Development of cosmic muon calibration methods for the longitudinal segmented sampling lead/scintillator hadron calorimeter at the NA61/SHINE, CBM, BM@N and MPD experiments

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Forward hadron calorimeter tasks

To determine the global event characteristics in nucleus-nucleus collisions - the centrality of the collision, which is related to the number of participating nucleons, and orientation of the reaction plane, the forward hadron calorimeters are used in NA61/SHINE, CBM, BM@N and MPD experiments.

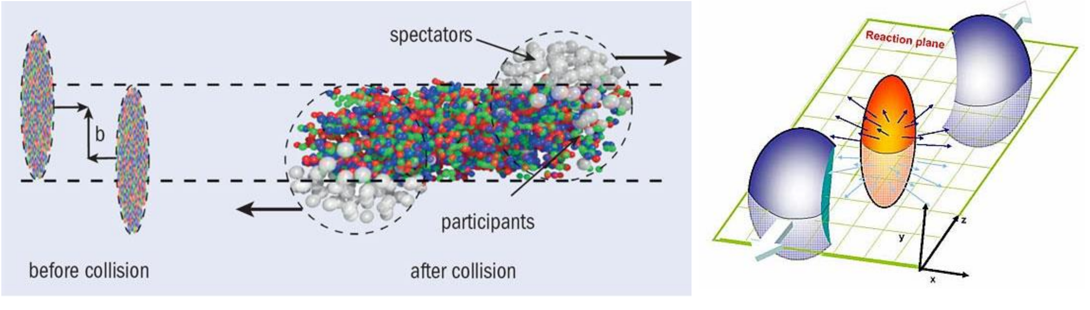


Fig.1 Centrality and Reaction plane

The event-by-event determination of the centrality and reaction plane orientation in heavy-ion interactions is one of important tasks in these experiments and is necessary to study the collective flow of identified particles, particle multiplicities and fluctuations and other observables.

Existing experiments

FHCal@BM@N **PSD@NA61/SHINE**

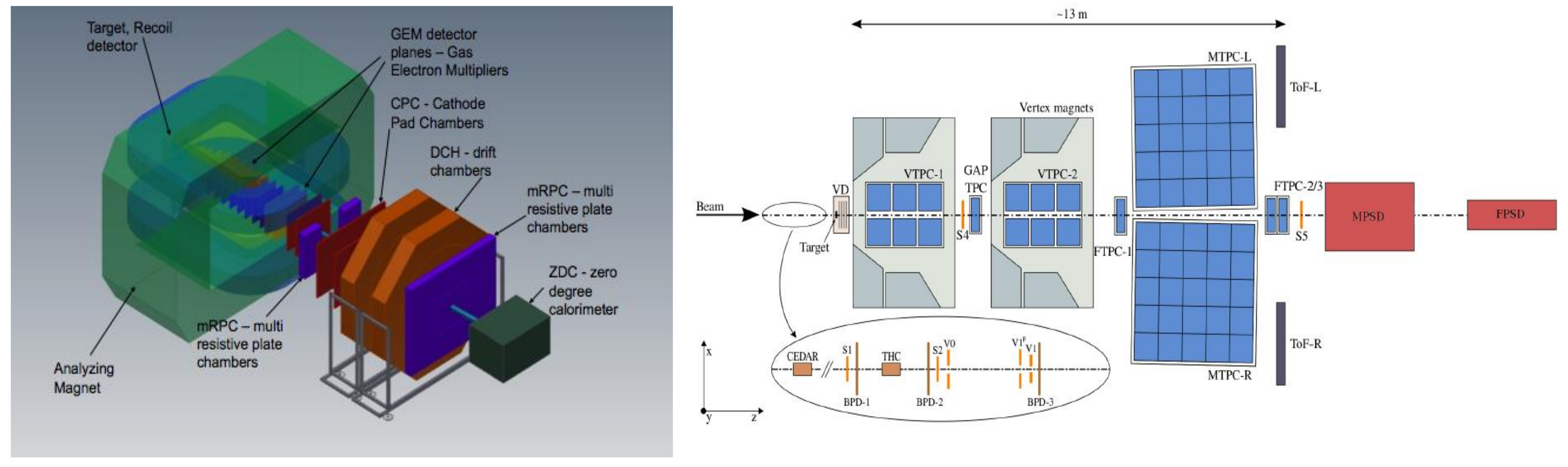
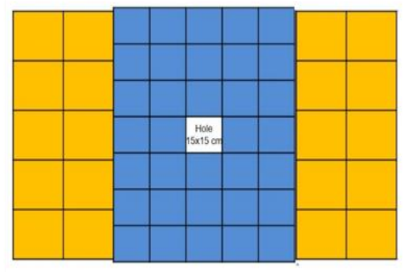
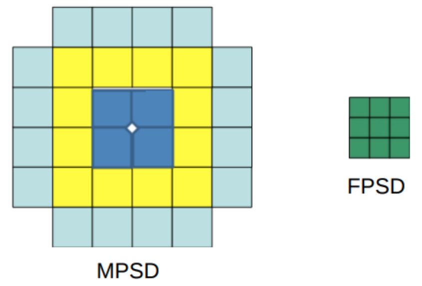


