Simulation of the electromagnetic calorimeter of the MPD detector and related tasks of the physical program of the NICA project.

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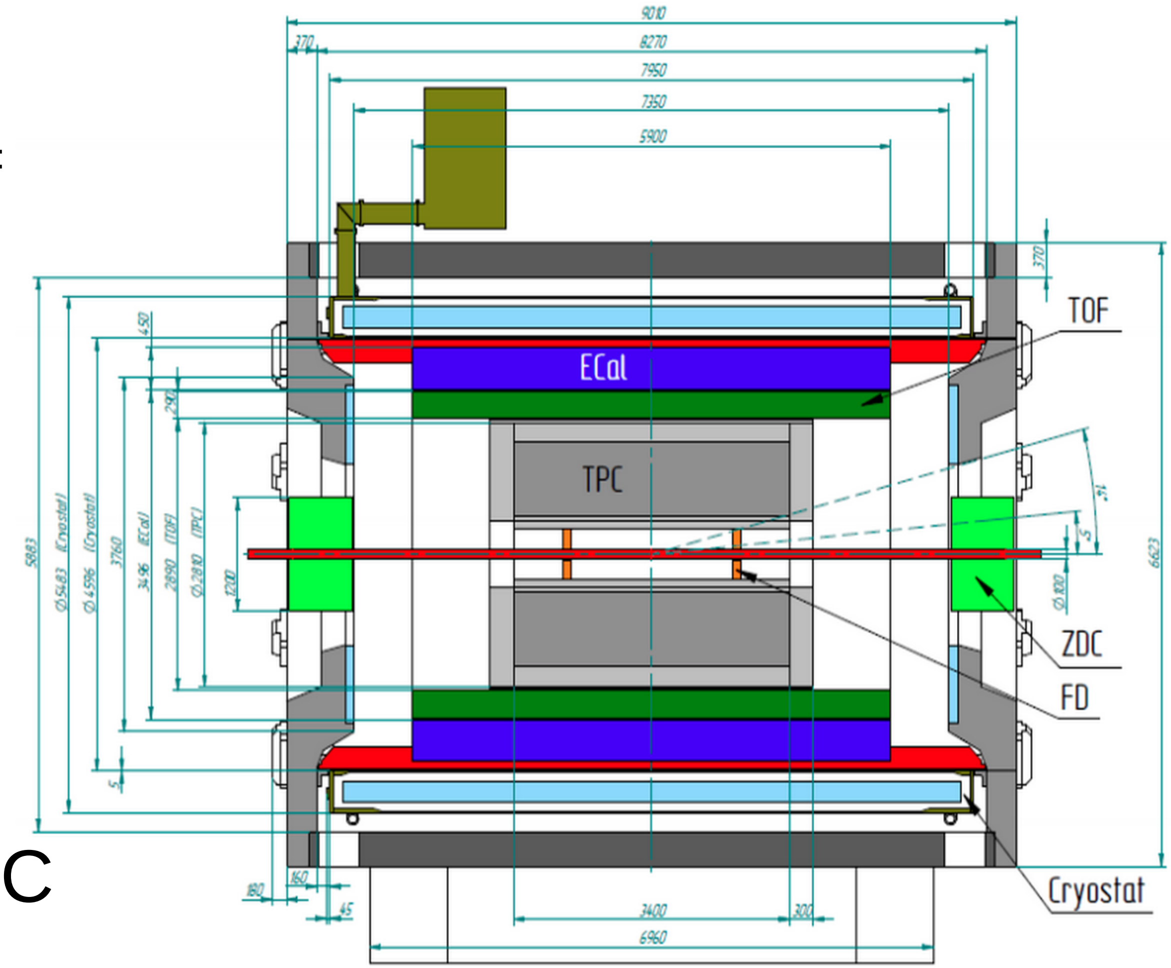
Report outline

- ECal short overview
- Geometry simulation
- Power frame simulation
- Influence of passive materials
- ECal main characteristics
- Comparison with test measurements
- Test of the ECal time characteristics
- First steps in ECal time response simulation
- Conclusions

MPD detector

ECAL(barrel)

Rin = 1.72 m, Rout = 2.21 m, L = 6 m
# Towers =38400
Shashlyk type PbSc
Weight = 60 tons.
Power frame in ECal volume ~ 10 ton of Carbon fiber with support for TOF,TPC
ITEP contribution- ECal **MC simulation**



Production of ECal modules and Power frame are in progress.

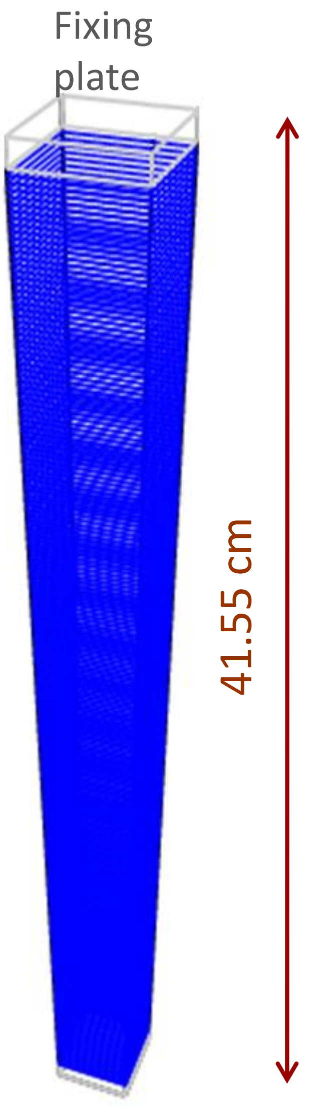
ECal tower

- "Shashlyk" technology
- Total number of towers : 38400
- Each tower has 210 lead (h = 0.3 mm) and 211 scintillation plates (FscScint – C_9H_{10}, h = 1.5 mm)
- Each lead plate is coating of the TiO_2 paint (h = 0.05 mm) with parameters:

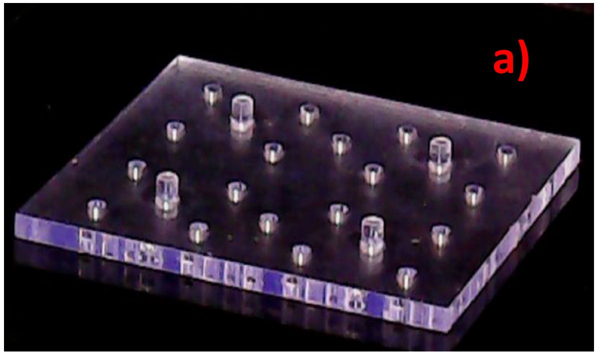
H (2.9 %) + C (17.2 %) + Ti (41.1 %) + O (38.9 %)

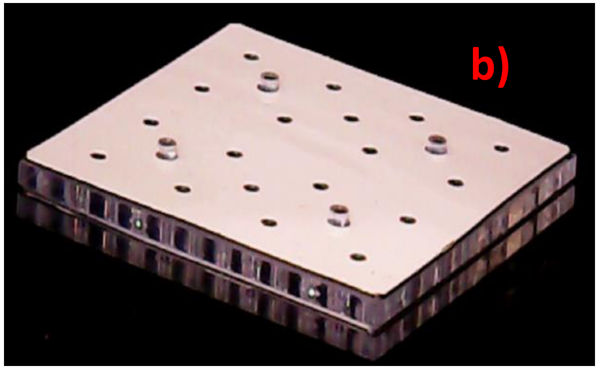
ρ = 1.18 g/cm^3, X_0 = 20.49 cm

- Tower is fixed by two plates on top and bottom (Kapton, h = 8 mm, $N_2C_{22}H_{10}O_5$, ρ = 1.42 g/cm^3, X_0 = 28.4 cm)
- Tower shape is described by the GEANT4 class TGeoArb8 – arbitrary trapezoid with 2×4 vertices. There are 64 types of the towers and up to 3 trapezoids is needed to describe one tower.
- Towers give a main contribution to number of the GEANT4 elements; total number of nodes ~ 16×10^6



Main tower elements – Lego plates

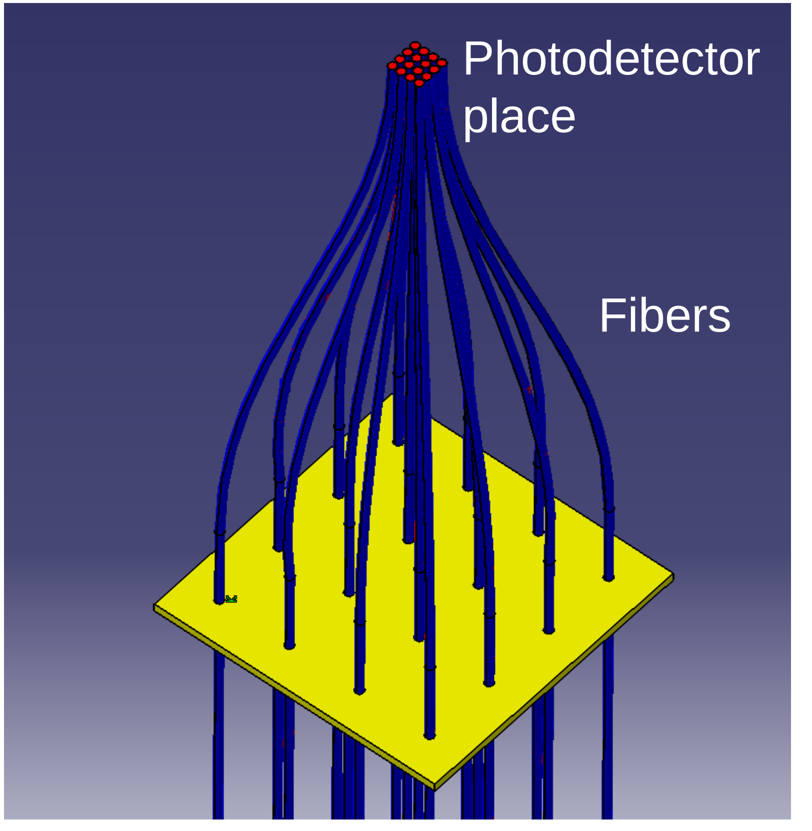




a) 40x40x1.5 mm^3 scintillator with 4 lego pins + 16 holes for Ø 1.2 mm WLS + 2 holes for Ø 1 mm fixing strings;

