Determination of the nuclear charge radius from precision spectroscopy of atomic helium

Research project objectives — The goal of this project is the determination of nuclear charge radii from the precise spectroscopy of the helium atom and light helium-like ions for comparison with values obtained from the corresponding muonic atom Lamb shift. More specifically, we aim to determine the charge radius of the He nucleus from the known $2^3S - 2^3P$ transition frequency with a relative precision of about $1.5 \cdot 10^{-3}$, which will be better than that from electron scattering and will be at least comparable with the expected accuracy of μHe determination.

Research project methodology — The $2^3S - 2^3P$ transition of He is particularly suitable for this purpose because it is relatively sensitive to the nuclear charge radius and can be calculated within the QED theory up to the $\alpha^7\, m$ order; this is because for triplet states the wave function vanishes at $\vec{r}_1 = \vec{r}_2$ and thus the most difficult contribution vanishes. We will perform calculations using dimensionally regularized custom developed nonrelativistic quantum electrodynamics (NRQED), and we expect these calculations will bring the theoretical accuracy to the 10 kHz level.

Expected impact of the research project on the development of science — The proton charge radius puzzle, the discrepancy in the determination of the proton radius from “usual” hydrogen and muonic hydrogen is one of the unsolved problems in physics. It may signal the existence of interactions that are not accounted for, a lack of universality in the lepton-hadron interaction, or incorrect values of physical constants. Moreover, there is no widely accepted extension of the Standard Model (SM), that could explain this discrepancy but at the same time not spoil agreement with other precision tests of SM. Therefore, comparison of the obtained charge radii with those from muonic atom measurements (μHe, μLi) will be the critical test of the Standard Model of fundamental interactions. If similar discrepancies are observed, this would be a clean signature of a new physics. In the opposite case, if agreement is found this would indicate severe experimental problems with hydrogen spectroscopy, which may influence the determination of fundamental physical constants, e.g. the Rydberg constant.