International Society for μSR Spectroscopy

Newsletter No. 20 – April 2022

Greetings from the President of ISMS

This will be my final newsletter as ISMS president, as we have decided to keep the MuSR conference synchronised with the rotation of the ISMS Executive. I would therefore like to thank the current team for all of their work over the last two years, with special thanks to Peter Baker as ISMS secretary, and wish Martin Mansson well for his term as president, which starts in August. We shall now hold an election for each of the Vice-President posts (listed at https://www.musr.org/executives). If you are interested in running for any of these positions please contact Peter Baker or I.

The last two years have been a uniquely challenging time for all aspects of our lives, including our scientific research. However, we continue to be grateful to the staff at each of the muon facilities for their work in allowing experiments to be carried out and facility-development projects to grow. Particularly encouraging news includes progress in the CSNS muon project, the new FLAME instrument at PSI, the M9H project at TRIUMF, the development of Super-MuSR at ISIS and the new experimental areas at J-PARC. Further details of these, and the many other ongoing development projects worldwide, can be found in this newsletter.

Another recent development is the new textbook *Muon spectroscopy: an introduction*, also advertised in the newsletter. The book, aimed at beginning graduate-level students, grew out of a summer school that took place at ISIS in 2019 and includes contributions from many practitioners of the technique. All of the profits from the book will go to ISMS in order to aid the society and its future projects.

As you'll be aware, the next MuSR conference takes place in Parma this year and we very much look forward to seeing you there. We are also now seeking expressions of interest for those wishing to host the next conference in 2025. If you are interested, please contact Peter Baker or I. We expect the announcement of the 2025 event be made at the Parma conference, where we shall also hold the next ISMS general assembly.

Best wishes, and I look forward to seeing you in Parma,

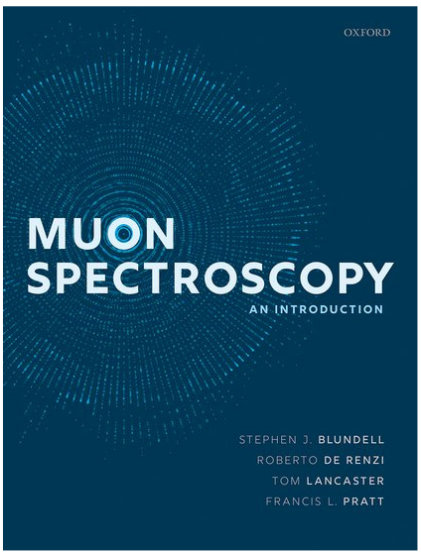
Tom Lancaster

ISMS President.

(tom.lancaster@durham.ac.uk)

Muon spectroscopy: an introduction is now published

https://global.oup.com/academic/product/muon-spectroscopy-9780198858966



Oxford University Press has now published Muon Spectroscopy: an introduction, a new textbook on the technique of muon spin rotation and relaxation. This book has been edited by Stephen Blundell (Oxford), Roberto De Renzi (Parma), Tom Lancaster (Durham) and Francis Pratt (ISIS).

This modern, pedagogic introduction to muon spectroscopy is written with the beginner in the field in mind, but also aims to serve as a reference for more experienced researchers. The key principles are illustrated by numerous practical examples of the application of the technique to different areas of science and there are many worked examples and problems provided to test understanding. The book vividly demonstrates the power of the technique to extract important information in many different scientific contexts, all stemming, ultimately, from the exquisite magnetic sensitivity of the implanted muon spin.

Aimed at beginner graduate students, this book provides a comprehensive introduction to muon spectroscopy and its uses in, among other applications, the study of semiconductors, magnets, superconductors, chemical reactions, and battery materials.

- This textbook highlights the relevance of muon spectroscopy to many scientific areas across physics and chemistry
- Introduces the technique including theoretical foundations and practical and computational skills
- Draws on the expertise of a large team of contributors, while maintaining consistency in its pedagogical style and systematic presentation of topics
- Equally suitable as a course text and as an aid to independent study

The International Society for µSR Spectroscopy

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UPDATE: MuSR-2020 Parma, Italy

The long delayed MuSR2020 conference will run from Monday 29th August to Friday 2nd September, 2022. An in-person meeting is planned, which will be held at the Science and Technology Campus, University of Parma. Invited speakers include Bruce Gaulin, Giacomo Ghiringhelli, Reizo Kato, Ioan Pop, Jorge Quintanilla, Roberta Sessoli, Martin Wilkening and Reiner Zorn.

A Student Day will be held on Sunday 28th August, when a mixture of lectures and student presentations is planned. Limited Conference support is available for Early Stage Researchers upon request and subject to attendance of the Student Day.

