The OLVE-HERO calorimeter prototype beam tests at SPS CERN

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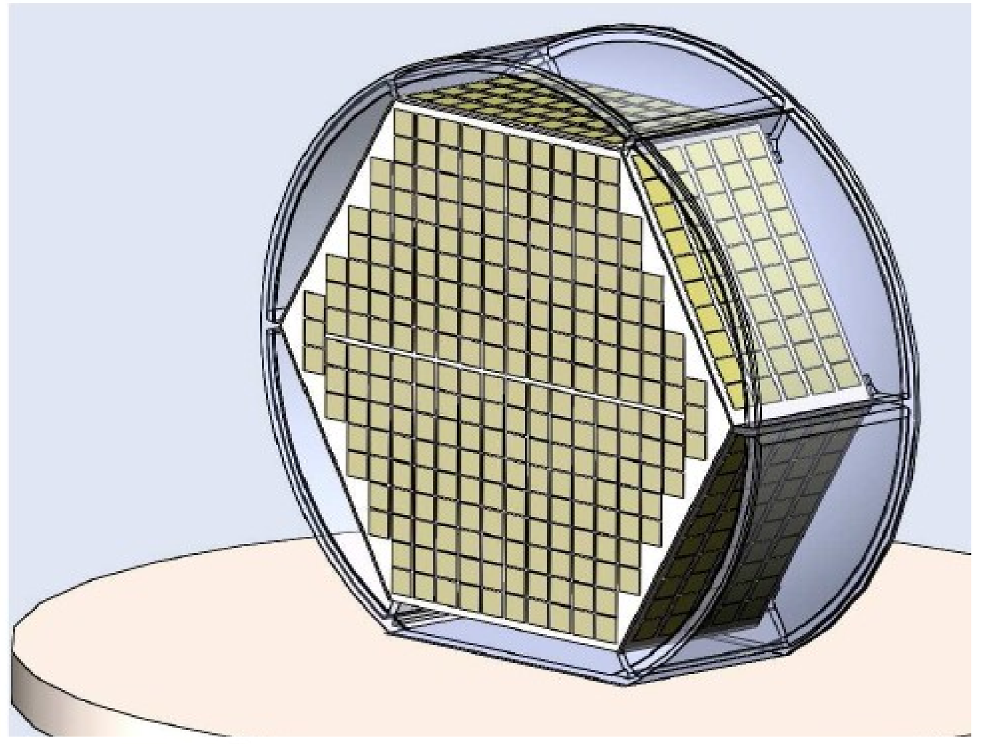
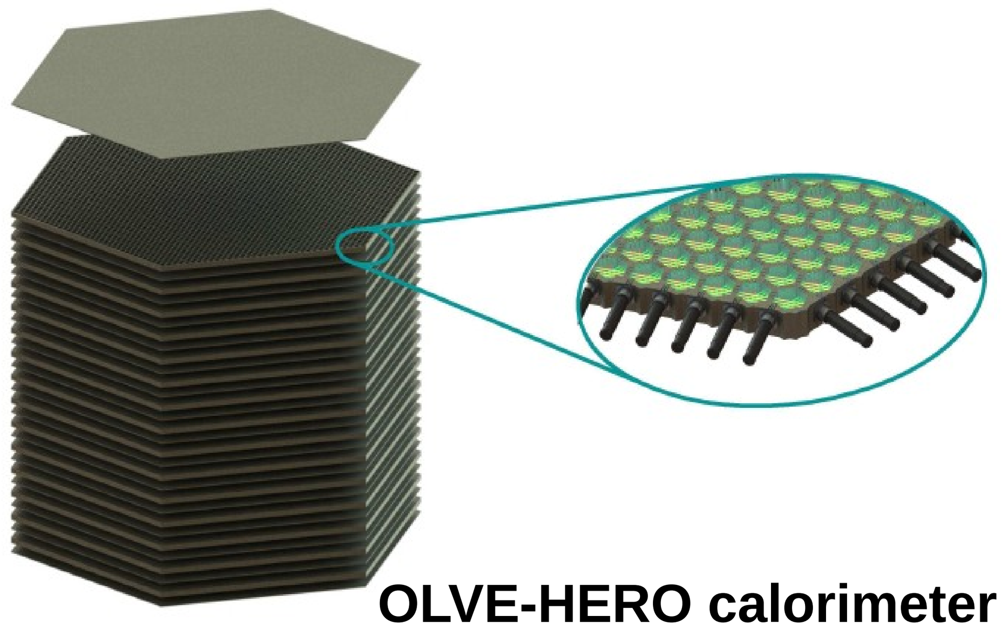




OLVE-HERO calorimeter

Geometry of the OLVE-HERO calorimeter
Diameter of the circumscribed circle 2025 mm
Height 455 mm, weight ~ 10 tons
Number of registration channels 3060.

