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Intensity variation of the Cosmic Muon Induced Annihilation Line

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► Cosmic muons produce showers of secondary particles (e-, e+), mainly in the detector shielding

► Consequently, these particles produce bremsstrahlung and annihilation quanta .

► If photon energy exceeds the threshold energy of $2m_ec^2$ (1022 keV), it can create a e-e+ pair in the field of nucleus. The probability of this creation depends on Z^2 and increases with the energy of photon. At rest, the e+ will annihilate with an e-, creating two quanta of 511 keV.

► muon can directly produce e+e- pair in the field of atomic nucleus, μ(Z, e+ e- Z)μ

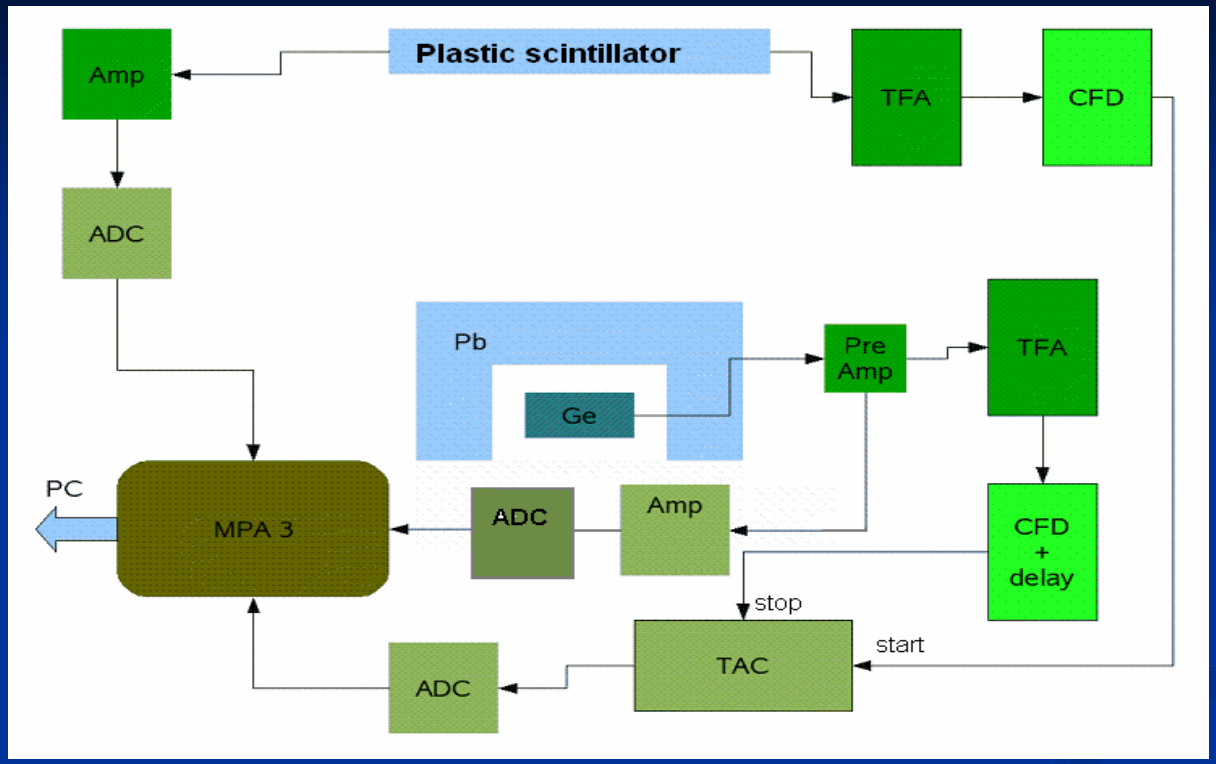
► The Doppler broadened annihilation line is seen in all background spectra of Ge detectors

