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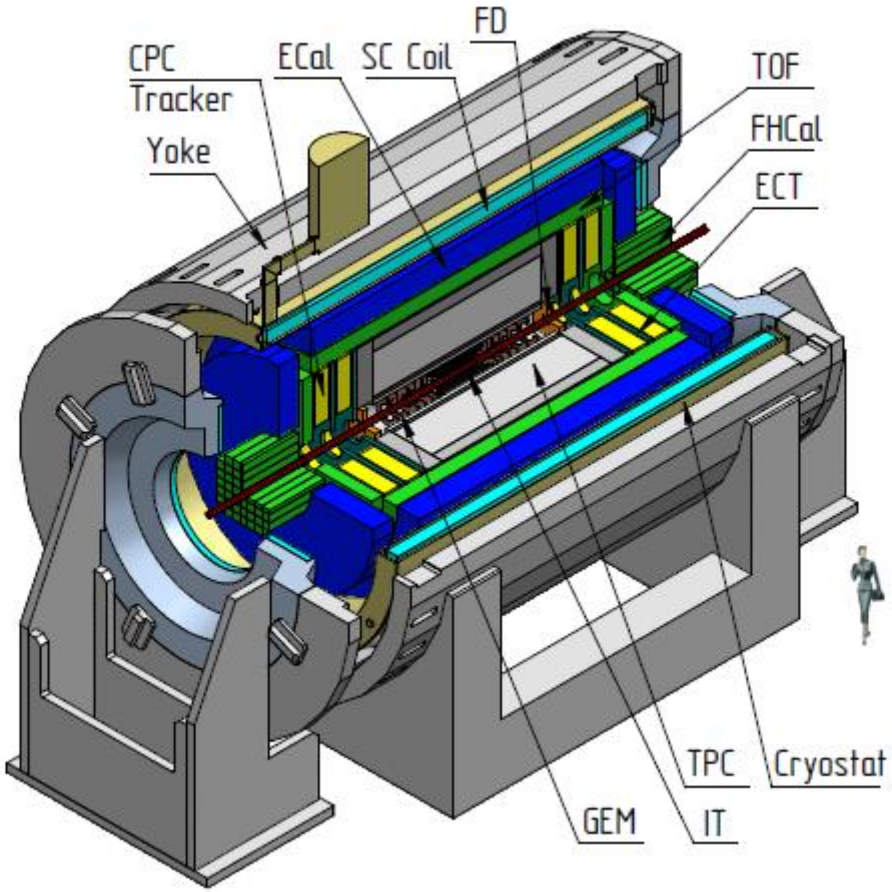

Simulation of the total MPD/ECal setup for cosmic ray calibration

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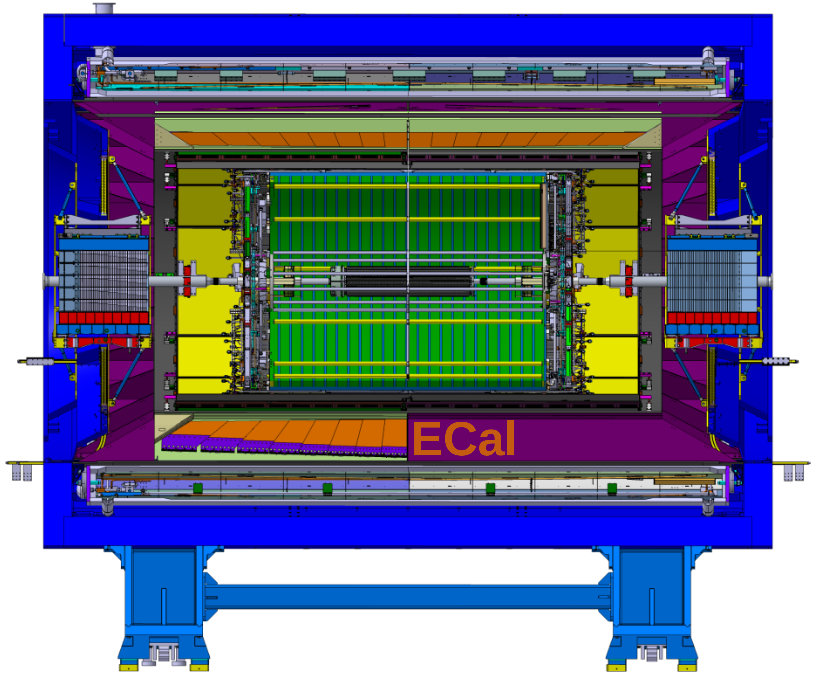
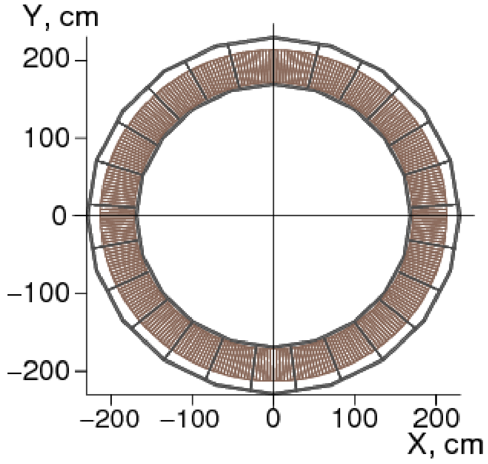
Introduction

- As part of an international project, a multi-purpose detector MPD is under construction for operation at the heavy-ion accelerator complex NICA.
- One of the main elements of the detector is the electromagnetic calorimeter ECal, designed to register the main probes of quark-gluon plasma – direct photons and electron-positron pairs
- The calorimeter has a cylindrical structure and consists of 2400 modules (38400 cells)
- Currently, 1600 of total modules were produced in Russia (three facilities) and in China (five universities)
- Preliminary calibration of the limited number of modules was performed on electron beam at LPI (Troitsk), all produced modules were tested in JINR on specific stands using vertical cosmic muons
- Cosmic muons are widely used for calorimeter calibrations. Problems arise when transversal sizes of the towers are small and calibration in vertical position with muons running along tower axis is extremely time consuming and technically complex. A typical way to avoid this problem is to calibrate towers in any position based on tower thickness assuming small correction on current position
- The purpose of this report to show that calibrating ECal with cosmic muons is nevertheless possible. It will be done by simulation and the first half-sector test measurement





