SIDDHARTA Technical Note IR - 4

Preliminary Monte Carlo simulation of the **SIDDHARTA**

(**S**ilicon **D**rift **D**etector for **H**adronic **A**tom **R**esearch by **T**iming **A**pplication)

toroidal setup

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Content

1. Introduction

A preliminary version of the Monte Carlo simulation for the SIDDHARTA setup was presented in [1]. The setup investigated in [1] is DEAR-like, i.e. is developing itself above the pipe, consequently having a rather reduced (12% for hydrogen density of 6g/l) stopping power for kaons. Since then, in collaboration with the DAΦNE staff, a new solution was investigated. The key-element of the new solution is the possibility to employ, when SIDDHARTA will enter on machine, a pipe with a diameter much smaller than the ~9 cm one used by DEAR. This possibility is considered as realistic by the DAFNE staff, moreover offering to DAFNE itself new degrees of freedom in dealing with the optics (since a reduced diameter pipe allows to employ small permanent quadrupoles near the IP). The new diameter of the pipe should be between 3 and 5 cm, still under investigation.

Consequently, a new SIDDHARTA setup was designed, which takes full advantage of the new small-diameter pipe. The setup becomes toroidal-like, embracing the entire IP-region, and not only a small part situated above the pipe. The design and optimization of the new setup is performed along few lines. One of this is the study of the performance of the setup by Monte Carlo simulations. The goal of the present updated Monte Carlo simulation is 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.**

As it will be shown, the new concept of toroidal setup brings an increase of the signal by a factor about 30.

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 toroidal setup

The preliminary toroidal setup contained in the SIDDHARTA Monte Carlo simulation program is based on a simple, but realistic, geometry, which schematizes the main features of the setup foreseen for the new experiment.

The main elements of the setup are:

- ***the SIDDHARTA pipe*** **–** being the “revolutionary” element with respect to DEAR, built in beryllium, having a diameter between 3 and 5 cm – still to be decided; to be conservative, in the present Monte Carlo program the diameter was taken to be 5 cm;

- ***the degrader*** – which ,for the moment, was considered as uniform around (cylinder) the pipe (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), plastic scintillators – acting as kaon monitor as well and giving the trigger signal for the SDDs employed by SIDDHARTA;
- ***the hydrogen volume***, toroidal, around the pipe, starting at a distance of about 1.5 cm from the pipe, with an inner diameter of 8 cm and an outer one of 18 cm, 8 cm length, containing hydrogen with a density of 3 g/l - ~ same as the one in DEAR, in order to be able to perform a comparison independent of yield behaviour as function of density;
- ***the target exit window***, built in Kapton, 75 μm thick;
- ***the SDD detectors***: 18 detectors, 12 (4x3) cm^2 each, for a total surface of 216 cm^2, placed all around the target, 1mm distance from target wall.

The setup as built in Monte Carlo simulation program is shown in Figures 1 (crossview) , 2 (sideview) and 3 (3-dimensional).

