ID de Contribution: **2** Type: **Non spécifié**

Probing the general axion-nucleon interaction in water Cherenkov experiments

mardi 20 mai 2025 11:30 (30 minutes)

We consider an axion flux on Earth consistent with emission from the Supernova explosion SN 1987A. Using Chiral Perturbation Theory augmented with an axion, we calculate the energy spectrum of $a + N \to N + \gamma$ as well as $a + N \to N + \pi^0$, where N denotes a nucleon in a water tank, such as the one planned for the Hyper-Kamiokande neutrino detection facility. Our calculations assume the most general axion-quark interactions, with couplings constrained either solely by experimental data, or by specific theory scenarios.
We find that even for the QCD axion – whose interaction strength with matter is at its weakest as compared with axion-like particles – the expected Čherenkov-light spectrum from neutrino-nucleon interactions is modified in a potentially detectable way. Furthermore, detectability appears significantly more promising for the $N+\pi^0$ final state, as its spectrum peaks an order of magnitude higher and at energies twice as large compared to the $N + \gamma$ counterpart. Given the rarity of SN events where both the neutrino and the hypothetical axion burst are detectable, we emphasize the importance of identifying additional mechanisms that could enhance such signals.

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Classification de Session: Beyond the Standard Model

Classification de thématique: BSM