Fig.2.1 Hadron calorimeters of BM@N and NA61 experiments



34 inner modules (MPD type);
20 outer modules (CBM type);
Total weight – 17t.



32-moduled MainPSD +
9-moduled ForwardPSD (both CBM type);
Total weight – 16t+4.5t.

Fig.2.2 Left: FHCAL@BM@N structure; Right: MPSD@NA61/SHINE structure

Future experiments

PSD@CBM **FHCal@MPD**

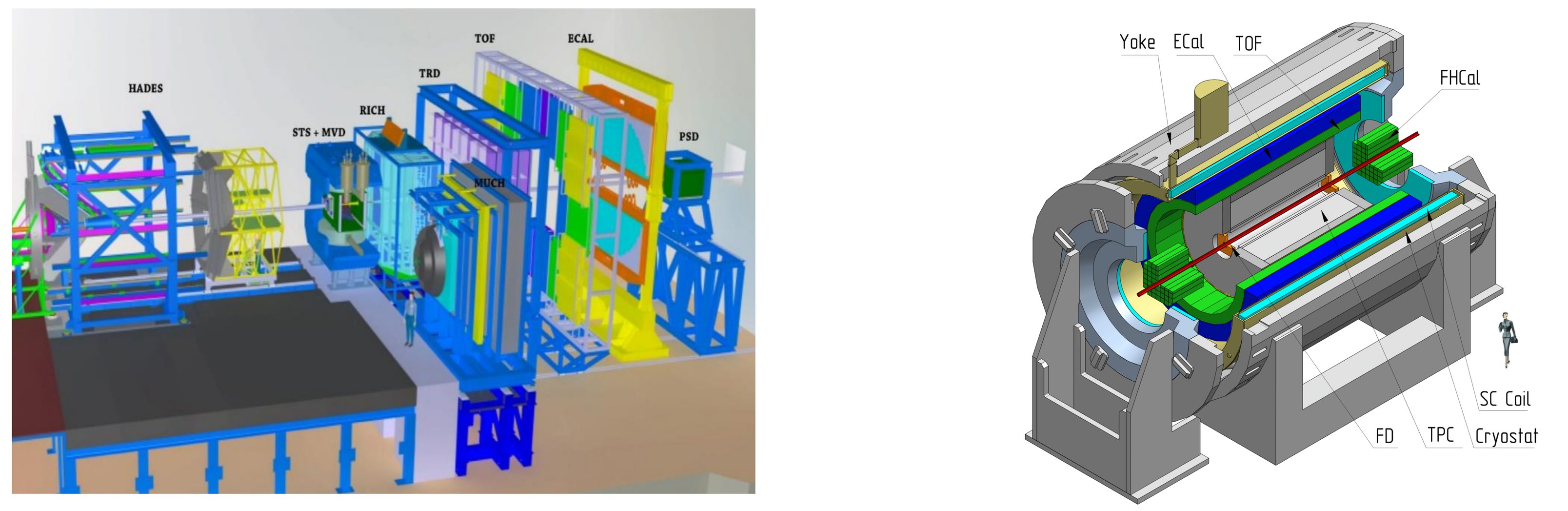
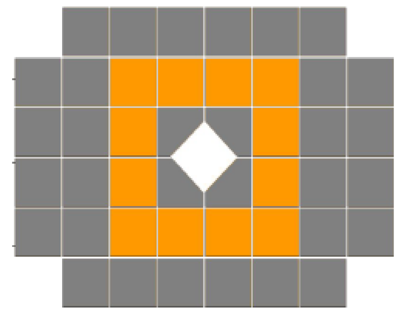
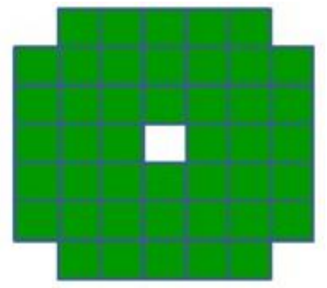


