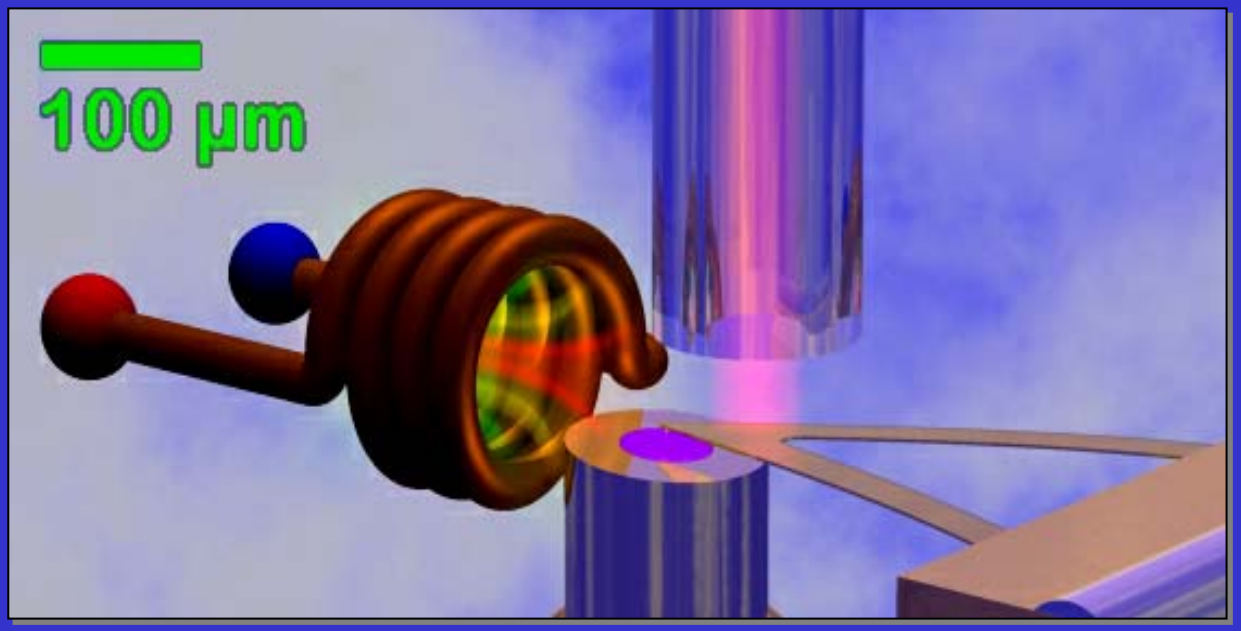
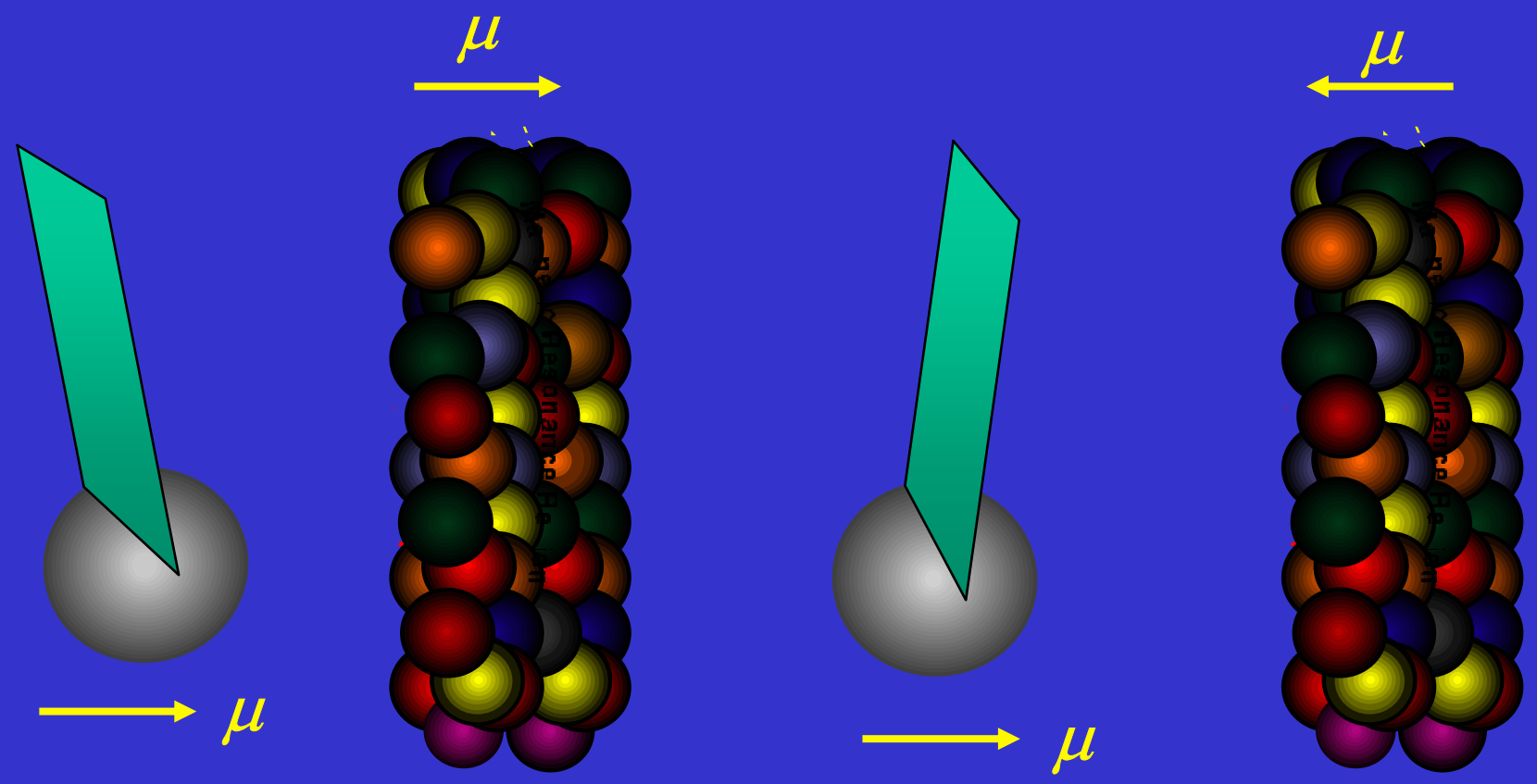
Force-Detected Nuclear Magnetic Resonance of Unstrained Gallium Arsenide with Applications to the Development of Spintronic Devices

Lee E. Harrell and Doran D. Smith



Force-Detected NMR: Marriage of Two Technologies:

