TRIUMF summer school 2011

β-NMR and Low Energy μSR cont'd

R.F. Kiefl

Photo: TRIUMF

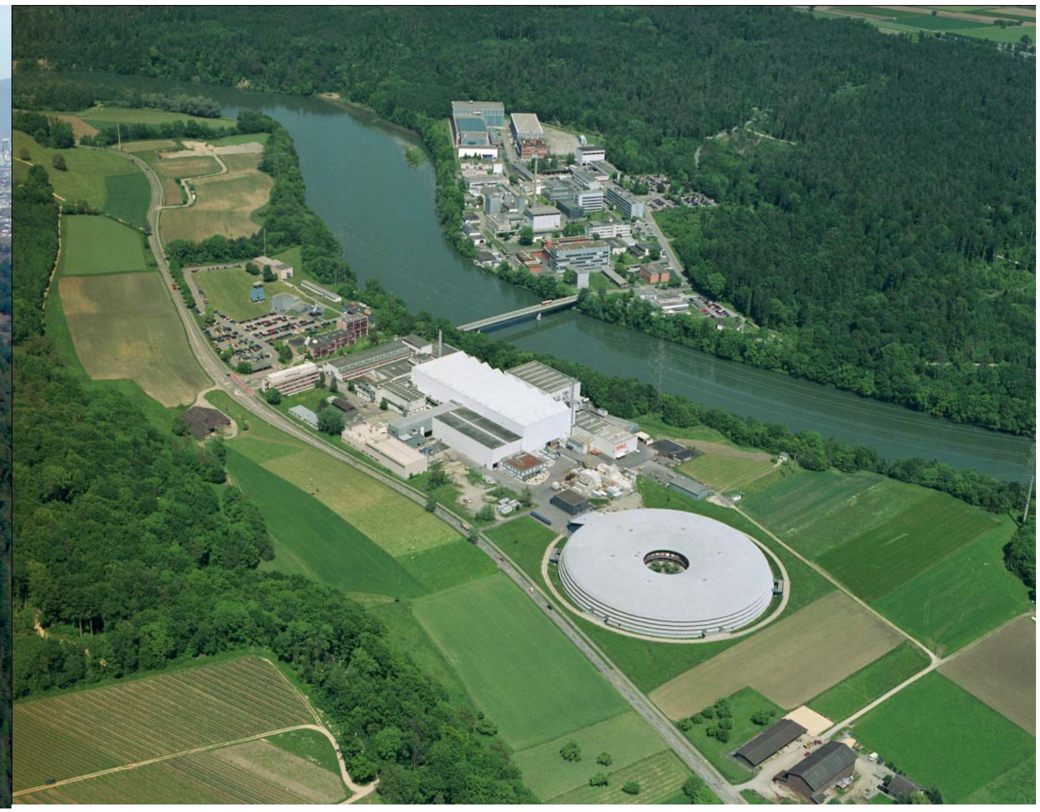
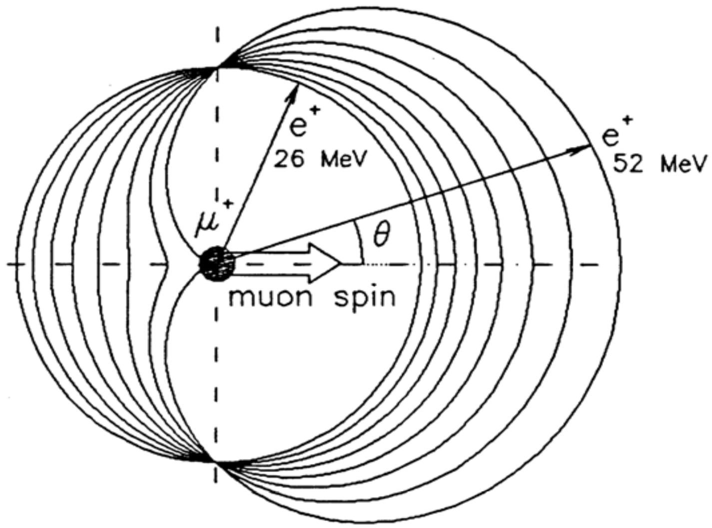


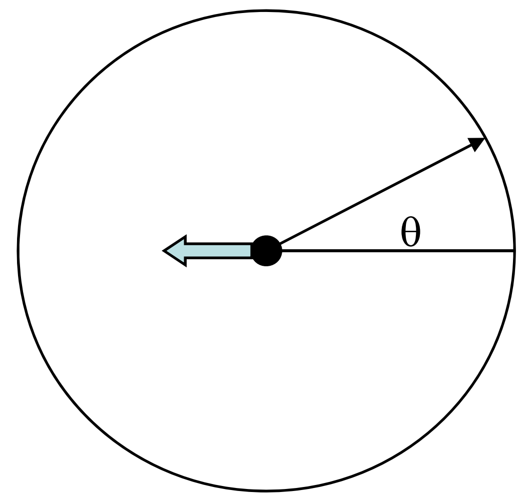
Photo: Paul Scherrer Institute

Properties of the muon and ^8Li

$\mu^+ \longrightarrow e^+ + \nu_e + \bar{\nu}_\mu$

$^8Li \longrightarrow {}^8Be + e^- + \nu_e$





Spin = 1/2
γ = 135.55MHz/T
<A>= 0.33
Polarization = 95%
Lifetime = 2.19714(7) μs

Spin=2, Q=33 mb
γ =6.30 MHz/T
<A>=-0.30
Polarization= 70%
Lifetime= 1.2s

Part II: Applications

-applications of low energy μSR

-direct measure of the field profile and magnetic penetration depth in the Meissner state of superconductors i.e $YBa_2Cu_3O_x$ $Co_xBaFe_{2-x}As_2$

-applications of β-NMR

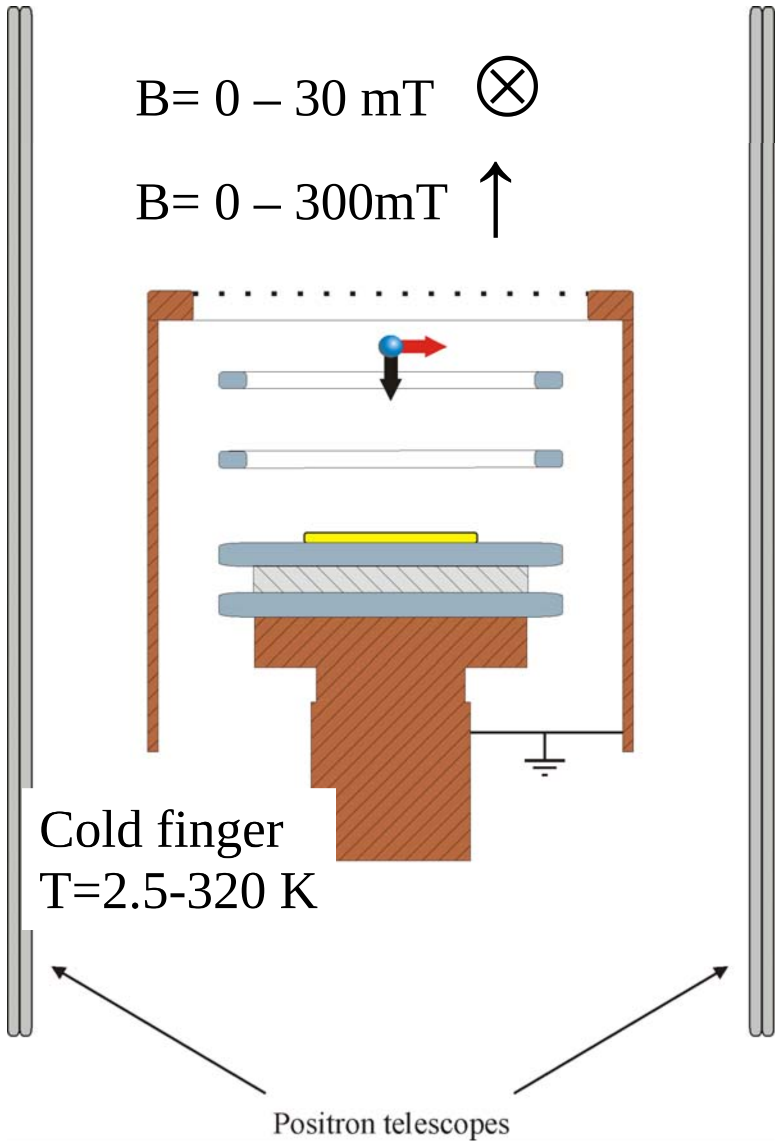
-superconducting critical fluctuations in Ag/Nb and Pb films

