Energy calibration of FHCal with cosmic muons at BM@N experiment

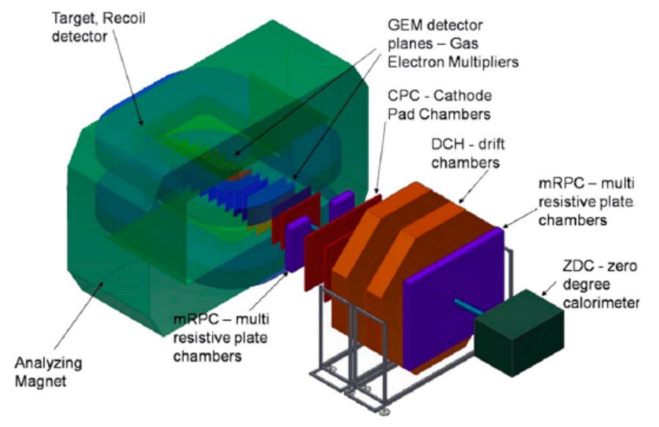
A.Izvestnyy[1], N.Karpushkin[1,2], F.Guber[1,2], S.Morozov[1,3], O.Petukhov[1,3]

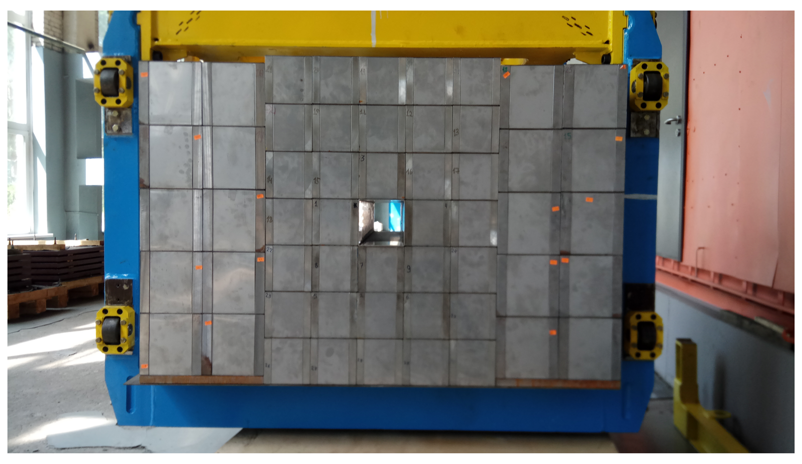
[1]*Institute for Nuclear Research, Moscow, Russia; pr. 60-letiya Oktyabrya 7a, Moscow, Russia*
[2]*Moscow Institute of Physics and Technology, Moscow, Russia*
[3]*Moscow Engineering Physics Institute , Moscow, Russia; Kashirskoe highway 31, Moscow, Russia*

The Forward Hadron Calorimeter is one of the sub-detectors of the BM@N experimental setup at JINR, Dubna. It consists of 54 lead-scintillator modules of two types with the transverse sizes 20x20 cm2 and 15x15 cm2. These two types of modules are subdivided into 10 and 7 individual longitudinal sections, respectively. Each section provides the independent light and amplitude signal readout with silicon photomultipliers (SiPMs). High signal to noise ratio of SiPM allows detection of cosmic rays with low energy depositions in FHCal longitudinal sections. A method for cosmic muon track reconstruction is discussed. A procedure for energy calibration based on muon track length and energy deposition in each section is proposed. Experimental results of FHCal cosmic calibration are presented.

BM@N FHCal

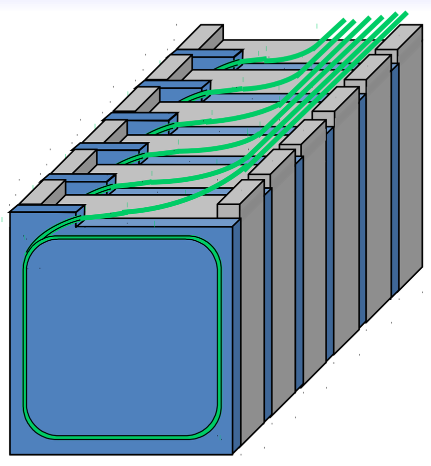
BM@N (Baryonic Matter at Nuclotron) is an experiment for studying interactions of various ion beams with a fixed target. It is based at the Nuclotron/NICA accelerating complex at JINR, Dubna. Kinetic energy of the ion beams provided by Nuclotron ranges between 1 and 6 GeV per nucleon. Data taking in beams of carbon, argon and krypton has been performed with gold ion beam acceleration planned for year 2021.[1]

