Combined Xe – CsI calorimeter of CMD3 detector

V. Shebalin
on behalf of CMD3 collaboration

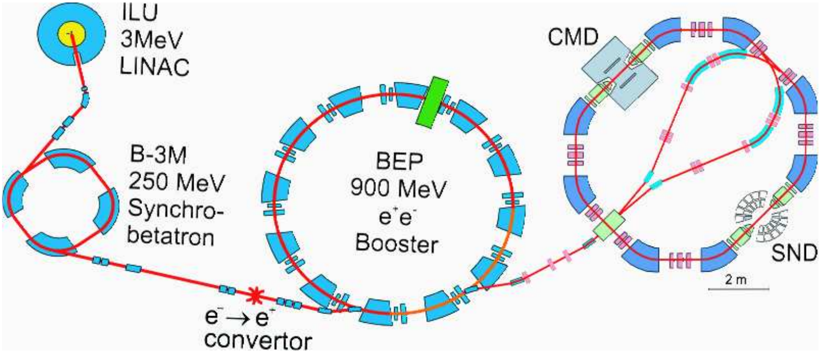
Budker Institute of Nuclear Physics, SB RAS

INSTR2014

Outline

- CMD-3 detector
- LXe calorimeter
- CsI calorimeter
- Cosmic calibration
- Bhabha calibration
- Clusters reconstruction
- Photon energy and coordinate correction
- Conclusion

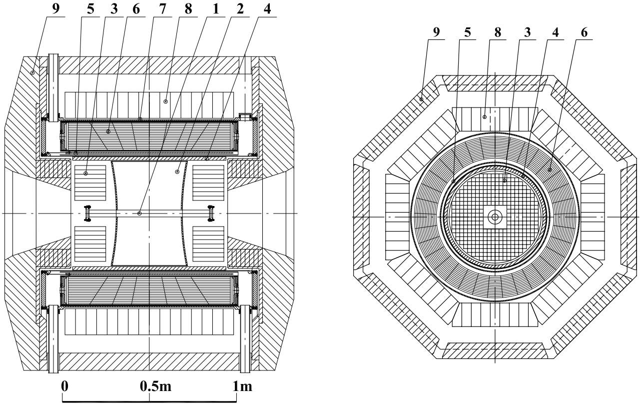
VEPP-2000



VEPP-2000

- e^+e^- collider
- $E_{c.m.s.} = 0.3 \div 2\text{GeV}$
- SND and CMD3 detectors are mouned at interaction points
- $L_{project} = 10^{32}\text{cm}^{-2}\text{s}^{-1}$, $L_{exp.max} = 2 \cdot 10^{31}\text{cm}^{-2}\text{s}^{-1}$
- 2010-2013 year of operation: $L_{int}(\text{CMD3}) \approx 60\text{pb}^{-1}$

CMD3 detector



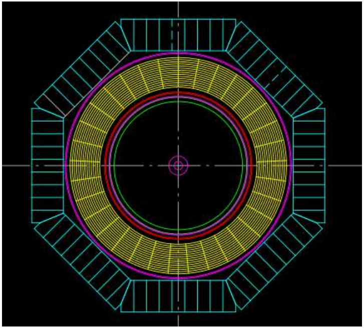
1 – beam pipe, 2 – drift chamber(DC), 3 – BGO endcap calorimeter, 4 – Z-chamber, 5 – superconduction solenoid, 6 – Liquid Xe(LXe) barrel calorimeter, 7 – TOF, 8 – CsI barrel calorimeter, 9 – Yoke

- Magnetic spectrometer, B = 13kGs
- Thin cuperconducting solenoid is mounted in the same vessel with LXe calorimeter. Passive material in front of barrel calorimeter is $0.35X_0$ (6.27g/cm^2)
- 3 calorimeter systems: barrel LXe and CsI calorimeters and endcap BGO calorimeter

Combined barrel calorimeter

Tasks

- Measurement of photons energy in wide range from 10MeV upto 1GeV
- Measurement of photons coordinates
- Form a signal for neutral trigger



