MAC/MuSAC-2016 Meeting

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MAC Report

I. Facility Overview

Introduction and J-PARC Overview:

The J-PARC Director Prof. N. Saito gave an introduction and overview of the J-PARC status and operations. He reported the history of the beam power to MLF and plans for future running, working towards high power but keeping safe and stable operation with efficiency aiming at greater than 90 %. Developing collaborations were outlined between J-PARC and domestic universities, overseas institutions and the industrial sector. Finally, a set of charges was given to MAC to evaluate the facility operation and make suggestions for improvements.

MLF Overview:

Prof. T. Kanaya, the new Director of the Materials and Life Science Experimental Facility (MLF), gave an overview of operations in FY2016. A low power stable operation of MLF at 150 kW continued using a backup mercury target #2 in the 2016B term with an efficiency of 96 % after a 200 kW beam operation in the 2016A term.

The low power operations were inevitable due to the troubles encountered in the mercury target system and the neutron moderator in FY2015. The target system problem will be solved by installing new target #8 with a monolithic structure followed by the introduction of constraint-free type targets. The moderator was overhauled successfully to recover helium refrigerator performance. The beam power is expected to resume 300 kW and increase to 600 kW in FY2017.

With the near completion of neutron instrument construction, the number of unique users in J-PARC MLF is reaching around 1,000. The first Neutron and Muon school held in November attracted 29 graduate students and young scientists from eight countries. It gave good opportunities to learn about science with muons through lectures and hands-on experiments using neutron and muon instruments at MLF.

MAC will be looking forward to successful improvements of the target system to enable stable high intensity primary proton beam operation.

MUSE Facility Overview:

An overview of the status of the MUSE facility was presented by Prof. R. Kadono. After the replacement of the superconducting solenoid of the decay muon line (D-line), the momentum range of the negative muons is expanded to cover 65 keV to 54 MeV. This will open up new applications based on muonic- X-ray elemental analysis as a function of depth.

A new surface muon channel (S1), which is officially open from April 2017, will reduce the heavy load on the D-line. As a result, the D-line will be shifted to become a special line dedicated to high-momentum muons and negative muon experiments. This will also reduce the load on facility staff for setup change.

The first ultra-slow muons were generated in February 2016 and although the increase in the number of ultra slow muons generated is still quite slow, the overall progress in MUSE facility is very reasonable and acceptable.

Inter-University Research Program:

Following clearance of the backlog of approved experiments caused by the unanticipated beam interruptions in 2015, the IURP is returning to a normal mode of operation. The anomalously low success rate for newly proposed experiments in 2016 is a transient effect of this recovery, and early indications show that it is returning to a more normal value near 50 %. It is anticipated that these perturbations will not have any serious long term effects on the user community.

As the facility gradually makes the transition from the construction phase to a phase characterized by increased scientific production, it seems important to have a clearly expressed plan for the user support role played by facility scientists. It is imperative to provide this support to enable users to be as productive as possible, while simultaneously continuing development of the facility and it may be an advantage to formalize this support responsibility. Following the success of the neutron/muon school held in 2016, it is also important to have a plan to encourage new international users to propose experiments and to further enable growth of the user community beyond the local experts. This will also take some "scientist-power" investment for outreach and training. It is necessary that time be budgeted for these activities.

It is an encouraging sign of a healthy user community that the user proposals continue to diversify beyond traditional areas of application of muons. Support for this diversification (e.g. by providing new and unconventional sample environments) should be continued to the greatest extent possible.

II. MUSE Activity

Muon Production Target/Scraper:

We appreciate that stable operation of the new rotating target has now been achieved for more than two years. To monitor the state of the target the members of the target group have intensively developed diagnostic systems to record the sound spectrum, temperature and content of gas emissions.

Radiation safety and treatment of radioactive materials are of great importance and a significant development in this area is that the method for volume reduction of used muon target assembly units by remote controlled cutting has now been successfully demonstrated.

S-line:

Substantial progress has been made in the S1 setup with an operating and substantially improved spectrometer brought online, and importantly with the first user experiments recently accomplished on this line. Automated beam tuning and diagnostics have made a significant contribution to the now highly optimized beam spot, which is the key to many measurements that are limited by small sample size. This is a very important development to address the bottleneck of demand on the D1 line and will enable a substantial increase in scientific productivity immediately while development continues on the U-line.

While development is largely limited by manpower, it would be useful to have an articulated plan for further development of the S-line that would enable additional science areas to be covered.

D1/S1 μSR spectrometer/DAQ upgrade:

We are very pleased to learn about the steady progress that has been made in this area in order to solve the problems pointed out in the previous MAC. The newly installed automatic beam line tuner (ForTune) provides successful and reliable tuning for both D1 and S1-lines, resulting in a small and bright beam spot at the sample position. This is very beneficial, directly leading to a high counting rate and/or a decrease in the sample volume needed for μSR measurements.