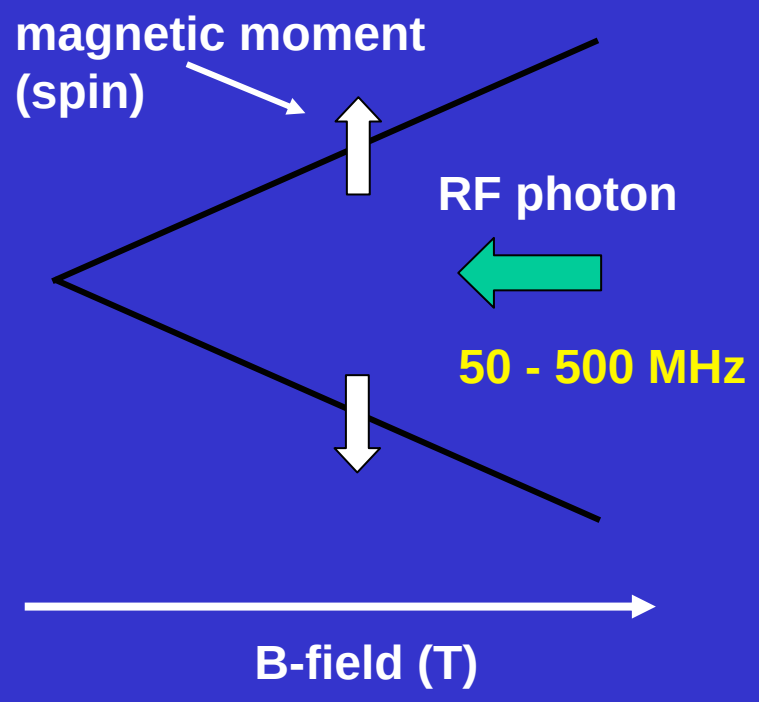
1) force detection – interaction between two magnets



