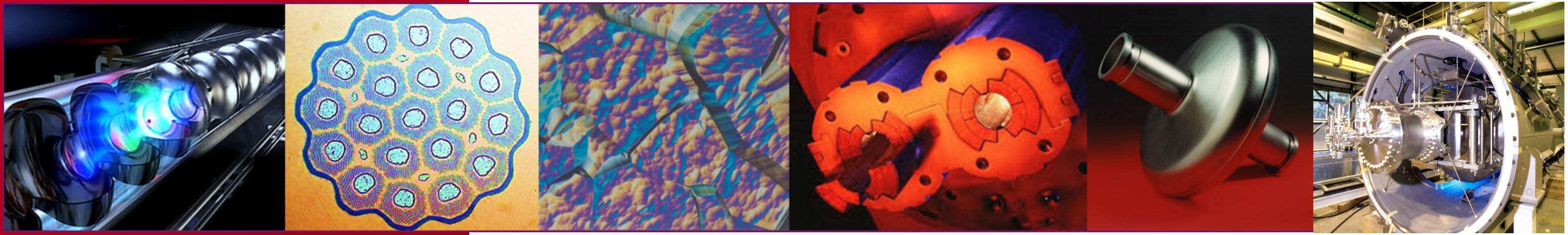
DE LA RECHERCHE À L'INDUSTRIE

PROGRESS ON CHARACTERIZATION AND OPTIMIZATION OF MULTILAYERS



18th International Conference on RF Superconductivity
Lanzhou, July 17-21, 2017

C. Z. ANTOINE

www.cea.fr

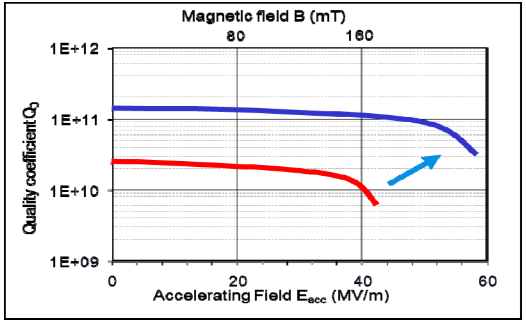
Outline

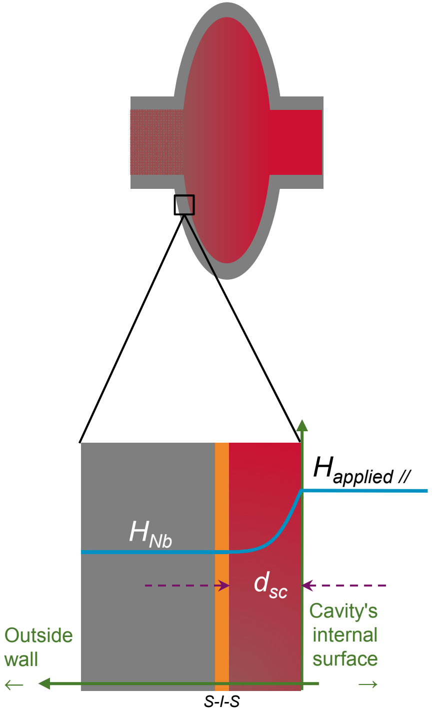
- **Introduction**
  - Multilayers concept
- **MLO worlwide**
  - Theory
  - Multilayer deposition facilities
  - Sample cavities
  - What do we measure ($H_P/H_{C1}/H_{SH}$) ?
- **Screening Power of NbN Layer**
  - Last results and discussion
- **Conclusion and Perspectives**

Introduction

Why multilayers superconductors for SRF cavity ?

- Overcome Nb monopoly by higher Hc_1 superconductors multilayers[1]
- ML coating of Nb cavity by insulator layer and SC layer ($d_{sc} < \lambda$)
  - Higher Hc_1 => higher accelerating field in the cavity
  - Magnetic screening of the Nb cavity
  - Enhancement of Hc_1 by higher T_c SC thin films $T_c > T_c^{Nb}$
  - $R_s^{NbN} \approx \frac{1}{10} R_s^{Nb}$ => $Q_0^{multi} >> Q_0^{Nb}$





$$H_{Nb} = H_{appl}\, e^{-\frac{d}{\lambda}} \; *$$

- Several superconductors are proposed :NbN, MgB_2, Nb_3Sn or dirty Nb
- In this work, we will study the NbN coating effect on H_{c1}

MULTILAYERS WORLWIDE

THEORY (S-I-S & S-S)

Triumf
Junginger
S-S **WEXA05**
Proximity effect

Cornell
Sethna/Liarte
(S-S) **WEXA07**

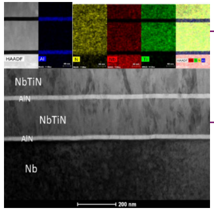
ODU-**Gurevich**
(S-I-S & S-S)
Effect of thickness, of Nb sub layer

KEK - **Kubo**
(S-I-S & S-S)
Effect of thickness, of Nb sub layer, and insulator thickness

Gurevich, A., 2006. Enhancement of RF breakdown field of SC by multilayer coating. Appl. Phys.Lett., 88: 012511.
Gurevich, A., 2015. Maximum screening fields of superconducting multilayer structures. AIP Advances, 5(1): 017112.

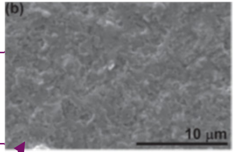
Kubo, T., 2016. Multilayer coating for higher accelerating fields in superconducting radio-frequency cavities: a review of theoretical aspects. Superconductor Science and Technology, 30(2): 023001.

