LA-UR-16-29519
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Title: Organic Scintillator Detector Response Simulations with DRiFT

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Intended for: ISR-1 Seminar Series

Issued: 2016-12-19

Organic Scintillator Detector Response Simulations with DRiFT

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ISR-1 Seminar, Los Alamos National Laboratory
Los Alamos, New Mexico,
November 22nd, 2016

DRiFT – A Detector Response Function Toolkit

- Accurate detector modeling is a requirement to design systems in many non-proliferation scenarios.
  - By determining a Detector's Response Function (DRF) to incident radiation, we can characterize measurements of unknown sources.
- More efficient design processes (cost and time)
- Realistic radiation sources may not be available
- DRiFT is intended to post-process MCNP® output and create realistic detector spectra.
  - Leverages the ability of MCNP® to simulate complex radiation sources, materials and geometries.
  - DRiFT includes detector physics not present in many radiation transport codes.
- Capabilities currently under development include the simulation of semiconductor, gas, and as will be discussed in this work, <u>scintillator detector physics.</u>

MCNP® Associated Packages

- Several are under development in XCP-3:
  - MCNPTools (C.J. Solomon, C.R. Bates)
  - Intrinsic Source Constructor (C.J. Solomon)
  - DRiFT – Detector Response Function Toolkit (M.T. Andrews, C.R. Bates, E.A. McKigney)
- These packages are being used along with newly implemented correlated fission capabilities in MCNP6.2 (M.E. Rising) at LANL.
- Details were presented at the 2016 *Advances in Nuclear Nonproliferation Technology and Policy Conference* in Santa Fe, NM.
  - More information, see: ANTPC 2016 workshop slides at mcnp.lanl.gov or contact Avneet Sood: sooda@lanl.gov

Other Scintillator Simulation Codes

- SCINFUL, NRESP – can simulate neutron interactions in organic scintillators using MC methods, limited in particle source definitions

- Modifications to MCNP®, MCNP®X to add scintillator capabilities, MCNPX-PoliMi, and MCNPX-ESUT use older versions of MCNP®X and experimentally measured detector-specific coefficients to reproduce resolution effects.

$$\frac{\Delta L}{L} = \sqrt{\alpha^2 + \frac{\beta^2}{L} + \left(\frac{\gamma}{L}\right)^2}$$

- Scintillator simulations have been recently performed in GEANT4 through the modelling of optical photon transport, they can create PSD plots, however optical photon transport simulations are computationally expensive.

DRiFT – A Detector Response Function Toolkit for MCNP Output

- DRiFT is intended to leverage the extensively verified radiation transport capabilities of MCNP6®.
- Post-processes MCNP output (using MCNPTools), so as new features are added, DRiFT users can readily incorporate them into their simulations.
- DRiFT detector resolution is reproduced by the variances in signal due to fluctuations in scintillation yields, PMT noise, and quantization error.
- DRiFT is very fast because it ***does not model optical photon transport*** however this has a few drawbacks, namely:
    - Users must input their own optical transport factors (or use default settings which may not be applicable to their particular setting).
    - Effects of optical photon transport on energy resolution are not currently reproduced by DRiFT.

DRiFT design

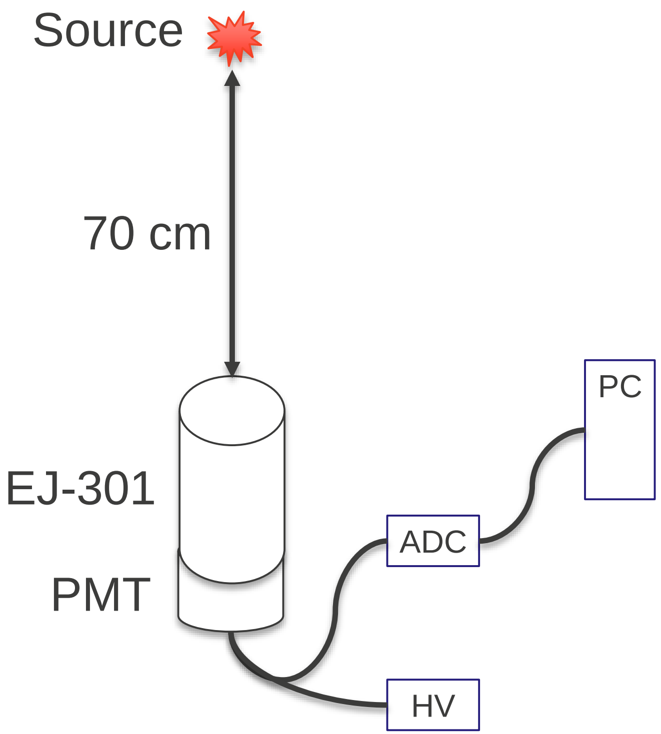
- Modern C++ 11 based framework
- Main routine:
  - Read configuration file
  - Read primary datafile into memory (PTRAC or mctal)
  - Perform detector modelling steps as specified in configuration
- Each process (digitization, PMT effects, scintillation) can be a standalone C++ class which accepts some set of data objects (energy histogram, list mode recoil events, etc.)
- Different combinations of processing can be performed on the same set of original data for trade-off studies

DRiFT Organic Scintillator Simulations

- Focus of the remainder of this presentation.
- Work began mid-2015, most mature DRiFT capability
- DRiFT simulations have been compared to neutron and photon measurements of complex energy spectra, and pulse shape trends measured by EJ-301 detectors.

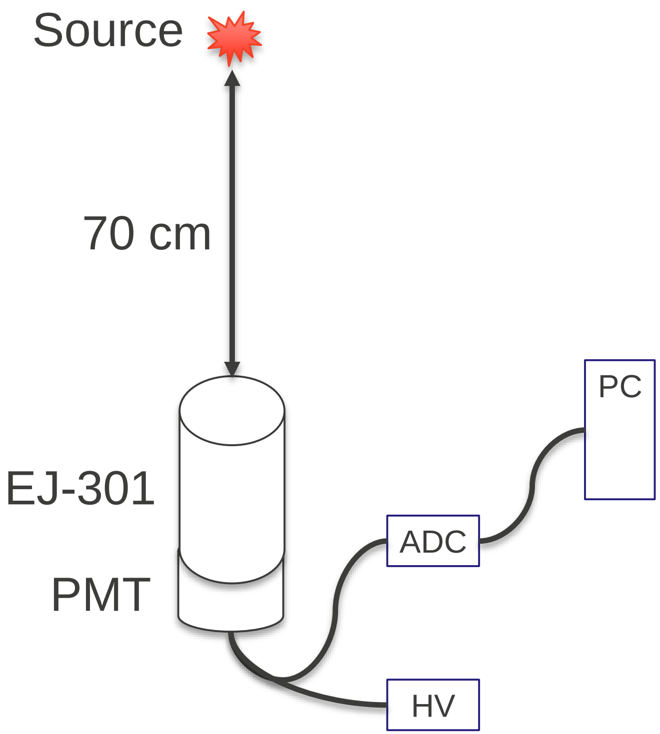
Scintillation Measurements

- Sources were placed 70 cm from the front of an cylindrical scintillator coupled to a PMT.
- ^{252}Cf and PuBe neutron sources
- ^{228}Th and ^{22}Na sources used for gamma measurements.
- Detector – EJ 301 Liquid Scintillation
- Pulses are recorded and post-processed in the data analysis framework ROOT.

