

# Forward hadron calorimeter at MPD/NICA

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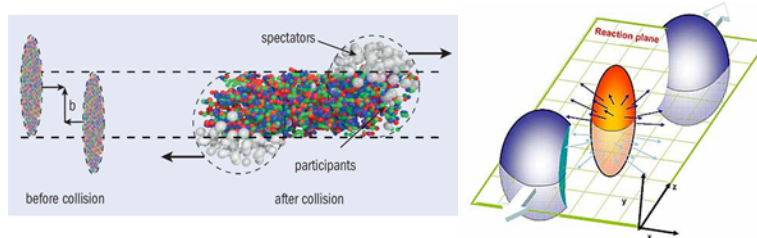
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**Abstract.** Forward hadron calorimeter (FHCAL) at MPD/NICA experimental setup is described. The main purpose of the FHCAL is to provide an experimental measurement of a heavy-ion collision centrality (impact parameter) and orientation of its reaction plane. Precise event-by-event estimate of these basic observables is crucial for many physics phenomena studies to be performed by the MPD experiment. The simulation results of FHCAL performance are presented.

## 1. introduction

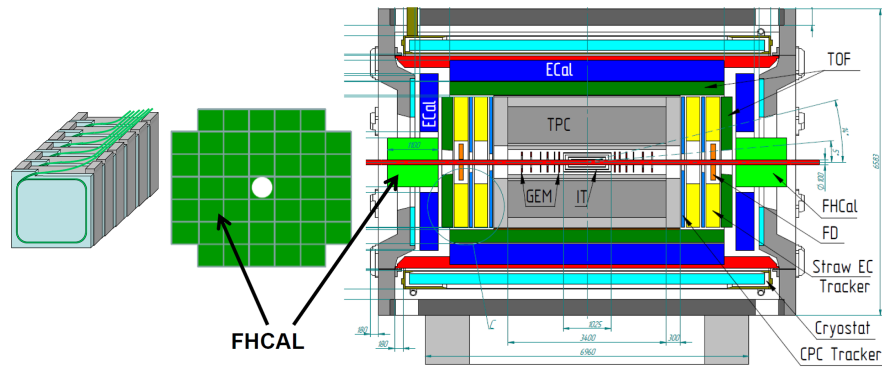
Forward hadron calorimeter (FHCAL) together with Time Project Chamber (TPC), Time-Of-Flight (TOF), Electromagnetic Calorimeter (Ecal) and Fast Forward Detector (FFD) are basic parts of the MPD experimental setup at NICA, Dubna, Russia [1]. As any heavy-ion experiment the MPD needs to characterize the ion collisions, i.e. to measure the geometry of heavy ions collisions. The main purpose of the FHCAL is to provide an experimental measurement of a heavy-ion collision centrality (impact parameter) and orientation of its reaction plane. Precise event-by-event estimate of these basic observables is crucial for many physics phenomena studies to be performed by the MPD experiment. The schematic definition of the impact parameter and the reaction plane are presented in figure 1, where vector  $b$  connects the centers of the colliding nuclei and represents the ideal centrality or impact parameter. The plane crossing the vector  $b$  and beam axis  $Z$  (figure 1, right) defines the reaction plane.



