Report of the KEK/J-PARC

Muon Science Advisory Committee (MuSAC)

and

Muon Advisory Committee (MAC)

MuSAC/MAC-2021

April 2022

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MuSAC/MAC-2021 was held as a zoom virtual meeting on February 2nd, 7th, 14th and February 21st, 2022.

I Facility Overview

Greetings from IMSS

Professor N. Kosugi, Director of KEK-IMSS, opened the meeting with a short overview of the location of the Institute of Materials Structure Science (IMSS) within the landscape of the large-scale research facilities operated by KEK, JAEA and CROSS. IMSS is one of 19 inter-university national research institutes and laboratories. It is responsible for the operation and the academic user programs of multi-probe research facilities for materials and life science with photons and slow positrons at the Photon Factory, and with muons and neutrons at J-PARC (MLF).

The four quantum beam facilities of IMSS are employed for research in a wide range of applications to comprehensively study materials on the atomic level in condensed matter/materials science to polymers and biomolecules. The various quantum beams are used in a combined and collaborative manner to understand the diversity and multifaceted nature of materials and life science on different length and time scales. IMSS combines materials structure science at the quantum beam facilities with its Center for Integrative Quantum Beam Science and Structural Biology Research Center.

J-PARC Overview/Charges to MAC

J-PARC Director Professor T. Kobayashi presented an overview of J-PARC, emphasizing the use of versatile quantum beams for a wide range of research fields at the Materials & Life Science Experimental Facility (MLF), Hadron Experimental Facility, Neutrino Experimental Facility, and the Transmutation Experimental Facility. MLF is currently in operation for about 160 days per year. MAC congratulates J-PARC for achieving a new record stable proton beam power of 740 kW being delivered to MLF, and for the record-high, world-class availability of 97%. The strategy of J-PARC for improving the neutron target and increasing the beam power step-by-step clearly pays off, and MAC supports the plan of J-PARC to further increase the beam power step-by-step to 1 MW in JFY 2024.

The main ring (MR) is in a long shutdown from July 2021 until end of 2022 for a power supply upgrade, which will allow to increase the FX(SX) beam power from 500(65) kW to 750(80) kW. A further increase to 1000(100) kW until 2026 is feasible.

MAC highly appreciates the continuous efforts in improving safety at J-PARC by organizing safety days and actions for safer work. The actions for safer work led to an extended summer shutdown to mitigate radiation risks during neutron target replacement.

Finally, a set of charges was given to MAC.

MLF Overview

Professor T. Otomo, MLF Division Head, reported the status of the MLF facility. The neutron target maintenance scheduled in the summer shutdown required more time than expected and delayed the restart of the beam by 1.5 months. MAC highly evaluated the stable operation of the proton beam at 700 kW. The COVID-19 pandemic forced to cancel overseas user beam times while domestic users were not affected. MAC welcomes the implementation and progress of remote experiment control systems beneficial for users under travel restrictions and easy access to neutron and muon facilities. MAC recognizes, that this mode of operation can be only a transitional measure to continue the operation and user program of the facility during the pandemic. The additional load on local staff is not sustainable, and the education of the next generation of scientists cannot by accomplished by remote operation of experiments.

MAC acknowledges the large number of proposals submitted to MLF and the slight increase in scientific output, indicating the large interest of the user's community and increasing impact of MLF in science.

MAC appreciates the new online database of MLF publications. The outreach activities for increasing industrial cooperation are impressive and one of the strengths of MLF.

Present Status of Muon Science Lab/Charges to MuSAC

Professor K. Shimomura, Head of the IMSS Muon Division MUSE, explained the relationship between MuSAC and MAC, stating that although the advisory committee members are the same, MuSAC and MAC are held separately. MuSAC (Feb. 2) reports on and discusses the science being developed at IMSS, while MAC (Feb. 7) reports on the progress of facility development and consult on facility operations. Prof. K. Shimomura then presented the charge of MuSAC in detail. Next, he explained the personnel changes in the Muon Science Division over the past year, noting that one faculty member has been appointed, one PostDoc has been promoted to special assistant professor, one temporary technical staff member has been added, and a JSPS PostDoc has been accepted. MAC acknowledges the tireless efforts of the Muon Science Division to reinforce its staff. This was followed by an overview of the current status of the four beamlines. The good news is that in the past year, the S2 area has been completed and is now in the commissioning phase, and after 10 years of hard work, the H line has reached the stage where beam can be extracted.

