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CALIBRATION AND RECONSTRUCTION PERFORMANCES OF THE KLOE ELECTROMAGNETIC CALORIMETER

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ABSTRACT

A review of the methods used to calibrate and to reconstruct energy and time with the electromagnetic calorimeter of the KLOE experiment is presented. The performances heve been evaluated with the first data collected at DAΦNE in 1999. An energy resolution of $5.7\%/\sqrt{E(\mathrm{GeV})}$ has been achieved, together with a time resolution of $\sim$54 ps/$\sqrt{E(\mathrm{GeV})}$ plus 50 ps constant term, well matching the design requirements.

1 Introduction

The main aim of the KLOE experiment [1] is the study of the CP violation in the decays of the neutral kaons at the DAΦNE φ-factory in Frascati [1, 2]. The

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detector consists of two main parts: a large volume drift chamber (DCH) [3] and an electromagnetic calorimeter (EMC). The EMC has been designed to detect photons coming from the decays of $K_{L,S} \rightarrow \pi^0\pi^0$ in order to measure the $K_{L,S}$ decay vertex and to reject the $K_L \rightarrow \pi^0\pi^0\pi^0$ background. Good efficiency for photons down to 20 MeV, together with hermeticity and good energy and time resolution are required.

The EMC [4] is a sampling calorimeter made of grooved lead foils, 0.5 mm thick, interleaved with layers of scintillating fibres of 1 mm diameter, glued by means of an epoxy resin. The fibre:lead:glue ratio is 48:42:10, the radiation length is about 1.6 cm and the average density 5.3 g/cm^3. The EMC consists of a barrel part, about 4 m diameter, divided into 24 modules 4.3 m long and 23 cm thick ($\sim$15 X_0) of trapezoidal section, and two endcaps each made of 32 "C"-shaped modules with different lengths. Fibres run along the axis in the barrel and vertically in the endcaps. The read-out granularity is about 4.4 x 4.4 cm^2 for a total of 4880 cells; each cell is connected at both ends to a photomultiplier (PM) through a plexiglas light guide. Since the whole detector

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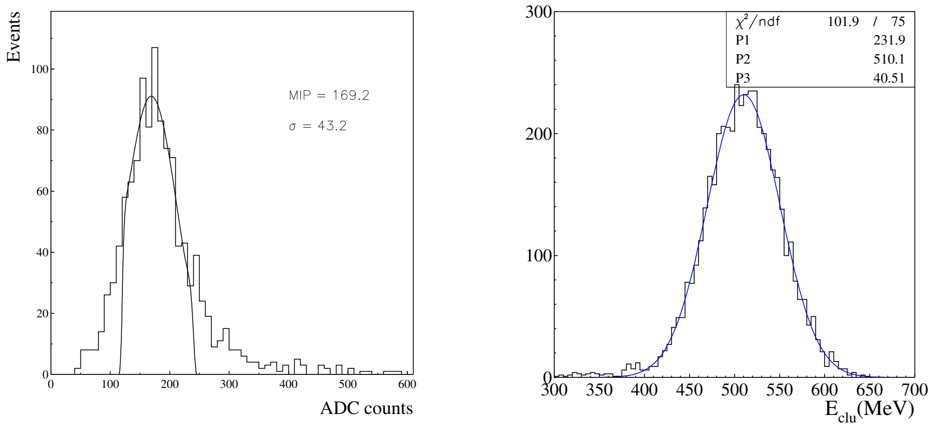

Figure 1: *Left: example of MIP; right: photon spectrum for* $e^+e^- \rightarrow \gamma\gamma$ *after the calibration.*

is located inside a superconducting solenoid producing a 0.53 T magnetic field, fine mesh PMs have been used.

The EMC has been installed in 1998, and on April 1999 the first collisions were observed in DAΦNE. The integrated luminosity of 2.4 pb^{-1} collected in the 1999 run, has been used to setup the calibration procedures described in this paper.

2 Energy calibration

The first calibration of the EMC is performed with cosmic rays, by selecting minimum ionizing particles, and measuring, for each read-out cell, the peak of the energy release at the calorimeter centre, called MIP(fig.1.a). In a typical cosmic ray run (about one day data-taking), 1000 events per cell are collected, and this corresponds to a statistical accuracy in the MIP determination of $1 \div 2\%$.

