

Preliminary Monte Carlo simulation of the
SIDDHARTA

(Silicon Drift Detector for Hadronic Atom
Research by Timing Application)

setup and performances

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1. Introduction

The goal of the preliminary Monte Carlo simulation of the SIDDHARTA setup was twofold:

- to check the performance of the setup in terms of signal for kaonic hydrogen and kaonic deuterium and compare it with DEAR;
- to check the performance of the setup in terms of hadronic (synchronous) background.

The importance of the second item is very relevant, since, how it was proved in the BTF tests on a SDD prototype device, the asynchronous background (mainly generated by Touscheck effect) can be made negligible by the use of triggerable large area SDDs, so that the synchronous background remains the major source.

The Monte Carlo simulation was performed in the framework of the GEANT 3.21 package, with an improved and corrected version to take into account processes involving X rays below 10 keV; in particular, the subroutines GBRSGE and GBRELE were checked and modified such as to reproduce the physical behavior of the Bremsstrahlung process. The simulation is based on the Monte Carlo program checked on real data in the DEAR experiment.

The first version of the SIDDHARTA Monte Carlo was built around a simplified, but realistic, setup.

The setup is briefly presented in Section 2, while in Section 3 the results of the simulation are reviewed. A discussion of the Signal/Background ratio and a comparison with DEAR is performed in Section 4, while the last Section is dedicated to the Conclusions.

2. SIDDHARTA Monte Carlo preliminary setup

The preliminary setup described in the SIDDHARTA Monte Carlo simulation program is based on a simple, but realistic, geometry, which schematizes the actual setup foreseen for the new experiment [1].

The main elements of the setup are:

- *the DEAR pipe* – considered the same one as for DEAR (built with 650 μm of Carbon Fiber and 250 μm of Aluminium), having a diameter of 9 cm;
- *the degrader* – which ,for the moment, was considered as uniform (since no boost was considered; it was, however, proved by DEAR that the boost effect can be corrected when knowing the crossing angle of the beams, correctly shaping the degrader), built in Hostaphan;
- *the hydrogen volume*, cylinder, 219 mm of diameter, 7 cm height, placed at 3 cm above the DEAR pipe; the hydrogen density considered in the present simulation is 6 g/l;
- *the target exit window*, built in Kapton, 75 μm thick;
- *the SDD detectors*, array of seven detectors, 30 cm^2 each (total 210 cm^2), placed in the horizontal plane, 2mm above the hydrogen target.

The setup is shown in Figures 1 (sideview) and 2 (topview).

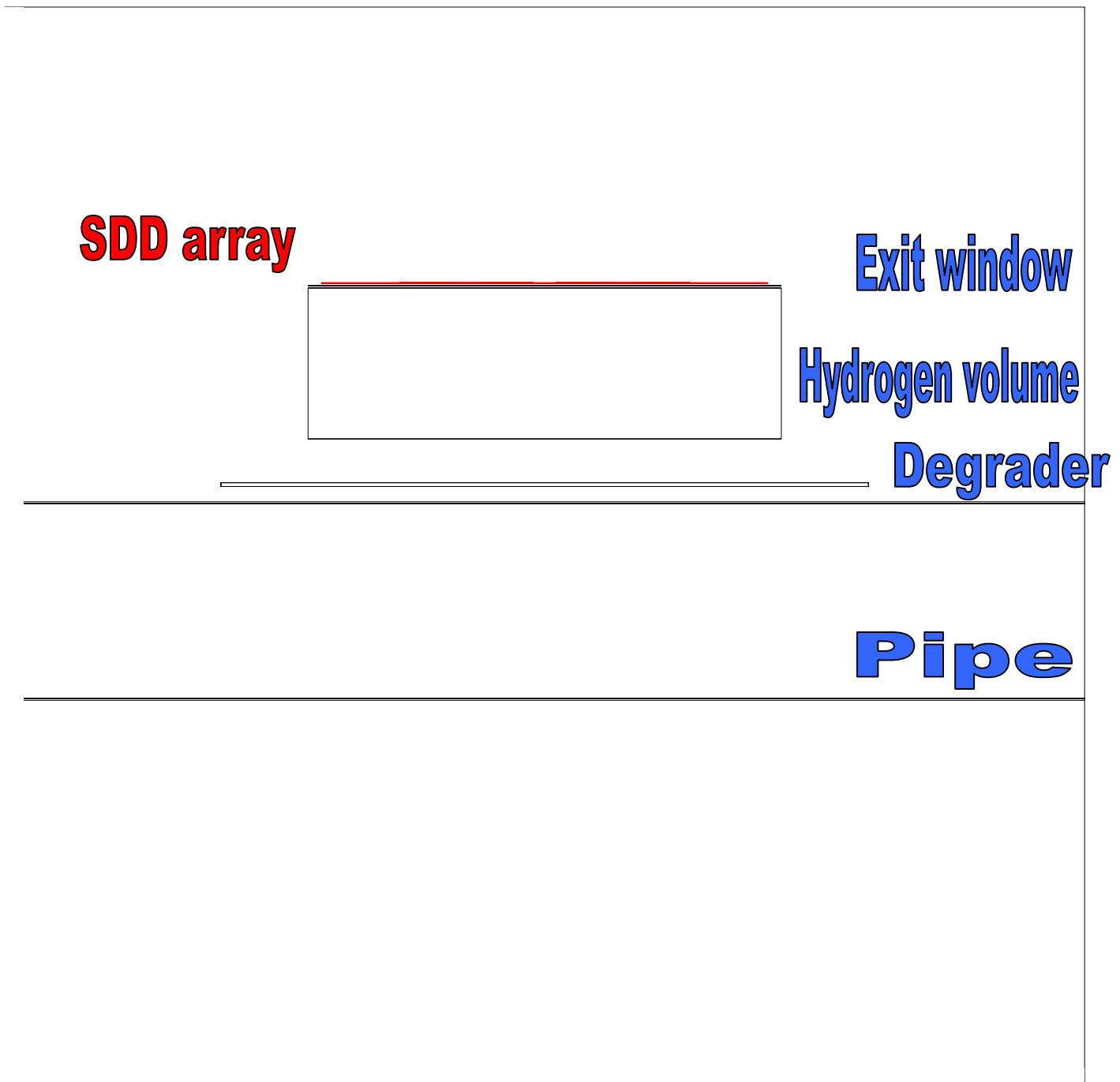


Figure 1: Sideview of the SIDDHARTA setup considered in the Monte Carlo simulation

