PROCEEDINGS OF SCIENCE

Understanding $\Lambda(1405)$ nature in the low-energy kaon-nuclei interactions within the AMADEUS program

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on behalf of AMADEUS collaboration

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The AMADEUS collaboration has the goal to perform unprecedented measurements in the field of the low-energy charged kaons-nuclei interactions, by completing the existing KLOE detector with a dedicated setup in the inner region. As a preliminary step towards the realization, the AMADEUS team has analyzed the 2002-2005 KLOE data, studying the processes resulting from the negative kaons nuclear absorption in the entrance wall of the KLOE Drift Chamber (containing mostly carbon) and in the gas filling it, mostly helium. These analyses already produced unique results, especially in the $\Sigma\pi$ and $\Lambda\pi$ final states. In particular, it was proven that an in-flight component is present in the KLOE data, which allows the investigation of a larger invariant mass region with respect to the old bubble chamber experiments, leading to a deeper comprehension of the $\Lambda(1405)$ nature. The proof of the presence of an in-flight componente in the 2002-2005 KLOE data is presented, together with a discussion of its implications in the determination of the $\Lambda(1405)$ resonance shape.

52 International Winter Meeting on Nuclear Physics - Bormio 2014,
27-31 January 2014
Bormio, Italy

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PoS(Bormio2014)039

1. The key role of the $\Lambda(1405)$ and its puzzling nature

The low energy $\bar{K}N$ interaction remains nowadays one of the most fascinating, and at the same time poorly known, fields of the QCD in the strangeness sector; its connection with the explicit chiral simmetry breaking is indeed matter of discussions in the scientific community and one of the main subject for several experiments, as clearly stated by W. Weise in a lecture on the QCD vacuum and its hadronic excitation [1]. This can be better understood observing Fig.1, where the real and imaginary part of the K^-p scattering lenghts are shown. It is then clear how the presence of a resonance just below the K^-p threshold $(1432 MeV/c^2)$ can not be neglected; on the contrary, it is fundamental to have a full comprehension of this resonance in order to be able to include it in the theoretical models. The scattering amplitude can be constrained above threshold rather precisely exploiting kaonic atoms [2].

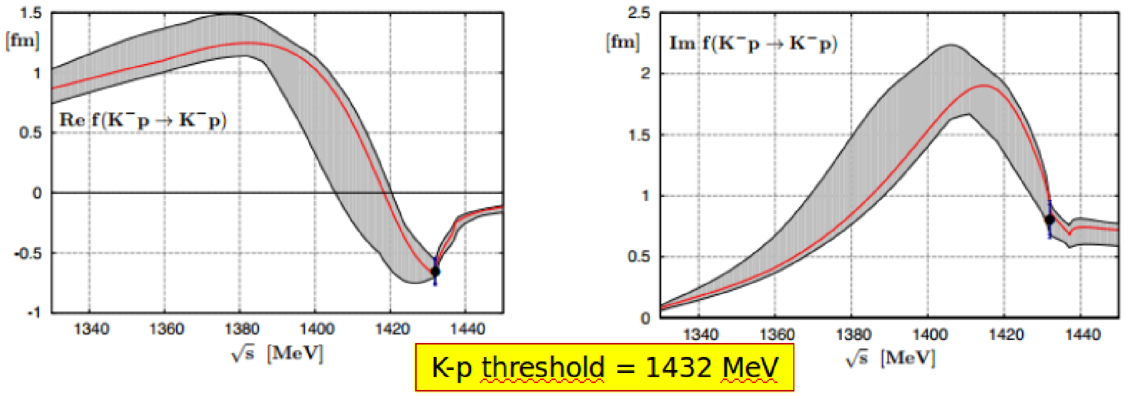

Figure 1: Real part (left) and imaginary part (right) of the $K^-p \to K^-p$ forward scattering amplitude extrapolated to the subthreshold region. The empirical real and imaginary parts of the K^-p scattering length deduced from the recent kaonic hydrogen measurement performed by the SIDDHARTA experiment [2] are indicated by the dots including statistical and systematic errors.

