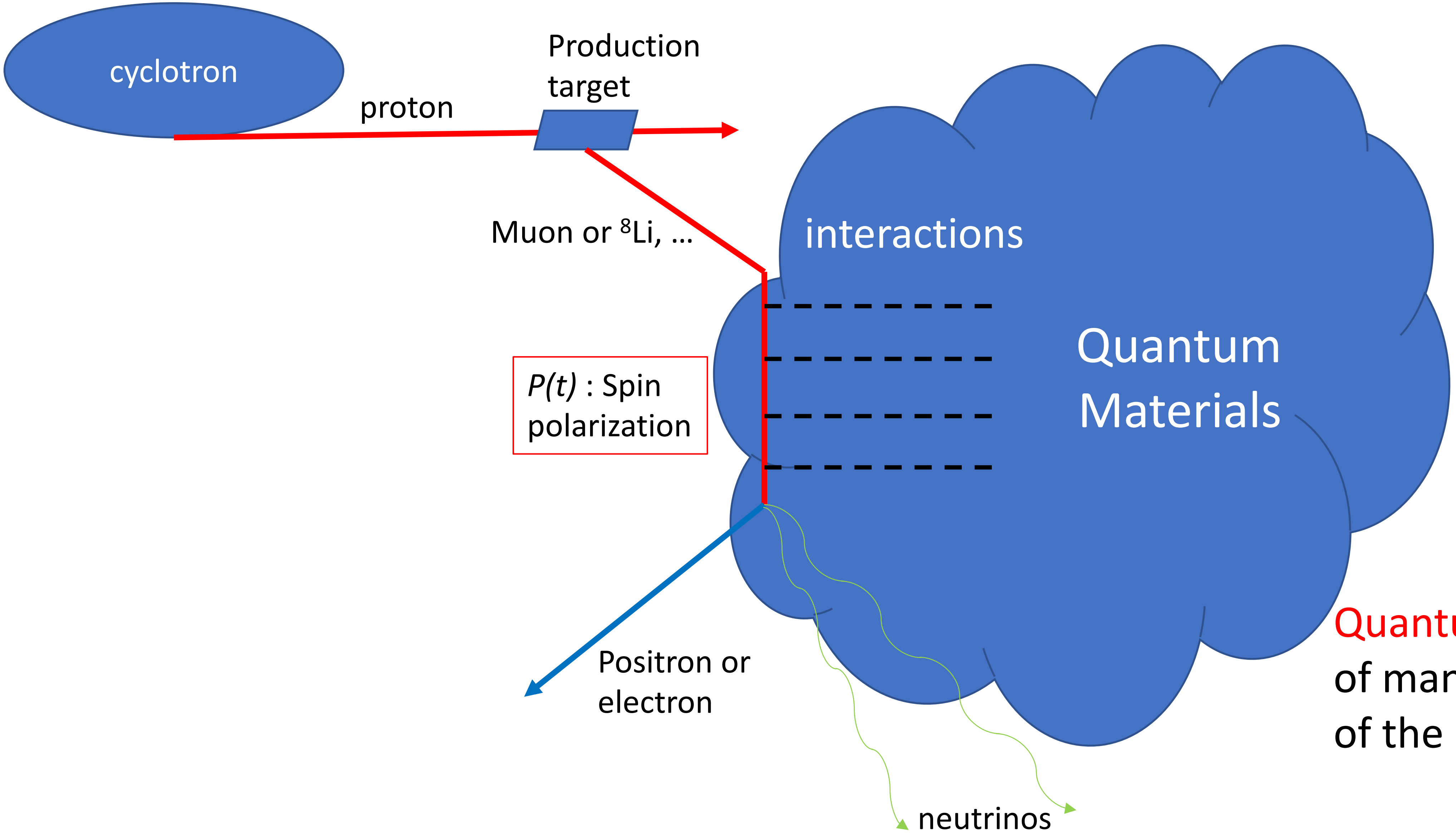
# Quantum Materials

Kenji M. Kojima

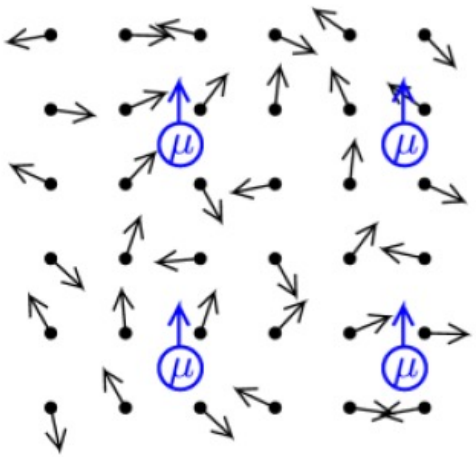
# Quantum Materials Research and CMMS at TRIUMF

