ISIS Muon Training Course ñ Building a Spectrometer

1. Building the Spectrometer

This experiment is intended to provide an introduction to the concepts necessary in designing and building a µSR spectrometer. In the course of the experiment, a simple spectrometer will be constructed and a variety of calibration measurements run to demonstrate its performance.

The key parts of a spectrometer were discussed in the talk ëMuon instrumentation and practical aspects of µSRí, and this spectrometer will consist of a magnet, two detectors, the necessary electronics to process detected counts and a computer to control the experiment, store the results and carry out analysis. The following points provide a guide to the steps necessary to put the spectrometer together, and raise some questions along the way. The instructions shown in red should be followed exactly to avoid damage to equipment, otherwise feel free to experiment!

• Site the magnet to accept incoming beam and arrange a method for supporting samples in the correct position (thereís no cryostat for this simple spectrometer!), leaving a metallic plate to intercept the beam. For the experiments youíll be running with this spectrometer, itís probably best to arrange for the field vector to be transverse to the muon polarisation and vertical. Connect the power supply to the magnet and apply a current (the maximum current that should be applied is 5A). A Hall probe is available to allow a rough calibration of field against current to be made.

• Two detectors are provided, together with some clamps for support. Some part assembled detectors are also available to show how theyíre constructed. In deciding where to put these detectors you need to consider factors such as where the muon beam enters the spectrometer, the direction of the initial muon polarisation and how the polarisation will evolve in the applied field. Once youíve decided on their location clamp them in position, but please be very careful handling these detectors as they are extremely fragile.

• Each detector needs a signal cable (black) and a high voltage cable (red) to be connected to the base of the photomultiplier tube. Be sure that the high voltage is off when connecting/disconnecting the red cable. These cables run to the back of the MuSR cabin where the electronics for processing the counts is located. Open the beam blocker and then go into the cabin and find the cables; connect one of the signal cables to an oscilloscope and the high voltage cable to the high voltage power supply (this may already have been done).

• Apply -1300V to one of the photomultiplier tubes and look at the signal on the oscilloscope. You should see a large number of pulses due to detected positrons. Why is there a distribution in pulse heights? Try changing the applied voltage (but do not apply more than -1600V) to investigate how the pulse amplitude changes with applied voltage. Finally, apply a voltage and check that the second detector is counting.
• Find the signal from the Cerenkov detector and connect to a second channel on the oscilloscope (which should be set to trigger on this channel). This detector is located about 25m upstream of the MuSR spectrometer, and is used to start the data acquisition for each instrument. What does the Cerenkov signal look like and why? Measure the time difference between the Cerenkov signal and the first positron pulses. Why does this time difference occur and is it reasonable?

• Look at the time distribution of the pulses from the photomultiplier tube following the Cerenkov. Is the time structure as you'd expect?

• The signal from each of the photomultiplier tubes is passed through a discriminator (located in the NIM crate), with the threshold set to remove small pulses arising from sources other than muon decays. The setting of this threshold and the voltage on the photomultiplier tube are critical to the correct operation of the detector; at one extreme all pulses are accepted, at the other only the largest will be counted or even none at all! Consider the effect on the experiment of running close to either extreme. What factors constitute a “good” setting?

• Setup the oscilloscope to look at the positron counts (discriminator input; use the linear fan-in fan-out to duplicate the signal) on one channel and the output of the discriminator on the other. The second output of the discriminator should be terminated to 50Ω. Try changing the discriminator threshold and see what happens. Once you are happy that the threshold is set correctly, adjust the discriminator pulse width to be about 5ns. What would be the effect on the data of lengthening this pulse?

• Set the threshold and pulse width of the second discriminator up exactly as the first, and then plug the output of each into the Time to Digital Converter (TDC) card located in the CAMAC crate. The Cerenkov signal should be plugged into the Frame Start connection, located on a separate module on this crate. You should now be ready to take data.

• The computer and software used to control this experiment is a standard setup used by ISIS muons, and should have already been configured to work with this simple spectrometer. Start a run; you should see two histograms collecting data, one for each detector. Consider the best method for data analysis.

• The current delivered by the power supply for the magnetic field is voltage programmable, and may be controlled by the computer using the Digital to Analogue Converter (DAC) card located in the CAMAC crate. Connect the card to the power supply using the supplied lead and check currents can be programmed from the computer.

