The study of characteristics and calibration of the electromagnetic calorimeter for the NICA/MPD detector

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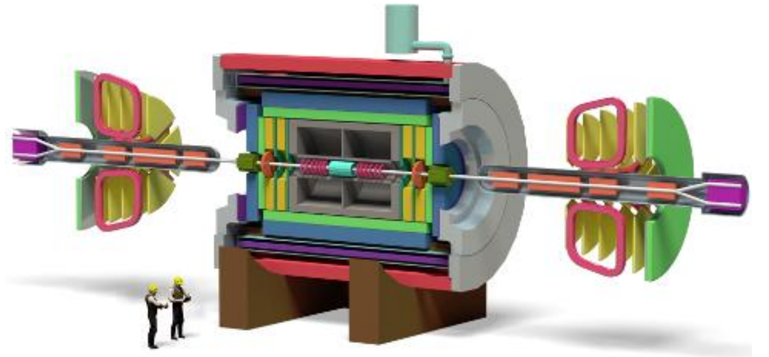
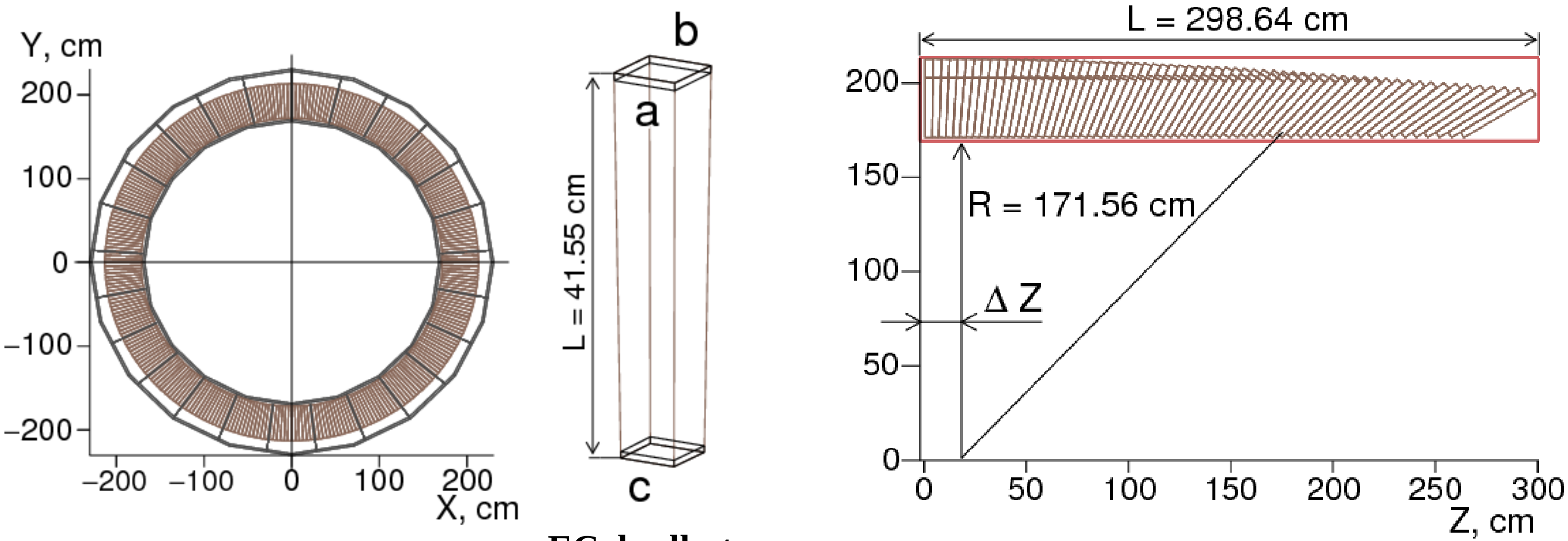
Project summary



- ✓ The main aim of is to prepare for testing, calibration and studying the characteristics of the ECal modules, as well as the beginning of these measurements
- ✓ Project has joined three institutes (JINR, LPI , ITEP) and included 9 members
- ✓ LPI has a unique S – 25R «Pakhra» electron synchrotron, which can gives us both electron conversion beam (in operation from 2020) and extracted beam, a good tools to test calorimeter modules. The launch of the extracted beam can increase beam energy from 300 to 500 MeV
- ✓The modernization of LPI was also supported by RFBR grant through purchase different apparatus
- ✓ New type of the calorimeter modules was tested on electron beam in the beginning of this year at LPI, new measurements are also planned soon. Data analysis and simulation are carried out at JINR and ITEP

Final ECal construction



ECal cell - tower

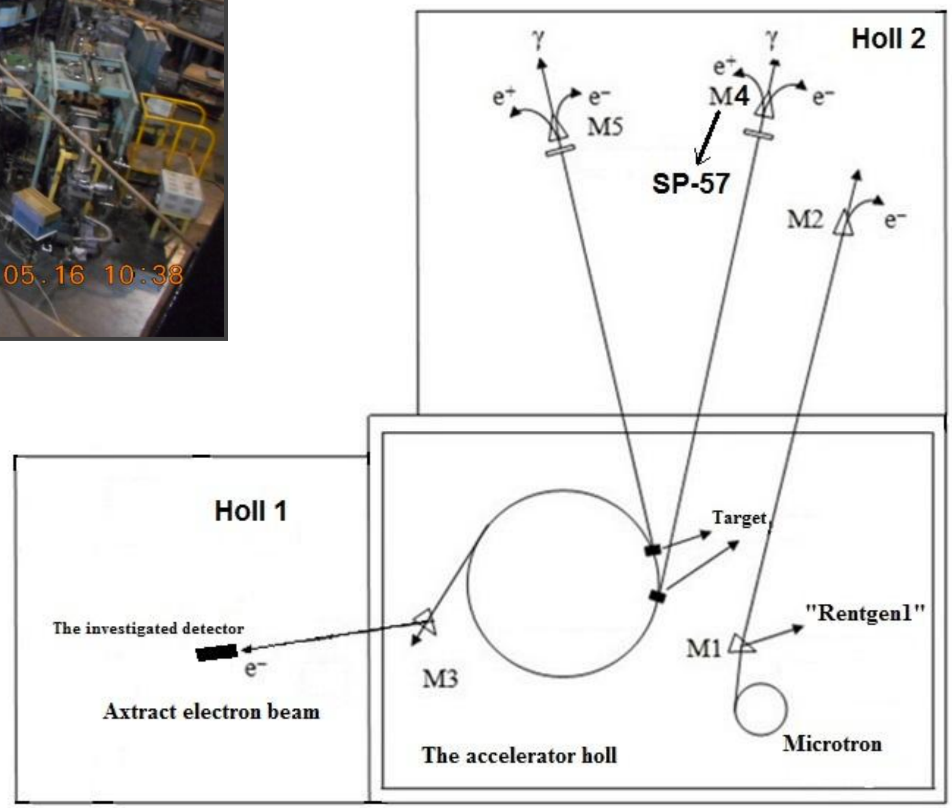
- ✓ECal geometry is close to projective, that means all cells are oriented to the NICA collider beams crossing area. ECal consists from 2400 modules of different types
- ✓ Each module consists from 16th cells (towers) fixed by the special gule (N towers = 38 400)
- ✓ Tower calorimeter has a sampling structure consisting of active medium (scintillator, width = 1.5 mm) and absorber (lead, width = 0.3 mm). Total number of such layers in cell is equal to 210.
- ✓The shapes of the towers are approximately truncated pyramids with base of 4×4 cm^2, more accurately described by a set of trapezoids (milling angle = 0.9^0 along Z and 1.2^0 in XY – plane)

