SIDDHARTA Technical Note IR - 1

Tests of prototype Silicon Drift Detectors to be used in **SIDDHARTA**

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

performed at the

Beam Test Facility (BTF) of LNF

in the period

21 – 31 July 2003

SIDDHARTA Collaboration
25 August 2003

Content

1. Introduction: from DEAR to SIDDHARTA

In the present Report, the results of a series of tests, started on 21st July 2003 and lasted until 31st July 2003, on small area chips of Silicon Drift Detectors (SDD) are presented. Large area SDDs are planned to be the X-ray detectors of the new experiment SIDDHARTA. The tests were performed at the Beam Test Facility of Laboratori Nazionali di Frascati, with the aim **to check the SDD performance and trigger capability in realistic beam conditions,** i.e. in presence of the background of a particle beam similar to that encountered by performing the DEAR experiment on the DAΦNE machine.

The **SIDDHARTA** (Silicon Drift Detector for Hadronic Atom Research by Timing Application) experiment represents the natural development, from scientific and technical points of view, of the DEAR (DAΦNE Exotic Atom Research) experiment, along the line of research dedicated to exotic atoms at DAΦNE. Its motivations are nourished from the results obtained by DEAR, briefly summarized below, of which an improvement and an extension are aimed.

In October 2002 the degrader optimization procedure at DEAR for the kaonic hydrogen measurement has allowed a final measurement of kaonic nitrogen. For the first time, a pattern of three transitions, the $7 \rightarrow 6$ at 4.6 keV, the $6 \rightarrow 5$ at 7.6 keV and the $5 \rightarrow 4$ at 14 keV, was measured. The yields were found in good agreement with cascade calculations – calculations triggered by the experimental results obtained by DEAR. The good statistical evidence (14σ on the better seen line), as well as the absence of fluorescence lines (in the energy region of kaonic nitrogen transitions) allowed a quality jump with respect to the previous measurement of kaonic nitrogen performed and published by DEAR (Phys. Lett. B 535 (2002) 52). The charged kaon mass could be deduced with a precision of about 250 keV, confirming the potentiality of the method for a future precision measurement in a dedicated experiment.

In the last two months of 2002 the kaonic hydrogen measurement was performed; experimental data corresponding to an integrated luminosity of about 60 pb^{-1} were collected. Data analyses are in progress. The preliminary results (analyses performed in Frascati and Vienna) show that a precision 2-3 times better with respect to the KEK experiment is achievable. If confirmed, this will represent the best measurement of kaonic hydrogen ever performed.

In spite of this very positive result, the scientific program of DEAR – **a measurement of kaonic hydrogen with eV precision and the first measurement of kaonic deuterium**, in order to determine the kaon – nucleon sigma terms, was only partially achieved. As a matter of fact, in spite of a background reduction of a factor more than 100 (during the DEAR history) in the Interaction Region, the kaonic hydrogen measurement was performed with a Signal/Background ratio about 1/100. To be able to perform a measurement of the shift and width of kaonic hydrogen at the eV level, a ratio close to unity is needed. As far as the kaonic deuterium measurement is concerned, the 2p -> 1s yield was evaluated to be 3 – 10 times lower than the kaonic hydrogen one – what makes unfeasible such a measurement with the DEAR setup on the actual machine.

In fact, the advantages of CCD (Charge-Coupled Device) detectors, in terms of background rejection, based on different energy release by an X ray and a charged particle (pixel pattern recognition), proved to be not sufficient, given the background level of DAΦNE.

A logical way to reject the contribution of background particles hitting the detector is to implement a trigger system which limits data acquisition within a fixed time window. This cannot be done on a CCD, in which the readout time is of the order of the tens of seconds. The search of a detector with the same performances of a CCD in terms of efficiency and energy resolution for soft X-rays (1 – 30 keV), fast enough, however, to implement a trigger system, turned out in large area Silicon Drift Detectors (SDD), which can be triggered. In Section 2 of this report the characteristics of SDDs are briefly recalled.

By using SDDs, it becomes possible, in principle, to bring near unity the S/B ratio in case of kaonic hydrogen and kaonic deuterium and therefore to make precision measurements of the K_α line shifts, the original DEAR scientific programme. It becomes as well possible to extend this programme to the measurement of kaonic helium, of great interest being connected to one of the most fascinating and actual problems concerning the behavior of hadrons in nuclear matter, the deeply bound nuclear mesonic states. A never studied exotic atom, the sigmonium ($\Sigma^- p$), becomes also accessible. This is the new project SIDDHARTA.

The present report is presenting the experimental results of a first test of a prototype SDD array on the Beam Test Facility (BTF) of the Frascati Laboratories in a background environment similar to that of DAΦNE. The asynchronous background was simulated by the use of external sources (Fe and Sr), as described in Section 3, so to have the possibility to measure the trigger effect on the measured spectrum. These are the first tests ever performed involving a triggered SDD in an electron pulsed beam.

The tests started on 21st July 2003 and lasted until 31st July 3002.

A series of measurements, all giving very positive results, were performed, testing: detector performance (energy resolution, stability, linearity) and as well the triggering capability, under different incident rates and time window for coincidence. The results of these tests are presented in Section 4.

Conclusions are drawn in Section 5 , while in Section 6 future plans are briefly presented.

2. Silicon Drift Detectors

Silicon drift detectors were originally proposed [1] as an improved alternative to silicon microstrip detectors in high energy physics applications. Radiation hardness, 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. Few years after the first applications, the Silicon drift detectors were developed as an X-ray spectroscopic tool, due to a series of characteristics impossible to implement (all together) in any other X-ray detector:

- high efficiency (near to unity) in a wide range of X-ray energies (from few hundreds eV to about 15 keV) due to the relatively thick sensitive layer, typically few hundreds micron;
- good energy resolution, achievable with a minimal cooling reached by Peltier coolers, which eliminates the need to employ liquid Nitrogen or expansion cryostats;
- high speed of operation (10^4 to 10^6 particle/s, according to the requested precision and topology);
- low internal electromagnetic background with respect to other thicker (crystal) detectors;
- good energy separation between minimum ionizing particles and photons;
- low EMI noise due to the integrated front-end transistor;
- possibility of choosing the topology according to the needs of the experiment.

In Figure 1 the main characteristics of an SDD are compared to the same ones for similar devices: PIN and Si(Li). The SDD characteristics, in terms of energy resolution and timing of the signal formation, are making it the ideal device to be used in the SIDDHARTA experiment, for exotic atom X-ray transitions precision measurements.

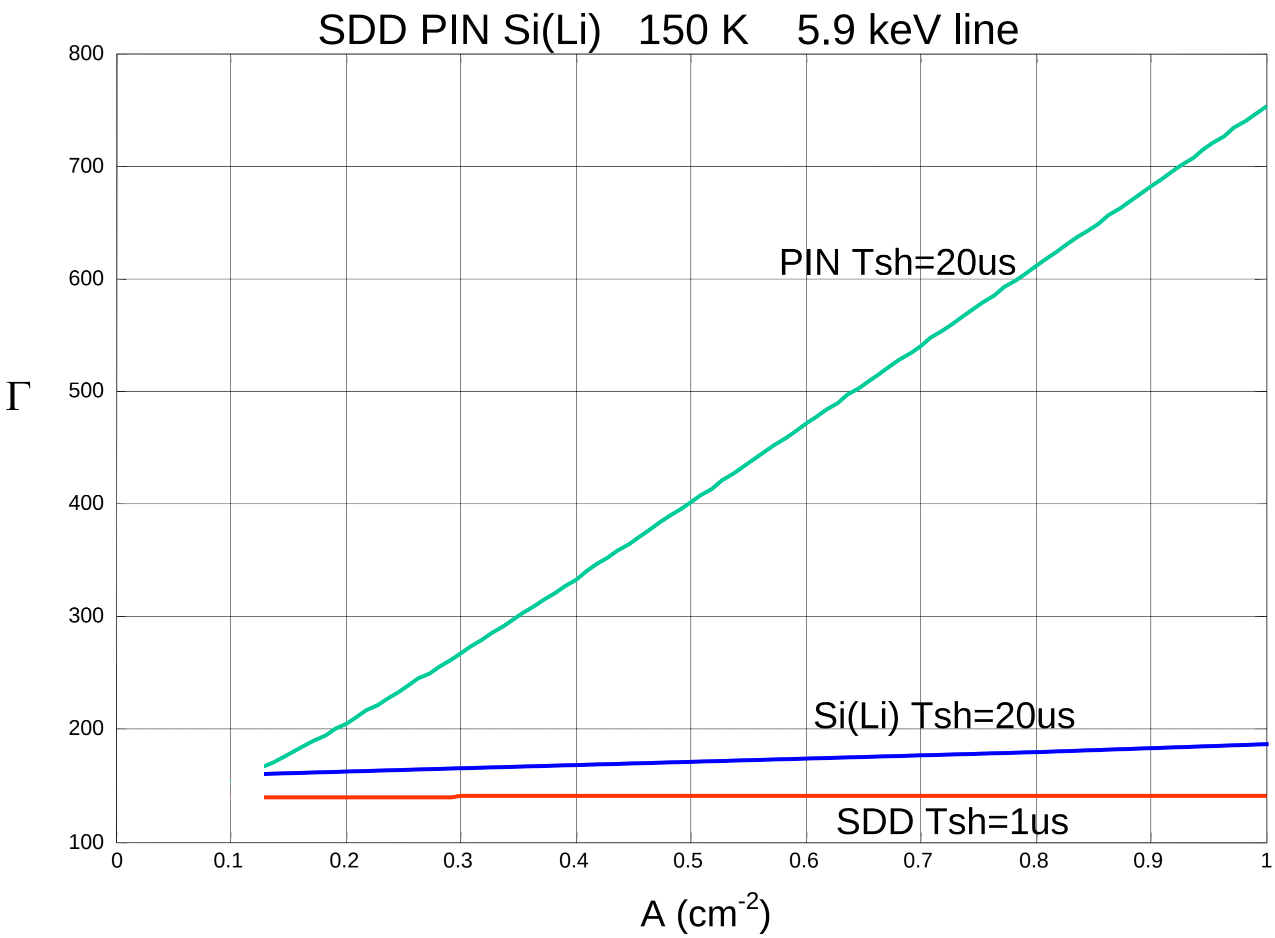

Figure 1: Comparison of the characteristics of SDD, PIN and Si (Li) detectors.

(A = detector surface, Γ = FWHM)

The goal of SIDDHARTA is to take advantage of both excellent fast readout and energy resolution of spectroscopic SDDs and to enlarge the area of usage of these detectors in triggered applications. This will give the possibility to detect rare events in a high background environment as DAFNE.

The present Report present **first tests ever performed** with such a device, in terms of energy resolution, stability, linearity and **trigger performance**, in an environment similar to DAΦNE, the BTF of LNF.

3. The experimental setup

3.1 The Beam Test Facility of LNF

The electron beam of the Beam Test Facility (BTF) of Frascati Laboratories has been employed to produce soft electrons and positrons able to excite, by fluorescence, X-ray lines from selected elements, providing, at the same time, the fast timing signal that allowed to study the SDD behavior under trigger conditions.

The BTF is an experimental facility of LNF dedicated to test detectors. Secondary electrons and positrons of energy selectable from 25 MeV up to 850 MeV, produced by the Frascati Linac, can be delivered. The beam bunches have a width that can be varied from 1 ns to 8 ns, and a frequency tunable from 1 Hz to 49 Hz. The actually allowed current can be varied from 1 to 1000 electrons (positrons) per second. All details on the BTF facility can be found in ref [2].

During the present testing, the BTF beam was operated at an energy of ~500 MeV. The reason for that choice had motivations both practical and physical. The practical one was that the BTF is normally operated in parasitic way, when the LINAC is dummy between one injection and another of electrons and positrons into DAΦNE rings, which is its main scope. The injection energy in DAFNE is 510 MeV, and hence an energy was selected very close to the injection one, in order to reduce dead times in setting and tuning the Linac working parameters. The physical reason was that, since the SDD will have to operate inside DAΦNE, it seemed worthy to use a primary energy as close as possible to that one used in the real working conditions.

3.2 Prototype SDD used for testing

The test setup installed at the BTF contained an array of 7 SDD chips, each one with an area of 5 mm^2 with 300 μm depletion layer. A picture of the SDD array is shown in Figure 2.

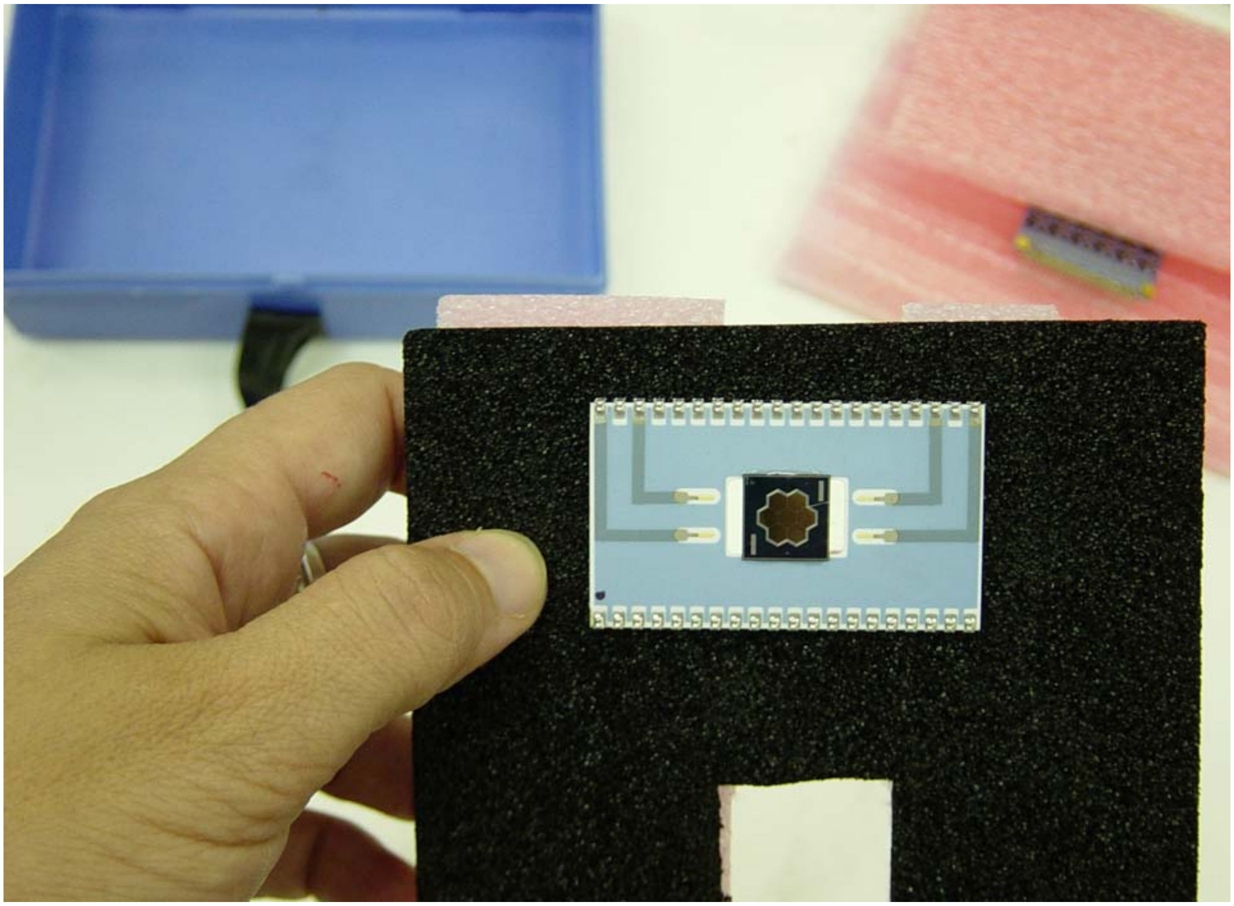

Figure 2: SDD prototype array containing 7 SDDs chips, 5 mm^2 area each, used for tests at BTF

The SDDs device was cooled down to about –42 ^{0}C (by the use of a Cryotiger system), the temperature being stable in the range of 2-3 ^{0}C along all the periods of DAQ. The main temperature variation was registered from day to night, an example being shown in Figure 3. Of course, for the SIDDHARTA setup on DAΦNE the temperature control system – as in the DEAR case – will keep the temperature stabilized at the level of 0.1 ^{0}C.