2. Testing the Spectrometer

Once the spectrometer can successfully collect data, there are a number of calibration measurements that can be run. The first two, calibration of the magnetic field and determining the maximum asymmetry for the spectrometer, should certainly be done, as these are essential for other measurements. You probably won’t have time to try everything else suggested, just do those that seem the most interesting. Either the
measurement of the ISIS pass band or determining time zero would be suitable for overnight runs.

- **Calibration of the magnetic field**
  
The easiest method of calibrating the magnetic field is to use the precession frequency of muons stopped in a metal plate, when the field is applied transverse to the muon polarisation. In this case all muons will thermalise into a diamagnetic state, and a number of short runs at different current settings should allow an accurate calibration of field against the current and value set on the computer.

- **Determining maximum asymmetry for the spectrometer**
  
The maximum asymmetry for the spectrometer can easily be determined by measuring the precession of muons stopped in a metal plate in a transverse magnetic field (20G or so).

- **Investigating the effect of detector position on asymmetry**
  
Using a transverse magnetic field, measure the asymmetry as a function of the detector position. How does the asymmetry change as the detector is moved out of the plane of the muon precession?

- **Investigating the effects of positron degraders on count rate and asymmetry**
  
Using a transverse magnetic field, measure the asymmetry and count rate in a detector as brass plates are added in front of the detector to attenuate the positron flux. How do these parameters vary and why?

- **Measuring the muon spot size and steering the beam to optimise beam to target**
  
Using a large Haematite sample and a 20mm diameter Silver mask, estimate the muon spot size by determining the fraction of muons falling on the mask. The measurement should be made in a transverse magnetic field; what signals would you expect from the Silver and Haematite and how does this allow us to separate them? There are steering magnets to adjust the beam in the vertical and horizontal directions; try using these to optimise the fraction of the beam falling on the Haematite.

- **Studying the effect of material in the muon beam on beam spot size**
  
Following on from the last measurement, the effect of adding material in the muon beam on the spot size can be investigated. Try adding various numbers of Titanium foils at different positions in front of the sample. Is the result as you'd expect? Where might this be a problem when you're building a real spectrometer? If you'd like to take the analysis further, there's a free program for modelling the interactions of particles with matter at [http://www.srim.org/](http://www.srim.org/). Try simulating the experiment setup and see if the results agree with the experimental data.
• Measuring the count rate as a function of collimating slit setting

Measure the count rate for a number of collimating slit settings (do not open the slits beyond 50). Is the relationship linear? If not, why?

• Determine the range of muons in Titanium

Using a transverse magnetic field, measure the asymmetry as Titanium foils are added in front of a Haematite sample. What signals would you expect from the Titanium and Haematite, and how much material (in mg/cm²) does it take to completely stop the muon beam? Is the shape of the curve as you’d expect, and why isn’t there a sharp cut-off as the Titanium foils are added?

• Measuring the detector solid angle and total number of muons in the beamline

An ideal detector array would cover the full 4π solid angle to maximise counting rate. In practice, considerations such as the need for beam and cryostat access lead to a reduced solid angle, and the detectors of both EMU and MuSR cover only around 50% of the full solid angle. By measuring areas and distances from sample, estimate the solid angle coverage for one of your detectors. Measure the count rate in the detector (use the Haematite sample to depolarise the muon beam; why?) and hence determine the total muon flux in the beamline.

• Measurement of the ISIS pass band

The width of the ISIS muon pulse (80ns) results in a small time uncertainty for muon implantation. What would you expect the effect of this to be on the transverse µSR signal as the applied field/precession frequency is increased? The effect can be studied by measuring the muonium signal in Quartz for small transverse fields, where a precession of approximately 1.3MHz/G is seen. Try following the asymmetry of the muonium signal for precession frequencies of up to 12MHz.

• Calibration of Time Zero

An accurate knowledge of Time Zero, the time between the start of data acquisition (triggered by the Cerenkov signal) and the centre of the muon pulse, is essential for proper data analysis. A good value can be determined by making a series of measurements in increasing transverse magnetic fields; if Time Zero is correct the phase of the precession signal will be independent of field/frequency. Assuming the field can be programmed automatically, this is therefore a good measurement to leave running overnight.