An Electromagnetic Calorimeter Based on Liquid Krypton with Tower Read-Out Structure

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Abstract

An electromagnetic calorimeter of novel design has been constructed for an experiment devoted to the study of the decays of neutral kaons. Experimental requirements, design choices, and some construction details are discussed, together with results obtained in a test run performed in Summer 1996.

I. THE EXPERIMENT NA48 AT CERN

The Experiment NA48 at CERN [1] is designed to study CP Violation in the decays of neutral kaons. The detector will measure $\pi^o\pi^o$ and $\pi^+\pi^-$ final states from decays of K_L and K_S mesons. Evidence for Direct CP violation appears as a deviation from unity in the *double ratio*:

$$R = \frac{\Gamma(K_L \to \pi^o\pi^o)}{\Gamma(K_S \to \pi^o\pi^o)} \Big/ \frac{\Gamma(K_L \to \pi^+\pi^-)}{\Gamma(K_S \to \pi^+\pi^-)}$$

The relative contributions of Direct and Indirect CP violation are given by the ratio ε'/ε, related to the double ratio by:

$$R = (1 - 6 \cdot Re\, (\varepsilon'/\varepsilon))$$

In order to achieve the required experimental sensitivity (0.1% in R), the detector is exposed to a K_L beam of high intensity ($\approx 6 \cdot 10^5$ decays per pulse of 2.4 s). Systematic uncertainties in acceptance and efficiency are reduced selecting the same fiducial decay volumes, and measuring the four decay channels simultaneously.

II. EXPERIMENTAL REQUIREMENTS ON CALORIMETER

Decays of K mesons into $\pi^o\pi^o$ are reconstructed imposing that the four photons detected by the calorimeter have invariant mass equal to the kaon mass, checking that the kaon candidate parent is collinear with the beam direction, and that gamma pairs can be reconstructed as originating from π^o decays. The main detector requirements can be classified as follows.

A. Background Rejection

In order to control the background to $K_L \to \pi^o\pi^o$ due to the copious $K_L \to \pi^o\pi^o\pi^o$, the detector must accurately reconstruct the invariant mass of photon pairs. This requires good resolution in the energy (better that 1% rms above 20 GeV), and in the shower transverse position (about 1 mm rms above 20 GeV). The photon energy range of interest is 3-100 GeV.

B. Boundary of Fiducial Volume

Since the decay coordinate z is obtained from energy and transverse position measurements in the calorimeter, the need of accuracy in the size of the fiducial decay volumes translates into the necessity of high precision in the absolute scale and in linearity, in both energy and position measurements. The geometry of the detector must be intrinsically very accurate (systematic deviations not larger than ±0.1 mm over distances of 1 m). Similarly, the non uniformity in the energy measurement should not exceed 0.5%, and the absolute energy scale must be calibrated to a few 0.01%.

C. Tower Read-Out

A read out based on longitudinal cells increases the ability to resolve showers close in position (in order to improve rejection of $3\pi^o$ background), and/or time (to reduce the effect of accidentals).

D. Time Measurement

The identification of K_L vs. K_S is obtained looking for coincidences between the time measurement performed by the calorimeter, and the signal from a beam hodoscope [2] placed on the proton beam line directed to the K_S target. A time resolution better than 0.5 ns rms on single showers is required.

III. BASIC DESIGN

We have chosen a detector based on liquid Krypton, guided by the following reasons:

1. Homogeneous detectors are characterized by smaller stochastic fluctuations;
2. The signal to noise ratio is large enough to allow short shaping time;
3. Gain-unity detectors are more stable and allow an accurate calibration of the read-out electronics;
4. A tower read-out is chosen in order to minimize shower overlapping and effects of accidentals.

The main physical properties of liquid Krypton are listed in Table 1. The read-out structure is formed by strips approximately parallel to the shower axis. The cross-section of each read-out cell is a square with side equal to 2 cm.

Compared to the most usual design in which the read-out electrodes are place orthogonal to the shower axis, our design is more demanding in terms of geometrical accuracy. This is because the *geometrical* gain of each cell is inversely proportional to the anode to cathode gap width, and an accuracy of

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Paper Presented at the *1996 IEEE Nuclear Science Symposium*, November 3-9, 1996, Anaheim CA

0.5 % (50 μm) is needed to achieve a response uniformity in the energy measurement at the level of a few 0.1% over the calorimeter face.

The finite thickness of the electrodes determines a dead volume which appears as a variation of response with the position of the shower axis inside the cell lattice. This effect is further increased by the limited band-width of the read-out electronics: the charge deposited in the active volume within ≈ 300 μm of the anodes is only partially measured by the *initial current* read-out, and the response for showers with axis laying on the anodes is about 4 % lower than the average [3].

Table 1
Properties of Liquid Krypton.