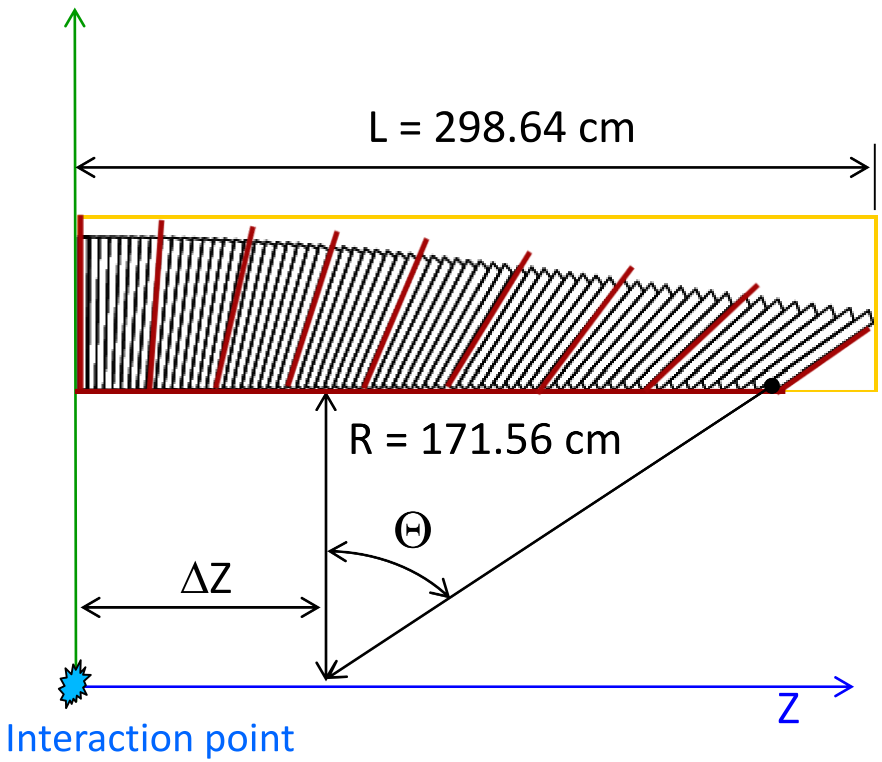
b) 0.3 mm white painted Pb plate added

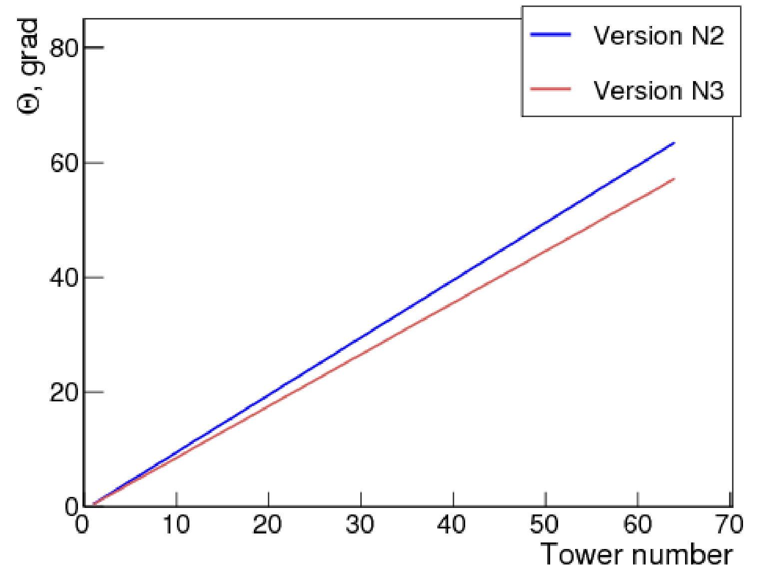
Photodetector - MPPC Hamamatsu S13360-6025PE 6x6 mm^2 (240x240 = 57600 cells)

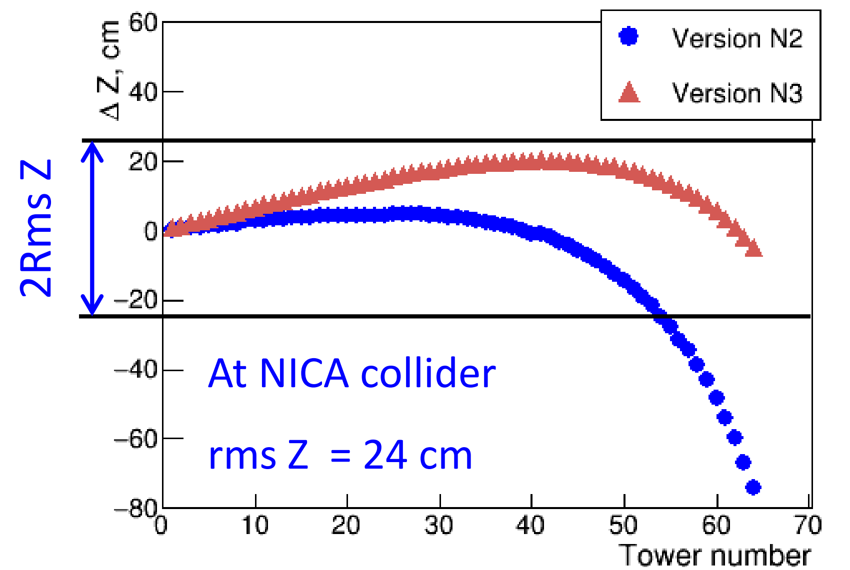


WLS fibers -
double clad Kuraray Y-11(200)

Projective geometry



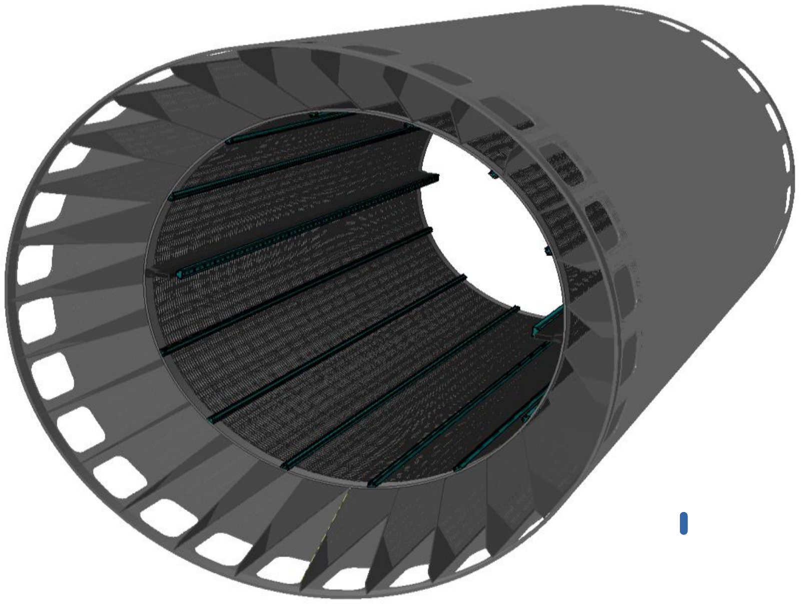




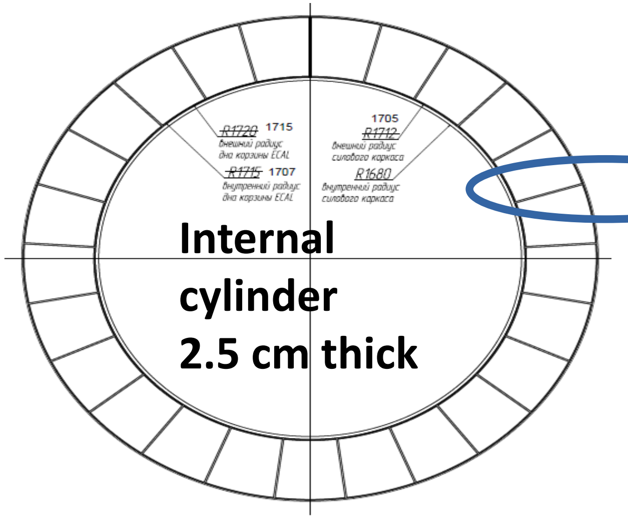
- ✓ Modules are combined from 2×8 towers
- ✓ 64 different towers are placed along Z – axis at different Θ - angles with a step of 0.9 degrees, fixed to simplify production