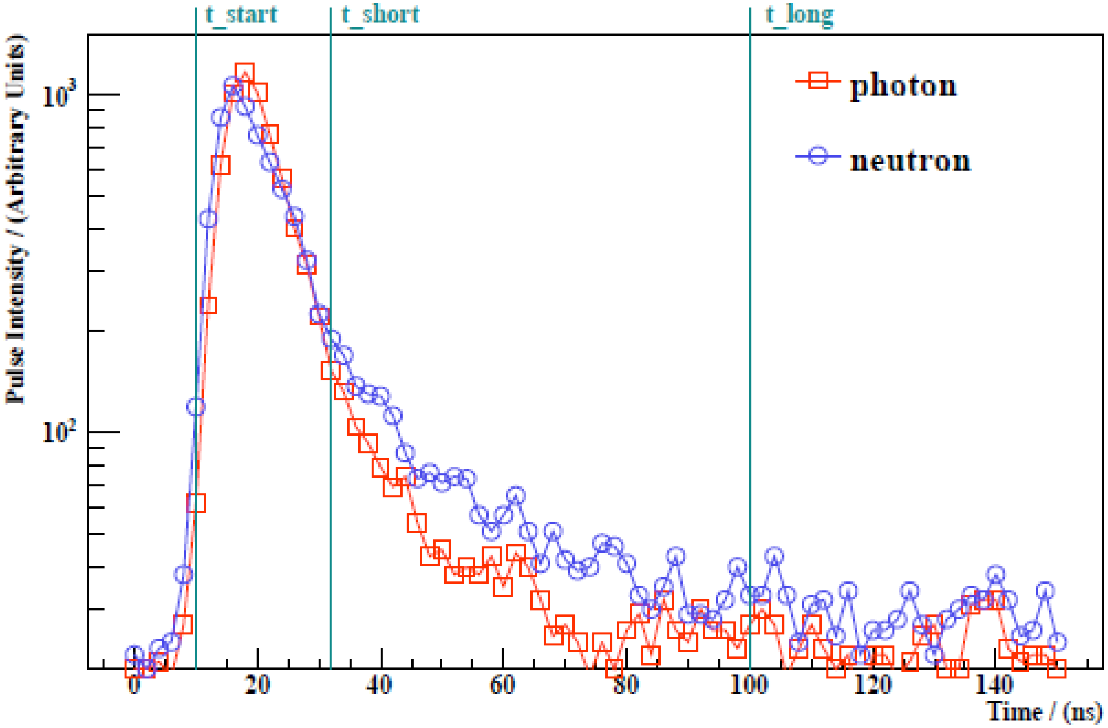


Scintillation Measurements

- Incident neutrons create proton recoils
- Incident photons create electrons
- These charged particles create fluorescence in excited molecules which de-excite and release light (photons).
- Light travels to the PMT's photocathode where it is converted into photo-electrons.
- Electrons are multiplied by dynodes in PMT to create a larger current in the PMT.



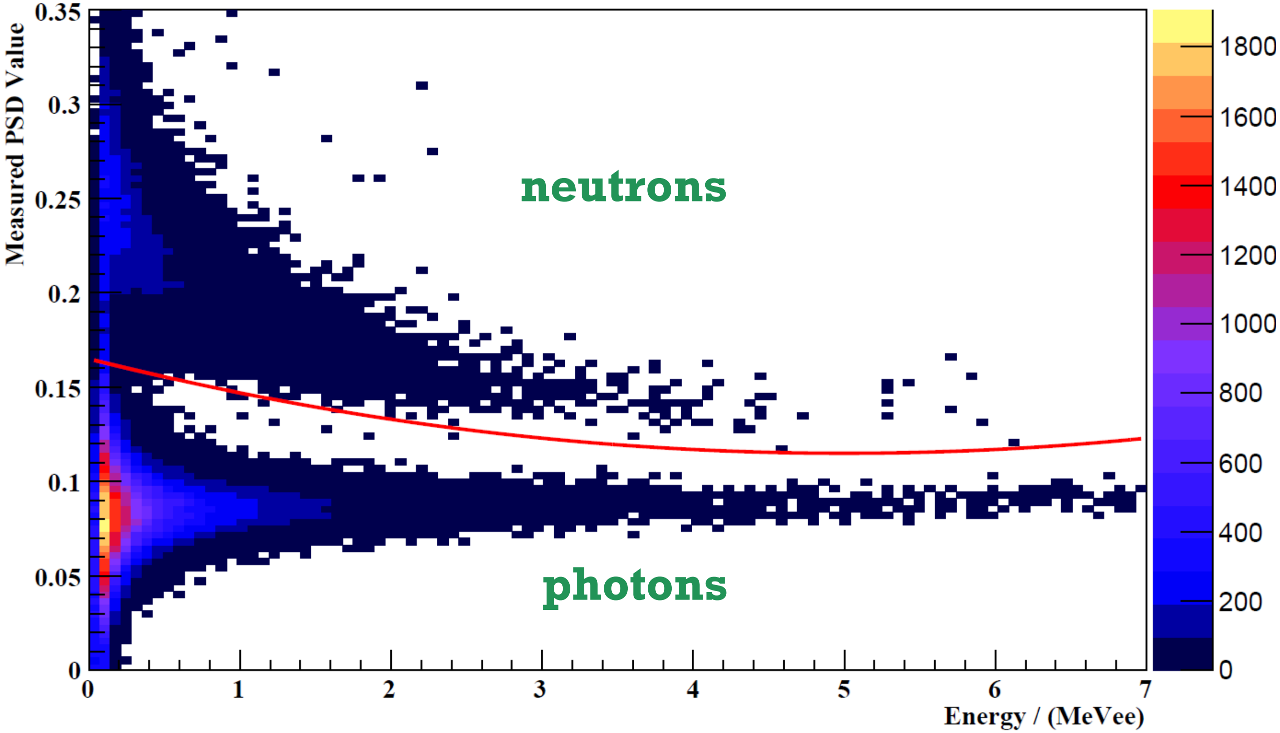
Scintillation Measurements



- Light produced is quoted in MeVee
- Conversion of proton energy into MeVee is non-linear.
- Light output intensity is time-dependent and unique to incident radiation (photon vs. neutron).

