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SEARCH FOR ϕ^{--} PENTAQUARKS IN COMPASS*

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We report the results of the $\Xi^-\pi^\pm$ and $\overline{\Xi}^+\pi^\pm$ mass distribution studies performed on the COMPASS data taken in 2002 and 2003. The studies were triggered by the NA49 experiment observation of the exotic ϕ^{--} state at the $\Xi^-\pi^-$ invariant mass of 1860 MeV and width <20 MeV. COMPASS data analysis does not confirm the existence of this state.

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1. Introduction

Several experiments have announced observations of narrow peaks in the pK^0 and nK^+ invariant mass spectra centered at about 1540 MeV and having widths consistent with the experimental resolutions. These peaks are interpreted as a Θ^+ pentaquark state predicted by Praszałowicz [1] and Diakonov, Petrov and Polyakov [2]. If Θ^+ exists it should be accompanied by other pentaquark states. Search for these was performed by the NA49 experiment at CERN and resulted in $\phi(1860)^{--}$ and $\phi(1860)^0$ pentaquark candidates [3]. Also a $\overline{\phi}(1860)^{++}$ signal was observed while no $\overline{\phi}(1860)^0$ one was found. Statistical significance of the signal is low, of the order of 5.6 σ, and the existence of the $\phi(1860)$ pentaquark needs confirmation. Several experiments attempted searches for the NA49 signal. This paper reports the results of COMPASS obtained on the data collected in 2002 and 2003.

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2. COMPASS detector

COmmon Muon and Proton Apparatus for Structure and Spectroscopy (COMPASS) is a two-stage magnetic spectrometer. It is located at the CERN Super Proton Synchrotron (SPS). The COMPASS Collaboration consists of over 250 physicists from 11 countries. In 2002 and 2003 the experiment was running using a 160 GeV polarized μ^+ beam. The main objectives of the physics programme were measurements of the gluon polarization inside a nucleon, inclusive DIS asymmetry, spin flavor separation, diffractive vector mesons production and the Λ hyperon polarization. Dedicated hadron spectroscopy runs are planned after 2005. However, large statistics and a very good quality of the 2002 and 2003 data makes it possible to use them in the hadron spectroscopy studies.

The COMPASS target is composed of two separate solid state ^{6}LiD cells, each 60 cm long and 3 cm in diameter, separated by a 10 cm gap. The target is polarized in longitudinal (80% of the beam time) and transverse (20%) directions with respect to the beam. The direction of polarization was flipped regularly, so that any possible polarization dependence averages out in this analysis. Bulk of the data has $Q^2 < 1$ GeV (quasi-real photoproduction). Particles produced in the interactions are traced and identified in two spectrometers each containing tracking, identification devices and calorimetry. Large Angle Spectrometer (LAS) is designed to detect particles with momenta >0.4 GeV and emission angles >30 mrad with respect to the beam. Small Angle Spectrometer is dedicated to particles with momenta >4 GeV and angles <30 mrad. Each spectrometer is equipped with magnets and hadronic calorimeters. Hadrons identification relies on the Ring Imaging CHerenkov counter located in LAS. Identification of the muons is done via filtering through absorbers. To match different fluxes of particles in different parts of the spectrometer several kinds of tracking detectors are used. Scintillation Fibers and Silicon Microstrips are used for tracking close to the beam region. Further away of the beam Gas Electron Multipliers and Micro Mesh gas detectors are located. The tracking in the outer parts of the spectrometer is performed by Drift Chambers, Straw Tubes and Multiwire Proportional Chambers. For more details concerning the apparatus see [4].

3. $\phi(1860)$ pentaquark search

In the COMPASS data analysis all four $\Xi^-\pi^-$, $\Xi^-\pi^+$, $\overline{\Xi}^+\pi^+$ and $\overline{\Xi}^+\pi^-$ invariant mass spectra were studied. In these spectra signals of ϕ^{--}, ϕ^0, $\overline{\phi}^{++}$ and $\overline{\phi}^0$ may be observable. The investigated decay chains were:

$$\phi^{--} \rightarrow \Xi^-\pi^- \rightarrow \Lambda\pi^-\pi^- \rightarrow p\pi^-\pi^-\pi^- \,, \tag{1}$$

