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Contents
SOLAR NEUTRINOS AS BACKGROUND IN DIRECT DARK MATTER SEARCHES.

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Abstract. The coherent contribution of all neutrons in neutrino nucleus scattering due to the neutral
   current is examined considering the boron solar neutrinos. These neutrinos could potentially become
   a source of background in the future dark matter searches aiming at nucleon cross sections in the
   region well below the $10^{-10}$ pb, i.e a few events per ton per year.

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INTRODUCTION.

The universe is observed to contain large amounts of dark matter [1, 2], and its contribution to the total energy density is estimated to be $\sim 25\%$. Even though there exists firm indirect evidence from the halos of dark matter in galaxies and clusters of galaxies it is essential to detect matter directly.

The possibility of direct detection, however, depends on the nature of the dark matter constituents, i.e the WIMPs (weakly interacting massive particles). Supersymmetry naturally provides candidates for these constituents [3]. In the most favored scenario of supersymmetry, the lightest supersymmetric particle (LSP) can be described as a Majorana fermion, a linear combination of the neutral components of the gauginos and higgsinos. Other possibilities also exist, see, e.g. some models in universal theories with extra dimensions [4],[5]. Since the WIMPs are expected to be very massive ($m_{\text{WIMP}} \geq 30$ GeV) and extremely non-relativistic with average kinetic energy $\langle T \rangle \simeq 50$ keV ($m_{\text{WIMP}}/100$ GeV), a WIMP interaction with a nucleus in an underground detector is not likely to produce excitation. As a result, WIMPs can be directly detected mainly via the recoil of a nucleus $(A,Z)$ in elastic scattering. The event rate for such a process can be computed by a standard procedure (see recent work [6] and references therein). Since the particle physics parameters will most likely result in very small cross sections, the future dark matter experiments, like the XENON-ZEPLIN [7], aim at detecting 10 events per ton per year. At this level one may encounter very bothersome backgrounds. One such background may come from the high energy boron solar neutrinos [6], [8] (the other neutrinos are characterized either by too small energy or much lower fluxes).

During the last years various detectors aiming at detecting recoiling nuclei have
been developed in connection with dark matter searches [7] with thresholds in the few keV region. Furthermore it has become feasible to detect neutrinos by measuring the recoiling nucleus in gaseous detectors with much lower threshold energies [9], exploiting the neutral current interaction [10]. This interaction, through its vector component, can lead to coherence, i.e. an additive contribution of all neutrons in the nucleus.

In this paper we will calculate the recoil spectrum for boron solar neutrinos and compare it with that associated with WIMPs, both for a light and a heavy target.

A BRIEF DISCUSSION OF THE RATES FOR DIRECT WIMP DETECTION

Before proceeding with the evaluation of the event rate for nuclear recoils originating from the neutrino nuclear scattering we will briefly summarize the results recently obtained [6]. The event rate for the coherent WIMP-nucleus elastic scattering, which is given by:

\[
R = \frac{\rho(0)}{m_{\chi^0}} \frac{m}{m_p} \sqrt{\langle \nu^2 \rangle} \sigma_{p,\chi^0,\mu_r(A)}^{S,\mu_r(A)} \left( A t_{coh} (1 + h_{coh} \cos \alpha) \right)
\]

(1)

where \( \sigma_{p,\chi^0}^{S,\mu_r(A)} \) is the coherent WIMP-nucleon cross section, \( \mu_r(A) \) the WIMP-nucleus reduced mass. The parameter \( t_{coh} \) takes into account the folding of the nuclear form factor with the WIMP velocity distribution, \( h_{coh} \) deals with the modulation [11] due to the motion of the Earth and \( \alpha \) is the phase of the Earth (zero around June 2nd).

The number of events in time \( t \) due to the scalar interaction, which leads to coherence [6], is:

\[
R \approx 1.60 \times 10^{-3} \times \frac{t}{1\text{y}} \frac{\rho(0)}{0.3\text{GeVcm}^{-3}} \frac{m}{1\text{Kg}} \frac{\sqrt{\langle \nu^2 \rangle}}{280\text{km s}^{-1}} \frac{\sigma_{p,\chi^0}^{S,\mu_r(A)}}{10^{-6}\text{pb}} f_{coh}(A, \mu_r(A))
\]

(2)

Assuming a constant nucleon cross section we get the differential rate indicated in Fig. 1. The total (time averaged) coherent event rate is shown in Fig. 2.

ELASTIC NEUTRINO NUCLEON SCATTERING

The cross section for elastic neutrino nucleon scattering has extensively been studied. It has been shown that at low energies it can be simplified and be cast in the form: [12],[13]:

\[
\left( \frac{d\sigma}{dT_N} \right)_{weak} = \frac{G_F^2 m_N}{2\pi} \left[ \left( g_V + g_A \right)^2 + \left( g_V - g_A \right)^2 \left[ 1 - \frac{T_N}{E_\nu} \right]^2 + \left( g_A^2 - g_V^2 \right) \frac{m_N T_N}{E_\nu^2} \right]
\]

(3)
where $T_n$ is the energy of the nucleon, $m_N$ the nucleon mass and $g_V, g_A$ are the weak coupling constants:

$$g_V = -2\sin^2 \theta_W + 1/2 \approx 0.04 \quad g_A = \frac{1.27}{2}, \quad (\nu, p) \quad g_V = -1/2 \quad g_A = -\frac{1.27}{2}, \quad (\nu, n)$$

