Status of the FAMU experiment at RIKEN-RAL for a precision measurement of the Zemach radius of the proton in muonic hydrogen

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* https://web.infn.it/FAMU/the-project/

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The general disagreement among different measurements of the charge radius of the proton, also called "proton radius puzzle", is still an open problem in Nuclear and Subnuclear Physics. If this discrepancy is confirmed, it may be related to processes beyond the Standard Model. The FAMU experiment (Fisica degli Atomi MUonici), led by INFN at the Rutherford Appleton Laboratory (UK), is designed to measure the Zemach radius of the proton in muonic hydrogen (μH) with 1% relative uncertainty, which would shed some light on this discrepancy, which is still not understood. In addition, the definition of the Zemach radius as a convolution between the electric and magnetic form factors (G_E, G_M) of the proton makes this measurement a good probe to verify the strong interaction theory in the prediction of the relationship between these two QCD nuclear parameters.

In the FAMU experiment, a 60 MeV/c negative muon beam is produced using the ISIS synchrotron at the RIKEN-RAL muon facility. The beam, monitored by a scintillating fibre hodoscope, is directed against a gaseous hydrogen-oxygen target, producing muonic hydrogen atoms (μH). A custom-made Mid-InfraRed (MIR) laser, with tunable wavelength around 6.8 μm, is injected into the cryogenic chamber filled with the gas mixture, to stimulate the resonant spin-flip in μH atoms. The probability of the muon transfer to an oxygen atom, followed by delayed X-ray emission around 120 keV, is enhanced. As a consequence, this delayed X-ray emission acts as a marker for the spin flip process. A set of $LaBr_3$ scintillating crystals, supported by a HPGe detector, are used to detect this marker, looking for a resonant excess as a function of laser wavelength, and the resonant wavelength corresponds to the spin-flip energy in μH. The FAMU experiment enables the measurement of this value with a relative uncertainty around 10^{-5}, which is used to determine the Zemach radius through QED calculations, with a relative uncertainty better than 1%.

The activity of the FAMU Collaboration in the last 10 years enabled the final optimisation of the detector-target setup as well as the gas working condition in terms of temperature, pressure and gas mixture ratio. As part of this activity, the profiles of muon transfer for different gas mixtures were measured in detail as a function of temperature and pressure, showing accordance with the few data available in the literature, and a net discrepancy with the theoretical predictions for this process.

As of mid-2023, we have finally reached the optimal working conditions for the experiment, having successfully coped with many technological challenges, and we are ready to start the experimental campaign. In particular, the beam hodoscope, the germanium detector and the $LaBr_3$ scintillators read by SiPMs and PMTs have been thoroughly optimised in these years to fit best the experiment needs in terms of solid angle coverage, efficiency, energy resolution and time performance. In fact, the radiation emitted by the target after muon irradiation is dominated by prompt emission. Reaching an optimum between energy resolution and time performance has therefore proved crucial to successfully carry out the measurement.