Snowmass2021 - Letter of Interest: exploration of a new model for neutrino oscillations using a kiloton-scale neutrino detector at the Advanced Instrumentation Testbed in Boulby England

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As described in a companion LOI [1–3], AIT is a joint United States and United Kingdom project to test and demonstrate a range of antineutrino-based monitoring technologies for detecting nuclear reactors. The US and UK sponsors are conducting an independent evaluation of a number of possible detector designs for possible deployment at AIT. Candidate detectors based on gadolinium-doped water and water-based liquid scintillator detection media are being considered in the effort termed Neutrino Experiment One (NEO). The detectors make use of the inverse beta decay interaction, which produces a robust signal against most backgrounds. AIT is primarily focused on technology development for nonproliferation. However, here we describe an intriguing possible early use of AIT, in order to study a recently developed interpretation of neutrino interactions[4] that offers an alternative to the prevailing PMNS model, and is consistent with current world oscillation data at all energy scales. the interpretation proposes an alternative quantum mechanical picture for the observed phenomena of neutrino oscillations. It is assumed that neutrinos interact via diabatic (or localised) interactions with a new particle field, which changes their flavor. The particle field is called the flavon to reflect its flavor-changing character. In the model it is further assumed that each neutrino flavor state can only have a single associated mass, thereby making them fundamental particles of nature. The effective masses associated with matter interactions replace the concept of neutrino mixing angles. The 26 kilometer standoff of AIT offers a timely opportunity for an experimental test of the new concept, in which a dramatic difference between PMNS-type and flavon-based oscillations would be revealed in a relatively short run-time. Here we summarize the model features and describe the potential sensitivity at the AIT site for kiloton-scale water-based detectors.

NF Topical Groups: (check all that apply □/■) ■ (NF1) Neutrino oscillations
■ (NF2) Sterile neutrinos
■ (NF3) Beyond the Standard Model
□ (NF4) Neutrinos from natural sources
■ (NF5) Neutrino properties
□ (NF6) Neutrino cross sections
□ (NF7) Applications
■ (NF8) Theory of neutrino physics
■ (NF9) Artificial neutrino sources
■ (NF10) Neutrino detectors

I. THE FLAVON MODEL IN A NUTSHELL

In a nutshell the flavon model proposed in [4] assumes that flavor transitions occur at localised interaction points instead of the internal continuous oscillation assumed by the PNMS model. The neutrino changes from flavor e to μ with an energy perturbation $f_{e\mu}$. The neutrino excited state E_{ν_μ} has an effective mass that is not proportional to this energy transfer due additional external effects contributing to the effective mass.

The electron neutrino disappearance formula under these conditions is found to be,

$$P_{ee} = 1 - \frac{f_{e\mu}^2}{\left(\frac{\Delta m^2_{\nu_{\mu e}}}{4E_\nu}\right)^2 + f_{e\mu}^2} \sin^2\left(t\sqrt{\left(\frac{\Delta m^2_{\nu_{\mu e}}}{4E_\nu}\right)^2 + f_{e\mu}^2}\right) \equiv 1 - \sin^2(2\theta_{e\mu}(E_\nu, \Delta m_{\nu_{\mu e}}))\sin^2\left(w(E_\nu, \Delta m_{\nu_{\mu e}}, f_{e\mu})t\right), \quad (1)$$

where an arbitrary non-constant mixing angle can be defined as $\theta_{e\mu}(E_\nu, \Delta m_{\nu_{\mu e}})$. This formula has the same form as the standard two-neutrino PNMS oscillation formula, which has the form,

$$P_{ee} = 1 - \sin^2(2\theta_{12})\sin^2\left(t\frac{\Delta m^2_{12}}{4E_\nu}\right), \quad (2)$$

except at low and high periods. For very long period ($wt \ll 1$) the oscillation probability has no E_ν component ($P_{ee} \approx 1 - f_{e\mu}^2 t^2$). In the case of the very short period ($wt \gg 1$), as the sin terms averages to 1/2 the oscillation probability gains a $\sim 1/E_\nu^2$ feature under certain conditions. It is claimed in [4] that anomalous features as measured by LSND, MiniBoone, Gallex/SAGE can be explained by this precise Flavon formula.

