Beta-SRF at TRIUMF

A Unique Facility to Characterize SRF Materials Near Fundamental Limits

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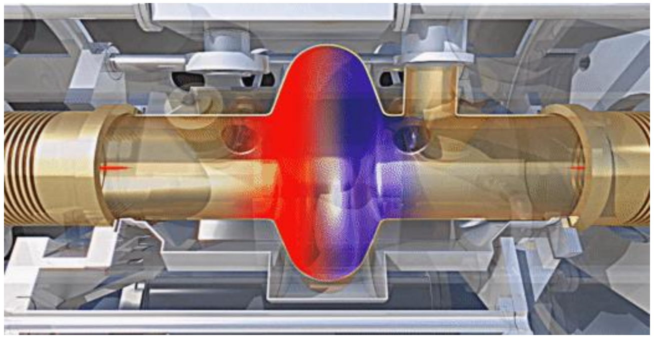
Outline

- Motivations
- β-NMR Technique
- A New High-(parallel)-field Spectrometer
- First β-NMR Results in SRF samples at 50 mT
- Summary

RF Linear Accelerator

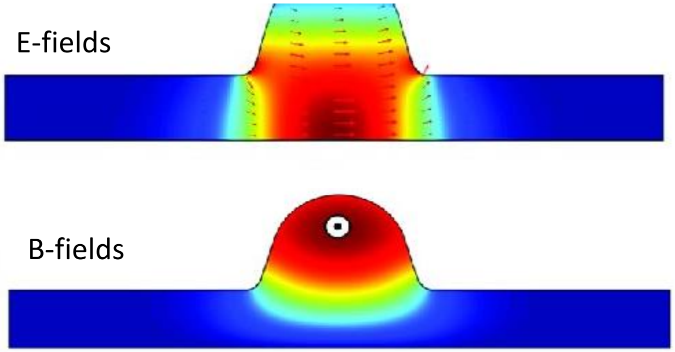


RF Particle Acceleration

- Use RF (EM)-field to accelerate particles to higher energies

RF Cavities

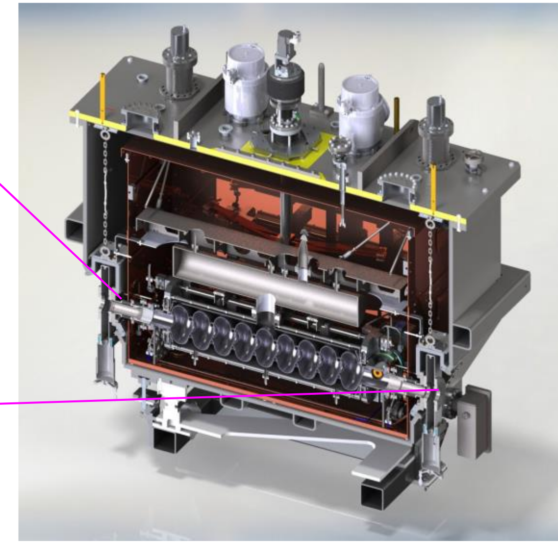
- **RF Standing waves**
  - ✓ Increase E-field (**acceleration**)
  - X Increase B-field (**dissipation cavity wall**)

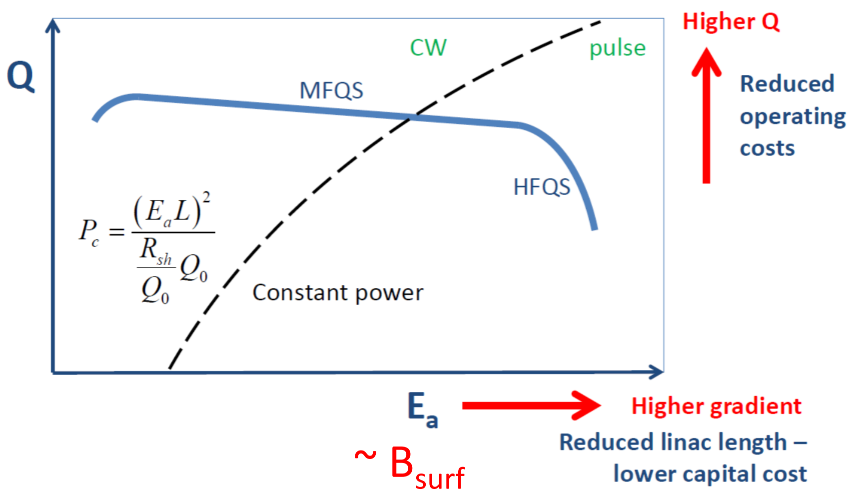


Superconducting RF Cavity

Minimize dissipation

- ~ 10^5 lower dissipation
- Superconducting Nb (Tc~9 K)
- Cryomodule
  - Cryogenic cooling $T < T_c$
  - Magnetic Shielding

