MCNP Detector Simulations with DRiFT's Digitizer Class

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INTRODUCTION TO DRIFT

DRiFT (**D**etector **R**esponse **F**unction **T**oolkit) is a modular C++ code under development of Los Alamos National Laboratory (LANL) [1]. DRiFT is intended to be applied to MCNP®[2] output (PTRAC) to simulate realistic detector spectras. DRiFT is modular and flexible, it allows users to mix and match detectors, digitizers and other components using DRiFT or user-generated files. DRiFT is under active development, comparisons to organic scintillator detectors have been performed and capabilities are currently being expanded upon to include gas and semiconductor type detectors.

DRiFT features include scintillator detector response (validated for EJ-301), multiple output formats (ASCII, ROOT) and the tracking source particle information for each detector event [3]. Digitizer response was previously included inside the Scintillation class and unavailable as a standalone module. As additional detector types, specifically High Purity Germanium (HPGe) detector capabilities are added, the digitizer response has been rewritten as a stand alone module and exapanded on. This summary describes the digitizer simulation features including pulse pile-up as applied by DRiFT.

DRIFT'S DIGITIZER CLASS

DRiFT's digitizer output is intended to simulate the raw waveforms collected during experiments. Ideally both the measured waveform and DRiFT simulated output could be run through the same analysis script. Many radiation detection scenarios are limited in time allotment for measurement and analysis, this simulation capability allows experimentalists to assess their instrumentation settings and analysis codes before measurement data is collected.

Detector Physics Applied Before the Digitizer Class

DRiFT applies a detector response to events collected as MCNP PTRAC (**P**article **TRAC**king) output. Information including source particle energy, time, position and events inside the detector (for example, proton recoil from incident neutrons in scintillator detectors) are all present in the PTRAC file and post-processed by DRiFT. The DRiFT module `TimeDistribution` can be used to distribute the source and event particles in time after reading in a user-defined activity. This feature assumes that the source particles generated in the MCNP simulation had no time-distribution.

DRiFT's digitizer class expects to be passed a current calculated in a previous step. In the case of scintillators this current is calculated by: i) converting a charged particle's energy into photons, ii) distributing these photons in time using user-supplied or default time profiles dependent on charged particle type, iii) calculating the quantum efficiency of the PMT/scintillator interface, and iv) applying a gain based on PMT specifications and applied voltage. At each step noise arising from signal fluctuations and PMT contributions (dark current) are added. The current is saved as an event's pulse shape which is passed into the digitizer class.

Digitizer Keyword Options

Digitizer keywords which can be provided by the user are selected in Table I. If these values are not defined in the configuration file DRiFT will display a warning in the terminal and default to the values displayed in Table I. The majority of these values can found on the technical specification sheets provided by digitizer manufacturer. Several options are settings that are selected by the experimentalist, and those analyzing measurement output.

Digitization of Pulses

The Digitizer class first reads in the relevant keywords provided by the user and defaults to the values in Table I if specifications are absent. If the user omits keyword values DRiFT will provide a warning in the terminal and display the value used. A voltage to ADC bit value is calculated using the `voltage_range` and `resolution` keywords. The `DC_offset` and `resolution` values are used to determine maximum pulse amplitudes before saturation.

The pulse currents passed to the digitizer are separated in time intervals corresponding to the digitizer `rate` (which may be specified in the DRiFT input or a default value of 500 MHz is used). The terminal resistance of the digitizer, digitizer resolution, and voltage range are used to calculate a voltage which is converted into an ADC (analog-to-digital conversion) value resembling those read from a measurement.

Pile-Up

If the `pileup` is specified in the input, each PTRAC event (those originating from the same source particle) will be compared to subsequent pulses in that detector cell. If a following event is registered in the same detector with a time difference less than the length of the digitizer sample (which is dependent on `rate` and `samples`), the event is flagged as a possible pile up. Any pulse current value within the digitizer window is added to the previous event's current before the analog-to-digital conversion. Currently it is assumed that the dead-time of digitizer following a pulse is as long as the sampling length meaning that any pulses contributing to the preceeding one would not be recorded sepaerately.

Pulse Triggering and Shape Discrimination

Digitizer triggering is simulated by searching for the highest ADC value for each pulse. If this value exceeds the trigger ADC threshold, `trigger_ADC`, the event will be recorded as a

TABLE I. DRiFT digitizer keywords and default values.

Keyword	Description	Unit	Default
`pileup`	should DRiFT simulate pile up events		no
`rate`	sampling rate of digitizer	samples/s	500.e6
`resolution`	number of digitizer bits		16384
`voltage_range`		V	2.0
`DC_offset`		bits	10 % of digitizer range
`trigger_ADC`	pulse trigger threshold	ADC Bits	90
`start_point`	location of the beginning of the pulse, used to specify time and PSD determinations		0.1
`samples`	number of samples to be written		256
`PSD`	calculate a PSD value		no
`s_gate`	short gate (for Pulse Shape Discrimination (PSD))	s	22e-9
`l_gate`	long gate (for PSD and energy determinations)	s	90e-9

pulse. The trigger start position is found, `start_point`, and used along with the short and long gates (`s_gate, l_gate`) to calculate a pulse shape discrimination (PSD) value if desired by the user. The digitizer ADC values are saved along with calculated PSD values for the user to access if desired.

Conversion to Energy

In the majority of cases it is expected the user will not want all of the details DRiFT is capable of simulating. If they wish for DRiFT to perform the energy calibration it does so by calculating the pulse integral of a 1 MeVee energy deposition in the detector volume. This pulse integral is used to calculate energy values for each simulated pulse which can be easily plotted using DRiFT's histogram option, or read from generated ASCII files.

