Review of muSR studies for SRF applications

Tobias Junginger

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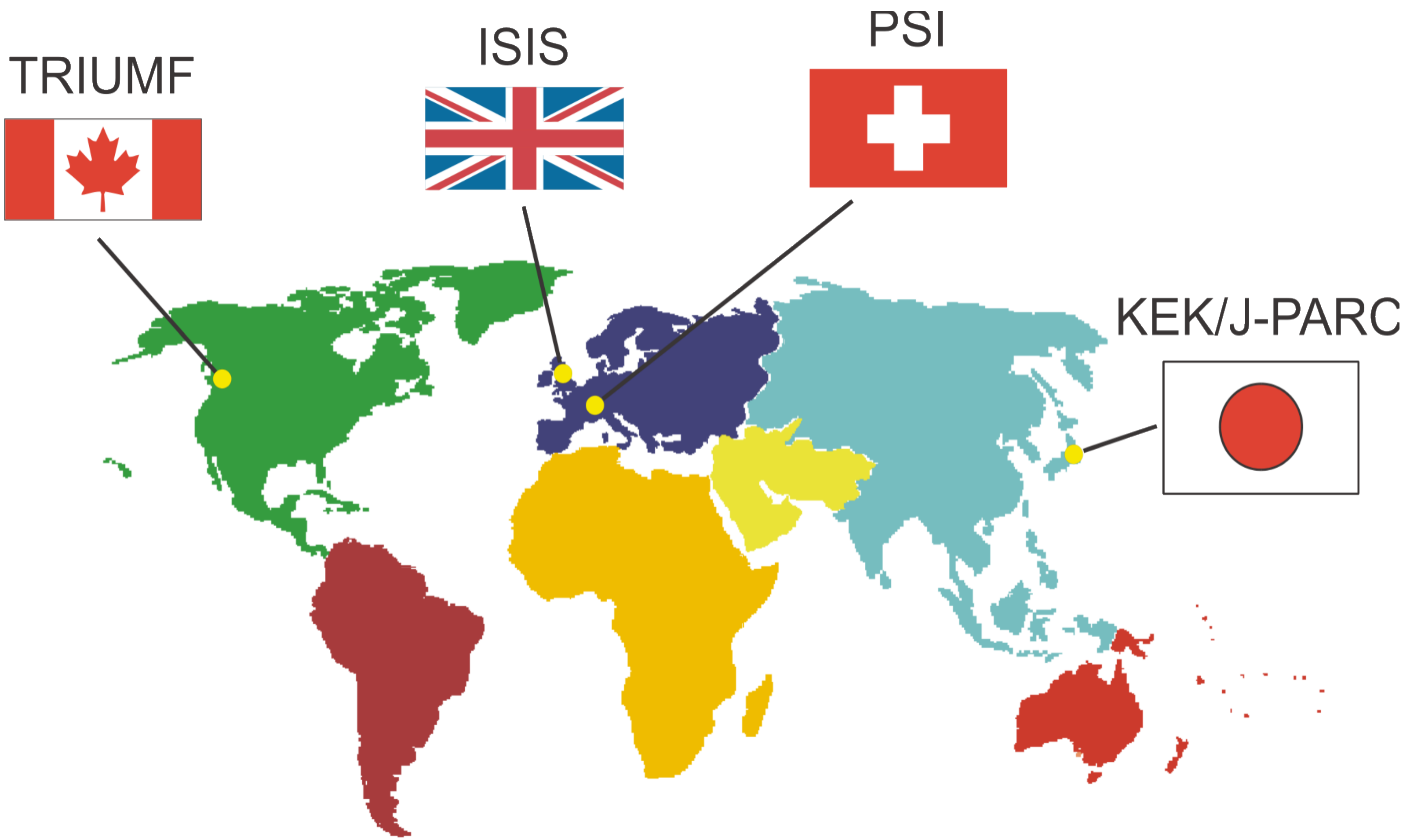
Affiliations as of time of collaboration

µSR Facilities Around the World



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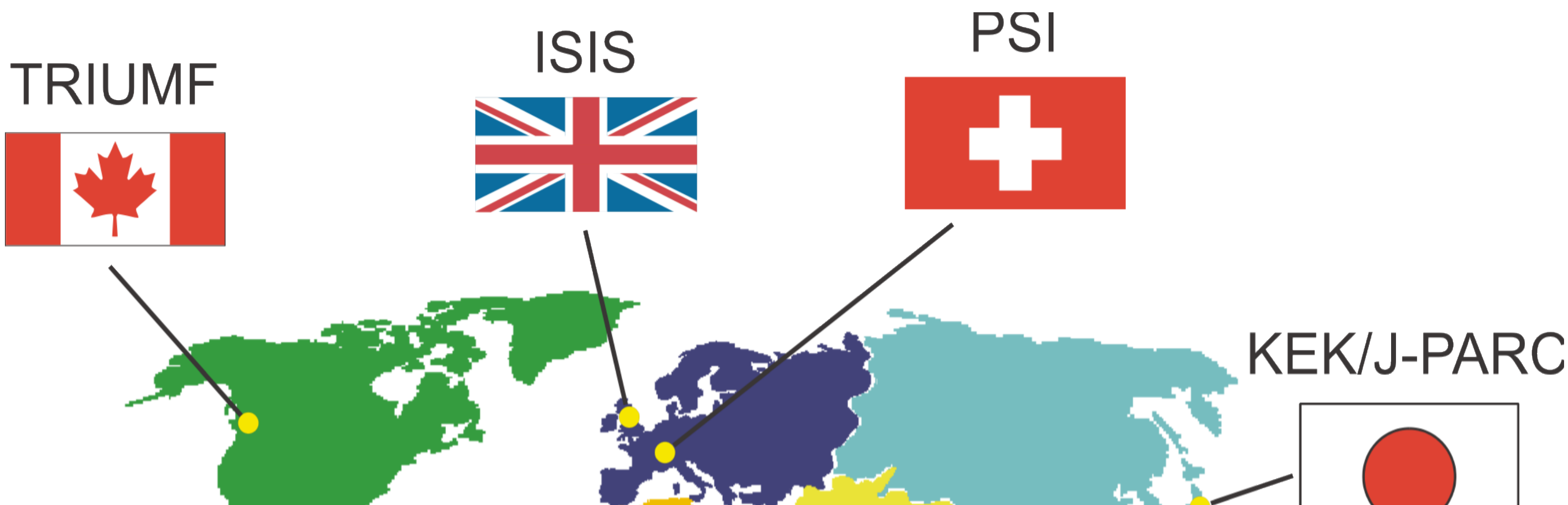


Summary:

muSR is a technique that allows to measure localized magnetic fields. Using this technique we show:

1. A layer of higher T_c material on niobium can push the field of first flux entry from a field consistent with H_{c1} to a field consistent with H_{sh}.

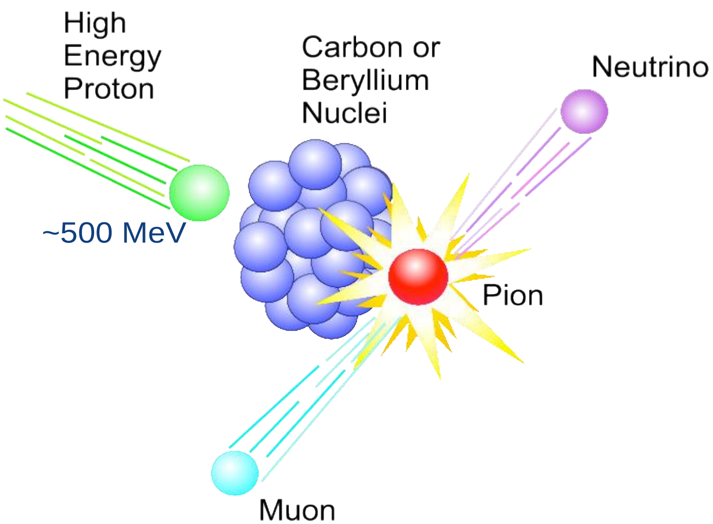
2. For multilayer systems without insulator there is a wide range proximity effect to be considered

3. There is strong evidence for magnetic impurities on the surface of Nb/Cu samples

Outline

1. Introduction to muSR
2. Using muSR as a local magnetometer (TRIUMF)
    1. Inducing superheating in niobium by thin film coating
3. Low Energy muSR (PSI)
    1. Proximity effects in NbTiN/Nb and NbTiN/AlN/Nb samples
    2. Magnetic Impurities in Nb/Cu films
4. Summary
5. Outlook
    1. BetaNMR

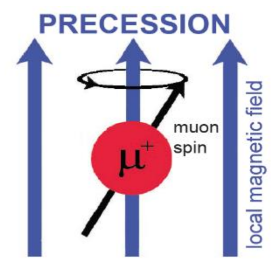
Muon production and decay



$$\pi^+ \rightarrow \mu^+ + \nu_u$$

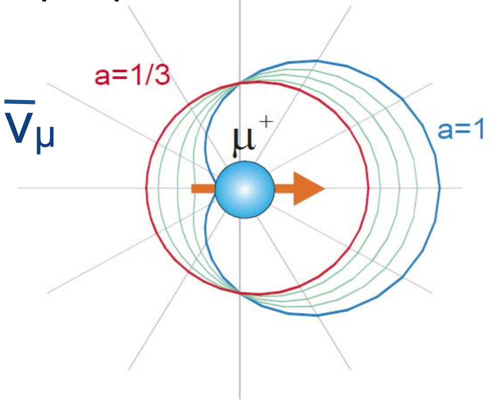
Muons are 100% spin polarized with kinetic energy of 4.1MeV

Muons are deposited ~100micron deep in a sample (bulk probe) – spin precesses with frequency dependent on local magnetic field

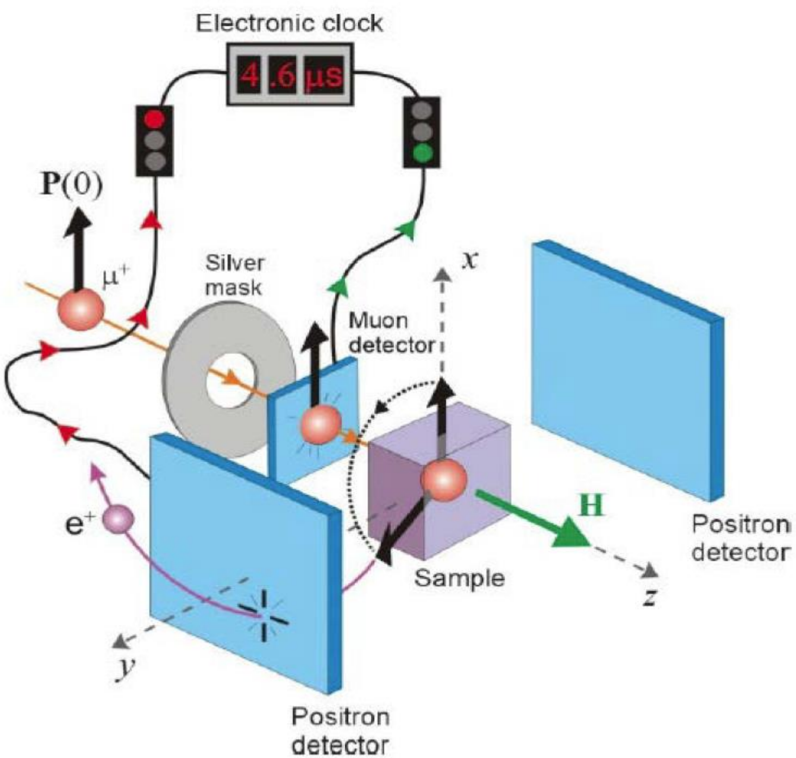


Muon decays in $\tau_{1/2}$=2.2μsec - emits a positron preferentially along the μ^+ spin direction