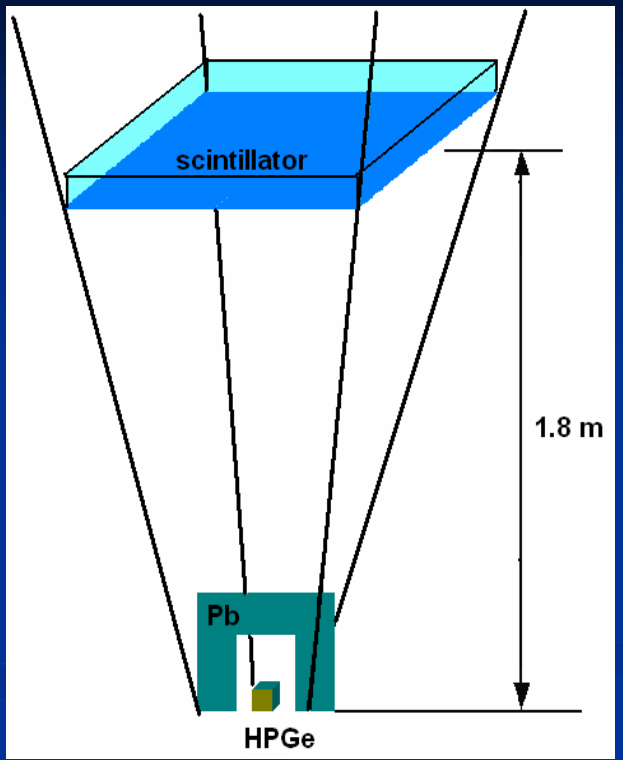
► The production of positron annihilation radiation by cosmic muons in different materials , near the sea level , is already measured [Puzovic,Anicin]. It is found that the *average rate* of annihilation emission per unit mass of material can be expressed as $R` = q\ Z^2/A$, with q = 8.1(3) x 10^{-6} $s^{-1}g^{-1}$. In the case of lead (the most frequently used shielding material of HPGe detectors) , the calculated rate is 2.6 x 10^{-4} $s^{-1}g^{-1}$.

► The *time dependence analysis* of the annihilation line intensity can improve the background events simulation of HPGe systems with extremely low counting rate.
Intensity variation of annihilation line is correlated to the variation of Compton continuum caused by annihilation photons scattering.

► Hence, the low-background experiments, generally, and low-background experiments based on searching for the time variation of spectral events number (in the low energy spectral region), would have better procedures for identification of rare events (for example WIMP detection) taking into account variation of all annihilation events .