XY ECal view

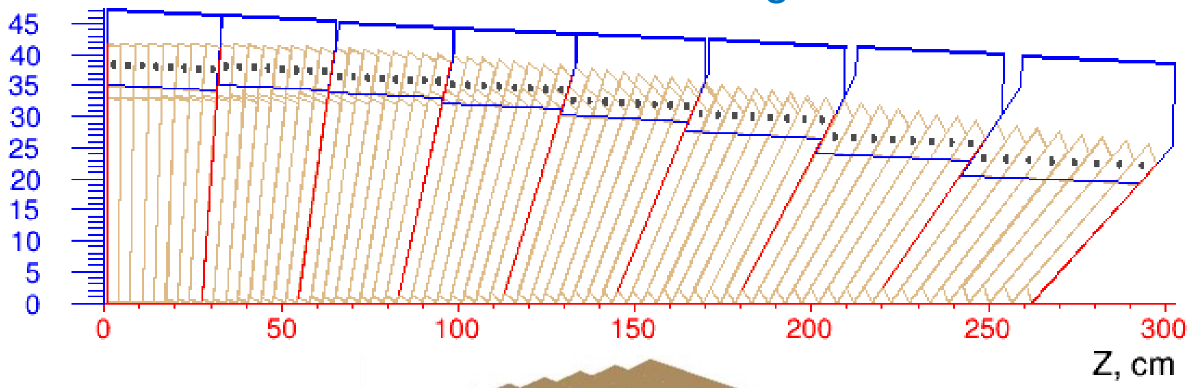
Inner radius: 171.3 cm

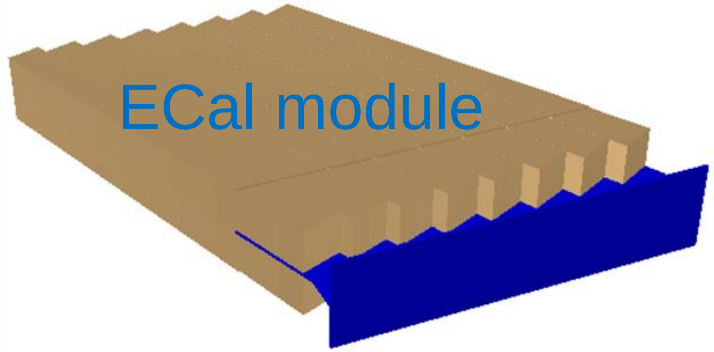
Half-sector length: 312 cm

- ✓ ECal geometry is close to projective, that means all towers look to the intersection point of collider beams
- ✓ Cylindrical power frame produced from carbon fibers supports ECal, TPC, TOF systems
- ✓ Calorimeter has a cylindrical structure divided on 50 half-sectors (25 from both side)
- ✓ Each half-sector (basket) has 48 ECal modules
- ✓ Each basket has only internal walls, so all modules are glued both to the walls of the basket and to each other
- ✓ Each module consists from 16 towers fixed by the special glue
- ✓ Cooling systems of 2 types (by air and by water)

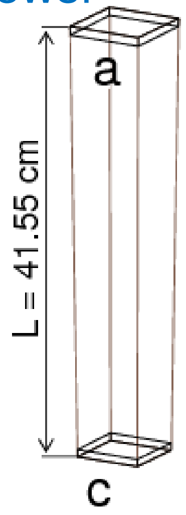
- Each cell (tower) consists of 210 alternating tiles which are 1.5 mm scintillator and 0.3 mm lead
- All towers have truncated pyramid shapes with a base of 4 × 4 cm^2 by two different milling angles (0.9° along the *Z* - axis and 1.2° in the XY - plane)
- Each lead plate is coated by the Ti_2O_2 paint
- Light produced in scintillators is transferred by sixteen WLS fibers to SiPM

