Registration of charged radiation from ^{252}Cf using Timepix detector

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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.

Within continuous program of investigating the response of Timepix detectors to different kinds of radiation about 1.2 millions frames were obtained detecting radiation from ^{252}Cf source. Each frame consists of a number of events registered in the detector during a fixed time interval (typically 0.1 sec). The main attention was paid to registration of fragments from spontaneous fission of ^{252}Cf, as this was the first measurement of heavy charged particles by the Timepix detector. The response of Timepix on a charged particle is a cluster - compact group of pixels in which the total particle energy is deposited. Several problems which are discussed: identification of event, analysis of parameters of events, calibration of pixels, study of the shape of clusters, detecting bad regions in the Timepix detector.

1. Introduction

The hybrid silicon pixel device Timepix [1] was developed at CERN by Medipix collaboration. It is based on its predecessor Medipix2. In difference from Medipix2 device Timepix has time over threshold (TOT) mode of operating which allows direct energy measurement. Within continuous program of investigating the response of Timepix detectors to different kinds of radiation a source ^{252}Cf was used to study the response of Timepix detector on fragments from spontaneous fission of ^{252}Cf. This was the first measurement of heavy charged particles by the Timepix detector. A study of the response of Medipix2 detector on fragments from spontaneous fission of ^{252}Cf was fulfilled in this Laboratory (FLNP JINR) and its results were described in [2]. Important part of analysis data from the Timepix detector is calibrating of pixels. This procedure has two different aspects: to obtain normalizing coefficient of amplification of each pixel to obtain the same output value from all pixels for the same charge obtained by pixel and absolute calibrating to obtain value of energy in MeV-s. In this work we will discuss the next points: some parameters of the Timepix detector, experiment, data processing, identification of event, parameters of events, pixel normalizing, form of α and fragment clusters, bad areas in the Timepix detector.

2. Timepix device

The Timepix device consists of a semiconductor detector chip (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 noise of analog circuitry is about 650 electrons. Each Timepix pixel can work in one of three modes:

Medipix mode - Counter counts incoming particles.

Timepix mode - Counter works as a timer and measures time of the particle detection.

Time over threshold (TOT) mode - Counter is used as Wilkinson type ADC allowing direct energy measurement in each pixel.

Each individual pixel of the Timepix device in TOT mode is connected to its own analog circuitry and AD converter. Thus the device contains 65536 independent ADCs to be calibrated to energy.

External shape of the Timepix device is shown in Fig.1. Some technical parameters of the detector are shown in Fig.2. Logic of processing the Timepix detector with α-event is demonstrated in Fig.3.

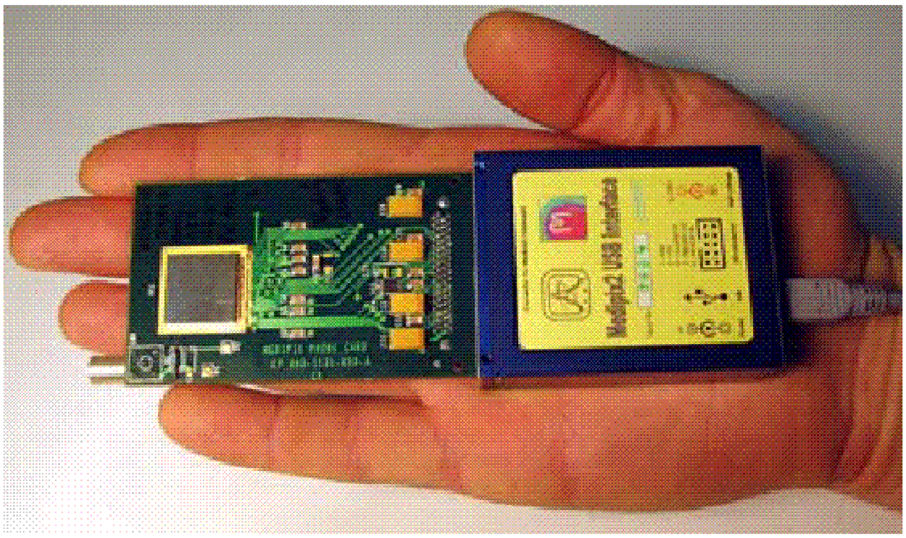

Fig.1. External shape of the Timepix device

Single particle often creates signal in a cluster of adjacent pixels. 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. The charge collected by each pixel in the cluster can be measured with the Timepix device. The total charge can be revealed by summation of all these fractional charges i.e. by determination of the cluster volume. As the charge collection speed depends on applied bias voltage the cluster size (number of pixels in the cluster) also depends on that voltage.

