TRIUMF

Canada’s national laboratory
for particle and nuclear physics
and accelerator-based science

New insights for reaching higher gradients from muSR sample studies

Bob Laxdal, Tobi Junginger, P. Kolb, Y. Ma, Z. Yao

Collaborators:
- Rob Kiefl (UBC)
- A-M Valente (JLab)
- S. Posen, A. Grassellino (FNAL)
- D. Hall, M. Liepe (Cornell)
- T. Tan (Temple U.)

TTC, Saclay – June 7, 2016

Summary and content

Summary

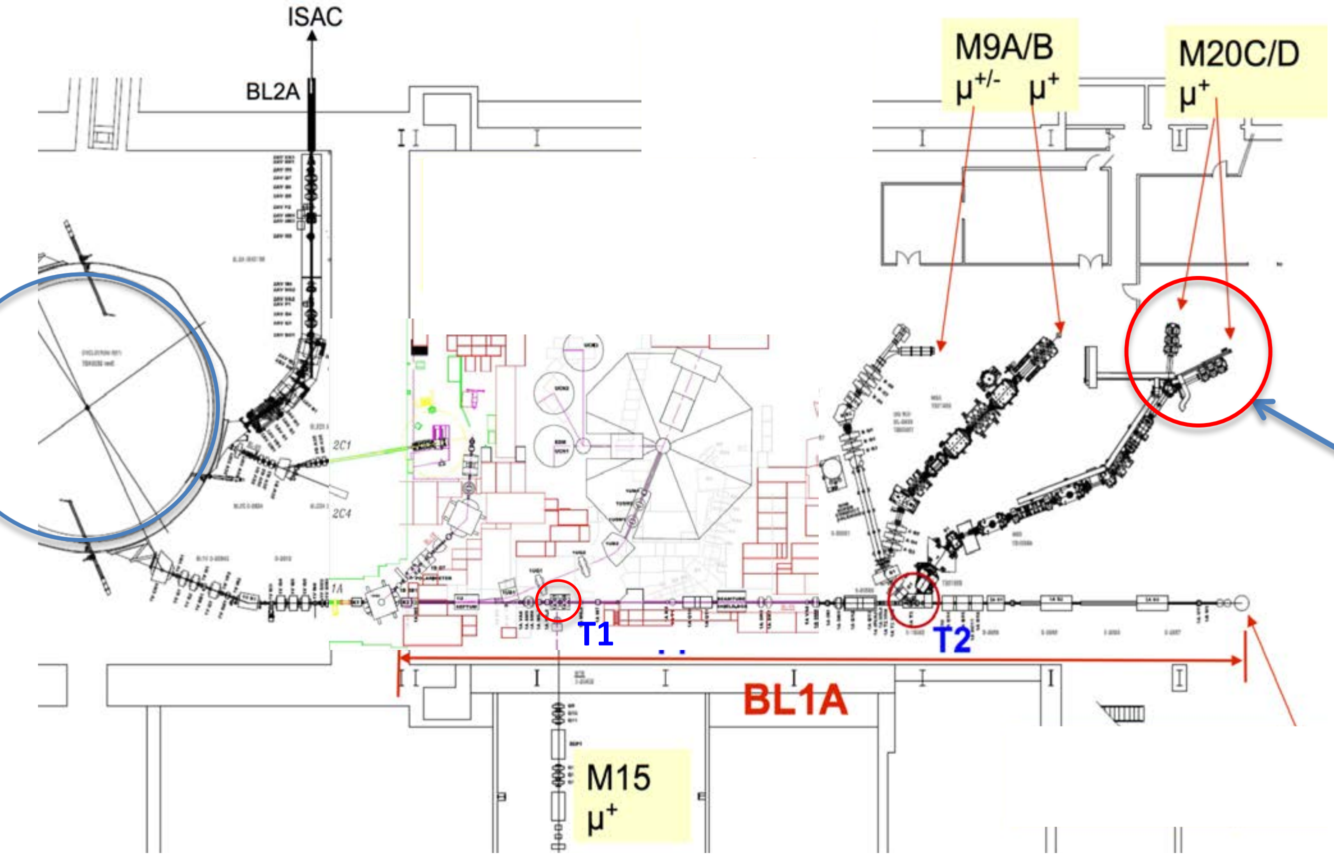
A layer of higher T_c material on niobium can push the field of first flux entry from a field consistent with H_{c1} to a field consistent with H_{sh}

Content

- Background: Introduction to muSR
- Experiment: Using muSR as a local magnetometer
- Results: - Role of geometry and pinning
  - Nb3Sn on niobium and bulk niobium

Reference: SRF2015 - *CHARACTERIZATION OF SRF MATERIALS AT THE TRIUMF μSR FACILITY - Laxdal et al*
- TESTING NB3SN COATING USING μSR - Laxdal et al

TRIUMF muSR Facility

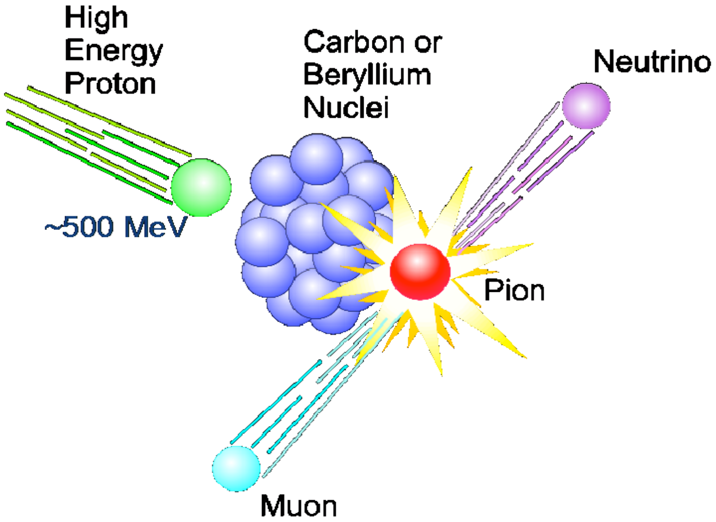


- muSR facility operational at TRIUMF since the early eighties
- 500MeV proton beam from the TRIUMF cyclotron produces muons at two production targets

