MAC-2018 Meeting

Held on March 1st and March 2nd 2019
at J-PARC Center, Tokai

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I. Facility Overview

Introduction and J-PARC Overview

Professor N. Kosugi, Director of KEK-IMSS, welcomed the panel and introduced the IMSS activities at J-PARC and the KEK Tsukuba campus. IMSS, responsible at KEK for carrying out multi-probe research for life and materials science with photons, positrons, muons and neutrons, is asking for suggestions to efficiently operate the KEK beamlines at the two facility sites with the current limitations on budget and manpower. Then J-PARC Director Professor N. Saito gave an overview of J-PARC status and activities, highlighting the scientific output of MLF and the particle physics program. At MLF, there is an increasing importance of the combination of industrial applications and academic research. The J-PARC accelerator and MLF continued the 500 kW operation in JFY 2018, again providing stable beam with > 90% availability. Operation at 1 MW has been demonstrated for one hour in July, and preparations for routine operation at beam power > 500 kW are continuing. Within MUSE the S1 user program has been established, U-line commissioning is in progress and the construction of the H-line power substation is under way. Finally, a set of charges was given to MAC to evaluate the facility operation and make suggestions for improvements.

MLF Facility Overview

Prof. T. Kanaya, the Director of the MLF, showed an overview of facility status and beam operations in FY2018. A stable operation at 500 kW beam power has been maintained, with a successful one-hour beam test on targets at 1 MW. Plans with improved neutron targets with constrain-free structure with a gradual increase of the beam power are revealed. The overall output in scientific publications from the MLF shows a continuous upward trend accompanied with the increase of the number of users.

MUSE Facility Overview

Prof. R. Kadono presented an overview of MUSE facility. MUSE has been accepting 500 kW proton beam since April 2018. The target system was tested with 1MW beam for one hour, and the results show that it is ready for a long-term test. One concern was the damage of a coaxial joint of the rotating muon target found in the shutdown period. Necessary measures such as an improved monitoring and interlocking system were taken to minimize the possible problems during proton beam operation. Detailed comments on the progress in each of the experimental areas will be given in subsequent sections of the report.

Inter-University Research Program

Although there was concern about a significant reduction of the number of proposals in 2018A, the results of the following two terms show a solid recovery: 49 proposals in 2018B and 54 in 2019A. This recovery is closely tied to the achievement of stable operation of the S1 beamline that has increased beam time availability into the community. MAC also appreciates that the MUSE staff efforts to expand the user base has paid off as an increase in the number of international users and P-type proposals. MAC recommends continuing a careful survey of the degree of satisfaction of users and various levels of outreach activities.

Scientific results from the Inter-University Research Program maintain a high standard of productivity, achieving the second highest number of annual publications in the past ten years. MAC was impressed to see that a variety of significant studies have recently been completed by the members of the program. A few highlights are the observation of ferromagnetic fluctuations in heavily doped high-Tc Bi2201 cuprates, identification of a novel Griffiths phase in a layered iridate, and a muon-neutron multiprobe study on quantum fluctuations in a spin-1/2 uniform triangular lattice. It is also highly appreciated that a joint research initiative between IMSS and Toyota CRDL, Inc. has steadily been developing to establish the technique to non-destructively determine the distribution of Li metal in battery materials using negative muons.

MAC is also very pleased to hear that the development of science and technology regarding negative muons at MUSE provided crucial contributions to the approval of the project of "Toward new frontiers: Encounter and synergy of state-of-the-art astronomical detectors and exotic quantum beams" for the Grant-in-Aid for Scientific Research on Innovative Areas in 2018. This will accelerate the further progress in generation of the focused negative-muon beam followed by the establishment of the muon-microscope technique.

Although MAC recognized that several personnel actions (promotions, hires and changes) have been made carefully but steadily in the past year, the importance of strategic human resource management will become increasingly important and urgent in view of retirements expected in very near future, together with the ongoing expansion of the MUSE facility. MAC has a strong concern about the shortage of manpower, particularly regarding the maintenance of M1/M2 tunnels involving the muon target with a risk of breakdown, and the active management of the ultra-slow-muon project.