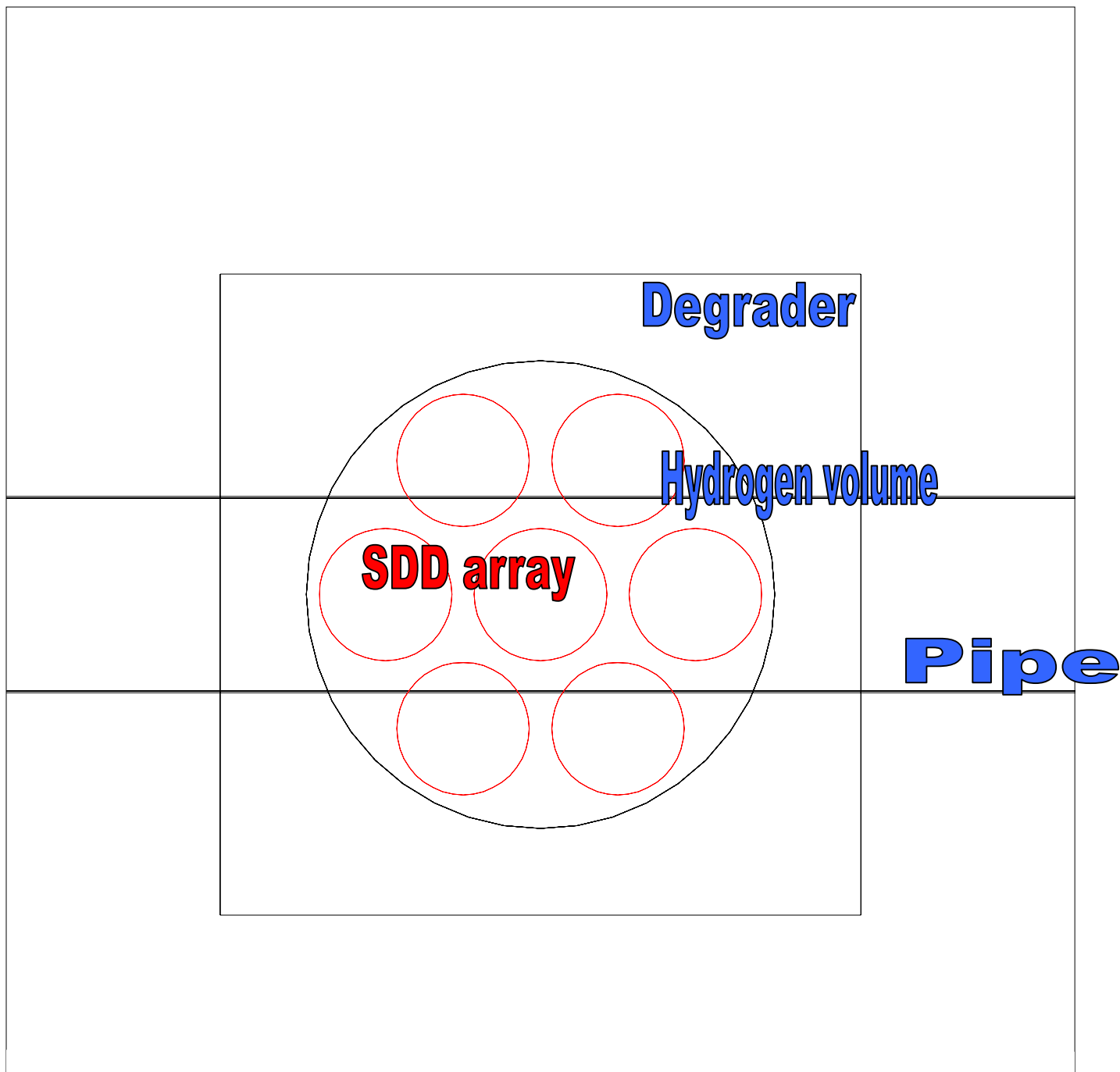


Figure 2: Topview of the SIDDHARTA setup considered in the Monte Carlo simulation

The simulation proceeds by generating a number of ϕ -decays (according to the branching ratios) and tracking the particles through the setup.

The negative kaons stop inside the hydrogen (deuterium) target, give birth to X rays of energies corresponding to kaonic hydrogen (deuterium) K_α transition at 6.3 keV (7.8 keV). The yield of the transition is added off-line, as a multiplicative factor. These X rays are then tracked and those arriving to the SDDs are registered with all the available information: vertex, direction, energy, deposited energy, such as to be able to extract all the necessary information to obtain the performance of the setup.

The results of the simulation are reported in Section 3.

3. Monte Carlo results for kaonic hydrogen

The performances of the SIDDHARTA setup are evaluated according to few key-informations.

For kaonic hydrogen:

- percentage of kaons stopped inside the hydrogen target;
- number of registered X rays of 6.3 keV (K_α transition) – giving the signal;
- background – given by all those particles coming from secondaries related to the ϕ -decay (hadronic synchronous background), depositing energy inside the SDD in the same energy region of the signal (~ 6 keV).

In what follows, all these key-parameters are discussed, comparing the results with the DEAR ones, when possible.

3.1 *Kaons stopped in the hydrogen target*

A number of 200,000 ϕ -decays was generated. The number and the distribution of the kaons stopped inside the hydrogen target, and potentially giving birth to a kaonic hydrogen atom, were recorded (Ntuple).

