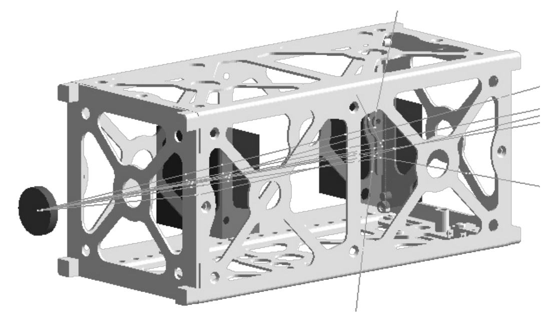
Simultaneous Deposited Energy and Interaction Position Determination in Monolithic Scintillators



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Abstract

A study of several methods to obtain simultaneous measurements of deposited energy and interaction position in monolithic $CeBr_3$ and $LaBr_3$ scintillator crystals using a 12x12 matrix of 3mm^2 silicon photomultipliers was performed by simulation and experiment. A multistep method for analysis and reconstruction of the data is being implemented. Two data acquisition and analysis systems - from commercially available modules and an in-house design - are being built to validate the simulation results and are currently undergoing calibration and testing. The tested detector system can perform spectroscopy with energy resolution reaching the specification limits of the scintillator crystals. Depending on the applied sequence of methods spatial resolution of 0.66mm with σ =0.88mm was achieved after applying the developed event classification and separation algorithms. An investigation of a ML-based algorithm for classification in applications where complex detector geometries prevents the development of an efficient analytical or numerical solutions is ongoing.

Introduction

In HEP and nuclear physics experiments there is a demonstrated need for small-size, robust and reusable detector components and acquisition systems that can be operated in resource-limited environments and provide measurements limited by the physical properties of the available primary detector. Applications of such components would have applications beyond research.

The presented research investigates the possibility to develop such a component based on recently developed fast, high-yield and high resolution crystal scintillators and SiPM-based readout. A set of simulations, an analysis framework and two integrated hardware solutions were developed and are in the process of testing and iterative improvement.

Simulation and Modeling

A GDML-based Geant4 simulation package was developed to allow fast investigation of different geometries, sensor-to-readout couplings and channel readout arrangements. Primary object of investigation were widely available $CeBr_3$ and $LaBr_3$ cylindrical and rectangular prism scintillators, coupled to multi-pixel SiPM matrices. A typical simulation target is shown on figure 1. As the goal of the research is quantifying the ability to obtain simultaneously readings for energy as well as interaction position (or its projection onto the sensor matrix

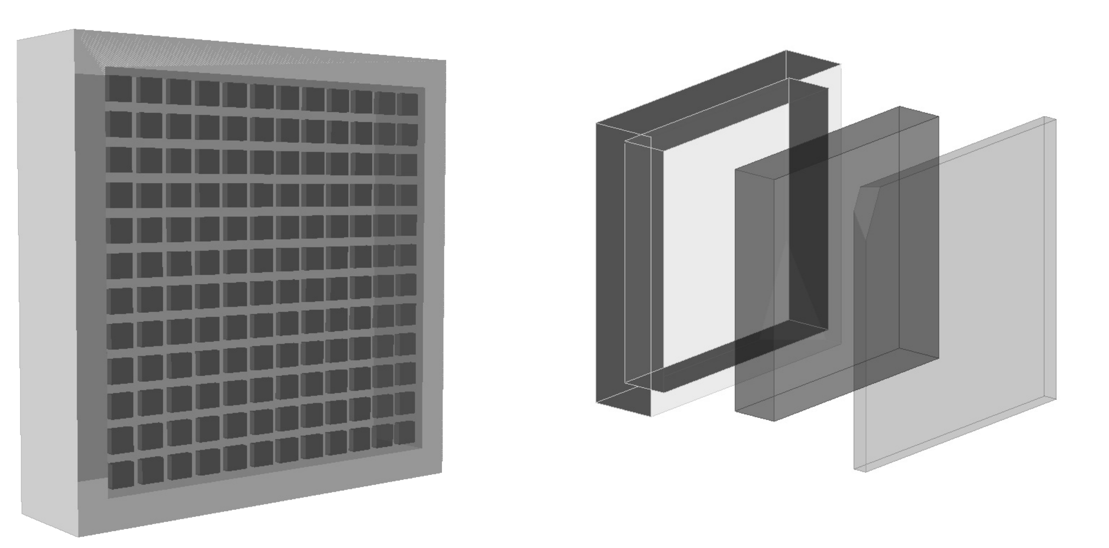

Figure 1. Typical scintillator simulation target. Left: Scintillator with the attached SiPM sensitive detector matrix. Right: Exploded view of the scintillator - reflective case, crystal, cover for hygroscopic protection.

plane), both reflective and diffuse enclosure surfaces were modelled and simulated. All planned electronic readout and acquisition systems were simulated by collecting individual SiPM sensitive detector data and aggregating them using each system's readout setup.

