# KAONNIS

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## 1 The KAONNIS scientific program

KAONNIS represents an integrated program in the field of the low-energy kaon-nucleon/nuclei interaction studies. Under KAONNIS the following activities are performed:

- the study of kaonic atoms by the SIDDHARTA and SIDDHARTA-2 experiments
- the study of kaon-nuclei interaction at low energies in the framework of AMADEUS.

We present in what follows these scientific lines, together with the 2012 activities and the plans for 2013. The KAONNIS scientific program and its realization are partially financed within the FP7 HadronPhysics2 and HadronPhysics3 EU programs.

## 2 The SIDDHARTA and SIDDHARTA-2 experiments

The objective of the SIDDHARTA (Silicon Drift Detector for Hadronic Atom Research by Timing Application) experiment and of its successor, SIDDHARTA-2, is to perform high precision measurements of X-ray transitions in exotic (kaonic) atoms at DAΦNE.

The precise measurement of the shift and width of the 1*s* level with respect to the purely electromagnetic calculated values, in kaonic hydrogen and kaonic deuterium, generated by the presence of the strong interaction, through the measurement of the X-ray transitions to this level, will allow the first precise experimental extraction of the isospin dependent antikaon-nucleon scattering lengths, fundamental quantities in understanding low-energy QCD in strangeness sector.

The accurate determination of these scattering lengths will place strong constraints on the low-energy $K^-N$ dynamics, which, in turn, constraints the SU(3) description of chiral symmetry breaking in systems containing the strange quark. The implications go from particle and nuclear physics to astrophysics.

SIDDHARTA performed the most precise measurement of kaonic hydrogen and the first exploratory one of kaonic deuterium. Moreover, the kaonic helium 4 and 3 transitions to the 2p level were measured, for the first time in gas in He4 and for the first time ever in He3. Presently, a major upgrade of SIDDHARTA, namely SIDDHARTA-2, is under way, with the aim to measure kaonic deuterium and other types of kaonic atoms in the coming years.

### 2.1 The SIDDHARTA setup

SIDDHARTA represented a new phase in the study of kaonic atoms at DAΦNE. The previous DEAR experiment's precision was limited by a signal/background ratio of about 1/70 for the kaonic hydrogen measurement. To significantly improve this ratio, a breakthrough was necessary.

An accurate study of the background sources present at DAΦNE was redone. The background includes two main sources:

- synchronous background: coming together with the kaons -related to $K^-$ interactions in the setup materials and also to the $\phi$-decay processes; it can be defined as hadronic background;
- asynchronous background: final products of electromagnetic showers in the machine pipe and in the setup materials originating from particles lost from primary circulating beams either due to the interaction of particles in the same bunch (Touschek effect) or due to the interaction with the residual gas.

Accurate studies performed by DEAR showed that the main background source in DAΦNE is of the second type, which shows the way to reduce it. A fast trigger correlated to a kaon entering into the target would cut the main part of the asynchronous background. X rays were detected by DEAR using CCDs (Charge-Coupled Devices), which are excellent X-ray detectors, with very good energy resolution (about 140 eV FWHM at 6 keV), but having the drawback of being non-triggerable devices (since the read-out time per device is at the level of 10 s). A new device, which preserves all good features of CCDs (energy resolution, stability and linearity), but additionally is triggerable - i.e. fast (at the level of $1\mu$s), was implemented. The new detector was a large area Silicon Drift Detector (SDD), specially designed for spectroscopic application. The development of the new 1 cm$^2$ SDD device, together with its readout electronics and very stable power supplies, was partially performed under the Joint Research Activity JRA10 of the I3 project"Study of strongly interacting matter (HadronPhysics)" within FP6 of the EU.

