Results of TGE Study in 0.03-10 MeV Energy Range in Ground Experiments near Moscow and Aragatz

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Ground-based experiments with scintillator gamma-spectrometers were conducted to study the spectral, temporal and spatial characteristics of TGEs as well, as to search the fast hard X-ray and gamma-ray flashes possibly appearing at the moment of lightning. The time of each gamma-quantum interaction was recorded with ~15 us accuracy together with detailed spectral data. The measurements are similar to ones reported at TEPA-2015 but some important improvement of the instruments was done for summer, 2016 season. First, GPS module was used to synchronize the instrument time with UTC. The accuracy of such synchronization allows one to look at the gamma-ray data at the moment of lightning fixed by radio-wave detector or any other instrument. Second, the energy range of gamma-spectrometers was shifted to higher energies where the radiation of natural isotopes is absent. In this case one can see background changes connected with particles accelerated in thundercloud together with the background increases during the rain caused by Rn-222 daughters. Long-term measurements with two instruments placed in different points of Moscow region were done in 2016 season. First one based on CsI(Tl) 80x80 mm has energy range 0.03-6 MeV. The range of the second one based on CsI(Tl) 100x100 mm is 0.05-10 MeV. A dozen of thunderstorms with increase of Rn-222 radiation were detected but no significant increase of gamma-ray flux above 3.2 MeV was observed at these periods. The result of the search for short bursts at the moment of lightning fixed by radio-wave detector working in MSU will be discussed as well as the results of the study of slow variations. A lot of data was obtained from the experiment with small gamma-ray spectrometer (40x40 mm NaI(Tl) at mountain altitude in Armenia at Aragatz station. The analysis of readings during the TGE periods indicates on the presence of Rn-222 radiation in low-energy range (E<1 MeV). The use of larger detector with good spectrometric characteristics is necessary for more significant conclusion

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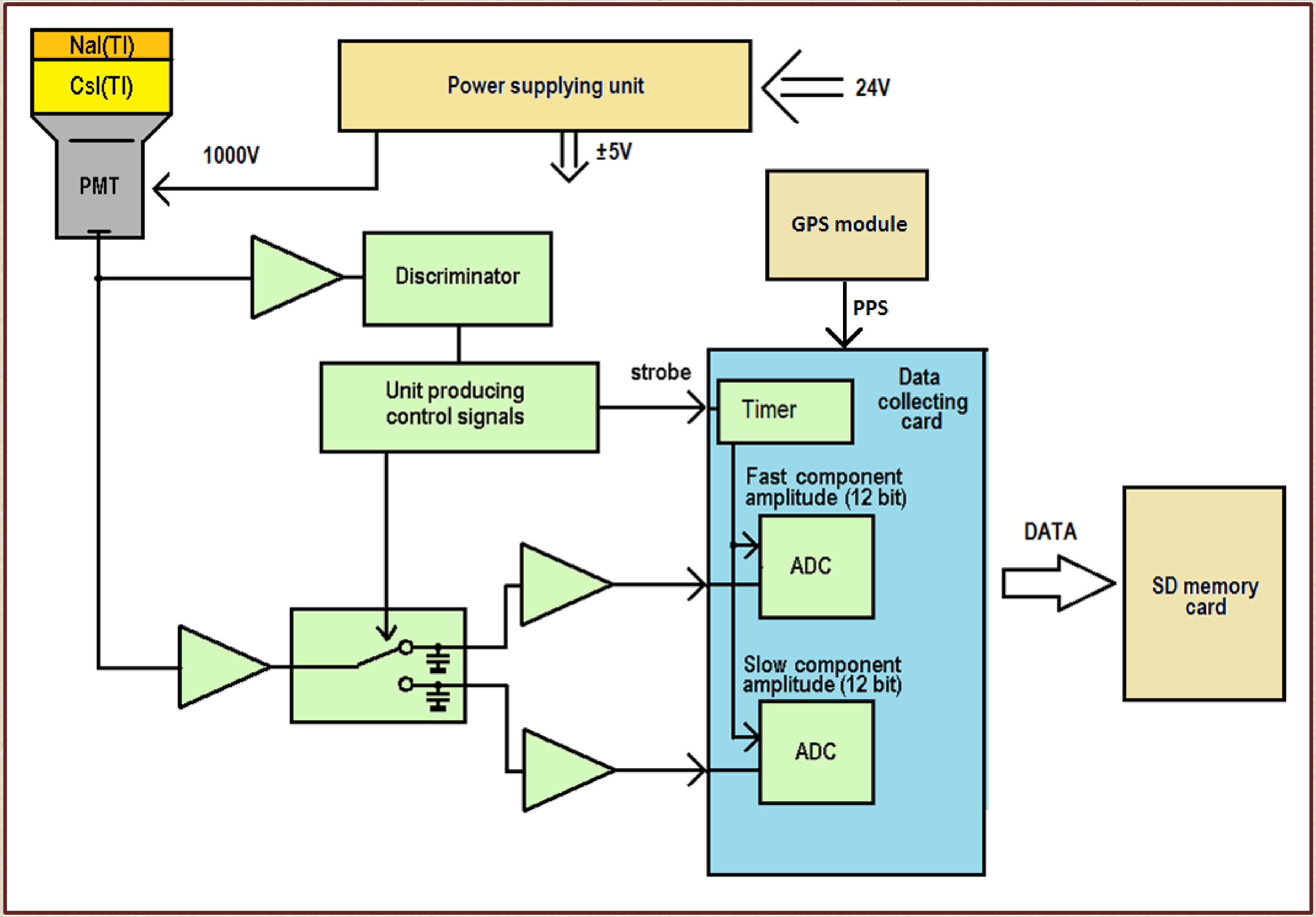
Scientific goal:

- Study of spectral characteristics of TGEs in 20-10000 keV range
- Measure of the direction of TGE gamma-radiation
- Search for fast gamma-ray flashes from lightning

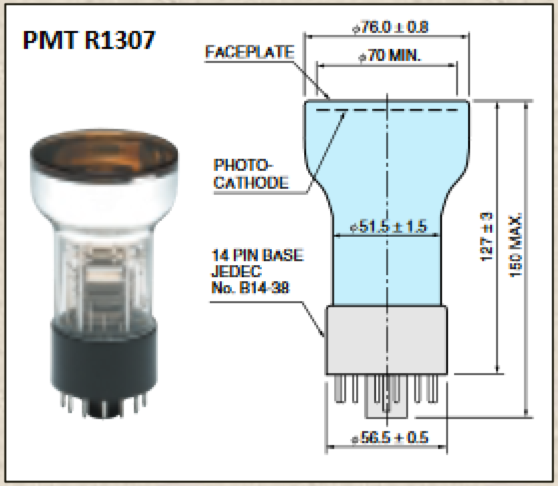
Principles of instrument design:

- Detectors are scintillator spectrometers with NaI(Tl) or CsI(Tl)
- Electronics allows to analyze pulse shape in order to use phosvich detectors and to remove imitations of gamma-events by thunderstorm electric discharges
- Recording all data in “event” mode with fine time resolution
- All data are recorded to SD card for further analysis
- Exact timing with GPS receiver
- Measurements with collimated detector placed on rotating platform are provided

Design of instrument electronics



Analog part of instrument electronics

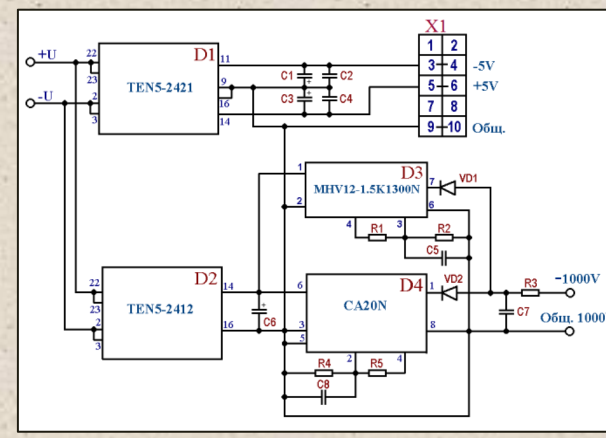


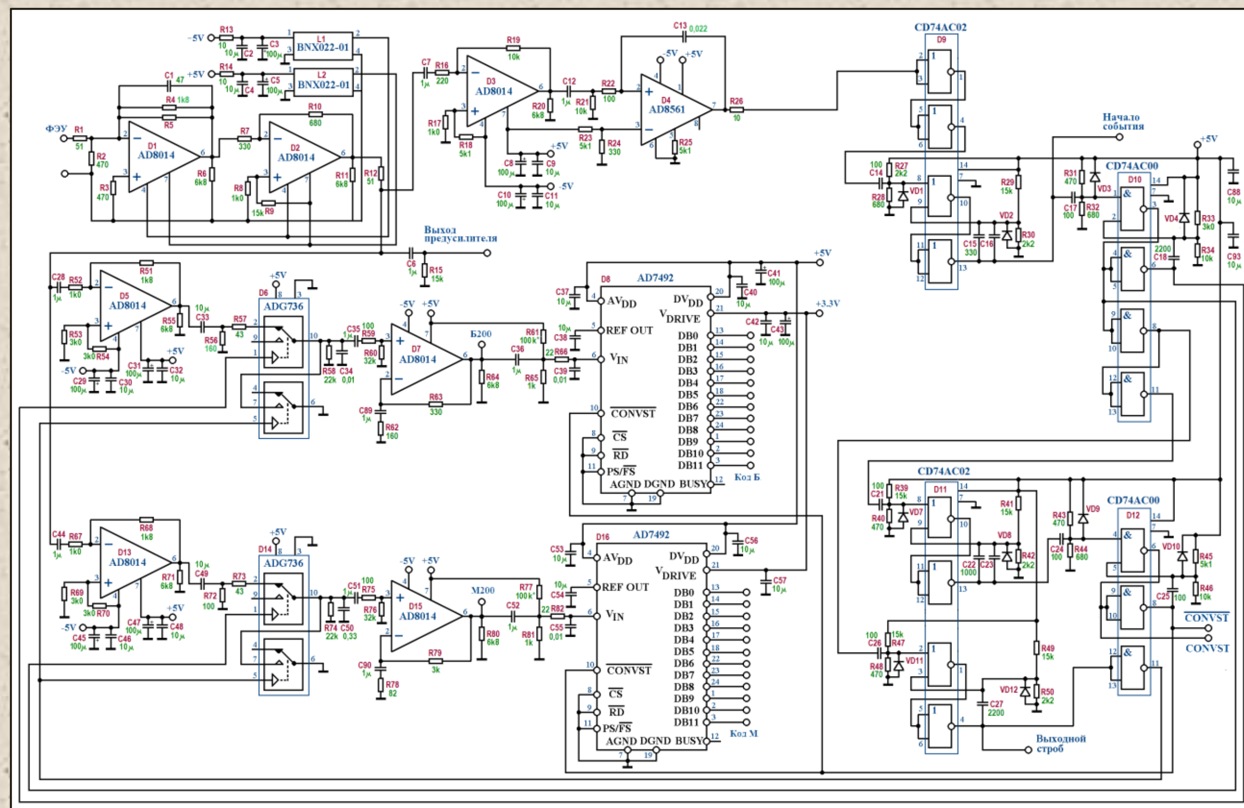
HV supplier

TracoPower THV series

Low Voltage supplier

TracoPower TEN5





Amplifiers

AD8055, AD8014

Comparator

AD8561

SPDT switch

ADG736BRM

Simple logics

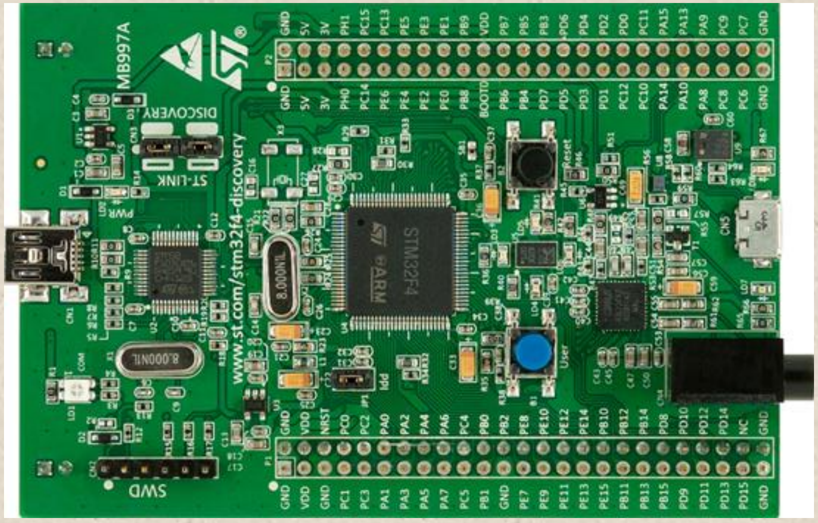
74AC00, 74AC02

ADC

AD7492 or external ADC of MCU

Digital electronics and data format

- **Producing time data with accuracy 15 mcs. Stability of internal timer is ~1s/day and synchronysation via GPS every second**
- **Forming data frames each second.**
- **Producing ~15mcs timer data starting at the beginning of the frame**
- **Interrupt on the request from analog card and digitize pulses of fast and slow components**
- **At the beginning of a frame digitize signal on the aditional analog input**



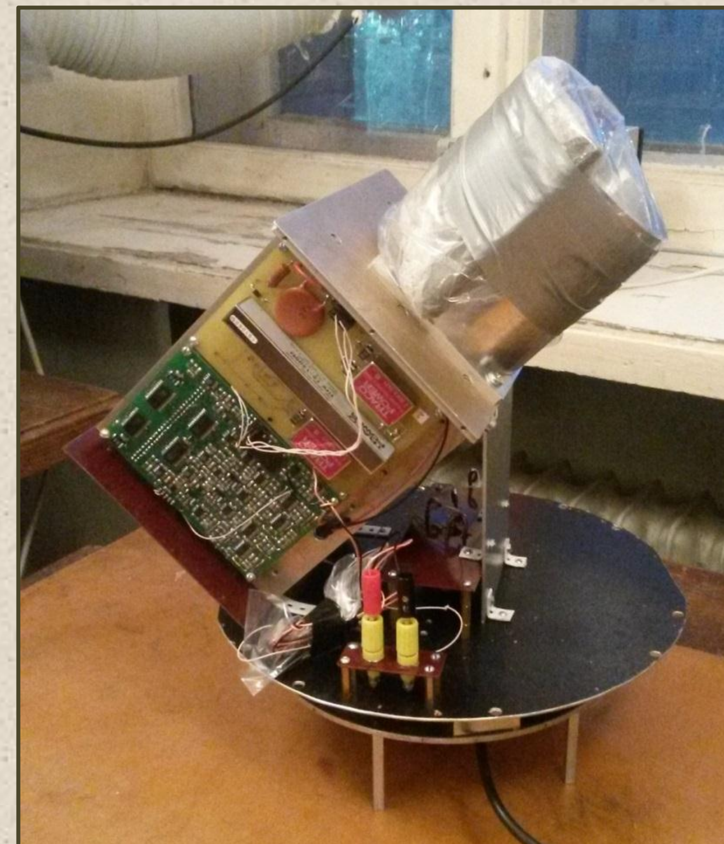
Board STM32F4 DISCOVERY with Cortex M4 microcontroller

