Development of a Radiation Detector with Particle Discrimination for Nuclear Security Applications

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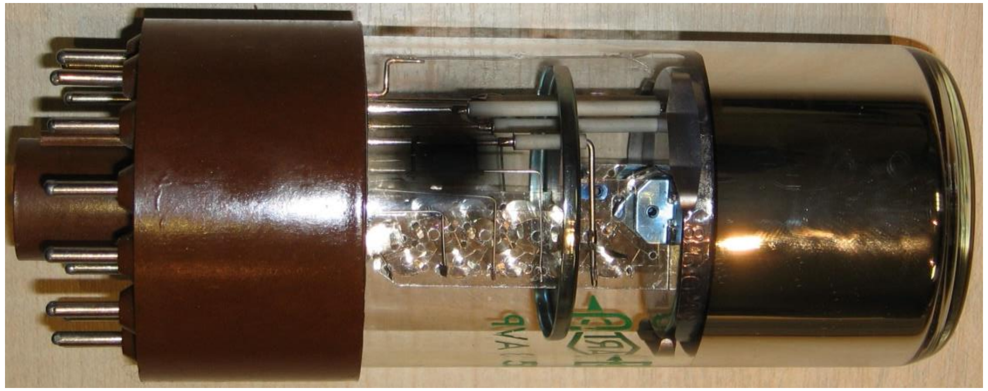
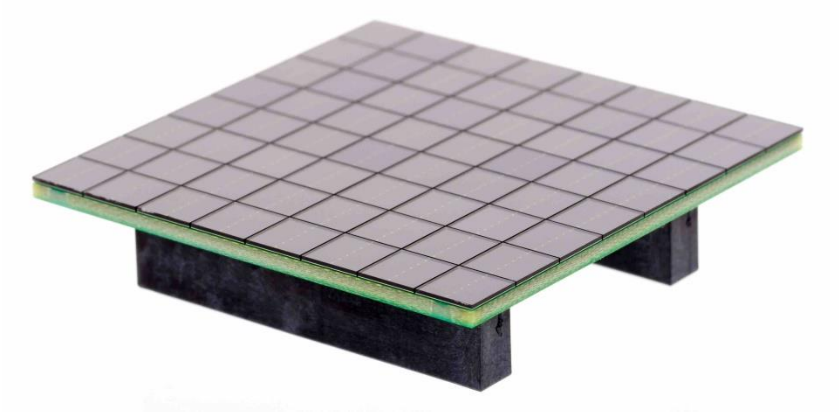
Motivation

- The detection of special nuclear materials are of the upmost importance in boarder security and global nuclear threat reduction
- Detection of these materials require the detection of multiple types of radiation, namely neutron and gamma radiation
- This is usually done with the combination of plastic scintillator and ^{3}He proportional counters
- There is currently a shortage of ^{3}He driving the development of suitable replacements for these detectors

Silicon Photomultipliers(SiPMs)

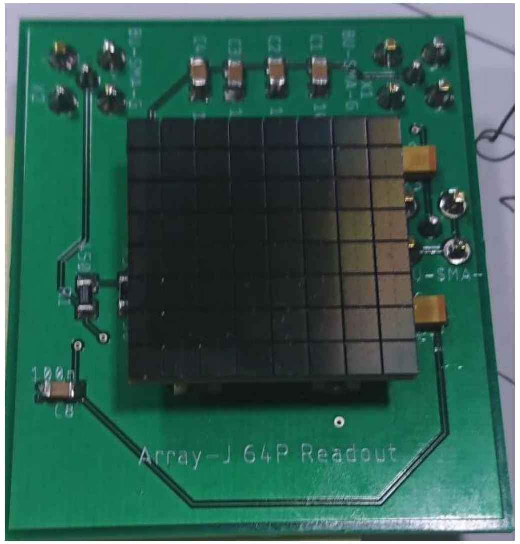
Photomultiplier Tube: high voltage, fragile and bulky





