Silicon drift detectors for hadronic atom research - SIDDHARTA

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The development of triggerable large area silicon drift detectors for the spectroscopy of soft X-rays will provide us means for a new experimental program at the DAΦNE facility of LNF to measure X-ray transitions in kaonic deuterium and helium. These transitions are sensitive to the low energy antikaon-nucleon interaction. The new technique will improve the suppression of background by more than 2 orders of magnitude, and thus allow to measure kaonic deuterium X-rays for the first time ever.

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1 INTRODUCTION

The kaonic atom experiments [2] [3] require to do high resolution X-ray spectroscopy in the radiation environment of an accelerator, which is a challenge to experimental techniques. In the SIDDHARTA project (Silicon Drift Detectors for Hadronic Atom Research by Timing Application) a triggered soft X-ray detection system is being developed. In fig. 1 the principle of the system is sketched.

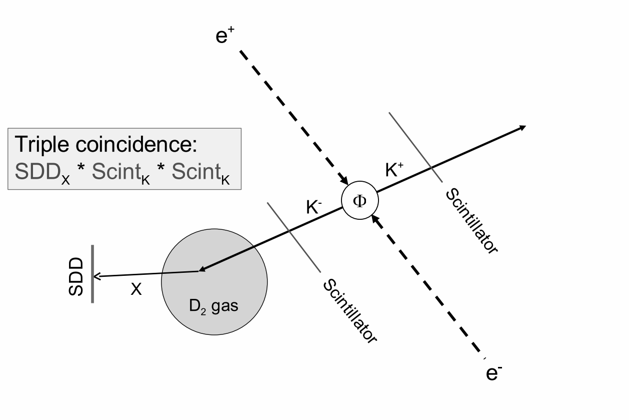

Figure 1: Scheme of the triggered detection system for kaonic X-rays.

A kaonic atom is formed when a negative kaon enters a medium, looses its 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. 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. Experimental results for kaonic deuterium are not available, although the case (as the kaonic hydrogen case) is of high scientific interest [4] [5] [6] [7].

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 yield a much better energy resolution.

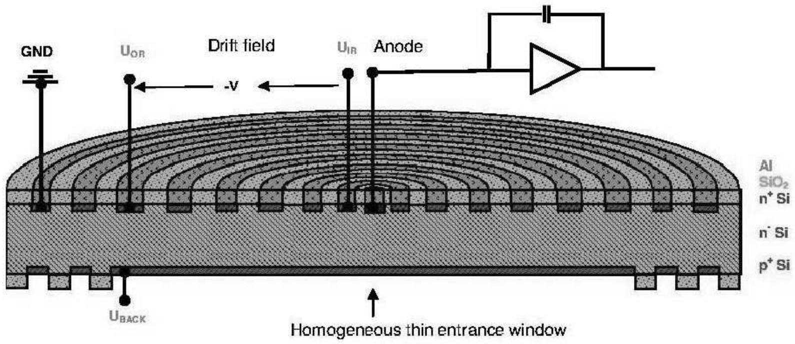

Figure 2: Scheme of a Silicon Drift Detector with circular geometry.

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 in 2007. 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.

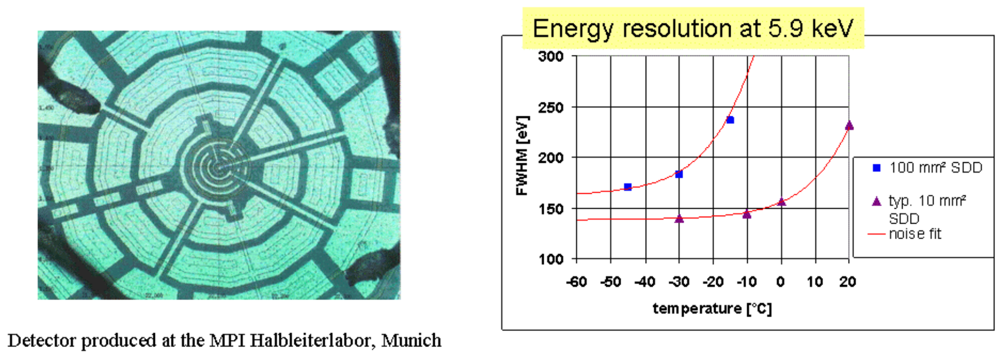

Figure 3: Central region of the chip (left), energy resolution (right).