MULTILAYER DEPOSITION FACILITIES

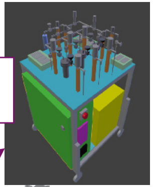


Jlab : NbN, NbTiN, ECR
THPB073

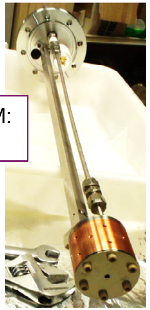
Temple U.: MgB_2, hybrid CVD/PVD
THPB068



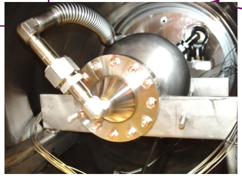
CEA Saclay: ALD



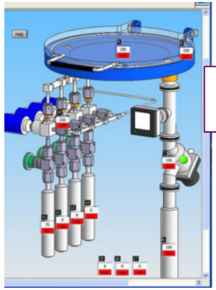
IPNO/CSNSM: NbN, MBE



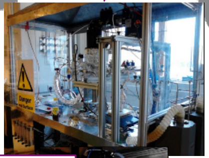
ANL: NbN,etc…
ALD

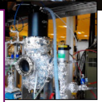


KEK and coll : ALD, IBS, DCMS
THPB055
THPB056

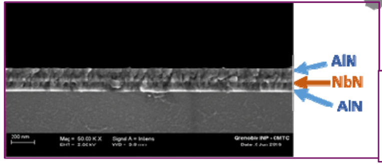


ODU : NbN, ALD



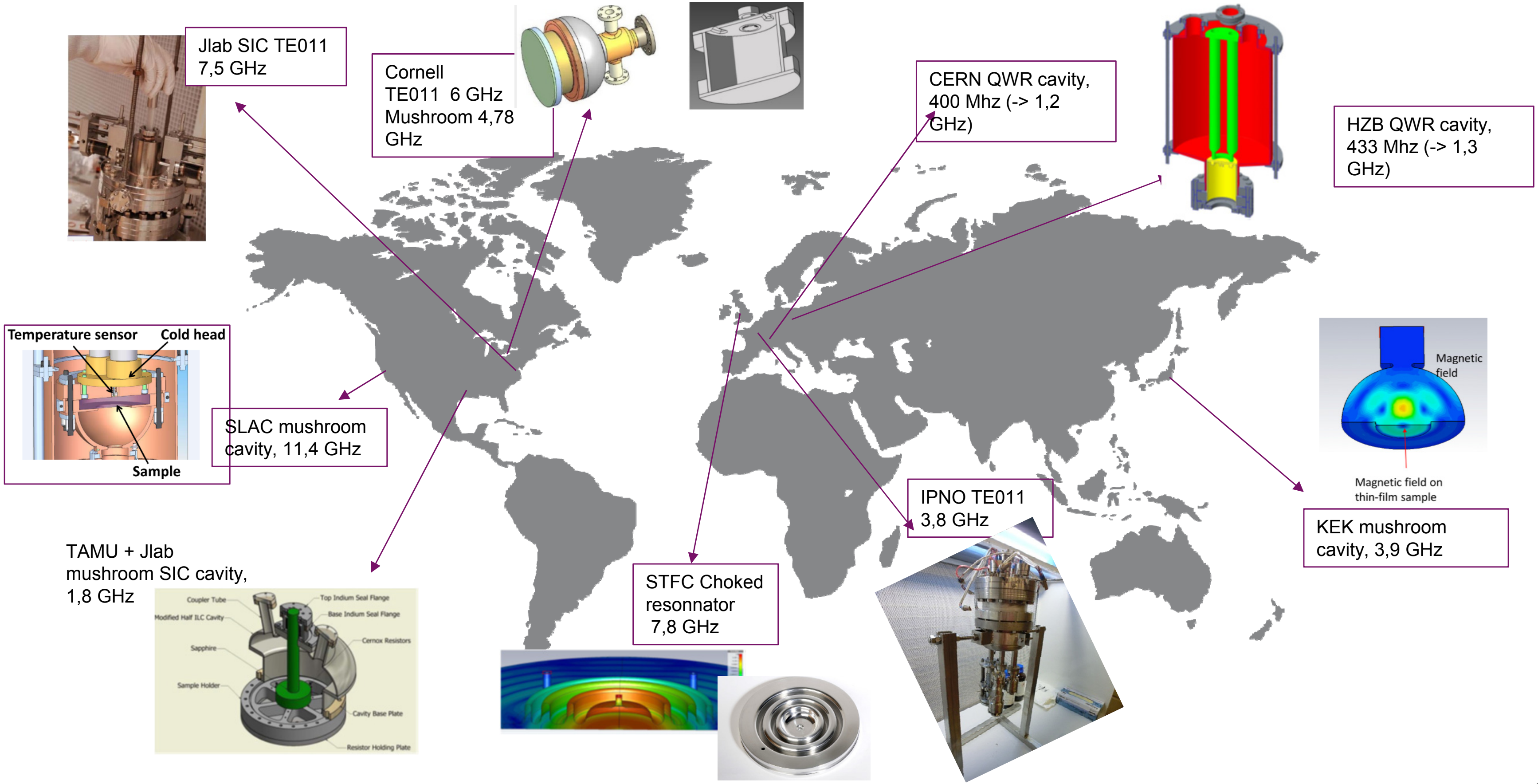


STFC:PVD: DC, pulsed, HIPIMS, (PE)CVD, (PE)ALD
Nb, NbN, Nb_3Sn, MgB_2, etc
TUPB103



