Coherent elastic scattering between neutrinos and nuclei*

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Abstract

In the limit of low momentum transfer for neutrino nuclei elastic scattering is expected to observe a coherent superposition that increases the nucleus cross section. This effect was already observed for scattering for electrons, but due to experimental difficulties it have never been verified in neutrino scattering. The next generation of dark matter detectors probably will be sensitive to this interactions.

A study of the expected signal produced by coherent elastic scattering for neutrinos from different sources (solar, atmosphere, diffuse flux from supernovae, reactors and accelerators) was made. Considering a conservative threshold 1 keV, as a detectable nuclear recoil, the most promising source to be observed is the ^8B neutrinos produced in the Sun, with an expected rate of 100 events/(ton·year). Another promising source is the reactor, but the use of this source is quite dependent of the possible distance between reactor and detector. For a detector far 1 km from the reactor it is expected 10 events/(ton·year), but if be possible decrease this distance for 100 m the rate would be increased to 1000 events/(ton·year).

INTRODUCTION

The coherent elastic scattering is the consequence of constructive interference on the interaction of neutrinos and nuclei. It is expected that when the transfered momentum (Q) is small when compared with the nucleus radius (R_0), $QR_0 \lesssim 1$, the neutrino loses the capacity to distinguish among individual nucleons and interact with the atom nucleus as a whole, increasing his cross-section [1, 2]. The equation that describes the neutrino-nucleus coherent elastic scattering as a function of nuclear recoil (T) and incident neutrino energy (E_ν) is:

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

where G_F is the Fermi Constant and M is the nuclear mass. This equation includes a term, $Q_w = N - Z * (1 - 4sin^2\theta_W)$, that describes the coherent superposition of nucleons cross-section (N is number of neutrons and Z is the number of protons and $sin^2\theta_W \simeq 0.231$ is the weak mixing angle) and a form factor, $F(Q^2) = \frac{3}{QR_0} e^{\frac{-(Qs)^2}{2}} \left(\frac{sin(QR_0)}{(QR_0)^2} - \frac{cos(QR_0)}{QR_0}\right)$, to describe the loss of coherence with increasing momentum transfer ($R_0^2 = (1.2A^{1/3})^2 - 5s^2$ fm^2

and $s = 0.5$ fm are constants from adopted nuclear model). The form factor can be described as a function of the transfered momentum using the relation $Q^2 = 2MT = E_\nu^2(1 + cos\theta)$.

ATMOSPHERIC NEUTRINOS AND DIFFUSE FLUX FROM SUPERNOVAE NEUTRINOS

Atmospheric neutrinos are produced by cosmic ray interactions in the atmosphere [3]. Neutrinos from diffuse flux from supernovae are a stationary flux originated on the superposition of bursts emitted by all supernovae [4]. As can be seem in Fig. 1, both categories present relatively low fluxes, making difficult their detection. Recently, they attracted more interest once they can imitate the WIMP expected signal in direct search for dark matter [5].

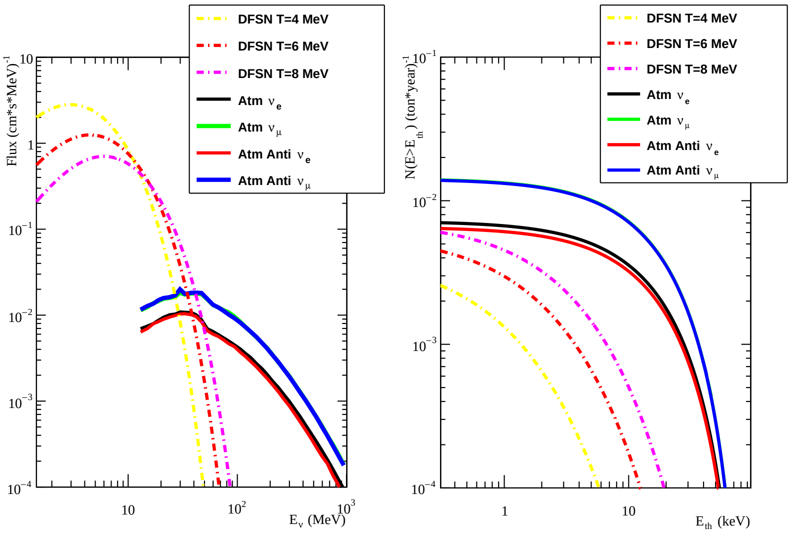

FIG. 1: Fluxes and expected number of events over threshold for atmospheric neutrinos and diffuse flux from supernovae neutrinos.