7b - Frame start marker - E4 57 B4 C0 3F 66 99
4b – Frame number
6b - Time – YY MM DD hh mm ss
2b – Number of events in the frame
4b – Number of counts of 15mcs timer during the frame
2b – ADC data for external analog input
N*(3b+3b) – Data records: ADC data + timer value
4b – Frame end marker – CC 11 00 00

Gamma-ray spectrometers used in this work:

Detector: NaI(Tl) 40x40 mm
PMT: ФЭУ-176
Range: 20 кэВ-1 МэВ
Resolution 12% at 662 keV

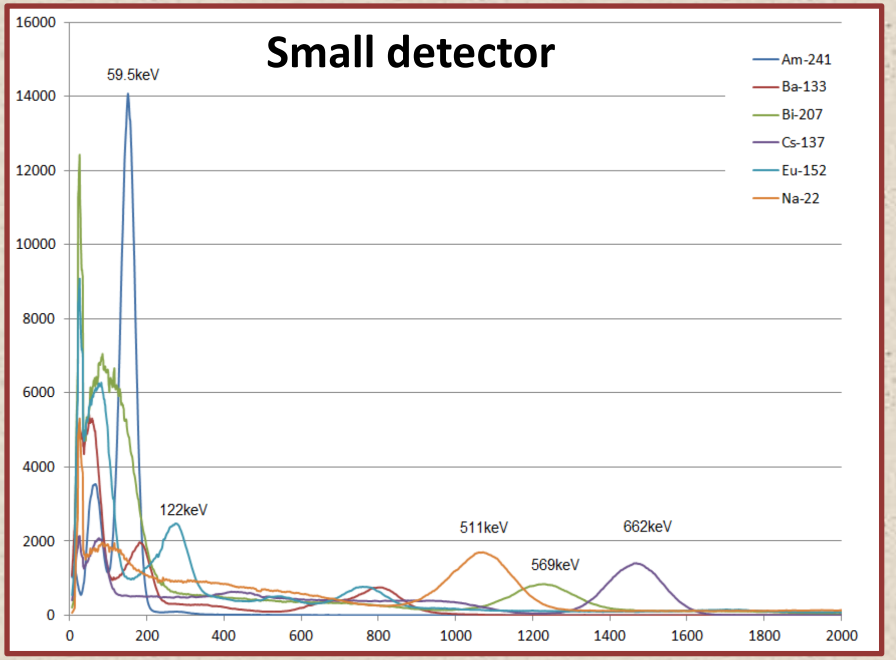
Detector: CsI(Tl) 80x80 mm
PMT: Hammamatsu R1307
Range: 20 кэВ-3 МэВ
Resolution 7.5% at 662 keV
Placed on rotating platform

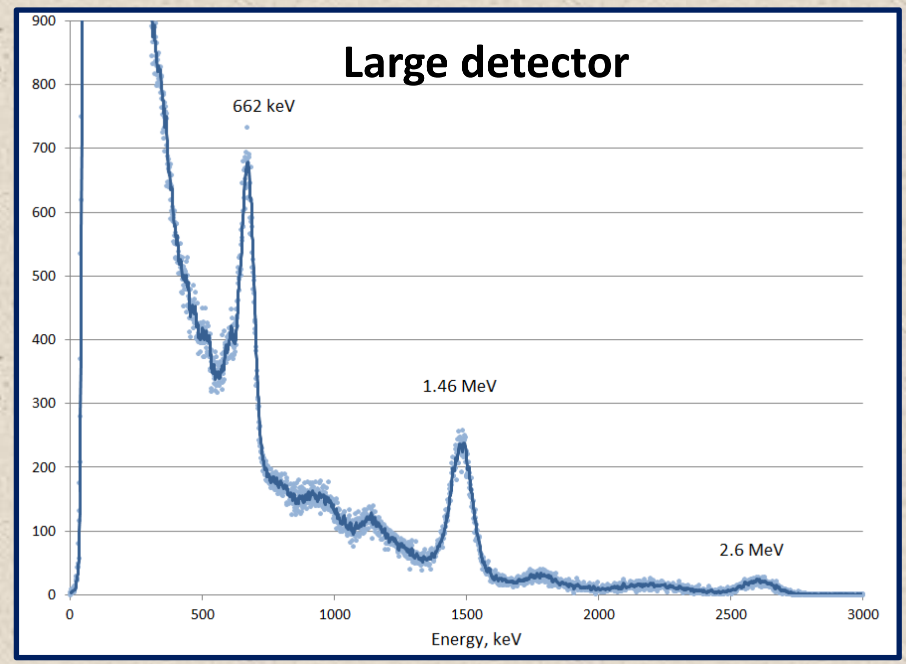


Calibration and data processing

Gamma to gamma data were processed and three kinds of secondary files were produced:

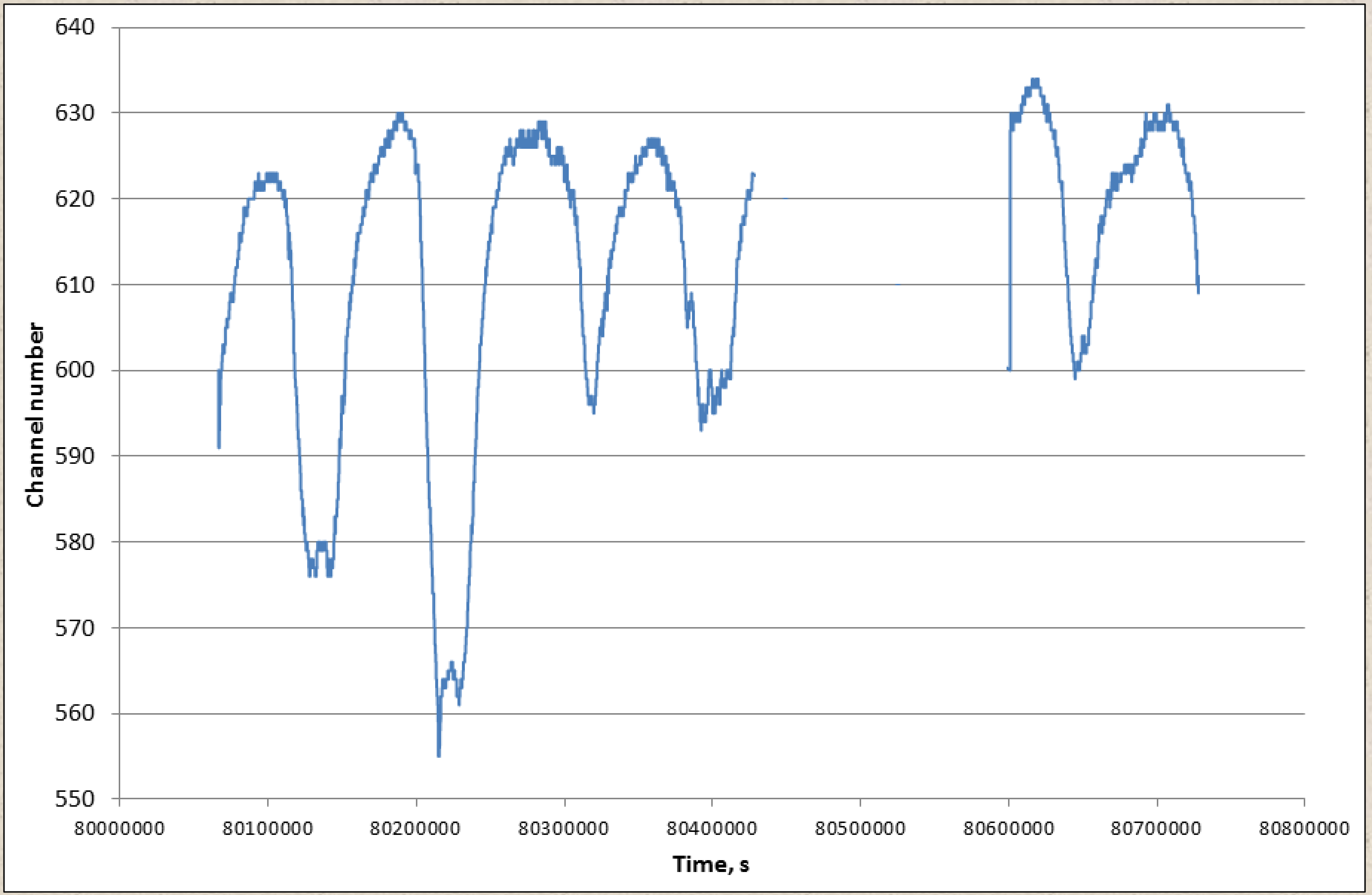
1)Monitoring time sequences in several energy channels with 1s resolution
2)Detailed energy spectra for requested periods
3)Event data sequences (useful for short burst search)





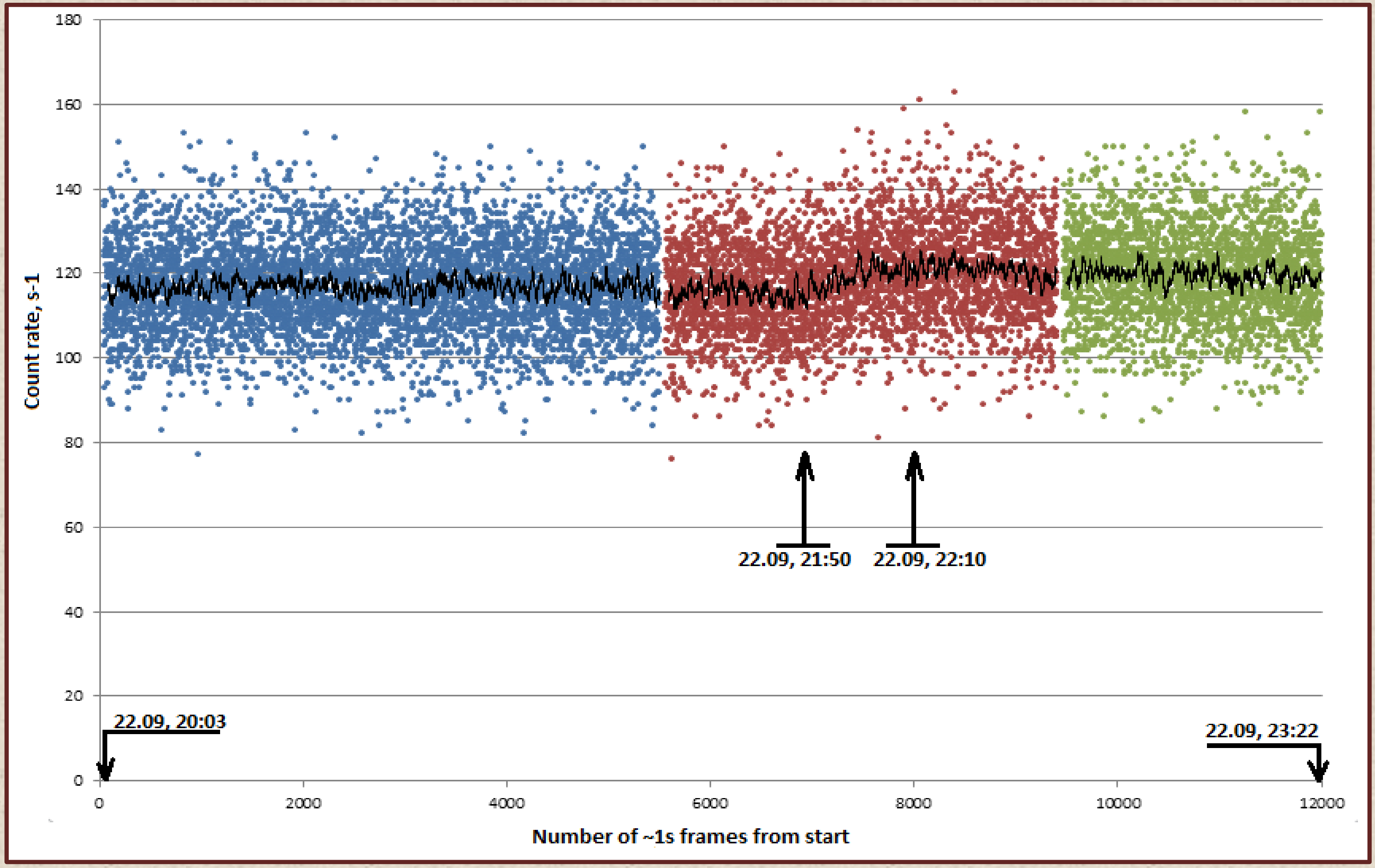
***Autocallibration** alhorythm was used for large detector data: every 300s of the data the program determined the actual position of well visible 1.46 MeV background gamma-line of K-40, then the energy of gammas in keVs was calculated. It allowed to minimize the effects of false variations connected with temperature drift of the detector characteristics*

