Kaon-nucleon/nuclei interaction studies by kaonic atoms measurements: the SIDDHARTA experiment at DAΦNE

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The SIDDHARTA experiment (SIlicon Drift Detector for Hadronic Atom Research by Timing Application) had the aim to perform a precise measurement of K-series kaonic hydrogen x-rays and the first-ever measurement of the kaonic deuterium x-rays to determine the strong-interaction energy-level shifts and widths of the lowest lying atomic states.

These measurements offer a unique possibility to precisely determine the isospin-dependent kaon-nucleon(KN) scattering lengths which are directly connected with the physics of the KN interaction.

The experiment combined the excellent low-energy kaon beam generated at DAΦNE, allowing to use gaseous targets, with excellent fast X-rays detectors: Silicon Drift Detectors. SIDDHARTA was installed on DAΦNE in autumn 2008 and took data till late 2009.

Apart of the kaonic hydrogen and kaonic deuterium measurements, we have performed the kaonic helium transitions to the $2p$ level (L-lines) measurements: for the first time in a gaseous target for kaonic helium 4 and for the first time ever for kaonic helium 3. In this paper, an overview of this experiment and preliminary results are presented, together with future plans.

1. The SIDDHARTA scientific case

The precision measurement of kaonic atoms at the DAΦNE accelerator of the LNF-INFN Laboratories was performed in the framework of the SIDDHARTA international Collaboration. The SIDDHARTA experiment continued and deepen the successful line, initiated by the DEAR experiment [1], in performing precision measurements of X-ray transitions in exotic (kaonic) atoms at

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The scientific aim of the experiment is a precision determination of the isospin-dependent antikaon-nucleon scattering lengths, through few eV precision measurement of K_α line shift (ϵ) and width (Γ) in kaonic hydrogen, and a similar, first time measurement of kaonic deuterium. SIDDHARTA measures the X-ray transitions occurring in the cascade processes of kaonic atoms.

The strong interaction between the kaon (hadron) and the nucleus causes a shift (ϵ) in the energy of the last energy levels from their purely electromagnetic values and a finite lifetime of the state - corresponding to an increase in the observed level width (Γ).

For kaonic hydrogen and kaonic deuterium, the K-series transitions are of main experimental interest, since they are the only ones affected by the strong interaction; for higher n-states the effect is very small.

The shift(ϵ) and the width(Γ) of the $1s$ state for kaonic hydrogen and kaonic deuterium are related in a fairly model-independent way to the real and imaginary part of the complex s-wave scattering length, a_{K^-p} and, respectively, a_{K^-d} [2].

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 in SU(3) description of chiral symmetry breaking.

2. The SIDDHARTA experimental setup

The precision obtained by the DEAR experiment for the kaonic-hydrogen X-ray transitions to the $1s$ level [1], was clearly limited by the poor signal to background ratio (1/70), so another experimental technique had to be developed to reduce the huge background: large area soft X-ray detectors with good energy and timing resolution, high counting rate capability and enough robustness to be operated in the radiation environment of an accelerator, namely the Silicon Drift Detector(SDD).

The SIDDHARTA experimental setup [3] consists of main three parts: a kaon detector, an X-ray detection system and a cryogenic target system.

An overview of the experimental setup is presented in Fig. 1.

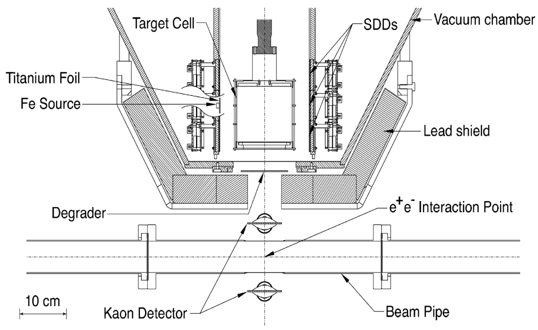

Figure 1. The SIDDHARTA setup.

The whole system was installed at the e^+e^- interaction point of the DAΦNE collider. The target cell is cylindrical, with a radius of 6 cm and a height of 12 cm. It was filled with gaseous hydrogen, at an equivalent of 0.01 of the liquid hydrogen density.