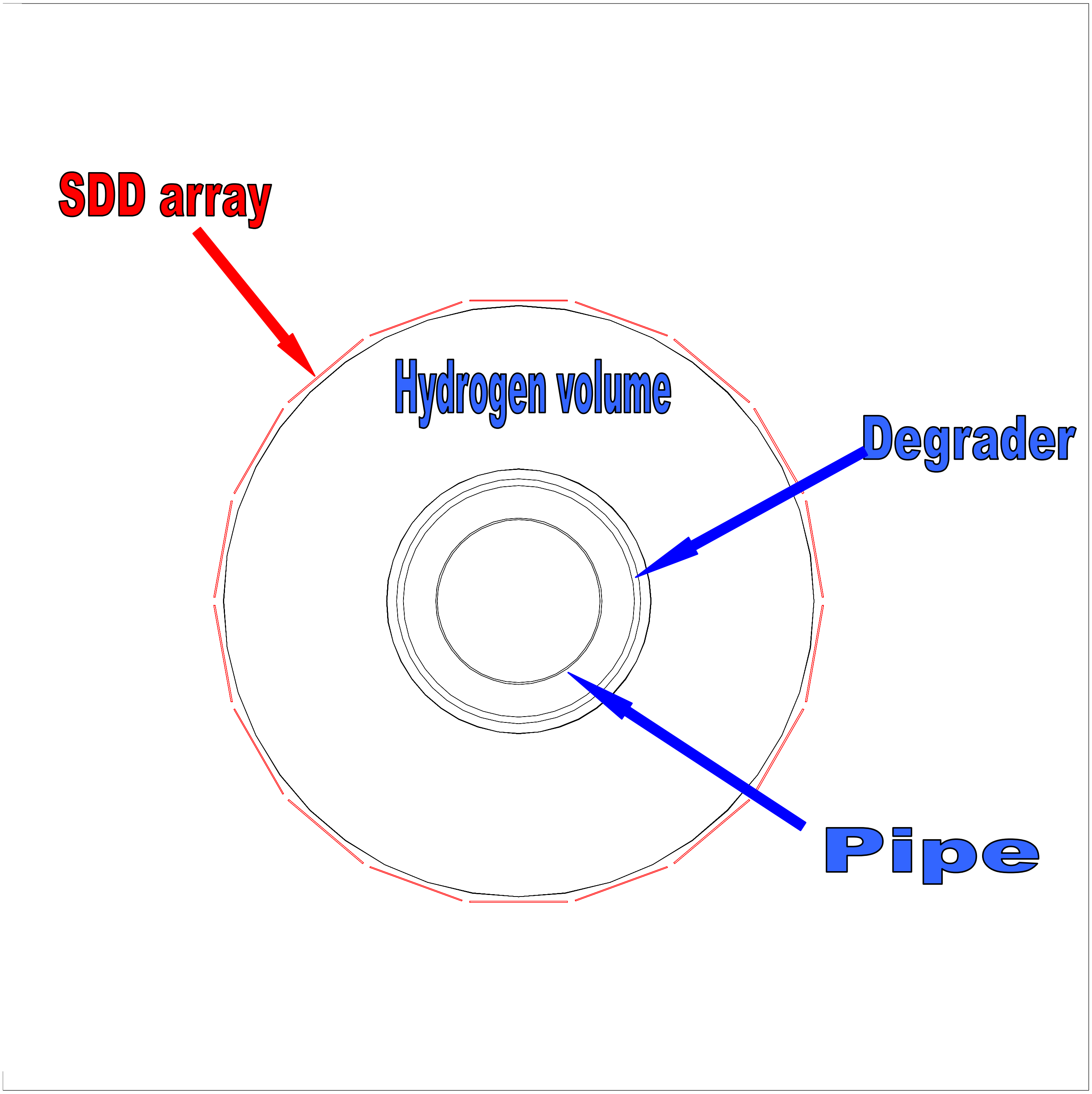

Figure 1: Crossview of the SIDDHARTA toroidal setup considered in the Monte Carlo simulation