- magnetic phase transition in STO/LAO multilayers

- spin diffusion across EuO/Si

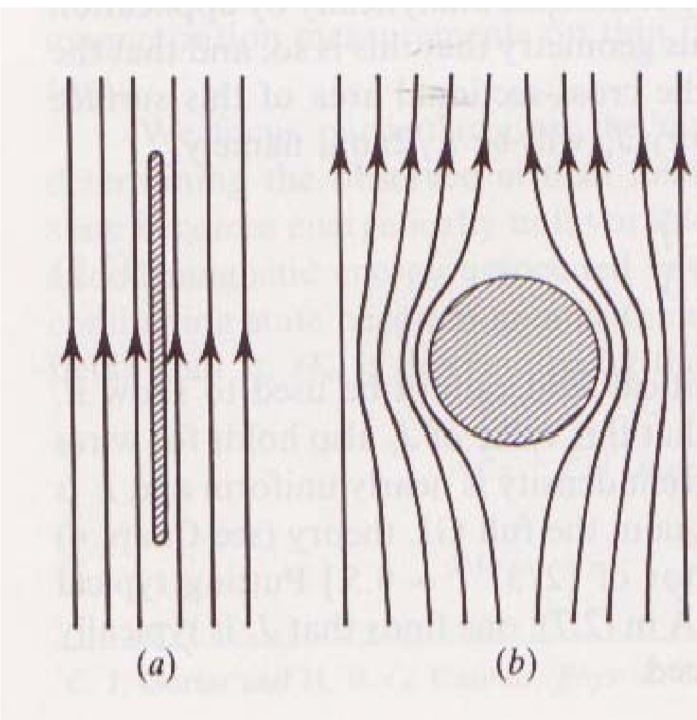
-**conclusions**

Direct measure of field profile in Meissner state of a superconductor with LEμSR



Meissner effect and the London penetration depth

$$1/\lambda^2 = \frac{4\pi n_s}{mc^2}$$



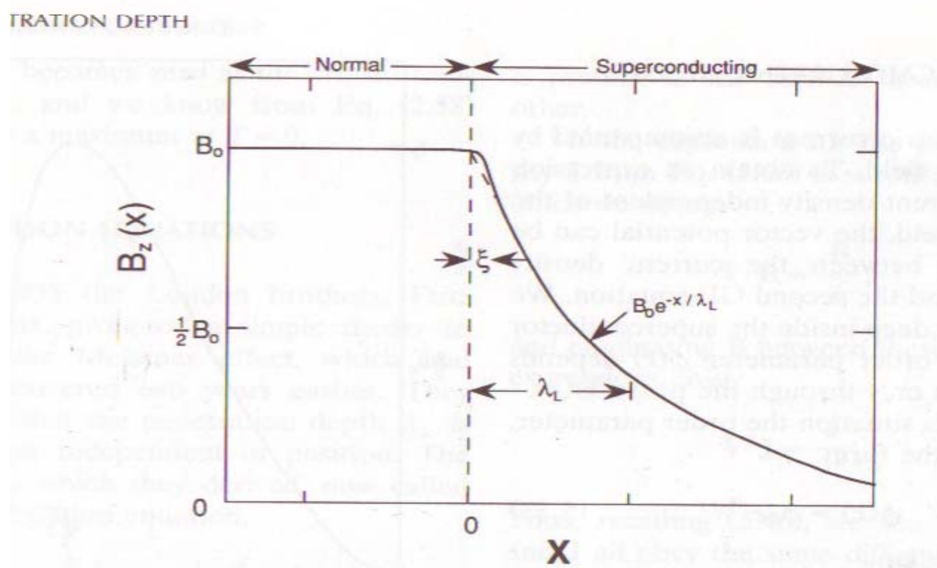
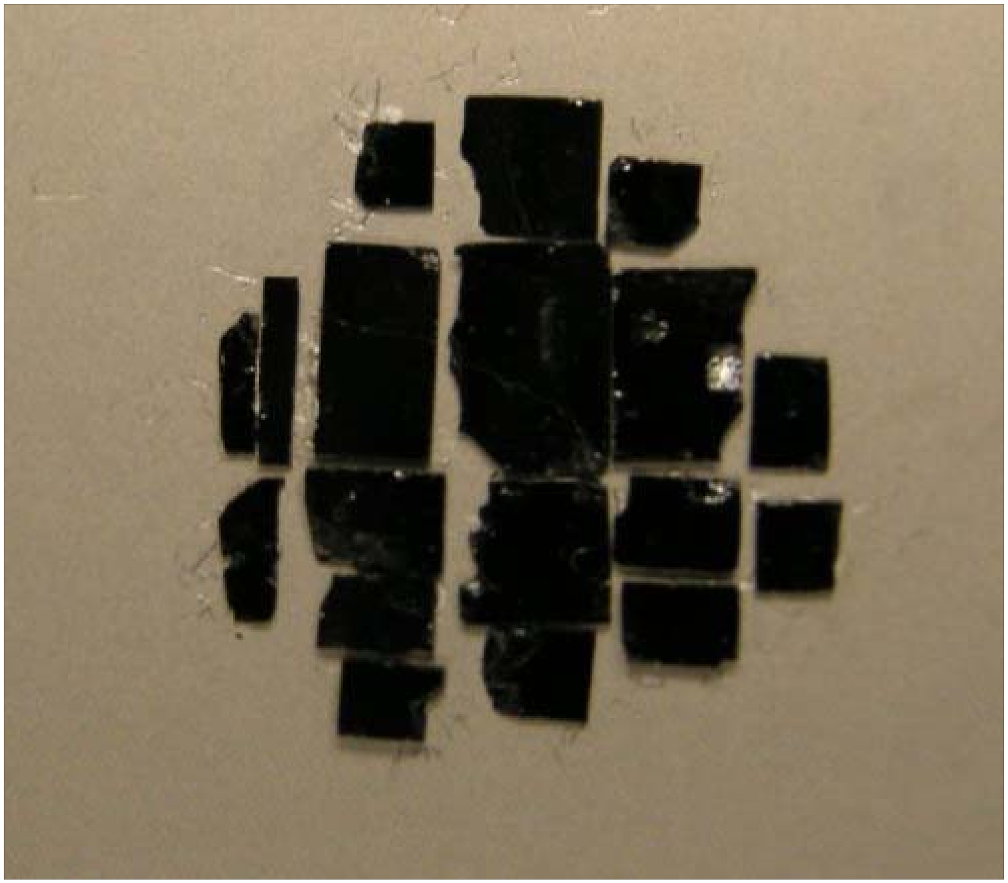


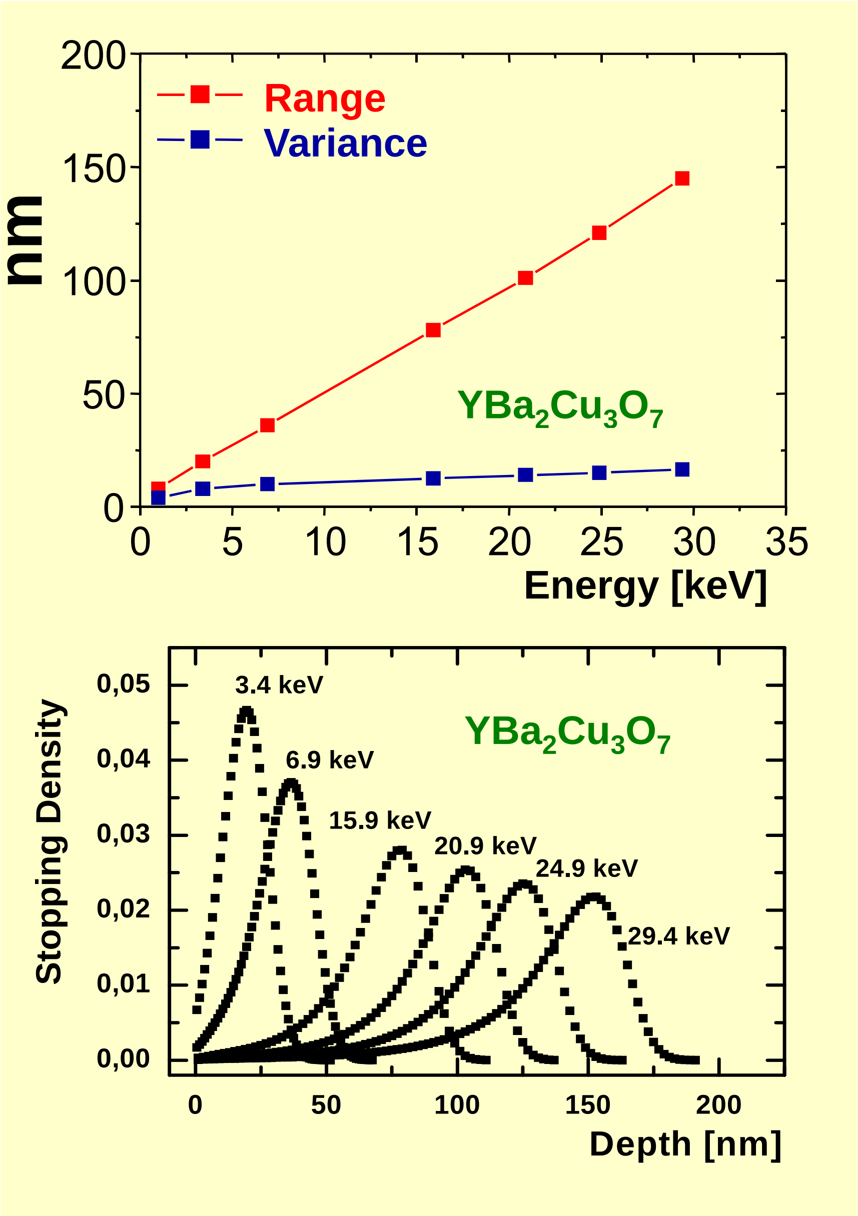
Figure 5.8 Exponential decay of a constant applied magnetic field $B_z(x)$ inside a superconductor for the case $\lambda_L > \xi$. Note the small deviation from exponential behavior within a coherence length ξ of the surface.

$YBa_2Cu_3O_{6.92}$ mozaic made at UBC



- Sample: $YBa_2Cu_3O_{6.92}$
- >95% detwinned
- T_c=94.1 K, ΔT_c<0.1K
- Area: ~55 mm^2

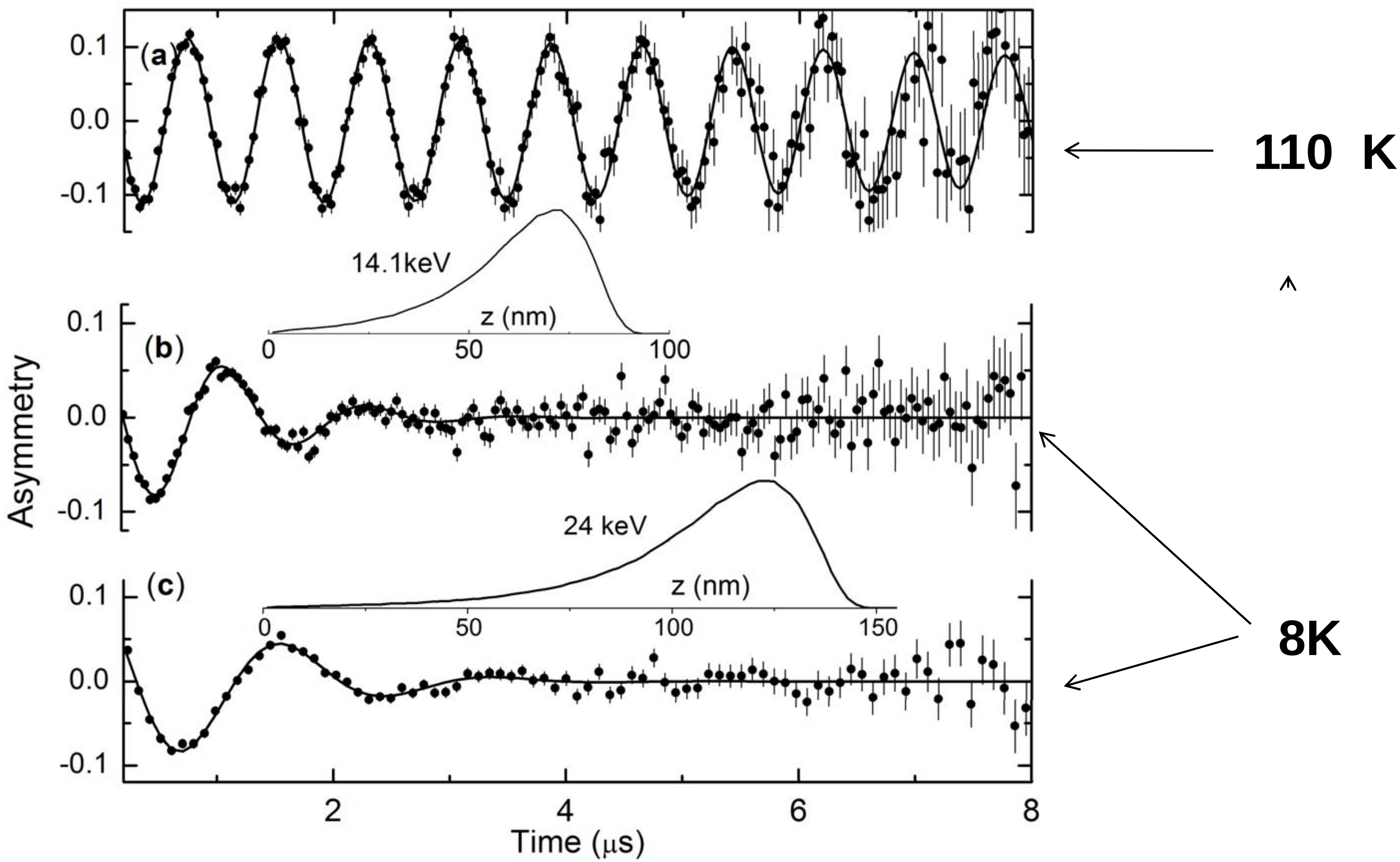
Implantation profiles of LE-μ $YBa_2Cu_3O_7$



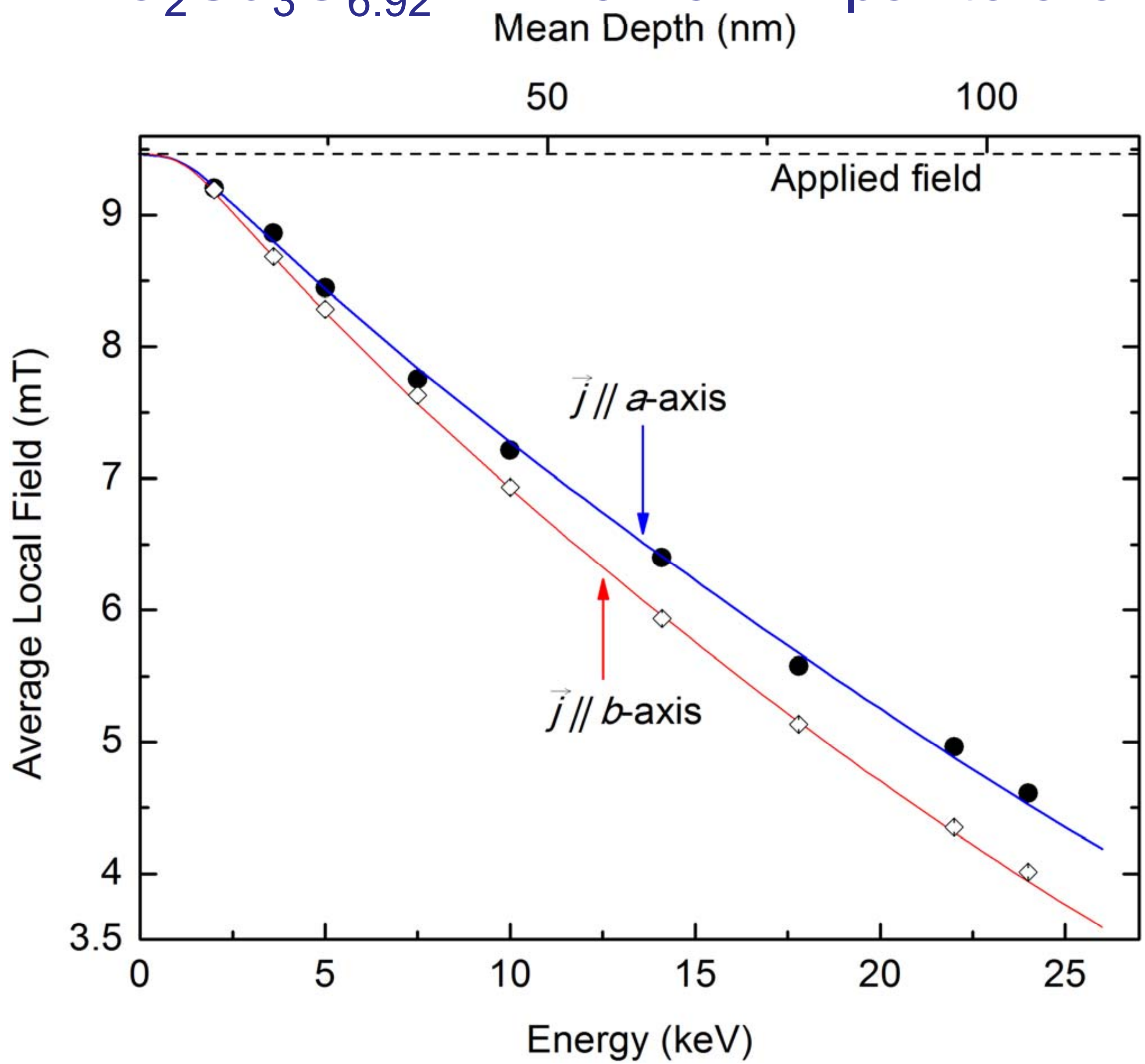
stopping profile calculated with Monte Carlo code Trim.SP by W. Eckstein, MPI Garching, Germany

see E.Morenzoni et al., NIM **B192** (2002)

