Unique Scientific Facility
Experimental Complex
NEVOD

EAS spectrum in thermal neutrons measured with PRISMA-32

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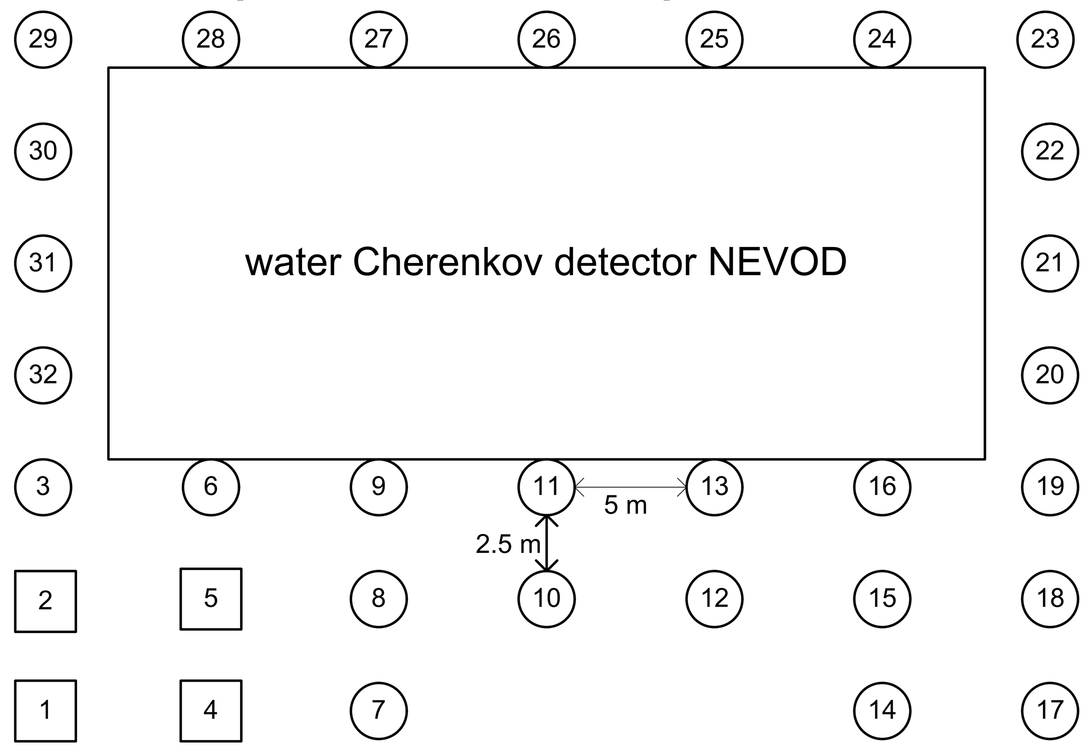
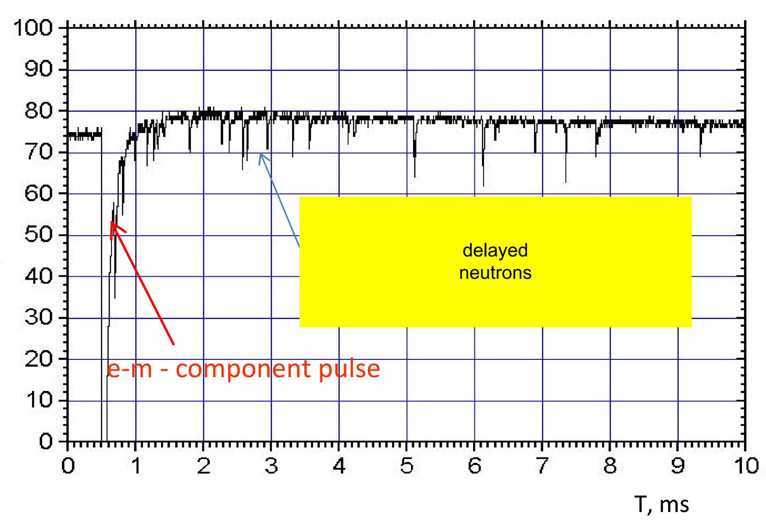
Hadronic component of Extensive Air Showers is very important but neutron component practically has not been studied up to now. Absence of effective and inexpensive neutron detectors of large area limited these studies for many years. Developing of such detectors in INR RAS [1], called as en-detectors, allowed one to use them for construction of the novel type EAS array (PRISMA project) [2,3]. The first array of such type PRISMA-32 consisting of 32 en-detectors has been constructed in MEPhI in frame of MEPhI–INR co-operation. The detectors are sensitive to electromagnetic (e) and neutron (n) EAS components and record thermal neutrons accompanying EAS on a whole area of the array. Details of the array can be found elsewhere [4-6]. The spectrum in the number of EAS hadrons (neutrons) is measured; this spectrum agrees with a power law function with integral index β= -1.95±0.05.

