The NA48 Liquid Krypton Calorimeter Description and Performances

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Abstract

The NA48 experiment at CERN[1] aims at making a precision study of direct CP violation in the neutral kaons, by measuring $Re\left(\frac{\varepsilon'}{\varepsilon}\right)$ with an accuracy better than 0.02%. To achieve this goal, the experiment requires a neutral detector with fast response, high efficiency in a high-rate environment ($\sim$ `MHz`), long-term stability, sub-nanosecond time resolution, millimetric space precision, and an excellent energy resolution (1%) in the $5 \rightarrow 100$ `GeV` range. To achieve these performances, a quasi-homogeneous Liquid Krypton calorimeter has been chosen, designed with a projective tower geometry, high transversal segmentation, and fast digital readout. The calorimeter was operative during the '97 data taking period, its performances were thoroughly studied, and found to be in agreement with design requirements. A detector description and performances analysis are here presented.

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1 Introduction

The NA48 collaboration attempts at measuring the $\mathcal{CP}$-violating parameter $Re\left(\frac{\varepsilon'}{\varepsilon}\right)$ with an accuracy $\simeq 2 \times 10^{-4}$. A non–zero value of ε' would constitute an experimental evidence of direct $\mathcal{CP}$ violation. This quantity can be extracted out of the experimentally observable "double ratio" R,

$$\begin{aligned} R &= \left|\frac{\eta^{00}}{\eta^{+-}}\right|^2 = \frac{\Gamma\left(K_L \to \pi^0\pi^0\right)}{\Gamma\left(K_S \to \pi^0\pi^0\right)} \Big/ \frac{\Gamma\left(K_L \to \pi^+\pi^-\right)}{\Gamma\left(K_S \to \pi^+\pi^-\right)} \\ &= 1 - 6Re\left(\frac{\varepsilon'}{\varepsilon}\right) + \mathcal{O}\left(\frac{\varepsilon'}{\varepsilon}\right)^2 \end{aligned} \tag{1}$$

The statistical error being dominated by the number of $K_L \to 2\pi^0$ decays, a few million of them are to be identified. In a similar way, all systematic uncertainties must be minimised. The NA48 detector has beed designed to cope with these two requirements.

2 The NA48 Detector

- two simultaneous, quasi-collinear K_L and K_S beams,
- a *tagger* to identify decays from each beam,
- a *magnetic spectrometer* to measure the charged modes $K_{L,S} \to \pi^+\pi^-$,
- a *liquid krypton calorimeter* for the neutral modes $K_{L,S} \to 2\pi^0 \to 4\gamma$,
- other subdetectors for background rejection and redundant identification .

In order to keep a steady acquisition in a high-rate environment ($\sim MHz$) during several years, the detectors are required to be fast, efficient and stable. Moreover, $\mathcal{CP}$-violating decay channels have to be identified in presence of important backgrounds, e.g.

signal	dominant background
$K_L \to 2\pi^0$	$K_L \to 3\pi^0$
B.R. $\sim 0.09\%$	B.R. $\sim 21.6\%$
$K_L \to \pi^+\pi^-$	$K_L \to \pi e \nu_e$
B.R. $\sim 0.2\%$	B.R. $\sim 37.8\%$

The analysis requires backgrounds to be rejected to a $\lesssim 0.1\%$ level. This condition can be translated in terms of calorimetric performances as:

$$\begin{array}{rcll} \sigma_T & < & 500.\ \mathtt{ps} & \\ \sigma_{X,Y} & < & 1.\ \mathtt{mm} & \\ \sigma_E/E & \lesssim & 1.\% & (E_\gamma \sim 25\ \mathtt{GeV}) \\ \mathtt{linearity} & \simeq & \mathtt{few}\ 10^{-3} & (5 \rightarrow 100\ \mathtt{GeV}) \end{array}$$

3 The Liquid Krypton Calorimeter

NA48 uses a quasi-homogeneous calorimeter, made up of some 10 $\mathtt{m}^3$ of liquid krypton. In order to ensure a good transverse granularity, given the krypton 6.1 cm Molière radius, the calorimeter is segmentated into 13212 cells of area 2×2 $\mathtt{cm}^2$. The calorimeter depth is 1.25 m, which corresponds to some 27 radiation lengths ($X_0 \simeq 4.7$ cm).

The calorimeter is built following a projective geometry, pointing towards the Kaon fiducial decay region (about 114 m upstream). In order to minimise energy losses for showers developing close to the anodes, ribbon electrodes follow a 48 mrad zig-zag along the projectivity lines. To ensure a gap uniformity within 0.4%, distance between electrodes is kept constant by means of regular spacers.

