Proximal magnetometry of magnetic monolayers and ultra-thin films

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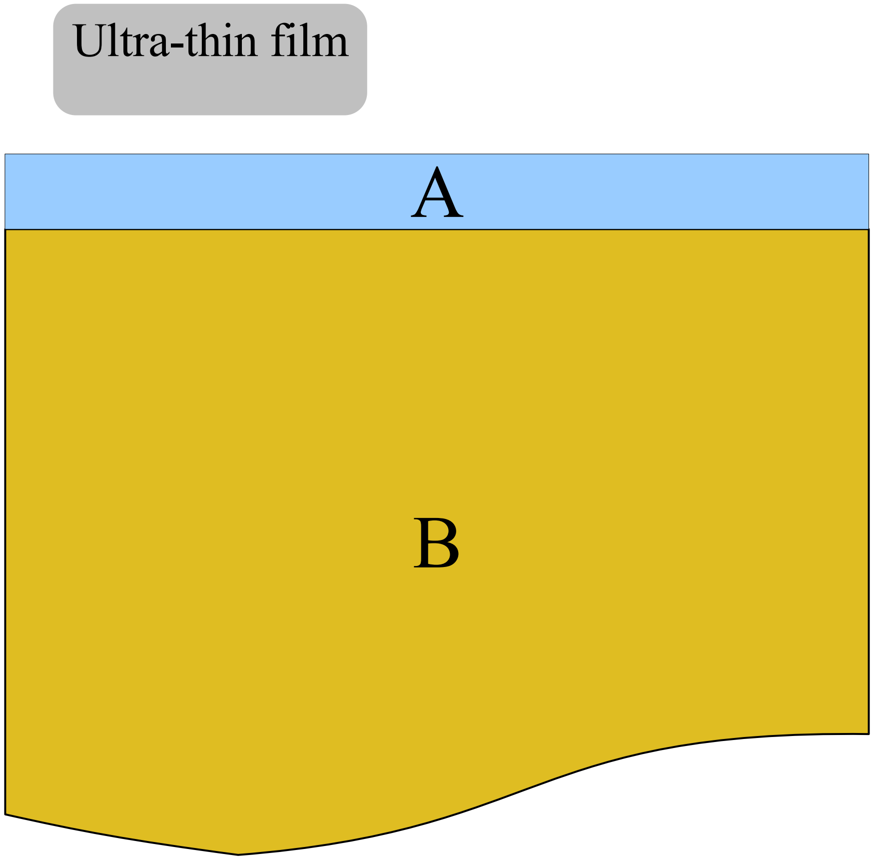
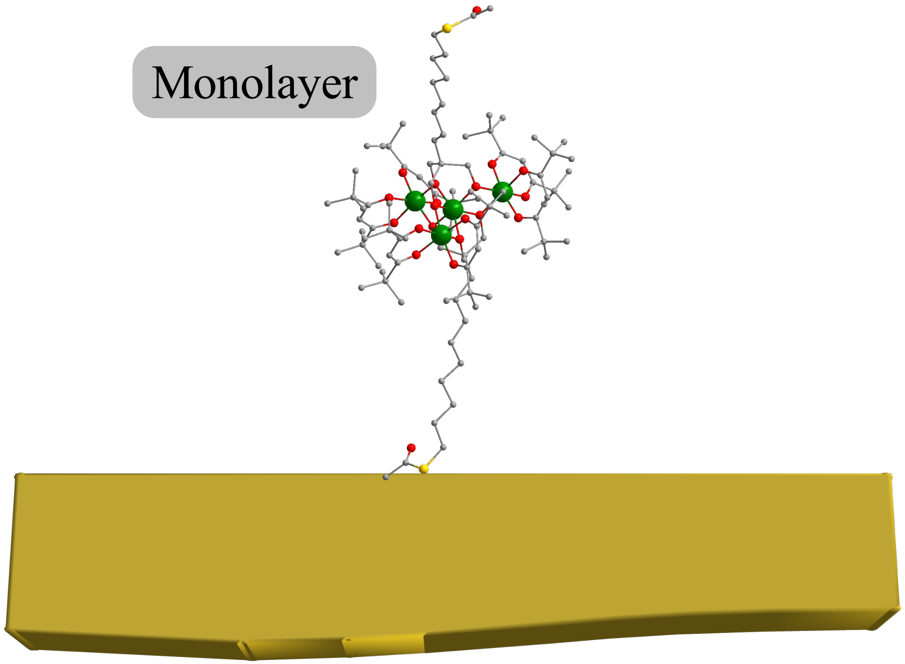
Outline

- Introduction
  - LE-μSR and β-NMR and their application for magnetic monolayers and ultra-thin films
  - Some experimental results
- Numetical Calculation
  - Field distribution
  - Depth dependence
- Summary and Conclusions

Introduction:
Magnetic monolayers and ultra-thin films



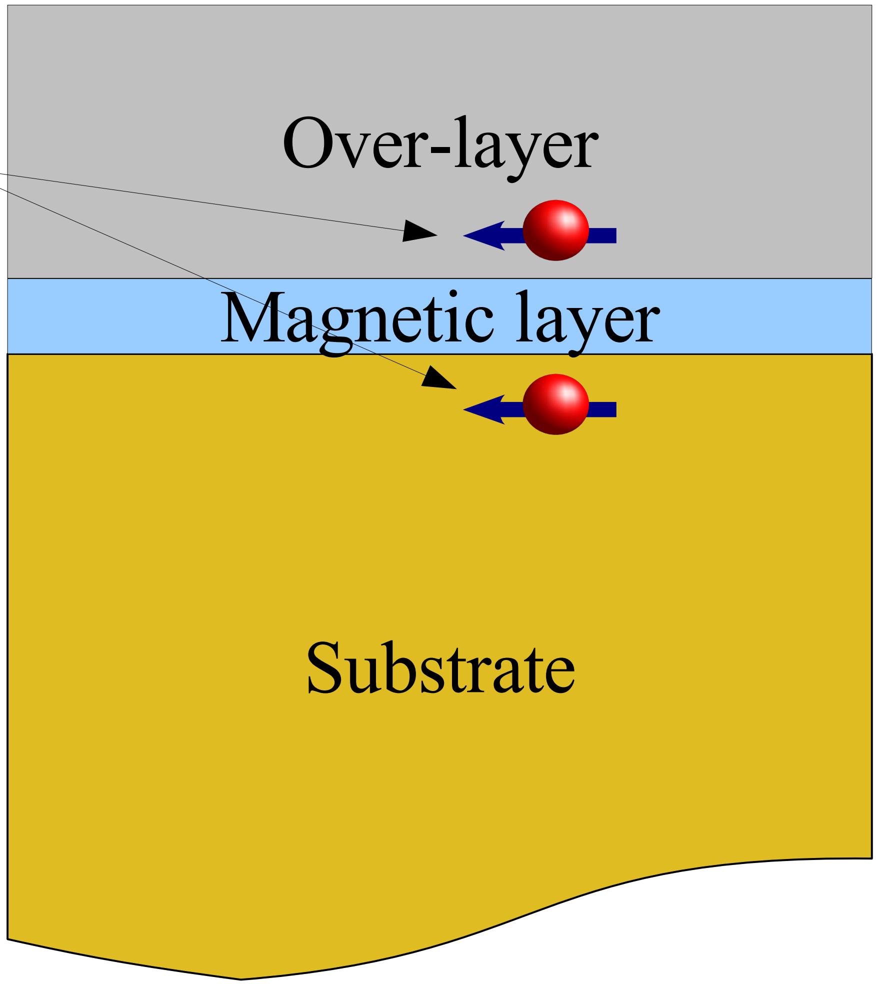


- A magnetic system – monolayer, ultra thin film, islands etc.
- Insufficient stopping material to implant a local probe.

Can we measure their magnetic properties?

Proximal magnetometry using a local probe

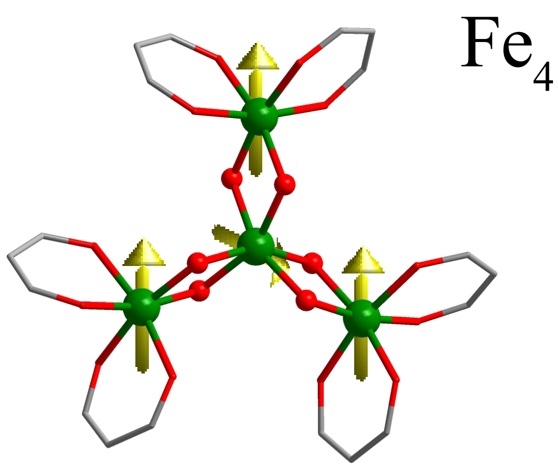
- Implant the probe above or below the magnetic layer.
- Measure dipolar fields from the magnetic layer.