We anticipate opening registration for the conference 16th May, 2022. For the latest news please visit https://indico.stfc.ac.uk/e/musr2020.

The conference is being jointly organised by the muon groups at the University of Parma in Italy and at ISIS at the Rutherford Appleton Laboratory in the UK. We look forward to seeing you all at the meeting!

Roberto De Renzi and Adrian Hillier

(Joint Chairs)

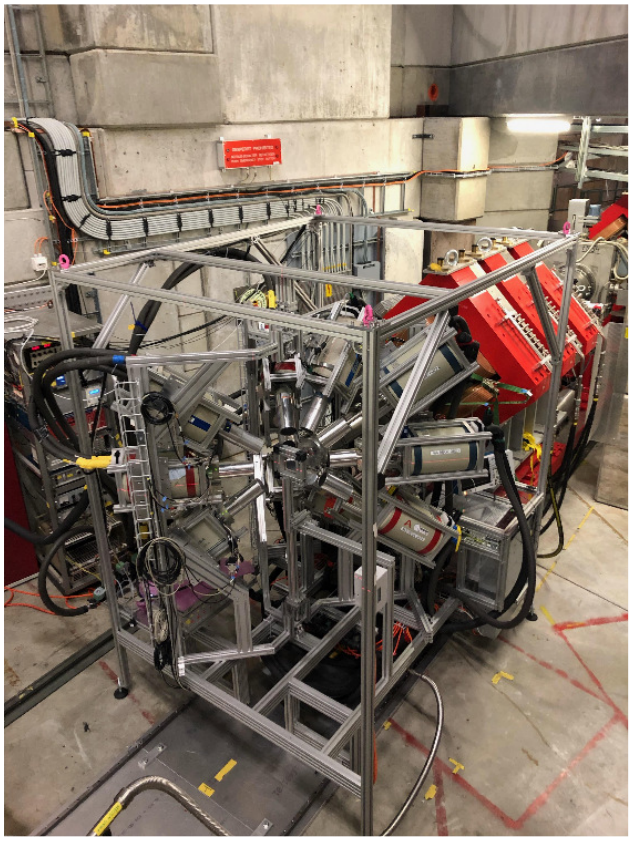
Con il Patrocinio del Comune di Parma

PARMA 2020 la cultura batte il tempo | CAPITALE ITALIANA DELLA CULTURA

UNIVERSITÀ DI PARMA

Science & Technology Facilities Council
ISIS Neutron and Muon Source

News from PSI



New MIXE setup in πE1, Dec 2021

Although the Covid-2019 pandemic still led to severe travel restrictions in 2021 and mainly remote operation of experiments at SμS, the user program at the PSI High Intensity Proton Accelerator HIPA was running smoothly during the 8.5 months operation period from April 12 to December 23. At SμS, 299 submitted proposals were requesting beam time in 2021, a new all-time record, leading to an average instrument oversubscription of 2.8. In total, the five instruments Dolly, GPD, GPS, HAL-9500, and LEM were available for user operation during 871 experimental days (without instrument development times). While the mail-in-service for samples and remote operation worked well, it became clear that this mode of operation could be only a transitional measure to continue to run the user program during the pandemic. The additional load on local staff is not sustainable, and the training of the next generation of muon users cannot be accomplished by remote operation of experiments.

For 2022 and the following years, we expect a slightly shorter run cycle of 8 months from May to December due to the requirements of shutdown work of HIPA. The proton beam current will be limited to 2.0 mA for 2022 and 2023 due to the upgrade program in the injector 2 cyclotron. HIPA will continue to run with the slanted target E, yielding 30-60% higher muon rates in the surface muon beam lines installed at target E. In 2021, the slanted target has been in operation for the first time for the full run period of 8.5 months, and thanks to the new ball bearings developed at J-PARC, no target replacement was necessary in 2021. In the coming years, SμS operation will continue with two calls per year, with deadlines on June 1st and December 1st.

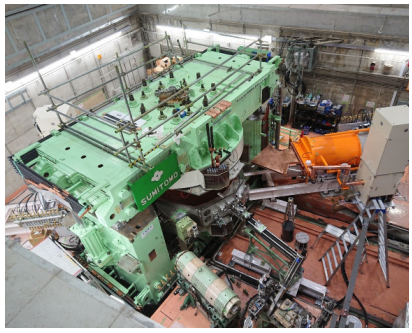
Problems due to the pandemic and in the manufacturing of the 3.5-Tesla magnet led to a further delay of the commissioning of the new FLAME instrument. The magnet was finally delivered to PSI in February 2022, and the site acceptance test was started end of March 2022, with a delay of 23 months. We expect test and expert user experiments end of 2022, and we are planning to open regular user operation in 2023. At LEM, a thin film preparation chamber with a base pressure $< 2\times10^{-9}$ mbar has been successfully used for the first time to prepare high quality and large area organic films (CuPc and $TbPc_2$) for LEM experiments in December 2022. The chamber is equipped with two large area evaporators, an ion sputtering gun, a thickness monitor, and a substrate heater. The chamber is designed such that it is possible to transfer thin film samples in vacuum directly to the LEM spectrometer.

