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The AX-PET project: Demonstration of a high resolution axial 3D PET

E. Bolle [a], A. Braem [b], C. Casella [c,*], E. Chesi [d], N. Clinthorne [e], E. Cochran [d], R. De Leo [f], G. Dissertori [c], G. Djambazov [c], V. Fanti [b,1], K. Honscheid [d], S. Huh [e], I. Johnson [g], C. Joram [b], H. Kagan [d], W. Lustermann [c], F. Meddi [h], E. Nappi [f], F. Nessi-Tedaldi [c], J.F. Oliver [i], P. Pauss [c], M. Rafecas [i], D. Renker [g], A. Rudge [d], D. Schinzel [c], T. Schneider [b], J. Seguinot [b], S. Smith [d], P. Solevi [c], S. Stapnes [a], P. Weilhammer [d]

[a] *University of Oslo, NO-0317 Oslo, Norway*
[b] *CERN, PH Department, CH-1211 Geneva, Switzerland*
[c] *ETH Zurich, CH-8092 Zurich, Switzerland*
[d] *Ohio State University, Columbus, OH 43210, USA*
[e] *University of Michigan, Ann Arbor, MI 48109, USA*
[f] *INFN Sezione di Bari, I-70122 Bari, Italy*
[g] *Paul Scherrer Institute, CH-5232 Villigen, Switzerland*
[h] *University of Rome "La Sapienza", I-00185 Rome, Italy*
[i] *IFIC, E-46071 Valencia, Spain*

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ABSTRACT

The AX-PET is a new geometrical concept for a high resolution 3D PET scanner, based on matrices of axially oriented LYSO crystals interleaved by stacks of WLS, both individually read out by G-APDs. A PET demonstrator, based on two detector modules used in coincidence, is currently under construction.

1. Introduction

Improving sensitivity while maintaining very good spatial resolution is a crucial issue in PET devices. In conventional (radial) geometry PET, these two aspects are strictly anti-correlated. One of the biggest instrumentation challenges is indeed the precise measurement of the depth of interaction (DOI) of the photons in the detector. The precise determination of the DOI is the only way to avoid parallax errors, which would lead to a non-uniform spatial resolution over the entire field of view; on the other hand, a precise DOI measurement is often achieved at the cost of the detection efficiency (e.g. small size crystals).

The AX-PET project proposes a novel geometrical concept for a PET, in which DOI measurement and detection efficiency are decoupled, and can be both improved at the same time.

2. Detector description

The AX-PET module (Fig. 1) [1,2] is a matrix of 6×8 LYSO scintillating crystals[2] ($3 \times 3 \times 100\,mm^3$ each), axially oriented in the tomograph. A fine granularity hodoscope of 26 wavelength shifting (WLS) strips[3] ($0.9 \times 40 \times 3\,mm^3$ each) is placed underneath and perpendicularly to each of the six layers of LYSO, for the detection of the axial coordinate of the photon interaction point in the crystal. Each layer is optically and mechanically separated from the others by carbon fiber plates. Both crystals and WLS strips are individually readout by Multi-Pixel Photon Counters (MPPC),[4] multiple avalanche photodiodes operated in Geiger mode. These devices are characterized by high PDE ($\sim 30\%$), high gain, compactness and insensitivity to magnetic field, which would make it possible a future co-registration of the PET data with MRI.

The described geometry, combined with the high achieved photoelectrons yield, allows the direct measurement of the three coordinates of the photon interaction point in the crystals. This is valid in a wide energy range, from the full energy deposition of the annihilation photons (511 keV) down to a minimum detectable deposited energy of about 50 keV for the Compton-scattered photons. The spatial resolution in all the three coordinates can be tuned simply through the granularity of the scintillator bars and WLS strips; in the present design, a total spatial resolution of a

* Corresponding author.
E-mail address: Chiara.Casella@cern.ch (C. Casella).
[1] On leave of absence from INFN and University of Cagliari, Italy.
[2] Prelude 420 ($Lu_{1.8}Y_{0.2}SiO_5 : Ce$), Saint Gobain.
[3] EJ-280-10x, ELJEN Technology.
[4] S10362-33-050C (for the LYSO) and 3.22×1.19 octagon-SMD (for the WLS), Hamamatsu.

