Measuring the magnetic properties of monolayers of single molecule magnets

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Outline

- Introduction
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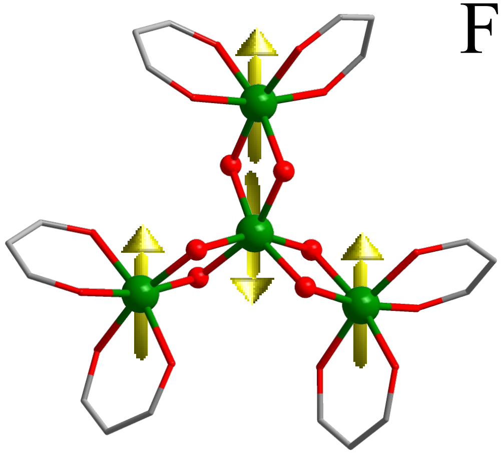
  - Monolayers of SMMs
- Low energy μSR and β-NMR
  - Low Energy β-NMR Measurements
  - Low Energy μSR Measurements
- Summary and Conclusions

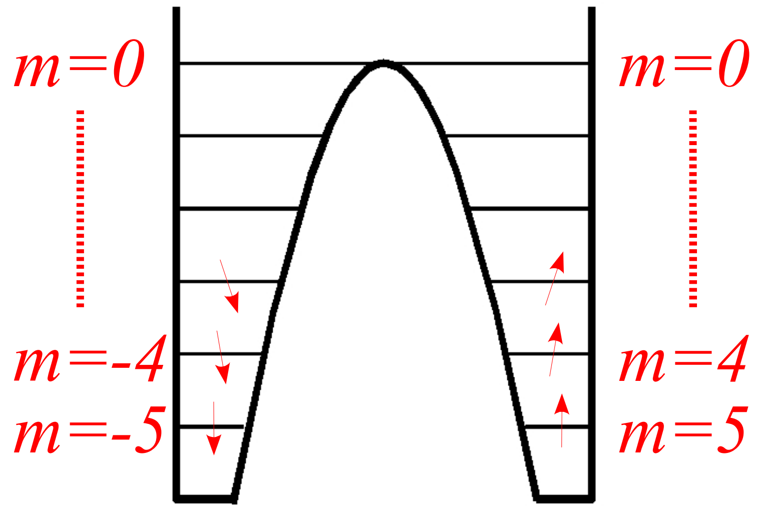
Single Molecule Magnets



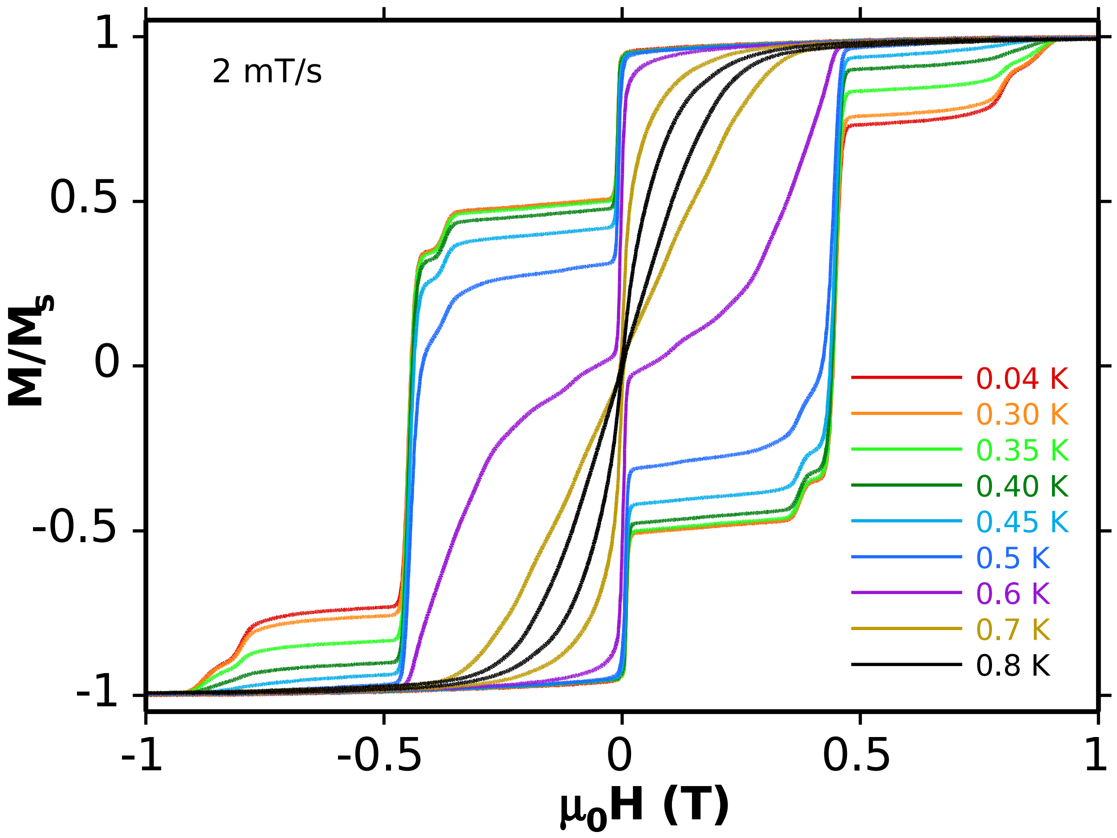
Fe$_4$

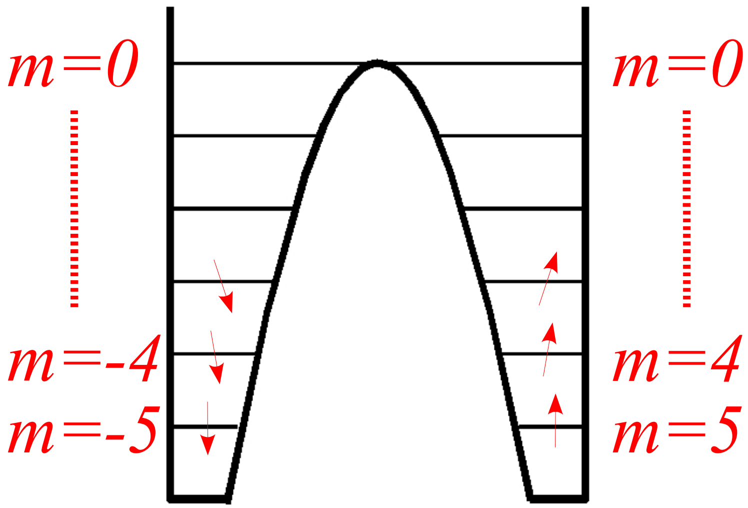
$$\boldsymbol{H} = -DS_z^2 - g\mu_B H_z S_z$$

