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AMADEUS PHASE-1: PHYSICS, SETUP AND ROLL-IN PROPOSAL

The AMADEUS Collaboration

Abstract

A proposal for the Phase-1 of the AMADEUS experiment at DAΦNE is presented. It includes the physics goals, the setup design, the Monte Carlo simulations and the luminosity requests; a roll-in proposal is also put forward.

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1 Introduction

The scientific case of the so-called "deeply bound kaonic nuclear states" (dubbed as well "kaonic nuclear clusters") is hotter than ever, both in the theoretical and experimental sector. While from theoretical point of view there are theories advocating the existence of deeply-bound kaonic nuclear clusters, with binding energies, for the case of K^-ppn for example, as large as 100 MeV, there are papers claiming that such deeply bound states do not exist. The few existent experimental answers are not free of ambiguities either: some early experimental findings were not confirmed (KEK), while FINUDA experiment at DAΦNE continues to find possible signatures of deeply bound states.

What emerges is the strong need for a complete experimental study of the scientific case, i.e. a clear and clean experiment, measuring kaonic clusters both in formation and in the decay processes. As clearly shown in the AMADEUS Letter of Intent [1], the AMADEUS experiment represents the answer to this request. AMADEUS plans to perform the first dedicated, full acceptance, high resolution measurement of kaonic nuclear clusters in formation and decay processes, at the upgraded-DAΦNE facility, using the K^--stopped processes by implementing the KLOE detector in the central region with a dedicated setup.

We present in this document a proposal for the construction and installation of the so-called AMADEUS PHASE-1, as well as the physics program and luminosity requests. The Phase-1 of the experiment has the aim to give a definite answer to the question of the existence of the K^-pp , K^-ppn and K^-pnn kaonic nuclear clusters and to measure their properties (binding energies, width and decay channels). At the same time, processes from "classical kaonic-nuclear physics", such as the dynamics of two- and multi-nucleon absorption by stopped K^-, will be investigated either for the first time or in order to obtain more accurate results than those few reported in the literature. Cross sections, branching ratios, rare hyperon decay processes and $\Sigma - \Lambda$ conversion in nuclei will be studied, taking advantage of the unique kaon-beam quality delivered by DAΦNE and of the unique characteristics of the KLOE detector. This Phase-1 will be then followed by a second phase (after 2010) in which more detailed and accurate measurements, with higher statistics, will be performed, both for the already measured states and for other types of nuclei.

The roll-in proposal for AMADEUS Phase-1 will be also put forward. The requests and the time schedule are fully compatible with the DAΦNE upgrade scheme and take into account the plans of the SIDDHARTA and the KLOE-2 experiments.

SIDDHARTA will start working after the completion of the machine upgrade, with a progam that extends up to the second half of 2008. Recently, KLOE-2 [2] put forward a proposal for the roll-in late autumn 2008. The AMADEUS plan is to install the Phase-1 experimental setup at the end of the first period of data taking of KLOE2, presumably late 2009, and to take data for an integrated luminosity up to about $4fb^{-1}$, so tentatively until autumn 2010.

We briefly present in the section 2 the scientific case of AMADEUS Phase-1; section 3 introduces the experimental setup, while in section 4 Monte Carlo simulations for this setup are presented. Section 5 summarizes the luminosity requests and presents the roll-in plan, while the future AMADEUS plans, post Phase-1, are briefly discussed in section 6. The conclusions, in section 7, finalize the report.

2 The scientific case for AMADEUS Phase-1

In what follows we shall briefly present an update of the deeply bound kaonic nuclear states (DBKNS) scientific case, from theoretical and experimental point of views; then we shall discuss the scientific case of AMADEUS Phase-1, which integrates the case of DBKNS with other items of the strangeness nuclear/hadronic physics.

2.1 The deeply bound kaonic nuclear states

The study of the deeply bound kaonic nuclear states, the confirmation or denial of their existence, is a hot topic nowadays in hadronic physics that has became even hotter in the recent two years, not suprisingly, since they might be the ideal scenario for the study of the modification of the hadronic masses inside the nuclear medium with all deriving consequences.

Although such states were predicted by Wycech [3] some time ago, only recently the availability of experimental facilities (KEK, FOPI and DAΦNE in particular) for studying these kind of exotic nuclei, has delivered first experimental results which triggered a vivid discussion, initiated with the publication of the paper by Akaishi and Yamazaki [4], where a phenomenological $\bar{K}N$ potential is formed in a way that reproduces the experimental data from kaonic hydrogen [5] and scattering lenghts experiments [6], and considers the Λ(1405) resonance as a $K^{-}p$ quasi-bound state. This is made assuming a nuclear medium dependence of the isospin I=0 $\bar{K}N$ real amplitude at the Λ(1405), since, from the experimental data previously cited, the interaction is known to appear "repulsive" at threshold in free space. A strongly attractive $\bar{K}N$ interaction in nuclear matter favors the existence of nuclear bound states of kaons in nuclei, while contracting the core of the resulting kaonic nucleus, producing a cold and (rather) dense nuclear system.

The binding energies for such exotic nuclear systems may be large (100 MeV) and their widths, consequently, rather narrow due to the unavailability of the $\Sigma\pi$ decay channel.

The possible formation of a deeply bound kaonic nuclear state could provide information concerning the modification of the kaon mass and of the $\bar{K}N$ interaction in the nuclear medium, with many important consequences in hadronic and nuclear physics, with astrophysics implications on the formation and evolution of compact stars. Nuclear dynamics under extreme conditions could be also investigated.

Since the 2002 Akaishi's and Yamazaki's paper, however, many things have happened - an intense dabate is ongoing, which needs clear and complete experimental results, the very aim of AMADEUS.

A brief introduction to the debate (not complete, since "earth is moving under our own feet") is given in the next subsection.

