Exploration of Possible Quantum Gravity Effects with Neutrinos I: Decoherence in Neutrino Oscillations Experiments

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Abstract. Quantum gravity may involve models with stochastic fluctuations of the associated metric field, around some fixed background value. Such stochastic models of gravity may induce decoherence for matter propagating in such fluctuating space time. In most cases, this leads to fewer neutrinos of all active flavours being detected in a long baseline experiment as compared to three-flavour standard neutrino oscillations. We discuss the potential of the CNGS and J-PARC beams in constraining models of quantum-gravity induced decoherence using neutrino oscillations as a probe. We use as much as possible model-independent parameterizations, even though they are motivated by specific microscopic models, for fits to the expected experimental data which yield bounds on quantum-gravity decoherence parameters.

1. Introduction

If microscopic black holes, or other defects forming space-time foam, exist in the vacuum state of quantum gravity (QG) [1, 2], this state, in our view, will constitute an “environment” which will be characterised by some entanglement entropy, due to its interaction with low-energy matter.

The matter system in such a case behaves as an open quantum mechanical system, exhibiting decoherence, which has in principle detectable experimental signatures. In the context of a phenomenological parametrization of quantum-gravity induced decoherence the first tests along these lines have been proposed in [3]. A more microscopic consideration was given in [4], where the proposed parametrization of decoherent effects of quantum gravity was forced to obey the Lindblad [5–7] formalism of open systems, employing completely positive dynamical semigroup maps. This latter phenomenology, however, may not be a true feature of a quantum theory of gravity.

In general, for phenomenological purposes, the important feature of such situations is the fact that gravitational environments, arising from space-time foam or some other, possibly semi-classical feature of QG, can still be described by non-unitary evolutions of a density matrix $\rho$. Such equations have the form $\partial_t \rho = \Lambda_1 \rho + \Lambda_2 \rho$, where $\Lambda_1 \rho = \frac{1}{\hbar} [\rho, H]$ and $H$ is the hamiltonian
with a stochastic element in a classical metric. Such effects may arise from back-reaction of matter within a quantum theory of gravity [3, 8] which decoheres the gravitational state to give a stochastic ensemble description. Furthermore within models of D-particle foam arguments [9] in favour of a stochastic metric have been given in [10]. The Liouvillian term \( \Lambda \rho \) gives rise to a non-unitary evolution. A common approach to \( \Lambda \rho \), is to parametrise the Liouvillian in a so-called Lindblad form [5, 7] but this is not based on microscopic physics. We note at this point that any non-linear evolutions that may characterise a full theory of QG (see e.g. a manifestation in Liouville strings [11]), can be ignored to a first approximation appropriate for the accuracy of contemporary experimental probes of QG. Generically space-time foam and the back-reaction of matter on the gravitational metric may be modelled as a randomly fluctuating environment; formalisms for open quantum mechanical systems propagating in such random media can thus be applied and lead to concrete experimental predictions. The approach to these questions have to be phenomenological to some degree since QG is not sufficiently developed at a non-perturbative level.

One of the most sensitive probes of such stochastic quantum-gravity phenomena are neutrinos [12–21], and in particular high-energy ones [22, 23]. For example, as pointed out recently in [14], the tiny mass differences between neutrino flavours may themselves (in part) be the result of a CPT violating quantum-gravity background. The phenomenon, if true, would be the generalisation of the celebrated Mikheyev-Smirnov-Wolfenstein (MSW) effect [24, 25]. The latter arises from effective mass differences between the various neutrino flavours, as a result of different type of interactions of the various flavours with matter within the context of the Standard Model. The phenomenon has been generalised to randomly fluctuating media [26], which are of relevance to solar and nuclear reactor \( \beta \)-decays neutrinos. This stochastic MSW effect will be more relevant for us, since we consider space-time foam, as a random medium which induces flavour-sensitive mass differences. If we can extrapolate [27] semi-classical results on black-hole evaporation, in both general relativity [28] and string theory [29] to the quantum gravity foamy ground state (assuming it exists and characterizes the ground state of some (stochastic) quantum-gravity models, it follows that microscopic black holes which are near extremal (and therefore electrically charged) would evaporate significantly less, compared with their neutral counterparts. Thus, we may assume [14, 27], that near extremal black holes in the foam would “live” longer, and as a result they would have more time to interact with ordinary matter, such as neutrinos. Such charged black holes would therefore constitute the dominant source of charge fluctuations in the foam that could be responsible for foam-induced neutrino mass differences according to the idea proposed in [14]. Indeed, the emitted electrons from such black holes, which as stated above are emitted preferentially, compared to muons or other charged particles, as they are the lightest, would then have more time to interact (via coherent standard model interactions) with the electron-neutrino currents, as opposed to muon neutrinos. This would create a flavour bias of the foam medium, which could then be viewed [14, 27] as the “quantum-gravitational analogue” of the MSW effect [24, 25] in ordinary media (where, again, one has only electrons, since the muons would decay quickly). In this sense, the quantum gravity medium can be partially responsible for generating effective neutrino mass differences [14]. As already indicated by earlier phenomenological studies [19] of quantum-gravity induced decoherence models for neutrinos, only a small part of the neutrino mass differences and mixing can be attributed to interactions of the neutrinos with the medium of the quantum-gravity space-time foam. Nevertheless, the list of models examined so far [14, 19, 27] is not by any means an exhaustive list. Hence we consider the issue of the effect of quantum gravity on the size of the neutrino oscillation parameters an open one and worthy of further investigation. We also remark that in our quantum gravitational MSW scenario [14, 19] the charged black holes lead to a stochastically fluctuating medium. Consequently we will adopt the formalism of the MSW effect for stochastically fluctuating media [26], where the density of electrons is now...
replaced by the density of charged black hole/anti black hole pairs.