Tower location along Z- axis

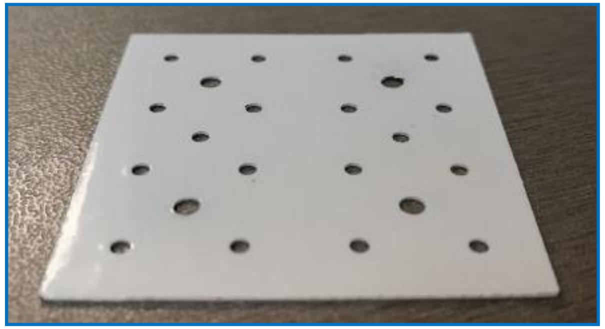




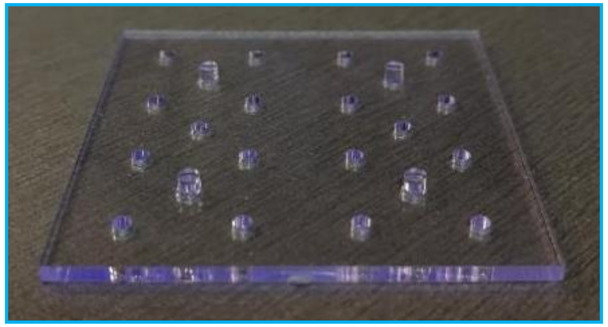
One tower

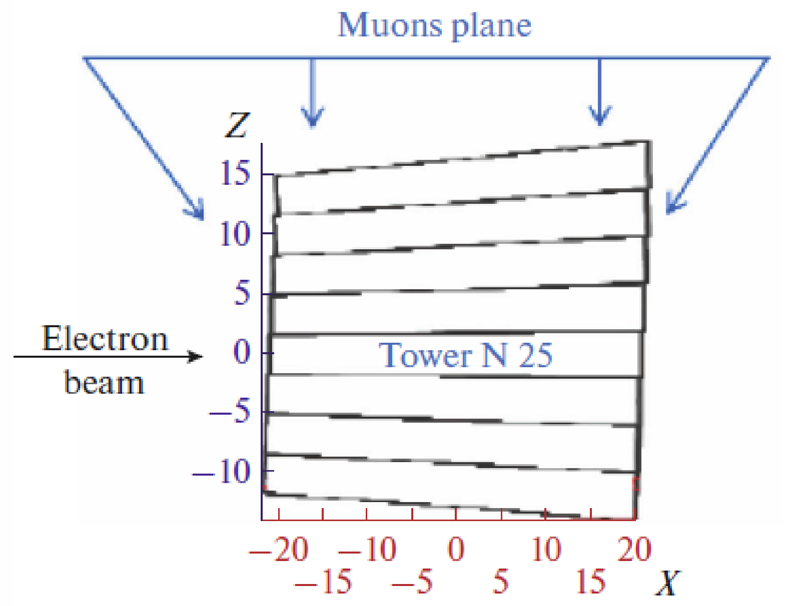


Lead plate

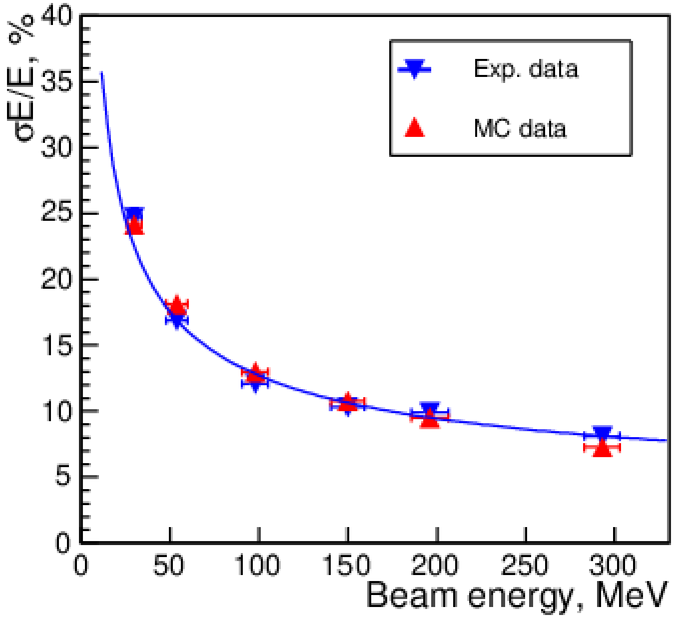


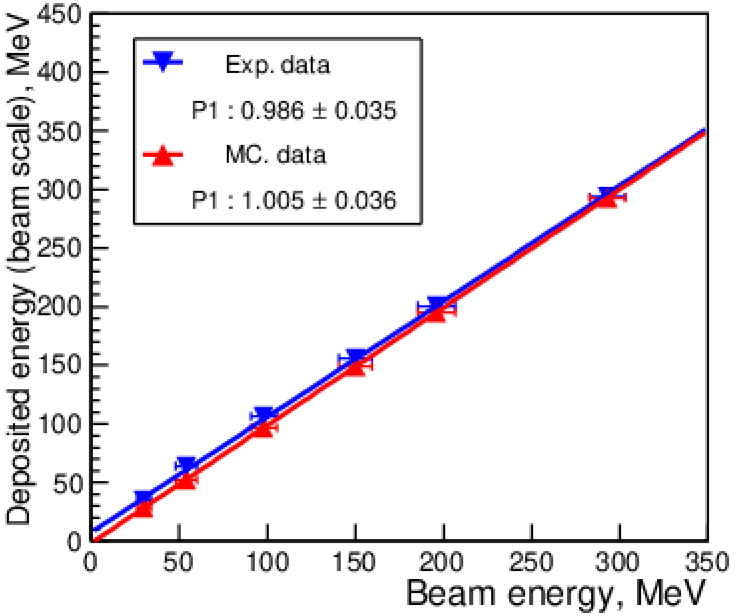
Scintillation plate





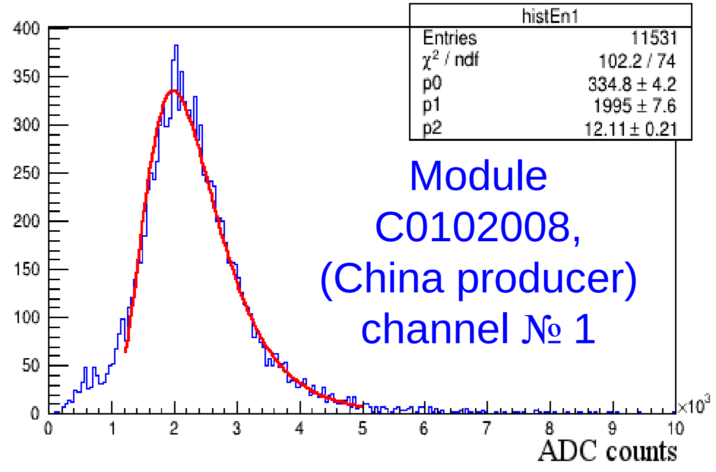
- ✓ Calibration was done on the conversion electron beam at S25-R «Pakhra» accelerator (LPI, Troitsk)
- ✓ Three module were joined to the assembly (48 towers, 6 in YZ) × 8 in XZ
- ✓ All towers were calibrated on the transverse cosmic muons to align the energy release in them
- ✓ Six electron beam energies were used

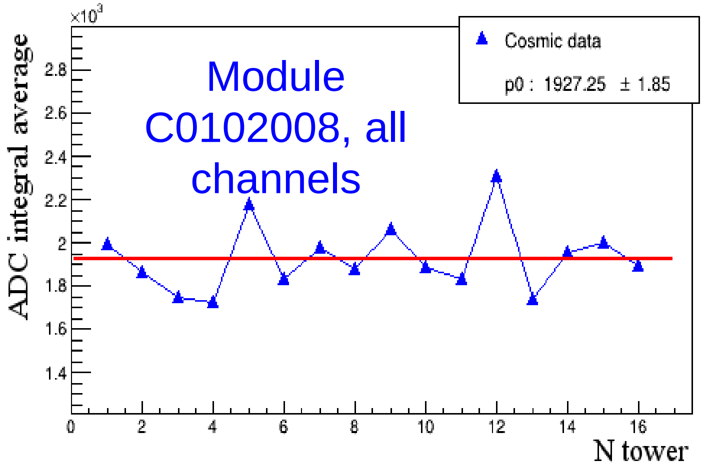


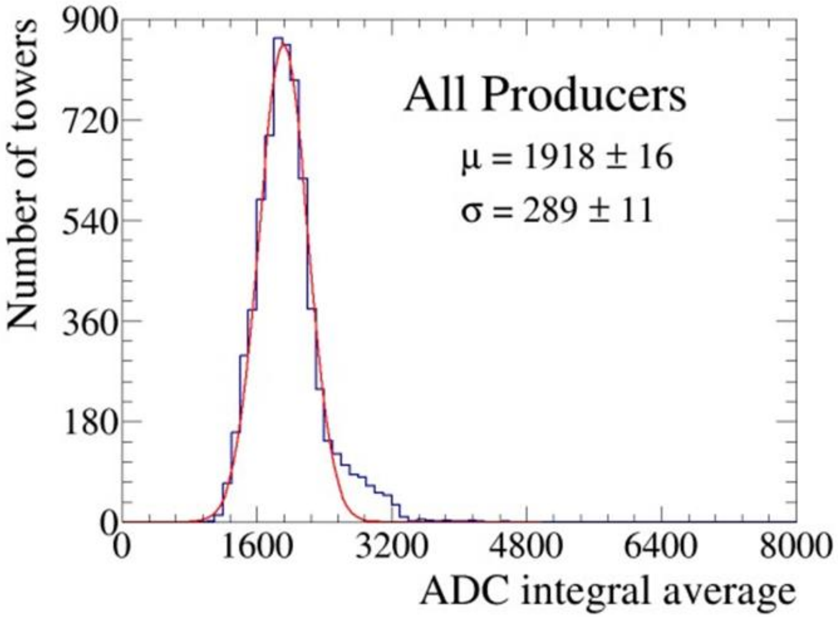


- ✓ Deposit energy is defined by all towers
- ✓ σE/E ~ 3.8 % / $\sqrt{E(GeV)}$. MC and data are in a good agreement within ~ 5 ÷ 6 %
- ✓ Linearity is observed well for MC data, but for experimental data there is a deviation and scale coefficient is less than unity