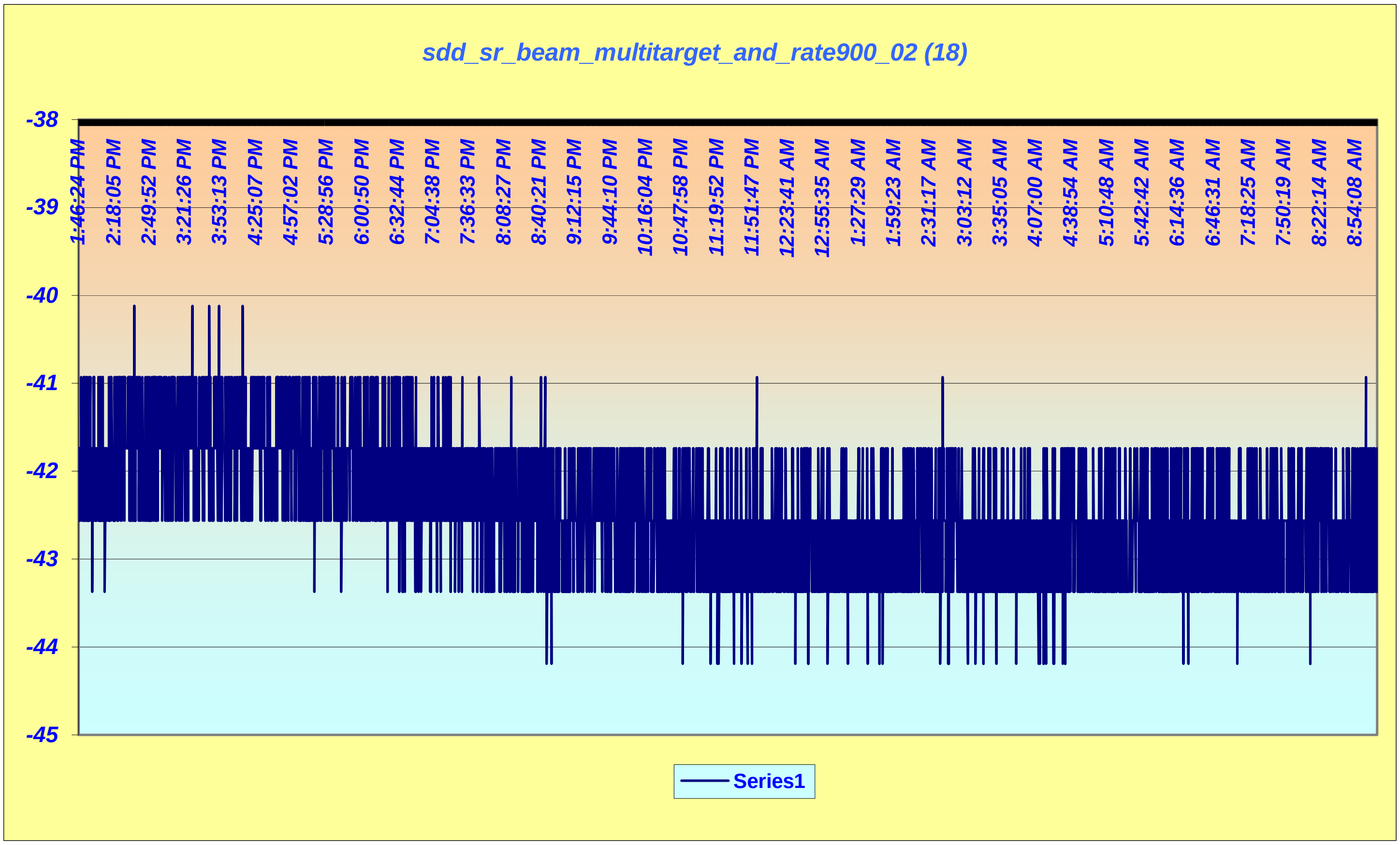

Figure 3.: Example of the day-night temperature variation: SDD temperature behavior (in ^{0}C) from 30 July, 1.46 p.m., to 31 July 2003, 9.09 a.m.

The temperature variation was taken into account in analysing stability and linearity of SDDs.

3.3 Electronics for the test setup

For the test setup a prototype electronics was built by Milano and Frascati groups. This represents the first version of the electronics to be further developed and improved for the final setup. A Note is being written containing the detailed description of this electronics [3].

The readout electronics and the preamplifier were specially designed, being shown in Figure 4 (readout) and Figure 5 (preamplifier).

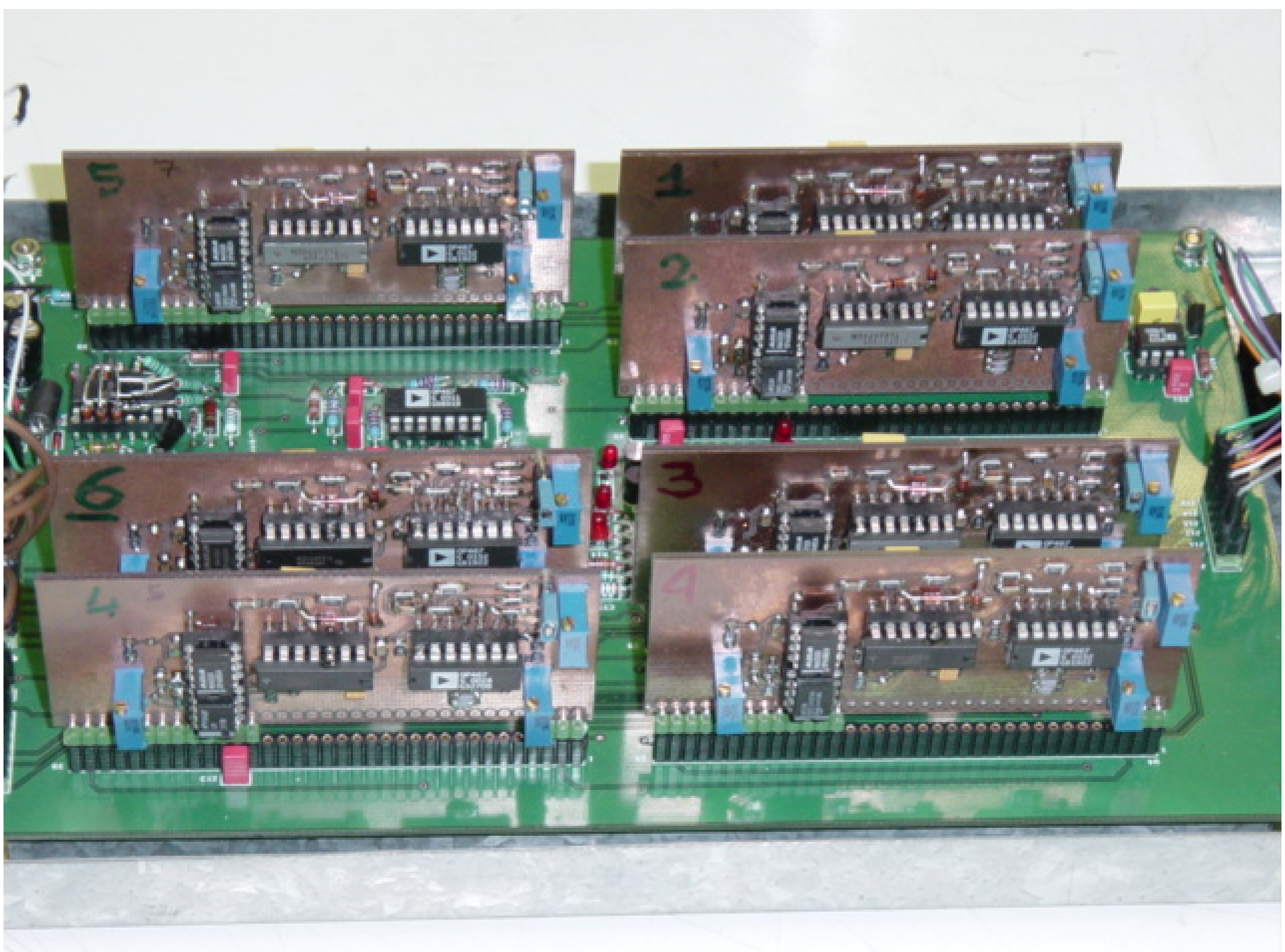

Figure 4: Readout electronics for the SDD test setup

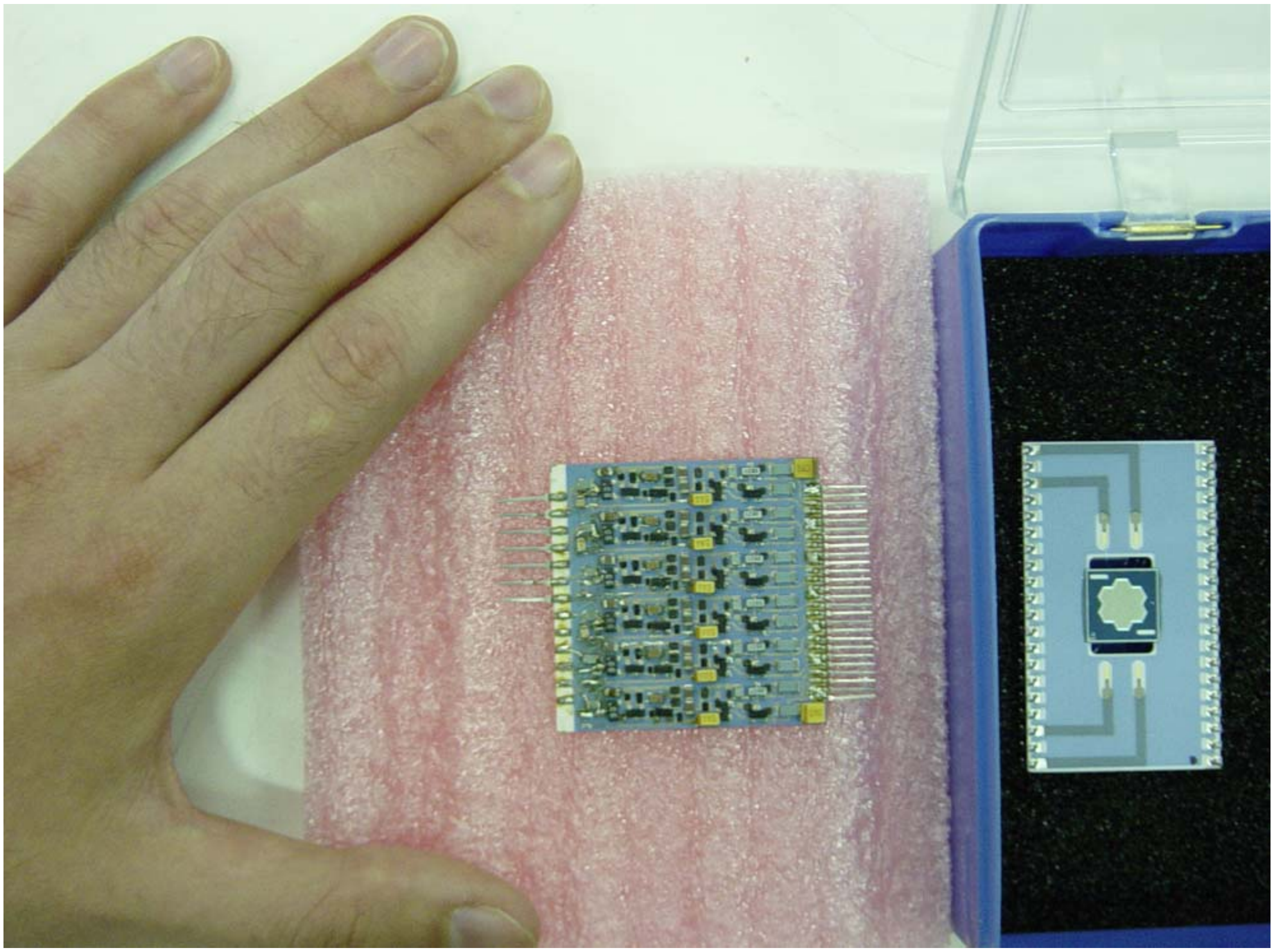

Figure 5: Preamplifier and SDD prototype array used for the BTF tests.

Electronics was calibrated such as to have a dynamic range for SDD from about 1 to 20 keV; all those particles depositing an energy higher than 20 keV were counted as overflows.

3.4 Test setup

In order to degrade the preliminary electron energy, to excite fluorescence X-ray lines, a lead slab was put on the BTF beam, whose thickness was chosen by means of an e.m. shower MonteCarlo calculation to produce secondary particles continuously distributed in energy from few MeV to zero. A Pb thickness of 2 cm turned out to be a good compromise between "energy softness" and particle intensity of such produced secondary beam. The secondary beam particles were let to impinge on a set of selected materials in the configuration shown in Figure 6.

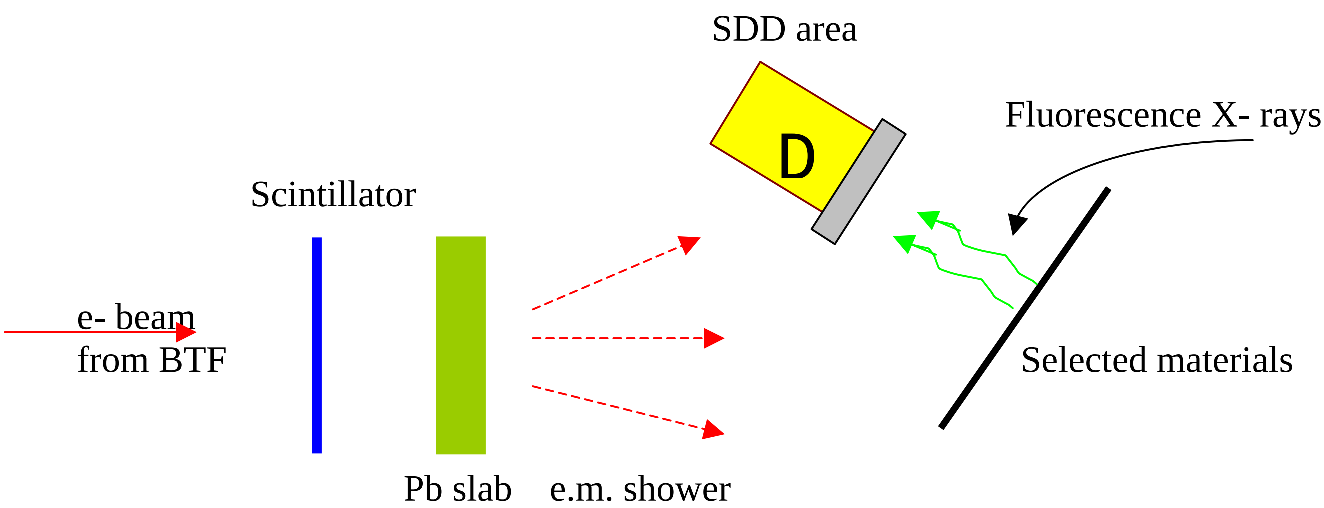

Figure 6. The initial test experimental setup mounted in the BTF area (D = SDD array).

Before producing the e.m. shower in the lead slab, the primary BTF beam hit a thin scintillator (see Fig. 6), one of the two used for the Kaon Monitor in the DEAR experiment [4], to provide a fast triggering signal. The scintillator dimensions were (2 x 80 x 150) mm, thickness, height and length, respectively. The scintillator (NE104 type) was seen by two fast phototubes (PM), XP2020 type, mounted at the two (2 x 80) mm ends of the slab, by means of properly shaped light guides. The anode signals of each PM was sent to a CAEN ND235 NIM Constant Fraction and Mean Timer that produced a NIM output whose timing was independent on the particles hitting position on the scintillator. This output was then sent, after pasing through a CAEN Dual Timer N93B to one of the input of an AND/OR CAEN Login Unit N455, the other input of which was fed by the SDD logic signal passing through a LECROY835 Discriminator. The output of this module was used to enable DAQ. Fig 7 shows the scheme of the front-end electronics of the test setup.

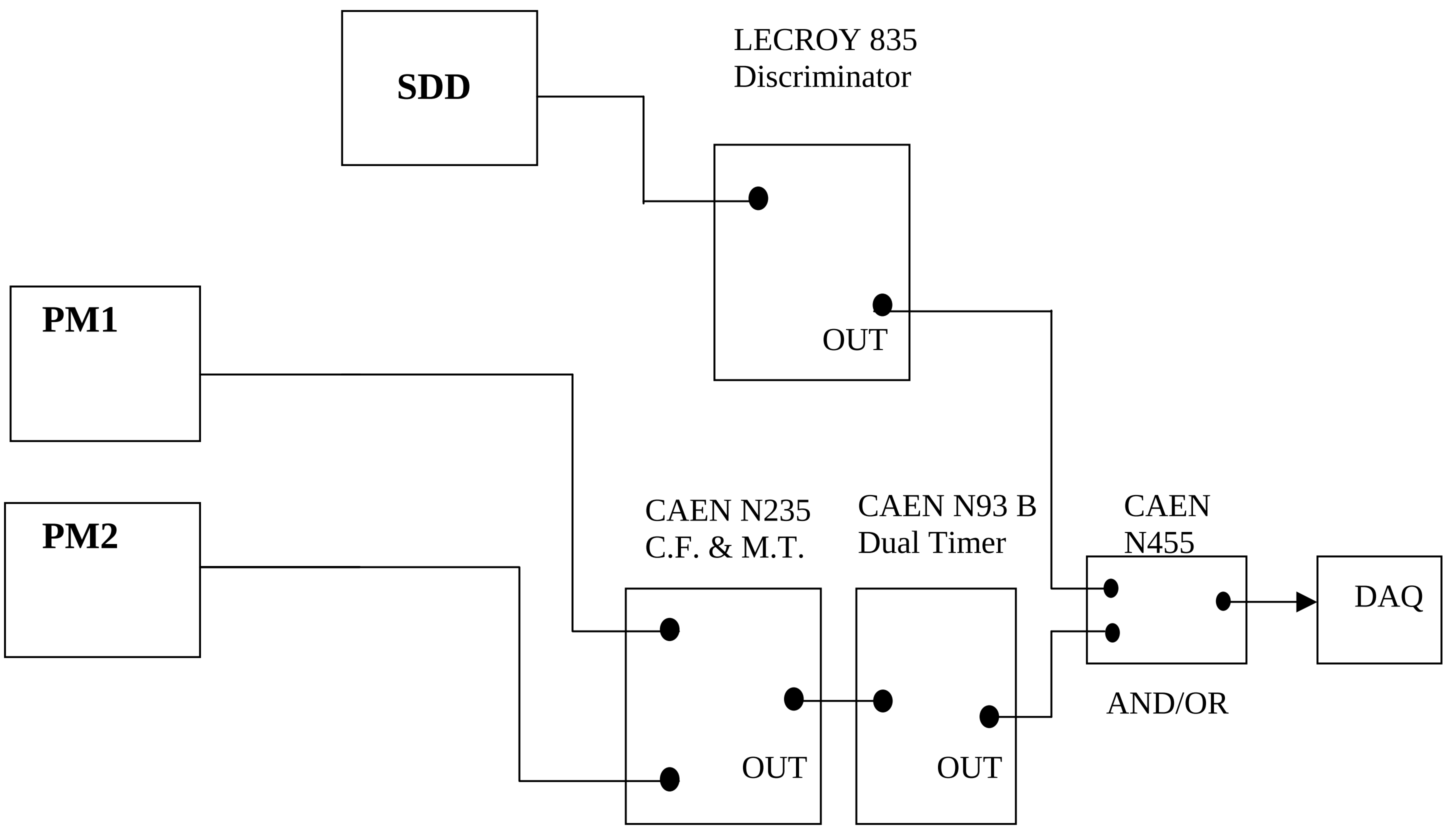

Fig. 7 The electronics scheme of the test setup on BTF

Since the signal from the SDD had a jitter of about 800 ns, the width of the scintillator signal feeding the AND/OR unit was adjusted to 1 microsecond (Fig. 8a).