D=0.64 K, S=5, DS^2=16 K

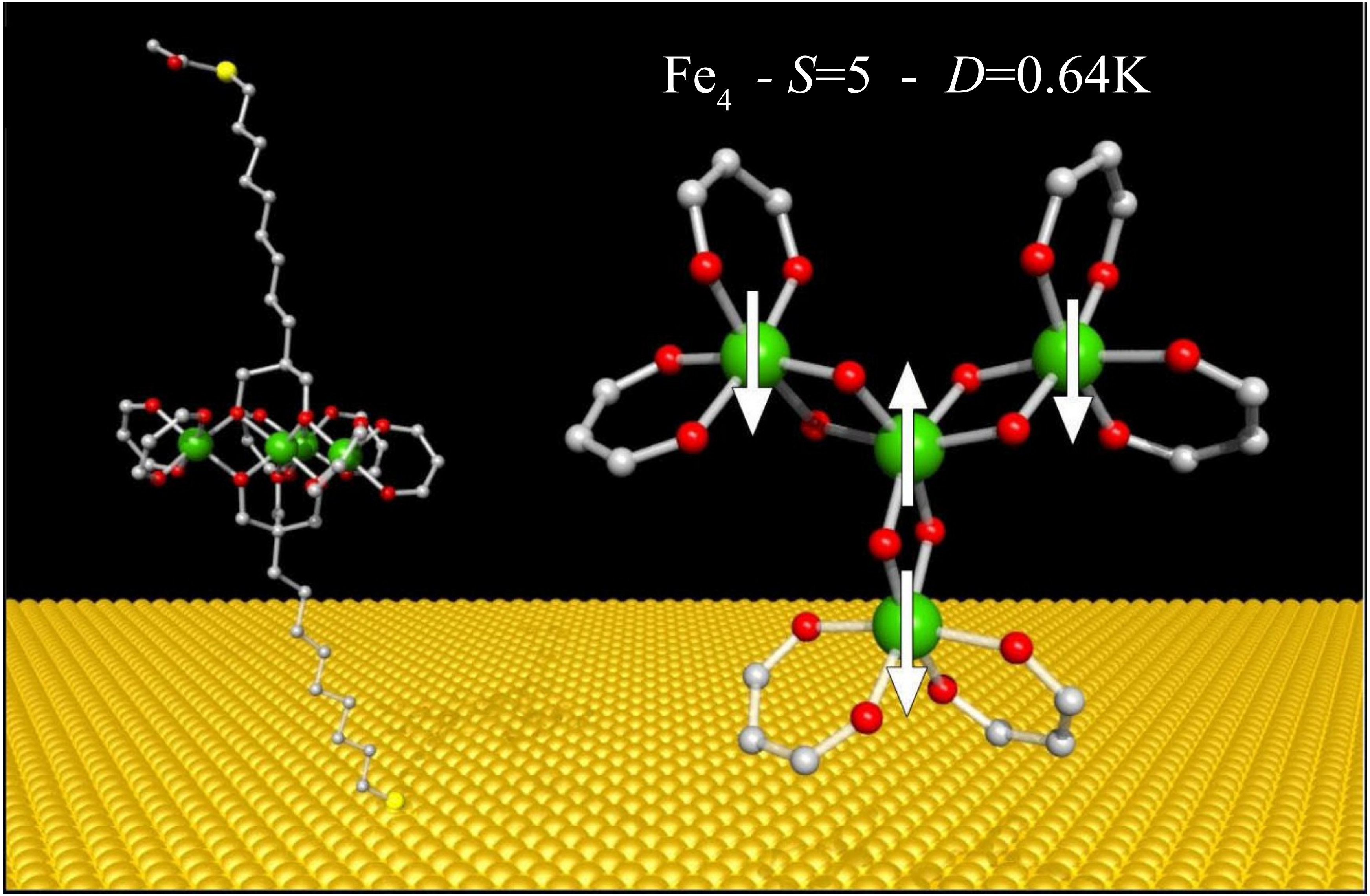


Magnetic Properties of SMMs





Monolayers of Fe_4 on Si and Au



Mannini et al, Nature Mater. 8, 194–197 (2009)

Why Monolayers of SMMs

Motivation to use SMM Mono-layers

- Any potential future application requires addressing individual molecule
- Allows controlling geometry and environmental effects, e.g. dipolar coupling.

Difficulties

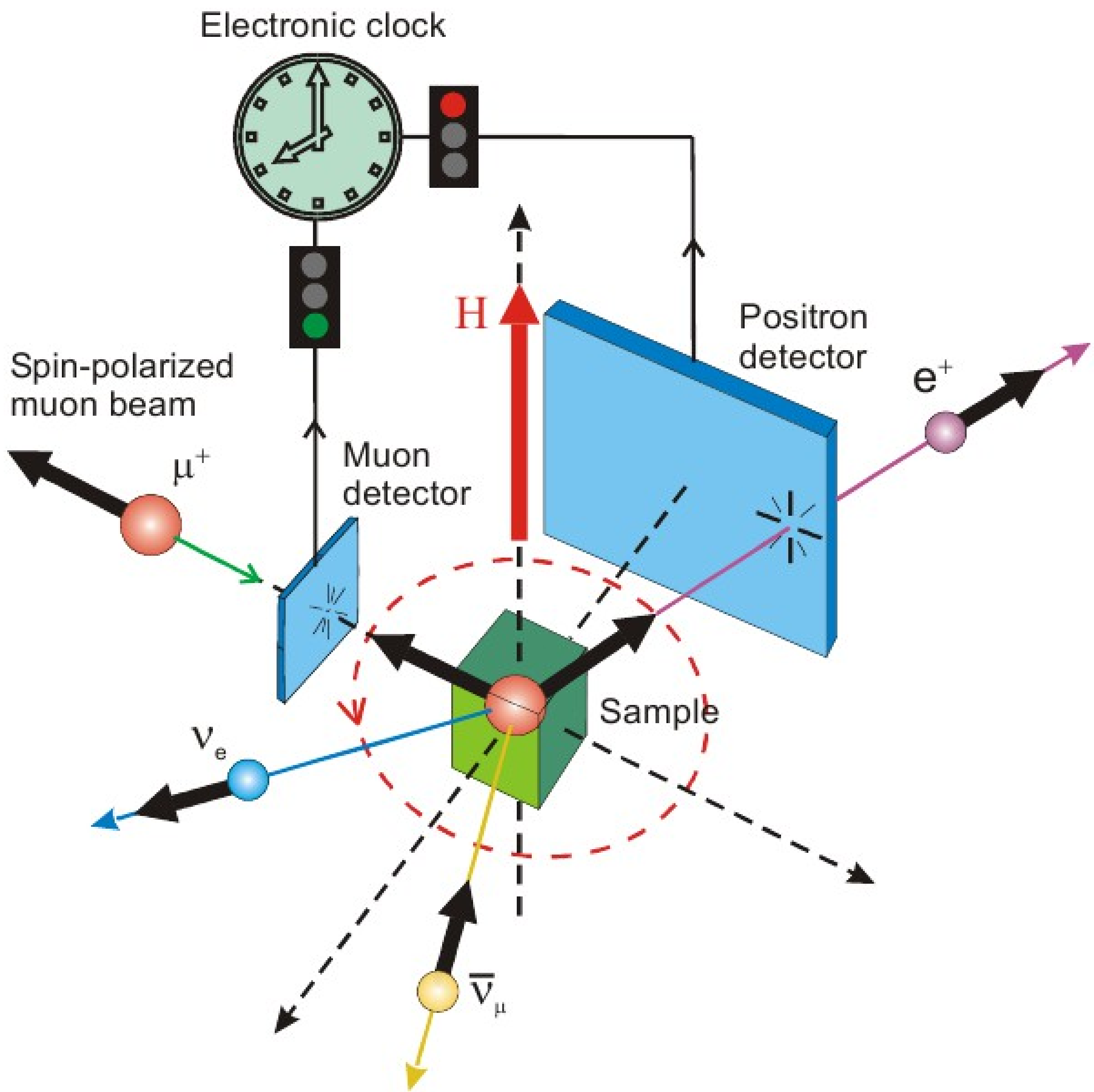
- Cannot be studied by conventional bulk techniques such as magnetometry and NMR.

