Compact segmented hadron calorimeter for detection of low energy spectators at MPD/NICA facility

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The Forward Hadron Calorimeter (FHCal) for the detection of the protons and neutrons in energy range of 1-5 GeV is discussed. The calorimeter will measure a heavy-ion collision centrality and orientation of the reaction plane. FHCal consists of two identical arms placed at the left/right sides from the beam collision point. Each FHCal part consists of 44 individual modules with the transverse sizes 15x15 cm^2. Since the calorimeter will operate inside the superconductive magnet with limited available space its length is about one meter or 4 interaction lengths only. Nevertheless, it contains almost full hadron shower at energies up to 5 GeV.

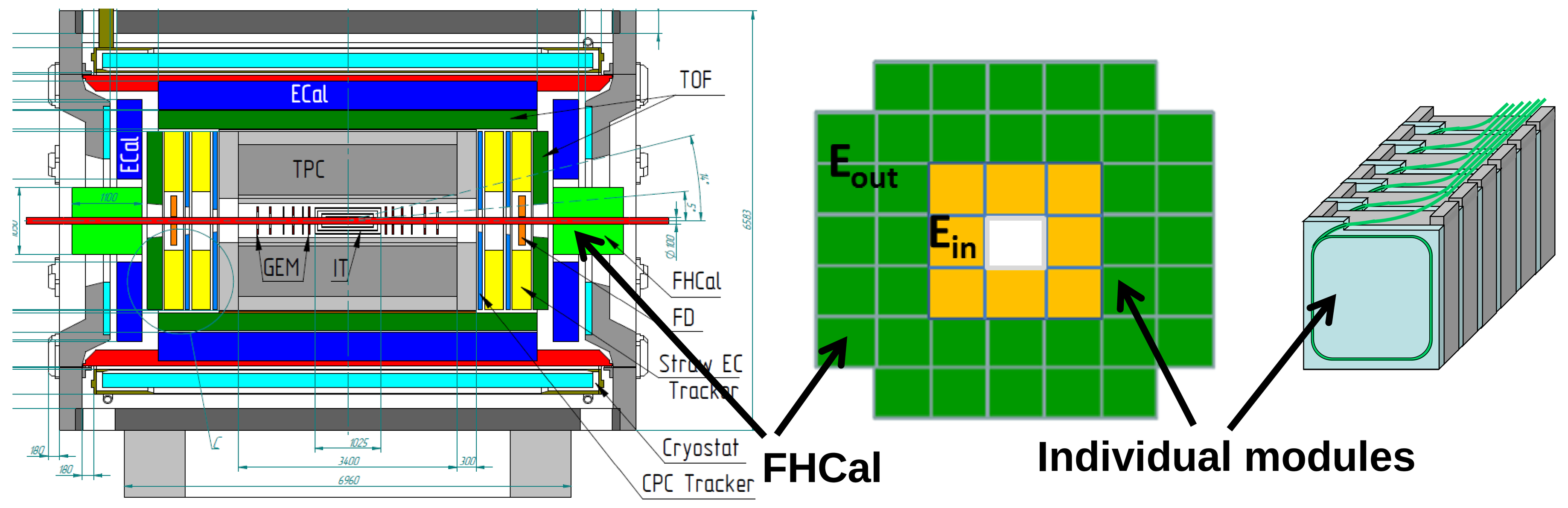

Fig.1 **The MPD setup (left), schematic structure of FHCal (center) and module structure (right). FHCal is subdivided into two parts for the measurements of centrality.**

Forward hadron calorimeter (FHCal) together with Time Projection Chamber (TPC), Time-of-Flight (TOF), Electromagnetic Calorimeter (ECal) and fast Forward Detector (FD) are basic parts of the MPD experimental setup at NICA, Dubna, Russia [1]. As any heavy-ion experiment, the MPD needs to characterize the ion collisions, i.e. to measure the geometry of heavy ions collisions. The main purpose of the FHCal is to provide an experimental measurement of a heavy-ion collision centrality (impact parameter) and orientation of its reaction plane. Precise event-by-event estimate of these basic observables is crucial for many physics phenomena studies to be performed by the MPD experiment. FHCAL consists of two identical arms placed at the left/right sides from the beam collision point, **see Fig.1**. This is a modular lead-scintillator compensating calorimeter designed to measure the energy distribution of the projectile nuclei fragments (spectators) and forward going particles close to the beam rapidity.