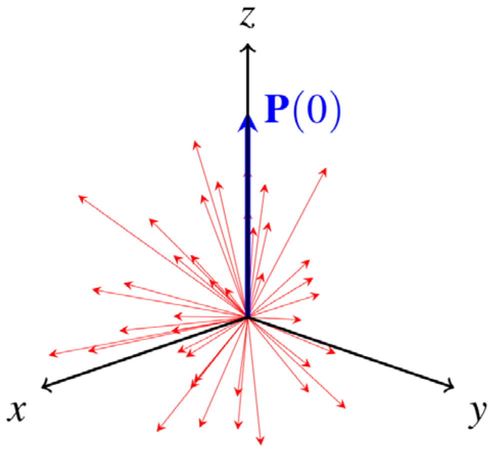


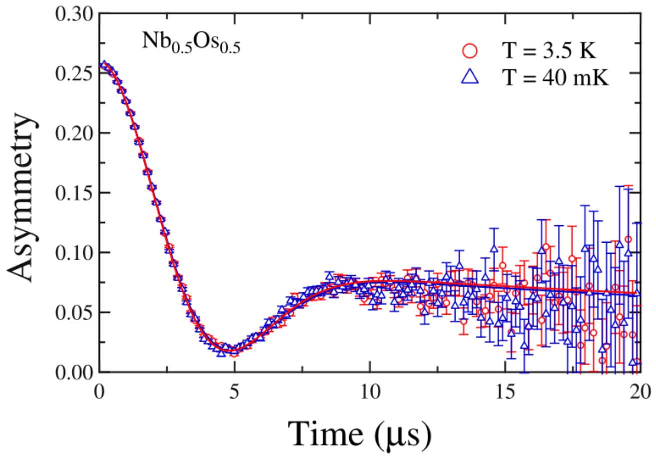

Quantum phenomena
of many electrons
of the matter

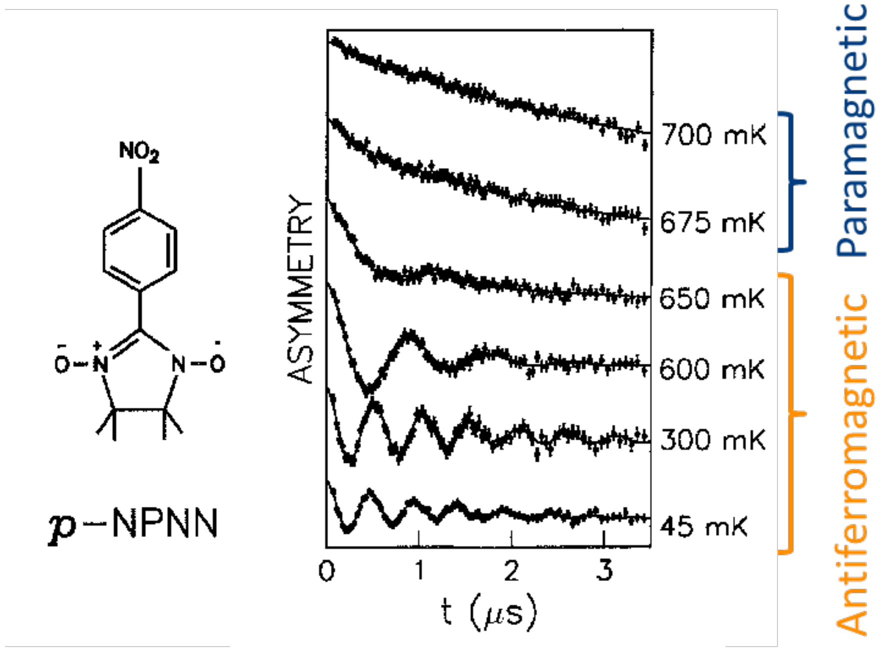
From Iain’s slide

# Magnetism and spin fluctuations

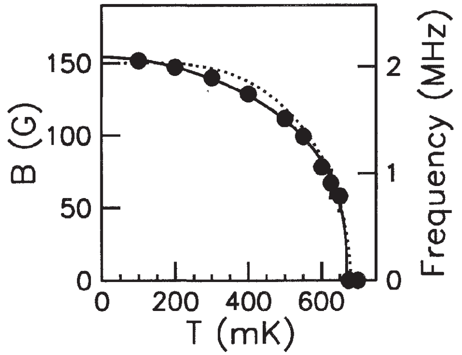



Quantum Spin liquids



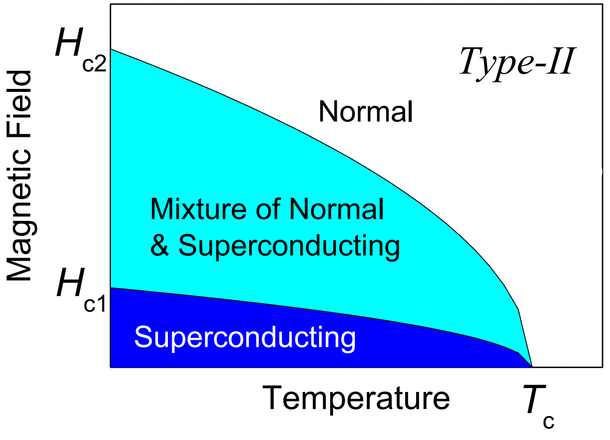

