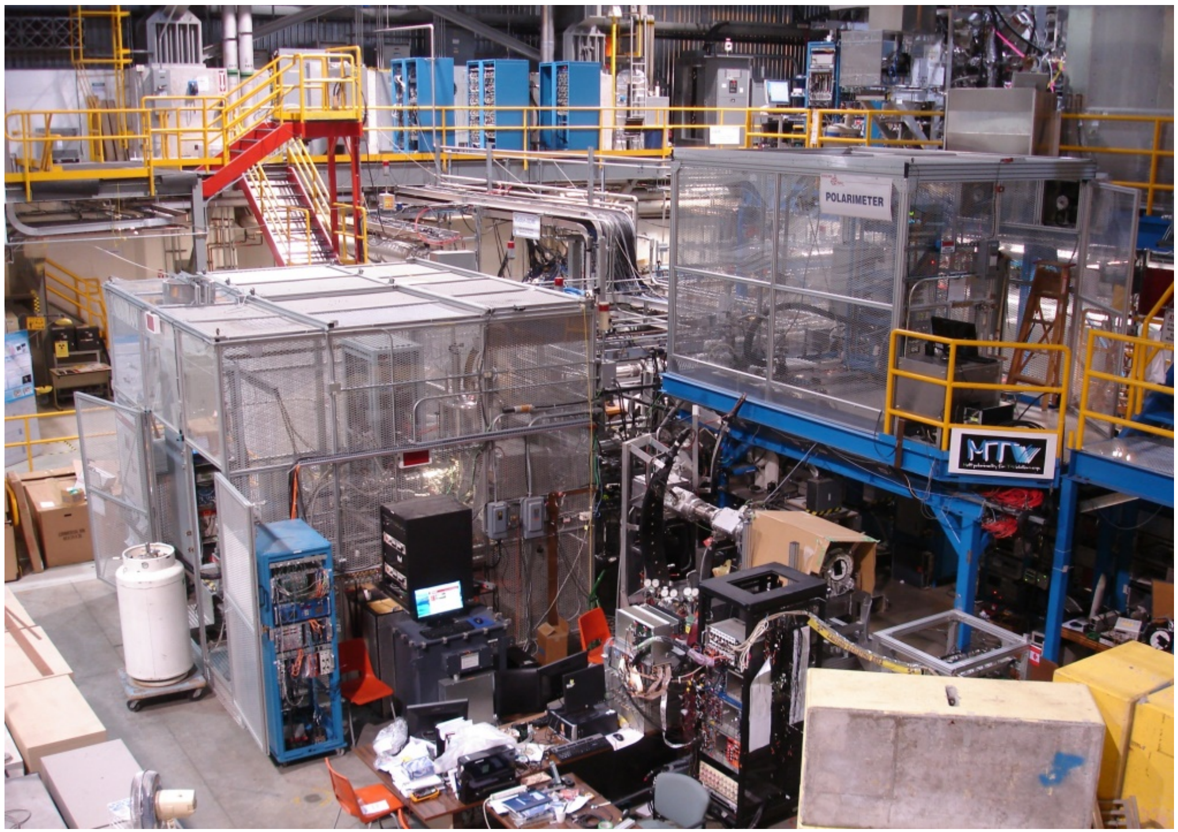
ISAC20 Science Week Symposium

β-NMR at ISAC The Early Days

R.F. Kiefl   Physics and Astronomy, SBQMI and TRIUMF



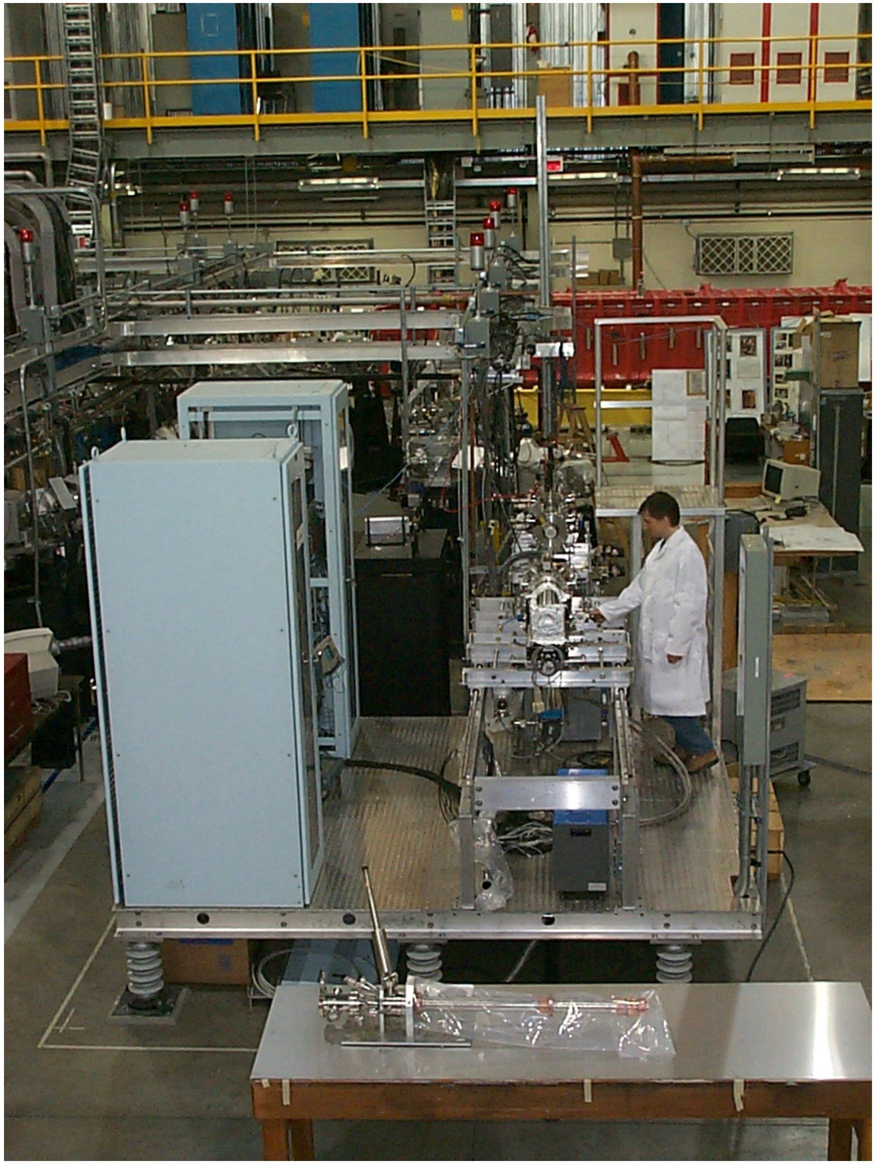
- in the beginning

- scientific motivation

- principles of β-NMR

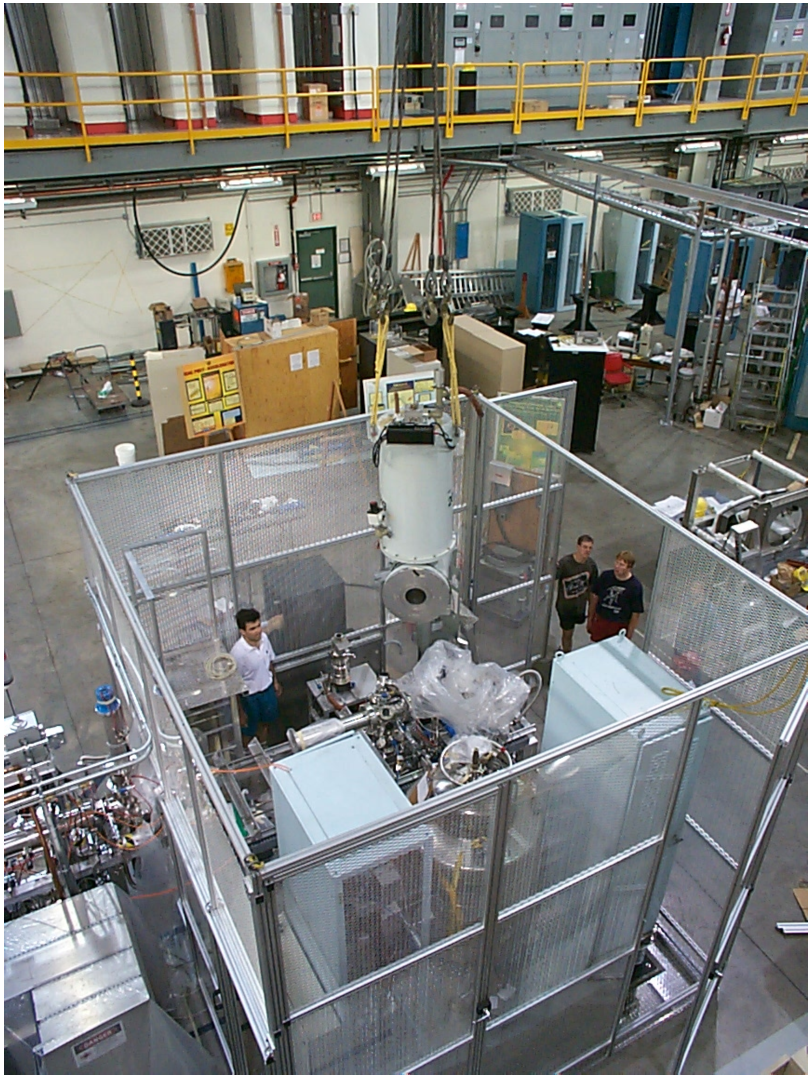
- early results

