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Constraining non standard neutrino interactions

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Non-standard interactions (NSI) arise naturally when considering physics beyond the Standard Model. In particular, they can have an important influence in the solar neutrino analysis. The current status of NSI constraints will be discussed and the perspectives of future neutrino experiments will be briefly outlined.

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1. Introduction

The discovery of neutrino oscillations represents a great progress in the physics of elementary particles. In particular the non zero neutrino mass is a hypothesis that appears in many models beyond the Standard Model, and it might be possible that neutrino experiments could give a hint about the mass generation mechanism. In this decade, there has been a great improvement in the knowledge of the parameters involved in the neutrino oscillation mechanism [1], and it is natural to ask if the precision reached so far could give a hint on the nature of the mechanism generating masses and mixings.

Neutrino non-standard interactions (NSI) constitute an unavoidable characteristic feature of gauge models of neutrino mass, for example, models of the generic seesaw type [2]. Another interesting example of neutrino NSI is in the context of low-energy supersymmetry without R-parity conservation [3] where one may also have, in addition to bilinear [4], also trilinear L violating couplings in the super-potential.

In what follows we will focus on nonstandard interactions that can be parametrized with the effective low–energy four–fermion operator for neutral currents[1]:

$$\mathscr{L}_{NSI} = -\varepsilon_{\alpha\beta}^{fP} 2\sqrt{2} G_F \left(\bar{\nu}_\alpha \gamma_\mu L \nu_\beta\right)\left(\bar{f}\gamma^\mu P f\right), \tag{1.1}$$

where P = L, R and f is a first generation fermion: e,u,d. The coefficients $\varepsilon_{\alpha\beta}^{fP}$ denote the strength of the NSI between the neutrinos of flavors α and β and the P–handed component of the fermion f. In particular, we will study the case when the fermion f is either a d type quark or an electron.

2. Non standard interactions of neutrinos with d-quark

Constraints coming from the neutrino interactions with d-type quark can be obtained from different experimental results, either from accelerators or from the solar neutrino data. Concerning the solar neutrino data, it is possible to perform a global analysis including the most recent results from the radiochemical experiments, Homestake[6], SAGE [7] and GALLEX/GNO [8] , the zenith-spectra data set from Super-Kamiokande I [9], as well as the results from the three phases of the SNO experiment [10]. The latest measurement of the ^{7}Be solar neutrino rate performed by the Borexino collaboration [11, 12] can also be included in the analysis. Finally, for this kind of analysis, it is mandatory to include the latest data released from the KamLAND reactor experiment [13], in order to obtain better constraints for the NSI parameters.

In the case of accelerator experiments, one of the most useful data come from the results reported by the CHARM collaboration, that was an accelerator experiment measuring the ratio of the neutral current to the charge current cross section for electron (anti)neutrinos off quarks. In particular, they reported results for the $\nu_e q \to \nu q$ cross section, or, more precisely, they measured the relation [14],

$$R^e = \frac{\sigma(\nu_e N \to \nu X) + \sigma(\bar{\nu}_e N \to \bar{\nu} X)}{\sigma(\nu_e N \to e X) + \sigma(\bar{\nu}_e N \to \bar{e} X)} = 0.406 \pm 0.140 \tag{2.1}$$

[1] A recent study of CC NSI have been shown in Ref. [5]

Table 1: Constraints on the NSI couplings at 90% C L from the combined analysis of solar, KamLAND and CHARM data [15] .

two parameters at a time		
$-0.5 < \varepsilon_{ee}^{dV} < 1.2$	$-1.8 < \varepsilon_{\tau\tau}^{dV} < 4.4$	
$-0.4 < \varepsilon_{ee}^{dA} < 1.4$	$-1.5 < \varepsilon_{\tau\tau}^{dA} < 0.7$	
one parameter at a time		
$-0.2 < \varepsilon_{ee}^{dV} < 0.5$	$-1.1 < \varepsilon_{\tau\tau}^{dV} < 0.4$;	$1.6 < \varepsilon_{\tau\tau}^{dV} < 2.2$
$-0.2 < \varepsilon_{ee}^{dA} < 0.3$	$-0.2 < \varepsilon_{\tau\tau}^{dA} < 0.4$	

Both in the case of the CHARM experiment, as well as for the case of the solar neutrino data analysis, it is possible to consider the effects of NSI and obtain constraints for them. The results of a fit performed recently [15] are shown in Table 1. In this table, the constraints on the NSI parameters are shown both using the most popular approach [16, 17] that consists on varying only one parameter at-a-time and fixing the remaining parameters to zero, as well as using two parameters at a time, since a one-parameter-at-a-time analysis is fragile and might miss potential cancellations in the determination of the restrictions upon NSI strengths.

