Report from the Muon Science Advisory Committee (KEK-IMSS) and Muon Advisory Committee (J-PARC Center)

April, 2014

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(and Muon Advisory Committee)
Held on February 27 - 28th 2014
at J-PARC, Tokai

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Table of Content

I. Overview Session

Prof. K. Yamada, Director of the Institute of Material Structure Science (KEK) gave the welcome address and presented first the charges to the committee (MuSAC) from the part of IMSS. In his introduction he stressed the importance of the muon at the same time a unique probe of condensed matter and a fundamental elementary constituent in particle physics.

This talk was followed by the introduction of Prof. Y. Ikeda, director of J-PARC center, who as well presented questions to the committee (MAC) and overviewed the J-PARC activities. He stressed the exceptional character of FY2013, where also important technical progress was achieved. He gave a detailed report of the accident at the hadron machine in May 2013 and of all preventive measures, which have been implemented since then to reinforce the safety standards. They are very well summarized in the following guiding criteria: safety comes first, perform science with safety in mind and achieve world-class results in a safe research environment.

Important milestones concerning the accelerator complex have been the acceleration to 400 MeV with the LINAC and the demonstration that RCS is ready to deliver beam at more than 500 kW power. The plans for FY2014 are centered on the full recovery from the accident at the hadron machine and achievement of a stable user operation under a reinforced safety management. The committee was pleased to year that no major changes in the power up schedule in the next 5 years are envisaged and that the user program is foreseen from mid-February with initially 200 kW power. After the summer shutdown a restart with more than 500 kW is scheduled.

Dr. Arai gave a report of the Materials and Life Science Facility activities.

Also in this division action has been taken to improve the security framework.

The committee was pleased to hear about the detailed progress achieved in the past year. Construction work, R and D and maintenance in MLF involved many instruments. At the moment there are 21 neutron instruments, three are under construction and one in the commissioning phase. At the four muon ports one beam line is in commissioning phase and one in construction

Prof. Miyake summarized the activities of the MUSE facility. The accident at the Hadron Experimental Facility prompted also a reconsideration of the safety situation, especially around the muon production target. The sealing of the muon target was improved with a double sealing structure. Very positive is that comparative tests showed that even with a single hatch the sealing was very good.

Prof. Kadono reported about the Inter-University Research Program. The long shutdown at J-PARC this past year severely limited the number of μSR experiments that could be carried out at MUSE. With only the D-line operational, beam time was already scarce. The committee considered these constraints in its evaluation of the Inter-University Research Program, and concluded that the present situation is not conducive to a highly-productive research program. Nevertheless, MuSAC/MAC is impressed with the quality of the research that has been carried out with very limited beam time and preliminary instrumentation; noting that some of the work over the past year has been published in high-impact journals. Based on what has been accomplished, the research program at MUSE has a promising future.

II. MUSE Facility

Muon Production Target:

The status of the fixed muon target that is currently installed and the progress with the development and commissioning of a new rotating muon target were reported by Mr. S. Makimura. For stable long term operation of the target under the high level proton irradiation produced by 1 MW operation of the accelerator, the installation of a rotating muon target is mandatory before working at these levels.

The accidental leak of radioactive material in the Hadron Experimental Facility in May 2013 has led to a comprehensive reassessment of the general safety framework at J-PARC and a delay in the schedule to install a rotating target, originally planned for December 2013.

Discussions with PSI experts about the rotating target took place in April 2013 and testing work has progressed on the durability of the bearings and the thermal stress following an accidental stop in the rotation. Following a safety review of the rotating target in September 2013, it was approved for installation in the beam and the installation is now scheduled for the summer of 2014. This new schedule requires the fixed target to be used beyond the period initially anticipated and so its lifetime was re-evaluated. The dimensional shrinkage rate was found to be low enough to safely allow this extension of operational period.

Work was presented on the upgrade of the target control system to detect target cracks via thermal imbalance and progress was reported on the development of the SiC rotating target required for the DeeMe experiment. A long-term storage vessel for the used target was scheduled for delivery in March 2014 and the commissioning is planned for summer 2014.