Accelerator complex S-25R «Pakhra» at LPI

✓ **S – 25R «Pakhra»** parameters :

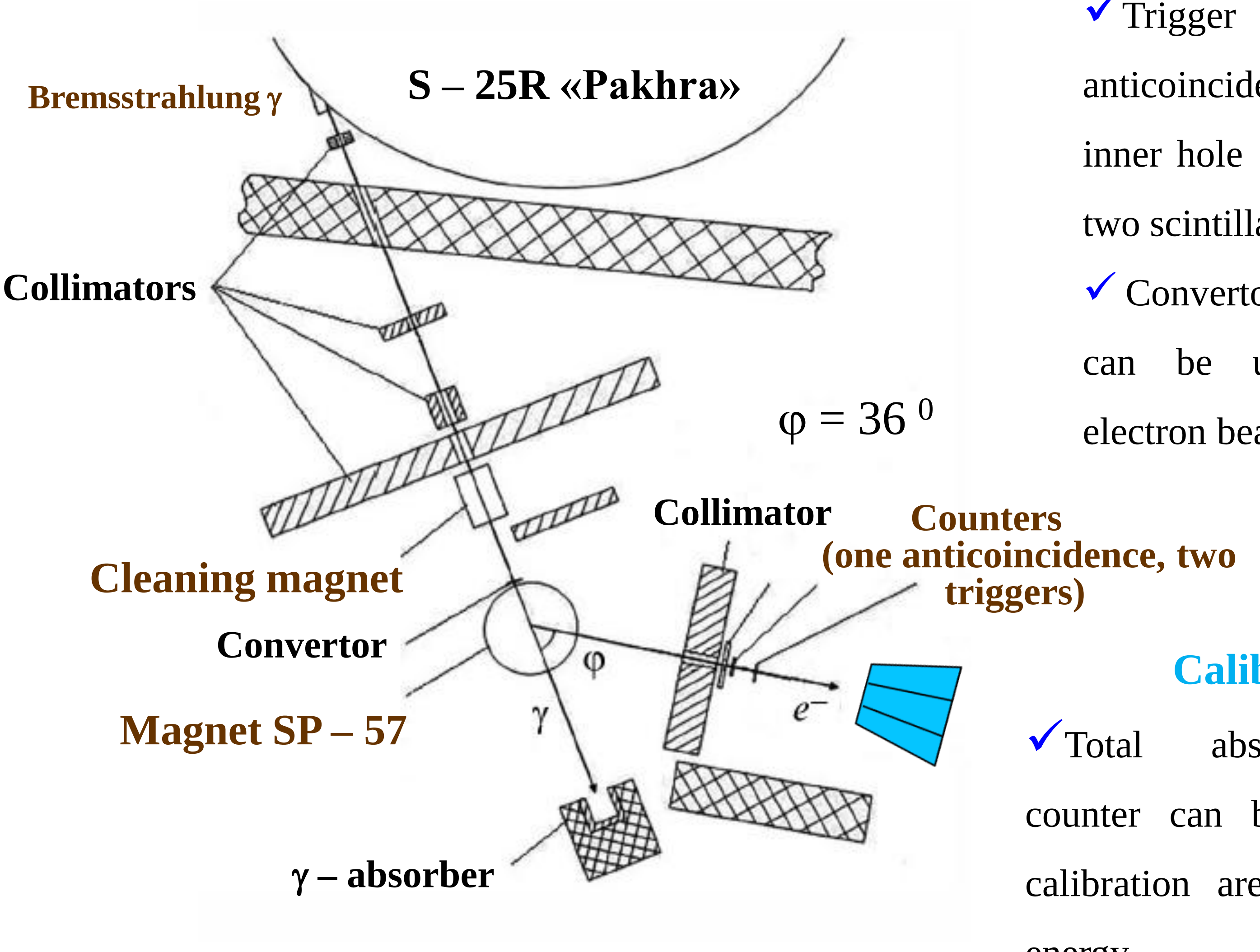
$E = 200 – 850$ MeV

$I_0 = 2 \times 10^{12}$ e^- / second



- ✓ Two calibration area are ready to test detectors
- ✓ Holl1 : extracted electron beam with energy until 500 MeV and intensity ~10^3–10^5 e^-/sec
- ✓ Holl2 : secondary electron beam with energy until 300 MeV

Secondary electron beam at «Pakhra»



- ✓ Trigger signal : one anticoincidence counter with inner hole (d = 10 mm) and two scintillation counter
- ✓ Convertor and collimator can be used to optimize electron beam

