

## Multilayer scintillation detector for satellite research of short-term variations of high-energy charged particle flux in the Earth's magnetosphere

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**Abstract:** The detector system for telescope-spectrometer of high-energy charged particles is considered in this paper. Multilayer scintillation detector (MSD) is made on the basis of plastic scintillator plates (10 layers) viewed by photomultipliers. Two upper layers are strips of orthogonal scintillators. MSD can detect 3-30 MeV intense electron beams (up to  $\sim 10^5 \text{ cm}^{-2} \cdot \text{s}^{-1}$ ) and 30-100 MeV/nuc protons and isotopes of hydrogen and helium. Modeling based on experimental measurements of the detector show, that MSD can identify of light nuclei in cosmic-ray flux with good mass resolution (about 0.2 amu). Positrons can stop and annihilate in the MSD, so using topology events the detector system allows separating electrons and positrons in the total flux of the particles. MSD time resolution is about one microsecond and it can measure the time profiles of fast processes in the Earth's magnetosphere. Instruments based on the MSD intend to be used for space experiments on the International Space Station and also on other space vehicles, including small satellites. It is planned to study acceleration of high energy electrons during upper-atmospheric discharges (sprites, elves) and solar cosmic rays.

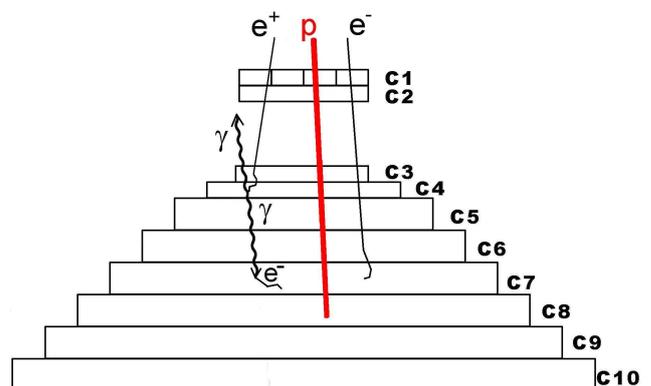
**Keywords:** scintillation detector, radiation belt, precipitation, magnetosphere, thunderstorm.

### 1 Introduction

Since first launches of satellites flux of charge particles has been investigating. Changing solar wind, solar flares, geophysical processes have an influence on Earth's magnetosphere. This leads to variation of trapped charged particle flux, precipitation of these particles from the radiation belt. Radiation belt behavior is important for space weather monitoring. Presented detector system is used to research various phenomena in satellite experiments in near-Earth space. This instrument has to measure processes of different duration from fractions of a second up to several minutes. It is important to identify detected particles. The detector system can detect high-energy charged particles, predominantly electrons and protons. Short-term variation of high-energy electron flux may be caused by various processes: solar flares, upper-atmospheric discharges, geological activities, strong thunderstorms and others. Variations of high-energy electron flux are investigated rather long time. In the eighties bursts of this flux were discovered in experiment Maria [1]. Investigation of these bursts has shown that some of them related to geophysical events such as earthquakes [2]. Further study showed that such bursts may be generated by heavy thunderstorms [3]. It is important to have good geometric factor to investigate possible source of local disturbances of high-energy electron flux in near-Earth space. Now two satellite experiments (ARINA on board Resurs-DK1 satellite and VSPLESK on the International Space Station (ISS)) are being carried on [4, 5]. Both detectors have the same characteristics and their geomfactors are about  $\sim 10 \text{ cm}^2 \cdot \text{sr}$ . It allowed identifying a significant number of bursts and to study individual events. But for the study of the dynamics events, there time and energy profiles a new instrument is required. This detector has to have geomfactor in some times more than previous instruments. This instrument has to detect short-term variations for to study electron magnetosphere injection during upper-atmospheric

discharges. Such instrument can also register  $\gamma$ -ray from sprites and elves [6] or severe solar flares. Instruments characteristics allow us to study earthquake precursors at a new level: we suggest that it will be possible to detect place of geophysical process which causes a disturbance of the magnetosphere. Also that instrument will be helpful for monitoring of space weather.