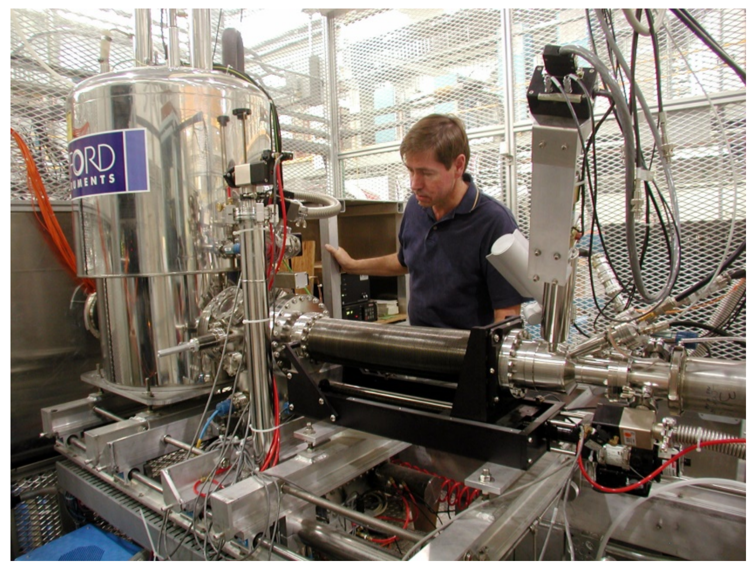
Beginngs of beta-NMR at ISAC



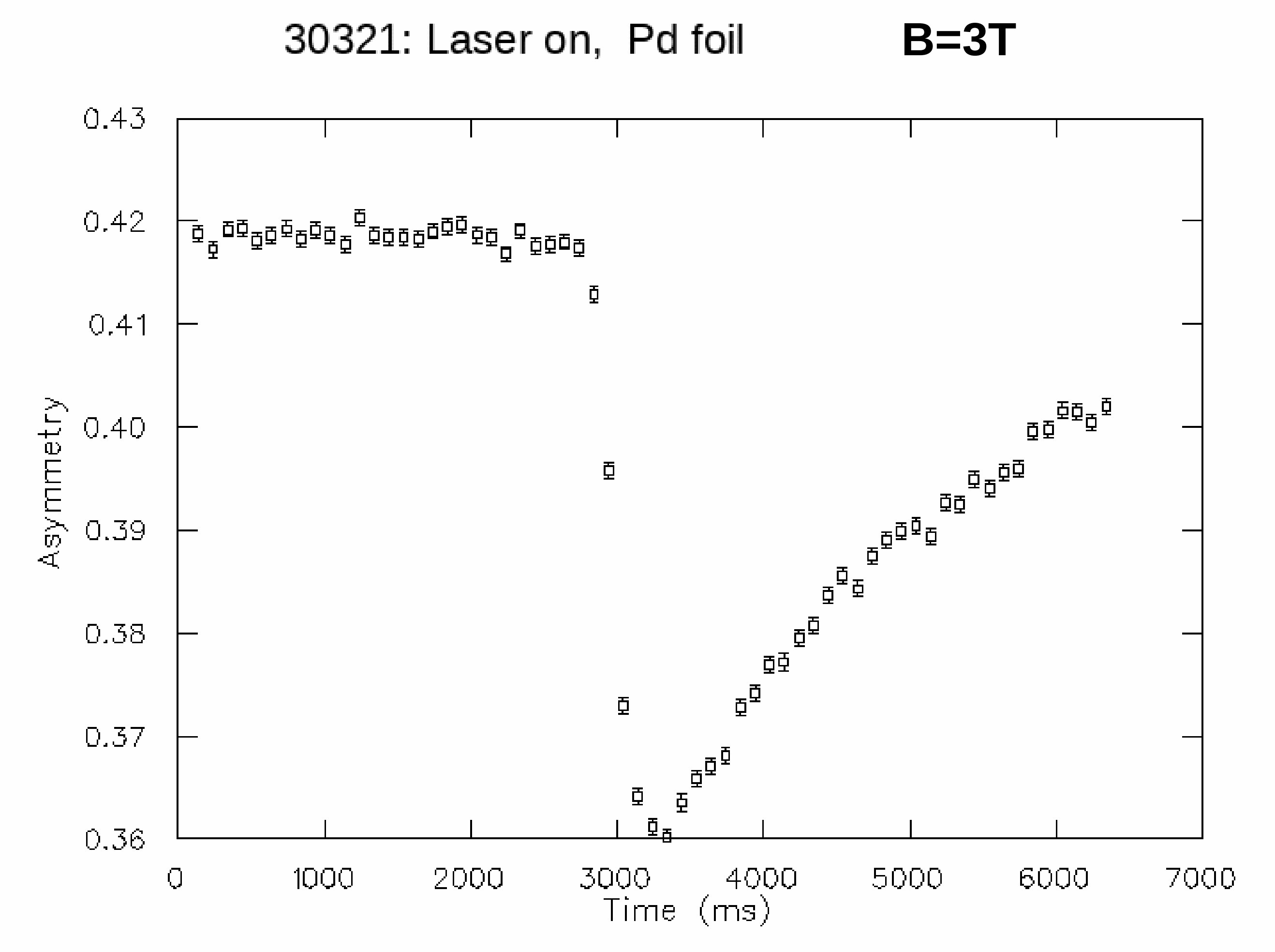
Alan Astbury
Gerald Morris
Phil Levy
Syd Kreitzman
Rene Poutissou
Pierre Amaudruz
Rick Baartman
Jaap Dornbos
Rahim Abasalti
Andrew MacFarlane now UBC
Zaher Salman (2002-2006) now PSI
Kim Chow (2000-2001) now UofA

Aug 20 1999??





