Liquid Krypton Calorimeter for KEDR

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The technique of electromagnetic calorimeter based on liquid noble gases is in progress for many years in the Budker Institute of Nuclear Physics (Novosibirsk). As a result of these efforts, the Liquid Krypton (LKr) calorimeter for the KEDR detector was constructed. The total amount of LKr is 27 tons. The results of the first year of operation of the calorimeter for the KEDR experiment are presented. The energy and spatial resolutions are discussed.

1. Introduction

An ionization chamber with noble liquid gas as working media is one of the oldest and well-known detectors [1]. However, the liquid krypton (LKr) was long time outlaw because of the small contamination of natural krypton by the β-radioactive isotope ^{85}Kr with the edge spectra energy of 0.67 MeV. The event of β-decay produces ionization in the gap of the chamber and it is an extra source of noise. Therefore the liquid krypton was considered to be inappropriate for calorimetry. However, the experiments with the prototypes of a full absorption calorimeter based on liquid krypton, performed in BINP(Novosibirsk), demonstrated that the energy resolution can be comparable with crystal calorimeters [2, 3, 6, 7]. In addition, the spatial resolution of LKr calorimeter for photons is mush better due to the measuring of the photon conversion point position [8]. As the outcome of the experiments with the prototypes, the LKr calorimeter for KEDR detector was designed [4, 5, 9].

The main advantages of the liquid ionization detectors as spectroscopic instruments are the following:

- Robustness
- Calibration simplicity (no intrinsic amplification, uniformity)
- High level of segmentation
- Radiation hardness.

2. Calorimeter design

The electromagnetic calorimeter of the KEDR detector [9] contains two parts: the end-cap based on CsI crystals and the barrel made of LKr ionization chambers. The layout of the LKr calorimeter is shown in fig. 1. The inner radius is 75 cm, the thickness is 68 cm (15 X_0), the length is about 3 m. To diminish the amount of LKr required, special aluminum rings are placed inside the cold barrel close to flanges and outer surface of the cylinder so that the LKr thickness is the same in any direction for particles originating from the interaction point. It saves about 5 tons of LKr, and total amount is 27 tons.

The electrode system is inserted into a hermetic aluminum vessel, which is located inside another one made of stainless steel. The space between the two vessels is occupied by shield-vacuum thermoinsulator. The cooling of the cryostat is provided by liquid nitrogen flowing through the tubes welded to the walls of the internal vessel. The entrance wall of the cryostat contains 1 mm of stainless steel an 14 mm of aluminum.

The layout of the electrode structure is shown in fig. 2. The electrodes of the ionization chambers are made of G10 foiled with copper and their thickness is 0.5 mm of G10 plus 2×18 μm of Cu. The 19.5 mm gaps between the electrodes are formed by cells of thin G10 spacers. The signal is read out from high voltage electrodes, divided into rectangular pads, forming towers, oriented to the interaction point. The entrance size of the towers is 10×10 cm^2. In the radial direction all the towers are divided into three sections. The odd electrodes of the first section (30 cm thick) are divided into strips of about 5 mm width. The strips orientation is along the beam line direction (z-axis) in four electrodes and along orthogonal direction (ϕ) in the other four. The strips are used for the photon coordinates measurement. The width of the towers and z-strips is increased along z-axis providing the uniform resolution in polar angle.

3. Electronics

The ionization chambers of the calorimeter are operated in the electron-pulse mode. The electron drift time in an electric field of 0.5 kV/cm is 10 μs. The measurement of the collected charge is provided

