Calorimetry at the CMD-3 Detector

Georgiy Razuvaev
on behalf of the CMD-3 collaboration

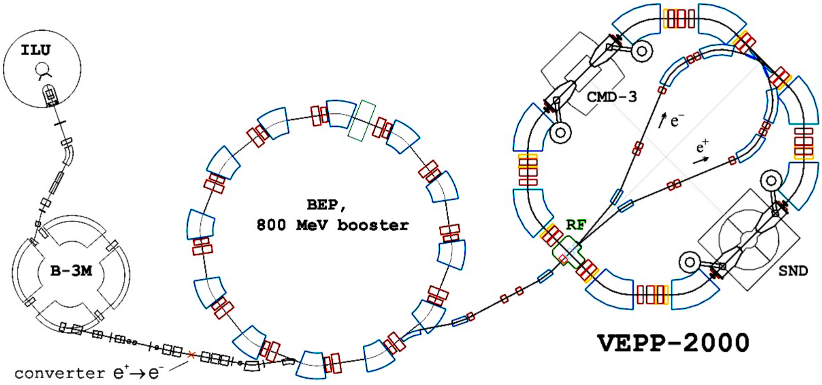
Budker Institute of Nuclear Physics
Novosibirsk, Russia

August 2016

Outline

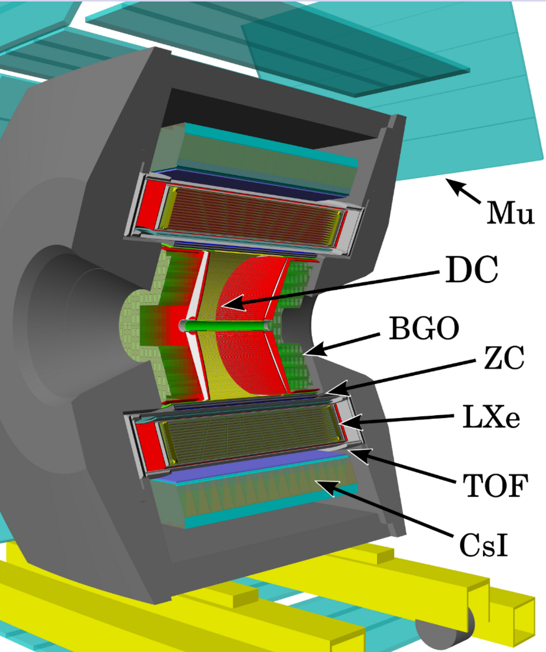
- VEPP-2000
- CMD-3
- Calorimeters Structure
- Cluster Reconstruction
- Electronics
- Calibrations
- Performance
- Perspectives
- Conclusion

VEPP-2000



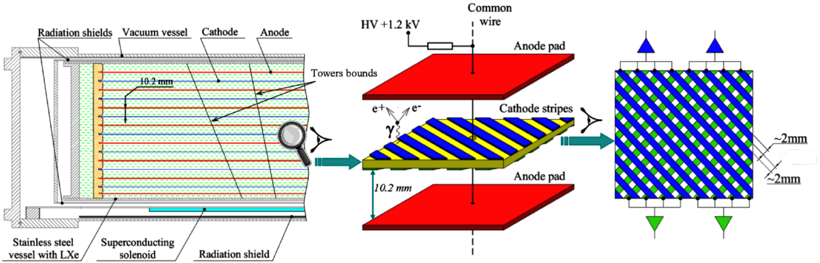
- $\sqrt{s} = 0.3\text{–}2\,\mathrm{GeV}$
- round beam optics
- beam current — 0.2 A
- beam length — 3.3 cm
- beam energy spread — 0.7 MeV
- $\mathcal{L} = 1 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ at $\sqrt{s} = 2\,\mathrm{GeV}$
- $\mathcal{L} = 2 \times 10^{31}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ at $\sqrt{s} = 1\,\mathrm{GeV}$

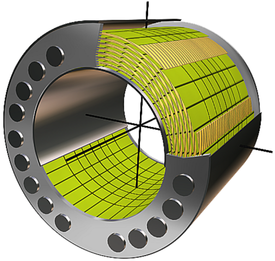
CMD-3 & Physical Program



- $R = \dfrac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}$
- $\sigma(e^+e^- \to 2h, 3h, 4h, ..)$, where $h = \pi, K, \eta, ..$
- $\rho', \rho'', \omega', \omega'', \phi', ..$
- CVC test
- $n\bar{n}$, $p\bar{p}$, formfactors and resonances
- ISR: $e^+e^- \to \gamma\gamma^*$ with $\gamma^* \to hadrons$
- 2γ physics: $e^+e^- \to e^+e^- + hadrons$
- Test of high order QED: $2 \to 4, 5$

