ENERGY CALIBRATION OF TIMEPIX PIXELS BELOW 60 keV

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Abstract: Timepix detector is a position sensitive pixel detector, which consists of a semiconductor detector chip (usually 300 μm thick silicon) bump-bonded to a readout chip. The detector chip is equipped with a single common backside electrode and a front side matrix of electrodes (256 x 256 square pixels with pitch of 55 μm). Each element of the matrix (pixel) is connected to its respective preamplifier, discriminator and digital counter integrated on the readout chip. The response of each pixel is proportional to the energy/charge deposited in it.

Energy calibration of Timepix detector was made in energy region from 0 to 60 keV with x-rays. Only one-pixel events were used. A set of 12 OSGI sources was tested for obtaining x-ray transitions in the desired energy region. It was found that ^{60}Co and ^{137}Cs sources do not have such transitions. Other sources have one or two transitions. Preliminary energy calibration of the detector was made using events from the whole area of it. Four sources ^{109}Cd, ^{133}Ba, ^{152}Eu and ^{241}Am were chosen for longtime measurements. Longtime measurements were performed using time from 19 to 263 hours. Determination of positions of 7 transitions was made in pixels of the detector. Not in all pixels this determination could be made. Hypothesis for function of calibration was invented which has six parameters. These parameters were found for the most number of pixels. Energy spectra of four sources were obtained from the whole area of the detector using the obtained matrix of parameters.

1. Introduction

The hybrid pixel device Timepix [1] was developed at CERN by Medipix collaboration. It is based on its predecessor Medipix2. The device consists of a semiconductor detector chip from Si, GaAs or CdTe with thicknesses: 300, 700 or 1000 μm bump-bonded to a readout chip. The detector chip is equipped with a single common backside electrode and a front side matrix of electrodes (256 x 256 square pixels with pitch of 55 μm). Each element of the matrix (pixel) is connected to its respective preamplifier, discriminator and digital counter integrated on the readout chip. This device can register different types of particles which give charge in volume of a detector and matrix of pixels can give position, track or area of registered event. More detailed description of possibilities of Timepix detectors using can be seen in two presentations [2,3].

Timepix uses a high frequency clock with frequency up to 80 MHz as time/clock reference for per-pixel energy or per-pixel time measurements. Each pixel of the Timepix detector can be independently configured to run in one of four different operating modes [4]: (1) Masked mode: pixel is off, (2) Counting mode: 1-count for each signal over threshold (the counter is incremented by one when the energy of the interacting particle crosses the preset threshold level), (3) Time-over-Threshold (ToT) or energy mode: the counter is incremented continuously as long as the signal is above threshold (the counter is used as Wilkinson type ADC allowing direct energy measurement in each pixel), and (4) Time-of-arrival (ToA) or time mode: the counter is incremented continuously from the time the first hit arrives until the closure of the shutter (end of the time window or acquisition exposure).

A single particle often creates signal as almost round spot. It is because the charge created by the particle is spreading out during the charge collection process and it can be finally collected by several adjacent pixels forming the cluster. As the charge collection speed depends on applied bias voltage the cluster size (number of pixels in the cluster) also depends on that voltage. In addition cluster size depends on the energy of registered particle. Therefore information about energy can be obtained from cluster size.

If all pixels of Timepix detector are configured to run in ToT mode of operating one can obtain the total charge in cluster by summation of all fractional charges from each pixel i.e. by determination of the cluster volume.

As each pixel has own preamplifier parameters of amplification in circuits are different and in ToT mode cluster volumes from particles with the same energy will differ in different positions of the detector. To overcome this trouble each pixel should be individually calibrated. Thus differences in amplification will be corrected.

Timepix detector gives different response to different particles. X-rays induce a small number of pixels and charge particles can excite big clusters according to energy of particles. For energy calibration in different energy regions different particles must be used.

In measurements with Medipix detectors a sequence of frames from exposition during some preset time window are registered. There are events of different types of charge particles on frames and after measurements events of desired types must be chosen and analyzed.

In this work pixels of silicon Timepix detector with a thickness of 300 μm were calibrated by x-rays from an OSGI set of γ-radiation. As the boundary of sensitivity of silicon detector with a thickness of 300 μm is about 60 keV calibration was provided up to this energy.

2. Experiment

Silicon Timepix detector with name L07 had thickness 300 μm. Bias 100 V was chosen for calibrating by x-rays from γ-sources. There is a preset parameter in Timepix detector circuit – IKRUM. This parameter sets a time window in which the pulse from charge in a pixel is processed. If this window is wide more full charge collection in pixels occurs, if it is narrow the resulting charge will be smaller. IKRUM=1 gives the most wide window in which the pulse is processed. For these measurements the parameter IKRUM=1 was chosen. X-rays produce small clusters in Timepix detector – from 1 pixel to 4 pixels. Only one-pixel clusters were used for the calibration.

