A low energy cooling test area at RAL

Rhea Stewart, ISIS Muon Group

International Muon Collider Collaboration: Demonstrator Workshop, FERMILAB

1st November 2024

Purpose of this talk:

Highlight the potential impact of the Demonstrator R&D on muon programs in condensed matter and materials science.

- Low energy (keV)
- High brightness
- More control

In this workshop we will:

- Review the progress on design of the muon cooling Demonstrator.
- Identify potential host sites and associated timelines within which the Demonstrator could be deployed.
- Identify associated science programmes that could be synergistic with the development, construction and operation of the Demonstrator.

Starts 30 Oct 2024, 10:00
Ends 1 Nov 2024, 17:00
US/Central

Fermilab - Wilson Hall
One West
Fermi National Accelerator Laboratory
Batavia, IL

Provide some information about the ISIS muon source and what opportunities there may be to perform R&D for the Demonstrator using our existing muon beams.

In particular, for the final cooling stage < ~100Mev/c

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Outline

- Preamble: the ISIS pulsed MuSR facility
- RIKEN-RAL port 3 as a possible low energy muon test facility
- How the beam parameters and available space may be suitable for testing aspects of the Demonstrator R&D
- Why the MuSR community cares

MuSR facility map – present and future

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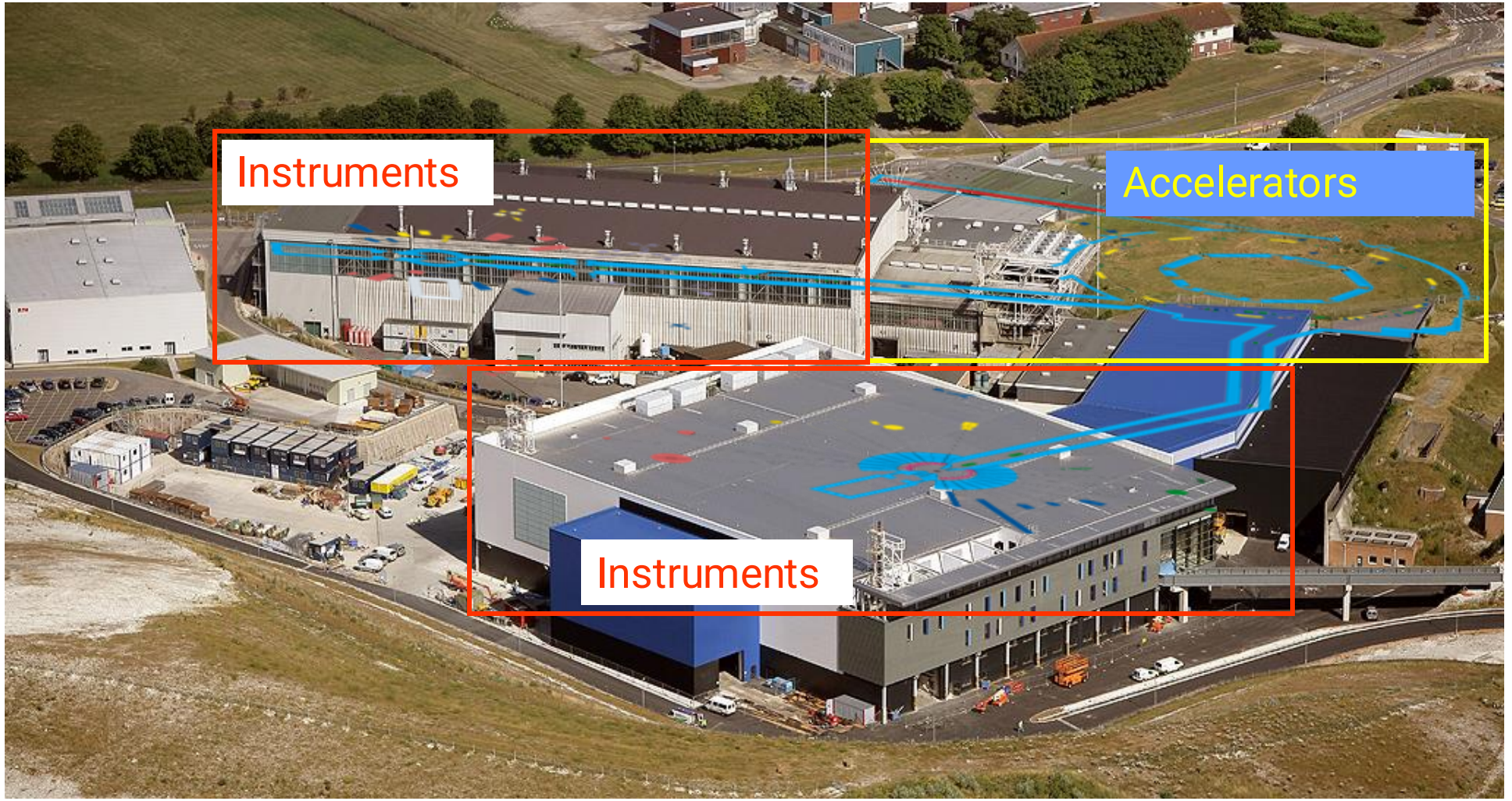
ISIS Neutron and Muon Source