2.2 Theoretical debate around the deeply bound kaonic nuclei case

Currently, the intense theoretical debate undergoing shows even more the importance of the AMADEUS physics case and reinforces the need to perform it in the near future.

There exist, actually, several different theoretical approaches to the problem, bringing arguments either for, or against the existence of the deeply bound kaonic nuclear states. The already presented phenomenological description of the $\bar{K}N$ potential by Yamazaki and Akaishi, reiterated lately [7], predicting deeply bound states, has been recently confirmed in the framework of the Skyrme model [8], also predicting high binding energies for the ppK^- state.

On the other hand, a different many-body calculation, taking into account the two-nucleon absorption process, leads to potentially non-observable states with small binding energies and large widths [9]. This last approach explains the already produced experimental evidences in terms of Final State Interactions [10].

In between the two extremes of the theoretical debate, there are predictions of shallower potentials than those which lead to the kaonic clusters: the 3-body Faddeev calculations [11] predict deeply bound states only in heavy systems; as well as it does a treatment using density dependent potentials [12].

As stressed recently by Weise in an overview paper of the scientific case [13], from the theoretical point of view, in order to have a clear assessment on the possible existence of the deeply bound kaonic nuclear clusters, one needs to use (know):

- Realistic $\bar{K}N$ interactions
- Realistic NN interactions
- Realistic $\bar{K}NN$ absorption

In that paper it is concluded that the K^-pp system might be not so deeply bound as originally thought - and the decay width, consequently, large enough such as to make it very difficult to experimentally detect. Deeply bound kaonic nuclear states in heavier systems might however exist, with large widths. The need for clean and complete experimental results is stressed in this work.

Let us remark, in the closure of this subsection, the most common thought of theoreticians working in the field, quoting a recent paper overviewing the status of the problem, from A. Gal [14]: "It is clear that the issue of $\bar{K}$ nuclear states is far yet from being experimentally resolved and more dedicated, systematic searches are necessary".

Having briefly presented the theoretical status, let's now see which is the experimental situation.

2.3 Experimental status overview

From the experimental point of view, several approaches have been followed, bringing to first experimental results in the field. More dedicated experiments are planned at upgraded or upcoming machines.

The first studies were made using the missing mass spectroscropy in the process generated by a stopped K^- in a liquid helium target in KEK [15][16], in which indications for the existence of deeply bound (BE more than 150 MeV) tribaryonic states K^-ppn and K^-pnn were found, although the second was lately withdrawn [17], arguing an experimental artifact. Using the same spectroscopy thechnique, (K^-,n) reactions in-flight on a water target were studied at BNL-AGS [18], indicating again a possible strong attractive interaction.

FINUDA experiments performed at DAΦNE using K^- stopped technique in various targets is analyzing the recently collected data during the 2006-2007 run; it has already published the signal of a K^-pp state [19] from Λp invariant mass spectroscopy, and K^-ppn from its Λd decay [20] from a previous run performed in 2003. Also with the invariant mass spectroscopy, heavy ion collision generated DBKNS were studied at FOPI [21], where indications of a strange tribaryon DBKNS might have shown up. The E549 experiment performed at KEK in 2005 is studying, with larger statistics, the previously seen K^-ppn signal [22].

In parallel, data from older, not dedicated, experiments were re-analyzed, as in the case of OBELIX (performed at CERN), claiming the existence of K^-pp DBKNS in the $\bar{p}$ ^{4}He annihilation at rest [23], or analyses of pp, pC processes in propane bubble chamber at Dubna [24].

What emerges, however, is an experimental status of the DBKNS search with few, low statistics and not complete results, which are, rightly, not easy to be attributed to a DBKNS interpretation, since other scenarios (Final State Interaction, just to name one) cannot be excluded. From here the need to perform in the future new dedicated experiments, which should attack the DBKNS search both in formation and in the decay processes, as completely as possible. Such experiments have to solve the DBKNS puzzle, and, for sure, will have implications in hadronic and nuclear physics, as well as in astrophysics. These new, dedicated planned experiments are: E15 at J-PARC (starting from 2009 [25]) with K^- induced reactions in flight, a new FOPI run, with a dedicated forward detector, from nucleus-nucleus, proton-proton and proton-nucleus collisions at GSI, and, of course, AMADEUS at an upgraded DAΦNE.

In the next subsection we shall present the AMADEUS Phase-1 scientific aim.

2.4 AMADEUS Phase-1 scientific aim

AMADEUS's main aim is to perform the first full acceptance, high precision measurement of DBKNS both in formation and in the decay processes, by implementing the KLOE detector with an inner AMADEUS-dedicated setup, containing a cryogenic target and a trigger system, which will be presented in the next Section.

In Phase-1, AMADEUS plans to perform DBKNS search in the process of K^- stopped in high-density gaseous ^{3}He and ^{4}He targets, in order to search for strange di-(K^-pp) and tri - baryon (K^-pnn, K^-ppn) DBKNS and to measure their binding energies and their widths. The processes for the case of a ^{4}He target are shown in Fig. 1.

Based on the very good performance of the KLOE detector to measure charged and neutral particles (more detailed discussion in next Section) it is expected that at the end of Phase-1, after having integrated a luminosity of about 4 fb^{-1} (see Sections 4 and 5) a definite answer will be given to the question related to the existence of DBKNS in light-systems, and, if existent, their parameters will be measured. Possibly further indications related to the spin-orbit splitting and quantum numbers might emerge.

After this first phase, a second phase of AMADEUS will follow (after 2010), with an upgraded setup and with a higher luminosity request, in order to refine the study for light targets and to complement it for heavier targets, so as to have a complete and systematic spectroscopy of DBKNS along the periodic table.