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

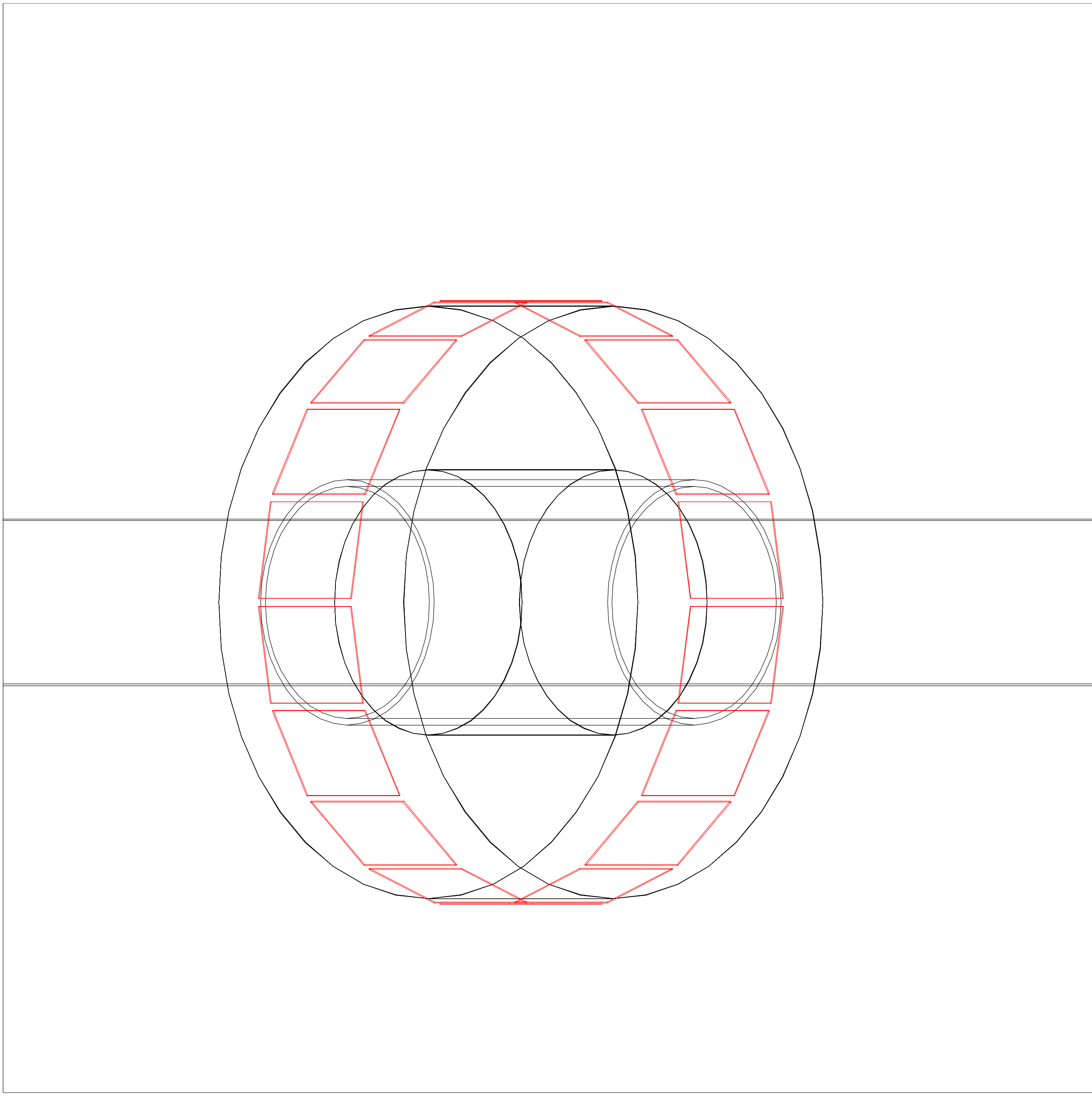

Figure 3: 3-D view of the SIDDHARTA toroidal setup considered in the Monte Carlo simulation

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 hydrogem:

- 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 30,000 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 where all dimensions are in cm.

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.

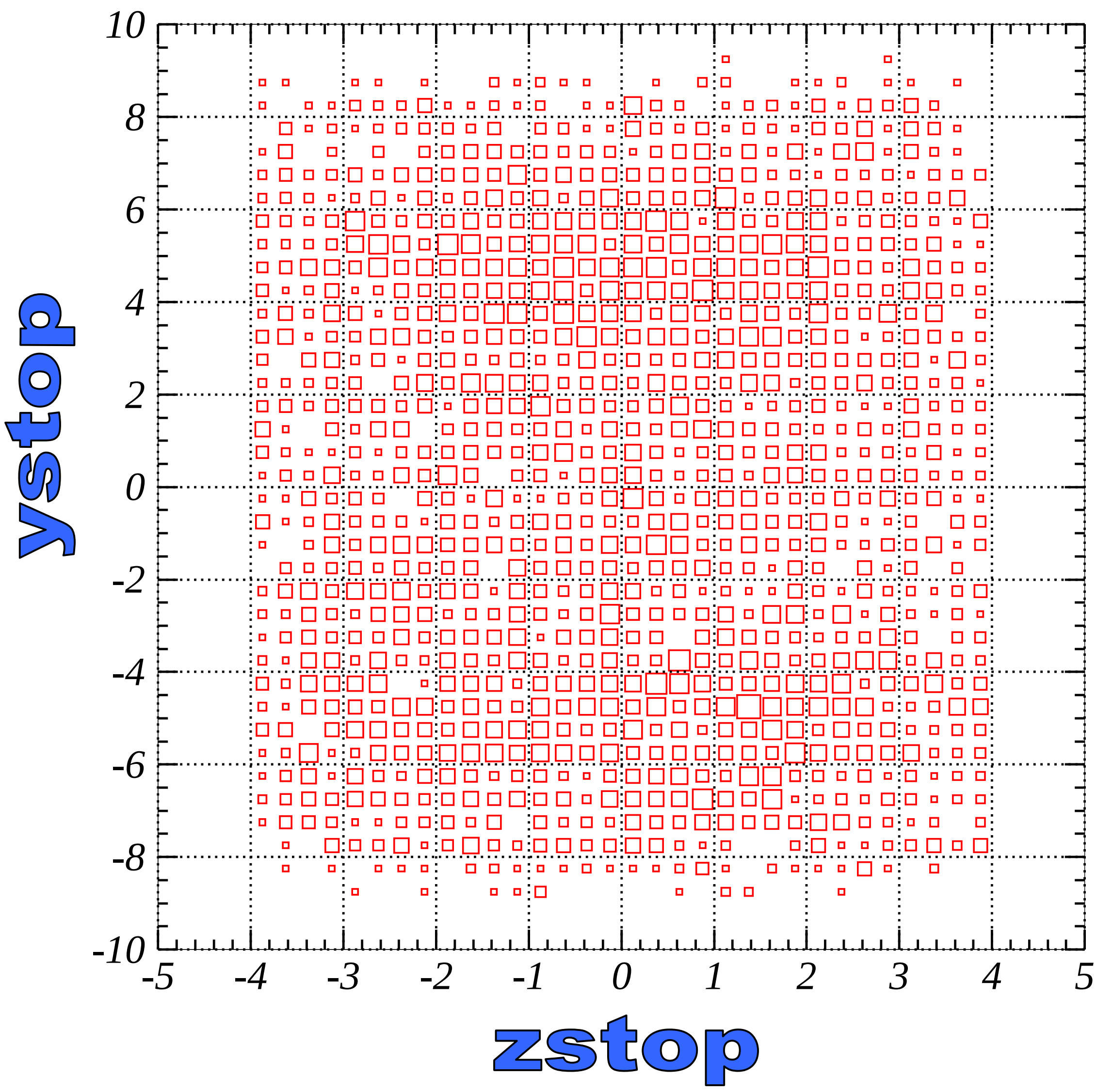

Figure 4: Bidimensional y versus z distribution of the kaons stopped inside the hydrogen volume.