The ISIS pulsed neutron and muon source



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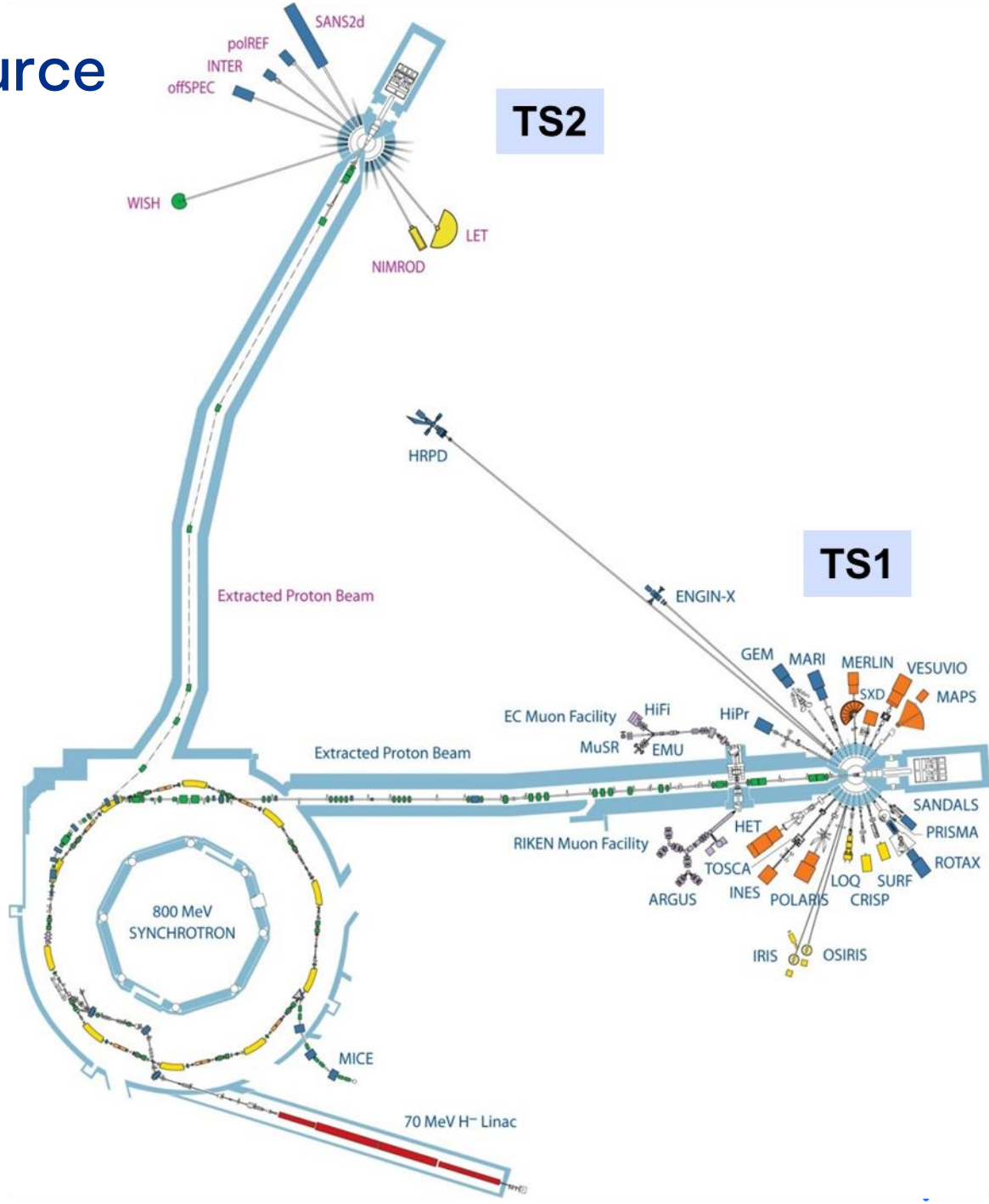
ISIS Neutron and Muon Source

A World Centre for **Condensed Matter Science** with Neutrons and Muons

Typical year: 1200 experiments, 3000 visitors, 30 countries, 600 publications

The ISIS pulsed neutron and muon source

- Spallation source driven by a proton synchrotron
- First stage: 70 MeV H^- linac
- Main ring: 800 MeV H^+ synchrotron
- Beam current 200 mA, 160 kW source power
- 50 Hz pulsed source
- Two target station experimental halls: TS1 and TS2
- Two neutron targets and one muon target
- Around 35 instruments (6 muon instruments)



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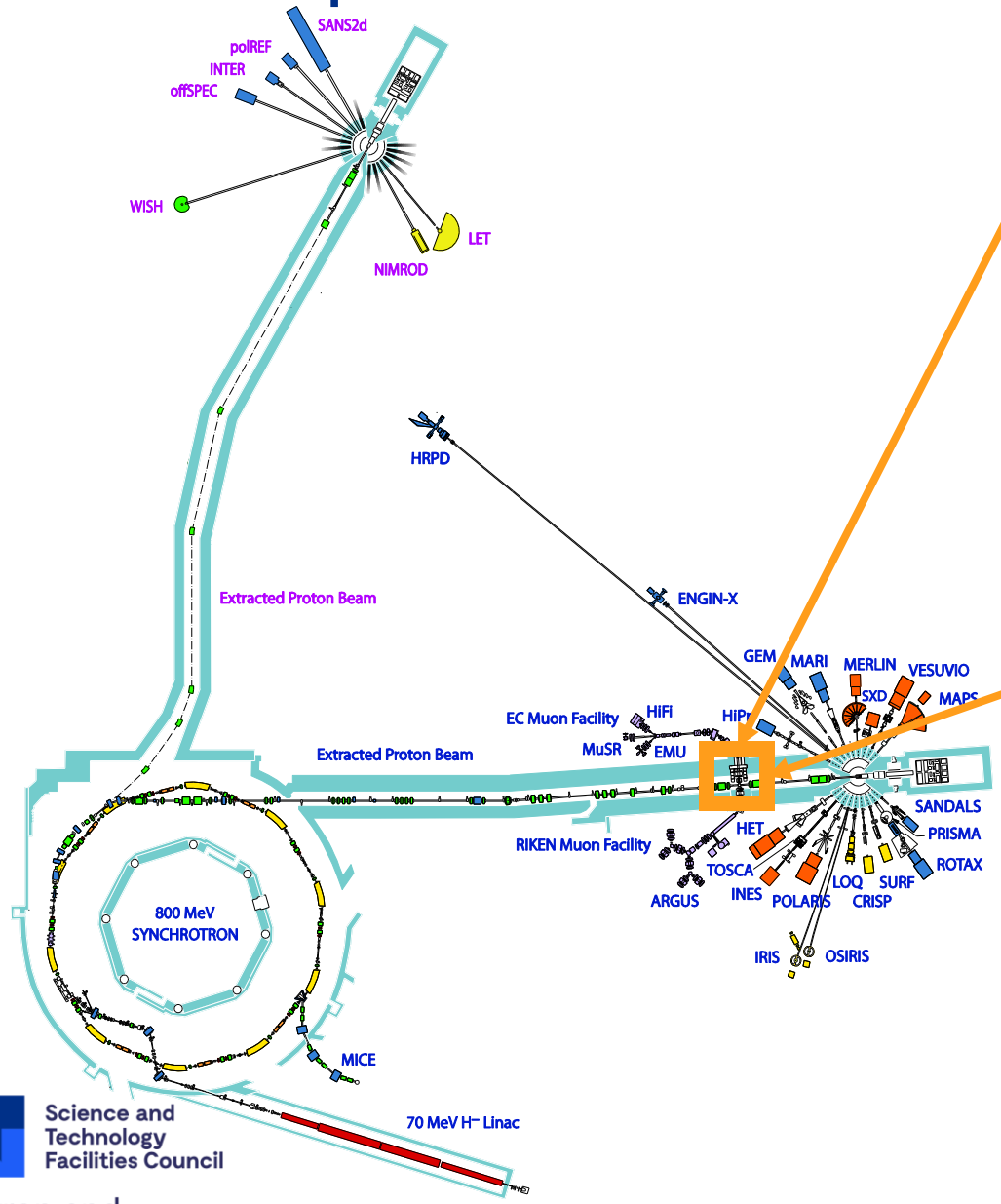
ISIS Neutron and Muon Source