Frame and baskets

Material carbon fiber

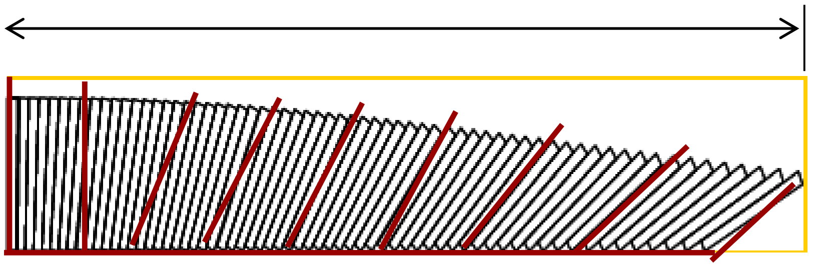


25 Sectors for 2x25 Baskets



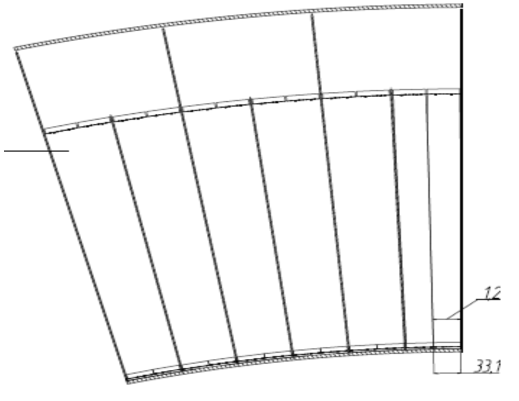
Walls 1 cm thick

L = 298.64 cm



Basket bottom 8, walls 5 and 2 mm thick

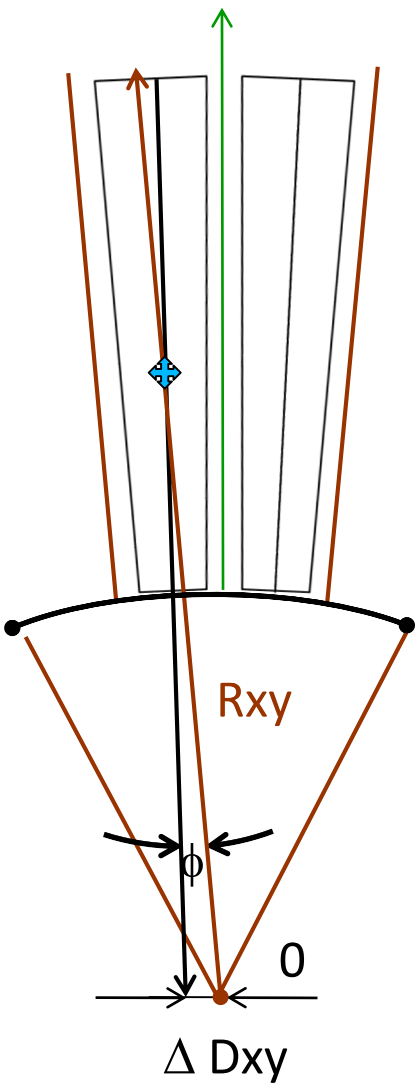
Material fiberglass

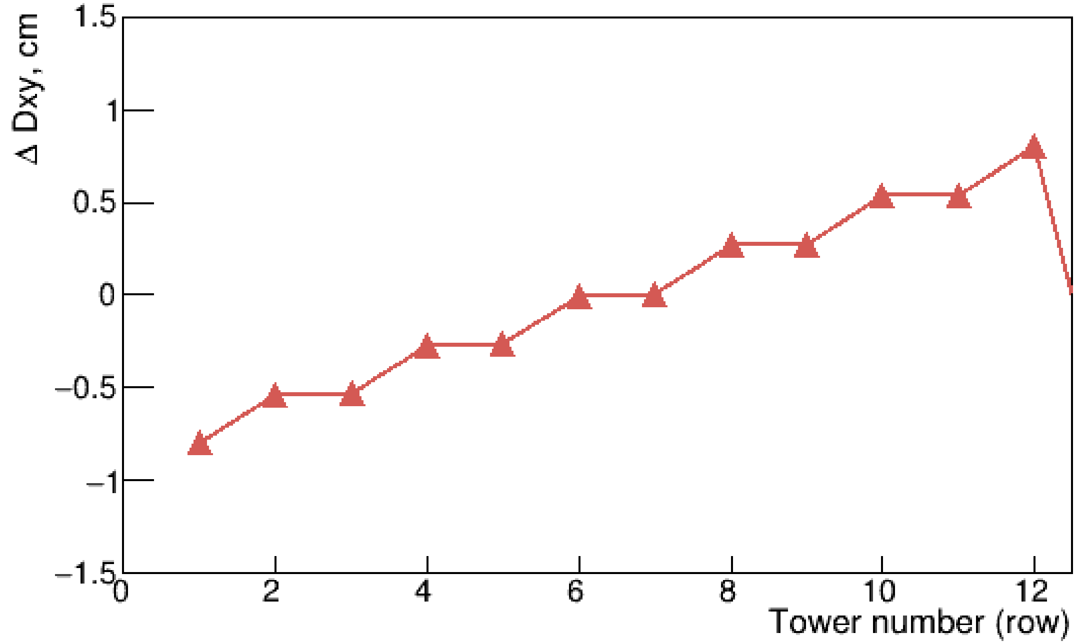


Walls 2 mm thick

Basket for 8x6 Modules (1 ton)

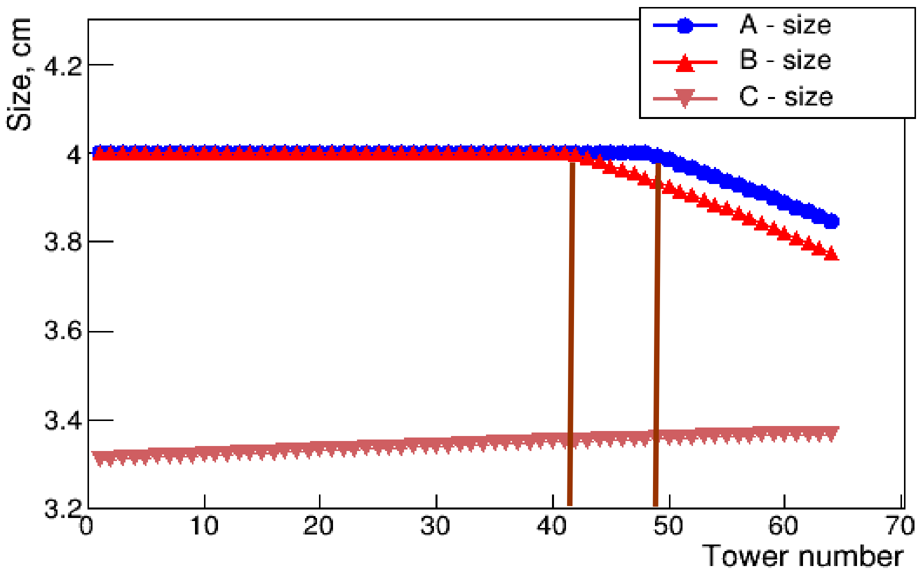
Towers of one basket in XY-plane

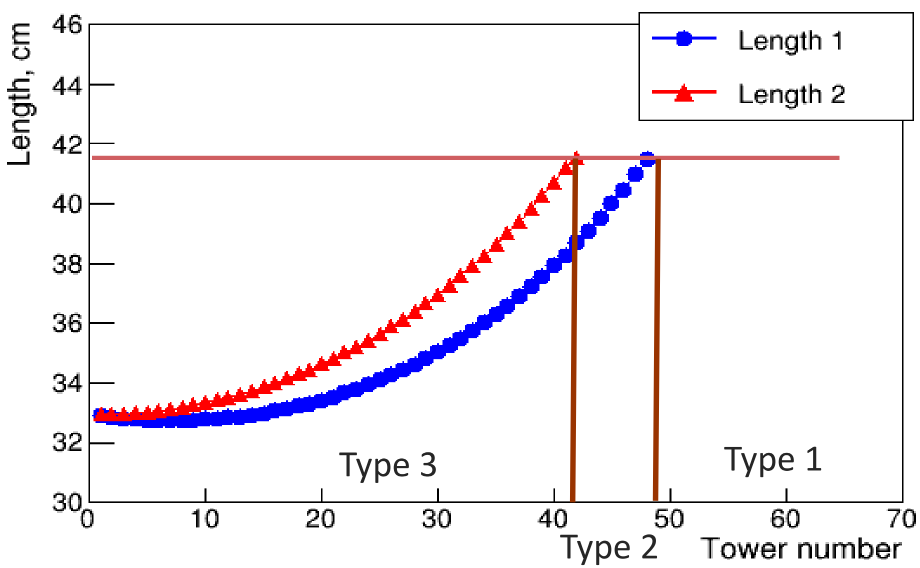


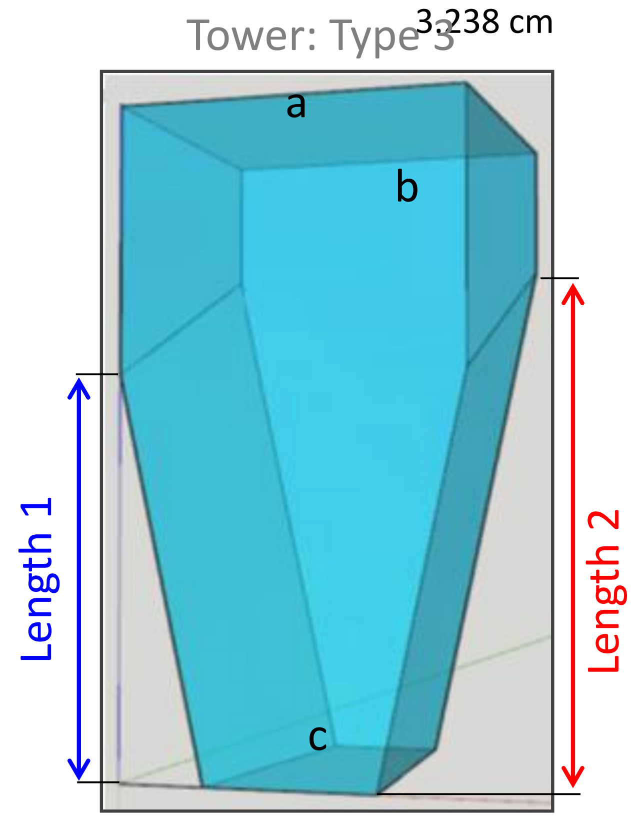


- Generally, the ECal geometry was planned to be a projective, but small asymmetry for towers position in XY plane is presented
- Displacement of towers in XY plane can be estimated by formula : Δ Dxy = $\phi \times$ Rxy (Rxy – radius of the tower center)

Tower parameters



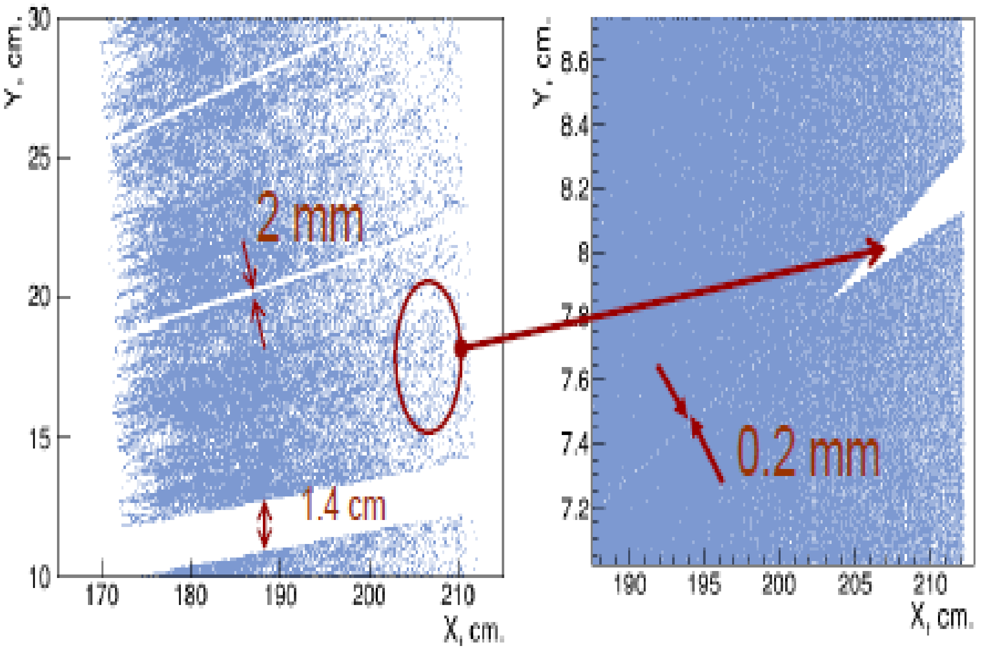




- ✓ A, B and C parameters are calculated precisely on a basis of two milling angles
- ✓ Three trapezoids : towers 1 ÷ 41; two trapezoids : towers 42 ÷ 48; one trapezoid : towers 49 ÷ 64