Looking in the Particle Data Group publications (PDG, [3]), the reported value for the $\Lambda(1405)$ mass is obtained through the fit [4] of old bubble chamber data [5], where the sample is constituted by events in which a K^- is stopped on a ^4He atom and then proceed toward an atomic cascade reaching zero momentum when interacting with the nucleon; these are the so called at-rest events. This reported value is highly debated in the scientific community due to the fact it has been obtained picturing the $\Lambda(1405)$ as a single polre resonance while the latest theoretical models, based on a coupled channel approach, pictures the $\Lambda(1405)$ as a double pole resonance; the first pole, located around $1405 MeV/c^2$ is mostly coupled to the $\Sigma\pi$ channel whilst the second one, located around $1420 MeV/c^2$, is mostly coupled to the $\bar{K}N$ channel [6]. With in-flight reactions one can reach a wider invariant mass region, having the possibility to observe events in which the kaons are not stopped in the atomic orbit but directly interacts on the nucleon with a non-zero momentum. It becomes then evident how, in order to understand the nature of the $\Lambda(1405)$ resonance, such kind of measurment is mandatory.

2. DAΦNE and KLOE

The KLOE [7] detector at DAΦNE [8] offers an excellent opportunity to perform a complete study of the $\Lambda(1405)$ resonance through all its three $\Sigma\pi$ decay channels simultaneously [9, 10, 11] and, as will be later shown, represents the first opportunity to perform studies with both in-flight and at-rest events. The KLOE detector is installed at the DAΦNE collider of the Laboratori Nazionali di Frascati-INFN [8], where the Φ resonance is created almost at rest via the collisions between $510\,MeV/c$ momentum electrons and positrons. The decay products of the Φ resonance, mostly charged kaons (with B.R. $\simeq 50\%$) and the particles resulting from their interactions, are then detected by the KLOE detector. The KLOE detector has a $\sim 4\pi$ geometry and an acceptance of 98%; it consists of a large cylindrical Drift Chamber (DC) and a fine sampling lead-scintillating fibers calorimeter, immersed in an axial magnetic field of $0.52\,T$ provided by a superconducting solenoid, see Fig. 2.

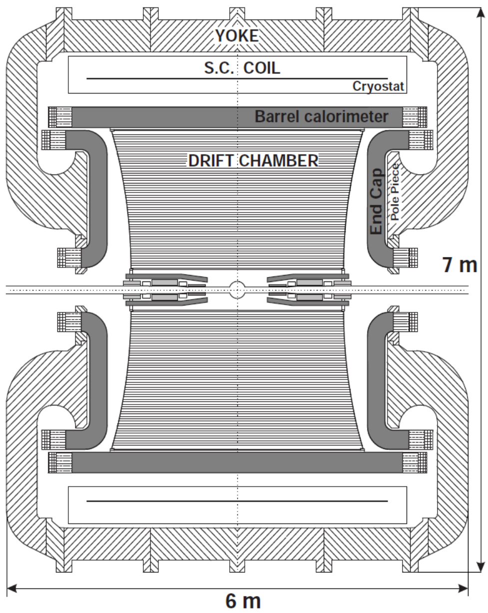

Figure 2: Section of the KLOE detector along the x-z plane.

The DC [12] has an inner radius of $0.25\,m$, an outer radius of $2\,m$, a length of $3.3\,m$ and is centered in the beam interaction point. The whole DC support structure is made of carbon fiber. The chamber is uniformly filled with 12582 drift cells, organized in coaxial layers (12 inner and 46 outer). The gas mixture filling the chamber is composed 90% in volume of ^4He and 10% of C_4H_{10} (Isobutane). The chamber is characterized by excellent position and momentum resolutions. Tracks are reconstructed with a resolution in the transverse $R-\phi$ plane $\sigma_{R\phi} \sim 200\,\mu m$ and a resolution along the z-axis $\sigma_z \sim 2\,mm$. The transverse momentum resolution for low momentum tracks ($(50 < p < 300)\,MeV/c$) is $\frac{\sigma_{p_T}}{p_T} \sim 0.4\%$.

The KLOE calorimeter [13] is composed of a cylindrical barrel and two endcaps, providing a solid angle coverage of 98%. The volume ratio (lead/fibers/glue = 42:48:10) is optimized for a high light yield and a high efficiency for photons in the range $(20-300)\,MeV/c$. The average density is $5\ g/cm^3$ and the radiation length is $X_0 \sim 1.5\,cm$.