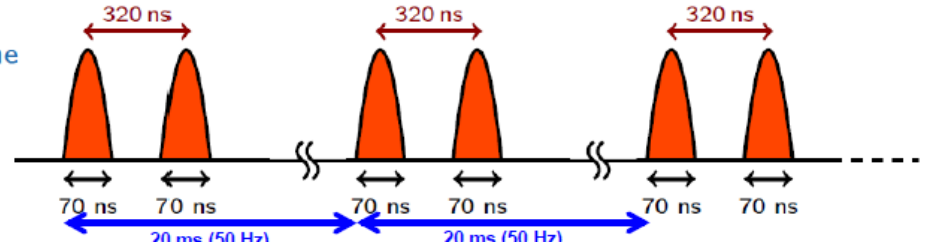
The ISIS pulsed neutron and muon source



Muon target

- Graphite target
- Takes ~3-5% of the proton beam

Beam time structure



New beam compression now gives 40ns pulses.

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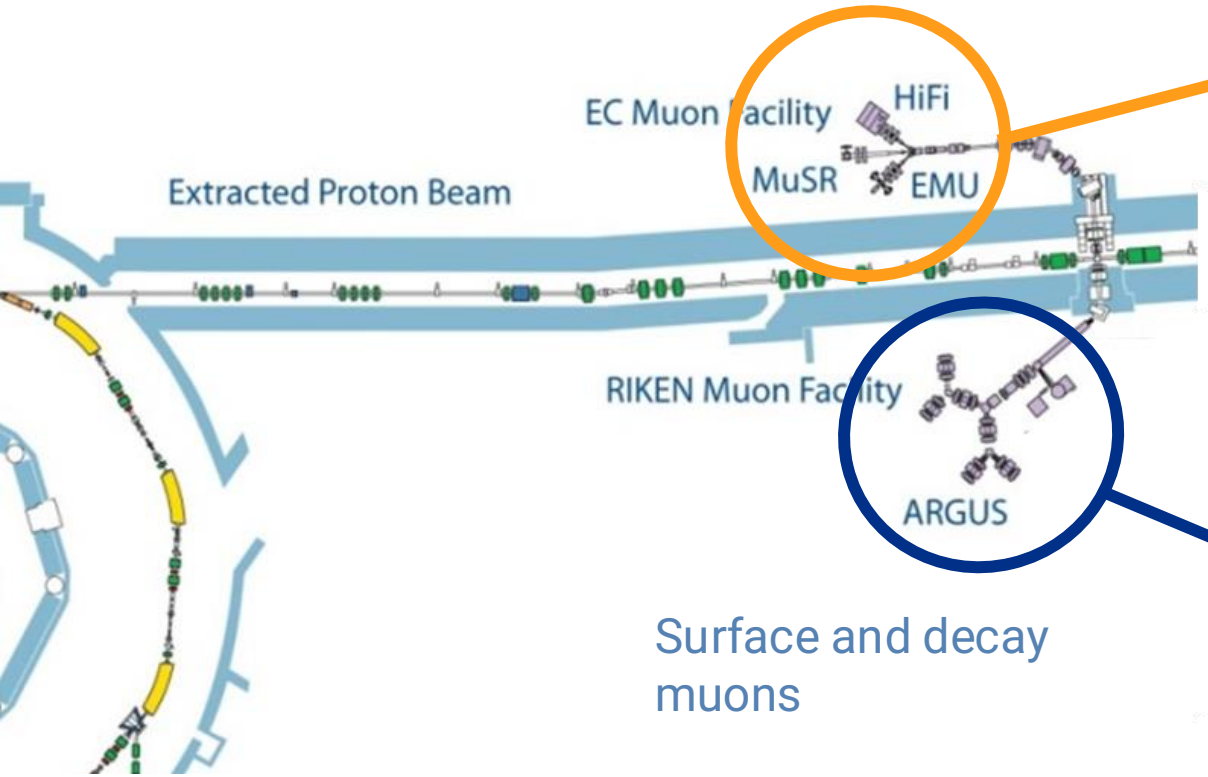
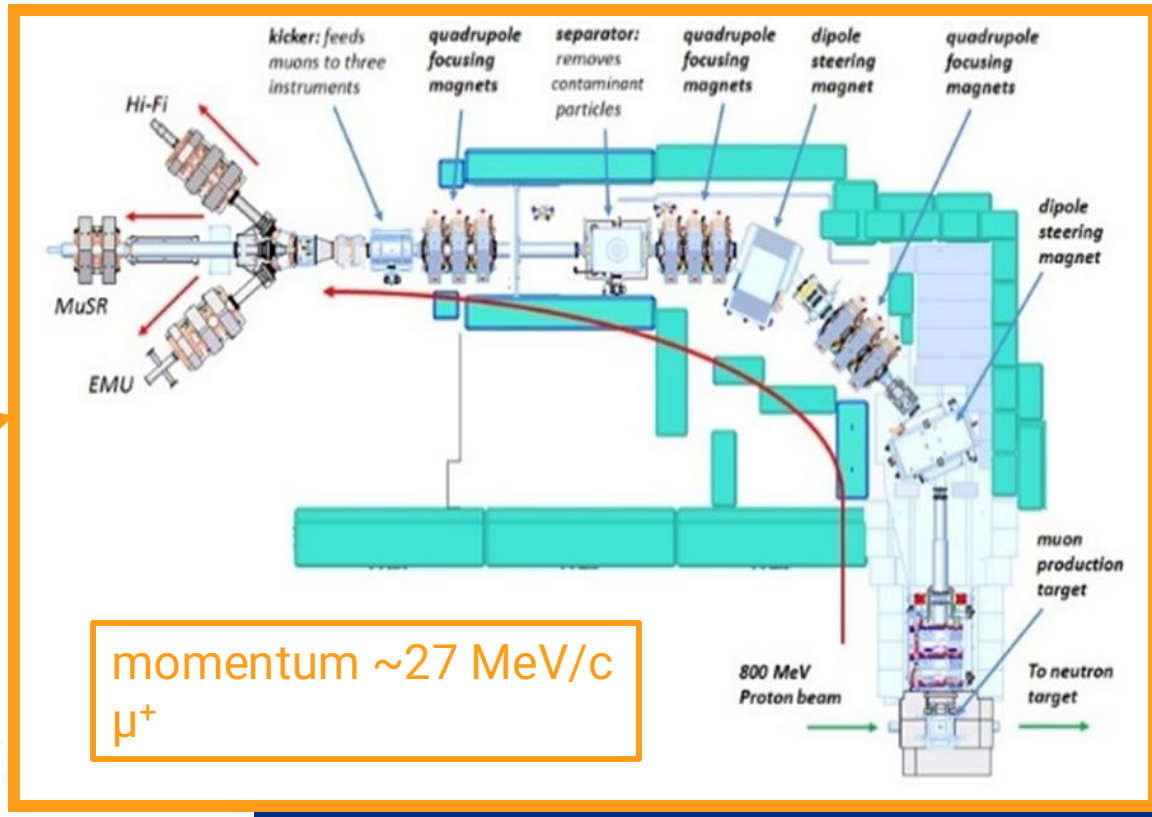
Muon beamlines and Instruments

