New interactions: past and future experiments

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Abstract. In this talk I will review the present status and future perspectives of some popular extensions of the conventional three-neutrino oscillation scenario, from a purely phenomenological point of view. For concreteness I will focus only on three specific scenarios: non-standard neutrino interactions with matters, models with extra sterile neutrinos, and neutrino decay and decoherence.

1. Introduction

Most of the talks presented at this conference are devoted to different aspects of what we can call the "*standard*" neutrino oscillation scenario: only three neutrino flavors involved, no interactions beyond those predicted by the Standard Model, and neutrino conversion completely due to non-zero neutrino masses and mixing. In this talk I will instead focus on some of the *alternative* models which along the years have been proposed as possible explanations of the various neutrino anomalies. Since none of these models is presently able to account by itself for all the experimental evidence, I will always consider the case where New Physics is introduced *in addition* to the conventional neutrino masses, rather than *in alternative* to them. In this context, I will discuss the implications of each model for neutrino oscillations, the bounds which can be put on its parameter space from the analysis of present data, and the potentialities offered by futures experiments to further improve these bounds.

The list of non-standard mechanisms for neutrino conversions proposed so far is very large: it includes models of neutrino magnetic moment, long-range leptonic forces, mass-varying neutrinos, violation of fundamental principles, and much more. For definiteness and lack of space, I will focus here only on three models, which in my view have received most of the attention during the last few years: non-standard interactions with matter, extra sterile neutrinos, and neutrino decay and decoherence. Note that my approach in what follows will be purely phenomenological: I will not make any reference to the theoretical motivations of each model, focusing only on its experimental implications.

2. Non-standard interactions with matter

The effective low-energy Lagrangian for neutrino interactions with matter predicted by the Standard Model is:

$$\mathcal{L}_{\text{SM}}^{\text{eff}} = -2\sqrt{2}G_F \sum_{\beta} \left([\bar{\nu}_\beta \gamma_\mu L \ell_\beta][\bar{f}\gamma^\mu L f'] + \text{h.c.} \right) - 2\sqrt{2}G_F \sum_{P,\beta} g_P^f [\bar{\nu}_\beta \gamma_\mu L \nu_\beta][\bar{f}\gamma^\mu P f] \tag{1}$$

Table 1. Present bounds at 90% CL on the NC-like NSI couplings $\varepsilon^{fP}_{\alpha\beta}$ from non-oscillation experiments. Limits have been obtained by varying each $\varepsilon_{\alpha\beta}$ one at a time, with all the others set to zero.

