Activity of MuSIC Muon Beam line at the RCNP Cyclotron Facility 2020

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During the long shutdown for the AVF cyclotron upgrade, the MuSIC muon group have been developing some experimental apparatuses for resuming beam commissioning and experiments. In this article, we will report recent progress of the MuSIC development and introduce a new paper in the MuSIC beam line.

1 New drift chamber for 2-dimensional elemental imaging for non-destructive muonic X-ray analysis

One of the key applications in the MuSIC beam line is the muonic X-ray analysis for various elements using negative muon beam. Muonic X-ray analysis has great advantages in several ways; non-destructive elemental analysis from light to heavy elements, depth profile analysis, isotopic measurement for heavy elements and measurement of chemical condition (redox state). The previous successful measurements for various meteorites (E411 in November 2015 [1], E528 in June 2018) showed feasibility of the non-destructive muonic X-ray analysis for meteorites, and open up possibilities to asteroidal sample return missions (Hayabusa2 and OSIRIS-REx) and successive future meteorite non-destructive analyses. One remaining technical challenge is to obtain the 2-dimensional (2d) imaging of the meteorites without any destruction. For this purpose, a new gaseous drift chamber have been developed for imaging an incident muon beam profile shown in Fig 1. Since a continuous (DC) muon beam has great advantage to be tracked one-by-one with the drift chamber, a source position and an energy of the muonic X-ray can be identified by combining with a germanium detector.

The drift chamber consists of 6 wire-layers and covers an effective beam size of 40 mm $\times$ 40 mm. A spatial resolution of few hundred μm is required with low-material composition inside the chamber in order to reduce a scattering effect using a low momentum beam around 30 MeV/c. These conditions enable us to map 2d non-uniform composition at a near-surface of meteorites.

The first performance test was done using a 7 MeV proton beam at the Institute for Integrated Radiation and Nuclear Science, Kyoto University. The proton beam was successfully tracked with a spatial resolution of $\sim$ 500 μm as shown in Fig. 2 [2]. At present, we are proceeding further analysis especially for multi-hit events to improve the resolution and tracking efficiency for effective use of the muon beam [3].

We plan to install a newly designed detector system for muonic X-ray analysis as shown in Fig. 3, which comprises of germanium detectors, trigger counters, and the drift chamber. After the muon beam commissioning, we will start a feasibility study with the MuSIC muon beam (E575, approved) for the 2d imaging. We expected that this detector system is applicable for various researches of the muon X-ray analysis

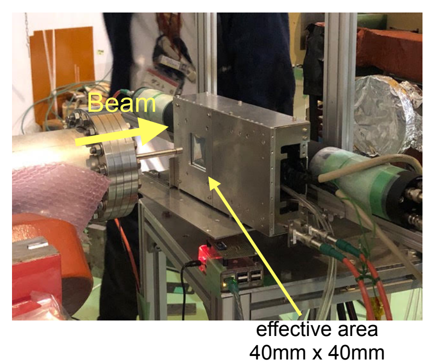

Figure 1: Photograph of newly developed tracking drift chamber taken in the test experiment with the proton beam.

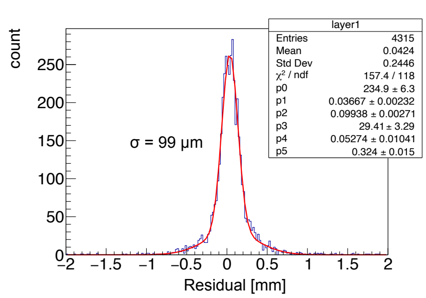

Figure 2: Spacial resolution of the drift chamber measured with the proton beam in the performance test.

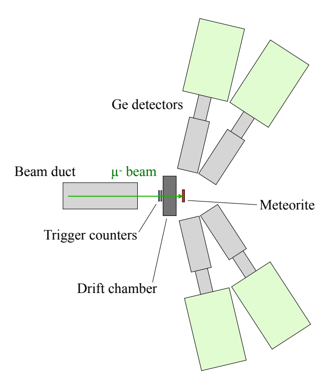

Figure 3: Schematic view of the proposed 2d imaging system for muonic X-ray analysis.

proposed to the MuSIC muon beam line, such as other non-destructive elemental analysis and chemical analysis. Furthermore, we expect that this drift chamber can be utilized as a versatile profiler for the negative and positive low-energy muon experiments.

2 New cooling system for μSR at MuSIC

Another key application in the MuSIC beam line is the μSR (Muon Spin Relaxation, Rotation and Resonance) measurement using the positive muon beam. A muon is utilized as a sensitive magnetic probe to explore new materials in condensed matter physics, in particular for magnetism and superconductivity researches. We have constructed a μSR measurement system at RCNP-MuSIC aiming for establishing the one of the DC-μSR site in the world. For this purpose, a new μSR spectrometer, detectors, data acquisition system (fast and slow controls) and a cryogenic system have been developed and commissioned for user experiments [4]. Two user experiments have been already performed (E517, W. Higemoto et al., E536, S. Tajima, et al.) in 2019 before the long shutdown. We found that there were some beam and technical issues to be addressed for future measurements. One issue is to minimize "beam-off duration" during a beam time. At the moment, we need much time technically to change a sample. It is mainly because of a direct contact between a sample holder and a cold head of a cryostat (Microstat, Oxford Instruments) in the existing system. We will separate them and dissipate heat from the sample holder with a cooled gas in order to change a sample more quickly without heating up to a room temperature. For this improvement, we designed a new sample holder, cooling chamber, target chamber and beam counters.

Figure 4 shows a photograph of a newly designed vacuum chamber and a sample holder. The sample holder is inserted in a gas chamber (not shown in the Figure) with a helium gas, and then the chamber is cooled down using the cryostat. A beam defining counter and a veto counter are mounted very close to a sample in the vacuum chamber at 4 K in order to reduce a beam-contaminated positron background and other backgrounds from muons stopped near the target setup. There remain a number of technical challenges of these gas cooling system and the counters to keep stability under the severe practical experimental condition. We are now proceeding the assembly and preparing essential R&D studies without muon beam. After the beam commissioning, we will test it with the muon beam with other upgraded components of slow control and cooling system. We expect these challenges will lead to significant improvements of μSR spectra by reducing systematic errors and increasing effective beam time.

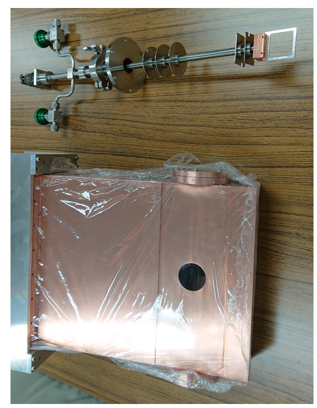

Figure 4: Photograph of a newly designed sample chamber and sample holder.

3 Recent result

Since the first muon beam, several experiments has been completed and data analysis have been going on during the shutdown. Recently Dr. M. Inagaki and his collaborators published a new paper. They performed experiments to measure muon transfer reaction by the muonic X-ray analysis method from June 17 to June 18, 2017, and from October 8 to October 9, 2018 in the MuSIC beam line. They measured the formation rate of muonic carbon atoms for benzene and cyclohexane molecules in liquid samples to investigate the chemical effect on the muon capture process through a muon transfer reaction from a muonic hydrogen atom. Their results are published in Radiochemica Acta [5].

References

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