Grenoble INP: NbN, NbTiN, ALD, CVD
CEA Grenoble: NbN, RMS

R_S CHARACTERIZATION/SAMPLE CAVITIES



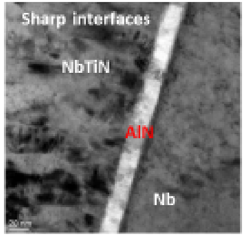
LOWER R_{BCS}

R_{res} to be improved…

RF characterization of NbTiN/AlN/Nb structures

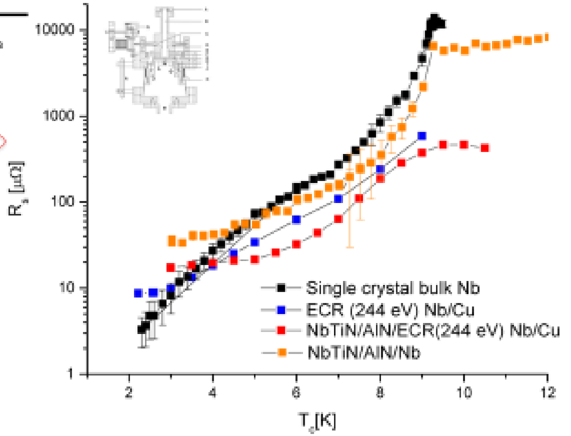
SIS structures coated on ECR Nb/Cu film: 24h-bake, coating and annealing for 4 h at 450°C.

	AlN	NbTiN
N_2/Ar	0.33	0.23
Total pressure [Torr]	2×10^{-3}	2×10^{-3}
Sputtering Power [W]	100	300
Deposition rate [nm/min]	~ 2.5	~ 18
Thickness [nm]	20	150
Tc [K]	N/A	16.9



TEM cross-section (FIB cut) of NbTiN/AlN/Nb/Cu structure

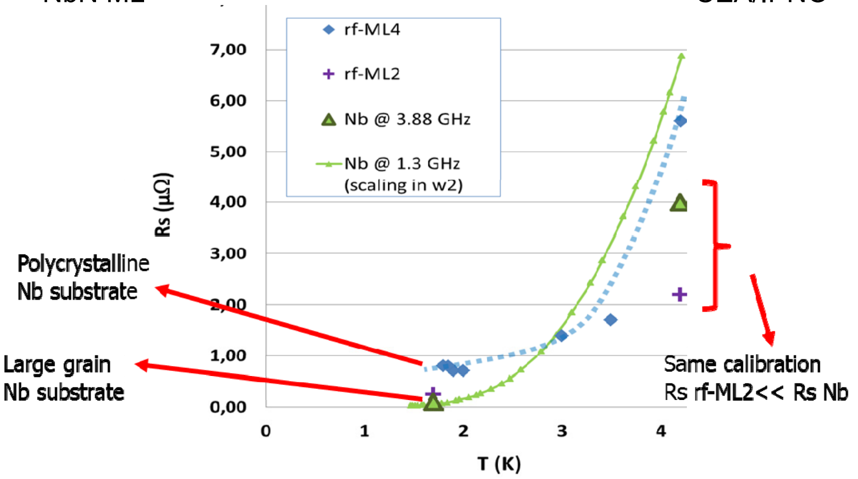
RF Measurement in 7.5 GHz sapphire-loaded TE_{011} cavity



Lower BCS resistance beyond 4 K for SIS coated surfaces compared to standalone ECR film & bulk SC Nb.

A-M Valente-Feliciano - SRF 2017 Jefferson Lab

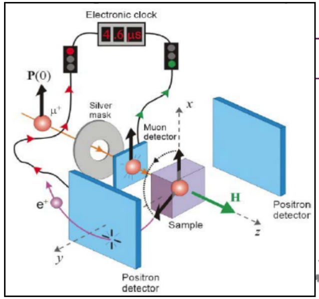
NbN ML [Baumier, 2013] CEA/IPNO



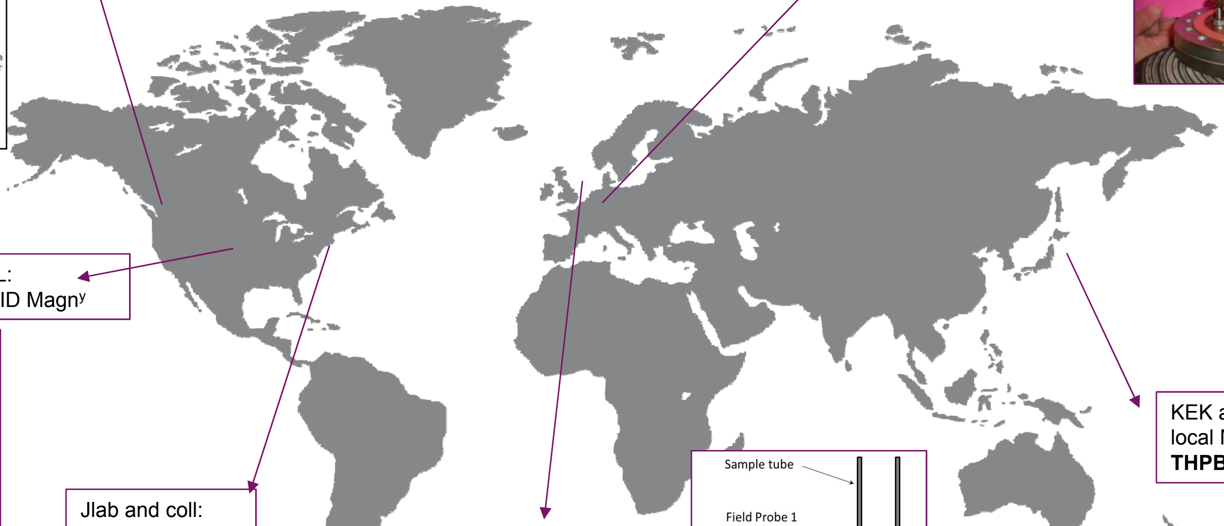
[A.M. Valente-Feliciano, 2013
+ THPB073]

- Please go on efforts on sample cavities !!!

