MODELING ^{8}B SOLAR NEUTRINO DETECTION WITH CEνNS

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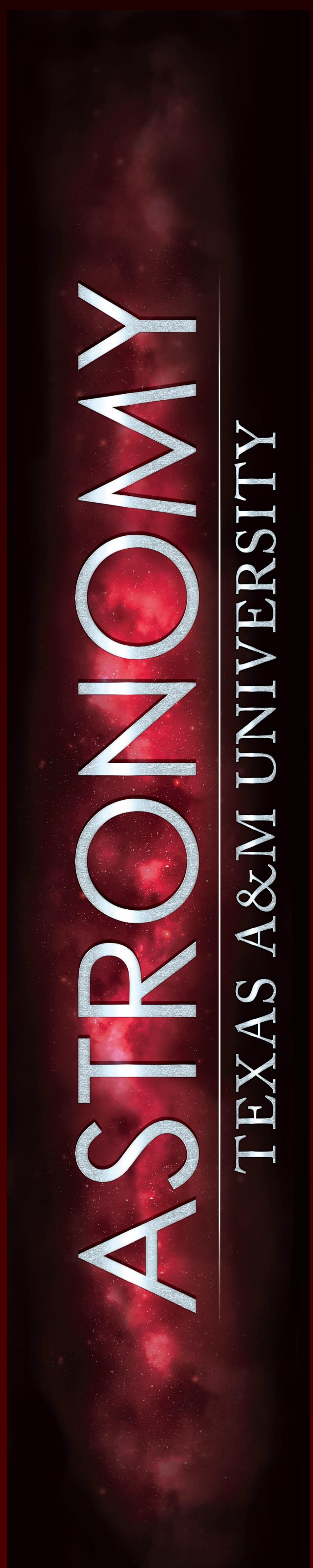

ABSTRACT

In the continuing search for dark matter and information about the energy density of the universe, it is becoming increasingly evident that many answers may come from the study of neutrinos. This work discusses methods used to create models for the observation of coherent elastic neutrino-nucleus scattering (CEvNS) events in search of Weakly Interacting Massive Particles (WIMPs), a leading dark matter candidate. We focus on the ^{8}B produced solar neutrinos, which represent the most abundant background source in dark matter searches. Eliminating this background using threshold recoil energy cuts is essential to increasing the likelihood of detecting WIMPs. For our two nuclear targets, xenon and argon, our model predicts a flux of ~10^3 and ~10^2 events per year respectively over all threshold energies for a ton-scale detector. Introducing a threshold recoil energy of ~5 keV will eliminate the ^{8}B neutrino background in xenon and argon detectors, meaning the likelihood of detection of WIMPs scales linearly with the detector.

INTRODUCTION

Dark matter searches attempt to determine the source of ~23% of the energy density of the universe. One of the primary candidates for dark matter are Weakly-Interacting Massive Particles, which are searched for using underground neutrino detectors in CEvNS events[1]. In CEvNS, a neutrino scatters off of a target nucleus which recoils coherently, from which the recoil energy is transferred into scintillation light. We will be working with the coherent scattering of ^{8}B solar neutrinos, produced by:

$$^{8}B \rightarrow \, ^{7}Be^{*} + e^{+} + \nu_e$$

This process produces the greatest flux of neutrinos from astrophysical sources that constitute the dominant background in WIMP recoil signals. With the elimination of the background through threshold recoil energy cuts, the WIMP-nucleon cross section scales linearly with the detector, whereas in the presence of a background the scaling must be modified. Other background neutrino sources, including helium-proton *(hep)* , atmospheric, and supernova neutrinos are not considered as they offer minimal contribution to the neutrino background compared to the ^{8}B process.

COHERENT ELASTIC NEUTRINO-NUCLEUS SCATTERING

In CEvNS, one of the definitive traits of a detector is the differential cross section. This is usually defined as a function of T, the recoil kinetic energy, E_ν, the energy of the scattering neutrino, and M, the mass of the nuclear target. This differential cross section is given by:

$$\frac{d\sigma(E_\nu,T)}{dT} = \frac{G_f^2}{4\pi} Q_w^2 M \left(1 - \frac{MT}{2E_\nu^2}\right) F(Q^2)^2$$

G_f is the Fermi coupling constant in natural units, the weak nuclear charge is $Q_w = N - (1 - 4\sin^2\theta_w)Z$, where N is the number of neutrons and Z is the number of protons in the target nucleus, and θ_w is the weak mixing angle. M is the mass of the nucleus given by $M = AM_N$, where $A = N + Z$ is the mass number and $M_N = 931$ MeV is one atomic mass unit in natural units.

