PROCEEDINGS OF SCIENCE

$\Lambda - p/d/t$ correlations with the KLOE Drift Chamber by the AMADEUS collaboration

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In the framework of the AMADEUS experiment the $\Lambda - p/d/t$ correlations following K^- nuclear absorption in helium were investigated. To this end KLOE data from 2004-2005 were reanalysed using the detector itself as an active target. The invariant masses and angular correlations will be compared with old bubble chamber data and with the most recent experiments (FINUDA, KEK, DISTO), completing the picture of the investigations on the single and multi-nucleon absorption of low energy K^- in light nuclei.

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1. Introduction

AMADEUS (Antikaon Matter At DAΦNE: Experiments Unraveling Spectroscopy) has the goal to study fundamental aspects of low-energy QCD in the strangeness sector, in order to gain information on the modification of the hadron masses and interactions in the nuclear medium. Among other measurements it is planned to perform studies of antikaon absorption on light nuclei, where one of the aims is the search for deeply bound kaonic nuclear states (DBKNS). Those states, as predicted by Wycech [1] and Akaishi and Yamazaki [2], are generated by the strong $\bar{K}$N interaction in the isospin I=0 channel. As a first step of the AMADEUS experiment, older KLOE data (from 2004-2005) were used to study Λp, Λd and Λt correlations. These final states give the opportunity to investigate single and multi-nucleon absorption, important for disentangling this type of processes from a possible signal due to the formation of a bound state. Theoreticians are calculating the values for the binding energies and widths of the predicted states, especially for the K^-pp one, but depending on the model and type of calculation significantly different results are obtained [3, 4, 5, 6, 7]. To clarify the situation, more experimental data are needed. Until now several experiments presented their results, but the interpretation is not conclusive, so the puzzle remains unsolved. Two main experimental approaches have been used in the search for K^-pp clusters: p-p and heavy ion collisions, as, for example, in the DISTO experiment [8] and a low momentum or stopped K^- interactions in light nuclei, as in the FINUDA [9] and KEK-PS E549 [10] experiments. The second approach is used also in our experiment. To interpret well the results we need to have precise knowledge of the shape and characteristics of the single and multi-nucleon absorption processes of a K^- interacting on a light nuclei, for which we still have a limited knowlege since the branching ratios have been extracted using only 1000 events from an old bubble chamber experiment [11]. The Λp correlation studies from the K^- interaction in the KLOE drift chamber volume will be presented, together with Λd and Λt channels, and will be compared with the existing results from other experiments.

2. Data and events selection

The AMADEUS project is planned as a dedicated setup inside the KLOE detector placed on the DAΦNE collider at LNF-INFN in Frascati, Italy. DAΦNE (Double Anular Φ-factory for Nice Experiments) [12] is a Φ factory, a double-ring e^-e^+ collider, operating at the center of mass of the Φ meson, decaying at $\simeq$ 50% B.R. to almost monochromatic low momentum K^+K^- pairs ($\simeq$127 MeV/c). The KLOE detector [13] consists of a large cylindrical Drift Chamber (DC), surrounded by a lead-scintillating fibers calorimeter, immersed in a magnetic field of 0.52 T. The drift chamber volume is filled with gas containing mainly ^4He ($\simeq$ 90%), and a smaller amount of isobutane ($\simeq$ 10%). As a step 0 of AMADEUS the tests of the behavior of the KLOE detector for hadronic physics purposes have beed carried out and the Monte Carlo simulations showed that 0.1% of K^- should stop in the DC volume, while 10 times more stop in the carbon entrance wall of the DC. This would lead to hundreds of events for K^- hadronic interactions at rest. The KLOE detector has the excellent acceptance of $\simeq$ 96% and an excellent resolution (e.g. for Λ(1116) the momentum resolution is Δp (FWHM)/p = 0.01 and the invariant mass resolution is $\sigma = 0.289 \pm 0.003 MeV/c^2$). The listed features make KLOE an ideal detector for hadronic physics in the strangeness sector. The first step of AMADEUS consists in reanalysing the sample of about 1 fb^{-1} integrated luminosity of the old KLOE data (measurements performed from 2004-2005) using the detector itself as an active target. Particles selection and identification is done using the dE/dx information, measured with the truncated mean of ADC counts from the wires hit in the DC and the momentum of the track, as it is shown in Fig. 1.