PRISMA-32

Detectors #1, 2, 4 and 5 are of square shape 0.75 sq. m each; others – cylindrical 0.36 sq. m.
Detectors #1 – 16 compose cluster P1, and detectors 17 – 32 compose cluster P2.

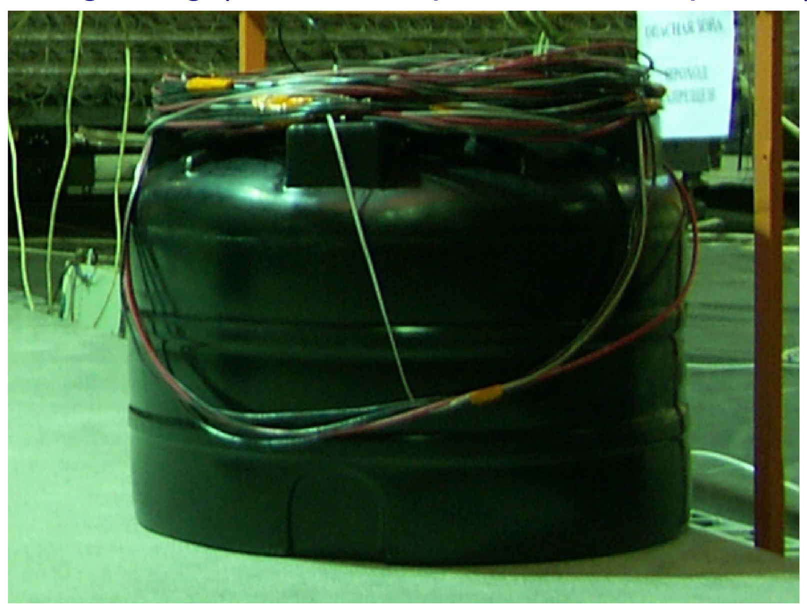


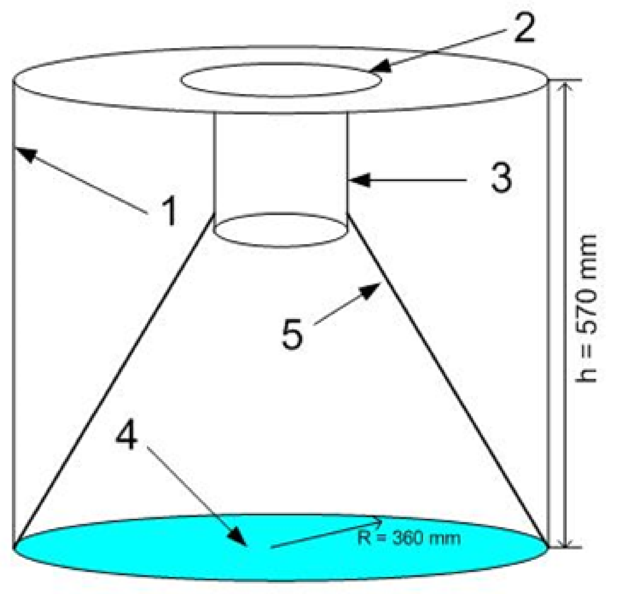
PRISMA-32 experimental setup



EAS event: neutrons & electrons numbers and timing

32 en-detectors array (composed of two 16-detector clusters) is located inside the experimental hall situated on the 4th floor of the NEVOD building around the water pool in MEPhI. The latter explains its inhomogeneous structure. Thin layer (~ 30 mg/cm^2) of special inorganic scintillator ZnS(Ag) + ^{6}LiF of 0.36 m^2 area is placed at the bottom of cylindrical polyethylene (PE) 200 l tank which is used as the detector housing. An efficiency of the en-detector for thermal neutron recording was found to be 20%. FADC (ADLINK 10 bit PCI slot PCI-9810) is used for pulse shape digitizing (20000 samples with a step of 1 μs).