The trigger in SIDDHARTA was given by a system of scintillators which recognized a kaon entering the target making use of the back-to-back production mechanism of the charged kaons at DAΦNE from $\phi$ decay: of the type:

$$\phi \rightarrow K^+K^-. \tag{1}$$

The SIDDHARTA setup contained 144 SDD chips, 1 cm$^2$ each, placed around a cylindrical target, containing high density cryogenic gaseous hydrogen (deuterium or helium). The target was made of kapton, $75\mu$m thick, reinforced with aluminium grid.

The SIDDHARTA setup was installed on DAΦNE in late summer 2008, see Figure 1 - and the period till the end of 2008 was used to debug and optimize the setup performances (degrader optimization included). The kaonic atoms (hydrogen, deuterium, helium4 and 3) measurements were done in 2009 and data analysis followed by the data analyses.

### 2.2 SIDDHARTA activities in 2012

SIDDHARTA was in data taking until 9 November 2009. In 2012 the group activity was dedicated to the kaonic deuterium analysis and to the upgrade of the setup, SIDDHARTA-2, to perform in the future the kaonic deuterium and other precision kaonic atoms measurements.

#### *2.2.1 Kaonic deuterium results*

The X-ray spectrum from the kaonic deuterium experiment is shown in Fig. 2. The data analysis had the aim to extract the yield of the K-transitions. We obtained, after adding the error components quadratically:

- total Kd K-series yield: Y($K_{total}$)= 0.0077 ± 0.0051
- This corresponds to a Kd yield Y($K_{\alpha}$)= 0.0019 ± 0.0012