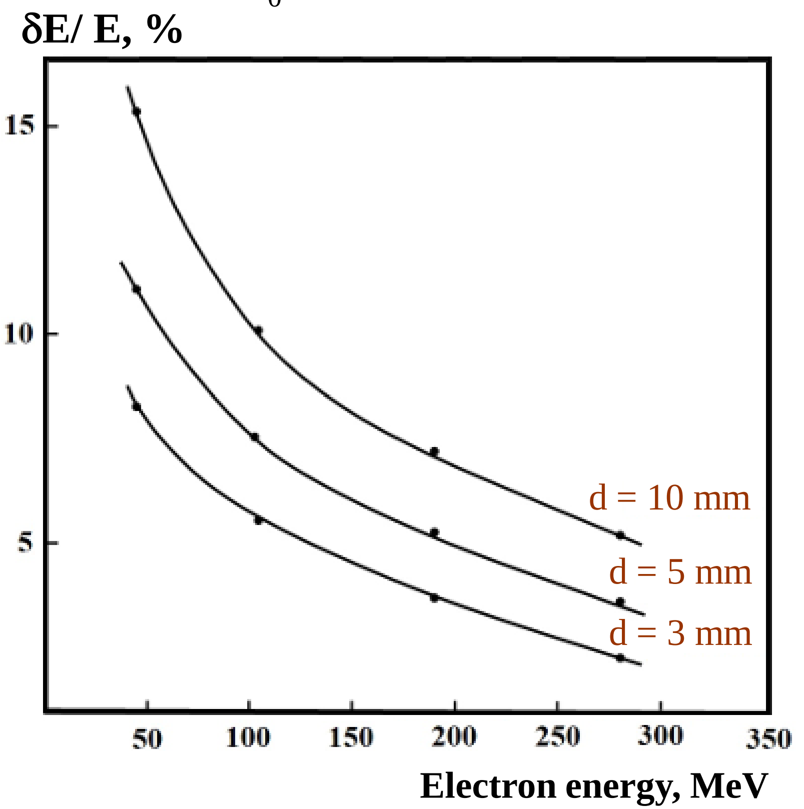
Calibration area

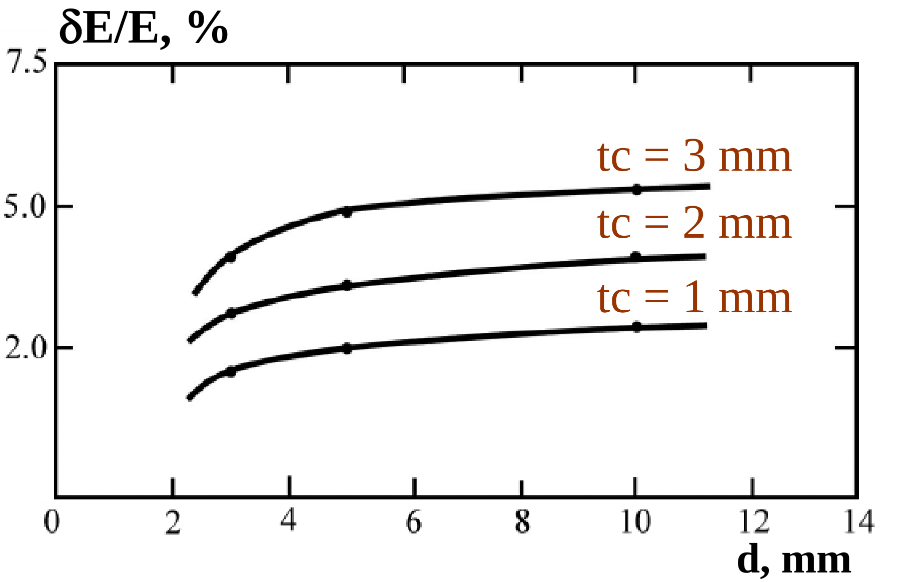
- ✓ Total absorption Cherenkov counter can be positioned in the calibration area to define electron energy

Calibration electron beam resolution

- ✓ Beam energy resolution depends from collimator diameter (d) and convertor thickness (tc)
- ✓ Electron beam was optimized at d = 5mm and tc = 1 mm with intensity :

$I_0 \sim 10\ e^- /$ second





Calibration beam energies

Beam energy, MeV	Energy resolution , %
30	13.8
54	11.0
98	7.5
150	6.3
196	5.4
293	3.4

High intensity beam modernization

- ✓In 2019-2020, the modernization of the slow extraction system and transportation of the high intensity electron beam was performed
- ✓ Main purpose : electron energy should be increased to 500 MeV with possibility to change the beam intensity till ~10^3–10^5 e^-/sec and beam resolution ~ 1%
- ✓ During the commissioning of the high-intensity electron beam, the water cooling system was put into operation and the elements of the electronic control system for the magnets were replaced. Using the video monitoring technique, an electron beam with an energy of 300 MeV was sequentially passed through all elements of the magneto-optical channel to the calibration area
- ✓ Additional collimators were produced to reduce beam intensity. Special coordinate platform, which can move till 100 kg in different position, is ready
- ✓For the stable operation of the «Pakhra» accelerator, a MI-456A magnetron manufactured in the factory «Phasa» (Rostov, Russia) was purchased for the grant as well as other different apparatus (pulse generators, oscillographs, power supplies, etc.)

Cosmic ray generator (muons)

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

✓ Cosmic ray flux at sea level has $\cos^{N-1}$ dependence, where N – power of the energy distribution [*P. Shukla, Int.J.Mod.Phys. A33 (2018) no.30, 1850175*]

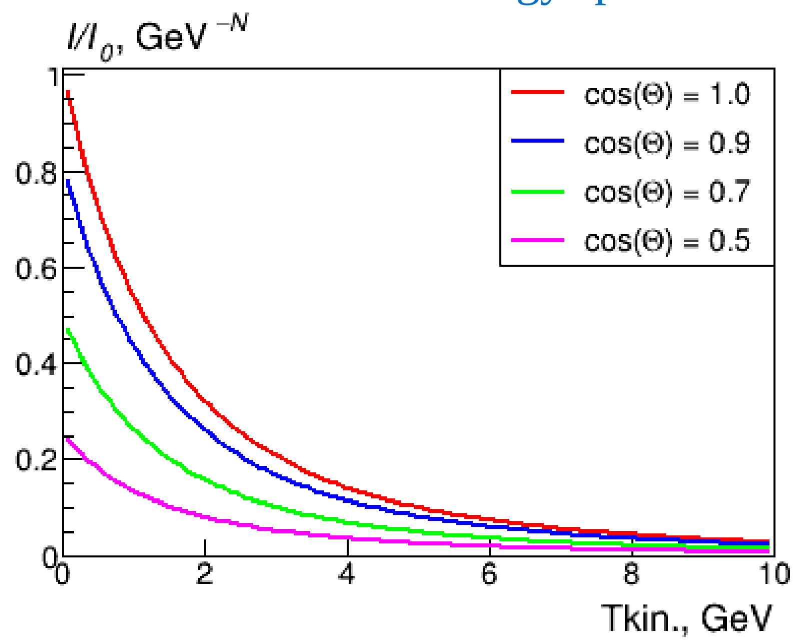
$$I / I_0 = (E_0 + E)^{-N} \times \cos^{N-1}\Theta / (1 + E/854);$$
$$E_0 = 4.29, N = 3.01$$

✓ cos Θ – zenith angle, E – energy;

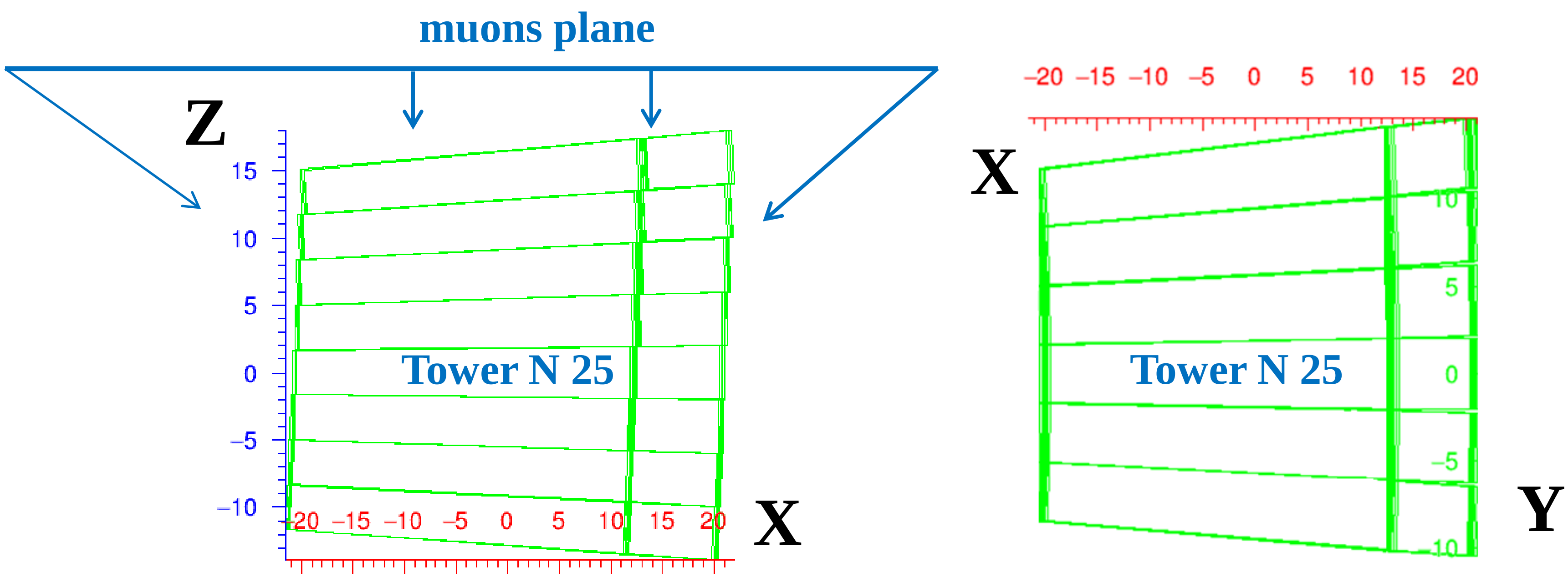
this formula is valid for muons, not for proton part