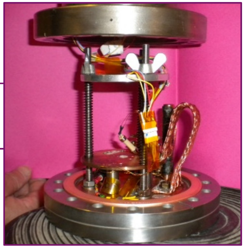
TRANSITION FIELD MEASUREMENT



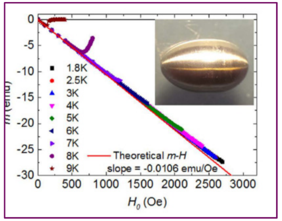
Triumf μ-SR



CEA Saclay: Local Magn^y
THPB038

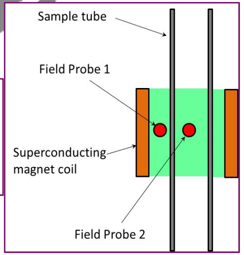


LANL:
SQUID Magn^y



Jlab and coll:
SQUID Magn^y

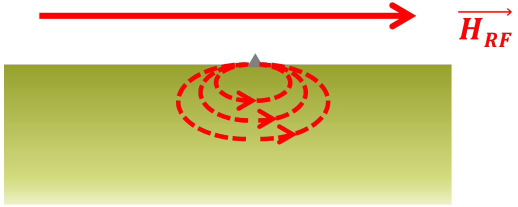
STFC:SQUID Magn^y
AC/DC magnetic susceptibility,
Penetration facility

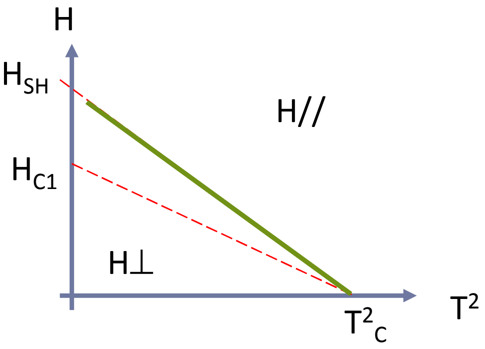


KEK and coll :
local Magn^y
THPB058

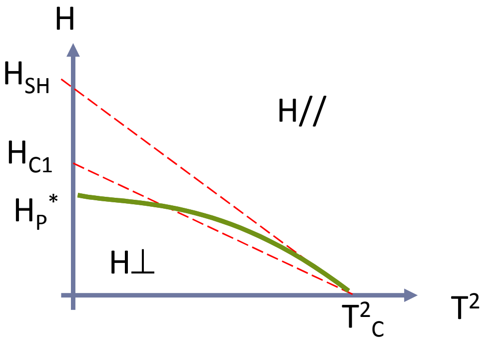
Vortex penetration

- In real world cavities behavior is dominated by a few number of defects.
- It is very important to measure the penetration field of samples in realistic conditions



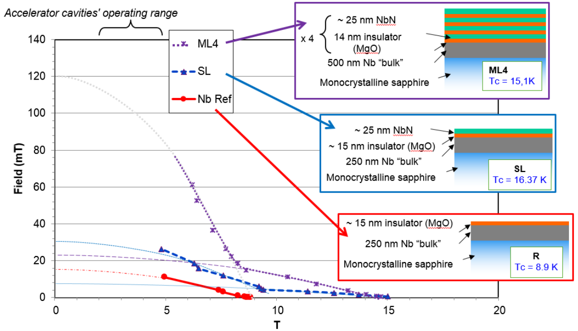


Ideal case



** Not even taking into account geometric factors…*

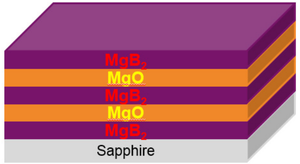
HIGHER $H_P/H_{C1}/H_{SH}$!

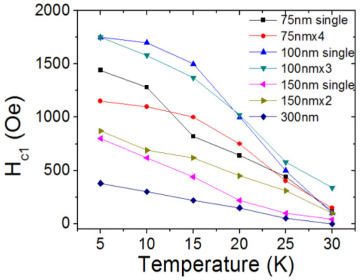


ML sample : 250 nm Nb + (14 nm MgO + 25 nm NbN) x **4** *[Baumier, 2013]*

Multilayer tested for the first time B_{C1} > 55 mT @ 8K !

Multilayers





Alternating MgB_2-insulator structures have been fabricated on sapphire substrate:

- 40 nm MgO as insulating layer, sputtered.
- MgB_2 deposited by HPCVD *ex situ*. 150, 100, and 75 nm in thickness.

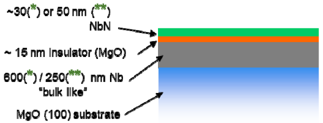
T_c near 40 K for 100 and 150 nm films. Lower for 75 nm film.

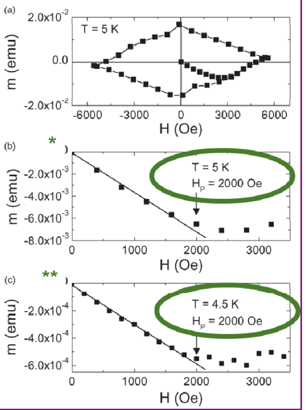
Multilayer films with thin MgB_2 layers show higher H_{c1} than the 300 nm film even though the total thickness are the same.