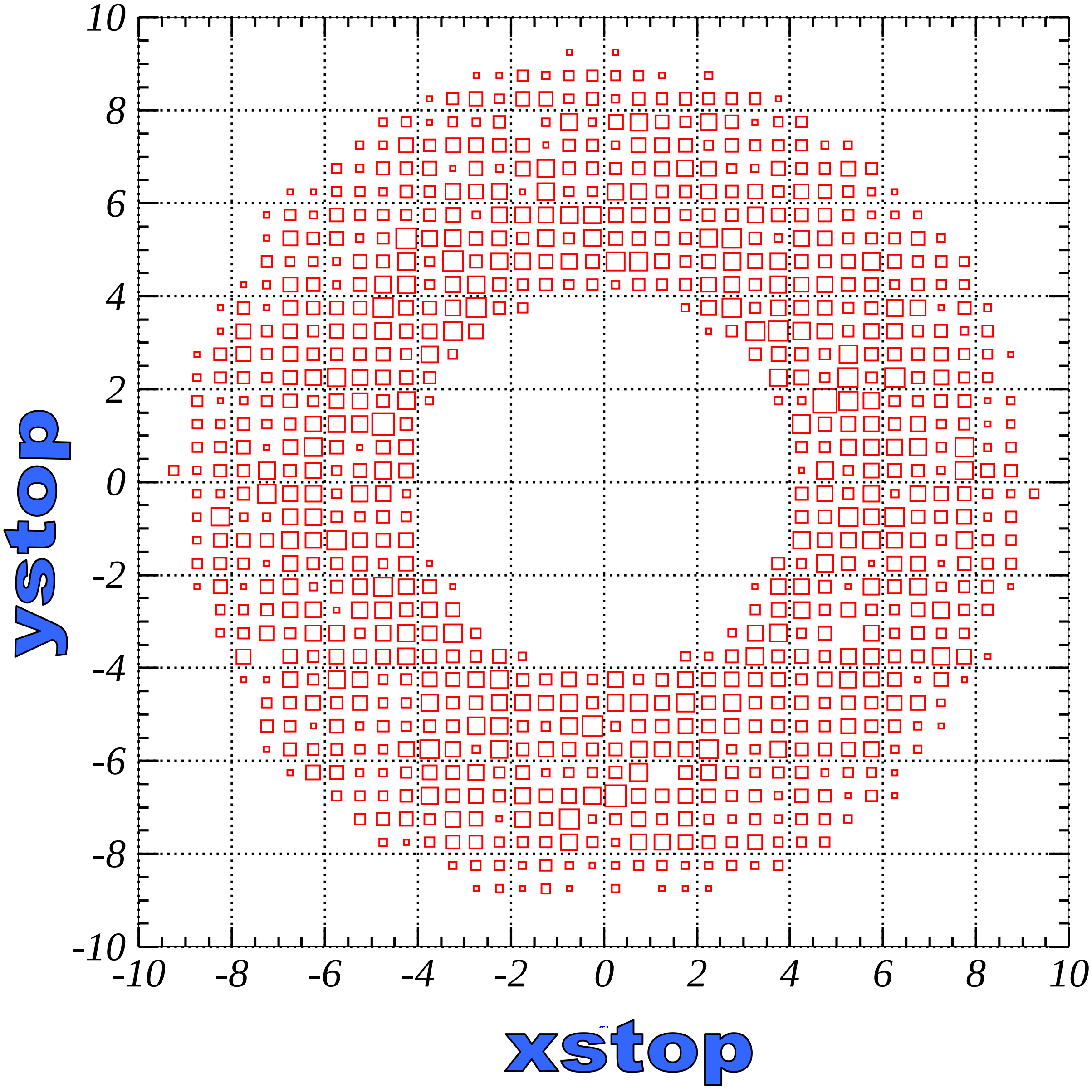

Figure 5: Bidimensional y versus x distribution of the kaons stopped inside the hydrogen volume.

