Towards Coherent Neutrino-Nucleus Scattering Detection: Low-Energy Ionization Yield in Liquid Argon

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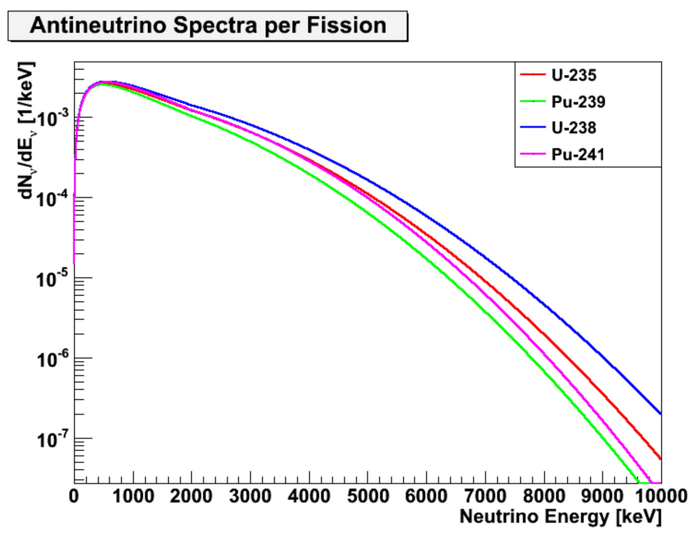
Coherent neutrino-nucleus scattering (CNNS) is an as-yet undetected neutrino interaction predicted by the Standard Model. Detection of CNNS could provide benefits for applications such as antineutrino-based nuclear reactor monitoring and astrophysics research (flavor-independent solar and supernova neutrino detection). As the first step in the search for CNNS using dual-phase noble gas detectors, it is necessary to first measure the ionization yield, i.e. the amount of ionization produced in nuclear recoils predicted for CNNS, in the range of typical neutrino energies used in future CNNS experiments. We have built a small dual-phase argon detector (~150 g active mass) for the purpose of measuring the ionization yield with elastic neutron scatters. We will use a 1.93 MeV proton beam to bombard a lithium target producing neutrons via the $^{7}Li(p,n,)^{7}Be$ reaction. The neutrons will then primarily scatter off of the ~80 keV resonance of ^{40}Ar providing a source of nuclear recoils. With this method, we will be able to perform a measurement of the ionization yield at E_{recoil} ~7 keV, the energy relevant for the search for reactor antineutrino coherent scatter in argon. We will present in detail the method of measurement along with our progress on the measurement of the ionization yield in liquid argon (LAr). We will also present the expected sensitivity of a dual-phase argon detector for detecting CNNS.

Coherent Neutrino Scatter via Nuclear Reactor Antineutrinos

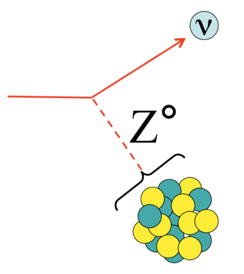
The total number of antineutrinos emitted during the fission process varies from isotope to isotope.