Left-handed	Right-handed	Process	Experiment	Reference
$-0.03 < \varepsilon^{eL}_{ee} < 0.08$	$0.004 < \varepsilon^{eR}_{ee} < 0.15$	$\nu_e e \to \nu e$ $\bar\nu_e e \to \bar\nu e$	LSND Reactors	[5,6]
$-1 < \varepsilon^{uL}_{ee} < 0.3$	$-0.4 < \varepsilon^{uR}_{ee} < 0.7$	$\nu_e q \to \nu q$	CHARM	[7]
$-0.3 < \varepsilon^{dL}_{ee} < 0.3$	$-0.6 < \varepsilon^{dR}_{ee} < 0.5$	$\nu_e q \to \nu q$	CHARM	[7]
$\lvert\varepsilon^{eL}_{\mu\mu}\rvert < 0.03$	$\lvert\varepsilon^{eR}_{\mu\mu}\rvert < 0.03$	$\nu_\mu e \to \nu e$	CHARM II	[6,7]
$\lvert\varepsilon^{uL}_{\mu\mu}\rvert < 0.003$	$-0.008 < \varepsilon^{uR}_{\mu\mu} < 0.003$	$\nu_\mu q \to \nu q$	NuTeV	[7]
$\lvert\varepsilon^{dL}_{\mu\mu}\rvert < 0.003$	$-0.008 < \varepsilon^{dR}_{\mu\mu} < 0.015$	$\nu_\mu q \to \nu q$	NuTeV	[7]
$-0.5 < \varepsilon^{eL}_{\tau\tau} < 0.2$	$-0.3 < \varepsilon^{eR}_{\tau\tau} < 0.4$	$e^+e^- \to \nu\bar\nu\gamma$	LEP	[6,8]
$\lvert\varepsilon^{uL}_{\tau\tau}\rvert < 1.4$	$\lvert\varepsilon^{uR}_{\tau\tau}\rvert < 3$	rad. corrections	τ decay	[7]
$\lvert\varepsilon^{dL}_{\tau\tau}\rvert < 1.1$	$\lvert\varepsilon^{dR}_{\tau\tau}\rvert < 6$	rad. corrections	τ decay	[7]
$\lvert\varepsilon^{eL}_{e\mu}\rvert < 0.0005$	$\lvert\varepsilon^{eR}_{e\mu}\rvert < 0.0005$	rad. corrections	$\mu \to 3e$	[7]
$\lvert\varepsilon^{uL}_{e\mu}\rvert < 0.0008$	$\lvert\varepsilon^{uR}_{e\mu}\rvert < 0.0008$	rad. corrections	$\mathrm{Ti}\,\mu \to \mathrm{Ti}\,e$	[7]
$\lvert\varepsilon^{dL}_{e\mu}\rvert < 0.0008$	$\lvert\varepsilon^{dR}_{e\mu}\rvert < 0.0008$	rad. corrections	$\mathrm{Ti}\,\mu \to \mathrm{Ti}\,e$	[7]
$\lvert\varepsilon^{eL}_{e\tau}\rvert < 0.33$	$\lvert\varepsilon^{eR}_{e\tau}\rvert < 0.28$	$\nu_e e \to \nu e$	LEP+LSND+Rea	[6,8]
$\lvert\varepsilon^{uL}_{e\tau}\rvert < 0.5$	$\lvert\varepsilon^{uR}_{e\tau}\rvert < 0.5$	$\nu_e q \to \nu q$	CHARM	[7]
$\lvert\varepsilon^{dL}_{e\tau}\rvert < 0.5$	$\lvert\varepsilon^{dR}_{e\tau}\rvert < 0.5$	$\nu_e q \to \nu q$	CHARM	[7]
$\lvert\varepsilon^{eL}_{\mu\tau}\rvert < 0.1$	$\lvert\varepsilon^{eR}_{\mu\tau}\rvert < 0.1$	$\nu_\mu e \to \nu e$	CHARM II	[6,7]
$\lvert\varepsilon^{uL}_{\mu\tau}\rvert < 0.05$	$\lvert\varepsilon^{uR}_{\mu\tau}\rvert < 0.05$	$\nu_\mu q \to \nu q$	NuTeV	[7]
$\lvert\varepsilon^{dL}_{\mu\tau}\rvert < 0.05$	$\lvert\varepsilon^{dR}_{\mu\tau}\rvert < 0.05$	$\nu_\mu q \to \nu q$	NuTeV	[7]

where the first and the second term describe charged-current (CC) and neutral-current (NC) interactions, respectively. Here $P \in \{L, R\}$, (f, f') form an SU(2) doublet, and g^f_P is the Z coupling to the fermion f. Non-standard neutrino-matter interactions (NSI) can be introduced by generalizing each term of Eq. (1). CC-like NSI are severely constrained by their implications in the charged-lepton sector, and although it has been shown that there is still room for sizable effects at neutrino experiments [1–4], they are usually ignored in the literature, so I will not discuss them here. As for NC-like NSI, a common parametrization is:

$$\mathcal{L}^{\mathrm{eff}}_{\mathrm{NSI}} = -2\sqrt{2}G_F \sum_{P,\alpha,\beta} \varepsilon^{fP}_{\alpha\beta}\,[\bar\nu_\alpha\gamma_\mu L\nu_\beta][\bar f\gamma^\mu P f] \quad \text{with} \quad \varepsilon^{fP}_{\beta\alpha} = (\varepsilon^{fP}_{\alpha\beta})^* \tag{2}$$

where $\varepsilon^{fP}_{\alpha\beta}$ denotes the strength of the non-standard interactions between the neutrinos of flavors α and β and the left-handed or right-handed components of the fermion f.

In Table 1 we summarize the present limits on $\varepsilon^{fP}_{\alpha\beta}$ from various *non-oscillation* experiments. Clearly only the interactions of neutrinos with the constituents of ordinary matter, $f = e, u, d$, are experimentally accessible. As can be seen, the bounds are usually at the percent level when a ν_μ is involved, weak but still relevant (better than unity) when a ν_e is present, and almost nonexistent for ν_τ. Note that these limits have been obtained by varying each $\varepsilon_{\alpha\beta}$ one at a time;

in general, when correlations among different $\varepsilon_{\alpha\beta}$ are included the bounds become weaker [5,6].

