On the PRISMA Project

Yuri V. Stenkin \textsuperscript{a}*

\textsuperscript{a}Institute for Nuclear Research of Russian Academy of Sciences
117312, Moscow, RUSSIA

A novel type of Extensive Air Shower (EAS) array is proposed and described. It is shown that only new approaches to the so called “knee problem” could solve this complicated and old problem.

1. Introduction

There exist (or existed) very few experiments specially designed to solve the 50 years old “knee problem” in cosmic ray. The best of them, namely, KASCADE and Tibet AS\(\gamma\) gave very precise and interesting but contradicting each other results \[1\] and they did not solve the problem. It became even less clear. On my opinion only new approaches based on the new ideas could solve this complicated and old problem. The idea of a novel type of array for EAS study proposed by us for the first time in 2001 \[2\] has been developed in 2008 to the PRISMA (PRImary Spectrum Measurement Array) project. 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 \[3\], then hadron component should also be the main component to be measured in experiments. Therefore, we have developed a novel type of EAS array detector (en\textsuperscript{-}detector) capable to record hadronic component through thermal neutrons detection and electronic component as well \[4\]. 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 \(^{6}\text{Li}\) up to 90\%. Spreading these detectors over a large area on the Earth’s surface one can obtain an hadron calorimeter of practically unlimited area. Due to rather fast response of the scintillator (the fastest light component is equal to \(\sim 40\) ns) these detectors equipped with constant fraction discriminators can even be used for EAS timing.

2. The PRISMA project

2.1. Introducing remarks

As it was already mentioned, the PRISMA experiment is aimed to solve the “knee problem” in cosmic ray spectrum. The best way to do so could be direct cosmic ray spectrum measurements. Unfortunately, it can not be performed due to very low intensity of cosmic ray with energy above 1 PeV. That is why we are pressed to use an indirect EAS method. But, as a payment for that, one have to make very complicated and model dependent recalculations from measured parameters to primary ones. Solving the inverse task one should be sure that: i) solution exists and ii) measured parameters are connected with real ones by the known dependencies. Both points are not known a priori. Solving the direct task one also have to introduce many parameters by hand, concerning the using model details, cosmic ray mass composition, existence or absence of the “knee” in primary spectrum etc. \[5\]. Traditionally EAS arrays measure electron component first of all. This is not the best choice but the simplest and the most convenient one because the electronic component is the most numerous one and it produces a great bulk of ionization, which is used for detection. However, it is the secondary EAS component that is the mostly

*e-mail: stenkin@sci.lebedev.ru
sensitive to EAS longitudinal development which is formed by the cascading high energy hadrons. These two components are in a dynamic equilibrium. But, the equilibrium exists only while hadrons exist. When the cascading hadrons are fully exhausted (note that the number of such hadrons is rather small below the maximum of shower development and exponentially decreases up to 0 with the depth in the atmosphere), the equilibrium violation occurs. This occurs at primary energy of $\sim 100$ TeV/nucleon. It changes the EAS properties dramatically and results in a visible break (“knee”) in electromagnetic components (including Cherenkov light as a tertiary component) \[5, 6\]. Interpretation of the data obtained with traditional EAS array is very complicated and ambiguous. Therefore, the best way is to record the primary EAS component, namely hadronic one. Sure, other components should be record as well but, mostly for additional and inter-calibrating purposes. The PRISMA experiment will realize this approach. Similar to a simple optical prism which splits white light to its components, the PRISMA will measure EAS in hadronic, muonic and electronic components separately.

