Use MgB_2 Coated Ellipsoids as an Approach to Study the Vortex Penetration Field (B_{vp}) of SRF Cavities

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Outlines

- Motivation:

a) MgB_2 for SRF cavities.

b) Why coat an ellipsoid.

- Experiments:

a) Ellipsoids design and machining.

b) Ellipsoids coating.

- Results and conclusions:

a) Constant *T*, *m*-*H* measurement.

b) Constant *H*, *m*-*T* measurement.

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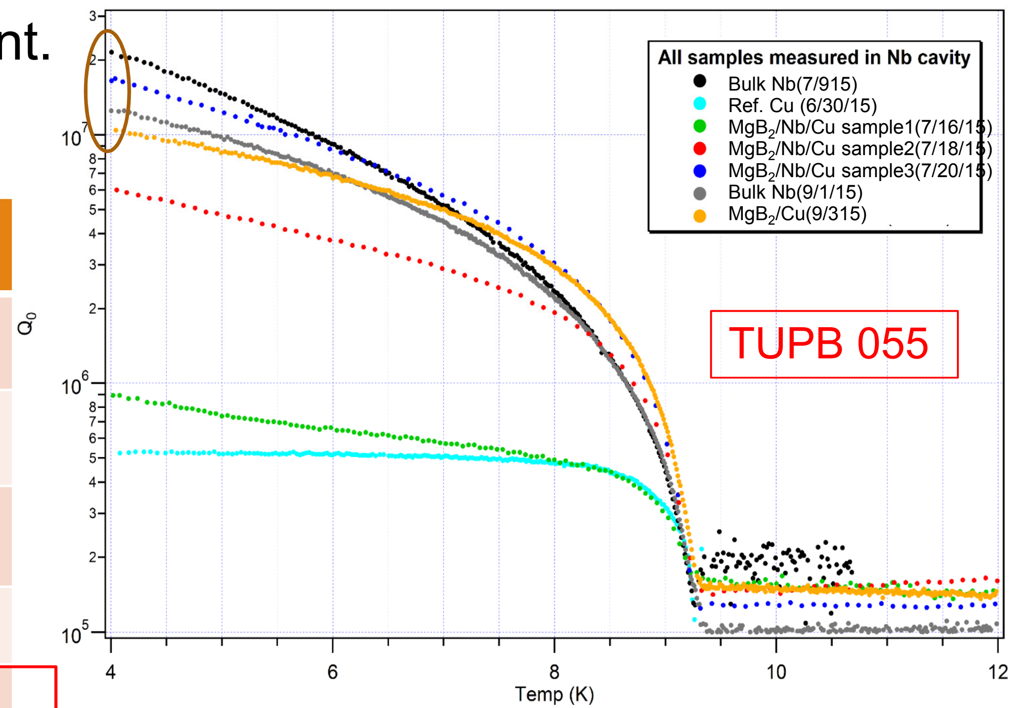
MgB_2 for SRF application

Look for the material beyond Nb:
- Large Δ and small ρ_0 => low R_{BCS}.
- High B_c & B_{c1} (film) => high gradient.
- Cheaper material cost.
- High T_c: reduce cryogenic cost.

	Niobium	MgB_2
T_c (K)	9.3	40
ρ_0 (μΩ cm)	5	0.1
Δ (meV)	1.5	7.2(σ)2.4(π)
$B_c(0)$ (T)	0.2	0.3
B_{c1} (mT)	170	<50 bulk >200 thin film

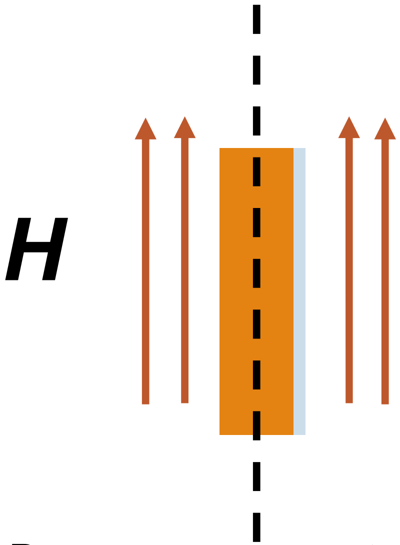
Cannot use bulk MgB_2, only coated cavity