Dynamics of magnetic moments

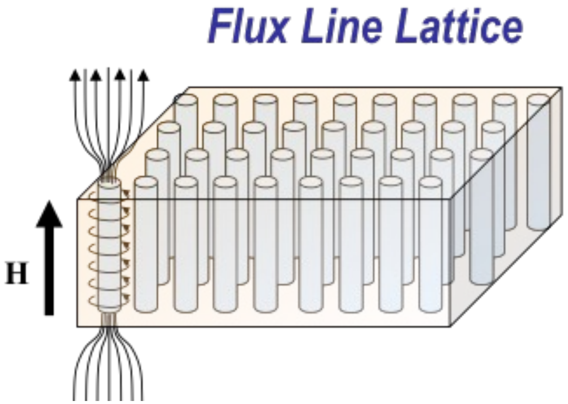
Magnetic ordering

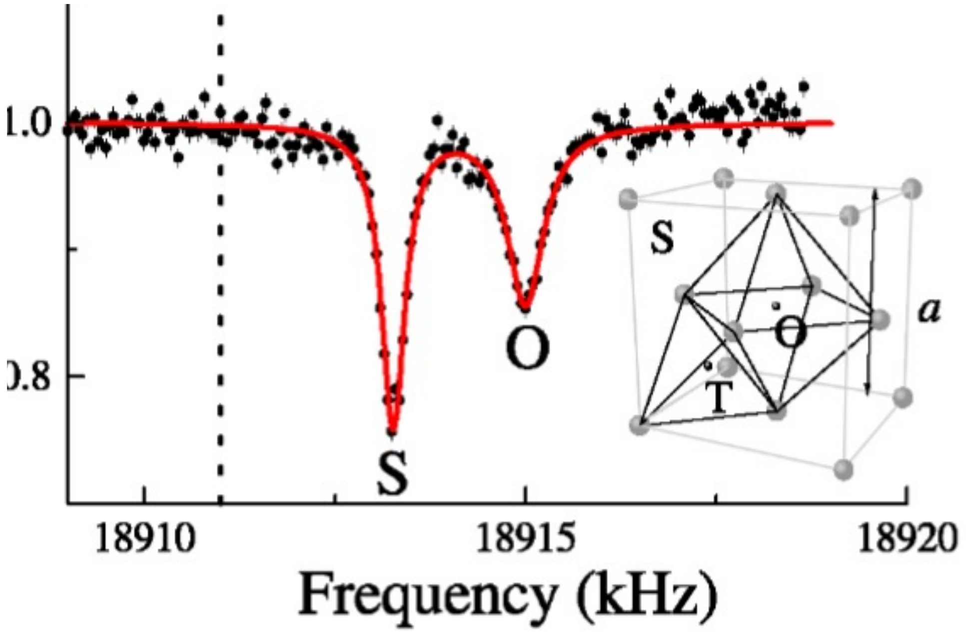
From Iain’s slide

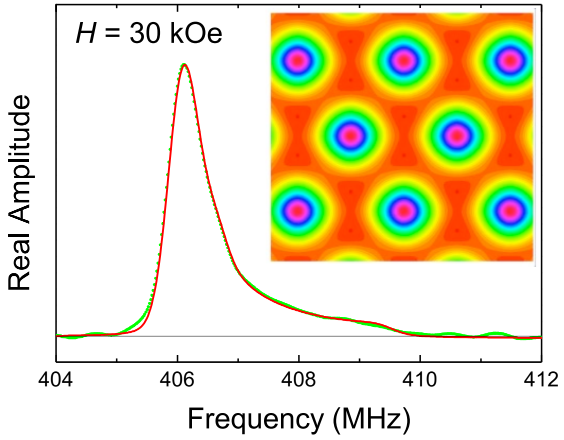
# Superconductivity

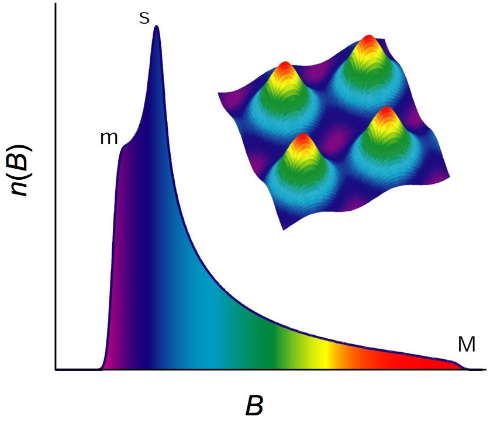
## Phase of electron wavefunctions (super and normal)



