Measuring the pinning strength of SRF materials with muon spin rotation

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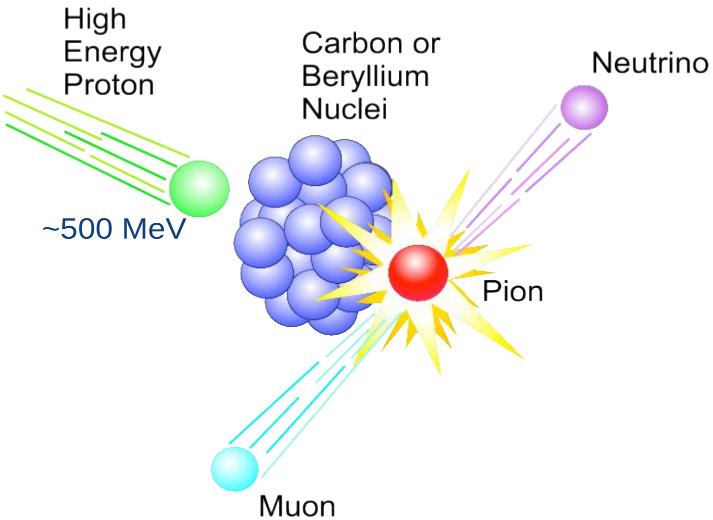
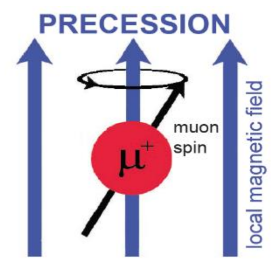
Muon production and decay



$$\pi^{+} \rightarrow \mu^{+} + \nu_{u}$$

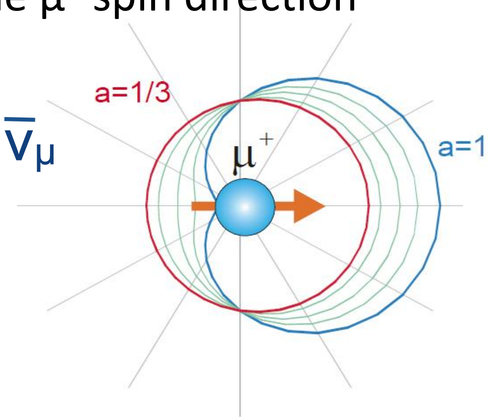
Muons are 100% spin polarized with kinetic energy of 4.1MeV