Overall the committee was again impressed by the high level of engineering of the small team involved in this important project.

Handling of the Used Muon Production Target:

Handling and storage of used muon production targets was described by Dr. N. Kawamura. The rotating target unit has been designed to allow cutting of the used target unit into three sections with widely different associated dose rates. The most active section located around the carbon target area requires storage for 5 years. A storage cask is being manufactured and will be delivered and commissioned in 2014. The storage space for such active targets in the MLF is limited and an additional dedicated storage facility is urgently needed. A budget has been approved to construct a new storage facility and it will be built by JAEA construction division with scheduled completion in 2016. At that point the targets stored at MLF will be moved to the new facility. This storage facility will be used by other J-PARC divisions (e.g. neutron, hadron) as well as by muons. However a limited budget allocation for the construction has required the capacity of the storage facility to be reduced from the original plan.

The committee recommends that coordinated arrangements be made for the storage of the used targets across all the relevant divisions and that the specification and budget of the shared storage facility be scaled accordingly.

D1/D2 μSR Spectrometer Upgrade:

Optimizing the experimental stations on the D1 and D2 legs of the muon D-line has been considered by MuSAC/MAC to be of high priority to generate competitive muon science during the development of MUSE. At present there is high demand for very limited beam time on the D-line, a problem that has been compounded by the lack of an appropriate spectrometer for the D1 leg. Over the past year there have been significant upgrades of the D-line to meet the requirements of a growing user base, including the installation and commissioning of a new versatile spectrometer on the D1 leg. The spectrometer includes the utilization of the Kalliope detector technology developed by MUSE staff, and has higher event rates that make more efficient use of the high muon beam intensity at J-PARC. Moreover, the same spectrometer can be used for longitudinal or transverse-field experimental arrangements, with the ability to rapidly change between these two configurations. These features constitute a major advancement in the experimental capabilities of the MUSE facility, which should translate to a substantial increase in quality scientific output.

MuSAC/MAC discussed the benefits of installing a similar spectrometer on the D2 leg, which is currently not being used for experiments involving standard mSR configurations. While this would help accommodate the high demand for μSR beam time, it would also divert manpower from vital areas of the current MUSE development. The committee feels that efforts at this time should focus on achieving full experimental capabilities on the D1 leg and the S1-line currently under construction, rather than developing or modifying an existing mSR spectrometer for D2.

U-line/Ultra Slow Muon Beam Line:

Dr. Y. Ikedo explained the current status of the construction and commissioning of the U-line. The committee appreciated the clever idea to use $^{6}Li^{+}$ and $^{7}Li^{+}$, which are naturally present in the tungsten target to test and optimize the transport of the ultra-slow-muon beam. As a result, even without muon-beam due to the accident in Hadron Facility, it was successfully demonstrated that the beam-transport of U-line is working as expected and that the design performance is likely to be achieved. Nevertheless, in order to double-check the overall performance of the beam on the U-line, the committee would like to know more the following beam parameters; 1) beam spot, 2) emittance, and 3) positron background level, when the muon-beam will be available.

The committee heard about problems in the cooling system for the superconducting transport solenoid. It appears to be a serious problem, since at the moment there is no clear explanation of these troubles.

Laser System:

Mr. J. Nakamura presented the current status of the development of the laser system producing the 122 nm photons used for the Mu ionization, a key element for an efficient ultra-slow muon production.

To fulfill the requirement of a stable laser for a beam of good quality and narrow pulse width, a system composed of solid state devices is being investigated. 122 nm photons are produced by four-wave mixing using 820 nm photon and two 212 photons.

The committee was impressed by the significant advances in the past year. The team succeeded in manufacturing a novel Nd:YgAg ceramic material used for amplification and confirmed its high performance. Intensities of 30 mJ for 820 nm and 10 mJ for 313 nm photons have been obtained, which are close to the initial goal. Through further R&D we expect the enhancement of the intensity and stability conditions to reach the ultimate goal of a power of 10 μJ 122 nm photons.

