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M3.4 - IMAGING USING SEGMENTED DETECTOR

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LIST OF ACRONYMS AND ABBREVIATIONS

$LaBr_3$:Ce	A transparent scintillator material that offers the best energy resolution obtained so far. Hygroscopic, has to be encapsulated. Emission at 380 nm
SiPM	Silicon Photo Multiplier: solid state single photon sensitive devices based on an avalanche diode compact. SiPM are compact, low voltage operation, and insensitive to magnetic field
ASIC	Application Specific Integrated Circuit: i.e. an integrated circuit (IC) customized for a particular use.
PMT	Photo Multiplier Tube. The traditional standard glass tube technology using Photo-cathode and dynode amplification to convert scintillator light to electric pulse. Several different types of PMTs have been tested in our previous reports.
Dynamic Range	Detection is built on a linear conversion from impinging energy to a digital number.
PDE	Photon detection efficiency
DT5751	CAEN pulse digitizer, converts analogue signals to digital numbers for further analysis (1 GHz sampling frequency)
FWHM	Full Width at Half Maximum; a way of determining the resolution obtained with the crystals, When given in % the FWHM has been divided by the Full-Energy peak position inthe spectrum.
FSR	Full Scale Range

Executive Summary

In this JRA, we exploit novel scintillator materials. The focus is on developing the capability to simultaneously detect high-energy gamma rays, neutrons and charged particles. The emphasis is on features like energy resolution, position sensitivity, high rate capability, and insensitivity to magnetic fields or radiation hardness are of differing importance.

This milestone is strongly cross -related between the different TASks of the JRA. The specific work presented has mainly been performed by the participating groups of INFN (F. Camera) and CNRS (G. Hull) with some inputs from the rest of the collaboration.

As was discussed in the project application a large number of new promising scintillator materials are becoming commercially available. These new materials have to be characterized. The result of such study is particularly interesting for the companies that produce new scintillator materials as often they cannot perform such tests themselves as this requires infrastructures that only University and Research Centers exhibit.

In this milestone, we are aiming for the imaging properties obtained choosing the optimum fast scintillator material in combination with novel sensors and readout systems..

Introduction

The scintillator material LaBr3:Ce can today be considered a reference in gamma spectroscopy because of its outstanding performances. These crystals are well known to provide a short and bright light pulse if compared with other commercially available scintillators. Further, recent developments in readout-sensors, especially using SiPM technology instead of the standard Photo Multiplier Tubes (PMT) have brought to the market sensors having low dark-count, high Photon detection efficiency (PDE) that can provide a high Dynamic Range (DR) readout of $LaBr_3$. In addition to compactness, SIPM provides insensibility to magnetic fields, low-voltage operations.

This milestone is a continuation of the work performed within the TASK1 as described in the Milestone M3.0 deliverable 9.1 but is strongly cross-related between the tasks and so to the deliverable D9.5 of Task 2 Phoswich Detectors. The work presented here has mainly been performed by the group of the Politecnico di Milano - INFN section of Milano.

SECTION 1 THE READOUT SENSOR AND INTEGRATED ELECTRONICS

The recent developments in SiPM technologies have brought to the market low-dark-count, high-PDE detector that can provide a high Dynamic Range (DR) readout of LaBr3. In addition to compactness, SIPM provides insensibility to magnetic fields, low-voltage operations and electromagnetic compatibility. The key advantage of this technology coupled to bright scintillators is the capability of a multichannel readout that does not worsen the spectroscopy resolution allowing, in addition, imaging reconstruction to compensate Doppler effect distortion as depicted by figure 1.