There are 12 isotopes in the OSGI calibration OSGI γ-ray set: ^{152}Eu, ^{133}Ba, ^{54}Mn, ^{88}Y, ^{109}Cd, ^{139}Ce, ^{60}Co, ^{57}Co, ^{228}Th, ^{241}Am, ^{113}Sn and ^{137}Cs. In the first measurements the spectra of volumes of one-pixel clusters from the whole area of the Timepix detector for each source of the calibration set were obtained. Each spectrum was measured in the same live time 100 s. Sources ^{60}Co and ^{137}Cs are not useful for calibration as long as there are no peaks in their spectra lower 60 keV. There are some peaks in spectra of other sources. At the next step energy calibration was obtained using peaks from these spectra. Positions and energies of peaks used for calibration are shown in Tab.1. Calibration according to positions and energies of peaks from Tab.1 is shown in Fig.1. It can be seen that from 13 to 60 keV curve of calibration is likely as straight line.

Now it must be formulated what steps are needed to obtain result of calibration of Timepix detector. Positions and energies of some number of peaks must be obtained for

Table 1. Information for energy calibration from spectra of OSGI sources.

Position	E_γ (keV)	N_m *)	Isotope
5.5	3.29	284	^{113}Sn
15.0	4.29	3192	^{133}Ba
6.5	4.65	263	^{139}Ce
22.5	5.415	6274	^{54}Mn
22.5	5.64	7804	^{152}Eu
26.5	6.40	3230	^{57}Co
45.0	12.3	4380	^{228}Th
52.0	13.9	13784	^{241}Am
51.0	14.15	69	^{88}Y
51.0	14.41	534	^{57}Co
65.0	22.16	65730	^{109}Cd
68.0	24.2	45	^{113}Sn
79.0	30.9	6646	^{133}Ba
80.0	33.44	26	^{139}Ce
93.0	40.11	1915	^{152}Eu
125.0	59.54	184	^{241}Am

*) – N_m –count in the maximum of peak

each pixel of Timepix detector. For this one must choose some number of sources and measure spectra from these sources sufficient time to find the peak positions in each pixel. It is seen from Tab.1 that ^{109}Cd source is the most intensive from our OSGI set. This source was included in the list of sources for long measurements. Other source which must be included is ^{241}Am as the spectrum from this source has peak about 60 keV – the highest energy in Tab.1. Two more sources were chosen for the measurements: ^{133}Ba and ^{152}Eu. These 4 sources give 7 peaks in the whole region of sensitivity of silicon Timepix detector. Some information about longtime measurements is shown in Tab.2. Energies of peaks which positions should be determined are demonstrated in the fifth column of Tab.2.