S Beam Line

In a strategy to increase the user community and scientific output, construction of the surface muon beam line (S-line) is one of the key elements of the J-PARC/MUSE. After the shutdown period in the first half of 2013, the construction has continued with steady progress including installation of power supply yards, cabin for researchers, and concrete shields. This has been possible under a funding for construction from a special supplemental budget.

The design of an electric kicker system adopting the fast- bi-polar high voltage power supply has been finalized after careful consideration. We expect the beam delivery first to S1 equipped with a novel new spectrometer as the one in D1.

H Beam Line:

Dr. N. Kawamura presented a status report on the development of the H beam line. The initial potential users have now converged to a design of the front end part of the channel that can provide a versatile high flux of positive and negative muons with variable momenta from 30 MeV/c to 120 MeV/c. The front-end components were installed in the summer 2012 shutdown, however associated cabling work remains to be completed in the 2014 summer shutdown before the radiation level becomes too high in that area.

The three active proposed experiments for the H-line are 1) MuHFS, designed to measure the muonium hyperfine parameter to the high precision needed for the analysis of g−2 experimental data, 2) DeeMe, the search for μ-e conversion in a nuclear field, a process that is forbidden by the standard model of particle physics and 3) g−2/EDM, an experiment that will measure the anomalous magnetic moment of the muon to a precision of 0.1 ppm. The conceptual design of the downstream magnets needed for these experiments is almost complete and mechanical design is under way. All three H-line experiments have made significant progress in their preparation and in establishing strong international collaborations and a schedule of operation between them is emerging. The scientific urgency of the three proposed long-term projects for the H-line requires that the H-line receive adequate funding to complete construction and for this reason the committee supports the current plan to develop the H-line ahead of the construction of the S2-S4 lines.

III. Research Projects (S-Type proposals)

Nondestructive Element Analysis by Muonic X-ray:

The proposal is conducted under the joint research program utilizing “quantum beams” in collaboration with neutron and other beam facilities to foster synergy and complementarity. This is an application-oriented program, being suited to the production oriented needs of industrial companies. Taking full advantage of non-destructive element analysis using muonic x-rays, i.e. deep penetration ability of the high-energy x-ray of the range of MeV, one can expect to obtain depth-dependent information of the element composition.

Two major problems to overcome for routine uses of this analysis technique have been addressed. One is the long time required for data collection and the pileup problem of x-ray detectors, which is severe especially for pulsed muon beams. For this an array of detectors will be prepared. The development of multi-pixel detectors is also within this scope. The other is the large beam size. To reduce this problem a Pb collimator covered with Al-plates will be installed.

We encourage this program and expect that it will lead to a good example of industrial application of muon science in future.

μSR Study of Strongly Correlated Electron Systems:

Dr. W. Higemoto explained the recent improvements in the D1 spectrometer instruments and the perspectives for the application in the field of the strongly correlated electron systems. One notable improvement in FY2013 was the development of a fly-past system, which was installed to gain efficiency for detecting positrons emitted from a sample against background noise. A vacuum tank attached to the downstream end of the magnet bore ensures that the fly-past muons stop well away (~ 1 m) from the detectors. The test results show that the installed system has significantly raised the S/N ratio, but still there is room for improvement. MuSAC acknowledge that further efforts in achieving the best performance of this system has been made by optimizing beam line parameters with use of a newly developed 3D beam-profile monitoring system. The upgrade of the magnet system adopted for the; modular positron detector system (Kalliope) is also a significant development. Furthermore, progress regarding the development of high-pressure cells for μSR measurements has been made. Dr. Higemoto proposed several interesting scientific issues to be studied by means of μSR techniques using the upgraded spectrometer. In particular, investigation of the unconventional superconducting state of uranium compounds with much higher statistical accuracy is expected to bring new insights into the symmetry of the superconducting order parameters and the nature of weak magnetism, which is debated. MuSAC is pleased to hear that his proposal was approved at the first stage of S-type project, and hope for an early decision about the requested permission to work with actinide materials in MLF.