The kaon detector [4] consists of two scintillators installed on the top and bottom of the beam pipe in the IR, which detects the K^+K^- signal in coincidence, using TOF technique. The slow kaon pairs are clearly separated from the fast minimum ionizing particles (MIPs), due to excellent time resolution ($\leq$ 100ps FWHM) and the stability of the clock pulses (380 MHz) delivered by DAΦNE.

The kaonic hydrogen X-rays were detected using recently developed large are Silicon Drift Detectors (SDD), having an active area of 1 cm^2 and a thickness of 450 μm [5]. After detailed performance tests, 144 SDDs, chips were installed surrounding the target cell.

The SIDDHARTA experimental setup was installed in DAΦNE accelerator in middle 2008 and started to take data from end 2008 until December 2009. The big part of the data taking was dedicated to the hydrogen and deuterium data, the main goal of the experiment, but we have, as well, performed measurements of kaonic helium4 and, for the first time ever, of kaonic helium3 atoms. The analysis of these data is ongoing and, in this paper, only preliminary results are shown.

3. Kaonic Helium4 measurement

To test and optimize our experimental technique, we measured the L-transitions for kaonic helium4 atoms, in particular the transition $3d \rightarrow 2p$, L_α transition. The use of this transition is motivated by its yield, a factor at least 10 times higher than the kaonic hydrogen K_α one.

Part of the data for kaonic helium4 atoms, was taken for about two weeks in January 2009, while a Fe55 source was installed inside the apparatus. In this way, detailed studies of systematic of calibration was done. The result obtained from these data for the $2p$ level strong interaction shift of the kaonic helium4 is [6]:

$$\Delta E = E_{exp} - E_{e.m.} = 0 \pm 6(stat) \pm 2(syst) eV \quad (1)$$

More kaonic helium4 data were taken during 2009 without the Fe55 source. The preliminary X-ray energy spectrum for the new kaonic helium4 data is shown in Fig. 2.

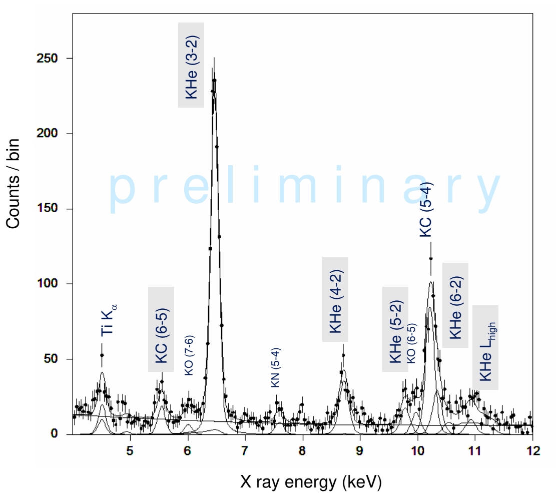

Figure 2. Kaonic helium 4 X-ray spectrum

The kaonic helium4 L_α line at 6.4 keV is clearly seen, together with the other kaonic helium4 L-lines and background lines.

The kaonic helium has physics-interest in itself: before the KEK E570 [7] experiment, the experimental data were in contradiction with theory (so called "kaonic helium puzzle"). The resultant shift obtained by the SIDDHARTA experiment [6] confirms the result obtained by the E570 group, definitely solving the "kaonic helium puzzle". Presently, the data analysis of the overall kaonic helium4 data is ongoing, in order to get a better precision and information about yields of L-lines.

4. Kaonic Helium3 measurements

During the SIDDHARTA data taking, we measured also the L-transitions for kaonic helium3, for which no experimental data existed until now.