FHCAL module construction

Each of two FHCal parts consists of 44 individual modules. with the transverse sizes 15x15 cm^2. The module includes 42 lead-scintillator sandwiches with the sampling ratio 4:1 (thicknesses of lead plates and scintillator tiles are 16 mm and 4 mm, respectively. Light readout is provided by WLS-fibers embedded in the grooves in scintillator tiles that ensures high efficiency and uniformity of the light collection over the scintillator tile within a very few percent. WLS-fibers from 6 scintillators are viewed by single photodetector at the end of the module.

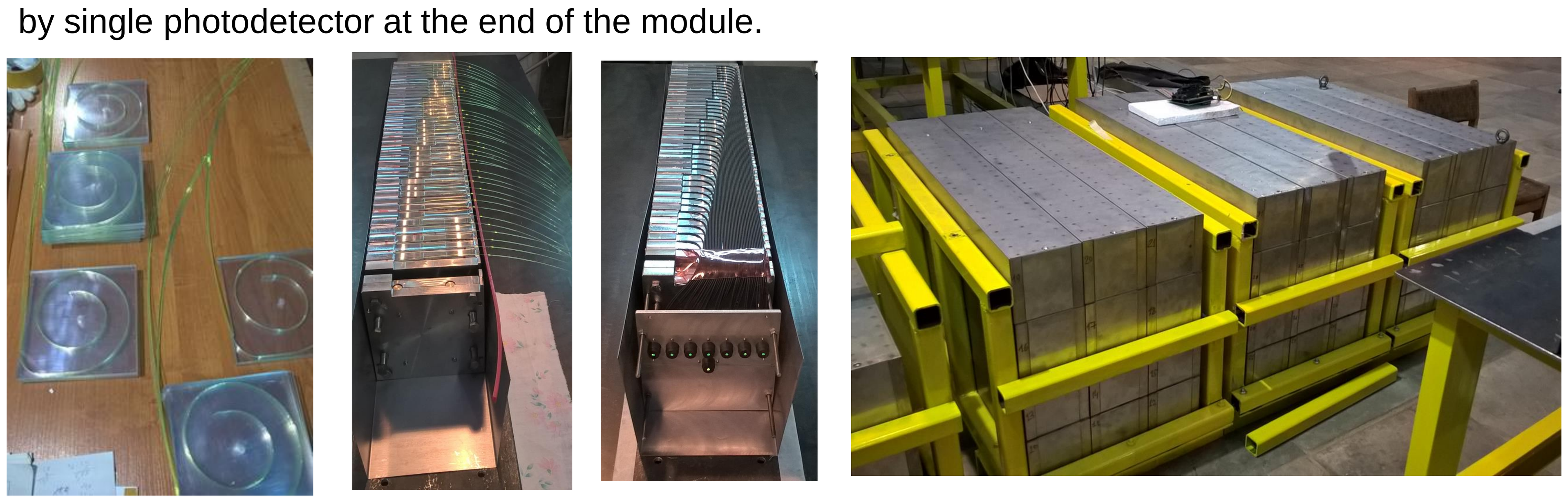

Fig.2 **Photos of the different stages of FHCal module production. Left – scintillator tiles with the glued WLS-fibers. Center – module with lead/scintillator sandwiches before and after WLS-fiber aligning. Right – assembled modules.**

Longitudinal segmentation of the calorimeter modules requires 7 compact photodetectors coupled to the end of WLS-fibers at the rear side of the module. The use of micropixel avalanche photodiodes, (or silicon photomultipliers, SiPMs) is an optimum choice due to their remarkable properties as high internal gain, compactness, low cost and immunity to the nuclear counter effect and magnetic field. Hamamatsu MPPC S12572-010C/P with the pixel size 10x10 μm^2 were selected to ensure high dynamic range of detected energies.

