Performance of the BGO Endcap Calorimeter of the CMD-3 Detector

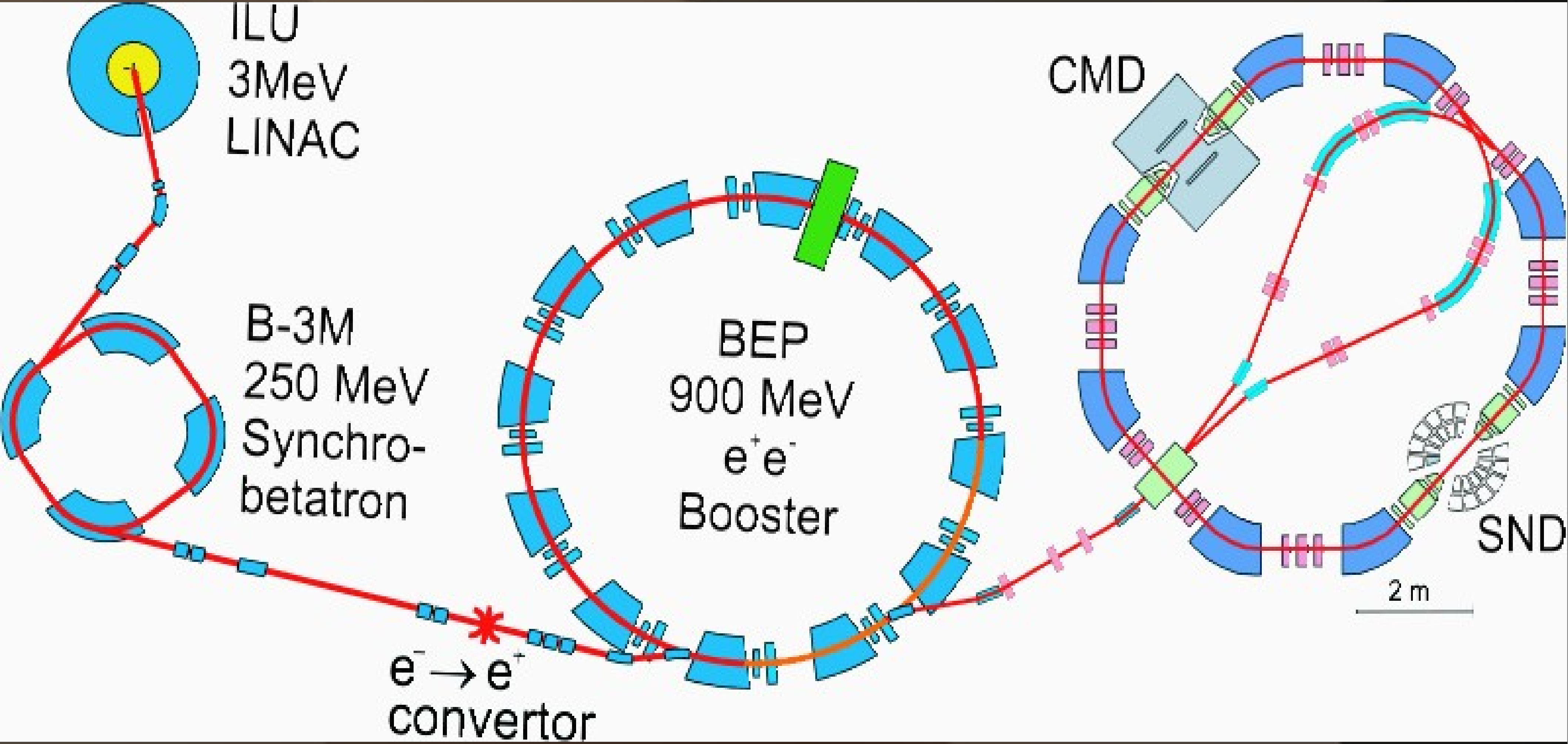
On behalf of BGO group:

R.R. Akhmetshin
D.N. Grigoriev
V.F. Kazanin
A.E. Kuzmenko
Yu.V. Yudin

INSTR14

February 28, 2014

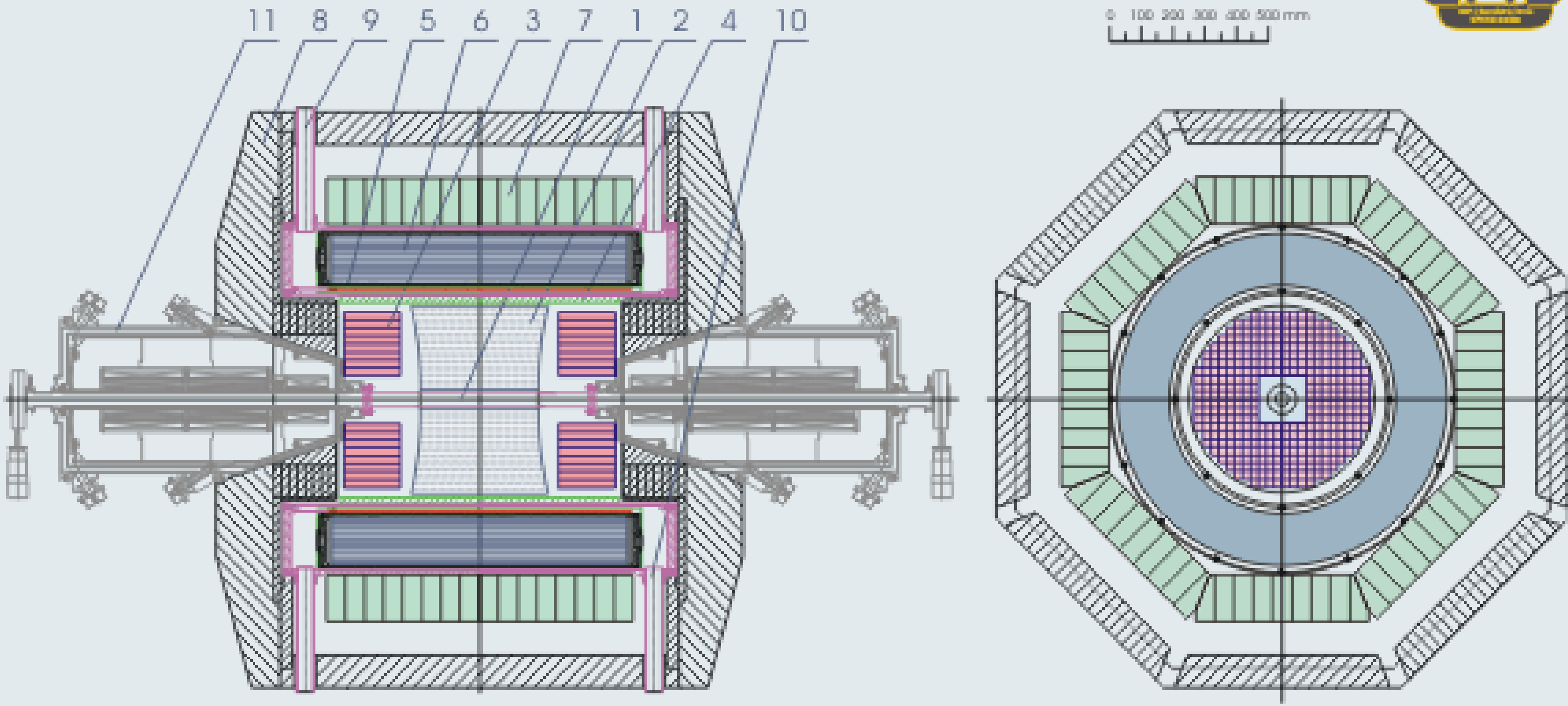
VEPP 2000 electron-positron accelerating complex



Energy range: 320 – 2000 MeV in c.m.
Planned luminosity at 1000 MeV is 10^{31}, at 2000 MeV is 10^{32} $1/cm^2s$.
Total integral luminosity for 2010-2013 is about 60 pb^{-1}.

