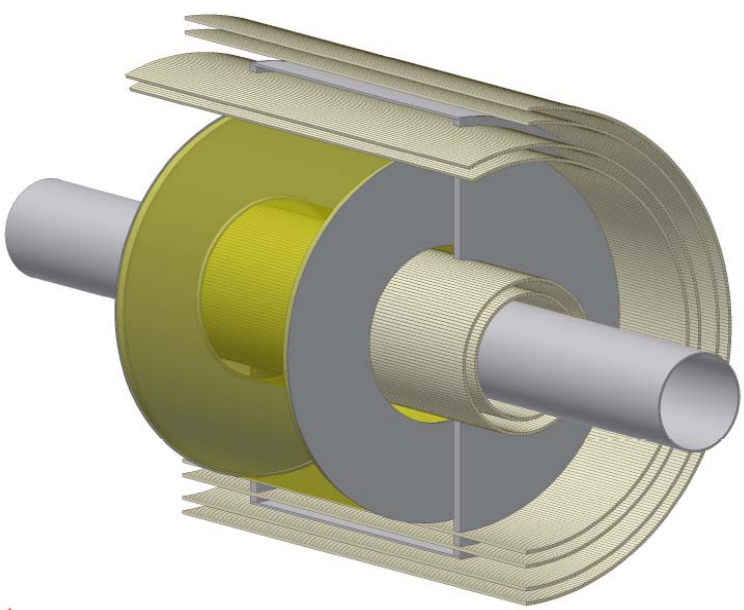
Letter of Intent

Study of deeply bound kaonic nuclear states at DAΦNE2

AMADEUS Collaboration



March 2006

Antikaon

Matter

At

DAΦNE:

Experiments with

Unraveling

Spectroscopy

111 scientists from 33 Institutes of 13 Countries listed below signed this Letter of Intent

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Quantum chromodynamics is conceptually simple. Its realization in nature, however, is usually very complex. But not always.

Frank Wilczek *"QCD made simple"*
Physics Today online, August 2000, Volume 53, Number 8, Part 1, pag. 22

From exotic atoms to exotic nuclei

Contents

Executive Summary

Scientific case

The scientific case on which is founded this Letter of Intent – study of deeply bound kaonic nuclear states - deals with one of the most important, yet unsolved, problems in hadron physics: *how the hadron masses and hadron interactions change in the nuclear medium and what is the structure of cold dense hadronic matter.*

Deeply bound kaonic nuclear states ($\overline{\mathrm{K}}$*-nuclear cluster*s) offer the *ideal conditions for investigating* the way in which the *spontaneous and explicit chiral symmetry breaking pattern of low-energy QCD changes in the nuclear environment.* The cold high-density nuclear matter of kaonic nuclear states could also provide information on a *transition from a hadronic phase* to a *quark-gluon phase,* with colour superconductivity. Therefore information on changes of *vacuum properties of QCD* and on *quark condensate* could also be obtained.

Present and future experiments

Some *experimental indications of* $\overline{\mathrm{K}}$*-nuclear clusters* have been recently obtained at KEK (E471) and also at DAΦNE (FINUDA), GSI (FOPI) and BNL-AGS (E930).

Looking at current and future experiments planned in the world, it turns out that, after the closure of KEK in December 2005, three facilities will be active in the field: FINUDA at LNF-DAΦNE, FOPI at GSI, in Europe, and J-PARC in Japan. FINUDA uses (K^-, π^-) reactions to produce kaonic clusters. FOPI adopts the production technique of *nucleus-nucleus* and *proton-nucleus collisions.* J-PARC will produce kaonic clusters via *K^-–induced reactions in flight.*

The role of DAΦNE

DAΦNE has proven to be a machine where hadronic physics in the strangeness sector can achieve important results. These results were obtained in dedicated measurements, which exploited the unique "kaon beam" coming from the decay of the Φ's produced in $e^+ e^-$ collisions.

DAΦNE will be upgraded in luminosity for the running experiments until end 2008 and will eventually become a new facility characterized by high luminosity as Φ-factory and a wider energy range.

The new facility, capable of delivering 10 fb^{-1} per year, on which a 4π dedicated detector like KLOE, complemented with AMADEUS will be installed, will become *the world scientific pole to study kaonic nuclei using K^- induced processes at rest, as indicated in the original work of Akaishi and Yamazaki.* This is a *complementary approach* with respect to the other two mentioned above, to be seen as part of a global strategy to attack the major open problems of low-energy QCD.

Scientific programme

The scientific programme of AMADEUS consists of *precision spectroscopy studies of a number of light kaonic nuclei,* as function of their baryon number A and isospin T, followed by measurements of medium heavy nuclear targets.

It is based on four objectives:

1. The first objective is to determine the quantum numbers (spin, parity, isospin) of all states, including excited ones, in addition to their binding energies and decay widths. Masses of kaonic clusters are obtained by measuring, in formation, proton and neutron distributions in missing mass spectra. In KLOE the proton spectra can be obtained with a 1-2 MeV precision. For the neutron spectra, the precision, under study, is of the order of 2-4 MeV.

2. The most interesting problem with respect to the *identification of excited states* of kaonic nuclei is *the measurement of the spin-orbit interaction* by detection of $p_{1/2} - p_{3/2}$ spin-orbit splitting which is predicted to be as large as 60 MeV for the small size of kaonic nuclei, therefore fully compatible with the precisions obtainable with KLOE.

3. As all the states of kaonic nuclei are quasi-stationary, important *information on their structure* is contained in their *total and partial decay widths.* Until now, only an upper limit, $\Gamma < 21$ MeV, is known for a kaonic tribaryon state and no information on partial decay channels is available. Total decay widths, accessible via the formation process, can be resolved in AMADEUS at the 1-3 MeV level for proton spectra, and few MeV–still under study–for neutron spectra. For what concerns the decay channels, the partial decay widths can be resolved at the level of 2-3 MeV up to less than 8-10 MeV (depending on the channel).

4. An even more detailed structure information can be extracted from a Dalitz analysis of three-body decays of kaonic nuclei, as was pointed out recently by Kienle, Akaishi and Yamazaki.

Detector requirements

The detector requirements for the complete determination of all formation and decay channels of kaonic nuclear clusters are fully satisfied by the KLOE detector, complemented with AMADEUS. We recall here briefly the KLOE performances:

- acceptance 96%
- drift chamber momentum resolution for charged particles $\sigma_p/p \leq 0.4$ %
- spatial resolution of vertices in drift chamber: 3 mm
- dE/dx capacity for particle identification: implemented in drift chamber
- energy resolution for photon the in e.m. calorimeter $\sigma_E/E \approx 5.7\ \%/\sqrt{E(GeV)}$
- time resolution of the e.m. calorimeter $\sigma_t = (54/\sqrt{E(GeV)} + 50)$ ps
- photon impact point resolution $1cm/\sqrt{E(GeV)}$ along the longitudinal coordinate and 1 cm along the transverse coordinate
- π^0 mass resolution to 2-3% (reconstruction)

All these figures of merit make the KLOE detector a very suitable detector for the proposed programme. The charged particles coming in formation and decay processes of kaonic clusters are in the energy range where KLOE detector is optimized, in terms of efficiency and performances. Moreover, the neutral pions, often generated in the decay processes, are as well in the energy range where KLOE is optimized for their detection. The reconstruction of the strange-baryons (Σ, Λ) can be done by a suitable detection of the secondary charged and neutral particles generate in their decay process. Many of the interesting channels end up with a neutron, either in formation process and/or in the decay one. The neutron will be detected by the e.m. calorimeter of KLOE. Monte Carlo simulations for the detection efficiency have been performed and measurements on a neutron beam of a test facility have been planned.

The neutron energies range from 10-20 MeV up to about 200 MeV. The neutron detection efficiency obtained from an AMADEUS Monte Carlo simulation of the e.m. calorimeter of KLOE turned out to be 20 - 30% at the lower energies to 50-60% at the higher ones, to be checked experimentally.

For the integration of the AMADEUS setup within KLOE – targets system and trigger - a solution under study is to install AMADEUS within the drift chamber of KLOE (central region diameter: 50 cm), using a toroidal target, surrounding the interaction region, placed around the beam pipe. The pipe which will be used can be of the same type used for DEAR/SIDDHARTA. A degrader, which might be an "active" one, i.e. a scintillator (or scintillating fiber) detector which gives the back-to-back topology to trigger on kaons generated from the Φ-decay, is placed around the pipe, just before the target.

The AMADEUS collaboration considers as well the use of an inner tracker, to have more information about the formation of the deeply bound stated. Since KLOE collaboration envisages the use of an inner (to the Drift Chamber) vertex detector (see KLOE-2 EoI) a merging of the two interests might give birth to an unique inner vertex detector, to be used by both groups.

Formation of an International Collaboration

This Letter of Intent has been promoted by physicists of the international collaboration DEAR/SIDDHARTA, which are working on DAΦNE since 1996 and where they will be still engaged until end 2008. To the DEAR/SIDDHARTA collaborations belong 11 institutions from 8 different countries. The interest raised in the international community by *kaonic atoms physics at DAΦNE* involved, since the beginning, also scientists from outside Europe, as Japan, USA and Canada, which actively participated and are participating to the experiments at DAΦNE. *They represent the "hard core" of an international collaboration for the study of deeply bound kaonic nuclear states.*

A dedicated detector on an upgraded DAΦNE, would represent the *only facility in the world where K^- induced reactions at rest are studied.* It is worthy to recall as well that Frascati National Laboratories are a recognized *European Research Infrastructure* of EU in the Fifth and Sixth Framework Programs and therefore they benefit of the EU funds for Transnational Access. This means that European groups from eligible countries (actually 33) and scientists from extraeuropean countries, but belonging to groups of eligible countries, may apply for access to Frascati in the next Seventh Framework Programme and work on the upgraded DAΦNE fully reimbursed.

In conclusion, a variety of arguments, suggest that a dedicated facility in Frascati to study deeply bound kaonic nuclear states receive a very favorable acceptance from the world scientific community. As demonstration of this, this Letter of Intent has been signed by 111 scientists from 33 Institutions of 13 countries.

Initial programme of measurements and integrated luminosity requirements

An initial programme will be based on the study of the dibaryonic (on ^{3}He target) and the T=0,1 tribaryonic states (on ^{4}He target). The following measurements will be performed:

1. mass and total widths with semi-exclusive measurements.

For an arbitrarily chosen integrated luminosity L_{int}= 200 pb^{-1}, considering the typical tribaryons formation reactions $K^- + {}^4He \rightarrow (K^-pnn)+p$ and $K^- + {}^4He \rightarrow (K^-ppn)+n$, detecting the ejected protons and neutrons, respectively, in missing mass spectra, assuming a conservative value for the cluster formation probability of $Y=1\times10^{-3}$, *the number of observed K^-pnn clusters seen in the proton spectra is 2.4×10^5* and *the number of observed K^-ppn clusters seen in the neutron spectra is 6×10^4*. If one detects additionally the decay Λ's in a semi-exclusive experiment, a reduction factor F = 0.23 is introduced.

With such spectra, which are expected to be background free, one can determine the binding energy and width of the kaonic clusters.

By considering also the dibaryonic states, using ^{3}He target, the *overall luminosity requirement for semi-exclusive measurements of mass and total widths is about 2 fb^{-1}*.

2. Partial decay widths

If one, wants to detect also the decay channels which contain Σ hyperons and neutrons, *an additional luminosity L_{int} =2 fb^{-1} is needed for the two targets.*

3. Correlations

The size and density distribution of kaonic clusters can be studied by observation of momentum correlation in the 3-body decays.

For a pioneering study of 3-body particle correlations, an additional luminosity of about 2 fb^{-1} is needed for the two target nuclei.

In conclusion, an initial programme based on the study of the ^{3}He and the ^{4}He targets, to investigate dibaryonic and the T=0,1 tribaryonic states, requires an integrated luminosity from 2 fb^{-1} to 6 fb^{-1}, according to the depth of the investigation.

Costs evaluation

The costs to implement KLOE with the AMADEUS setup include the *beam pipe* on the interaction point, the *cryogenic target system* and the *kaon monitor trigger.*

The cost of the beam pipe (aluminum and carbon fiber) is *150 K€.*

The gas handling system includes the *cryogenic system*, the *target cell* with *vacuum pumping* and *mechanics*, for an estimated cost of *160 K€.*

The trigger (kaon monitor) is composed by *scintillating fibers* (two cylindrical layers) with *APD readout* for a total cost of *300 K€.*

The global estimated costs of the AMADEUS setup is 610 K€.

This costs evaluation does *not* take into account the *inner tracker,* to be eventually built in cooperation with the KLOE Collaboration and whose costs will be eventually shared between the two collaborations.

Start of experiment

The start of the experiment can be fixed around 2010-2011.

1 Introduction

This Letter of Intent is focused on one of the presently hottest topics in hadron physics, the case of *deeply bound kaonic nuclear state* (called also *kaonic nuclear cluster*s). The only way to confirm their (debated) existence and study their structure is to perform an experimental measurement, possibly with the most performant detector on the most suitable machine. This is precisely what we propose in this LoI: a measurement with a dedicated 4π setup – the AMADEUS setup, a complementation of the KLOE detector – capable to detect formation and decay of a kaonic cluster, on an upgraded DAΦNE, the best machine to produce a clean, intense, monochromatic beam of antikaons.

The existence of deeply bound kaonic nuclear states would represent a new paradigm in strangeness nuclear physics, having many impacts and leading far-away. Because $\overline{K}$-nuclear clusters represent indeed the *ideal conditions* for investigating the way in which the spontaneous and explicit chiral symmetry breaking pattern of low-energy QCD changes in the nuclear environment. Cold dense matter is formed, a phase transitions from hadronic matter to a kaon condensed matter or to a quark-gluon phase could be expected.

The hypothesis of deeply bound kaonic nuclear states is only four years old, in the structured form of a phenomenological model (Akaishi and Yamazaki). A successful example of *deeply bound pionic atomic states* does already exist, after their observation at GSI in 1996 (Yamazaki, Kienle, *et al.*). The deeply bound states in pionic atoms have become an important tool *to test partial chiral symmetry restoration* in hadronic matter.

Sections 2 and 3 discuss the scientific case and the experimental foundations of the Akaishi and Yamazaki model.

Section 4 shows the so far obtained experimental indications of $\overline{K}$-nuclear clusters, mainly at KEK (E471), and also at DAΦNE (FINUDA), GSI (FOPI) and BNL-AGS (E930). Ongoing and future programs at world level are as well indicated.

In *Section 5,* the planned upgrading of the DAΦNE luminosity for the presently running experiments is described, together with the plan for a new facility optimized in luminosity as Φ-factory, and with a wider energy range. AMADEUS installed on the upgraded DAΦNE will become the *only facility in the world where the method suggested by the authors of the original hypothesis, namely K^- induced reactions at rest, can be applied*.

Preliminary to the definition of the experimental setup it is vitally important to identify methods to study binding energies, level widths, angular momenta, isospin, sizes, densities, etc of kaonic nuclear clusters. This is done in *Section 6,* in which the "Detector requirements for the AMADEUS programme" are defined.

All these requirements are satisfied by the KLOE detector, integrated in the central region with the target and trigger system of AMADEUS, as described in *Sections 7, 8* and *9*. *It will be possible, for the first time, a complete determination of all formation and decay channels of a kaonic nuclear cluster.*

The scientific programme is described in *Section 10* and consists of precision spectroscopy studies of a number of light kaonic nuclei as a function of their baryonic number and isospin, followed by measurements of medium heavy nuclear targets.

Sections 11 describes the potential formation of an international collaboration, based on the enthusiastic acceptance received from the scientific community of this Letter of Intent: 111 scientists from 33 Institutions of 13 Countries signed it.

Section 12 contains the integrated luminosity requirement for an initial programme on two light targets.

Sections 13 and *14* deal with costs and start of the campaign of measurements.

In *Section 15* conclusions are drawn.

2 The scientific case of kaonic nuclear clusters

2.1 A new paradigm in strangeness nuclear physics

A new paradigm in strangeness nuclear physics is represented by the recently studied *"Nuclear $\overline{K}$ bound states in light nuclei"* by Y. Akaishi and T. Yamazaki [1], whose experimental indications come from KEK [2, 3 ,4], LNF [5], GSI [6] and BNL [7].

The hypothesis of nuclear $\overline{\mathrm{K}}$ bound states relies on the I=0 $\overline{\mathrm{K}}$N interaction in few-body nuclear systems, which should favor *discrete nuclear bound states of $\overline{K}$,* together with a shrinking of the nucleus, thus producing a *cold dense nuclear system*.

The features of such exotic nuclear states are:

- large *binding energies* (100-200 MeV) and *narrow widths*, less than (20-30 MeV), since the $\Sigma\pi$ decay channel is closed energetically and, additionally, the $\Lambda\pi$ channel is forbidden by isospin selection rule;

- *high-density cold nuclear matter* around K^-, (few times ρ_0, normal nuclear density), which could provide information concerning a *modification of the kaon mass and of the $\overline{K}$N interaction in the nuclear medium*. How hadrons behave and how their properties change in nuclear medium is interesting and important from the viewpoint of spontaneous and explicit symmetry breaking of *QCD* [8]. The masses of light hadrons are largely of dynamical origin and reflect the symmetry pattern of QCD.

Moreover,

kaonic nuclear clusters could provide information on a *transition from the hadronic phase to a quark-gluon phase* [9]. At low baryon densities, matter exists in aggregates of quarks and gluons with their colour charges combined to form neutral (colour-singlet) objects. This is a domain of *low-energy QCD*, the physics of the hadronic phase in which mesons, baryons and nuclei reside. In this phase, the QCD vacuum has undergone a qualitative change to a ground state characterized by strong condensates of quark-antiquark pairs and gluons, as shown in the QCD phase diagram of Fig. 1. *At large quark densitie*s and Fermi momenta, another sector of the phase diagram, it is expected that Cooper pairing of quarks sets in and induces *transitions* to a complex pattern of *superconducting and superfluid phases*. Information on changes of *vacuum properties of QCD* and *quark condensate* could therefore also be obtained.

Empirical information could as well be obtained on whether *kaon condensation* can occur in nuclear matter, with implications in *astrophysics*: *neutron stars, strange stars*.

Finally,
Nuclear dynamics under extreme conditions (*nuclear compressibility*, etc) could be investigated.

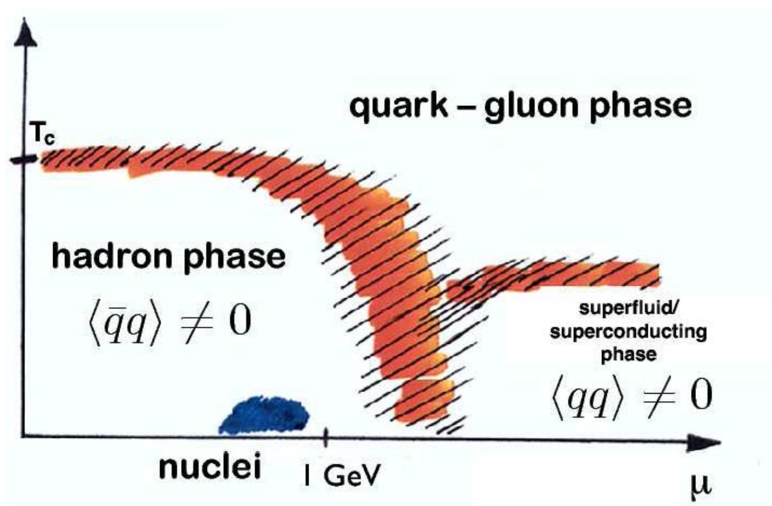

Fig. 1. Illustration of the QCD phase diagram [9].

2.2 Production mechanisms

Different mechanisms may produce a $\overline{\mathrm{K}}$ nuclear state:

1. *Stopped K^- reactions on light nuclei*, with ejection of a proton or a neutron as *spectators,* detected in *missing mass spectra*. Example: ^{4}He ($K^-_{stopped}$, n) reaction, which is a nuclear Auger process.
2. *In-flight reactions*, with detection of the outgoing particles in *missing mass spectra.*
   2.1 *Knock-out reactions (K^-, N)*, where one nucleon is knocked out in the formation stage.
   2.2 *(K^-, π^-) strangeness exchange reactions on proton-rich "nuclei" such as p-p that are unbound without the presence of K^-.*

3.1 Proton-nucleus and

3.2 Nucleus-nucleus collisions, where $\overline{K}$ clusters are identified via invariant mass spectroscopy of their *decay products.*

Here we examine in detail the various production mechanisms.

1. *Stopped K^- reactions* were studied in the original proposal of Akaishi and Yamazaki for three light nuclei: ^{3}He, ^{4}He and ^{8}Be [1]. *Preliminary experimental indications of deeply bound $\overline{K}$ nuclear states have been obtained with this approach [2, 3 ,4].*

   The formation of the exotic state proceeds in the following way (see Fig. 2, referred to the ^{4}He($K^-_{stopped}$, n) reaction):

- the K^- is stopped in an atomic orbit of ^{4}He forming the exotic atom K^- ^{4}He;
- after decay of the kaonic atom, the K^- interacts with the nucleus and forms deeply bound kaonic nuclear state (K^-ppn) by expelling a neutron.
- eventual peaks in the missing mass spectra of the ejected nucleons indicate the formation of the nuclear states and allow to deduce mass and width of the state.

