Notes on Xe code

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In order to accurately describe the neutrinos produced in the Sun, and to be able to take into account possible NSI effects in the neutrino-matter interaction, we will use the expression for the differential neutrino rate [1]

$$\frac{dR}{dT} = N_T \int \frac{d\phi_\nu}{dE_\nu} Tr\left[\rho \frac{d\zeta}{dT}\right] dE_\nu \tag{1}$$

where T is the recoil energy, N_T the number of targets in the detector, $\frac{d\phi_\nu}{dE_\nu}$ the neutrino flux at the source, ρ is the density matrix, and $\frac{d\zeta}{dT}$ is the generalized differential cross-section. We need these three ingredients to make our rate, and we will be ready to rock and roll.

The neutrino flux at the source can be obtained from [2], Figure 2; we just need to interpolate in the ^8B line. This is the expected flux at the Earth (this is, $L = 1\, a.u.$) without oscillations, so it is the flux at the source, but already measured in Earth.

For the density matrix, we just follow [1]. The entries are given in eqs. 35 - 40. The most remarkable thing is that the matter-modified solar mixing angle, θ_{12}^m, is averaged over all the Solar radius, using a ^8B solar distribution function extracted from [3], Figure 2.8.

Finally, for the generalized cross-section we take the usual expression of the CEνNS cross-section, using the Menéndez form factor we are interested in studying [4]. First, as we are now interested in Xenon, we have to change the nuclear response functions, with a parametrization now given in [5], where we have to take into account the relative abundance of each Xenon isotope. Also, the form factor (and the related cross-section, in general) is in scalar form, as in the reference they assume only one flavor. We generalize their result by adding flavor-general NSI coefficients $\varepsilon_{\alpha\beta}$, which in turn modify the Wilson coefficients in [4], eq. 5:

$$C_q^V \to (C_{q,SM}^V)_{\alpha\beta} = C_q^V \delta_{\alpha\beta} - \sqrt{2} G_F \varepsilon_{\alpha\beta}^{qV} \tag{2}$$

where G_F is the Fermi constant. Then, the rest of the expressions of the cross-section are easily generalized to matrix form.

1 Validation

To validate our code we perform several tests; first, to test verify our differential cross section, we compare it with the one-flavored version we have been using up until now for CsI, getting the same results in all the diagonal entries. We have also checked the behaviour of the nuclear response functions and compared them against the Cs and I functions, obtaining similar behaviours.

Then, to see if the density matrix is correct, the first we did was checking that $Tr\left[\rho\right] = 1$, and that $Tr\left[\rho^2\right] \leq 1$ for several situations. We have computed the first entry, ρ_{ee}, and checked against [6], Figure 1, with good agreement, as can be seen in Figure 1.

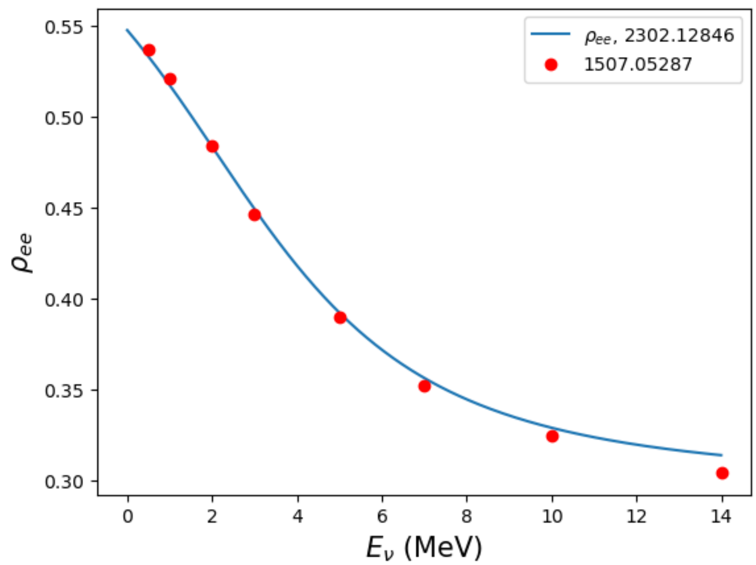

Figure 1: Comparison of first entry of our density matrix with [6].