✓ Generator was developed in the framework of MpdRoot, where muons are produced as function of energy (0 – 10 GeV) and zenith angle

Cosmic muons energy spectra



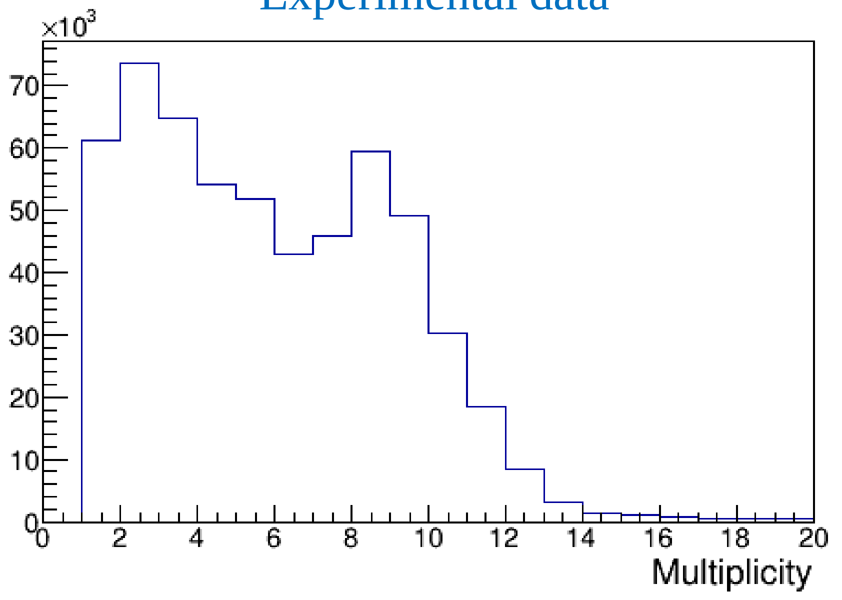
MC muons production

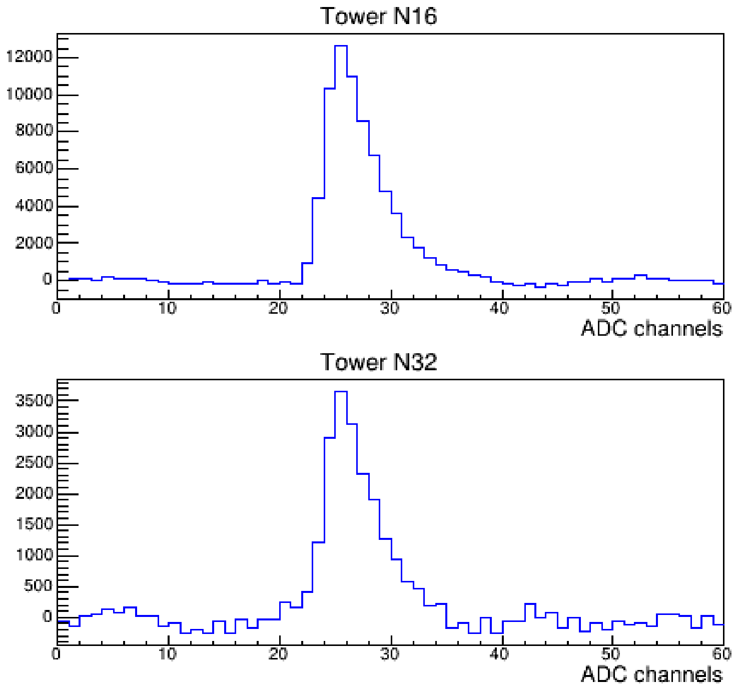


- Geometry of one module of the first type (emcModule0) is extracted from file emc_v3.root directly to add in the mpdroot frame (only this detector)
- Three module were joined to the assembly (48 towers, 6 in YZ) × 8 in XZ), as for experimental data
- Comic muons are generated from large plane at Z_0 = 20 cm in all directions, selected only particles passing detector area

Run with cosmic muons

Experimental data



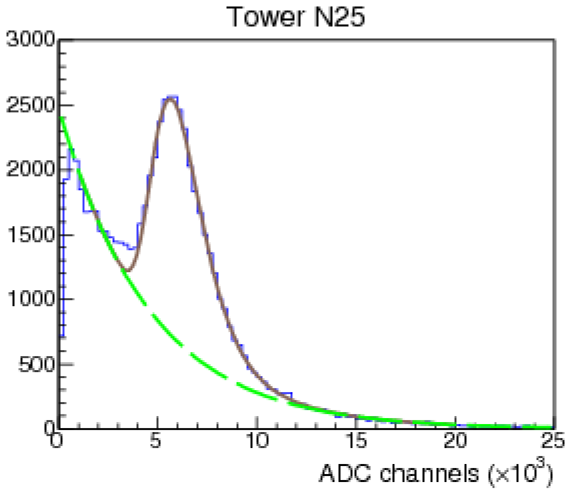


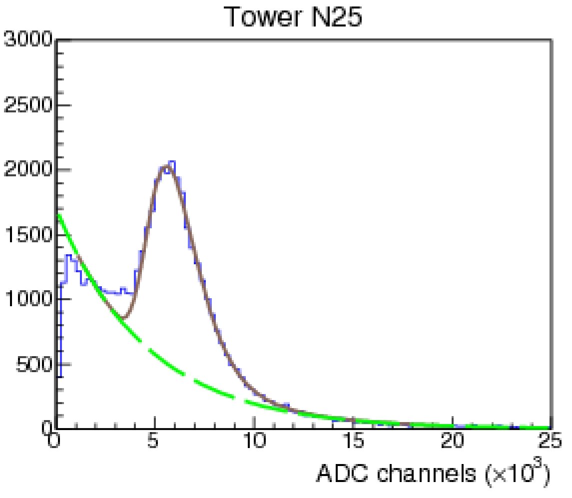
- Multiplicity of the module assembly is large number (until 15 tower / one muon).

