Instrumentation for μSR

or

Building a Spectrometer!
Outline

- Experiment Overview
- The Detector Chain
- Making an Instrument
Overview...
Getting the Muons

Protons, energy 800MeV

Graphite target. Pion production (lifetime 26ns).

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

Implanted muons (lifetime 2197ns)

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

Surface muons, 100% spin polarised

Muons implanted as a pulse, FWHM 80ns

Not symmetric because of pion decay

Protons, energy 800MeV
Muon Decay

- $\mu$SR depends on detecting positrons from implanted muons
- Need time of decay and direction for time differential measurements
- Positron emitted preferentially along $S_\mu$ (what if there’s a field?)
- Positron energies and asymmetry can be tuned by degrader

\[
W(\theta) = 1 + a \cos(\theta)
\]

Average over all energies

Highest energy positrons

\[
a = 1/3
\]
Experiment Geometries

Decide on experiment, then position detectors to maximise asymmetry, count rate, etc

Transverse

Field out of screen

Longitudinal

Field parallel to beam
Have enough detectors

- **Cope with rates at a Pulsed source:**
  1000s muons stopped / pulse,
  Very high instantaneous counting rates at short times,
  Require several counts / detector / pulse,
  Detector responds at limited speed,
  Segment detectors to avoid deadtime (see Pabi’s talk)
  Typically 32 detectors for ~20-30MeV/hr

- **What about a Continuous source – PSI/TRIUMF?**

- **Cover a large solid angle:**
  Efficient counting, but
  Need to allow for beam/cryostat entry!
  Typically $2\pi$ coverage
Other considerations

- **Magnetic field coils**
  Resistive or superconducting …
  Coils are required for the **main field**, 
  **calibration field** and **compensation for the Earth’s field**.

- **Mounting for Sample Environment**
  Leave space to accommodate experiment kit
Real Spectrometers

ARGUS (RIKEN-RAL)  
MuSR (ISIS)  
HiFi (ISIS)  
GPD (PSI)  
Chronus (RIKEN-RAL)  
High-Time (TRIUMF)
Detector Chain...
If NO time evolution of muon polarisation positron count rate is: \( N(t) = N_0 \exp(-t/\tau_\mu) + B_g \)

Usually, there is a time evolution of the muon polarisation. Studying this is where the physics lies.
The Detector Chain

Particles to Light
Transmission
Light to electrons
Reject Noise, Logic Output
Measuring time
Scintillators: *Particles to Light*

- Energetic particles cause luminescence
  - High efficiency
  - Ensure sufficient track length (5-10mm thickness usual)
- Fast response (ns) and rapid recovery
  - Spectral range can be selected (matched to PMT)
  - Plastic typically used for µSR (but many others, e.g. liquid, gases)
Lightguides: *Transmission*

- Made from plastic (e.g. perspex)
- Conducting light by internal reflection
- External reflector incl. transmission
- Constant area (light incompressible!)
- Adiabatic (gradual change in shape)
Photomultipliers: *Light to e\(^{-}\)*

- Quantum efficiency and Peak response must be selected
- Field sensitive – place in low field using a lightguide
- Set gain by adjusting HV
Chronus: *High Segmentation*

Forming the detector chain for a High Density detector array …
Solid-state Photomultipliers?

Si Photomultipliers now popular at Continuous sources …
Why aren’t we using them at ISIS at the moment?

At a ‘continuous’ source … counting one muon at a time
• Very high timing resolution
• Deadtime not important

At a ‘pulsed’ source … counting 100s muons at a time
• Modest timing resolution
• Very high data rates, Deadtime huge issue

Properties of SiPMs well-suited to continuous muon sources, R&D on-going to understand their behaviour at high data rates
Discriminators: Logic Output, Reject Noise

- Leading edge triggers as input voltage rises through preset threshold
  - Output is a (logic) pulse of preset width
  - Double pulse resolution important (why?)
- Setup Threshold (~75mV) and Pulse Width (5-10ns)
Time to Digital Convertor: *Measuring time*

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

A histogram of pulse heights enables us to adjust the HV for:
- Uniform response between detectors (why?)
- Gain appropriate to intended discriminator threshold

~50mV, threshold for discriminators
Discriminators

We can also scan the **discriminator threshold** to check how things are setup.

The result should be consistent with our histogram of pulse heights.
Is it worth the effort?

Yes, because we get cleaner signals and improved data
Time Zero and First Good Data

- Times are referenced to the centre of the muon pulse (‘Time zero’). Fitting starts from the point where good clean data is available (‘First good data’)

- The values of ‘Time zero’ and ‘First good data’ vary according to spectrometer
Making an instrument...
Control electronics

- Control and analysis PCs
- DAE-II: TDCs and period card
- Discriminators
- High voltage for PMTs

- Clean environment
- Air conditioned room (lots of heat!)
- Separate from people (lots of noise!)
Control Computer

**Acquisition, control and storage**

- Accumulate and manage data
- Experiment running in closed area – remote control essential!
- LabView used to control kit
- Automated running desirable (!)
- ‘Nice’ interface
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
- Fast E-Field Switching of a Pulsed Surface Muon Beam: The commissioning of the European Muon Facility at ISIS, G.H. Eaton et al, Nuclear Instruments and Methods A 342 (1004) 319-331