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Section A
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Calibration and reconstruction performances of the KLOE electromagnetic calorimeter

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Abstract

The main aim of the KLOE experiment at DAΦNE, the Frascati ϕ-factory, is to study CP violation in the K^0–$\bar{K}^0$ system. Requirements on shower detection are very stringent. An hermetic, lead-scintillating fiber sampling calorimeter has been chosen and built. A review of the methods used to calibrate and reconstruct energy and timing is reported in this paper. Emphasis is given to the calibration procedures developed using the 2.4 pb^{-1} collected in 1999. An energy resolution of $5.7\%/\sqrt{E/\mathrm{GeV}}$ is achieved together with a linearity in energy response better than 1% above 50 MeV. A time resolution of $\sim 54\,\mathrm{ps}/\sqrt{E/\mathrm{GeV}}$ is also measured on samples of radiative Bhabha and Φ decays. © 2001 Published by Elsevier Science B.V.

1. Introduction

The main task of the electromagnetic calorimeter, EmC, is to reconstruct the K_L^{00} decay and to efficiently reject the K_L^{000} background. At KLOE [1] the vertex reconstruction of the decay is performed by measuring the arrival time to the calorimeter of even a single photon. These requirements correspond to the following design specifications: (1) $\sigma_E/E \sim 5\%/\sqrt{E/\mathrm{GeV}}$; (2) σ_T better than 70 $\mathrm{ps}/\sqrt{E/\mathrm{GeV}}$; (3) full efficiency for γ's in the range 20–280 MeV; (4) hermeticity.

The EmC is a fine sampling lead-scintillating fibers calorimeter with photomultiplier (PM) readout whose basic structure consists of an alternating stack of 1 mm fibers' layers glued between thin grooved lead foils. The final composite has a fiber:lead:glue volume ratio of approximately 48:42:10, a density of $\sim 5\,\mathrm{g/cm^3}$ and a radiation length, X_0, of ~ 1.6 cm. The EmC central part, barrel, approximating a cylindrical shell of 4 m inner diameter, 4.3 m active length and 23 cm thickness, consists of 24 modules. Two end-caps, consisting of 32 "C" shaped modules, close hermetically the barrel. The detector is readout at both ends by fine mesh PMs with cells granularity of $\sim 4.4 \times 4.4\,\mathrm{cm}^2$ for a total number of 4880 channels. The EmC modules and the front-end electronics were fully installed in KLOE at the beginning of 1998. The calorimeter has been fully operational since then.

2. Energy and timing performances

After the installation, a first calibration and equalization in response of the calorimeter has been performed with cosmic rays by selecting minimum ionizing particles (MIP) and measuring, for each calorimeter channel, the peak of the energy released at calorimeter center. The accuracy of MIP determination was typically of $\sim 1\%$. When the magnetic field was raised at the nominal value of 6 kG, the average calorimeter response lowered of $\sim$5% with a widening in the distribution of more than 30%. By adjusting the PMs high voltages, we equalized the whole calorimeter at a $\sim$5% level.

On April 1999, the first collisions were observed in DAΦNE; at the end of the first physics run, in December 1999, an integrated luminosity of $\sim$2.4 pb^{-1} has been collected. Bhabha and $e^+e^- \rightarrow \gamma\gamma$ events have been used to set the energy and time scales. The setting of the energy scale relies on $\gamma\gamma$ events that, in average, do not suffer energy losses passing through the beam pipe or the drift chamber walls. A scale factor of $\sim$38 (33) MeV/MIP is obtained in the barrel (endcap) calorimeter; considering the average number of photoelectrons (pe) per MIP (35 pe/MIP) measured at the Cosmic Rays Stand [2], a light yield of 2000 pe/GeV is estimated, at calorimeter center, when summing both sides. Using the KLOE tracking system, the e^+, e^- momenta of radiative Bhabha's were measured determining with good accuracy the γ's energy (E_γ). In the energy range between 20 and 400 MeV, the fractional difference between the calorimeter response and E_γ as well as the corresponding energy resolution are reported in Fig. 1. In order to avoid the showers affected by lateral energy leakage, only the γ's impinging