Thermal variations of the position of K-40 line

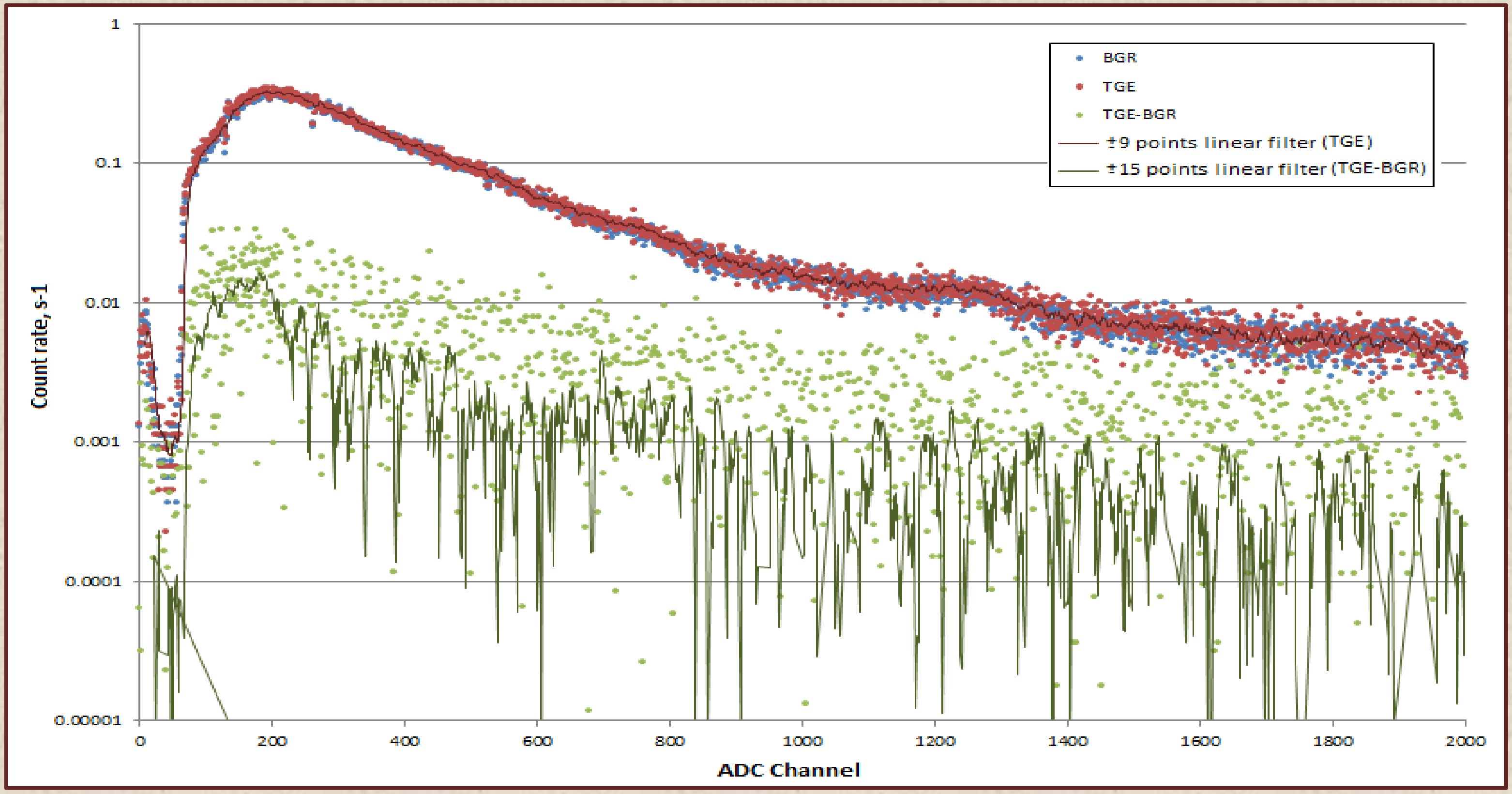


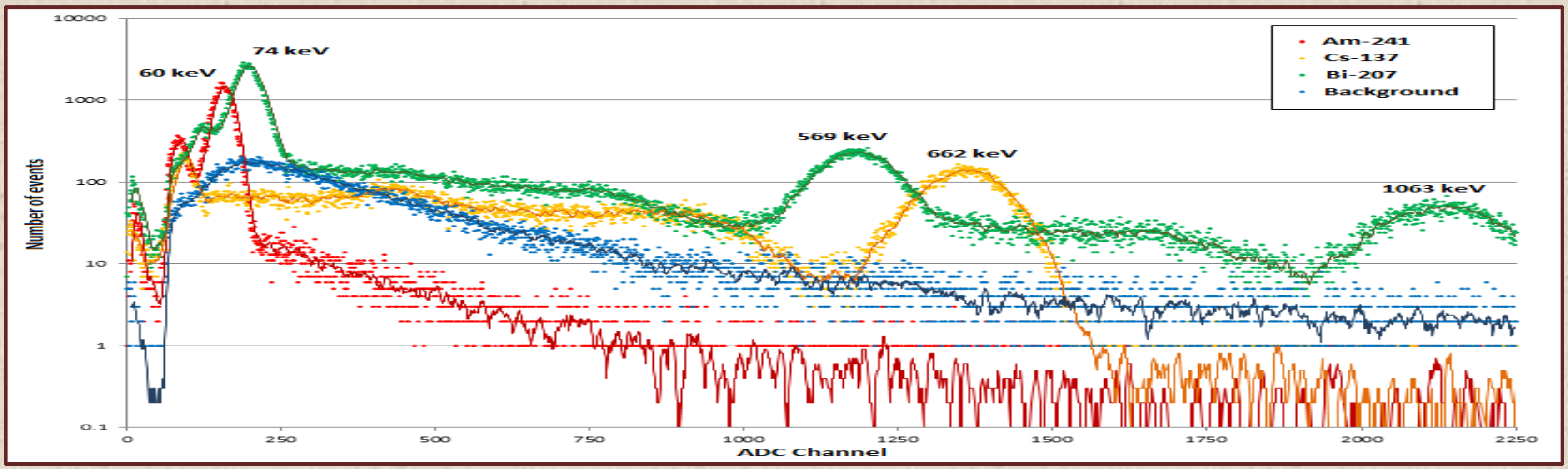
Measurements with NaI(Tl) detector in Nor-Amberd

22.09.2014 (during TEPA-2014)

