Title: DRiFT – A Detector Response Function Toolkit for MCNP® Output

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DRiFT – A Detector Response Function Toolkit for MCNP® Output

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Outline

- **Why use DRiFT?**
- **What is DRiFT**
- **Modelling an EJ301 measurement**
  - Measurement description
  - Measurement results
  - Simulation description
  - DRiFT Modeling process
  - DRiFT results
- **DRiFT availability**

Why use a detector response package

Why model detectors:

- Accurate detector modeling is a requirement to design systems in many radiation detection scenarios.
  - By determining a Detector’s Response Function (DRF) to incident radiation, we can characterize unknown sources.
- More efficient design processes (cost and time)
- Realistic radiation sources may not be available

Why not use just MCNP:

- MCNP has transport physics but no standard framework for detector effects (ad-hoc methods have been added)
- Modern experiments require modeling the entire detector system
  - EJ301 Scintillator: proton recoil (MCNP), **scintillation light production**, scintillation light transport, **PMT gain**, **digitization** (**ADC** or MCA)

DRiFT – A Detector Response Function Toolkit

- Under-development at Los Alamos National Laboratory

- 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>

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.) and returns a process data object decided by the application developer
- Different combinations of processing can be performed on the same set of original data for trade-off studies

DRiFT Organic Scintillator Simulation Capabilities

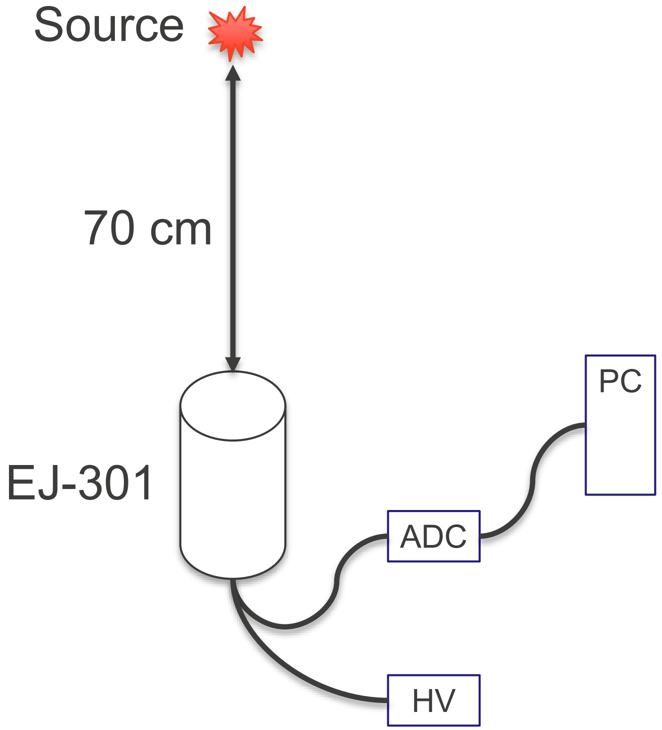
- Focus of the remainder of this presentation.

- Work began mid-2015, most mature DRiFT capability

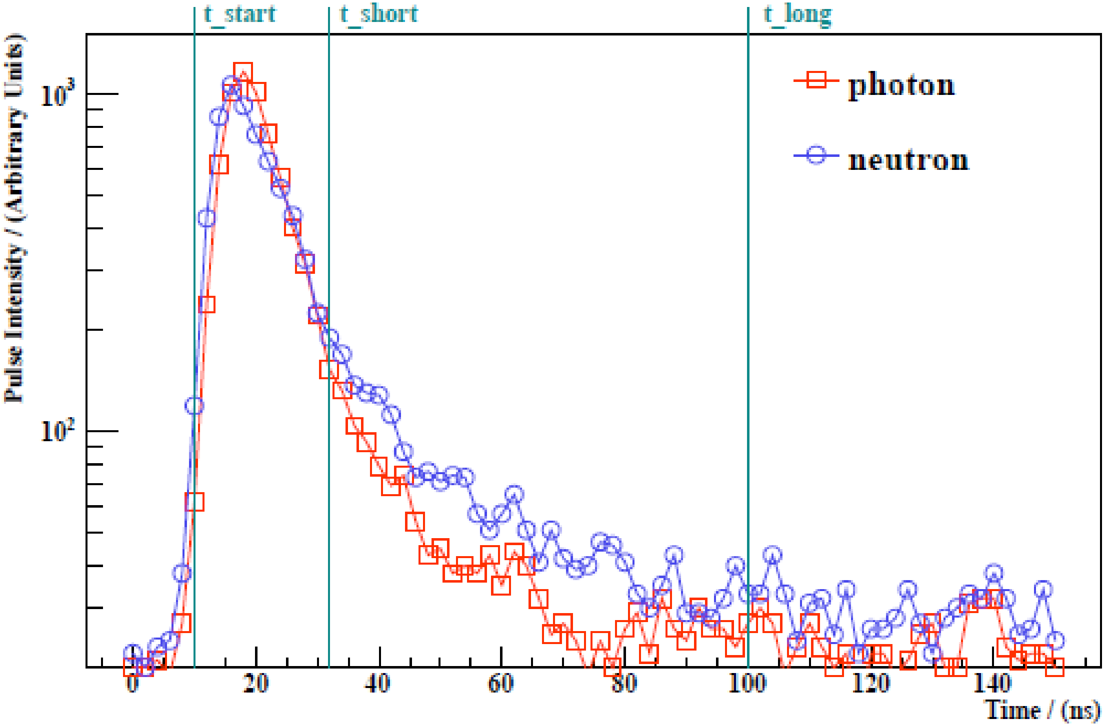
- DRiFT simulations have been compared to neutron and photon measurements of complex energy spectra, and pulse shape trends as measured by EJ-301 detectors.

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.