Motivation and data taken

The fundamental problem of modern physics is to establish the nature of dark matter, the existence of which is firmly established by the gravitational effects and analysis of the anisotropy of microwave radiation. Dark matter particles can interact with each other, generating ordinary particles, including gamma rays and electron-positron pairs with energies determined by the mass of the initial hypothetical particles. To find dark matter particles in this direction, precision measurement of electron and gamma-ray spectra up to several tens of TeV is required. However, additional direct measurements of CR at energies up to 1000 TeV with element resolution and measurements of gamma-ray quanta flux of TeV energies are required. Due to the small flow rate of CR, its effective measurement at such high energies requires a large geometric factor.

A project of the OLVE-HERO space detector is proposed within the framework of the Federal Space Program for CR measurement in the range 10^{12}-10^{16} eV and will include as a main detector the large ionization-neutron 3D calorimeter with a high granularity and geometric factor of ~16 $m^2 \cdot sr$. The 3D structure of the calorimeter will allow registering CR particles coming from different directions. As the main OLVE-HERO detector is expected an image calorimeter of a boron loading of plastic scintillator with tungsten absorber. Such a calorimeter allows to measure an additional neutron signal which will improve the energy resolution of the detector. The more importantly, the rejection power between electromagnetic and nuclear CR components will be increased by factor ~100 in the whole energy range. The boron loading scintillator detector prototype was designed and tested at the H8 beam line area at CERN SPS during Pb ion run in 2019. Preliminary results of the beam tests and the corresponding Monte-Carlo simulation is presented.

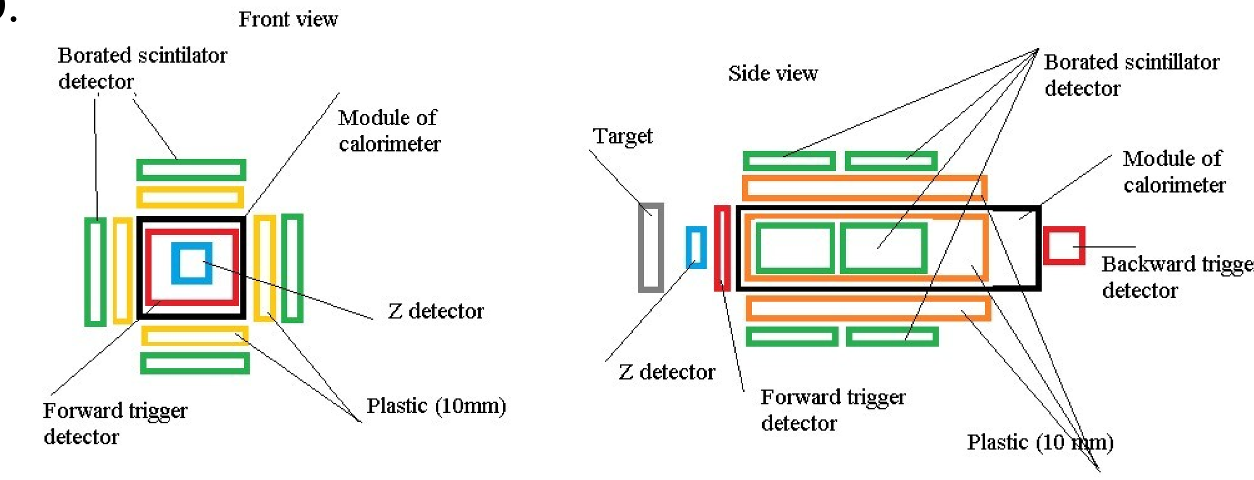
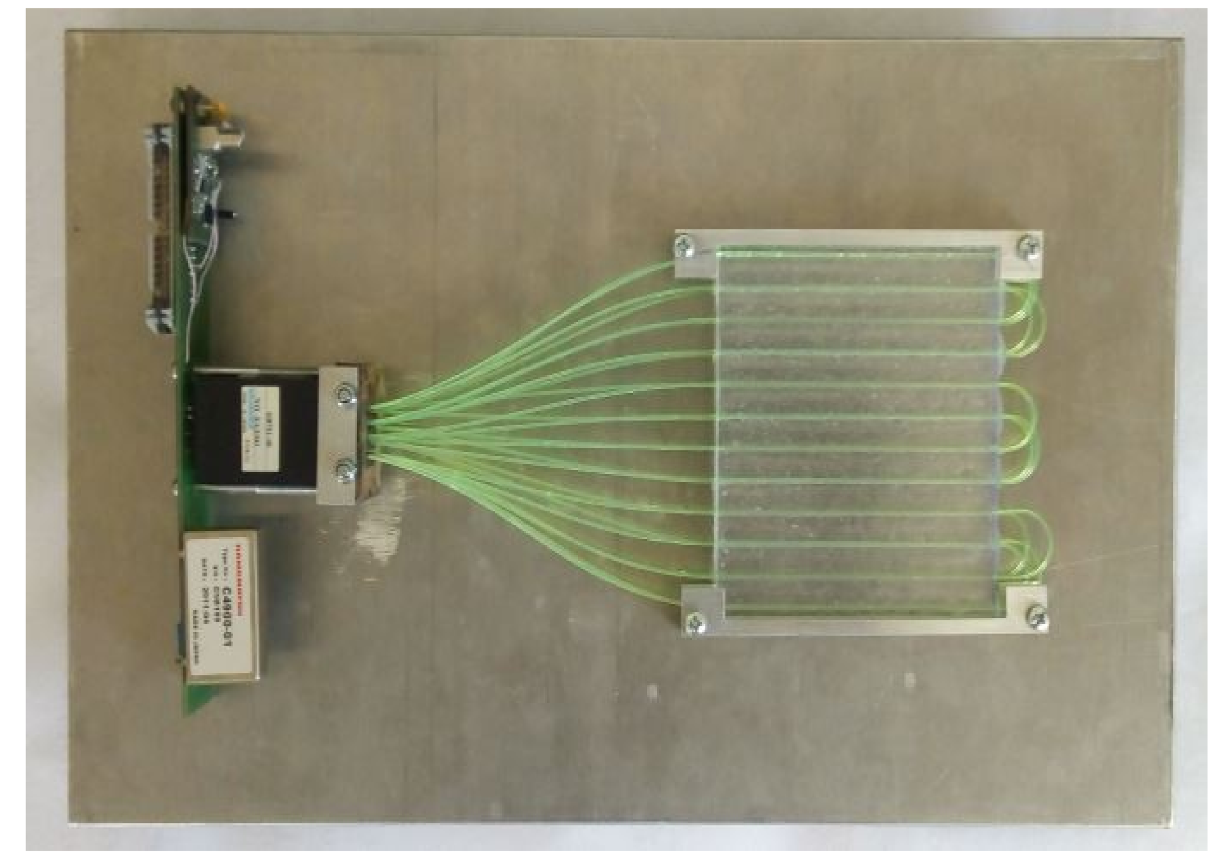


