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Forward Hadron Calorimeter (FHCal) at MPD/NICA

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Forward hadron calorimeter (FHCal) together with Time Project 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 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.

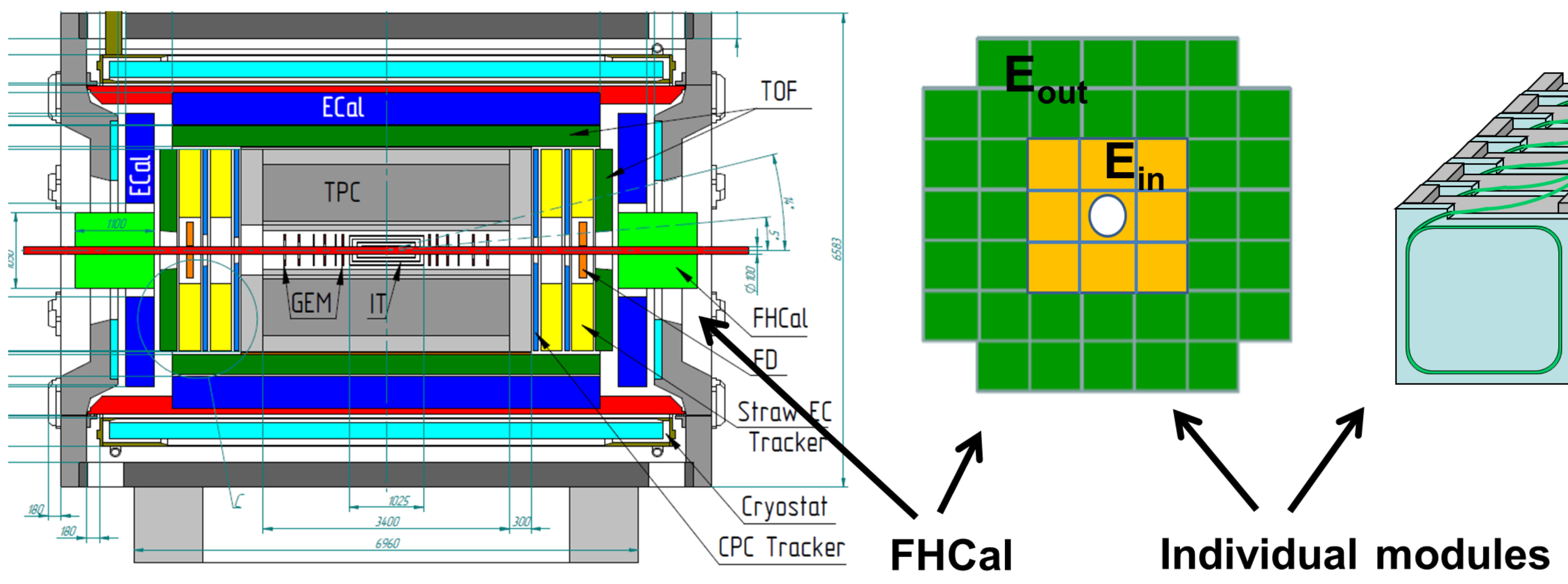

Fig.1 **The MPD setup (left), schematic structure of FHCal (center) and module structure(right). FHCal is subdivided into two parts for the measurements of centrality.**

Since the heavy fragments escape into beam holes, it is not possible to discriminate the central and peripheral collisions using only the deposited energies in FHCal. The subdivision of the calorimeter into two, inner and outer parts (*see Fig.1*), and the calculation of the energy depositions E_{in} and E_{out} separately in these calorimeter parts allows the construction of new observable, *energy asymmetry:*

$$A_E = (E_{in} - E_{out}) / (E_{in} + E_{out}).$$

Taking the two-dimensional correlation between the energy asymmetry, A_E and full energy deposition in calorimeter**,** *Fig.2*, one would be possible to resolve the ambiguity in the centrality determination The negative and positive parts of A_E correspond to the central and peripheral events, respectively.