$$\phi^0 \rightarrow \Xi^-\pi^+ \rightarrow \Lambda\pi^-\pi^+ \rightarrow p\pi^-\pi^-\pi^+ \,, \tag{2}$$

$$\overline{\phi}^{++} \;\to\; \overline{\Xi}^{+}\pi^{+} \to \overline{\Lambda}\pi^{+}\pi^{+} \to \overline{p}\pi^{+}\pi^{+}\pi^{+}\,, \tag{3}$$
$$\overline{\phi}^{0} \;\to\; \overline{\Xi}^{+}\pi^{-} \to \overline{\Lambda}\pi^{+}\pi^{-} \to \overline{p}\pi^{+}\pi^{+}\pi^{-}\,. \tag{4}$$

Only events containing reconstructed incoming and scattered μ^+ were included in the analysis. The cut on the geometrical target limits was imposed discarding the events with primary interaction outside its volume. All particles with momenta larger than 140 GeV were assumed to be misidentified beam muons and removed.

3.1. Λ and $\overline{\Lambda}$ selection

The reconstruction of Λ and $\overline{\Lambda}$ states was performed by studying their decay vertices with two outgoing particles of opposite charge. In case of Λ a positive particle was assigned a proton mass and a negative one — a pion mass. For $\overline{\Lambda}$ the assignment was opposite. To reduce the combinatorial background originating mainly from the target volume a demand that a vertex of the $\Lambda(\overline{\Lambda})$ decay should be downstream the target was imposed. Vertices corresponding to the photon conversion $\gamma \to e^+e^-$ were removed by requirement $|\cos\theta^*| < 0.9$, with θ^* being the cms emission angle of the negative particle with respect to the $\Lambda(\overline{\Lambda})$ flight direction. The mass spectra of Λ and $\overline{\Lambda}$ candidates are presented in Fig. 1. They were fitted by a sum of a Gaussian for the peak and a polynomial parametrising the background. For the further analysis the $\Lambda(\overline{\Lambda})$ candidates of masses in the $\pm 3\ \sigma$ window around the center of the peak were taken.

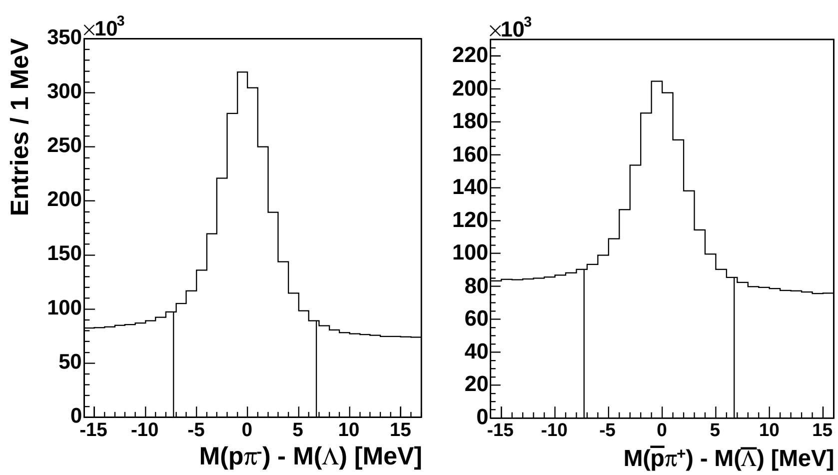

Fig. 1. The $p\pi^-$ ($\overline{p}\pi^+$) invariant mass spectra with respect to the nominal Λ mass. Vertical lines show the mass window that is used in following analysis.

3.2. Ξ^- and $\overline{\Xi}^+$ selection

In order to obtain $\Xi^-(\overline{\Xi}^+)$ sample the $\Lambda(\overline{\Lambda})$ candidates were paired with π_Ξ candidates in the event. The π_Ξ candidate was defined as follows. It was a particle not used in the $\Lambda(\overline{\Lambda})$ reconstruction, having an appropriate charge — negative for Ξ^- and positive for $\overline{\Xi}^+$ — and not attached to a primary vertex. Moreover, pairs of the $\Lambda(\overline{\Lambda})\pi_\Xi$ tracks for which the distance of the closest approach was greater than 0.8 cm were discarded. The point of the closest approach had to be located downstream the primary and upstream the $\Lambda(\overline{\Lambda})$ vertex. Such π_Ξ candidates were assigned with a pion mass and $\Xi^-(\overline{\Xi}^+)$ state was reconstructed, *cf.* Fig. 2. The invariant mass spectra were then fitted with the same functions as described for the $\Lambda(\overline{\Lambda})$. For further analysis cascade hyperons in the $\pm 3\ \sigma$ windows around the center of each peak were taken.