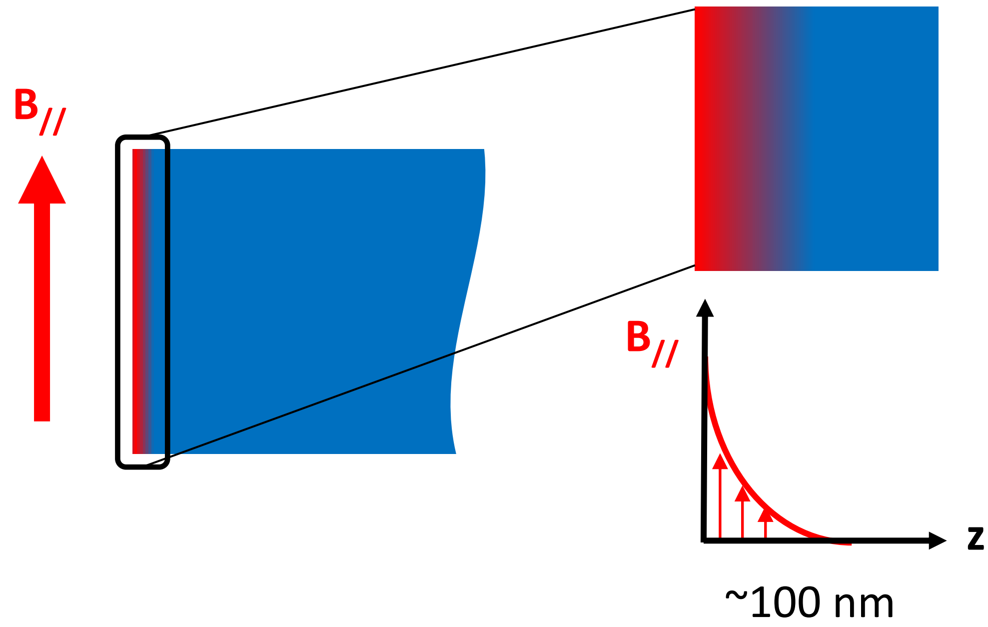




Characteristics of SRF cavities

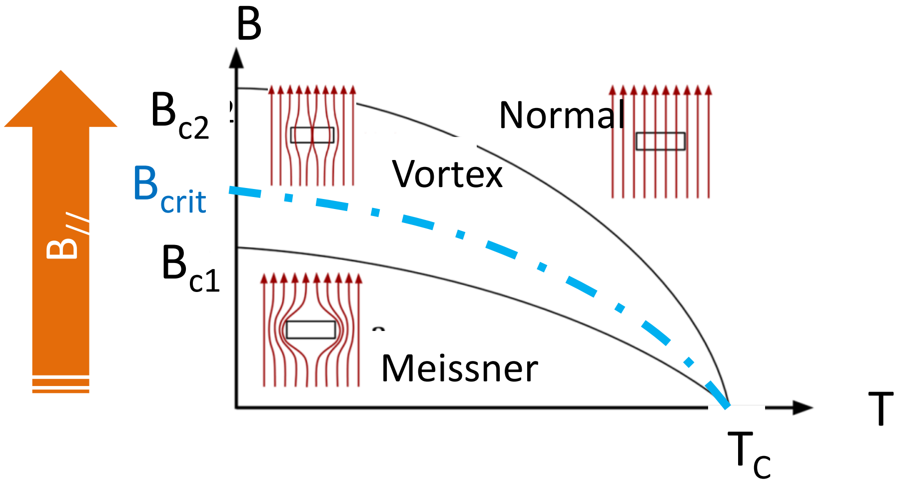
- Higher Q → lower dissipation
  Higher Ea → higher energy + shorter accel.
- Q rapidly degrades at higher gradient, i.e. higher magnetic fields.

Role of Near Surface



Magnetic field affects SC

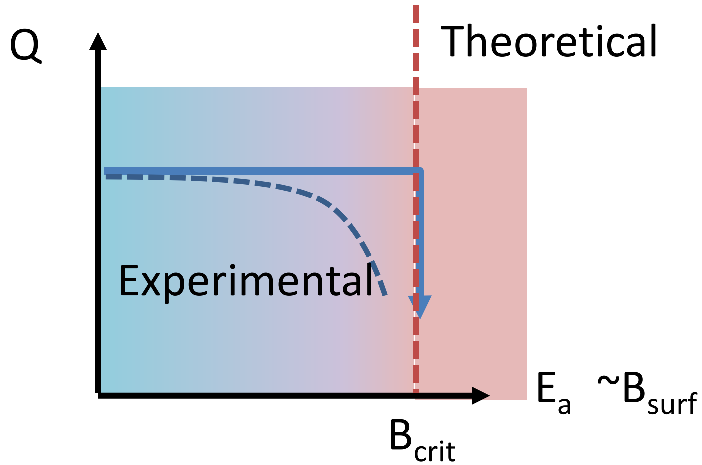
- Magnetic fields screened at H < H_{c1} within (λ_L: London penetration depth)