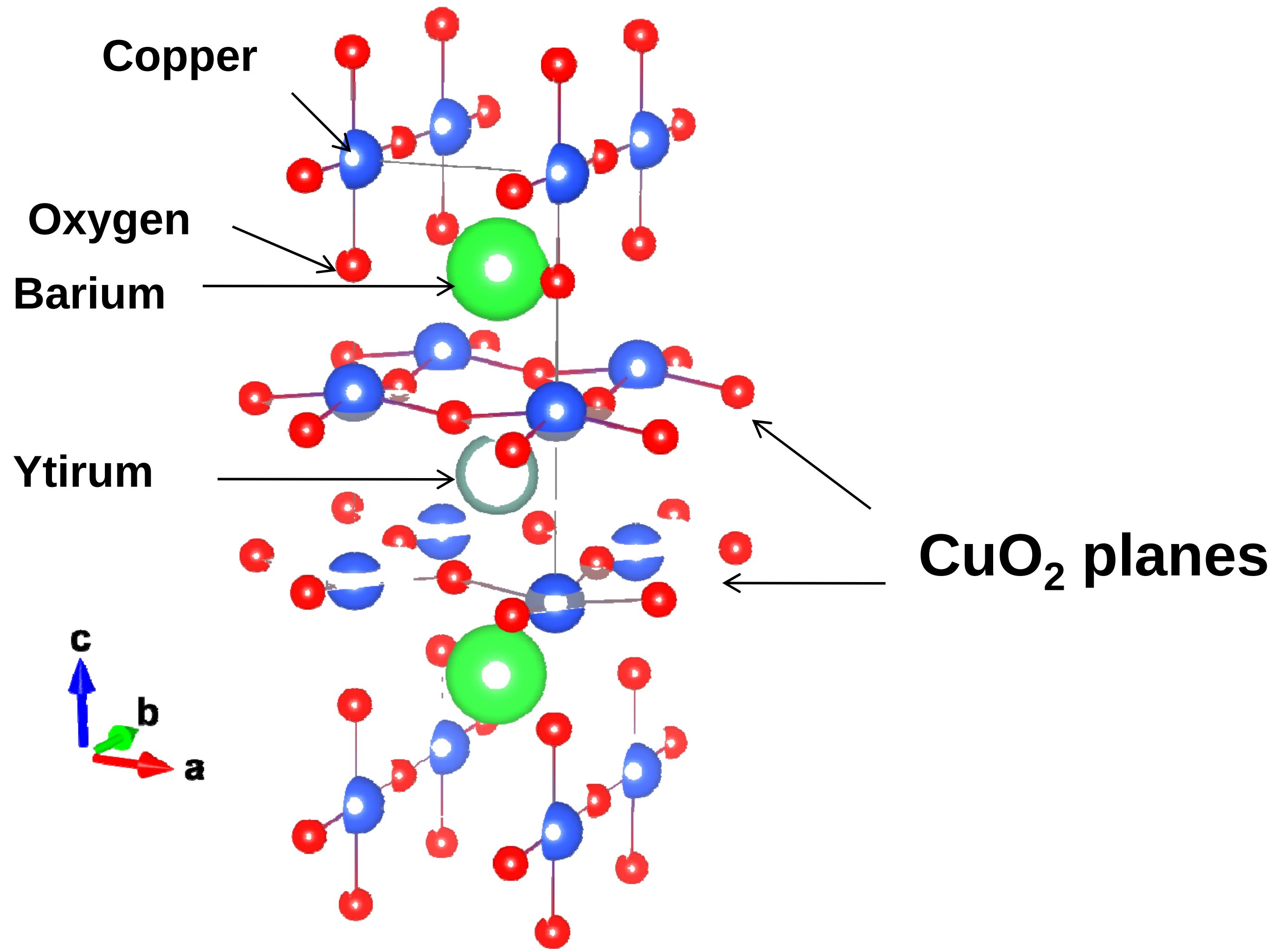
$YBa_2Cu_3O_{6.92}$ B=9.46 mT par to a-axis



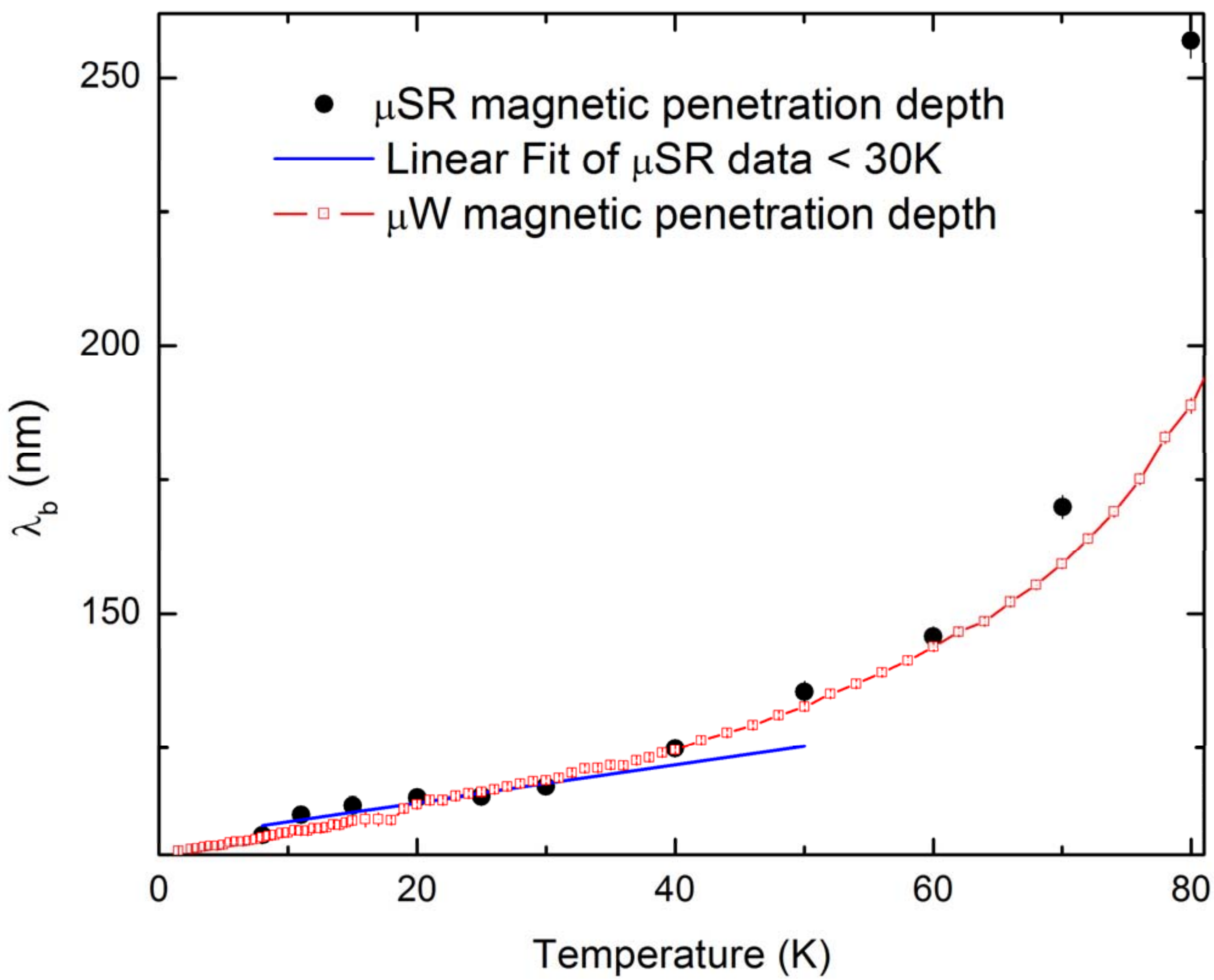
$YBa_2Cu_3O_{6.92}$ B=9.46 mT par to a-axis



