New bounds on the Standard Model Extension coefficients in the proton sector from Rabi-type hyperfine spectroscopy of deuterium

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The Standard Model (SM) and General Relativity (GR) form the cornerstone of modern physics, describing fundamental particles and interactions. Bridging the gap between these frameworks still remains a key challenge, particularly due to gravity's exclusion from the SM and the incompatibility of quantum mechanics with GR. There have been many effective field theory approaches, which try to address this gap. However, the Planck scale suppression makes observable experimental signatures originating from such theories extremely tough to deal with. The Standard Model Extension (SME) [1] framework emerges as a pivotal effective field theory that integrates SM and GR while permitting Lorentz and CPT symmetry violations [1, 2, 3] and providing a basis for experimental and theoretical investigations of these fundamental symmetry violations. In its initial stages, the Lorentz violating operators in SME were restricted to mass dimensions $d \leq 4$ and was popularly known as the minimal SME. Later on, operators of arbitrary mass dimensions were also included in the so called non-minimal SME, opening the path for additional searches of Lorentz violation [4].

The Lorentz violating perturbations contribute to energy shifts in atomic spectra at the leading order of momentum of the electron or the nucleons [5, 6]. The sensitivity of the SME coefficients controlling the amount of Lorentz violation is proportional to $\delta\nu_{\text{exp}}/\langle|p_w|^k\rangle$, where $\delta\nu_{\text{exp}}$ is the experimental limit on the frequency shift in an atomic spectrum and p_w is the momentum of the particle of flavor $w \in \{\text{e, p, n}\}$. The relative momentum of the proton in the deuterium nucleus is about 5 orders of magnitude higher than the momentum of the proton in hydrogen. Based on theoretical estimates [7], a 10 Hz limit on the $\delta\nu_{\text{exp}}$ in deuterium would surpass the sensitivity of the proton coefficients in the non-minimal SME as compared to that of 0.1 mHz limit in hydrogen [8] by 5 orders of magnitude for $k = 2$ and by 15 orders of magnitude for $k = 4$.

In the pursuit of Lorentz violating signals, we performed the hyperfine spectroscopy measurements in deuterium focusing on any observation of the sidereal variations [5, 6, 7] of the measured transition frequencies. This talk will provide an overview of the in-beam Rabi type experimental setup that we used for the measurements, with a focus on the lumped mode microwave structure [9, 10] inspired Doubly split ring resonator (DSRR) used as a spectrometer. The talk will report on the constraints on the spherical coefficients for Lorentz violation in the proton sector in non-minimal SME obtained via measurement of the σ transitions in deuterium $(F = 3/2 \rightarrow F = 1/2,\ \Delta m_F = 0)$. The constraints on the spin-dependent SME coefficients for proton have been improved by 5 and 15 orders of magnitude for $k = 2$ and, $k = 4$ respectively. For the first time, bounds have been placed on the spin-independent proton SME coefficients for $k = 2$ and $k = 4$

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