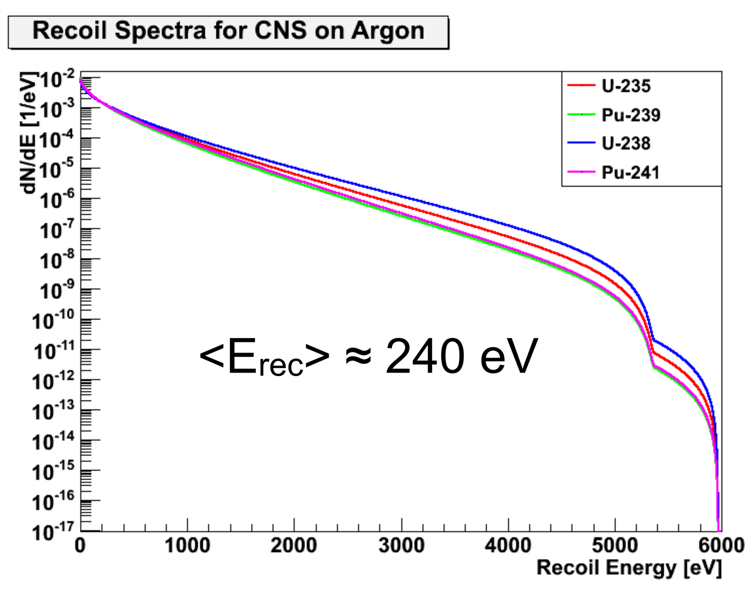


- Increased cross section over inverse β decay
- Very low recoil energies
- Unknown ionization yields
- Measure the ionization yield at ~7 keV
  - Develop dual-phase Ar detector
  - Elastically scatter neutrons of Ar

It is predicted by the Standard Model that the neutrino can interact with an entire nucleus instead of a single nucleon, an interaction called coherent neutrino-nucleus scattering (CNNS). One benefit of CNNS is the increase in cross section over inverse β decay. One major challenge in detecting CNNS are the small nuclear recoil energies.

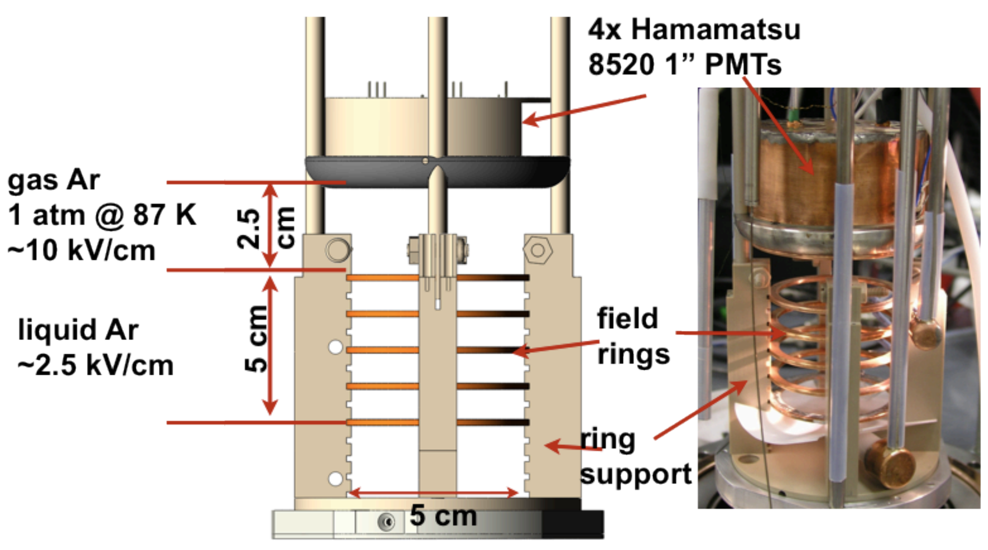
$$\lambda_{\nu} \gg R_{\text{nucleus}} \approx 1.25 \text{ fm} A^{1/3}$$

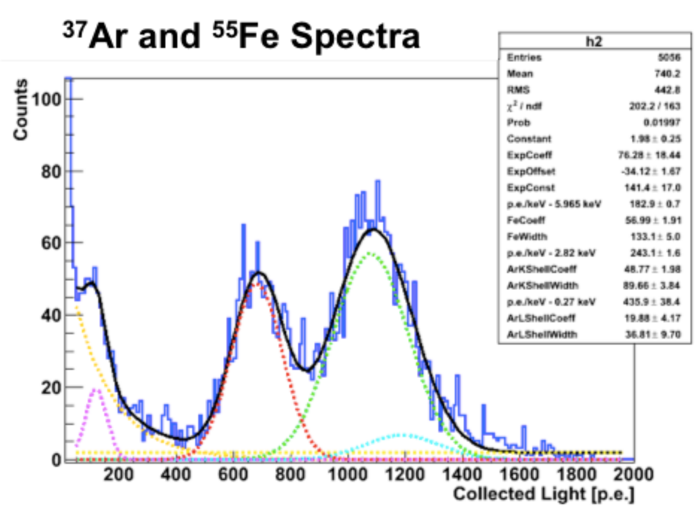




Detector Development and Operation

- We have measured 10% sigma energy resolution at the 5.9 keV ^{55}Fe peak
- Demonstrated the ability to observe single liquid electrons
- Obtain 2.8 keV ^{37}Ar K-shell peak and the 0.27 keV L-shell peak; sensitivity down to ~0.1 keVee
- Next step is to measure the ionization yield at keV energies





See poster 195 by S. Sangiorgio et al. for full detector details.

