University of Sheffield

Novel Neutron-Gamma Detectors for Borehole Applications

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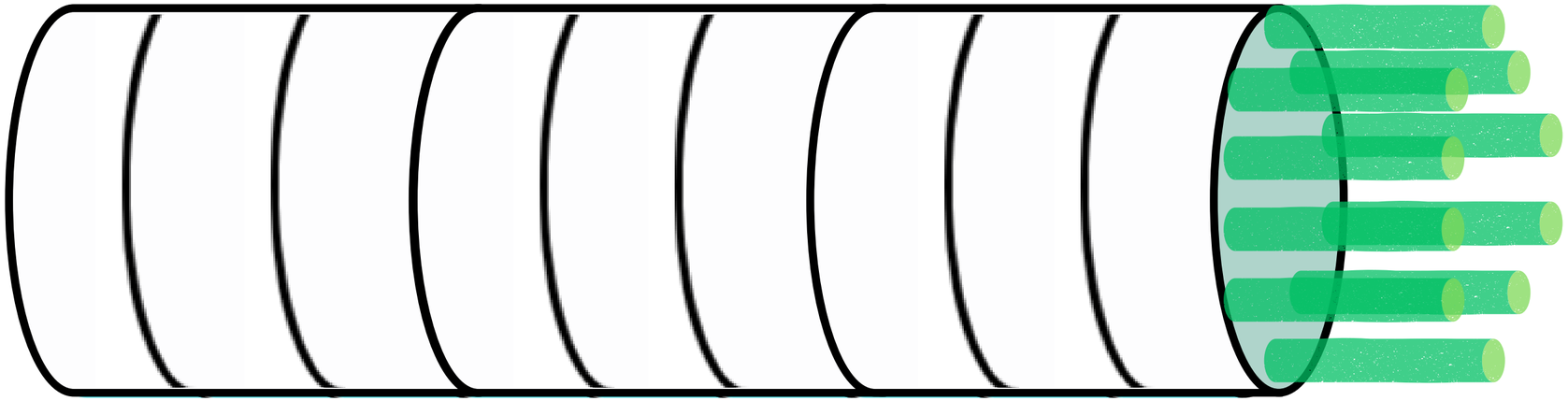
Nuclear Well Logging

- High activity neutron source placed down a borehole
- **Neutrons thermalized and captured by formation fluids occupying pore-space in rocks**
- The resulting radiation detected can be used to infer information regarding the hydrogen content in the formation
- This work explores possibilities of using **BN:ZnS neutron converter foils coupled to plastic scintillator for a neutron-gamma tool measuring hydrogen content**
- Aim is to design for use with Deuterium-Tritium pulsed neutron generators to encourage adoption of alternatives to radioisotope sources (AmBe or Cf-252)

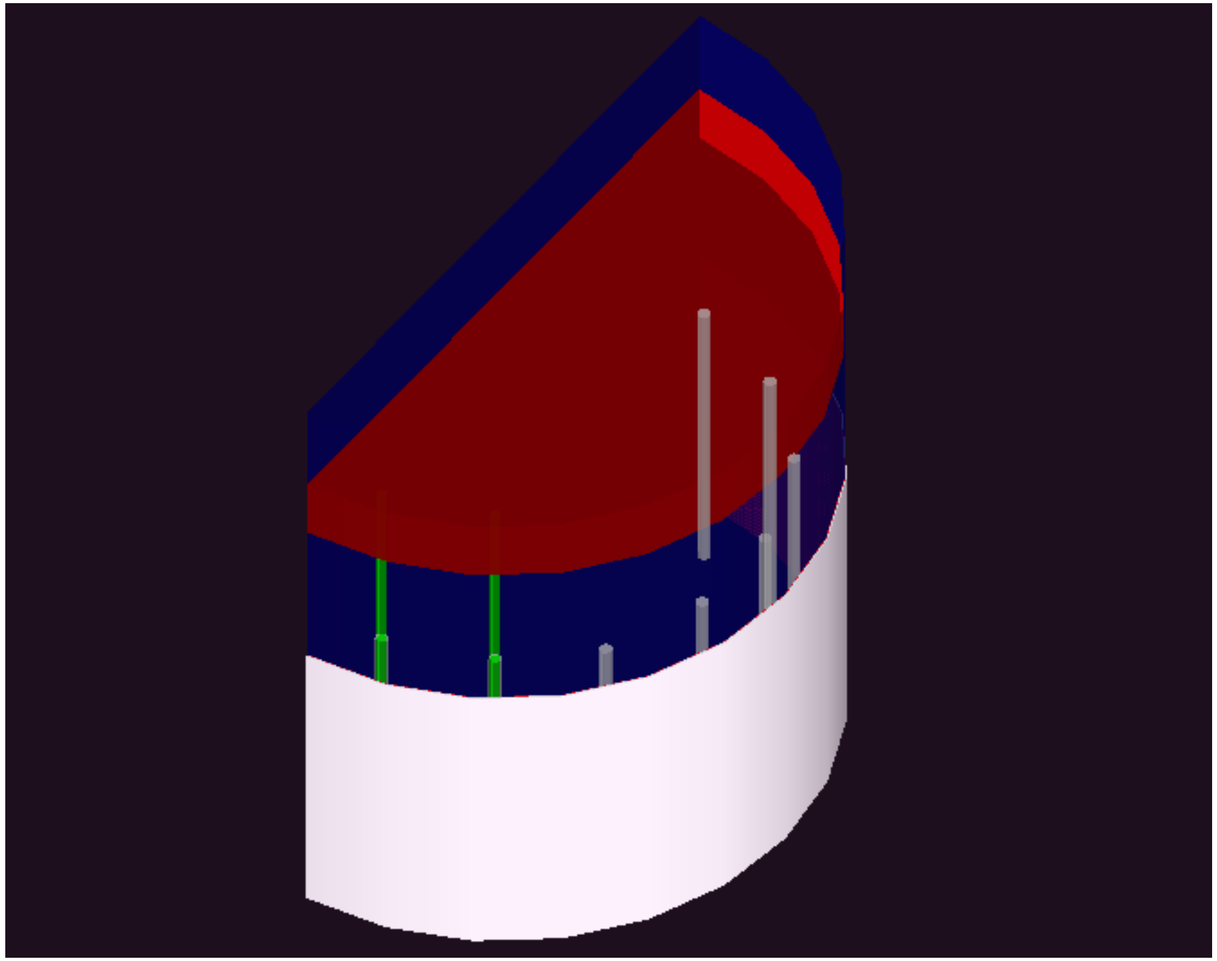
Initial Prototype Designs

- Typically well-logging detectors look at near-far ratios in geological analysis
- Potential for a segmented detector with the ability to isolate scintillator-foil modules from one another
- Neutron-Gamma sensitivity in same volume - Pulse Shape Discrimination required
- Explored potential to do this with fibre readout from individually isolated modules