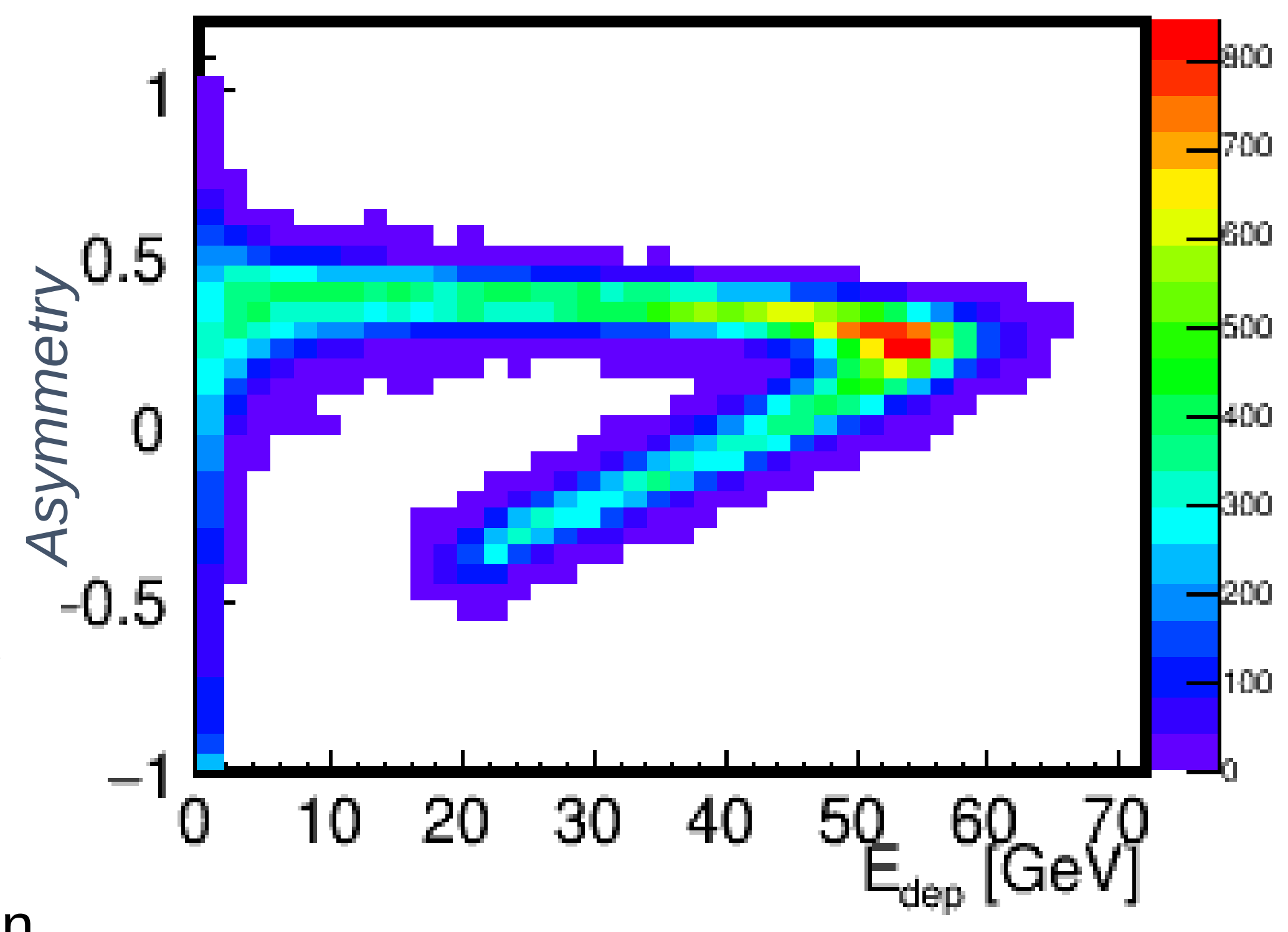

Fig.2 **Two-dimensional correlation between the energy asymmetry and full energy deposition in calorimeter. Maximum colliding energy of NICA is used in simulation.**

FHCAL module construction

The *FHCal module transverse sizes* of *15x15 cm²* were chosen to match the size of the hadron showers. Each module of hadron calorimeter consists of 42 lead-scintillator tile sandwiches with the sampling ratio *4 : 1* (thickness of the lead plates and scintillator tiles are 16 and 4 mm, respectively) that satisfies the compensation condition. According to simulation, the sampling fluctuations provide the energy resolution of calorimeter as: $\frac{\sigma_E}{E} \sim \frac{55\%}{\sqrt{E(GeV)}}$. The beam tests of the calorimeter with the same sampling *[2]* confirm the results of simulation.

Light readout is provided by the *WLS-fibers* embedded in the grooves in scintillator plates that ensures high efficiency and uniformity of light collection over the scintillator tile within a very few percent. WLS-fibers from each 6 consecutive scintillator tiles are collected together and viewed by a single photodetector at the end of the module. The longitudinal segmentation in 7 sections ensures the uniformity of the light collection along the module. The photos of assembled modules are presented in *Fig.3.*