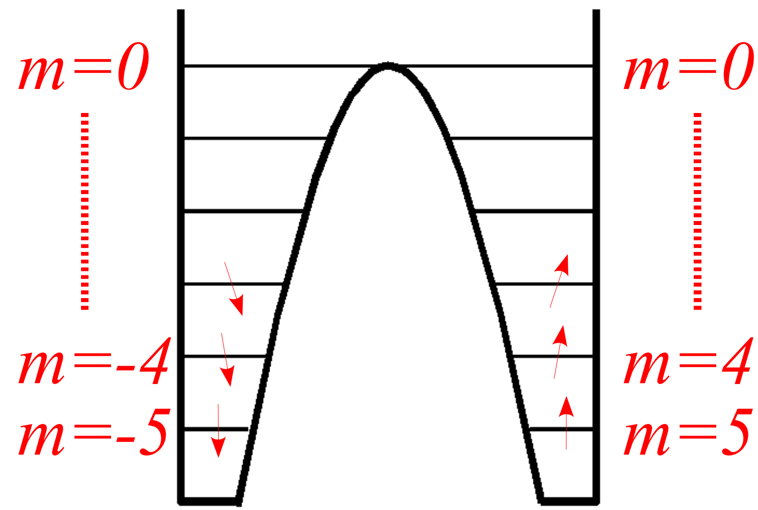


Below is a better option

- The probe can be *close* to the magnetic layer
- *Narrower* stopping distribution

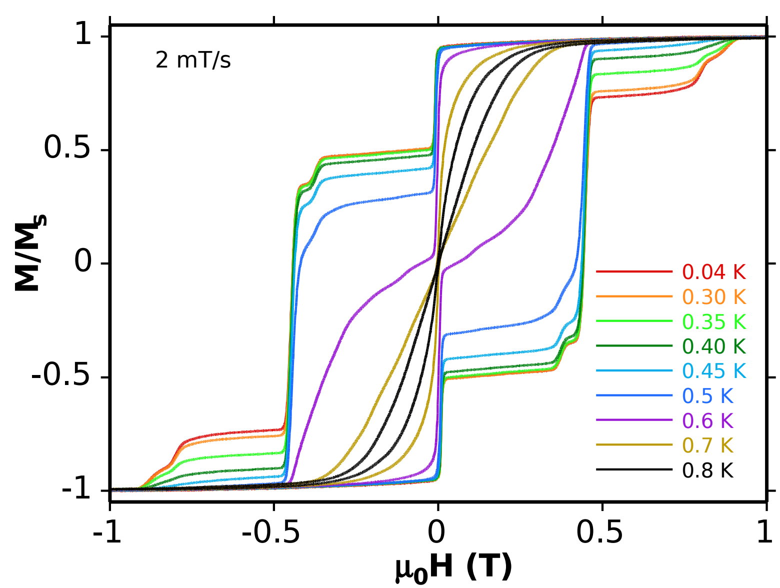
Single Molecule Magnets



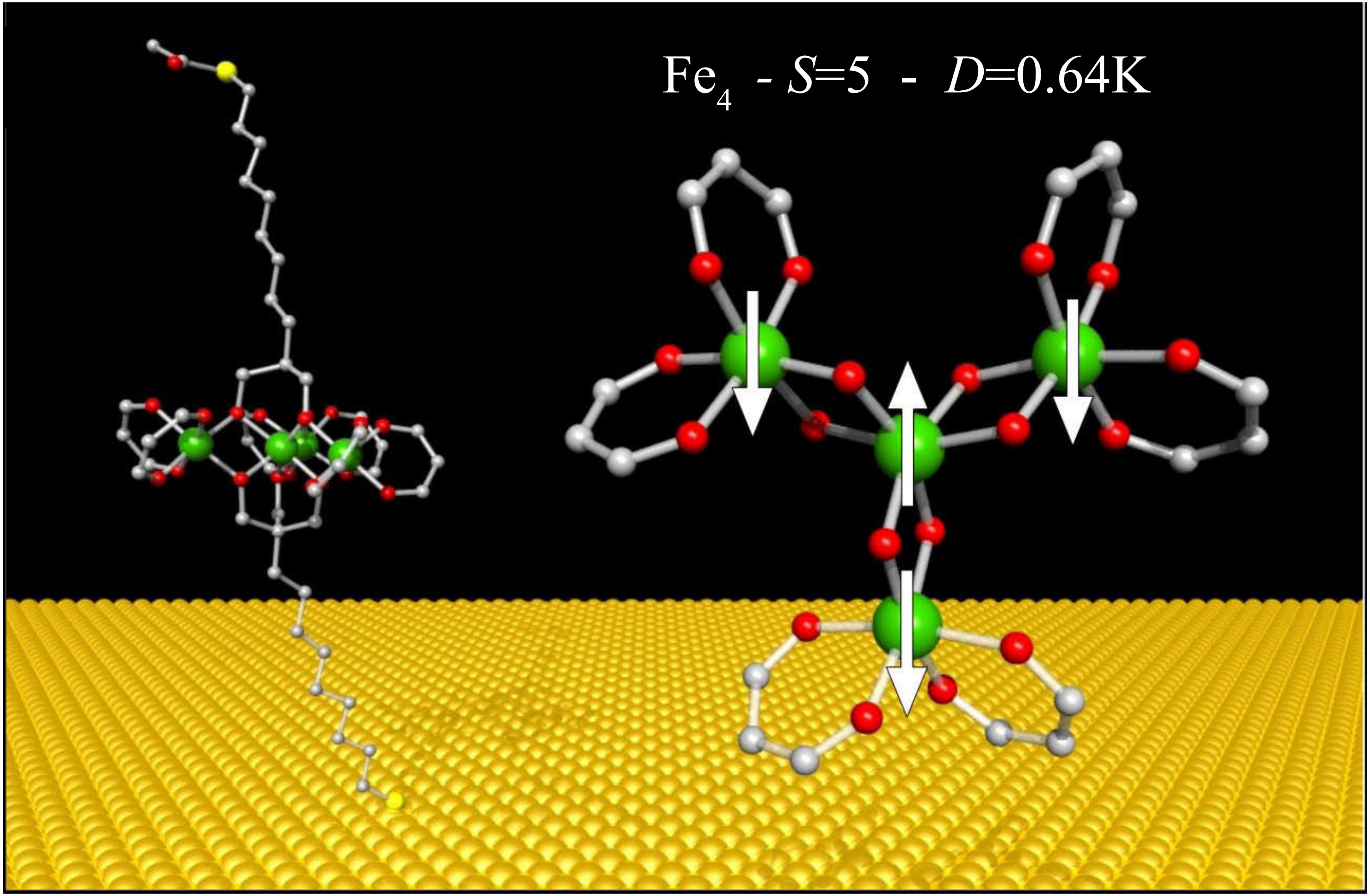


$$\boldsymbol{H} = -DS_z^{\,2} - g\mu_B H_z S_z$$

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

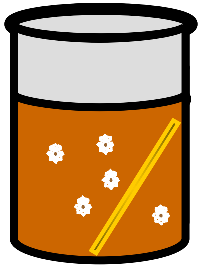


Monolayers of Fe_4

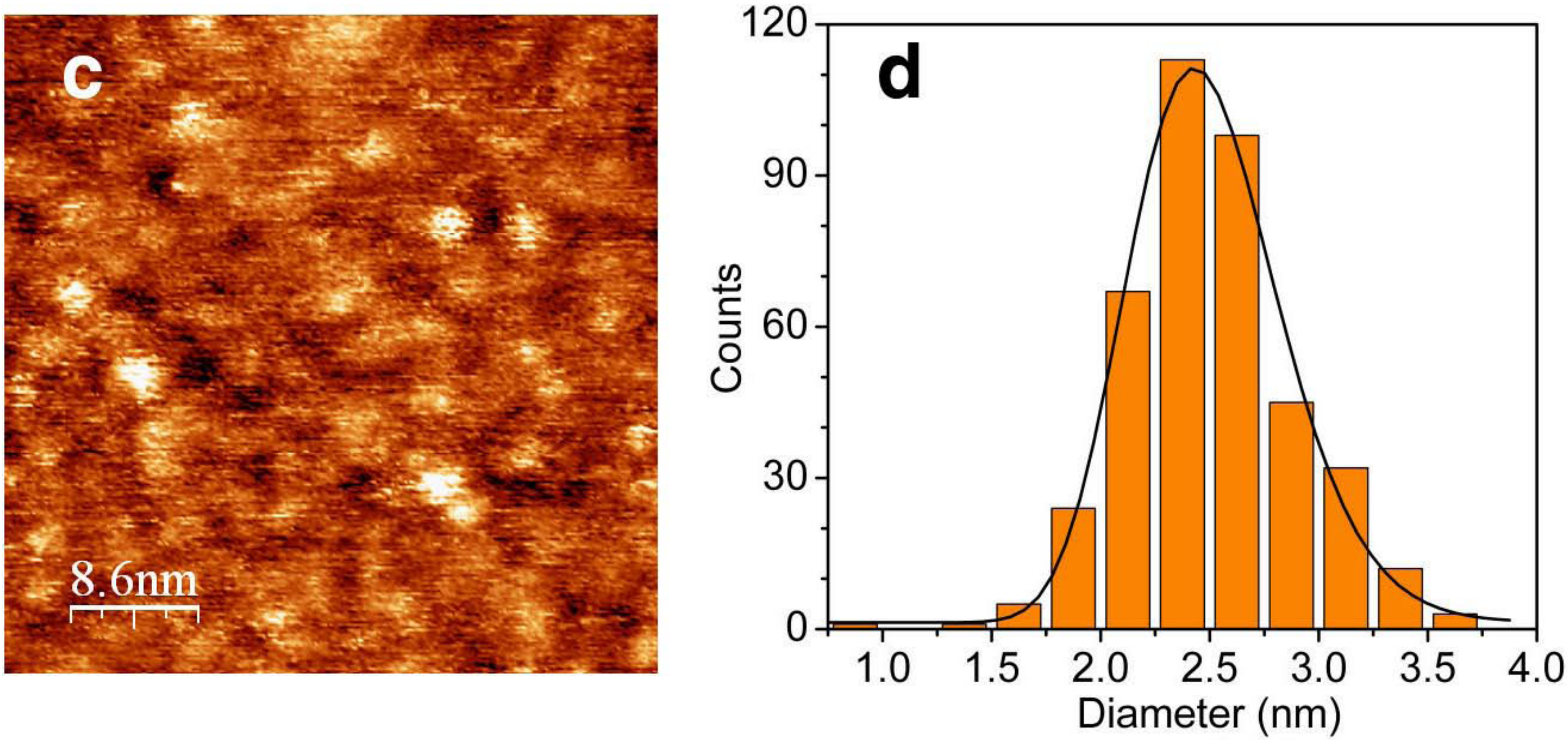


Mannini et al, Nature Mater. 8, 194–197 (2009)