Beyond the main goal of AMADEUS, based on the excellent performance of the KLOE/AMADEUS detector, we plan to perform other more "classical" measurements, by no mean less important. Such measurements are being longly awaited and are extremly important in hadronic physics and, as we shall briefly mention, in astrophysics. We dedicate the next subsection to these measurements, dubbed "enriched AMADEUS

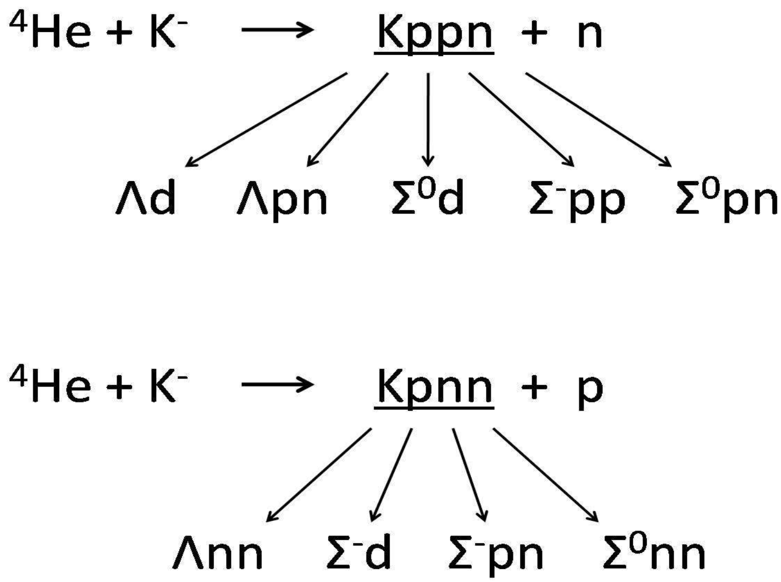

Figure 1: Kaonic tribaryonic clusters formation and decay channels in K^- stopped in ^{4}He processes.

case".

2.4.1 The enriched case of AMADEUS

In parallel to the search of the deeply bound kaonic nuclear states, AMADEUS will be able to perform first class measurements on low energy K-nucleus interaction and on hyperon physics, out of which we mention:

- Low-energy charged kaon cross sections on Helium (3 and 4), which could be nicely determined at momentum lower than 100 MeV/c; such experimental data are completely missing today and they are badly needed by any theory dealing with low-energy strangeness physics, since studies of two- and multi-nucleon absorption including their dynamics are of special importance. Gas in the target can be changed, if it turns out to be interesting, to hydrogen and deuterium for short, dedicated runs.

- The K^- nuclear interactions in Helium will copiously produce hyperons. Such hyperons can be studied in order to obtain various types of information: for example, the analysis of pion-hyperon mass spectra will allow to study the s-wave interefer-ence with the p-waves.

- Related to the above item, a key role in astrophysics (cooling of compact stars) is played by the decays of $\Lambda(1116)$ and charged-Σ in channels with neutrino. The Branching Ratios of these channels might be determined at a more precise level than the present one by AMADEUS.

- Resonance states as the elusive-in-nature but so important Λ(1405) or the Σ(1385) could be better understood with high statistics; their behaviour in the nuclear medium can be studied too.

Part of these measurements need dedicated data (with moderate luminosity request).

3 The AMADEUS Phase-1 experimental setup

From a detailed study of the expected formation and decay processes of the tribaryonic states shown in Fig. 1, one can infere which are the ideal characteristics for the detector optimized to do such a measurement. Such a detector, in our case identified already at the level of the the LOI [1], with KLOE implemented in the central region with a dedicated setup, fulfills the following requirements:

- 4π acceptance in order to suppress possible kinematical biases;

- high efficiency of reconstruction for charged particles that should cover a wide momentum spectrum. Capability for tracking particles from the formation and decay of the exotic clusters, and from hyperons disintegration processes involved in the chain;

- good momentum and vertex reconstruction resolutions to perfom invariant mass spectroscopy;

- capability to detect neutrons in a broad momentum range and other neutral particles (photons) with good efficiency (and resolution);

- high density gaseous target (filled with helium) where to stop as many negative kaons as possible;

- implementation of a trigger/tag system giving the number of kaons entering the target.

Protons and neutrons from the formation process should be detected in a range of momentum from 200 to 500 MeV/c, and the decay products, including the secondaries from hyperon decays, should cover a much wider spectra, up to 800 MeV/c. The capacity of the detector to resolve these kind of particles and to reconstruct the relative vertices, is very important, considering the background generated by "classical" nuclear interactions of the kaons in Helium. The high efficiency for charged particles of KLOE will play a crucial role in the measurement, as well as the recently proved capability of neutron detection with high efficiency, that has been reported by the KLOnE experiment after sucessful test measurements performed at TSL [26].

Lately, the KLOE detector capability to reconstruct hyperons with a very good resolution, ideal for DBKNS studies, and important for the enriched AMADEUS case, was proven by AMADEUS in analysing the existent KLOE data, as shown in the next subsection.

3.1 KLOE detector capability to reconstruct hyperons

One of the first output of the fruitful collaboration between the AMADEUS and the KLOE groups has been the results of the analysis of a sample of the 2005 KLOE data searching for hadronic interactions of the K^- in the ^{4}He gas of the KLOE Drift Chambers [27].

Previous to the start of AMADEUS, it was put forward to KLOE in 2006 the proposal to start searching for possible kaonic nuclear clusters produced in the helium gas filling the Drift Chamber volume already present in the 2 fb^{-1} existent KLOE data. After a Monte Carlo simulation study, performed with the KLOE Monte Carlo program, showing the potential presence of a considerable amount of hadronic interactions inside the helium volume, AMADEUS started dedicated analyses on 400 pb^{-1} of KLOE real data. The strategy is focused on the identification of possible specific decay products of the kaonic nuclear clusters: specifically into channels containing the $\Lambda(1116)$ hyperon, present in most of the expected decay channels of the bound states, which was identified through its decay to the proton and negative pion channel, which happens in 64% of cases.