- Measured EJ-301 scintillation pulses from incident neutron and photons.

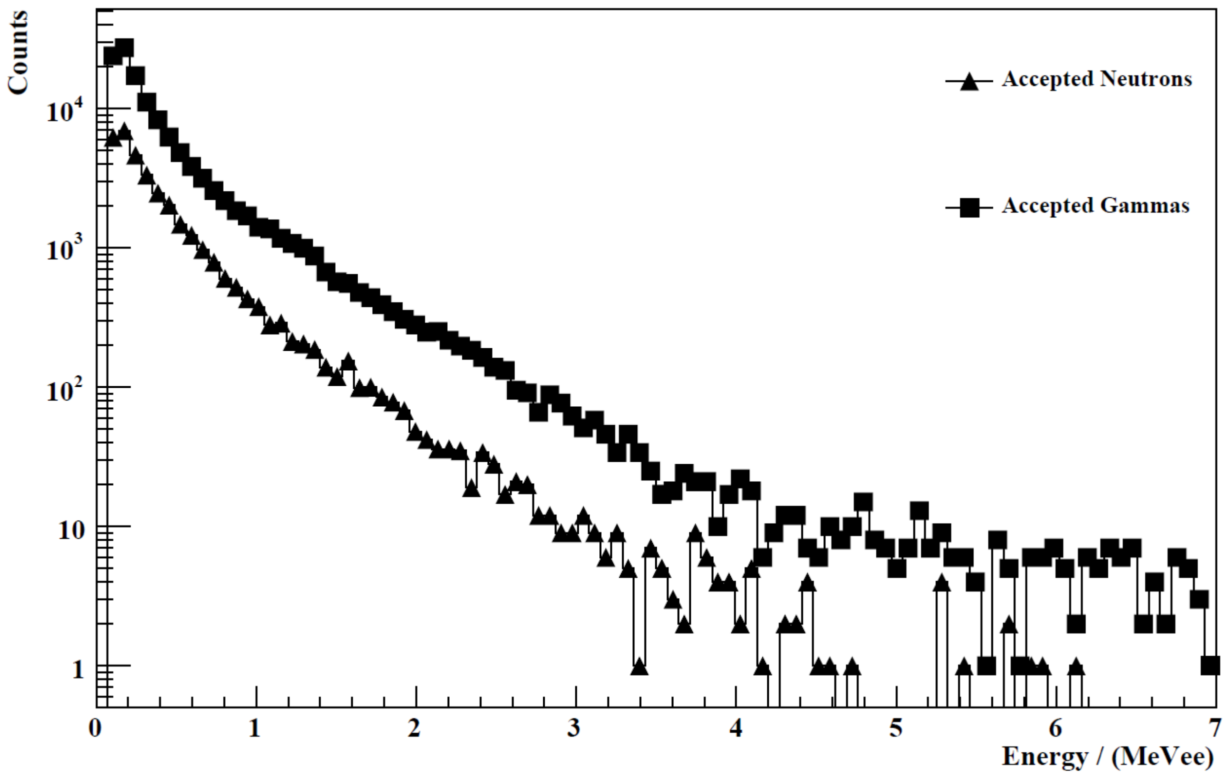
Scintillation Measurements



$$PSD = \frac{Q_s - Q_f}{Q_s}$$

- Measured EJ-301 scintillation pulses from incident neutron and photons.

Scintillation Measurements



$$PSD = \frac{Q_s - Q_f}{Q_s}$$

- Measured EJ-301 scintillation pulses from incident neutron and photons.

MCNP6® Simulations

Scintillator is given a density and atomic ratio corresponding to manufacturer specs:

Detector	Type	H:C Ratio	Density / g cm^{-3}	Scintillation Yield
EJ-301	Liquid	1.212	0.874	12,000 γ/MeVee
EJ-212	Plastic	1.103	1.020	10,000 γ/MeVee

- MCNP Intrinsic Source Constructor (MISC, CJ Solomon) is used to create source photon spectra.
- Particle TRACking (PTRAC) card used to record recoil proton's energy, and time as a binary.
  - PTRAC files are post-processed with mcnpTools (CJ Solomon, C.R. Bates)

DRiFT Simulations

- DRiFT reads an input file containing keywords
- DRiFT reads the PTRAC file by calling mcnpTools

[global]		
Datasource	=	mcnp
Datafile	=	ocf252p
Modeltype	=	event (ptrac)
[Scintillation]		
Detector	=	EJ301
Particle0	=	Proton
Particle1	=	electron
Quenching_data	=	Dekempeener
S_gate	=	22e-9
L_gate	=	90e-9
Sampling_rate	=	500e6
PMTType	=	9821B

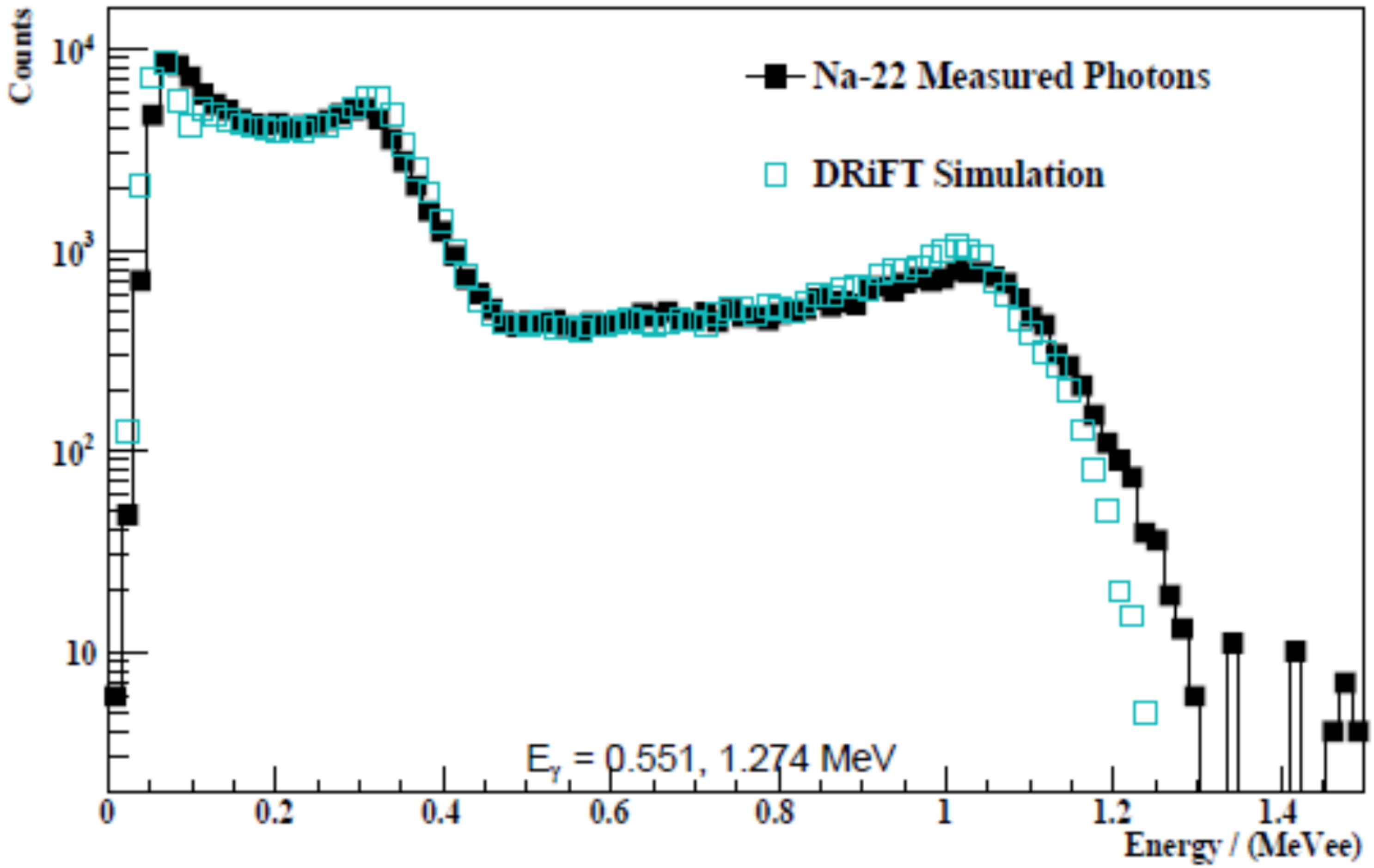
DRiFT Simulations – Calculating Photo-electrons