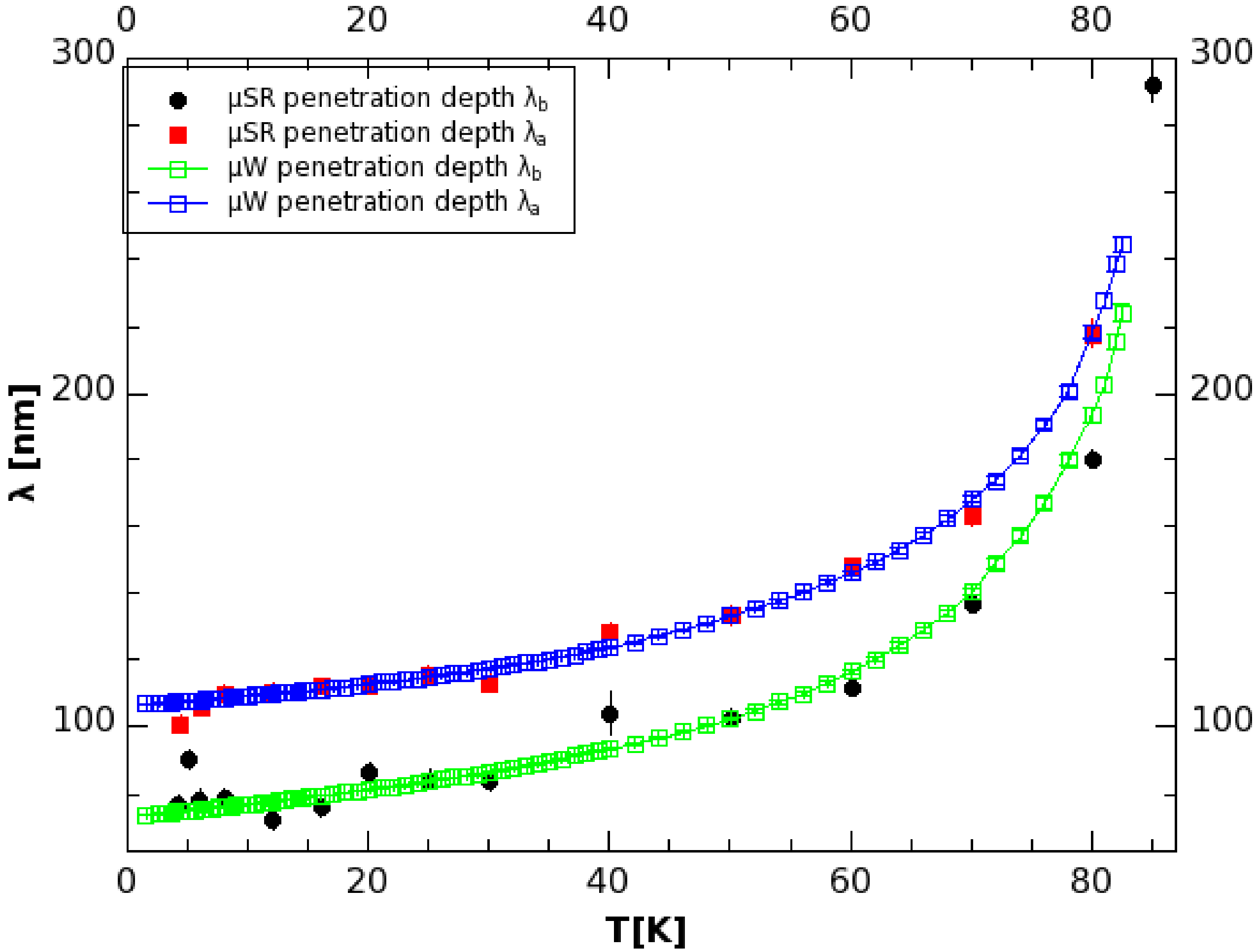
Crystal structure of $YBa_2Cu_3O_7$



$YBa_2Cu_3O_{6.92}$ B=9.46 mT par to a-axis



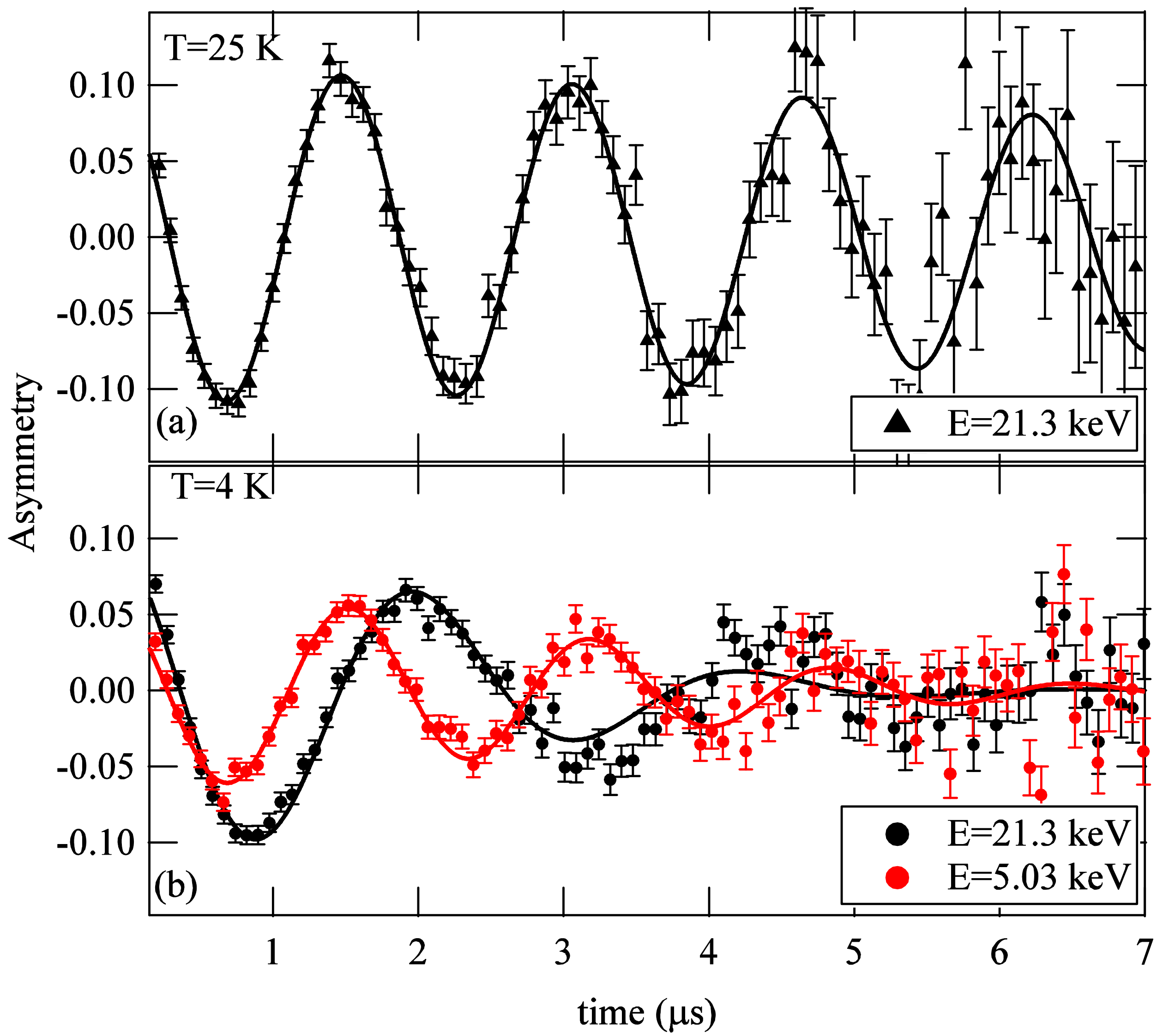
$YBa_2Cu_3O_{6.995}$ B=5 mT



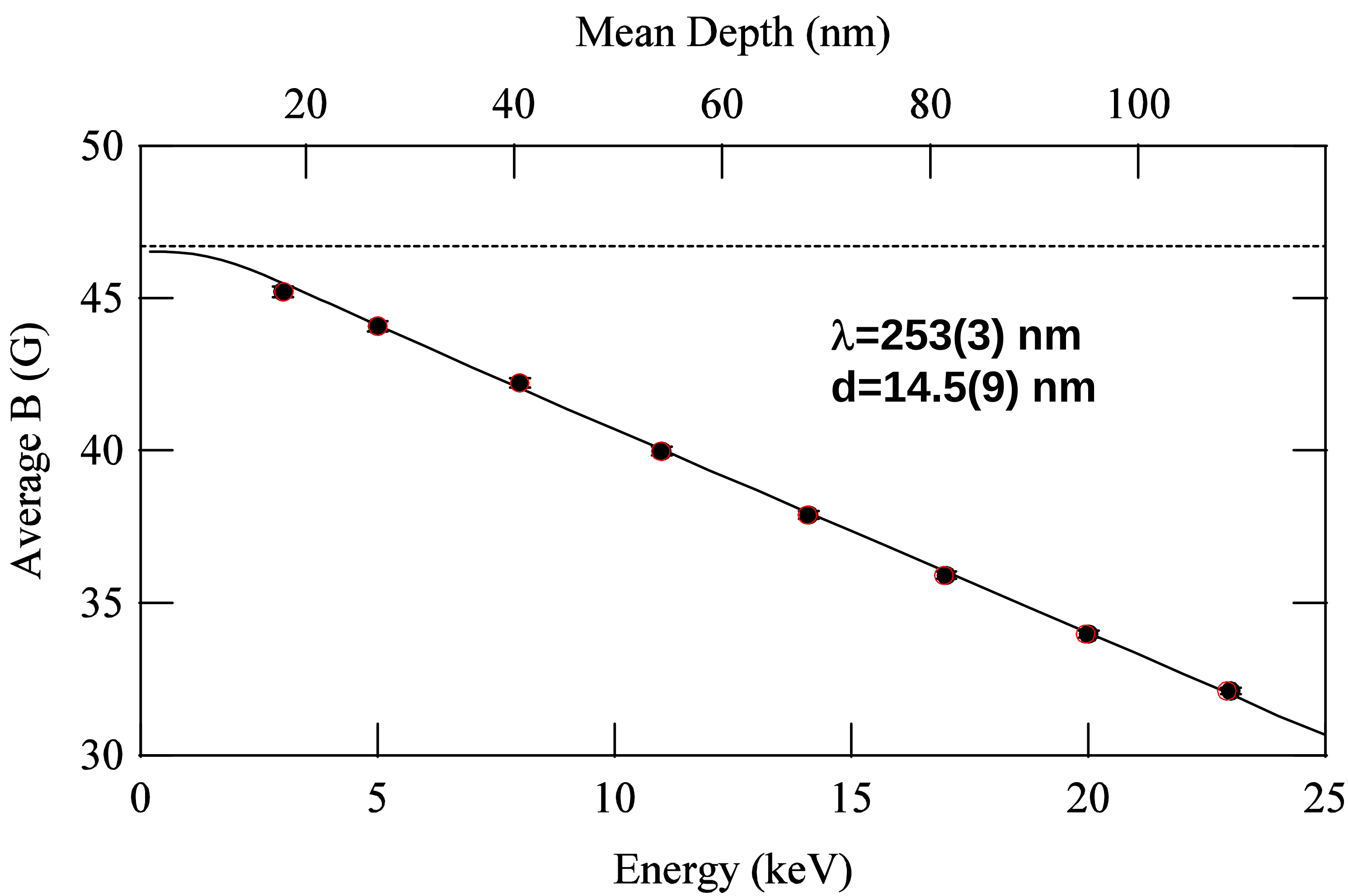
Summary of results on YBCO

λ_a (nm)	λ_b (nm)	λ_{ab} (nm)	λ_a/λ_b	Comment
$126 \pm 0.8 \pm 3$	$105.5 \pm 0.7 \pm 3$	$115.3 \pm 0.5 \pm 3$	1.19 ± 0.01	$YBa_2Cu_3O_{6.92}$
$107.9 \pm 2.1 \pm 3$	$85.6 \pm 0.5 \pm 3$	$96.1 \pm 1.1 \pm 3$	1.26 ± 0.02	$YBa_2Cu_3O_{6.998}$
		118 ± 0.4		conventional μSR in vortex state
		146 ± 3		low energy μSR in thin film at 20 K
160	100	126.5	1.6	IR reflectivity at 10 K
103 ± 8	80 ± 5	91 ± 7	1.29 ± 0.07	ESR on Ortho-I $YBa_2Cu_3O_{6.995}$
		150 ± 10	1.16 ± 0.02	μSR at 10 K
		138 ± 5	1.18 ± 0.02	SANS at 10 K

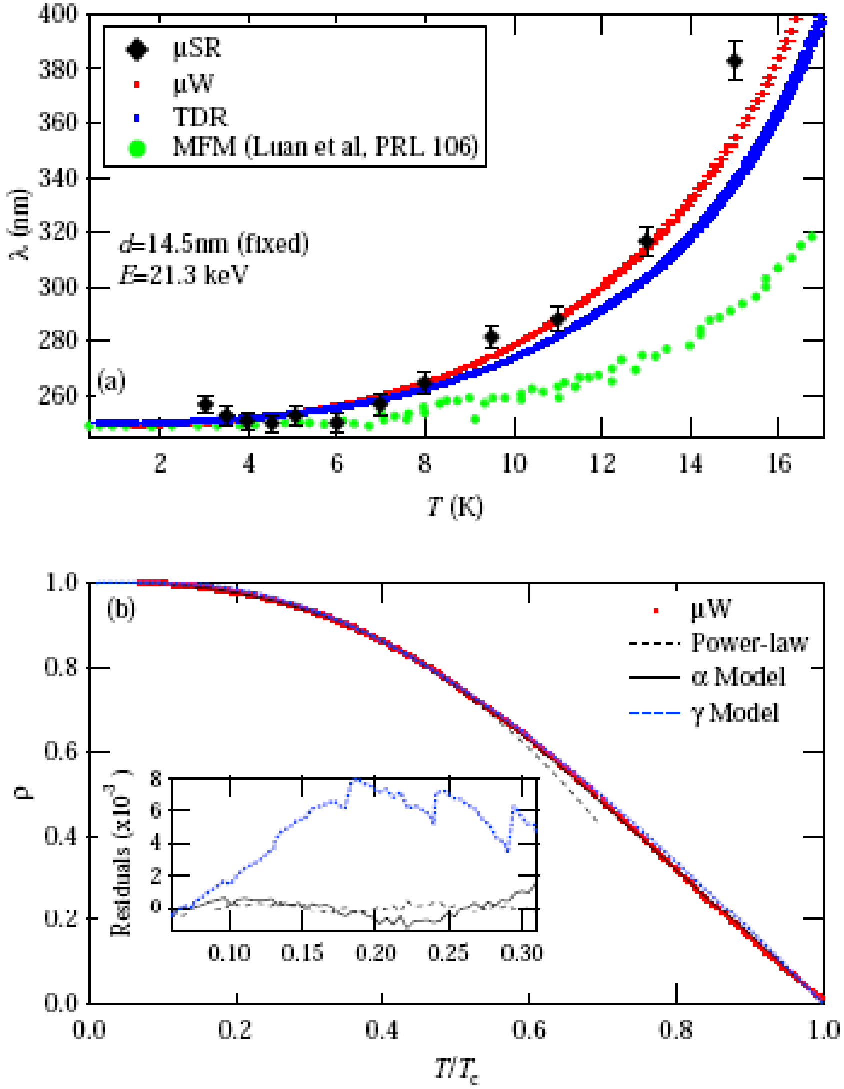
Single Xl of $Ba(Co_{0.074}Fe_{0.926})_2As_2$
Tc=21.7 K B=4.7mT