reverse μ → reverse force → at cantilever resonant frequency → Q enhancement

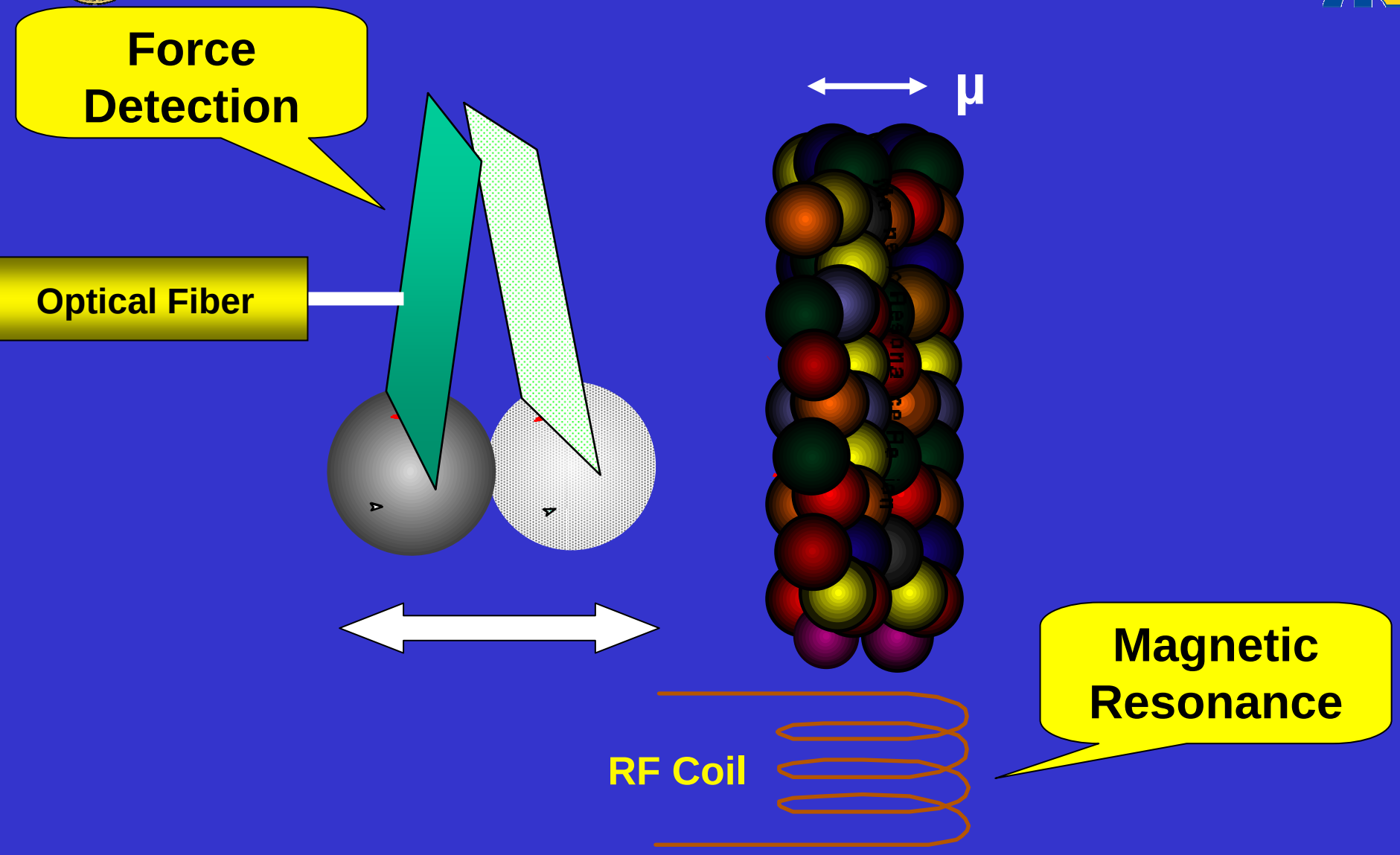
2) Magnetic Resonance

energy absorption by a transition

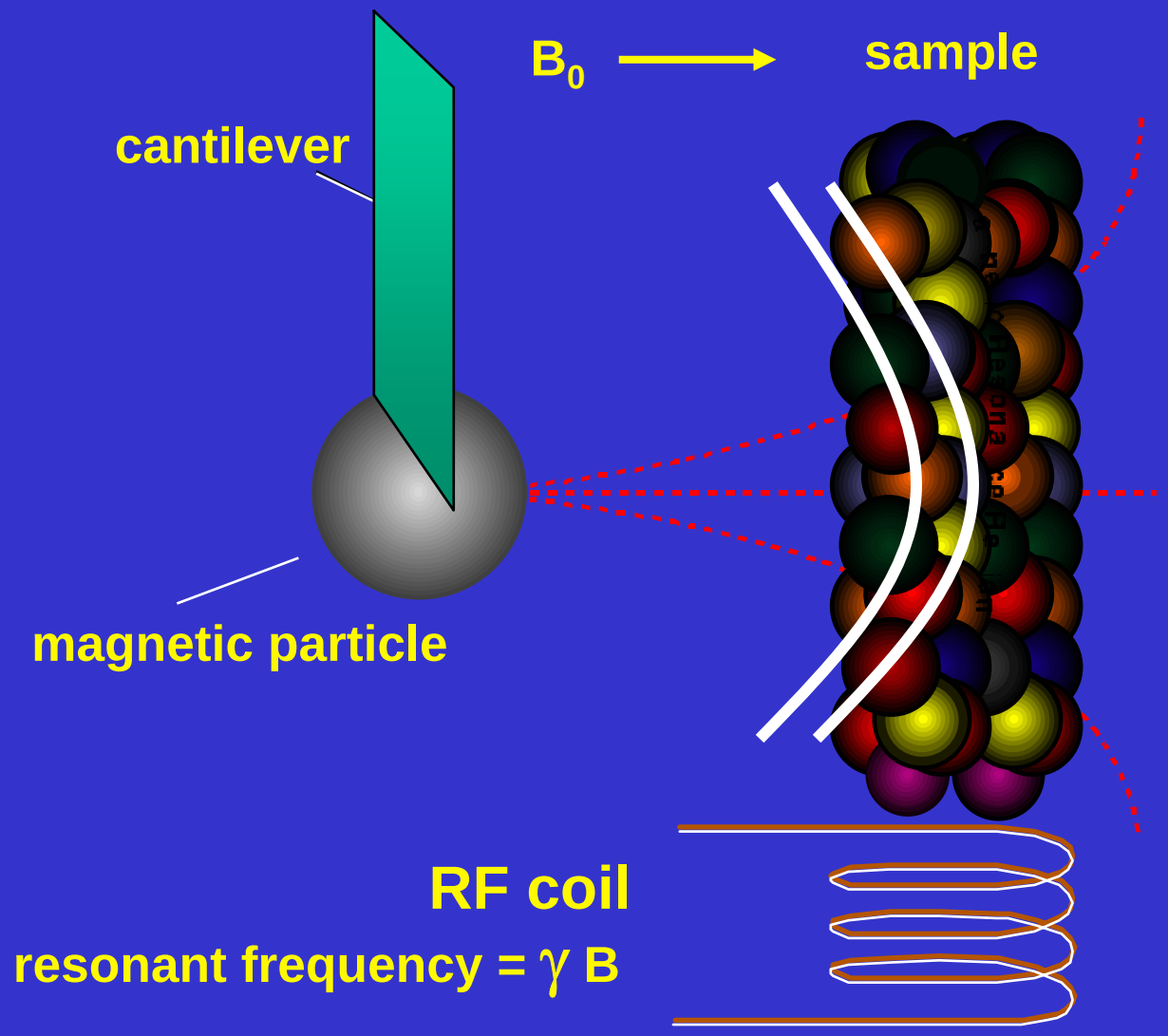


resonant frequency = γ B

Force-Detected NMR



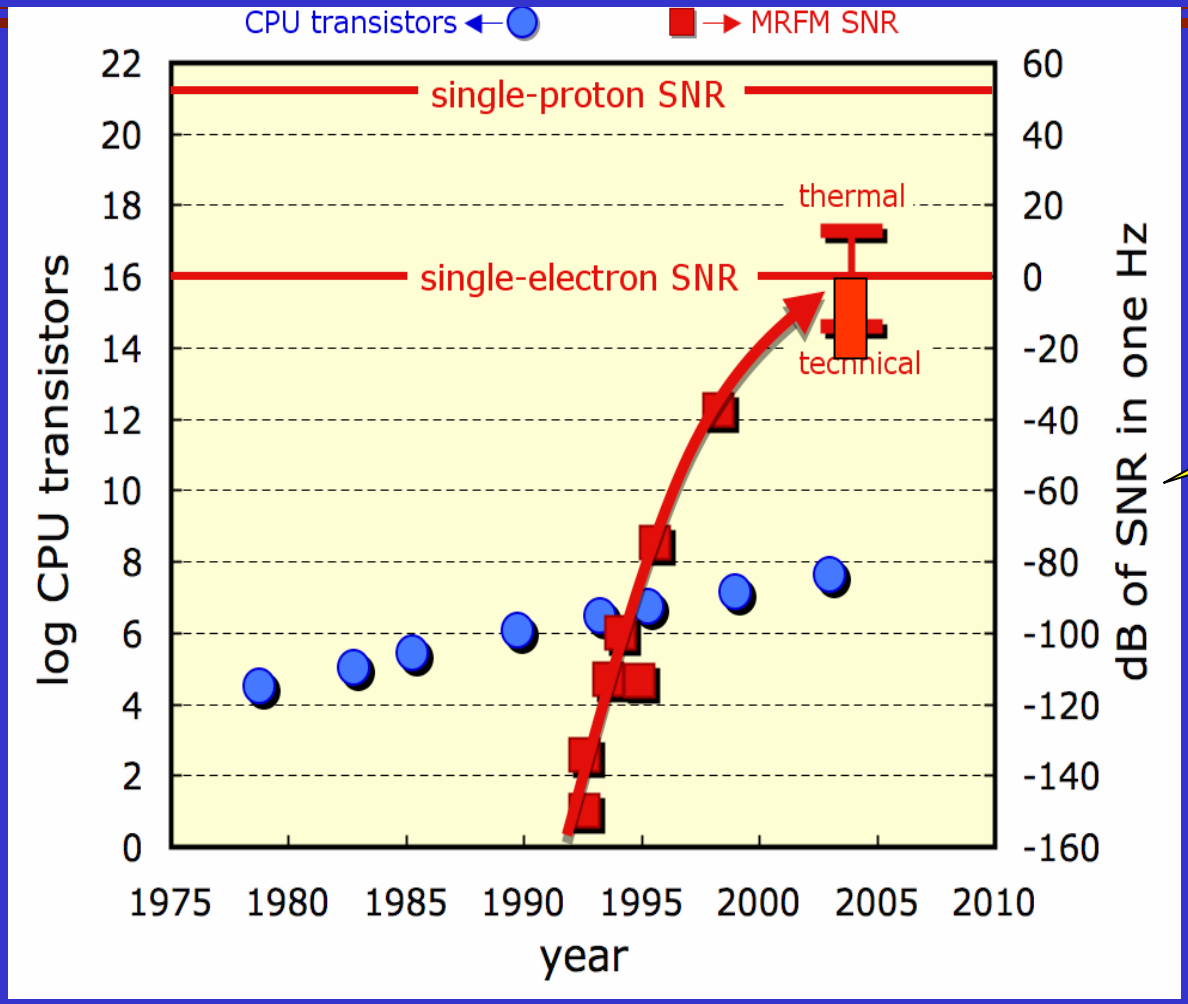
Magnetic Resonance Imaging (MRFM)



Because of the magnetic field gradient, the RF frequency selects the spatial slice where the spins are resonant.

