2-Neutron Simulations for the Development of Causal Gates

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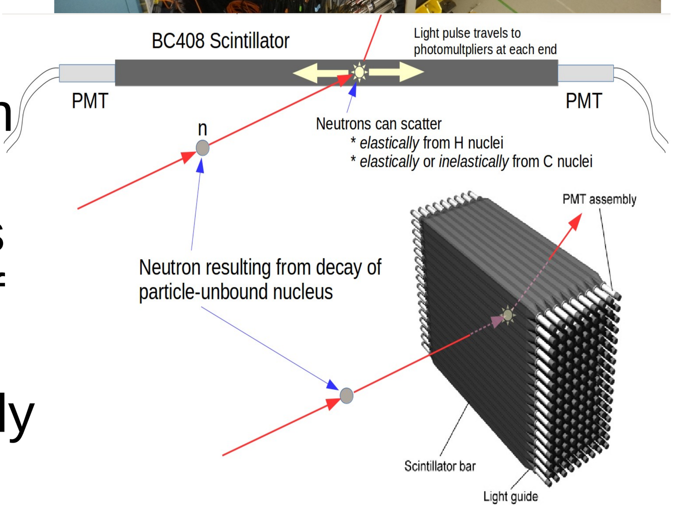
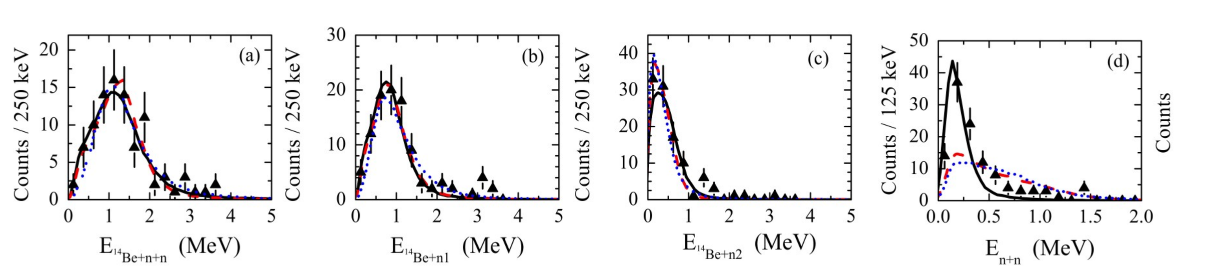
MoNA LISA Array

The Modular Neutron Array (MoNA) and the Large multi-Institutional Scintillator Array (LISA) each contain 144 neutron detector bars, made of organic scintillator and used to detect fast neutrons. The arrays are located at the National Superconducting Cyclotron Laboratory (NSCL) on the Michigan State University campus, and are used to study neutron-rich isotopes that decay through various types of neutron decay. The MoNA collaboration consists of 10 primarily undergraduate institutions.

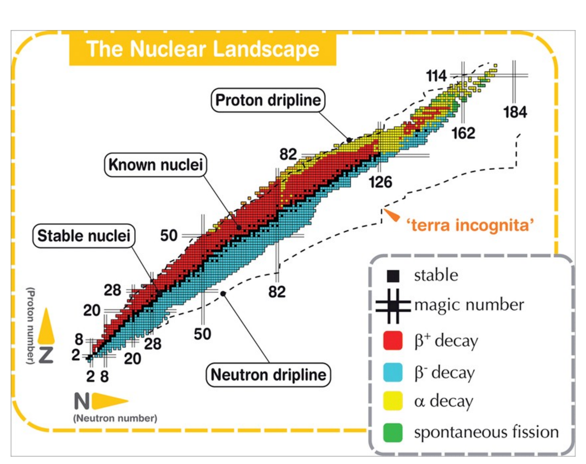


Motivation Behind Neutron Scattering Experiments

These experiments can tell us a number of things about neutrons and isotopes. One of the most important pieces of data that can be drawn from them is the decay energy for a given decay. These can be summed up in plots like the one shown below for ^{16}Be.



[1]Decay energy plots from the decay of ^{16}Be.



[2]Chart of the nuclides showing the various isotopes of elements. The MoNA collaboration looks at neutron-rich isotopes to the right of the valley of stability.