2.1 The production of kaonic nuclei can be also achieved with *in-flight (K^-, N) reactions* [10, 11], schematically shown in Fig. 3. The nucleon is knocked out in the forward direction, leaving a kaon scattered backward in the vertex where the K+N→K+N reaction takes place. The reaction can thus provide a virtual K^- or $\overline{K}^0$ beam which excites the $\overline{K}$ nuclear state. The momentum transfer which characterizes the reaction depends on the binding energy B of the kaon in the nucleus: to excite states well bound in a nucleus (B ≈ 100 – 200 MeV) the momentum transfer is of the order of 0.3 ÷0.4 GeV/c and does not appreciably depends on the incident kaon momentum (p_{K^-} = 0.5 ÷ 1.5 GeV/c).

2.2 The *strangeness exchange reactions* (K^-, π^-) can as well lead to the production of $\overline{K}$ bound states [12]. One of the advantages of this reaction is to produce very exotic $\overline{K}$ bound systems. The I=0 $\overline{K}N$ pair, which possesses a strong attraction, gives an essential clue to lower the energy of a bound system. Thus, K^-pp, K^-ppp and K^-pppn systems on non-existing nuclei in nature, can be produced from d(K^-, π^-), ^{3}He(K^-, π^-) and ^{4}He(K^-, π^-) reactions. In the K^-pp system, the K^- attracts the two protons to form a bound state with estimated B = 48 MeV and Γ = 61 MeV [12]. The state is lying more deeply than Λ(1405), but still above the Σπ threshold. See, however, the experimental result of FINUDA: B ≈ 115 MeV [5]. In this production mechanism, a kind of *trapping process* for the incoming energetic K^- must be envisaged. The *abundant production of Λ(1405)* and *Λ(1520)* in K^-- induced reactions, which was observed in past bubble-chamber experiment, [13, 14, 15], might give a hint on the production of exotic $\overline{K}$ nuclei.

With reference to the production of the K^-pp system, of particular interest is the study of the K^-+d reaction, which was investigated in deuterium bubble chamber [14, 15] to obtain information on the elementary process:

$$K^- + \text{“n”} \rightarrow \Lambda(1405) + \pi^- \qquad (2.1)$$

In this case, the Λ(1405) acts *as a doorway state to produce K^- bound state***,** as shown in Fig. 4. Once a Λ(1405) is formed in a target nucleus A=(B+n) after an elementary "hard" process (2.1), it remains in the nucleus B and serves as a "seed" of strong attraction to produce a K^- bound state in the core nucleus C.

While propagating in the residual nucleus B, the Λ(1405) may either decay to $(\Sigma\pi)^0$ or get "dissolved", because of its "soft" character, into a $\overline{K}$ bound nuclear state.

An intriguing question is of course whether or not the (K^-, d) bubble chamber experiments [14, 15] showed any evidence of the production of the K^-pp system. Unfortunately, the pion spectrum is not available anymore.

3.1 *Protons of 3.5 – 4.5 GeV on a deuteron target* can produce K^-pp nuclear cluster through the elementary reactions

$$p+"n"\rightarrow \Lambda^* + K^0 + p \qquad (2.2)$$

$$p+"p"\rightarrow \Lambda^* + K^+ + p \qquad (2.3)$$

where "n" and "p" are a neutron and a proton in the target nucleus and $\Lambda^* \equiv \Lambda(1405)$. The elementary cross sections, although not well known, can be estimated to be around 20 μb by using the experimental spectra of Λ, Σ, and (Σ(1385) + Λ(1405)) obtained with 3.5 GeV/c protons by DISTO at Saclay [16], in combination with the NN cross section for $\Lambda K^+ N$ production (around 200 μb).

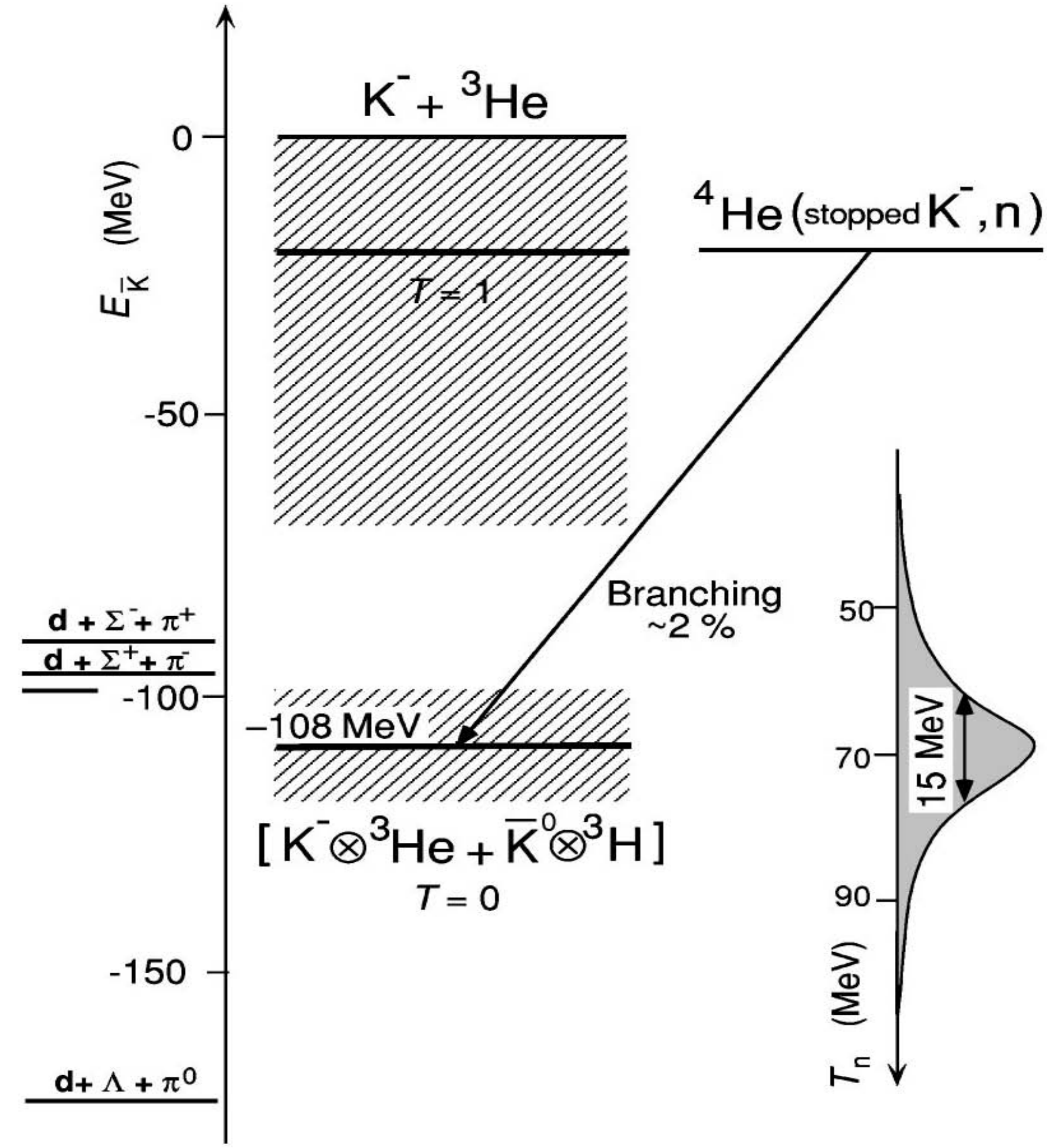

Fig. 2. Energy level diagram of the $K^- + {}^3He$ system. The T = 0 state can be excited and signaled with a neutron emission from stopped K^{-} on ${}^4He$. The neutron spectral distribution is also shown. Isospin in nuclei is indicated by T, following the usual convention [1].

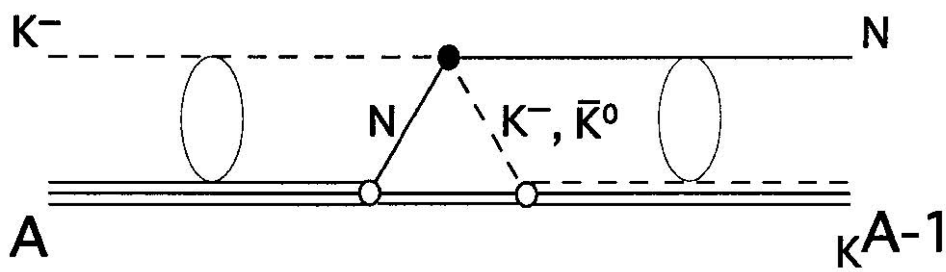

Fig. 3. Diagram for the formation of kaonic nuclei via the (K^-, N) reaction. The kaon, the nucleon, and the nucleus are denoted by the dashed, thin solid, and multiple lines, respectively. The kaonic nucleus is denoted by the multiple lines with the dashed line. The filled circle is the KN→KN amplitude while the empty circles are the nuclear vertices. The bubbles represent distortion [10].

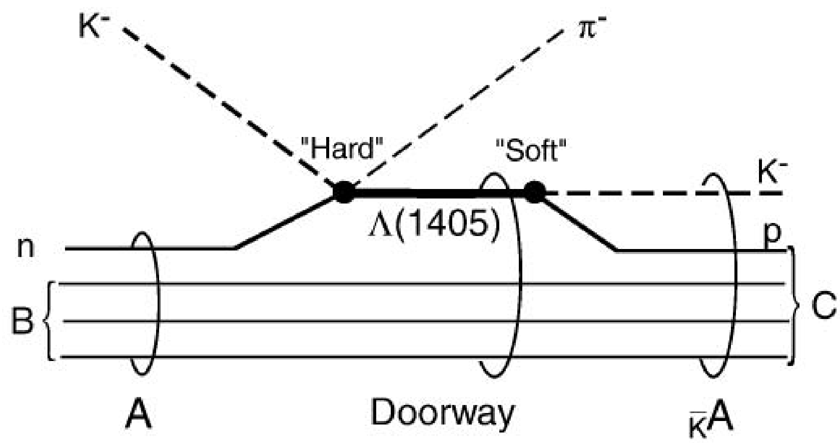

Fig. 4. Diagram for the production of $\bar{K}$ bound states in (K^-, π^-) reactions through Λ(1405) as a doorway [12].

In the reaction on deuterium, $p\Lambda^*$ serves as a doorway to form the K^-pp system:

$$p + d \rightarrow [p + \Lambda^*] + K^0 + p_s \rightarrow K^-pp + K^0 + p_s \qquad (2.4)$$

where p_s denotes the proton spectator. In this reaction a missing mass spectrum for K^-pp can be constructed from the energies and momenta of the incident p and the emitted $K^0(\rightarrow \pi^+ + \pi^-)$ and p_s.

Once the K^-pp is identified in the formation channel (missing mass spectrum), its decay pattern can be studied: an invariant mass spectrum for the decaying K^-pp can be reconstructed. Thus, full kinematical constraints in both formation and decay channels will be obtained.

3.2 Using *heavy-ion collisions*, $\overline{K}$ *clusters may be identified as residual fragments ("*$\overline{K}$ *fragments")* in nuclear collisions [17]. Since high–density fireballs with large strangeness content are provided in heavy-ion reactions, $\overline{K}$ clusters are expected to be abundantly produced. In particular, the thermal equilibrium model [18] predicts substantial populations of $\overline{K}$ clusters [19], as is shown in Fig. 5.

$\overline{K}$ clusters are produced and identified by detecting both K^0 mesons, from the invariant mass of $\pi^+ + \pi^-$, and Λ hyperons from the invariant mass of $p + \pi^-$. As a further step, the invariant mass spectra from the charged particles trajectories are reconstructed:

$$K^-pp\ (T = ½) \rightarrow \Lambda + p \qquad (2.5)$$

$$K^-npp\ (T = 0) \rightarrow \Lambda + d \qquad (2.6)$$

$$K^-ppp\ (T = 1) \rightarrow \Lambda + p + p \qquad (2.7)$$

The yields (multiplicities) for the production of K^-pp, K^-ppp and K^-pppn systems are about 1%, and thus invariant mass spectroscopy is applicable. Once the $\overline{K}$ clusters are established, they can be used to study the reaction dynamics of heavy-ion fireballs.

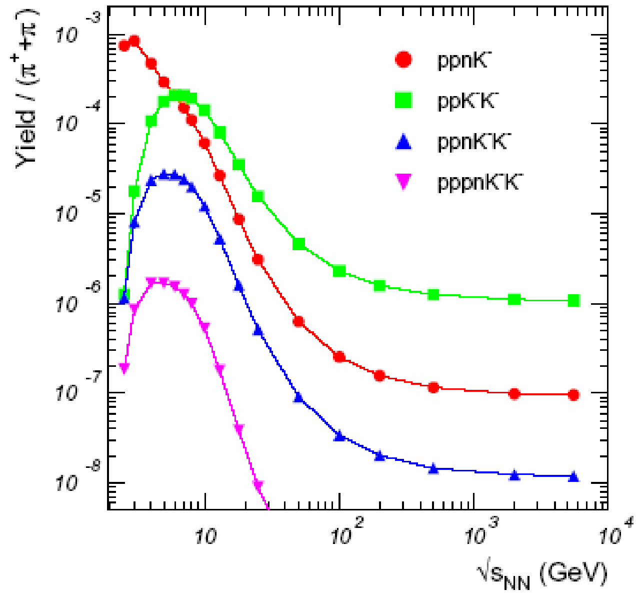

Fig. 5. Theoretical estimates of typical $\bar{K}$ cluster yields in heavy ion reactions based on the thermal equilibrium model [18, 19].

3 From low-energy $\bar{\mathrm{K}}$N interactions to $\bar{\mathrm{K}}$–nuclear clusters: experimental foundations of the model

Wolfram Weise [8] has recently addressed this basic question: *"to what extent does our present knowledge of low-energy $\bar{\mathrm{K}}N$ interactions support the hypothesis of narrow $\bar{\mathrm{K}}$-nuclear states introduced by Akaishi and Yamazaki?"*

Akaishi and Yamazaki constructed a quantitative $\bar{\mathrm{K}}$N interaction model [1] on a *phenomenological basis* so to simultaneously reproduce: 1) *the low-energy $\bar{K}N$ scattering data*, 2) *the kaonic hydrogen shift of the ground state* and 3) *the binding energy* and *decay width of Λ(1405),* asserted to be an I=0 quasi-bound state of $\bar{\mathrm{K}}$N.

The *g*-matrix method was used and the case of light nuclei, ^{3}He, ^{4}He and ^{9}Be was considered. Discrete $\bar{\mathrm{K}}$-bound states, K^-ppn , K^-ppnn, $K^-2\alpha$ were predicted, showing the following characteristics:

1. the I=0 $\overline{K}N$ interaction is strong enough to shrink the nucleus against the nuclear incompressibility.
2. The binding energies are extremely large due to the strong attractive potential, helped by the nuclear shrinkage effect, so that the bound states lie below the threshold of the main decay channel $\Sigma\pi$, thus inferring the presence of quasi-stable discrete bound state (width Γ < binding energy B).

   It is worthy to recall that the possibility of deeply bound kaonic nuclear states in presence of a strong $\overline{K}N$ attractive potential was firstly indicated by S. Wycech in 1986 [20, 21].

A successful example of *deeply bound mesonic states*, is represented by the discovery, in 1996, of deeply bound pionic *atomic* states: the observation of narrow *1s* and *2p* states of π^- in ^{207}Pb and ^{205}Pb [22]. These states are important tools for testing chiral pion-nucleus dynamics and the quest for fingerprints of *partial chiral symmetry restoration in baryonic matter* [23, 24, 25]. However, the mechanism at work in forming deeply bound states of *pionic atoms* are quite different from the one thought to be responsible for the formation of *kaon-nuclear* bound states [8]. Binding a negatively charged *s*-wave pion at the surface of a heavy nucleus is a matter of subtle balance between Coulomb attraction and the repulsion resulting from the pion-nuclear strong interaction.

In this Section, we discuss the experimental foundations of the Akaishi and Yamazaki model.

3.1 Antikaon-nucleon optical potential

It is well known that the *s*-wave *K^-nucleon scattering length* is *repulsive* (the real part is negative), as it comes out from all K^- nucleon scattering data extrapolated at threshold [26]. Moreover, a measurement of kaonic hydrogen performed at KEK [27], recently confirmed by the DEAR experiment at DAΦNE [28], has shown that the *energy shift* of the *1s* atomic orbit of kaonic hydrogen is of *"repulsive type"*.

It is, however, possible that the actual *K^-p interaction* is *attractive in nuclear matter*, although it appears repulsive from the scattering data and from the energy shift of the kaonic hydrogen. This occurs *if* the *s*-wave, isospin I=0, *Λ(1405) resonance is a bound state of $\overline{K}N$.* Since Λ(1405) lies just below the K^-p threshold, scattering *through* this resonance gives rise to a *repulsive* contribution to the scattering amplitude at threshold [29].

This conclusion is supported also by other considerations. A systematic re-analysis of all existing data of K^--atoms heavier than the hydrogen, suggested a strong non-linear dependence of the real part of the K^- nuclear optical potential on the nuclear density ρ [30]. This turns out in a *sign change, from repulsive to attractive,* of the optical potential at rather low density *in medium* as compared to its value in free space [31].

This effect can be readily understood by analogy to the proton-neutron (p,n) scattering [32]. The interaction between the proton and the neutron is *attractive*, but the scattering length in the deuteron channel (I=0, S=1) is *repulsive*, due to the existence of the *deuteron as a bound state*. In nuclear matter, however, the deuteron disappears, largely due to Pauli blocking, and the true attractive nature of p-n interaction emerges.

Simple arguments from low-energy scattering show that the existence of a bound state below threshold *always* leads to a repulsive scattering length [33].

In the bound state picture of Λ(1405), analogously to the deuteron case, the scattering *through* the resonance gives rise to a repulsive contribution and the change of sign of the optical potential can be simply understood as the effect of the Pauli blocking of the proton inside the Λ(1405) (the kaon, being a boson, is not affected by the Pauli blocking), which leads to an *upward shift* of the resonance towards the K^-p threshold, where it ceases to exists. Also in this case, *the "dissolving" of the bound state allows the true nature of the K^-p interaction to emerge.* All this is represented in Fig. 6 where, just below the threshold corresponding to the atomic states, the dominant I=0 *s*-wave scattering amplitude f^I changes from repulsion in free space to attraction in the medium, *due to the dissolution of Λ(1405)*. At threshold ($E_{\overline{K}N} = 0$) the scattering amplitude is equal to the scattering length a^I (definition of scattering length). When $E_{\overline{K}N}$ falls below the Σπ threshold, the imaginary part of $f^{I=0}$ vanishes and gives no contribution to the decay of a very bound state in a nucleus.

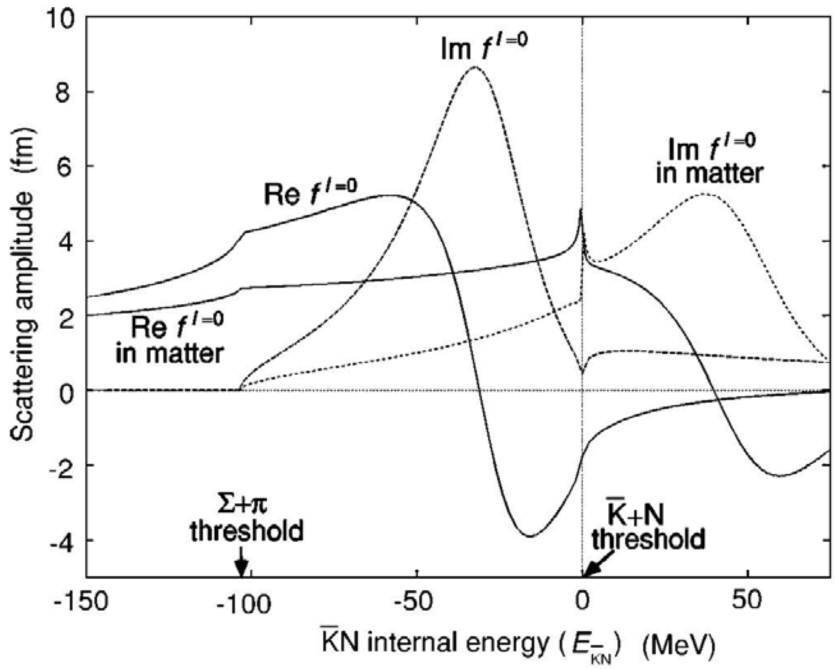

Fig. 6. Calculated scattering amplitudes $f^{I=0}$ of $\bar{K}N$ in free space and in nuclear matter versus the internal energy $E_{\bar{K}N}$ [1].

3.2 The kaonic hydrogen case

The measurement of kaonic hydrogen performed at KEK [27] solved the long standing *"kaonic hydrogen puzzle"*, by confirming the scattering data, the energy shift of the 1*s* atomic level turning out of "repulsive type".

The same upward shift of the ground state was obtained recently by the DEAR experiment on DAΦNE [28], which measured shift and width in kaonic hydrogen with *unprecedented precision.* The DEAR data, together with existing information on K^-p scattering, the πΣ mass spectrum and measured K^-p decay ratios at threshold, set tight constraints on the theory and have consequently revived the interest in this field. We cite here: Meissner, Raha and Rusetsky [34]; Borasoy, Nissler and Weise [35, 36]; J. Oller, J. Prades and M. Verbeni [37]; Weise [8]; Ivanov [38].

