inside superconducting dipole magnets, allowing momentum determination from the track curvature. Typical values for the total momentum resolution are $dp/p^2 = 0.3 - 7.0 \times 10^{-4}$ (GeV/c)$^{-1}$ depending on the track length and topology.

The interactions were produced with a beam of 158 GeV/c protons impinging upon a cylindrical liquid hydrogen target of 20 cm length and 2 cm transverse diameter. The measured trigger cross section was 28.2 mb of which 1 mb was estimated to be elastic scattering. Thus the detector was sensitive to most of the inelastic cross section of 31.8 mb.

3. Analysis and results

The data sample consists of about 6.5 M events. For each event the primary vertex was determined. Events in which no primary vertex was found were rejected. To remove non-target interactions the reconstructed primary vertex had to lie within ±9 cm in the longitudinal (z) and within ± 1 cm in the transverse (x, y) direction from the center of the target. These cuts reduced the data sample to 3.75 M events.

3.1. $\Xi\pi$ channels

The first step in the analysis is the reconstruction of V^0 and cascade candidates, by locating their decay vertices. The detailed description of the selection procedure can be found in [1]. To study the inclusive production of Ξ_5^{--}, Ξ_5^0 and their antiparticles, the Ξ^- and $\bar{\Xi}^+$ candidates were selected within ± 0.015 GeV/c^2 of their nominal masses. This reduces the data sample to 1640 events containing one Ξ^- and 551 events containing one $\bar{\Xi}^+$.

To search for Ξ_5^{--} (Ξ_5^0) the selected Ξ^- candidates were combined with primary π^- (π^+) tracks. To select πs from the primary vertex, their $|b_x|$ and $|b_y|$[1] had to be less than 1.5 cm and 0.5 cm, respectively, and their dE/dx had to be within 1.5 σ of their nominal Bethe–Bloch value. Figure 1 shows the resulting $\Xi^-\pi^-$ and $\Xi^-\pi^+$ invariant mass spectra. The shaded histograms are the mixed-event background, obtained by combining the Ξ^- and the π candidates from different events. With these (loose) cuts a peak at ≈ 1.86 GeV/c^2 is visible in $\Xi^-\pi^-$ invariant mass spectrum. In the $\Xi^-\pi^+$ invariant mass spectrum the only clearly visible resonance is the $\Xi(1530)^0$. The mass from the Gauss fit (inset in figure 1) agrees with the nominal

[1] Extrapolated track impact position in the x (magnetic bending) and y (non-bending) direction at the main vertex.

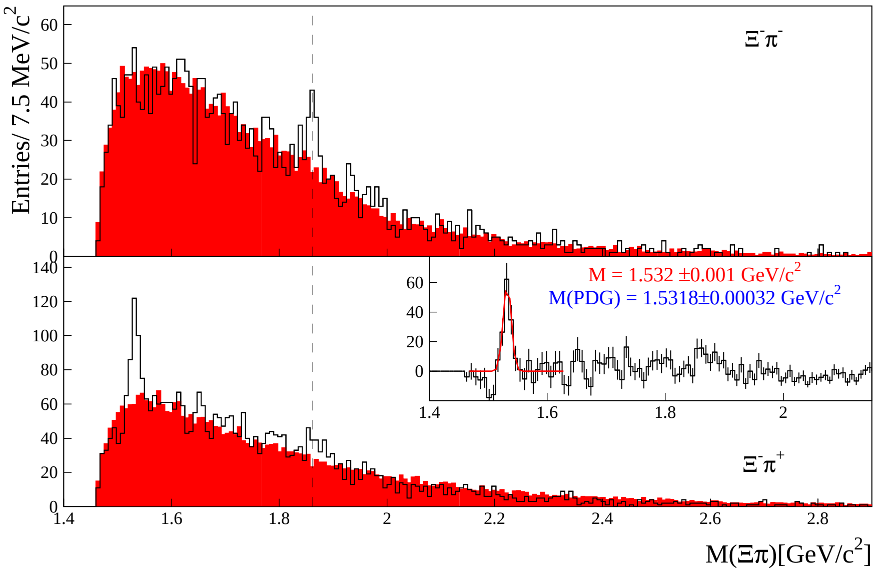

Fig. 1. $\Xi^-\pi^-$ and $\Xi^-\pi^+$ invariant mass spectra. The cuts are explained in the text. The inset shows background subtracted $\Xi^-\pi^+$ spectra with the result of Gauss fit to the $\Xi(1530)^0$.