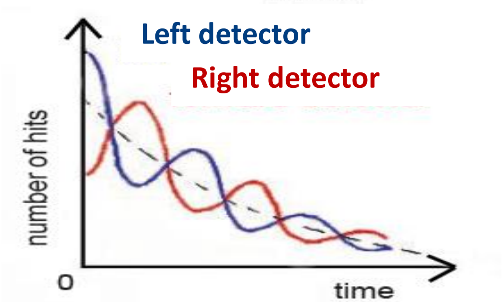
$$\mu^+ \longrightarrow e^+ + \nu_e + \bar{\nu}_\mu$$



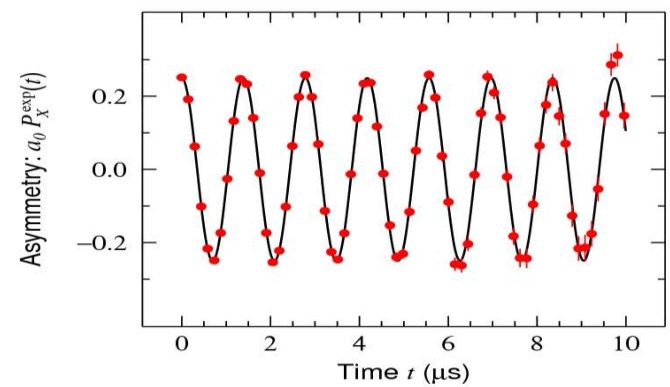
Muon Spin Rotation – muSR



- Muons are deposited one at a time in a sample
- Muon decays emitting a positron preferentially aligned with the muon spin
- Right and left detectors record positron correlated with time of arrival
- The time evolution of the asymmetry in the two signals gives a measure of the local field in the sample

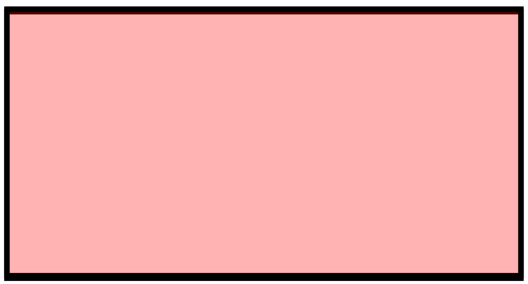


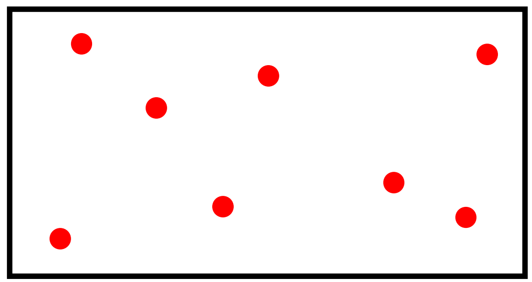
$$a_0 P_y(t) = \frac{N_L - N_R}{N_L + N_R}$$

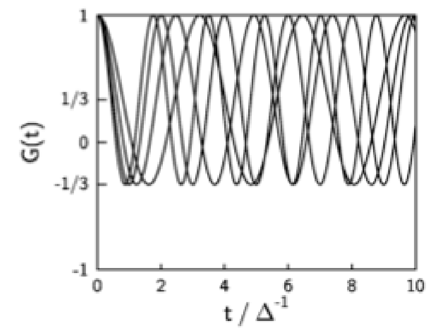


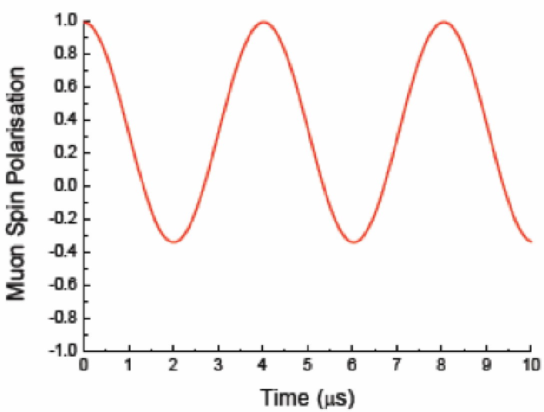
Magnetic Volume Fraction

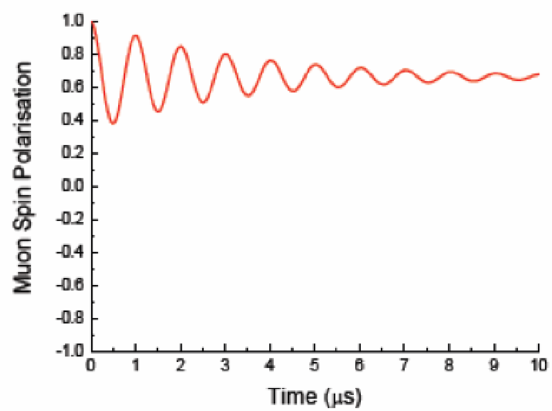
Uniformly weakly magnetic	Non-magnetic with magnetic impurities	Static distribution of random fields

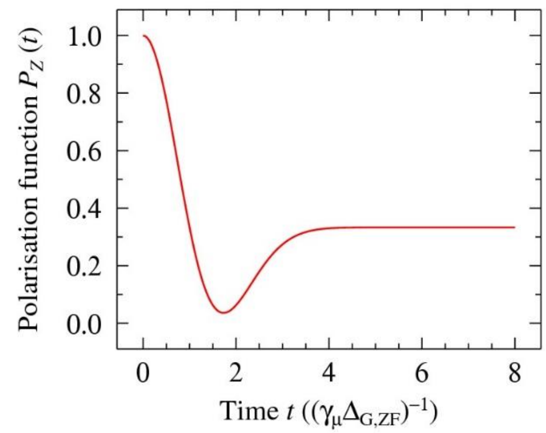






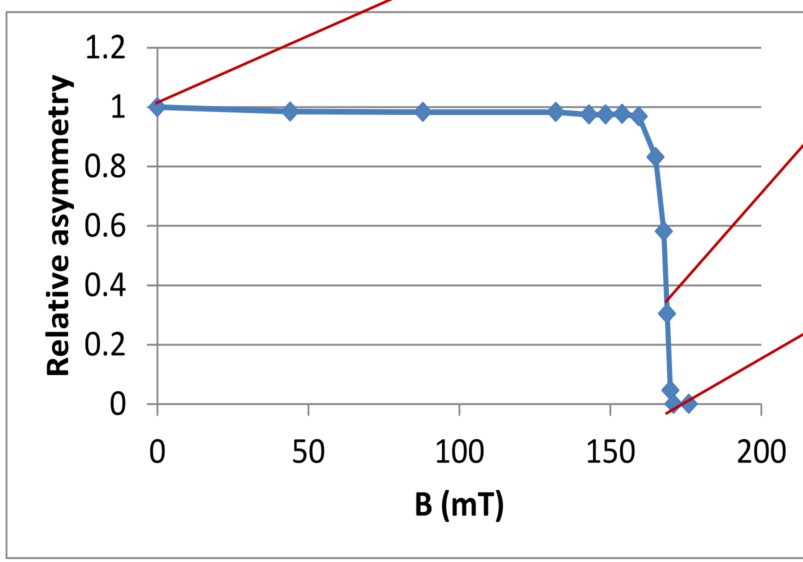


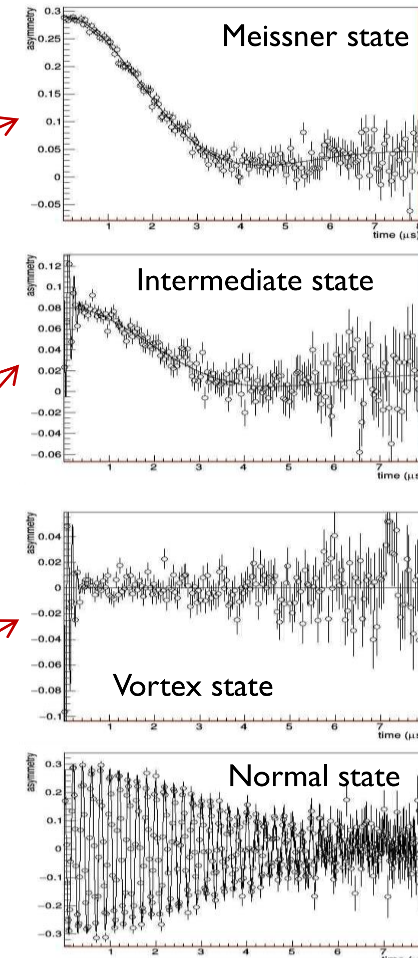




Using muSR as local magnetometer

- A sample is cooled in zero field - asymmetry measurements are taken as a function of applied magnetic field
- The relative asymmetry at t=0 gives a measure of the volume fraction sampled by the muons that does not contain magnetic field
- A variety of samples and sample geometries have been characterized in this way

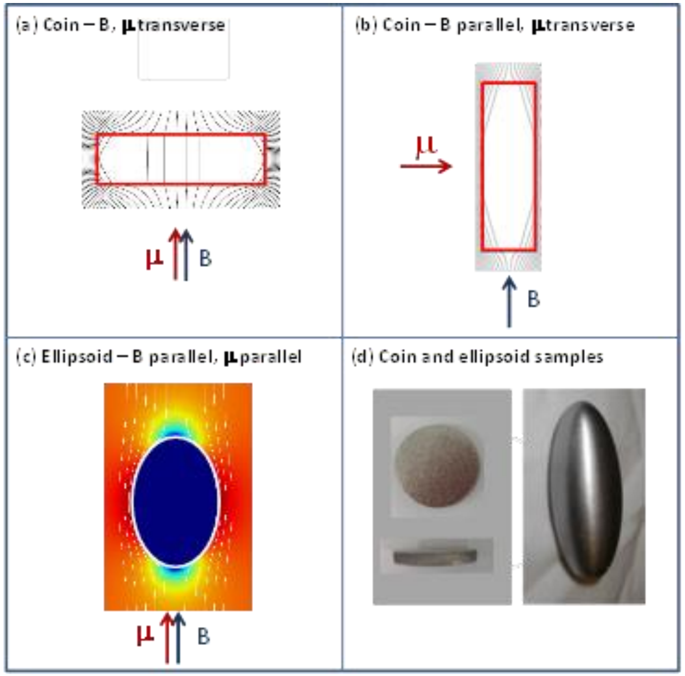


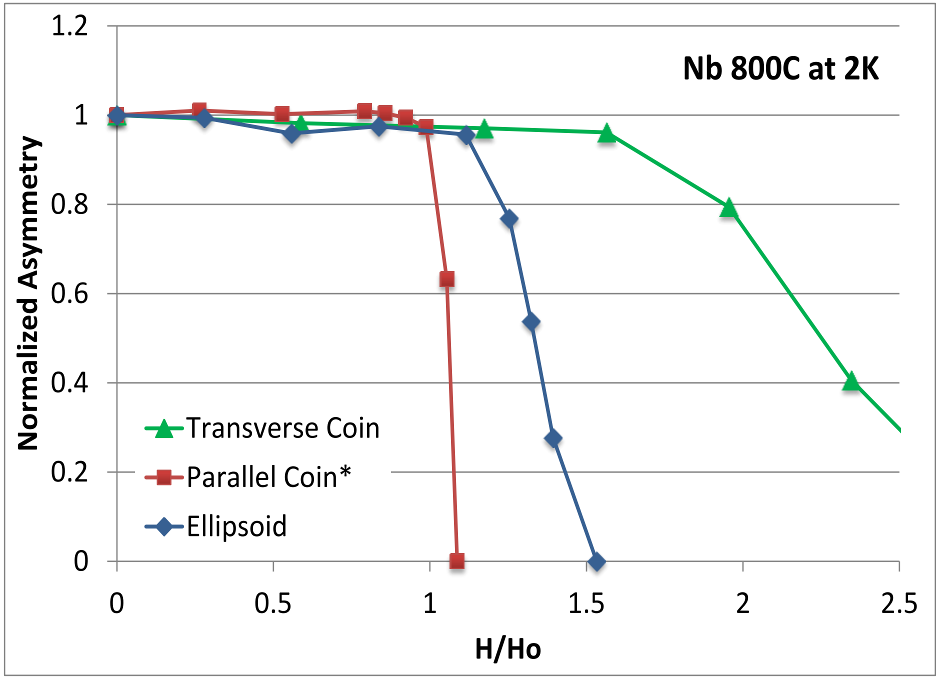


The field of first entry and the role of pinning in different geometries

a) Transverse coin samples are sensitive to pinning - delays flux break in to the centre
b) Parallel coin geometry is insensitive to pinning
c) Ellipsoid samples are less sensitive

