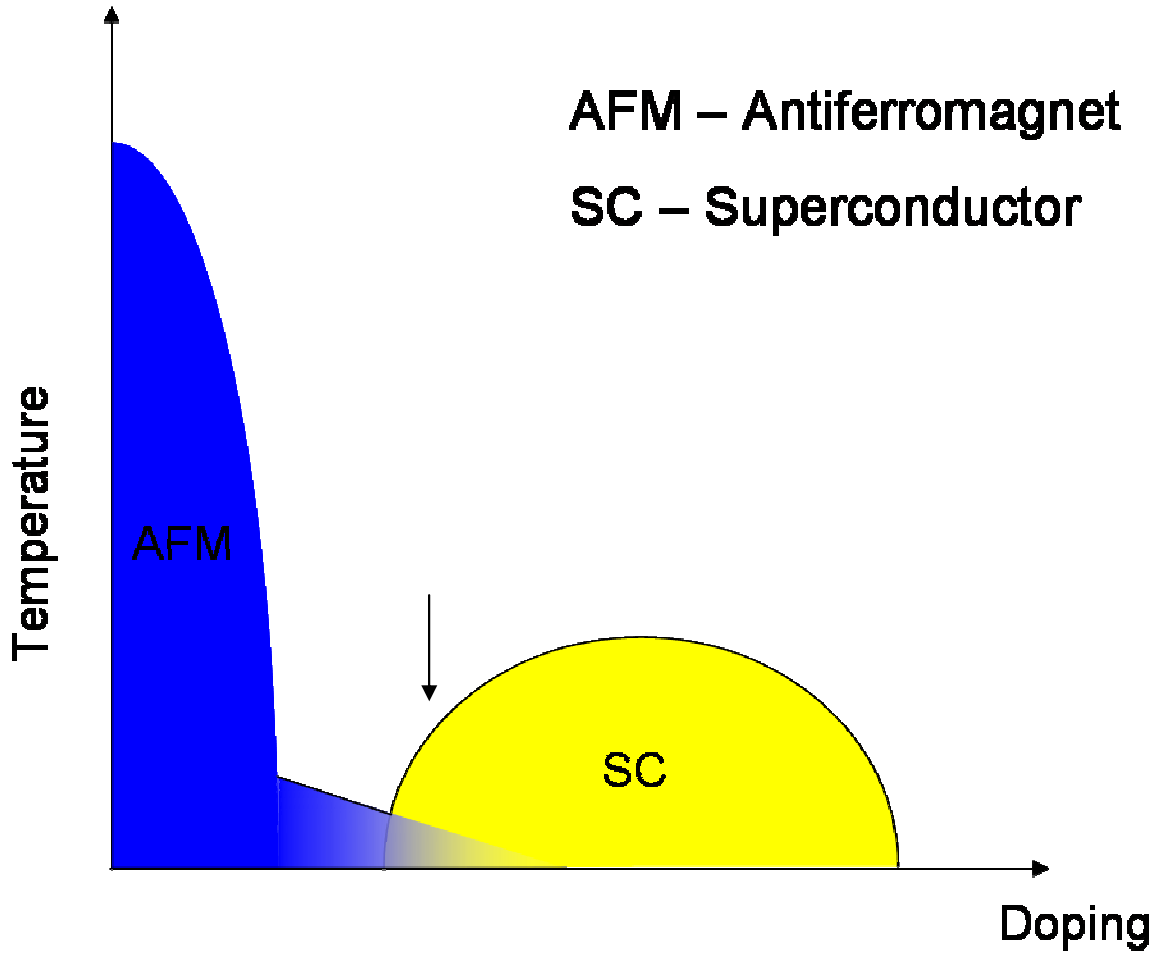
The interaction between the magnetic and superconducting order parameters in a $La_{1.94}Sr_{0.06}CuO_4$ wire

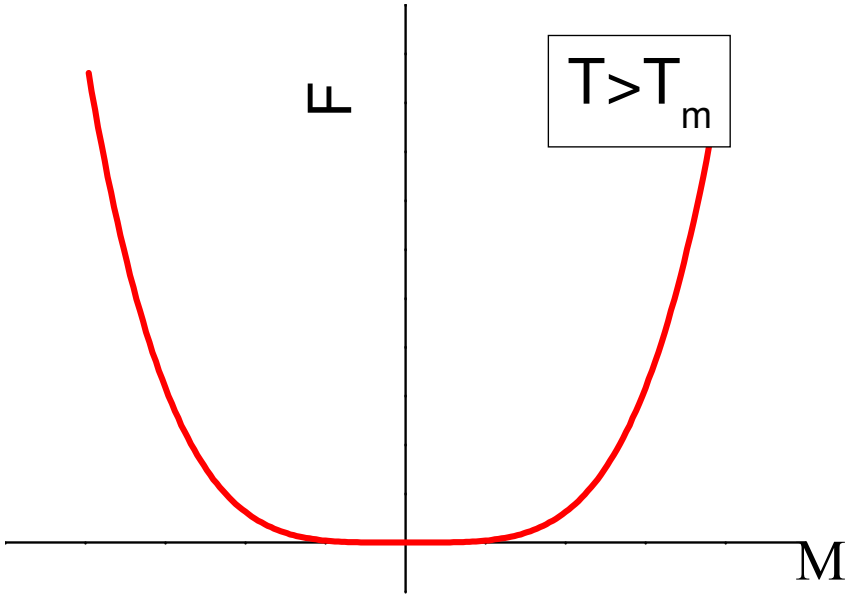
1) M. Shay, A. Keren, G. Koren, A. Kanigel, D. Podolsky; Technion.

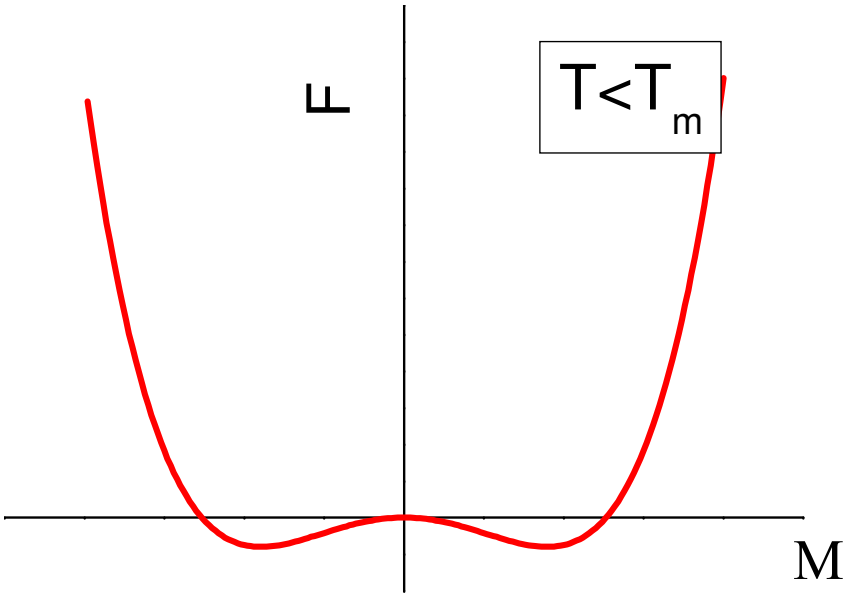
2) E. Morenzoni and the LEM team; PSI, Switzerland.