(PDG) mass value for the $\Xi(1530)^0$, suggesting a systematic error on the absolute mass scale below 0.001 GeV$/c^2$.

For further analysis, several additional cuts were applied. It was found from simulation that the background below the assumed peak at $\approx$ 1.86 GeV$/c^2$ can be reduced by the restriction $\theta > 4.5°$ (with θ being the angle between the Ξ and π direction calculated in the laboratory frame). In addition to this cut, a lower cut of 3 GeV$/c$ was imposed on the π^+ momenta to minimize the large proton contamination, and a lower cut on the dE/dx of the π^+ at 0.5σ below the nominal Bethe–Bloch value to reduce K$^+$ contamination. Figure 2 shows the combined $\Xi^-\pi^- + \bar{\Xi}^+\pi^+$ and $\Xi^-\pi^+ + \bar{\Xi}^+\pi^-$ spectra with these additional cuts. The enhancements around 1.86 GeV$/c^2$ are now seen in all cases.

Gauss fits to the background subtracted spectra of the Ξ_5^{--} and its antiparticle and Ξ_5^0 and its antiparticle (shown as inset in figure 2) yield peak position of 1.862$\pm$0.002 GeV$/c^2$ and 1.864$\pm$0.005 GeV$/c^2$, respectively.

The robustness of the Ξ_5^{--} peak was investigated by changing the width of accepted regions around the nominal Ξ^- and Λ masses, by varying the dE/dx cut used for particle selection, by selecting tracks with different number of points, by using different b_x and b_y cuts, as well as by investigating events with different topologies. In all cases the peak at 1.86 GeV$/c^2$ proved to be robust.

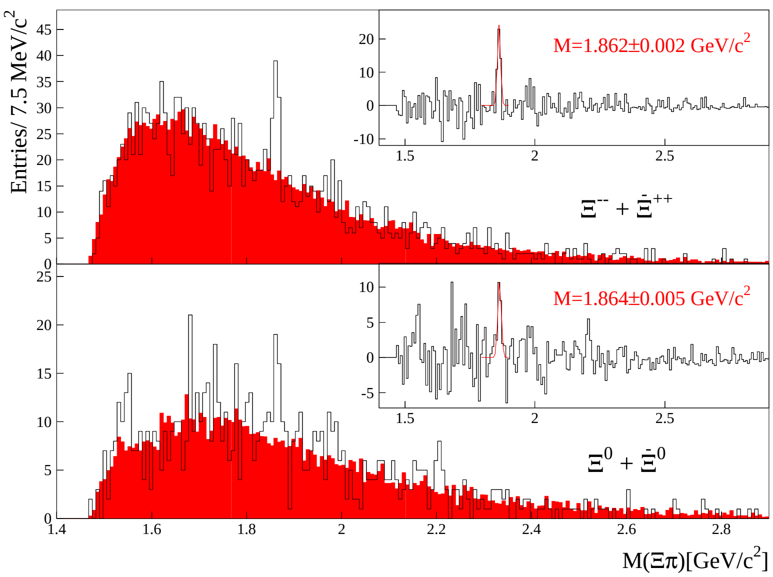

Fig. 2. The combined $\Xi^-\pi^- + \bar{\Xi}^+\pi^+$ and $\Xi^-\pi^+ + \bar{\Xi}^+\pi^-$ spectra after the final cut. The inset shows background subtracted spectra with the result of Gauss fit.

Further, the influence of resonances, including the possibility of particle misidentification was carefully investigated. The events that contain $\Xi^-\pi^+$ candidates within ± 10 MeV$/c^2$ around the nominal $\Xi(1530)^0$ mass were rejected. The selected negative pions were combined with all positive particles, under various mass hypotheses [3]. Figure 3 shows the invariant mass spectra obtained after these additional cuts. The peak in $\Xi^-\pi^-$ spectra remains clearly visible.

However, the $\Xi^-\pi^-$ spectrum is very sensitive to the quality of the Ξ^- and π^- selection, and to see resonances these should have only a minimal amount of contamination. This is demonstrated in figure 4, which shows the $\Xi^-\pi^-$ invariant mass for progressively higher Ξ^- and π^- purity: Figure 4(a) shows the results after selecting Ξ^- and Λ candidates within 15 MeV around their nominal invariant mass, and the proton and π^- dE/dx within 3 σ of their nominal Bethe–Bloch values; figure 4(b) shows the results when the Ξ^- is additionally purified with its $|b_x| < 2$ cm and $|b_y| < 1$ cm, and the π^-, from the Ξ^- decay with its $|b_y| > 0.5$ cm; figure 4(c) shows the results after selecting the primary π^- candidates with their $|b_x| < 1$ cm and $|b_y| < 0.5$ cm and dE/dx within 1.5 σ of their nominal Bethe–Bloch value; figure 4(d) finally shows the results, with the primary π^- dE/dx within 1 σ. Above results (presented without the Θ cut) clearly show the importance of the particle identification, precise main vertex and particle momenta determination.

