A vacuum ultraviolet frequency comb for the excitation of the 229-Thorium isomer

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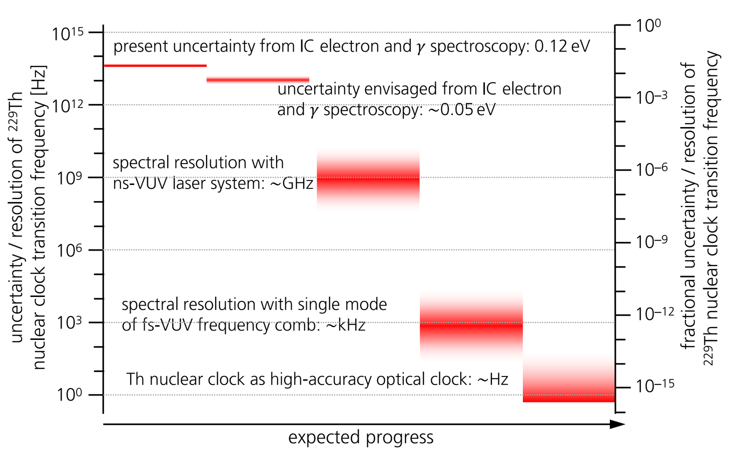
The isotope 229-Thorium features a low-energy (8.28 ± 0.17 eV) nuclear-excited state, the so-called thorium isomer [1]. This unique property makes it the only nuclear transition accessible with current laser technology and suitable for the operation as a nuclear clock. Such a clock has applications in fundamental physics [2] and the potential to surpass the precision achieved by current atomic clocks [3]. To drive the nuclear transition, we are building a tabletop VUV frequency comb that uses high-harmonic generation (HHG) to coherently transfer a high po-wer infrared frequency comb at 1050 nm to a frequency comb centered around 150 nm (H7).

VUV frequency comb

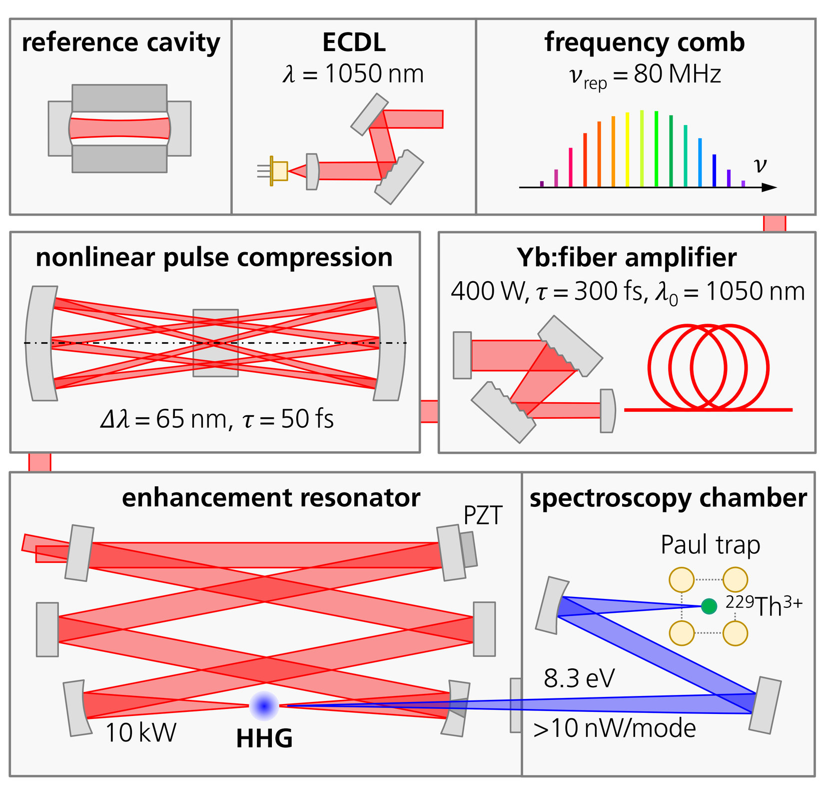
To enable the excitation of the ^{229}Th nucleus, the VUV frequency comb has to reach a high power per comb mode (>1 nW/mode), a small comb-mode linewidth (kHz) and has to cover the search range around 150 nm. The system comprises the following elements:

- A commercial low-noise IR frequency comb at 80 MHz repetition rate, including an optical reference system at 1050 nm.
- A commercial high-power fiber amplifier at 1050 nm (400 W, 5 µJ, 300 fs).
- An MPCSB nonlinear pulse compression to reach 50 fs pulses, allowing a higher HHG efficiency and larger spectral coverage.
- An enhancement resonator with 10 kW circulating power and HHG target. The resonator allows reaching the high intensity for HHG (>1e13 W/cm²) at the high repetition rate of the frequency comb, it boosts the conversion efficiency and suppresses high-frequency phase noise.

