1.5.8 JRA8 – Muon-S

Coordinator: 10 - CNR INFM
Partners: 1 – STFC, 5 – PSI, 16 – U. Oxf

Project objectives

Muons provide a unique probe of the atomic level properties of materials. The muon technique has applications across a wide variety of areas, including magnetic materials, superconductors, semiconductors and molecular or polymeric systems. Muons provide a complementary method of studying materials to other techniques such as neutron scattering and magnetic resonance, and are used by many research groups across Europe.

The present JRA involves the two European muon facilities, ISIS at the Rutherford Appleton Laboratory in the UK and the Swiss Muon Source at the Paul Scherrer Institut in Switzerland, together with academic partners at Oxford and Parma Universities. Its aim has been to develop new technologies for the muon method in order to extend the technique's capabilities and further develop the ISIS and PSI muon sources for the benefit of the user community. In particular, both muon facilities are aiming to build new muon instruments which enable the application of high magnetic fields. Many of the JRA objectives have been to do with developing these high field instruments.

Specifically, the JRA has been aimed at developments in three areas:

1. Detectors for muon spectroscopy; in particular, development of fast-timing detectors and those capable of providing position information (Work Package 1).
2. Muon instrument simulation; in particular, the development of code to enable full simulation of muon spectrometers (Work Package 2).
3. Advanced experimental methods, in particular development of novel pulsed techniques (Work Package 3).

Detectors: Work Package 1
A key aim with regard to detector development has been to explore development of a new type of detector for the muon technique, avalanche photo diodes (APD)s, which are compact, very fast in their response and also resistant to high magnetic fields. Different APDs have been investigated to explore their suitability. These tests have included:

- Development, testing and use of a muon beam profile monitor based on scintillating fibres and APDs. This device has proved both a useful test of APDs, together with having application for monitoring the effects on muon beams of applied magnetic fields.
- Development and demonstration of a scintillator detector based on APD technology.
- Construction of a new detector array for the ALC muon instrument at PSI based on APDs – the first ever muon instrument to use an APD detector array.

In addition, the detector development work package has also explored the use of position-sensitive detectors for muon spectroscopy. This has the potential to significantly improve muon measurements and enable much smaller samples of materials to be studied. This work has involved numerical simulation to explore the characteristics of the detectors that would be needed, together with development of a prototype detector.

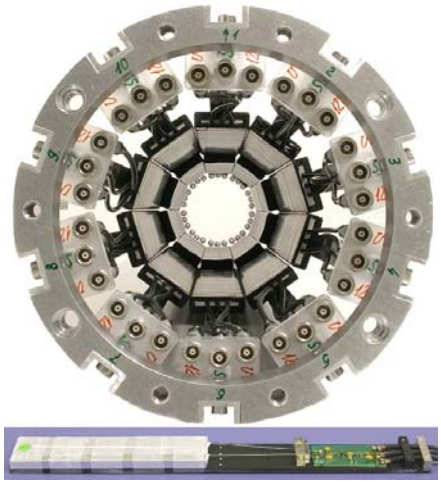

Figure J8.1: This image shows a picture along the beam direction of the new detector array for the ALC muon instrument at PSI, together with one of the individual detector array elements. This detector array is based upon APD technology, developed under the JRA, and is the first ever muon detector system to not be based on traditional photomultiplier tubes. The detector array geometry was designed using the new simulation package also developed under the JRA.

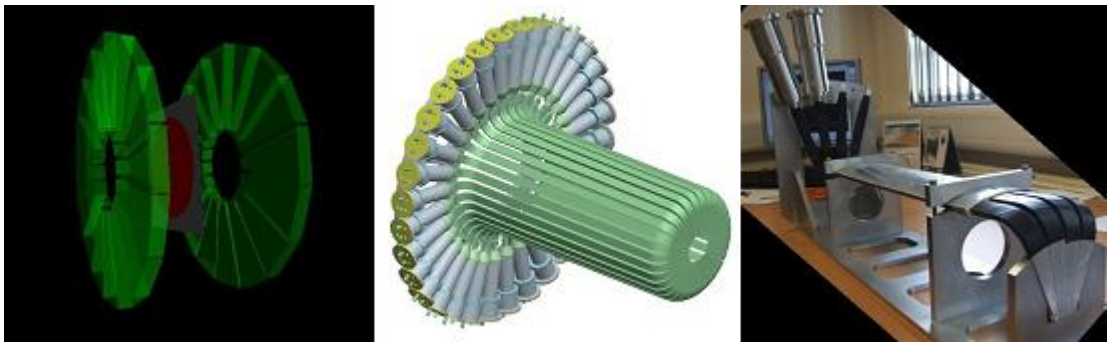

Figure J8.2: This image shows the development of detectors for the new high field instrument at ISIS. Left: representation of the detector scintillators from the muon instrument simulation programme. Middle: design drawing of the detector array. Right: a group of four of the actual detectors, delivered to ISIS in June 2008.

Instrument simulation: Work Package 2

The development of new muon instruments working in high fields is only possible if the instruments can be simulated in advance to enable their correct design. This work package has seen the development of a simulation package for muon instruments, based on the existing particle physics simulation library GEANT4. The package allows characterisation of an incoming muon beam, correct modeling of the muon decay process, and simulation of the performance of variable detector geometries. It has been tested by comparison with experimental data, and has subsequently been used to design the detector array for the high field muon instrument at ISIS, for the ALC instrument and a proposed new high field instrument at PSI.

Advanced techniques: Work Package 3

This work package has aimed to develop extensions to the muon technique to increase its scientific capabilities. Specifically:

- Development of in-situ AC-susceptibility measurements. This has been successfully achieved.
- Development of radio-frequency (RF) muon methods. A variety of developments has taken place, including the development and application of multi-pulse RF techniques, extension to microwave frequencies and development of small sample, high-temperature measurements.

- Attempts have been made to develop acoustic muon spin resonance techniques. Further work is needed to explore this technically-demanding technique.

Methods

A variety of methods have been employed, including:

- Development of entirely new detector technology for muon measurements. All previous muon instrument detector arrays have used photomultiplier tubes. The use of APDs is an entirely novel approach which opens up new possibilities.
- The development of muon instrument simulation, using GEANT4, is also the first time that a muon instrument simulation package has been made available for the technique.
- Development of new RF muon methods has opened up new scientific capabilities, and these have been demonstrated in studies of proton conductors and of hydrogen-related shallow donor states in semiconductors.

Impact

The impact of the JRA has been very high. Specifically:

- Demonstration of the feasibility of using APDs for fast-timing, high field muon applications
- Construction of a beam profile monitor using APD technology
- Construction of the world's first muon detector array built on APDs
- Creation and testing of the first muon instrument simulation package
- Use of the simulation package to design detector arrays for three muon instruments, two of which are presently in construction
- Development of RF muon techniques which have opened new science possibilities to the user community