Our compound



Ginzburg-Landau Model





$$F = b \cdot (T - T_m)\left|M\right|^2 + U_m \left|M\right|^4$$

GL model for SC and magnetic order parameters with chemical potential

$$\mathcal{G} = a(T)|\Delta|^2 + U_s|\Delta|^4 + b(T-T_m)|M|^2 + U_m|M|^4 + U_{sm}|\Delta|^2|M|^2 + \mu|\Delta|^2$$

Demler *et. al.* Rev. Mod. Phys. **76** 909 (2004).

Our research question.

How much is U_{sm}?

Measure M vs. supercurrent I?

Start from GL free energy

$$F = a(T)\left(1 - I^2 / I^2_{c2}\right)|\Delta|^2 + U_s|\Delta|^4$$
$$+ b\cdot(T - T_m)|M|^2 + U_m|M|^4$$
$$+ U_{sm}|M|^2|\Delta|^2$$

Prediction

$$\delta T_m = T_m(I) - T_m(0) = \frac{2U_{sm}}{b}\frac{I^2}{I_{c2}{}^2}$$

The magnetic transition temperature, T_m, changes when current is applied

The U_{sm} measurement

- Flow $J \sim J_c$ in a SC wire.

Since $J_c \sim 10^5$ A/cm^2

a thin wire is needed.

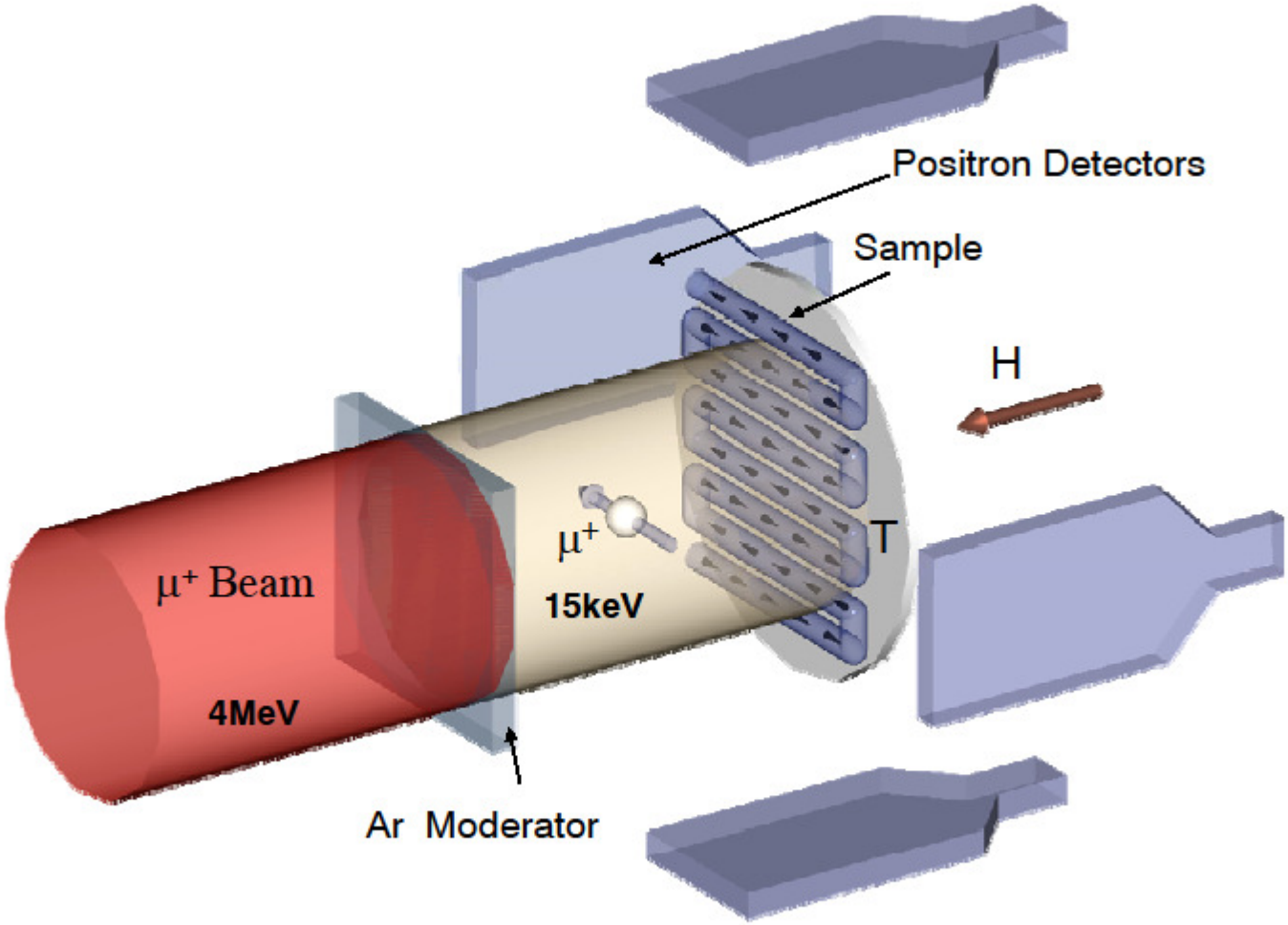
- Hold it at a constant T.

Not trivial since we inject power.