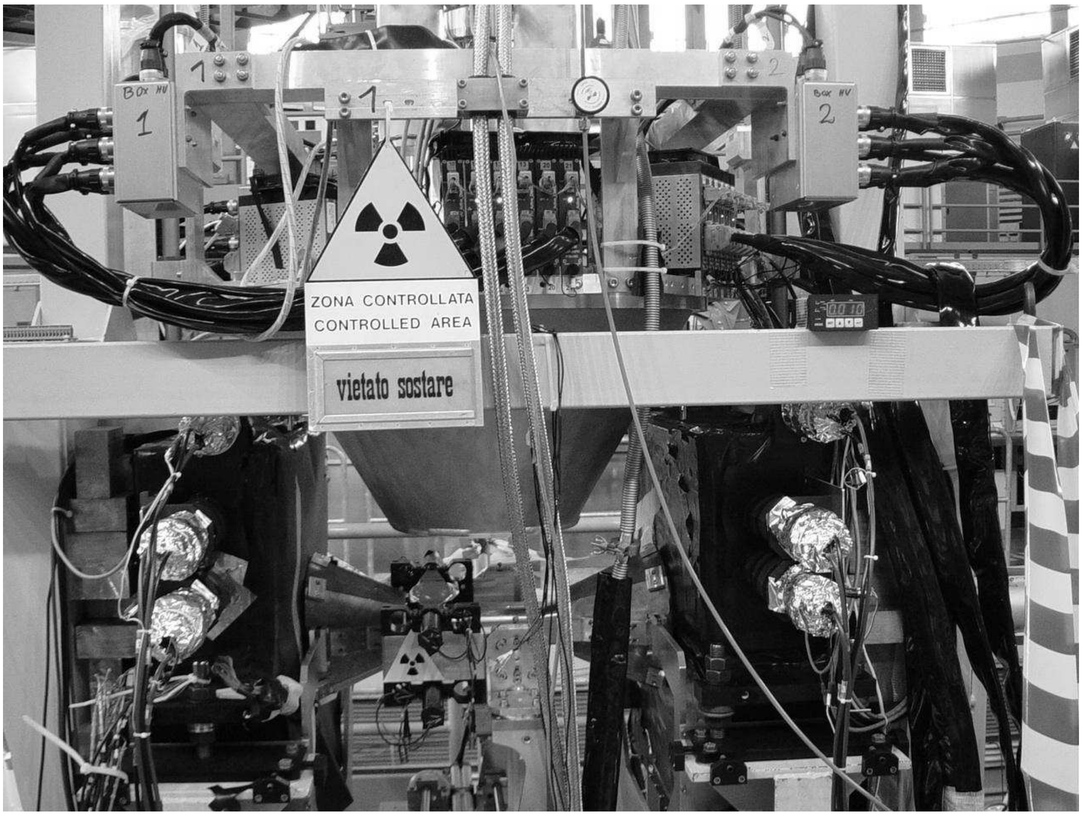


Figure 1: The SIDDHARTA setup installed at DAΦNE

Such values are compatible with what is expected, namely a yield of a factor about 10 smaller then the KH yield, estimated to be to 2% for $K_\alpha$. For the yield values given above, the upper limits for the yields are (CL 90%):

- Y($K_{total}$) $<$ 0.00143
- Y($K_\alpha$) $<$ 0.0039

### 2.3 *SIDDHARTA-2*

In 2010 the proposal for the SIDDHARTA upgrade was put forward. The upgrade of SIDDHARTA to SIDDHARTA-2 is based on four main modifications:

- Trigger geometry and target density: By placing the upper kaon-trigger detector close in front of the target entrance window, the probability that a triggered kaon really enters the gas and is stopped there is much improved. Making the detector smaller than the entry area gives away some signal, but suppresses efficiently the kaonic lines from "wallstops" (kaons entering the gas volume, but passing from the inside of the target to the cylindrical walls). The number "signal per trigger" goes up, which also reduces the accidental background coming along with every trigger. We plan as well to double the gas density which enhances the gas stops and further reduces the wall-stops.
- $K^+$ discrimination to suppress kaon decay background: A "kaon stopper" scintillator is placed directly below the lower kaon trigger scintillator. When a $K^-$ is stopped there, only one (large) signal from pileup of stopping and kaon-absorption secondaries is seen, whereas when

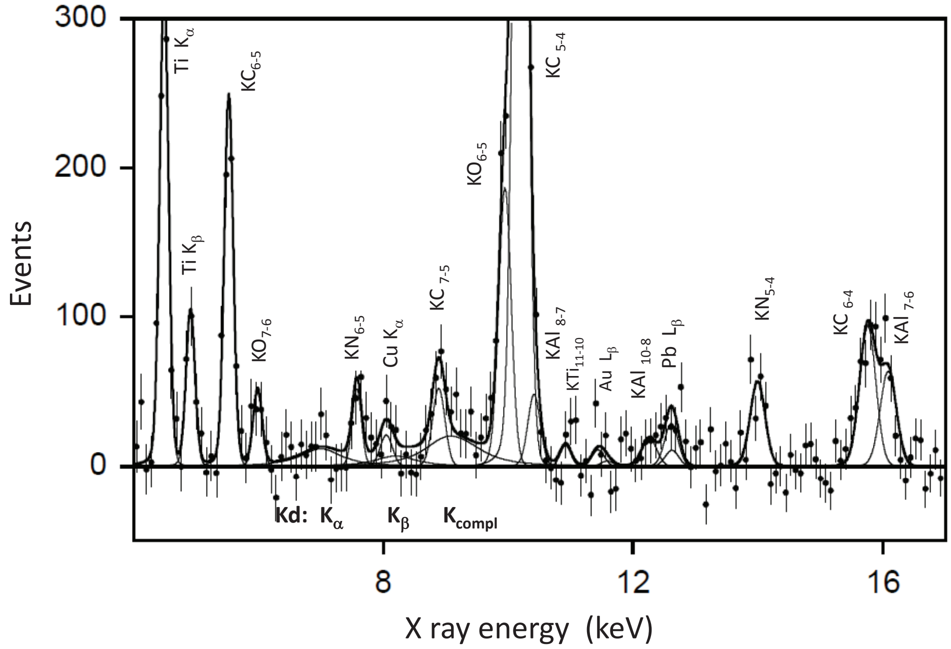


Figure 2: X-ray spectrum from the kaonic deuterium experiment. The continous background fit-component is already subtracted. Fit with fixed Kd transitions shift and width (-805,750 eV) and fixed yield ratio of the individual K-transitions. Integrated luminosity 100 $pb^{-1}$. The lines from the kaonic X-rays due to stops in the window foils and from X-ray fluorescence excited by background are labeled. Note the excess of events in the region of a possible signal.