3 MONTE CARLO SIMULATION

In the GEANT Monte Carlo simulations 3 geometric setups were tested: all assume the use of the existing beam pipe with an outer radius of 4.6 cm. The kaon triggers (2 groups

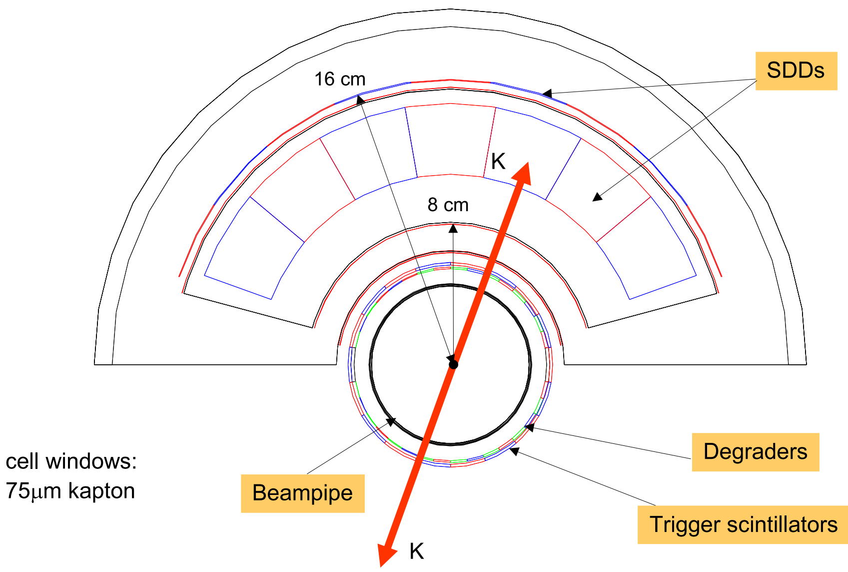

Figure 4: Setup 1. "Cake" type

of 9 1.5 mm thick plastic scintillators stripes) were modelled at 5.6 cm distance from the beam axis in cylindrical topology (Setup 1 "cake") or in 2 planar groups. The kaon momentum variation due to the lateral boost originated by the beam crossing angle of 15 mrad is compensated by segmented degraders. The gas target cell in case 1 is of toroidal shape with an inner distance from the beam axis of 8 cm, a length of 10 cm, an outer radius of 15.5 cm and a angle coverage of 140 degrees. For this design 2 rows of 9 SDD elements are places on the cylindrical surface and 7 elements on the front and 7 elements on the back side of the cylinder segment. This makes 32 elements of 6 cm^2 active area each, so in total 192 cm^2. Setup 2 "boxer" consists of 2 target cells in 2 individual insolation vacuum vessels and are placed at 180 degrees in back-to-back geometry. The cells have a radius of 10.4 cm, and each is surrounded by 2 octagons of SDD elements. The third layout is in the style of the DEAR setup, namely using one cylindrical cell surrounded by 3 'rings' of 11 SDD cells each.

All setups use hexagonal fiber grid structures to support the thin (75 micrometer kapton) target windows. Figure 5, 6, 7 show the designs.

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. They have the time structure of the beam bunches (3 ns), however, since a pair of charged kaons is produced in the average only all 6000 μs, we call beam background 'asynchroneous background'.