First resonance on Pd foil July 11, 2000

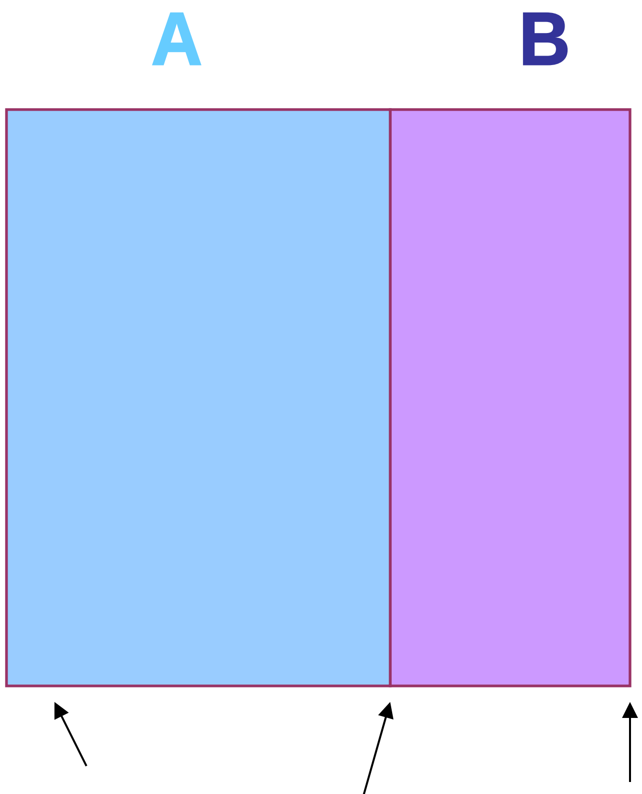


Comparison of magnetic resonance techniques

	NMR	**μSR**	**β-NMR**
Polarization	< 1%	100%	70%
Probing particle/nuclei	any stable nucleus with spin, e.g. ^{1}H	μ^{+}	any beta decay radioactive nucleus with spin. e.g. ^{8}Li
Sensitivity	10^{17} spins	10^{7} Spins	10^{7} spins
Detection Method	Electromagnetic	Anisotropic beta decay	Anisotropic beta decay
Nuclear spin	I = ½ (H)	I = ½	I = 2 ($^{8}Li^{+}$)
$1/T_1$ range (s^{-1})	10^{5} - 10^{2}	10^{-8} – 10^{-4}	10^{-2} - 10^{2}
Depth range	bulk	10-100 nm or mm	10-100nm

General Scientific Motivation:

Exploring the collective behaviour of electrons near an interface.



NMR
Neutrons
μSR

LEμSR
Resonant
Xray scatt.
βNMR

ARPES
STM

-superconductor/vacuum, e.g. YBa2Cu3Ox

insulator/vacuum, SrTiO3

-ferromagnet /metal, e.g. Ag/Fe,

-semiconductor/ferromagnet, spintronics e.g. EuO/Si GaAs/Mn

-insulator/insulator $SrTiO_3$ /LaAlO3 ,

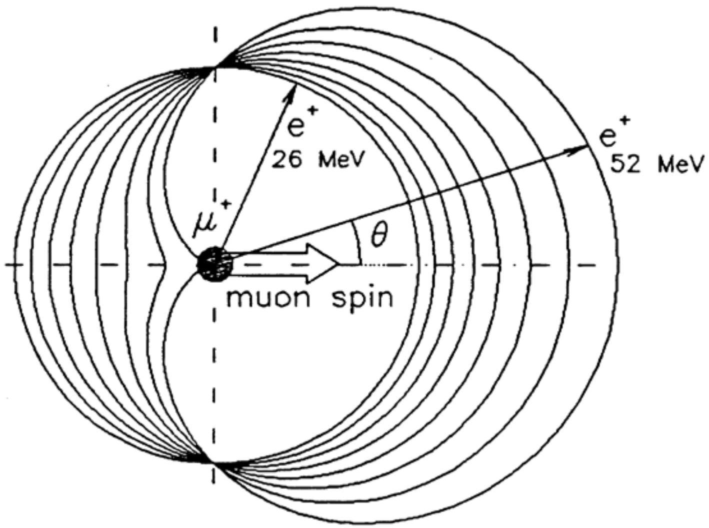
-
superconductor/metal, proximity effect Ag/Nb