SRF @ M20 C and D-leg

TRIUMF

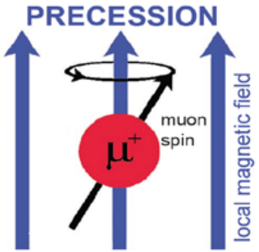
Muon production and decay



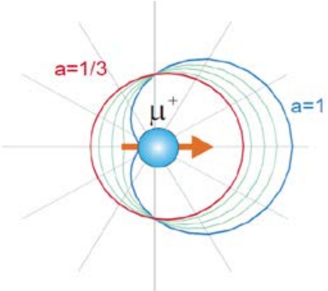
$$\pi^{+} \rightarrow \mu^{+} + \nu_{u}$$

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

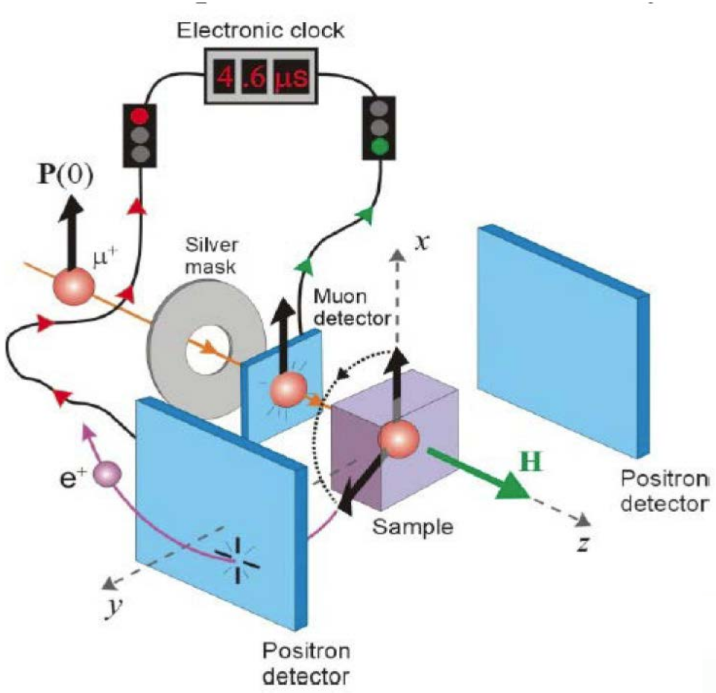
Muons are deposited ~100micron deep in a sample (bulk probe) – spin precesses with frequency dependent on local magnetic field



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

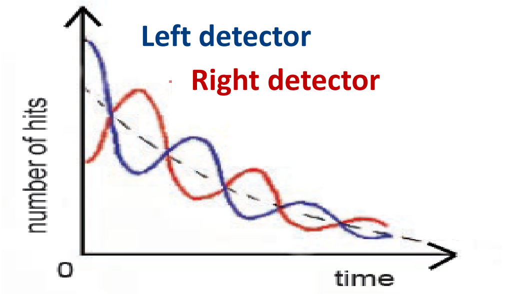


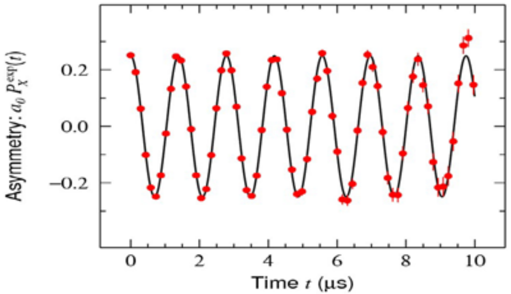
Muon Spin Rotation – muSR



$$a_0 P_y(t) = \frac{N_\mathrm{L} - N_\mathrm{R}}{N_\mathrm{L} + N_\mathrm{R}}$$

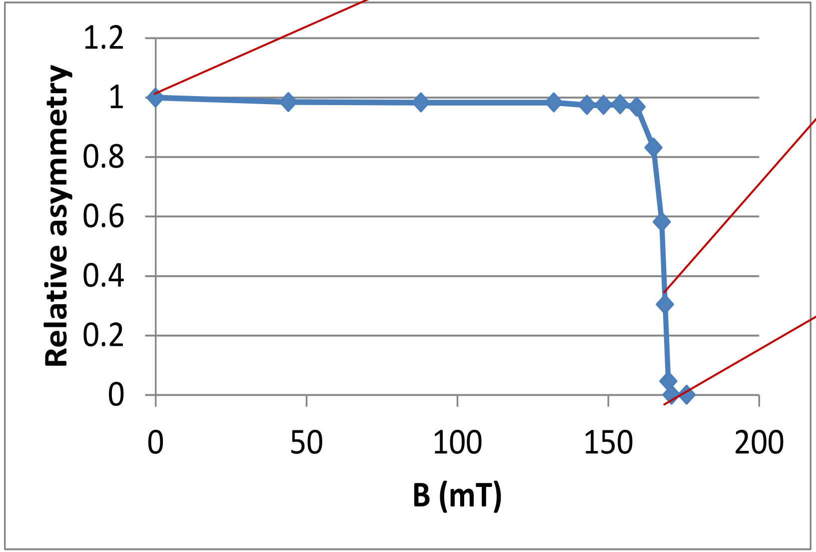
- Muons are deposited in a sample
- Muon decays emitting a positron preferentially aligned with the muon spin
- Right and left detectors record positron correlated with time of arrival
- The time evolution of the asymmetry in the two signals gives a measure of the local field in the sample

