New forward hadron calorimeter for the BM@N heavy ions experiments

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for the BM@N Collaboration
**NICA (Nuclotron based Ion Collider fAcility) at JINR, Dubna**

- **essential upgrade of existing accelerator complex**
- **construction of Collider** to provide collisions of:
  - ion species from \( p \) to \( Au \) at energy range \( \sqrt{S_{NN}} = 4 - 11 \) GeV
  - polarized \( p\ u\ d\ ) up to energy \( \sqrt{S} = 27 \) GeV (\( p \))
- **construction of 3 detectors**: Baryonic Matter @ Nuclotron (BM@N), Multi Purpose Detector (MPD) and Spin Physics Detector (SPD)
Construction of the NICA accelerator Complex, both BM@N & MPD detectors and infrastructure are going close to schedule.
Physics goals of heavy ion experiments at NICA

- The equation of state of nuclear matter;
- Modification of the properties of hadrons in a superdense nuclear matter;
- Search for phase transitions and critical point.

The experiments at BM@N, NICA, HADES, STAR and CBM complement each other and cover different areas of the phase space.
BM@N at Nuclotron

- Beam vacuum pipe
- Upgrade of all detector systems
- New FHCal instead of the ZDC

BM@N upgrade 2019 -2020

<table>
<thead>
<tr>
<th>Year</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>fall 2020-2021</th>
<th>2022 and later</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam</td>
<td>d(↑)</td>
<td>C</td>
<td>Ar,Kr, C(SRC)</td>
<td>C,Kr,Xe</td>
<td>up to Au</td>
</tr>
<tr>
<td>Max. beam intensity, Hz</td>
<td>0.5M</td>
<td>0.5M</td>
<td>0.5M</td>
<td>0.5M</td>
<td>2M</td>
</tr>
<tr>
<td>Trigger rate, Hz</td>
<td>5k</td>
<td>5k</td>
<td>10k</td>
<td>10k</td>
<td>20k—50k</td>
</tr>
</tbody>
</table>
ZDC already used on experiments with $^6$C, $^{18}$Ar and $^{36}$Kr beams. At these experiments ZDC has been used to measure centrality of nucleus-nucleus collisions.
Reasons for ZDC replacement with new FHCAL

- Radiation hardness problems

**FLUKA sim:**
AuAu, 4 AGeV, 100 μm Au target, beam 2x10^6 Au/sec

- Problem with use the ZDC for centrality measurements in heavy ion experiments at BM@N energies – non monotonic dependence of energy deposition in the ZDC from the centrality.

New FHCAL (Forward Hadron CALorimeter) with beam hole was proposed for future heavy ions experiments on BM@N.
FHCAL at the BM@N instead of ZDC

Central part – 36 nodules (7.5x7.5cm²).
Outer part 68 modules (15x15cm²).

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Central part – 34 MPD NICA modules (15x15cm²).
Outer part – 20 PSD CBM modules (20 x20cm²).
PSD@CBM (SIS100, FAIR) and FHCAL@MPD (NICA)

BM@N FHCAL is assembled from lead/scintillator modules already constructed for the CBM (FAIR) and MPD (NICA) heavy ion experiments.

Experiments starts at 2024+
Au beam 4 – 11 AGeV, beam rate $10^8$ ions/sec
Reaction rate 1 MHz

44 modules, 200x200mm$^2$
Beam hole (20 x 20 cm$^2$).

Experiments starts at 2022+
AuAu, $\sqrt{s_{NN}}$ = 4 - 11 GeV, beam luminosity $10^{27}$ cm$^{-2}$sec$^{-1}$.
Reaction rate 50 kHz

FHCAL@MPD

2 x 44 modules, 150x150mm$^2$
Beam hole (15 x 15 cm$^2$).

The modules constructed for these calorimeters have been used for the FHCAL at BM@N.
The FHCAL has transverse and longitudinal segmented structure and consists of separate modules.