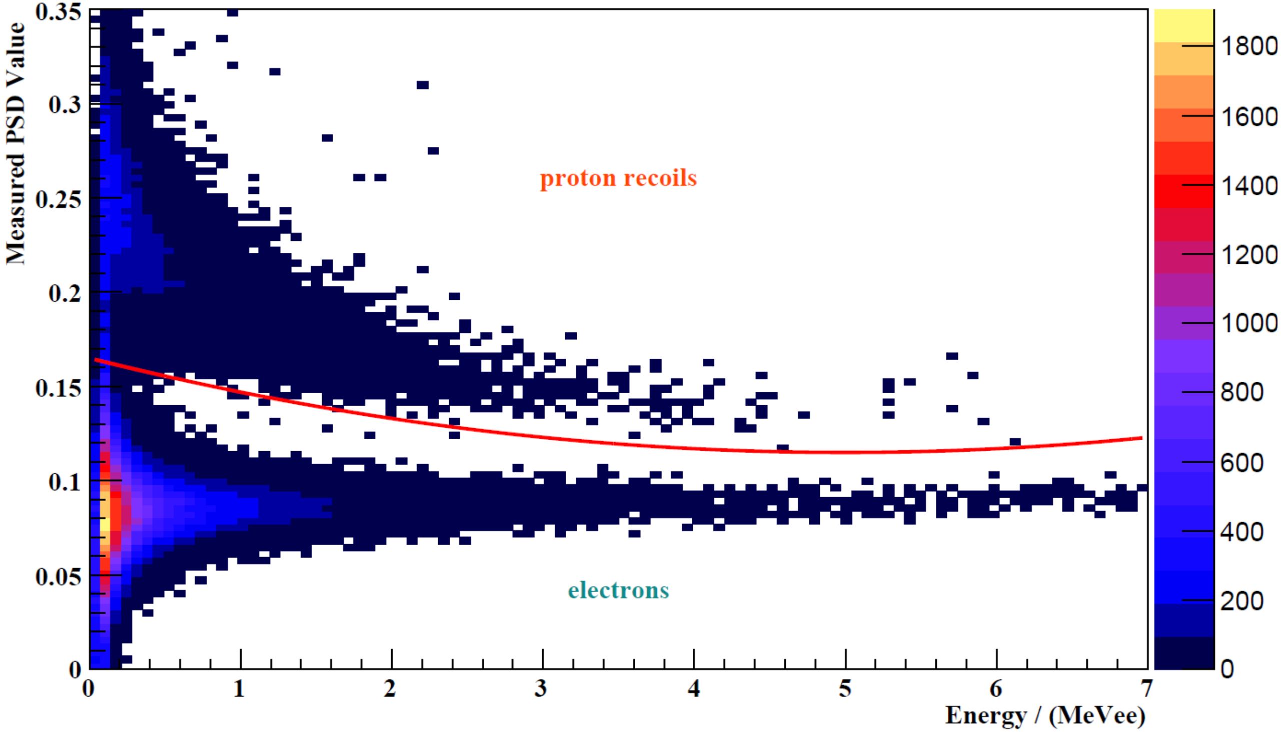
Scintillation Measurements



- 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.

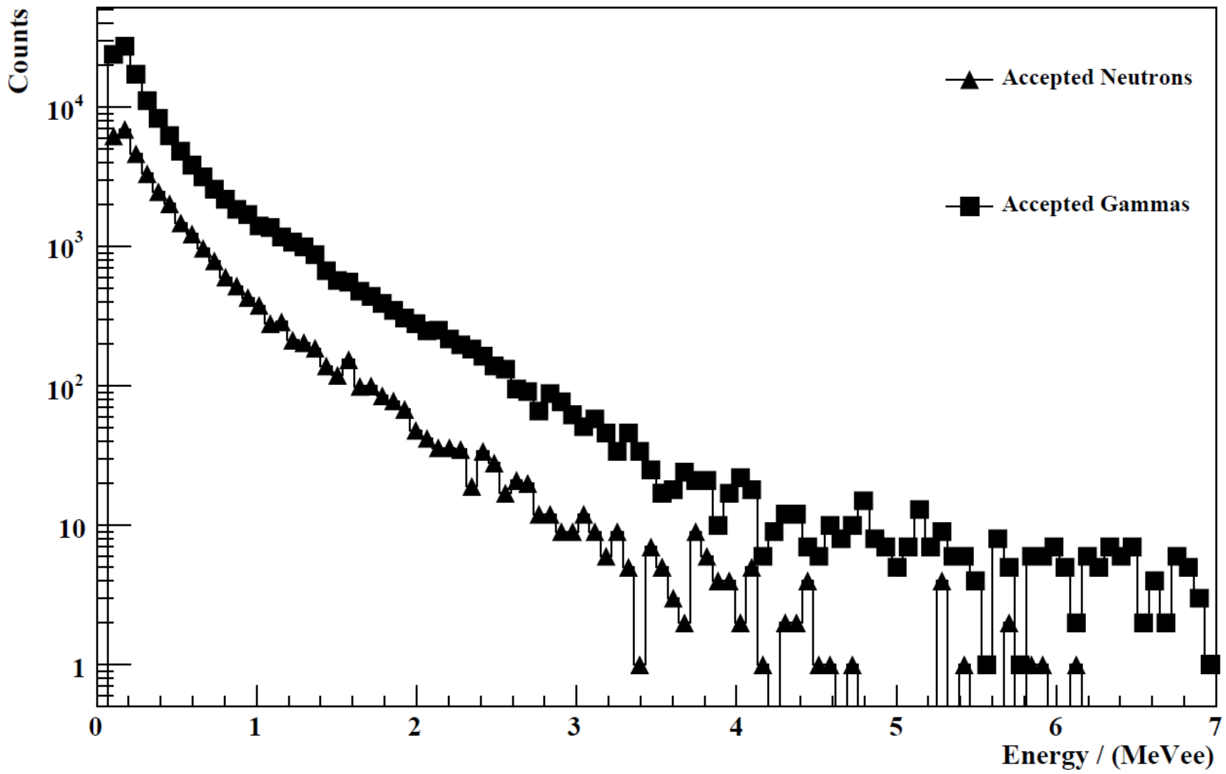
Scintillation Measurements



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

- Tail to total PSD value as a function of energy

Scintillation Measurements



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

- Extracted neutron and photon spectra after pulse shape discrimination

MCNP6® Simulations of organic scintillators

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 Calculator (MISC) 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

DRiFT Simulations

- DRiFT reads an input file containing keywords
- DRiFT reads the PTRAC file by calling mcnpTools
- Currently protons, electrons, alphas, deuterons, helium-3, tritons are supported.

[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.

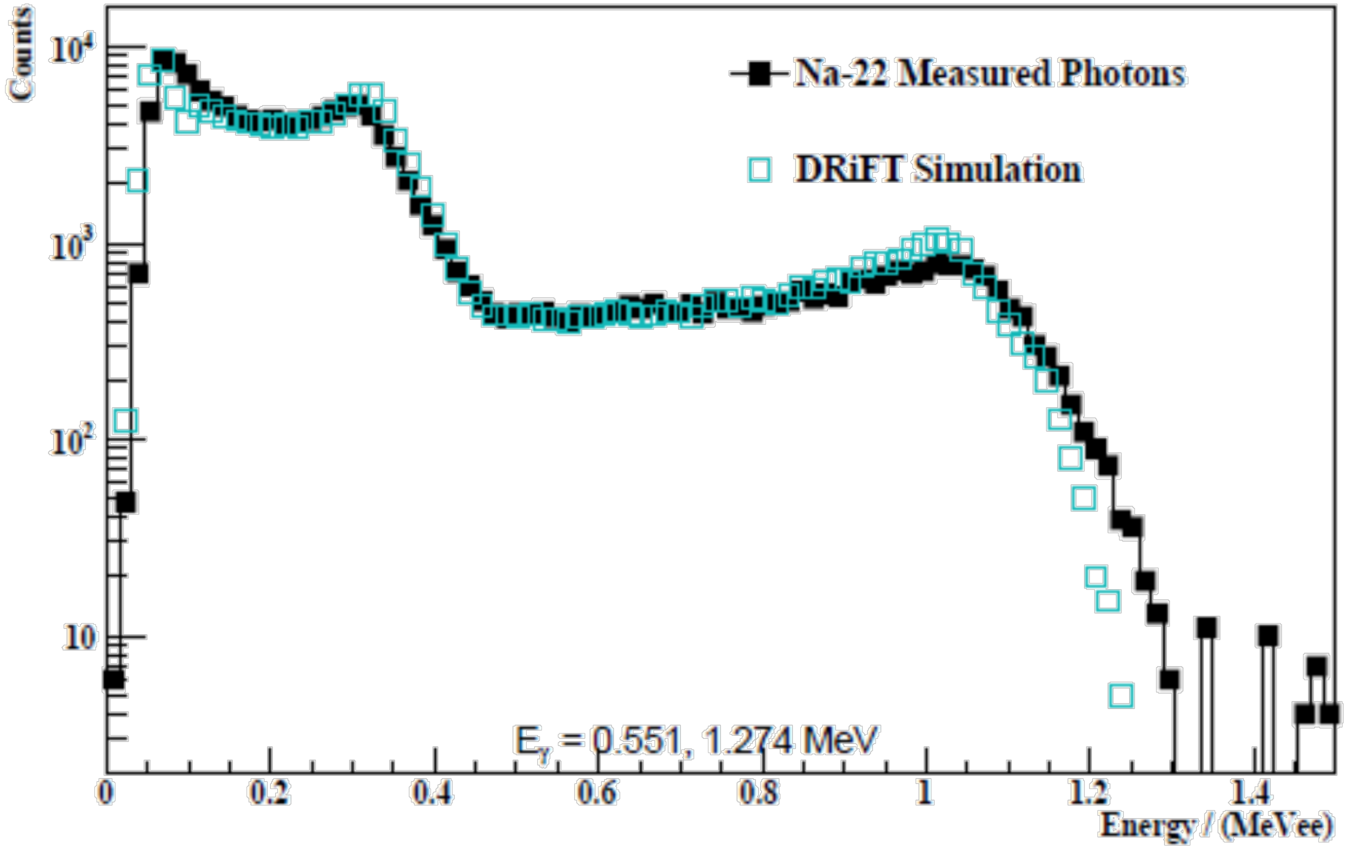
DRiFT Simulations – Simulating Pulse Shape