The preliminary X-ray energy spectrum for kaonic helium3 data, is presented in Fig. 3

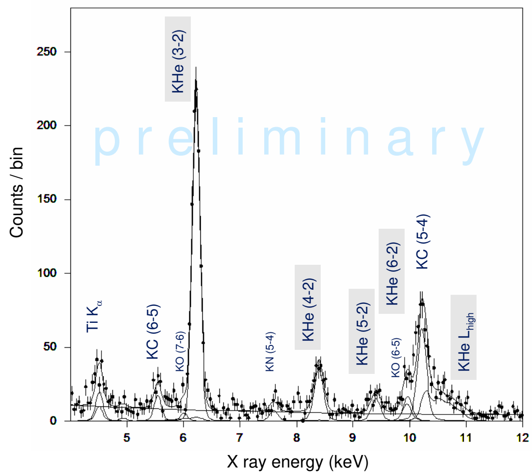

Figure 3. Kaonic helium3 X-ray spectrum

The kaonic helium3 L_α line at 6.2 keV is clearly seen, together with the other kaonic helium3 L-lines and background lines.

The analysis is undergoing and will be soon published.

5. Kaonic Hydrogen measurements

The main part of the data taking campaign was dedicated to the Hydrogen target.

Figure 4 shows the K-H preliminary X-ray energy spectrum. The two peaks at 4.5 and 5.5 keV correspond to: the Ti fluorescence lines, coming from the Ti foil, which is activated by the kaons and background, and to the Kaonic-Carbon 6 $\rightarrow$ 5 (at 5.5 keV) X-ray transitions, produced at the target walls.

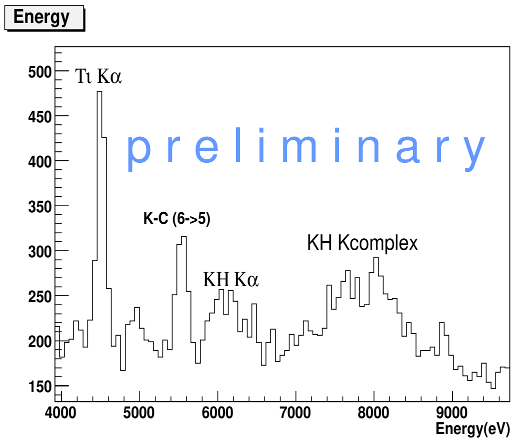

Figure 4. Kaonic hydrogen X-ray spectrum.

The other two broad peaks are the kaonic hydrogen K_{α}line (5.8-6.4keV region) and the $K_{complex}$ (K_{β},K_{γ} ...) lines (7.0 - 9.0 keV region). For fitting the kaonic hydrogen signal a Voigt function is used for each X-ray transition (K_{α},K_{β},K_{γ}...) where the energy level shift with respect to the electromagnetic value is common to all lines, and the same for the width.

The analysis for kaonic hydrogen is undergoing, with the aim to arrive at a more precise measurement than the DEAR experiment (or similar).

In the kaonic deuterium case, the accumulated statistics is not enough to distinguish a clear signal. The data analysis is ongoing.

6. Conclusions

The SIDDHARTA experiment performed in 2009 precision measurements of kaonic helium (3 and 4)and kaonic hydrogen. It performed as well the first ever exploratory measurement of the kaonic deuterium. DAΦNE proved to be an ideal kaonic atoms factory, representing an unique opportunity to study in a complete way the kaon-nucleon/nuclei physics at low energy. Presently, data analyses are ongoing. In parallel plans for an upgrade of the experimental setup for an enriched scientific case for the near future are being considered.

7. Acknowledgements

We acknowledge the support of the European Community-Research Infrastructure Integrating Activity Study of Strongly Interacting Matter (acronym HadronPhysics2, Grant Agreement n. 227431) under the Seventh Framework Programme of EU. We thank the DAΦNE accelerator division for the excellent working conditions provided to SIDDHARTA and for their friendly collaboration.

REFERENCES

1. G. Beer et al., Phys. rev. Lett. 94, (2005)212302.
2. S.Deser et al., Phys. Rev. 98(1954) 774 ; T. L. Truemann, Nucl. Phys. 26 (1961) 57; A. Deloff, phys. Rev. C 13 (1976) 730.
3. J. Zmeskal, Progr. Part. Nucl. Phys. 61 (2008) 512.
4. V. Lucherini, et al., Nucl. Instrum. Methods A 496 (2003) 315.
5. P. Lechner, et al., Nucl. Instrum. Methods A 458 (2001) 281.
6. M. Bazzi, et al., Physics Letters B 681 (2009) 310-314.
7. S. Okada, et al., Physics Letters B 653 (2007) 387.