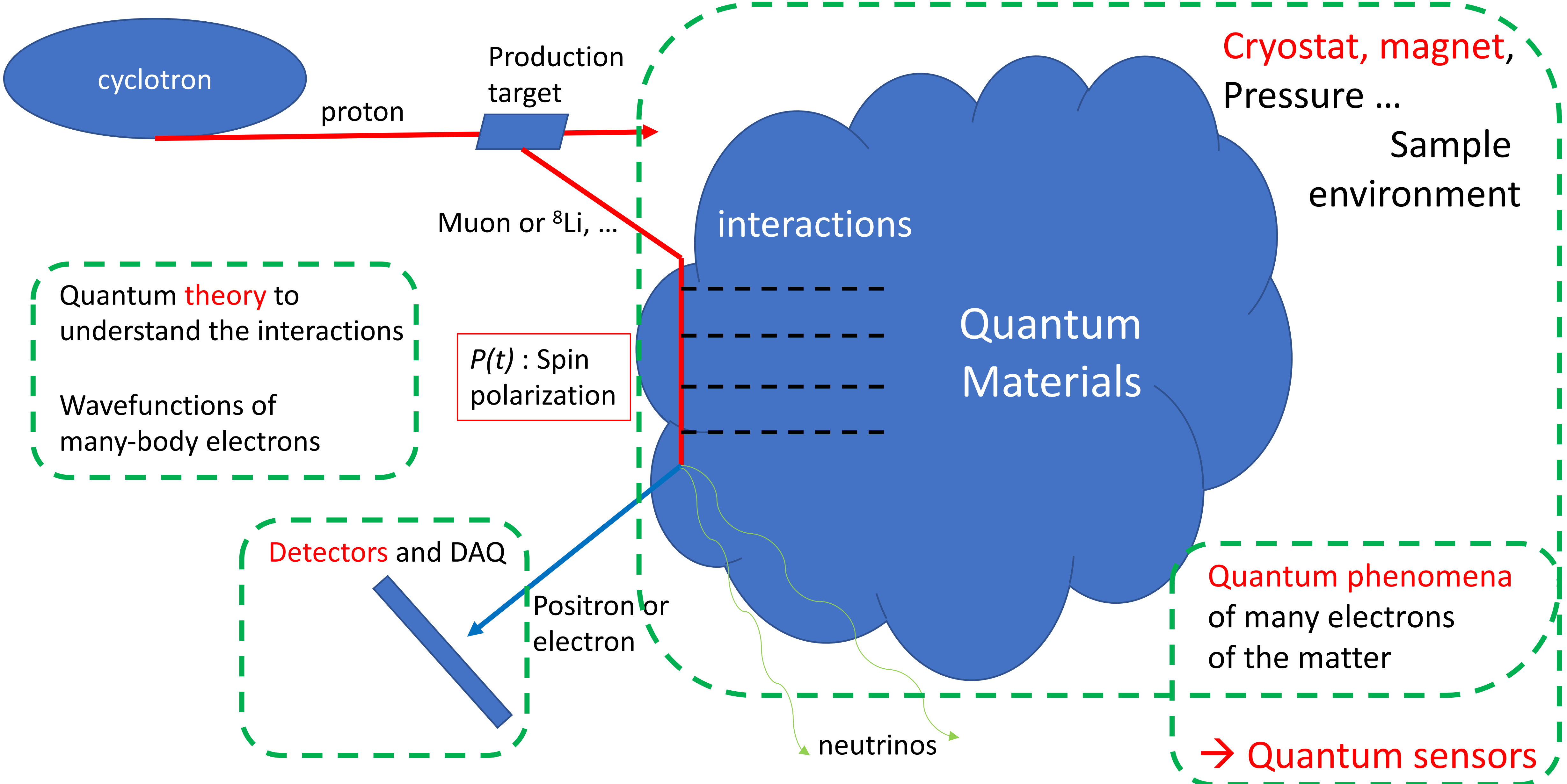




## Local magnetic fields

# Quantum Materials Research and CMMS at TRIUMF



# An example of Quantum Sensor

30th International Symposium on Superconductivity (ISS2017) IOP Publishing
IOP Conf. Series: Journal of Physics: Conf. Series **1054** (2018) 012054 doi:10.1088/1742-6596/1054/1/012054

IEEE Trans. Appl. Supercond. (2021) J. Low Temp Phys. (2024)

1ns TDC (2018-2023)
Belle-II and J-PARC muon
↓
30ps TDC (2024-)
J-PARC Hadron hall