"sensitive slice"

History and Progress: 1991-2004



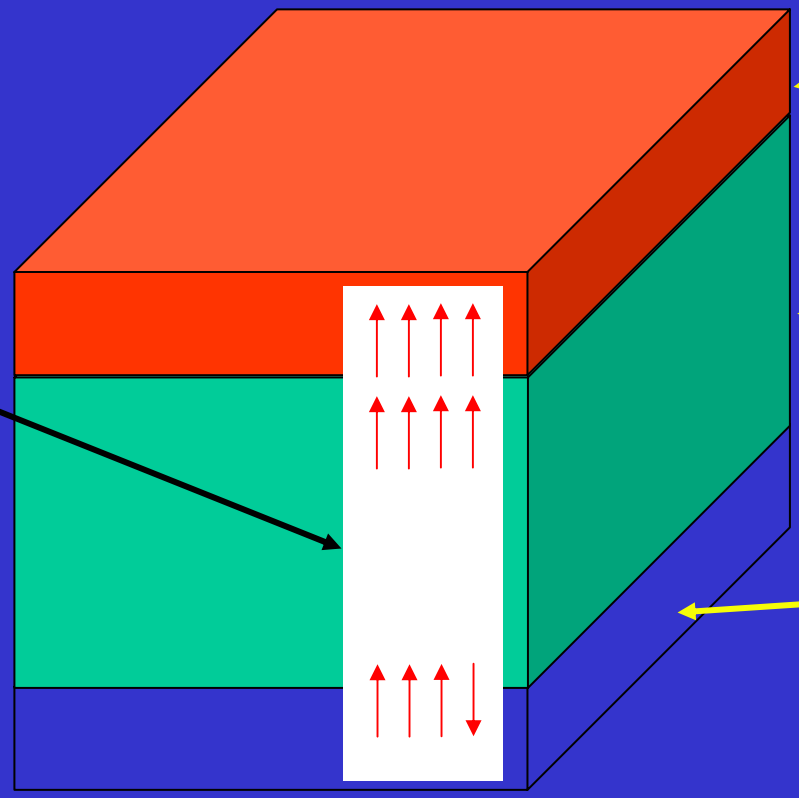
Moore's law for MRFM

minimum detectable magnetic moment ~ (1/grad-B)(bandwidth T m_{eff} f_c / Q)$^{1/2}$

colder smaller cleaner

Specific Example: Spintronics SpinLED

- As spin polarized electrons transit the drift region they (indirectly) lose their polarization to the nuclei.
- MRFM measures the nuclear polarization.



(indirect measure of electron polarization)

ARL Milestones

1996: Empty lab.

1998: Invent new geometry enabling high-field NMR with magnet-on-tip: SPAM geometry (Springiness Preservation by Aligning Magnetization).

1999: 4 K NMR achieved.

2001: FD-NMR of GaAs.

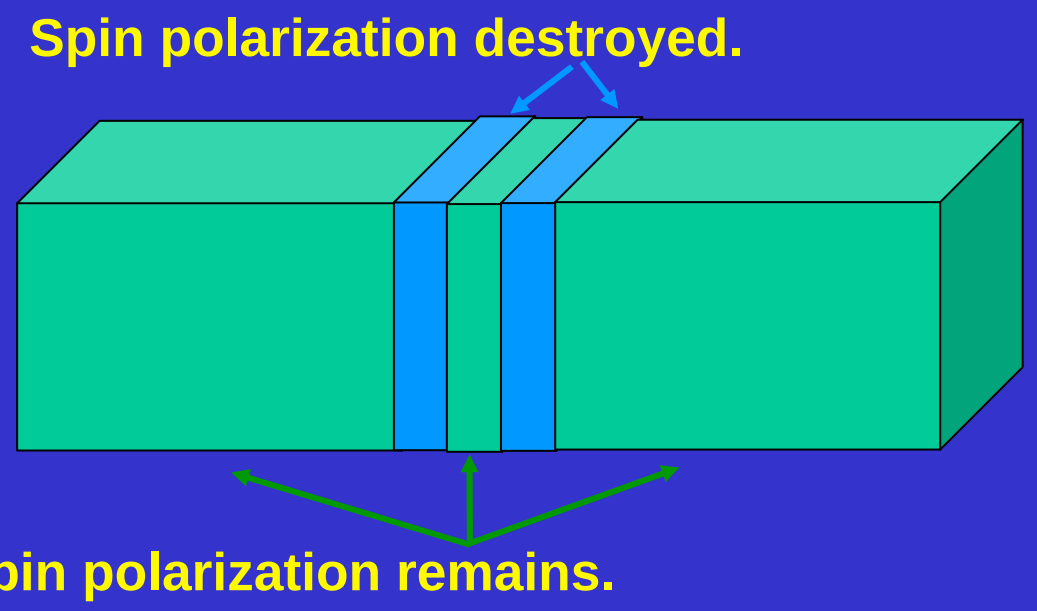
2002: 500 nm resolution NMR-MRI (1-d).

2003: High-field NMR with magnet-on-tip.

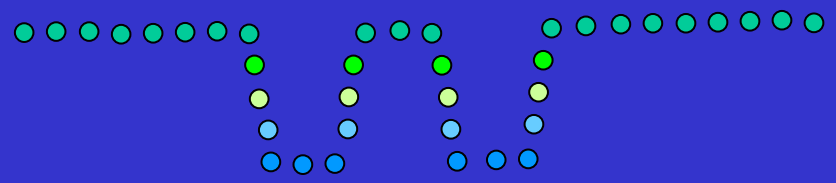
NMR-MRI Resolution

Three Plane Resolution Test

1) Create polarization pattern.