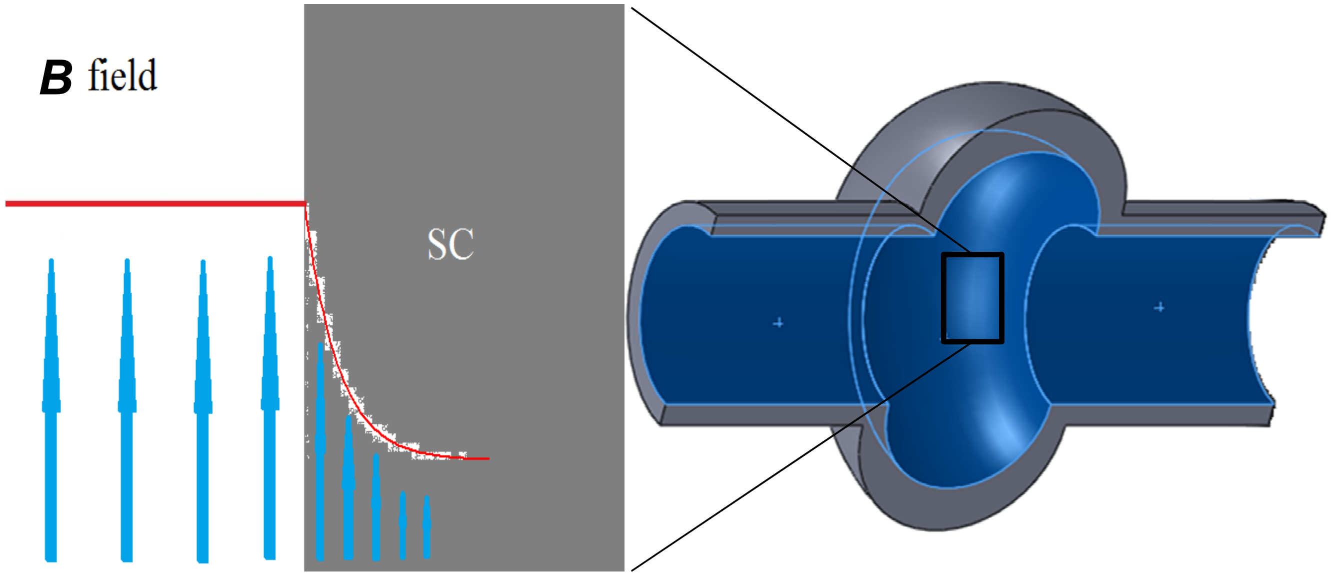


Measurement @SLAC.
MgB_2/Nb/Cu, MgB_2/Cu

Why ellipsoid

Vortex penetration generate loss.
Difference between thin film B_{c1} study and real cavity application.





B_{c1} measurement of SC thin films.
> 400 mT for 100 nm MgB_2 film.

