Measurement methods of charged particle registration efficiency of a plastic scintillation detector prototype for an anticoincidence system of the “SIGNAL” experiment

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“Signal” experiment for Interhelioprobe mission

The INTERHELIOPROBE [1,2] mission aims at study of the inner heliosphere and the Sun at close distance and from out-of-ecliptic orbit. One of experiments on the board on spacecraft is “SIGNAL”[3]. It is developing for the study of solar gamma-ray using the xenon gamma-ray spectrometer. The main scientific tasks of “SIGNAL” experiment are:

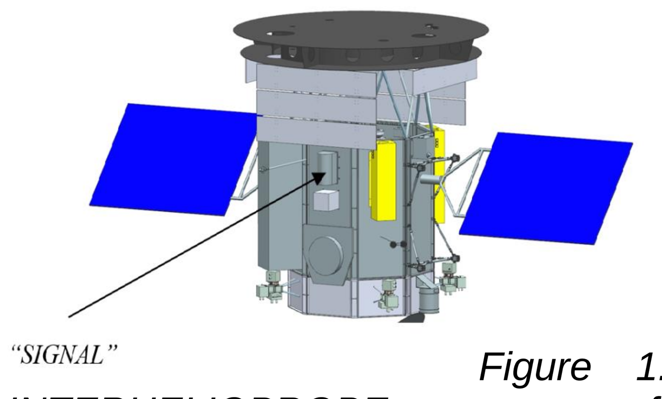

Figure 1. INTERHELIOPROBE spacecraft and position of “Signal” equipment .

1. Research of X-ray and gamma emission in lines and continuum in energy range 30 keV - 5 MeV;
2. Study of gamma-ray bursts of Galactic and Metagalactic origin;
3. An analysis of gamma-ray lines near the Earth and Venus;
4. Charged particle fluxes registration along the spacecraft trajectory.

Scientific equipment and anticoincidence detector system

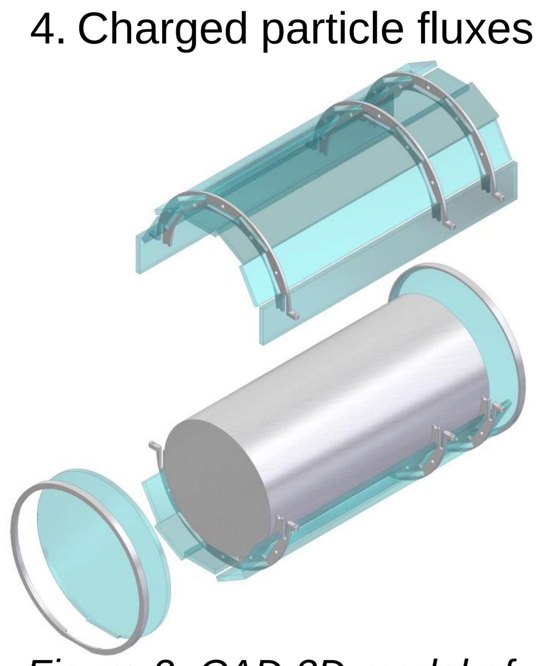

Figure 2. CAD 3D model of the Xenon gamma-ray detector surrounded by anticoincidence detectors.

The main part of SIGNAL experiment scientific equipment is xenon gamma-ray detector (XeGD) [4]. It is an ionization chamber with Frisch grid, filled with high-pressure xenon (density of ~ 0.3 g/cm^3) and operating in pulse mode. Detector is surrounded by scintillator anticoincidence detector (ACD), which protect from charged cosmic-ray particles.

Electric signals produced by anticoincidence detector system will be used for formation of veto signal. During this timeframe Digital Electronics Unit will reject signals from XeGD.

The experimental setup for testing scintillators

The prototype of anticoincidence detector is made of plastic scintillator BC-408 based on polyvinyltoluene manufactured by Bicron [5]. Barrel part of ACD consists of plates. The size of each plate is 325x40x5 mm. For light detection Silicon Photomultipliers MicroSC-30035-X13 manufactured by Sensl [6] (SiPM) of 3x3 mm^2 size are used. Endcaps are disks of 140 mm diameter and 5 mm thin.

Scintillator was warped in Tyvek used as diffuse light reflector. For light transmission between Silicon Photomultipliers and scintillators silicon optical grease BC-630 was used. SiPM were supplied by 29V biasing voltage.