B. Borasoy, R. Nissler and W. Weise wrote in [35]:

"In conclusion, the present updated analysis of low-energy K^-–proton interactions, combining the next-to-leading order chiral SU(3)effective Lagrangian with an improved coupled-channels approach, emphasizes the importance of the constraints set by the new accurate kaonic hydrogen data from the DEAR experiment. At the same time this analysis points to questions of consistency with previously measured sets of K^-p scattering data. Developments aiming for a precision at the level of a few electron volts in the shift and width of kaonic hydrogen, foreseen at DAΦNE in the near future, will further clarify the situation."

This precision measurement constitute the SIDDHARTA programme at DAΦNE [39], to be performed in 2007 and 2008. The goal is to reach a few eV precision in the kaonic hydrogen and to measure the kaonic deuterium for the first time.

The kaonic deuterium case is much less known: both the yield of the *2p→1s* transition and the strong interaction shift and width of the *1s* state are evaluated within large uncertainties [40, 41]. We estimated that a 10 eV precision in shift might be reached with about 500 pb^{-1} of integrated luminosity. Both $\overline{K}N$ isospin dependent scattering lengths can be then determined.

A precise determination of $\overline{K}N$ scattering lengths is fundamental in the strangeness sector of hadron physics [40] and is *crucial in the investigation of deeply bound kaonic nuclear states*.

It is worthy to underline that DAΦNE is the only laboratory in the world where such precision measurements can and will be performed. The other existing facilities with kaon beams do not have in their programmes such measurements, due to the fact that they are employing extracted beams of relatively high momenta (up to 2 GeV/c), so that the study of kaonic atoms is very inefficient.

3.3 The kaonic helium case

There is a crucial information about the formation of a specific deeply bound kaonic nuclear state – precisely, the K^{-} ^{3}He system – which depends on the result of the measurement of the X-ray transitions in the K^{-} ^{4}He atom [42]. The branching ratio for the formation of the nuclear state is given by the ratio of partial and total absorption widths of the atomic states of kaonic helium. The total width Γ_{tot}^{exp} is, however, not well known. There are three experiments which observed kaonic helium atomic transitions from the 3*d* to the 2*p* level [43-45]. The latter two experiments are known to show evidence for an anomalous energy shift and width of the 2*p* state. If the experimental average is used, $\Gamma_{tot}^{exp} = 55 \pm 34$ eV. Then, estimating the partial width of the order of 1eV, the formation branching ratio turns out about 2%.

However, all the theoretical widths are around Γ_{tot}^{th} = 2-4 eV [46]. Analogous discrepancy between experiments and theoretical estimates exists for the shifts [47]. This is what is dubbed *"the kaonic helium puzzle"*.

The relevance of the solution of the kaonic helium puzzle for the understanding of deeply bound kaonic nuclear states has been explicitly stressed [48]. The measurement will provide a crucial information on the nature of the two strange tribaryons, $S^{0}(3115)$ and $S^{+}(3140)$, recently seen by the E471 collaboration at KEK, via K^{-} capture in ^{4}He [2, 3, 4]. The ^{4}He kaonic atom is going to be measured in a test experiment (E570) at KEK, just before its closure, using SDD detectors. Given the nature of the "kaonic helium puzzle", where experiments disagree each other and differ by more than one order of magnitude from theories, a *precision measurement* is compelling. This can be done, and will be done, on ^{4}He and ^{3}He, to look also at isotopic effects, by the SIDDHARTA experiment on DAΦNE in the future kaonic atoms campaign [39]. Preliminary Monte Carlo simulations, performed for the SIDDHARTA setup with a gaseous ^{4}He target show that a measurement with a precision of few eV can be performed at DAΦNE with about 200 pb^{-1} of integrated luminosity. Similar estimations hold for the ^{3}He case.

Finally, it must be recalled that the capability to detect kaonic helium X-rays transitions might turn out extremely useful in implementing an *X-ray trigger* to reduce the background in the measurement of kaonic nuclear states with AMADEUS.

3.4 Low-energy kaon-nucleon scattering

Another key ingredient of the phenomenological model of Akaishi and Yamazaki is represented by the bulk of low-energy kaon-nucleon scattering data [26].

The updated analysis of low-energy K^- - proton interactions of Borasoy, Nessler and Weise [35], which combines the next-to-leading order chiral SU(3) effective Langragian with an improved coupled-channels approach, emphasizes the importance of the constraints set by the new accurate data of DEAR, but as well points to questions of *consistency* with previously measured sets of K^-p scattering data.

To check the depth of these inconsistencies, namely if a physics case does indeed exist, one will perform with SIDDHARTA a still more accurate measurement of kaonic hydrogen [39]. At the same time, the attention must be focused on the bulk of scattering data. It is then worthy to examine the state-of-the art of the field and the perspectives [49].

3.4.1 Status of low-energy kaon-nucleon scattering

The season of systematic investigation of kaon-nucleon interactions suffered an abrupt ending around 1980, with the closing down of most of machines and beam lines dedicated to this branch of hadronic physics.

Despite many valiant efforts to resurrect the field (the European Hadron Facility and KAON at TRIUMF, just to name the bravest), the few remaining kaon beam lines have been barely sufficient to keep hypernuclear physics alive.

So, many of the statements on the successes of flavour SU(3) – just to mention one single case in the physics of the Standard Model – so abundant in particle physics textbooks are in reality based on a handful of old, low-statistics, low-resolution experiments, performed using kaon beams with momenta hardly less than some hundreds MeV/c, that nobody would even think today of proposing to a selecting committee.

Of course kaon beams have problems not presented by pion beams (which indeed have continued to be in – relative – availability), but the physics to be performed with them can not be replaced by anything else.

It is enough to mention that, while $G_{\pi NN}^2$ is known to a few percent, uncertainties on $G_{KN\Lambda}^2$ and $G_{KN\Sigma}^2$ are at the levels, respectively, of about ten and thirty percent, not to speak of pion-hyperon coupling, "known" via $\overline{K}N$ phase shift coupled-channel analysis, where standard dispersive techniques yield errors of order 100%!

Also, a cursory glance at the PDG tables shows that there are a lot of "missing" Λ and Σ states (not to mention the even more missing Ξ's and Ω's).

3.4.2 Recent hopes for progress at DAΦNE

In a kinematical range not available to conventional fixed-target experiments, Φ-factories such as DAΦNE in Frascati can prove invaluable, being sources of almost monochromatic K^+, K^- and K_L of about 100 MeV/c, which can be degraded down to few tens of MeV/c.

KLOE, while doing its job of collecting neutral kaon decays looking for the tiny effects of CP violation, and in the meanwhile also reaping a good harvest of more conventional hadronic physics (cross sections, radiative decays, etc), has collected many tens of thousands of interactions of the kaons with the helium filling the huge wire chamber.

The design of FINUDA should also allow the observation of kaon-nucleon interactions, and in particular the collaboration plans to take data on charge–exchange of K_L's on the hydrogen of plastics scintillators.

A proposal to study kaon-nucleon interactions in a liquid hydrogen target around the interaction point of FINUDA already exists [50-53].

In a Φ-factory, the kaon beam is intrinsically clean, a situation unattainable with a fixed target machine. There, the minimum beam momentum is limited by the distance from the experiment to the production target and by the consequences of kaon decay in flight. The kaons have to be energetic enough to survive the trip. The several hundred MeV/c momentum beams require the use of moderators, thereby enhancing the beam contamination, especially pions, at the experiment.

An upgraded DAΦNE to study $\overline{K}$-nuclear clusters with a 4π detector, might include in its scientific program $K^{\pm}$ scattering on nucleons/nuclei to build up a high quality set of data.

3.5 The Λ(1405)

The third ingredient of the phenomenological model of Akaishi and Yamazaki [1] is the existence of the Λ(1405) resonance, asserted to be an I=0 bound state of the $\overline{K}N$ system, with a binding energy $E_{\overline{K}N}$ = -29.5 MeV from the I=0 $\overline{K}N$ threshold (-27 MeV from the K^-p threshold).

The assertion is supported by studies of Weise *et al.* based on chiral SU(3) theory [31], which show that the I=0 $\overline{K}N$ interaction is attractive enough to from the Λ(1405). As well, the Juelich group using a boson exchange potential [54], showed that all the ω, ρ, σ mesons work coherently to give a strong attraction between a $\overline{K}$ and a N which accommodates a K^-p bound states, identified as Λ(1405).

Another possibility is that the Λ(1405) is a three-quark state (or an admixture of the two interpretations) [55]. If this would be the real scenario, one of the strongest arguments of the Akaishi and Yamazaki model is substantially weakened.

Establishing which is the dominant component of Λ(1405) has therefore a strong impact on the hypothesis of K^- nuclear clusters.

Precise K^-N measurements at threshold, foreseen in the SIDDHARTA programme [38], will substantially improve the knowledge of the sub-threshold $\overline{K}N$ dynamics and contribute to clarify the nature of Λ(1405).

More information can come from the measurement of two-body branching ratios in K^- absorption at rest, a field covered only by very scarce bubble chambers data, which is precisely the kind of reactions to be studied with AMADEUS. Specifically, one can investigate *in-medium corrections to the branching ratios in* K^- *absorption at rest and their effect on the charged* $\pi^{\pm}$ *spectrum* [32]. The in-medium corrections are due to Pauli blocking, which arises if the Λ(1405) is assumed to be a $\overline{\mathrm{K}}$-nucleon bound state and leads to a density- and momentum-dependent mass shift of the Λ(1405). Upward shift of the Λ(1405) mass leads, as we have seen, to an attractive $\overline{\mathrm{K}}\mathrm{N}$ potential. The mass shift of Λ(1405) is expected to appear most clearly if it is created in the nuclear medium with a small momentum. The K^- absorption at rest is one possibility. For this reaction, the experimental charged pion spectra are available for several nuclear targets. The Λ(1405) mass shift moves the I=0 amplitude upward in energy but does not affect the I=1 amplitude. It therefore modifies the relative phase and strength of I=0 and I=1 amplitudes leading to different branching ratios for the reactions $K^- p \rightarrow \pi^0 \Lambda$,

$\pi^- \Sigma+$, $\pi^0 \Sigma^0$, $\pi^+ \Sigma^-$, as compared to the free ones.

3.6 Astrophysics implications

In the last years it became clear that strangeness has to be included as a new degree of freedom in astrophysical relevant systems. By this point of view, the discovery and the measurement of the properties of deeply bound kaonic nuclear states can play an important role.

The neutron stars, for example, in the same way as it might be for kaonic nuclear clusters, probe the QCD at high densities and small temperature. Created by supernovae explosions, neutron stars are compact remnants with masses between 1 and 2 times the solar mass, and radii about 10 km. The central densities are thought to be several times the normal nuclear matter density.

Kaons can appear in this dense hadronic matter; as they have spin zero, will form a Bose condensate in a neutron star. For a sufficiently reduced effective energy of the antikaons – which could be probed by kaonic nuclear clusters – neutrons will be transformed to protons and antikaons, or, equivalently electrons to antikaons and neutrinos [56, 57]:

$e^- + p + n \rightarrow \nu + n + n$ (Neutron star);

$\rightarrow \nu + K^- + p + n$ (Nucleon star with kaon condensate) at $\sim 3\rho_0$

At sufficiently high density, the transition to the deconfined strange quark matter should appear; this kind of transition might allow for the existence of a new class of compact stars: strange quark star [58, 59].

A large region of the interior of the star may form geometric structures in the mixed phase of nuclear matter, kaon condensate matter and strange quark matter, see Fig. 7.

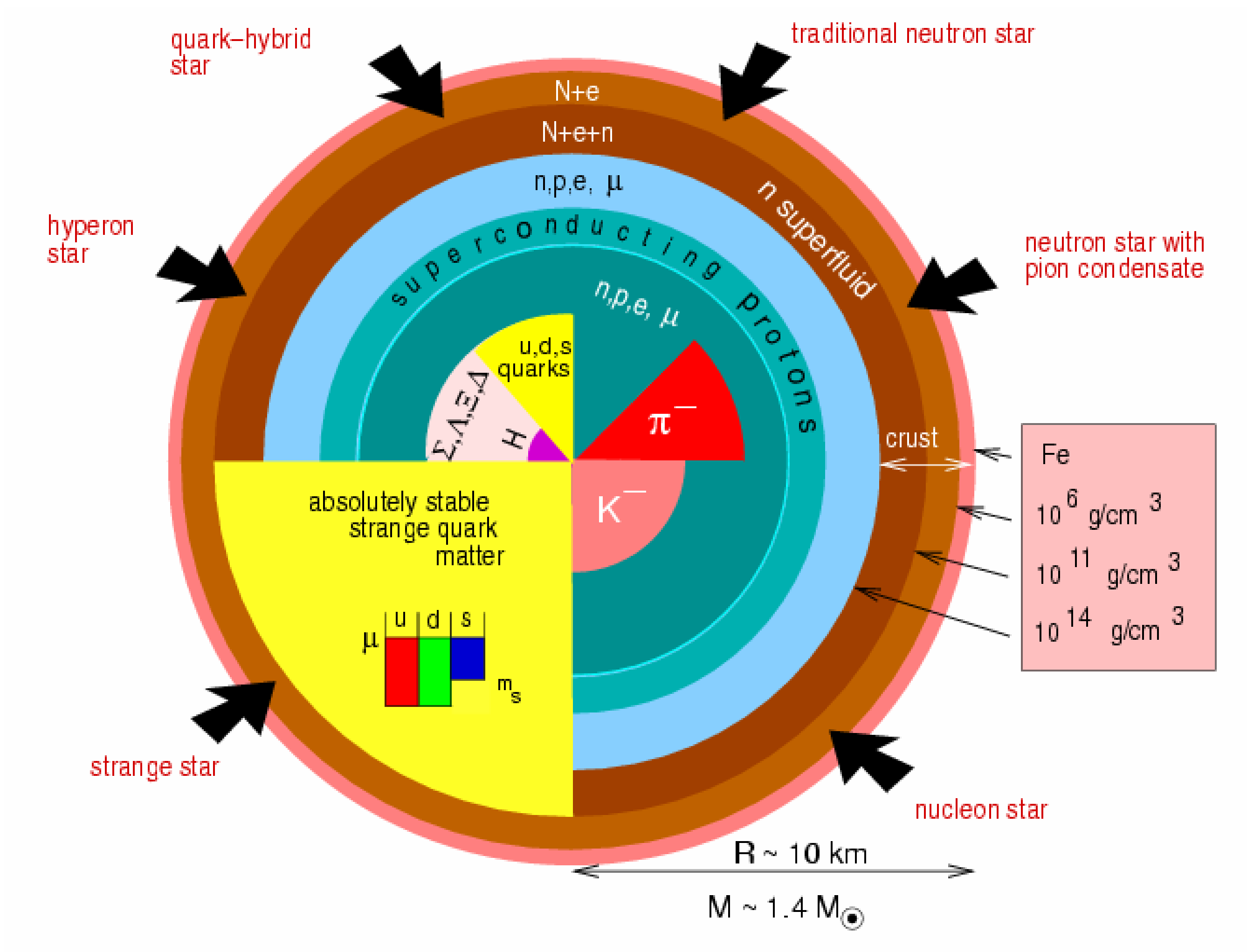

Fig. 7. The possible composition of a "neutron/strange/quark star" [57].

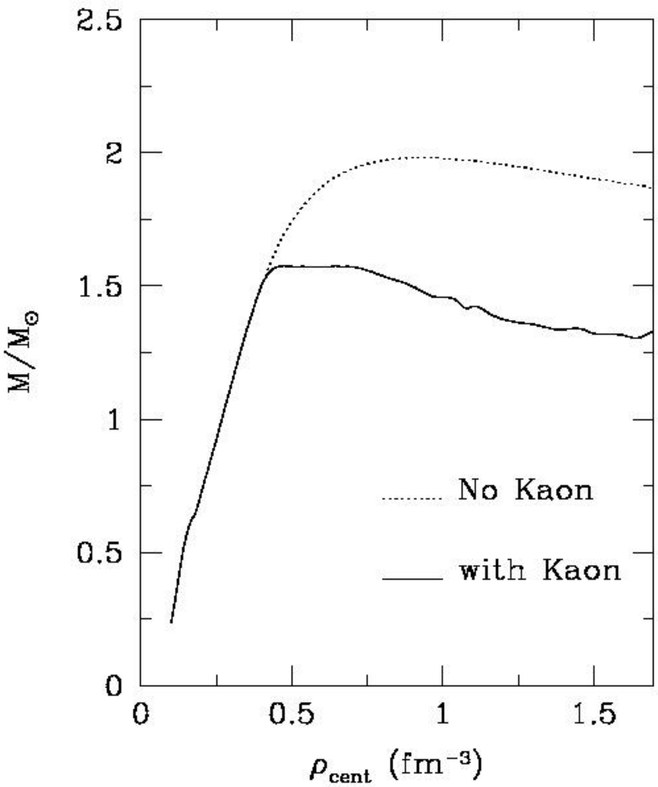

Fig. 8. The collapse of a star to a black hole is "helped" by the strangeness contribution [57].

This kind of structure would allow smaller radii than the ordinary neutron stars, and this might explain the structure of debated astronomical objects recently measured: 3C58 and RX J1856, which appear to have radii/mass ratios (still debated) unexplained by "normal" neutron star composition.

Another signal has been proposed recently for the existence of the two phases mixed with the normal one: namely the neutrino flux from a proto-neutron star in a supernova [60]. A newly born hot neutron star with a strange phase can support more mass with respect to a cold one, so the cooled neutron star has to collapse to a black hole (Fig. 8).

All these items, which were only sketched, are showing that the study in the laboratory of the deeply bound kaonic nucear states might open the door to understanding processes of extreme importance in the astrophysical sector.

4 Experimental indications of deeply bound kaonic nuclear states and future programmes

4.1 E471, KEK

The first hint of deeply bound kaonic nuclear states is ascribed to the experiment E471 at KEK [2, 3, 4]. In this experiment, along with the original proposal of Akaishi and Yamazaki, negative kaons were stopped in a superfluid helium target and the time-of-flight of neutrons/protons, detected by neutron-counter walls at ± 2m from the target, was measured [42]. An overview of the experimental setup is shown in Fig. 9.

The results are shown in Fig. 10. In the missing mass spectrum of the ${}^4He(K^-_{stopped}, p)$ reaction (Fig. 10, top), *a monoenergetic peak can be observed*, with a statistical significance of 8.2σ. The peak is interpreted as the *formation of the neutral tribaryon S^0 (3115)* with isospin T=1, and the following values for mass, width and binding energy are given:

$$M_{S^0} = 3117.7^{+3.8}_{-2.0} \text{ (syst.)} \pm 0.9 \text{ (stat.) MeV}, \qquad (4.1)$$

$$\Gamma_{S^0} < 21.6 \text{ MeV}, \qquad (4.2)$$

$$B_{S^0} = -194 \text{ MeV with respect to } K^- + p + n + n \text{ rest mass}. \qquad (4.3)$$

In the missing mass spectrum of the ${}^4He(K^-_{stopped}, n)$ reaction (Fig. 10, bottom), *experimental indication of another strange tribaryon S^+ (3140)*, with a statistical significance of 3.7σ was observed. The isospin is T=0, with the following values for mass, width and binding energy:

$$M_{S^+} = 3140.0^{+3.0}_{-0.8} \text{ (syst.)} \pm 2.3 \text{ (stat.) MeV}, \qquad (4.4)$$

$$\Gamma_{S^+} < 21.6 \text{ MeV}. \quad (4.5)$$

$$B_{S^+} = -169 \text{ MeV with respect to } K^- + p + p + n \text{ rest mass}, \quad (4.6)$$

so the state is about 25 MeV higher than the previously observed S^0 (3115). The major decay mode is $S^+ \rightarrow \Sigma^\pm NN$.