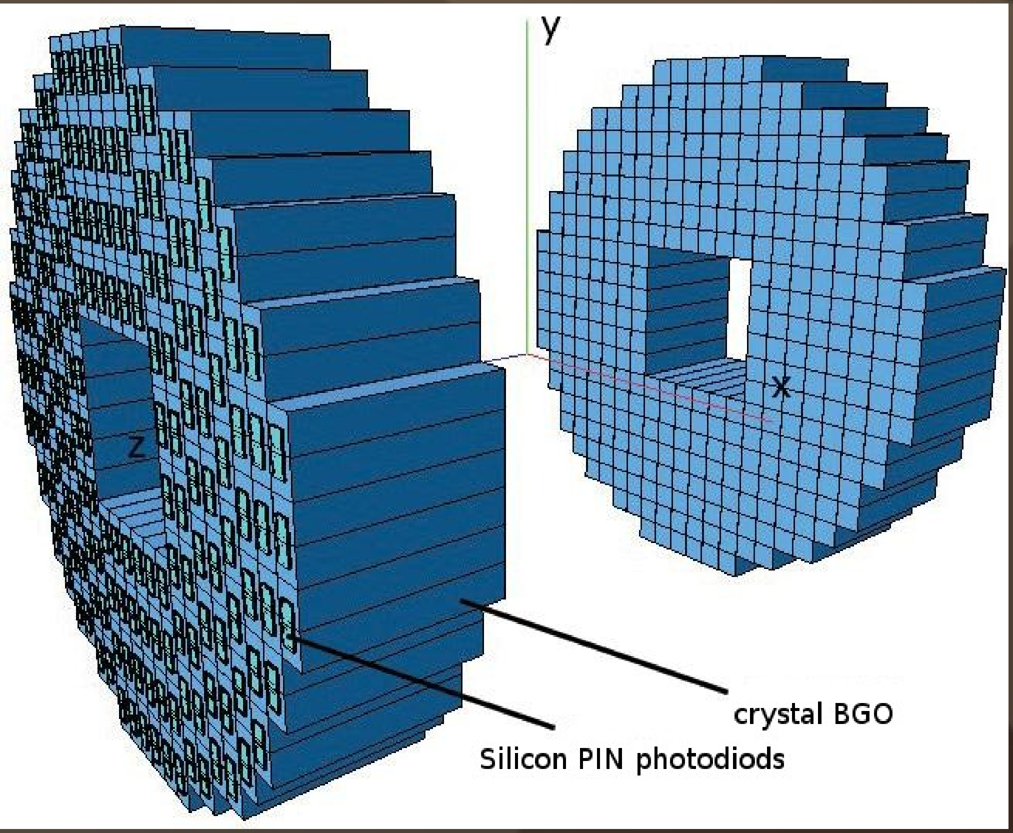
CMD-3 DETECTOR

HTTP://CMD.INP.NSK.SU



1 - Vacuum pipe
2 - Drift chamber
3 - BGO endcap calorimeter
4 - Z-chamber
5 - Superconducting solenoid
6 - LXe calorimeter
7 - CsI barrel calorimeter
8 - Yoke
9 - LHe supply
10 - Vacuum pumpdown
11 - VEPP2000 superconducting magnetic lenses

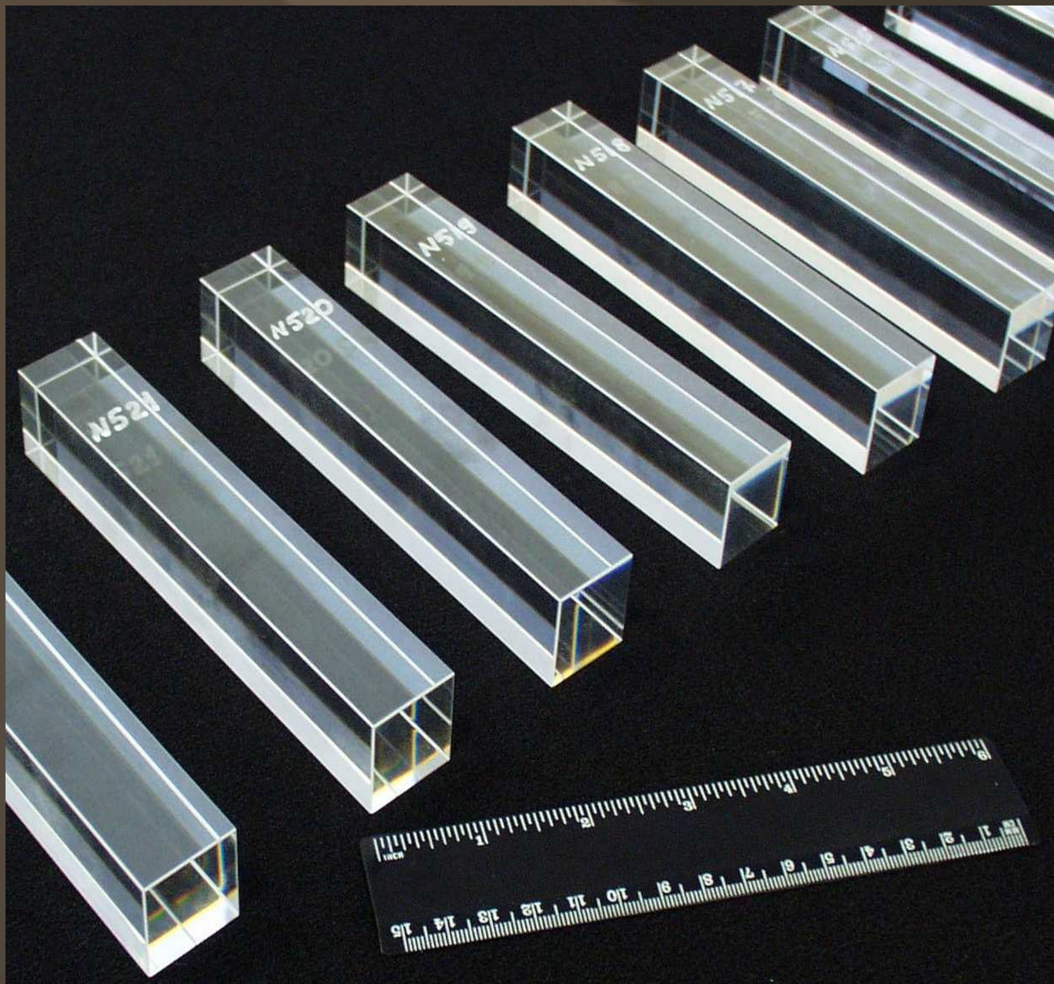
EndCap BGO Calorimeter



3d view of EndCap Calorimeter

General parameters of the EndCap BGO Calorimeter			
Polar-angle region	16-49° и 131-164°	***Light readout***	Silicon PIN photodiodes (Hamamatsu S3590-08)
Solid angle	0.3× 4π sr	Transverse dimensions	12.7× 14.5 mm^2
Solid angle of complete calorimeter (barrel+BGO)	0.96× 4π sr	Sensitive area	1 cm^2
		Quantum efficiency	80%
Scintillating material	BGO	Dark current	<5 nA
Number of crystals	680	Capacitance	40 pF
Crystal dimensions	25× 25× 150 mm^3		
Radiation length	13.5 X_0	Signal	420 electrons/MeV
Weight	450 kg	Electronic noise	500 electrons
		Energy equivalent of noise	1.2 MeV