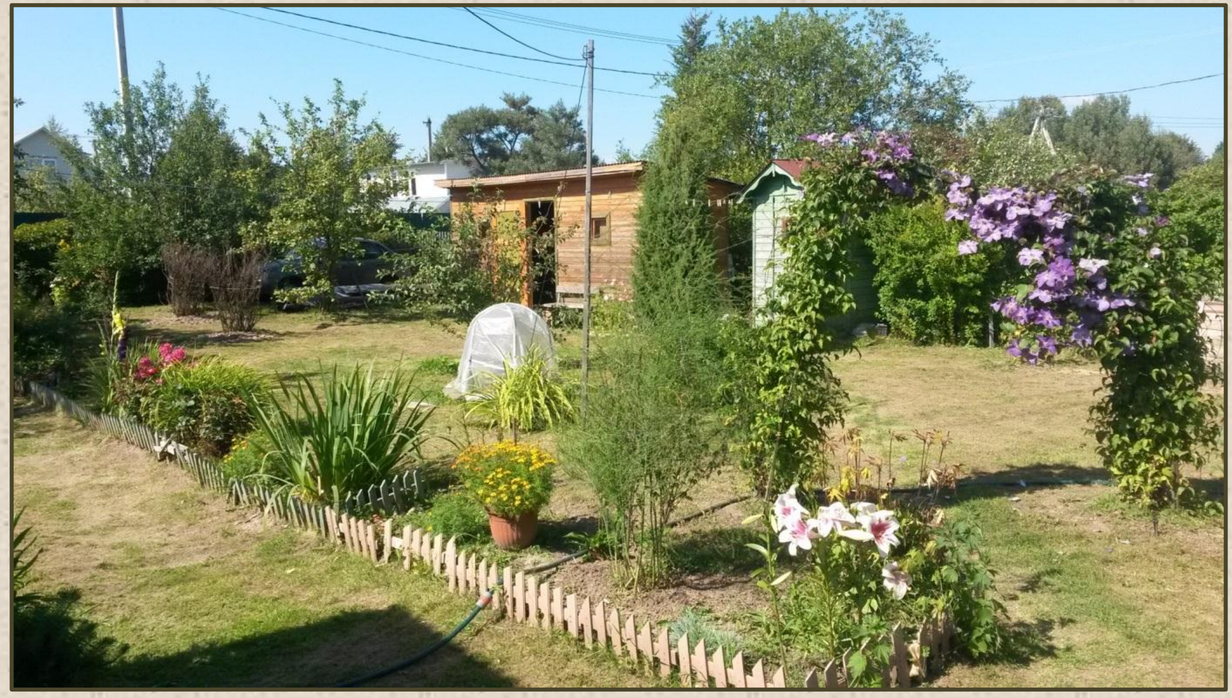


Energy spectrum of TGE 22.09.2014

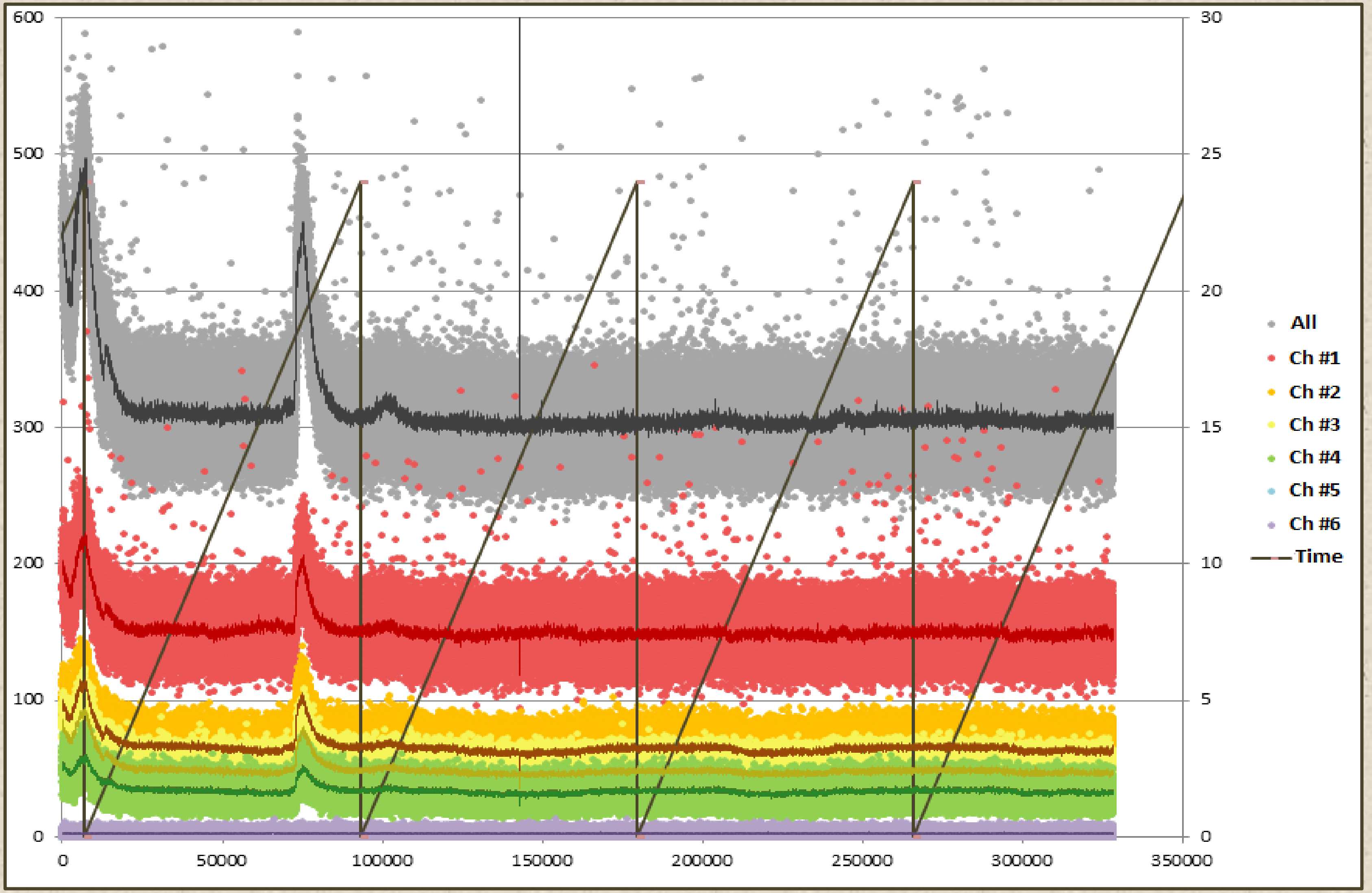




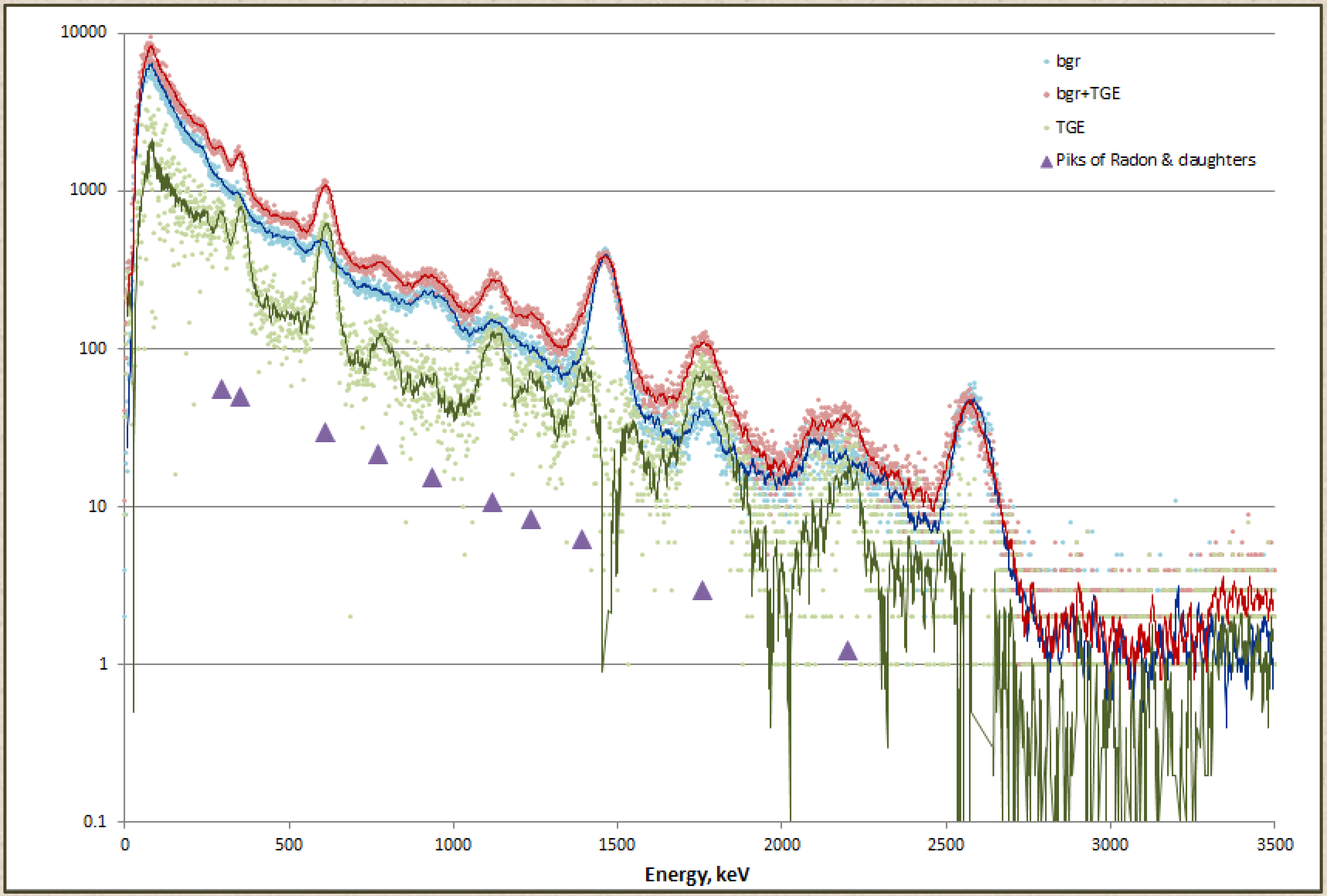
Observations 50 km North from Moscow



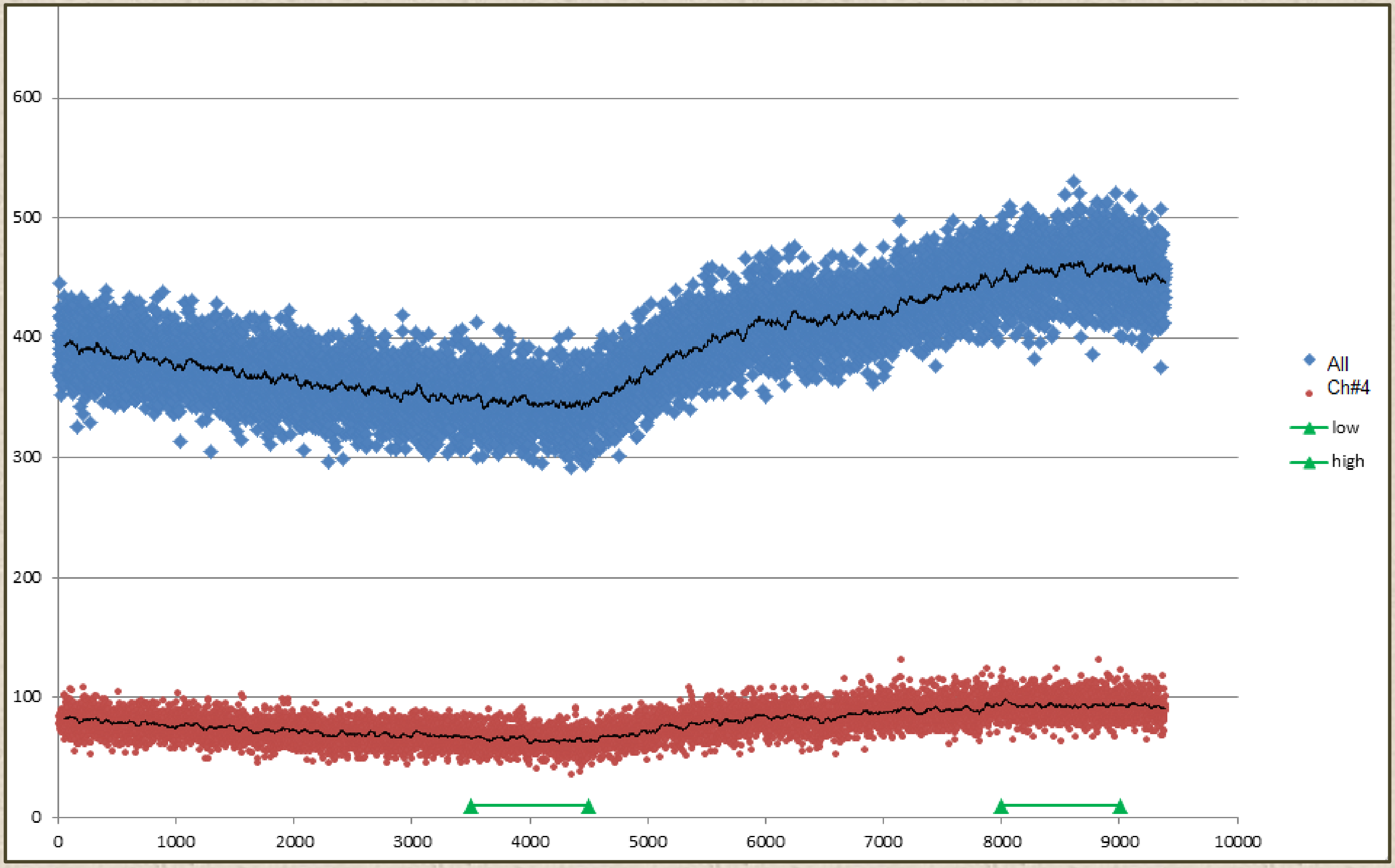
27-30 of July 2015.
Conditions: thunderstorms (peaks), rain, next - clear weather



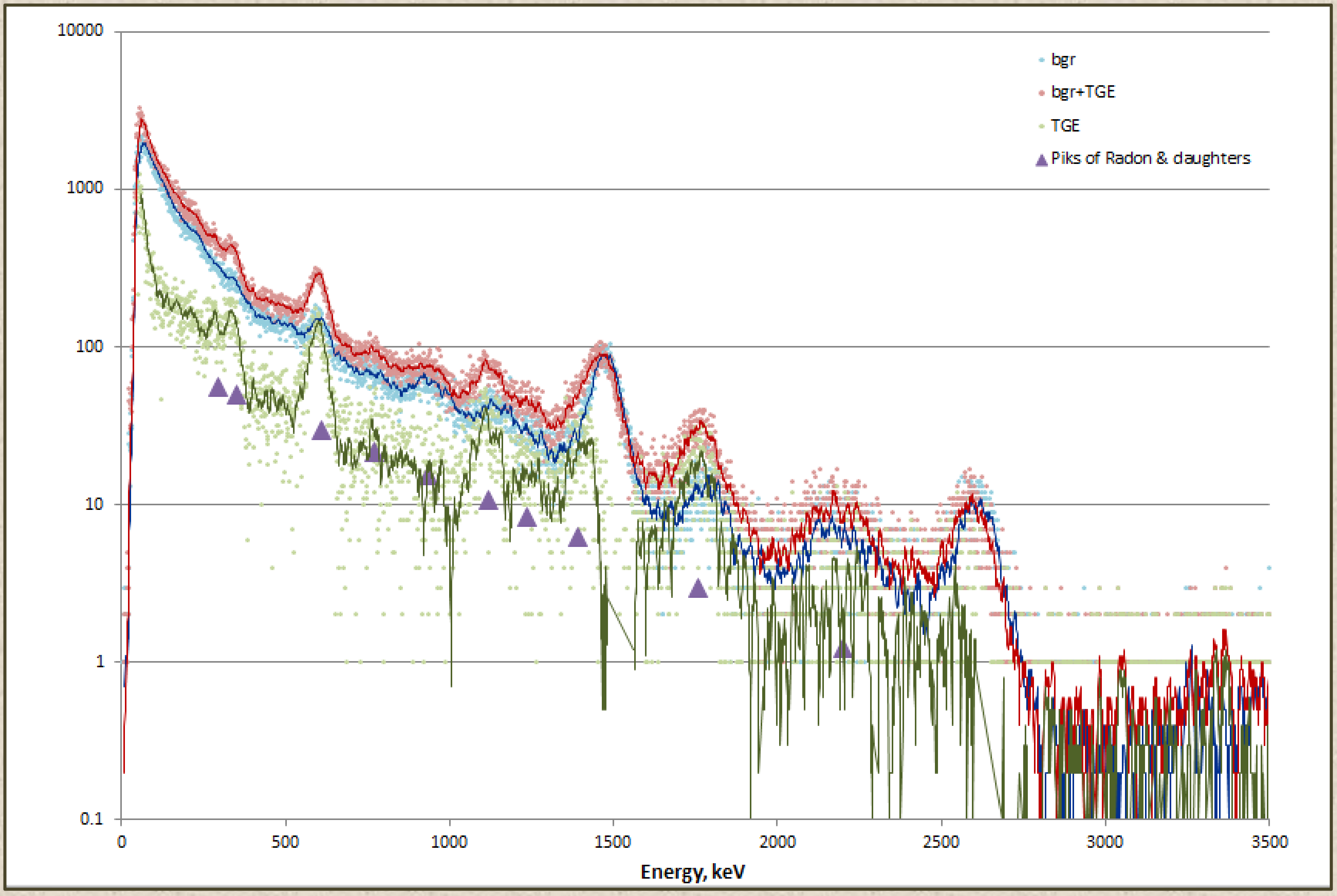
Energy spectrum of TGE 28.07.2015



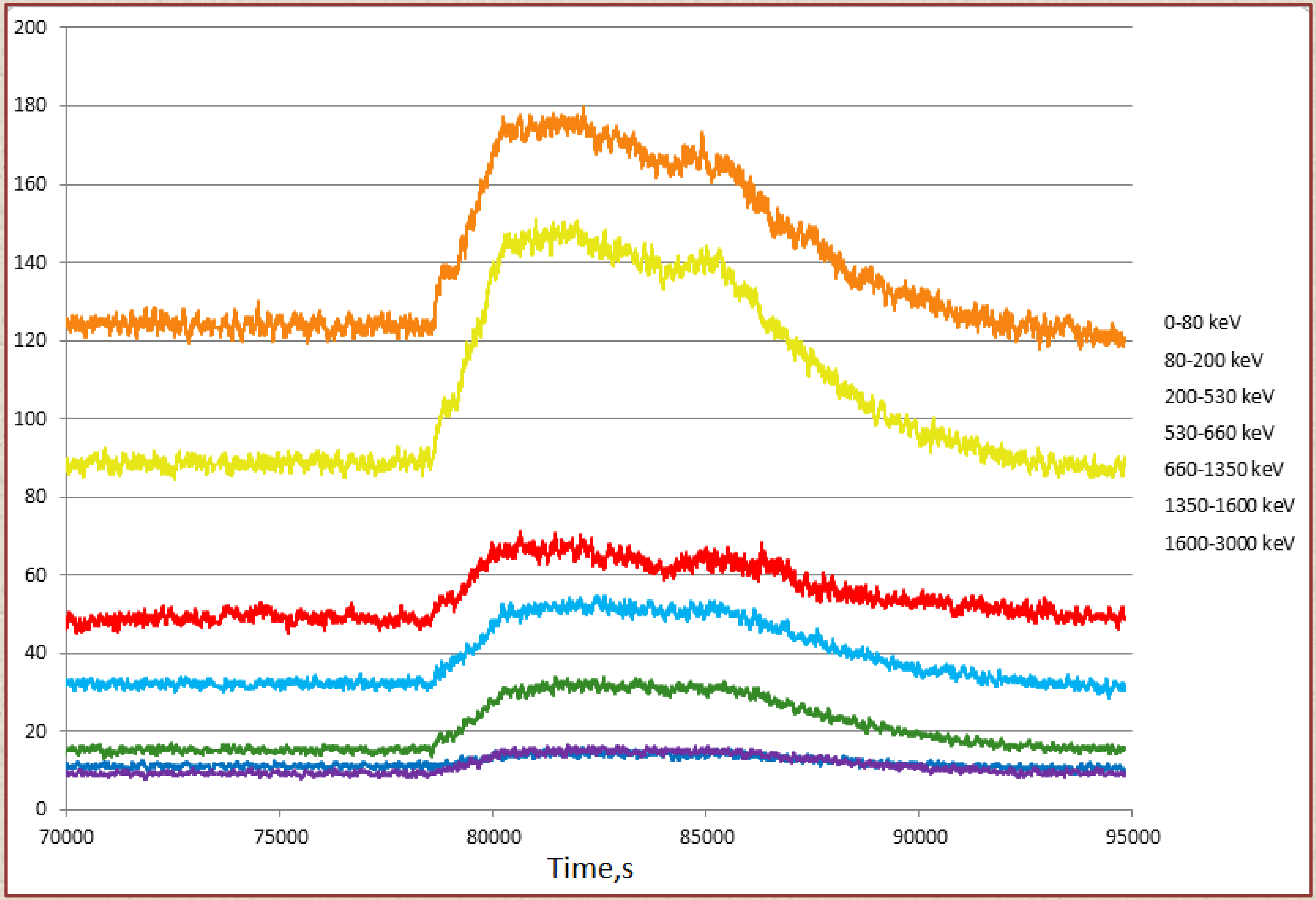
05 of September 2015.
Conditions: small rain without thunderstorms