MaPMT or SiPM arrays

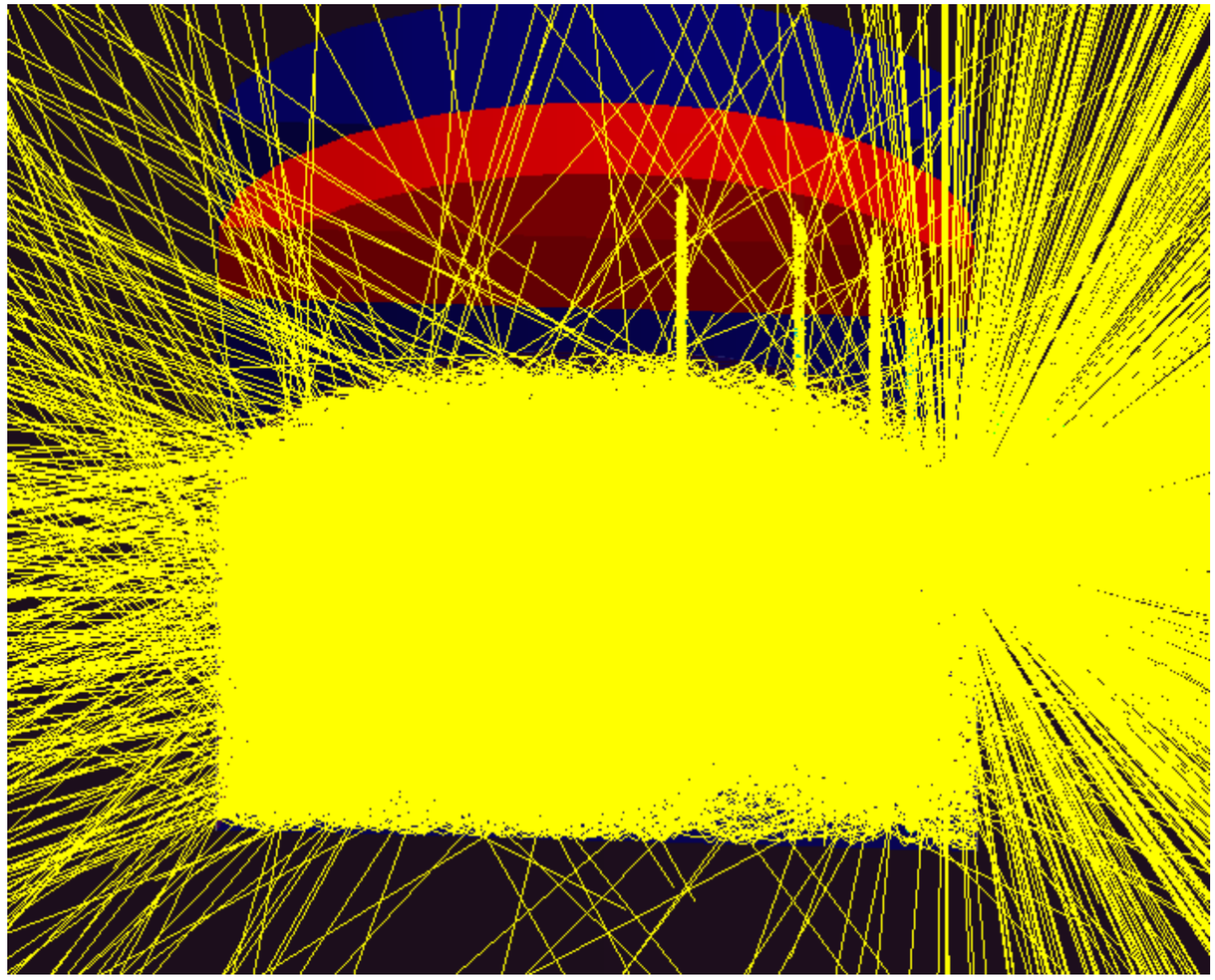
GEANT4 Optical Simulation



Simulation geometry to explore limitations of fibre readout from foil-wrapped scintillator modules

- Fibre-based design
- EJ200 scintillator coupled to BN:ZnS(Ag) converter foils
- Incident thermal neutron flux - captures in foil or on H yielding gammas detected in PS
- First explored simpler case of direct PMT readout
- Then BCF-91A WLS fibres in grooves for optical transport to PMT as shown (left)

GEANT4 Optical Simulation



A simulated neutron capture event in which four fibres transmit light onto a PMT. Photon hits are processed into realistic pulses through a simulated PMT response.

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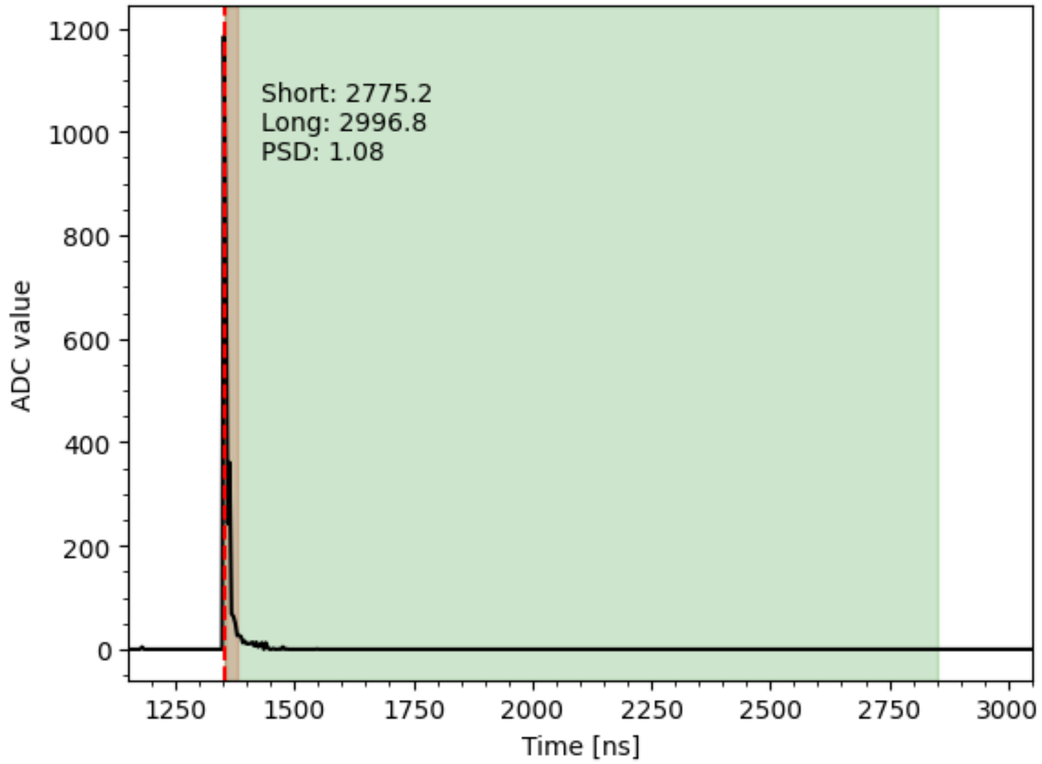
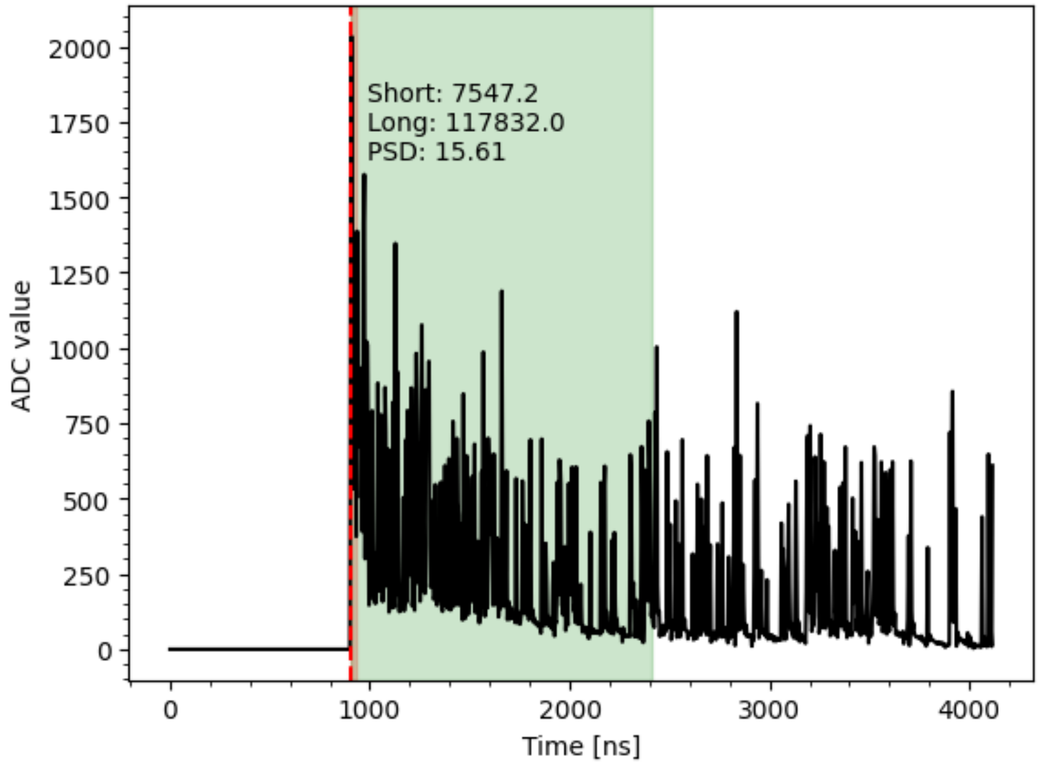
BN:ZnS(Ag) and PS - Pulse Shape Discrimination