- CBM PSD module - 60 Pb/scint. samples - (Pb(16mm), Scint(4mm), 20 x 20 cm²)
- MPD FHCAL module - 42 Pb/scint. samples - (Pb(16mm), Scint(4mm), 15 x 15 cm² (sampling ratio 4:1)

- Length of the MPD module – 4 \( \lambda_{\text{int}} \), CBM module – 5.6 \( \lambda_{\text{int}} \)

- Light collections – 6 WLS fibers (Kuraray Y-11(200)) from 6 sequentially scint. tiles (one section) are combined in one optical connector at the end of module.

- Light readout: 10 MPPC (3x3 mm²) per CBM module and 7 MPPC per MPD module.

- Weight of the CBM PSD module – 500 kg.
- Weight of the MPD FHCAL module – 200 kg.

Longitudinal segmentation of FHCAL provides uniformity of light collection along the module and will be used for cosmic muons track reconstruction for energy calibration. (S.Morozov presentation tomorrow).
Hamamatsu MPPCs are used for light detection at BM@N.

Hamamatsu S12572-010P
Sensitive area - 3 x 3 mm²
Number of pixels - 90 000
Nominal gain - 1 x 10⁵, Gain variation ~1% /1°C
Pixel recovery time ~ 10 ns
PDE -12%
Two-stage amplifiers; HV channels; LED calibration source.
MPD module - 7 channels;
CBM module – 10 channels;

The readout electronics

64 channel 62.5 MS/s ADC64 boards (AFI, Dubna).
FHCAL Slow Control at BM@N, MPD and NA61/SHINE

FHCAL slow control is based on the system module developed at Dubna and provides:

- Control of HV at photodetectors (MPPC);
- Temperature control of photodetectors;
- Correction of temperature drift of MPPC;
- Monitoring of MPPC gain with stabilized light source.
During 2010-2018 first forward hadron calorimeter assembled from similar lead/scintillator modules with SiPMs readout has been used at NA61/SHINE in heavy ion experiments Be+Be, Ar+Sc, Xe+La and Pb+Pb at beam energy range 13 -150 AGeV. Beam rate – 2x10^5 ions/spill

Energy resolution and linearity response at beam energy range 2-10 AGeV ?
No experimental data for these type of modules.
Muon identification (left) and muon amplitude distribution in one of module section (right).

Hadrons identification on T10 with TOF between 2 quartz Cherenkov detectors.
Energy resolution and linearity response

\[ \sigma = \sqrt{\frac{0.54}{E}} + 0.046^2 + \frac{0.5}{E} \]

Energy resolution vs number of sections

Centrality measurement by FHCAL with beam hole?

Centrality measurement at NA61 by PSD without beam hole

Problems with centrality measurement at BM@N by FHCAL with beam hole

FHCAL BM@N

How to resolve the ambiguity in centrality measurements with FHCAL at BM@N?
**Forward Hodoscope in the FHCAL beam hole**

**FH:**
16 quartz detectors 160 x 10 x 4 mm. Light readout of each det. side with two 3x3 mm MPPCs.

**PCB with 32 MPPC and FEE**

This method of centrality determination is under the development.

**FH occupancy for AuAu@4AGeV**
FHCAL with transvers and longitudinal segmentation structure has been developed and constructed for BM@N to measure centrality and reaction plane in heavy ion experiments at beam energy range $1.5 – 4.5$ AGeV.

CBM PSD and MPD FHCAL modules has been used for the BM@N FHCAL.

FHCAL consist of modules with lead/scintillator sampling and WLS light collection. Hamamatsu MPPC are used for signal detection.

Sampling ADCs with 64Ms/sec are used for readout.

BM@N FHCAL modules performance has been studied at CERN test beams.

At present, FHCAL is installed on BM@N. Tests and calibration on cosmic is in progress. First experiment at BM@N after upgrade is expected in 2021.

Acknowledgments.
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Thanks for your attention
Energy deposition for hadron beam 3 GeV/c in central module sections.