β**NMR** at ISAC

β−detected Nuclear Magnetic Resonance and spin relaxation for materials science.

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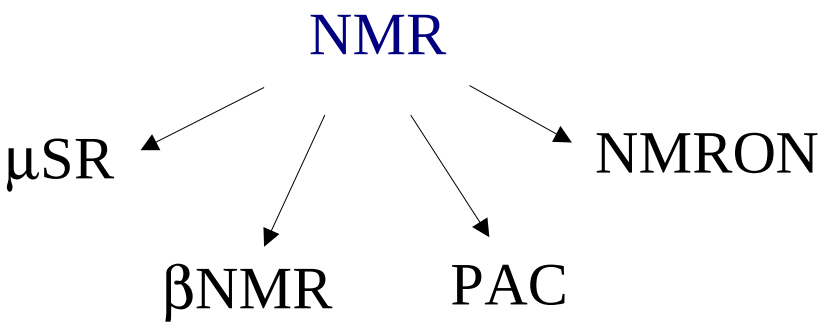
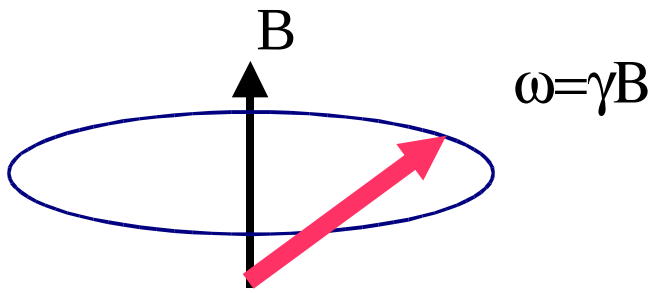
TRIUMF

RIA workshop
LANL, 30−31 Oct. 2000

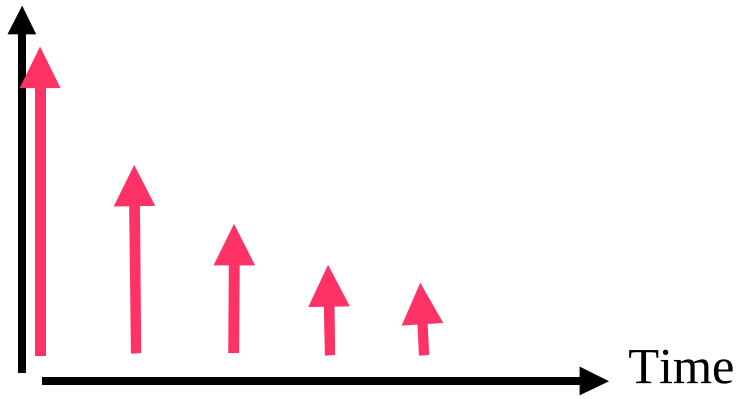


Time evolution of the polarization is characterized by

Precession in the local magnetic field

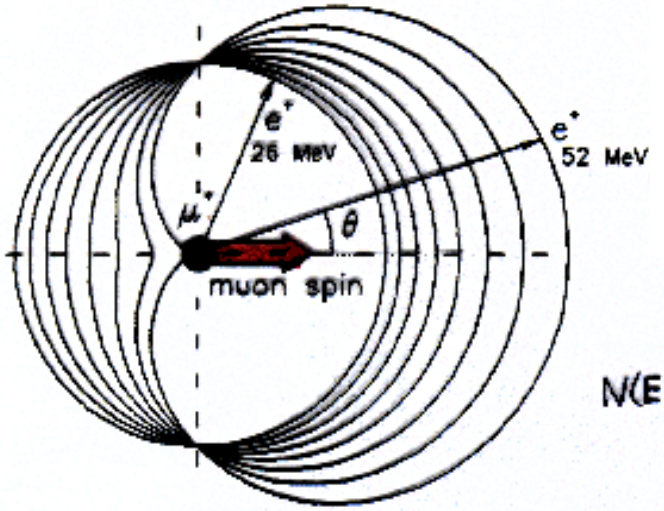


and/or relaxation.