SiPM: robust, low voltage and compact

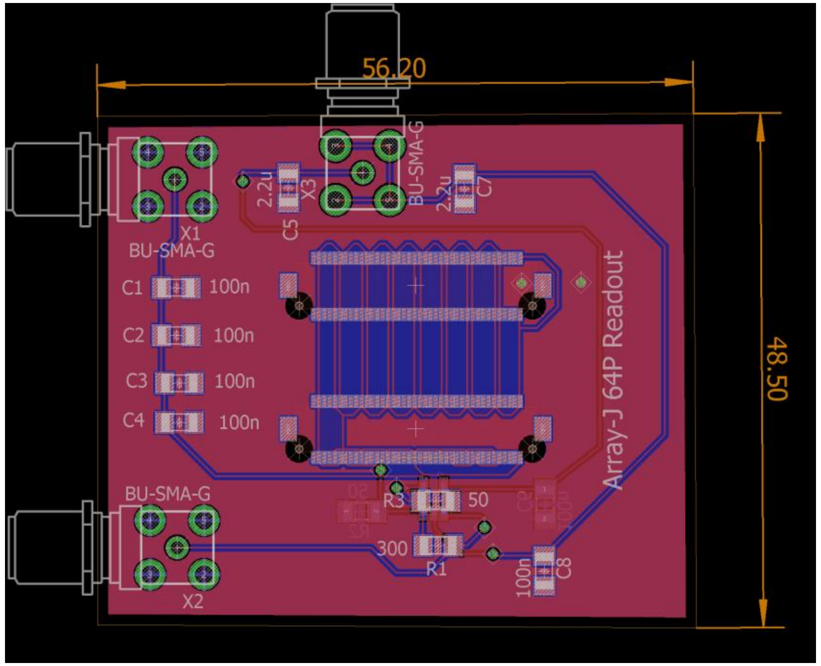
Detector



- The goal is to replace the PMT usually used for PSD with SiPM arrays
- We have constructed a prototype based on the 8x8 3mm array of SensL J-series SiPMs

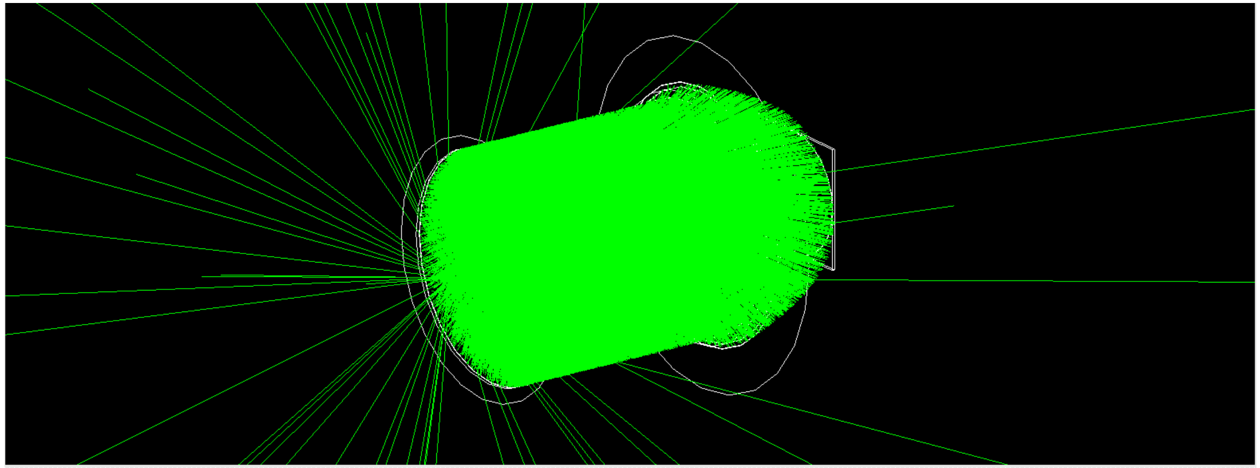
Electronic Design

- A PCB was designed to provide bias, readout and amplification for the 8x8 SensL SiPM array based on the Ti-OPA846 opamp
- It provides a amplification of 10 in a non-inverting regime in order to maximise gain-bandwidth product wile maintaining stability



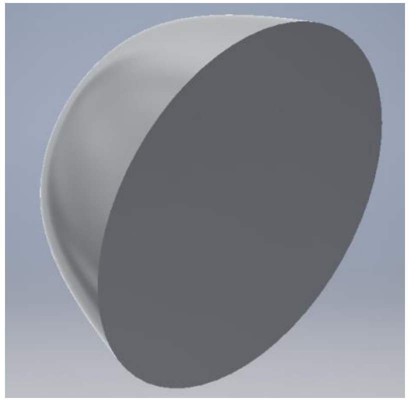
Detector Simulation

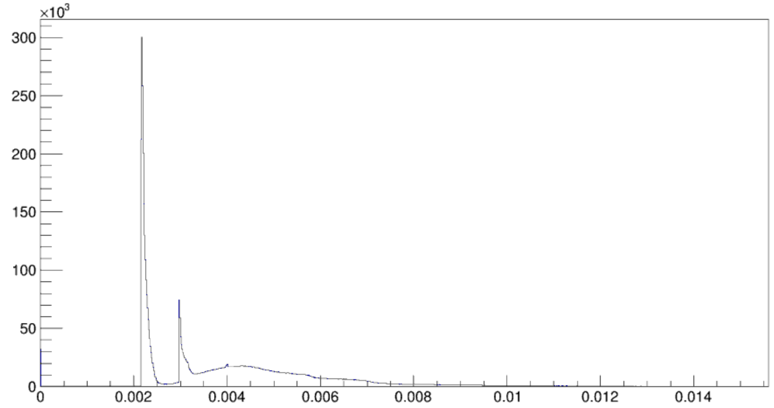
- The detector geometry was simulated using Geant4
- The scintillator was programed to produce light with light output based on the data sheet for the scintillators
- The produced photons were then propagated through the detector geometry