STM of Monolayers of Fe_4

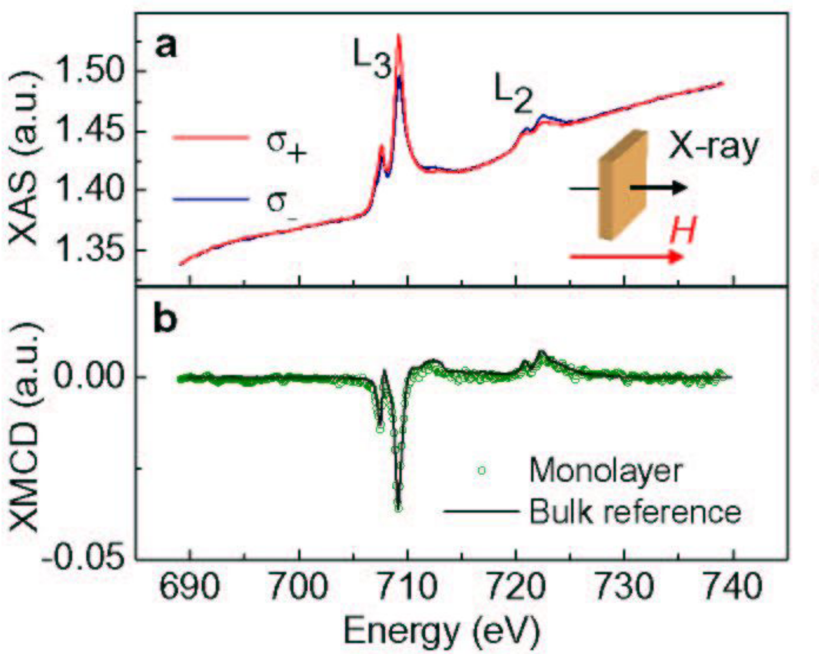


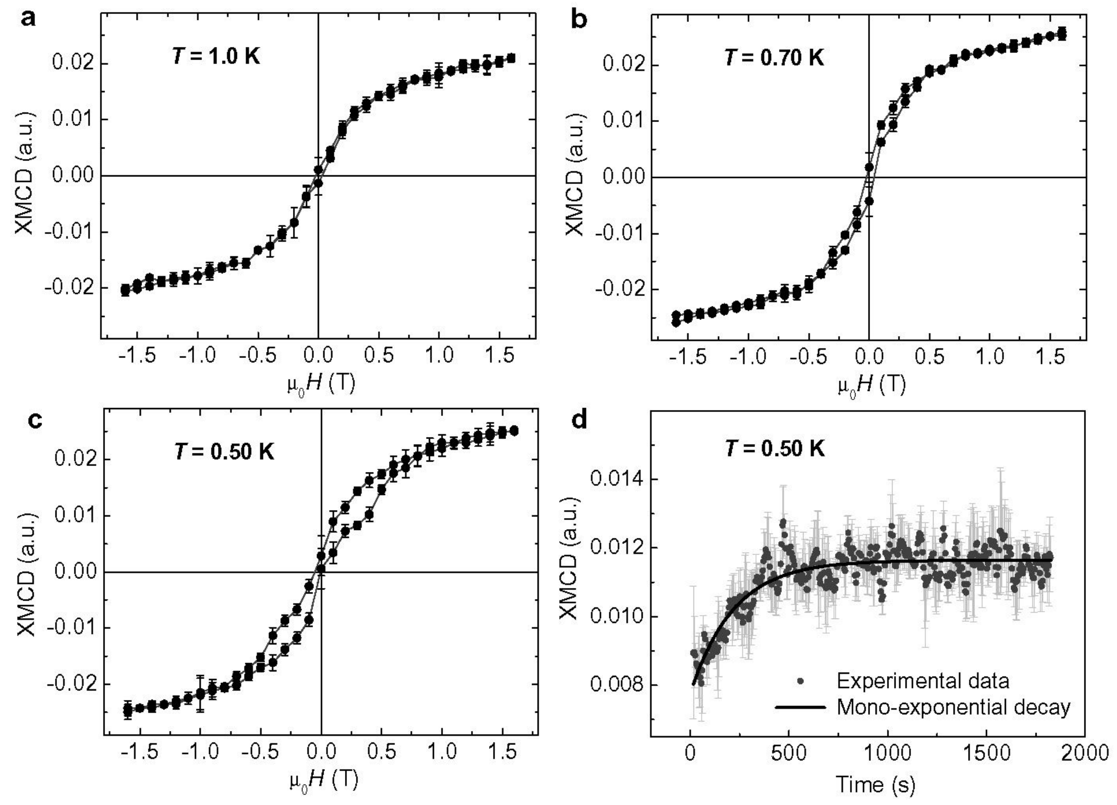
Au(111) on mica, f.a., 0.5 mM solution in CH_2Cl_2, 20 h



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

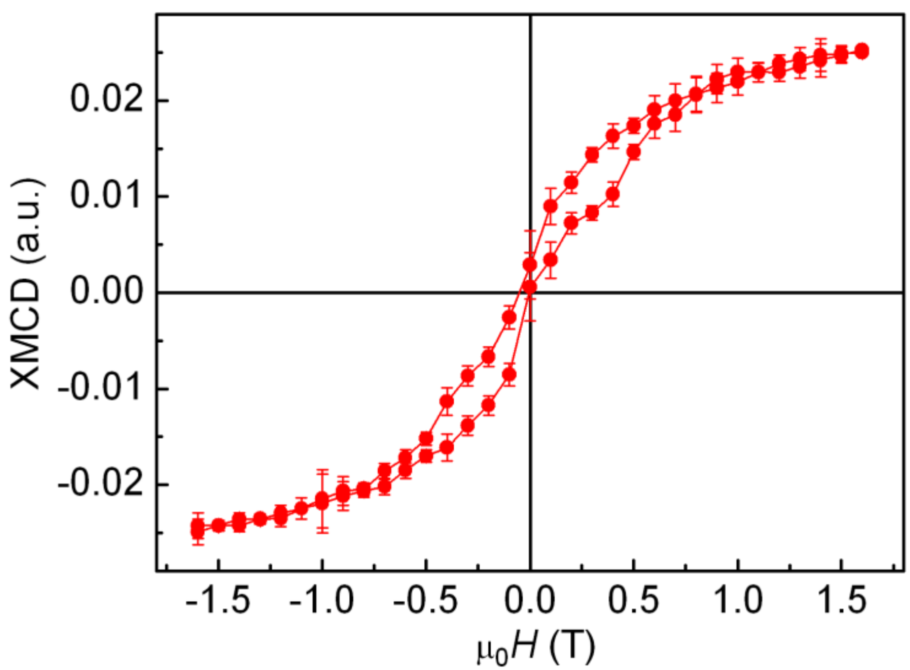
XMCD on Monolayers of Fe_4



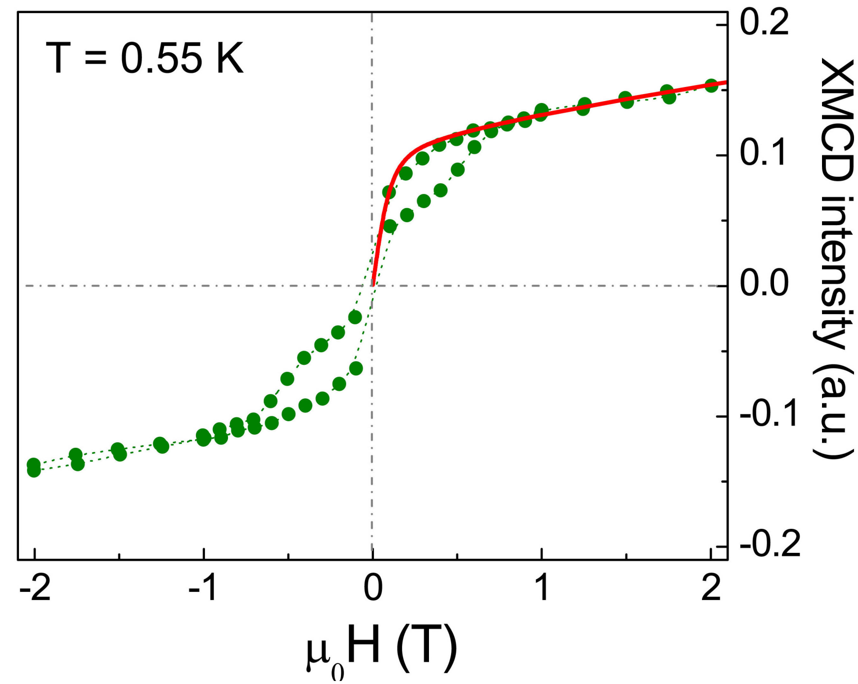


Mannini et al, Nature Mater. 8, 194–197 (2009)