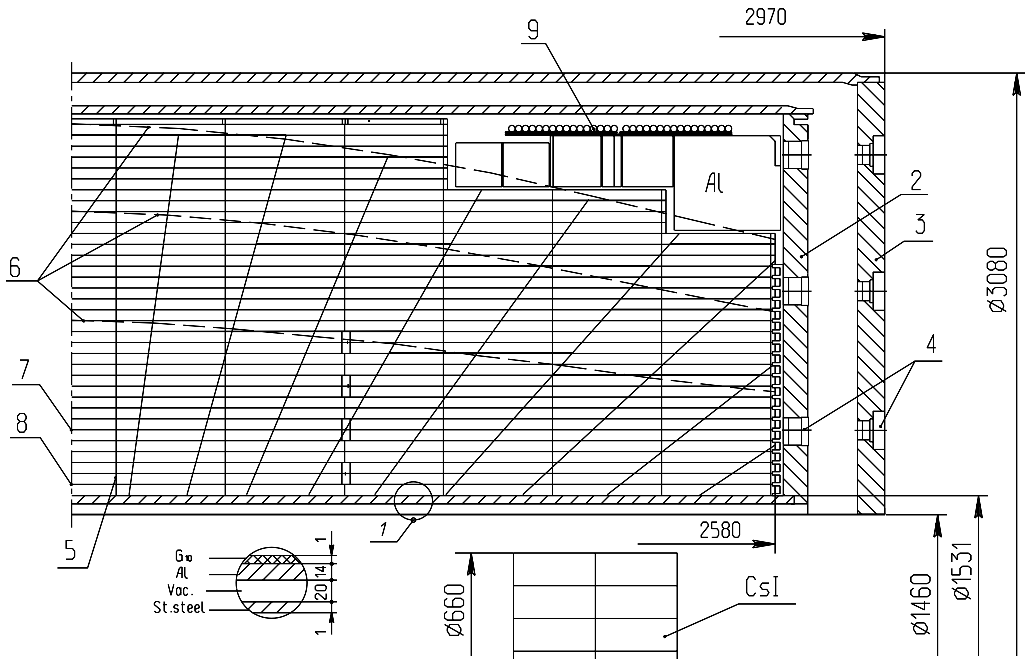

Figure 1: The layout of the LKr calorimeter. 1 — entrance wall, 2 — cold flange, 3 — warm flange, 4 — multipin connectors, 5 — spacers, 6 — lines of equal thickness, 7 — strip electrode, 8 — high voltage (tower) electrode, 9 — high voltage plates.

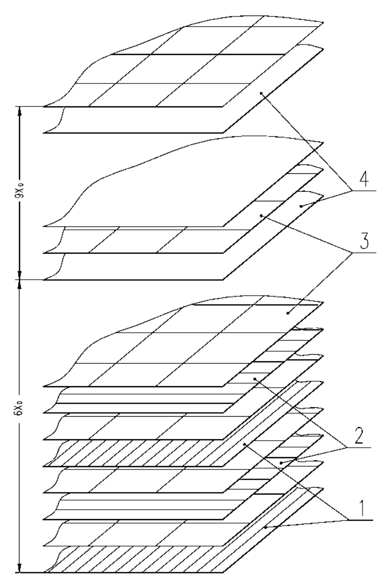

Figure 2: The scheme of the electrode structure. 1 — z-strips, 2 — ϕ-strips, 3 — towers, 4 — grounded electrodes.

by the charge sensitive preamplifiers based on FET NJ1800D. The preamplifiers are assembled on motherboards mounted on the warm flanges of the cryostat. All the preamplifiers are connected to the signal electrodes through cold and warm multipin connectors. Each motherboard contains 48 preamplifiers.

The signal from the preamplifier is fed to the RC-2CR shaper by twisted pair of 40 m length. The amplitudes are digitized by 12-bit analogue-to-digit converter (ADC) operating in the peak detector mode. To cover the full dynamic range, we use two ADC with high and low sensitivities (0.1 and 1 MeV/ADC count, respectively) for each tower channel. The total number of electronics channels is 7240; There are 2304 towers, 1864 z-strips and 3072 ϕ-strips.

3.1. Calibration

The relative calibration of electronics are performed by injecting the known amount of charge to the preamplifier input through precisely measured capacitance (nominal value is 6 pF). During the calibration procedure we measured the pedestal, linearity and the gain of each electronic channel. The calibration constants are determined by the linear fit of the channel response to the test pulse. We use the special calibration generators which simulate the shape of current pulse, produced by a real particle in the calorimeter. We have 38 such calibration generators.

The calibration capacitances were measured with the accuracy of 0.3%. The nonlinearity of the electronics was measured to be less than 0.2 and 2 MeV for channels with high and low sensitivities, respectively. These two factors and the uncertainties in the

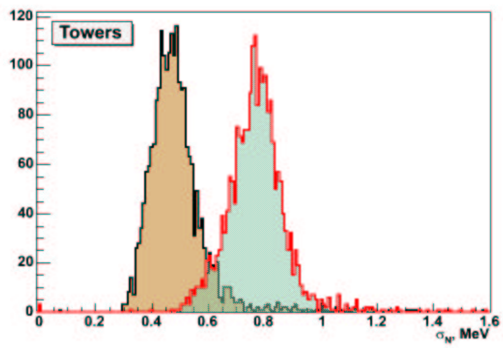

Figure 3: The distribution of the measured noise for all tower channels in LKr calorimeter. The full histogram is for the high voltage switched off,the semitransparent histogram is for the high voltage switched on.

relative calibration of the special generators determine the accuracy of the relative calibration of electronics.

3.2. Noise

There are three different sources of the noise: the electronic noise, the LKr radioactivity and the coherent noise.