We relied on KLOE vertex reconstruction, searching for vertices with opposite charged particles. The negative track, a negative pion candidate, is searched among those with low dE/dx in the drift chamber. For the positive tracks, since protons are expected to leave the DC volume, an associated cluster on the EMC with low energy deposit is required for high momentum tracks. The protons selected with this procedure show as well a nice "proton signature" in the confrontation of the track momentum with the dE/dx in the chamber wires. This signature is required as well for positive tracks without any associated EMC cluster, although long enough to potentially reach the EMC. These correspond to slow protons that does not release enough energy to generate a signal in the calorimeters. The dE/dx dependency on the momentum is used to add to the selection these slower energy protons.

The signal shape in the invariant mass spectrum for the selected pairs is shown in Fig. 2. It is splitted in two subsamples: events with vertex position in the radial projection fulfilling the condition: $\rho_{vertex} > 28$ cm corresponding to Λ tentatively produced and decayed in the Drift Chambers volume; and events with vertices fulfilling the condition: $\rho_{vertex} < 28$ cm, corresponding to Λ produced in the DC inner wall. The Λ momentum spectra - which is related with the underlying physics - can be seen also inserted in the correspondent pictures. The latter have been added due to the nice and important first hand physics which might be done with kaons stopping in Carbon (main component of DC entrance wall), as for example the behaviour of the $\Sigma(1385)$ mass in a nuclear enviroment [28].

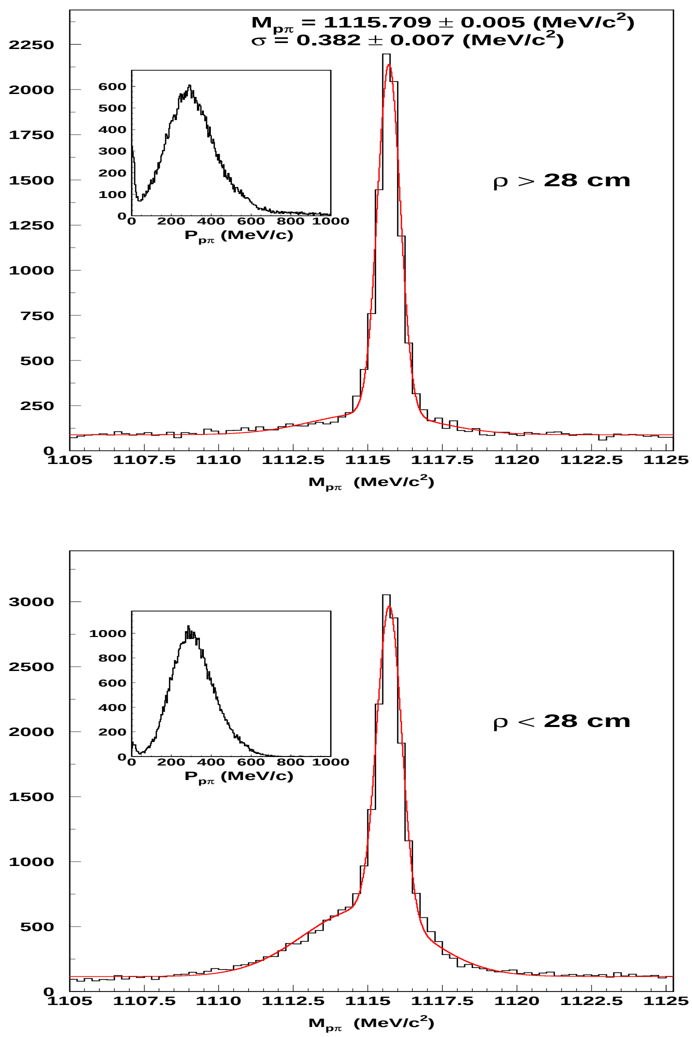

Figure 2: Λ invariant mass reconstruction for $\rho_{vertex} > 28$ cm (top) and $\rho_{vertex} < 28$ cm (bottom). The Λ momentum is shown as well in the insert.

In the figures, a fit was performed to the central region of the invariant mass spectra. The fitting function contains a gaussian distribution for the signal with the flat background described by a constant. In the bottom plot, for events produced in Carbon, a third component appears as an asymetric tail on the left side of the signal. This component is due to Λ events which have the pions and/or protons loosing energy in the DC wall and consequently, shifted towards a lower invariant mass and are fitted using a second gaussian at the left of the main peak. The fit results, reported in the figures, show a resolution of σ = 0.38 $\pm$ 0.01 MeV/c^2. We selected a total amount of $\sim 37{\times}10^3$ Λ events for the 400 pb^{-1} integrated luminosity collected. The number of events and the quality of the signal opens the door for studies of many hadronic physics hot topic items, including, of course, the DBKNS ones.

The KLOE data analyses is undergoing, in the search for DBKNS. For what concerns AMADEUS and the present proposal, what matters is the **excellent** capacity of KLOE to measure hyperons, not only deduced, but experimentally proved.

Combined with the capacity of KLOE calorimeter to measure neutrons, this insures the necessary conditions for AMADEUS to do the first complete experimental study of DBKNS ever performed.

3.2 AMADEUS Phase-1 technical design

In order to be able to perform the dedicated measurements of DBKNS reported in Section 2.1, we need to implement the KLOE detector in the central region (in the hole inside Drift Chamber) with a dedicated setup containing:

- a cryogenic target where to stop as many kaons as possible - so to enhance the formation of DBKNS;

- a trigger system, triggering on charged kaons entering the target, in order to reduce the DAQ rate possibly only for processes generated by charged kaons.

