First Results from beta-NMR for SRF Samples

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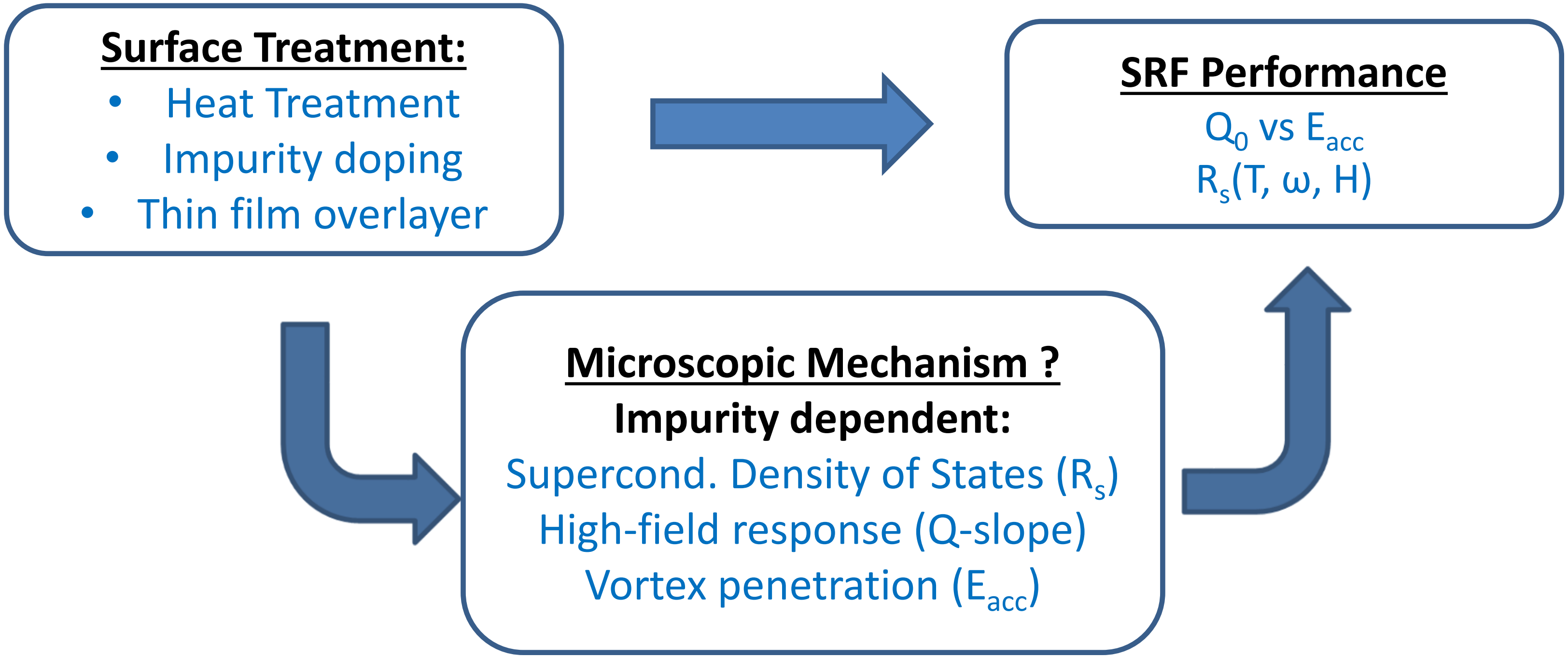
Outline

- Motivations
- beta-NMR facility
  - High-field upgrade
  - Method Developments
- Results
  - Field Profile
  - Temperature Dependence
- Summary & Outlook

Motivations



Surface Treatment:

- Heat Treatment
- Impurity doping
- Thin film overlayer

SRF Performance

Q_0 vs E_{acc}

$R_s(T, \omega, H)$

Microscopic Mechanism ?

