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EU Funded research in FP7 – An overview of the Muon JRA

Overview

Europe is fortunate in having two muon sources that are complementary and together offer researchers access to the full range of µSR spectroscopic methods. The µSR technique is remarkably versatile, encompassing studies of magnetism, superconductivity and spin and charge transport, while providing a highly sensitive hydrogen analogue to probe semiconductors and proton conductors. The technique has an important role beyond condensed matter physics, and offers chemists a valuable method for investigating the fundaments of reaction kinetics. It is also a great tool for the study of organic radical structure and dynamics in solids, liquids and gases. The work of this JRA has stimulated the development of a broad range of technologies that are now making a significant impact on European muon research.

Developing µSR in high magnetic fields

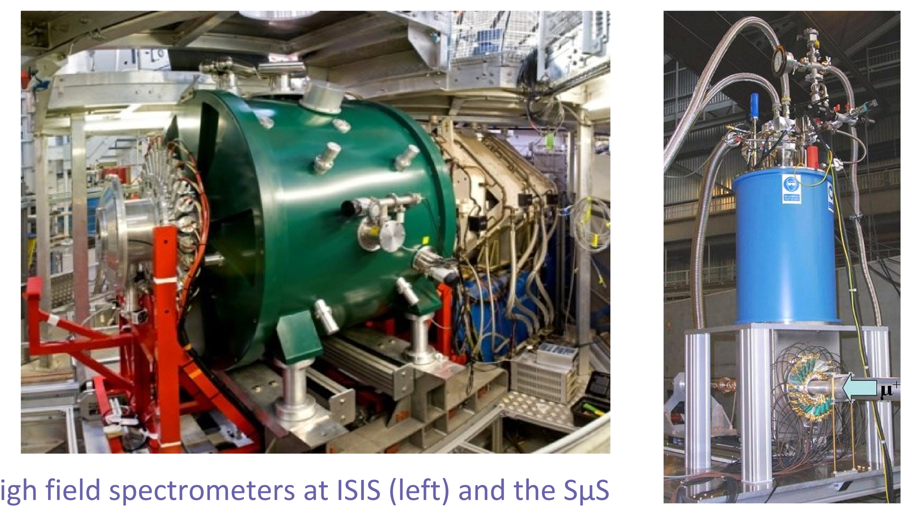
Designing a spectrometer for µSR in high magnetic fields is uniquely challenging. Developing new technologies for high field µSR has been a significant aim of this JRA.

Accomplishments

- **ISIS instrument:** Optimised for spin relaxation measurements with 5T field parallel to the muon spin polarisation. Measurements covering temperatures 25mK to 1200K.
- **SµS spectrometer:** Optimised for fast-timing spin rotation measurements with 9.5T field perpendicular to muon spin polarisation. Dilution temperatures available.

Applications

- Superconductivity
- Heavy fermion systems
- Frustrated magnetism
- Molecular nanomagnetism
- Molecular radicals
- Reaction kinetics



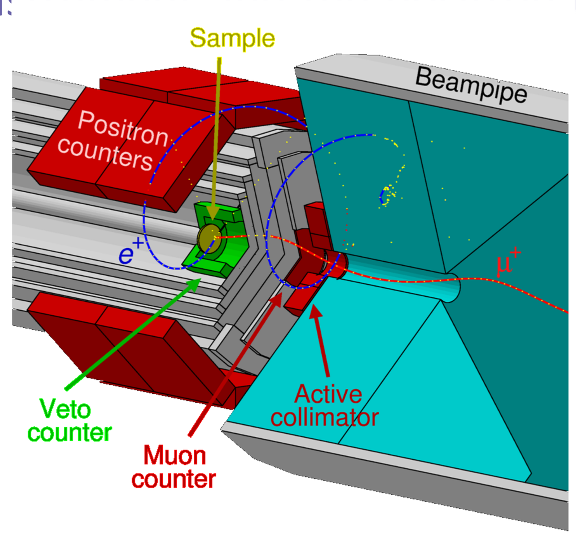
High field spectrometers at ISIS (left) and the SµS

Simulation codes and beam diagnostics for instrument optimisation

A comprehensive suite of codes was developed for instrument simulation. Modelling includes the profile of the muon beam through the instrument and the positron track to the detector.