SOLAR NEUTRINOS

Solar neutrinos are produced in the nuclear reaction in the solar core and quickly reach the Earth. Their fluxes are relativily large, but their energies go just up to ~ 20 MeV, what limitates theirs detection once the maximum nuclear recoil (T_{max}) for a nucleus with mass (M) produced by a neutrino with energy E_ν is given by $T_{max} = E_\nu^2/M$, as showed in Fig. 2.

In this work was used the fluxes from Bahcall Website (http://www.sns.ias.edu/ jnb/) and the monoenergetic fluxes are not considered.

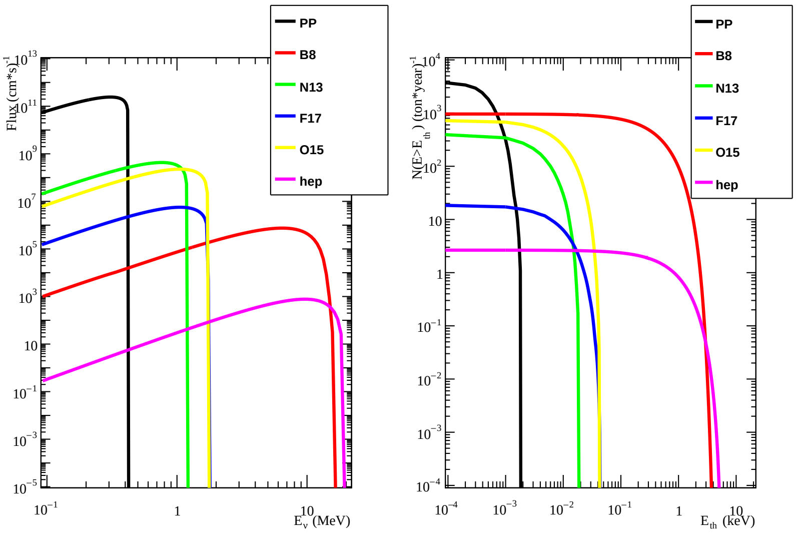

FIG. 2: Fluxes and expected number of events over threshold for solar neutrinos.

REACTOR NEUTRINOS

An preliminary extension of this study was made considering reactor neutrinos. These sources have their fluxes quite dependent of the used setup (distance, power, etc). In this work, to estimate a rate of coherent elastic scattering on xenon due to reactor neutrinos was used the neutrino spectrum presented in [6], considering also 100% ^{235}U composition, 5 GW thermal power and 1 km of distance between the reactor and the detector. The results are showed in Fig. 3.

CONCLUSIONS

It is expected that neutrino-nuclei coherent elastic scattering be observed soon. The improvement in detection techniques allows to observe nuclear recoils with energies in order of 1 keV in ton scale detectors. The neutrino background represents a limit on the sensitivity that direct dark matter detectors can reach, once they can interact through coherent elastic scattering with nuclei. In this work we reproduced the results in [5] with good agreement and extended the study to neutrinos from reactors and accelerators.

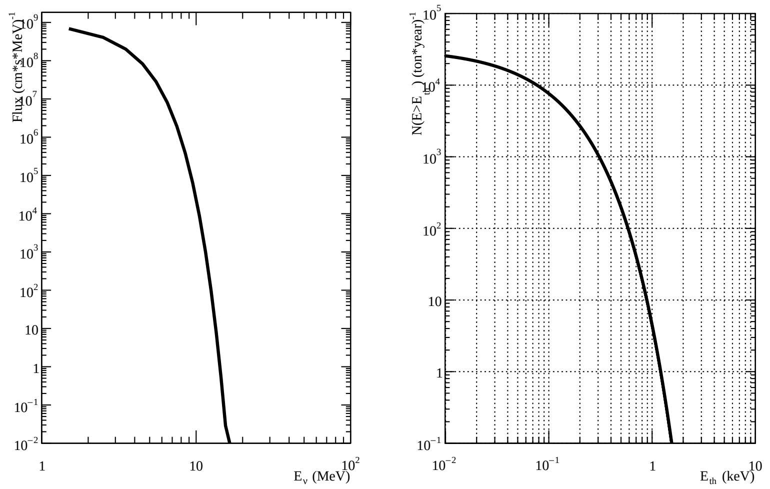

FIG. 3: Fluxes and expected number of events over threshold for reactor neutrinos.

The best source to detect neutrino-nuclei coherent elastic scattering considering a threshold of 1 keV should be the solar neutrinos from ^8B with $\sim$ 100 events/(ton·year). Another good source should be the reactor, but in this case the viability is too much dependent of setup, mainly the distance. The case showed in Fig. 3 presents a rate of $\sim$ 10 events/(ton·year), but this number can be increased up to $\sim$ 1000 events/(ton·year) if the detector could be placed 100 m far from reactor.

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