Field profile in $Ba(Co_{0.074}Fe_{0.926})_2As_2$
T=5 K B=4.7mT



Temperature dependence of λ (top) and $1/\lambda^2$ (bottom) in $Ba(Co_{0.074}Fe_{0.926})_2As_2$



Superconducting Proximity effect

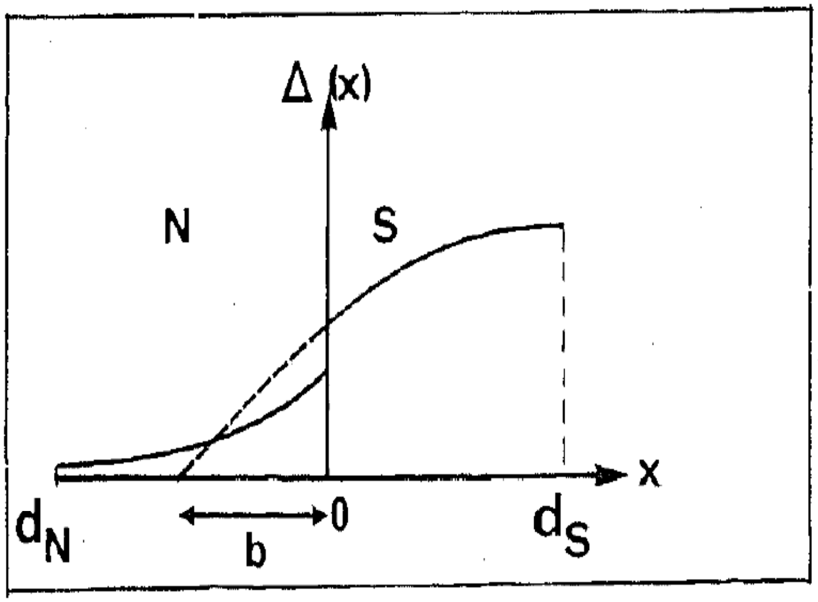
– The sc order parameter in N is non-zero, even without any the pairing interaction. The decay length of the sc order parameter into N is set by the properties N. For a free electron gas it diverges as 1/T.

$F(x) = \langle \Psi_\uparrow(x)\Psi_\downarrow(x) \rangle$, Induced condensation amplitude in N

$x > 0$, distance from the NS interface

$F(x) = \Phi(x) e^{-\frac{x}{\xi_N}}$, x large

$\Phi(x)$ slowly varying function of x



Clean limit: $\ell > \xi_N$: l, electron mean free path in N

$$\xi_N(T) = \frac{\hbar v_F}{2\pi k_B T},$$ v_F, Fermi velocity in N

Dirty limit : $\ell < \xi_N$ ($\rightarrow$ leakage of pairs in N diffusive)

$$\xi_N(T) = \sqrt{D \cdot \tau} = \sqrt{\frac{\hbar v_F \ell}{6\pi k_B T}}$$

de Gennes et al.

Tunneling electron spectroscopy in CuAl wires

$\xi_N(T)$ length scale of proximity effect in conventional S can be large ~ 100 nm

$$\xi_N = \frac{\hbar v_F}{2\pi T} \qquad \xi_N << l$$

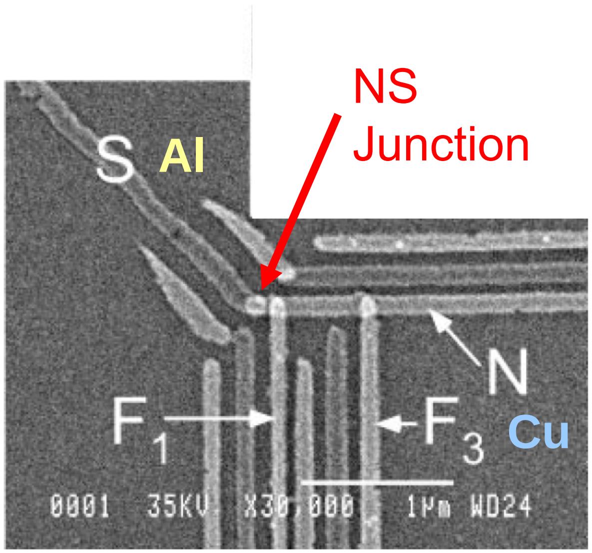
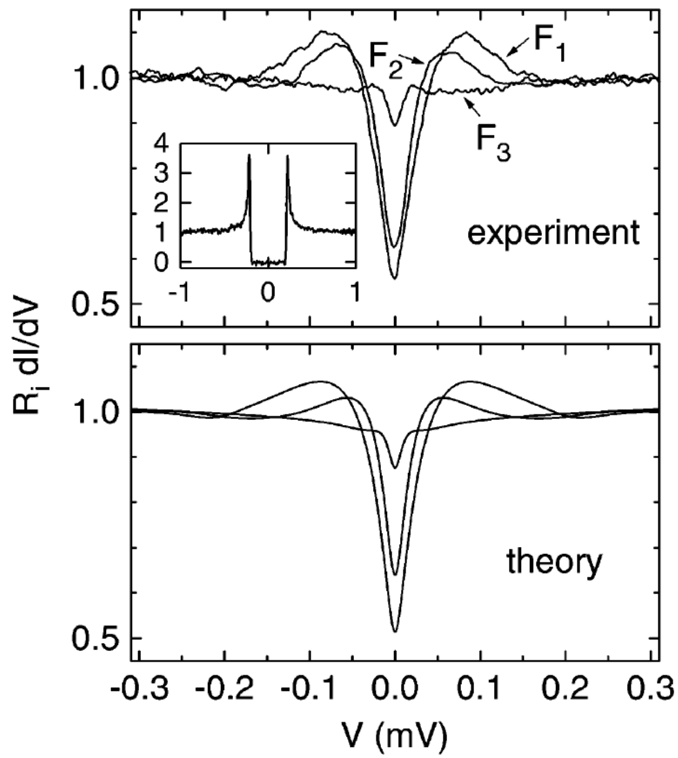


FIG. 1. SEM photograph of the sample: a normal (copper) wire N, horizontal, is in good contact with a superconducting (aluminum) wire S, diagonal on the left, at their overlap. Two normal (copper) fingers, vertical, labeled F_1 and F_3, are connected to the wire through very opaque tunnel barriers. The density of states in the normal wire is given by the differential conductance of the tunnel junction as a function of voltage. On a similar device, a third finger, labeled F_2, is placed at an intermediate distance.

Normalized differential conductance:



Density of states at positions:

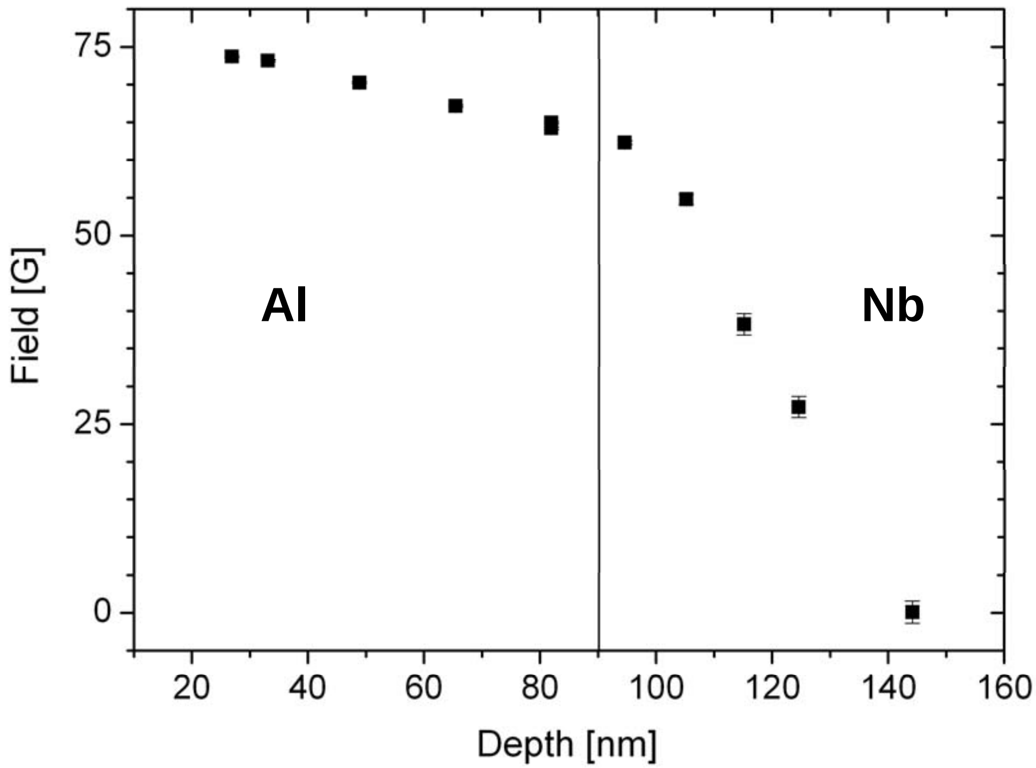
F_1, F_2, F_3:

200, 300, 800 nm from NS interface

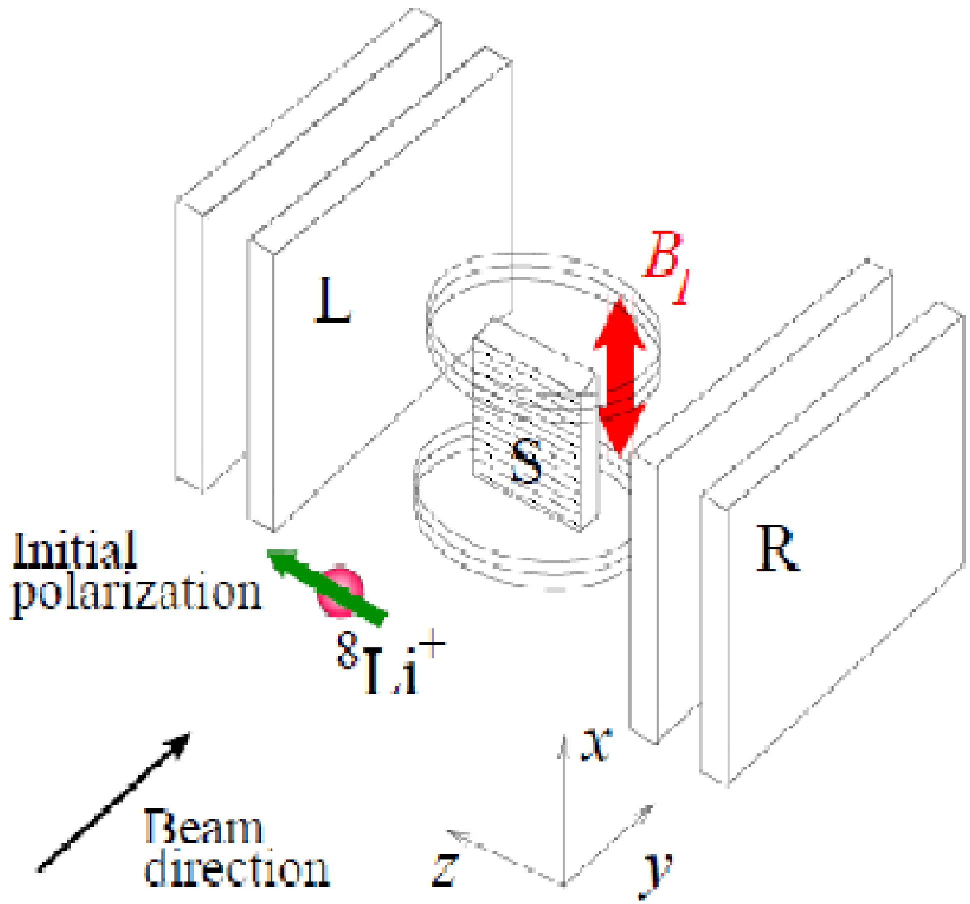
S. Guéron et al., PRL, 77, 3025 (1996)