The electronic noise has to be treated together with the LKr radioactivity because the noise of radioactivity depends on the shaping time. The detailed evaluation of the electronic noise and radioactivity contribution to the LKr calorimeter energy resolution was performed in [10]. Since the value of the radioactivity noise rises with the shaping time increasing as $\sqrt{\tau}$ and the electronic noise decreases with τ, there is the optimal shaping time minimizing the sum of these effects. For the parameters of liquid krypton we have, the optimal shaping time for tower channels is about 1.5 μs. For the strips channel, the noise of radioactivity is much smaller because of the small detection volume. Therefore, to reduce the electronic noise, the shaping time of 4.2 μs for the strip channels was selected.

The distributions of the measured noise for all tower and strips calorimeter channels are shown in fig. 3 and 4, respectively. The full histograms are for the high voltage switched off (only electronic noise) and the semitransparent histograms are for the high voltage switched on (electronic noise and radioactivity). The total value of electronic noise and radioactivity is less then 1 MeV for the tower channels and it is less then 0.6 MeV for the strip channels.

The pick-up noise in electronic channels is tested in the process of the electronic calibration and its level is less than 0.2 MeV.

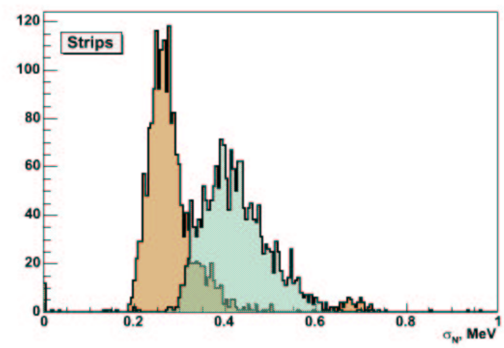

Figure 4: The distribution of the measured noise for all strip channels in LKr calorimeter. The full histogram is for the high voltage switched off,the semitransparent histogram is for the high voltage switched on.

4. Calorimeter performance

The KEDR detector carries out the experiments at the e^+e^- collider VEPP-4M [11] in the charmonium states energy region and close to the threshold energy of tau lepton pair production. The first cycle of the experiments was devoted to the new precision measurements of masses of the charmonium states [12, 13]. The resonant depolarization method for the beam energy calibration is used [15]. At the moment, the KEDR carries out the experiment on the precise measurement of τ lepton mass [14]. The measured energy dependence of the τ pairs production cross section is used for the mass determination.

The LKr calorimeter has started the full-scale operation, as the part of the KEDR, in 2004. Some key parameters, characterizing the calorimeter performance, were obtained using the experimental data.

4.1. Energy resolution

The energy resolution of LKr calorimeter in the large energy range was measured with the Bhabha scattering events. In fig. 5 the distribution of the deposited in calorimeter energy for these events is shown. The energy resolution is equal to $(3 \pm 0.1)\%$. The expected value from Monte Carlo simulation for 1.8 GeV is 2.4%.

The energy resolution in the small energy range is reflected in the resolution of the π^0 meson mass, reconstructed in calorimeter, because of the low energy spectra of π^0 mesons originated from Ψ meson decays. In fig. 6 and 7 the distributions of the two photons invariant mass reconstructed in calorimeter are shown. The first distribution is for the photons coordinates reconstructed using only tower amplitudes, the second one is for the photons coordinates reconstructed using the strip structure of the calorimeter. In the second

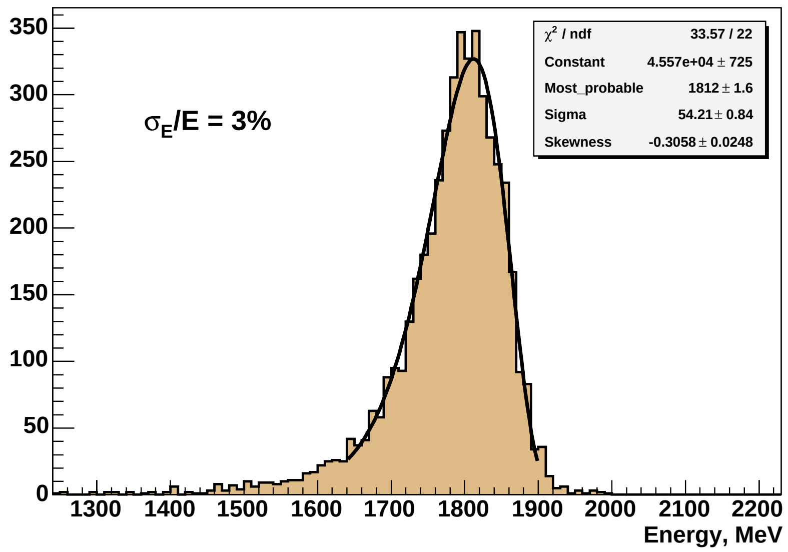

Figure 5: The distribution of the deposited in calorimeter energy for the Bhabha scattering events. The beam energy is 1.8 GeV.