Light Guide Design

- The simulation was used to inform the design of a light guide to couple the scintillator to the array, due to the mismatch in size and shape
- The design which was decided upon was manufactured in PMMA

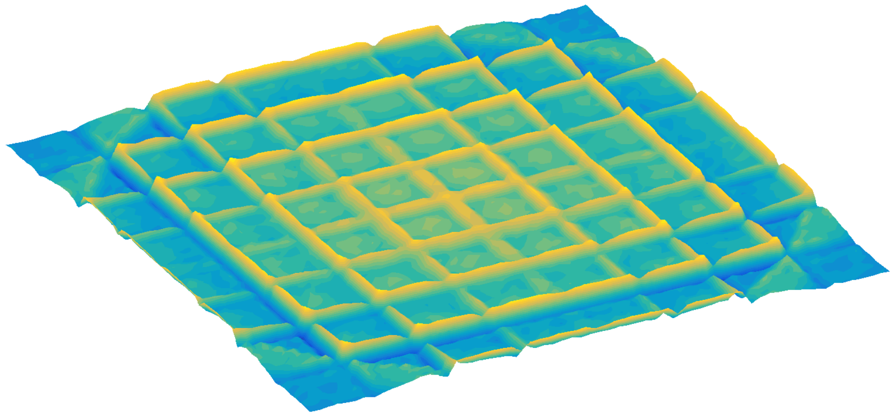




Light arrival time

Detector Simulation

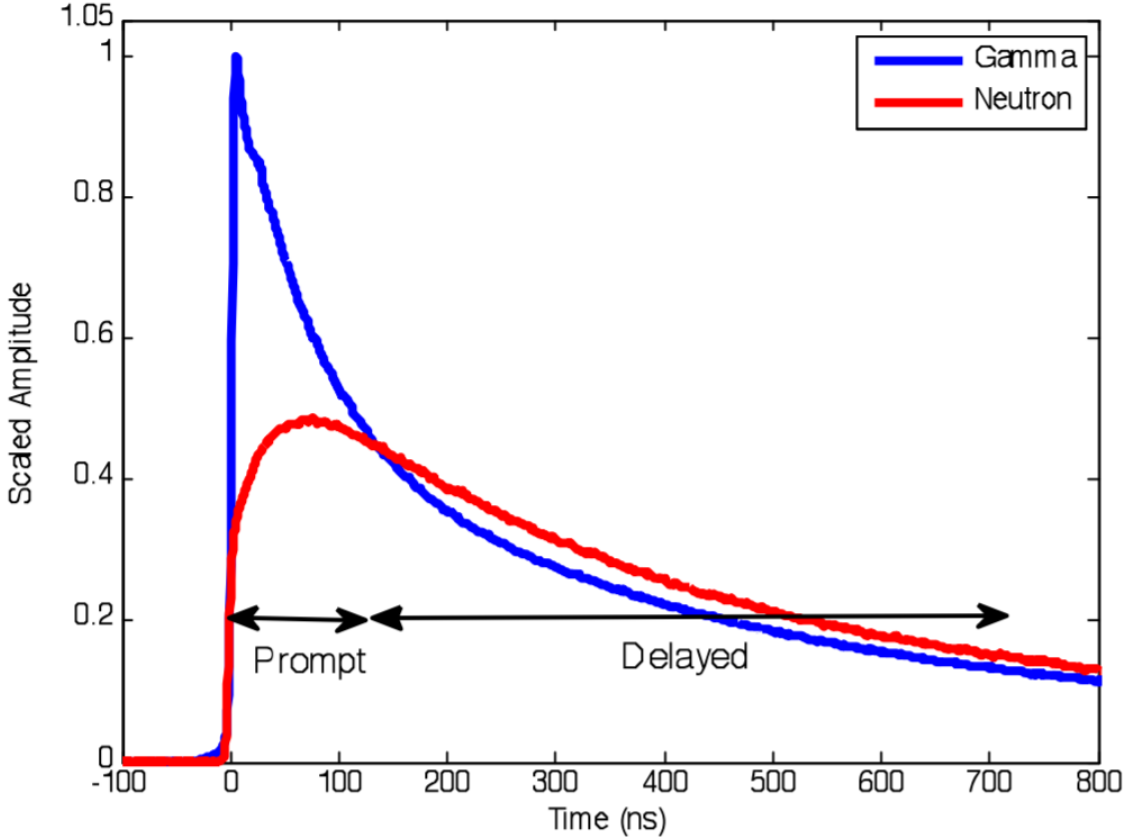
- The time of arrival of the photons were evaluated and seen to not vary by a large amount
- The light field at the SiPM surface was evaluated and is shown in the figure



