Comparing EAS registered with PRISMA-32 array and CWC NEVOD

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Abstract. Results of comparing events detected with two detectors of the Experimental complex NEVOD: PRISMA-32 array and Cherenkov water calorimeter (CWC) NEVOD – are presented. The PRISMA-32 is an array for simultaneous registration of the EAS electron-photon and neutron components. It consists of 32 en-detectors deployed over the area of about 500 m², along the perimeter of the CWC NEVOD. The CWC NEVOD is a detector of a calorimetric type with a volume of 2000 cubic meters in which the registration system of 91 quasispherical modules (546 FEU-200 photomultipliers) is placed. CWC provides measurement of the intensity of Cherenkov radiation from any direction with practically the same efficiency.

1. Introduction
Studies of high and super-high energy cosmic rays through the detection of EAS with ground-based installations originate from the 50-ties of the last century. To carry out these studies, lots of facilities measuring different parameters (the number of charged particles, the number of muons, the shower core energy at observation level and others) have been created. The results of the experiments are not always consistent with each other, especially in the “knee” region of the cosmic ray energy spectrum.

For better explanation and deeper understanding of the processes associated with this energy range, in recent years a trend towards the development and implementation of new methods and approaches to EAS studying is observed. One of such methods is the investigation of the EAS neutron component which has not been practically studied till present [1]. In order to study EAS neutron component in Experimental complex NEVOD, the PRISMA-32 installation [2] was created and the URAN array [3] is being deployed.

In the experimental complex NEVOD, several installations aimed at this energy region are being operated: the Cherenkov water detector (CWD) NEVOD [4] and calorimeter (CWC) [5]. Comparison of data between these installations will allow to bind information on EAS neutrons to the characteristics of extensive air showers obtained by the electron-photon component.

2. PRISMA-32 array and CWC NEVOD
PRISMA-32 is a system of 32 en-detectors composed into two 16-detector clusters located inside the experimental hall on the 4th floor of the NEVOD building around the water tank in MEPhI (figure 1). The neutrons are recorded as delayed pulses within a time gate of 20 ms. It is more than sufficient to collect main part of thermal neutrons produced by EAS hadrons. On-line program pre-analyzes the data and stores the energy deposit (above a threshold of 5 m.i.p.) and the number of recorded neutrons.
in each detector. The 2-fold coincidence trigger condition is applied for each cluster of 16 en-detectors to store the data [2].

Figure 2 shows the en-detector design where: 1 is PE water tank; 2 is polyethylene (PE) lid; 3 is FEU-200 PMT; 4 is scintillator; 5 is light reflecting cone. Thin layer (~ 30 mg/cm$^2$) of a special inorganic scintillator ZnS(Ag) + $^6$LiF of 0.36 m$^2$ area is placed at the bottom of cylindrical PE 200 l tank which is used as the detector housing. The efficiency of the en-detector for thermal neutron recording was found to be 20%. Registration of scintillation flashes is provided by FEU-200 placed on the lid of the tank. Flash-ADC (ADLINK 10-bit PCI slot PCI-9810) is used for pulse shape digitizing (20000 samples with a 1-µs step).

Cherenkov water calorimeter NEVOD with volume of 2000 m$^3$ (9 m depth) is located on the surface of the ground in the MEPhI campus and is intended for the registration of all major cosmic ray components [5]. The detecting lattice consists of alternating planes: four planes with 16 quasispherical modules (QSMs) and three planes with 9 QSMs each. In turn, each plane is formed with vertical clusters consisting of 4 or 3 QSMs. The distance between the modules is 2.5 m along the water reservoir axis, 2.0 m across it and 2.0 m in the vertical direction (figure 3).

Quasispherical module consists of a waterproof aluminum housing, intra-module electronics and six FEU-200 photomultipliers with plastic protective illuminators. QSM dimensions are 0.56×0.56×0.56 m$^3$. It includes six flat photocathode photomultipliers oriented along the axes of the orthogonal coordinate system. Such detecting system registers Cherenkov radiation from any direction with almost equal efficiency (figure 4).
Figure 5 shows the amplitude distribution of the charged component of EAS, based on data obtained for two years of operation of the PRISMA-32 (2016-2017 years) in a double logarithmic scale. Figure 6 shows the amplitude distribution of the deposit of charged particles, based on data obtained for two years of operation of the CWC NEVOD (2016-2017 years) in a double logarithmic scale. The amplitude distributions shown in figure 5 and figure 6 have a similar form, as well as close values of the slope of the spectrum. These facts make it possible to carry out studies of characteristics of EAS using information obtained with both installations.

3. Results

The event counting rate in PRISMA-32 is significantly lower than in CWC NEVOD. Therefore, in the trigger system PRISMA-32 a special output was organized for the trigger system of CWC NEVOD. The trigger is generated with ≥ 2 detectors with A ≥ 4 mV in one of the PRISMA-32 clusters. In this case, a file with the main event data (time and event number) is generated in the PRISMA-32 and CWC NEVOD settings, and a label is placed in the CWC NEVOD data. Further, only events that have been triggered in both PRISMA-32 clusters are selected, and these events in CWC NEVOD data are searched. Data from the joint operation of the PRISMA-32 and CWC NEVOD installations for more than two years have been used.

During the data analysis, various selection criteria were used:

1) in each cluster of PRISMA-32 ≥ 2 detectors A ≥ 12 mV and \( \Sigma E \geq 100 \) ADC codes;

2) in each cluster of PRISMA-32 ≥ 2 detectors A ≥ 12 mV, \( \Sigma E \geq 100 \) ADC codes and in one of the clusters \( N_n \geq 4 \) neutrons;

3) in each cluster of PRISMA-32 ≥ 2 detectors A ≥ 12 mV, \( \Sigma E \geq 100 \) ADC codes and in each cluster \( N_n \geq 4 \) neutrons.

During this period, the PRISMA-32 installation has detected 68295 events and the CWC NEVOD has registered 9699107 events. Using the aforementioned criteria, the sets of joint events in two installations were obtained: criteria 1 - 4405 events, 2 - 1251 events, 3 - 623 events. Based on the data obtained, the correlation dependences were plotted (figure 7) and the regression coefficients were calculated (table 1). Under the conditions 1 and 2 for selecting events, there is no obvious correlation. Correlation improves with more strict selection criteria for events. For selection criteria 3, regression coefficient was estimated as \( 1.05 \times 10^4 \) code ADC/photoelectron.

**Table 1: Regression coefficients:**

| N  | \( K, \) code ADC/photoelectron |
|----|---------------------------------|
| 1  | \( (0.65 \pm 0.06) \times 10^4 \) |
| 2  | \( (0.89 \pm 0.05) \times 10^4 \) |
| 3  | \( (1.05 \pm 0.03) \times 10^4 \) |
Figure 7. Correlations between the amplitudes of responses of PRISMA-32 and CWC NEVOD for different selection criteria (1, 2 and 3).

4. Conclusion
A method for searching joint events registered in the PRISMA-32 and CWC NEVOD installations has been developed. The analysis of the selected joint events has revealed the agreement of topologies of responses of two installations. Correlation dependences of the responses of the installations to the EAS electron-photon component were obtained. The obtained correlation dependences show that one ADC code in PRISMA-32 corresponds to about $10^{4}$ photoelectrons in CWC NEVOD. Further, the technique for the EAS core position determination according to the data of the PRISMA-32 installation will be developed and the extensive air showers with axes crossing the working volume of the CWC NEVOD will be selected.

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