Moreover, another candidate peak was found in the neutron spectrum *at around 3117 MeV, where the isobaric analogue state of S^0 (3115), denoted S^+ (3115), is expected.*

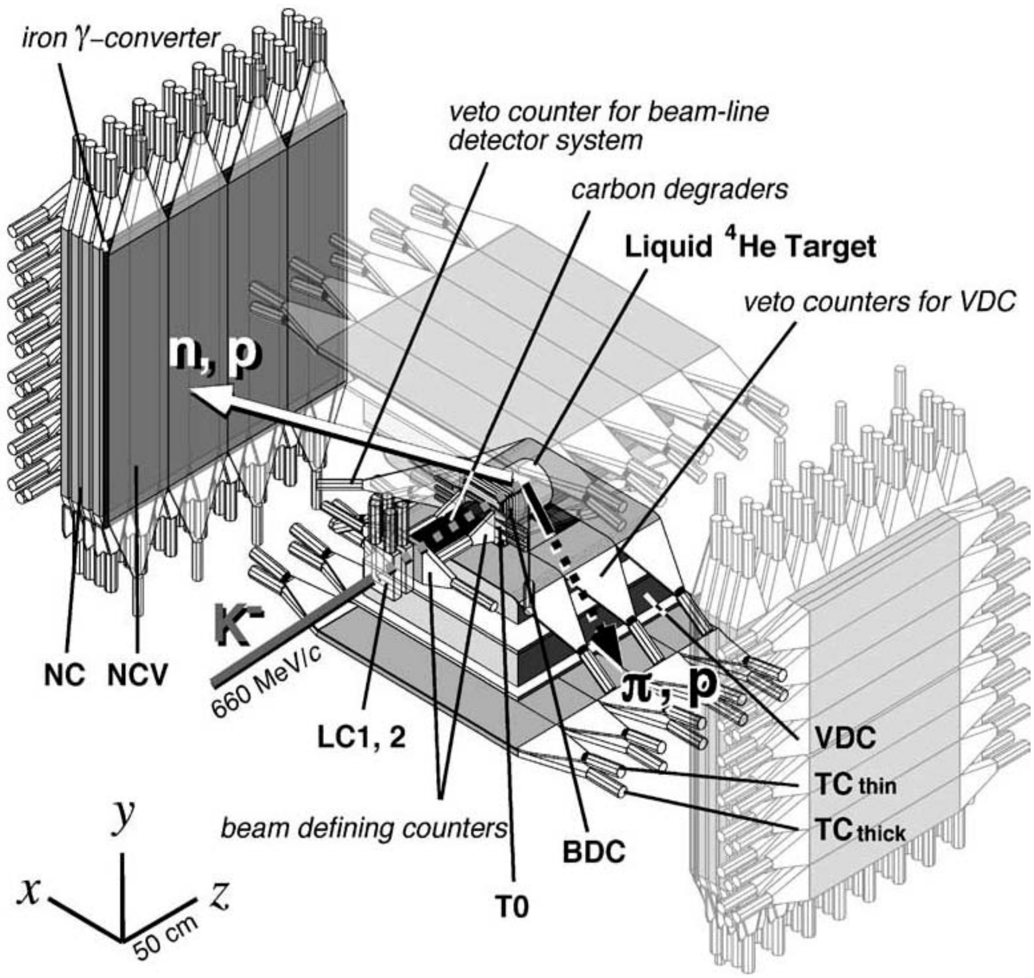

Fig. 9. An overview of the experimental setup of E471 at KEK. LC1, 2: Lucite Cerenkov counter, T0: beam timing counter, BDC: beamline drift chamber, VDC: vertex drift chamber, TC_{thin} and TC_{thick} (3 cm) trigger counter, NCV: neutron-counter charged-particle veto, NC: neutron-counter wall [2].

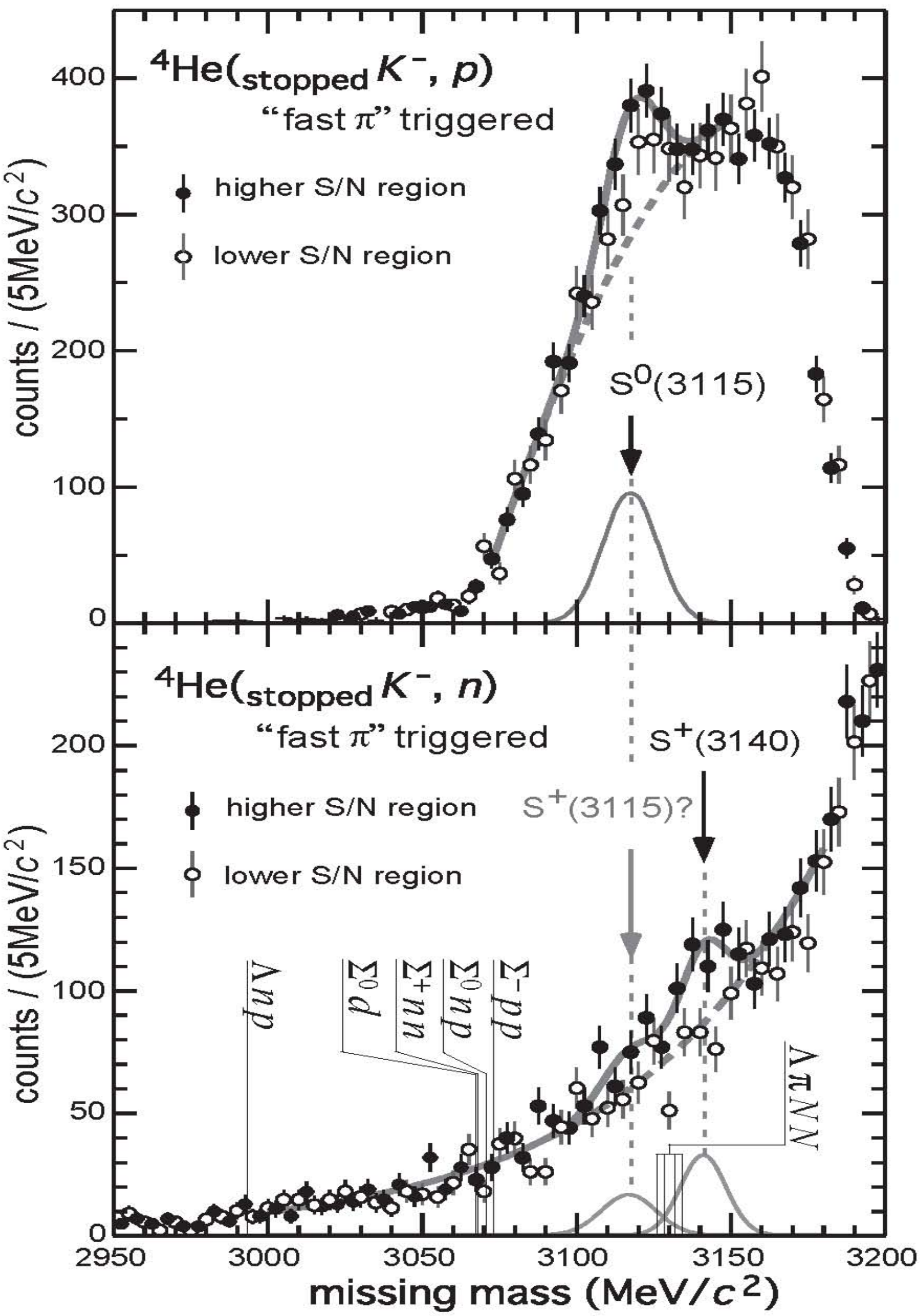

Fig. 10. Missing mass spectra of the ^{4}He($K^-_{stopped}$, p) reaction (top) and the ^{4}He($K^-_{stopped}$, n) reaction (bottom), measured at KEK by E471 [3].

4.2 FINUDA, LNF-DAΦNE

The “strangeness exchange reaction” (K^-, π^-) was used by the FINUDA experiment at DAΦNE [5] to produce $\overline{K}$-bound states on proton-rich nuclei, such as p-p, which are unbound without the K^-. The process was K^- absorption on very thin light targets (^{6}Li, ^{7}Li and ^{12}C).

When a K^- interacts with two protons, one expects that a hyperon-nucleon pair is emitted in the opposite direction. The measured angular correlation between Λ’s and protons in all targets indeed indicated the existence of this kind of reactions. Being so evident the correlation between a Λ and a proton, it is naturally expected that the two particles are emitted from a “K^-pp” intermediate system.

If the process were simply two-nucleon K^--absorption process, then the mass of the system should be close to the sum of the kaon mass plus the two protons mass, namely 2370 MeV. *The invariant mass distribution of the Λ–p pairs*, shown in Fig. 11, shows, however, a *significant mass decrease* with respect to the expected values, being peaked around

$$M_{\Lambda+p} = 2255 \text{ MeV}. \qquad (4.7)$$

The peak in the Λ+p invariant mass spectrum is interpreted as a kaonic bound nuclear state with binding energy and width:

$$B_{\Lambda+p} = -115^{+6}_{-5} \text{ (stat.)}^{+3}_{-4} \text{ (syst.) MeV} \qquad (4.8)$$

$$\Gamma_{\Lambda+p} = 67^{+14}_{-11} \text{ (stat.)}^{+2}_{-3} \text{ (syst.) MeV}. \qquad (4.9)$$

4.3 E930, BNL-AGS

At BNL, the in-flight knock-out (K^-, N) approach was followed [7]. Specifically, the (K^-, n) reaction on a water target was studied. Neutrons were measured by an array of neutron counters placed 6.8 m downstream of the target. The neutron momentum spectrum was obtained with the time-of-flight technique.

In Fig. 12, the missing mass spectrum of the $^{16}O(K^{-}, n)$ reaction is shown. Here the horizontal axis is the binding energy of K^{-} to ^{15}O. The distinct peak at zero energy is the quasi-free peak of the reaction on proton. An appreciable amount of strength in the bound region can be seen. *A peak at around 90 MeV corresponds to a kaonic nuclear state* where the kaon is in the *p*-shell.

4.4 FOPI, GSI

Ni+Ni collisions at an incident energy of 1.93 AGeV at GSI were studied with the 4π detector FOPI [6]. Heavy-ion collisions at beam energies close to the strangeness production threshold could offer an alternative way to produce deeply kaonic nuclear states, observed so far only in kaon-induced reactions. The two-body final state Λ+d represents one of the possible decay channels of the kaonic nuclear cluster $K^{-}ppn$.

The reconstructed invariant mass distribution Λ+d is shown in Fig. 13, in comparison with MonteCarlo simulations of signal and background. It was verified that *a resonance introduced in Ni+Ni MonteCarlo events can be reconstructed correctly* (middle row), while no resonance-like structure is generated due to the analysis method (lower row). *The remaining excess in the data has a mean mass*

$$M_{\Lambda+d} = 3160 \text{ MeV}, \tag{4.10}$$

corresponding to a binding energy

$$B_{\Lambda+d} = -149 \text{ MeV}, \tag{4.11}$$

and a width

$$\Gamma_{\Lambda+d} \approx 100 \text{ MeV}. \tag{4.12}$$

It can be interpreted as a $\overline{K}$ *nuclear cluster.*

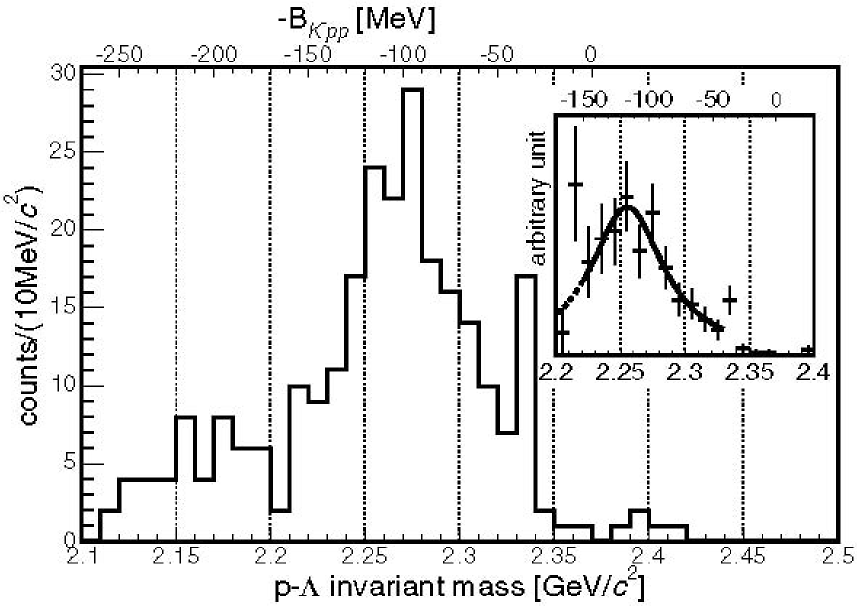

Fig. 11. Invariant mass spectrum of a Λ and a proton measured by FINUDA at DAΦNE in a back-to-back correlation ($\cos\theta^{Lab}<-0.8$) from light targets before the acceptance corrections. The insert shows the result after the acceptance correction for the events which have two protons with well defined good tracks [5].

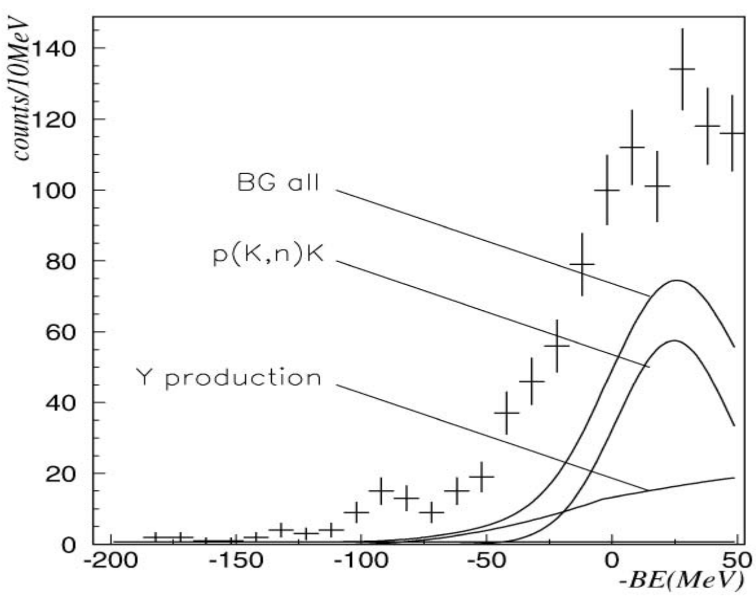

Fig. 12. Missing mass spectrum of the $^{16}O(K^-, n)$ reaction measured by E930 at BNL-AGS. See text for details [7].

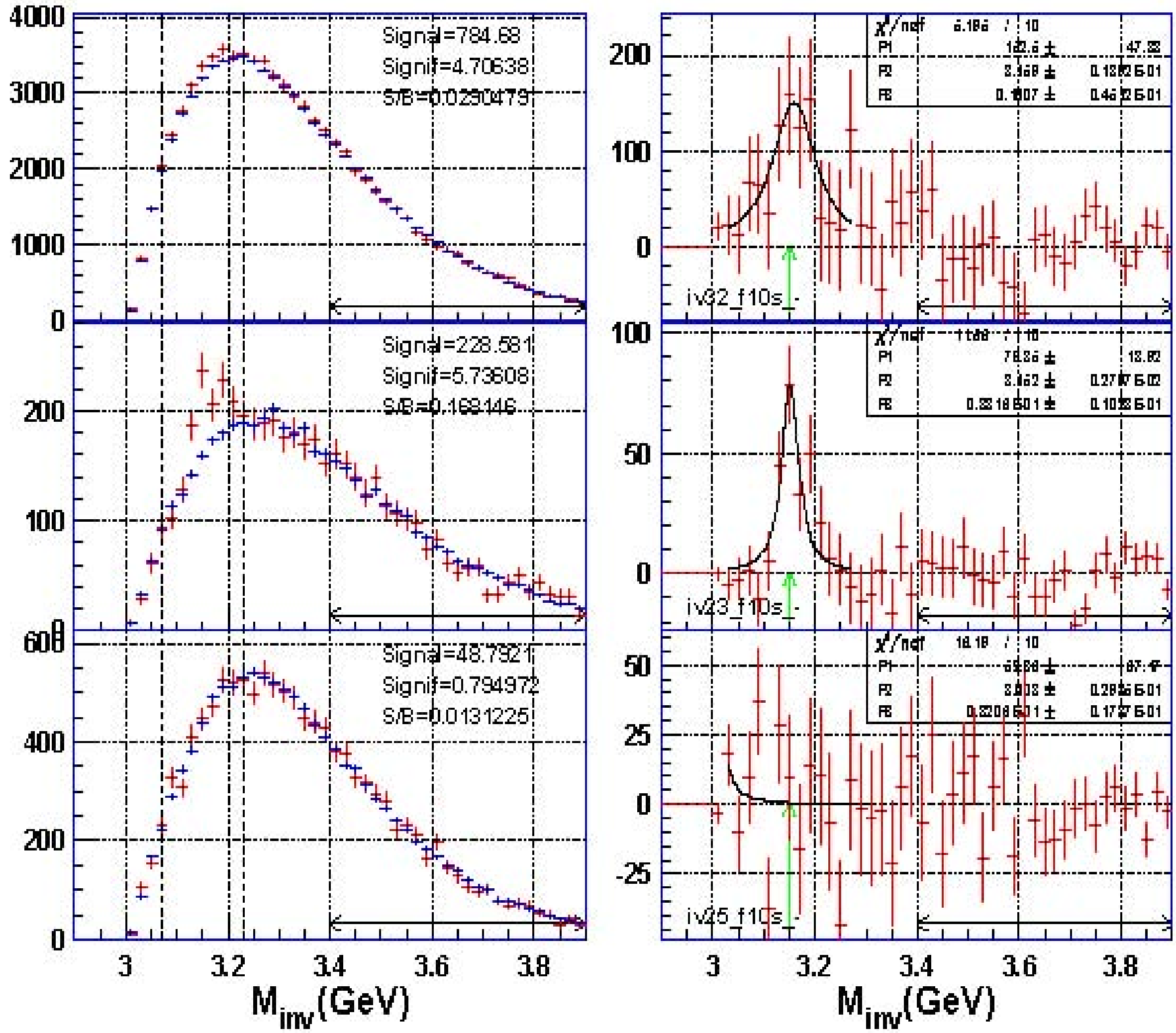

Fig. 13. Distributions of invariant mass of Λ-d pairs measured with FOPI at GSI in data (top), signal-MonteCarlo (middle) and background-MonteCarlo (bottom) [6].

4.5 Ongoing and future experiments

4.5.1 E549, KEK

The KEK facility has been closed in December 2005. Prior of its closure, an upgrade of E471, called E549, has taken data from May 2005 with the primary goal to confirm the existence of the two strange tribaryons observed by E471: the neutral $S^0(3115)$, T=1, in the proton spectrum, and the charged $S^+(3140)$, T=0, in the neutron spectrum.

In the proton spectrum, E549 has taken inclusive data with newly constructed proton tracking chambers and dedicated high resolution TOF counters. In the about one month scheduled running time, the $S^0(3115)$ statistics has been increased by a factor more than 5 and peak position/width/formation rate can be determined with much improved accuracy. Analysis is in progress.

4.5.2 E549/E570, KEK

For the neutron spectrum, in which evidence of the $S^+(3140)$ was observed, statistics can only linearly increase with the beam time. Therefore, neutron data have been taken both in the running time of E549 and during data taking of the connected experiment E570, whose goal is to measure kaonic helium X rays.

The global neutron statistics should become close to that of the proton spectrum in E471. Analysis of neutron data from E549 is in progress.

4.5.3 FINUDA, DAΦNE-LNF

The plan of FINUDA is to investigate via invariant mass and missing mass spectra the formation of strange dibaryons and tribaryons with an overall statistics corresponding to about 1 fb^{-1} integrated luminosity. The following light targets will be used: ^{6}Li, ^{7}Li, ^{9}Be, D_2O, ^{13}C.

4.5.4 Experiments at J-PARC

The 50 GeV PS of J-PARC will provide a unique playground for the study of deeply bound kaonic nuclear states [61]. The high kaon beam intensities (~ 10^6 $K^{\pm}$/s) which can be obtained are planned to be used in dedicated experiments. Differently from DAΦNE, the momenta of the kaon beam obtainable at J-PARC will be rather high: in one line (K1.1) about 1 GeV/c and in another one (K1.8) about 1.8 GeV/c.

There are two Letters of Intent which propose scientific programmes which are partially/totally dedicated to deeply bound kaonic nuclear states studies:

- **LoI 06*:*** *"New Generation of Spectroscopy and of Hadron Many-Body Systems with Strangeness S=-2 and S=-1",* mainly dedicated to the study of the strangeness –2 systems and to the γ-ray Hypernuclei spectroscopy. In this letter, in a short final note, a general interest towards the field of deeply bound kaonic states is expressed.
- dedicated **LoI 10**: *"Study of Dense $\overline{K}$ Nuclear Systems",* which considers two kinds of processes to produce kaonic nuclear cluster: (K^-, N) and (K^-, π^-), reactions. Moreover, the possibility of creating double-kaon bound states via (K^-, K^+) and (K^-, $\overline{K}^0$) processes is considered.
  - *Production of kaonic nuclear states with (K^-, N*) reactions will be observed by the missing mass spectra of the (K^-, p) and (K^-, n) reactions. Outgoing protons will be measured by a spectrometer to be built by J-PARC. A standard detector system (plastic scintillators, drift chambers, Cherenkov counters) will equip the spectrometer. For neutron detection, a momentum resolution of 10 MeV/c will be required, which implies a combination of neutron counters with high time resolution and a time-of-flight length of 10 m. Light nuclear target, d, ^{3}He, ^{4}He, ^{12}C and Si will be used in the first phase of the experiment.

  - *Production with the (K^-, π^-) reaction.*

    The first step of the experimental program is the study of the process:

$$K^- + d \rightarrow (K^-pp) + \pi^-. \qquad (5.1)$$

The experiment is proposed to be performed at the K1.1 beam line, with a beam line spectrometer and the SPES-II spectrometer. For the tagging of the decay products from the K^-pp bound state, the Cylindrical Detector System (CDS), constructed for the BNL E906 experiment, will be used. Once the existence of such a K^-pp bound system is well defined, the study of the $^4He(K^-, \pi^-)K^-pppn$ reaction will be performed, where the K^-pppn system with the binding energy of ≈ 190 MeV will be produced.

- *Double-kaon nuclear states*

In a kaonic nuclear state the $\overline{K}$ acts as a *contractor* of the surrounding nucleons with a shrinkage effect on nuclear matter which turns out in an increase of the average density up to 3 times the normal value. *One can compress nucleons even further with double-kaon bound states*, as shown in Fig. 14.

