The ProtoPRISMA array for EAS study

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Abstract: A prototype of the PRISMA project array has been developed and started running on the base of the NEVOD detector at National Research Nuclear University MEPhI. It consists now of 16 detectors of a novel type (*en-detector*) sensitive to two main EAS components: electromagnetic (e) and hadronic (through thermal neutrons (n)) ones. The purpose of the array is testing of the proposed experimental method of EAS neutron and electromagnetic components recording, optimization of the detector design and data acquisition system. First experimental results are shown.

Keywords: Extensive Air Shower, neutrons, detector.

1. Introduction: the PRISMA project

The idea of a novel type of array for EAS study proposed for the first time in 2001 [1] has been developed in 2008 to the PRISMA (PRImary Spectrum Measurement Array) project [2]. The PRISMA experiment is aimed to solve the ``knee problem'' in cosmic ray spectrum. It is based on a simple idea: as the hadrons are the main EAS component forming its skeleton and resulting in all its properties at an observational level then hadron component should be the main component to be measured in experiments. Therefore, we have developed a novel type of EAS array detector (*en-detector*) capable to record hadronic component through thermal neutrons detection (n) and electronic component (e) as well [3]. The detector looks like a usual EAS detector but with a specific thin inorganic scintillator sensitive to thermal neutrons and having low sensitivity to charged particles. A thin layer of scintillator consists of an alloy of the mixture of the old inorganic scintillator ZnS(Ag) plus LiF enriched with ^{6}Li up to 90%. Spreading these detectors over a large area on the Earth's surface one could obtain an hadron calorimeter of very large area (10^4 m^2 in the starting variant of the PRISMA, which can be expanded later). Due to rather fast response of the scintillator (the fastest light component is equal to ~40 ns) these detectors equipped with constant fraction discriminators can even be used for EAS timing.

2. ProtoPRISMA array

A prototype of the PRISMA project array (ProtoPRISMA-16) has been developed and started running on a base of the NEVOD-DECOR detector at National Research Nuclear University MEPhI. It consists now of 16 en-detectors situated inside the experimental building at a level of 4th floor just around the NEVOD water pool. The layout of the array is shown in fig. 1.

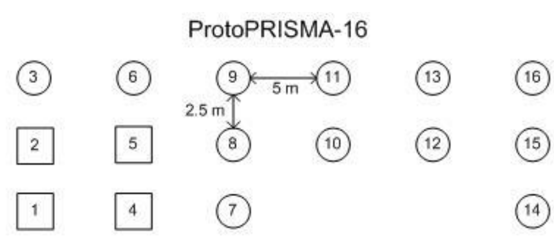

Figure 1. The ProtoPRISMA-16 layout.

Its asymmetrical layout is explained by the experimental hall geometry. The detectors No 1, 2, 4 and 5 are shaped as usual EAS detector pyramid and has the scintillator area equal to 0.75 m^2. They are the detectors from our previous prototype (NEUTRON [4]) and their neutron recording efficiency is equal to ~20%. All other detectors have cylindrical shape with the scintillator area equal to 0.36 m^2. It is now our standard en-detector made on a base of commercial polyethylene (PE) water tank of 200 liters volume. Design of this detector is shown in fig. 2. The scintillator is situated on it bottom and is viewed by a single 6’’ PMT (FEU-200). Simplified Monte-Carlo simulations of light collection have shown that cylindrical geometry is not optimal for light collection, while pyramid or cone gives much better result. On the other hand, it is difficult to find commercial box of pyramidal or conical shape. That is why we use cylindrical tank with light reflecting cone inside it. As a result we obtained very simple and cheap detector with suitable performances. ZnS(Ag)+^{6}Li is very effective scintillator for heavy particle detection. It produces 160000 photons per a neutron capture through the reaction ^{6}Li(n,α)t + 4.8 MeV. It allows us to collect more than 50 photoelectrons from PMT photo-cathode per n-capture. Monte-Carlo simulations have shown that the presence of PE (8 mm thickness tank walls) increases the neutron recording efficiency in comparison with that for open scintillator. This effect depends on neutron energy. For 1/E neutron spectrum the neutron capture recording efficiency rises by a factor of 2 up to ~40% due to additional neutron moderation ability of PE. Therefore, the usage of plastic housing for en-detector makes the detector even more sensitive to neutrons, while our old steel pyramid boxes decreased the sensitivity by 2% due to neutron capture in iron.