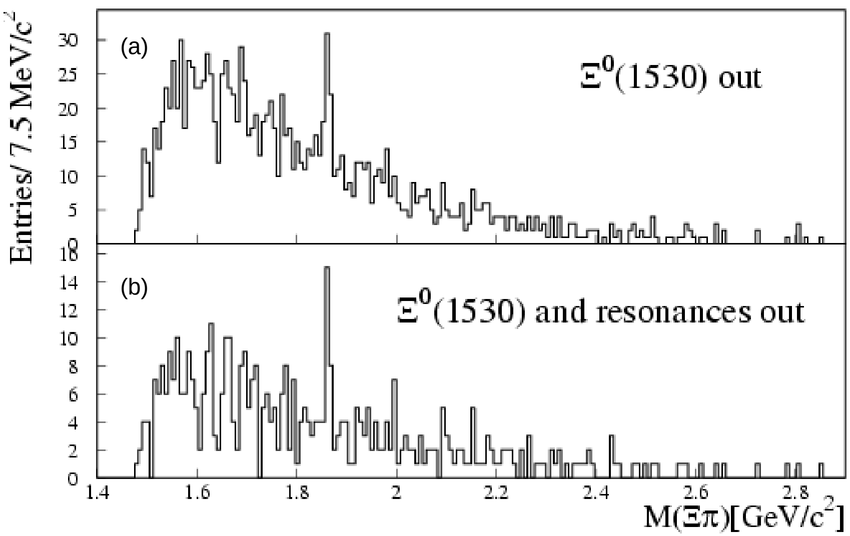

Fig. 3. $\Xi^-\pi^-$ invariant mass distribution (a) events with $\Xi(1530)^0$ candidates were rejected (b) in addition, primary pions that can contribute (under different mass hypotheses) to the known resonances were excluded.

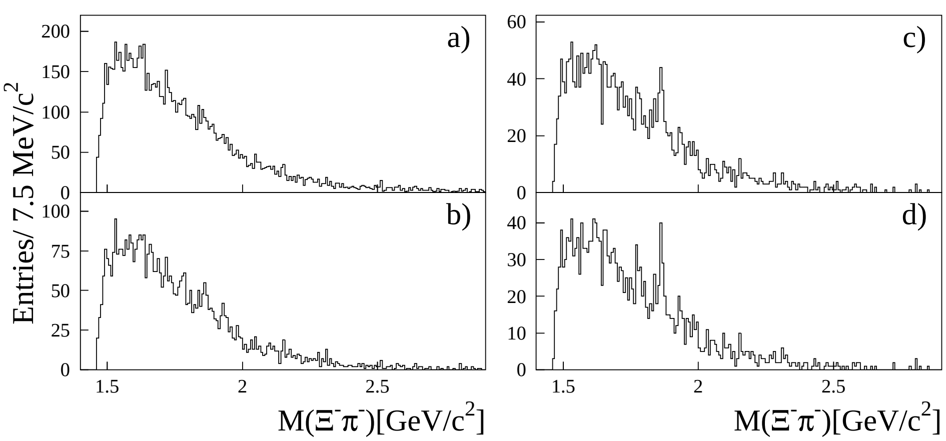

Fig. 4. $\Xi^-\pi^-$ NA49 invariant mass distribution for progressively better $\Xi^-\pi^-$ selection. See text for details.

3.2. $pK^0_{\rm S}$ *channel*

The exotic Θ^+ hyperon was searched for through its strong decay to $K^0_{\rm S}p$, followed by a weak decay, $K^0_{\rm S} \longrightarrow \pi^+\pi^-$. The first step was the reconstruction of the $K^0_{\rm S}$ candidates by locating their vertices. To achieve this, the pions were selected by requiring their dE/dx to be within 3 σ around the nominal Bethe–Bloch value, and tracked backwards through the magnetic field. The V^0 was constrained to lie on the track with more VTPC points. A 4-parameter χ^2 fit was performed to find the V^0 position along the longer track and the three momentum components of the other track at this point. To reduce background bellow the K_S^0 peak several additional cuts were applied.