a $K^+$ is stopped, the kaon-decay particles are seen after the signal from the stopping (mean $K^+$ lifetime 12.8 ns). Using a flash-ADC we will be able to efficiently distinguish the 2 cases. In addition, we will use scintillators surrounding the target to measure $K^-$ absorption secondaries pions). The time window for gas stops is about 4 ns wide. By this condition we also suppress stops in the entry window.

- Active shielding: The scintillators surrounding the target will also be used in prompt anti-coincidence if the spatial correlation of SDD and scintillator hits indicates that it originated from a pion ("charged particle veto"). An anticoincidence covering the SDD time window of about 600 ns (with the exception of the 4 ns of the gas stopping time) will reduce the accidental background. Although the scintillators have only low efficiency for gammas, the abundance of secondaries from the electromagnetic showers allows a relevant reduction of accidental ("beam") background. The upper trigger scintillator has 2 functions, it is also used as an anticoincidence counter: after the kaon and eventual prompt kaon-absorption secondaries pass, it vetos beambackground.
- Operating SDDs at a lower temperature: tests indicate that an improvement of the timing resolution by a factor of 1.5 is feasible by more cooling. The signal enhancement by a factor 2 to 3 is due to moving the target cell closer to the IP, by changing its shape, by a better solid angle of the SDDs and by the higher gas density. In such conditions, with an integrated luminosity of 800 $pb^-1$ a precision of about 70 eV for the shift, and 160 eV for the width are attainable, resulting in a relative precision similar to that obtained for kaonic hydrogen.

In 2012 various tests on prototypes were performed, together with Monte Carlo simulations to optimize the setup.

More details can be found in the various presentations to the LNF International Scientific Committee on the LNF-INFN web-site.

### 2.4 Activities in 2013

The LNF group main activities in SIDDHARTA and SIDDHARTA-2 for 2013 are the following ones:

- analysis of widths of kaonic helium transitions to 2p level and publications;
- analysis of the yields for kaonic hydrogen and helium and publication of results;
- Monte Carlo simulations for the SIDDHARTA-2 setup and physics;
- construction of the SIDDHARTA-2 setup: target, veto counters, new trigger, new cryogenic systems;
- definition of the strategy for SIDDHARTA-2 measurements (including interaction region definition and construction).

The SIDDHARTA scientific program is important part of the Network LEANNIS (WP9) in the framework of the EU FP7 HadronPhysics3 program.

## 3 The AMADEUS proposal and 2012 activities

The low-energy (< 100 MeV/c) kaon-nuclei interaction studies represents the main aim of the AMADEUS experiment. In order to do these type of measurements, in a most complete way, by detecting all charged and neutral particles coming from the $K^-$ interactions in various targets with an almost $4\pi$ acceptance, the AMADEUS collaboration plans to implement the existent KLOE detector in the internal region of the Drift Chamber with a dedicated setup (see Figure 3). The dedicated setup contains the target which can be either solid or a gaseous cryogenic one, a trigger (TPC-GEM) and a tracker system (scintillating fibers read by SiPM detectors).