In what follows we report on study [30] of decoherence induced by non-linear space-time foam fluctuations as a subdominant effect in neutrino oscillations at CNGS and J-PARC beams after giving an overview of the framework of decoherence phenomena in neutrino experiments. In particular in [30] we presented the damping signatures and the associated fitting functions, which might be due to either the "quantum-gravitational analogue" of the MSW effect or the stochastic fluctuations of the space-time metric background. We considered various stochastic models of foam, which lead to different damping signatures, depending on the details of the underlying characteristic distribution functions [31] and estimate the sensitivity of CNGS and J-PARC experiments to the parameters of quantum-gravitational decoherence entering the set of the above-mentioned damping signatures.

2. The combined fit to Quantum-Gravity Decoherence Signatures

The various types of decoherence can be mainly distinguished by the form of their exponential damping factor, as far as the power of the oscillation length $L$ in the exponent is concerned, and the associated energy dependence [32]. Model independent data fits should combine, in general, the various types of decoherence-deformed oscillations, given that dominance of one or the other type may not be necessarily a feature of a quantum-gravity model.

For our studies [30] we use two sets of the one and two parametric models covering the main variety of phenomenologies for quantum gravity induced decoherence phenomena. The first set of the models under consideration concerns the presence of linear Lindblad-type mapping operator in the equation for the evolution of the density matrix for the pure neutrino quantum states [12, 13, 16, 17, 20, 33]. The oscillation probabilities corrected for the decoherence effects with different energy dependence in the exponentials read

- no neutrino-energy dependence

$$P_{\nu_{\mu} \to \nu_{\tau}} = \frac{1}{2} \sin^2(2\theta_{23}) \left[ 1 - \exp(-5 \cdot 10^6 \gamma_0 L) \cos \left( \frac{2.54 \Delta m^2}{E L} \right) \right]$$  \hspace{1cm} (1)

- inversely proportional to the neutrino energy (e.g. the case of Cauchy-Lorentz type of stochastic foam [31]

$$P_{\nu_{\mu} \to \nu_{\tau}} = \frac{1}{2} \sin^2(2\theta_{23}) \left[ 1 - \exp\left(\frac{-2.54 \gamma_2^2 L}{E} \right) \cos \left( \frac{2.54 \Delta m^2}{E L} \right) \right]$$  \hspace{1cm} (2)

- proportional to the neutrino energy squared

$$P_{\nu_{\mu} \to \nu_{\tau}} = \frac{1}{2} \sin^2(2\theta_{23}) \left[ 1 - \exp(-5 \cdot 10^{27} \gamma_2 E^2 L) \cos \left( \frac{2.54 \Delta m^2}{E L} \right) \right]$$  \hspace{1cm} (3)

where $\gamma_0$, $\gamma_2^{-1}$ and $\gamma_2$ are measured in eV, eV$^2$ length and eV$^{-1}$ respectively the mass square difference $\Delta m^2$, is measured in eV$^2$, the energy $E$, is measured in GeV; and the path, $L$, is measured in km.

