LSC 6.2: A Phenomenological Framework for Neutrino Propagation and Detector-Frame Tensor Anisotropy

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Abstract

LSC 6.2 is an arXiv-safe synthesis draft extending the public LSC 6.0 phenomenological framework. It keeps the conservative propagation-measurement coupling of LSC 6.0 and formulates detector-frame anisotropy through an explicit rank-2 tensor. The model is not presented as confirmed new physics; it is an effective proposal requiring global fitting, numerical simulation, and independent constraints from gallium experiments, KATRIN, and IceCube. This work does not claim a fundamental origin of the effect, but provides a testable phenomenological ansatz.

1 Introduction

LSC 6.2 is a conservative extension draft of the public LSC 6.0 framework. The public LSC 6.0 record is available at `https://zenodo.org/records/19780616`, and the related GitHub release is available at `https://github.com/luciferprosun/LSC-6.0/releases/tag/v1.0.0`. We propose a detector-frame tensor ansatz for neutrino energy reconstruction and angular response.

The effect can be interpreted as an effective direction- and energy-dependent phase correction, without invoking a literal refractive index for neutrinos. The model remains phenomenological.

2 Theoretical Framework

The core LSC 6.0 observable ansatz is retained,

$$E_{\text{true}}(x) = E_\infty \, G(g_{\mu\nu}, \Phi(x)), \tag{1}$$

$$E_{\rm rec} = E_{\rm true}\left(1 + \alpha_D D_{ij}\hat{p}^i\hat{p}^j\right). \tag{2}$$

Here G is a dimensionless propagation factor, E_∞ is the conserved reference energy, D_{ij} is an effective spatial detector-response tensor in the laboratory frame, $\hat{p}^i$ is the reconstructed direction unit vector, and α_D controls the detector-level contribution. The limiting condition is

$$\lim_{\Phi\to 0,\,\alpha_D\to 0} E_{\rm rec} = E_\infty. \tag{3}$$

3 Mathematical Formulation

The propagation factor is expanded as

$$G(g_{\mu\nu}, \Phi(x)) = 1 + \delta_G(x) + O(\delta_G^2). \tag{4}$$

The detector tensor is decomposed into isotropic and anisotropic components,

$$D_{ij} = D_{ij}^{\rm iso} + \Delta D_{ij}. \tag{5}$$

The effective fractional shift is then

$$\frac{\Delta E}{E} \simeq \delta_G + \alpha_D \Delta_D, \qquad \Delta_D = D_{ij}\hat{p}^i\hat{p}^j. \tag{6}$$

The anisotropic part is parameterized by a traceless rank-2 tensor,

$$D_{ij} = \delta\left(n_i n_j - \frac{1}{3}\delta_{ij}\right), \tag{7}$$

where δ is the dimensionless anisotropy magnitude and n_i is a preferred detector-frame direction. For an IceCube-style implementation, n_i may be aligned with a measured ice-flow or crystal-orientation-fabric axis; the corresponding ice-light propagation anisotropy is treated as a detector systematic, not automatically as a neutrino-sector signal. The contraction entering the observable response is

$$D_{ij}\hat{p}^i\hat{p}^j = \delta\left[(\hat{p}\cdot n)^2 - \frac{1}{3}\right]. \tag{8}$$

The reconstructed energy is therefore modeled as

$$E_{\rm rec}(\hat{p}) = E_{\rm true}\left(1 + \alpha_D D_{ij}\hat{p}^i\hat{p}^j\right). \tag{9}$$

A bounded first-order effect may be summarized as

$$\Delta m^2_{ij,\rm eff} \simeq \Delta m^2_{ij}\left(1 + \epsilon_D\right), \qquad \epsilon_D = D_{kl}\hat{p}^k\hat{p}^l. \tag{10}$$

The effective energy entering the oscillation phase is

$$E_{\text{eff}}(x) = E_{\text{true}}(x) \left[1 + \alpha_D D_{ij} \hat{p}^i \hat{p}^j\right]. \tag{11}$$

The oscillation phase is then written in the standard ultra-relativistic form

$$\Delta\Phi_{ij} = \int_0^L \frac{\Delta m_{ij}^2}{2E_{\text{eff}}(x)}\, dx. \tag{12}$$

This is a compact phenomenological ansatz and not a microscopic derivation. In the limit $D_{ij} \to 0$ and $\delta_G \to 0$, the standard three-flavor neutrino oscillation framework is recovered.