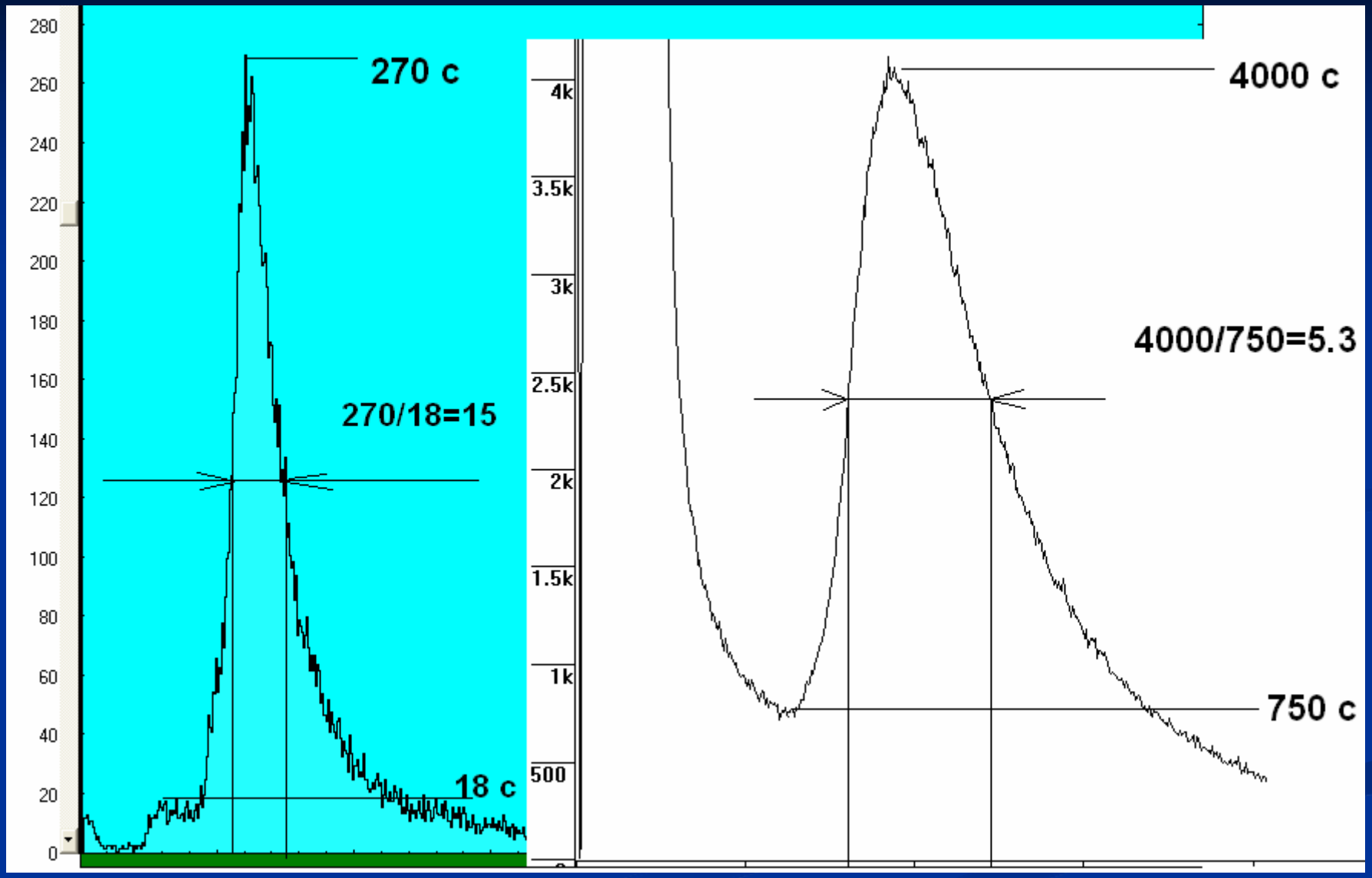
The scheme of the experimental setup





►The plastic scintillation detector (dimensions of 0.5 m x 0.5 m x 0.05 m) and the HPGe extended range (GMX) detector operate in the coincidence mode ; plastic detector treshold ~ 5 MeV; mass of the Pb shield 708 kg; solid angle plastic -Ge detector 0.077 sr

► We used the MPA-3 multiparameter system for data acquisition. Only the coincidence events from TAC module, Ge detector and plastic scintillator are registered by the system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240
220
200
180
160
140
120
100
80
60
40
20
0
270 c
270/18=15
18 c
4k
3.5k
3k
2.5k
2k
1.5k
1k
500
4000 c
4000/750=5.3
750 c

