EPJ Web of Conferences **66**, 11033 (2014)
DOI: 10.1051/epjconf/20146611033

CEPA: A *LaBr*$_3$*(Ce)/LaCl*$_3$*(Ce)* phoswich array for simultaneous detection of protons and gamma radiation emitted in reactions at relativistic energies

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Abstract. A prototype CEPA4, made of four optically isolated phoswich-crystals of $LaBr_3(Ce)$+$LaCl_3(Ce)$ packed together in one can of Al, was tested with high energy protons (70-230 MeV) at the cyclotron of Krakow. Further, the response to different gamma radiation standard sources and cosmic muons was determined. Shape analysis of the pulses derived from the four individually coupled PM-tubes was performed and were used as input functions for Monte Carlo simulations in order to simulate the efficiencies and resolutions of a final detector design consisting of 750 such phoswich crystals arranged in a cylindrical disc.

1 Introduction

Sophisticated detectors made of fast scintillator materials, properly segmented for Doppler correction and adapted to high level electronics and mechanical integration are more and more needed when measuring the complete kinematics of nuclear reactions at relativistic energies. Satisfying these needs, we are designing the forward end-cap of the CALIFA calorimeter [1] that is to detect protons and gamma radiation in the experiments of the R3B@FAIR collaboration. Towards this design, a prototype (CEPA4) made from four rectangular optically isolated scintillator crystals packed in one Al-can was constructed for us by Saint Gobain. Each crystal is a 2.7x2.7x10 cm^3 phoswich made of $LaBr_3(Ce)$ and $LaCl_3(Ce)$, as will be described later. The response to high energy protons in the range of 70-230 MeV in steps of 10 MeV was determined at the cyclotron of Krakow. The reconstruction of the incident proton energy was performed analyzing the detected pulse-shape using a digitizing data acquisition system.

2 Experimental measurements with CEPA4

2.1 CEPA4 design

The prototype CEPA4, see (Figure 1), is an array of a 2x2 rectangular crystals. Each crystal is in a phoswich configuration made from a 40 mm long $LaBr_3$ crystal optically glued to a 60 mm long

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$LaCl_3$ crystal, each with an entrance surface of 27x27 mm^2. The package is encapsulated in one can of Al with a wall thickness of 0.5 mm and having an end window of 5 mm glass (Figure 1 left). Onto the glass window we have glued 4 individual PM-tubes (Hamamatsu R5380). In order to keep the PM-tubes in place and as protection of the detector and easy handling, the full package is attached to a standard ISO160 flange, and surrounded by an Al cylinder of 2mm wall thickness having a 1 mm end window. This unit is vacuum tight and can be fixed to a vacuum chamber when to be used in beta decay studies. A MSX25-500 Double-Sided Silicon Strip Detector (DSSSD) is positioned in front of the scintillator package with the purpose of proton/gamma selection and obtaining position data of the proton events. In the figure is also shown the plastic support structure used when operated in air (Figure 1 right).

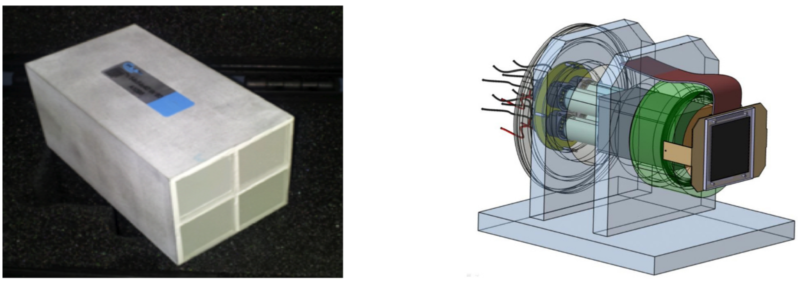

Figure 1. To the left is shown a photo of the CEPA4 package seen from the glass window side. To the right is shown a sketch of CEPA4, attached onto the ISO160 flange and with the DSSSD placed in the front, on its plastic support structure .

2.2 CEPA4: response to protons

The CEPA4 was tested in March, 2013 for protons of energies ranging from 70 MeV to 230 MeV in steps of 10 MeV (dE/E<1%), at the Bronowice Cyclotron Center at the Henryk Niewodniczanski Institute of Nuclear Physics in Krakow, Poland. The detector was positioned at 1 m from the beam exit window, at an angle of 18^o with respect to the beam. The PM-tube pulses for each of the different energies were recorded and an analysis of the pulses shape was performed off-line to reconstruct the primary energy of the protons [2]. The two-layered detector can be used as a $\Delta E - E_{Tot}$ telescope or as a double energy-loss detector ($\Delta E_{LaBr3} + \Delta E_{LaCl3}$) in order to determine the initial proton energy.

In order to separate the response obtained in the $LaBr_3$ to the one obtained the $LaCl_3$ crystals, one can follow the procedure explained in reference [3] analyzing the pulses plotting the I_{Tail} vs I_{Total}. Having done this separation one can construct the E_{LaBr_3} vs E_{Tot} (Figure 2). A rough estimate of the energy resolutions (3 - 6 %) was made on-line determined from proton pulses detected via the PM tube using standard analogue electronics coupled to peak sensing ADC. There is a clear change in the resolution due to the punch throughs at 135 MeV and at 200 MeV. For higher energies (>200 MeV) the increase in resolution (< 8%) is in agreement with the increase in width of the energy distribution also seen in the E_{LaBr_3} vs E_{Tot} plot. Further analysis of the digitized signals is needed to fully characterize the detector response.

