A Multi-Layered Approach to Multi-Neutron Filtering

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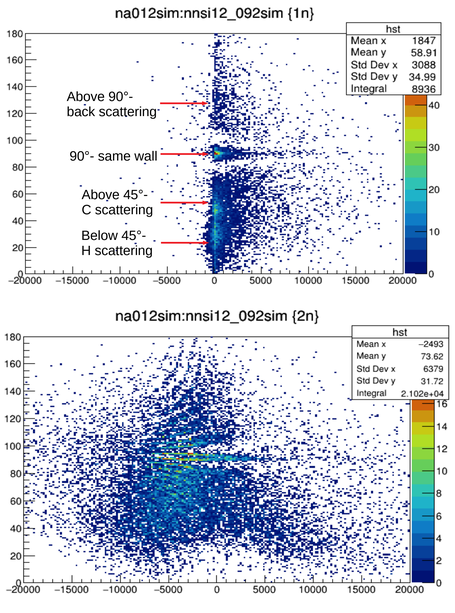
Introduction to MoNA

The Modular Neutron Array (MoNA) is a collection of 144 plastic scintillator detectors, 200cm in length. The MoNA Collaboration uses these neutron detectors to study the decays of neutron unbound isotopes at NSCL and soon FRIB.

We have developed a **multi-neutron filter** for experiments in which the nucleus decays by several neutrons to determine which hits in MoNA belong to independent neutrons. **This requires discerning the difference between 1n scattering events and true 2n events.**

Neutron Spacetime Interval

- The neutron spacetime interval (NSI) can be used to differentiate whether individual hits in MoNA might be **causally connected**
- The NSI is defined as
- $nsi = v_{beam}{}^2 t^2 - p_{12}{}^2$
- Upper figure shows scattering angle vs. NSI from simulation for 1n scattering
- Lower figure shows 2n scattering, where band structure is due to geometric combinations of MoNA bars

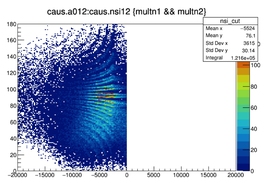


Hit Clusters in MoNA

For fast neutrons scattering in MoNA,

- (n,p) charge exchange scattering can produce additional signals in adjacent bars (hit clusters)
- difficult for 1n events to produce more than one cluster since it loses most of its energy
- we **interpret multiple clusters as belonging to individual neutrons** (even though their hit pattern may appear causal)

Causality Filters

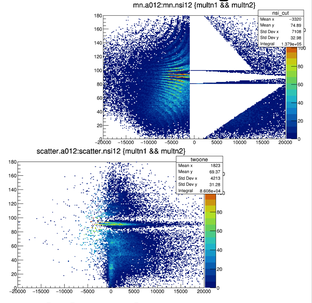


Left: Traditional causality cut accepts hit pairs with p_{12}> 30cm and v_{12}>v_{beam} (p_{12}=path length, v_{12}=relative velocity between hits), which indicates a 2n event

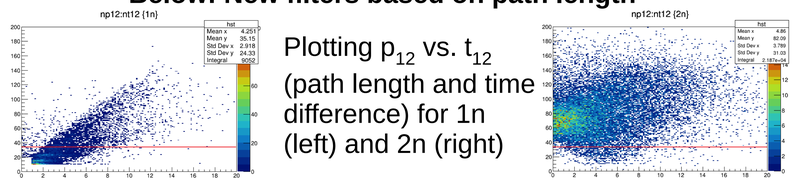
Lower 2n yield, but also low 1n background

Right: Initial angle-nsi plot cut cut out all events that occur in highly populated 1n regions according to a predetermined cutout shape (upper)

Lower plot shows regions where 1n and 2n overlap. Regions that remove 1n also exclude many 2n.



Below: New filters based on path length



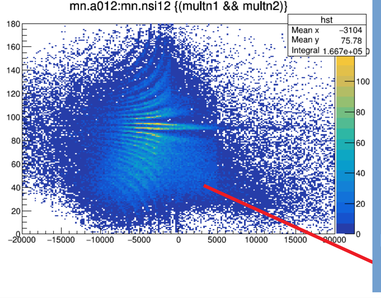
Plotting p_{12} vs. t_{12} (path length and time difference) for 1n (left) and 2n (right)

Average p_{12} for 1n scattering and 2n differ significantly- fair separation between regions of density suggests new filter technique

Multi-Layered Filtering

We combine **nsi cut, path length,** and **cluster event filtering** to keep as many 2n events and exclude as many 1n scatter events as possible

We can use cleaner filters on high statistics experiments to optimize 2n/1n signal-to-noise; more generous filters on low statistics experiments to boost 2n yield

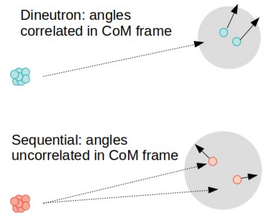


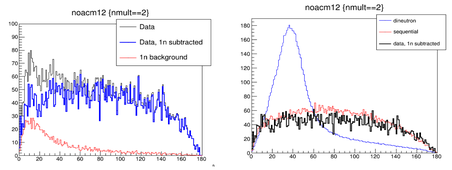
Causal Test	Noise to signal	2n yield
Traditional causality cut	1.21%	64.16%
P_{12}-restricted clusters	1.56%	77.2%
Clusters	2.66%	79.63%
P_{12}-augmented clusters	3.84%	87.46%

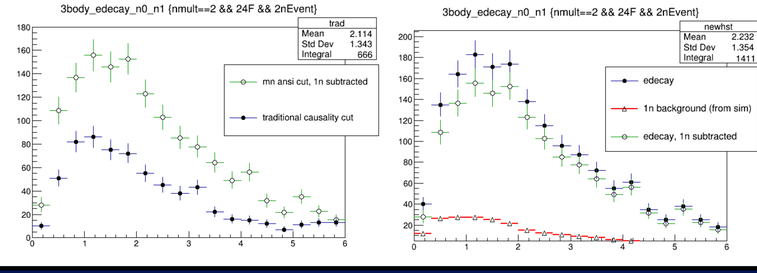
Accounting for 1n Background

Any filter will always admit some 1n background. We want to **understand the 1n contribution** to determining both 2n neutron decay mode and E_{decay} values.

- We can estimate **decay mode** (sequential, dineutron, …) based on opening angle between neutrons in the center of mass
- We can simulate 1n background to subtract its contribution to results
- A test of our filter using $^{26}F \rightarrow {}^{24}F+n+n$ data confirms the sequential nature of the decay and reproduces the $\mathbf{E_{decay}}$ spectrum with higher statistics; we then simulate 1n background in order to subtract its contribution to the results







Looking Forward

As the research program continues, we plan to:

- Continue refining filter parameters to optimize 2n statistics and reduce 1n background
- Expand filtering to include energy deposited in hits
- Evolve filtering approach and apply to other experiments

Acknowledgments

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