II. MUSE Facility Activity

Muon Source Facility: M1/M2 Area

It is crucial to guarantee the radiation safety of the facility, at both the current 500 kW, and the future 1 MW, both for workers and for the neighbouring community. MUSE personnel continues their responsible stewardship of the proton beamline M1/M2 tunnel, taking active measures to mitigate the radiation hazard, primarily from tritium.

While the track record in this area is excellent, in comparison with other facilities throughout the world, it is unusual that facility scientists would be given such a task. Moreover, with such limited manpower, this represents a substantial diversion of effort away from their principal role in facility development and operation.

Muon Production Target

The muon production target is key infrastructure for the entire MUSE facility, and thus crucial to maintain reliable safe operation with minimal downtime. During the 1 MW test, the target was found to operate according to prediction, but a longer term test is essential to be sure it can bear the extra heat load safely. This test should be a very high priority to determine if any modification will be necessary in future with regular 1 MW operation.

Previously, it was thought that the target lifetime would be limited by the bearings of the rotating wheel, so it was surprising to hear that the coupler on the rotating feedthrough failed. The replacement plans for the second coupler, involving significant radiological hazards, are in place and seem sound. A backup plan to replace the entire target is also prepared. The origin of the failure has been identified to be an inappropriate manner of key groove machining. New couplers, properly fabricated, will surely make another breakage unlikely.

Development of target monitoring capabilities continue, motivated by the need to ensure safe operation including all foreseeable failures. In this effort, it would be useful to connect the MUSE target effort with other groups with expertise in these issues, both in Japan (e.g. Haba at Riken) and abroad (PSI). One can anticipate in the near future that the demands of developing and refining the target will subside, and a rather lower demand regime will follow. It would be appropriate to remove direct responsibility for the target from MUSE and place it on a larger J-PARC wide entity tasked with operation and maintenance of targets.

μSR Spectrometer and sample environment

With sufficient and predictable muon beam time, the next key criterion to expand the user base and increase the scientific productivity of MUSE is to ensure the spectrometer capabilities are available for the users. This includes functioning data acquisition and sample environment (primarily field and temperature). In this respect, the facility continues to progress and mature with the S1 and D1 areas providing duplicate capabilities in many cases. In one respect, D1 remains a bottleneck for the demand on the low temperature dilution fridge. This is particularly problematic as the demand for negative muons at D2 will continue and these two are largely incompatible. The new 3He fridge may mitigate this to some extent, but it may also be worth considering some means to duplicate the dilution fridge capability at S1. The users may be willing to try to raise funding for this.

Another key criterion for a flourishing user facility is a reliable data acquisition system. While the DAQ works quite well, it still suffers from occasional problems, and surprisingly this accounts for some significant downtime. An occasional problem that can be addressed in less than an hour would be acceptable (tolerable), but if there are problems that account for loss of days of beam time (a significant fraction of the time for a single user), then effort is still required to reach an acceptable level of reliability. It is clear that while the system operates very well, refinements are still in order, for example, the DAQ should not be so dependent on the continuous availability of a good network connection to Tsukuba. Since this is a key capability for facility operation on an ongoing basis, there should be a clear plan in place to maintain and improve the DAQ system on an ongoing basis into the future. The 1MW operation of the DAQ looked very promising with reasonable results at the maximum count rates. In the run up to regular 1MW operation, it is important to anticipate issues such as detector deadtime related distortions to be prepared to address them as required.

Negative Muons at D2

A continuous commissioning effort has successfully enabled the simultaneous beam usage at the D1 and D2 lines with the electric beam kicker to direct each of the two bunches of the muon beam of a momentum up to 30 MeV/c to different beam lines. An upgrade of the radiation shield for the neutrons emitted after negative muon capture by nuclei was implemented. Experiments with negative muon beams of 40 MeV/c can safely be conducted. Electric discharge of the Wien filter at the operation voltage higher than 150 kV was reported. The issue will be resolved in the next summer maintenance period and the filter will be operable at 250 kV.

The world's first measurement of the μ^{-}SR of the Kubo-Toyabe function at the D1 port was also reported as a remarkable achievement in FY2018.