Test of FHCal modules with cosmic muons

After the module assembling, the light yield of all longitudinal sections was measured by using the cosmic muons crossing all 7 sections in module. Nevertheless, the low statistics of horizontal muons forces to use other events with muons crossed two or three neighbor sections in module, **Fig.3, a**.

Light yield distribution in the longitudinal sections of FHCal module for the muons crossed two neighbor sections in module is shown in ***Fig.3, b***. As seen, muon deposits of about 40 photoelectrons/section. It makes possible the energy calibration of the FHCal modules with the cosmic muons during the calorimeter operation in MPD setup. The behavior of the light yield distribution reflects the attenuation of the light in the WLS-fibers with different length, **Fig.3, c**.

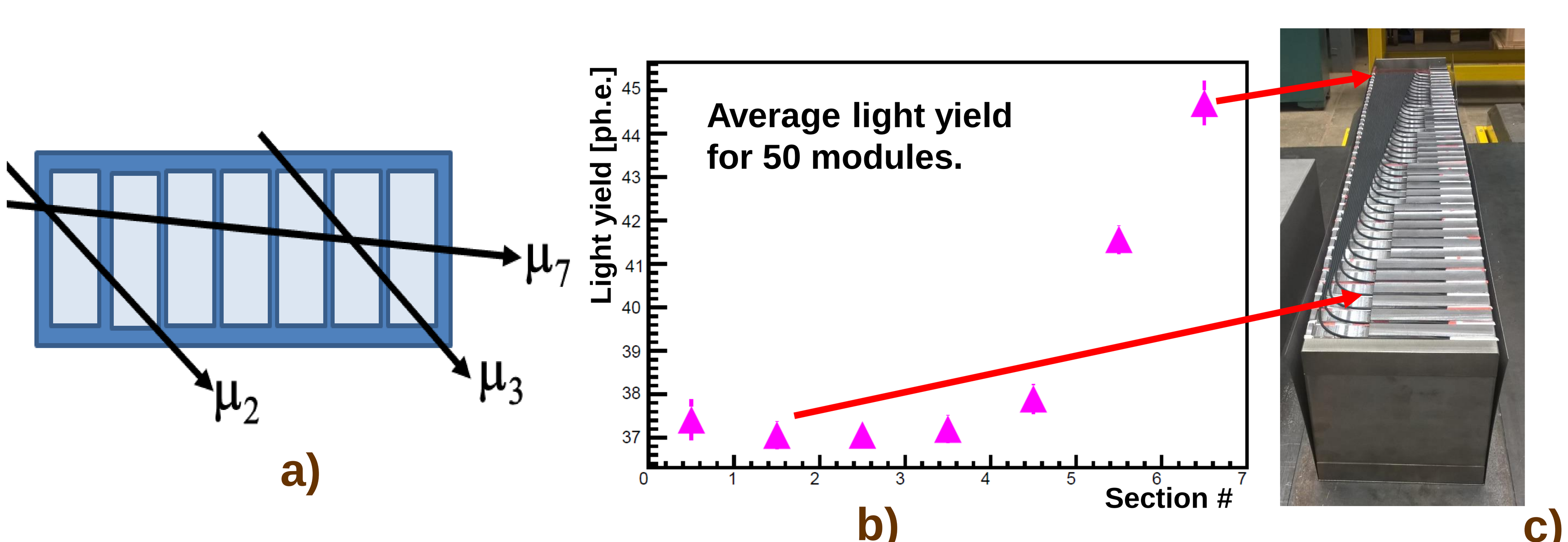

Fig.3 **Measurements of the light yield in longitudinal sections of module with cosmic muons.**

Light yield depends on WLS-fiber length.

Test of calorimeter modules at proton beam.

To check the expected performance of FHCal, 9 individual modules with larger sizes were arranged in 3x3 array and installed at the platform. These modules [2] have the same structure but consist of 60 lead/scintillator sandwiches grouped in 10 longitudinal sections. Tests were done at T9/T10 beam lines at CERN in 2017-2018.