Phase Diagram

- Meissner (loss-less) → Vortex (strong dissipation) = SC Quench
- Quench field in the order of "critical field" ~ 200 mT

Reaching Fundamental Limit

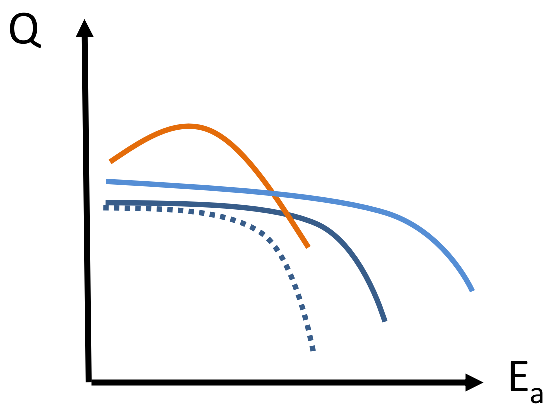


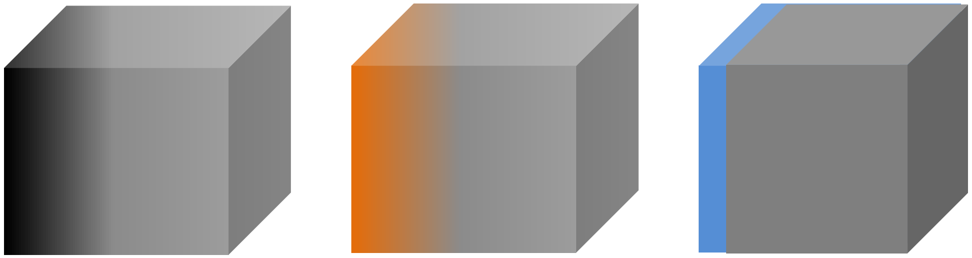
Theoretical Limit of SRF Performance

- Ideal → Q constant until SC quench
- Reality → Q degrades, quench at $B < B_{quench}$

Higher Q and higher E_a

- Macroscopic performance → nanometer RF surface
- Reduce dissipation & increase B_{quench} limit





Available Tools

Ideal Probe for SRF

- ✓ Depth profile of the near surface ~ 100 nm
- ✓ Measure local (penetrating) magnetic field
- ✓ Parallel B-field up to 200 mT

Existing facilities for SRF studies

- TRIUMF: HE-muSR → No depth control, parallel-fields up to 300 mT
- PSI: LE-muSR → Depth control, limited to (parallel-fields) ~ 30 mT
- TRIUMF: β-NMR → Depth control, limited to (parallel-fields) ~ 24 mT

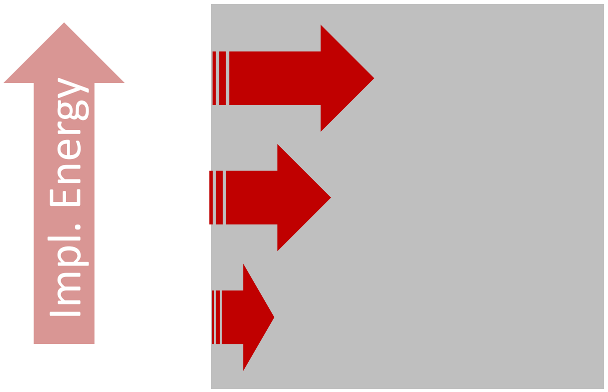
New capability at TRIUMF:
"Beta-SRF"
Depth profile of local fields
up to 200 mT

β-NMR Technique

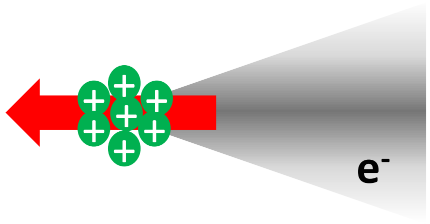
Unique Probe

- **Radioactive spin-polarized ions**
  - Nanometer-scale **depth-control (deceleration)**
  - **Direct monitor** of spin
  - **Local (magnetic) field** sensitive

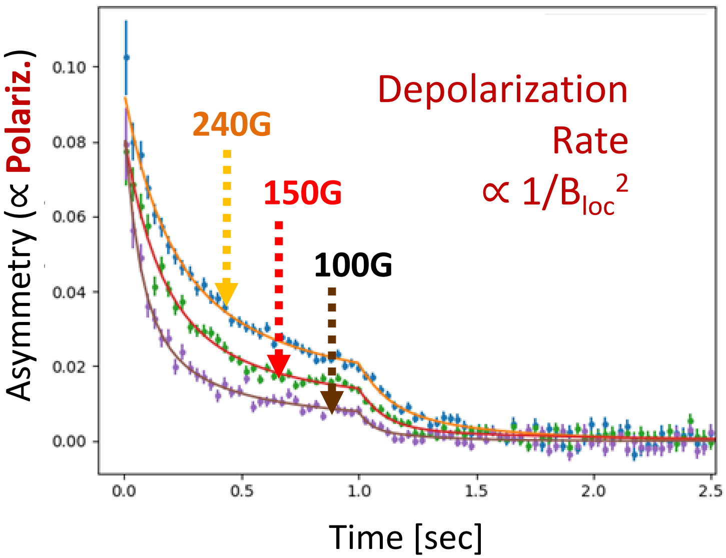
"Depth-profiling"



