JINR PARTICIPATION IN THE TUS AND NUCLEON SPACE EXPERIMENT PREPARATION

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Abstract

The JINR team participates in a preparation of the two space experiments: TUS and NUCLEON, together with SINP MSU that is principal investigator and the other space organizations. The TUS space experiment is aimed to study energy spectrum, composition and angular distribution of the Ultra High Energy Cosmic Rays (UHECR) at $E \sim 10^{20}$ eV. The TUS mission is planned for operation at the end of 2011 at the dedicated “Mikhail Lomonosov” satellite. The main aim of the NUCLEON space experiment is the measurement of the cosmic rays flux, composition and a possible anisotropy in the energy range 10^{11}–5×10^{14} eV. The NUCLEON mission is planned for operation at the end of 2013.

1. Introduction

The TUS space experiment is aimed to study energy spectrum, composition and angular distribution of the Ultra High Energy Cosmic Rays (UHECR) at $E \sim 10^{20}$ eV. The TUS mission is planned for operation at 2012 at the dedicated “Mikhail Lomonosov” satellite. The TUS detector will measure the fluorescence and Cherenkov light radiated by EAS of the UHECR using the optical system – Fresnel mirror-concentrator of 7 modules of ≈ 2 m^2 area in total. A production of the flight model of the optical system is in progress. Status of

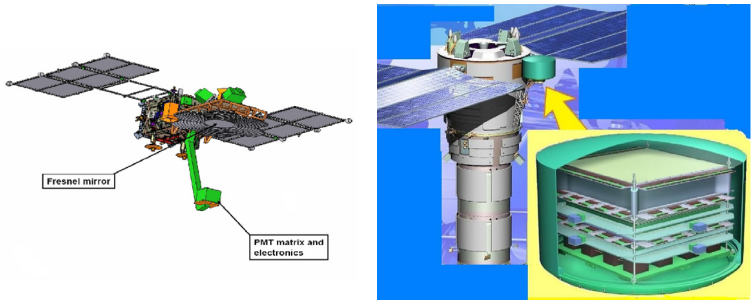

Fig. 1: Left: the TUS detector at the "Mikhail Lomonosov" satellite, right: scheme of NUCLEON detector at the RESURS type satellite

the Fresnel mirror production, the method and results of its optical parameters measurement are presented

The TUS project task is an experimental study of UHECR. The fluorescent and Cherenkov radiation of Extensive Air Showers (EAS) generated by UHECR particles will be detected at night side of the Earth atmosphere from the space platform at heights 400-500 km. It will make it possible to measure the CR spectrum, composition and arrival directions at $E > 7 \times 10^{19}$ eV beyond the GZK energy limit. There are two main parts of this detector: a modular Fresnel mirror and a matrix of PMTs with corresponding DAQ electronics. The SINP MSU (main investigator), JINR and Consortium "Space Regatta" together with several Korean and Mexican Universities are collaborating in the TUS detector preparation. The TUS mission is now planned for operation at the dedicated "Mikhail Lomonosov" satellite shown in Fig. 1.

Main TUS parameters are: mass < 60 kg, power consumption ≈ 65 W, data rate 200 Mbytes/day (1 EAS event contains ≈ 80 Kbytes), Field-of-View ± 4.5 degree, number of pixels 16×16 (Hamamatsu type R1463 PMT: 13 mm tube diameter, multi-alcali cathode, UV glass window), pixel FOV ≈ 10 mrad, Fresnel mirror area is 1.8 m^2, focal distance 1.5 m.

Photo detector and electronics consists of 256 PMT pixels with the time resolution 0.8 μs and the spatial resolution 5×5 km (for the orbit height of 500 km). The digital integrators allow us to use the same photo detector to study different phenomena in the atmosphere in wide time interval: from $\sim 100\ \mu$s (EAS) to 1 ms – 100 ms (transient luminous events, TLE) and up to 1 s (micrometeors). A prototype of such photo detector was tested during 2 years of "Universitetsky-Tatiana" mission [1].

In the TUS photo detector box the pinhole camera is added for study of TLE. The pinhole camera consists of multianode PMT and a hole at the focal distance from the PMT cathode. In design of the camera the multianode PMT of JEM-EUSO type is used [2]. The JEM-EUSO UV sensor will be tested in TLE data taking by the pinhole camera.

The main idea of this project is to develop a method and to design a scientific instrument being able to measure the Cosmic Ray (CR) flux, composition and a possible anisotropy in the energy range 10^{11}–5×10^{14} eV with the high precision charge resolution. At the same time the principal condition is that this instrument should be relatively light (weight < 200 kg) and of small dimensions (size <1.0 m^3) to be of use on regular serial Russian satellites as an additional load. That makes possible long duration (5 years) regular flights and provides the rather low price of the project.