Also, it is very good news that users are able to monitor the current status of the measurement through the local network via the IROHA2 program and more widely via a web interface, particularly due to the distance between MLF and nearby accommodation. If users could additionally change the experimental parameters, such as the statistics for the current run, then the monitor system would be even more useful.

The monolithic positron detector units, Kalliope, look to become more reliable and robust against environmental variations. The capacity of Kalliope is estimated to be enough to cover the decay positron rates even at 1 MW operation. A possible problem will be how to find the best operating conditions for 1280 channel detectors and how to fit such a large amount of raw data. For dealing with such a problem, MUSE may need to collaborate closely with a dedicated computational science team.

Negative muons at D2:

The commissioning status of negative muons at the D-line was reported by Mr. Hamada and Prof. Miyake. The replacement of the old solenoid with one of a new wide and warm bore in FY2015 has led to a capability for delivering a negative muon beam with a momentum of as low as 3.7 MeV/c or 65 keV.

The introduction of an automated beam line tuning program ForTune and a scintillation fiber beam profile monitor has increased the time-wise efficiency of beam line parameter optimization for high intensity and good beam profile. The achievement of a narrow beam momentum bite will be useful for depth selective elemental analysis. Demonstration of μ^-SR on some elemental materials is promising for future applications of the intense negative muon beam.

U-line/Ultra Slow Muons: Beam line:

The MAC is pleased to see the first successful generation of ultra slow muons (USM) by laser ionization at J-PARC, and congratulates all persons involved for this excellent achievement. This represents an important milestone towards the setup of the USM facility. The current estimated rate of USMs of about 80/s at 150 kW proton beam power at the intermediate position F3 of the USM transport system is a good starting point for further optimization of i) the U-line beam transport onto the tungsten target, ii) the laser system, and iii) the USM transport system.

For significantly increasing the USM rate MAC considers as essential steps – besides improvements on the quality of the Nd:YGAG amplifier and the reliability and long term stability of the laser system – a detailed understanding of the source properties, i.e. the beam transport onto the tungsten target, an improved understanding of the USM beam transport, and the determination of the muon polarization at the USM sample position. Due to the modification of the U-line by insertion of an axially focusing magnet, a determination of the beam size, rate and polarization at the tungsten target position is highly recommended. 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.

The optimization of the beam transport is progressing, and supported by beam transport simulations using the musrSim package. Striking differences between experimental and simulated tunings have been encountered for one element, the electrostatic quadrupole Q4, and to a lesser extent for quadrupoles Q1 and Q3. A detailed study to reveal the origin of these differences is suggested. Uncertainties in the muon detection efficiency for the used MCP detectors – and therefore in the estimated USM rate – can be reduced by measuring the positron rate at the sample position with the MCP as a target, and correcting for the solid angle of the positron counters. Unclear at the moment is the measured significant drop of the USM rate in time-of-flight (TOF) distributions between positions F5A and the sample position F6A, which is supported by a corresponding drop in beam transport simulations. MAC recommends MUSE to address these problems in the forthcoming commissioning phase.

The expected increase of proton beam power from 150 kW up to 600 kW in JFY2017 should translate into a USM rate of several hundred per second at the μSR spectrometer. This should be sufficient to carry out first USM μSR experiments to demonstrate the capabilities of the facility.

U-line/Ultra Slow Muons: Laser system:

The development and operation of a dedicated laser system for photoionization of muonium is central to a number of activities at MUSE, including the ultra slow muon facility, the g−2 experiment and the muon microscope. Its reliable, uninterrupted operation at a high performance level is a primary goal to be achieved.

We are very pleased to note that very good progress in this challenging area has been made, most notably with the production of ultra-slow muons by photoionization of muonium at J-PARC twelve months ago and continuous improvement of the rates thereafter. The hiring of a dedicated laser expert is very visible and produced the expected results.

Still a point of concern is the generation of sufficient Lyman-alpha radiation. MUSE depends on a single company developing and delivering the crucial Nd:YGAG ceramic. The collaboration with this company needs the full support of the management. Alternatives to this material have been explored, however this has not yet produced a viable fallback solution. Presently refractive index variations in the material of first choice are being addressed. For the further development of this very crucial optical frequency mixing component MAC advises to attract specialized expertise, possibly through hiring an external expert for a sabbatical period.

Now that the pioneering stage has successfully resulted in the first USMs, MAC further recommends MUSE to prepare the laser facility for continuous operation by making technical adjustments in order to ease maintenance and repairs. This includes providing for quick exchange of essential components such as optical windows which are subject to damage (by. e.g. unavoidable color center formation). Sufficient stocks of high quality spare parts should be kept available.

