SIDDHARTA

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1 The SIDDHARTA scientific program

The objective of the SIDDHARTA (Silicon Drift Detector for Hadronic Atom Research by Timing Application) experiment is to continue, to deepen and enlarge the successful scientific line, initiated by the DEAR experiment in performing precision measurements of X-ray transitions in exotic (kaonic) atoms at DAΦNE.

The few eV precise determination of the shift and width of the $1s$ 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 determination of the isospin dependent antikaon-nucleon scattering lengths.

The shift ϵ and the width Γ of the $1s$ state of kaonic hydrogen are related to the real and imaginary part of the complex s-wave scattering length, a_{K^-p}, through the Deser formula (in the isospin limit):

$$\epsilon + i\Gamma/2 = 2\alpha^3\mu^2 a_{K^-p} = (412 \text{ eV fm}^{-1}) \cdot \mathrm{a_{K^-p}} \qquad (1)$$

where α is the fine structure constant and μ the reduced mass of the K^-p system. In the isospin limit, i.e. in the absence of the electromagnetic interaction and at $m_d = m_u$, a_{K^-p} can be expressed directly in terms of the scattering lengths for isospin I=0 and I=1:

$$a_{K^-p} = \frac{1}{2}(a_0 + a_1) \qquad (2)$$

A similar relation applies to the case of kaonic deuterium and to the corresponding scattering length a_{K^-d}:

$$\epsilon + i\Gamma/2 = 2\alpha^3\mu^2 a_{K^-d} = (601 \text{ eV fm}^{-1}) \cdot \mathrm{a_{K^-d}} \qquad (3)$$

An accurate determination of the K$^-$N isospin dependent 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 DEAR measurement on kaonic hydrogen, performed in 2002 (Phys. Rev. Lett 94 (2005), 212302):

$$\epsilon = -193 \pm 37(stat.) \pm 6(syst.) \text{ eV} \qquad (4)$$

$$\Gamma = 249 \pm 111(stat.) \pm 39(syst.) \text{ eV}. \qquad (5)$$

has already triggered an increased activity of the theoretical groups working in the low-energy kaon-nucleon interaction field, as well as in more general non-perturbative QCD.

The SIDDHARTA experiment aims to improve the precision obtained by DEAR by an order of magnitude and to perform the first measurement ever of kaonic deuterium. SIDDHARTA plans as well to perform accurate measurements on kaonic helium transitions to the 2p level (L-series). Other measurements (as sigmonic atoms or the precise determination of the charged kaon mass) are as well considered in the scientific program.

2 The SIDDHARTA setup

SIDDHARTA represents a new phase in the study of kaonic atoms at DAΦNE. The DEAR precision was limited by a signal/background ratio of about 1/70. To significantly improve this ratio, a breakthrough is 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 ϕ-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 recently developed device, which preserves all good features of CCDs (energy resolution, stability and linearity), but additionally is triggerable - i.e. fast (at the level of 1μs), was implemented. This new detector is a large area Silicon Drift Detector (SDD), specially designed for spectroscopic application. The development of the new 1 cm^2 SDD device, together with 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 will be given by a system of scintillators which will recognize a kaon entering the target making use of the back-to-back production mechanism of the charged kaons at DAΦNE from ϕ decay of the type:

$$\phi \rightarrow K^+K^-. \tag{6}$$

Successful tests of SDD detectors were performed in 2003-2007 at the Beam Test Facility of Frascati (BTF), The results of these tests showed, in DEAR-like conditions, a trigger rejection factor of 5 x 10^{-5} - which will allow to SIDDHARTA to perform few eV precision measurements.

The SIDDHARTA setup contains 144 SDD chips of 1 cm^2 each, placed around a cylindrical target, containing high density cryogrenic gaseous hydrogen (deuterium). The SDDs are grouped in units od 3 detectors, read individually, Fig. 1; units of 18 SDDs are then realized, Fig. 2. The target is made of kapton, 75 μm thick, reinforced with aluminium grid, see Figure 3.