Test of the simulation program

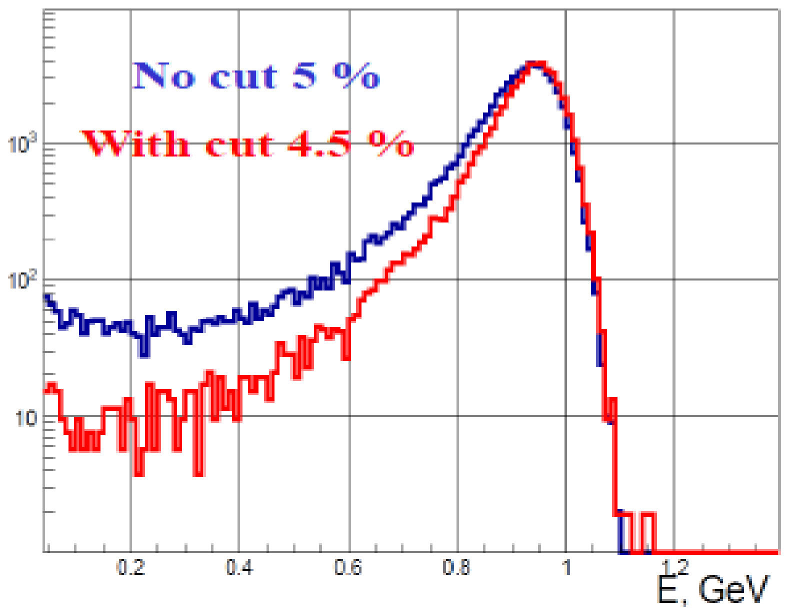
Test on the simulated photons. 1 cm frame wall and 2 mm walls of the basket are clearly seen.
At the greater statistical sample the features of the space between the towers in the module can be traced at sub mm level.



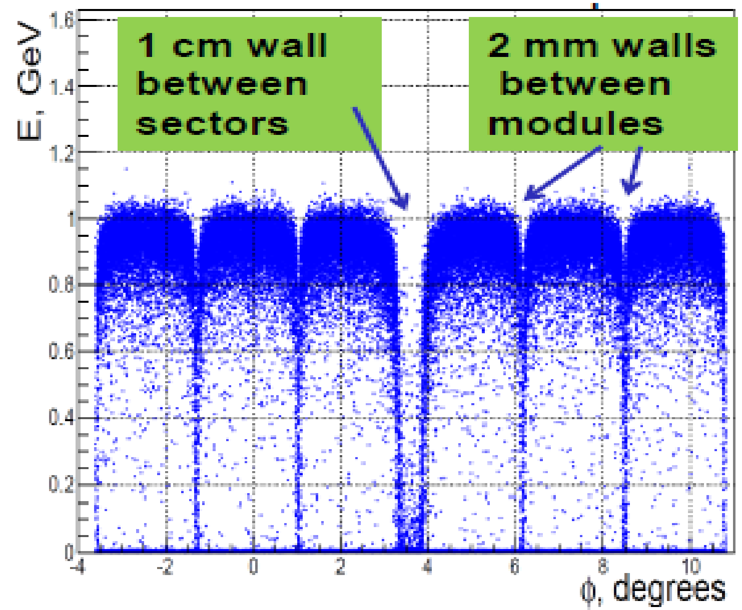
Hit production is based on geometric criteria. FindNode with Geant4 miss few percents of Geant4 points and has not been used. Simple cluster finder used "area around hit with maximal energy deposition" method. Area of 5x5 towers is good for low multiplicity and is slightly larger then the area within Molier radius which is 6 cm.

Test on the cluster level

ECAL response to 1 GeV photons

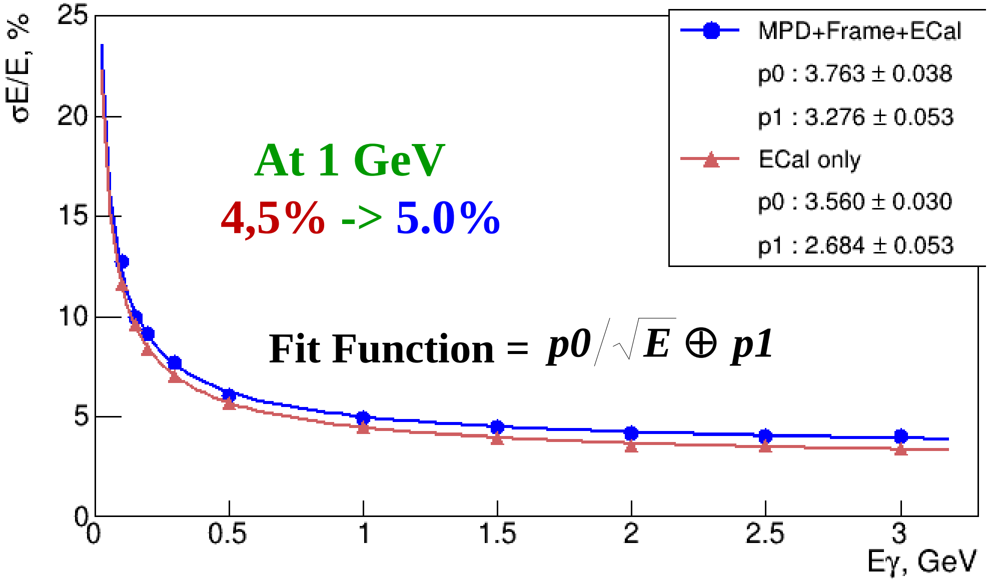


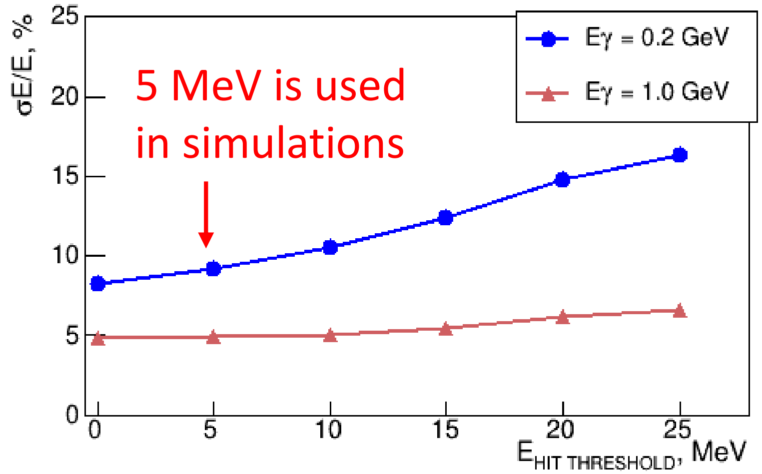
Effect of power frame passive materials on ECAL response

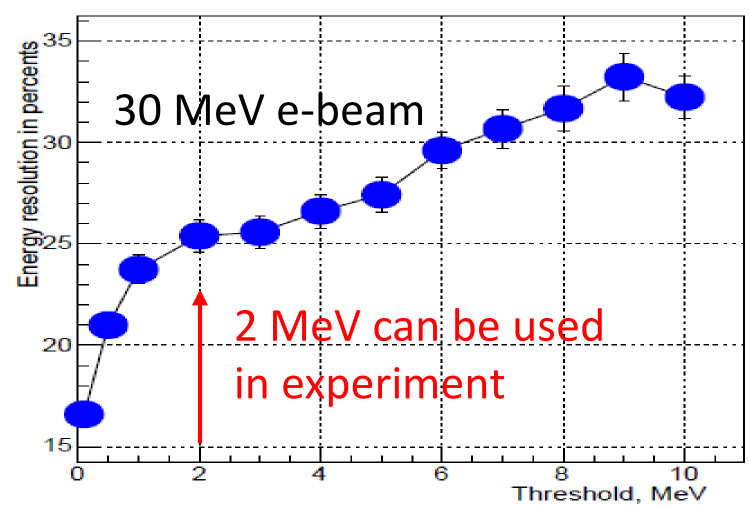


The cut rejects photons with hit position near the walls. The passive materials of the walls result in increase of non-gaussian low energy tail and uncertainty in energy resolution determination. But overall degradation of energy resolution is small ~ 0.5 %.