[Teng, Xi – Temple University]

SQUID !!!

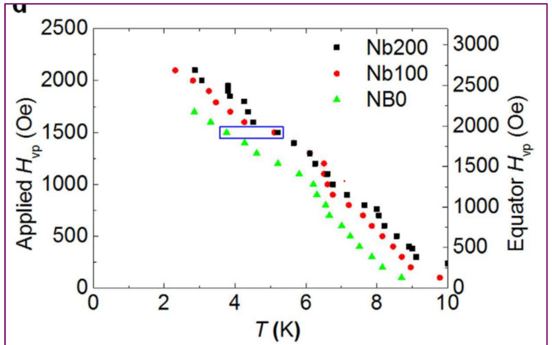
[Lukaszew, 2012]





Compare with what is expected for bulk Nb : ~1300 Oe @ 4.5 K !

Bilayers

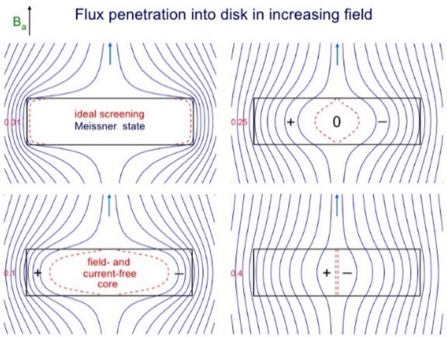


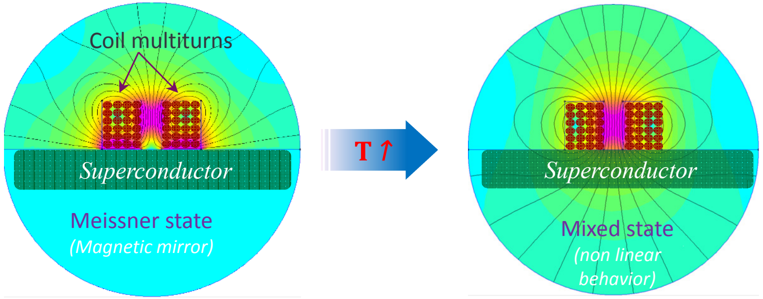
[Tan, 2016]

ACTIVITIES AT SACLAY AND COLLORATORS

H_{c1} Measurement: need for Local Magnetometer

- **Conventional Magnetometer (SQUID) gives ambiguous results:**
  - Uniform field around the sample
  - Demagnetization (orientation, edge, shape) effects
  - Exact local field configuration not known (if alignment not perfect, strong transverse moment always present)
- **Go for local probe!!!**

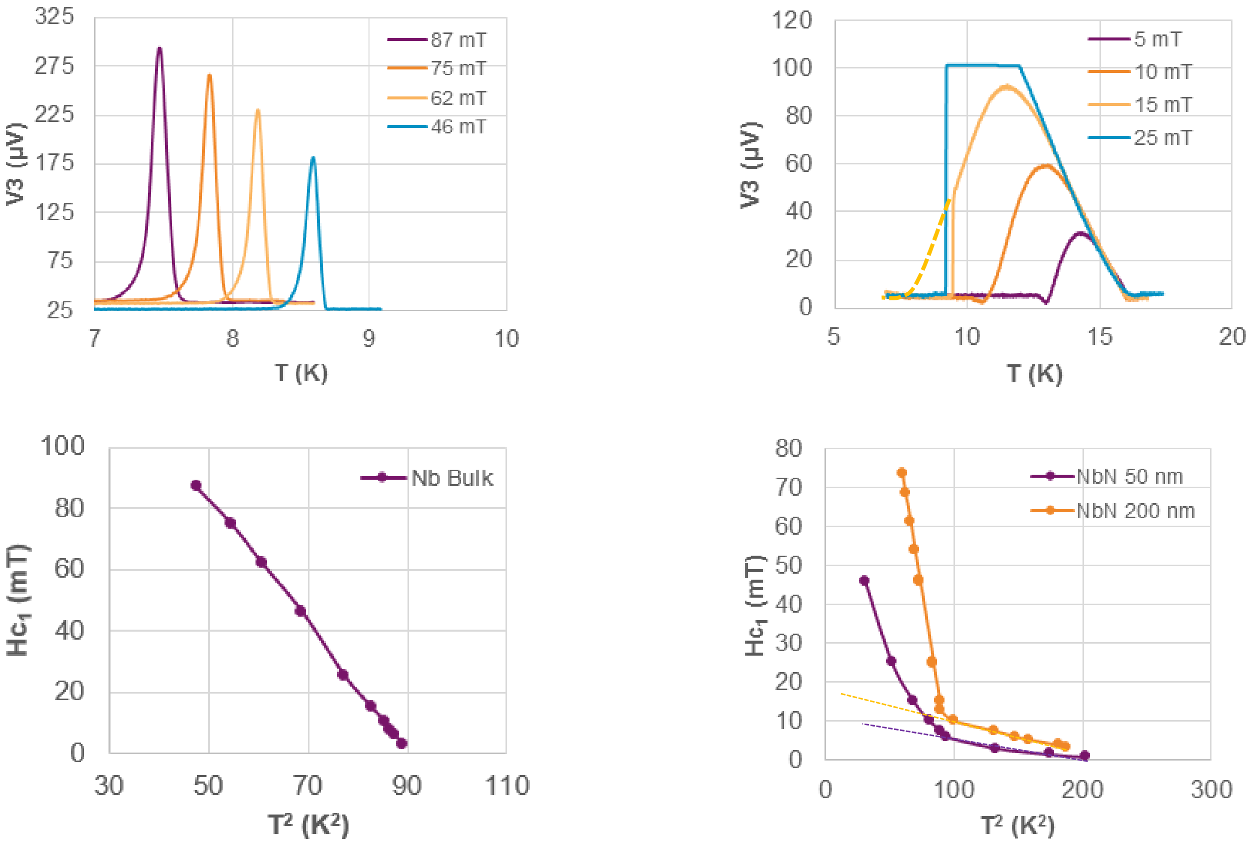




J. H. Claassen, et al. Rev. Sci. Instrum, Vol. 62, 4 (1991).
M. Aurino, et al., Journal of Applied Physics, 98. 123901 (2005).