On-line operation of the Timepix device and data readout visualizing is made possible by the USB-based readout interface [3] which links by standard USB port into any PC. Operating and monitoring of the system is driven by the Windows-compatible software package Pixelman [4]. Data stream acquisition and storage proceed on-line at overall rate of about 5 frames per second. Each frame consists of a number of events registered in the detector during a fixed time interval.

Experimental

There were two experiments with different sources. The first experiment was made with ^{244}Cm source. Detector registered α-particles with energies 5805 keV (76,4%), 5763 keV (23.6%) and others with very small intensities. Time of exposure ΔT was 0.3 s. Mean value of events in one frame was about 1000. Number of α-particles in one frame was about 30. Measurement went on 2 days.

The second experiment was made with ^{252}Cf source. Detector registered α-particles with energies 6118 keV (81.6%), 6076 keV (15.2%) and others with very small intensities and fragments from spontaneous fission (SF) of ^{252}Cf. There were two sets of data: one with ΔT=0.2 s and other with ΔT=0.1 s. Value of events in one frame varied from 300 up to 2000 from run to run. Number of α-particles in one frame was about 40 when ΔT was 0.2 s and about 20 when ΔT was 0.1 s. Measurement went on 9 days. All electronic parameters were the same in these two experiments.

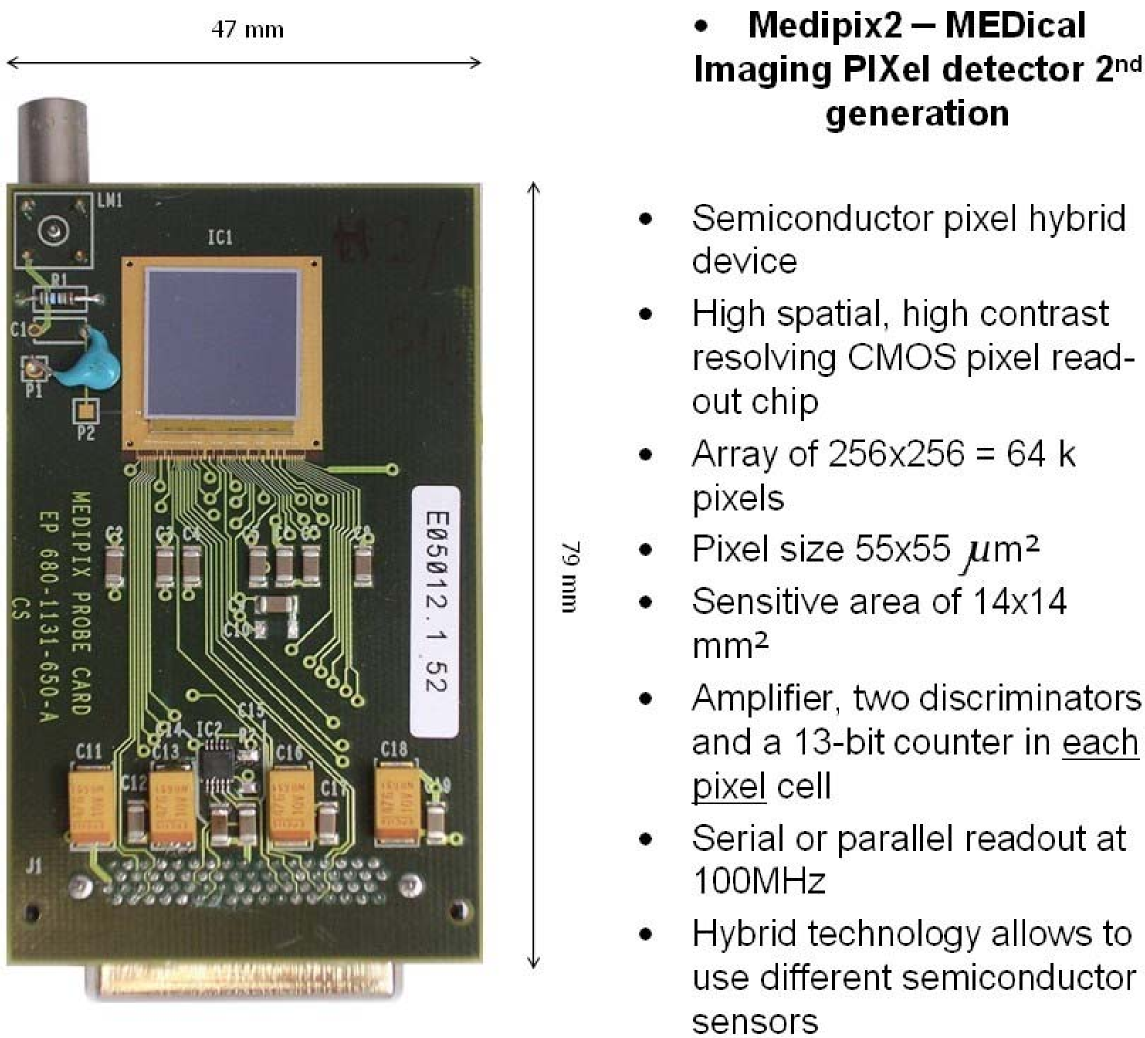

Fig.2. Some technical parameters of the Timepix detector