We realize the potential that exists for a good collaboration with the g−2 experiment and the development of the muon microscope, where a laser system with identical central specifications will be needed.

H-line:

MAC notes the steady progress in the experimental hall concerning setting up the H-line. In particular the front end devices, H-line elements and the iron shielding, including that for the H1 area to house the DeeMu/muonium HFS experiments, are in place. We got a very positive impression from the installations to the present point that we have seen in the experimental hall.

We particularly applaud the creation of a new position for a physicist dedicated to the H-line. This will be important to efficiently complete the H-line and organize the logistics and infrastructure.

Still a point of concern is the available electrical power in the area. The laboratory management is encouraged to arrange for a schedule to upgrade the power in the area that enables completion of the beam line. This will enable a timely start of the physics programme for the envisaged fundamental physics experiments and the scientific experiments with the muon microscope.

III. MAC General Comments

No major disruptions to operation were suffered this year and the facility is on a good track towards becoming a productive user facility from this year onwards. The recent dip and recovery in beam availability will take several years to work through to a recovery in publications.

S1 development has gone very smoothly and MAC congratulates MUSE on that achievement. The potential delay in H-line construction causes some concern. Progress towards a facility attracting new domestic and international users will be greatly assisted by the provision of sufficient manpower (i.e. at international standard level of 2 or more support scientists per instrument) in order to fully support the user programme.

Limited manpower to operate and maintain the beam lines has been a continuing problem so we congratulate the facility for obtaining two additional staff members. Further staff resources in user support will be needed for efficient exploitation of the investments in the facility.

MAC congratulates the staff of MUSE for achieving the first ultra-slow muons and the U-line is making good progress despite the delay in obtaining nonlinear optical components of sufficient quality. The laser ionization of muonium is central to many projects and should be supported at high priority. Given the importance of obtaining optical material of good enough quality for high power operation, other options should be explored as a backup.

MuSAC Report

I. Overview and Research Projects (S-Type Proposals)

KEK-IMSS Introduction and Overview:

KEK-IMSS Director Prof. K. Yamada gave an introduction to MuSAC and its relation to MAC, explaining that whereas MAC covers the activities of J-PARC MUSE, MuSAC covers activities of KEK-IMSS Muon Science Laboratory staff both within J-PARC and elsewhere (e.g. at TRIUMF, PSI or RIKEN-RAL). He then presented the MuSAC charge to the committee, covering beamline operation and future plans at J-PARC, as well as ideas for expanding the muon community and the MUSE group and consideration of the ideal relation between MAC and MuSAC.

Frontiers of research on condensed matter, life science, and particle physics explored by ultra slow muon microscope:

A sub-mm muon beam size is a highly welcome development since it opens up a completely new field of muon applications in device characterization. It will allow the investigation of small device structures with areas of the order of 100 μm^2 which can be produced with much higher quality compared to large area samples. Such small samples significantly ease the application of homogeneous electric fields and large current densities, which is of prime importance for the extension of μSR to the investigation of multi-ferroic and spintronics devices.

The ultra slow muon (USM) microscope represents a unique extension of muon beam applications which is only available at J-PARC. Due to the long down time of the U-line in the past years the project has been significantly delayed compared to the original research plan. The evaluation committees of the project therefore approved extension of the research plan and dedicated usage of the U-line and ultra slow muon beam to March 2019, which is highly supported by MuSAC.

The beam size of the re-accelerated USM is decreasing as a function of energy, and is expected to reach a size of about 10 μm at 250 keV, where the mean implantation depth is of the same order. Due to multiple scattering processes during slowing down in the sample, the effective final beam spot size is increased. The MuSAC recommends carrying out a SRIM simulation to study the effect of multiple scattering on the lateral distribution of the stopped muons to determine the minimum beam spot size for which multiple scattering effects do not lead to a significant increase of the stopped muon distribution compared to the spot size of the beamline-focused incident muon beam. This will determine the maximum energy to be envisaged in the re-acceleration section.

Critical to the project is the efficient generation of the USM beam. The optimization of U-line muon beam transport and of the generation of USM – with the laser system being of pivotal importance – should be pursued with high priority.

Precision measurement of muonium hyperfine structure and muon magnetic moment:

Observation of the resonance of the muonium ground state hyperfine structure in zero magnetic field in the last year is very encouraging and it will lead to a significant new number. Work on systematics at zero field will be of high importance and relevance for the work at high field. The results are important for g−2 at J-PARC and elsewhere.

Search for muon-electron conversion utilizing pulsed proton beam from RCS (Rapid-Cycle Synchrotron)

The equipment is well prepared and waiting for the opportunity to measure in the H1 area. We are confident that the scheduling can be organised by mutual agreement with the muonium hyperfine structure experiment. For DeeMe particular attention should be paid to the opportunity time window for the experiment, requiring the H-line to be completed in good time.

