THE KAONIC HELIUM CASE

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The only three existent kaonic helium X-ray transition measurements at present are referring to the transitions to 2p level. These measurements are more than 30 years old and the obtained results, affected by big errors, are much larger than those predicted by optical models. It is thought that the optical model is inadequate, due to the presence of the $\Lambda(1405)$ resonance, not properly taken into account. Because the nucleons in the helium nucleus are tightly bound, the effective energy of the K^-p interaction (1432 MeV at threshold) is in helium much closer to the energy of the resonance than in other nuclei. It is then planned to measure the kaonic helium X-ray transitions to the 2p level in the framework of the SIDDHARTA (SIlicon Drift Detector for Hadronic Atom Research by Timing Application) experiment, at the DAΦNE collider of Frascati National Laboratories, and to confirm or not the discrepancy reported by the previous experiments with a much smaller error.

1. Introduction

A kaonic atom is formed whenever a negatively charged kaon enters a target, loses its kinetic energy and is eventually captured into a high atomic Bohr orbit, replacing one of the outer electrons. The kaon then cascades down through its own series, initially by Auger transitions in which orbital electrons are ejected (not valid for kaonic hydrogen) and in later stages by emission of X rays. Finally the particle in a state of low angular momentum will be absorbed by the nucleus via the strong interaction. This strong interaction is the reason for a shift of the energy of the lowest atomic levels from their purely electromagnetic values, whilst the absorption reduces the lifetime of the states, broadening the X-ray transition to this final atomic levels.

The study of kaonic hydrogen atom can give information about the strong interaction parameters (shift and width) of the $1s$ level. Such kind of measurement was performed lately at the DAΦNE accelerator by the DEAR experiment - and will continue, together with the measurement of kaonic deuterium, in the framework of SIDDHARTA Collaboration [1].

For what concerns the kaonic helium, the situation today is rather ambigous: the only 3 existent experiments, performed more than 20 years ago, give, within few σs, results, for the $2p$ strong interaction parameters, which are about 2 order of magnitude different with respect to the theoretical

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[§] also at: Technical University Munich, 80290 Germany predictions, performed in the framework of an optical model calculation. A new precise measurement is then badly needed; this measurement might be performed as well in the framework of the SIDDHARTA experiment.

In Section 2 the present experimental situation is reviewed, while in Section 3 the results are discussed together with the theoretical predictions. In Section 4 the case of kaonic helium measurement in SIDDHARTA is presented while in Section 5 some conclusions are drawn.

2. Review of the Kaonic helium experimental results

There are three experiments which performed the kaonic helium measurement up to now [2,3,4]. All these experiments used liquid helium as target and Si(Li) detectors and measured the strong interaction parameters (shift and width) for the $2p$ level. The obtained results are reported in Table 1.

Table 1. Strong interaction parameters for the $K^{-4}He$ atoms

ΔE_{2p} (eV)	Γ_{2p} (eV)	Ref.
-41 ± 33	-	[2]
-35 ± 12	30 ± 30	[3]
-50 ± 12	100 ± 40	[4]

The average values extracted from these results are:

$$\Delta E_{2p} = -43 \pm 8 \; eV \tag{1}$$

$$\Gamma_{2p} = 55 \pm 34 \; eV \tag{2}$$

These results are more than 20 years old and by far of being precise measurements. However, as discussed in the next Section, there are indications from these results of a strong disagreement with the theoretical predictions based on simple Optical Models.

3. Theoretical predictions for kaonic helium

The optical model calculations, using a 3 parameter Fermi distribution for the nuclear density $\rho(\mathrm{r})$ and a mean value for the scattering length $\bar{a} = 0.34 \pm 0.03 + i(0.84 \pm 0.03)$fm, obtained from a fit [5] to all available measurements for nuclei with $Z > 2$, give for the strong interaction parameters fr kaonic helium the following results [6]:

$$\Delta E_{2p} = -0.13 \pm 0.02 \ eV \tag{3}$$

$$\Gamma_{2p} = 1.8 \pm 0.05 \ eV \tag{4}$$

With more sofisticated forms for ρ(r) the obtained results are very similar.

Comparing the experimental with theoretical results, obtained from the optical model calculations, there are two orders of magnitude of difference. Many speculations were and are being done concerning the reason of this disagreement. One of the reasons might be related to the fact that the nucleons inside the ^{4}He are tightly bound, resulting in an effective energy for the kaon-nucleon interaction (1411 MeV) very close to the $\Lambda(1405)$ resonance. The consequence of this might be the fact that the parameters which fit the data for heavier nuclei (further away from the $\Lambda(1405)$ resonance) might not fit the kaonic helum values.