3. Non standard interactions of neutrinos with electrons

It is also possible to consider neutrino interactions with electrons in order to get constraints on the NSI parameters. In this case, again, one can study either the solar neutrino data [18], or laboratory experiments [19].

For laboratory constraints it is possible to consider, for example, the cross section of the interaction $e^+e^- \to \nu\bar{\nu}\gamma$. In this process, neutrino-electron NSI could increase or decrease the expected number of events. The best data on such interaction has been collected by the four LEP experiments: OPAL, ALEPH, L3 and DELPHI [20].

The $\nu_e e$ and $\bar{\nu}_e e$ scattering processes can also be taken into account. The cross section for the elastic scattering interaction $\nu_e + e^- \to \nu_e + e^-$ was measured by the Liquid Scintillator Neutrino Detector (LSND) using a μ^+ decay-at-rest ν_e beam at Los Alamos Neutron Science Center [21]. On the other hand, the $\bar{\nu}_e e$ scattering has been measured by different reactor experiments like Irvine [22], Rovno [23] and the most recent MUNU experiment [24].

Finally, for the NSI of muon type neutrinos, the CHARM II collaboration results are very restrictive for NSI parameters. The collaboration used a massive 692 ton target calorimeter followed by a muon spectrometer to detect the $\nu_\mu + e \to \nu_\mu + e$ and $\bar{\nu}_\mu + e \to \bar{\nu}_\mu + e$ scattering processes. The neutrinos were produced by a 450 GeV proton beam accelerated in the Super Proton Synchrotron (SPS) for 2.5×10^{19} protons on target [25].

For the solar neutrino data, an analysis similar to the one described in the previous section can be applied to this case. The result of two different analysis performed using the solar neutrino data [18], and laboratory experiments [19] respectively, are shown in Table 2.

Table 2: Constraints on the NSI couplings at 90% C L from solar neutrino data [18] and from a combined laboratory analysis [19].

Experiment		
	two parameters at a time	
Solar	$-0.036 < \varepsilon_{ee}^{eL} < 0.063$	$-0.27 < \varepsilon_{ee}^{eR} < 0.59$
laboratory	$-0.14 < \varepsilon_{ee}^{eL} < 0.09$	$-0.03 < \varepsilon_{ee}^{eR} < 0.18$
laboratory	$-0.033 < \varepsilon_{\mu\mu}^{eL} < 0.055$	$-0.040 < \varepsilon_{\mu\mu}^{eR} < 0.053$
Solar	$-0.16 < \varepsilon_{\tau\tau}^{eL} < 0.11$	$-1.05 < \varepsilon_{\tau\tau}^{eR} < 0.31$
laboratory	$-0.6 < \varepsilon_{\tau\tau}^{eL} < 0.4$	$-0.4 < \varepsilon_{\tau\tau}^{eR} < 0.6$

4. Perspectives and conclusions

We can see from the previous sections that there is still a lot of room for improvement in the determination of the NSI parameters, especially for the case of the interactions with d type quarks.

There are different experimental proposals that could give stronger bounds on the parameters that have been studied here. In particular, for the case of the interactions with quarks, different experimental setups, such as long baseline neutrino experiments and neutrino factories, have been considered [28], as well as the most challenging case of coherent neutrino nucleus scattering [29], while for the case of NSI with electrons there are new experimental proposals for measuring the neutrino scattering off electrons, such as Texono [26] and NuSong [27].

With neutrino physics entering into a precision era, the study of non standard interactions of neutrinos is a promising subject of study that could shed light on the physics beyond the Standard Model. In this work I have summarized the current status for the constraints on most of the NSI parameters.

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