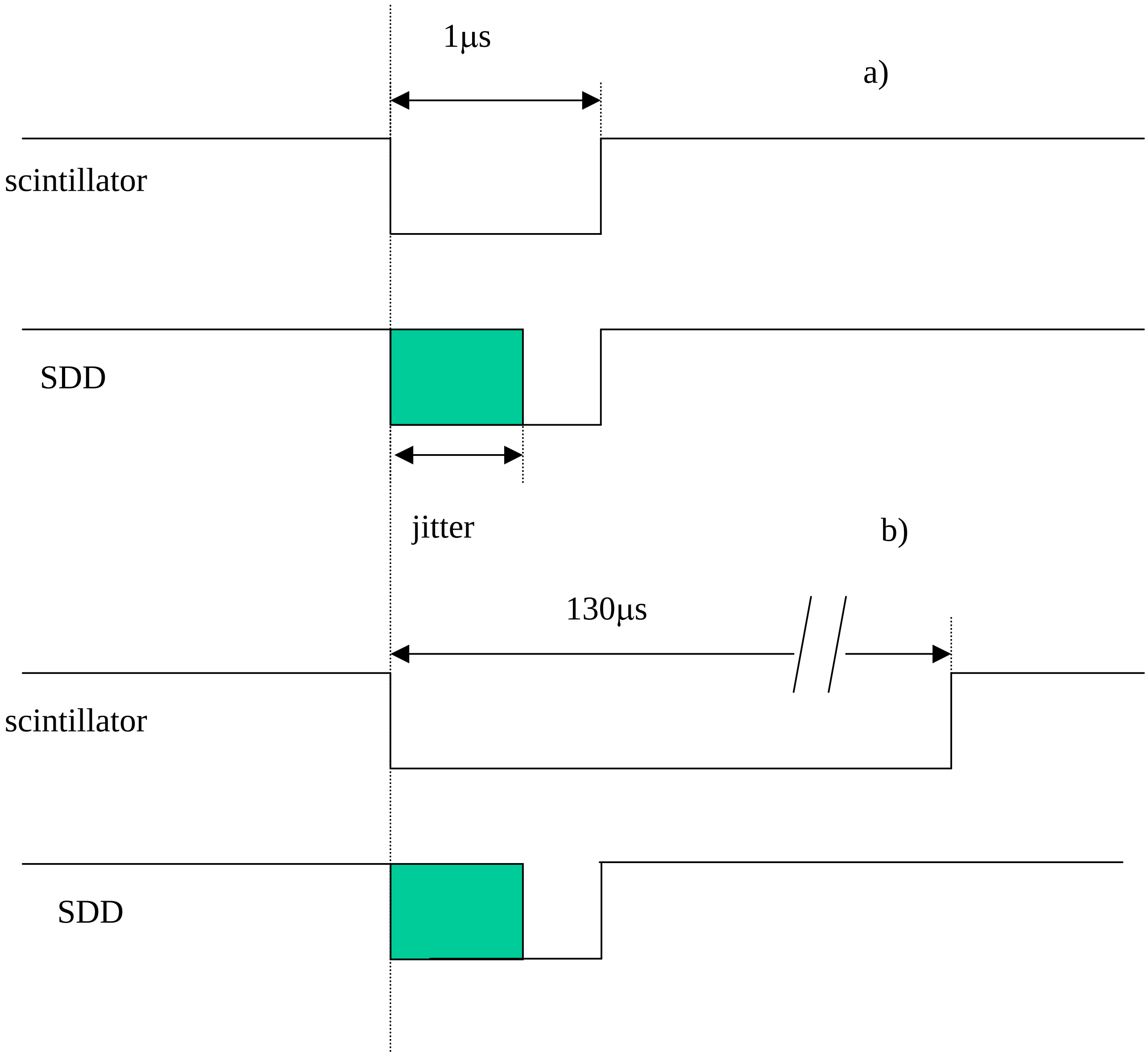

Fig. 8 Scintillator and SDD signal widths

Fig. 6 shows the test setup configuration. The emerging secondaries from the e.m. cascade arrived to a set of foils of selected materials (Cu, Zr), disposed at about 45 degrees with respect to the primary beam flight line. Hitting these slabs, fluorescence X-ray transitions could be excited and the generated X-rays, traveling backward at about 45 degrees, opposite to the primary beam direction, reached the SDD and were detected ("reflection geometry"). The SDD itself was mounted oriented with the entrance window forming an angle of about 45 degrees with respect to the primary BTF beam axis, facing the material slabs but not being directly invested by the secondary particles. In such conditions, the SDDs could see the fluorescence lines generated on the selected materials, superimposed to a continuous background formed by the soft secondary electrons, positrons and photons created in the e. m. cascade and arriving on the detector window due to subsequent interactions and backscattering in the materials around the SDDs.

The spectrum of the fluorescence X-ray lines could then be measured. The continuous background spectrum, being generated by the same BTF primary beam, was synchronous with the "good" signal represented by the fluorescence lines .

To generate an asynchronous background, i.e. not time-correlated with the “signal”, we employed a radioactive source. The source, properly facing the SDD, could conveniently generate the wanted asynchronous background. In the test setup, we indeed inserted two sources. One, a Sr source, due to its beta spectrum of maximum energy 2.24 MeV, produced a continuous asynchronous background of soft electrons and photons and also an asynchronous structured background (Ni transitions). The other, a Fe source, produced the K_α and K_β X-ray Manganese lines.

In such a way, we were able to explore the SDD performance and the trigger effect in suppressing the asynchronous background, both continuous and in the form of unwanted X-ray peaks, which is exactly the situation occurring in DAΦNE.

The final test setup with the radioactive sources generating the asynchronous background, is shown in Figure 9.

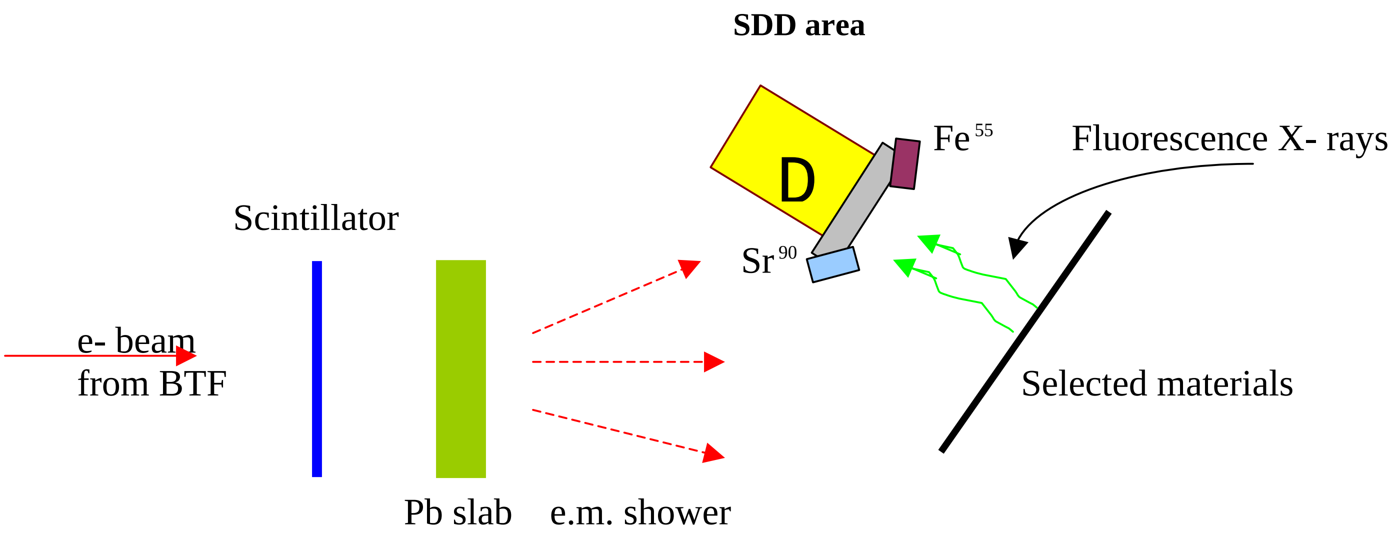

Figure 9. The final test experimental set up mounted in the BTF area (D = SDD array).

Both the test setups of Figure 6 and 9 were used.

That of Fig. 6 was used to verify, first of all, the feasibility to generate with the BTF beam fluorescence X-rays on the selected materials, to be used as “signals” on the SDDs and to show that, in such a configuration, the spectra were, as expected, the same both triggering and not triggering the SDDs.

The configuration of figure 9 was used to show the capability of the trigger system. Without any trigger (AND/OR circuit working in OR mode) the fluorescence peaks generated by the BTF beam were non detectable, due to the much higher continuous background produced by the Sr beta source, while the background Mn peaks were clearly seen. On the contrary, triggering the SDDs with the scintillator (AND/OR circuit working in AND mode), the fluorescence peaks generated by the beam clearly appeared, being the continuous background produced by the Sr beta source and the X-ray background Mn peaks effectively suppressed, even at the greatest "illumination" possible of the SDD with such sources, as described in the following Section. The results of all measurements with the test setup are described in Section 4.

In figures 10, 11 and 12 pictures of the setup used at BTF are shown.

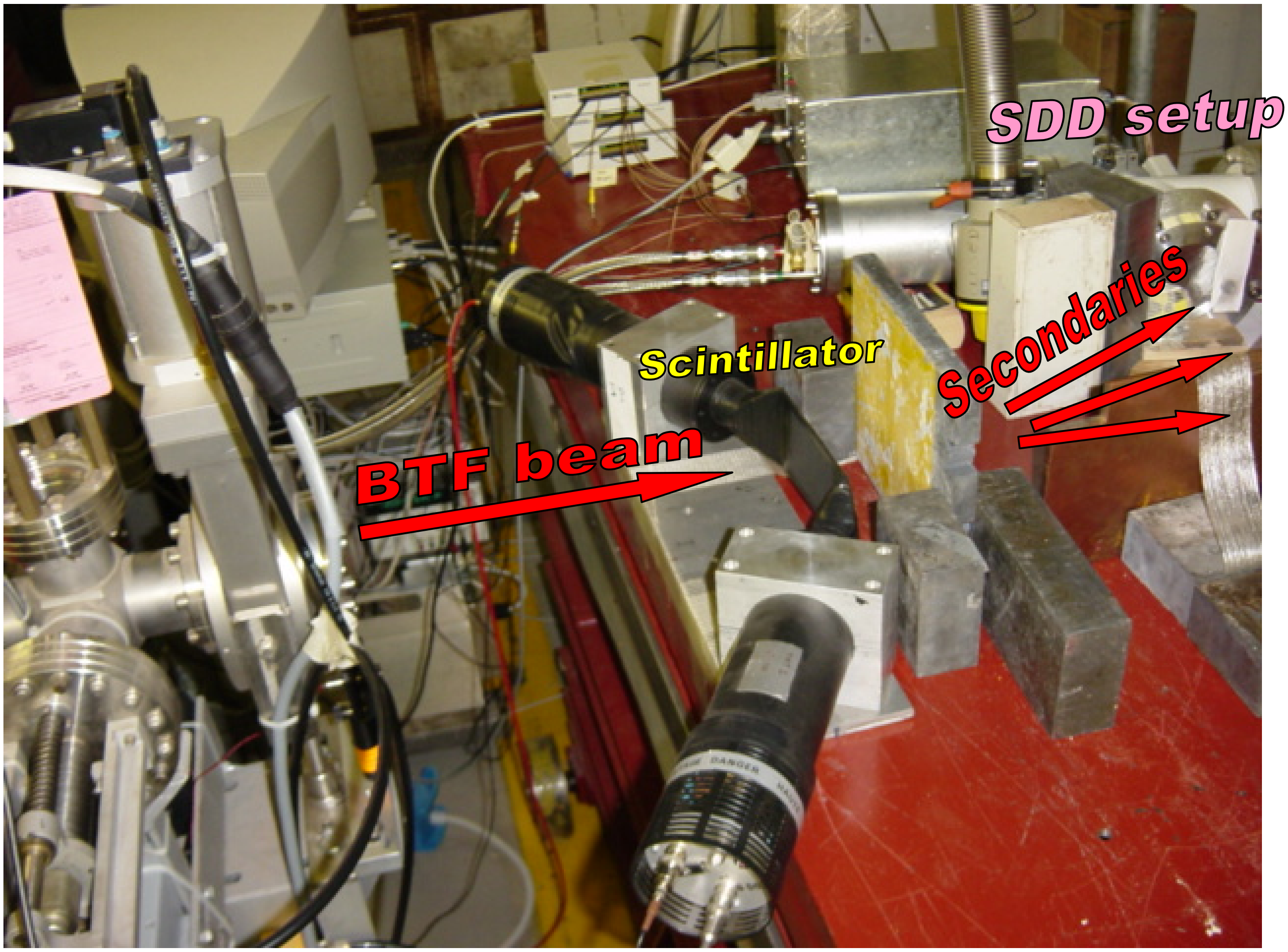

Figure 10: The test setup installed at BTF – global view.

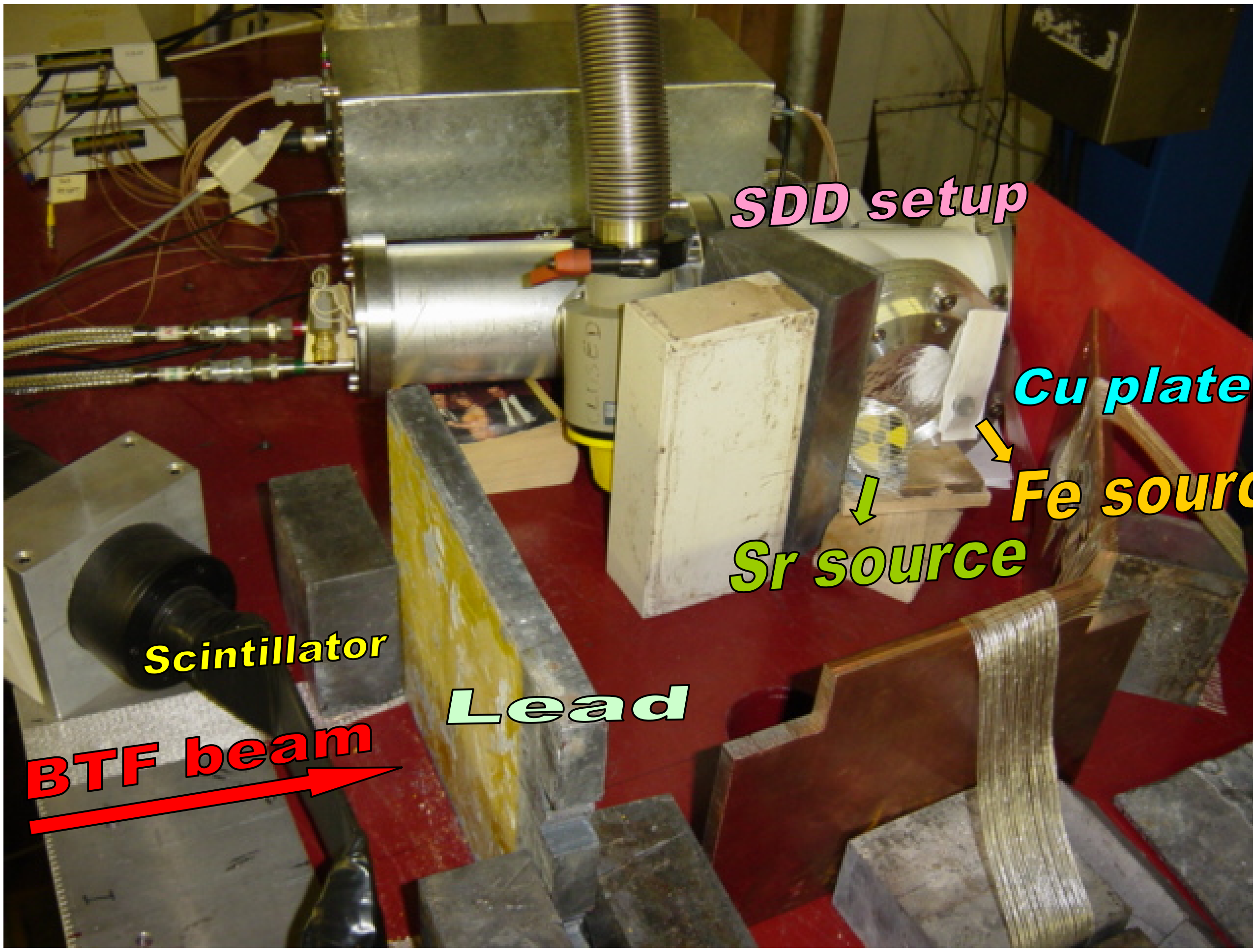

Figure 11: The test setup installed at BTF with the two sources (Fe and Sr) to generate asynchronous background.