3.1 The LKr electronics readout

In order to minimise noise, the induced triangular signal in the cell electrodes (drift time 3 μs) is read by preamplifiers[2] (PA) inside the krypton. It is then differentiated by transceivers[3] (time constant $RC = 10$ns) and sent through twisted cables to the Calorimeter Pipeline Digitisers[4] (CPD), for final shaping. The CPD signal generates a sharp peak, with a 70 ns FWHM, that is processed by means of a optimal filtering algorithm to evaluate pulse height and extract energy and time.

Asynchronous digital sampling is done every 25 ns, with a 4 gain, 10 ADC bit dynamic range, covering an energy interval from 3.5 MeV up to 50 GeV per channel. Gain dispersion being the order of 3%, a calibration signal is sent at the PA level and used for gain equalisation and offset determination. This calibration procedure, done in parallel with physics data acquisition, shows that gain stability is maintained within a 0.1% level. Offset variations (typically of the order of 0.1 ADC/ ^0C) are permanently monitored.

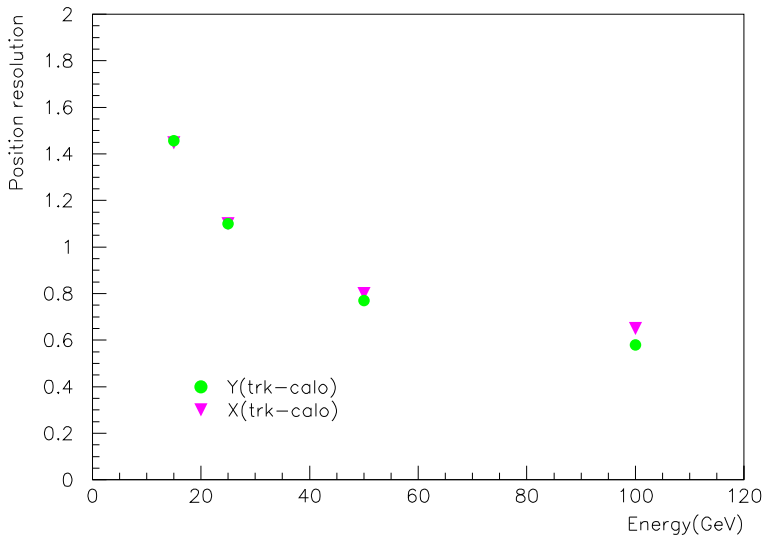

Figure 1: LKr and spectrometer position measurement for electrons. Vertical scale is in mm.

4 LKr performances

LKr electronics was completely setup for the 1997 data-taking period. High voltage was set at 1500 Volts to prevent failure of a few blocking capacitors; also, one LKr column (out of 64) disconnected from high voltage during cooling, generating a $\sim$ 15% acceptance loss for the neutral modes. Some 650 000 $K_L \to 2\pi^0$ decays were successfully collected by the end of the '97 run, and the physics data was used to evaluate the LKr performances.

4.1 LKr time and position resolutions with electrons

SPS electrons at fixed energies (15, 25, 50, and 100 GeV) were used to evaluate the position and time performances.

Figure 1 shows the position resolution as a function of electron energy. Above 25 GeV, both horizontal and vertical projections are evaluated with a resolution better than 1 mm. Intrinsic time performances are defined as the time difference for the most energetic neighbour cells in an electron shower. Figure 2 shows a time resolution of 260 ps, while small inefficiencies (i.e. time differences greater than 2 ns) are below 10^{-4}, and were shown to be linked to accidentals[5].

