Neutrino-Induced Neutron Detectors at the Spallation Neutron Source

#428

Jacob Daughhetee, *on behalf of the COHERENT Collaboration*
University of Tennessee

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Neutrino-Induced Neutrons

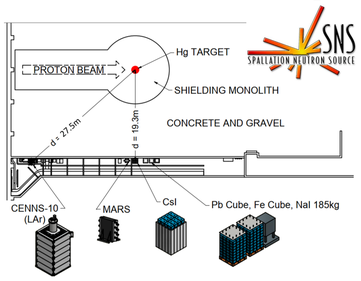
Neutrino-nucleus interactions can yield excited nuclear states which may decay via the emission of neutrons:

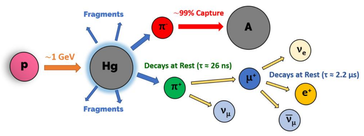
$$\nu_e + {}^{208}Pb \rightarrow {}^{208}Bi^* + e^- \quad \text{(CC)}$$
$$\hookrightarrow {}^{208-y}Bi + x\gamma + \boxed{yn}$$

$$\nu_x + {}^{208}Pb \rightarrow {}^{208}Pb^* + \nu'_x \quad \text{(NC)}$$
$$\hookrightarrow {}^{208-y}Pb + x\gamma + \boxed{yn}$$

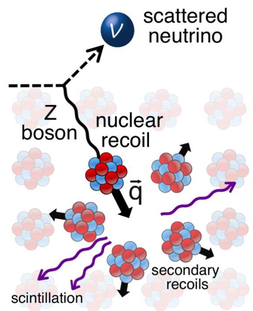
- Neutrino-induced neutrons (NINs) are a potential background for experiments searching for nuclear recoils from coherent neutrino scattering or dark matter at pion decay-at-rest sources.
- NIN production on lead is a detection channel for galactic supernovae in the HALO experiment [1].
- Highly relevant to r-process nucleosynthesis in supernovae [2].
- This process has yet to be observed and suffers from large theoretical uncertainty.

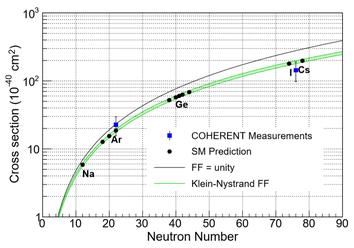
COHERENT Experiment & NINs

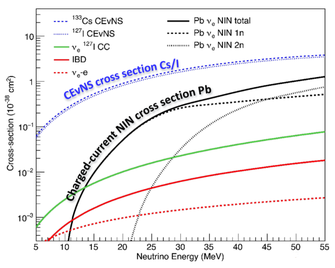




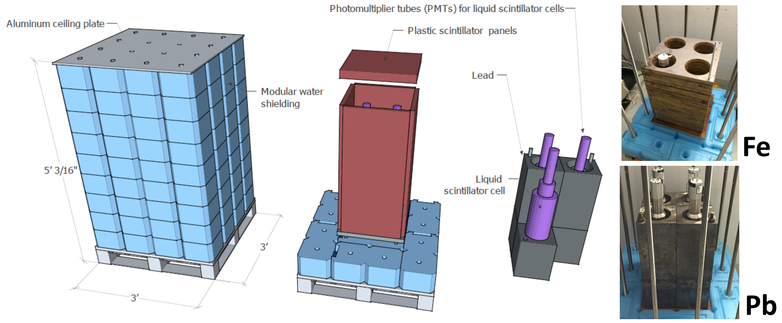
- The Spallation Neutron Source at Oak Ridge National Laboratory is also powerful neutrino source!
- 1.4 MW proton beam delivered to target at 60 Hz in 400 ns FWHM bunches.
- First measurement of coherent elastic neutrino-nucleus scattering (CEvNS) [4].
- COHERENT seeks to measure CEvNS on multiple nuclear targets.
- Use of Pb shielding in detectors → large target mass for NIN production.
- Neutron scatters may mimic neutrino signal.