Then fine corrections to the cell intercalibration are applied by equalizing the response to the electromagnetic (e.m.) showers produced by Bhabha scattering events. Finally the energy scale is set by using $e^+e^- \rightarrow \gamma\gamma$ events, since photons do not lose energy passing through the beam-pipe and and the

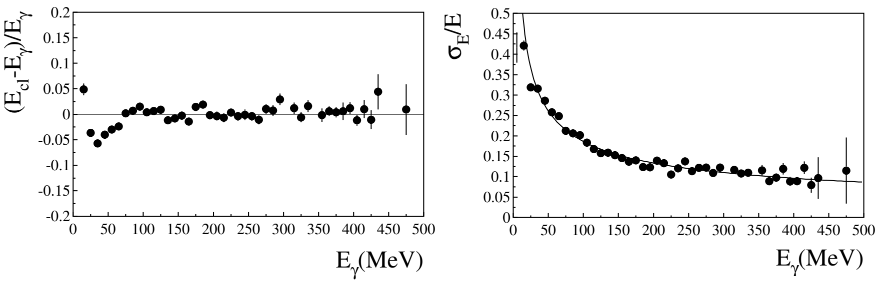

Figure 2: $e^+e^- \to e^+e^-\gamma$ *events; left: linearity of the response; right: energy resolution.*

DCH walls(fig.1.b). The energy scale turns out to be 38 MeV/MIP, that, taking into account the number of photoelectrons (p.e.) per MIP measured in the cosmic ray test of the calorimeter modules [5], corresponds to a light yield of about 1 p.e./MeV deposited at the calorimeter centre per read-out side. This calibration with e.m. showers is performed by selecting on-line Bhabha and $\gamma\gamma$ events, and by analyzing them with an automatic procedure starting every 100 nb^{-1} of integrated luminosity (corresponding to about 8 hours of data-taking at the present luminosity).

The EMC performances on energy reconstruction have been evaluated by exploiting $e^+e^- \to e^+e^-\gamma$ events. The energy of the photon can be determined with good accuracy by measuring the momenta of e^+ and e^- with the DCH, and then compared to the energy measured by the EMC. In fig.2 are reported the differential linearity and the energy resolution in the range $20 \div 500$ MeV. The non-linearity is below 1% for $E_\gamma > 75$ MeV, while at lower energies a drop down to 5% is observed. The overall energy resolution turns out to be dominated by the sampling fluctuations:

$$\frac{\sigma_E}{E} = \frac{5.7\%}{\sqrt{E(\mathrm{GeV})}} \oplus 0.6\% \qquad (1)$$

As examples of energy reconstruction with the KLOE EMC, in fig.3 are reported the $\gamma\gamma$ invariant mass for 3-photon events (from $\varphi \to \eta\gamma$, $\pi^0\gamma$, with $\eta, \pi^0 \to \gamma\gamma$), and the 4-photon invariant mass for events with a $K_S \to \pi^0\pi^0$ decay. The reconstructed masses agree within 1% with the PDG values [6].

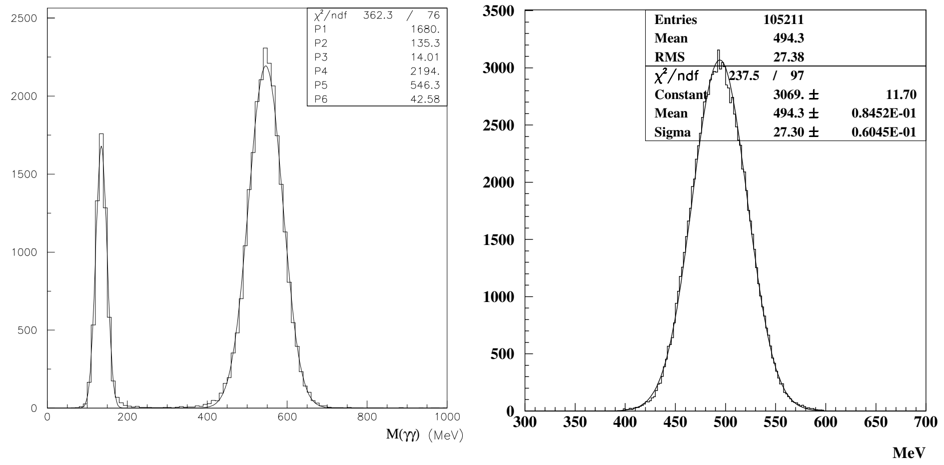

Figure 3: *Left:* $\gamma\gamma$ *invariant mass for* $\varphi \to \eta\gamma$ *,* $\pi^0\gamma$*, with* $\eta, \pi^0 \to \gamma\gamma$*; right: 4 photon invariant mass for* $K_S \to \pi^0\pi^0$*.*

3 Timing calibration

Cosmic rays are also used to provide a first calibration of the time response: from the difference of the arrival times of the signal at both ends of a cell, the offsets difference (Δt_0) and the effective velocity of light in the fibres (v_{eff}) are determined. In order to align the time response of the cells among each other also the sums of the offsets have to be measured. This is done by selecting high momentum tracks in the DCH and by minimizing the residuals of the linear fit to the time-position relation with an iterative procedure.

One hour data-taking is sufficient to calibrate the time offsets with an accuracy of 30÷40 ps, and the v_{eff} with an accuracy of 0.3% (the average value is 16.7 cm/ns). A check of the validity of the calibration procedure is obtained by plotting the measured velocity of cosmic ray as a function of the track momentum (fig.4.a). This is fit to the relation $\beta = p/\sqrt{p^2+m^2}$ taking the particle mass as a free parameter: a good agreement with the muon mass is obtained.