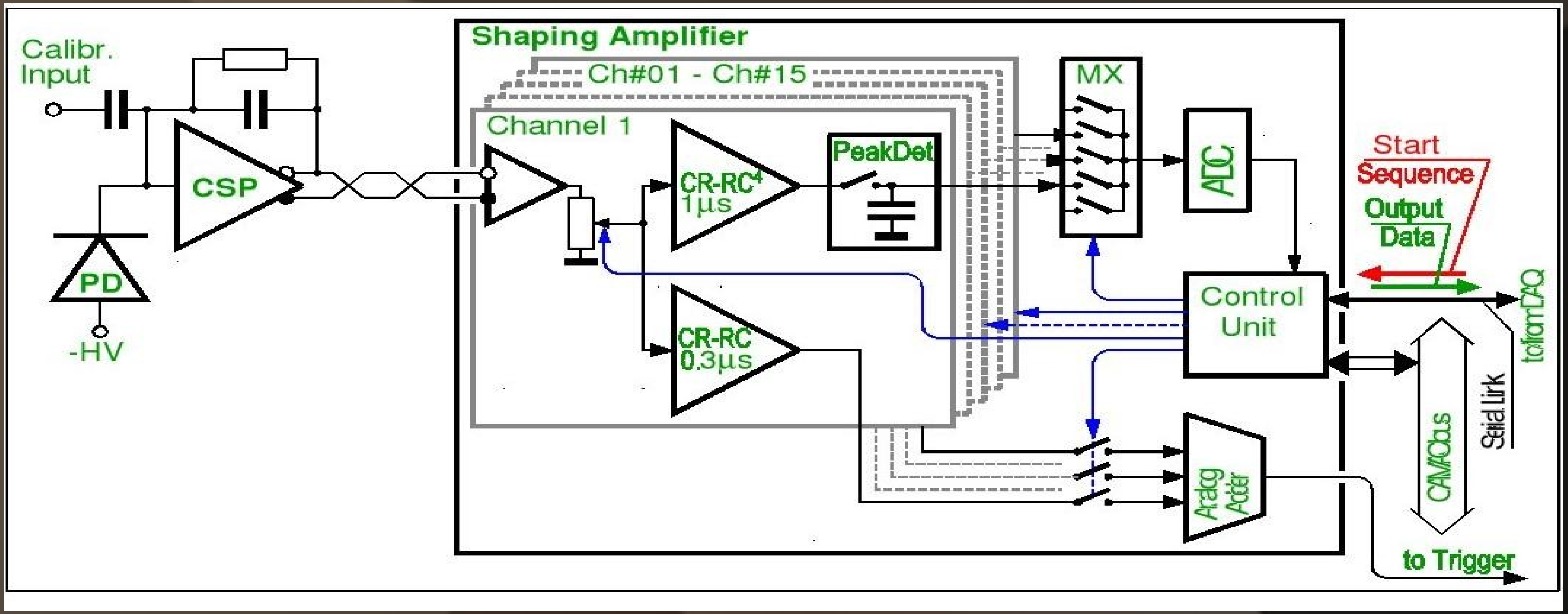
BGO crystals



BGO crystals from the Institute of Inorganic Chemistry

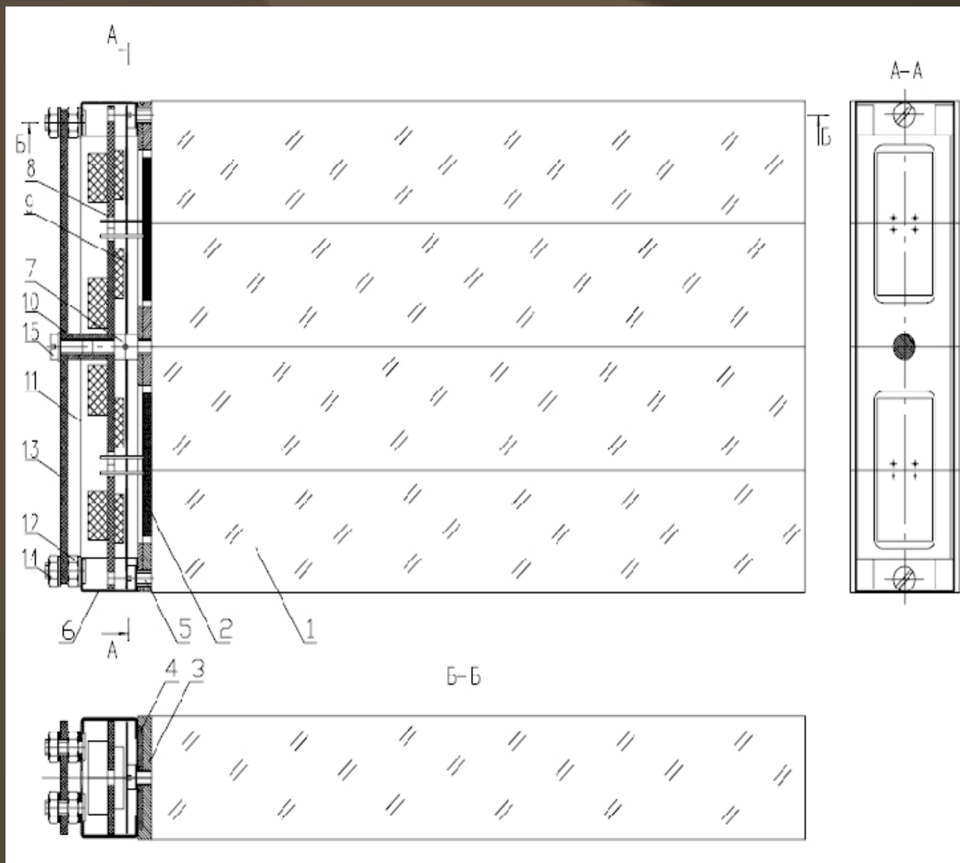
- A modified Chokhralsky method characterized by low temperature gradients and developed at the Institute of Inorganic Chemistry (IICh, Siberian Branch, Russian Academy of Sciences) was used to grow BGO crystals;
- Most crystals come from CMD-2 detector, but about 5% of them were substituted with new ones, produced in IICh (Novosibirsk) with better parameters in respect to old ones and high radiation hardness;
- Crystals' sides are polished and light is collected at photodiode with full inner reflection;
- Optical attenuation length is 7-10 m at λ=480 nm.

The layout of the BGO electronics

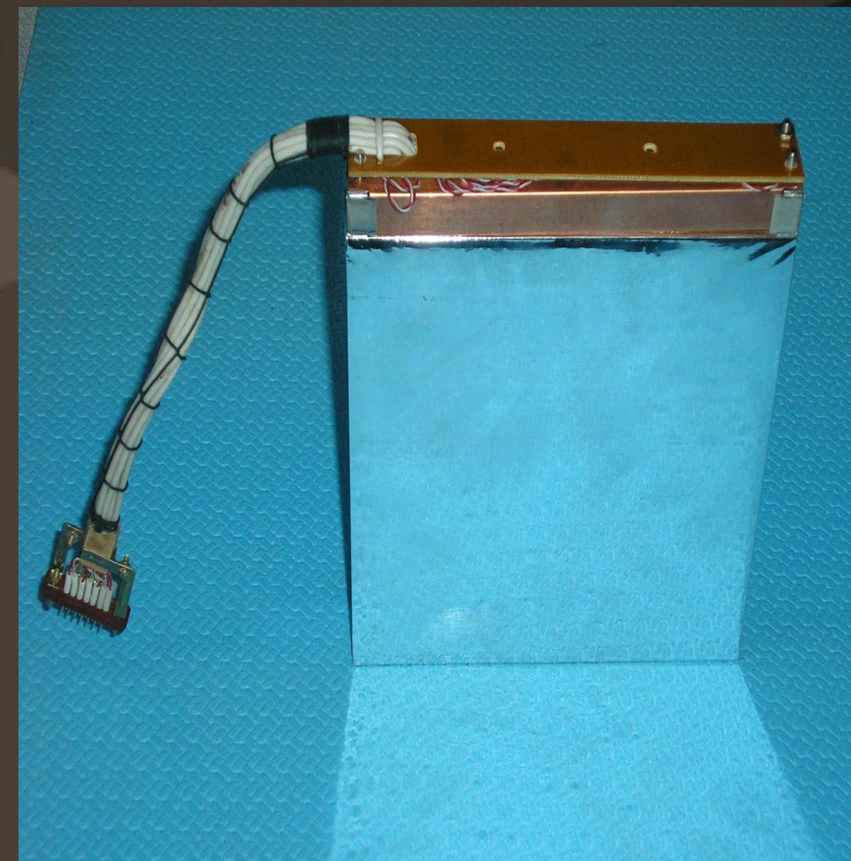


- Charge-sensitive preamplifiers (CSPs) are placed inside the detector near photodiodes (PDs) to decrease noise;
- Shapers and digitizers are outside on a common board;
- The shaper has 2 shaping times: 4 μs in energy channel and 0.3 μs in trigger channel (summed by 15 channels);
- Gain of the shaping amplifiers can be varied up to 4 times via computer control for equalization of the channel responses.

