Zero-field spin relaxation of Low energy Muons In ferromagnetic nickel and silver

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Abstract

LE-μSR is a unique technique that relies on the moderation of muons from 4 MeV to "slow muons" of few keV energies. However, the beam spot of the moderated muons at the sample position is about 2 cm in diameter [1]. This limits the study of small samples especially high purity single crystals [2]. Using LE-μSR to study small samples faces the challenge of differentiating the signal of the small fraction of the muons stopping in the sample from the the larger fraction landing elsewhere. Suppressing the background signal also helps to resolve a weakly relaxing signal, for example due to spontaneous magnetization in time reversal symmetry breaking superconductors such as SrRuO. [3] or possibly in YBCO [4,5].

The background problem can be overcome by using a backing plate covered by a well studied material such as silver or a ferromagnetic material (FM), which contributes a slow or non-relaxing signal, that can be distinguished from the signal of the studied sample. In a ferromagnetic like Ni, the fraction of muons that miss the sample experiences a broad distribution of static internal magnetic fields (~1 kG), and hence exhibits a fast relaxing asymmetry to a 1/3 slow relaxing tail during the first 100 ns, minimizing the background contribution to the overall signal [2]. the Silver is an alternative backing material because of its temperature and energy independent and large asymmetry.

Experimental setup

- μ^+ are transported from the moderation chamber with an energy of 15 keV.
- These muons are sent to the sample plate which is biased to a high voltage (-13 to 13 keV).
- This allows for energies between 0.5 to 30 keV, corresponding to up to 300 nm depth.
- The plate is coated with 125 microns of nickel or silver.

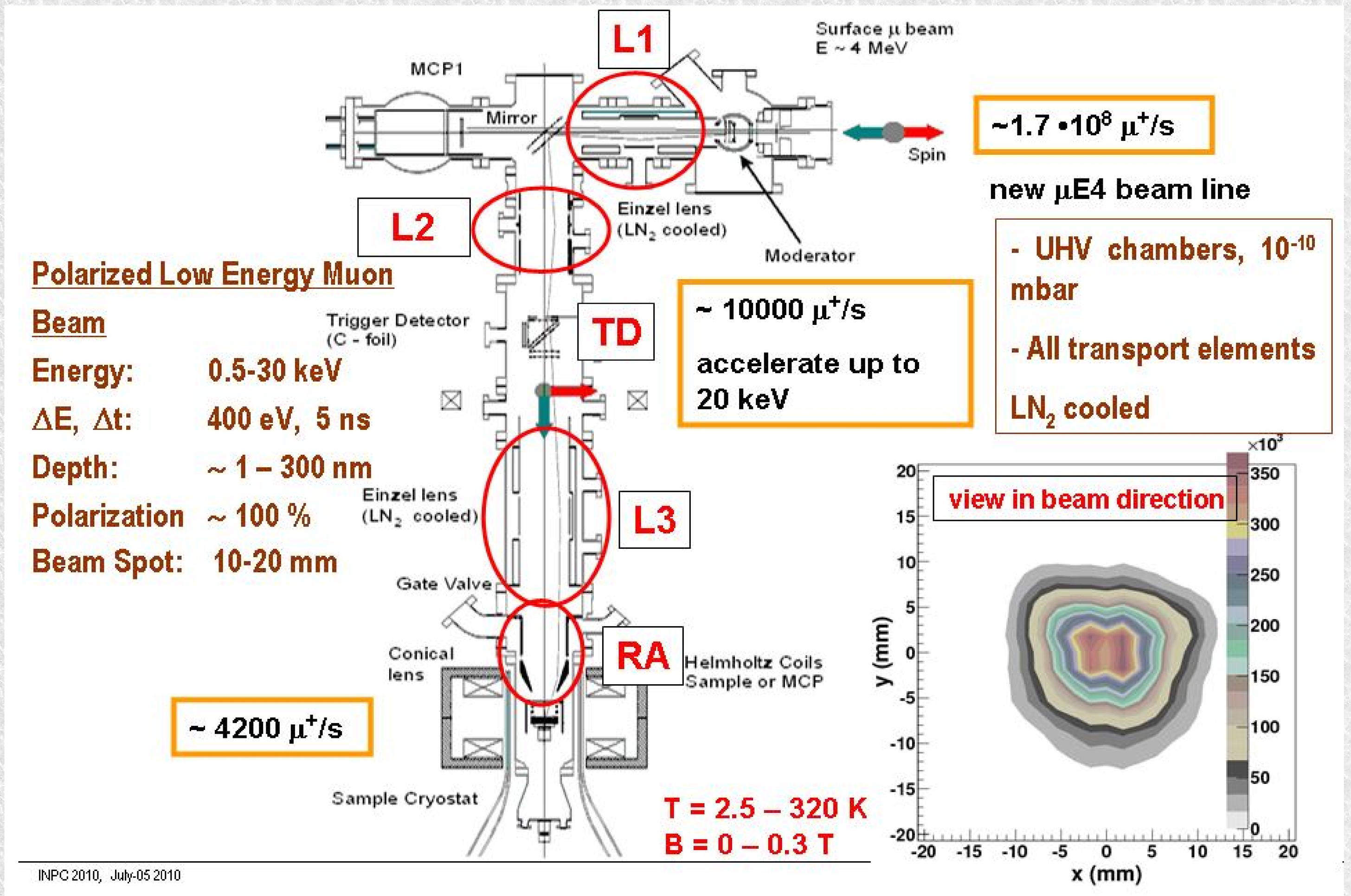
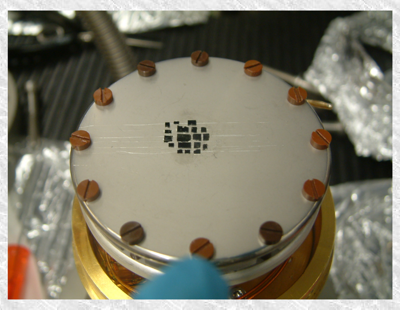