Meissner screening in

Al(Si0.03)(90nm) Nb (270nm) 4.5K, 75G

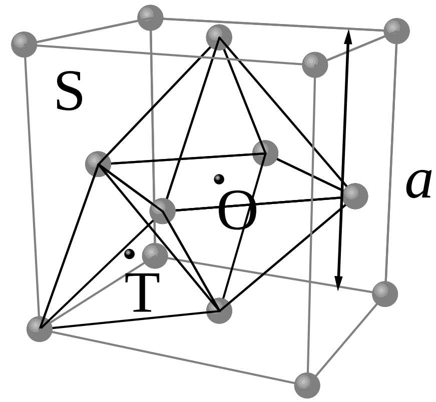


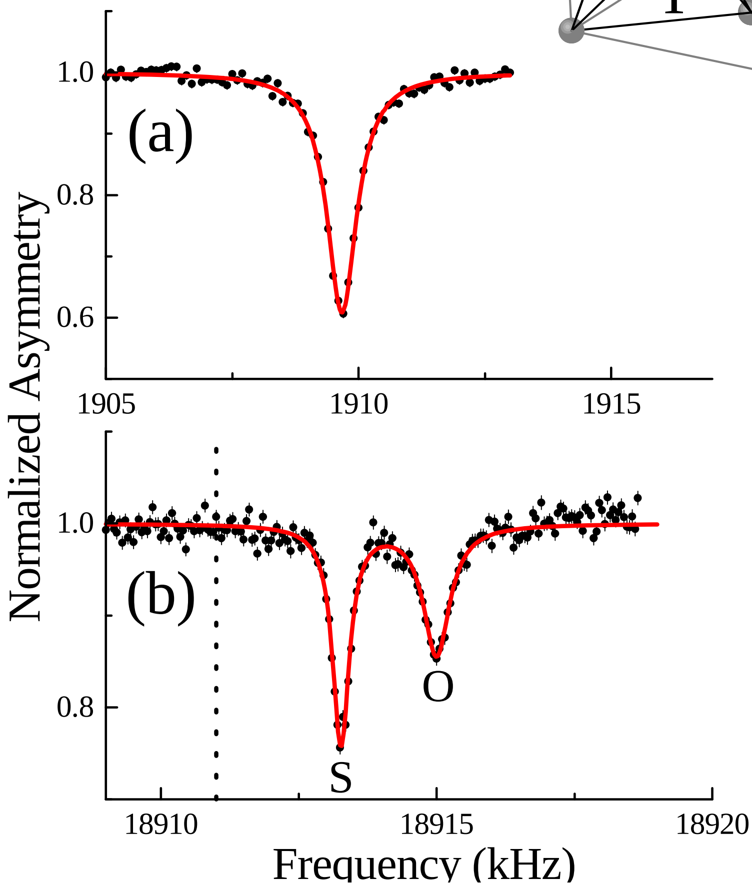
ISAC Low Field β-NMR Spectrometer

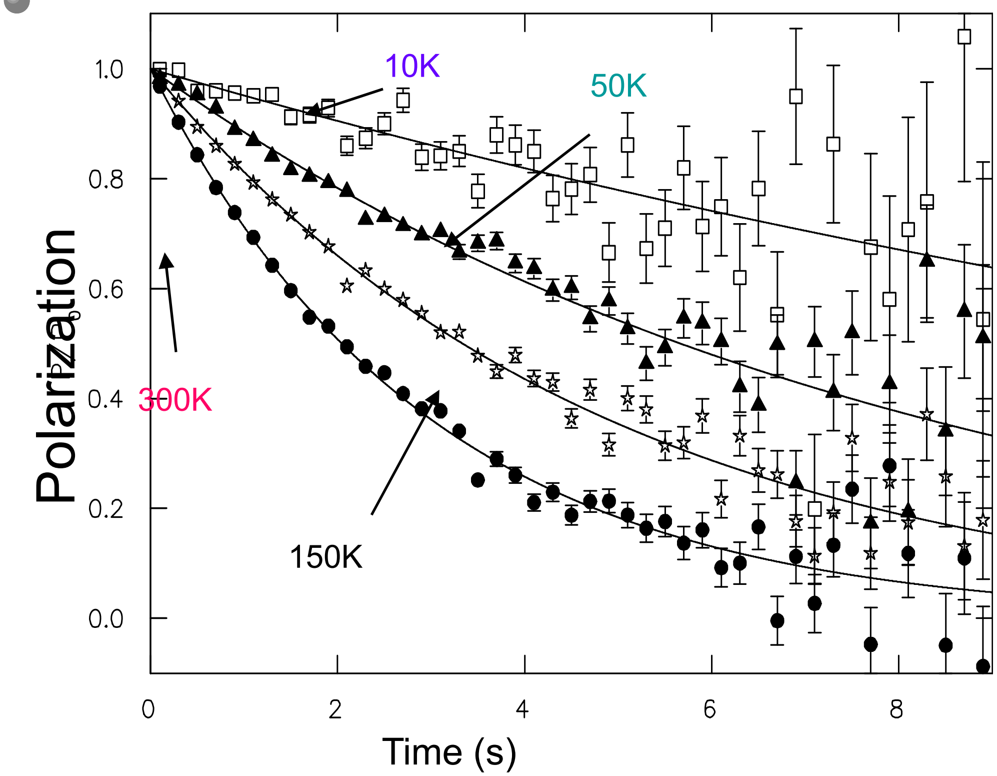


β-NMR of ^{8}Li in 50nm film of Ag on $SrTiO_3$ at 5 keV

G.D. Morris et al, PRL **73,** 15601 (2004).