Mu Hyperfine Parameter (Muonium Hyperfine Structure):

Muonium can be considered a light hydrogen isotope consisting of only two leptons with significantly different mass. With the to our present knowledge point-like, structureless leptons the atomic theory of the system can be calculated to very high precision, higher than it is possible for hydrogen and any of its isotopes containing hadrons. Therefore muonium is optimally suited system for high precision QED tests and for determining most precise values of fundamental constants. In particular the fine structure constant obtained from a bound state rather than from single charged particles, important muon properties such as its mass (m_μ) and its magnetic moment (μ_μ/μ_p). Presently, a new generation of precision experiments is coming up. Those experiments are strongly interrelated: the muonium hyperfine structure, muon g−2 and rare muon decays. In particular, the muonium hyperfine structure provides the ratio of the muon to proton magnetic moments which is of crucial importance for the evaluation of the upcoming muon g−2 experiments at Fermilab and at J-PARC. Therefore the results of the new muonium hyperfine structure experiment, which very convincingly promises improved results, are urgently needed for a model independent interpretation of the g−2 measurements, where New Physics might be revealed. Muonium can also provide a stringent test for the validity of CPT and Lorentz invariance with Planck scale sensitivity. With muonium in particular, the selection of sensitively tested particles has been extended to the second generation.

This experiment at J-PARC aims at a very precise determination of the hyperfine structure interval of muonium in its ground state and the muon magnetic moment through measurements of Zeeman transitions in a strong magnetic field. The experiment plans to reproduce first the measurements at the field values used at LAMPF (1.72 T) and has a potential to go to much higher fields where a potential for higher accuracy in particular for the magnetic moment exists. For this experiment, polarized muons will be stopped in a Kr gas target. They form muonium atoms inside of a microwave cavity which is tuned to two Zeeman transition frequencies at one particular magnetic field. The signals from the chosen transitions are associated with a flip of the muon spin polarization and can be observed through the change in the decay distribution of the positrons from muon decays. The experiment will improve over the previous similar experiment by Liu et al. at LAMPF, which was the most accurate muonium spectroscopy measurement so far. Also that experiment had employed the technology of 'Old Muonium' for significant line narrowing. It provides a basis for other fundamental muon experiments and for the system of adjusted fundamental constants. For the new experiment it will be important to conduct a larger number of measurements at several different pressures, in particular at the lowest possible densities, in order to obtain a reliable extrapolation of the measurements towards the vacuum values of the transition frequencies.

The collaboration has made good progress in the development of the experiment at J-PARC. The key issues of the project have been worked on with good progress: an intense muon beam line, purchasing of a strong large bore superconducting magnet, a long rf-cavity, a Kr chamber, a positron detector, a profile monitor and most relevant careful systematic error studies. It has been recognized that the experiment needs to be conducted down to the lowest possible gas pressures, i.e. a few 100 mbar, in order to successfully minimize the influence (and uncertainty) of a nonlinear pressure dependence for the transition frequencies. In the large bore superconducting magnet a sufficiently homogeneous magnetic field can be provided. With the higher muon beam flux and the realistically available beam time it appears very achievable to gain one order of magnitude improvement over the LAMPF result. This is a very significant advance for the verification of QED dominated theoretical calculations on a most fundamental purely leptonic two-body system as well as for the determination of the muon magnetic moment/muon mass. The latter is to a very large part independent of the correctness of theory. For the present hyperfine structure experiment the full exploitation of the high intensity muon beam at the H-line of J-PARC-MUSE will be essential. A narrow momentum bite at high muon flux will be important to optimize the experiment's accuracy. Of course, constant refinement of the experiment by, e.g., GEANT simulations is essential to optimally utilize the beam time. The collaboration is also addressing the issue of absolute magnetic field calibration. Shape effects associated with the H_2O calibration samples are carefully considered. The experimenters will also identify the best field measurement method (pulsed or cw) for such an experiment.