Density	2.41 g/cm^3
Radiation length	4.7 cm
Molière radius	4.7 cm
Boiling point at 1 bar	119.8 K
Radioactivity	500 Bq/cm^3
Electron drift velocity at 1.5 kV/cm (5 kV/cm)	0.27 cm/μs (0.36 cm/μs)
Dielectric constant	≈ 1.7

Our detector is optimized to cope with the two effects above, adopting the design shown in figure 1. The electrodes are formed by ribbons (Cu-Be, 40 μm thick) stretched between front and back plates, made of fiber-glass reinforced epoxy. The proper accuracy in gap width is achieved by the use of accurately machined 5 spacer-plates (fiber-glass reinforced epoxy, 5 mm thick), longitudinally spaced by 21 cm, which guide the ribbons in an *accordion* geometry. The accordion angle (± 48 mrad) is sufficient to reduce the non-uniformity to a smooth variation with amplitude of about ± 0.5 % [4].

IV. OTHER GENERAL CHARACTERISTICS

A. Detector Geometry

The active surface of the detector extends from the beam pipe (8 cm radius), to an octagonal outer boundary with inscribed circle of 128 cm radius. The total number of read -out cells is 13248, formed by 26632 ribbons. The transverse size of the cells increases linearly from the front-plate, across the spacer-plates, and to the end-plate, for a total variation of 1.1%. This corresponds to a projective geometry, as seen from the decay volume of the K_S beam, 110 ± 6 m upstream of the front-plate. This design provides the most uniform electrode geometry to photons from kaon decays, and makes the measurement of the shower axis insensitive to the depth of the initial conversion.

B. Cryostat

The detector is contained in a cryostat, formed by an outer aluminum vessel [5] and an inner stainless steel vessel. The thickness of the windows upstream of the active volume is equal to 4 mm (Al), and 2.9 mm (steel) respectively. The cold window was obtained from hydroformation, and the inner, concave side is filled by a honeycomb structure made in Aluminum and sealed from the krypton volume by a 0.5 mm steel foil. The thickness of the detector front-plate is 50 mm plus 3 mm corresponding to the average thickness of an additional plate, placed between the detector and the honeycomb filler, and designed to compensate for the deformation of the detector planarity due to the load from ribbons (5.4 tons), and that of the inner window, due to the liquid krypton pressure (1.1-1.9 bar) against the insulating vacuum. The total amount of material upstream of the active volume corresponds to 0.58 X_0.

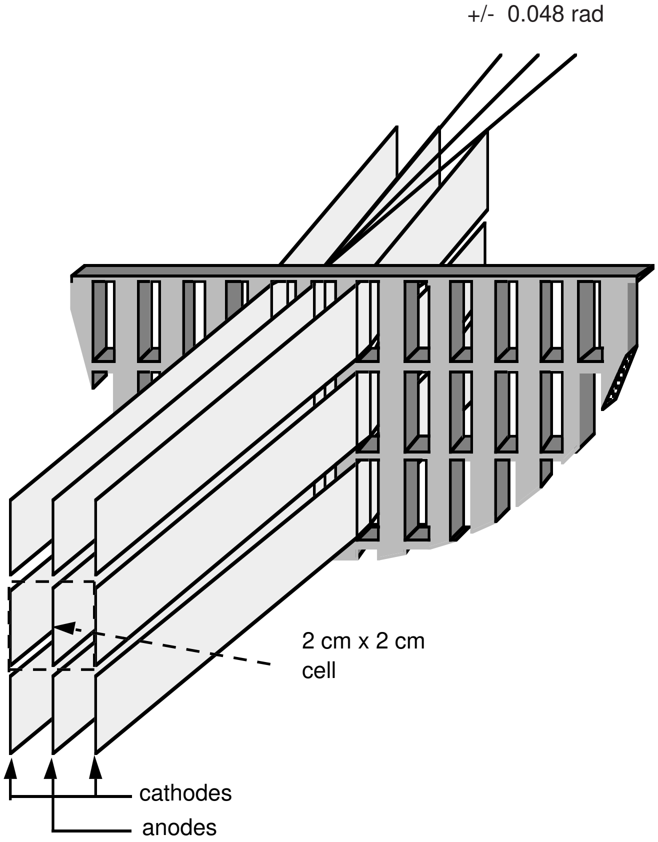

Figure 1: Detail of read-out cells with ribbon electrodes and spacer plate.

C. Cryogenics and Purification

About 9 cubic meters of liquid Krypton are contained in the cryostat at a temperature of 121 K. The temperature is maintained by liquefying the Krypton evaporated by thermal input to the cryostat, and bringing it back into the vessel [3]. Less than 1 liter of liquid is evaporated per minute. The vapor is continuously filtered [3]. A stable electron lifetime of about 40 μs has been achieved during 7 weeks of operation. This value is satisfactorily larger than the drift time across the read-out cells.