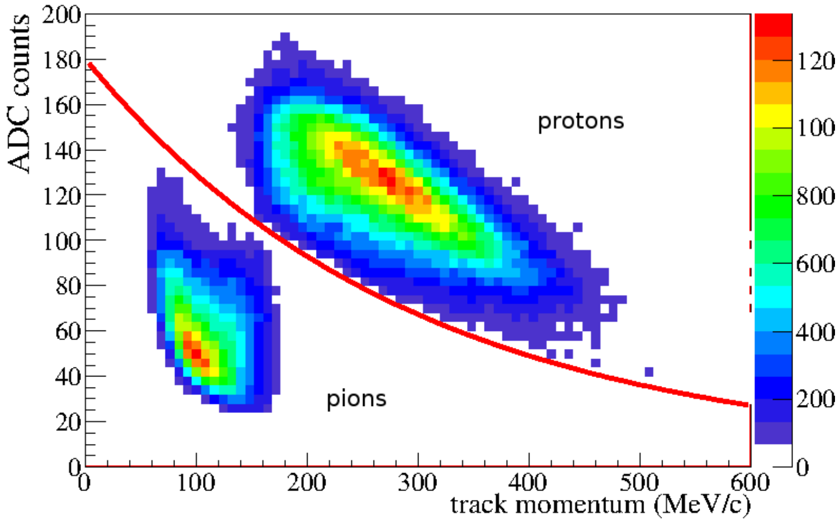

Figure 1: *dE/dx (in ADC counts) vs. momentum for the selected proton (up) and pion (down) tracks in the final selection. The proton selection function is displayed in red.*

The $\Lambda(1116)$ identification is done through the reconstruction of its decay vertex $\Lambda \to p + \pi^-$, and it is used to tag the K^- absorption. This leads to already mentioned very precise reconstruction of the Λ invariant mass, shown in Fig. 2.

Once the Λ has been identified, it is extrapolated back along its expected decay path and an additional charged track, coming from the same vertex is searched for, selecting in this way the Λp, Λd and Λt events. Both the Λ and the absorption vertices have a reconstruction efficiency of about 20 %.

3. Studies of Λp/d/t correlations

The Λp mass spectrum is shown in the left side of Fig. 3. The blue curve represents all the reconstructed Λp events, while the red curve (with a doubled statistics) represents the events where a negative pion is found in the final state too. The presence of the pion is a characteristic signal of the K^- absorption on one nucleon. In the right side of the Fig. 3, the momenta of the Λs (up) and of the protons (down) are shown.

To characterize the invariant mass spectrum, a thorough study of the possible undergoing processes contributing to the final state was considered. In a first step single (1NA) and double (2NA) nucleon absorption processes and internal conversions have been taken into account:

1. *1NA:* $K^- n \to \Lambda\, \pi^-$*:* direct Λ production after a K^- absorption on a single nucleon.

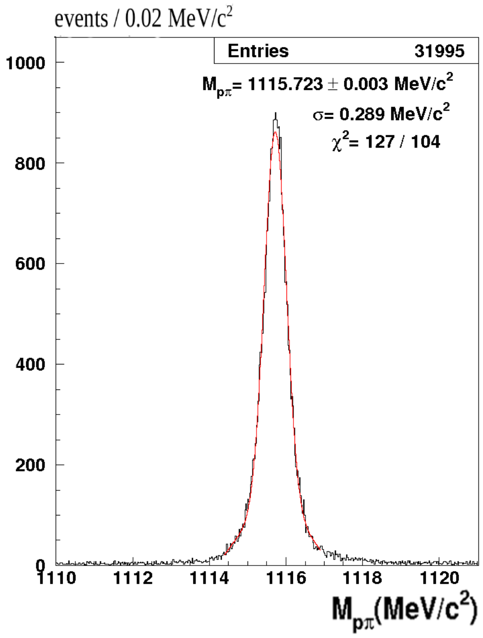

Figure 2: *The invariant mass spectrum for the pion-proton pairs.*

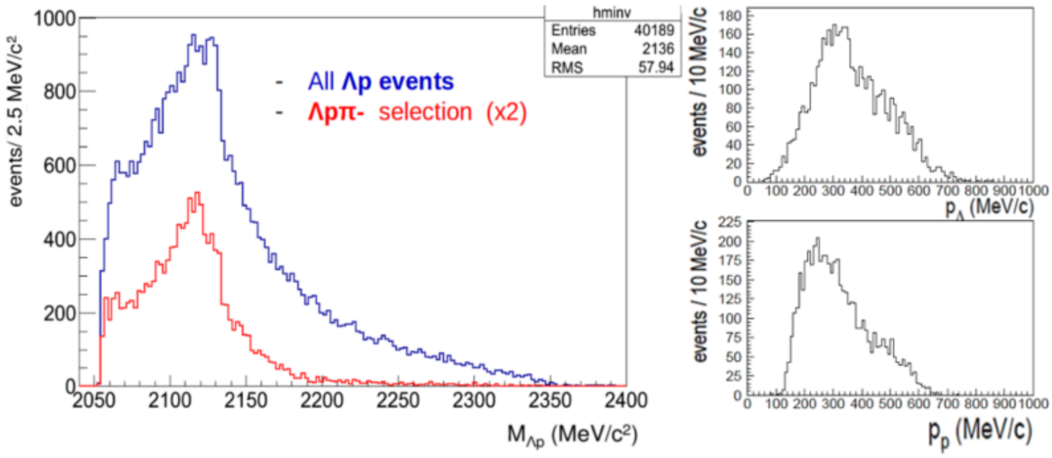

Figure 3: *Left: The* Λp *invariant mass spectrum: blue curve - all the* Λp *pairs, red curve -* $\Lambda p\pi^-$ *events. Right: momenta of the* Λ*s (up) and protons (down).*