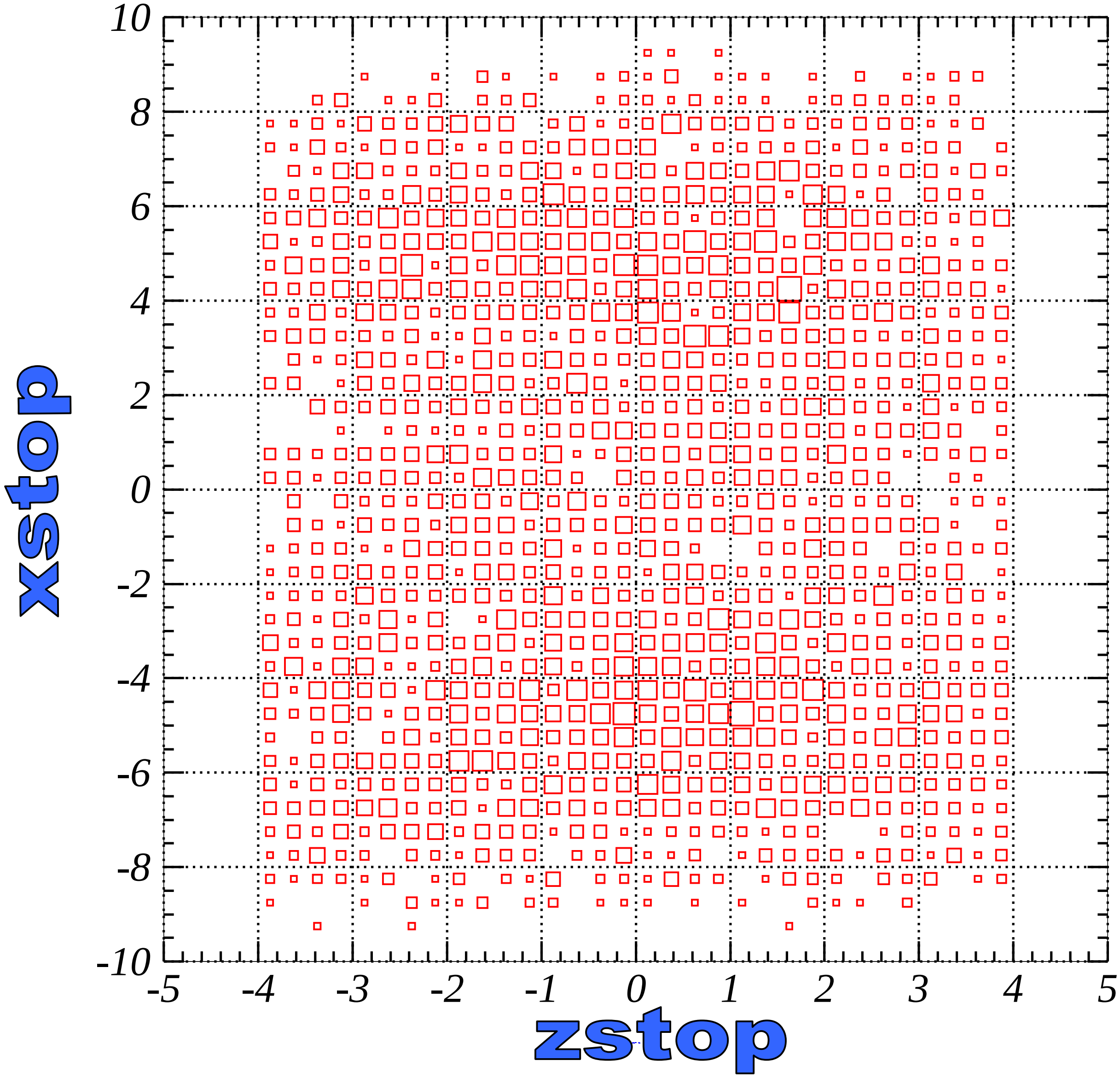

Figure 6: Bidimensional x versus z distribution of the kaons stopped inside the hydrogen volume.

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

4468

representing a percentage of

~30% 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 15 is gained by geometry, for the same hydrogen density in the preliminary toroidal SIDDHARTA setup, with respect to the DEAR case.

3.2 Signal

In oderd 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 30,000 generated ϕ-decays, this number is

858 x yield   X rays of 6.3 keV registered by SDDs

In order to compare this number with the one obtained by DEAR, one should start from the Monte Carlo number of X rays of 6.3 keV recorded by the DEAR setup, which, for 300,000 generated ϕ-decays is **295 x yield.** Since the yield of the transition is the same in the 2 situations (same density), one directly obtain the ratio of the 2 signals by comparing the 2 previous numbers, DEAR and SIDDHARTA, normalized to the number of ϕ-decays, obtaining:

$$\mathbf{R = (858/30{,}000) / (295/300{,}000) = 29}$$

It follows, starting from DEAR result, (60 X/pb^{-1}), that the signal in SIDDHARTA is:

$$\mathbf{S = \sim 1800\ X\ rays/pb^{-1}\ \ (K_{\alpha}\ transition\ 6.3\ keV)}$$

CONCLUSION:

A factor of about 29 in SIGNAL, with respect to DEAR, is gained in toroidal setup SIDDHARTA due to the new geometry, and to 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 μs, 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 ϕs.