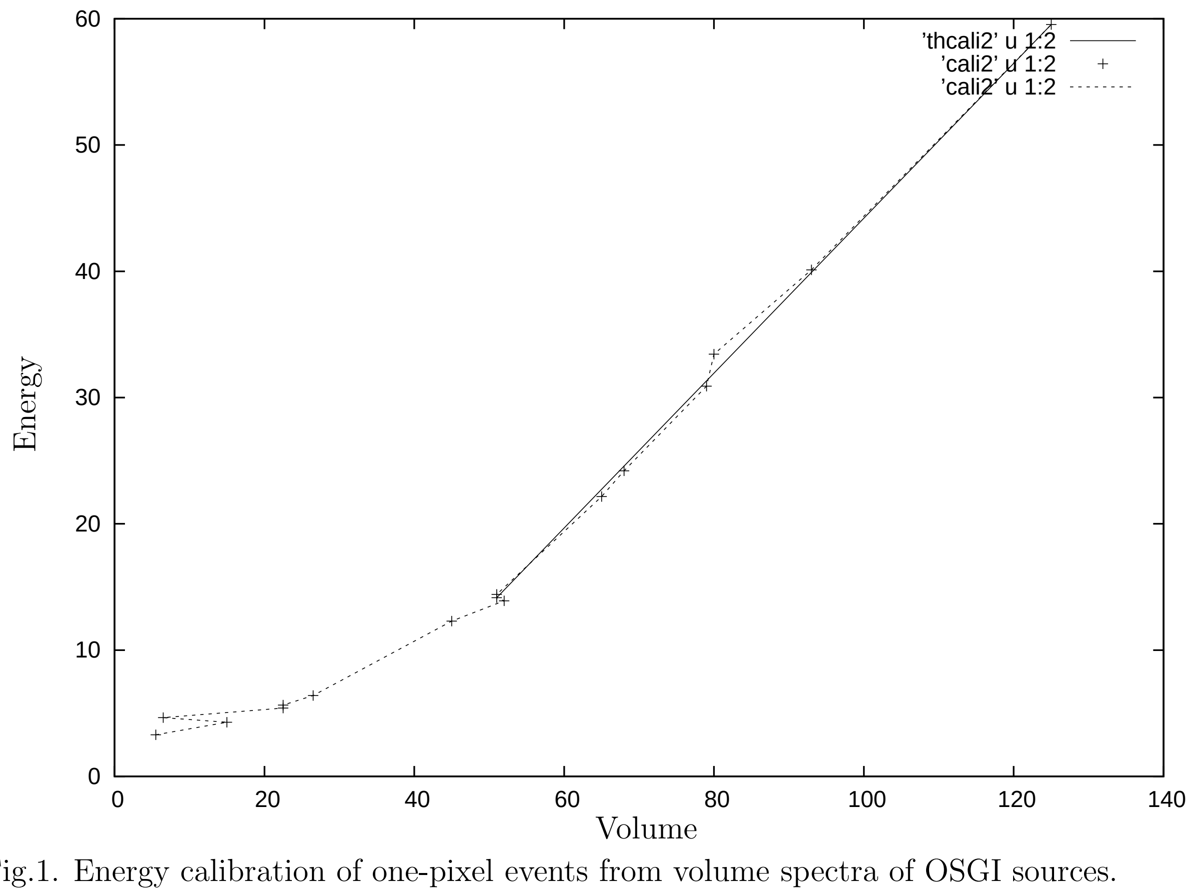

Fig.1. Energy calibration of one-pixel events from volume spectra of OSGI sources.

Table 2. Information about longtime measurements

Source	Time of frame (s)	Full time	Number of frames	E_γ (keV) of peaks
^{109}Cd	0.02000	19 hours	1092233	22.16
^{133}Ba	0.05000	23 hours	969155	4.29, 30.9
^{152}Eu	0.05000	49 hours	1961670	5.64, 40.11
^{241}Am	0.10000	263 hours	6579984	13.9, 59.54

3. Processing of data

At the first step of data analysis spectra with full statistics of volumes of one-pixel events from the whole area of Timepix detector for four sources were obtained and are shown in Figs.2-5.

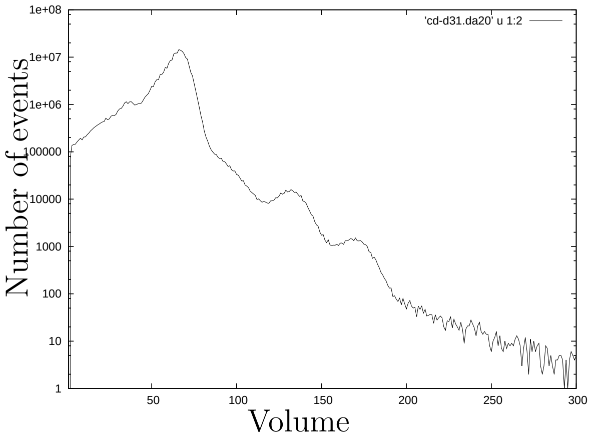

Fig.2. Volume spectrum of one-pixel events from ^{109}Cd source from the whole area of the detector with 22.16 keV transition

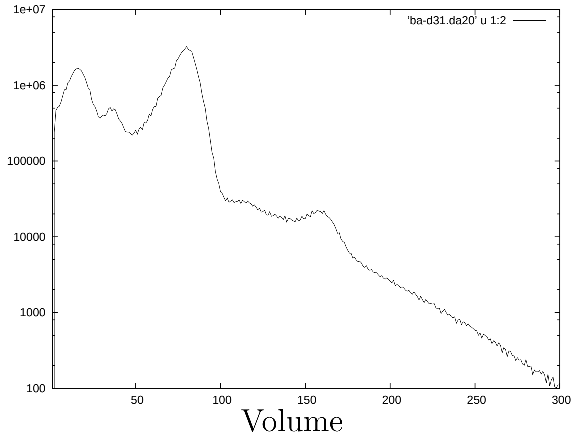

Fig.3. Volume spectrum of one-pixel events from ^{133}Ba source from the whole area of the detector with 4.29 keV and 30.90 keV transition

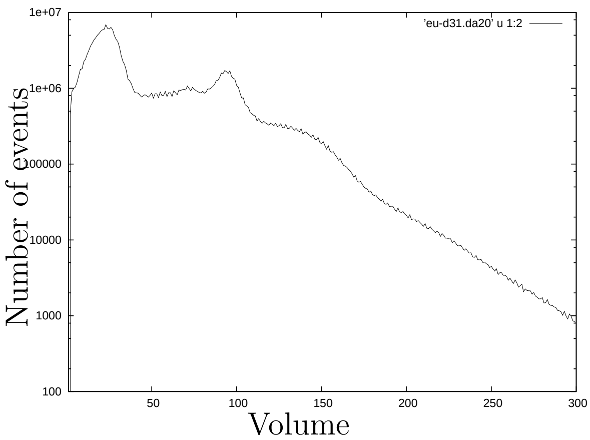

Fig.4. Volume spectrum of one-pixel events from ^{152}Eu source from the whole area of the detector with 5.64 keV and 40.11 keV transition