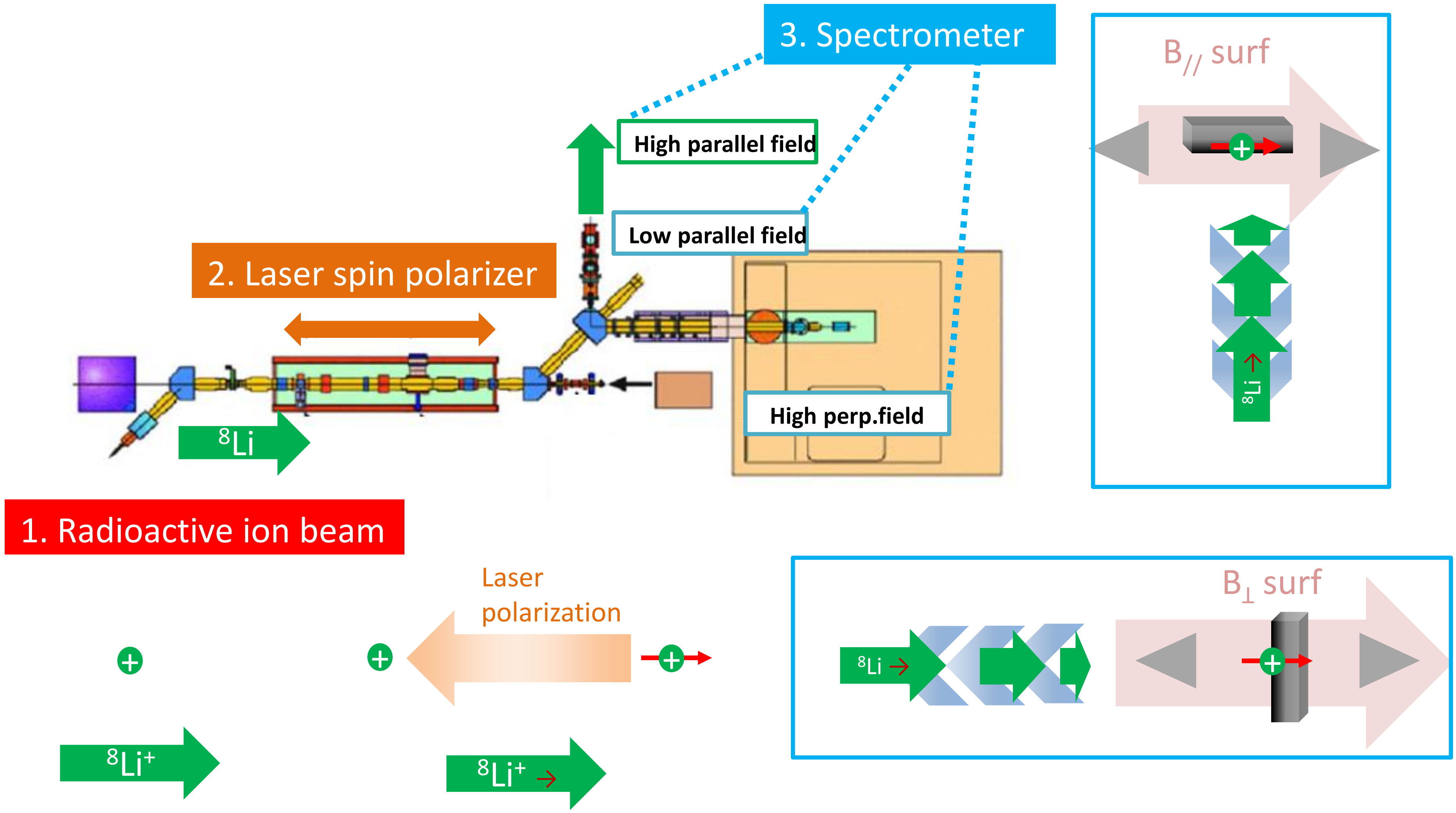
"Direct-monitor of spin"