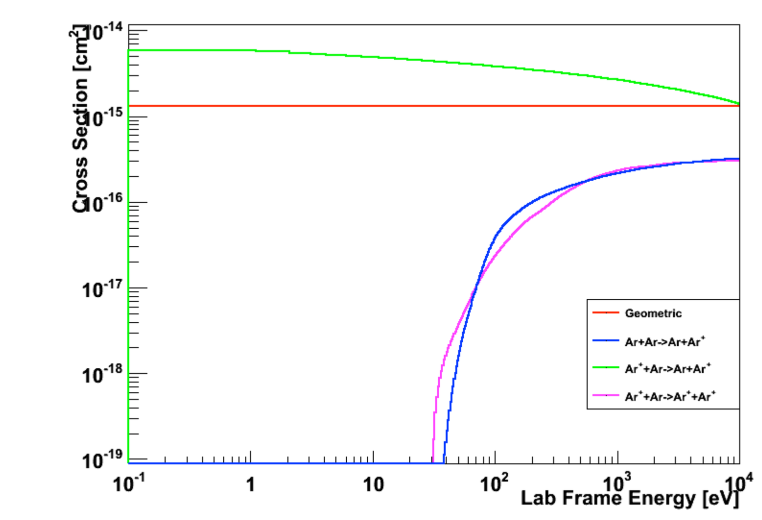
Unknown Ionization Yields

Another challenge in detecting CNNS is that nuclear recoils result in less observable signal than electronic recoils of equal energy. This phenomenon is referred to as nuclear quenching. The ionization yield for the nuclear recoils must be measured experimentally.

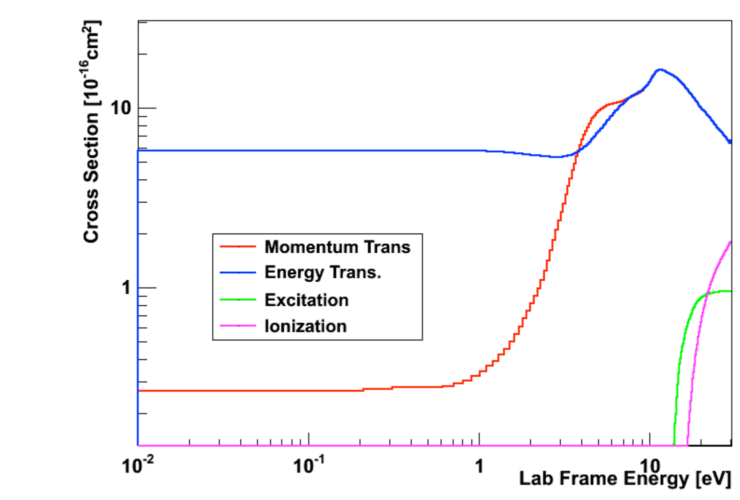
$$q_{\text{ion}}(E) = \frac{N_{\text{ion}}^{\text{nucl}}(E)}{N_{\text{ion}}^{\text{elec}}(E)} = \frac{N_{\text{ion}}^{\text{nucl}}(E)}{\frac{E}{W}}$$

We have generated an atomic collision based simulation to try to predict the ionization yield at sub 10 keV energies in LAr.