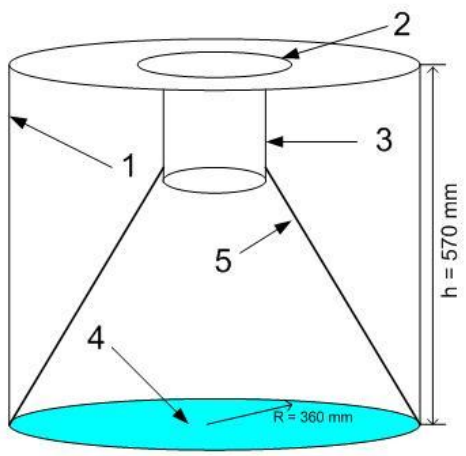

Figure 2. Disign of the standard en-detector.
1 – PE water tank; 2 – PE lid; 3 – PMT FEU-200; 4 - scintillator ZnS(Ag)+^{6}LiF; 5 - light reflecting cone.

Two digitizers (PCI slots) are used for each PMT signals: from 12th and from 7th dynodes. Thus, we can measure energy deposits in a wide dynamic range of ~ 10^4. The digitizers work at a frequency of 1 MSamples/s. The time gate for neutron measurements is equal to 20 ms or 20000 samples. All pulses are integrated in preamplifier with a time constant equal to 1 µs. In a case of powerful EAS when all triggers are generated, full pulse shape is stored (20000 x 16 samples). Otherwise, only energy deposit and the number of recorded neutrons in each detector are stored. The trigger system is very simple. Due to low counting rate of en-detectors (~1 s^{-1} at sea level) each hit of any detector produces the first level trigger for all ADC’s. Then On-Line program analyses the information and produces the second level triggers (soft triggers): M1 if 3 or more detectors were hitted, M2 if sum of energy deposit in all detectors exceeded 50 rel. particles and M3 if total number of recorded neutrons exceeded 4. Depending on these trigger conditions the information is stored on hard disk. If none of these triggers were produced then only monitor information is stored.

3. First results

The array started running at the beginning of this year. A few first months were spent for the detectors calibration, On-Line program adjusting and data analysis program development. That is why we have now only

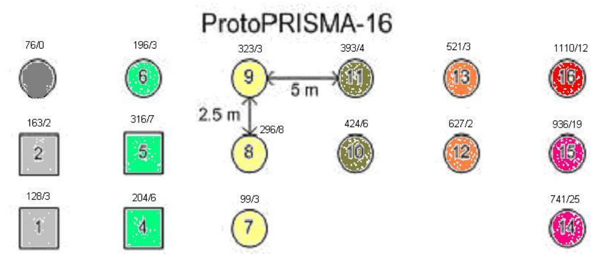

Figure 3. An example of a recorded event.

very preliminary data with poor statistics. We deal with a very new technique and even data analysis is not obvious a priori. As a first step we applied a traditional EAS analysis to our data: seeking the EAS core position, finding EAS size (N_e) using NKG-function for electromagnetic component only. Processing of the neutron component is now under developing. An example of one of the most energetic recorded up to now shower (LOG$_{10}$(N_e) = 6.5, N_n =106) is shown in fig. 3 where the number of recorded particles / neutrons for all 16 detectors are shown above each detector icon. The expanded part of the event oscillogram for one detector is shown in fig. 4. One can see that 3 delayed neutron pulses

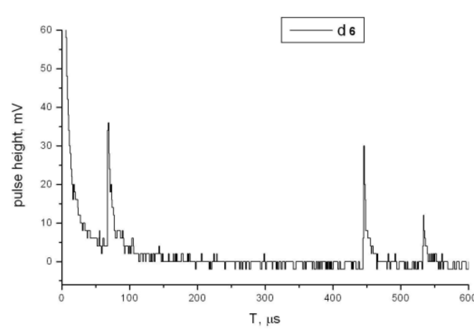

Figure 4. An example of the expanded oscillogram for one detector #6 in time interval 0 – 600 µs.

integrated with τ = 1 μs following the first EAS pulse at T=0, are clearly seen here.