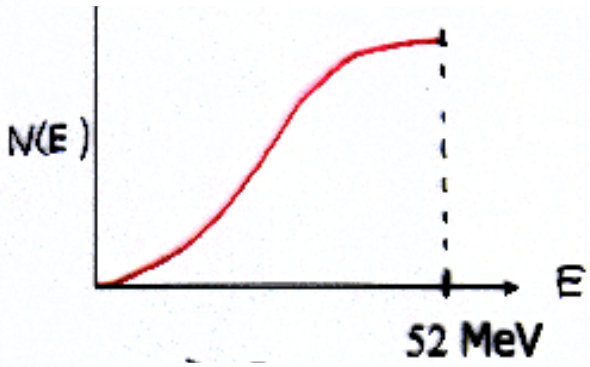
muon versus nuclear β–decay

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

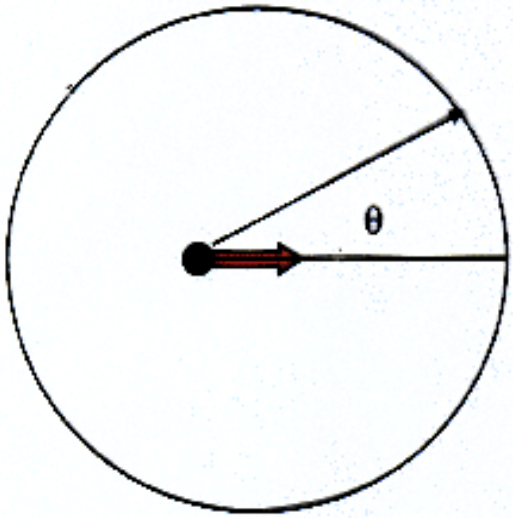


$1 + A(E)\cos\theta$

Z=1
Spin=2 (Q=0)
γ=135.54MHz/T
<A>=1/3
τ=2.2μs

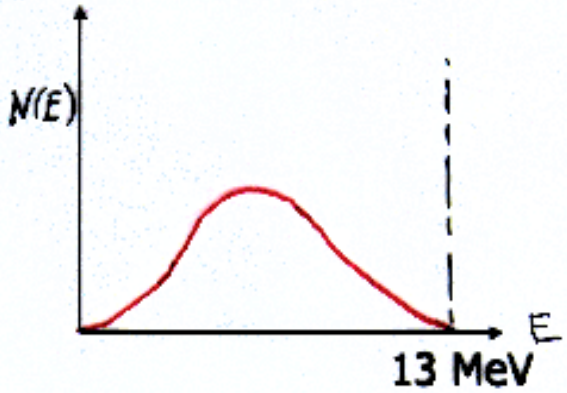


$^8Li \longrightarrow {}^8Be + e^- + \bar{\nu}_e$



$1 + A\frac{\bar{v}}{c}\cos\theta$

Z>=3
Spin=2
γ=6.3MHz/T
<A>=1/3
τ=1.21s



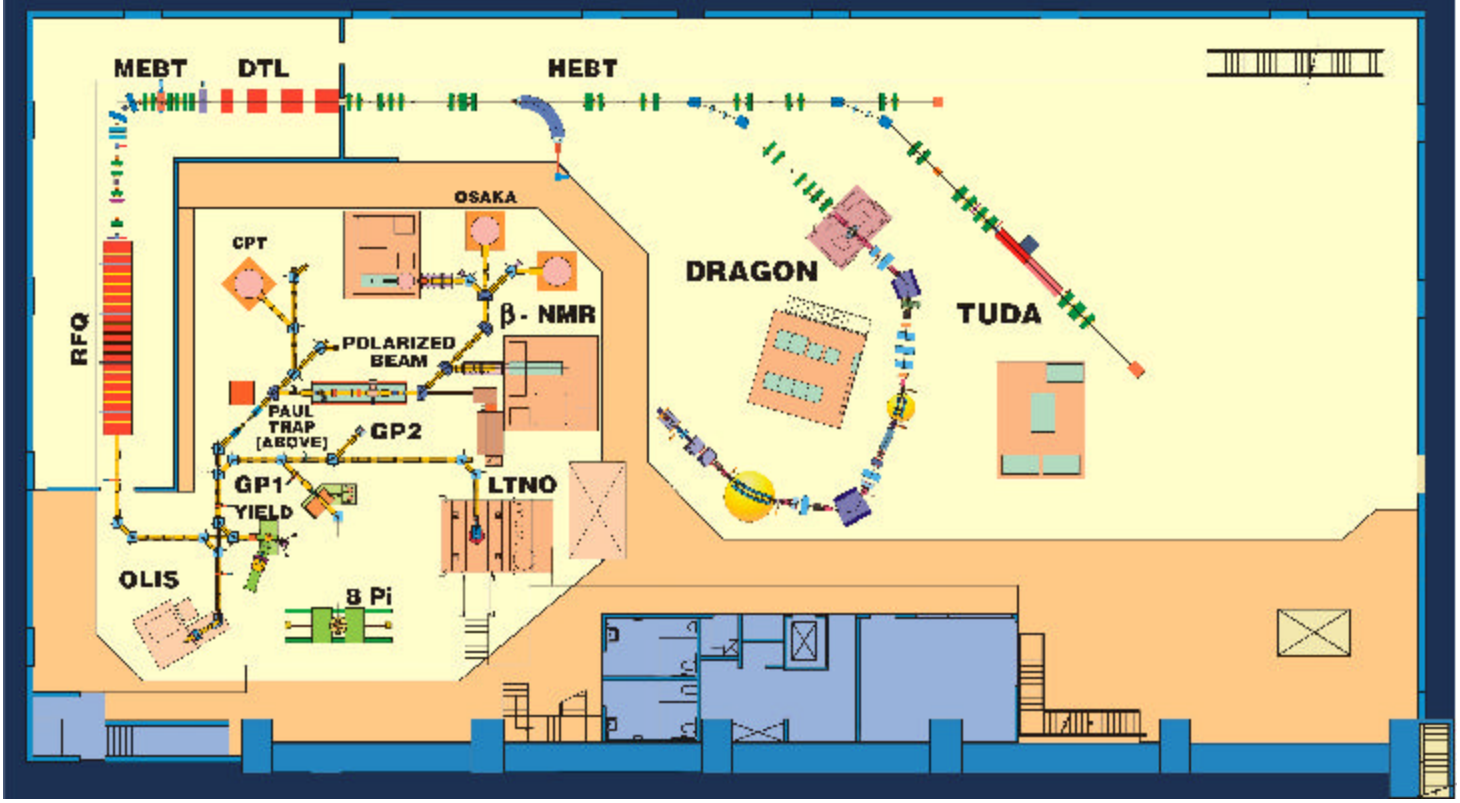
Comparison of NMR with Nuclear−Detected Techniques

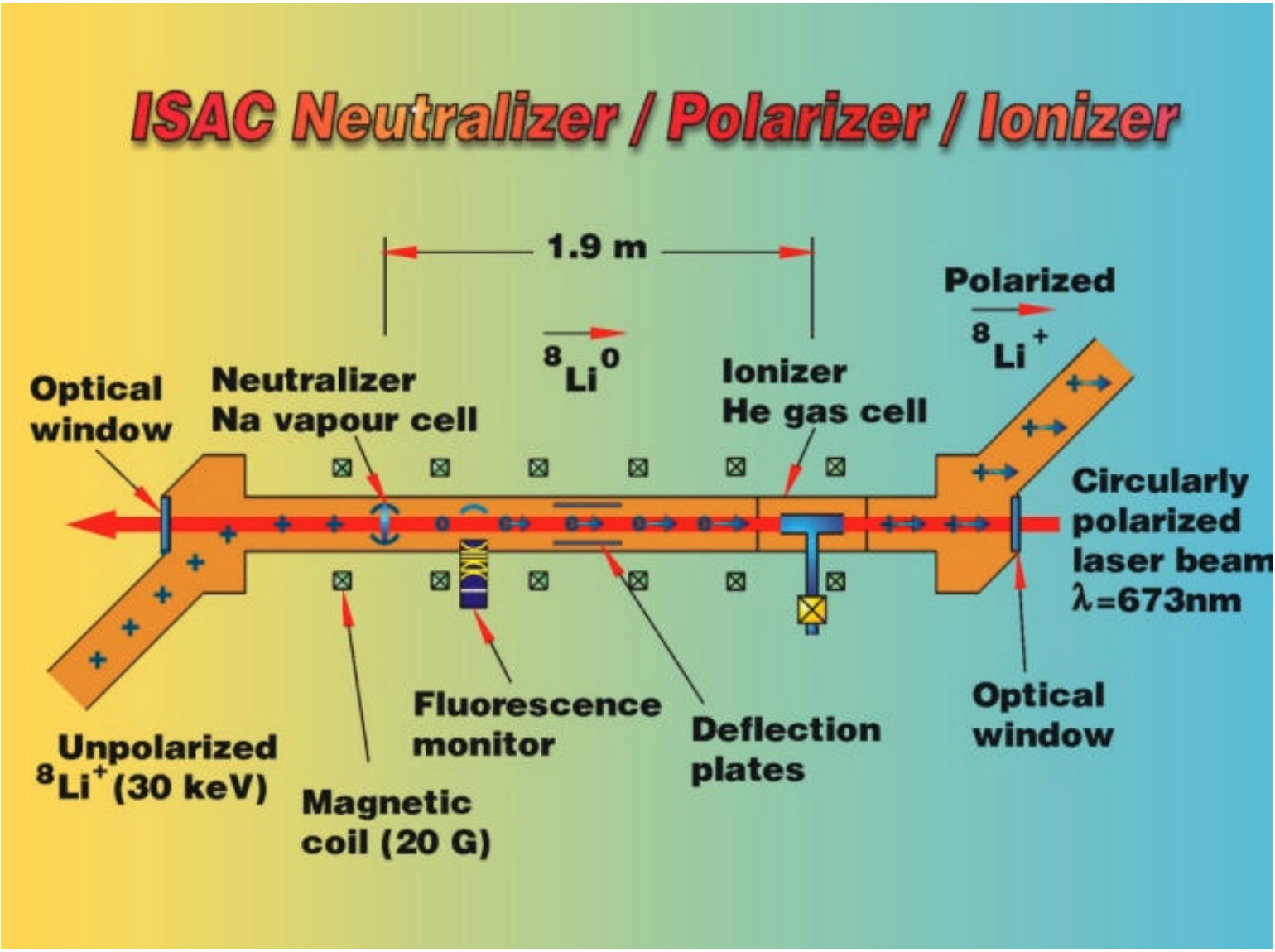
	NMR	μSR	βNMR
Polarization:	<0.001	>0.8	
Detection:	electronic	anisotropic decay	
Sensitivity:	10^{18} spins	10^{7} spins	
T_1 range [s]:	10^{-5}−10^{2}	10^{-8} − 10^{-4}	10^{-3} −10^{3}
Depth:	−	0.5mm	10 − 2000A
Rate:	−	10^{4}	$>10^{6}$
Resolution [G]: $(\gamma\tau)^{-1}$	10^{-4}	10	10^{-4}
Bulk			
Interfaces	✓	✓	✓
Impurities			✓
		✓	✓