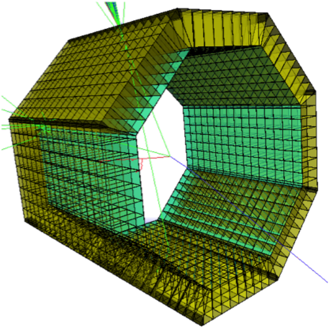
LXe Calorimeter

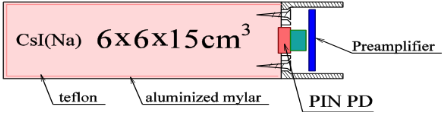




- Solid angle: $0.8 \times 4\pi$
- 8 cylindrical anodes: 264 towers
- 7 cylindrical cathodes: 2112 strips
- Thickness: $5.4\,X_0$

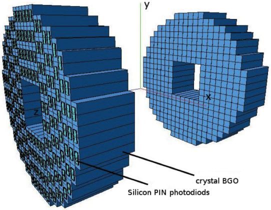
CsI calorimeter

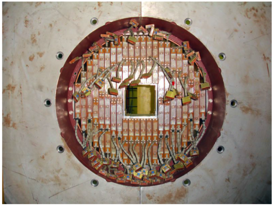


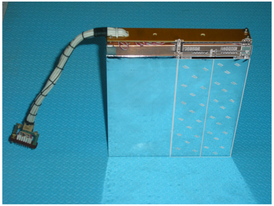


- Solid angle: $0.7 \times 4\pi$
- 1152 counters based on CsI(Tl) and CsI(Na) crystals
- Crystal size: $6\,\mathrm{cm} \times 6\,\mathrm{cm} \times 15\,\mathrm{cm}$
- Thickness: $8.1\,X_0$

BGO calorimeter







- Polar angle range: 16°–49° and 131°–164°
- Solid angle: $0.3 \times 4\pi$
- 680 BGO crystals
- Crystal sizes: $2.5\,\text{cm} \times 2.5\,\text{cm} \times 15\,\text{cm}$
- Thickness: $13.5\,X_0$

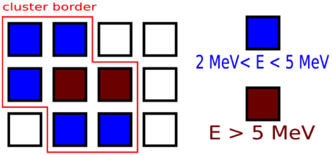
Calorimeter Parameters

	LXe	**CsI**	**LXe+CsI**	**BGO**	**LXe+CsI +BGO**
Solid angle	$0.8 \times 4\pi$	$0.7 \times 4\pi$	$0.7 \times 4\pi$	$0.3 \times 4\pi$	$0.94 \times 4\pi$
Thickness	$5.4\,X_0$	$8.1\,X_0$	$13.5\,X_0$	$13.5\,X_0$	
# of channels	2112 strips 254 towers	1152	3518	680	4198
Total mass	1200 kg 400 L	2500 kg	3700 kg	450 kg	4150 kg

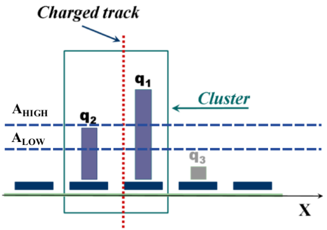
Passive material before LXe: $0.35\,X_0$
Passive material between LXe and CsI: $0.25\,X_0$