2. *1NA:* $K^- N \to \Sigma\,\pi^-$, $(\Sigma\,N')\pi^- \to (\Lambda\,N')\pi^-$ pionic process with an extra proton from the Σ/Λ conversion after a K^- absorption on a single nucleon.

3. *2NA:* $K^- NN \to \Lambda N$: direct production of Λ after a double nucleon absorption process.

4. *2NA:* $K^- NN \to \Sigma N$, $(\Sigma N)N \to \Lambda N'(N)$: double nucleon absorption process with a Σ/Λ conversion on an another nucleon from the helium, not involved in a previous absorption process.

Monte Carlo simulations, as expected, indicate that the lower part of the invariant mass spectrum can be described by the 1NA processes, which is confirmed by the red line presented in Fig. 3, while the higher part of the spectrum contains the events occured in 2NA. To be more precise, the lowest part of the Λp invariant mass spectrum is populated with the processes of the first type by the K^-n $\rightarrow \Lambda\ \pi^-$(p) reaction - the proton in the parenthesis being the spectator. At slightly higher masses the processes of a second type are contributing the spectrum by the reaction K^-n $\rightarrow \Sigma^0\ \pi^-$ $\rightarrow \Lambda(p)\pi^-$, where the Σ hyperon undergoes the internal conversion on a proton (Σ p → Λ p). In the central part of the spectrum, contributions of the fourth type of processes arise - double nuclear absorption of K^- on np or on pp producing the Σ^0 particle, followed by the internal conversion on p or n, respectively, to produce the Λpn in the final state. The region corresponding to larger Λp invariant masses contains the third process - direct Λ production after a double nucleon absorption of K^- on two protons. A similar explanation was proposed by the KEK collaboration in [10]. Other possible processes which could contribute to the spectra should be investigated too. Once all possible contributing processes have been simulated, the fit will show if there is still room for a deeply bound K^-pp state. This analysis will give a lot of information about the stated processes themselfs and also some interesting quantitative outputs, for example 2NA rate per stopped kaon. While the studies of the Λ-proton correlations are still undergoing, we also started the studies of the Λ-deuteron and Λ-triton channels. The Λd channel study will be compared with the other experiments which published data on this type of studies, while for the Λt channel the number of events is higher then in any up to date published work. Only one old experiment [14], which reported 3 events, and FINUDA [15] with 40 events presented results until now. In Fig. 4 we present a very preliminary angular distribution of the Λ-triton pairs extracted from our data, for comparison with the FINUDA published one.

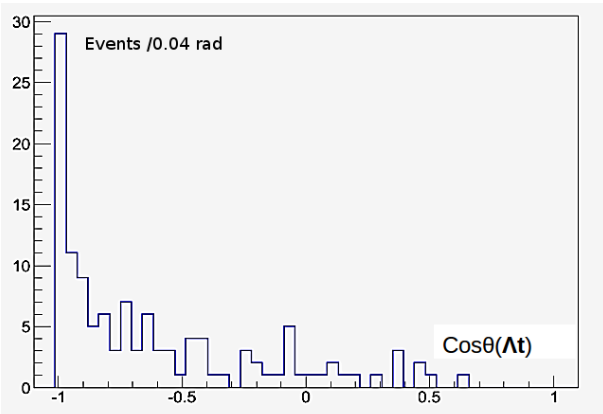

Figure 4: *Cosine of the angular Λt pair distribution.*

4. Conclusions and perspectives

In this paper the Λ-p/d/t correlations investigated in the framework of AMADEUS, searching for possible deeply bound kaonic nuclear states and studing interesting aspects of the single and multi-nucleon absorption processes of antikaons and internal conversion of sigma hyperon, are discussed. Further analyses efforts are needed, especially in the recently opened Λd and Λt channels. In 2012 a half-cylindrical solid pure carbon target was inserted inside of KLOE detector and the data collected are presently being analysed. The possibility of inserting other types of solid (Li, Be) and gaseous (d, ^3He,^4He) targets is actually considered, in parallel with ongoing R&D activities for the AMADEUS refined setup (inner tracker and trigger system).

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