4 Phenomenological Implications

The relevant output of LSC 6.2 is a set of test classes: angular anisotropy, detector dependence, energy-dependent residuals, and sidereal modulation. Representative archive diagnostics are shown in Figs. 1–4. A representative value $\delta \sim 0.05$ is used for illustration; it is not a fitted or claimed measurement.

For binned event data, the conservative comparison can be written as

$$\chi^2 = \sum_k \frac{[N_{\text{obs},k} - N_{\text{pred},k}(D_{ij}, \delta_G)]^2}{\sigma_k^2}, \tag{13}$$

with

$$\sigma_k^2 = \sigma_{\text{stat},k}^2 + \sigma_{\text{sys},k}^2. \tag{14}$$

Each bin k may include reconstructed energy, zenith angle, azimuth, and time. A null test corresponds to $D_{ij} \to 0$ and $\delta_G \to 0$ within experimental uncertainties.

5 Discussion

The tensor language is the primary mathematical structure of LSC 6.2. The effect can be interpreted as an effective direction- and energy-dependent phase correction, without invoking a literal refractive index for neutrinos. The model must be checked against gallium source experiments, KATRIN beta-spectrum constraints, IceCube anisotropy searches, and standard three-flavor oscillation data. Known IceCube ice-light propagation anisotropies, including crystal-orientation fabric and hole-ice effects, must be treated as backgrounds or nuisance systematics before any neutrino-sector interpretation is attempted.

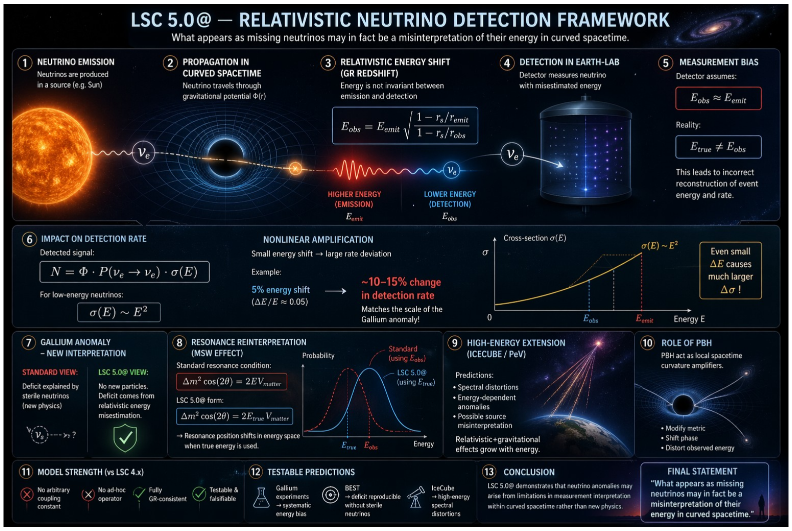

Figure 1: Unified propagation and detector-response framework.

6 Conclusion

LSC 6.2 provides a stable arXiv-safe synthesis of the LSC 6.0 effective model with an explicit detector-frame anisotropy tensor. The next required step is numerical fitting with explicit priors on δ_G, α_D, and the angular coefficients of D_{ij}.