U-line/Ultra Slow Muons: Beam line

Good progress has been made in beam tuning and beam transport simulations, which allowed ultra slow μSR experiments on Ag in magnetic fields up to 0.14 T and for the first time at implantation energies down to 500 eV. The measured ultra-slow muon rate at the intermediate focus F3A could be increased from 70/sec to 120/sec, measured with a MCP detector. The detected rate in the positron spectrometer at the sample position reached about 22/sec. Taking into account the solid angle of 17% of the spectrometer, this translates into at least 130 ultra-slow μ^{+}/s at the sample position. The measured beam spot size at sample position is about 10 mm FWHM (about twice larger than expected from simulation), and the measured time-of- flight distribution is 10 ns FWHM. The observed decay asymmetry of 0.1 indicates a USM beam polarization of about 40%, which might be partially coming from the cloud-muon contamination of the U-line surface muon beam, reducing the U-line beam polarization to less than 90%. Further progress has been made in the improvement of the positron spectrometer performance and the magnetic shielding of the stray magnetic field of the last axial focusing superconducting solenoid of the U-line. The effect of stray field on the muon beam transport has been minimized in the simulation by asymmetric operation of the electrostatic quadrupoles.

Open issues to be addressed are i) disagreements between experiment and simulation of beam spot sizes and transmissions from F3A to sample position, and ii) the estimation of the rate of ionized Mu atoms at the tungsten source, using the known transmission from the beam transport simulations. This rate is of fundamental importance, since it allows estimating the overall USM generation efficiency. This is key information for understanding and optimization of the laser ionization process – which is in addition crucial for the planned g-2 experiment and the Transmission Muon Microscope at the H-line. MAC suggests increasing the solid angle of the positron detectors to reduce the time needed to record a μSR spectrum with the currently low USM rate.

Laser System

Achievements of the previous year include an upgrade of the laser system to improve the stability of operation (modifications of the optical table), and a significant improvement in the timing jitter and peak power of the ω2 generation, which is important for stable generation of the Lyman-α light.

The problem of the high-quality large size Nd:YGAG laser ceramic is still not solved. Two routes of improvement are currently envisaged: a bonded large size Nd:YGAG has been obtained and is under evaluation, and an alternate material (transparent Nd:YSAG ceramic) was obtained, where the emission spectrum was as expected (but not yet tested for Mu ionization). There is still a factor 25 missing in the laser pulse energy (4 μJ compared to the design 100 μJ).

H-line

MAC is pleased to see the construction of the new power station is ongoing and completion is expected during FY2019. Since the beam-line has the highest priority, we strongly support the effort of J-PARC center to secure any additional budget to deliver the first beam in 2020. MAC applauds the willingness of the DeeMe team to contribute to the building and commissioning of the beam line to ensure the timely start of the physics run with the high intensity beam.

MLF Second Target

Working groups of J-PARC MLF division and of the Japanese Science Societies for Neutron and Muon Research continued their evaluation plans for a future target station 2 in MLF. This plan includes an upgrade of the proton beam power to 1.5 MW, a splitting of the proton beam in front of the existing MLF hall by a fast magnetic kicker, and the building of a new experimental hall with a combined muon/neutron spallation target. Improvements of a factor 20 of neutron intensities, and a factor 50 – 100 of muon intensities are expected, allowing for new kind of applications of muon micro beams under extreme conditions (high pressure, high external magnetic field), bio science (small protein crystals), and industrial applications. A CDR is in preparation, and a letter of intent will be submitted in March 2019 to the Science Council of Japan (SCJ) for the Japanese Master Plan of Large Research Projects. The MLF second target is a project for the time horizon beyond 2030 and MAC furthermore supports this important development of initial ideas for future large-scale muon projects at J-PARC.