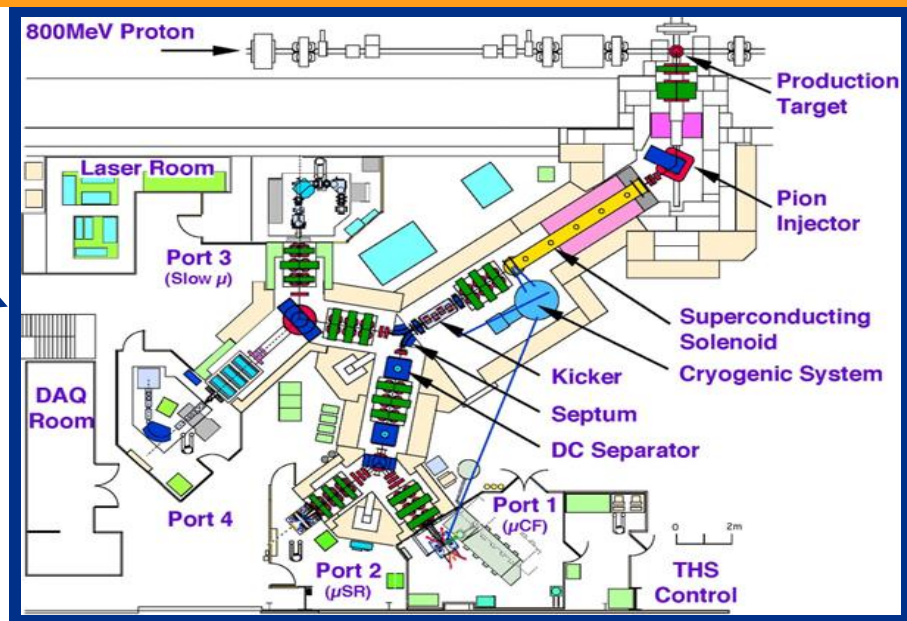
Surface muons





momentum ~27 MeV/c
μ^+

Surface and decay muons



momentum ~ 15- 100 MeV/c
Variable implantation depth.
μ^+ & μ^-

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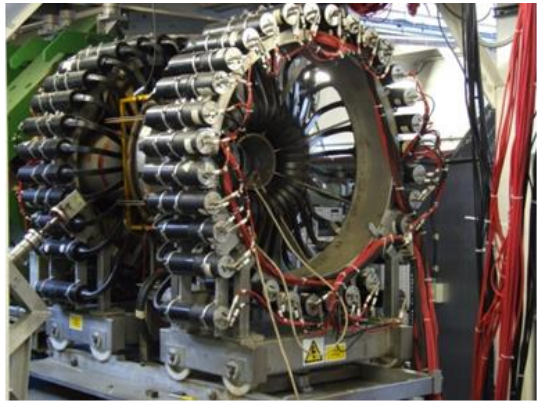
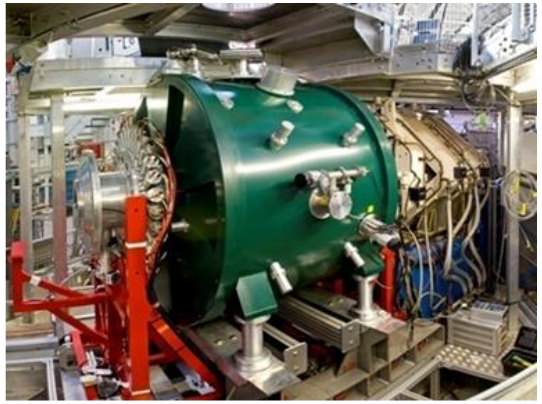
The ISIS Muon Instruments

EC muons

EMU

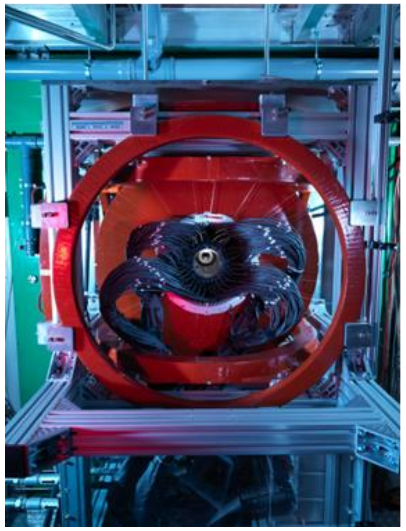


MUSR



HIFI

RIKEN-RAL



CHRONUS

ARGUS

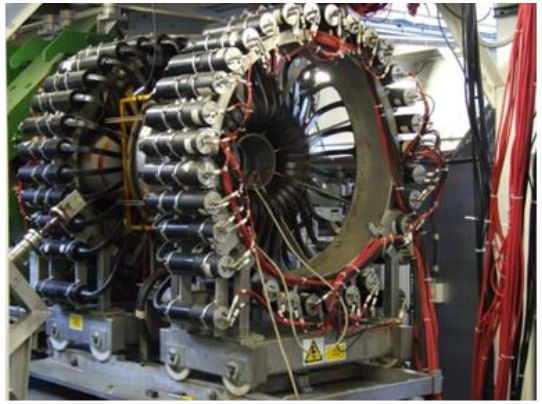
+ RIKEN-RAL beam ports 1 & 3 for longer term experiments.