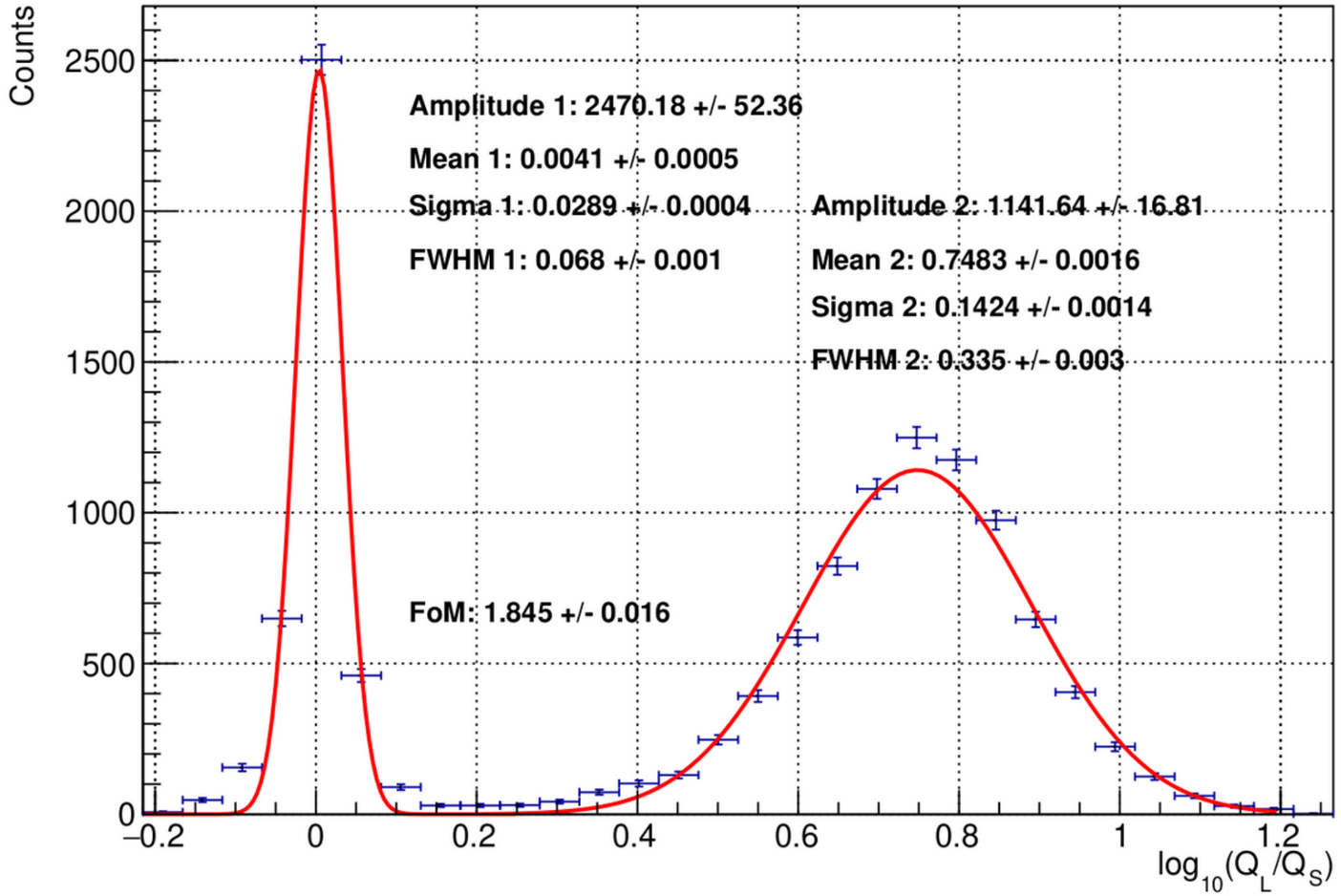


Gamma



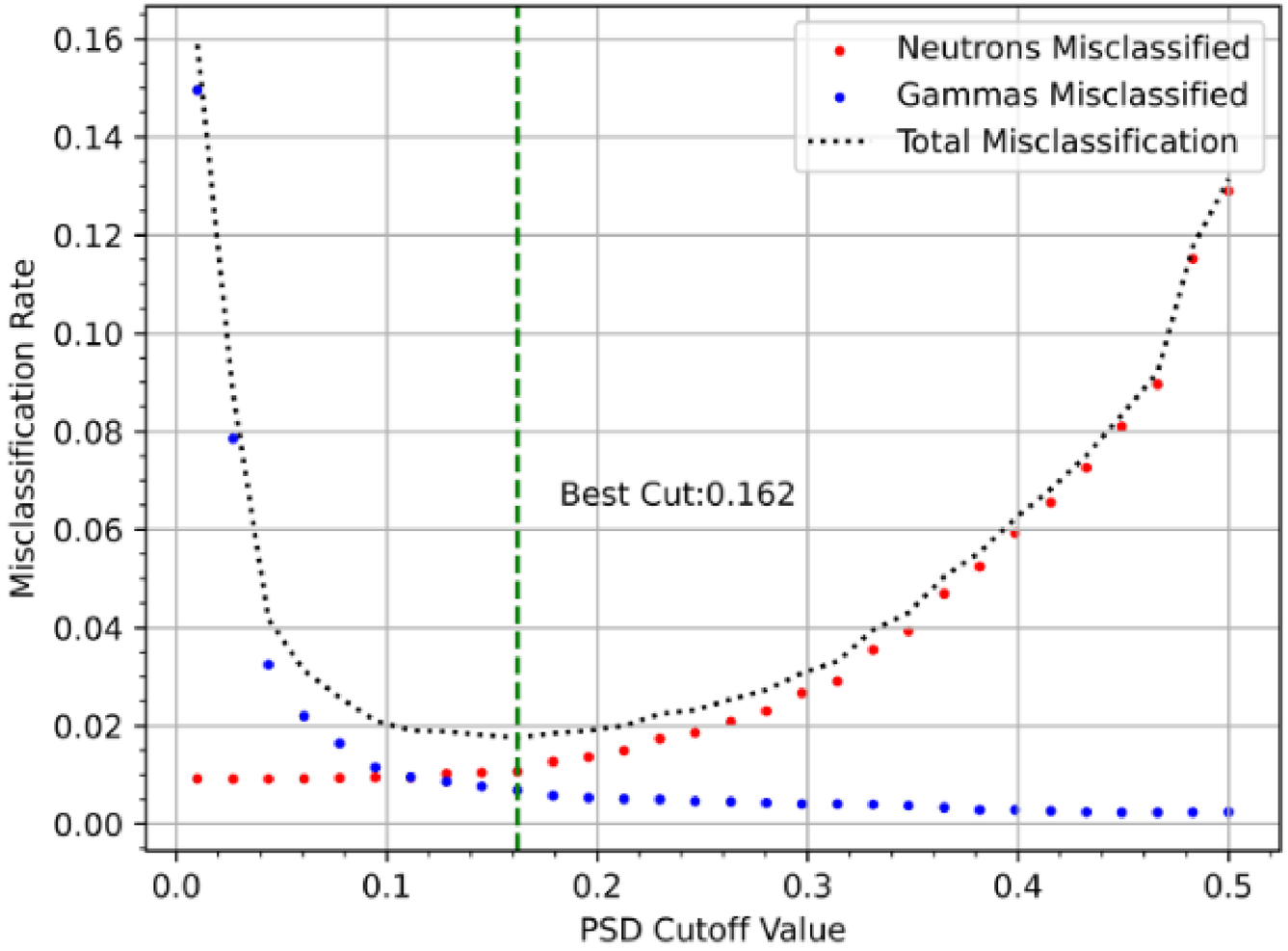
Neutron

GEANT4 Optical Simulation - Direct Readout