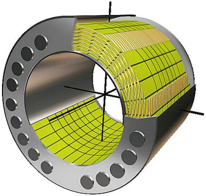
Advantages

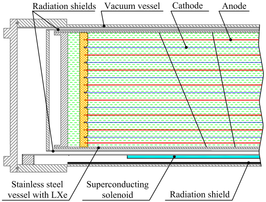
- LXe strips structure provides high spatial resolution, allows measurement of specific energy loss and shower profile
- Full thickness of barrel calorimeter is $13.5X_0$ and provides energy resolution of 8% for 200MeV and 4% for 1GeV energy deposition

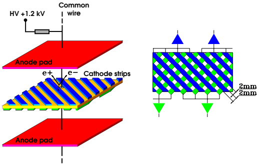
Disadvantages

- Passive material between LXe and CsI is $0.25X_0$

LXe calorimeter





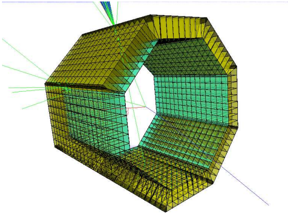


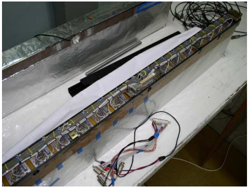
Calorimeter structure

- 14 cylindrical ionization chambers devided by 15 electrodes with 10.2mm gap
- 8 anodes and 7 cathodes
- Anodes are devided into 264 towers provide energy measurement:
  8 towers along Z axis
  33 towers along azimuth angle
- Cathodes are devided into 2112 strips to measure coordinate
- Strips on opposite sides of cylinder are mutually perpendicular
- Thickness – $5.4X_0$

LXe calorimeter is desctibed in details in K.Mikhailov poster

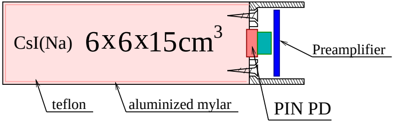
CsI calorimeter



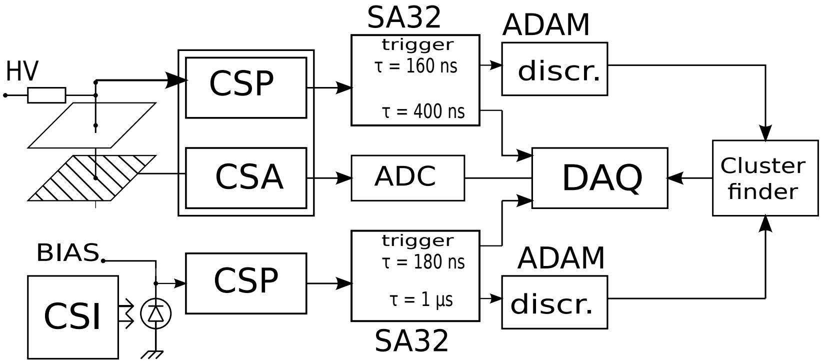


Calorimeter structure

- 8 octants × 9 modules × 16 counters
  1152 counters in total
- Counters are made of CsI(Tl) or CsI(Na) crystals
- Scintilation light is read out by Hamamatsu PIN PD mounted on the surface of the crystal
- PIN PD sensitive area is $10 \times 20\text{cm}^2$
- Active material thickness – $8.1X_0$



Calorimeter electronics



Calibration of energy deposition

Task

$$E_i = k_i(A_i - p_i)$$

k_i is to be determined

Calibration steps

- Calibration with pulse generator:
  - p_i determination
  - electronics stability monitoring
- Calibration with cosmic particles of LXe and CsI calorimeters
- Final LXe calibration with events of e^+e^- elastic scattering (Bhabha calibration)