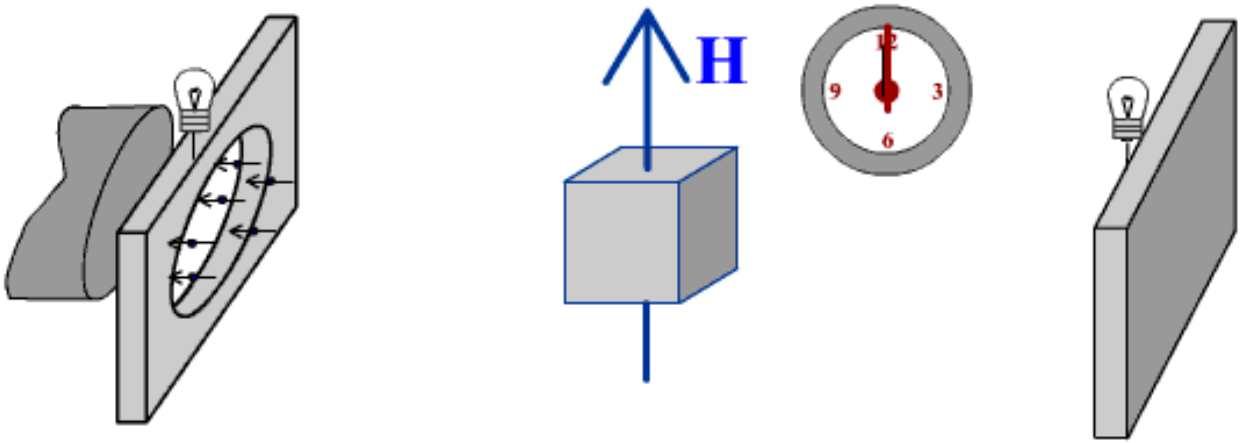
- Measure M.

Low energy muons (LEM) are needed.