### 2 The multilayer scintillation detector

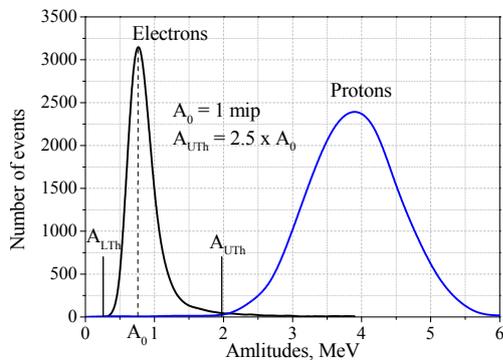


**Fig. 1:** Scheme of MSD. Examples of particle identification

The multilayer scintillation detector (MSD) consists of a stack of scintillation plates  $C_1 - C_{10}$  with thickness of 5 and 10 mm made of polystyrene. Each of them viewed photomultipliers. Scheme of MSD presents on Fig.1. Two upper layers ( $C_1, C_2$ ) are strips of orthogonal scintillators. It provide required angular resolution. Other layers  $C_3 - C_{10}$  are a pyramid of scintillators. All scintillators have

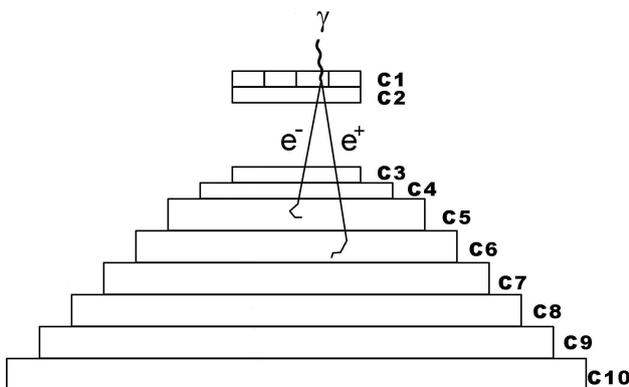
high transparency (attenuation length  $L \sim 2$  m), good conversion efficiency and short decay time (about 3 ns). As photodetectors used fast photomultipliers Hamamatsu R5611A-01.

MSD is expected to identify various types of particles and their energy. First of all a particle have to stop in MSD for accurately determination of particle energy, so we use  $C_{10}$  as an anticoincidence detector. It is electrons with energy from 3 to 30 MeV and protons with energy from 30 to 100 MeV. Energy determines by range of the particles (number of passing layers) with accuracy 10-15% [1]. To pre-identify electrons and heavy particles (proton and light nuclei) energy losses in  $C_1, C_2$  detectors are used. Detected electrons are relativistic particles so their energy deposition much smaller than proton energy deposition (detected protons are non-relativistic). The lower threshold reduces noise photomultipliers (Fig.2).



**Fig. 2:** Identification of electrons/positrons and protons.

The upper adjustable threshold allows splitting electrons and protons by energy deposition. The lower threshold is chosen on 0.1 mip (minimum ionization particle,  $A_0$  on the figure) level, which corresponds to the  $A_{LTh}$  amplitude, the upper threshold is chosen on 2.5 mip level, which correspond to the  $A_{Th}$  amplitude. We adjust the upper level to identify electrons and protons with probability of imitation better then 1%. [7, 8]



**Fig. 3:** Scheme of MSD. Examples of  $\gamma$ -quantum identification

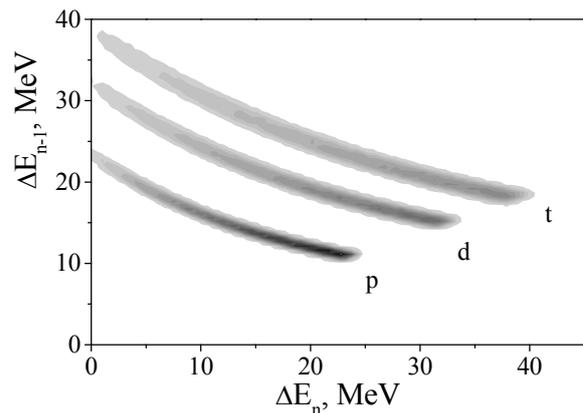
Positrons can detect by studying topology of event. Energy losses of protons are the same like electrons but after stopping positron annihilates and  $\gamma$ -quants with energy

511 keV can interact with scintillators of other detectors. If one of  $\gamma$ -quants moves in the same direction like positron we can determine this event (Fig 1). Topology of that events is described by the following formula:  $C_1 \times C_2 \times C_3 \times \dots \times C_n$  (the absence of  $C_{n+1} \times C_{n+2}$ , where  $n=3, \dots, 7$ . Maximum efficiency for positrons for the aperture of the MSD is of the order of 20%.