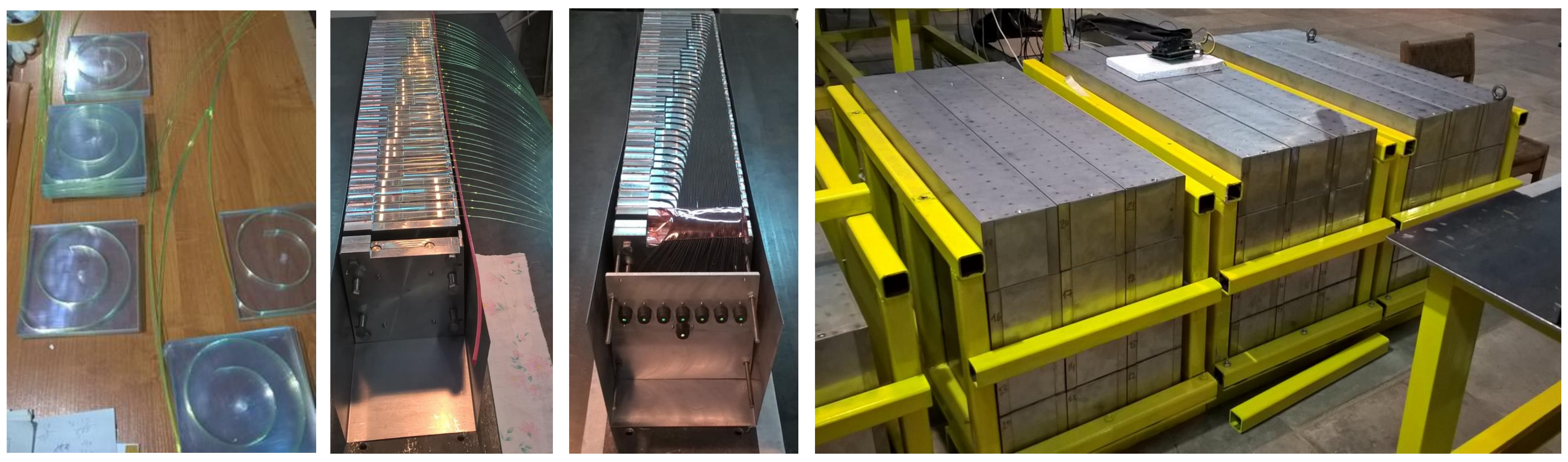

Fig.3 **Photos of the different stages of FHCal module production. Left – scintillator tiles with the glued WLS-fibers. Center – module with lead/scintillator sandwiches before and after WLS-fiber aligning. Right – assembled modules.**

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 μm² were selected to ensure high dynamic range of detected energies.

To optimize the light collection efficiency from the scintillators some R&Ds on the groove shapes were performed. Namely, a few types of the scintillator tiles were produced with *circular and spiral grooves*. The tests of all tiles were performed with ^{90}Sr β-source and trigger counter below the scintillator tile to detect the electrons passed through the scintillator. The outer end of WLS fiber was glued into special optical connector that was viewed by Hamatsu MPPC. The measurements of the light amplitude were done with the step of 2 cm along the diagonal of the scintillator.

The results of measurements are shown in *Fig.4.* One can see, that both, circular and spiral grooves give similar results with the light yield of about 20 photoelectrons with 1% average space nonuniformity in the light collection. The spiral groove provide slightly better parameters and were selected for the design of FHCal modules. The tiles are wrapped in reflector TYVEC.