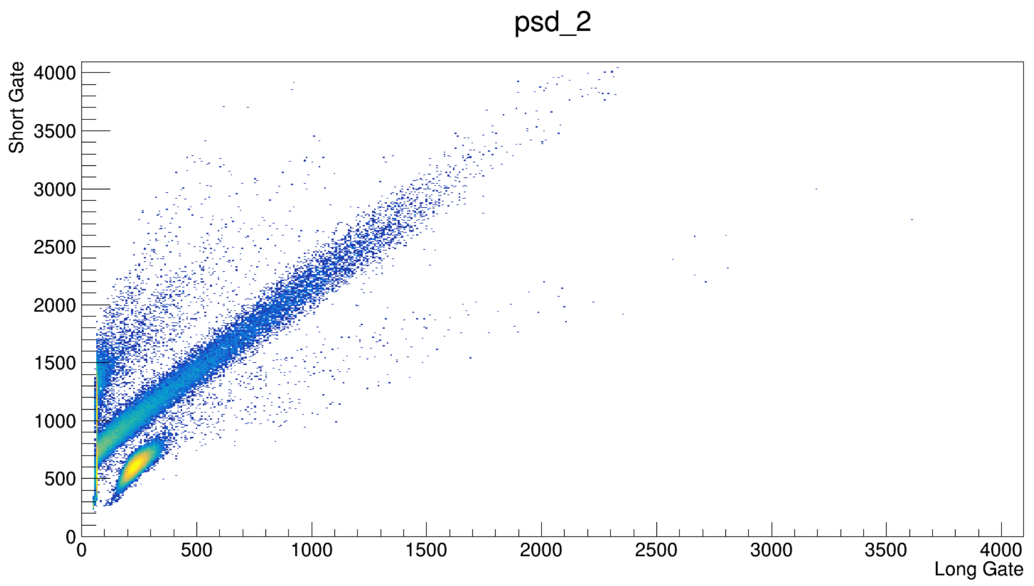
Gamma Neutron Detection with CLYC

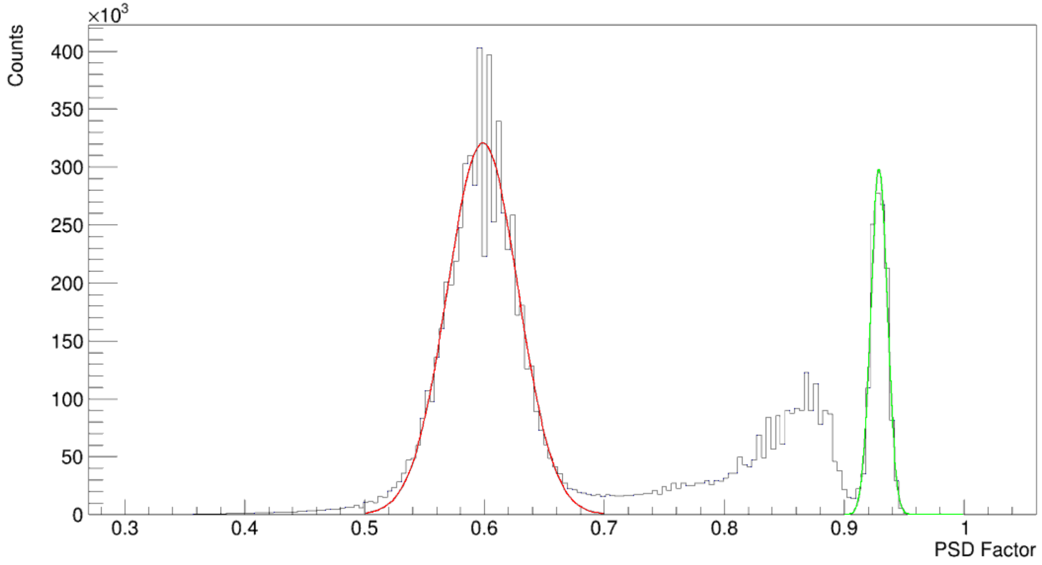
CLYC has 4 main scintillation processes :
Direct electron-hole capture by Ce^{3+}(10s ns)
V_k formation and electron diffusion(100s ns)
Self-trapped excitation(STE)(few μs)
Core-valence luminescence(few ns)

For neutrons only V_k formation and STE occur giving a less prompt pulse with longer tail



