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Muonium and Muonic Helium Hyperfine Structure Precision Measurements at J-PARC MUSE

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At the J-PARC Muon Science Facility (MUSE), the MuSEUM collaboration is planning new measurements of the ground state hyperfine structure (HFS) of both muonium and muonic helium atom.
Muonium (a bound state of a positive muon and an electron) and muonic helium (a helium atom with one of its electrons replaced by a negative muon) are both hydrogen-like atoms. Their respective ground-state HFS results from the interaction of the electron and the muon magnetic moment, and they are very similar but inverted because of the different signs of their respective muon magnetic moments. High-precision measurements of the muonium ground-state HFS are recognized as the most sensitive tool for testing bound-state quantum electrodynamics (QED) theory to precisely probe the Standard Model [1] and determine fundamental constants of the positive muon magnetic moment and mass. The same technique can also be employed to measure muonic helium HFS and obtain the negative muon magnetic moment and mass. Moreover, muonic helium HFS is also a sensitive tool to test and improve the theory of the three-body atomic system.
The MuSEUM collaboration already performed HFS measurements at zero magnetic field at MUSE D-line of both muonium and muonic helium atom, with results more accurate than previous measurements [2-4]. High-field measurements are now in preparation at the MUSE H-line, using ten times more muon beam intensity than at the D-line, and with decay positrons/electrons being more focused on the detector due to the high magnetic field, we aim at improving the accuracy of previous measurements by ten times for muonium and hundred times or more for muonic helium. Furthermore, a new experimental approach to recover the negative muon polarization lost during the muon cascade process in helium is being investigated by repolarizing muonic helium atoms using a spin-exchange optical pumping (SEOP) technique [5], which would drastically improve the measurement accuracy, and where a direct improvement by a factor of ten may be realized. An overview of the different features of these new HFS measurements and the latest results will be presented.

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[2] S. Kanda et al., Phys. Lett. B 815, 136154 (2021)
[3] S. Nishimura et al., Phys. Rev. A 104, L020801 (2021)
[4] S. Fukumura et al., EPJ Web Conf. 262, 01012 (2022)
[5] A. S. Barton et al., Phys. Rev. Lett. 70, 758 (1993)

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