Next, the status of inter-university research was explained. The fact that the number of applications has increased, and the adoption rate has doubled since last year, is an encouraging trend, but it seems that the time has come to formulate and publish a firm policy or guideline on the appropriate allocation of beamtime, such as the ratio of beamtime between S-type and general use proposals. MAC is very pleased to see that the joint use of the D- and S-line is progressing well, and that the number of publications is increasing steadily and in good balance.

MUSE Facility Overview

Professor R. Kadono, Leader of the Muon Science Section, reviewed the present status of the MUSE facility with some highlights covering the latest developments since the last MAC meeting.

The member list and the MUSE organization were explained. The number of members working in the muon section is 49 in total including 13 permanent staff, and six fixed term researchers. Three types of categories were defined for the muon instruments: the muon production instrument (muon source), the secondary beam lines (DL, UL, SL, and HL), and the muon instruments (D1, D2, U1A/B, S1, S2, and H1). S2 and H1 are newly added to the muon instruments category. Instrument managers are designated to each instrument. While the increase of permanent staff is good news, still, most of the instruments suffer severely from lack of manpower for a regular user operation.

MAC applauds the MUSE team for the installation of the new beamlines and acknowledges the J-PARC/KEK management for providing the budget for this important, urgently needed extensions of the facility. MAC highly appreciates the allocation of funds by J-PARC management to build the 3rd muon target.

II MUSE Facility Activity

Muon Source and M1/M2

MAC is very pleased to see that plans are underway to prepare the replacement of muon targets ahead of plan due to priority budget allocation provided by J-PARC, KEK-IMSS, and KEK. The required budget of 35 M JPY for target completion has to be provided in 2022. We are encouraged that there is tangible progress in preparing the HIP cooling water tubing for the new target. It is necessary to regenerate some fabrication know-how that has been lost to enable construction of the new target. This will be crucial if there are any further unanticipated target failures, and it will also be necessary when the target reaches its normal end of life. Importantly, the target replacement plan also involves temporary and long-term storage of the spent targets which is a crucial issue that must be addressed to mitigate the risks of target failure on the entire muon program. MAC strongly supports the transitioning of the responsibilities to the engineering staff to free researchers for more appropriate tasks. MAC understands that the M1/M2 tunnel continues to demand manpower, while there was no detailed report. While this is without doubt an essential task, this is not the kind of responsibility that would be assigned to the staff at other muon sources. This is particularly significant in the context of the extreme shortage of manpower at MUSE.

MAC reiterates the recommendation to use manpower and the specific expertise of staff more efficiently and effectively for the overall productivity and safe operation of J-PARC.

D-line

MAC acknowledges to have the responsibility for beamlines and instruments separated to better understand the distribution of manpower within MUSE.

The D-line is the oldest muon beamline at J-PARC and was built with many re-used parts. MAC is pleased to see that some renovation of the beamline is underway that involves training of new personnel in the specialized tasks of building and maintaining beamlines. The D-line continues to be remarkably productive in terms of science. This is due in part to its world-leading abilities to provide beams of low momentum decay muons. As the demand for negative muons for muonic X-ray elemental analysis continues to grow, there will be increased competition with the demand for positive surface muons.

S-line

One of the long-term concerns at this beamline has been the crucial kicker and its power supplies that generated down-time due to multiple failures. The systematic work from the MUSE staff to solve the problem has now resulted in a much-improved situation where the power supply failures are virtually eliminated, and MARX circuit failures are under control. In addition, the relocation of the power-supplies outside the concrete shield further ensures that any failure will only result in few hours of down-time compared to several days that was previously needed to resolve the situation. The stable operation of the kicker is clearly essential for the operation of both S1 and S2 instruments and MAC wishes to congratulate the staff for their hard and successful work.

