100 eV – 400 eV Nuclear Recoils from Neutron Capture: Calibrations and Background

A.N. Villano and P. Cushman

School of Physics & Astronomy, University of Minnesota, Minneapolis, MN, USA

March 31, 2017

This project is to precisely measure nuclear recoils following thermal neutron capture for the benefit of future generation of sub-GeV dark matter detectors. The energy range for the recoils (100 eV–700 eV in germanium) gives calibrations for dark matter detectors near the 1 GeV dark matter mass, and illuminates a potential background sourced by *thermal* neutrons. Further, the precise calibration can constrain an important lower energy process which dramatically affects nuclear recoils at 10's of eV energy scale–the energy loss due to single Frenkel defect creation in solids.

For a first measurement at the University of Minnesota we plan to inject thermalized neutrons into a new low-threshold germanium detector developed for SuperCDMS and trigger on the escaping capture gammas, thus observing the prompt nuclear recoils directly, rather than inferring the nuclear recoil energy from the resulting gamma lines [1]. This will be the first direct measurement of such nuclear recoils in germanium with the energy range 100–700 eV. The background environment is made manageable by the high-energy gamma coincidence requirement.

The existing infrastructure at the University of Minnesota consists of a dilution refrigerator with a well-developed DAQ, housing a low-threshold (350–450 eV for nuclear recoils) detector using transition-edge sensors (TES) and read out by superconducting quantum interference devices (SQUIDs). This phonon readout [2] has $\sim$17% energy resolution near threshold. We also have a Pu-Be neutron source that produces 1×10^6 neutrons/s, two 8 inch diameter 6 inch thick NaI(Tl) scintillation gamma detectors, one 3 inch diameter 4 inch thick HPGe gamma detector, thermalization material (polyethylene), and detector shielding material (lead). With these materials a basic facility to measure nuclear recoils from capture has been constructed. Initial funding will be used to perform a first experiment in this facility for an approximately 2 month running period. It is expected that with modest funding this technique can be generalized and accomplished for many detector materials at one of the future calibration facilities discussed in this workshop [3, 4].

A detailed nuclear-recoil spectrum has been constructed for germanium and silicon, the first materials envisioned for this measurement. Because of the expected lifetimes of intermediate states populated by the capture cascade, the capture spectra are stretched to low energies. In Fig. 1 the nuclear-recoil capture spectra are shown for germanium and silicon. For both spectra at every intermediate level only the highest-energy branchings are considered and unknown level lifetimes are replaced with the lowest-multipolarity Weisskopf estimates [5].

In addition to a good calibration standard in the very low energy region, this process may be a background that some experiments–particularly those with no or imperfect active vetoing–need to consider. Figure 1 shows each spectra normalized to a fairly small (but arbitrary) thermal neutron flux of 1 n/cm^{2}day. It is seen that for this neutron flux and modest sized detectors (100's of cm^3) one can obtain several counts per week. Further, if these capture spectra are sampled sparsely, they may appear to be a dark matter signal.

It is expected that the first measurement of these recoils in solids will take place at the University of Minnesota in the Summer of 2017. Improvements to the technique are hoped to allow the method to be employed at planned calibration facilities for the next-generation light dark matter detectors [3, 4].

With the existing equipment the first measurement could reach 8σ significance in 60 days at the University of Minnesota. The operations cost for this is expected to be around $17k. The cryogens needed for the facility have an estimated cost of $100/day giving a total cost of about $6k over the running period.

Other improvements to the facility (improved moderation, additional coincidence detectors, etc.) totaling around $27k in additional funding would allow the measurement to reach levels that allow nuclear recoil scale cali-

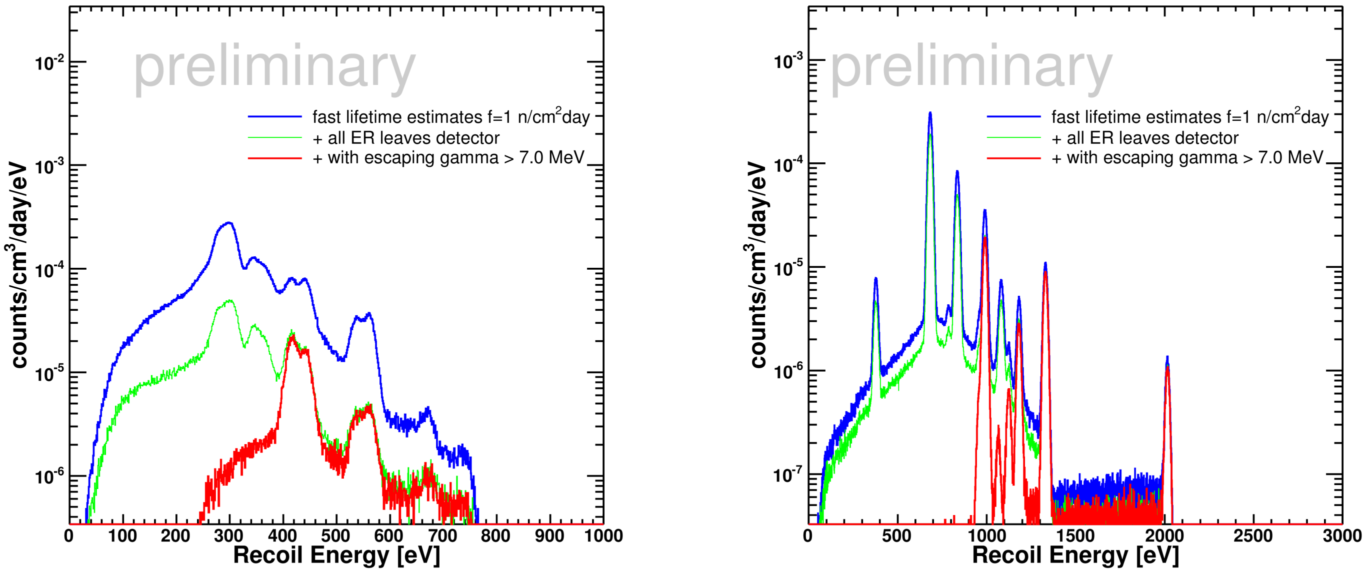

Figure 1: (left) Germanium nuclear recoil spectrum following neutron capture in a 6 inch diameter, 1.5 inch thick detector. (right) Silicon nuclear recoil spectrum following neutron capture in a 6 inch diameter, 1.5 inch thick detector. In each case the cascades are modeled assuming that at each level only the highest-energy branchings are followed and all unknown level lifetimes are replaced with the lowest-multipolarity Weisskopf estimates. The spectrum has been normalized to a fairly small (but arbitrary) thermal neutron flux of 1 n/cm^{2}day.

bration of a germanium detector at the 10% level below 400 eV in just 8 days. Funding scenarios for instrumenting a general-purpose dark matter detector calibration facility with this technique can and should be explored [3, 4].

References

[1] K. W. Jones et al. *Phys. Rev. A*, 11:1347–1353, Apr 1975.

[2] R. Agnese et al. *Phys. Rev. Lett.*, 116:071301, Feb 2016.

[3] Enectali Figueroa-Feliciano. Facilities, Fermilab, SNOlab. In *US Cosmic Visions Workshop 2017*, College Park, Maryland, Mar. 23-25 2017.

[4] Phillip Barbeau. NR calibration at TUNL. In *US Cosmic Visions Workshop 2017*, College Park, Maryland, Mar. 23-25 2017.

[5] V. F. Weisskopf. Radiative transition probabilities in nuclei. *Phys. Rev.*, 83:1073–1073, Sep 1951.