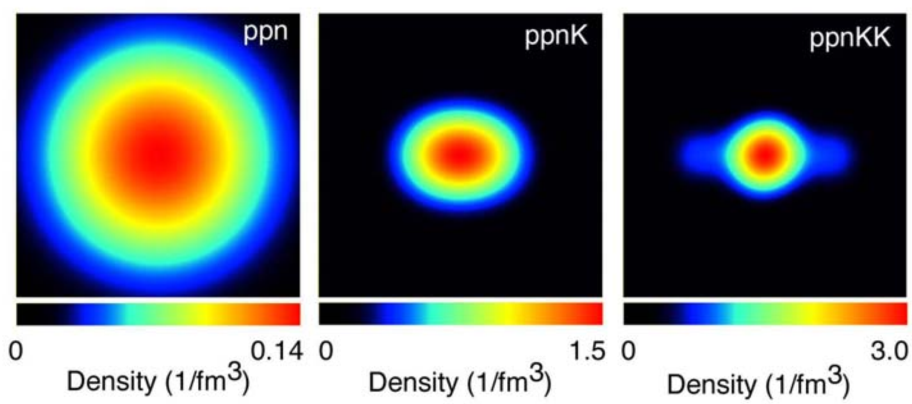

Fig. 14. Density distribution of ppn (= ^3He) (left), K^-npp (center) and K^-K^-npp (right) obtained by a new framework of antisymmetrized molecular dynamics (AMD) [17, 62].

To excite two-kaon bound states several processes are possible, namely (K^-, K^+) and (K^-, $\overline{K}^0$) reactions, as shown in Fig. 15. The kinematics are similar, so let's discuss the first process as a model case.

- Production with (K^-, K^+) reactions

The (K^-, K^+) process can be performed by a single nucleon reaction. The second negative kaon is produced through virtual Φ-production:

$$K^- N \rightarrow K^- N \Phi \quad . \tag{5.2}$$

The threshold momentum to produce Φ on a single nucleon at rest is ≈ 2.6 GeV/c. If one considers the direct (K^-, K^+)-pair production

$$K^- N \rightarrow K^+ K^- K^- N, \tag{5.3}$$

the required incident momentum is getting smaller.

The production of double-$\overline{K}$ bound nuclear states via (K^-, K^+) reactions requires an incident K^- momentum of ≈ 2.1 ÷ 2.5 GeV/c. This momentum range exceeds that of the presently planned K1.8 beam line, unless the binding energy is very large (300÷400 MeV). Rebuilding some critical magnets or constructing a new beam line might turn out necessary.

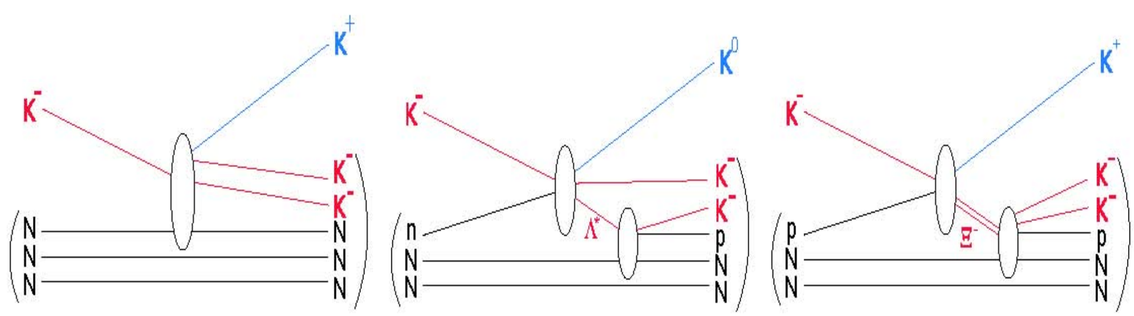

Fig. 15. Production processes of double-kaon nuclear states [LoI 10 J-PARC].

4.5.5 FOPI, GSI Al-Al

On the basis of the results obtained in Ni+Ni collisions [6], where a resonance structure in the Λ+d pairs invariant mass spectrum was observed with FOPI at 3160 MeV, search for kaonic nuclear clusters in 2 AGeV Al-Al collisions has taken data (August 2005). The aim was to reduce the combinatorial background and increase the statistics with respect to the previous measurement.

4.5.6 FOPI, GSI p-d

By making use of the excellent capability of the FOPI detector in identifying both K^0 and Λ, 3.5÷4.5 GeV protons on a deuterium target will be used [63] in 2007. Formation of Λ(1405) in a hard initial process and then use of the Λ(1405) as a doorway to form the K^-pp clusters, is the two-step process followed:

$$p + d \rightarrow [\Lambda(1405) + p] + K^0 + p \rightarrow K^- p\, p + K^0 + p \qquad (5.4)$$

In this reaction, a missing mass spectrum of K^-pp can be constructed by measuring K^0 and p.

Moreover, according to the decay pattern:

$$K^- p\, p \rightarrow \Sigma^{\pm} + \pi^{\mp} + p \qquad (5.5)$$

$$\text{or} \rightarrow \Lambda + p$$

an invariant mass spectrum can also be built. This experiment took a test run in October 2005. Analysis is in progress. Proton indirect reactions on C target will follow, to produce kaonic nuclei with A>2. Dalitz analysis of 3-body decays will be developed.

5 Upgrading DAΦNE

DAΦNE will be upgraded in luminosity for the running experiments through a series of R&D specific works. This multi-stage process will represent the first necessary step towards the realization of a new facility, upgraded in luminosity and having a wider energy range, up to 2.4 GeV c.m.

In Table 1 the luminosity and energy features of the new facility are reported.

Energy @ center of mass (GeV)	1.02	2.4
Integrated Luminosity per year (fb^{-1}) >	10	1
Total integrated luminosity (fb^{-1}) >	50	3
Peak luminosity (cm^{-2} sec^{-1})	10^{33}	10^{32}

Table 1. Luminosity and energy features of the new facility [64]

5.1 The road towards a new facility

The new facility will greatly benefit from the R&D work to increase the luminosity of DAΦNE for the actual running experiments until end 2008.

High luminosity implies continuous injection. Therefore the *priority upgrad*e of DAΦNE, to be kept in the new facility, is the *upgrade of the injection system*, which consists of:

- *Doubling of transfer lines*
- *Installation of fast stripline injection kickers.*

This upgrade allows better efficiency, faster injection, virtually no background during injection.

Other specific R&D works to increase luminosity, propedeutic as well to the understanding of the critical parameters of the machine, are:

- *shielding of the Ion Clearing Electrodes (IEC)* in the wigglers, to decrease the electron ring impedance so to obtain shorter bunches;
- *upgrading of the transverse feedback system* with the new SLAC modules, so allowing higher currents and more stable beams;

- *modelling of the wigglers poles,* to eliminate wiggler non-linearities. This turns out in an increase of the ring energy acceptance and the beam lifetime;
- *Ti coating in the wigglers chambers of the positron ring,* to increase the positron current.

The new facility will make use of: DAΦNE buildings, DAΦNE infrastructures, DAΦNE injection system + upgrade of transfer lines, large part of magnets, diagnostics.

It is as well planned to have: new dipoles, wigglers, RF system, vacuum chamber, interaction region and the application of new technologies

5.2 The advantage of an upgraded DAΦNE for AMADEUS

DAΦNE has proven to be a machine where hadron physics in the strangeness sector can achieve important results. These results were obtained in dedicated measurements, which exploited the unique features of "kaon beam" coming from the decay of the Φ's produced in $e^+ e^-$ collisions.

The new facility, characterized by a peak luminosity around 10^{33} $cm^{-2}s^{-1}$ [64], can play with AMADEUS a special role in studying kaonic nuclear clusters in Frascati Laboratories. In fact, the future experiments in Japan (J-PARC) [61] will produce kaonic nuclear states only with *K^--induced reactions in-flight* (p_{K^-} =1÷2 GeV/c), either in (K^-, N) or in (K^-, π^-) processes. Therefore, the upgraded DAΦNE with AMADEUS will *become the scientific pole for studying kaonic nuclear states with K^--induced reaction at rest.*

AMADEUS will take advantage of:

- Low-momentum (127 MeV/c), medium intensity charged kaons: ≈ 1500/s at $L \approx 10^{33}$ $cm^{-2}s^{-1}$;
- Low momentum spread (<0.1%);
- $K^{\pm}$ pairs produced in a back-to-back topology;
- hadronic background intrinsically low – differently from that of an extracted beam.

These features imply:

low-momentum kaons with low-momentum spread give the possibility to use either *gaseous targets* (as proved by DEAR) or *thin solid targets* (as proved by FINUDA). *This simplifies the experimental apparatus* (and reduces costs). In the same time, the use of thin targets (Beryllium, Carbon, etc) greatly simplify the reconstruction/trigger features and reduces background.

another great advantage of the use of a gaseous target is related to the *neutron background generated by negative pion absorption*. This was one of the crucial background sources in the E471 experiment at KEK, where the first indications of kaonic nuclei were seen. As result of a quasi-free hyperon production in K^- induced processes, followed by hyperon decay, a large number of low energy π^- is produced. The pions can stop quite easily in the materials of the frame which contains a liquid target and in the liquid itself. A pion of ≈ 50 MeV/c stops in few cm in a liquid helium target. Pions at rest react with nuclei in a two-nucleon absorption process, which dominantly yields to two neutrons in the final state: $\pi^- N\, N \rightarrow n\, n$. Unfortunately, the Q-value of the reaction is ≈ 140 MeV and so the process produces neutrons of energy up to 70 MeV, which is exactly in the area of interest. The yield of these background neutrons depends on the equivalent g/cm^2 of the target, namely on density and thickness, and on the materials put around the target itself. All this will be reduced in AMADEUS and therefore the neutron background substantially cut.

the back-to-back topology which characterizes K^- production, can be used to trigger on (K^-, K^+)-pairs, so selecting K^-induced events.

another trigger system might be implemented by taking advantage of the X rays emitted in the decay of the kaonic atoms, created in the initial stage of the process. The effectiveness of this X-ray trigger will depend on the signal/background ratio.

6 Detector requirements for the AMADEUS programme

Preliminary to the definition of the experimental setup of the AMADEUS project, it is vitally important to identify *methods* to study the characteristic features of the kaonic bound nuclear systems: binding energy, level widths, angular momenta, isospin, sizes, densities, etc. This can be done by *not only observing the production stage of the* $\overline{K}$*-clusters* via missing mass spectroscopy, *but also their decay products,* since their momentum correlations contain information on the internal structure of the exotic system. It is therefore necessary to use a *4π detector capable of detecting all particles created in both the formation and decay of the* $\overline{K}$*-clusters.* This is similar to the FOPI detector at GSI Darmstadt, where the formation of $\overline{K}$-clusters in heavy-ion collisions and in a p-d reaction is studied. A necessary *major improvement beyond all currently existing detectors* will be the addition of the *capability to detect neutrons in addition to charged particles in 4π geometry,* which will, for the first time, allow the *complete determination of all formation and decay channels.*

Exotic nuclear states in light nuclei produced with (K^-, N) reactions, at rest or in flight, the first ones mandatory when working at DAΦNE, will be observed by the *energy distribution of the ejected protons and neutrons* via the missing mass spectra of the (K^-, p) and (K^-, n) reactions. Outgoing protons (400÷500 MeV/c) will be measured in the 4π detector by a magnetic spectrometer equipped with counters and drift chambers. The emitted neutrons (400÷500 MeV/c) will be detected by a surrounding array of neutron detectors using time of flight techniques for momentum determination.

Using a 4π detector system surrounding the target, charged decay particles and neutrons from kaonic nuclei can be identified event by event, and their 4-momenta can be determined. The exotic states are expected to predominantly decay into final states containing Λ and Σ hyperons and protons, deuterons or larger systems of nucleons. The formation and decay processes of the (K^-ppn) strange tribaryon after K^- absorption on ^{4}He are shown in Fig. 16.

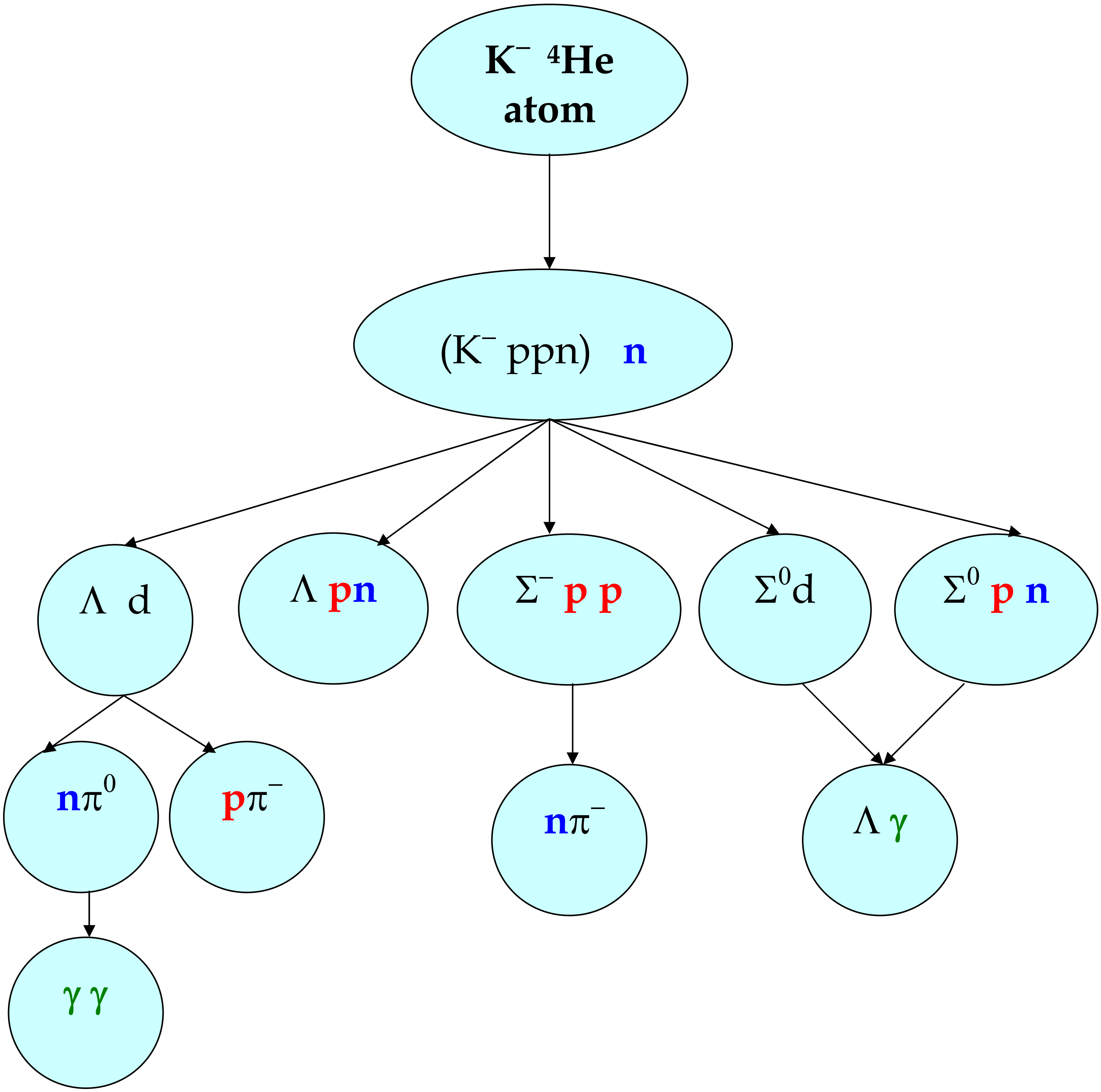

Fig. 16. Formation and decay of the $K^{-}ppn$ strange tribaryon, after K^{-} absorption on ^{4}He.

The most important feature of a detector is therefore the *reconstruction capability for Λ and Σ* hyperons from the invariant mass of their decay products Λ's and Σ's from the decay of light $\overline{K}$–nuclear clusters, like K^- pp, K^- ppn, K^- pnn will have maxima momenta of 500÷700 MeV/c. The same holds for the other decay products of the $\overline{K}$–nuclear clusters, like protons, neutrons and deuterons. The decay of these high-momentum Λs and Σs produces protons and neutrons of 500÷800 MeV/c and pions of 200÷300 MeV/c, including π^0 and photons. A good momentum resolution for these particles is mandatory for a clean reconstruction of Λ's and Σ's.

From this data, *frame-invariant Dalitz plots* can be constructed, which are expected to reflect the size and density of the initial exotic state.

7 The KLOE detector

The detector requirements for the AMADEUS program, presented in the previous Section, are satisfied by the KLOE detector, implemented in the central region with a specific AMADEUS target system.

In this Section, the performances of the KLOE detector are presented.

KLOE, Fig. 17, is a large acceptance (96%) general purpose detector, originally designed to study the CP-violation in the neutral-kaon system [65]. Its versatility allowed to perform a rich physics program, including measurements of radiative Φ-decays, numerous decays of charged and neutral kaons and measurements of hadronic cross-sections. The most interesting channels measured by KLOE have branching ratios going from 10^{-3} to 10^{-6}, for which the good momentum resolution for charged products, excellent energy and time resolution for photon detection are fundamental. We mention that these branching ratios are of the same order of magnitude, 10^{-3}, or even much smaller, than the estimated branching ratios of the deeply bound kaonic nuclear states [66].

KLOE has solenoidal geometry, and consists of a large helium drift chamber (DC), surrounded by a fine sampling lead-scintillating fiber electromagnetic calorimeter (EMC), and it is immersed in a 0.52 T field of a superconducting solenoid.

The DC [67] is a cylinder of 25 (198) cm inner (outer) radius, 332 cm long, containing 12.582 drift cells distributed in 58 cylindrical layers. For the 12 inner layers the cell dimensions are 2 x 2 cm^2, while for the 46 outer ones 3 x 3 cm^2. All wires (sense + field + guard) are stereo wires, with an angle alternating from layer to layer, increasing from 60 mrad for the innermost layer to 150 mrad to the outermost one. The spatial resolution is 150 μm in the rΦ plane, while along z direction it depends on the stereo angle, being about 2 mm. The chamber is filled with a mixture of 90% Helium and 10% isobutane. Its performance for charged particles having momenta in the range 100-500 MeV/c is $\sigma_{p_t}/p_t < 0.4\%$ for the large-angle tracks. The vertices inside the chamber are reconstructed with a spatial resolution of about 3 mm. The fact that the chamber is instrumented with ADCs supplements the particle identification capability with the dE/dx information for the reconstructed tracks.

The e.m. calorimeter (EMC) [68] is of sampling type, made of layers of lead and scintillating fibers, with a volume proportion lead: fiber: epoxy = 42:48:10; the total thickness is 23 cm (15 X_0). The EMC is composed of a barrel and two endcaps, with the barrel divided in 24 modules and each endcap in 32 (vertical) ones. The endcaps have a C-shape such as to close the solid angle as much as possible.

The light from scintillating fibers is seen by PM tubes at each end, in order to determine the time of flight and impact point along the fiber direction. The readout is segmented in depth into 5 planes (4.4 cm thick each, except for the outermost which is 5.2 cm thick) and in the coordinate transverse to the fibers into columns 4.4 cm thick. There are 4.880 PMs in total. In order to complete the coverage of the solid angle, two small calorimeters (QCAL [69]), made of lead and scintillating tiles, are wrapped around the small-β quadrupoles.

The PM signals are sent to ADC for amplitude analysis, to TDC for time-of-flight measurement and to the trigger modules. The energy resolution for the photons is $\sigma_E/E = 5.7\%/\sqrt{E(GeV)}$, while the time resolution is $\sigma_t = [54/\sqrt{E(GeV)} + 50]$ ps. The photon impact point is measured with a precision of 1 cm/$\sqrt{E(GeV)}$ along the fibers and ~ 1 cm in the transverse coordinate.