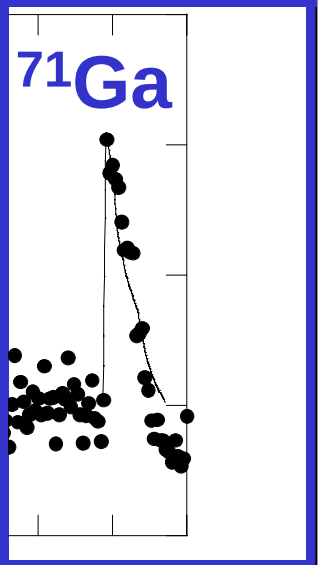


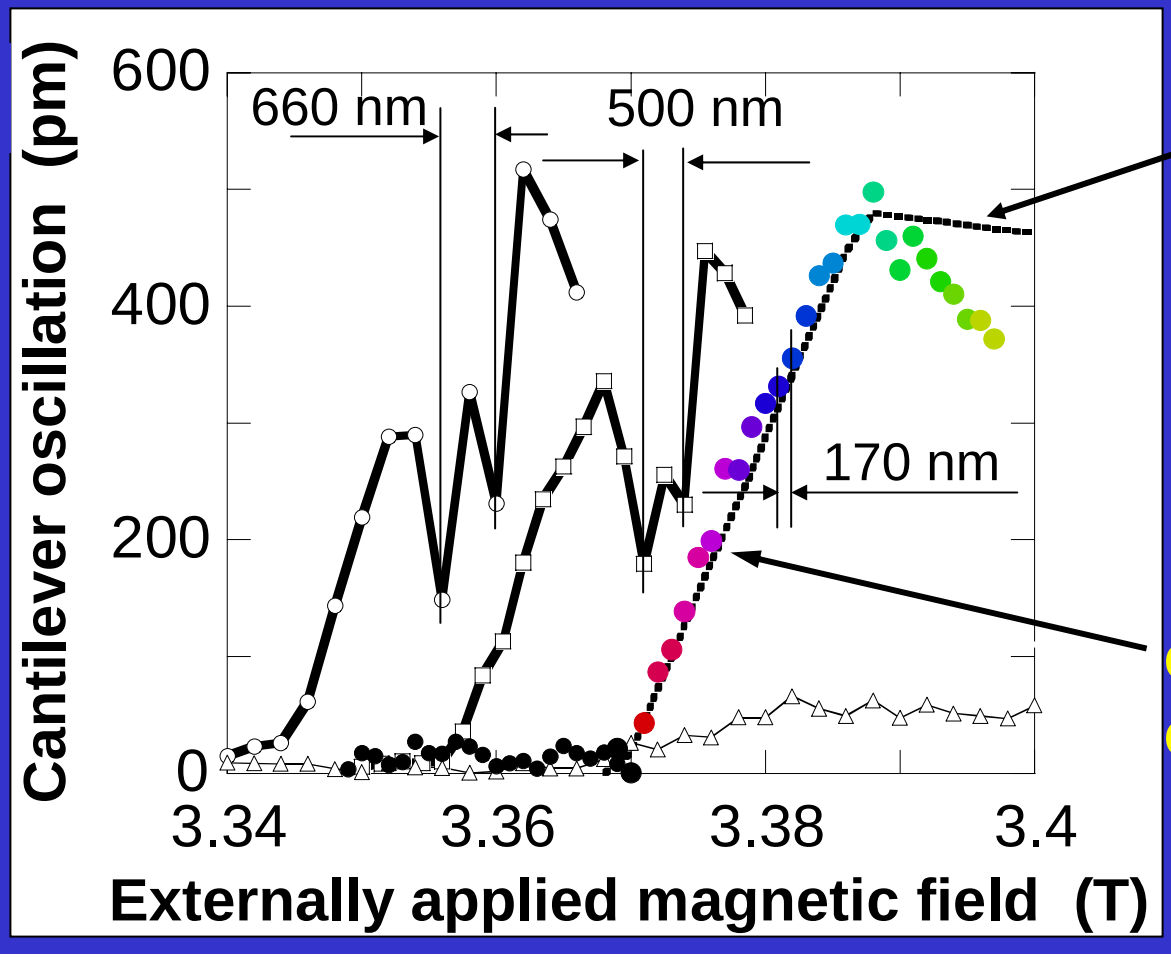
2) Image polarization pattern.



Spin polarization measured.

500 nm Resolution with NMR-MRFM (MRI)

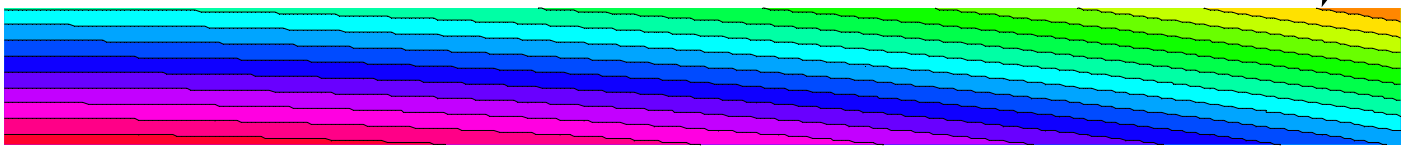




theory

colors correspond

3 microns



Sample Center

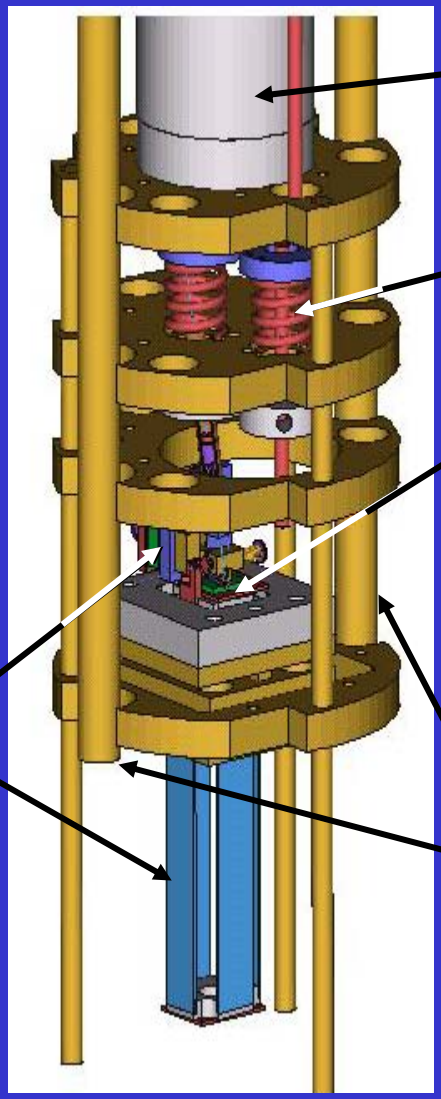
30 microns

The Three Dimensional Probe Head

- Designed with 3D CAD.
- 63 unique parts (not screws, washers, wire).
- 36 custom designed & machined parts.

Vacuum operation, 4 K.

Relative XYZ motion of sample and cantilever while cold. Relative position of each axis measured with fiber based interferometer (z-axis installed).



Bellows vibration isolation.

10 um positioning for the RF coil.