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

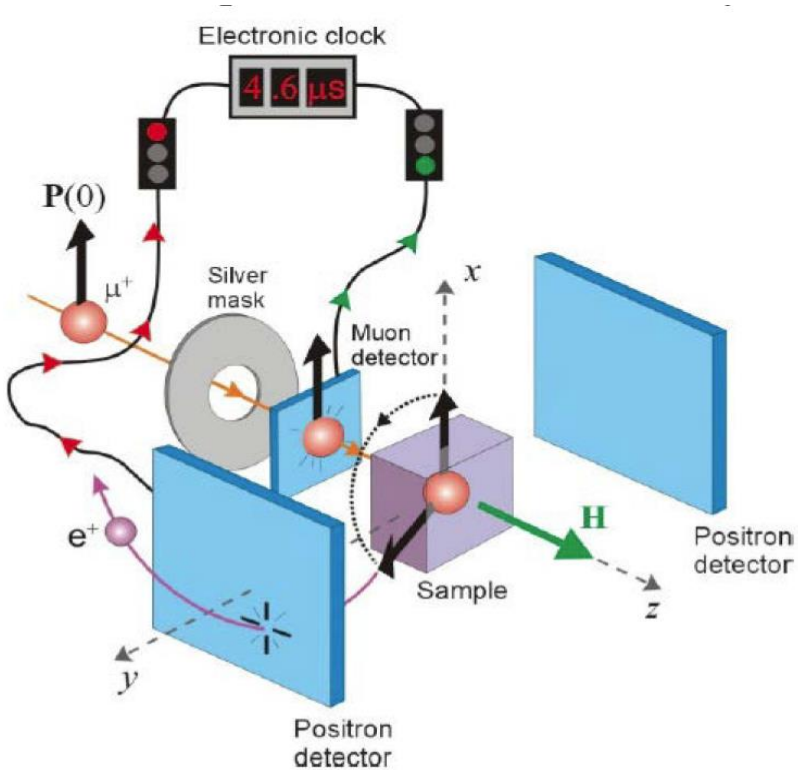


Muon decays in $\tau_{1/2}$=2.2μsec - emits a positron preferentially along the μ^{+} spin direction

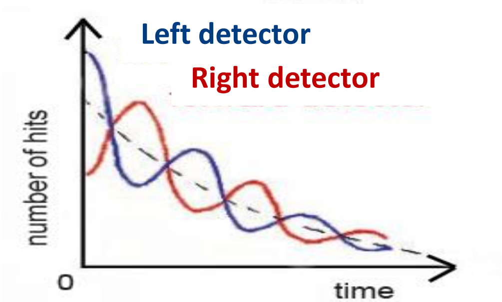
$$\mu^{+} \longrightarrow e^{+} + \nu_{e} + \bar{\nu}_{\mu}$$



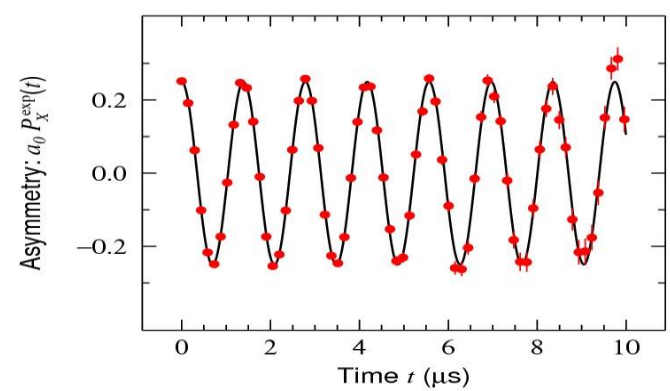
Muon Spin Rotation – muSR



- 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

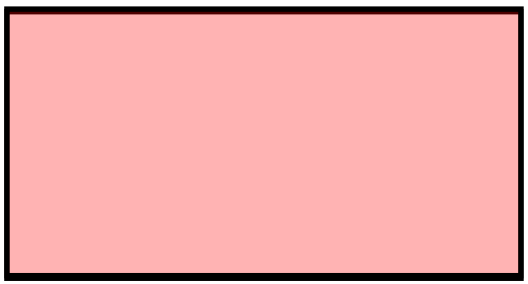


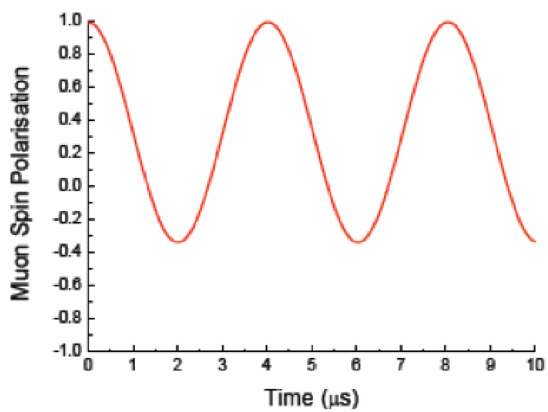
$$a_0 P_y(t) = \frac{N_L - N_R}{N_L + N_R}$$