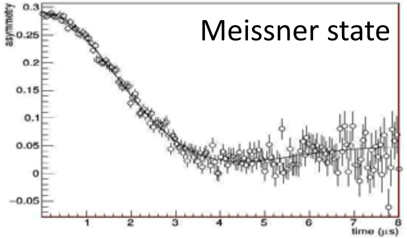


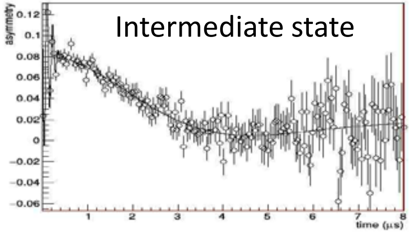


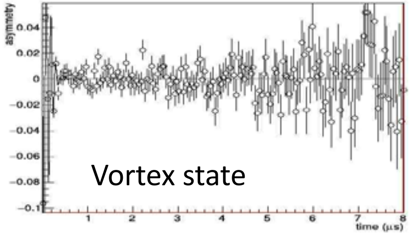
Using muSR for SRF material studies

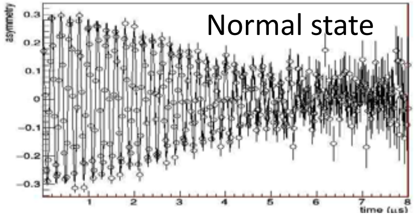
- A sample is cooled in zero field - asymmetry measurements are taken as a function of applied magnetic field
- The relative asymmetry at T=0 gives a measure of the volume fraction sampled by the muons that does not contain magnetic field
- A variety of samples and sample geometries have been characterized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





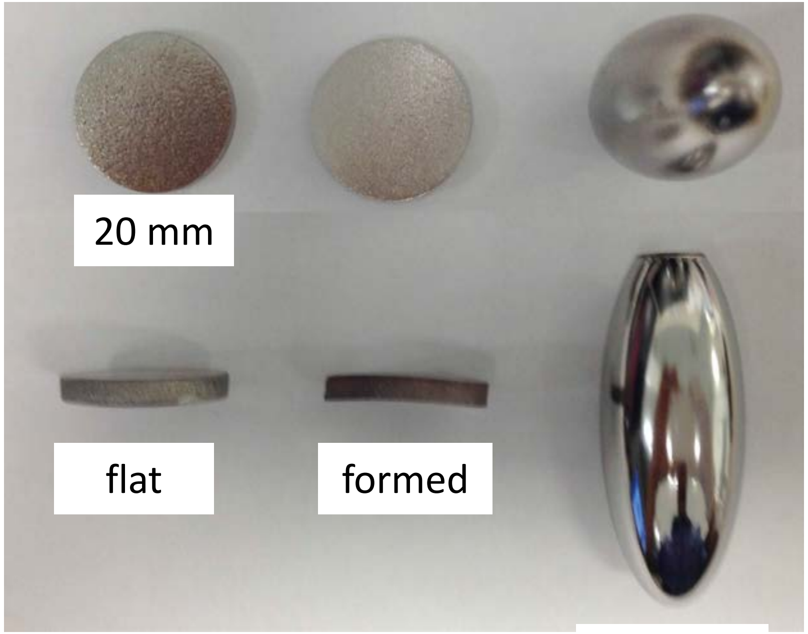


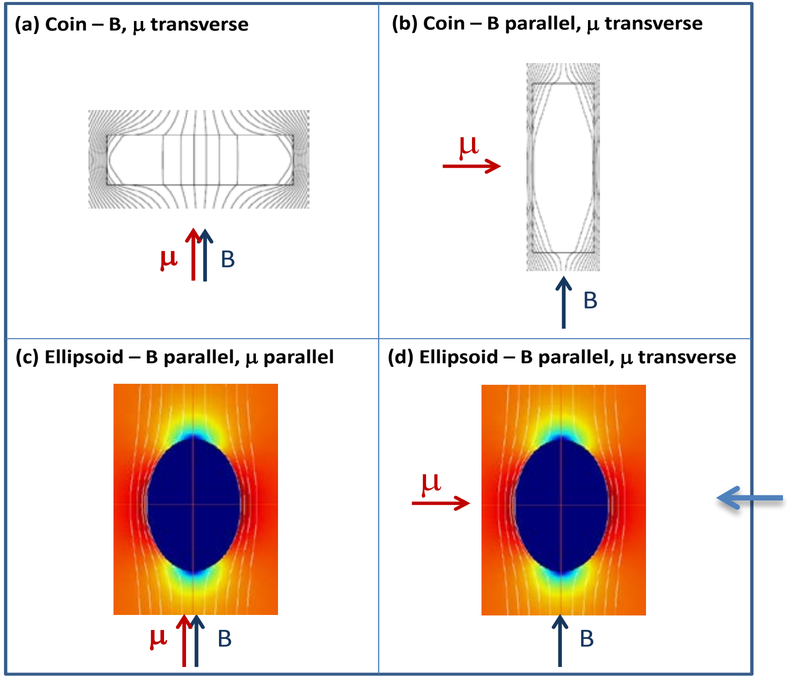




Samples and geometries

Coins, ellipsoids and cavity cut-outs can be tested with the magnetic field being perpendicular or parallel to the surface