The NUCLEON charge range sensitivity is up to $Z \gg 30$. Such a measurement is motivated by the "knee" problem: change of the slope and composition in the cosmic ray energy spectrum from $E^{-2.7}$ to $E^{-3.0}$ at energies about 10^{15} eV and the CR anisotropy measurements in MILAGRO [3], ARGO YBJ [4], TIBET [5] and IceCube [6] at the 10–100 TeV energy intervals. The NUCLEON instrument is planned to be launched by the KOSMOS type satellite (Fig. 1) in 2013 with exposure time in orbit of about 5 years.

2. Status of the TUS Fresnel Mirror Production and Tests

The Fresnel mirror module prototypes were produced and tested in 2008-2009. The mirror module consists of the multilayer carbon plastic and aluminium honeycomb support to keep its properties stable in the day and night part of the space orbit cycle with the temperature difference of ± 80 °C. In Fig. 2 the technological Fresnel mirror module and the fiducial net are shown inside of a thermo vacuum

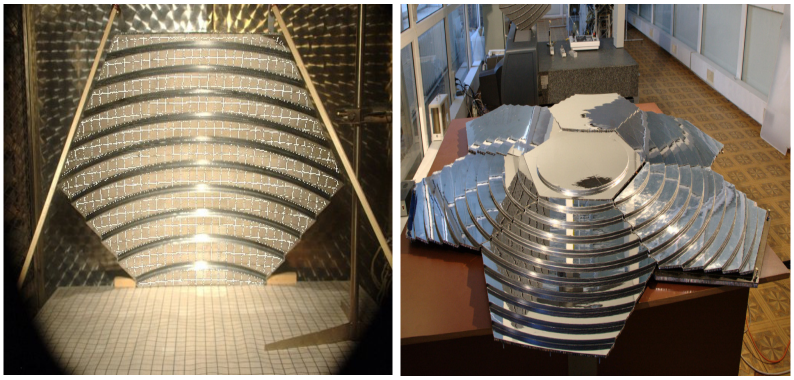

Fig. 2: Left: the mirror module test in thermo vacuum camera at temperature ± 80 °C and pressure 0.02–1.0 atm. Right: the preassemble of the technological Fresnel mirror before tests

camera during tests at temperature ± 80 °C and pressure 0.02–1.0 atm. The fiducial net reflection was used to check the mirror optical quality. The tests gave a positive result – no essential difference in the mirror properties was found. The image lines were obtained by the off-line reconstruction fit of reflected fiducial net lines to quantify deviations between expected and measured mirror surface.

The technological prototype of the segmented 7-module Fresnel mirror produced in 2010 is shown in Fig. 2. The mirror was successfully tested according to the space qualification requirements. Test devices with the mirror are presented in Fig. 3.

The main TUS collaboration task is production of flight model of the Fresnel mirror in 2011. The work is in progress: eight lateral and two central modules were fabricated and covered by reflective aluminium and protective MgF_2 layers. Various measurements of the optical parameters of the mirror modules were fulfilled. At the moment the flight TUS Fresnel mirror production is at the conclusive phase.

3. The Optical Parameter Measurements

The optical parameters measurement is the important part of the TUS preparation program. Results of this measurement are impor-

Fig. 3: The technological Fresnel mirror at space qualification tests

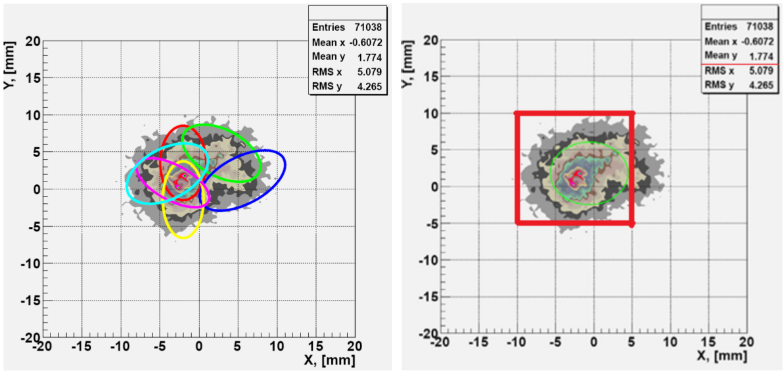

Fig. 4: The laser beam spot image distribution on the focal screen for the lateral Fresnel mirror modules (left panel) in comparison with the photo-receiver pixel size (right panel)

tant for future data analysis, especially for an evaluation of the systematic uncertainties. Also in this measurements the best mirror modules were selected among all produced ones.

The special procedure was elaborated to measure the mirror module optical parameters. The Eclipse 700/1000 coordinate measuring machine from Carl Zeiss, complimented by a laser head and a web camera, was used for the PSF (point spread function) measurements of the lateral and central TUS Fresnel mirror modules.