III. Research Projects (S-type Proposals)

Precision Measurement of Mu Hyperfine Structure and Muon Magnetic Moment

Progress on the muonium hyperfine structure and muon magnetic moment experiment MuSEUM has been reported. The zero-field resonance measurement of νhfs reached now a world-record statistical precision of about 1 kHz, a factor 20 improvement in the past 2 years, and about 30% better compared to the LAMPF experiment of 1999. The present expected systematic error is about 8 Hz (2ppb), and 20 ppb on the magnetic moment for the final experiment in high magnetic field. In the next five years, a factor of 200 improvement in statistics compared to the LAMPF experiment is expected, requiring the availability of the H- line from FY2020. This will bring the experimental accuracy of νhfs to a few Hz (a few ppb), which is in the range of the most precise theoretical calculations, and thus allowing for the most precise test of bound state QED.

Frontiers of Research on Condensed matter, Life Science, and Particle Physics explored by Ultra-Slow Muon Microscope

An update of the USM microscope has been presented. The prospects of the project are still unique, offering real space 3D μSR mapping and probing of electronic states and spin states and their dynamics across interfaces with ~10 μm spatial resolution. However, the project suffered from significant delays due to long J-PARC shutdown times since 2011, and from the limited USM rate of the order of 100/s due to the limitations in the generation of Lyman- α light. The further steps are not clear from the presentation, and MAC recommends the preparation of a plan on the further strategy, especially in view of the problems in the generation of a sufficient rate of USM. MAC has a concern about the project progress after the end of the external funding.

Search for Muon-Electron Conversion utilizing Pulsed Proton Beam from RCS

The DeeMe project received stage-2 approval from the muon-PAC at KEK/IMSS, and the detector system is now ready to use. Completion of the H-line should have highest priority in order to run the experiment in a timely manner, to provide a result before COMET phase-I, and in order to maximize the potential of a major discovery at J-PARC. MAC applauds the willingness of the DeeMe team to contribute to the building and commissioning of the beam line to ensure the timely start of the physics run with the high intensity beam.

Development of General-Purpose μSR Spectrometer with Semi-conductor- based Optical Detectors and Measurement of New Element Strategy Samples with New Functions

Good progress has been reported in the application of μSR to the characterization of hydrogen states in the technologically relevant semiconductors ZnO and InGaZnO4 (IGZO). Publications on the results are in preparation, while other studies of the MUSE team on interstitial hydrogen in FeS2 and on electronic correlation ins Y2C were published in PRB in 2018, with the FeS2 paper receiving special attention in the Physics Buzz Blog run by APS. MAC is pleased to see the production of interesting results within the MEXT "Elements Strategy Initiative to Form Core Research Center for Electron Materials", and MAC is looking forward to see new results in upcoming experiments on new functional materials.

Application of Muon Radiography for the "Photon and Quantum Basic Research Coordinated Development Program"

MAC acknowledges the good progress being made in the negative muon radiography program for non-destructive elemental analysis using muonic x-rays. The application to depth selective lithium concentration determination in lithium ion batteries with a few tens of micrometres resolution is remarkable.

Development of D1 Spectrometer Instruments and μSR experiment in Strongly Correlated Electron Systems

Several improvements of the D1 spectrometer have been implemented to reduce the back- ground contribution in the μSR spectra. These include a large bore spectrometer magnet, development of a new beam monitor, beam tuning and the development of a fly-past chamber. This allows now measuring small samples (5x5mm2) with a high muon decay asymmetry, down to mK temperatures by using a dilution refrigerator. These improvements are beneficial for the investigation of crystals of strongly correlated electron systems, which are often only available in small amounts/sizes. MAC is looking forward to seeing new results of topical questions in strongly correlated electron systems.

Transmission Muon Microscopy

The Transmission Muon Microscope TμM at the H2-line is in a R&D phase where several prototype components are being prepared for tests. If successful, this facility will offer unique capabilities to visualize nanoscale structures and function of >~10-μm-thick specimen. As in the case of the USM microscope, the feasibility of the TμM will crucially depend on the USM generation, which is currently limited by the generation of intense Lyman-α pulses. MAC suggests the preparation of a plan of the further strategy and a time frame within the realization of the project is planned.