The three 2-dimensional distributions of the kaons stopped inside the hydrogen target are shown in Figures 3, 4 and 5.

The x, y and z directions are oriented such as:

- z – along the beam direction;
- y – in height;
- x – orthogonal to the 2 previous ones.

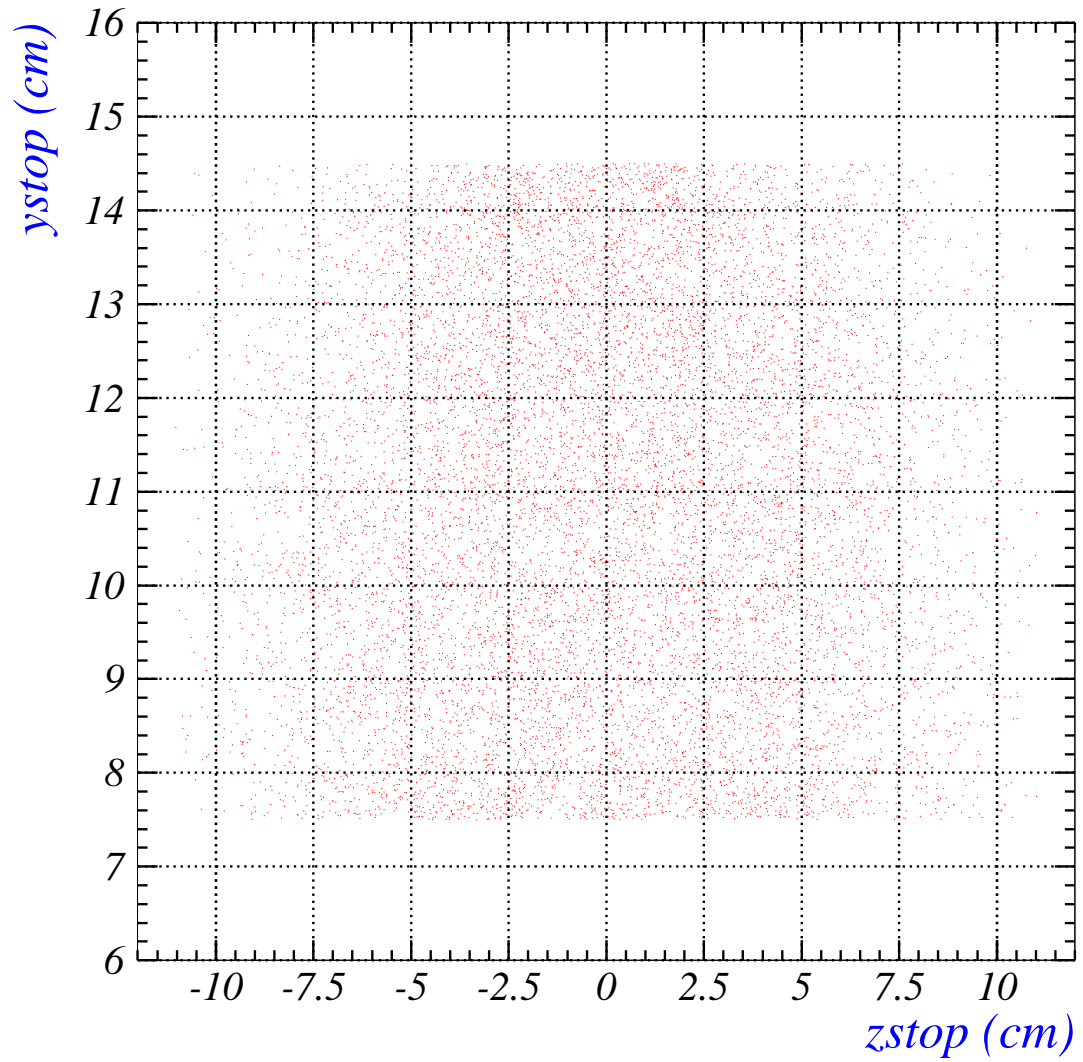


Figure 3: Bidimensional y versus z distribution of the kaons stopped inside the hydrogen volume.

