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Content

[Title]

Task 2.5: Design and construction of Zero Degree Calorimeters for NICA and CBM (INR RAS, NPI CAS) M1-M48

1. Introduction

The BM@N (Baryonic Matter at Nuclotron) is a fixed target experiment at the NICA Nuclotron accelerator complex [1]. In 2017-2018 the first experimental data on particle production have been obtained in interactions of carbon, argon and krypton ions with different targets and at several beam energies up to 4.5 AGeV and the Zero-Degree Calorimeter (ZDC) has been used to measure the centrality in ion-ion collisions [2]. The photo of the ZDC is shown in the left panel of figure 1. The ZDC calorimeter has a modular structure - its central part consists of 36 modules with a transverse dimension of 7.5x7.5 cm^2 and 68 modules with a transverse dimension of 15x15 cm^2 in the outer part [3]. Each module consists of 64 layers (5 mm scintillator + 10 mm Pb). Light collection from all scintillator plates in the module is provided by a WLS plate placed on one side of the module and is detected by a single photo multiplier (PMT) placed at the end of the module, as illustrated in the right panel of figure 1.

The main drawback of the ZDC is the absence of longitudinal segmentation of the calorimeter modules, which led to signal saturation effects visible even for argon beam data. Finally, it has been shown by FLUKA simulations, that the radiation doses from ionizing and non-ionizing particles in central modules of the ZDC expected for future experiments with heavy ion beams at energies up to 4 AGeV and at increased beam rates of up to $2x10^6$ ions per second will be too high. The radiation damage in the central modules will reduce the light yield,

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and deteriorate the ZDC performance. Therefore, the BM@N Collaboration decided to replace the existing ZDC by a new calorimeter, and, in order to be more specific, this device was named "Forward Hadron Calorimeter" (FHCal). For similar reasons, the new forward hadron calorimeter of the CBM experiment, which consists of the same modules as the FHCal, is called "Projectile Spectator Detector".

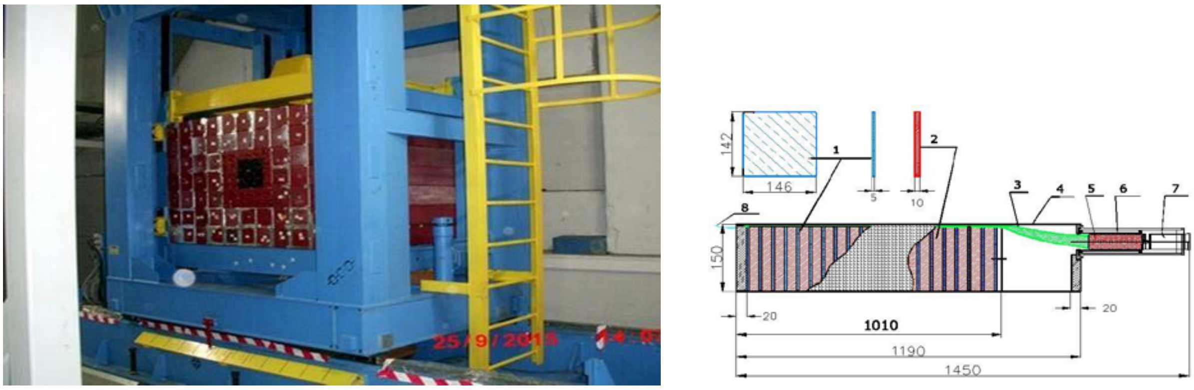

Fig. 1: Left: Photo of the BM@N ZDC. Right: Schematic view of the ZDC module (details see in [3].

2. The FHCal for the BM@N experiment

In order to avoid the radiation damage of the central FHCal modules by the intense particle beam, the FHCal will have a hole in the center for the beam and the heavy beam fragments produced in the target. This square-shaped hole will reduce both the radiation dose from charged particles and the neutron background in the rear end of the calorimeter, where the photodetectors and electronics are located. A schematic view of the FHCal is shown in the left panel of figure 2. The FHCal has been already assembled in 2020 using the available modules of the PSD of CBM at FAIR [4] and of the FHCal of MPD at NICA [5], which have been initially designed and constructed at INR RAS, Moscow.

Twenty PSD modules are installed in the outer area of the FHCal at BM@N. These modules will be temporarily used in the BM@N experiment until the CBM experiment will start operation at FAIR, according to the signed agreement between the CBM Collaboration, JINR (Dubna) and INR RAS (Moscow). A schematic view of one PSD CBM module is shown

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in the right panel of figure 2. The PSD modules have a transverse size of 20x20 cm^2, and a longitudinal size corresponding to 5.6 nuclear interaction lengths. The modules consist of 60 lead/scintillator layers with a sampling ratio 4:1, the thickness of the lead plates and scintillator tiles are 16 mm and 4 mm, respectively. The light readout from each scintillator is performed by WLS-fibers embedded in a groove in the scintillator plate. The WLS fibers from each 6 consecutive scintillator tiles are combined together and connected to a single photodetector at the end of the module. The longitudinal segmentation of the modules into 10 sections avoids a non-uniform light collection along the module.