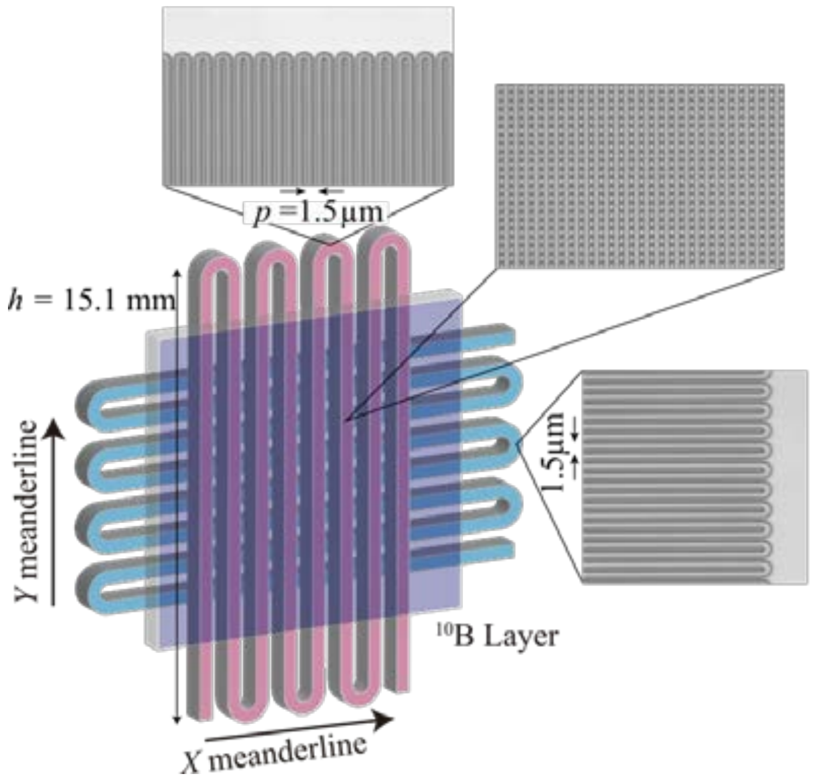



**Figure 1.** Schematic diagram of a CB-KID

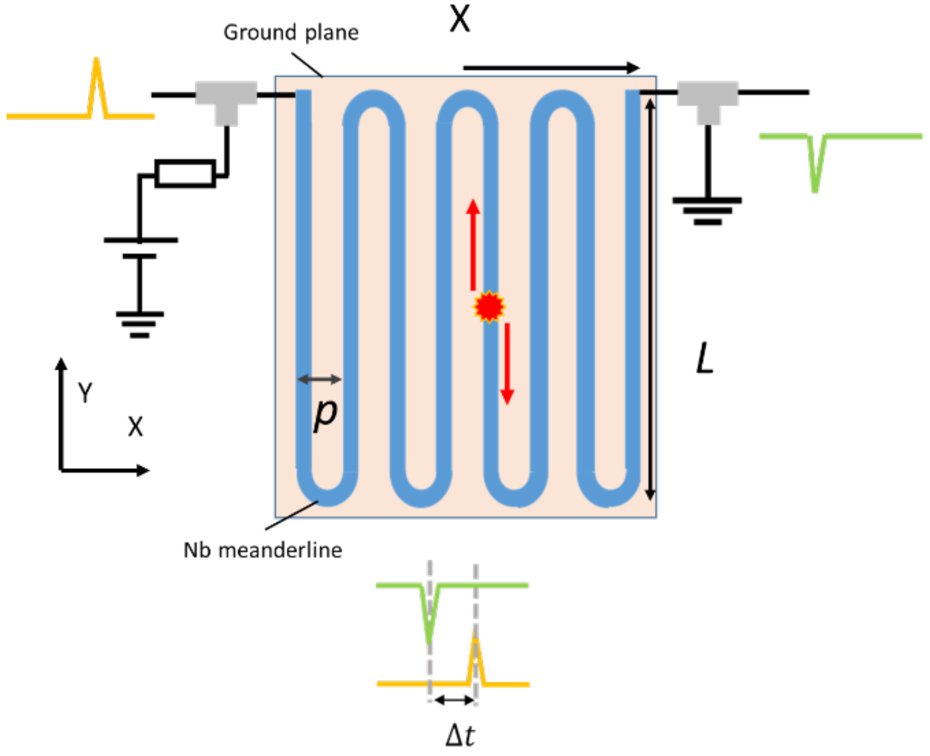
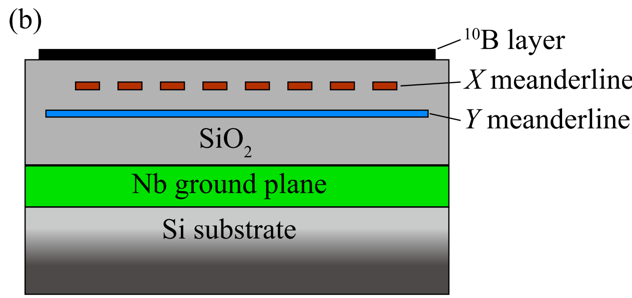
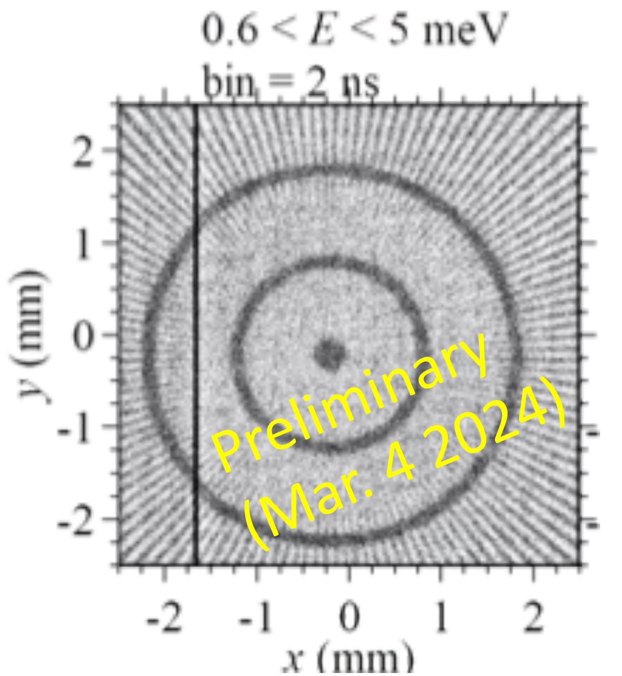



