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THE SIDDHARTA PROJECT - EXPERIMENTAL STUDY OF KAONIC DEUTERIUM AND HELIUM

M. CARGNELLI *

Stefan Meyer Institut für subatomare Physik
Austrian Academy of Sciences
Boltzmanngasse 3, 1090 Vienna, Austria

We are preparing a new experimental program at the DAΦNE facility of LNF to measure X-ray transitions in kaonic deuterium and helium. The hadronic shift and the width of the atomic ground state are sensitive quantities for studying the low energy antikaon-nucleon interaction. Combined with the results from our kaonic hydrogen experiment DEAR this will allow to determine the isospin-dependent scattering lengths. The new kaon-trigger and fast X-ray detectors will provide a suppression of background of more than 2 orders of magnitude, and thus allow to measure kaonic deuterium X-rays for the first time ever.

1 Introduction

In the SIDDHARTA project (Silicon Drift Detectors for Hadronic Atom Research by Timing Application) a triggered soft X-ray detection system is being developed. The kaonic atom experiments [3] require to do high resolution X-ray spectroscopy in the radiation environment of an accelerator, which is a challenge to experimental techniques. In fig. 1 the principle of the system is sketched.

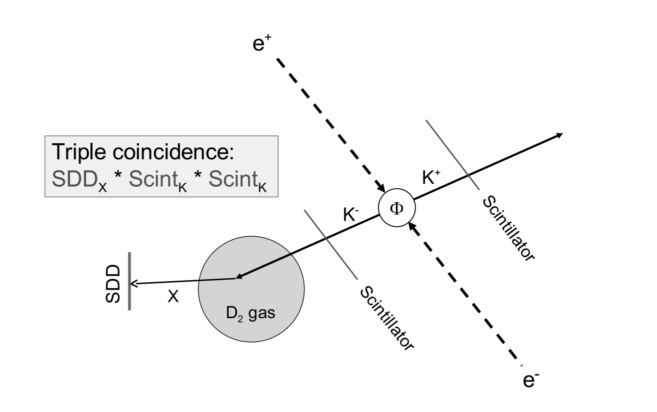
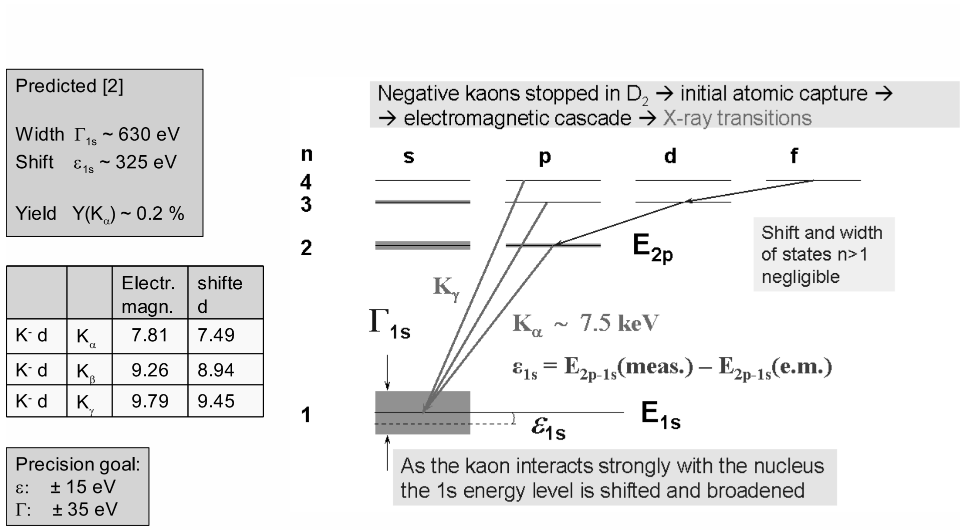


Figure 1. Scheme of the triggered detection system for kaonic X-rays.

A kaonic atom is formed when a negative kaon enters a medium, looses its

*ON BEHALF OF THE SIDDHARTA COLLABORATION kinetic energy through ionization and excitation of the atoms and molecules and eventually is captured, replacing the electron, in an excited orbit (n $\simeq$ 25). Via different cascade processes (Auger transitions, Coulomb deexcitation, scattering) the kaonic atom deexcites to lower states.