The second set of the models concerns the gravitational MSW stochastic effect with linear and quadratic time dependent fluctuations of space-time foam described by

$$P_{\nu_{\mu} \to \nu_{\tau}} = \frac{1}{2} - \exp(-\kappa_1) \frac{\cos^2(2\theta_{23})}{2} - \frac{1}{2} \exp(-\kappa_2) \cos \left( \frac{2.54 \Delta m^2}{E L} \right) \sin^2(2\theta_{23})$$  \hspace{1cm} (4)

where the exponential damping factors are chosen as
• no energy dependence, with linear

$$\kappa_1 = 5 \cdot 10^9 \alpha^2 L \sin^2(2\theta); \quad \kappa_2 = 5 \cdot 10^9 \alpha^2 L(1 + 0.25(\cos(4\theta) - 1))$$  (5)

quadratic

$$\kappa_1 = 2.5 \cdot 10^{19} \alpha_1^2 L^2 \sin^2(2\theta); \quad \kappa_2 = 2.5 \cdot 10^{19} \alpha_1^2 L^2(1 + 0.25(\cos(4\theta) - 1))$$  (6)

and combined time evolution

$$\kappa_1 = (5 \cdot 10^9 \gamma_1^2 L + 2.5 \cdot 10^{19} \gamma_2^2 L^2) \sin^2(2\theta);$$
$$\kappa_2 = (5 \cdot 10^9 \gamma_1^2 L + 2.5 \cdot 10^{19} \gamma_2^2 L^2)(1 + 0.25(\cos(4\theta) - 1))$$  (7)

• proportional to the neutrino energy, with linear

$$\kappa_1 = 5 \cdot 10^{18} \beta^2 E L \sin^2(2\theta); \quad \kappa_2 = 5 \cdot 10^{18} \beta^2 E L(1 + 0.25(\cos(4\theta) - 1))$$  (8)

quadratic

$$\kappa_1 = 2.5 \cdot 10^{28} \beta_1^2 E L^2 \sin^2(2\theta); \quad \kappa_2 = 2.5 \cdot 10^{28} \beta_1^2 E L^2(1 + 0.25(\cos(4\theta) - 1))$$  (9)

and combined time evolution

$$\kappa_1 = (5 \cdot 10^{18} \gamma_1^2 E L + 2.5 \cdot 10^{28} \gamma_2^2 E L^2) \sin^2(2\theta);$$
$$\kappa_2 = (5 \cdot 10^{18} \gamma_1^2 E L + 2.5 \cdot 10^{28} \gamma_2^2 E L^2)(1 + 0.25(\cos(4\theta) - 1))$$  (10)

• proportional to the neutrino energy squared, with linear time evolution

$$\kappa_1 = 5 \cdot 10^{27} \beta_1^2 E^2 L \sin^2(2\theta); \quad \kappa_2 = 5 \cdot 10^{27} \beta_1^2 E^2 L(1 + 0.25(\cos(4\theta) - 1))$$  (11)

The energy and the path length in (5)-(11) are measured in GeV and km respectively, while the parameters in damping exponentials are given in eV in respective power (see Table 1 for details).

3. Sensitivity of CNGS and J-PARC beams to quantum-gravity decoherence

In this section we study the expected sensitivity of the CNGS and J-PARC beams to the quantum gravitational decoherence phenomena described by (1)-(11), considering them as subdominant contributions to the atmospheric oscillations effects.

Both CNGS and J-PARC are conventional neutrino beams where neutrinos are produced by the decay of secondary particles (pions and kaons) obtained from the collision of the primary proton on a graphite target. For the CNGS beam, the protons come from the CERN-SPS facility with a momentum of 400 GeV/c whereas in the case of the J-PARC [34] the protons are produced in Tokay (Japan) and have a momentum of 40 GeV/c. The expected number of protons on target per year at the nominal intensity is 4.5 \times 10^{19} and 1 \times 10^{21} respectively for the CNGS and J-PARC beam and the envisaged run length is 5 years in both cases.

Both beams will be used for long baseline neutrino experiments which, starting from a \( \nu_\mu \) beam, will search for neutrino oscillations. The OPERA experiment will measure neutrino events on the CNGS beam using a 2 kton detector which relies on the photographic emulsion technique, located at a baseline of 732 km; the first neutrino events were observed in August 2006 [35].