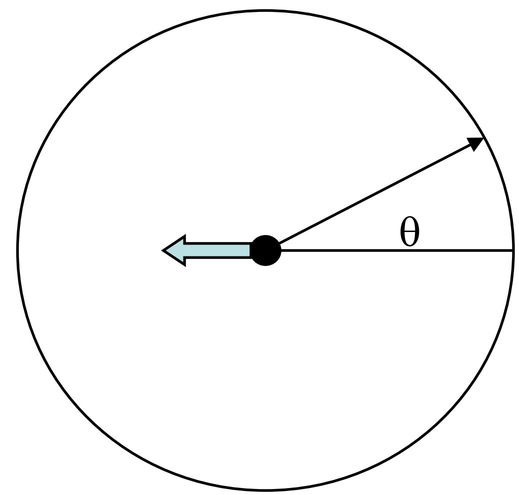
topological insulators Bi2Se3, SmB6

Properties of the muon and ^{8}Li

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

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

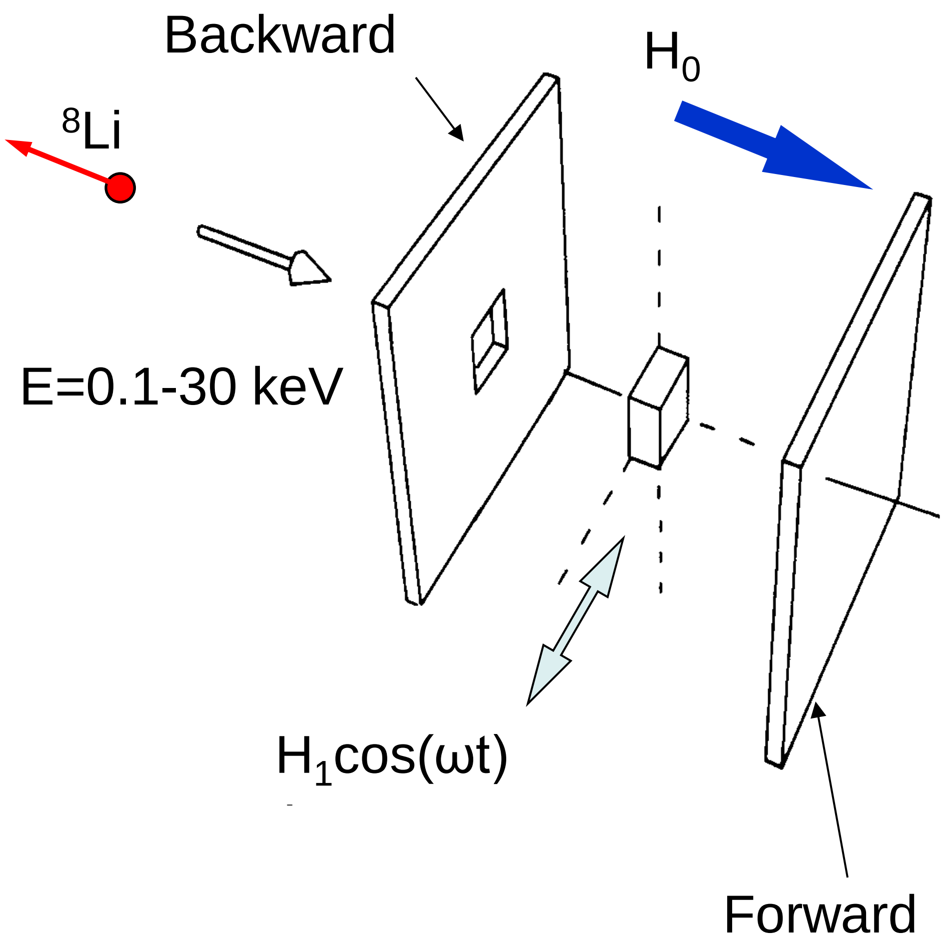


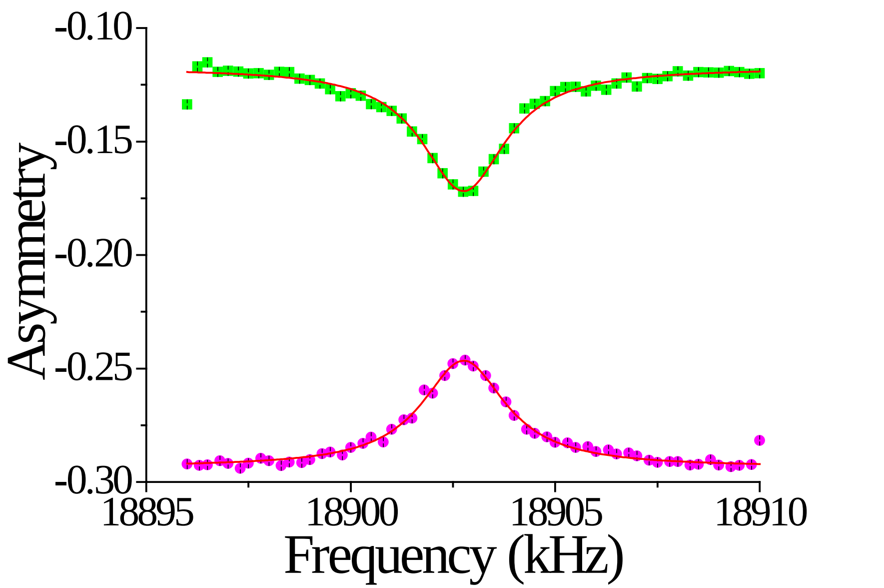


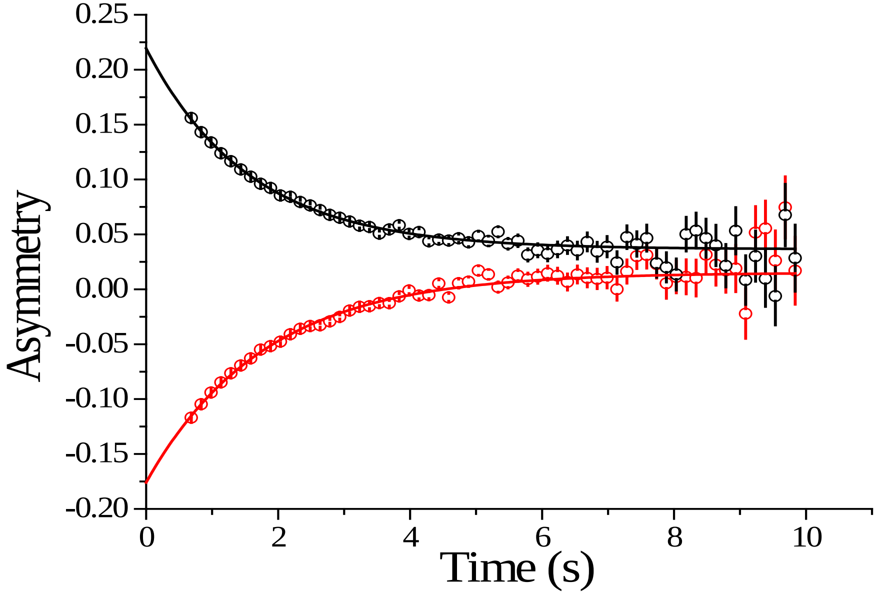
Spin = 1/2
γ = 135.55MHz/T
<A>= 0.33
Polarization = 95%
Lifetime = 2.19714(7) μs

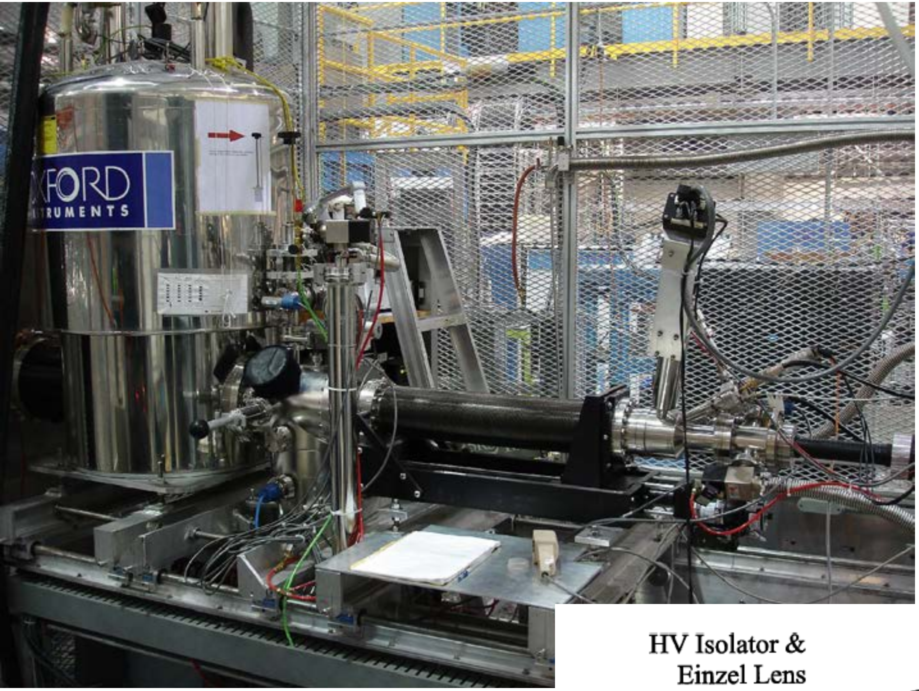
Spin=2, Q=33 mb
γ =6.30 MHz/T
<A>=-0.30
Polarization= 70%
Lifetime= 1.2s