- All three geometries are useful to characterize the material





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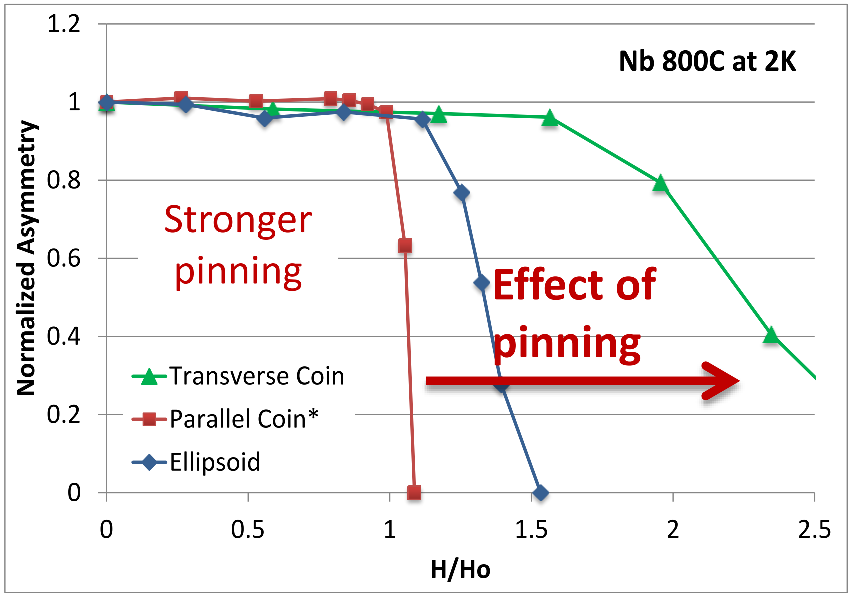
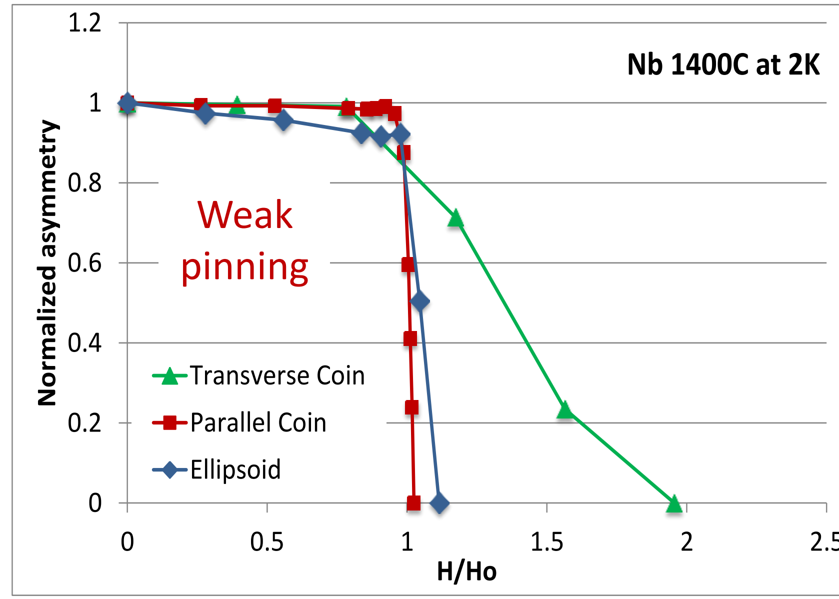




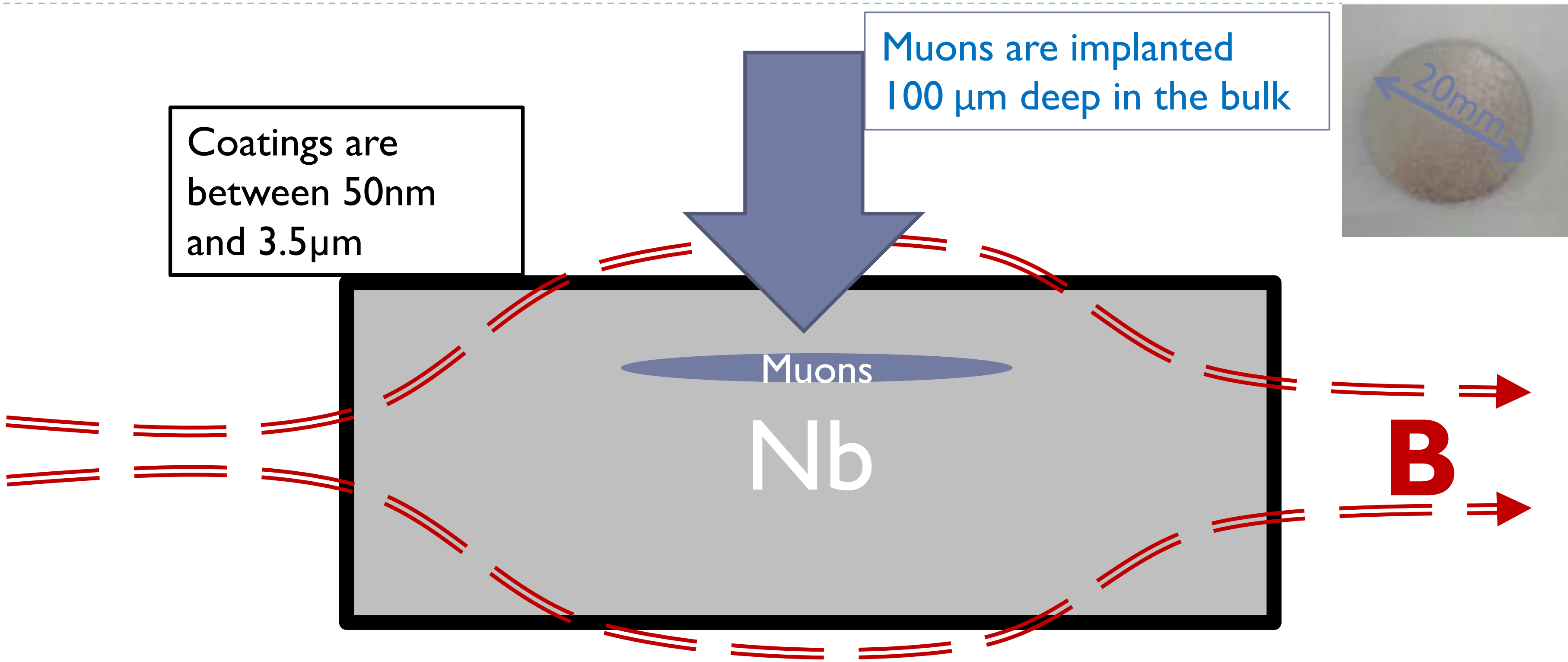
800C baked samples – pinning is clearly seen in different H_{entry} between transverse, parallel coin and ellipsoid geometry

1400C heat treatment for three geometries

- virtually eliminates pinning from the Nb
- H_{entry} is equal for all geometries

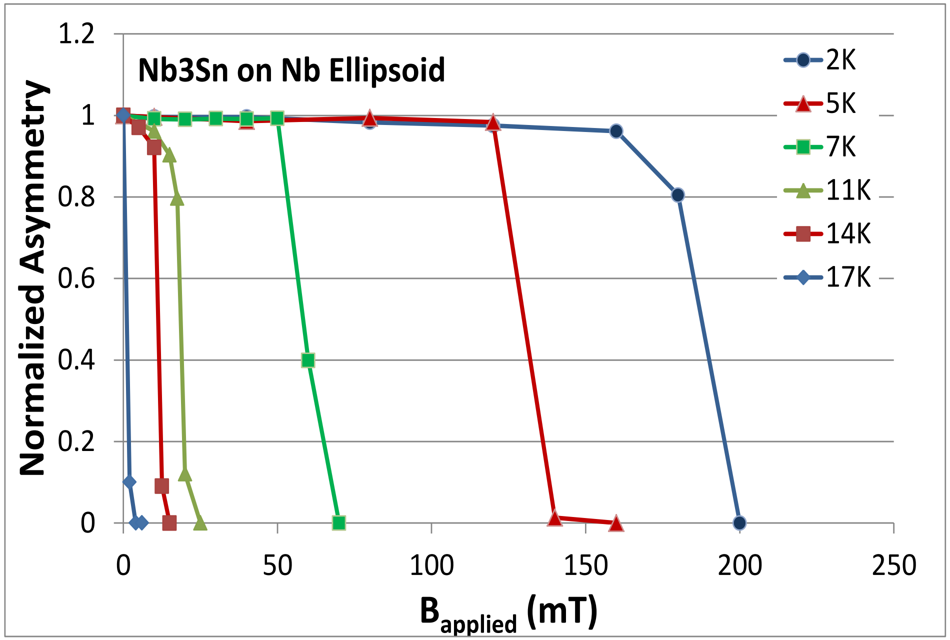
- **Our baseline substrate for thin film tests is 1400°C annealed niobium**
- **The parallel field configuration is used to determine the field of first entry**
- **Measurements in transverse geometry measure the pinning strength**

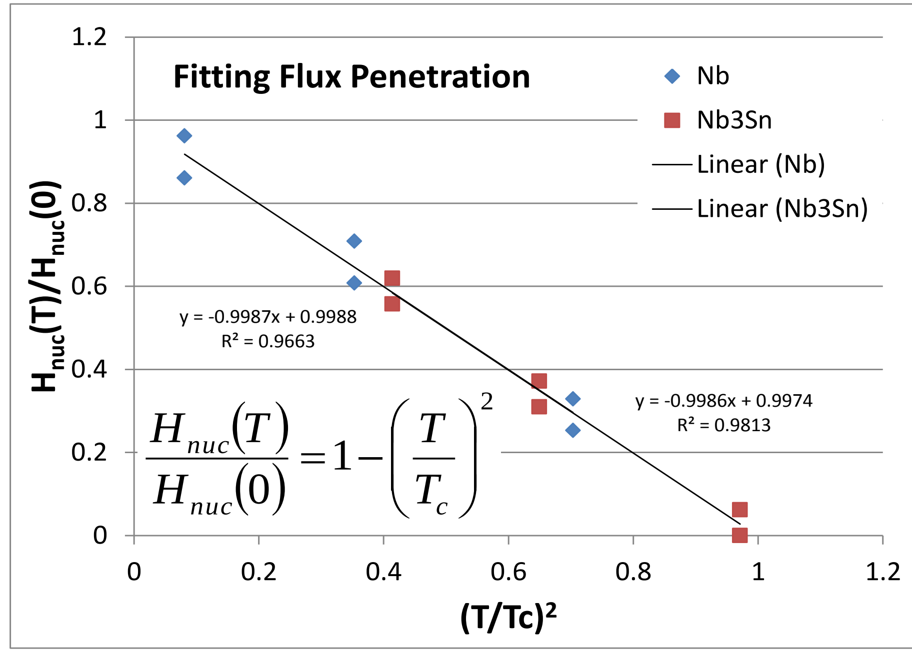
Testing coated samples with muSR as a local magnetometer