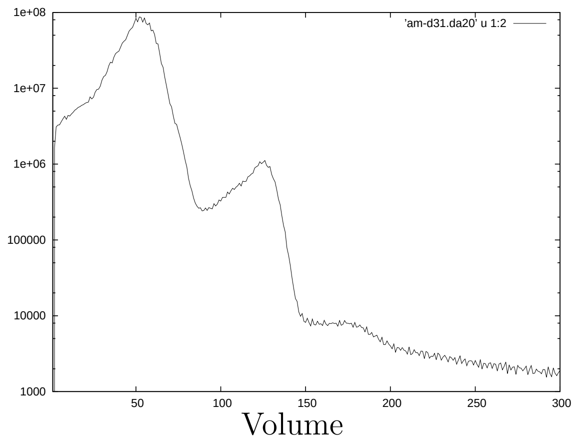

Fig.5. Volume spectrum of one-pixel events from ^{241}Am source from the whole area of the detector with 13.90 keV and 59.54 keV transition

Furthermore spectra of 65536 pixels have been obtained and positions of desired peaks have been found. Initially spectra from ^{109}Cd source were analyzed. Spectra from all pixels are shown in Fig.6. It is seen that spectrum from one pixel is wrong and doesn't have information about peak position. In addition it is seen that in some pixels there are noises in the low channels with different intensity.

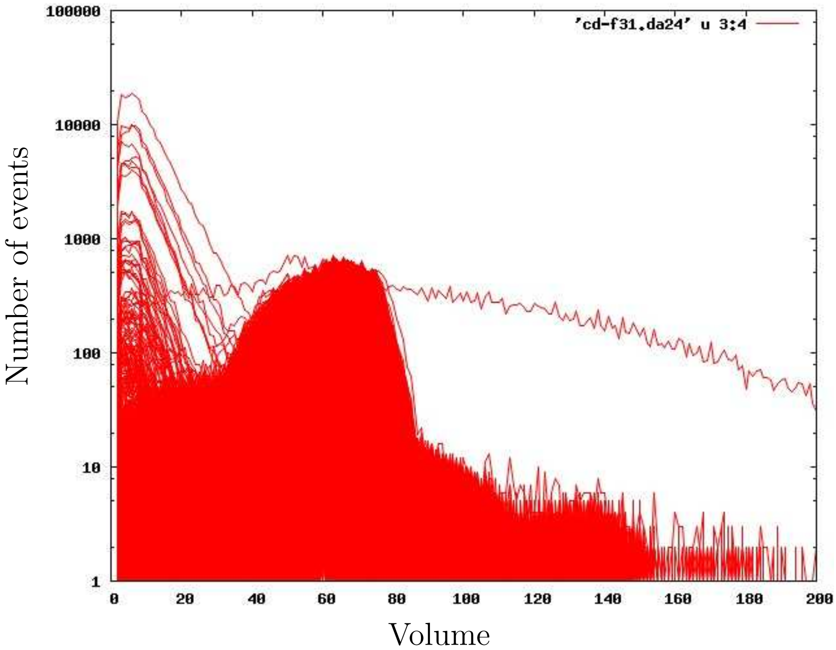

Fig.6. 65536 spectra from ^{109}Cd source

After obtaining position of 22.16 keV peak from ^{109}Cd source in all pixels matrix of recalibrating data was obtained which moves peak in all spectra to the same position and new spectra with this matrix were calculated. This gave better resolution of peak in spectrum from the whole area of the detector. As indicator of resolution height of peak was used: if the heigher is the heigh the better is the resolution. Such procedure was performed once again. Spectra from the whole area without recalibration and after two steps of recalibration are shown in Fig.7. It is seen that results of the first and the second recalibrations are practically the same. Then measurements with other sources were processed. As the measurement with ^{109}Cd was more quick than other measurements conditions with background in the low channels of other spectra are worse.

In the measurement with ^{133}Ba source information about the first peak 4.29 keV in many pixels is absent. Two matrices for recalibrating spectra were obtained. The first matrix must set peak 4.29 keV in all pixels in the same position and the second matrix must set peak 30.9 keV in the same position. Comparison of spectrum from the whole area without recalibration and with recalibration which sets the first peak in the same position is shown in Fig.8. Such comparison with recalibration which sets the second peak in the same position is shown in Fig.9.

65536 spectra from ^{152}Eu source were obtained. Desired peaks are about 22 and 93 channels (see Tab.1). For those pixels in which positions of desired peaks were found matrices of recalibrations were obtained. The result of recalibration of 5.64 keV peak is shown in Fig.10 and the result of recalibration of 40.11 keV peak is shown in Fig.11.