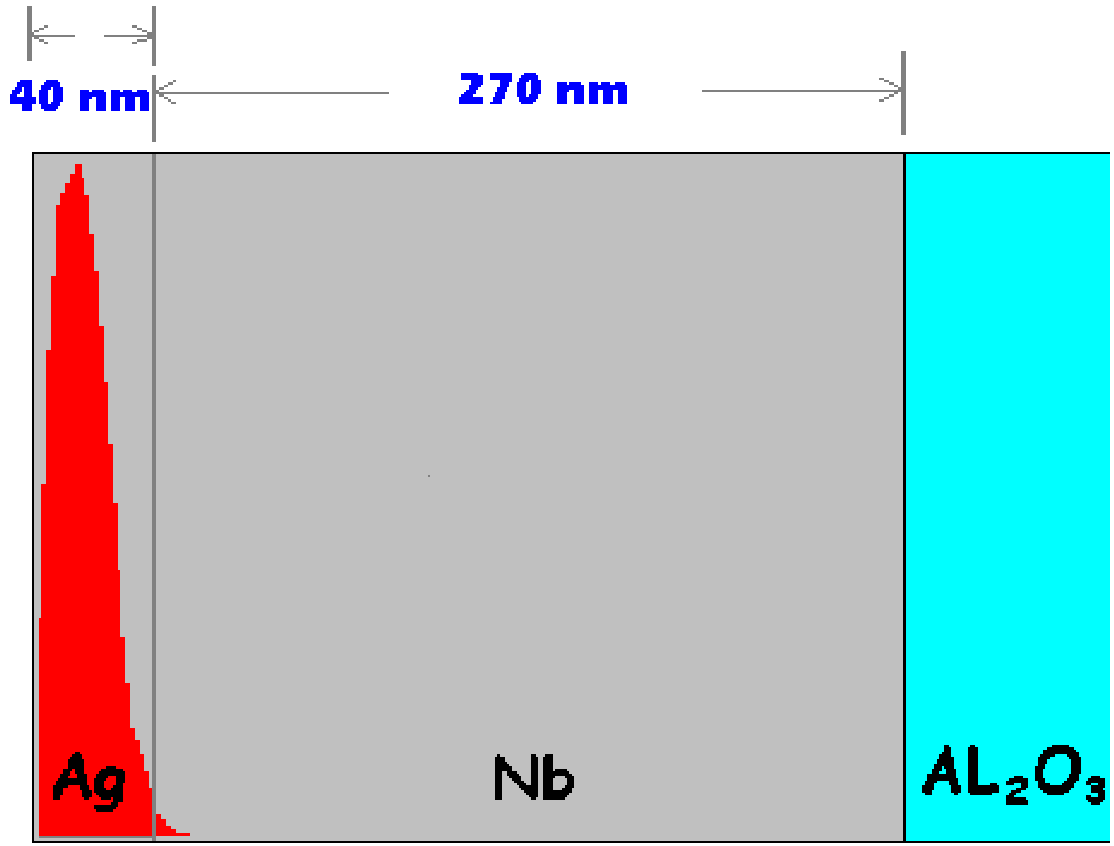




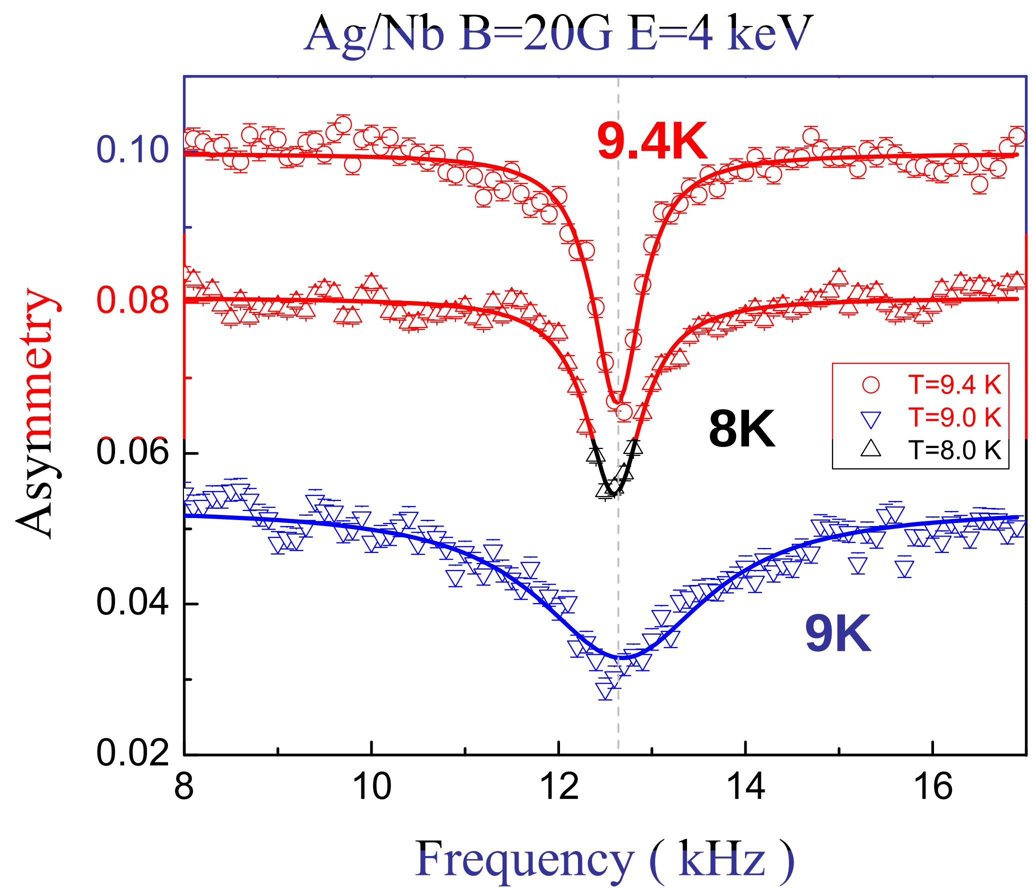


Stopping profile of ^8Li in Ag/Nb film E=4 keV

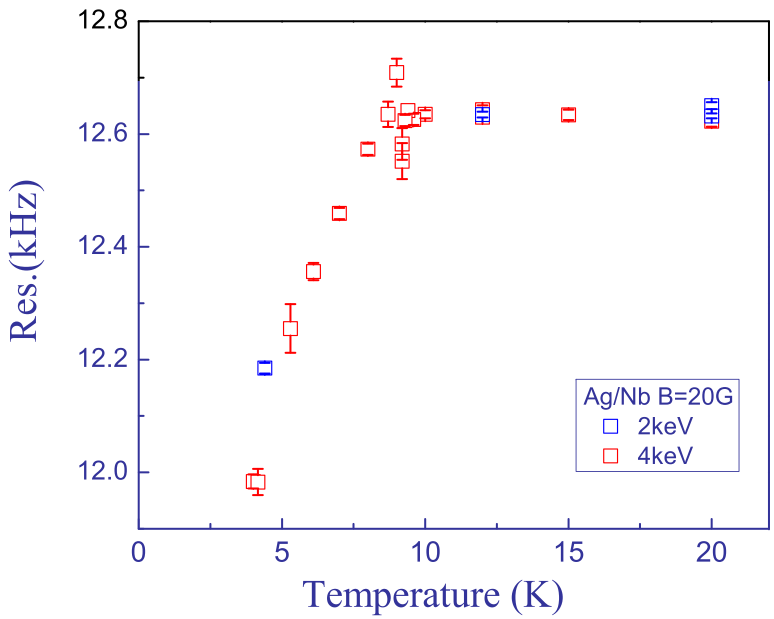
D. Wang

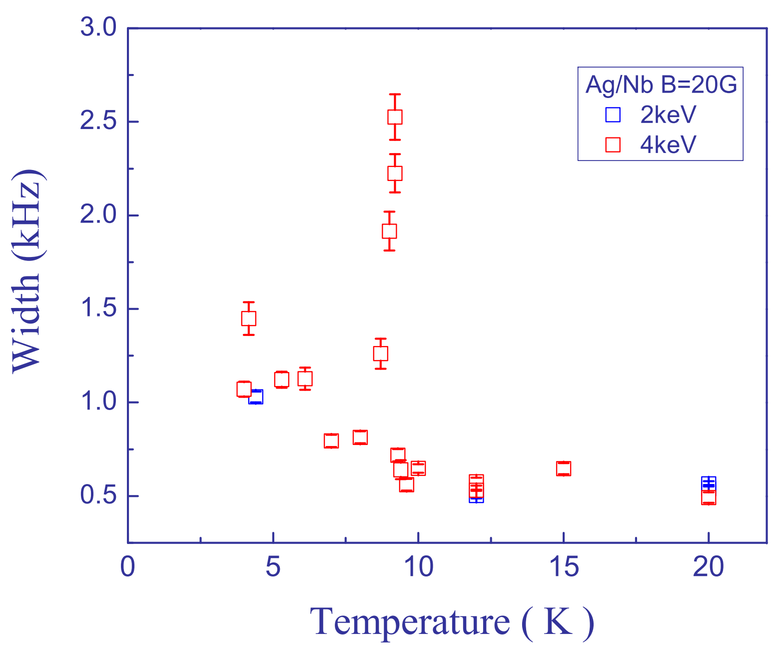


Low field β-NMR resonance in Ag(40nm)/Nb(270nm) film
Tc Nb=9.0K, D. Wang

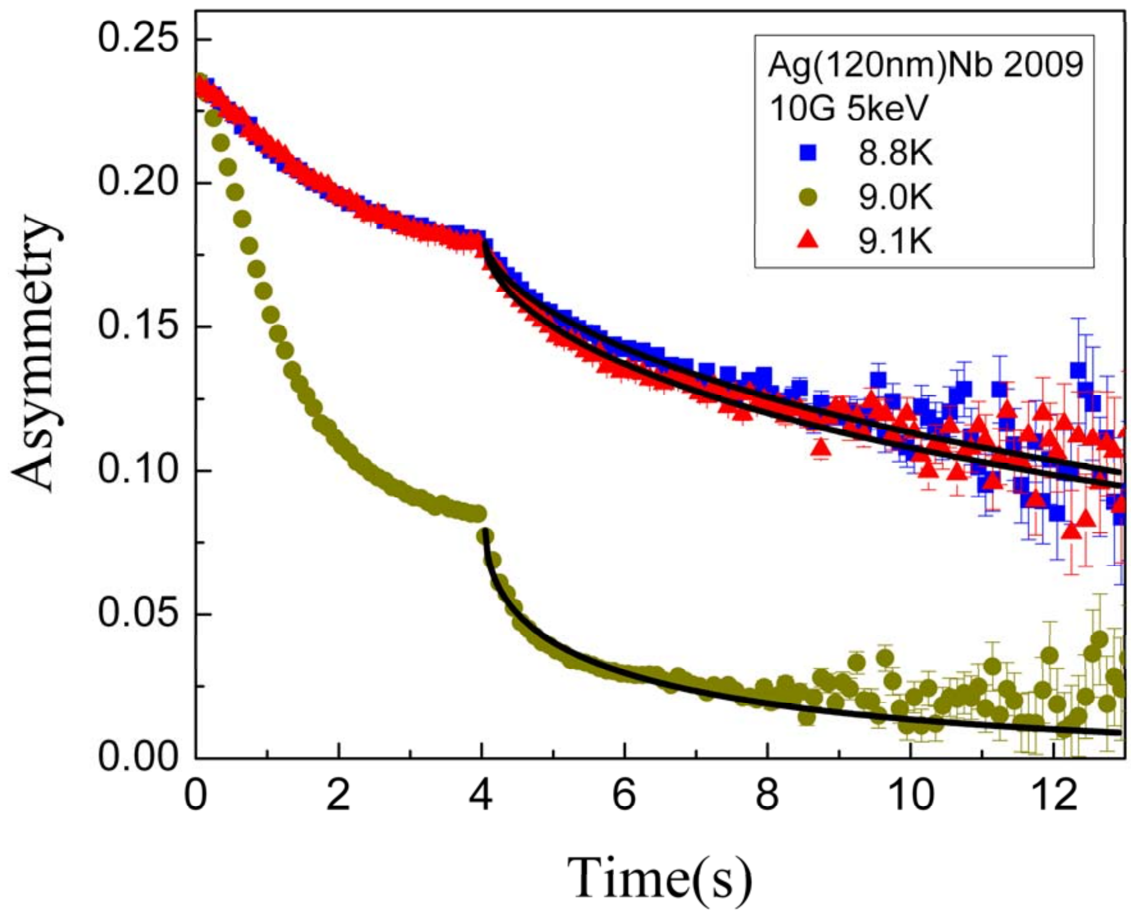


T dependence of β-NMR resonance in Ag/Nb film, D. Wang

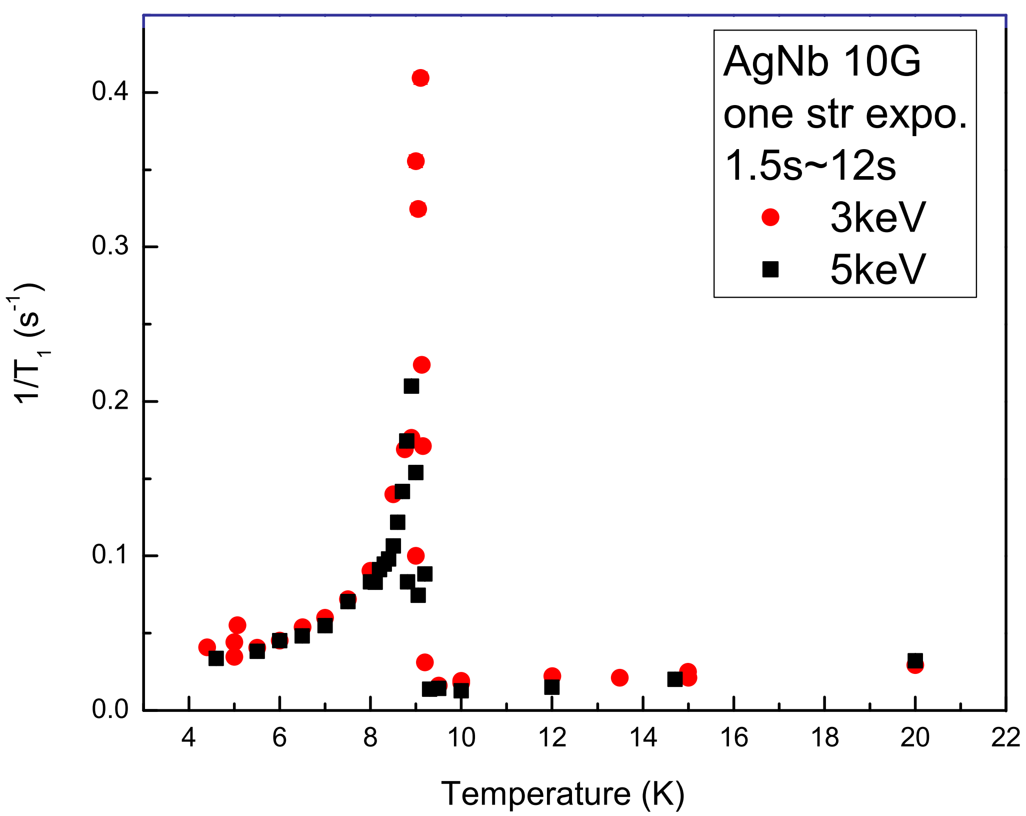




Fluctuation Peak in $1/T_1$ in 120nmAg/270nmNb

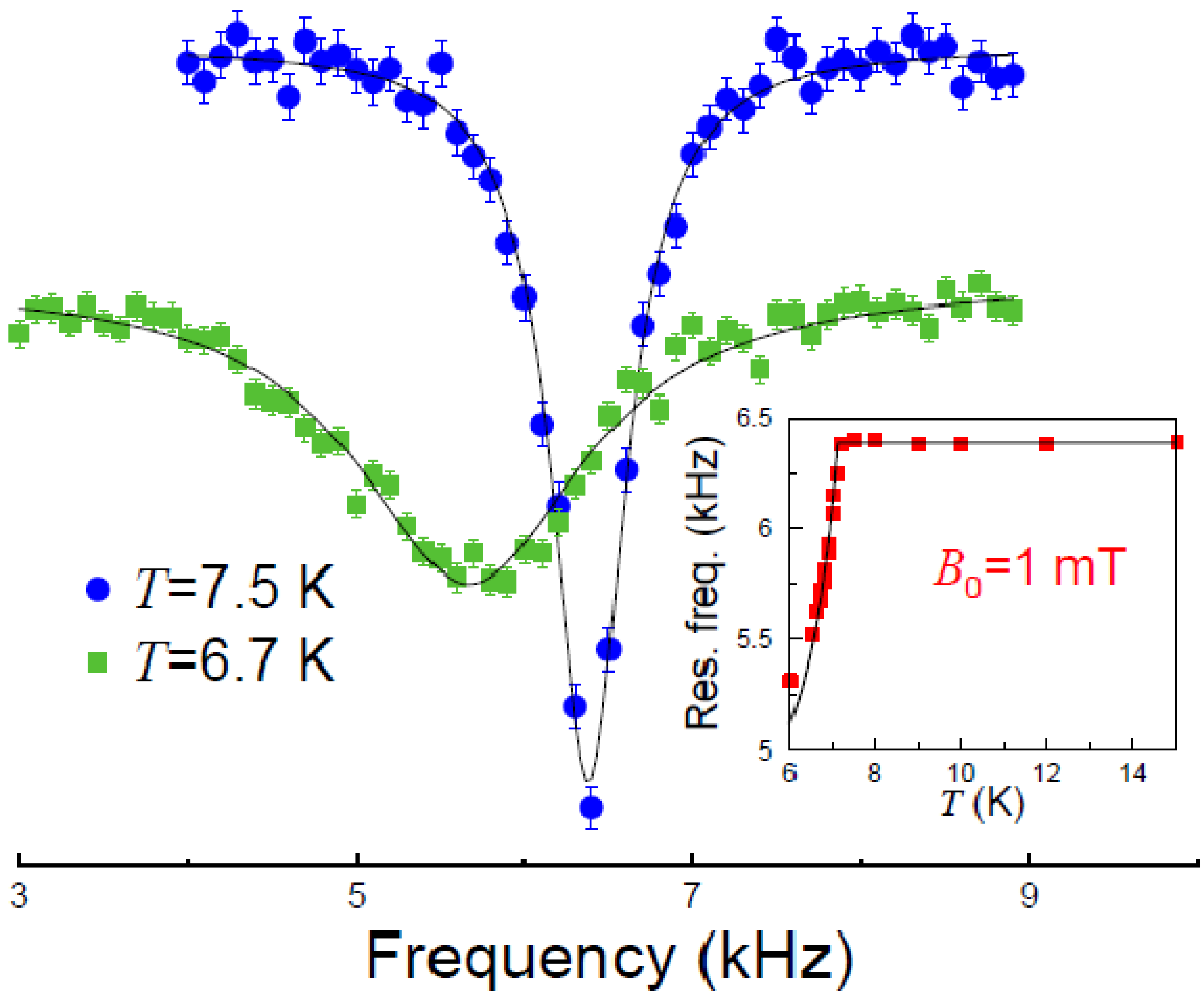


Critical slowing down of fluctuations in the induced SC order parameter.