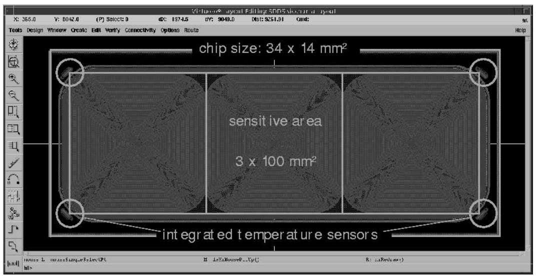

Figure 1: *SDD layout on the readout side: 3 SDD cells, read independently, each of 1 cm^2 area, monolithically integrated on one chip.*

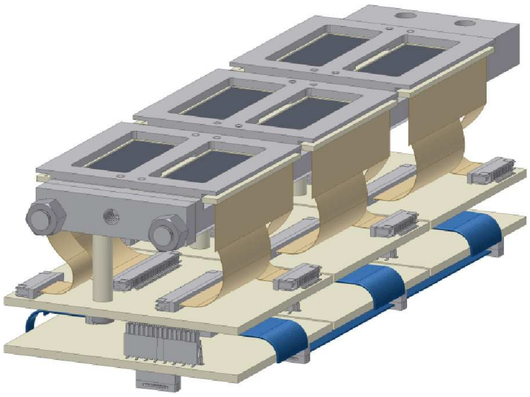

Figure 2: *An 18 cm^2 SDD unit, containing 18 SDD individual chips.*

Figure 3: *The SIDDHARTA target cell, done in kapton, reinforced with an aluminium grid. It will contain about 3 liters of cryogenic and high density hydrogen (deuterium) gas.*

8 SDD 18 cm^2 units will be placed all around the target cell, as shown in Figure 4. The SIDDHARTA setup was installed on DAΦNE in summer 2008 - as discussed in the next section.

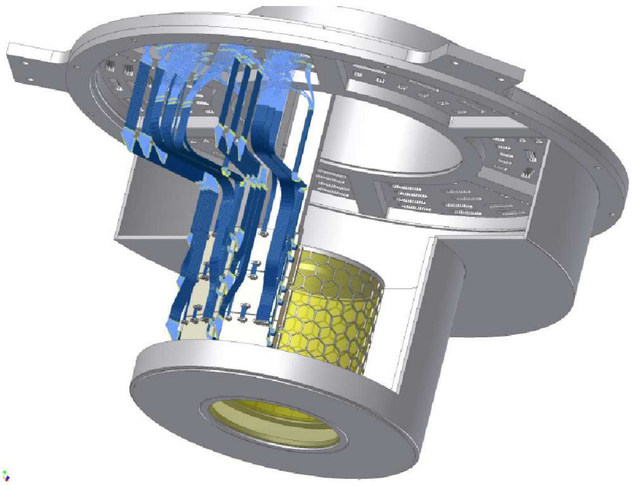

Figure 4: *The SIDDHARTA target cell surrounded by SDD units (detail).*

3 Activities in 2008

In what follows, we present the main 2008 SIDDHARTA activities performed at LNF.

3.1 Installation of SIDDHARTA setup on DAΦNE

The SIDDHARTA setup was installed on the DAΦNE collider in 2008: the trigger system, composed by 2 scintillators one above, one below the beam pipe - measuring the back-to-back charged kaons and giving the trigger to the SDD detectors, was installed in early Spring 2008, Figure 5, was tested and optimized in collaboration with DAΦNE team; the full setup was installed in September 2008, Figure 6.

The installation of the setup was followed by a period of debud and tests; a lead shielding was as well installed: a layer of 5 cm of lead below and around the setup, in order to shield the SDD detectors from the high background.

3.2 First SIDDHARTA measurements

After the setup debug, in the period November - December 2008 the degrader optimization was performed (degrader has to be optimized taking into account the boost of the ϕ-particles; the optimization is done in a range of 100 μm) - by measuring the kaonic helium transitions to the 2p level; this measurement is easier than the kaonic hydrogen one (being the yield of transitions much bigger) and, in the same time, represents a measurement interesting in itself, worthy to be published.

