Recent experimental developments on coherent neutrino-nucleus interactions and related aspects

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Abstract. In this article a new technique for neutrino detection using CCDs is presented.

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INTRODUCTION

Since its invention as memory devices, CCDs have been widely used as imaging detectors because of their capability to obtain high resolution digital images of objects placed in its line of sight. In particular, scientific CCDs have been extensively used in ground and space-based astronomy and X-ray imaging. The combination of high detection efficiency, low noise, good spatial resolution, low dark current and the capability to make them thicker (more detection mass) has encouraged its use for the detection of other kind of particles such as neutrons, dark matter in DAMIC experiment, etc. In this article presents the analysis to extend its use to neutrino detection. In particular its capabilities are analyzed considering a source of low energy neutrino such as a nuclear reactor which produces antineutrinos up to 12MeV of energy. This also gives the bases for a new neutrino experiment called CONNIE to be installed a nuclear the Angre Nuclear Plant in Brazil in 2013.

One of the most important features of CCDs is their very low noise (7eV) [**? ? ?**] which allows the detection of low energy nuclear recoils what highly increases the total cross section of the detector by the coherence of the neutrino-nucleus scattering interaction. This extra cross section given by its low energy threshold compensates the use of tons-massive detectors, and opens a new window in neutrino detection. In fact, available CCDs nowadays, allows the construction of CCD based detectors in volumes less than 1000cm3 with silicon active masses of 10g to 100g, like it was built for dark matter detection for the DAMIC experiment [**?**]. The low energy threshold can also give very good information about the physics involved in the neutrino-nucleus coherent scattering which has never been observed.

NEUTRINO INTERACTION WITH MATTER

The mayor contribution to the total cross section of neutrinos with matter depends on the energy range of interest. In this case, a nuclear reactor is assume as a source of neutrinos for a first test and therefore the range of interest covers the low energy part up to 12 MeV.

For reactor antineutrinos ($\bar{\nu_e}$) the larger cross section is given by the neutrino-nucleus coherent neutral current interaction, as was mentioned before. In this process, a neutrino of any flavor scatters off a nucleus transferring some energy. The standard model cross section for this process is given by [**?**]:

$$\frac{d\sigma}{dE_{rec}} = \frac{{G_F}^2}{8\pi}[Z(4sin^2\theta_w - 1) + N]^2 M(2 - \frac{E_{rec}M}{{E_v}^2})|f(q)|^2$$

where M, N and Z are the mass, neutron number and atomic number of the nucleus, respectively, E_v is the neutrino energy and E_{rec} is the nucleus recoil energy, $f(q)$ is the nucleus form factor at momentum transfer q. This form factor can be used in good approximation as $|f(q)| \sim 1$ (the corrections are a few percent only)[referencia]. This formula is

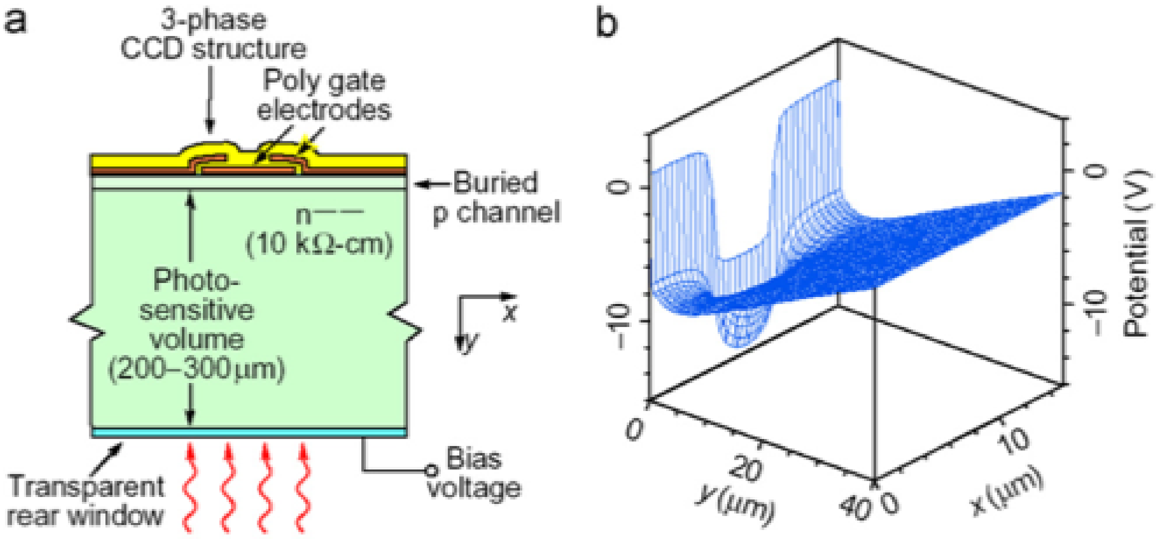

FIGURE 1. Fig. 1. CCD structure

applicable at E_ν <50 MeV where the momentum transfer (Q^2) is small such that $Q^2R^2 < 1$, where R is the nuclear size[referencia]. At low momentum transfer, the nucleon wave function amplitudes are in phase and add coherently, so the cross section is enhanced by $\sim N^2$.

