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SIDDHARTA: THE FUTURE OF EXOTIC ATOMS RESEARCH AT DAΦNE

Mihai Iliescu *
INFN, Laboratori Nazionali di Frascati, C. P. 13,
Via E. Fermi 40, I-00044 Frascati, Italy

ABSTRACT

The SIDDHARTA (SIlicon Drift Detector for Hadronic Atom Research by Timing Application) experiment represents the scientific and technical development of the DEAR experiment, along the scientific line dedicated to exotic atoms at DAΦNE. The scientific program consists in a measurement of kaonic hydrogen K_α lines with eV precision and the first measurement of kaonic deuterium, in order to determine the kaon- nucleon sigma terms. The objective was only partially achieved by DEAR, who performed the best available measurement of kaonic hydrogen. SIDDHARTA collaboration is developing a new set of large area, triggerable X-ray Silicon Drift Detectors (SDD), which will improve by 2 orders of magnitude the background rejection, allowing accomplishing the proposed objectives. Results from the tests performed with two prototypes (7 x 5 mm^2 and 1 x 30 mm^2) on DAΦNE Beam Test Facility, will be presented.

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* On behalf of SIDDHARTA Collaboration

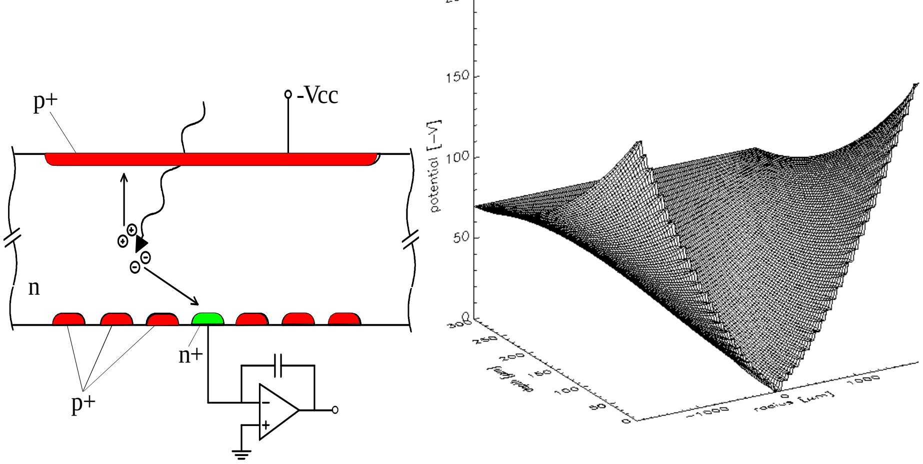
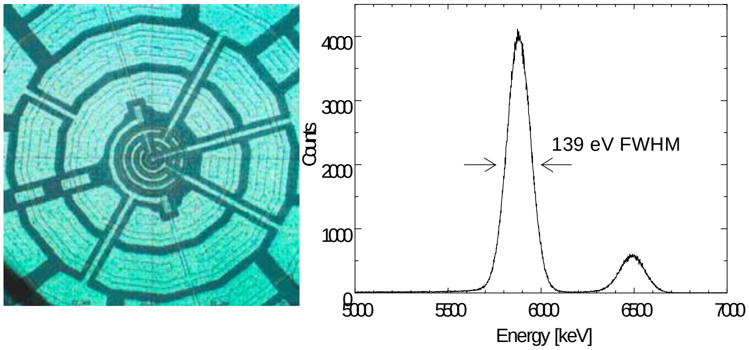


Figure 1: *SDD layout and potential model used in charge transport calculation.*

1 General description of SDD detectors

Silicon drift detectors were proposed by Gatti and Rehak in '83 [1] as an alternative to conventional drift chambers. Radiation hardness resistance, spatial and time resolution, compactness, as well as the easiness to be interfaced to fast readout systems made them a leading detector in the field, presently used by most advanced experiments [2]. Few years after, this kind of detector was developed as an X-ray spectroscopic tool, due to a series of characteristics that cannot be achieved (all together) by other X-ray detectors. Some of the most important ones are listed below.



a. b.