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 30,000 ϕs is shown in Figure 7.

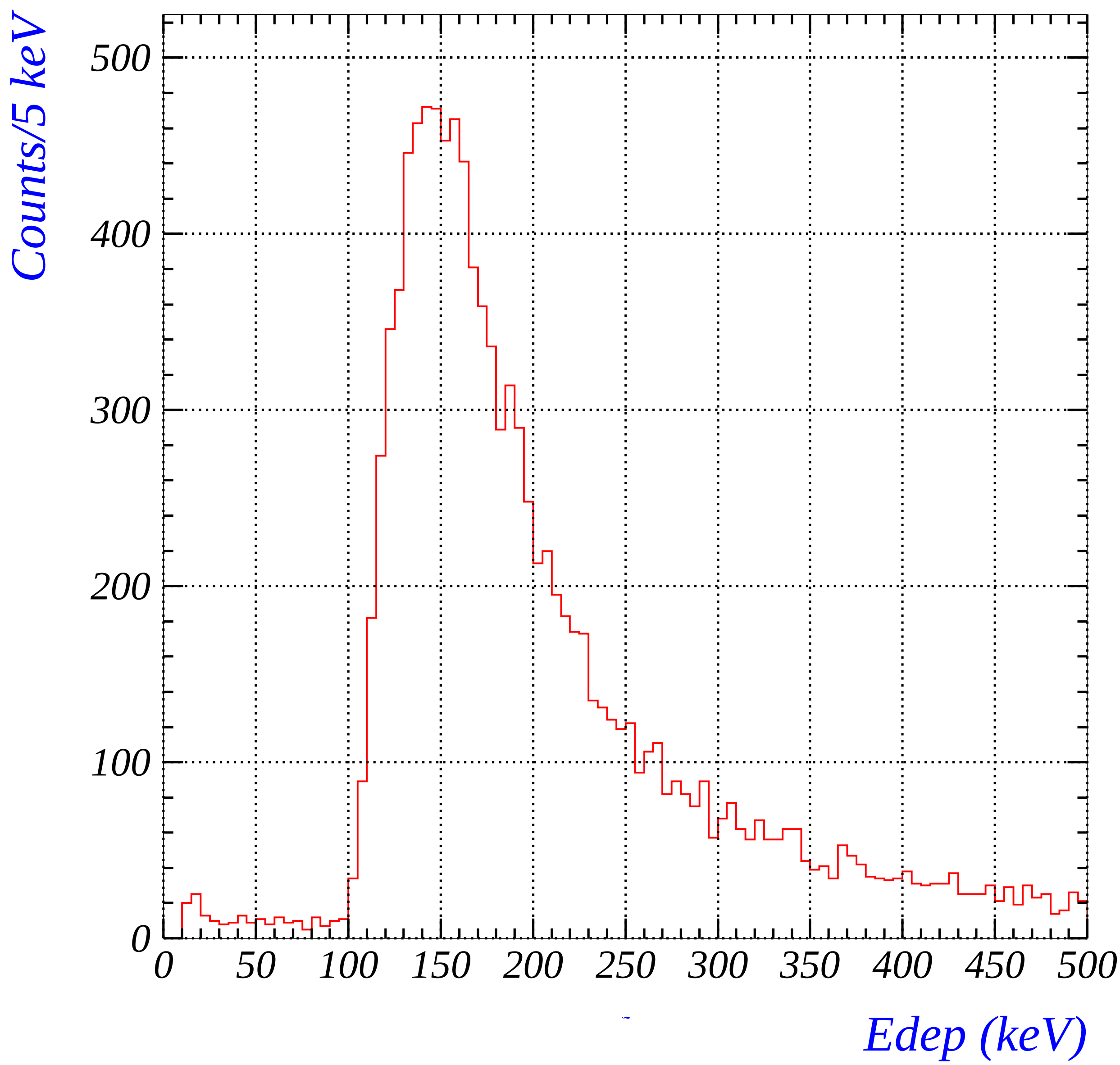

Figure 7: Energy deposited in SDDs by the hadronic background particles – overall spectrum.

As seen from Figure 7, the energy deposited inside SDD by MIPs has a peak at about150 keV – far away from the dynamical range of the SDD (in the CCD case - depletion layer 30 μm - the energy deposited by MIPs has a peak at 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 8.