Impurity dependent:

Supercond. Density of States (R_s)

High-field response (Q-slope)

Vortex penetration (E_{acc})

New Tool to study:

- Local field -> small beam-spot
- Depth profile -> nm resolution
- High-parallel-field
- ➢ simulate fields in SRF cavities,
- ➢ study intrinsic non-linear high-field response

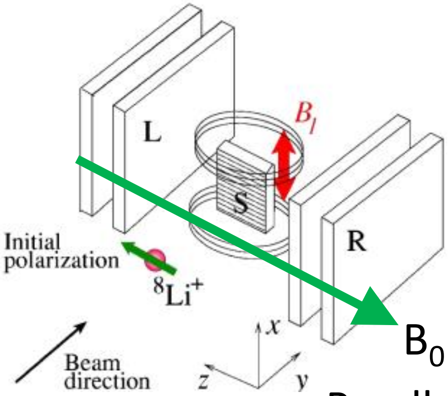
bNMR Facility

Implants **<u>radioactive spin-polarized ions ($^8Li^+$)</u>** into samples:

- Depth-resolved [~5-300 nm] by HV deceleration
- Interacts with the surrounding local magnetic field
- Monitor spin polarization time-evolution via asymmetric beta-decay

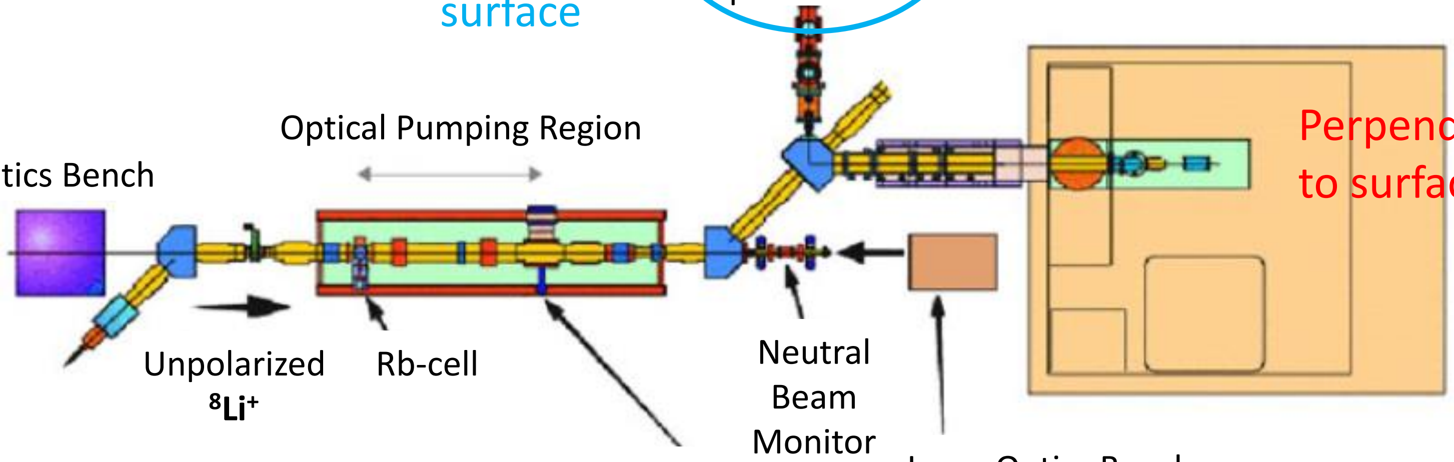
Complementary technique to LE-μSR (muon spin resonance).

Ten orders of magnitude more sensitive than conventional NMR.