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

Non-destructive elemental analysis using muonic x-ray has been explored under the platform of "Multi Probe Imaging by multi-quantum beams". This project covers applications to probe industrial products like Li-batteries. The MUSE staff members are making efforts to solve several issues for muonic X-ray analysis such as the enhancement of the limited detection efficiency and reducing the background to allow application to smaller samples. We appreciate the successful introduction of several diagnosis methods to check and control the beam size and the momentum bite. We are also impressed by recent progress of 3D imaging analysis using the pin-hole camera type approach with multi-arrayed CdTe X-ray detectors.

Development of general-purpose μSR spectrometer with semiconductor-based optical detectors and measurement of New Element Strategy samples with new functions:

The spectrometer is now fully functional and is making progress with the science. A fly-past chamber, compact transverse field coils and a flash lamp system were commissioned in FY2016 and further sample environment options are to come in FY2017.

Development of D1 spectrometer instruments and μSR experiment in strongly correlated electron systems:

Many improvements have been made to the sample environment and background on the D1 spectrometer and it is now ready for the programme of measurements on strongly correlated electron systems.

Development of polymer dynamics probing method using magnetic marker:

This is a good area of application for μSR spectroscopy, filling a gap in the dynamical spectrum between other more established techniques such as NMR and QENS. Results for polybutadiene have been obtained using both diamagnetic probe states and radical probe states. The radical probe results are notably different from the diamagnetic probe results, but not yet fully understood.

A strong link with industrial collaborators (Sumitomo Rubber) is a notable feature of this project.

Muon g−2/EDM:

This proposal of experiments to check g−2 anomaly initiated in 2009 has now reached the stage of submitting the detailed report of the technical design review. As a whole, we appreciate the remarkable progress that has been made by steady and efficient R&D. MuSAC takes note that a dedicated thorough expert review of the project had been held in November 2016 which was very positive.

However, it is noted that one of the remaining critical issues to be solved is efficient and stable ionization of Mu by Lyman-alpha lasers, as is the case for the U-line experiments.

Transmission Muon microscopy:

The proposed transmission muon microscope represents another unique extension of the MLF capabilities. It is very challenging, since it requires a very high rate of 10^6/s of ultra slow muons (USM), and an efficient re-acceleration of USMs to 10 MeV, where the relative momentum spread has to be kept very low at a $<10^{-7}$ level in order to achieve the required coherence length of the order of μm. This large coherence length is mandatory in order to be able to use the 10 MeV muon beam for the first time as a muon wave for phase contrast microscopy on samples with thickness on the 10 μm scale with spatial resolution of <= 20 nm – these are microscopy features which cannot be provided by standard microscopy techniques such as transmission electron microscopy, optical microscopy or X-ray microscopy. If successful it offers the unique possibility to study live biological cells, which would boost the field of muon applications to life science with the possibility of high impact results.

The setup needs a several meters long re-acceleration section, and therefore it has to be located at the H-line in the H2 area, in parallel with the g−2 experiment which also requires the highly demanding rate of 10^6/s of ultra slow muons, which means that both experiments rely on the efficient generation of USM. Some of the required R&D work for the acceleration section can be already carried out at the U1B leg, where the muon micro-beam is being setup using the same induction acceleration technique for ultra slow muons which is proposed to be used for the 10 MeV transmission microscope.

The ability to test the feasibility of the proposed setup before making a major investment in this project is a plus. As in the g–2 experiment and the ultra-slow muon setup at the U-line, this project depends crucially on the laser development for the ultra-slow muon generation, which should be supported with high priority.

II. MuSAC General Comments

These three beamlines D1/D2/S1 are judged to be reasonably well equipped for a variety of experimental programmes and an increasing number of users will benefit from this.

For commissioning of the ultra-slow muon beam line various improvements are under way and further modifications to the system to improve operational reliability are encouraged.

The publication rate from the facility appears to be consistent with international standards. The impact seems reasonable given the short time scale involved.

For future plans it is important to develop a roadmap extending beyond H1 construction to include S2-S4 and H2, H3.

To stimulate domestic/international collaboration on the construction and operation of the beam lines, having a clearly demonstrated fully functioning USM beamline is likely to be the best catalyst.

One way to expand the muon user community would be to start by expanding links and overlap with the neutron community e.g. by holding further joint training schools.

Enlarging the group of experienced muon scientists will clearly be necessary in order to carry out the wide-ranging long term plans of the MUSE group. The age and retirement profile of the current group members determines the urgency and timescale needed for this. One contribution to this enlargement goal could be to explore opportunities for joint appointments with universities that will enable greater access to students as future group members.

It is clear that there is extremely strong overlap between the areas covered by MAC and MuSAC and it is suggested that in future an agreed common charge between MAC and MuSAC would be a great simplification.