**Figure 2.** Diagram of signal generation and



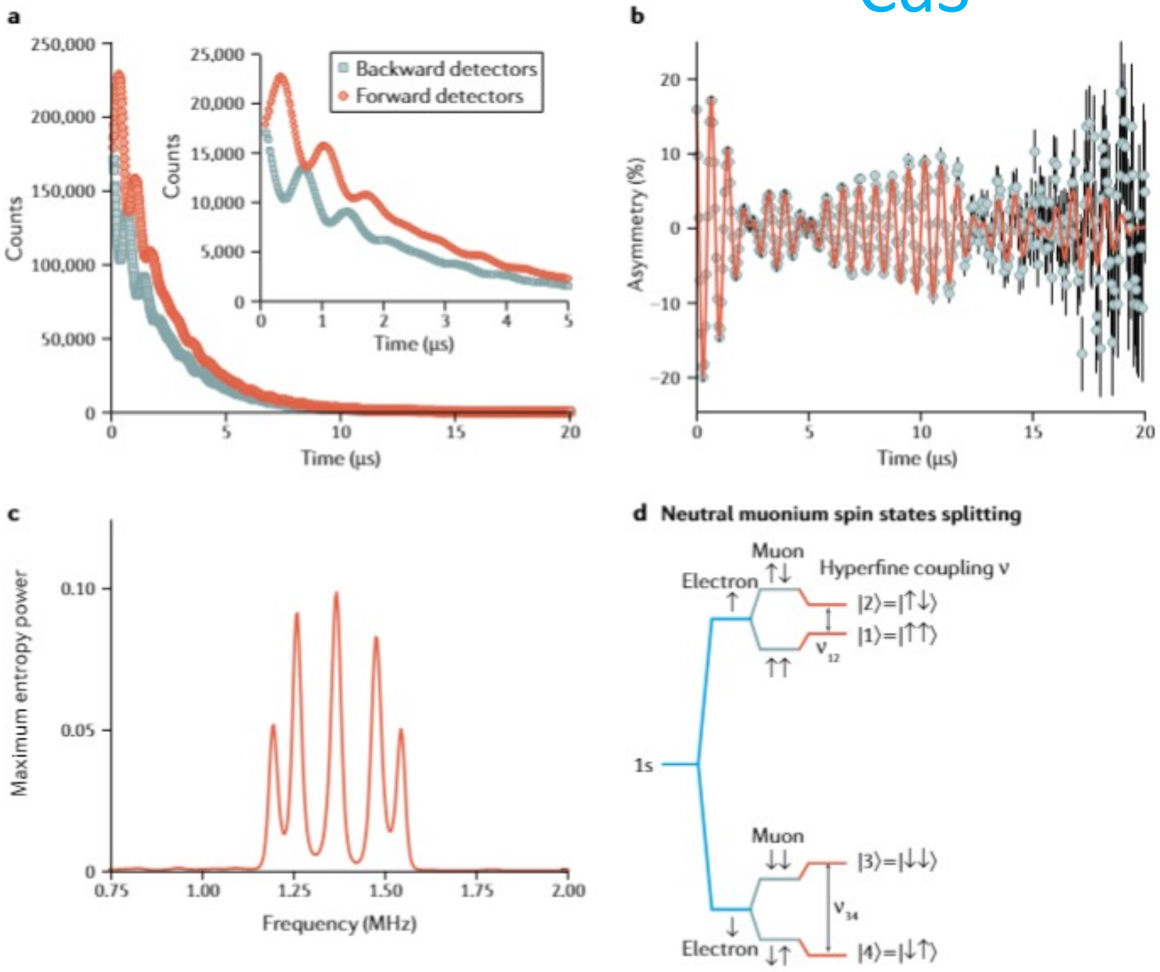

1.5µm pitch Nb-Superconducting meander lines 15x15mm

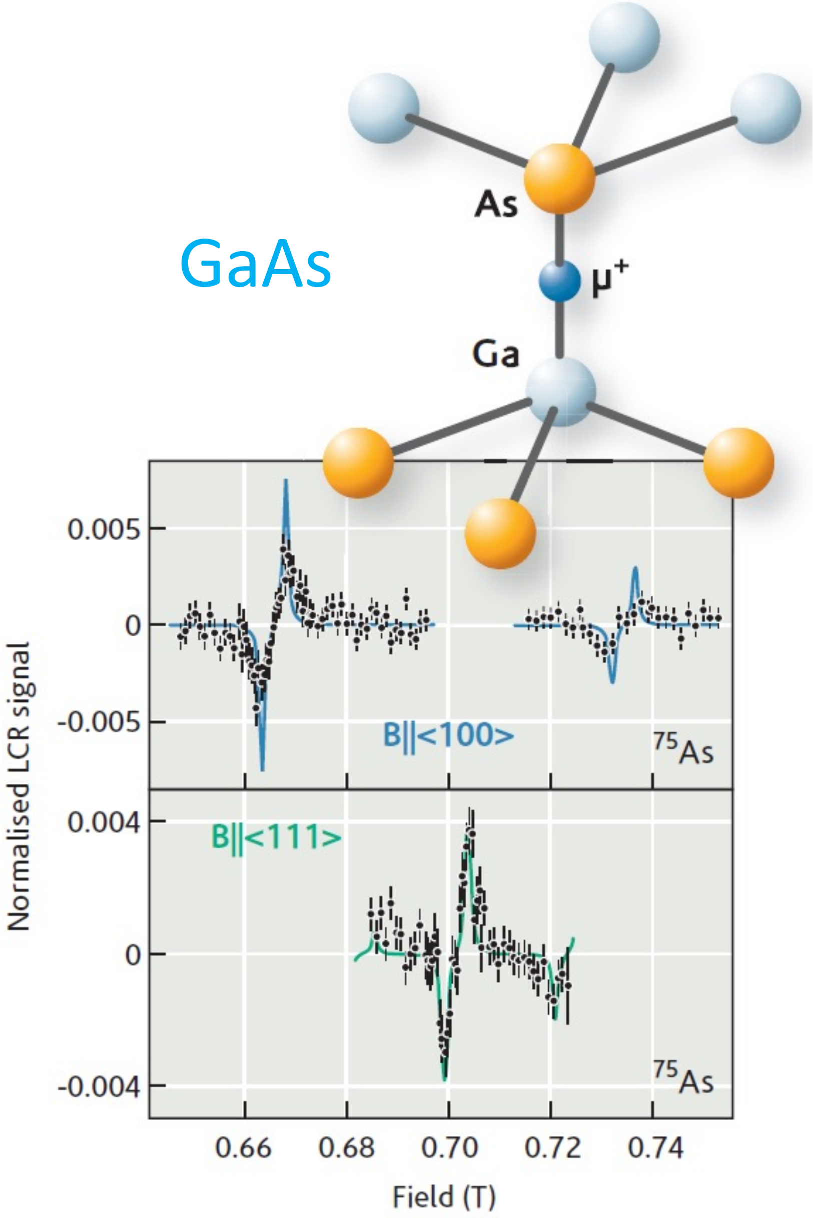
30 ps TDC is developed in KEK and shared all in Japan.