- Parallel field configuration. Field will first break in at the corners at 0.82 H_{entry} and move to the center at 0.91 H_{entry}. Only the field in the center is probed
- Above Tc of niobium we measure the field of first entry of the coating only, below Tc of niobium we measure the higher H_{c1} or H_{sh}

Nb3Sn on Nb Ellipsoid results



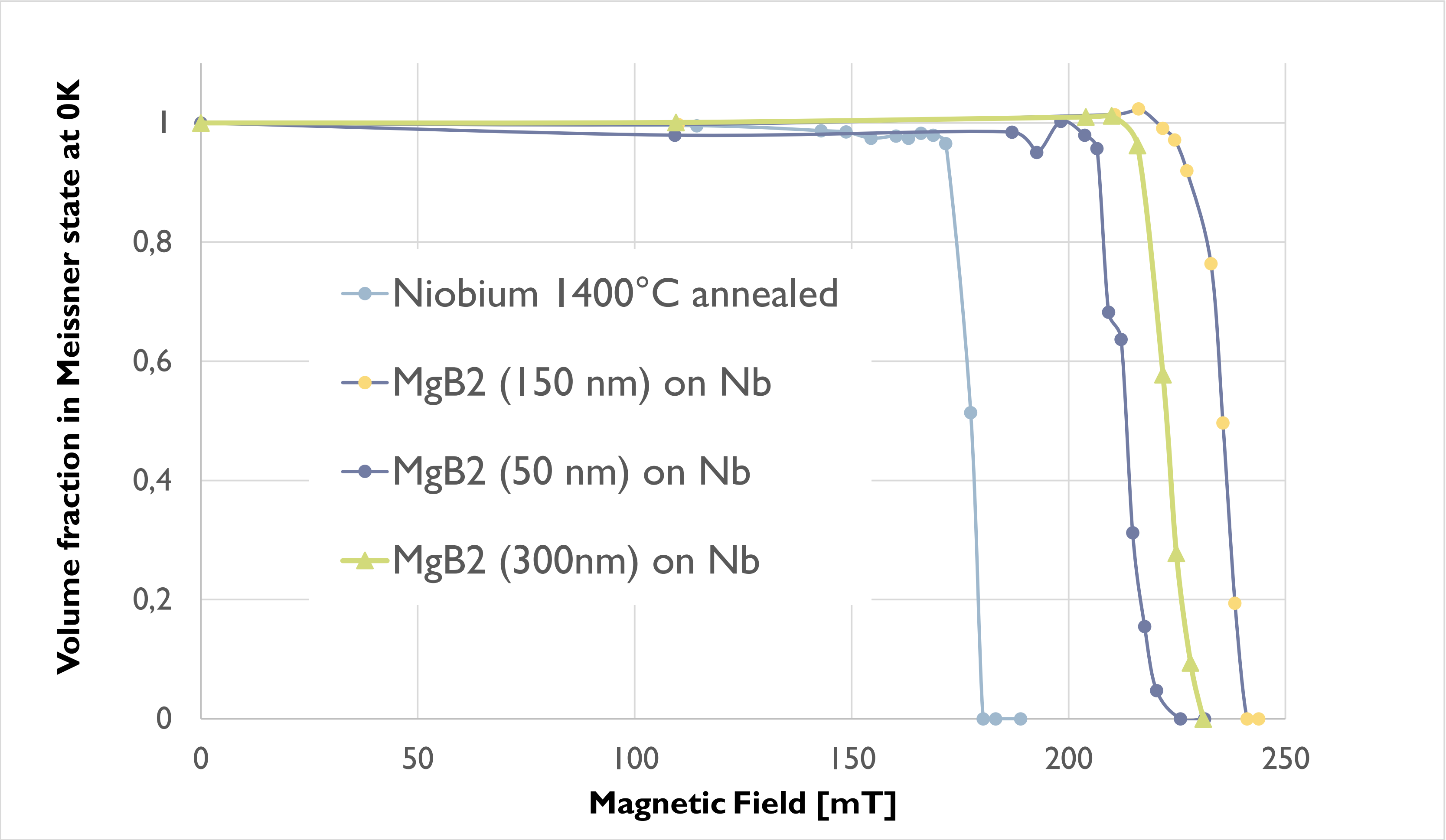


Material	$H_{nucleate}$ (0) [mT]	T_c [K]
Niobium	227	9.36
Nb3Sn	37.1	17.3

Below 9.25K we seem to measure Hsh of niobium, above 9.25K Hc1 of Nb3Sn.

→ If the film induces superheating in niobium this should be independent on thickness

Testing coated samples (MgB2)



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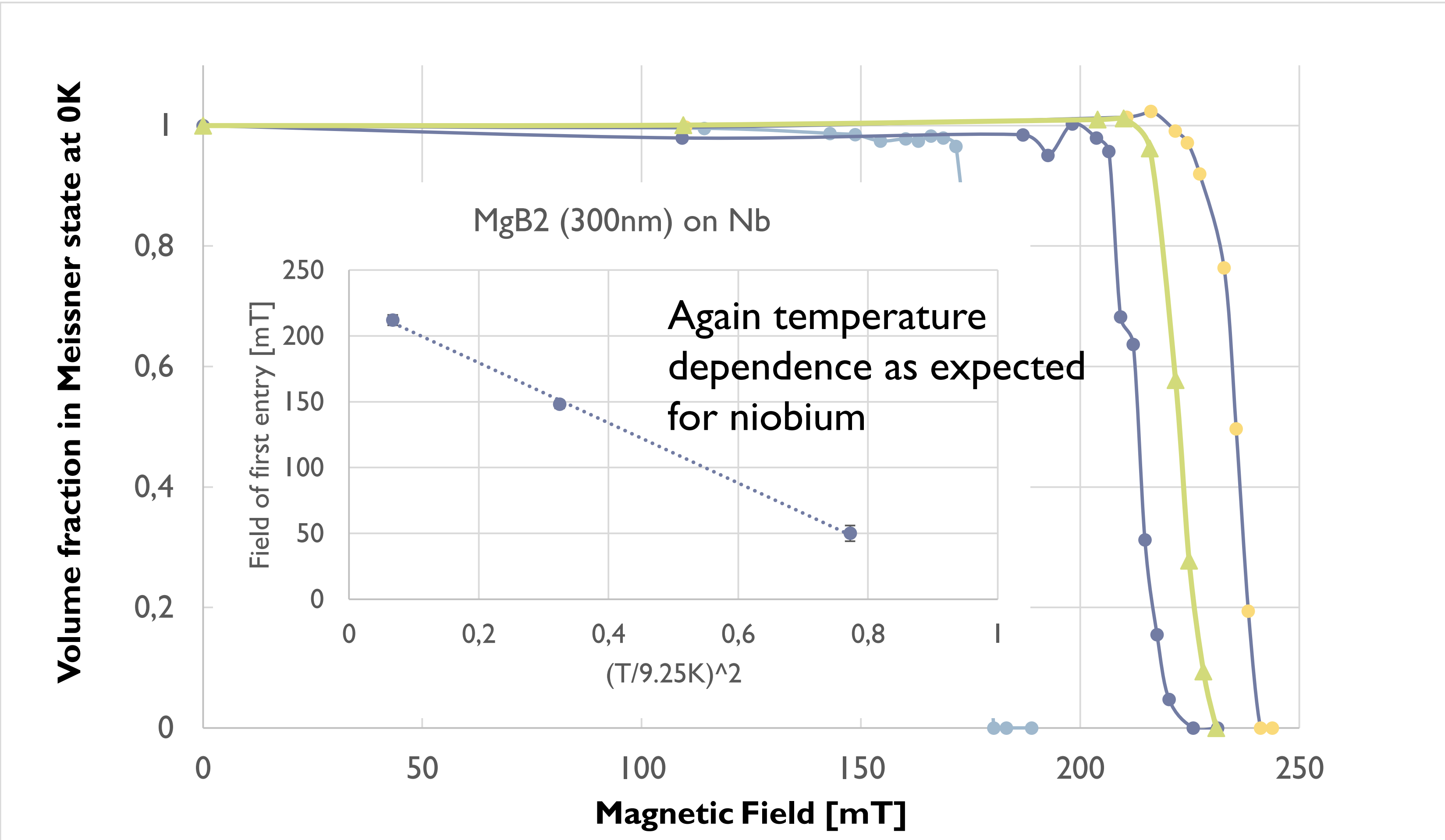
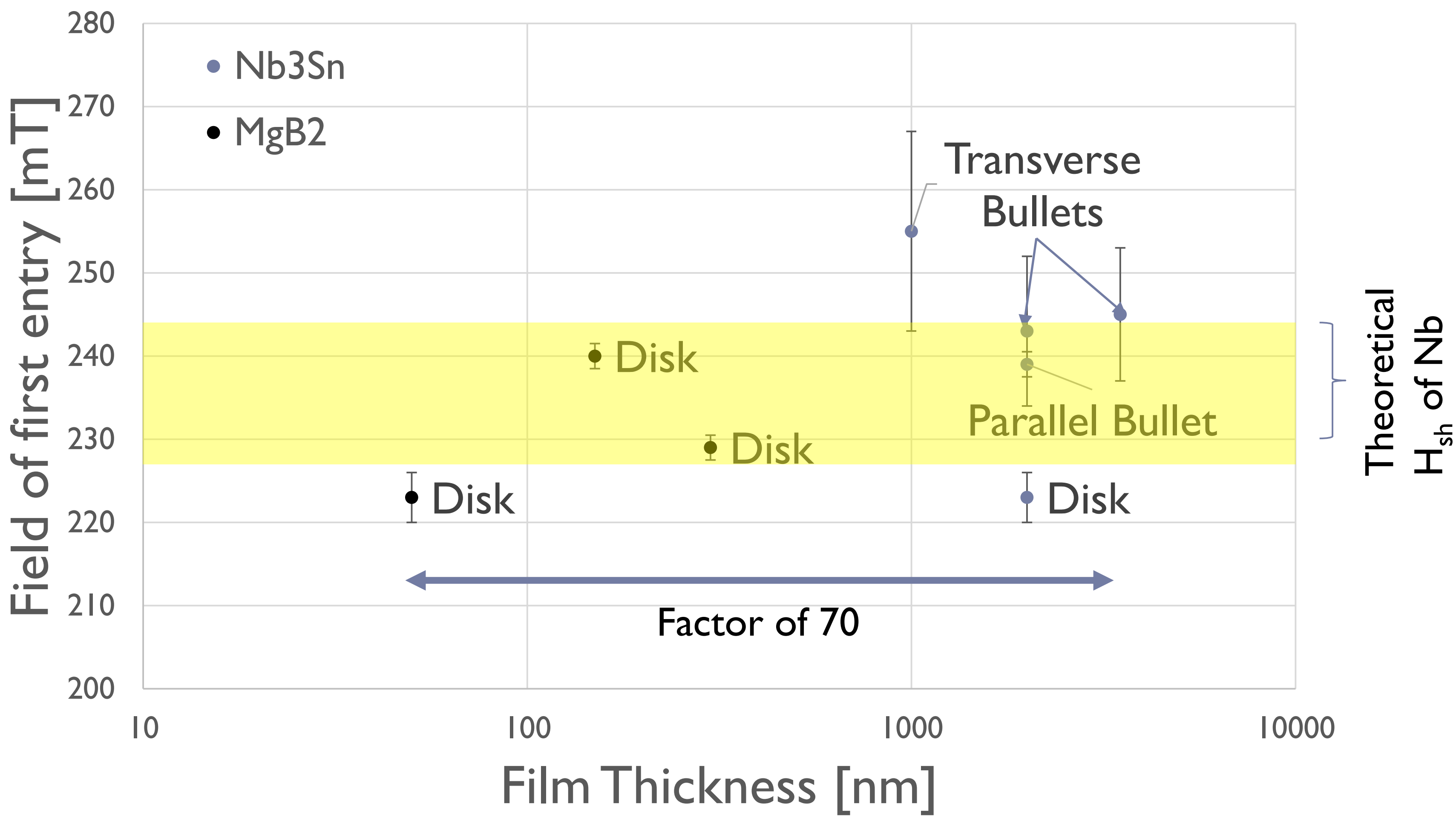


