Performance of the Scintillator System Prototype of the NUCLEON Space Experiment

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Abstract

The NUCLEON space experiment has been proposed to perform direct measurements of CR energy spectrum and composition up to $E \sim 10^{15}$ eV. The NUCLEON detector consists of layers of different detectors: scintillator detectors with WLS fibers and silicon pad and microstrip ones. The results of beam and space qualification tests of the scintillator detectors are presented.

1. Introduction

One of the old and still unresolved astrophysical problems is the knee in the CR energy spectrum at $3 \cdot 10^{15}$ eV which was discovered by G.B.Khristiansen in 1958 [1]. Two hypotheses are considered: (i) there is no knee but a new property in strong interactions at such energies or (ii) there is a knee in the primary CR spectrum. There are indications that the composition of CR changes, but the interpretation of the EAS measurements including the latest KASKADE data [2] is heavily dependent on Monte-Carlo simulation based on the accelerator data.

The new balloon experiments [3] and long-term and large-aperture space experiments like NUCLEON and ACCESS [4] are going on or in preparation. The main purpose of NUCLEON is measurements of the CR energy spectrum and composition at the $10^{11} - 10^{15}$ eV energy range including the fluxes of heavy CR nuclei beyond the iron peak.

2. Apparatus

The well-known experimental fact is that the average transverse momentum of the secondary particles is practically independent of the initial energy while the multiplicity increases logarithmically. This property will be used in NUCLEON to measure the primary particle energy by determining the angular distribution of secondary charged and neutral particles.

Two types of detectors are proposed for the NUCLEON experiment: mi-

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crostrip or pad silicon detectors and scintillator detectors with WLS fibers. In one of the options considered the first part of NUCLEON consists of two layers of silicon detectors of thickness 300 μm followed by a few layers of thin plastic scintillators of thickness $\sim$1.0 mm and then by a few layers of scintillator strip detectors of thickness $\sim$ 5 mm alternated by carbon layers as targets. The measurement of the primary trajectory, charge and vertex is the main task of these detectors. The designed primary charge resolution is at the level of 0.5%.

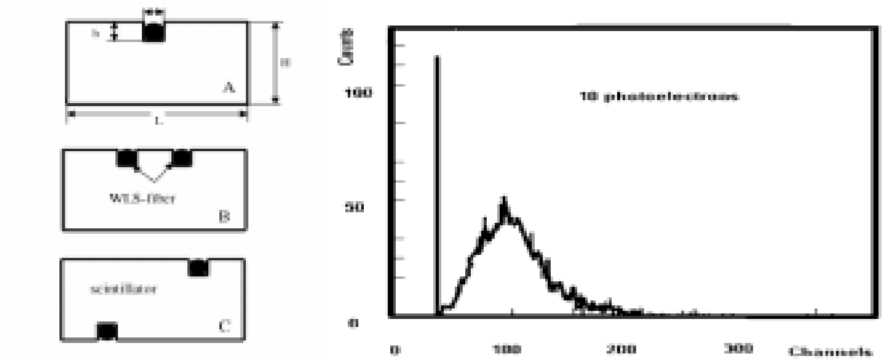

Fig. 1. Left - transverse section of scintillator strips with WLS fibers: H=5 mm, L=7.5 mm, fiber diameter d=1 mm. Right - typical spectrum of cosmic muons .

The second part of NUCLEON consists of a γ-converter , two layers of silicon microstrip detectors with 50 μm pitch and two layers of scintillator strips of thickness 5 mm. The pair of silicon layers of orthogonal microstrips provides measurements of angular profiles for each transverse direction independently to improve the energy resolution. Scintillator layers serve for generating multilevel trigger signals. According to Monte-Carlo simulation the energy resolution of $\sim$70% is expected for individual events. The Russian "KOSMOS" type satellite will be used for the NUCLEON apparatus with exposure time in orbit $\geq$1 year.

3. Test of scintillator detectors

Scintillator detectors with WLS fibers are commonly used in experiments of high energy physics[5]. In comparison with the proper characteristics of scintillators the main virtue of such detectors is much longer attenuation distance for light in fibers ($\approx 10m$) due to the effect of full internal reflection inside fibers with multicladding. It gives a possibility to use such detectors in the space astropartical experiments.

Several types of scintillator strips of polystyrene were studied (Fig.1). The 1 mm fiber was glued in groves of $1.5 - 2.0$ mm in depth by optical glue BC-600.