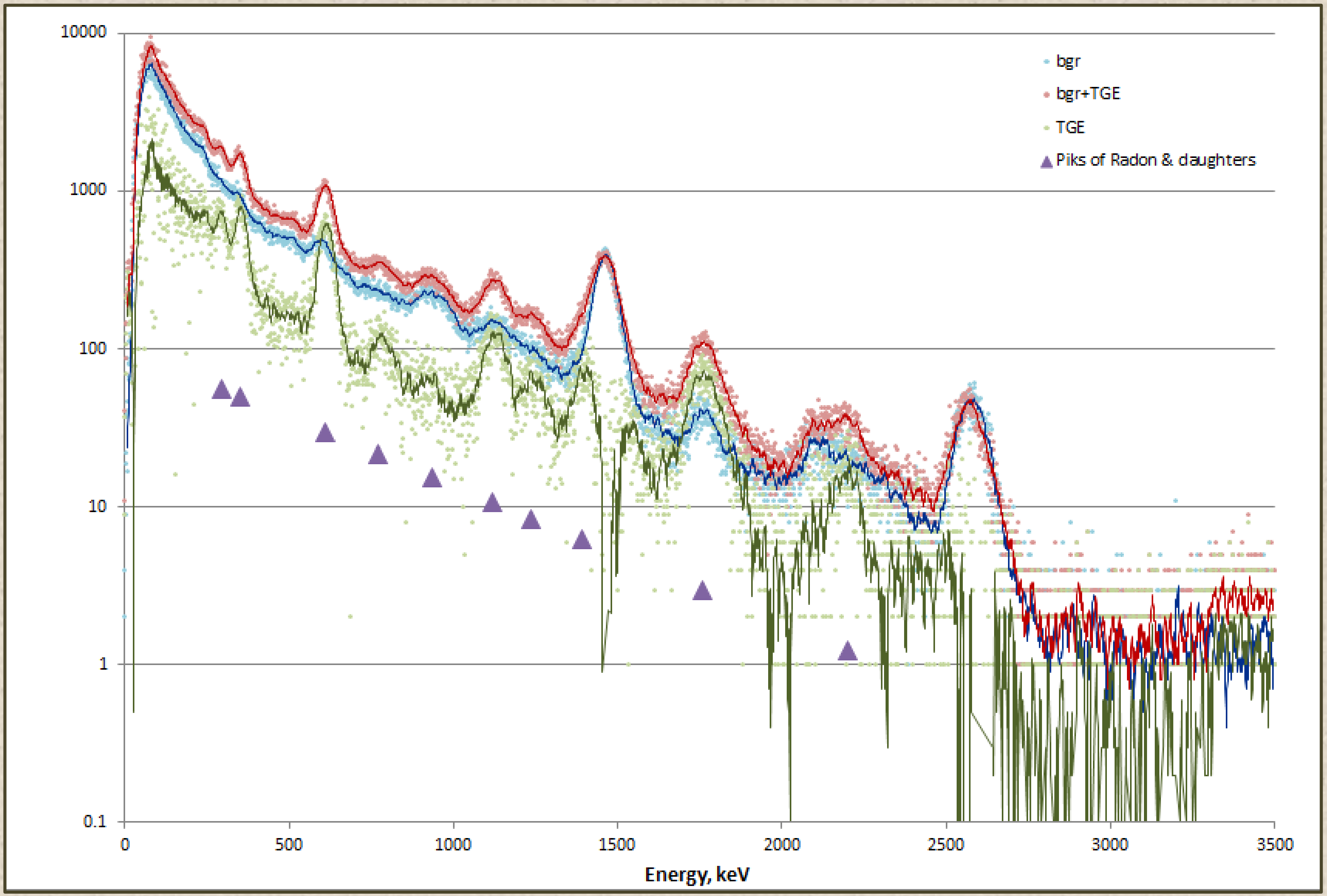
Energy spectrum of 05.09.2015



27 of September 2015.
Conditions: clear weather, then thunderstorm with powerful rain, then the rain stopped and the sun appeared



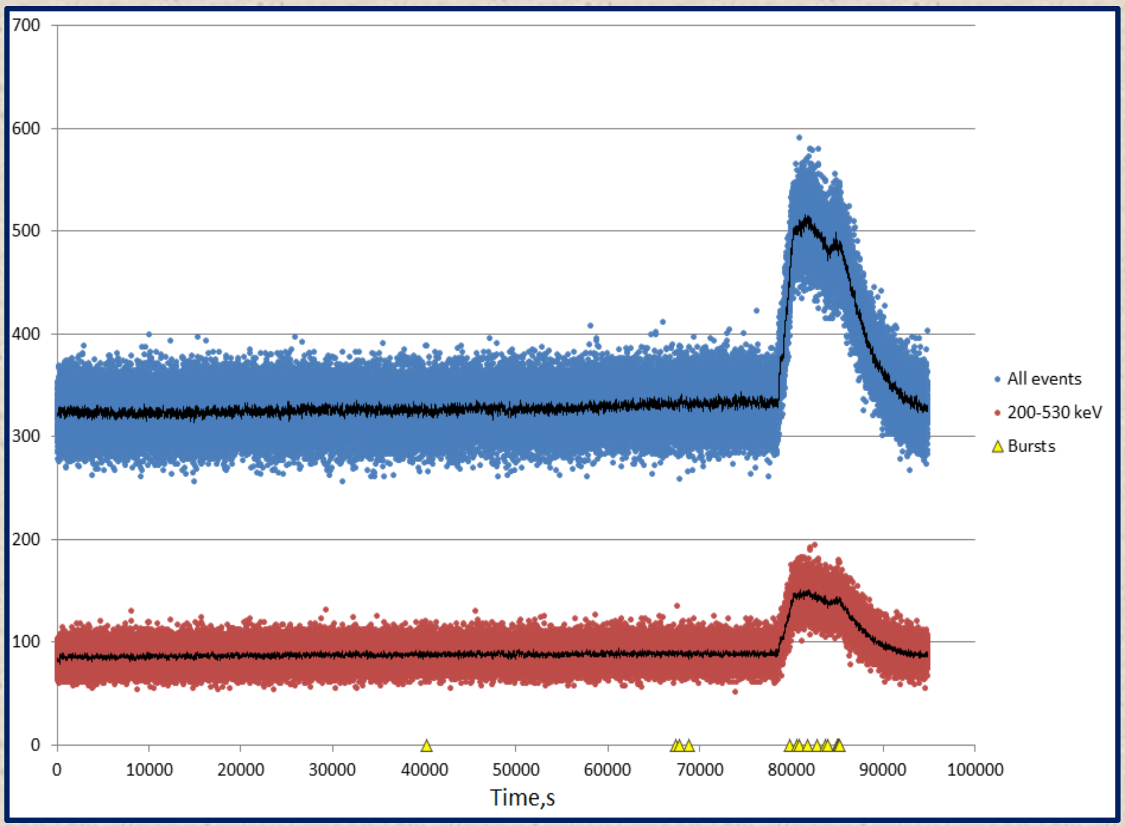
Energy spectrum of TGE 27.09.2015

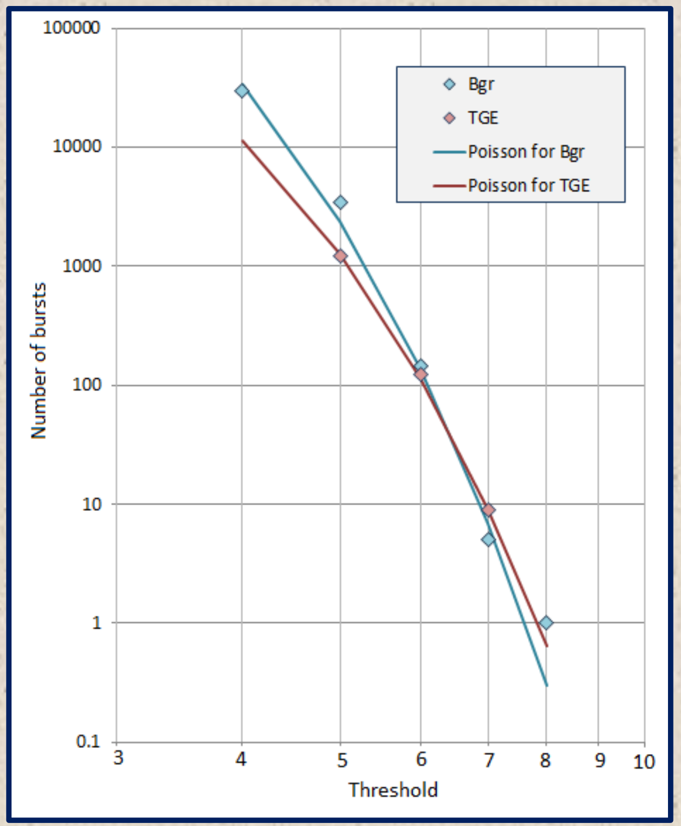


Search for short bursts

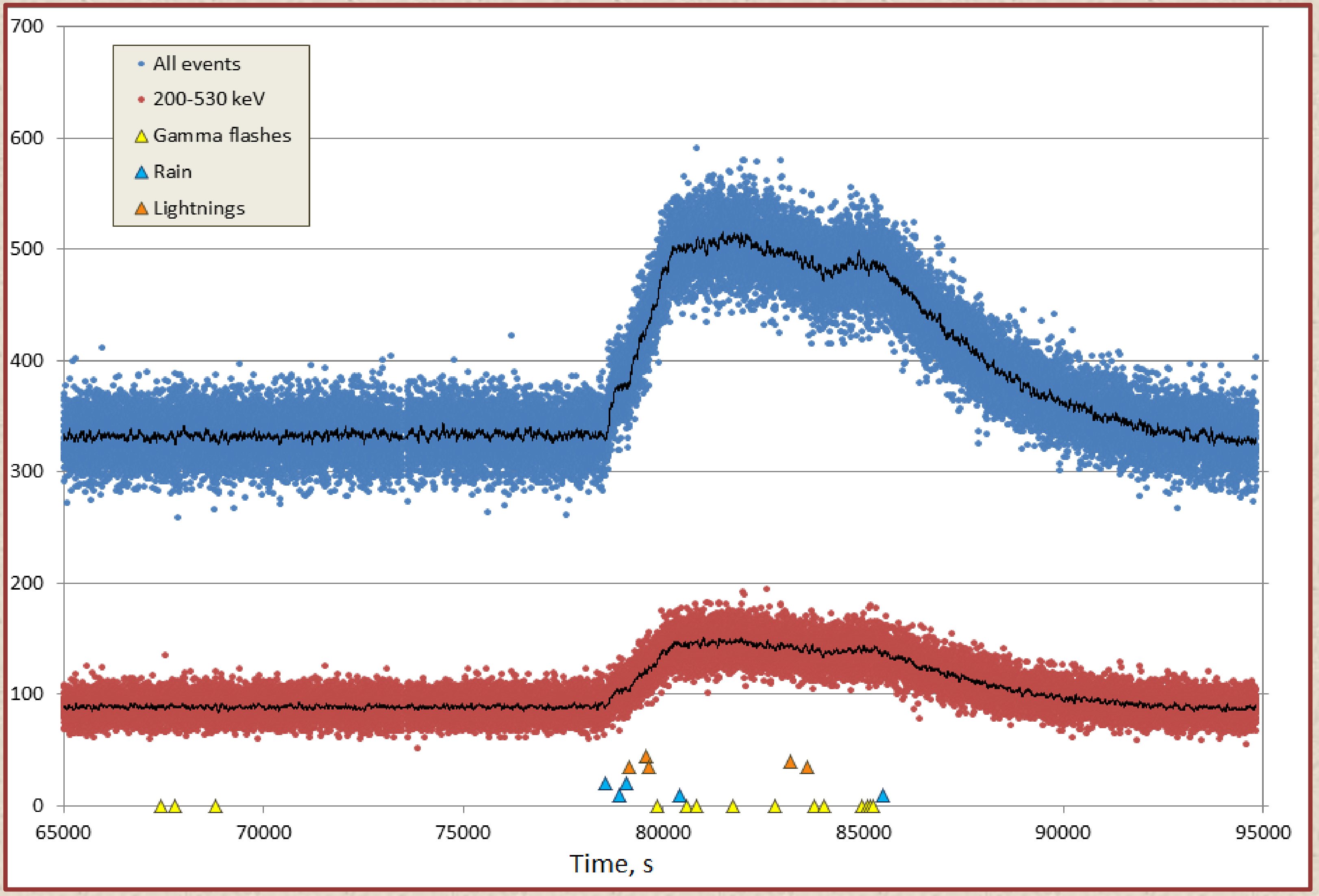
The data of thunderstorm 27.09.2015 were processed. The moments of short burst candidates when >7 gammas occur in 1 ms were determined (yellow triangles)

The graph of expected number of imitations vs threshold value shows that probably all candidates pointed on the left figure are random and the criterion must be some harder with threshold of 9 gammas per 1 ms. Such events were not observed.



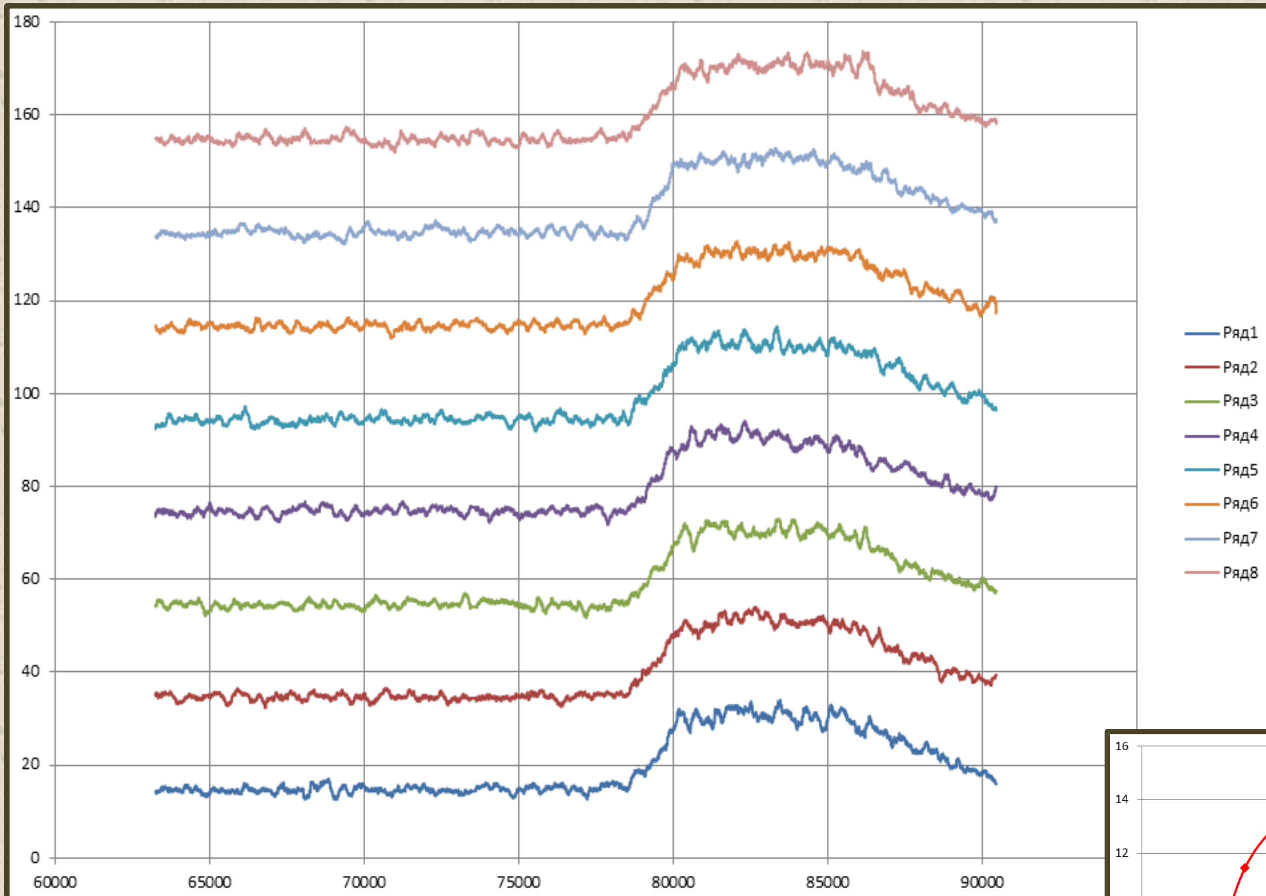


Comparison with weather

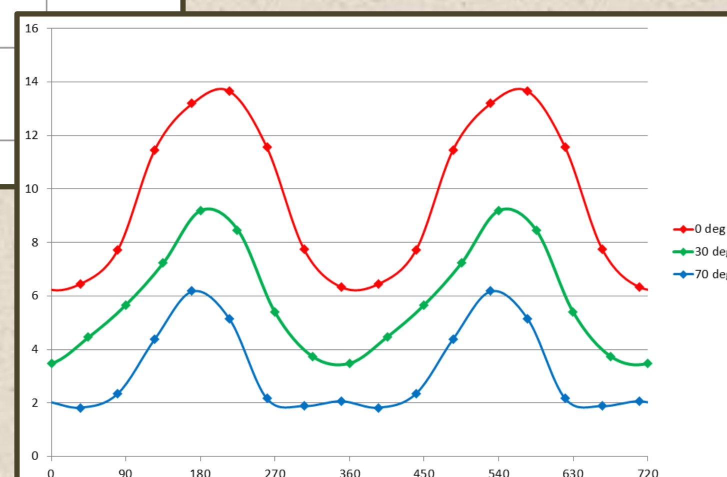


1) There are no gamma-ray flashes at the moments of lightnings
2) The moment of gamma-ray flux increase exactly coincide with the rain start.
3) When the rain stops the TGE decays exponentially with time index ~1h