How do we measure their magnetic properties?

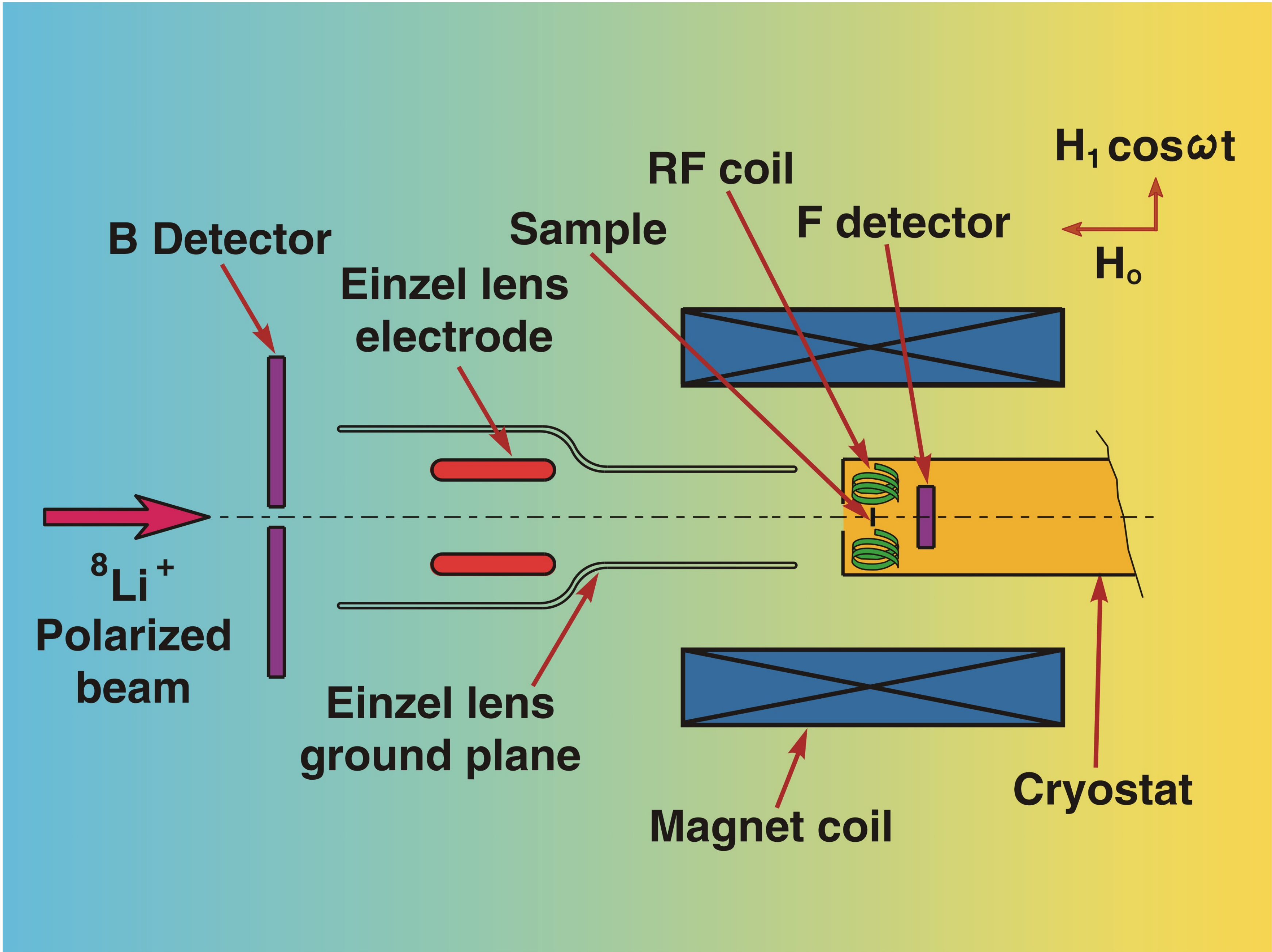
Magnetic Resonance Methods - Comparison

	NMR	μSR	LE-μSR β–NMR
Polarization	<0.01	~1 >0.65	
Detection Method	Electronic pickup	Anisotropic β decay	
Sensitivity	10^{17} spins	10^{7} spins	
T_1 range(s)	10^{-5} - 10^{2}	$10^{-8} – 10^{-4}$	$10^{-8} – 10^{-4}$ $10^{-3} – 10^{3}$
Range	N/A	0.5 mm	10 Å – 4000 Å
Applied field	high	any	any