As pointed out by Batty [6] no simple modification of the value for $\bar{a}$ however gives a good fit to the helium data, unless a kaon-nucleus bound state is invoked, since these bound states can give rise to large energy shifts and widths in the atomic states. Better (but not perfect) agreement with experimental data can be obtained for $\bar{a} = 1.203 \pm 0.006 + i(0.010 \pm 0.001)$fm or $\bar{a} = 3.718 \pm 0.018 + i(0.032 \pm 0.002)$fm, so when the imaginary part is small.

Recent coupled channel calculations [7] are showing, however, the way for a possible agreement of the theory with experimental results.

At this stage, it is of utmost importance for the understanding of the underlying physics to perform new experiments, with an improved accuracy. This will become possible in the framework of the SIDDHARTA experiment at the DAΦNE accelerator at Frascati National Laboratories.

4. Kaonic helium measurement in SIDDHARTA

SIDDHARTA (SIlicon Drift Detector for Hadronic Atom Research by Timing Application) [8] experiment is a continuation of the DEAR (DAΦNE Exotic Atom Research) [9] experiment - which performed the most precise measurement of kaonic hydrogen to day at the DAΦNE Collider [10]. The primary goal of SIDDHARTA is an eV precision measurement of kaonic hydrogen and kaonic deuterium transitions, measurement which will allow to extract isospin dependent antikaon-nucleon scattering lengths at a precision unattained before.

The new feature to be used in SIDDHARTA is the detector: the newly developed large area Silicon Drift Detector (SDD) [11], which should allow the reduction of the background (by applying a μs level trigger) present in DEAR by some orders of magnitude.

In the next Sections, a brief description of the SDD detector and of the tests performed with a preliminary setup, are given.

4.1. *Large Area Silicon Drift Detectors*

The Silicon Drift Detectors (SDD) were developed as position sensitive detectors which operate in a manner analogous to gas drift detectors [11]. Recently, SDD started to be used as X-ray detectors in X-ray fluorescence spectroscopy, electron miniprobe analysis systems and synchrotron light application. SDDs with sensitive areas of up to 10 mm^2 are commercially available since several years. The typical energy resolution is better than 140 eV (FWHM) at 5.9 keV and -20 degrees centigrade.

The outstanding property of a SDD is its extremely small anode capacitance, which is independent of the active area. Thus, the electronics noise is very low, and much shorter shaping times than for PIN diodes or Si(Li) detectors can be used. The two main noise contributions of a detector are the leakage current and the capacitance. The equivalent noise charge increases linearly with the capacitance but only with the square root of the leakage current, which is correlated to the temperature. The leakage current depends on the detector area, but due to the drift principle the anode size and thus the capacitance is constant. Then, it can be expected that SDDs with much more than 10 mm^2 area still have a good energy resolution. Taking then into account the small shaping time, a trigger application of large area SDD as an X-ray detector, with a time window limited by its active area (drift time) can be envisaged. One of the ideal applications of such a triggered large area SDD detector is the measurement of exotic atoms X-ray transitions . The X-ray energies, ranging from few to tens of keV, are well in the range of maximum efficiency of SDDs, while a trigger based on a time-window of the order of μs was demonstrated by Monte Carlo simulation to dramatically reduce the background and to allow a precision measurement of exotic atom transitions. The trigger in this case is given by the specific process which generated the K^- at DAΦNE, namely a back-to-back reaction of the type:

$$\phi \to K^+K^-. \tag{5}$$

A program to develop such kind of large area (1 cm^2) triggerable SDD detectors, with integrated electronics (JFET) on it, started as a collaboration of MPI (Max-Planck Institut), PNSensors, Politecnico di Milano and LNF.

4.2. *Experimental requests*

The experimental requests put forward for the new large area triggerable SDD detectors with integrated JFET and equipped with a newly under development electronics, to be used for X-ray measurements, are:

- energy range of interest: 0.5 - 20/40 keV, with a selectable gain;
- capability to operate under mainly high energy events (background), with an event rate of the order of KHz/channel;
- energy resolution: better than 140 eV (FWHM) at 6 keV of energy;
- stability and linearity better than 10^{-4} for a precision measurement;
- trigger at the level of 1μs.

Total number of channels to be processed: 200 (for a total area of 200 cm^2); eventual use of multiplexing - to be optimized. This is the first application in which SDDs are used with a trigger system.