Testing coated samples (Nb3Sn and MgB2)



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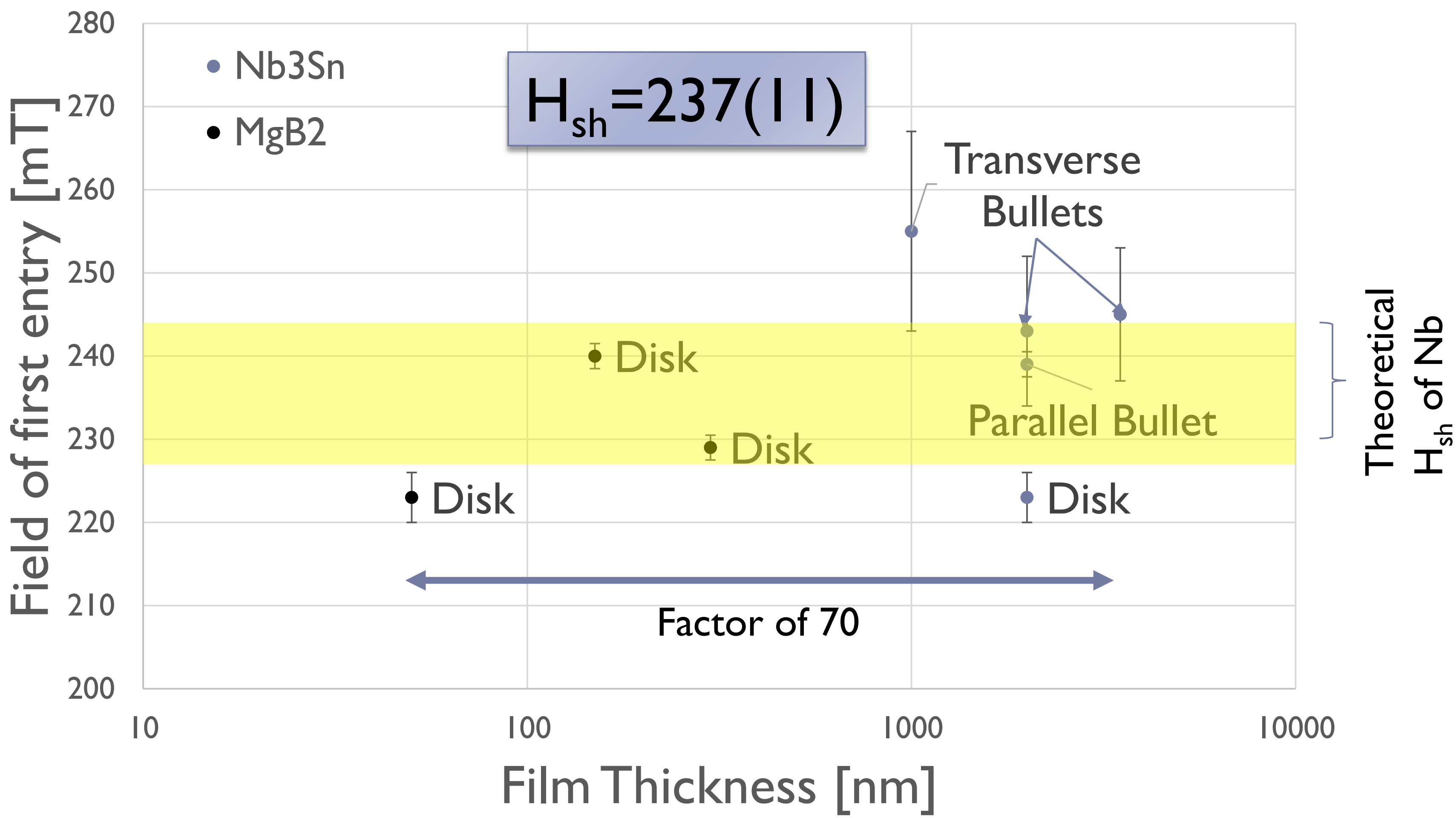

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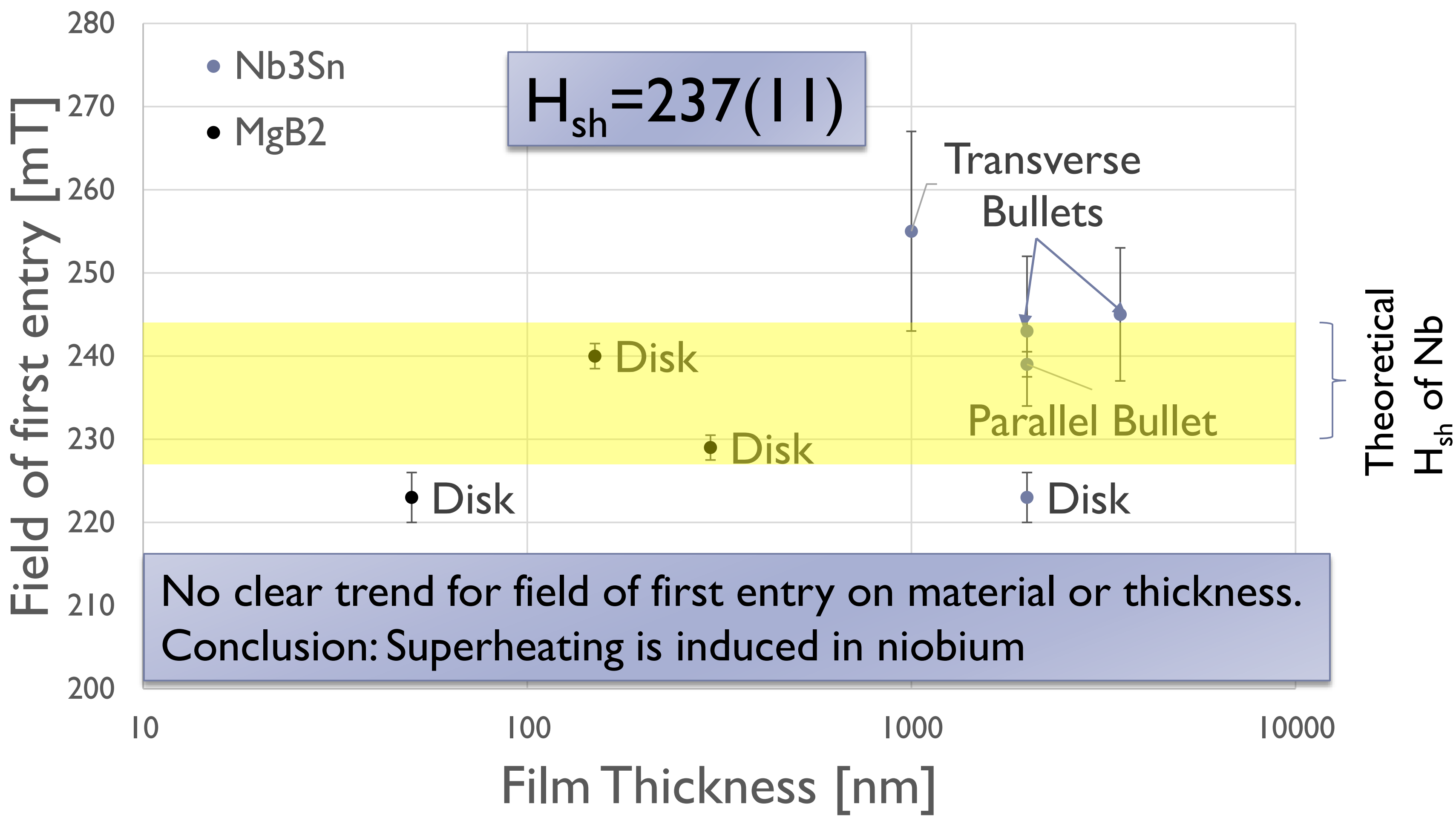

No clear trend for field of first entry on material or thickness.
Conclusion: Superheating is induced in niobium

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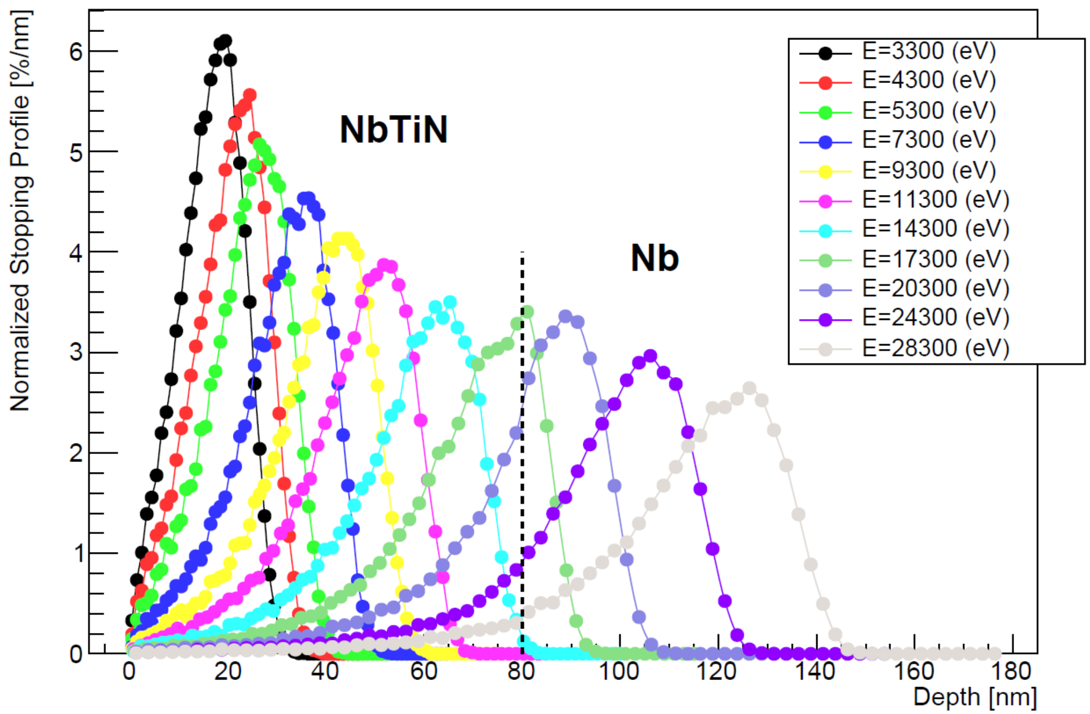
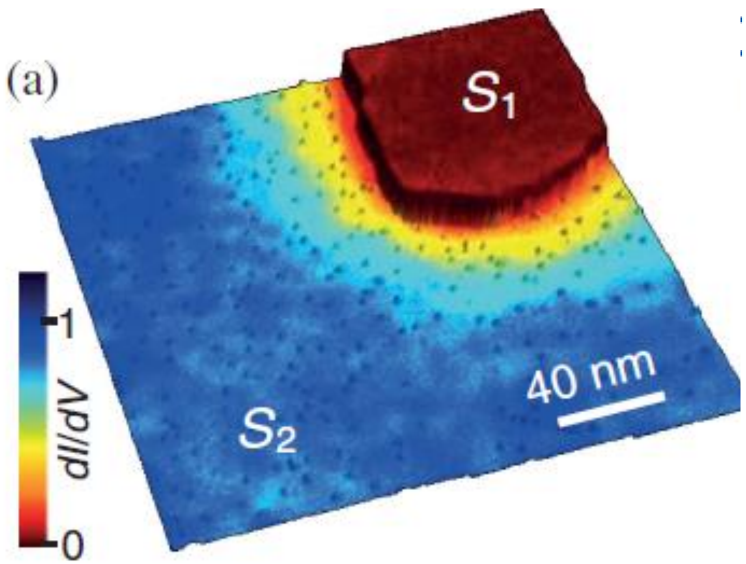
Low energy muons

- Low energy muons can be stopped in a variable depth between 0 and ~100nm
- Ideal for testing layered structures
- Parallel fields limited to 25mT
- Has been applied to test two samples
  - NbTiN(80nm) on Nb
  - NbTiN(80nm)/AlN(20nm) on Nb



Field parallel to sample surface – Meissner Screening NbTiN (80nm) on Nb

- Magnetic field decays with a single exponential
- 223(7) nm is short for NbTiN
- Proximity effect?



