Welcome to the ISIS muon training course

Adrian Hillier
ISIS Muons
Outline

- Introduction to ISIS
- The ISIS accelerator
- Neutrons at ISIS
- Muons at ISIS
Introduction to ISIS
A World Centre for Condensed Matter Science with Neutrons and Muons

The ISIS Pulsed Neutron and Muon Source

Accelerators

Instruments

Instruments
The ISIS Accelerators

- 70 MeV H− Linac
- MICE
- Extracted Proton Beam
- 800 MeV SYNCHROTRON
- Linear accelerator
- Ion source
- Synchrotron accelerator

- 800 MeV proton beam
- Extracted proton beams (to targets)

Ion source

Linear accelerator

Synchrotron accelerator
The ISIS Accelerators

The beginning - the Ion Source

Produces H⁻ ions and accelerates them to 665 keV.
The middle - the **Linear Accelerator**

Accelerates the $\text{H}^-$ ions to 70 MeV.
The ISIS Accelerators

The final stage - the Synchrotron Accelerator

- H⁻ ions stripped to protons
- Protons travel ~10,000 times round
- Accelerated to 800 MeV (84% light speed)
The ISIS Targets

- Tantalum targets
- Neutrons produced by ‘spallation’
- Heat dissipation is 160 kW TS1, 40 kW TS2
Muon Production Target

- Made of graphite
- Gets to perhaps 900K
- Takes ~5% of the proton beam
The ISIS Pulsed Neutron and Muon Source

- ISIS runs ~150 days per year
- It runs in ‘cycles’ of 30-40 days each
- ISIS is controlled from the Main Control Room - which is always staffed
Neutrons at ISIS

30 neutron instruments
'Neutrons tell you where atoms are and what atoms do'
Neutrons - a tailor-made probe

• Neutron wavelength and energy ‘just right’ (25meV ~ 1.8 Å)
  – *structure and dynamics*

• Neutron cross-section
  – *isotopic dependence*

• H / D contrast
  – *nuclear form factor*

• Magnetic Moment
  – *magnetic order & excitations*

• Weak probe
  – *theoretical interpretation*

• Highly penetrating
  – *bulk probe*
  – *complex SE*
Achievements of neutron scattering
- the evolution and diversification of neutron scattering over the past 40 years
The European Muon Facility
The EC Muon Facility

- HiFi
- MuSR
- EMU

**Diagram Notes:**
- **kicker:** feeds muons to three instruments
- **separator:** removes contaminant particles
- **dipole steering magnet**
- **quadrupole focusing magnet**
- **800 MeV proton beam**
- **muon production target**
- **to neutron target**
‘Surface’ muons

- Proton collisions produce pions, e.g. 
  \( p + p \rightarrow p + n + \pi \)
- Some pions stop in the target
- They decay to muons, which escape if formed near the target surface
- Muons collected into the beam line
- Polarisation 100%
The EC Muon Facility

Quadrupole focusing magnets
Focusing the beam - quadrupole magnets

- Quadrupole magnets focus in one direction, defocus in the other.
- So they appear in our beamline in 2’s or 3’s
- Allow tuning of the beam by varying the current
The EC Muon Facility

Dipole Steering magnets
Bending the beam - dipole magnets

- Get the beam round corners!
- Also exclude neutral particles or those of the wrong charge
- Act as a momentum filter
The EC Muon Facility

Separator

kicker: feeds muons to three instruments
separator: removes contaminant particles
dipole steering magnet
quadrupole focusing magnet

800 MeV proton beam
muon production target

to neutron target

HiFi
MuSR
EMU

Science & Technology Facilities Council
ISIS
Cleaning the beam - the separator

- E and B fields, mutually perpendicular
- Acts as a velocity filter
- E and B field forces cancel for particles of the correct velocity
- Gives a 6° spin rotation

\[ F_{\text{mag}} = B \cdot q \cdot v \]
\[ F_{\text{elec}} = E \cdot q \]
The EC Muon Facility

Kicker:
- feeds muons to three instruments
- separators: removes contaminants
- dipole steering magnet
- quadrupole focusing magnet

800 MeV proton beam

Science & Technology Facilities Council
ISIS
Splitting the beam - the kicker

- Central electrode
- Charged positively for first muon pulse
- Splits the first pulse in two
- No voltage for second muon pulse
- Second pulse goes straight through

![Diagram of beam splitting](attachment:image.png)
Splitting the beam - the kicker
EMU