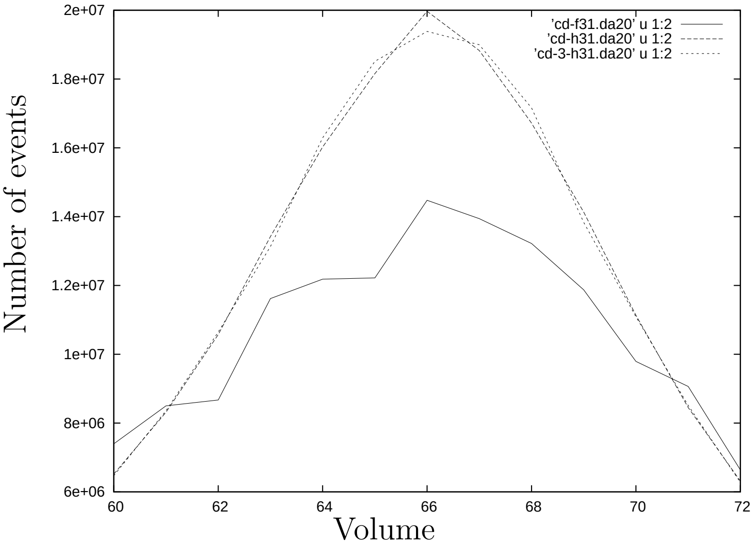

Fig.7. Spectra of one-pixel volumes from ^{109}Cd source without recalibration and after the first and the second recalibration

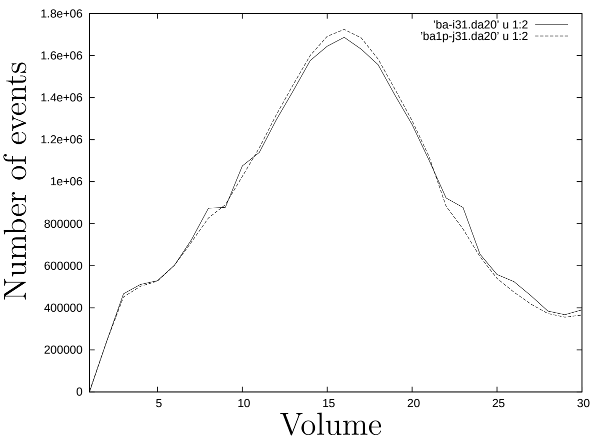

Fig.8. Spectra of one-pixel volumes from ^{133}Ba source without recalibration and after recalibration which must set 4.29 keV peak in the same position in all pixels

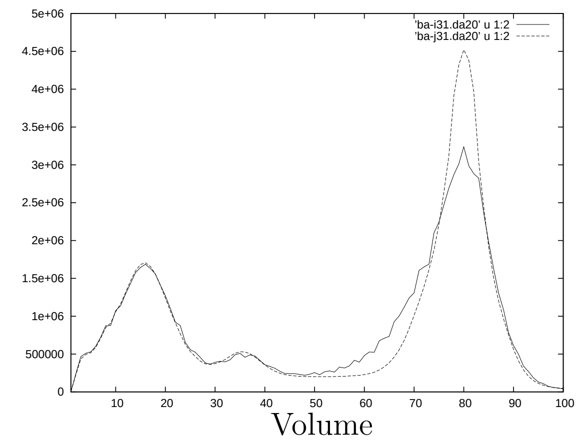

Fig.9. Spectra of one-pixel volumes from ^{133}Ba source without recalibration and after recalibration which must set 30.9 keV peak in the same position in all pixels

Measurement with ^{241}Am source had the longest time (see Tab.2). As the first transition 13.9 keV is more intensive than transitions in other sources (except ^{109}Cd source) (see Tab.1) and the second transition 59.54 keV has highest energy problem with noises in pixels must be not so hard as in measurements with ^{133}Ba and ^{152}Eu sources. 65536 spectra from ^{241}Am source were obtained and the result of calibrating matrix for 13.9 keV peak is shown in Fig.12. The result for 59.54 keV peak is shown in Fig.13.

4. Energy calibration of Timepix detector

After obtaining positions of 7 peaks from longtime measurements in all pixels one can prepare energy calibration of Timepix detector. As the first step energy calibration of spectra of volumes of one-pixel events from the whole area of the detector was obtained. Data for this calibration are presented in Tab.3. Function for calibrating must be invented.

