

The ISIS Muon Facility now and into the future

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MELODY meeting, CSNS

6th November 2023



ISIS Neutron and Muon Source



Outline

- 1 Muon user facilities map – present and future
- 2 The ISIS pulsed muon source
- 3 Science areas and some science highlights
- 4 Current upgrade projects and future plans



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- 1 Muon user facilities map – present and future
- 2 The ISIS pulsed muon source
- 3 Science areas and science highlights
- 4 Current upgrade projects and future plans

Next Muon Training School: 18th – 22nd of March 2024 at ISIS

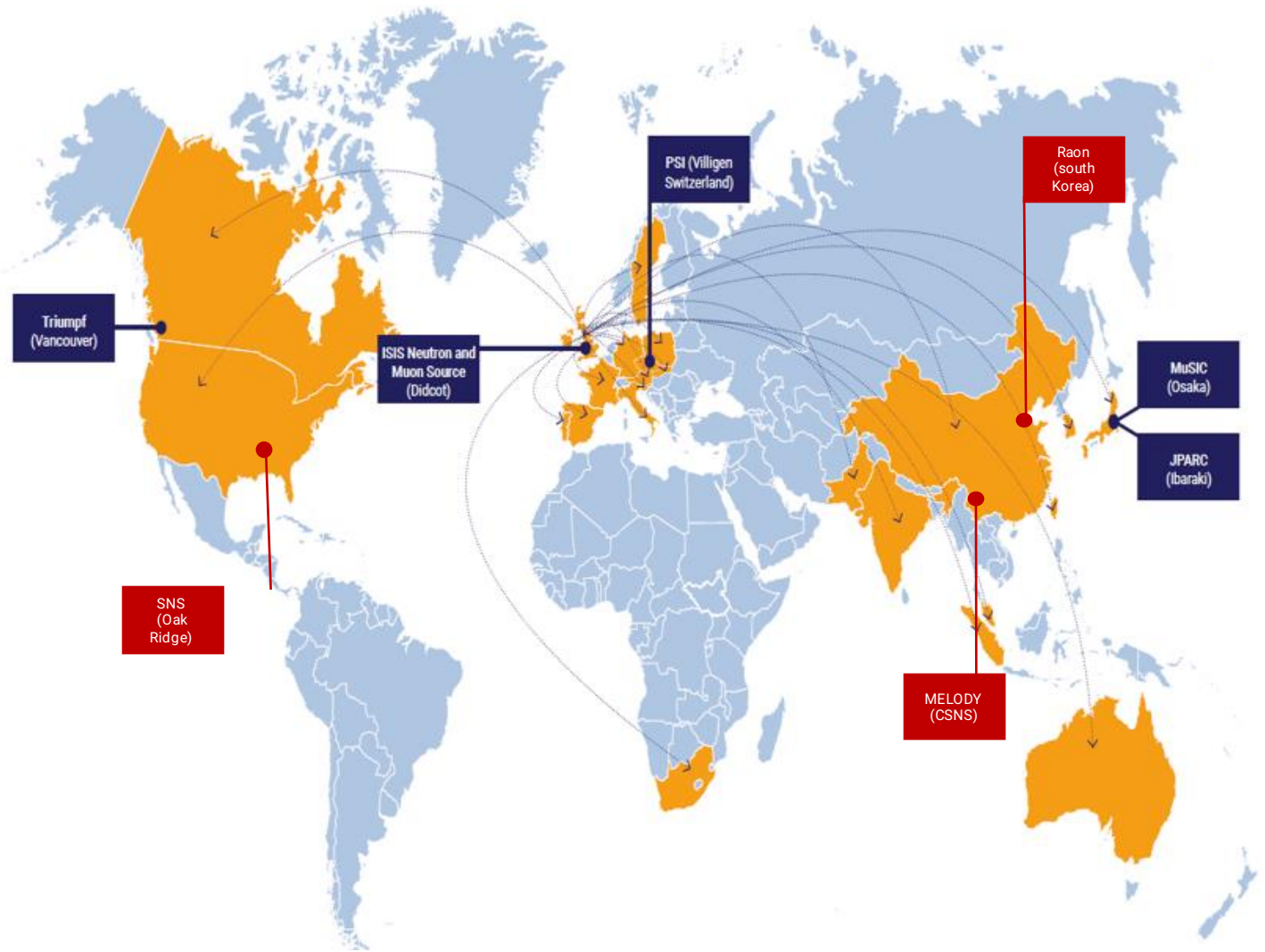
Muon Spectroscopy: An Introduction, Editors: [Stephen J. Blundell](#), [Roberto De Renzi](#), [Tom Lancaster](#), [Francis L. Pratt](#), OUP 2022