U-line (LASER)

MAC is pleased to see the continuous optimization of beam transport and monitoring of U1A/B-lines, resulting in a record-small beam size of 1.8 mm at the intermediate position F3, where the USM rate is reported to be about 200 Hz. MAC highly appreciates the attempts to measure the rate and spot size of the beam at the end of the Super-Omega beamline with a semiconductor pixel detector. This is an important measure to determine the overall generation efficiency of ultra-slow muons (USM). Data analysis framework is being developed. New high-efficiency muonium emitters at room temperature are under investigation, which is essential for more efficient generation of USM with smaller initial phase space.

For increasing the Lyman-α intensity, a new pumping scheme of the Nd:YSAG ceramic is in preparation, where the side-pumped long ceramic will be replaced by an end-pumped short ceramic material. Automatic, remote alignment of the laser beams and remote control of steering mirrors will reduce damage of the mirrors and maintain long-term stability of the system. MAC applauds the team for the formation of a new, multi-institutional laser collaboration of experts with different backgrounds and skills, which MAC considers as an important step to significantly increase the Mu ionization probability in near-future.

MAC is concerned about the too low manpower for a sustainable user facility operation

H-line

MAC congratulates the involved teams on the successful installation and commissioning work for the H1 line, including e.g. the electric panel boards for the H1 user experiments. In addition to the responsible J-PARC physicists, 25 additional people contributed to the beam commissioning which just started on January 15, 2022.

Power supply problems did not allow so far for high momentum operation, while surface muon beams are not much affected. It is very important to fix the HS1 power supplies for higher currents. It is assumed that this could be achieved soon.

Another top priority is the commissioning of the electro-static separator. This device is absolutely essential and all necessary resources should be made available as soon as possible. Presently, one measures about 65 times more positrons than muons in the beam, which at the low momenta corresponds well to the expected factor of about 50 but which is too large for most experiments. Also manufacturing work and installation still needs to be completed for the planned and necessary slit system in the beamline.

In parallel, the H2 design has been simplified and further detailed and seems to be progressing well. Other work on H2 is also advancing, e.g. concerning radiation safety and interlock design. The application process for safety approval is ongoing with the nuclear regulation authorities. While progress appears good, additional budget may still have to be secured.

The further schedule for the H1 beamline and area should be specified. Important steps include commissioning of the separator, higher momenta, and negative muon beams. However, as soon as possible, also production runs for DeeMe and MuSEUM should be scheduled as they are in a position to deliver world-leading physics results in the near future.

Considerable progress was made towards establishing the building for the H2 area. Important in this respect is a new six-year grant-in-aid funding and submission of a KEK request for full construction funding.

D1/S1 Instrument (μSR)

MAC is very pleased to see that the D1/S1 instruments are now generating an increasing publication output with several high-impact articles. A minor comment is that it could have been beneficial to see “tags” on the publications if the results from S1 or D1 or both, to better analyze the situation. The samples environment suite available for the instruments is very impressive, including the full temperature range from dilution and ^{3}He cryostats up to the furnace. It is excellent that the staff has managed to resolve the cold leak of the dry lemon CCR, which will allow systematic measurements in a wide temperature range at S1. MAC very much encourages a closer future collaboration with the neutron sample environment team. This could clearly be a more efficient setup and also partly relieve the workload of the instrument support staff.

The progress of the high-field CYCLOPS spectrometer reported problems with cooling of the superconducting coil. This is the responsibility of the manufacturer, who is now carrying out the repair work. It would be interesting to show an estimate for the time needed for this work.

MAC considers it urgent to complement the beamtime support staff on their hard and extensive work to ensure steady scientific output, especially considering the extra effort to run experiments for remote users during the Covid pandemic.

Finally, MAC strongly supports the continuation of educational efforts conducted at D1/S1 with their involvement in the Neutron and Muon School. This is a very important task that will secure the expansion/regrowth of future generations of μSR scientists and users.

