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

Precition test and search for new physics beyond the Standard Model by precise laser spectroscopy of purely leptonic atoms

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Purpose and Background of the Research

●Outline of the Research

Almost all physical phenomena can be explained by the Standard Model (SM) of particle physics. Although it is very successful theory, it cannot explain several phenomena such as existence of dark matter or matter-antimatter asymmetry in our universe. Thus it is one of the most important subject in the fundamental physics to develop a comprehensive theory beyond the Standard Model.

In the history of physics, evolution of precision measurement technology was often the strong driving force to develop a new physics theory. For example, the SM was based on the successful development of Quantum-Electrodynamics (QED). QED theory development was triggered by a discovery of Lamb-shift in 1947. The Lamb shift was discovered by the evolution of precision microwave spectroscopy technology.

What approach would be better to search a new physics beyond the SM? To answer this question, we will measure energy levels of purely leptonic atoms by using modern techniques for atomic spectroscopy. From expected results, we verify the SM and investigate if there is any effects of new physics beyond the SM.

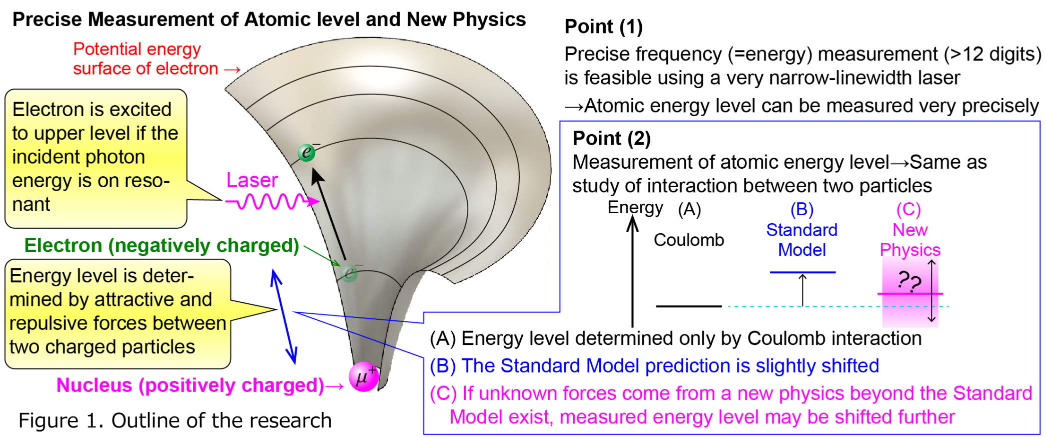

Figure 1. Outline of the research

●Muonium: key of our research

Muonium (Mu) is one of the isotopes of hydrogen atoms. Mu consists of a positive muon (the second generation lepton) and electron (the first generation lepton). It is an artificial atom because its lifetime is only about 2 micro seconds. The most important feature of Mu is that its energy levels can be precisely calculated by the SM because it is the simplest atom consists of two point particles. According to the SM calculation, the energy level is shifted from the one calculated only including the Coulomb interaction (Fig. 1(B)). If there is another effect from a new physics beyond the SM, measured energy level may be shifted further (Fig. 1(C)). Therefore, the precise measurement of the energy level of Mu would pave the way to search for new physics beyond the SM.

●Method and Features of the project

In the past measurement, number of Mu was very small and the accuracy of results was statistically limited. In our project, we have already succeeded to obtain large number of Mu by using new technologies listed below:

1. By using world's highest intensity pulsed muon beam available at J-PARC
2. By using a porous silica aerogel as a new target for Mu production (Figs. 2 and 3)

We also developed a state-of-the-art laser system (Fig. 3). By these improvements, we have already obtained several hundreds times larger signal than the past experiments.

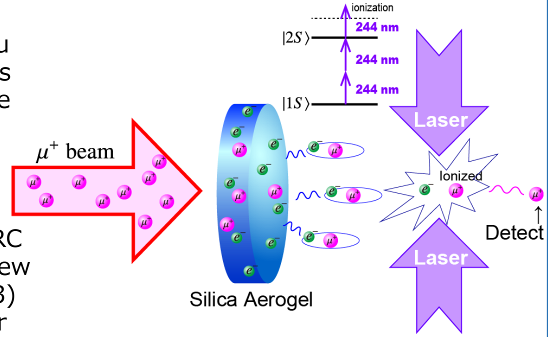

Figure 2. Outline of Mu production thorough detection. Muons stopped in the aerogel form Mu by capturing electrons, then emitted. When laser is on resonant, Mu are ionized and then detected.

Expected Research Achievements

●Improve accuracy of muon mass (the fundamental physical constant)

In order to evaluate the SM from the energy level measurement of the Mu, the muon mass must be determined more precisely, because it is required as an input for theoretical calculation. The present experimental uncertainty of the muon mass is 120 ppb (ppb = 10^{-9}). This uncertainty is almost three-order of magnitude worse than that of the electron (0.3 ppb). Thus, it is impossible to evaluate the energy shift shown in Fig. 1(B) (38 ppb) because the mass uncertainty is much larger than the SM prediction in the present situation.

The muon mass can be precisely determined by improving the accuracy of 1S-2S transition frequency of the Mu. This is because a mass term greatly affects the 1S-2S transition frequency, therefore if we precisely measure it experimentally, the measured results can be used to determine the muon mass.

We improve the accuracy of muon mass by precise laser spectroscopy of the 1S-2S transition frequency of Mu. As a result, the SM prediction can be precisely evaluate.

The fundamental physical constants should be determined as precise as possible, because they are the basis of all scientific measurements. Our results improve all scientific measurements related to muon and electron.

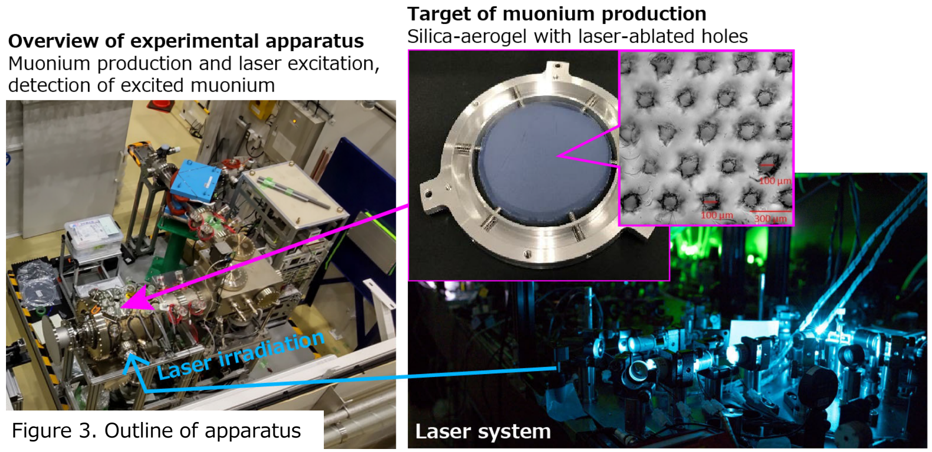

Figure 3. Outline of apparatus

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