Muon Spin Spectroscopy, Nature Reviews Methods Primers, Hillier et al, Jan 2022

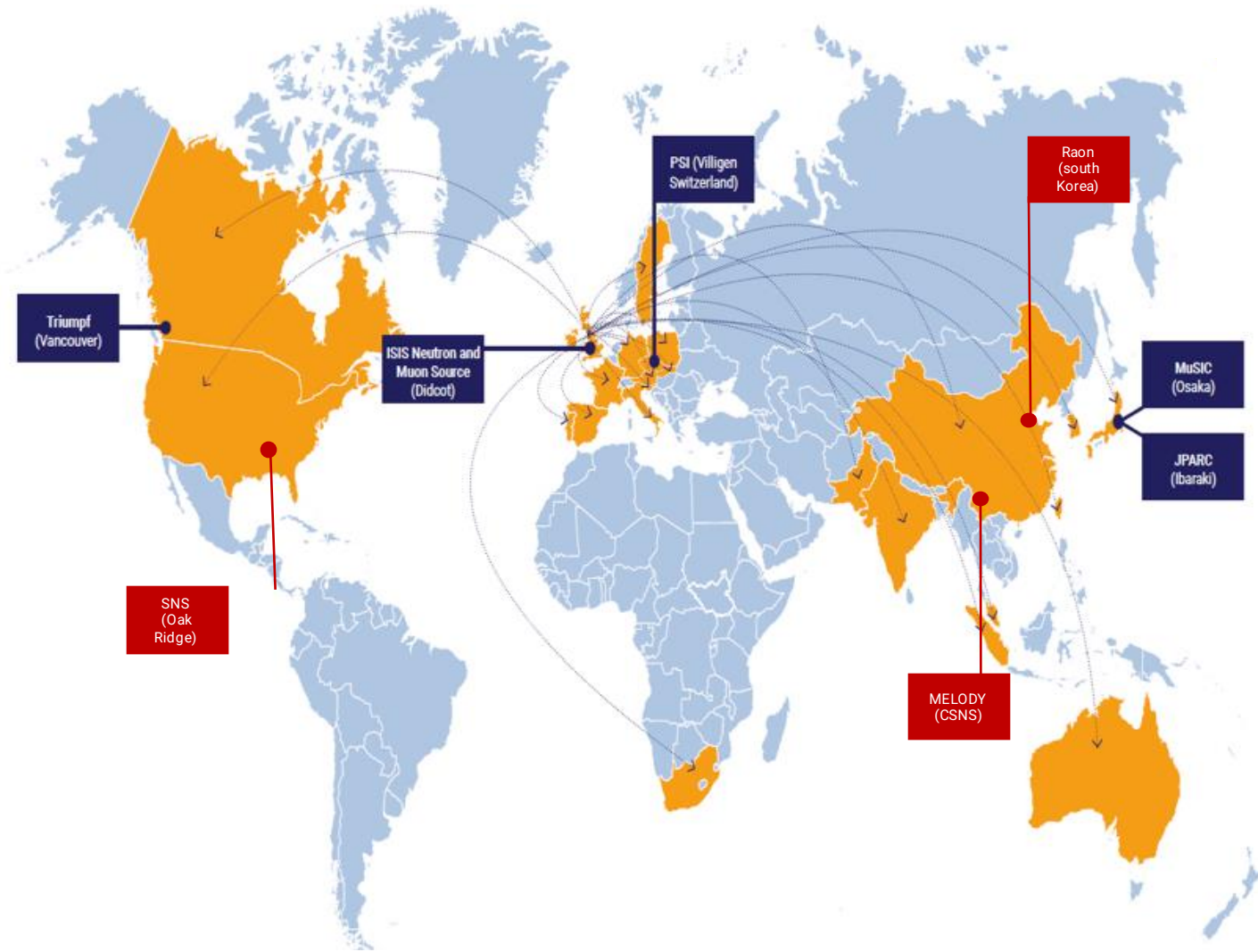
<https://pan-learning.org/>



1 Muon facility map – present and future

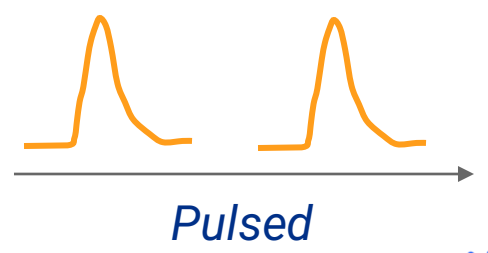


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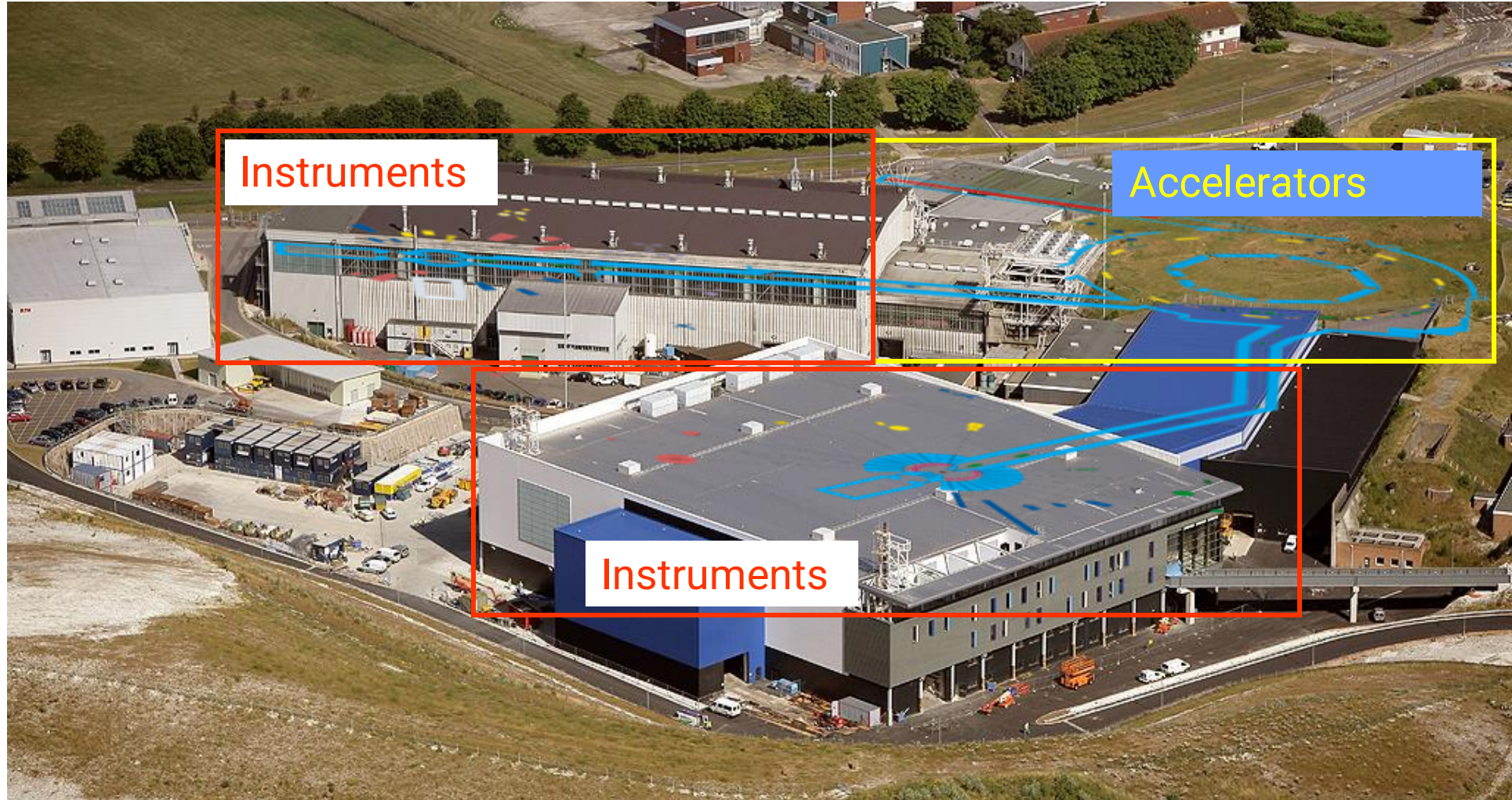


Spin polarised μ^+ and μ^- beams

low energy (0.5 - 30)keV
surface: ~ 4 MeV
Decay: (15 - 60)MeV

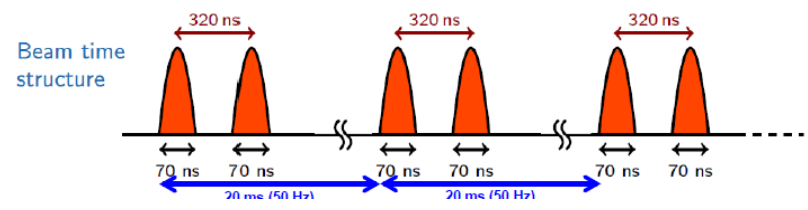
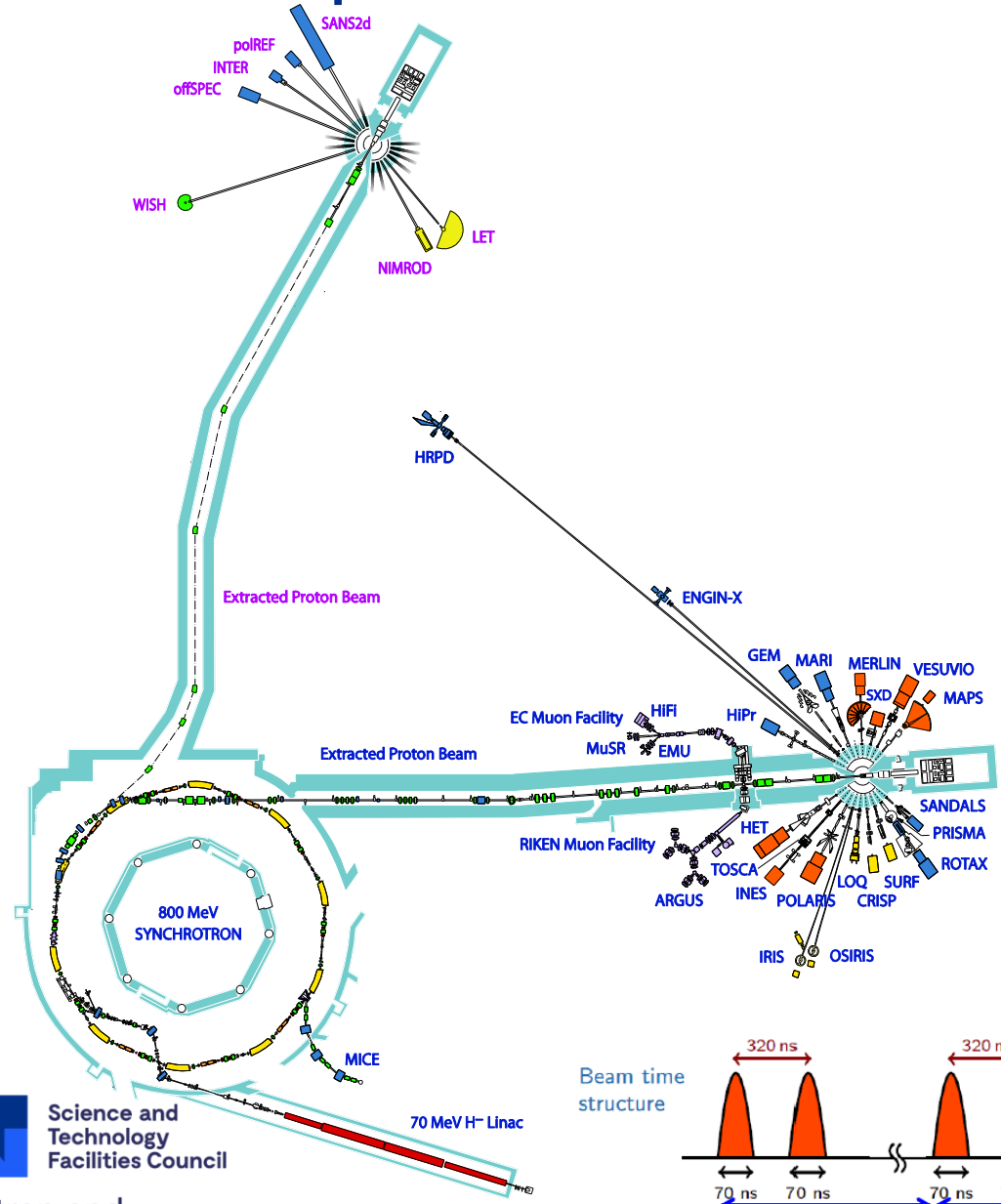