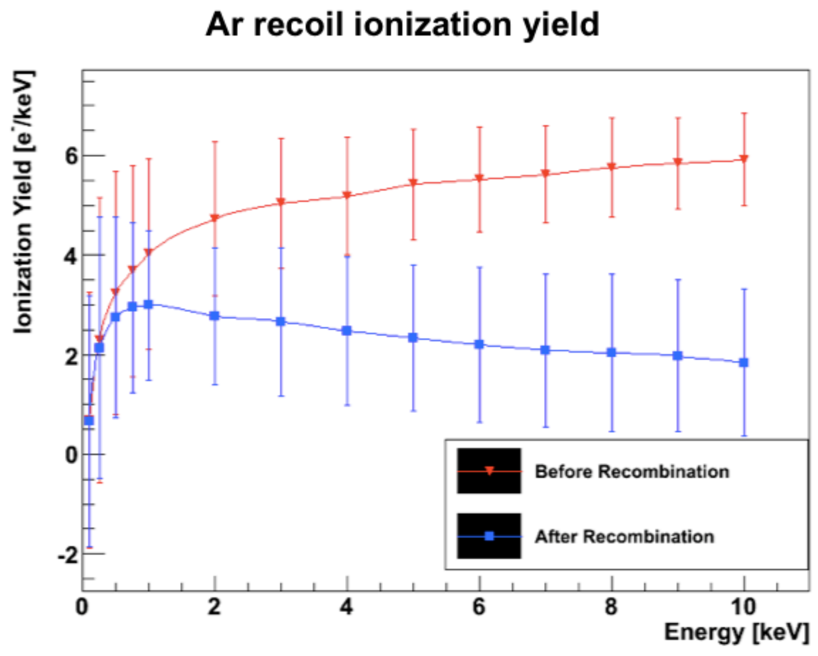
The inelastic cross sections decrease towards lower energy with a threshold of $2^{*}E_{\text{ioniz}}$



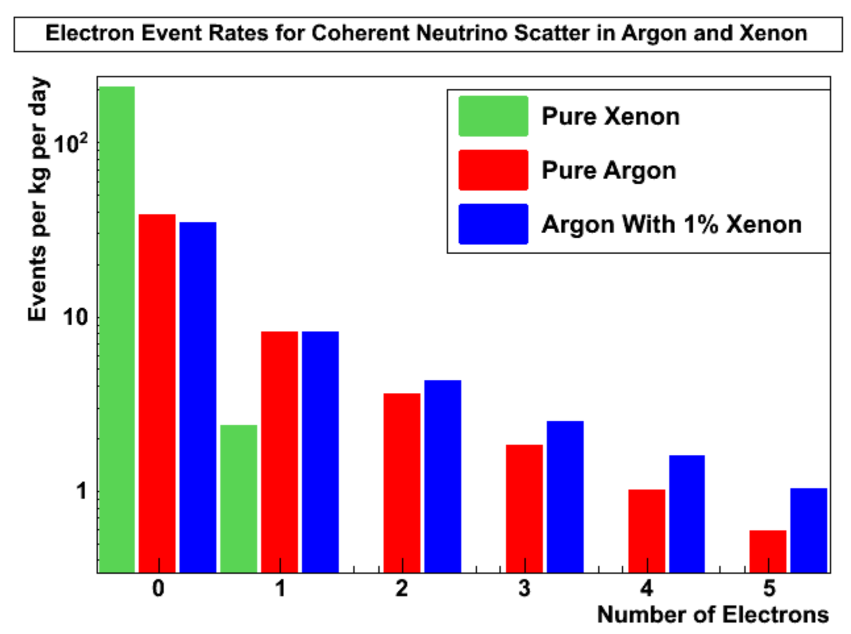
Random collisions of electrons and ions induce energy and momentum transfer, along with ionization and excitation at higher electron energies



Predicted ionization yields in liquid Ar based on an atomic collision based Monte Carlo model for an electric field of 1 kV/cm