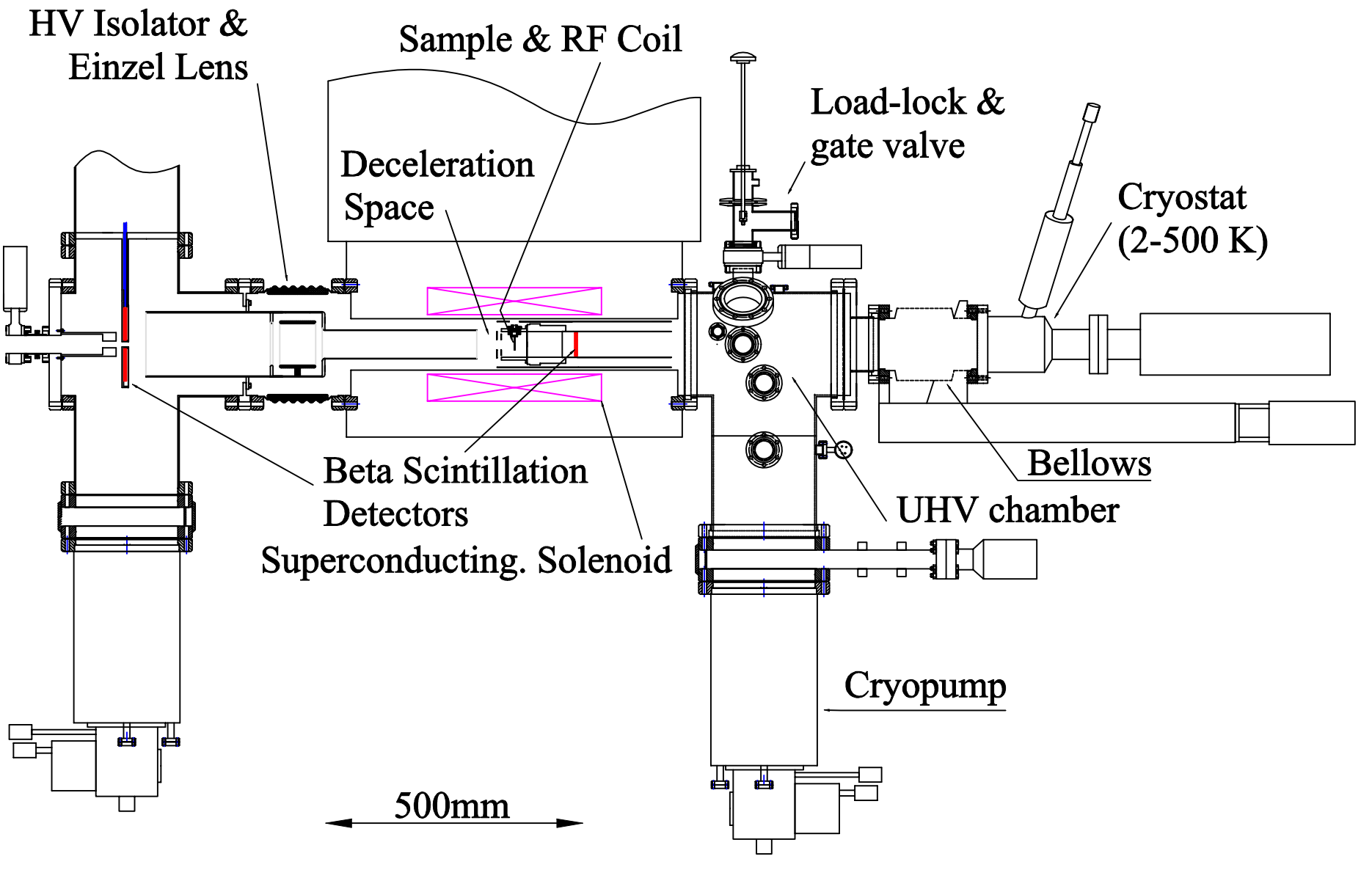
Suitable Isotopes for βNMR at ISAC

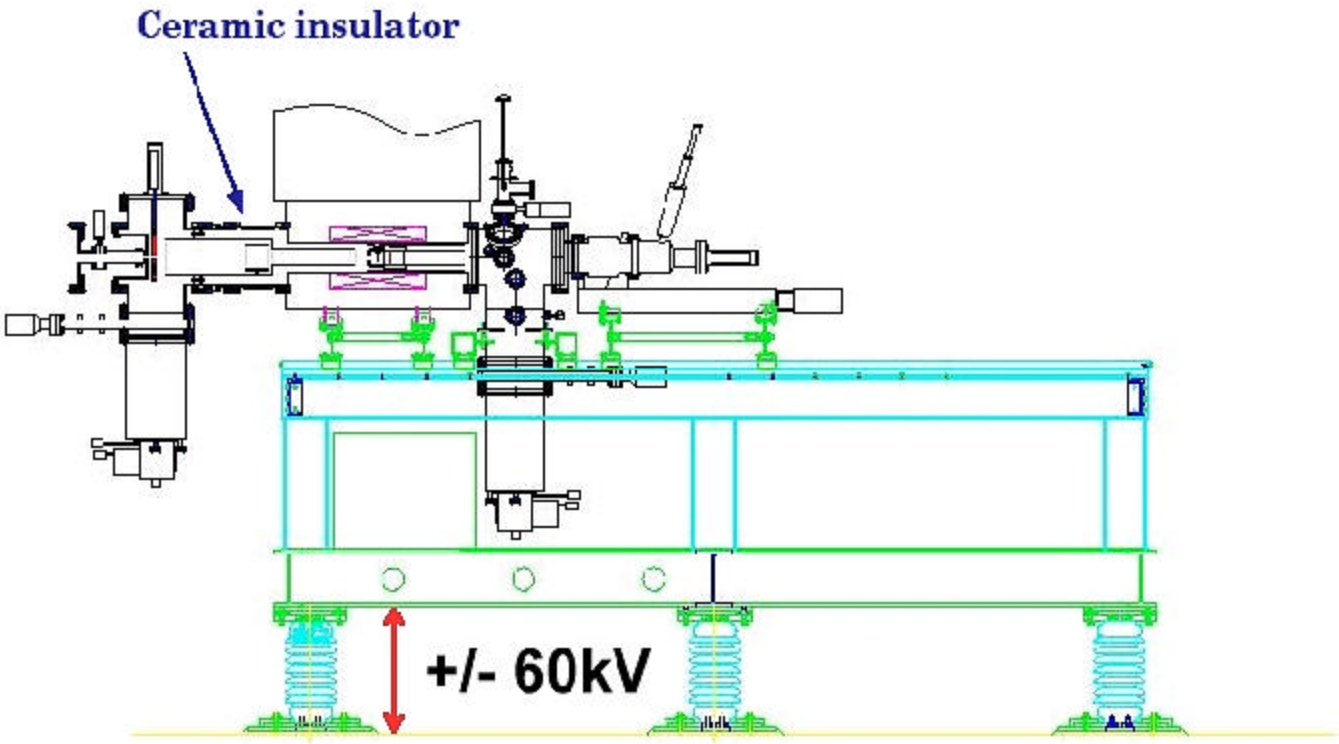
Isotope	I	$t_{1/2}$[s]	γ[MHz/T]	A_0	Yield [s^{-1}]
^{8}Li	2	0.8	6.3	0.33	10^8
^{11}Be	½	13.8	22	0.3	10^7
^{15}O	½	122	10.8	0.66	10^8
^{19}O	5/2	26.9	4.6	0.71	10^8
^{17}Ne	½	0.1		0.33	10^6