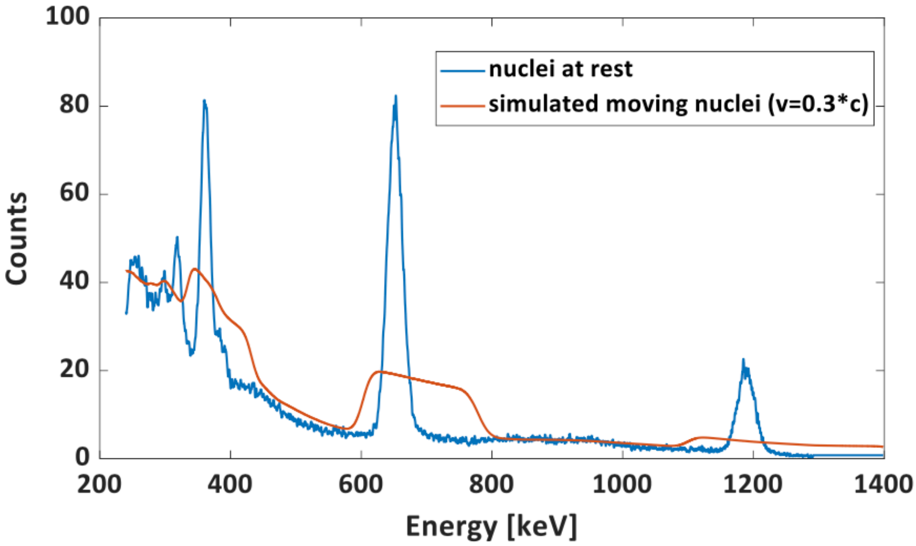


Fig. 1. Simulated Doppler effect induced spectrum broadening. Large volume detectors introduce a large uncertainty in the angle determination that could destroy the detectors energy resolution. This effect can be reduced using position sensitive light sensor as SiPM.

While state of the art front-end electronics, in particular ASICs, are suitable for standard DR applications, wide DR experiments require novel solutions to accomplish this goal. The project aims to develop a wide energy range (100 keV – 20 MeV) gamma-ray spectrometer and imager with state of the art energy resolution, based on a 3” x 3’’ crystal coupled to a 144 NUV-HD SiPMs matrix that is currently under production by FBK (Trento, Italy).

This SiPM matrix is composed by nine 4x4 SiPM tiles and first prototypes is under test and it is the main topic of an ENSAR2 fellowship which is going to start. A test bench setup allowed to perform the characterization of the SIPM and crystal type with a scalable readout of 1” or 2” LaBr3 crystals, providing state of the art resolution with SiPM readout of 3.2% @662 keV [1]. The signal range impinging on every different SiPM was simulated and measured with the aforementioned setup, and produced a design of a specific 8-channel ASIC meant to cope with the high dynamic range of the application [2]. The ASIC was produces (outside ENSAR2 resources) in 2018.

For the prototypes, in order to be able to read the entire SiPM matrix using only one ASIC with 8 channels, a parallel-merging strategy has been adopted. Exploiting the same readout electronics, two prototypes with two different SiPM merging strategies were designed: one was optimized for dynamic range and one optimized for imaging reconstruction (see figure 2). Once tested the prototypes, a system with a large number of ASICS (channels will allow to have both the features at the same time. In the following the results obtained with the two configurations will be briefly presented.

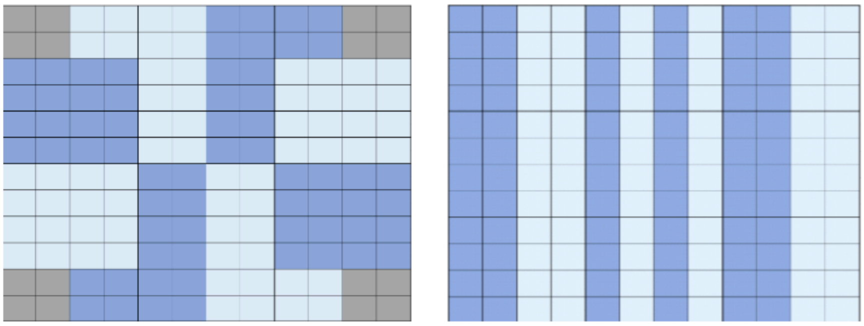


Fig. 2: SiPM merging strategies, the first is optimized for spectroscopy while the second is optimized for position reconstruction. Increasing the number of available channels a combination of the two features will be possible.

Section 2 SPECTROSCOPIC PERFORMANCE

In order to optimize the dynamic range of the application with only 8 analog channels available a distributed merging strategy was adopted as previously explained and also shown in figure 2. Each channel is connected to the same number of SiPM but distributed in such a way that the light should be uniformly distributed between the different SiPMs tiles; namely the matrix center SiPM tiles were connected to those of the sides. The uniformity of the channel level spectra allowed a larger energetic dynamic range because saturating events were shared between all the channels.

The ASIC integrates the different signals and provide a sampled output value to be digitalized by the 12 bit ADC of a STM32f4 microcontroller. The data are digitally summed and the resulting spectrum is showed in figure 3. The instrument was used to acquire multiple radioisotopes to perform a linearly calibrated energy resolution measurement at room temperature. Using a 3”x3” $LaBr_3:Ce$ crystal a FWHM resolution of 3.4% @ 662 keV was measured without any data processing nor gain calibration (the reference sheet provided by St.Gobain gives 2.9 % at 662 keV).