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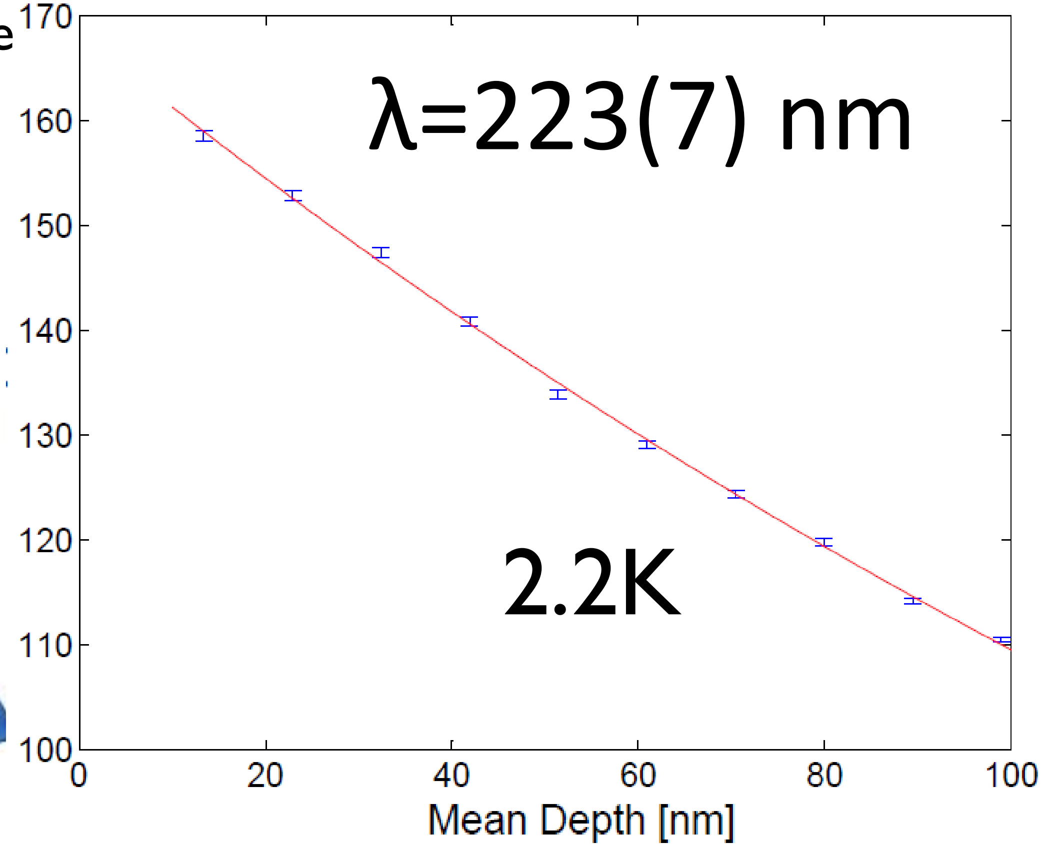

$$\lambda_L \propto 1/\sqrt{n_S}$$

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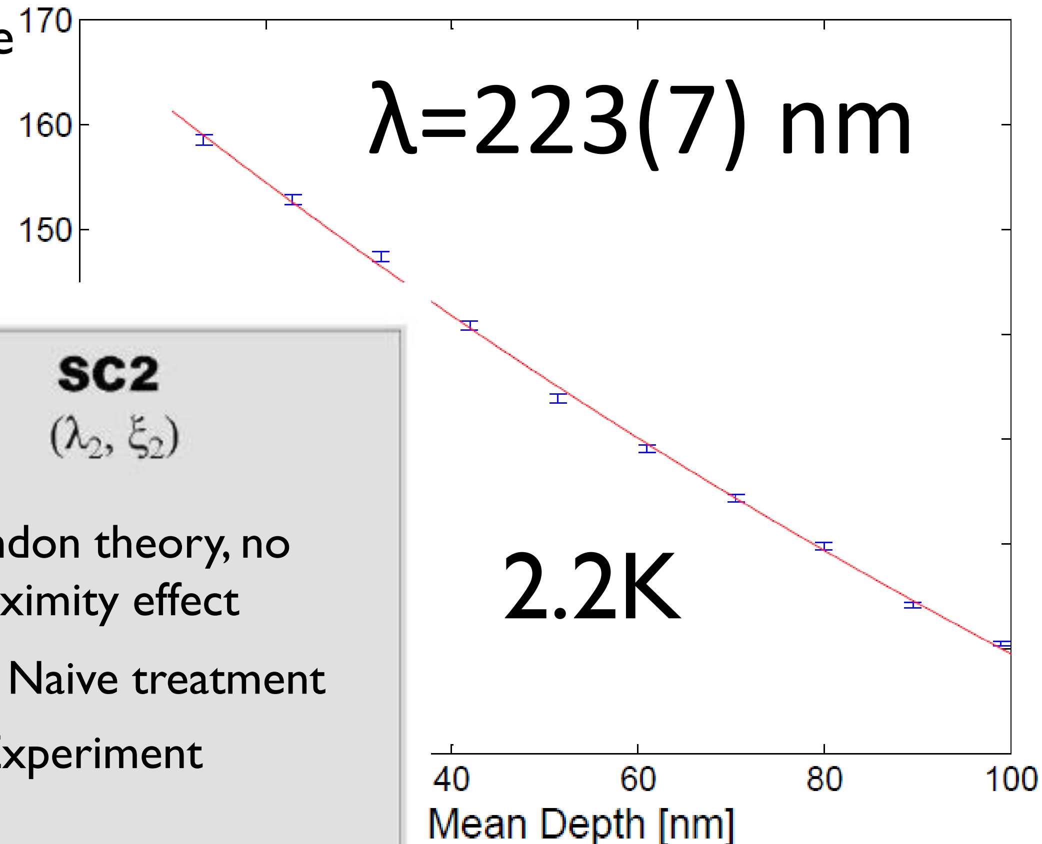
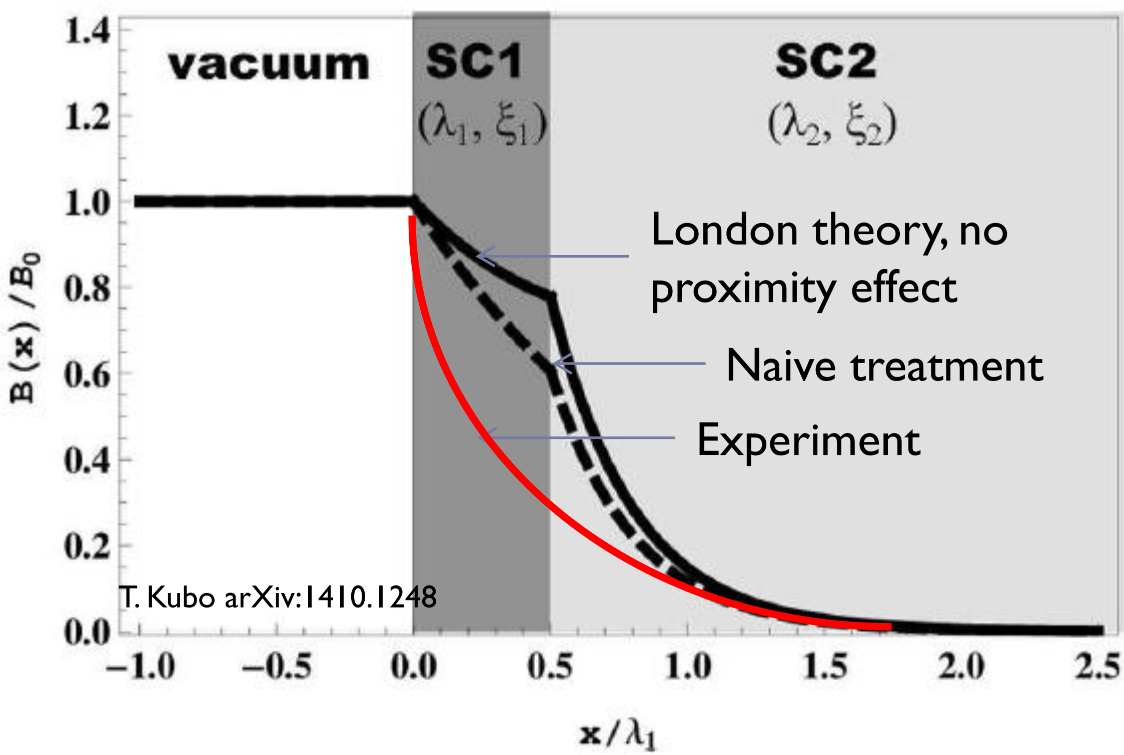
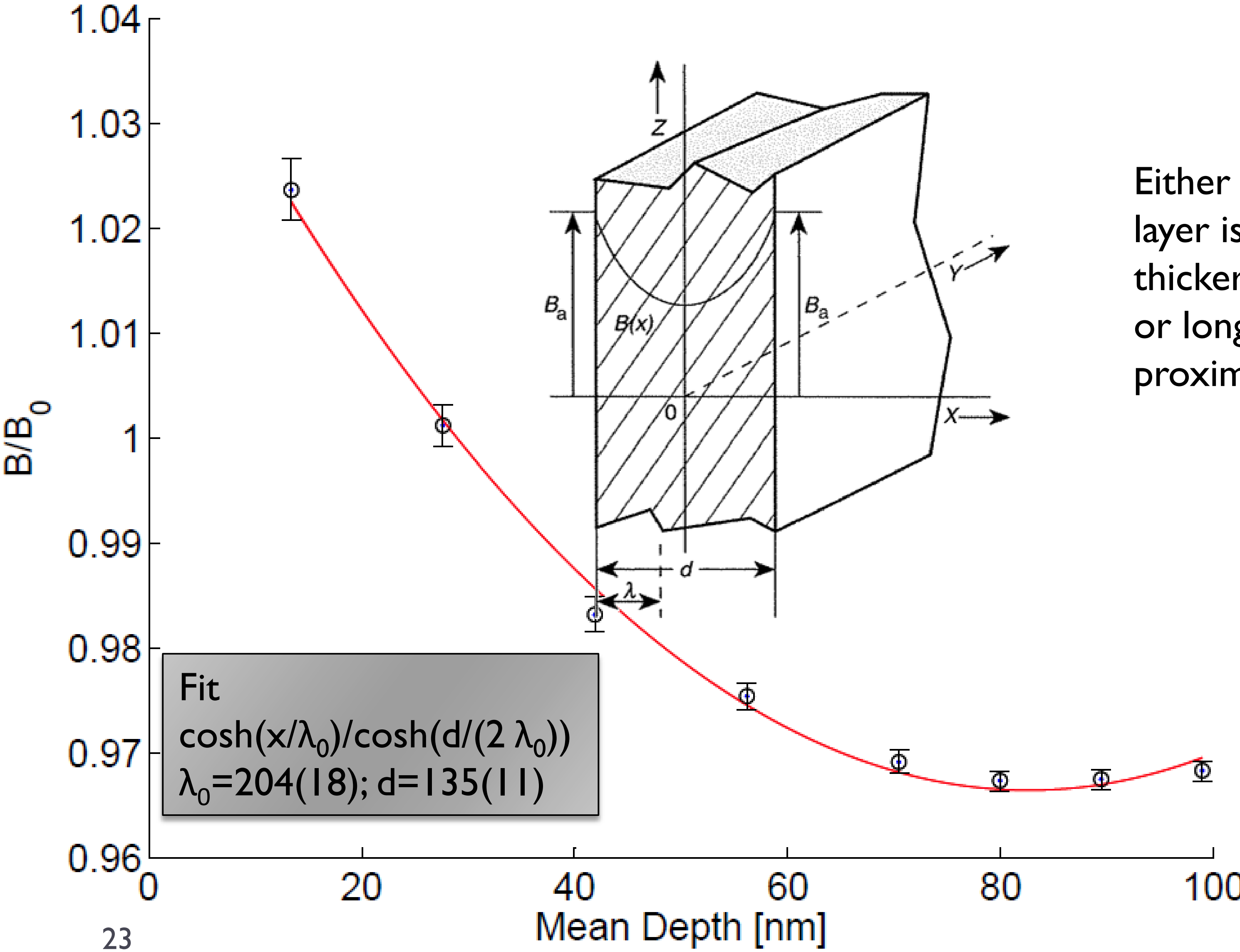