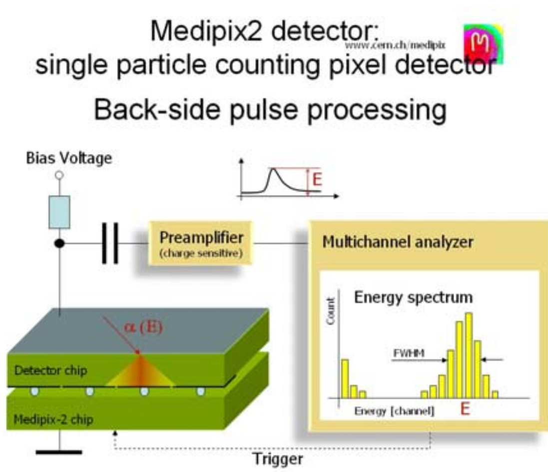

Fig.3. Logic of processing the Timepix detector with α-event

Data processing

About 260000 frames were obtained in experiment with ^{244}Cm source and more then 1.2 millions frames were written during experiment with ^{252}Cf source.

Data processing consists from some steps: reading frame, isolating of events and composition of list of events in the frame, identification of events, selection of events of desired type and statistical analysis desired events in desired runs of measurement.

Identification of event

There are two sources of events in the experiment: events from source studied and events of cosmic rays which always present in frames. Some events of the same type can be detected from these two sources (for example: electrons and X-rays). Nature of event can be determined from size and shape of cluster which event forms: X-rays form small clusters from 1 to 4 compact pixels (see Fig.4), electrons give long not straight tracks (see.Fig.5). Long straight tracks (see Fig.6) are from cosmic meson-s. As long as the main sense of this work was devoted to study of response the Timepix detector to hard charged particles attention was paid to α-particles and fragments from source. These particles give round clusters which sizes are connected to their energies. Size of α-cluster was about 50 pixels and size of fragment was about 150 pixels. Frame with many α-clusters and one cluster from fragment is shown in Fig.7.