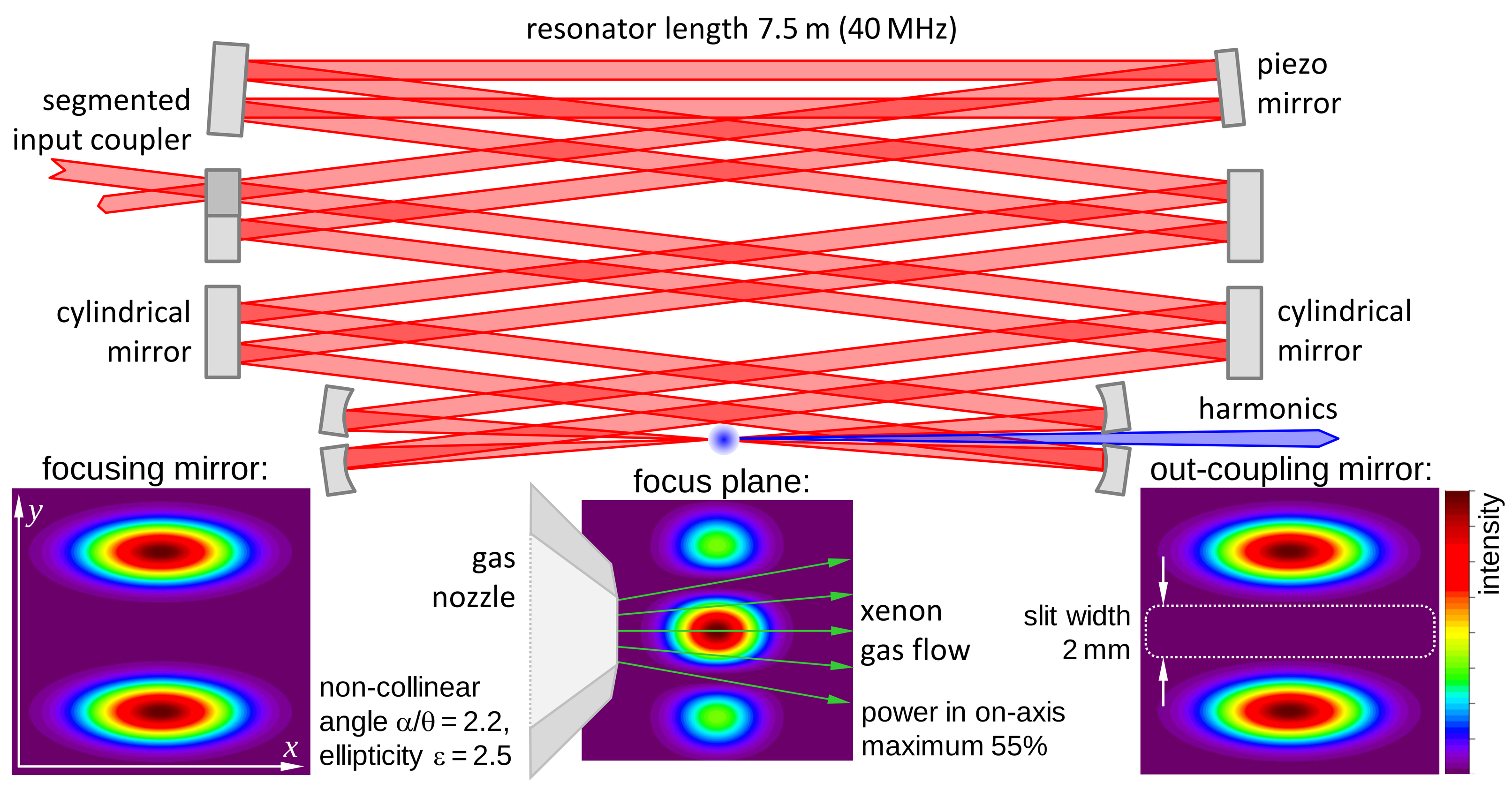
The VUV frequency comb will be installed at LMU München in 2023 and combined with a Paul trap for $^{229}Th^{3+}$ ions within the ThoriumNuclearClock project (ERC Synergy Grant). The VUV comb will be used to search for the nuclear transition, possibly reducing the uncertainty of the transition frequency by 10 orders of magnitude. Subsequently, it can be used to operate a nuclear clock.