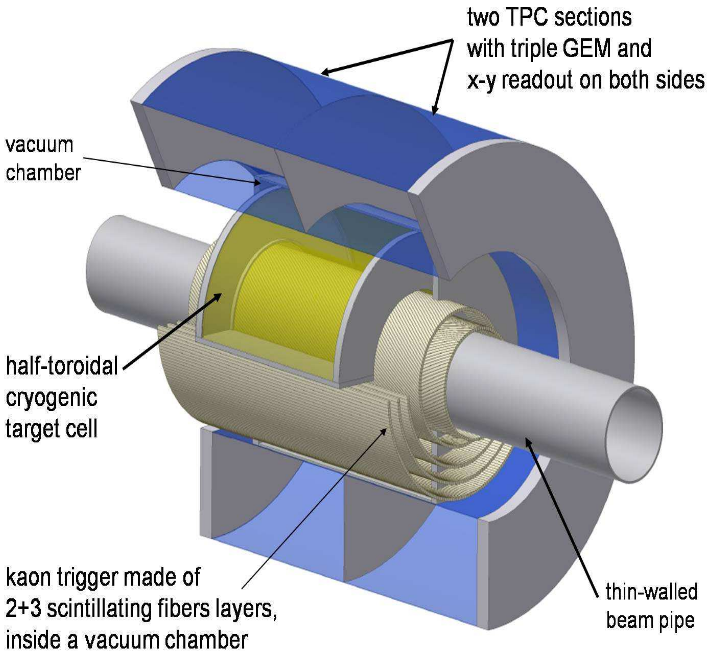


Figure 3: The AMADEUS dedicated setup implemented in the Drift Chamber of the KLOE detector. In this situation a cryogenic gaseous target is used.

The negatively charged kaons can stop inside the target or interact at low energies, giving birth of a series of processes we plan to study. Among these, a key-role is played by the generation of $\Lambda(1405)$ which can decay into $\Sigma^0\pi^0$, $\Sigma^+\pi^-$ or $\Sigma^-\pi^+$. We plan to study all these three channels in the same data taking. Another important item is represented by the debated case of the "kaonic nuclear clusters", especially the $K^-pp$, and $K^-$ -ppn cases. We can study these channels by measuring, for example, their decays to $\Lambda p$ and to $\Lambda d$. In the same time, many other kaon-nuclei processes will be investigated, either for the first time, or in order to obtain more accurate results than those actually reported in literature. Cross sections, branching ratios, rare hyperon decay processes will be investigated, taking advantage of the unique kaon-beam quality delivered by DAΦNE and of the unique characteristics of the KLOE detector.

As targets to be employed, we plan to use gaseous ones, like d, $^3$He or $^4$He and solid ones as C, Be or Li. In the summer of 2012 a first dedicated target, half cylinder done in pure carbon was realized and installed inside the Drift Chamber of KLOE as a first setup towards the realization of AMADEUS (see Figure 4). The target thickness was optimized such as to have a maximum of stopped kaons (about 24% of the generated ones) without degrading too much the energy of resulting charged particles inside the target material. In the period of data taking a total integrated luminosity of about 80 pb$^{-1}$ was achieved. The analysis of these data will provide new insights in the low-energy interactions of charged kaons in the nuclear matter. For the future, other targets are planned to be used compatible with the beam assignment.

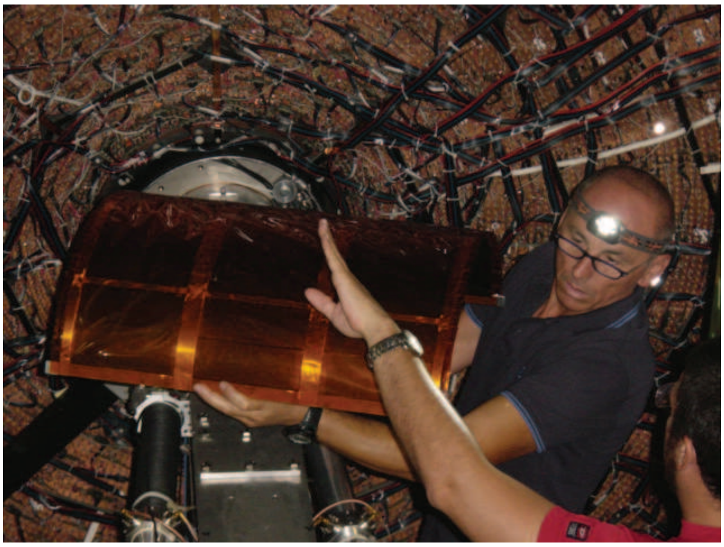

Figure 4: The AMADEUS carbon target (half cylinder) installed inside the Dift Chamber of KLOE detector.