- Optical photons are distributed in time using pre-defined intensity profiles.
- 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.
- Time interval sizes are matched to the sampling rate of the digitizer
- Optical transport factor and quantum efficiency factors are applied to photons. The remaining number of photons/electrons is sampled from a Poisson distribution.
- Shot noise and gain contributions are included in the calculation of the PMT current.

DRiFT Simulations – Additional Features

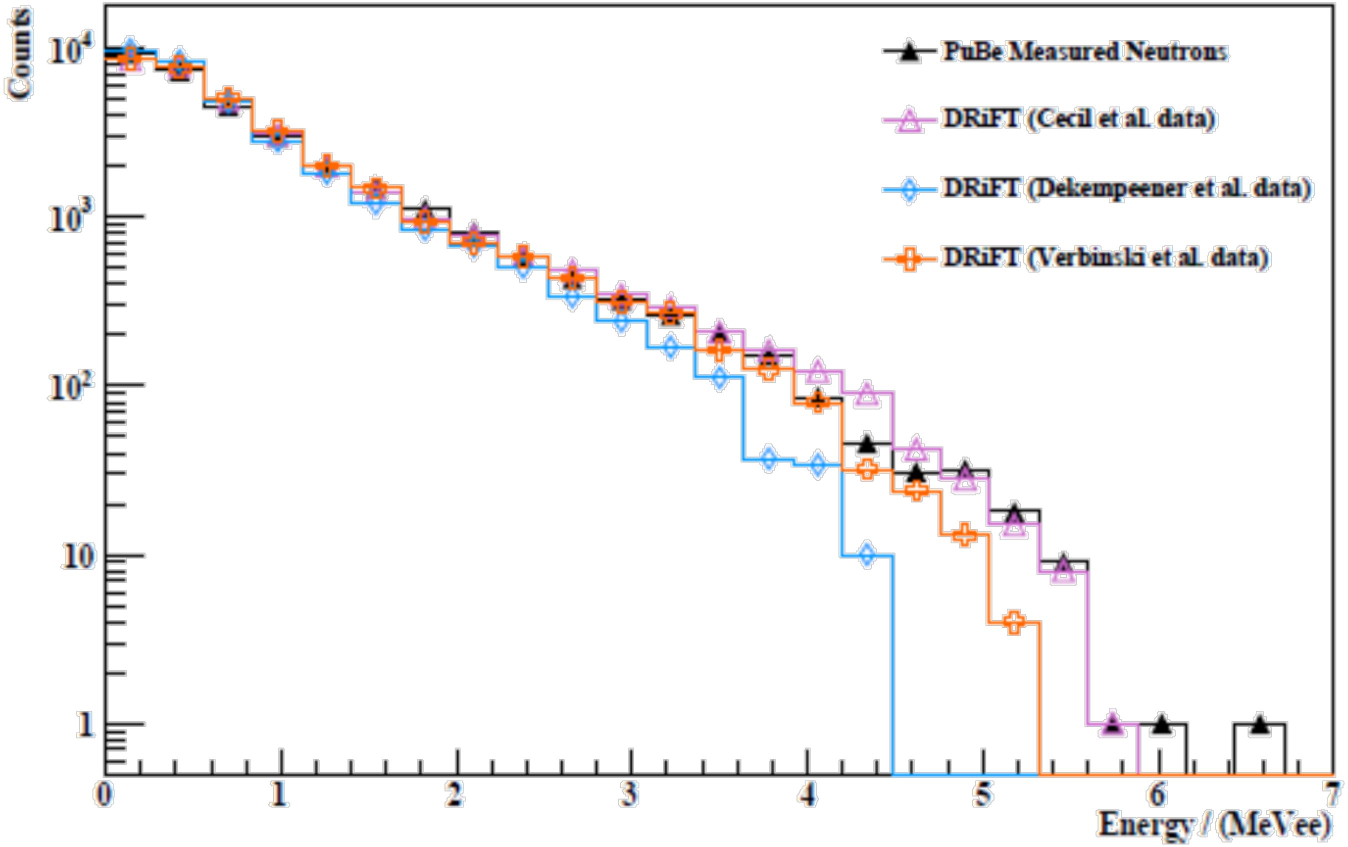
- Can convert PMT current into ADC units
- Set: Threshold, bits, range
- Study common digitizer effects:
    - ADC threshold effects with noise in waveform
    - Clipped pulses
    - Loss of spectral resolution due to ADC resolution
- Flexibility when calculating Pulse Shape Discrimination (PSD) values.
    - User can specify the long and short time gates used