Energy resolution for photons







Electronics permits to work with up to 2 MeV threshold for hits

- ✓ Energy resolution was obtained for two cases : MPD (TPC and TOF) + Power Frame + ECal and ECal only
- ✓ It is in reasonable agreement with rectangular prototype tests at 1 GeV: measurenent->6%, MC->4.6%
- ✓ Contribution of the Power Frame is small

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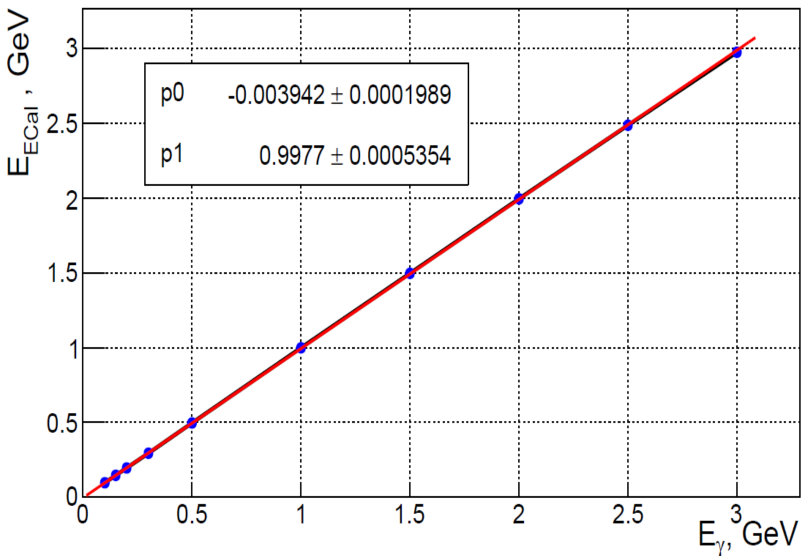
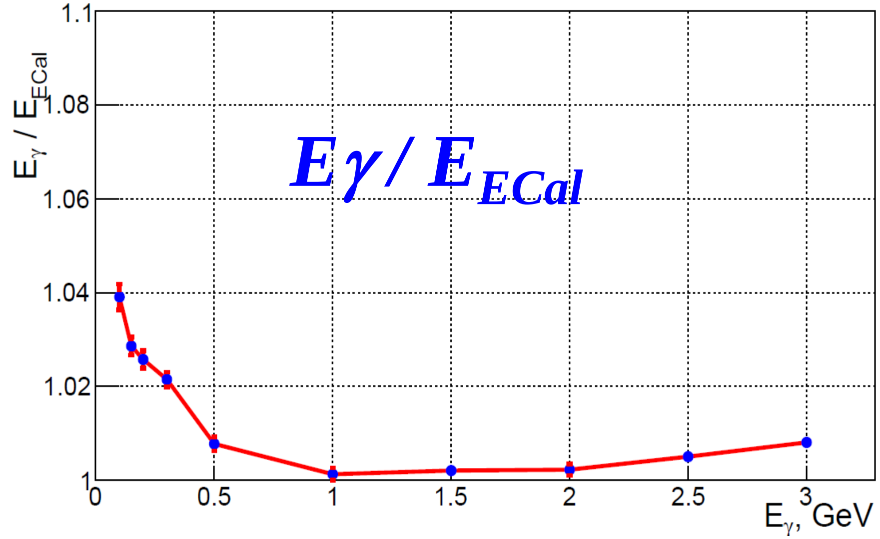
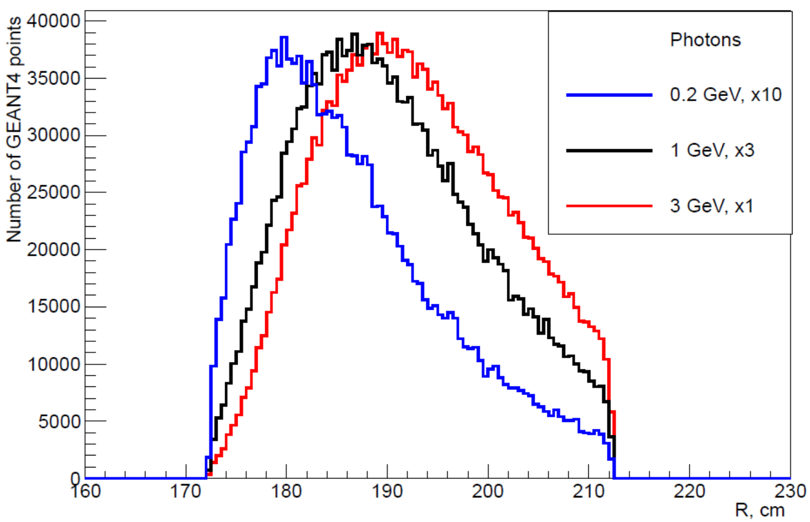
Linearity test



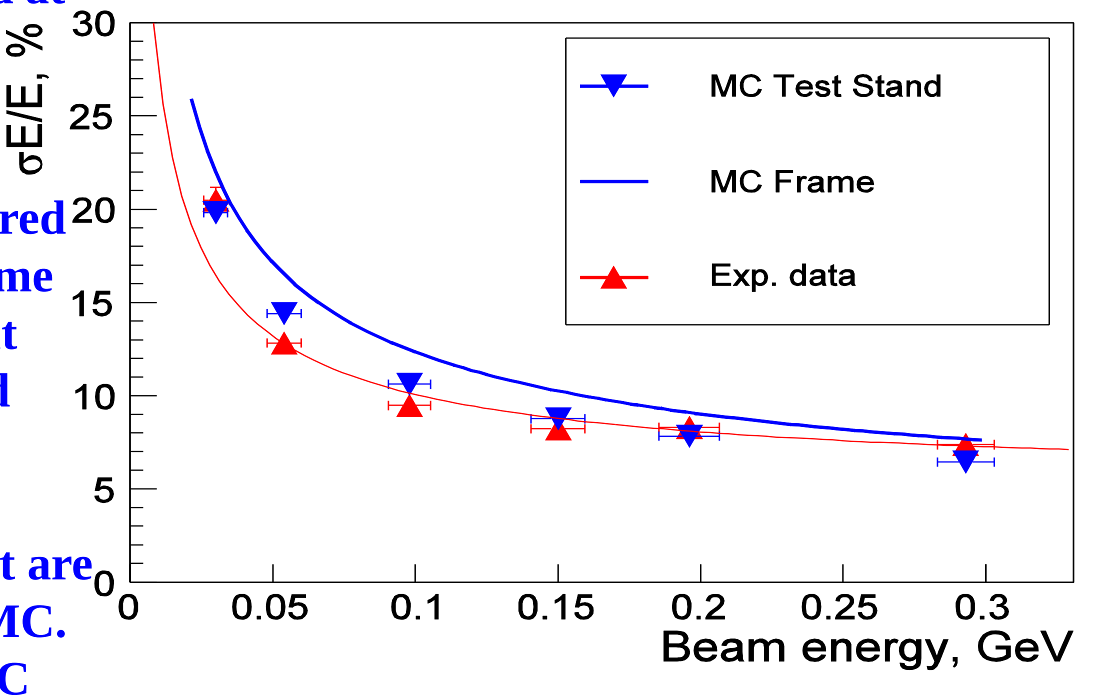




- ✓ Good linearity of ECal response
- ✓ Small 4% deviation from linearity at 100 MeV is due to 5 MeV threshold
- ✓ Deviation of 1% at 3 GeV is possibly connected with a electromagnetic shower leakage for 11.2 X_0 length of ECal

Comparison with tests at electron beam

Three modules have been tested at electron beam of Pakhra accelerator .
Electron energy - 30-300 MeV
Simulation program was prepared for the stand which used the same modules as in ECal, but without passive materials of basket and frame.

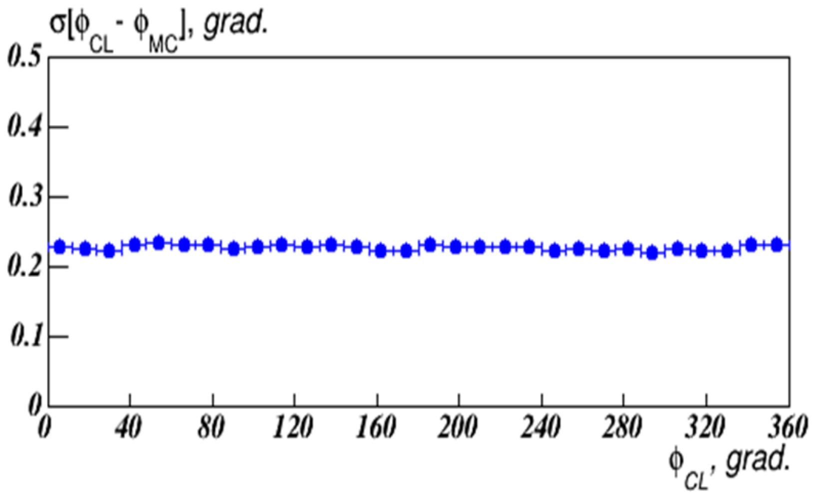


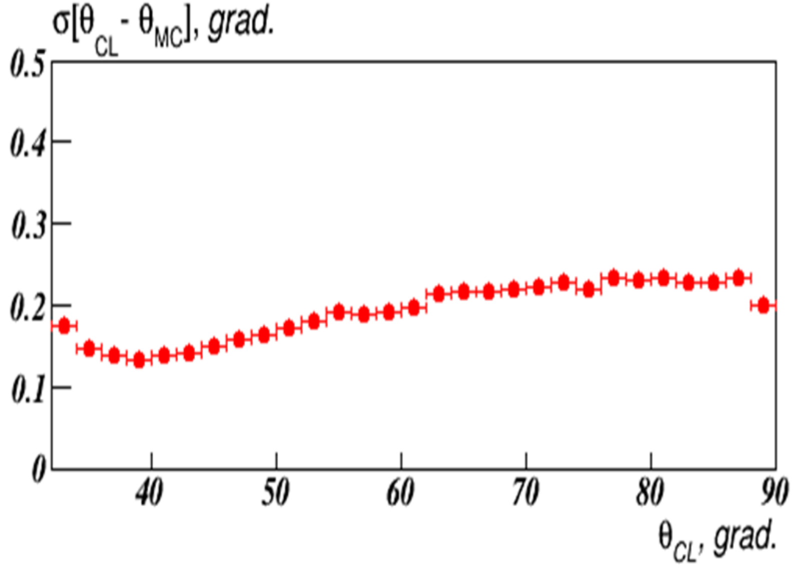
Energy resolution measurement are in reasonable agreement with MC. It is better by 1-2% than for MC simulation in ECal environment.

Beam energy spread was subtracted from experimental data.

It is planned to perform measurements adding passive materials for more close approximation to existing in ECal.