- DRiFT treats each particle separately to properly determine the amplitude and shape of the resulting pulse.
- The PTRAC particle's electron equivalent energy (MeVee) is determined for the specific particle type and original energy using quenching data specified in input.
- The scintillation yield (12,000 photons/MeVee for EJ-301) is used to determine the mean number of photons produced.
- The actual number is sampled from a Poisson distribution.

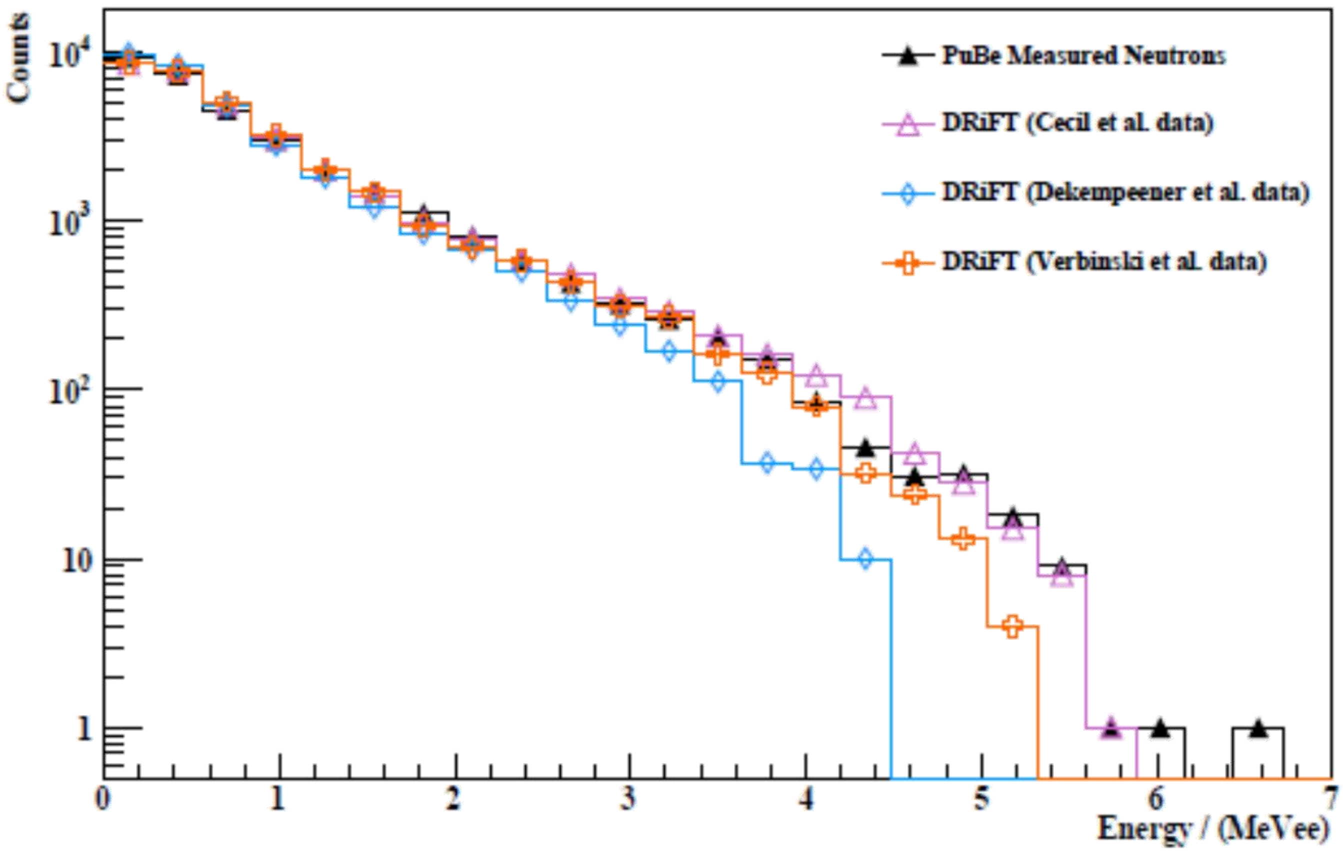
DRiFT Simulations – Simulating Pulse Shape

- Optical photons are distributed in time using pre-defined intensity profiles.
- Time interval sizes are matched to the sampling rate of the digitizer
- For histories with more than one recoil, the relative difference in time stamps is used to determine the initiation of their contribution to the overall count.
- Optical transport factor and quantum efficiency factors are applied to photons. The remaining number of photons/electrons is sampled from a Poisson distribution.
- Noise contributions are included in the calculation of the PMT current.

