DOOM – Digitisation Of Optical Monte carlo

A Digitisation Tool for Detector Emulation of SABRE South and other Low Background Experiments

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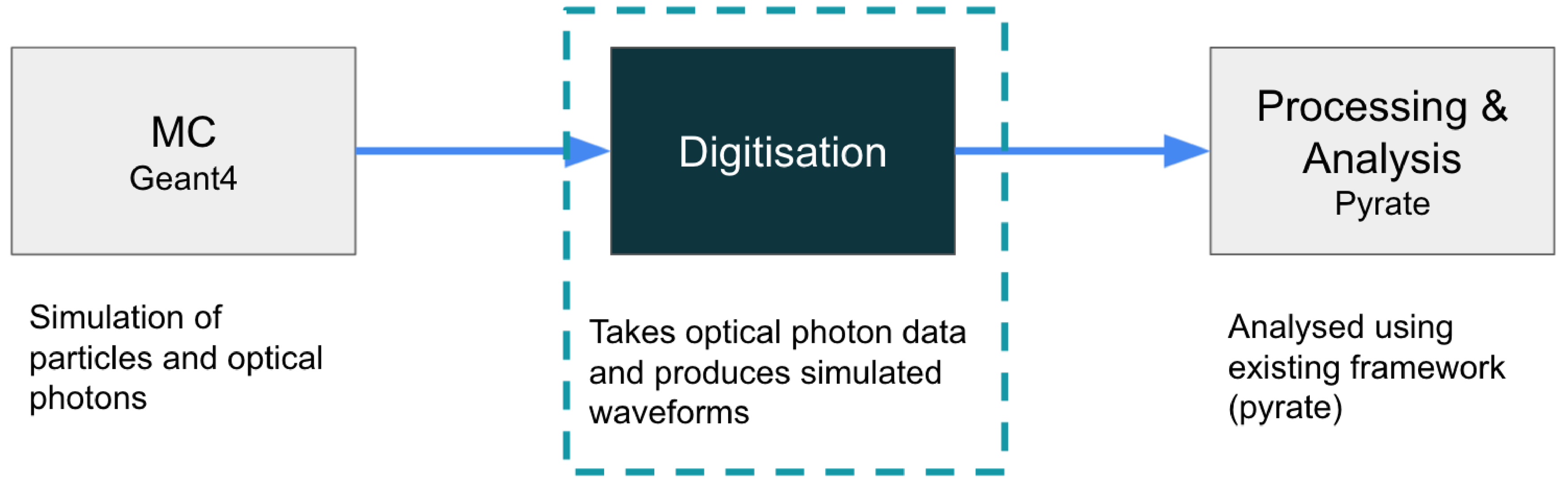
Low background experiments such as dark matter direct detection studies are typically limited by low rates, small signals, and the isotropic nature of scintillation light. This means that advanced reconstruction tools such as particle identification and localisation rely on detector simulations. A key step in developing these reconstruction tools is the transformation of physics simulations (typically performed in Geant-4) into a waveform-like object which mimics the detector and data acquisition process. This process is called digitisation.
We present here a digitisation tool developed for the SABRE Experiment. It takes as an input the output from a typical Geant4 MC with optical physics and outputs the resulting "waveform" for each PMT, along with crucial information from the generating MC event (initial particle identity and 4-momentum, energy deposition and position in detector). This file can then be passed into a processing and analysis framework, and the simulated "waveform" analysed using the same methods as experimental data.

Aim

To transform simulated Monte Carlo data (e.g., Geant4 outputs) into realistic waveforms that can be analysed identically to real data.
Most MC simulations return the arrival time of photons at a PMT cathode, but do not emulate the PMT and DAQ effects on the resulting event. These transformations will vary based on the PMT and digitizer system used, which are based as inputs to this tool.



Inputs and transformations

DOOM uses a range of inputs to fully emulate the entire acquisition process. These include inputs to model the PMT response and the DAQ system. These are configurable for each channel allowing each PMT in the SABRE detector to be uniquely emulated.

