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CCALT: A Crystal CALorimeter with Timing for the KLOE-2 upgrade

M. Cordelli, E. Danè, S. Giovannella *, M. Gatta, F. Happacher, A. Lucà, S. Miscetti, A. Saputi, I. Sarra, G. Pileggi, B. Ponzio

Laboratori Nazionali di Frascati, INFN, Italy

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ABSTRACT

The KLOE-2 detector has been successfully rolled in inside the new interaction region of the DAΦNE machine, which is still in its commissioning phase. Construction of detector upgrades is in progress to provide larger acceptance both for charged particles and photons. The CCALT calorimeters will be placed in front of the inner quadrupoles, inside the apparatus, thus increasing the acceptance for prompt decay channels. They consist of two barrels of LYSO crystals, read-out with large area SiPM. This choice provides high efficiency for low energy photons and good timing performances, needed to reject machine background events. Tests of a calorimeter prototype were carried out both with electron and photon beams, showing high light yield and good timing capabilities. The construction of the CCALT detector is in progress and will be completed in few months, in time for installing it over the new interaction region.

1. Introduction

In the new design of the DAΦNE interaction region [1], the position of the inner quadrupoles leaves place for inserting two crystal calorimeters to detect low energy photons in the angular region between 10° and 18°, thus increasing the acceptance of the KLOE-2 central calorimeter for rare eta and kaon decays, such as $K_S \to \gamma\gamma$, $\eta \to \pi^0\gamma\gamma$, $K_S \to \pi^0\pi^0\pi^0$ [2].

The proposed solution is to insert an homogeneous calorimeter immersed in a 0.52 kG axial magnetic field, CCALT [3], based on the new generation of crystals, LYSO, characterized by a very high light yield (60% of NaI), 40 ns emission time, high density and radiation length. These crystals match the request of a high efficiency for low energy photons and of an excellent time resolution needed to sustain the high level of machine background events ($\sim$100 kHz/crystal). In order to maximize the light collection and improve its timing performance we have tested its response both with the fastest Hamamatsu APD and with large area SIPMs from FBK-IRST.

2. Calorimeter prototype: test beam results

We have built a calorimeter prototype, made by an inner matrix of nine $(20 \times 20 \times 150)\ \mathrm{mm}^3$ LYSO crystals, read-out by $(10 \times 10)\ \mathrm{mm}^2$ Hamamatsu avalanche photodiodes (APD S8664-1010), surrounded by twelve $PbWO_4$ crystal scintillators for outer leakage recovery (three Moliere radius in total), read-out by bialkali photomultipliers. We have tested it using cosmic ray particles (CR) and with electron (beam test facility, BTF, at Frascati, 2010) and photon (MAMI accelerator facility at Mainz, 2011) beams. A full Geant4 simulation of the prototype, describing all construction details has been also developed. Photon transportation and longitudinal response uniformity have not yet been included.

The CR test was used to equalize the response of the inner matrix crystals, triggering events with an external scintillator counter on top of the prototype. Good minimum ionization particles (MIPs) are selected by requiring a fired raw of crystals, with no energy in the lateral ones. Single channels are calibrated at the 2% level, with an average MIP value of 100–120 ADC counts.

The measurements carried on at the BTF resulted in a light yield of 2000 photoelectrons per MeV and in a very good time resolution: $\sigma_T = 49/120$ ps for 500/100 MeV photons, respectively. The calorimeter prototype shows also a very good energy resolution of $\sim 5\%$ at 100 MeV, as measured at the very precise tagged photon beam of MAMI. Simulated events well reproduce measured energy and position resolutions, after including the cross talk in the inner matrix (1–2%) and an ad hoc 4% additional Gaussian fluctuation to take into account not uniformity in longitudinal response.

3. Test of single crystals with SiPM read-out

Due to space constraints and thermal considerations, the final choice for the read-out is Large Area $((4 \times 4)\ \mathrm{mm}^2)$ SiPM from ADVANSID. This results in a loss of $\sim$4 in time resolution, of

* Corresponding author.
E-mail address: simona.giovannella@lnf.infn.it (S. Giovannella).

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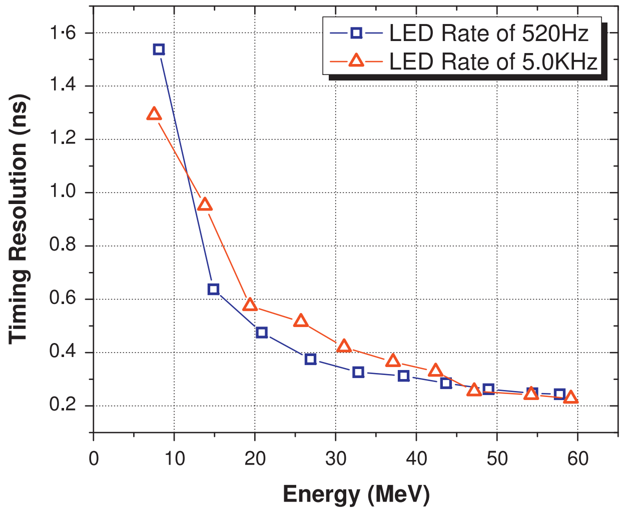

Fig. 1. Time resolution for a single LYSO crystal read-out by large area SiPM. The two curves are obtained with different LED rates.