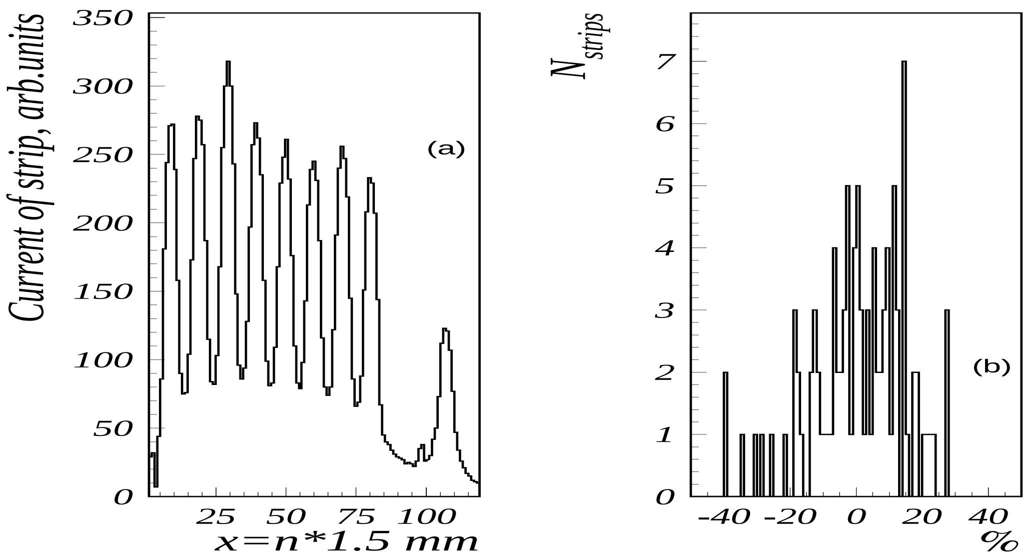

Fig. 2. Left - signals of test with β-source ^{90}Sr moving across a strip plane. Right - dispersion of the average relative amplitudes of 192 strips.

Unpolished strip surface was covered by teflon band to provide diffuse reflection of light. Application of chemical polystyrene foam instead of teflon band to the strip surface leads to 20% increase in light output. The typical cosmic muon spectrum is shown in Fig.1. Average signal at the PMT cathode is at the level of 10 ph.e. in the case of mirror reflection at the opposite end of fiber. A few planes of scintillator strips were produced. They were tested with one- or multychannel PMTs. Photodiodes, β-source ^{90}Sr, cosmic muons and accelerator muon beam were used to initiate a light signal inside strips. An example of the test with a radioactive source moving across strips is presented in Fig.2.

As mentioned above, thin scintillator detectors could be used in the NUCLEON setup to measure the charge of incoming particles. Such a possibility was tested with the detector prototype which consists of a scintillator plane of thickness 1 mm and a WLS fiber grid with 10 mm pitch fixed on the scintillator surface by glue. The plane with fibers was covered by tyvek paper to provide diffuse reflection of light. All or a part of fibers were connected to PMT HAMAMATSU 5900. Results of the test are presented in Fig.3a that indicates a possibility to measure heavy nucleus charge. This conclusion has to be confirmed in nuclear beam tests.

4. Mechanical tests of scintillator strip detectors

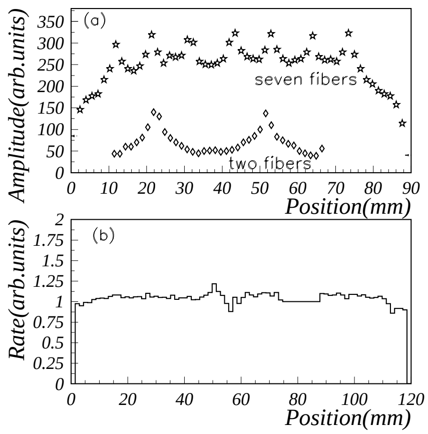

Fig. 3. a) Thin scintillator test with β-source ^{90}Sr. b) The relative light output of strips measured before and after mechanical tests.

Several prototypes of the plates in space configurations were tested to optimize their parameters and check the mechanical stability at the launch. The outgoing fibers are the most delicate part. Besides, because of space limitation the fibers should be bent at 90° and the curvature radius should be at least 10 cm to avoid cracking of the cladding and destruction of the reflection conditions. To meet these requirements the space between strips and PMT with bent fibers was filled in by polyurethane with the density of $0.17 g/cm^3$. The light output of strips was measured before and after mechanical tests and shown in Fig.3b. The problem of ageing is under consideration.

5. Conclusion

The launch of the NUCLEON detector into orbit in 2006 gives the possibility of taking more precise CR data at $10^{11} - 10^{15}$ eV and new data for nuclei with $Z > 30$ at energies around 10^9 eV/nucleus. Prototypes of scintillator strip detectors were produced and tested with encouraging results for their use in space experiments.

6. References

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