Section 1: Muon Spin Rotation

Muons are elementary particles belonging to a family of particles called leptons that includes the more familiar electron. One can think of the positive muon as a light proton with a mass of one ninth of the proton mass and magnetic moment approximately 3.2 times larger than that of the proton. The availability of a spin polarized 4.1 MeV positive-muon beam has opened up the possibility to use muons as an extremely sensitive and versatile magnetic microprobe. Surface muons have an energy of 4.1 MeV and they therefore have a stopping range in a solid that varies from 0.1 to 1 mm.

Positive muons decay to a positron, muon antineutrino and electron neutrino. The angular emission of positrons is well characterised, with the emission direction being correlated with the muon's spin at time of decay. Thus, by measuring the direction and the timing of a statistically significant number of decay positrons it is possible to follow directly the evolution of the muon's spin ensemble as a function of time after implantation. This allows a wealth of information to be gained about the host material in which the 100% spin polarised muons are implanted and come to rest. They can act as passive local magnetic microprobes, for example directly measuring magnetic field distribution at the implanted site with very high sensitivity (less than 0.1 mT). Being able to follow the evolution of the spin with time means that the magnetic field experienced by the muon can be determined through the measurement of the Larmor precession of the muon spin. In a magnetic field the spin will precess about the field direction with a frequency ω_μ proportional to the field B

$$\omega_\mu = \gamma_\mu B \qquad\qquad (2.1)$$

where $\gamma_\mu/2\pi = 135.5$ MHz T^{-1} is the gyromagnetic ratio for the muon.

The spin rotation can be observed using two (or more) positron counters, *a* and *b*, mounted on the opposite sides of the sample. The number of positrons detected by each counter as a function of time ($H^a(t)$ and $H^b(t)$) reflects the time dependence of the muon spin polarisation along the axis of observation defined by the two detectors:

$$H^a(t) = N_0^a \cdot \exp\left(-t^a / \tau_\mu\right) \cdot \left[1 + A^a(t)\right] + C^a \qquad (2.2)$$

$$H^b(t) = N_0^b \cdot \exp\left(-t^b / \tau_\mu\right) \cdot \left[1 + A^b(t)\right] + C^b \qquad (2.3)$$

where $N_0^{a,b}$ is the initial counts at zero time, $\tau_\mu \sim 2.2\mu s$ is the muon's lifetime, $C^{a,b}$ is the time independent background and the asymmetry $A^{a,b}(t)$. The asymmetry contains all of the information about the time evolution of the muon's spin polarisation.

Section 2: Low Temperature Ordering of Sm Moments
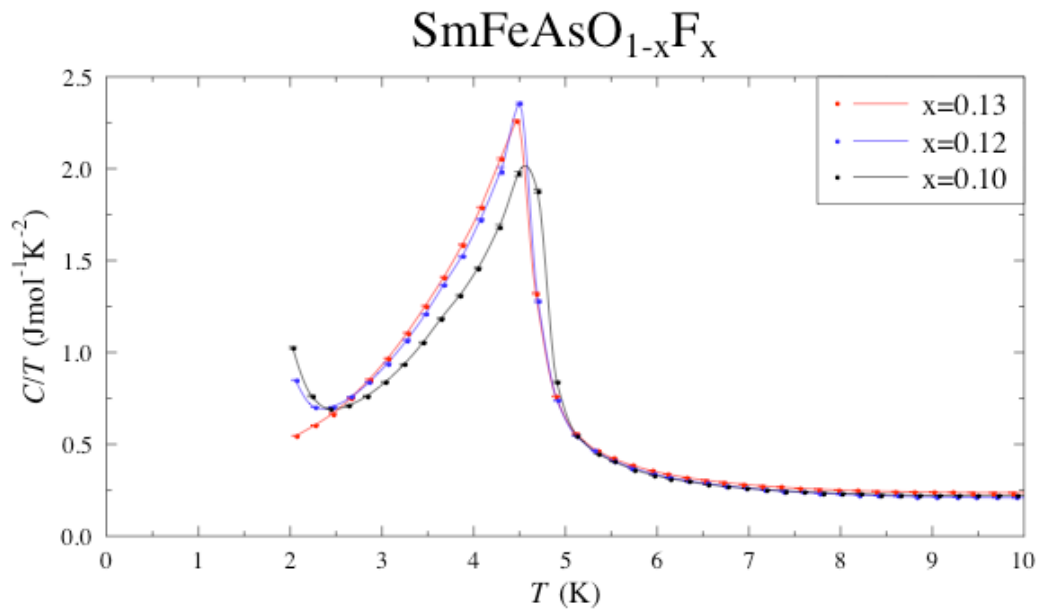
$$SmFeAsO_{1-x}F_x$$