Schematic of a β-NMR Experiment









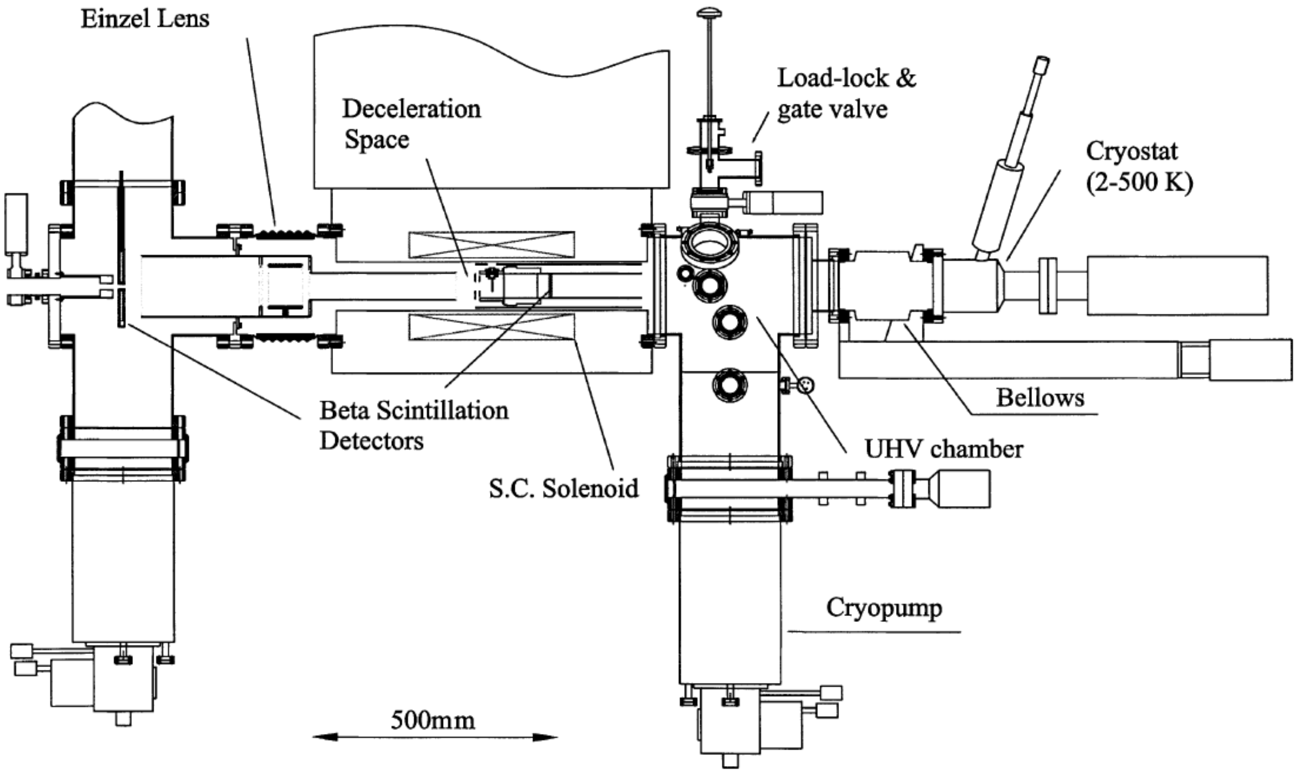
High Field NMR Spectrometer :