From Iain's slide

# Quantum sensors vs. Semiconductor knowledge from CMMS probes

CdS



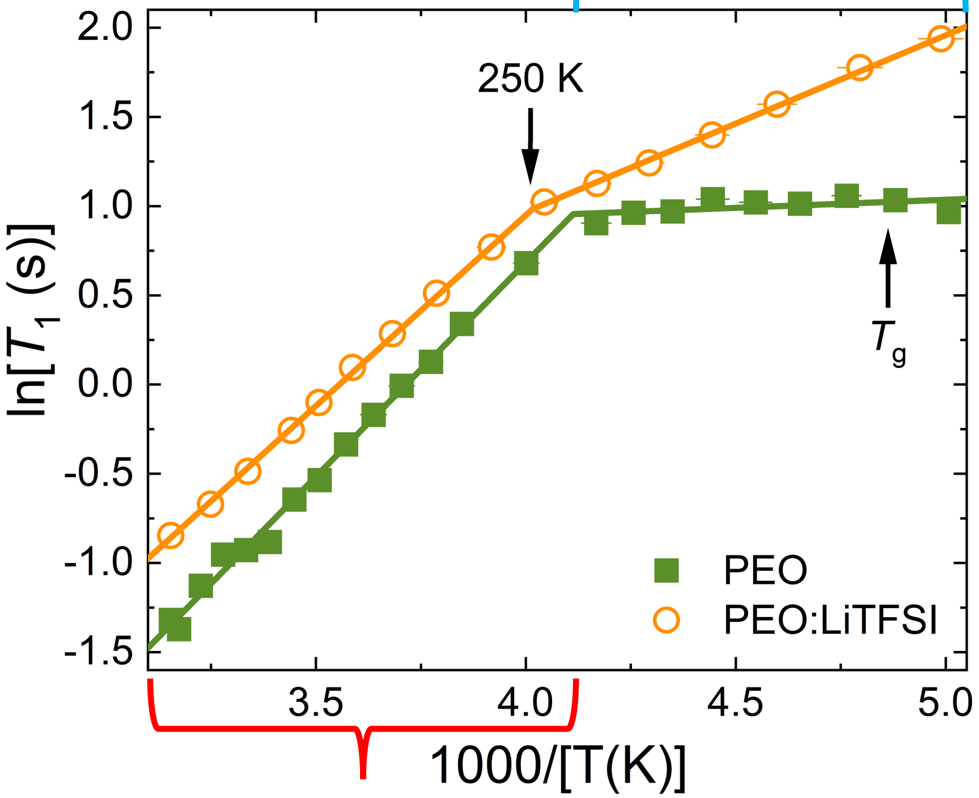



From Iain's slide

# Quantum sensors vs. Diffusion knowledge from CMMS probes

Rattling of $^8Li^+$ within one cage

**Low temperature**

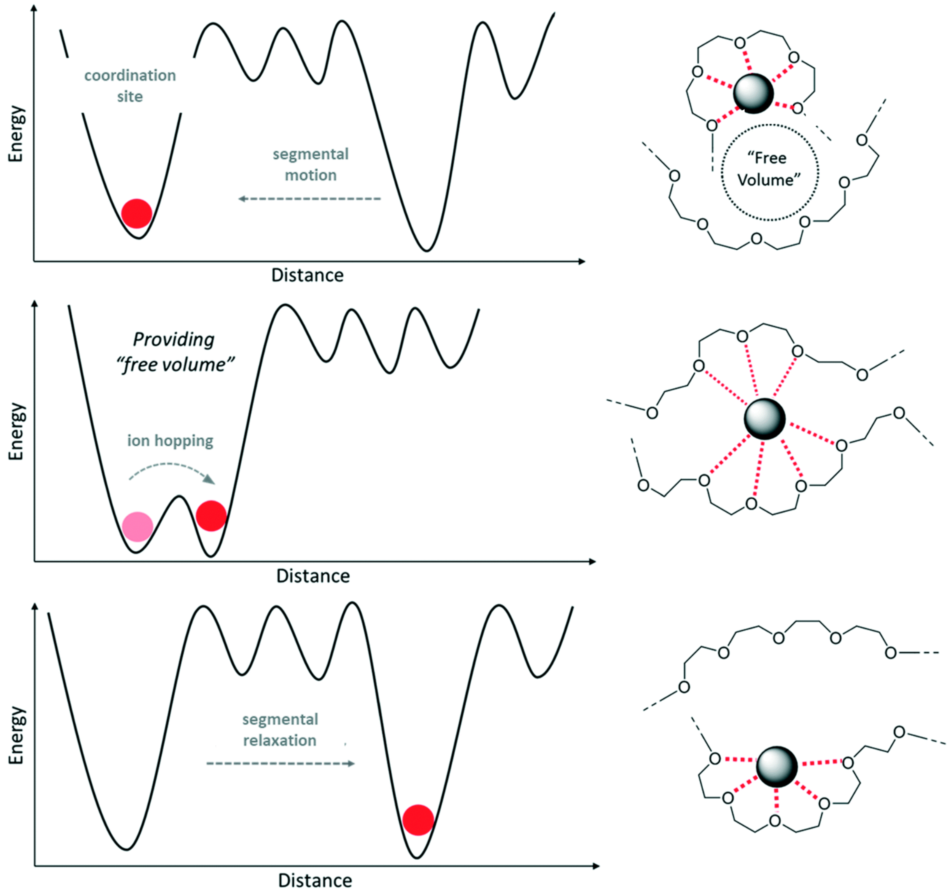



**High temperature**

Hopping of $^8Li^+$ between cages

Slope $\propto E_a$

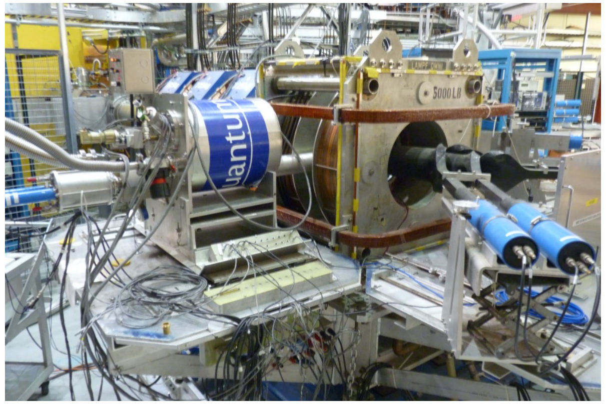
Intercept $\propto \tau_0$



From Iain’s slide

# μSR Spectrometers (=Sample environment + Detectors and DAQ)

## LAMPF



- 4 x Helmholtz
- 0.3 T / *z*, 10 mT / *x, y*
- Miss Piggy: 1.7 – 330 K
- Gas flow: 2.8 – 330 K
- Oven: 290 – 900 K