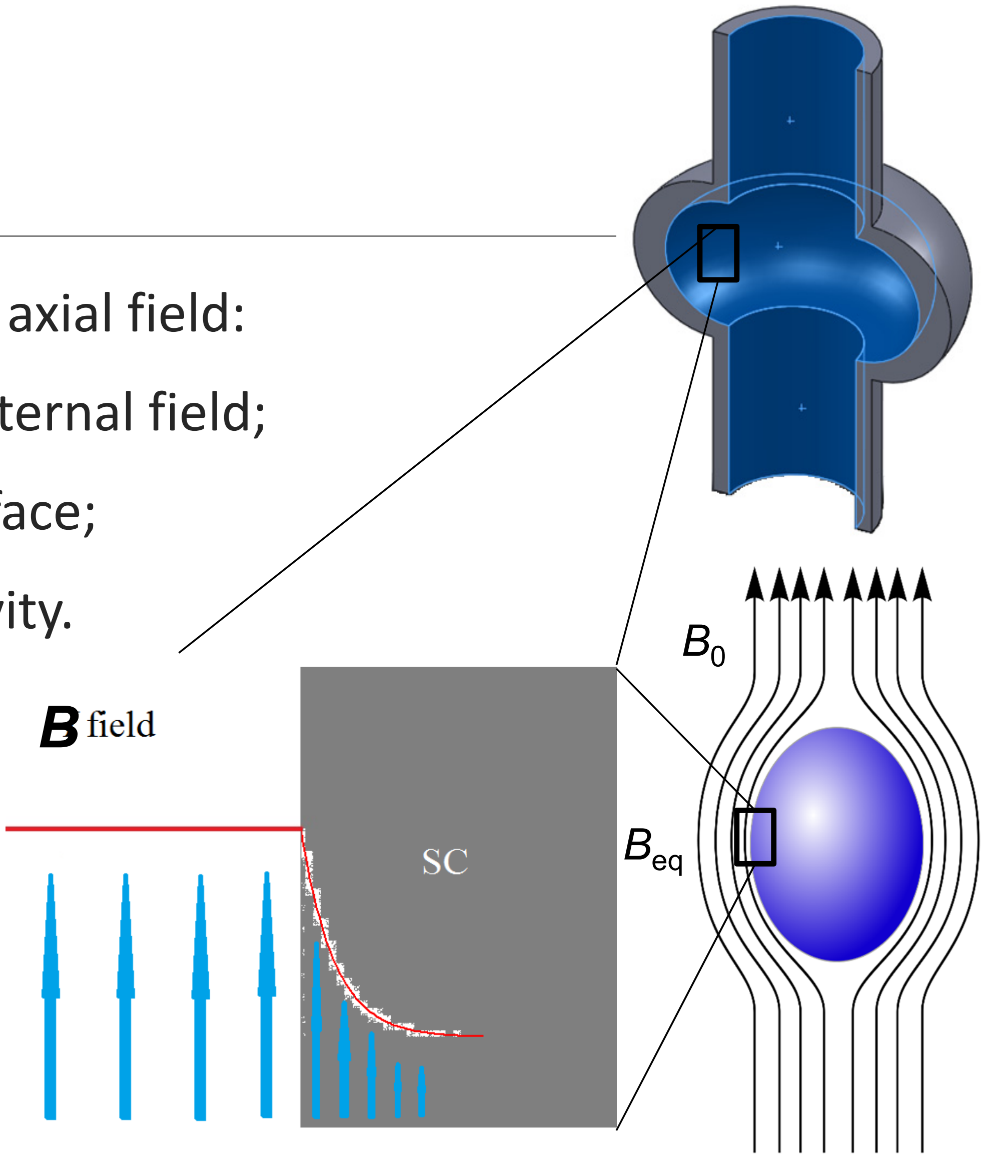
Beringer et al 2013

Field distribution near cavity surface

Why ellipsoid

- Superconducting ellipsoid in an axial field:
  - Meissner effect ensures zero internal field;
  - Expelled field parallel to its surface;

An ellipsoid is an inversed SRF cavity.



Note:

B is strongest at equator due to

Demagnetization effect.

$B_{eq}=B_0/(1-N_c)$

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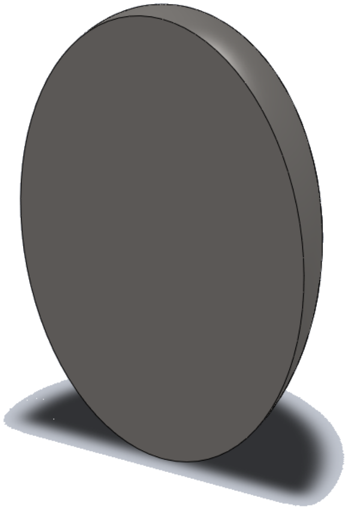
Nb Ellipsoid Geometry



- Geometric calculation
- 2c = 8 mm, 2a = 2b = 5 mm

  (maximum size allowed by magnetometer)
- Demag factor : N_a = 0.2186

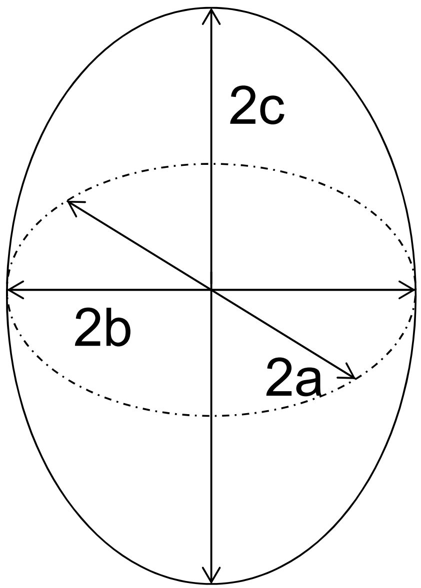
  N_b=N_c=0.3907
- Volume = $\frac{4\pi}{3}abc$ = 0.01047 cm^3
- Meissner slope = m/H_0 = $\frac{abc}{3(1-N_a)}$

  = 0.01066 emu/Oe

$$4\pi M = -H$$

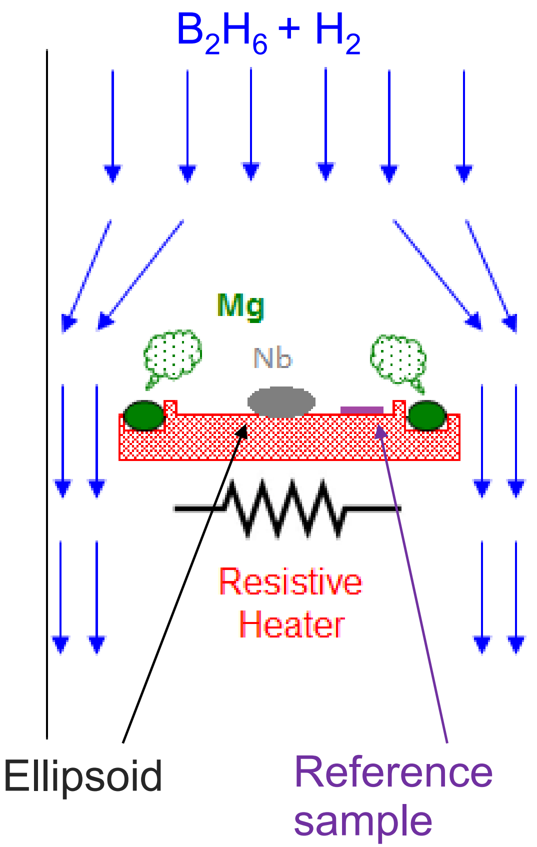
$$H = H_0 - N_a 4\pi M$$

$$H_0 = 4\pi M(1-N_a) = \frac{3m}{abc}(1-N_a)$$



Actual slopes range from 0.0100 to 0.0103 emu/Oe. Shows we have a precise machining and good alignment

MgB_2 coating (HPCVD*)



3 successive depositions to deposit a shell,

A reference sample is put aside of the ellipsoid in the first deposition.