The form factor, $F(Q^2)^2$, is a function of the four momentum and measures the deviation from coherence at high recoil energies. Assuming complete coherence, we will ignore the form factor for this analysis. Typical nuclear targets for CEvNS examined in this work include noble gases such as xenon and argon, for which we anticipate a nuclear recoil on the order of keV, with incident neutrino energies in the ~1-100x10^3 keV range.

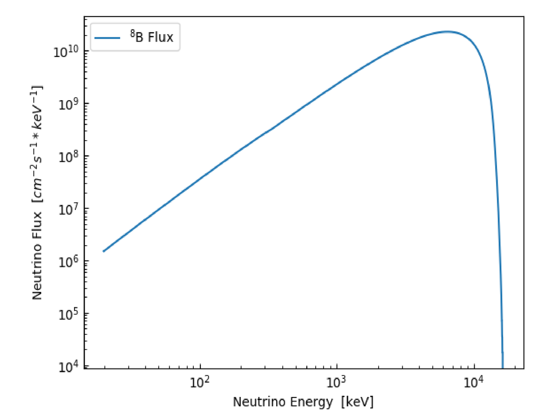

Figure 1. Flux for ^{8}B solar neutrino background. The ^{8}B process dominates all other astrophysical and atmospheric neutrino background processes for neutrino energies less than ~16x10^3 keV.

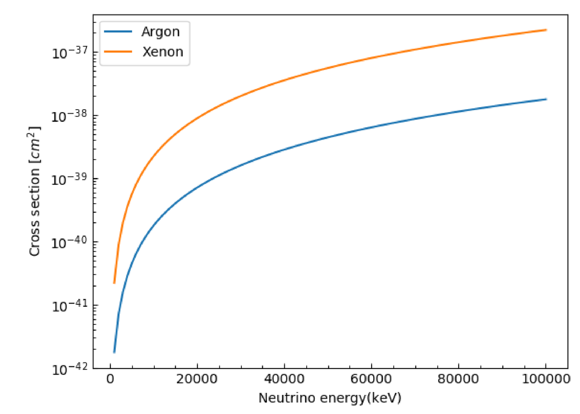

Figure 2. Scattering cross section as a function of neutrino energy for two nuclear targets, xenon and argon. Note that cross section is larger for xenon, the larger nuclear target.

The range of possible recoil kinetic energies for a struck nucleus is 0 to T_{max}, defined as:

$$T_{max} = \frac{2E_\nu^2}{M + 2E_\nu}$$

The events presented here will exist within the regime of $M \gg 2E_\nu$, where there is a corresponding minimum neutrino energy for a fixed recoil energy is given by:

$$E_{\nu,min} = \sqrt{MT/2}$$

EVENT RATES

To find event rates, we must first determine the cross sections of the nuclear targets[2]. We do this by integrating the expression of the differential cross section over the range of T for the two nuclear targets, xenon and argon.

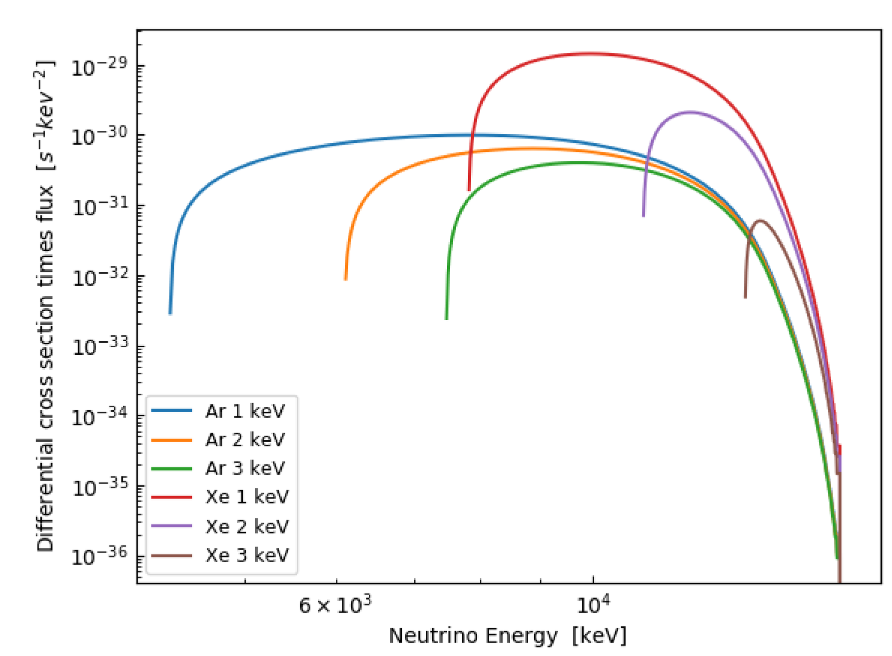

Figure 3. Differential cross section multiplied by flux as a function of neutrino for two nuclear targets, xenon and argon. This figure shows the range of neutrino energies probed by a given recoil energy T. This is important for understanding the mapping between incoming neutrino energy and outgoing nucleus energy.