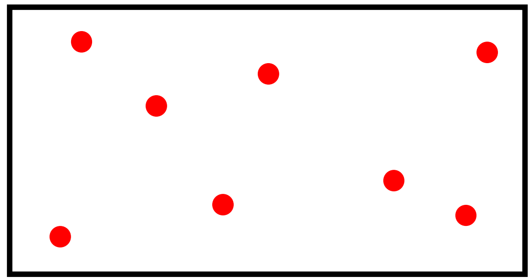
Magnetic Volume Fraction

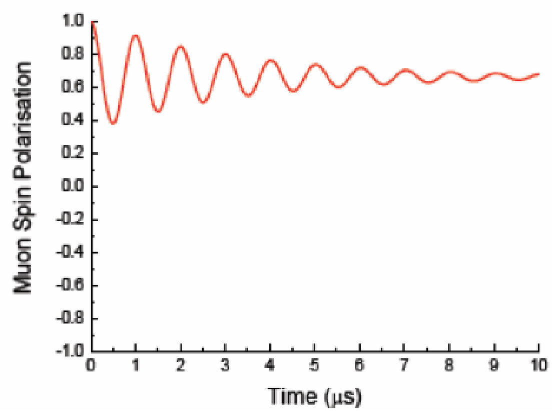
Uniformly weakly magnetic



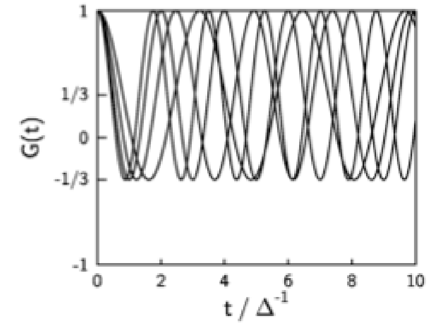


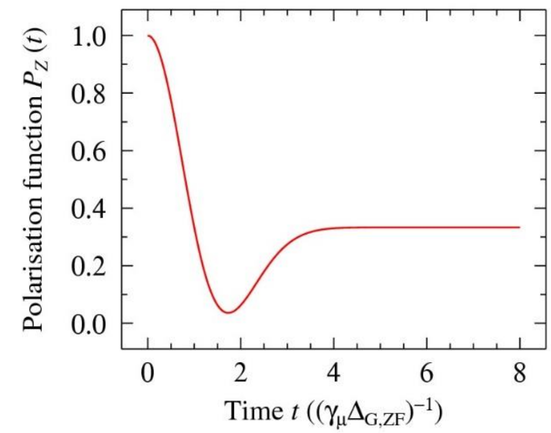
Non-magnetic with magnetic impurities





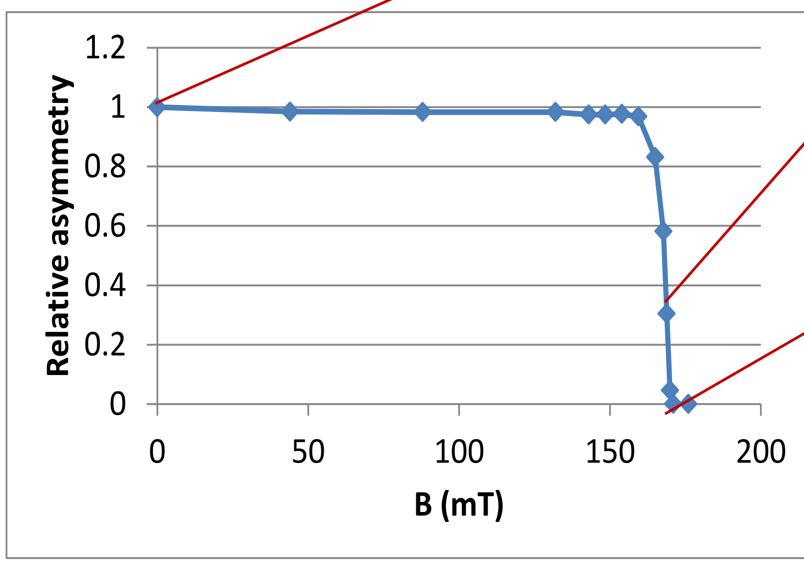
Static distribution of random fields

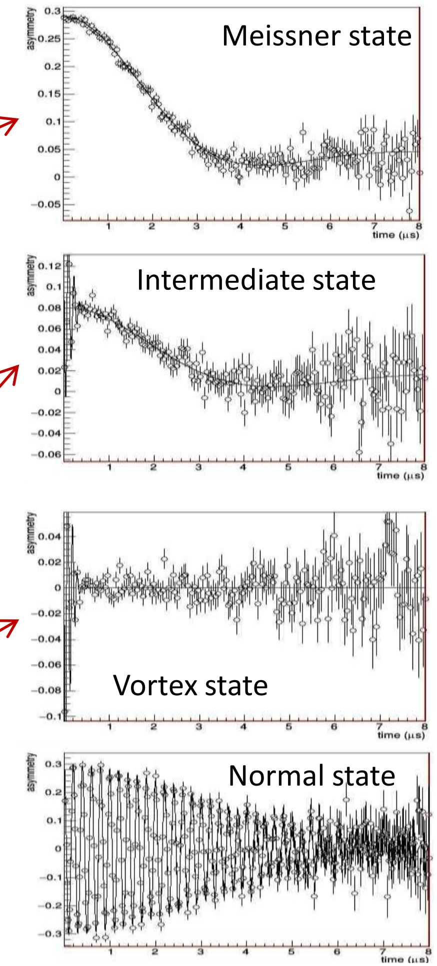




Using muSR as local magnetometer