Module testing on cosmic rays







- ✓ All 1600 modules were tested at JINR on four special stands
- ✓ To test towers in the module transverse muons have been used, when all towers located in a row are triggered
- ✓ This method permits us to strongly suppress low energy exponential component and allows to select one clear peak corresponding ~ 6 MeV energy deposition
- ✓ Mean value of this peak (ADC integral average) shows a testing result

Generator of the cosmic rays (muons)

✓ Parameterization of the cosmic ray spectra (atmospheric muons) obtained from experimental data and covers wide energy range

✓ Assuming a flat Earth is leads to $\cos^{N-1}$ dependence, where N – power of the energy distribution [P. Shukla, Int.J.Mod.Phys. A33 (2018) no.30, 1850175]

$$I / I_0 = (E_0 + E)^{-N} \times \cos^{N-1}\Theta / (1 + E / 854);$$
$$E_0 = 4.29, N = 3.01$$

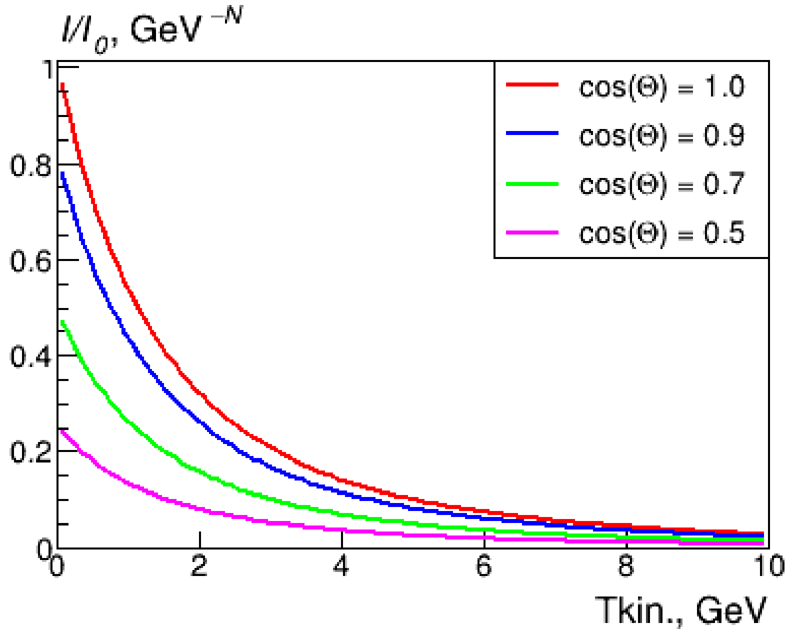
✓ cos Θ – zenith angle (Θ – angle between particle and perpendicular to the ground), E – energy; this formula is valid for muons, not for protons part

✓ This physical event generator was implemented in the frame of the mpdroot to produce 20x10^6 initial events in the standard root format

✓ Initial coordinates are defined by the surface of the cylinder (R = 600 cm, L = 760 cm) covering the experimental setup with some space margins

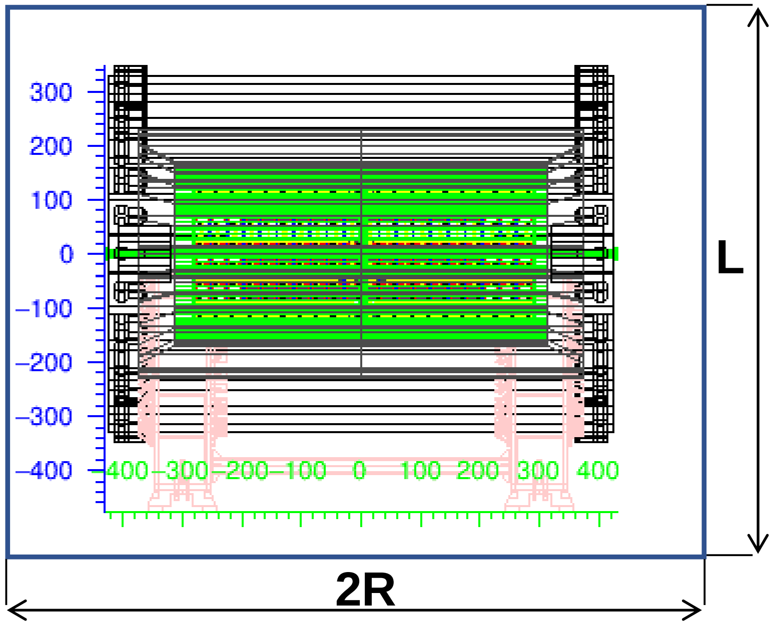
✓ To accelerate generation of cosmic tracks, only those one are accepted for consideration that are directed to the ECAL area