Scintillators and Photon Counters

For the experimental measurements, two $CeBr_3$ crystals with size 51x51mm^2 and thickness of 10 and 25mm, and one $LaBr_3$ cylindrical crystal with D=2.54mm/H=25.4mm were used. The pixel counters are On-Semi (formerly Sensl) 30035 type SiPMs with 35um cell size, 4774 individual cells per pixel and with total pixel size of 3x3mm^2, assembled in a 12x12 pixel matrix with pitch 4.6mm.

Readout

Three different readout systems were built and are undergoing testing. Two are based on commercially available modules and are used to test the usability of different channel summation schemes; a prototype was developed in-house to digitize individual SiPM pixels and enable the application of more advanced event classification algorithms in the data processing stage.

Summating readout was implemented using AiT instruments' 4-channel readout and Row-and-Column readout modules. Both solutions allow in principle the construction of a readout system capable of simultaneous estimation of position and

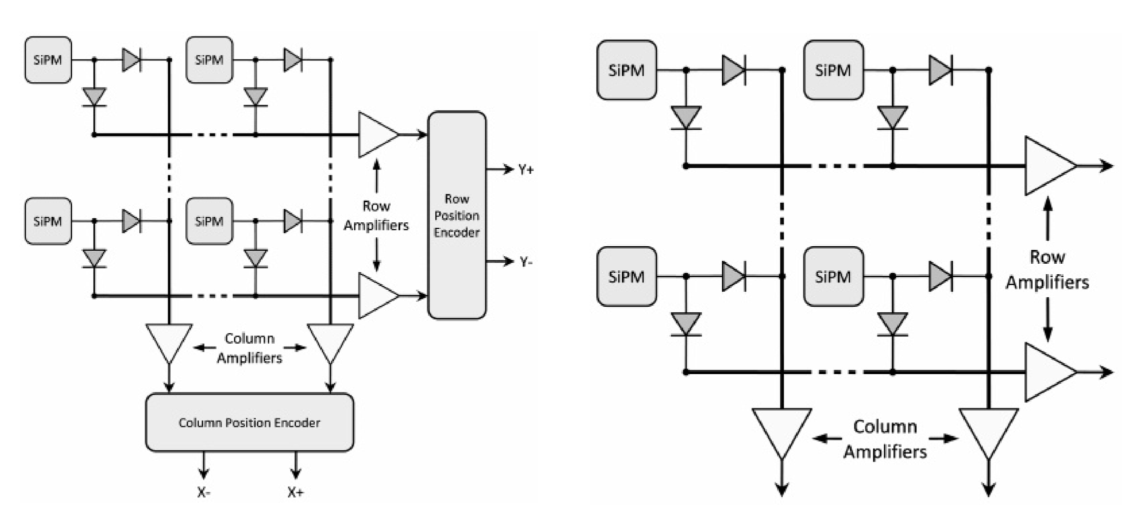

Figure 2. Channel-summing readout schematic of AiT Instruments' modules. Left: 4-channel summation. Right: Row-and-Column summation. Source: AiT website.

energy using small number of expensive DAC channels. Theoreticlally, the position resolution of the channel summation system is no different from the resolution of an individual readout system using the centroid method. The resolution of the 4-channel system was studied for performance with a non-segmented scintillator.

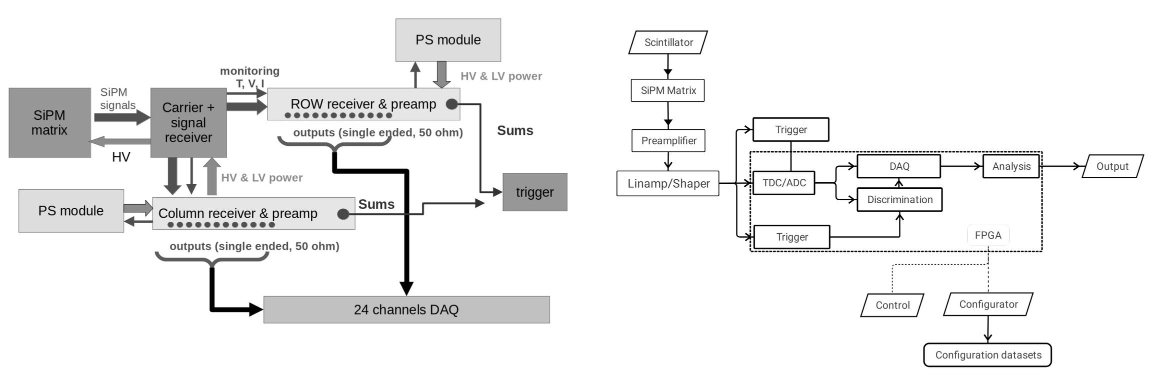

Figure 3. Left: Data acquisition using AiT instruments' channel summing technologies. Right: Schematic of Individual Readout Based on Amplitude-to-Time transformation and measurements of ToT and ToA using an FPGA-based TDA algorithms.