+ elemental analysis sharing the Chronus port

The ISIS Muon Instruments

EC muons

EMU



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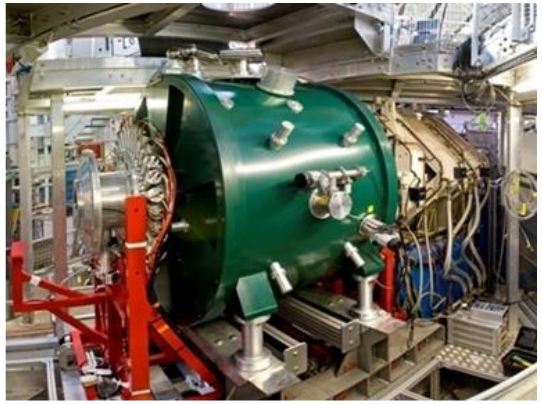

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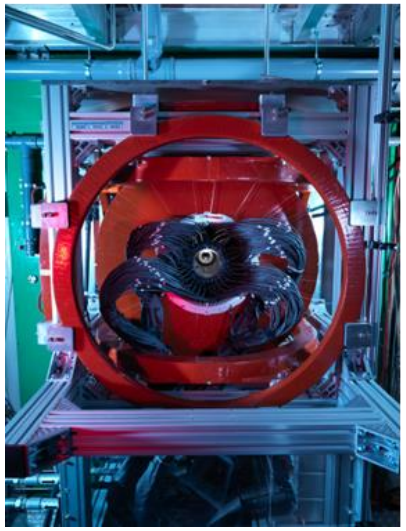

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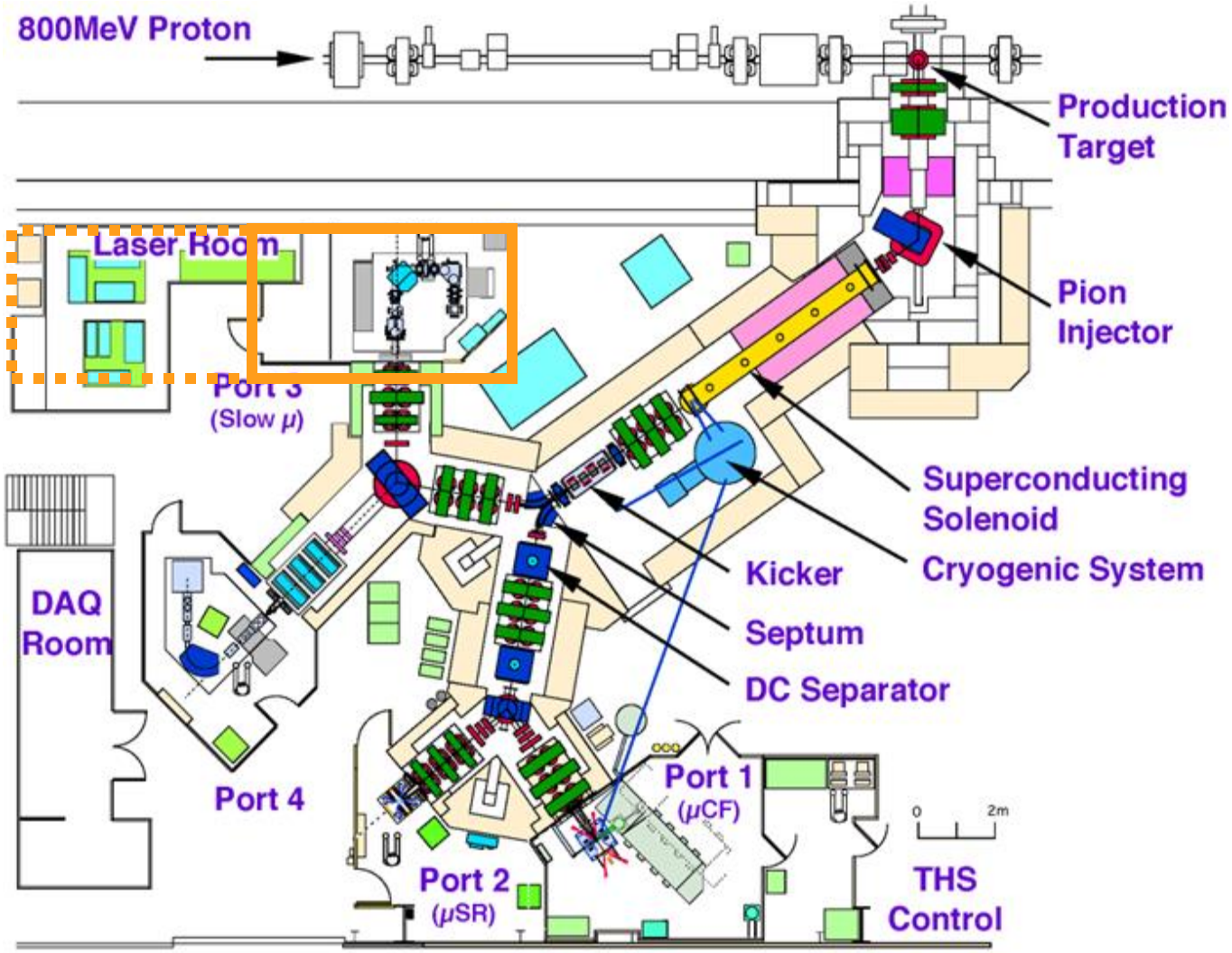
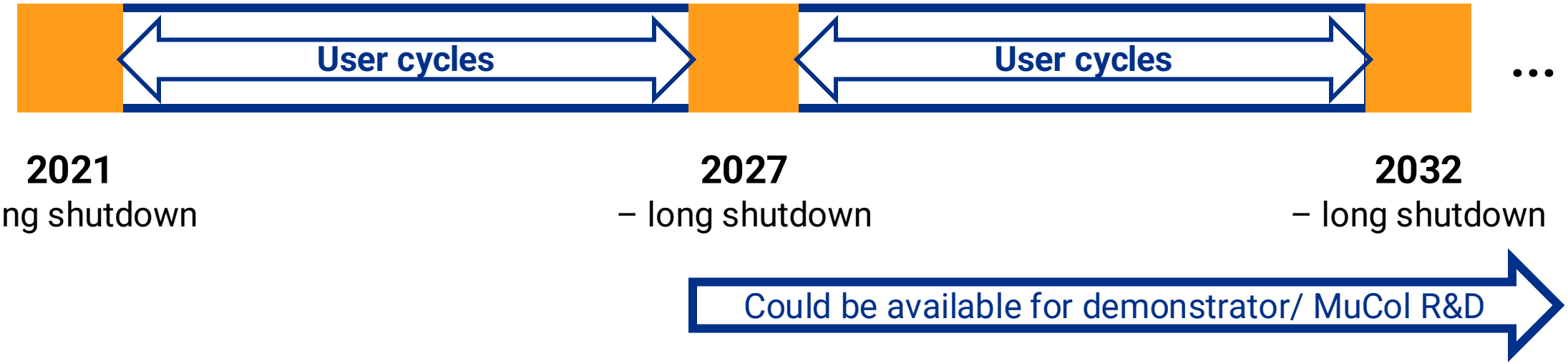
+ elemental analysis sharing the Chronus port