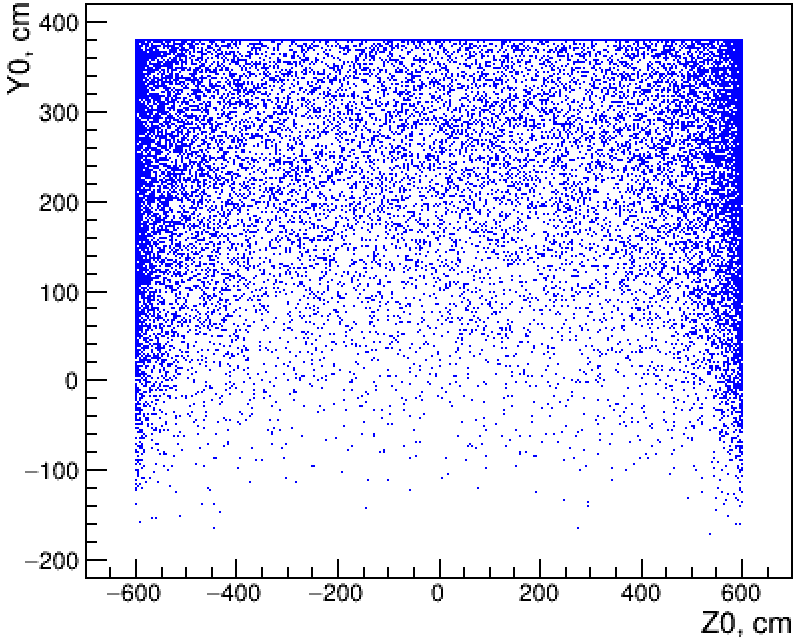
Cosmic muons energy spectra

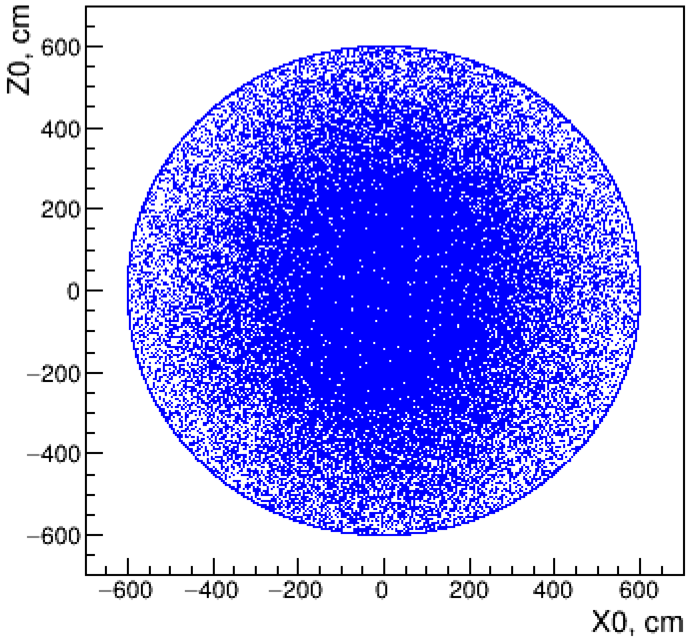


Track initial position for muons

MPD setup

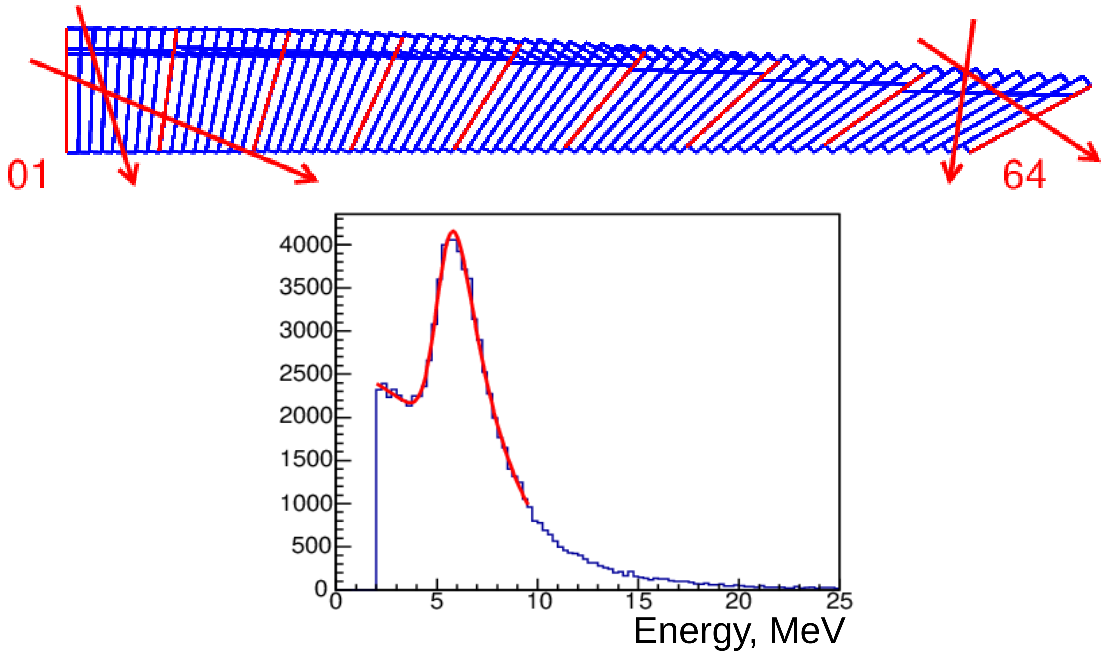




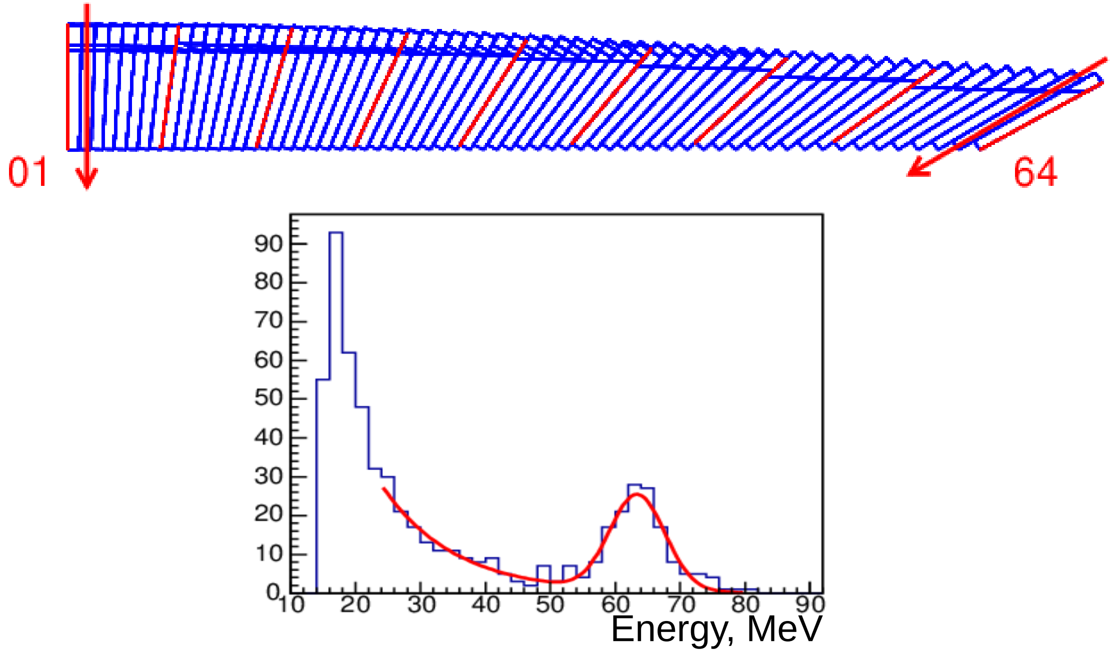


- Initial coordinates are defined by the surface of the cylinder (R = 600 cm, L = 760 cm) covering the experimental setup with some space margins
- To accelerate generation of cosmic tracks inside ECal, only those tracks are accepted for consideration that are directed to the ECAL area
- This cut suppress tracks produced in the bottom cylinder region with $Y_0 < 0$