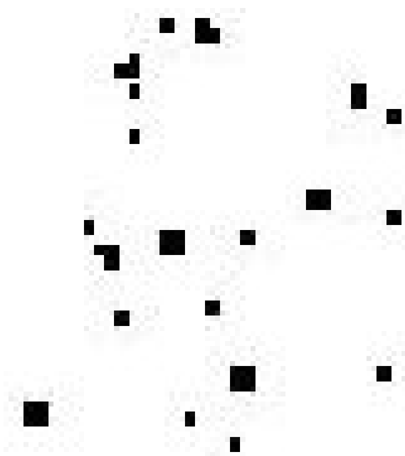

Fig.4. Part of frame with clusters from X-rays

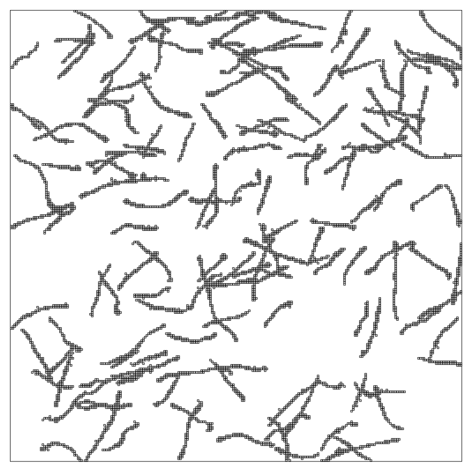

Fig.5. Frame with tracks from electrons traveling in layer of detector

In this figure one can see the problem which must be resolved: events often are overlapping to each other. This connects to the exposition time ΔT and counting rate. Because of the counting rate from ^{252}Cf source number of events in one frame was about 1000 and number of α-particles was about 40. To diminish ΔT is not profitable because the time of writing frame to disc is 0.2 s and smaller ΔT gives more loss of full information. Overlapping events must be detected and removed. Three algorithms were used to do this: selection by size of cluster, test of roundness of spot of cluster and revealing of two maxima in 3-dimensional form of cluster.

The Timepix detector in TOT mode gives charge received in each pixel and cluster is 3-dimensional body volume of which is proportional to full energy of charged particle if it's path is fully inside the volume of the detector. As the thickness of the detector is

300 μm α-particles with energies up to 16 MeV fully lay in the silicon. Fragments have shorter path due to big charge. Form of 3-dimensional body of cluster is 3-dimensional Gaussian. As long as the energies of α-particles and fragments from ^{252}Cf are 6118 keV and about 90 MeV accordingly and areas of their clusters differ in 3 times the height of cluster from fragment must be significantly more then the height of α-cluster.

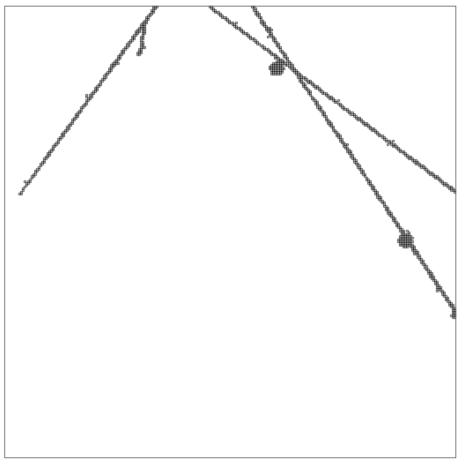

Fig.6. Three long tracks from high energy cosmic particles (meson-s)

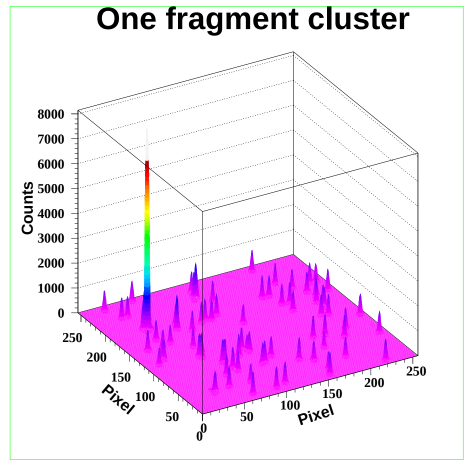

Fig.7. Many clusters from α-particles and one cluster from fragment

Parameters of event and selection of α and fragment events

To select desired events one must use some parameters which are about the same for events of one nature and differ for different types of events. It is reasonable to choose the next parameters: size of cluster, maximal value in the cluster and position of cluster. As position it was used the mean weighted x and y values. These values are real and in some circumstances integer parts of these values are used as number of pixel to which this event belongs. Two distributions of sizes of clusters are shown in Fig.8. One distribution is from run with ΔT=0.2 s and the other from run with ΔT=0.1 s. The most peak is peak of α-particles and other peaks are overlapping α-s. Due to overlapping peak from fragments can not be seen. In these circumstances selection by maximal value in clusters must help to select fragments. Two distributions of maximal values in clusters are shown in Fig.9: one with ΔT=0.2 s and other with ΔT=0.1 s.