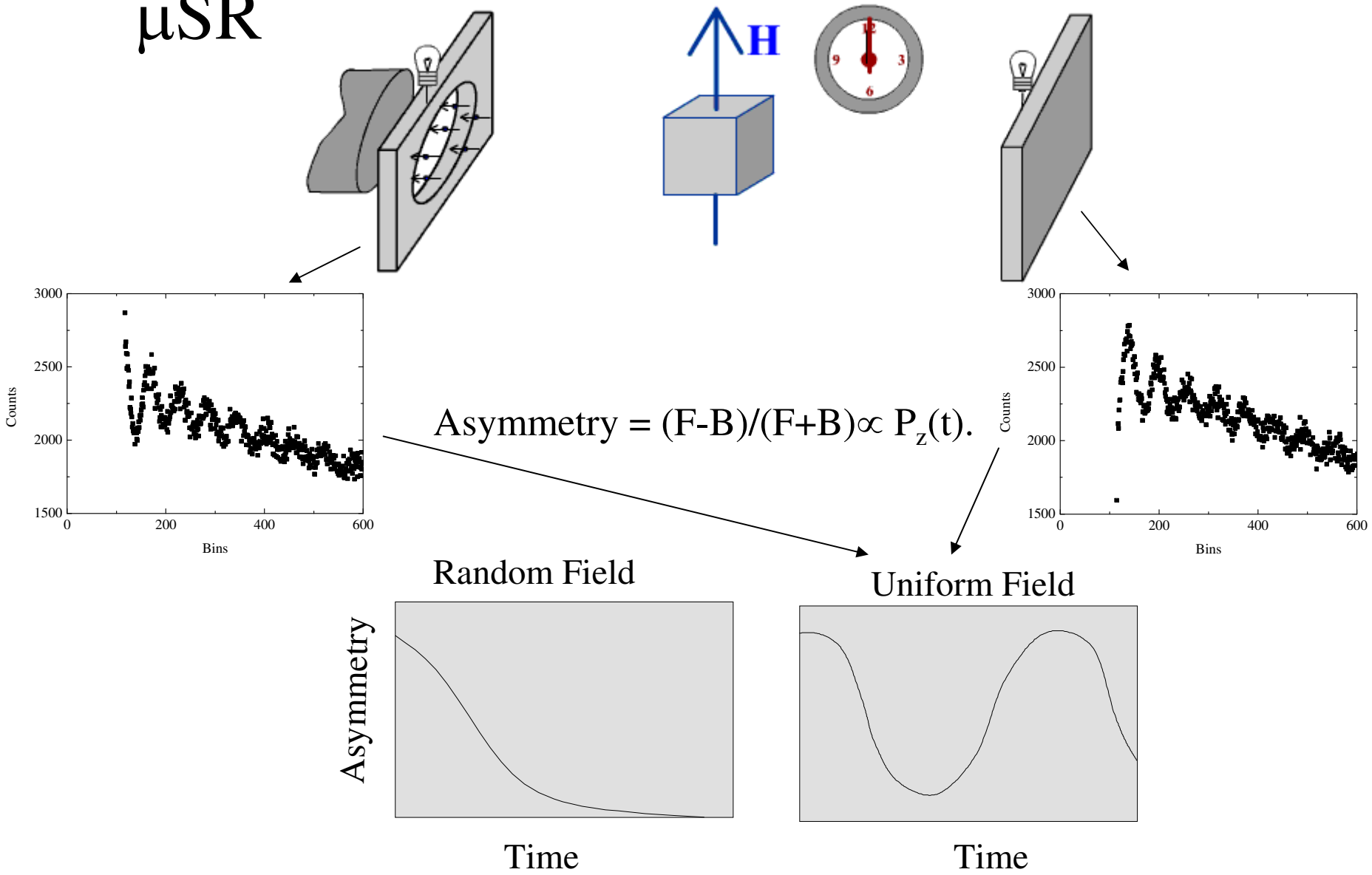
Low Energy Muons



Principals of μSR

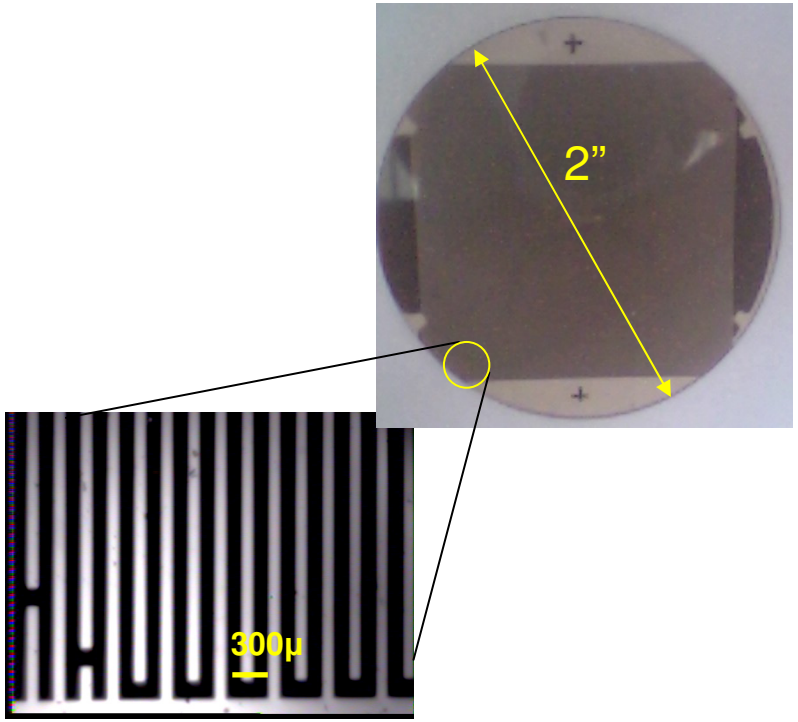


Principals of μSR



The sample

A long (8m) and thin ($0.5x100\mu m^2$) meander $La_{1.94}Sr_{0.06}CuO_4$ wire

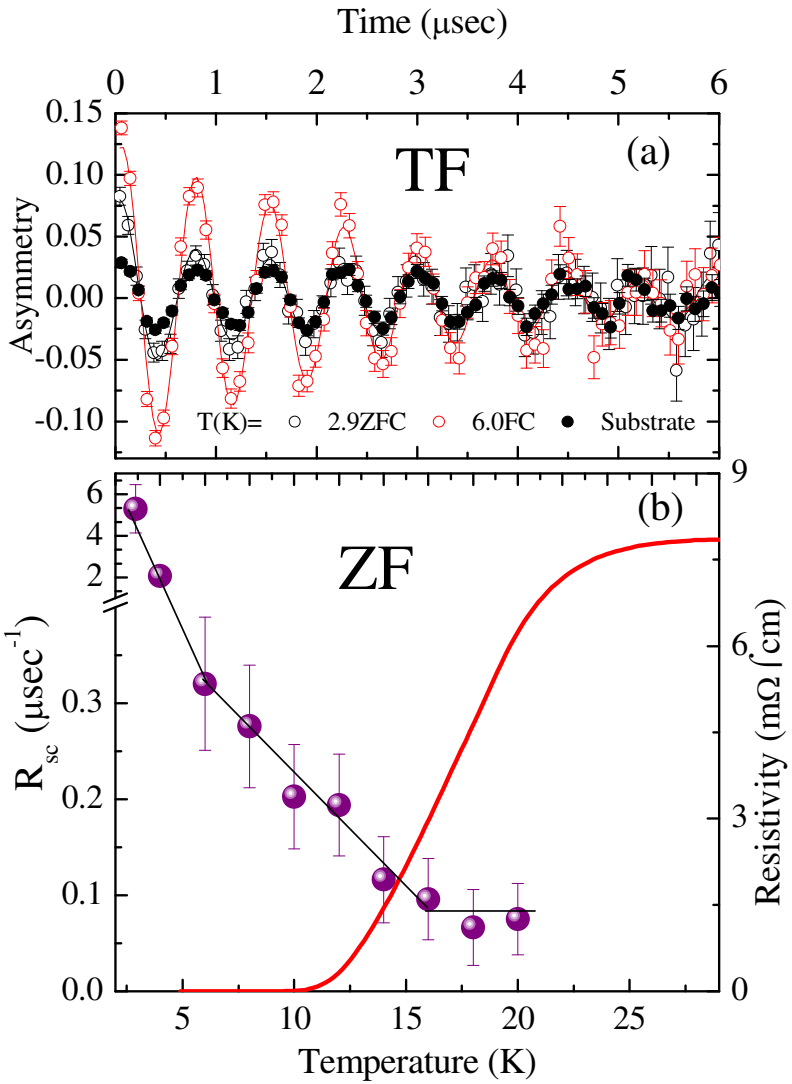


Samples are prepared in Gad Koren’s lab at the Technion

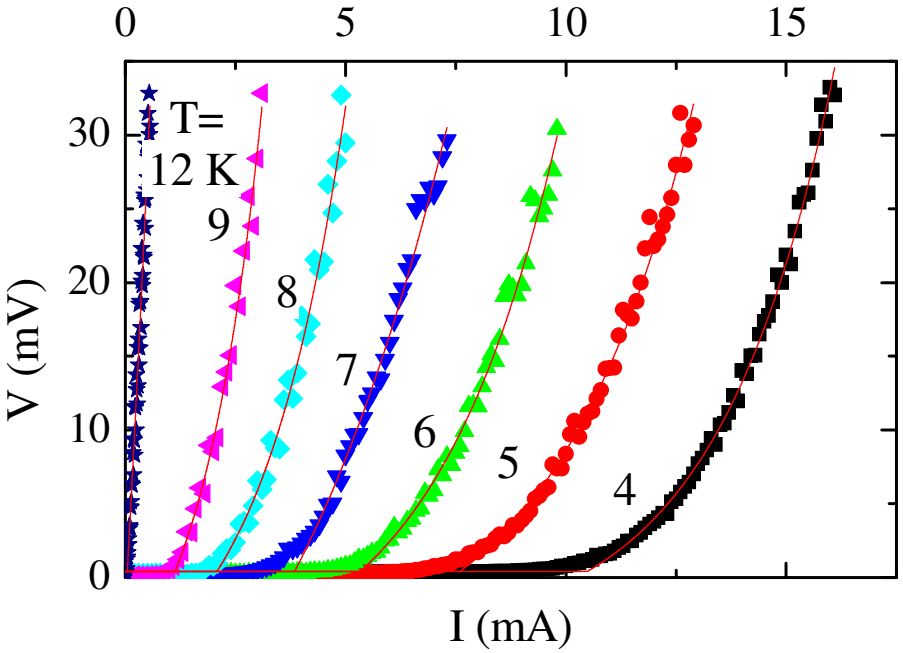
Sample characterization

Transverse field and resistivity

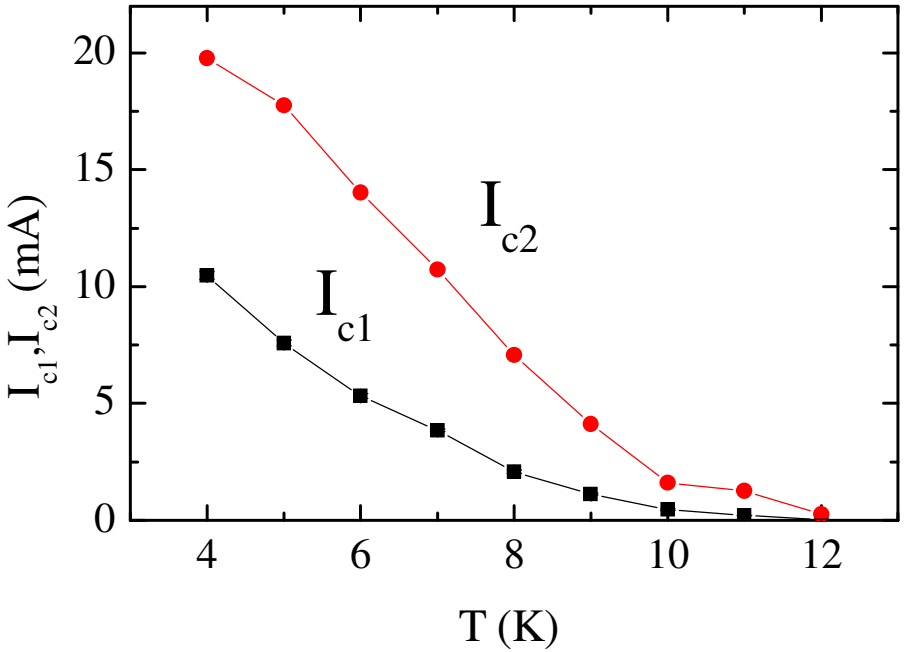
- SC volume is ~100%.
- T_c~16 K.
- Penetration depth is ~ to sample thickness.