Neutrino Cubes

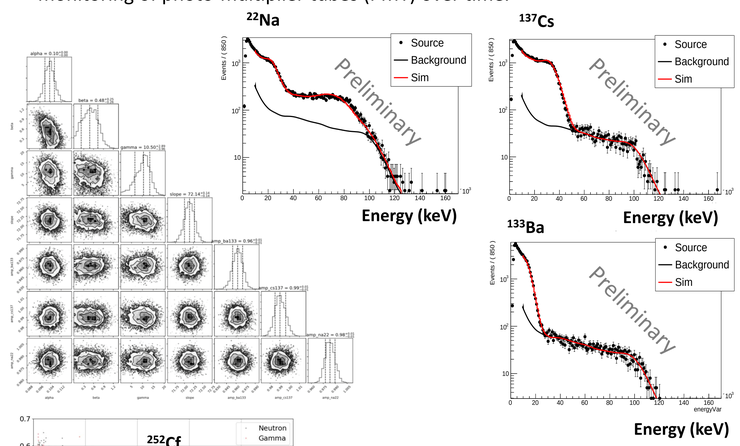


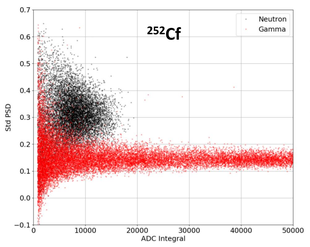
From left to right: Detector with water shielding; shielding remove to show muon veto panels; inner detector Pb target with embedded scintillator cells.

- Dedicated NIN detectors deployed on pallets in Neutrino Alley at the SNS.
- Two currently operating detectors featuring a 1000 kg Pb and 700 kg Fe target respectively.
- Liquid scintillator cells embedded in target material search for neutrons matching expected time profile from SNS neutrinos.
- In their present configuration, both detectors feature 2 2.4 L and 2 1.4 L liquid scintillator cells.
- Data acquisition triggered via scintillator cell signal in coincidence with SNS protons on target signal.

Calibrations

- Gamma calibrations (^{22}Na, ^{137}Cs, ^{133}Ba) performed approx. twice a year allow for monitoring of photo-multiplier tubes (PMT) over time.

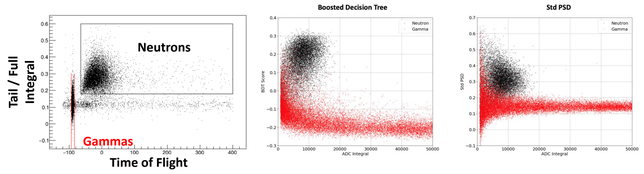




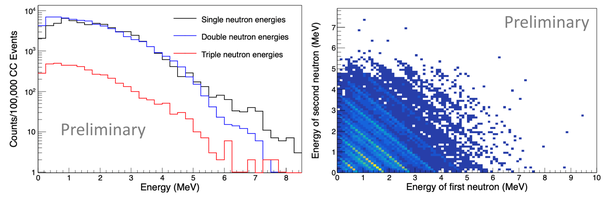
- Simulated spectra are generated for each source and simultaneously fit to calibration data.
- Steady-state background spectra also used to monitor for detector changes.
- Time-tagged ^{252}Cf source gives sample of nuclear recoil events for event discrimination studies.

Analysis Status

- Pb (Fe) detector has been collecting data since 2015 (2017).
- Data quality cuts set; calibrations finalized.
- Machine learning applied to waveform information to improve event discrimination at low recoil energies:

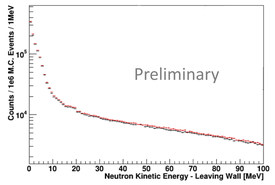


- No theoretical predictions for NIN spectra from pion DAR electron neutrinos (theory focused on SNe neutrinos); use of MARLEY (**M**odel of **A**rgon **R**eaction **L**ow **E**nergy **Y**ields) to generate predictions for Pb at the SNS.



Predicted neutron spectra for Pb NINs Energy correlation for multiple neutron emission.

- Beam-related neutrons represent an important background for NIN analysis; many simulations performed to understand expected energy and timing distributions.



Left: Simulated incident neutron spectrum from SNS neutrons at the Neutrino Cube detector location.

- Blind analysis scheme in place; data cuts and fitting procedure to be established shortly.
- Results of NINs search in Pb and Fe coming soon!

References

[1] C. Duba, F. Duncan, J. Farine, A. Habig, A. Hime, et. al., "HALO: The helium and lead observatory for supernova neutrinos", J.Phys.Conf.Ser. 136 (2008)
[2] Y. Z. Qian et. al. "Neutrino-induced neutron spallation and supernova r-process nucleosynthesis", Phys Rev C 55 (1997).
[3] D. Akimov et. al (The COHERENT Collaboration). "Observation of coherent elastic neutrino-nucleus scattering", Science 03 Aug 2017.

Acknowledgements

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