All events with maximal value more then 2000 are fragments and using this value for selection distribution of sizes of cluster for fragments was obtained (see Fig.10). Small right peak in this spectrum is peak of events in which α overlaps fragment. Big peak is peak of natural fragments. It can be seen that this peak have not two maxima and this means that one can not obtain light and hard groups of fragments separately in this experiment using sizes of clusters for selection.

Normalizing of pixels

All 65536 pixels of the detector have own amplifiers and these amplifiers can have different amplification. The task is to obtain normalizing matrix in which there is amplification coefficient for each pixel. When we use this matrix we can obtain the same yield from all pixels for the same energy of detecting particles. The task of normalizing is not simple because charged particles give big clusters and energy of one particle is distributed between many pixels. In ^{252}Cf measurement we have very intense α-peak and the resolution of this peak is about 6-7 %. One can hope to obtain better resolution. after using normalizing matrix.

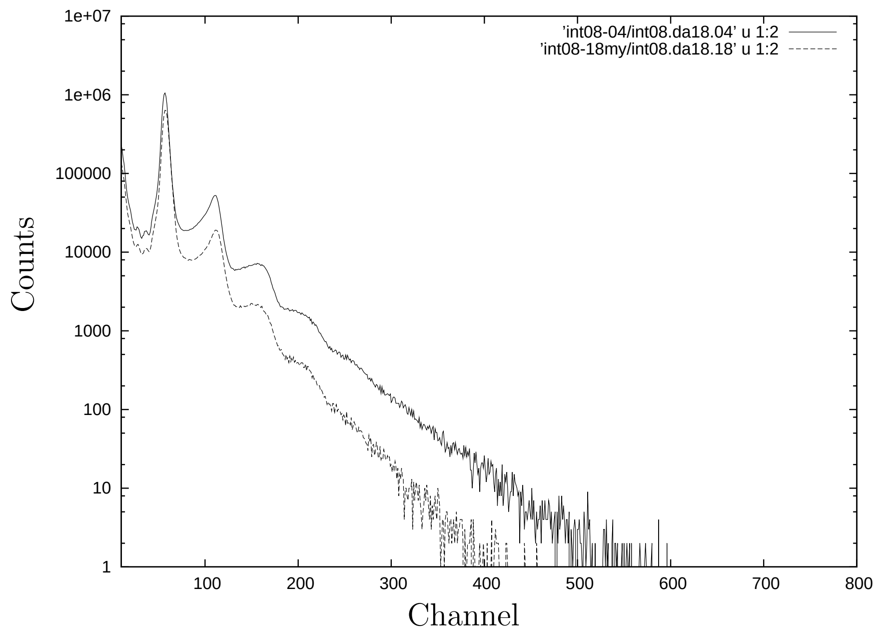

Fig.8. Two distributions of sizes of cluster in runs 04 (ΔT=0.2 s) and 18 (ΔT=0.1 s).