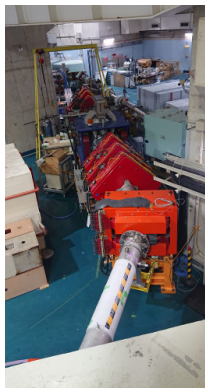
For the negative muon project for elemental analysis MIXE (Muon Induced X-ray Emission), a new setup with all electronics on-board has been designed, developed, and successfully operated in 2021. It enables a very flexible use of Ge detectors and significantly eases sample mounting. The year 2021 has seen an important strategic initiative of PSI and the University of Zurich for a major upgrade of HIPA in the years 2027 and 2028.

The IMPACT project (Isotope and Muon Production using Advanced Cyclotron and Target technologies) aims for the installation of a new proton target for the production of radioactive isotopes to be used in radiochemistry, radiopharmacy, and nuclear medicine, and the replacement of target M and the corresponding beam lines pM1 and pM3 by a new target H with two High-Intensity Muon Beam lines (HIMB), based on large aperture, normal conducting solenoids. Surface muon beam rates up to 10^{10}/s will be delivered to the end of the new mH1 beam line for particle physics applications. The new mH3 will feed the existing spin-rotator for the GPS and FLAME spectrometers, where m^+ rates of up to 10^8/s are expected. In order to cope with this huge rate for continuous beam µSR experiments, new Si-pixel detectors for m^+/e^+ vertex reconstruction with position resolution of < 1 mm will be developed in collaboration with the Laboratory for Particle Physics at PSI, and the University of Zurich. A workshop, held per zoom between April 6 and 9 in 2021, discussed the science case and is summarized in this document: https://arxiv.org/abs/2111.05788. The proposal for IMPACT is currently under evaluation by the Swiss National Science Foundation (SNSF), and the result will be published in July 2022. If approved, the project will start in 2025, and finish with a 1.5 years shutdown of HIPA in 2027 and 2028 for the installation.

Thomas Prokscha, Hubertus Luetkens

News from RCNP-MuSIC





New AVF accelerator and MuSIC muon beamline

RCNP (Research Center for Nuclear Physics, Osaka University) has still been in the long shutdown for upgrading the AVF cyclotron accelerator since 2019. During the shutdown, no beam experiments have been done. The Covid-19 pandemic restricted to the face-to-face classes, conferences and workshops in Osaka but the facility and accelerator upgrade works have been progressed. We are currently in the final stage to commission magnets and RF system for the beam injection and acceleration. We are anticipating that the muon beam will return for users this year.

The newly upgraded AVF cyclotron (figure left) is not dedicated to the proton beam but can provide various kinds of ion and RI beams with a variable energy for the nuclear physics research, short-lived RI production and researches with the secondary beams of neutrons, unstable nuclei and muons. For the muon beam, the proton is accelerated with the upgraded AVF cyclotron and the existing Ring cyclotron. The first goal is to provide a more stable proton beam at 392 MeV, 1.1 mA. In the future the proton beam intensity will increase up to 11 mA step by step with accelerator and muon beamline commissioning. The muon beam will then increase by an order of magnitude compared with the previous positive and negative muon beam intensity.

For the muon beamline (figure right) we are developing the cryogenics apparatus using GM coolers and the detector for general μSR experiments. We are also developing an incident beam tracking drift chamber for the negative muon beam. It will be combined with the Ge detectors to aim the 2-dimensional elemental analysis at RCNP-MuSIC.

RCNP calls for new research proposals twice a year. However, feasible experiments are limited with the RCNP-MuSIC muon beam. If you submit the proposal to RCNP-MuSIC, we will appreciate to contact us in advance. (our homepage: http://www.rcnp.osaka-u.ac.jp/index_en.html)

Dai Tomono

ISMS Executive Committee

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Secretary: ***Peter Baker, ISIS, UK***
If you have comments on any aspect of the ISMS, please contact a committee member.