Method 1 : signal from inclined tracks

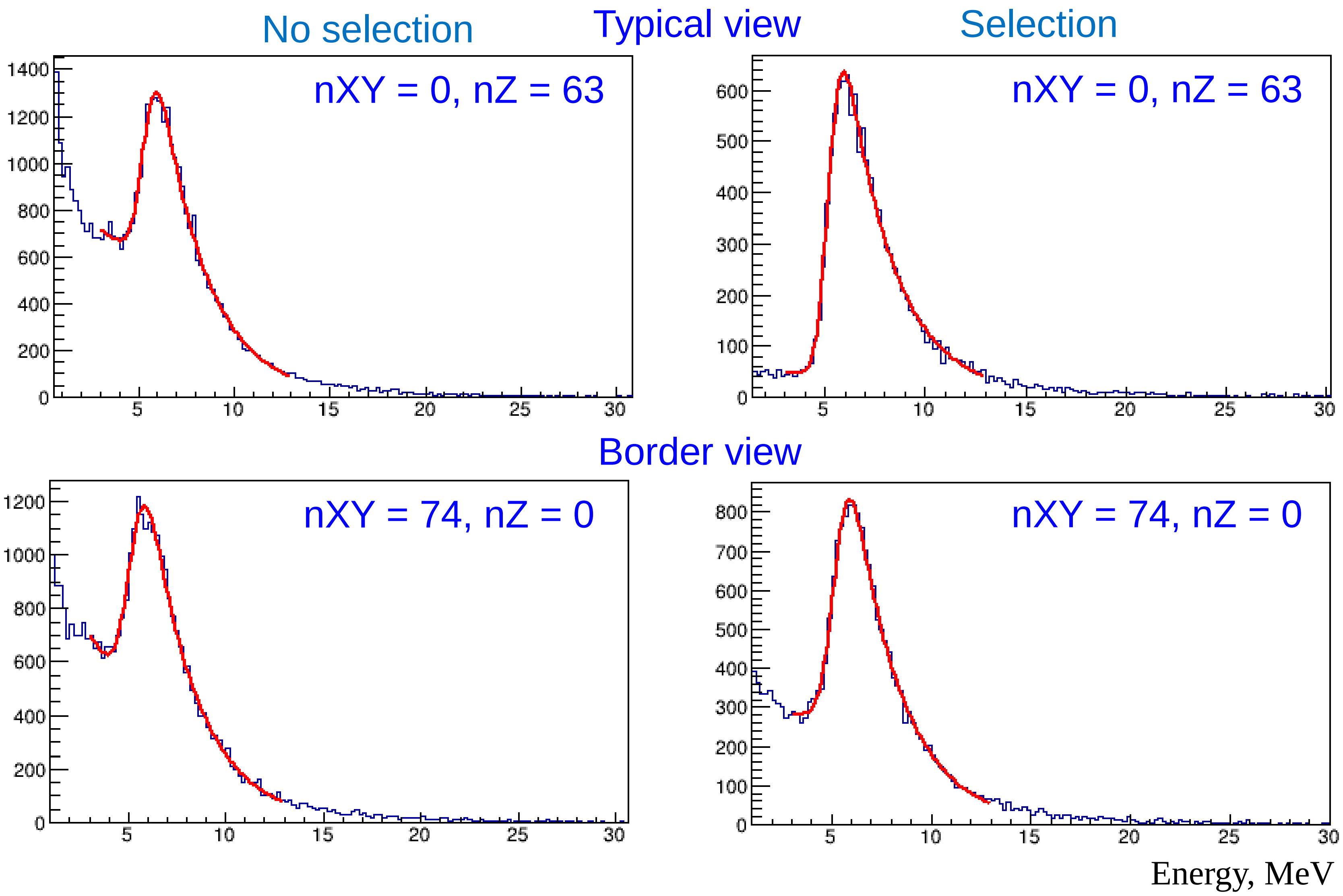


Method 2 : signal from longitudinal tracks

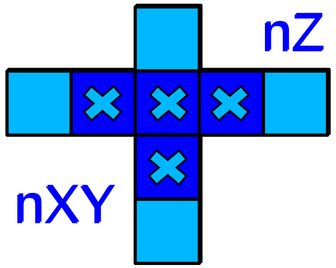


- ✓ Fast method, applicable for all tower rotation
- ✓ Energy deposition equal ~ 6 MeV, this value should be slightly depending from tower position
- ✓ Features of the applicability of this method on the full geometry of ECAL can be defined using MC calculations
- ✓ This method is used now for testing produced modules

- ✓ All muons in tower pass the same length
- ✓ Energy deposition equal ~ 60 MeV
- ✓ Method doesn't depend from tower position
- ✓ It takes too long time to collect the required statistics, possible not be applicable for highly inclined towers