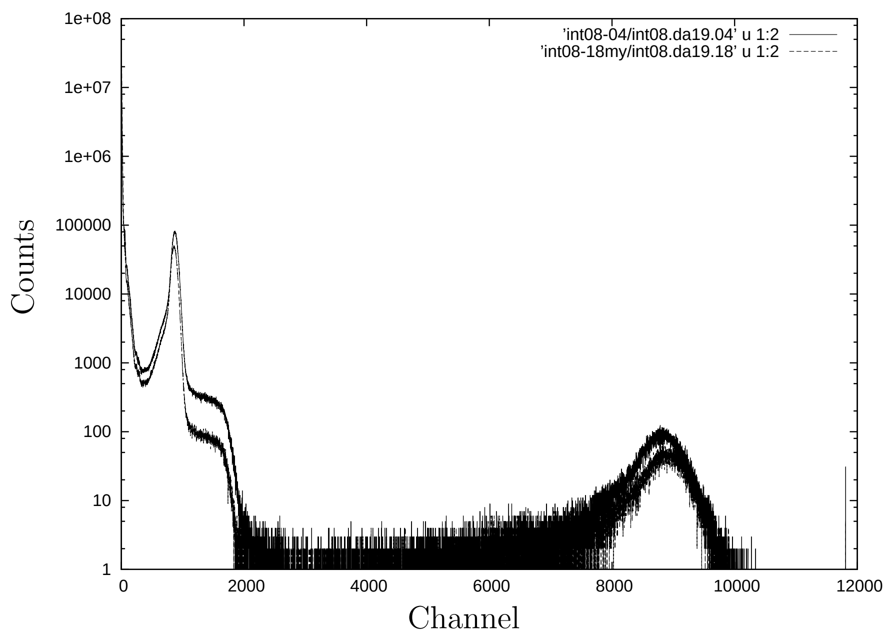

Fig.9. Two distributions of maximal values of energy in one pixel in runs with ΔT=0.2 s and ΔT=0.1 s.

During normalizing procedure some areas in the Timepix detector have found to be bad, namely, response of these pixels on the charge was very small. These pixels were remembered and normalizing of bad pixels did not made.

When amplification coefficients of pixels are different one can not obtain good resolution because of the events with the same energy in different parts of detector will give different response. There is some method to obtain better resolution in these circumstances. We will named this method as 'mosaic mode'. One can unite some near pixels and consider this union as small detector. At the area of full detector one can have many such small detectors. For each detector one can obtain its energy spectrum. If in these spectra there is big clear peak one can determine its position and gather all spectra with shifts to locate this peak in one position. Resolution in this spectrum will be better. If amplification coefficients of pixels are about the same mosaic mode does not give better resolution. Therefore mosaic mode may indicate if coefficients of pixels are different. How many pixels one must unite in small detector depends from statistics. There must be good peak in each spectrum.

In ^{252}Cf measurement there is big peak of α-particles with energy about 6118 keV. Full statistics of this peak was about 800 events in one pixel. This permits to use one pixel as small detector in mosaic mode even in different runs. Energy spectrum was obtained in mosaic mode and this spectrum has better resolution than ordinary spectrum. Part of ordinary spectrum and spectrum from mosaic mode are shown in Fig.10.

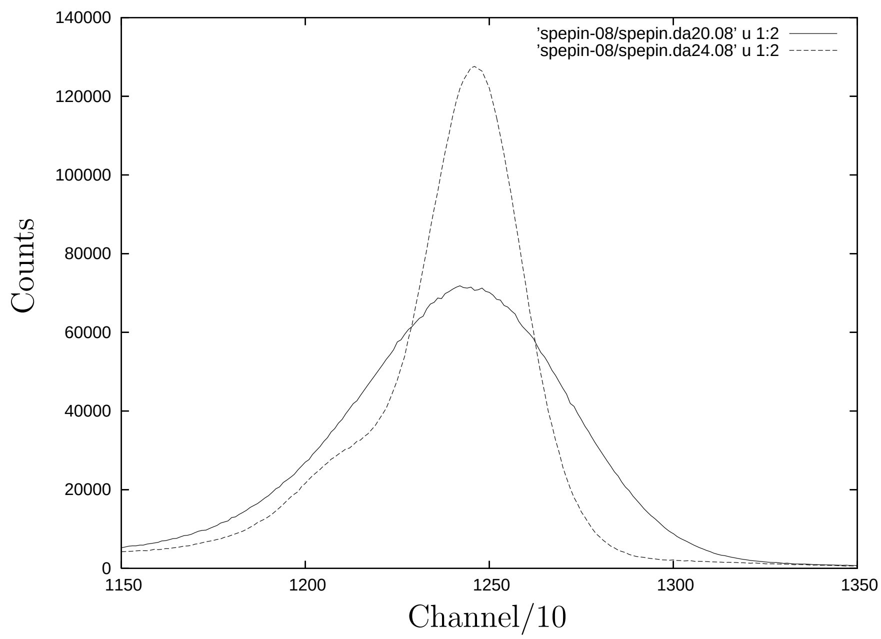

Fig.10. The comparison of spectra of energies from ordinary mode and from mosaic mode for 08 run.