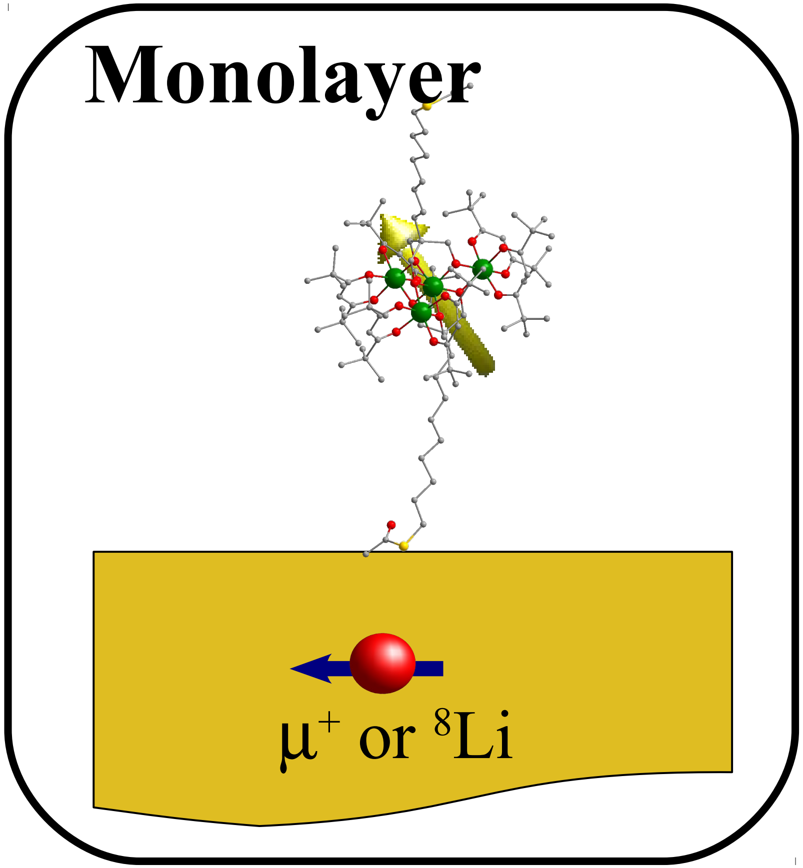
The μSR Technique

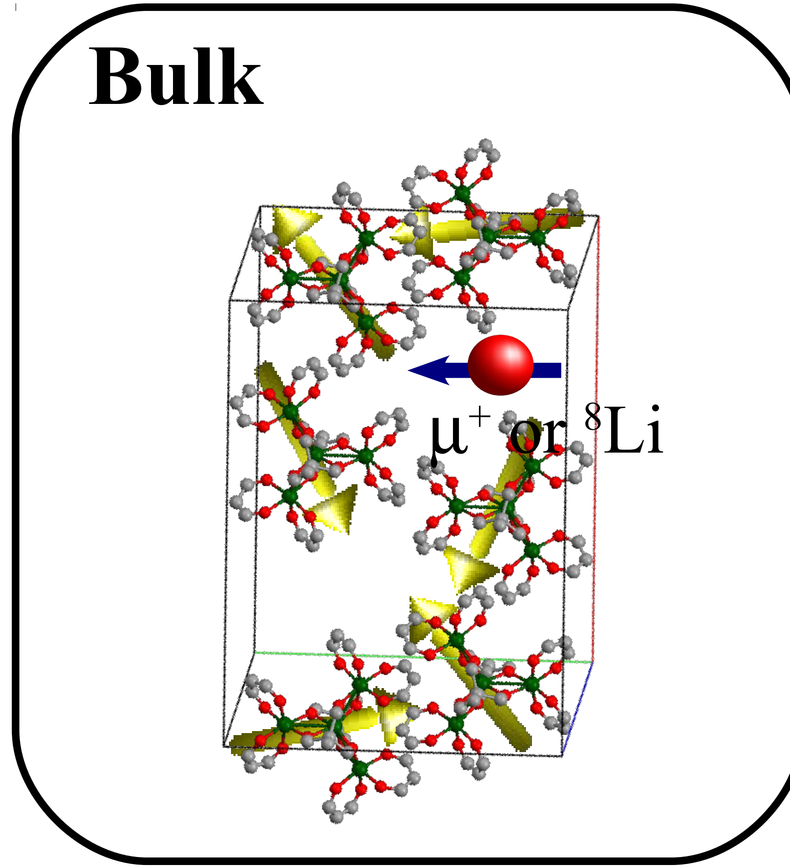


The β-NMR Technique

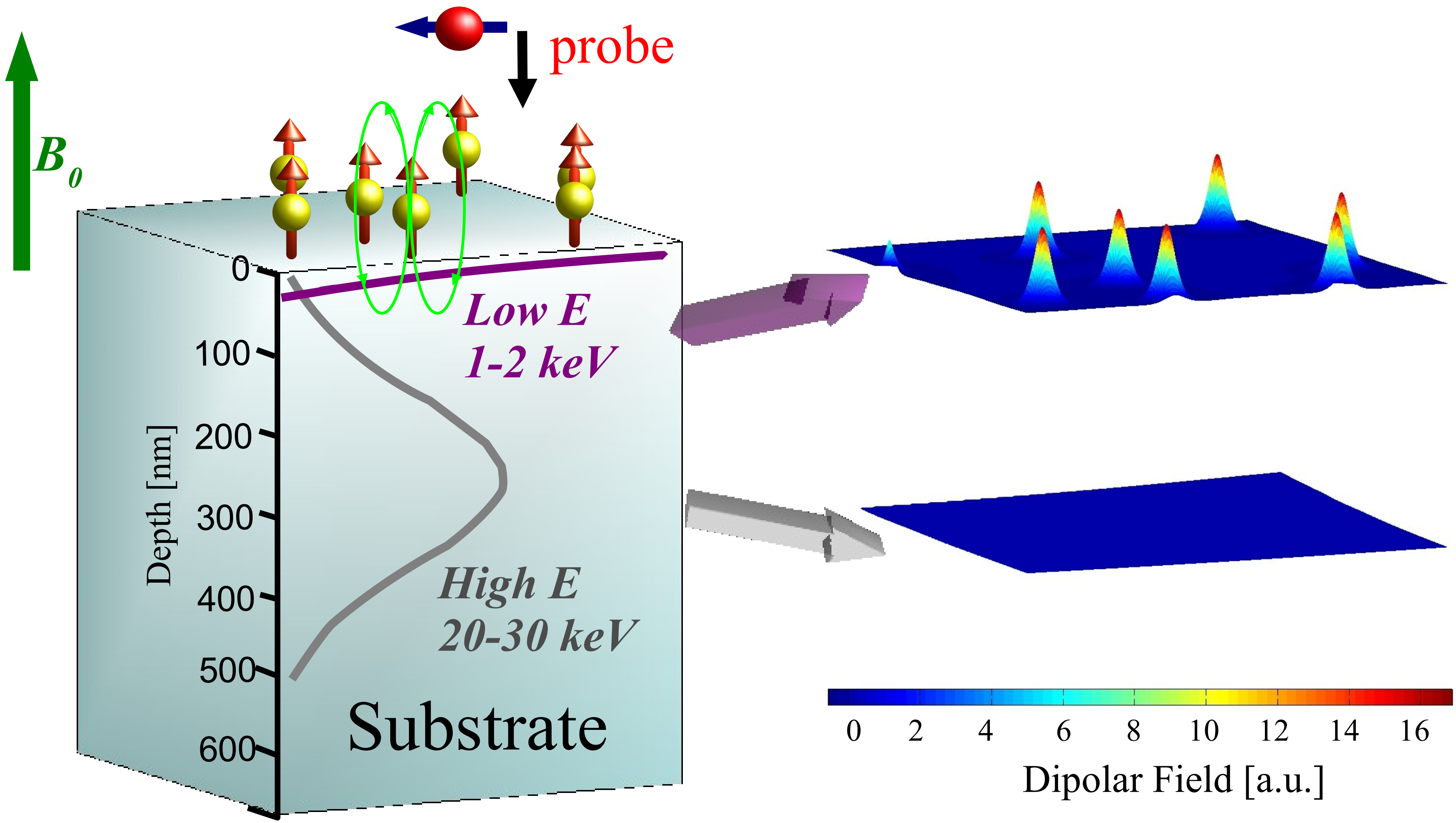


What does the spin probe see ?