(a) Coin – B, μ transverse

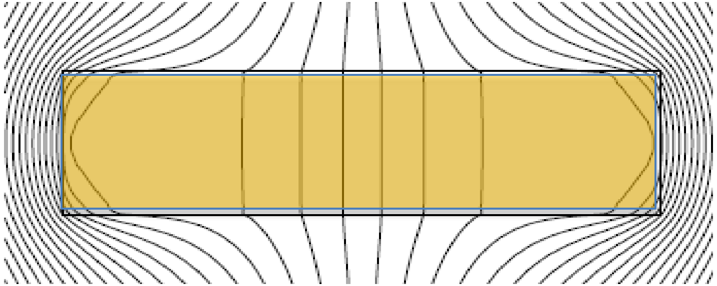
(b) Coin – B parallel, μ transverse

(c) Ellipsoid – B parallel, μ parallel

(d) Ellipsoid – B parallel, μ transverse

Next test

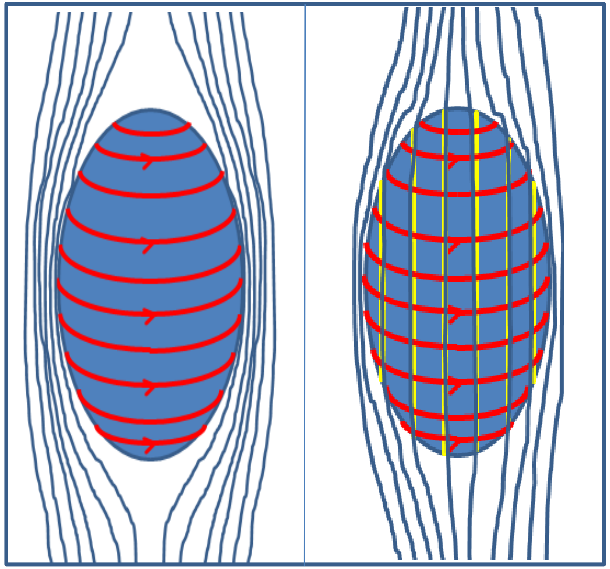
Geometry considerations for coins and ellipsoids



Flux applied to a thin circular disk (coin) transverse to an applied field*

Flux nucleates at the corners until flux lines join then move to the centre to minimize energy - Pinning centers add 'resistance' to mobility of flux moving from the edges to the centre – increases H_{entry} compared to a pin-free case

*E.H. Brandt, Physica C 332 (2000) 99-107.



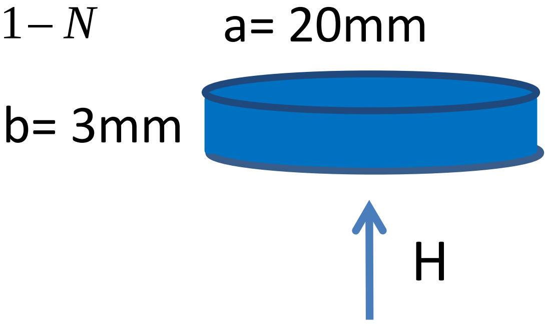
Flux applied to an ellipsoid

Flux nucleates at the equator and distributes uniformly through the sample for the pin free case - Flux redistribution is impeded by pinning

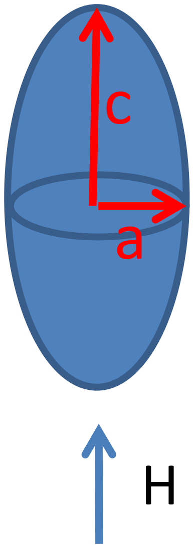
Demagnetization factor

$$H_{edge} = \frac{H}{1-N}$$

N=0.77



$$\frac{H_{applied}\big|_{entry}}{H_{nucleate}} = \tanh\left(\sqrt{0.67\frac{b}{a}}\right) = 0.31$$



N=0.13

$$N_z = \frac{1-e^2}{e^3}\left(\operatorname{arctanh} e - e\right)$$

$$e = \sqrt{\left|1 - a^2/c^2\right|}$$

$$\frac{H_{applied}\big|_{entry}}{H_{nucleate}} = 0.87$$

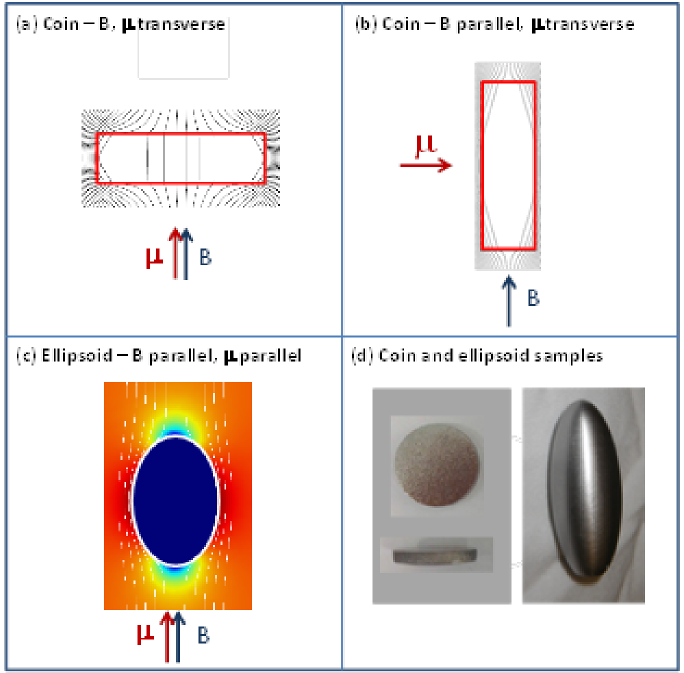
Sample	N	$H_{applied}\|_{entry} / H_{nucleate}$	H_0 (mT)
Transverse coin	0.77	0.31	51
Parallel Coin	0.2	0.91	150
Ellipsoid	0.13	0.87	144