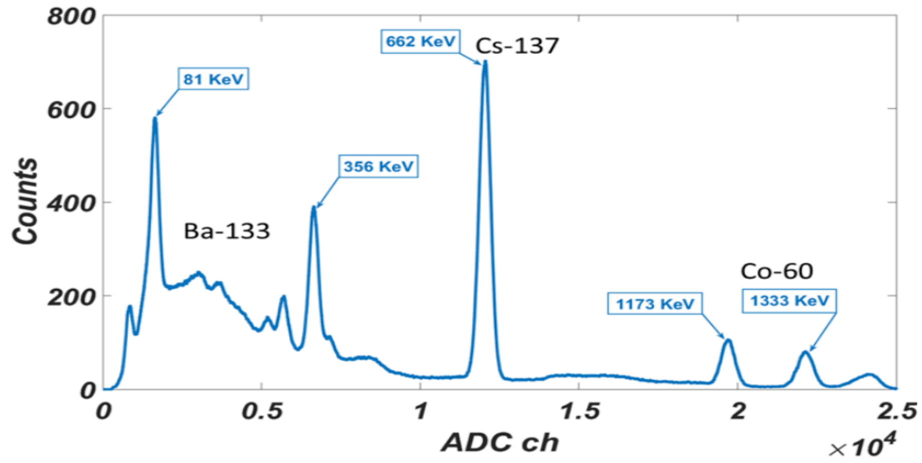


Fig. 3: energy spectrum obtained with the described instrument. A 4 energies calibration demonstrated a 3.4% FWHM @ 662keV and a 4 MeV Full Scale Range (FSR).

The SiPM biasing voltage was not changed during the 20 minute acquisitions because the SiPM tile temperature did not show any significant change. Reducing the ASIC gain at the lowest available value (1V/1nC) and pulsing the SiPMs with a calibrated laser source, we were able to acquire the spectrum from 30 keV up to equivalent energy of 5 MeV without saturation.

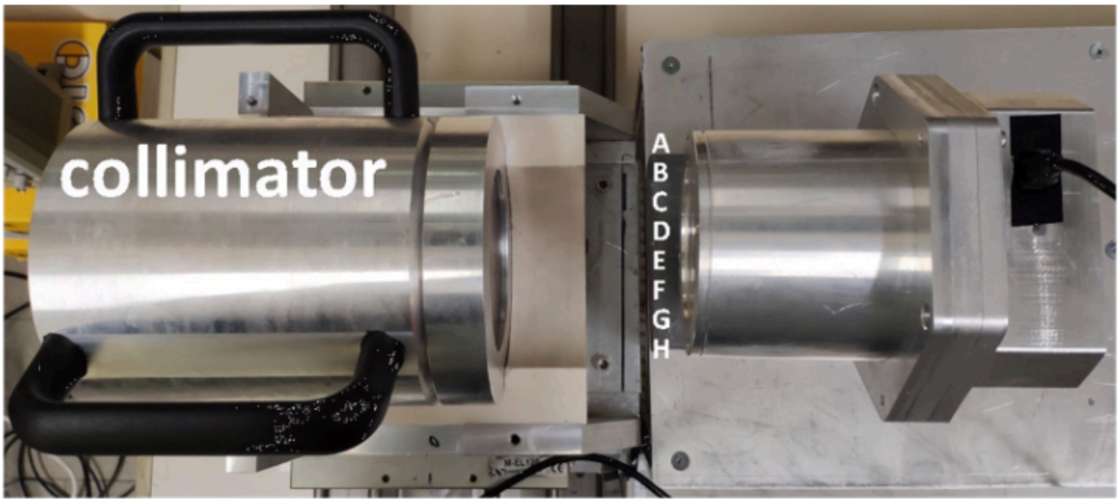
SECTION 3 POSITION RECONSTRUCTION

Because of the low number of channels available, the position sensitivity was implemented only in one dimension, namely that associated to the 'theta' angle used in the Doppler Broadening correction [3].