D2 Instrument (X-ray etc)

Experiments at this productive beamline led to 16 publications in 2021. As a recent highlight, the Ryugu sample was measured at this beamline. Introducing a new muonic X-ray measurement chamber with three slots for new Ge detectors and a new wide inlet aperture passing the beam without blocking is expected to improve the detection efficiency and S/N ratio. MAC is concerned that the general use beamline with extensive freedom of instrument setup by users requires long assisting work of beamline staff, who are currently already being overloaded. Some of the overload is likely to be mitigated in future by increasing the efficiency in setup preparation and tuning, and by providing a more efficient access of users to MLF using e.g., an automatic registration system.

U1A Instrument (USM)

MAC is pleased to see the progress in the continuation of preparation for Day-1 μSR experiments with ultra-slow muons (USM). Positron background from the muonium target could be successfully shielded, with a significant increase of a factor of five in the signal-to-noise ratio. Problems with the temperature stabilization of the positron spectrometer will be fixed in 2022, as well as the reduction of thermal load on the sample which doesn't allow to reach temperatures below 4 K at the moment. A next generation front-end electronics is under development, which will allow recording μSR data with a time resolution of about 3 ns, determined by the laser pulse width during USM generation.

MAC is concerned about the feasibility in increasing the USM rate to > 1000 Hz in the coming two years, as it is defined in the project timeline. The progress in increasing the Lyman-α pulse energy is about 20%, and it is not clear how this translates into an increase in USM rate. Another matter of concern is the reduction of decay asymmetry due the geometry of the μSR spectrometer, lowering the figure-of-merit of μSR experiments with USM.

MAC acknowledges and supports the combination of sample growth by PLD and transfer of samples under ultra-high vacuum to U1A as an important step towards unique experiments on surface-sensitive effects.

S2 Instrument

Doctor T. Adachi gave an overview of the facilities in the S2 area, which is one branch of the S-line. At present, the S2 area is being developed for the muonium 1s–2s transition measurement described by Dr. S. Uetake in Section III. Dr. Adachi presented the current status of the muon beam in the S2 area in detail. MAC is very pleased to see that the double bunch kicker worked as designed, and that the first muon beam reached the area in July 2021, finally tuned to the expected rate of $3x10^6$ μ^+/s at 28 MeV/c. MAC congratulates the MUSE team for this great success and progress, that the muon beam is well tuned and that the required beam intensity for the experiment is obtained simultaneously in both S1 and S2 areas. Currently, due to manpower issues, the S2 area is dedicated to one type of experiment. For the long term, MAC recommends the MUSE management to evaluate, how the area can be developed for versatile usage under the constraint of available resources.

III Science Projects (S-type proposals)

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

Element Strategy: Microscopic mechanism of hydrogen-sensitive properties in inorganic materials

This comprehensive S-type project combines a series of quantum beams (muons, neutrons, X-rays) to study the role of hydrogen within a group of materials relevant for technological developments (e.g., semiconductors, ferroelectrics, etc.). Here the power of muons/μ^+SR in simulating the electronic state of interstitial hydrogen is clearly essential for the project. This S-type proposal has continuously been very productive and 2021 is not an exception, where several articles have been published/submitted. It is worth noticing that some of the later publications are results generated from pure MUSE experiments. MuSAC acknowledges the importance of this project and congratulates the project leaders for the excellent progress and high rate of steady scientific output.

Research on the integration of arts and sciences

Professor Y. Miyake reported the progress of elemental analysis research using muonic X-rays. The method is important because: 1) it is non-destructive to the sample; 2) it can sense deep inside the material far from any contaminated surface layers; 3) by varying the muon energy, the probe depth can be tuned to study composition in a depth-resolved manner. It is thus complementary to other widely used methods like X-ray fluorescence which is sensitive to the surface region. Much of the progress has centered questions in cultural heritage and archaeology. This has led to fruitful collaborations with researchers in these fields. The effort is clearly flourishing as reflected in the six symposia organized so far, and several publications. MuSAC recognizes this as a very positive development and encourages MUSE to continue to facilitate it. However, this application competes directly with other uses of the D-line, necessitating some consideration of the balance between users. It will be important to prioritize the highest impact research, but it is very difficult to assess the relative value of research in very different fields. The changing setups in the D2 area, where the muonic X-ray experiments are carried out, is quite labor intensive. MuSAC suggests that it would be worthwhile to explore possibilities to streamline this either by scheduling or making setups more easily interchangeable.