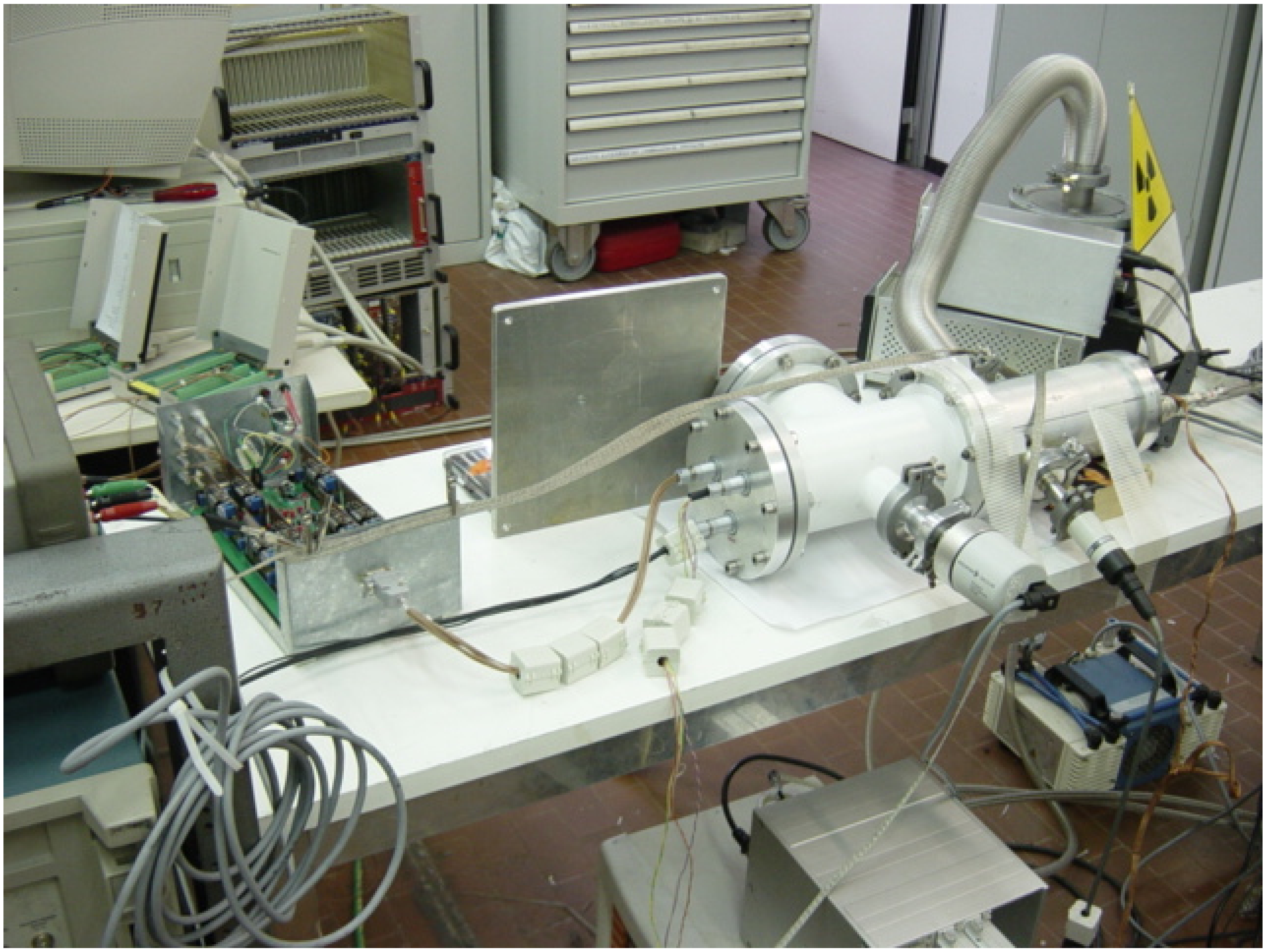

Figure 12: The test setup laboratory tests: detail of readout system is seen

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4. *Results of the measurements performed at the BTF*

4.1. Performed measurements

The test setup shown in Figure 10 was installed in the BTF hall on 21st July. A series of measurements started soon after. The measurements concerned:

- energy resolution of the SDD chips in the experimental hall;
- stability of the energy calibration;
- linearity of the energy scale: SDD channel versus energy;
- test of the triggering capability;

The results of these tests are shown in the next Subsections.

4.2. Measurement of the energy resolution at the BTF

In order to measure the energy resolution of the SDD chips of the test setup in the experimental BTF hall, an Iron source was used to illuminate the SDDs (see Fig. 11). The two K_α and K_β transition of Manganese, at 5.899 and 6.490 keV were than used to obtain the calibration and to further deduce the energy resolution.

The spectra of the 7 SDDs, obtained in a run lasting about 16 minutes, are shown in Figures 13 and 14, while the results are summarized in Table 1.

Table 1: Measured resolution of the SDDs used in the prototype array in the BTF Hall

SDD number	***Resolution at 5.899 keV (Γ in eV)***
1	**300 +/- 8**
2	**270 +/- 7**
3	**230 +/- 6**
4	**200 +/- 5**
5	**195 +/- 5**
6	**200 +/- 5**
7	**175 +/- 5**

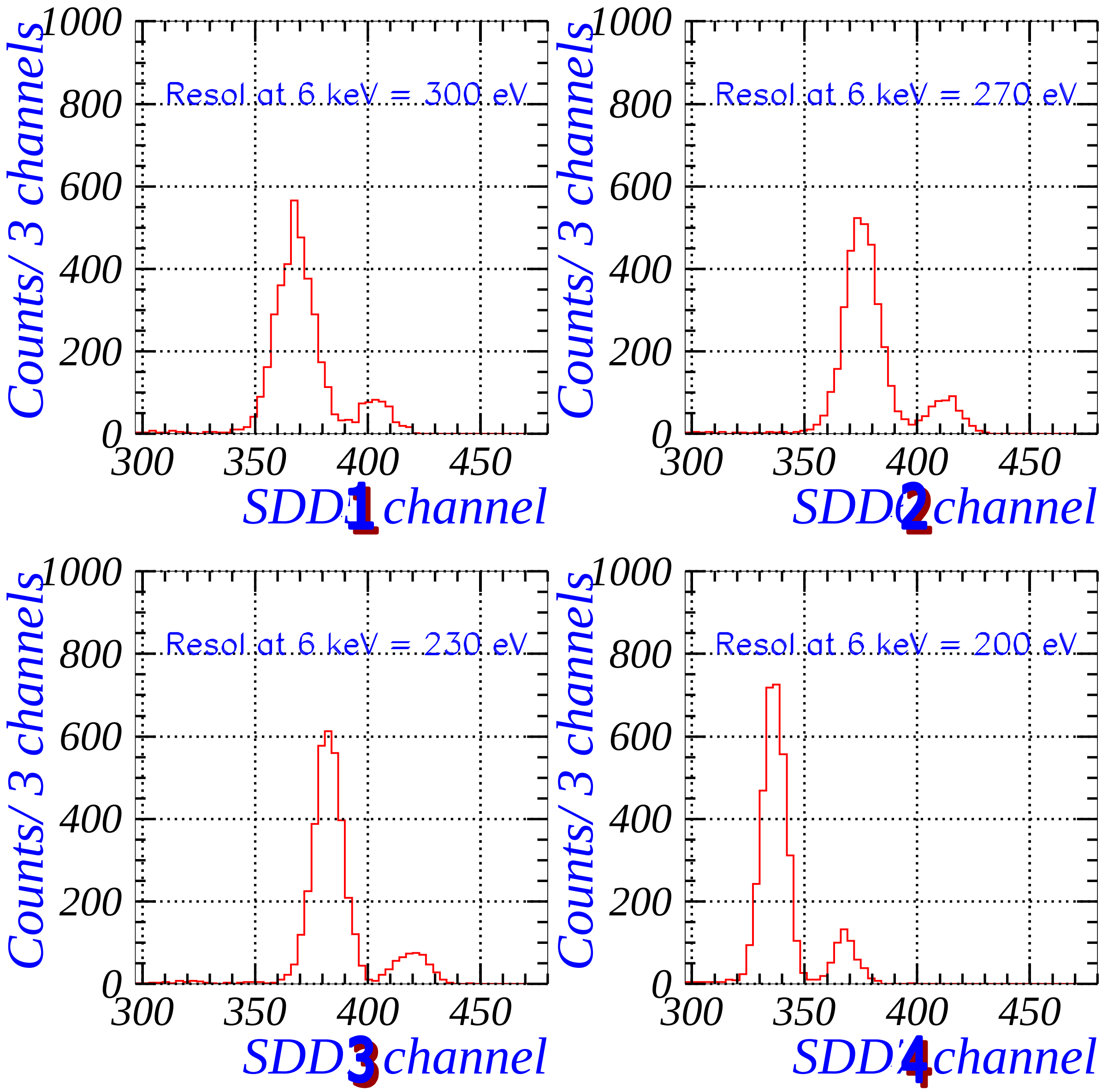

Figure 13: The experimental resolution of the first 4 SDDs of the test setup mounted in the BTF Hall.

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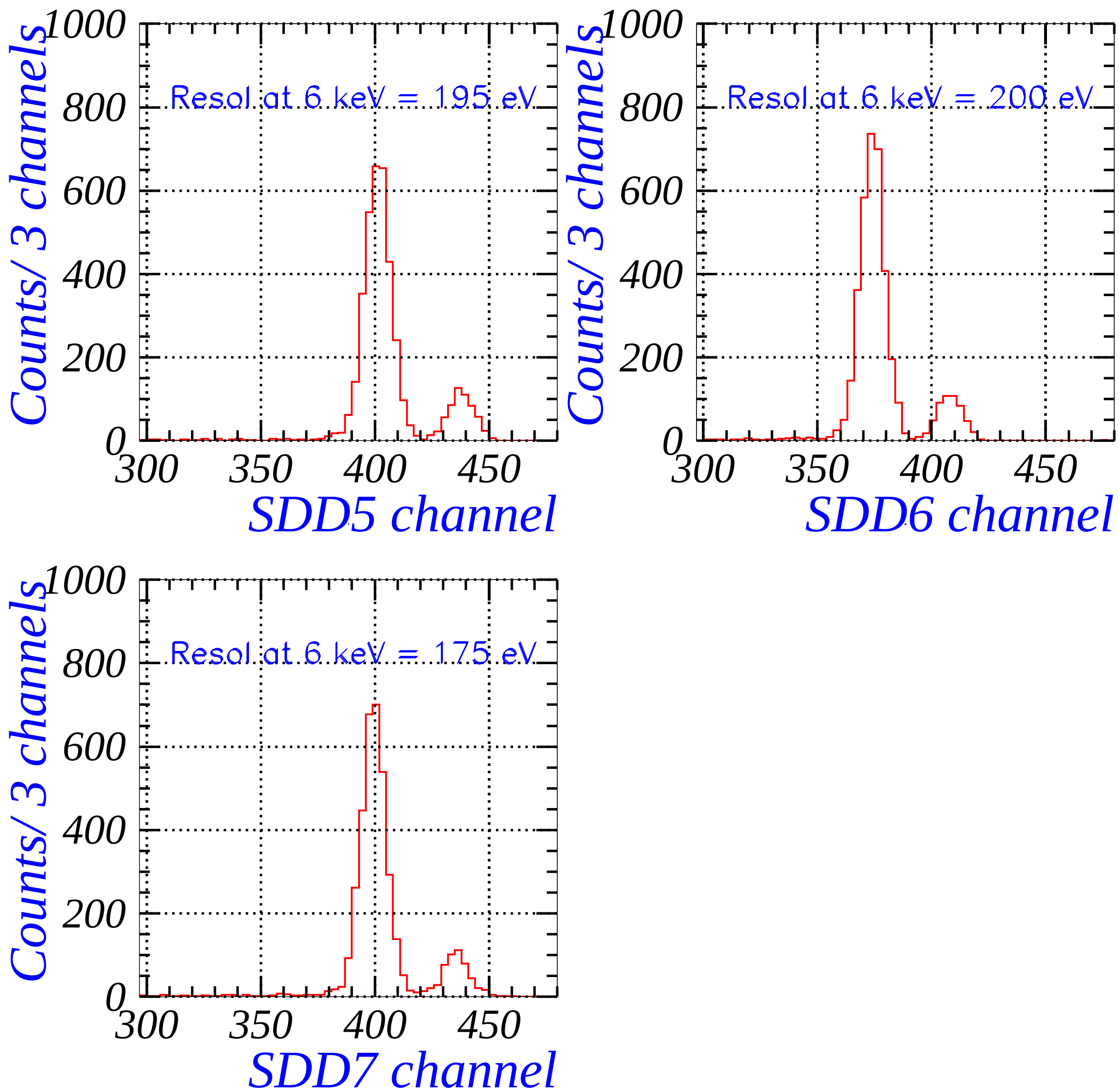


Figure 14: The experimental resolution of the last 3 SDDs of the test setup mounted in the BTF Hall.

As can be seen from the Figures and from Table 1, the experimental resolution of the 7 SDDs is varying between 175 and 300 eV at about 6 keV of energy.

The results, considering that were obtained with a preliminary version of electronics and without a proper filtering of the noise, are very encouraging and make us confident that an experimental resolution of about 140 eV can be achieved, as shown in Fig. 1.

4.3. Measurement of the stability of the energy calibration

The stability of the SDD detector is a very important parameter for a precision measurement of energy, which is the goal of the SIDDHARTA experiment. A measurement of the stability of the energy calibration was performed. What was actually done, was to check the scale calibration, working under different conditions of rate on SDDs and trigger and in different days. In particular, the position of the Mn K_α line was considered. A series of 4 measurements were then selected to perform the final check:

a) a measurement with only the Fe source (no beam), performed on 28 July, lasting about 16 minutes, with an incident rate on SDDs of about 80 Hz (Figure 15 a));

b) a measurement with Sr and Fe sources (no beam), performed on 24 July, lasting 20 minutes, with an incident rate on SDDs of about 60 Hz (Figure 15 b));

c) a measurement with beam and with the Fe and Sr sources, without trigger (OR), performed on 25 July, lasting about 18 minutes, with an incident rate on SDDs of about 1000 Hz (Figure 15 c));

d) a measurement with beam, with Sr and Fe sources, with the trigger window of 130 μs, with trigger on and the coincidence window at 130 μs, performed between 26 and 27 July, lasting 14 hours, with an incident rate on SDDs of about 500 Hz and a coincidence rate of about 8 Hz (Figure 15 d)).

The measured spectra for the 4 selected measurements (referring to the SDD 7) are shown in Figure 15, while the results of the fit are reported in Table 2.

