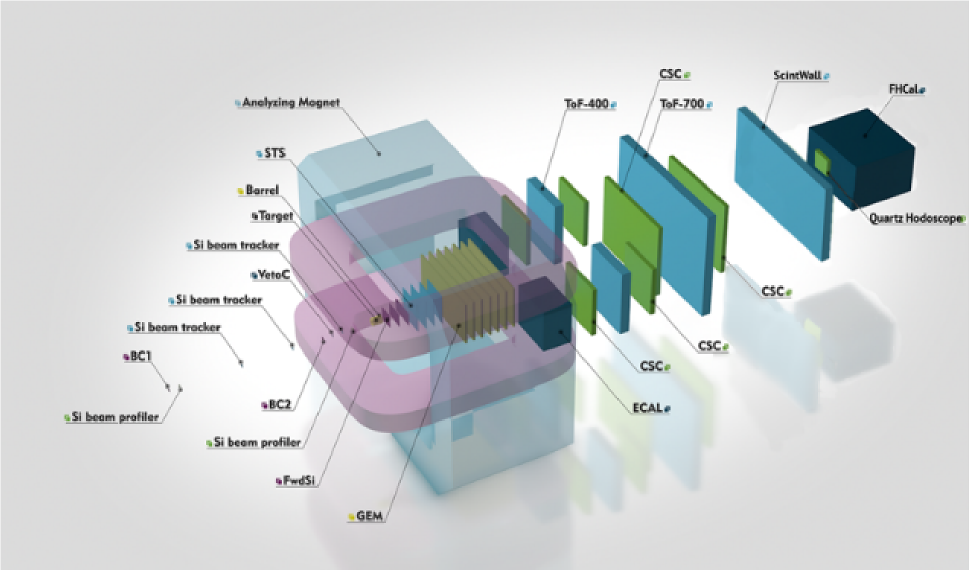
Commissioning of the forward detectors to measure spectators in nucleus-nucleus reactions at the BM@N

A. Izvestnyy on behalf of INR RAS

BM@N experiment

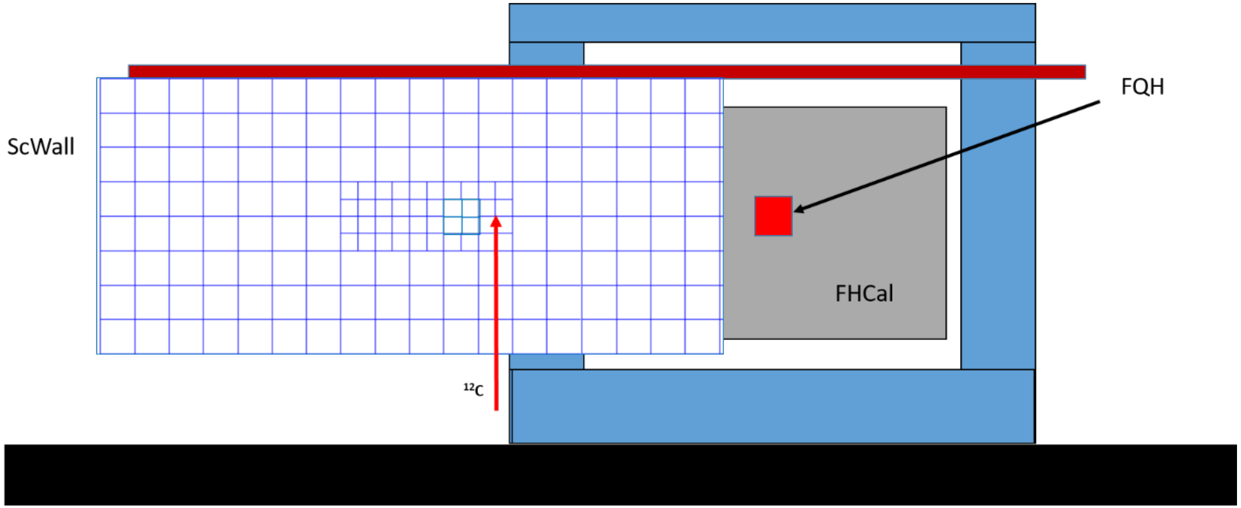


Barionic Matter at Nuclotron (BM@N) setup:

- Fixed target
- Ion beam with energy of up to 4.5 AGeV from Nuclotron of the NICA accelerator complex at JINR, Dubna
- Large aperture analyzing magnet

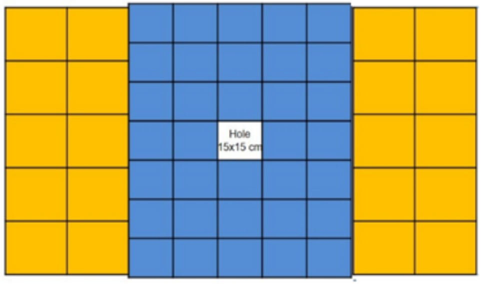
The BM@N experiment is designed to study the QCD state diagram in the region of high baryon density and azimuthal asymmetry of charged particle production in heavy nuclei collisions.