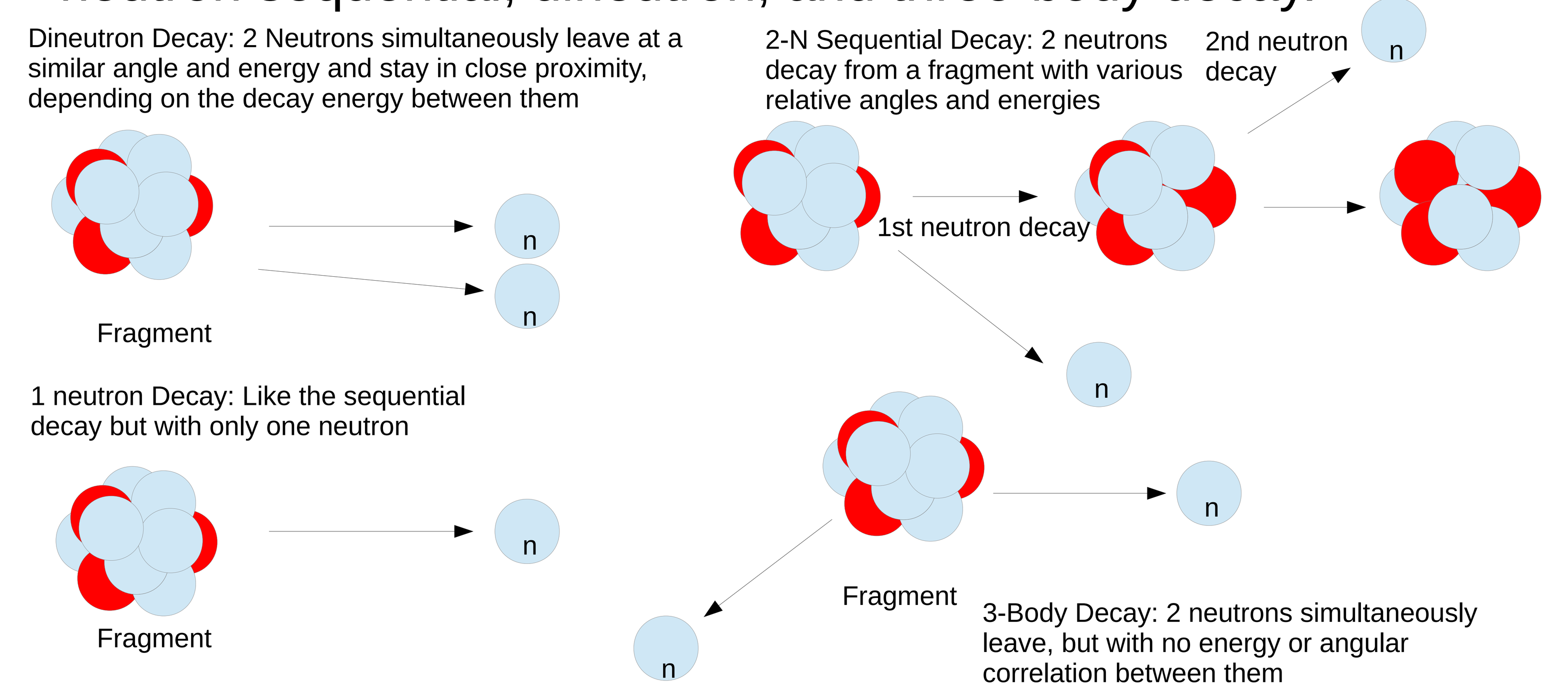
From these decay plots, we can learn about the relative stability of various isotopes, based on how much energy is released through the decay. This helps fill in the chart of the nuclides, which is like the periodic table but includes all the various isotopes of an element.

GEANT4 Simulation and ROOT

- Analysis was done using ROOT, an object-oriented program developed by CERN for particle physics data analysis. Additionally, Python scripts were created to help automate tasks.
- We wrote numerous C++ macros to aid in analysis, primarily to plot complicated spectra.
- Simulations were done using GEANT4 and Menate_R neutron scattering cross section packages

Types of Neutron Decay

The isotopes that we look at can decay in a number of different ways. The main types of decay are 1-neutron, 2-neutron sequential, dineutron, and three-body decay.

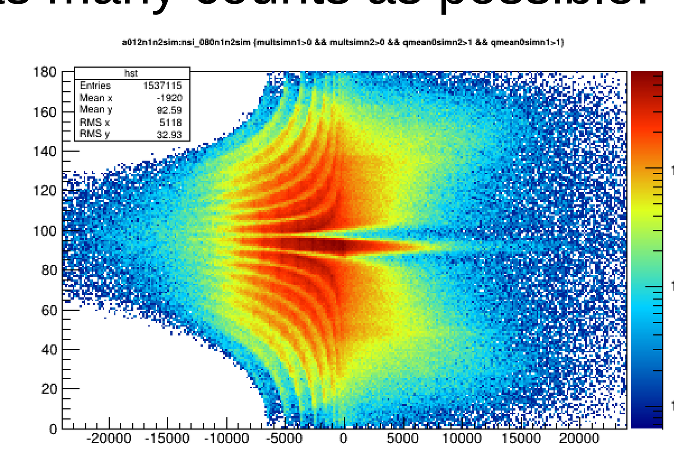


These decays each have different decay energy profiles, and it is important to be able to differentiate them to better understand how an unstable nucleus functions.