Fig. 1. Schematic view of the OLVE-HERO prototype on the SPS test beam at CERN



Scintillation detector plane of the OLVE-HERO prototype,

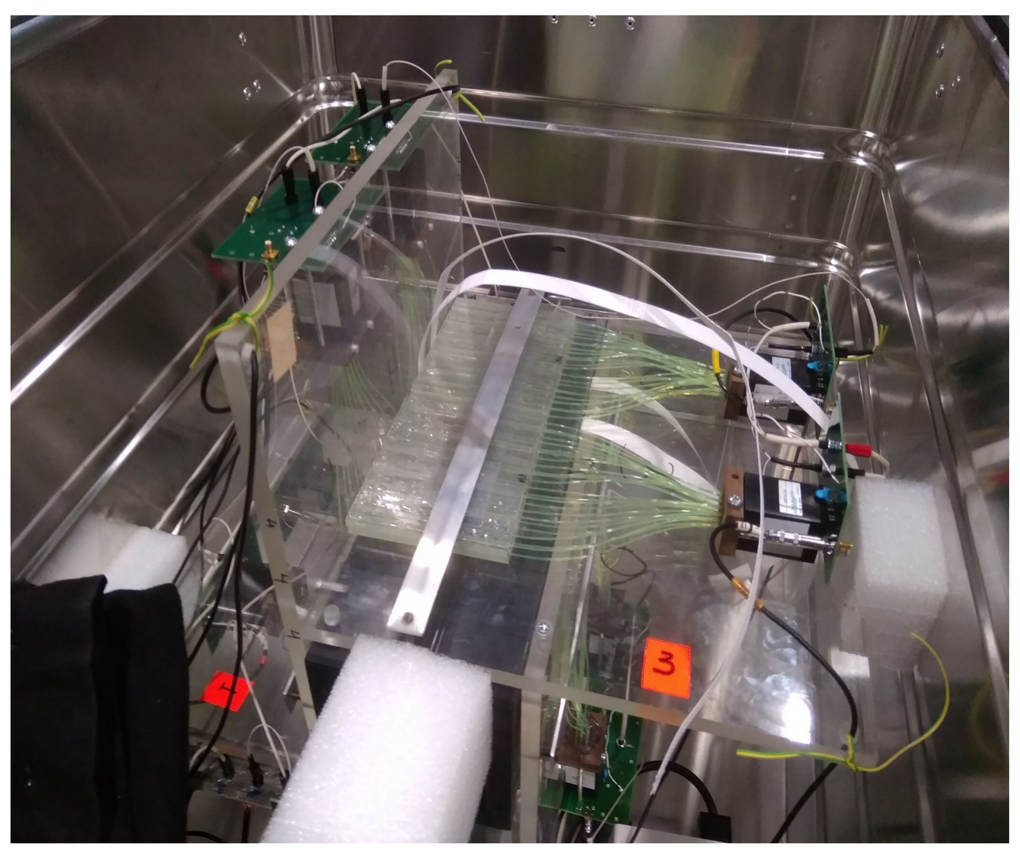


Figure 2. The borated scintillator planes OLVE-HERO inside of light-tight metal container

