MPD electromagnetic calorimeter simulation

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Recently, the full design of the ECal / MPD structure and its power supporting frame made of carbon fiber was almost completed.

Last modifications proposed by the VBLHEP design department led to significant changes of the calorimeter structure.

This report gives a brief description of the new ECal geometry, the modification of simulation procedure and the current basic parameters of the calorimeter.

Current ECal geometry simulation is based on the standard software of the MPD detector: MpdRoot and FairSoft.

ECal geometry is stored in the ROOT – file (~mpdroot/geometry/emc_v3.root).

New calorimeter geometry has a lot of different elements (~ $19 \times 10^6$) and includes power frame, supporting baskets for calorimeter modules, modules combined from ECal towers, specific tower of the different types, and tower structure till Pb and scintillation plates.

New physical parameters of the ECal characterizing last geometry version will be also presented in report.
MPD power frame

- Power frame supports ECAL and TOF parts
- Material – carbon composite. For MC used mixture (graphite + epoxy):
  \[ H (7.4\%) + C (80.9\%) + O (11.7\%) \]
  \[ \rho = 1.38\, \text{g/cm}^3, \quad X_0 = 30.4\, \text{cm} \]
- Low radial edge gives 8.2% \( X_0 \) before ECAL
- Power frame consists from 25 transverse and two radial edges
Baskets for ECal modules

- 25×2 baskets move inside power frame
- Material – fiberglass:
  \[ H \ (5.8 \%) + C \ (43.1 \%) + Si \ (14.8 \%) + O \ (36.3 \%) \]
  \[ \rho = 1.9 \ g/cm^3, \ X_0 = 18.4 \ cm \]
- Total weight of one container ~ 1200 kg (empty container weight ~ 60 kg)
Lower container wall

- Lower radial edge of container has a lattice structure to prevent background production (radial width = 0.5 cm)
- Lattice has a non-periodic hole size along OZ - axis, grid width is constant (3.0 cm)
- Non-periodic hole size duplicates tower projection on OZ - axis
Towers are merging into modules by special glue, which is included in the ECal geometry. Glue is a Ti–epoxy mixture:

\[ H \ (4.9 \%) + C \ (46.1 \%) + Ti \ (16.5 \%) + O \ (32.5 \%) \]

\[ \rho = 1.2 \text{ g/cm}^3, \ X_0 = 26.51 \text{ cm} \]

- Each basket has 6×8 modules
- Modules are constructing from 2×8 towers of different types
- Eight modules with different shapes have been approved
- In the GEANT4 geometry such shape can be describe by the polygon volume, which has 50 cross sections and repeated a shape of eight towers
Total number of towers: 38400

Each tower has 210 lead (h = 0.3 mm) and scintillation plates (FscScint – C\textsubscript{9}H\textsubscript{10}, h = 1.5 mm)

Each lead plate is coating of the Ti\textsubscript{2}O\textsubscript{2} paint (h = 0.05 mm) with parameters:

\[ \text{H (2.9 \%) + C (17.2 \%) + Ti (41.1 \%) + O (38.9 \%)} \]
\[ \rho = 1.18 \text{ g/cm}^3, X_0 = 20.49 \text{ cm} \]

Tower is fixed by two plates on top and bottom (Kapton, h = 8 mm, N\textsubscript{2}C\textsubscript{22}H\textsubscript{10}O\textsubscript{5}, \rho = 1.42 \text{ g/cm}^3, X_0 = 28.4 \text{ cm})

Tower shape can be described by the GEANT4 class TGeoArb8 – arbitrary trapezoid with 2×4 vertices at two parallel planes perpendicular to central axis

Sensitive volume in MpdRoot is a scintillation plate

Towers give a main contribution to number of the GEANT4 elements; total number of nodes ~ 16 \times 10^6
ECal geometry has 64 trapezoids with different sizes (a, b, c) positioning along Z – axis

As a result of the module milling, three types of tower shapes were selected

For Type 2 and Type 3 we use compound volume, consisting from 2 and 3 trapezoids
Tower parameters

A, B and C parameters are calculated precisely on a basis of two milling angles

Three trapezoids: towers 1 ÷ 41; two trapezoids: towers 42 ÷ 48; one trapezoid: towers 49 ÷ 64
Each container has 8 modules

Modules is combined from 2×8 towers

64 different towers are placed along Z – axis at different Θ - angles

Interaction point

L = 298.64 cm

R = 171.56 cm

ΔZ

Θ

NICA collider rings:

Rms Z = 24 cm
Generally, the ECal geometry was planned to be a projective, but small asymmetry for towers position in XY plane is presented.

Displacement of towers in XY plane can be estimated by formula: $\Delta D_{xy} = \phi \times R_{xy}$ (Rxy – radius of the tower center).

This effect is related to a special milling of towers and different edges of the supporting structure.
Geometry check with MC points

✓ Check overlaps on a level of $10^{-5}$ cm.
To create hits in ECal we use a class `MpdHitCreation`

Each hit is defined by three numbers (number of basket, number of hit in XY – plane, counterclockwise enumeration from 0 to 300, and number of hit along Z – axis, or 0 - 63 at Z < 0 area; 64 - 127 at Z > 0)

Hit is a sum of all MC points in the tower scintillator; coordinate of each hit is defined in the center of tower

Our software determines hit due to geometrical parameters extracted from ECal ROOT – file. It’s important to do, since ROOT function `FindNode` gives the wrong solution at the level of 2-3 %

Cluster algorithm is based on the merging neighboring hits close hits into cluster starting from initial hit with maximal energy deposition