Update from the Centre for Molecular and Materials Science (CMMS) at TRIUMF

The COVID-19 pandemic and the M9-T2 repair resulted in the μSR beam time in 2020 being reduced by about 50% compared with a regular year, which is approximately 275 days of beam delivered to M15 and M20. In 2021, we delivered more beam to μSR experiments than in any year from 2013 – 2019. This was achieved due to a significant fraction of the time being collaborations between local and remote experimenters. We are cautiously anticipating more in person experiments in 2022, but this will depend on the progress of the COVID-19 pandemic.

We are currently completing the M9A beamline with commissioning scheduled for the summer beam period. Recent technical opportunities with regards to handling large arrays of SiPM/APD detectors need to be fully assessed before completing the design of the 3T spectrometer. The beamline and spectrometer will be optimized for rapid sample characterization with user-friendly operation. We anticipate M9A will be available to experimenters in fall 2022.

The M9H project has progressed as scheduled despite COVID-19 pandemic challenges. This project focuses at upgrading the decay muon channel at CMMS, to provide high intensity/luminosity muon beam, with the possibility of having transversely spin polarized muons at sample. The major highlights regarding the current status of the project are:

• The project is finalizing detailed design of the beamline components and has proceeded to focussing on the design of its spectrometers and beam monitors.

• Tenders for the remaining high-cost end-station devices, i.e., the 4T 3-axis accessible superconducting magnet and the dilution refrigerator are due at the end of March.

• The M9H beamline and spectrometer are scheduled to commence operation in April 2023 and April 2024, respectively.

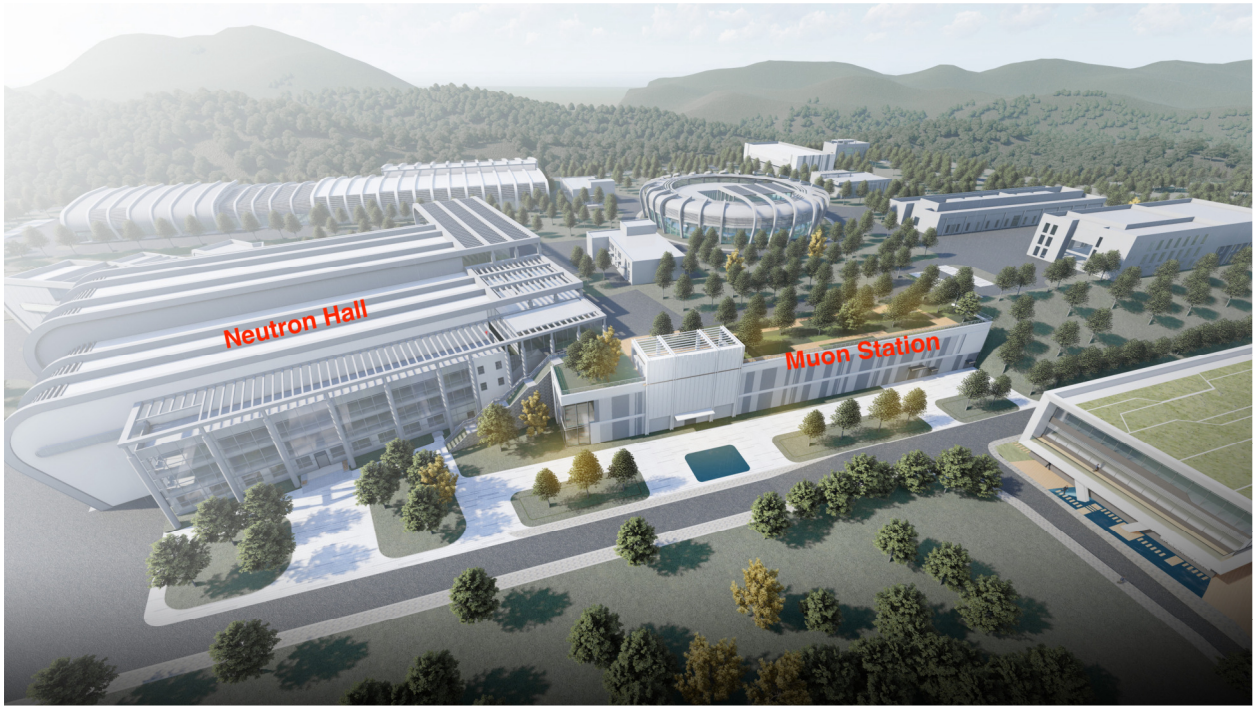
βNMR experiments lost a significant amount of time in 2021 due to issues with ISAC and commissioning of the mid-field βNMR spectrometer, which is downstream from the present low field βNQR spectrometer and has a maximum field of 2 kG parallel to the sample surface. Further commissioning of the spectrometer is needed but the spectrometer will be available for scheduled experiments in the summer beam period.