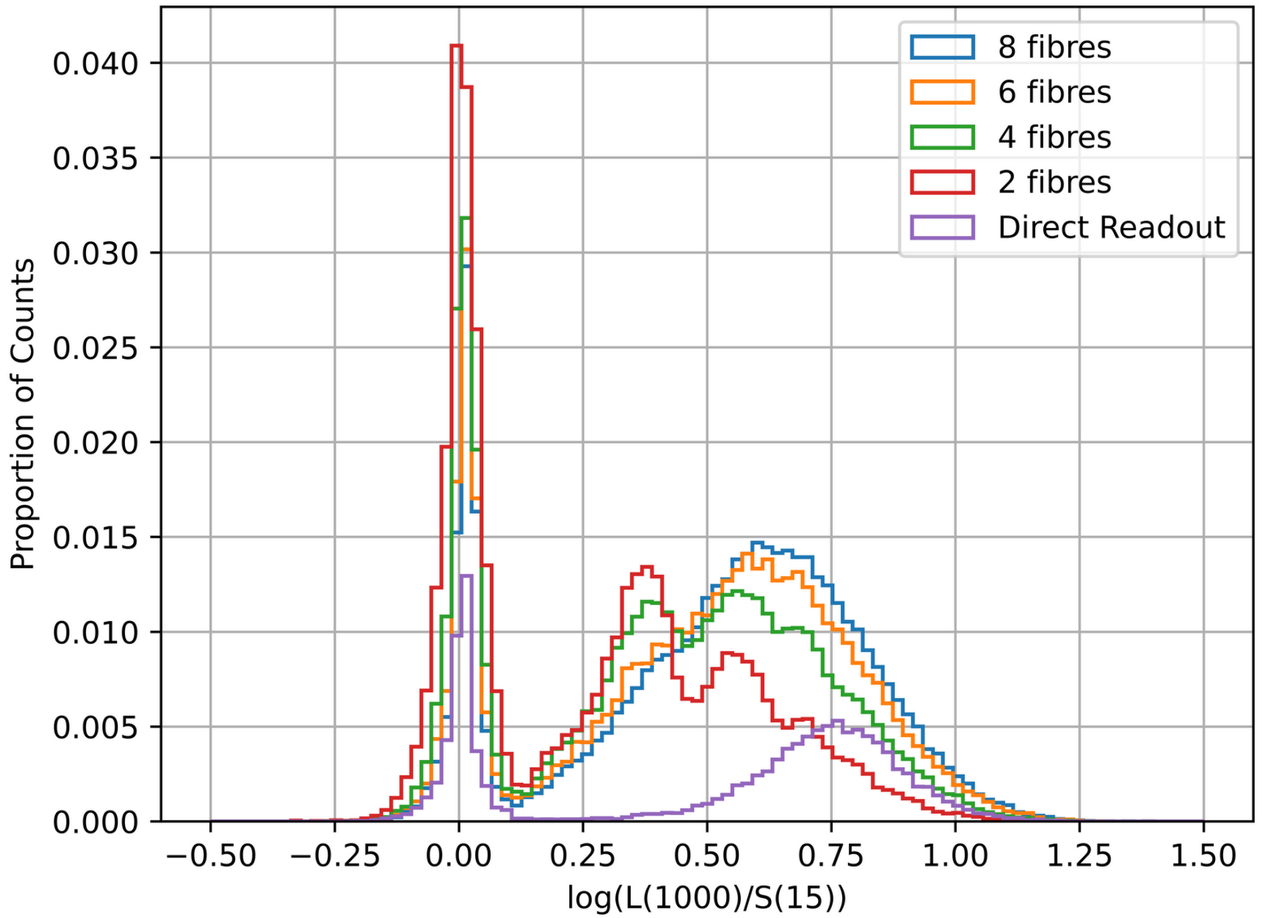
PSD performance for a PMT directly coupled to the face of a hemicylindrical block of EJ200 wrapped with BN:ZnS converter foils

