Resonant Addressing of Ultra-Narrow Nuclear Transitions

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Narrow optical resonances for quantum transitions in atoms, molecules, quantum dots, rare-earth doped crystals and color centers are the bases of fundamental quantum optics and its wide scope of practical applications in frequency standards, quantum sensors, quantum communication and simulation, *etc.*. In ultra-narrow nuclear resonances, much higher quality factors (such as $\sim 10^{20}$ in ^{45}Sc), occurring at room temperature in solids, can exceed the record value achieved in atomic clocks due to the inherent recoilless nature of these nuclear resonances at the hard X-ray frequencies ($1 - 10$ keV range).

This enables an appealing nuclear platform for new precision metrology, including time dilation at extreme scales, relativistic geodesy and search for the dark matter. However, the coherent control of such ultra-narrow resonances and their quantum interfacing with the resonant X-ray photons remain challenging.

In this talk, we review a new project aimed at resonant addressing of the super-narrow (1.4 feV line width) nuclear resonance at 12.4 keV transition in ^{45}Sc with X-ray radiation from the EuXFEL. It's a collaborative project with the groups of Yuri Shvyd'ko (ANL), Ralf Röhlsberger (DESY), Gianluca Geloni (EUXFEL), and Jörg Evers (MPI for Nuclear Physics, Heidelberg). We also discuss the possibility to enhance the spectral intensity of XFEL radiation within a narrow spectral width of the nuclear resonance, by using the far-off-resonant spectral wings, for increasing the efficiency of the interaction of an XFEL radiation with nuclei. The idea behind it is to apply a magnetic field gradient along the X-ray field propagation direction (similar to our recent proposal on quantum nuclear memory [1] to expand the spectral range of the photon-nuclei interaction, and flip the gradient with a lower magnitude after the passing of the incident photon. This leads to a coherent forward scattering in a narrower spectral range, thereby boosting the spectral intensity.

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References

[1] X Zhang, W-T Liao, A Kalachev, R Shakhmuratov, M Scully and O Kocharovskaya, Phys. Rev. Lett. **123**, 250504 (2019)