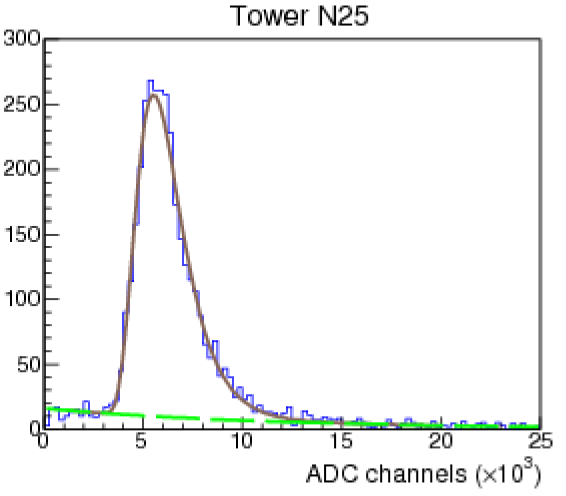
It's a good way to collect large statistics

- Signal is defined by sum from 20 to 40 ADC channel
- Background is subtracted from signal and estimated from 1 to 20 channel
- For better presentation, it's useful to add scale coefficient = 10^{-3}

Different methods to cosmic rays selection







✓ Method 1: all events, low energy part can simply describe by exponential function

✓ Method 2: multiplicity > 7, less statistics, but tail still exists

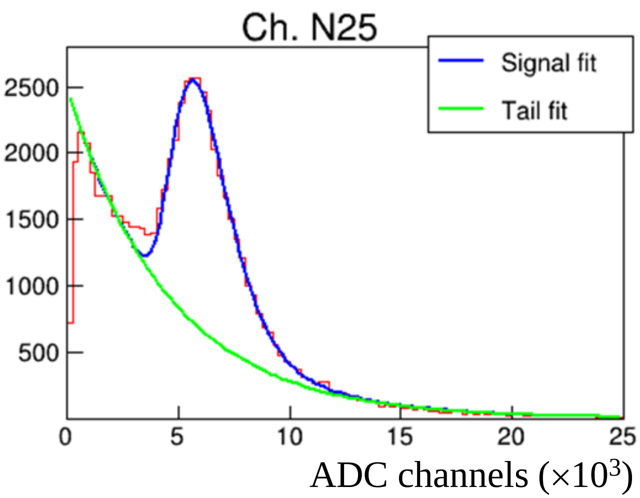
✓ Method 3: two (upper and lower towers in line give a trigger), tail is eliminated

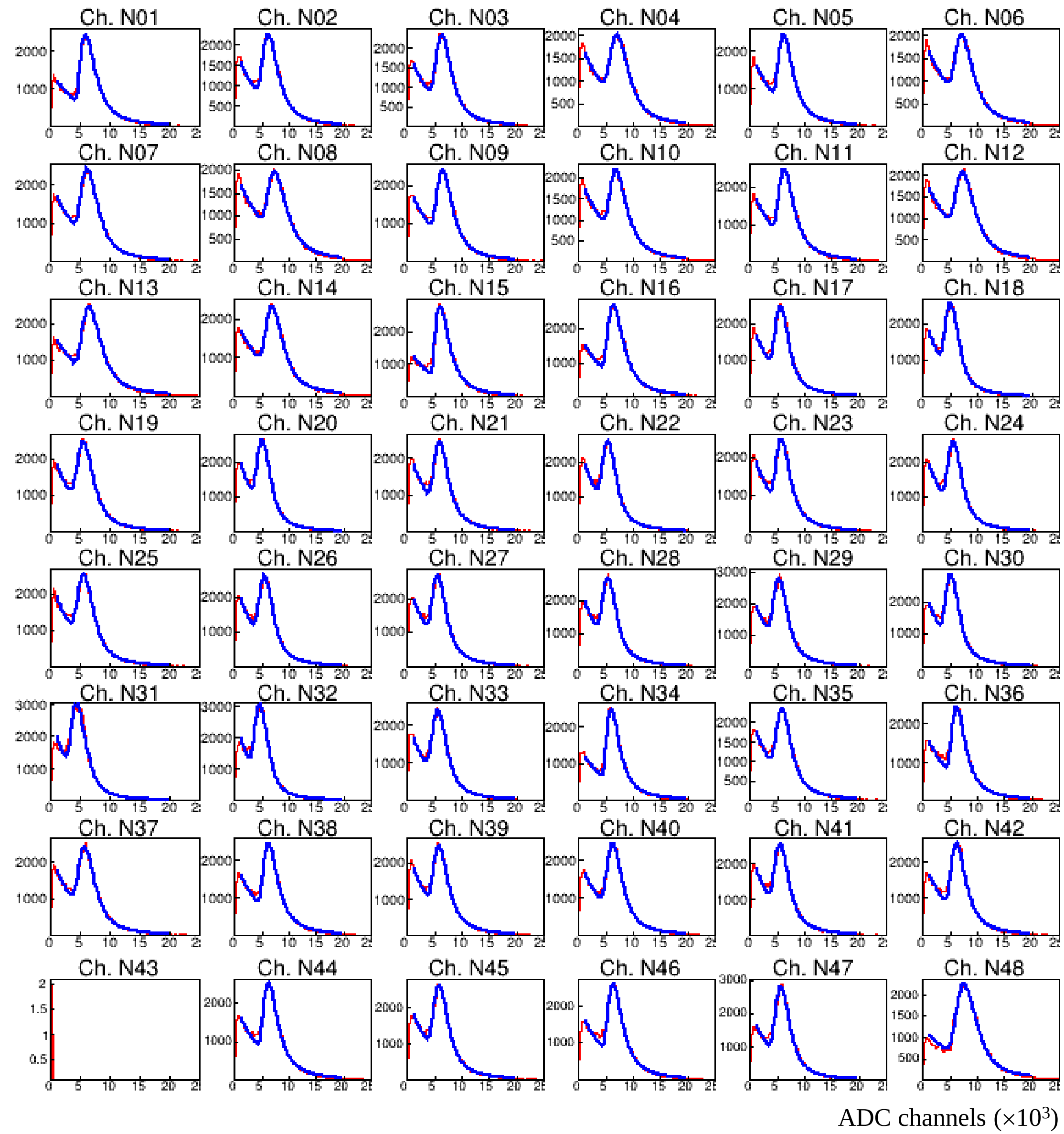
✓ Method N3 can clearly define the characteristic peak, but the final statistics are seven orders of magnitude less

✓ For future analysis we selected method N1 to have more statistics.