Test for directivity

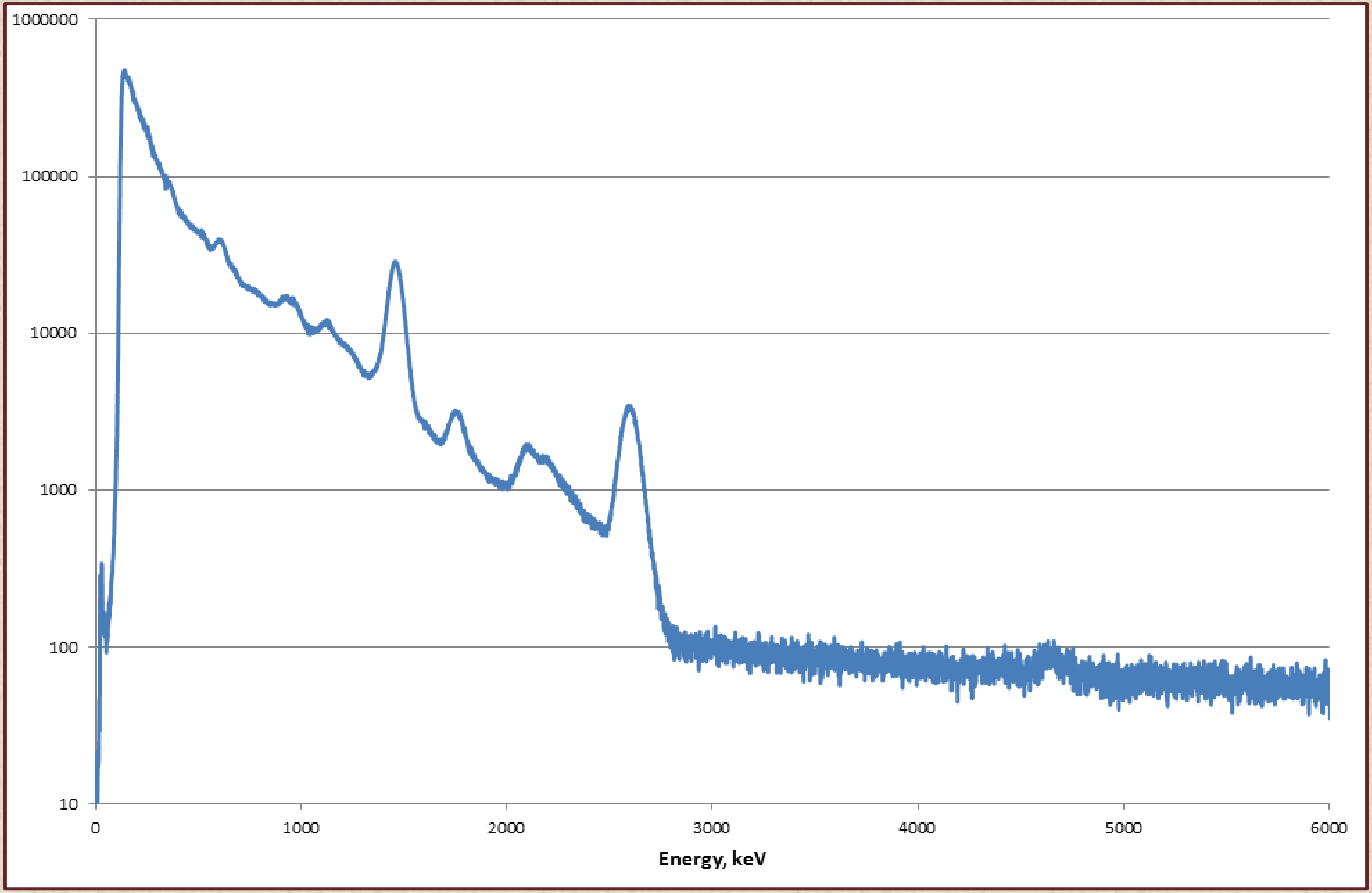


Monitoring data plotted separately for 8 directions (graphs are shifted with 20 unit step)