7 References

References

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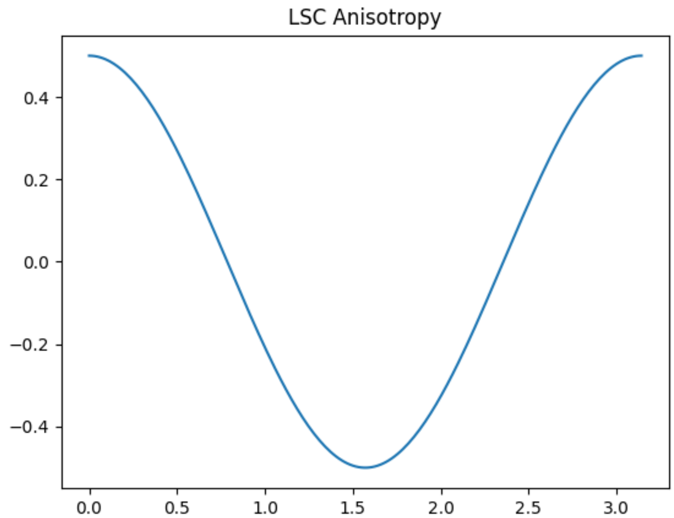

Figure 2: Anisotropic response diagnostic for angular or directional effects.

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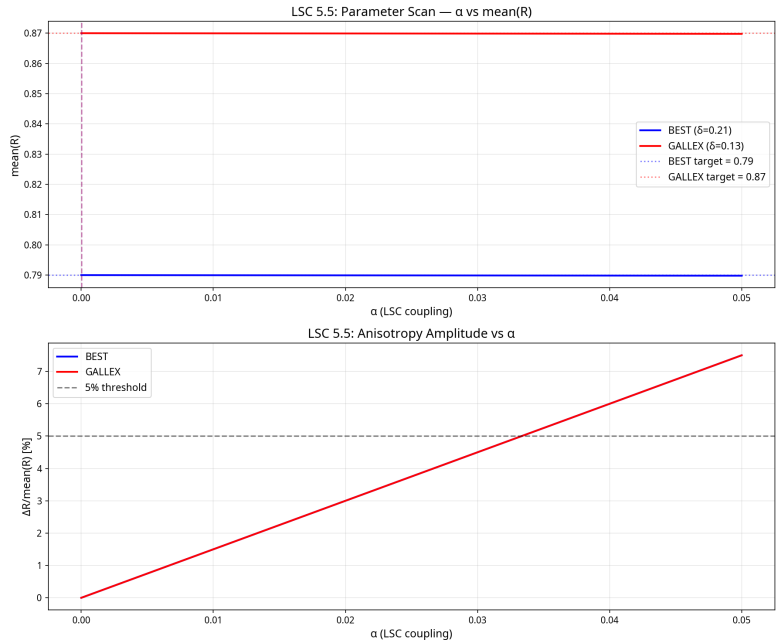

Figure 3: Parameter-scan diagnostic for effective LSC coefficients.

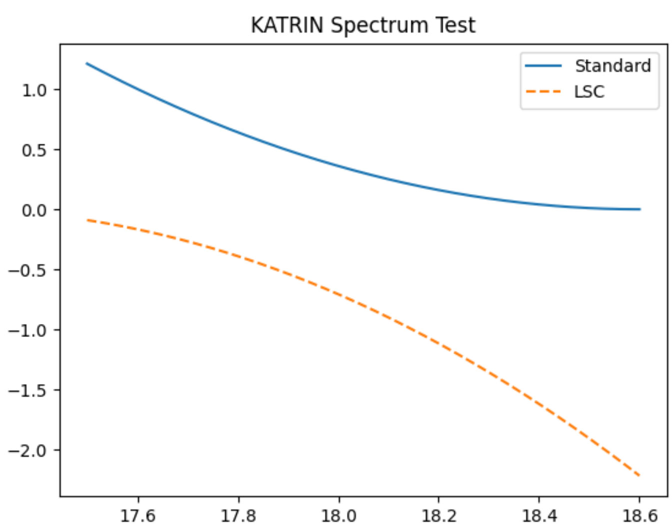

Figure 4: KATRIN-style consistency diagnostic.