B_0

Parallel to surface



Parallel to sample surface

Zero/Low Field β-NQR/NMR Spectrometer

Optical Pumping Region

Optics Bench

Perpendicular to surface

Unpolarized $^8Li^+$

Rb-cell

He re-ionizer cell

Neutral Beam Monitor

Laser Optics Bench

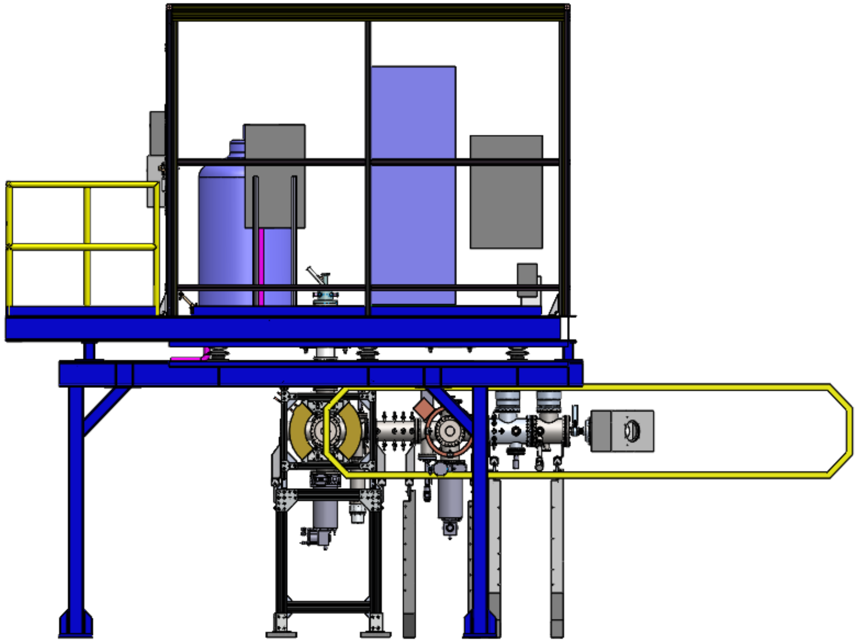
High-field upgrade

Objective: [1]

- Upgrade the low-field spectrometer to high-parallel-field (~200 mT)
- No such facility available for high-parallel-field studies (LE-muSR, low-field limited)
- Higher magnetic rigidity than muons -> easier beam steering & focusing

Upgrade Status:

- Ready for current beamline disassembly
- All major vacuum components assembled & tested off-line
- Commissioning before the next bNMR beamtime in Spring 2021



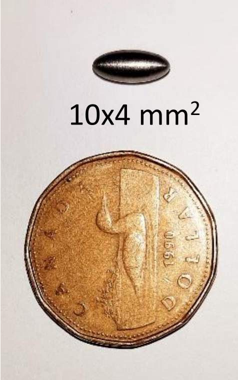
Method Developments

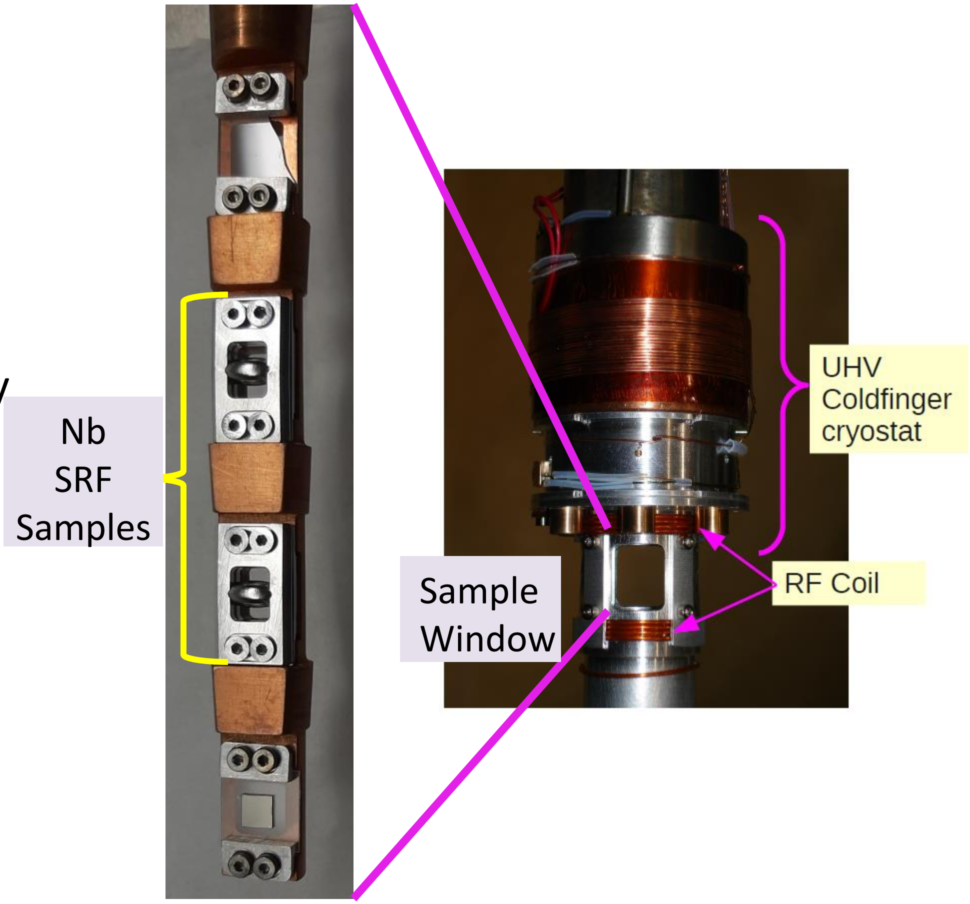
Previous studies of SRF samples with muons: [2]