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

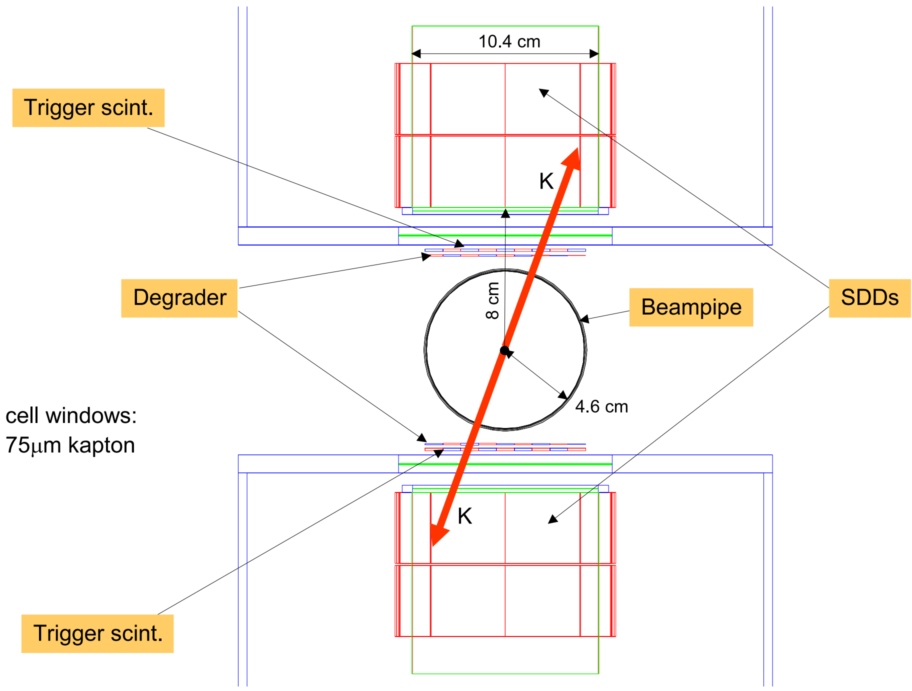

Figure 5: Setup 2: "Boxer" type

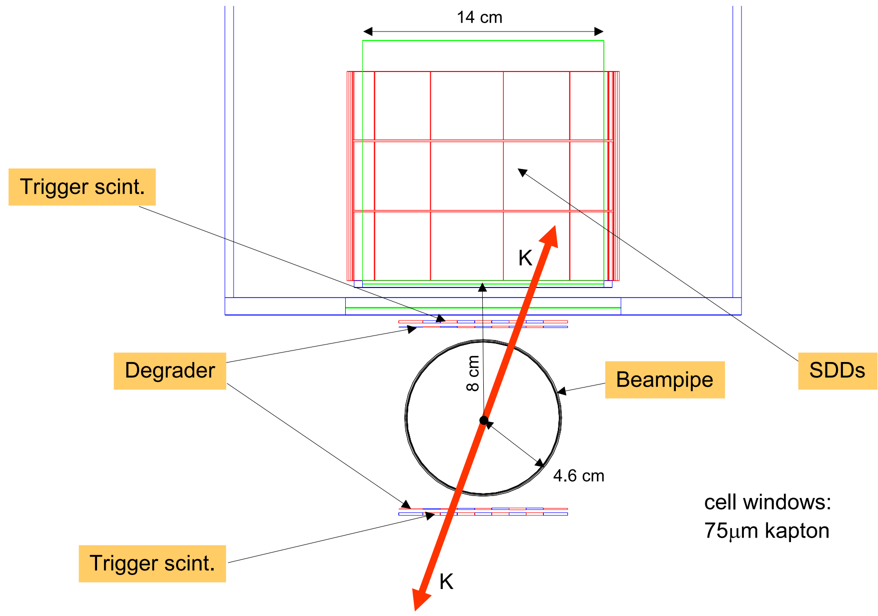

Figure 6: Setup 3. DEAR like type

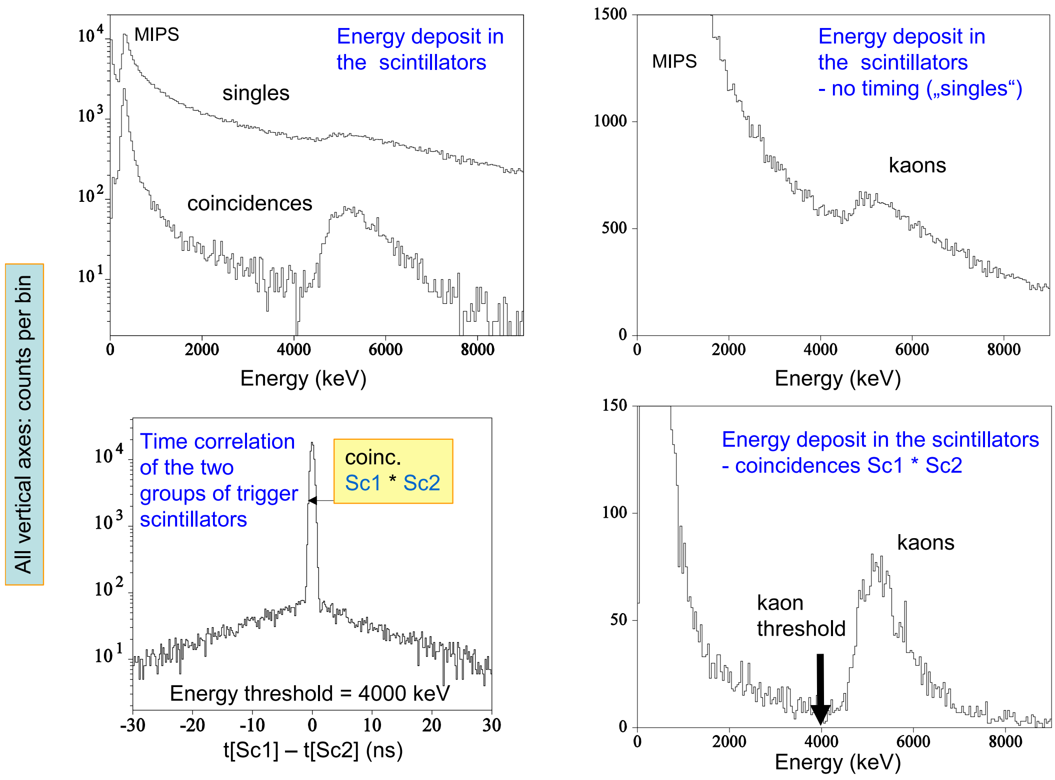

Figure 7: Spectra of the trigger scintillators

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 scintillator-groups have a deposited-energy signal above the kaon-threshold and a fast time correlation (1 ns). See fig. 7.

The production rate of charged kaon pairs is 150 s^{-1} for an expected luminosity of 10^{32} cm^2 s^{-1}.

The beam background was modelled such that a rate of 200 s^{-1} is seen by the 192 cm^2 SDDs. By analyzing SDD events up to 190 μs before a valid trigger, this background was monitored. (see fig. 8)

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 coming in prompt coincidence with trigger kaons, and alternatively asynchroneous events. See fig.8. Relevant numbers 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.