Angular resolution

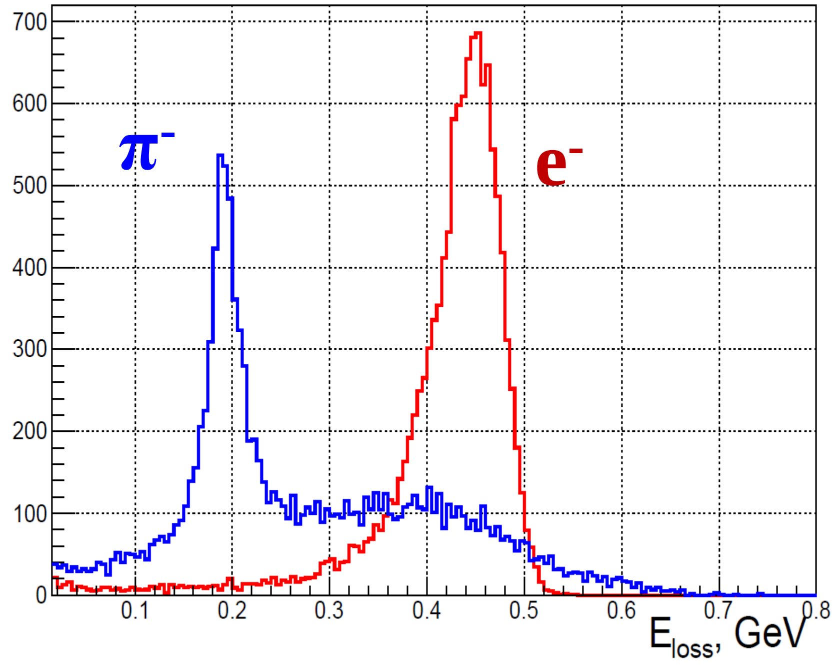




✓ Angular resolution of the ECal cluster in angles ϕ and Θ at $E\gamma = 1.0$ GeV is only slightly worse than in the previous version where it varied from 0.16 to 0.09 degrees

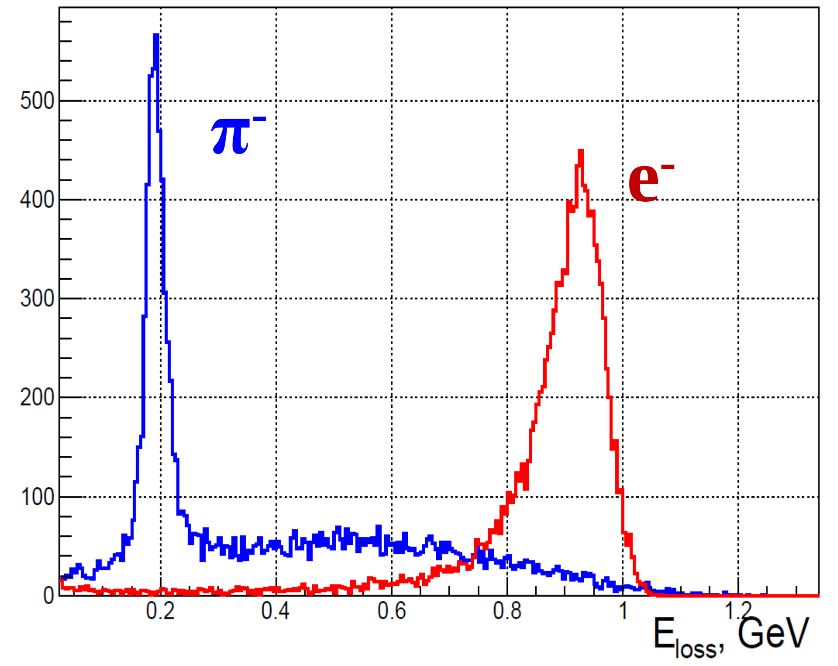
π/e separation by ECal

500 MeV



At 2σ level pion contamination in electron peak is 22% with electron efficiency of 80%, at V2-version it was 15%.

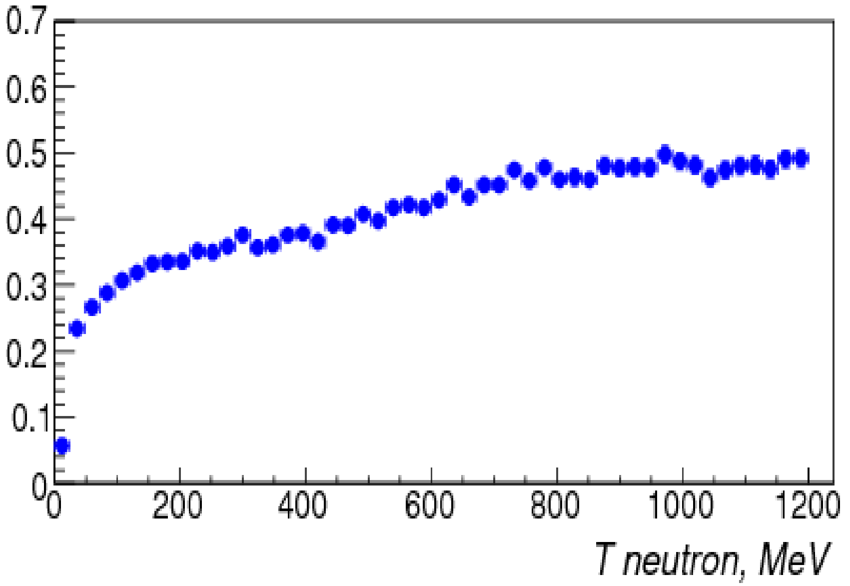
1000 MeV



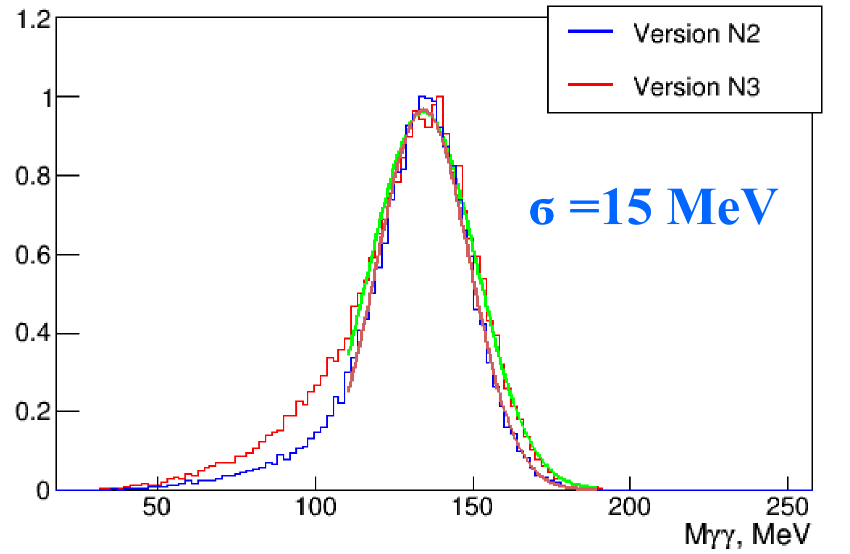
At 2σ level pion contamination in electron peak is 7% with electron efficiency of 80%, at V2-version it was 5%.

Neutron efficiency, pion mass resolution

Neutron Detection efficiency



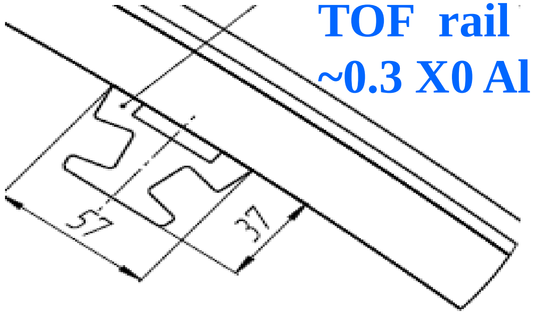
✓ π^0 invariant mass , $P\pi^0 = 0.2$ GeV/c



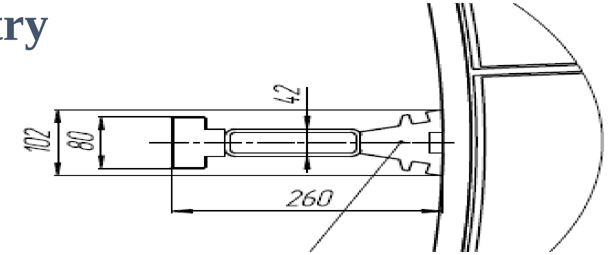
It is good, neutron can be registered with 30-50% efficiency.
It is bad, ECal will register neutron background

✓ ***π^0* – invariant mass resolution has not changed, but mass distribution demonstrate the low mass tail.**