Prelminary Results

All three systems have been studied by simulation for energy resolution. For positional resolution, the row/column summation and individual readout systems have been studied. The 4-channel summation system has been tested experimentally and found to provide very low position resolution when used with a monolithic crystal. Research is ongoing to complete and test the row/column summation and individual readout systems for positional resolution in hardware.

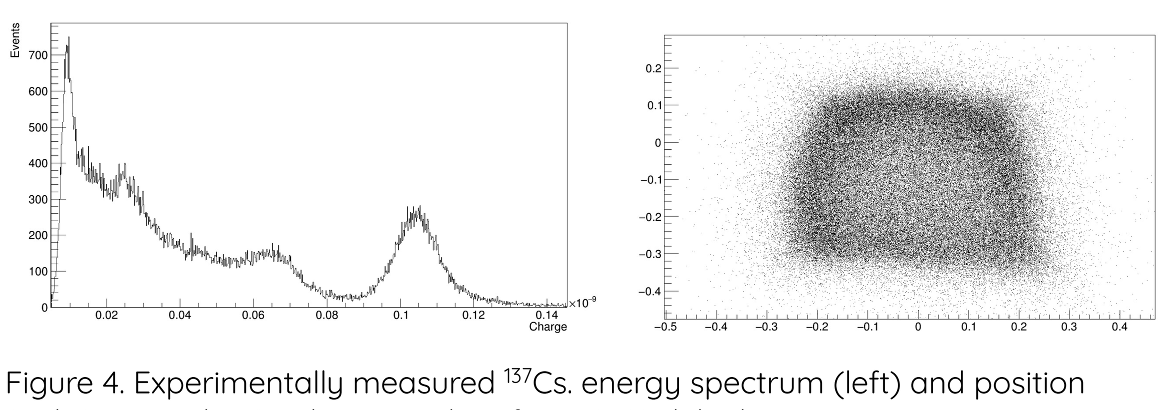

Figure 4. Experimentally measured ^{137}Cs. energy spectrum (left) and position (right), using the 4-column readout from AiT. While the spectrum measurements are close to the expected resolution, the position measurements (shown in units of SiPM pixel size) are too crude to be of experimental value.

The 24-channel summation system and the individual pixel readout systems have been studied by simulations and analysis algorithms have been applied to generated data in expectation of completion of the hardware, which is expected to be complete by the end of the year.

For spectroscopy, the expected energy resolution for the two systems is, again, very much in line with the vendor-provided single PMT measurements (summary of the energy resolution simulations is provided in Table 1). The slight increase in the

Line energy	Simulation resolution	Experimental resolution
[kev]	[%]	[%]
122	6.4	5.0
244	5.6	4.2
344	4.7	3.7
778	3.0	2.4
1408	4.0	3.0

Table 1. Energy resolution (experimental and simulated) of a LaBr3 monolithic crystal.