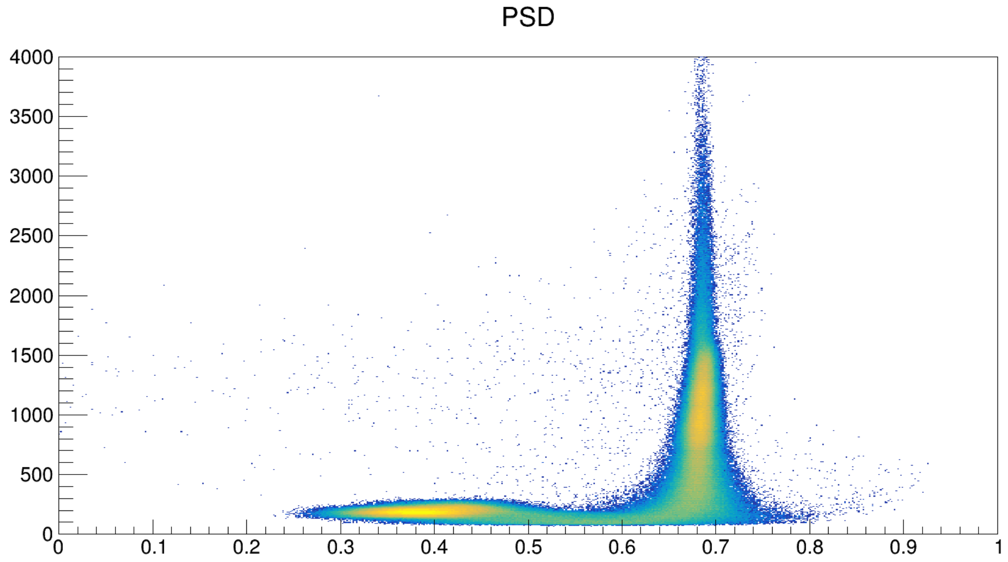
Gamma Neutron Detection with CLYC

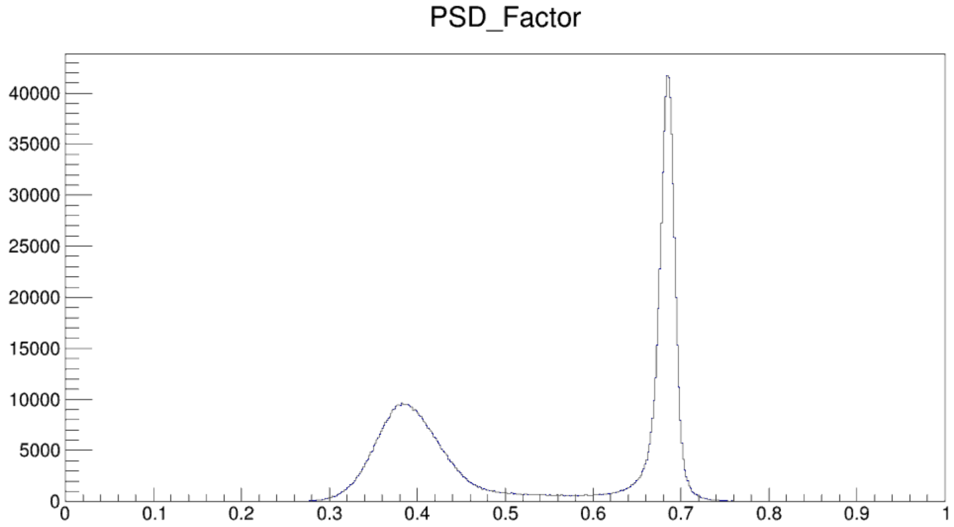




- The PSD performance of CLYC coupled to Photonis XP2262 PMT
- A clear separation was seen between gamma and neutron excitations
- Due to a fault that had developed in the scintillator sample we have, the energy resolution was significantly impaired
- According to literature, the energy resolution should be around 4.5% at 662kev gamma rays