Module of BGO calorimeter



Layout of module of BGO calorimeter

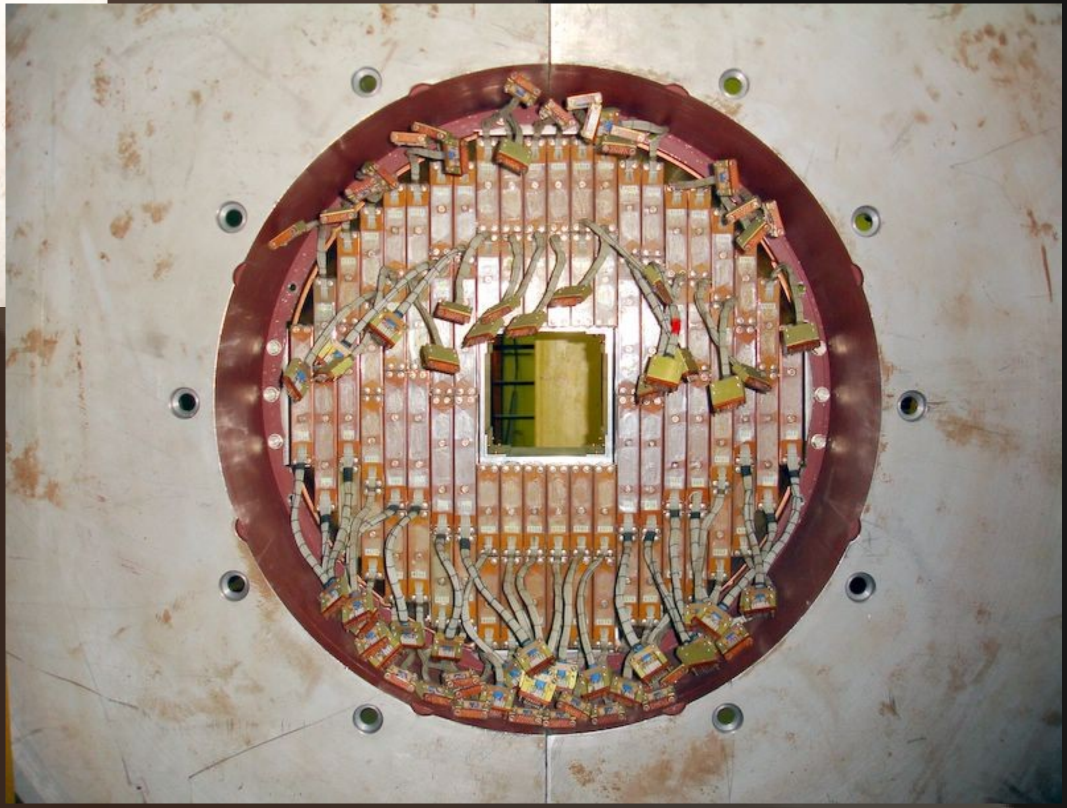


The assembled module of BGO calorimeter

Crystals are combined in modules for easier placement into the detector.
2 types: 116 modules of four crystals and 36 modules of six crystals.
The cover of the module is made from 20 μm aluminized mylar for optical and electrical screening and 70 μm mylar for mechanical protection;
The crystals and electronics holder are fixed together by thermal shrinking of the mylar bag.

First assembly of the BGO calorimeter

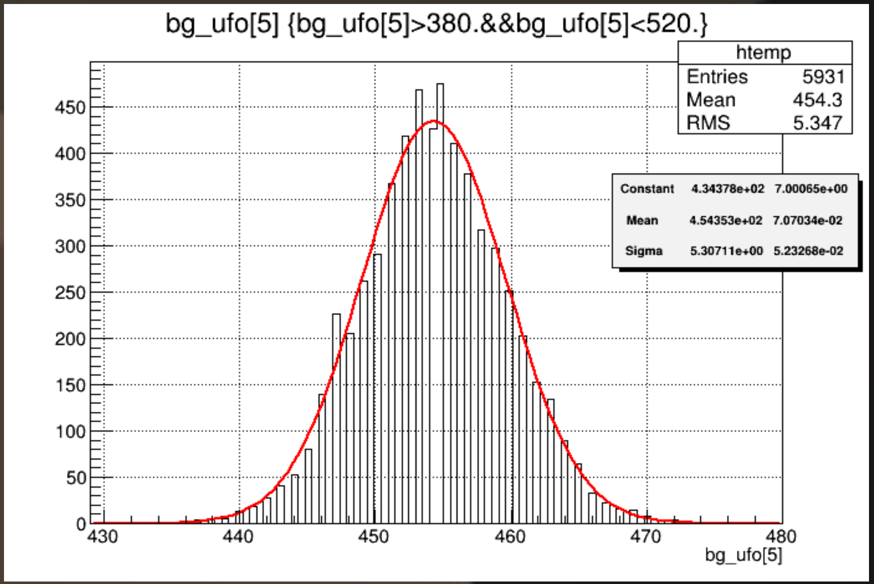
- After module production a test assembly was performed



Calibration procedure

Three types of calibration

- **Pedestal calibration** - *pedestal measurement* – no input signal, random trigger from pulse generator;
- **Electronic calibration** – *measurements of electronic gain* – input signal from pulse generator. Dispersion values are used in reconstruction procedure;
- **Cosmic calibration** – *ADC to MeV conversion coefficients measurements* – no accelerator work, special BGO based trigger, 2-3 hours of data taking are enough for statistical precision of 1%.



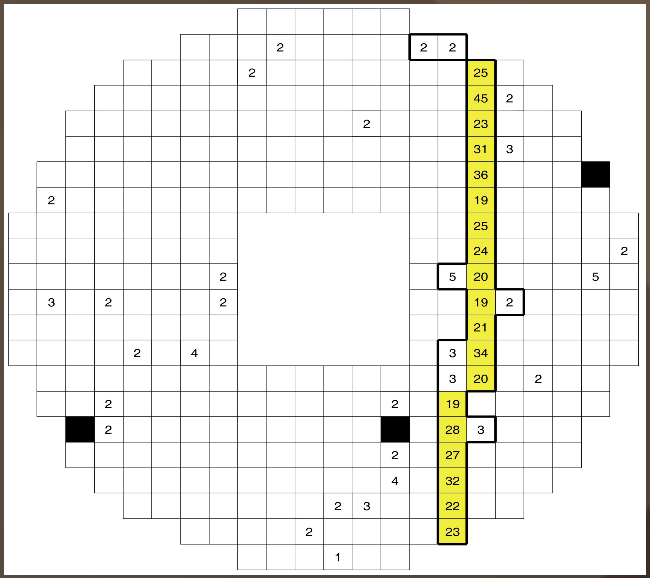
Typical spectrum of an electronic calibration signal is fitted with the Gaussian distribution.

Another procedure to calibrate calorimeter is using **the passage of cosmic rays during data taking**.

Calibration procedure

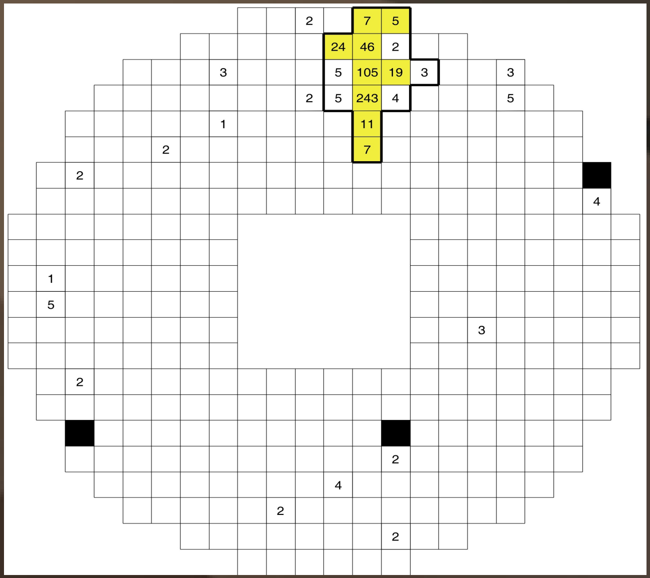
Cosmic calibration during data taking

- The main background is from shower events. To extract passage of cosmic muons through the calorimeter we use special parameters of BGO clusters (shape and energy deposition distribution);



Typical cluster from cosmic event

- *Elongated cluster with average energy in the crystal 20 MeV*



Typical cluster from shower event

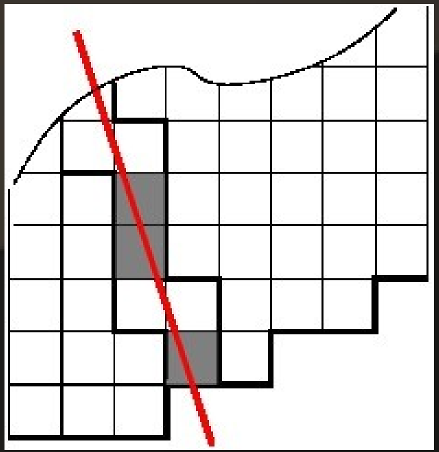
- *Compact round cluster with most energy deposited in the central crystals*

- To distinguish cosmic events from beam events we use the **ratio of the main moments** of inertia of the cluster shape (in analogy with a solid body) and the **average crystal energy** deposition and the energy deposition **dispersion between crystals** within each cluster. The residual contamination is <1%;
- Only events without charge trigger are used to suppress muons and pions with large angle to the vertical direction.