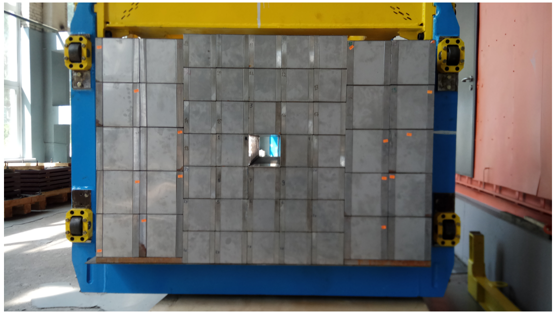
Forward detectors at the BM@N



- Forward Hadron Calorimeter: measurement of spectator energy and transverse distribution for collision centrality and event plane reconstruction
- Scintillation Wall: charged nuclear fragments detection for correction of nuclear fragmentation models
- Fragment Quartz Hodoscope: detection of beam ions and heavy spectators for collision centrality measurement

Forward Hadron Calorimeter

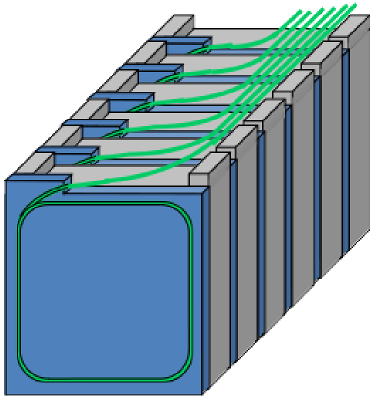


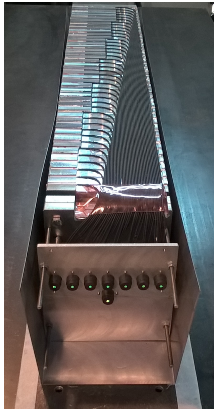


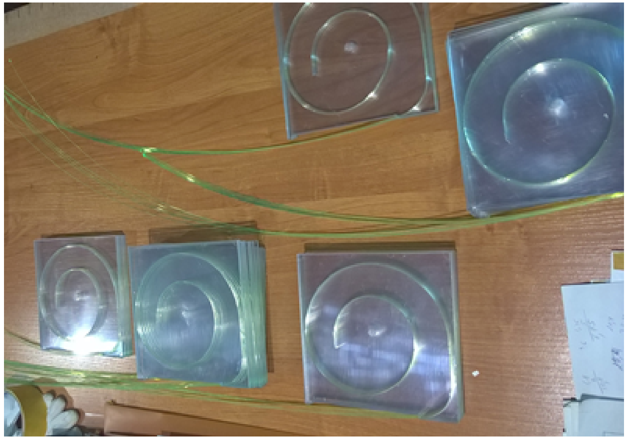
FHCal is a modular lead-scintillator calorimeter

- 20 modules with transverse size 20x20 cm^2 and active part 120 cm long (manufactured for the CBM, FAIR experiment)
- 34 modules with transverse size 15x15 cm^2 and active part 84 cm long (identical to the MPD-NICA FHCal modules)
- 15x15 cm^2 beam hole in the center
- Installed on a remote-controlled movement platform

FHCal modules





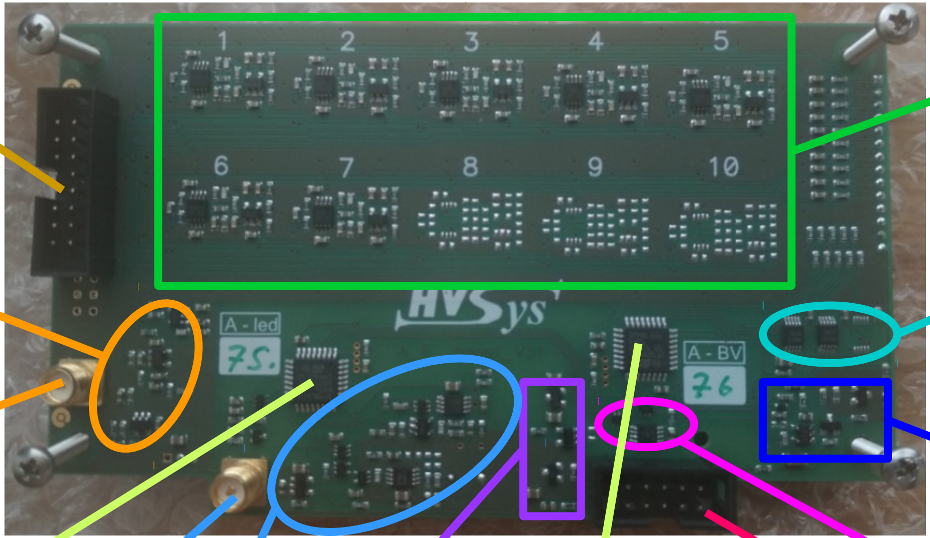


- Lead-scintillator sampling structure with 16mm thick lead degraders and 4mm thick polystyrene scintillator plates
- Scintillators wrapped in Tyvek reflector
- Light collected by 1mm WLS optical fibers glued into grooves in the scintillator plates (spiral grooves for large modules and circular grooves for small modules)
- Optical fibers from each six consecutive scintillators combined into one optical connector forming 7 longitudinal sections for small modules and 10 for large ones
- Loopback optical connector for photodetector testing and calibration using LED flash

FHCal Front-End Electronics: photodetectors

- Hamamatsu S12572-010P MPPC photodetectors with 3x3 mm^2 sensitive area
- Supply voltage filters for cross-talk suppression
- Temperature sensor
- Optical insulation
- LED flash aperture
- Aluminum plate on the back side of the PCB
- Produced in two variations for 7-section and 10-section modules
- Attached directly to the rear end of a module

