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

Chiara Casella (ETH Zurich - CH-8092 Zurich, Switzerland)
for the AX-PET collaboration

DETECTOR DESCRIPTION

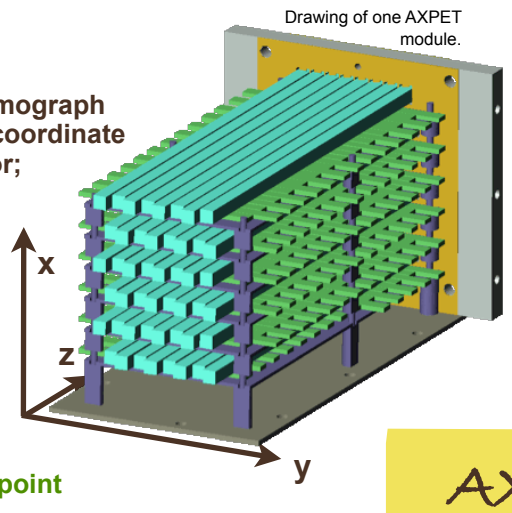
PET MODULE :

- Matrix of 6x8 LYSO scintillator crystals, axially oriented in the tomograph
- In each layer, hodoscope of 26 WLS strips for detection of axial coordinate
- Each scintillator and WLS individually coupled to a photodetector; Al coating applied on the side opposite to the photodetector
- Photodetectors : Multi Pixel Photon Counters (G-APD's)

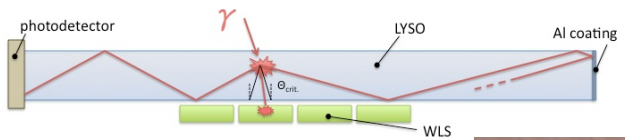
DETECTION PRINCIPLE :

- Role of the crystals: Reconstruction of the (x,y) coordinate and measurement of the deposited energy
- Role of the WLS: Collection of the scintillator light which is not trapped in the crystal by the total internal reflection (i.e. with incident angles Θ < Θc)

  => Reconstruction of the axial (z) coordinate of the γ interaction point



Drawing of one AXPET module.



Detection principle of the AXPET, based on scintillator bars and WLS strips, for the 3D measurement of the position of the gamma interaction point.

DETECTOR COMPONENTS :

LYSO (LuYSiO:Ce) Prelude 420TM (Saint Gobain)
- non hygroscopic
- Density: 7.1 g/cm³
- Peak emission: 420 nm
- λ_attenuation: 1.2 cm (@511 keV)
- Light yield: 32000 photons / MeV
- Decay time: 41 ns
- Refraction index: 1.82 (@420 nm)
- Dimensions : 3(x) x3(y) x100(z) mm³

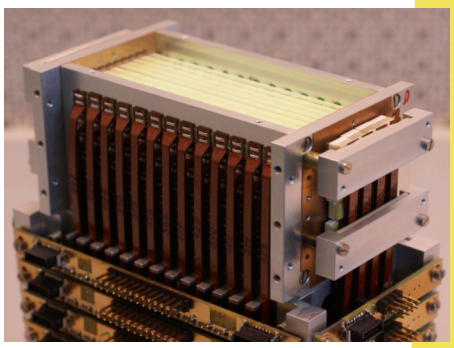
PHOTODETECTORS MPPC - Multi Pixel Photon Counter (Hamamatsu)
- Multiple Avalanche Photodiodes operated in Geiger mode (G-APD's)
- PDE ~ 30%
- for crystals : MPPC S10362-33-50C (3x3 mm²; 3600 pixels)
- for WLS's : MPPC octagon SMD (3.2x1.2 mm²; 782 pixels)
- Individually glued to LYSO and WLS with optical glue: Dow Corning Silastic 3145 RVT, n=1.5

WLS strips EJ-280-10x (ELJEN technology)
- Max absorption wavelength: 425 nm
- Max emission wavelength: 490 nm
- Decay time : 8.5 ns
- Transmission coefficient: 0.86
- Dimensions : 0.9(x) x40(y) x3.1(z) mm³