Expected progress in the uncertainty of the 229Th transition frequency within the ThoriumNuclearClock project. Next to our VUV frequency comb, a ns-VUV laser system is set up at PTB and a solid-state HHG source at TU Wien [4].



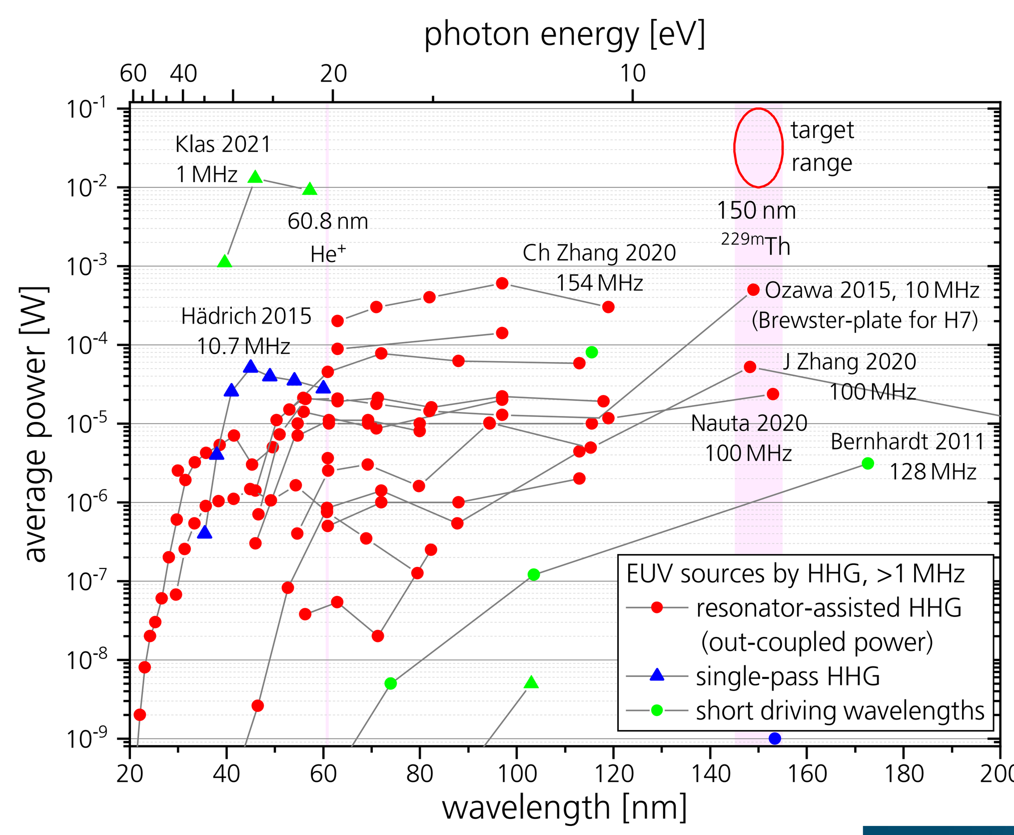
Sketch of the VUV frequency comb setup under construction.



Sketch of the noncollinear HHG enhancement resonator for geometrical output coupling.

Resonator-enhanced high-harmonic generation

- Noncollinear laser resonator for efficient geometrical output coupling of harmonics (> 60% for H7). Mechanically stable and demonstrated concept of using common mirrors for both circulating pulses [5].
- Cylindrical mirrors yield elliptic eigenmode with a smaller focus diameter in direction of gas flow to minimize cumulative plasma effects.
- We are aiming at >10 mW outcoupled VUV power by using shorter pulses and a higher impinging power than previously reported systems.



Overview on the state of the art of coherent VUV/EUV sources with high repetition rate (>1 MHz).

A frequency comb in the VUV or EUV enables further applications in spectroscopy. Moreover, spatially coherent sources in the VUV to XUV, which can be realized by HHG, offer numerous applications in science and industry, e.g. photo emission spectroscopy, microscopy, lithography, and metrology.

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