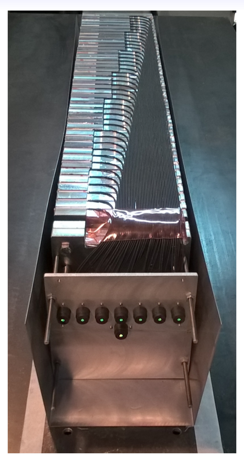


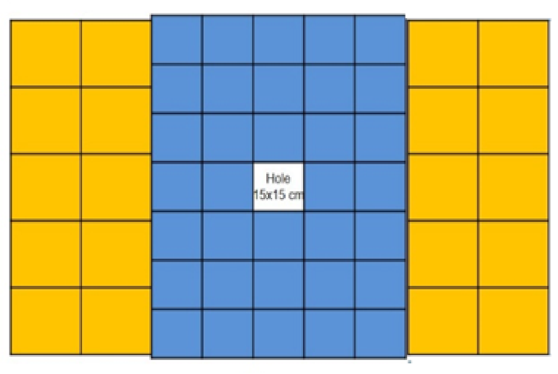


FHCal (Forward Hadron Calorimeter) was assembled and installed at BM@N in 2019. Like ZDC in previous runs, it will be used for event plane and centrality determination. It consists of 54 lead-scintillator modules with a 15 cm by 15 cm square beam hole and is mounted on a moving platform in place of ZDC.

Calorimeter modules



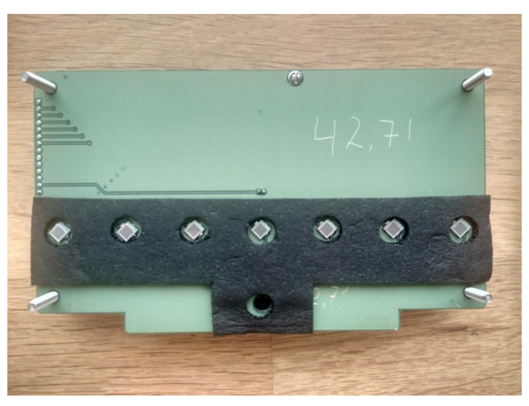


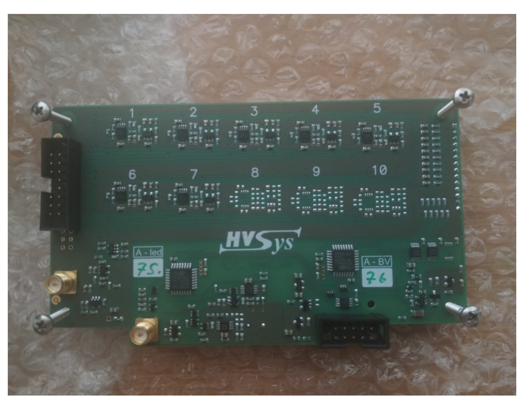


Two types of modules are used in FHCal: 34 modules with 15x15 cm^2 transverse size identical to ones used in future NICA/MPD setup and 20 larger modules with 20x20 cm^2 transverse size designed for CBM experiment. Modules contain 16 mm lead and 4 mm polystyrene scintillator tiles with WLS fiber light collection. Every six consecutive scintillators are read out by one photodetector. Smaller modules are 4 radiation lengths and contain 42 scintillator tiles while larger modules are 5.6 radiation lengths with the total of 60 scintillator tiles.

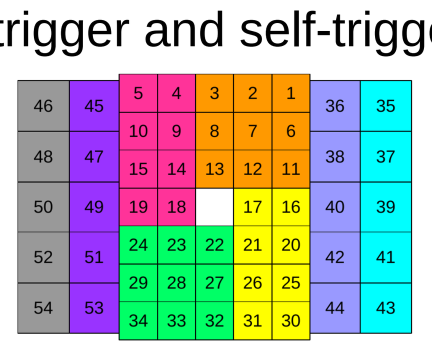
Electronics and trigger

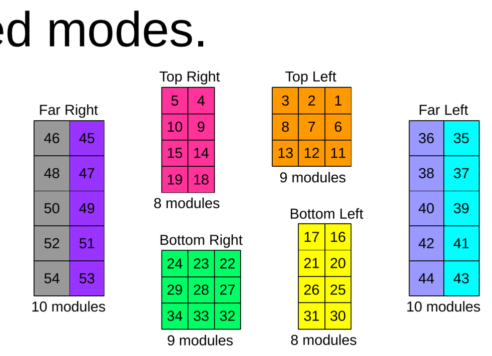
Front-End Electronics assemblies for FHCal modules were produced at JINR, Dubna. They include Hamamatsu MPPC photodetectors for every section in a module with individual voltage adjustment capability. Also every assembly has preamplifier and ADC driver analog stages, a temperature sensor, an externally synchronizeable LED for photodetector tests and an attenuated analog sum output for use in trigger systems. All FEE assemblies are remotely controlled via a System Module unit which allows for software voltage adjustment for temperature compensation.