Development of Causal Gates

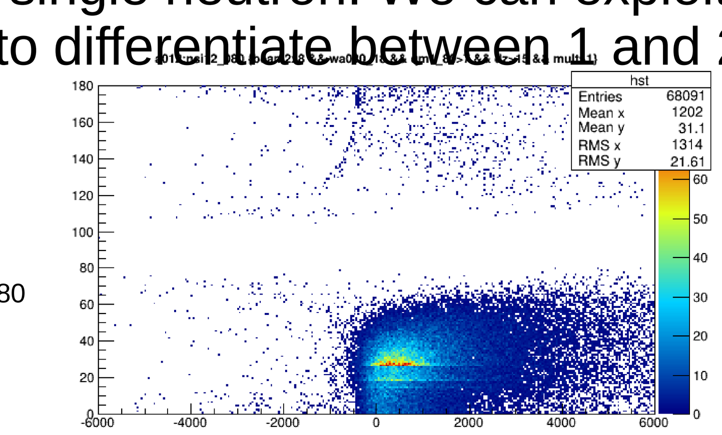
When we produce simulations, we can include as many events (neutron scatters) as we want. However, with experimental data, there is often a shortage of data, such as only a few hundred counts over the duration of a one-week experiment. Thus, we needed to create a method of filtering out all of the 1 neutron events while keeping as many counts as possible. One way of doing this is by looking at the scattering angle (θ_{12}) between the neutrons and the neutron spacetime interval (nsi):

$$nsi = (v_b \Delta t)^2 - r_{12}^{\;2}$$



A sample plot of scattering angle vs. nsi. The units for angle (y-axis) are in degrees, and the units of nsi are cm². This plot was made from a 3-body decay file of 80 MeV neutrons.

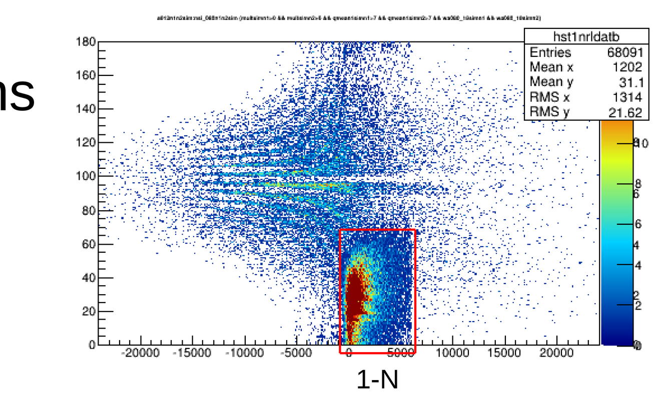
where v_b is the velocity of the neutron beam, r_{12} is the pathlength between hits, and Δt is the time between the hits. If the nsi is positive, the speed required to create both hits is less than the beam velocity v_b, and the two events could be causally linked. If the nsi is negative, then the speed is greater than v_b, and the scattering cannot be caused by a single neutron. We can exploit this to make a better causal filter to differentiate between 1 and 2 neutron decays. To illustrate this, we plotted the nsi vs angle plot for 1-neutron decays



1-neutron scattering angle vs. nsi for 80 MeV data

Development of Causal Gates (cont.)