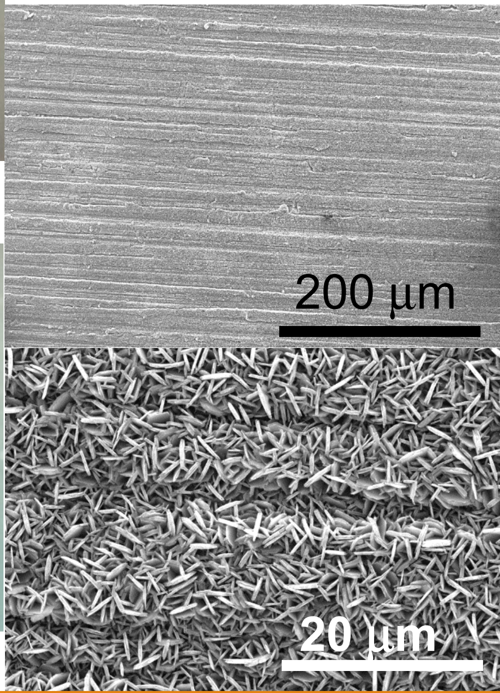
Sample is marked with “Nb + reference sample thickness”. Actual thickness of the shell is 1.5~3 times.

3 samples: Nb0(uncoated), Nb100, Nb200

Nb0

Nb200

SEM: Nb100



*:Zeng et al Nat. Mater. 2002.

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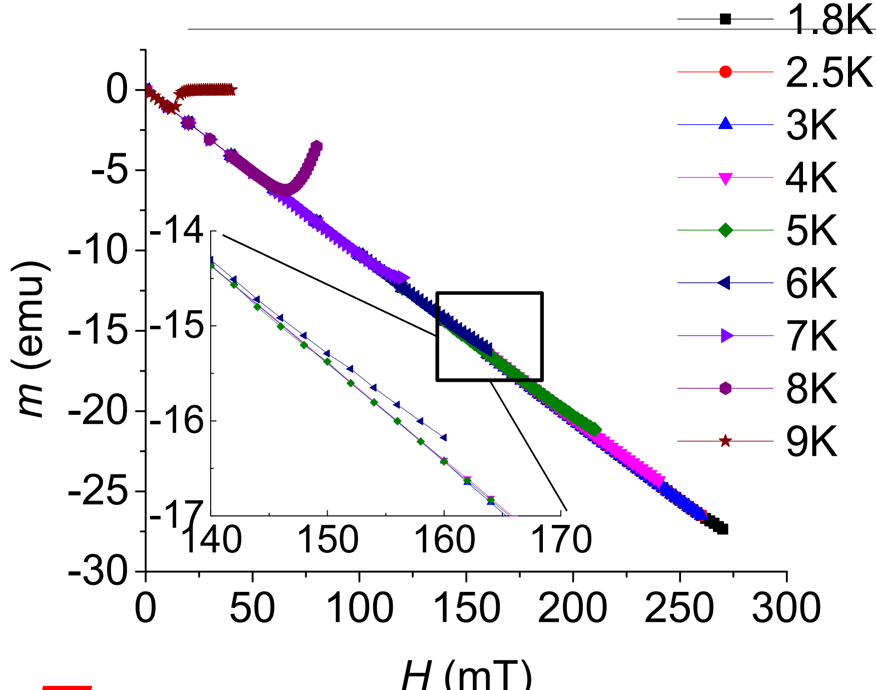
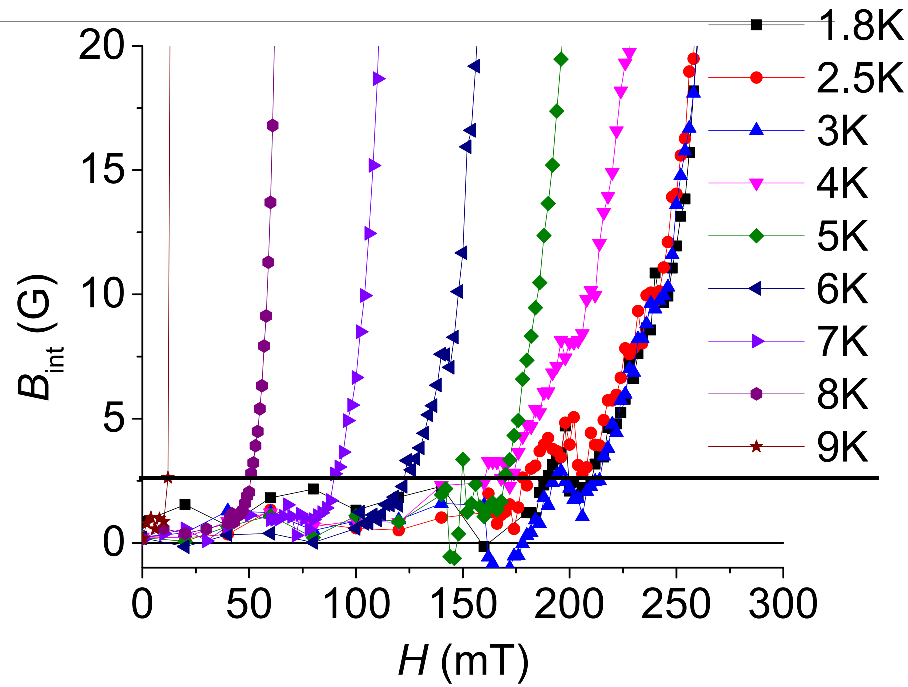
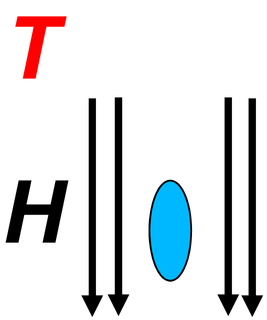
B_{vp} measurement: ZFC *m* vs *H*