FHCal Front-End Electronics: preamplifiers and voltage regulation



LVDS ribbon cable connector for the ADC

Analog sum and voltage offset circuits

Analog sum output

LED flash control MCU

LED flash synchronization input

LED flash circuit

Preamp end MCU supply voltage regulators

MCU for voltage and temperature control

Ribbon cable connector for power supply and control via HVSys System Module

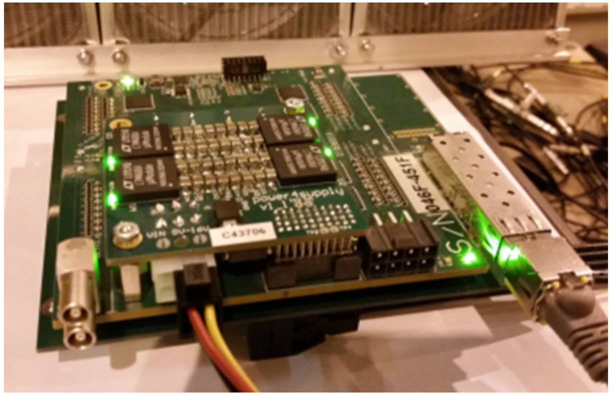
Preamplifiers and ADC drivers with differential output

Individual channel voltage adjustment DACs

Common MPPC voltage regulation circuit

RS-485 bus transceiver

FHCal ADCs

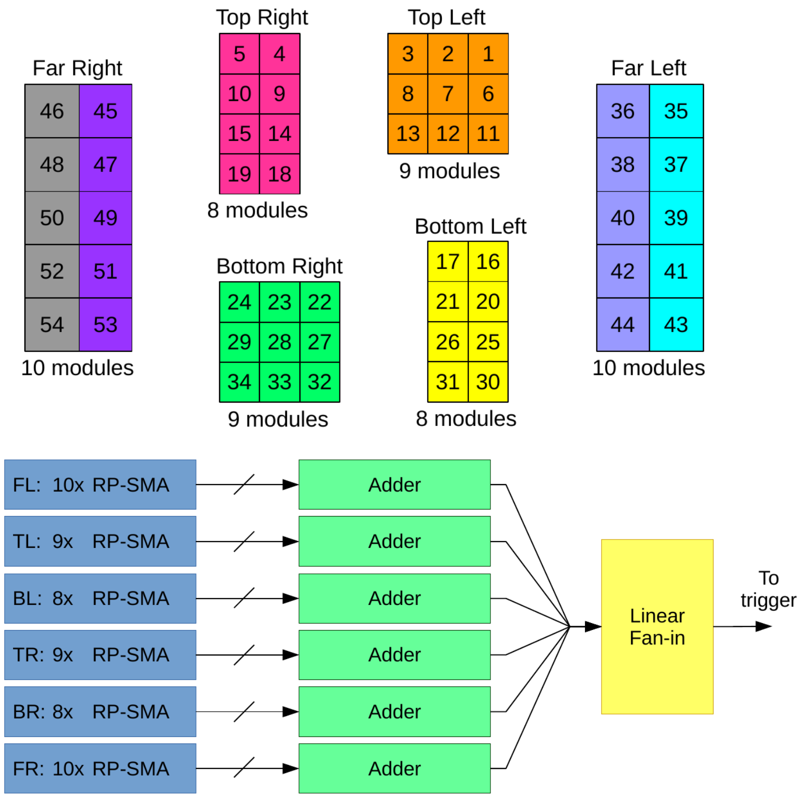


8 ADC64s2 sampling ADC boards:

- 64 channels
- 62.5 MHz sampling frequency
- Up to 1024 samples per event
- Trigger from external TTL signal or self-trigger with adjustable channel thresholds
- Zero suppression
- Time synchronization via White Rabbit network

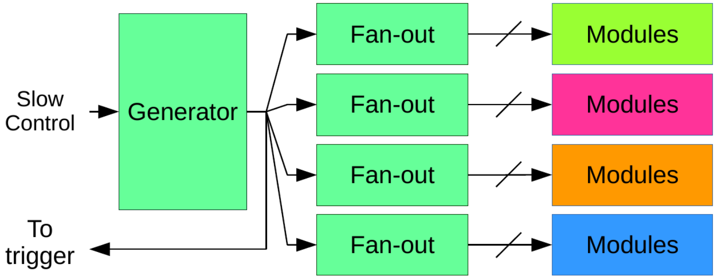
One ADC can read up to six 10-section modules or up to nine 7-section modules. On this rear view schematic of the FHCal the modules are color coded by their connection to the ADC boards

FHCal analog sum output



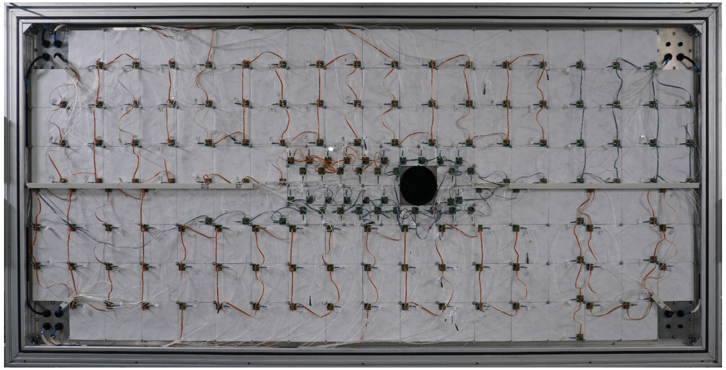
- Custom signal adder boards with adjustable channel attenuation are used to combine the analog sum outputs from the modules
- Each board has 12 inputs
- 6 boards are used to collect signals from the parts of the calorimeter as shown on the schematic
- Another board combines these 6 signals to produce the total calorimeter response signal
- Resulting signal is sent to the BM@N DAQ trigger system and can be used during the calibration of the FHCal on the cosmic muons