Cluster Reconstruction

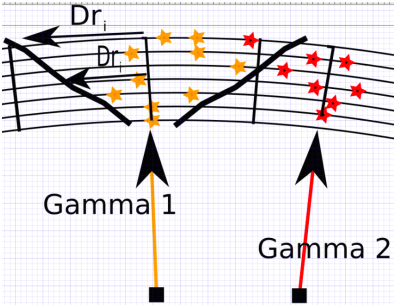
Crystals & Towers



Strips

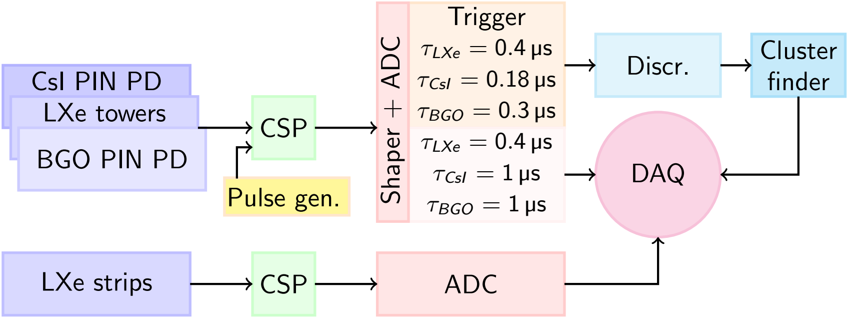


Close Photons Reconstruction



Strip information are used to distinguish two photons. It is a new algorithm under development.

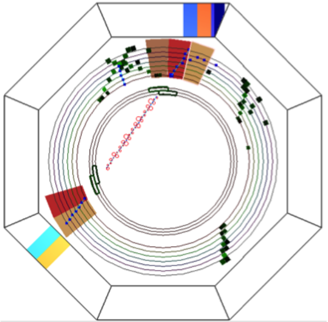
Electronics Layout

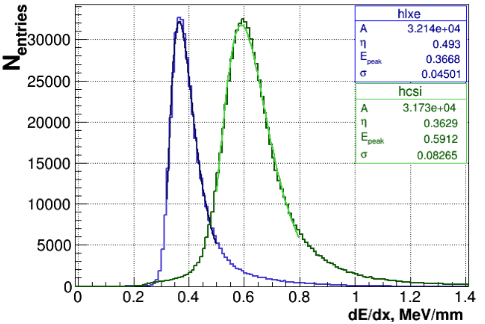


Calorimeters Calibration

LXe+CsI		BGO
LXe	CsI	
Preliminary calibration w/ a pulse generator		
Measurement of the pedestals, electronic gains and noises		
	Calibration w/ cosmic in special runs	
Calibration during data taking		
Calibration w/ cosmic		
Calibration w/ $e^+e^- \to e^+e^-$		Absolute energy calibration w/ $e^+e^- \to \gamma\gamma$

Barrel Cosmic Calibration

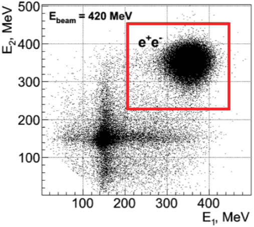


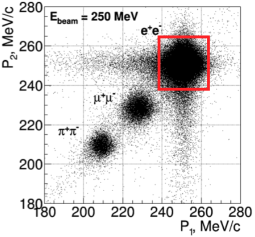


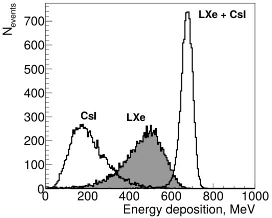
- Cosmic particle events in experimental runs
- Tracks in LXe are used
- Path length L_{LXe}, L_{CsI}

- Distribution of $\epsilon = E/L$
- Calibration coefficients $k_i = E^{MC}_{peak}/E^{EXP}_{peak}$

Barrel $e^+e^- \to e^+e^-$ Calibration

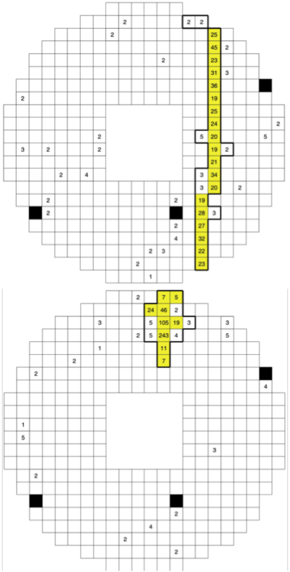






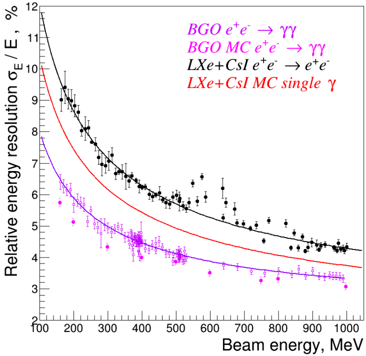
- n — event number; i, j — LXe channel indexes
- $\chi^2 = \sum_n^N \left[E_j^{MC}(\theta, \varphi) - \sum E_i^n k_i - E_{CsI}^n\right]^2 / \sigma^2(\theta)$
- $\chi^2 \to min$
- $\frac{\partial \chi^2}{\partial k_i} = 0 \implies \sum_j k_j Q_{ij} = R_i$
- $Q_{ij} = \sum_{n=1}^N E_i^n E_j^n / \sigma^2,\ R_i = \sum_{n=1}^N E_i^n E_{MC}^N / \sigma^2$
- $k_i = \sum_j R_i (Q^{-1})_{ij}$