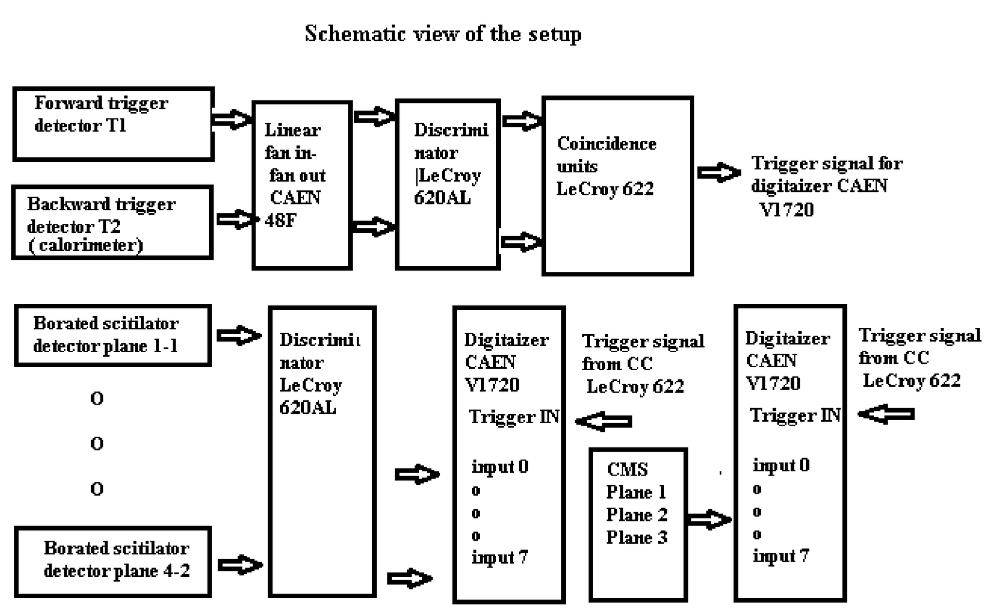


Figure 3. The measurement scheme.

For the purpose of the experimental investigation of the neutron deceleration effects up to thermal energies, a prototype of the detector was designed and produced. Its schematic view is presented on Figure 1. OLVE-HERO prototype was made to study of the rejections capability between the electromagnetic and hadron CR components in the beam test experiments. The prototype consists of a 3 layers silicon detectors of the charge measurement system (CMS) of beam particle in front of forward trigger detector T1 that is following by backward trigger detector T2 which is a calorimeter type shashlyk with PMT H8711-10 HAMAMATSU readout consisting of 109 layers of 1.5 mm plastic scintillator plates and 0.8 mm tungsten converters of total size 120x120x240 mm^3 and ~15 radiation lengths. Eights plates of borated scintillator (BS) of 120x100x5 mm^3 are located around lateral sides of calorimeter module with 10 mm plastic moderator planes in between. All detectors for exception of CMS are placed in a light-tight metal container.

On the Figure 2 the photo of the two detecting planes of the borated scintillator are presented: grooves were cut into 5 mm scintillator plane where the 1 mm WLS fiber of KURARAY was pasted. Signals from fibers are gathering to the collector and going to the photocathode 16-channel PMT type H8711-10 HAMAMATSU. The far end of the fiber was polished and covered by silver to reflect the light signal. The signal of the last PMT dynode was used to record the detector amplitudes of the events selected by the trigger.

The interest in neutron detection is that its interaction with the detector matter occurs with a delay and can therefore be measured independently of the signal of charged secondary particles which give simultaneous non-delayed counts in all planes of the detector. Evaporation neutrons which produced in the target and calorimeter that is working as a moderator registered the same borated detecting planes after slowing down to thermal energies. However, the neutron signal occurs only in case if the neutron was captured by ^{10}B to form α-particle according to reaction with a total energy of 2.78 MeV

$$n + B^{10} \rightarrow Li^{7} + \alpha + \gamma + 2.78\ MeV.$$

Most of the energy in this reaction (1.47 MeV) takes α-particle and spends on the production of scintillation signal which is equivalent to the signal of an electron with an energy of 76 keV. The α-particle has negligible mean free path and is registered at the place of its formation in the detector. Increasing of the rejection power between the electromagnetic and hadron-nuclear primary particles will be carried out by measuring the neutron signal in the detector which is in factor 30-50 more weak in case of electromagnetic interactions.