**Figure 1.** Schematic definition of the impact parameter  $b$  (left) and the reaction plane (right).

## 2. FHCAL in MPD/NICA experimental setup

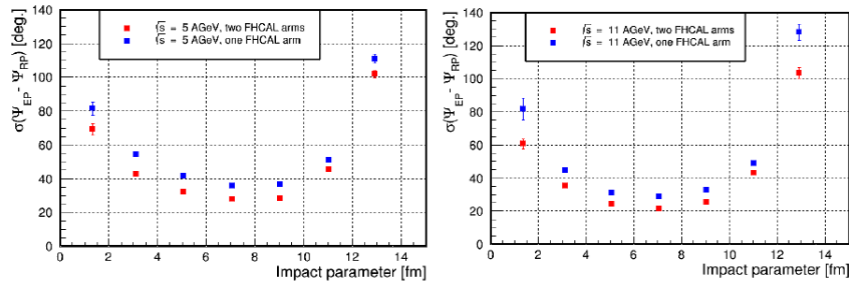
FHCAL [2] consists of two identical left/right arms placed at the distance of about 3.2 meters from the beam collision point. This is a compensating lead-scintillator calorimeter designed to measure the energy distribution of the projectile nuclei fragments (spectators) and forward going particles produced close to the beam rapidity. The main design requirements of the FHCAL are (a) forward rapidity coverage and sufficient energy resolution to allow for precise collision centrality determination and consequently of the number of participating nucleons and (b) granularity in the plane transverse to the beam direction which is needed for the reaction plane reconstruction. The proposed modular design of the FHCAL covers large transverse area around the beam spot position such that most of the projectile spectator fragments deposit their energy in the FHCAL. The schematic design of the FHCAL module, the structure of the FHCAL and its position in MPD setup are shown in figure 2. The calorimeter consists of 45 individual modules with the transverse sizes  $15 \times 15 \text{ cm}^2$  each. The FHCAL module has 4 interaction lengths and included 42 lead/scintillator sandwiches. The thickness of lead pates and scintillator tiles are 16 mm and 4 mm, respectively, that provides 4:1 compensating ratio. The light in the scintillator tiles is read out by the WLS-fibers embedded in the grooves inside the scintillator. Each 6 consecutive WLS-fibers are viewed by a separate photodetectors that ensures the segmentation of the FHCAL module in 7 longitudinal sections.



**Figure 2.** Schematic design of the FHCAL module (left), the structure of FHCAL calorimeter (middle) and its position in MPD setup (right).

## 3. Determination of the reaction plane orientation with FHCAL

Due to the momentum transfer between participants and spectators, the spectators are deflected in the course of the collision. For non-central collisions, the asymmetry of the initial energy density in the transverse plane is aligned in the direction of the reaction plane, and the spectator deflection direction is correlated with the impact parameter (or reaction plane) direction. The plane spanned by the directions of the beam and spectator deflection (spectator plane) can be used as an estimate of the reaction plane orientation. The estimated azimuthal angle of the spectator plane is called the event plane angle,  $\Psi_{EP}$ . The difference between the reconstructed event plane and true reaction plane reflects the angular resolution of the event plane and is shown in figure 3. As seen, the proper transverse segmentation and the energy resolution of FHCAL ensure the reconstruction of the event plane orientation with the accuracy of about 300 for the mid-central events.



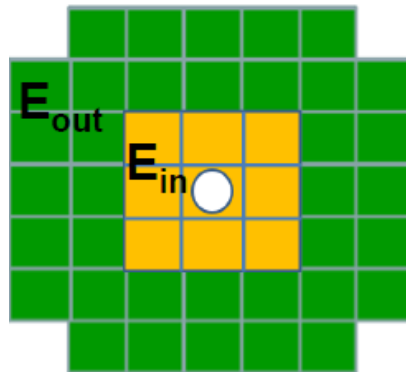
**Figure 3.** The dependence of the event plane resolution on the impact parameter for beam energy  $\sqrt{sNN} = 5\text{GeV}$  (left) and  $\sqrt{sNN} = 11\text{GeV}$  (right). Blue and red points correspond to the one and two arms of calorimeter, respectively.

#### 4. Determination of the centrality with FHCAL

Since the impact parameter  $b$  and the multiplicity of the spectators are correlated, the energy deposited in FHCAL can be used for collision centrality determination. The most central events correspond to a low spectator multiplicity (or a small energy deposition in the FHCAL), while peripheral events result in large amount of spectators (large energy deposition in the FHCAL). Unfortunately, the centrality dependence of the energy deposited in the FHCAL is non-monotonous in case of a beam hole in the central module. This is an obvious effect of the acceptance loss for forwardly emitted fragments. As a result, it is not possible to discriminate central collisions and peripheral ones using FHCAL energy deposition alone. Therefore, additional information on the coordinate spectator distribution at the FHCAL surface is used.