GEANT4 Optical Simulation - Direct Readout



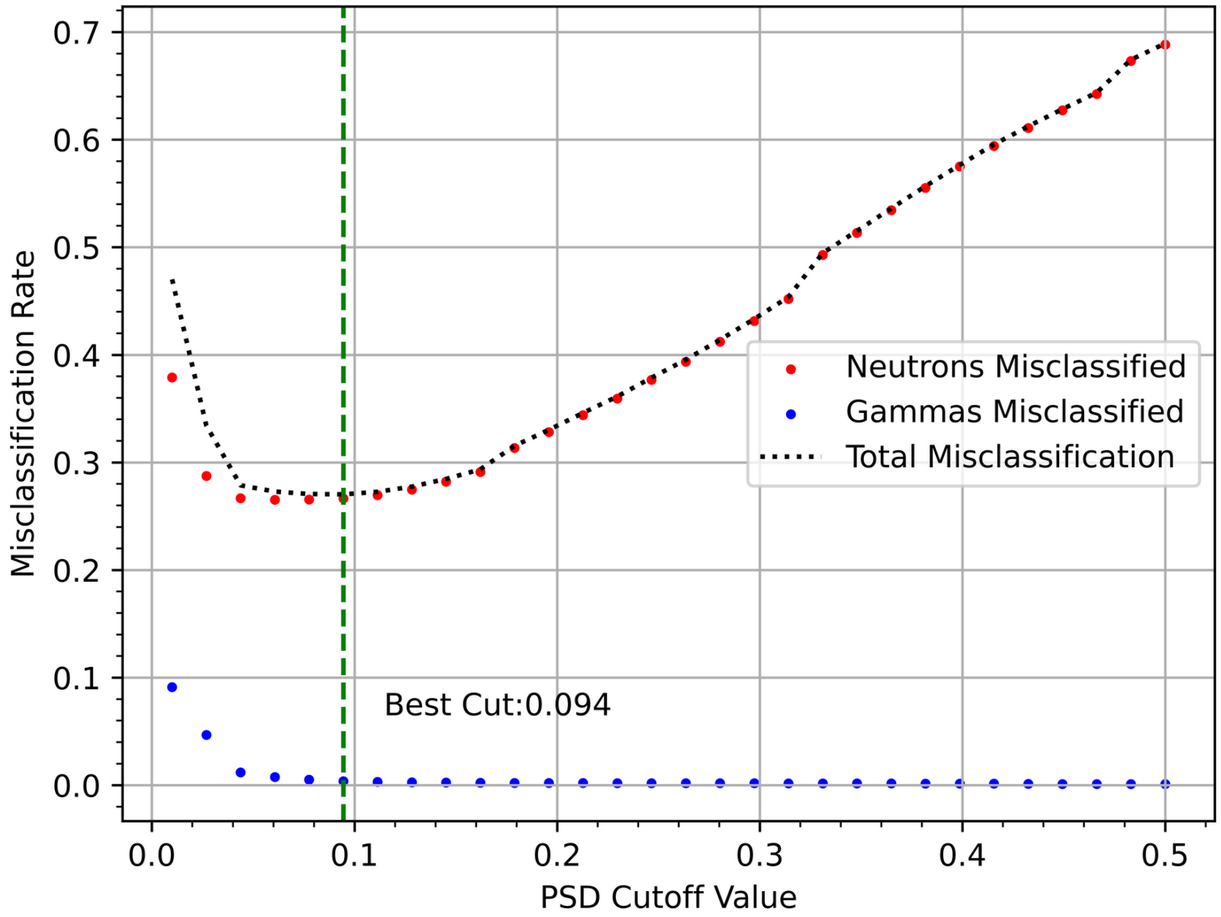
Misclassified events show us a more complete picture of the PSD capability, we are misclassifying around 1.8% of total events

GEANT4 Optical Simulation - Fibre Readout



With reduced light available to use in PSD, we expect and do see some degradation in our PSD capability, distributions smear, some display odd features

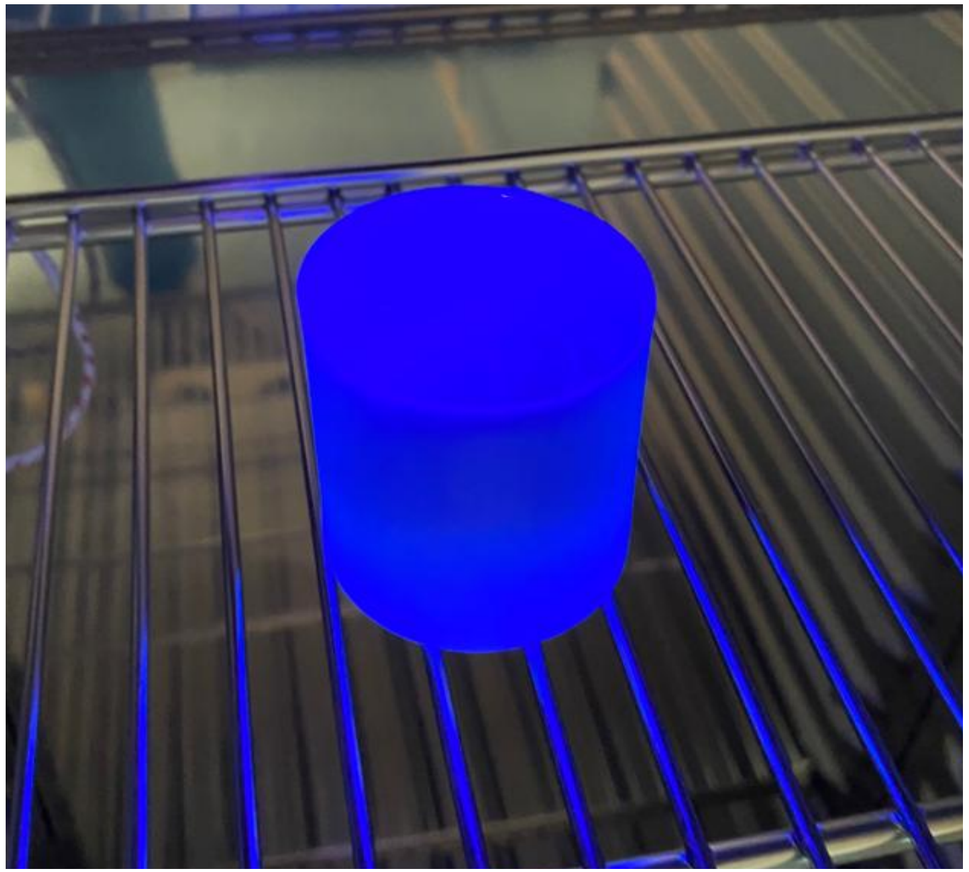
GEANT4 Optical Simulation - 8 Fibre Readout



There is significant misclassification of neutron events due to degradation of their characteristically large pulses. This causes neutron events to appear as gamma events.

Detector Design Decisions

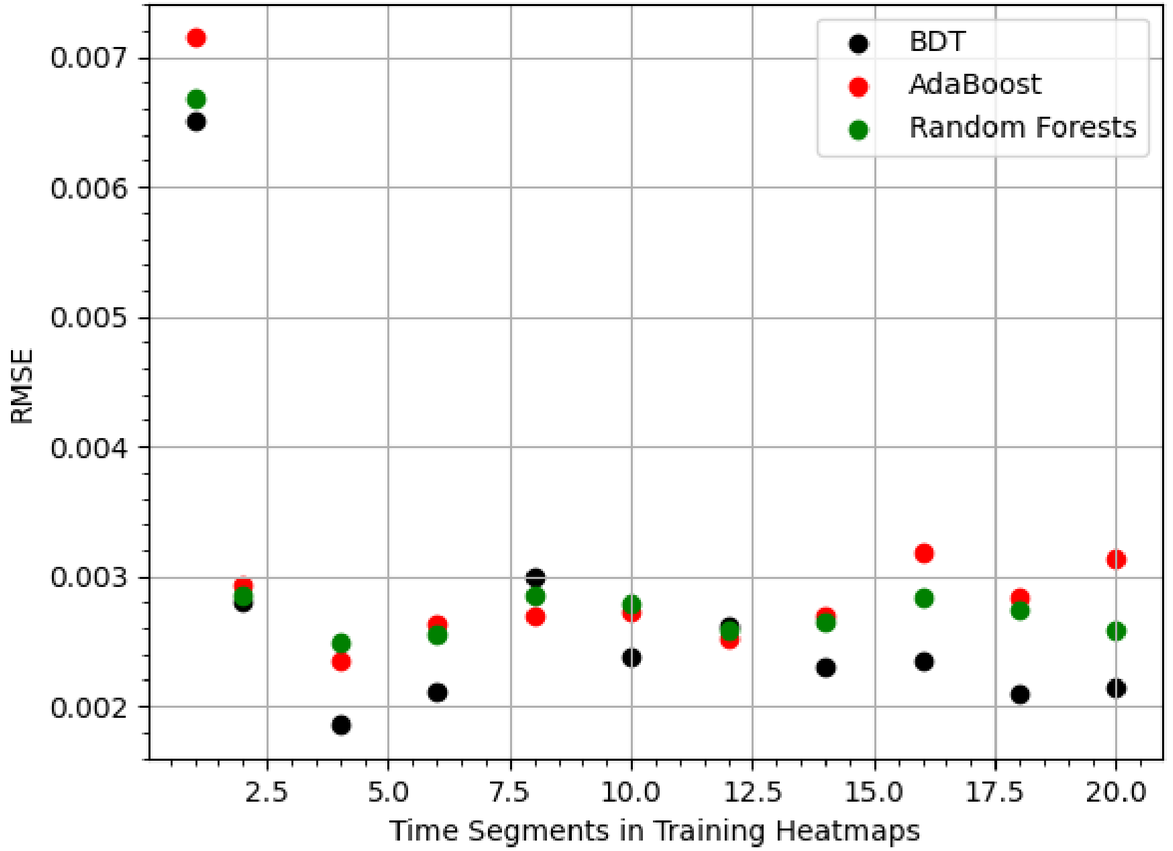
- Fibre readout unsuitable, detector modules must couple directly to PMTs
- FoM = 1.845 for direct readout with 1.8% misclassification
- **Low-cost mixed-field detection**
- In-house scintillator casting allows for flexibility in geometry
- Further simulations performed to examine ideal size of scintillator-foil combinations coupled to 5 cm PMTs
- Scintillator cast, coupled to foils for testing
- Casting allows fast prototyping of geometries