Encounter and synergy of state-of-the-art astronomical detectors and exotic quantum beams

This S-type project yielded three remarkable achievements. Two used an ultra-high energy resolution TES calorimeter. The measurement of the muonic Ne X-ray energy accompanying the muonic 5g9/2-4f7/2 transition of 6297.27 eV (statistical error: 0.04 eV, systematic error: 0.07 eV) agreed with the most advanced QED theoretical prediction of 6297.26 eV. The 2^{nd} example is the measurement and theoretical interpretation of the deexcitation dynamics of a muonic Fe atom having one or more inner shell electron holes.

MuSAC is very pleased to see the first application of a muon beam to a sample brought to earth by a space mission. The non-destructive analysis of C, N and O concentrations with a specially designed muonic X-ray measurement chamber of a sample from the asteroid Ryugu – returned by the Hayabusa2 mission without exposing to the earth atmosphere – reveals new insights into planetary science.

MuSAC congratulates the team for these important, excellent and impressive results.

Search for the muon-electron conversion utilizing pulsed proton beam from RCS – DeeMe

The collaboration reported the DeeMe spectrometer construction to be complete and ready for data taking. A decay-in-orbit (DIO) measurement with a small sector magnet was performed in the D2-area. A data blinding scheme was indicated. MuSAC congratulates the collaboration to a comprehensive paper on the special MWPCs that was published in NIMA. Further gas tuning for good MWPC performance in terms of gain and HV behavior has been successfully performed, including test beamtime at the KURNS-LINAC.

DeeMe is in a 5-year funding extension period of the project (2019-2023). It is very important to get beam in the H1 area and to start physics data taking as soon as possible. The DeeMe collaboration is actively participating to H-line commissioning.

The plan for JFY2022 includes installation of DeeMe in H1 area (April-May) and a request for 30 days of running in June. Initial data would be analyzed in July-September and 60 additional days of beam time are asked for later in the year. MuSAC supports the request for early running and for the assignment of sufficient beam time to obtain a reasonable data set for an initial result.

Precision measurement of muonium hyperfine structure and muon magnetic moment – MuSEUM/MuHFS

MuSAC congratulates the collaboration for their 2021 publications on microwave cavities (PTEP), the zero field results based on 2017 data (PLB), and 2018 data (PRA) including the comprehensive description of Rabi oscillation spectroscopy.

The collaboration reports good progress on preparation for data talking in H1. MuSEUM measured and analyzed (presented as preliminary result) transition frequency shifts in different Kr-He gas mixtures. As requested by the committee, a blinding scheme of the correct microwave frequency for data analysis has been presented. This will be very important when experimental sensitivity surpasses previous efforts. Successful magnetic field shimming to 0.27 ppm uniformity over the relevant experiment volume has been achieved. MuSEUM continues to work successfully on NMR probes, both, conventional to be compared to previous experiments and very promising developments with new ^{3}He probes which promise high accuracy for future campaigns.

MuSAC is pleased to see that the MuSEUM collaboration is continuing its active participation in H-line commissioning.

