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14. ABSTRACT

Significant progress was made during the second funding year towards the goal of commissioning and characterizing a high resolution breast PET camera. We have received about 25% of the modules needed to construct the camera and about 80% of these passed our functionality criteria. We managed to construct 2 fins with 16 modules each and connect them to the readout electronics. We acquired data from these fins.
We constructed two times one layer of one cartridge, including the finalized signal conditioning and readout electronics, as well as the high voltage biasing circuitry. Energy resolutions of 11.8 +/- 0.3% FWHM at 511 keV are obtained and a coincidence time resolution of 9.8 +/- 0.7 ns FWHM was measured.
The construction of a block setup showed that we are able to identify multiple interaction photo-events, which allows us to increase the sensitivity of the camera significantly and is an indication of the possibility of the camera to measure interaction locations in 3 dimensions.
The reported results show that we are on our path to construct the breast dedicated PET camera described in the project. We have overcome technical problems related to electronic noise. We plan to use the 1mm3 resolution PET camera to assist in breast cancer management by resolving inconclusive mammograms, performing local staging and analyzing response to therapy.

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1 Introduction

The DOD funded project titled 'Commissioning and Characterization of a Dedicated High-Resolution Breast PET Camera' aims at enhancing the role of PET in breast cancer management by constructing a high resolution PET camera. PET is an imaging modality whereby lesions are visualized based on biochemical activity, rather than lesions' morphology, which is visualized by other imaging modalities such as mammography, MRI, and ultrasound. We will test this high-resolution PET system in the following indications: (1) resolving inconclusive screening mammograms which often show up for patients with dense breasts, (2) enhance staging accuracy, and (3) monitor the response to neo-adjuvent therapy. Dedicated high-resolution cameras can detect smaller lesions and thus enhance the precision of the images. Because of their high sensitivity these cameras can also reduce the injected patient dose. We aim to achieve 1 mm^3 resolution using a unique detector design that is able to measure annihilation radiation coming from the PET tracer in 3 dimensions, using many $1 \times 1 \times 1$ mm^3 scintillation crystals.

2 Research accomplishments as outlined in SOW

1. **Building a block setup: months 1-6**
   Goal of the first task in this project was to test camera detection concepts, obtain experience working with many channels and perform image reconstruction. We used dual modules that each contain 2 position sensitive avalanche photodiodes (PSAPDs) coupled to 8×8 array of $1 \times 1 \times 1$ mm^3 LYSO crystals. The two PSAPDs are mounted on a thin flexible circuit and are multiplexed as described in [**?**].

   As mentioned in last year's annual report we had experienced substantial electromagnetic interference forcing us to redesign part of the setup. In the first 6 months of this funding period (FY02) we managed to successfully build the block setup. Due to limited resources we could only build a blocksetup with 4 modules instead of the planned 16. Nonetheless the setup allowed us to investigate interactions in the detector as a benchmark for the final system. Results are presented in [**?**] and show that our setup is sufficiently noise free to trigger on individual photo electric events. This is non-trivial given the dense packing of modules and electronics. We show that cross-talk between neighboring modules is sufficiently low. We are also able to determine the interaction location of the 511 keV photon in 3 dimensions using multiple interaction events. Figure 1 provides data for multiple interaction events that are a combination of Compton interactions in one layer and photo-electric absorption in another.

2. **Acceptance test of the LSO-PSAPD modules: months 7-15**
   As reported in last year's annual report the acceptance testing was delayed due to HV problems. Delivery of 'hot' modules started in the 5th month of this funding year (November 2011). Since then we received about 600 modules of the total 2400. These modules all went through our acceptance test with an acceptance rate of about 80 %. With an updated setup we are now testing about 2 modules per hour, which is about half as fast as anticipated in the statement of work . The reduced rate is due to taking data at multiple bias voltages to ensure we are selecting the correct bias voltage. Reference [**?**] mentions the effects of bias voltage on the PSAPD performance.