✓ All methods should be checked to independence of peak position vs tower location

Energy spectra fit

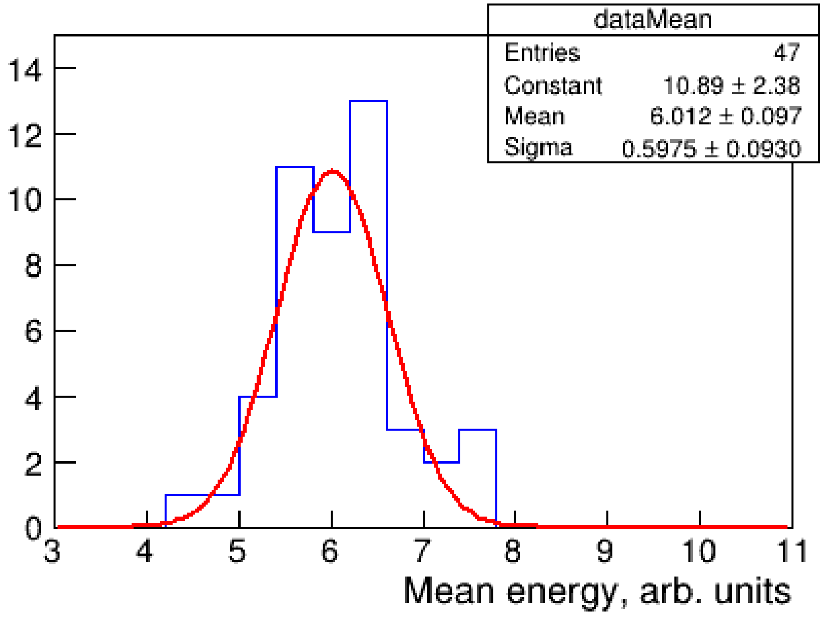


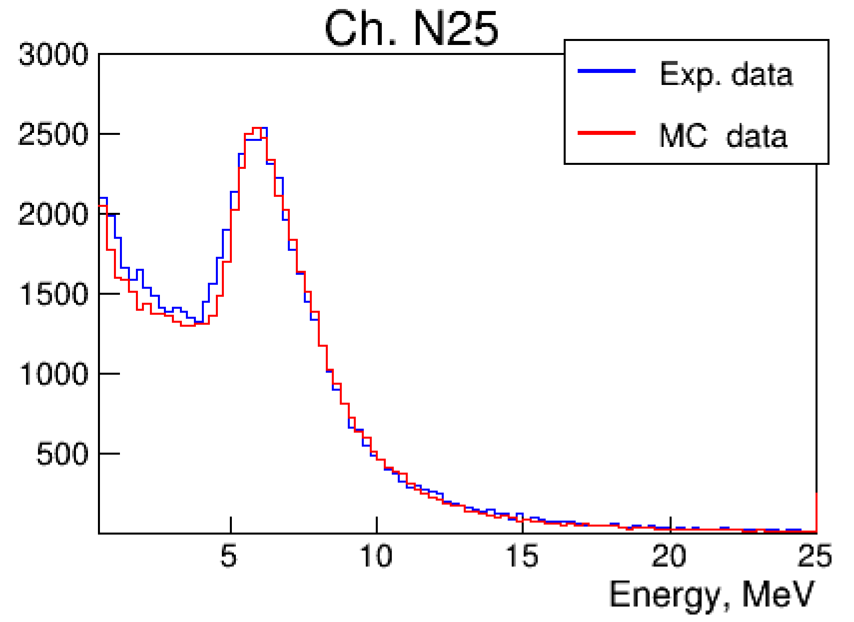


- ✓ Clear peak from muons can be a reliable tool for calibration
- ✓ Fit is a sum of two functions (signal and exponential tail)
- ✓ Signal fitting function :

$$\sim (x - x_0)^{\alpha} / x^{\beta}$$

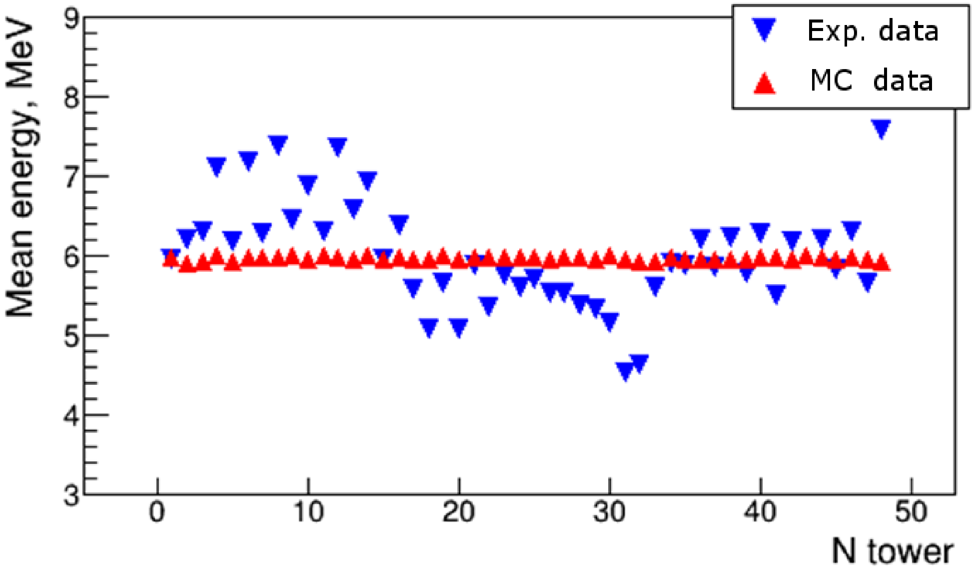
MC and experimental data comparison



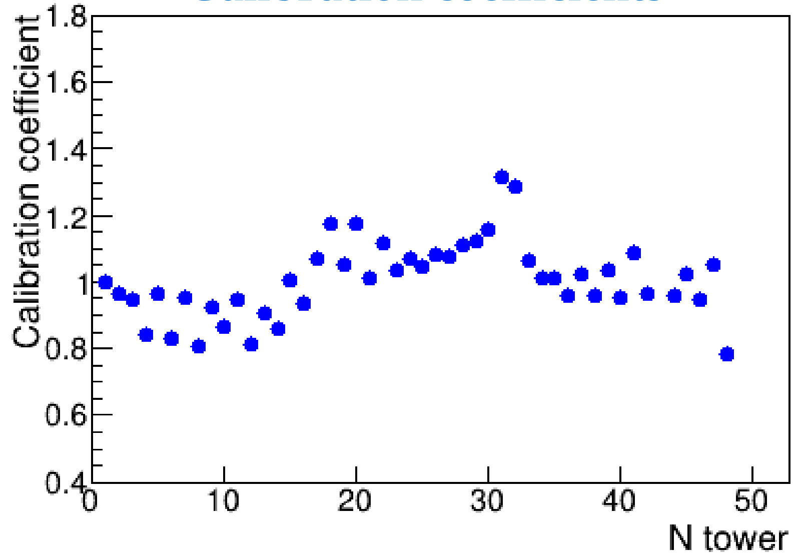


- ✓ Experimental and MC data are in a good agreement
- ✓ MC peak is stable for all 48 towers and equal to 5.95 MeV
- ✓ Experimental data are varied for different modules (each 16 towers)
- ✓ Experimental mean value (peak position) is 6.01 (first tower, arb. units) and comparison with MC gives conversion factor ~ 0.99 MeV