Cosmic calibration

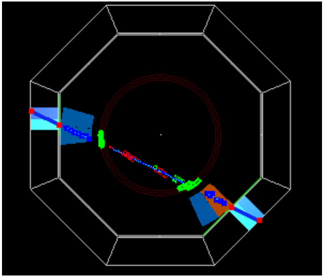
Method

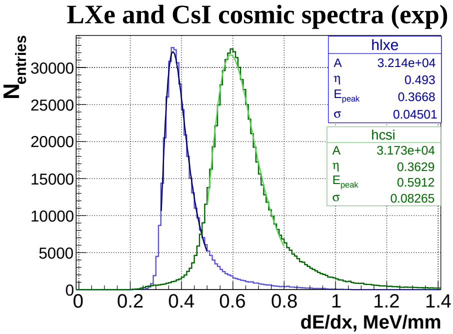
- LXe track crosses only one LXe tower or CsI crystal
- 3×3 matrix with the center in the crossed tower(crystal)
- $E_{center} > 20$ MeV
- $(E_{3\times3} - E_{center}) < 10$ MeV

$$\epsilon = E_{3\times3}/L$$

$$f(\epsilon) = A\, e^{\frac{-\ln^2(1+\eta(\epsilon - E_p)/\sigma)}{2\sigma_0}}$$

$$k_i = E_p^{MC}/E_p^{exp}$$

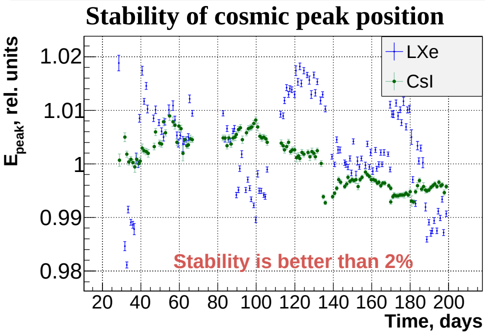




Cosmic calibration

- Cosmic events from standard experimental runs that pass the trigger are used. Cosmic events rate $\nu \approx 70\text{Hz}$
- Calibration for each channel with statistical error of about 1.5% for LXe and 3% for CsI. Data taking takes about 2 weeks.
- Day-by-day calibration – normalization coefficient for 8 LXe towers(same azimuth angle) or for whole CsI calorimeter is measured.

Before day-by-day calibration:

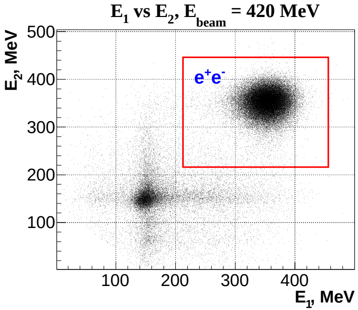


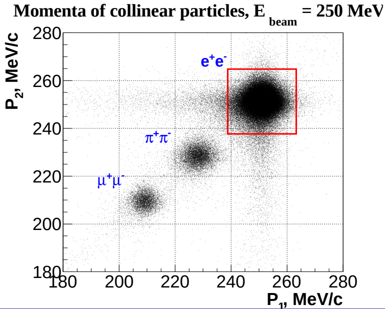
After day-by-day calibration coefficients are applied the stability is better than 0.5%

Bhabha calibration

Events selection

- 2 tracks in DC
- $|\theta_1 + \theta_2 - \pi| < 0.05$
- $|\phi_1 - \phi_2| < 0.05$
- $|\mathrm{p} - \mathrm{E_{beam}}| < 3 \cdot \sigma_\mathrm{p}$
- $\mathrm{E_{beam}}/2 < \mathrm{E}_{1,2} < 1.05 \cdot \mathrm{E_{beam}}$





Bhabha calibration

LXe coefficients

$$\chi^2 = \sum_{n=1}^{N} \frac{(E^j_{mc}(\theta,\phi) - \sum E^n_i k_i - E^n_{CsI})^2}{\sigma^2(\theta)}$$

$$\chi^2 \to \min$$

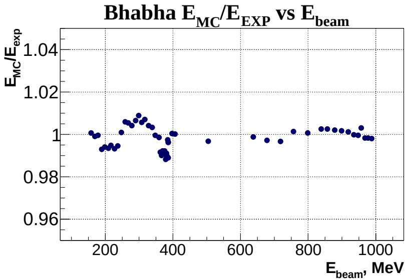
$$\frac{\partial \chi^2}{\partial k_i} = 0 \Rightarrow \sum_j k_j Q_{ij} = R_i,$$