PMT inputs

- **Quantum efficiency (QE) :** probability that a photon hitting the PMT cathode is successfully transformed into a photoelectron
- **Transit time (TT) :** time photon takes to travel length of PMT
- **Single Photoelectron (SPE) model :** the charge and pulse shape generated within the PMT for one PE
- **Noise:** baseline fluctuations and random noise effects

Digitiser inputs

- **Sample rate:** dictates minimum time binning
- **Resolution:** smallest difference discernible by system
- **Units:** ever important for further analysis

Use cases

The primary use of DOOM is in the development of advanced reconstruction tools for SABRE South. By digitising Monte Carlo simulations it is possible to create accurate data sets of events with known initial position and energy.
Some of the planned tools include:

- Identify event location and direction
- Position corrected energy deposition
- Particle identification in the active veto

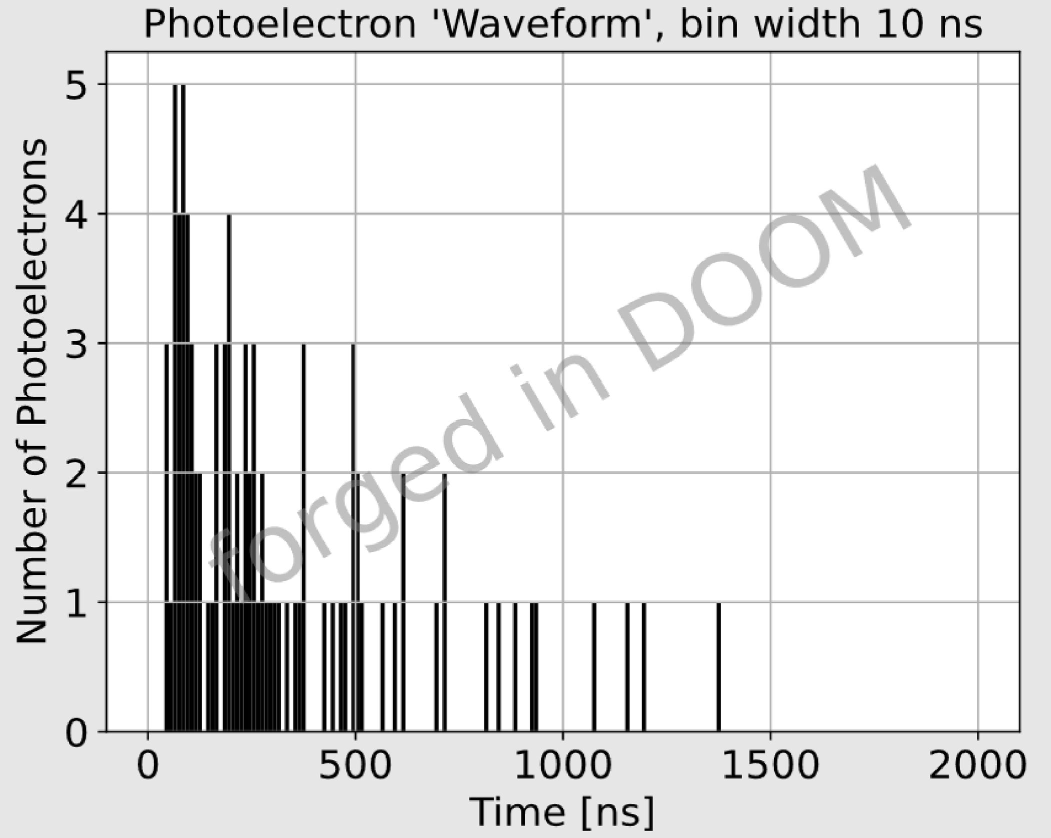
Future plans

Development of DOOM is ongoing. We aim to add features including multi-channel triggering across multiple detectors, additional PMT effects including saturation, and spatial effects, and more complex single photoelectron models.