Amplitudes of signals of the BS plates, the calorimeter and CMS plates were recorded in a time window of 16 μs after the generation of the beam particles trigger . The trigger was produced by simultaneous signals of forward trigger detector T1 and backward trigger detector (calorimeter) T2 as shown in Figure 3 that presents the measurement scheme

Preliminary results of beam tests at SPS CERN

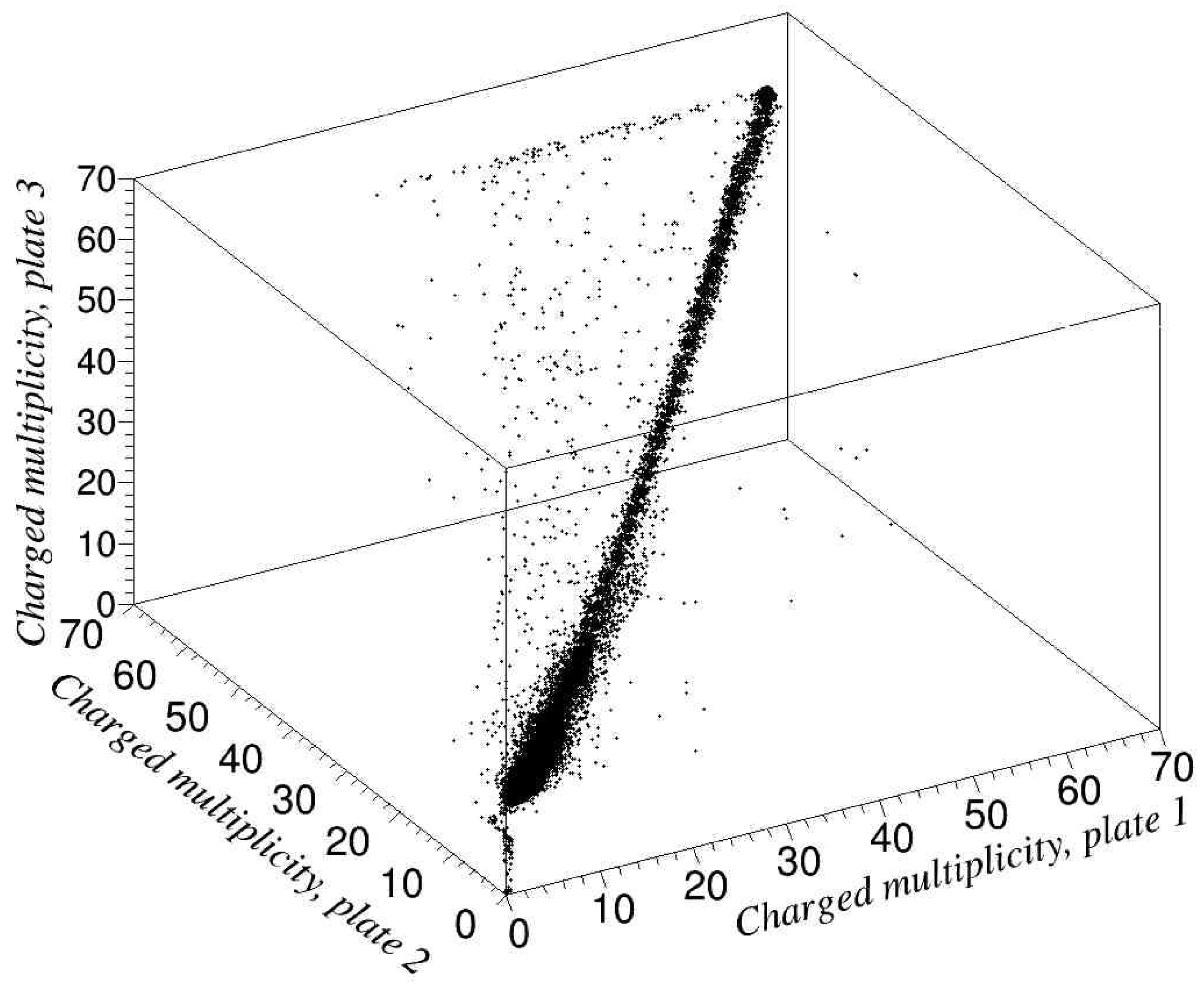


Figure 4. Amplitude correlation of CMS detectors

Tests of the prototype were carried out at the SPS CERN on the test beams area. Fragmentation nuclei from the lead nucleus with an energy of 13 Gev/c and a rapidity in the test channel A/Z = 2.1 - 2.2 were used. The intensity of a beam of nuclei is ~5000 particles per spill. .

An example of the recorded data in the 16 µs time window is shown in Figure 5. Beam particle interaction in the target generates a cascade of secondary particles which gives signals in all the detectors almost instantly with trigger signal that is shifted on 3.5 µs for visibility. Besides of coincided signals in the trigger time there are visible two delayed signals also at the ~5.5 and ~8.5 µs. They are typical BS signals of thermal neutrons.

The histograms in Figure 6 were filled with the number of neutron picks for all events and its time dependence are presented. The number of signals after the trigger time decreases in the 16 trigger time decreases in the 16 µs time window and is interpreted as neutron signals. The detector-3 plot is empty due to it was inoperative at the time.

There is clear necessity of the Monte-Carlo simulation for better understanding of the obtained results. The Monte-Carlo study was carried out using the framework of software packages FairRoot and Geant4. In Figure 7a the amount of α-particles creating in BS detectors and decreasing in 16 µs time interval is presented. The time when the beam particle enters the prototype is zero. To check the effect of boron on the number of α-particles yield the stimulation was obtained without boron in the BS detectors (figure 7b).