For this phase of the experiment we do not plan to use an inner tracker detector, which will be, however, implemented in the second phase of AMADEUS (see Section 6).

Such a setup has, moreover, to be compatible with the new Interaction Region of the DAΦNE accelerator, as upgraded in 2007. We present in Fig.3 the overall AMADEUS Phase-1 setup, where the Interaction Region geometry and elements are very similar to the ones present in SIDDHARTA.

As seen in the figure, in the space left free inside the Drift Chamber we will install a half-cylinder cryogenic target and a trigger system based on scintillating fibers. In what follows more technical details will be given.

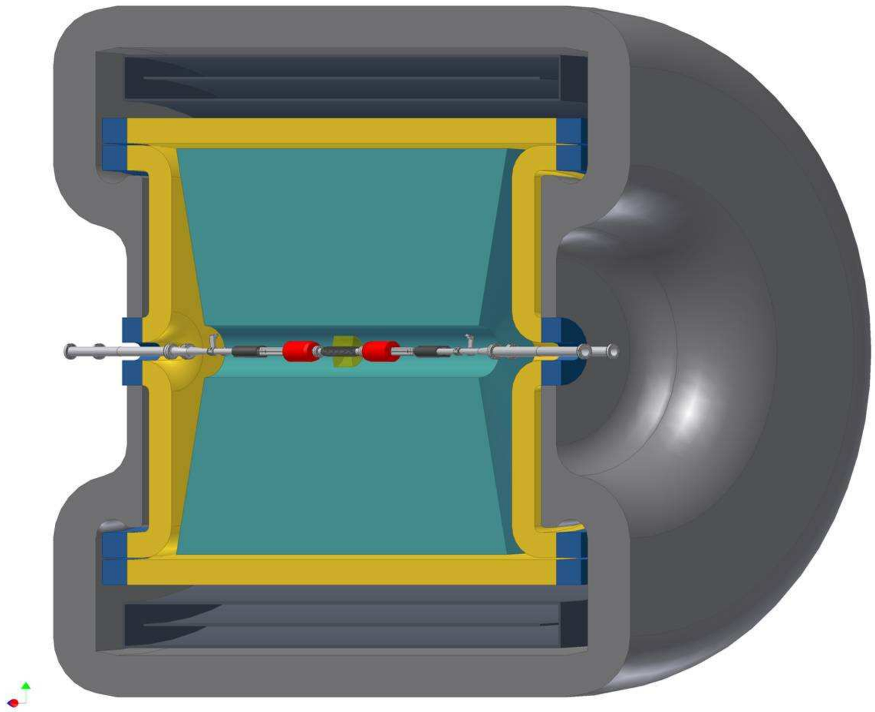

Figure 3: The AMADEUS Phase-1 setup implemented in KLOE in the DAΦNE upgraded interaction region.

3.2.1 The AMADEUS cryogenic target

A detailed view of the central AMADEUS region is shown in Fig. 4.

The cryogenic target of AMADEUS has semi-toroidal shape, with inner radius of 5 cm and the outer one of 15 cm; the length is 20 cm. This target should be low-mass, in order to allow the particles to come out as much as possible undisturbed - for future measurements to be performed in DC and EMC of KLOE detector.

It will be built by a 100 μm plastic (kapton) layer reinforced with a structure done in carbon fibers, very similar to the one used for the SIDDHARTA cryogenic target [29].

The target will be filled with high density cryogenic gas, ^{4}He or ^{3}He, 10 K temperature and 1-2 bar pressure, so to have a density high enough to stop most of the K^- entering the target. A prototype of the target is under construction and is going to be tested in the first half on 2008.

It has to be mention that the AMADEUS group has a long, worldwide recognized, experience in designing, building and operating such cryogenic targets.

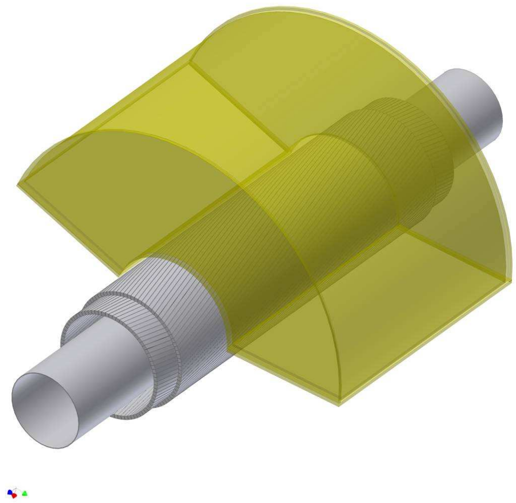

Figure 4: The AMADEUS Phase-1 cryogenic target and trigger system in the KLOE detector central region.

3.2.2 Kaon trigger system

We plan to use a kaon trigger system around the beam pipe, before the target entrance window, which should allow to reduce the background at the DAQ level. Such a system should be able to:

- trigger on the back-to-back topology of the process in which charged kaons are generated;
- be fast;
- work in the magnetic field of KLOE;
- be small - i.e. capable to be installed in the reduced space at disposal;
- be integrated in the overall KLOE DAQ and Slow Control schemes (for AMADEUS runs).

We are studying a trigger detector based on the technical solution of scintillating fibers read by APDs. The plan is to build a trigger system containing 2 layers of scintillating fibers with dimensions of individual fibers: length 30 cm; radial direction dimension 1 mm; width 2 mm, read out at both ends by APDs. The two layers should have radius of

4 and 4.5 cm, and a stereo angle of 30 degrees. The planned trigger system is shown in Fig. 4.

An additional view of the central region of AMADEUS Phase-1 is shown in Fig. 5. A prototype of the trigger system is being built and will be tested in early 2008 at the BTF facility of LNF.

