The trigger system preparation of the NUCLEON space experiment

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***Abstract*. The aim of the NUCLEON experiment is a measurement of cosmic rays flux and composition with high statistics in the near of "knee" region (the energy spectrum 10^{11}-$5{\times}10^{14}$ eV and charge range up to Z∼30) of the long duration orbit space flight. The design and production of the technological trigger modules are performed including front-end and digital electronics of the data acquisition system. The trigger module prototypes were successfully tested at the CERN SPS accelerator pion beam in 2008. The flight trigger module production is in progress. The trigger system conception, the results of beam tests are presented.**

***Keywords*: trigger system, NUCLEON experiment, cosmic rays**

I. Introduction

One of the old and crucial astrophysical problem is the origin of the knee in Galactic cosmic ray energy spectrum (change of the slope from $E^{-2.7}$ to $E^{-3.0}$) at $\sim 10^{15}$ eV which was discovered by G.B.Khristiansen and G.V.Kulikov in 1958 [**?**]. Below 10^{13} eV, the spectrum and composition are well known from direct observations with detectors flown on balloons and earth satellites. However, at higher energies, the CR flux is smaller and is more difficult for direct observations. A lot of results were obtained with the EAS investigations by the ground based detectors but they are not yet conclusive due to discrepancies between them. Thus the knee location in cosmic ray energy spectrum of the different nuclei components remains still unknown, mostly due to the absence of reliable data, as the CR composition in this region. To improve situation the data of the individual elemental energy spectra from protons to nickel before the knee at 10 TeV to 1 PeV must be substantially improved. Among the wide arsenal of modern experimental methods for energy measurement in energy region $>$ 1 TeV only the ionization calorimeter (IC) method may be applied over a wide energy range for all CR nuclei simultaneously. Even a thin calorimeter have rather large weight $\sim$ about 2-3 tons, and as a result, such investigations become very expensive.

The main idea of the NUCLEON project is to design and to create scientific device with large aperture and a relatively light weight being able to measure elemental spectra of cosmic rays in a wide energy range E $\sim$ 10^{11}-10^{14} eV in the long duration orbit space flight. The method is based on event by event measurement of spatial distribution of the charged and neutral secondary particles which were produced in the inelastic nuclear interaction in the target of the detector and have passed through layers of silicon micro strip detectors and thin converters to produce e+e- pairs of the secondary gammas. This technique is known as KLEM (Kinematic Lightweight Energy Meter) [**?**],[**?**].

The first task of the NUCLEON trigger system is to suppress the huge flux of low-energy cosmic rays (E $<$ 100 GeV) by selection of events with high multiplicity that is increased at the energy increasing. These low-energy events are the main source of background and are suppressed by the trigger of the 1-st level. The task of the second level trigger is a measurement and rejection of CR events which are out of the detector aperture. Therefore, the final goal of the trigger system is the selection and rejection of data flux to a limited volume that can be transferred to the ground data acquisition and control centrum for the further off-line analysis.

To study these problems the design and production of the technological NUCLEON trigger modules were performed including front-end and digital electronics of the data acquisition system. In the next section the technical conception of trigger system will be presented in detail.

II. The NUCLEON set-up geometry and trigger system description.

The NUCLEON device includes charge and energy measuring systems, the trigger system, data acquisition and control electronics and data transmission system. All systems are mounted inside a pressurized aluminium container.

The charge measuring system consists of 4 silicon detector layers in the volume of 53 cm $\times$ 53 cm $\times$ 2.5 cm. Every silicon detector layer contains 64 subdetectors 6.2 cm $\times$ 6.2 cm $\times$ 0.3 cm. Every of subdetectors is divided by 16 pads with the $\sim$ 2.4 cm^2 size. These pad detectors are used for precise charge measurements of incoming charged CR particles.

The energy measuring system consists of 6 identical layers of one-sided micro-strip silicon detectors along

X, Y direction alternatively. Every silicon micro-strip layer occupies a volume of 53 cm × 53 cm × 1 cm and contains 72 subdetectors with 62 mm × 62 mm × 0.3 mm size connected in 9 ladders of 8 subdetectors linked in series. A micro-strip pitch optimization has been done with the MC simulation and pitch size of 0.46 mm was obtained.

The carbon block of 50 cm × 50 cm × 9 cm size after the charge measuring system and before the first double (X and Y) layers of the energy measuring system is used as a target. Two identical tungsten gamma-converter layers of 50 cm × 50 cm × 0.7 cm ($2X_o$) size are located before the second and third double layers of the micro-strip silicon detectors.