m vs. *H*



Internal *B* vs. *H*

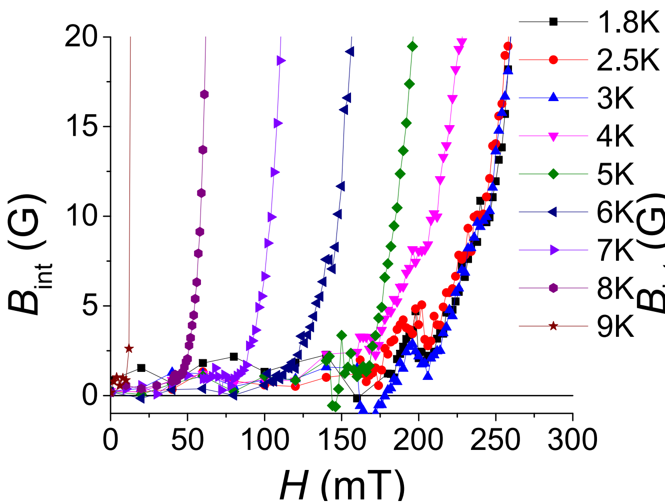


Bare Nb ellipsoid

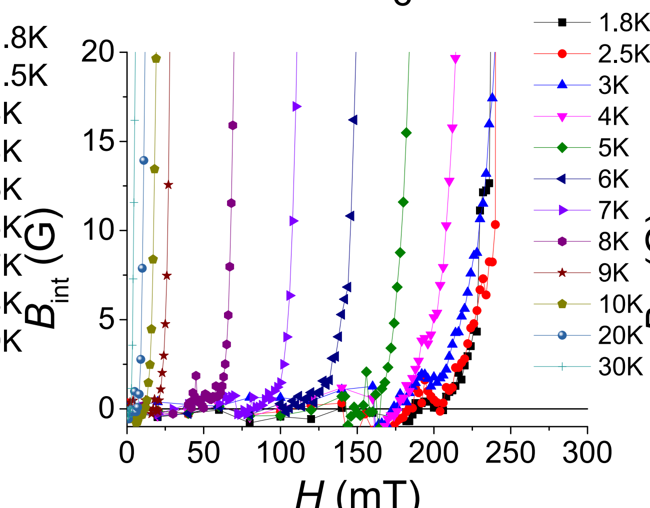
VP at B_0 reaches B_{vp}. Shown by B_{int}.
B_{vp} ~ 170 mT at 1.8 K for Nb0.
Method idea: Constant *T*, measure B_{vp}.