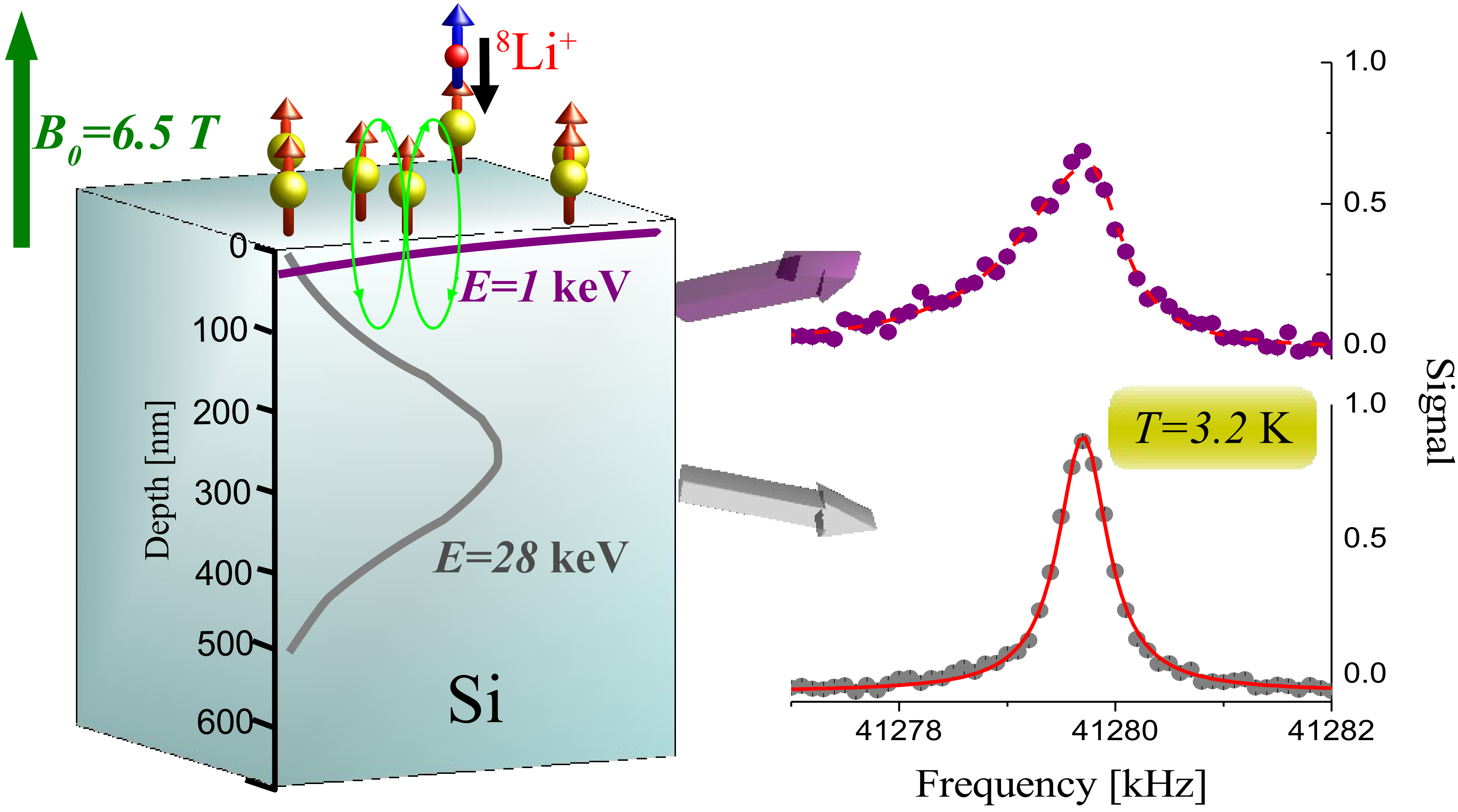




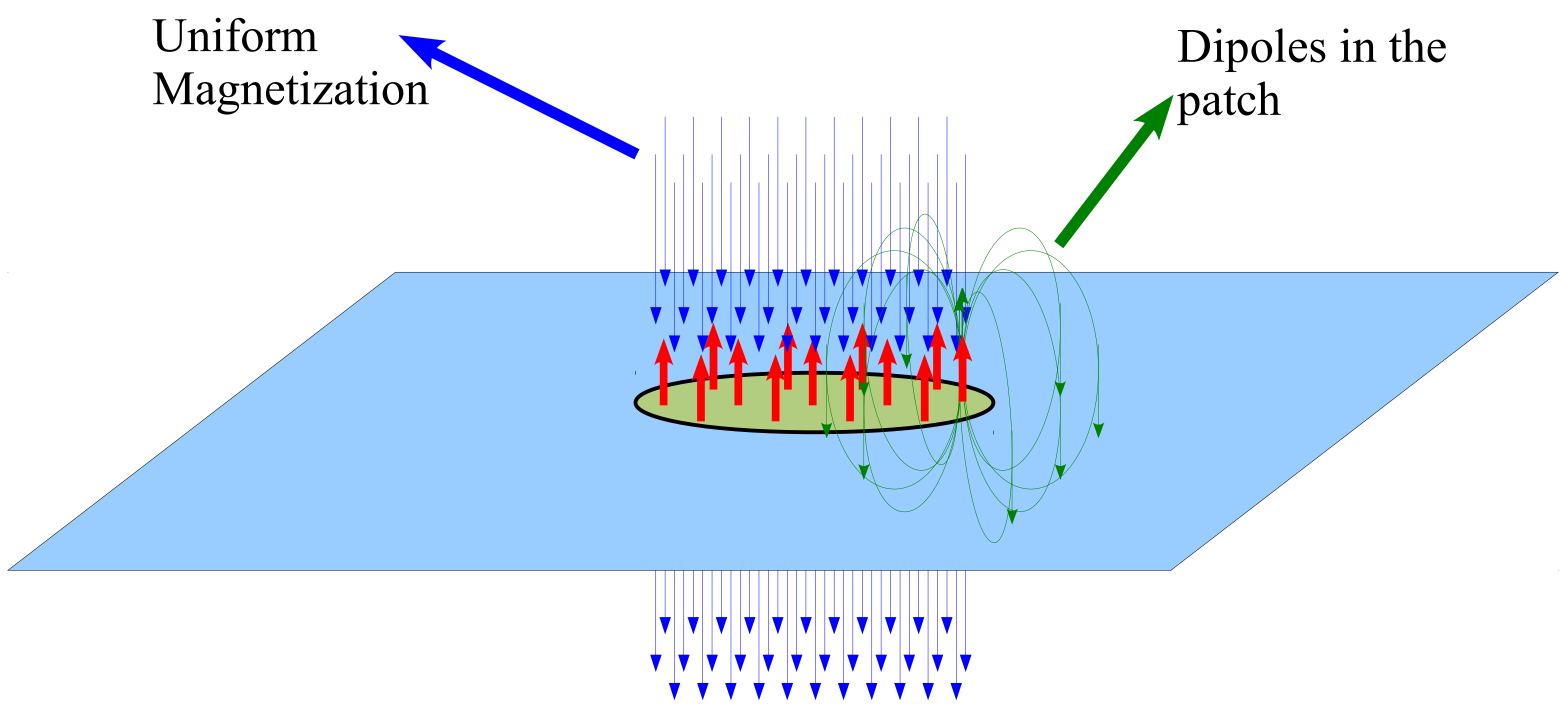
Dipolar Fields in the Substrate



β-NMR in Fe_4 on Si



What do we measure ?