Figure 2: *a) The SDD integrated JFET. b)* Fe^{55} *spectrum (Mn K lines) measured with a 30* mm^2 *SDD at -40 C*

The high resolution of X-ray SDDs (near to Fano limit for silicon) is achieved by cooling and using a transport scheme which allows collecting the charges to a small anode. This last one has a low capacity and therefore, low noise level and high signal voltage (see Fig. 1). A key element for driving out a good signal from the collecting anode, is the integrated JFET amplifier. This one ensures a low sensitivity to electromagnetic interference and to parasitic capacitance. An image of the central part of the detector, containing the JFET structure, is presented in Fig. 2a.

In Fig. 2b, the Mn K_α fluorescence spectrum, measured with a large area SDD prototype (30 mm^2) is shown. The resolution obtained with a minimal cooling (139 eV FWHM at -40 Celsius) represents a very good result for a detector of this size.

The thickness of the SDD active layer represents another important characteristic. The commonly used values (300-500 microns) ensure at the same time a high quantum efficiency in the range of interest (near to unity, see Fig. 3) and a good energy separation between low-energy X-rays and minimum ionizing particles (peaked above 180 keV). In addition, the silicon layer is thin with respect to crystal detectors, and therefore, gives a low contribution to the electromagnetic cascade (low internal background).

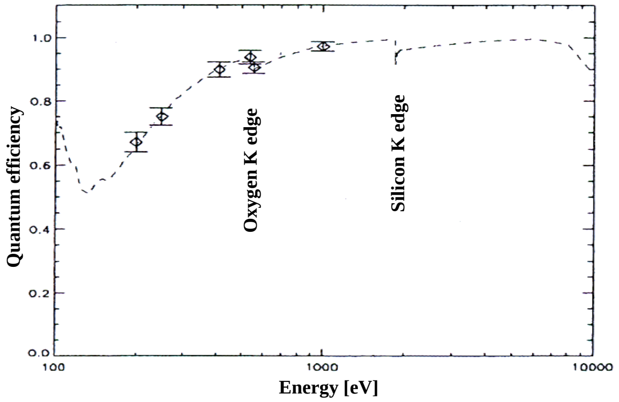


Figure 3: *The quantum efficiency of a 300 micron thick device.*

One of the most important features of the SDDs is the high speed of operation (10^4 to 10^6 particle/s, according to the requested precision and topology). This characteristic, (together with the possibility of obtaining high energy resolutions for large active areas) represents the key element of the choice of this device as main detector of SIDDHARTA. A comparison between different X-ray detectors in terms of shaping time and resolution as a function of area is shown in Fig. 4.