m-H measured MgB_2 on Nb ellipsoid

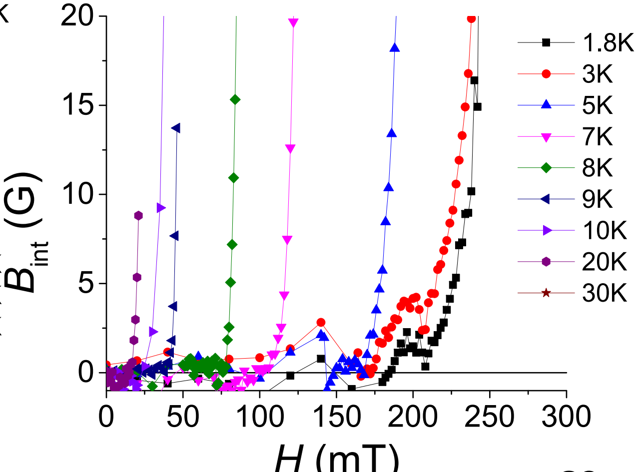
Nb0 T_c 9.3K



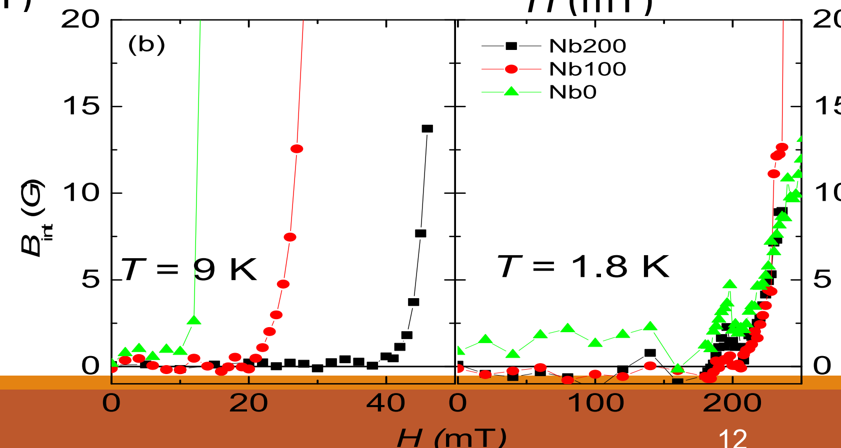
Nb100 T_c 36.7 K



Nb200 T_c 38.2 K

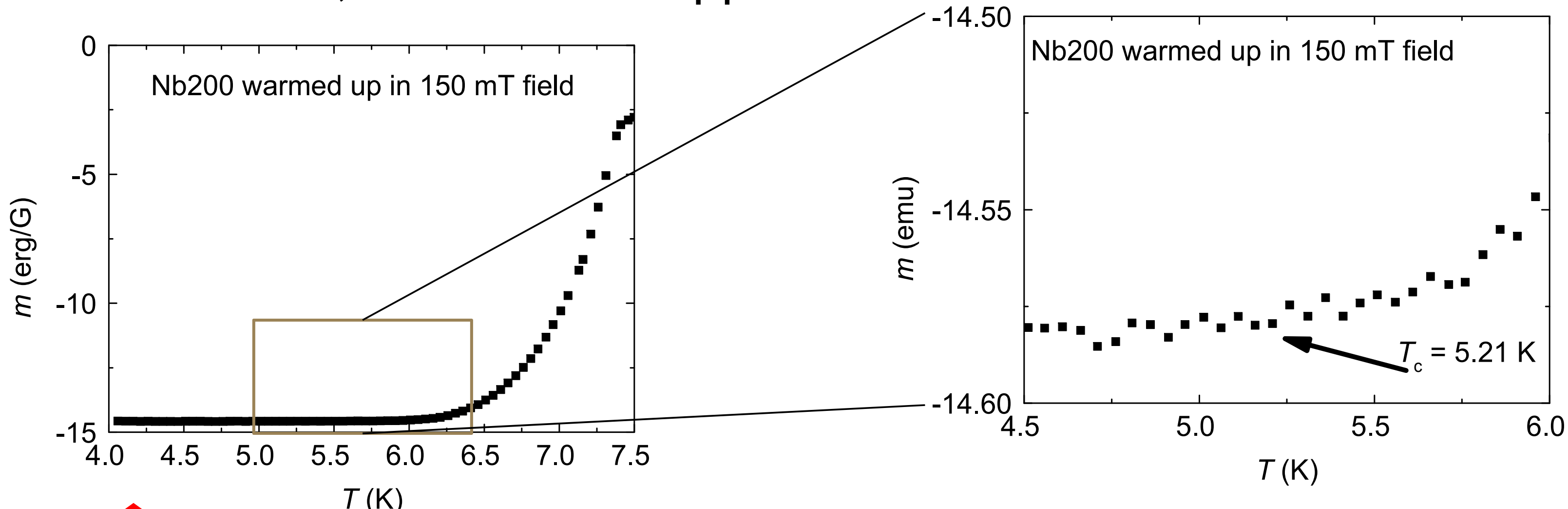


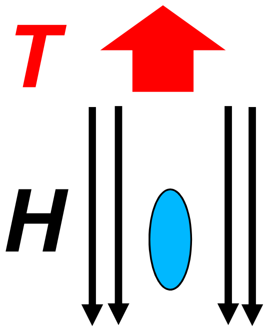
- *m-H* method works perfect at low field but meets problem at high field



B_{vp} measurement: ZFC *m* vs *T*

Sample ZFC then warm up in field. Sample curve measured on Nb200, 150 mT field applied after ZFC to 3 K.