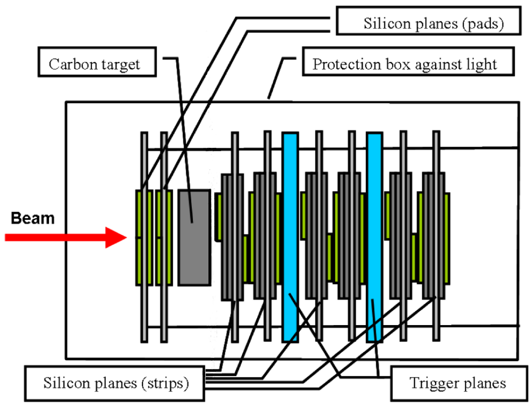

Fig. 1. The NUCLEON prototype on the beam in the CERN SPS

The trigger system consists of 6 scintillation strip layers to select high multiplicity events. Each scintillation layer of 16 strips is used to measure the integral signal of layer with the single-channel PMT for the trigger of the first level and the individual signals of each strip with the 16 channel PMT for the the trigger of the second level[**?**].

The strip size is 5 mm × 31 mm × 500 mm. In each strip 7 multi-cladding WLS KURARAY Y-11 fibers are glued and grouped into 3 groups. Two groups of 2 fibers are connected to the single-channel PMT HAMAMATSU H5773 and the group of 3 fibers are connected to the one channel of 16 channel PMT HAMAMATSU H8711. The light signals of the whole plane gather for each of two single-channel PMT's. Two single-channel PMT's were used for each plane for the duplication of the 1-st level of trigger. The reservation is needed to raise reliability of the 1-st level of trigger.

The PMT HV values and the thresholds of the front end electronics may be changed by commands from control centrum to regulate the trigger conditions.

III. The NUCLEON prototype beam test

The NUCLEON detector prototype, readout and data acquisition electronics has been tested on SPS CERN with H2 test beam of 200, 250, 350 GeV/c pions and muons of the beam halo. The beam spot was ∼ 1.5 cm × 0.5 cm and low intensity 10^3-10^4 particles per second due to data acquisition requirements. The structure of the NUCLEON setup is shown in Fig. **??**. It consists of:

1) 4 planes of silicon pads detectors;
2) 6 micro-strip silicon planes of 256 strips of 460 μm width with lead converters between of them;
3) carbon target of 68 mm thickness;
4) trigger system of two double layer 16-strip scintillator detectors;
5) a few lead gamma-converters of 3 mm thickness.

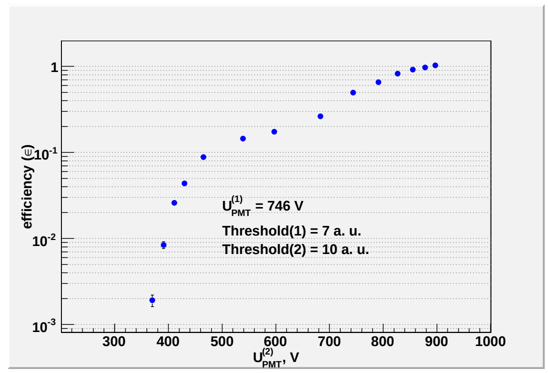

Fig. 2. Rejection efficiency dependence on a PMT HV tension for down-stream plane

The trigger layer consists of two scintillator strip planes directed orthogonal to each other. Each plane has ∼ 160 mm × 160 mm dimension and 10 mm × 5 mm strip cross section. Two trigger layers were located down-stream of the target, a few converters and silicon micro strip detectors. The most part of the data taking was done at the normal setup orientation to the beam direction as is shown in Fig. **??**. Besides, small part of the data taking was done at 16 and 26 degrees between the beam direction and setup axis.

Rejection efficiency of trigger is defined as a part of selected events respect to the total number the incoming beam particles measured by beam monitor counters. The trigger efficiency dependence was studied on the PMT HV tension ($U^{(1)}_{PMT}$, $U^{(2)}_{PMT}$ for up- and down-stream planes respectively) and on the trigger electronic thresholds measured in "arbitrary units" (1 a.u. ≈ 2.5 μV). Results are presented in Fig. **??** - Fig. **??**.