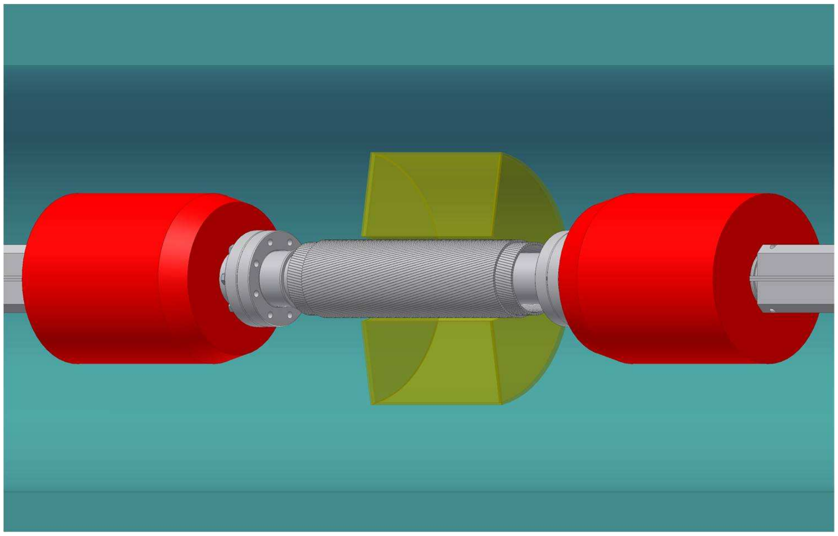

Figure 5: The AMADEUS Phase-1 setup: central region, detail.

3.3 Technical items needing special attention

Implementing the dedicated AMADEUS Phase-1 setup inside KLOE requires not only to design and built the necessary AMADEUS items (target, trigger system) but requires as well special attention to other technical items which are concerning either the interaction with KLOE or/and the one with DAΦNE.

Such items are:

- The beam pipe: the beam pipe of AMADEUS is different from the KLOE one (AMADEUS does not need a spherical beam-pipe); we plan to develop together with KLOE and DAΦNE a beam pipe technical solution which should be easy to extract/implement. Special attention will be dedicated to the mechanical supports.

- Cryogenic target: we are performing dedicated studies not only for the target itself, but for its mechanical supports and cooling power needed, as well as to how to bring the cryogeny inside.

- Trigger system: we study a technical solution for the trigger system, including the optimization of geometry and cablings bringing in/out signals.

- Slow controls: we study the slow control system (to be complemented to the KLOE one) for the specific AMADEUS items.

- DAQ: software and hardware. We are aware and started already to collaborate with KLOE on the item of DAQ needs, from software and hardware points of view. While it is rather clear that we will rely on KLOE solution for the software, eventually developing dedicated on-line and (mostly) off-line analyses and Monte Carlo simulations, the hardware should be care of AMADEUS, with expertize from KLOE.

4 Monte Carlo AMADEUS Phase-1 simulations

A dedicated Monte Carlo simulation for AMADEUS Phase-1 has been developed in the framework of the AMADEUS collaboration. The program is based on GEANT 3.21 package and implements the AMADEUS geometry presented in the previous Section.

A Monte Carlo drawing of the setup - its central region - is shown in Fig. 6.

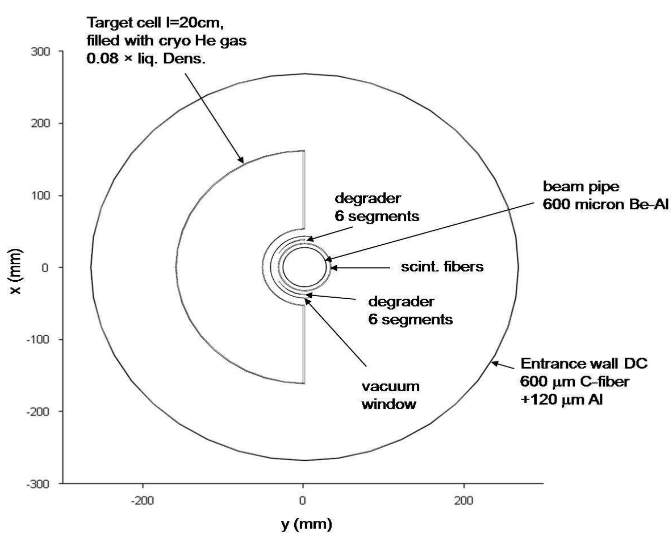

Figure 6: Monte Carlo drawing of the central region of AMADEUS Phase-1 setup.

The simulation reproduces as much as possible the geometry and the beam parameters, in particular the crossing angle of about 55 mrad (generating a boost). The target was positioned on the lower-momentum kaons side (anti-boost), so as to have the positive kaons on the side with higher boost, which allows these kaons not only to be detected by the AMADEUS trigger system, but to arrive and to be detected by KLOE DC (giving additional handle in selection of processes induced by negative kaons in the AMADEUS target detecting decayed positive kaons in DC opposite to AMADEUS).

The target was filled with 4He gas at a density of 0.08 liquid density (corresponding to 2 bar pressure at 10 K temperature); a degrader system was optimized (entrance of target) - such as to have as many kaons stopped in the target as possible.

With this geometry ϕ-decay processes, with a 20 MeV/c boost in opposite direction with respect to the target, were generated.

The stopped K^- inside various materials were recorded, with special attention to the fraction of stopped kaons inside the gaseous target. Such fraction is 20% of the overall number of generated kaons, corresponding to more than 70% of the kaons arriving at the target.