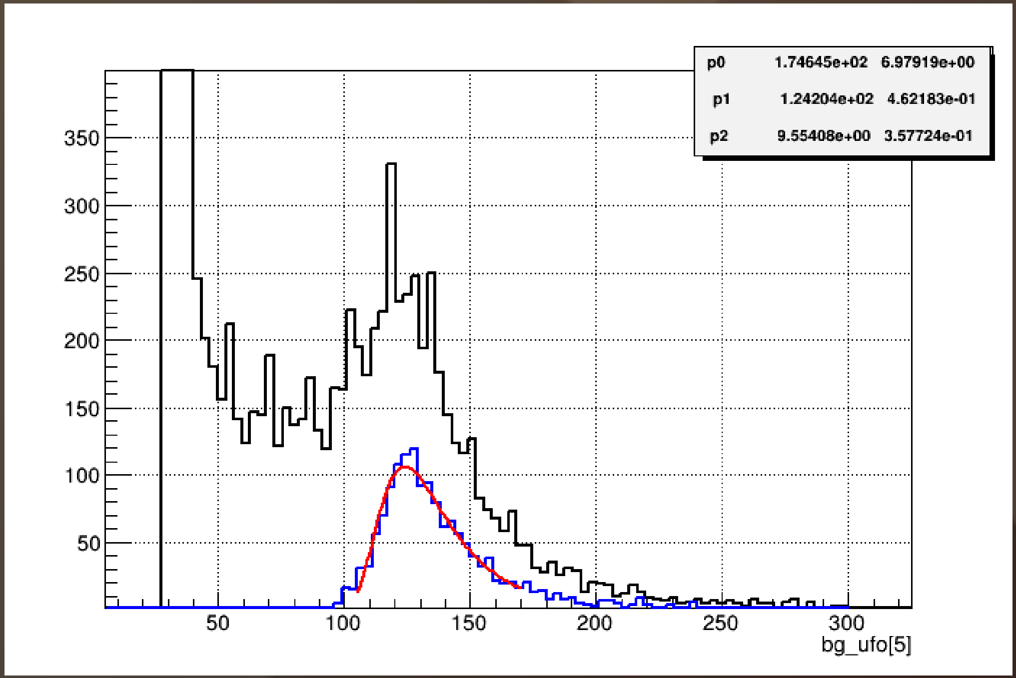
- *The efficiency of cosmic rays selection is evaluated at the level of 90%; 2 days of data taking is enough for statistical precision of 1%.*

Calibration procedure III
Face-to-face (f2f) algorithm

- Select signals in crystals from vertical cosmic muons – to reduce fluctuation of muon path length in crystals;
- Select crystals for calibration only if adjacent upper and lower crystals are triggered while lateral ones are not;
- Used to suppress noise in spectrum;



The idea of f2f algorithm. Only hatched crystals are selected.



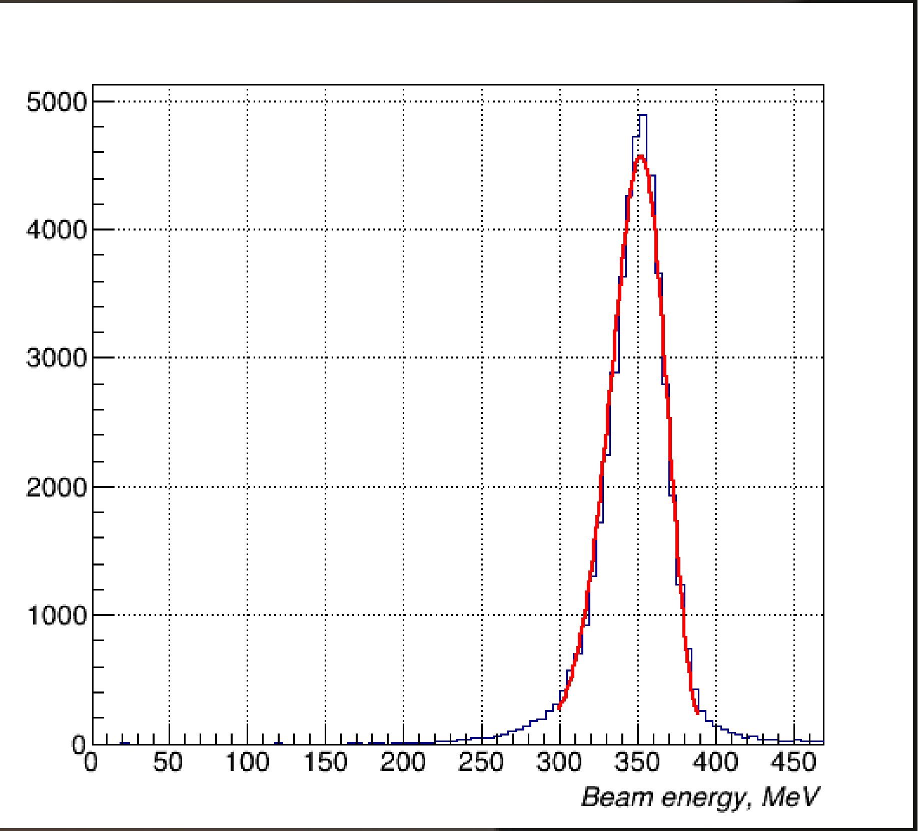
The result of f2f algorithm: spectrum of cosmic signals before and after f2f algorithm applying.

- F2f selection algorithm is applied to crystals of cosmic cluster to reduce track length fluctuations;
- Spectra are fitted with the approximation of the Landau distribution around most probable energy deposition.

Fitted peak corresponds to 22.7 MeV (value taken from MC).

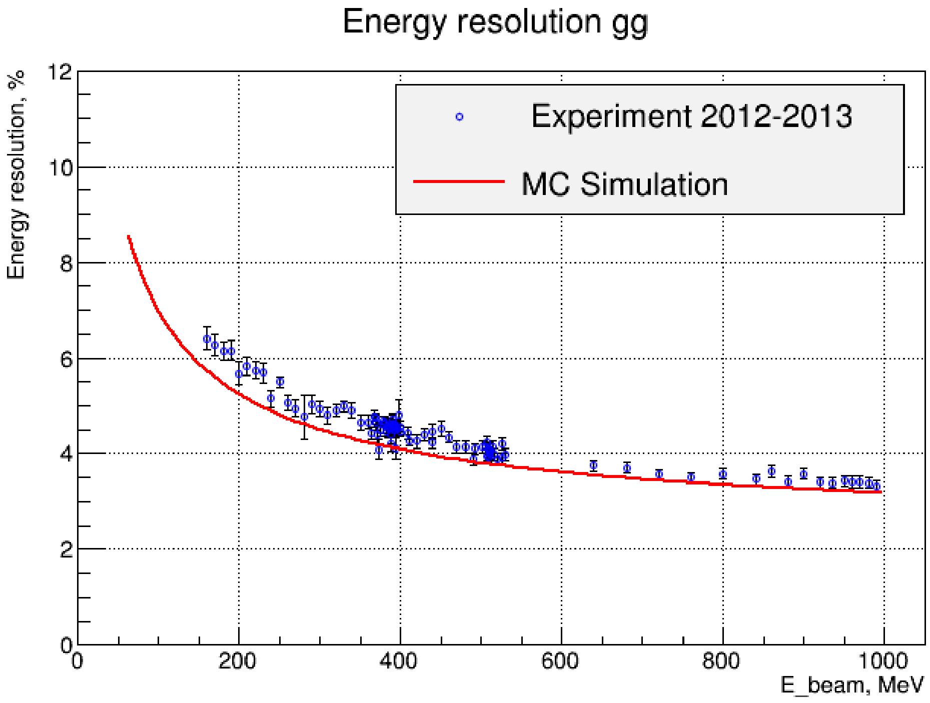
Energy resolution – events selection

- Energy resolution was calculated using two-photon annihilation and Bhabha events in BGO calorimeter.
- Selection cuts:
- Number of clusters 2 or more;
- 2 most energetic clusters are in different endcaps;
- These 2 clusters are collinear;
- Sum energy of 2 clusters > E_beam;
- No clusters in barrel calorimeter.