Cast scintillator under UV lamp for final detector prototype - before foil wrapping
Epoxy based with 1% doping PPO:POPOP

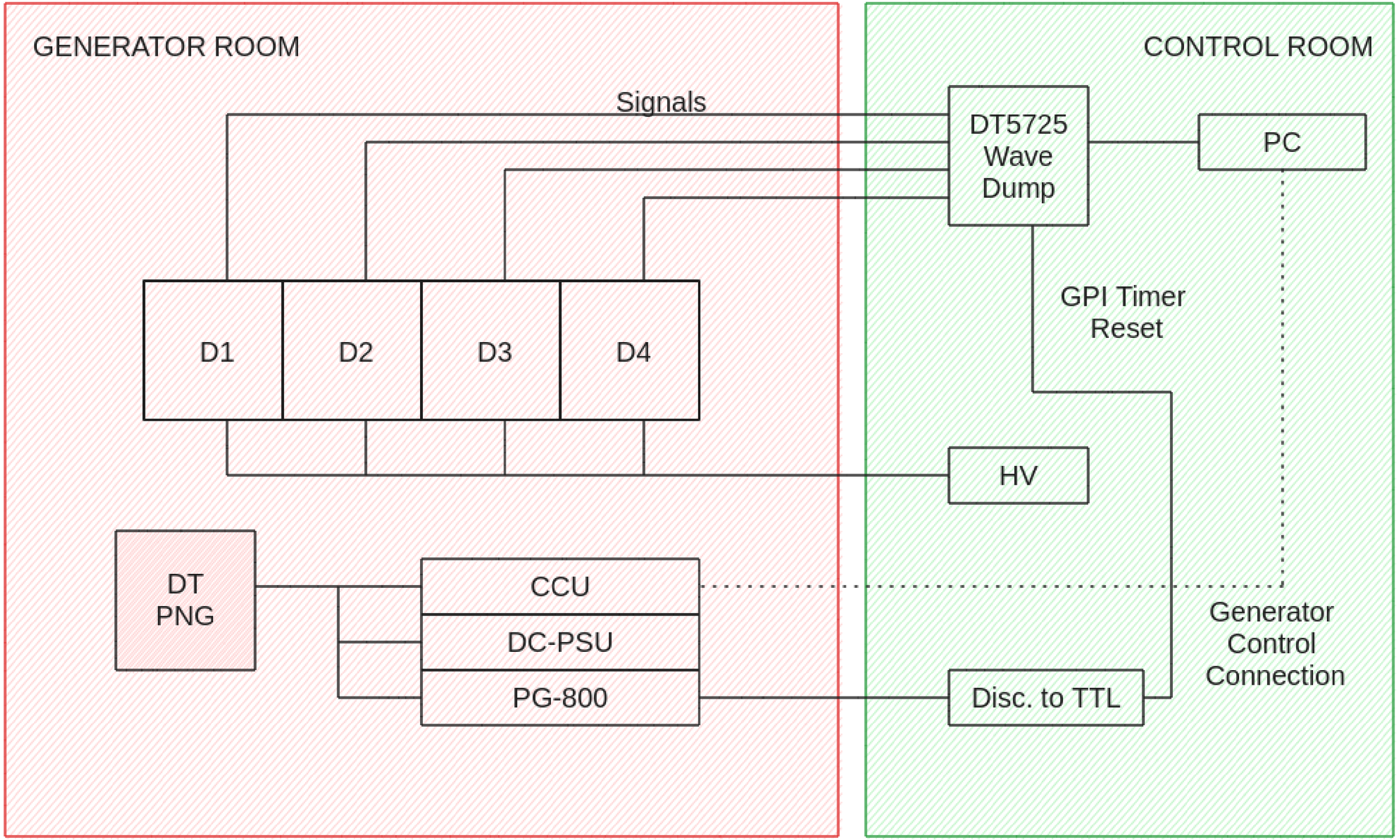
Why Pulsed Neutron Generators?

- We can turn them off - reduced operator dose
- If lost downhole, not as much of an issue as radioisotope sources
- If stolen, much more difficult to repurpose for nefarious means
- **Timing can provide additional information**
- Simulations of test formations with the UoS D-T PNG used to predict hydrogen content in moderator filled boxes