Precision Measurement of Anomalous Muon Magnetic Moment/EDM

The collaboration of the g-2/EDM experiment has now grown to 102 members from 8 countries. Preparations including construction of experimental components and developments are advancing well to measure the anomalous magnetic moment and the electric dipole moment of the muon in a completely different way compared to the BNL/FNAL method. It represents a key experiment for testing the standard model, and it received now stage-2 status from the IPNS director, and a stage-2 recommendation by the IMSS-PAC. Next milestones are the construction of the H-line, the laser ionization of muonium at the H-line to generate USM, to accelerate the thermal muons, and to receive the full funding for the entire experiment. MAC strongly supports this experiment, but expresses concerns about the efficient generation of Lyman-α light for producing USM, which is critical also for the TμM project and for the U-line experiments. MAC is pleased to hear that alternative solutions for the USM production are under consideration as a backup plan.

IV. General Comments and Recommendations

MAC is pleased to see the outstanding work of the MUSE team in all fields of its responsibilities, and acknowledges the achievement of another year of stable operation at 500 kW beam power. This translated into a significant increase of the number of annual publications in the past ten years. A one-hour test at 1 MW last July was successfully carried out, thanks to the experiences gained from operation in previous years. We are looking forward to stable long-term operation at 1 MW beam power. MAC is very pleased to see the growing interest from broad scientific communities in muon science at J-PARC.

MAC recognizes that safe operation of MUSE continues to be of highest priority. An appropriate plan has been set up to avoid tritium release from the muon production target. The muon target experienced an unexpected failure of a coaxial coupler. A good repair/exchange plan is available, and continuous improvements on monitoring of the status of the muon target, including improved interlocking system, will ensure a safe operation of the facility.

The research reports presented to MAC demonstrate the rich field of muon applications, from fundamental particle physics to condensed matter physics, material science, elemental analysis, and ideas to use the muons as novel microscopy/tomography probe. This broad field of topical applications is a unique strength of the MUSE facility.

MAC recommends shifting away the responsibility for the safe delivery of proton beam from the MUSE staff to a single dedicated J-PARC-wide group with the expertise and capabilities to deal with these issues in a uniform site-wide manner, ensuring a uniform safety concept. MAC strongly recommends transferring the present MUSE people responsible for M1/M2 proton beam delivery and muon production target to support MUSE users in order to develop and establish a strong and stable muon user community with the highest international standards. In this way a uniform operation combining KEK and JAEA resources is achievable, which is key to the further success of MLF. It will also be helpful to increase efforts to make tighter collaborations with Universities.

The laser for USM generation is of pivotal importance for the experimental program at MUSE. MAC recommends setting up an external advisory team of laser experts to evaluate the present situation, and as a mid-term measure, to establish a "laser development and maintenance team" under the responsibility of J-PARC to ensure long-term stable laser operation for the various experiments requesting USM.

MAC strongly supports the effort of J-PARC to secure the additional budget for the construction of the H-line to deliver first beam in 2020, in order to start as soon as possible the exciting science program with the experiments muonium hyperfine structure, muon g-2/EDM, DeeMe and the muon transmission microscope.

MAC recommends providing project and risk management plans for the further U-line/USM commissioning including the issue of efficient generation of USM, and for the completion of the S2-S4 areas.

APPENDIX I

Members of MAC:

Hiroshi Amitsuka (Hokkaido University)
Andrew MacFarlane (University of British Columbia)
Kenya Kubo (International Christian University)
Martin Mansson (Royal Institute of Technology)
Takashi Nakano (Research Center for Nuclear Physics)
Thomas Prokscha (Paul Scherrer Institute) Chair
Tadayuki Takahashi (Institute for the Physics and Mathematics of the Universe)

Unable to attend: Klaus Kirch (ETH Zurich and Paul Scherrer Institute)

APPENDIX II

Charges given to MAC:

- Evaluate the appropriateness of the facility operation and its upgrades with respect to the following points :
  - safe, stable and efficient operation towards the production of science in a timely manner
  - timely construction of beam lines and their preparation to maintain the uniqueness of the facility, attracting not only domestic users, but also international users

- Any suggestions for improvements are appreciated. Our particular concerns include, but are not limited to, the following :
  - Limited manpower to operate and maintain the beam lines
  - Urgency of commissioning of the U-line, preparation for H-line construction and the remaining S beam lines