Figure 1.1: Sketch of LEM apparatus. The rates are for a proton current of 2mA. The total muon rate entering the LEM apparatus is 4.2×10^{8} s; 40% are hitting the $3\times3\,cm^2$ moderator target.



Small YBCO single crystals mounted onto a Nickel coated plate

Typical spectra

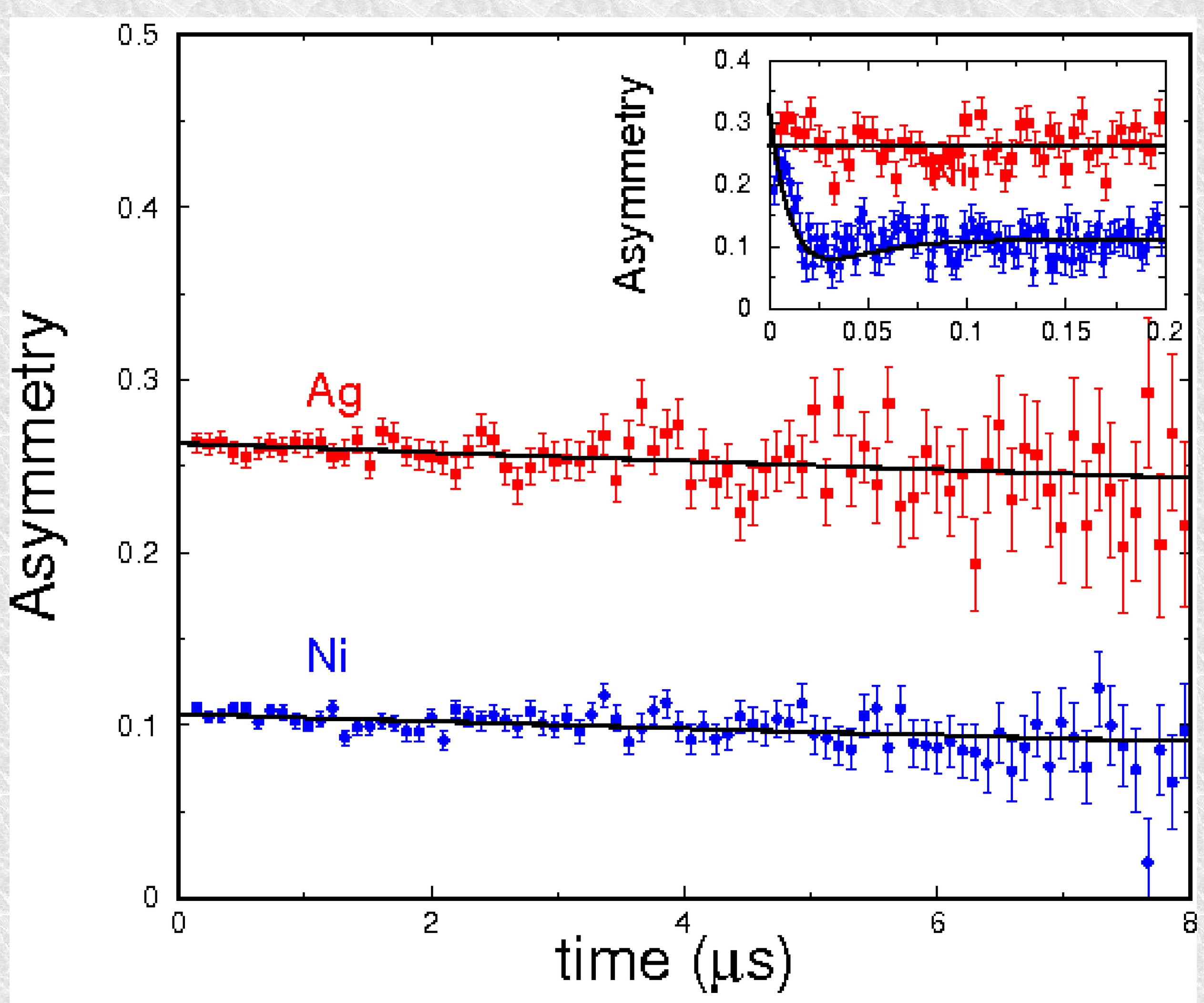


Figure 1: A typical asymmetry of 14 keV muons implanted in Ni and Ag in zero field at 100 K. The solid lines are fits done using a single exponential. Inset: asymmetry in the first 200 ns fit with a Kubo-Toyabe Lorentzian function in nickel and an exponential in silver.

Since the Ni is ferromagnetic with a Curie temperature of T_C = 631 K, the implanted muons experience a large hyperfine field, and the corresponding spin polarization precesses and depolarizes during the first 100 ns. This fast-relaxing signal is thus removed from the time window of interest, and one fits the weakly relaxing asymmetry which represents 1/3 of the initial asymmetry.

