【Grant-in-Aid for Scientific Research (S)】

Broad Section B

Title of Project : Precision test of electroweak theory and search for new physics beyond the Standard Model by laser spectrocsopy of purely leptonic atoms

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Keyword : Muonium, precision laser spectroscopy, electroweak theory, new physics beyond the Standard Model

【Purpose and Background of the Research】

Search for new physics beyond the Standard Model is one of the most important subjects in the elementary particle physics. In this project, we precisely measure energy levels of "purely leptonic atoms" by using modern techniques for atomic spectroscopy. The results provide a precision test of the electroweak theory –a part of the Standard Model– and pave the way to search a yet unknown new particle couples to the electron and the muon.

Atomic physics experiments using simple hydrogen atoms have played the most important role in the evolution of physics during the 20th century. In addition, after the invention of optical frequency comb in 1999, the technique of precise optical frequency measurements is rapidly advanced. Nowadays the experimental uncertainty of 1S-2S transition of hydrogen atoms (~10^{15} Hz) becomes ~10 Hz. However, theoretical calculations of hydrogen energy levels have not been confirmed very well by experiments. This is because the nucleus in the 'ordinary atoms' consists of composite particle of hadrons. As a result, the proton radius is impossible to predict by theories, and the energy level uncertainty originated from it is >100 kHz even such a simple hydrogen atom. The uncertainty is 4 order of magnitude larger than the experiment.

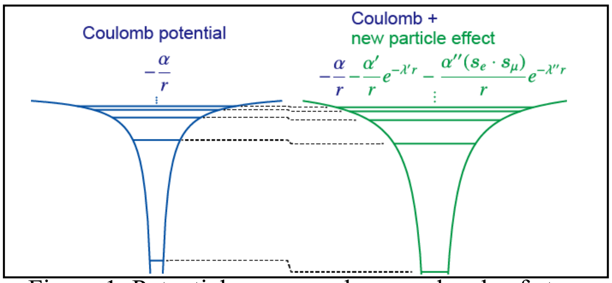

Figure 1: Potential energy and energy levels of atom

【Research Methods】

The difficulties can be overcome by using Muonium (Mu) –purely leptonic atoms. Mu can be seen as an isotope of hydrogen but the big difference between Mu and ordinary atoms is that Mu consists of leptons: elementary particles with no complex structure. Thus the precise calculation of its energy levels is feasible. Actually, energy shifts of -65 Hz originate from the electroweak interaction has already been predicted. In the previous experiments, however, large number Mu production was difficult, so the statistical uncertainty was the primary source of uncertainty.

In this project, we perform precision spectroscopy of purely leptonic atoms by using (1) the latest technique of laser spectroscopy, (2) high-quality muon beam at J-PARC, and (3) precise calculation method based on the electroweak theory. The results provide a stringent test of electroweak theory. Moreover, we can investigate effects of new physics through the Mu spectroscopy.

【Expected Research Achievements and Scientific Significance】

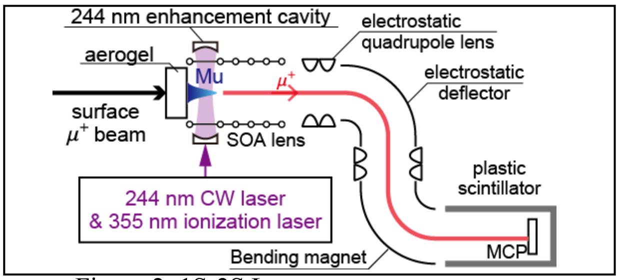

Figure 2: 1S-2S Laser spectroscopy system

The present uncertainty in the muon mass (one of the fundamental physical constants) can be greatly reduced by improving the experimental precision of the 1S-2S transition frequency of Mu, which is measured in this project. As a result, uncertainties in the calculation of Mu energy levels is greatly reduced. If we found any difference between the energy levels predicted by the electroweak theory and measurement, that implies effects of new physics. Such results would make a big paradigm shift in the elementary particle physics.

【Publications Relevant to the Project】

・A. Yamaguchi, S. Uetake, S. Kato, H. Ito, Y. Takahashi, "High-resolution laser spectroscopy of a Bose-Einstein condensate using the ultranarrow magnetic quadrupole transition", New. J. Phys. 12, 103001 (2010)

・Y. Miyamoto, S. Uetake, M. Yoshimura *et al.*, "Externally triggered coherent two-photon emission from hydrogen molecules", PTEP2015, 081C01 (2015)

【Term of Project】 FY2019-2023

【Budget Allocation】 154,300 Thousand Yen

【Homepage Address and Other Contact Information】

http://www.xqw.okayama-u.ac.jp/