As depicted by figure 2 the SiPM were merged in vertical arrays, narrower in the center and larger on the crystals sides. Thanks to a 470 MBq Cs-137 collimated source it has been possible to evidence a position sensitivity of the realized prototype. A collimated gamma ray beam was used to irradiate the detector in 8 different positions, from one side of the crystal to the other. In the top panel of figure 4, a picture of the used experimental apparatus is shown. In the bottom panel of figure 4 it is shown the result of the first hit position measurement and reconstruction when the collimated beam of 662 keV gamma rays enter from the SiPM side.

The data were acquired and analyzed offline. Once the events corresponding to the Cesium peak have been selected, the signal distribution among the different channel was used to create a light distribution model.

from a dataset obtained with the ANTS2 software [4], simulating the same operative conditions. These models were used to sort the data coming from other acquisitions and the ability of guessing the position of the impinging gamma rays. The position was guessed with a position-dependent probability: in figure 4 is showed that a $\sigma < 1$ cm was measured in the center, while on the sides a larger resolution was observed ($\sigma < 2$ cm).



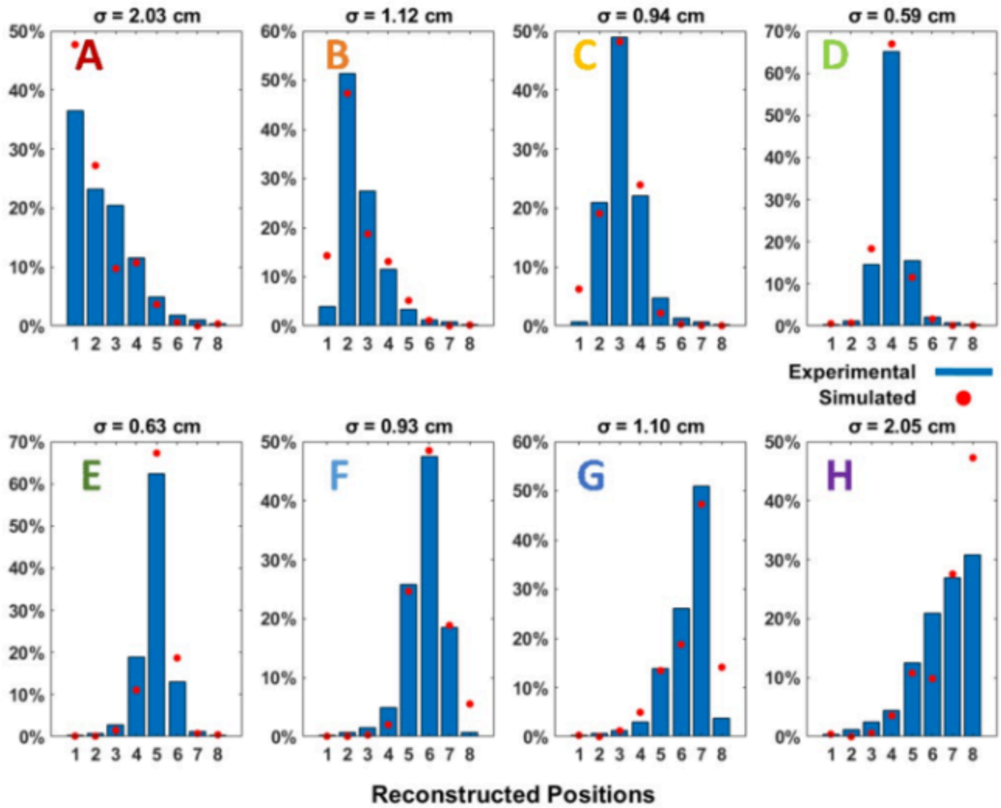


Fig. 4: position of interaction measurement and results. After having measured the light distribution coming from 8 known positions, it has been possible to create a model able to reconstruct the position of interaction with a maximum uncertainty of 2 cm.

SECTION 4 CONCLUSIONS AND FUTURE WORK

The release of a USB powered 3”x3” $LaBr_3$ spectrometer and imager based on a 144 SiPM matrix is expected to be produced in near future. The instrument exploits the 8 channels high dynamic range ASIC used in these tests (the ASIC is named GAMMA) and a microcontroller readout system, (the system is named LAILA [5]).

In order to extend the dynamic range of the 8 analog channels instrument to the maximum Full Scale Range (FSR), a distributed merging scheme was adopted for the SiPM matrix. A calibrated spectrum proved the 3.4% FWHM resolution using a 3”x3” LaBr3. In the near future this system will be tested on a co-poped LaBr3:Ce-Sr2 where an energy resolution better than 2.9% at 662 keV is expected.