To find the event rate, we integrate the differential event rate[3] given by:

$$\frac{dR(T)}{dT} = \int_{E_{\nu,min}}^{\infty} \frac{d\sigma(E_\nu,T)}{dT}\frac{dN}{dE_\nu}dE_\nu$$

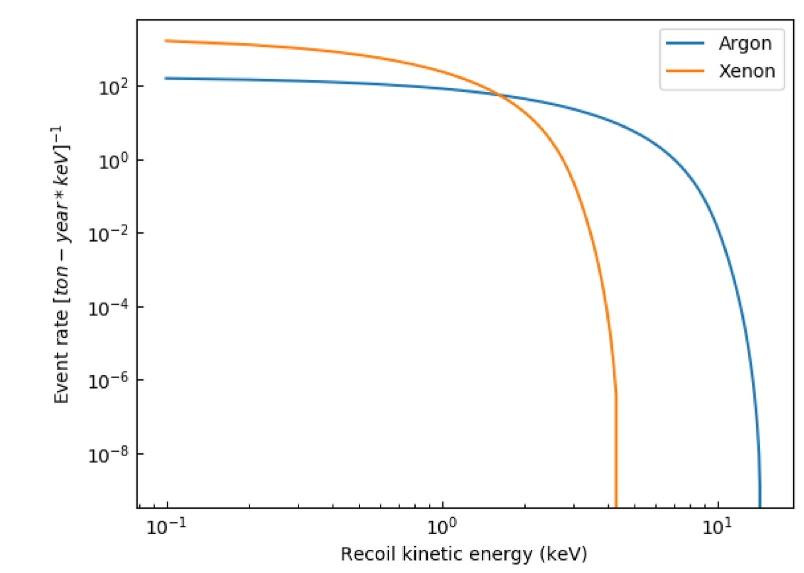

Figure 4. Event rate R(T) for two nuclear targets, xenon and argon.

EVENTS ABOVE THRESHOLD

We return to the elimination of the ^{8}B background by introducing a threshold kinetic energy, T_{min}. To model the nuclear recoil events over a threshold kinetic energy we integrate the event rate over a range from T_{min} to T_{max} and plot the results as a function of the threshold kinetic energy.

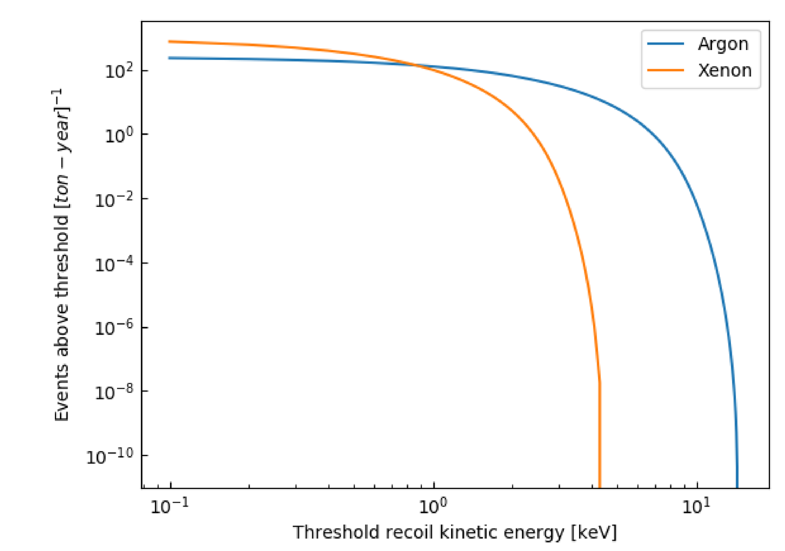

Figure 5. Events above threshold recoil energy for two nuclear targets, xenon and argon.

From Figures 4 & 5, we show that most of the ^{8}B coherent scattering events are confined to low recoil energy regimes. We expect future detectors to have thresholds ~5 keV, where a significant increase in ^{8}B detections would be seen if thresholds were lowered. The introduction of the threshold recoil energy eliminates the ^{8}B neutrino background, which indicates that the WIMP-nucleon cross section will scale linearly with the detector.

CONCLUSION

In this project, we have presented the ^{8}B produced solar neutrino recoil spectrum at dark matter detectors, and our model predicts ~10^3 ^{8}B and ~10^2 ^{8}B scattering events detected over all threshold recoil energies for xenon and argon detectors respectively. With the elimination of the ^{8}B neutrino background, the WIMP-nucleon cross section scales linearly with the detector, indicating a greater likelihood of detecting WIMP interactions. In future work, we intend to model variations in these theoretical recoil spectra due to variability in the Fermi coupling constant, using Markov Chain Monte Carlo (MCMC) sampling.

CITATIONS

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