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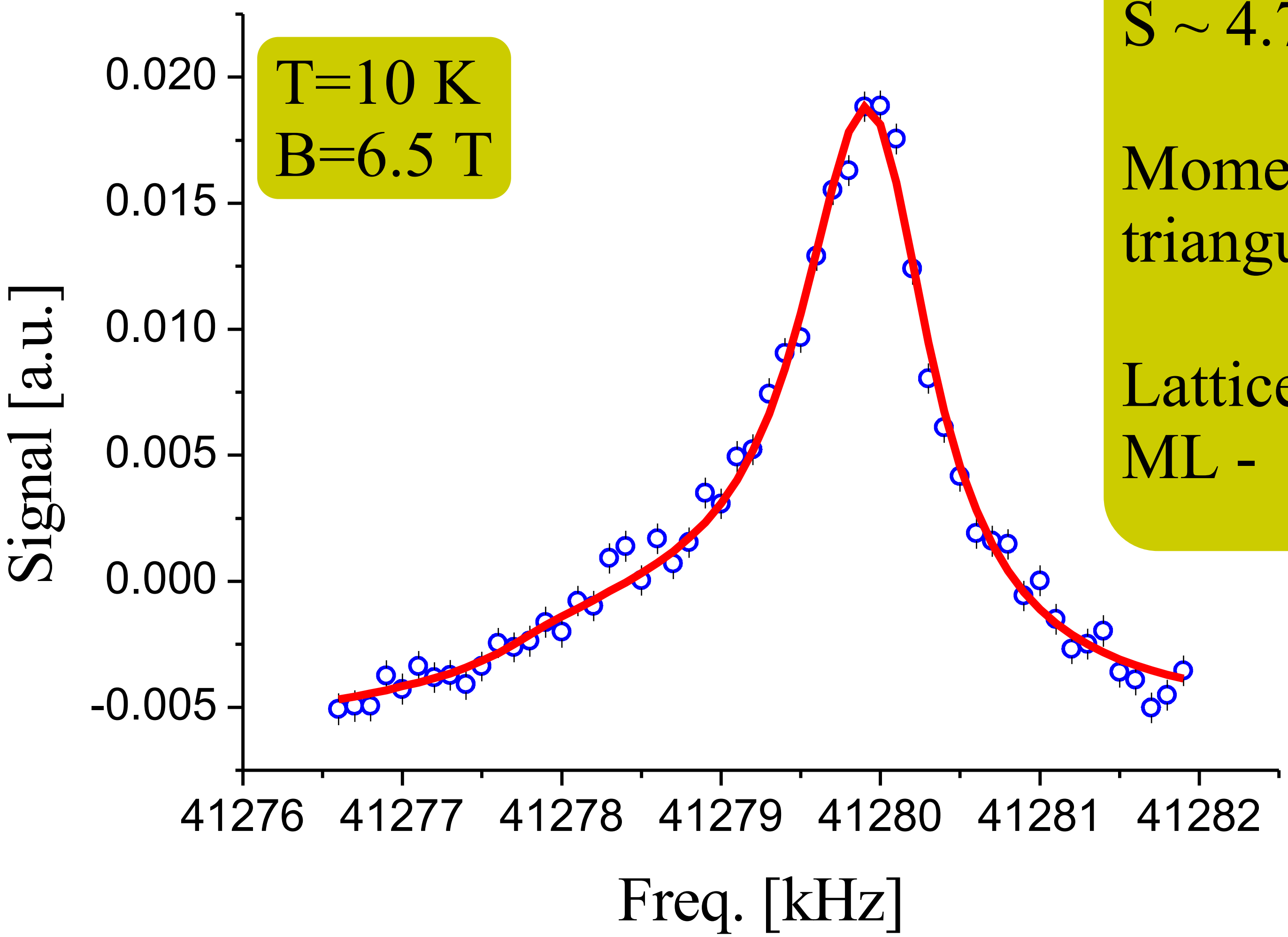


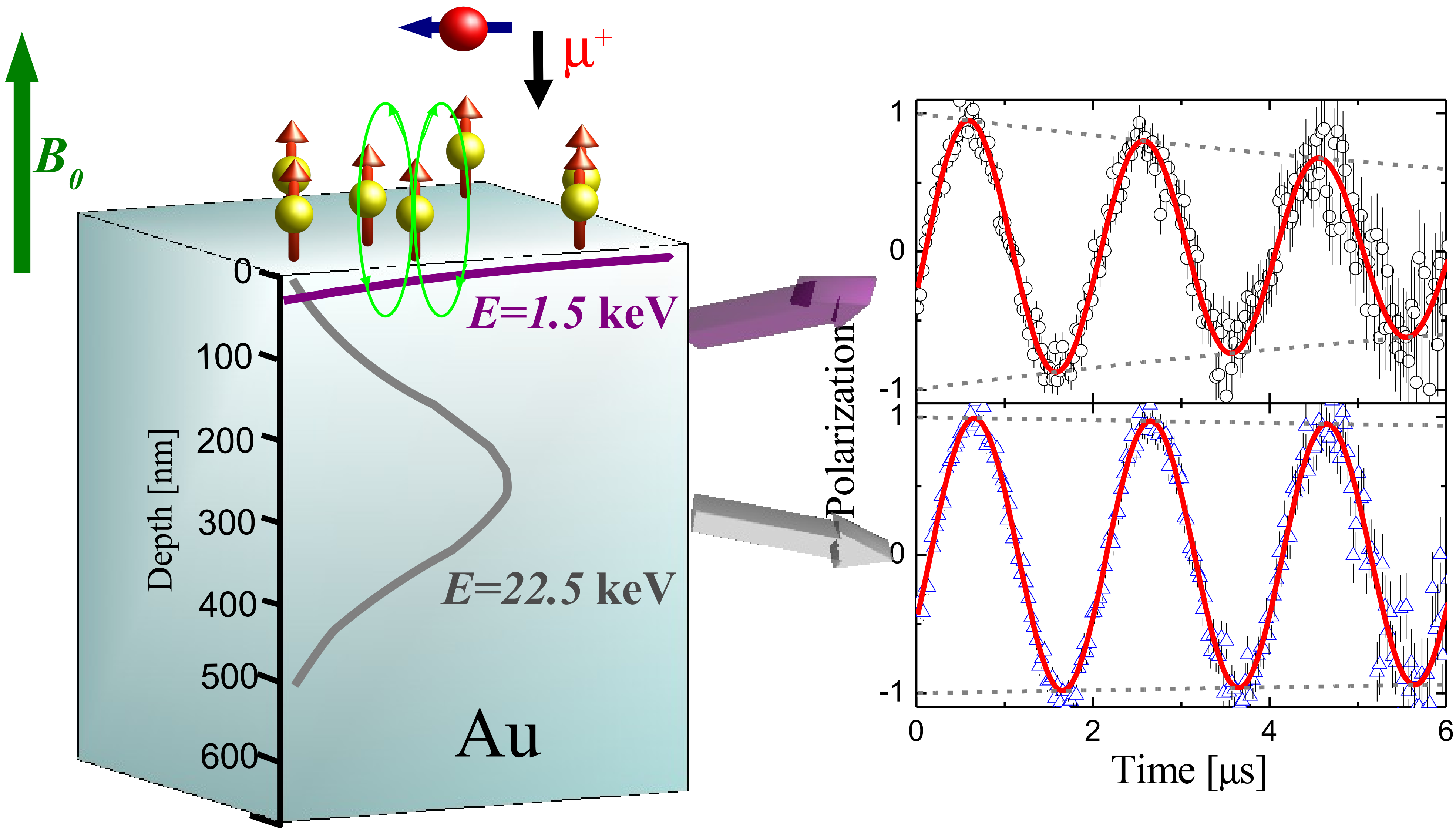
Model line:

S ~ 4.7

Moment on disordered triangular lattice:

Lattice constant	~ 8 nm
ML - substrate	~ 1nm

LE-μSR in Fe_4 monolayer on gold



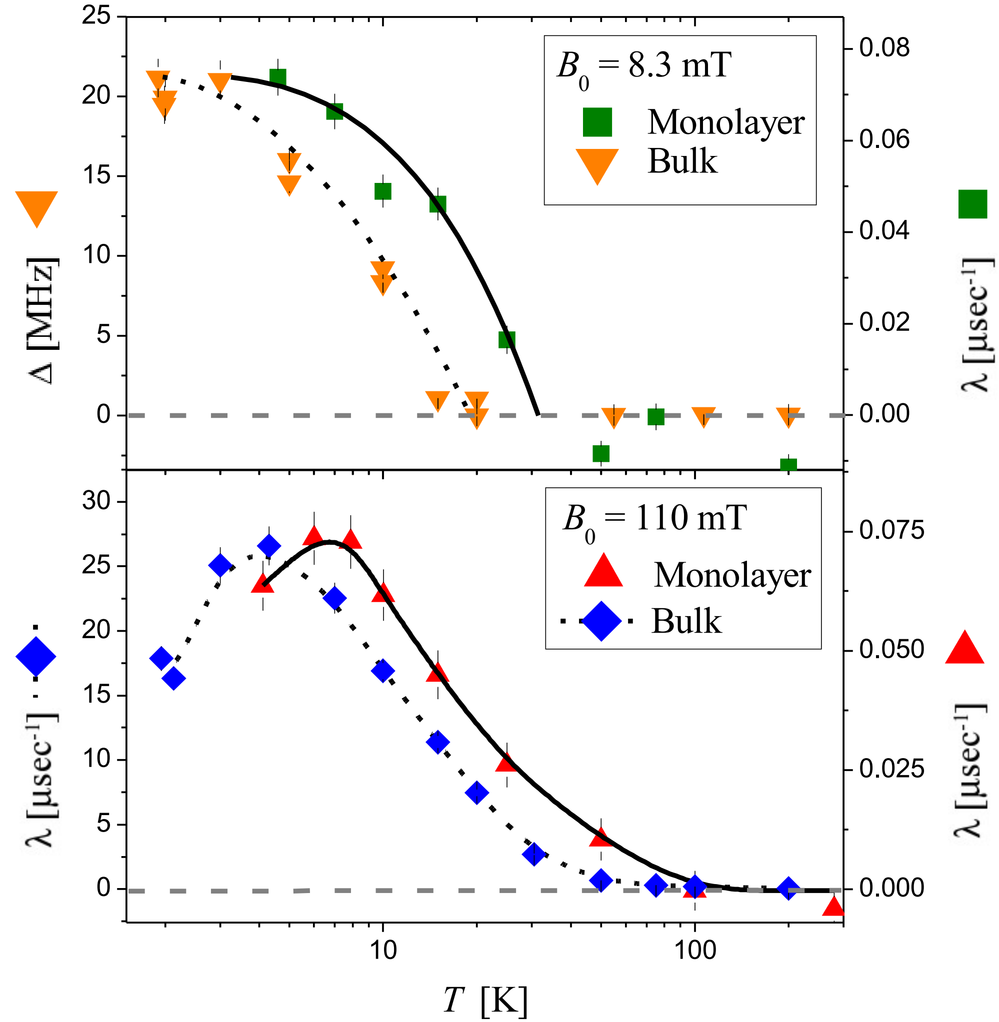
Salman et al, arXiv:0909.4634v1

μSR (Bulk) and LE-μSR (Monolayer) Measurements

In the bulk we observe static magnetic fields below ~20 K.

The relaxation rate in Fe_4/Au scales with the relaxation rate in bulk Fe_4.

There is a exponential *T* shift between LE-μSR compared to bulk μSR measurements.



Salman et al, arXiv:0909.4634v1

μSR (Bulk) and LE-μSR (Monolayer) Measurements

Scaling bulk/monolayer results:

Dipolar fields 300/1, i.e. the muons are ~7 times further from Fe_4

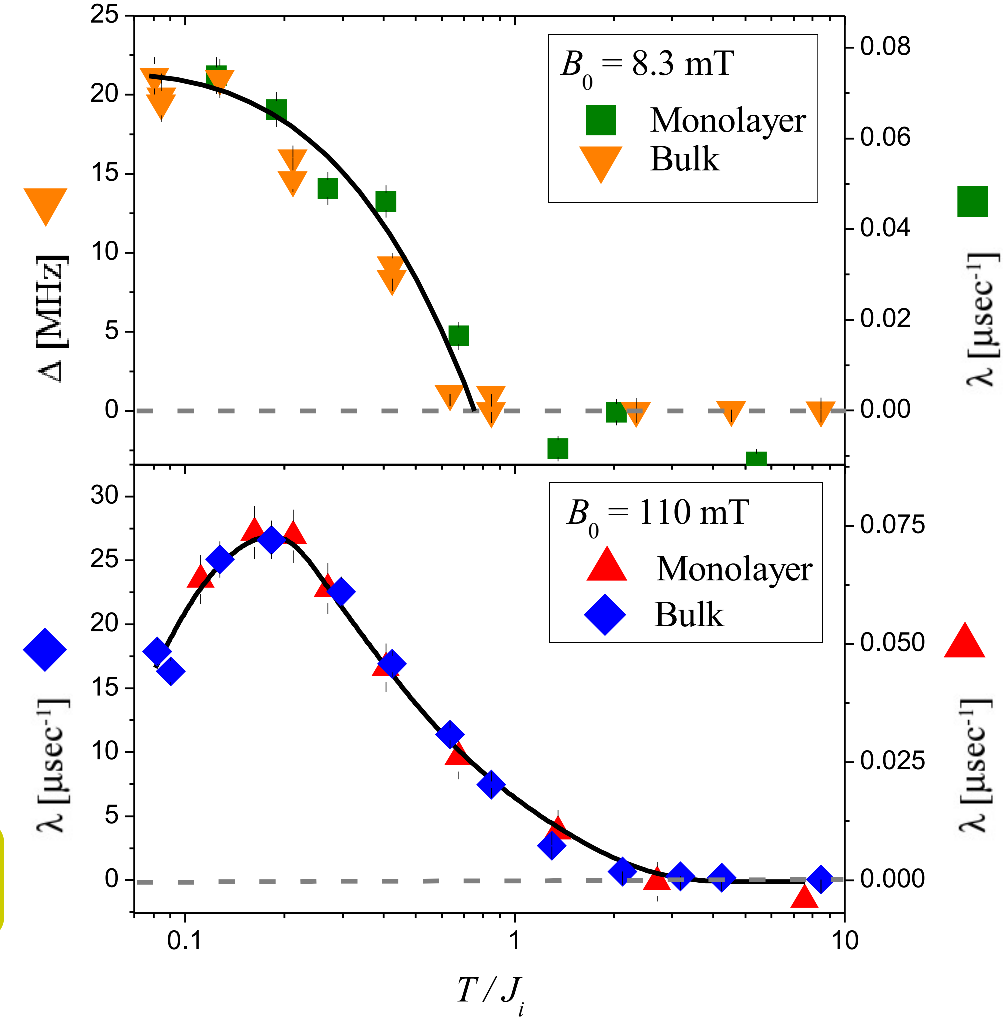
For bulk we know

J_i=23.6 K

To scale monolayer with bulk

J_i=37(1) K

J_i is ~60% Larger in the Monolayer



Summary and conclusions

- Low energy μSR and β-NMR can be used a "proximal" magnetometers. Sensitive enough to measure monolayers of magnetic material.

- Fe_4 SMMs exhibit SMM properties even in monolayers.

- The energy scale of Fe_4 spin states seem to differ from bulk.

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β-NMR

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and thank you ...