Fig.3.1 Hadron calorimeters of CBM and MPD experiments



44 modules
200x200mm^2;
Beam hole 20x20 cm^2;
Total weight – 22t.



2x44 modules
150x150mm^2;
Beam hole 15x15 cm^2;
Total weight – 17.5t.

Fig.3.2 Left: PSD@CBM structure; Right: FHCal@MPD structure

Calorimeter modules structure

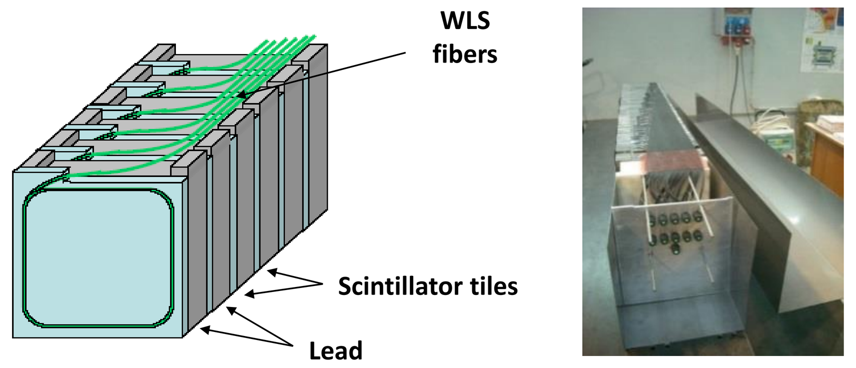
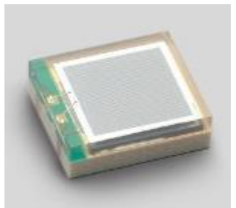


Fig.4 Modules structure

- **Longitudinal structure: Pb/Scint tiles layers: (Pb(16mm), Scint(4mm) grouped in sections.**
- **Light collection – by WLS fibers from 6 sequentially placed scintillator tiles in one section to one optical connector at the end of module.**
- **Light readout: Hamamatsu MPPC (3x3mm^2).**
- **Readout electronics: sampling ADC.**



Hamamatsu S12572-010P
Sensitive area 3x3 mm^2
Number of pixels 90 000
Nominal gain 1x10^5
Pixel recovery time 10 ns

Since in major part of the experiments it is not possible to organize a muon beam for calibration, the only way to calibrate is to use cosmic muons.

