Pulse shape simulations for organic scintillation detectors using GEANT4

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1. Introduction

- The temporal shape of the output pulse formed following the interaction of ionising radiation with a scintillator material enables characterisation of the incident radiation.
- Pulses can be represented by an exponential rise time and multiple decay time constants which relate to the scintillation mechanism of the material.
- Time constants differ with particle type, allowing the extraction of information from the pulse shape on the type of interacting radiation using the technique of pulse shape discrimination (PSD).
- PSD is used for the separation of gamma and neutron induced signals in the presence of a mixed radiation field.
- Plastic scintillators exhibiting PSD properties represent a promising, solid-state alternative to the use of organic liquids and crystals for the detection of neutron and gamma radiation.

Aims and motivation

- The aim of this study is the accurate simulation of pulse shapes from plastic scintillation detectors capable of PSD.
- This has the potential to enable the PSD performance of organic scintillation detectors to be assessed in the early stages of detector design.
- Factors which reduce PSD performance may then be mitigated to obtain the greatest level of PSD achievable.
- This is of importance for plastic scintillation detectors since the PSD of these materials are known to diminish due to various factors affecting the shape of the pulse, including scintillator geometry **[1]** and the position of particle interaction in the scintillator **[2].**
- In this work, the Monte Carlo toolkit GEANT4 has been used to simulate the temporal pulse shapes from EJ-276, a PSD-capable plastic scintillator developed by Eljen Technologies.
- Unlike previous studies **[3]** all three decay time constants of EJ-276 have been modelled using new methods available in the latest version of GEANT4.

2. GEANT4 optical photon tracking

- GEANT4 is an object-oriented C++ Monte Carlo toolkit for simulating the passage of particles through matter **[4].**
- Particles and their interactions can be tracked through arbitrarily complex geometries, material compositions and electromagnetic fields.
- GEANT4 is widely used for the simulation of inorganic and organic scintillation detectors due to its ability to generate scintillation and track individual photons up to their detection at a sensitive region defined by the user.
- Scintillating materials are characterised by light yield (photons/MeV), photon emission spectrum and the distribution of emission times.
- Figures 1 and 2 show the constructed EJ-276 detector following one and many gamma particle interactions, respectively.

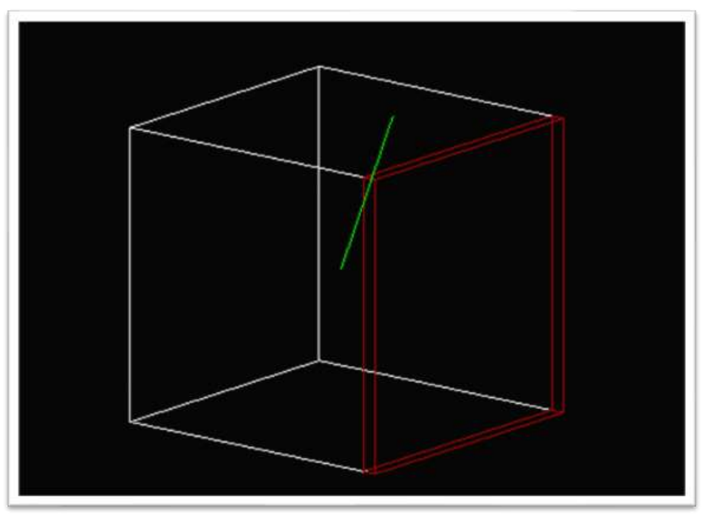

Figure 1. EJ-276 detector following interaction with 2 MeV gamma ray (in green). PMT is coloured red.

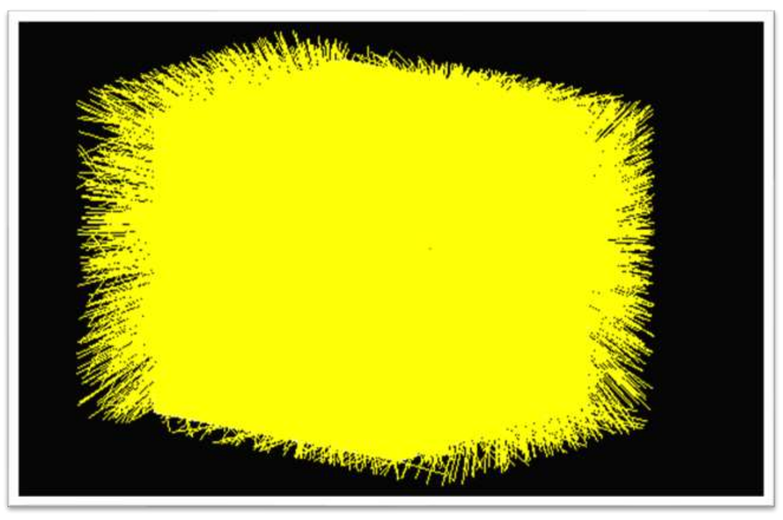

Figure 2. EJ-276 detector following interaction with > 1 gamma ray. Many scintillation photons are generated (shown in yellow)