The RIKEN-RAL facility – port 3



- μ+ and μ- available in the momentum range 15 - 100 MeV/c
- 10^5 – 10^6 μ/s
- Beam spot ~ 30x30mm2
- Single or double pulse mode
- Port 3 available space:
  - existing port: ~ 4m x 6m
  - Possibility to gain ~ 6m by expanding the port.

RIKEN-RAL port 3 – relevant timelines



- The ISIS muon facility operates a full user program, with 5 operational cycles/ year.
- Short shutdowns between cycles typically 1 – 1.5 months.
- Long shutdowns of 9-12 months roughly every 5 years – precise timings decided nearer the date
- Running history available here

- **Other commitments:** instrument development and industry experiments in port 3 until 2026.

How does this fit in with cooling tests for the demonstrator?

Cell no.	Solenoid length m	Stage* length m	Max. B_z on-axis T	Low B_z on-axis T	Absorber length m
1	1.48	1.48	44.63	4.63	0.85
2	1.75	4.57	44.63	4.63	0.47
3	1.00	6.61	44.63	4.63	0.47
4	1.00	7.75	44.63	4.63	0.40
5	1.00	5.09	44.63	4.63	0.30
6	1.11	6.86	44.63	4.63	0.25
7	1.33	7.06	42.00	2.00	0.30
8	0.80	6.70	42.00	2.00	0.10
9	1.48	8.37	41.00	1.00	0.17
10	0.95	6.76	40.80	0.80	0.08
11	0.95	7.60	40.80	0.80	0.05

Table 5.6: Baseline final cooling cell hardware in terms of cell geometry, solenoid fields and absorbe geometry

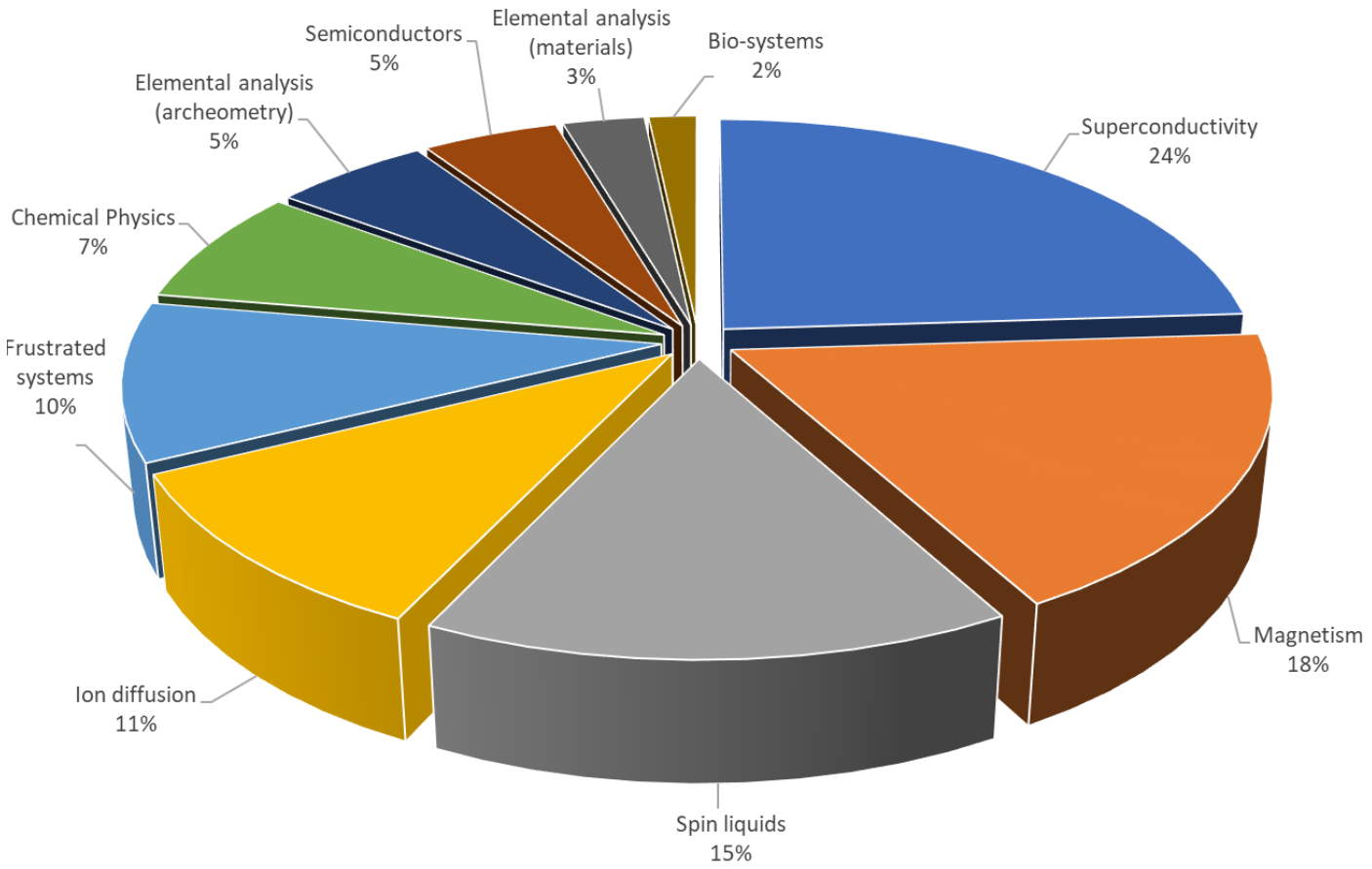
Cell no.	RF freq. MHz	Num. RF	Tot. RF len. cm	Max. RF grad. MV/m	Rot RF phase deg	Initial KE MeV	Final KE MeV	Energy spread MeV	Bunch len. mm
1	0.0	0	0	0	0	73.8	39.4	4.4	141
2	111.1	10	2.5	19.81	-180	53.7	32.7	2.8	241
3	56.9	17	4.25	14.17	90	53.0	32.5	4.1	406
4	40.1	17	4.25	11.9	51	49.0	31.4	3.9	348
5	34.9	9	2.25	11.11	-10	35.6	16.9	5.7	781
6	30.6	15	3.75	10.4	-54	28.3	14.7	2.7	1256
7	11.6	19	4.75	6.823	-82	32.6	13.3	3.1	1319
8	16.2	9	2.25	8.04	67	21.4	14.0	3.2	1692
9	13.4	13	3.25	7.32	67	24.1	12.4	3.5	1962
10	8.2	13	3.25	5.39	-6	16.5	8.8	2.8	2702
11	5.7	15	3.75	4.48	-96	16.3	11.2	2.9	3013