Gamma Neutron Detection with CLYC

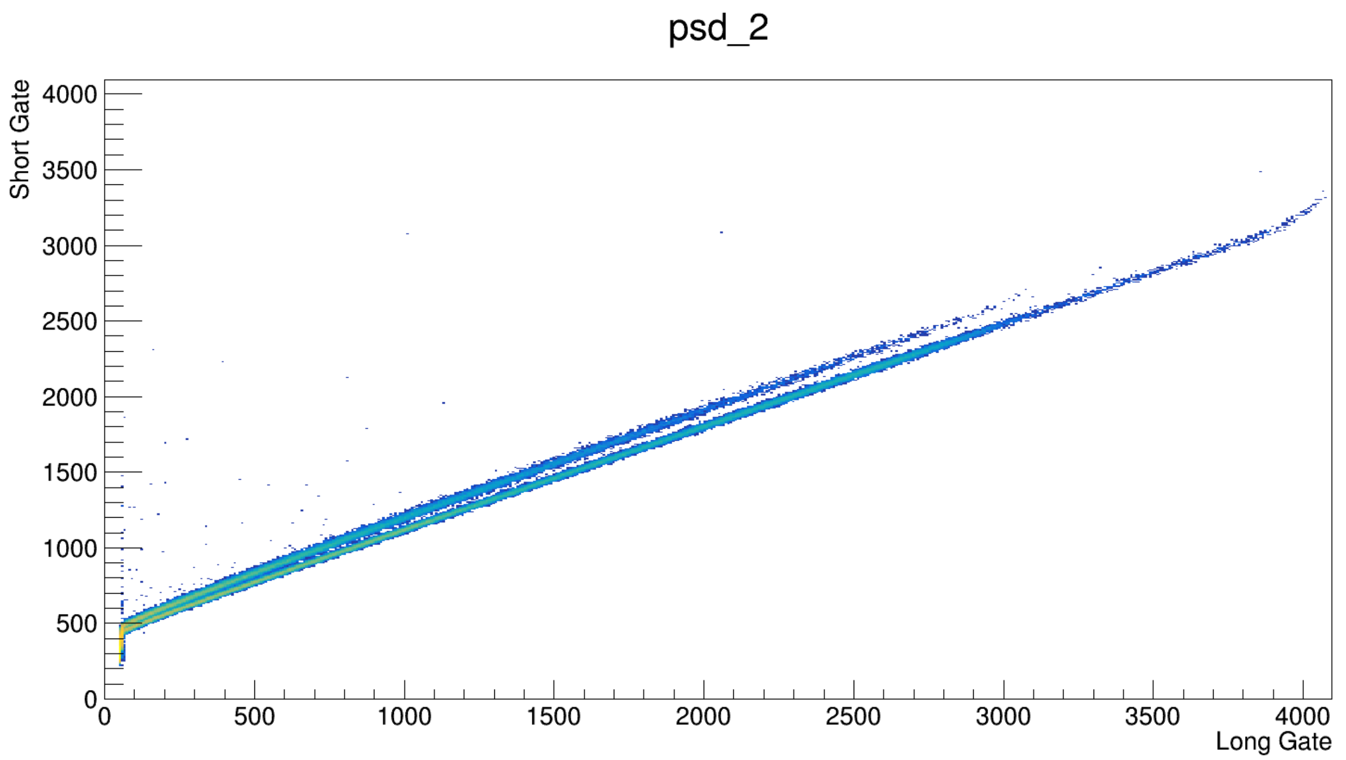




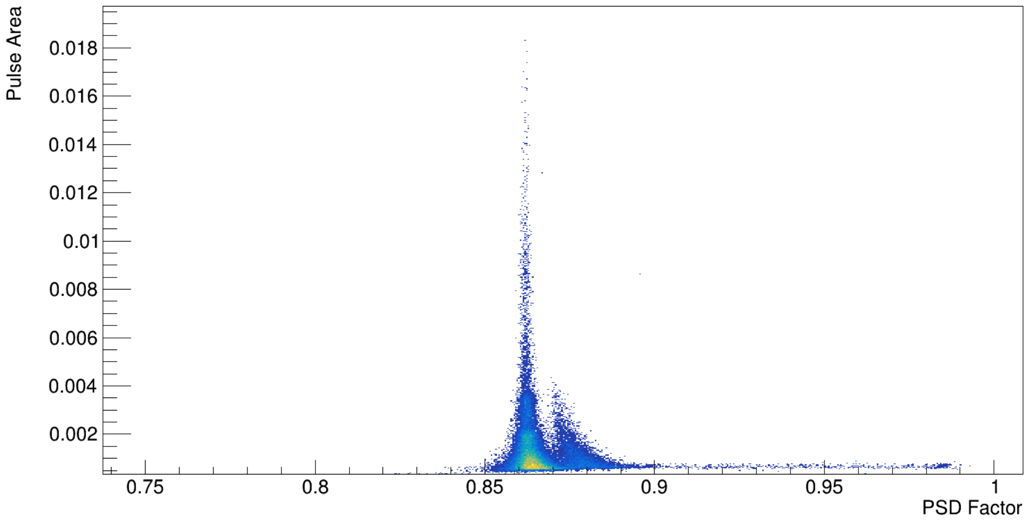
- Repeating this experiment with the SiPM based detector
- We see good discrimination between neutron and gamma spices
- This showed a FoM of 2.769