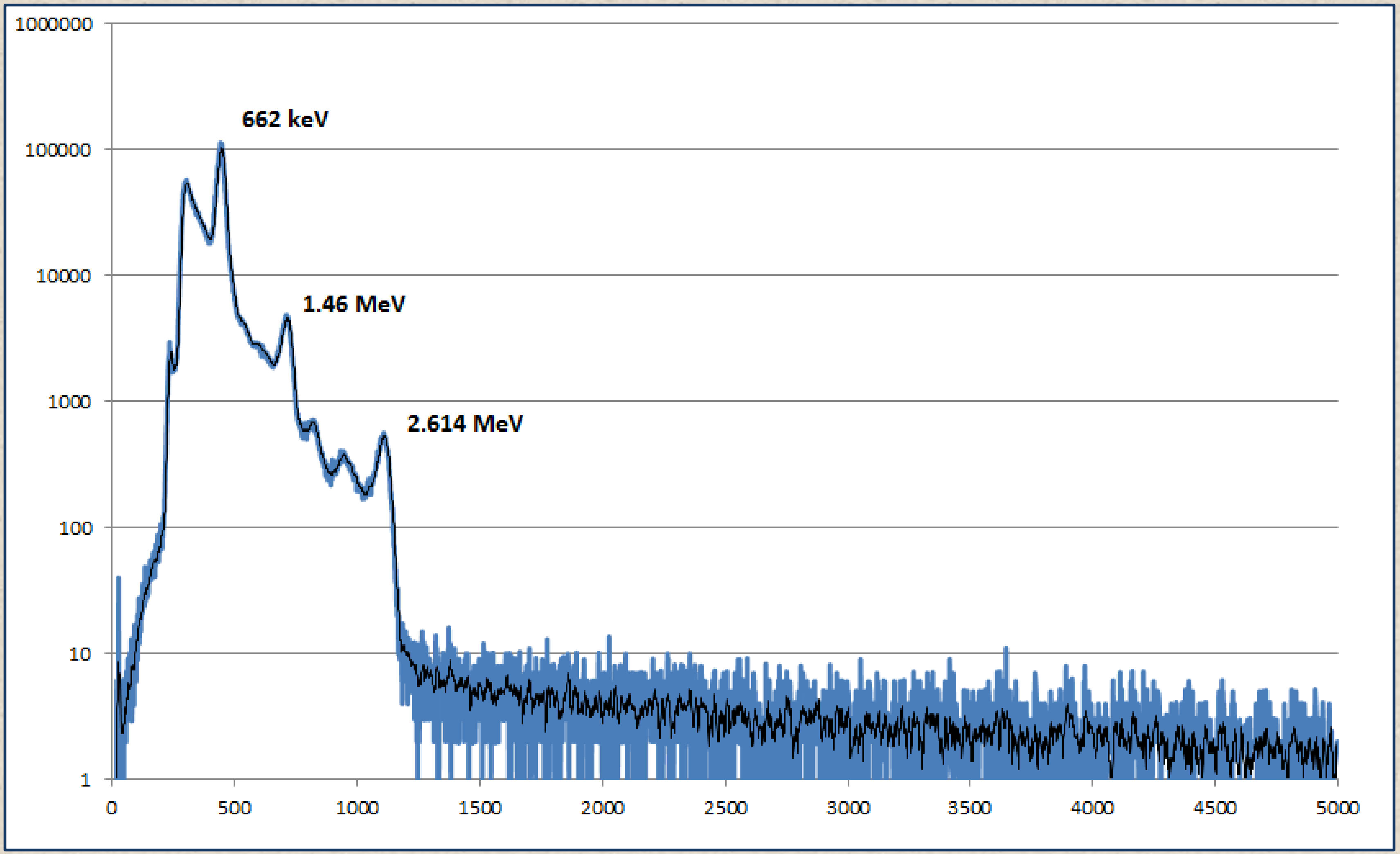


Angular characteristics for 662 keV for tetta=0 deg, 30 deg and 70 deg

Measurements in extended energy range

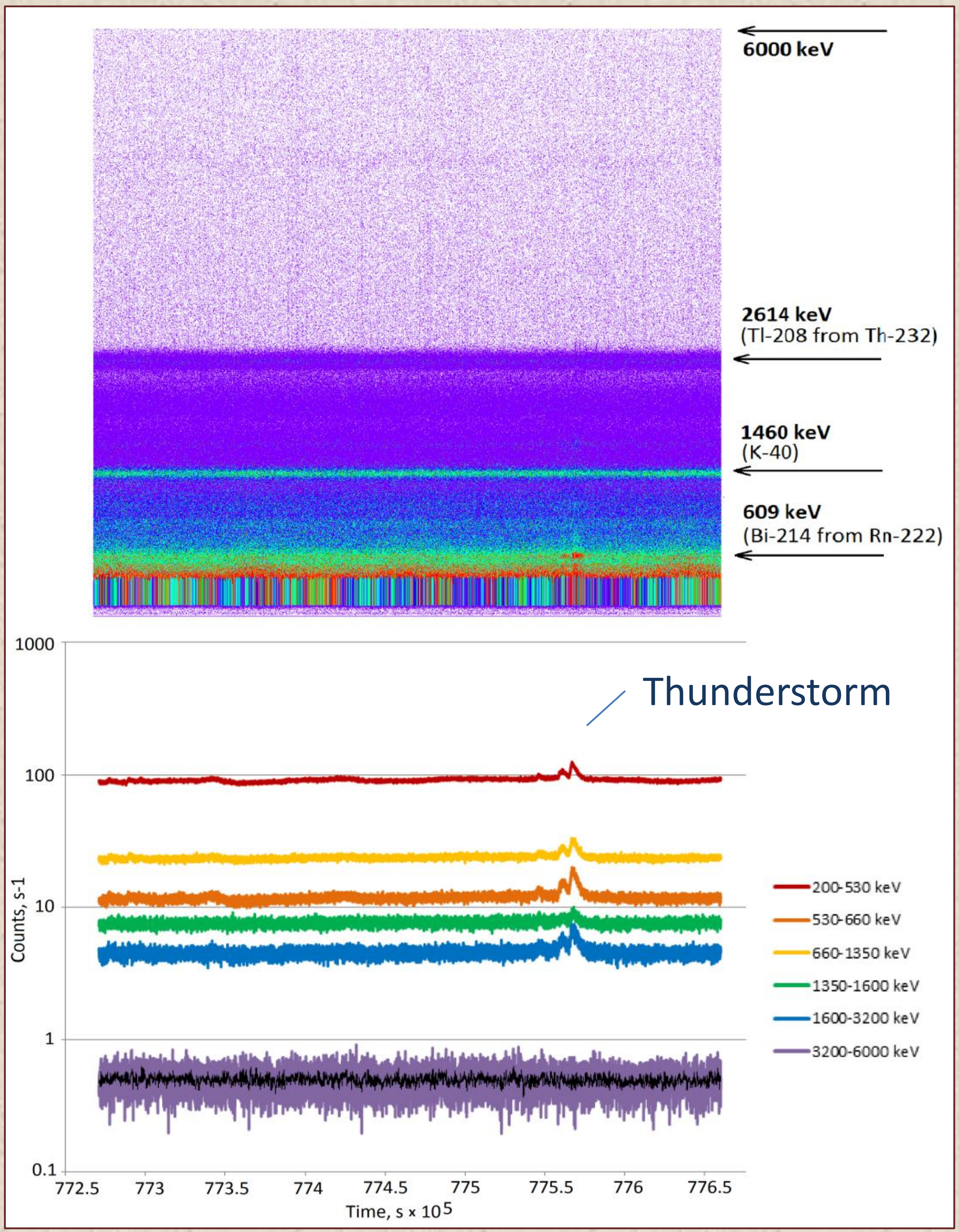


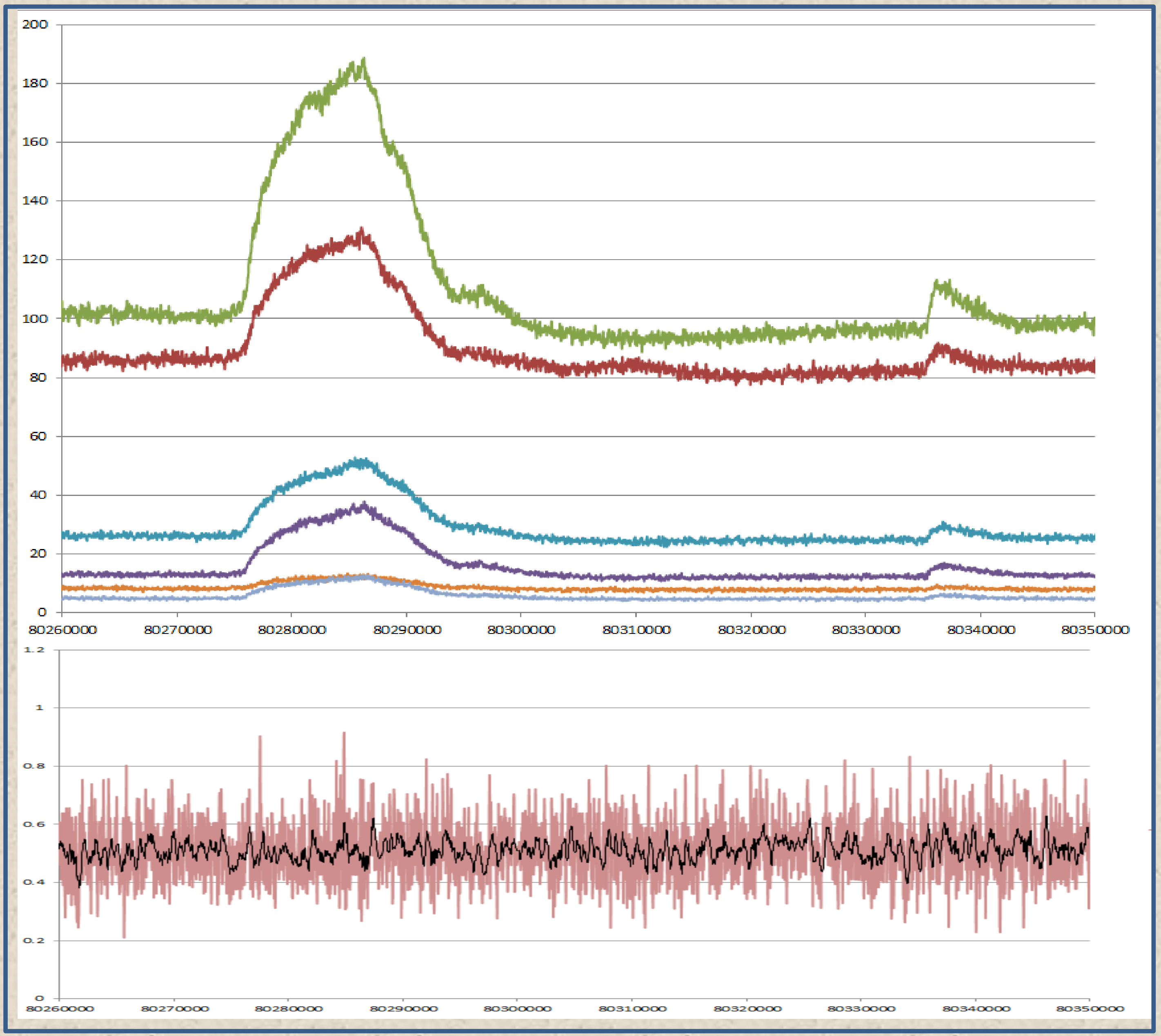
Calibration energy spectrum obtained with 10 cm CsI(Tl) detector on 2016, may (in energy range up to 15 MeV)



One can see no change of gamma-ray flux in energy range E>3200 keV.

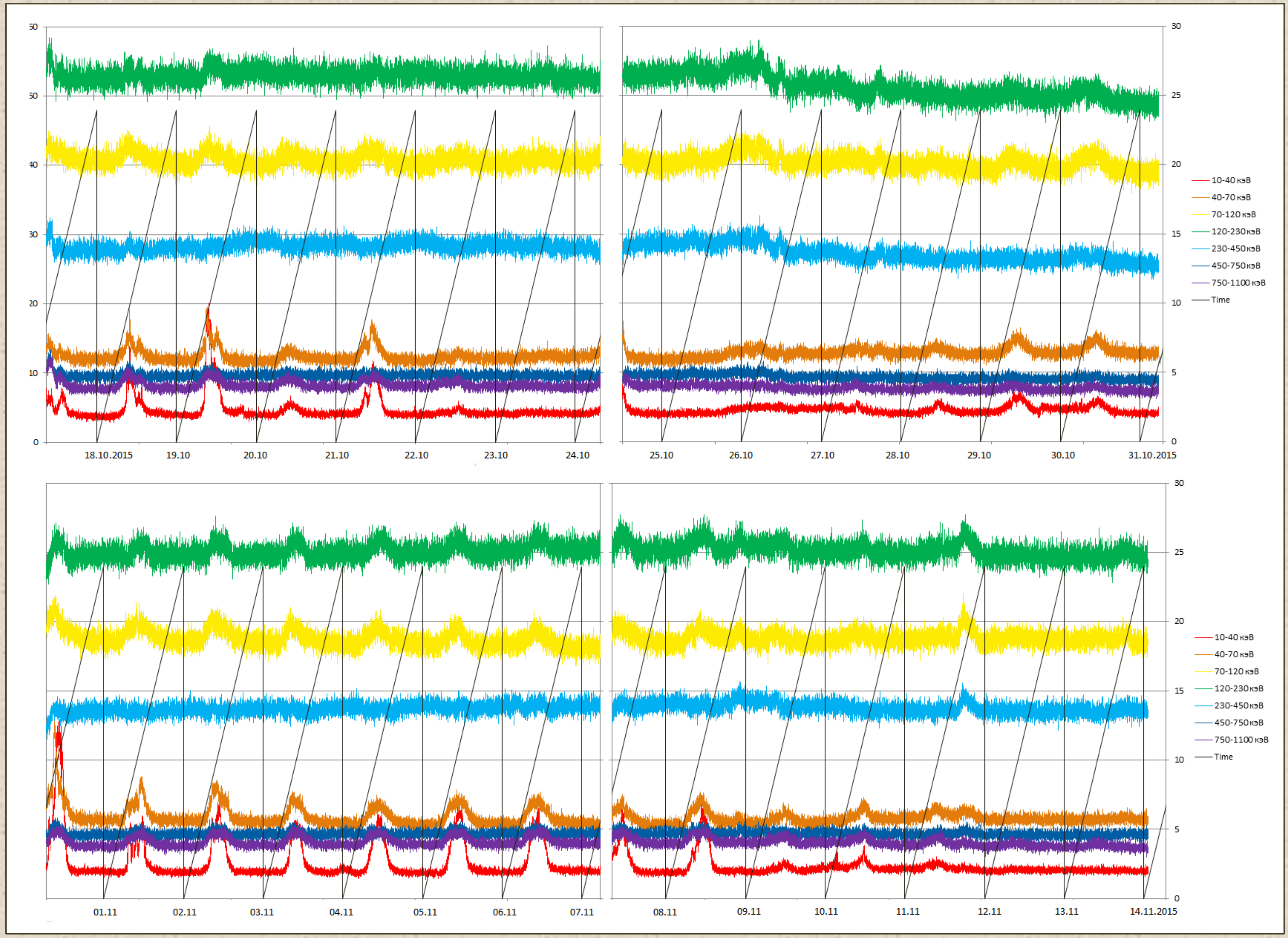
The increase of the instrument readings in low energy range can be explained by Rn-222 daughters.





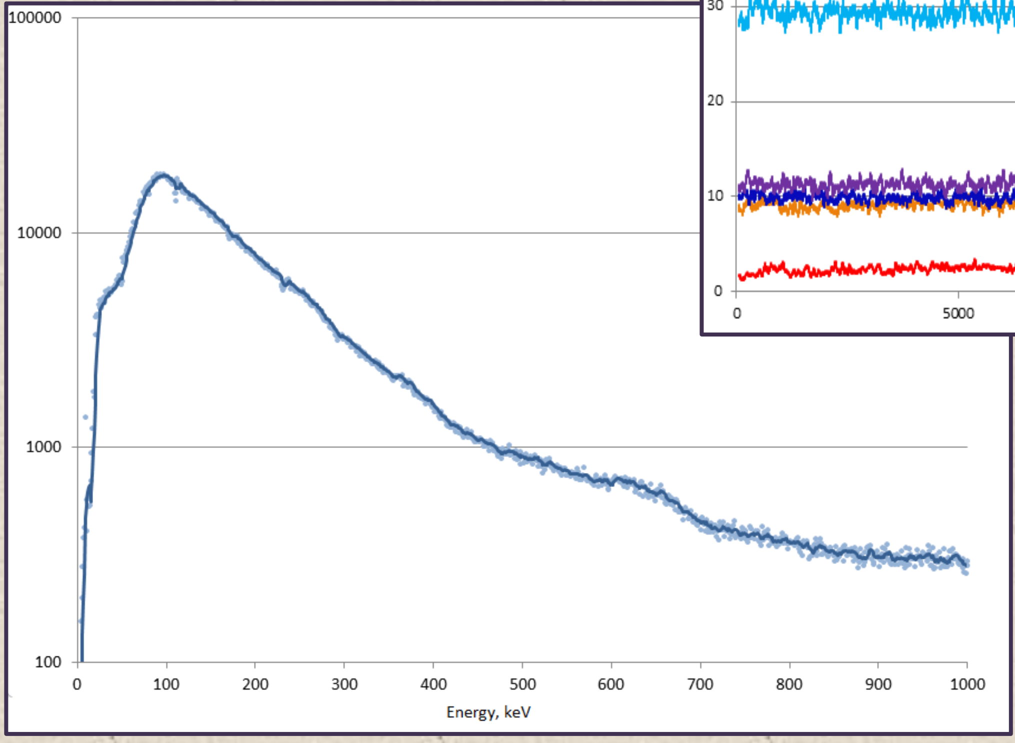
Increase in 3200-6000 keV range s 1.4%. It corresponds to 1.8 sigma level of significance

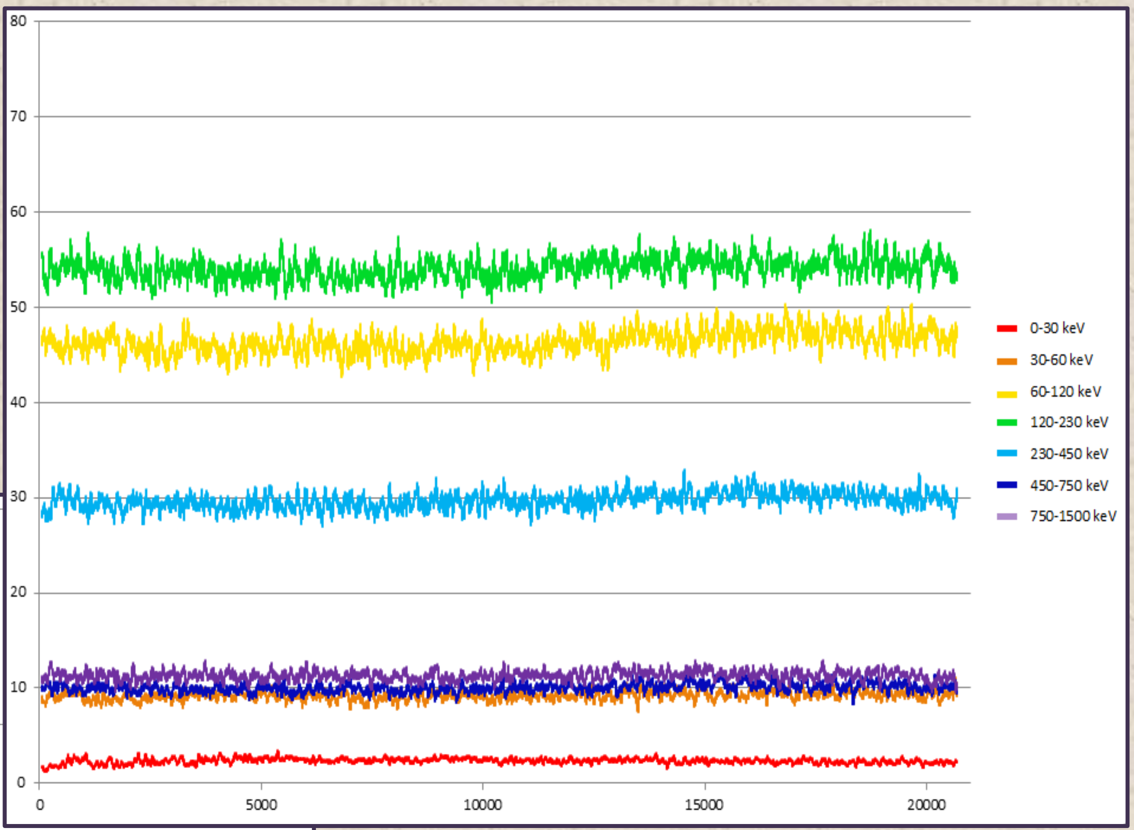
Gamma-ray flux monitoring on Aragatz mountain (3200 m)