The distribution of the stopped kaons inside the setup is shown in Fig. 7

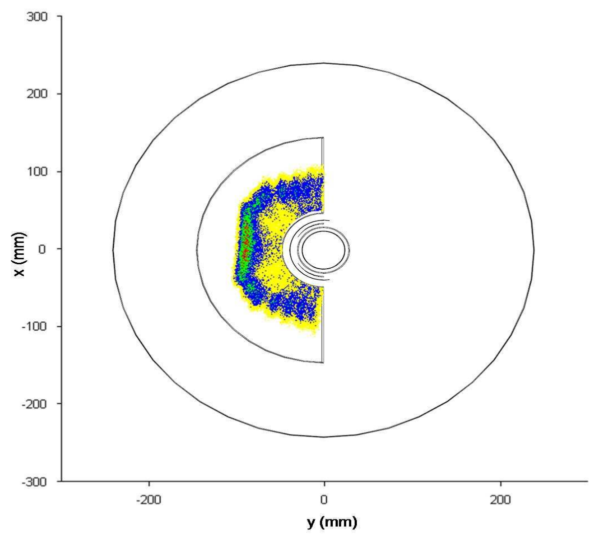

Figure 7: K^- stopped distribution inside AMADEUS.

Further on, for each stopped kaon we generated a DBKNS according to the processes shown in Fig. 1. Notice that, as an example, the binding energy considered and the width of the DBKNS were 120 and 24 MeV respectively. The momentum distributions of each particle was recorded and are shown in Fig. 8.

It is clear from the figure that AMADEUS implemented in KLOE is able to detect such particles; of course clever solutions should be found to disentangle the real DBKNS signal from the kaon-induced nuclear reactions leading to productions of hyperons which

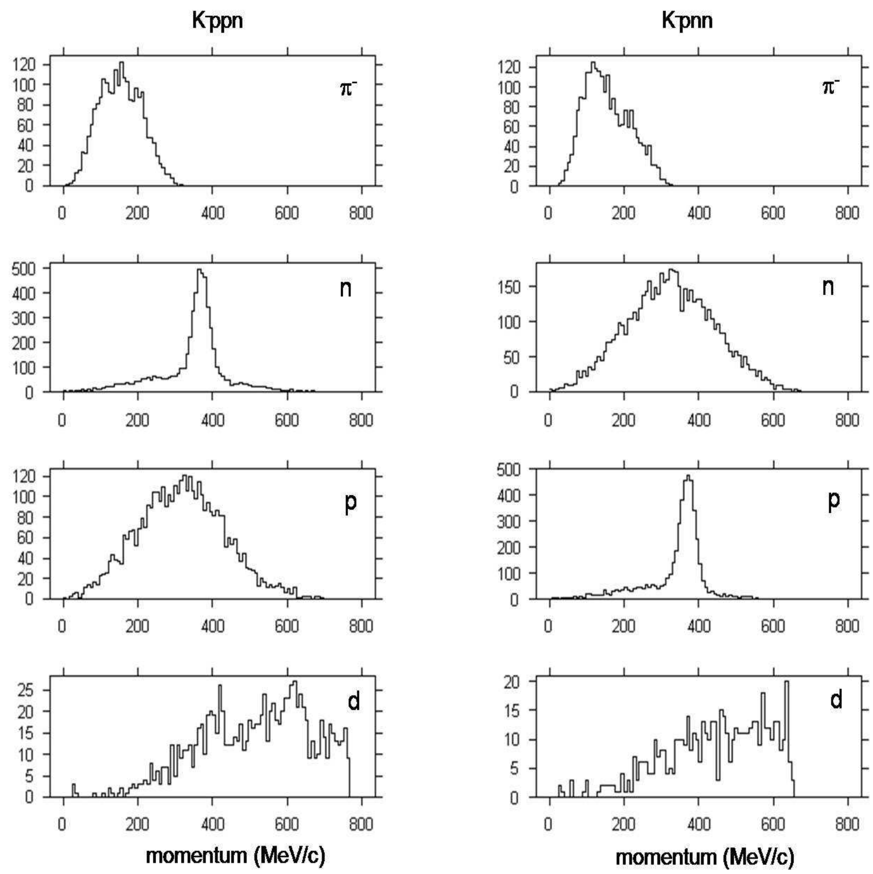

Figure 8: Momentum distribution of particles coming from the DBKNS formation and decay processes.

are not related to DBKNS production. We are confident in learning more about these type of processes from the present KLOE data analyses. The Monte Carlo simulation program is being implemented with these processes in order to find the way to disentangle DBKNS from other processes.

The present Monte Carlo program will be further on implemented with the KLOE MC (as far as geometry and physics processes are concerned), in order to have an overall KLOE/AMADEUS MC simulation program.

Based on these Monte Carlo calculations, we present in the next Section the luminosity requests for AMADEUS Phase-1, together with an implementation and roll-in schedule.

5 Luminosity request, implementation plan and proposal for the roll-in

The physics program for AMADEUS Phase-1 will be based on the study of the dibaryonic and tribaryonic states on ^{3}He and ^{4}He targets, as discussed in Section 2.

Let's now calculate, based on the Monte Carlo simulations presented in the previous section and on some "educated guesses", the number of DBKNS which are potentially measurable by AMADEUS, and based on which we shall put forward a luminosity request for AMADEUS Phase-1. In order to do this, we will pay particular attention to the so-called "golden channel":

$$K^- +^4 He \rightarrow (K^- ppn) + n$$

$$(K^- ppn) \rightarrow \Lambda + d$$
$$\rightarrow (p + \pi^-) + d$$

We start with an integrated luminosity of 2 fb^{-1}, and make the assumptions of a yield of DBKNS formation of 0.1% with a decay BR in the Λd channel of about 10% (with Λ decaying to $p\pi^-$). Then we should obtain the following number of DBKNS events in this channel:

2 fb^{-1} x 3 μb x 0.5 (BR) x 0.2 (stopped) x 0.001 (yield) x 0.1 (Λd) = 60000 events

If one considers the detection efficiencies (estimated to about 20-40%) then we remain with a total number of 12000-24000 events in this golden channel. If we wish to supply these events with the missing mass technique, then we have to take into account the neutron detection efficiency, estimated to be about 30-40%, and then we remain with about 3000-10000 events for which both missing and invariant mass can be, in principle, reconstructed, allowing so to have a complete information regarding the formation and decay of DBKNS in light systems.