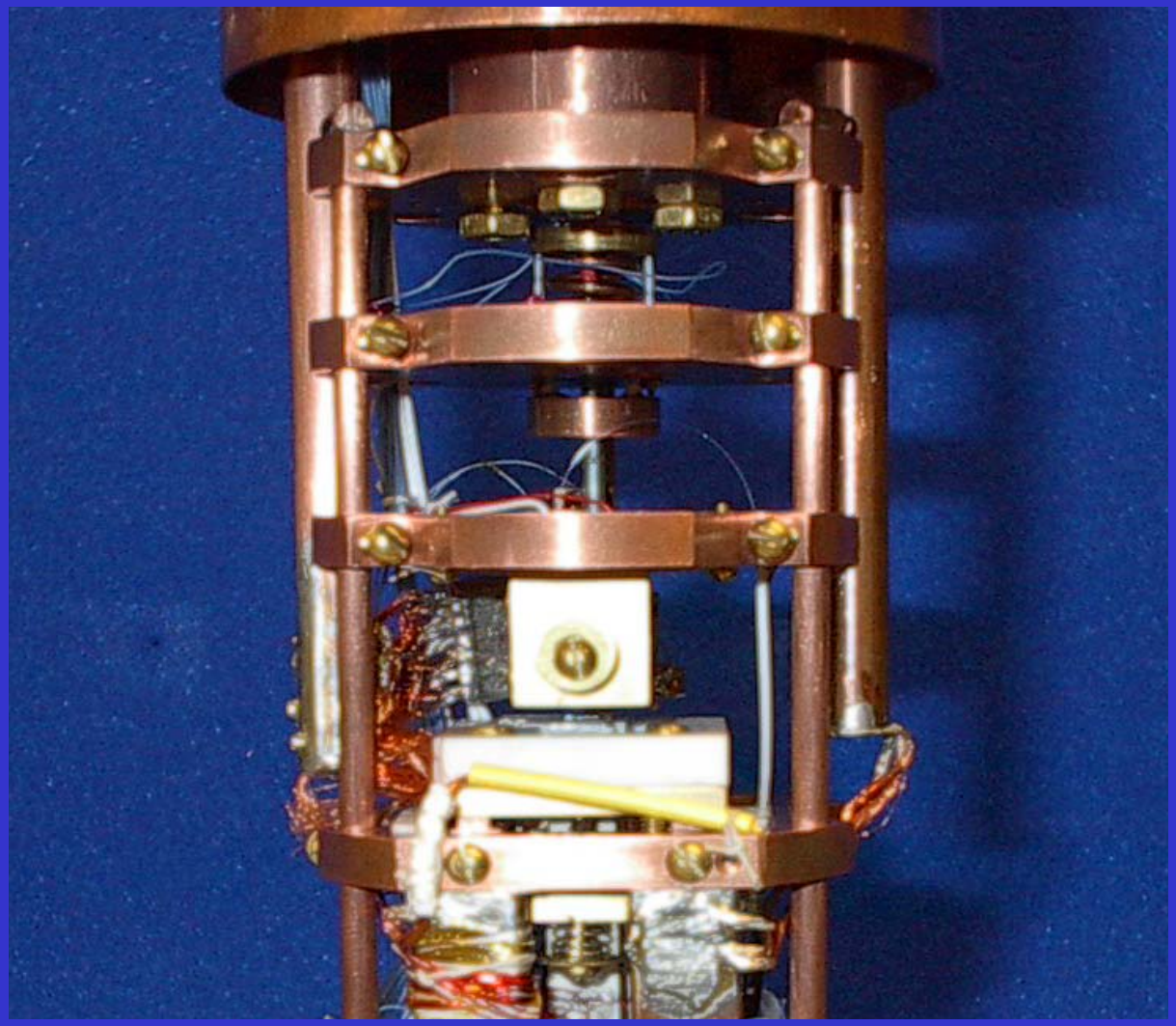
20 Gauss (lab frame) of RF from 0.5 mm diameter coil.

Sample can be a device with leads.

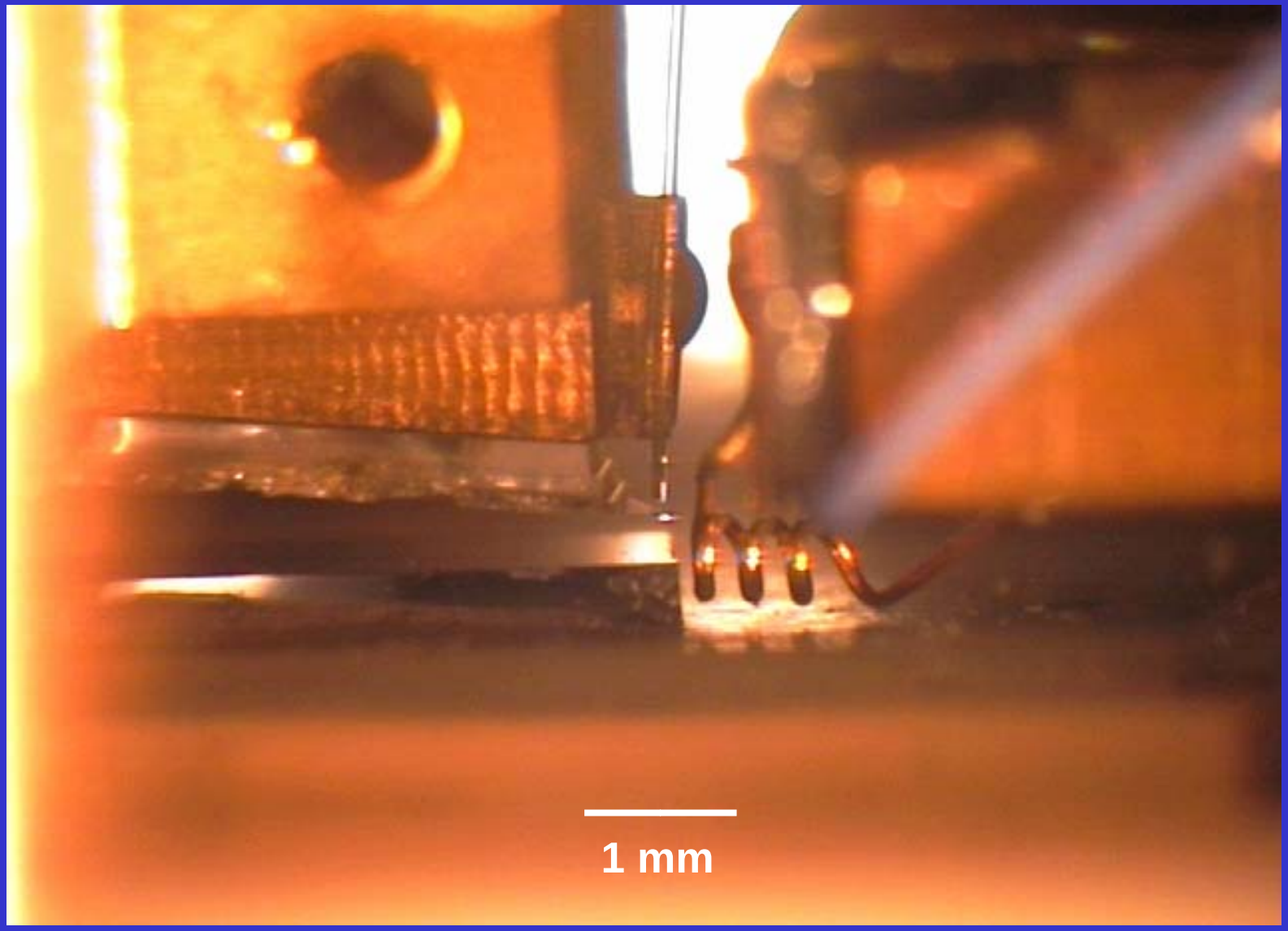
Independent cooling for sample and RF (1 Watt). Cooling must not transmit vibrations.