To obtain normalizing matrix we use uniform spoiling method. This method consists from two steps. The first step is the next: we use only events of α-particles from good pixels and for each such pixel obtain two-dimension matrix. The mean weighted position is determined for each event and this event is attributed to pixel which is in this position. We have information about the number of events which added to each pixel. The second step is to normalize all two-dimension matrixes on the number of events which was from 400 to 1000 in one pixel and add all data in one 256×256 matrix. When the number of events in each pixel is big there must be the same energy in each pixel and differences are only from different amplification. Now we can obtain coefficients for each pixel to have the same value for all pixels. Using this matrix of coefficients we can obtain spectrum of energies of α-particles. We also can obtain spectrum from mosaic mode. Comparison of normalizing spectrum and such spectrum from mosaic mode is shown in Fig.11. There are two spectra from Fig.10 in this Fig. also.

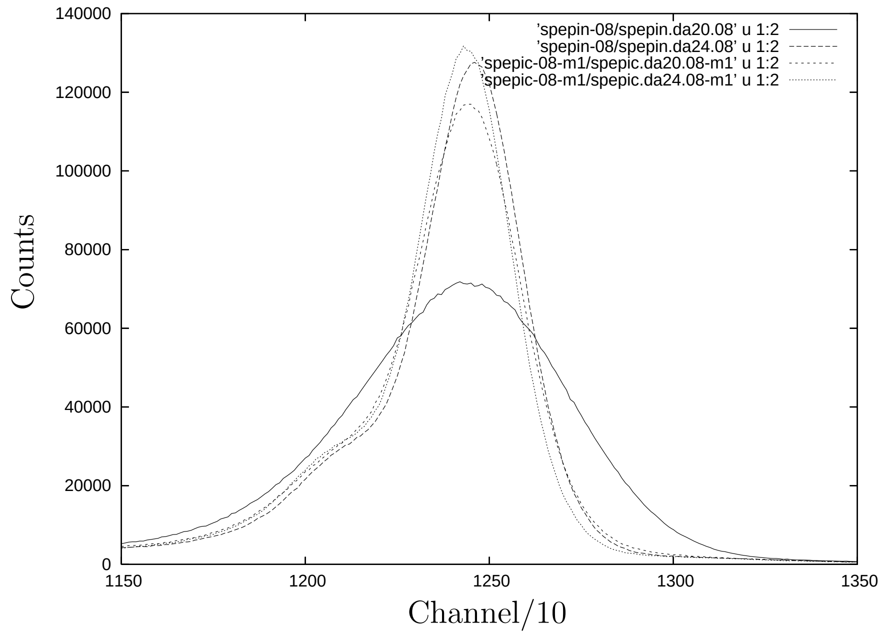

Fig.11. The comparison of spectra of energies from ordinary mode and from mosaic mode for 08 run. 1 and 2 - without normalizing; 3 and 4 - with normalizing

It can be seen that spectra from mosaic mode are very close, peak after normalizing is slightly higher than it without normalizing. Peak in ordinary mode after normalizing is more higher than peak without normalizing but it is lower than peaks in mosaic mode.

Energy spectrum with full statistics of ^{252}Cf measurement with normalizing is shown in Fig.12. Two groups of fragments light and hard are separated well. Form of spectrum of fragments is not good because the source was thick.