We suggest to detect neutral particle like  $\gamma$ -quantum. For registration  $\gamma$ -ray from various phenomena detector  $C_1$  use like anticoincidence detector. Than MSD register secondary particles (electron-positron pairs) which be created as a result of their interaction with the detector  $C_1$ . It is shown on Fig.3. Therefore  $C_1$  detector should have good efficiency. Efficiency of the detectors  $C_1$  and  $C_{10}$  are  $\sim 99.9\%$ , and all other detectors MSD - better than 99% for charged particles. Efficiency of  $\gamma$ -ray registration is about 2%.

### 3 Calculation of MSD characteristics

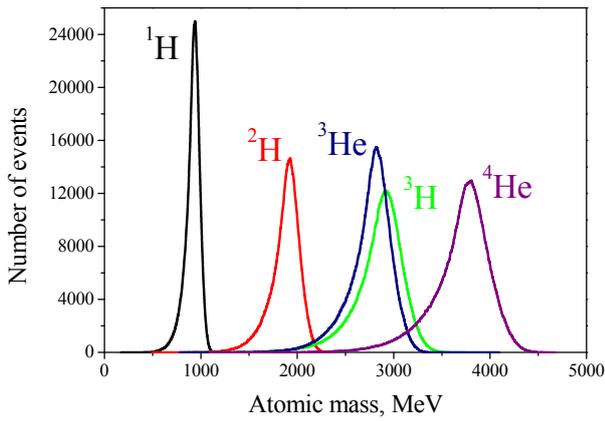
Cosmic rays, which are supposed to be studied in satellite experiments beside protons and electrons include a helium nucleus and other nuclei of light elements. It is possible to register isotopes of hydrogen and helium nuclei by MSD. Also we assume to study other light nuclei in cosmic rays. We intend to identify them by a method described below. As we said before all particles have to stop in the MSD. Our calculations show that comparing energy loss in the detector where a particle was stopped and the previous one, we can identify isotopes of hydrogen (Fig.4) and main isotopes of helium. It is important that we can identify only those particles are stopped in the MDS to avoid of uncertainty in the energy. For calculation it was used the dependence of the amplitude resolution of photomultipliers output amplitude, the fluctuation of the ionization loss and the incidence angle of the falling particles.



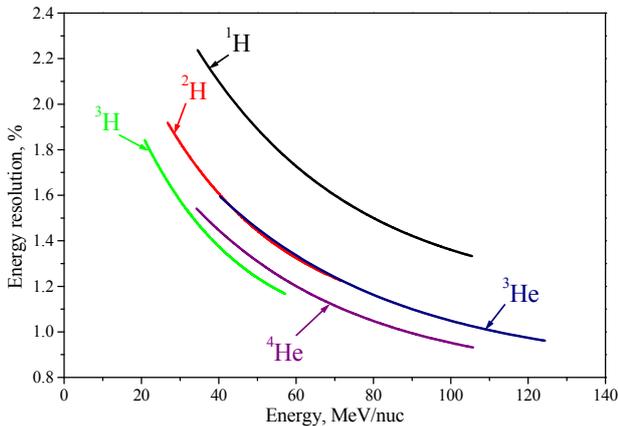
**Fig. 4:** Identification of protons, deuterons and tritons by comparing the energy loss in the detector, where the particle is stopped and the previous one.

Also we took into account the fluctuation of the ionization loss and the incidence angle of the particles. It is important that the MSD has to have reasonable homogeneity of light collection. Detectors have heterogeneity smaller than 10 %. Using calculated Bragg curve in Monte-Carlo simulation the dependence of the mass resolution of MSD was calculated (Fig.5). All isotopes of hydrogen and helium are well allocated. Tritium and  $^3\text{He}$  can not be identified by

mass, but because of the double charge of helium isotope separation is possible on relative energy deposited in the layers of the MSD. The difference between the measured masses of  $^3\text{H}$  and  $^3\text{He}$  is much more than real. But calculations show that if the mass of the particle to recover more carefully, using energy losses in all passing layers, the mass of  $^3\text{He}$  will coincide with the mass of the  $^3\text{H}$ . Energy resolution for various particles and light nuclei are presented on Fig.6. With increasing energy detected particle increases the accuracy of its mass. Calculated geometric factor of the MSD is  $\sim 40\text{cm}^2 \cdot \text{sr}$ .

