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Nuclear photo-excitation for quantum control and metrology

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Nuclear physics studies atomic nuclei and their constituents and interactions. While not particularly spectacular from nuclear physics point of view, the photo-excitation of low-lying nuclear states opens the new field of nuclear quantum optics and may bring substantial progress in the field of metrology. These developments aim to exploit the fact that nuclei are very clean quantum systems, well isolated from the environment and benefiting from long coherence times. The talk will follow these perspectives at the borderline between nuclear and atomic physics on the one hand side and metrology and quantum optics on the other hand side. First, the present status of the efforts to use the unique low-lying ^{229}Th isomer at approx. 8.34 eV for a nuclear frequency standard will be briefly discussed, including the recent experimental success in laser excitation of the so far lowest known nuclear transition energy [1].

Second, combining the advantages of x-rays and nuclei, a prominent incentive is to use nuclei to exploit x-rays as the future quantum information carriers or for novel probing technologies based on quantum effects. A tool for this are resonant nuclear transitions, for instance the 14.4 keV Mössbauer transition in ^{57}Fe . The control of x-rays in resonant interactions can be achieved in the combination of a cavity or equivalent structured media to support the coupling to certain modes of radiation only and an ensemble of identical scatterers that allow to gain control over the radiation via collective effects. Promising x-ray quantum optics effects have been so far observed in thin-film layered structures in both cavity [2] and recently in waveguide geometries [3]. The talk will focus on quantum control opportunities in these structures, using nuclear resonances to control single x-ray photons.

[1] C. Zhang et al., Nature 633, 63 (2024)

[2] J. Haber et al., Nature Photonics 11, 720 (2017)

[3] L. M. Lohse et al., arXiv:2403.06508 (2024)

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