A LYSO-based compact detector system for nuclear science applications

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Introduction

In the field of experimental nuclear physics it has often been observed that signatures of exotic nuclear states are suppressed in the dominant presence of long lived background states. In order to extract detailed physics information regarding these short lived states, it becomes imperative to devise methods which can focus on these channels of interest. Exploring, identifying and understanding the structure of such nuclei can answer questions regarding not only nuclear structure studies, but can also play a key role to address several astrophysical issues.

This has been made possible by considerable development on the technical aspects of detector physics as well the back end electronics and data processing. The current most advanced technology with regards to this is the use of segmented high purity germanium detectors employing the pulse shape analysis (PSA) algorithm. This recent leap in technology on both fronts- hardware as well as software has resulted in a drastic improvement of array efficiencies to ~30% as compared to earlier arrays that used high purity germanium detectors (HPGe) [1].

The 3-d position sensitivity of the detectors used in these arrays is based on the principle of identifying different shapes of the charge pulses arising due to different interaction points inside the detector volume. A database of pulses is created with a unique pulse shape for each point of interaction. Experimentally obtained pulses are then compared to this database and the exact location of an interaction can be deduced. In order to create this database, the detector needs to be scanned using a known radioactive source and a position sensitive detector setup using the methodology of positron-annihilation correlation (PAC). PAC employs the use of 511 keV annihilation photons (from ^{22}Na source) in order to scan an HPGe detector in correlation with a position sensitive detector (PSD) [2].

A LYSO-crystal [3] based PSD system has been developed using a segmented position sensitive photomultiplier tube (PS-PMT) [4]. This kind of a setup with a precise spatial resolution can be very useful for scanning high purity germanium detectors that utilize pulse shape analysis algorithms for signal processing. The assembly's characterization has been undertaken at the Variable Energy Cyclotron Centre (VECC, Kolkata), and the results are reported here. The electrical signals from the PS-PMT were processed using nuclear instrumentation modules (NIM) and Versa Modular Europa (VME) electronics.

Test Details

In order to understand the precision up to which the position information of an interaction within the detector may be correctly estimated, the scintillator crystal was coupled head-on to the PS-PMT using a refractive index matching silicone based optical grease. The crystal's polished top surface was then covered with Teflon tape, aluminum foil and black tape to ensure complete light locking with the PS-PMT. In order to negate effects of ambient magnetic fields, the detector assembly was housed in a 5 mm thick cylindrical aluminum casing. The LYSO crystal's dimensions were optimized for maximum efficiency and minimum parallax errors at: 3 mm thickness and 3 inch diameter. Since LYSO has presence of intrinsic activity, data was recorded in coincidence with a secondary detector: barium fluoride (dimensions: tapered, front dia. 2.5 cm, back dia. 2 cm, length ~2 cm, time resolution: ~310 ps), using PAC technique. In order to understand the position sensitivity of the setup, it was important to create a two-dimensional map of the detector and place the source at different places. This method helps understand the ability of the setup to distinguish closely spaced gamma sources. Additionally, in order to further reject the intrinsically generated counts of LYSO, a TDC spectrum was recorded in coordination with the barium fluoride detector used (fig 1). The 2-d map was created using the equation given below (similar equations used for horizontal as well as vertical position mapping). Figure 2 displays the 2-d equivalent plots for central spot irradiation and other irradiation spots as well.

$$X_{position} = \left[\left(\frac{X_{right} - X_{left}}{X_{right} + X_{left}}\right) * G + A\right]$$

X_{right}: position signal from right half of detector
X_{left}: position signal from left half of detector
G: gain factor
A: offset factor

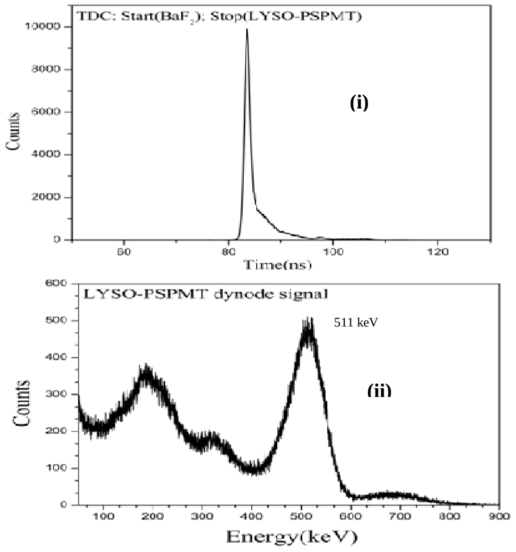

Fig. 1. *(top) TDC coincidence spectrum and (bottom) dynode energy signal spectrum of LYSO-PSPMT*

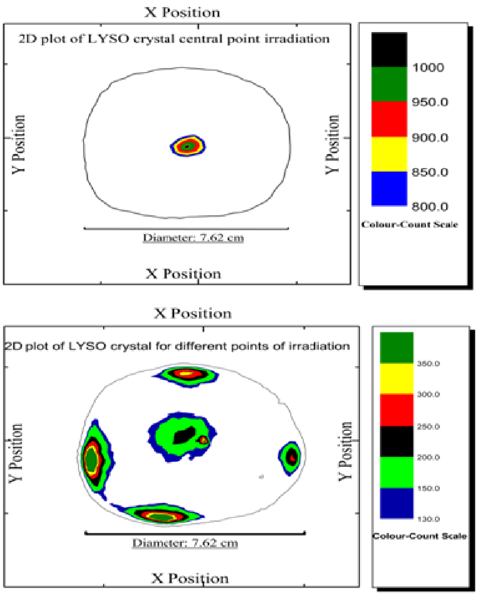

Fig 2. *(top) LYSO crystal's central portion irradiated by a γ ray source and (bottom) various points of the crystal irradiated by the γ ray source. The intensity of counts is highest for those points where the γ ray strikes the crystal.*

Results

This setup has been tested for position information regarding gamma photons interacting within the crystal material using anti-coincidence veto mechanism. Position sensitivity has been found to be in the anticipated range of a 5-7 mm. Further improvement in the spatial resolution is expected upon use of advanced data fitting algorithms.

Acknowledgement

The authors acknowledge C. Bhattacharya for providing the test facilities at VECC. A. Banerjee acknowledges Department of Science and Technology for INSPIRE fellowship (IF 130390). A.B and S.M acknowledge University of Delhi and FAIR collaboration for funding.

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