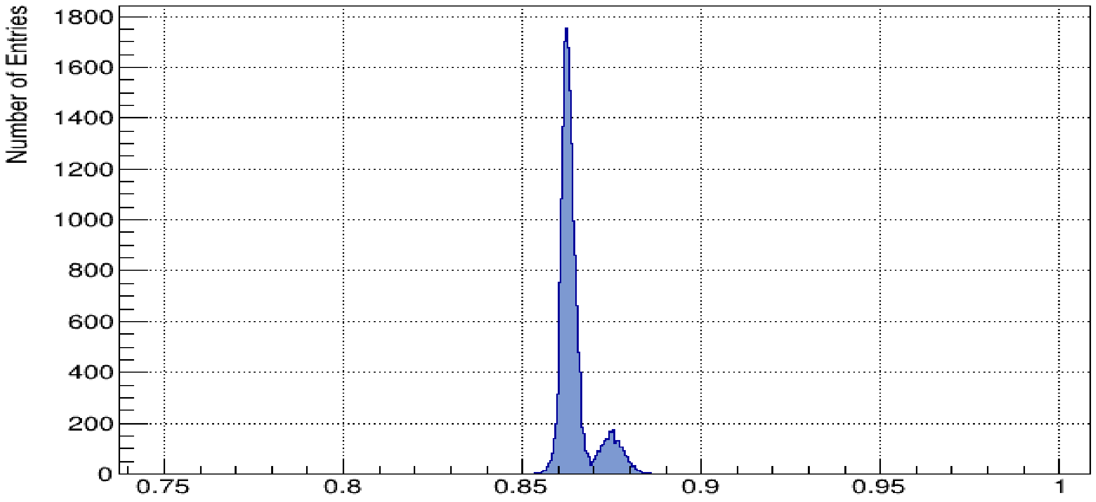
Gamma Neutron Detection with EJ-299

- EJ-299 is a plastic scintillator which is suitable for neutron detection and PSD with gamma, neutron and alpha radiation
- The EJ-299-33A was connected to the same photonis XP2262 PMT and data taken
- We seen a reasonable separation between gamma radiation and neutrons across the whole energy range



Gamma Neutron Detection with EJ-299

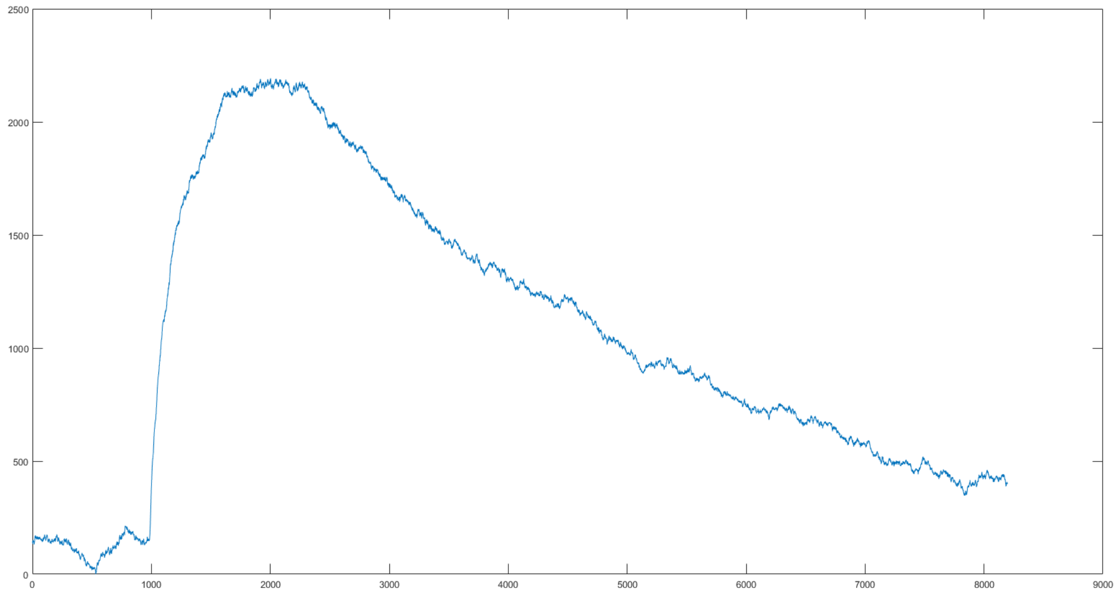




- Repeating the experiment with the SiPM based detector
- We see good separation of gamma and neutron spices
- This showed a FoM of 0.935