2 The ISIS pulsed neutron and muon source

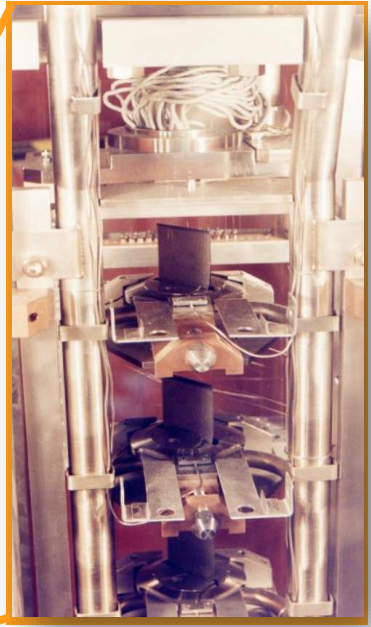
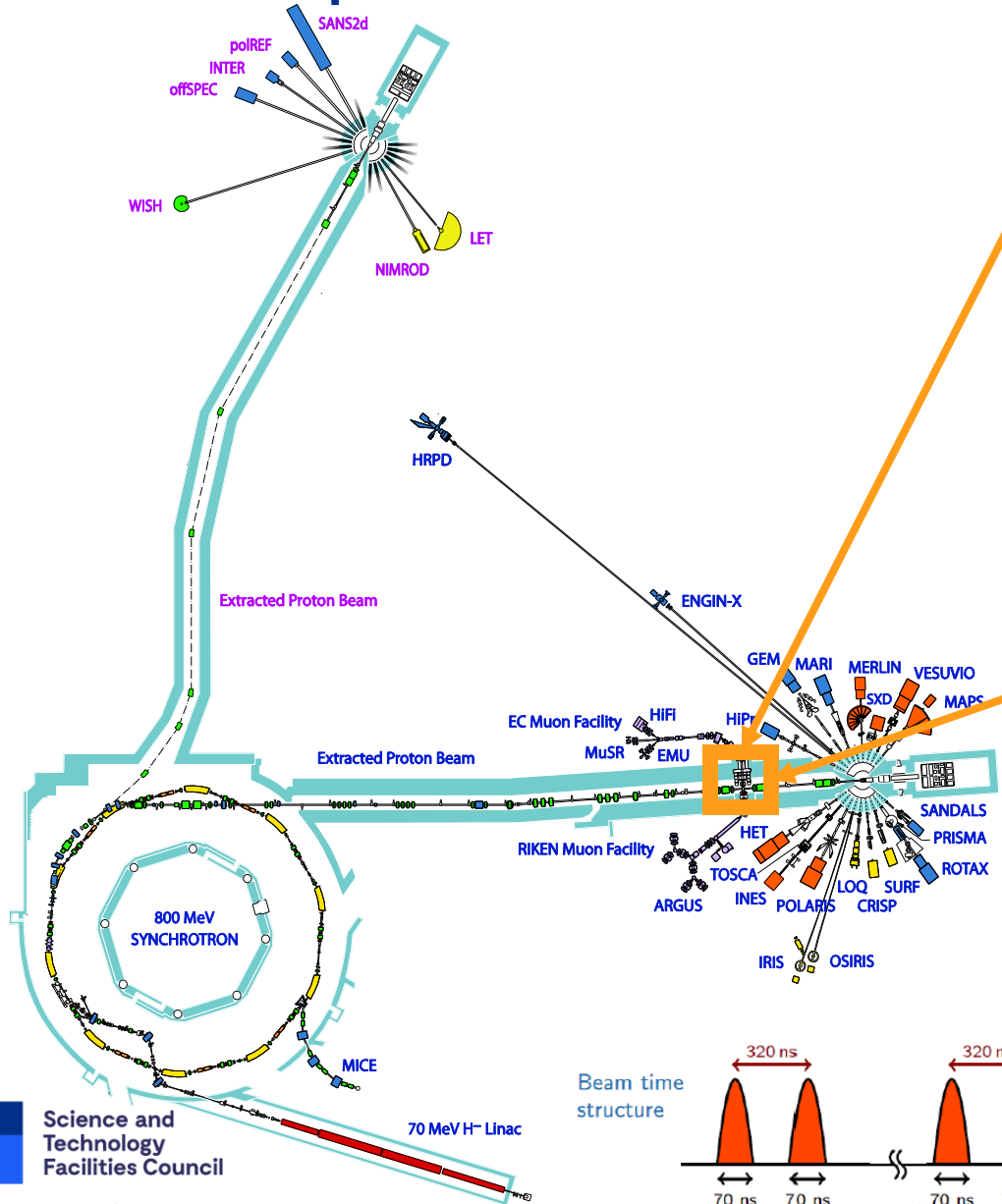


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The ISIS pulsed neutron and muon source

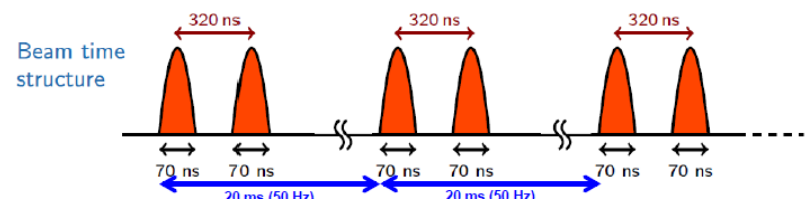
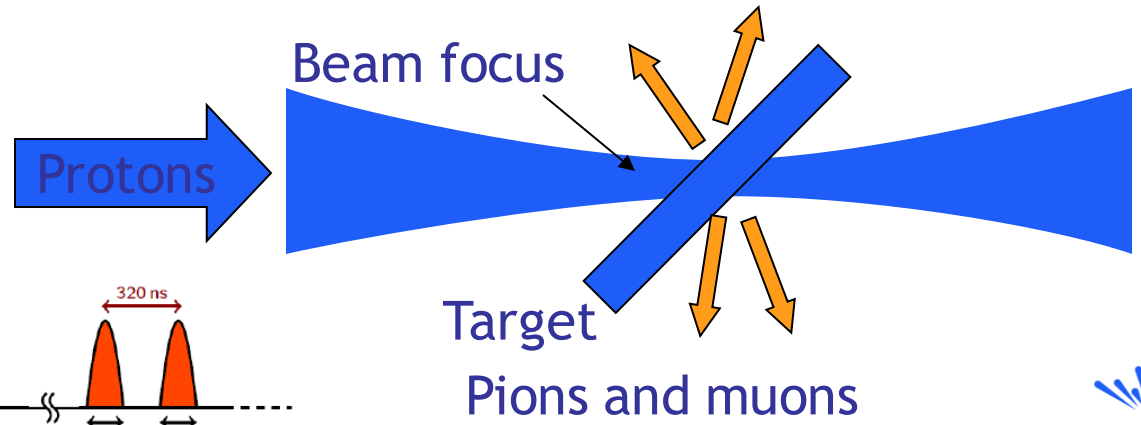


2 The ISIS pulsed neutron and muon source

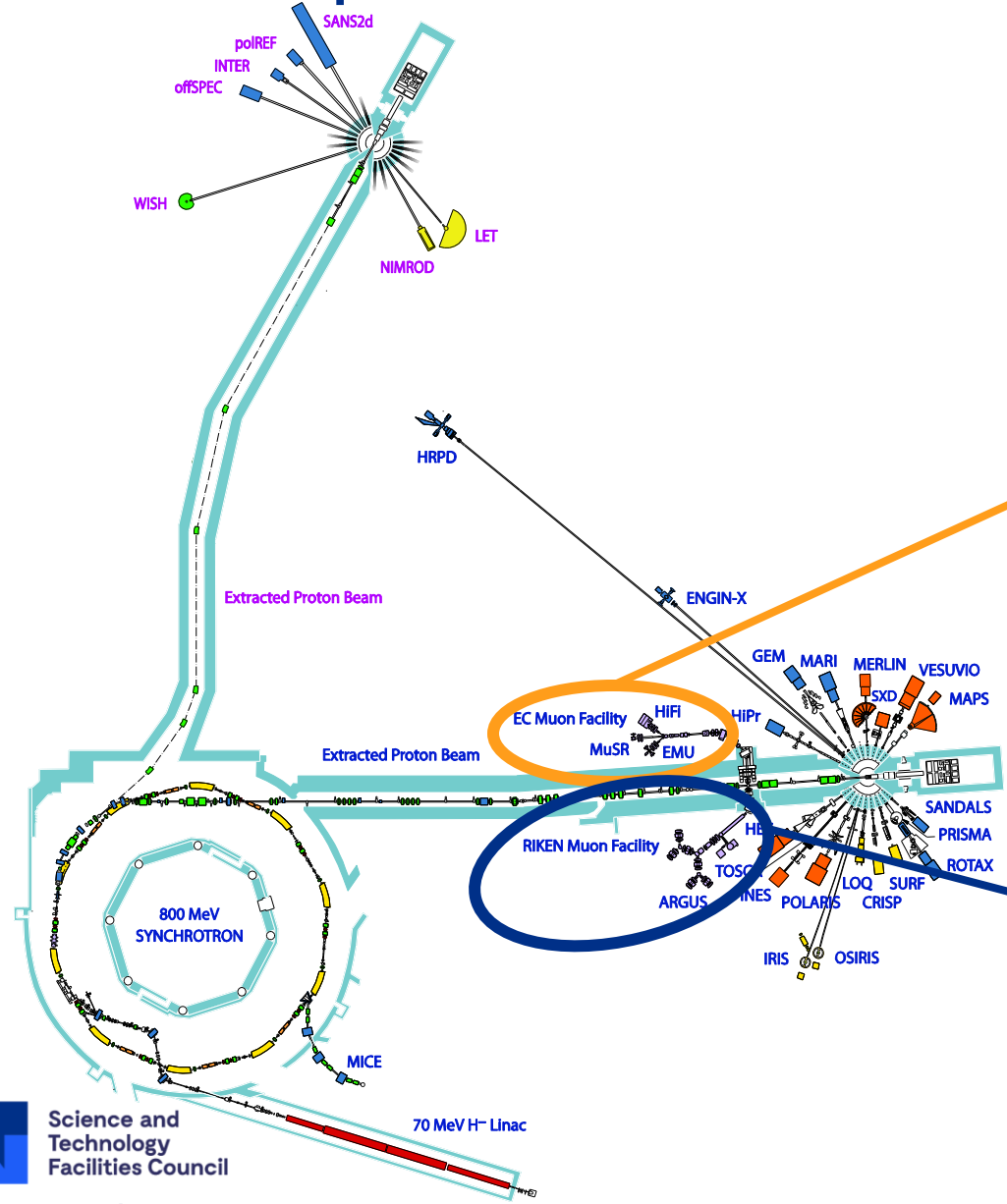


Muon target

- Graphite target
- Takes ~5% of the proton beam



2 The ISIS pulsed muon source – muon facility



EC muons (EMU, MUSR & HIFI)