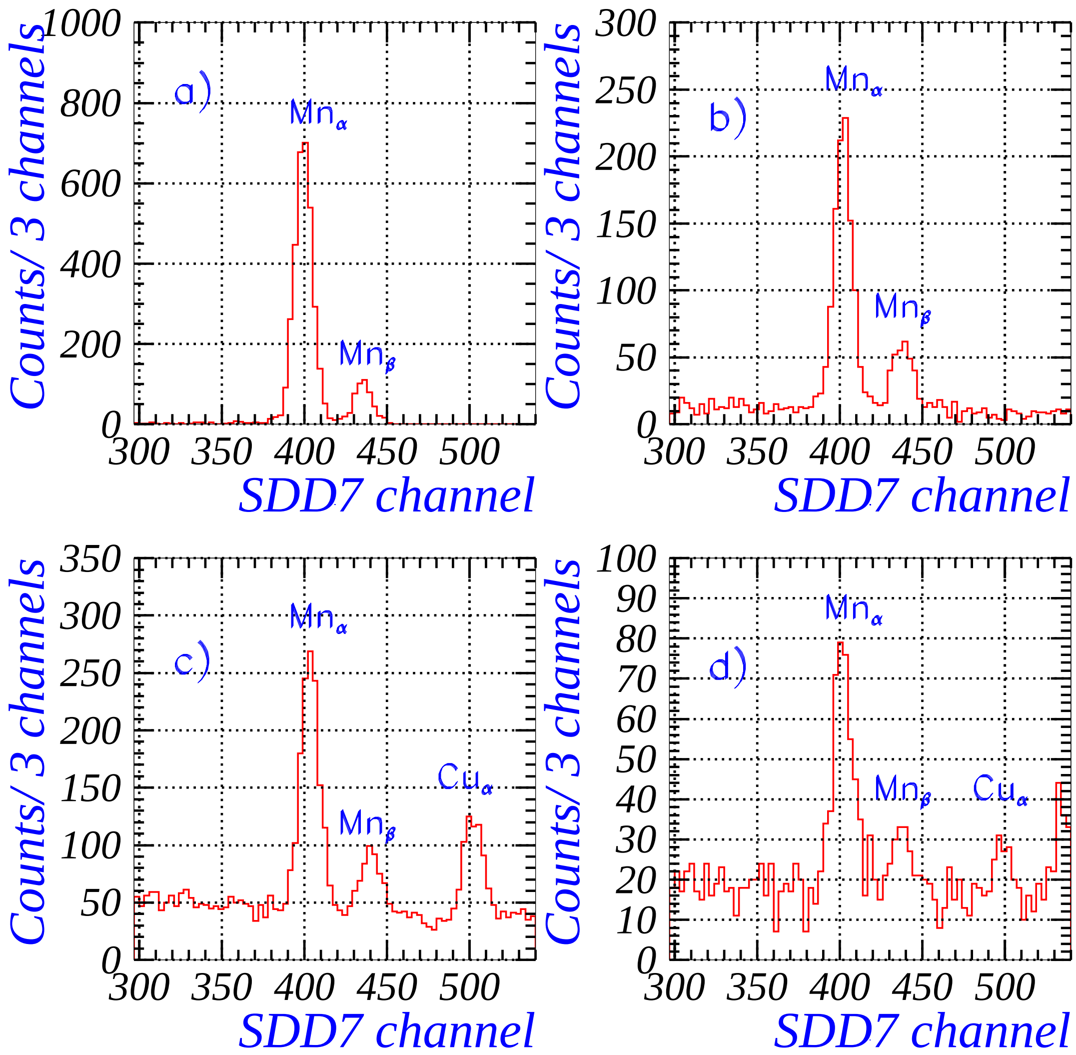


Figure 15: Measurements to check the stability of the energy calibration of SDDs under different rates on SDDs and trigger conditions and in different days: a) only Fe source, no beam, 16 minutes DAQ, performed on 28/07/03, rate 80 Hz; b) Fe and Sr sources, no beam, 20 minutes DAQ, performed on 24/07/03, rate 60 Hz; c) Beam on, Sr and Fe sources, no trigger, 18 minutes DAQ, performed on 25/07/03, rate 1000 Hz; d) Beam on, Sr and Fe source, active trigger, 14 hours DAQ, performed on 26-27/07/03, incident rate 500 Hz, triggered rate 8 Hz.

Table 2: Stability of the Mn K_α position during the tests at BTF (example for SDD 7)

Measurement	***Position of the Mn K_α peak (SDD 7)***
a)	**400.0 +/- 0.1**
b)	**402.0 +/- 0.2**
c)	**403.3 +/- 0.2**
d)	**401.4 +/- 0.4**

Comment: the errors quoted in Table 2 are only statistical. One should also take into consideration the error due to temperature variations occurring in long lasting measurements including day and night, like the measurement d). This variation induces a systematic error of the order of about 2 channels. Taking this into consideration, the stability of the energy scale was positively checked in the limit of ~ 2/400, i.e. at a level of 0.5%.

4.4. Measurement of the scale linearity

The linearity of the SDD answer – no. of channel as a function of energy - was checked by analysing measurements taken in different experimental conditions (after having checked the stability of the energy calibration, see 4.3) in order to have as many as possible (7 at the end) points to perform the fit and to check whether the function is linear or not.

In particular, the SDD 4 was considered for this test, and the selected measurements were:

1) a measurement with beam, with Sr and Fe sources, with TRIGGER ON (AND) and the trigger window of 130 μs, performed in the night between 26 and 27 July, lasting 14 hours, with an incident rate on SDDs of about 500 Hz and a triggered rate of about 8 Hz (Figure 16);
2) a measurement with beam, with only the Sr source, with TRIGGER ON (AND), standard 1 μs window , performed from 30 to 31 July, lasting 20 h and 30 min, with an incident rate about 900 Hz and a trigger rate of about 8 Hz (Figures 17 and 18).

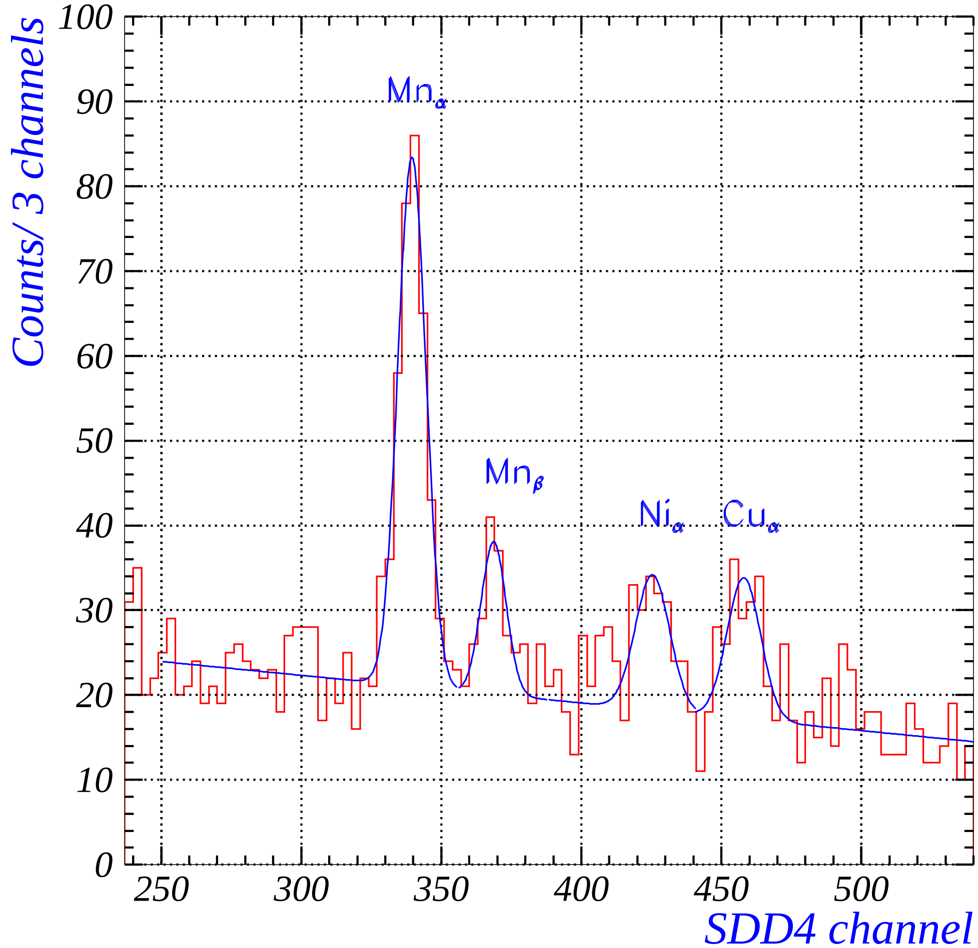


Figure 16: SDD4 fitted spectrum in a measurement with beam, with Sr and Fe sources, with trigger on (AND) and the trigger window of 130 μs, performed in the night between 26 and 27 July, lasting 14 hours, with an incident rate on SDDs of about 500 Hz and a coincidence rate of about 8 Hz; background peaks corresponding to Mn, and Ni from the Iron source are clearly seen. The “signal” Cu peak is as well visible.

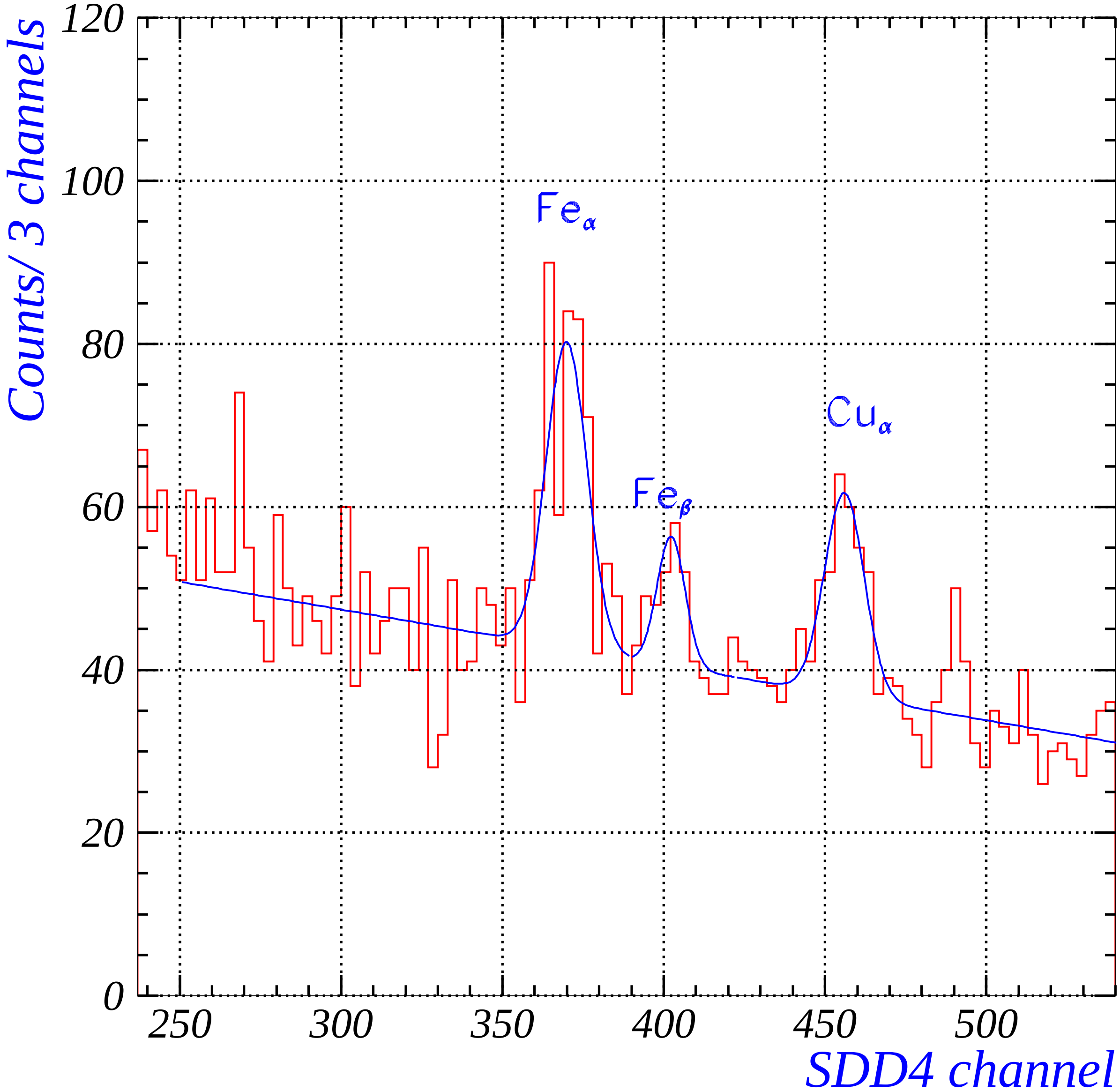


Figure 17: SDD4 fitted spectrum in measurement with beam, with only Sr source, with trigger on (AND) and the standard 1 μs coincidence window, with a multimaterial target (Iron, Copper, and Zirconium foils), performed from 30 to 31 July, lasting 20 h and 30 min, with an incident rate about 900 Hz and a coincidence rate of about 8 Hz. “Signal” peaks corresponding to Fe and Cu transitions are clearly seen.

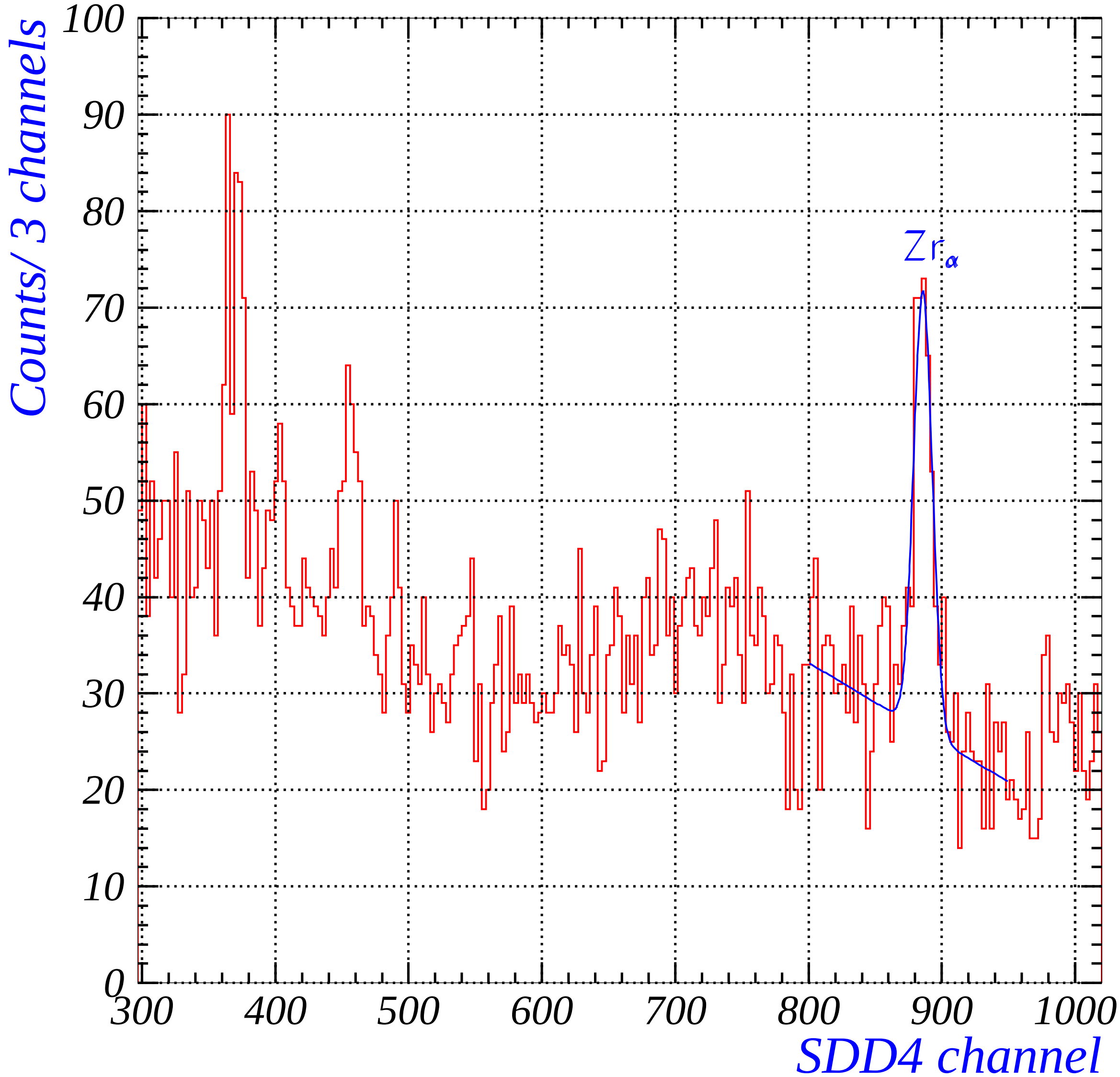


Figure 18: SDD4 fitted spectrum in measurement with beam, with only Sr source, with trigger on (AND) and the standard 1 μs coincidence window, with a multimaterial target (Iron, Copper, and Zirconium foils), performed from 30 to 31 July, lasting 20 h and 30 min, with an incident rate about 900 Hz and a triggered rate of about 8 Hz. The peak corresponding to the Zr K_α line is clearly seen.

After having performed the fit of the spectra, the obtained results were used to check the scale calibration under the hypothesis of a linear behavior, of the type: no. channel = a + b * energy (eV). A systematic error of about 1.5 channels was added to the statistical error, in order to account for the temperature variation between the 2 measurements. The linear fit gave a χ^2/NDOF of 1.03. The values of the fit parameters turned out:

a = 11.491 +/- 2.21

b = 0.05550 +/- 0.0024 (eV^{-1})

The result of the fit is shown in Figure 19, where the experimental peak positions together with the linear fitting curve are shown.