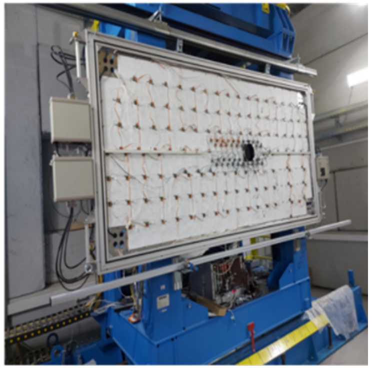
FHCal LED flash system

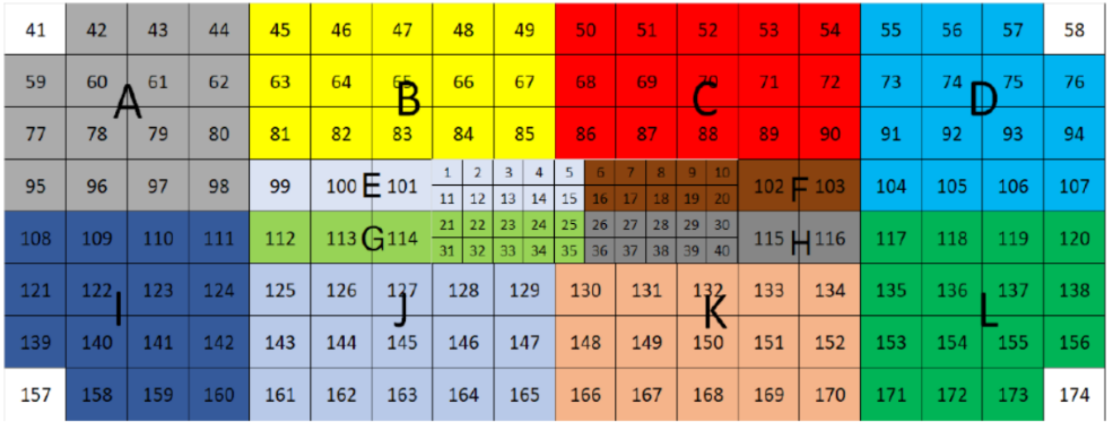


- Custom generator and fan-out boards are used in the LED flash synchronization system
- Each board has 16 outputs
- A remotely controlled generator board produces signal for the fan-out boards and the trigger system
- Four fan-out boards distribute the synchronization signal to the modules of the FHCal as shown on the color coded schematic
- Synchronized LED flash allows the simultaneous testing of photodetectors on all modules
- Analysis of statistical parameters of LED flash spectra for various flash amplitudes allows to estimate the relation of signal amplitude and number of photoelectrons produced in the photodetector