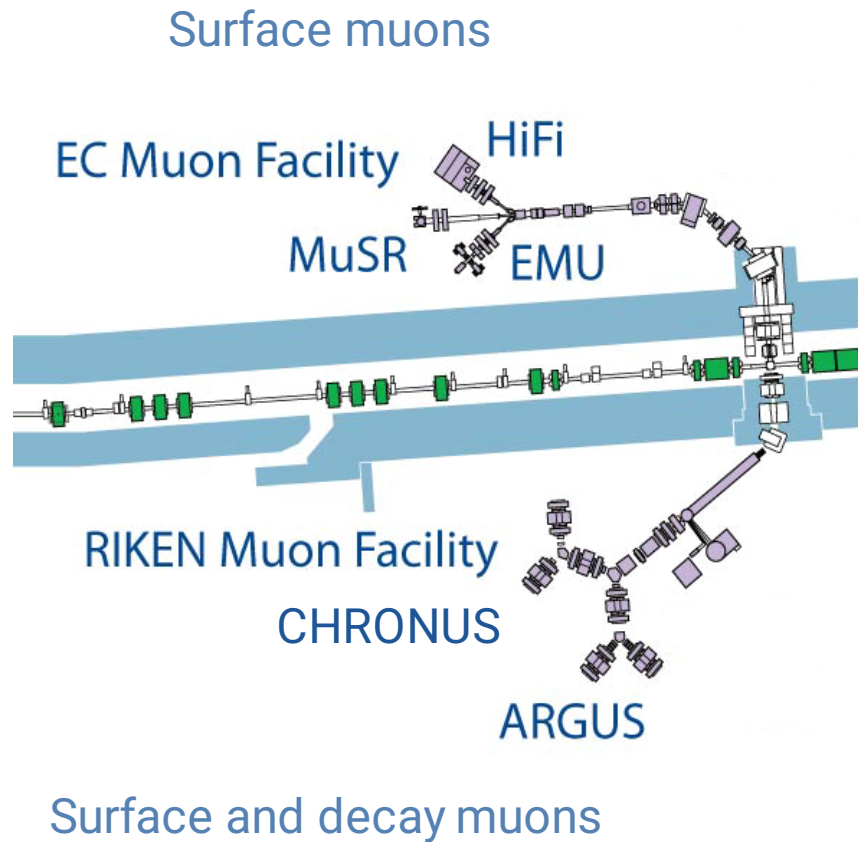
Surface Muon beam
100% spin polarised
Fixed momentum ~27 MeV/c
Pulses split between beamlines

RIKEN-RAL(CHRONUS, ARGUS & MuX)

Decay Muon beam
Positive or negative muons
Spin polarised
Variable momentum ~15- 120 MeV/c
Pulses can be split between beamlines



2 The ISIS pulsed muon source – our instruments



Instrument	Detectors	Rate (MEv/h) [Double pulse]
ARGUS	192	50 [100]
CHRONUS	606	50 [100]
EMU	96	150
HiFi *	64	80
MuSR	64	70

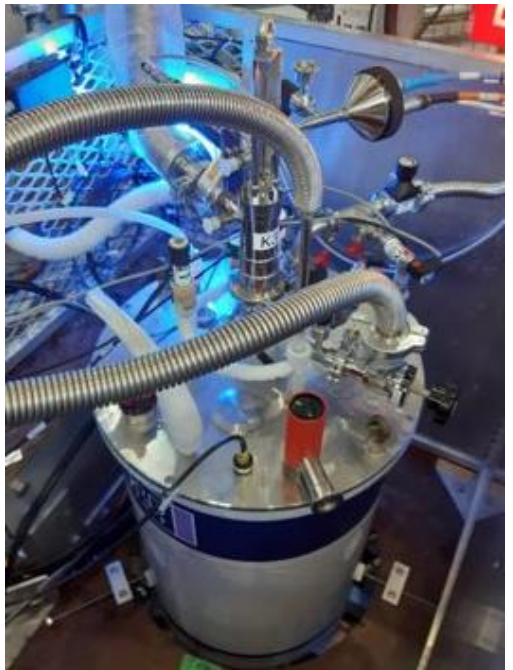
*Now with improved options for laser experiments

Also on the RIKEN-RAL beamlines:

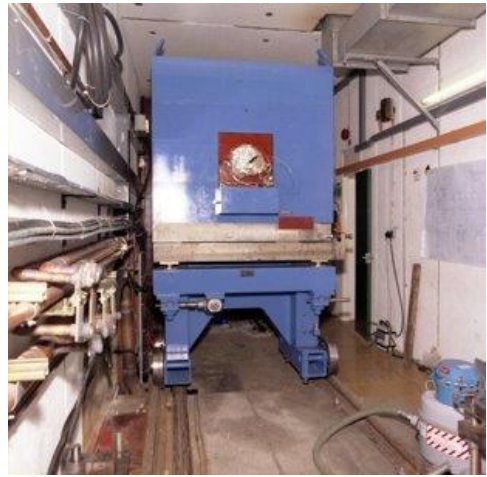
- Negative muon elemental analysis
- FAMU muonic hydrogen experiment
- Muon development beamline