Then, we perform a full computation of an expected number of events using this formalism. For that, we use the fact that the Borexino collaboration recently measured the flux of ^8B neutrinos from the Sun, obtaining a rate of $0.223\,cpd/100\,ton$ per day [7]. We are going to try to get this number.

First, we apply equation 1. However, Borexino detects electron neutrinos via Electron-neutrino Elastic Scattering ($E\nu ES$), so we will have to use the adequate cross-section (in eq. 49 of [1]).

The integration in neutrino energies is performed between $E_\nu^{min}(T) = 0.5(T + \sqrt{T^2 + 2m_e T})$ [1] and $16\,MeV$, the maximum energy for our neutrino flux. We also integrate in electron recoil energy, with a threshold energy $T_{min} = 3.2\,MeV$ [7], and a maximum recoil energy of $16\,MeV$, taking into account that the maximum recoil energy given a neutrino energy E_ν is $T^{max} = E_\nu^2/(E_\nu + m_e/2)$ (which we implement via a Heavyside function when integrating in E_ν) [8]. We also have to compute the number of targets, which can be done assuming 100 tonnes of scintillator material (pseucodumene), and taking into account that the scattering is against electrons. With this, we obtain a rate of $0.235\,cpd/100\,ton$ per day, in good agreement with the collaboration's result, which validates the density matrix computation (and also this cross-section, although it is not the one we are going to be using).

Finally, we can check with [9] the differential rate in Xenon, which they provide in their Figure 1. We now use the CEνNS cross section and Xenon data, obtaining Figure 2.

As can be seen, we get a very good agreement, which validates the use of the cross section and density matrix together.

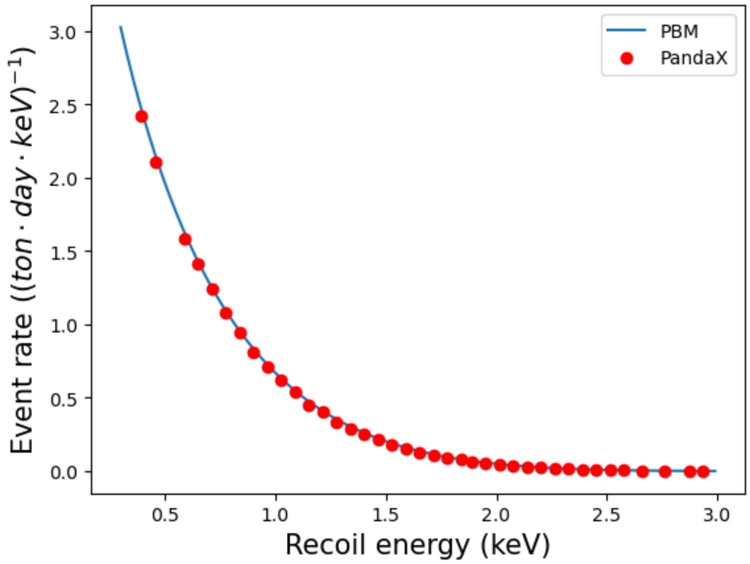

Figure 2: Differential rate fror ^8B solar neutrinos' CEνNS in Xenon, compared with [9].

References

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A Cross section normalization for curve plotting

In order to get the adequate normalization for our cross section, normalized the cross section given in the DR so that $\langle\sigma\rangle_\Phi(SM) = 1$. In this way we are actually plotting

$$\frac{\langle\sigma\rangle_\Phi}{\langle\sigma\rangle_\Phi(SM)}$$

Then this expression is what corresponds to the value of our multiplicative constant $k = 1$, since we are inputting in our computation

$$\frac{d\sigma}{dT} \to k\frac{d\sigma}{dT}$$

and so for $k = 1$ we would be just using the SM cross section.