Energy spectrum obtained on Aragatz station (3200 m) 04.10.2015

Energy spectrum

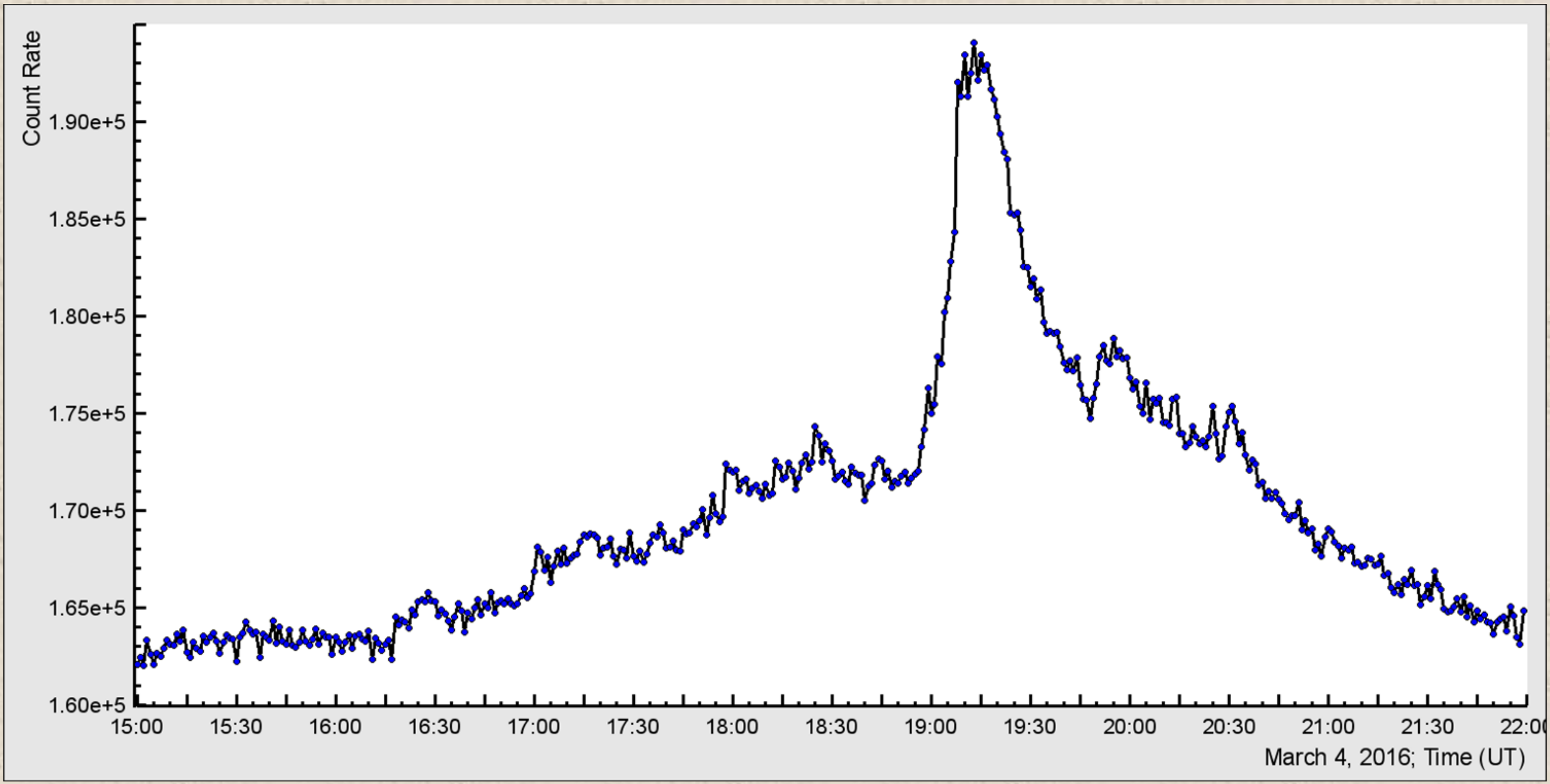




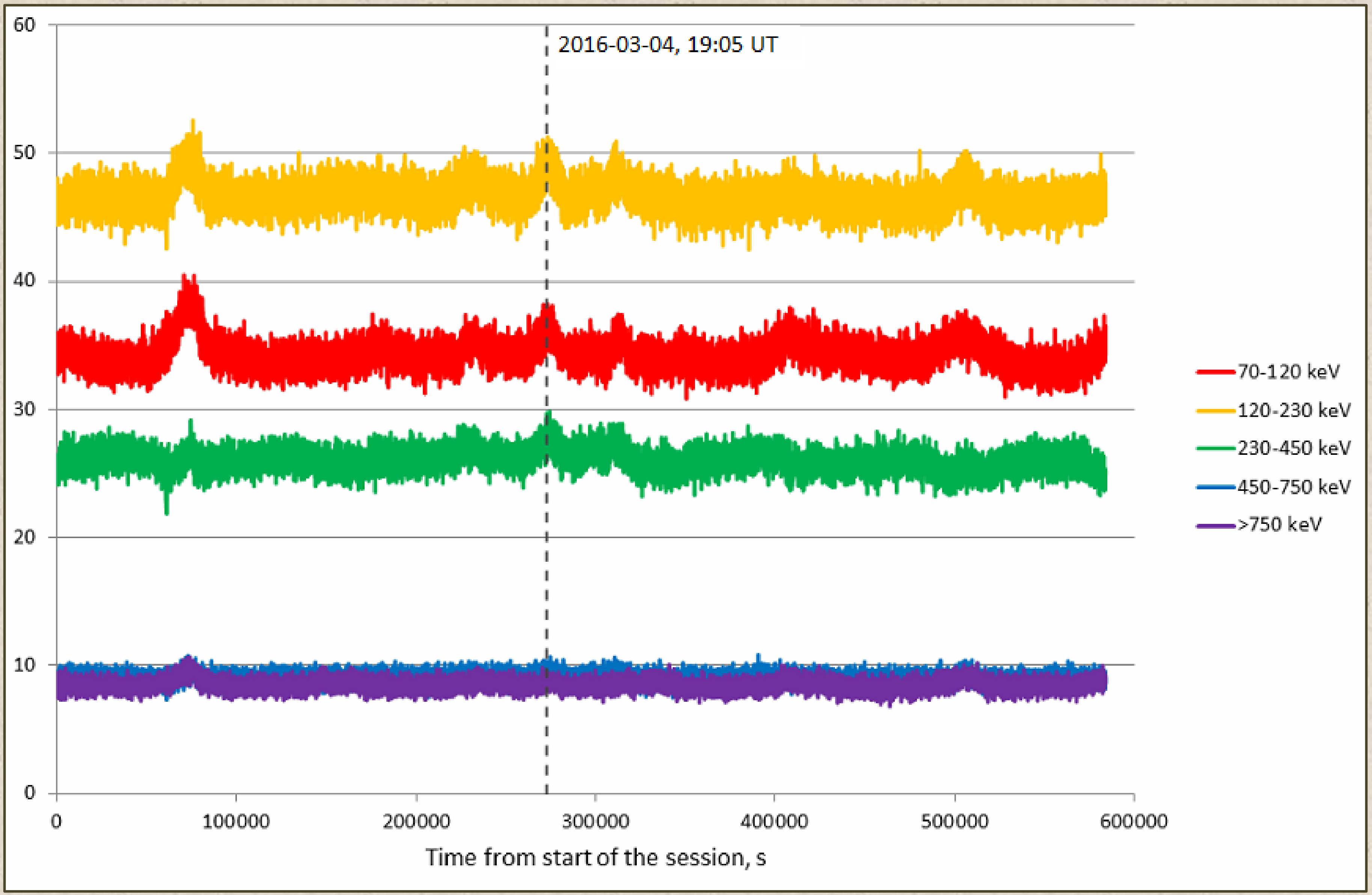
Monitoring in several channels

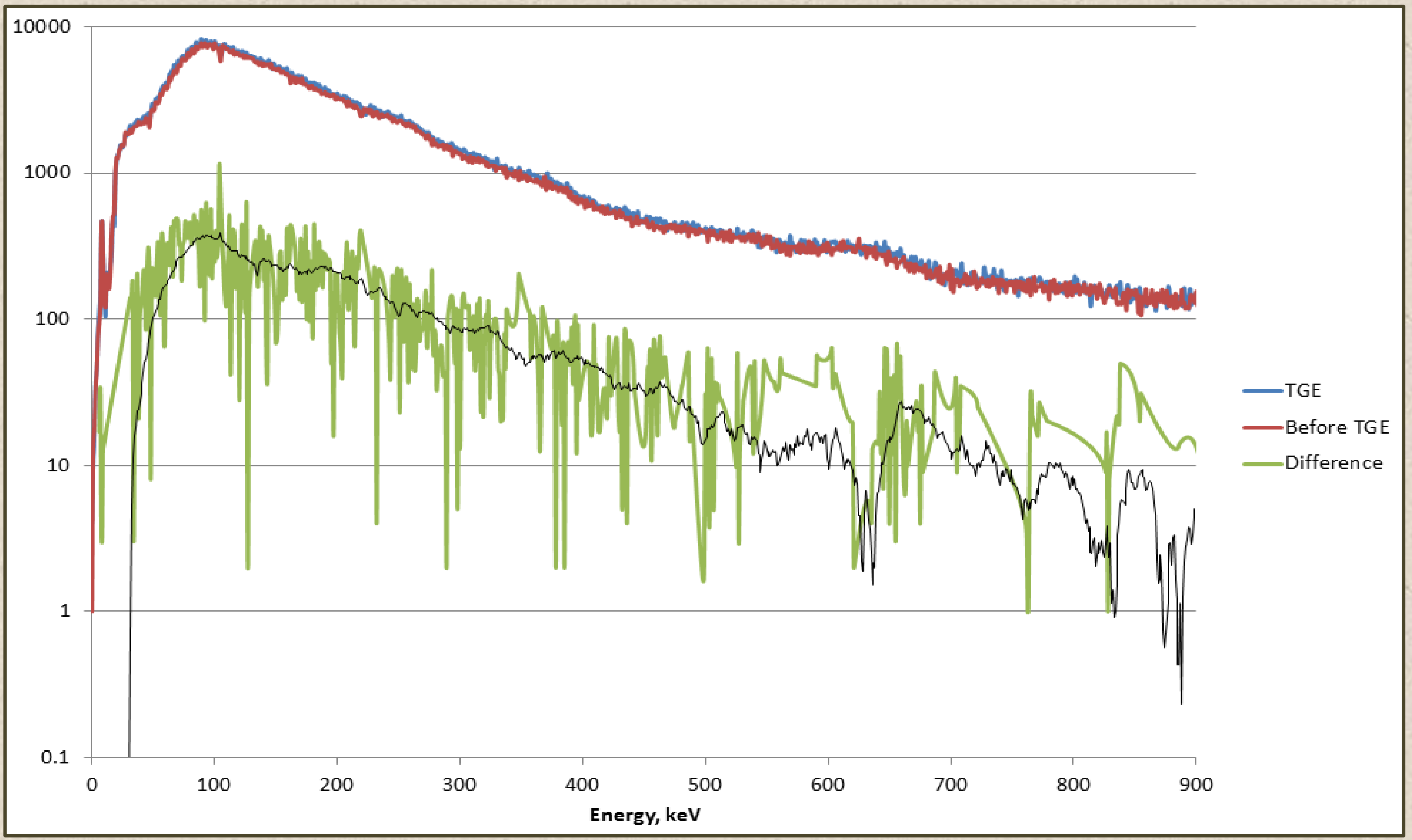
Measurements on Aragatz during TGE 2016-03-04

From A.Chilingaryan group



From SINP MSU gamma-detector

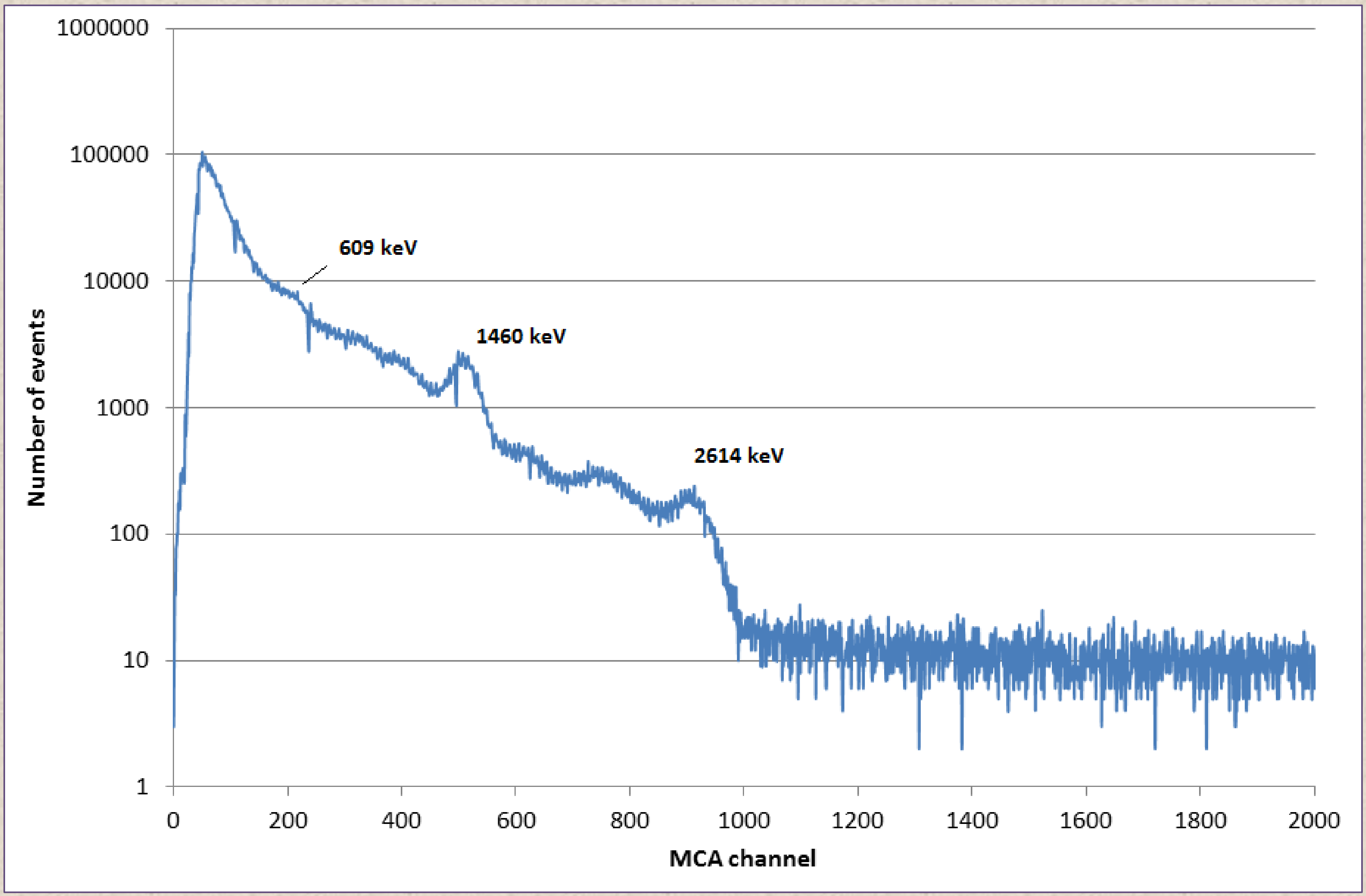




One can not conclude whether the 609 keV line is present in additional radiation spectrum or not.

The detector on Aragatz must be improved to have better sensitivity for gamma-lines detection

Background spectrum measured 03.10.2014 in Nor-Amberd with modified gamma-ray spectrometer (5cm NaI(Tl)



Conclusions:

- Rn-222 (with daughters) is responsible for most of gamma-background variations in energy range E<2.5 MeV observed at the moment of rainfall.
- No significant increase of 3200-6000 keV gamma-ray flux during thunderstorm was observed in Moscow region.
  3 sigma upper limit is $2.4 * 10^{-4}$ $cm^{-2} * s^{-1}$
- No short flashes were observed during thunderstorms
- Gamma-spectrometer with enough good energy resolution (~10% on 1 MeV) working in the energy range including E>3MeV is needed.

The measurements will be continued!

Thank You!