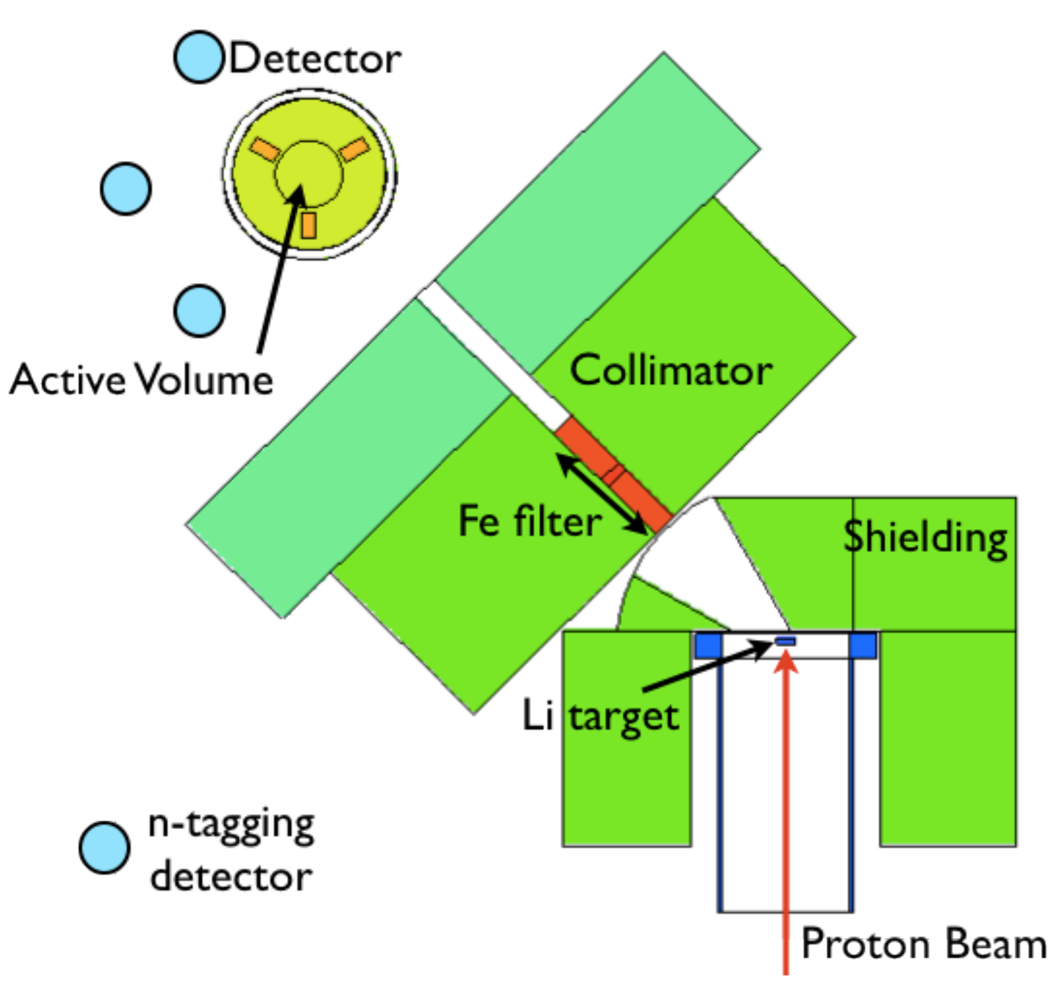


Number of electrons generated in a CNNS recoils from a nuclear reactor antineutrino source in LXe and LAr based on the atomic collision based Monte Carlo model.