- Building a setup ~operating conditions for SRF (2K-20K; H >> 150 mT)
  - Magnet size << sample size (infinite plane approx.)
  - Field decreases quickly away from the coil
  - Measurement of H_{C1} on sample without edge/demagnetization effect
  - Exploring new SCs /multilayers close to accelerator operating condition

Screening Power of NbN Layer

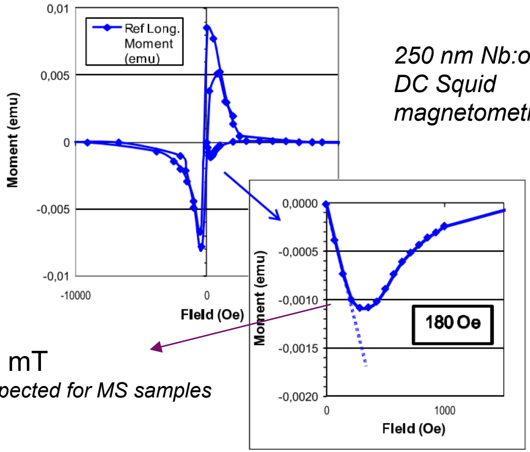


NbN coating by Magnetron Sputtering

- NbN single layers series
  - NbN SL / “thick” Nb layer
    - Magnetron sputtered
    - MgO as dielectric layer

Nb (nm)	MgO (nm)	NbN (nm)	T_C (K)
250†	14	0	8.9
250†	14	25	15.5
500	10	50	15*
500	10	75	14.1*
500	10	100	14*
500	10	125	14.3*
500	10	150	15.9*
500	10	200	15*

† Not same batch, deposited on the same conditions, but substrate = sapphire (actual thicknesses)
*As determined with magnetometry, see below.



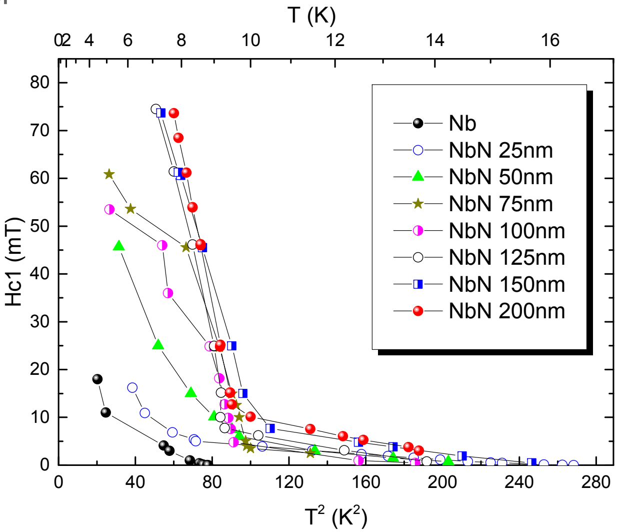
250 nm Nb:on saphire DC Squid magnetometry @ 4.5 K

~ 18 mT
As expected for MS samples

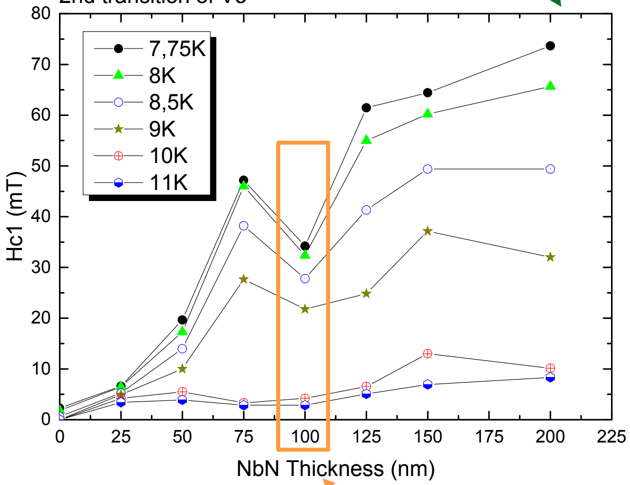
Nb-MgO-NbN TRILAYERS

Transition field (H_{SH} here ?)