Three Dimensional Probe Head

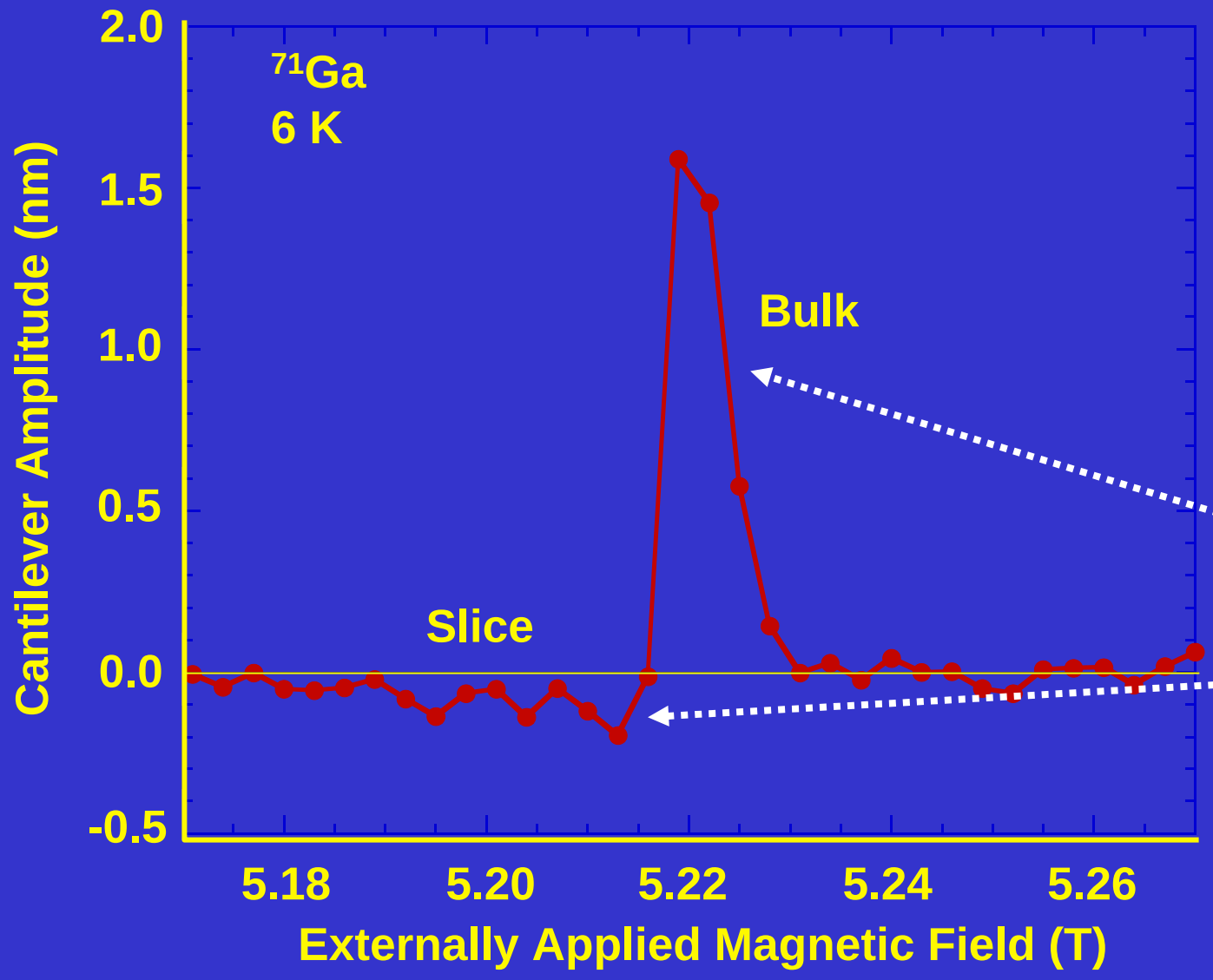
6.35 cm (2.5”)