4.3. *Preliminary measurements*

4.3.1. *BTF tests with a 7 chips array prototype*

Preliminary tests were performed at the Beam Test Facility (BTF) at Frascati with a prototype SDDs array: 7 chips of 5mm^2 each. A trigger was implemented and tested with a time window of 1μs. A synchronous (with BTF beam) as well as an asynchronous background (Fe and Sr sources) were implemented and it was checked that the rejection factor is in agreement with what expected. In Fig. 1 the results of the tests with the trigger are shown [8].

4.3.2. *Preliminary laboratory tests with a 30 mm^2 chip*

Preliminary measurements in laboratory with a SDD chip of 30 mm^2, shown in Fig. 2, were performed in June 2004. The chip was cooled at -40^0 C (by the use of a cryotiger) and a shaping time of 0.75 μs was used. The energy resolution measured was of 139 eV (FWHM) at 5.9 keV, as seen in Fig. 3.

The tests will be continued with the trigger measurements on the BTF.

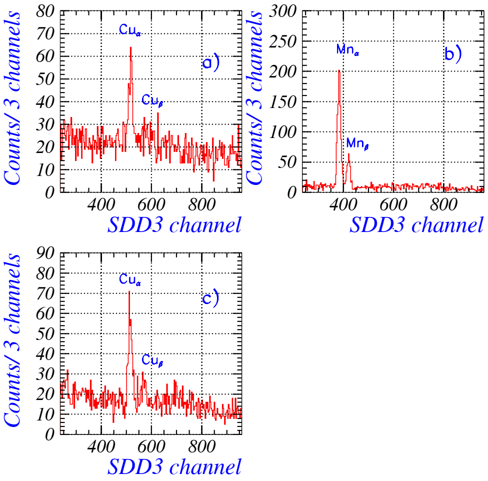

Figure 1. *a) No trigger, only BTF signal which excites the Cu-line, 5 Hz rate - 16 hours of DAQ; b) No trigger, 60 Hz, BTF signal (Cu) covered by Sr plus Fe radioactive sources as asynchronous background - 20 minutes DAQ; c) same as b) but trigger on, 5Hz as in a) - 16 hours of DAQ.*

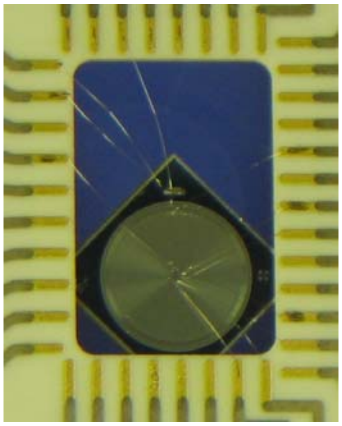

Figure 2. *The 30 mm^2 SDD chip used for testing in the laboratory.*

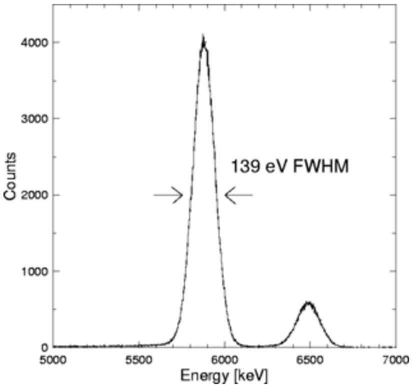

Figure 3. *The X-ray spectrum from an Iron source as measured in the laboratory with the 30 mm*^{2} *SDD chip.*

4.4. *The 1 cm*^{2} *SDD chip*

The 1 cm^2 SDD chip to be used in the SIDDHARTA experiment is under production, at PNSensors (Germany). The electronics is under development. The SDD layout on the readout side is shown in Fig. 4.

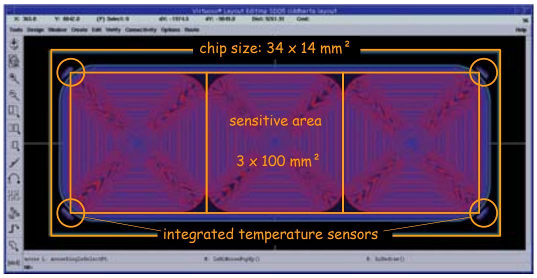

Figure 4. *SDD layout on the readout side*

The sensitive area per chip (containing 3 SDDs) is 3 cm^2; the SDDs are squared with round corners. The maximum diagonal drift length is 5.15 mm (centerlines) and 6.4 mm (diagonal).