The azimuthal decay angle, ϕ, is defined as the angle of the daughter's decay plane with respect to the original V^0 direction. Real particle decays are expected to populate the ϕ distribution uniformly. However, the vertical magnetic field bends tracks in the horizontal x–z plane, and any track momentum misalignment would result in their displacement also within this plane. For $\phi = 0$ or $\pm\pi$, the tracks will be displaced within the decay plane. and primary (background) tracks could have their opening angle increased, resulting in fake V^0s. For other decay angles the tracks can only be bent out of the decay plane, and would not cross and result in V^0 candidates. To exclude these regions of poorer signal to background ratio, for K_S^0 particles the allowed values of ϕ are limited to $|\cos(\phi)| < 0.9$. The combinatorial background is concentrated close to the target as primary tracks will naturally come together at the main vertex. Therefore, the distance between the primary and the decay vertex of the K_S^0 particles is taken to be at least 12 cm. To ensure that K_S^0 originates from the main vertex its $|b_x|$ and $|b_y|$ had to be less than 1 cm and 0.5 cm, respectively. In addition all pairs satisfying Λ and $\bar{\Lambda}$ mass hypothesis are rejected. The resulting $\pi^+\pi^-$ invariant mass spectrum is shown in figure 5(a).

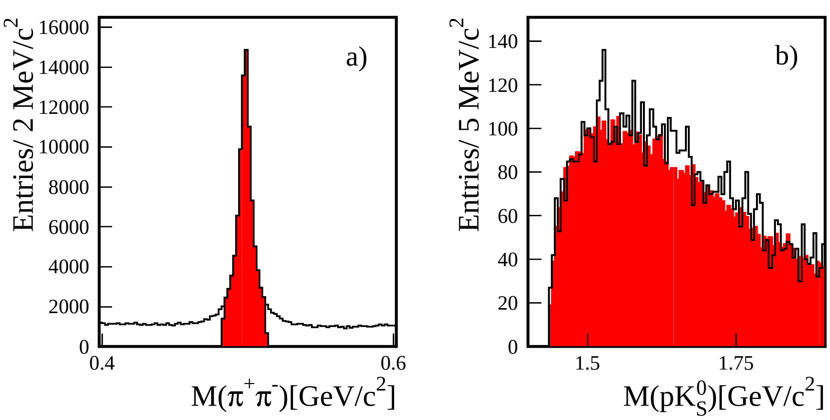

Fig. 5. (a) The $\pi^+\pi^-$ invariant mass spectrum. The shaded histogram indicates the range of the selected K_S^0 candidates. (b) The pK_S^0 invariant mass spectrum. The shaded histogram is the normalized mixed-event background. For the applied cuts see text for the details.

To study the pK^0_{S} invariant mass spectrum the K^0_{S} candidates were selected within ± 0.015 GeV$/c^2$ of their nominal masses. Then, these candidates were combined with primary protons. To select protons from the primary vertex, their $|b_x|$ and $|b_y|$ had to be less than 1.0 cm and 0.5 cm, respectively. A lower cut of 5 GeV$/c$ was imposed on the proton momenta to minimize the large pion and kaon contamination, and a lower cut on the dE/dx of the proton at 0.5 σ below the nominal Bethe–Bloch value to reduce K^+ contamination. Selecting the pK^0_{S} pairs with transverse momenta 0.2 GeV$/c < p_{\mathrm{T}} < 0.9$ GeV$/c$ and absolute rapidity $|y| < 0.75$ we obtain the results shown in figure 5(b). The shaded histogram is the mixed-event background, obtained by combining the proton and the K^0_{S} candidates from different events. A narrow resonant structure at ≈ 1.526 GeV$/c^2$ is visible, as an candidate for the exotic Θ^+ particles in *pp* data at SPS energy.

4. Conclusions

The evidence for the existence of a narrow state in $\Xi^-\pi^-$ invariant mass spectra with a mass of 1.862 ± 0.002 GeV$/c^2$ and width below the detector resolution of about 0.018 GeV$/c^2$ is presented. This state is identified as a candidate for the hypothesized exotic Ξ_5^{--} baryon with $S = -2$, $I = 3/2$ and a quark content of $(dsds\bar{u})$. $\Xi^-\pi^+$ and the corresponding antiparticle spectra show indication of enhancements at the same mass.

Very preliminary results from pK^0_{S} invariant mass spectrum indicates the existence of a narrow resonant structure at ≈ 1.526 GeV$/c^2$ which could be identified as a candidate for the exotic Θ^+ particle. If ongoing analysis at NA49 confirms the above results this will be for the first time that two exotic baryons are obtained in the same data sample.

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