XMCD on Fe_4 : Bulk vs. Monolayer

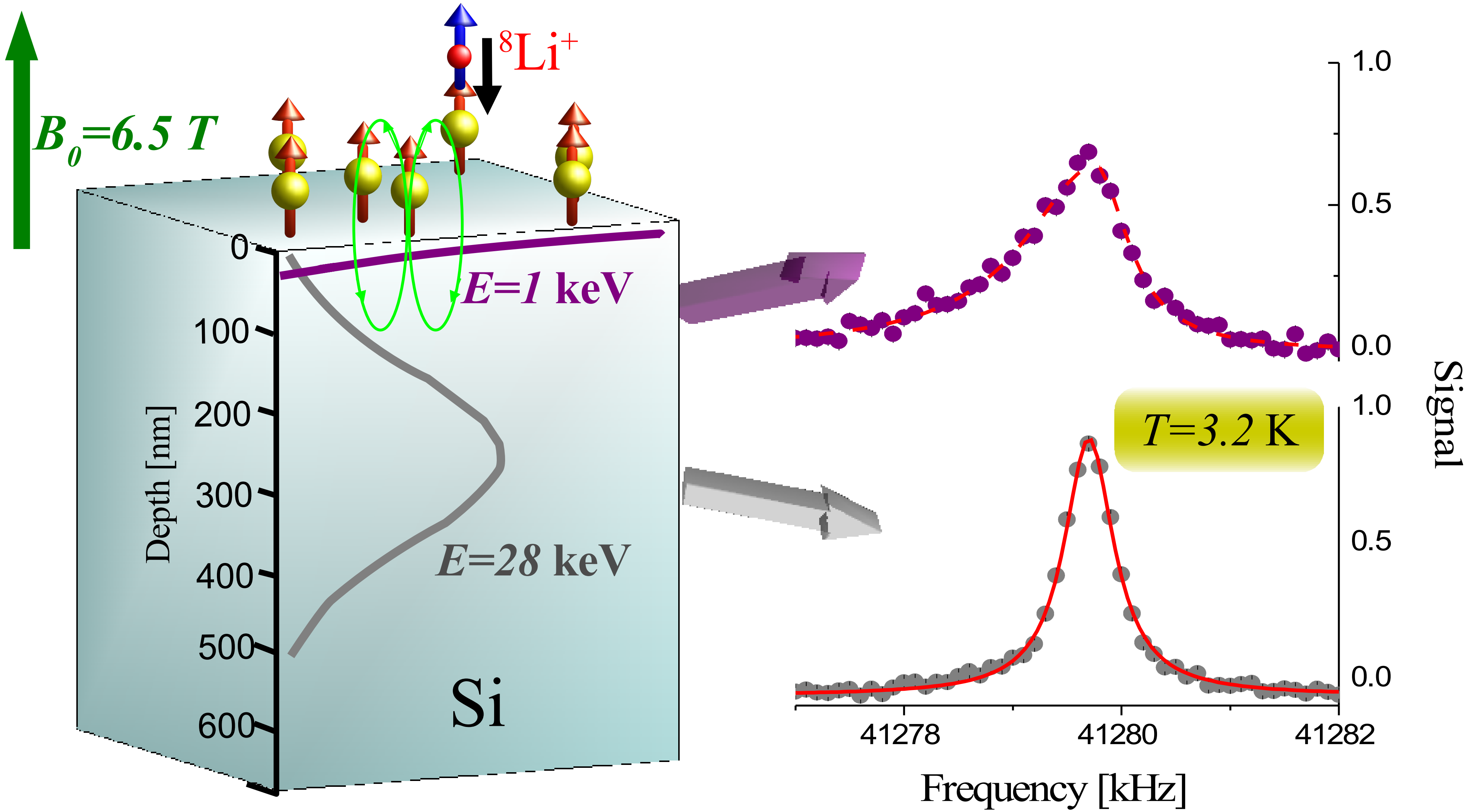


Mannini et al, Nature Mater. 8, 194–197 (2009)

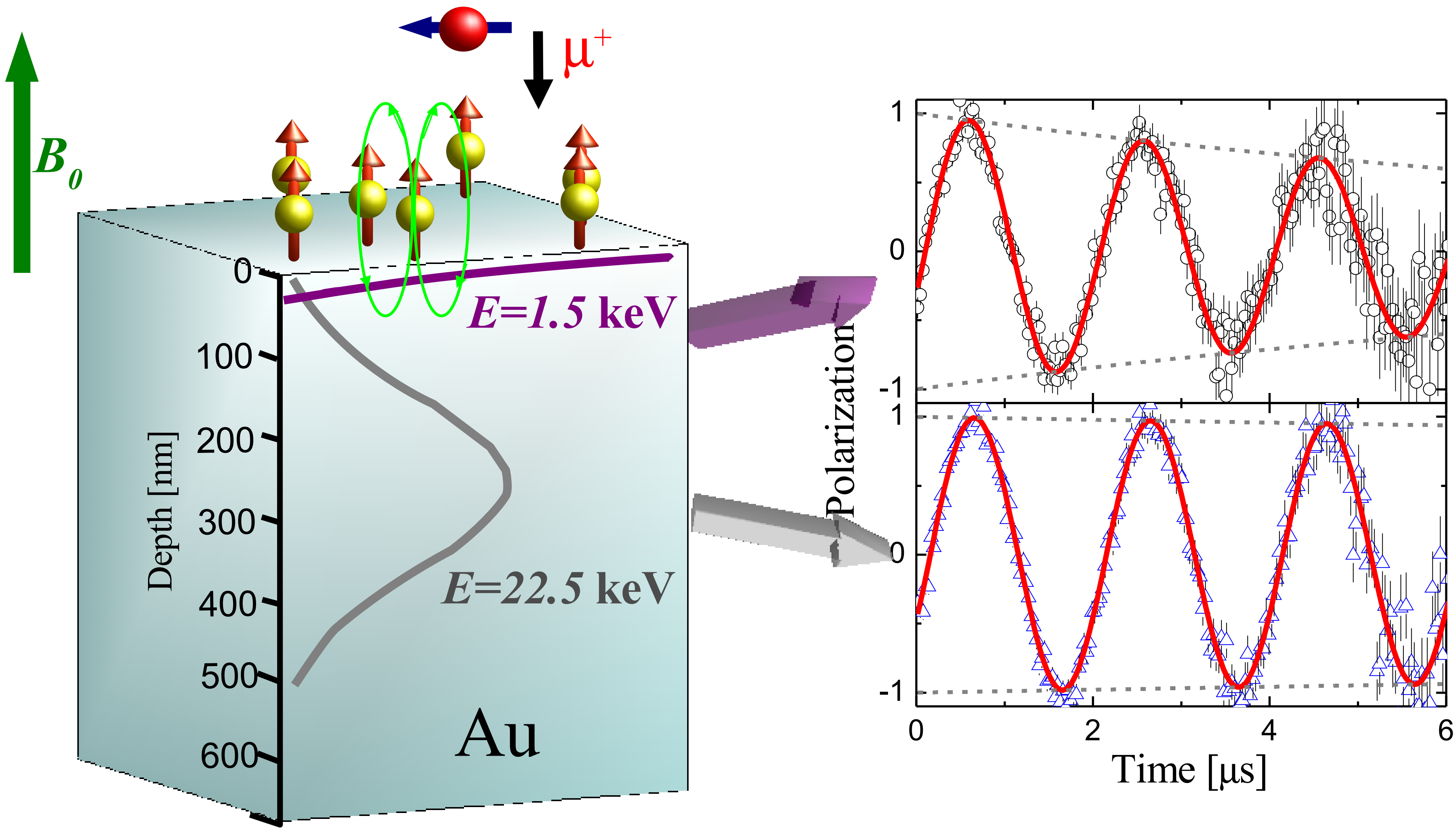


Mannini et al, Adv. Mater. (2008)