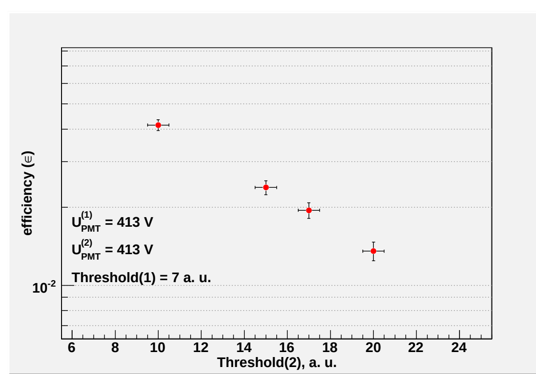

Fig. 3. Rejection efficiency dependence on a threshold of down-stream plane

The rejection efficiency dependence on PMT HV - $U^{(2)}_{PMT}$ for down-stream trigger module is presented in Fig. **??** with the threshold values - 10 and 7 a.u. for down- and up-stream plane electronics respectively. The up-stream plane PMT HV tension is fixed $U^{(1)}_{PMT}$ = 746 V. At the initial HV value $U^{(2)}_{PMT}$ = 900 V. In this case the number of selected events is equal to the beam particle number. At the final HV tension $U^{(2)}_{PMT}$ = 370 V, rejection efficiency becomes equal nearby $2{\cdot}10^{-3}$.

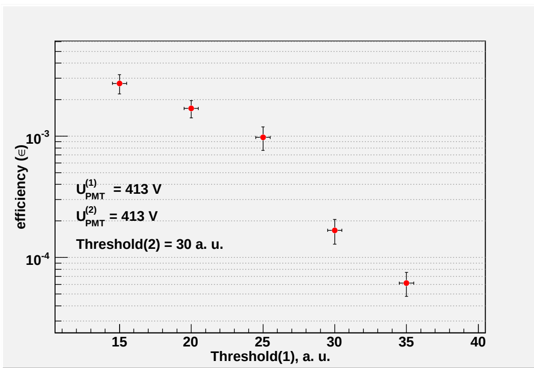

Fig. 4. Rejection efficiency dependence on a threshold of up-stream plane

At the next step the PMT HV values of up- and down-stream trigger modules were fixed $U^{(2)}_{PMT}$ = $U^{(1)}_{PMT}$ = 413 V. The consecutive increasing of the threshold values on the down-stream module from 10 to 20 a.u. was carried out at the fixed value of a threshold on the down-steam plane (7 a.u). The rejection efficiency has changed from 0.041 to 0.014 and is shown in Fig. **??**.

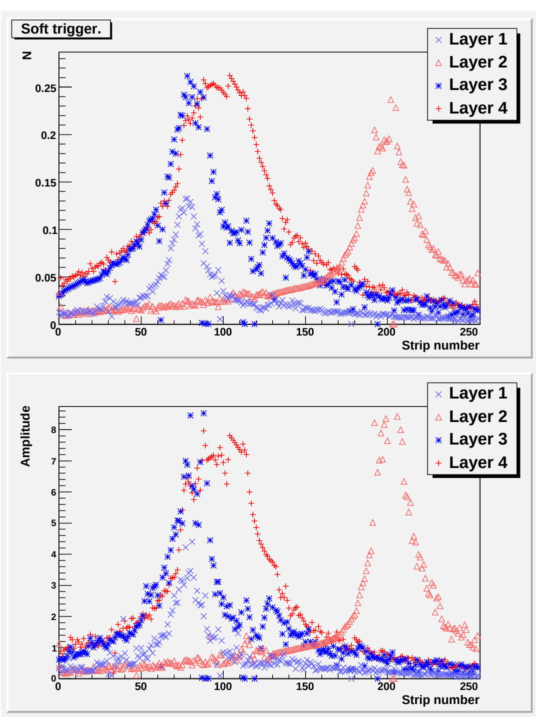

Fig. 5. The normalized integral distributions of hitted strips with the soft trigger conditions

The same PMT HV values 413 V of up- and down-stream trigger modules were used in the final test. The threshold on the up-stream module has been fixed to 30 a.u., and the threshold on the down-stream module raised from 15 to 30 a.u. that leads to the rejection efficiency changing from $2.7{\cdot}10^{-3}$ to $6{\cdot}10^{-5}$ (Fig. **??**).

It was naturally to check the trigger efficiency by the multiplicity measurements of the selected events with the silicon micro strip detectors. During this data taking period the setup axis was turned to the beam axis at 16^{o}. Two data sets were obtained with the soft and hard trigger conditions at 350 Gev pion beam. The average multiplicity of selected events depends on the front end electronics threshold value and on the PMT HV tension. The lesser thresholds and higher PMT HV tensions corresponds to the more soft trigger and more low average multiplicity and vice versa. Four best silicon micro strip layers were used in this analysis.