An example of the PSF measurement for the lateral Fresnel mirror modules is presented in the Fig. 4. The two-dimensional x, y-web

Fig. 5: Left: the PSF angular dependence of the lateral Fresnel mirror module. Right: the spot image distribution on the focal screen for the central mirror modules

camera coordinate plot of the laser beam images on the focal mirror plane is shown. The PSF parameters are by the definition RMSx and RMSy of this distribution which are RMSx = 5.1 mm and RMSy = 4.3 mm – both are reasonably inside of the photo receiver pixel size that is 15×15 mm^2.

The PSF dependence of angles between light source (parallel laser beams) direction and the mirror optical axis that is important for the EAS track image reconstruction on the PMT matrix was measured. An example of such dependence for the lateral mirror module is presented in the Fig. 5. The green and magenta ellipses correspond to PSF positions at $\varphi = 0^\circ$ and $\varphi = 45^\circ$ respectively and $\theta = 1^\circ$, 2°, 3°. 4° those are angles between laser beam direction and optical axis, the blue ellipses correspond to PSF positions at $\varphi = 90^\circ$ and $\theta = 1.5^0$, 3.0°, 4.5° etc. The PSF angular dependencies for the other lateral modules are similar.

4. The NUCLEON Space Experiment Preparation

The design, production and tests of the NUCLEON trigger system including the trigger electronics is the JINR responsibility including the FE and DAQ electronics to elaborate the 1-st and 2-nd level trigger signals. The trigger module consists of two X-, Y-planes of 16 scintillator strips and each plane is equipped by the pair of 1-channel PMTs and a 16-channel PMT.

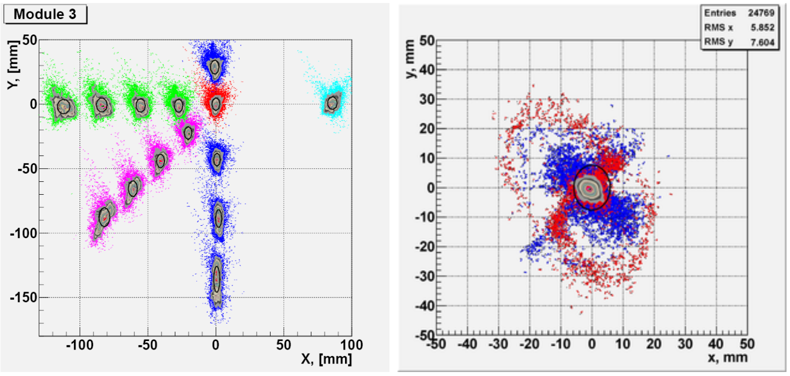

Fig. 6: Left: three modules of the NUCLEON flight trigger system prototype. Right: the technological NUCLEON detector at the design bureau “Arsenal” (St. Petersburg) test facility

The trigger system has a few levels of duplication to provide reliability during 5 years of the data taking in space. The prototype trigger system was produced and tested at the SPS CERN H2 test beams of the π^- energy interval 200–350 GeV and of MIPs – halo muons. The conclusion is the trigger system technical parameters correspond to the initial requirements to the triggers of the 1-st and 2-nd levels: the tuning of the 1-channal PMT HV and the thresholds of the DAQ electronics give the possibility to suppress 350 GeV π^--events down to 6×10^{-5} as is needed for the NUCLEON experiment in space. The beam test result is shown in Fig. 7.

5. Conclusion

The technological TUS mirror was successfully tested in 2010 according to the space qualification requirements. The optical parameters of the flight mirror are in reasonable correspondence both with the Field-of-View of the TUS photo receiver as well as with the PMT pixel size. The TUS mission is planned for operation at the 2012 at the dedicated “Mikhail Lomonosov” satellite for 3 years of data taking [7].

The complex space qualification tests of the NUCLEON technological apparatus were fulfilled at the ARSENAL space center of

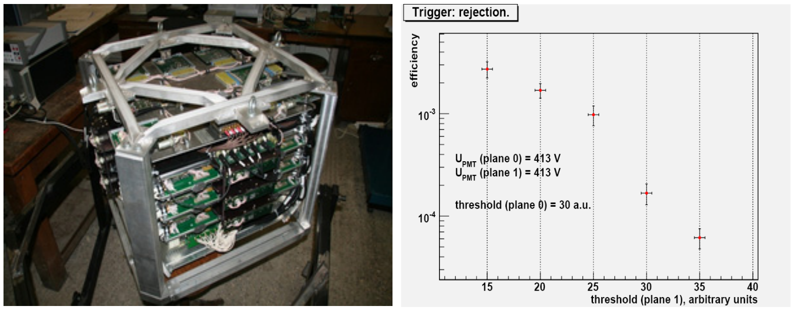

Fig. 7: Left: assembling of the technological NUCLEON detector prototype for the CERN SPS beam test. Right: result of the trigger efficiency system test at the 350 GeV π^- beam

St. Petersburg in 2010 and at the SPS CERN H2 test beams afterwards which are presented in Fig. 6 and Fig. 7. The flight NUCLEON detector production is in progress including the micro calorimeter. The NUCLEON collaboration aim is to be ready for a launch and the data taking from orbit at the end of 2013.

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