Energy calibration was done with beam 6 GeV/c muons crossed all 10 sections of modules, **Fig.4**.

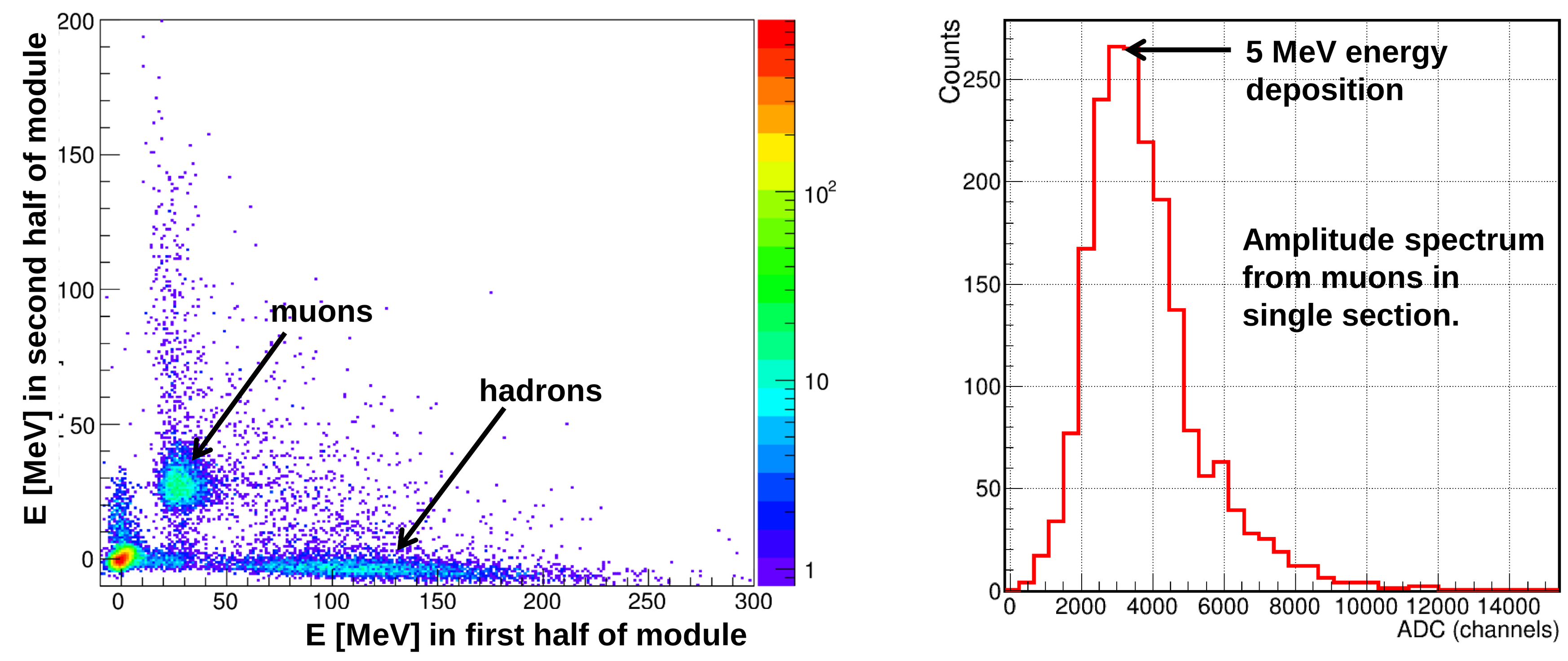

Fig.4 **Energy calibration of longitudinal sections with beam muons.**

After **muon calibration** the proton energy deposition in each section of 3x3 modular array was calculated. Due to the longitudinal segmentation one can possible to measure hadron spectra in calorimeter with different active lengths. **In Fig.5, left,** the amplitude spectra are presented for the active calorimeter lengths from 1 section to 9 sections. Also, the longitudinal profile of deposited energies is presented in **Fig.5, right.**