Fine corrections to these time offsets are obtained with $\mathrm{e}^+\mathrm{e}^- \to \gamma\gamma$ events,

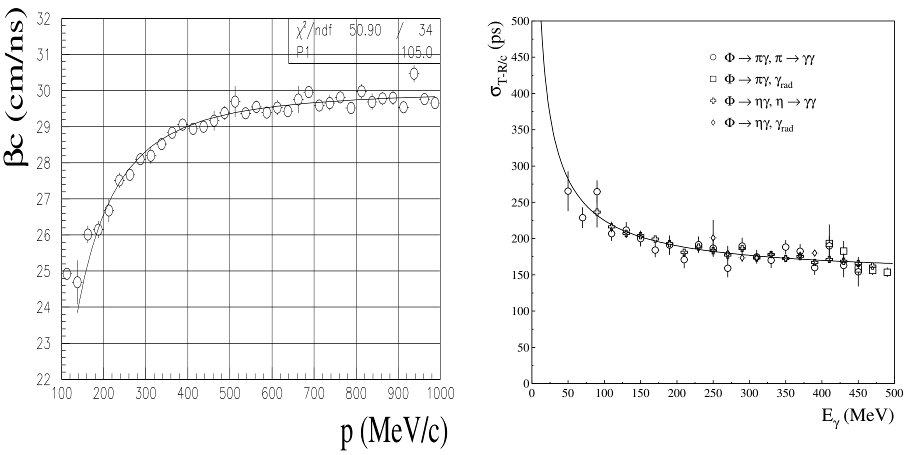

Figure 4: *Left: velocity vs momentum for cosmic muons; right: time resolution as a function of E_γ for photon from φ radiative decays.*

reaching an accuracy of 10÷20 ps.

The time resolution has been evaluated by measuring the quantity $t-r/c$ for the prompt photons from the radiative decays $\varphi \rightarrow \eta\gamma, \pi^0\gamma$, where t is the measured arrival time of the photon on the EMC, r/c is its expected time of flight, assuming that it is produced at the nominal centre of the detector. One obtains (fig.4.b):

$$\sigma_{t-r/c} = \frac{54\mathrm{ps}}{\sqrt{E(\mathrm{GeV})}} \oplus 147\mathrm{ps} \qquad (2)$$

By comparing the $t-r/c$ distributions for $e^+e^- \rightarrow \gamma\gamma$ events at small and at large polar angles, three main contributions to the constant term can be separated: 55 ps due to the bunch lengths, 120 ps due to the uncertainty in the interaction time and 50 ps due to residual miscalibration of the detector.

The velocity spectrum of the K_L interacting in the EMC (fig.5.a) is an example of timing performance; the average value is β_L=0.213 and the width $\delta\beta_L$=0.004 is essentially due to the machine energy spread (δE$\simeq$ 1 MeV). Thus the measurement of β_L can be used to monitor the centre of mass energy of DAΦNE with accuracy comparable to that obtained using the measurement of the momenta of π^+ and π^- from K_S decays in the DCH.

The time resolution enters directly the accuracy of the neutral vertex

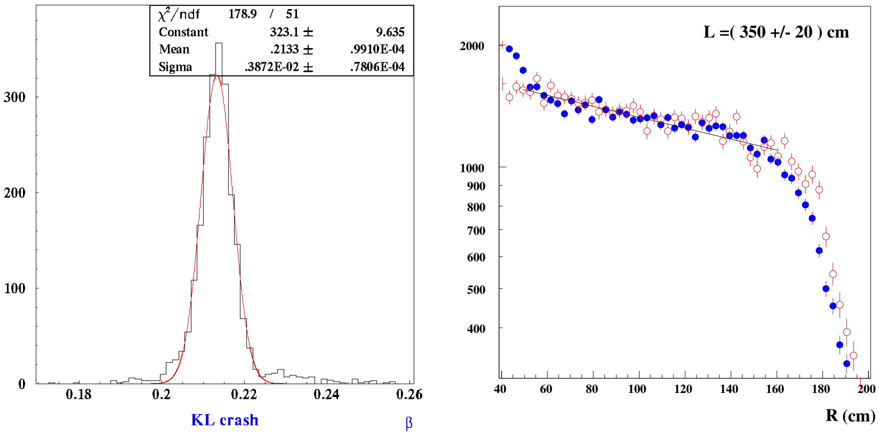

Figure 5: *Left: velocity spectrum for of K_L interacting in the EMC; right: decay length for $K_L \to \pi^0\pi^0\pi^0$ (open points) compared to the $K_L \to \pi^+\pi^-\pi^0$ one (full points).*

reconstruction: in fig.5.b the measurement of the K_L decay length for the events $K_L \to \pi^0\pi^0\pi^0$ is shown to be in good agreement with the same quantity obtained with the DCH from $K_L \to \pi^+\pi^-\pi^0$.

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