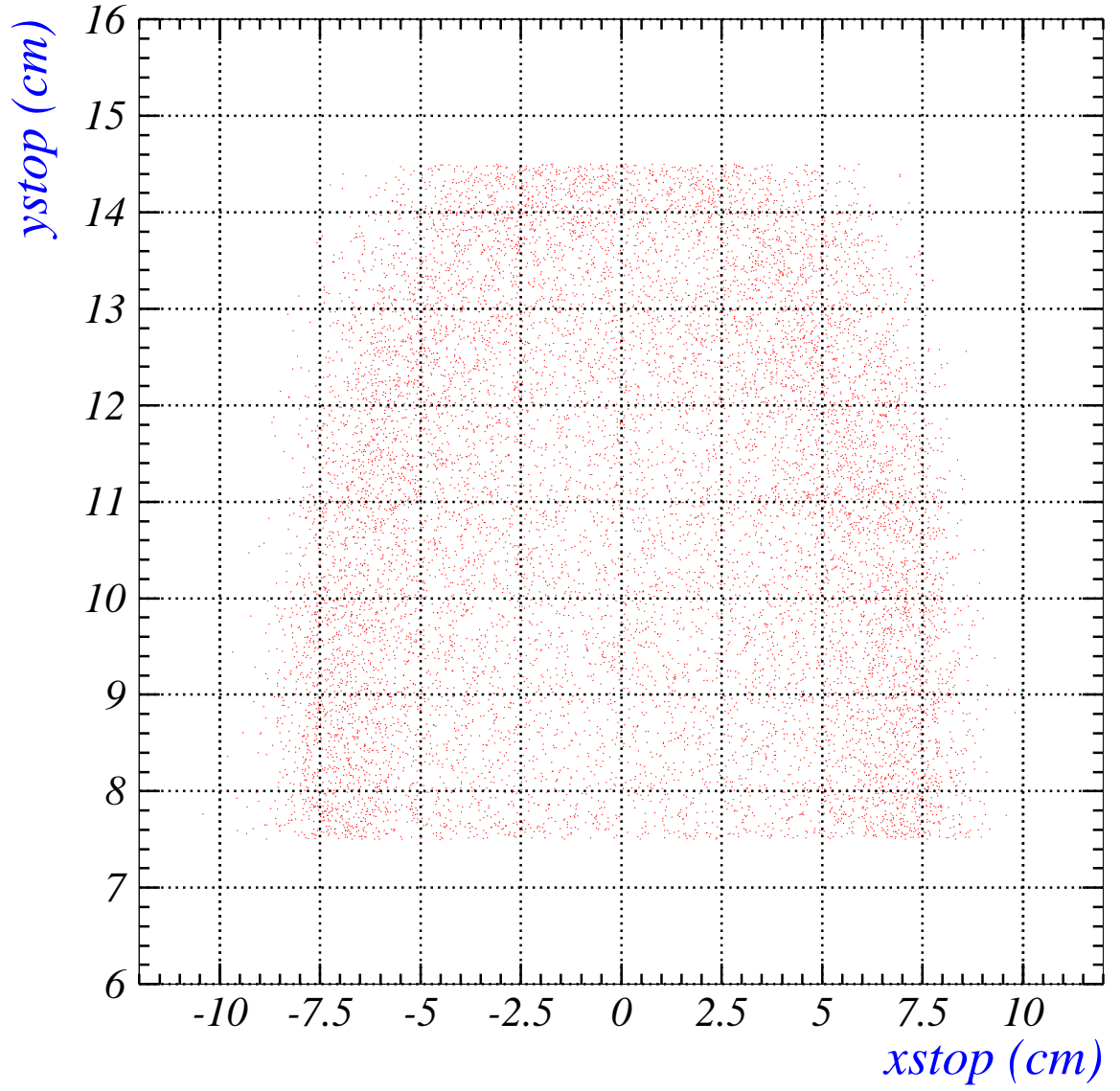


Figure 4: Bidimensional y versus x distribution of the kaons stopped inside the hydrogen volume.

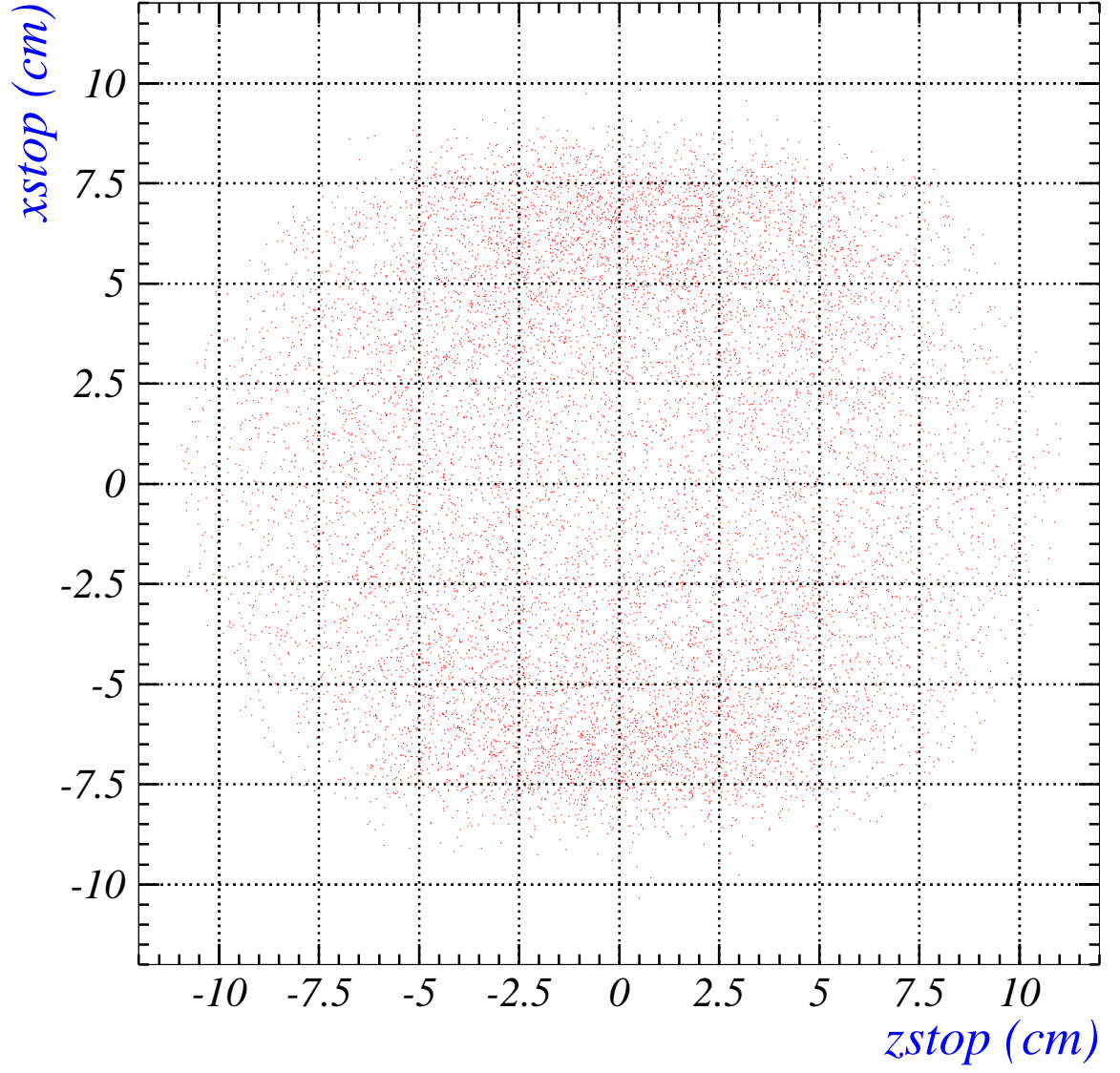


Figure 5: Bidimensional x versus z distribution of the kaons stopped inside the hydrogen volume.