Other activities done in 2012:

- R&D for the trigger system: a prototype based on scintillating fibers read by Silicon Photo-Multipliers (see Fig. 5) was tested at the PSI pion beam.
- R&D for the inner tracker - a small TPC-GEM prototype, Fig. 6, for traking performance.
- Monte Carlo simulations.

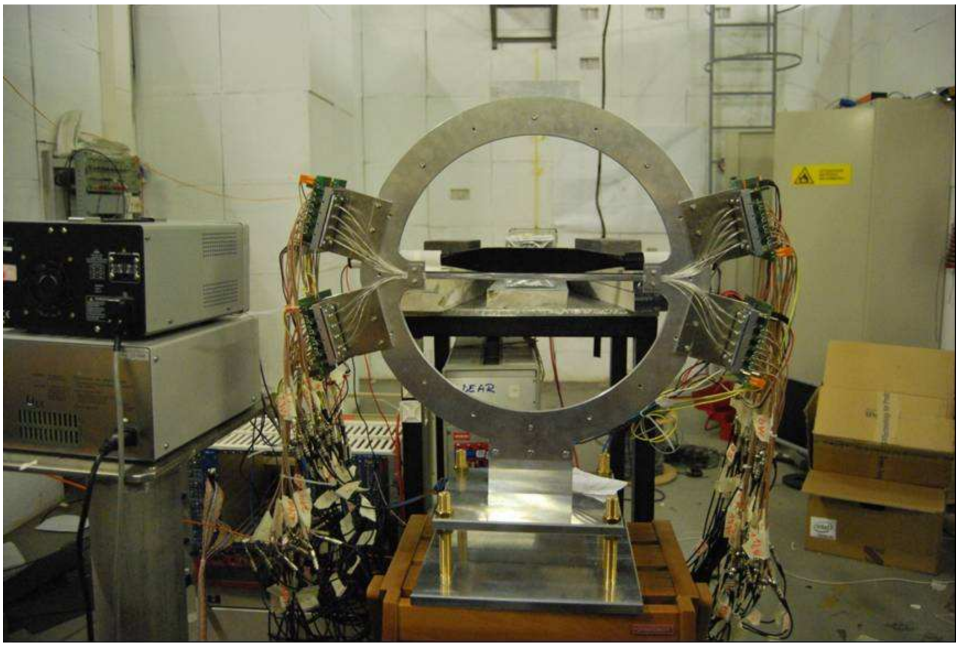

Figure 5: The AMADEUS trigger ptototype, based on scintillating fibers read at both ends by SiPM