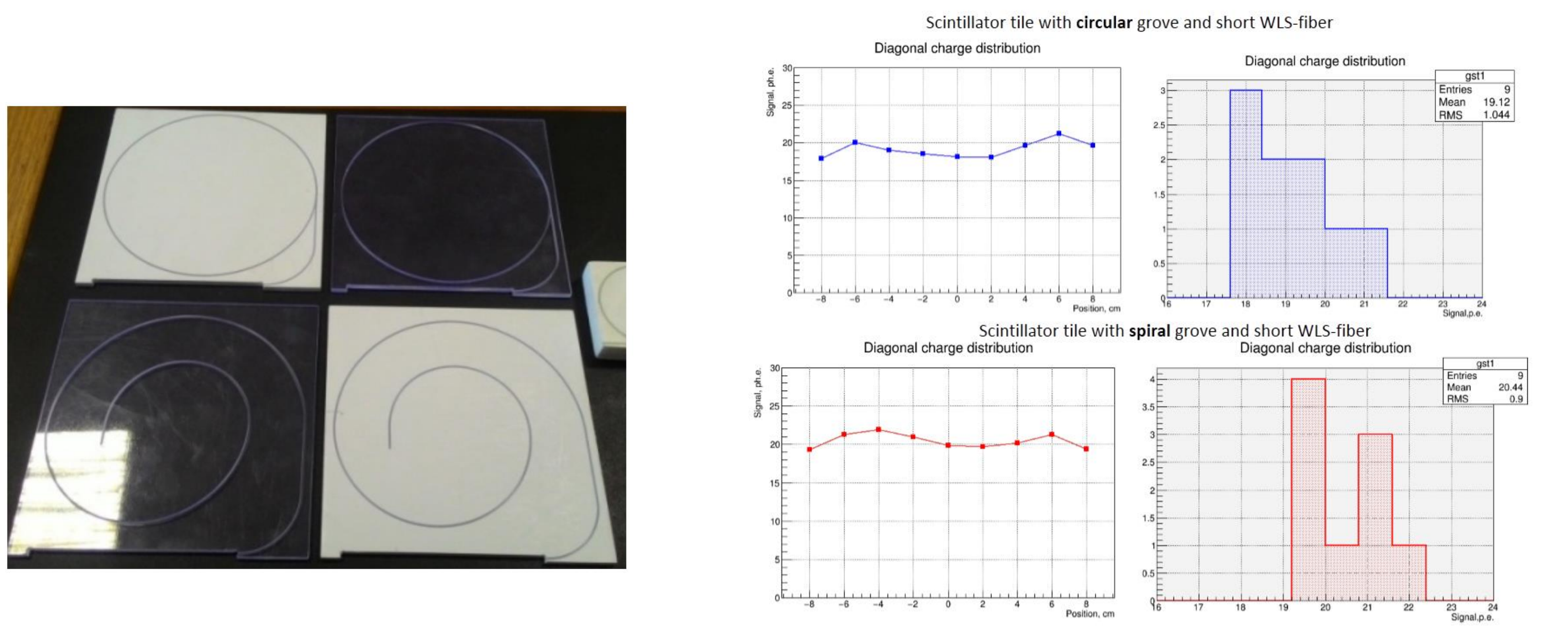

Fig.4 **Photo of scintillator tiles with different reflectors and shapes of grooves (left). Right - the light yield along the diagonal of scintillators with different types of the groves. TYVEC reflector was used for the measurements.**

Test of FHCal modules with cosmic muons

The *individual calibration* of longitudinal sections is essential for the monitoring of the light yield behavior. After the module assembling, the light yield of all longitudinal sections was measured by using the cosmic muons crossing all 7 sections in single module. Nevertheless, the low statistics of horizontal muons forces to use other events with muons crossed two or three neighbor sections in module. The amplitude spectra for these two groups of events are shown in *Fig.5.* One can see, that the peaks are more visible in case of muon cross three sections because the pass lengths of muons in the scintillator tiles are less spread.

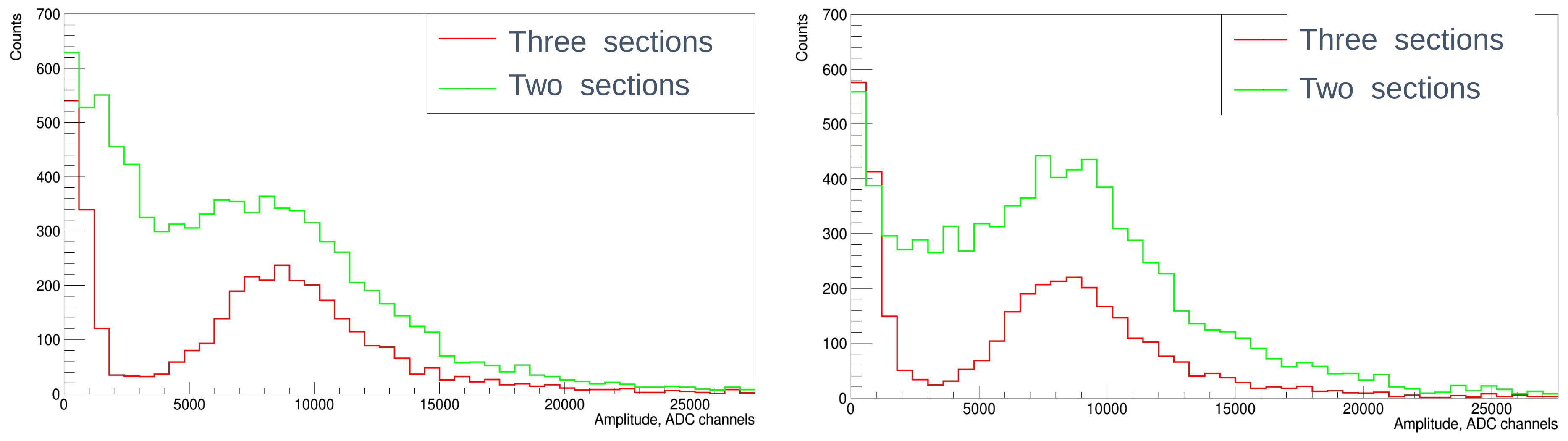

Fig.5 **Amplitude spectra for the events with muons crossed two or three neighbor sections in module.**

Conclusion

FHCal is intended for the determination of the collision geometry at MPD/NICA. It 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 6 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 procedure of the energy calibration of the modules with cosmic muons is now elaborating. The light yield of each longitudinal section is about 50 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.

References

1. *http://nica.jinr.ru*
2. *D. Finogeev et 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