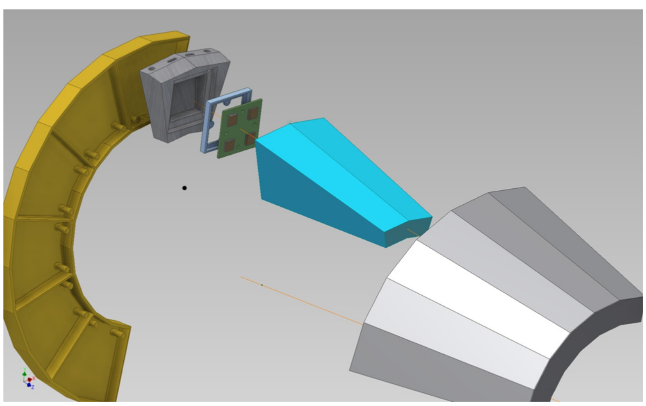

Fig. 2. CAD drawing of the crystal arrangement in the aluminum shell and SiPM board.

which 2.5 due to the area reduction and 1.6 due to the lower quantum efficiency. The usage of SiPM still satisfies detector requirements, adding the possibility to increase read-out granularity due to the lower cost with respect to APD.

We have tested the timing performances and the dependence of the response on rate firing single crystals of $(20\times20\times150)\,\mathrm{mm}^2$ with a UV LED and reading them out with the ADVANSID SiPMs. Both time resolution and energy response are stable for different LED rates, up to 100–200 kHz. In Fig. 1, the achieved time resolution is shown as a function of the equivalent photon energy for 0.5 and 5 kHz LED rate.

4. CCALT: final design and construction status

An exploded view of the final drawing of one CCALT calorimeter is reported in Fig. 2. Each calorimeter is composed by four aluminum wedges, each constituted by three sectors, for a total of twelve modules. Each module has a granularity of four projective crystals, for a total of 96 read-out elements. Crystals have

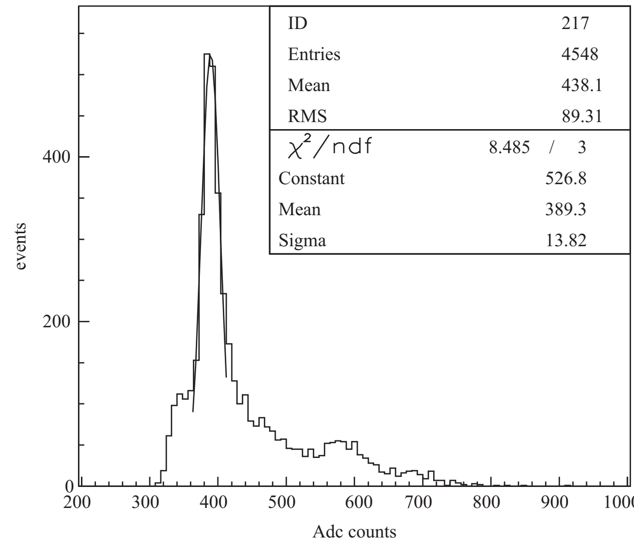

Fig. 3. Energy distribution for ^{22}Na source, using a single crystal of the CCALT calorimeters.

trapezoidal shapes, with transverse dimensions of $\sim(1.5\times2)\,\mathrm{mm}^2$ in the read-out plane, $\sim(0.5\times1.5)\,\mathrm{mm}^2$ in the front side. They are optically separated, each one being wrapped with Tyvek wrap. The total crystal length is 8.5 cm, corresponding to 8 X_0. Crystals are read-out by a $(4\times4)\,\mathrm{mm}^2$ surface mount SiPM, mounted in groups of four on a home made designed printed circuit board (PCB), following the geometry of the crystals.

The first two CCALT crystals, produced from SICCAS, were delivered and are under test using a ^{22}Na source and PM read-out. The energy distribution for one of the two is reported in Fig. 3. A 10% energy resolution in obtained at 511 keV.

The assembly of the CCALT calorimeters is expected to be completed in few months from now. The aluminum support shells are ready. Crystals are currently under production from SICCAS, and are expected to be delivered by mid of June. Concerning the read-out system, the $(4\times4)\,\mathrm{mm}^2$ SiPMs from ADVANSID have already been produced, while the PCBs will be ready by end of June. The preamplifiers and the LED calibration driver are under construction. For the front end electronics, standard ADC and TDC boards from the KLOE detector will be used.

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