Scintillation Wall

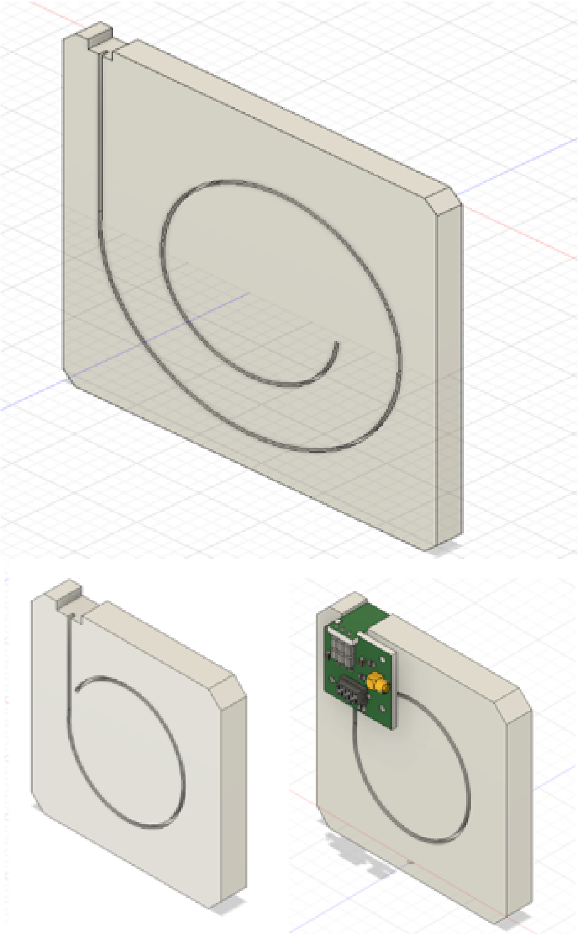






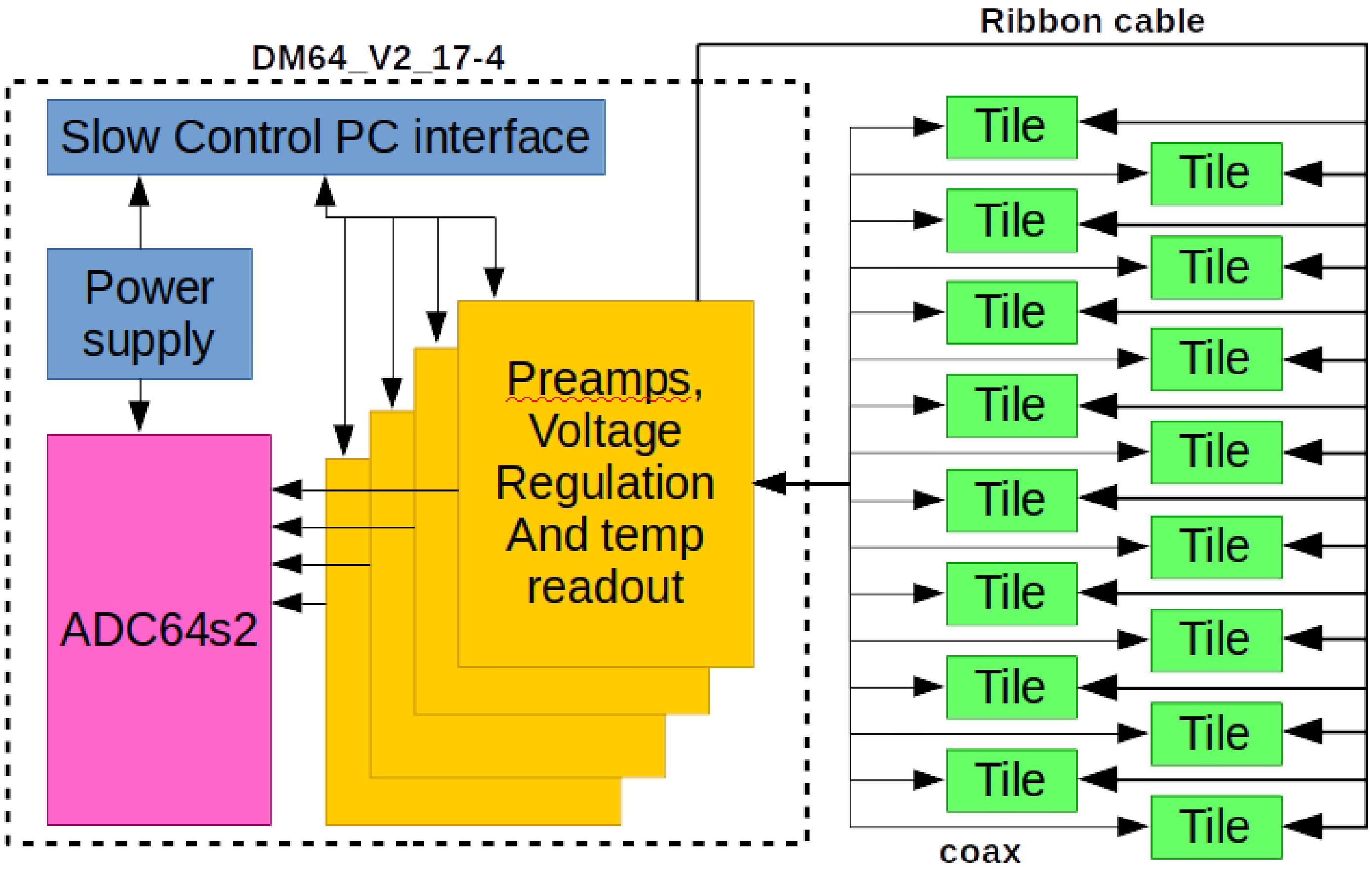
- 36 small scintillator tiles with size 75x75x10 mm^3
- 130 large scintillator tiles with size 150x150x10 mm^3
- 15x15 cm^2 beam hole can be replaced with four more small scintillators
- The tiles are subdivided into 12 groups (labeled A-L), each group has common voltage supply with individually adjustable channels and one tile with a temperature sensor
- ScWall is mounted on a rail allowing for manual adjustment of horizontal position

ScWall scintillator tiles



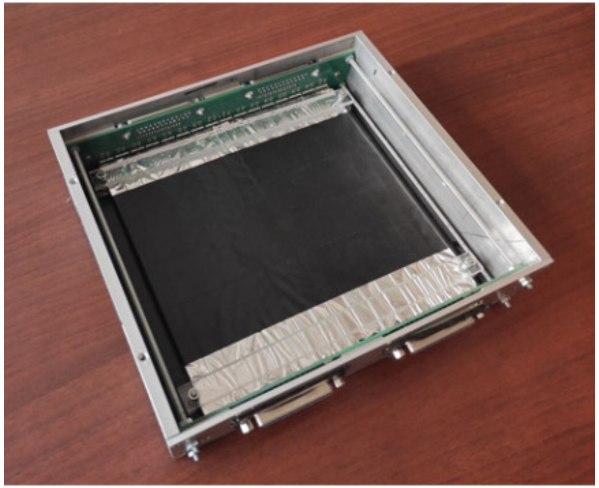
- Polystyrene based plastic scintillator
- The corners of the tiles are cut at 45° angle allowing for precise positioning and firm attachment of each tile to the case of the ScWall
- 1.5 mm deep grooves cut into scintillator surface
- Spiral grooves for large tiles and circular grooves for small ones
- Y11(200) WLS fiber glued into the grooves
- Scintillator tiles are wrapped in diffuse reflector
- PCB assembly with S13360-1325CS Hamamatsu MPPC photodetector, supply voltage filter and temperature sensor (one per group) is placed in a cutout on the edge of the tile so that the MPPC is directly coupled with the end of the WLS fiber
- Electron beam tests demonstrated light yield of 32 p.e. with nonuniformity of ±2% for large tiles and light yield of 55 p.e. with nonuniformity of ±1.3% for small tiles