0.5 T main field, longitudinal

+ 150 G transverse fields

+ Stray field compensation

96 Detectors

Data Rates - single pulse
120MeV/hr

Fly-past

Temperature range of 40 mK- 2000 K
MuSR

0.3 T main field, longitudinal
+ 20 G transverse fields
+ Stray field compensation
64 Detectors
Data Rates -
single pulse 45 MeV/hr

Temperature range of 40 mK- 1000 K
MuSR

0.07 T main field, transverse
+ Stray field compensation
64 Detectors
Data Rates -
  single pulse 45 MeV/hr

Temperature range of 40 mK- 1000 K
HiFi

5 T main field, longitudinal
+ 400 G auxiliary field (for field switching, e.g. ALC)
+ 2 x 100 G transverse fields
+ Stray field compensation

Data Rates upto 200 Mev/hr

Temperature range of 40 mK- 2000 K
RIKEN-RAL Muon Facility

Largest UK-Japan science collaboration

First muons 1994

4 experimental areas
- condensed matter
- other ‘exotic’ uses of muons
RIKEN

800MeV Proton

Production Target

Pion Injector

Allows high momentum +’ve and -’ve muons

Port 3 (Slow \(\mu\))

DAQ Room

Port 4

Port 1 (\(\mu\)CF)

Port 2 (\(\mu\)SR)

Laser Room

DAQ Room

DC Separator

Kick

Sep

THS Control
RIKEN-RAL Muon Facility

ARGUS (Port 2)

New spectrometer - Chronus (Port 4)

• pressure studies
• laser stimulation
Researchers at Vanderbilt University used RIKEN-RAL facility to investigate effects of muons on state-of-the-art microelectronic memories.

Collaborators from industry including Marvell Semiconductors, Cisco Systems, and Texas Instruments.

Muon-induced data errors clearly observed in multiple devices.

Results will support investigation into error rates of commercial electronics and have just been published in 2014 IEEE International Reliability Physics.
ARGUS

0.4 T main field, longitudinal

+ 100 G transverse fields

+ Stray field compensation

Data Rates (single pulse)
upto 50 Mev/hr

Temperature range of 25 mK- 600 K

Pressure Cell 0-6.4 kbar (2 - 300 K)
CHRONUS

0.4 T main field, longitudinal

+ 100 G transverse fields

+ Stray field compensation

Data Rates (single pulse) up to 50 Mev/hr

Temperature range of 300 mK - 600 K
CHRONUS

600 G main field, transverse

+ Stray field compensation

Data Rates (single pulse) upto 50 Mev/hr

Temperature range of 300 mK - 600 K
Exciting muons

Stimulation of your sample and muons is possible

Light (HiFi)