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

The neutrons are recorded as delayed pulses inside a time gate of 20 ms. It is more than enough to collect a great bulk of thermal neutrons produced by EAS hadrons [7]. 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. 2-fold coincidence trigger condition is applied for each cluster of 16 en-detectors to store the data. Additionally, during off-line data processing 6-fold coincidence (from 32) is used for the event selection.

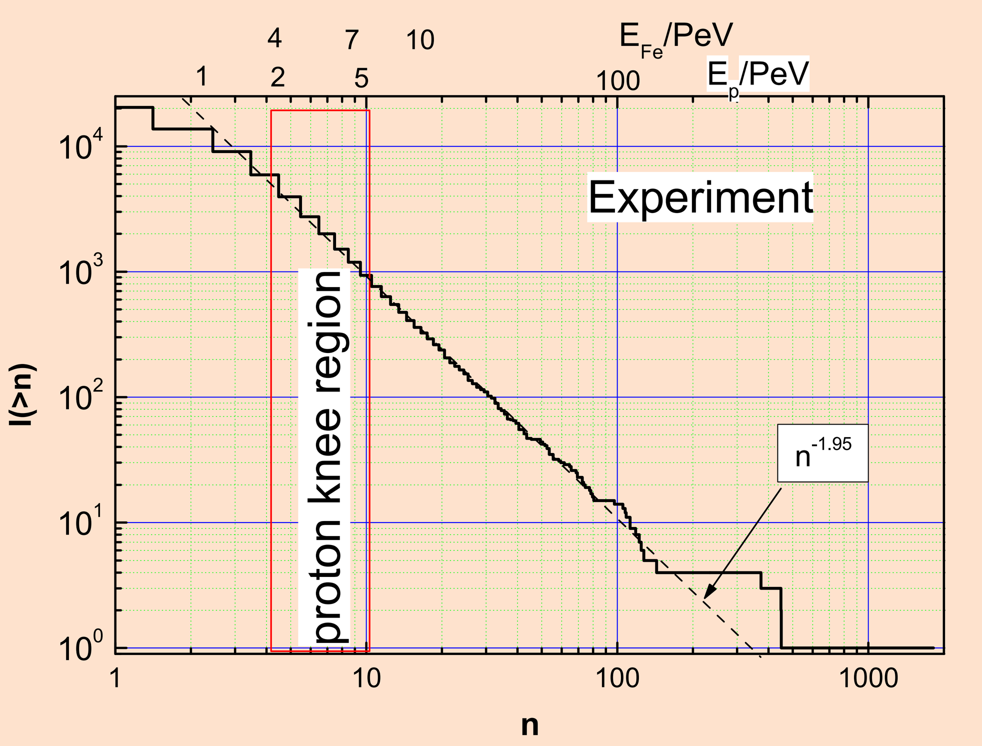
Method and results

We applied a traditional maximum-likelihood analysis of EAS, employing the Nishimura-Kamata-Greisen (NKG) function for the electromagnetic component to find the position of the EAS axis, its age, EAS size (N_e). Also the total number of recorded neutrons was determined. As it has been shown earlier [8], the total number of secondary neutrons (mostly evaporation) is proportional to the number of hadrons passing through the array area. Therefore, the measuring the EAS size spectrum in thermal neutrons is equivalent to that in the number of hadrons. Taking into account that hadrons are the main EAS component forming its structure, one could expect that the number of recorded neutrons would be the most adequate primary energy estimator. Therefore the EAS size spectrum in thermal neutrons can be easily used for primary cosmic ray energy spectrum recalculation. At this step, CORSIKA-based Monte-Carlo simulations were made only to calculate the relation between the number of recorded neutrons and primary energy.