Waveform fitting

Advantages of the fitting procedure:

- **More correct determination of signal charge**
- **Working with small signals near the noise level**
- **Pick-up and pile-up identification**
- **True signal recovery**

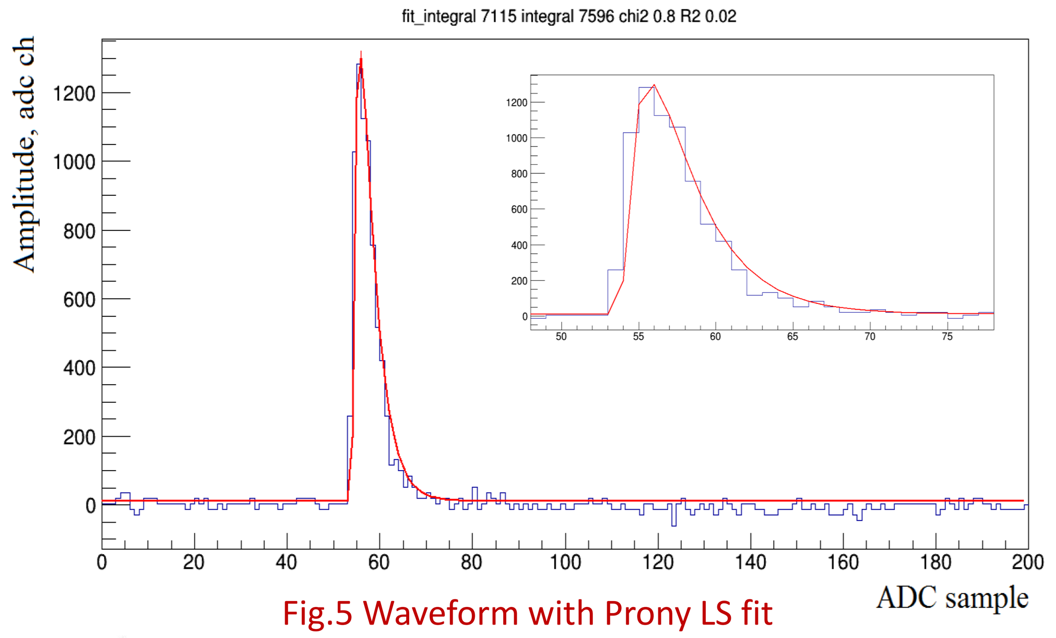


Fig.5 Waveform with Prony LS fit

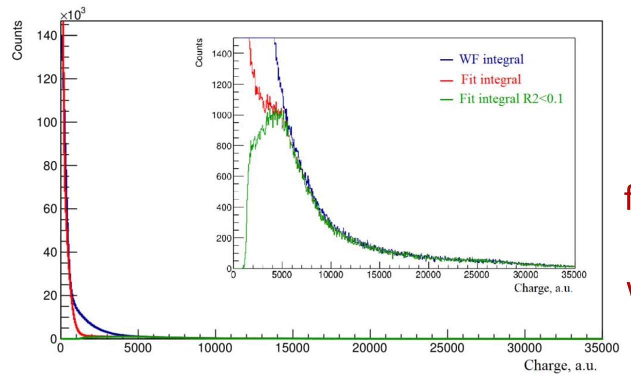


Fig.6 Charge distributions calculated by waveform integral (blue), fitting function integral (red) and fitting function integral with true events selection (green)

Fit quality assessment

Coefficient of determination*

$$R^2 = \frac{\sum_{n=1}^{N}(x[n]-\hat{x}[n])^2}{\sum_{n=1}^{N}(x[n]-\bar{x})^2}$$

$x[n]$ and $\hat{x}[n]$ are the experimental and model values of the variable, respectively. $\bar{x}$ is the experimental values average.

Adjusted coefficient of determination *

$$R^2_{adj} = R^2\frac{N-1}{N-\lambda}$$

N is the number of measurements, λ is the number of model parameters.