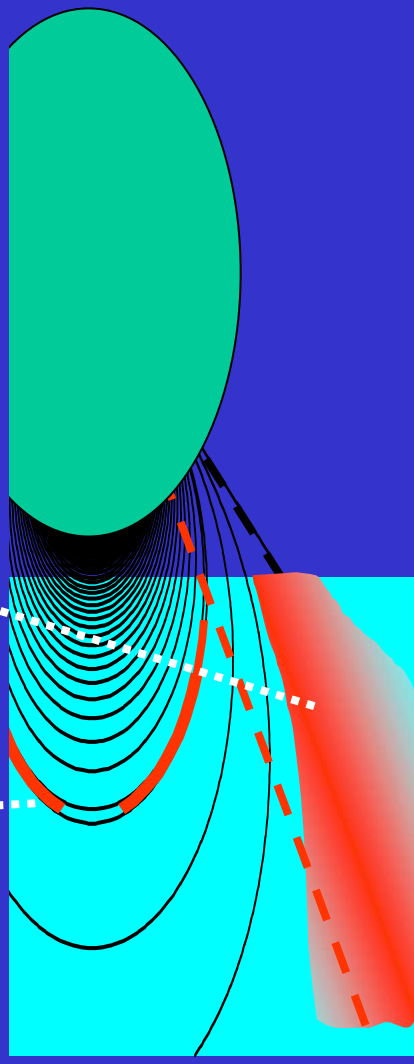


Interaction Region – Close Up

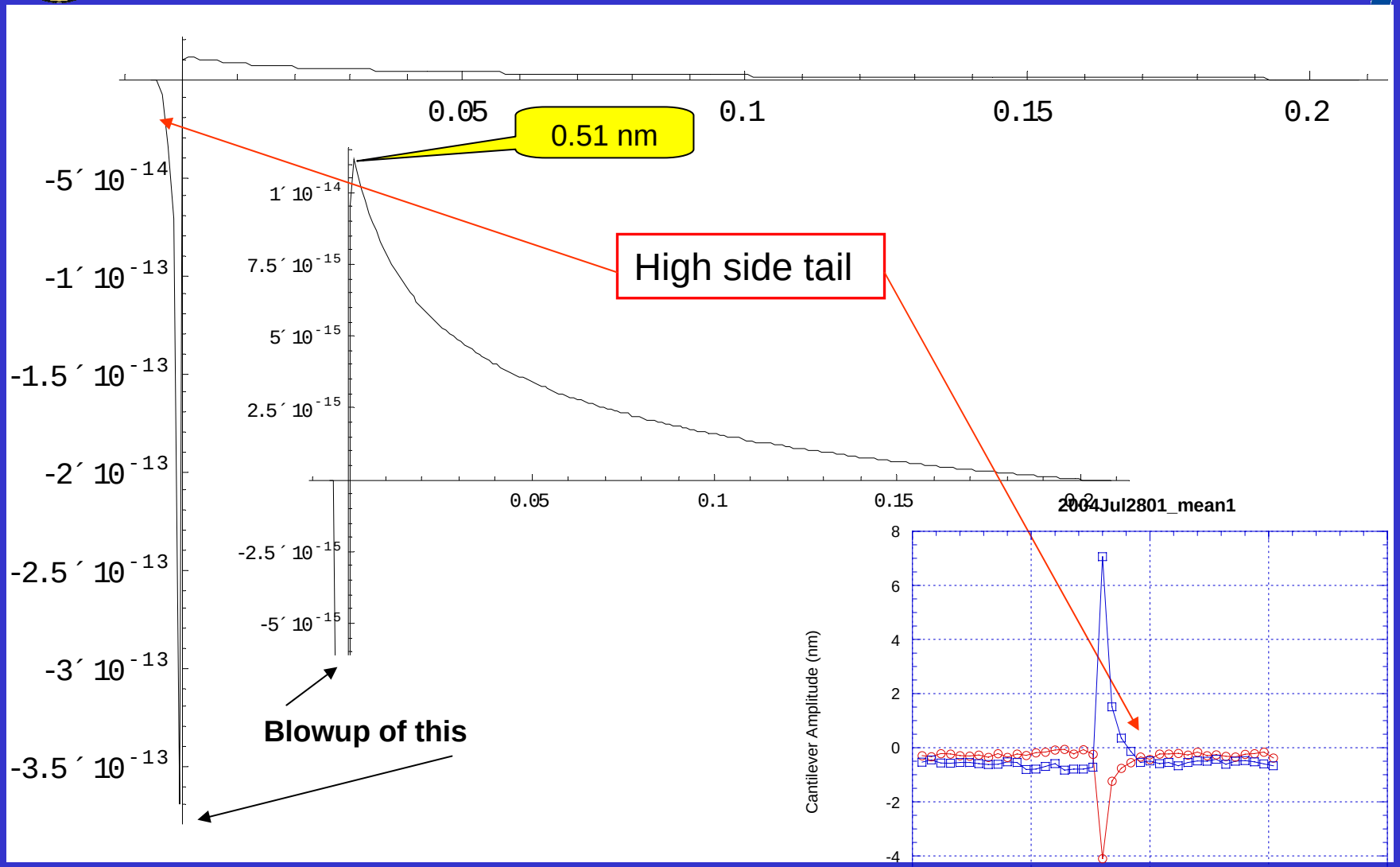
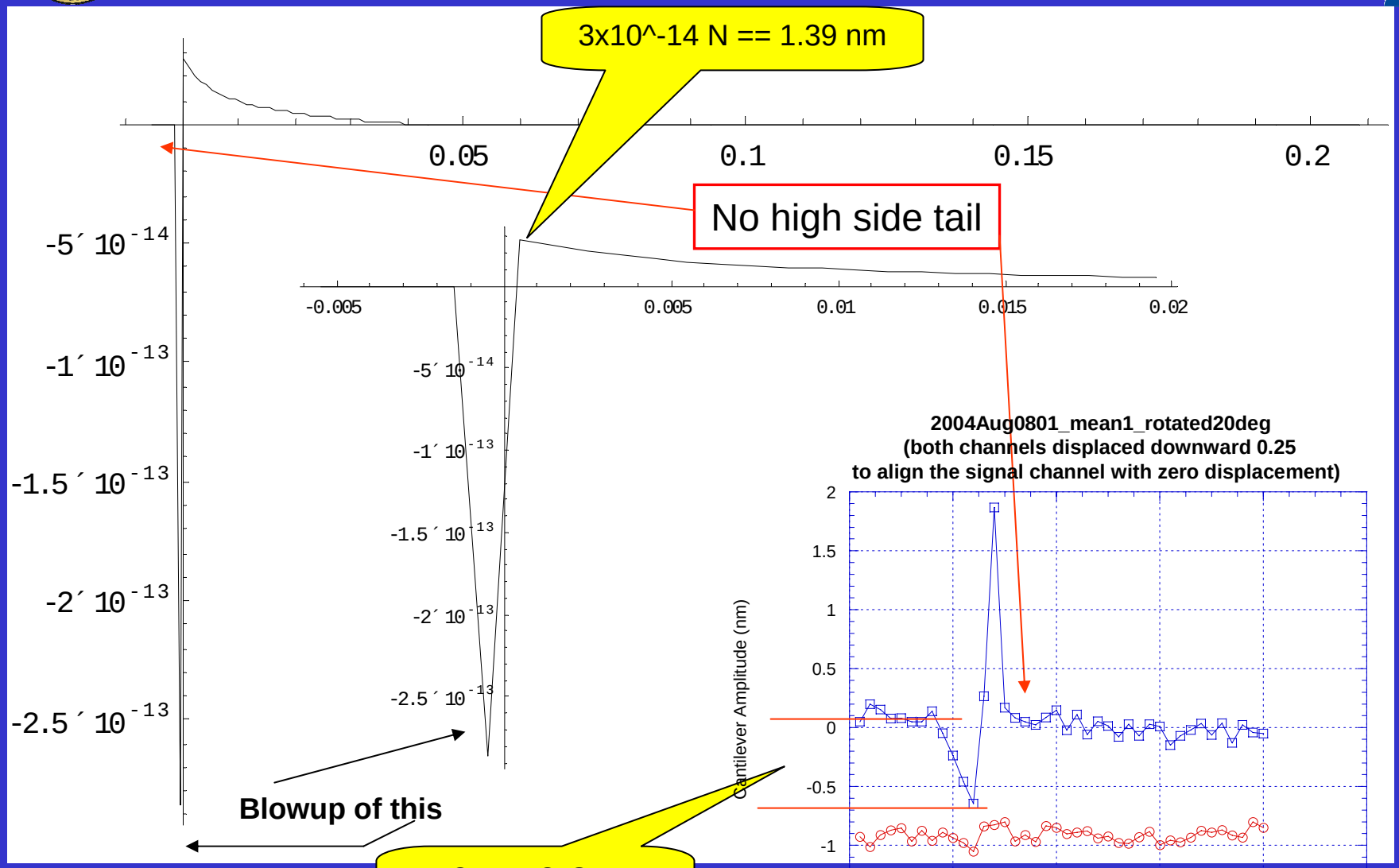


High-Field NMR with Magnet-on-Tip: 3D Probe





10 μm Diameter Sphere, Half Plane Sample, 1 um off of the Surface



10 um Diameter Sphere, Half Plane Sample, 5 um off of the Surface