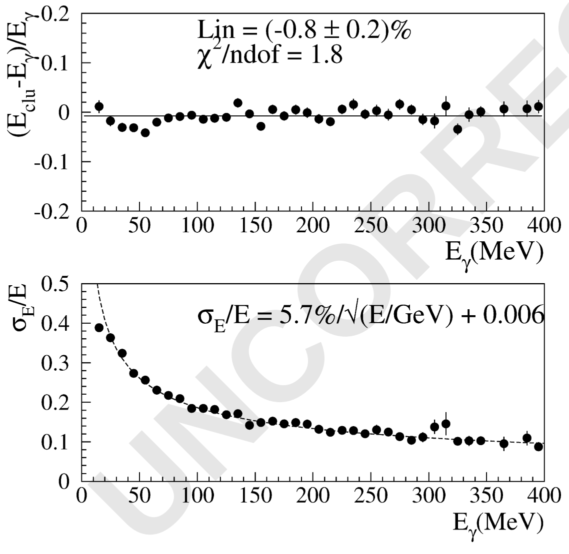

Fig. 1. $e^+e^- \rightarrow e^+e^-\gamma$: (a) Differential linearity vs. E_γ (b) Energy resolution vs. E_γ.

farther than 50 cm from the light guides are considered. The energy resolution obtained scales as $\sigma/E \simeq 5.7\%/\sqrt{E/\mathrm{GeV}}$; the constant term is practically negligible. The linearity in response is better than 1% for energy above 50 MeV while a linearity drop up to 4% is observed between 20 and 50 MeV. The resolution is in good agreement with test beam results considering that showers located in the regions between modules are also used. In these "small" cracks an average drop in response of $\sim$10% is observed. Work is in progress to understand the response in these areas and to correct the residual non-linearity. As a check of the energy scale calibration, the invariant mass of π^0,η and K_s decaying in n γ's final state are reconstructed. These masses result in agreement within 1% with the corresponding PDG values.

The times measured at the two ends of a cell, $T_{A,B}$, allow us to reconstruct the arrival time of particles and the coordinate along fibers. The difference between the time offsets at the two ends, ΔT_0, and the speed of the light in the fibers, V_f, are determined fitting the raw $T_A - T_B$ spectra obtained with around 10^6 cosmics. The precision on the ΔT_0 determination is of $\sim$40 ps, while the relative error on V_f is $\sim$0.3%. The average value of V_f found (16.7 cm/ns) is in agreement with expectation and with independent measurements done using the tracking chamber. Assuming "c"–speed and fitting the measured time pattern of the fired cells in straight cosmic ray ($P_t > 5$ GeV) events, the time offset of each single channel is determined with a precision of $\sim$30 ps. A check of this calibration is given by the velocity measurement of cosmic rays as a function of their momentum. A fit to the measured distribution with the relativistic velocity $c\beta = cp/\sqrt{p^2+m^2}$, provides a value in good agreement with the muon mass. Similar methods are used also in K_{e3}, $K_{\mu3}$ events to get the pion and muon masses. The absolute time scale in e^+e^- collisions is set, event by event, imposing the fastest cluster timing to be consistent with the expected γ's time of flight. Using $e^+e^- \rightarrow \gamma\gamma$ the period of the accelerator radio frequency, RF, is obtained. A difference of $\sim$1% between the measured and nominal RF period is found. Work is in progress to correct the

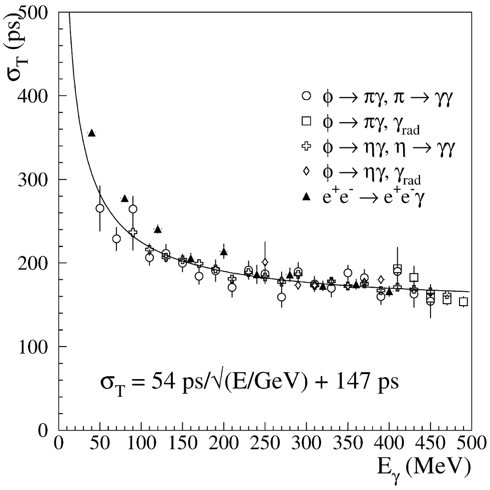

Fig. 2. Time resolution as a function of E_γ.

TDC timing for this scale factor. In order to evaluate the time performances of the calorimeter, "prompt" γ's from radiative Bhabha's and radiative Φ decays are used. The quantity, $D = T - R/c$, where T is the cluster mean time and R is the distance of the cluster from the interaction point, allows the measurement of the timing performances; the average of the D distribution shows the precision in the time setting while the σ indicates the resolution. In Fig. 2 the σ_T as function of E_γ is reported, the best parametrization indicates a scaling law as: $54\,\text{ps}/\sqrt{E/\text{GeV}}$ for the stochastic term (which is in agreement with old measurements) and a constant term (147 ps) to be added in quadrature. This last contribution is due to residual miscalibration ($\sim$ 50 ps) and to longitudinal and time spread of the bunches ($\sim$ 140 ps). The reconstruction of neutral vertices is satisfactory as demonstrated by the measurement of K_L lifetime (350 ± 20 cm) in K_L^{000} events and by the resolution of ~ 1.6 cm obtained comparing charged-neutral vertices in K_L^{+-0} events.

References

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