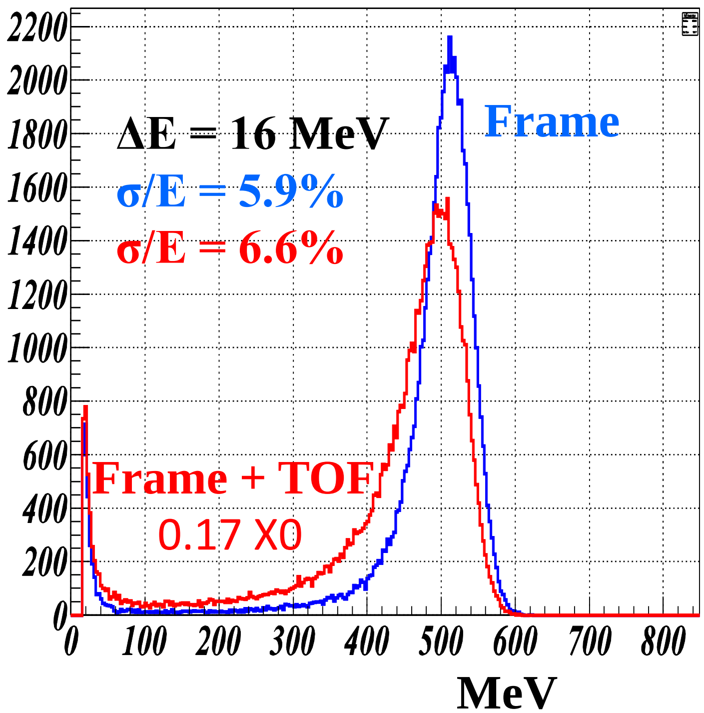
Influence of TOF and TPC rails

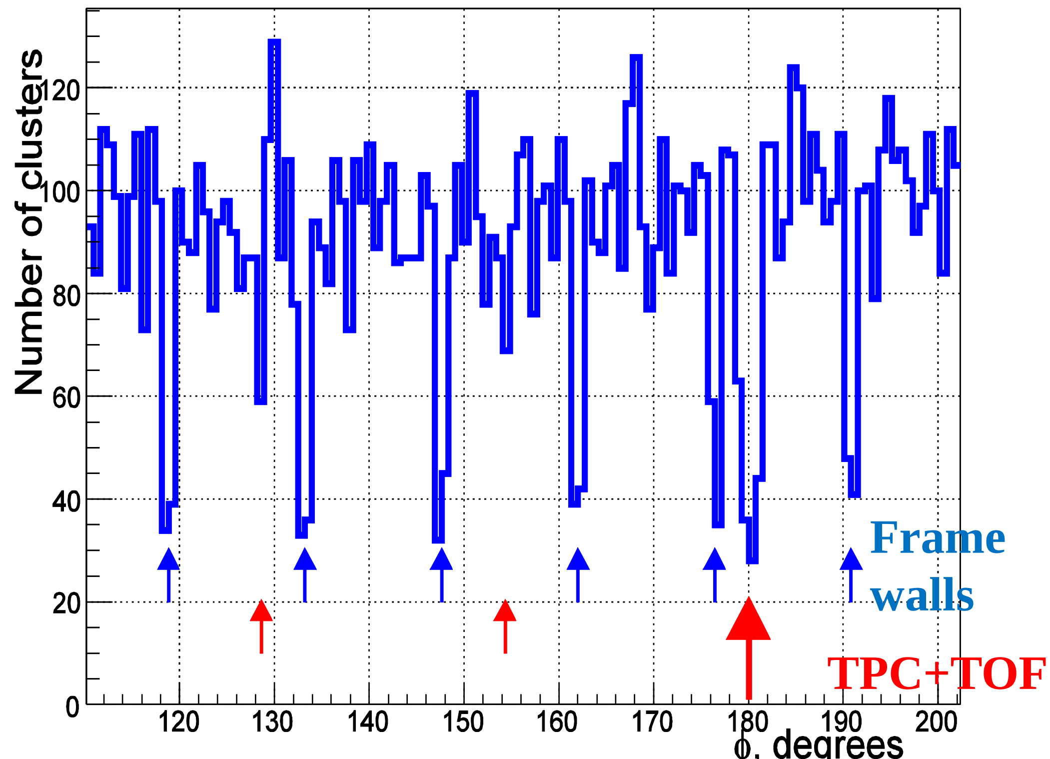


In august 2020 these rails were added to TOF geometry



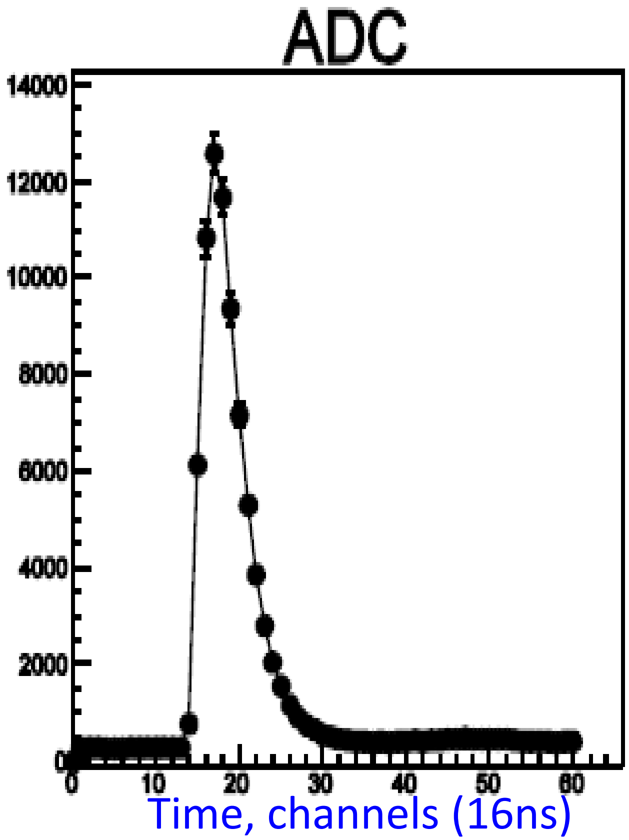
500 MeV photons

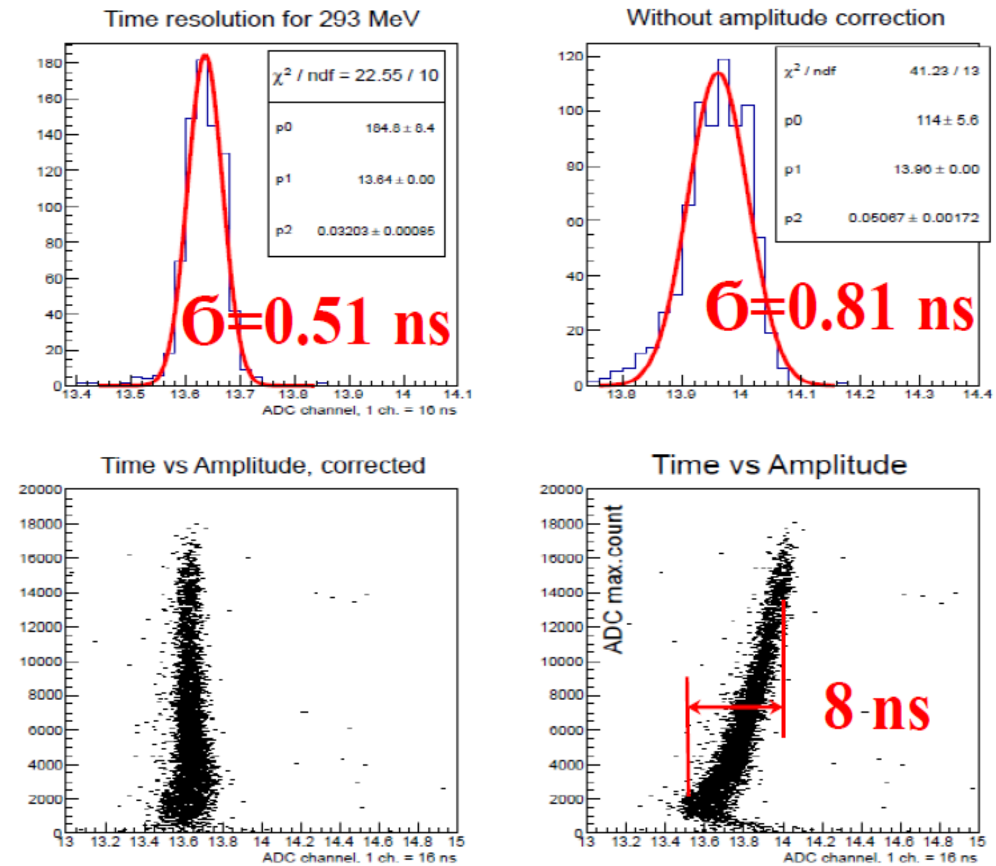




TOF rails are not seen,
TPC rail gives dead zone of 2 degrees

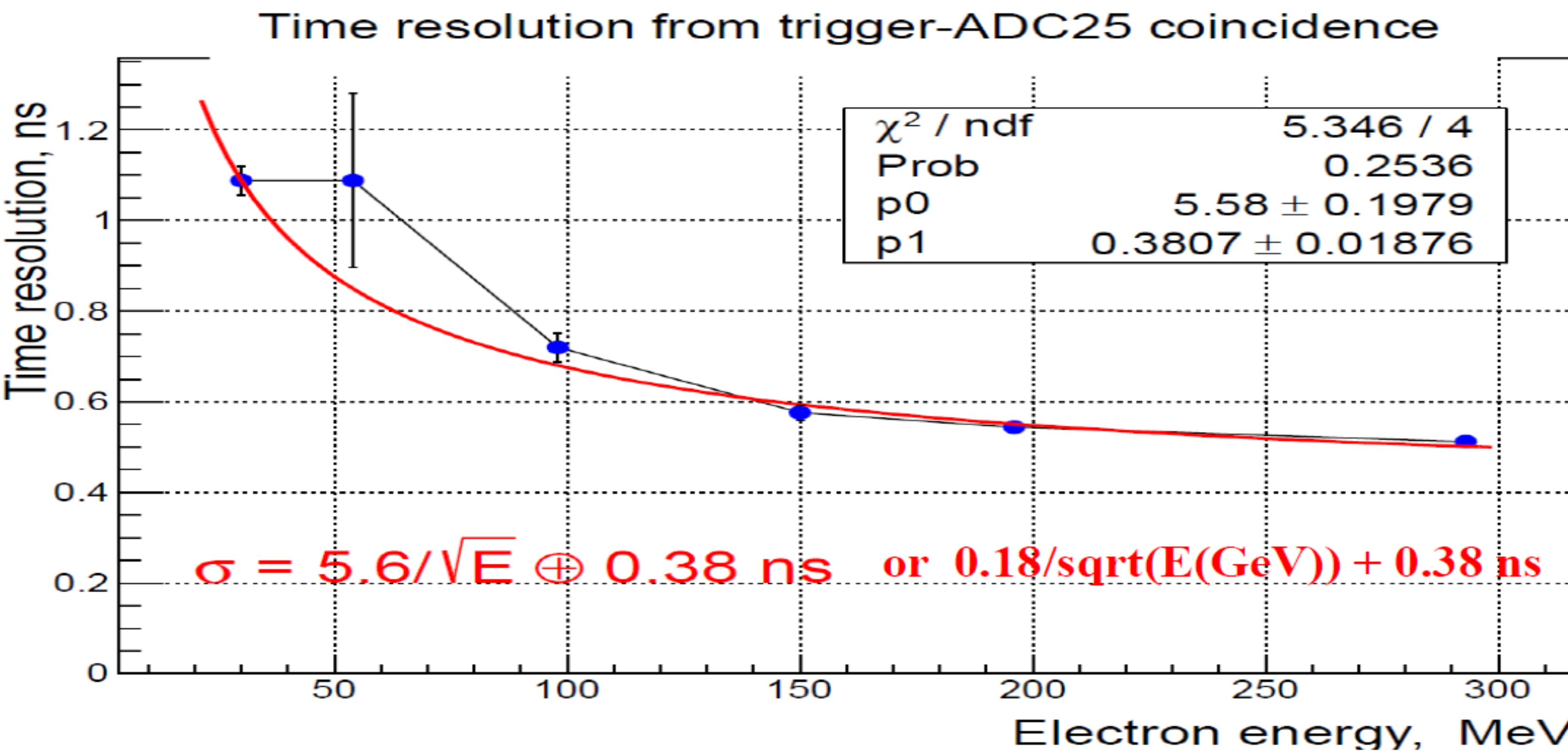
Time resolution - Tower and beam counter





Constant fraction method with amplitude correction. Timing from two ADC counts above and below CF value with linear interpolation . CF= 0.5 for ADC25 and 0.2 for trigger. Tabulated amplitude correction.