ISAC EXPERIMENTAL HALL



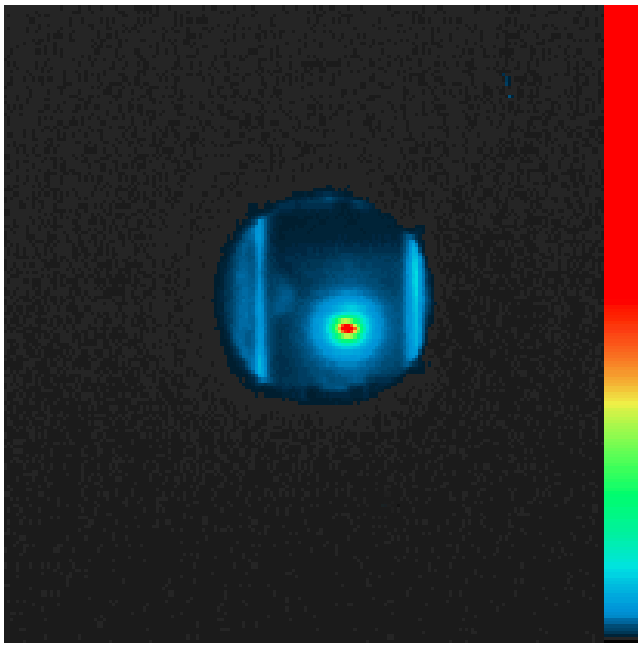

ISAC Neutralizer / Polarizer / Ionizer
1.9 m
Polarized
$^{8}Li^{+}$
$^{8}Li^{0}$
Optical window
Neutralizer
Na vapour cell
Ionizer
He gas cell
Circularly polarized laser beam
λ=673nm
Unpolarized
$^{8}Li^{+}$(30 keV)
Magnetic coil (20 G)
Fluorescence monitor
Deflection plates
Optical window


HV Isolator &
Einzel Lens
Sample & RF Coil
Load-lock &
gate valve
Deceleration
Space
Cryostat
(2-500 K)
Beta Scintillation
Detectors
Superconducting. Solenoid
Bellows
UHV chamber
Cryopump
500mm



Ions are implanted at variable energy by biasing the entire experiment.