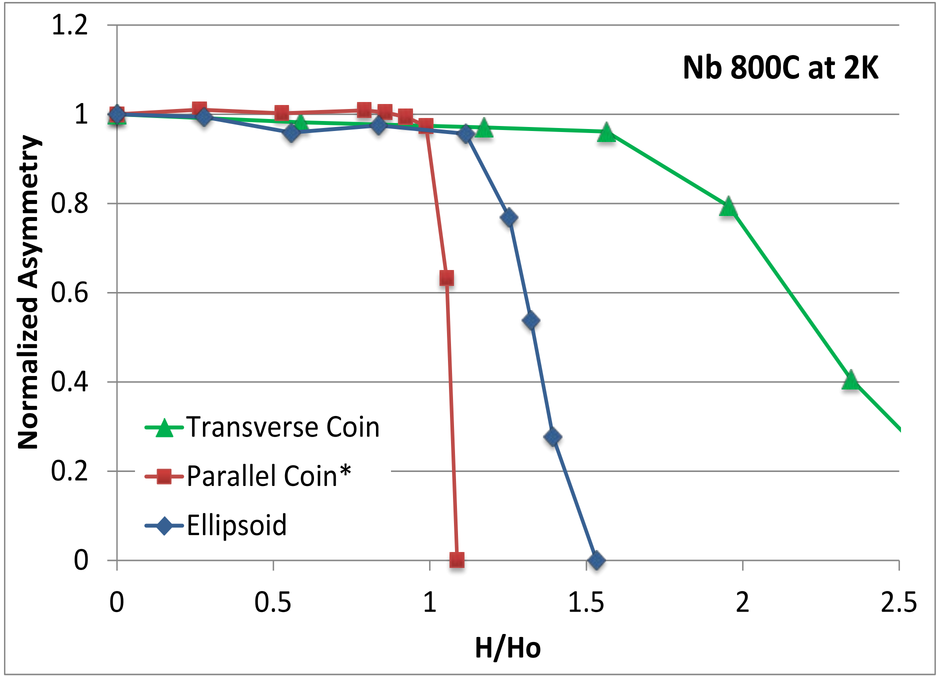
Demagnetization factor *N* for standard test samples and associated ratio of $H_{applied}|_{entry}$ to $H_{nucleate}$ field. H_0 is the expected entry field (at 2.5K) assuming $H_{nucleate}$ [0K] =180mT.

Role of pinning

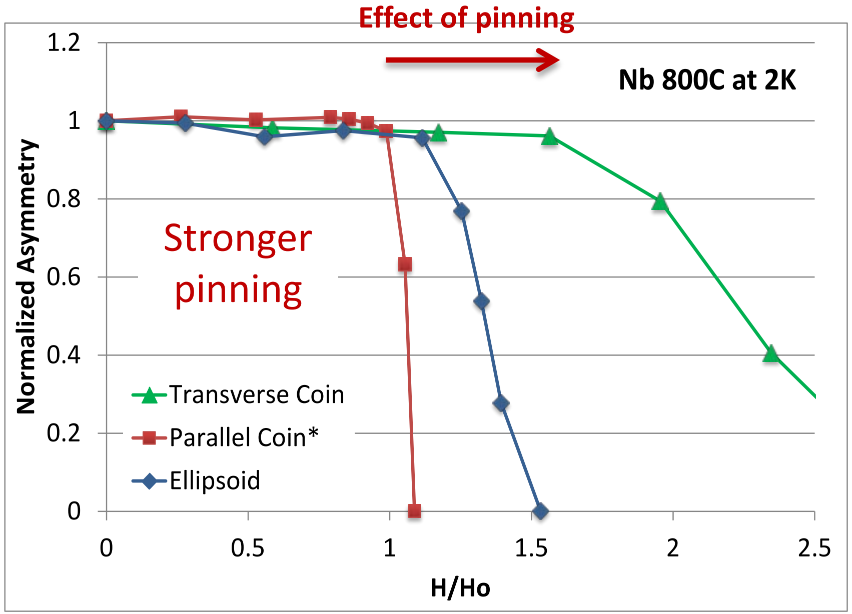
a) Transverse coin samples are sensitive to pinning - delays flux break in to the centre
b) Parallel coin geometry is insensitive to pinning
c) Ellipsoid samples are less sensitive

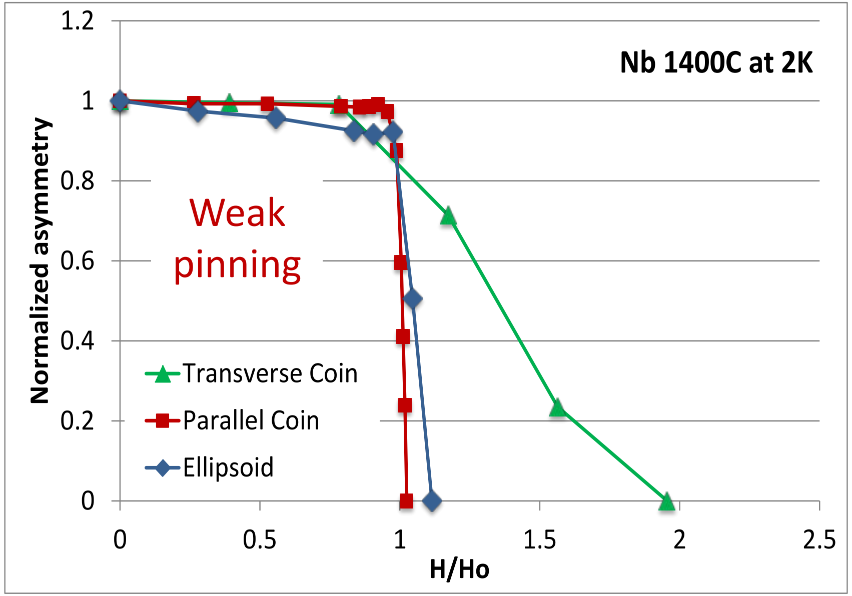
- All three geometries are useful to characterize the material





Role of pinning – 1400C anneal





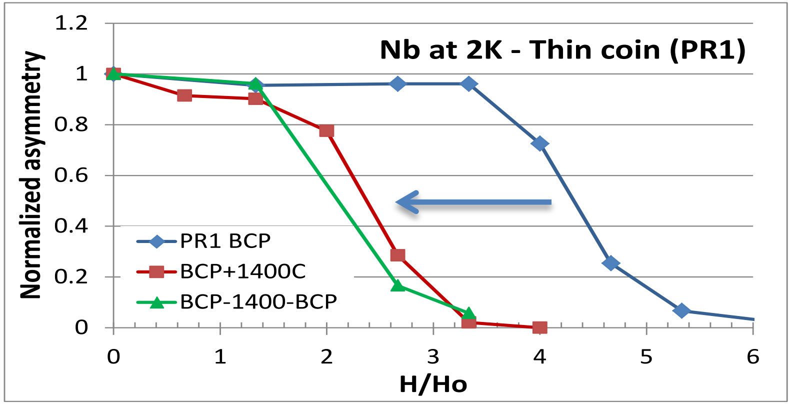
800C baked samples – pinning is clearly seen in different H_{entry} between transverse, parallel coin and ellipsoid geometry