2.2. Prototypes

To ensure that proposed idea works properly we constructed two prototype arrays: one at mountain level (“Multic”, Baksan) and another one at sea level (“Neutron”, Moscow). Both prototypes consist now of 4 similar en-detectors. Detectors of “Multic” prototype are of 0.375 $m^2$ and that of “Neutron” prototype are of 0.75 $m^2$ each. Detector lay-outs are also different (details could be found elsewhere [3, 4, 5, 9]). Here only some preliminary results obtained with the prototypes will be shown and discussed. Thermal neutron EAS component (“neutron vapor”) could give us very interesting information that has never been used in practice before. As it was shown [7] these neutrons accompanying EAS may be of two sources: first one is the atmosphere (atmospheric neutrons) and next one is ground or soil under the array (local neutrons). These neutrons have different time distribution due to to different life time in different media. Life time of thermal neutrons in soil or concrete or other usual constructed materials (excluding wood) is equal to $\sim 1$ ms, while that in air depends on altitude and is equal to $\geq 50$ ms, in accordance with thermal neutron absorption cross sections. These two kinds of neutrons carry absolutely different information about EAS structure and they can be separated experimentally. Fig. 1 shows the results of Monte-Carlo simulations obtained using CORSIKA (ver. 6501) showers for primary proton and iron, applied to a prototype setup. It is seen that two branches of neutrons originated from air and from soil give different time parameters ($\tau_1$ and $\tau_2$). The experimental time distributions obtained with our prototypes [2] qualitatively confirm this: both of them can be fitted by a similar two-exponential curve. In fact the difference between $\tau_1$ and $\tau_2$ is not as large as expected due to a mixing effect. Nevertheless, the difference is enough to be separated experimentally. The figure shows also that events from primary protons or iron can be separated using this method. I should emphasize that experimental time distributions could differ each other being dependent on trigger conditions, on the array geometry, etc. The higher the shower size, the more neutrons are detected and different ratio between the two branches is observed. Sure, the measured time parameters depend on the experimental details: on the detector distance to EAS core position, on the media surrounding the detector, array altitude etc. Our data were obtained for arrays situated inside the experimental building and should differ from that one could measure in open air. Nevertheless, the time parameters can be calculated for any detector location and can be measured experimentally. In our case we have a difference in time parameters between two arrays situated at different altitudes, within a factor of $\sim 2$.

2.3. The PRISMA lay-out.

Central part of the PRISMA will consist of a large area (at least 100 x 100 $m^2$) covered with en-detectors $\sim 1$ $m^2$ each) as a rectangle grid with 5 m spacing (see fig. 2). This area is enough to obtain $\sim 10^4$ events a year in the “knee” region with cores lies inside it. For higher energy additional outside en-modules are envisaged. These
Figure 1. Time distributions. Results of Monte-Carlo simulations for primary $p$ and Fe.

Figure 2. The PRISMA lay-out (top and side view).
detectors will record hadronic (thermal neutrons “vapor”) and electromagnetic components. This is one of the project advantages because the same detectors will record two EAS components and will give two density maps of these components with a rather good resolution. These maps could be superimposed and compared off-line. And also, usage of the same detectors for two purposes makes the project cheaper and more reliable. The possibility to enlarge the array later without any problem is another project advantage. Additional advantages could be found in [4].

Muons are the next important EAS component which give an integral EAS characteristics. A number of large area muon detectors are envisaged. They form an outer ring (shaped as a square) consisting of 1200 individual 1 m² detectors of the same design as en-detectors but with usual 5-cm plastic scintillators. Threshold energy for this detectors is equal to 1 GeV (under 500 g/cm² of soil absorber). The central underground muon detector design is not still fixed. Probably it could be a fine-structured track detector of at least 100 m² in total or it could look like a continuous carpet of 20x20 individual 1 m² detectors. And finally, 4 x 25 such detectors placed on the surface will be used as outer trigger detectors.

Table 1
Main features of the PRISMA array.

| Feature                        | Value            |
|--------------------------------|------------------|
| primary energy range, (eV)     | $\sim 10^{13} - 10^{16}$ |
| energy resolution, (%)         | $\sim 10$        |
| angular resolution, (degree)   | $\sim 1$         |
| core location accuracy, (m)    | $< 2$            |

3. Conclusion

The project of a novel type of EAS array is proposed. We do believe when running this array will solve the “knee” problem. Location of this experiment is not fixed yet. It depends on the collaboration of institutions, which is still open for other participants. High altitude location is more preferable. It would be very interesting to locate PRISMA at the Tibet high mountain plateau nearby the existing arrays of Tibet ASγ and Argo YBJ or combine it with recently proposed [9] new project LHAASO. Any new proposals and collaborators are welcome.

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