2.3 CEPA4: response to gamma radiation and muons

For the response to gamma radiation, standard sources (^{22}Na, ^{137}Cs and ^{60}Co) were used at our laboratory in Madrid. Arranging the sources in different positions along the crystals units, we can identify in

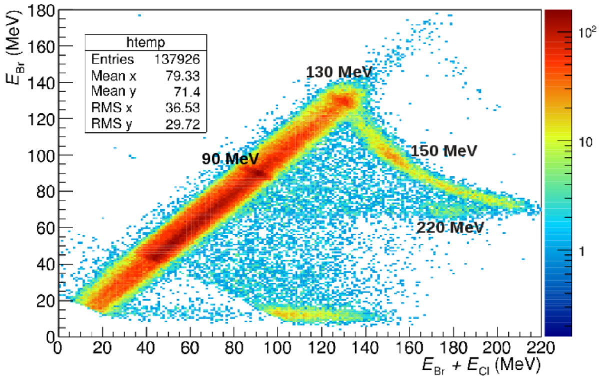

Figure 2. Bi-dimensional histogram of the energy deposited in CEPA4 $LaBr_3$ crystals vs the total energy deposited in all the CEPA4 crystals for a mixed data-set including several runs with mono-energetic protons in the range 70 - 220 MeV.

which crystals ($LaBr_3$ or $LaCl_3$) gamma events have deposited energy and calculate the resolution of the crystals. Figure 3 shows $LaBr_3$ and $LaCl_3$ crystals resolutions averaged between the four CEPA4 phoswich units and measured twice for each crystal at different time (April, 2012 and Oct, 2013). It is remarkable the good energy resolution of the CEPA4 $LaBr_3$ crystals (2.8% @ 1.332 MeV) and it is in agreement with [3]. Cosmic muons were detected using the same experimental set-up as in the proton test in Krakow mentioned above. In this case the detector was placed to have the muons impacting from different directions so that one could obtain clean $LaBr_3$ and clean $LaCl_3$ signals. Further, using correlation pattern recognition [2], traces of pulses were decomposed and reconstructed, so that the part that deposited energy in the $LaBr_3$ crystal were distinguished from the ones that deposited in the $LaCl_3$ only or in both crystals. These signals could then be used further on in the Geant 4 simulations.

3 Simulations

Using the results from the CEPA4, the front end cap was designed with 750 individual crystals of 4 cm $LaBr_3$ and 6 cm $LaCl_3$ length [4]. Especially for this purpose, during the proton test in Krakow, CEPA4 was turned 90^o to the beam so that most of the protons impinged directly either in the $LaBr_3$ crystals or in the $LaCl_3$ ones. The highest pulse amplitudes detected by the PM tube corresponded to the protons that deposited energy in the $LaBr_3$ crystals (higher light yield) and the lower ones in the $LaCl_3$. These pulses were de-noised, background subtracted [2] and fitted to exponential functions dependent on the energy so that they could be used as input functions for the Monte Carlo simulations using the R3BRoot package [5].

Bi-dimensional histograms of I_{Tail} vs I_{Total} were constructed and converted to plots of the E_{LaBr_3} vs E_{Tot}, which was projected on the E_{Tot} axis and the 1D histograms were fitted to Gaussian functions so that CEPA peak efficiencies and resolutions were simulated. Using the optical pulses detected in the proton-test as input an agreement with the CEPA4 response observed in the experiment could be obtained.

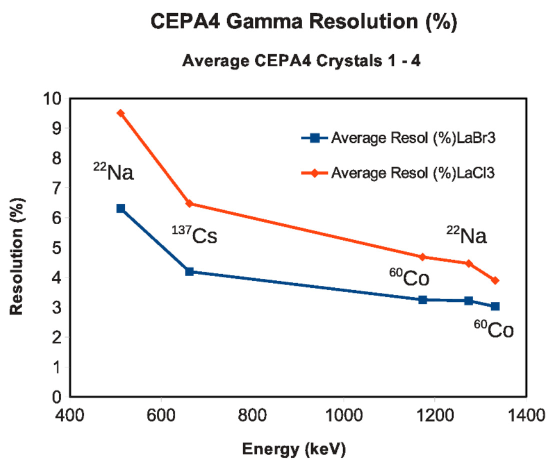

Figure 3. Averaged gamma radiation resolutions of $LaBr_3$ and $LaCl_3$ CEPA4 crystals for different gamma radiation standard sources.

4 Conclusions

We present in this work the experimental response obtained for mono energetic protons in the range (70 - 230 MeV) impinging on an array of 2x2 rectangular phoswich ($LaBr_3$ and $LaCl_3$) scintillator crystals. An analysis of the pulse shapes for different energies allowed us to detect and determine even protons of higher energies than the punch trough (> 200 MeV). The pulses detected by the PM tube are used to simulate realistic proton pulses for different energies for a bigger detector design consisting of 750 crystals, a possible design of the forward end-cap of the CALIFA calorimeter [4] being built for the future R3B experiments. The prototype, CEPA4, was further experimentally tested for gamma radiation (^{22}Na, ^{137}Cs and ^{60}Co) and with cosmic muons.

Acknowledgements

This work was supported by the Spanish CICYT under the project numbers FPA2009-07387 and FPA2012-32443. J. Sánchez del Río thanks the ERANET NUPNET for the financial support via the project GANAS.

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