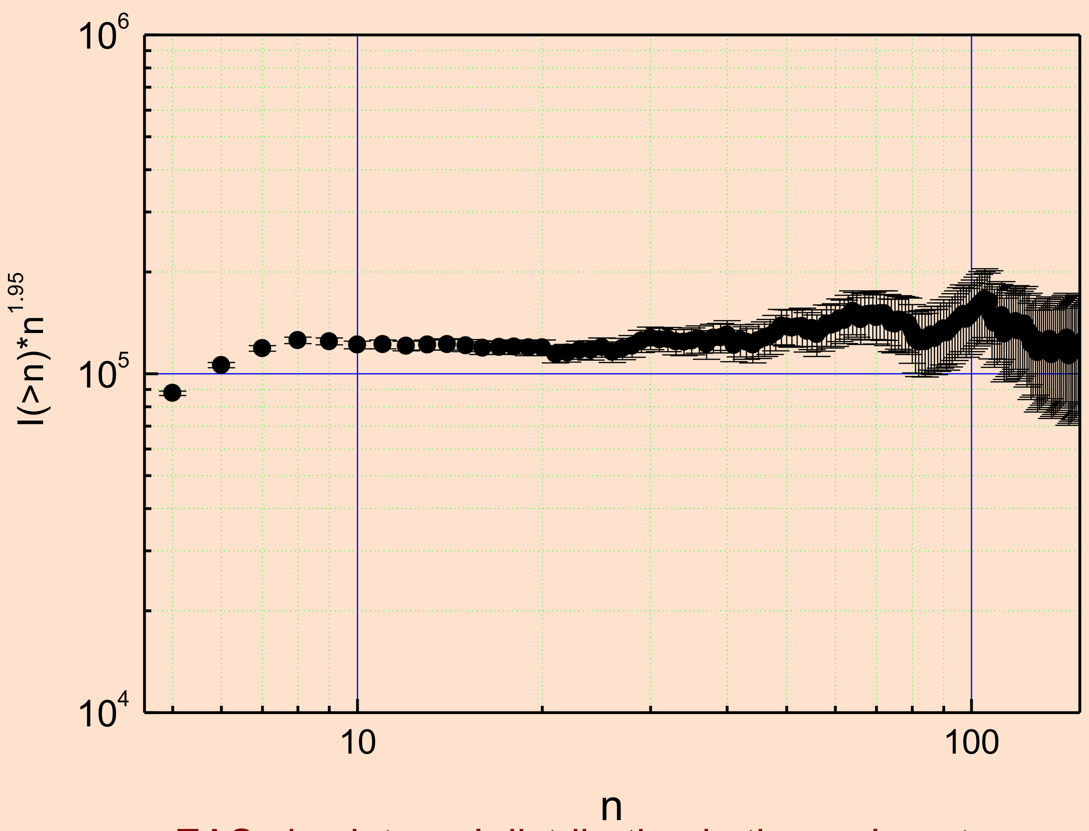
EAS size distribution in thermal neutrons measured by PRISMA-32 for 3 years.

As it is mentioned above, a standard procedure was used to locate EAS axis and to estimate other parameters. In addition, a distribution in the number of recorded neutrons was accumulated for events with the axis inside the array area. As one can see, the integral distribution follows a power law with index β = -1.95 ± 0.05. Primary energies (both for protons and iron) calculated using preliminary CORSIKA simulations are shown at the figure top.

The same data multiplied by $n^{1.95}$ are shown in the figure below. It is seen that the power law index for the integral spectrum is very close to -1.95 and is close to our expectations in a case of pure power law primary spectrum with the index of γ = -1.7. It demonstrates that the EAS size spectrum in thermal neutrons within the experimental errors as well as primary cosmic ray spectrum can be well fitted with a pure power law function.