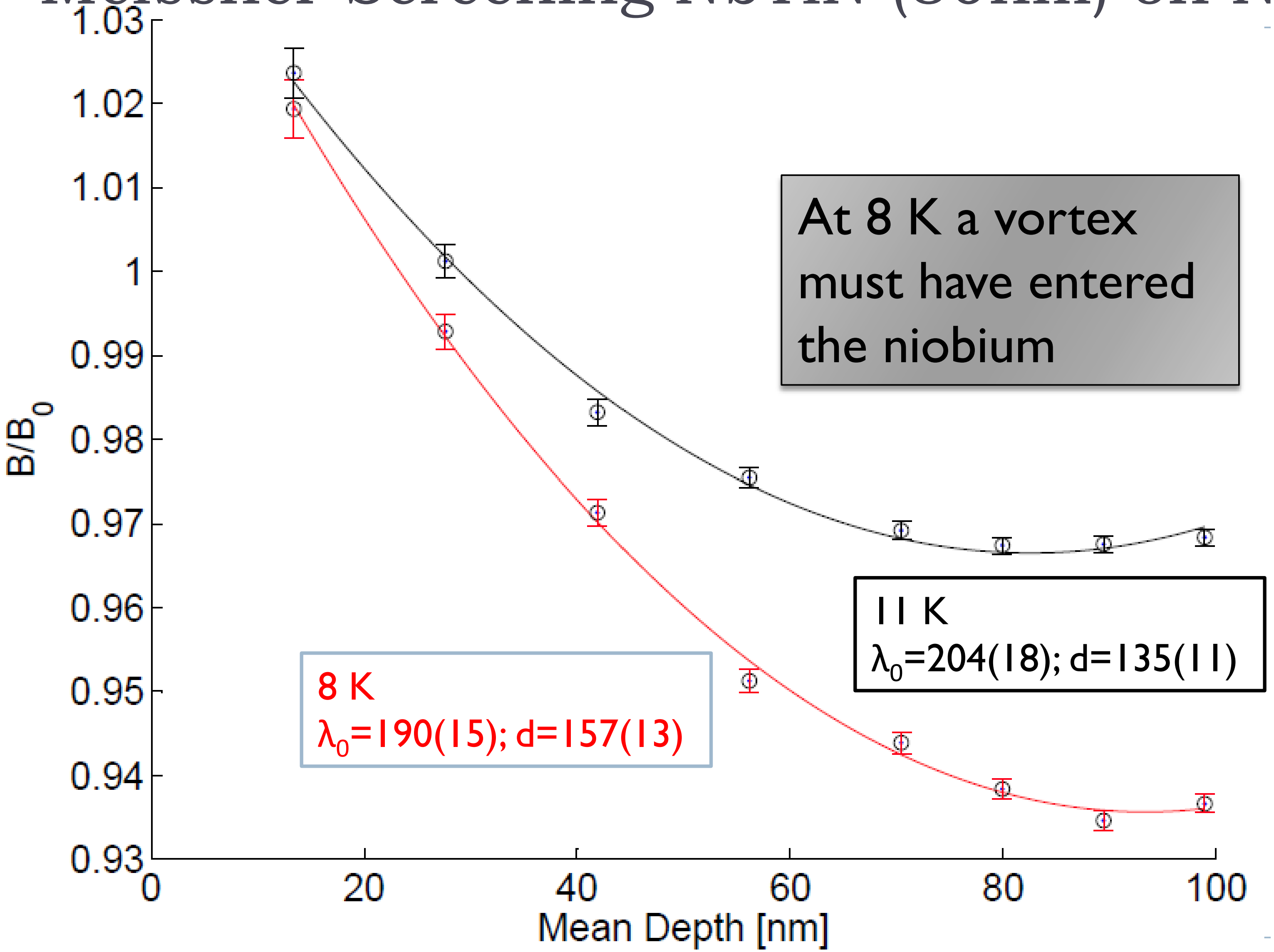


Field parallel to sample surface – Meissner Screening NbTiN (80nm) on Nb

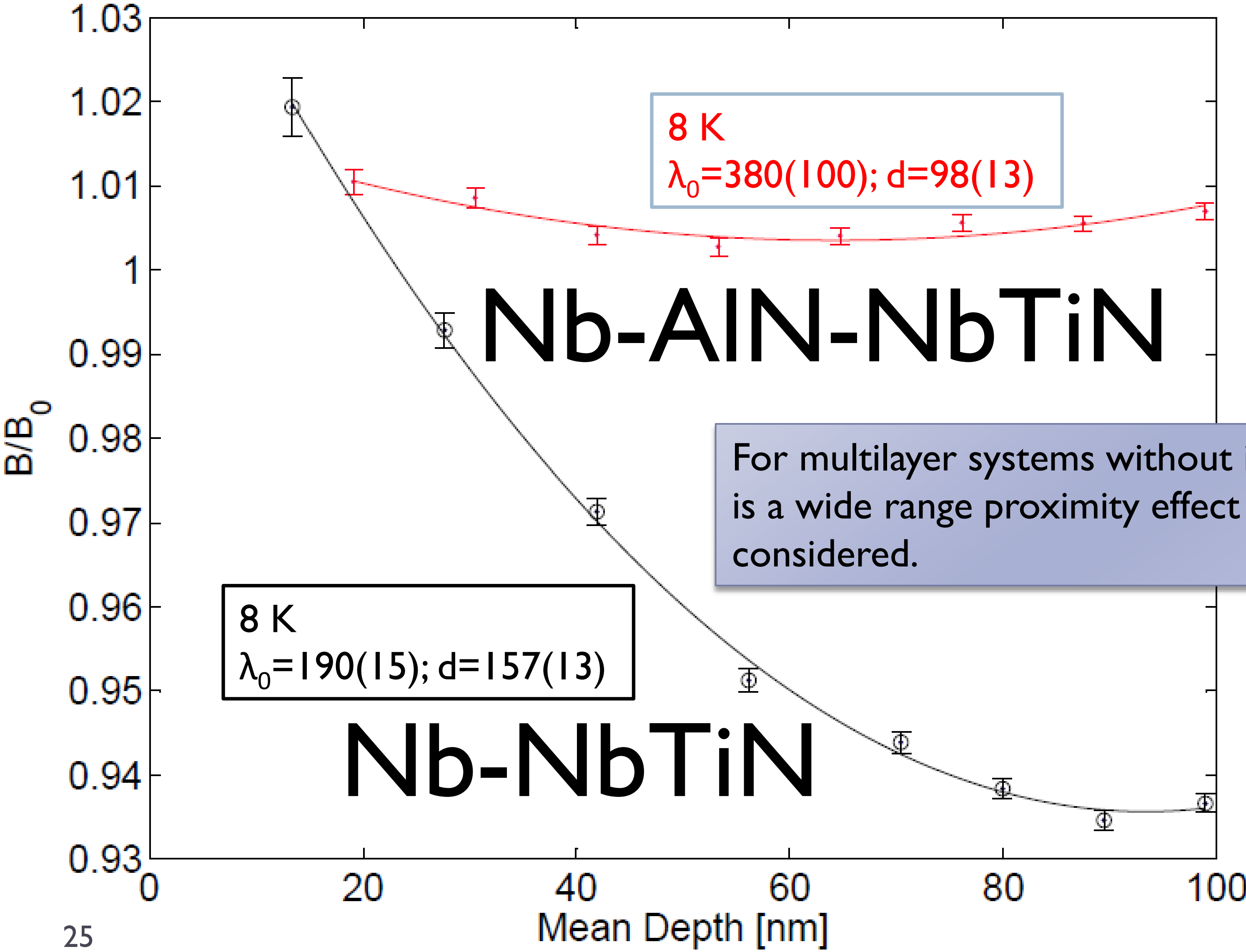


Either the NbTiN layer is significantly thicker than 80 nm or long range proximity effect

Field parallel to sample surface – Meissner Screening NbTiN (80nm) on Nb



Comparison to SIS Multilayer



For multilayer systems without insulator there is a wide range proximity effect to be considered.

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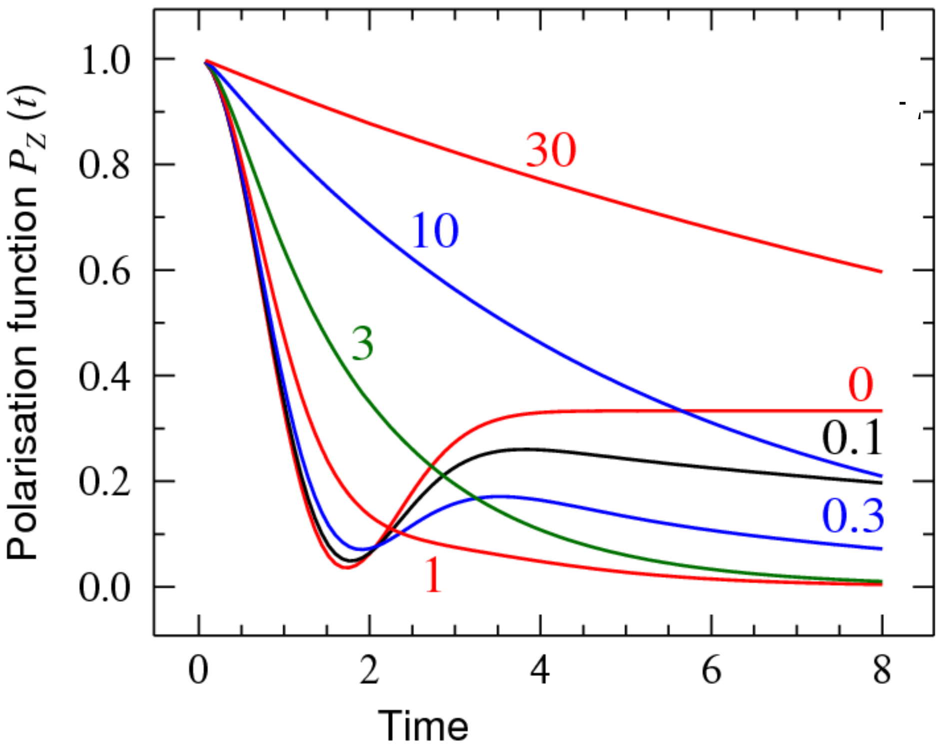
Fluctuating Random Fields



Polarization function for different fluctuation rates. The "0" function corresponds to a Gaussian distribution of random fields.