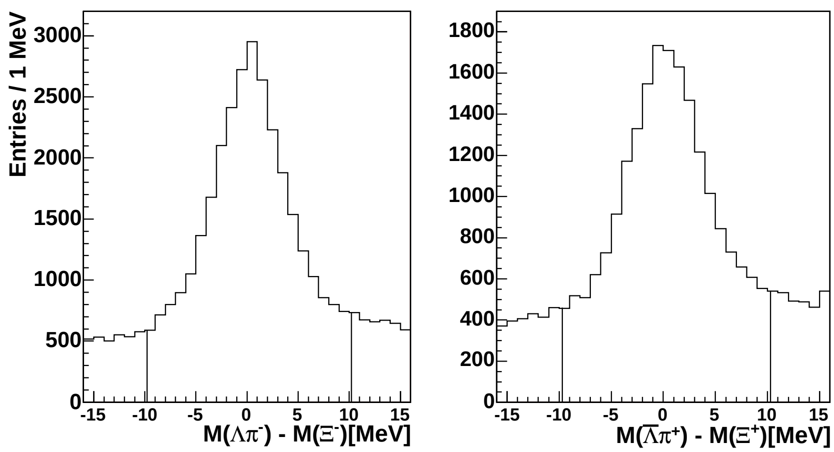

Fig. 2. The $\Lambda\pi^-$ $(\overline{\Lambda}\pi^+)$ invariant mass spectra with respect to the nominal Ξ^- mass. Vertical lines show the mass window which is used in the following analysis.

3.3. $\Xi^-\pi^\pm$ and $\overline{\Xi}^+\pi^\pm$ mass spectra

To obtain invariant masses of the $\Xi^-\pi^-$, $\Xi^-\pi^+$, $\overline{\Xi}^+\pi^+$ and $\overline{\Xi}^+\pi^-$ systems particles pointing into the primary vertex and not used in the previous steps of the analysis were assigned with a pion mass and paired with $\Xi^-(\overline{\Xi}^+)$ candidates. In the two charge combinations, $\Xi^-\pi^+$ and $\overline{\Xi}^+\pi^-$, the well known $\Xi(1530)^0$ and $\overline{\Xi}(1530)^0$ states are clearly visible, *cf.* Fig. 3. Invariant mass spectra of four $\Xi\pi$ systems are shown in Fig. 4. No other states except for the two mentioned above are found on the plots. The arrows indicate the positions where the NA49 effect was observed. The upper limit on the num-

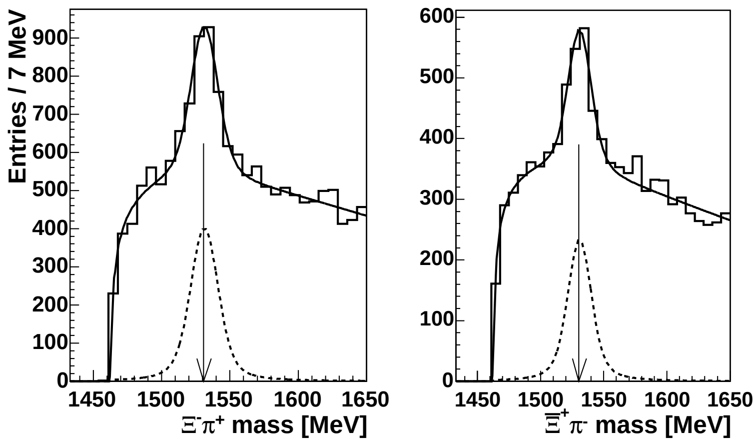

Fig. 3. The $\Xi^-\pi^+$ ($\overline{\Xi}^+\pi^-$) invariant mass spectra. Arrows indicate the $\Xi(1530)^0$ mass. Solid lines mark the fit results — Voigtian peak and a background parametrization of the form $(m - m_0)^{p_1}\ \exp(-p_2\, m - p_3\, m^2)$. Dashed lines mark the signal after background subtraction.