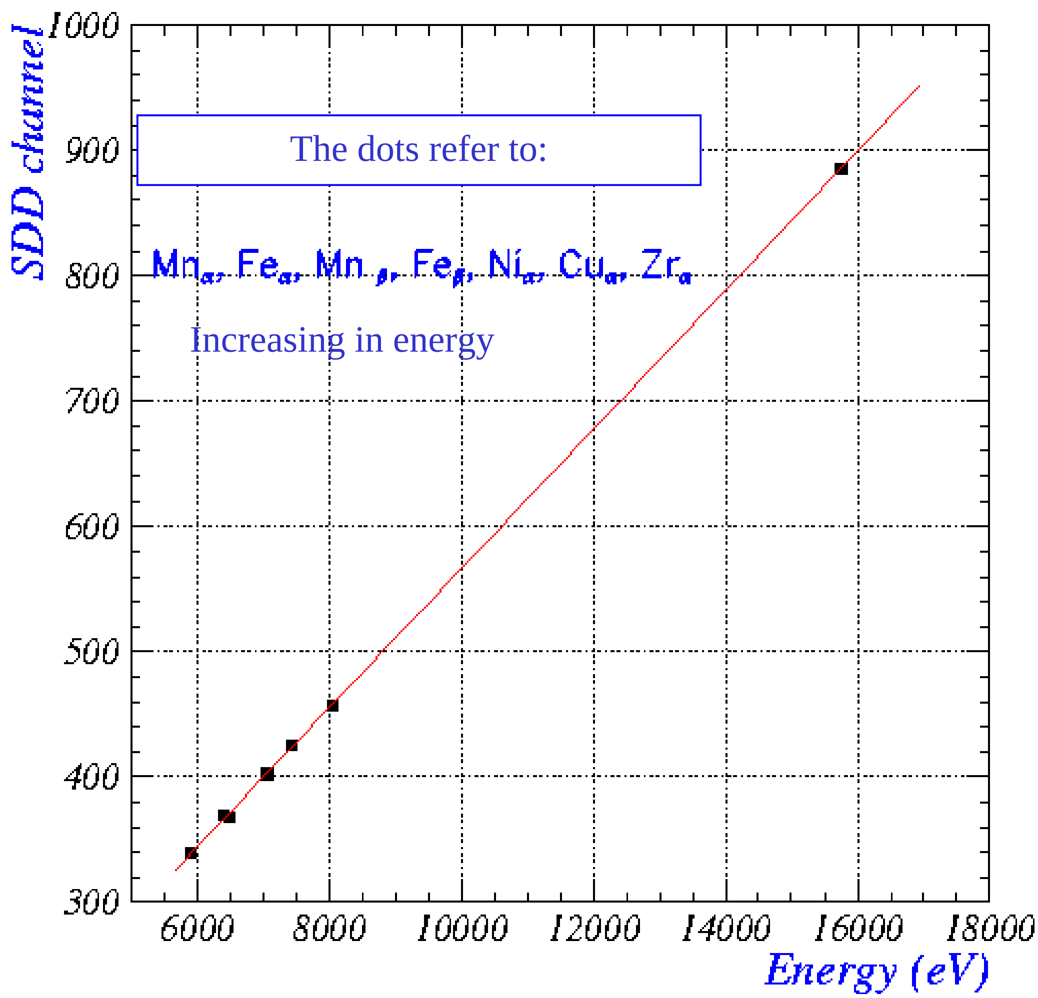


Figure 19: Linearity of the SDD4 chip: experimental values together with the linear fitting curve.

In conclusion, the linearity at 6 keV was checked on BTF to be at about the 0.8% level; further tests – in order to arrive at 0.1% level, with be performed in the laboratory.

4.5. Trigger performance

The main aims of the measurements performed at BTF, with a dedicated setup containing a prototype SDD array, was to check the SDDs answer under realistic beam conditions – in terms of types of particles and energy – and, specifically, under trigger conditions. The trigger was given by the coincidence between a thin scintillator slab hit by the primary BTF electron beam (see Fig. 6) and the SDDs. This tests were performed for different incident rates and for different coincidence windows.

4.5.1 Choice of the working conditions

The choice of the working conditions was performed on the basis of the expected experimental conditions in the SIDDHARTA Project [5,6,7]. These, in turn, can be extrapolated from the measurement of kaonic hydrogen in DEAR.

4.5.1.1 Expected SIDDHARTA performance

a) signal rate – kaonic hydrogen –extrapolated to SIDDHARTA: 1 event each 300 seconds, giving a rate of 3.3 x 10^{-3} Hz;

b) the incident flux of background particles on 100 cm^2 of CCD in DEAR was about 400 Hz, represented mainly by *asynchronous* Touscheck effect generated particles (charged and X rays): extrapolated to the 200 cm^2 in SIDDHARTA one gets about 1000 Hz (taking into account the higher efficiency for X ray in the region of interest of SDD with respect to CCD);

c) rate of kaons entering in setup and giving the trigger: 3 Hz;

In these conditions the use of a trigger window of 1 μs on SDD should give for SIDDHARTA:

a) Asynchronous structured and continuous incident background:

$\mathbf{R_B = 1000\ Hz}$ **(27)**

b) Trigger rate from kaons:

$\mathbf{R_t = 3\ Hz}$ **(28)**

c) Coincidence window:

$\mathbf{C_w = 1\mu s}$ **(29)**

d) Kaonic hydrogen event rate:

$\mathbf{S_{KH} = 3.33 \times 10^{-3}\ Hz}$ **(30)**

e) Efficiency for kaonic hydrogen event production = number of events/ number of triggers:

$\mathbf{Eff = Ev_{rate}/R_t = 3.33 \times 10^{-3}/3 = 1/900}$ **(31)**

so one KH event for 900 triggers;

f) Casual background event rate:

$\mathbf{R_{casual} = 3 \times 1000 \times 10^{-6} = 3 \times 10^{-3}\ Hz}$ **(32)**

With these numbers, one can calculate the ***trigger rejection factor***:

$$\mathbf{R = (Acquisition\ of\ background/event)_{trigger\ on} / (Acquisition\ of\ background/event)_{trigger\ off} =}$$

$$\mathbf{= (Nr.\ Trigger/ev)_{on} \times C_w / (1/Ev_{rate}) = 900 \times 10^{-6} / 300 = \underline{3 \times 10^{-6}}} \quad \mathbf{(33)}$$

Now let's calculate the S/B rate by using the trigger, considering the fact that the background in the "region of interest" is about 10% of the total incident background:

$\mathbf{B_{RI} = 1000 \times 0.1 = 10^2\ Hz}$

$\mathbf{R_{casual}^{RI} = 3 \times 10^2 \times 10^{-6} = 3 \times 10^{-4}\ Hz}$

$$\mathbf{(S/B)trigger = 3.3 \times 10^{-3} / 3 \times 10^{-4} \approx 11/1}$$

The same calculation is valid for the **kaonic deuterium**, with the exception that, in this case, the signal is about 5 times less with respect to kaonic hydrogen, then **S/B ≈ 2/1.**

4.5.1.2 Incident rate on the prototype SDD setup at BTF

- In **SIDDHARTA**, the rate of **1000 Hz on 200 cm^2** (200 channels, each 1 cm^2 or 400 channels, each ½ cm^2) means **5 (2.5) Hz/channel**.
- If we choose an incident rate of **60 Hz at BTF**, one has **8.5 Hz/channel**, value comparable with that expected in SIDDHARTA.
- If the incident rate is **1000 Hz**, one can study detector performance and trigger capability at **142 Hz/channel**. i.e. in **condition about 30 times more demanding** with respect to what expected in SIDDHARTA.

4.5.2 Trigger test for an incident rate ~ 60 Hz with the Fe and Sr sources

In order to perform a first test of the trigger performance applied to SDDs installed at BTF, the following series of measurements was performed:

1) a measurement lasting 16 hours (23-24/07/2003), without the Fe and Sr sources (**No asynchronous background**), with the "signal" given by the Cu lines, with TRIGGER ON (AND); a coincidence rate for the array of 7 SDDs of about 5 Hz was measured (Figure 20 a));
2) a measurement lasting 20 minutes (24/07/2003), with the Fe and Sr sources, with the "signal" given by the Cu lines, with TRIGGER OFF (OR); an incident rate on SDDs of about 60 Hz was measured (Figure 20 b));
3) a measurement lasting 16 hours (23-24/07/2003), with the Fe and Sr sources as in the previous measurement, with the "signal" given by the Cu lines, with TRIGGER ON (AND); a coincidence rate for SDDs of about 5 Hz was measured (Figure 20 c)).

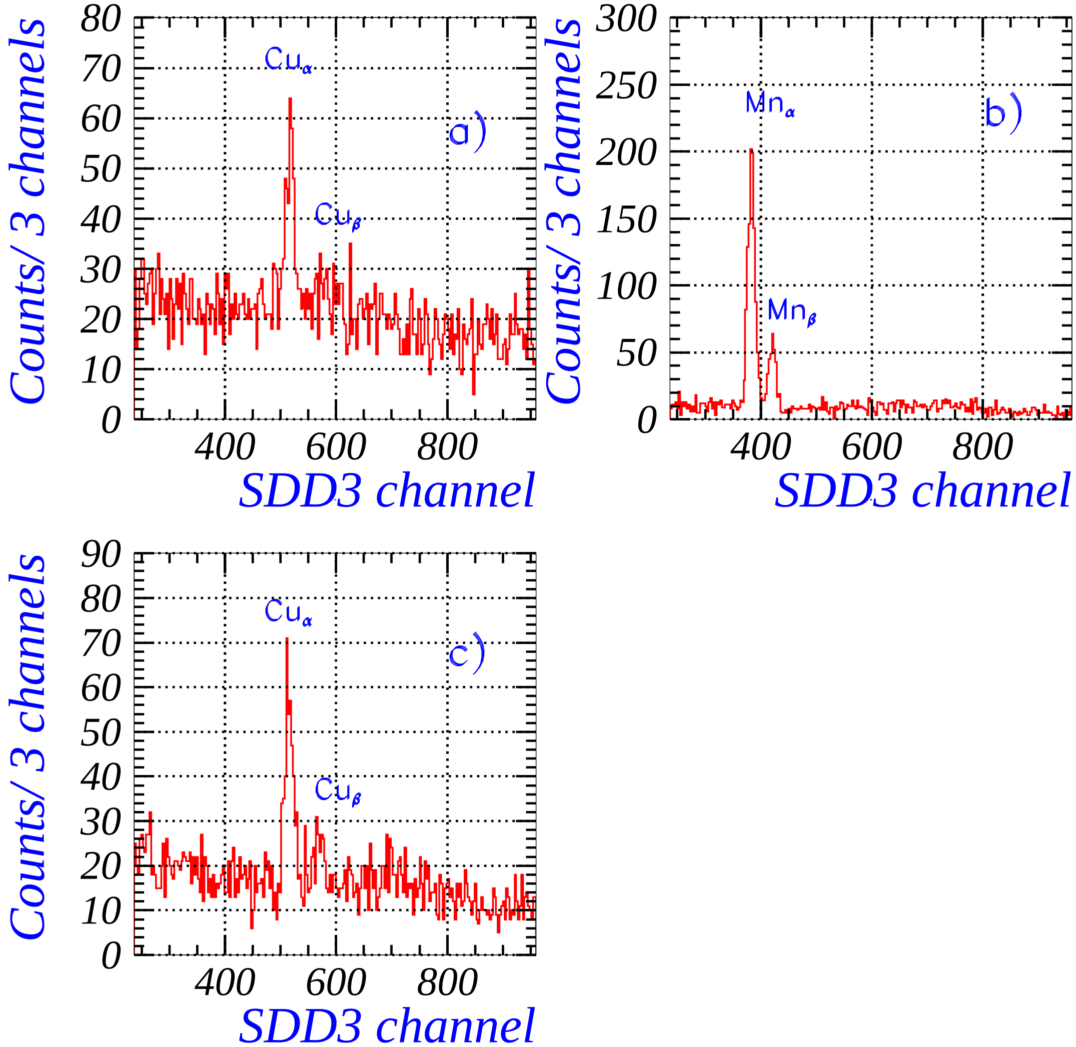


Figure 20: Test of the trigger performance for the SDD3; a) spectrum for a measurement lasting 16 hours (23-24/07/2003), without sources (only synchronous background), with the BTF beam exciting a Cu plate near the SDDs ("signal"); TRIGGER ON (AND); a rate of about 5 Hz on the array of 7 SDD was measured; b) spectrum for a measurement lasting 20 minutes (24/07/2003), with the Fe and Sr sources (asynchronous background), with the BTF beam exciting a Cu plate near the SDDs; TRIGGER OFF (OR); an incident rate on the SDDs of about 60 Hz was measured; c) spectrum for a measurement lasting 16 hours (23-24/07/2003), with the Fe and Sr sources as in b), with the BTF beam exciting a Cu plate near the SDDs ; TRIGGER ON (AND); a coincidence rate on SDDs of about 5 Hz was measured

As it can be seen from the figures, the spectra in Fig. 20 a) and 20 c) are identical (in the limits of BTF variations). The first one was obtained without the Fe and Sr sources, i.e. without asynchronous background, with trigger on (AND), and is used to have a normalization, while the second one was obtained with the Fe and Sr sources, i.e. in presence of asynchronous background, using trigger, which, as seen from the Figure, completely cut the background (structured and unstructured) given by asynchronous sources. The spectrum with the asynchronous background sources without trigger is shown in Figure 20 b). In this spectrum the Mn lines (Fe source), as well as a continuous background (Sr source) are clearly visible. The Copper lines and the continuous background in Fig. 20 a) and c) can be considered respectively as the "signal" and as the synchronous background (i.e. generated by the same signal as the one giving the trigger). The synchronous background cannot obviously be eliminated by the trigger, as shown by both figures. One thing worth to be mentioned, is that in the energy range in which SDDs are sensible for this test (1–20 keV) only about 10% of the overall incident particles are detected; all the remaining ones, depositing more energy, are counted as overflows.

Let's now give a quantitative estimation of the results.

Reduction of the asynchronous background (structured (Mn) and unstructured (continuous))

The analysis of the spectra shown in Figure 20 shows that the spectra in Figure 20 a) and 20 c) are basically ***identical***. The first one was obtained without asynchronous background, with trigger on (AND), with a time window of 1 μs, while the second one is obtained in the presence of asynchronous structured (Mn) and unstructured (continuous) background, same trigger as before. The asynchronous background, shown in Figure 20 b), where no trigger was activated, is completely cut by the trigger, while no good event is lost.

Numerically:

a) Asynchronous structured and continuous incident background:

R_B = 60-5 = 55 Hz **(1)**

b) Trigger rate from BTF facility:

R_t= 50 Hz **(2)**

c) Coincidence window:

C_w = 1μs **(3)**

d) "Good" synchronous event rate:

Ev_{rate} = 5 Hz **(4)**

out of which the number of "signal" events, the Cu K_α event, is:

S = 300 events in 16 hours on one SDD (5)

e) Efficiency for production of one good event, i.e. number of events /number of triggers:

Eff = Ev_{rate}/ R_t = 5/50 = 1/10 **(6)**

so one "signal" event for 10 triggers;

f) Casual background event rate after trigger:

$R_{casual} = 50 \times 55 \times 10^{-6} = 2.75 \times 10^{-3}$ Hz **(7)**

With these numbers, one can calculate the ***trigger rejection factor R***, by applying three complementary methods, giving of course the same result:

i) **$R = R_{casual} / R_B = 2.75 \times 10^{-3} / 55 = \underline{5 \times 10^{-5}}$** **(8)**

ii) **$R = (S/B)_{off} / (S/B)_{on} = (5/55) / (5/2.75 \times 10^{-3}) = \underline{5 \times 10^{-5}}$** **(9)**

iii) **R = (Acquisition time of backg/event) $_{trigger\ on}$/(Acquisition time of backg/event) $_{trigger\ off}$ = (Nr. Trigger/ev)$_{on}$ x C_w / (1/Ev_{rate}) = $10 \times 10^{-6} / 0.2 = \underline{5 \times 10^{-5}}$** **(10)**

Conclusion 1:

For a total incident rate of 60 Hz on 7 channels (7 SDDs) with a total surface of 35 mm^2, the rejection factor measured at BTF, when the trigger rate is 50 Hz and the triggered good event rate 5 Hz, with the trigger coincidence window of 1 μs, is <u>5 x 10^{-5}</u>

4.5.3 Trigger test for an incident rate 1000 Hz with the Fe and Sr sources

With the same setup used for the previous test, but getting the Sr source closer (to have a higher rate) the trigger performance was re-checked by two measurements:

1) a measurement lasting 18 minutes (25/07/2003), with the Fe and Sr sources, with the BTF beam exciting a Cu plate near the SDDs, with the TRIGGER OFF (OR); an incident rate on SDDs of about 1000 Hz was measured (Figure 21 a));

2) a measurement lasting 12 hours and 40 minutes (25-26/07/2003), with the Fe and Sr sources, with the BTF beam exciting a Cu plate near the SDDs, with the TRIGGER ON (AND); a coincidence rate on SDDs of about 5 Hz was measured (Figure 21 b));