The total number *of kaons stopped inside hydrogen* is:

12447

representing a percentage of

~12.5% of all generated negative kaons.

This number is to be compared with:

~ 2% of all generated negative kaons in the DEAR case

CONCLUSION:

A factor of about 6 is gained by geometry and higher hydrogen density in the preliminary SIDDHARTA setup with respect to the DEAR case.

3.2 *Signal*

In order to obtain the kaonic hydrogen signal, one should start from the number of X rays of 6.3 keV recorded by the system of SDD detectors. For the 200,000 generated ϕ -decays, this number is

1800 x yield X rays of 6.3 keV registered by SDDs

In order to transform this number in X rays/pb-1, one needs to know the yield of the transition. DEAR has measured, at a density of about 2.1 g/l, an yield about 2-3 %. In these conditions it is reasonable to assume that at 6 g/l the yield of the transition is about 1-2%.

It follows that the signal is:

$$S = \sim 270-540 \text{ X rays/pb}^{-1} \text{ (K}_\alpha \text{ transition 6.3 keV)}$$

This number is to be compared with the

$$S = \sim 80 \text{ X rays/pb}^{-1} \text{ (K}_\alpha \text{ transition 6.3 keV)}$$

measured by DEAR.

CONCLUSION:

A factor of about 3-7 in SIGNAL, with respect to DEAR, is gained in SIDDHARTA due to the new geometry, the higher hydrogen density and the use of the SDD as detector (double surface and higher efficiency).

3.3 *Hadronic (synchronous) background*

After having demonstrated by the tests performed in July 2003 at BTF on SDD prototype array that the asynchronous background (generated mainly by particles lost due to the Touscheck effect) can be made negligible in the SIDDHARTA case, if the SDDs are triggered by a trigger with a time window of 1-2 μ s, the main source of background to deal with is represented by the synchronous background, i.e. all those particles temporally correlated with the produced kaons and therefore with the event. This kind of background is essentially generated by the hadronic processes initiated by the produced kaons, followed by e.m. cascades, and by other decay channels of ϕ s.

The Monte Carlo simulation performed with the setup described in Section 2 investigated the hadronic background, establishing an upper limit for the described geometry.

In order to obtain the upper limit, all particles depositing energy in the SDDs were recorded, with special attention to those particles which are depositing less than 20 keV of energy, which represents the region of interest and the dynamic range of SDDs.

The spectrum of the overall energy deposited in a 400 μm SDD by the hadronic background coming from the 200,000 ϕ s is shown in Figure 6.

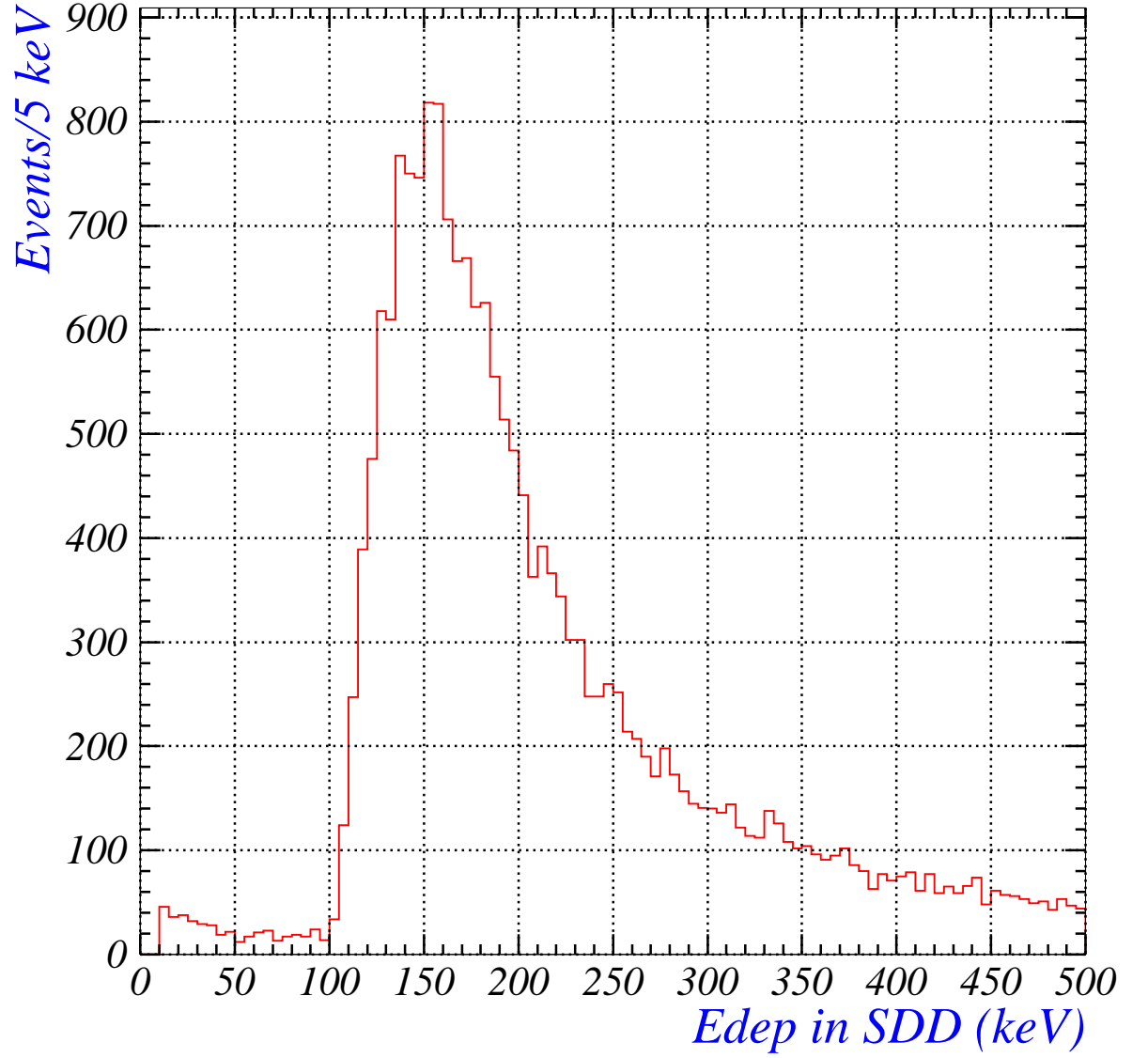


Figure 6: Energy deposited in SDDs by the hadronic background particles – overall spectrum.

