Instrumentation

Adam Berlie
ISIS Muon Group
Protons, energy 800MeV

Graphite target.

Pion production (lifetime 26ns).

\[ \pi^+ \rightarrow \mu^+ + \nu_\mu \]

Implanted muons (lifetime 2197ns)

\[ \mu^+ \rightarrow e^+ + \text{neutrinos} \]

Surface muons, 100% spin polarised

Muons implanted as a pulse, FWHM 80ns

Not symmetric because of pion decay

Protons, energy 800MeV

Graphite target.

Pion production (lifetime 26ns).

\[ \pi^+ \rightarrow \mu^+ + \nu_\mu \]
What do we get or have to deal with at a pulsed source?

- High Rates
  - 1000’s muons implanted per pulse
- Large number of muon decays at short times
  - Multiple detectors
- Detector response time
- Low Background
- Can count to long times
The ISIS Beamlines

South Side, EC-Muons

North Side, RIKEN-RAL Muons
The Instruments

EMU

MUSR

HIFI

CHRONUS

ARGUS

Also have RIKEN-RAL Ports 1 and 3
So the question is, how do we get from the muons in your sample to you here at ISIS?

Explore this idea from cradle to grave with emphasis on a pulsed source.
The supply chain

First, we need a way to detect positrons from muon decay.

Scintillators:
- give off light when hit by a positron
- High efficiency
- Fast response (ns) and rapid recovery
- Spectral range can be selected (matched to PMT)

Plastic scintillators

Be mindful of track length (5-10 mm)

And...plastic typically used for μSR (but many others, e.g. liquid, gases)

We wrap the scintillator material in a reflective coating to increase the intensity of the light.
The supply chain

How do we then collect the light? We need to turn this into a signal.

Use photomultiplier tubes (PMTs) – convert pulse of light into a voltage
- Requires high voltage across PMT
The supply chain

Discriminators to … discriminate noise against a muon decay (positron)

Leading edge triggers as input voltage rises through preset threshold

Output is a (logic) pulse of preset width
The supply chain

- Multi-hit TDC
- Common start for all channels
- Measure time between start trigger and positron events
- Time bins determined by clock (typically 16 ns bins at ISIS)
- TDCs buffer multiple hits following the muon pulse to avoid distortion

Plastic scintillators

Time to Digital Converter

Start (Čerenkov)

\[ \tau_1 \]

\[ \tau_2 \]

Positron events

Input

Threshold

Output

300ns

200Amps

22 Mar 1994

12:07:10
The supply chain

- Plastic scintillators
- PMTs
- Discriminators
- Time to Digital Converter
- To you!
The DAQ in real life

Cables from Discriminators to TDC

Discriminators 16 channels per card

Cables from detectors

TDCs in rack

HV supply for PMTs

Inside a cupboard that is air conditioned and clean!
What do we need to consider?

1. How do we make the most of our high rates?

- 1000’s muons implanted in sample per pulse
- Lots of muon decays at short times
- Dead time

Positrons emitted over a distribution of angles – think transverse vs longitudinal experiments

So we also want to maximise solid angle

And… positron energies and asymmetries can be tuned by degrader
What do we need to consider?

1. How do we make the most of our high rates?

   Solid angle coverage, where do you want detectors?

   Small area vs. large area – typically $2\pi$

   Need to leave room for cryostats and beam entry!

   Overcome all of this using detector arrays i.e. lots of detectors covering a wide angle

   ARGUS – 192 detectors
What do we need to consider?

1. How do we make the most of our high rates?
   Also can consider detector array design…

Are there any advantages or disadvantages?
What do we need to consider?

2. Timing?

- Use a Cherenkov detector upstream to get Time zero ($t_0$)
- How do you know when your data starts?

![Diagram with timelines and labels: Start Trigger, Time zero, First good data, 80ns, Muon Pulse, µSR Signal]
What do we need to consider?

3. How do we get the best data?
   - Positron emission from all the muon decays over a wide angle
   - Double counting
   - Noise
   - Making sure we use our discriminators to it’s best!
   - Same for our detector HV

Data from EMU
What do we need to consider?

Is all this effort worth it?

Yes, if you define “data quality” = rate x $A_0^2$
Have lots of detectors!
- CHRONUS – 606 detectors
- Multianode PMTs
- Need to get light from scintillator all the way to the MAPMT
Development

Could we use Si or solid state photo multipliers?