A preliminary result indicating correctness of our core location procedure based on NKG - function is shown in fig. 5. Core location using neutron component is now in progress. We plan to extend the array up to 32 en-detector this year. The array area will be increased by a factor of 3. After this we'll start full-scale data acquisition and data processing.

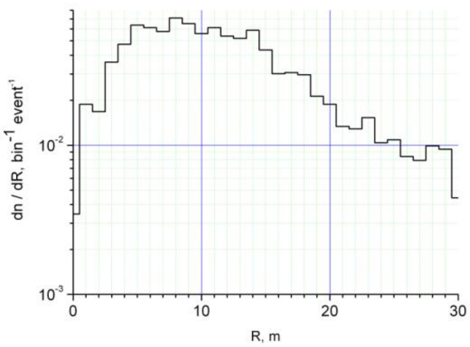

Figure 5. EAS core location distribution obtained through electromagnetic component only for events selected by M1 trigger (center of the array corresponds to R=0).

Another result obtained with ProtoPRISMA is shown in fig. 6. The plot displays in integral form how does the mean number of recorded neutrons depend on the number of detectors involved in the event. Again, as in our previous prototype NEUTRON result (see [4] or our presentation here: ID 185), the dependence is very close to exponential one and even absolute values are close each other. Sure, the exponent parameters are different because the arrays are different: 16 detectors now and only 5 detectors in NEUTRON. The plot also shows that the number of recorded neutrons is enough to be measured starting from the lowest trigger multiplicity (M=3) while the measured chance coincidence level for neutron counting is acceptably low. Note that at higher altitude both these values will be also higher due to larger flux of hadrons.

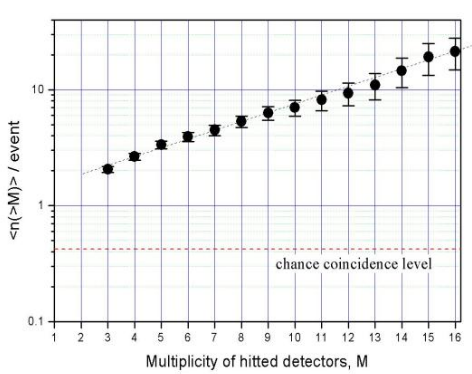

Figure 6. Mean number of recorded neutrons as a function of a multiplicity of hitted detectors.

4. Discussions

The PRISMA project based on a novel principle of EAS study is now close to be realized. Several stages of the array prototyping have shown the performances of the method, parameters of the thermal neutron flux accompanying the EAS passage and allowed us to develop and test a novel type of EAS detector – en-detector, capable to record two main EAS components: hadrons and electrons. This makes the array very informative and rather cheap. Our standard en-detector based on a commercial PE tank also has shown very good performances: rather high efficiency for thermal neutron detection, rather good light collection and very good stability. These parameters as well as low sensitivity to single charged particle passage make it possible usage of the detector in counting mode for low intensity neutron background flux variations and its monitoring.

We have to add that next prototype of 7 en-detectors will be constructed next year in collaboration with our Chinese colleagues in Yangbajing just above the ARGO-YBJ array. It will make us possible to check the method at high altitude (where the flux of hadrons is much higher and therefore the threshold for primary cosmic rays will be lower) and to make calibration using the ARGO facilities [5]. Our final goal is embedding of central en-carpet of the PRISMA to the future LHAASO array [6].

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