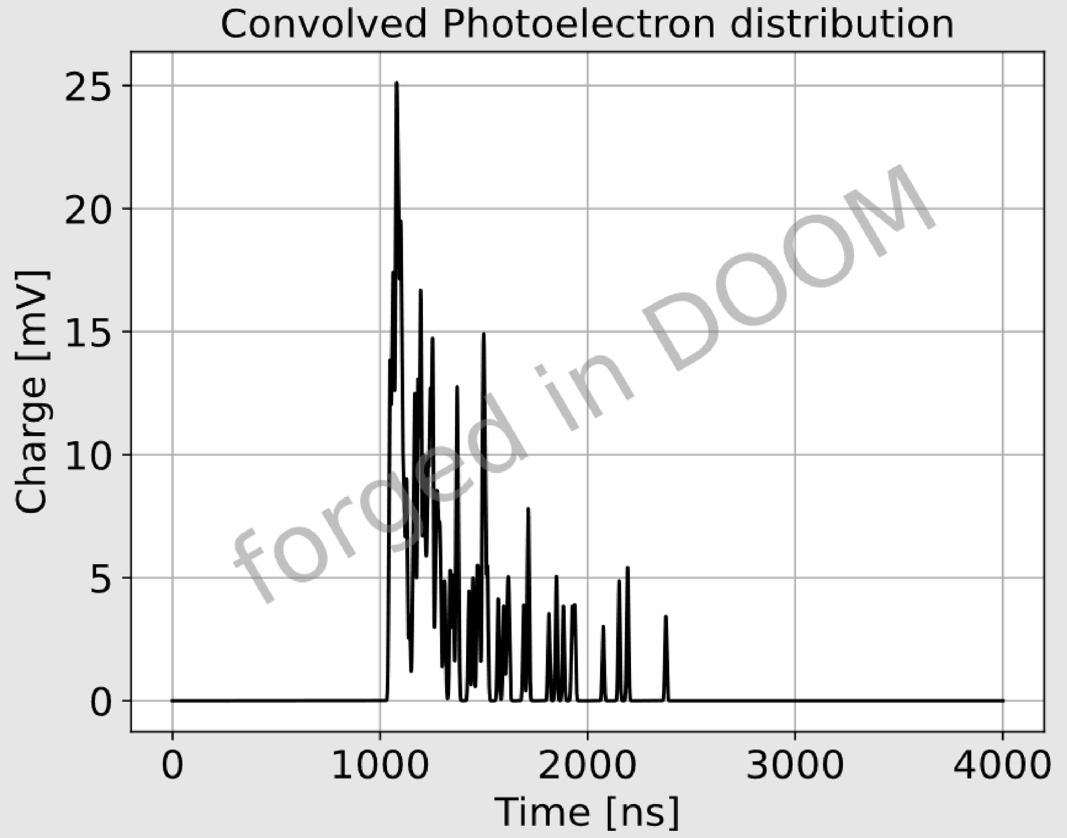
While designed for use with the SABRE experiment our intention is the final version of DOOM will allow for the definition of any bespoke detection system to be used for any low background experiment.

Digitisation Process

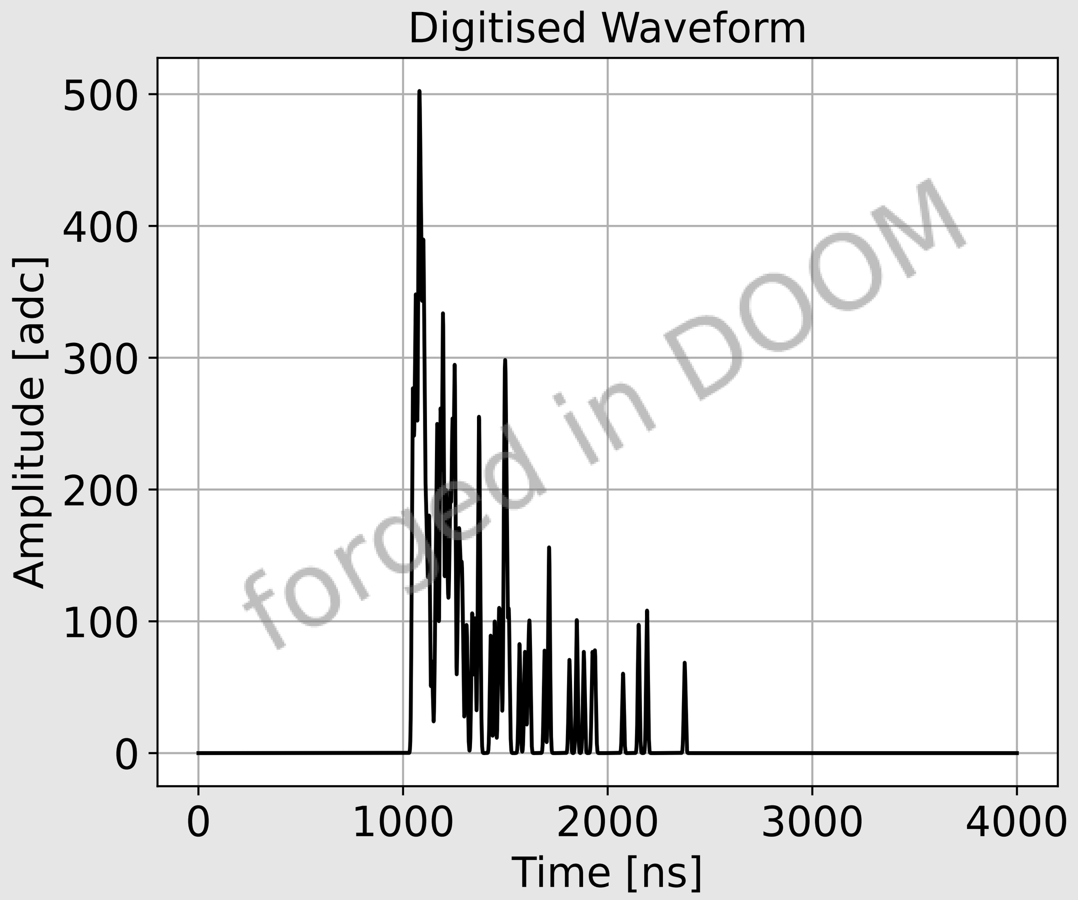
1. Read in list of photon arrival times. Apply quantum efficiency and correct for transit time of PMT