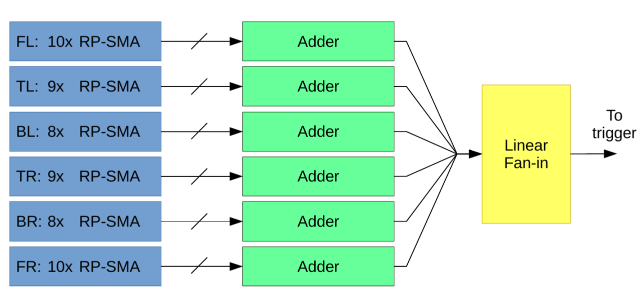




Data acquisition is performed by eight ADC64s2[2] units manufactured at JINR, Dubna. This model of 64 channel 62.5 MS/s 12-bit sampling ADCs was previously used for ZDC signal readout and therefore can be easily integrated into BM@N data acquisition system. ADC64s2 units are capable of time synchronization via White Rabbit network and can function both in external trigger and self-triggered modes.

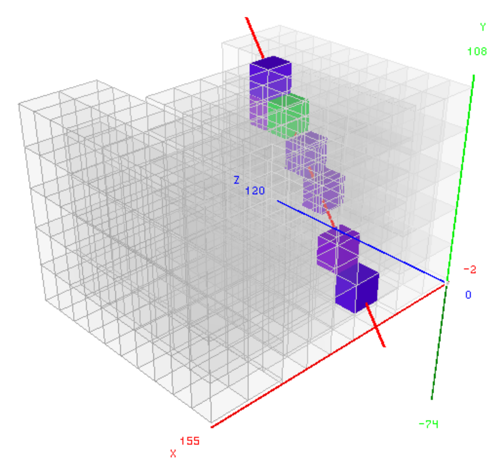






Custom 12 channel analog sum modules with adjustable attenuation for every channel were produced at JINR, Dubna. These modules were used to produce the sum of all signals in central part of the FHCal consisting of 34 smaller modules. This signal was then used to trigger synchronous data readout from 8 ADC64 units.

Cosmic calibration

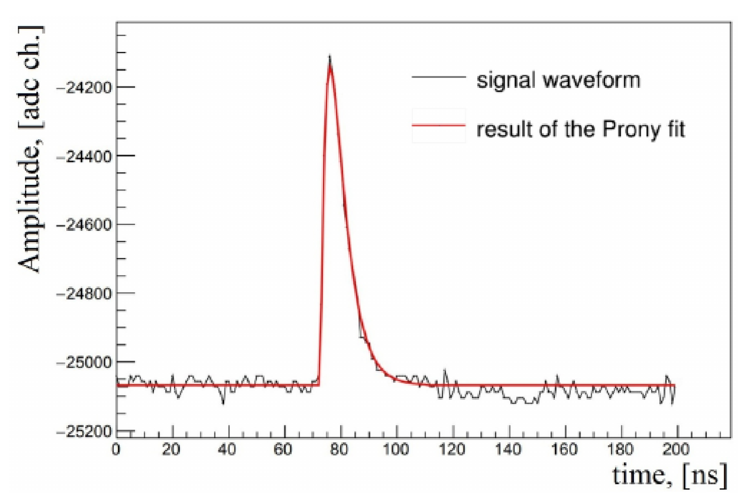


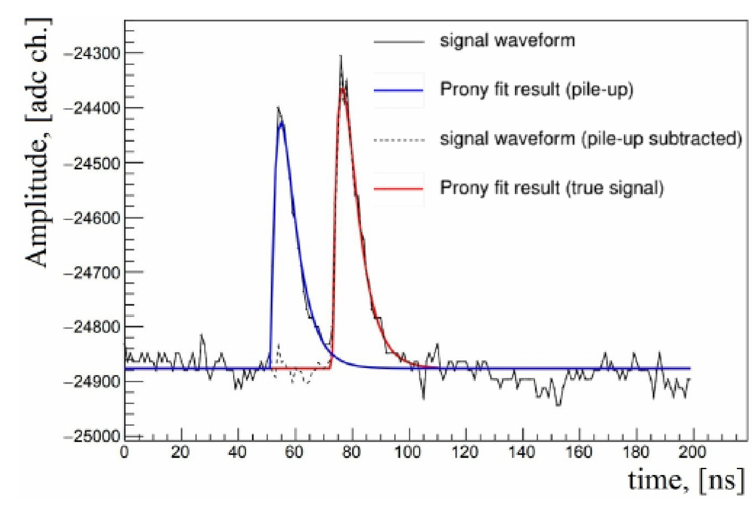
Since muon beams are unavailable at the BM@N setup, energy calibration of the FHCal can only be performed by using cosmic particles. This is complicated by variation of deposited energy in dependence of track position and orientation. Longitudinal and transverse segmentation of the calorimeter allows for muon track reconstruction to improve calibration efficiency.