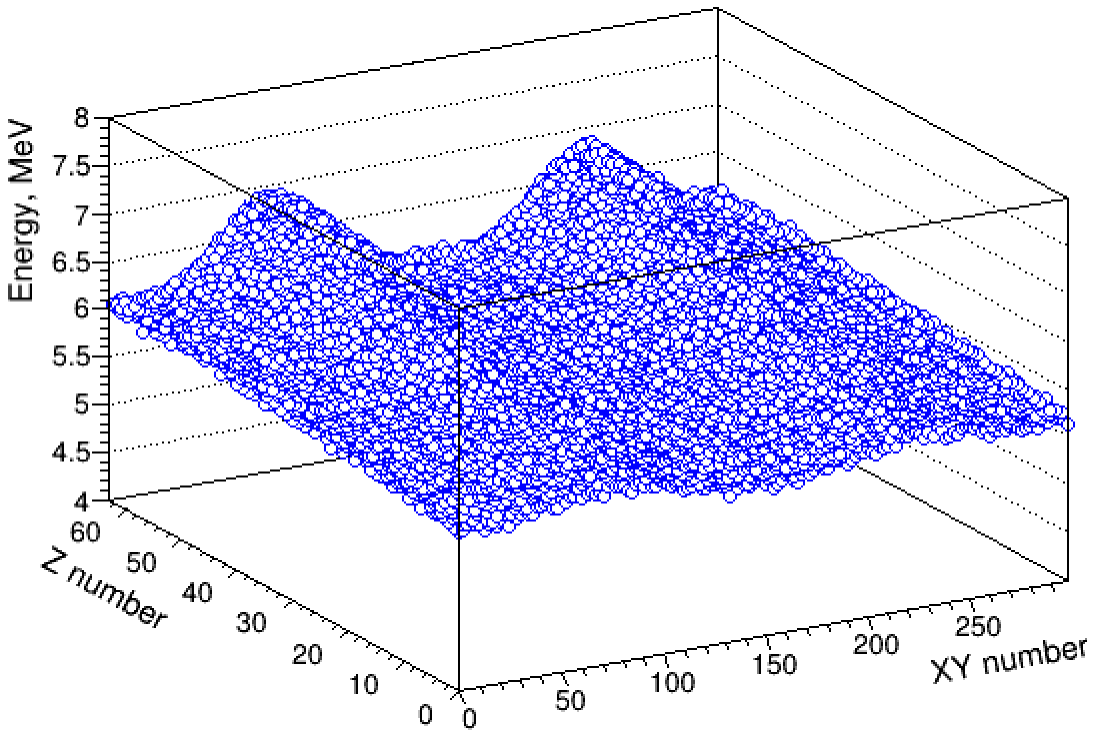


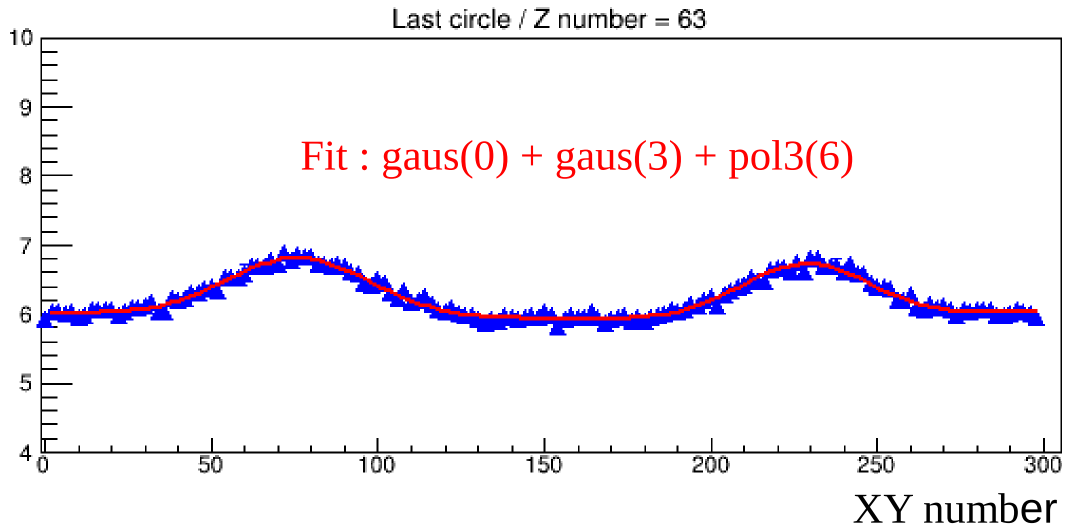
- ✓ Selection : triggered more than three, considered central (XY line and Z line are based on OR logic)

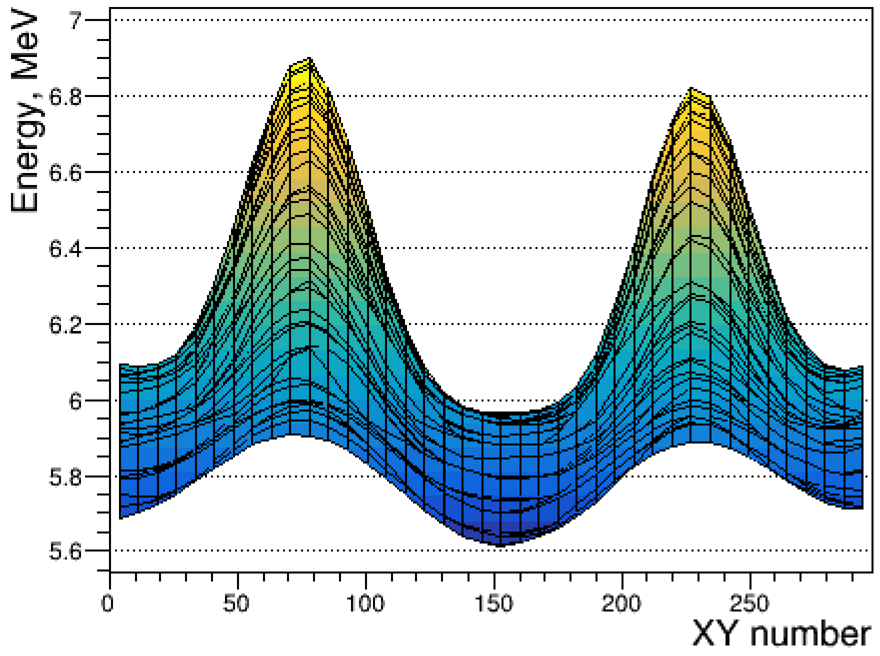


- ✓ It gives a good suppression of the low-energy background
- ✓ Border line of towers shows less background suppression, but the main peak is clearly visible due to the tower incline
- ✓ For all towers: total number of selected events : 0.9×10^8