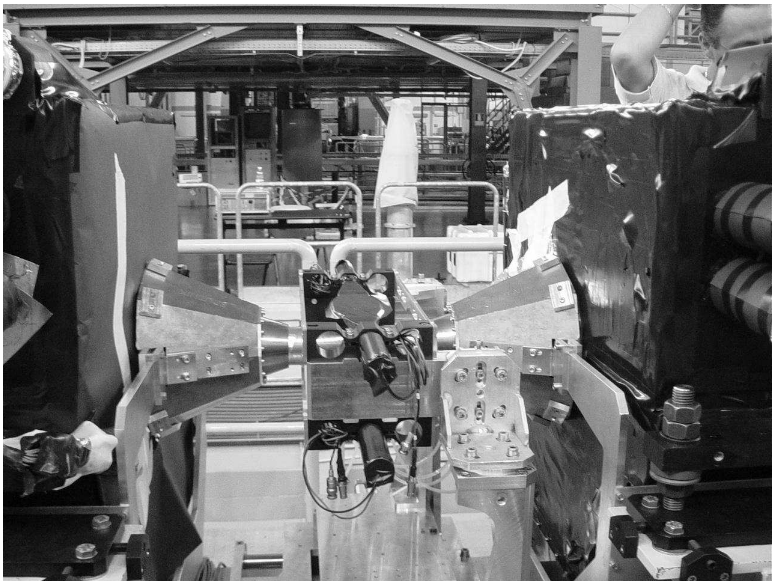

Figure 5: *The SIDDHARTA trigger system installed at DAΦNE.*

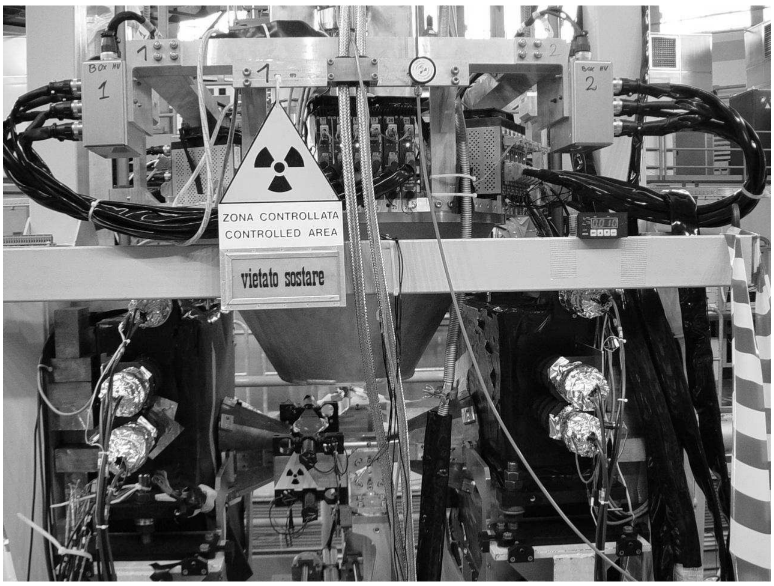

Figure 6: *The SIDDHARTA full setup installed at DAΦNE.*

A typical preliminary example of the obtained spectra is given in Figure 7: in the upper histogram the spectrum obtained without trigger signal is shown, while in the lower part the same spectrum with trigger signal is given. The trigger rejection factor was estimated to be at the level of 7 x 10^{-5}, perfectly in agreement with what expected. The L-lines transitions in kaonic helium are clearly visible; this is the first measurement performed in gaseous helium; data are going to be published.

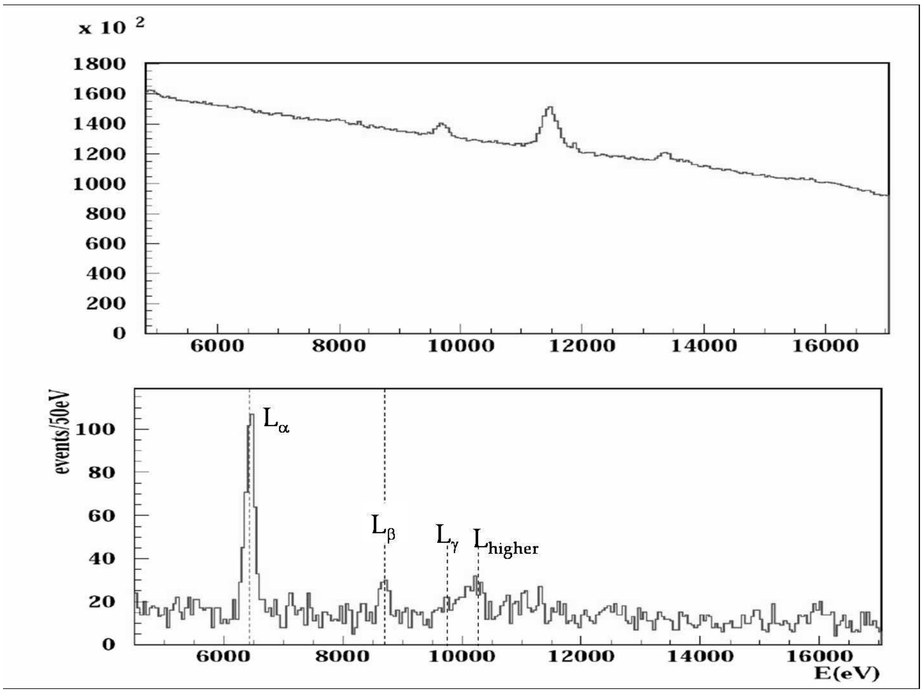

Figure 7: *Kaonic helium preliminary measurement - upper spectrum: measured without trigger, the visible lines are coming from gold transitions (gold is present in infinitesimal amount in the readout electronics); lower spectrum - the triggered spectrum: kaonic helium transitions to the 2p level, the L-series, are clearly visible.*

4 Activities in 2009

The LNF group main activities in SIDDHARTA for 2009 are the following ones:

- finalize analyses of kaonic helium data and publish them;
- measurement of kaonic hydrogen;
- measurement of kaonic deuterium;
- data analyses and Monte Carlo simulations.