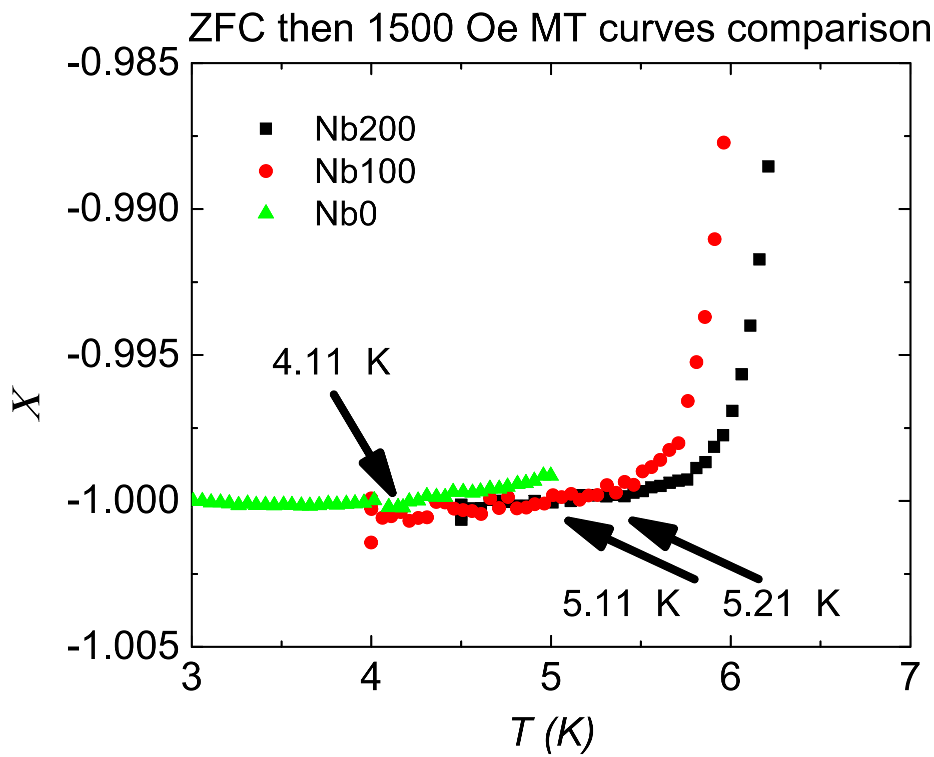
m vs. *T*

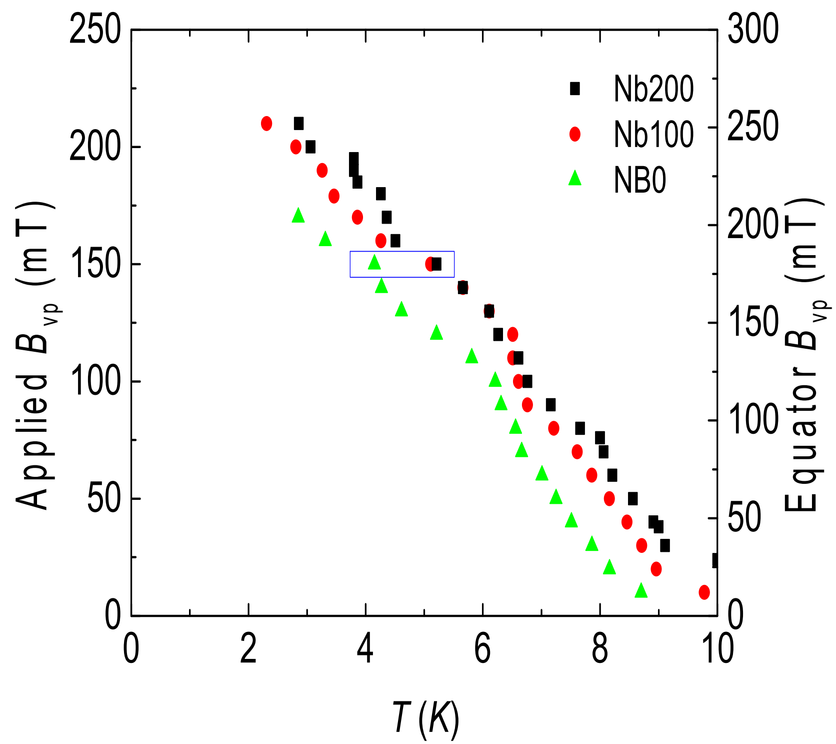
B_{vp} = 150 mT at 5.21 K for Nb200

Nb200 ellipsoid

VP at B_{vp} decrease to B_0. Shown by Δm.
Method idea: Constant *B*, measure *T* correspond to the fixed B_{vp}.