Data taking for cosmic calibration was performed using BM@N run control system. Data was recorded in mstream binary format. At the first stage of data processing binary files were decoded and waveform was analyzed to produce time and amplitude characteristics. At the second stage these variables were used to reconstruct a track of the cosmic particle. Then energy deposited in the sections of the calorimeter was normalized to the track length in every section. Both stages of data processing were done using software developed at INR, Troitsk.

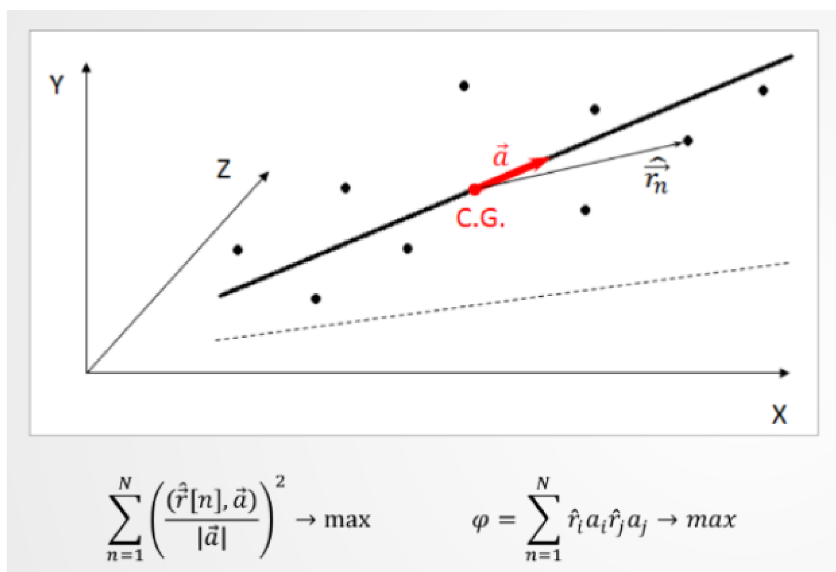
Waveform analysis

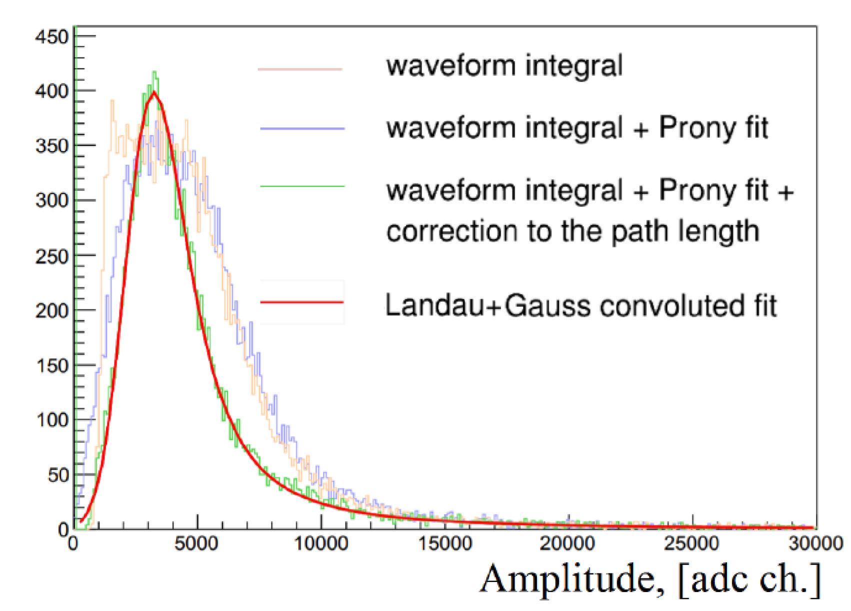
Prony least squares method[3] was used to analyze waveforms acquired by ADCs. This method uses a linear combination of exponential components to fit a data sample and has been shown to be able to reconstruct individual signals from pileup events and to reject noise by using fitting function quality assessment criterion. After completion of fitting procedure signal amplitude, waveform integral and time of arrival are available for further analysis.





Track reconstruction





Least squares method[4] was used for track reconstruction. First, the center of gravity of deposited energy in the sections of the calorimeter is found. Then a quadratic form φ on a unit vector $\bar{a}$ is maximized to find an eigenvector corresponding to a maximum eigenvalue. This vector provides the track direction. After that signal amplitudes from the track hits are corrected to the known track lengths in the scintillator tiles of the calorimeter sections.

Acknowledgments

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4. S. Morozov, D. Finogeev, M. Golubeva, F. Guber, A. Ivashkin, A. Izvestnyy, M. Kapishin, N. Karpushkin and O. Petukhov, JINST 15, no.05, C05050 (2020)