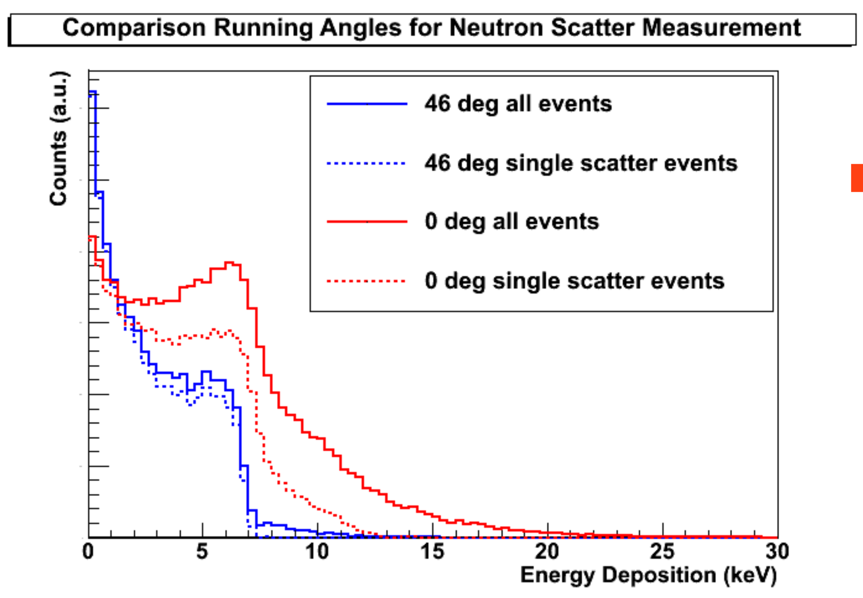
- Unknown ionization yield in liquid argon at low keV energies
- Only have a Monte Carlo model predicting the ionization yield at these low energies
- To better know the sensitivity of the CNS detectors, the ionization yield must be measured at keV energies

Ionization Yield Measurement

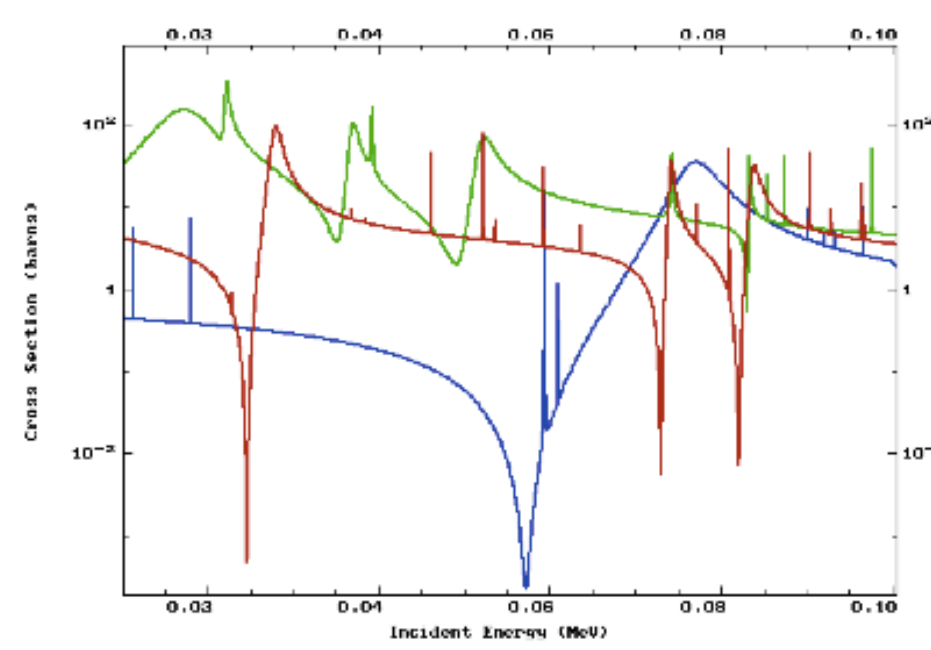


Using a 1.93 MeV proton accelerator at the Center for Accelerator Mass Spectrometry (CAMS) at LLNL, neutrons are generated up to an energy of ~75 keV through the $^{7}Li(p,n)$ ^{7}Be reaction.