Results – Photon Spectra Comparisons



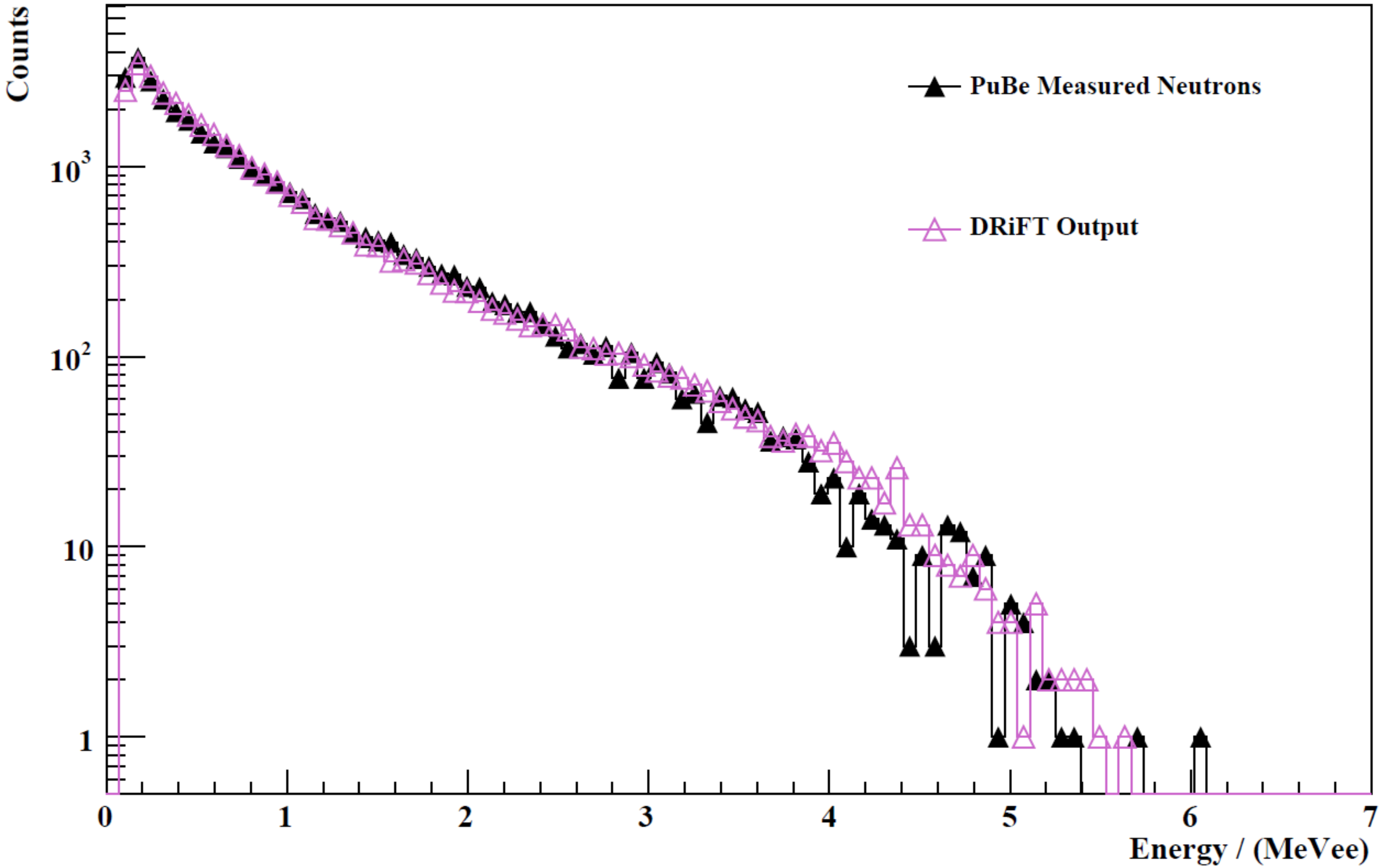
Real energy broadening is slightly larger than predicted from theory

Results – Neutron Spectra Comparisons



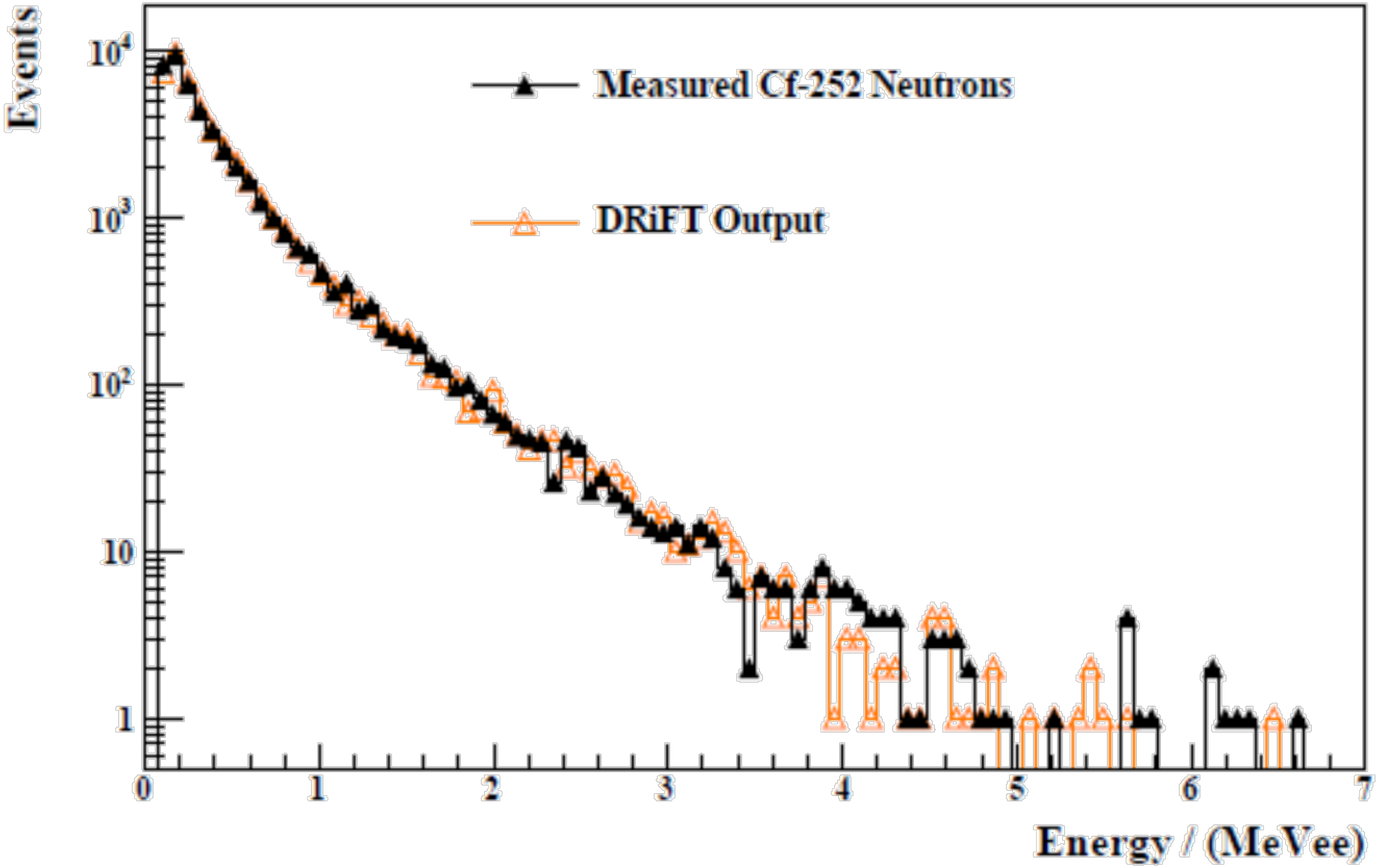
- DRiFT can be used to compare different light output models

Results – Neutron Spectra Comparisons



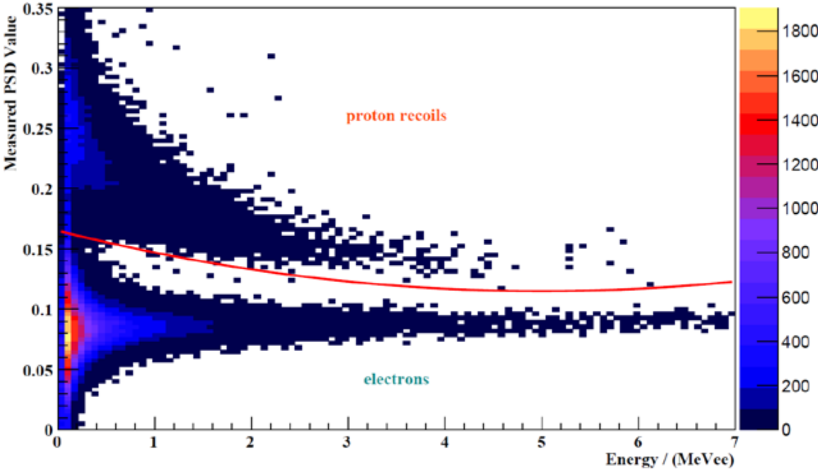
- Best model compares well with finer binning