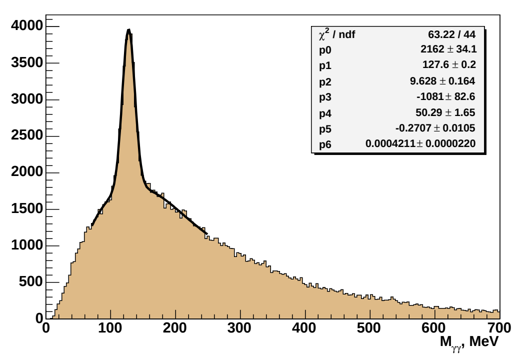

Figure 6: The distribution of the two photons invariant mass reconstructed in calorimeter. The photon position is determined by the tower cluster center of gravity.

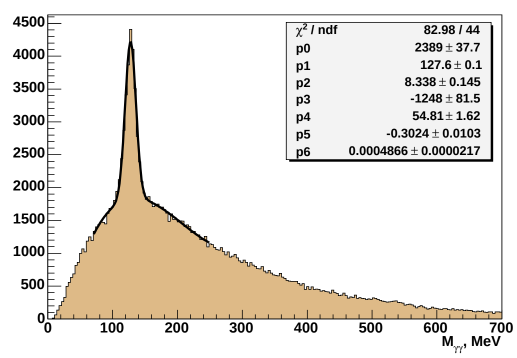

Figure 7: The distribution of the two photons invariant mass reconstructed in calorimeter. The photon position is determined in the strip structure of the calorimeter.

case, the spatial resolution of the reconstructed photon position is much better and therefore the resolution of the reconstructed π^0 meson mass is improved from 9.6 ± 0.2 MeV to 8.3 ± 0.2 MeV. The Monte Carlo simulation gives 9.0 ± 0.1 MeV and 7.6 ± 0.1 MeV, respectively.

4.2. Space resolution

The space resolution of the LKr calorimeter was only measured for minimum ionization particles using the data of the cosmic ray runs. The tracks of cosmic muons are reconstructed in the strip structure of the calorimeter. Then, the distributions of the difference between the strip cluster coordinate and the reconstructed track position are filled for each layer of strips. In fig. 8 that sort of distributions are shown for three layers of ϕ strips. On the assumption that the space resolution is the same in these three layers, we can obtain it for middle (ϕ_2) layer as $\sigma_{exp} = 0.50 \times \sqrt{3/2} = (0.62 \pm 0.02)$ mm. The Monte Carlo gives $\sigma_{MC} = 0.44 \times \sqrt{3/2} = (0.54 \pm 0.02)$ mm.

The spatial resolution of the LKr calorimeter for photons was measured in the experiment with the prototype of the calorimeter. The details of this experiment were described elsewhere [7]. The space resolution of 1.3 mm at 0.2 GeV and 0.8 mm at 1.0 GeV has been obtained.

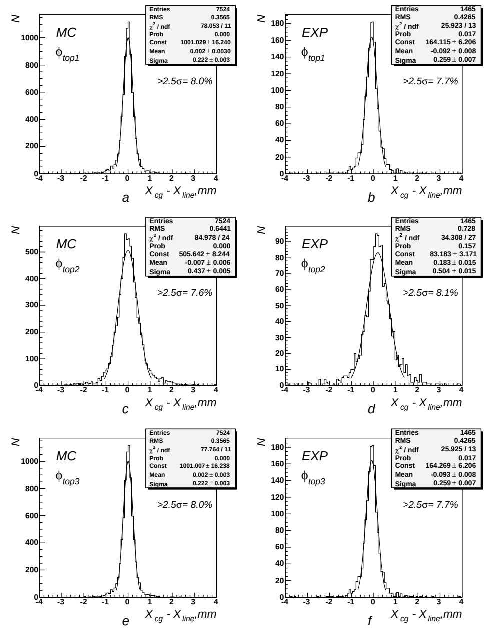

Figure 8: The distributions of the difference between the strip cluster coordinate and the reconstructed track position for three layers of ϕ strips.

5. Conclusion

The LKr calorimeter for KEDR detector was constructed and is operating for the experiments at the VEPP-4M collider. The obtained physical parameters of the calorimeter are close to the designed ones.

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