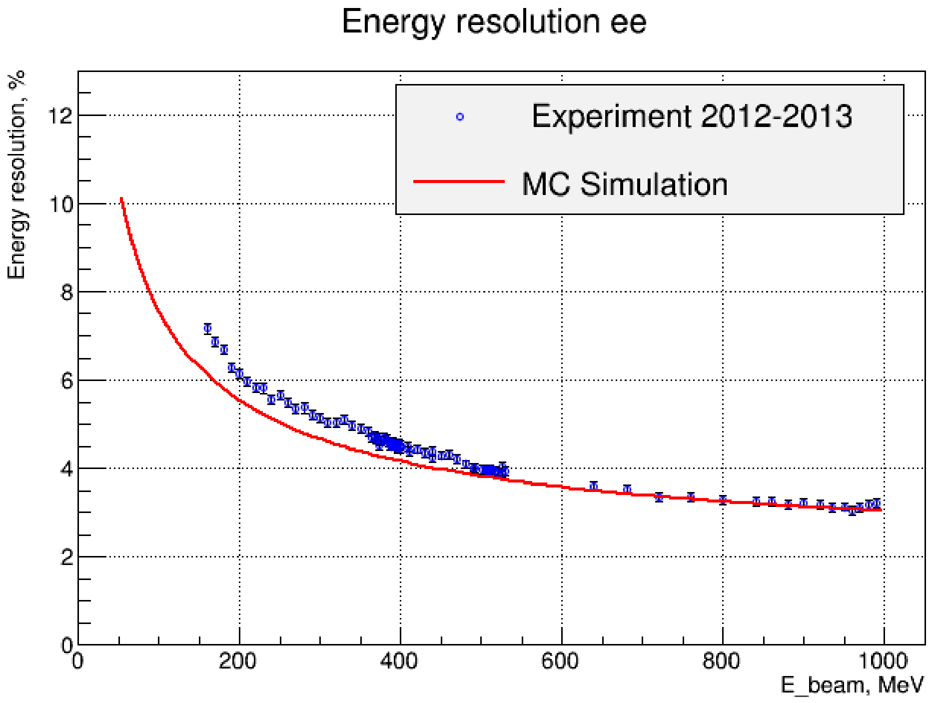


Spectrum of the energy deposition is fitted with the logarithmic Gaussian distribution.

Preliminary energy resolution



Two photon annihilation



Elastic Bhabha scattering

Energy resolution vs beam energy

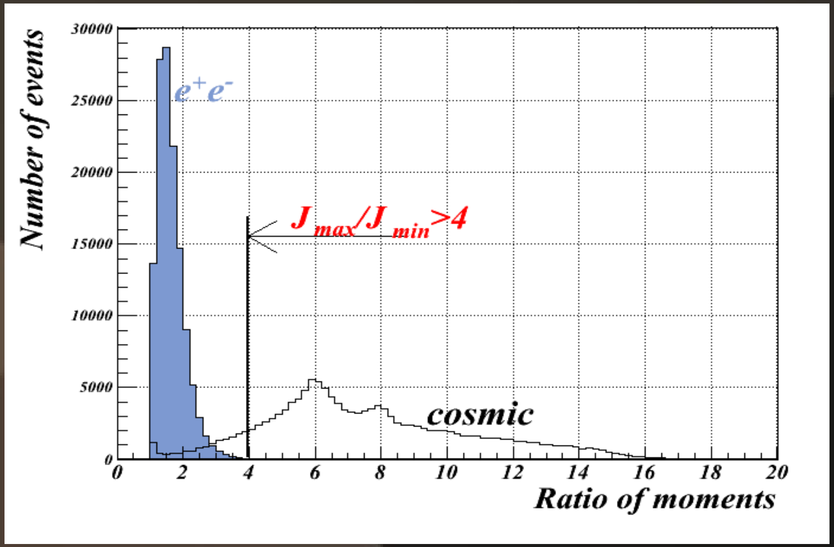
- The energy resolution was measured in all energy points where data was collected – wide range from 160 to 1000 MeV per beam;
- Resolution at the level of 3-3.5% at 1 GeV per beam is reached;
- Some disagreement between experimental data and MC is under study.

Conclusion

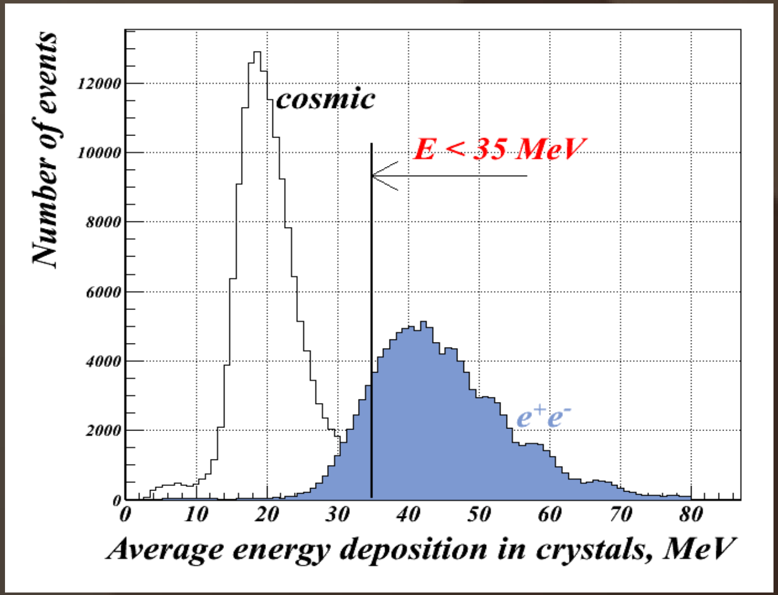
- The endcap calorimeter has been installed in the detector and participated in data taking which started at 2010;
- The calibration procedure has been developed and used during all 3 physical seasons. More than 400 calibrations were performed to increase quality of the data;
- The data analysis is undergoing.

Thank you for your attention!

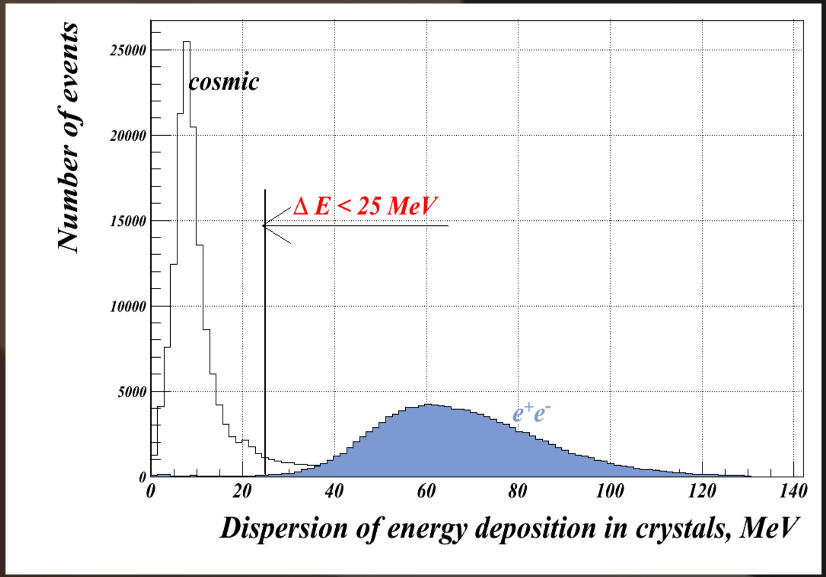
Selection cuts to distinguish cosmic events from beam events