II. PROJECTED SENSITIVITY AT THE AIT SITE

Figure 1 (left) shows the set of four antineutrino parameters which reproduces for multiple set of experiments the expected oscillation predictions using a global fit with a $\Delta\chi^2$ method. AIT-NEO [1–3] is positioned at a standoff that will allow a test of the PNMS model with one month of data using a rate-only analysis. Within 7 months of data taking the Flavon model could be confirmed based on a rate-only analysis.

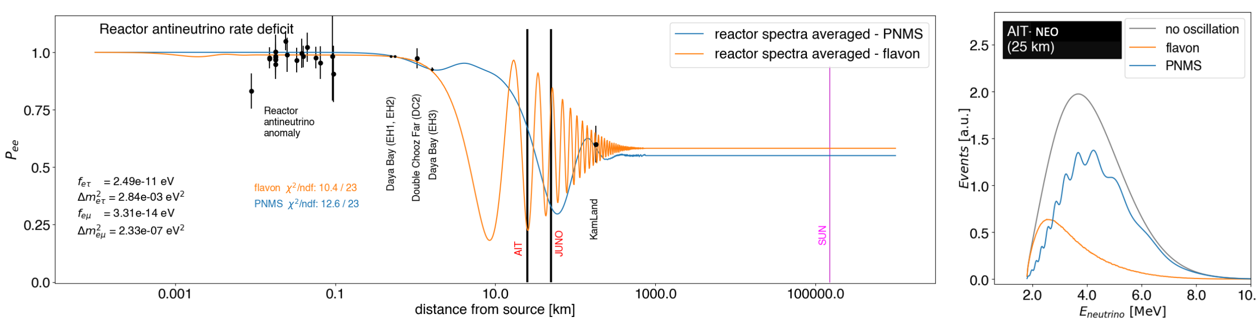

FIG. 1. (Left) Oscillation behavior as a function of distance ($t \to L/\beta c$) from source for PNMS and flavon model. (right) Projected neutrino spectra at the AIT site.

Figure 1 (right) shows the expected neutrino spectra at the AIT site. The Gd-water and WBLS technology have different energy threshold and will be sensitive to part of this energy spectra. Each of these experiments will be sensitive to making a pronouncement on the Flavon model. A multiple experimental phase approach would allow a more thorough measurement of the flavon behavior in a rate+shape analysis.

III. SUMMARY

AIT will be in a position to test the PNMS model in a baseline that has not been probed yet by reactor experiments. AIT will be able to test the flavon-only model (Equation 1) within a year and this independently of the technology choice.

[1] O. A. Akindele *et. al.* A Snowmass2021 Letter of Interest for the deployment of kiloton-scale neutrino detectors at the Advanced Instrumentation Testbed in Boulby England URL https://www.snowmass21.org/docs/files/summaries/NF/SNOWMASS21-NF7_NF10-IF9_IF0_Adam_Bernstein-096.pdf

[2] O. A. Akindele *et. al.* Snowmass2021 — Letter of Interest: a kiloton-scale gadolinium-doped water detection concept for Neutrino Experiment One at the Advanced Instrumentation Testbed in Northern England URL https://www.snowmass21.org/docs/files/summaries/NF/SNOWMASS21-NF7_NF10-IF9_IF0_Adam_Bernstein-097.pdf

[3] O. A. Akindele *et. al.* Snowmass2021 - Letter of Interest: a kiloton-scale water-based liquid scintillator detection concept for the Advanced Instrumentation Testbed in Northern England URL https://www.snowmass21.org/docs/files/summaries/NF/SNOWMASS21-NF7_NF10-IF9_IF0_Adam_Bernstein-098.pdf

[4] M. Bergevin, Reinterpreting Neutrino Oscillations, arxiv 2002.12269 doi:https://arxiv.org/abs/2002.12269. URL https://arxiv.org/abs/2002.12269