Temperature Calibration

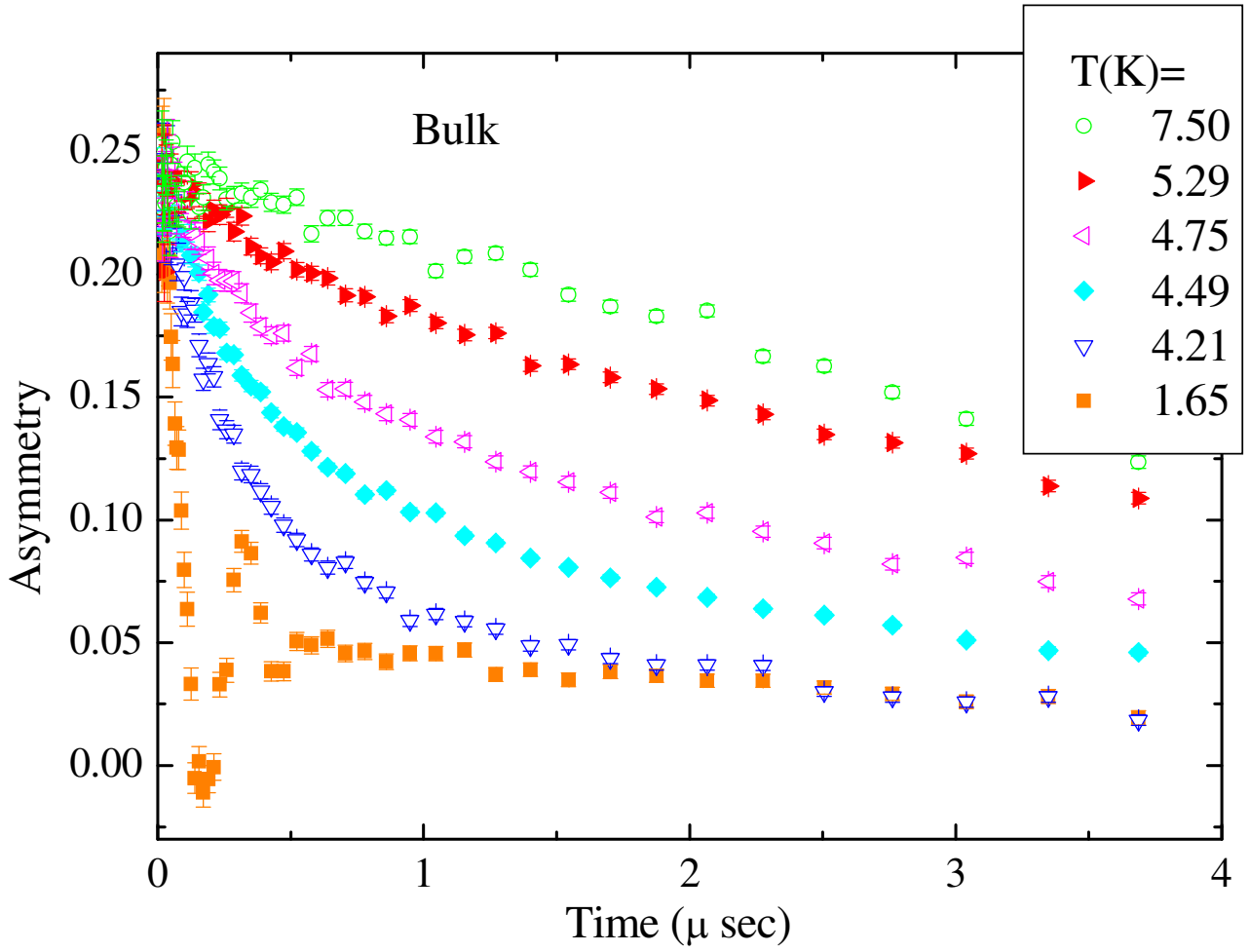


Temperature accuracy ~ 0.01 K



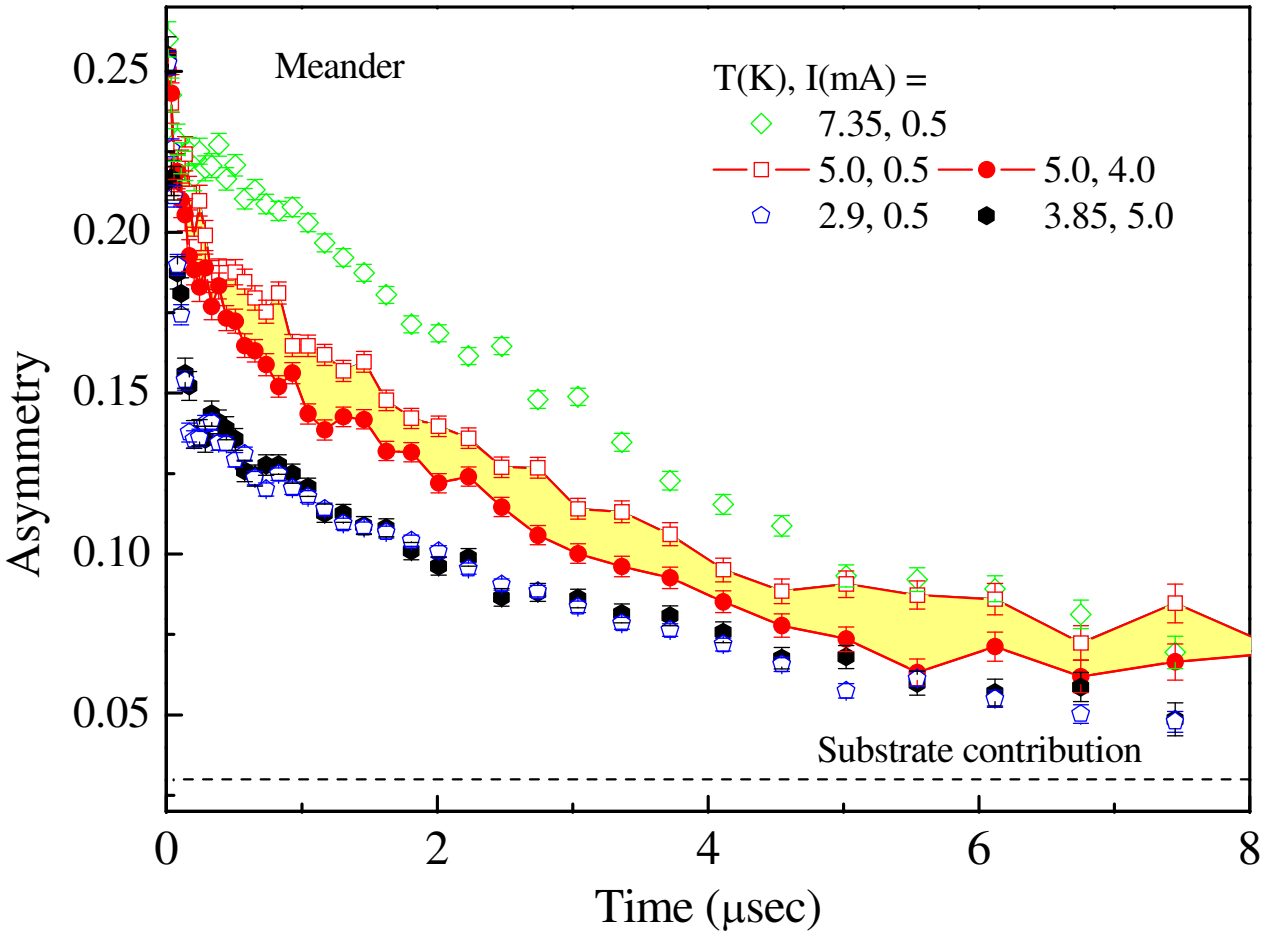
Bulk measurements

Zero field



Magnetic transition occurs around 5K.
At low T the magnetic volume is 100%.

Main Raw Data



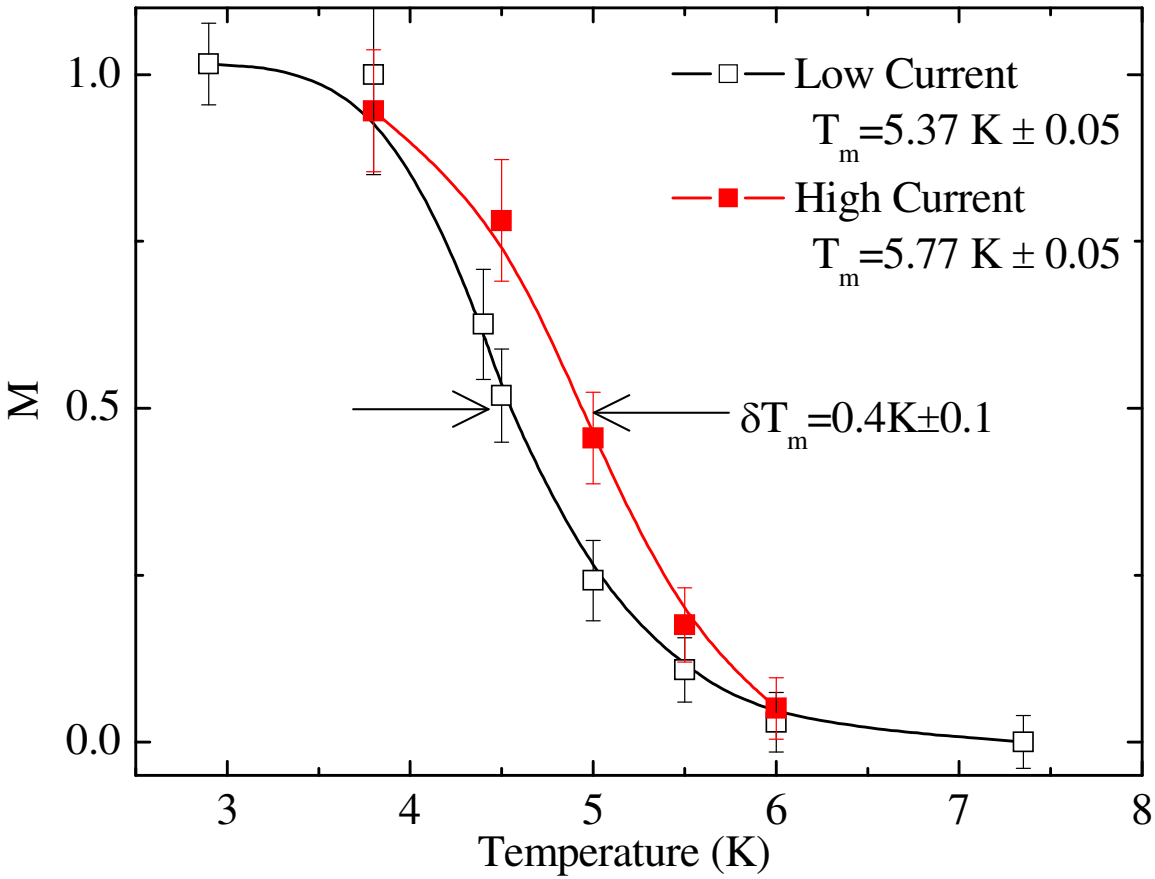
At 5K a current of 4mA increases magnetism.
At low T, I or T do not affect the magnetization.

Analysis

$$M = \frac{\langle Asy \rangle^{-1}(T) - \langle Asy \rangle^{-1}(\infty)}{\langle Asy \rangle^{-1}(0) - \langle Asy \rangle^{-1}(\infty)}$$