3. Multiple decay time constant modelling

- GEANT4 has been used to track individual scintillation photons up to their detection at the surface of the PMT. At this point, their time of arrival is recorded and the generated data histogrammed.
- Simulated pulse shapes represent the arrival time distribution of scintillation photons reaching the photodetector.
- Previously, GEANT4 users were limited to no more than two decay time constants, thus impacting on the overall accuracy of the pulse shape simulations.
- In this work, all three EJ-276 decay times and their relative weightings for both neutrons and gamma rays have been included, using experimental values from *Iwanowski-Hanke et al* (table 1) **[1].**
- Simulated pulses from an EJ-276 scintillator in response to gamma and neutron radiation are shown in figures 3 and 4, respectively.

Particle	A	$\tau_{1\,(ns)}$	B	$\tau_{2\,(ns)}$	C	$\tau_{3\,(ns)}$
n	0.580	4.5	0.180	20	0.240	170
γ	0.740	4.3	0.140	18	0.120	140

Table 1. Decay time constants and relative weightings for EJ-276 plastic scintillator. Data taken from [1]

Pulse decay function with three decay time constants

$$y(t) = Aexp\left(-\frac{t}{\tau_1}\right) + Bexp\left(-\frac{t}{\tau_2}\right) + Cexp\left(-\frac{t}{\tau_3}\right)$$

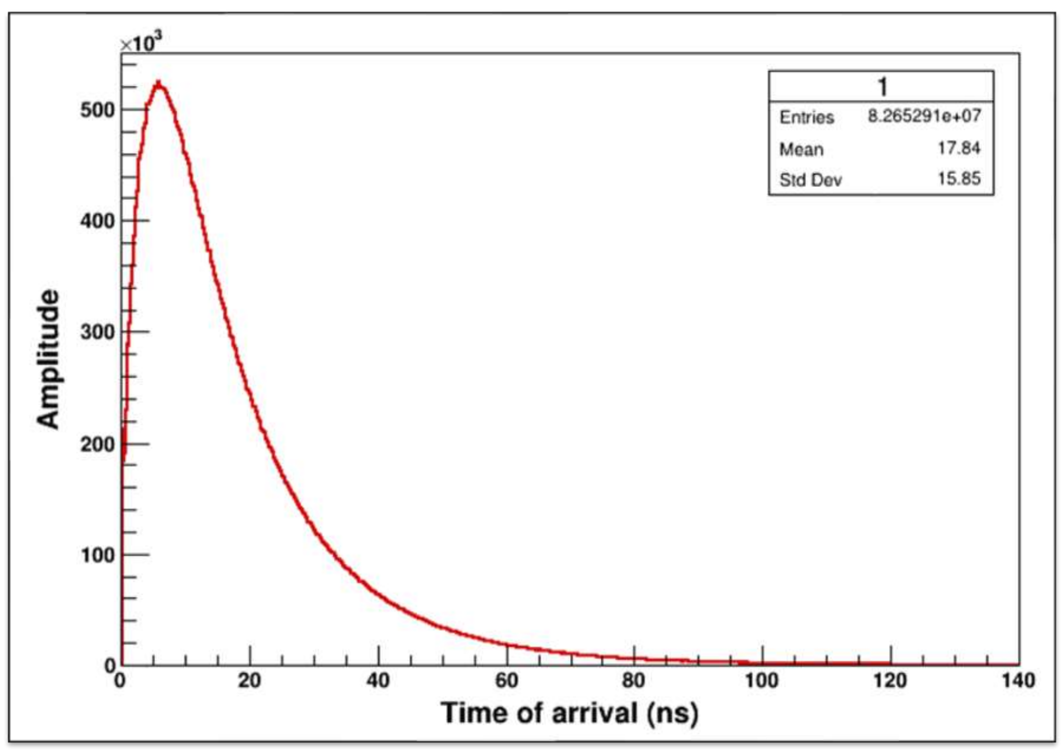

Figure 3. Average simulated pulse shape for EJ-276 scintillator in response to 2 MeV gamma rays