What can we learn on non-standard interactions from *oscillation* experiments? Neutrino production usually occurs through CC processes, hence it is not affected by NC-like NSI. High-energy (above 100 MeV) neutrinos are detected through the observation of the charged lepton produced in CC interactions, but some solar neutrino experiment uses signatures sensitive to NC processes (for example, $\nu + e \to \nu + e$ elastic scattering in SK and Borexino, or $\nu + d \to \nu + p + n$ in SNO). As for neutrino propagation, in the presence of NSI an extra term appears in the matter potential, $V_{\alpha\beta}^{\text{NSI}} = \sqrt{2} G_F \sum_f N_f \varepsilon_{\alpha\beta}^{fV}$, with $\varepsilon_{\alpha\beta}^{fV} = \varepsilon_{\alpha\beta}^{fL} + \varepsilon_{\alpha\beta}^{fR}$. Hence neutrino oscillation experiments can provide information on non-standard interactions. Note that due to the very strong bounds on $\varepsilon_{\mu\mu}^{fP}$ and $\varepsilon_{e\mu}^{fP}$ (see Table 1) it is common practice in numerical analyses to assume $\varepsilon_{\mu\mu}^{fV} = 0$ and $\varepsilon_{e\mu}^{fV} = 0$ from the very beginning.

The impact of NSI on solar neutrinos has been studied in detail. One interesting fact is that the observed deficit of solar ν can be perfectly explained by *NSI only*, *i.e.* without the need of mass-induced oscillations [9, 10]. However, KamLAND is not affected by NSI and requires $\Delta m_{21}^2 \neq 0$, hence this pure NSI solution is no longer interesting. Combined oscillation + NSI analyses of solar and KamLAND data have therefore been performed [11–13], but the bounds they impose on the NSI parameters are very weak. Hence at present no interesting information on NSI can be extracted from solar data. Note, however, that none of these analyses takes into account the Borexino result presented at this conference.

The situation for atmospheric neutrinos is quite different. Although a complete three-neutrino analysis cannot be done due to the very high number of parameters involved, partial analyses have been performed. NSI in the $\mu - \tau$ sector ($\varepsilon_{e\alpha} = \varepsilon_{\alpha e} = 0$) have been studied in [14, 15], finding that the bounds on the NSI parameters implied by atmospheric data are very strong. The most recent fit including also accelerator experiments [16] gives $|\varepsilon_{\mu\tau}^V| \leq 0.038$ and $|\varepsilon_{\tau\tau}^V| \leq 0.12$ at 90% CL, with $\varepsilon_{\alpha\beta}^V \equiv \varepsilon_{\alpha\beta}^{eV} + 3\varepsilon_{\alpha\beta}^{uV} + 3\varepsilon_{\alpha\beta}^{dV}$ (the factor 3 is the approximate N_u/N_e and N_d/N_e ratio in the Earth matter). Note that the bounds on $\varepsilon_{\tau\tau}$ listed in Table 1 are more than one order of magnitude weaker. NSI in the $e - \tau$ sector ($\varepsilon_{\mu\alpha} = \varepsilon_{\alpha\mu} = 0$) have been considered in [17–19], and in this case the sensitivity to the NSI parameters is much poorer. In particular, the bound on $\varepsilon_{e\tau}^V$ is of order unity, hence worse than those imposed by non-oscillation experiments. As for the bound on $\varepsilon_{\tau\tau}^V$ previously quoted, it still hold provided that it is reinterpreted as a bound on the combination $\varepsilon_{\tau\tau}^V - |\varepsilon_{e\tau}^V|^2/(1 + \varepsilon_{ee}^V)$. This demonstrates that correlations among different parameters can have very important consequences.

Let us now turn to *future* experiments. The potentialities of neutrino factories for the determination of NSI parameters was first considered in [20], where it was shown that they will provide complementary information to atmospheric neutrino experiments. However, it was soon realized that due to degeneracies between NSI and oscillation parameters the sensitivity of a neutrino factory to θ_{13} could be seriously spoiled in the presence of NSI [1, 21]. The situation became less dramatic if data from two different baselines were combined [21]. More recent studies confirm these results, and show that while an experiment with a single baseline is strongly affected by degeneracies [2], a two-baseline configuration (*e.g.*, 3000–4000 and 7000–7500 km) can simultaneously provide a robust determination of the oscillation parameters and strong constraints on non-standard interactions [22–24].