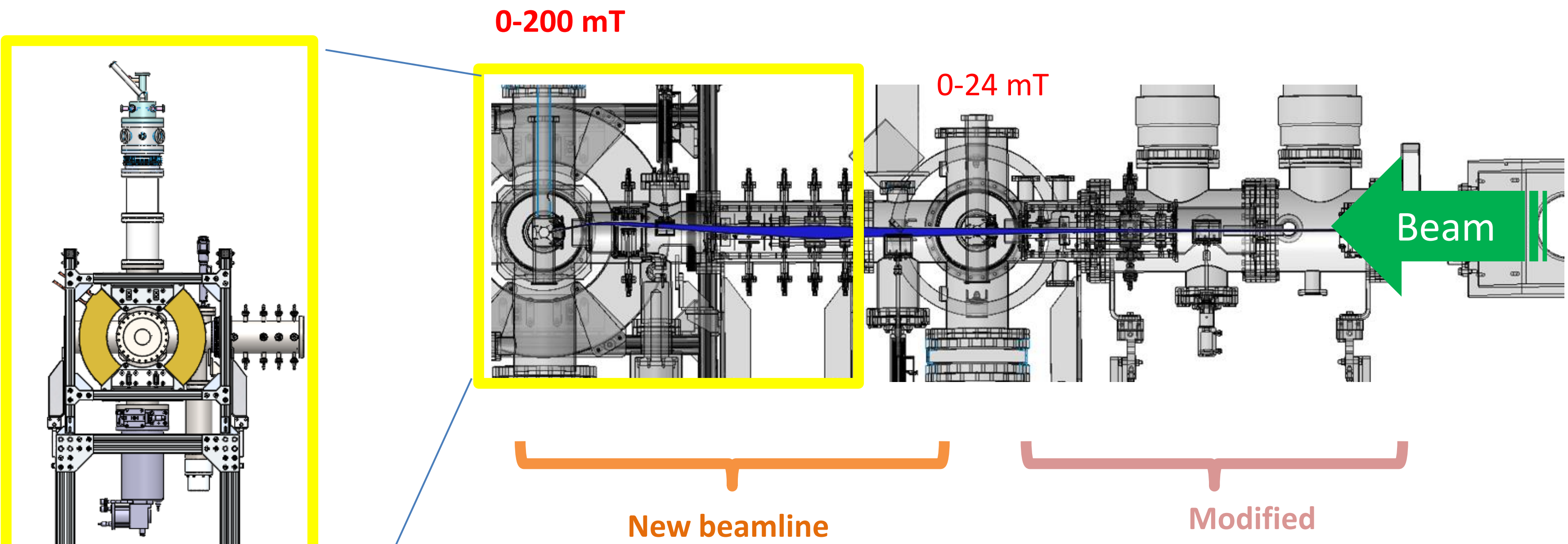
"Local-field sensitive"