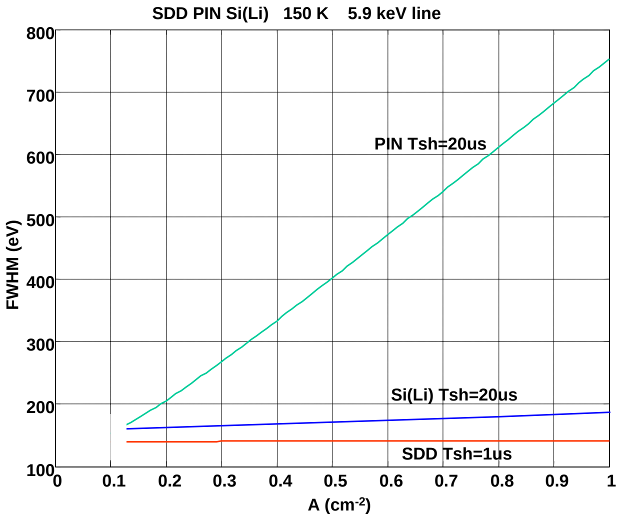


Figure 4: *Resolution and shaping time for different X-ray detectors.*

The relatively fast response of SDDs (few hundred nanoseconds) was poorly used in spectroscopic applications, until now. The only benefit taken was the high rate of acquisition. This is due to the fact that the timing of a drift chamber is usually given by another detector hit by the same particle. This technique could not be employed in the case of spectroscopic SDDs due to the high absorption of X-rays in a very thin layer of material. In the case of SIDDHARTA experiment, the exotic atom X-rays can be correlated with the kaon entrance in the target, which constitute the trigger. In consequence, our design is taking advantage of both energy and time resolution of spectroscopic SDDs, enlarging the area of usage of these detectors in triggered applications. This gives the possibility to detect and measure with accuracy very rare X-ray signals, in a high background environment.

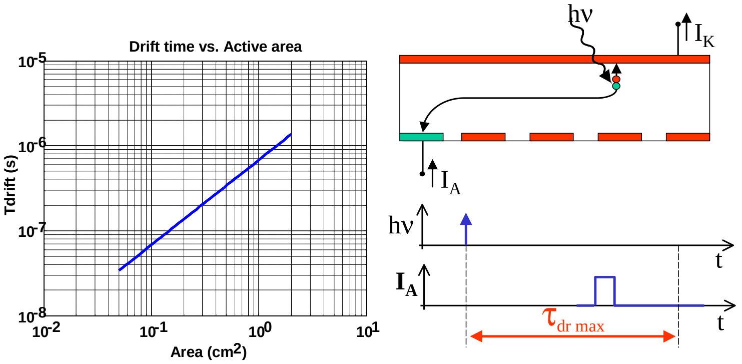


Figure 5: *SDD drift time as a function of area*

The detection of rare events also requires a large active area. SIDDHARTA group designed and start building a detection system with an active area of about 200 cm^2, a timing precision better than 1 microsecond and an energy resolution below 170 eV, at the level of Mn K_α line. The simulations show that both parameters (energy and time resolution) can be achieved by a multi-cell device, each cell having an active area of 1 cm^2. The system will operate under vacuum, at -125 Celsius.

The main parameter, which determines the trigger time window and therefore, the background rejection efficiency, is the drift time. This depends on detector size, high voltage used in transport and material characteristics (charge mobility). A calculation with parameters chosen according to experimental needs is presented in Fig. 5. This shows that maximum drift time expected in the case of 1 cm^2 device would not exceed 800 ns.

2 Signal and background expectations for SIDDHARTA

In the first phase of our scientific program, the best available data on kaonic Hydrogen was acquired by using the DEAR setup, based on X-ray CCDs. Despite the topological background rejection offered by CCDs and the effective shielding of the setup, a relatively low signal to background ratio was obtained (1/70). The main contribution to background came from machine lost electrons, via Touschek effect. This (asynchronous) part of background can be strongly suppressed by a triggered device with a time window of 1 microsecond, to a level of 1/20 of the signal (becomes negligible). The remaining part of background is produced by synchronous processes (hadronic background) and was estimated by Monte Carlo calculations. The expected signal to background ratio is about 5/1 in the case of Kaonic Hydrogen and 1./4 in the case of kaonic Deuterium. A test of the trigger rejection power was done at DAΦNE Beam Test Facility. The result can be seen in Fig.6. The upper side represents a non-triggered acquisition with the BTF beam, a continuous background source (Sr 90), an Fe^{55} source and an excited material (Ni), while the lower part shows a spectrum, in the same background conditions, triggered with the BTF beam, which induces Cu excitation. A clean selection of Cu fluorescence events can be observed, impossible to distinguish in the first case due.

A version of the SIDDHARTA setup (optimal topology is presently under study), to be prepared and operative by 2006, is shown in Fig. 7, while expected Monte Carlo results for kaonic Hydrogen are shown in Fig. 8.

