JAEA-ASRC muon research at J-PARC MUSE

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Abstract. The Japan Atomic Energy Agency (JAEA)-Advanced Science Research Center (ASRC) has developed experimental equipment at the J-PARC MLF muon science facility (MUSE) for muon spin rotation/relaxation experiments. We have extracted part of the muon beam into a muon spectrometer constructed downstream from the Decay/Surface muon beam line. The current status of our project is discussed here.

1. Introduction

The Muon Science Facility (MUSE) at the J-PARC Materials and Life Sciences Facility (MLF) will be utilized for various fields of science, including nuclear and condensed-matter physics and chemistry. Muons are created at MUSE from pions which are generated in a graphite target impacted by a 1MW, 3GeV proton beam; the pions decay into muons with a half-life of 26 ns. These muons are collected by magnets and an intense pulsed muon beam is delivered to the muon experimental area.

The JAEA-Advanced Science Research Center (ASRC) is building the experimental apparatus for muon spin rotation/relaxation experiments at the J-PARC-MLF-MUSE facility. In this article, we present the current status of the ASRC muon research.

2. ASRC muon research

The ASRC muon research program was started in FY2005. The main purpose of our research is the study of f-electron materials using the µSR technique as a microscopic magnetic probe. In some f-electron systems, a tiny and fluctuating magnetic field plays the dominant role in determining the f-electron characteristics, and µSR has great sensitivity to detect these fields. The intense muon beams at J-PARC will allow us to understand the details of a specific magnetic state, and thus J-PARC has great merit in the study of f-electron systems.

For our ASRC µSR experiments a muon beam is extracted downstream of the Decay/Surface muon beam line of MUSE, as a branch of that beam line. A positive muon beam with momentum of 29MeV/c (surface muon) and a positive or negative decay muon beam with a momentum of 20-50MeV/c can be delivered to the experimental area (D1 area). This beam line has a “beam slicer” to obtain higher time resolution, as discussed below. Figure 1 shows a layout of the beamline which we have installed. The main components are two triplet quadrupole magnets and the beam slicer. This beamline is connected to the bending magnet (DB3) of the Decay/Surface muon line.

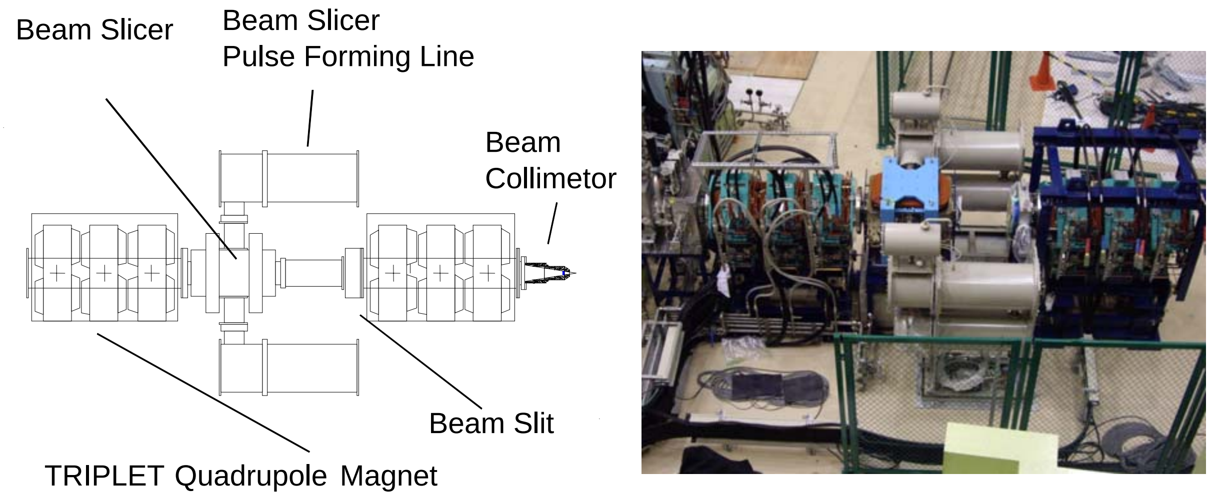

Figure 1. Layout of the ASRC equipment (top view) and photograph of D1 area.

Two sets of triplet quadrupole magnets are used as the focusing device. The maximum magnetic field gradient is 1.675 T/m at 375 A, which was determined from calculations of the beam optics and a desire to produce muons with momenta of up to 50MeV/c. The bore radius of the magnet is 300mm. Star-shape vacuum ducts are installed into each magnet. These magnets are connected to power supplies which are controlled from the Experimental Physics and Industrial Control System (EPICS) [1].

One of the main instruments is the "beam slicer." For pulsed-beam μSR experiments, the observable muon spin precession frequency is restricted by the width of the muon pulse. Since the time structure of the muon pulse is about the same as that of the proton pulse, the width of the muon pulse is longer than 100ns. In addition, the proton beam has two bunch structures, and this fact also suppresses the observable muon spin precession frequency. To overcome the limited time resolution which comes from the time structure of the proton beam, a muon beam slicer was installed. The beam slicer consists of an electric kicker, a pulsed electric power supply, which has a fast rise time, and a correction magnet. A rise time for the electric field less than 20ns (10-90%) and a pulse width of about 300ns have been achieved. This will allow a chopped muon pulse width of less than 30ns.