Table 5.7: Short rectilinear final cooling cell RF parameters. 0^o phase is on-crest mode.

* or more compact (~1.6 - 5.6m) for the more demanding long rectilinear option.

- Possible for individual stages to be tested in the available space.
- Can tune the input beam through the energy range expected as input for the different stages
- Beam less intense but relative performance still informative?

Why the ISIS MuSR community might care?



Breakdown of proposals for muon beamtime as a total for Rounds 19/2, 20/1, 22/2, 23/1

- 2-3 x oversubscription rate for our instruments, so higher throughput or more instruments desirable.
- Required sample sizes for full beam currently up to 20x20mm2. Would like to minimise this by reducing beam spot.
- Implantation depths at ISIS currently um to mm range – can't measure thin films, surfaces and interfaces.
- A high flux beam useful in opening up new science areas, e.g. biophysics & catalysis.

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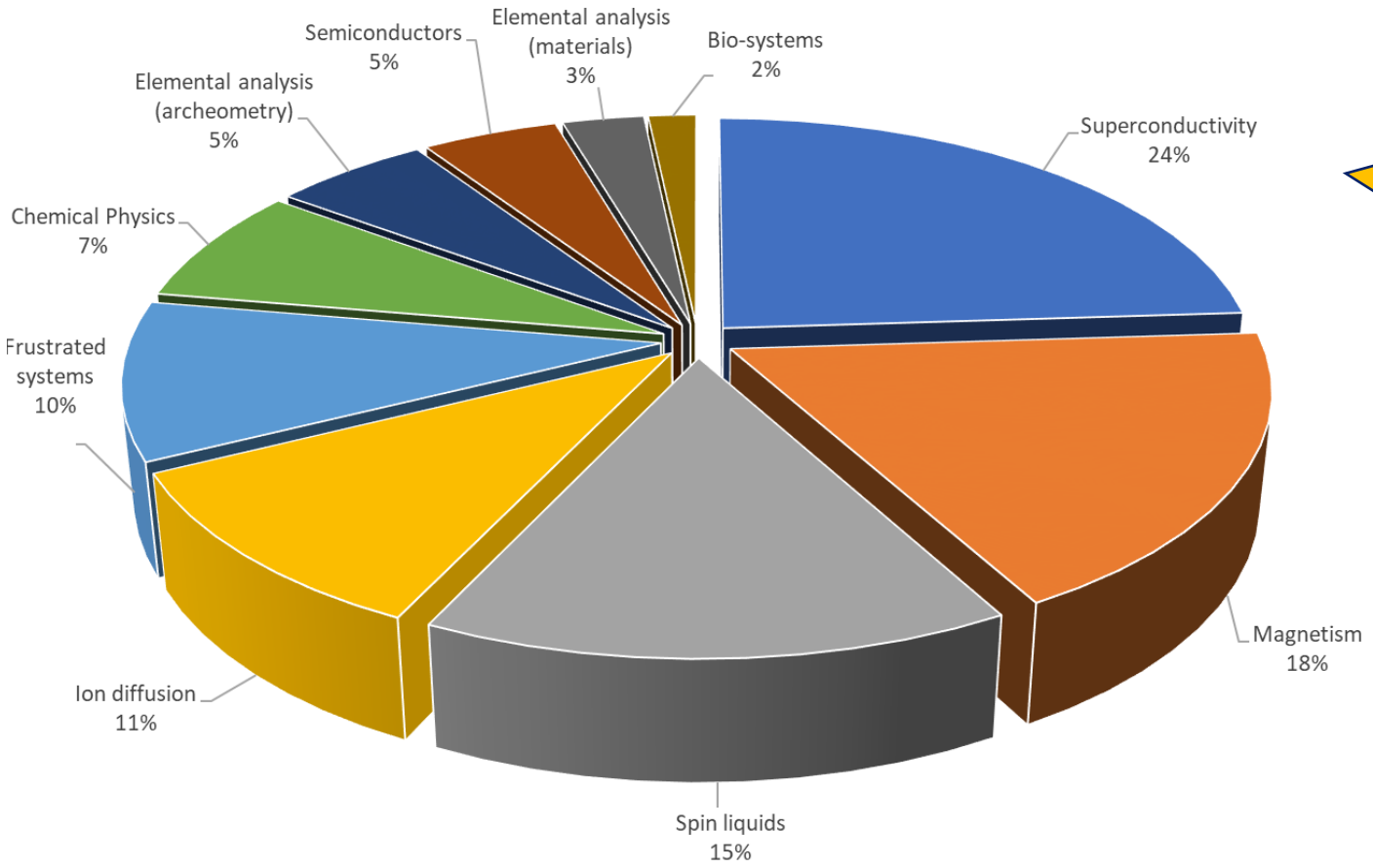