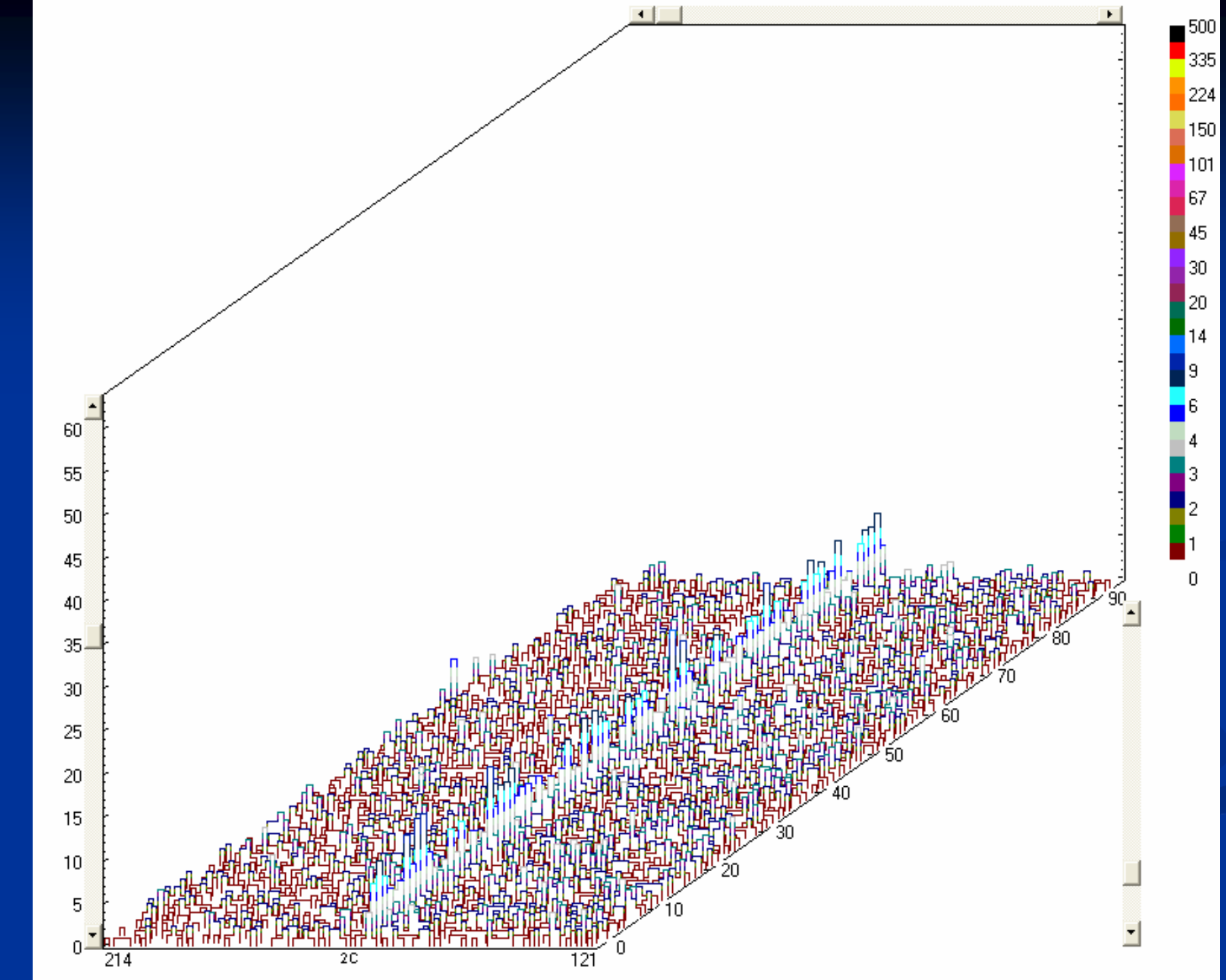

MPA-3
MPA-3
ADC
ADC
ADC
ADC

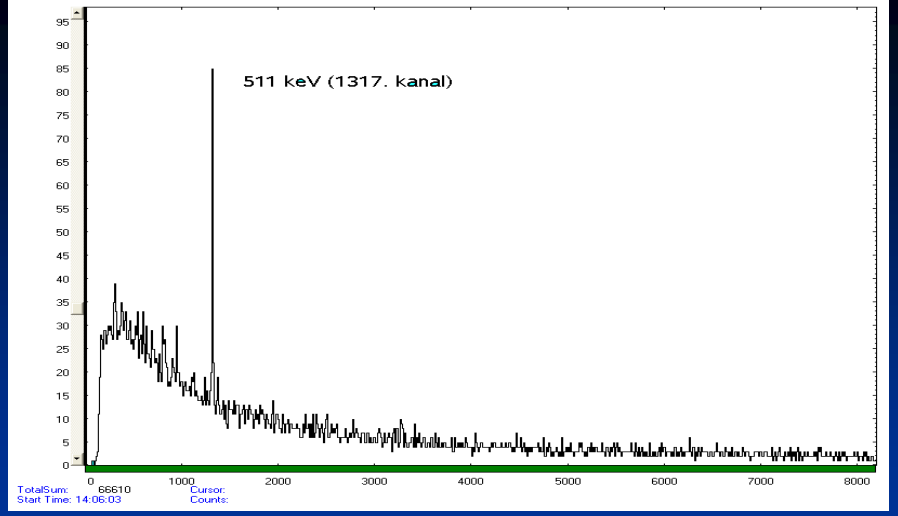
►The TAC range was 10 μs (i.e. maximal time interval between two coincidence pulses from plastic detector-START pulse and Ge detector -STOP pulse) and FWHM of the true coincidence peak in the TAC spectrum was 250 ns. The relative number of events outside of coincidence peak was only 7 % (including delayed true coincidence events) Hence, the contribution of the random events to the coincidence Ge spectrum is negligible.

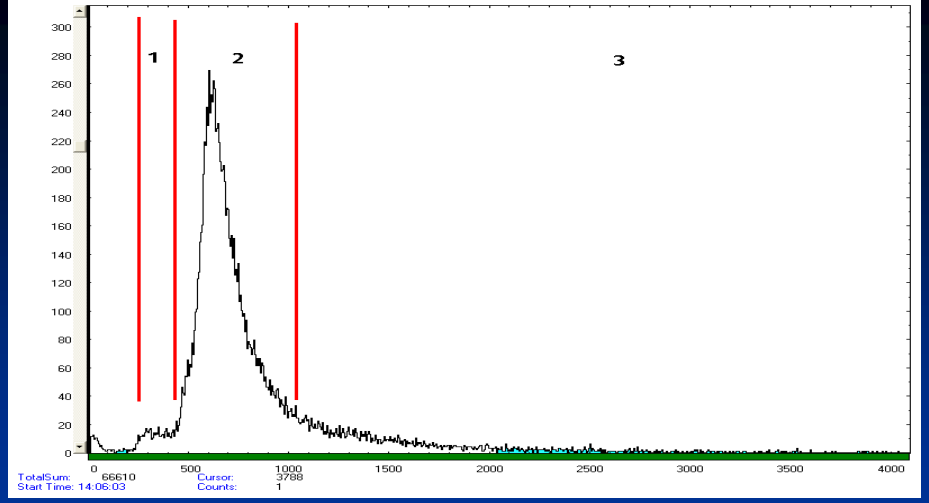
►Without TAC module, the coincidence resolving time of the circuit would be about 50 μs ,leading to higher contribution of the random events.

►The total time of data acquisition was 1 688.4 ks (from November 17-th to December 7-th of 2006.).

►The MPANT program is used for acquisition of the following spectra: coincidence spectrum of Ge detector, coincidence spectrum of plastic detector, TAC spectrum, the two-dimensional (2D) time dependent spectrum of plastic detector and two-dimensional time dependent spectrum of HPGe detector. The 2D spectrum represents the time variation of events number in each channel of Ge spectrum, or spectrum of plastic detector . The events are registered in steps of 5 h.