For registration of charged particle (atmospheric muons) reference telescope consisted of two scintillators of 30x30x10 mm size and PMT FEU-60 was used. The block scheme of the experiment is shown in figure 6. For electronic signal processing NIM modules (LeCroy 428F, Caen N840, Caen N978, Ortec CO4020, Caen N1145) were used.

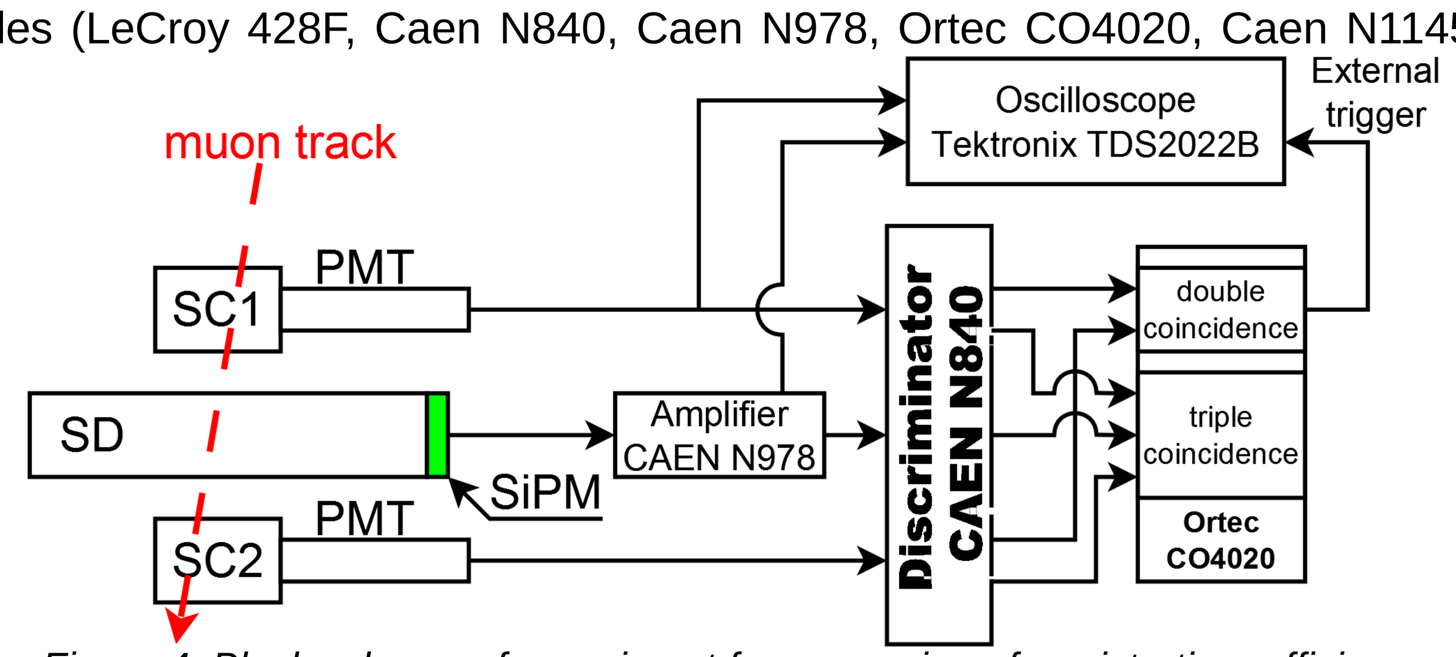

Figure 4. Block scheme of experiment for measuring of registration efficiency

Methods for efficiency registration measurement

For measurement of charge particle efficiency registration we used two methods based on triple to double coincidence ratio of atmospheric muons detection. For double coincidence reference scintillation telescope was used. Third signal from tested scintillator plate with 2 SiPM placed at the endcap was amplified 6 times by Caen N978. Detectors send signals to leading edge discriminator Caen N840. It generates standard NIM pulses of 40ns width. Also, signals were split by LeCroy 428F fan-in-fan-out NIM module to register it by oscilloscope TDS2022B. Ortec CO4020 was used to organize double (two telescope scintillators) and triple (two telescope scintillators + tested scintillation plate) coincidence.