2 The ISIS pulsed muon source – some recent upgrades



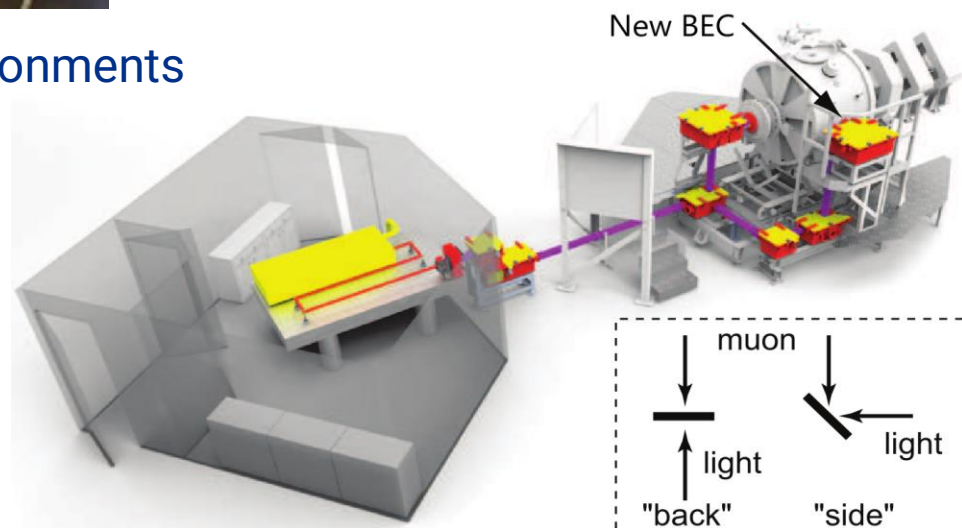
Updated sample environments



Muon collimator replaced



RIKEN-RAL Refurbishment



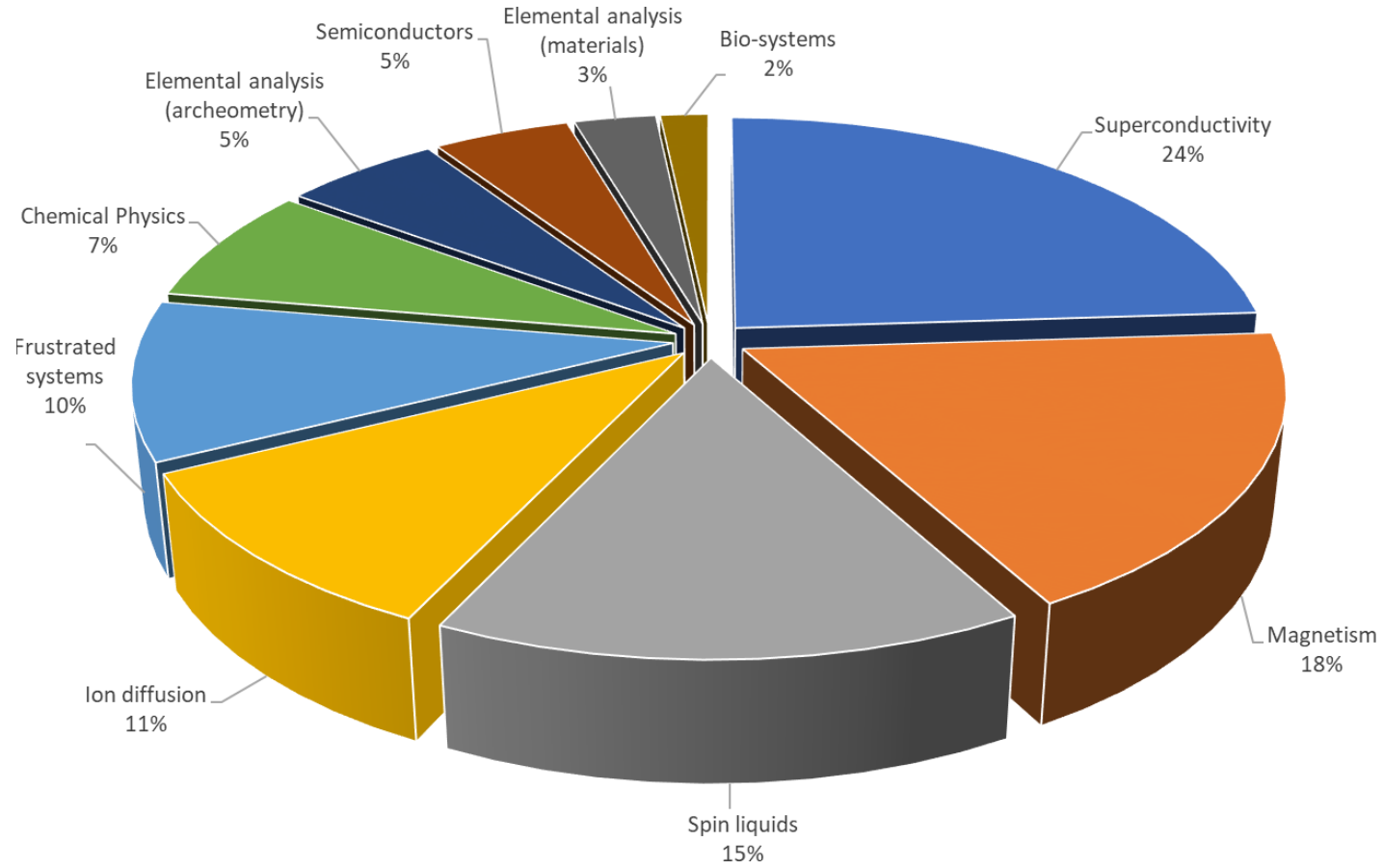
HiFi laser improvements



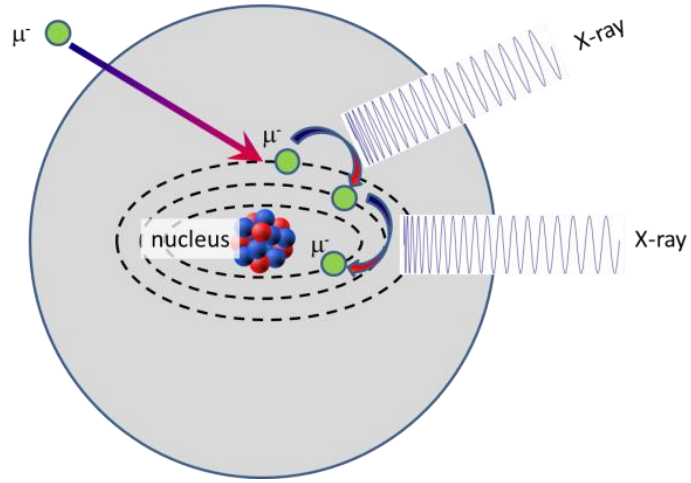
WiMDA (and other software) updates



Science areas



3 Science highlights I – elemental analysis in cultural heritage



non destructive,
penetrating,
variable
implantation depth

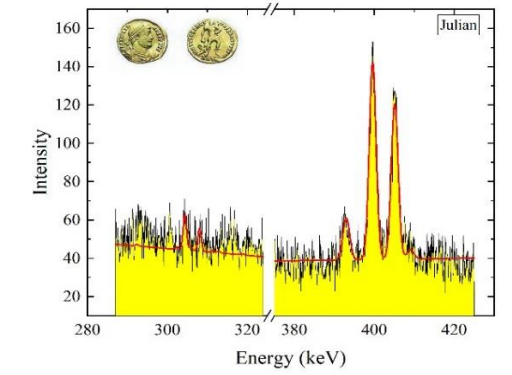
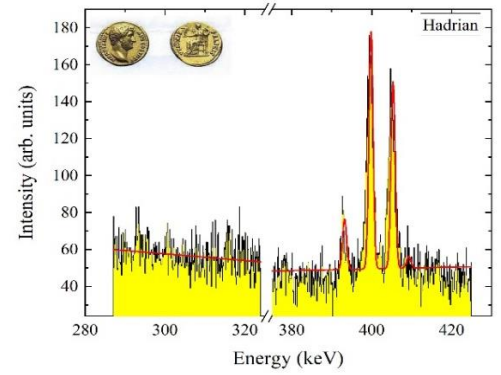
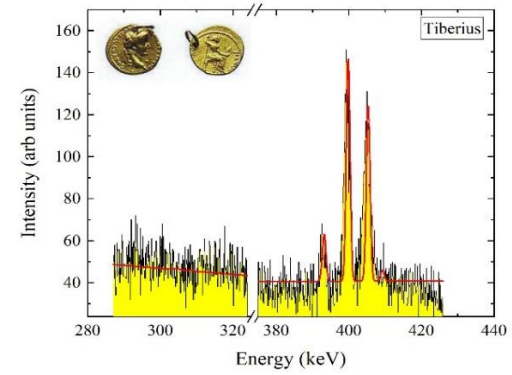
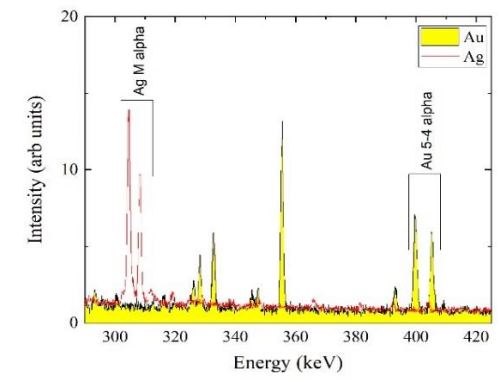
μ^- captured by nuclei



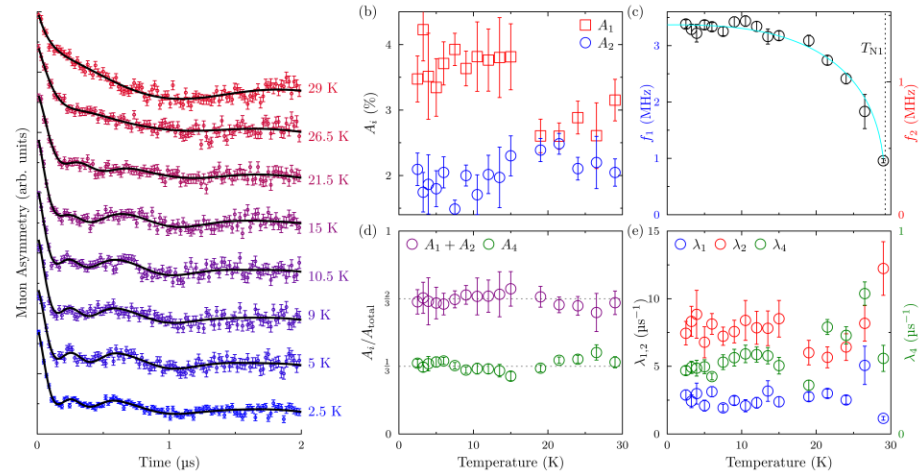
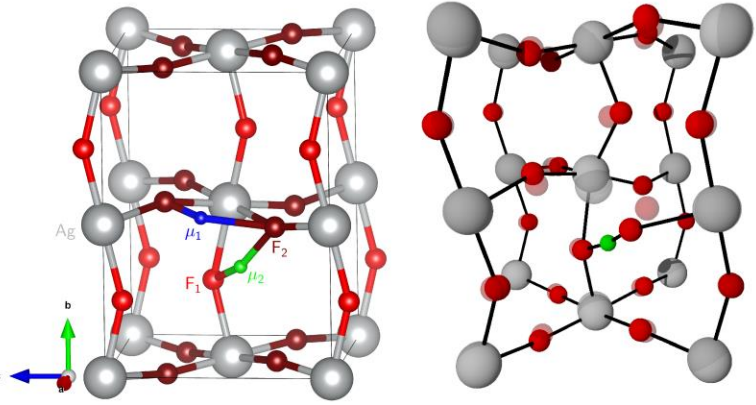
transition energies atom dependent