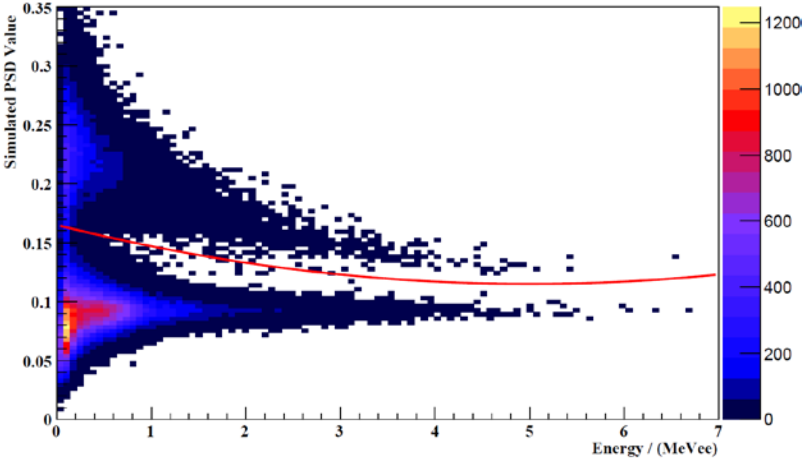
Results – Neutron Spectra Comparisons



Same model works well for ^{252}Cf

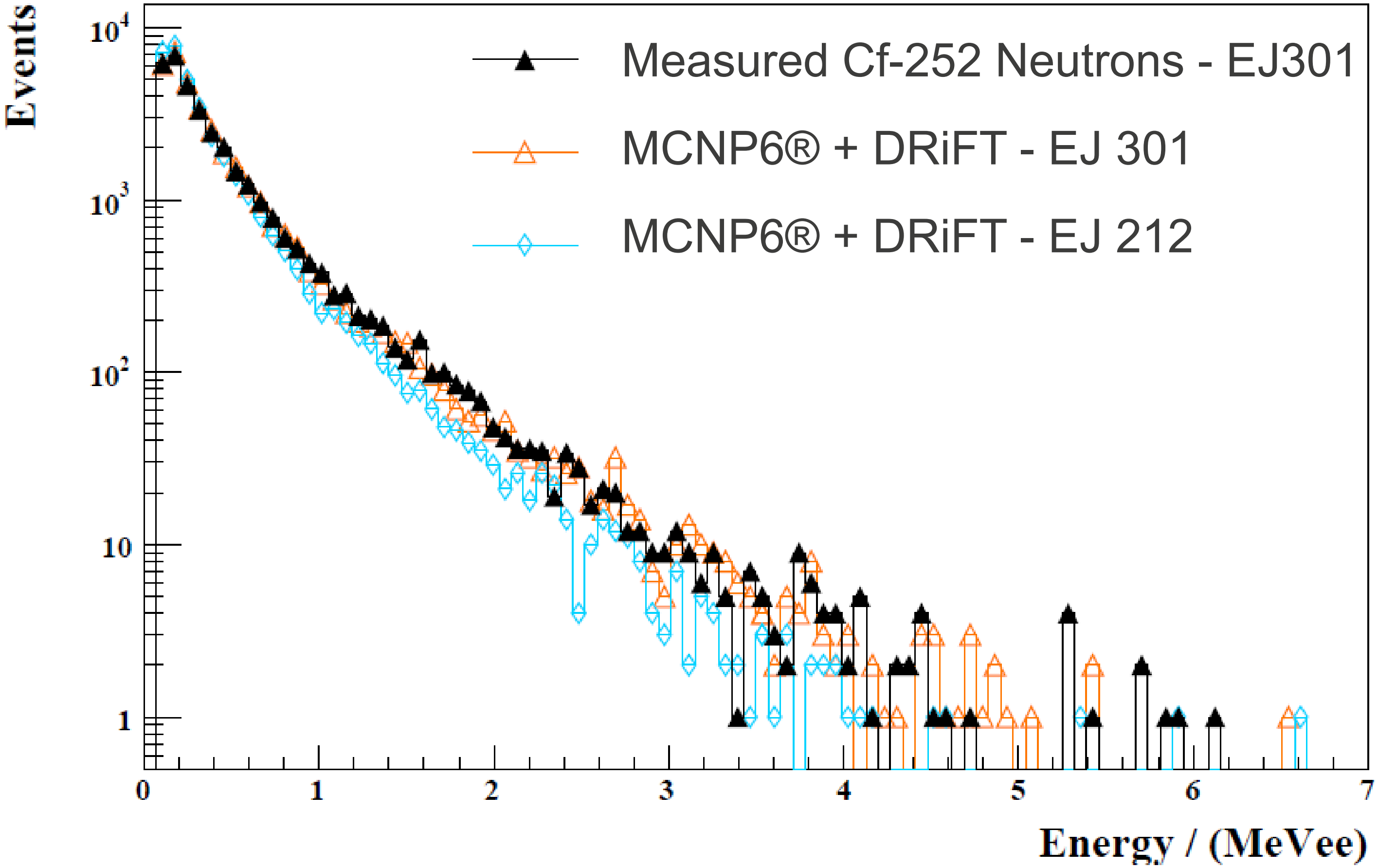
Results – Pulse Shape Discrimination Plots: Cf-252