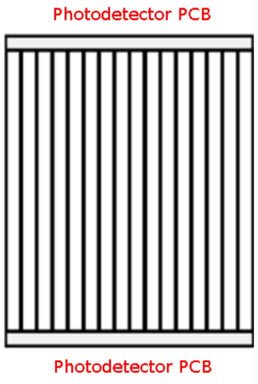
ScWall electronics

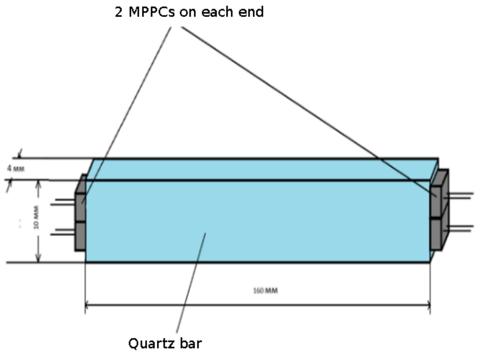


- Three DM64_V2_17-4 integrated readout and control boxes
- Each box contains power supply, ADC64s2 board (see “FHCal ADCs”), 4 front-end boards and a PC interface for DCS
- Each front-end board has 16 preamplifiers, voltage regulator with individually adjustable channels and temperature sensor readout
- Each group of scintillator tiles is connected to one front-end board with ribbon cable for common MPPC voltage supply and temperature sensor and coaxial cables for voltage adjustments and signal readout

Fragment Quartz Hodoscope

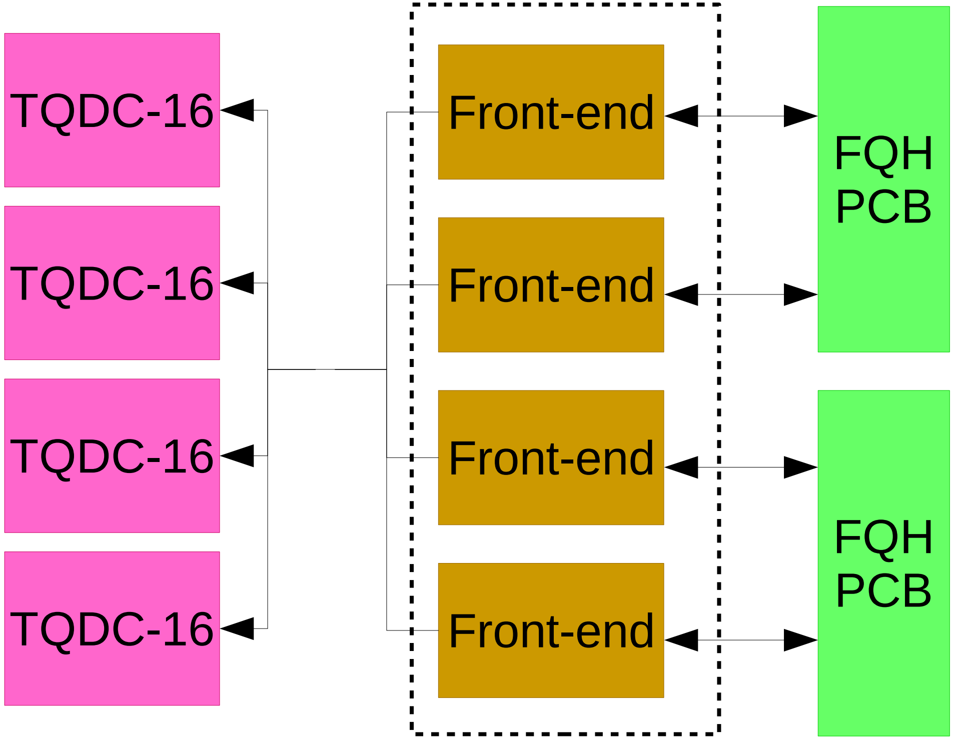






- 16 quartz bars with size 160x4x10 mm^3 wrapped in mylar-based reflector
- Cherenkov light detected on each end of the bar by two S14160-3015PS Hamamatsu MPPC photodetectors connected in parallel
- Photodetectors installed on two PCBs
- Each PCB has a temperature sensor and supply voltage filters
- Optically insulated case made of aluminum and stainless steel
- FQH is installed on the FHCal beam pipe and completely covers the beam hole
- Electron beam tests demonstrated light yield of 4.5 to 4.9 photoelectrons and spatial nonuniformity of ±5%