Deposited energy vs tower position

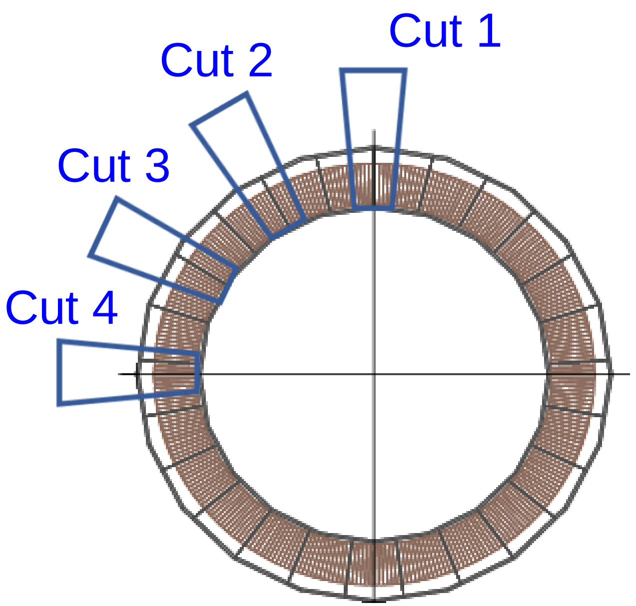


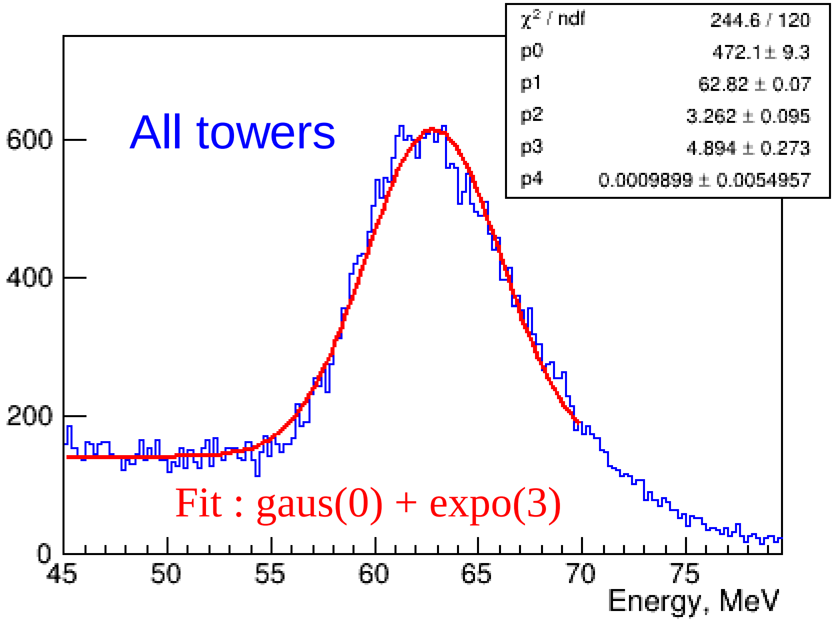


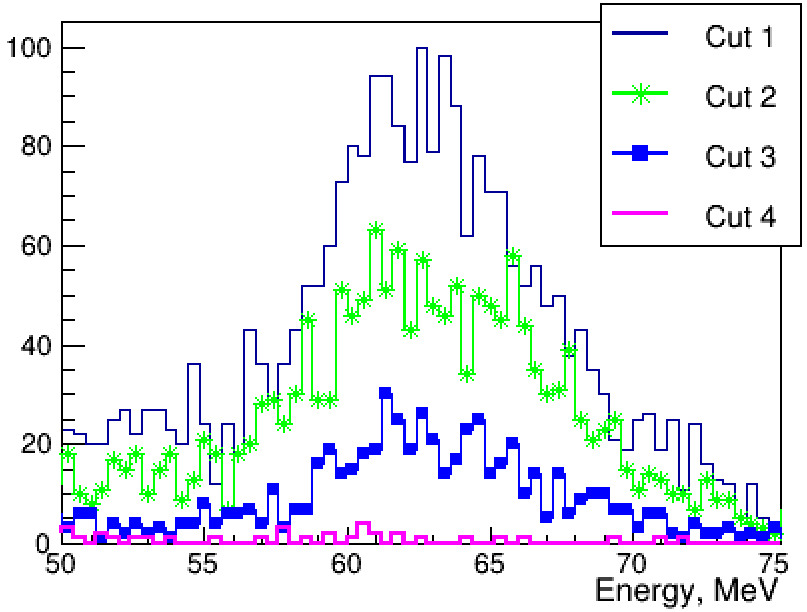


- 3Dim shows mean deposited energy versus tower position
- Dependence is not flat and can be fitted by a set of functions
- At fixed Z position every slice is described by :

  2 Gaussians + 3rd degree polynomial function
- Final result – array of the resulting functions with size equal to 64
- 3Dim profile of array looks smooth

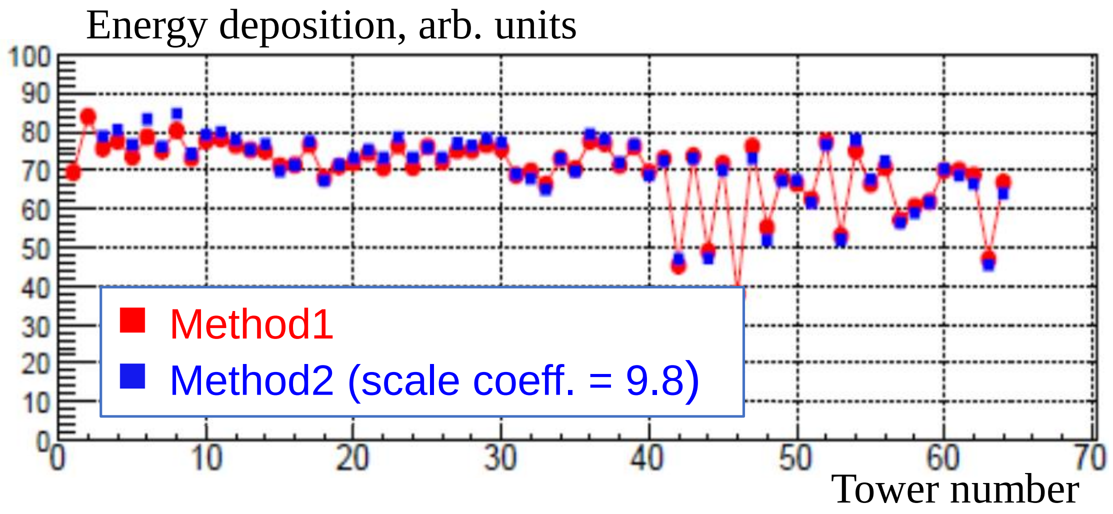


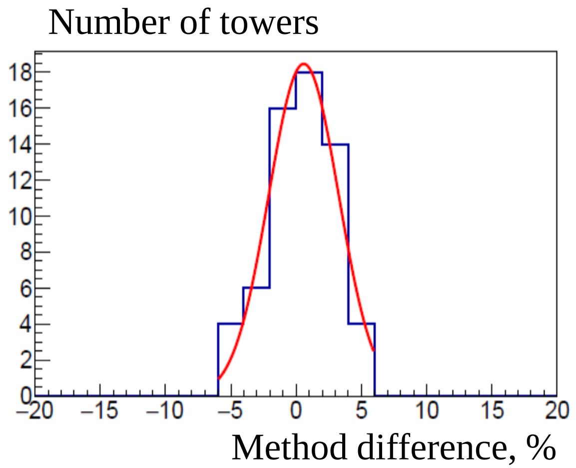




- The central tower is triggered, there is no signal in the neighboring towers
- In this case, an energy deposition should be the same for all towers in the complete ECal assembly
- Tower signal is taking into account in that case the deposited energy > 1 MeV
- For all towers: total number of selected events (sum under energy deposition peak) ~ 20×10^3
- Cut 1 – Cut 4 means different limit on XY number and all Z numbers (width equals to 10 line along Z)
- Signal is absolutely suppressed for Cut 4, that corresponds to the horizontal component of cosmic muons

Comparison of two methods (exp.data)





- ✓ Data were collected on cosmic data measurements during a long time data taking
- ✓ Experimental setup was represented by one cluster (one line : 2×64 towers) located horizontally
- ✓ Plots shows data from first 4 modules (64 towers) in the beginning of cluster
- ✓ Two peak were found and fitted by the same functions
- ✓ Positions of these two peaks show the same behavior and can be compared using definite scale factor
- ✓ Methods are in good agreement with accuracy of 2.7 %

Conclusion

- The final calorimeter assembly procedure is approaching. 83% of calorimeter is expected to be ready soon
- Next step of this activities – calibration using cosmic rays separate baskets with modules and, finally, a complete calorimeter assembly located in the MPD detector
- This report demonstrates two methods of the ECal calibration using MC data and specific generator of the cosmic rays (muons)
- For inclined muon tracks, where energy deposition energy is ~ 6 MeV, simple selection was implemented to obtain a good view of the energy deposition distribution. This method depends from tower position in the total ECal setup. Peak location as a function of the tower position is defined and described by a set of the fitted functions
- Next method, based of the registration of the longitudinal tracks, was also tested. Selection by the absence of signals in neighboring towers made it possible to identify such a peak with an average energy release in the region ~ 60 MeV
- Both method are applicable for vertical position of the towers. For inclined towers, especially at angles around 90^0, second method cannot be applied

Thank for your attention