All cluster parameters are also energy weighted
## Version 2 and 3 comparison

<table>
<thead>
<tr>
<th><strong>ECal parameters</strong></th>
<th><strong>Version 2</strong></th>
<th><strong>Version 3</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of nodes</td>
<td>$\sim 19 \times 10^6$</td>
<td>$\sim 16 \times 10^6$</td>
</tr>
<tr>
<td>ECal total weight* (tons)</td>
<td>$\sim 60$</td>
<td>$\sim 65$</td>
</tr>
<tr>
<td>Power Frame</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Baskets</td>
<td>2×8 (no material)</td>
<td>2×25 (fiberglass)</td>
</tr>
<tr>
<td>Number of modules in basket</td>
<td>No</td>
<td>6×8</td>
</tr>
<tr>
<td>Tower radius in space (cm)</td>
<td>172</td>
<td>171.56</td>
</tr>
<tr>
<td>Total number of towers</td>
<td>43008</td>
<td>38400</td>
</tr>
<tr>
<td>Tower length (cm)</td>
<td>43.095</td>
<td>41.55</td>
</tr>
<tr>
<td>Number of tower types</td>
<td>64</td>
<td>64</td>
</tr>
<tr>
<td>Number of tower shapes</td>
<td>1</td>
<td>1 ÷ 3</td>
</tr>
<tr>
<td>Number of layers per tower</td>
<td>221</td>
<td>210</td>
</tr>
</tbody>
</table>

* Weight of the detector estimated in the ROOT – frame
New physics ECal parameters

- ECal geometry efficiency, $E_\gamma = 1.0$ GeV
- $\pi^0$ invariant mass, $p(\pi^0) = 0.2$ GeV

**θ - efficiency**

**φ - efficiency**

- New ECal geometry efficiency goes down, but not significantly in comparison to the previous
- $\pi^0$ – invariant mass demonstrates a small enlargement in width and more essential increase of the low energy tail due to new design features (more detailed – report of V. Kulikov, ITEP)
Conclusion

Quasi-spherical ROOT - geometry of ECal was done for MpdRoot software. It consists from $16 \times 10^6$ elements and includes power frame, 25 baskets, specific ECal modules, which combined from $2 \times 8$ towers. New geometry was proposed by the VBLHEP Design Department including special materials for different ECal parts.

New geometry is stored in the emc_v3.root file. The quality of the ECal geometry was tested in the ROOT frame for overlaps on the level of $10^{-5}$ cm.

Two MpdRoot classes (MpdHitCreation and MpdClusterCreation) gives us a possibility to estimate the physical parameters of calorimeter. MpdHitCreation is used a geometrical prediction based directly on the current version to create hit. Other software part to produce a cluster is working only for low multiplicity and should be updated.

In case of the geometry completeness, ROOT file will be transferred to git.jinr.ru. Next efforts should focus on optimal way to create the ECal cluster both for neutral and charged particles. Any ideas to separate hadronic and electromagnetic showers will be tested.
Thank You
Geometry acceptance

- ECal geometry efficiency at $E_{\gamma} = 1.0$ GeV
- Angular resolution of the ECal cluster by angles $\phi$ and $\Theta$ at $E_{\gamma} = 1.0$ GeV

θ - efficiency

$\phi$ - efficiency

$p_0 : \ 0.9511 \pm 0.0058$

$p_0 : \ 0.9483 \pm 0.0064$
Energy resolution

Energy resolution is defined for two cases:

1. MPD (TPC and TOF) + Power Frame + ECal
2. ECal only

Contribution of the Power Frame is not significant.

MPD detector parts are slightly corrupted the energy resolution of ECal.

Fit Function = \( p_0 / \sqrt{E} \oplus p_1 \)

\( E_\gamma = 200 \text{ MeV} \)

\( E_\gamma = 1 \text{ GeV} \)

- Energy resolution is defined for two cases:
  - MPD (TPC and TOF) + Power Frame + ECal
  - ECal only
- Contribution of the Power Frame is not significant.
- MPD detector parts are slightly corrupted the energy resolution of ECal.
Right slide – energy deposit of \( \gamma \)'s in ECal tower (hit) at different energies (\( E_\gamma = 0.2, 1.0 \) GeV)

Left slide – energy resolution of the cluster vs hit threshold at different \( E_\gamma \)

Threshold growing for a hit leads to an increase in the energy resolution

This effect is more sufficient for \( \gamma \)'s with low energies
NICA collider rings:

- Rms Z (bunch length ~ 60 cm): 24 cm
- Rms X = Rms Y ~ 0.0 cm
- Gaussian smearing of $\pi^0$ vertex along Z-axis

$\sigma M_{\gamma\gamma} / M_{\gamma\gamma} \sim 10.6\%$ (definite vertex)
$\sigma M_{\gamma\gamma} / M_{\gamma\gamma} \sim 11.8\%$ (vertex smearing)

$\cos \theta_{\gamma\gamma}$ - angle between cluster and real $\gamma$ directions

$E_{\gamma} / \text{hit} > 5$ MeV
Neutron registration by ECal

✓ CB calorimeter at Mainz (A2 experiment) installed on the MAMI photon facility
✓ CB: NaI crystals, length of 40.7 cm
✓ Neutron efficiency obtained in the A2 experimental data close to MPD/ECal simulation
✓ So, neutrons gives a significant background to the neutral component
✓ EM shower has a compact time in ECal and many cells are fired; hadronic shower has a big time difference between energy depositions in the early and late stages
✓ An effective way to separate neutrons from light particles and photons will be investigated
✓ Possible way to separate photos and neutrons is a correct investigation of time shapes

Detection efficiency at CB/A2

MC detection efficiency at MPD/ECal

M. Martemianov, V. Kulikov, JINST 10 (2015), T04001