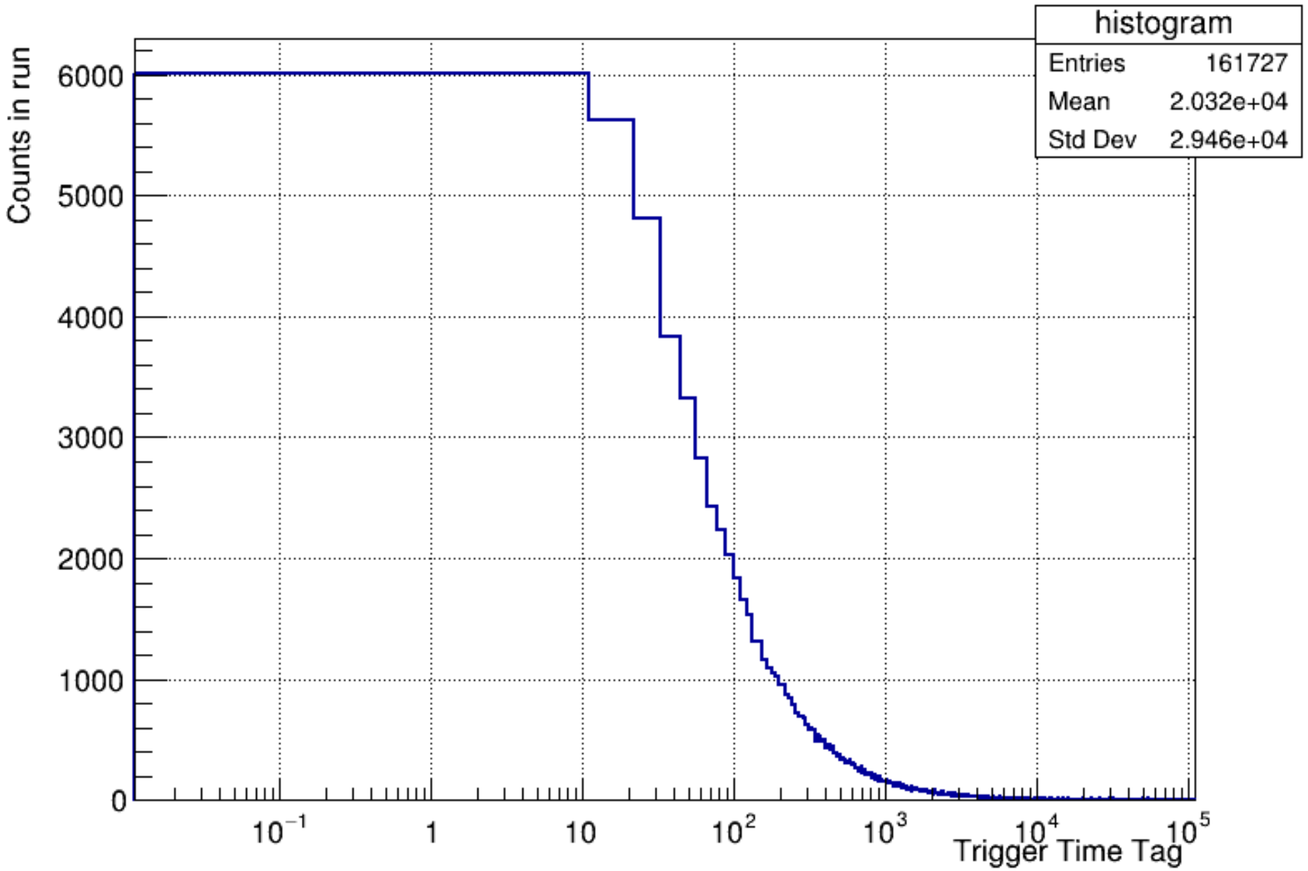
ML models trained on simulated detector response heatmaps to predict hydrogen index. Training heatmaps of 2XN dimensions (2 detectors with N time bins)

D-T Neutron Facility Setup



Preliminary Tests

- Position information simply based on origin detector
- **Time information relative to neutron pulse**
- This data can be used to make predictions of hydrogen index for surrounding material - **significant calibration required dependent upon environment**
- **Preliminary single detector data - prone to pile up at short time after pulse**



Time-after-neutron-pulse recorded for all triggers in a single detector module

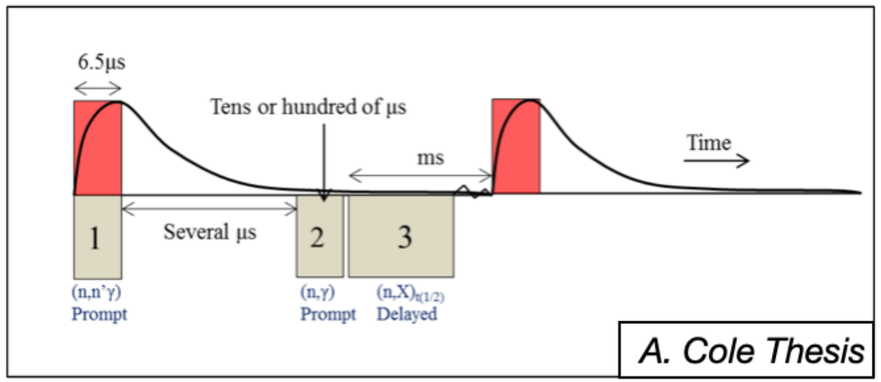
D-T Neutron Facility - Upcoming Tests

- Sediment with varying water content to be placed in parallel with detector
- Water content varied
- **Detector response expected to track hydrogen content from simulations**
- Replacement of far end of shielding with sediment filled box
- Examine potential improvements in predictions for analysis including timing information

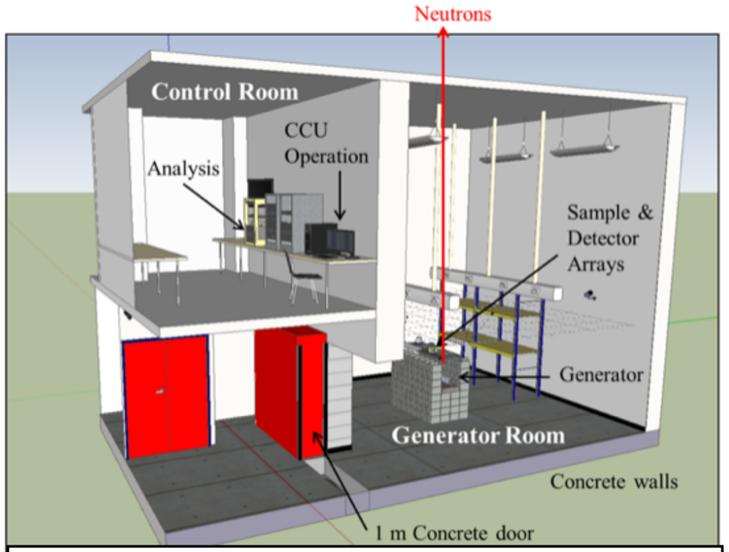
UoS D-T pulsed neutron generator contained in magnetite concrete castle

Sheffield D-D/D-T generator

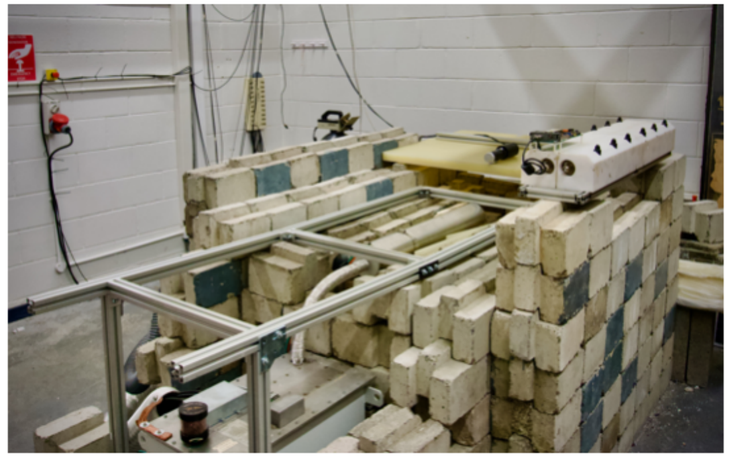
- Dedicated lab for fast neutron sensor development at Sheffield.
- Sealed radiation sources and a **NSD-Gradel pulsed-neutron** generator for neutron activation.
- Short ~6.5us pulse-width.
- Maximum flux = 2x10^6 n/s.
- Maximum pulse rate = 30Hz.