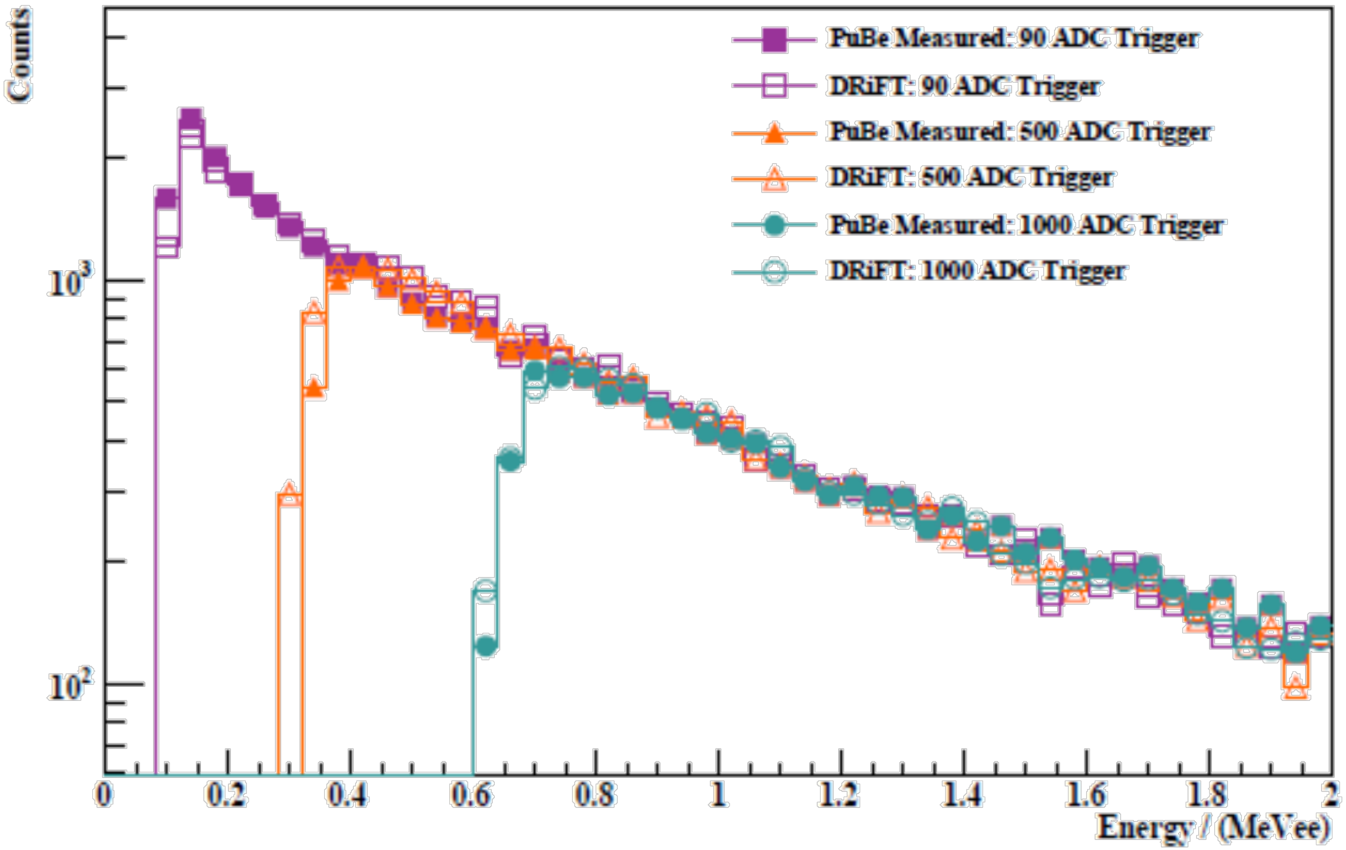


DRiFT accurately reproduces n/γ pulse shapes as a function of energy

Additional Features: Detector Selection



Additional Features: Trigger Thresholds



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

DRiFT Availability

- Available for friendly testing on LANL HPC computers.
  - Point of Contact: Cameron Bates batesca@lanl.gov
- Planned public release with MCNP 6 in late 2016

Conclusions & Future Work

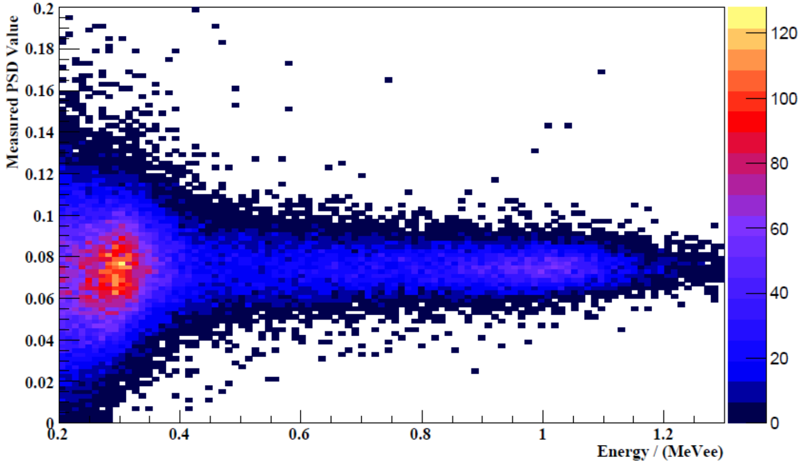
- The capabilities of DRiFT to simulate organic scintillation response have been demonstrated.
- DRiFT is flexible, allowing the user to specify PMT type, quenching data scintillation material, and trigger thresholds.
- Energy spectra and pulse shape discrimination (PSD) trends for incident photon and 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. Questions?

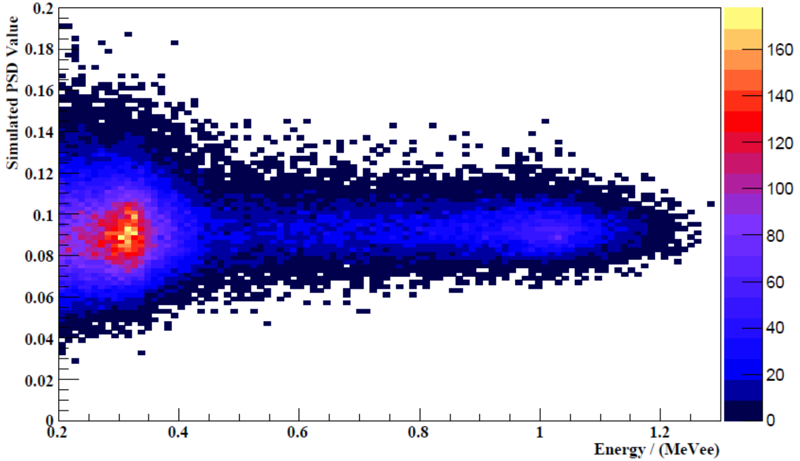
- **Acknowledgements:**
  - Funding for this work was provided by the Los Alamos National Laboratory Directed Research and Development (LDRD) program.
  - Measurement data from K. Meierbachtol is greatly appreciated.