The T2K experiment will use the J-PARC beam measuring neutrino events with the Super-Kamiokande [36] detector (a water cerenkov detector with an active volume of 22.5 kton) at a baseline of 295 km.
Although CNGS beam designed in a way to be optimised for the $\nu_\mu \rightarrow \nu_\tau$ oscillation searches through the detection of $\tau$ lepton production in a pure $\nu_\mu$ beam there is also a possibility to measure $\nu_\mu$ spectrum by reconstructing $\mu$ from the charged current (CC) events caused by $\nu_\mu$. Moreover, for this experiment, we can take advantage of high mean value for the energy of $\nu_\mu$s which makes the exponential damping factors more pronounced for some cases described in the previous section.

The number of $\mu$ is given by the convolution of the $\nu_\mu$ flux $d\phi_{\nu_\mu}/dE$ with the $\nu_\mu$ CC cross section on lead $\sigma_{\nu_\mu}^{\text{CC}}(E)$, weighted by the $\nu_\mu \rightarrow \nu_\mu$ surviving probability $P_{\nu_\mu \rightarrow \nu_\mu}$, times the efficiency $\epsilon_{\mu\mu}$ of muon reconstruction of a given detector:

$$\frac{dN_{\mu\mu}}{dE} = A_{\mu\mu} \frac{d\phi_{\nu_\mu}}{dE} P_{\nu_\mu \rightarrow \nu_\mu} \sigma_{\nu_\mu}^{\text{CC}}(E) \epsilon_{\mu\mu}$$

(12)

where $A_{\mu\mu}$ is a normalisation factor which takes into account the target mass and the normalisation of the $\nu_\mu$s in physical units. In our study we assumed an overall efficiency $\epsilon_{\mu\mu}$ of 93.5% for the OPERA experiment and of 90% for the T2K one as stated in the experiment proposals.

To estimate quantitatively the sensitivity of CNGS on $P_{\nu_\mu \rightarrow \nu_\tau}$ described by (1)-(11), we simulated the theoretical spectra of the reconstructed $\nu_\mu$ events for various values of damping parameters (for details see [30]). For the best-fit values [38] of the atmospheric neutrino parameters we used: $\Delta m^2 = 2.5 \cdot 10^{-3}\text{eV}^2$; $\theta_{23} = 45^\circ$.

The 3 $\sigma$ sensitivity on the damping parameters is found by applying a cut on the value of the $\chi^2$ of 9 and 11.83 respectively for 1 d.o.f. and 2 d.o.f.

As the CNGS beam is designed to observe $\nu_\tau$, neutrinos will have a high energy with a mean value of about 17 GeV. This represents an advantage since it makes the exponential damping factors more pronounced for some cases described in the previous section.

To generate the expected neutrino spectra of the CNGS beam measured by the OPERA experiment we used a fast simulation algorithm described in [37]. We present in Fig.1 a typical simulated spectrum of the expected number of $\mu$ events including the effects of decoherence (for the case of an inversely proportional dependence on neutrino energy) as a subdominant suppression of the probability inferred from the atmospheric neutrino experiment [38].

Contrary to the OPERA experiment, the T2K experiment was designed to observe $\nu_\tau$ and the mean energy is much lower: the maximum of oscillation at the given baseline of 295 km corresponds to a neutrino energy of about 600 MeV and a narrow spectra at the selected energy will be obtained using the so called off-axis technique [39]. The spectrum covers the region of the first maximum of oscillation and this is a region where the QG effects could be easily observed due to the small number of $\nu_\mu$ CC events expected in case of no QG damping exponents, as it can be seen in Fig 2.

Our results for the sensitivity of CNGS to one parametric decoherence damping exponentials in $P_{\nu_\mu \rightarrow \nu_\tau}$ are summarised in second column of Table 1. Also, for two parametric fits (7) and (10), the 3 $\sigma$ CL sensitivity contours are presented in Fig. 3 and Fig. 4.

Our results obtained using the same way of analysis quantified by (12) for the sensitivity of T2K to one parametric decoherence damping exponentials in $P_{\nu_\mu \rightarrow \nu_\tau}$ are summarised in third column of Table 1. Also, for two parametric fits (7) and (10), the 3 $\sigma$ CL sensitivity contours are similar to those obtained for CNGS.

The T2K experiment yields a better limit on the damping parameters only in the case where the effect has no energy dependence or contains inversely proportional to the neutrino energy exponent, as expected given the low energy spectrum. In all the other cases, the dependence on the baseline disfavours the short baseline of T2K with respect to OPERA.

