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 (CEνNS) events in search of Weakly Interacting Massive Particles (WIMPs), a leading dark matter candidate. We focus on the $^8$B solar neutrino background. The $^8$B process dominates all other astrophysical and atmospheric neutrino background processes for neutrino energies less than $\sim 10^4$ keV. The range of possible recoil kinetic energies for a struck nucleus is $0$ to $T_{\text{max}}$, defined as:

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

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 given by:

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

EVENT RATES

To find event rates, we must first determine the cross sections of the nuclear targets. 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.

INTRODUCTION

Dark matter searches attempt to determine the source of $\sim 23\%$ 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 CEνNS events. In CEνNS, 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:

$$^8B \rightarrow ^7Be + e^- + \nu_e$$

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-neucleon 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 CEνNS, 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, $E_{\nu}$, the energy of the scattering neutrino, and $M$, the mass of the nuclear target. This differential cross section is given by:

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

$G_F$ is the Fermi constant coupling in natural units, the weak nuclear charge is $Q = N - (1 - 4\sin^2\theta_W)Z$, where $N$ is the number of neutrons and $Z$ is the number of protons in the target nucleus, and $\theta_W$ is the weak mixing angle. $M$ is the mass of the nucleus given by $M_{\text{el}} + M_{\text{Z}}$, where $A\text{=Ne}Z$ is the mass number and $M_{\text{Ne}}=931$ 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 CEνNS 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 $\sim 10^{3}$ to $10^{4}$ keV range.

CITATIONS


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