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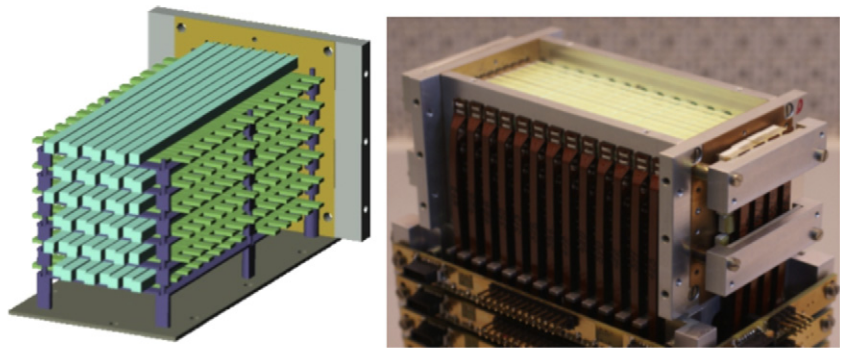

Fig. 1. The full AX-PET module. On the left: drawing of the module, with the six layers of crystals and WLS. On the right: photograph of the fully assembled module, inside its mechanical structure; part of the kapton cables connecting the photodetectors to the electronics is also visible.

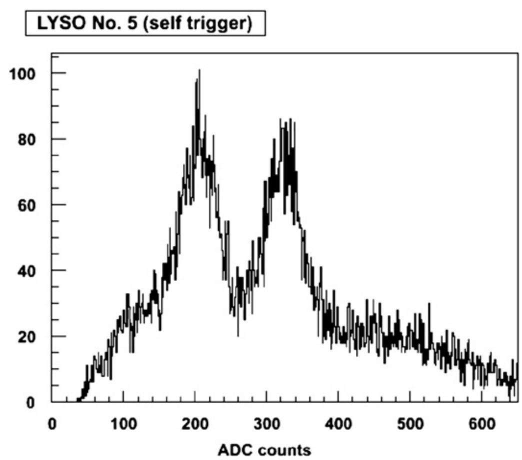

Fig. 2. Typical energy spectrum of intrinsic radioactivity in one LYSO crystal, in the "pre-module" matrix arrangement.

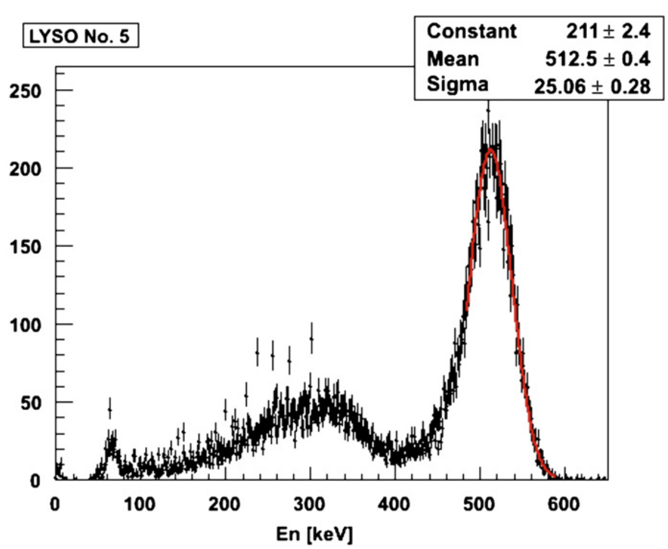

Fig. 3. Typical energy distribution of the photons detected in one crystal (out of the 16 in the "pre-module" matrix), when the matrix is exposed to 511 keV annihilation photons from a ^{22}Na source. A high energy discriminator threshold ($\sim$400 keV) on the summed energy of the matrix is used for the trigger. The spectrum shown is already energy calibrated. An energy resolution of about 11.5% FWHM is measured.