Another possibility to observe the effect on the T2K neutrino beam is to select a longer baseline, namely to locate the detector at about 1000 km in Korea. Studies of beam upgrades
Figure 1. The number of reconstructed $\nu_\mu$ CC events in OPERA as a function of the neutrino energy with (blue line) and without (red line with error bars) QG decoherence effect included in case of inversely proportional dependence on neutrino energy. $3\sigma$ difference between the expected and QG disturbed spectra is shown.

Figure 2. The number of reconstructed $\nu_\mu$ CC events in T2K as a function of the neutrino energy with (blue line) and without (red line with error bars) QG decoherence effect included in case of inversely proportional dependence on neutrino energy. $3\sigma$ difference between the expected and QG disturbed spectra is shown.

Figure 3. The expected CNGS sensitivity contour at $3\sigma$ CL, with two decoherence parameters contributing to the combined time evolution of the gravitational MSW effect (with stochastic metric fluctuations), calculated for damping with no energy dependence.

Figure 4. The expected CNGS sensitivity contour at $3\sigma$ CL, with two decoherence parameters contributing to the combined time evolution of the gravitational MSW effect (with stochastic metric fluctuations), calculated for damping proportional to the neutrino energy.
Table 1. Expected sensitivity limits at CNGS, T2K and T2KK to one parametric neutrino decoherence for Lindblad type and gravitational MSW (stochastic metric fluctuation) like operators [30]. These results are obtained for the “true” values of the oscillation parameters fixed at $\Delta m^2 = 2.5 \times 10^{-3} \text{eV}^2$ and $\theta_{23} = 45^\circ$ [38].

| Lindblad-type mapping operators | CNGS | T2K | T2KK |
|---------------------------------|------|-----|------|
| $\gamma_0 \ [\text{eV}] ; ([\text{GeV}])$ | $2 \times 10^{-13} ; (2 \times 10^{-22})$ | $2.4 \times 10^{-14} ; (2.4 \times 10^{-23})$ | $1.7 \times 10^{-14} ; (1.7 \times 10^{-23})$ |
| $\gamma_{21} \ [\text{eV}^2] ; ([\text{GeV}^2])$ | $9.7 \times 10^{-4} ; (9.7 \times 10^{-22})$ | $3.1 \times 10^{-5} ; (3.1 \times 10^{-23})$ | $6.5 \times 10^{-5} ; (6.5 \times 10^{-23})$ |
| $\gamma_2 \ [\text{eV}^{-1}] ; ([\text{GeV}^{-1}])$ | $4.3 \times 10^{-35} ; (4.3 \times 10^{-26})$ | $1.7 \times 10^{-32} ; (1.7 \times 10^{-23})$ | $3.5 \times 10^{-33} ; (3.5 \times 10^{-24})$ |

| Gravitational MSW (stochastic) effects | CNGS | T2K | T2KK |
|----------------------------------------|------|-----|------|
| $a^2$ | $4.3 \times 10^{-13} \text{eV}$ | $4.6 \times 10^{-14} \text{eV}$ | $3.5 \times 10^{-14} \text{eV}$ |
| $a_1^2$ | $1.1 \times 10^{-25} \text{eV}^2$ | $3.2 \times 10^{-26} \text{eV}^2$ | $6.7 \times 10^{-27} \text{eV}^2$ |
| $\beta^2$ | $3.6 \times 10^{-24}$ | $5.6 \times 10^{-23}$ | $1.7 \times 10^{-23}$ |
| $\beta_2^2$ | $9.8 \times 10^{-37} \text{eV}$ | $4 \times 10^{-35} \text{eV}$ | $3.1 \times 10^{-36} \text{eV}$ |
| $\beta_1^2$ | $8.8 \times 10^{-35} \text{eV}^{-1}$ | $3.5 \times 10^{-32} \text{eV}^{-1}$ | $7.2 \times 10^{-33} \text{eV}^{-1}$ |

and a large liquid Argon detector of 100 kton in Korea were carried out [40] in the framework of CP violation discovery. We considered this option, called T2KK, and studied the possibility to constrain damping parameters in this case. The proposed upgrade at 4 MW of the beam was taken into account which results into $7 \times 10^{21}$ p.o.t. per year and a running time of 4 years was envisaged.