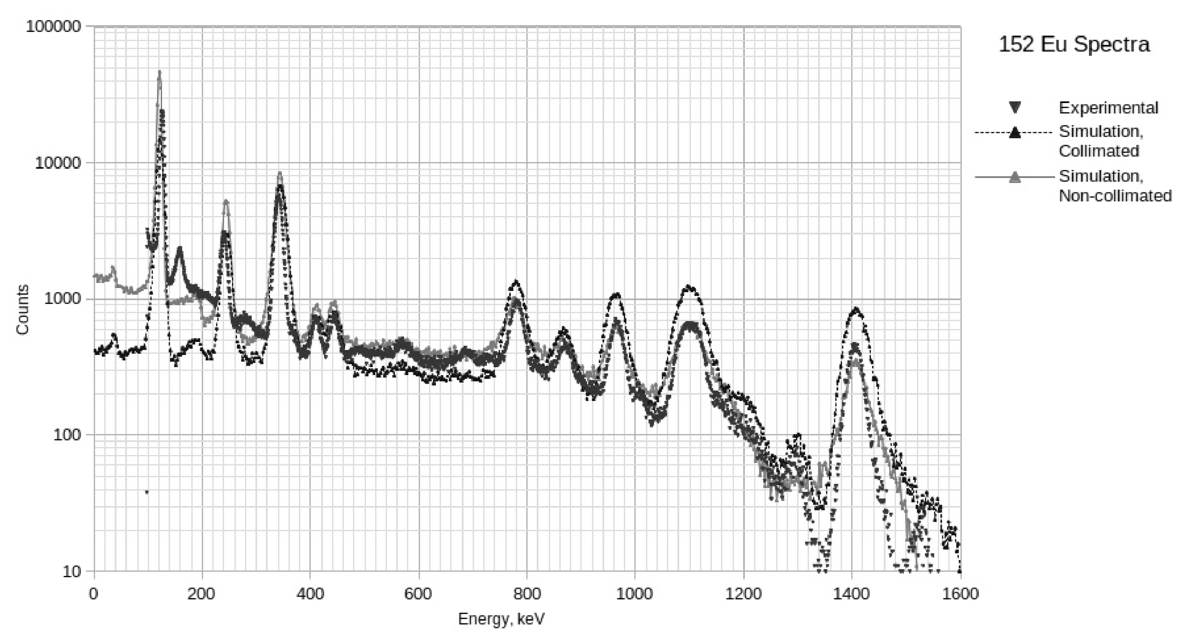

Figure 5. Simulated and experimental data of ^{152}Eu spectra from an in-house readout system for a comparable number of events.

resolution compared to the vendor results can be attributed to differences between the model and the actual crystals.

The baseline for the study of determination of position of interaction is the centroid method.

For the chosen SiPM matrix, the obtained results for unclassified "pictures" of the interaction that include single or multiple interactions (dx = 1.36mm, σ =1.84 mm). A significant increase in the precision of the calculated position was observed (dx = 0.66mm, σ =0.88 mm) after classifying events into single and multiple interaction events, and performing estimates of the individual interactions for every event.

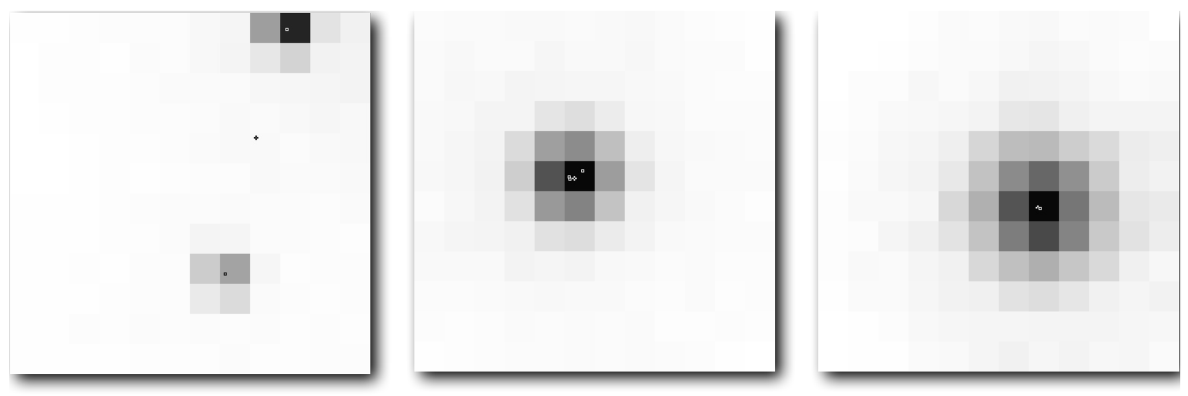

Figure 6. Position estimate simulations for the channel summation/individual readout system without classification. Leftmost: worst case. Middle: median case. Rightmosts: best case.

Dicsussion

The largest errors in the position determination with the simple application of the centroid method are appearing unsurprisingly in the frames, where several interactions of the same event happen in different frame locations and have similar deposited energies (Fig. 6, left). The position of interactions where the events are clustered (Fig. 6, middle) or there are single events (Fig. 6, right) is determined with a much better precision.

This is a satisfactory result for the system with channel summation, as it allows position measurements with a limited number of ADC channels.

To further reduce the error in position determination, two approaches were tried with the simulated data provided by the individual readout. The first was to attempt to separate events into multiple and single interactions, and determine position interaction only for the latter class. This, however, comes at the cost of losing some detection efficiency and may not be appropriate in some experiments.

The second approach is to use the distribution of the intensity of the photon flux accross the SiPM matrix to estimate the number of interactions and compute their positions individually. For this task, two algorithms were used - a naive implementation of maxima detection and supervised machine-learning. Both implementations deliver similar results for classifications into single/multiple events.

Several strategies to improve the classification algorithms are under investigation.

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