Energy dependence

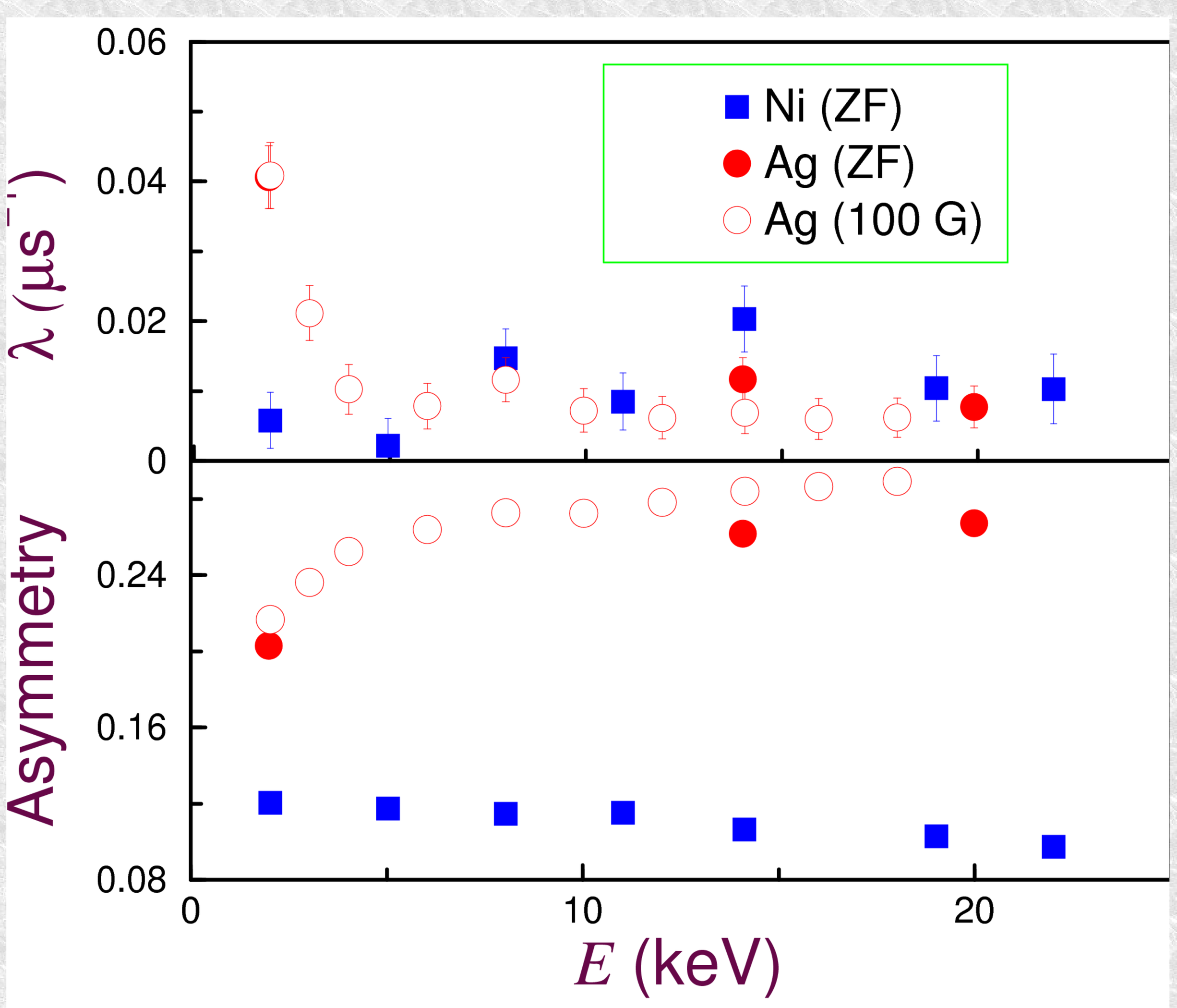


Figure 2: The energy dependence of the relaxation rate (top), and the asymmetry (bottom panel) in nickel (squares) and silver (full circles), measured in zero field and 5 K, and in silver (opaque circles), measured in a transverse field of 100 G and 100 K.

The damping rate is energy independent in nickel and is smaller than 0.02 MHz at all energies. In silver, there is a slight increase in the damping rate below 4 keV due to the reflected muons. This also leads to a decrease in the asymmetry.