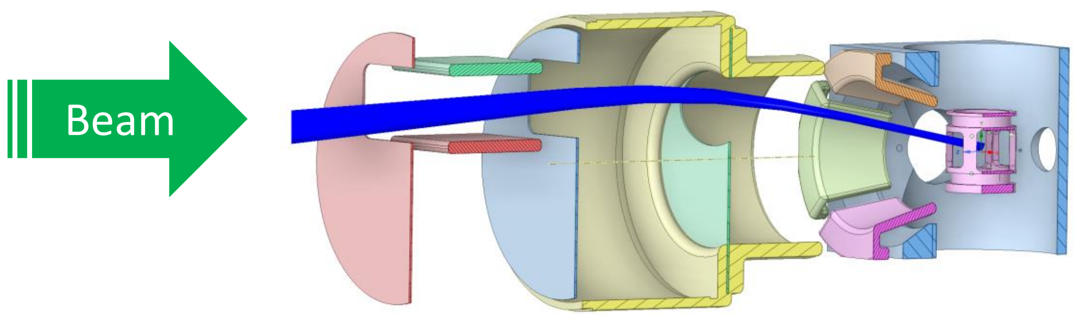


TRIUMF Beta-NMR Facility



High-Parallel-Fields Spectrometer





<u>Essential Components</u>

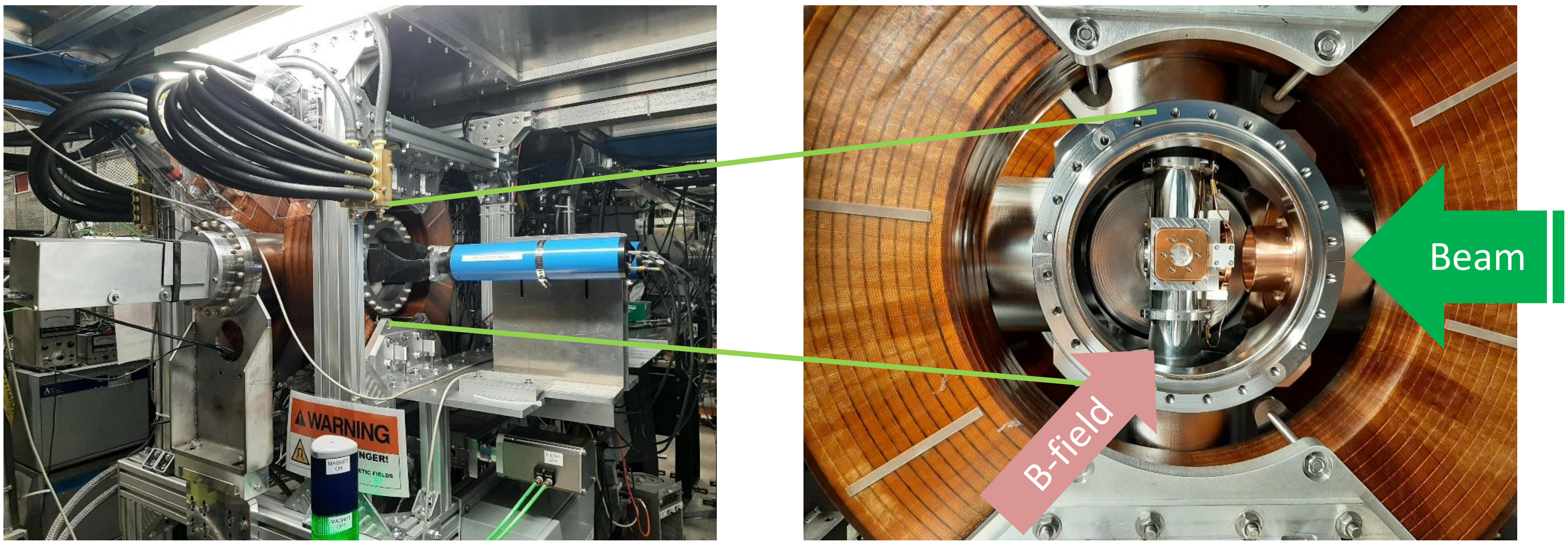
- ✓ Ion optics & diagnostics
- ✓ Coils up to 200 mT
- ✓ Decelerator electrode
- ✓ High-fields PMT
- ✓ UHV + cryostat

Transverse Deflection:

Easier to compensate with heavier ions than muons

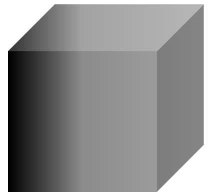
Installed Infrastructure

- Beamline Commissioned → August 2021
- First experiments at 50 mT→ October 2021

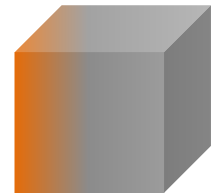


Depth Profile at 50 mT

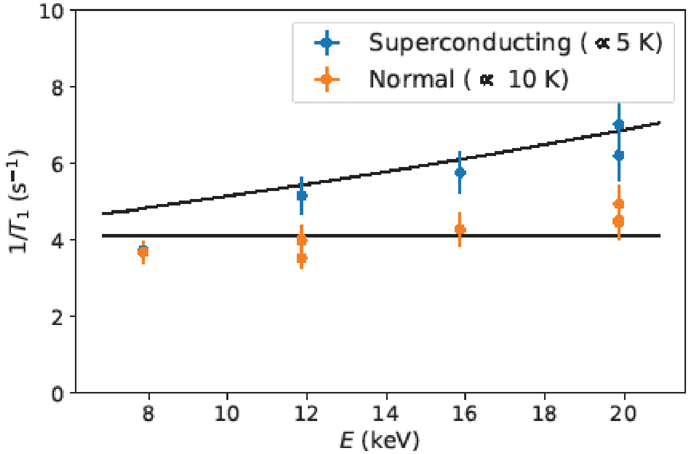
Nb
(heat-treated)



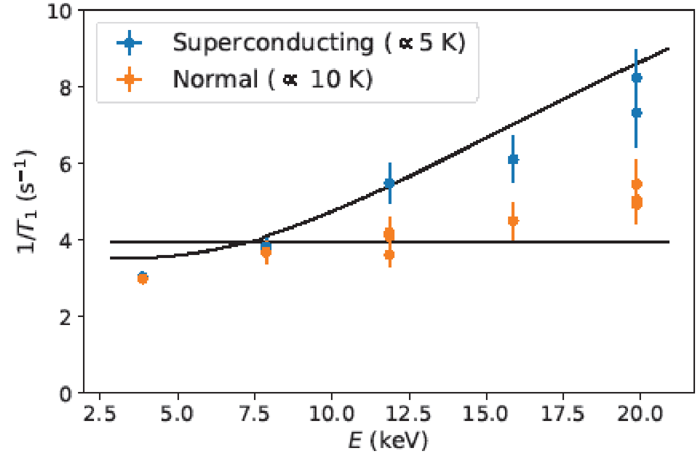
Nb
(heat-treated + N2)