   After testing a number of these modules it became clear that we needed to modify some of our signal conditioning electronics. This required about a month of optimizing the capacitors and resistors used in the signal conditioning network. Reference [**?**] reports on the updated

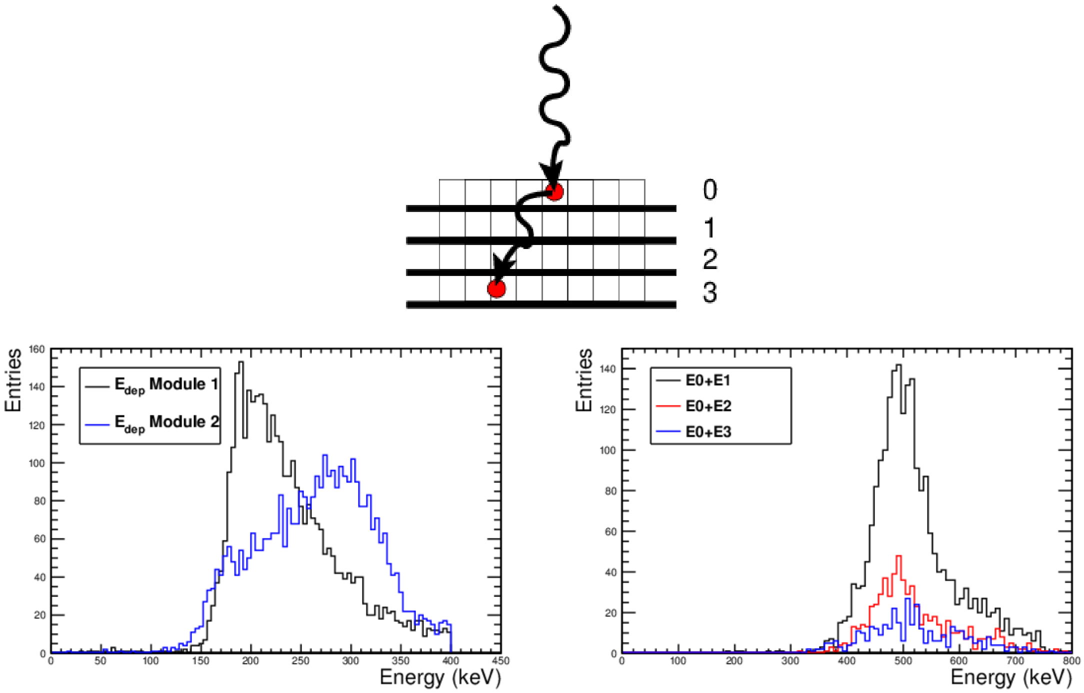

Figure 1: Upper frame shows a schematic of a multiple interaction event in the blocksetup of 4 modules. In this particular event, the 511 keV photon undergoes Compton scatter in layer 0 and is subsequently photo-electrically absorbed in layer 3. The lower left figure shows the distribution of energy depositions in the first layer and in the second layer. As expected, on average, less energy is deposited in the first layer compared to the second layer. The lower right figure shows the sum of the energy deposited in layer 0 and 1, layer 0 and 2 and layer 0 and 3 respectively. We see that the energy adds up to 511 keV. We also see that the first combination has more events than the other which is expected from the detector geometry.

signal conditioning electronics.

Software was written to test many modules. The software is able to analyze the test data and assign a score to each unit. Results of these tests are uploaded to a web server so they are accessible at any time. We are also able to select the ideal bias voltage in a semi-automated way.

3. **Camera Construction: months 16-26**

3a Assembly of one panel and testing: months 16-22

Due to delay in the module construction and the development of the electronics, assembly of one panel incurred significant delay. We only finished the construction of two times one layer of one cartridge during this funding period. Nonetheless this is a major breakthrough, as all electronics to be used in the final system are in place and are functional, as well as data acquisition and analysis software.

The electronics developed includes (1) the high voltage (HV) board, which distributes HV to each individual module, (2) the signal conditioning board with bias resistors and attenuation circuitry, (3) the RENA board, responsible for charge amplification and digitization and (5) the data acquisition board (DAQ), responsible for communication with the computer. All components are indicated in Figure 2.

In order to construct the electronics required for two cartridges we needed to verify performance of the 64 RENA chips used in the cartridge. To accomplish this we built a chip test stand and used a pulser to verify functionality of each chip to be used in the system. Reference [**?**] reports on this test setup and its outcomes.

Apart from the significant development in readout electronics, substantial effort was put in developing readout and analysis software to monitor the data from the camera. Analysis software was written for calibration purpose. Energy resolutions of typically 11.8 ± 0.3 % FWHM were obtained. For coincidence timing we achieved 9.8 ± 0.7 ns FWHM.