- Field of first vortex penetration and pinning strength for different treatments
- Bulk probe (not depth-resolved) – Implantation depth about 150µm

Current studies:

- Depth-resolved (HV deceleration)
  up to 24 mT (4-300 K)
  - Can probe vortex penetration on the nanometer scale
- Longer time scale enables complementary information (depth resolved DOS)





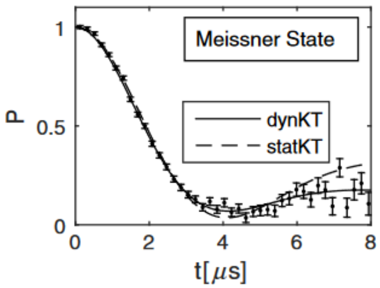
bNMR Signal

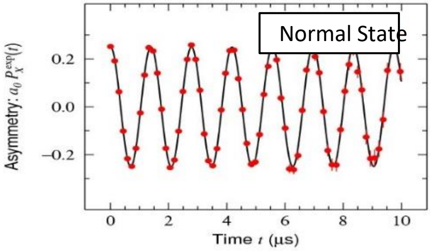
<u>Difference with µSR:</u>

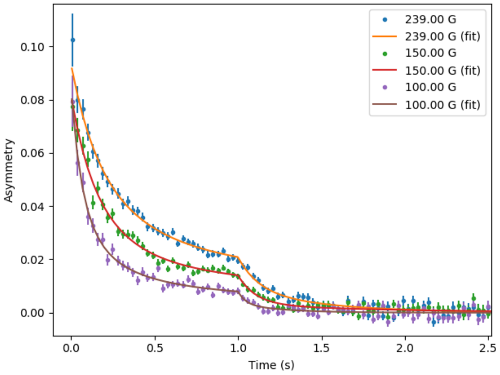
- Probe radioactive nuclei: commonly use Li-8
  - ➢ Sensitive to longer time scale due to longer lifetime (compared to muons)
    - ▪ Indirect probe of the local field (field dependence)
    - ▪ probe relaxation phenomena due to electrons / quasiparticles (temperature dependence)

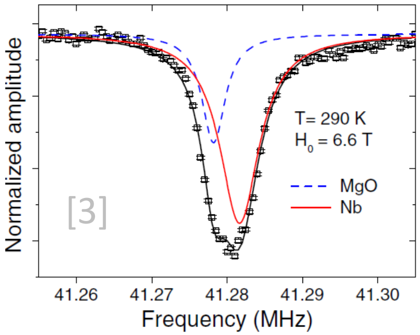
µSR:
internal field -> precession

B-NMR
internal field: relaxation & resonance (high-field)