Supplemental Slides

Results – Pulse Shape Discrimination Plots: Na-22

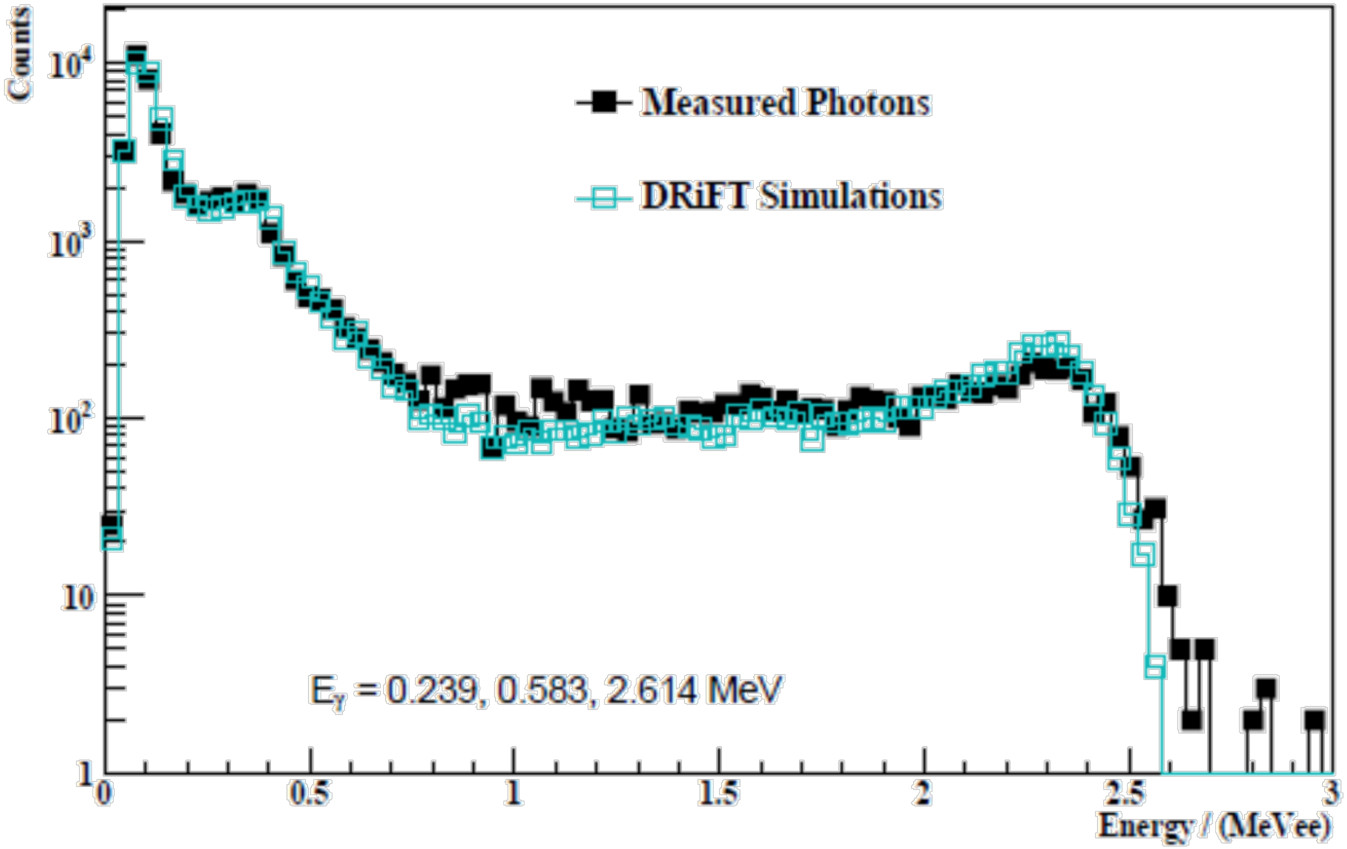


(a) Measured

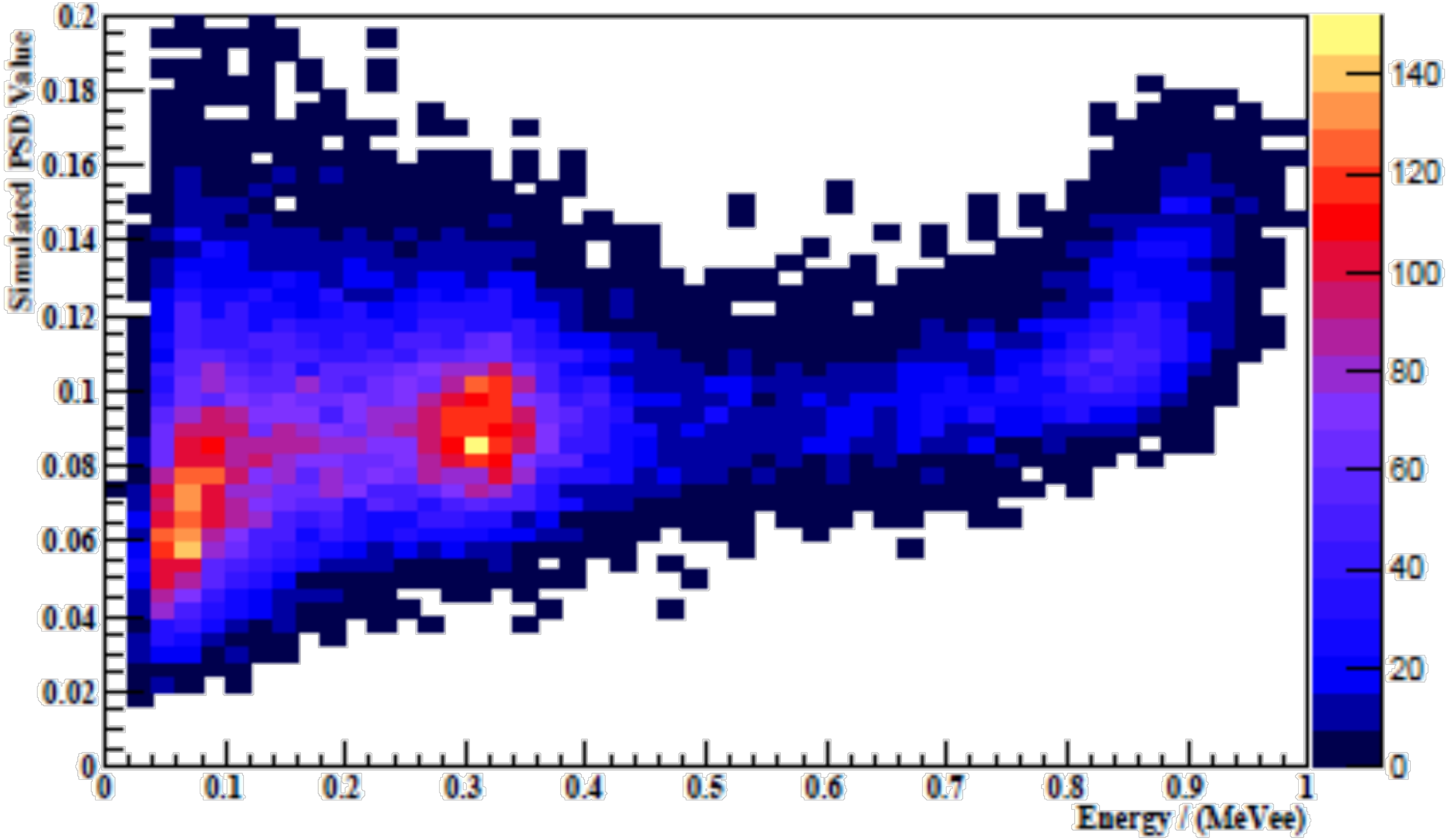


(b) DRiFT

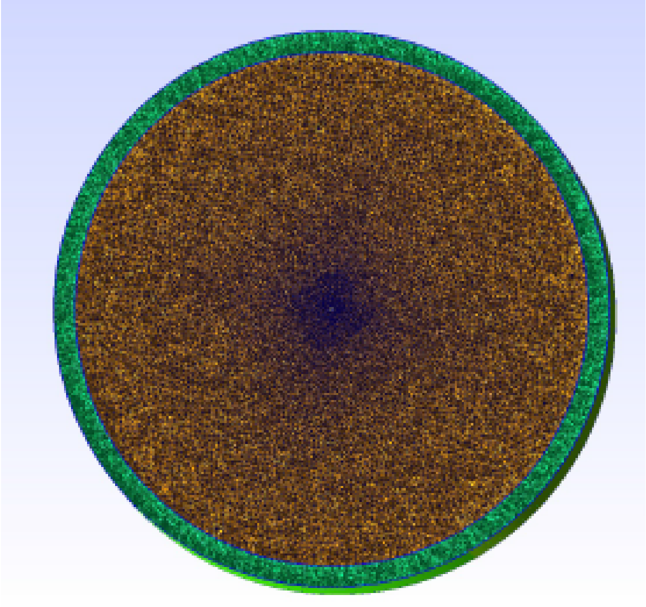
Results – Photon Spectra Comparisons



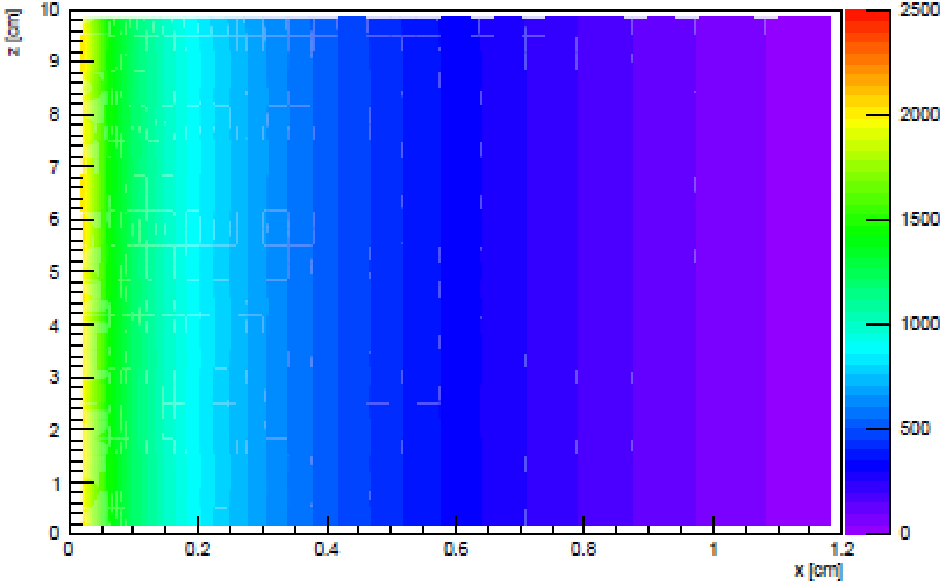
Additional Features: Clipping Pulses



Future Work: Gas Detector Simulations



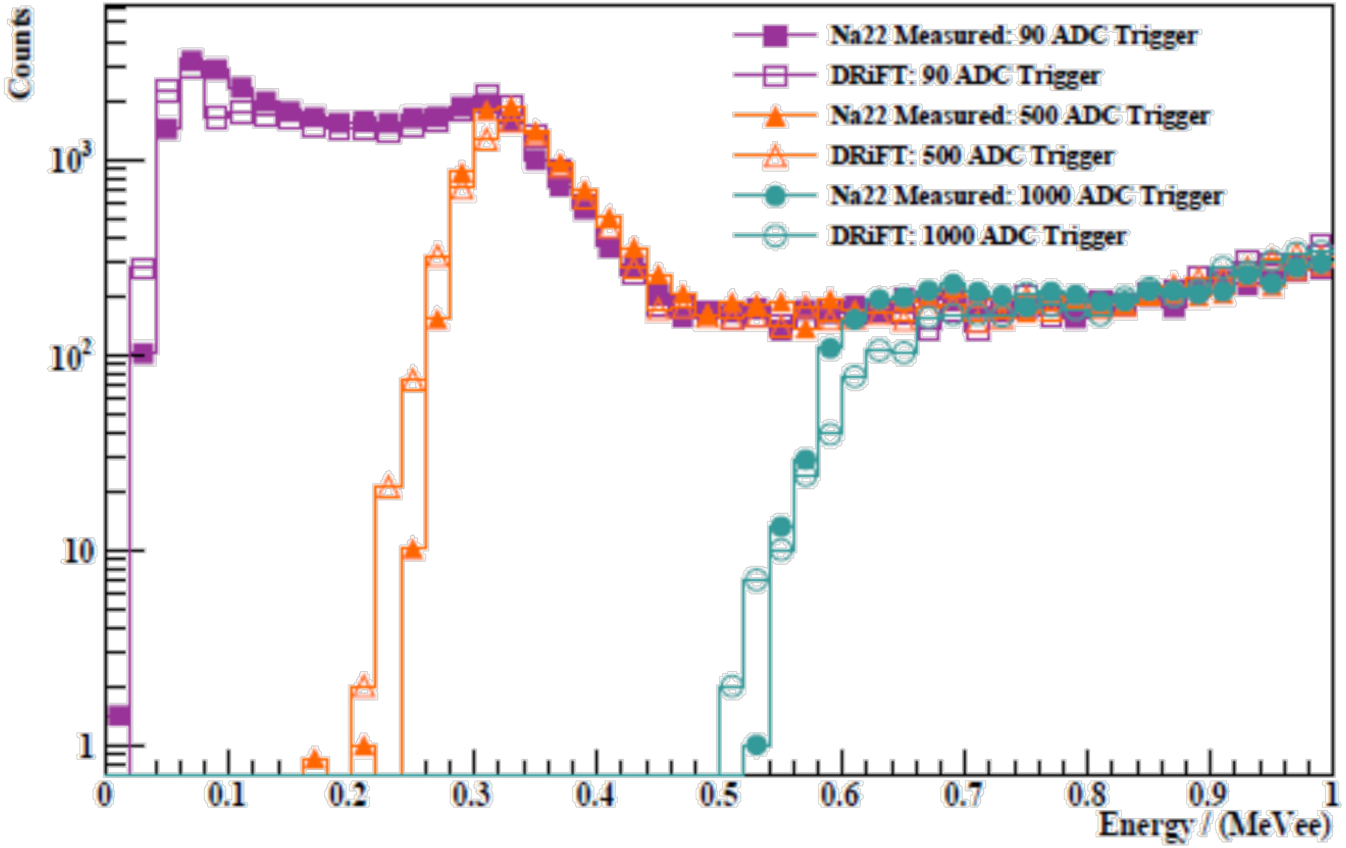
(a) Gmsh generated 3D Mesh