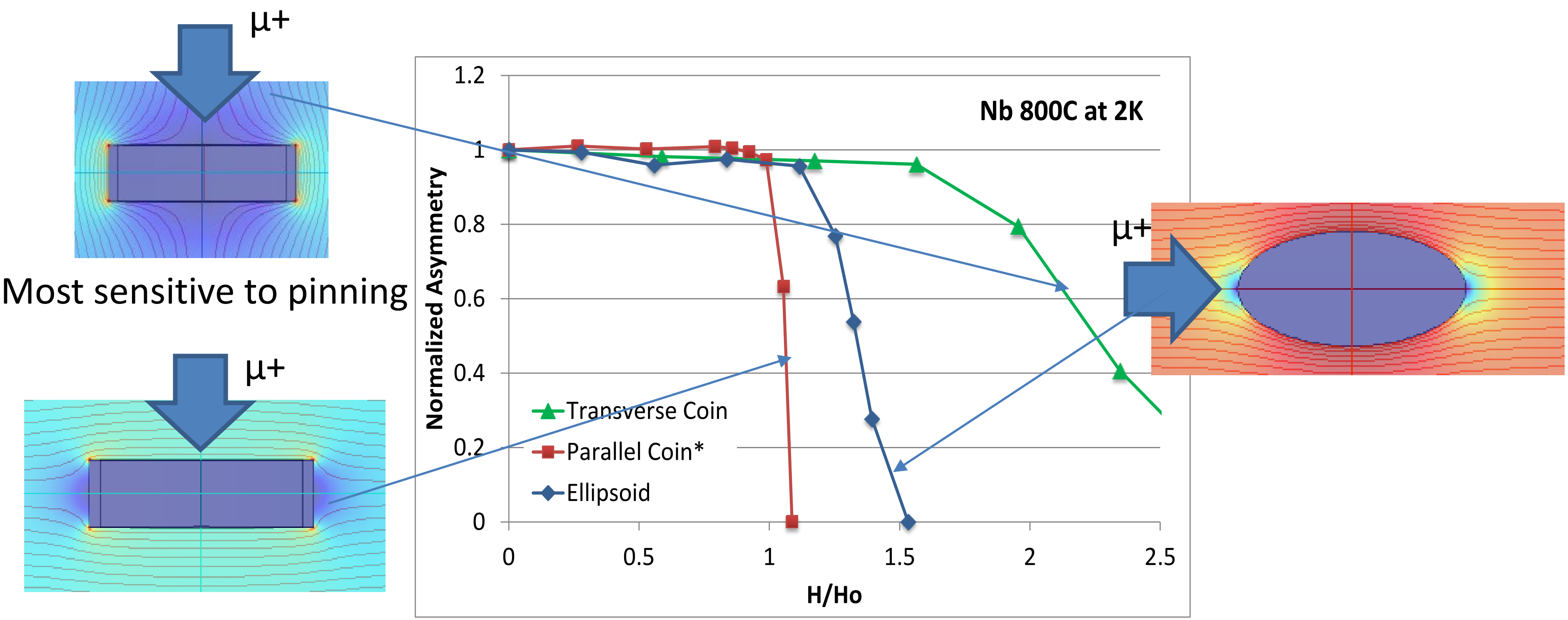
- A sample is cooled in zero field - asymmetry measurements are taken as a function of applied magnetic field
- The relative asymmetry at t=0 gives a measure of the volume fraction sampled by the muons that does not contain magnetic field
- A variety of samples and sample geometries have been characterized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