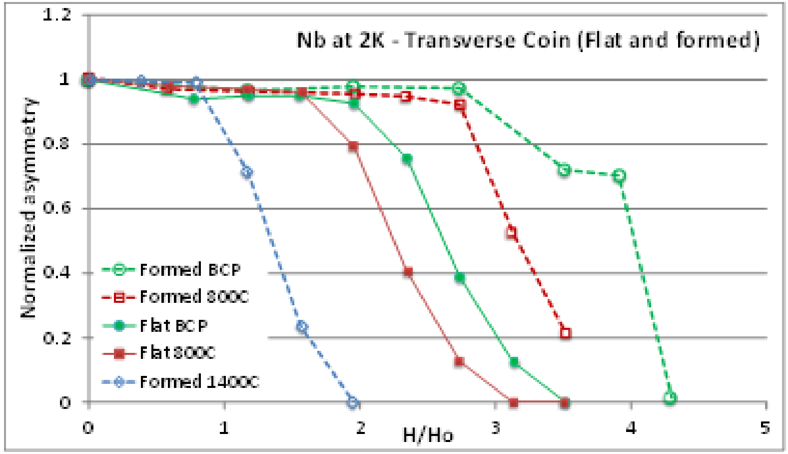
1400C heat treatment for three geometries

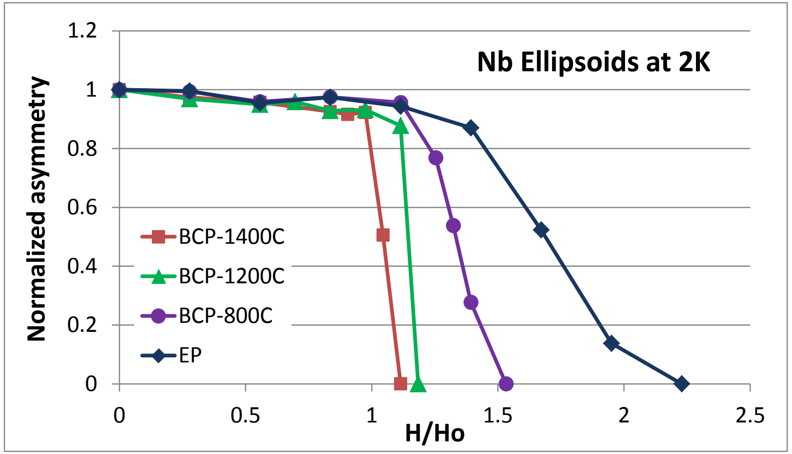
- virtually eliminates pinning from the Nb
- H_{entry} is equal for all geometries

Pinning strength as a function of treatment

- Pinning changes significantly by forming and surface treatment
- High temperature treatment (1400) very effective at eliminating pinning but even lower temperatures (800-1200) have a positive effect
- Pinning characteristics can impact flux expulsion



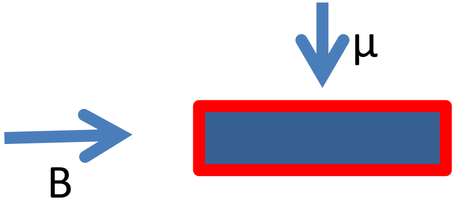




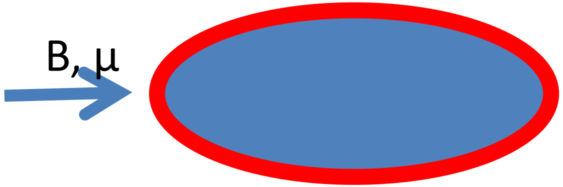
Nb3Sn on Nb

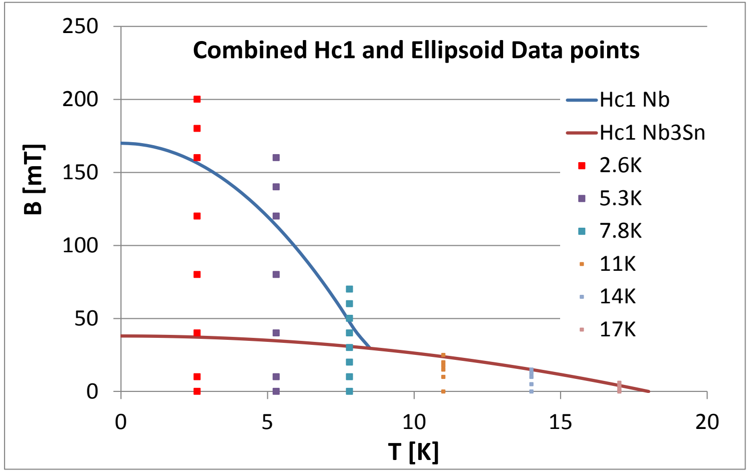
Nb3Sn coating measurements

- A Nb ellipsoid and a Nb coin were coated with 2 microns of Nb3Sn at Cornell
- The coin was tested in parallel geometry at 2.5K (only)