5 Publications 2008

5.1 List of Conference Talks

1. C. Curceanu (Petrascu), “Kaonic atoms and nuclei measurements at the DAΦNE accelerator”, talk at the 14th International QCD Conference, QCD08, 7-12 July 2008, Montpellier, France

2. C. Curceanu, “AMADEUS experiment”, talk at the Vienna FOPI meeting, 24 April 2008, Vienna, Austria

3. A. Scordo, “Kaonic atoms measurement at DAΦNE: the SIDDHARTA experimet”, talk at the XIII Frascati Spring School ”Bruno Touschek” in Nuclear, Subnuclear and Astroparticle Physics, May 12th-16th, 2008, Frascati, Italy.

4. O. Vazquez Doce, “The AMADEUS experiment: search for kaonic clusters at DAΦNE”, talk at the XIII Frascati Spring School ”Bruno Touschek” in Nuclear, Subnuclear and Astroparticle Physics, May 12th-16th, 2008, Frascati, Italy.

5. O. Vazquez Doce, “The AMADEUS experiment: search for kaonic clusters at DAΦNE”, talk at the 10th International Workshop on Meson Production, Properties and Interaction (MESON2008), 6-10 June 2008, Kracow, Poland

6. O. Vazquez Doce, “KLOE data analyses in the search for kaonic clusters and AMADEUS experiment”, talk at the International Conference on Exotic Atoms EXA08, 15-18 September 2008, Vienna, Austria

7. C. Curceanu (Petrascu), “Kaonic atoms measurements at the DAΦNE accelerator”, talk at the International Conference on Exotic Atoms EXA08, 15-18 September 2008, Vienna, Austria

8. O. Vazquez Doce, “The AMADEUS experiment: deeply bound kaonic nuclear states at DAΦNE”, talk at the XCIV Congresso Nazionale Societa’ Italiana di Fisica, 22-27 September 2008, Genova, Italy

9. A. Romero Vidal, “Kaonic atoms measurements at DAΦNE: the SIDDHARTA experiment”, talk at the XCIV Congresso Nazionale Societa’ Italiana di Fisica, 22-27 September 2008, Genova, Italy

10. O. Vazquez Doce, “Preliminary results from KLOE data analyses in the search for kaonic clusters”, talk at the Vienna FOPI meeting, 24 April 2008, Vienna, Austria

11. O. Vazquez Doce, “The AMADEUS experiment: study of the kaonic clusters at DAΦNE”, talk at the XLVI International Winter Meeting on Nuclear Physics, January 2008, Bormio, Italy

5.2 Papers and Proceedings

1. C. Curceanu *et al.*, Modern Phys. Lett. A **23**, 2524 (2008).

2. M. Bazzi *et al.*, Few-Body systems **44**, 79 (2008).

3. R.S. Hayano *et al.*, Modern Phys. Lett. **A23**, 2505 (2008).

4. M. Bazzi *et al.*, "New precision measurements of the strong interaction in kaonic hydrogen", Proceedings of the International Conference on Muon Catalized Fusion and related Topics, Dubna, JINR 2008, p. 218

5. J. Marton *et al.*, "Low-energy kaon-nucleon interaction studies with x-ray spectroscopy", Proceedings of the XLVI Winter meeting on nuclear physics, Bormio 2008, Ricerca Scientifica ed Educazione Permanente N. 129, 2008, p. 121.

6. J. Marton *et al.*, "New X-ray detectors for exotic atom research", Proceedings SORMA-west, Symposium on Radiation measurements and applications, Berkeley, USA, 2008, IEEE, in press

7. J. Zmeskal *et al.*, "Kaonic Atoms at DAΦNE - the SIDDHARTA Experiment", Proceedings of the 10th International Workshop on Meson Production, Properties and Interaction, 6-10 June 2008, Krakow, Poland, in press in International Journal of Modern Physics.

8. E. Widmann *et al.*, "Kaonic Atoms at DAΦNE - the SIDDHARTA Experiment", Proceedings of PANIC08 - in press.

9. C. Curceanu *et al.*, "Kaonic atoms measurements at the DAΦNE accelerator", Proceedings of the EXA08 International Conference, 15-18 Sept. 2008, Vienna, in press in Hyperfine Interactions.

10. C. Curceanu *et al.*, "Kaonic atoms and nuclei measurements at the DAΦNE accelerator", Proceedings of the 14th International QCD Conference, Montpellier, France, in press in Elsevier publication series.