RESULTS & DISCUSSION

Pulse Saturation

Reference [4] describes a simple test case used by DRiFT to assess code performance. In short, MCNP simulates neutron emissions from a Cf-252 source which create proton recoils in a detector volume filled with EJ-301 organic scintillator material. The protons are recorded and saved as a PTRAC output to be post-processed by DRiFT. DRiFT applies a detector response using PMT and digitizer settings corresponding to those provided by the experimentalist. A comparison of DRiFT simulations with measurements is shown in Figure 1.

Figure 2 shows DRiFT output after an incorrect PMT voltage was used the simulation. The applied voltage was too high resulting in a larger PMT gain used when calculating the pulse current. When this was converted into an ADC value in DRiFT's digitizer class the pulses were saturated, creating the spectra shown in Figure 2. This example demonstrates an advantage of DRiFT when preparing for measurements. The users can try different digitizer and PMT settings and quickly discern if they are appropriate.

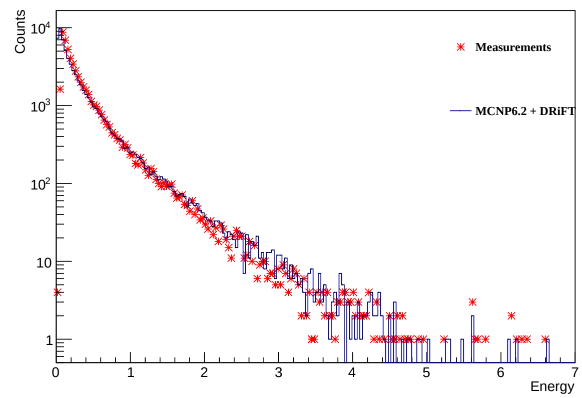

Fig. 1. Digitizer processing with correct PMT voltage

Lost Counts and Pile-up

Figure 3 displays the percentage of counts lost in four digitizers with varying sampling rates, ADC thresholds, and sampling sizes, each processing the same MCNP output. True counts were determined by performing DRiFT simulations with `pileup = no`. Identical simulations were performed for each true count rate with the `pileup` feature turned on. As expected the percentage of pulses lost as a function of activity increases considerably. A lower ADC threshold results in significantly more counts, also as expected. DRiFT now reproduces the effect of increasing sampling size on lost counts.

Figure 4 is generated from the same four digitizer simulations and shows the probability of a true event with no pile-up contributions. This is a useful value for measurements of an energy spectra as it indicates how many pulses are distorted. The percentage of pulses distorted by pile up effects is displayed as a warning by DRiFT if it exceeds 10 %.

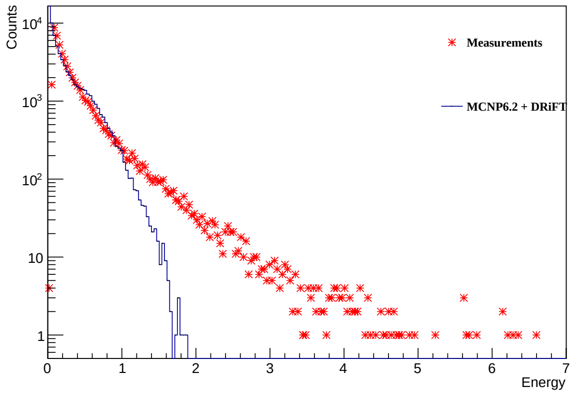

Fig. 2. Digitizer processing with an incorrect applied PMT voltage

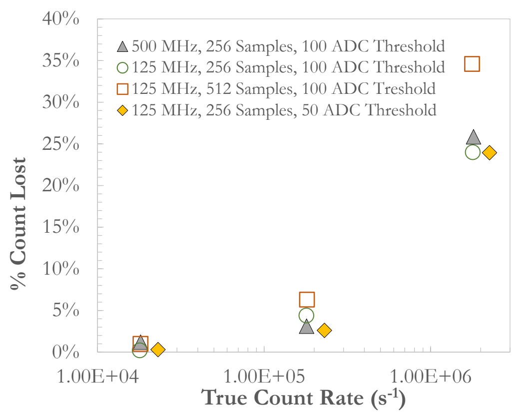

Fig. 3. Percentage of counts lost.

CONCLUSIONS

The digitizer module in DRiFT is now standalone so that it is not limited to scintillator simulations. Digitizer features the user can define now include: sampling rate, resolution, sample size, DC offset and trigger ADC. The pile-up feature can be turned on and off and used to estimate dead-time and pile-up contributions. This digitizer module will be compatible with additional detector types as they are included in the future. In the future the digitizer options will be expanded to include the ability to simulate global triggers (when all detector channels write out at the same time). DRiFT is a valuable simulation tool, it allows scientists to estimate pile-up and dead-time effects of their desired instrument arrangement. It can be used in advance of measurements to consider varying detector and digitizer configurations.

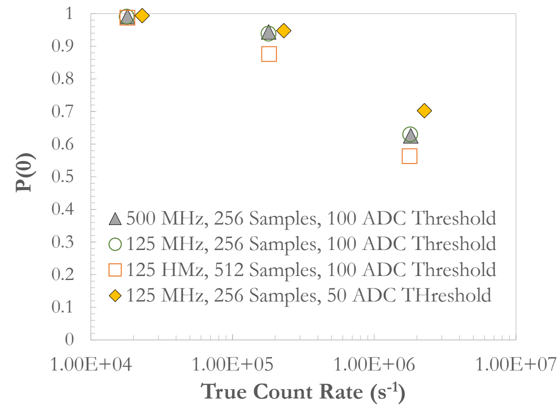

Fig. 4. Probability of a true event with no pile-up contributions.

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