A similar number of events might be obtained for the other channels.

Based on the above calculations, the luminosity request for AMADEUS Phase-1 is:

- 2 fb^{-1} of integrated luminosity with He4 target in order to study the tribaryon DBKNS
- 1-2 fb^{-1} of integrated luminosity with He3 target in order to study the dibaryon DBKNS
- 0.5 fb^{-1} of integrated luminosity for low-energy kaon-nuclear dedicated measurements (see Section 2.4.1)

for an **overall integrated luminosity of 3.5 - 4 fb^{-1}** .

With the luminosity upgrade of DAΦNE, the machine should deliver at least 600 pb^{-1} per month, which means that the overall AMADEUS Phase-1 program could be completed in about 8 months (considering installation).

5.1 Implementation plan and roll-in proposal

In what follows an implementation plan for AMADEUS Phase-1 is presented, together with a roll-in proposal:

- **Cryogenic Target preparation:** a first prototype will be built and tested within 2008; the final target will be built and tested in the first half of 2009.

- **Trigger system:** a first prototype containing 20 fibers read at both ends by APDs, is being prepared and will be tested on BTF in early 2008; a second prototype, with greater dimensions and two layers , will be built and tested at BTF within 2008; the final detector will be designed and built within first half of 2009.

- **Beam pipe:** a mixed team KLOE-DAΦNE-AMADEUS will study this delicated item and will provide technical solution for the beam pipe and its mechanical support; the beam pipe for AMADEUS will be ready in the first half of 2009.

- **Monte Carlo simulations:** will be developed continuously in parallel with the preparation of the setup and in collaboration with KLOE.

- **Slow Control and DAQ (software and hardware):** will be done in collaboration with KLOE; work already started.

- **training to use KLOE detector:** AMADEUS group offers to participate - in modalities to be optimized and decided - to the first phase of KLOE installation and DAQ in 2009 (a MoU is being prepared).

- **AMADEUS assembly:** the AMADEUS inner setup - the specific one - will be assembled and tested in the second half of 2009 so as to be ready for:

- **roll-in of AMADEUS:** roll in at the end of 2009 - beginning 2010, compatible with KLOE end of first DAQ period.

- **AMADEUS DAQ:** for an integrated luminosity of about 3.5 - 4 fb^{-1}, in 2010.

6 AMADEUS Phase-2

After AMADEUS Phase-1 the matter of the existence of DBKNS will be potentially solved. If existent, AMADEUS will measure for di- and tri-baryon DBKNS the binding energies and their decay channels, performing measurements in formation and decay processes. Possible other indications related to the spectroscopy of these states will emerge (isospin splitting; quantum numbers; Dalitz-like plots...). In parallel, many kaon-nuclear interaction processes will be as well measured.

A second phase of the experiment will then have the aim to:

- Improve and complement the setup with different possible technical solutions, in order either to reduce the background and/or to perform more refined (better resolution) - dedicated measurements;
- eventually to install an inner tracker, inside the DC of KLOE: we are considering two possible solutions, either cylindrical GEM detectors or a TPC-GEM combination. This solution will be matter of collaboration with KLOE, since KLOE2 needs as well an inner tracker for the second measurements campaign;
- increase the statistics for di- tri-baryon DBKNS following the suggestions which will come out from Phase-1 of the experiment;
- study DBKNS produced in heavier targets as: Li, B, Be, C and beyond (we have seen their importance in Section 2);
- complete the physics program by:
  - determination of binding energies, decay widths and quantum numbers of all states, including excited ones,
  - measurement of the spin-orbit interaction,
  - determination of partial widths of kaonic nuclear states by observation of all decay channels,
  - following suggestions by Kienle, Akaishi and Yamazaki (ref), a Dalitz analysis of the 3-body decays of the kaonic nuclei will reflect the momentum wave functions and the angular momentum transfer, so one can study the size of kaonic nuclei and assign spin and parity to the decaying state,
  - obtain, as a by-product, informtion concerning the multi-nucleon absorption mode.

Such a second phase of the experiment will require an implementation and an upgrade of the setup; we preview an integrated luminosity request of about 10-20 fb^{-1}.

7 Conclusions

A proposal for the Phase-1 of the AMADEUS experiment at DAΦNE was presented. This phase has the goal to perform the first complete measurement ever (in formation and decay processes) of di - and tri-baryon DBKNS in Helium (3 and 4). It will give definite answers to the controversed item of the existence of DBKNS in light systems and measure their parameters. Other important measurements in strangeness hadronic/nuclear physics will be as well performed.

The AMADEUS Phase-1 setup implements the actual KLOE detector in the inner region with a cryogenic target and a trigger system. The technical items were clearly identified and a schedule for their construction and implementation put forward.

The luminosity request is of about 4 fb^{-1}, with a roll-in schedule to start at the end of 2009. It was estimated that the DAQ period should last about 8 months (for an upgraded DAΦNE delivering about 3 times the integrated luminosity per month achieved in the first half of 2007).

This phase will be followed by a second AMADEUS phase, in which AMADEUS will be implemented with an inner tracker and will perform higher statistics measurements in ^{3}He, ^{4}HE, and investigate DBKNS in heavier nuclei.

DAΦNE could become the only place in the world where such measurements (Deeply Bound Kaonic Nuclear States complemented with low-energy kaonic nuclei physics) could be performed in a complete and unambigous way, and this will be done by AMADEUS.

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