Beam spot imaging: ^{8}Li on Scintillator



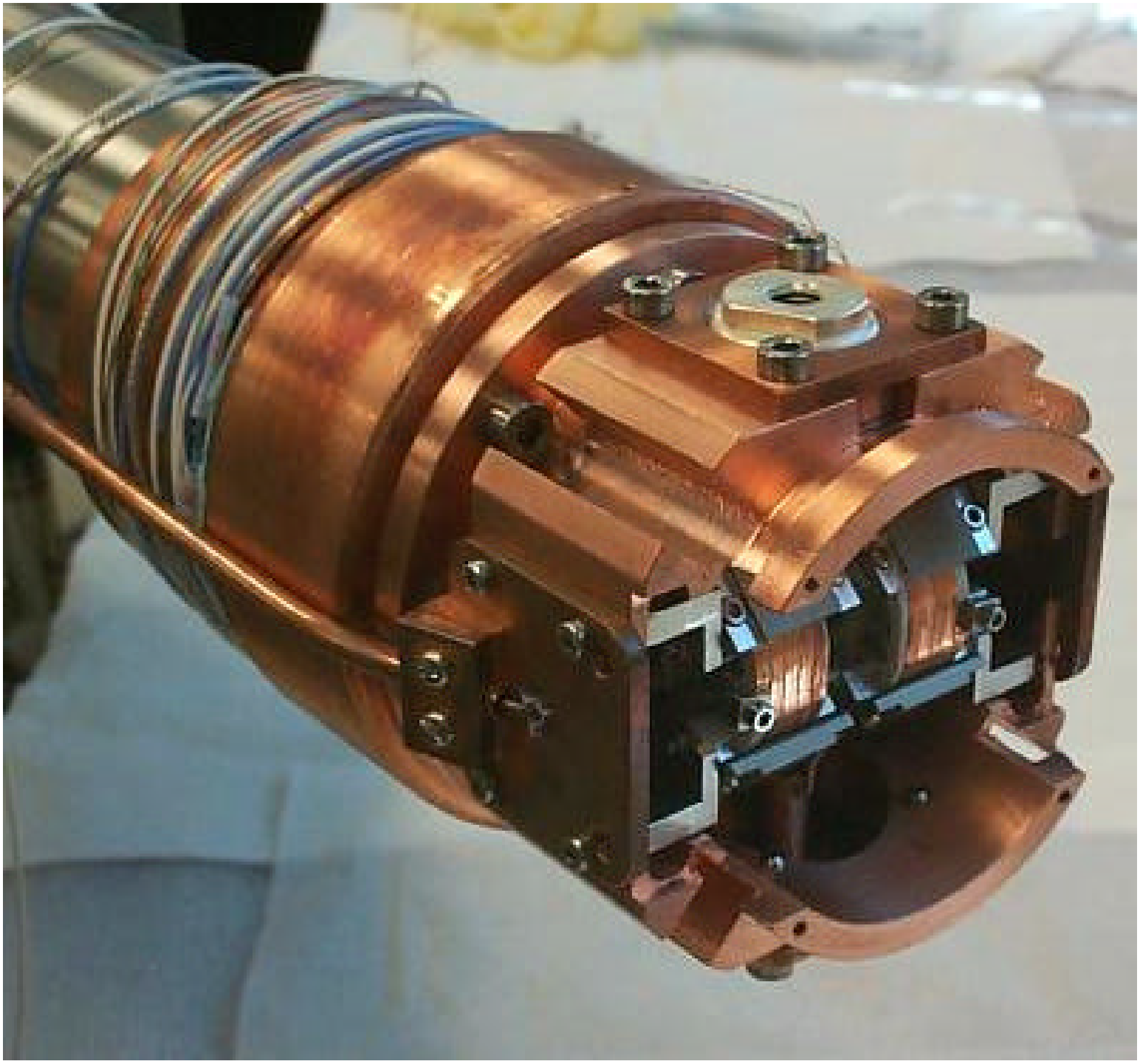
8mm

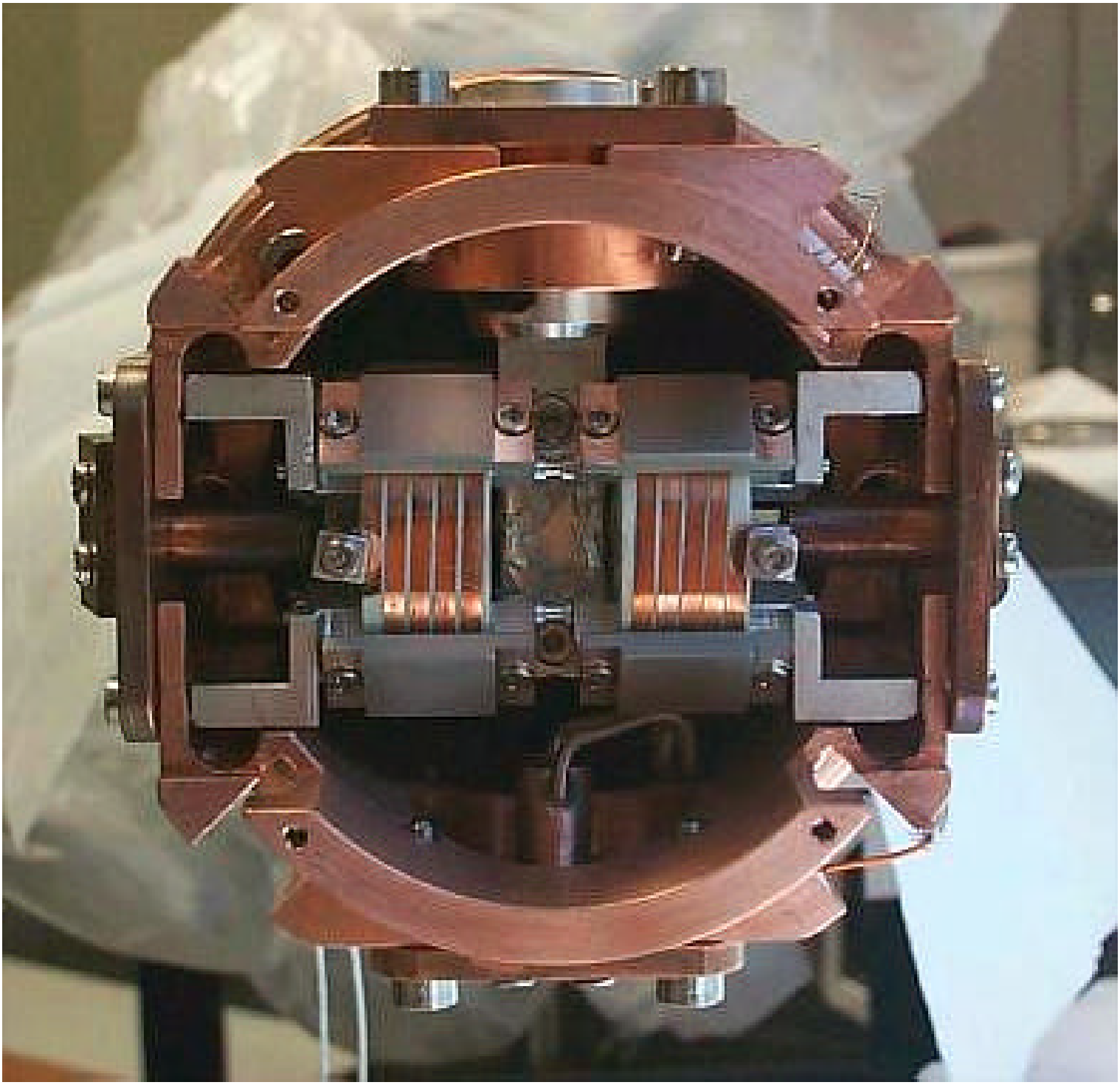
A small beam spot is essential to enable experiments on high quality, small, single−crystal samples.

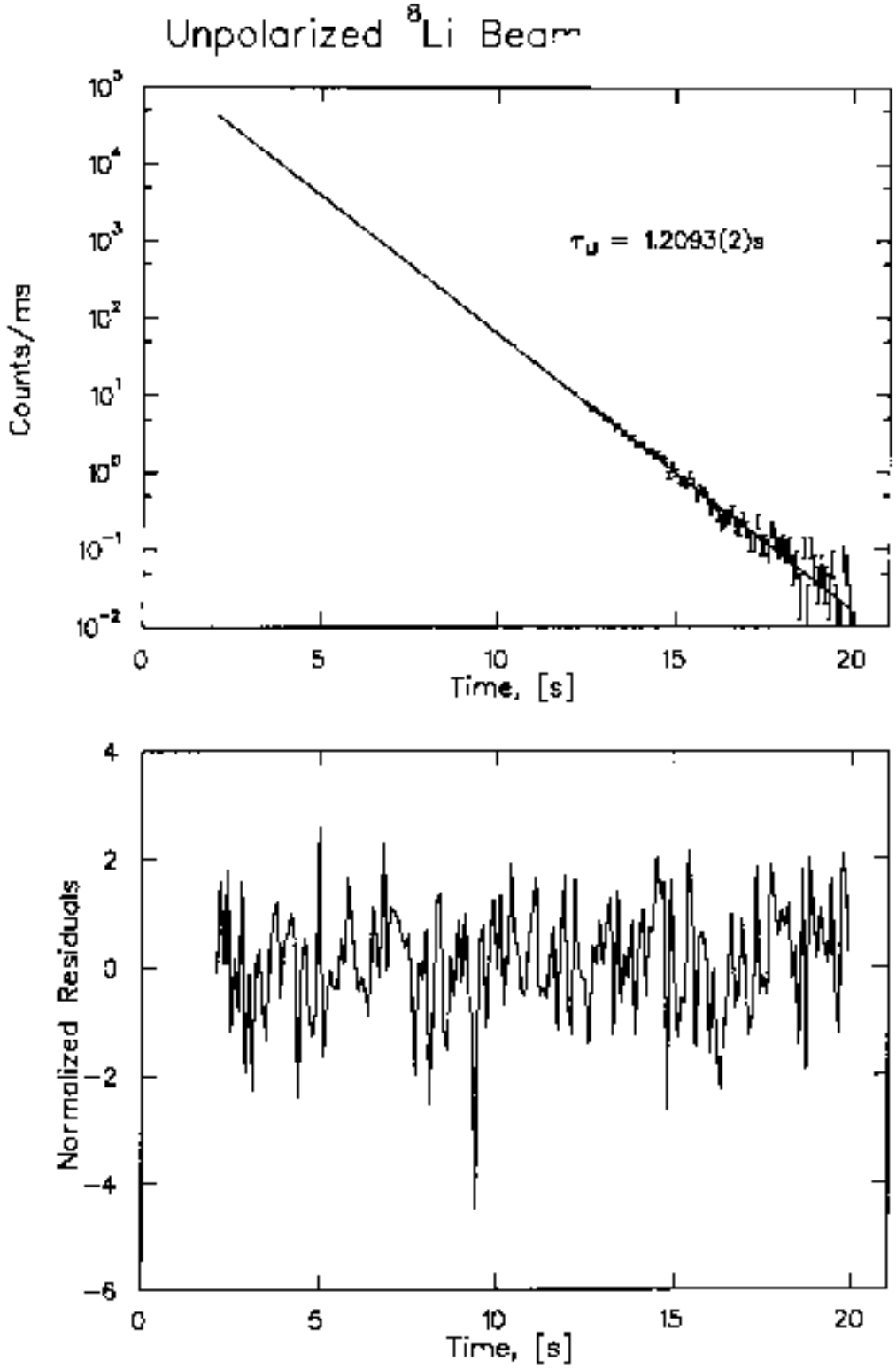
CCD image above shows where energy is deposited by α's :