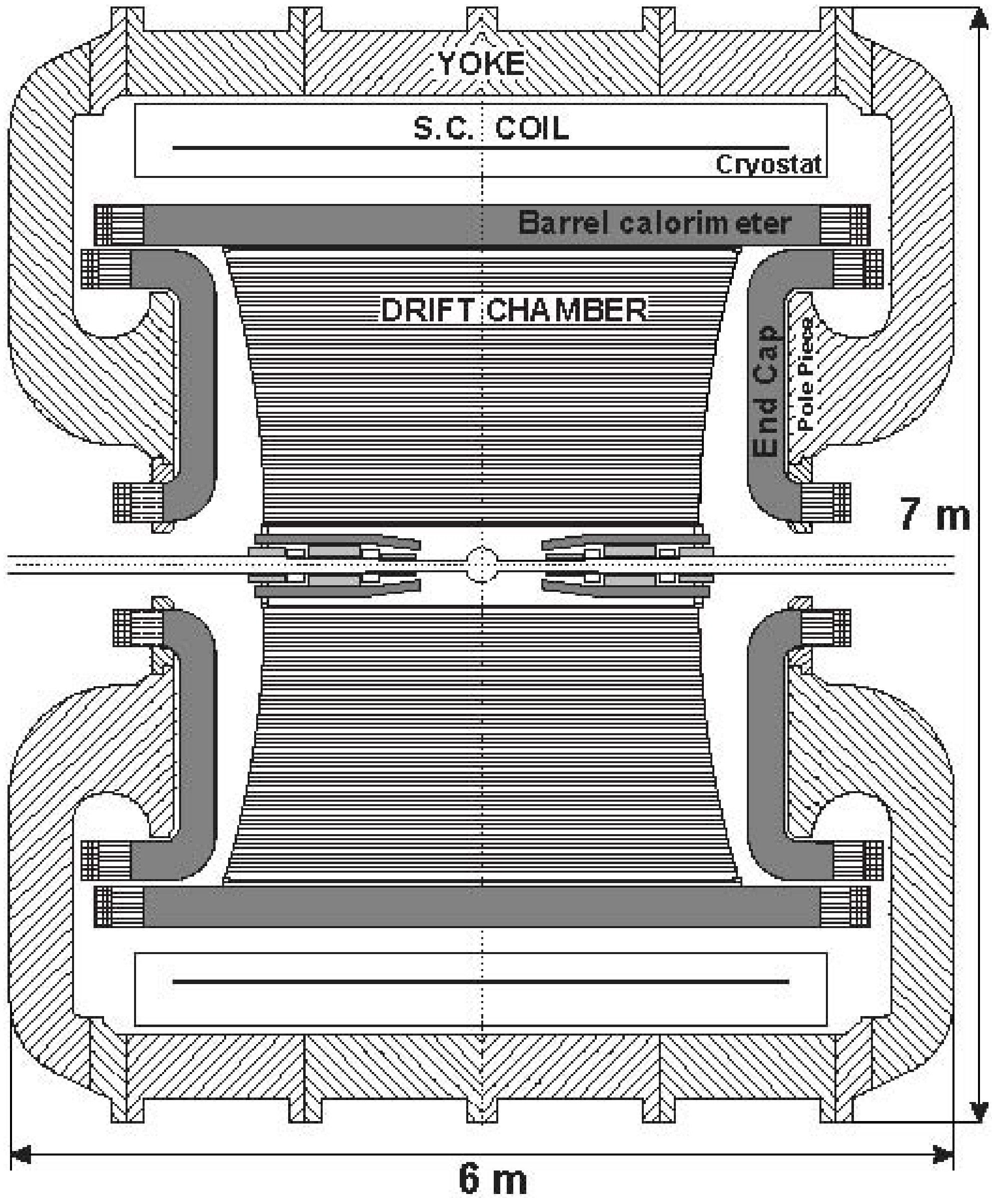

Fig. 17. Schematic side view of the KLOE detector

The trigger which was used for the KLOE physics is based on energy deposited in 88 calorimeter sectors and on drift-chamber signals, and is divided in four levels. For more information on the trigger system, as well as on the DAQ one, see [70, 71].

As examples of the KLOE performances, we reproduce the following figures [70, 71]:

- Momentum resolution as a function of polar angles for Bhabha events (Fig. 18);
- Invariant mass distribution for $K_s \rightarrow \pi^+\pi^-$ events (Fig. 19);
- Reconstructed invariant mass distribution for a) π^0's; b) $K_s \rightarrow \pi^0\pi^0$ (Fig. 20).

All these figures of merit make the KLOE detector a very suitable detector for the AMADEUS measurements. The charged particles coming from AMADEUS, in formation and decay processes, are in the energy range where KLOE detector is optimized, in terms of efficiency and performances. Moreover, the neutral pions, often generated in the deeply bound kaonic nuclei decay processes, are as well in the energy range where KLOE is optimized for their detection. The reconstruction of the strange baryons (Σ, Λ) can be done by a suitable detection of the secondary charged and neutral particles generate in their decay process. An AMADEUS-KLOE common working group, in the framework of the KLOE K-charged physics sub-group, started to work on the strategy of detection of multi-vertex processes (specific to deeply bound states decays), with the goal to identify and develop algorithms specific for their detection.

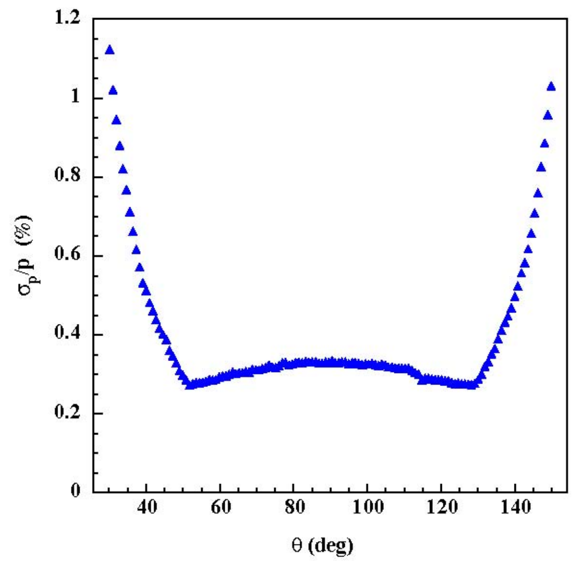

Fig. 18. Momentum resolution as a function of polar angles for Bhabha events

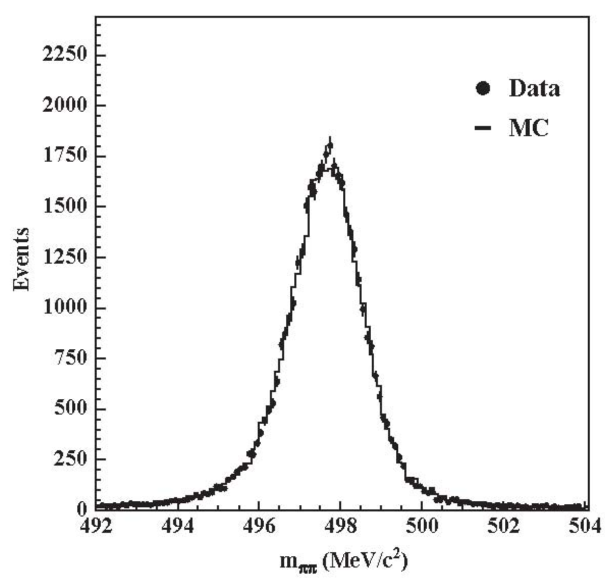

Fig. 19. Invariant mass distribution for $K_s \to \pi^+\pi^-$ events

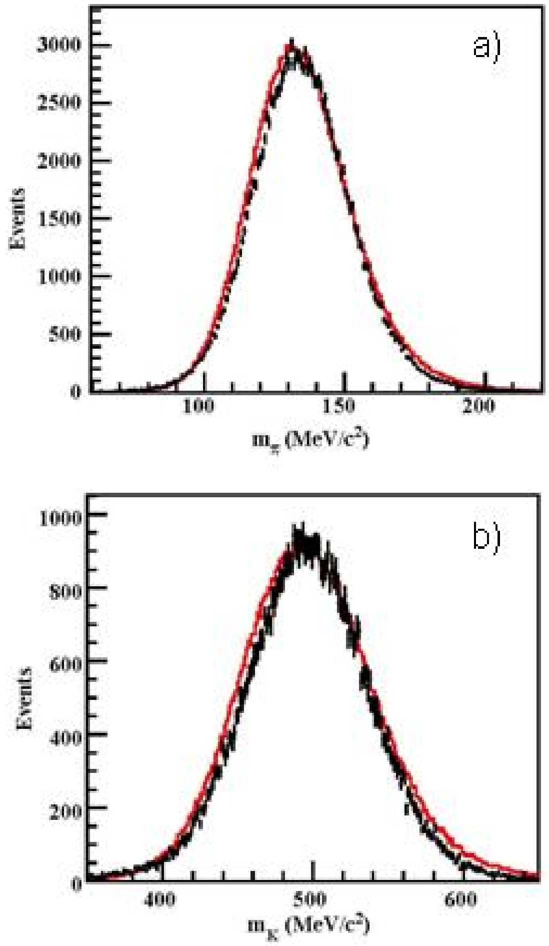

Fig. 20. Reconstructed invariant mass distribution for a) π^0's; b) $K_s \rightarrow \pi^0\pi^0$ (continuous line: Monte Carlo simulation results)

The implementation of AMADEUS in KLOE represents a specific problem to deal with. One has to find a suitable place within KLOE where AMADEUS can place its target(s)-system, a trigger (based on the back-to-back charged kaons topology) and, eventually, a vertex detector. The latter might be used in common by KLOE and AMADEUS and, therefore, be developed in a cooperation between the two groups. The location of a possible AMADEUS setup inside KLOE was identified, around the Interaction Region, inside the DC, as shown in Figure 17.

The AMADEUS implementation in KLOE and related items are described in Section 9.

A second item needs as well to be dealt with: the neutron detection. Many of the interesting channels end up with a neutron, either in formation process and/or in the decay one. This makes the neutron detection an item needing special care. The neutron should be detected by the EMC, already present in KLOE. The programme of KLOE physics did not require neutron detection. We evaluated, from the time resolution of the KLOE calorimeter, that the energy resolution for neutrons of about 500 MeV/c, coming in the process of formation of deeply bound kaonic nuclear states on helium, is of the order of 3%. Another aspect to be considered, is the efficiency of the neutron detection by the EMC. This aspect is considered in the next Section, where Monte Carlo simulation results, as well as plans for experimental determination of the neutron detection efficiency of EMC, are given

Summary of KLOE performances:

- acceptance 96%
- drift chamber momentum resolution for charged particles $\sigma_p/p \leq 0.4$ %
- spatial resolution of vertices in drift chamber: 3 mm
- dE/dx capacity for particle identification: implemented in drift chamber
- energy resolution for photon the in e.m. calorimeter $\sigma_E/E \approx 5.7\%/\sqrt{E(GeV)}$ (GeV)
- time resolution of the e.m. calorimeter $\sigma_t=(54/\sqrt{E(GeV)}+50)$ ps
- photon impact point resolution $1cm/\sqrt{E(GeV)}$ along the longitudinal coordinate and 1 cm along the transverse coordinate
- π^0 mass resolution to 2-3% (reconstruction)

8 The neutron detection with KLOE

The KLOE e.m. calorimeter (EMC) (Figure 21), briefly described in the previous Section, plays an important role in the AMADEUS measurement of neutral particles. While its performance for the measurement of γ's and the reconstruction of π^0's have been fully measured, understood and explored in many of the KLOE existent measurements, its performance for neutron detection have not been investigated so far.

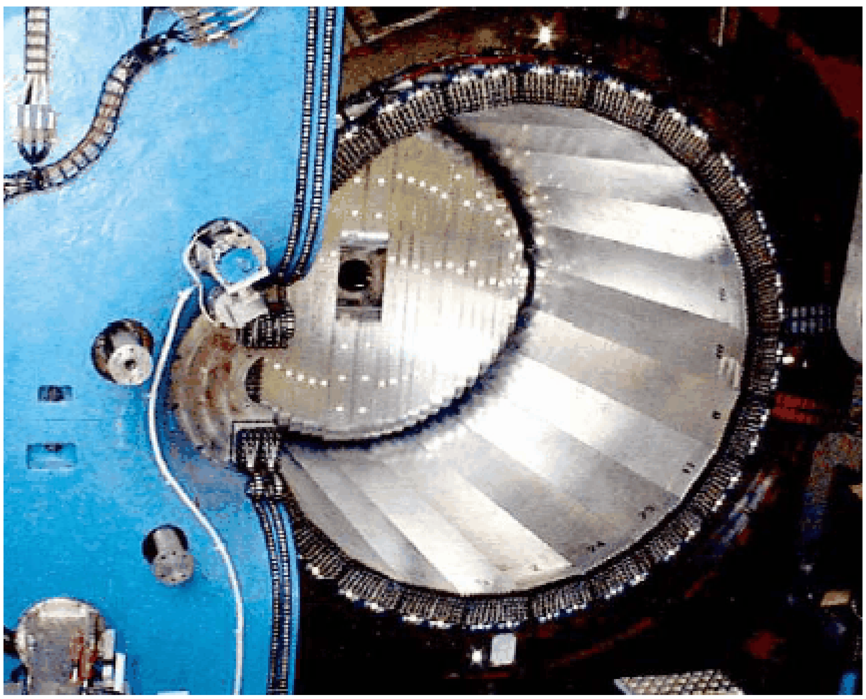

Fig. 21. KLOE e.m. calorimeter (24 barrel modules)

We recall the EMC performance for particle identification via time-of-flight:

$\sigma_E/E = 5.7\%/\sqrt{E(\mathrm{GeV})}$

$\sigma_t/= 54\ \mathrm{ps}/\sqrt{E(\mathrm{GeV})} \oplus 50\ \mathrm{ps}$

High efficiency down to 20 MeV.

Other peculiarities of the KLOE calorimeter are:

- the volume ratio Pb:scint:glue of 42:48:10 has been chosen to maximize the calorimeter sampling fraction and correspondingly increase the light yield (~1 p.e./MeV/side at 2 m distance). This high light yield reflects in an excellent time resolution which roughly scales as $\tau / \sqrt{N(p.e.)}$ with $\tau \approx 2$ ns;
- the very high sampling frequency allows also to obtain an energy resolution which is a factor $\sqrt{2}$ better than sampling calorimeters made alternating layers of Pb and scintillator slabs with similar volume ratio;
- the very thin lead layers used and the high sampling frequency is also chosen to get high efficiency for low energy photons.

Bearing on all these figures, the KLOE calorimeter can be used to measure the neutrons emitted in the process of formation/decay of the deeply bound kaonic nuclear states and, consequently, to allow to perform high precision spectroscopic measurements of these states.

One of the key figures related to the neutron detection by the KLOE e.m. calorimeter is the efficiency as a function of energy. No information is available concerning this parameter.

In order to get information concerning the neutron detection efficiency:

- Monte Carlo simulations have been performed;
- an efficiency measurement, together with KLOE team, on a neutron beam, using a prototype of the KLOE e.m. calorimeter has been planned.

In what follows, both these items are briefly presented.

8.1 Monte Carlo simulation results (preliminary)

8.1.1 Energy range of neutrons for AMADEUS physics

In order to obtain the efficiency of the KLOE e.m. calorimeter for neutrons, one has, firstly, to obtain the neutron energy spectrum, in the formation/decay processes of interest. We considered the formation process of the strange tribaryon K^-ppn following K^- absorption in ^4He and neutron knock out.

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

The (K^-ppn) cluster can then decay in the following channels:

$$\begin{aligned} K^-ppn &\rightarrow \Lambda + d \\ &\rightarrow \Lambda + np \\ &\rightarrow \Sigma^- + pp \\ &\rightarrow \Sigma^0 + d \\ &\rightarrow \Sigma^0 + np \end{aligned}$$

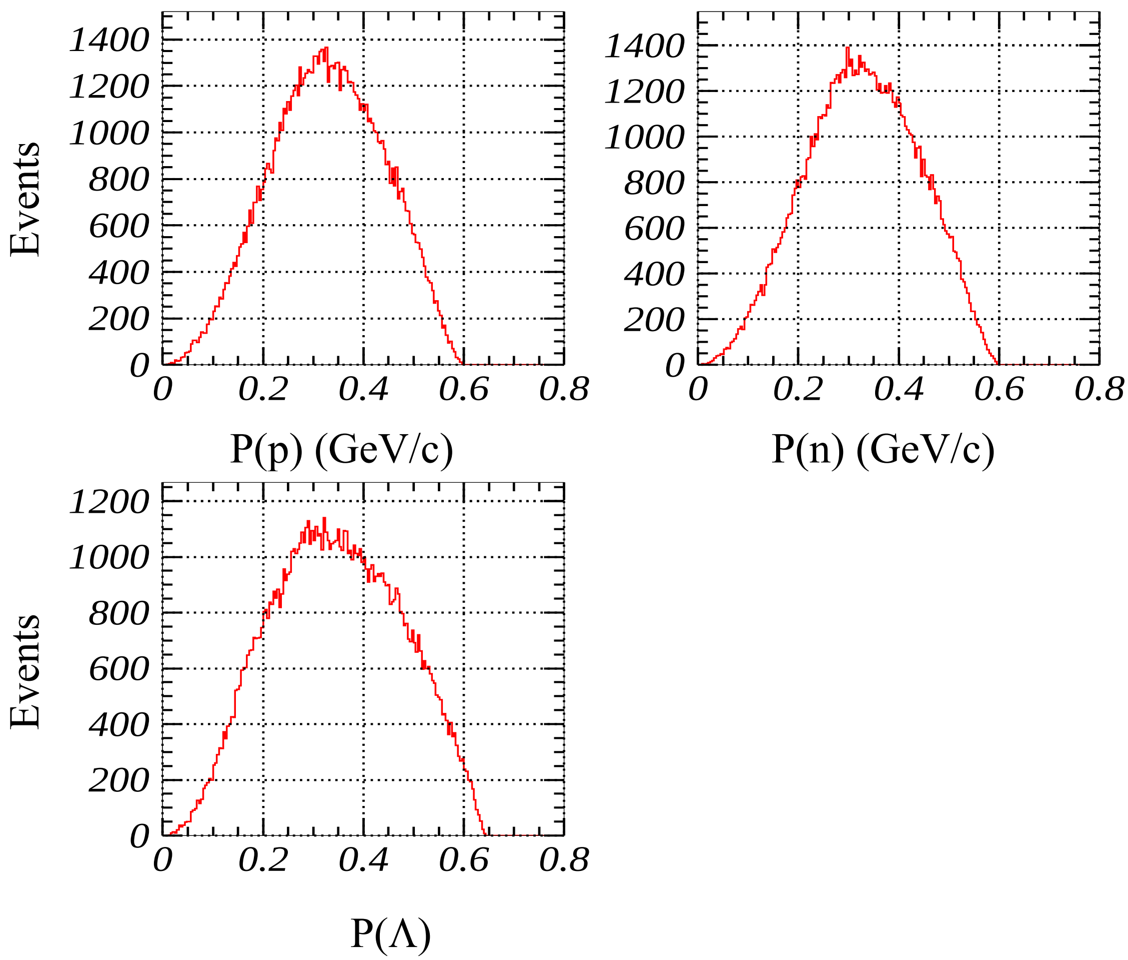

Fig. 22. The momenta distributions of particles resulting from the Λpn decay channel of the strange tribaryon (K^-ppn)

The neutron spectrum, considering the parameters (mass) of the kaonic nuclear cluster being those measured at KEK [72], has a structure composed by a (quasi) monochromatic component (in formation phase) and a continuous one (decay process).

The "monochromatic" component, as measured by KEK, has a momentum of about 510 MeV/c (energy about 140 MeV), while the neutron continuous component starts from low momenta (few tens MeV/c) and extends till 600 MeV/c (about 180 MeV). We give in Figure 22 the momentum spectra obtained for the decay channel:

$$K^{-}ppn \rightarrow \Lambda + n + p$$

The decaying Λ then produces a neutron in the final state in 36% of cases.

A similar work has been done for all possible decay channels generating a neutron in the final state, showing that the energy range of interest for AMADEUS physics includes neutrons from 10-20 MeV up to about 200 MeV.

8.1.2 AMADEUS KLOE-EMC simulations

Having the neutron energy spectrum, the next step was to generate these neutrons in the framework of a GEANT 3.21 based KLOE-like e.m. calorimeter simulation (with GEANT FLUKA [73]) and to register the efficiency [74].

The KLOE-like e.m. calorimeter was simulated such as to reproduce as realistic as possible the real one, where the real one has the following characteristics:

- the calorimeter structure consists of a stack where alternating layers of scintillating fibers of 1 mm diameter are glued inside thin grooved lead layers of 0.5 mm thickness.
- the composite has a volume ratio Pb:scint:glue of 42:48:10, corresponding to a density of 5.0 g/cm^3 and a radiation length X_0 of 1.5 cm. The final stack has a depth of 23 cm (15 X_0) corresponding to about 200 planes of lead/fibers.

One quarter of the calorimeter was modelled, the azimutal angle 0-90 degrees was subdivided in 8 modules. Each module consisted of a lead converter with an inner radius of

199.9 cm and an outer radius of 222.1 cm. The total length was 440 cm. In these 8 volumes the fibres were placed as copies of cylindrical volumes with 0.05 cm radius (1mm

diameter). By taking the tangential pitch of 1.35 mm and the radial pitch of 1.2 mm, the number of fibres in each module was 56079.

8.1.3 Simulation results – neutron detection efficiency

In order to obtain a result for neutron detection efficiency, the inner part of the KLOE apparatus was removed from the model and the neutrons were made to start isotropically from the centre of the apparatus (the beam interaction point). The neutron momentum was sampled uniformly in the interval 100-1300 MeV/c. The sum of deposited energies in the fibres (starting from 0 ‘no signal generated’) of one module was histogrammed versus the incoming neutron energy. The ratio of the number of neutrons depositing energy versus the total number of incoming neutrons gives the intrinsic efficiency. The values are given for 2 lower thresholds of the deposited energy: 3 and 1 MeV. Only signals produced by protons were taken into account.

The result of the preliminary Monte Carlo simulation for the intrinsec efficiency of the KLOE e.m. calorimeter for neutrons are then shown in Figure 23.