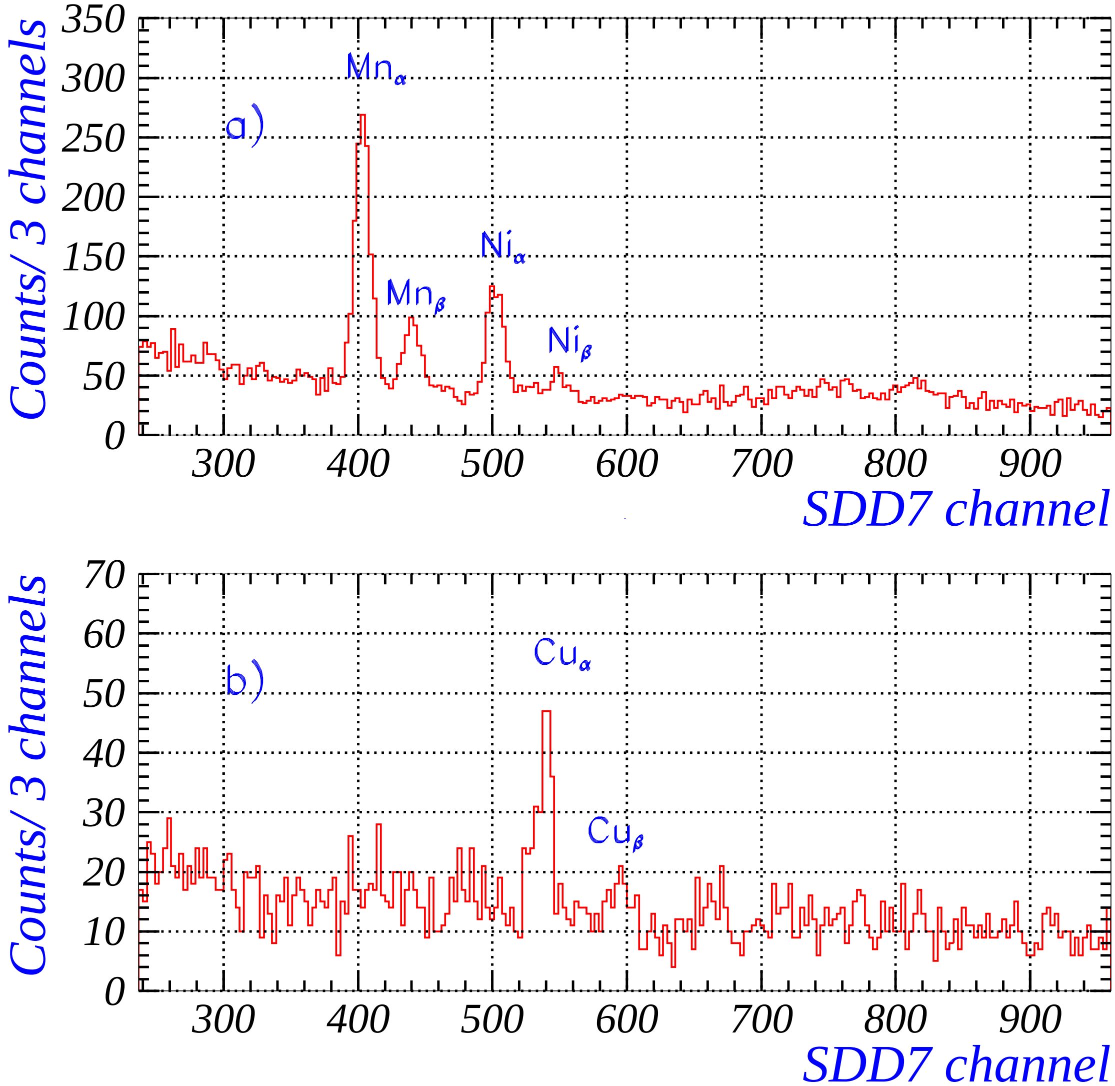


Figure 21: Test of the trigger performance for an incident rate of about 1000 Hz; a) spectrum for a measurement lasting 18 minutes (25/07/2003), with Fe and Sr sources, giving the asynchronous background, with the BTF beam exciting a Cu plate near the SDDs, representing the "signal", with the TRIGGER OFF (OR); an incident rate on SDDs of about 1000 Hz was measured; Ni peaks are excited by the Sr source – asynchronous background; b) spectrum for a measurement lasting 12 hours and 40 minutes (25-26/07/2003), with the Fe and Sr sources, with the BTF beam exciting a Cu plate near the SDDs, with the TRIGGER ON (AND); a coincidence rate on SDDs of about 5 Hz was measured.

A first observation is the fact that the spectrum obtained with trigger (Figure 21 b)) is the same one as in Figure 20 c) – i.e. the one obtained with trigger and incident rate 60 Hz on 7 SDDs area. This means that trigger works as well for an incident rate of a factor about 15 higher, completely cutting the asynchronous background while no event is lost. The asynchronous background, continuous and structured (Mn and Ni – excited by Sr) is clearly visible in Figure 21 a) where no trigger is active and is disappearing imposing the trigger condition as shown in Figure 21 b).

Lets' now give a quantitative estimation of the results.

Reduction of the asynchronous background (structured (Mn) and unstructured (continuous))

The analysis of the spectra shown in Figure 21 b) and Figures 20 a) shows that they are (normalized) basically ***identical***. The first one was obtained ***with*** asynchronous structured (Mn) and unstructured (continuous) background, with trigger on (AND), with a time window of 1 μs, with an incident rate of 1000 Hz, while the second one ***without*** asynchronous background, with the same trigger as before. The asynchronous background, shown in Figure 21 a) – where no trigger was used, is completely cut by the trigger condition.

Numerically:

a) Asynchronous structured and continuous incident background:

$\mathbf{R_B = \sim 1000\ Hz}$ **(11)**

b) Trigger rate from BTF facility:

$\mathbf{R_t = 50\ Hz}$ **(12)**

c) Coincidence window:

$\mathbf{C_w = 1 \mu s}$ **(13)**

d) "Good" synchronous event rate:

$\mathbf{Ev_{rate} = 5\ Hz}$ **(14)**

out of which the number of "signal" events, the Cu K_α events, is:

S = 250 events in 12 hours 40 min on one SDD (15)

e) Efficiency for good event production, i.e. number of events /number of triggers:

$\mathbf{Eff = Ev_{rate} / R_t = 5/50 = 1/10}$ **(16)**

so one "signal" event for 10 triggers;

f) Casual background event rate after trigger:

$$\mathbf{R_{casual} = 50 \times 1000 \times 10^{-6} = 5 \times 10^{-2}\ Hz} \qquad \mathbf{(17)}$$

With these numbers, one can calculate the ***trigger rejection factor R***, by applying three complementary methods:

i) $$\mathbf{R = R_{casual} / R_B = 5 \times 10^{-2} / 1000 = \underline{5 \times 10^{-5}}} \qquad \mathbf{(18)}$$

ii) $$\mathbf{R = (S/B)_{off} / (S/B)_{on} = (5/1000) / (5/5 \times 10^{-2}) = \underline{5 \times 10^{-5}}} \qquad \mathbf{(19)}$$

iii) $$\mathbf{R = (Acquisition\ time\ of\ backg/event)_{trigger\ on} / (Acquisition\ time\ of\ backg/event)_{trigger\ off} =}$$
$$\mathbf{(Nr.\ Trigger/ev)_{on} \times C_w / (1/Ev_{rate}) = 10 \times 10^{-6} / 0.2 = \underline{5 \times 10^{-5}}} \qquad \mathbf{(20)}$$

Conclusion 2:

For a total incident rate of 1000 Hz on 7 channels (7 SDDs) with a total surface of 35 mm^2, the rejection factor measured at BTF, when the trigger rate is 50 Hz and the event rate 5 Hz, with the trigger coincidence window of 1 μs, is <u>5 x 10^{-5}</u> .

The rejection factor is independent on the incident background frequency, since accordingly the number of casuals is changing.

Since it will be used at a later stage (4.6), we calculate the **Mn K_α rate with trigger off:**

$$\mathbf{Rate\ Mn\ K_\alpha\ with\ trigger\ off = 1800 / 18\ min = \sim 1.7\ Hz} \qquad \mathbf{(21)}$$

4.5.4 Trigger test for a multitarget setup

Finally, the trigger test was repeated using the Sr source for asynchronous background and a multi-material target to simulate the "signals" (i.e. fluorescence X rays). The multi-material target contained: Iron, Copper and Zirconium. The measurements performed were:

1) a measurement lasting 16 hours and 20 minutes (28-29/07/2003), without sources, with the BTF beam exciting the multi-material target near the SDDs, with the TRIGGER ON (AND); a coincidence rate of about 10-12 Hz for 7 SDDs was measured (Figure 22);

2) a measurement lasting 20 minutes (31/07/2003), with Sr source, with the BTF beam exciting the multi-material target near the SDDs, with the TRIGGER OFF (OR); a rate of about 900 Hz for 7 SDDs was measured (Figure 23);

3) a measurement lasting 20 hours and 30 minutes (30-31/07/2003), with the Sr source, with the BTF beam exciting the multi-material target near the SDDs, with the TRIGGER ON (AND); a coincidence rate of about 10 Hz for 7 SDD was measured (Figure 24).

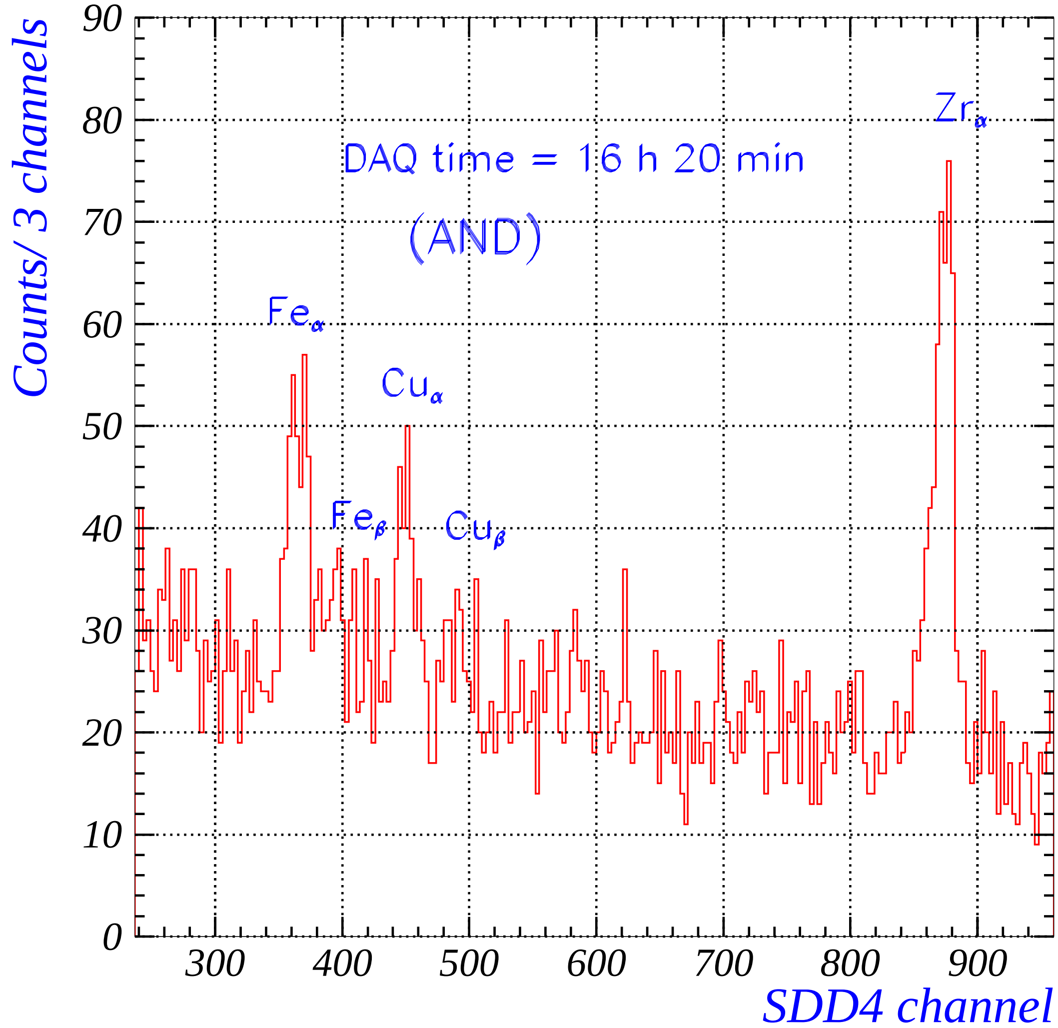


Figure 22: Spectrum corresponding to SDD4 in a measurement lasting 16 hours and 20 minutes (28-29/07/2003), without sources, with the BTF beam exciting the multi-material target near the SDDs, with the TRIGGER ON (AND); a coincidence rate of about 10-12 Hz for 7 SDDs was measured; Fe, Cu and Zr lines are excited by the products of the shower generated by the BTF beam, representing the “signal”.

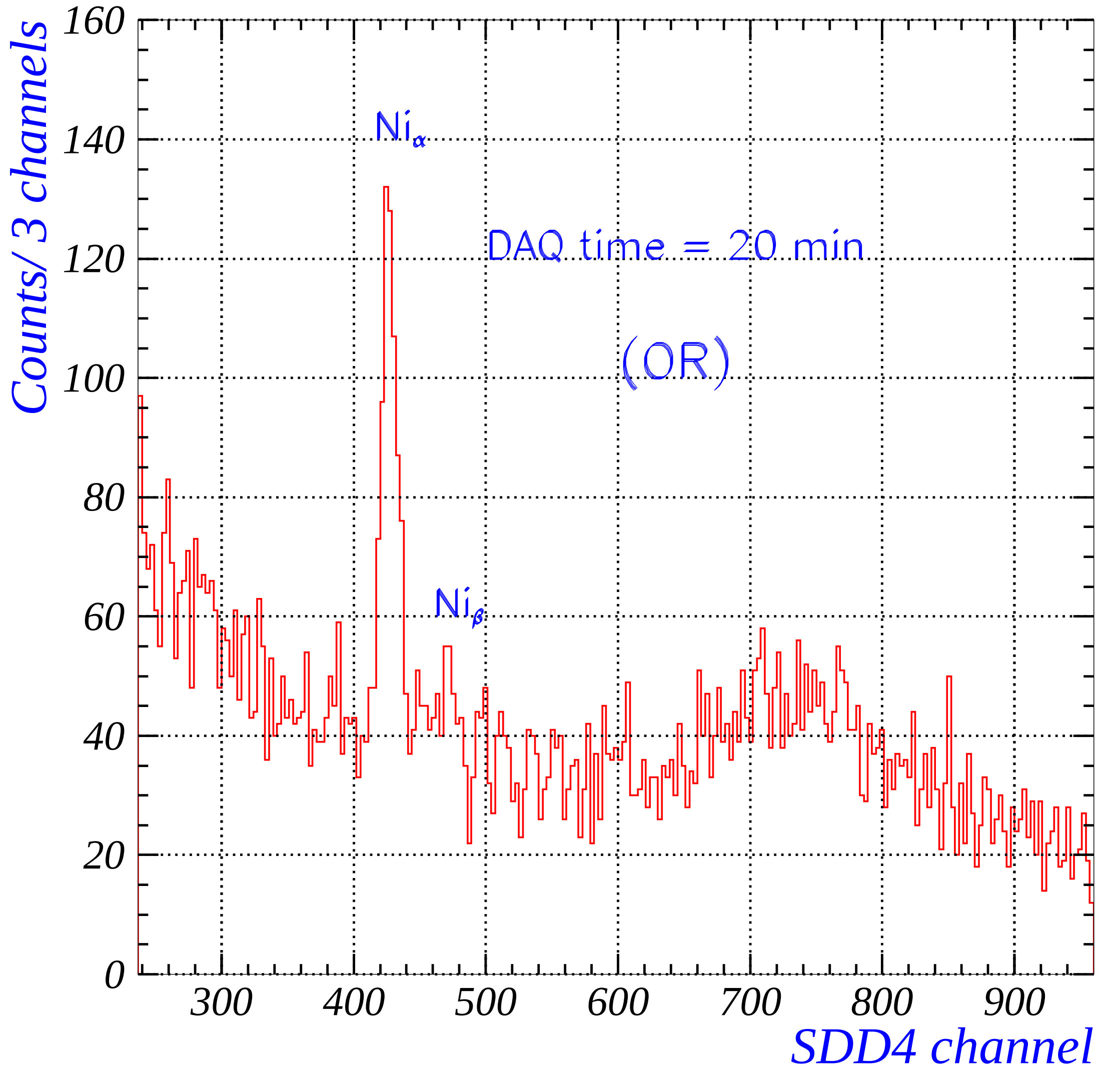


Figure 23: Spectrum corresponding to SDD4 in a measurement lasting 20 minutes (31/07/2003), with the Sr source, with the BTF beam exciting the multi-material target near the SDDs, with the TRIGGER OFF (OR); a rate of about 900 Hz for 7 SDDs was measured; Ni is excited by Sr – so it represents asynchronous background.