D. Scintillating Fibers Hodoscope

The calorimeter active volume contains an auxiliary detector, formed by scintillating fibers, mounted on the second spacer-plate. The fibers are grouped in bundles with diameter of 5.5 mm, and are contained in an epoxy-fiberglass tube, with outer diameter equal to 7 mm. The tubes are fixed to the spacer-plate, between planes of ribbons, which are separated by

9.93 mm. The fibers extend from the horizontal detector axis to the outer boundary, where groups of bundles are formed and directed to PM tubes located on the detector front-plate, outside the active volume. Whenever showers in the same half-detector will not overlay in the horizontal position, the scintillating fibers will provide a time measurement independent from that obtained from the ionization pulses.

V. CONSTRUCTION AND QUALITY CONTROLS ON DETECTOR ELEMENTS, AND ASSEMBLY

Tight requirements are placed on the construction of the detector components in order to achieve the geometrical accuracy discussed above, and quality test have been performed throughout construction and assembly.

The ribbon electrodes have been constructed from Cu-Be reels manufactured according to tight specification on flatness and straightness of edge-cut [6]. Both parameters were continuously monitored during electrode construction. A dedicated device unrolled the raw material, cut it at the required length, pressed corrugations in proximity the electrode ends, and provided proper termination for connections to electrode end-plates and read-out electronics. The corrugations near the ribbon ends are required to provide the electrodes with the mechanical compliance (0.7 N/mm) necessary to proper tensioning, solving problems related to deformation of detector end-plates, and to thermal contraction. The length (12 and 25 mm respectively on front and back end) and the amplitude of corrugations (± 1 mm) are small enough not to affect the performance of the detector [4].

The plates of the electrode structure have been produced from epoxy-fiberglass composite material [7], and built with an intense work at milling machines [8], [9]. The need to machine large surfaces, with tolerances in the 0.03-0.1 mm range, has forced us to consider a construction in two half-detectors. The machining of the spacers plates [9], which involved individually cutting 133160 slots, has taken 4 months, and has included a careful quality control on the delivered elements.

The assembly of ribbons and support structure has been done handling the ribbons in groups, corresponding to a plane of electrodes (253 planes in each half-detectors). Specific tools were used to handle simultaneously up to 128 ribbons, holding them by the mechanical/electrical connector at the downstream end, and to pass them across the slots in the 5 spacer-plates , and through holes in the end-plate.

Figure 2 shows one half-detector after ribbon assembly. The scintillating fibers are clearly visible, together with stainless steel rods holding the structure plates at the outer boundary. Final operations included coupling of the half-detectors around the beam-pipe, rotation about the detector axis by 90 degrees, final ribbon tensioning, installation of the read-out electronics on the back-plate, and insertion in the cryostat.

VI. READ-OUT ELECTRONICS

The electronic read-out is sketched in figure 3.

The front-end electronics [10] is directly mounted on the detector back-plate. This choice optimizes electronic noise and rapidity of signal extraction. The charge preamplifiers are based on Silicon J-FET, mounted on SMD hybrids. The calibration system is located near the preamplifiers. A DAC converter stores charge on calibration capacitors, and a DMOS switch triggers a RC circuit injecting a signal similar to an ionization pulse.