		Electr. magn.	shifted
K^- d	K_α	7.81	7.49
K^- d	K_β	9.26	8.94
K^- d	K_γ	9.79	9.45

Figure 2. Overview: X-ray transitions and strong interaction observables in kaonic deuterium.

When a kaon reaches a low-n state with small angular momentum, strong interaction with the nucleus causes its absorption. The strong interaction is the reason for a shift in the energies of the low-lying levels from the purely electromagnetic values and the finite lifetime of the state corresponds to an increase in the observed level width. See figure 2 for the situation in kaonic deuterium. Kaonic helium is more easy to measure, since the X-ray yield is higher [4].

2 Silicon Drift detectors

Silicon Drift Detectors (SDDs) are based on the principle of sideward depletion introduced by Gatti and Rehak [1] in 1984 . In an advanced SDD design optimized for X-ray spectroscopy (see fig. 3), the concentric ring-shaped n+ strip system for the generation of the drift field as well as the collecting anode in their center are placed on one side of the structure, while the opposite surface is a non-structured p+ junction acting as the radiation entrance window. There is no field-free region in the device. That means the whole volume is sensitive to the absorption of ionizing radiation. Each electron generated in this volume has to fall down to the point of lowest potential energy, which is the anode in the center of the front side. The small value of the anode capacitance (which is almost independent of the detector area) results in a large amplitude and a short rise time of the output signal. Compared to conventional photodiodes the SDDs can be operated at higher counting rates and of yield a much better energy resolution.

SDDs combine a large sensitive area with a small value of output capacitance and are therefore well suited for high resolution, high count rate X-ray spectroscopy as required in the kaonic atom experimental program at LNFrascati. The SDDs to be used in these experiments have a near quadratic structure (see fig. 4) with an active area of 1 cm^2 and a thickness of 450 μm. Three of these structures are integrated on one chip, 2 chips make up a SDD detector element. First prototypes with smaller area were tested and show an excellent energy resolution due to the low leakage current level obtained by the refined processing technology. This makes it possible to operate SDDs even at room temperature or with moderate cooling. The timing resolution will be around 500 ns FWHM.

SIDDHARTA is a Joint Research Activity within the I3 Hadron Physics project (6th framework program of the European Union). It is carried out in cooperation with LNF, MPI, PNSensor, Politecnico Milan and IFIN-HH (Bucarest).

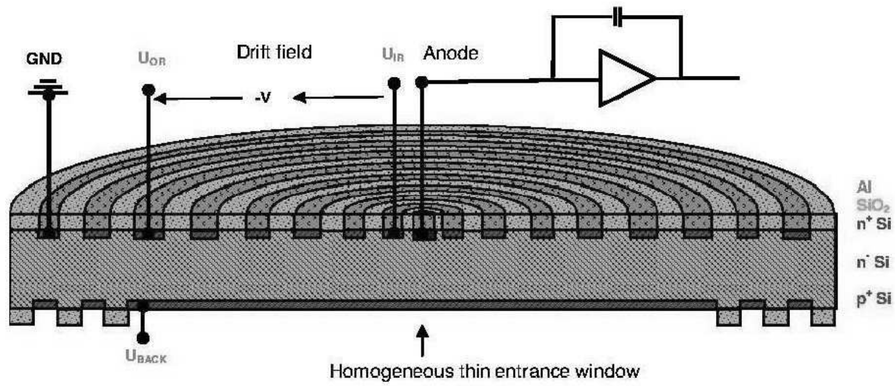


Figure 3. Scheme of a Silicon Drift Detector with circular geometry.

3 Monte Carlo Simulation

The GEANT Monte Carlo simulation uses the following geometry: the existing beam pipe with a radius of 4.5 cm, the kaon triggers (2 groups of 1.5 mm plastic scintillators stripes) are modelled at 5.5 cm distance from the beam axis. The kaon momentum variation due to the lateral boost originated by the beam crossing angle of 15 mrad is compensated by shaped degraders. Two gas target cells and their insolation vacuum vessels are placed at 180 degrees in back-to-back geometry. The cells have a radius of 6 cm, the entrance window is at 7 cm from the beam interaction point. The cylindrical X-ray exit window (75 μm kapton) is supported by a hexagonal fiber grid structure, the SDD modules are placed at 6.7 cm from the center axis of the gas cell, they have in total 200 cm^2 of active area. Figure 5 shows the design.