The potentialities of forthcoming and long-term facilities have been discussed in a number of papers. Coherent scattering of low energy neutrinos is very sensitive to NSI with quarks, and offers the possibility to improve dramatically the bounds on ε_{ee}^{qV} and $\varepsilon_{e\tau}^{qV}$ [25,26]. In the context of solar neutrinos, the precise measurement of the ^{7}Be line in Borexino can provide very important information on NSI [27]. The sensitivity to θ_{13} of MINOS [28] and of beta-beams [29] can be seriously spoiled if NSI are present; this problem, which affects all single-baseline experiments, can be efficiently resolved by the combination with a reactor experiment [3]. OPERA is too small to provide any useful information on $\varepsilon_{e\tau}^V$ and $\varepsilon_{\tau\tau}^V$ [30], but it may help in the determination of

$\varepsilon^V_{\mu\tau}$ [31], to which T2KK will also have a good sensitivity [32].

3. Models with extra sterile neutrinos

In April 2007 the MiniBooNE collaboration released their first data [33] on a search for $\nu_\mu \to \nu_e$ appearance with a baseline of 540 m and a mean neutrino energy of about 700 MeV. This experiment did not find any signal compatible with two-neutrino oscillations, however an unexplained 3.6σ excess was observed in the low-energy region. The primary purpose of this experiment was to test the evidence of $\bar{\nu}_\mu \to \bar{\nu}_e$ transitions reported by the LSND experiment at Los Alamos [34] with a very similar L/E range. Since the mass-squared differences required to explain the solar, atmospheric and LSND experimental results in terms of neutrino oscillations differ from one another by various orders of magnitude, there is no consistent way to reconcile these three signals using only oscillations among the three known neutrinos. A popular way to solve the LSND problem is to invoke an extension of the three-neutrino mixing scenario, where at least three mass-square differences are available due to the introduction of one or more extra (sterile) neutrino states. An updated analysis of such models including also the MiniBooNE result was presented in Ref. [35]. It was found that:

- four-neutrino models are ruled out since (a) the don't allow to account for the low energy event excess in MiniBooNE, (b) MiniBooNE result cannot be reconciled with LSND, and (c) there is severe tension between *appearance* ($\nu_e \to \nu_\mu$ and $\nu_\mu \to \nu_e$) and *disappearance* ($\nu_e \to \nu_e$ and $\nu_\mu \to \nu_\mu$) experiments;
- five-neutrino models provide a nice way out for problems (a) and (b), but fail to resolve (c);
- six-neutrino models do not offer qualitatively new effects with respect to the previous case.

In all the cases the authors find severe tension between different sub-samples of the data, hence they conclude that at the light of present experimental results it is *not* possible to explain the LSND evidence in terms of sterile neutrinos.

Since the existence of sterile neutrinos beyond the three known ones is a very interesting issue by itself, it is worth to consider it irrespectively of whether the LSND anomaly is confirmed or not. A number of studies discussing the sensitivity of future experiments to extra sterile states have been presented, in the context of Opera [36], of neutrino factories [37–39], of β-decay experiments [40], and of neutrino telescopes [41–43]. It should be noted that all these works still assume that the extra neutrinos are heavier than about 1 eV, whereas once LSND is dropped there is no reason to make any assumption on the mass of the sterile states. However, this general case has been considered only in a very few works [44–47].

4. Neutrino decay and decoherence

Although the theoretical motivations for neutrino decay and neutrino decoherence are very different, they are characterized by the same phenomenological signature: an exponential damping of the flavor conversion probabilities. Hence we will discuss them together.

Concerning neutrino decay, from the phenomenological point of view we should distinguish two possible situation: $\nu_i \to \overset{(-)}{\nu_j} + X$, *i.e.* when the decay product include one (or more) detectable neutrinos, and $\nu_i \to X$, *i.e.* when the decay products are completely invisible. In the first case, the energy distribution of the daughter neutrino(s) is model-dependent, whereas in the second case the process is completely described by the *neutrino lifetime* τ_i and the evolution equation is obtained by adding an imaginary part to the vacuum Hamiltonian, $H_0^m \to H_0^m - i\Gamma_0^m$, with

$$H_0^m = \frac{1}{2E_\nu}\,\mathrm{diag}\left(0, \Delta m^2_{21}, \Delta m^2_{31}\right) \quad \text{and} \quad \Gamma_0^m = \frac{1}{2E_\nu}\,\mathrm{diag}\left(\frac{m_1}{\tau_1}, \frac{m_2}{\tau_2}, \frac{m_3}{\tau_3}\right). \tag{3}$$

Note that since the neutrino masses m_i are unknown, one typically quotes τ_i/m_i as the neutrino lifetime. Interference effects between oscillations and decay [48] are usually neglected.