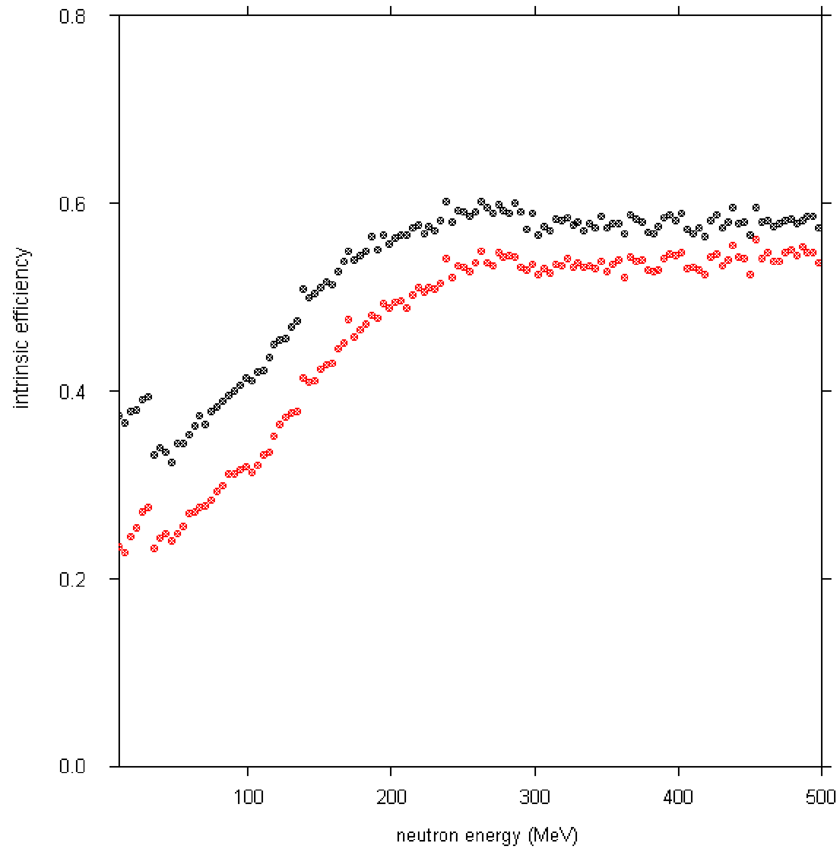

Fig. 23. Neutron detection efficiency – AMADEUS Monte Carlo results for KLOE EMC. The lower points correspond to 3 MeV threshold on the deposited energy, while the upper ones to 1 MeV

A comment is necessary at this point: as seen in Figure 23, there is a discontinuity at an energy of neutron around 20 MeV; this is a well-known behavior of GEANT and is related to the fact that below this energy the accuracy of GEANT for neutron interaction (more generally for hadronic interaction) is insufficient – only standalone FLUKA programs are trustable below 20 MeV.

8.1.4 Summary and comments

We reported in Fig. 23 the results for the KLOE EMC calorimeter for the neutron detection efficiency as function of energy. The neutron detection efficiency goes from 20-30% at the lowest energies to 50-60% to higher ones to be checked by measuring. Various effects of treating the signals (as for example the threshold influence) will be implemented in the AMADEUS Monte Carlo simulation in future.

In order to experimentally determine the efficiency of the KLOE e.m. calorimeter for neutrons, a KLOE-AMADEUS group is planning to perform a measurement on a neutron beam, using a prototype of the KLOE e.m. calorimeter, consisting of half of a KLOE-barrel.

The prototype already exists – it was used at the beginning of KLOE already for testing EMC performance at PSI and at CERN.

For what concerns the facility where this test should be done, some choices are under consideration:

- TSL neutron beam at Uppsala - Sweeden
- Neutron facility at Louvain-la-Neuve - Belgium
- IDIS facility - England

To the TSL neutron beam, a beam request was already done. The neutron beam facility at TSL, Figure 24, has a neutron beam with energies going from 20 to about 180 MeV [75].

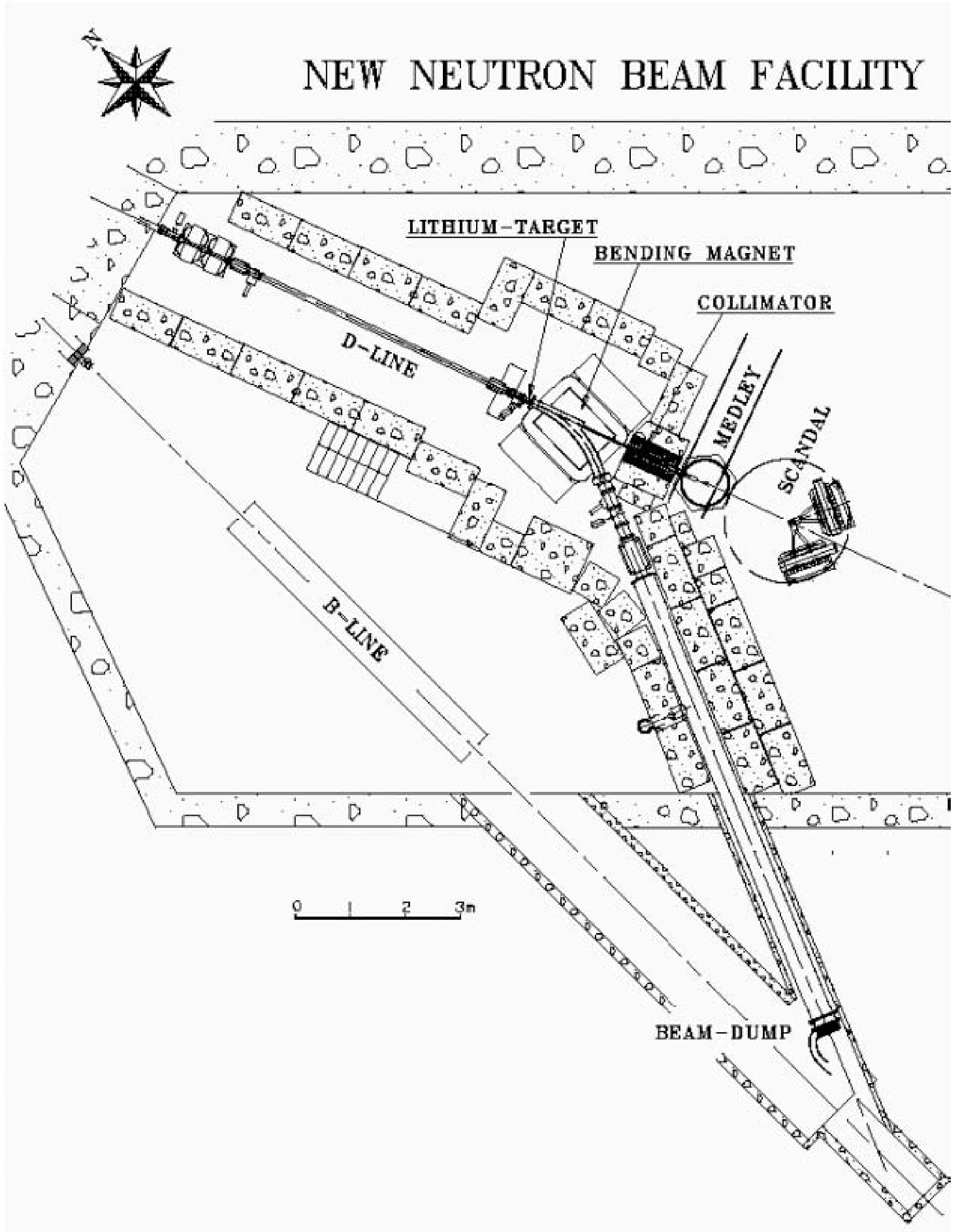

Fig. 24. The TSL neutron beam facility [75]

The possibility to use the TSL neutron beam is under investigation – specifically for what concerns the tagging of the neutrons and the possibility to normalize to the total neutron flux. A lively interaction with TSL neutron beam Responsible (Dr. Hans Calen) is undergoing.

The other two facilities are as well considered, and a decision will be taken within Spring 2006 – such as to perform the test within autumn 2006.

We conclude by saying that this test will give an answer to the pending question of KLOE e.m. calorimeter efficiency for neutrons, a crucial item for the AMADEUS experiment. In the same time, it is a very useful test and playground for checking the results of various Monte Carlo simulations.

9 Implementing AMADEUS with KLOE

9.1 AMADEUS in KLOE

The scientific program of AMADEUS needs stopped kaons; then, one of the most important parts of the AMADEUS setup is the target apparatus where the kaons will stop with high efficiency passing an active degrader. We will use gaseous as well as solid targets. While the installation of solid targets is easy to be dealt with, this is not so for the more challenging case of gaseous targets. A preliminary solution for implementing AMADEUS within the Drift Chamber of KLOE, is shown in Figure 25. The central region within KLOE has a free area with a diameter of 50 cm.

The gaseous target has to supply gas densities in the order of 10% of liquid density (LD) – in order to increase the probability to stop kaons in the target volume, taking into account the limited space available for the target cell. We have to mention that the AMADEUS group has a long proven and well established experience in dealing with high-density gaseous target cells, successfully applied for example in the framework of the DEAR experiment [28] and to be applied in SIDDHARTA [39]. DEAR, for example, worked with a hydrogen gaseous target kept with a pressure of about 2 bar and a temperature of 23 K, achieving a density of about 30 times the NTP one.

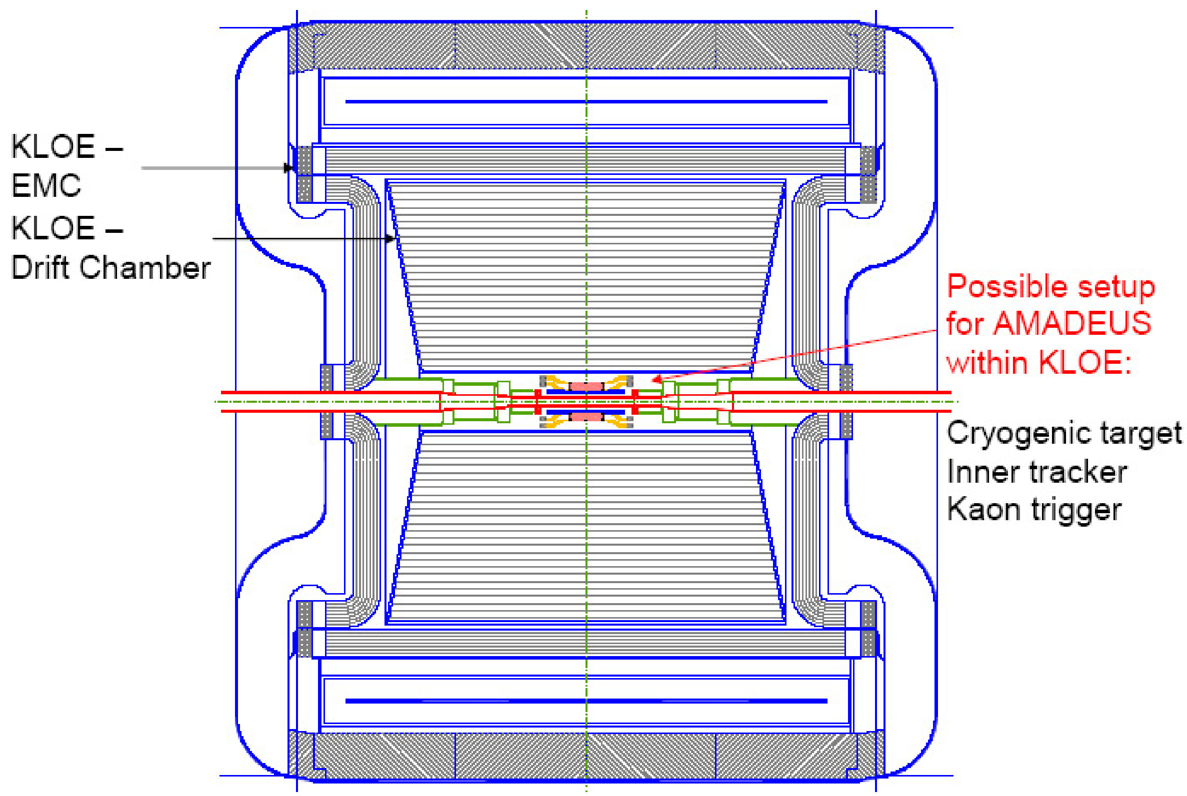

Fig. 25. Possible setup for AMADEUS within KLOE

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In this solution we propose a half-toroidal cryogenic target (Figure 26) placed in the Interaction Region in close distance to the AMADEUS cylindrical beam pipe. The gaseous AMADEUS target is under study with the aim to design a target cell to be used for deuterium, helium-3 and helium-4 with as less material as possible, but still solid enough to achieve gas densities about 10% of LD, in order to stop at least 25 % of the overall generated negative kaons.

A first draft of the target cell takes into account a cryogenic cell basically made of Kapton with a reinforcement structure made of aluminium. A pressure of about 5 bar should be reached at temperatures between 10 K and 30 K. For the target filled with helium with a pressure of 5 bar at a temperature of 10 K, a density equivalent of 150 times the

NTP density will be achieved. Such a prototype is actually under construction by the AMADEUS collaboration, in parallel with a design of mechanical supports which integrates the AMADEUS setup within the KLOE drift chamber.

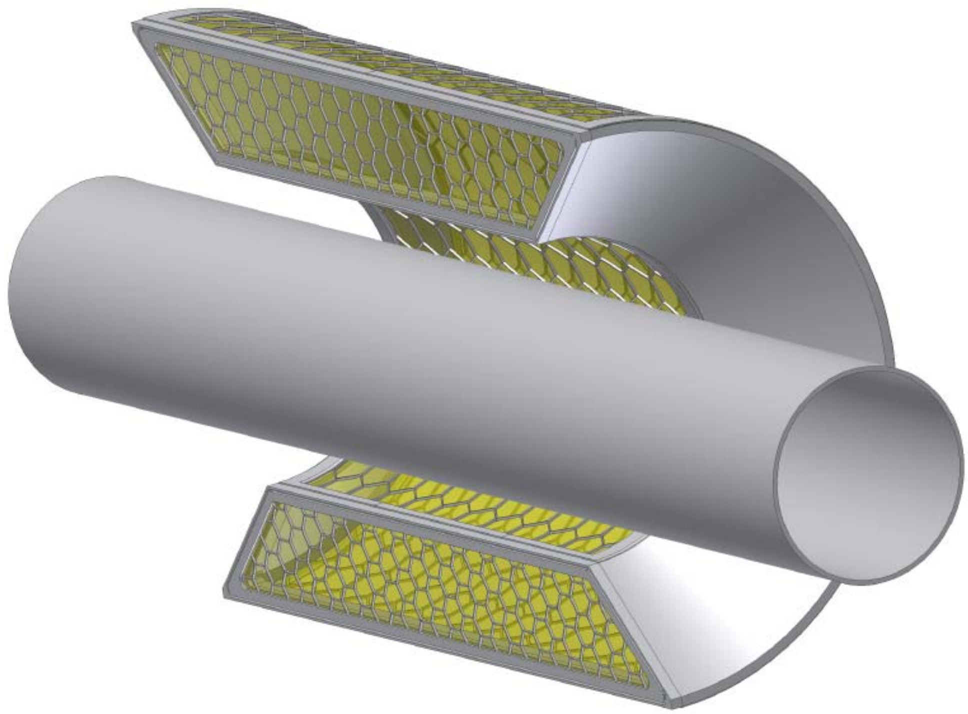

Fig.26 Sketch of the cryogenic target cell of AMADEUS

Although, in principle the existing DEAR/SIDDHARTA beam pipe might be used for AMADEUS, the favoured option is a combined design: vacuum chamber – beam pipe – cryogenic target – scintillating fibers (kaon trigger detector), which of course make it necessary to re-design the beam pipe as an integral part of the vacuum chamber.
The main characteristics of the DEAR/SIDDHARTA beam pipe are as follows: a diameter of 90 mm and a length of 750 mm (including flanges) with the pipe made of aluminium 250 μm thick, with reinforcement layers of Carbon Fiber with a total thickness of 650 μm.

A close look to a possible setup for AMADEUS inside KLOE is presented in Figure 27, where the AMADEUS target and surrounding detectors are shown.

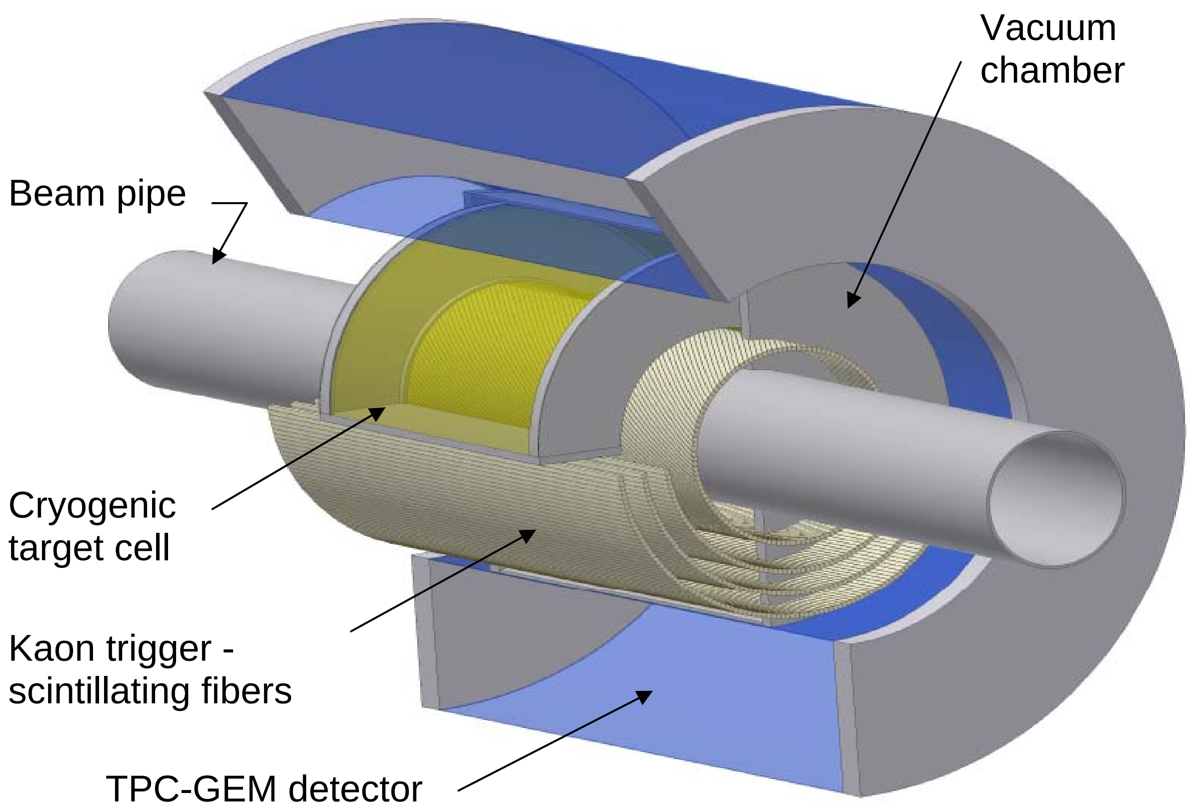

Fig. 27. AMADEUS setup within KLOE

As seen from Figure 27, AMADEUS considers the idea of designing a Time Projection Chamber (TPC) with a Gas Electron Multiplier (GEM) setup as inner tracker surrounding the target cell, in order to have, together with the stopping point information from the kaon trigger, a much better constraint in the position determination of formed deeply bound kaon nuclear clusters. Together with the KLOE DC a much better handle on track reconstructions of the involved particles coming from the formation and decay processes of deeply bound nuclear clusters will be achieved.

The kaon trigger which gives the back-to-back topology to trigger on kaons generated from the Φ-decay, consist of an inner cylindrical layer of scintillating fibres and in addition of three half-cylindrical layers opposite of the target cell to clearly identify the positively charged kaons.

The goal is to build a detector with high efficiency, a time resolution below 500 ps and high granularity. The inner layer of the detector consists of 400 channels of scintillating fibres of 1 mm^2 area. The fibers are glued on both sides to “Geiger-mode” APDs. Reading out both sides of the fiber results in a suppression of noise and allows a position resolution in z direction of a few mm. the fibers are a special type of BICRON BCF with a decay time of 1.5 ns, optimized for high time resolution.

The three outer layers consist of 250, 300 and 350 channels, respectively, to clearly identify K^+ and to define their direction, which is necessary to improve the determination of the stopping area of the negatively charged kaons.

Monte Carlo simulations (Figure 28) show that it is necessary to have the vertex detector as close as possible to the target region to clearly identify the tracks coming from the formation of kaon nuclear clusters and discriminate them from the huge background of produced charged particles via kaon decay, kaon absorption and so on.