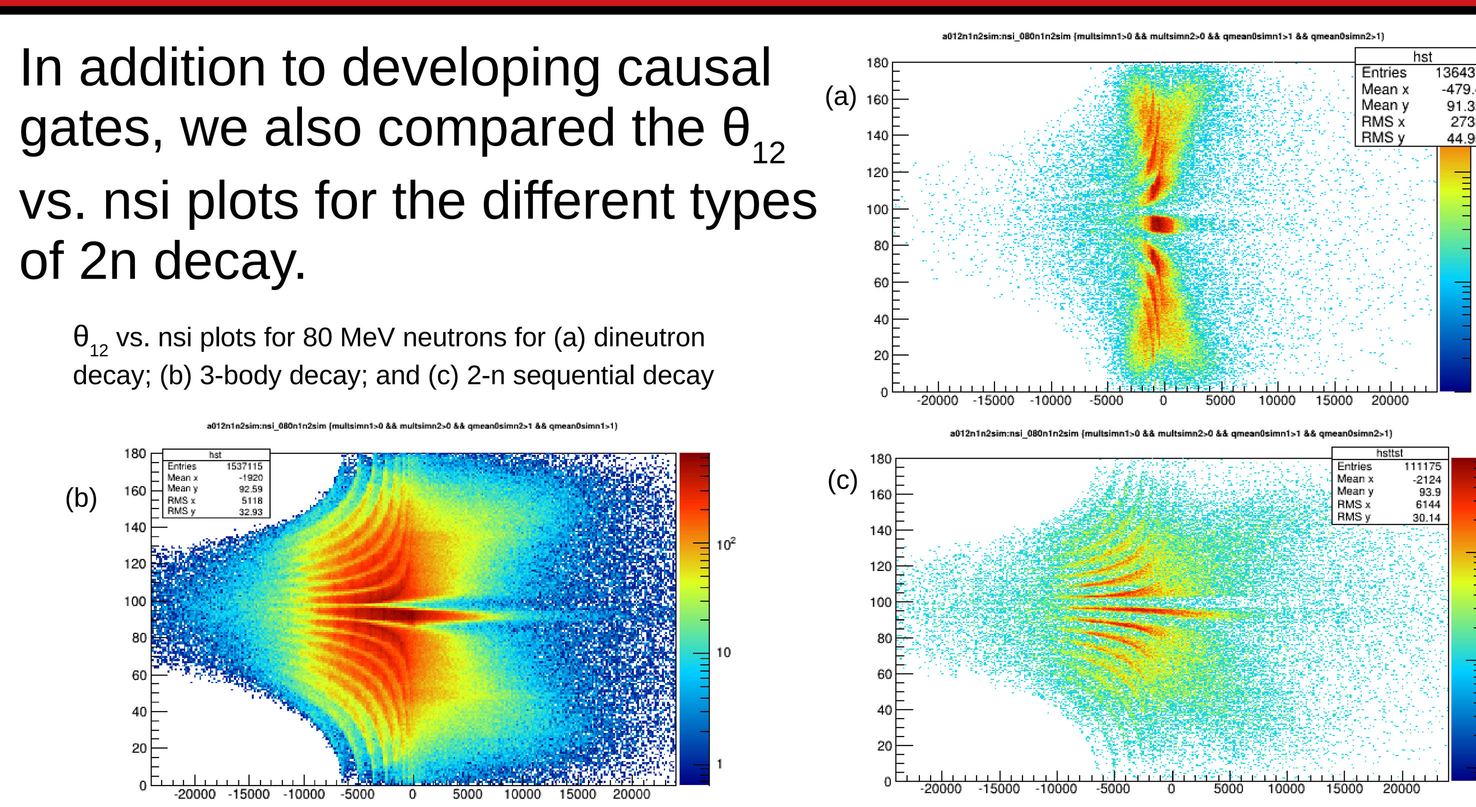
After applying additional gates (filters) to the 2-Neutron simulations so that the plots are showing the same things, we plotted the 1-n data and the 2-n simulation together. This shows how the 1-n region can be effectively removed by applying a gate that removes 1-n data in the red box (veto).



a012 vs . nsi plot that shows how the 1-n region can be removed, with only losing minimal 2-n events

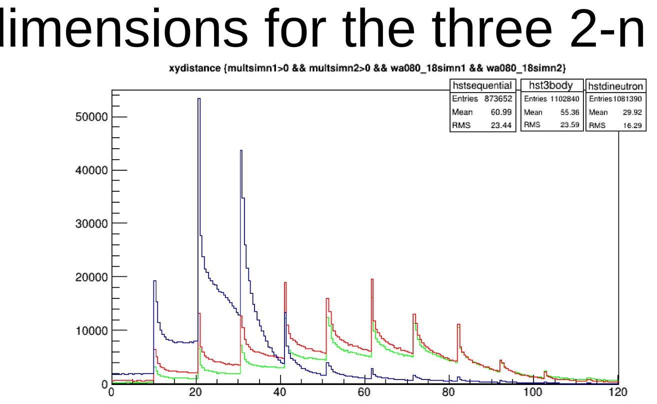
Other Key Signatures

In addition to developing causal gates, we also compared the θ_{12} vs. nsi plots for the different types of 2n decay.



θ_{12} vs. nsi plots for 80 MeV neutrons for (a) dineutron decay; (b) 3-body decay; and (c) 2-n sequential decay

We also looked at the distance between hits in the x and y dimensions for the three 2-n decay types.



The blue curve is from the dineutron file, the red is from 3-body, and the green is from 2-n sequential.

References

1. A. Spyrou et al, Phys. Rev. Lett. 108 102501. (2012).
2. A. Galata, PhD. Istituto Nazionale di Fisica Nucleare. 2015.

Acknowledgements

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