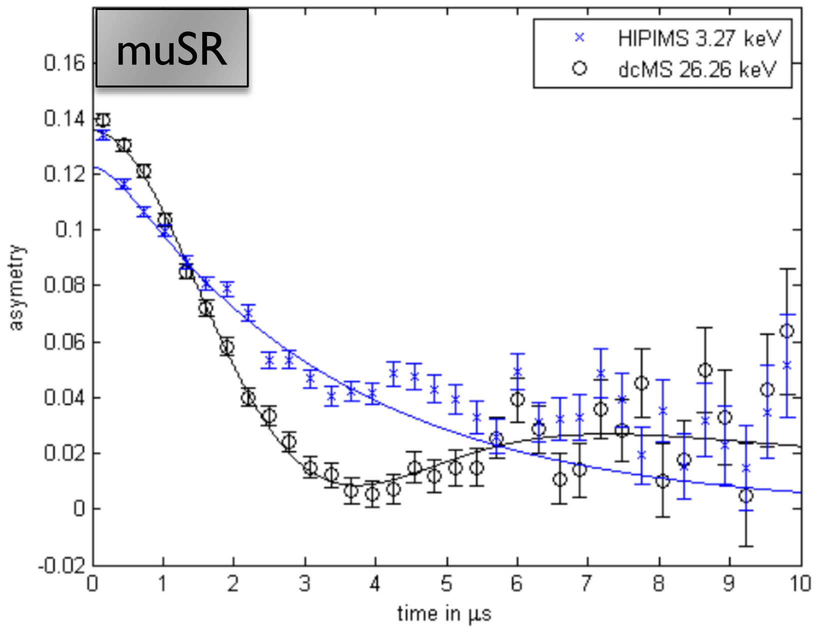
Slow Fluctuations

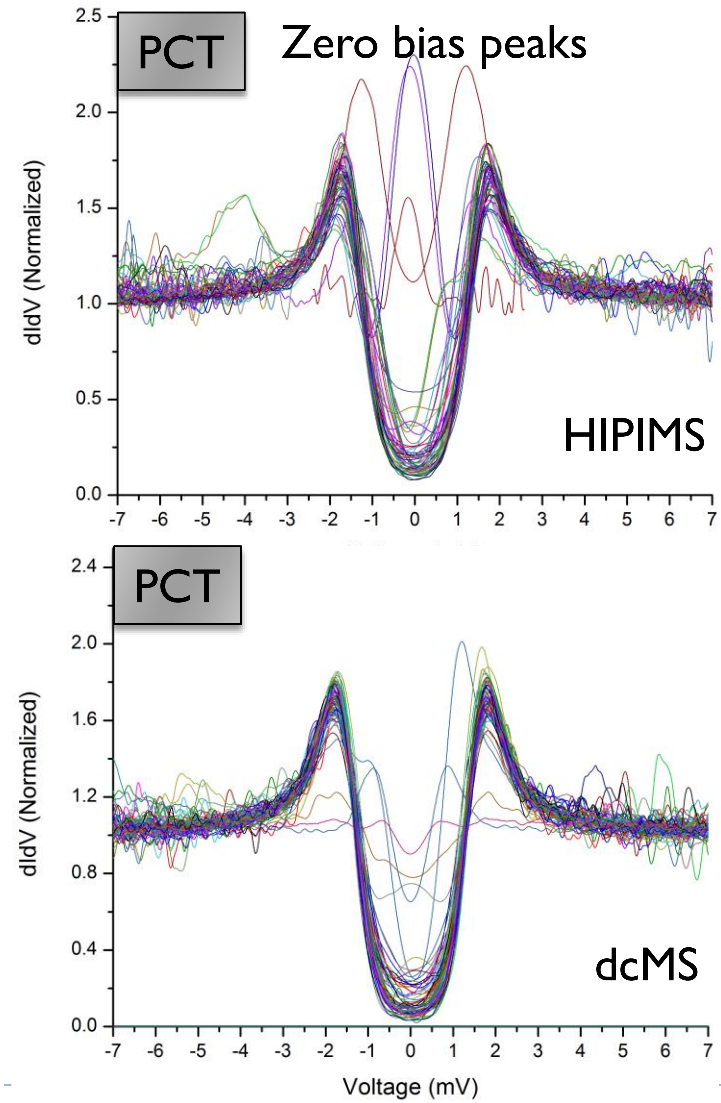
Main effect is relaxation of the ⅓ tail at long times, because 1/3 of the muons see a field in spin direction and do not process

Fast Fluctuations

No recovery. For faster fluctuations slower depolarization (motional narrowing)

Evidence for Magnetic Impurities in Nb on Cu samples





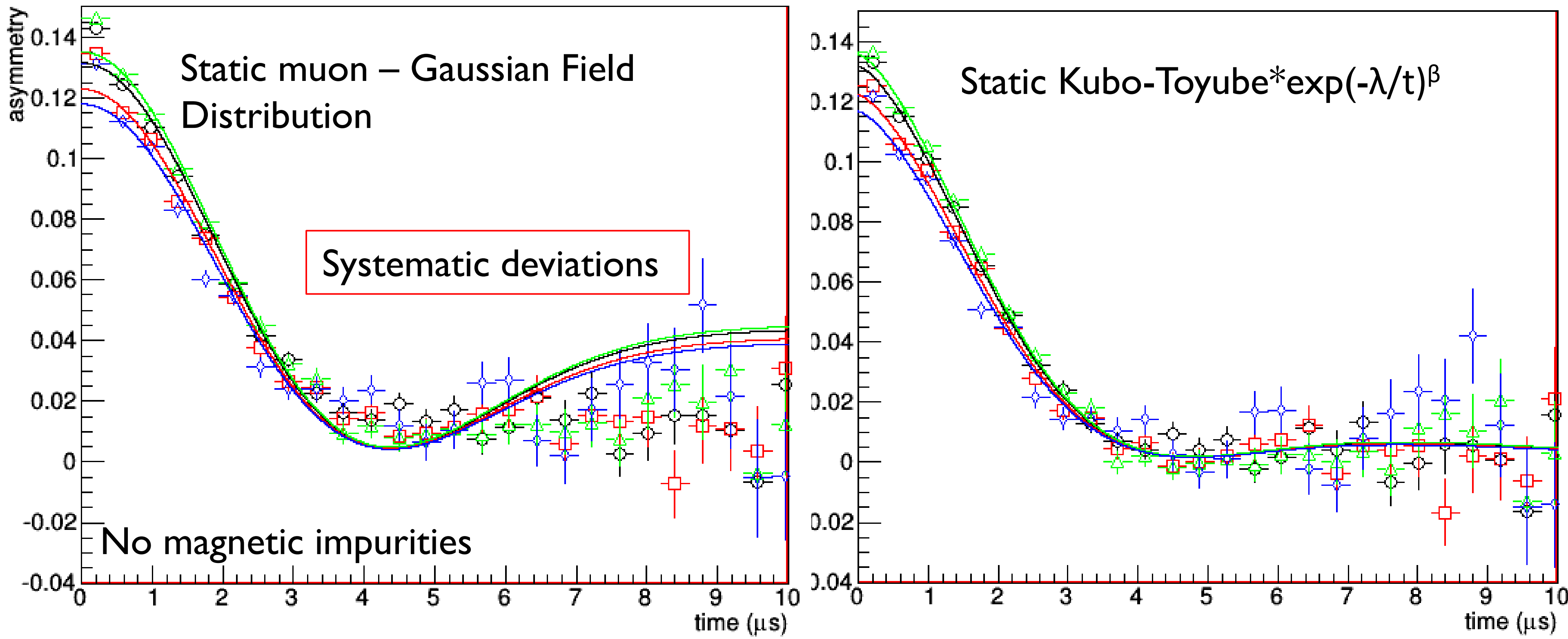
- HIPIMS shows strong fluctuations
  - Muon diffusion?
  - Magnetic Impurities?
- Magnetic Impurities supported by zero bias peaks observed with point contact tunneling (PCT) from ANL (T. Proslier)

Additional tests with a nitrogen overlayer

- We grew a nitrogen overlayer on the sample
- Stop the muon in the nitrogen but close to the niobum surface
- In nitrogen the muon is known to be static
- Deviations from the static Kubo-Tuyabe function will give evidence for magnetic impurities

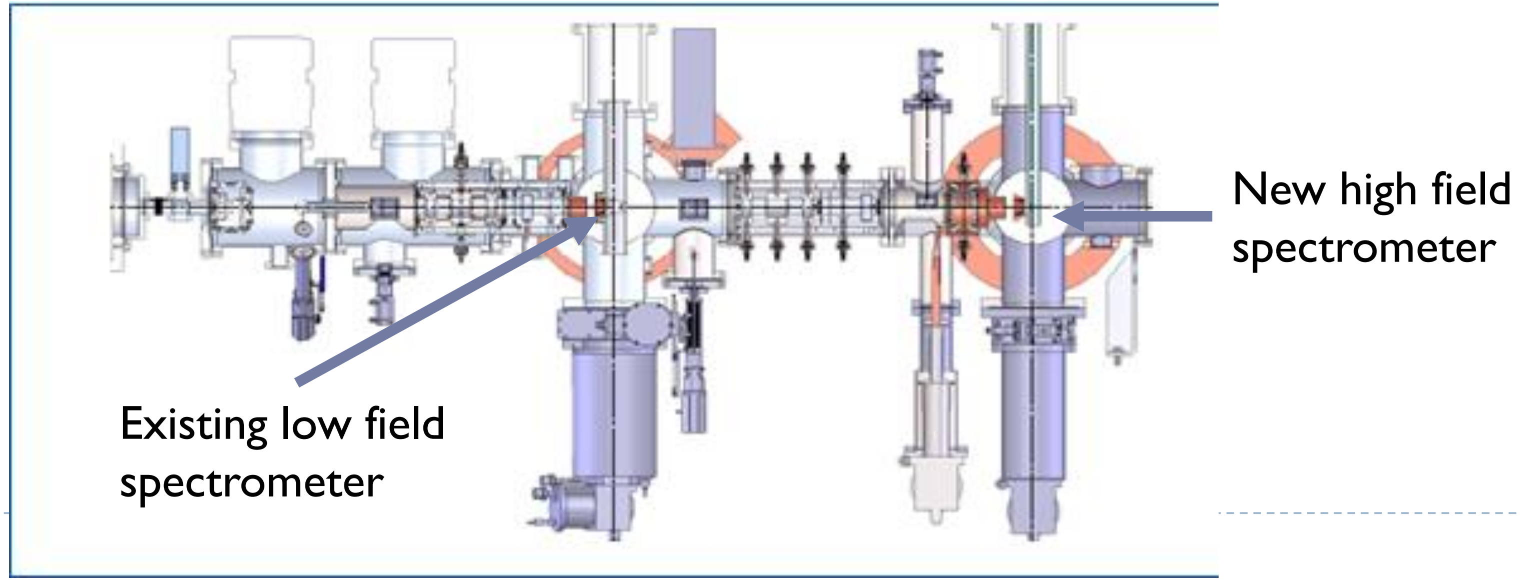
Measurements with N2-overlayer

- There is no muon diffusion in the N2-overlayer
- If there are no <u>magnetic</u> impurities in the Nb a staticGssKT function would fit the data



New beta-NMR beamline at TRIUMF for SRF studies

- Beta-NMR @ TRIUMF is a unique facility to characterize magnetic properties of materials at surfaces and film interfaces
- Similar to muSR but uses radioactive ions like 8Li implanted in bunches not one by one
- Like LEmuSR it can probe the superconductor through the London layer and depth profile thin films
- New high field spectrometer is being installed to allow high field (near Hc1) parallel to sample face (to replicate rf fields)
- TRIUMF will provide a unique facility in the world for diagnosing new treatments (doping), new materials (Nb3Sn) and new structures (SIS layers)



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Questions?