We note that the accuracy of the hyperfine structure splitting measurement comes primarily from the magnetic moment of the muon and the electron and field homogeneity. Therefore the measurement can reach higher accuracy than the absolute field calibration itself. Nevertheless, the experiment and apparatus offer presently unique possibilities to study systematic field measurement effects of highest relevance also for muon g−2. The design of the apparatus (magnet, cavity), detector system and the beam line (H line) have been making further good progress and the committee was impressed to see already lots of dedicated hardware delivered to the prospected beam area. The collaboration follows a robust strategy towards achieving their goal of an improved measurement. MuSAC emphasizes that this project must be realized at J-PARC. The prospected results are of highest importance not only for fundamental physics. The committee strongly supports and encourages further efforts to get the funding and resources which are necessary to realize this important experiment. At the same time the committee recommends to allocate sufficient manpower and resources towards this project to assure speedy progress. It will be crucial to maintain speed and assure the quality of the results which are internationally awaited. For efficient progress we recommend to exploit fully the possible synergies with the other users of the upcoming H-line.

A μ-e Conversion Search Experiment in J-PARC MLF DeeMee (μN-eN Conversion):

The process $\mu^{-}+Z \rightarrow e^{-}+Z$ violates charged lepton flavor. The experiment probes for New Physics beyond the present Standard Model of Particle Physics. The experiment has been suggested for the H-line at J-PARC. It is highly motivated from theory and it has a very robust discovery potential for charged lepton number violation at its goal sensitivity of 10^{-13} (graphite target), resp. 10^{-14} (SiC target). This is more than one to two orders of magnitude higher sensitivity than previous experiments worldwide. For full success it is desirable that this experiment will have its results before other experiments (COMET/Phase-2, Mu2e), which plan to search/observe the same process with higher ultimate precision, will come into their production stage. The proposed experiment is therefore very timely right now.

MuSAC acknowledges the Stage-2 approval in January 2014 by the PAC and the significant work of the collaboration that led to this. This is a consequence of the large and structured efforts that went into overcoming the criticism which was posed by the 2012 PAC. Significant progress in the ongoing R&D work such as, e.g., detectors and rotating SiC target which are carried out in part in collaboration with international recognized top laboratories around the world. Background due to prompt bursts can be marginalized by appropriate kicking and even better reduced by a novel HV-switching technique which is employed for the detectors. The tests prove that the aimed for accuracy can be achieved. The concept of the experiment is stable and should produce the prospected demanding limit (or even find a signal). MuSAC further acknowledges that detectors can be constructed with funds from Grand-in-Aid for Scientific Research and that the experiment can now move ahead with the newly achieved Stage-2 status.

In view of the new precision territory, the demanding challenges of the experiment and the competition coming up the experiment need support and constant adequate funding to achieve its goals before others. In particular the construction of the new beam line (H-Line) becomes urgent now. Since the line can also be shared efficiently between the DeeMee experiment, the muonium hyperfine structure experiment and the muon g−2 project, MUSAC recommends that the construction and commissioning of the H-Line be given high priority. Collaboration on this issue between the experiments is recognized and appreciated.

Muon g−2/EDM

The measured value of muon magnetic anomaly (muon g−2) presently deviates from the Standard Model in Particle Physics almost by some 4 standard deviations. This might be a hint that the present standard theory is incomplete and that there is New Physics. In order to secure/ validate a significant discrepancy between theory and experiment at least some 5 standard deviations are required. For this on the experimental side a new experiment is coming up at Fermilab in the United States which uses muons at magic momentum around 3 GeV and a novel experiment with a quite different approach is proposed for J-PARC. The latter exploits an ultra-cold (low energy) muon beam which is obtained from laser photo-ionization of muonium atoms.

Towards the production of ultra-cold muons remarkable progress has been reported concerning muonium production in vacuum. A significant increase in muonium yields has been obtained from drilled aerogel targets at TRIUMF in experiments that will be continued also at J-PARC and RIKEN-RAL. With present laser ionization schemes one can expect to have sufficient slow muons to catch up with the result of the BNL-821 experiment for μ^+. For the g−2 experiment a Lyman-α-laser has been installed and is being tested in the U-line. Concerning the precision field, where 0.1 ppm accuracy is required, a cw NMR system of KEK /University of Tokyo will be compared to the pulsed system developed at the Universities Heidelberg and Yale for the BNL experiment. Further work in progress concerns beam transport and injection, detectors (silicon strips) for high rates and in a magnetic field environment and acceleration of ultra-cold muons. This demonstrates that all major technical issues have been recognized and are being addressed.