Method 1. First method is a common way of calculation of triple to double ration using electronics set of discriminators, logic gates and counters. In our experiment we use Caen N840 discriminator, Ortec CO4020 logic unit and Caen N1145 counter. Dependence efficiency registration from voltage threshold was measured for 2 SiPM supplied by 29V

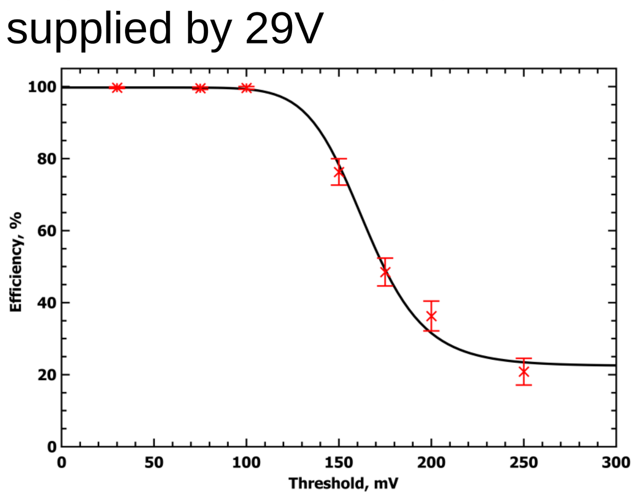

Figure 5. Efficiency registration measured by method 1.

To calculate efficiency and uncertainty for first method binomial distribution are used [7]:

$$\varepsilon = \frac{T}{D} \qquad (1) \qquad\qquad \sigma = \sqrt{\frac{T(D-T)}{D^3}} \qquad (2)$$

T – amount of triple coincidence, D – amount of double coincidence. Measurement Result and fitted curve are shown in figure 5.

Method 2. Second method is based on the signal amplitude histogram analysis. The histogram is obtained by measuring of parameters of signal waveforms captured using Tektronix TDS2022B oscilloscope. This device hasn’t inbuilt function for histogram analysis of signal. To record waveforms, we developed software to control and transfer data via USB from the oscilloscope to PC. The program is written in Python language using PyVISA package [8]. Block scheme of waveform acquisition system is shown on figure 6. Graphic user interface screenshot of the program is shown in figure 7.