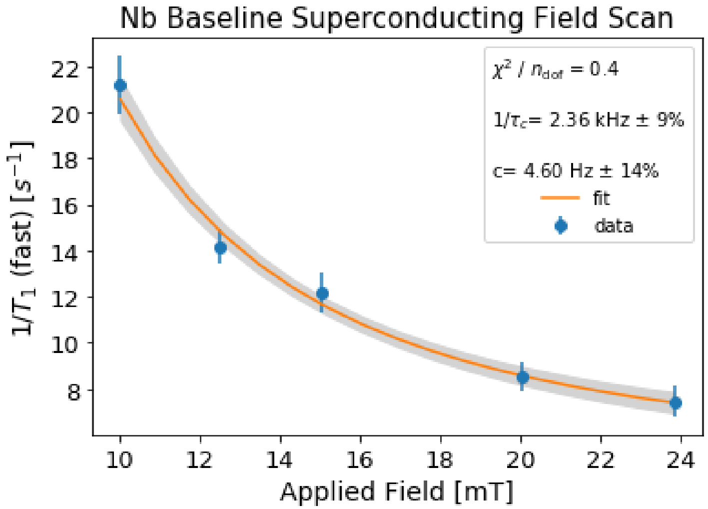


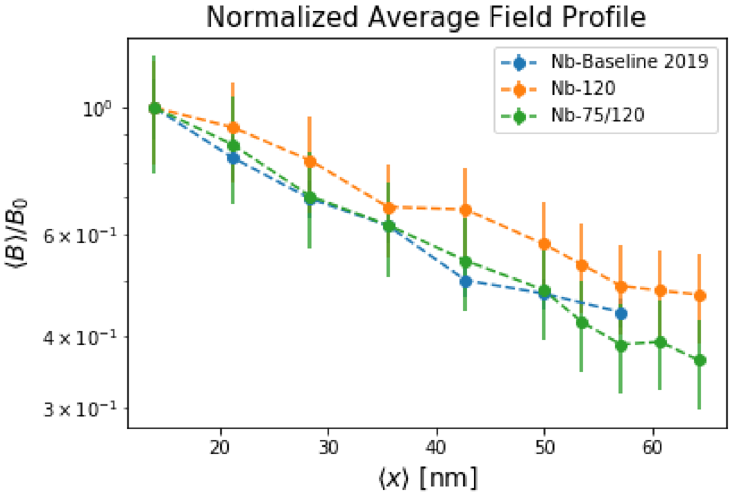






Field Profile





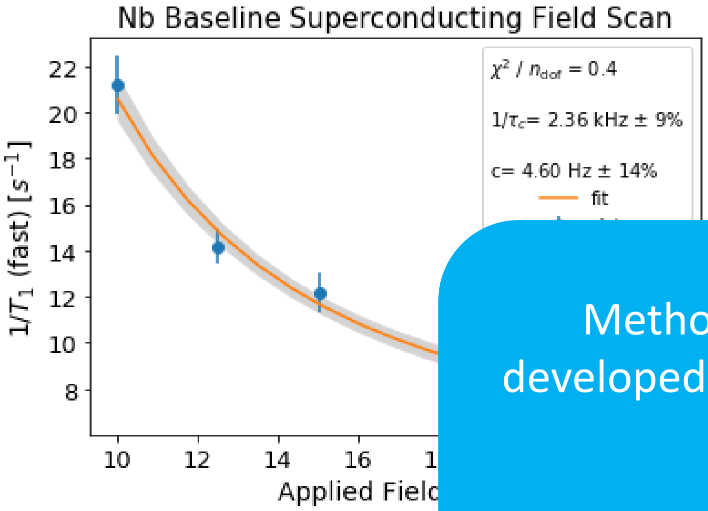
Objective of low-field measurements:

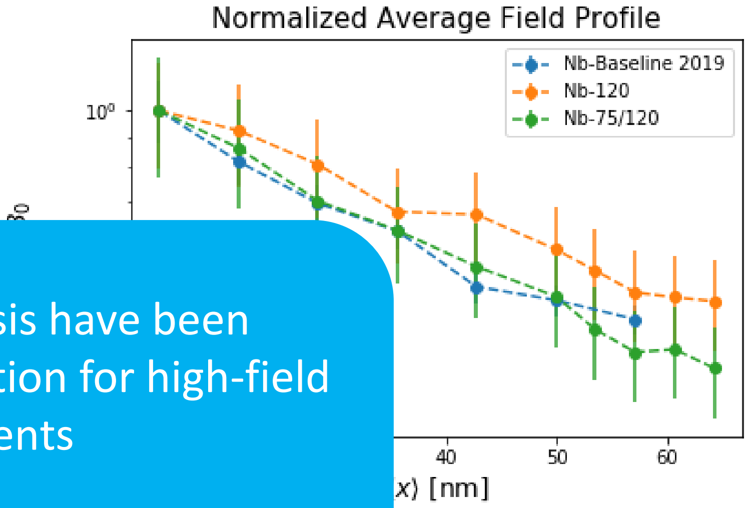
- Gain experience with bNMR facility operation & measurements technique -> three successful beam-time
- Methods & analysis for Nb has been developed for high-field experiments

Lessons learned:

- Sensitive to changes in screening by low temperature baking
- Absolute comparison of field profile for different samples is difficult at low-field (large error bar, low-statistics)
- Can be better distinguished at higher field and at H->H_{sh}

Field Profile





Methods & analysis have been developed in preparation for high-field experiments

High-field is crucial for better resolution of different samples

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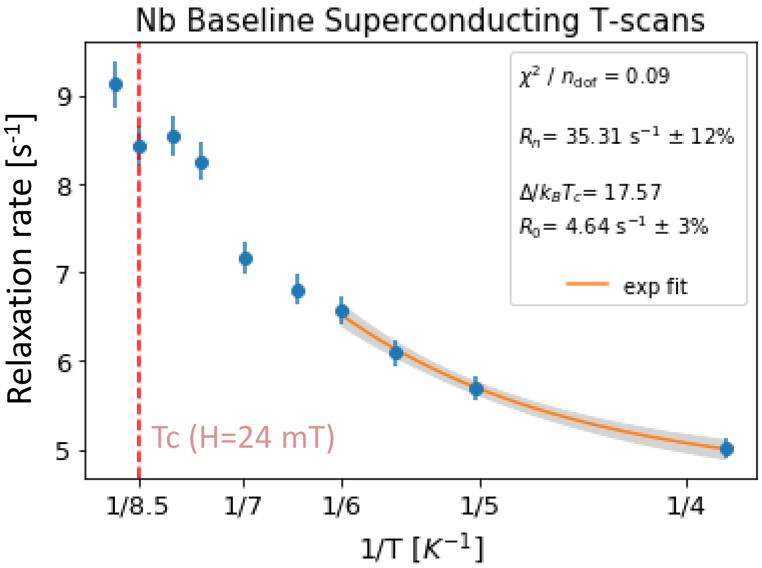
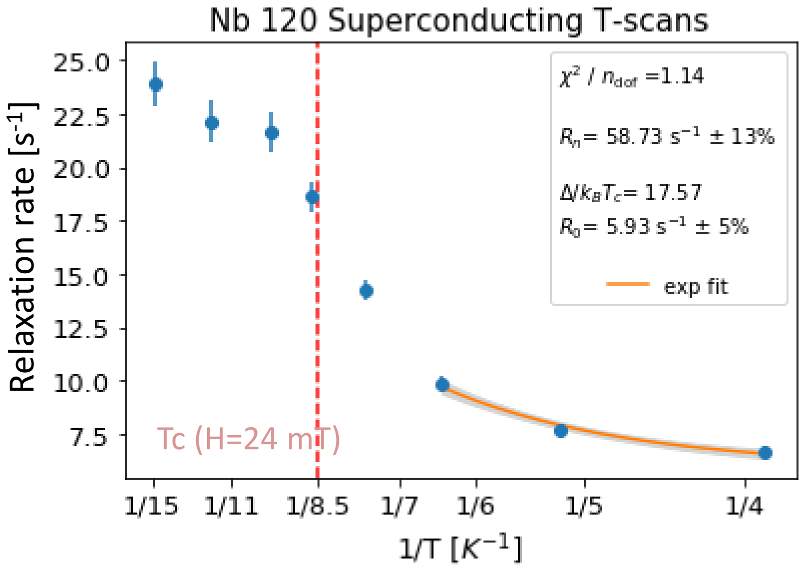
Temperature Dependence