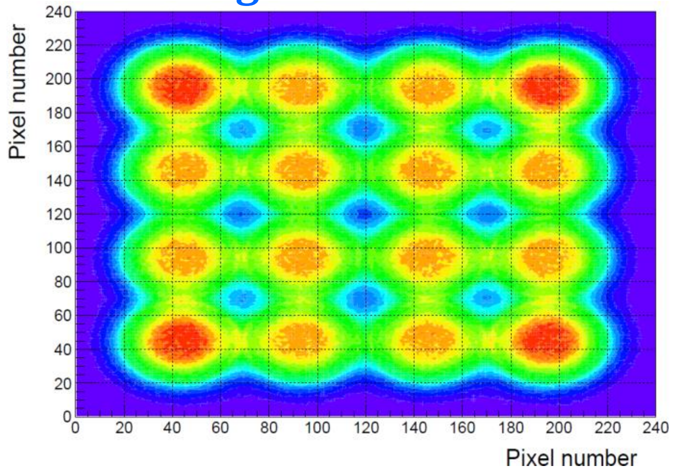
Energy dependence of time resolution

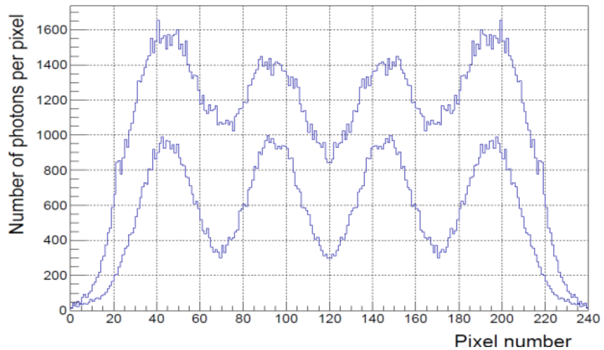


The fit function gives a reasonable fit to all data, apart from the 54 MeV point. Constant term is large, hopefully it is due to beam monitor time resolution, the statistical coef. is 0.18 ns. It means that time measurements with ECal can be done at sub ns level. Also at the test at DESY 0.21 ns resolution was obtained for few GeV electrons. But on prototype and with another electronics.

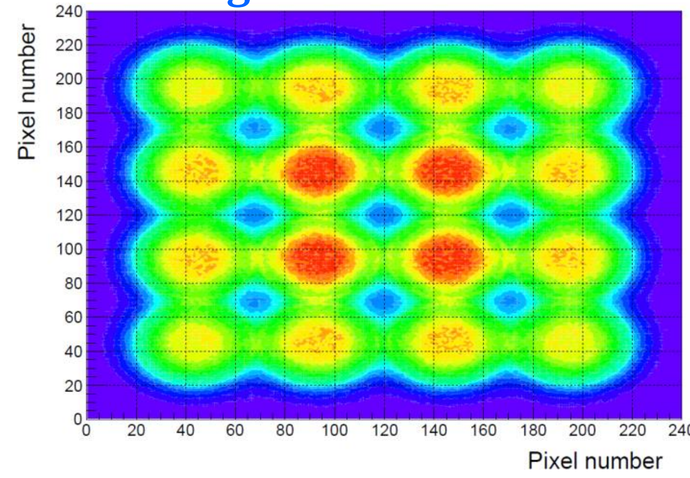
Simulation of light collection for ECal

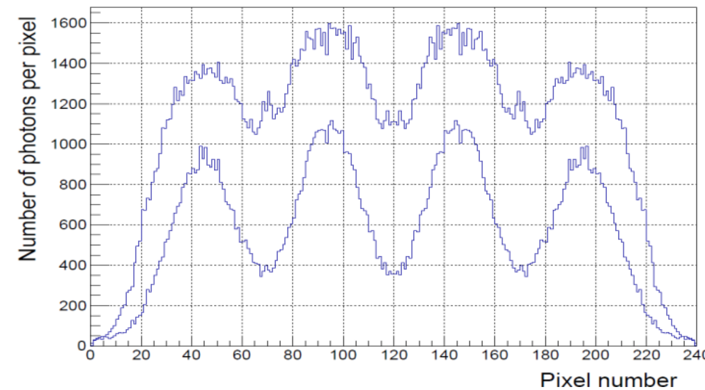
Volume light source





Point light source at Sc. center





$2*10^9$ photons at scintillator. Distance between fiber ends to 6x6 mm^2 Hamamatsu MPPC – 0.3 mm. At max. -15%, overall – 4 times. Can result in saturation, which seen at test at DESY at 2-3 GeV. We hope to simulate this effect when we unite light collection and shower development.

Conclusion

1. Simulation of ECAL geometry (version V3) has been developed, tested, available on git and are now used for physics analysis

2. Modified version of V3, which include full simulation of power frame is ready and will be released as soon as we will have full information on properties of materials used at production

3. Simulation of test stand geometry has been performed and was successfully used for ECal modules tests at bean and cosmic rays.

4. Simulation of ECal time resolution is in progress

This work has been supported by RFBR grant 18-02-40054

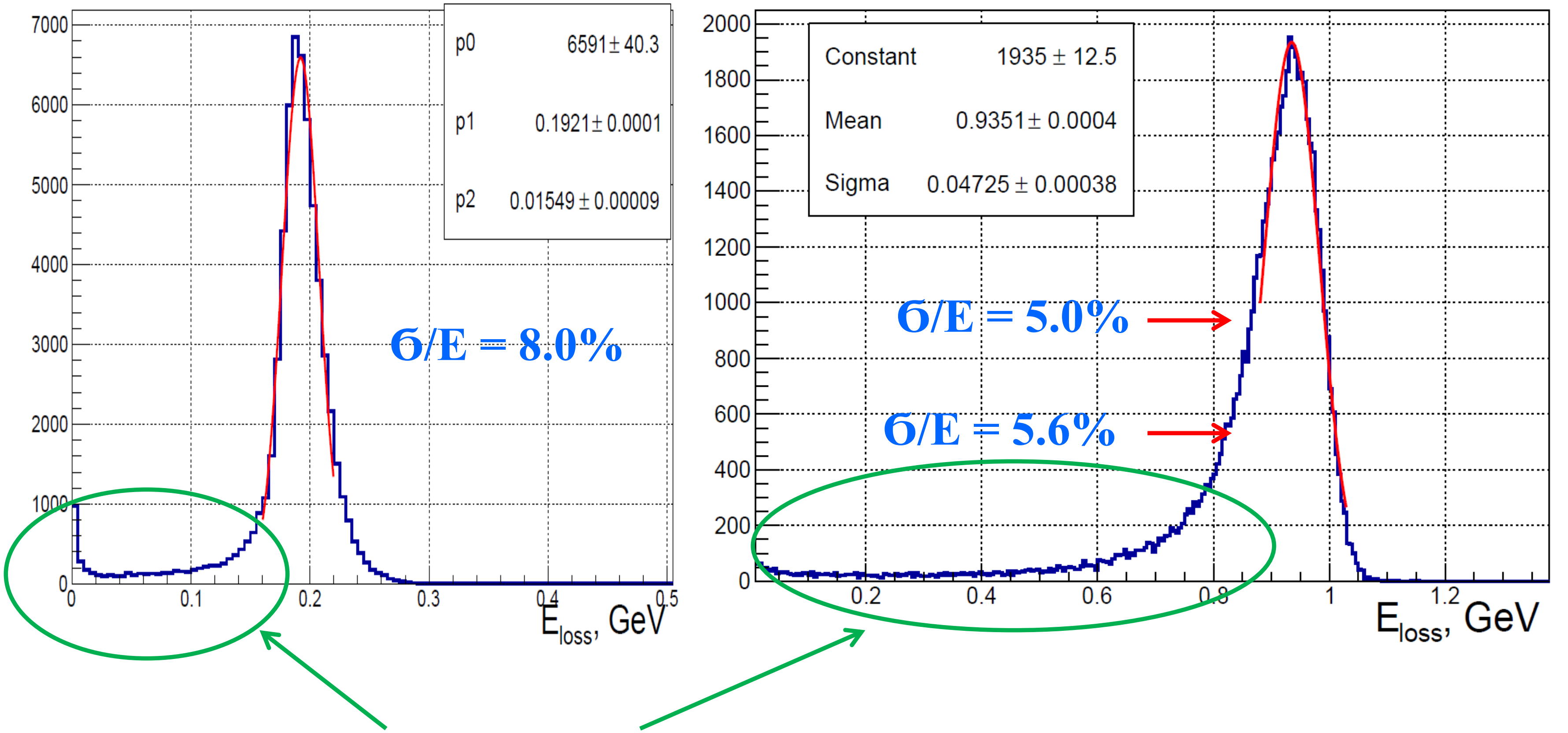
NICA

Thank You

1 GeV Muons and photons

Muons

Photons



Large non gaussian tails result in some uncertainty in parameters of the gaussian fit

Key Features of New ECal Geometry

- **New design of ECal 12 tons support structure results in changes in ECal geometry which were previously used for NICA physics simulation. These changes were discussed by Maxim.**
- **Additional passive material was added into towers as 50 µm TO_2 paint on both sides of Pb –plates. It seems to be small but it is 2.1 cm for all 210 layers that reduces the ionization signal by 7 %. But in real life, it is necessary to ensure good light collection.**
- **Additional passive material was added in front of ECal in the form of carbon fiber supporting cylinder 25 mm thick and 8 mm fiberglass bottom of the baskets. Both they add 12.7% Xo to TOF 17.2% Xo that gives in total 29.9% Xo. Although carbon fiber is expensive, but it is the best in terms of strength to radiation length.**
- **Additional passive material was added between the modules in the form of carbon fiber support beams and fiberglass walls of the baskets. In total, they occupy 8 % of the ECal area and absorb some energy from electromagnetic showers.**
- **These inevitable changes result in deterioration of the ECal performance, but to what extent it will be seen from the following presentation.**