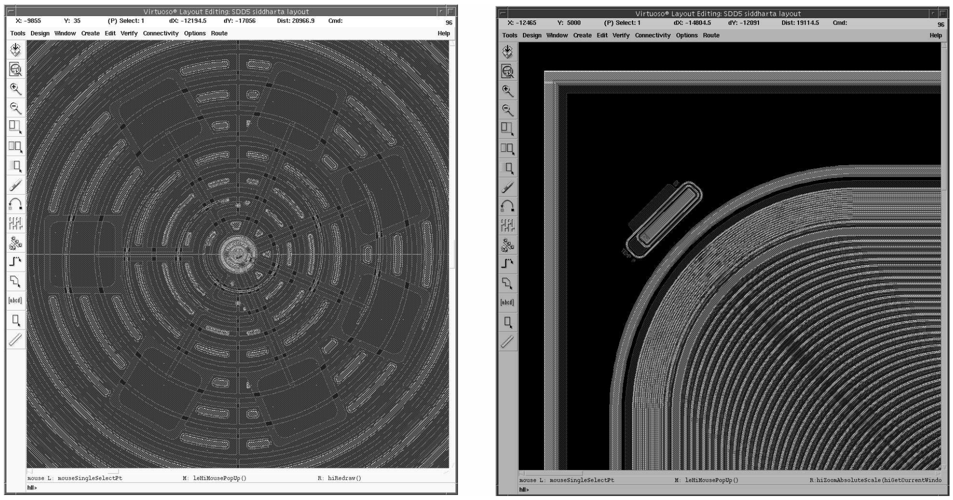


Figure 4. Chip layout for SIDDAHRTA, developed at PNSensor and MPE. SDD layout - readout side. Left: cell center. Right: cell edge.

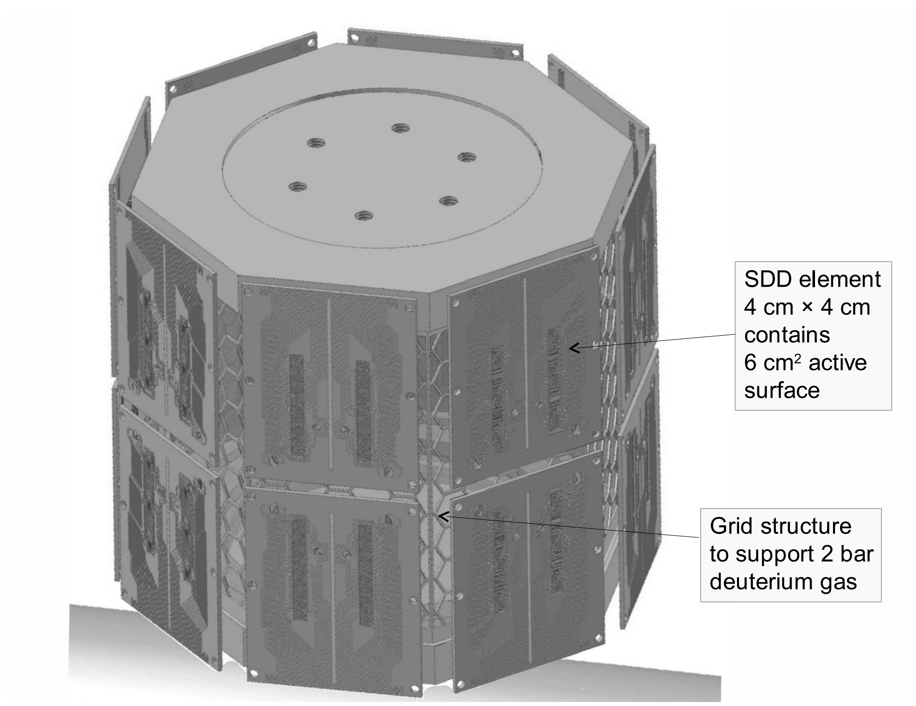


Figure 5. Cell design. Trigger scintillators omitted

The model for beam background contains 510 MeV e^+ and e^- which are moving in small angles (0.1 rad) along the beam. The spread from the beam axis is FWHM = 11 cm. This 'asynchroneous' background has no time correlation to bunch crossing.

Additionally Babha scattering is included: instead of a Φ, a bunch crossing can produce 510 MeV back-to-back e^+ and e^- pairs.