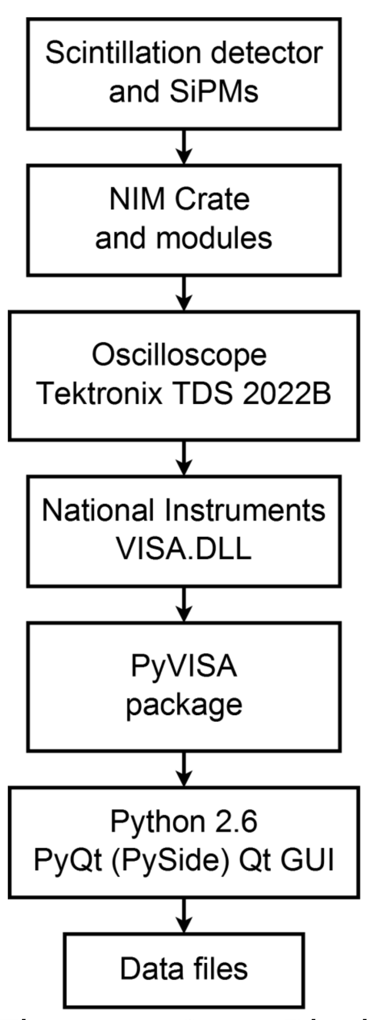

Figure 6. Block scheme of program for waveform capture

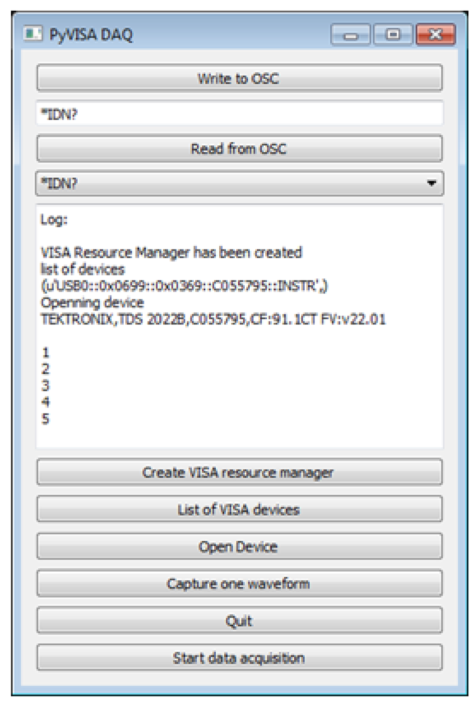

Figure 7. GUI of software for waveform recording

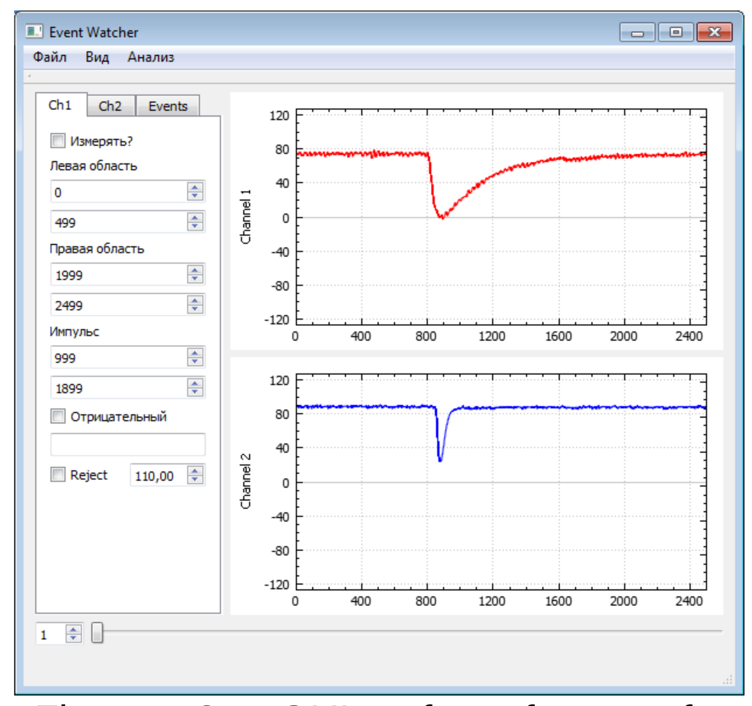

Figure 8. GUI of software for visualization and analysis of signal waveforms

Waveforms recorded to binary data files are used for analysis of signal parameters for amplitude distributions. To analyze obtained data software were developed using Qt Framework. On figures 8 and 9 same signals transferred to PC, recorded to data file and captured on oscilloscope display and are shown.

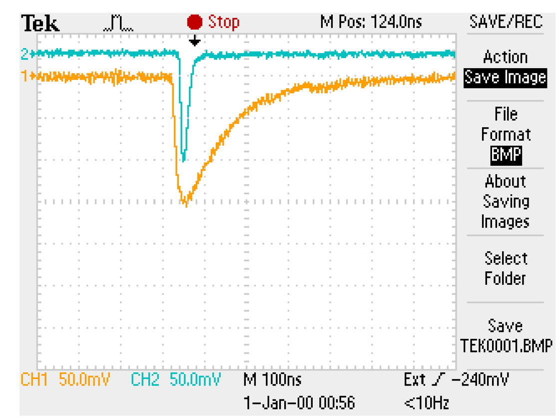

Figure 9. Signal waveforms captures by oscilloscope

On figure 10 signals amplitude distribution built from transferred data is shown. To calculate efficiency registration from built histogram we use the algorithm described below. Choose a voltage threshold *V* on the histogram. All events lower this threshold are particles “missed by tested telescope”. Events higher given threshold are registered particles and associated to triple coincidence. One can integrate the histogram to calculate function corresponded to “missed” particles and triple coincidences.