Precision measurement of the muon mass by 1S-2S laser spectroscopy of muonium

In order to reduce the muon mass uncertainty, laser spectroscopy of the 1S-2S transition of muonium is highly suitable. The transition from the 1S state to the 2S state is induced by a laser with a wavelength of 244 nm, which is generated from a laser with wavelength of 976 nm using second and fourth harmonic generators. Development of the pulse laser has been completed in March 2021, and the system was moved to Tsukuba in September 2021. An output power of 3 mJ at 244 nm was achieved, which is close to the target value of 5 mJ. Higher intensity is in principle possible but was not tested to avoid possible damage. The first beam commissioning at S2 area was completed in July 2021. The muon transport to the S2 area was optimized and a beam intensity of 3 x 10^6 μ^+/s was achieved. With the current muon and laser conditions, the signal rate is estimated to be 20 to 200 Hz. The laser excitation experiment has started on January 31st, 2022, and a first, preliminary result of the resonant laser ionization signal has been obtained.

MuSAC congratulates the collaboration for the very good and fast progress and is looking forward to the first physics runs results.

Muon g-2/EDM

The importance of the new measurement of the muon g-2 at J-PARC has even increased after the first result from FNAL reported last year, which turned out that it does not resolve the muon g-2 anomaly. The new result shows the g-2 value consistent with the former BNL result and the discrepancy between the updated average of the experimental value and the theoretical value has increased from the original value of 3.7 standard deviations to 4.2 standard deviations.

In FY2021, the preparation for the extension of the H-line has continued smoothly. The engineering design of the construction site of the new experimental building is ongoing. The basic design of the building has been updated and the engineering design will start in FY2022. The vacuum chamber, the extraction electrodes, and the coils for the magnet have been designed and are being fabricated. Development of the laser for ionization and the muon LINAC is ongoing.

A proposal aiming to test the ultra-slow muon (USM) source by using the 1s–2s transition, and the acceleration at the S2 area has been submitted to the KEK-IMSS PAC in November 2021.

MuSAC acknowledges and supports the attempt to test the alternative path of USM generation using the 1s–2s transition.

Transmission muon microscope

The feasibility study of the Transmission Muon Microscope (TμM) is under preparation in the U1B area. If successful, TμM will be a unique muon facility for completely new muon applications in functional visualization of biological objects and applications in material science, superior to existing TEM techniques.

In phase 0 of the project, a muon-accelerating flat-top RF cyclotron will be installed in the U1B area, connected to the USM beamline, and used to accelerate the slow muons from 30 keV to 5 MeV. In addition, a normal-conducting objective lens and a muon imaging camera will be connected, and the transmission muon microscope will be used for microscopic observations to demonstrate the principle of the transmission muon microscope. The beam commissioning uses an ultra-compact beam monitor, which is inserted inside the cyclotron to monitor the beam shape and timing. For the muon camera, a two-dimensional SOI detector (14×14 μm2 per pixel, 256×256 pixels, and 5×5 mm2 chip size) will be used. The goal is to prove the wave nature of muons by analyzing the data of muon diffraction experiments. So far, it was not possible to obtain enough statistics due to the currently low USM rate.

After successful completion of phase 0, phase 1 foresees the installation at the H-line in the H2 building and increasing the energy to 40 MeV, using the same LINAC as g-2.

IV General Comments and Recommendations

In the following, we use MAC synonymously for both, MuSAC and MAC.

MAC is very pleased to see the very stable proton beam delivery to MLF at a beam power of 740 kW with a world-class availability of 97%. MAC supports the strategy of J-PARC for the step-by-step increase of beam power towards 1 MW, with focus on stable operation of the facility.

MAC appreciates the continuous efforts on providing safe operation of the facility.

The impressive and important achievements of the MUSE facility are only possible thanks to the outstanding work of the MUSE team in all fields of its responsibilities. MAC is concerned about the current situation of permanent staff at MUSE, which will not allow a sustainable operation of the muon experiments and risks the full exploitation of the rich science program. The excellent publications in 2021 are a manifestation of the huge potential of muon applications at J-PARC.

MUSE pursues a well-balanced program between materials science, fundamental physics and developing new research directions (e.g., use of negative muons, Transmission muon Microscope TμM). Such a stimulating environment allows for the development of first-class scientists with broad perspectives, and the training of young scientists. MAC attributes the continuing interest from broad scientific communities in muon science at J-PARC to the wide-ranging scope of muon research at MUSE.