H : 0.1 – 9 T

E_{Li} : 0.1 – 30 keV

T : 3 – 300 K

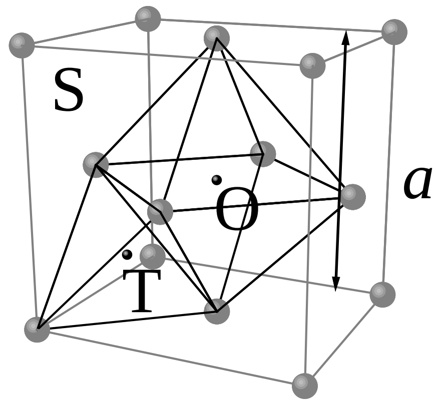
Beam // Magnetic field

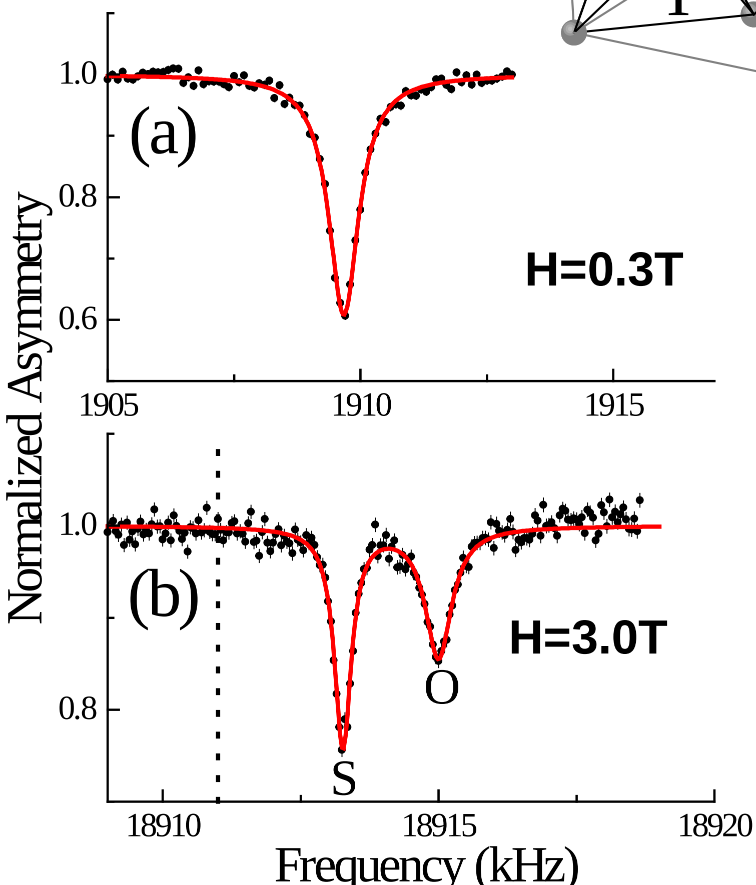


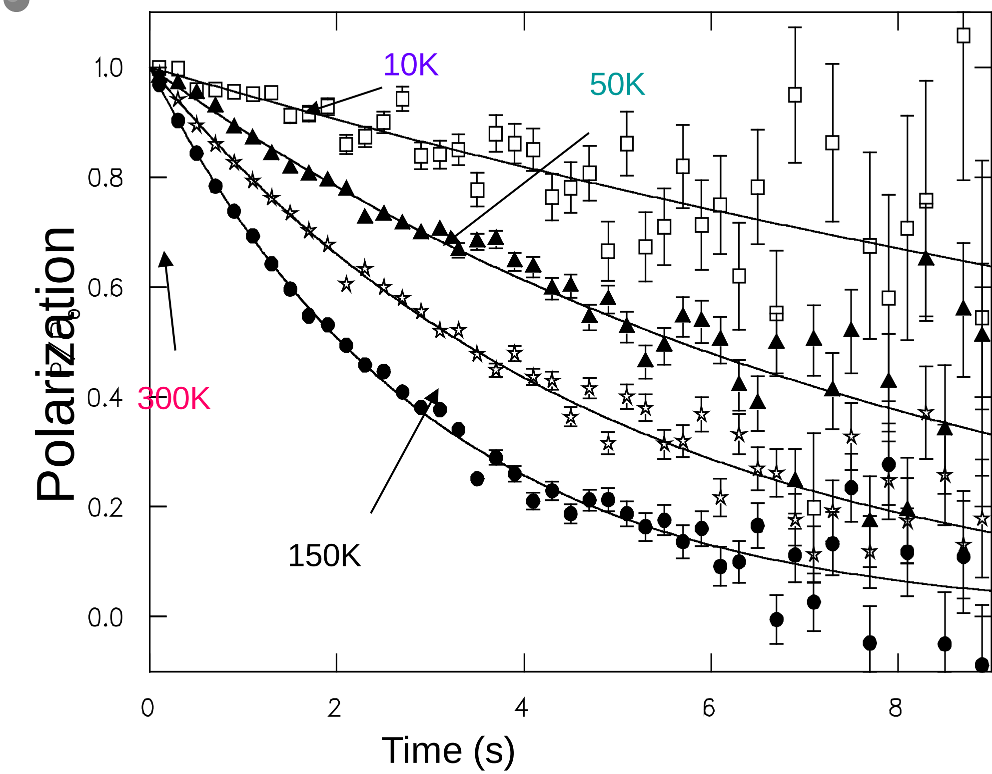
TRIUMF

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).