Our results for the sensitivity of T2KK to one parametric decoherence damping exponentials in $P_{\nu_e \rightarrow \nu_x}$ are summarised in fourth column of Table 1. This configuration yields better results than the T2K experiment and results comparable to the OPERA experiment. All bounds obtained in Table 1 are evaluated at the best-fit oscillation parameters.

4. Conclusions

It is instructive to compare the sensitivity limits presented in Table 1 with those derived from the analysis of atmospheric neutrino data [12] obtained at Super-Kamiokande and K2K experiments. The numbers of Table 1 in parentheses can be directly compared with the bounds [12]. In particular, the bound obtained in [12] at 95% C.L. on the Lindblad type operators with no energy dependence is close to the sensitivity estimated in our analysis in case of T2K and T2KK simulations. Although, the CNGS estimation is about an order of magnitude weaker, one should stress that the current limit is given at 99% C.L. under the assumption of the most conservative level of the uncertainty of the overall neutrino flux at the source. The bound on the inverse energy dependence given in [12] is close to the current CNGS estimates. T2K and T2KK demonstrate an improvement. In spite of the fact that the Super-Kamiokande data contains neutrino of energies up to $\sim$TeV, the sensitivity one obtains at CNGS to the energy-squared dependent decoherence is close, within an order of magnitude, to the bound imposed by atmospheric neutrinos and surpasses T2K and T2KK sensitivity bounds by $\approx 3$ and $\approx 2$ orders of magnitude respectively. The much less uncertain systematics of CNGS compared to the atmospheric neutrino data will
make the expected bound more robust as soon as the upcoming data from OPERA will be
analysed. Moreover, our results are also competitive with the sensitivity to the same Lindblad
operators estimated in [41] for ANTARES neutrino telescope, which is supposed to operate at
neutrino energies much higher than CNGS and J-PARC experiments.

Assuming that the decoherence phenomena affect all particles in the same way, which however
is by no means certain, one might compare the results of our analysis with bounds obtained
using the neutral kaon system [42]. The comparison could be done for the constant (no-
energy dependence) Lindblad decoherence model. The main bound in [42] in such a case reads
\[ \gamma_0 \leq 4.1 \times 10^{-12} \text{ eV}, \]
thus being about two orders of magnitude weaker than the sensitivity
forecasted in the present paper.

Finally, we compare the estimated sensitivity with the bounds obtained in [21] using
solar+KamLAND data. In principle, as in the case of the neutral kaon system, a direct
comparison is impossible, since the parameters investigated here for the \( \nu_\mu \rightarrow \nu_\tau \) channel need
not be the same for the \( \nu_\tau \rightarrow \nu_\mu \) channel. However, again, if these parameters are assumed to be
roughly of equal size, then one can see that the estimates of [21], which win essentially over the
CNGS, T2K and T2KK sensitivities only for the case of inverse energy dependent decoherence,
which strongly favours low neutrino energies (e.g. the case of Cauchy-Lorentz stochastic space-
time foam models of [31], for which the current limit would bound, on account of, the scale
parameter \( \xi \) of the distribution to (for details see [30, 31]): \( \xi < 5 \times 10^{-3} \) for neutrino-mass differences [21] \( |m_4^2 - m_\mu^2| = (7.92 \pm 0.71) \times 10^{-3} \text{ eV}^2 \). For the completeness, we mention that,
our best expected bound on the inverse-energy decoherence will imply, the bound on the \( \nu_\mu \) life
time \( \tau_{\nu_\mu}/m_{\nu_\mu} > 3 \times 10^{22} \text{ GeV}^{-2} \).

The precise energy and length dependence of the damping factors is an essential step in
order to determine the microscopic origin of the induced decoherence and disentangle genuine
new physics effects from conventional effects, which may also contribute to decoherence-like
damping. Some genuine quantum-gravity effects, such as MSW like effect induced by stochastic
fluctuations of the space-time, are expected to increase in general with the energy of the probe,
as a result of back reaction effected on space-time geometry, in contrast to ordinary-matter-
induced ‘fake’ CPT violation and ‘decoherence-looking’ effects, which decrease with the energy
of the probe [32]. At present the sensitivity of the experiments is not sufficient to unambiguously
determine the microscopic origin of the decoherence effects, but according to our estimations of
the most plausible energy-length dependencies for the MSW like decoherence the sensitivity of
CNGS and T2K will improve the current limits by at least two orders of magnitude and one
would arrive at definite conclusions on this important issue. Thus phenomenological analyses
like ours are of value and should be actively pursued when the data from OPERA and T2K will
become available.

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