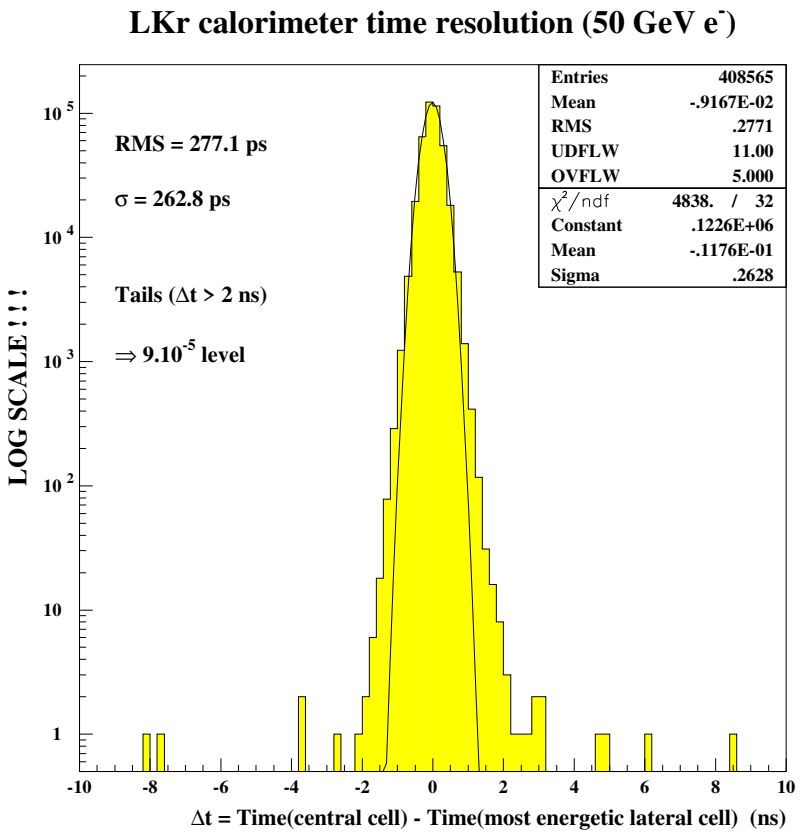

Figure 2: LKr time difference for neighbour cells.

4.2 LKr energy performances with K_{e3}

K_{e3} decays ($K_L \to \pi^{\pm} e^{\mp} \nu$) are used to compare electron momentum p, as measured by the magnetic spectrometer, with LKr electron shower energy E. This allows to test calibration, energy resolution and linearity. A GEANT simulation shows that K_{e3} electrons lose in average some 50 `MeV` before entering the cryostat. Figure 3 shows the E/P variation with energy, before and after correcting for this dE/dx energy loss. LKr energy response is linear within 0.2% in the $5 \to 100$ GeV range. Cell-to-cell uniformity (i.e. average E/p read by a single channel) is uniform within 0.43%, as shown in figure 4. The remaining variations were shown to be partially linked with uncertainties in the calibration electronics, and an iterative procedure with K_{e3} electrons was used to evaluate a set of cell energy factors, and optimise cell

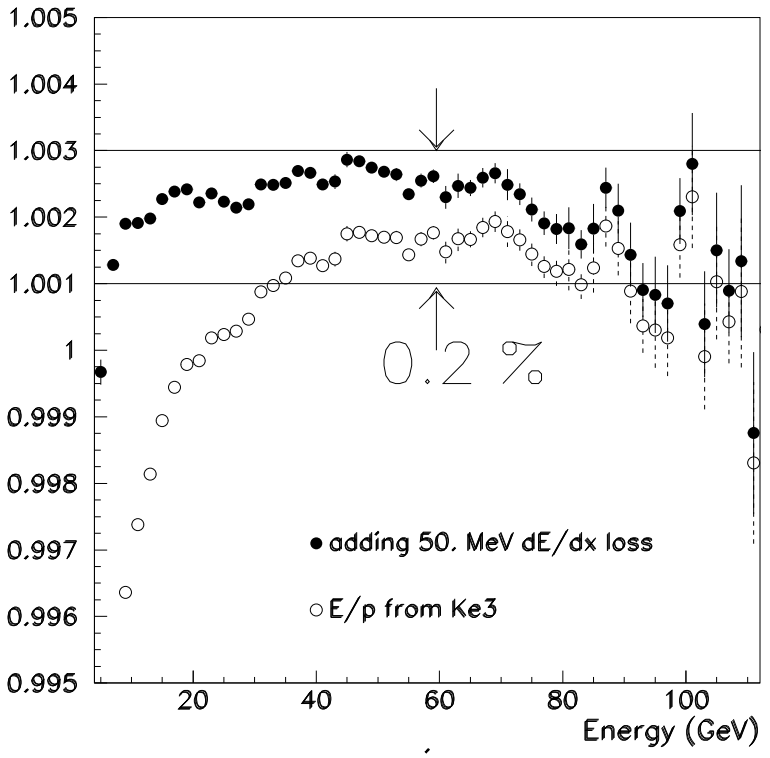

Figure 3: LKr linearity

energy readout uniformity. Magnetic spectrometer measurement of momentum worsening with energy, its contribution has to be substracted from the E/p resolution to obtain the pure LKr energy performance. From figure 5, the LKr energy resolution is evaluated as

$$\frac{\sigma\left(E\right)}{E} = \frac{3.5\%}{\sqrt{E}} \oplus \frac{110\ MeV}{E} \oplus 0.6\% \tag{2}$$

For the neutral modes detection the LKr performances yield a 1.1 MeV π^0 mass resolution. After weighting K_L events, the remaining $K_L \to 3\pi^0$ background under the signal is reduced to $\lesssim 0.1\%$.