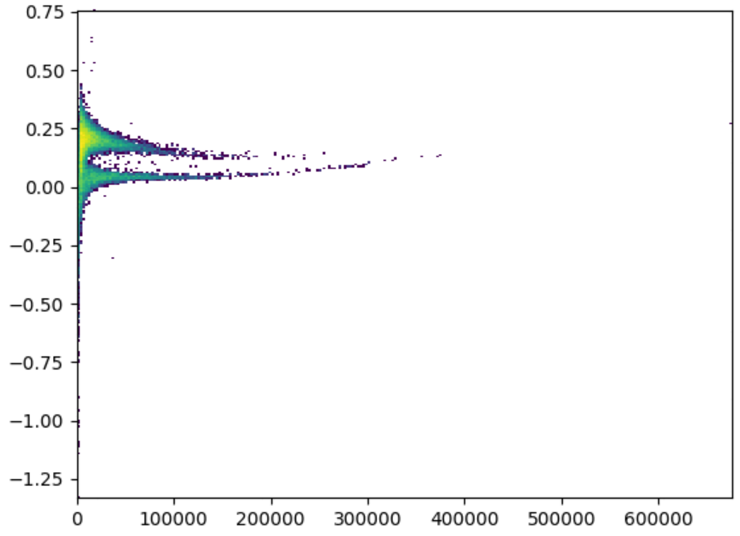
Work with Digitizer

- The ability to digitize full waveforms has given the ability to use a wide range of different algorithms to tackle the problem of PSD
- This allows for digital filters to be used which are tuneable in software
- Having the full waveform allows for different algorithms to be tested on identical data
- It also allows for optimisation of the algorithm parameters and for analysis to be done in both the time and frequency domain



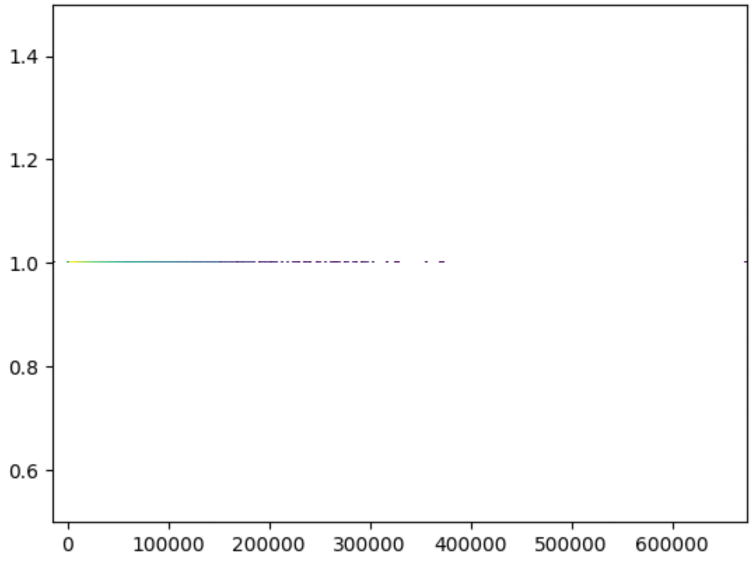
Frequency Domain

- The use of frequency domain techniques allows for some flexibility in processing
- Noise tends to have specific frequency distributions which can be used to reduce signal noise
- Scintillation mechanisms have two decaying exponential functions, which have different decay rates both in the frequency and time domain
- The best frequency components can be examined and can be deduced using automated methods

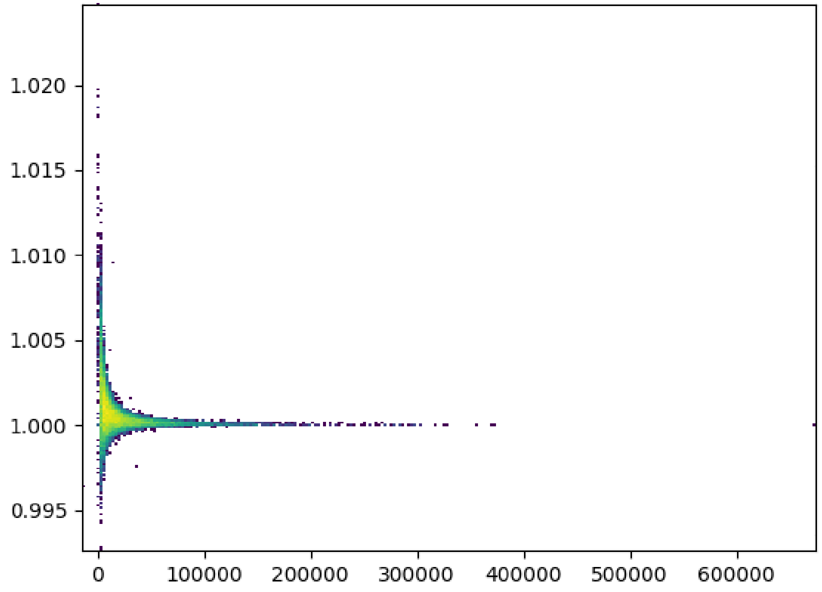


Digital Charge Comparison

- The standard charge comparison method can also be implemented in software
- This is done by taking two different integration windows with some delay in-between them
- The window sizes and delay



Window Size



Delay

Summary

- Silicon photomultipliers coupled with new scintillation materials offer an attractive alternative to ^{3}He proportional counter
- A detector based on SiPMs with CLYC:Ce or EJ299-33A seems to perform similarly to that of a PMT based system
- The wide availability of digitizers allows for use of and optimisation of many algorithms not commonly employed in PSD