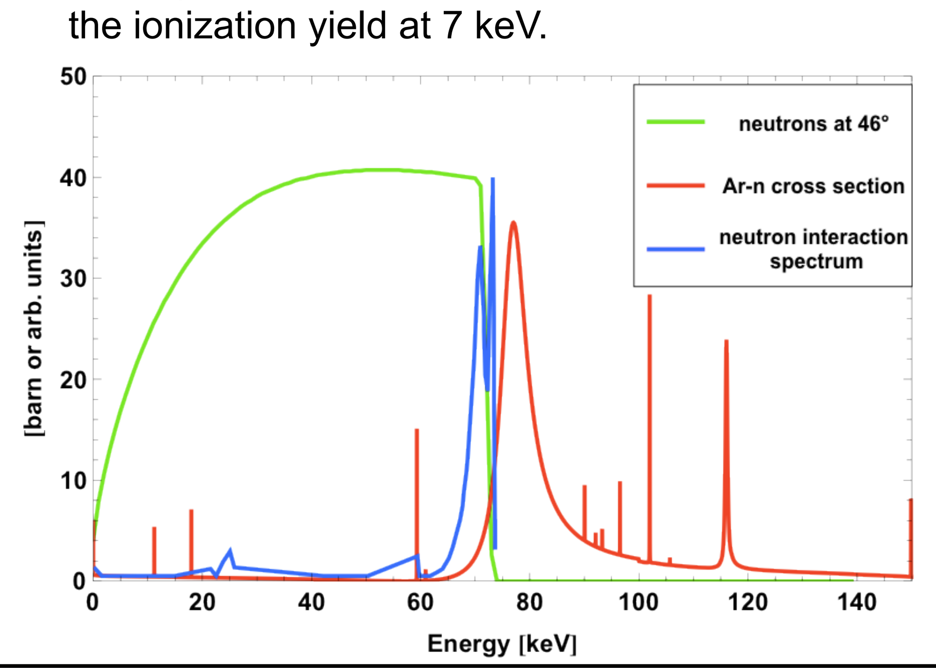
The detector will be placed off-axis at ~46° to reduce the likelihood of multiple scatters. This will allow for a cleaner end-point measurement of the recoil spectrum to obtain the ionization yield at ~7 keVr.



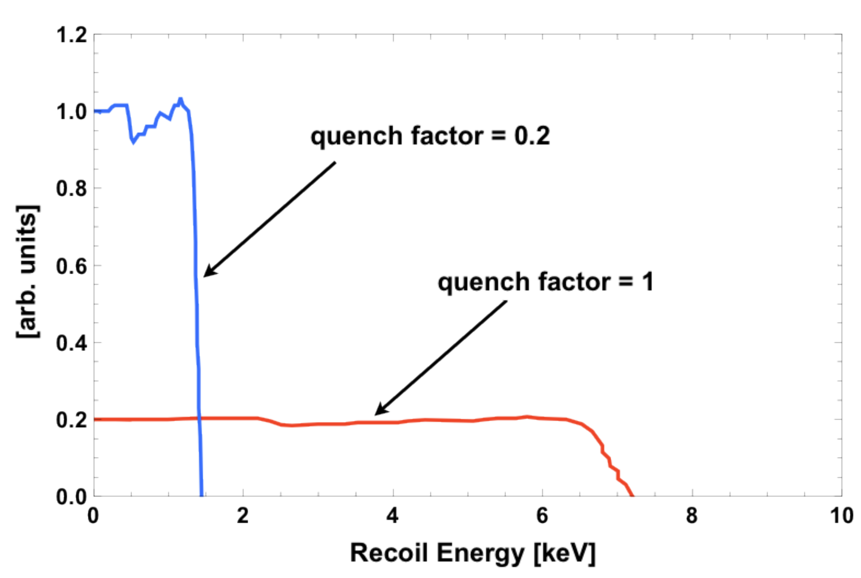
Neutron scatter cross sections for Fe (red), Ti (green), and Ar (blue).



We will use a Fe and Ti filter to selectively scatter the lower energy neutrons which will produce a flatter plateau and more distinct shoulder to obtain the ionization yield at 7 keV.



Simulated spectrum with the ionization yield equal to that of electronic recoils and assuming a constant ionization yield



With the quasi mono-energetic neutron beam from the Fe filter, we will be able to perform neutron tagging as well. This will result in a recoil energy peak providing the ionization yield as a specific point, down to ~1 keVr.

- Demonstrated sensitivity down to ~0.1 keVee
- We will first measure the ionization yield at ~7 keVr using elastic neutron scatters
- Using neutron tagging, we will be able to probe energies down to ~1 keVr
- Knowing the ionization yield will be useful to both the CNNS and Dark Matter communities

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