$$\langle Asy \rangle = \frac{1}{T}\int_0^T Asymmetry(t)dt$$

Main results



Current ~0.2I_{c2} makes T_m grow by 0.4K.

Heating, direct current, or T gradient are not responsible for this effect.

Main conclusions

From

$$\delta \mathrm{T}_m = \frac{2U_{sm}}{b}\frac{I^2}{{I_{c2}}^2}$$

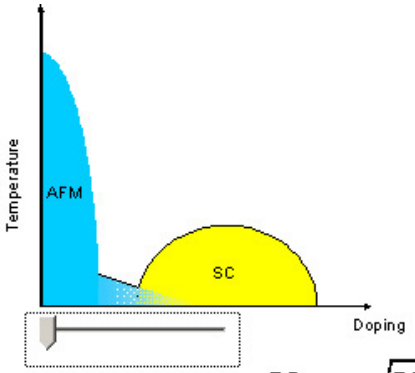
we find

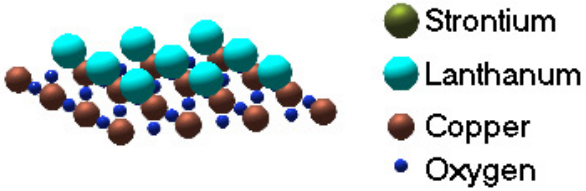
$$\frac{2U_{sm}}{b} = 3.6\mathrm{K}$$

with b dimensionless.