∝ $1/B_{loc}^2$



∝ depth

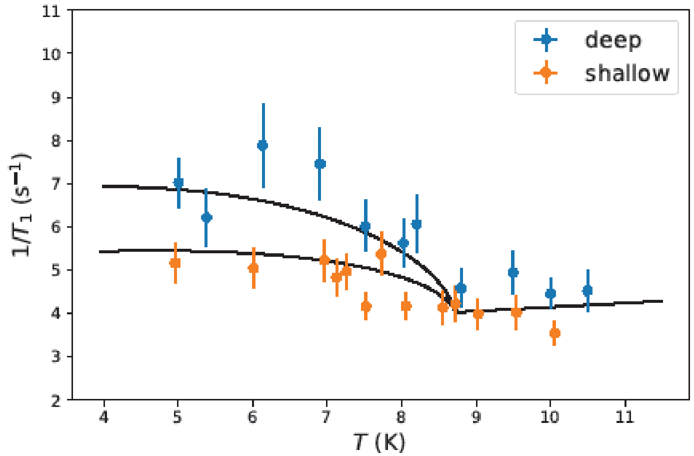


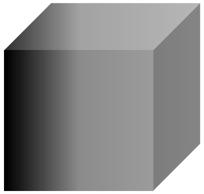
∝ depth

Probe is sensitive to Meissner screening

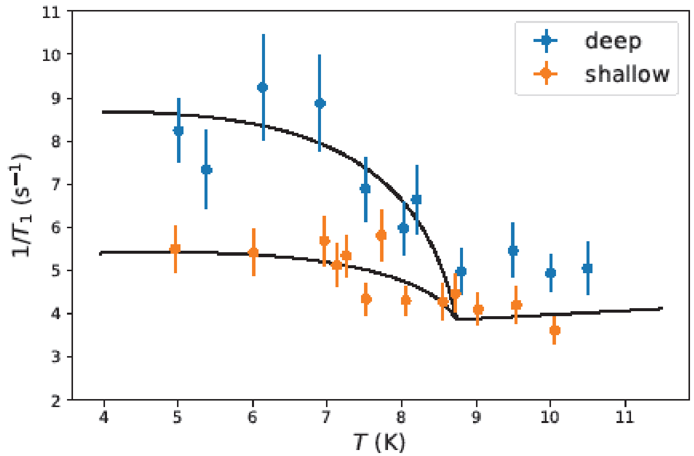
Sample Surface Variations

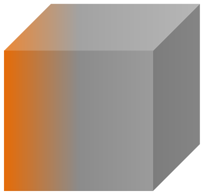
$\propto 1/B_{loc}^{2}$





Nb
(heat-treated)





Nb
(heat-treated + N2)

Clear difference in Meissner screening between samples

Summary

- New beamline @ 200 mT parallel-field
- First β-NMR measurements on SRF samples @ 50 mT

Future Outlook

- Upcoming beamtime at higher fields
- Additional capability: He-3 cryostats ~300 mK

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Acknowledgement

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Natural Sciences and Engineering Research Council of Canada

Conseil de recherches en sciences naturelles et en génie du Canada

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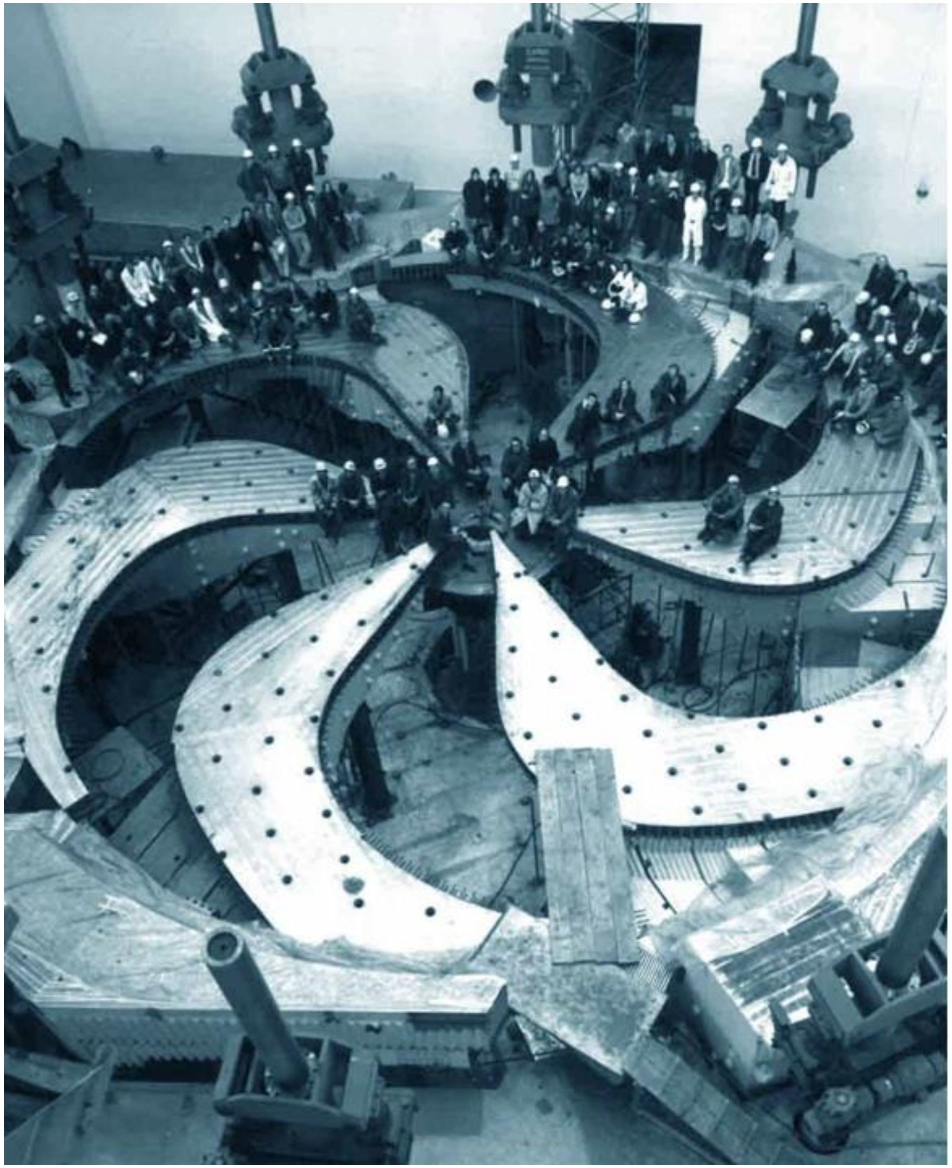
Thank you