Results of the calibration



Calibration coefficients

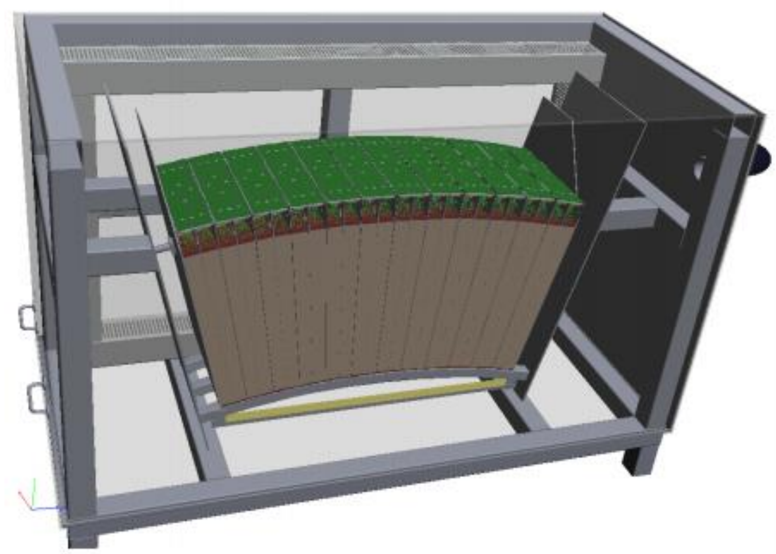


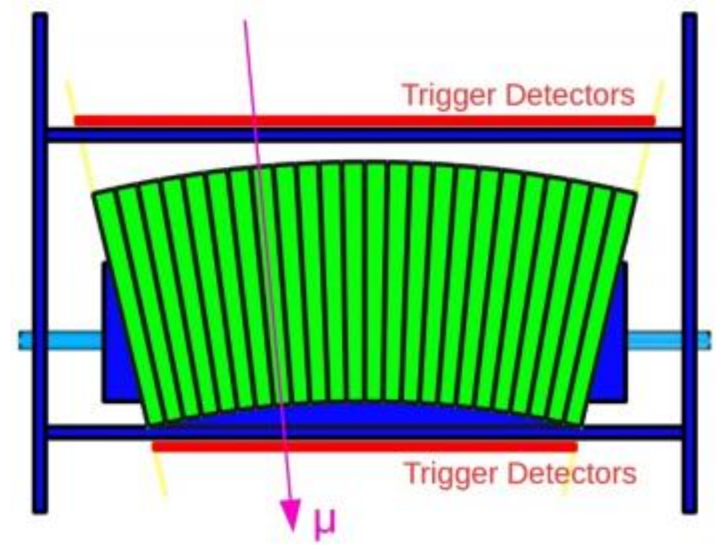
- Good method to perform a quality control of each produced tower/module
- Independence of the MC peak position from its number demonstrates a reliability of this calibration method
- It doesn't take a significant time to be done (one day/night is enough to test module)
- Calibration coefficients are defined concerning mean value, the fluctuation of this calibration coefficient ~ 10 %
- This calibration is used for further analysis to obtain electron energy

Calibration stand at JINR

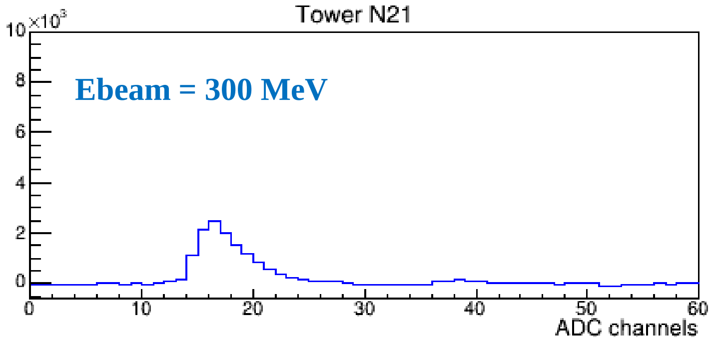
- ✓ To perform measurements a special stand was developed at JINR
- ✓ It can test simultaneously 12 modules
- ✓ External scintillation trigger detectors are selected transverse atmospheric muons
- ✓ Also «veto» signal from neighbor towers is implemented
- ✓ Experimental run on muons was carried out during 2 weeks
- ✓ That's enough to measure calibration coefficient with a statistical uncertainty less than one percent

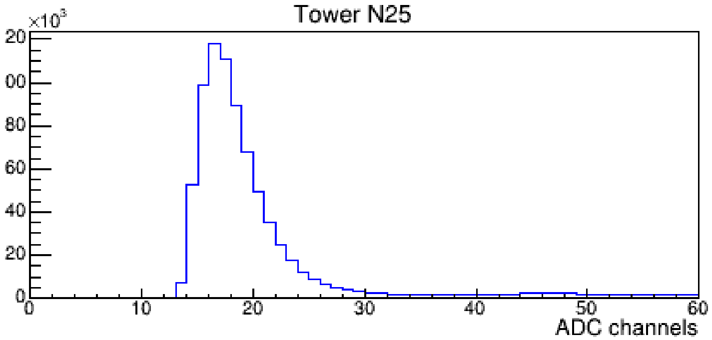
[*A. Yu. Semenov, JINST 15 (2020), C05077*]