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

a) Ellipsoids and flat coin samples can be used
b) If the field is applied transverse to the sample surface it will first penetrate at the edges. Pinning will then delay the flux entry to centre which is the region probed by muSR
c) Applying the field parallel to the sample surface or using ellipsoids reduces the sensitivity to pinning



Ho: Expected field of first entry determined by generic Hc1 of niobium and demagnetization factor of the samples

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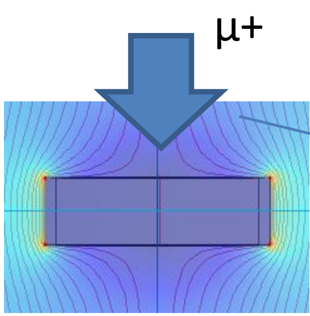
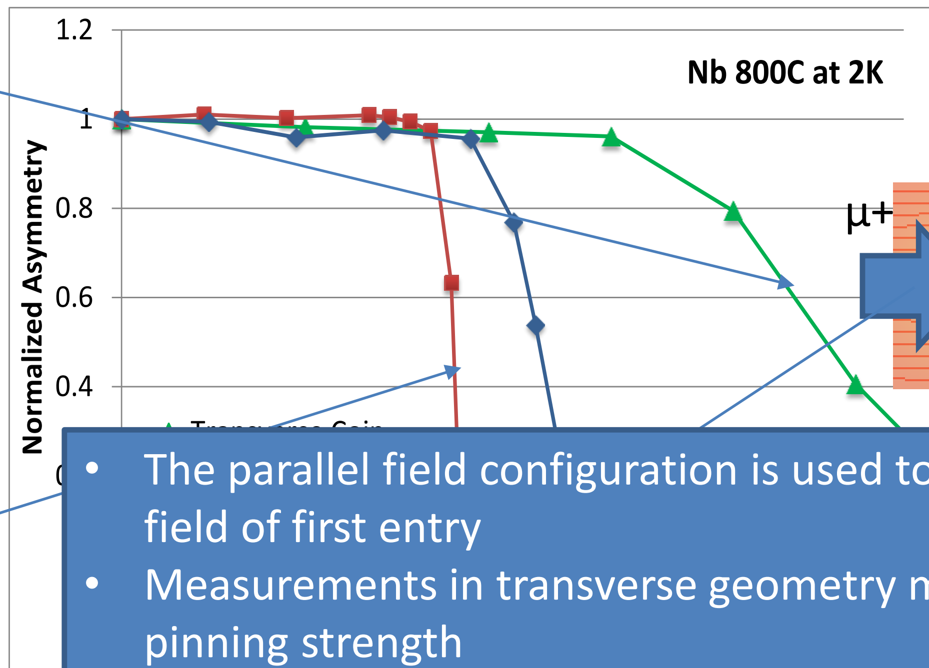
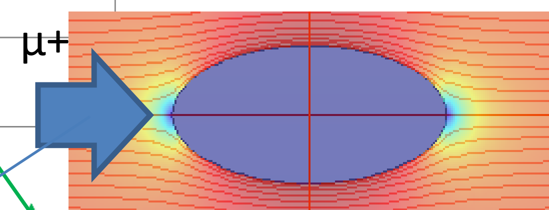
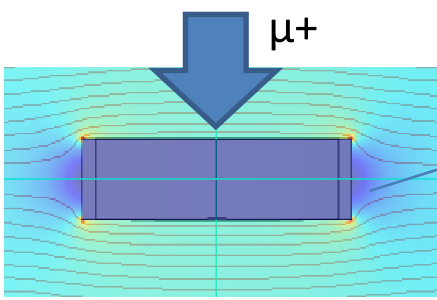


