Neutrino decay in dense matter

C.R. Das and **João Pulido**

Centro de Física Teórica de Partículas
Instituto Superior Técnico
Avenida Rovisco Pais, 1
1049-001 Lisbon
Portugal

Phys.Rev.D **83** (2011), 053009

Introduction

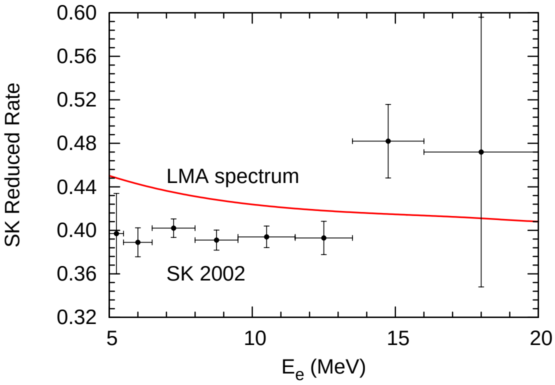
Although apparently dormant in the past three years, solar neutrinos is by no means a closed subject. In fact:

1. The low energy sector is still poorly known.
2. The widely accepted solution for the $\odot$ ν problem, LMA, is likely not to be the ultimate solution because of the discrepancy

R_{Cl}=2.9 - 3.1 SNU (LMA prediction)
R_{Cl}=2.56 $\pm$ 0.21 SNU (experimental)

Introduction

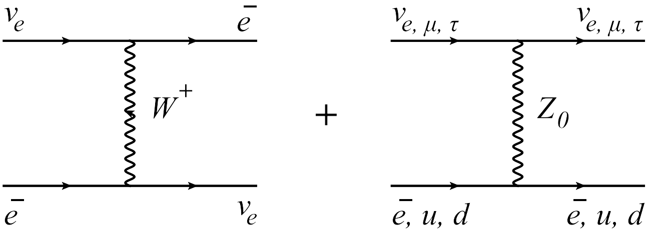
More important, may be the discrepancy



The LMA prediction for SuperKamiokande spectrum shows a negative slope against the energy whereas the data appear to be flat (the same for more recent data).

The Hamiltonian

In the standard case



Contribution from all four diagrams → interaction potential

$$V(SI) = V_c + V_n = G_F\sqrt{2}N_e\left(1 - \frac{N_n}{2N_e}\right)$$

where $V_c = (V_e)_{CC} = G_F\sqrt{2}N_e$ (CC contribution from electrons), $V_n = -(G_F/\sqrt{2})N_n$ (contribution from neutrons, NC only).

The Hamiltonian

In the non-standard case we consider

$$V(NSI) = G_F\sqrt{2}N_e\left[(\varepsilon^{eP}_{\alpha\beta})_{CC} + \left(-\frac{1}{2} + 2sin^2\theta_W\right)(\varepsilon^{eP}_{\alpha\beta})_{NC} + \left(1 - \frac{8}{3}sin^2\theta_W + \frac{N_n}{2N_e}\right)\varepsilon^{uP}_{\alpha\beta} + \left(-\frac{1}{2} + \frac{2}{3}sin^2\theta_W - \frac{N_n}{N_e}\right)\varepsilon^{dP}_{\alpha\beta}\right]$$

The full interaction potential is

$$V = V(SI) + V(NSI)$$

and the matter Hamiltonian

$$\mathcal{H}_M = G_F\sqrt{2}N_e\begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} + \begin{pmatrix} v_{ee}(NSI) & v_{e\mu}(NSI) & v_{e\tau}(NSI) \\ v_{\mu e}(NSI) & v_{\mu\mu}(NSI) & v_{\mu\tau}(NSI) \\ v_{\tau e}(NSI) & v_{\tau\mu}(NSI) & v_{\tau\tau}(NSI) \end{pmatrix}$$

$v_{\alpha\beta}$ (e, μ, τ) are the matrix elements of matrix $V(NSI)$

NSI couplings (ε) and numerical results

Our aims:

- Increase flatness of SK spectrum
- Improve Cl rate prediction
- Keep the quality of other rate predictions

Recall that each NSI Hamiltonian entry $v_{\alpha\beta}$ is a combination of parameters $\varepsilon_{\alpha\beta}^{e,u,d}$ of the form

$$v_{\alpha\beta} = (\varepsilon_{\alpha\beta}^{e})_{CC} + A(\varepsilon_{\alpha\beta}^{e})_{NC} + B\varepsilon_{\alpha\beta}^{u} + C\varepsilon_{\alpha\beta}^{d}$$

with $A,\ B,\ C$ as given before (they are functions of $\theta_W,\ N_e,\ N_n$).