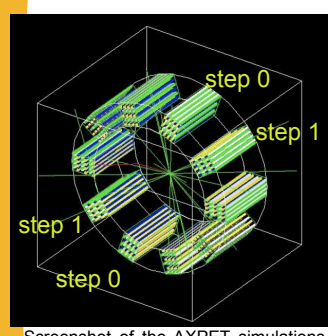
READOUT ELECTRONICS, DAQ and TRIGGER
- The signals from the MPPS's are distributed through fast amplifiers (OPA846) into 128-channels charge sensitive integrating VATA-GP5 chips. The chip is operated in sparse readout mode, with a relatively low detection threshold (~ 80 keV), to detect and reconstruct inter-crystal scattering.
- The external trigger (NIM logic) is the coincidence of the two 511 keV annihilation photons (one per module), with a high energy discrimination threshold (E_thr ~ 400 - 450 keV) on the module summed signal.

AXPET HIGHLIGHTS :

- Novel geometrical concept (axial arrangement)
- Full 3D reconstruction of the photon interaction point
- Precise measurement of the depth of interaction DOI (i.e. parallax error free system)
- High spatial resolution
  - tunable with the granularity (in the present design, a spatial resolution of ~ 1mm is expected in the 3 dimensions)
  - uniform along the field of view
- High sensitivity
  - can be increased (with the number of layers) without compromising the spatial resolution
  - high detection efficiency
- Possibility to reconstruct the Compton scattered events (Inter Crystal Scattering ICS), thus providing a further increase in the sensitivity


Photograph of the fully assembled module

GOAL OF THE PROJECT:

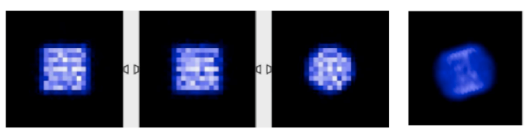


Screenshot of the AXPET simulations in a 5-steps acquisition. Each step corresponds to two modules used in coincidence.

The goal of the AX-PET project is to construct and fully characterize a demonstrator for a PET scanner consisting of two identical detector modules, used in coincidence on a rotating gantry. The measurements with the demonstrator (with point-like sources and conventional phantoms) will be used to validate the simulation and reconstruction software. Finally we will be able to predict the performance expected in various scanner configurations.

SIMULATIONS & RECONSTRUCTION

- Full Monte Carlo simulation of the detector (GATE / GEANT4 based package)
- C++ based image reconstruction software, performing System Matrix calculations (Siddon's algorithm) and MLEM reconstruction.


Example of reconstruction of a cylindrical extended source, with realistic input values for the energy resolution (ΔE=12%), time resolution (Δt=3ns) and coincidence window (τ=6ns). The source (radius = 5 mm; height = 10 mm) is simulated with GATE, with a small activity (A=1μCi) to reduce randoms, and a total statistics of 750k events.

CURRENT STATUS:

- All detector components selected and fully characterized.
- First full module assembled.
- Readout electronics & DAQ available and tested.
- Detector principle and first detector performance assessed in several previous test bench setups:
  - single crystal / WLS setups
  - reduced scale matrix setup
    1. 4x4 crystal setup
    2. 2-layers "pre-module" with full readout and DAQ chain
- Simulation and reconstruction: first successful reconstruction of simple (simulated) extended sources.

ACHIEVED PERFORMANCE :

MEASURED FROM PAST SETUPS :

- Energy resolution : 11.5% FWHM @ 511 keV
- High achieved light yield (~ 1000pe @511 keV)
- Axial spatial resolution : 1.1 mm FWHM

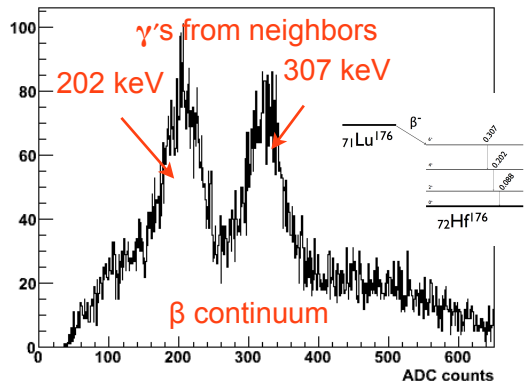
RECENT RESULTS FROM a REDUCED SCALE SETUP :

