Forward hadron calorimeters for fixed target heavy ion experiments

Sergey Morozov on behalf of INR RAS
Forward hadron calorimeters for fixed target heavy ion experiments

**NA61@SPS**
Start of operation after upgrade - 2021

**BM@N**
Start of operation after upgrade - 2020

**CBM@FAIR**
Start of experiments at FAIR - 2024
Forward hadron calorimeters for fixed target heavy ion experiments

NA61/SHINE strong interactions program

- wide range of system size in ion collisions: from Be+Be to Pb+Pb
- large range of beam momentum: 13 – 150 AGeV/c (GeV/c per nucleon)
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Number of interacting participants:

A – mass number of ion

\( E_a \) – beam energy per nucleon

\( E_s \) – energy carried by the non-interacting nucleons (projectile spectators) - measured with PSD

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Projectile Spectator Detector (PSD) gives a very important informations:

- centrality of nucleus-nucleus collisions:
- reaction plane orientation

PSD is a hadron sampling compensating calorimeter

- Pb/scintillator (4/1) 60 sandwiches in one module
- Modules 10 x 10 x 120 cm³ – central part
- Modules 20 x 20 x 120 cm³- outer part
- 10 longitudinal sections with 10 SiPM readout
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PSD on NA61 beam line

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NA61/SHINE PSD performance

PSD energy in MIPs

Energy scan

Reconstructed energy, [GeV]

Beam Energy, GeV

Ar, 13 AGeV/c, beam spot at module #6

Energy scan

Entries 3857
Mean 469.3
RMS 52.45
$\chi^2 / \text{ndf}$ 48.05 / 34
Constant 106.9 ± 2.7
Mean 484.6 ± 0.8
Sigma 25.09 ± 0.77

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Track multiplicity vs PSD reconstructed energy: Ar+Sc, T2 trigger

Ar + Sc data taking, Feb-Apr 2015

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Radiation effects:
- scintillators (ageing effects, reduction of light yield);
- photo-diodes (higher noise, drop of gain)

Affects the calorimeter performance

The relative light yield of the scintillators degrades by 25% after 2.5 kGy irradiation, and then slowly decreases by a further 20% with irradiation up to 14 kGy.
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NA61 beyond 2020: 10x more beam intensity → high radiation doses for PSD

Proposal: replace central part of PSD with new modules designed for CBM experiment:

Use small modules of PSD as “tail catcher”

beam

fragments passed the hole

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A. Senger
Fluka simulation for Pb beam at rate $5 \times 10^4$ ions/sec

Radiation and activation problems are now localized only in F-PSD which can be shielded by concrete blocks.

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Forward PSD (FPSD) construction and test on NA61 beam line

Energy resolution of FPSD

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PSD supermodule tests on CERN test beams

CERN PS T9 beamline

Beam momenta: 1-10 GeV/c
Particle ID: Cherenkov gas counter
Position of PSD: fixed

CERN PS T10 beamline

Beam momenta: 1-6 GeV/c
Particle ID: TOF system installed
Position of PSD: movable platform
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NA61/SHINE PSD upgrade to have a beam hole in the center

..to be continued in 2019
Forward hadron calorimeters for fixed target heavy ion experiments

NICA-Nuclotron acceleration complex (JINR, Dubna)

<table>
<thead>
<tr>
<th>Year</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2021</th>
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<td>Beam</td>
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<td>C</td>
<td>Ar,Kr</td>
<td>Kr,Xe</td>
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<td>10k</td>
<td>10k</td>
<td>20k→50k</td>
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</tbody>
</table>
Forward hadron calorimeters for fixed target heavy ion experiments

BM@N forward calorimeter upgrade

new FHCAL with beam hole

Expected high beam rate of gold ions: up to $2 \times 10^6$ Au/sec with energies up to 4.5 AGeV.

Doses from ionizing particles (left) and neutron fluence at the plane of MPPCs (right) in FHCAL at depth of 10 cm from the forward face (A. Senger simulation with FLUKA).
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BM@N forward calorimeter upgrade
Forward hadron calorimeters for fixed target heavy ion experiments

CBM experiment (GSI, Germany)

Beam rate: up to $10^8$ ions/sec (Au)
Reaction rate: up to $10^6$/sec (free streaming DAQ)
Energies: 2 – 11 AGeV

Doses at depth of 10 cm from the forward face of the PSD for Au+Au (A. Senger simulation with FLUKA)
Forward hadron calorimeters for fixed target heavy ion experiments

Energy asymmetry:

\[(E_{ZDC\_inner} - E_{ZDC\_outer})\]

\[(E_{ZDC\_inner} + E_{ZDC\_outer})\]

ZDC with hole (54 modules)

C+C, 4AGeV

\[\text{Entries 99968, Integral 9.997e+004}\]

Au+Au, 4.5AGeV

central events
Summary:

Forward hadron calorimeters with Pb+Scint sampling structure and SiPM readout have been developed and widely used in heavy ion fixed target experiments:

- NA61/SHINE experiment: ion-ion data taking are done from Be+Be (light system) to Pb+Pb (most challenging) during 2011-2018 data taking periods
  - upgrade of NA61/SHINE experiment will be prepared for 2020, new PSD calorimeter system will be used, beam hole in the main calorimeter

- BM@N experiment with ZDC: C, Ar, Kr beams with wide range of targets
  - new FHCAL with beam hole will be operated on BM@N experiment (modules for CBM and MPD will be used)

- CMB experiment is planned at GSI, PSD calorimeter with beam hole will be used

- energy asymmetry is a good method to estimate event centrality for calorimeter with beam hole in a center