BGO Cosmic Calibration



- Only events without charge trigger are used to suppress $\mu^{\pm}$'s and $\pi^{\pm}$'s with a large angle to the vertical direction
- 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)
- 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 %

Energy Resolution



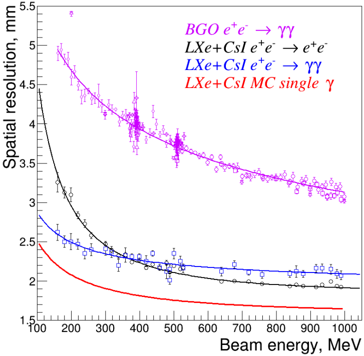
LXe+CsI

- No tracks in DC are detected
- Two clusters in the barrel calorimeter
- $|\theta_1 + \theta_2 - \pi| < 0.1$ and $|\varphi_1 - \varphi_2| < 0.1$
- $0.5 < E_{1,2}^{depos}/E_{beam} < 1.05$
- $\sigma_E/E = 0.034/\sqrt{E[\mathrm{GeV}]} \oplus 0.020$

BGO

- No hits in DC are detected
- Two most energetic clusters are collinear and in different endcaps
- $E_1^{depos} + E_2^{depos} > E_{beam}$
- $\sigma_E/E = 0.024/\sqrt{E[\mathrm{GeV}]} \oplus 0.023$

Spatial Resolution



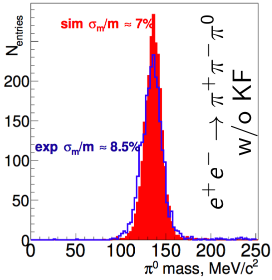
LXe+CsI

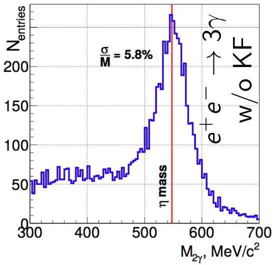
- $\sigma^{strips}_{\varphi,\,\theta}[\text{mrad}] = 3.7 + \frac{0.33}{0.25+E[\text{GeV}]}$
  $\sim$95 % of barrel hits
- $\sigma^{towers}_{\varphi(\theta)}[\text{mrad}] = 37(41) + \frac{3.6(3.5)}{100+E[\text{GeV}]}$
  $\sim$5 % of barrel hits

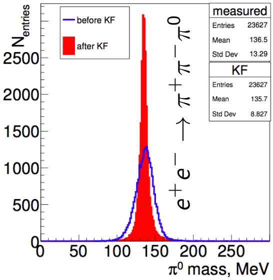
BGO

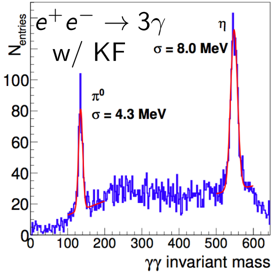
- $\sigma_x[\text{mm}] = 0.197 \oplus \frac{3.12}{\sqrt[4]{E[\text{GeV}]}}$

Experimental Results









Perspectives for Future Projects

- The experience of development, construction, maintenance and performance of the complex calorimetry is helpful for development of the future $c - \tau$ electromagnetic calorimeter.
- The $c - \tau$ factory is supposed to use a CsI(Tl) calorimeter.
- The option of a liquid noble gas based calorimeter with strip read-out is a good opportunity to increase the precision of photon conversion point measurement.

Conclusion

- The calorimeters have been installed into the CMD-3 detector and participated in data tacking since 2010
- The calibration procedures of the calorimeters have been developed and used during all 3 physical seasons
- The energy reconstruction procedures has been developed and applied
- The energy resolutions at 1 GeV have been determined $\sim$4.5 % in the barrel calorimeter and $\sim$3.5 % in the endcap calorimeter
- The spatial resolutions at 1 GeV have been determined $\sim$2 mm in the barrel calorimeter and $\sim$3 mm in the endcap calorimeter

Thank you!