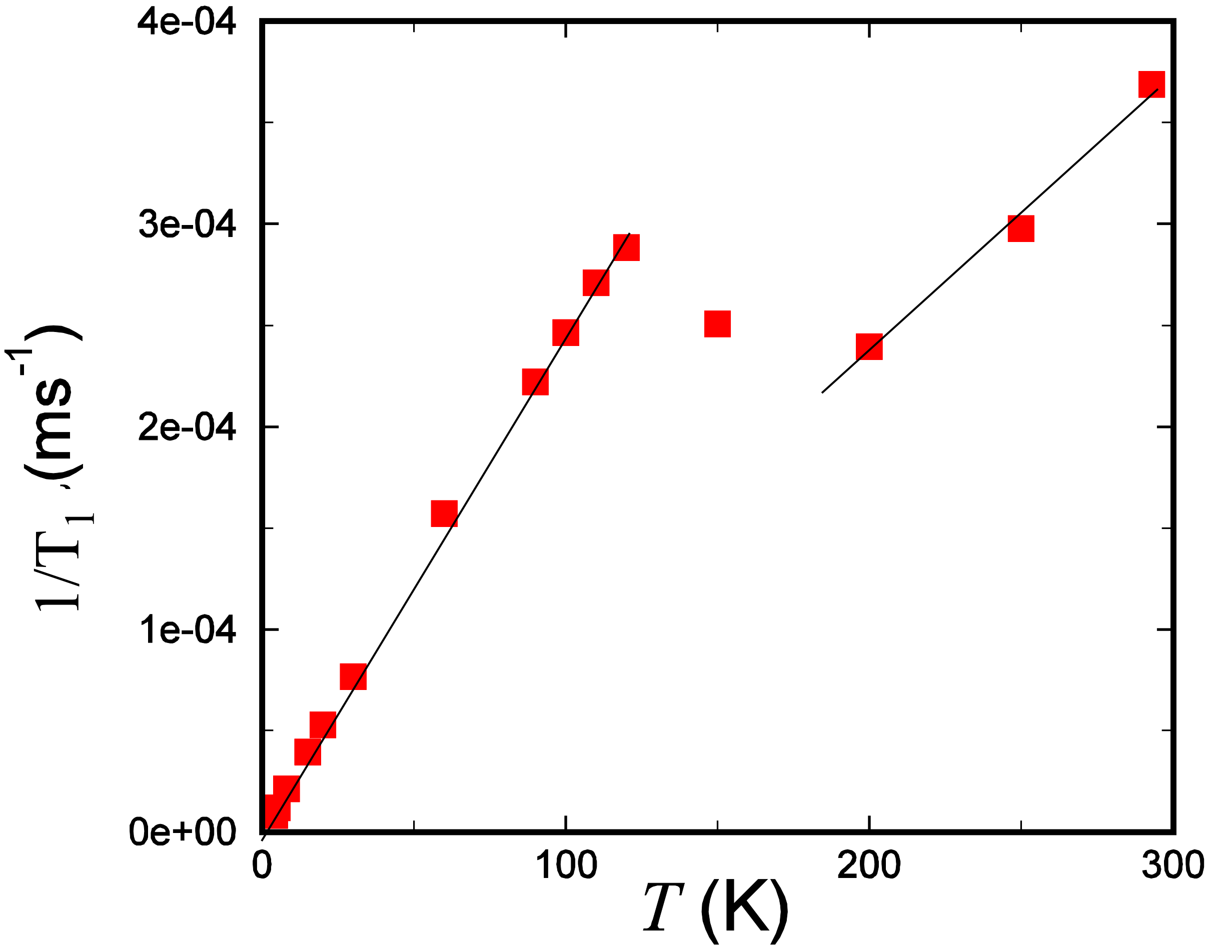






$1/T_1$ of ^{8}Li versus T in 50nm Ag on $SrTiO_3$

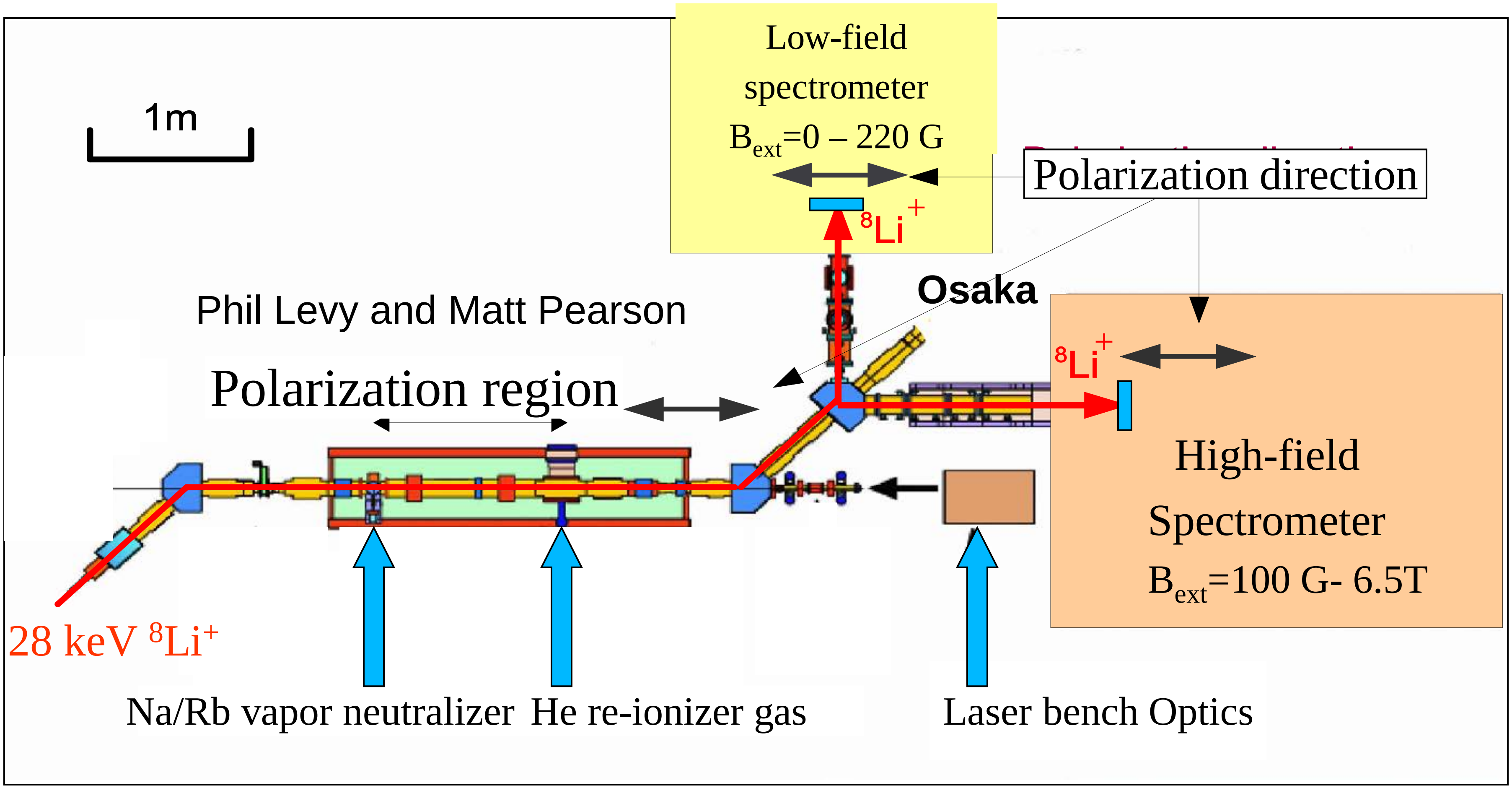
Morris et al PRL 93, 157601 (2004).



$$\frac{1}{T_1 T K^2} = 6.6\times10^4 K^{-1} s^{-1}$$

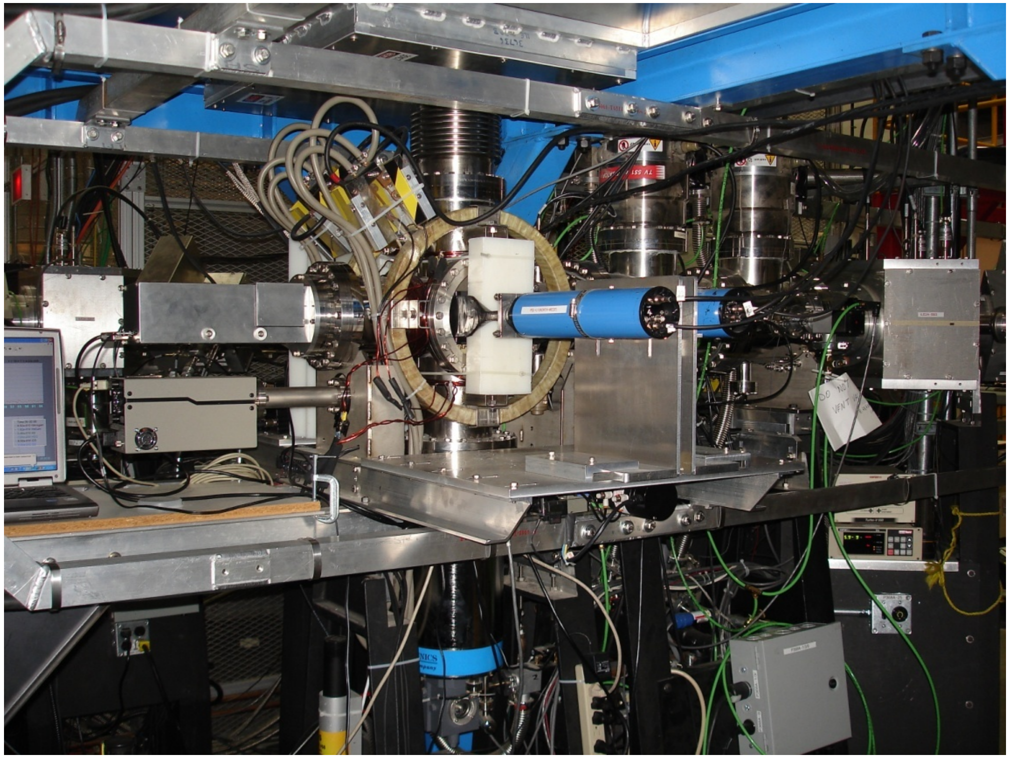
$$\frac{4k_B}{\hbar}\left[\frac{\gamma_n}{\gamma_e}\right]^2 = 8.32\times10^4 s^{-1} K^{-1}$$

β-NMR setup at ISAC



- Optical pumping with a tuned laser is used to achieve ~70% of spin polarization.
- Electrostatic deceleration is used to control the depth of the implanted ions (2-500nm)