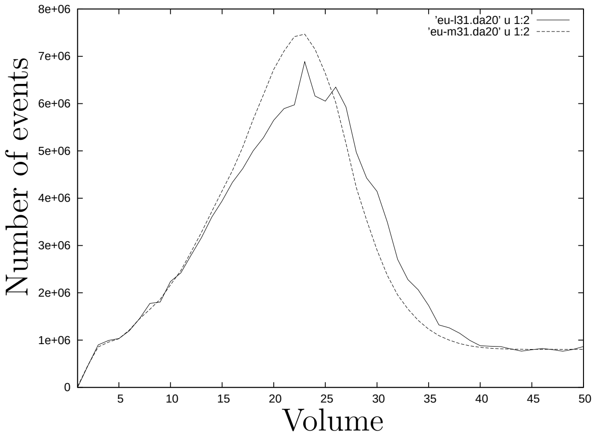

Fig.10. Spectra of one-pixel volumes from ^{152}Eu source without recalibration and after recalibration which must set 5.64 keV peak in the same position in all pixels

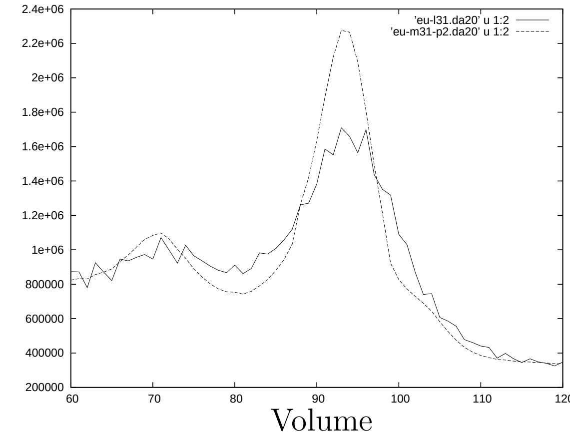

Fig.11. Spectra of one-pixel volumes from ^{152}Eu source without recalibration and after recalibration which must set 40.11 keV peak in the same position in all pixels

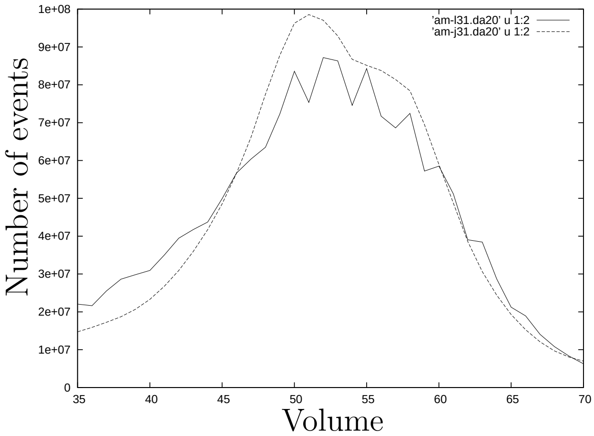

Fig.12. Spectra of one-pixel volumes from ^{241}Am source without recalibration and after recalibration which must set 13.9 keV peak in the same position in all pixels

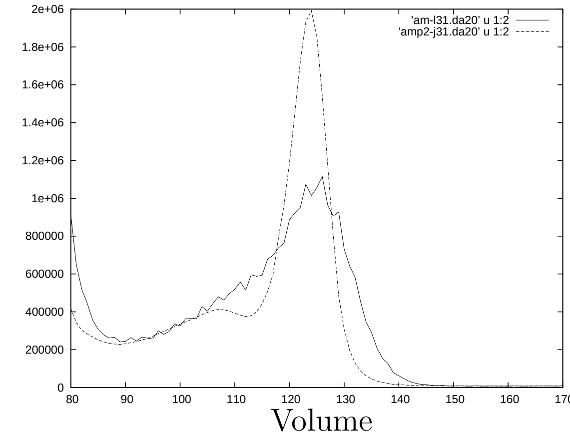

Fig.13. Spectra of one-pixel volumes from ^{241}Am source without recalibration and after recalibration which must set 59.54 keV peak in the same position in all pixels

Position	E_γ (keV)	N_m $^{*)}$	Isotope
16	4.29	$1.69*10^6$	^{133}Ba
23	5.64	$6.86*10^6$	^{152}Eu
53	13.90	$8.71*10^7$	^{241}Am
66	22.16	$1.45*10^7$	^{109}Cd
80	30.90	$3.24*10^6$	^{133}Ba
94	40.11	$1.71*10^6$	^{152}Eu
126	59.54	$1.11*10^6$	^{241}Am

$^{*)}$ – N_m –count in the maximum of peak

Table 3. Information for energy calibration from spectra obtained in longtime measurements.

As it is seen in Fig.1 from 13 up to 60 keV the calibration curve looks like a straight line. It is needed to use different function in the region from 0 up to 13 keV. For this region the following function was chosen for each pixel:

$$y = a_0 + a_1 \times x^{\alpha},$$

where x – count in pixel, y – energy, a_0, a_1, α – parameters, which are chosen to satisfy next conditions: the function and its derivative coincide with these parameters of straight line at y=13 keV. Other condition for this function – it must go through point which is between two points with energies 4.29 and 5.64 keV. Thus for each pixel 6 parameters must be determined – two parameters of straight line, value of point of staple and three parameters of function for low energy.