3. Beam Commissioning

On September 26, 2008, the first muon beam was delivered to the D1 area of J-PARC MUSE. Muon beam commissioning was carried out mainly with a μSR spectrometer (Dai-Omega) used previously at KEK-MSL. An imaging plate [2], or beam profile monitor, was also used to check the beam profile [4]. Recently, negative muons were successfully extracted at the D1 area and a negative muon spin rotation spectrum was observed. The details of the beam commissioning are reported in other articles [3,4].

We also examined the performance of the muon beam slicer. Figure 2 shows oscilloscope traces of the muon beam observed by an in-line scintillator. The beam is bent by the correction magnet located near the muon slicer. When an electric field is applied to the slicer, the muon beam returns to its original trajectory and can reach the scintillator. Here the electric field was synchronized to the timing of the second muon pulse so that only this second muon pulse could reach the muon spectrometer. This "single-pulse operation mode" is used for μSR measurements.

We have also succeeded in slicing the muon pulse itself. When an electric field is applied just before the second muon pulse goes away, only the tail of the pulse can reach the spectrometer and a narrower pulse is obtained. By using this "muon-slice mode," we have obtained a pulse width less than 37ns (FWHM). This muon-slice mode results in a loss of muons, however, so that a high-intensity muon beam is required to obtain sufficient muon intensity. In addition, as shown in Fig. 2, the electric-field pulse shape is not yet rectangular and development of the pulsed power supply is still ongoing. Details of the performance will be reported elsewhere.

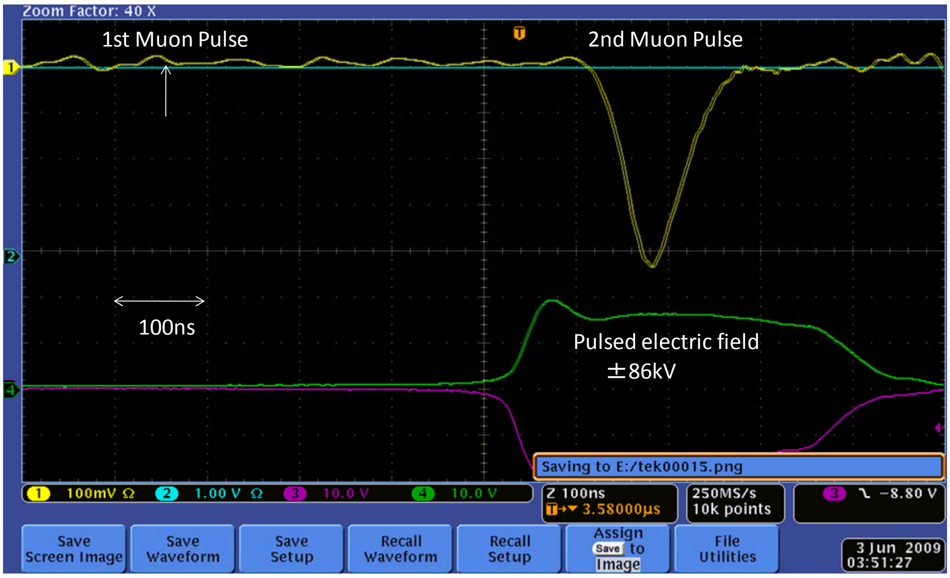

Figure 2. "Single-pulse operation mode" of the muon beam slicer. The first muon pulse is bent by a correction magnet and the second muon pulse is "kicked" by an electric field of ±86kV.

4. Experimental apparatus

We have also developed experimental apparatus for use at the D1 port. For example, a Gifford-McMahon refrigerator is used to cool materials down to 2K without liquid helium. The refrigerator possesses a large sample area and allows use of the "fly-pass method" for background reduction [5]. The development of a uniaxial pressure cell is also underway. The sample can be seen from outside of this cell and surface muons can be used with it, which is different from a hydrostatic pressure cell. Test experiments for this equipment will be performed soon.

5. Scientific Topics

One of the main subjects of the ASRC muon research program is the study of strongly correlated electron systems, especially f-electron systems. Examples of these topics include heavy fermions, anisotropic superconductivity, multipole ordering, physics in the vicinity of a quantum critical point (QCP), and unconventional magnetism (tiny moments, etc.). Studies of these topics are quite suitable for μSR experiments. For example, a small and fluctuating magnetic field is often seen near a QCP, and the high sensitivity of the muon probe is a good tool for such an investigation. The world's highest sensitivity will be obtained by using the intense muon beams of J-PARC, allowing us to obtain new insights into f-electron systems. Up to now we have already measured several Ce-, Sm- and Yb-based systems to clarify their dipole or multipole magnetic properties.

Recently, we have also performed muonic x-ray measurements at the D1 port. Negative muons of 19 MeV/c were implanted into sample gas to clarify the chemical effects of muonic atom formation processes, and several muonic x-rays were clearly observed. These details will be published elsewhere.

6. Summary

We have developed important experimental equipment which is essential for the J-PARC MUSE facility to carry out muon spin rotation/relaxation and muonic x-ray measurements. Our research will add new capabilities to MUSE, highly enhancing our knowledge of muon science.

Acknowledgement

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