can be compared to known spectra to find composition



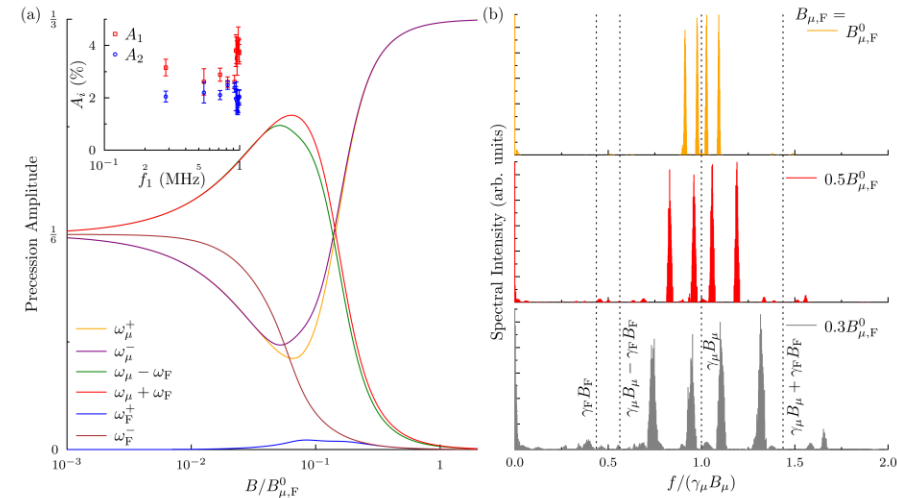
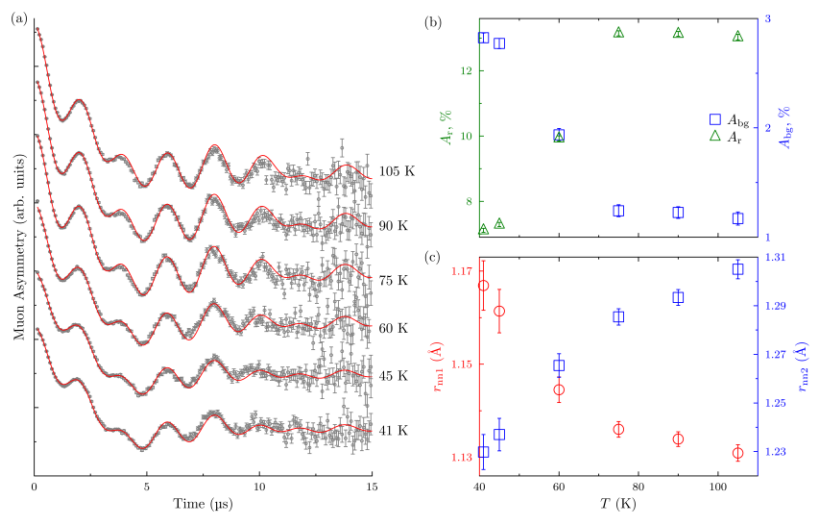
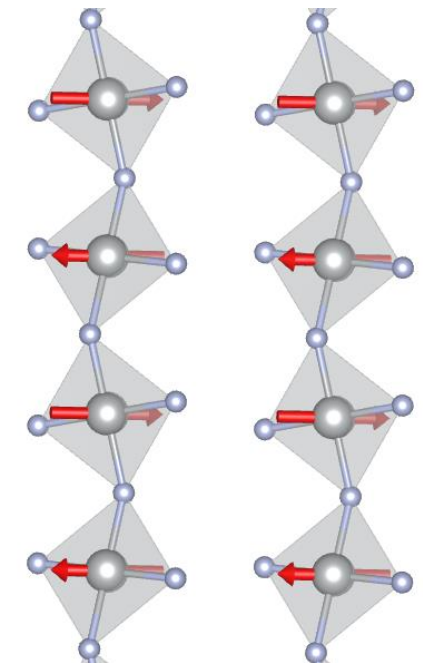
3 Science highlights II – KAgF_3 : Using F-- μ --F states to measure magnetic materials



Discover an A-type AFM structure with $\mu_{\text{Ag}} = 0.47 \mu_{\text{B}}$

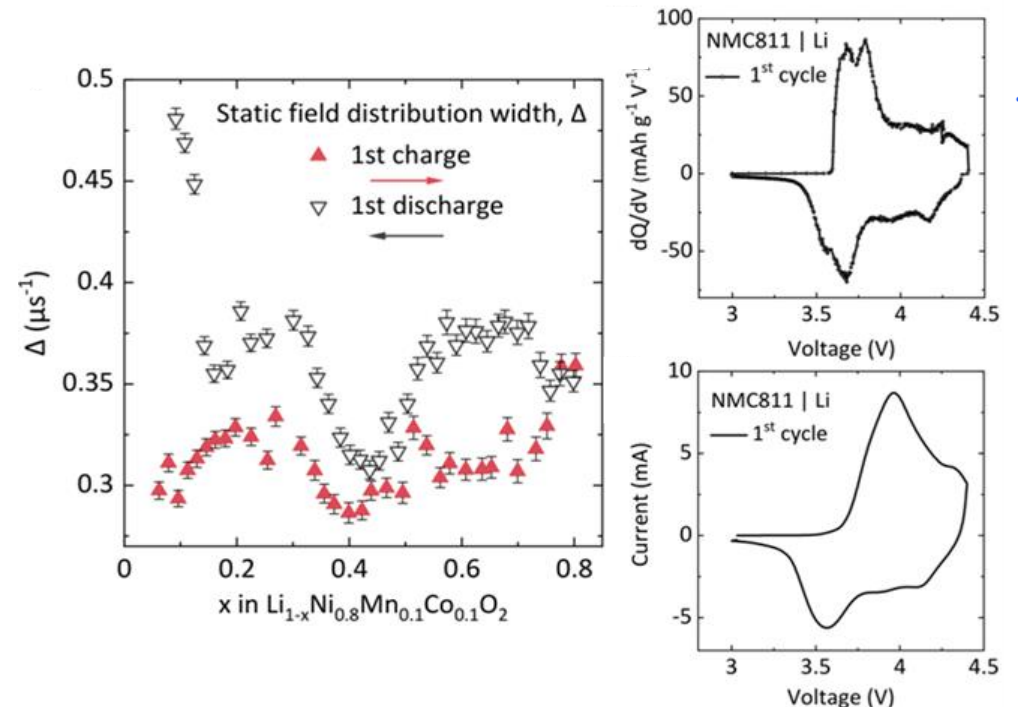
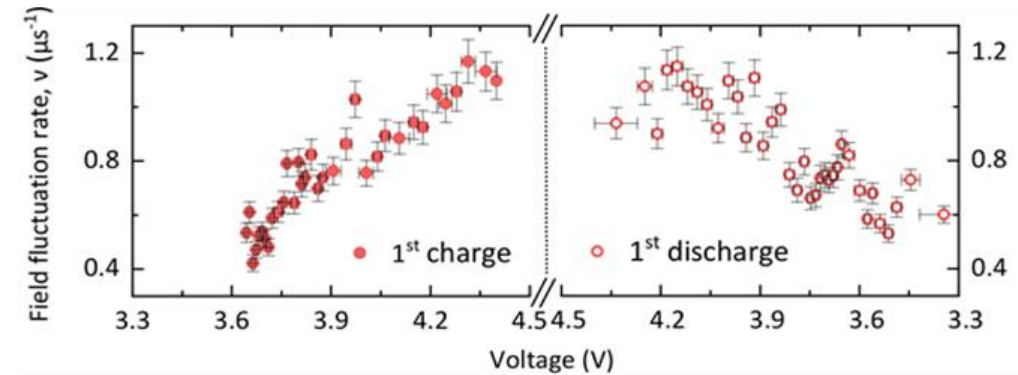
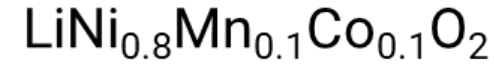
Use F-- μ --F states above T_c and DFT to find the muon site

Use magnetic oscillations to find the magnetic structure below T_c



3 Science highlights III – battery materials

- The motion of ions determines the charging rate of batteries and their power capacity.
- Battery materials change when charged and discharged. Muons are well placed to measure these changes
- In-operando measurements can track the materials through a full charge cycle, which takes 2 days at present.
- Higher rate and smaller beam spot will offer significant improvements to data quality



4 Development opportunities

Source and beam developments

- More intense beams
- High repetition rate pulsed sources
- Improved target design to increase muon/ pion yield
- Improved muon extraction (polarised and unpolarised)
- Higher energy beams for muon (and pion) imaging
- Highly collimated beams for imaging and to measure smaller samples
- More low energy muon facilities

Instrument developments

- Si pixel detectors, tracking detectors (muons in, positrons out)
- Bigger detector arrays
- Pulse slicing to increase/ cheat time resolution
- Digital signal processing of the raw event traces from detectors



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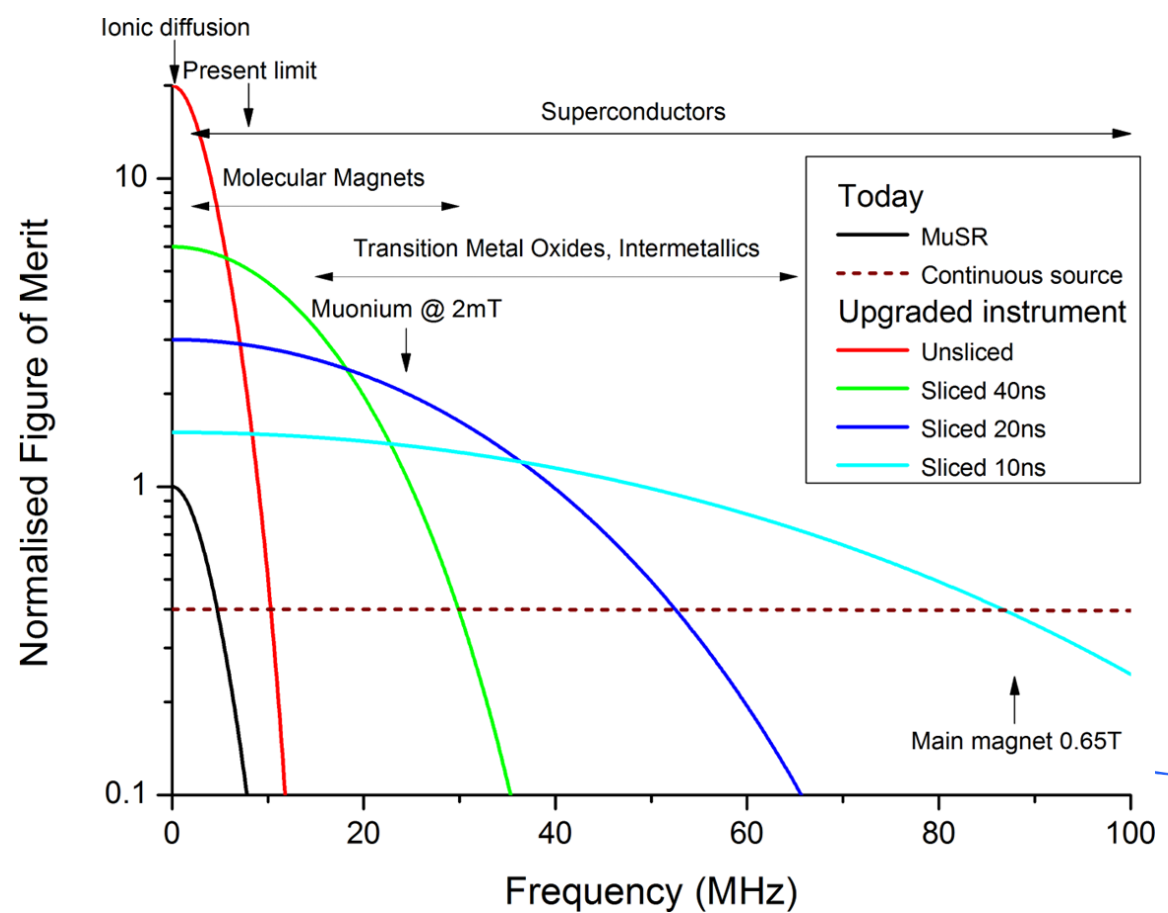
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Super-MuSR as part of the Endeavour project at ISIS



Super-MuSR upgrade – comparison to MuSR today

- Time-differential muon instrument with two modes of operation.
- Full pulse mode: high rate (~ 1500 MEv/h), existing resolution
- Sliced pulse mode: intermediate rate, intermediate resolution.