Ten Hamamatsu MPPCsS12572-010P with an active area of 3x3 mm^2 are installed as photodetectors in each module. The MPPCs are mounted on front-end electronics boards (FEE) at the end of the module. The light yield measured with cosmic muons is about 40-50 p.e./section.

The inner part of the FHCal consists of 34 modules with a similar structure like the PSD modules. However, these modules are smaller in transverse size (15x15 cm^2) and shorter in length, i.e. they have only 7 longitudinal sections, corresponding to about 4 nuclear interaction lengths. The light yield measured with cosmic muons is about 50-60 p.e./section for these modules. Similar modules have been constructed also for the FHCal of the MPD. The FHCal modules have been designed by INR RAS)Moscow) and NPI (Rez).

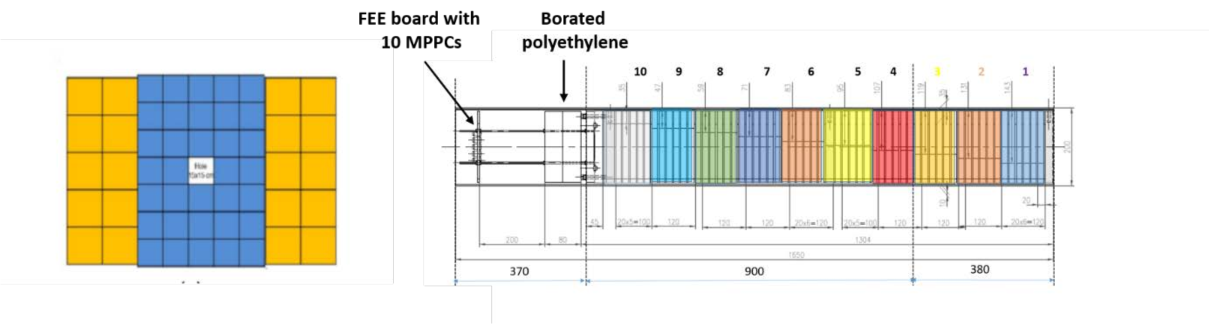

Fig. 2: Left: The scheme of the FHCal. Right: The scheme of the CBM PSD module used at the FHCal. The different colors indicate 10 longitudinal sections of the module.

A photo of the FHCal at BM@N is presented in the left panel of figure 3. The calorimeter is equipped with frond-end and readout electronics. For the data readout, a system of 8 ADC64s2 boards was assembled. Each board can read up to 64 channels of differential

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signal, all boards have been integrated into the common DAQ of the BM@N experiment. The communication cabling has been routed from the DAQ rack to the calorimeter and its systems. Ethernet cables are laid to all 8 ADC boards, as well as optical cables for transmitting signals from the White Rabbit (WR) system, and also coaxial cables to provide the ADC boards with trigger logic signals. Presently, the FHCal is ready for commissioning and calibration.

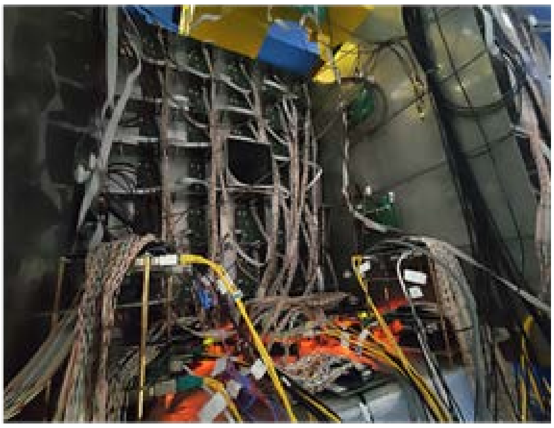

Fig. 3: Left: Photo of the FHCal front view installed at the BM@N experiment. Right: Rear view of the calorimeter with installed FEE and readout electronics.