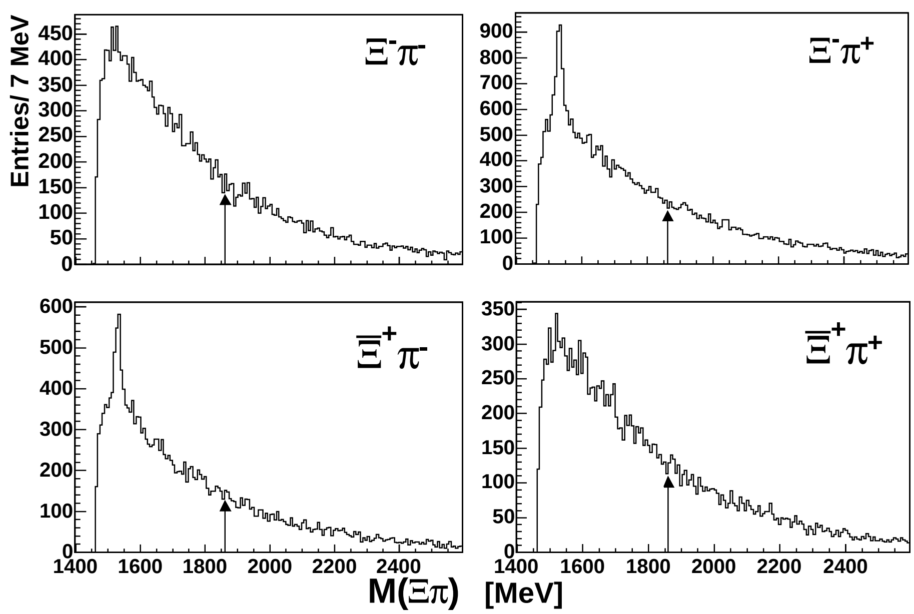

Fig. 4. $\Xi\pi$ invariant mass spectra of the four possible charge combinations. Arrows indicate the position of the $\phi(1860)$ signal observed in [3].

ber of events in a hypothetical peak located at that mass was obtained as follows. From a polynomial fit to the mass spectra for like sign pairs, excluding the possible resonance region from 1825 to 1895 MeV, we estimated the expected background. Three intervals of 28 MeV width, staggered by 14 MeV and the central interval centered at 1860 MeV were then investigated; corresponding entries were n_1, n_2, n_3. With the background estimated from the fit, b_1, b_2, b_3, we determined the quantity $\max_{i=1,2,3}(3\sqrt{b_i} + \max(0, n_i - b_i))$ and thus deduced upper limits for a possible excess of events. We obtained limits of 79 events for the $\Xi^-\pi^-$ and 89 for the $\overline{\Xi}^+\pi^+$ final state at a confidence level of 99%. There are also no narrow peaks visible in the (non-exotic) unlike sign pairs. If the ratio of the cross sections for Ξ^- and $\phi(1860)^{--}$ production is comparable in COMPASS and in NA49, we would expect the pentaquark signal in COMPASS containing about 400 counts.

Different additional cuts were tried to select the pentaquark signal. In particular the RICH particle identification was included to clean the Ξ^- and $\overline{\Xi}^+$ samples. The cuts did not change the negative result of the analysis.

4. Conclusions

The NA49 signal was investigated in the μA interactions at very low Q^2 collected by the COMPASS experiment. Having Ξ^- statistics 10 times larger than NA49, we would expect about 400 events of the $\phi(1860)^{--}$ signal. No significant structure was observed in the 2002–2003 COMPASS data and a signal stronger than 79 events was excluded at the 99% confidence level. The negative results were also obtained for $\phi(1860)^0$, $\overline{\phi}(1860)^{++}$ and $\overline{\phi}(1860)^0$ states. Recently other experiments have reported their results concerning the cascade pentaquark search. All of them were negative. Presently NA49 seems to be the only one which claims to see the $\phi(1860)$ state. For more detailed description of the COMPASS analysis and the overview of other negative results see [5].

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