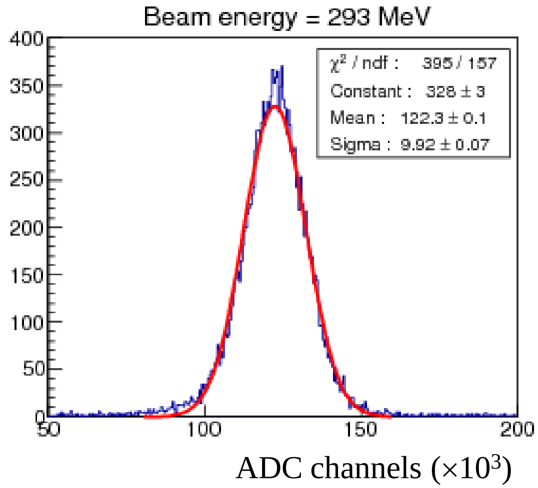




Electrons, MC and experimental data

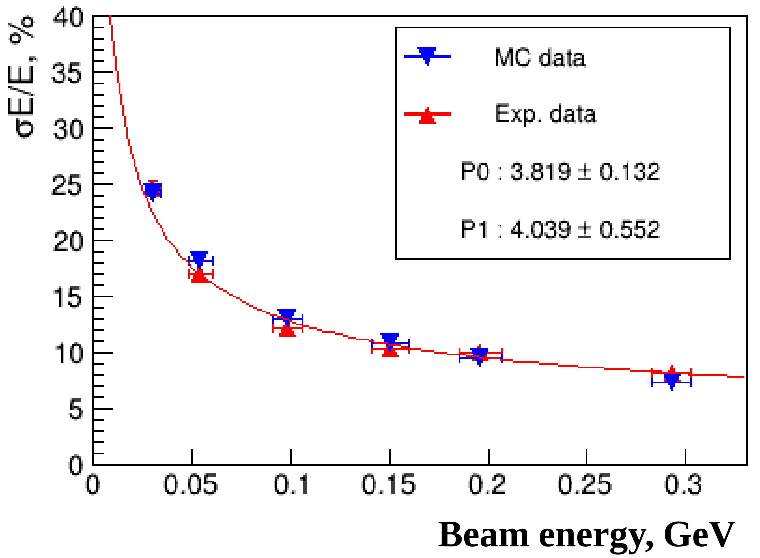


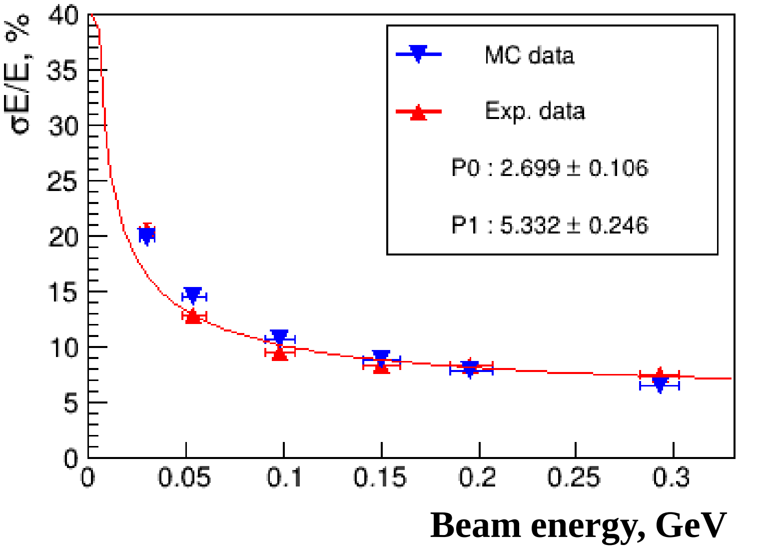




- ✓Electron beam is aimed to the center of tower N 25
- ✓MC simulation: electrons have initial position distributed uniformly by ϕ – angle with beam radius = 0.25 cm / X0 = – 30 cm
- ✓6 energies from 30 to 300 MeV are generated with beam spread calculated at LPI
- ✓ADC channels is summarized from 10 to 30 channels (signal), background is estimated from 1 to 10 channels.
- ✓ Energy deposition is defined by all towers
- ✓ Experimental peak can be simply described by the Gaussian function
- ✓Two calibration coefficients: each tower is calibrating by cosmic rays data and energy scaling coefficient

Electron beam (MC and experimental data)





✓ Measured energy resolution (with beam spread)

✓ Energy resolution (beam spread subtracted for exp. data, MC – zero beam spread)

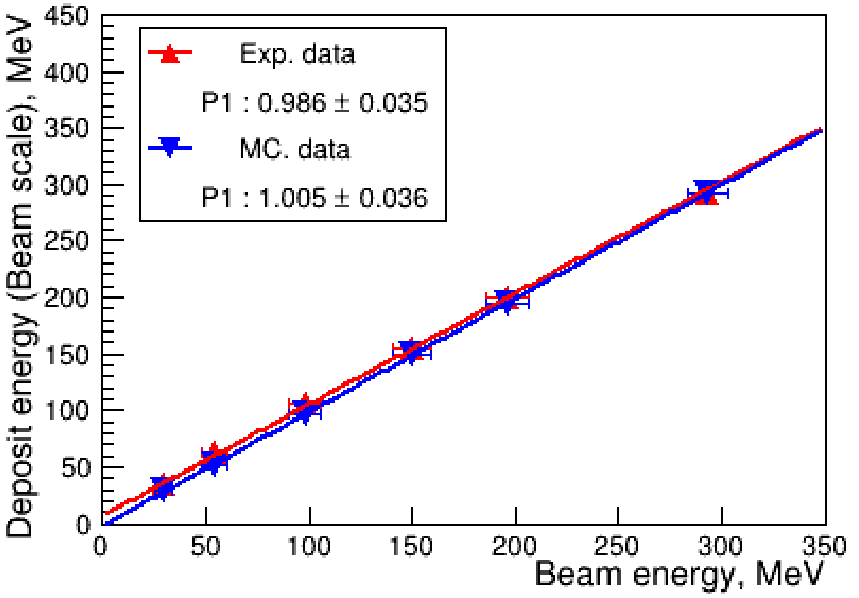
✓ The simulation also included beam energy spread ~ 10% for 54 MeV and ~3.4 % for 293 MeV

✓ Simulated and experimental data are in a agreement within about ~ 5÷ 6 %

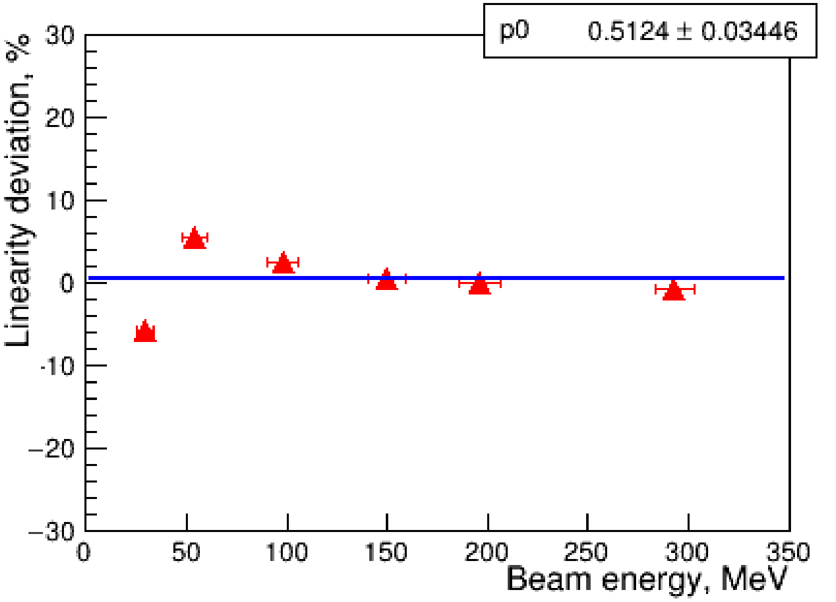
✓ The difference can be explain by following reason: 1) small uncertainties in material and module geometry; 2) Beam shape (we used the Gaussian shape for MC) and sufficient beam resolution

Calorimeter linearity

ECal linearity



Deviation from linearity



- ✓Calorimeter linearity is estimated with respect to the largest beam energy (293 MeV)
- ✓ Linearity is observed well for MC data, but for experimental data there is a deviation and scale coefficient is less than unity
- ✓Despite this, the linearity coefficients are consistent within errors limits
- ✓ Any reasons, that can change linearity for experimental data :

1) Uncertainty of the beam energy (~ 10 % of beam energy at 54 MeV) ; 2) Shower leaks from calorimeter assembly; 3)In general, light loss in tower fibers, this effect is larger for low energy electromagnetic shower

Conclusion and future plans

- ✓A significant number of the modules (~ 250) are in the process of production on the factory «Tensor» at Dubna (Russia)
- ✓The extracted electron beam at S – 25R «Pakhra» (LPI, Troitsk division) with energies until 500 MeV will be launched to study characteristics and calibration of the produced calorimeter modules. Addition calibration area is prepared for shifters during the calibration of equipment and detectors.
- ✓Calibration of the new produced modules will be carried out on cosmics to perform test quality, and limited number of modules – on electron LPI beam to measure a preliminary calibration characteristics
- ✓ MC simulation and test strategy are ready. MC and experimental data demonstrate a good agreement, but need additional adjustments
- ✓Development of methods for separation neutrons and photons in the ECal using the time features of electromagnetic and hadron showers