The ratio of the main moments of inertia of the cluster shape

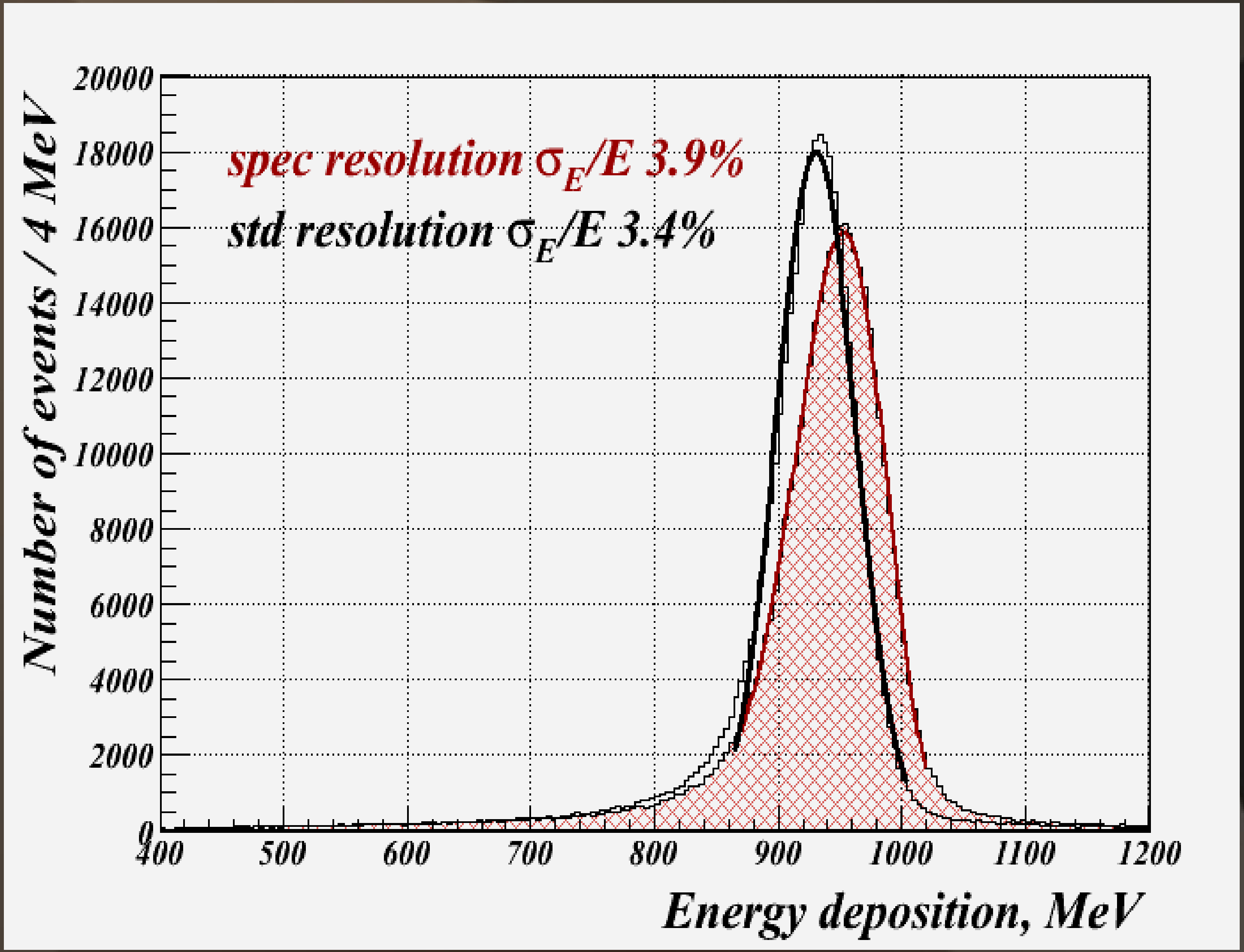


Average energy of crystals in the cluster

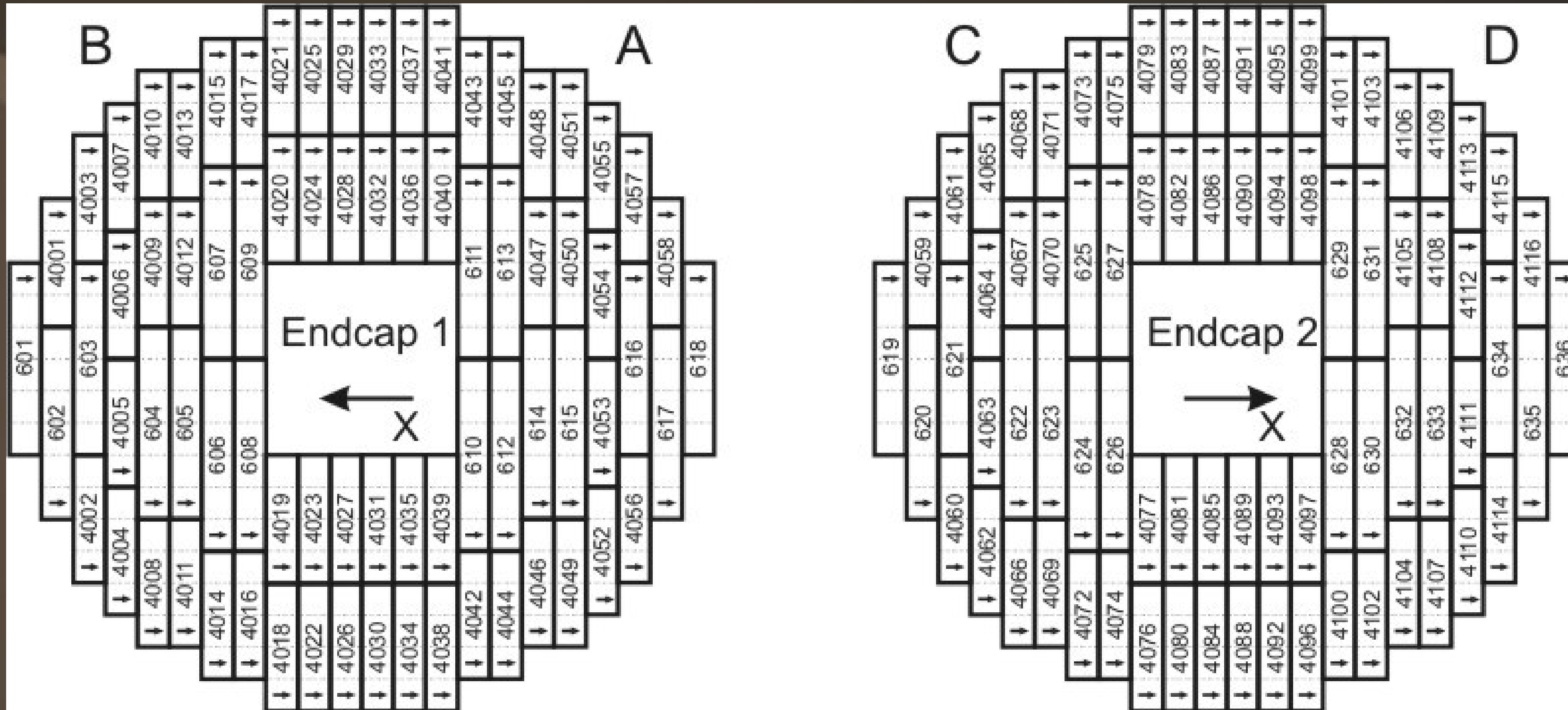


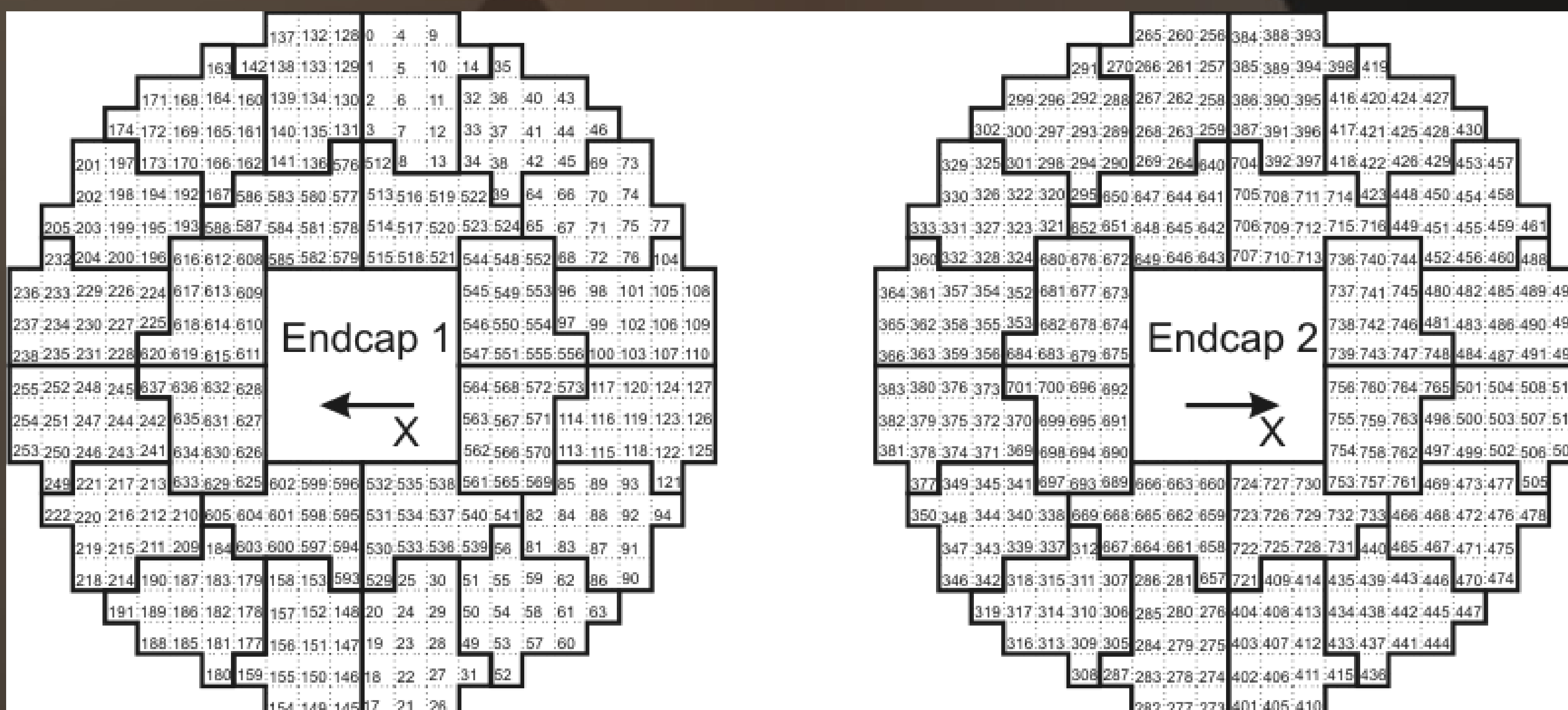
Dispersion of energy of crystals within each cluster