3. Development of the energy calibration method for the FHCal

Due to the unavailability of a muon beam at the Nuclotron accelerator, the FHCal cannot be calibrated directly with beam. Therefore, a method of energy calibration of the FHCal sections with cosmic muons was developed, using the longitudinal and transverse segmentation of the hadron calorimeter. The muon tracks will be reconstructed by an algorithm, which searches for tracks in the 3D space of the calorimeter sections. An example of a reconstructed muon track is shown in the left panel of figure 4. The electronics of the data acquisition system (ADC) is designed such, that signals from cosmic particles can be recorded both by self-triggering and by a trigger from an analog summing-up unit. Aggregated signals from the sections of all modules are collected, summed up and fed to the discriminator. By adjusting the

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discrimination threshold, the required minimum number of triggered sections is defined, in order to accurately determine the track of the muon that has passed through the calorimeter.

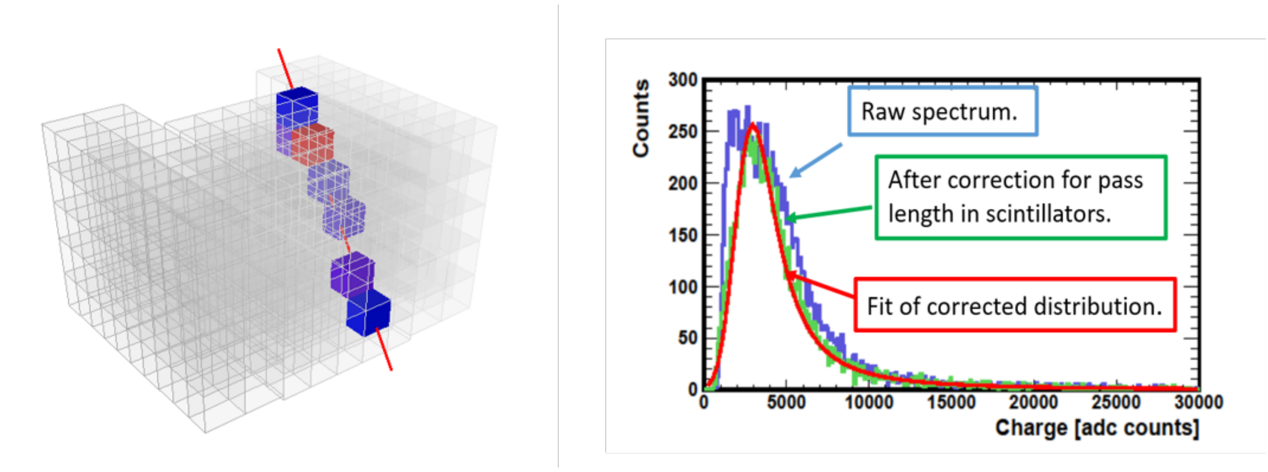

Fig. 4: Left: Sketch of a 3D view of a muon track in the FHCal. Right: Track length correction in one of the sections of the FHCal module. Blue curve: Muon spectrum before the correction. Green curve: Muon spectrum after the correction of the track length. Red curve: Corrected muon spectrum fitted by a Landau and a Gaussian function (langaus).

As illustrated in the right panel of figure 4, the corrected muon spectrum (green curve) is well described by the standard convolution function of Landau and Gaussian distributions (red curce). By determining the maximum of the distribution, the calibration constants can be found for all sections in all calorimeter modules. Presently, the central part of the calorimeter modules have been calibrated using both a self-trigger and a trigger based on an analog summing unit. The results of the developed method of energy calibration of FHCal modules by cosmic muons demonstrate an improvement in the calibration accuracy and the efficiency. Thus, the longitudinal segmentation of modules provides uniformity of the light collection along the module, a high dynamic range of the calorimeter response, and can be used for the FHCal section calibration with cosmic muons.

4. Development of a Detector Control System (DCS) for the FHCal in the BM@N

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The Detector Control System (DCS) for the FHCal should provide fast and stable access to all parameters of the FHCal FEE boards, and feature an extensible architecture for possible hardware upgrades. The DCS functions should include an online temperature correction, logging parameters to database, and should have a fast connection with multiple devices. The best solution for proposed DCS is a modular structure. All detector parts have capabilities to read or write some controller registers available on the bus. The registers can be described in the configuration files. Then adding a new module means simply creating a new configuration file. The detector parts can be grouped into modules for DCS display. Each module can display controls for all its parts: HV controller, LED controller etc. DCS for FHCal electronic boards are connected with a common RS-485 bus to the Control Box Unit (CBU). Since each module has two transceivers one can connect up to 64 electronic boards (FHCal modules) to the CBU. The BM@N setup has one CBU. The CBU has a possibility to connect to LAN and be controlled directly by one DCS PC. If more than one application needs to interact with the FHCal, hardware or software proxy can be used. The connection diagram is shown in fig. 5.