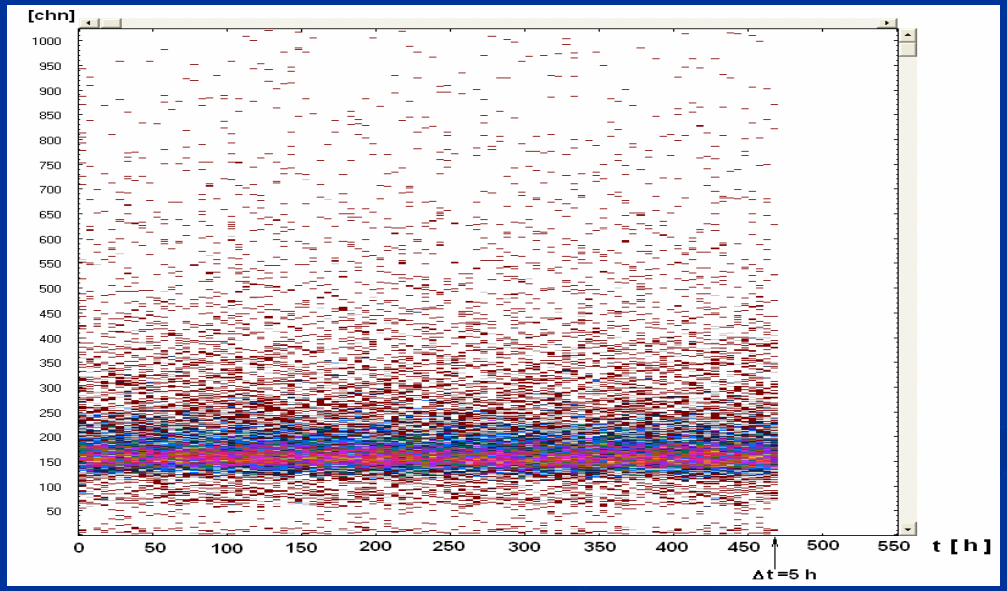

500
335
224
150
101
67
45
30
20
14
9
6
4
3
2
1
0
60
55
50
45
40
35
30
25
20
15
10
5
0
214
2C
121
0
10
20
30
40
50
60
70
80
90