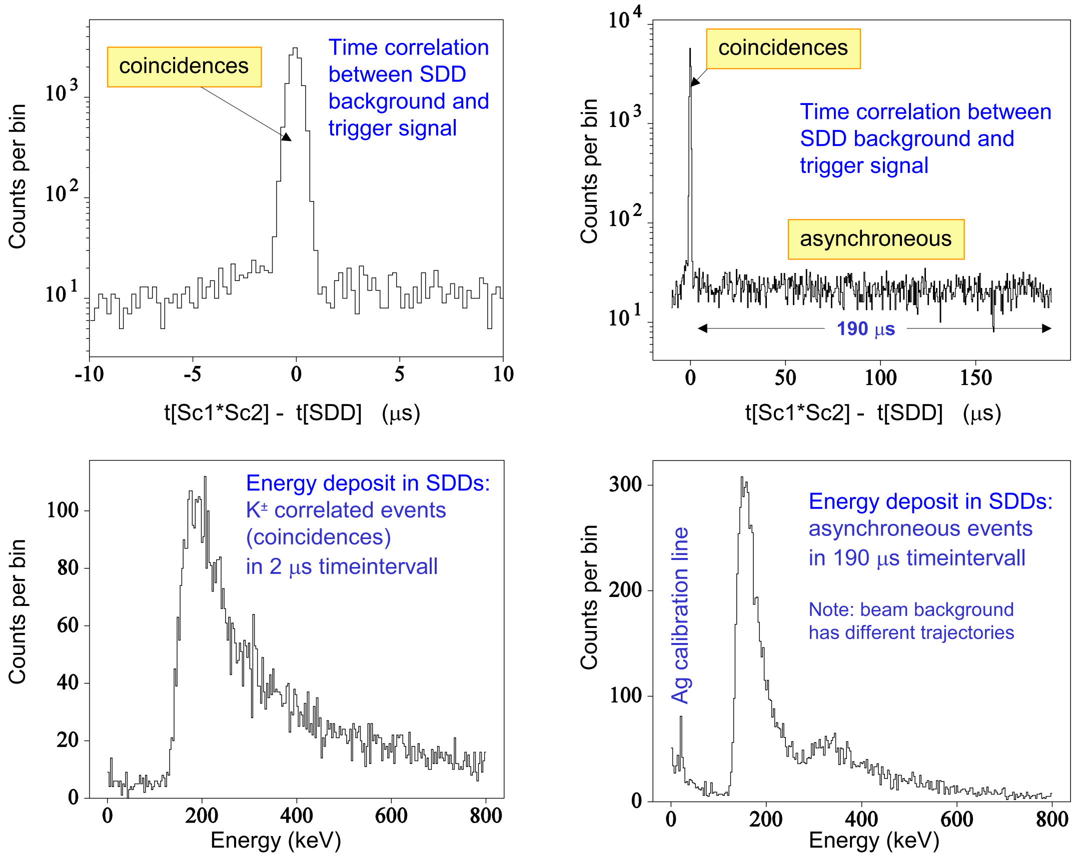

Figure 8: SDD spectra: time correlations (above), energy distribution (below)

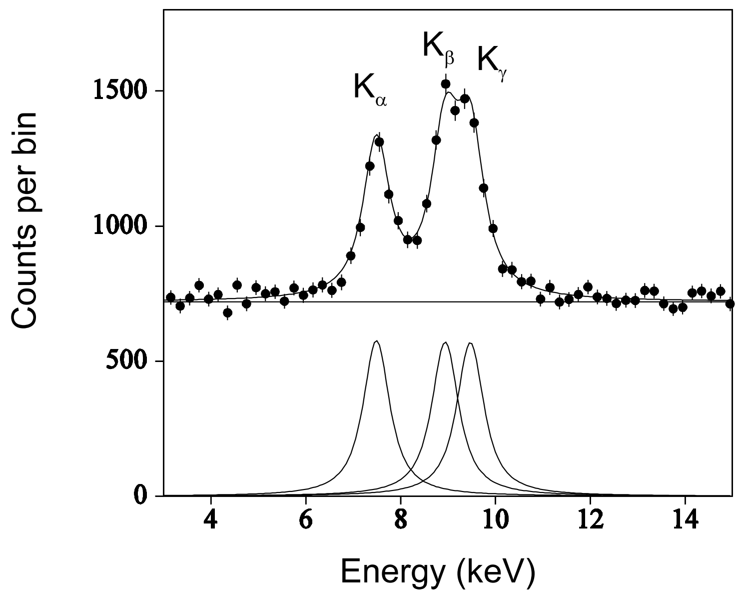

Figure 9: Fit of kaonic deuterium K-lines, 3000 K_α events, signal vs. background 1:1.

Table 1: Compilation of results for 3 setup geometries. The numbers give detected SDD events per produced $K^{\pm}$ pairs. The background is taken for a 800 eV region-of-interest at 7.6 keV. The coincidence width between SDD time and trigger time is 1 μs. The yield for the kaonic deuterium K_α transition is taken as Y = 0.2 %

Setup	Shape	$K^{-}d$ K_α signal	asynchroneous background	correlated background
1	Cake	$1.26 \cdot 10^{-5}$	$4 \cdot 10^{-7}$	$1.37 \cdot 10^{-5}$
2	Boxer	$9.42 \cdot 10^{-6}$	$2 \cdot 10^{-7}$	$1.23 \cdot 10^{-5}$
3	DEAR	$8.58 \cdot 10^{-6}$	$2 \cdot 10^{-7}$	$9.0 \cdot 10^{-6}$

4 CONCLUSIONS

The development and production of the new SDD detectors is in an advanced stage, first prototypes are currently being tested.

Using conservative assumptions for the available luminosity at the DAFNE facility (LNFrascati), the simulation of a kaonic deuterium experiment shows: In a beam period of 30 days we can expect a signal of 3000 K_α events at a signal to background ratio of 1:1 - fit simulations (see fig. 9) show that with such data the shift and width can be determined with a precision of $\approx$ 15 eV and $\approx$ 35 eV respectively, results which are eagerly awaited by the community in this field.

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