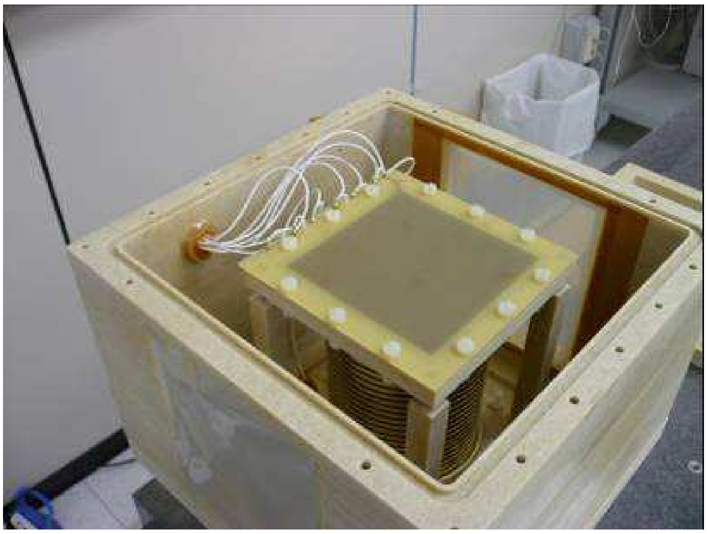

Figure 6: The TPC-GEM prototype

### 3.1 AMADEUS activities in 2013

The main activities of AMADEUS in 2013 will be:

- continuation of the R&D for the trigger system: tests of the prototype and readout electronics at BTF-LNF and PSI:
- continuation of the R&D for the inner tracker: tests of the prototype at BTF-LNF and PSI
- Monte Carlo simulations:
- finalization of the KLOE 2002-2005 data analyses for the search of processes due to $K^-$interaction in the Drift Chamber volume and publication
- analyses of data with carbon target
- definition of the experiment strategy

To be mentioned that the AMADEUS activities are supported in the framework of the EU FP7 HadronPhysics3, as WP24 (GEM), WP28 (SiPM) and WP9 (Network on kaon-nuclei interaction studies at low energies) programs.

**Acknowledgements**
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## 4 List of Conference Talks by LNF Authors in Year 2012

1. O. Vazquez Doce, Experimental studies of strong interaction in exotic atoms, Seminar at Excellence Cluster Universe, 8 February 2012, TUM, Munich.
2. O. Vazquez Doce, Lambda-p and Lambda-d correlations from $K^-$ interactions in the KLOE Drift Chamber, New trends in the low-energy QCD in the strangeness sector: experimental and theoretical aspects, ECT*, 15-19 October 2012, Trento, Italy.
3. M. Iliescu, Kaon-nucleon strong interaction in kaonic atoms: the SIDDHARTA program, The 20th International IUPAP Conference on Few-Body Problems in Physics (FB20), 20-25 August 2012, Fukuoka International Congress Center in Fukuoka city, Japan.
4. D. Sirghi, Kaonic helium 4 and kaonic helium 3 exotic atoms, New trends in the low-energy QCD in the strangeness sector: experimental and theoretical aspects, ECT*, 15-19 October 2012, Trento, Italy.
5. K. Piscicchia, Themodynamics for a self-gravitating system with cutoff enery, Seminar at Univerista degli Studi di Roma La Sapienza, 9 March 2012, Roma, Italy.

6. K. Piscicchia, Kaon-nuclei interaction studies at low energies (the AMADEUS project), Incontri di Fisica delle Alte Energie, 11-13 April 2012, Univeristy of Ferrara, Ferrara, Italy.
7. K. Piscicchia, Kaon-nuclei interaction studies at low energies (the AMADEUS project), 12th International Workshop on Meson Production, Properties and Intercation, MESON2012, 31 May-5 June 2012, Krakow, Poland.
8. K. Piscicchia, Production of $\Lambda(1405)$ by stopped and in-flight absorption $K^-$ in $^4$Helium and $^{12}$C, Mini-Workshop: The quest for Dense and Strange Hadronic Matter Role of the $\Lambda(1405)$ Hyperon, 31 July 2012, TUM, Munchen, Germany.
9. K. Piscicchia, Low energy kaon nuclei interaction studies through $\Sigma^0\pi^0$ channel with the KLOE detector, New trends in the low-energy QCD in the strangeness sector: experimental and theoretical aspects, ECT*, 15-19 October 2012, Trento, Italy.
10. H. Tatsuno, Kaonic $^3$Helium and $^4$Helium measurements in the SIDDHARTA experiment at the DAΦNE collider, New trends in the low-energy QCD in the strangeness sector: experimental and theoretical aspects, ECT*, 15-19 October 2012, Trento, Italy.
11. A. Scordo, Investigating low energy QCD with kaonic atoms: the SIDDHARTA experiment at DAΦNE, Poster presentation at the 50th International Winter meeting on Nuclear Physics, 22-27 January 2012, Bormio, Italy.
12. A. Scordo, Kaon nuclei interactions studies at low energy with a carbon target inside KLOE as a first step towards AMADEUS realization, New trends in the low-energy QCD in the strangeness sector: experimental and theoretical aspects, ECT*, 15-19 October 2012, Trento, Italy.
13. A. Rizzo, Kaonic atoms measurements at the DAΦNE collider: the SIDDHARTA experiment, Young Researcher Meeting in Rome -3rd edition, 20 Junary 2012, Universita degli Studi di Roma "Tor Vergata", Roma, Italy.
14. C. Curceanu, Unlocking the secrets of the kaon-nucleon/nuclei interactions at low energies: the SIDDHARTA and the AMADEUS experiments at the DAΦNE collider, HYP2012, 1-5 Octiber 2012, Barcelona, Spain.
15. C. Curceanu, From DEAR to SIDDHARTA - the strangeness adventure, New trends in the low-energy QCD in the strangeness sector: experimental and theoretical aspects, ECT*, 15-19 October 2012, Trento, Italy.