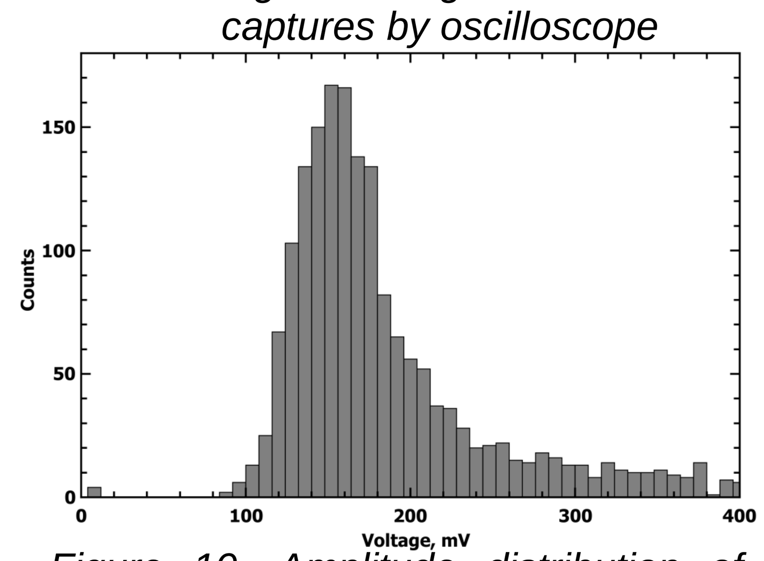

Figure 10. Amplitude distribution of signals from recorded datafiles

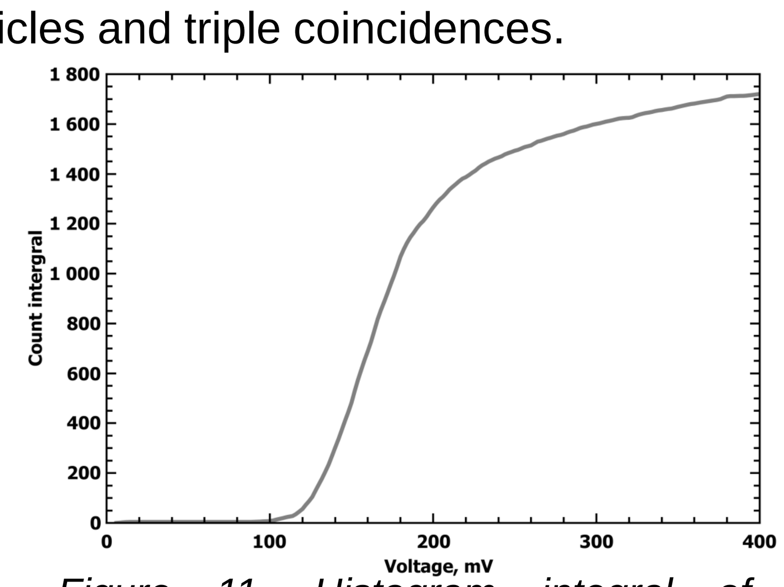

Figure 11. Histogram integral of amplitude distribution

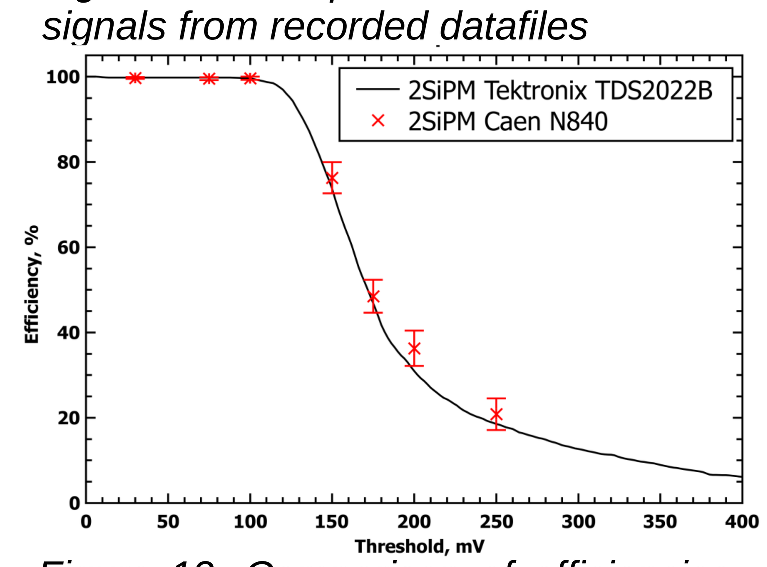

Figure 12. Comparison of efficiencies registration obtained by two methods

To calculate efficiency we use formula (3) and integration of signals amplitude histogram. Calculated using oscilloscope data and obtained by NIM crate system efficiencies are shown in figure 12. The results havegood agreement with each other.

$$\varepsilon(V) = 1 - \frac{\int_0^V H(x)dx}{\int_0^{V\max} H(x)dx} = 1 - \frac{\sum_{i=0}^{i=k} H_k}{\sum_{i=0}^{i=\max} H_k}$$

Conclusion

For the charged particle registration efficiency measurement of scintillator for anticoincidence detector of SIGNAL experiment software was developed to record waveform of signals by Tektronix TDS2022B and analyze amplitude distribution. This method allows to use all registered by scintillator events for efficiency calculation and decreases an acquisition time.

References

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