Results – Photon Spectra Comparisons

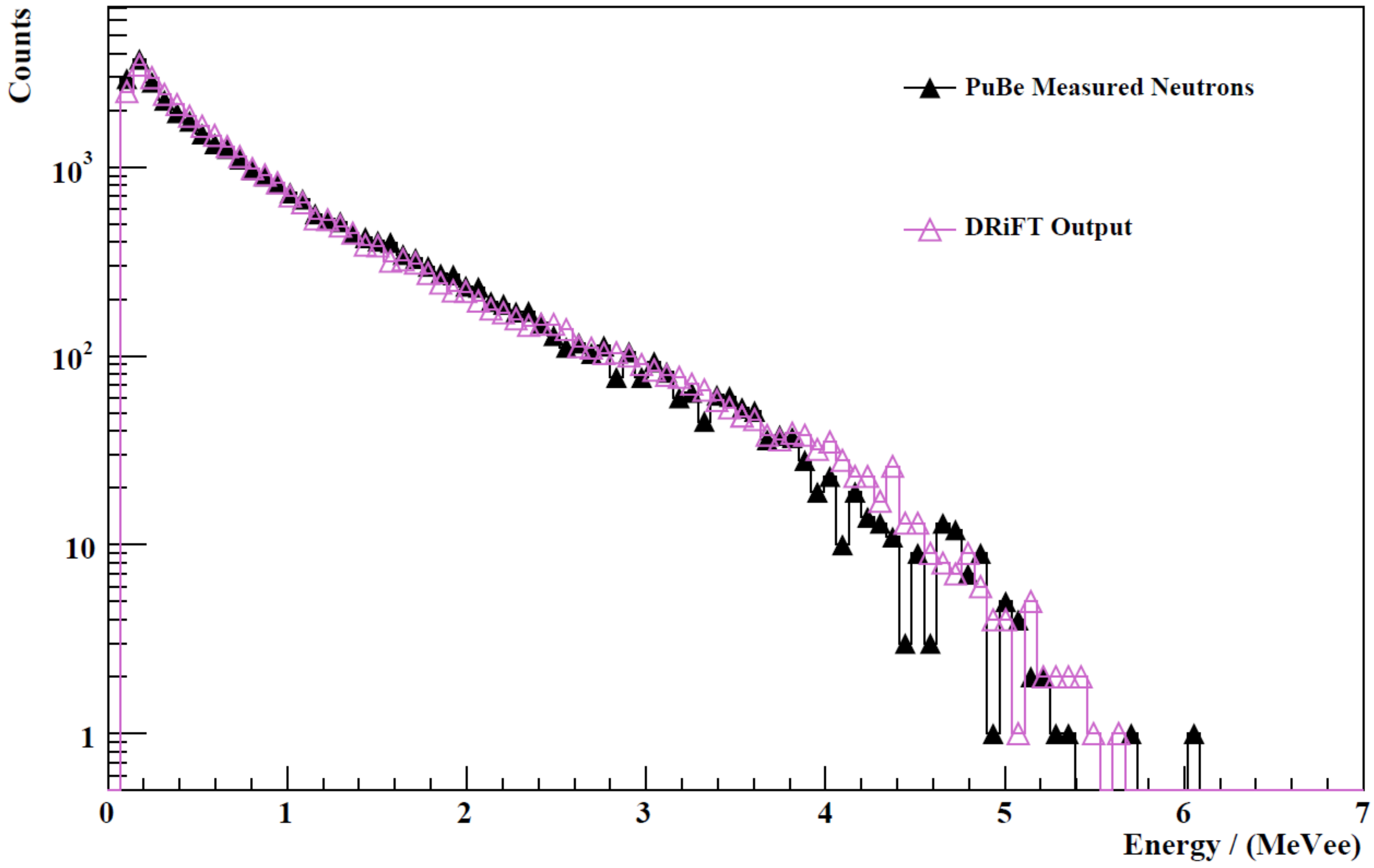


Results – Neutron Spectra Comparisons

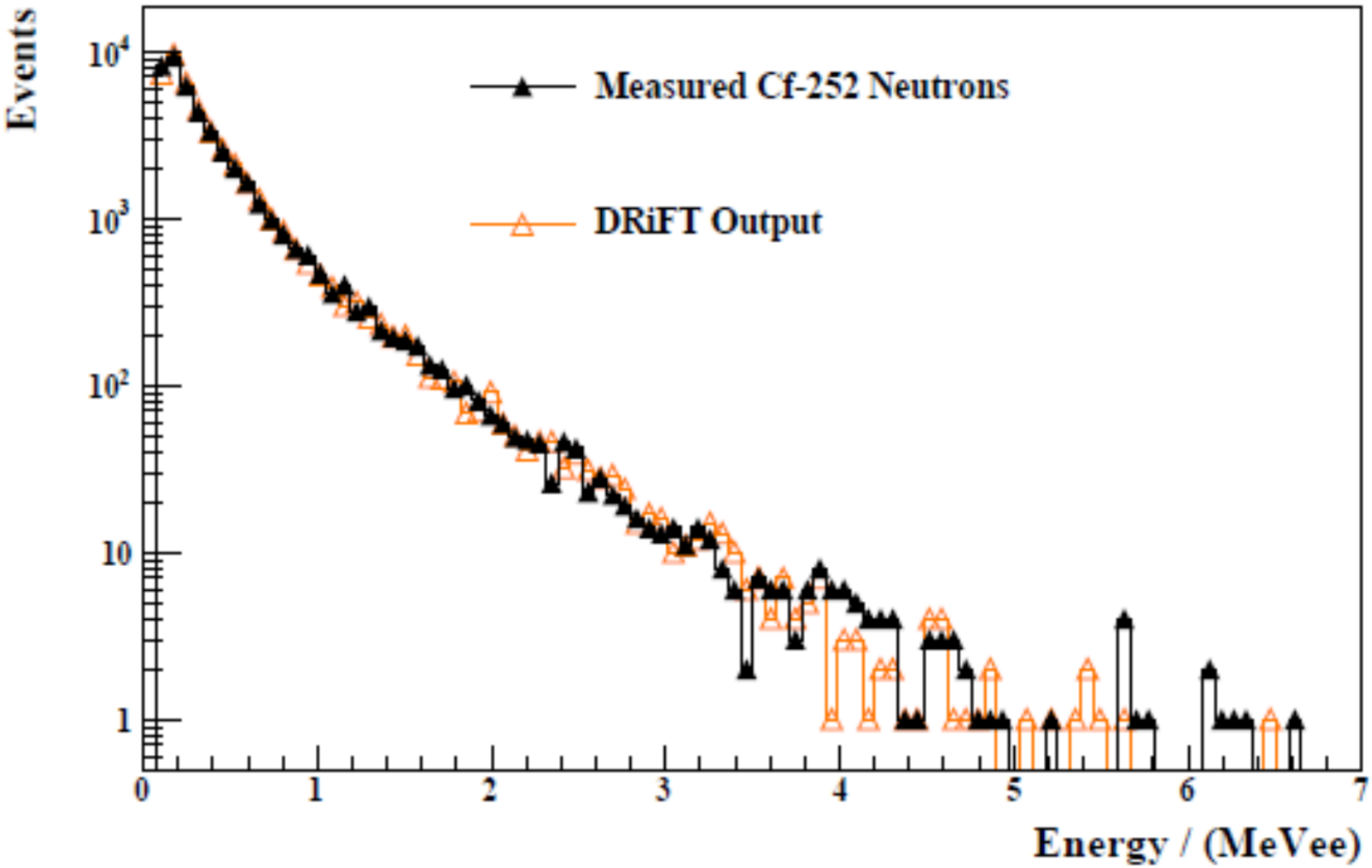


- DRiFT can be used to compare different light output models

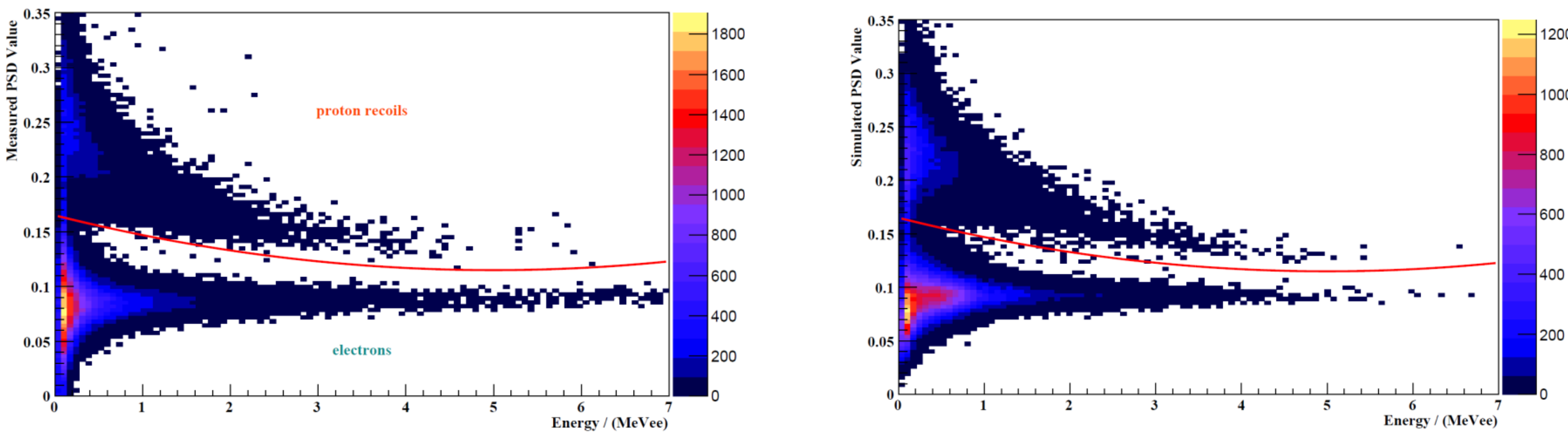
Results – Neutron Spectra Comparisons



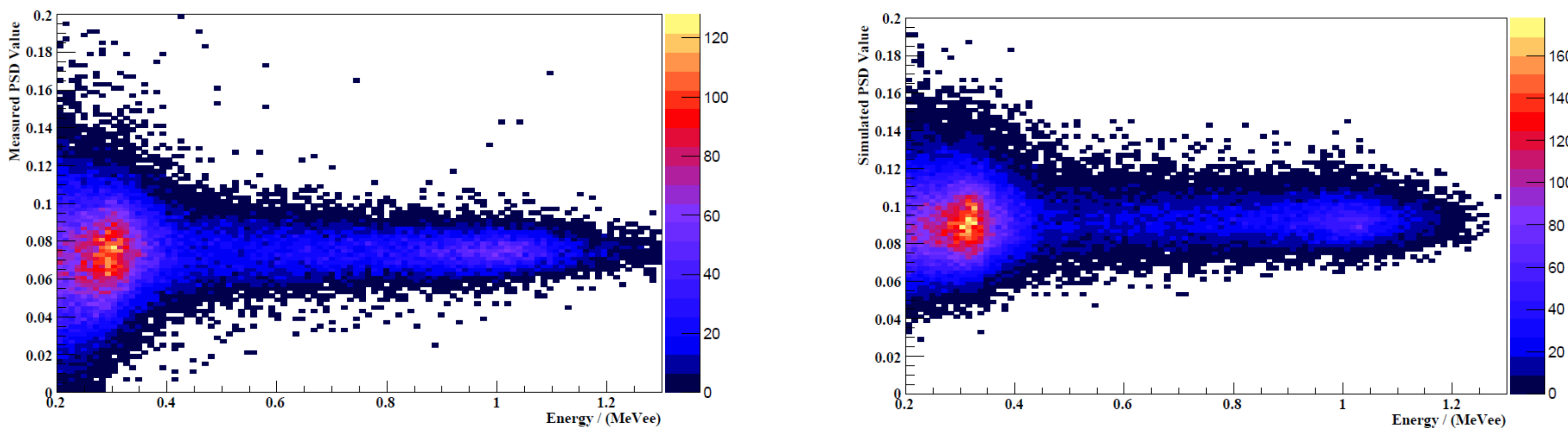
Results – Neutron Spectra Comparisons