High brightness beam

More control over the beam parameters

New detector technologies

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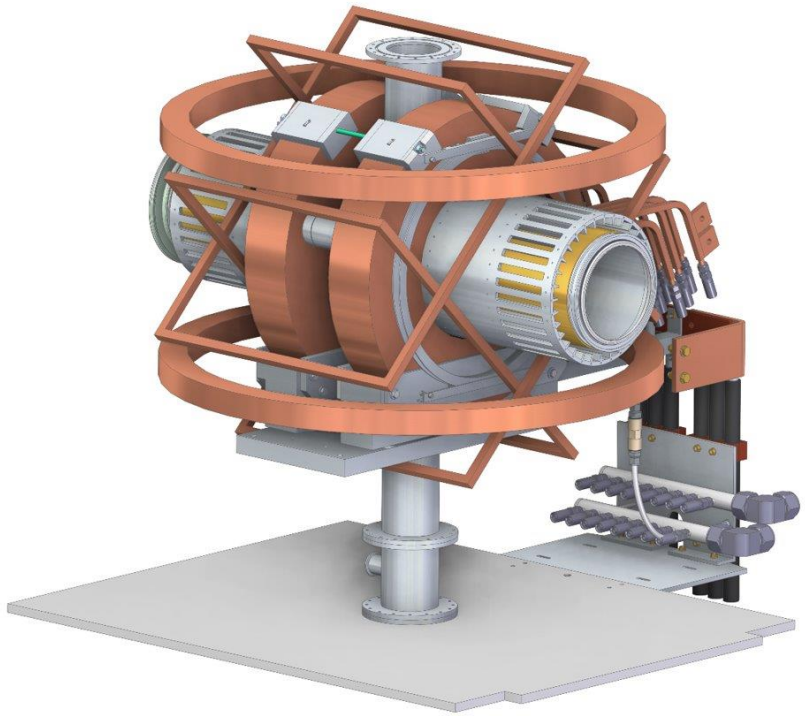
Breakdown of proposals for muon beamtime as a total for Rounds 19/2, 20/1, 22/2, 23/1

Super-MuSR: an aside on pulsed MuSR instrumentation

MuSR spectrometers at pulsed sources have historically been unable to use the full flux of the muon beam delivered. However, Super-MuSR changes this at ISIS – instrumentation has caught up.

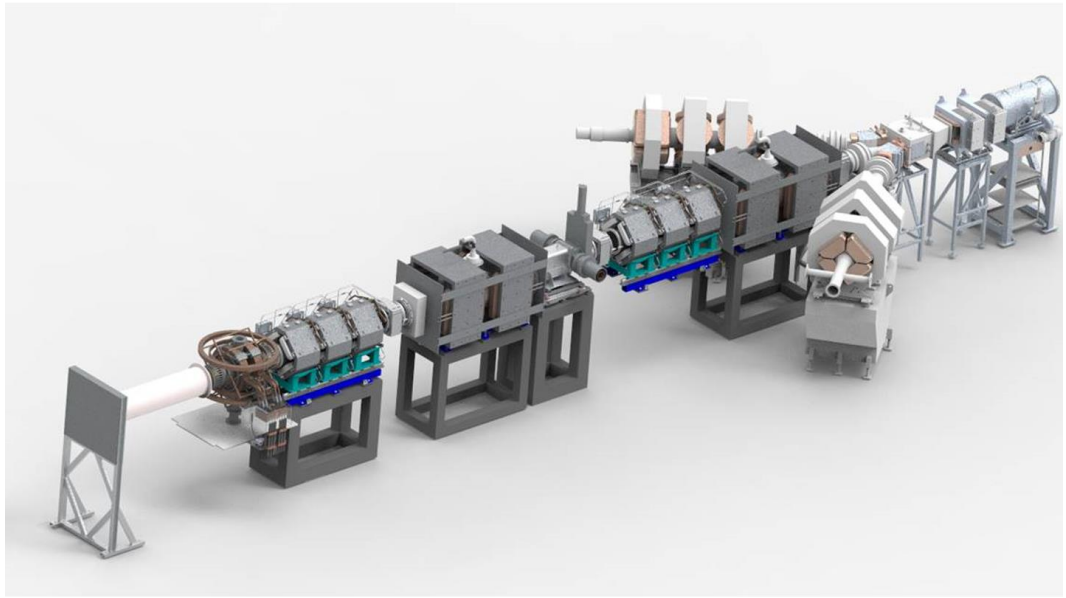
Detector and DAQ Improvements

Use full muon flux and maximise information per muon



Beamline improvements

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

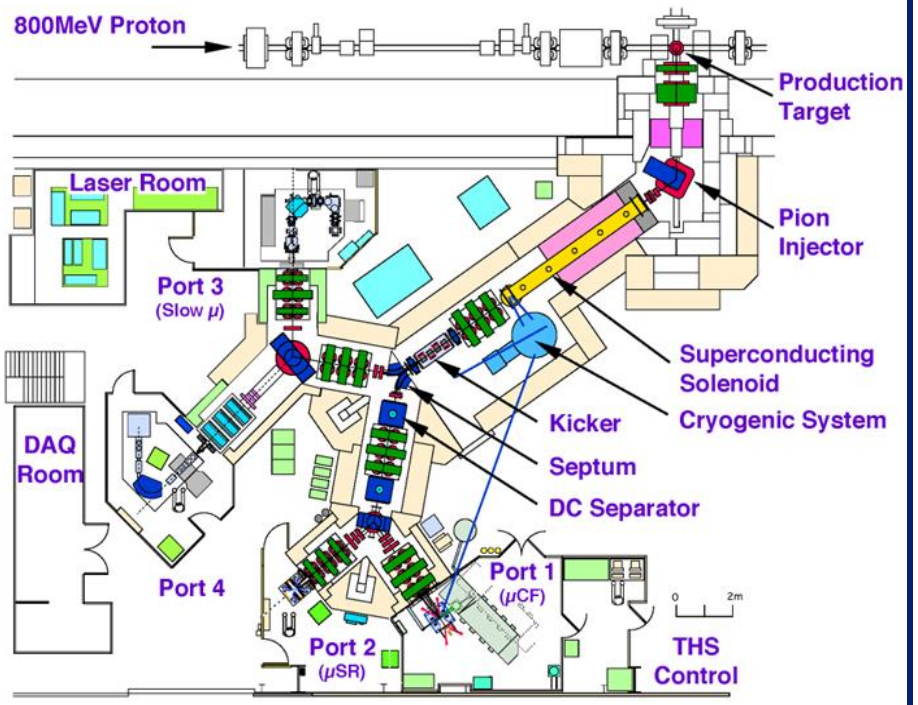


Summary

- The Muon facility at RAL could be a possible host site for a low energy cooling test area.
- R&D activity towards the muon collider could bring significant benefits to MuSR facilities e.g. new target designs, higher brightness beams, better control over our beams etc. – especially interesting to ISIS right now as we move towards ISIS-II.
- **One caveat: we really care about spin polarisation.**

Question

There has been a lot of discussion on what needs to be demonstrated to de-risk the muon collider. Can you see an application of our beam to the R&D program?



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