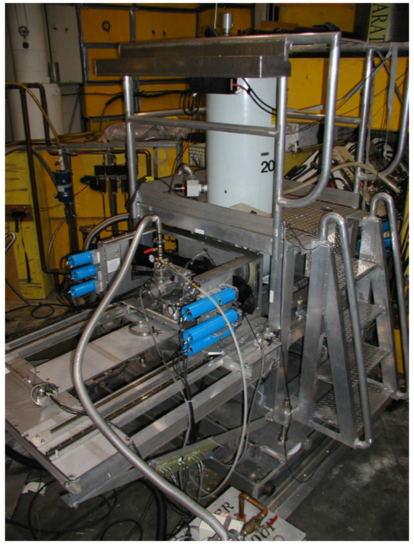
## NuTime

- Superconducting Solenoid
- 7.0 T / *z*
- $^{4}$He cryostat: 2 – 330 K

## DR

- Superconducting Helmholtz
- 5 T / *z*, 2.5 mT / *x*
- 15 mK to 10 K

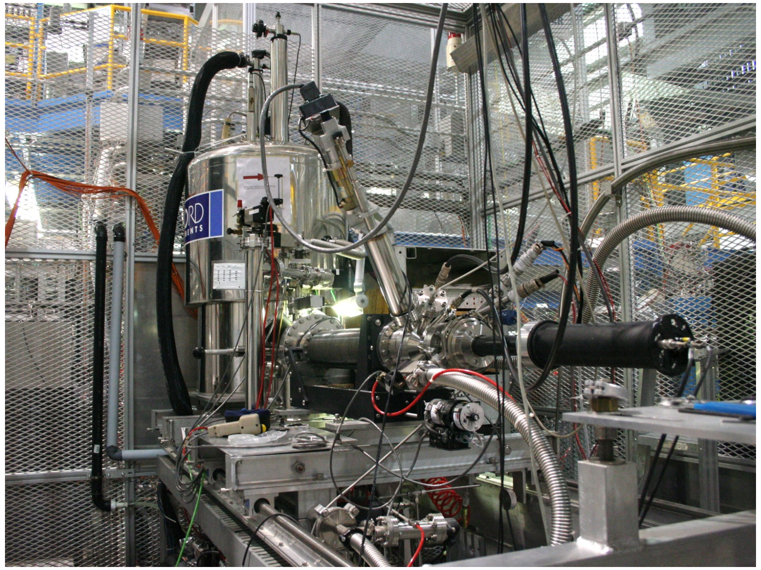
## Helios

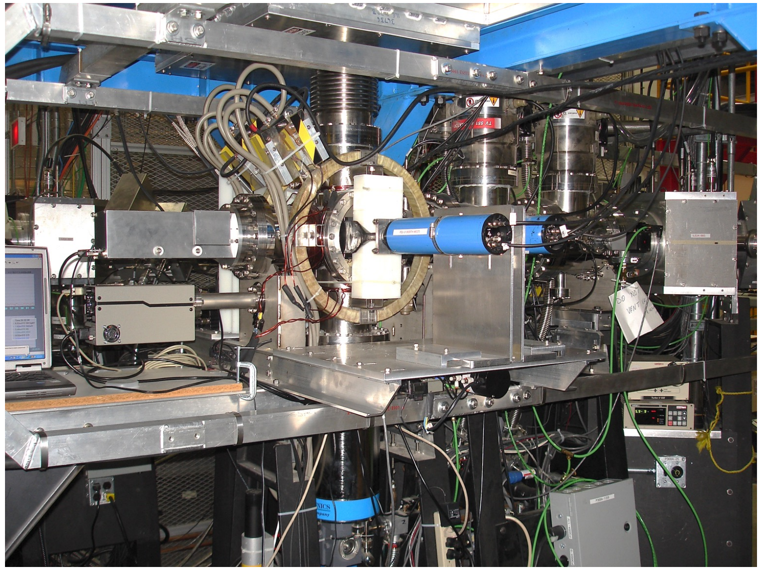


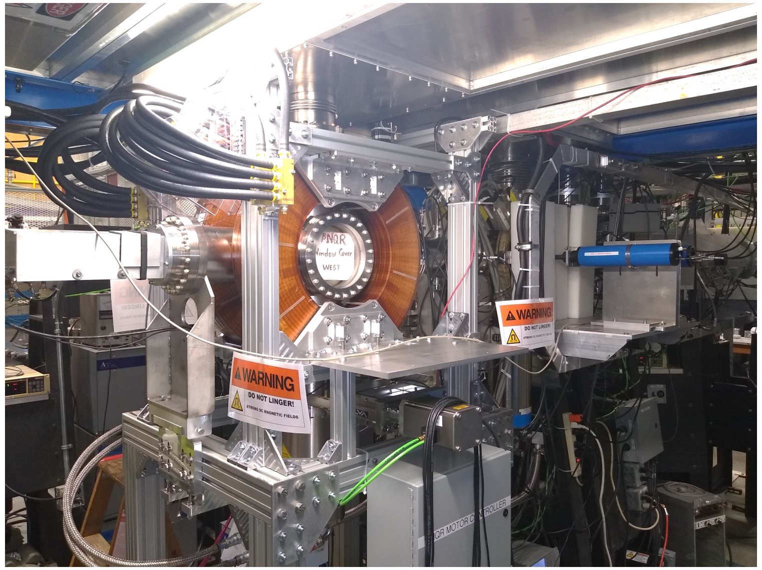
- Superconducting Solenoid
- 6 T / *z*, 2 mT / *y*
- Circulator: 250 – 475 K
- Gas flow: 2.8 – 330 K
- Oven: 290 – 900 K

From Iain's slide

# β-NMR Spectrometers (=Sample environment + Detectors and DAQ)








## βNMR

- Maximum magnetic field: 9 T
- Maximum magnetic field with RF: 6.55 T
- Temperature: 4 – 320 K

## Low-field βNQR

- Magnetic field: 0 – 24 mT
- Normal cryostat: 4 – 320 K
- Cryo-oven: 4 – 400 K

## Mid-field βNQR

- NSERC RTI funded + TRIUMF contribution
- Commissioned 2022
- Magnetic field: 0 – 0.2T
- Cryo-oven: 4 – 400 K

# Quantum Materials research in Quantum Strategy at TRIUMF

CMMS has strong a background on

- How quantum sensors (molecular or semiconductor-based) will behave.
- Detectors, Cryogenics, Magnets and Beamlines.
- Theory of many-body (electron) wavefunctions.

TRIUMF is a small and maneuverable society

- Close collaborations with interdisciplinary fields will be easy and beneficial.

*Quantum* is a good keyword to tie us together !