$^{8}Li \rightarrow {}^{8}Be + e^{-} + \nu$,

$\rightarrow 2\alpha$






Unpolarized ^{8}Li Beam
τ_u = 1.2093(2)s
Counts/ms
Time, [s]
Normalized Residuals
Time, [s]

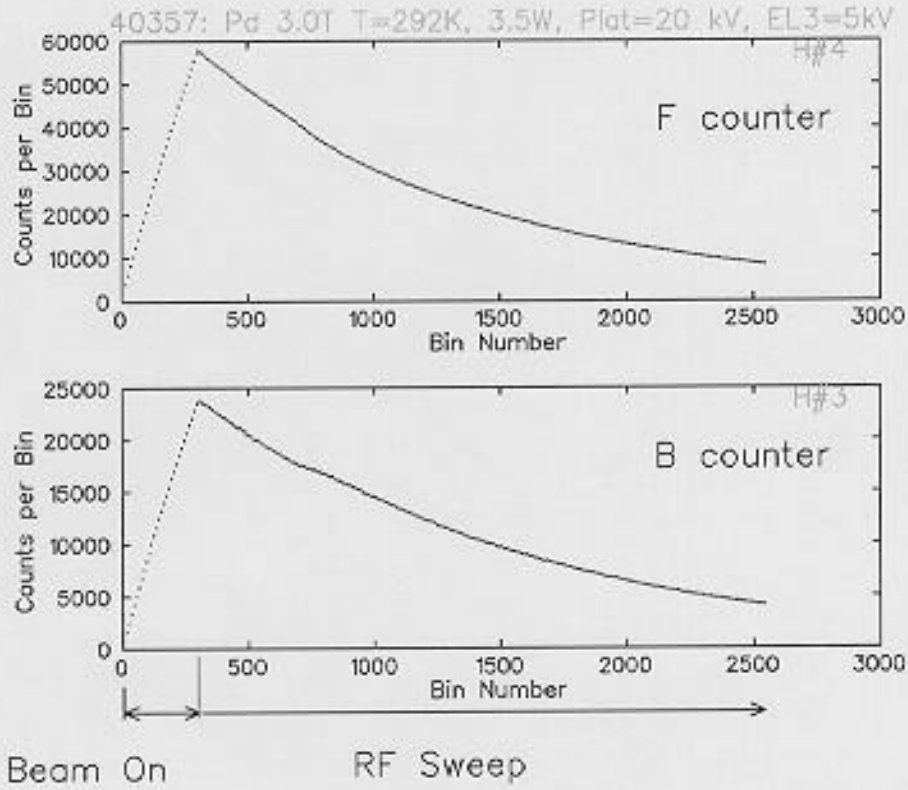
Data Acquisition and Control

In addition to event counting and histogramming, the DAQ system also:

- Controls RF frequency, phase, and amplitude modulation.
- Controls a beam kicker to pulse the beam.
- Controls beam polarization (+/− and off).

On the drawing board:

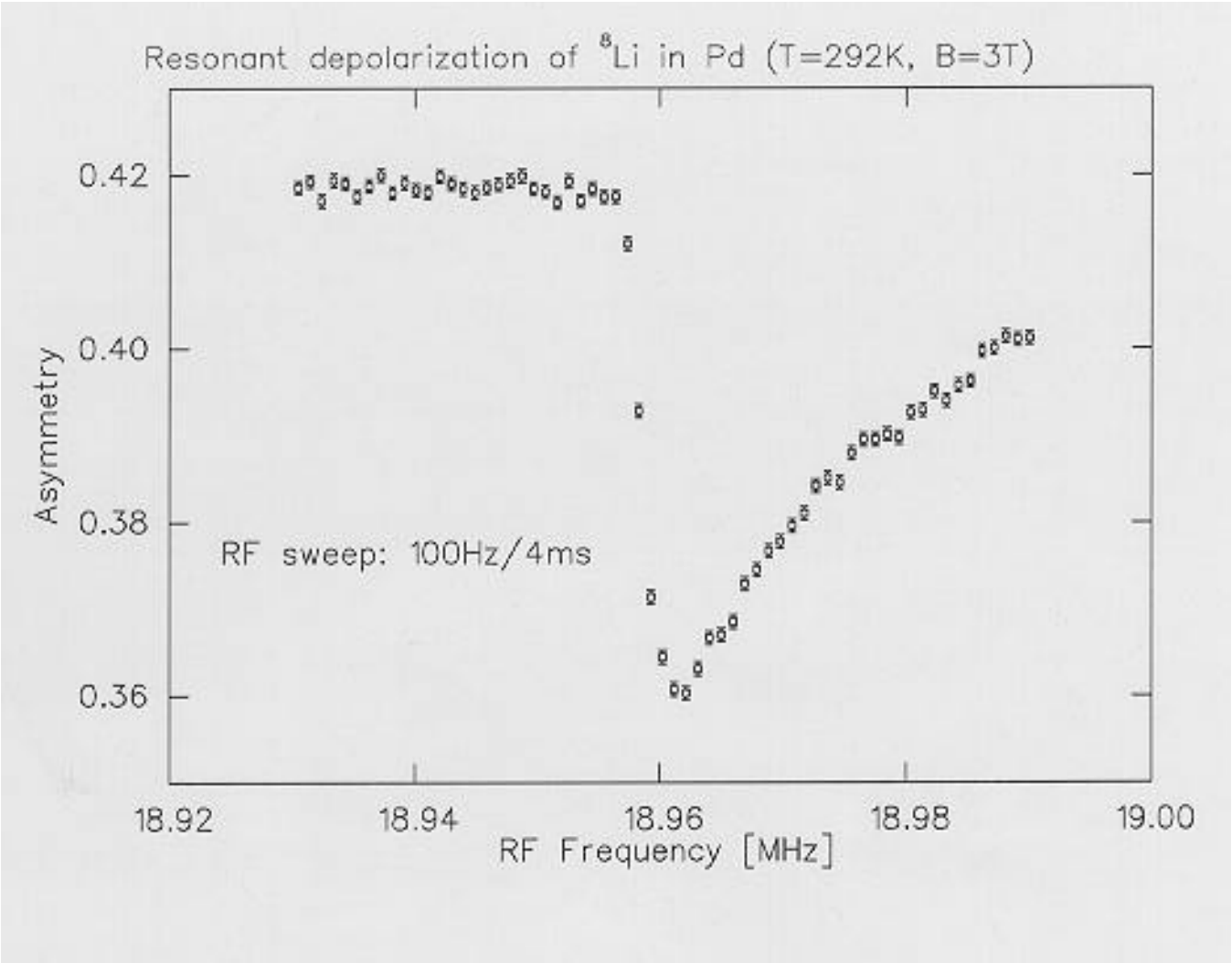
- A Paul trap will be added upstream from the polarizer to bunch the beam into very short pulses.
- A spin rotator will allow transverse high field expts.
- Dilution refrigerator.