β-NMR in Fe_4 on Si



LE-μSR in Fe_4 on Au



Salman et al, arXiv:0909.4634v1

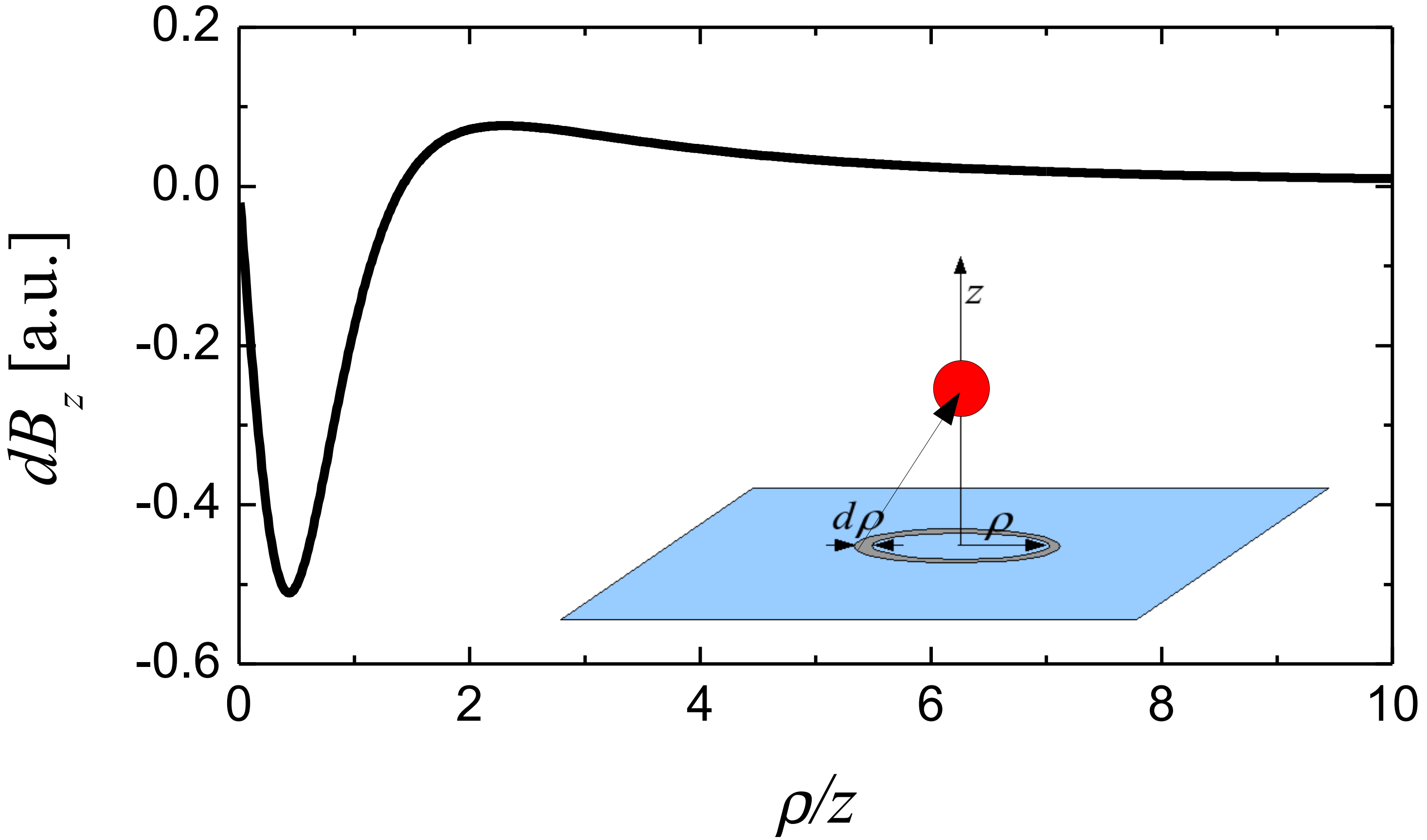
Uniformly magnetized sheet

First approximation – assume a uniformly magnetized sheet

➔Divide into annular regions

➔Integrate dipolar field contribution

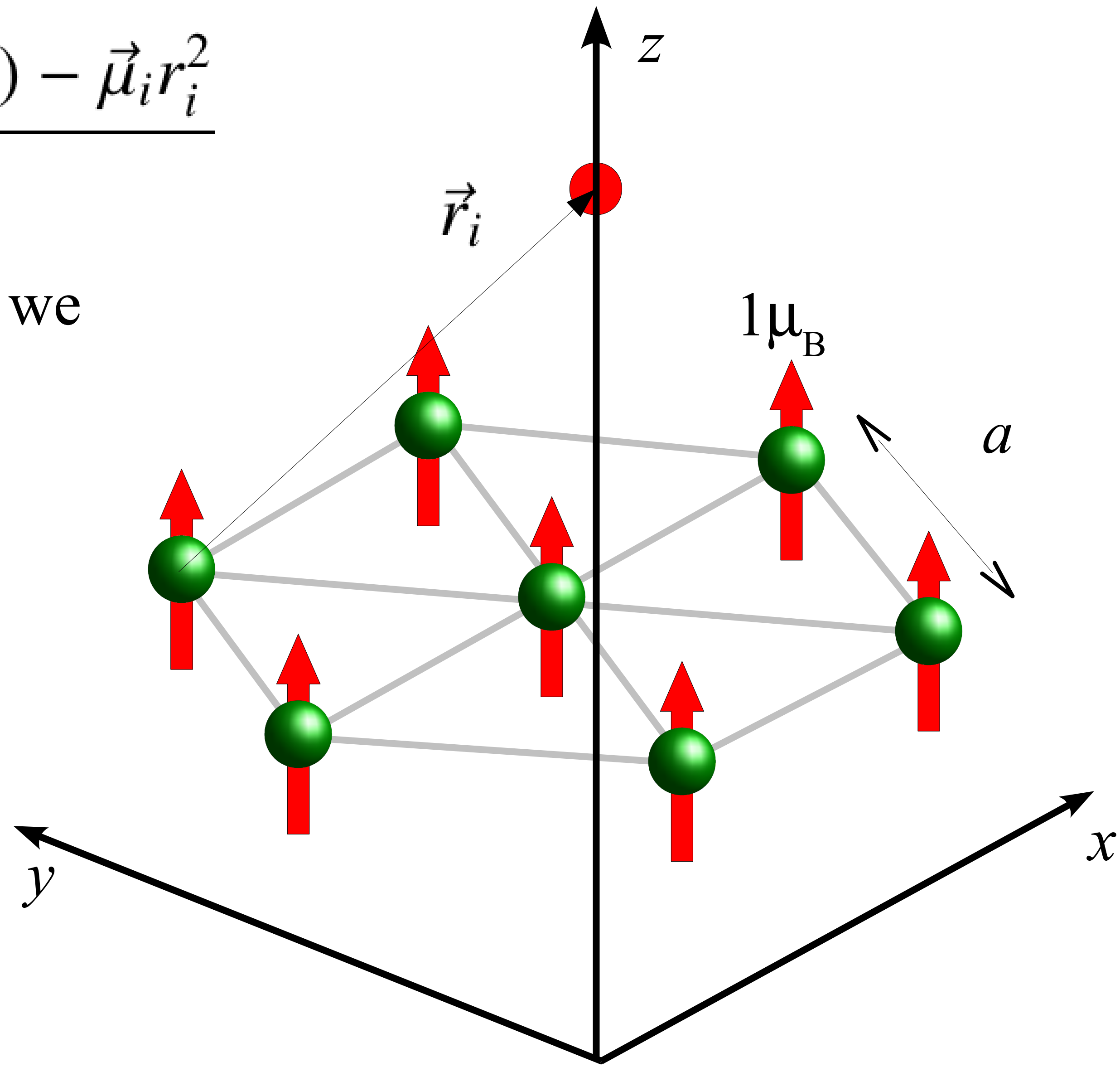
➔Dipolar field is zero



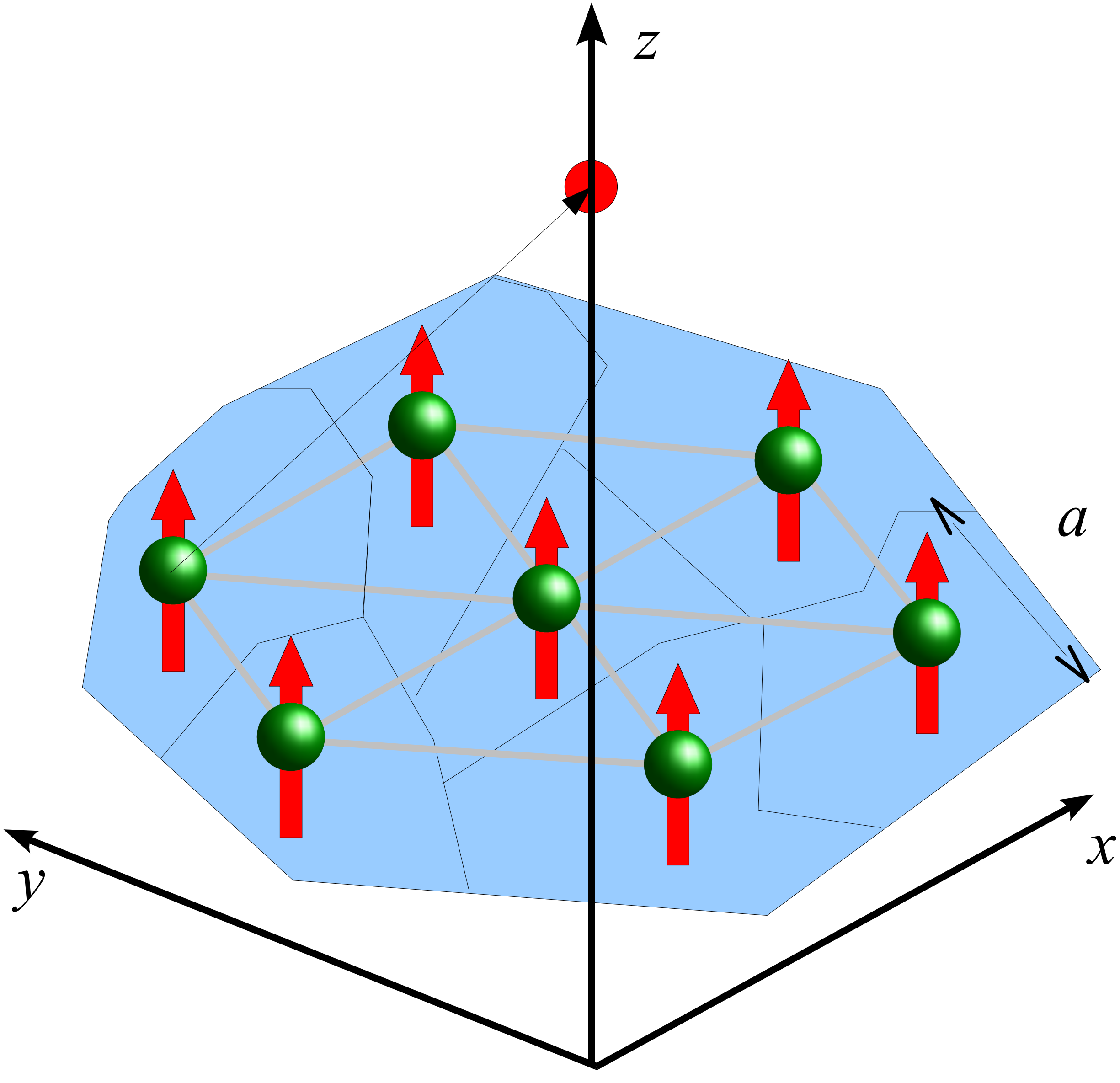
Local probe perspective

$$\vec{B}_i(\vec{r}_i) = \frac{\mu_0}{4\pi} \frac{3\vec{r}_i(\vec{\mu}_i \cdot \vec{r}_i) - \vec{\mu}_i r_i^2}{r_i^5}$$

In a LE-μSR or β-NMR we are interested in B_z only.