At a continuous source
- Count 1 muon at a time
- Don’t have to worry about dead times

At a pulsed source
- Count 1000 muons per pulse
- Timing resolution an issue
- Dead is a very big issue!

Properties of SiPMs well-suited to continuous muon sources, R&D on-going to understand their behaviour at high data rates
HIFI positron degraders

**POSITRON DEGRADERS**

Over the summer positron degraders were fitted to the HiFi detectors to improve the asymmetry and figure of merit.

The asymmetry in low field has increased from about 22 to 29% (see top figure) with more modest improvement above 1.5T.

For most users this means an increase in beam slit width can be tolerated while keeping the rate the same yet improving data quality.
Super-MuSR

Now:
- Slits
- Quad Doublet
- MuSR

Future:
- Slits
- Spin Rotator
- Quad Triplet
- Slicer
- Spin Rotator
- Quad Triplet
- Super MuSR
Super-MuSR
Super-MuSR

- 20x data rate
- High density array (for muons)
- 1200 detectors
- Outline design complete
- Prototypes tested
- Model section to be built this year
## Muon Instruments at ISIS

<table>
<thead>
<tr>
<th>Muon Instruments</th>
<th>MuSR</th>
<th>EMU</th>
<th>HIFI</th>
<th>ARGUS</th>
<th>CHRONUS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beam type / momentum (MeV/c)</strong></td>
<td>$\mu^+ / 28$</td>
<td>$\mu^+ / 28$</td>
<td>$\mu^+ / 28$</td>
<td>$\mu^+, \mu^- / 20-120$</td>
<td>$\mu^+, \mu^- / 20-120$</td>
</tr>
<tr>
<td><strong>Number of detectors</strong></td>
<td>64</td>
<td>96</td>
<td>64</td>
<td>192</td>
<td>606</td>
</tr>
<tr>
<td><strong>Detector solid angle (sr)</strong></td>
<td>$1.6\pi$</td>
<td>$2.2\pi$</td>
<td>$1.3\pi$</td>
<td>$0.8\pi$</td>
<td>$\pi$</td>
</tr>
<tr>
<td><strong>Data rate</strong> (Mev/hr)</td>
<td>60</td>
<td>150</td>
<td>80</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td><strong>Data quality ($a_0^2$.rate)</strong></td>
<td>4.7</td>
<td>8.3</td>
<td>3.5</td>
<td>2.6</td>
<td>2.0</td>
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<tr>
<td><strong>Beam utilisation</strong> (%)</td>
<td>8</td>
<td>25</td>
<td>20</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td><strong>Temp range (K)</strong></td>
<td>0.025 – 1000</td>
<td>0.025 – 1400</td>
<td>0.025 – 1400</td>
<td>0.025 - 600</td>
<td>0.3 - 600</td>
</tr>
<tr>
<td><strong>LF field range (T)</strong></td>
<td>0.3 (0.6)$^3$</td>
<td>0.5</td>
<td>5</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>TF field range (T)</strong></td>
<td>$\sim0.06^4$</td>
<td>0.015</td>
<td>0.01</td>
<td>0.01</td>
<td>$\sim0.06^4$</td>
</tr>
<tr>
<td><strong>Upper frequency (MHz)</strong></td>
<td>$\sim8$</td>
<td>$\sim8$</td>
<td>$\sim8$</td>
<td>$\sim8$</td>
<td>$\sim8$</td>
</tr>
<tr>
<td><strong>Flypast (small samples)</strong></td>
<td>N$^5$</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td><strong>Fast change ULT$^6$ sample environment</strong></td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td><strong>Laser capability</strong></td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td><strong>Gas phase capability</strong></td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td><strong>Pressure capability</strong></td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>

### Notes:
- Data rate represents the maximum data rate for undistorted time differential measurements of typical length.
- Percentage limit of available muons that can be counted while minimising detector deadtime effects, based on current detector solid angle.
- Longitudinal field limited by current detector configuration/technology.
- Field limited by reduction of asymmetry due to the finite muon pulse width.
- The beam spot size in MuSR is significantly smaller than for the other instruments, allowing comparatively small samples to be run with good results.
- Cryostats have their own vacuum jacket, allowing working system to be moved.
If you’d like to know more …

- **Uppset**: A pulsed electrostatic kicker to improve the mSR frequency response in the ISIS pulsed muon beam, A.I. Borden *et al*, Nuclear Instruments and Methods A 292 (1990) 21-29