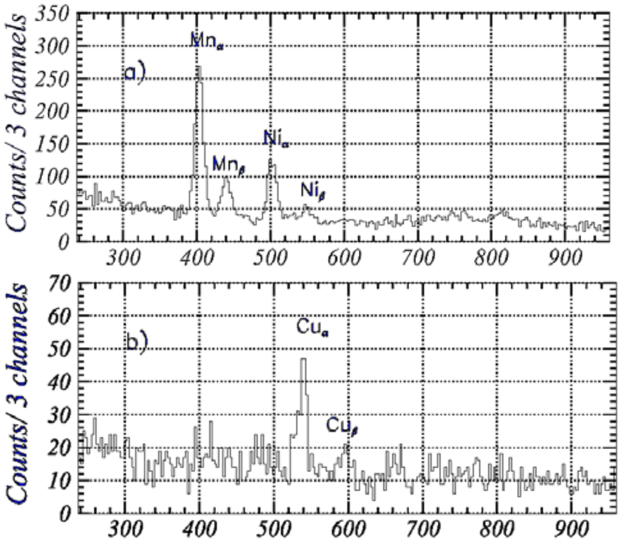


Figure 6: *SDD trigger test using 1 microsecond time window*

References

1. E. Gatti, P. Rehak, Nucl. Instr. and Meth. **225**(1984) 608.
2. E. Crescio *et al*, Nucl. Instr. and Meth. A **478** /1-2 321.

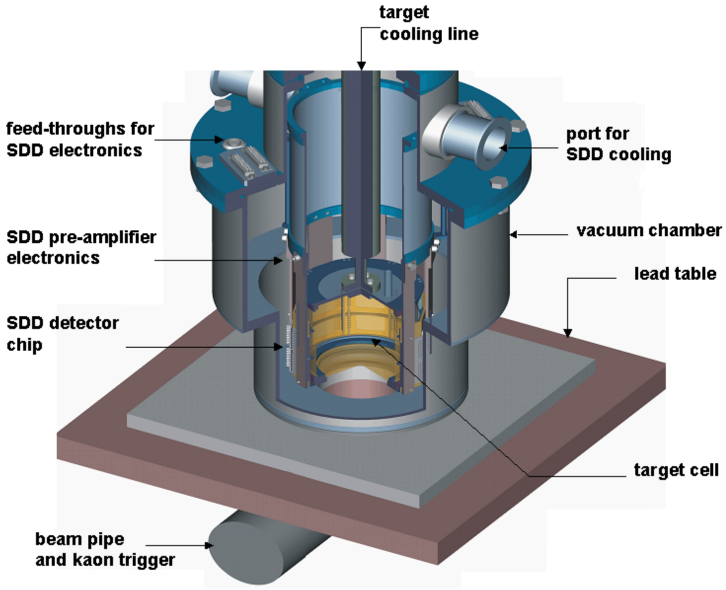


Figure 7: *SIDDHARTA setup (best shielding configuration)*

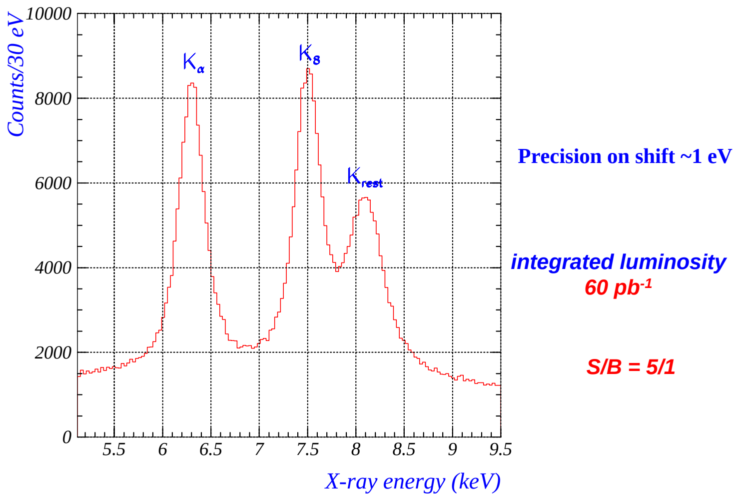


Figure 8: *Kaonic Hydrogen expected signal (Monte Carlo calculation).*