The summer Molecular and Materials Science Experiment Evaluation Committee (MMS-EEC) meetings were usually held in late June with a submission deadline in late May. Beam time in the Meson Hall usually starts at the beginning of May, which meant there was only a small amount of beam time (2 – 3 weeks) for people to demonstrate the feasibility of experiments and submit a progress report asking for more time. Often, we would not be able to accommodate experiments in this short time window, which would then lead to a delay of a year in running the follow-up experiments. To minimize this issue, both the submission deadline and the summer MMS-EEC meeting will be pushed back by about a month. The next submission deadline will be June 29th and the next MMS-EEC meeting will be held on July 25th and 26th. This will enable approximately 2 months of experiments to run prior to the submission deadline in a typical year. *–Iain McKenzie*

Progress report on the CSNS muon project

During last year, the muon source project, as an essential part of CSNS II upgrade, has gone through several rounds of internal review. The stand-alone target design is endorsed by the academic committee of CSNS for lower cost and lower risk. Up to 5Hz of proton pulses (about 100 kW in power) will be extracted from the RCS ring to the muon target station. Two muon beamlines (one surface and one decay muon beam) are designed to provide 6 terminals for various applications.

During the CSNS II project we will build the surface muon beam with one µSR spectrometer. The muon group has finished the feasibility study of the muon facility, and the report has been reviewed by the Chinese Academy of Sciences. The application has been submitted to the National Development and Reform Commission for the approval of funding. It is expected to receive the approval by September 2022, and we will start the construction by the end of this year.



The muon project has generated more and more interests from condensed matter scientists in China. In December 2021, the annual CSNS User Meeting had a dedicated µSR session for the first time. Users from several universities in China talked about their research with muons and gave constructive suggestions to the new muon project. The users urge that China should start the construction of the muon project as soon as possible for both Chinese µSR users and the international muon community.

Yu Bao

News from the µSR facility at RAON

From early 2021, µSR beamline has been under construction, and main components consisting of muon beamline such as muon production target chamber and dipole & quadrupole magnets are allocated without fine alignment. At this stage, we are installing utilities like coolant and electric power. While µSR beamline assembling, we face critical issues about accelerators and muon beamline.

RAON consists of two superconducting linear accelerators (SCLs). At the moment, only one SCL is under test for operation. The production of muon is impossible practically to prepare till the time planned. We cannot guarantee certain time to deliver high-energy protons. Another issue is the spin rotator as one of the main components for muon beamline. The spin rotator will be designed and fabricated by domestic corporations with no experience to build. This possesses a high risk to completion of muon beamline due to technical difficulties.

Notwithstanding the unequipped situation, every component in the muon beamline will be tested as follows. The transport efficiency test will be tested with the alignment of all components by using a radioactive calibration source (^{106}Ru, β^-). All magnets have to change electric polarity and scale the field down properly. As well we prepare thermal integrity tests for a muon production target and beam dump units. We employ an induction heating system as heat generated by induced eddy current in conducting materials. We quickly checked the system able to graphite, low-conducting material relatively. We will investigate the thermal stability of our muon production target and beam dump, and compare the experimental results with simulations using by ANSYS Maxwell software.

Presently we are not able to make sure of when the µSR instrument is available to open to users. Until all SCLs are ready to operate, we will make the muon beamline with minimizing defects with tests mentioned above.

Wonjun Lee

(Left) µSR beamline in RAON under construction. The beam pipe at the center of beamline should be replaced with spin-rotator. (Right) The upper side of disc shows the status after induction heating to graphite with no rotation and under high vacuum (~ 2×10^{-5} torr). The temperature estimation of the activated section is roughly 1500 °C by using thermocouple wires.

News from ISIS

Long shutdown and proposal rounds: Just after the last ISMS Newsletter, ISIS ran one operating cycle before starting the long shutdown that was delayed by Covid-19. Almost all the experiments were done by remote users and instrument scientists handling their samples. This continued to work successfully with all the samples that reached ISIS in time being measured before the shutdown and some addition rapid access experiments. The workload required to do this was not sustainable and ISIS expects all future experiments will be conducted with users attending in person.

Shutdown work at ISIS started in June 2021 and the accelerator tank 4 replacement was completed this February. The first cycle of running to Target Station 2 only has just finished. Work to upgrade the neutron target in Target Station 1 is continuing and commissioning beam should start around October.

Following the April 2022 proposal round with all instruments open, user experiments on the muon instruments are due to resume in November. Another proposal round for muon experiments will be held in October for experiments from March 2023.