We organize the ε's ($\varepsilon_{\alpha\beta}^{e,u,d} = |\varepsilon_{\alpha\beta}^{e,u,d}|e^{i\phi_{\alpha\beta}^{e,u,d}}$) in three matrices according to whether the charged fermion in the external line is $e,\ u,\ d$:

$$\begin{pmatrix} \varepsilon_{ee}^{e,u,d\ P} & \varepsilon_{e\mu}^{e,u,d\ P} & \varepsilon_{e\tau}^{e,u,d\ P} \\ \varepsilon_{e\mu}^{*e,u,d\ P} & \varepsilon_{\mu\mu}^{e,u,d\ P} & \varepsilon_{\mu\tau}^{e,u,d\ P} \\ \varepsilon_{e\tau}^{*e,u,d\ P} & \varepsilon_{\mu\tau}^{*e,u,d\ P} & \varepsilon_{\tau\tau}^{e,u,d\ P} \end{pmatrix}.$$

and analyse one coupling at a time (taking all others zero).

NSI couplings (ε) and numerical results

Our proposed NSI Hamiltonian is:

$$\mathcal{H}_{\mathcal{NSI}} = G_F\sqrt{2}N_e\left[x_1\begin{pmatrix} \frac{i}{2}\varepsilon & & \\ & -i\varepsilon & \\ & & \frac{i}{2}\varepsilon \end{pmatrix} + x_2\begin{pmatrix} \frac{i}{2}\varepsilon & & \\ & -i\varepsilon & \\ & & \frac{i}{2}\varepsilon \end{pmatrix} + x_3\begin{pmatrix} -\frac{i}{2}\varepsilon & & \\ & i\varepsilon & \\ & & -\frac{i}{2}\varepsilon \end{pmatrix}\right]$$

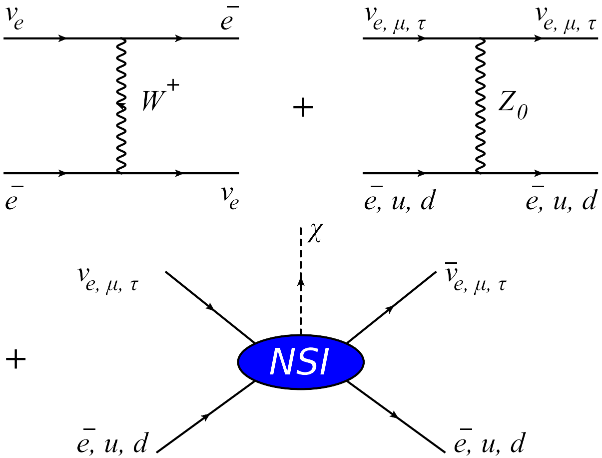
with $\varepsilon = 3.5 \times 10^{-4}$

and the fit with the LMA one:

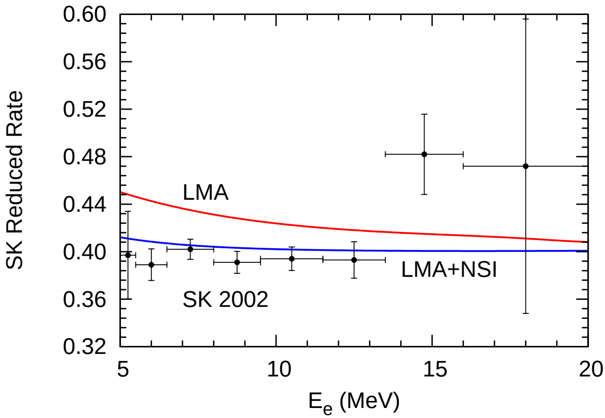
	Ga	Cl	SK	$\mathrm{SNO}_{\mathrm{NC}}$	$\mathrm{SNO}_{\mathrm{CC}}$	$\mathrm{SNO}_{\mathrm{ES}}$	χ^2_{rates}	$\chi^2_{SK_{sp}}$	χ^2_{SNO}	χ^2_{gl}
LMA	64.9	2.84	2.40	5.47	1.79	2.37	0.67	42.0	48.6	91.3
$-i\lvert\varepsilon^{e\,P}_{\mu\mu}\rvert$	69.7	2.74	2.23	5.47	1.68	2.26	0.11	40.3	45.0	85.4

Neutrino decay in solar matter?

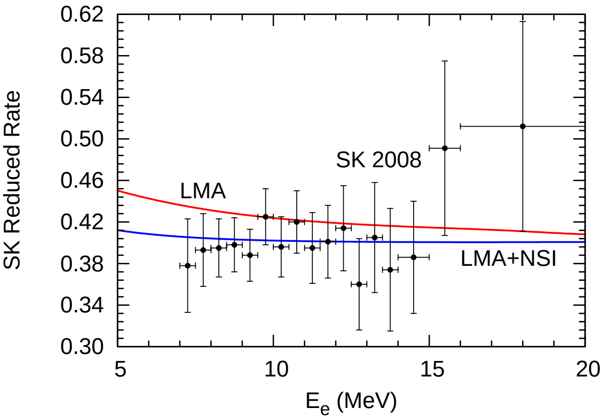
The full physical process in our model for neutrino propagation and decay through NSI in the sun is



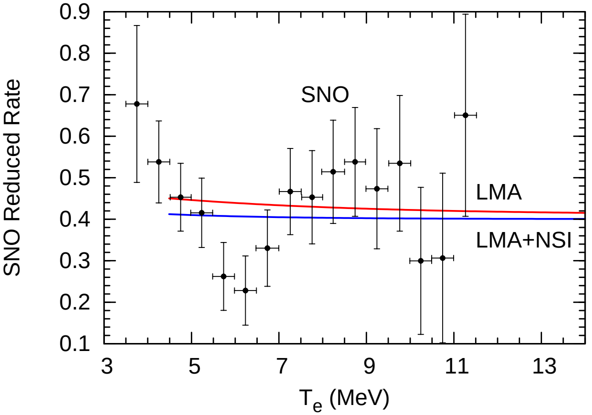
NSI couplings (ε) and numerical results



NSI couplings (ε) and numerical results



NSI couplings (ε) and numerical results



Neutrino decay in solar matter?

We have found the following result:

Any possibility for solving the flatness problem of the LMA predicted spectrum for SK on the basis of NSI requires imaginary diagonal couplings of the Hamiltonian. At the same time the Cl fit is improved and all other fits are preserved.

This implies that neutrino decay is involved in its matter propagation through the sun.

The number of neutrinos and antineutrinos should remain constant as a consequence of unitarity.

Two possibilities

1. Matter enhanced radiative decay or 'neutrino spin-light' $\rightarrow$ far too small in the sun
2. Decay into Majoron with neutrino or antineutrino emission (open possibility)

Neutrino decay in solar matter?

The total probability for $\bar{\nu}_e$ production:

1. is within the Borexino bound by 6 orders of magnitude and
2. within the KamLAND bound by 7-8 orders of magnitude.

To summarize:

Resolving the tension between LMA and the data can be done with NSI and implies neutrino decay in solar matter. This is consistent with the decay into a Majoron and a lighter antineutrino. Our results are independent of the detailed physics of Majoron models.

Neutrino decay in Supernova?

We have extended this model to Supernova simulations, and very important result will be reported in TAUP 2011 (5 - 9 September 2011, Munich, Germany).

The form used for the Hamiltonian in our numerical calculation does not take into account the extra physics of the Majoron models and corresponds therefore to a partial Hamiltonian, whose hermiticity is restored once the detailed Majoron emission process is taken into account.