The comparison of energy resolution between special cosmic calibration and cosmic calibration based on CMD3 trigger

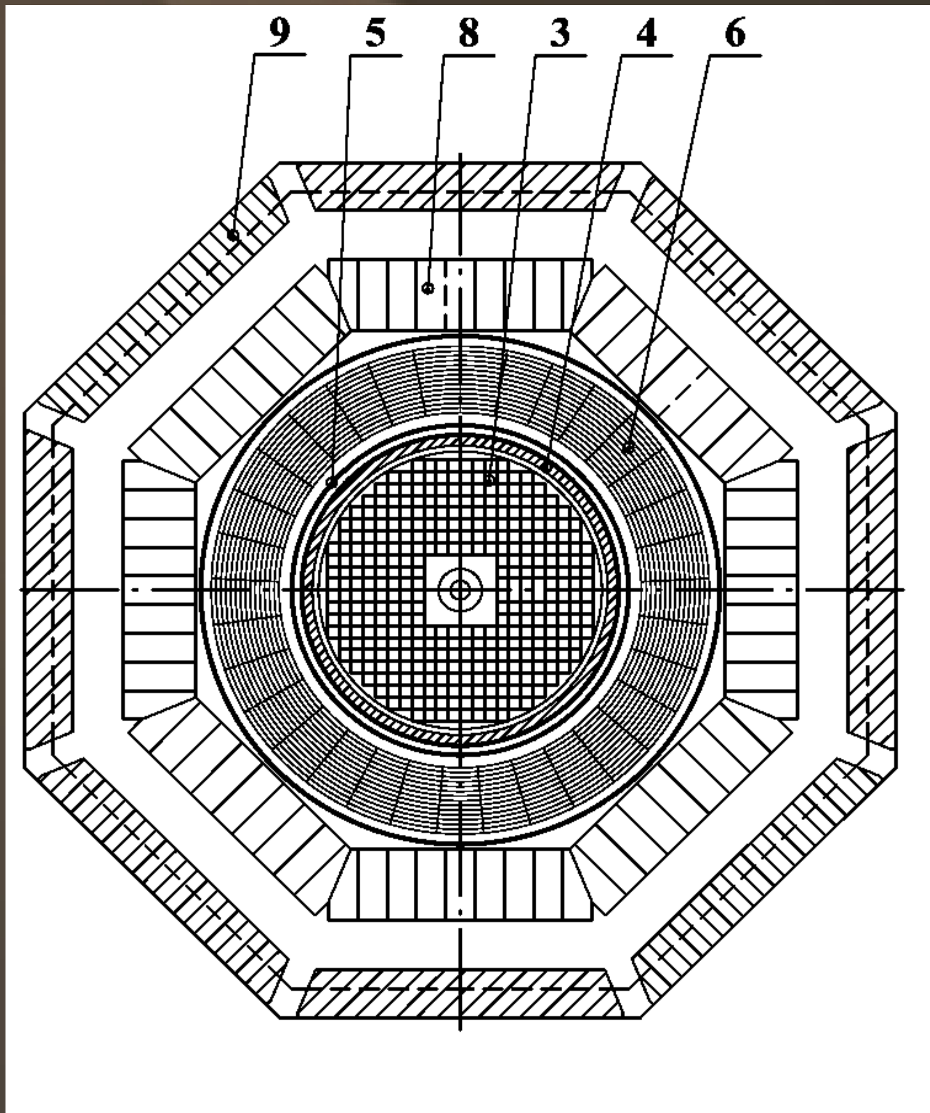


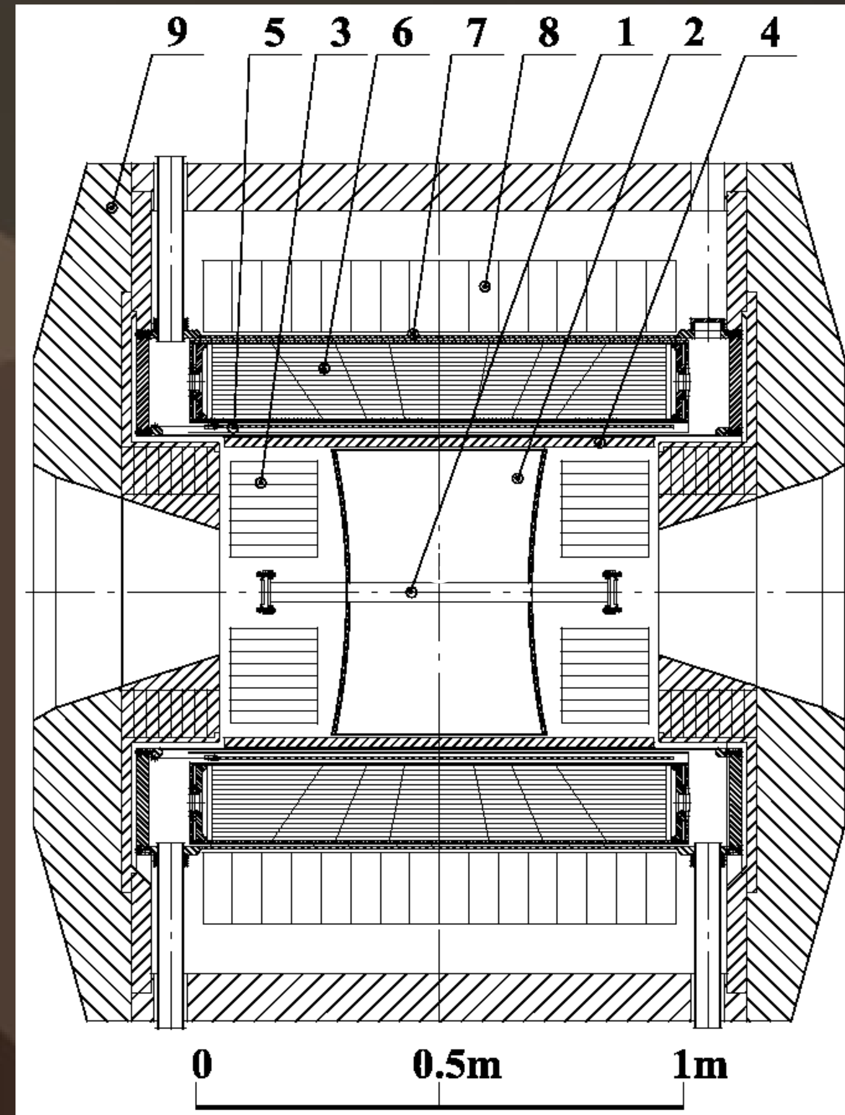
Energy deposition in clusters for elastic Bhabha scattering


B
A
C
D
Endcap 1
Endcap 2
X
X


Endcap 1
Endcap 2
X
X

CMD-3 Detector





1 – beam pipe; 2 – drift chamber; **3 – BGO endcap calorimeter**; 4 – Z–chamber; 5 – superconducting solenoid; 6 – LXe barrel calorimeter; 7 – TOF; 8 – CsI barrel calorimeter; 9 – yoke.