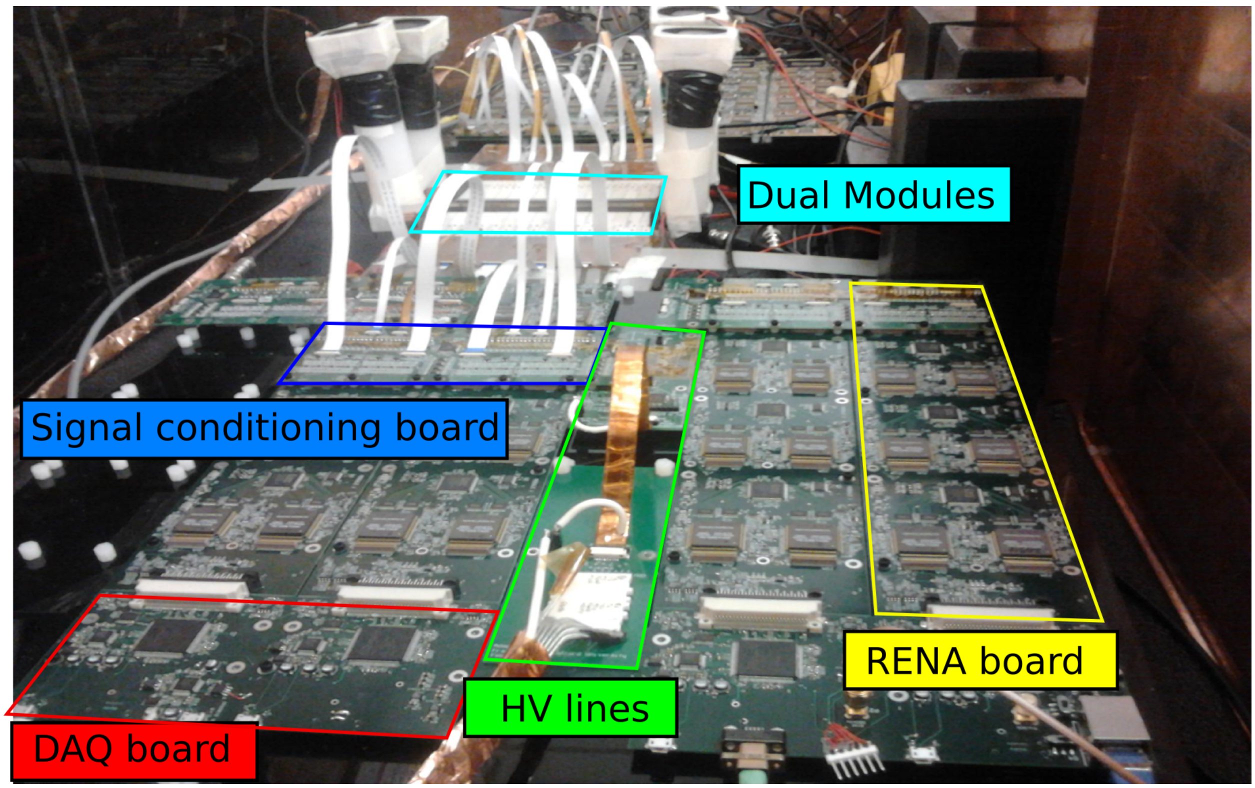

Figure 2: Photograph of the two layer setup. The picture is taken from one end of a cartridge. The electronics on the near and far boards are the same. The two layers of 16 modules are marked with a cyan box. The green box shows the high voltage supply lines to the modules. One of the 8 signal conditioning boards is marked in blue. These boards contain bias resistors and attenuation circuitry as described in [**?**]. One of the 4 RENA boards is indicated in yellow. All 8 RENA chips on each RENA board are clearly visible. The DAQ board (in red) is responsible for the communication between the electronics on the panel and a computer.

3 Key Research Accomplishments

- Based on the acceptance test of many modules, we finalized the attenuation scheme. These results are reported in [**?**].
- Using the block setup we experimentally verified the 3-D reconstruction concept. This concept is crucial for achieving our 1 mm^3 intrinsic resolution. Results from this setup are reported in [**?**].
- We managed to construct two layers of 16 modules with electronics as intended to be used in the final system. This setup verified functionality of all electronic components.
- We built the electronics for two cartridges.
- About 25 % of the modules to be used in the final system are tested and 80 % of those are accepted.