Table 2. Present bounds on neutrino decoherence in different two-neutrino oscillation channels, assuming a power law dependence $\gamma(E_\nu) = \kappa_n (E_\nu/\text{GeV})^n$. Bounds marked as "old" are in the same units as the corresponding "new" ones, and are taken from [59, 60].

$\nu_e \to \nu_x$ (95% CL)	$\nu_\mu \to \nu_\tau$ (90% CL)
$\kappa_{-2}^{\text{sol}} < 8.1 \times 10^{-29}$ GeV	$\kappa_{-2}^{\text{atm}} < 1.9 \times 10^{-22}$ GeV
$\kappa_{-1}^{\text{sol}} < 7.8 \times 10^{-27}$ GeV	$\kappa_{-1}^{\text{atm}} < 1.2 \times 10^{-22}$ GeV (old: 20)
$\kappa_{0}^{\text{sol}} < 6.7 \times 10^{-25}$ GeV	$\kappa_{0}^{\text{atm}} < 2.7 \times 10^{-24}$ GeV (old: 35)
$\kappa_{+1}^{\text{sol}} < 5.8 \times 10^{-23}$ GeV	$\kappa_{+1}^{\text{atm}} < 3.8 \times 10^{-27}$ GeV
$\kappa_{+2}^{\text{sol}} < 4.7 \times 10^{-21}$ GeV	$\kappa_{+2}^{\text{atm}} < 2.4 \times 10^{-30}$ GeV (old: 900)

In general, the strength of the bounds on the neutrino lifetimes increases with the baseline of the experiment imposing them. The best limit follows from the observation of neutrino events associated with the explosion of SN1987A, which leads to a bound $\tau_1/m_1 \gtrsim 10^5$ s/eV [49] on the lifetime of the lightest neutrino state ν_1. Bounds on ν_2 lifetime are much weaker, and are dominated by solar neutrino data. For the case of invisible decay, the non-observation of ν_2 disappearance implies $\tau_2/m_2 \gtrsim 8.7 \times 10^{-5}$ s/eV at 99% CL [50, 51], although it has been pointed out that this limit may not hold for quasi-degenerate neutrinos [52]. As for decay modes with secondary $\bar{\nu}_e$ appearance, KamLAND [53] and SNO [54] performed dedicated searches for antineutrinos coming from the Sun, yielding $\tau_2/m_2 > 1.1 \times 10^{-3}$ s/eV for hierarchical masses and $\tau_2/m_2 > 6.7 \times 10^{-2}$ s/eV for quasi-degenerate masses [53]. Limits on ν_3 lifetime follow from the analysis of atmospheric and long-baseline neutrino data, and given the much shorter path length they are considerably weaker than those quoted so far. A pure decay solution ($\Delta m^2_{31} = 0$) of the atmospheric deficit was still possible until a few years ago [55], but it is now ruled out by Super-Kamiokande [56]. Interestingly, atmospheric data also admit an hybrid oscillation + decay solution [57] with $\tau_3/m_3 \simeq 2.6 \times 10^{-12}$ s/eV and $\theta_{23} = 34^\circ$, which is however ruled out by MINOS, leading to the bound $\tau_3/m_3 > 2.9 \times 10^{-10}$ s/eV at 90% CL [58].

Neutrino decoherence can arise from a number of very different phenomena: averaging due to finite detector resolution, finite-size of the neutrino wave-packet, quantum-gravity interactions of neutrinos with the space-time "foam", and so on. Phenomenologically, decoherence lead to the appearance of a damping term $\mathcal{D}[\rho]$ in the evolution equation of the neutrino density matrix ρ: $d\rho/dt = -i[H, \rho] - \mathcal{D}[\rho]$. The specific form of $\mathcal{D}[\rho]$ is model-dependent, however it is common in the literature to make a number of conservative assumptions (complete positivity, unitarity, increase of the Von Neumann entropy, and conservation of energy in vacuum) which lead to the simple expression $\mathcal{D}[\rho] = \sum_\ell [D_\ell, [D_\ell, \rho]]$ with $D_\ell = \text{diag}(d_{\ell 1}, d_{\ell 2}, d_{\ell 3})$ in the vacuum mass basis. In this case the evolution equation in vacuum can be solved analytically, and three new parameters $\gamma_{ji} = \sum_\ell (d_{\ell j} - d_{\ell i})^2$ appear in addition to the usual ones. Note that in general γ_{ji} can depend on the neutrino energy.