## 5 Publications

### References


1. K. Piscicchia *et al* (AMADEUS collaboration), Kaon-nuclei interaction studies at low energies (the AMADEUS project) , EPJ Web Conf. 37 (2012) 07002.
2. M. Poli Lener *et al* (AMADEUS collaboration), Performances of a GEM-based Time Projection Chamber prototype for the AMADEUS experiment, arXiv:1302.3054 [physics.ins-det].
3. A. Scordo *et al*, Characterization of a scintillating fibers read by MPPC detectors trigger prototype for the AMADEUS experiment arXiv:1301.7268 [physics.ins-det].

4. H. Tatsuno *et al* (SIDDHARTA collaboration), Kaonic He-3 and He-4 measurements in the SIDDHARTA experiment at the DAΦNE collider, EPJ Web Conf. 37 (2012) 02002.

5. A. Scordo *et al* (SIDDHARTA collaboration), Investigating low energy QCD with kaonic atoms: The SIDDHARTA experiment at DAΦNE, PoS BORMIO2012 (2012) 009.

6. A. Rizzo *et al* (SIDDHARTA collaboration), Kaonic atoms measurements at the DAΦNE collider: The SIDDHARTA experiment, J.Phys.Conf.Ser. 383 (2012) 012004.

7. K. Agari *et al*, The K1.8BR spectrometer system at J-PARC,arXiv:1206.0077 [physics.ins-det].

8. M. Bazzi *et al* (SIDDHARTA collaboration), Measurements of the strong-interaction widths of the kaonic $^3$Helium and $^4$Helium 2p levels, Phys.Lett. B714 (2012) 40-43.

9. A. Rizzo *et al* (SIDDHARTA collaboration), Kaonic atoms measurements at the DAΦNE collider: The SIDDHARTA experiment, J.Phys.Conf.Ser. 348 (2012) 012003.

10. M. Bazzi *et al* (SIDDHARTA collaboration), Kaonic hydrogen X-ray measurement in SIDDHARTA, Nucl.Phys. A881 (2012) 88-97.

11. M. Bazzi *et al*, Experimental tests of the trigger prototype for the AMADEUS experiment based on Sci-Fi read by MPPC, Nucl.Instrum.Meth. A671 (2012) 125-128.

12. K. Piscicchia *et al* (AMADEUS collaboration), Kaon-nuclei interaction studies at low energies (the AMADEUS project), Il Nuovo Cimento, Vol. 36 (2013), 191.

13. M. Bazzi *et al* (SIDDHARTA collaboration), Study of kaonic deuterium X-rays by the SIDDHARTA experiment at DAΦNE, arxiv:1302.2797.