Figure 1: Heat capacity measurements showing the Sm moments ordering at low temperatures for three different dopings.
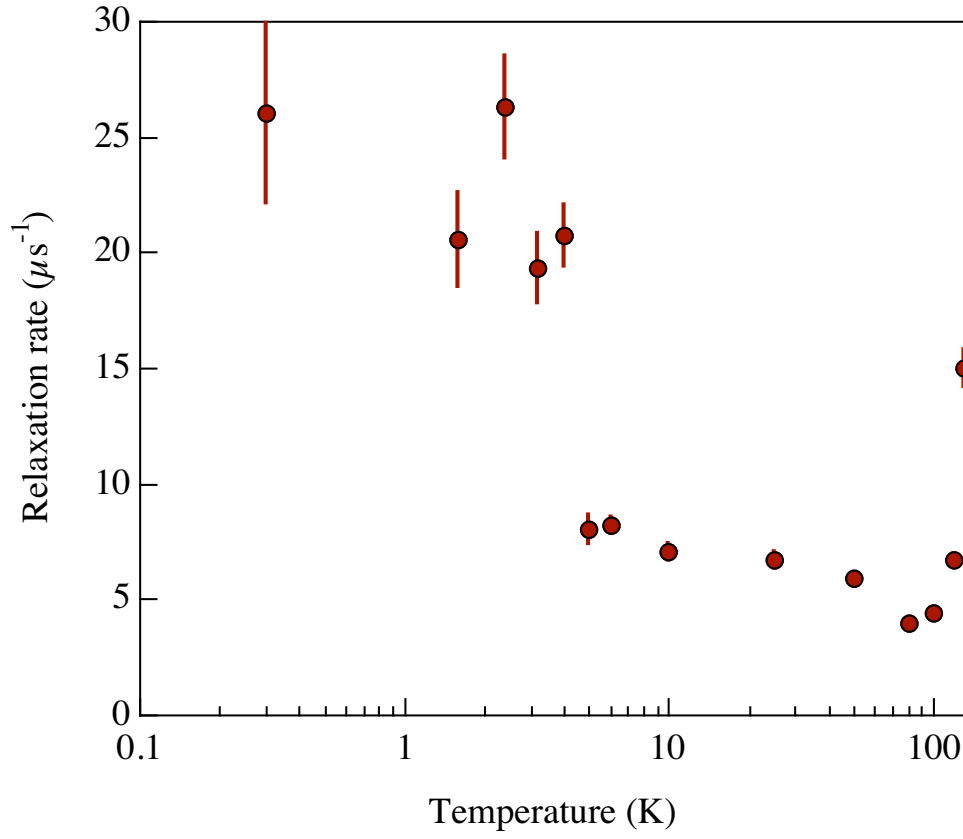
Figure 2: The Gaussian relaxation rate of the 23MHz oscillation (in the undoped parent compound), where a clear and dramatic increase is observed at T < 5 K, corresponding to the Sm moments ordering.
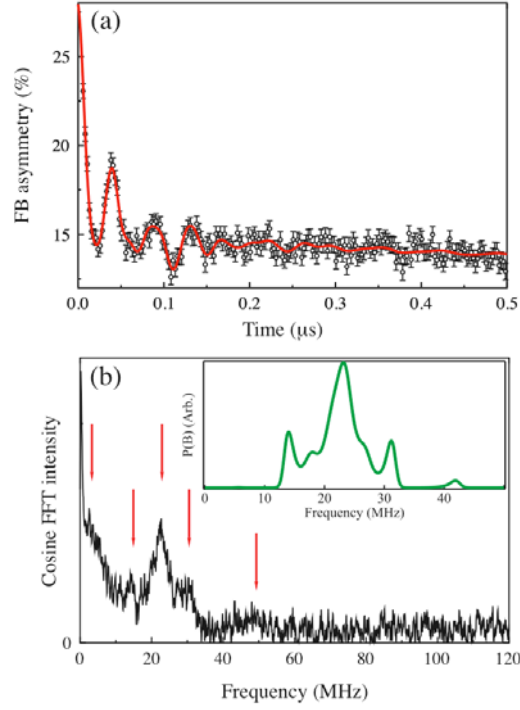
Figure 3: ZF-mSR spectra and analysis for the undoped parent compound at 0.3K. (a) A fit (red line) to the time domain data (black points) using a five component Gaussian relaxed oscillation. (b) The Cosine transform of the data shown in (a), where five peaks are clearly observed. The red arrows mark the frequencies obtained from the time domain fits. The inset shows a maximum entropy transform of the data shown in (a). We note that the maximum entropy algorithm has difficulty resolving low frequencies, and as a consequence only the four highest frequencies are observable. The additional frequencies observed at 0.3K are not present in the higher temperature data, which only show the 23 MHz signal (Fig. 1a of the main paper), suggesting that they are related to the ordering of the Sm moments at low temperatures.