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## **Design and Study of Scintillator Crystals coupled to Silicon Photomultipliers for PET Application**

### **Abstract**

A relatively new photodetector, the silicon photomultiplier (SiPM), is well suited for PET applications. It has similar sensitivity and gain to the industry standard photomultiplier tube (PMT), but has advantages such as smaller size and insensitivity to magnetic field. These properties make SiPMs an active area of research in the PET field. I will study a simplified setup, comprised of two antiparallel SiPM/LSO coupled detectors using a Na-22 positron source. The coincidence timing and energy resolution will be determined for several crystal geometries and SiPM configurations. To simulate the experiment, GEANT4 code will be formulated to reproduce the results. Once the code successfully simulates this simple set-up, it can be extrapolated to simulate more complicated (and realistic) detector designs.

### **Introduction**

Positron Emission Tomography (PET) is a medical imaging technique that is used to observe functional processes *in vivo*. The functional process of interest is observed by introducing a chemical tracer that is metabolized by certain tissues in the body. The tracer is doped with a radioisotope that undergoes positive beta decay. A large majority of current PET scans use fluorodeoxyglucose (FDG), a glucose molecule with an oxygen atom replaced by radioactive  $^{18}\text{F}$ . FDG enters the same metabolic pathways as glucose and is utilized for oncology and brain imaging [1].

Upon injection in the body, the tracer is concentrated in specific tissues, such as a tumor. Positrons emitted from beta decay annihilate with nearby electrons, generating back-to-back 511 keV photons that can be detected by a scintillator crystal coupled to a photodetector. The location of the annihilation event can be narrowed to a line of response (LOR) from two

coincident detections [1]. In PET systems with high timing resolution, the annihilation location can be further constrained to a segment on the LOR. This is known as time-of-flight (TOF) PET, where high timing resolution results in the reduction statistical noise. Advantages of TOF PET include faster computer processing times and better image quality [1-2].

## **Photodetectors and PET**

The standard photodetector in clinical PET machines is the photomultiplier tube (PMT). The high gain, fast response and high sensitivity of PMTs have made them a viable detector for PET, but there exist several drawbacks. One, the bulky size of PMTs puts a limit on the spatial resolution of a detector [1]. PMTs are also highly sensitive to magnetic fields. This makes it impossible to implement PET with magnetic resonance imaging (MRI), considered the future of biomedical imaging because of the combination of metabolic and anatomical information [3-4].

An area of active research is the study and application of silicon photomultipliers (SiPM). SiPMs are relatively small and insensitive to magnetic fields while achieving roughly the same gain and sensitivity as PMTs [4-5]. The SiPM is a semiconductor device made up of avalanche photodiode (APD) pixels connected in parallel. Each APD is an individual photon counter and the sum of all the APD pixels is the output of the SiPM. The APDs are operated in Geiger Mode, where the bias voltage applied is greater than the reverse breakdown voltage resulting in a large internal electric field. An incident photon causes a carrier to be injected into this electric field creating a large pulse that can be put into electronics. The specifications of the SiPM vary widely, but for PET applications the greater number of pixels (lower fill factor) is desired because of the high light input to the detector [3,5].

Studies of SiPMs have yielded promising results. Measurements of the inherent coincidence timing resolution using a splitted laser gave timing on the order of 100 ps, suggesting the viability of SiPM for TOF PET [6]. The coincidence timing between two LYSO/SiPM coupled detectors has been measured by Kim et al to be at best 240 ps [7]. However, there are challenges

to implementing SiPMs into a full scale PET machine. There is a moderate dependence of gain with bias voltage, so each SiPM would require its own voltage control. Temperature dependence is also an issue. Other challenges exist and are discussed in reference [7], but the potential benefits of SiPM photodetectors for PET make their implementation the next step in detector design.

## Experiment

- NIM electronics set-up and configured
  - include schematic of set-up in final paper
- constructed SiPM setup in black box
  - include photo of setup in final paper
- have implemented DAQ program
- wrote program to analyze coincidence timing
- currently trying to work with GEANT4 simulation
  
- include graphs/data
  - timing/energy resolution normal fitted, also adc/tdc output
  - also include graphs from simulation output once sim. is done
- compare experiment with simulation for several geometries

## References

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