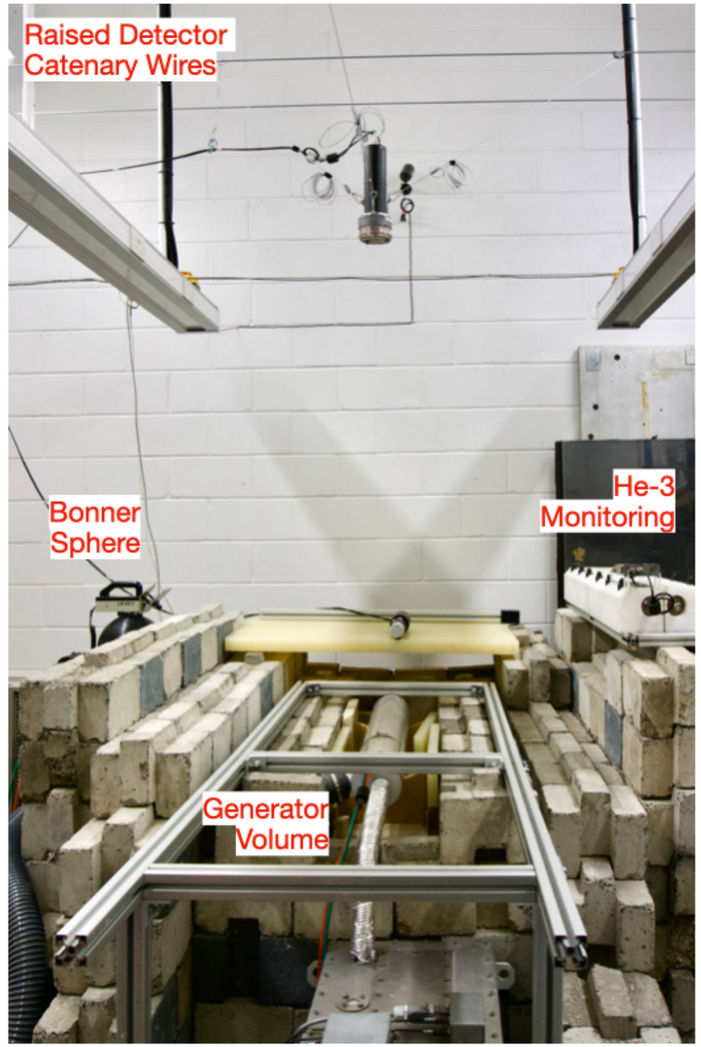


A. Cole Thesis



Sheffield Facility : A. Cole, J. McMillan





For facility enquiries : p.stowell@sheffield.ac.uk

Summary

- Radioisotope source replacement necessitates development of new D-T based tools
- Testing feasibility of converter foil coupled plastic scintillator as an alternative to commonly used He-3 based systems
- Simulations suggest good prediction of hydrogen index is possible with low RMSE
- Fibre readout based system not possible - rules out high segmentation
- Currently building and testing four-detector neutron-gamma sensitive system with directly coupled PMTs
- Will be tested with the UoS D-T neutron generator + mock rock testbed

Questions

Backup Slides - Lithium Foils

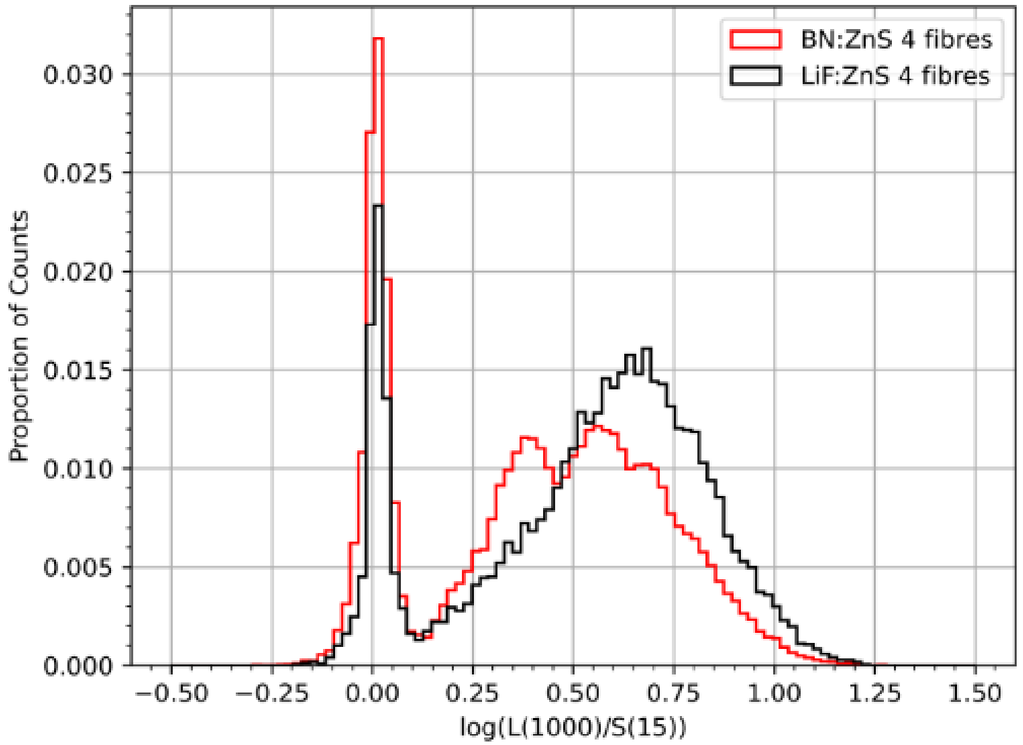
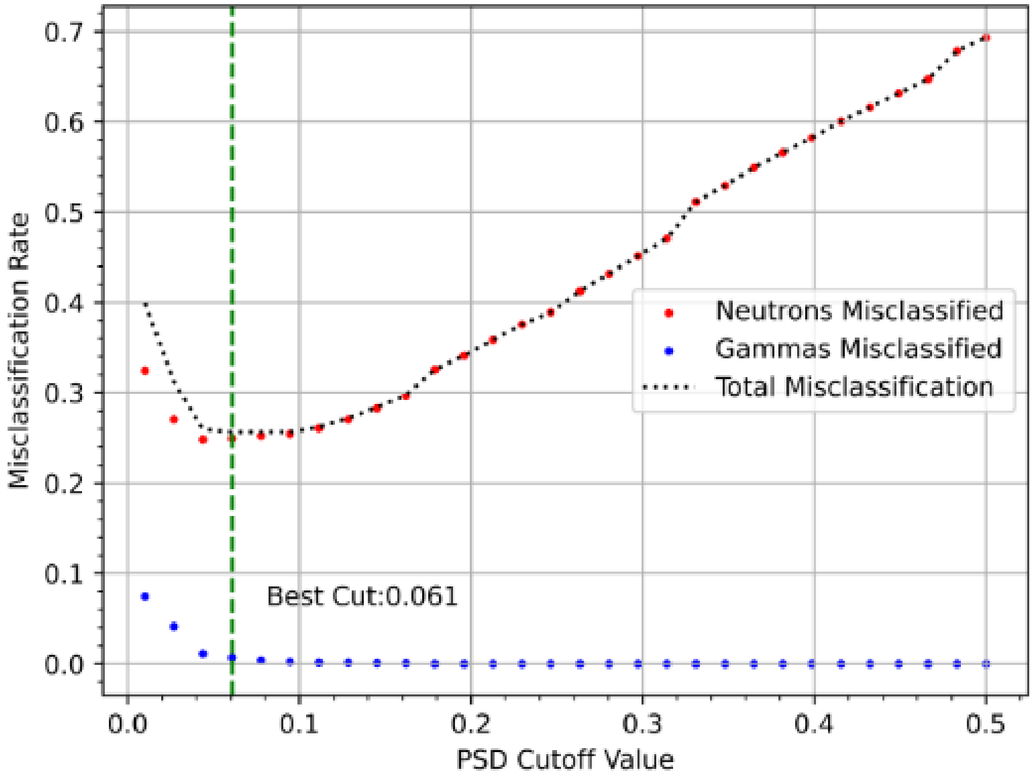


Figure 3.18: Relative performance of boron and lithium based foils.



Backup Slides - Converter Foils