The beam particle interaction generates evaporative and thermal neutrons in all detectors. Thus, the equilibrium of the thermal neutron density to beam flux intensity during the beam pulse is established. It will determine the value of a constant background signal in the future OLVE-HERO borated scintillator calorimeter. The Monte-Carlo distribution of the lifetimes for delayed and thermalized ~300000 neutrons was simulated to study this effect in prototype shown in the Figure 1 with carbon nuclear as beam particle and presented in the Figure 8 for one of the BS detector. The average neutron lifetime inside of the prototype is 5.216 ± 0.001 µs starting from the beam particle entrance.

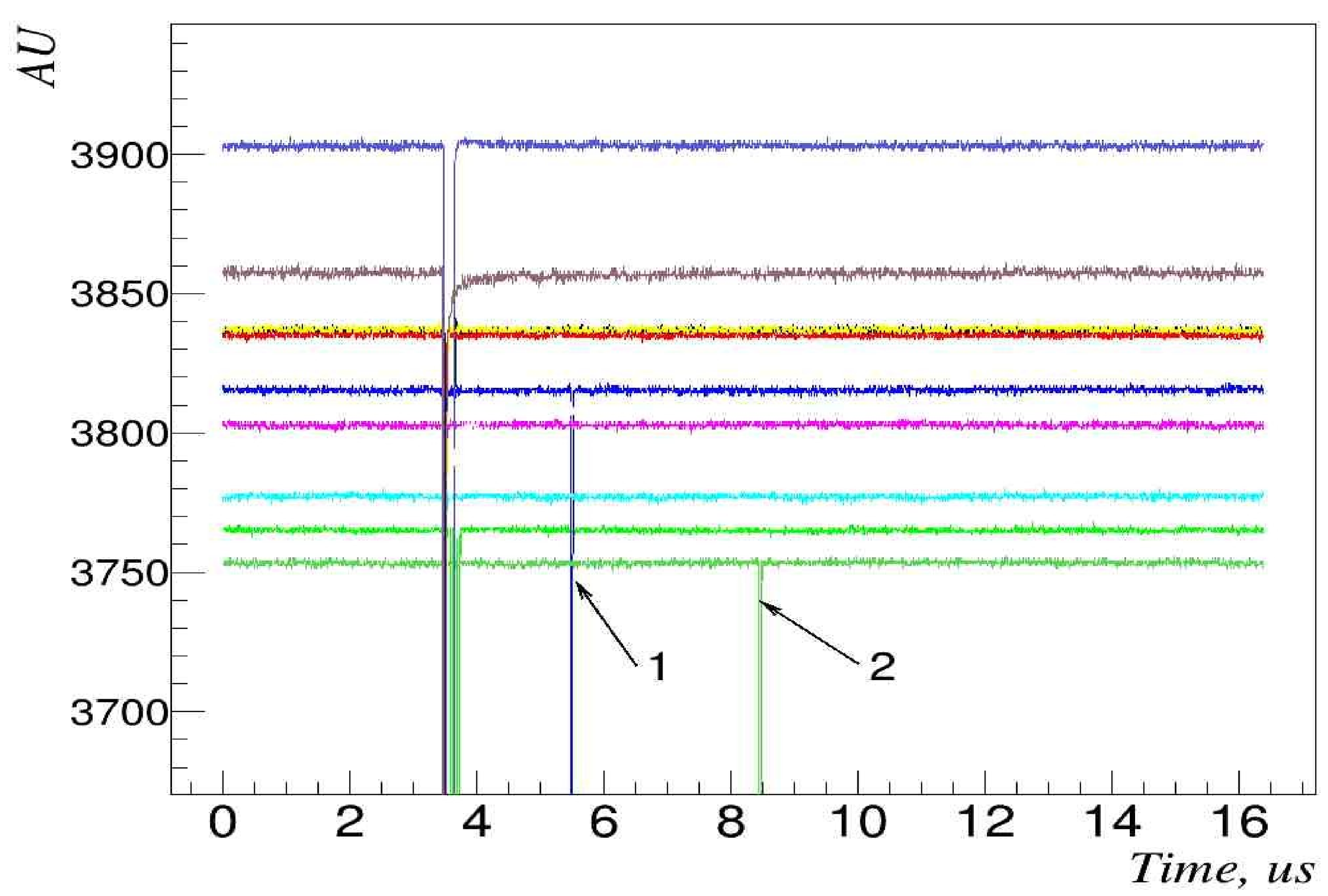


Figure 5. Example of time dependences for the single event amplitudes with neutron picks (1 and 2).