MAC evaluates the research program with negative muons as a very powerful extension of the facility with the potential of attracting new groups to use the muon beams at MUSE, and to make J-PARC/MUSE known to a much larger community. The research is broad, comprising general proposals, industrial applications, joint projects of humanities and sciences, and educational experiments. Several high-impact publications in 2021 have shown the huge potential of the program. MAC recommends to continue organizing workshops with non-muon experts to further promote the technique towards general use.

MAC acknowledges the scientific results from the Inter-University Research Program reflecting a high standard of productivity. MAC recommends MUSE management to work out a proper balance between general use and S-type proposals. Due to oversubscription of the muon facility, it is difficult for new user groups to get access to the instruments.

MAC applauds the efforts in building spare muon targets, providing a strategy for used target storage, and to make available the required resources: these steps are of utmost importance for the future of the facility. MUSE is doing an excellent work in maintaining and monitoring the M1/M2 channels.

MAC highly appreciates the installation of the S2- and H-line. The H-line should be completed with high priority. This allows starting the long-awaited particle physics programs at these lines to deliver word-leading physics results soon.

The muonium laser ionization program for the generation of ultra-slow muons (USM) is making slow progress. A new pumping scheme of the Nd:YSAG amplifier is in preparation to significantly enhance the laser pulse energy and the USM generation rate, which is of pivotal importance for MUSE (USM μSR, TμM, muon g-2/EDM). MAC considers the establishment of a larger collaboration of laser experts from different institutions as an important step to significantly increase the Mu ionization probability. We reiterate our recommendation to re-evaluate the status of the laser systems by external laser experts within the next two years. A report about the strategy of laser development should be submitted by end of 2022.

MAC is pleased to see the preparations for starting the user program in U1A. We recommend to revisit the geometry of the μSR spectrometer to increase the decay asymmetry. For significantly increasing the USM for μSR on a short term, MAC recommends evaluating the possibility of implementing a cryogenic moderator system while keeping the possibility to quickly switch to the laser ionization scheme.

MAC considers the Transmission muon Microscope as a unique extension of the MUSE facility. This project is very challenging, and its feasibility still needs to be demonstrated. Due to its unique prospects for muon applications in functional visualization of biological objects and applications in material science, MAC recommends to continue the feasibility study in U1B with high priority. The planning of the H2 building should include the option of installing the future 40-MeV TμM branch.

MAC appreciates the further increase of permanent staff by one person. However, additional staff are still needed with part of their duties assigned to the ‘instrument scientist’ role that includes assisting new users in preparing proposals and learning to run their experiments. MAC considers this as extremely important in the transition of MUSE to a users' facility. The scientific output of MUSE in 2021 is impressive in terms of impact, quality and number. However, this output could be only achieved with a large overload on staff, which is not sustainable for the operation as a user facility. Insufficient manpower is one of the most important concerns about the operation and further development of the facility.

MAC reiterates its recommendation to make available additional staff with part of their duties assigned to the ‘instrument scientist’ role. Developing a strong and stable muon user community relies on such support from the facility. As a first step, MAC recommends to strengthen the group of MUSE people being responsible for the M1/M2 proton beam line and muon production target. On a medium-term, MAC recommends to manage the safe delivery of proton beam by a J-PARC-wide group with the expertise and capabilities to deal with these issues in a uniform site-wide manner, which would also comply with international standards. In this manner, additional manpower can be released for running the muon science program at MUSE.

MAC recommends that MUSE management continue establishing new links of MUSE with other organizations to widely support the muon activities and community by increasing the number of staff to keep and enhance current and future activities. We recommend evaluating a closer involvement of KEK-IPNS in the user operation of the particle/nuclear physics program at MUSE.

MAC recommends MUSE management to draw up a long-term vision/road-map on the further development of the facility with clear assignments of staff and responsibilities, and to define the resources needed to realize this long-term vision. MUSE management should develop career plans for the next generation of scientists, to enable a sustainable long-term operation of the facility.

