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Towards Improving the Precision of the Negative Muon Mass via Muonic Helium HFS Spectroscopy

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uonic helium is a hydrogen-like atom composed of a helium atom with one of its electrons replaced by a negative muon. Its ground-state hyperfine structure (HFS), resulting from the interaction of the remaining electron and the negative muon magnetic moment, is very similar to muonium but inverted. High-precision measurements of the muonium ground-state HFS interval are recognized as the most sensitive tool for testing bound-state quantum electrodynamics (QED) theory [1] and also determining fundamental constants of the positive muon magnetic moment and mass. New precise measurements are now in progress by the MuSEUM collaboration at J-PARC [2]. The same microwave magnetic resonance method can also be used to precisely determine the muonic helium atom HFS interval and the negative muon magnetic moment and mass. The world's most intense pulsed negative muon beam at J-PARC MUSE allows for improving previous measurements and testing further CPT invariance by comparing the magnetic moments and masses of positive and negative muons (second-generation leptons), where an improvement by a factor of 50 or more is possible [3]. Also, a more precise determination of the muonic helium atom HFS interval will be beneficial to test and improve the theory of the three-body atomic system.

Already, measurements at MUSE D-line were performed utilizing the MuSEUM apparatus at zero field. Muonic helium atom HFS were measured at three different gas pressures to determine the HFS interval at zero pressure using methane as an electron donor to form neutral muonic helium atoms. The data analysis was just completed, and the accuracy obtained of 4.5 ppm is already better than both previous measurements [4,5]. Furthermore, a new experimental approach to recover the muon polarization lost during the muon cascade process is being investigated by repolarizing muonic helium atoms using a spin-exchange optical pumping (SEOP) technique [6]. The first laser repolarization experiment was recently performed. Finally, the preparation for high-field measurements at H-line is in progress, which will allow for improving the negative muon mass. An overview of the different features of these new muonic helium atom HFS measurements and the latest results will be presented.

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