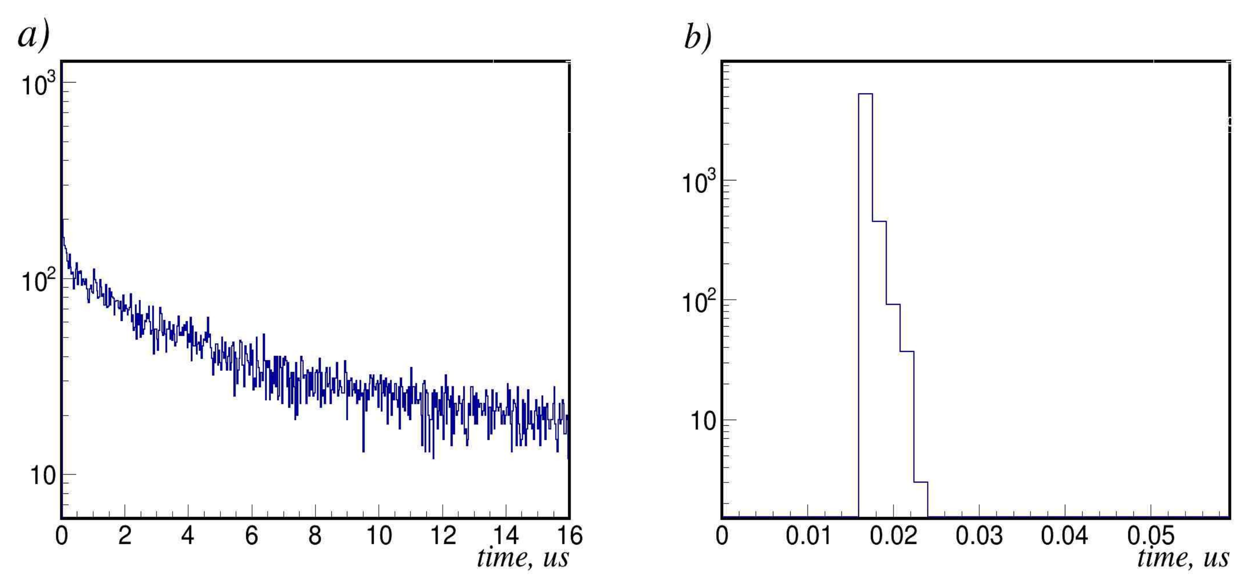


Figure 7. Monte Carlo simulation of the α-particles time creation in the prototype: a)with borated scintillator, b) without boron. Time shift in the right panel is due to distance between the beam entrance point and the scintillation detector.

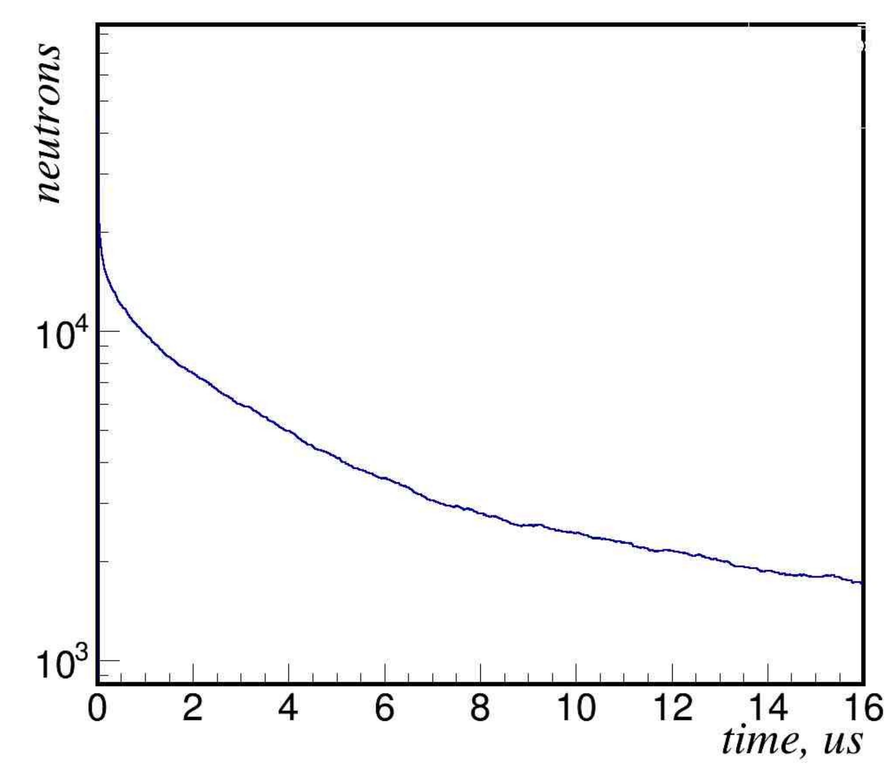


Figure 8. Monte-Carlo distribution of the lifetimes of delayed neutrons in the BS detector