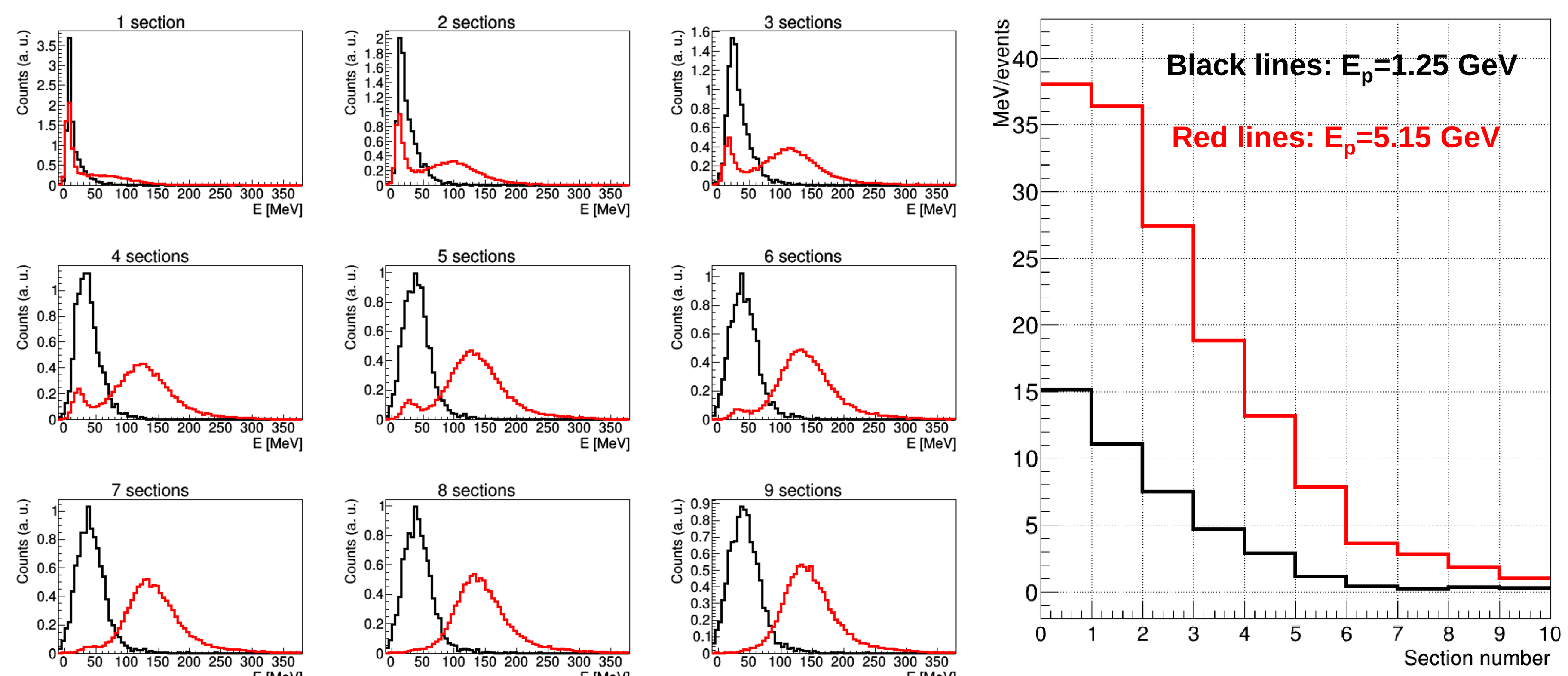

Fig.5 **Proton amplitude spectra in 3x3 modular array with different active length from 1 to 9 sections.**

Longitudinal profile of deposited energies from protons.