3. Evidence of an in-flight component

In the events occurring in the DC gas or in the DC entrance wall it is possible, thanks to the excellent KLOE resolution, to identify a subsample of K^- interacting on the hydrogen contained both in the DC entrance wall and in the gas. Let's consider the reaction $K^- p \rightarrow \Sigma^+ \pi^-$; from energy and momentum conservation it immediately follows that $|P_{\Sigma^+\pi^-}| = |P_{K^-}|$; this implies that a measurement of the momentum of the final $\Sigma\pi$ pair is a direct indication of the momentum of the interacting kaons. In the case of in-flight events, this momentum is the production momentum of the kaons ($P_{K^-} \simeq 127\,MeV/c$) after the energy loss by the crossing of the beam pipe and DC entrance wall. In Fig. 3, the 2D plots of the kinetic energy versus the momentum of the final pair for MC simulations of both at-rest and in-flight reactions are shown.

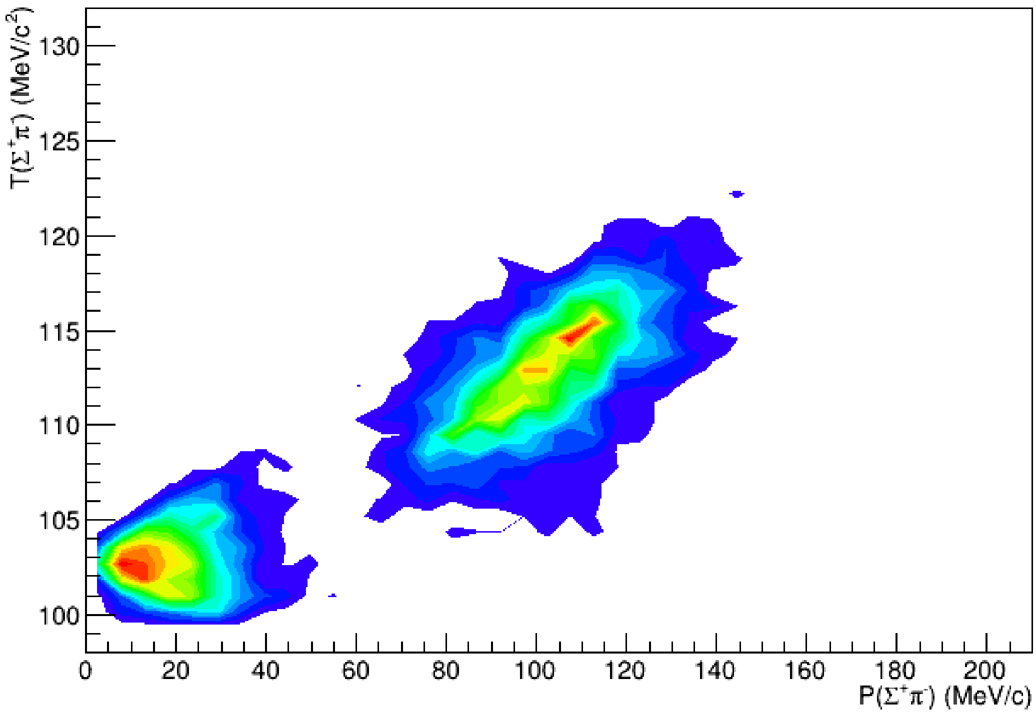

Figure 3: Momentum VS kinetic energy of the $\Sigma^+\pi^-$ pair produced in hydrogen for MC in-flight and at-rest events. The two event subsamples are clearly separated and can be then identified.

According to these MC simulations, is then possible to identify, if present, events where the momentum of the interacting kaons is not zero; in Fig. 4 the same plot is presented for the data (up) together with the plot of the final $\Sigma\pi$ momentum (bottom).

It has to be noticed that the at-rest peak is not loacated at zero momentum, as one could expect; this spread is due to the momentum resolution of the $\Sigma\pi$ pair around $15\,MeV/c$. These spectra, confirmed also for interactions occurring in ^4He and ^{12}C, represent the clear proof of the simultaneous presence of at-rest and in-flight events and open the door to the unique possibility to explore higher invariant mass region, not accessible untill now in experiments using kaons.