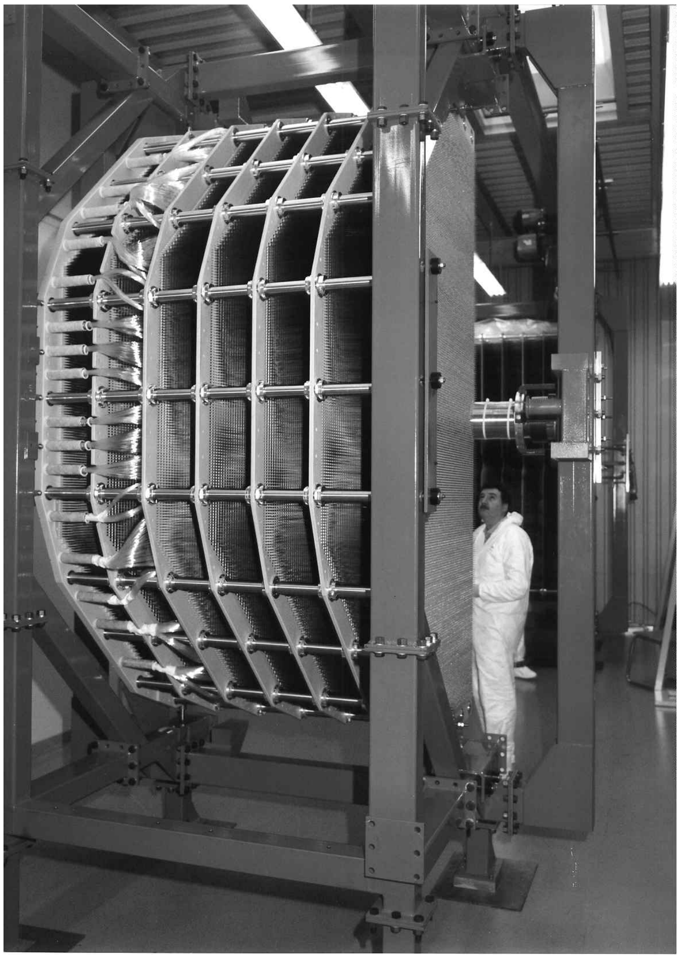

Figure 2: The electrode structure after assembly of ribbons.

In order to prevent damage to the preamplifier from occasional discharges occurring during high voltage ramp up, the front-end electronics includes a mechanical device capable of shorting to ground the preamplifier input lines. The system is formed by 64 units which slide vertically, controlled by a pneumatic system employing Krypton.

A second amplification stage is performed by transceivers [11], located just outside the feedthrough tower, in the upper part of the cryostat. They restore a faster signal rise-time (≈ 22 ns), and drive differential outputs.

Signals are then shaped with 80 ns FWHM, and digitized with 40 MHz FADCs [12]. In order to achieve the required 14 bits range, using 10 bits digitizers, the gain of the shaper is switched among 4 possible values. The gain information is recorded as 2 additional bits. Threshold values and persistence interval at lowest gain can be programmed. The output of the digitizers is sent to a 200 μs pipeline storage. Digital sums of 16 channels are also provided, in order to be used for triggering logic.

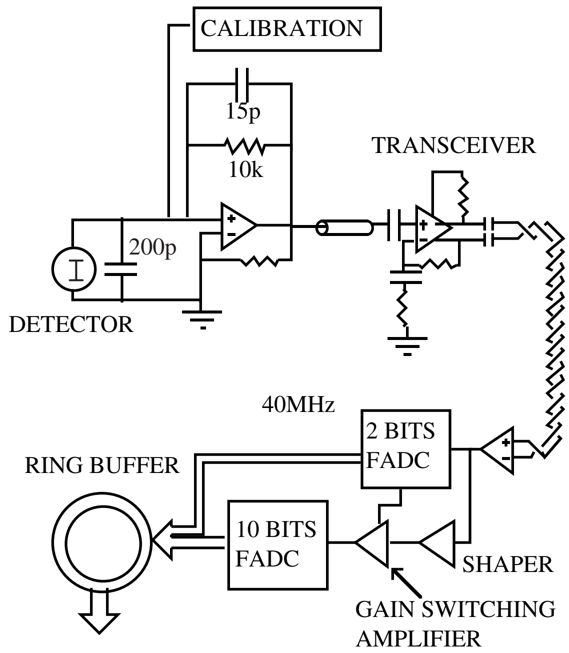

Figure 3: Scheme of read-out electronics.

VII. Detector Performance

During Summer 1996, the calorimeter was installed on the beam line with the other sub-detectors of the NA48 set-up. The full operation of the calorimeter was limited due to missing read-out electronics. We chose to read-out the entire active volume using auxiliary outputs available from the transceivers, corresponding to sums of 16 channels (2x8). Additionally, 384 channels near the center of the detector were equipped, where they could be tested with an electron beam.

Preliminary results from single-channel read-out are consistent with prototype tests [4]. For 50 GeV electrons, the energy resolution is about 0.7 %, and the space resolution is equal to 0.9-1.0 mm. The electronic noise for a cluster of 120 cells is equal to about 100 MeV.

The read-out of the sums has been useful to test data taking conditions and triggering logic. However, the sums cannot be easily calibrated. With no calibration at all, the average resolution, obtained measuring electrons from *ke3* decays, is equal to 3 %, and depends scarcely on the shower energy. The π^o mass from $K_{S,L}\rightarrow\pi^o\pi^o$ is reconstructed with rms resolution of about 3.5 MeV. Both figures should be reduced by a factor $\approx$ 3.5 with a properly calibrated, single-cell read-out.

VIII. Conclusions and Outlook

A quasi-homogeneous e.m. calorimeter based on liquid Krypton has been built for the experiment NA48 at CERN. The electrodes are longitudinal cells formed by metal ribbons. A preliminary test performed with electron and kaons beams has shown satisfactory results.

Full commissioning of the detector is expected for the first data taking of NA48, in Spring 1997.

IX. Acknowledgments

This detector has been built in a collaboration between several institutions. I wish to thank in particular collaborators and technical staff who contributed to the construction of the electrode structure. Contributions were also provided by collaborators not directly involved in this project. Among these, I wish to acknowledge the support of Saclay during design and assembly of the electrode structure.

X. References

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