Results – Pulse Shape Discrimination Plots: Cf-252



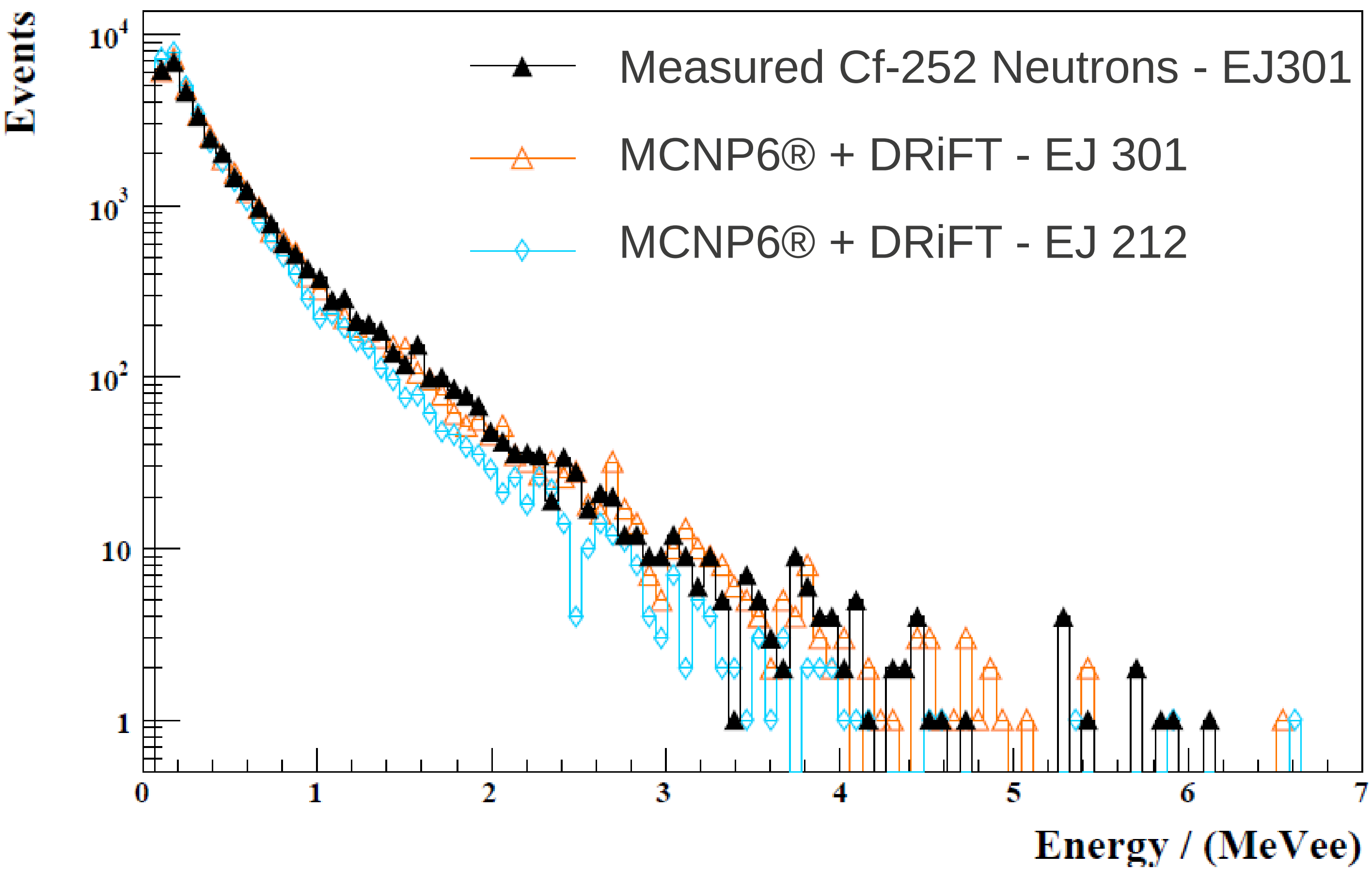
Results – Pulse Shape Discrimination Plots: Na-22



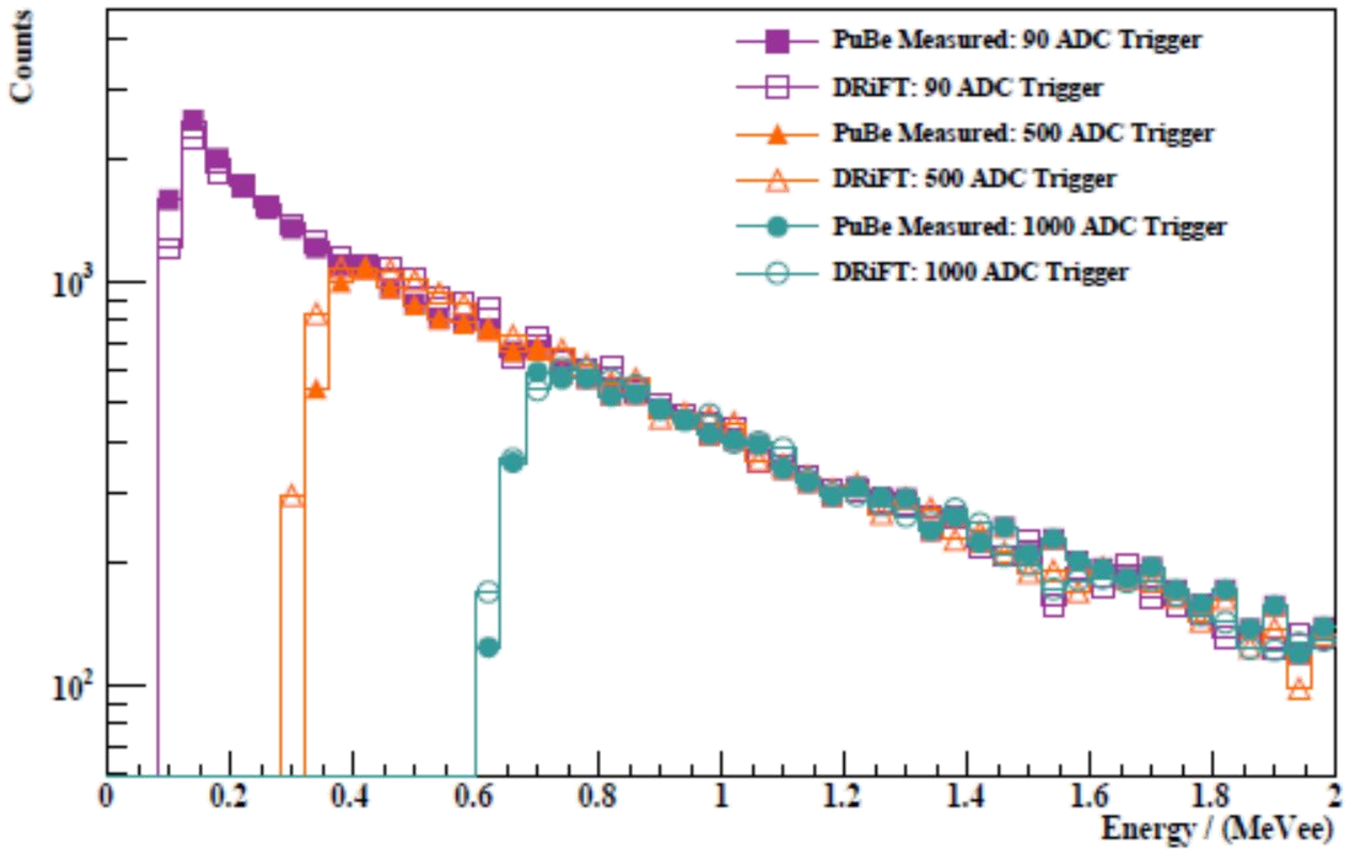
(a) Measured

(b) DRiFT

Additional Features: Detector Selection



Additional Features: Trigger Thresholds



- Trigger threshold effects can be accurately simulated if waveform noise is well modeled

DRiFT Applications at LANL

- NA-22 Funded Project: "Next-Generation Correlated Fission Event Simulations" PI: Patrick Talou
- Using MCNP6.2 with correlated fission physics packages
- DRiFT is used to properly simulate detector cross talk and correlated counts.
- Recently updated DRiFT to handle input from an unlimited number of detectors. If the correlated option is selected, it will output correlated counts only.