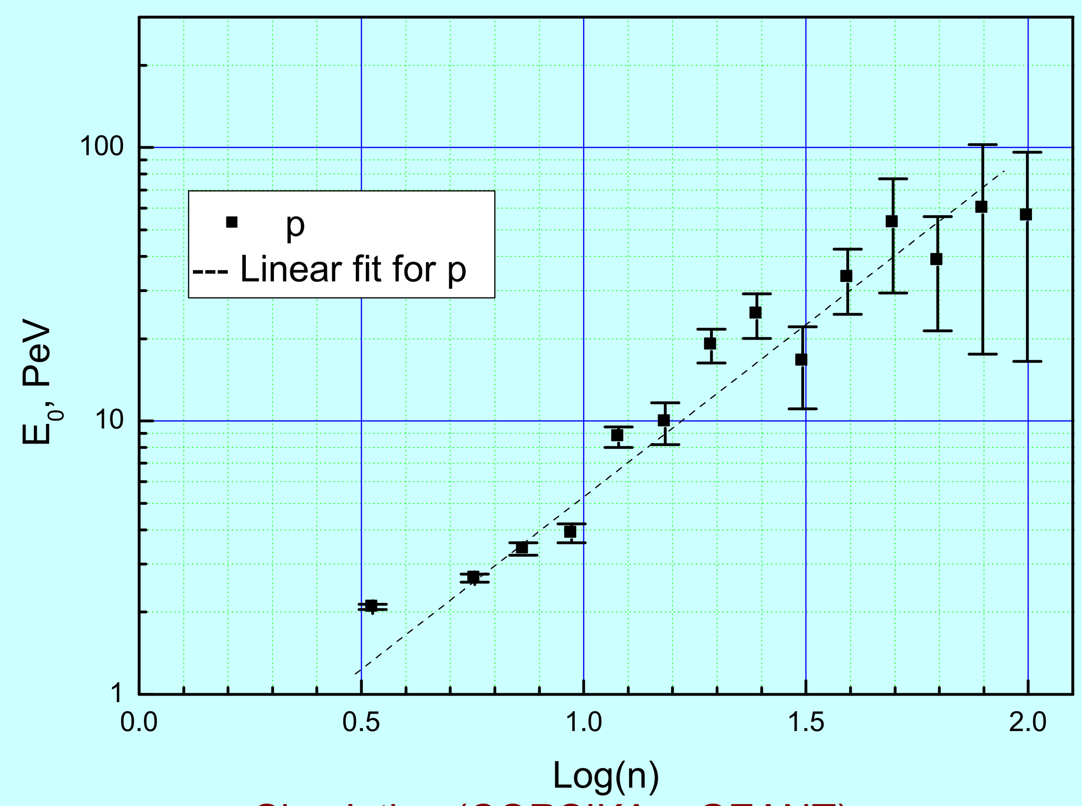
Experimental integral distribution in the number of thermal neutrons.



EAS size integral distribution in thermal neutrons multiplied by $n^{1.95}$

Simulation

Full-scale simulation based on CORSIKA and GEANT has been performed to obtain correlation between proton primary energy and recorded number of thermal neutrons in all detectors. The same program was used to process both simulated and experimental data. The calculations are in progress now and at this stage we show only results with rather poor statistics. Nevertheless, it is clear that the estimation of the knee region position will not be changed significantly in the future.



Simulation (CORSIKA + GEANT)

Conclusion:

A novel type EAS experiment (PRISMA-32) is running in MEPhI (Moscow) for more than 3 years. For the first time, EAS size spectrum in thermal neutrons was measured above the knee energy region. The results show that this spectrum agrees with a pure power law function with integral index β= -1.95±0.05.

http://ununevod.mephi.ru/en/

References:

[1] Yu.V. Sten'kin. Large scintillator detector for thermal neutron recording. In: Nuclear Track Detectors: Design, Methods and Applications ISBN: 978-1-60876-826-4, Editors: M. Sidorov and O. Ivanov, Nova Science Publishers, Inc., Chapter 10, 253 (2010).
[2] Yu.V. Stenkin. Thermal neutrons in EAS: a new dimension in EAS study. Nucl. Phys. B (Proc. Suppl), 175-176, 326 (2008).
[3] Yu.V. Stenkin. On the PRISMA project. Nucl. Phys. B (Proc. Suppl.), 196, 293 (2009).
[4] D. Gromushkin, V. Alekseenko, A. Petrukhin, et al. The array for EAS neutron component detection. JINST, 9, C08028 (2014).
[5] D.M. Gromushkin, V.V. Alekseenko, A.A. Petrukhin, et al. The ProtoPRISMA array for EAS study: first results. Journal of Physics: Conference Series, 409, 012044 (2013) .
[6] D.M. Gromushkin, V.I. Volchenko, A.A. Petrukhin, et al. Novel method for detecting the hadronic component of extensive air showers. Physics of Atomic Nuclei, 78, 349 (2015).
[7] Yu.V. Stenkin, D.M. Gromushkin, A.A. Petrukhin, et al. EAS thermal neutron lateral and temporal distributions. 33 ICRC, Brazil, ID 482.
[8] Yu.V. Stenkin, V.V. Alekseenko, D.M. Gromushkin, et al. Thermal neutron flux produced by EAS at various altitudes. Chinese Physics C, 37, 015001 (2013).

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