Work of obtaining 6 parameters for energy calibration for each pixel was made. As in some pixels the positions of peaks were not obtained, for these pixels parameters from calibrating of integrated spectra (see Fig.14) were used. For each source of longtime

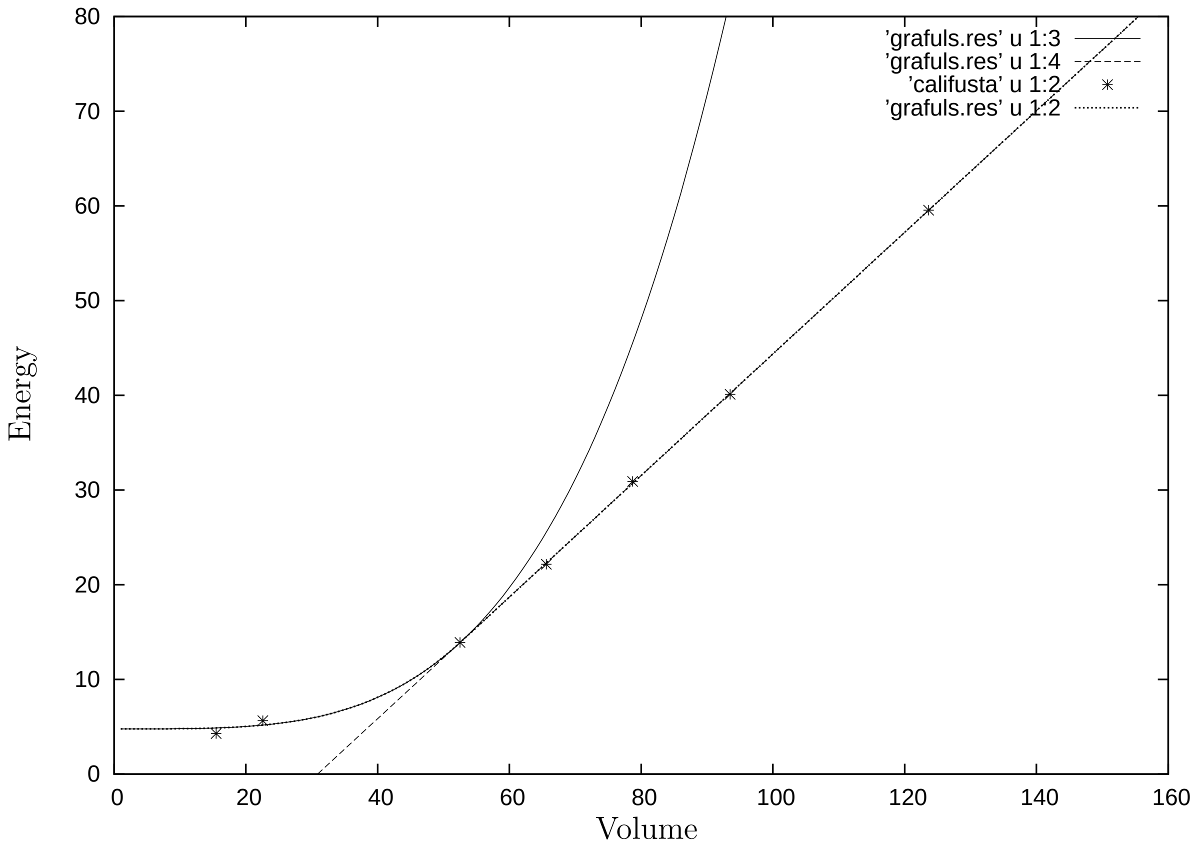

Fig.14 Energy calibration of longtime measurements from data of Tab.3

measurements spectra of energies from the whole area of the detector were obtained using matrix of parameters which was found for each pixel. Energy spectrum of ^{109}Cd source from the whole area of the detector is shown in Fig,15, spectrum of ^{133}Ba source – in Fig.16, spectrum of ^{152}Eu – in Fig.17 and spectrum of ^{241}Am source – in Fig.18.

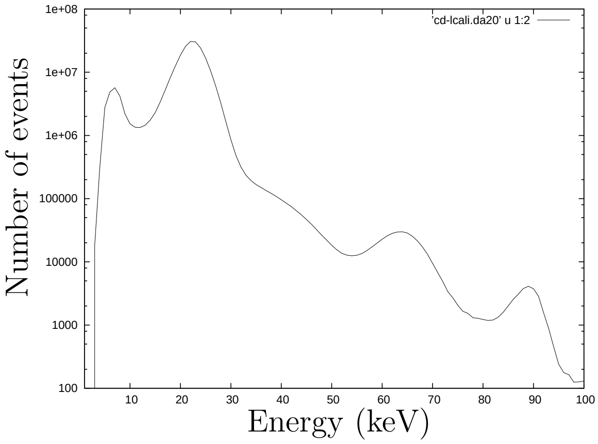

Fig.15. Energy spectrum of one-pixel events from ^{109}Cd source from the whole area of the detector with 22.16 keV transition