Nb Baseline Superconducting T-scans



Nb 120 Superconducting T-scans

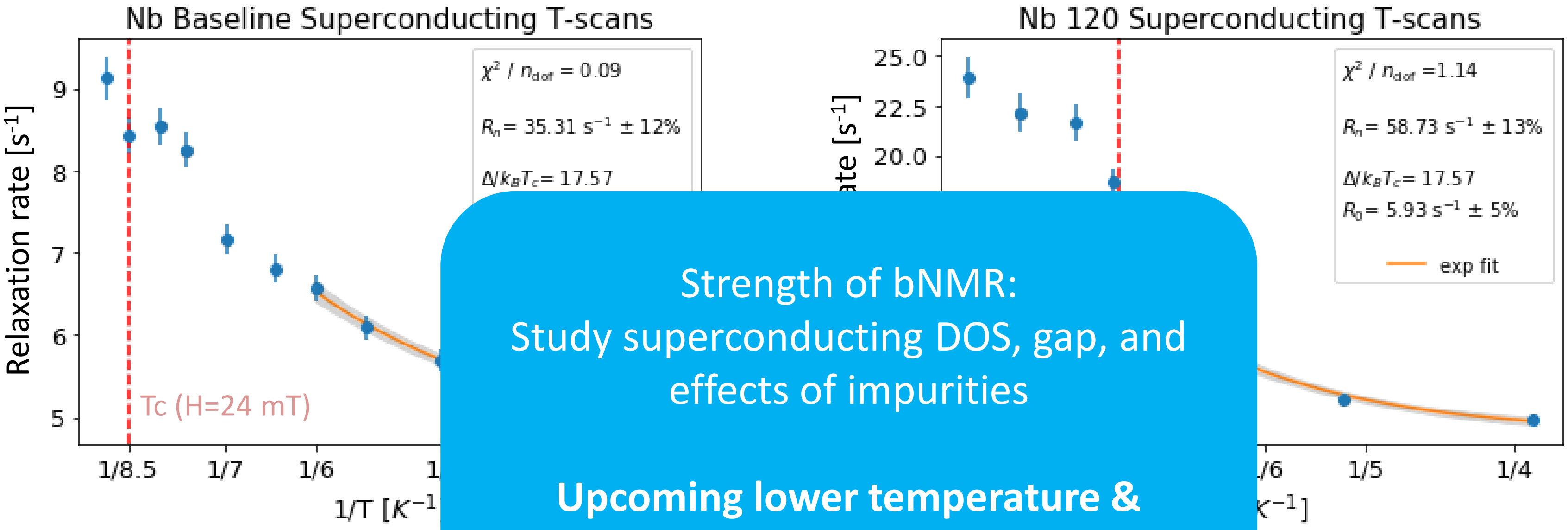
Longer timescale: probe ^{93}Nb (nuclei spins) interaction w/ supercond. excitations

- Very sensitive to the changes in the DOS due to superconducting transition
- Low-T limit ~ exp(-Δ/k_BT) -> study superconducting gap
- Residual (T-indep.) relaxation -> possible (para)magnetic impurities

Further studies

- Lower temperatures ($T<T_c/2$) -> commissioning of He-3 cryostat (down to 300 mK)
- Combined with depth-resolve -> depth-resolved DOS

Temperature Dependence



Strength of bNMR:
Study superconducting DOS, gap, and effects of impurities

Upcoming lower temperature & depth-resolved DOS

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Summary & Outlook

Summary

- bNMR is a technique complementary to µSR
- Strength of bNMR over µSR in studying superconducting electrons excitation
- High-field bNMR upgrade is nearing completion
- Methods developed for SRF samples field profile measurements with existing low field spectrometer