m-T measurement

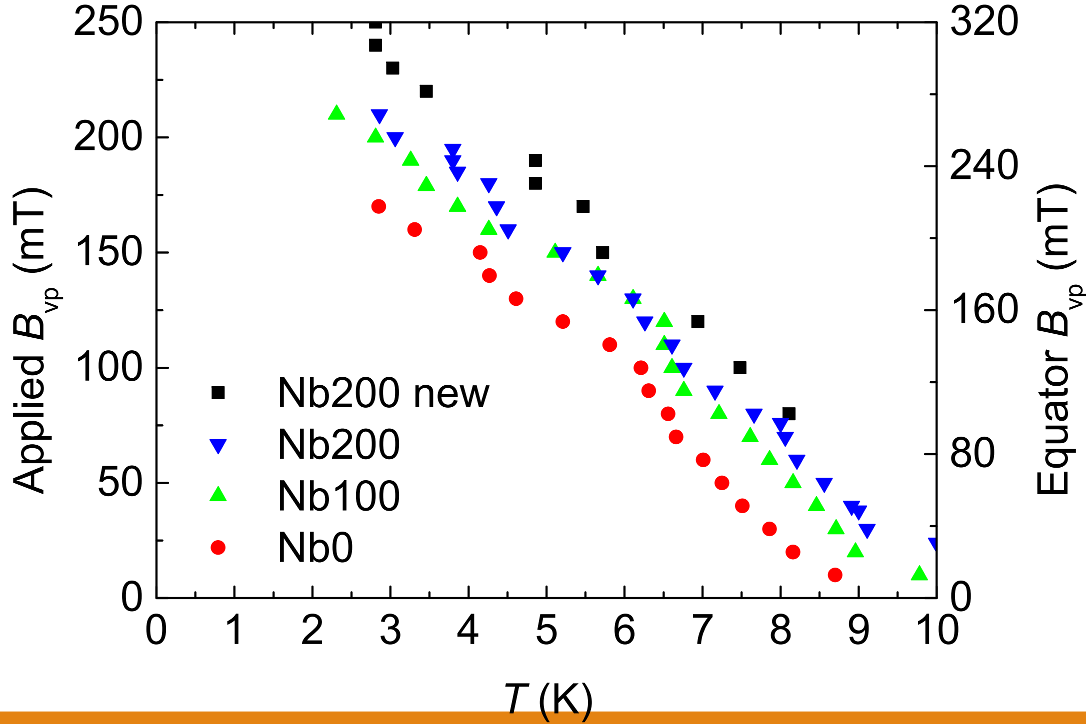




- ~40 mT enhancement observed. (60 mT considering demag)
- Constant ΔH_{vp} from 2K to 9K.

The enhancement depends on the quality (uniformity) of the film.

Another Nb200 sample with improved film surface quality was measured. It showed B_{vp} up to 250 mT (320 mT after considering demagnetization). 80 mT increment from 170 mT of bare Nb.

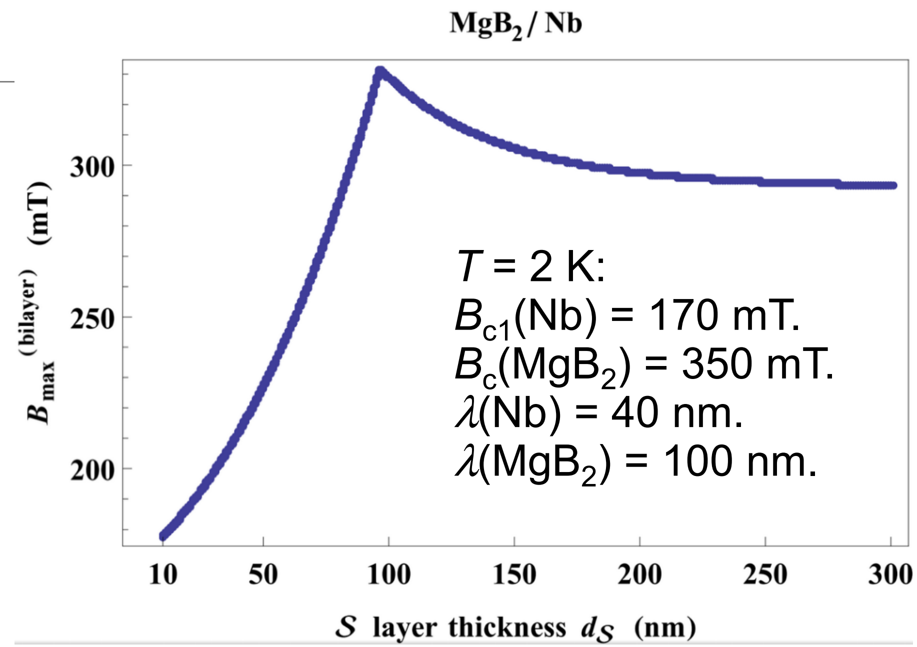


Possible explanation for constant ΔB_{vp}.

Kubo calculated the maximum ΔB_{vp} brought by a single layer of MgB_2. Predicted ΔB_{vp} is depending on film thickness, penetration depth (λ) and coherence length (ξ) of MgB_2.

For our structures, these 3 parameters are ~constant @ T < 10 K.

The enhancement is close to our measurement.



$$B_{v\,[\text{Fig.1(a)}]} = \frac{\phi_0}{4\pi\lambda_1\xi_1} \left(\equiv B_{v0}\right), \quad (4)$$

$$B_{v\,[\text{Fig.1(b)}]} = \frac{\phi_0}{2\pi d_S\,\xi_1} = \frac{2\lambda_1}{d_S} B_{v0}, \quad (5)$$

$$B^{(S)}_{v\,[\text{Fig.1(c)}]} = \frac{\cosh\frac{d_S}{\lambda_1} + (\frac{\lambda_2}{\lambda_1} + \frac{d_I}{\lambda_1})\sinh\frac{d_S}{\lambda_1}}{\sinh\frac{d_S}{\lambda_1} + (\frac{\lambda_2}{\lambda_1} + \frac{d_I}{\lambda_1})\cosh\frac{d_S}{\lambda_1}} B_{v0} \equiv B^{(S)}_v. \quad (6)$$

Kubo et al., Proc. IPAC2014, p. 2522.

Conclusions

- Enhancement of B_{vp} of an inside-out Nb cavity is achieved by MgB_2 coating. It added >60 mT on top of the 170 mT of Nb at 2 K. Possible higher gradient.
- Constant enhancement when T < 10 K indicates the possibility for working at 4.2 K. Reduce cooling cost.

Next step:

1. Is 60 mT/layer is the maximum? >100 mT from Kubo's calculation. Change d, increase film uniformity.
2. Is 60 mT/layer addable? Buffer layers and multilayers.

Thank you for your attention