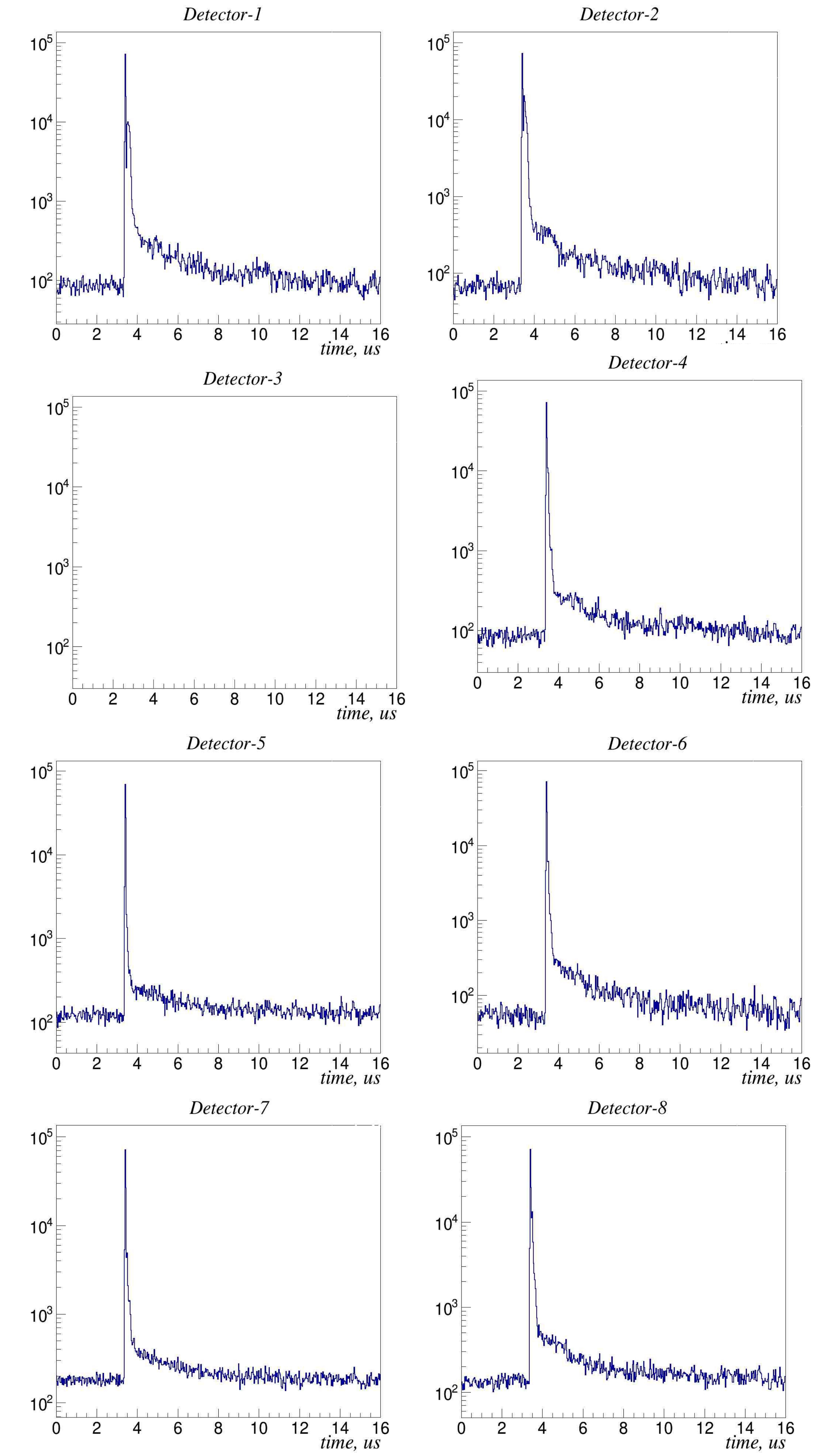


Figure 6. The time dependence of the BS neutron signals after the prototype shifts. Odd numbers of detectors are upstream of beam, even numbers are downstream of beam.

Conclusion:

The results of the OLVE-HERO prototype calorimeter tests on lead ion beams at the SPS CERN at 2018 are presented. From the beam test results and Monte Carlo simulation one can conclude that the borated scintillator detectors give a possibility to increase the rejection power between the hadron CR components and the electromagnetic one. Using a borated scintillator in the prototype together with a polyethylene moderator gives a clear picture of the appearance of delayed signals from the neutron capture by ^{10}B nucleus in the range of 0 - 16 µs after the primary interaction of the beam particle. The results are in qualitative agreement with the Monte Carlo simulation.

This CR flux will generate evaporative and thermal neutrons. Thus, the equilibrium of CR flux intensity and thermal neutrons density will determine the value of a constant background signal in the borated scintillator detectors. This background signal can “clog” the signal from the initial CR showers, therefore there is a fear that such a detector gives wrong results. To obtain the final answer, it is necessary to carry out additional tests on the beams, a special simulation of this effect taking into account the spectrum and composition of the CR, as well as the geometry of the detector. In order to optimize the design of the OLVE-HERO detector, the additional data analysis, Monte Carlo simulation and additional experiments are required in particular on the high energy electron beam.