The outline of the simulation is this: choose rates - start Φs and e with statistical time tags - track all secondaries, store deposited energies, store time tags - for a fraction of stopped K^- start a kaonic X-ray with an energy distributed as Voigt function with given width - add "experimental" time- and energy spread to timetags and deposited energies - handle 'Pile-up' events.

The data-aquisition trigger demanded that both back-to-back scintilators-groups have a deposited-energy signal above the kaon-threshold and a fast time correlation (10ns).

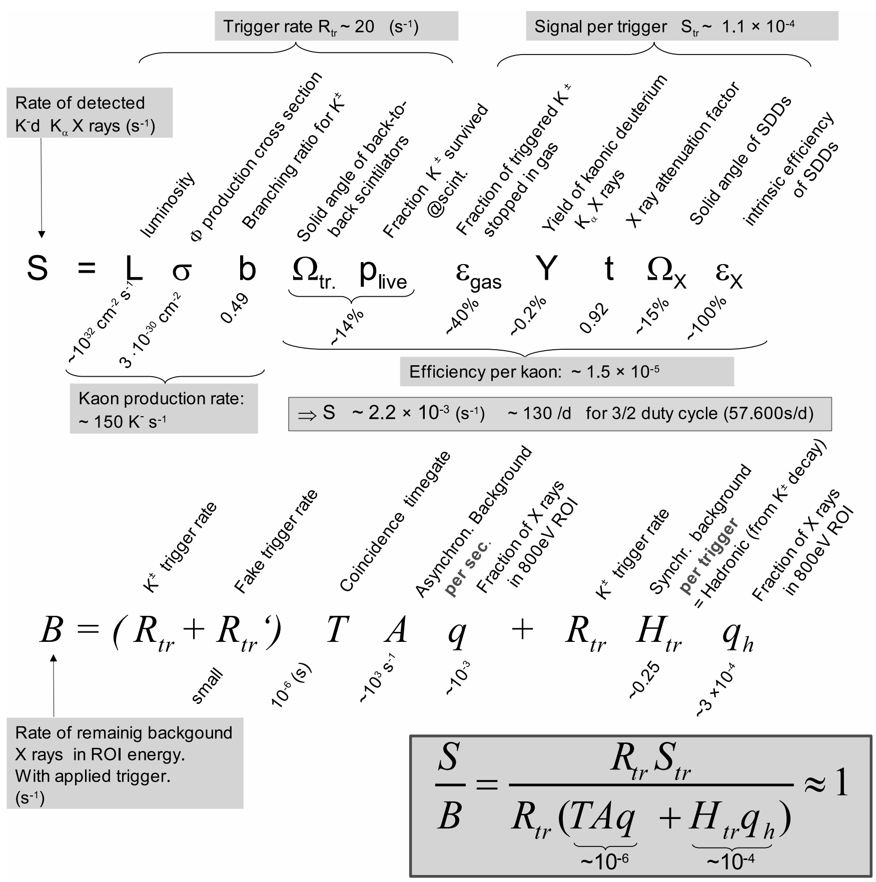


Figure 6. Signal rate estimation and signal-to-background

In a following step the stored event-data are processed and time correlations between SDDs and scintillators are calculated. This allows finally to select and histogram SDD events coinciding with trigger kaons within 1 μs. The relevant numbers derived are: triggers per second, triggers per produced charged kaon, stopped K^- in the gas, detected kaonic X-rays, detected kaonic X-rays per trigger, detected background. In fig. 6 to 8 a compilation of Monte Carlo results is given.