Local probe perspective

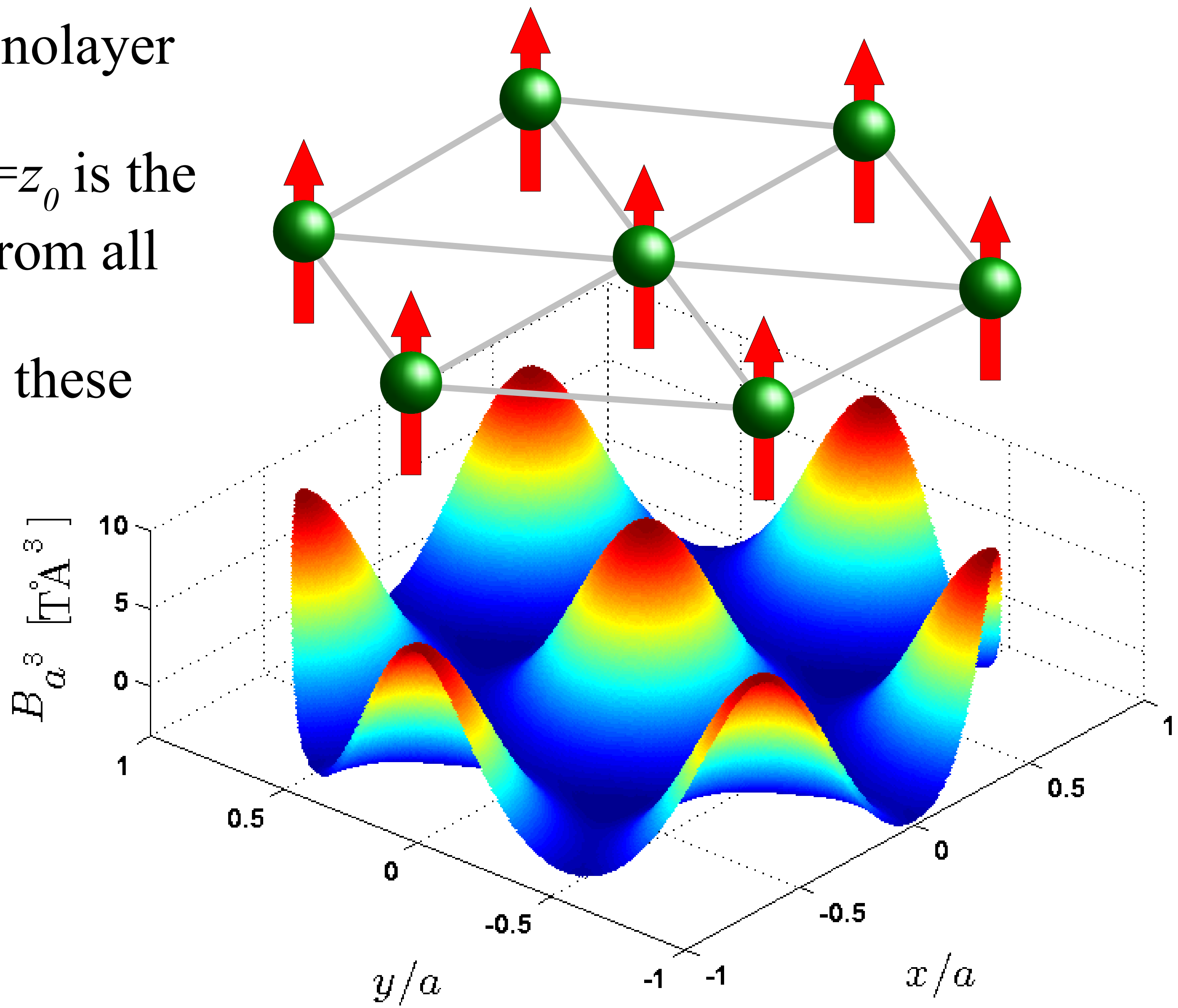


Dipolar field at a layer $z=z_0$

•Assume magnetic monolayer at $z=0$

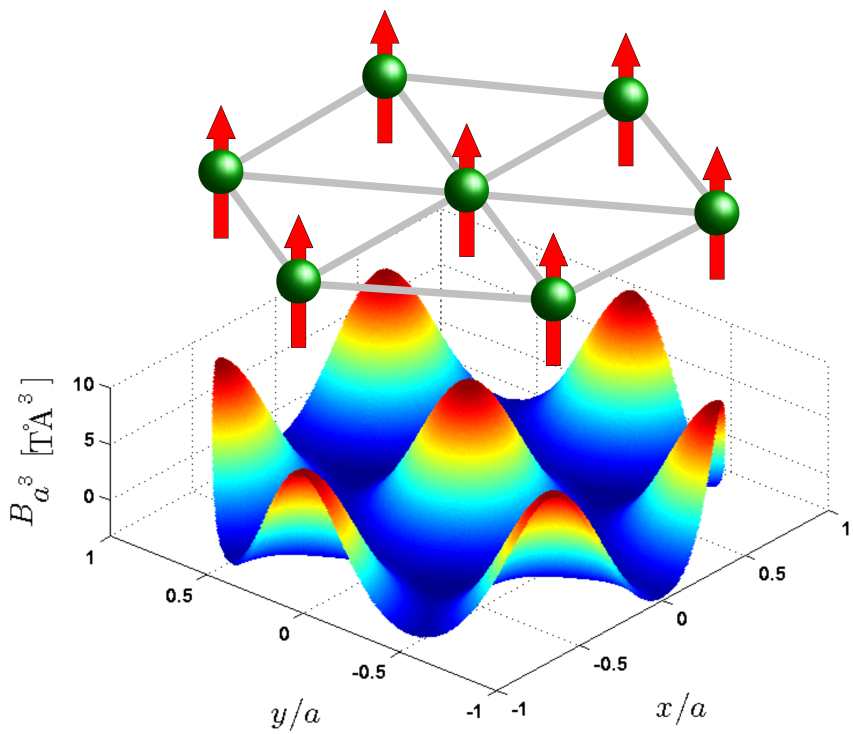
•The dipolar field at $z=z_0$ is the sum of contributions from all moments.

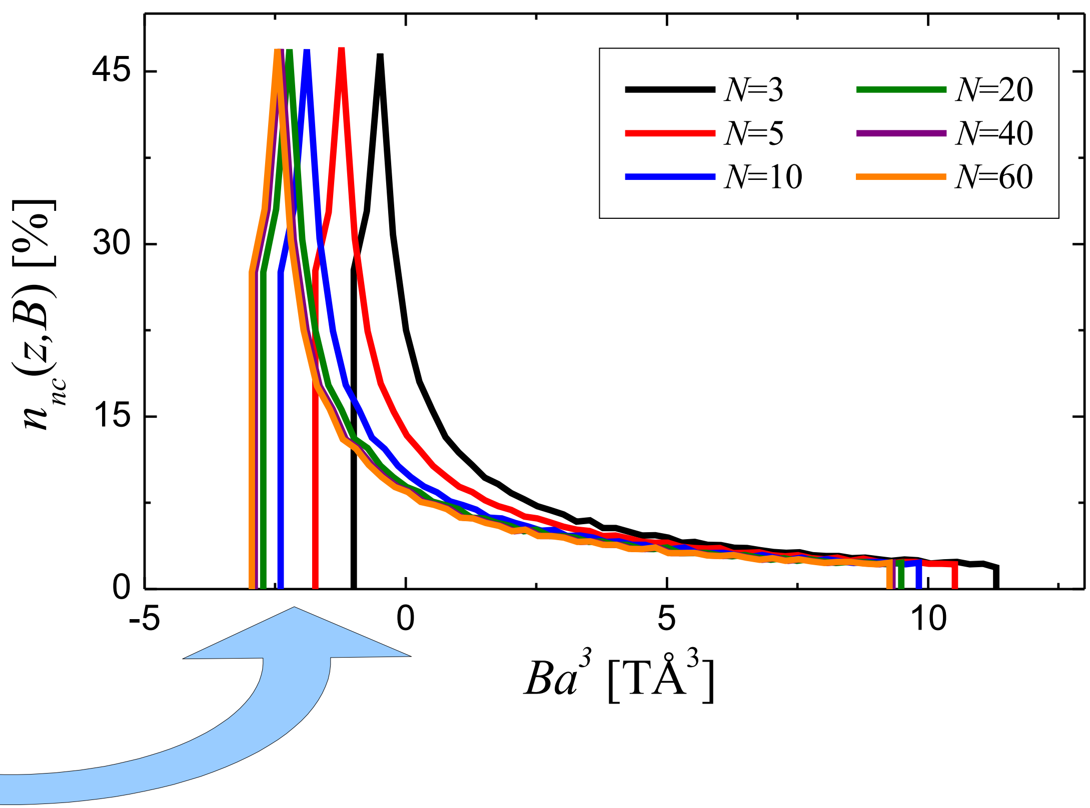
•A spin probe samples these fields



Field distribution sensed by the probe

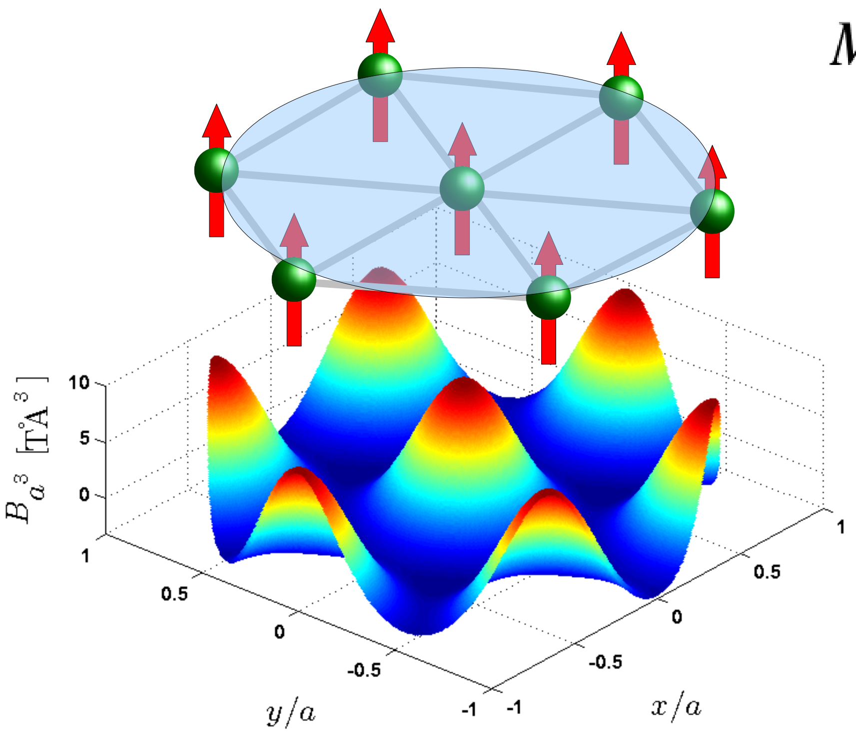
- Sum contributions from all moments in $\rho_0 = aN$
- The field distribution shifts due to the finite size of ρ_0 .