The elastic neutrino nucleus scattering is given by:

$$\left( \frac{d\sigma}{dT_A} \right) \text{weak} = \frac{G_F^2 m_N}{2 \pi} \left( N^2/4 \right) F^2(q^2) \left( 1 + (1 - T_A/E_\nu)^2 - \frac{A m_N T_A}{E_\nu^2} \right)$$

(5)

where $T_A$ is the energy of the recoiling nucleus and $F(q^2) = F(T_A^2 + 2A m_N T_A)$

To proceed further we must convolute the cross section with the neutrino spectrum. For the relevant boron solar neutrinos the normalized spectrum is shown in Fig. 3. The expected total neutrino flux is $\Phi_\nu = 5.15 \times 10^6 \text{cm}^2 \text{s}^{-1}$. The obtained differential cross section is shown in Fig. 4. Note that the cross section has been almost completely depleted beyond energies 1 and 5 keV for an intermediate ($^{131}$Xe) and light ($^{32}$S) targets respectively. Integrating the differential cross section down to zero threshold we find the event rates given in table 1. The event rates are almost two orders of magnitude smaller than the rates for WIMP detection obtained with a nucleon cross section of $10^{-9} \text{pb}$. 

**FIGURE 1.** We show the differential event rate $dR_{coh}/dQ$ for the coherent process, as a function of the energy transfer, for a WIMP mass, $m_\chi$, of 100 GeV in the case of $^{131}$Xe on the left and $^{32}$S on the right.

**FIGURE 2.** We show the total event rate for the coherent process as a function of the WIMP mass in the case of $^{131}$Xe for zero threshold on the left and 10 keV on the right.
Thus such neutrinos cannot be a serious background for WIMP searches in the region $10^{-9} - 10^{-10}$ pb. In any event, as we will see below, the neutrino induced recoils are less of a background problem in the realistic case of non zero energy threshold.

We should mention that the obtained rates are independent of the neutrino oscillation parameters, since the neutral current events are not affected by such oscillations. The above results shown in table 1, refer to an ideal detector with zero energy threshold. For a real detector, however, the nuclear recoil events are quenched, especially at low energies. The quenching factor for a given detector is the ratio of the signal height for a recoil track divided by that of an electron signal height with the same energy. The actual quenching factors must be determined experimentally for each target. In the present work we considered \[ Q_{\text{fac}}(T_A) = r_1 \left[ \frac{T_A}{1 \text{ keV}} \right]^{r_2} , \quad r_1 \simeq 0.256 , \quad r_2 \simeq 0.153 \] (6)

Due to the relatively low recoil energies the effect of threshold is crucial (see Fig 5). One clearly sees that the observed events are an order of magnitude down if the energy
TABLE 1. Comparison of the event rates for boron solar neutrino and WIMP detection. In evaluating the latter we assumed a nucleon cross section independent of the mass. The kinematics were obtained assuming two WIMP masses, namely 100 and 300 GeV. NoFF means that the nuclear form factor was neglected.

| target | $R_{\chi}(kg\cdot y)\times \sigma_{w}/10^{-9}pb$ | $R_{\nu}(kg\cdot y)\times \sigma_{w}/10^{-9}pb$ | $R_{\chi}(kg\cdot y)$ | $R_{\nu}(kg\cdot y)$:NoFF |
|--------|---------------------------------|---------------------------------|-----------------|-----------------|
| $^{131}Xe$ | 0.167                           | 0.934 × 10^{-3}                | 0.952 × 10^{-3} |
| $^{32}S$  | 0.033                           | 0.167 × 10^{-3}                | 0.168 × 10^{-3} |

threshold is 1 keV (2 keV) for Xe(S) respectively. Thus with quenching most signals get below the threshold energy of $\approx$ 1 keV. On the other hand the WIMP event rates are almost unaffected, unless the threshold energy becomes larger than 5 keV.

FIGURE 5. The ratio of the total cross section with threshold divided by that with zero threshold respectively. The thick (thin) line correspond to quenching (no quenching). Note that the observed events are an order of magnitude down, if the energy threshold is 1 keV.

CONCLUDING REMARKS

In the present study we considered the elastic scattering of WIMP-nucleus interaction and the corresponding elastic scattering of boron solar neutrinos. Our results can be summarized as follows:

1. The differential cross section for solar neutrinos decreases sharply as the nuclear recoil energy increases. It almost vanishes beyond 1 keV (5 keV) for intermediate (light target), like $^{131}Xe$ ($^{32}S$). On the other the corresponding event rates for WIMPs of mass $\approx$ 100 GeV extend further than 30 (150) keV $^{131}Xe$ ($^{32}S$) respectively.

2. The event rates for boron solar neutrinos at zero threshold energy and no quenching are 2-3 orders of magnitude smaller than those for WIMPs with a nucleon cross section $10^{-9}pb$. Thus solar neutrinos are not a serious background down to $10^{-10}pb$.

3. Since the nuclear recoil energy in solar neutrino scattering is smaller than that associated with heavy WIMPs, one can further substantially decrease its contribution by restricting the observation above a few keV without seriously affecting the corresponding WIMP rates. Thus neutrinos do not appear to be a serious background even at the level of $10^{-11}pb$. 

4. One may reduce this background still further by exploiting the quenching factors.
5. One may diminish this background further by exploiting the annual modulation of the signal (see e.g. [11] and references there in) or even better by performing directional experiments [14], [15], in which the direction of recoil is also measured, one will be able to select WIMP signals and discriminate against neutrino scattering.

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