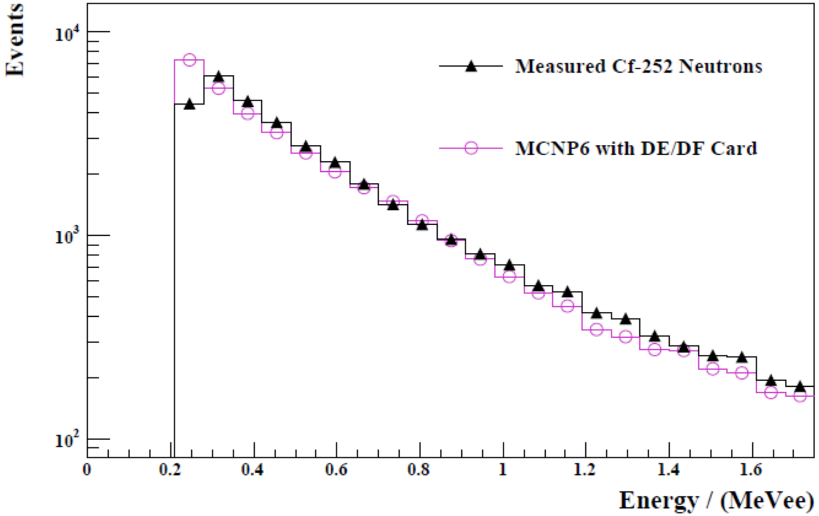
(b) Potential as a function of distance from anode

- An example of the detailed mesh generated by Gmsh (left) and the resulting electric potential (right) which is used by Garfield++ to calculate relevant detector properties.

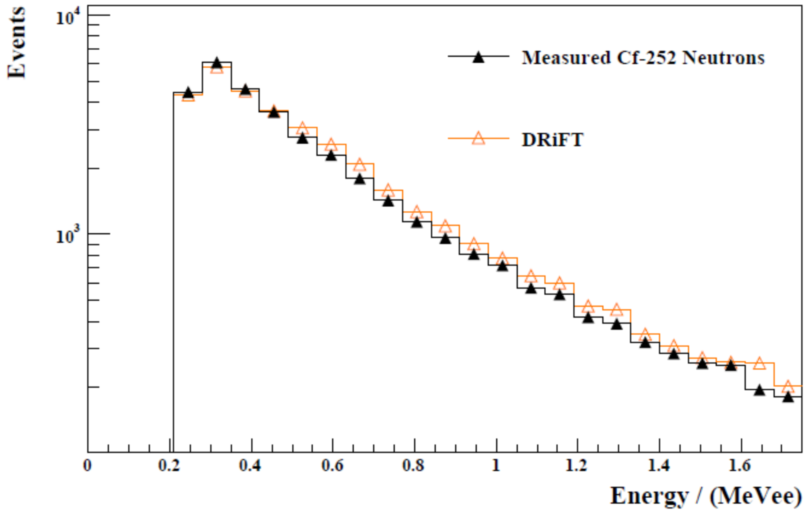
Additional Features: Trigger Thresholds



Results – Neutron Spectra Comparisons



(a) MCNP 0.2 - 1.75 $MeVee$



(a) DRiFT 0.2 - 1.75 $MeVee$