A "pre-module" setup of 16 LYSO crystals arranged in 2 layers, fully equipped with WLS, has been studied both with intrinsic radioactivity (self-triggering mode) and with a ^{22}Na source, in coincidence with a tagging scintillator (external trigger). The final complete FE and DAQ chain is used for the measurements.

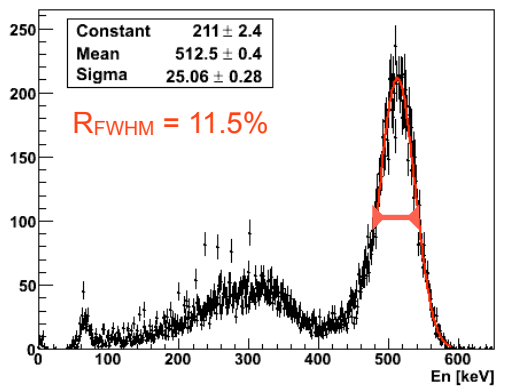
The typical spectrum of LYSO intrinsic radioactivity is measured when the crystals are arranged closely in the matrix (continuum β^- spectrum plus three peaks of defined energies: 88, 202 and 307 keV).

The peaks of intrinsic radioactivity, plus the photopeak (511 keV) provide an excellent tool for online and quickly repeatable calibration of the full chain (ADC counts to energy), needed because of the MPPC non linearity (5% saturation at 511 keV). A good energy resolution of 11.5% FWHM is achieved on the typical (calibrated) energy spectrum.

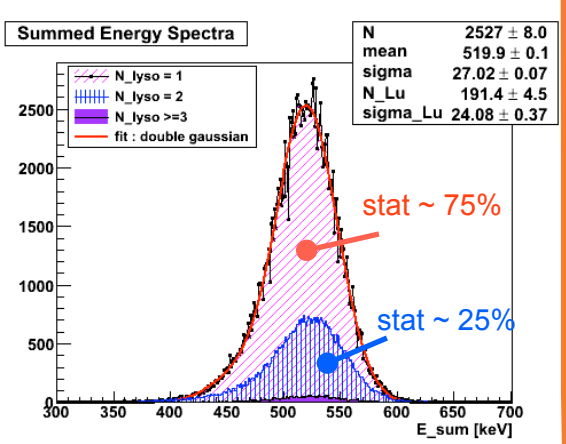
Although measured so far only with a partial geometry (16 crystals at maximum), the LYSO multiplicity study shows the good potential of the ICS reconstruction, with a substantial fraction of Compton scattered events (~ 25% of the total) which could be included in the reconstruction.



Typical measured spectrum of intrinsic radioactivity of a single LYSO crystal in a matrix arrangement.



Typical energy distribution of the photons detected in one crystal, when the matrix is exposed to the 511 keV annihilation photons from the ^{22}Na source.



Summed energy spectra of the lyso crystals in the matrix, corresponding to different crystal multiplicities (N_lyso = 1, 2, 3 or more). The asymmetry in the photopeak is explained by the Lu X-ray escape peak and represented by a double gaussian fitting function.

NEXT STEPS :

- Assembling of the 2nd module.
- Optimization of simulation and reconstruction software.
- Calibration of the single module response with a point-like ^{22}Na source, scanning several positions in the axial (xy) plane - @ CERN
- Two modules used in coincidence (both measurements and reconstruction) with the point-like ^{22}Na source - @ CERN
- Real PET events, with the two modules used in coincidence (on a rotating gantry) around phantoms filled with specific radiotracers (^{18}F) - @ Center for Radiopharmaceutical Science, ETH Zurich

more info? https://twiki.cern.ch/twiki/bin/view/AXIALPET/WebHome

May 2009