In spite of the enhanced cross section by coherence ($\sim N^2$), this elastic neutrino nucleus scattering has been difficult to observe due to the very small resulting nuclear recoil energies: the maximum recoil energy is $\sim 2E_\nu^2/M$, which is in the sub-Mev range. This measurement requires very low sensitivity detectors and very good control of the background.

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3.9 GW REACTOR $\bar{\nu}_e$ FLUX AT 30 METERS

In particular, it is interesting for the flux calculation to assume the real setup condition expected at the Angra Nuclear Plant: detector at 30 meters from a core of 3.95GW of thermal power. This scenario proposes a real situation for a neutrino experiment and gives the bases for the CONNIE experiment. In the order of 3.12×10^{16} fissions per second are held in a reactor per 1MW of thermal power, so in a reactor of power P (in MW) a number of $3.12\times10^{16}\times P$ are produced per second. As the reactor is an isotropic source of neutrinos, the neutrino flux at a distance L from the core is reduced by a factor of $4\pi L^2$, so the total neutrino flux at the detector is $7.3\times3.12\times10^{16}\times P/(4\pi L^2)$ = $22.7\times10^{16}\times P/(4\pi L^2)$, and the total spectrum of neutrino at the detector is the total spectrum shown in fig. **??** multiplied by the factor $3.12\times10^{16}\times P/(4\pi L^2)$ [**?** **?**]. For the CONNIE experiment, the total flux for all energies is 6.6×10^{12} $\bar{\nu}_e/cm^2/seg$.

EVENT ANALYSIS IN CCDS

This section is intended to cover the analysis of nuclear recoils events in silicon detectors assuming a nuclear reactor as the neutrino source. Using the differential cross section, the total antineutrino spectrum and the expected flux at the detector in the Angra Nuclear Plant revised below, the expected event spectrum in the detector is calculated and shown in figure **??**. The total number of events in the detector is 32.7 per day per kg, and assuming a 35eV threshold energy (5 times the RMS value of the CCDs) the number of events is 27.