DDM2021 and Muon Jamboree: We held two meetings in the autumn of 2021. The first discussed Detectors and Data Acquisition systems for muon experiments. There were 10 talks over two days with presenters and attendees coming from around the world. The Muon Jamboree held just before Christmas was attended by a total of 120 people. The Jamboree starting with a two half-day mini conference of science talks previewing the delayed MuSR2020 conference. This was followed by the ISIS Muon User meeting including student science talks and the Muon Illumination meeting discussing the new experiments that are being done at ISIS and elsewhere combining muon spectroscopy with optical stimulation.

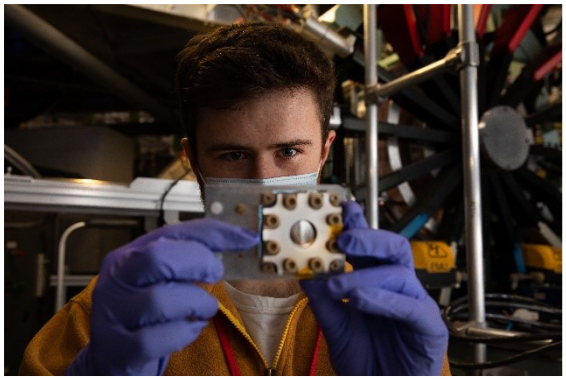
HiFi magnet repairs: Before the ISIS long shutdown, the HiFi instrument magnet suffered several quenches and had to be de-rated to complete as many experiments as possible. During the shutdown, the fault was found by the manufacturer to be in a current lead and the magnet has recently been returned to them for repairs. We anticipate the magnet will be reinstalled in good time for the first user experiments after the long shutdown.

HiFi magnet beginning its journey back to Cryogenic for repairs.

Super-MuSR project progress: The Super-MuSR upgrade project continues to progress as part of ISIS's wider Endeavour programme of new and upgraded instruments. The aim is to provide a high-rate mode with a counting rate 20x that of the current MuSR instrument and a higher-resolution mode providing 10x the present ISIS resolution. Detailed design work is now underway across all the aspects of the new instrument. Prototype pulse slicer power supplies have been produced, prototype detectors representing 2/64^{ths} of the full instrument and digitisers to record the data from them are under construction for testing when the muon beam returns in the autumn, and a memorandum of understanding has been signed with PSI to co-develop the spin rotators.

New instrument scientists: John Wilkinson is joining the ISIS muon group having just completed his DPhil at Oxford University and Rhea Stewart will be joining us from ETH Zurich, where she is currently a postdoctoral fellow. Both will be starting before the end of the long shutdown ready for experiments resuming.

In-operando cell for battery material measurements: One of the developments that has been completed during the ISIS shutdown has been completing a project with the group of Prof. Serena Corr at the University of Sheffield to enable in-operando measurements of battery materials. The BAM (Batteries and Muons) cell has been tested with a range of materials and can reproduce the electrochemical performance of standard laboratory cells while offering a large enough electrode area and volume to allow effective muon measurements.



Innes McClelland with the new BAM cell developed as part of his PhD project.

Muon training schools and online learning: With the long shutdown leaving only a short period for experiments in 2022, we do not expect to be able to run the next ISIS Muon Training School until 2023. In the meanwhile, lecture videos from previous training schools and a wide variety of other muon training materials are available at: https://e-learning.pan-training.eu/. There will also be a student day at the MuSR2022 Conference including some introductory lectures.

Adrian Hillier

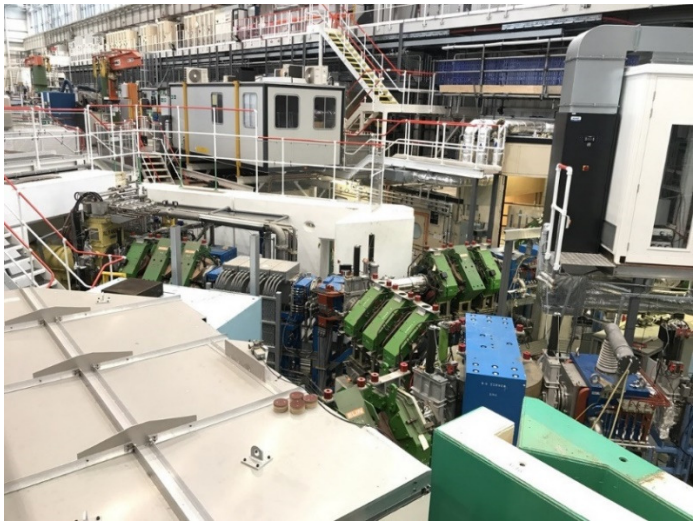
News from RIKEN-RAL

The RIKEN-RAL facility continued to successfully run experiments through the pandemic, with RIKEN scientists and users leading experiments remotely, with strong local support from ISIS scientists. This resulted in almost all the scheduled muon spectroscopy and elemental analysis experiments being completed. Major refurbishment of the facility is now underway (after 30 years of operation) during the ISIS long shutdown. The focus is on improving longevity and reliability, with upgrades to beamline operation.