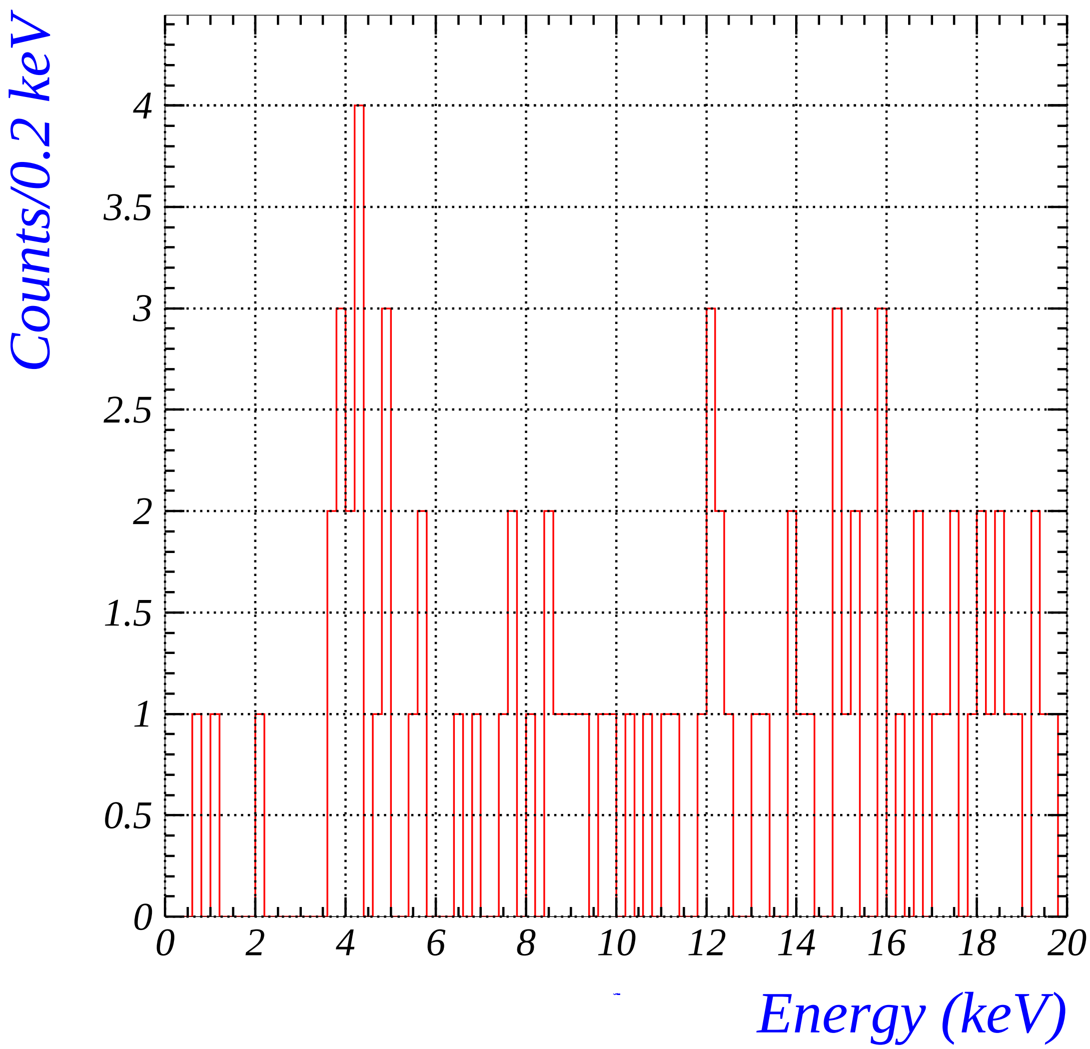

Figure 8: Energy deposited in SDDs by the hadronic background particles – below 20 keV.

The overall number of particles in the spectrum of Figure 7 is 80, from 1 to 20 keV. In this case, the background in the signal region, defined as about 500 eV around 6.3 keV, is:

80/19 x 0.5 = 2.1 events

for the 30,000 generated ϕ decays.

Normalizing to 1 pb^{-1} this number becomes:

B1 = ~ 216 particles/pb^{-1} (500 eV region around 6.3 keV)

It is worthy to be mentioned that part of the particles in Figure 8 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 8 becomes Figure 9.

In this case, the number of particles present in the spectrum is 26, and the background in the signal region, defined as about 500 eV around 6.3 keV, is:

27/19 x 0.5 = 0.7

for the 30,000 generated ϕ decays.

Normalizing to 1 pb^{-1} this number becomes:

B 2= ~ 50 particles/pb^{-1} (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.