- NbN single layers series
  - NbN SL / "thick" Nb layer
    - Magnetron sputtered
    - MgO as dielectric layer



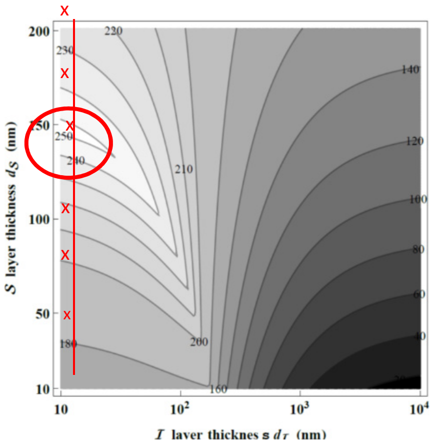
Saturation ?
***Maybe** it is still worth trying to go to thicker samples*



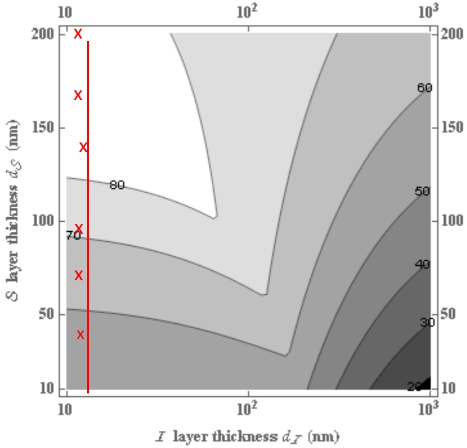
Maybe the sample quality is not good !

- The enhancement of the field penetration increases with thickness of NbN
- It reaches a saturation at thicknesses > ~100 nm

Theoritical predictions from T. Kubo



Ideal Nb substrate with B_{C1}=170 mT



Nb with defects, with B_{C1}=50 mT*

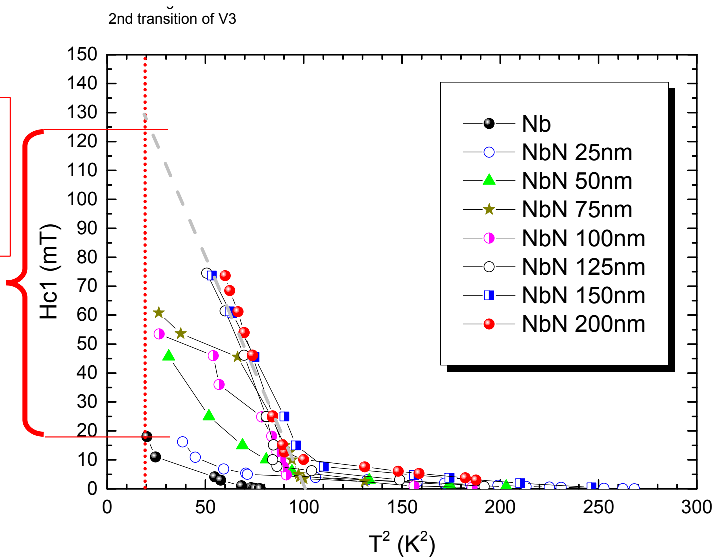
** e.g. morphologic defects that allow earlier vortex penetration See paper site earlier*

@ 4.5 K

~ + 110 mT?