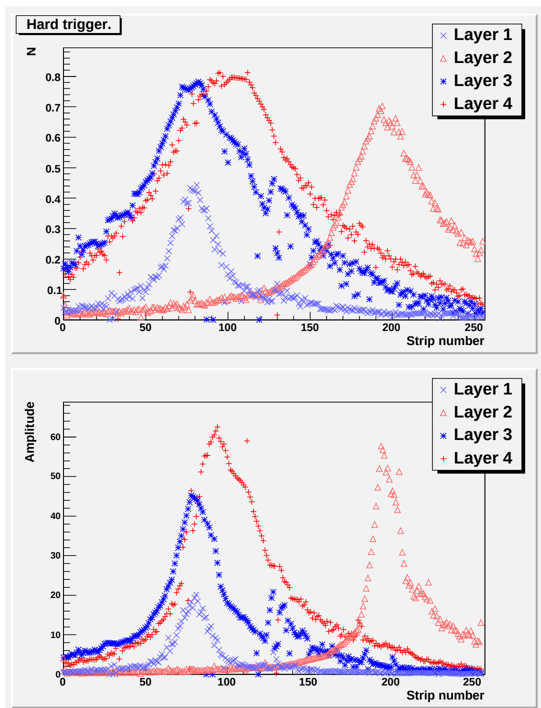

Fig. 6. The normalized integral distributions of hitted strips with the hard trigger conditions

The micro strip numbers and corresponding strip amplitudes of the selected events were recorded to the output file. Two types of plots were produced: (i) the normalized integral distributions of hitted strips summarized for the total number of selected events (upper plot in Fig. **??**, Fig. **??**) and (ii) the same distributions but hitted strips summarized with a weight that is equal to the signal amplitude (lower plot in Fig. **??**, Fig. **??**) to get energy deposition in the strip of multiple hits. The soft trigger conditions mean $U^{(1)}_{PMT} = U^{(2)}_{PMT}$ = 684 V and threshold values are 7 and 10 a.u. for the up- and down-layers respectively, for hard trigger $U^{(1)}_{PMT} = U^{(2)}_{PMT}$ = 413 V with threshold values are 7 and 15 a.u. It is clear seen the deviation of the peak positions for the second layer due to 16^o angle between beam direction and detector axes.

Integral values for all bins in Fig. **??** and Fig. **??** correspond to the raw data multiplicities in respected planes for upper plots and to corrected by weights multiplicities in respected planes for lower plots those are proportional to the energy depositions. The average value dependence for raw data and corrected multiplicities on the layer position are presented in Fig. **??** for the different trigger conditions. The widths of the multiplicity distributions in the different silicon planes are presented as uncertainty values. As seen from Fig. **??** the average multiplicity of secondary tracks is increased along the beam direction due to additional interactions of secondary particles in the converters those are between of the silicon micro strip planes.

This behaviour of the multiplicity dependence on the soft-hard trigger conditions are reasonably correspond to rejection efficiency dependence on the PMT HV tensions and the threshold variations that was discussed above.

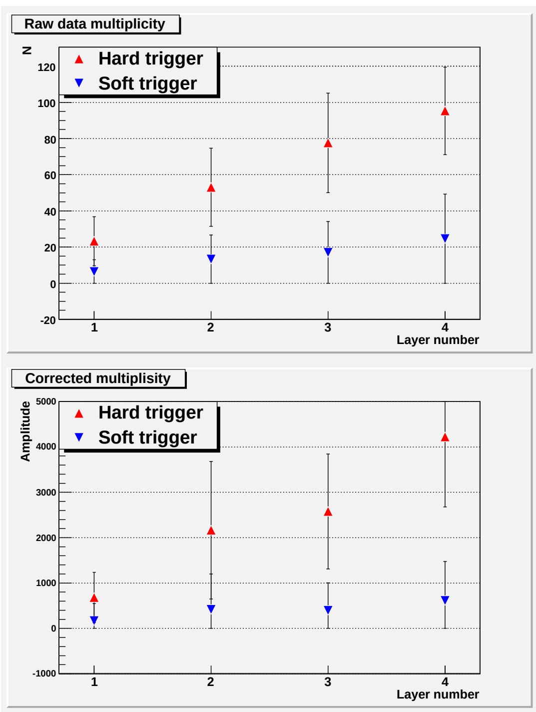

Fig. 7. The average value dependence for raw data and corrected multiplicities on the layer position

IV. Conclusion

The beam test of the NUCLEON trigger system were fulfilled. The rejection efficiency of the low energy 350 GeV pion events was obtained at the level up to 6×10^{-5} as is needed to study CR spectrum energy range E $\sim 10^{11}$-10^{14} eV that is the NUCLEON project aim.

V. Acknowledgements

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