Outlook

- Better resolution can be achieved at higher fields (close to H_{sh})
- More interesting studies ahead:
  - ➢ Depth resolved field of first vortex penetration
  - ➢ Depth-resolved superconducting DOS

Thank you

Merci

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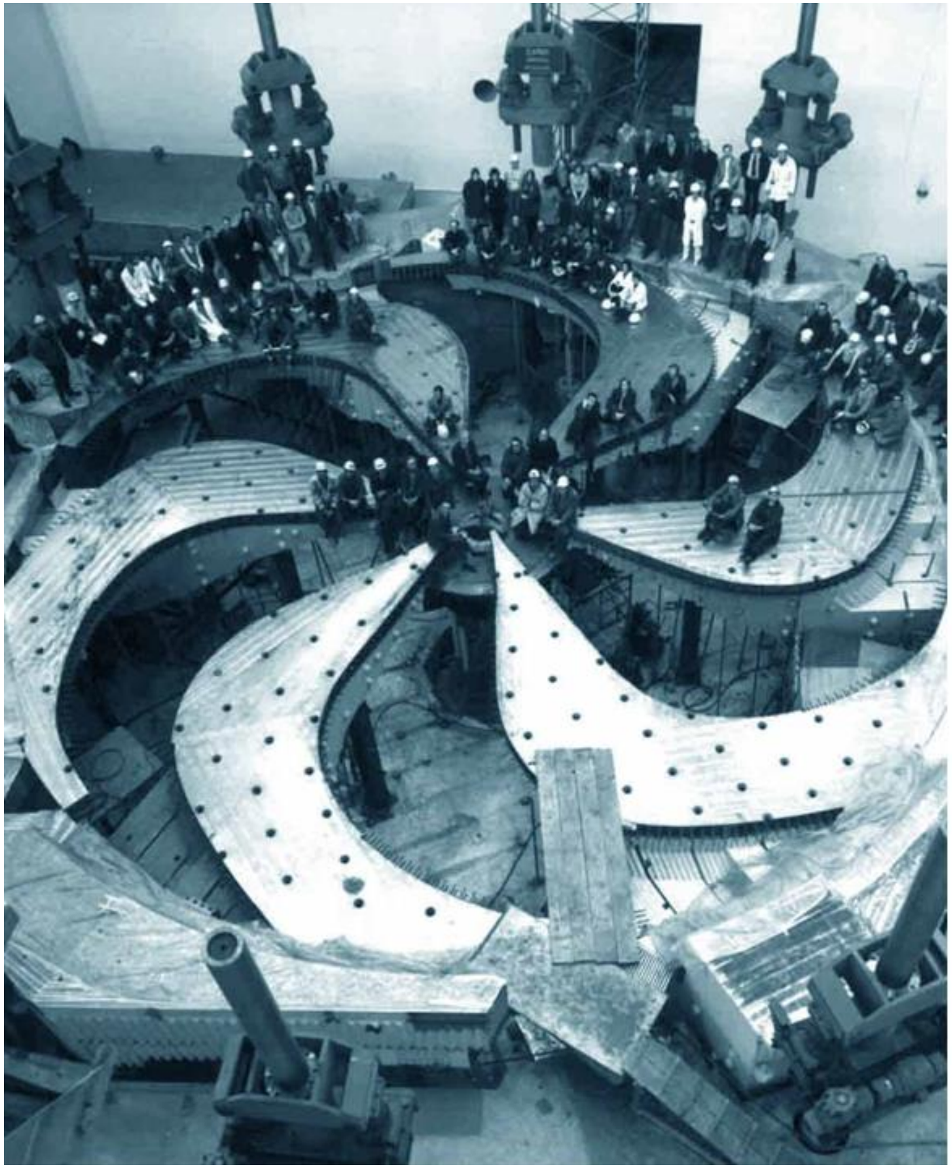

Discovery, accelerated

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