Using above amplitude spectra one can calculate **the energy resolution** for calorimeter with different active lengths, **Fig.6.**

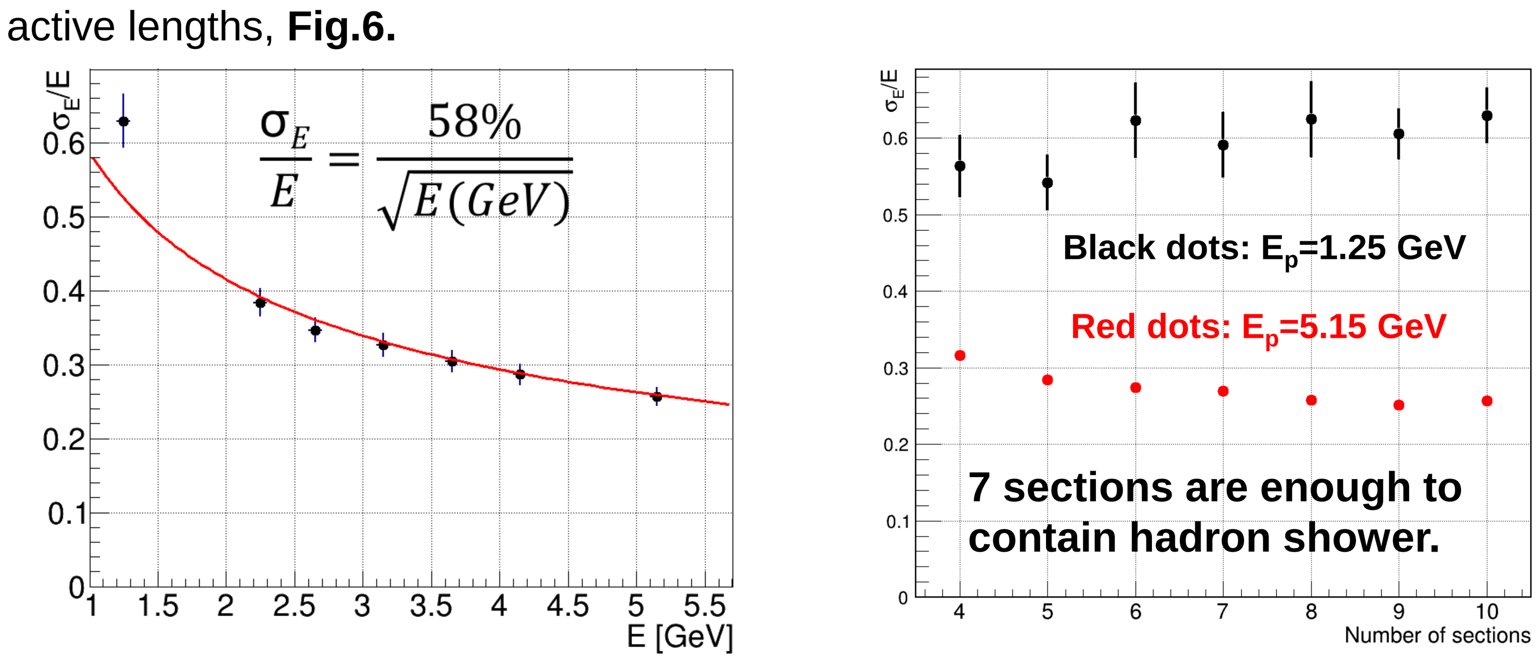

Fig.6 **Energy resolution for 3x3 modular array. Left – for whole array, right – for array with different active lengths.**

Conclusion

FHCal has fine segmentation in both transverse and longitudinal directions. The FHCal modules have 4 interaction lengths that is sufficient for the detection of the spectators with energies up to 5 GeV. The longitudinal segmentation in 7 sections ensures the uniformity of the light collection along the module and the measurement of the profile of hadron shower. The light yield of each longitudinal section is about 40 photoelectrons per minimum ionizing particle crossed the module. It allows the energy calibration of the FHCal modules with the cosmic muons during the calorimeter operation in MPD setup. **This work was supported by MPD/NICA collaboration and by RFBR grant № 18-02-40065.**

References

1. http://nica.jinr.ru
2. D. Finogeev at al., 2018, "The PSD CBM supermodule response study for hadrons in momentum range 2 – 6 GeV/c at CERN test beams" in *The 3rd International Conference on Particle Physics and Astrophysics*, KnE Energy & Physics, pages 333–339. DOI 10.18502/ken.v3i1.1763