APPENDIX I

Members of MuSAC/MAC:

Hiroshi Amitsuka (Hokkaido University)

Nori Aoi (Research Center for Nuclear Physics, Osaka)

Klaus Kirch (ETH Zurich and Paul Scherrer Institute)

Kenya Kubo (International Christian University)

Andrew MacFarlane (University of British Columbia)

Martin Mansson (KTH Royal Institute of Technology)

Thomas Prokscha (Paul Scherrer Institute) Chair

Tadayuki Takahashi (University of Tokyo)

APPENDIX II

Charges given to MAC:

1. Evaluation of the current status and future improvements of the target and M1M2.
2. Evaluation of the current status and future improvements of various beamlines and experimental equipment.
3. Evaluation of the current status and future improvements of the management and organization of the muon section.

APPENDIX III

Charges given to MuSAC:

1. Evaluate the "Transmission Muon Microscope" project, which is currently on the short list of the KEK Project Implementation Plan (PIP), in terms of its scientific value, technical feasibility, required resources including budget and personnel, and procedure for the implementation.
2. Evaluate the performance of the Inter-University Research Programs (IURP) for general use (focused on mSR) and make recommendations for improvement. (Reports from the MUSE staff will be given at MAC 2/7.)
3. Evaluate the current status of Ultra Slow Muon project, and make suggestions for improvement. (Reports from the MUSE staff will be given at MAC 2/7.)
4. Evaluate the IURP for those using negative muons (mainly conducted in the framework of IURP S1-type projects), and provide suggestions for promotion towards general use.

5. Evaluate the current status of the muon fundamental physics research being planned/conducted using the Hl and S2 instruments, and make recommendations for improvement.
6. Evaluate the performance of the management and organization of the Muon Science Programs in IMSS.

APPENDIX IV

Agenda for the MuSAC/MAC meeting of KEK/J-PARC in 2022

MuSAC agenda February 2nd

13:00~13:15	Greeting from IMSS	N.Kosugi
13:15~13:35	Present Status of Muon Science Lab and charge to MuSAC	K. Shimomura
13:35~13:55	Executive Session	
13:55~14:10	Break	
14:10~14:25	Element Strategy	R.Kadono
14:25~14:40	Research on the integration of arts and sciences	Y.Miyake
14:40~14:55	Encounter and synergy of state-of-the-art astronomical detectors and exotic quantum beams	T. Takahashi
14:55~15:10	DeeMe	M.Aoki
15:10~15:25	Break	
15:25~15:40	MuHFS	S.Nishimura
15:40~15:55	Mu 1s-2s	S. Uetake
15:55~16:10	g-2	T. Mibe
16:10~16:40	TμM (PIP)	Y.Nagatani
16:40~17:30	Executive Session	

MAC agenda, February 7th

13:00~13:20	J-PARC overview/charge to MAC	T. Kobayashi
13:20~13:40	MLF overview	T. Otomo
13:40~14:00	MUSE overview	R. Kadono

14:00~14:30	Executive Session	
14:30~14:40	Break	
14:40~14:55	Muon Source (Target+M1/M2)	S. Matoba/N. Kawamura
14:55~15:10	D-line	N. Kawamura
15:10~15:25	S-line	A. Koda/P. Strasser
15:25~15:40	U-line (LASER)	Y.Ikedo/Y. Oihsi/S. Kanda
15:40~15:55	H-line	T. Yamazaki
15:55~16:10	Break	
16:10~16:25	D1/S1 Instrument (μSR)	J. Nakamura/A. Koda
16:25~16:40	D2 Instrument (X-ray etc)	S. Takeshita/I. Umegaki
16:40~16:55	U1A Instrument (USM)	S. Kanda
16:55~17:10	S2 Instrument	T. Adachi
17:10~18:00	Executive Session	

February 14th

22:00~22:15	Summary from MUSE	K. Shimomura
22:15~22:30	Summary from local MAC	K. Kubo
22:30~23:15	Discussion	
23:15~24:00	Executive Session	

February 21st

22:00~22:30	Summary talk	T. Prokscha