Low & Zero Field NMR/NQR Spectrometer

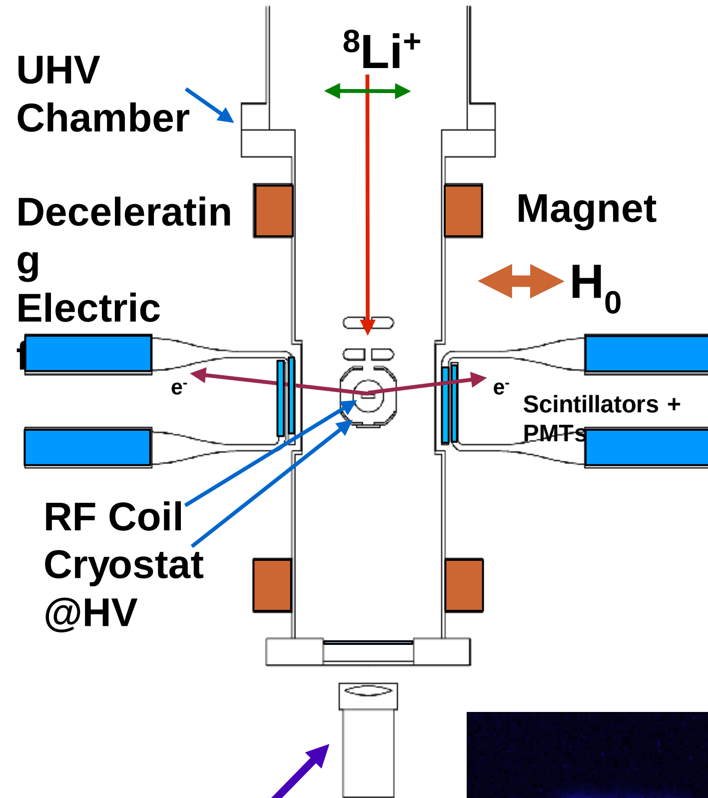


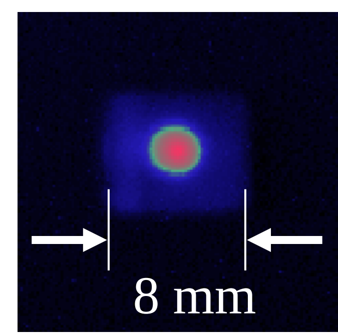
H : 0 – 22mT

E_{Li} : 0.5 – 30 keV

T : 3.5 – 300 K

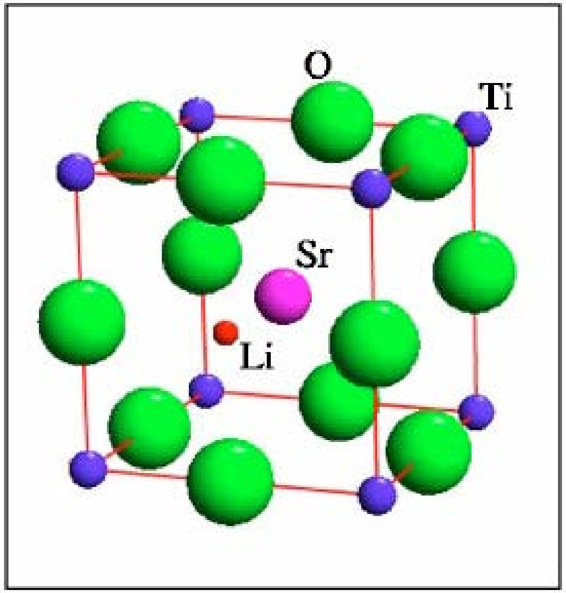
(view from above)





TRIUMF

$SrTiO_3$



-Simple cubic perovskite crystal structure .

-non magnetic insulator (but can easily be doped by heating to remove O.)

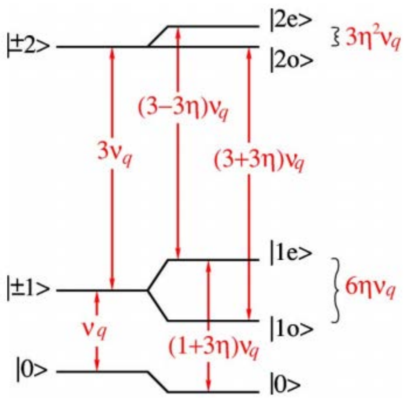
-2nd order structural phase transition at 100K.

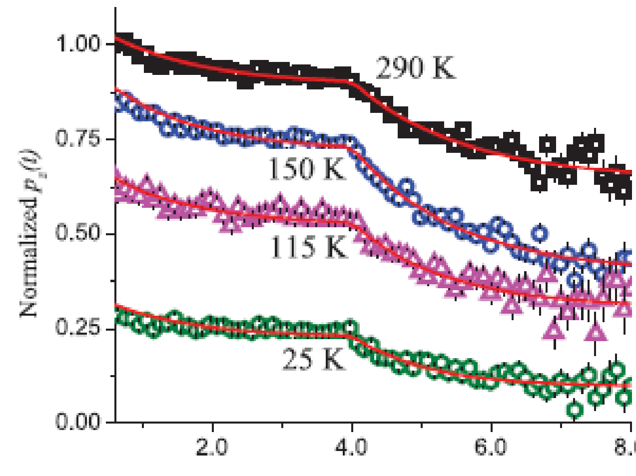
-used extensively as a substrate for thin films.

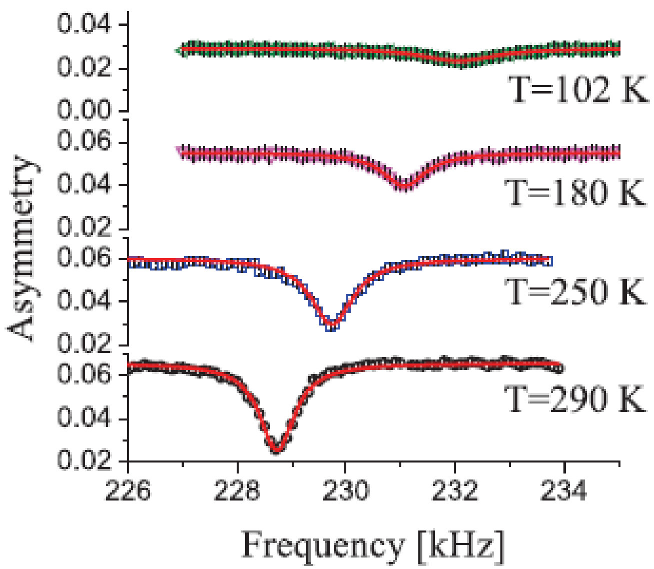
-quantum paraelectric on verge of becoming ferro-electric.

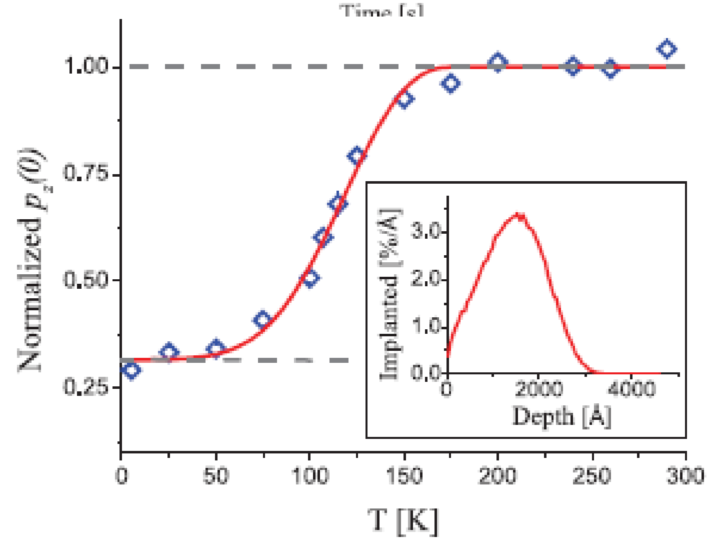
Near-Surface Structural Phase Transition of $SrTiO_3$ Studied with Zero-Field β-Detected Nuclear Spin Relaxation and Resonance

Z. Salman et al PRL 96, 147601 (2006)









Conclusion

The science motivation for betaNMR remains very compelling. The electronic, magnetic, structural properties(dynamics) of an interface/surface are distinct from the bulk properties. Beta-NMR at TRIUMF is unique and is one of the few methods which can explore these properties.

When developing a new technique making predictions about what you will see is very difficult. We rarely observed what was expected but it was almost always interesting.

I wish we had spent more time at the beginning of ISAC making it a multi user facility that could deliver beam to more than one experiment at time! The limited beamtime is a biggest challenge we face.

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