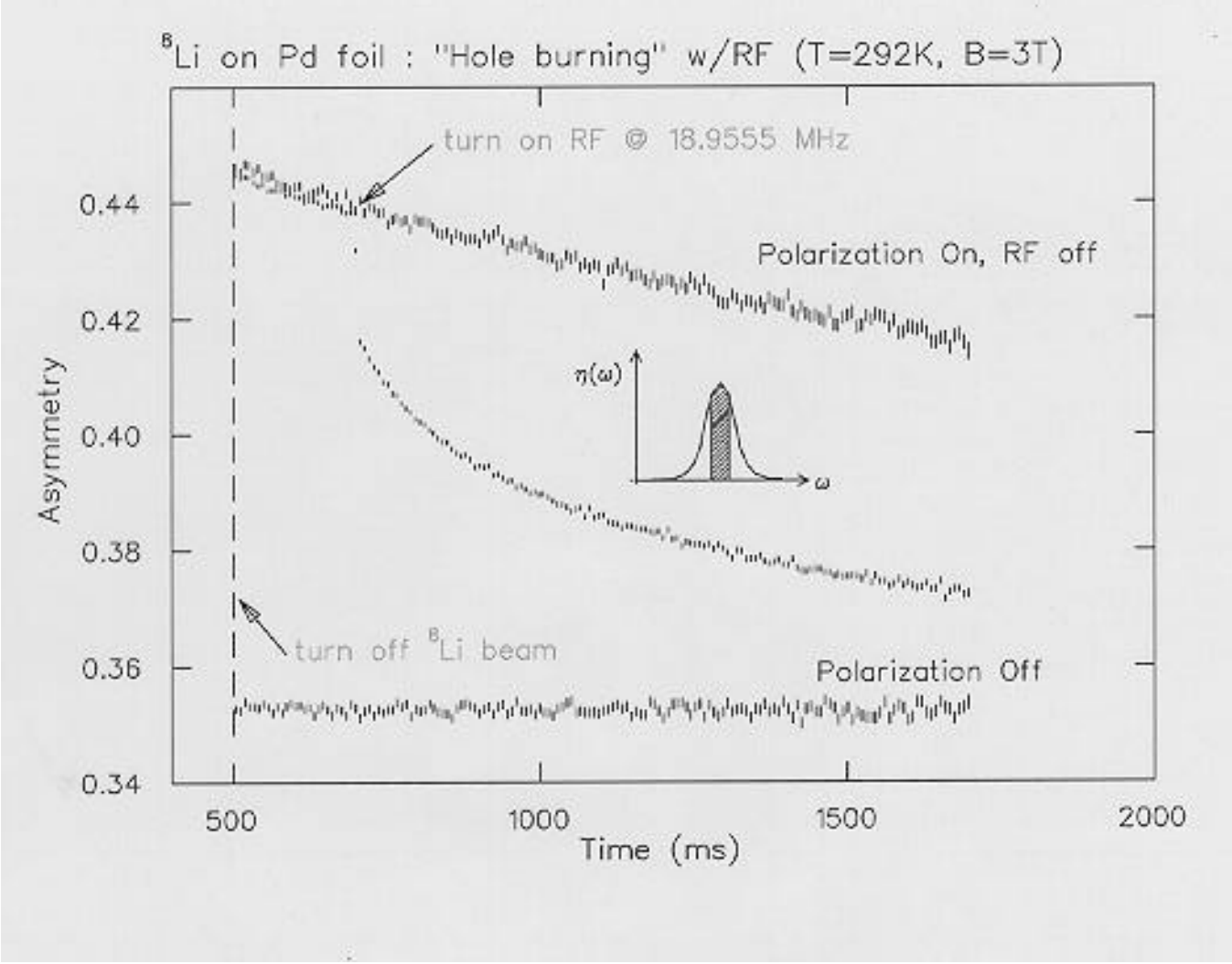


$$\text{Asymmetry } A(t) = \frac{N_B(t) - N_F(t)}{N_B(t) + N_F(t)}$$

Or, by switching the handedness of circularly polarized laser light, flip the beam polarization and extract a single-counter asymmetry

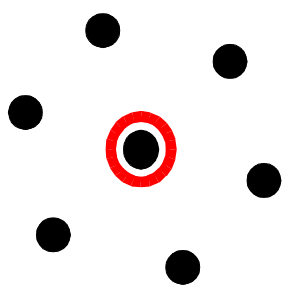
$$A_F(t) = \frac{N_F^+(t) - N_F^-(t)}{N_F^+(t) + N_F^-(t)}$$

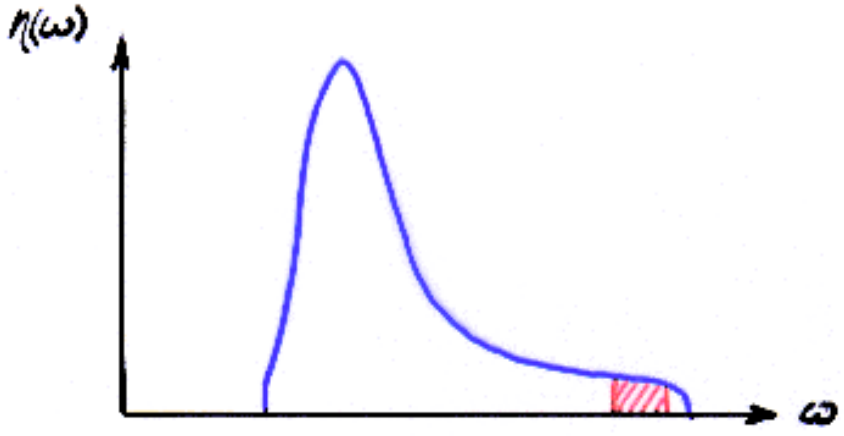

Resonant depolarization of ^{8}Li in Pd (T=292K, B=3T)
Asymmetry
0.42
0.40
0.38
0.36
RF sweep: 100Hz/4ms
18.92
18.94
18.96
18.98
19.00
RF Frequency [MHz]