Is U_{sm} big or small? We should compare with $\sqrt{U_s U_m}$.

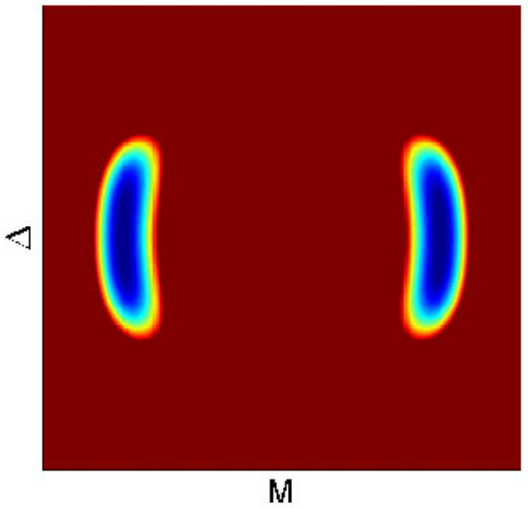
$$G = a(T)|\Delta|^2 + U_s|\Delta|^4 + b\cdot(T - T_m)|M|^2 + U_m|M|^4 + U_{sm}|M|^2|\Delta|^2 + \mu|\Delta|^2$$





Free Energy G

$U_{sm} < \sqrt{U_m U_s}$



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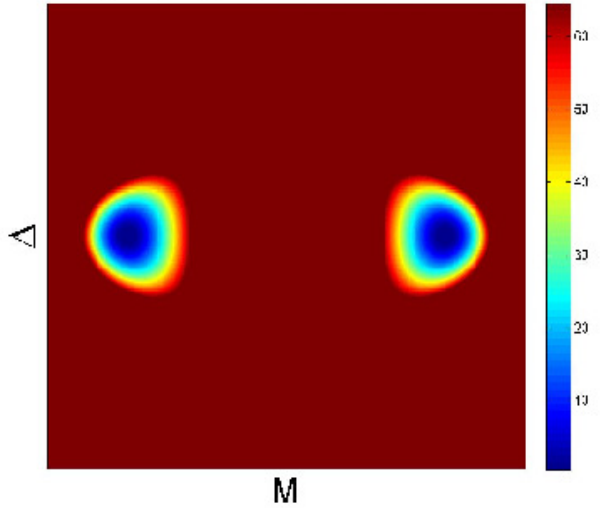
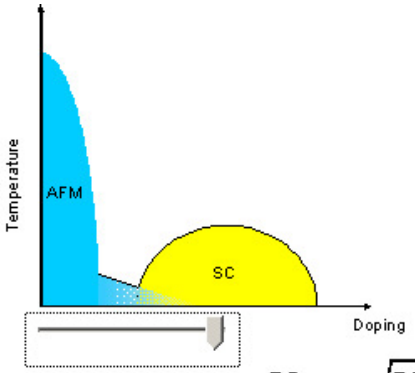
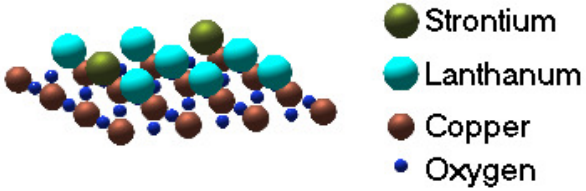


Material Visualization

$$G = a(T)|\Delta|^2 + U_s|\Delta|^4 + b\cdot(T - T_m)|M|^2 + U_m|M|^4 + U_{sm}|M|^2|\Delta|^2 + \mu|\Delta|^2$$





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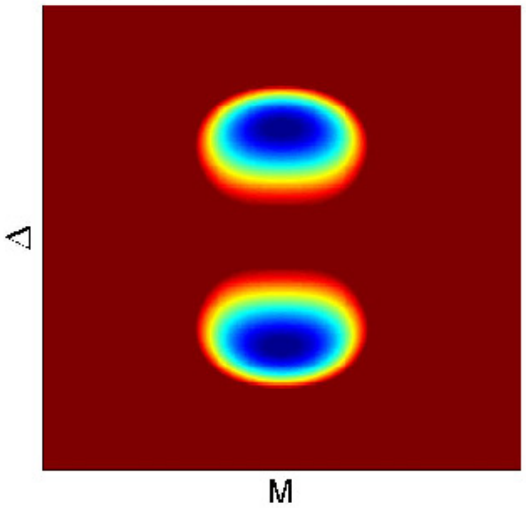

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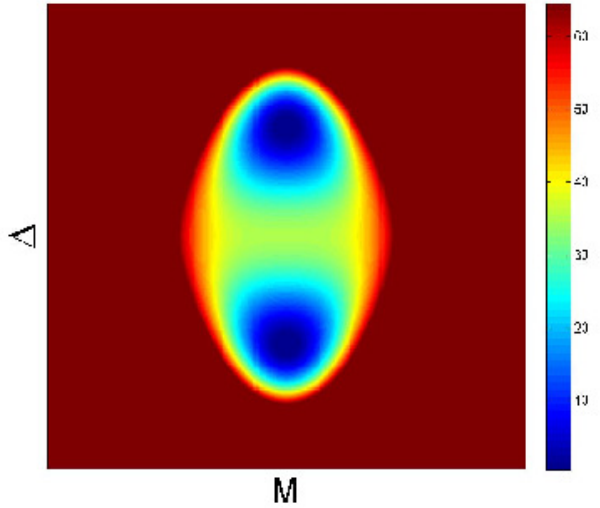

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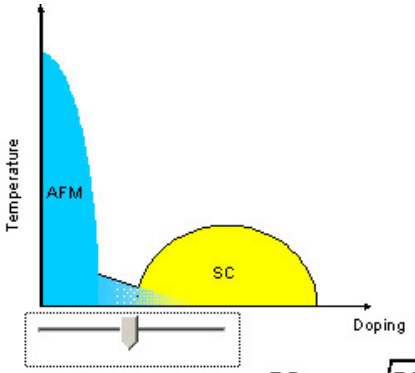