few cubic millimeters is expected, close to the limits imposed by the physics of the positron annihilation. The axial geometry and the modularity in the design give the intrinsic advantage of a

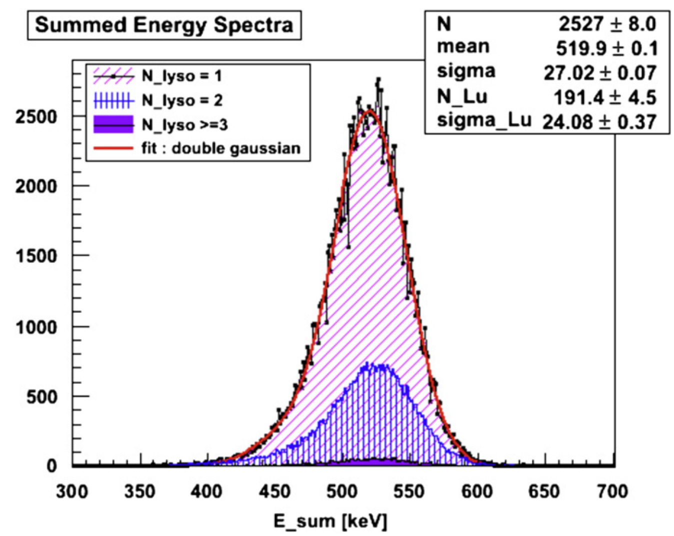

Fig. 4. Summed energy spectra of the LYSO crystals in the "pre-module" matrix, at different crystal multiplicities ($N_{LYSO} = 1, 2, 3$ or more). The plot refers to the same run conditions as described in Fig. 3. The percentages of events with 1 and 2 hit crystals are, respectively, 75% and 25%; the fraction of events with more than two crystals is negligible. The asymmetry observed in the detected photopeak is explained by the Lu X-ray escape peak (63 keV below the photopeak). A double Gaussian fitting function, with mean values E_0 and $E_0 - 63$ keV, well describes the data in the full range.

device in which a high sensitivity can be achieved (e.g. by increasing the number of layers) without compromising the resolution (which is determined by the granularity of the components). A further increase in the sensitivity is obtained by adding in the reconstruction the part of the Compton scattered events which could be resolved by Compton kinematics.

3. Detector performance

Characterization studies of the various components, as well as preliminary small scale prototypes, have demonstrated the feasibility of the AX-PET, showing high light yields ($\sim$1000 pe at 511 keV), and good axial resolution ($\sim$1 mm FWHM) [3,4]. Currently, a "pre-module", consisting of 16 LYSO and 52 WLS, arranged in two layers (i.e. one-third of the module), coupled with the full readout electronics and DAQ chain, is being tested. Energy calibration in the crystal is performed using both the photopeak (511 keV) and two of the peaks of intrinsic radioactivity of the LYSO (202 keV, 307 keV), as shown in Fig. 2. A good energy resolution of $\sim$11.5% FWHM (at 511 keV) is achieved, as shown in Fig. 3. The hits multiplicity (measured so far only with the incomplete geometry of 16 crystals) shows a high percentage of Compton scattered events ($\sim 25\%$ of the total statistics, see Fig. 4). A full Monte Carlo simulation and a dedicated image reconstruction software are developed. First successful reconstructions of (simulated) simple extended sources have been achieved.

4. Current status and future steps

The assembling of the first full module has been completed and the module is being calibrated at CERN with 511 keV photons from a pointlike ^{22}Na source, placed in different positions along the axial plane. The second module is presently under construction. The two calibrated modules will be used in coincidence, firstly with the ^{22}Na source (at CERN), and then on conventional phantoms filled with ^{18}F based radio-tracers (in the radiopharmaceutical center at ETH, Zurich), to assess the final performance of the demonstrator. Optimisation of the reconstruction software is, in parallel, ongoing.

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[4] E. Bolle, et al., in: Conference Record IEEE Meeting 2008, Dresden, 2008.