Presently, construction and testing of the SDD detectors and of the electronics and mechanical structures is in progress. The setup was presented in [1].

With SIDDHARTA, it was estimated that a measurement at eV level for kaonic helium $2p$ strong parameters becomes feasible with an integrated luminosity of about 100 pb^{-1}. The setup will be installed at DAΦNE in the end of 2006 and start taking data.

5. Conclusions

There is, apparently, a strong discrepancy between the experimental results, based on 3 experiments and theoretical predictions for the kaonic helium $2p$ strong interaction parameters. On experimental side, the three experiments are more than 20 years old and the overall precision, on the average values, is within few σs . New experimental results, with a better accuracy, are badly needed. Such an experiment is planned in the future in the framework of the SIDDHARTA Collaboration, at the DAΦNE accelerator in Frascati. A measurement at eV precision level can be reached. A summary of the actual situation concerning kaonic helium experiment/theory - with a projection of the SIDDHARTA precision, is shown in Fig. 5.

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References

1. C. Guaraldo, contribution to the present Proceedings.
2. C.E. Wiegand and R.H. Pehl, Phys. Rev. Lett. **27** (1971) 1410.
3. C.J. Batty *et al.*, Nucl. Phys. **A326** (1979) 455.
4. S. Baird *et al.*, Nucl. Phys. **A392** (1983) 297.
5. C.J. Batty, Nucl. Phys. **A372** (1981) 418.
6. C.J. Batty, Nucl. Phys. **A508** (1990) 89c.
7. M. Iwasaki, contribution to the present Proceedings.

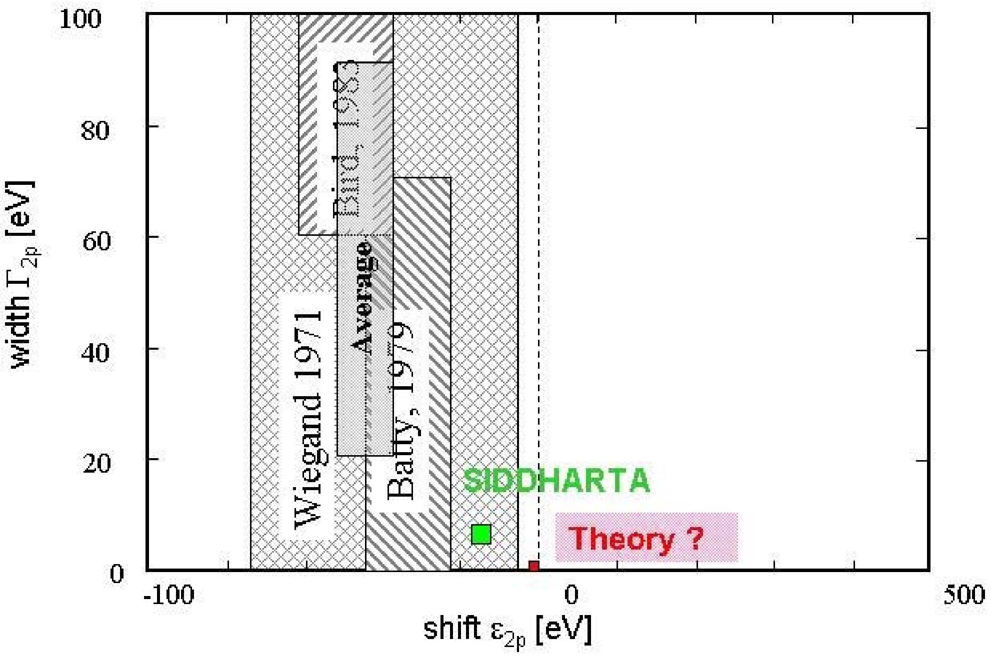

Figure 5. *Kaonic helium case: experiment versus theory and the SIDDHARTA projected result.*

8. J. Zmeskal, SIDDHARTA Technical Note IR-2 (2003); C. Curceanu (Petrascu), SIDDHARTA Technical Note IR-3 (2003). .
9. S. Bianco *et al.*, Rivista del Nuovo Cimento **22**, No. 11 (1999) 1.
10. G. Vignola, Proc. of the “5th European Particle Accelerator Conference”, Sitges (Barcelona), Eds. S. Myres *et al.*, Institute of Physics Publishing, Bristol and Philadelphia (1996) 22
11. E. Gatti, P.Rehak, Nucl. Instr. and Meth. **225** (1984) 608;
    E. Gatti, P.Rehak, Nucl. Instr. and Meth. **A235** (1985) 224.