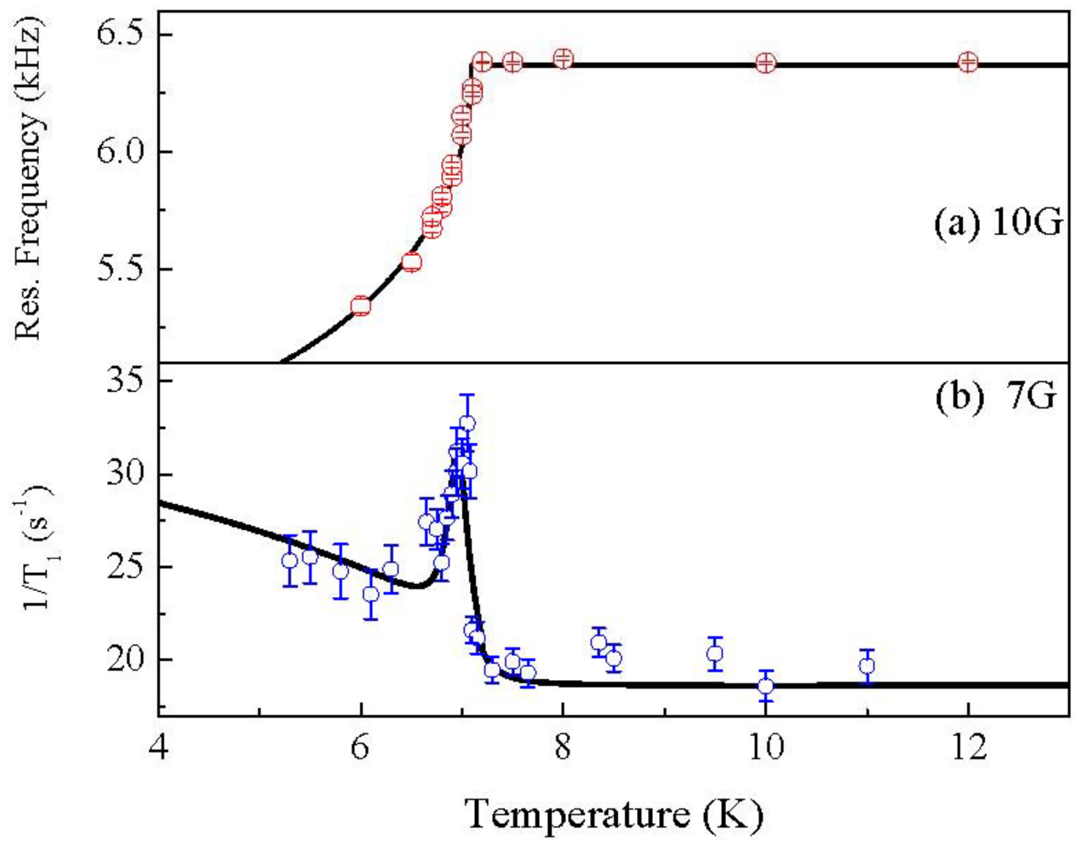


$$\frac{1}{T_1} = \frac{2\gamma^2 \Delta B^2 \tau_c}{1+\omega^2 \tau_c^{\ 2}} \approx 2\gamma^2 \Delta B^2 \tau_c$$

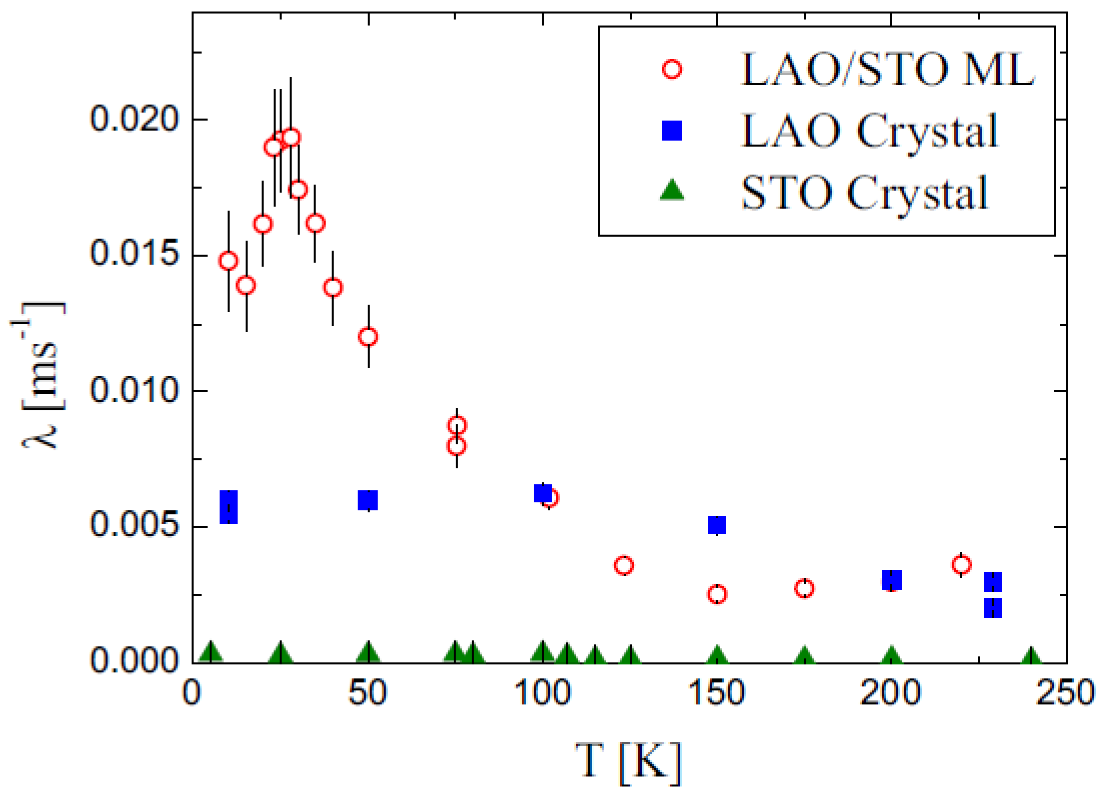
Meissner screening in 300 nm Pb
Tc=7.0K



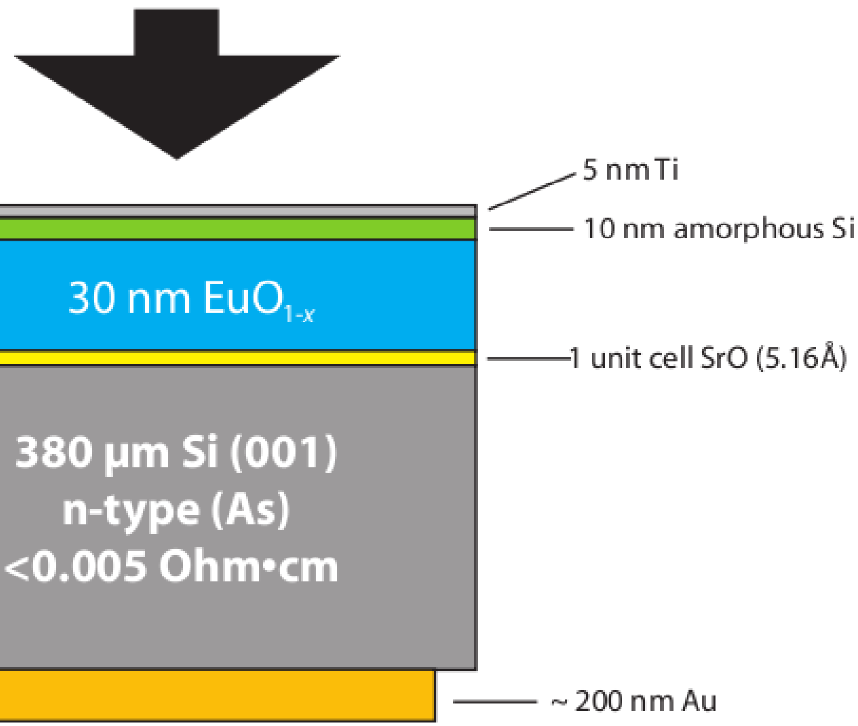
Meissner screening and critical fluctuations in 300 nm Pb Tc=7.0K



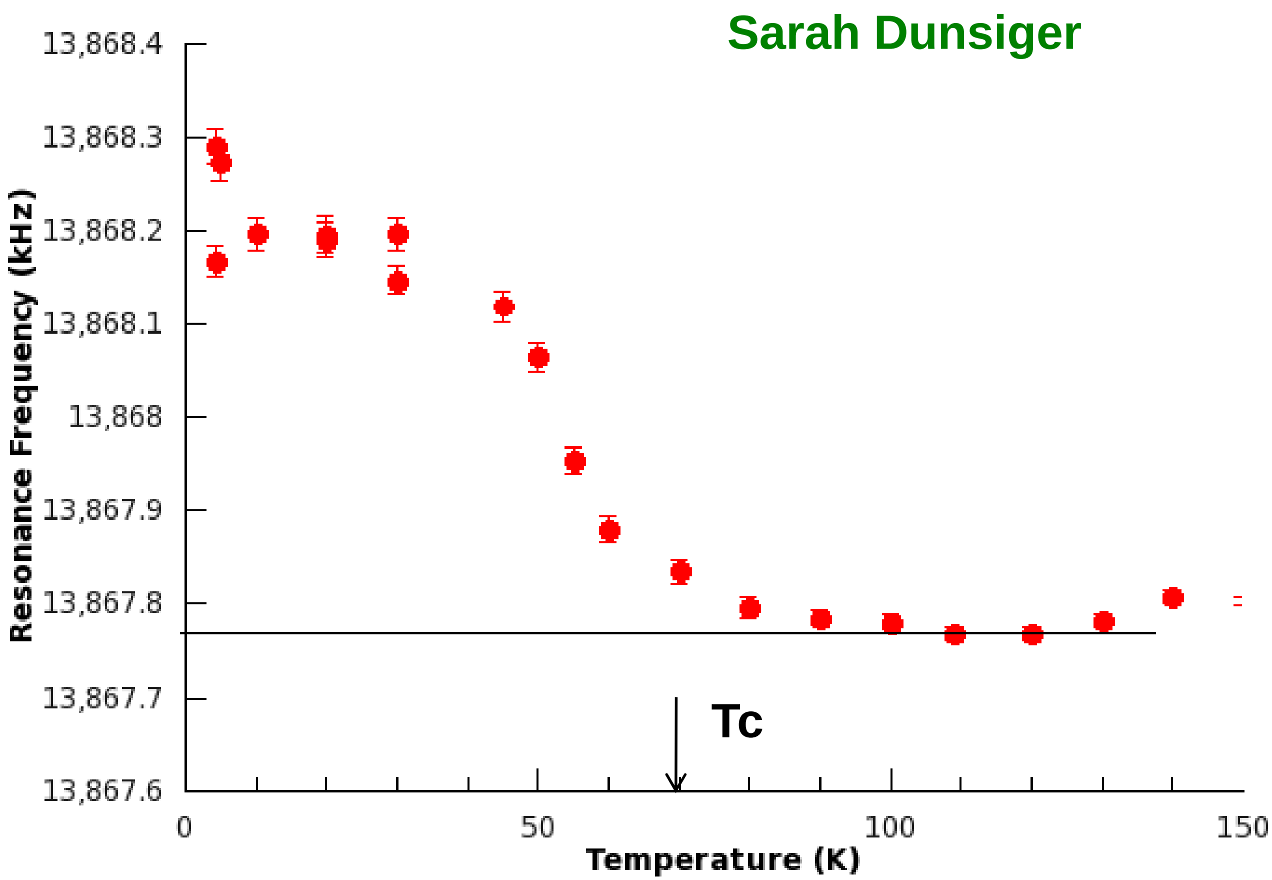
Spin relaxation in an STO/LAO multilayer
(10 unit cells STO +8 unit cells of LAO uc STO)
M1226 ,Zaher Salman's abstract



Magnetic ProximityEffect and SpinDiffusion in a EuO/Si
S. Dunsiger et al 2010 M1165, M1176



Larmor Frequency in EuO/Si device
E=28 keV, d=170 nm , B=2.2T



Low Energy μSR Collaborators

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W.A. MacFarlane, (UBC Chemistry)
G.D. Morris (TRIUMF)
S.R. Dunsiger (Tech.U.Munich),

SAMPLES:

YBCO XL's D. Bonn, W. Hardy, R. Liang (UBC PHAS)
Al/Nb, Ag/Nb films E. Kirk, (PSI)
CoFeAs P. Canfield, A Thaler Ames Lab

β-NMR Collaborators

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SAMPLES:

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Conclusion

- The electronic and magnetic properties of an interface are distinct from those of the two materials involved. They will play crucial role in development of future devices which continue to shrink in size.
- There are few methods to really probe such properties. Low energy β-NMR and LE-μSR provide unique way to measure magnetic properties in a depth dependent manner on nm length scale. The much different lifetimes of the muon and 8Li means that they are sensitive to much different timescales and are thus very complementary.
- The potential to discover something new and interesting is high.