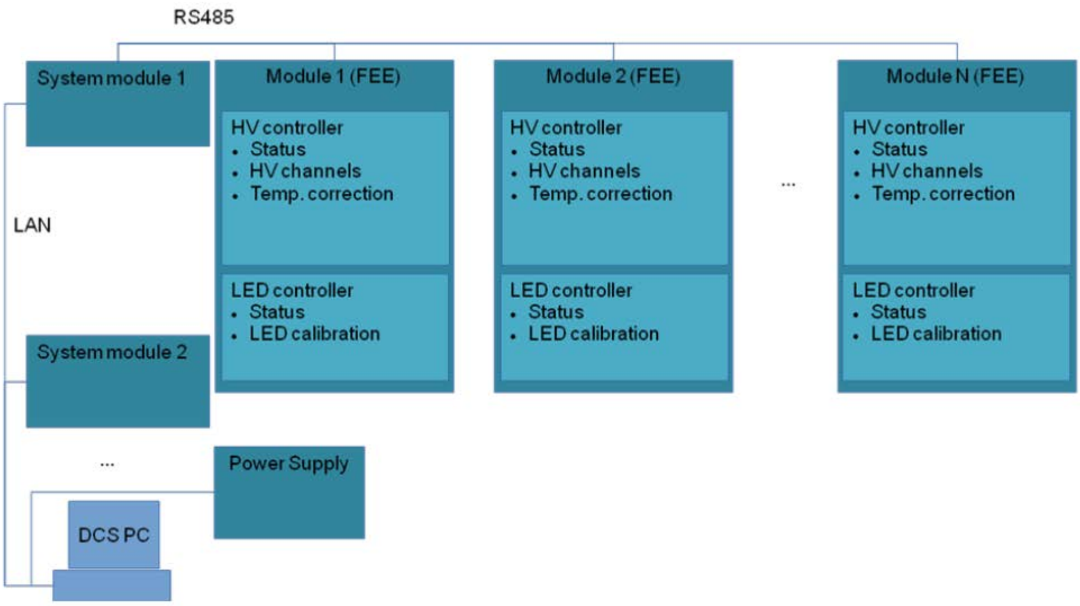

Fig.5.: DCS diagram.

For performance measurements and integration to common DCS with a few hundreds of readout channels, the required time to control a single channel or FEE board becomes crucial.

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The performance bottleneck is a relatively slow common serial bus. The proposed design of the FHCal DCS will be able to send all detector parameters to the experiment-wide tango-based DCS system [6] that will record this information to database. The integration plans are to include ”pytango” module into the FHCal DCS. The module will help to connect the common DCS to FHCal DCS on the software level instead of direct connection to hardware.

5. Conclusion

In forthcoming heavy ions experiments at the BM@N experiment. the new Forward Hadron Calorimeter (FHCal) will be used to measure the centrality of the collision, and the orientation angle of the reaction plane. During the year 2020, the calorimeter was completely assembled, including the installation of FEE boards with photodetectors in all calorimeter modules and readout electronics, with participation of researchers from INR RAS and NPI within the framework of CREMLINplus. The method of energy calibration of the FHCal module sections with cosmic muons by exploiting the longitudinal and transverse segmentation structure of the hadron calorimeter was developed and tested. The DCS hardware and software to control the parameters of the FHCal modules has been developed. It was shown, that the FHCal DSC provides the required performance for the needs of the calibration and running of the FHCal. After further testing and commissioning it will be used in the common DCS systems of BM@N and MPD experiments.

6. References

[1] Ablyazimov T.O. et al., Conceptual Design Report of BM@N. http://nica.jinr.ru/files/BM@N/BMN-CDR.pdf, 2013.

[2] M.Kapishin, Studies of baryonic matter at the BM@N and MPD experiments at Nuclotron/NICA, PoS (CORFU2018) 188.

[3] O.P. Gavrishchuk et al., Hadron calorimeter module prototype for baryonic matter studies at Nuclotron, Phys.Part.Nucl.Lett. 12 (2015) 2, 310-318

[4] Guber F and I.Selyuzhenkov., Technical Design Report for the CBM Projectile Spectator Detector (PSD),http://repository.gsi.de/record/109059/files/20150720-CBM-TDR-PSD.pdf (2015).

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[5] A. Ivashkin, D. Finogeev, M. Golubeva, F. Guber,A. Izvestnyy, N. Karpushkin, S. Morozov, Compact segmented hadron calorimeter for detection of low energyspectators at MPD/NICA facility, Nuclear Inst. and Methods in Physics Research, A 958(2020) 162240.

[6] P.V. Chumakov, D.S. Egorov, R.V. Nagdasev, V.B. Shutov, Multi-purpose detector (MPD) slow control system, historical background, status and plans, Proc. NEC (2017)

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