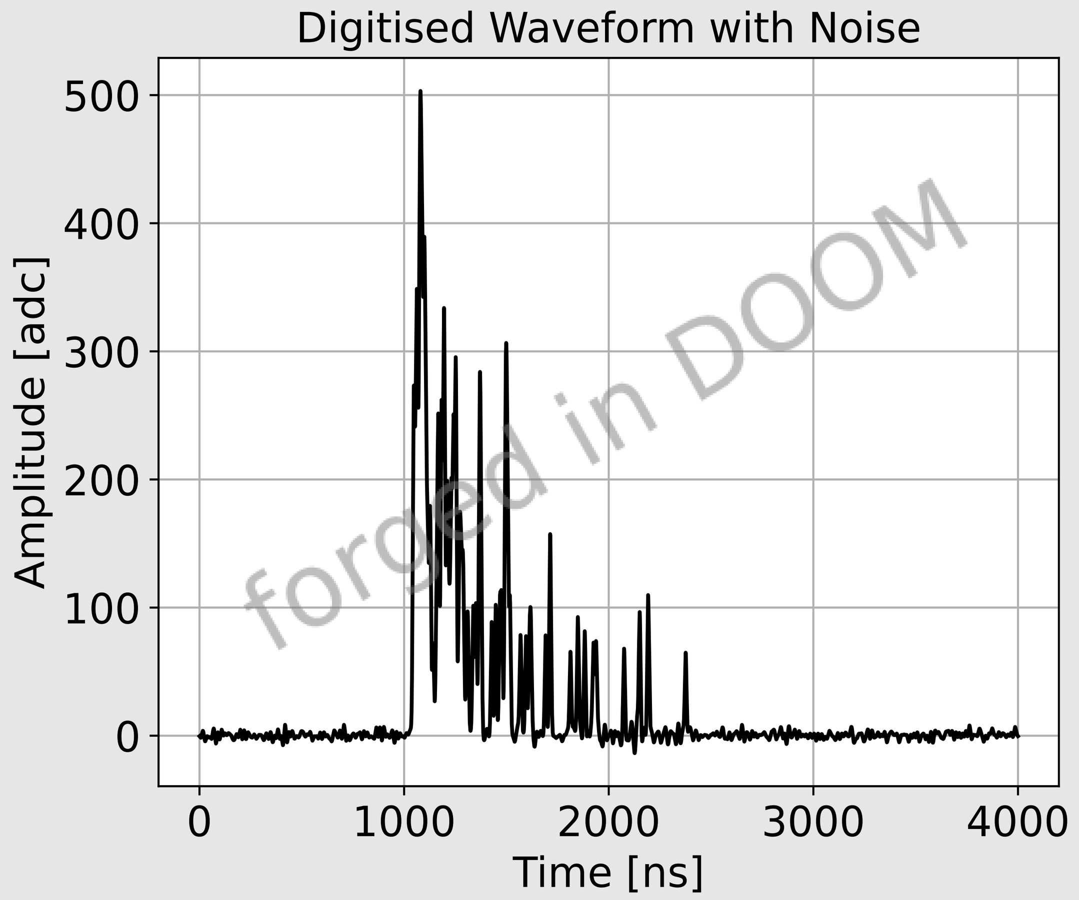
2. Determine each photoelectrons charge and convolve with SPE pulse to produce semi-continuous waveform



3. Digitise semi-continuous waveform emulating sample rate and precision of DAQ system



4. Add noise effects including baseline fluctuations, shot noise, and dark PE emissions



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