The experiment has made good progress in its present R&D phase. It is well motivated and promises an independent result for the muon magnetic anomaly with largely different and independent systematics from the Fermilab experiment. Its goal for μ^+ is realistic and reachable with the present approach and within realistic beam time. The smallness of the setup makes it a very attractive experiment. The J-PARC g−2 project exploits very constructively synergies with the ongoing muonium hyperfine structure project. In particular such collaboration is greatly acknowledged by MuSAC .

MuSAC realizes that J-PARC concentrates in the H-line on these three crown jewels of fundamental interaction research with muons. Provided that further sufficient manpower and resources can be made available each of the three experiments has a significant potential to shape the landscape in fundamental physics.

Element-strategy with High-performance μSR:

The committee was presented with an update of the S-proposal Elemental Strategy. As noted in the initial MuSAC/MAC assessment of this project, the scientific and application goals are impressive. However, because of proprietary research agreement, no results directly stemming from the experimental work under this proposal were shown at this year's meeting, and hence MUSAC/MAC could not evaluate scientific progress at this time. Instead the committee was informed about progress made in preparing for eventual μSR investigations of novel functional materials that will be systematically synthesized at an external institution and studied by other methods. The most notable progress made this past year has been the construction of a modernized dedicated μSR spectrometer for the S-line funded by the Elemental Strategy budget. This spectrometer is a duplicate of the one recently built for the D1 leg of the D-line, and will ensure μSR-based experimental work for this project can begin as soon as the S-line is completed later this year. However, further hardware and software development is needed to achieve the ultimate goal of an automated μSR measurement system, capable of efficiently collecting and analyzing spectra from multiple samples to provide quick feedback for continuing sample synthesis. This is a challenging goal under normal circumstances, exasperated by the ongoing MUSE construction that is limiting the time and manpower dedicated to the development of instrumentation. It may ultimately be necessary to resort to a more conventional and less ambitious approach, with data collection on fewer samples.

Muon Microscope Project (Kakenhi):

Prof. Torikai reported about the current situation of the Ultra Slow Muon Microscope (USMM) project, which involves almost all muon people in Japan. Besides the status of U-line explained above, the committee thinks that a complex laser system is the most difficult and essential part of this project, despite the proven stability of a laser beam in the Subaru astronomical telescope. The change of Nd:YGAG from a single crystal to a ceramic provided a significant improvement in the power and stability of the system. As a result, the schedule for getting official approvals for the components of the laser system seems to be reliable.

The committee also recognizes that even after the first USM beam will be delivered, it will take a long time to tune the beam and adjust the whole system. Even under this situation, the fact that 121 people from 10 countries joined the USM2013 international symposium indicates that USSM is a “rule-changer” tool for surface and interface science. Therefore, the committee recommends establishing a fair and clear procedure in the near future to select and prioritize experiments and proposals for using USMM.

ASRC (JAEA) – KEK Project:

Dr. W. Higemoto gave a brief summary on the latest development in the μSR spectrometer in D1 area, and reviewed the research results obtained in his leading JAEA (ASRC)-KEK project on the strongly correlated f-electron physics. The newly developed μSR spectrometer with a large-bore magnet system and the Kalliope detector, which was installed in the D1 area just one week before this meeting, is expected to bring significant improvement in the efficiency of data accumulation. The experimental studies in this project were focusing on the novel ordering phenomena due to the multipole degrees of freedom in various topical rare-earth compounds. In particular, MuSAC was impressed by their swift and careful μSR studies on the two new superconductors with quadrupole ordering, $PrRh_2Zn_{20}$ and $PrTi_2Al_{20}$: The ASRC group has revealed that both the compounds show no significant change in the relaxation rate at the very low superconducting transition temperatures (~ 0.06 K and 0.2 K, respectively) suggesting an even-parity order parameter. MuSAC acknowledges that the project has been achieving its aims on the base of a well-established relationship between the ASRC group and sample providers, and supports further progress in the future research plans presented.