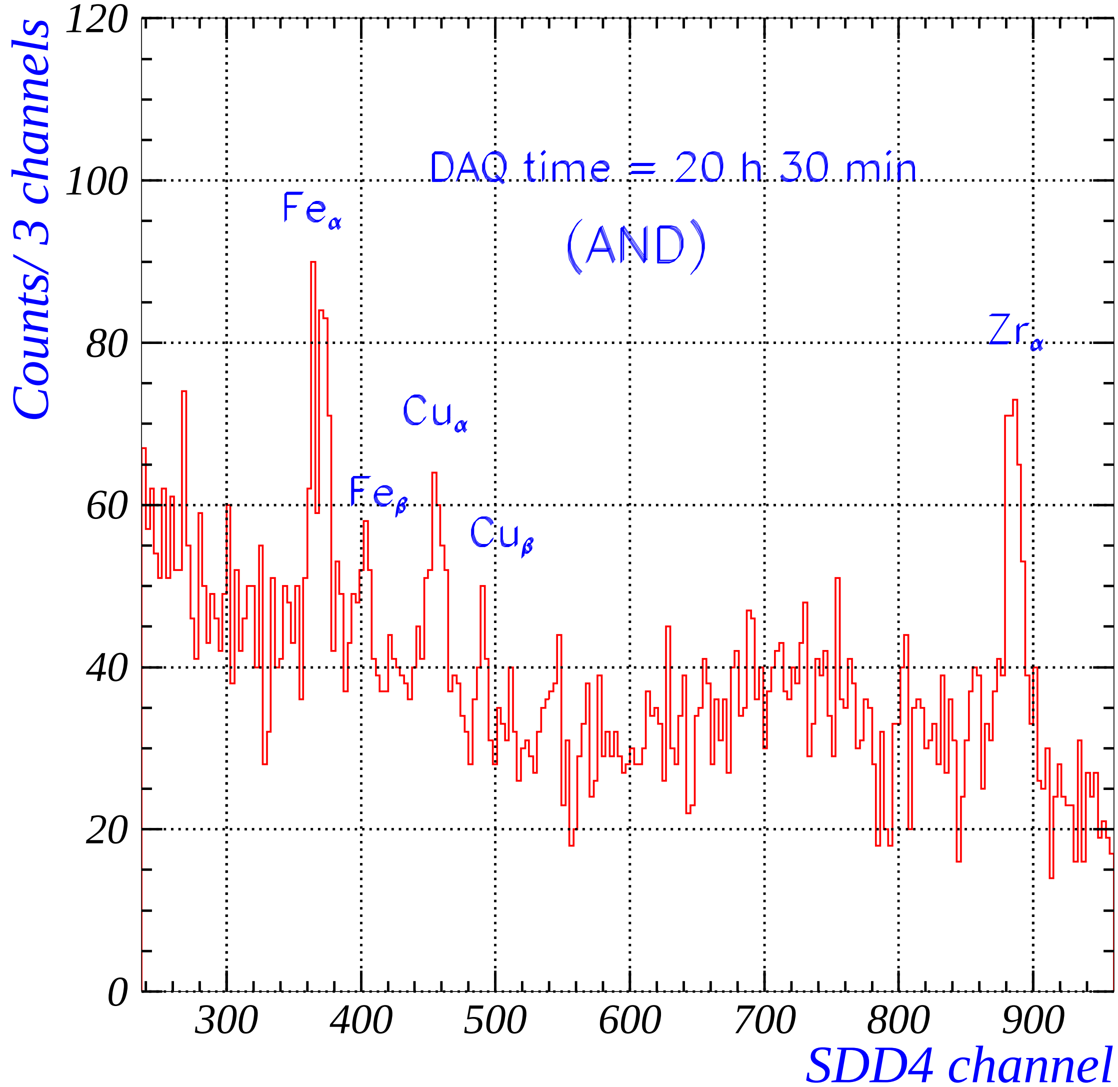


Figure 24: Spectrum corresponding to SDD4 in a measurement lasting 20 hours and 30 minutes (30-31/07/2003), with the Sr source, with the BTF beam exciting the multi-material target near the SDDs, with the TRIGGER ON (AND); a coincidence rate of about 10 Hz for 7 SDDs was measured; Fe, Cu and Zr are excited by the BTF beam.

The spectra in Figure 22 and 24, normalized to the same duration, are almost identical; the trigger condition eliminates the asynchronous background, continuous and structured (Ni) – presented in Figure 23, where no trigger was used - without loss of good events. The synchronous background could not obviously be eliminated.

The conclusions, in terms of background reduction, are identical to those derived at 4.5.2 (same rate of incident particles and same amount of Cu lines).

In this case, however, there are more than one signal possible: Fe, Cu and Zr lines, and it is proved that **the trigger is able to handle a multi-signal, i.e. K-complex, structure**.

4.5.5 Test of the trigger with different time window

A test concerning the trigger performance when the time window for the coincidence is increased from 1 to 130 μs was as well performed. This was realized by increasing the width of the signal of the thin scintillator hit by the BTF beam (see Fig. 8 b)). This test was performed as **an alternative of the increase of the incident background rate** (in fact, with the Sr and Fe sources at disposal 1000 Hz was the upper limit). The choice of the factor of increasing the time window was done in the following way: the goal was to perform a measurement in which "signal" (Cu K_α) and background (Mn K_α) lines were nearly at the same level. This in fact represents a measurement of the threshold, in terms of incident background rate, at which the trigger starts to include asynchronous background in the spectrum, the previous tests being only able to establish lower limits for this threshold. The setup was basically the same, the Sr source was positioned so to have an incident rate of 500 Hz, while the Iron source was left the same as in the previous measurements. The measurement lasted 14 hours (26 – 27/07/03) and the measured coincidence rate on 7 SDDs was about 8 Hz. The measured spectrum is shown in Figure 25.

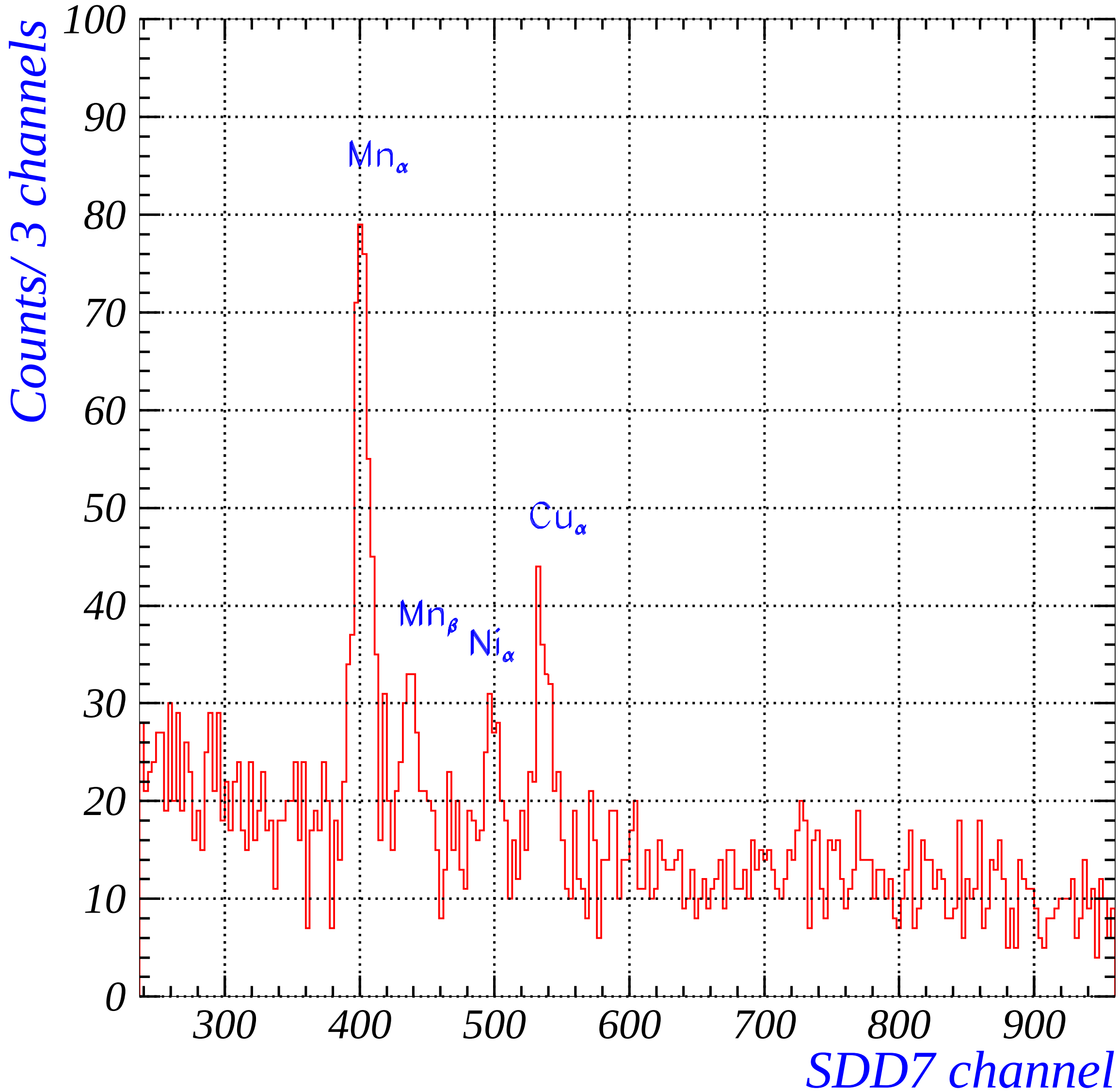


Figure 25: Spectrum corresponding to a measurement lasted 14 hours (26 – 27/07/03) , with a coincidence measured rate on 7 SDDs of about 8 Hz. The measurement was performed with TRIGGER ON, with a coincidence time window enlarged to 130 μs, with a setup with Cu plate near SDD, with the Fe and Sr sources.

The spectra in Figure 25 must be compared with the one in Figure 21 b), obtained in similar conditions (incident rate 1000 Hz, rate in coincidence about 5 Hz), but with a trigger window of 1 μs; the conclusion is that the aim to insert in the spectrum Mn and Ni lines (asynchronous structured background) at a level comparable with the signal, to check the limit of the trigger, was ***successful***.

Let's now give a quantitative estimation of the performed test:

4.5.5.1 Calculated versus measured number of Fe events

The test performed at a total incident rate of about 500 Hz, with an increased coincidence window, showed that the asynchronous background contribution starts to be important if the coincidence window is opened at 130 μs: for this experimental condition the structured asynchronous background is at the same level as the signal: Mn and Ni background are more or less the same as the "signal", i.e. Cu lines.

Numerically:

a) Asynchronous structured and continuous incident background:

R_B = 500 Hz **(22)**

b) Trigger rate from BTF facility:

R_t= 50 Hz **(23)**

c) Coincidence window:

C_w = 130 μs **(24)**

d) Calculated number of Fe events for Fig. 25, starting from (21)

N calc $_{Fe}$ = 1.7 Hz x 50 x 130 x 10-6 x 14 hours = ~ <u>560 events</u> **(25)**

Which compares very well with the

e) Measured number of Fe events in Fig. 25

N measured $_{Fe}$ = ~ <u>600 events</u> **(26)**

Conclusion 3:

For a total incident rate of 500 Hz on 7 channels (7 SDDs) with a total surface of 35 mm^2, , when the trigger rate is 50 Hz, with the trigger coincidence window of 130 μs, the number of measured Mn background events is the same, as the calculated one, proving that we understood well the trigger handling.

5. Conclusions

The main goal of the tests done at BTF with a test setup containing a prototype SDD array containing 7 SDD detectors, 5 mm^2 each, was to prove in realistic conditions the performance of (small area) SDDs, in particular under trigger conditions, never performed before. Timed SDDs are the X-ray detectors of the new Project SIDDHARTA. The main conclusion is that the tests were successful and the goal was achieved.

The tests were performed in the period 21st – 31st July 2003, and the main results are:

- measurement of **SDD energy resolution at 6 keV** in the BTF Hall: the best value is **175 eV –** with a preliminary electronics and without temperature control;
- **stability of the energy calibration** was checked up to a level of **0.5 %;**
- **linearity of the scale**: SDD channel versus energy **–** was checked up to **0.8 % at 6 keV**;
- **trigger** was tested for variuos geometries, incident rates and time windows: all tests shown that trigger **works very well**: no signal is lost and for **the asynchronous background is completely cut**.

6. Future plans

Presently, tests of large area (1 cm^2) SDD chips, built by MPE Munchen, are undergoing in the Politecnico Milano.

In Figure 26 a picture of this large area SDD, analogous to those which will be produced for SIDDHARTA, is shown, while in Figure 27 first laboratory test results are presented.

All these chips will be tested on BTF.

Finally, after refining – within the next 2-3 months – the final design parameters, the production run of the SDD to be used in SIDDHARTA will start.

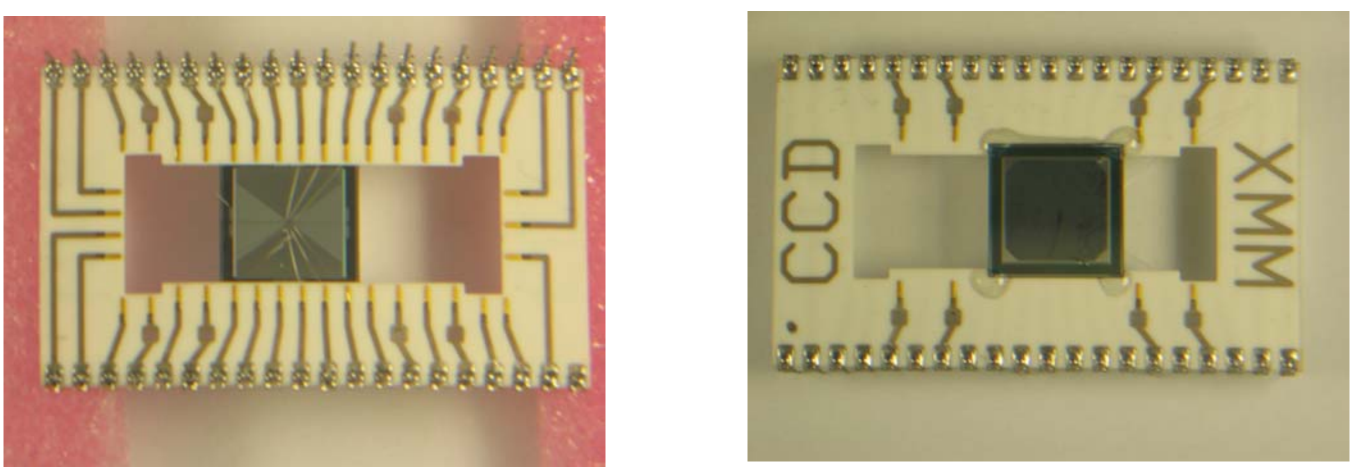
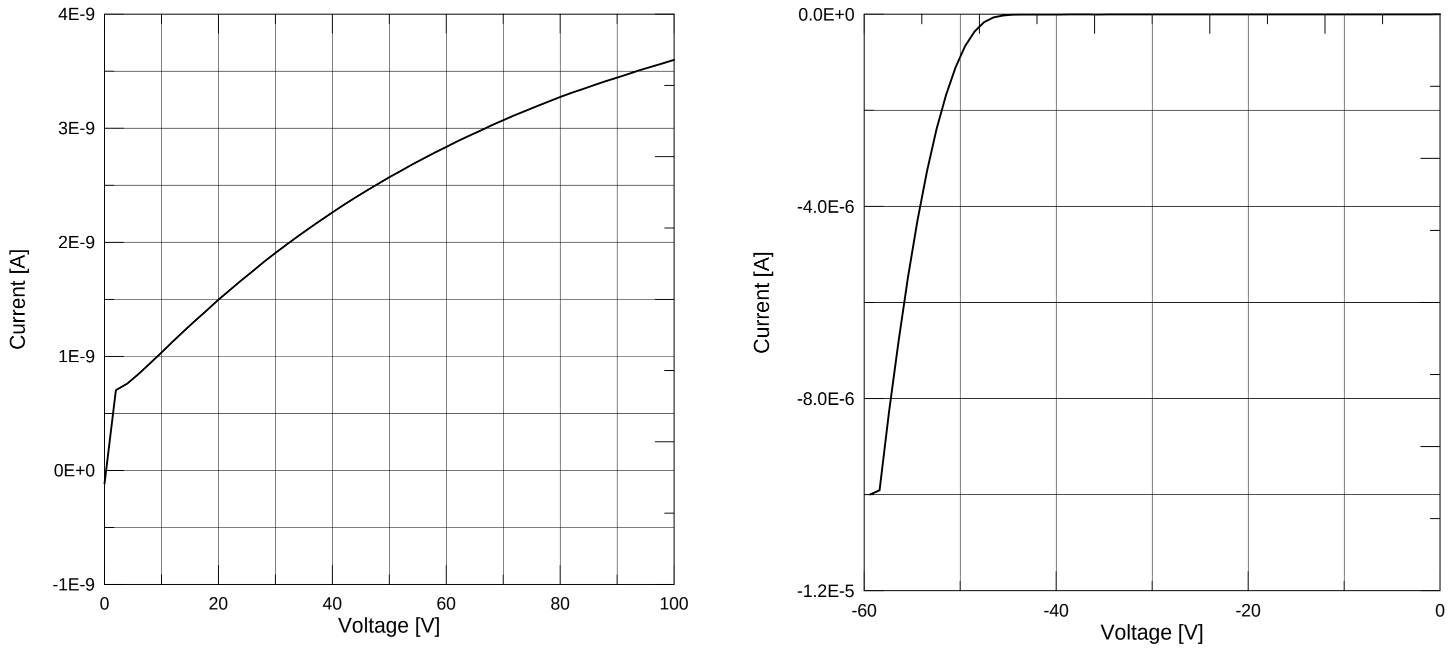


Figure 26: Picture of large SDD area (1 cm^2)



Leakage current ~ 3 nA @ room T

Voltage divider threshold voltage ~ -50V for 8 rings (⇒ 65 rings bias should be feasible with ~ - 400V)

Figure 27: Results of first tests of large SDD area in the Politecnico Milano laboratory.

7. Bibliography

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