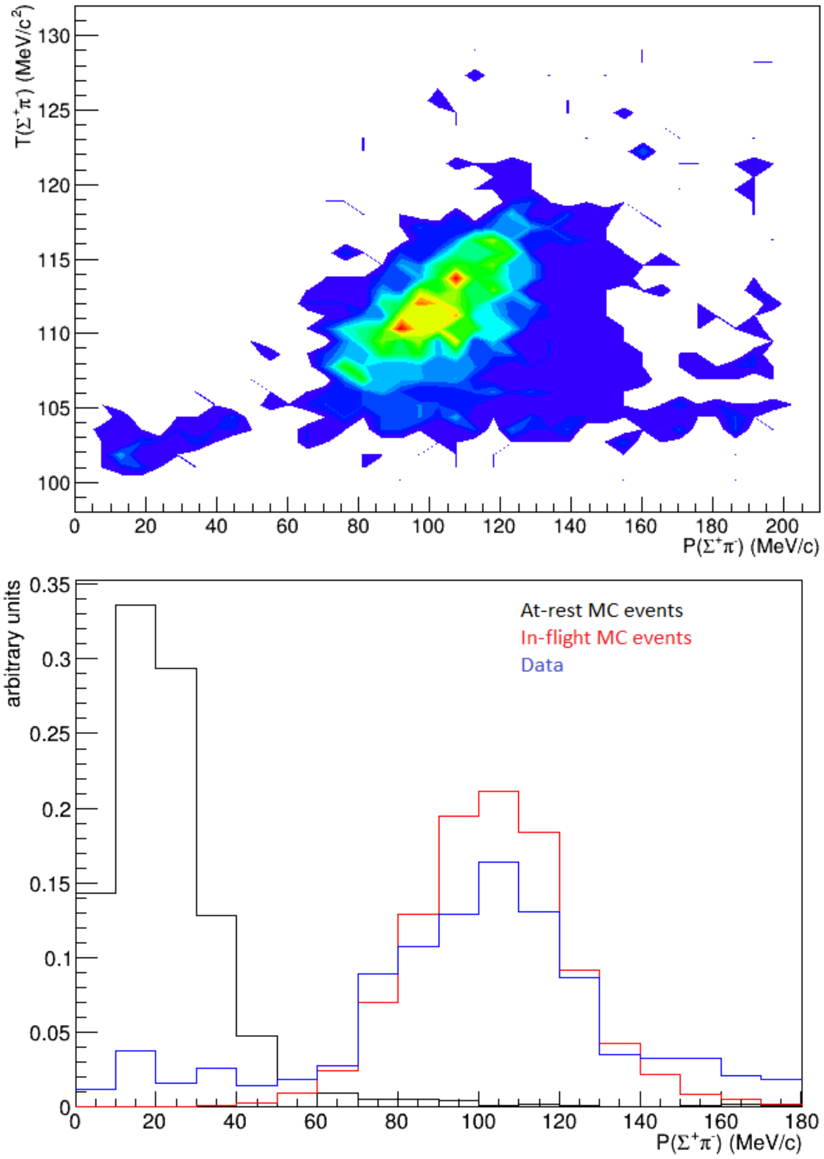

Figure 4: Momentum VS kinetic energy of the $\Sigma^+\pi^-$ pair (up); $P_{\Sigma^+\pi^-}$ for MC at-rest events (black), MC in-flight events (red) and data (blue) (bottom).

4. Conclusions

In this work we successfully investigated the possibility to study both in-flight and at-rest $\bar{K}N$ interactions with the KLOE detector at DAΦNE in the framework of AMADEUS, finding evidence of two components in the events sample occurring on hydrogen present in the DC; this feature has been also confirmed in events occurring on carbon and helium. This results open the possibility to study the controversial nature of the $\Lambda(1405)$ resonance, and to finally solve the puzzle between its single or double pole structure. These studies are presently undergoing for all the $\Sigma\pi$ decay channels of the $\Lambda(1405)$.

Acknowledgements

We would like to thank Fabio Bossi, Stefano Miscetti, Erika De Lucia, Antonio Di Domenico and Vincenzo Patera for the guidance and help in performing the analyses. We thank as well Antonio De Santis for his support and all the KLOE Collaboration for the fruitful collaboration. Part of this work was supported by the European Community-Research Infrastructure Integrating Activity "Study of Strongly Interacting Matter" (HadronPhysics2, Grant Agreement No. 227431, and HadronPhysics3 (HP3) Contract No. 283286) under the Seventh Framework Programme of EU.

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