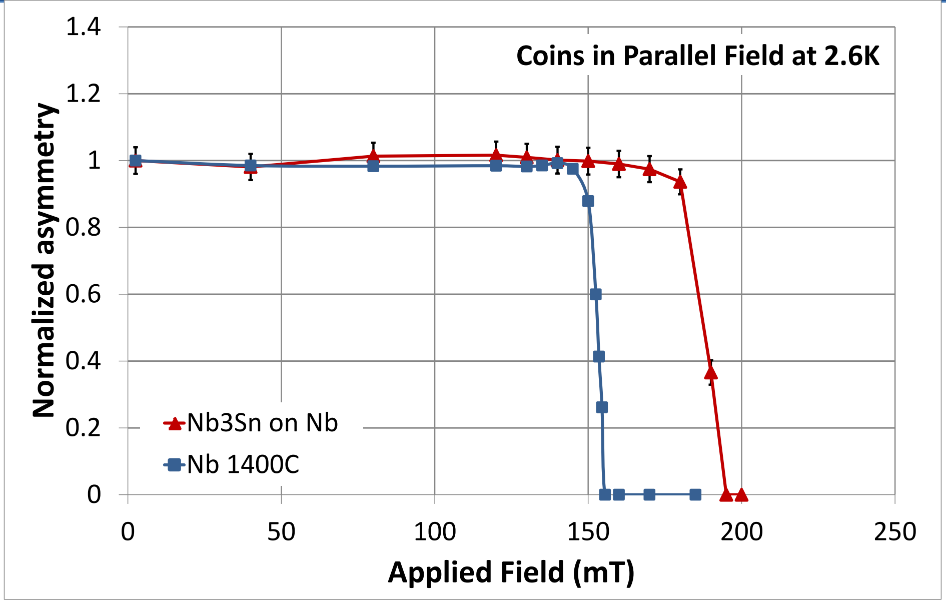


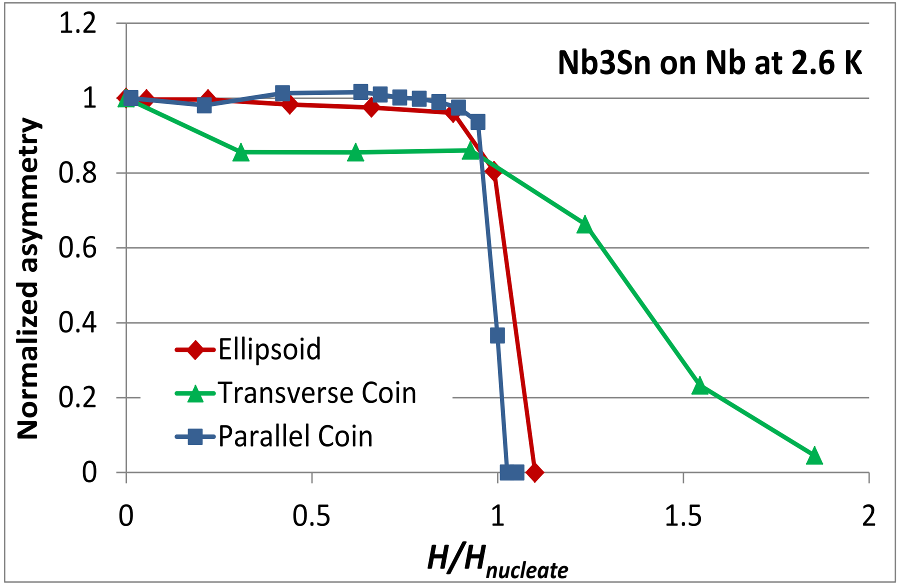
- The ellipsoid was tested as below at a number of different temperatures





Nb3Sn on Nb Parallel Coin Results

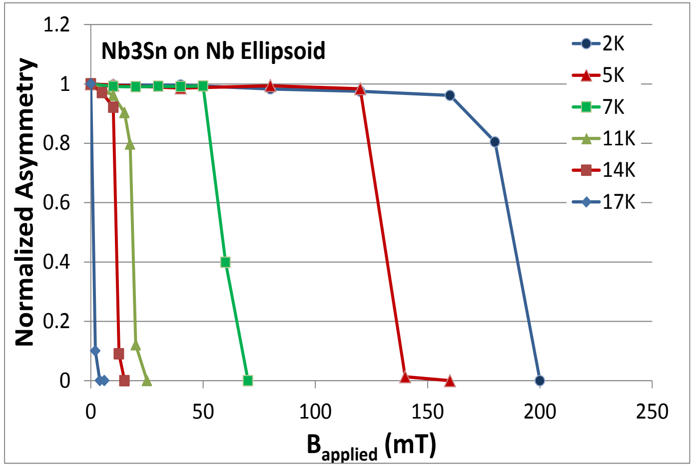


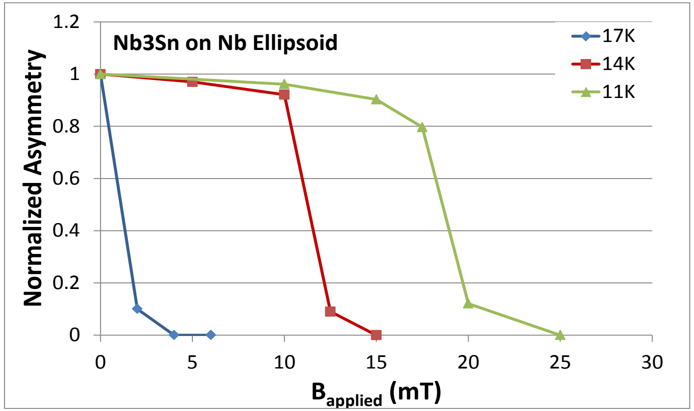


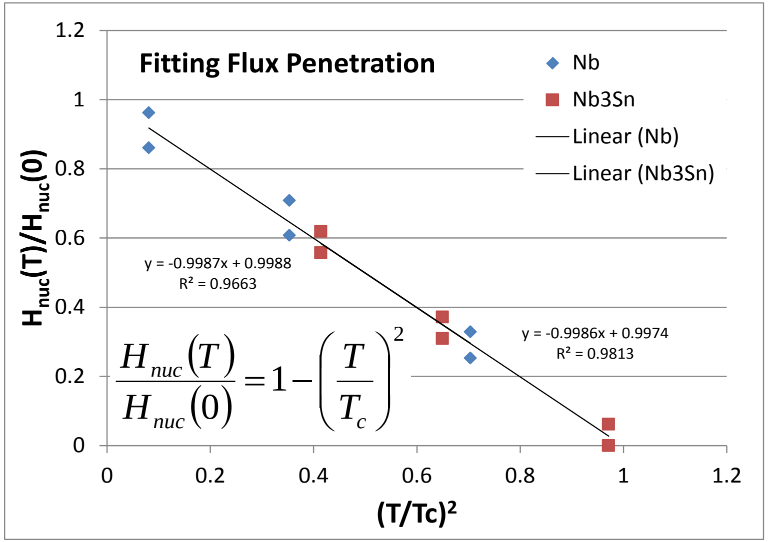
Parallel field result for Nb3Sn on Nb coin and annealed Nb coin for applied field at T=2.6K