As seen from Figure 6, the energy deposited inside SDD by MIPs is about 150 keV – far away from the dynamical range of the SDD (in the CCD case - depletion layer 30 μm - the energy deposited by MIPs is about 10-12 keV, coinciding with the region of interest). These particles, as seen from the BTF tests, are counted as overflows and do not create any sort of problem related with rate or secondary effects generated by the high deposited energy.

To be able to establish the real hadronic background, one should have a closer look at the energy region below 20 keV. The deposited energy spectrum in this region is shown in Figure 7.

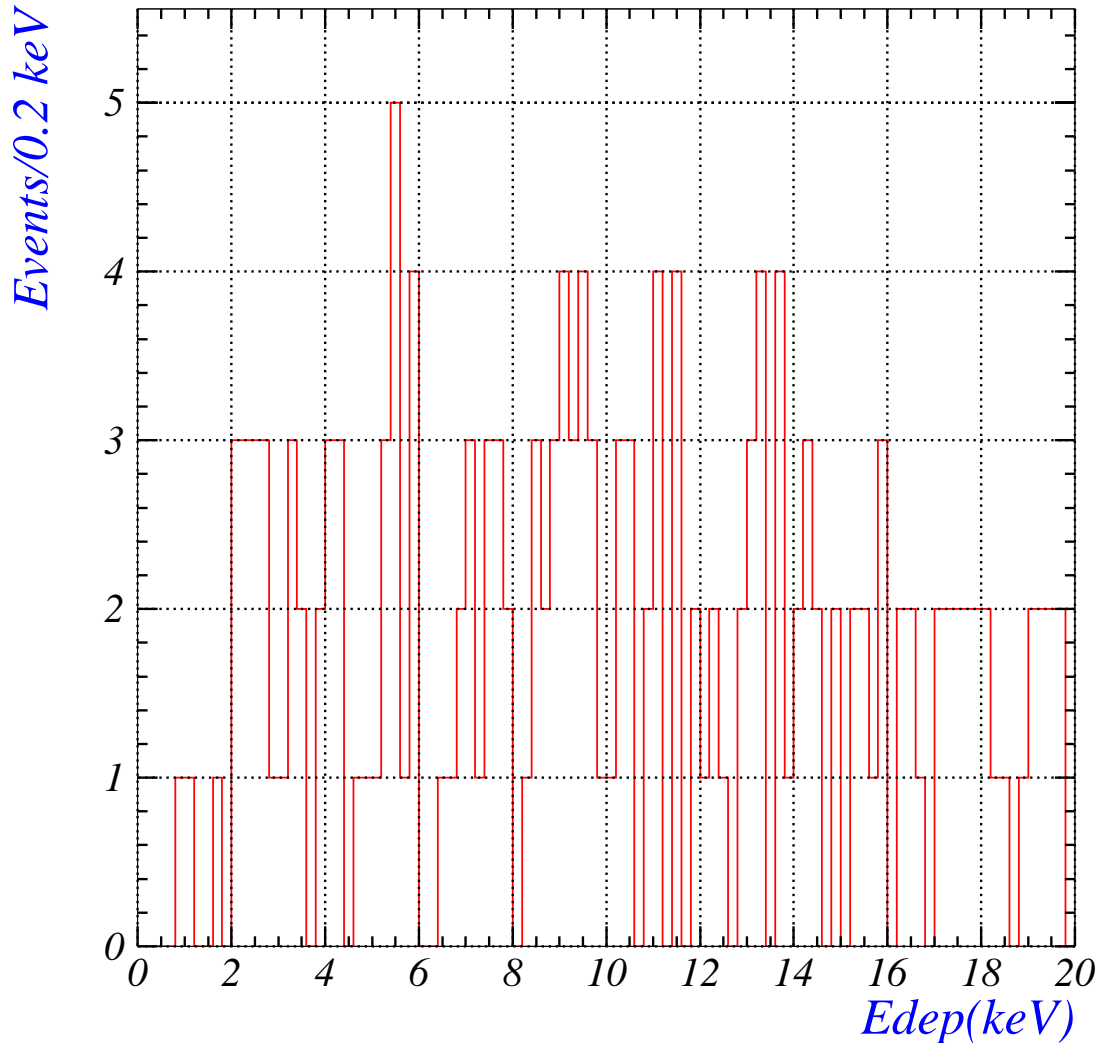


Figure 7: Energy deposited in SDDs by the hadronic background particles – below 20 keV.

The overall number of particles in the spectrum of Figure 7 is 168, from 1 to 20 keV. In this case, the background in the signal region, defined as about 500 eV around 6.3 keV, is:

$$\mathbf{168/19 \times 0.5 = 4.4 \text{ events}}$$

for the 200,000 generated ϕ decays.

Normalizing to 1 pb⁻¹ this number becomes:

$$\mathbf{B1 = \sim 70 \text{ particles/pb}^{-1} \text{ (500 eV region around 6.3 keV)}}$$

It is worthy to be mentioned that part of the particles in Figure 7 are generated inside the SDD by other primary incident particle. In this case the overall energy deposited inside SDD might be higher than the simple contribution given by the component below 20 keV. If one considers only the particles depositing energy below 20 keV and generated outside the SDD, Figure 7 becomes Figure 8.