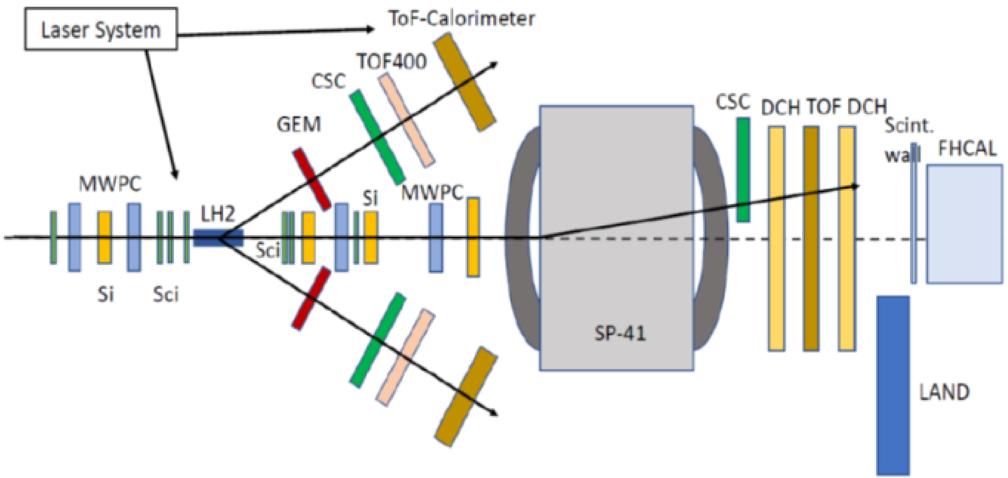
FQH electronics



- Preamplifier module contains four front-end boards
- Each board reads 8 channels, has high gain and low gain output for each channel and analog sum output, provides common supply voltage and per channel voltage adjustment and can read the temperature sensor (if present)
- Preamplifier module is controlled via HVSys System Module

- Four 16 channel TQDC-16 digitizers are used to readout both the high gain and the low gain outputs simultaneously
- TQDC-16 ADCs have 80 MHz sampling frequency and resolution of up to 14 bits
- ADCs are installed in a remotely controlled VME crate

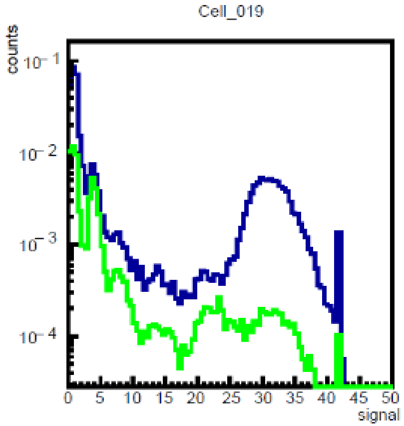
Forward detectors commissioning during the Short Range Correlations run in Feb-Mar 2022

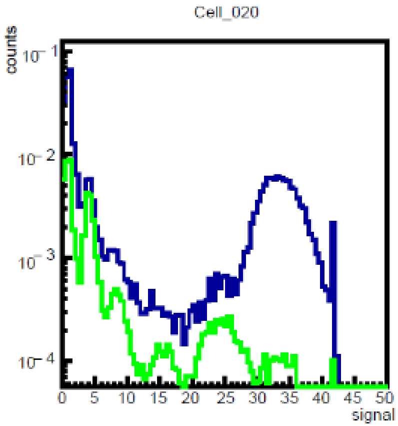


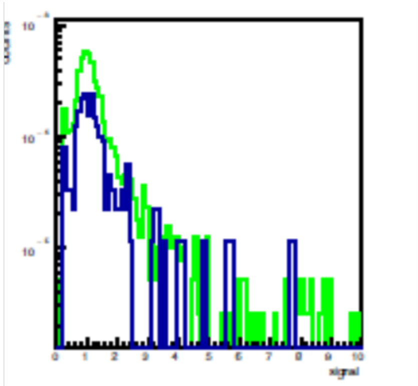
Short Range Correlations (SRC) experiment:

- Liquid hydrogen target and carbon beam with 3.5 AGeV/c momentum
- Additional beam detectors
- Two “Arms” with positioning, ToF and calorimetry detectors
- Trigger decision based on hits in one arm (Arm-OR) or both arms (Arm-AND)
- ScWall was used for charged fragments identification
- FHCal and FQH response was tested during beam detectors calibration with various values of magnetic field
- FHCal with FQH were positioned out of the beam during physics data taking

ScWall response



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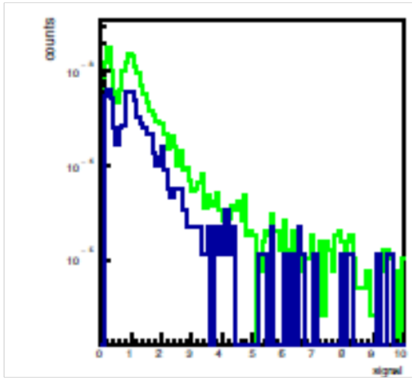
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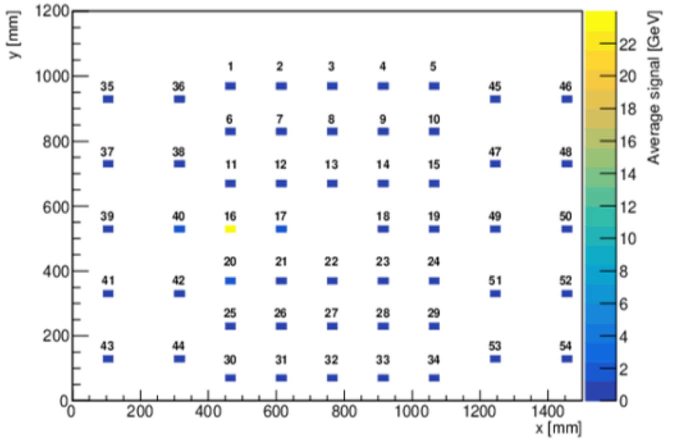
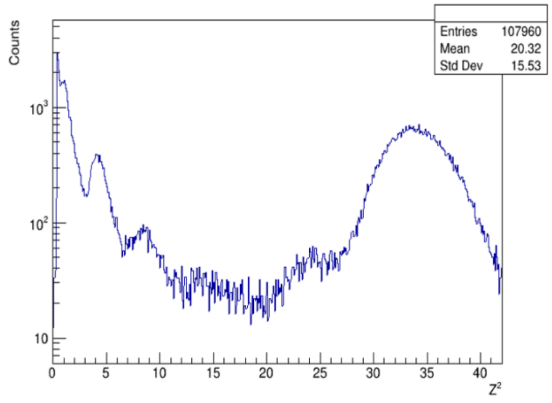
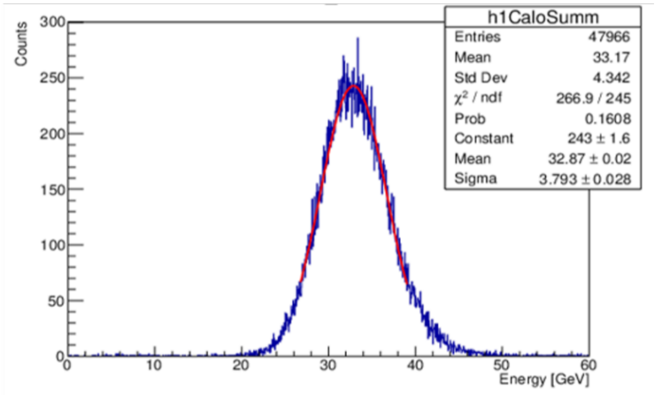
The beam was hitting cells 19 and 20 while cells 95 and 107 are farthest from the beam in the same horizontal row Blue line for spectra collected with **Beam Trigger (BT)** and green line for spectra collected with **Interaction Trigger (IT)**. Spectra are normalized by number of triggers.