RF techniques

Electric field

Microwaves

Pulsed Currents
Over 1000 publications many in high impact publications, such as Nature, Nature family, Science PRL.
<table>
<thead>
<tr>
<th>Time</th>
<th>Monday 19/03/18</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:30</td>
<td>08:45 START</td>
</tr>
<tr>
<td>09:00</td>
<td>Welcome and Introduction</td>
</tr>
<tr>
<td>09:15</td>
<td>Adrian Hillier</td>
</tr>
<tr>
<td>09:30</td>
<td>Tour of ISIS</td>
</tr>
<tr>
<td>09:45</td>
<td>09:00</td>
</tr>
<tr>
<td>10:00</td>
<td>10:15</td>
</tr>
<tr>
<td>10:30</td>
<td>10:45</td>
</tr>
<tr>
<td>11:00</td>
<td>11:15</td>
</tr>
<tr>
<td>11:30</td>
<td>11:45</td>
</tr>
<tr>
<td>12:00</td>
<td>12:15</td>
</tr>
<tr>
<td>12:30</td>
<td>12:45</td>
</tr>
<tr>
<td>13:00</td>
<td>13:15</td>
</tr>
<tr>
<td>13:30</td>
<td>13:45</td>
</tr>
<tr>
<td>14:00</td>
<td>14:15</td>
</tr>
<tr>
<td>14:15</td>
<td>14:30</td>
</tr>
<tr>
<td>14:45</td>
<td>14:55</td>
</tr>
<tr>
<td>15:00</td>
<td>15:15</td>
</tr>
<tr>
<td>15:30</td>
<td>15:45</td>
</tr>
<tr>
<td>16:00</td>
<td>16:15</td>
</tr>
<tr>
<td>16:30</td>
<td>16:45</td>
</tr>
<tr>
<td>17:00</td>
<td>17:15</td>
</tr>
<tr>
<td>18:00</td>
<td>18:15</td>
</tr>
<tr>
<td>19:00</td>
<td>19:45</td>
</tr>
<tr>
<td>08:30</td>
<td>08:45 START</td>
</tr>
<tr>
<td>09:00</td>
<td>Welcome and Introduction</td>
</tr>
<tr>
<td>09:15</td>
<td>Adrian Hillier</td>
</tr>
<tr>
<td>09:30</td>
<td>Tour of ISIS</td>
</tr>
<tr>
<td>09:45</td>
<td>09:00</td>
</tr>
<tr>
<td>10:00</td>
<td>10:15</td>
</tr>
<tr>
<td>10:30</td>
<td>10:45</td>
</tr>
<tr>
<td>11:00</td>
<td>11:15</td>
</tr>
<tr>
<td>11:30</td>
<td>11:45</td>
</tr>
<tr>
<td>12:00</td>
<td>12:15</td>
</tr>
<tr>
<td>12:30</td>
<td>12:45</td>
</tr>
<tr>
<td>13:00</td>
<td>13:15</td>
</tr>
<tr>
<td>13:30</td>
<td>13:45</td>
</tr>
<tr>
<td>14:00</td>
<td>14:15</td>
</tr>
<tr>
<td>14:15</td>
<td>14:30</td>
</tr>
<tr>
<td>14:45</td>
<td>14:55</td>
</tr>
<tr>
<td>15:00</td>
<td>15:15</td>
</tr>
<tr>
<td>15:30</td>
<td>15:45</td>
</tr>
<tr>
<td>16:00</td>
<td>16:15</td>
</tr>
<tr>
<td>16:30</td>
<td>16:45</td>
</tr>
<tr>
<td>17:00</td>
<td>17:15</td>
</tr>
<tr>
<td>18:00</td>
<td>18:15</td>
</tr>
<tr>
<td>19:00</td>
<td>19:45</td>
</tr>
</tbody>
</table>

**Time Monday 19/03/18**
- **08:30** Practical Session 1
- **08:45** START
- **09:00** Welcome and Introduction
  - Adrian Hillier
- **09:30** Tour of ISIS
- **10:00** Practical Session 2
- **10:45** COFFEE
- **11:30** Applications of Spectrometer
  - Adrian Hillier
- **12:00** Applications of Spectrometer
  - Adrian Hillier
- **12:30** Lunch
- **13:30** Applications of µSR - Magnetism
  - Tom Lancaster
- **14:00** µSR - Semiconductors
  - Rui Vilao
- **14:30** Lunch
- **15:30** µSR - Negative muons for Spectrometer
  - Stephen Blundell
- **16:00** µSR - Chemistry
  - Steve Cottrell
  - Nigel Clayden
  - Martin Månsson
- **16:30** Lunch
- **17:30** µSR - Superconductors
  - James Lord
  - Roberto De Renzi
- **18:00** Social Evening and Dinner
- **19:00** Farewell/ Prize Giving
  - Adrian Hillier

**Time Tuesday 20/03/18**
- **08:30** Practical Session 1
- **08:45** START
- **09:00** Welcome and Introduction
  - Adrian Hillier
- **09:30** Tour of ISIS
- **09:45** Applications of Spectrometer
  - Adrian Hillier
- **10:00** Tour of ISIS
- **10:30** COFFEE
- **11:30** Analysis of µSR Spectra
  - Adrian Hillier
- **12:00** Combination of µSR Spectrometer
  - Adrian Hillier
- **12:30** Lunch
- **13:30** µSR - Negative muons for Spectrometer
  - Stephen Blundell
- **14:00** µSR - Chemistry
  - Steve Cottrell
  - Nigel Clayden
  - Martin Månsson
- **14:30** Lunch
- **15:30** µSR - Superconductors
  - James Lord
  - Roberto De Renzi
- **16:00** µSR - Negative muons for Spectrometer
  - Stephen Blundell
- **16:30** Lunch
- **17:30** µSR - Chemistry
  - Steve Cottrell
  - Nigel Clayden
  - Martin Månsson
- **18:00** Social Evening and Dinner
- **19:00** Farewell/ Prize Giving
  - Adrian Hillier

---

**Important Notes**

- **A 3.5 minute presentation (no more than 3.5 minutes!)**
- **On one of the practicals that you have done during the week**
  - e.g.
    - what you were studying and why
    - what measurements you made and why
    - how you analysed the data
    - what results you got

Please give us your talks by Friday coffee break.