^{8}Li on Pd foil : "Hole burning" w/RF (T=292K, B=3T)
turn on RF @ 18.9555 MHz
Polarization On, RF off
$\eta(\omega)$
ω
turn off ^{8}Li beam
Polarization Off
Asymmetry
0.44
0.42
0.40
0.38
0.36
0.34
500
1000
1500
2000
Time (ms)

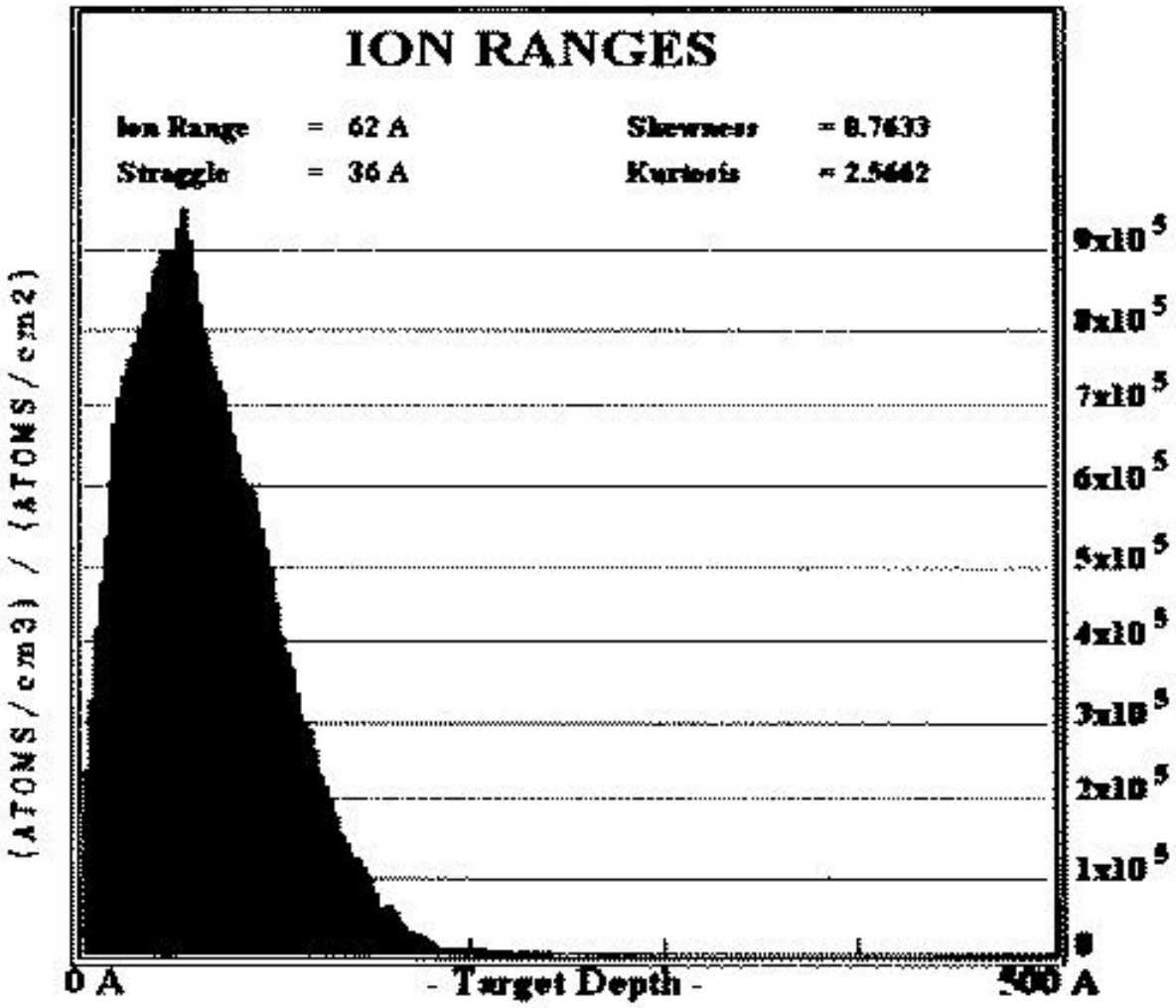
Superconductivity

- Use variable implantation depth to measure penetration depth in the Meissner state as a function of temperature and doping.
- Measurement of the magnetic field distribution and spin relaxation inside and around vortices by RF resonance.



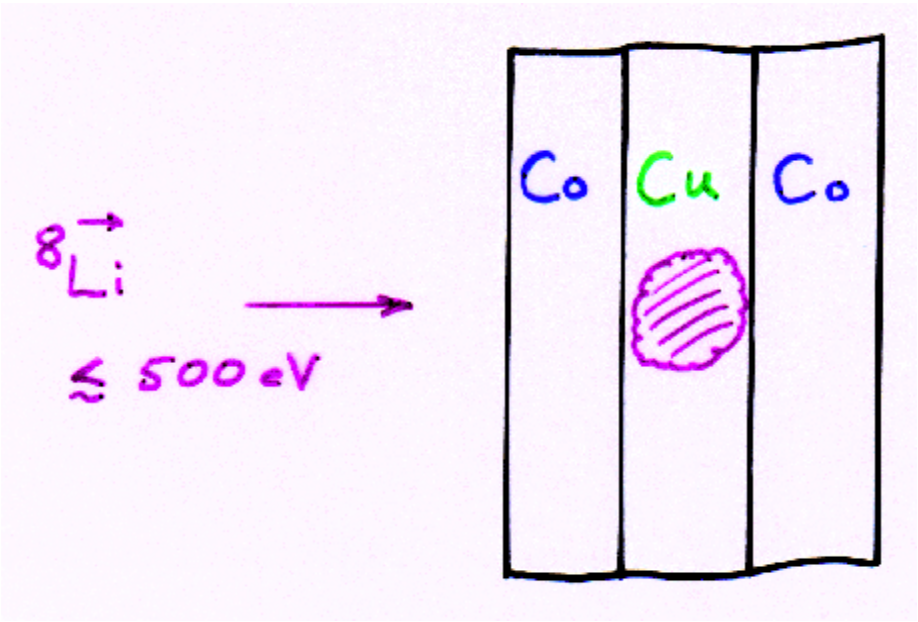


Li in YBCO @ 1 keV (SRIM calculation)



Semiconductors

- Electronic states of impurities − hyperfine interactions and binding of shallow centers.
- Diffusion of impurities and site determination.
- Thin films − electrons confined to 2D systems.

Magnetism

- Measure spin relaxation as a function of field and temperature to probe magnetic order and excitations.
- Use low energy implantation to study thin film magnetic multilayered materials − GMR.