4 Reportable Outcomes

4.1 Abstracts

- Abstracts submitted to the 2012 *IEEE Nuclear Science Symposium and Medical Imaging Conference*, to be held October 2012, Anaheim, California:
  1. A. Vandenbroucke, C. S. Levin: *Identifying and Sorting Crystal Pixel Locations in Position Sensitive Detectors Using Pictorial Structures*
  2. U. Yoruk, A. Vandenbroucke, P. D. Reynolds, C. S. Levin: *Design and Implementation of Scalable DAQ Software for a High-Resolution PET Camera*
  3. F. W. Lau, J.-Y. Yeom, A. Vandenbroucke, P. D. Reynolds, D. R. Innes, C. S. Levin: *A Cost-Effective Modular Programmable HV Distribution System for Photodetectors*
  4. P. D. Reynolds, F. W. Y. Lau, A. Vandenbroucke, D. R. Innes, U. Yoruk, C. S. Levin: *Characterization of One Plane from a 1mm3 Resolution Clinical PET System*

4.2 Publications

1. A. Vandenbroucke, T.J. McLaughlin, C.S. Levin Performance evaluation of a large area position sensitive avalanche photodiode coupled to an LSO crystal array as a function of temperature and bias voltage *J. Inst* **7**, P08001
2. F.W.Y Lau, A. Vandenbroucke, P.D. Reynolds, H. Ho, D. Innes, C.S. Levin Signal Conditioning Technique for Position Sensitive Photodetectors to Manipulate Pixelated Crystal Identification Capabilities *Trans. Nucl. Sci*, accepted for publication

4.3 Conference Records

1. P.D. Reynolds, F.W.Y. Lau, A. Vandenbroucke, C.S. Levin: *Study of Readout for Groups of Position Sensitive Avalanche Photodiodes Used in a 1 mm3 Resolution Clinical PET System, Nuc. Sci. Conf. Rec* **2012**, p 3253-3255

2. A. Vandenbroucke, F.W.Y. Lau, P.D. Reynolds, C.S. Levin: *Measuring 511 keV Photon Interaction Locations in Three Dimensional Position Sensitive Scintillation Detectors Nuc. Sci. Conf. Rec* **2012**, p 3635-3638

3. J. Zhai, A. Vandenbroucke, P.D. Reynolds, C.S. Levin: *Functionality Test of a Readout Circuit for a 1mm^3 Resolution Clinical PET System*, *Nuc. Sci. Conf. Rec* **2012**, p 3945-3949

4.4 Awards

This work was awarded with a distinguished postdoctoral scholar award at the 2011 Era of Hope meeting in Orlando, Florida.

5 Conclusions

Significant progress has been made during the second funding year towards the goal of commissioning and characterizing a high resolution breast PET camera. We have received about 25 % of the modules and about 80 % of these passed our functionality criteria. We managed to construct 2 fins with 16 modules each and connect them to the readout electronics.

We constructed two times one layer of one cartridge, including the finalized signal conditioning and readout electronics, as well as the high voltage biasing circuitry. Energy resolutions of 11.8 ± 0.3 % FWHM are obtained and a coincidence time resolution of 9.8 ± 0.7 ns FWHM was measured.

Building the electronics as intended to be used in the camera was a major breakthrough in this funding year. We anticipate that we can copy these readout electronics when constructing subsequent cartridges.

The block setup showed that we are able to identify multiple interaction photo-events, which allows us to increase the sensitivity of the camera significantly and is an indication of the possibility of the camera to measure interaction locations in 3 dimensions.

The reported results show that we are on our path to construct the breast dedicated PET camera described in the project. We have overcome significant technical problems. We plan to test the 1mm^3 resolution PET camera to assist in breast cancer management by resolving inconclusive mammograms, performing local staging and analyzing response to therapy.

References

[1] Lau F W Y, Vandenbroucke A, Reynolds P D, Olcott P D et al. 2010 Analog signal multiplexing for PSAPD-based PET detectors: simulation and experimental validation *Phys. Med. Biol.* **55**, 7149.

[2] A. Vandenbroucke, F.W.Y. Lau, P.D. Reynolds, C.S. Levin: *Measuring 511 keV Photon Interaction Locations in Three Dimensional Position Sensitive Scintillation Detectors Nuc. Sci. Conf. Rec* **2011**, p 3635-3638

[3] A. Vandenbroucke, T.J. McLaughlin, C.S. Levin Performance evaluation of a large area position sensitive avalanche photodiode coupled to an LSO crystal array as a function of temperature and bias voltage *J. Inst* **7**, P08001

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