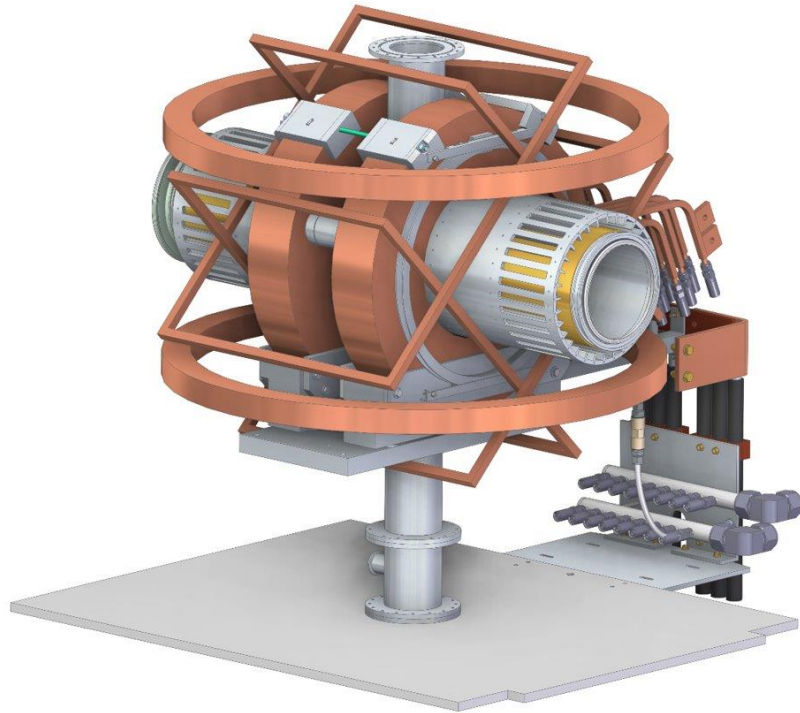


	MuSR	Super-MuSR
Detectors	64	~ 960
Solid angle coverage	40%	80%
Count rate (MEv/h)	70	~ 1400
Maximum freq. (field)	8MHz (0.06T)	~ 80 MHz (0.6T)
Spin rotation	None	0 to 75°
Min.sample (mm)	$\sim 10 \times 10$ on Ag	$\sim 3 \times 3$ in flypast



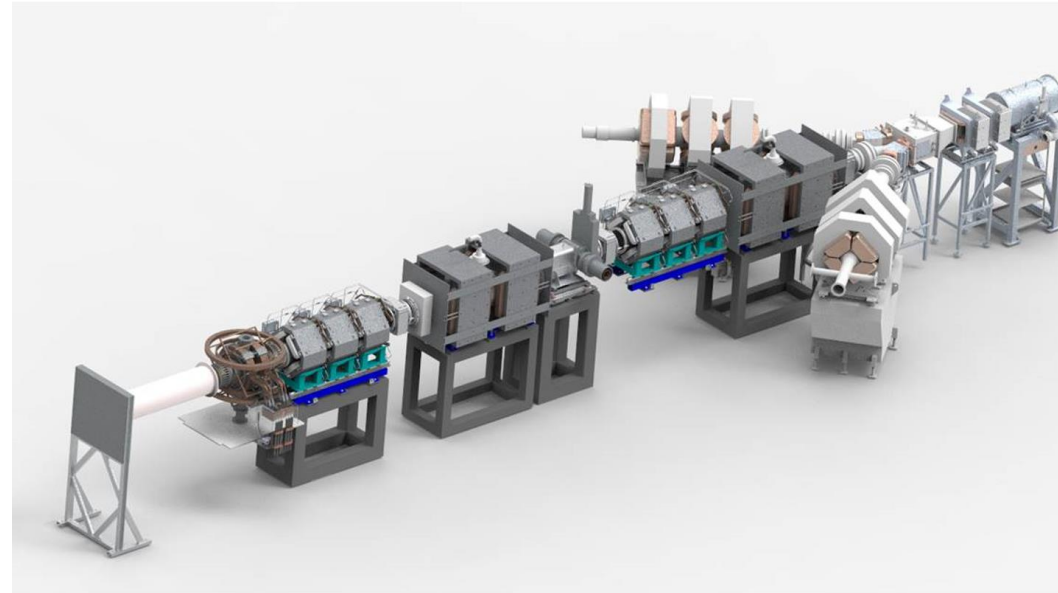
Detector and instrument improvements

- Use full muon flux and maximise information per muon
- New transverse magnet and cruciform with flypast tube
- Better zero-field (correcting quadrupolar terms)

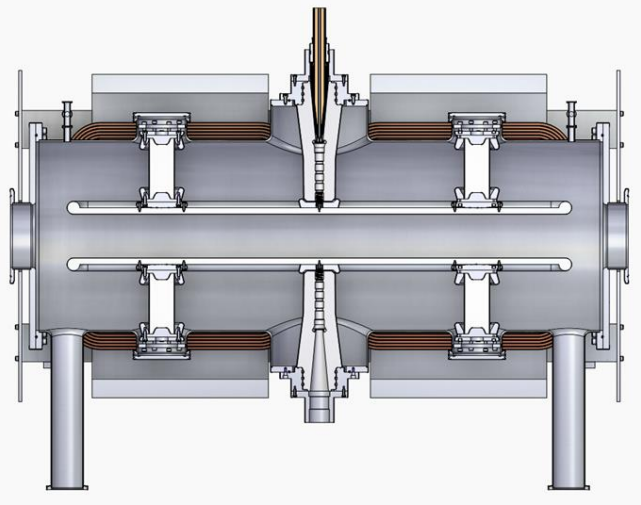


Beamline improvements

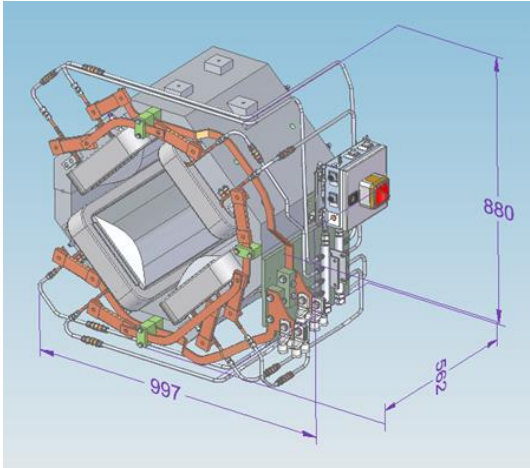
- Pulse slicer reducing muon pulse length to ~10ns
- Spin rotators allowing higher transverse field experiments



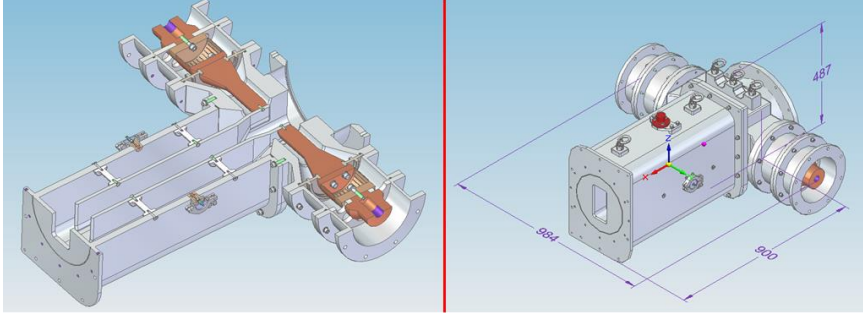
Super-MuSR upgrade – current status and progress