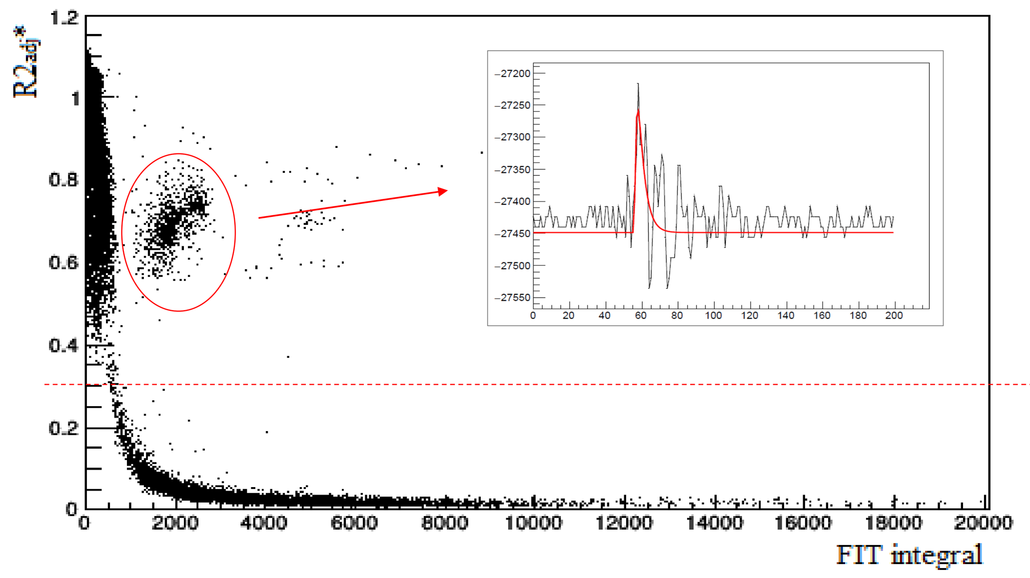


Fig.7 Coefficient of detemination : SignalCharge

Energy calibration approach

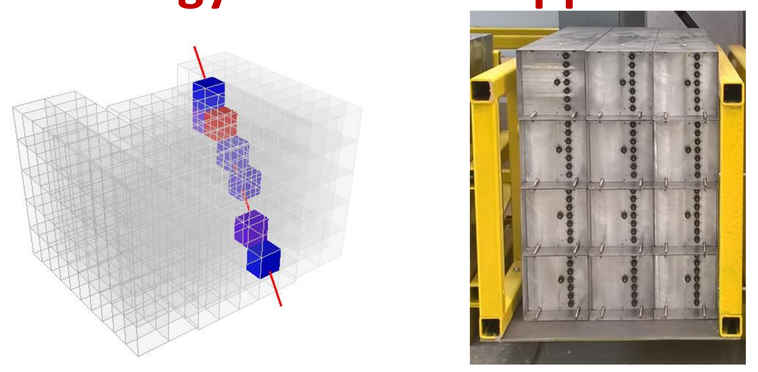


Fig.8 Calorimeter section triggered by cosmic muon (left); Photo of calo modules system with common trigger (right).

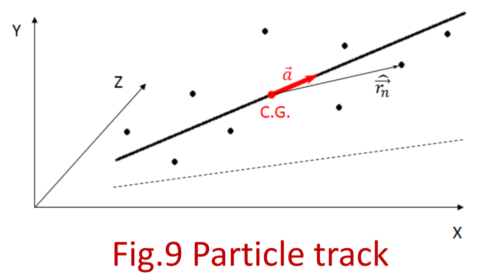


Fig.9 Particle track reconstruction illustration.

1) Selection of triggered sections by fit QA

2) Shift reference system to the center of gravity:

$$\vec{R}_{C.G.} = \frac{1}{N}\sum_{n=1}^{N} E[n]\,\vec{r}[n].$$

3) Extremum search: $\varphi = \sum_{n=1}^{N} \hat{r}_i a_i \hat{r}_j a_j \rightarrow max$

$$M = \begin{pmatrix} \sum_{n=1}^{N} r_n^x r_n^x & \sum_{n=1}^{N} r_n^x r_n^y & \sum_{n=1}^{N} r_n^x r_n^z \\ \sum_{n=1}^{N} r_n^y r_n^x & \sum_{n=1}^{N} r_n^y r_n^y & \sum_{n=1}^{N} r_n^y r_n^z \\ \sum_{n=1}^{N} r_n^x r_n^z & \sum_{n=1}^{N} r_n^y r_n^z & \sum_{n=1}^{N} r_n^z r_n^z \end{pmatrix} \xrightarrow{\text{Jacobi rotations}} \overrightarrow{EV}$$

Calibration results

Adjusted charge is calculated taking into account the thickness of the scintillator material traversed by the cosmic muon track.