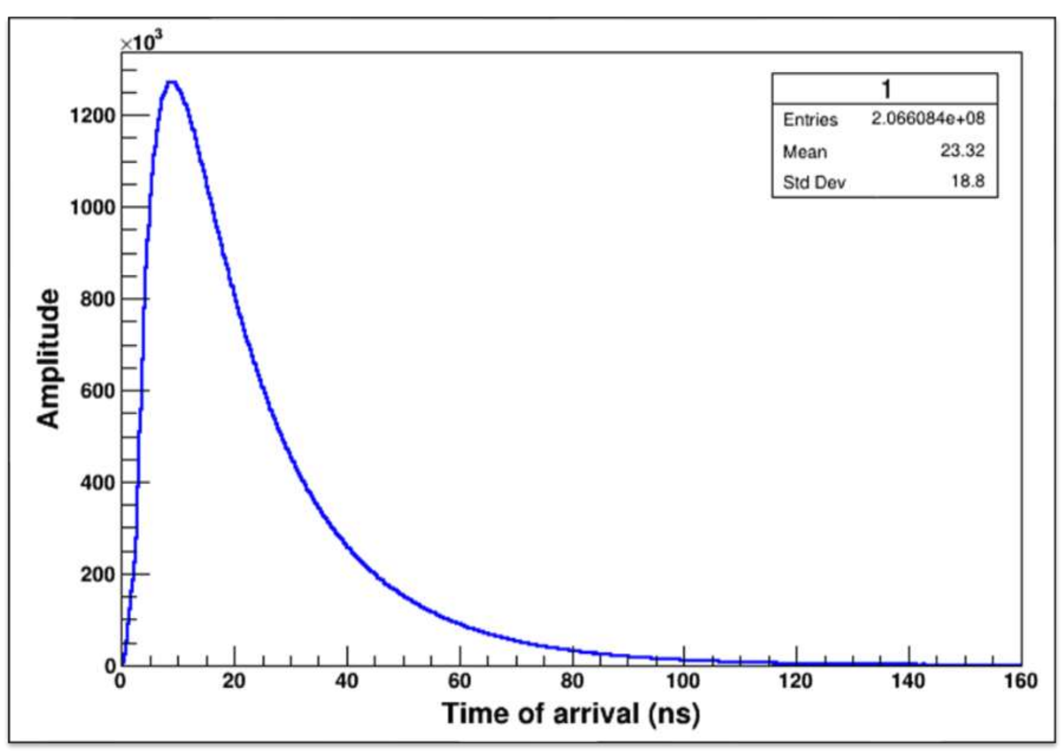

Figure 4. Average simulated pulse shape for EJ-276 scintillator in response to 2 MeV neutrons

4. Photomultiplier tube (PMT) response

- The simulated pulses do not include the influence of the photomultiplier tube (PMT) on the shape of the pulse.
- Similar studies have either neglected to include the PMT response or employed analytical approximations.
- Work by *Ogawara et al* **[5]** utilised a combination of GEANT4 simulations and experimentally measured PMT response functions to model the pulse shapes from different inorganic scintillators.
- Current studies are focused on experimentally determining the response of an ET-Enterprises 9214 PMT.
- This will be achieved using a pulsed laser with a wavelength in the region of peak emission of the EJ-276 scintillator and attenuating down to single photon level.
- This will then be integrated with simulations and compared with experimental measurements.

5. Conclusions and future work

- Temporal pulse shapes from an EJ-276 PSD-capable plastic scintillator coupled to a PMT have been simulated using GEANT4.
- All three stated decay time constants of EJ-276 have been input into the models, utilising new methods introduced in the latest version of GEANT4
- The pulses approximate what we might expect to be measured experimentally for neutron and gamma induced signals.
- Since the PMT impacts on the overall shape of pulses output from scintillation detectors, the PMT response should be included for accurate pulse shape simulations which match that which would be measured experimentally.
- Work is on-going to measure the temporal pulse shapes from an ET-Enterprises 9214 PMT and integrate this with existing GEANT4 simulated pulses.

References

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ANIMMA 2021
Prague, Czech Republic
June 21-25, 2021