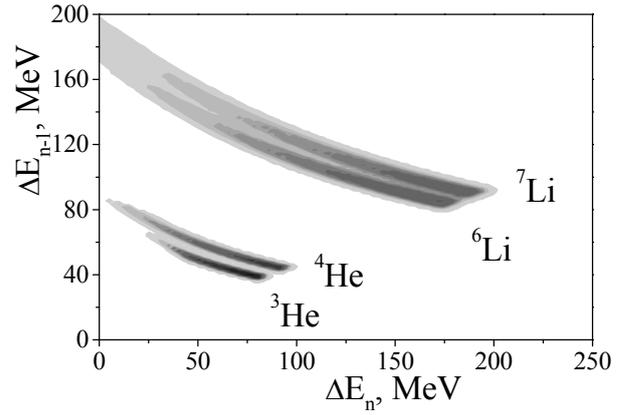


**Fig. 5:** MSD mass resolution for main isotopes of hydrogen and helium.

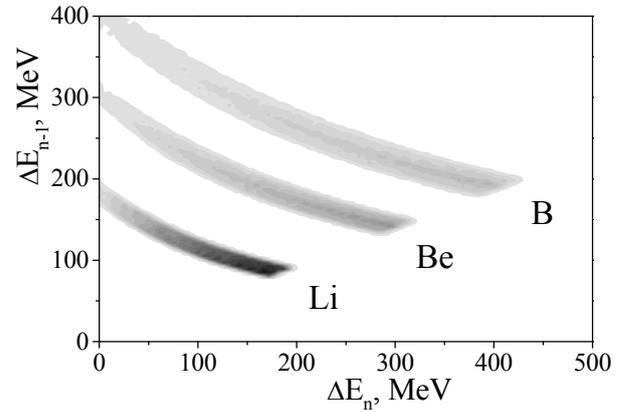


**Fig. 6:** MSD energy resolution for main isotopes of hydrogen and helium.

Also available for the identification and other light nuclei. With increasing atomic mass is not possible to identify the isotopes, but different nucleus can be identified rather good. Figure 7 shows an example of the identification of the nuclei of He and Li. Calculation show that we can identify such nuclei like Li, Be, B (Fig.8). The types of light nuclei and particles which can be identified by the MSD and the energy ranges for these nuclei and particles are presented on Tab.1. There are also evaluating the effectiveness of registration for these energy ranges.



**Fig. 7:** Identification isotopes of He and Li by comparing the energy loss in the detector, where the particle is stopped and the previous one.



**Fig. 8:** Identification of Li, Be, B by comparing the energy loss in the detector, where the particle is stopped and the previous one.

Type of particle	Energy range	Efficiency, %
$e^-$	3-30 MeV	$\sim 100$
$e^+$	5-15 MeV	$\sim 5$
p	30-100 MeV/n	$\sim 100$
$^2\text{H}$	27-70 MeV/n	$\sim 100$
$^3\text{H}$	20-57 MeV/n	$\sim 100$
$^3\text{He}$	40-120 MeV/n	$\sim 100$
$^4\text{He}$	35-105 MeV/n	$\sim 100$
Li	45-120 MeV/n	$\sim 100$
Be	50-140 MeV/n	$\sim 100$
B	60-170 MeV/n	$\sim 100$

**Table 1:** Energy range and efficiency of particle registration.

## 4 Conclusion

The results which presented in this paper are showed that MSD can identify light nuclei with good mass resolution (10-13%) in cosmic ray. Using topology of events MSD can register positrons. MSD has geometric factor  $\sim 40\text{cm}^2 \cdot \text{sr}$ , trigger system time resolution 20 ns, energy resolution 5-

10 %, angular resolution  $\sim 10^\circ$ . That MSD characteristics allow working in high flux of particles and researching fast processes in the Earth's magnetosphere with characteristic times of the order of a few milliseconds. The instrument can use for study earthquake precursors, upper-atmospheric discharges, strong  $\gamma$ -bursts in near-Earth space. We assume to place the MSD on the ISS, also instruments based the MSD can place on a small satellite.

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