Merci



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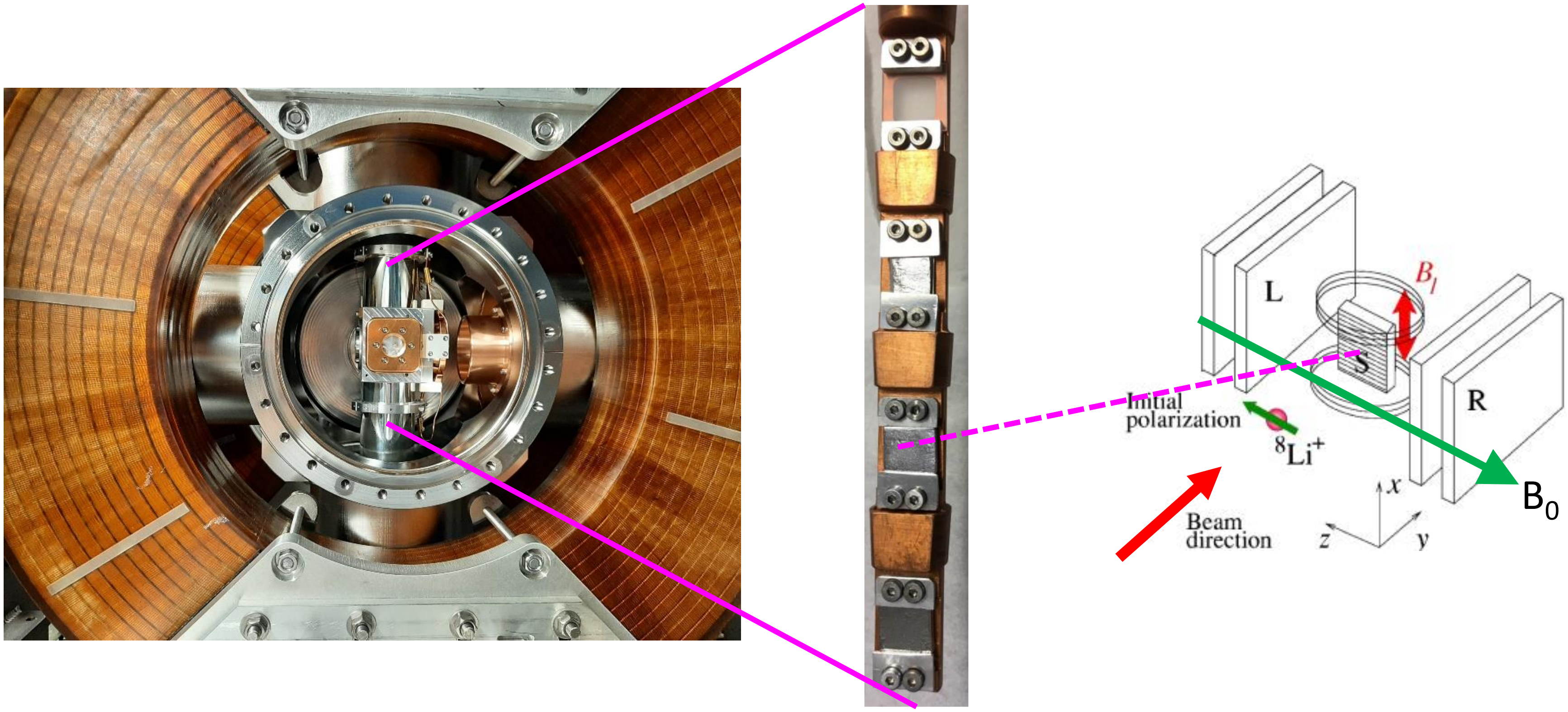
L
R
S
B_l
Initial polarization
$^8Li^+$
Beam direction
x
y
z
B_0