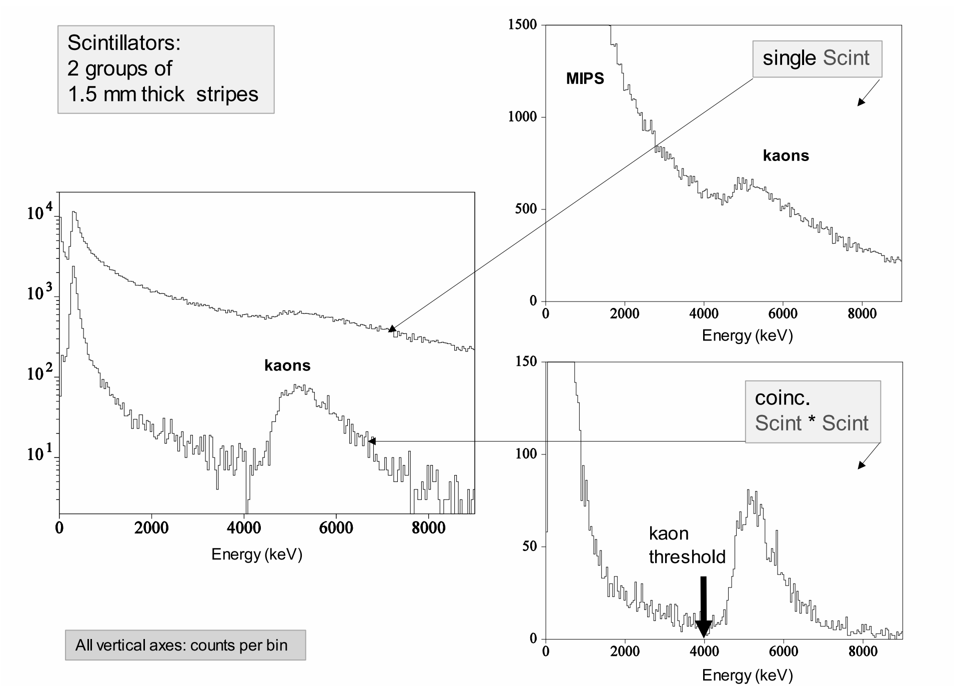


Figure 7. Simulation of the energy signal of the trigger scintillators. Without usage of the fast back-to-back coincidence the kaon signal sits on a very high background (”single” spectrum).

4 Conclusions

The development of the new SDD detectors is in an advanced stage.

Using conservative assumptions for the available luminosity, the simulation of a kaonic deuterium experiment shows: In a beam period of 30 days we can expect 4000 signal events at a signal to background ratio of 1:1 - fit simulations show that with such data the shift an width can indeed be determined to 15 eV and 35 eV respectively.

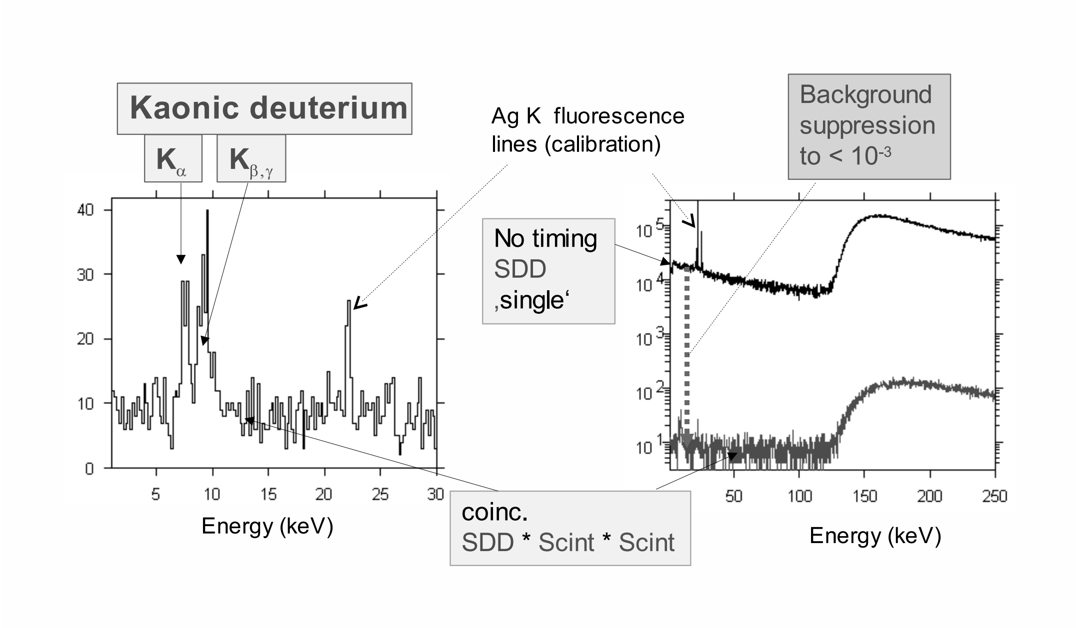


Figure 8. Simulation of the energy signal of the SDDs. The rise of the spectrum above 120 keV corresponds to the energy MIPS deposit in 450 μm Si. The remaining background in the "coincidence" spectrum comes primarily from the decay of the charged kaons.

Acknowledgements

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