Most sensitive to pinning

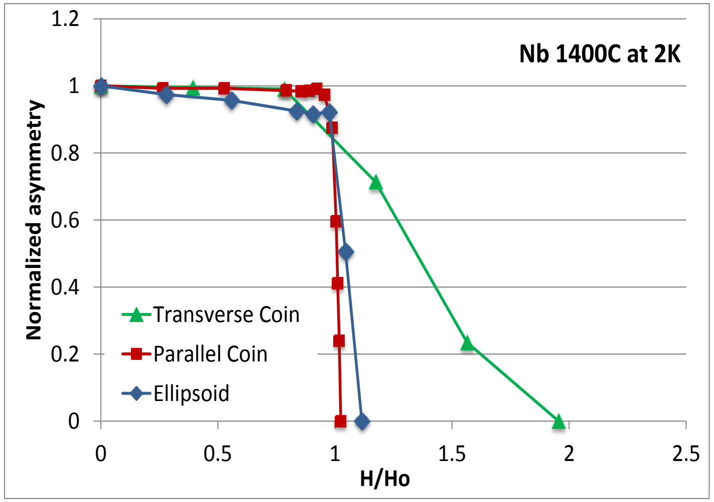




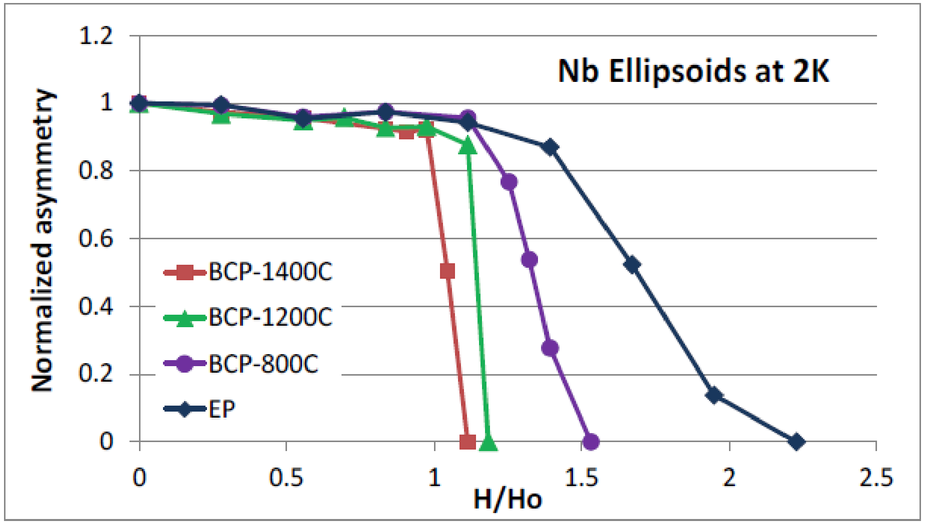


- The parallel field configuration is used to determine the field of first entry
- Measurements in transverse geometry measure the pinning strength
- **We can measure pinning strength and field of first entry of one sample using both geometries**