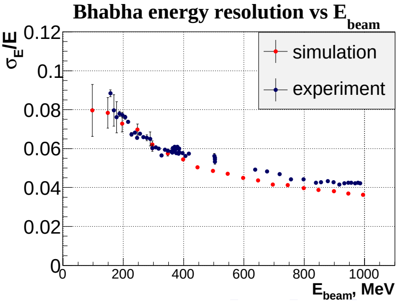
$$Q_{ij} = \sum_{n=1}^{N} \frac{E^n_i E^n_j}{\sigma^2}, R_i = \sum_{n=1}^{N} \frac{E^n_i E^n_{mc}}{\sigma^2}$$

$$k_i = \sum_j R_i (Q^{-1})_{ij}$$

n - event number, i, j - LXe channel indexes

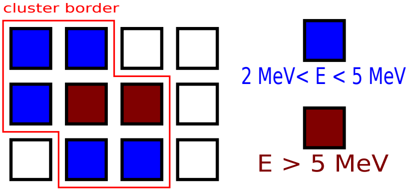
After the calibration is done:

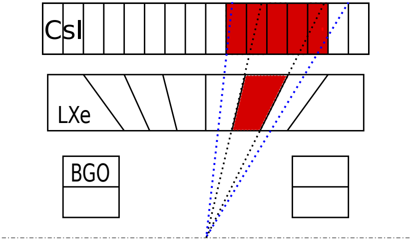




Cluster reconstruction

Because of the combined structure of calorimeter the clusters in diferrent subsystems have to be connected by some algorithm





Algorithm(both subsystems)

- For elements with E $>$ 5 MeV, neighbour elements are added to cluster if its energy $>$ 2 MeV
- Elements decided as 'neighbours' if they have common sides

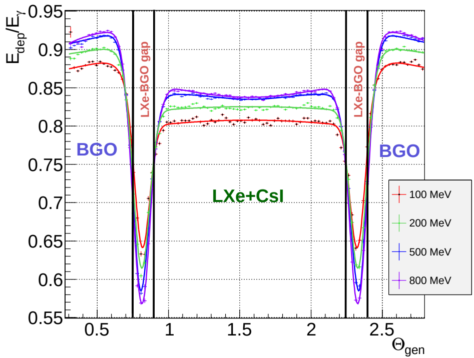
LXe-CsI connection

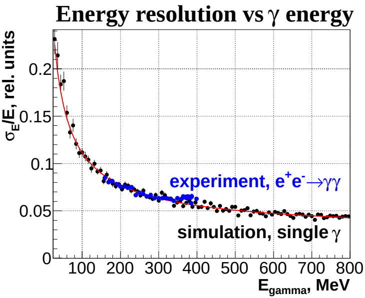
- CsI crystal is 'neighbour' to LXe tower if its center is inside the tower solid angle
- If CsI crystal neighbour to tower is hitted, than it is connected to the corresponding LXe cluster

Photons energy corrections

γ energy

- $E_{gamma} = f(E_{dep}, \Theta, \phi)$
- $f(E_{dep}, \Theta, \phi)$ is determined from simulation of single photons energy deposition





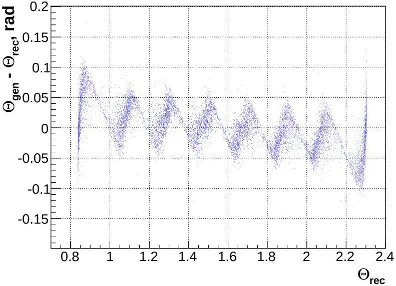
- Energy deposition E_{dep} is tabulated for 50 points of photon energy and 200 points by polar angle θ
- For measured energy deposition E_{dep} the photon energy is determined by linear aproximation