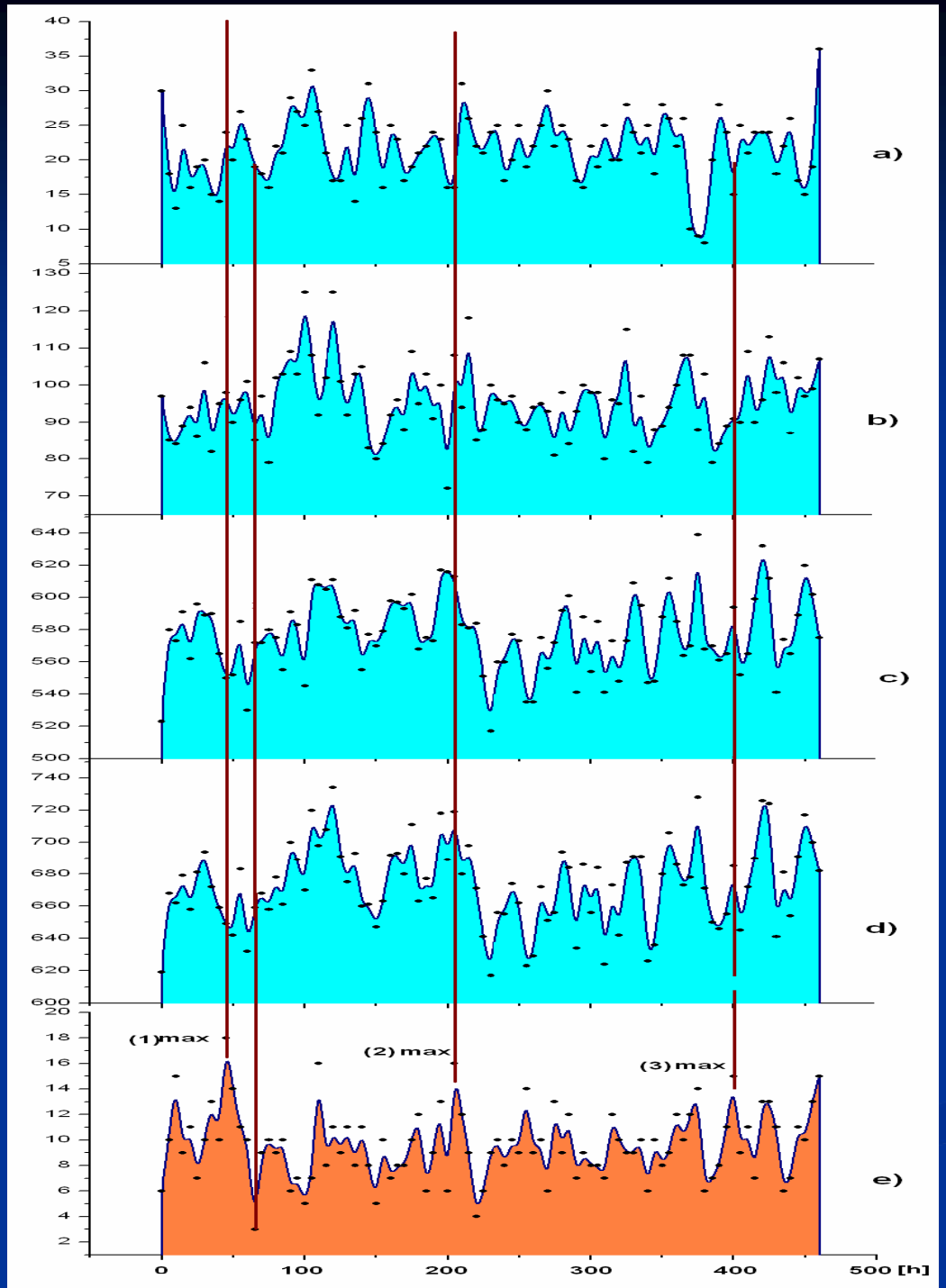


a) b)

- Coincidence spectrum of Ge detector(a). The most prominent is annihilation line.
- Coincidence spectrum of plastic detector (b)- different spectral regions of deposited energies : 1 (*5 MeV - 9 MeV*) , 2 (*9 MeV - 15 MeV*) , 3 (*15 MeV - 57MeV*)



► By selection of certain regions of 2D spectrum , and by projection of regions on the time axis we found the the total number of events depending on time in all channels of selected regions



■ The time variation of registered events

►The spectra a) , b), c) , d) represent the events number of plastic detector depending on time for different spectral intervals (a) :deposited energies 5 MeV - 9 MeV , b): 15 MeV - 57 MeV , c) : 9 MeV - 15 MeV , d) 5 MeV - 57MeV).

►Spectrum e) represents intensity variation of annihilation line (511 keV) registered by Ge detector.

►only small variations of muon flux are detected.

►For example, maximal number of events registered by plastic detector in the whole available energy region 5 MeV - 57 MeV during the time interval of 5 h is Imax = 734 , and minimal Imin = 617. At the 90% confidence level (1.645σ), these results can be expressed as 734 ± 44 and 617 ± 41 respectively

►Similar situation is with the variation of annihilation line (I max = 18 ± 7, I min = 4 ± 3 at 90 % confidence level)

►All annihilation events detected in spectrum of Ge detector originate from secondary particles produced in lead shield by muons which did not hit the Ge detector

►Otherwise, the signal caused by annihilation photon and signal of cosmic muon in the Ge detector are superposed, giving the high energy event (around 60 MeV)

►**maximal values of annihilation line are marked as *(1) max, (2) max and (3) max*. First maximal value, (1) max, has corresponding higher intensities in the spectrum b) (tail of deposited energies by cosmic muons in the plastic detector) and in the spectrum a) where the mainly contribution gives the soft component of cosmic rays.**

►**The second maximum is correlated only with the intensity of spectrum e). In this spectrum the time variations of events which correspond to the deposited energy of about 11MeV are presented (contribution of nearly vertical muons with mean energy about 2 GeV). Also, similar correlation was characteristic for the third maximum.**

►**The minimal value in the spectrum of annihilation line was in a good agreement with lower events number in all three spectral parts registered by plastic detector.**

Conclusions

During acquisition time , any prominent increase of annihilation events number did not registered.

The periodical changes of annihilation line intensity was not found. For detection of long-periodical variations , much longer acquisition time is necessary .

We found that the maximums of annihilation intensity can be correlated with higher number of events detected in different spectral regions of plastic detector.