- In cells 19 and 20 a peak corresponding to the particles with a charge of 6 is visible for the BT while for the IT peaks corresponding to particle charge of 1 to 5 are also visible
- In cells 95 and 107 the only visible peak corresponds to the particle charge of 1

FHCal response

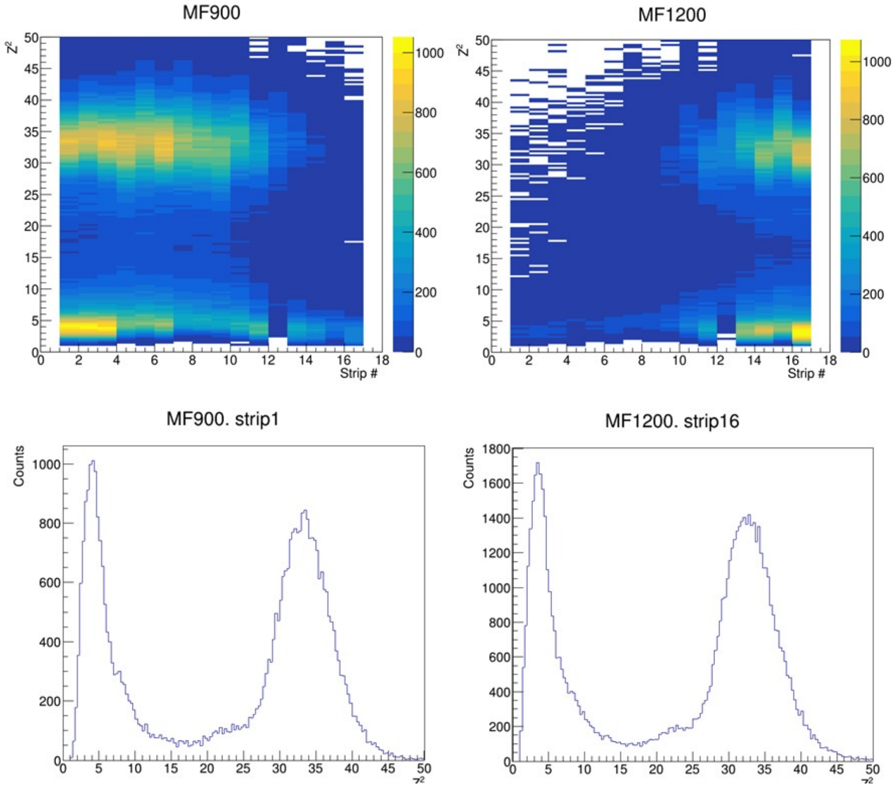






FHCal response was tested with the Beam Trigger while the target was absent. The beam was hitting module 16, as shown on histogram on the left. ScWall cell 24 was directly in front of module 16, spectrum from ScWall cell 24 is shown in the middle. Using data from ScWall cell 24 events with charge of 6 corresponding to the beam ions were selected. FHCal module 16 response for these events is shown on the right. Energy resolution of module 16 was 11.5% for the carbon ions with momentum of 3.5 AgeV/c.

FQH response



Data were collected with beam trigger and no target for various values of the analyzing magnet winding current. With the currents of 900 A and 1200 A beam hits were observed in the FQH as seen in the histograms of estimated particle charge vs quartz bar position.

On the spectra of bar 1 and 16 responses with magnet currents of 900 A and 1200 A respectively besides the carbon ion peak the peaks corresponding to particle charges of 2 and 5 are also visible. Presumably, their presence is caused by the beam interacting with air and detector material.

Conclusion

- Status of the new forward detectors installed during the BM@N upgrade was presented
- The forward detectors are designed for measurement of nuclear spectator energy and nuclear fragment charge
- The forward detectors allow to reconstruct collision centrality and reaction plane and to study nuclear fragment charge distributions
- First results of forward detectors response measurement during the SRC experiment run were presented