A new suite of sample environment is being purchased for CHRONUS, which includes a He exchange cryostat with both dilution refrigerator and sorption inserts. The kit is interchangeable with equipment recently purchased for the other muon instruments, helping to ensure sustainable operation into the future. Coupled with the refurbishment of the existing sample environment, the facility will continue to offer a range of temperatures from ~50 mK to 500 K, with improved reliability for user experiments.

For negative muon elemental analysis, new data acquisition system, control and analysis programs are being developed. These will bring MuX in line with other ISIS instruments. The number of publications from this area is steadily increasing. Detector design studies are underway aiming to achieve a potential 1-3 orders of magnitude increase in data rates.

Lastly, the beamline control is being improved under IBEX and this will particularly help control experiments requiring tuning or changes in momentum, including the rapidly developing elemental analysis programme. We are very much looking forward to seeing users back again physically when the facility starts operations again late this year.



RIKEN-RAL beamlines in the process of refurbishment

Isao Watanabe

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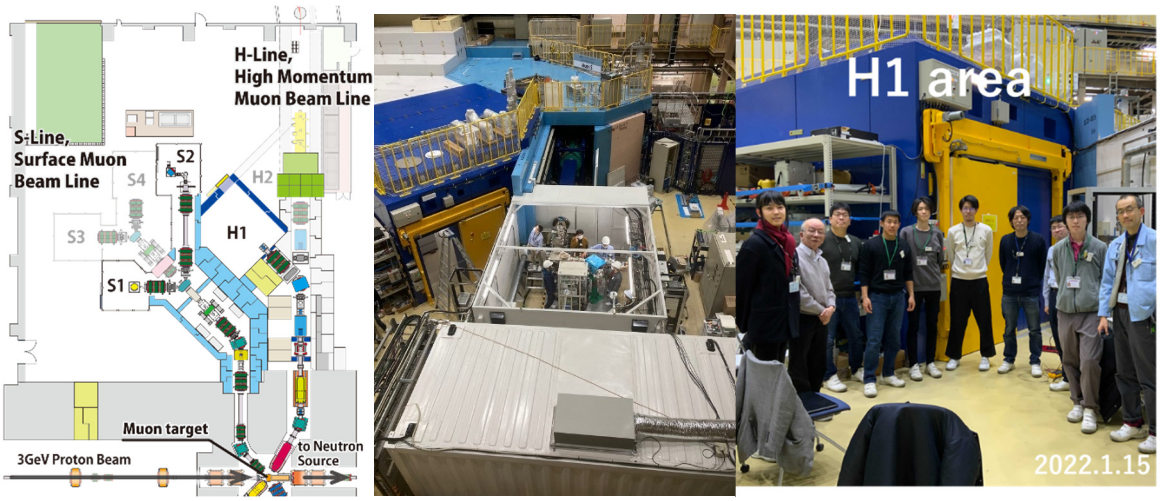
News from J-PARC

Two new experimental areas have started operation at the J-PARC MLF.

One is the S2 area, where a group led by Prof. Uetake at Okayama University has set up an apparatus for laser spectroscopy of muonium. Using the beam kicker in the S line, a double-pulse muon beam can be used as a single-pulse muon beam in the S1 and S2 areas simultaneously. Beam commissioning started in January 2022 confirmed that 3×10^6 /s of positive muons are extracted to the S2 area when the proton beam of 700 kW is operated. Permission to operate the laser has also been obtained, and tests and adjustments are underway in preparation for the experiments.

The other is the H1 area. The beamline is equipped with a muon capture solenoid, and experiments such as muon lepton flavour violation search and muonium resonance spectroscopy are planned. The adjustment work is going well and the user run is scheduled to start in June.



Akihiro Koda

News from the Muon Spectroscopy Computational Project.

The Muon Spectroscopy Computational Project (MSCP) [1] is a joint collaboration between ISIS and the Scientific Computing Department at the Rutherford Appleton Lab, which has been developing software, methods and expertise to help muon scientists interpret their experiments.

