X-Ray Free-Electron Laser Drives Nuclear Clock Isomer Scandium-45

Y Shvyd'ko[1]

[1] *Argonne National Laboratory, Lemont, USA*
Contact Email: shvydko@anl.gov

Precise timekeeping is indispensable in everyday life, science, and technology. It relies on reference oscillators with stable frequencies. Atomic clocks – the most precise time-measurement devices at present – use spectrally very narrow resonant transitions between electronic states in atoms as their reference oscillators.

With the advent of hard X-ray free-electron lasers (FELs), the use of extremely narrow resonant transitions in atomic nuclei as reference oscillators for ultra-high-precision clocks is now within reach. Nuclear oscillators are naturally more stable and more resilient to external perturbations than their atomic counterparts. Resonant excitation of a ultra-narrow transition in Scandium-45 nuclear isomer with hard X-rays became recently possible [1] due to the high spectral photon flux delivered by the European XFEL in self-seeded high-repetition-rate mode.

In this talk, the results of this experiment will be presented along with discussion of further developments of hard X-ray FELs required for ultra-high precision nuclear clocks.

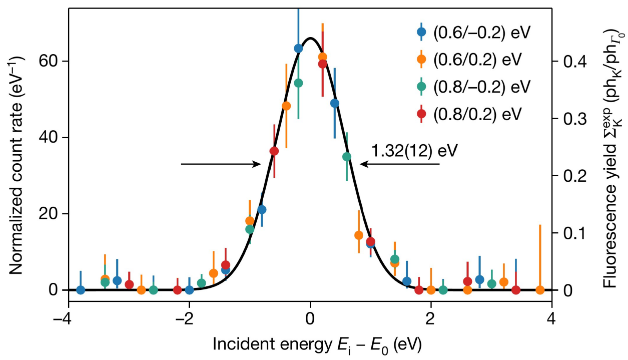

Figure 1: Resonance of the 12.4-keV nuclear transition in scandium-45 [1]. The resonance is shown as a function of the incoming X-ray photon energy E_i, with the observed line shape broadened by the spectral width of the incident rays ($\simeq$ 1.32 eV). During the search for the resonance, about 10^{20} near-resonant photons were directed at the ^{45}Sc target; only 93 nuclear decay events were detected. Because of the extremely low detector noise, this number was sufficient to reveal the ^{45}Sc resonance and measure the resonance energy $E_0 = 12{,}389.59 \pm 0.15$(stat) $+0.12$(syst) eV with high accuracy

References

[1] Y Shvyd'ko, R Röhlsberger, O Kocharovskaya *et al.*, Nature **622**, 471 (2023)