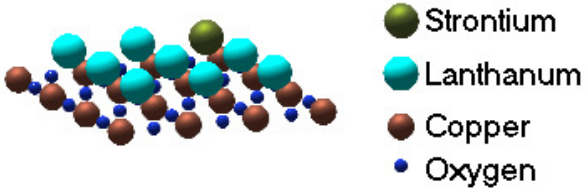

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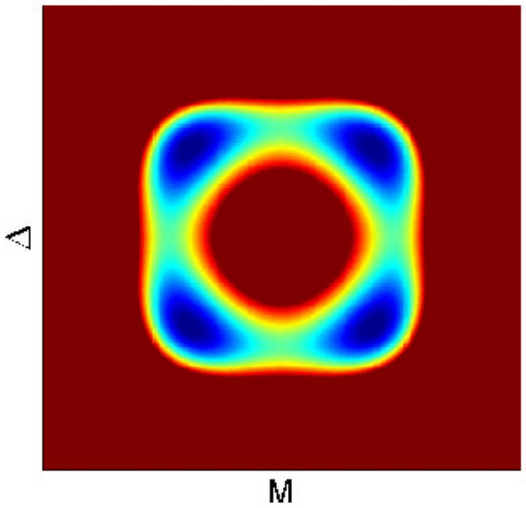

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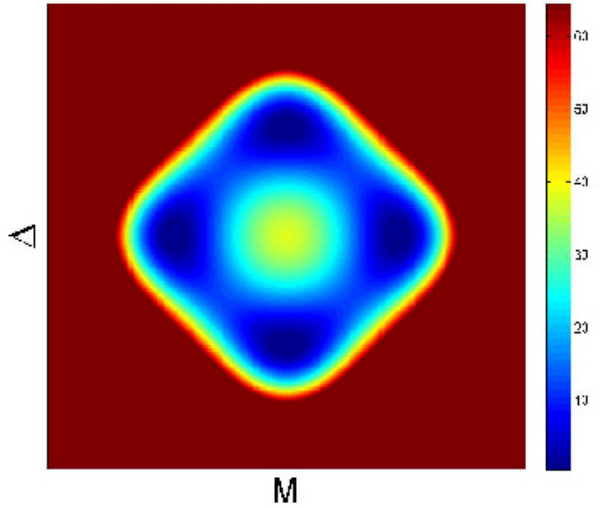

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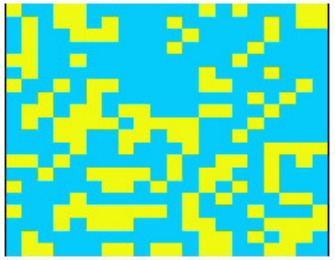


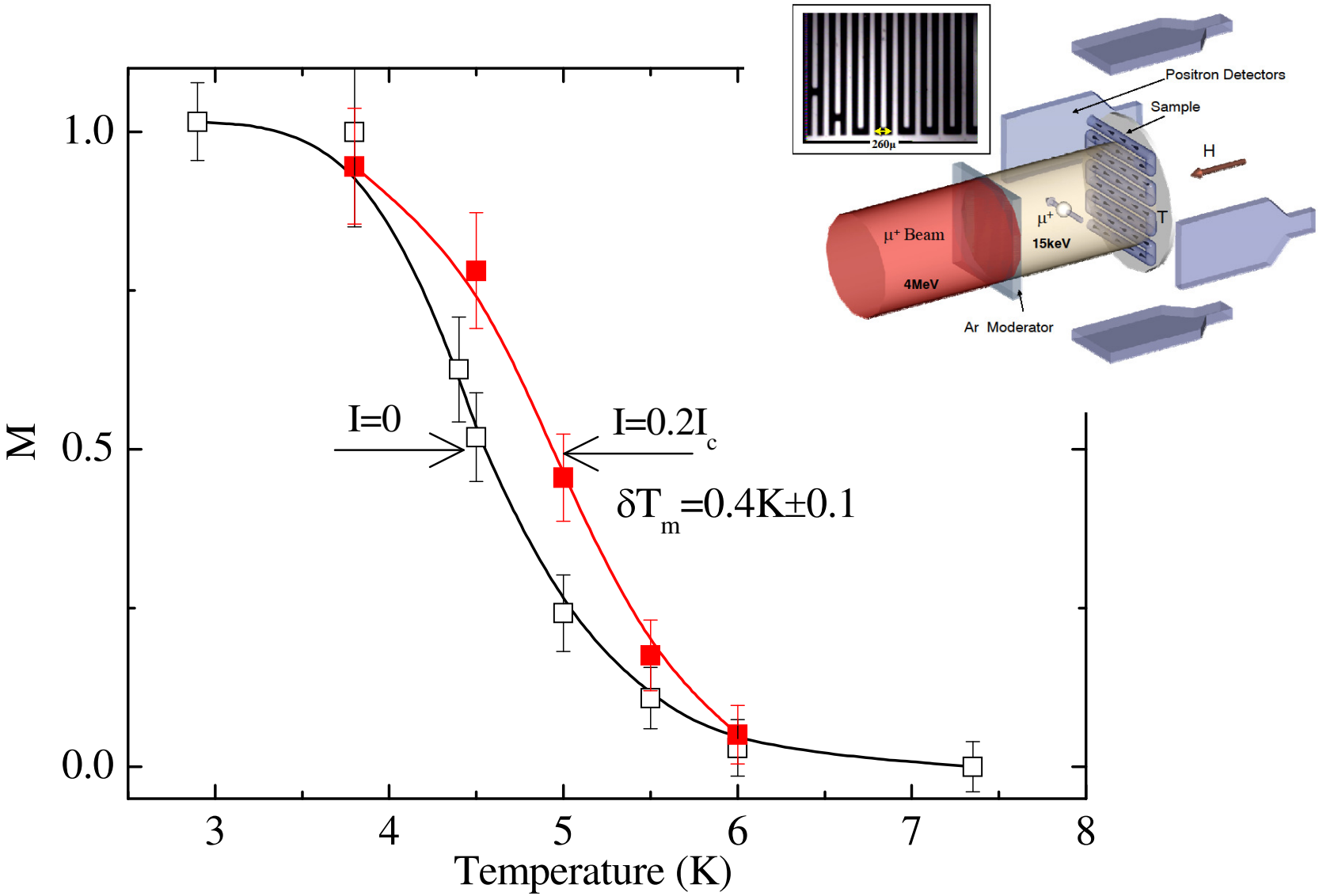
Sub-Conclusions

$$\frac{U_{sm}}{\sqrt{U_s U_m}} \approx \frac{U_{sm}}{\sqrt{T_c T_m}} \approx 0.36 \approx 1$$

The system is on the border between first and second order transition.

End

Cond-mat/0906.2047


1.0
0.5
0.0
M
3
4
5
6
7
8
Temperature (K)
I=0
I=0.2I_c
δT_m=0.4K±0.1
260μ
Positron Detectors
Sample
H
T
μ+ Beam
4MeV
μ+
15keV
Ar Moderator