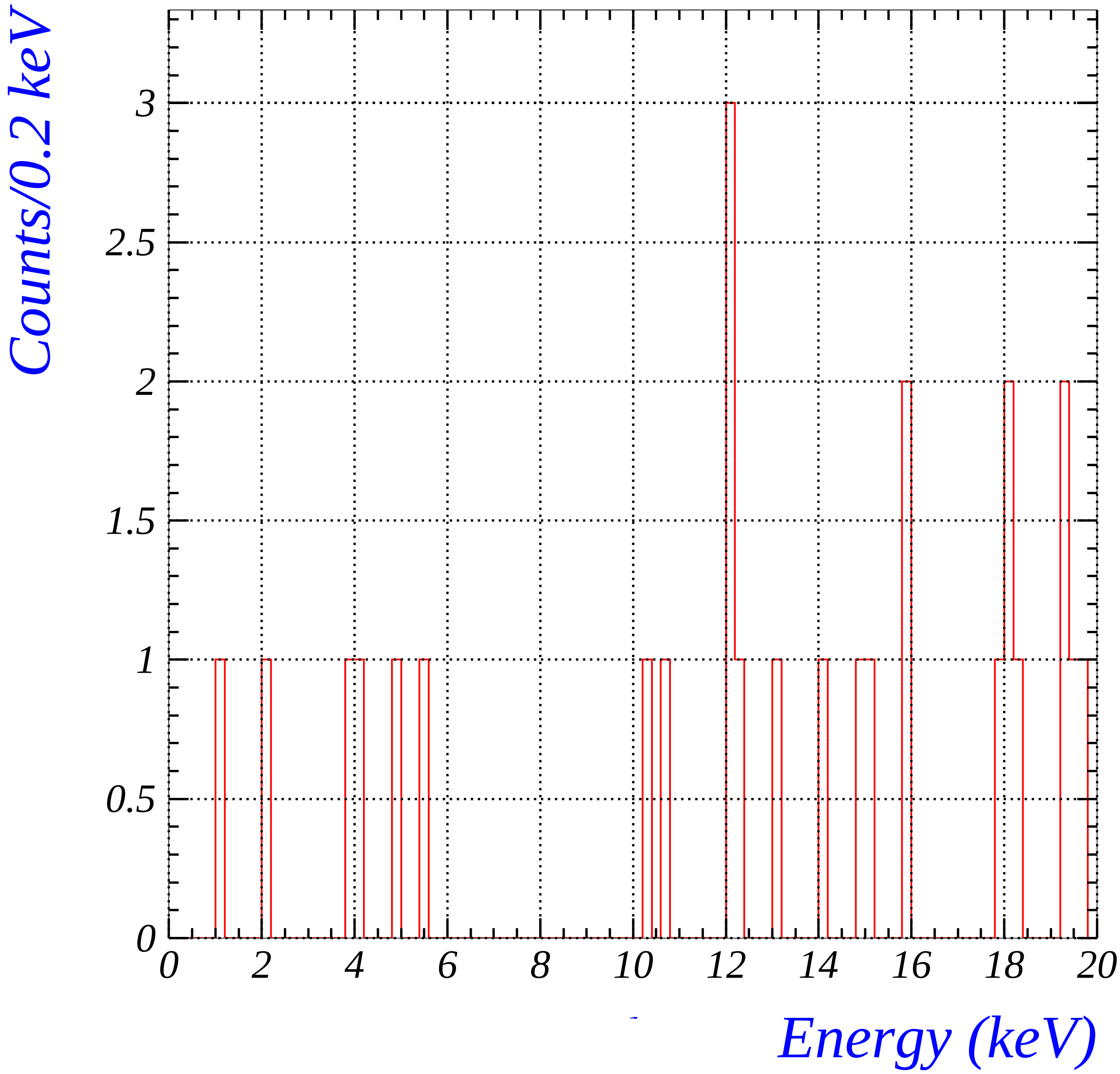

Figure 9: Energy deposited in SDDs by the hadronic background particles – below 20 keV and not generated inside SDD.

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.:

$$\mathbf{S = \sim 1800\ X\ rays/pb^{-1}\ \ (K_{\alpha}\ transition\ 6.3\ keV)}$$

$$\mathbf{B1 = \sim 216\ particles/pb^{-1}\ \ (500\ eV\ region\ around\ 6.3\ keV)}$$

Then, in case of kaonic hydrogen K_{α} transition, the S/B ratio is:

$$\mathbf{S/B = 1800 / 216 = 8/1}$$

To be compared with an:

$$\mathbf{S/B \sim 1/70 - 1/110}$$

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:

S = 180-600X rays/pb^{-1} (K_α transition 7.8 keV)

B1 = ~ 216 x 2 = 432 particles/pb^{-1} (1000 eV region around 7.8 keV)

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

S/B = 180-600 / 432 = 1/ 2.4 - 1.4/1

To be compared with:

S/B ~ 1/2000 – 1/400

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

5. Conclusions

A preliminary Monte Carlo simulation of a toroidal SIDDHARTA setup was performed. The simulation is based on a **realistic simplified version of the setup**, containing 216 cm^2, divided in 18 arrays of 12 cm^2 each, of SDD detectors.

The degrader was optimized such as to obtain as much as possible kaons stopped inside the target.

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 **8/1 for kaonic hydrogen** and **1/ 2.4 - 1.4/1 for kaonic deuterium**, are feasible.

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–3, "Preliminary Monte Carlo simulation of the SIDDHARTA (Silicon Drift Detector for Hadronic Atom Research by Timing Application) setup and performances" Catalina Curceanu (Petrascu), 25 August 2003