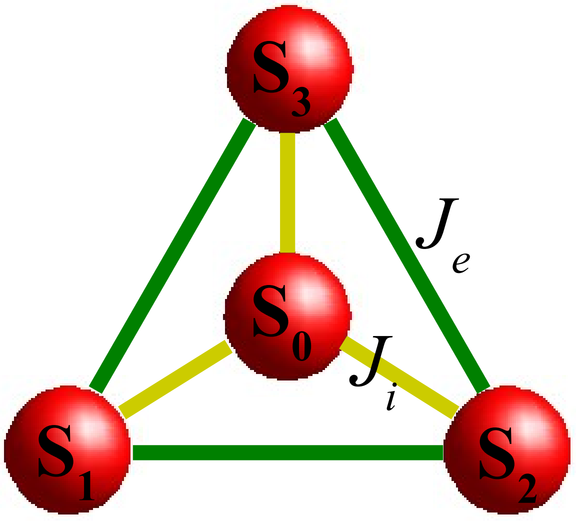
Fe_4 Spin Hamiltonian

$$H_0 = J_i S_0 \cdot \sum_k S_k + J_e [S_1 \cdot S_2 + S_2 \cdot S_3 + S_3 \cdot S_1]$$

J_i=23.6 K

J_e=-1.5 K

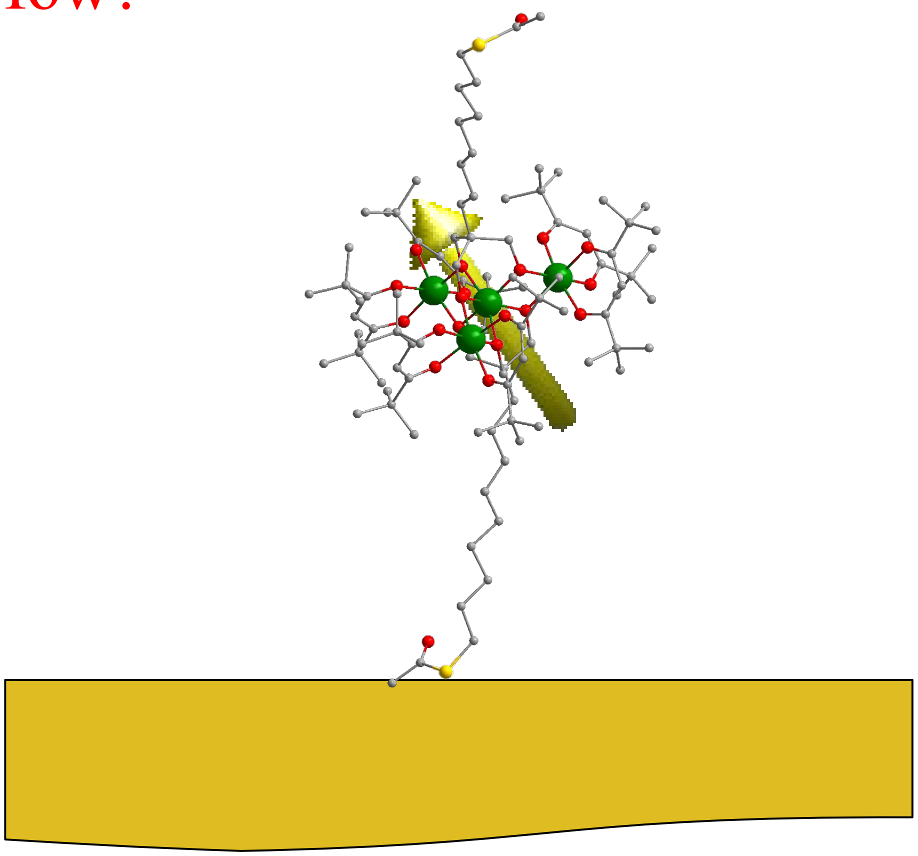
At high T the energy scale is determined mainly by the J_i

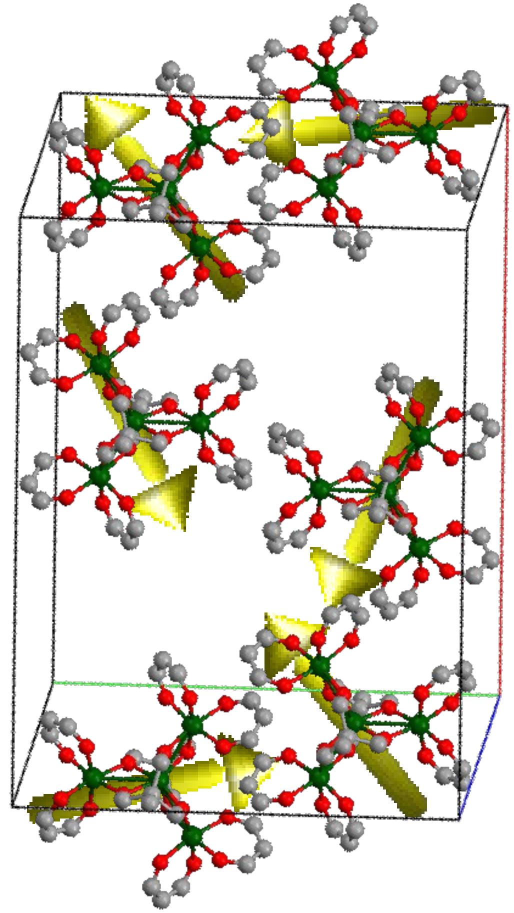


No surprise there is a difference between SMM in bulk and monolayer.

But why? Is it really a change in J_i?

How?





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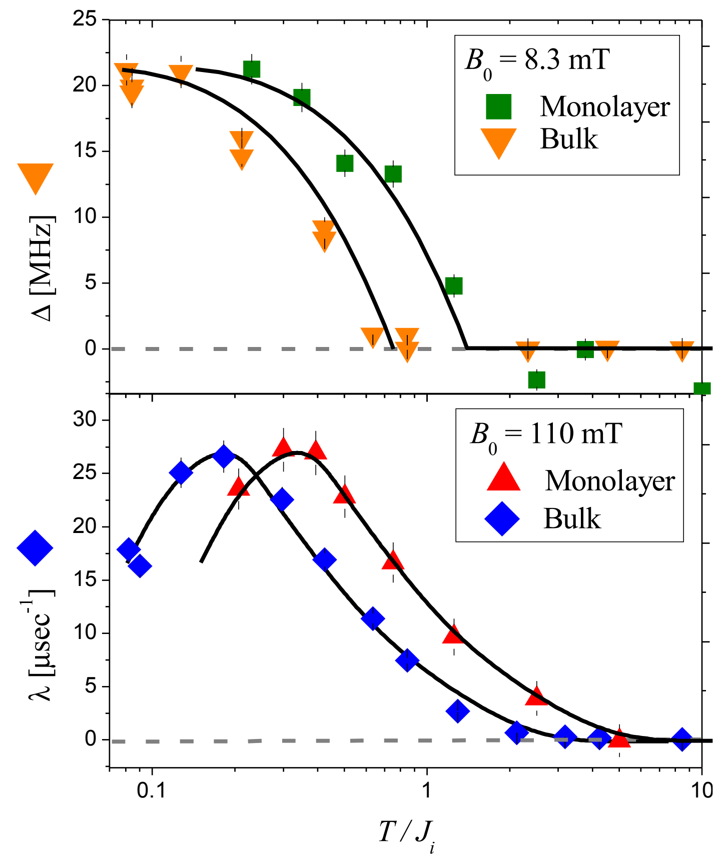

Differences: Fe_4 vs. Mn_{12}