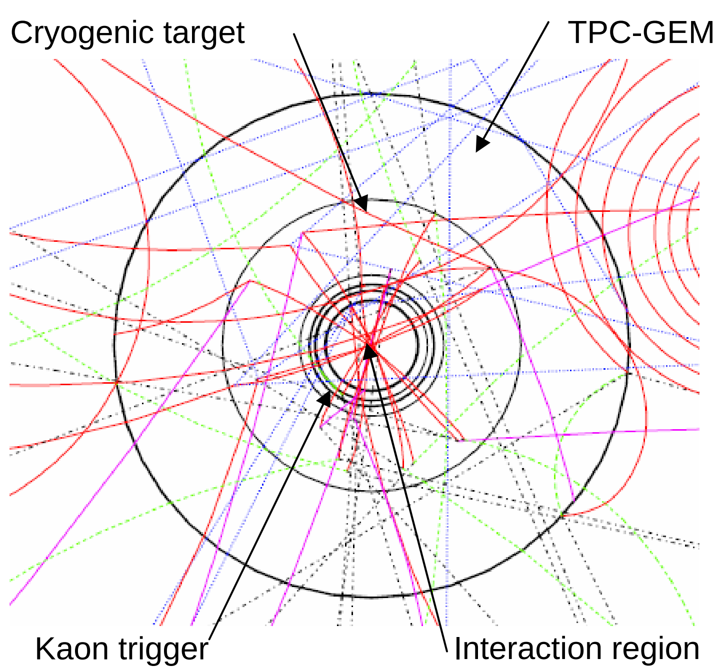

Fig. 28. Simulation of tracks coming from the formation of deeply bound kaonic nuclear states in ^4He (20 events)

Since KLOE collaboration envisages the use of an inner vertex Detector (KLOE-2 EoI) a merging of the two collaboration interests might give birth to a unique inner vertex detector, to be used then by both groups. The next paragraph is dedicated to a preliminary discussion of this item.

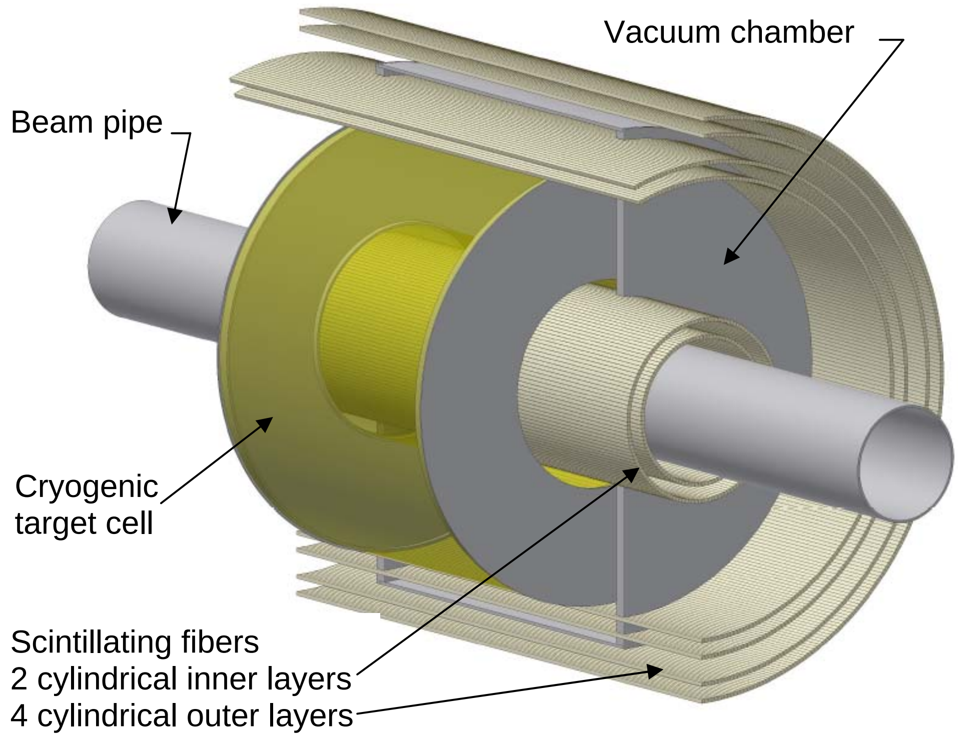

Fig. 29. Sketch of a possible setup with toroidal target, without TPC-GEM detector

Before going to the description of the inner tracker, we would like to make a small comment on the possibility to go for slightly different solutions for the AMADEUS setup: instead of the half-cylinder target, proposed above, we can – if background is under control – adopt a full-cylinder target, relying on the information, for the kaon trigger, coming only from inner scintillating fibre detectors. If, instead, we give up at the inner tracker – described in the next paragraph – with the price of, eventually, having a less accurate tracking, one can envisage a solution as shown in Figure 29, without TPC - GEM, but with a cylindrical target surrounded completely by a layer of scintillating fiber detectors.

9.2 Inner tracker as AMADEUS/vertex detector in KLOE

The design, test and construction of this detector might be done, and AMADEUS is pushing in this direction, in a common effort with the KLOE collaboration (for detector requirements see also the KLOE-2 EoI). A common effort started already in this direction. While it is clear that this detector has somehow different role in KLOE and AMADEUS, a solution satisfying both requests is envisaged and under study.

The AMADEUS setup within KLOE, might take advantage of the existence of a vertex detector, which tracks the charged particles close to their production in the cryogenic target cell of AMADEUS and together with the KLOE DC the background events will be drastically reduced.

A possible solution, which combines the solutions prospected by KLOE (silicon detector; long drift chamber; cylindrical GEM), and on which AMADEUS started to investigate is a TPC- GEM combination with x-y-readout taking as well into account the expertise on GEM detectors already existent at LNF, Frascati.

Our goal is to develop a small prototype of a cylindrical TCP (diameter 200 mm and a length of 300 mm) with a 3-layer GEM for electron multiplication and 2-dimensional pad readout.

Such a detector might interest in the future not only AMADEUS/KLOE – but other experiments in Europe and world-wide (for example in Japan, at J-PARC). For this very reason, it is our intention to put forward to the European Commission, in the framework of an Integrated Activity of the future FP7, the design, development, construction and characterization of a vertex detector in a collaboration which can be enlarged to all interested groups.

10 Precision spectroscopy of light and medium heavy kaonic nuclei with AMADEUS

The AMADEUS programme is based on *precision spectroscopy studies of a number of light kaonic nuclei,* as function of their baryonic number A and isospin T, and then of medium heavy nuclear targets.

10.1 Determination of binding energies, decay widths and quantum numbers of kaonic nuclear states

The *first objective* of such a structure programme is to *determine the quantum numbers* (spin, parity, isospin) *of all states*, *including excited ones, in addition to their binding energies and decay widths.* A precise measurement of the energies of a T=1 multiplet would give its Coulomb energy difference (about 4 MeV) and thus information on the size of kaonic nuclei. In KLOE proton spectra can be obtained with a 1-2 MeV precision. For the neutron spectra, the precision, under study, is of the order of 2-4 MeV.

10.2 Search for excited kaonic nuclear states for determination of the spin-orbit interaction

The most interesting problem with respect to the identification of excited states of kaonic nuclei is the *measurement of the spin-orbit interaction* by detection of $p_{1/2} - p_{3/2}$ spin-orbit splitting, which is predicted to be as large as 60 MeV for the small size of kaonic nuclei, therefore fully measurable with the precisions obtainable in KLOE. The study of the spin-orbit interaction gives an insight into the density change of kaonic nuclei at their surface and on the importance of relativistic strong binding effects.

10.3 Determination of total and partial widths of kaonic nuclear states by observation of all decay channels.

As all the states of kaonic nuclei are quasi-stationary, important information on their structure is contained in their *total and partial decay widths.* Until now, only a upper limit, $\Gamma < 21$ MeV, is known for a kaonic tribaryon state and no information on partial decay channels is available. The total and partial widths of decaying kaonic nuclei are determined by their wave functions and contain thus very basic structure information. For strongly bound systems, non-mesonic decay channels are the only open ones. They are of the type $NY \rightarrow p\Lambda$, $p\Sigma^0$and $n\Sigma^+$. All decay channels can be identified if the detector has neutron detection capability as planned. The $p\Sigma^0$ channel can be indirectly detected using the Λ-decay information from the $\Sigma^0 \rightarrow \Lambda + \gamma$ decay. The $n\Sigma^+$ channel is identified by its $nn\pi^+$ branch.

In paper by Ivanov *et al.* [76] the non-pionic total decay width of K^-pp turns out Γ=28 MeV. Also the partial widths to the Λ and Σ channels are calculated. By measuring these quantities, which are determined by squares of the transition amplitudes from the kaonic nuclei to the hadronic final states, basic structure information on the exotic states is obtained.

We have estimated that total decay widths, accessible via the formation process, can be resolved in AMADEUS at the 1-3 MeV level for proton spectra, and few MeV–still under study–for neutron spectra. For what concerns the decay channels, the partial decay widths can be resolved at the level of 2-3 MeV up to less than 8-10 MeV (depending on the channel).

10.4 Measurement of the 3-body decay

An even more detailed structure information can be extracted from a Dalitz analysis of three-body decays of kaonic nuclei, as was pointed out recently by Kienle, Akaishi and Yamazaki [77]. The Dalitz analysis of 3-body decays such as $K^-np \rightarrow \Lambda + p + \pi^-$,

$K^-ppp \rightarrow \Lambda+p+p$ or $K^-ppn \rightarrow \Lambda+p+n$, displays the intensities of correlated partial invariant mass spectra in the Dalitz plane. This distribution reflects sensitively the momentum wave functions of decaying state and its angular momentum transfer. By measuring Dalitz plots of three-body decay channels one can study the size of kaonic nuclei and assign spin and parity to the decaying states. Figure 29 shows an example of such Dalitz plots correlations for the strange tribaryon decay $K^-ppn \rightarrow \Lambda+p+n$.

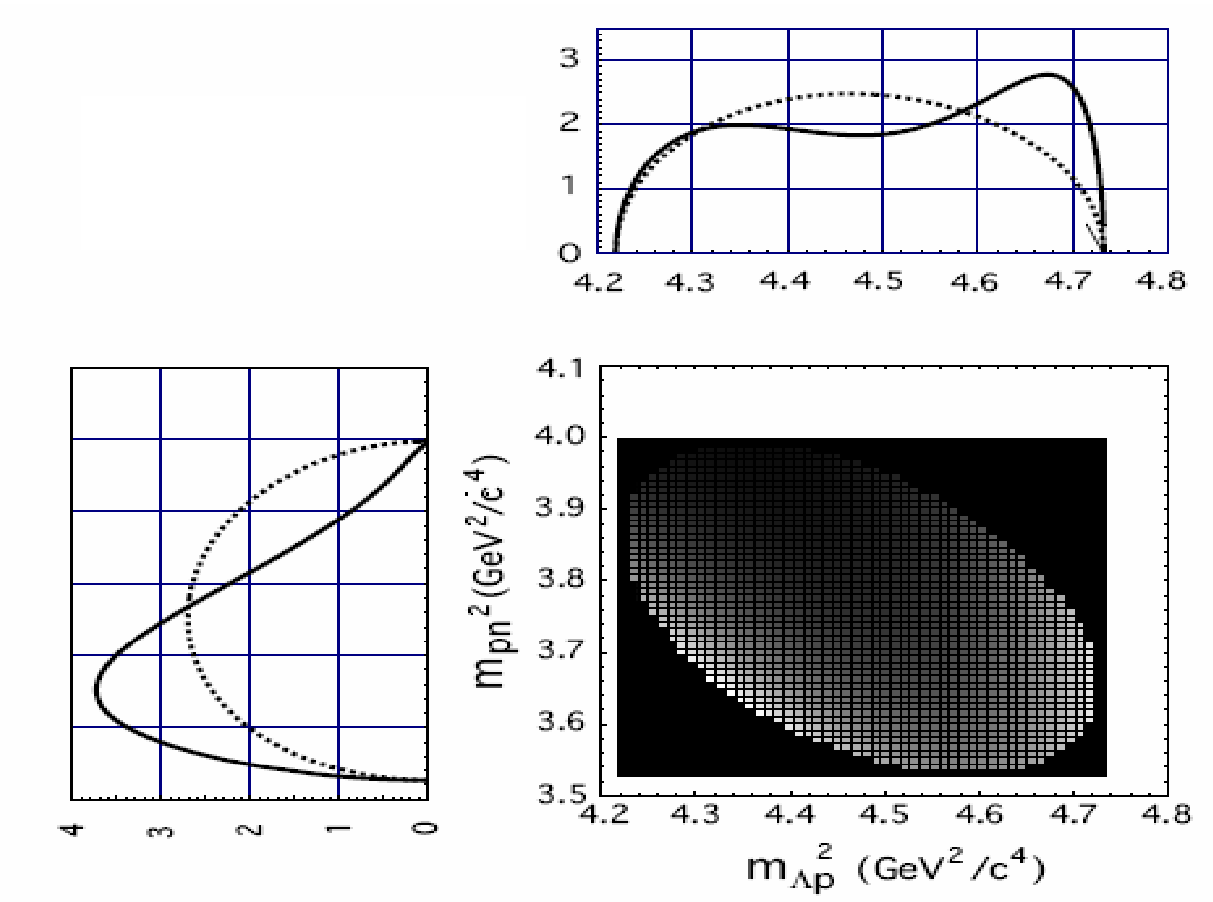

Fig. 29. The Dalitz-plot for the strange tribaryon decays $K^-ppn \rightarrow \Lambda+p+n$. The continuous curves are obtained in the hypothesis of a kaonic nuclear state three times more dense with respect to normal nuclear density, the dotted curves consider a normal nuclear density.

10.5 Structure of the strange dibaryon and tribaryon systems

The most fundamental systems which we plan to study are the *kaonic dibaryon states* K^-pp and K^-np, which are favorable produced using a *^{3}He gas target* in ^{3}He($K^-_{stopped}$, n/p) reactions. Their masses and their total widths will be determined by neutron and proton energy spectra measurements. Exclusive measurements of their decays allow to determine partial decay widths and also Dalitz plots in 3-body channels like $K^-np \rightarrow \Lambda + p + \pi^-$.

10.6 Two-nucleon absorption: measurement of two-nucleon knock-out reactions

In addition to one-nucleon knock-out reaction, *two-nucleon outgoing reaction studies* may be used to populate new states, so to perform exclusive measurements of all reaction and decay products. The interaction inside the nucleus of the K^- with two nucleons will affect on the width of the state (increasing) and as well on the final states which are accessible. The process $K^-NN \rightarrow YN$ is the so called non-pionic multi-nucleon absorption mode. It is a very important process and needs to be studied in detail using 4π geometry and detection of all outgoing channels.

10.7 Other opportunities

There is a very intriguing opportunity for the future to study with part of the proposed detector nuclear systems bound by two antikaons. Such "*double-strange nuclei"* would be very exciting to produce and study in view of the prediction of Akaishi and Yamazaki that such states would have roughly *twice the binding energy and density compared with kaonic nuclei bound by one antikaon.* The binding energy is so large that it would bring them in the regime of *kaon condensation* and the density so high that some theories predict *transition to the color superconducting phase.*

In an upcoming paper by Weise, Kienle and Yamazaki it will be proposed to use the *antiproton annihilation reaction on light nuclei* to produce and study double-strange nuclei in reactions such as:

$$\overline{p} + {}^4He \rightarrow (K^-K^-pnn) + 2K^+$$

As the binding energy of the $2K^-$ mesons is expected to be very large, it is possible to induce the annihilation reaction with *stopped antiprotons*, thus small momentum transfer will favour the formation of double-kaonic nuclear systems. A detector planned to study single-kaonic nuclei, is ideal for a detailed investigation of double-kaonic states by antiproton annihilation. It can be built in a way that it meets all requirements to identify and measure the energy of two K^+ mesons in the final state and detect also the decay products. *The ideal place to study these reactions would be the planned FLAIR facility at GSI Darmstadt,* which is expected to become operational around 2012.

The scientific programme of $\overline{K}$ nuclear clusters will be discussed in a dedicated meetings and in the dedicated Workshop: **“Exotic hadronic atoms, deeply bound nuclear states and antihydrogen: present results and future”**, to be held at ECT* (Trento), on June 19-24, 2006.

11 Formation of an international collaboration

This Letter of Intent has been promoted by physicists of the international collaboration DEAR/SIDDHARTA, which are working on DAΦNE since 1996 and where they will be still engaged until end 2008. To the DEAR/SIDDHARTA collaborations belong 11 institutions from 8 different countries. The interest raised in the international community by *kaonic atoms physics at DAΦNE* involved, since the beginning, also scientists from outside Europe, as Japan, USA and Canada, which actively participated and are participating to the experiments at DAΦNE. *They represent the “hard core” of an international collaboration for the study of deeply bound kaonic nuclear states.*

A dedicated detector on an upgraded DAΦNE, would represent the *only facility in the world where K^{-} induced reactions at rest are studied.* It is worthy to recall as well that Frascati National Laboratories are a recognized *European Research Infrastructure* of EU in the Fifth and Sixth Framework Programs and therefore they benefit of the EU funds for Transnational Access. This means that European groups from eligible countries (actually 33) and scientists from extraeuropean countries, but belonging to groups of eligible countries, may apply for access to Frascati in the next Seventh Framework Programme and work on the upgraded DAΦNE fully reimbursed.

In conclusion, a variety of arguments, suggest that a dedicated facility in Frascati to study deeply bound kaonic nuclear states receive a very favorable acceptance from the world scientific community. As demonstration of this, this Letter of Intent has been signed by 111 scientists from 33 Institutions of 13 countries.

12 AMADEUS integrated luminosity requirements for an initial programme on two light nuclei

An initial programme can be based on the study of the dibaryonic (on ^{3}He target) and T=0, 1 tribaryonic states (on ^{4}He target) performing the following measurements:

1. mass and total widths with semi-exclusive measurements.

For an arbitrarily chosen integrated luminosity L_{int}= 200 pb^{-1}, Φ -production cross section σ = 3μb, B($K^+ K^-$) = 0.49, we consider the typical tribaryons production reactions $K^- + {}^4He \rightarrow (K^-pnn)+p$ and $K^- + {}^4He \rightarrow (K^-ppn)+n$ and detect the ejected protons and neutrons, in missing mass spectroscopy. By assuming a conservative value for the cluster formation probability of Y=1×10^{-3}, *the number of observed K^-pnn clusters seen in the proton spectra is 2.4×10^5* and *the number of observed K^-ppn clusters seen in the neutron spectra is 6×10^4.*

If one detects additionally the decay Λ's in a semi-exclusive experiment, one would loose a factor F = 0.23, obtaining 5.6×10^4 and 1.4×10^4 semi-exclusive K^-pnn and K^-ppn events, respectively.

With such spectra, which are expected to be background free, one determine the mass and total width of the kaonic clusters.

By considering also the dibaryonic states, using ^{3}He target, an *overall luminosity requirement for obtaining mass and total width of dibaryons and tribaryons T=0,1 amounts about 2 fb^{-1}.*

2. Partial widths

If one wants to detect also the decay channels which contain Σ hyperons and neutrons, *an additional luminosity $L_{int} \approx 2\ fb^{-1}$ is needed.*

3. Correlations

The size and density distribution of kaonic clusters can be studied by observation of momentum correlation in the 3-body decays. *For studying 3-body particle correlations in dibaryonic and tribaryonic decays, an additional luminosity of about 1 fb^{-1} is needed for each target nucleus.*

Summary of required luminosity for an initial programme with two light targets

An initial programme for studying the binding energies and total widths of light kaonic clusters such as the K^-pp and K^-pn dibaryons produced in ^{3}He ($K^-_{stopped}$, n/p) and the T= 0, 1 tribaryonic states K^-ppn and K^-pnn produced in the ^{4}He ($K^-_{stopped}$, n/p) would require a luminosity of about 2fb^{-1}.

An extension of such a project to study, for selected decays of kaonic clusters, also the partial widths, would require additional 2 fb^{-1}.

A pioneering correlation study of the 3-body decays, asks for further 2 fb^{-1}.

In conclusion, an initial programme based on the study of the ^{3}He and the ^{4}He targets, to investigate dibaryonic and the T=0,1 tribaryonic states, would require an integrated luminosity from 2 to 6 fb^{-1}, according to depth of the investigation.

Further studies with different targets: Li, B, Be will depend on the outcome of the first experiments.

13 Costs estimation

The costs to implement KLOE with the AMADEUS setup include the *beam pipe* on the interaction point, the *cryogenic target system* and the *kaon monitor trigger.*

The cost of the beam pipe (aluminum and carbon fiber) is *150 K€.*

The gas handling system includes the *cryogenic system*, the *target cell* with *vacuum pumping* and *mechanics*, for an estimated cost of *160 K€.*

The trigger (kaon monitor) is composed by *scintillating fibers* (two cylindrical layers) with *APD readout* for a total cost of *300 K€.*

The global estimated cost of the AMADEUS setup is 610 K€.

This cost evaluation does *not* take into account the *inner tracker,* to be eventually built in cooperation with the KLOE Collaboration and whose costs might be eventually shared between the two collaborations.

14 Start of experiment

The start of the experiment can be fixed around 2010-2011.

15 Conclusions

The case of deeply bound kaonic nuclear states has recently attracted *a great attention both from theoretical and experimental sides. This Letter of Intent contains the* *proposal of investigating for the first time the debated existence of these states in a complete way, namely measuring both formation process and all decay channels.*

This will be possible by using the KLOE detector implemented by the AMADEUS setup on an upgraded DAΦNE.

The scientific programme of AMADEUS consists of precision spectroscopy studies of a number of light kaonic nuclei, followed by measurements of medium heavy nuclear targets.

An initial programme on two light targets, ^3He and ^4He, allows the study of the structure of dibaryons and T=0,1 tribaryons.

The luminosity requirement for a measurement of mass and total widths of these two strange kaonic nuclei amounts to few fb^{-1}.

This Letter of Intent has raised a great interest in the international community and has been signed by111 scientists from 33 Institutions of 13 Countries.

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