5 LKr in 1998

The blocking capacitors were replaced during the '97-'98 winter shutdown, and '98 data-taking was achieved successfully. The LKr was safely operated

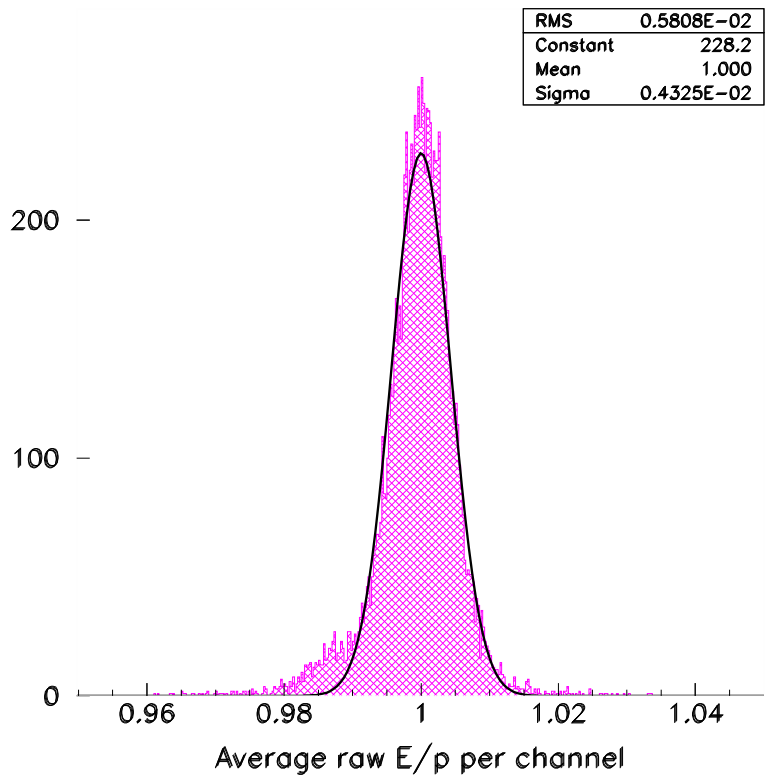

Figure 4: LKr cell-to-cell energy uniformity

at 3000 Volts, obtaining a 20% signal gain and a corresponding resolution improvement.

About 2×10^6 $K_L \to 2\pi^0$ events were added to the NA48 statistics.

6 Conclusions

LKr performances were tested with physics data during the '97 data-taking period. Its performances were shown to be within design requirements; in particular, background to the neutral modes was rejected up to a residual $\lesssim$ 0.1% level.

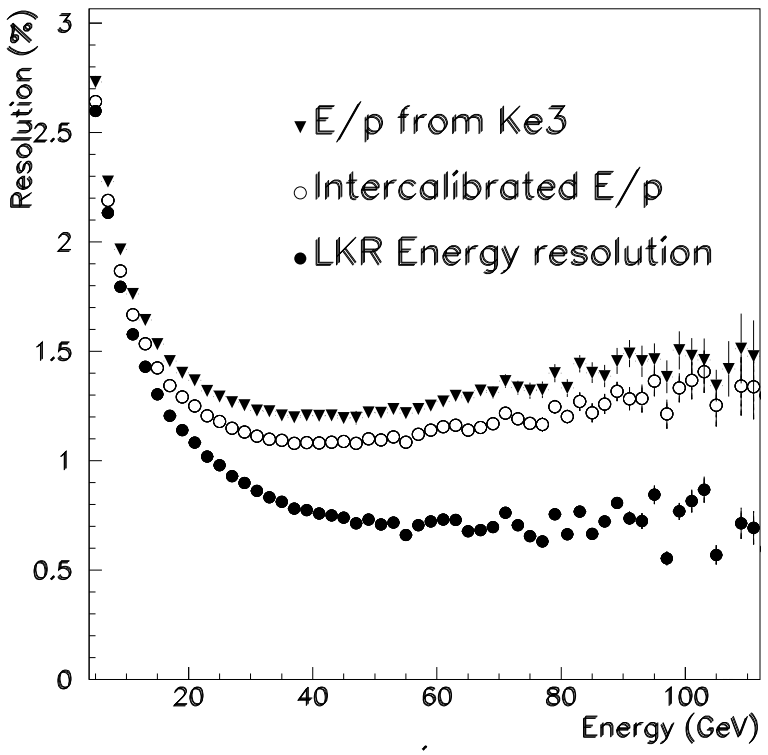

Figure 5: LKr energy resolution

References

[1] G.Barr et al. Proposal for a precision measurement of $Re\left(\frac{\varepsilon'}{\varepsilon}\right)$ in $\mathcal{CP}$-violating $K_L \to 2\pi$ decays (CERN/SPSC/90-22 SPSC/P252 1990)

[2] C.Cerri in Proc. of 6th Int. Conf on calorimetry in HEP. Frascati, June 8-14 1996, ed by Antonelli et al (Frascati Physics series)

[3] C.de la Taille et al, LAL/RT 97-05 (december 1997)

[4] B.Hallgren et al, CERN-EP/98-48 (march 1998)

[5] S. Crépé, Ph.D. thesis LAL 98-34 (may 1998)