Accomplishments

- Simulation codes based on Geant4 to model Incident muons and track decay positrons to the detector. Materials and field profiles are included
- Tool for analysing simulation results for various acquisition parameters
- Development of a field-insensitive beam camera for beam imaging in High Magnetic Fields



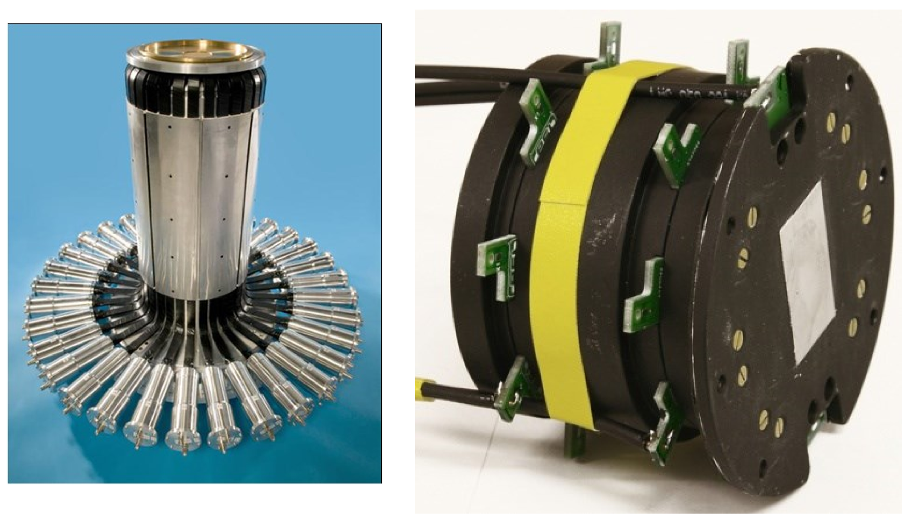
A study of the detector geometry and positron trajectories for the SµS high transverse field spectrometer

Detector optimisation

Significant work was carried out by simulation and experiment to optimise the instrument detector arrays for high magnetic field measurements.

Accomplishments

- **ISIS instrument:** successful use of extended light guides to move the field-sensitive photomultiplier tubes to a low field region
- **SµS spectrometer:** development of a novel detector array based on Geiger-mode avalanche photodiodes
- Fast-timing demonstrated to 9.5T, results insensitive to field



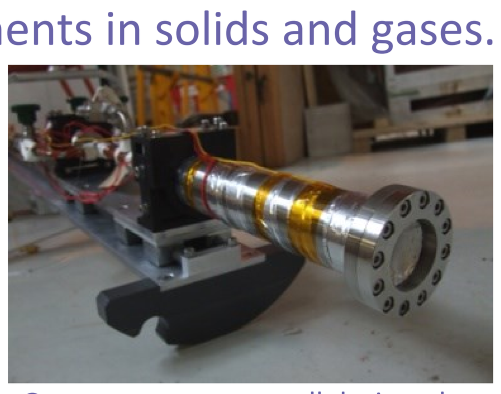
Detector array from the ISIS instrument (left) and a prototype detector module based on avalanche photodiodes developed at the SµS

µSR under Pressure!

Pressure is an important parameter in the investigation of the phase diagram of condensed matter systems. Its study might reveal new physical properties of materials. We developed sample environment for pressure measurements in solids and gases.

Accomplishments

- Solid sample pressure cell operating to 2.5GPa, optimisation of muon stopping range for low background
- Provision of gas target pressure cells for the ISIS high field spectrometer
- Possibility of RF techniques in the gas phase



Gas target pressure cell designed for the ISIS high field spectrometer

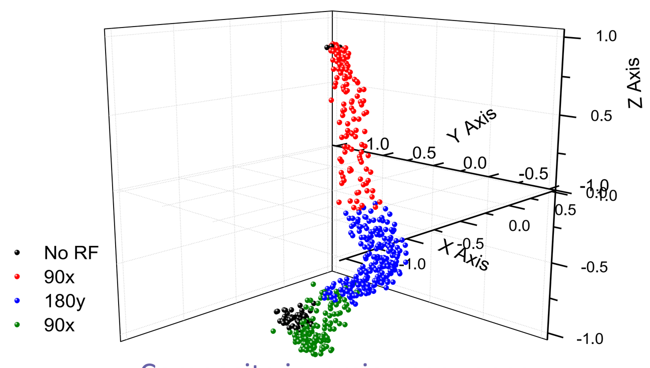
Novel Resonance Techniques

Novel NMR-style pulsed radio frequency (RF) resonance techniques were explored as a means of obtaining new information from µSR experiments.