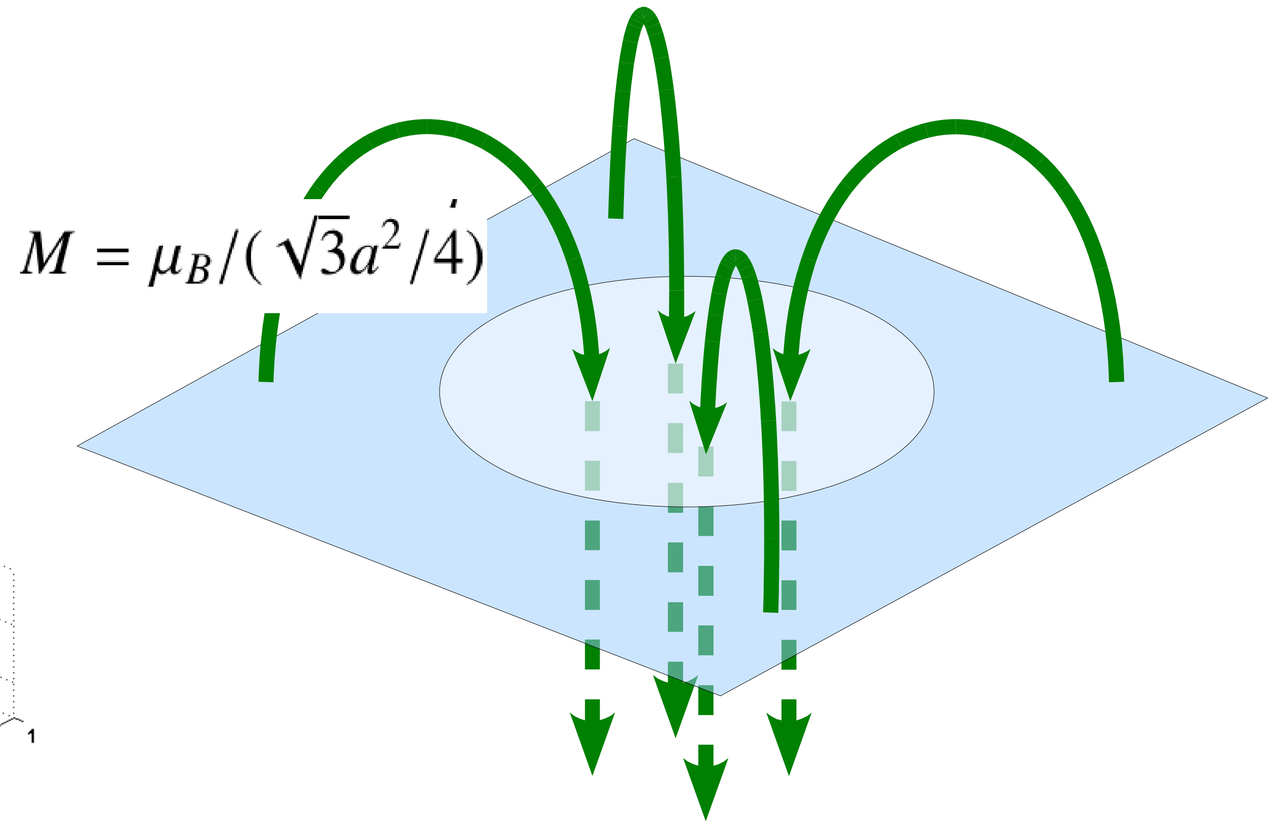




Correction of field distribution

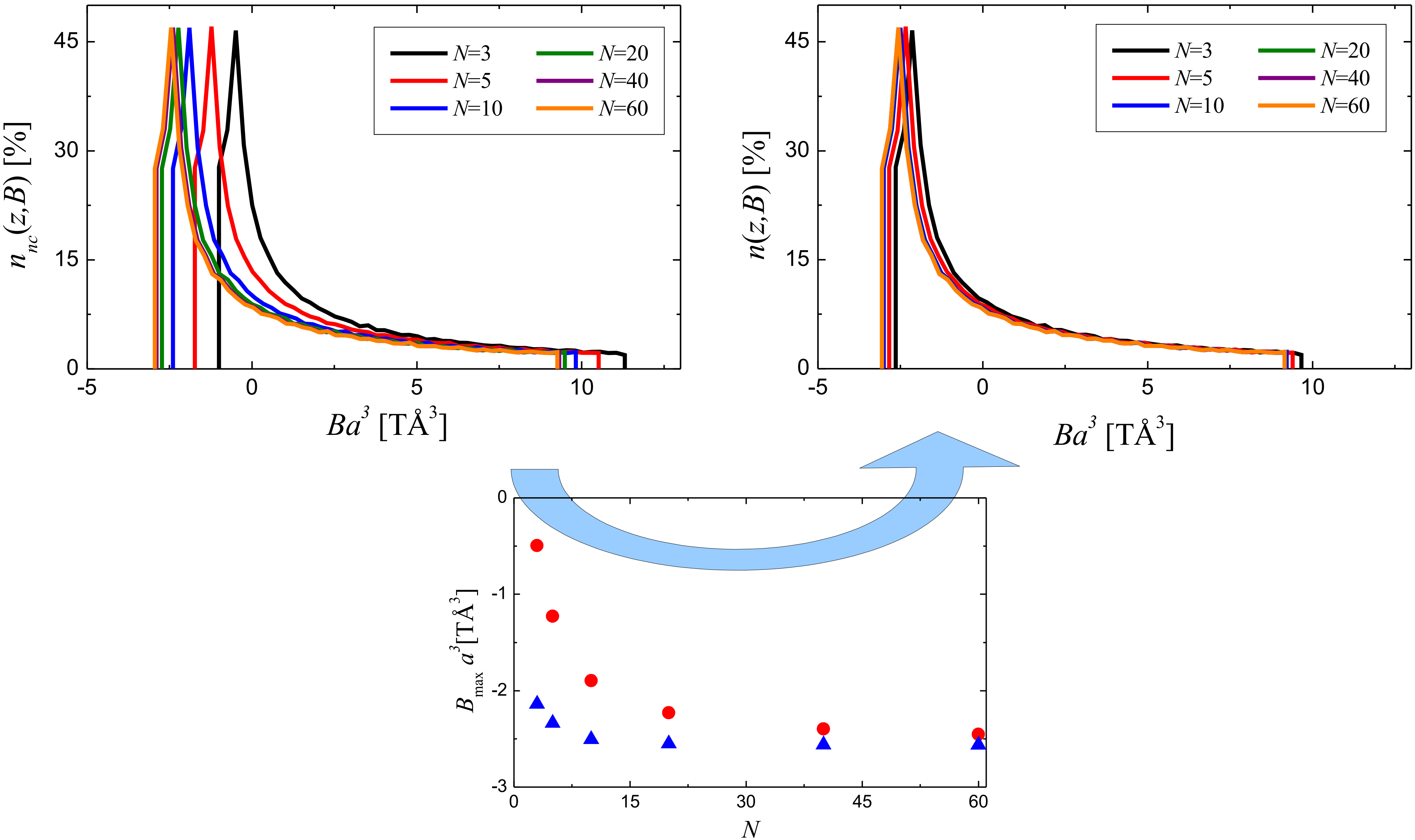
- Correction by taking the contribution of the rest of the monolayer.
- Outside $\rho_0 = aN$ the uniform magnetization approximation holds.





$$\frac{\mu_0 M}{2\rho_0(1+\zeta^2)^{3/2}} \quad \text{with} \quad \zeta = z/\rho_0$$