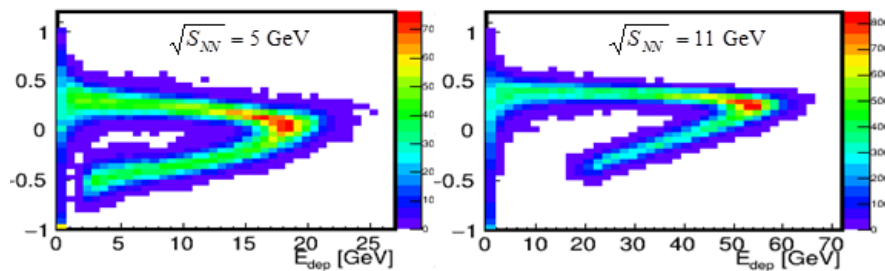
The subdivision of the calorimeter into two, inner and outer parts (see figure 4), and the calculation of the energy depositions  $E_{in}$  and  $E_{out}$  separately in these calorimeter parts allows the construction of new observable, energy asymmetry:

$$E_{As} = \frac{(E_{in} - E_{out})}{(E_{in} + E_{out})}$$

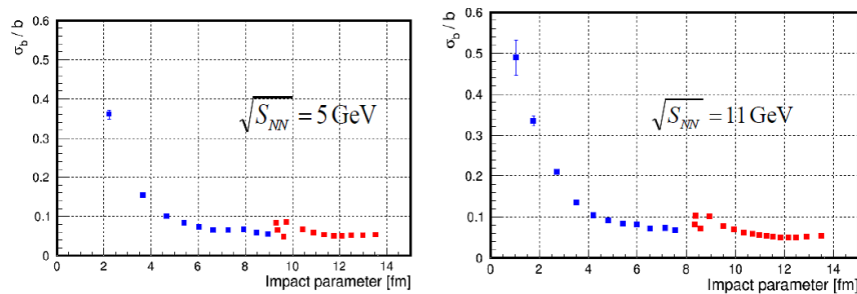


**Figure 4.** The scheme of FHCAL subdivision into two parts for the calculation of the energy asymmetry.

Taking the two-dimensional correlation between the energy asymmetry, EAs and full energy deposition in calorimeter Edep one would be possible not only to resolve the ambiguity in the centrality determination but also to improve the centrality resolution for the central events. In figure 5 such two-dimensional correlations are shown for beam energies  $\sqrt{s_{NN}} = 5$  and  $11\text{GeV}$ . The negative and positive parts of  $E_{As}$  correspond to the central and peripheral events, respectively. The corresponding centralities in given FHCAL energy bins are shown in figure 6 by blue and red dots for negative and positive parts of  $E_{As}$ , respectively. Note, that more sophisticated analysis of the two-dimensional correlations is possible, that would further improve the accuracy of the centrality determination.



**Figure 5.** The two-dimensional correlation between the energy asymmetry and full energy deposition in calorimeter.



**Figure 6.** Resolution of the centrality estimated from the two-dimensional correlation between the energy asymmetry and full energy deposition in calorimeter.

## 5. Conclusions

FHCAL is a key detector for the determination of the collision geometry at MPD/NICA. The expected FHCAL centrality resolution is below 10% for the most parts of the events. At the same time, the proper transverse segmentation and the energy resolution of FHCAL ensures the reconstruction of the event plane orientation with the accuracy of about  $30^\circ$ .

## References

- [1] <http://nica.jinr.ru>
- [2] [http://nica.jinr.ru/files/TDR\\_MPD/Forward%20Hadron%20Calorimeter\\_April\\_2016.pdf](http://nica.jinr.ru/files/TDR_MPD/Forward%20Hadron%20Calorimeter_April_2016.pdf)