Accomplishments

- New double resonance method where both muon and nuclear spins are simultaneously irradiated to decouple the nuclear dipolar interaction
- New composite spin inversion sequence for improving accuracy for RF spin rotation in RF µSR experiments
- Development of an NMR system to enable off-line tests of RF cavities
- Development of a high power RF insert for the ISIS high field spectrometer

RF insert for helium cryostat



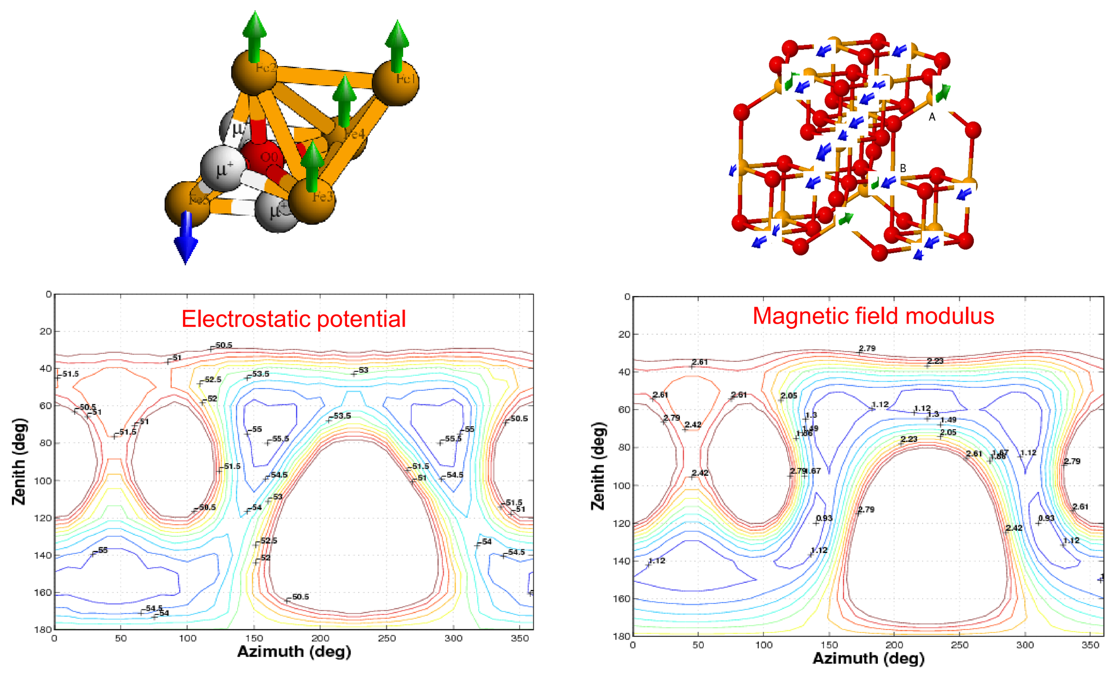
Composite inversion sequence

New software for data analysis: Simulation codes and Data Formats

We have explored new software methods both to support the analysis of complex experiments and to help the community share data and software between facilities.

Accomplishments

- Development of code to calculate electrostatic potentials and magnetic dipolar fields within magnetic materials
- Development of DFT methods for determining the muon site and hyperfine couplings of molecular muoniated radical species
- Extended NeXus file format for use at PSI and ISIS, with a subset proposed as a common exchange format for muon data



Visualisation of a structure and magnetic moment (top) and a search for muon sites by mapping electrostatic potentials and magnetic dipolar fields. Simulated µSR signals can be compared to experiment.

Further Research – During the second project under FP7 we are…

- **Software development for muon data analysis**
  Developing new data reduction methods , integrating analysis with simulation
- **Concept studies for future muon sources**
  Evaluating the potential for a muon micro-beam, studying target technologies and considering next generation muon production
- **Detector technologies**
  Evaluating SiPM detector technologies for use at a pulsed muon source

Recent publications

- N.J. Clayden *et al; J. Magn. Res.* 214, 144 (2012)
- A. Stoykov *et al; Physics Procedia* 30, 7 (2012)
- Z. Salman *et al; Physics Procedia* 30, 55 (2012)
- K. Sedlak *et al; Nucl. Instr. Meth. A* 696, 40 (2012)
- V. Vrankovic *et al; IEEE Trans. Appl. Supercond.* 22 (2012)
- A. Stoykov *et al; Nucl. Instr. Meth. A* 695, 202 (2012)
- S.F.J. Cox *et al; Physics Procedia*, 30 (2012)
- R. C. Johnson *et al; Phys. Rev. B* 86 (2012)
- N. Egetenmeyer *et al; Phys. Rev. Lett.* 108 (2012)
- Z. Shermadini *et al; Phys. Rev. B* 86 (2012)
- K. Sedlak *et al; Physics Procedia* 30, 61 (2012)
- S. Cottrell *et al; Physics Procedia* 30, 20 (2012)
- K. Mukai *et al; J. Appl. Phys.* 113 (2013)
- G. Prando *et al; Phys. Rev. B*, 87 (2013)

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