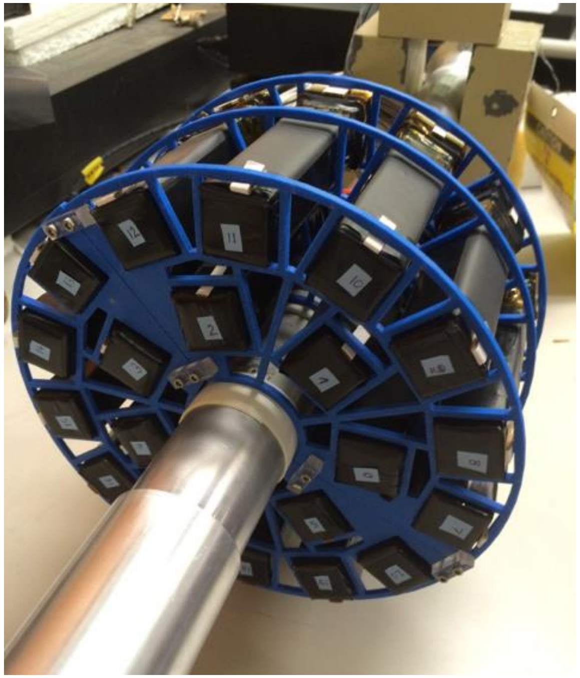
DRiFT Applications at LANL

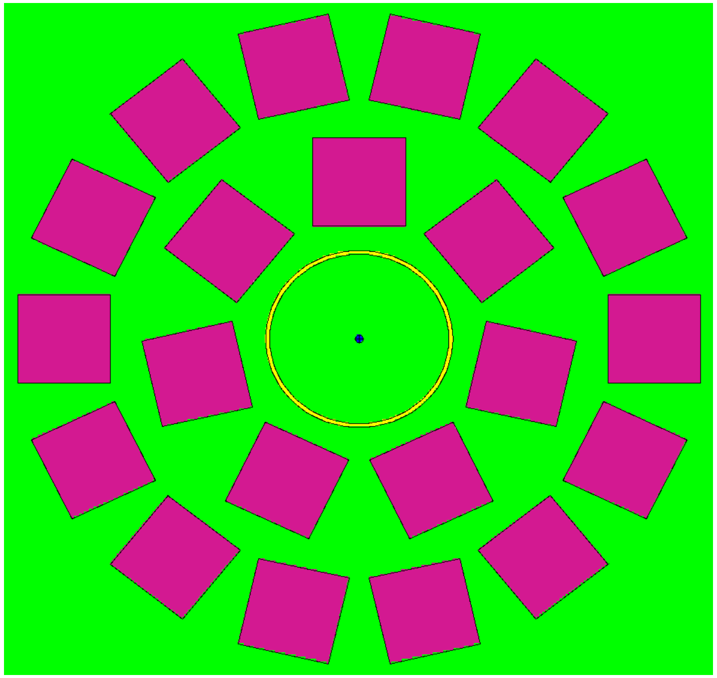
- NISC Setup to measure cross talk and spontaneous fission (K. Meierbachtol).

DRiFT Applications at LANL

- Simulation of NEUANCE array of stilbene detectors (M.Pinilla).

- Customized stilbene detector files were created for incorporation into DRiFT.





DRiFT Availability

- Available for friendly testing on LANL HPC computers (linux build).
  - Point of Contact: Cameron Bates batesca@lanl.gov
- Planned public release with MCNP6.2.
- More information, see: ANTPC 2016 workshop slides at **mcnp.lanl.gov** or contact Avneet Sood: sooda@lanl.gov (XCP-3 Group Leader)

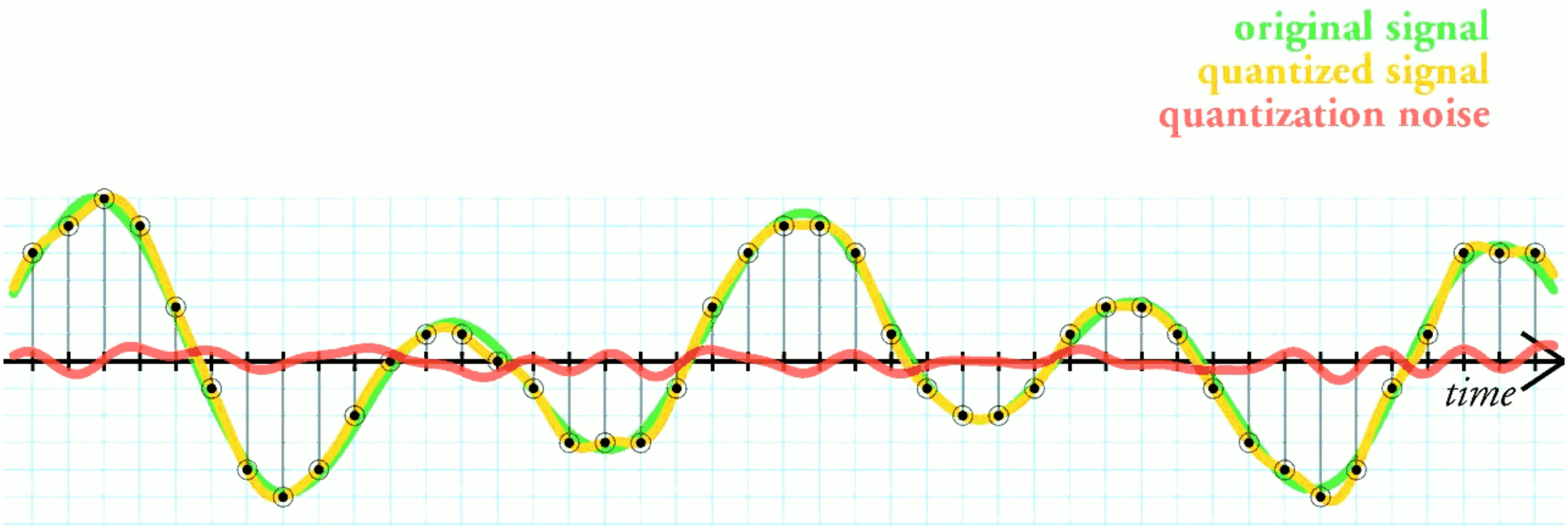
Conclusions & Future Work

- The capabilities of DRiFT to simulate organic scintillation response have been demonstrated.
- DRiFT is flexible, allowing the user to specify PMT type, quenching data scintillation material, and trigger thresholds.
- Energy spectra and pulse shape discrimination (PSD) trends for incident photon and neutron radiation have been reproduced by DRiFT.
- We are working with those designing correlated prompt fission data measurements at LANL.
- Future work includes an expansion of scintillator simulation capabilities, semiconductor, and gas detector response functions.

Thank you

Quantization Error

Analog (green) to digital (yellow) conversion results in quantization error.



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