Results are not due to pinning as 1200C Nb3Sn application renders almost pin-free result as demonstrated by transverse coin test

Nb3Sn on Nb Ellipsoid results





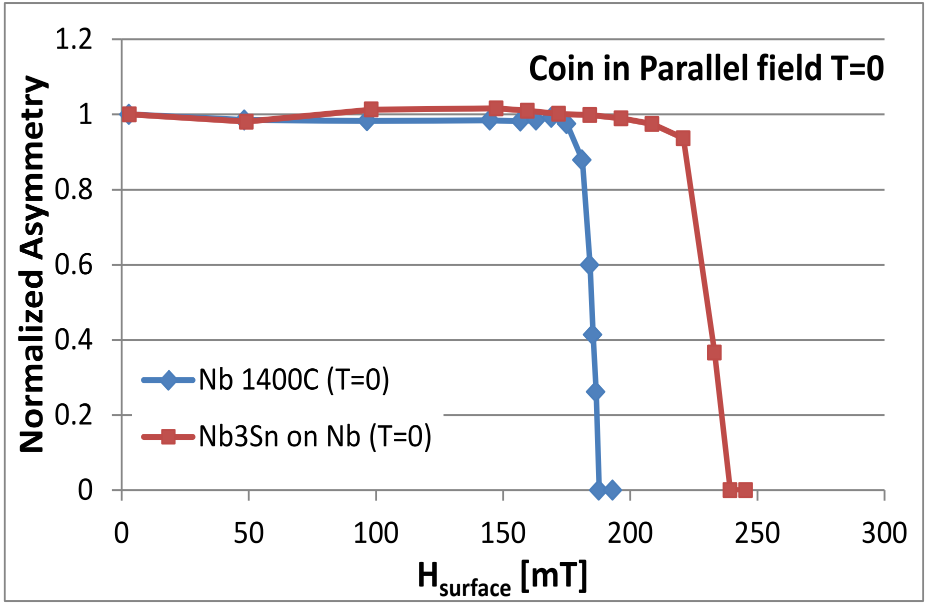


$$\frac{H_{nuc}(T)}{H_{nuc}(0)} = 1 - \left(\frac{T}{T_c}\right)^2$$

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

The fitted $H_{nuc}(0)$ and T_c for Nb and Nb3Sn based on the Nb3Sn coated Nb ellipsoid data.

Comments

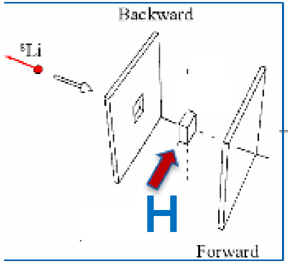


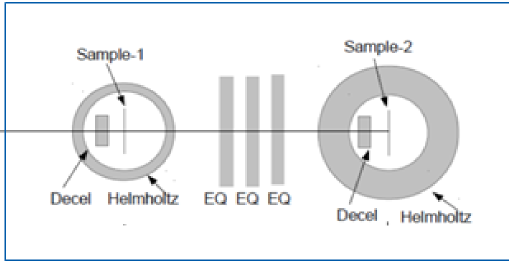
- An uncoated Nb sample in parallel geometry has flux breaking in at 180mT (at T=0) – consistent with H_{c1}
- A Nb coin coated with Nb3Sn has flux breaking in at 230mT (at T=0) consistent with H_{sh} of Nb
  - The ellipsoid coated with Nb3Sn has flux breaking in at 227mT (at T=0)
- Break in field for Nb3Sn was measured at 37mT (T=0) consistent with expected H_{c1}

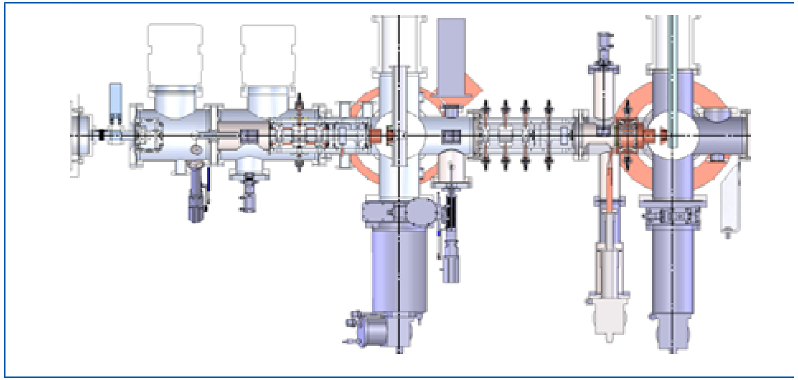
TRIUMF

New beamline at TRIUMF for SRF studies using beta-NMR

- Beta-NMR @ TRIUMF is a unique facility to characterize magnetic properties of materials at surfaces and film interfaces
- Perfect for SRF characterization of materials since 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)
- Will provide a unique facility in the world for diagnosing new treatments (doping), new materials (Nb3Sn) and new structures (SIS layers)







Utilizes 8Li ion soft-landing within 0-200nm of the surface – probe for exploring surfaces and interfaces

Summary and Outlook

Summary

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}

Outlook

- We will test this hypothesis on Nb_3Sn and MgB_2 of different thickness on Nb (TRIUMF) – next run July 18
- We will study the superconducting parameters at the interface of two superconductors using low energy muSR (PSI)

TRIUMF

Canada’s national laboratory
for particle and nuclear physics
and accelerator-based science

TRIUMF: Alberta | British Columbia | Calgary | Carleton | Guelph | Manitoba | McGill | McMaster | Montréal | Northern British Columbia | Queen’s | Regina | Saint Mary’s | Simon Fraser | Toronto | Victoria | Western | Winnipeg | York

Thank you!
Merci!

Follow us at TRIUMFLab