In this case, the number of particles present in the spectrum is 27, and the background in the signal region, defined as about 500 eV around 6.3 keV, is:

$$\mathbf{27/19 \times 0.5 = 0.7}$$

for the 200,000 generated ϕ decays.

Normalizing to 1 pb⁻¹ this number becomes:

$$\mathbf{B2 = \sim 11 \text{ particles/pb}^{-1} \text{ (500 eV region around 6.3 keV)}}$$

In reality, the background is a value between B1 and B2, but for what follows we'll consider B1 as an upper limit to the background.

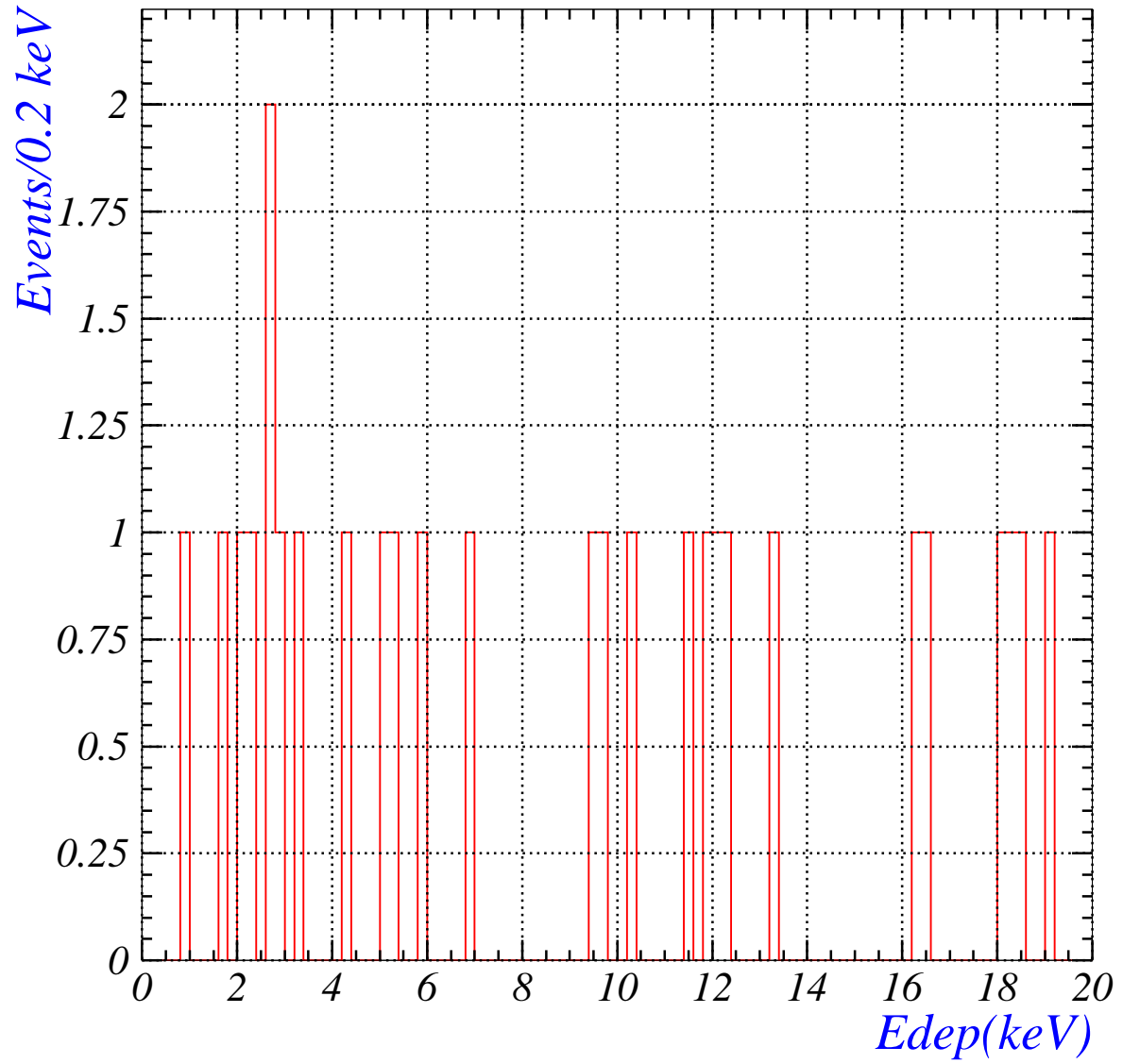


Figure 8: Energy deposited in SDDs by the hadronic background particles – below 20 keV and not generated inside SDD.

4. Signal to Background ratio and comparison with DEAR

4.1 *Kaonic hydrogen*

The signal/background ratio in the case of kaonic hydrogen is derived starting from the numbers given in Sections 3.2 and 3.3, i.e.:

$$S = 270\text{-}540 \text{ X rays/pb}^{-1} \text{ (K}_\alpha \text{ transition 6.3 keV)}$$

$$B1 = \sim 70 \text{ particles/pb}^{-1} \text{ (500 eV region around 6.3 keV)}$$

Then, in case of kaonic hydrogen K_α transition, the S/B ratio is:

$$S/B = 270\text{-}540 / 70 = 3.8/1 - 7.7/1$$

To be compared with an:

$$S/B \sim 1/70 - 1/110$$

measured by DEAR.

4.2 *Kaonic deuterium*

For kaonic deuterium the measurement has been never performed; however, there are strong indications, coming from cascade calculations and from pionic and antiprotonic deuterium measurements, that the yield should be 3-10 times less than that of kaonic hydrogen. Since the width is expected to be double, then, for a density of kaonic deuterium such as to have the same stopping distributions of kaons obtained for kaonic hydrogen, the results are:

$$\mathbf{S = 27-180 \text{ X rays/pb}^{-1} \text{ (K}_\alpha \text{ transition 7.8 keV)}}$$

$$\mathbf{B1 = \sim 70 \times 2 = 140 \text{ particles/pb}^{-1} \text{ (500 eV region around 7.8 keV)}}$$

Then, in case of kaonic deuterium K_α transition, the S/B ratio is:

$$\mathbf{S/B = 27-180 / 140 = 1/5 - 1.3/1}$$

To be compared with:

$$\mathbf{S/B \sim 1/2000 - 1/400}$$

for DEAR, what made this measurement impossible in the DEAR framework.