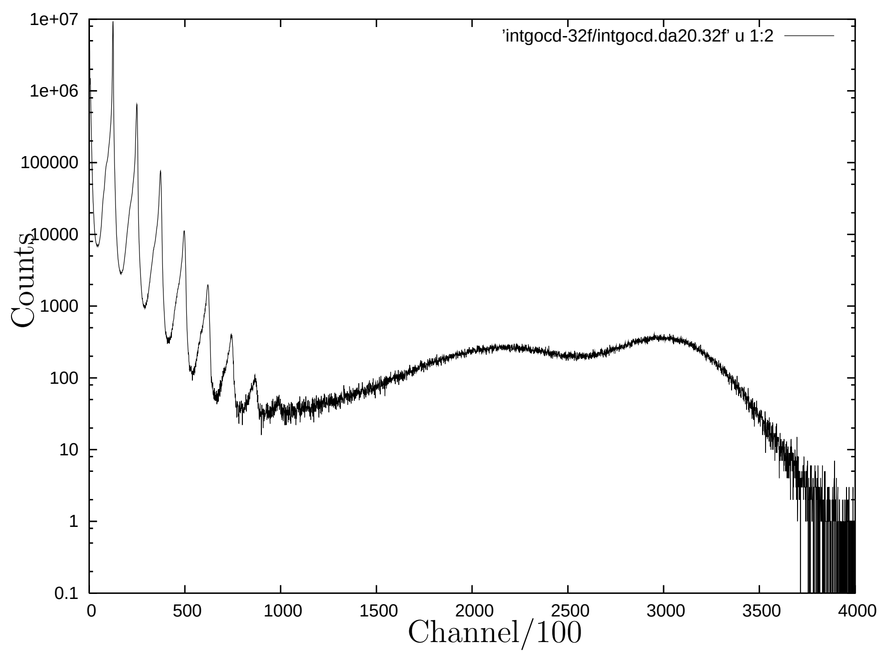

Fig.12. Energy spectrum with full statistics from ^{252}Cf measurement

Forms of α and fragment cluster

During the normalizing procedure form of α-cluster averaged by many events was obtained. Special run of calculations was made to obtain form of fragment cluster. These two forms are shown in Fig.13. There is difference between obtaining these forms: form of α-cluster is as averaging of events with about the same energy but form of fragment cluster was averaged from events with energies from about 40 up to 110 MeV.

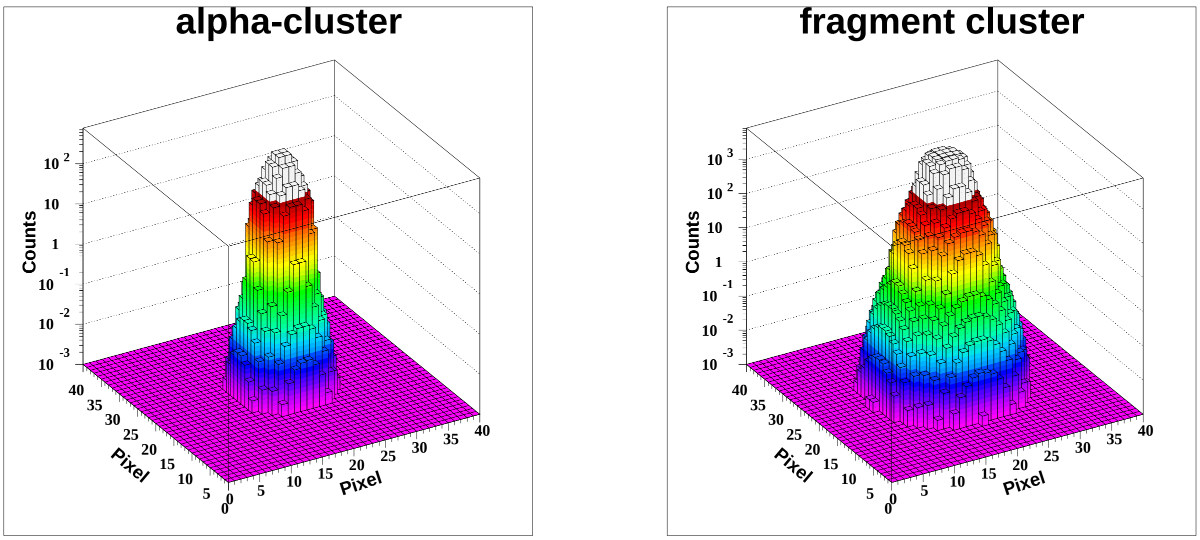

Fig.13. Averaged forms of α and fragment clusters

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