Temperature dependence

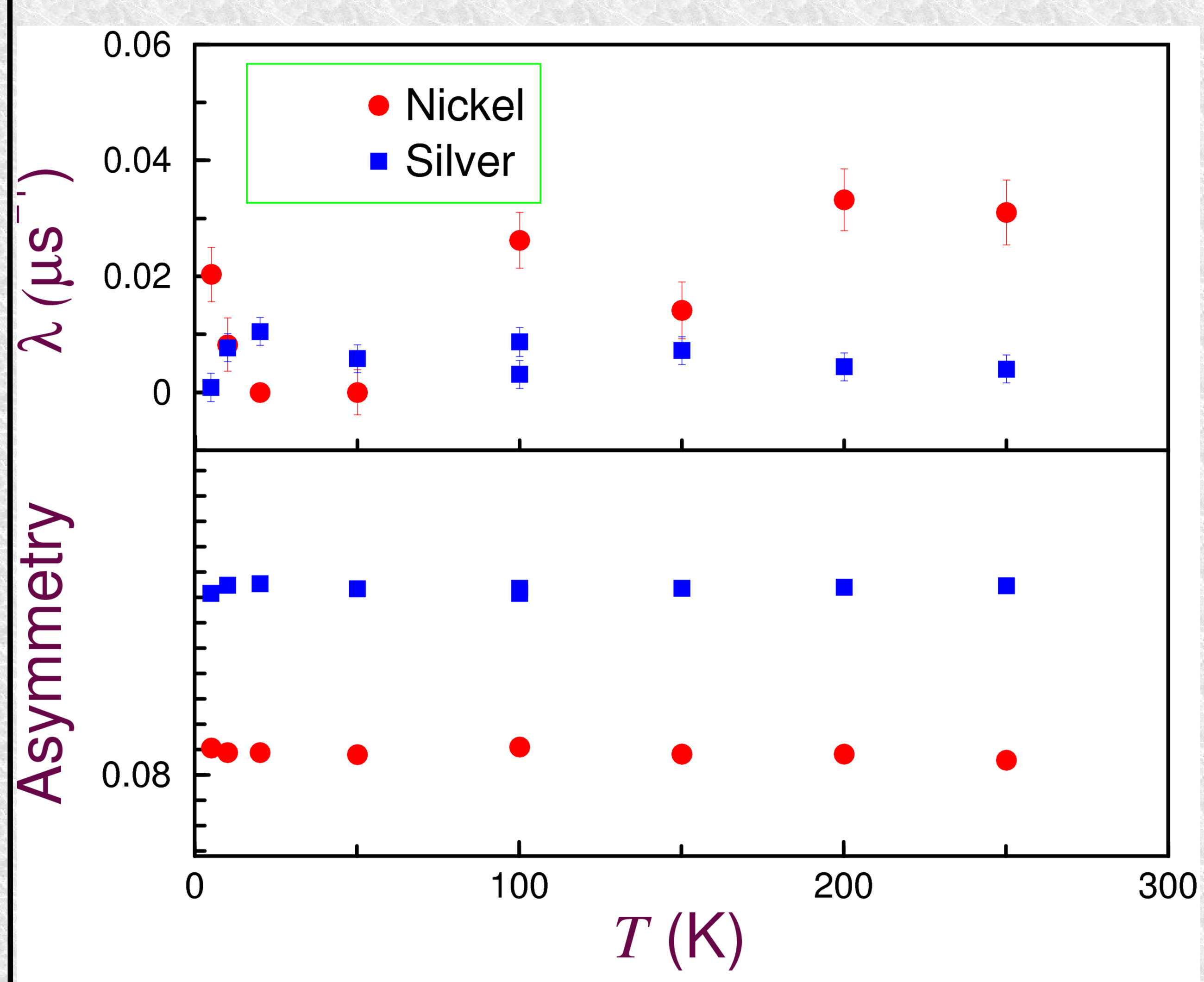


Figure 3: The temperature dependence of the damping rate (top) and asymmetry (bottom) at 14 keV in nickel (red circles) and silver (blue squares), measured in zero field.

This shows that the signal is not temperature-dependent in both nickel and silver. However one observes less statistical scatter of the damping rate in Ag compared to nickel. This is due to the larger measured asymmetry in silver.

Conclusions

Muon spin relaxation in nickel and silver have low relaxation rates of the order of 0.01 to 0.02 MHz. In both materials the observed signal is weakly energy and temperature dependent. Ag is a favorable material when studying temperature dependence of weak magnetism such as in TRSB superconductors as the asymmetry is higher and the damping rate is weaker and flatter than in Nickel. Thus one can easily resolve weak relaxation rates above 0.01 MHz using silver. Nickel, on the other hand, is useful when performing depth dependence studies, as the relaxation rate and asymmetry is not energy dependent, while silver shows a slight upturn in the relaxation rate at low energies. For experiments in an external field, nickel is a favorable as the background signal precesses at a frequency out of the window of interest set by the Larmor frequency.

References

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