Just to give an example of the expected spectrum, in Figure 9 it is shown the SIDDHARTA expected kaonic deuterium K_α spectrum for 200 pb^{-1} , with $S/B = 1/3$.

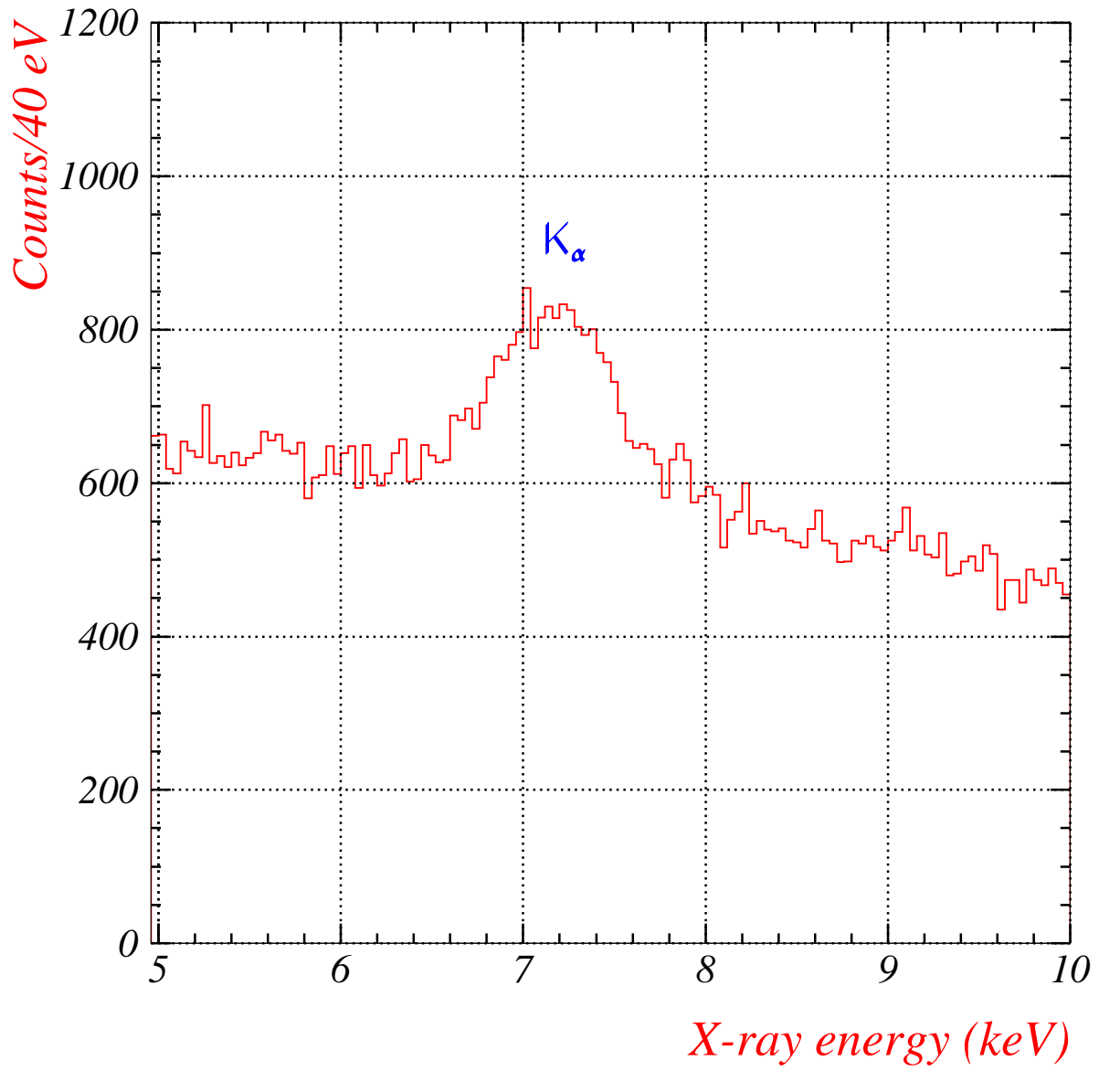


Figure 9: Kaonic deuterium simulated spectrum for $S/B = 1/3$ and 200 pb^{-1} of integrated luminosity.

5. Conclusions

A **preliminary Monte Carlo simulation of the SIDDHARTA setup** was performed. The simulation is based on a **realistic simplified version of the setup**, containing 200 cm^2 , divided in 7 arrays, of SDD detectors.

The degrader was optimized such as to obtain as much as possible kaons stopped inside the target; the geometry of the degrader which was considered is a simple one; further studies concerning a better shaping are undergoing.

The program was then run in order to obtain information concerning the

- signal (Kaonic hydrogen and kaonic deuterium);
- hadronic synchronous background

The obtained results (Section 4) show that the kaonic hydrogen as well as kaonic deuterium measurements, with the **S/B** ratios found (**3.8/1 – 7.7/1 for kaonic hydrogen** and **1/5 - 1.3/1 for kaonic deuterium**) are feasible.

Further studies, with different geometries, are undergoing, in order to further optimize the setup parameters.

Monte Carlo simulations concerning other relevant aspects of the SIDDHARTA scientific programme (kaonic helium, sigmonium, kaon mass) are in progress.

Bibliography

- [1] SIDDHARTA Technical Note IR-2, The preliminary SIDDHARTA experimental setup, J. Zmeskal, 25 August 2003.