As of today, the MSCP has produced a set of sustainable and user-friendly software tools for μSR. The tool **pymuon-suite**[2] uses Density Functional Theory-based calculations to obtain potential muon stopping sites using only theoretical calculations. **MuDirac**[3] is a simulation software for X-Ray Spectroscopy with negative muons, which estimates the frequencies and probabilities of transition between energy levels in muonic atoms. And **muspinsim**[4] is a software that simulates the spin

[1] https://muon-spectroscopy-computational-project.github.io
[2] https://github.com/muon-spectroscopy-computational-project/pymuon-suite
[3] https://muon-spectroscopy-computational-project.github.io/tutorial-folder/muDirac
[4] https://github.com/muon-spectroscopy-computational-project/muspinsim

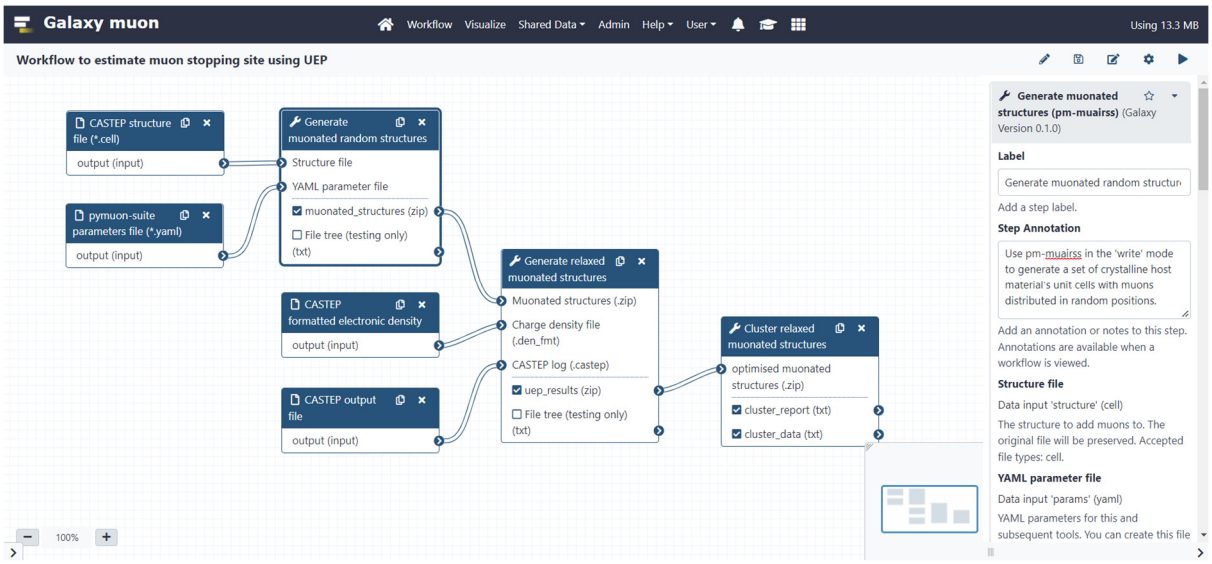
dynamics of a system of a muon plus other spins. It can simulate various common experimental setups -such as Avoided Level Crossing experiments or Transverse Field experiments- and account for hyperfine, dipolar and quadrupolar couplings.

The main objective of the MSCP for 2022 is to continue our interaction with users and our provision of computational tools and computational support. So far, all our tools are command-line tools that need to be installed locally or, in the case of **pymuon-suite** and **muspinsim,** can also be used in the **IDAaaS** virtual computing environment[5].

To improve the usability of our tools, the MSCP is now developing a GUI for these tools using the Galaxy platform[6]. Galaxy is an open, web-based platform for accessible, reproducible, and transparent computational research. It originated in the bioinformatics community but now spans many research domains, and our upcoming "Muon Galaxy" service will extend it to muon science in the coming months.

Muon Galaxy will contain "tools" corresponding to the MSCP's command-line tools, and "workflows" that chain these tools together. It will also include visualisations based on the **crystvis-js** crystallography visualisation tool[7]. Users can upload data, run tools, and download the output all through the web interface, meaning there's no need to know programming or the command line, and no need to install anything. The "history" of a Muon Galaxy analysis – all the input data, all the operations, and all the outputs – is fully preserved, and can be shared with other users or even made public (e.g. to supplement a paper). This offers a great bonus to reproducibility and transparency.

For more information contact: Leandro Liborio (leandro.liborio@stfc.ac.uk) or Eli Chadwick (eli.chadwick@stfc.ac.uk). If you'd like to receive updates when the Muon Galaxy service is available, you can provide your contact details in this form: https://forms.gle/NcMkHx82KifqYumQ7 .



An example Galaxy workflow for finding muon stopping sites.

[5] https://isis.analysis.stfc.ac.uk/
[6] https://usegalaxy.eu/
[7] https://github.com/stur86/crystvis-js