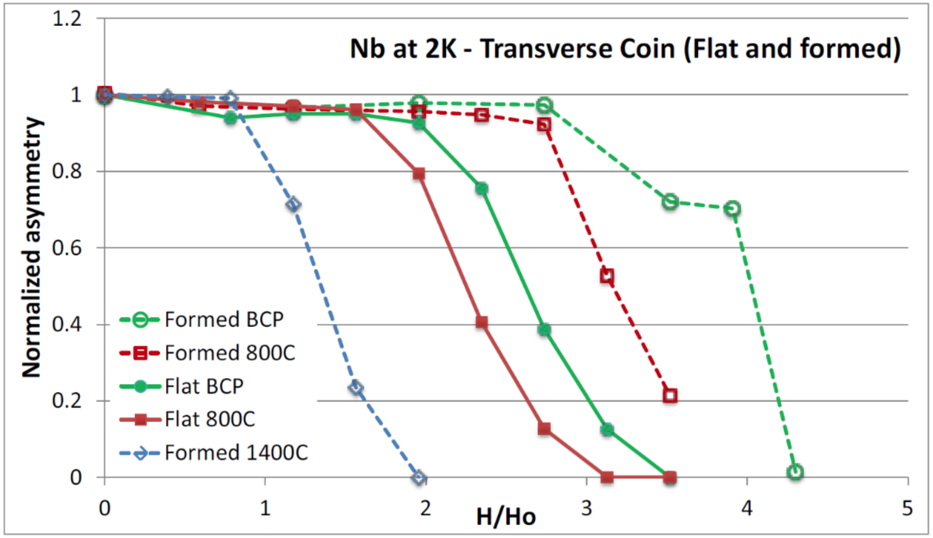
Bulk and surface treatments



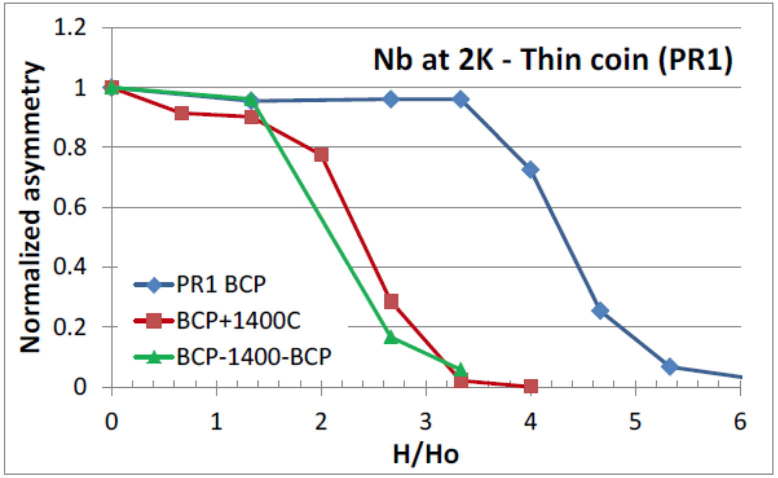
1400C virtually eliminates all pinning
Here H_{entry} is equal for all geometries



800C baking: still fairly strong pinning



Forming increases pinning
A 1400C bake virtually eliminates it completely



Surface treatments like BCP do not change the pinning strength of annealed samples

Summary

- Pinning is an important parameter for SRF since it can prevent flux expulsion during cooldown of cavities.
- We have developed a way to use muSR to measure the field of first entry and the pinning strength of SRF materials.
- Bulk pinning in the material changes considerably depending on the bulk and surface treatments.
- A 1400C heat treatment virtually eliminates pinning and surface treatments like BCP do not erase the effect.
- However a sample with strong pinning can have the pinning enhanced with BCP and 120C bake.