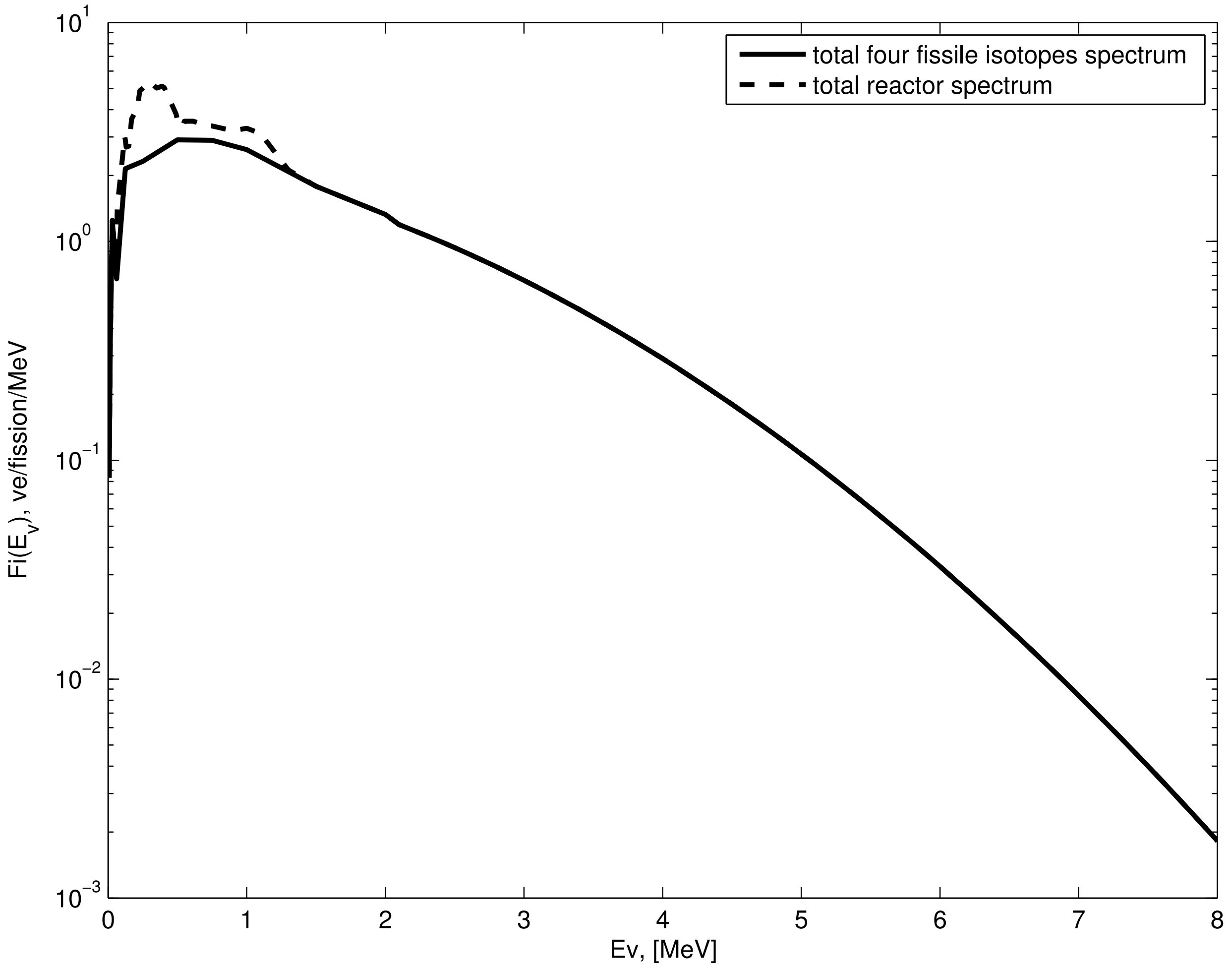

FIGURE 2. Total reactor antineutrino spectrum.

CONCLUSION

We have shown that the use of CCDs is a promising technique for detecting neutrinos. Their low noise level, good spatial resolution and the new available thicker substrates permits the detection of very low energy depositions what enhances the total cross section of the detector and allows the construction of low mass neutrino detectors. These detectors also allow the measurement of the coherent neutrino-nucleus cross section which has never been observed.

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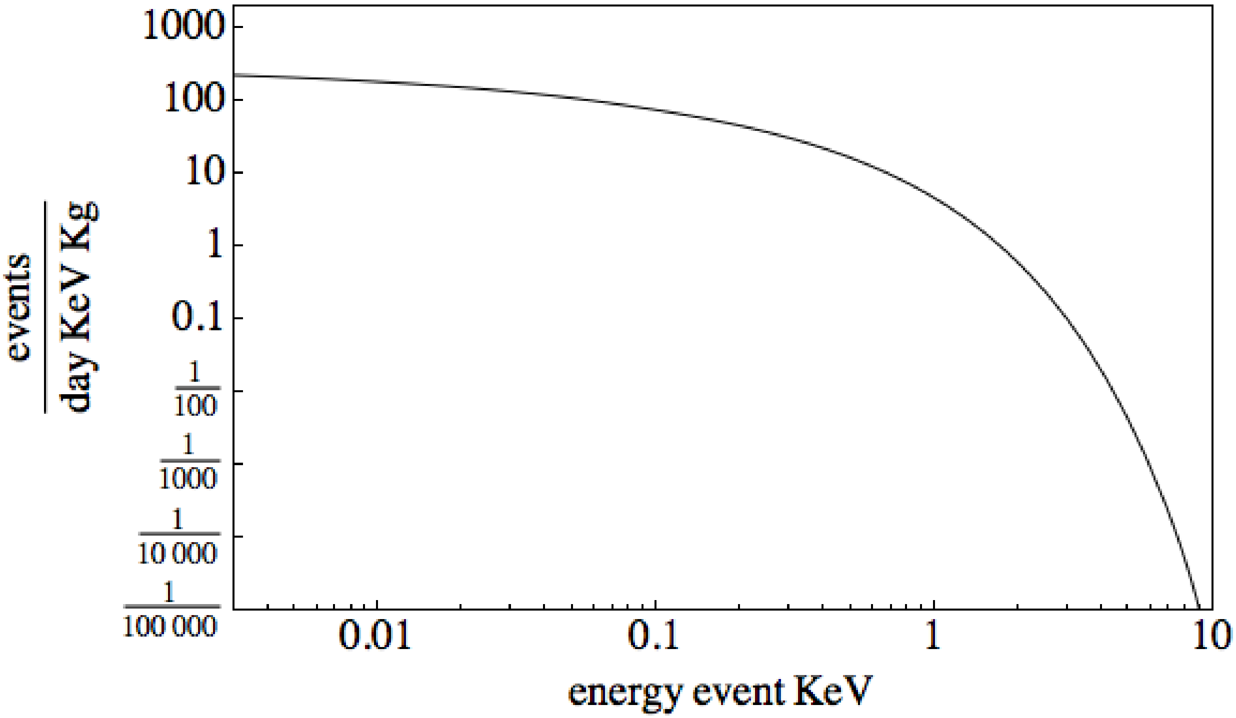

FIGURE 3. Spectrum of nuclear recoils events expected in Silicon detectors.

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