Phenomenological analyses performed so far focus on two-neutrino oscillations, for which only one γ at a time is relevant. Decoherence involving ν_e is constrained by KamLAND [61] as well as solar neutrino data [62]. For KamLAND, the relevant probability can be written explicitly,

$$P_{ee} = 1 - \frac{1}{2}\sin^2(2\theta)\left[1 - e^{-\gamma_{\text{sol}} L}\cos\left(\frac{\Delta m^2 L}{2E_\nu}\right)\right], \tag{4}$$

whereas for solar neutrinos matter effects cannot be neglected. The limits implied by a combined analysis of both experiments [62] assuming a power law dependence $\gamma_{\text{sol}}(E_\nu) = \kappa_n^{\text{sol}}(E_\nu/\text{GeV})^n$ are listed in Table 2. Decoherence in the $\nu_\mu \to \nu_\tau$ channel has been studied in the context of atmospheric and accelerator neutrino experiments. Similarly to the case of neutrino decay, a pure decoherence solution was originally allowed [59], but it is now ruled out at more than 3σ [56]. A combined oscillation + decoherence fit for $\gamma_{\text{atm}}(E_\nu) = \kappa_n^{\text{atm}}(E_\nu/\text{GeV})^n$ was first presented in [59, 60]; updated results including the latest SK-I and SK-II data as well as K2K and MINOS are reported in Table 2.

Various attempts have been made to explain the LSND results in terms of neutrino decay or decoherence in combination with oscillations, but usually other kinds of New Physics are needed as well: for example, decay + sterile neutrinos [63], decoherence + CPT-violation [64], decoherence with unusual L dependence [65], and so on. A very interesting model recently proposed [66] involves oscillations plus decoherence in the general three-neutrino scenario: assuming $\gamma_{21} = 0$ and $\gamma_{31}(E_\nu) = \gamma_{32}(E_\nu) = \kappa_{-4}^{\text{atm}}(E_\nu/\text{GeV})^{-4}$, this model succeeds to reconcile all the experimental evidence, except for the MiniBooNE low-energy excess, provided that $\kappa_{-4}^{\text{atm}} = 1.7 \times 10^{-23}$ GeV and $\sin^2\theta_{13} > (2.6 \pm 0.8) \times 10^{-3}$.

Only a few studies have been performed to investigate the sensitivity of future neutrino facilities to neutrino decay and decoherence. In [67] it was shown that decoherence effects can fake the determination of θ_{13} at reactor experiments, and that a neutrino factory can easily identify the presence of neutrino decay, whereas its ability to recognize decoherence depends on the specific shape of $\gamma(E_\nu)$. In [68] it was found that the bounds on decoherence parameters which can be put by CNGS and T2K are comparable with those derived from atmospheric neutrinos. A similar result also holds for T2KK [32], which in the context of decoherence models it is shown to be systematically better than the separate Kamioka-only and Korea-only configurations. On the other hand, the potentialities of future neutrino telescopes to detect decay and decoherence signatures have received considerable attention. Concerning neutrino decay [69–72], due to the extremely long distance traveled by astrophysical neutrinos their sensitivity to the neutrino lifetime is many orders of magnitude larger than conventional ground-based experiments. Moreover, neutrino decay can break the $1:1:1$ flavor ratio expected from a π-decay source, hence opening the possibility to measure oscillation parameters at neutrino telescopes [72]. As for decoherence, under our restrictive assumptions it is indistinguishable from averaged oscillations, however more general scenarios predicting unique signatures have been considered [73, 74].

5. Conclusions

In this talk I have discussed the phenomenological implications of different non-standard mechanisms for neutrino conversion. I have focused on three specific cases: non-standard neutrino interactions with matters, models with extra sterile neutrinos, and neutrino decay and decoherence. For what concerns non-standard interactions, we have shown that present bounds on NSI parameters are affected by strong degeneracies, which could spoil the sensitivity to θ_{13} of future long-baseline experiment and neutrino factories, but which can be efficiently resolved by the combination of experiments with two different baselines. Concerning sterile neutrino models, we have proved that none of them succeed in reconciling LSND with the results of the other neutrino oscillation experiments. As for neutrino decay and decoherence, we have reviewed and updated the present limits on the damping parameters, pointing out that future reactor and accelerator facilities can further enhance these limits and that neutrino decay can have non-trivial implications for neutrino telescopes.

Acknowledgments

Work supported by MICINN through the Ramón y Cajal program and through the national project FPA2006-01105, and by the Comunidad Autónoma de Madrid through the HEPHACOS project P-ESP-00346.

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