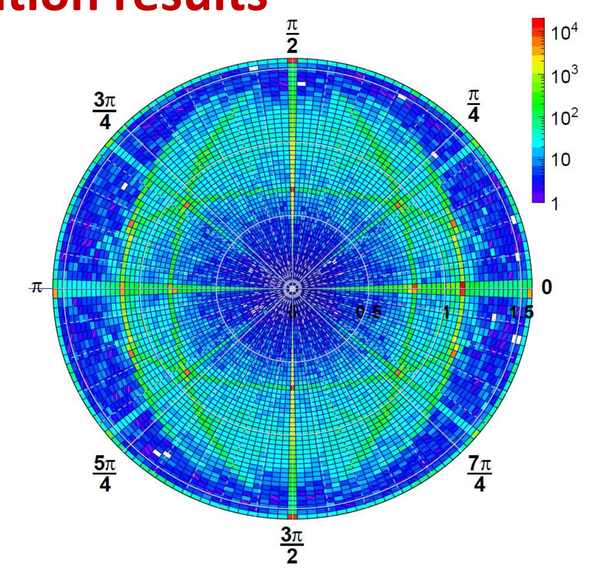


Fig.10 Particle track Zenith and Azimuthal angles. Distinct lines correspond to the topology of the calorimeter.

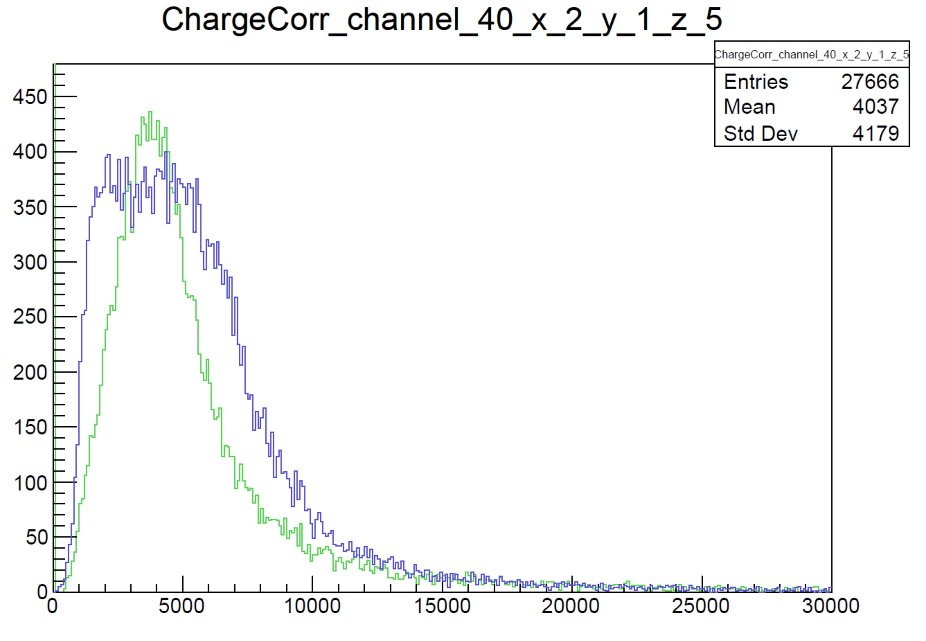


Fig.11 Charge distribution in calorimeter section before and after correction

Conslusions

- **A new method of waveform fitting is developed**
- **The fit QA is used to reject noise and pick-ups.**
- **Since the muon beam is absent in major part of the experiments, the energy calibration of the hadron calorimeter sections is possible only with cosmic muons.**
- **The presence of longitudinal segmentation of the calorimeter modules made it possible to use a new approach to the cosmic muon calibration, adjusting the energy deposition in calorimeter sections by the thickness of the scintillator traversed.**
- **The corrected energy deposition distribution has a more clearly defined maximum resulting in a more accurate energy calibration.**

Acknowledgements

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