Corrected field distribution

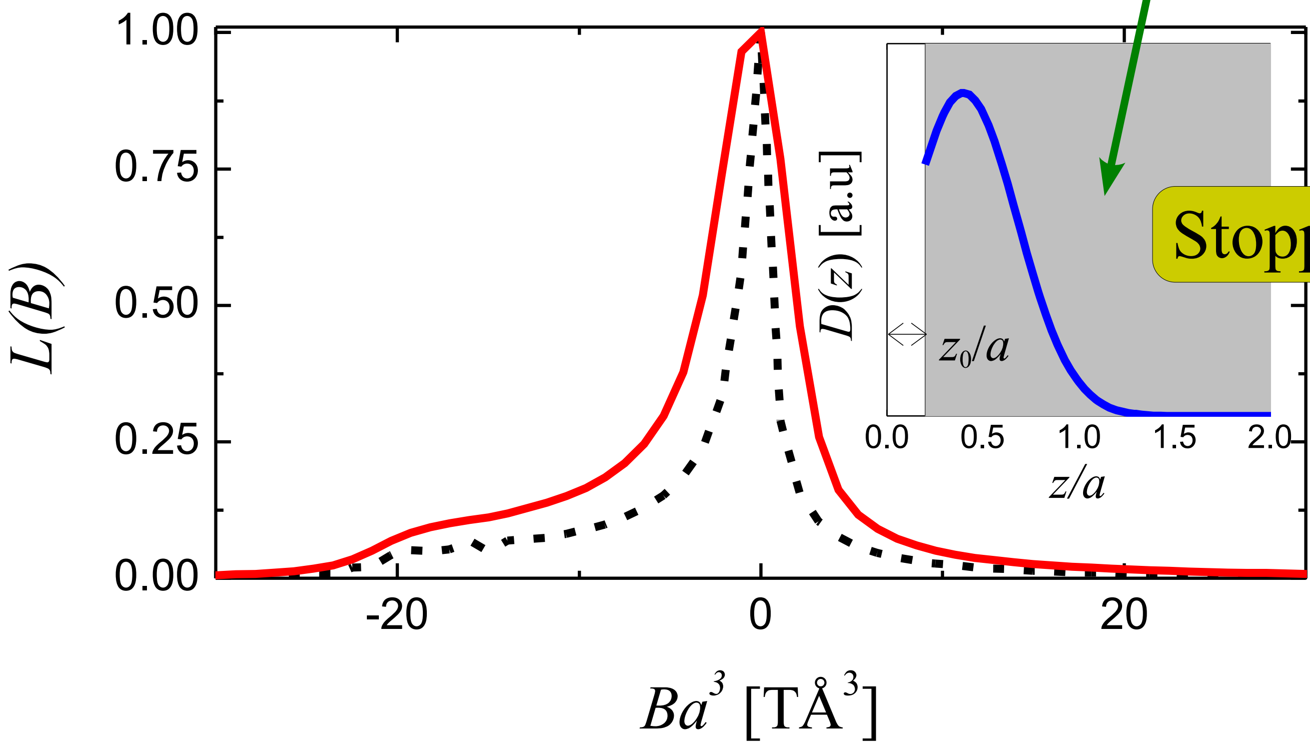


The effect of the stopping distribution

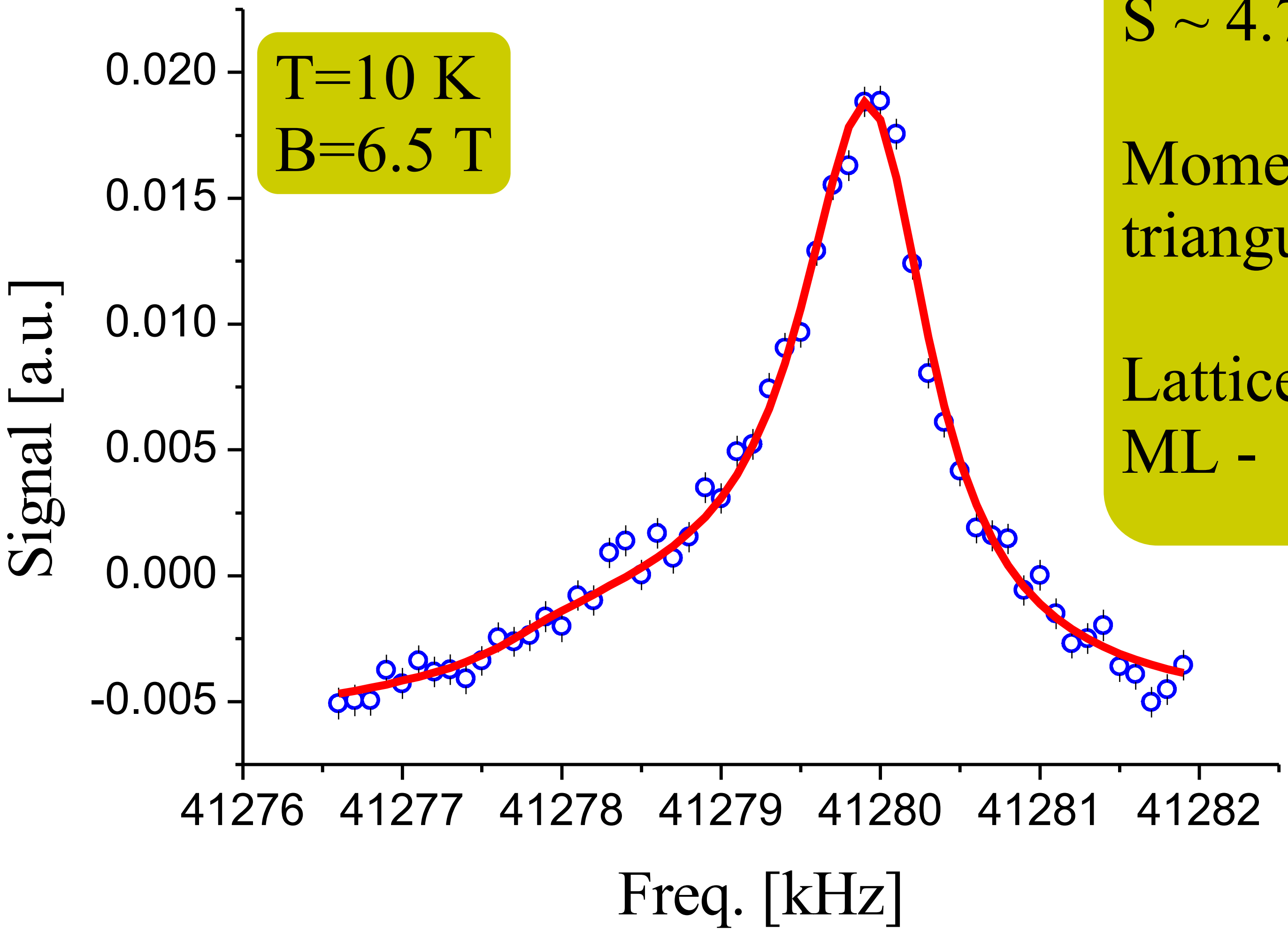
$$L(B) = I(B) * \int_{z_0}^{\infty} D(z) n(z, B) dz$$

Intrinsic line + disorder

Stopping distribution



β-NMR in Fe_4 on Si



Model line:

S ~ 4.7

Moment on disordered triangular lattice:

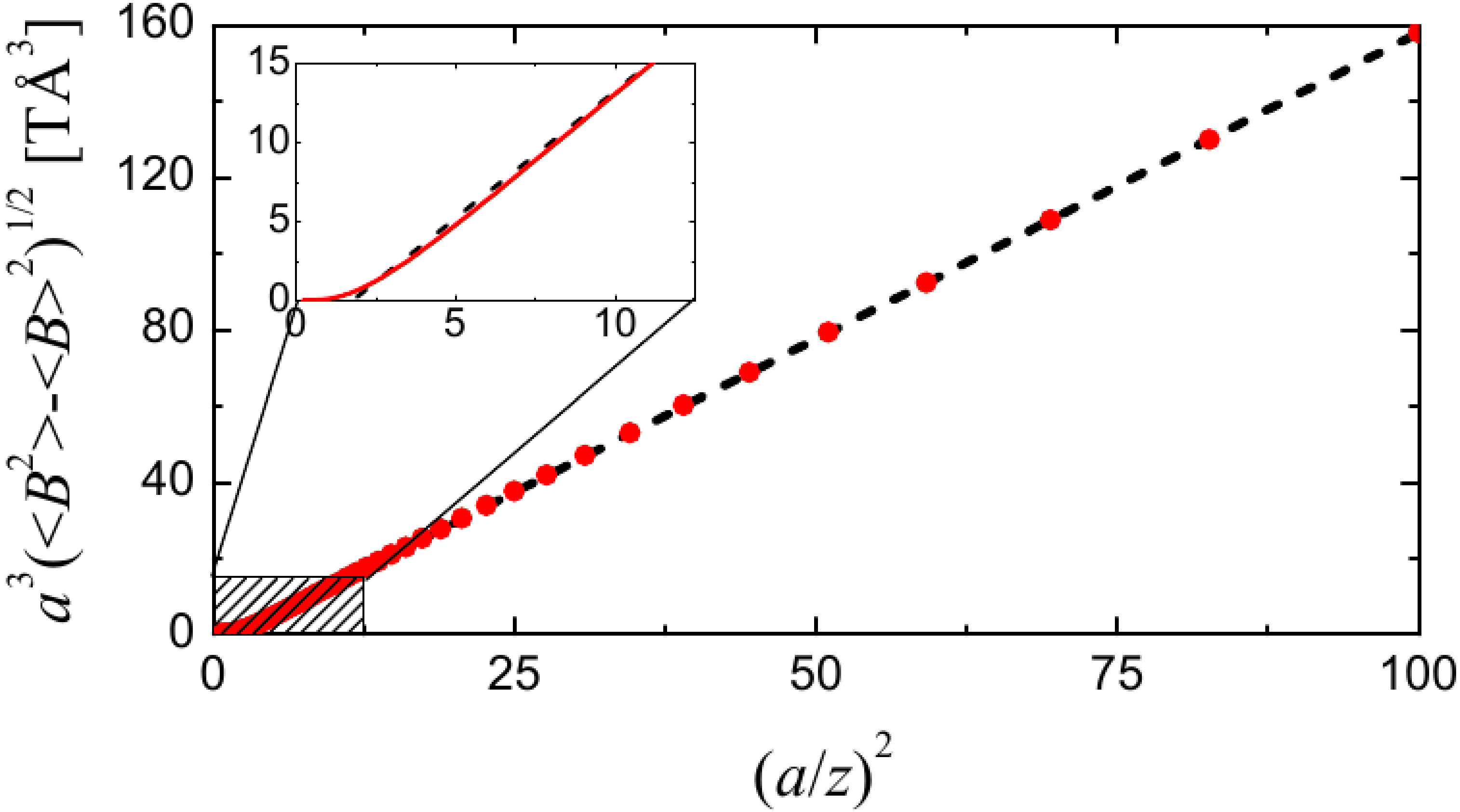
Lattice constant ~ 8 nm
ML - substrate ~ 1nm

Depth dependence of the width

•Much easier to look at the distribution width or broadening relative to the intrinsic width.

•The broadening is:

- Proportional to the RMS of the magnetic moment.
- Decreases like $1/z^2$



Summary and conclusions

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

•The field distribution depends on the characteristic length scale, average size of magnetic moment and distance between monolayer and substarte.

•The broadening due to a magnetic monolayer decreases like $1/z^2$ away from the monolayer and is proportional to the RMS of the magnetic moment.