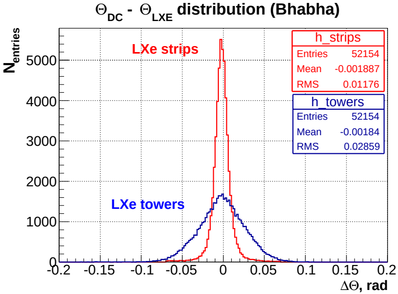
Photons coordinate correction

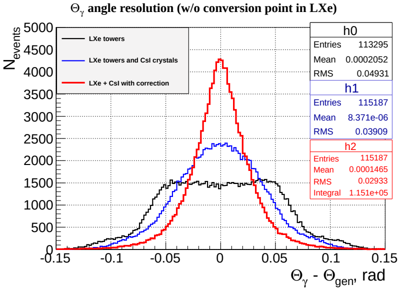
γ angles

- If the gamma conversion point is measured using LXe strips - no correction is needed (∼95% of photons)
- If there is no strips data:
  $x_i = \sum_{n=1}^{N} x_i^n E^n$, N - number of LXe and CsI channels in cluster
- Correction function for gamma angles w/o strip data is determined from simulation

No strip data for a cluster:



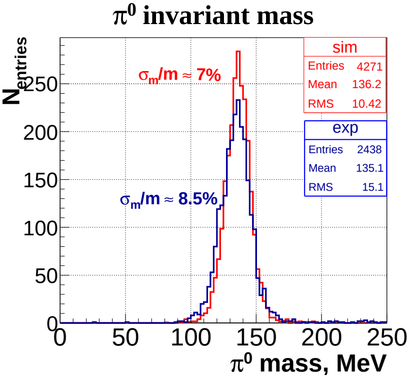


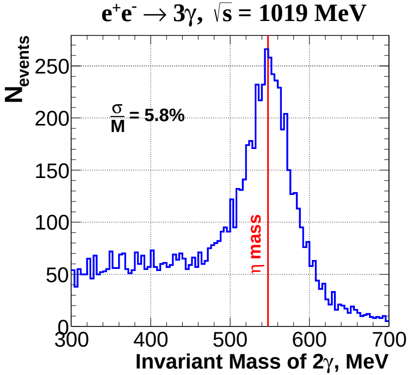


π^0 and η mass resolution

- $e^+e^- \to \pi^+\pi^-\pi^0$, $\pi^0 \to \gamma\gamma$
- $E_{cm} = M_\phi$

- $e^+e^- \to \eta\gamma$, $\eta \to \gamma\gamma$
- $E_{cm} = M_\phi$

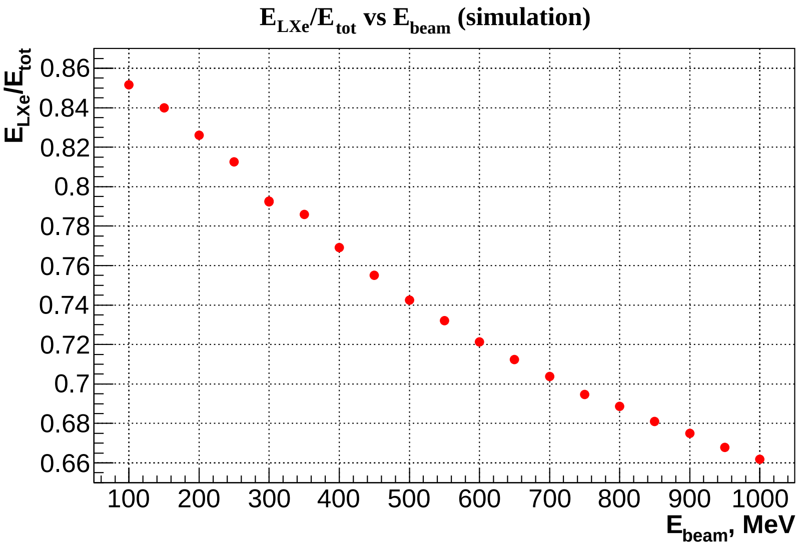




Conclusion

- Combined barrel calorimeter is working and shows good perfomance
- Energy calibration procedure of LXe and CsI calorimeters is developed
- Calibration accuracy is about 1% and 3% for LXe and CsI correspondingly
- Energy and coordinate correction functions for photons are determined
- The π^0 mass resolution is measured to be 8.5%

E_{LXE}/E_{total} ratio



Photons energy and coordinates resolution