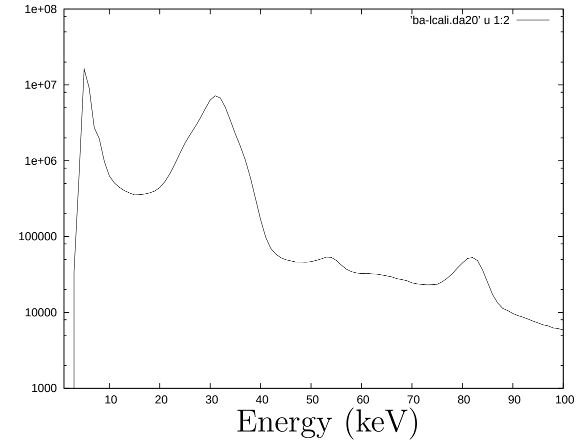

Fig.16. Energy spectrum of one-pixel events from ^{133}Ba source from the whole area of the detector with 4.29 keV and 30.90 keV transition

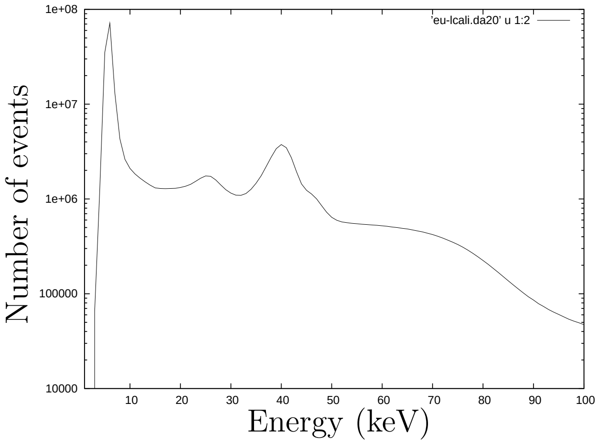

Fig.17. Energy spectrum of one-pixel events from ^{152}Eu source from the whole area of the detector with 5.64 keV and 40.11 keV transition

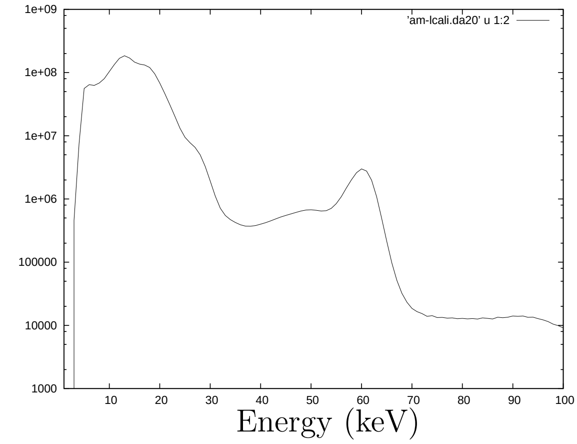

Fig.18. Energy spectrum of one-pixel events from ^{241}Am source from the whole area of the detector with 13.90 keV and 59.54 keV transition

5. Conclusion

Energy calibration of Timepix detector was made in energy region from 0 to 60 keV with x-rays. Only one-pixel events were used. Set of 12 OSGI sources was tested for obtaining x-ray transitions in the desired energy region. It is found that ^{60}Co and ^{137}Cs sources do not give transitions. Other sources give one or two transitions.

Preliminary energy calibration of the detector was made using events from the whole area of it (see Fig.1). Four sources ^{109}Cd, ^{133}Ba, ^{152}Eu and ^{241}Am were chosen for longtime measurements. Longtime measurements were provided using time from 19 to 263 hours (see Tab.2). Determination of positions of 7 transitions was made in pixels of the detector. Not in all pixels this determination can be made. Hypothesis for function of calibration was invented which has six parameters. These parameters were found for information from the whole area of the detector (see Fig.14) and for the most number of pixels. Energy spectra of four sources were obtained from the whole area of the detector (see Figs.15, 16, 17, 18) using matrix for pixels.

References

[1] X. Llopart, R. Ballabriga, M. Campbell, L. Tlustos and W. Wong, Nucl. Instr. and Meth. A 581 (2007) 485.

[2] S.Pospisil *et al.*, *http://isinn.jinr.ru/past-isinns/isinn-21/progr-24_05_2013/Pospishil.pdf*

[3] S.Pospisil *et al.*, *http://indico.cern.ch/event/284070/session/19/material/0/0.pdf*

[4] X. Llopart, M. Campbell, D. San Segundo, E. Pernigotti, and R. Dinapoli, IEEE T. Nucl. Sci. ,49(5), 1484-1488(2002)