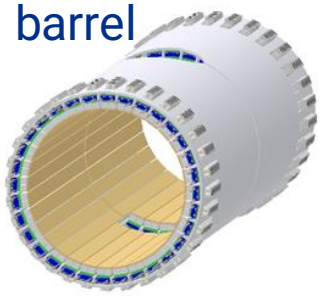
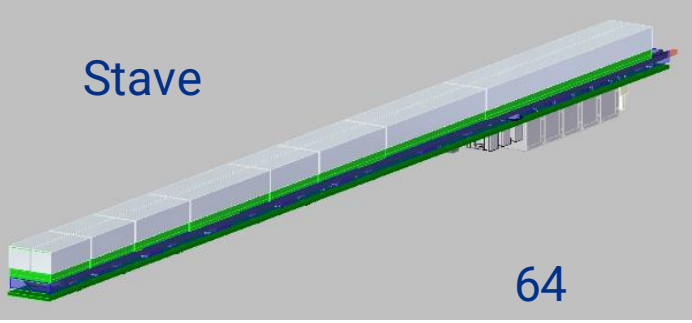
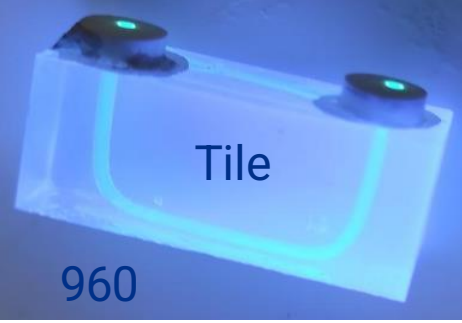
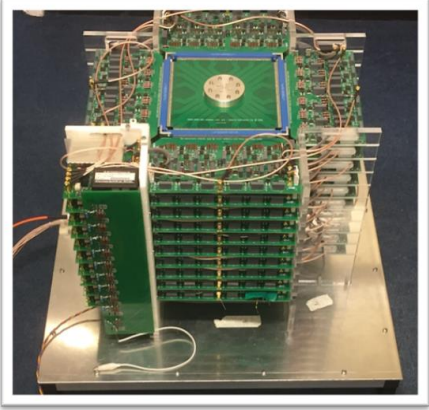
Spin rotators in final design stages. Thanks to PSI for guidance!



New, more efficient quadrupole magnet design – final review stage.



Pulse slicer – HV and RF feasibility testing. Power supply procured.

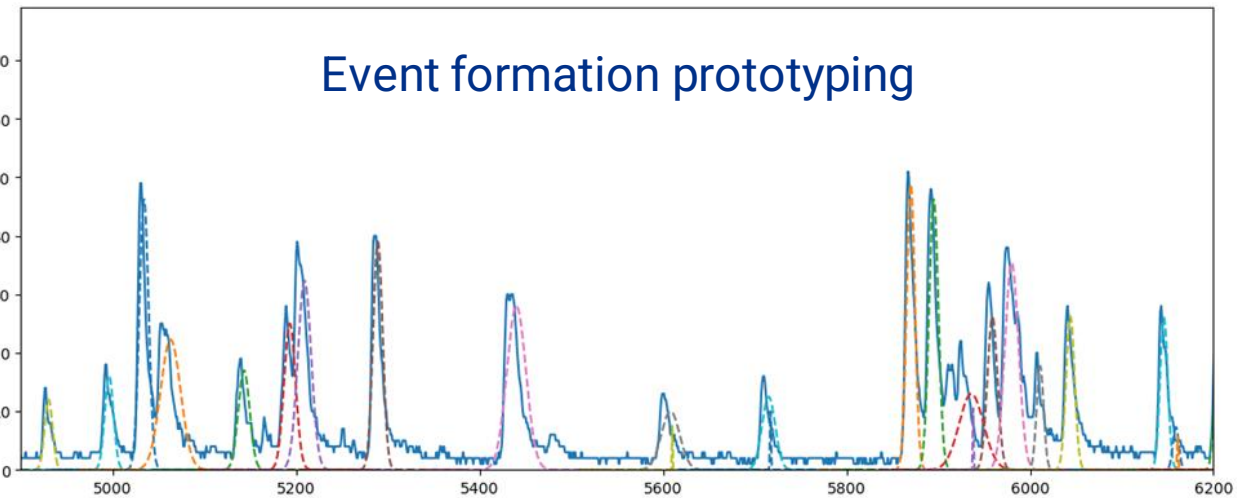
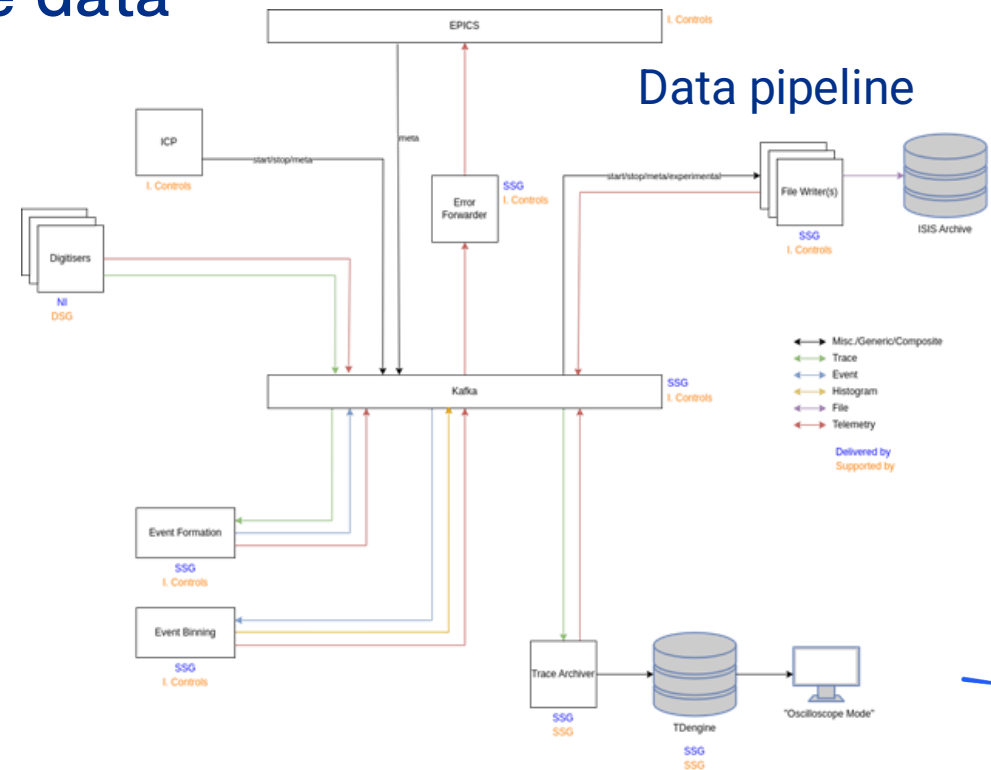


Detector system – V3 in prototyping phase and full design of barrel underway. Final design review expected summer 2024.



4 Super-MuSR upgrade – event mode data

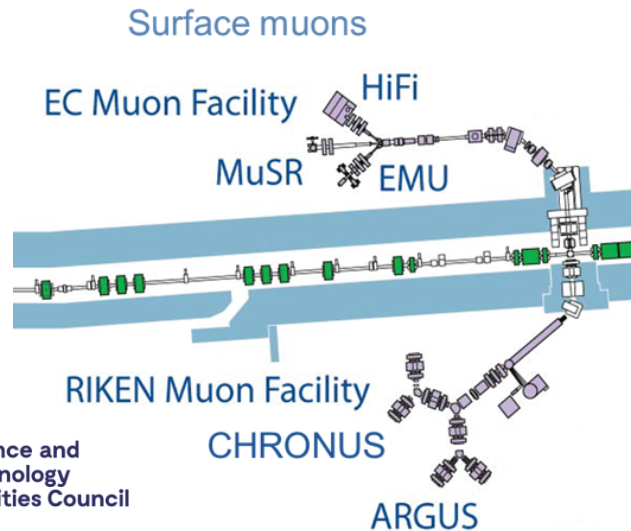
- Transferring data from the digitisers, and the instrument, to data files for MuSR analysis.
- Scheme is under development and testing has started, with the process of forming events from digital signals being worked on currently.
- New data pipeline will be run in parallel with the existing electronics on HiFi and MuSR starting next year!



Future development plans

Muon target and beamlines

- Improved Target Design and muon extraction/transportation
- Beamline Diagnostics
- Replacement of obsolete beamline components



Spectrometers

Improvement of the existing instrument

- Improved detector arrays
- Implementation of the digitising DAE for improved data rates.
- Development of improved pressure cells for studies of all states of matter.
- Development of the μ -SR programme.
- Improved Sample environment
- Improved Laser systems
- Analysis software

Looking at new instruments

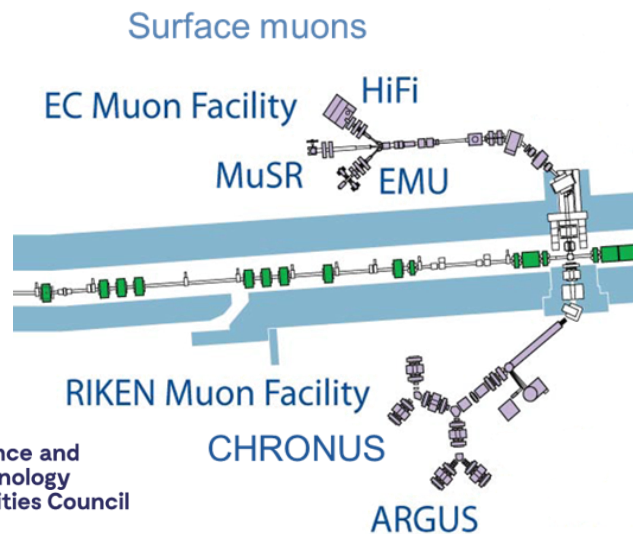
- Elemental analysis
- Low Energy muons



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Thank you!