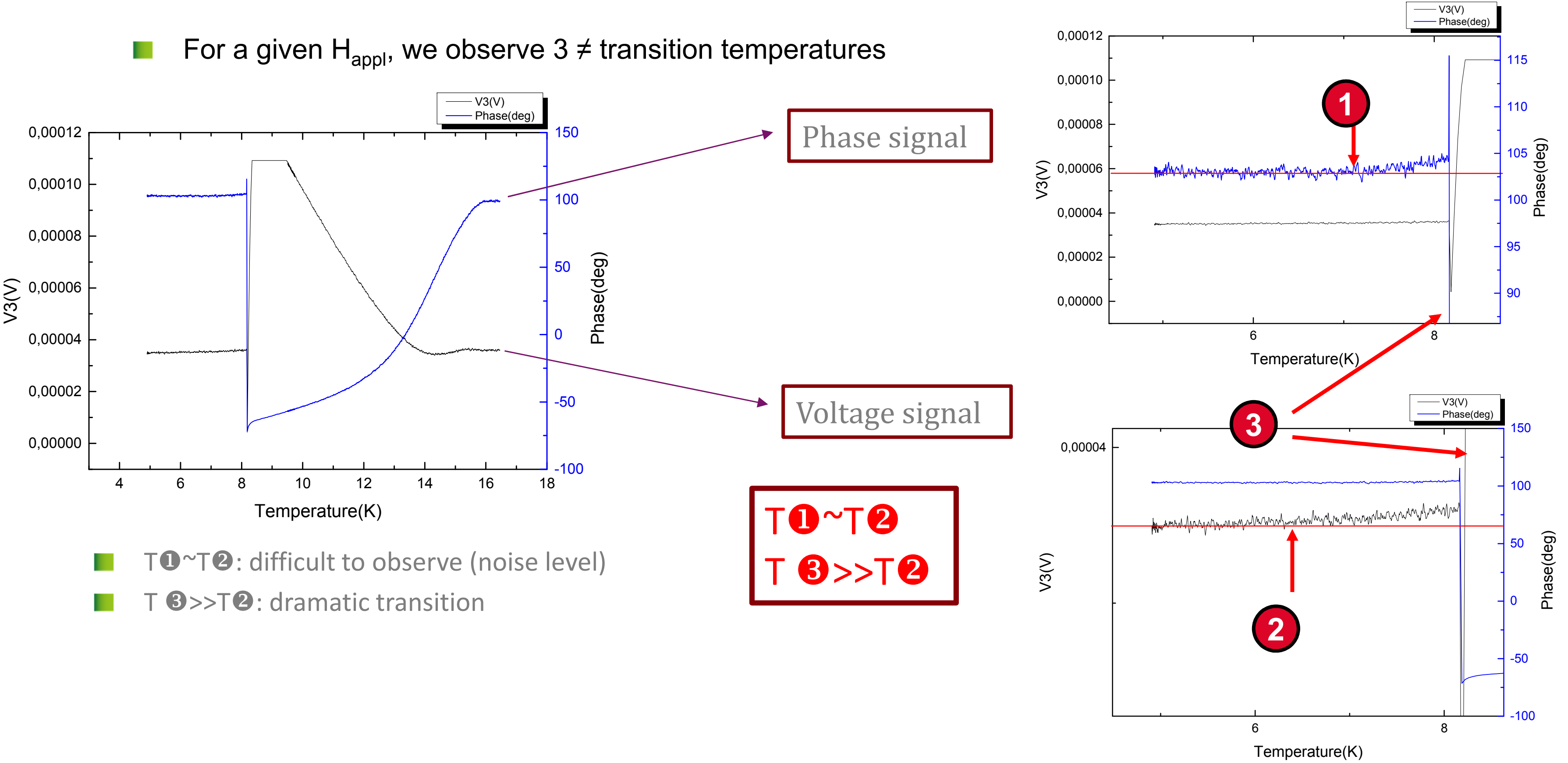
~25-30 MV/m

ILC shape



CLOSEUP OF 3rd HARMONIC SIGNAL

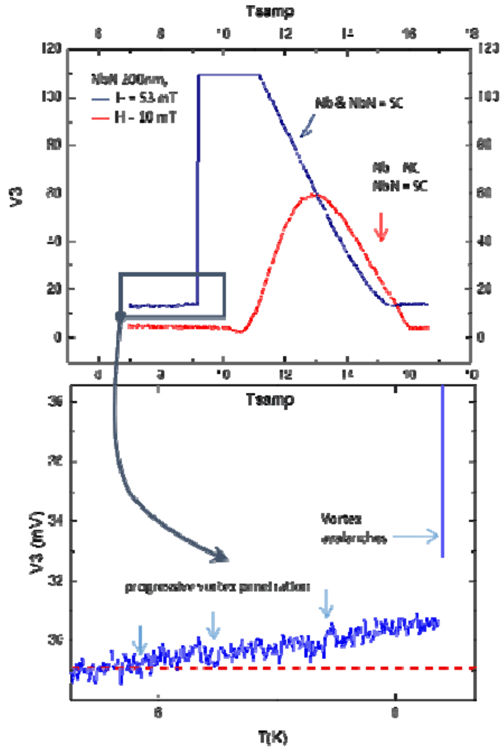
- For a given H_{appl}, we observe 3 ≠ transition temperatures

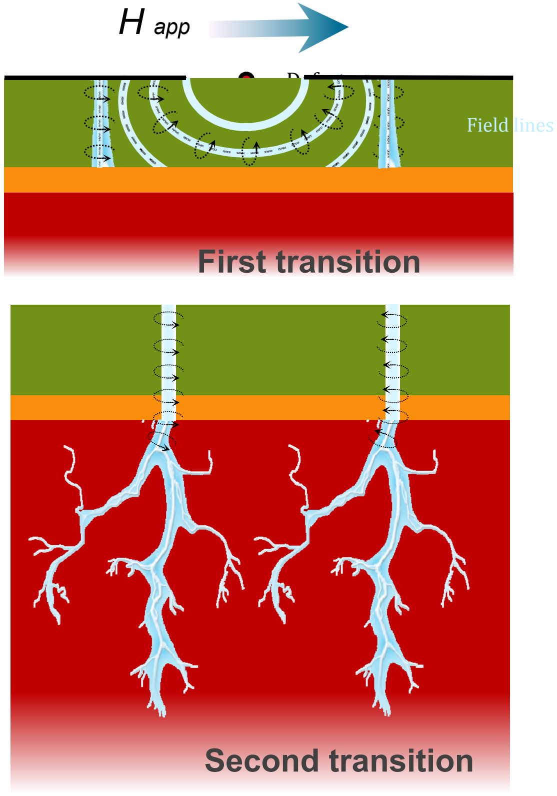


- T❶~T❷: difficult to observe (noise level)
- T ❸>>T❷: dramatic transition

ROLE OF THE DIELECTRIC LAYER !

- Why do we have two transitions ?





- Thin SC layer NbN
- Insulator MgO
- Thick SC layer Nb

- H // surface => surface barrier†
- A defect locally weakens the surface barrier
- 1st transition, vortex blocked by the insulator ~100 nm => low dissipation.
- 2nd transition, propagation of vortex avalanches (~100 µm) => high dissipation.
- **Dielectric layer = efficient protection !!!**

†*B. Bean and J. D. Livingston, Phys. Rev. Lett. 12, 14 (1964).*

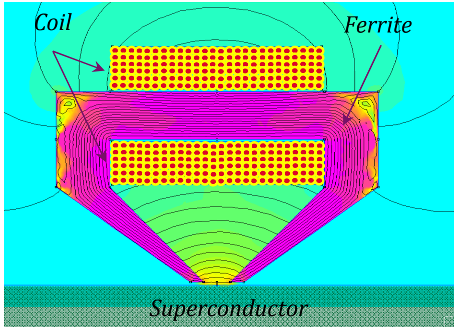
CONCLUSION AND PERSPECTIVES

Conclusion

- A local magnetometer has proven to be effective at measuring vortex penetration in conditions close to cavities operating condition.
- Very promising behavior of NbN layers
- S-I-S multilayers provide **best protection** of cavities against local penetration of vortices
- Sample gives results close to theory : optimization can soon be done theoretically
- Deposition methods inside cavities needs to be developed

Perspectives

- Enhancement of the maximum magnetic field applied on the sample, we hope to reach > 250 mT by:
  - Replacement the coil by a ferrite core inductor
  - Novel thermal design of the experimental setup
  - Study other superconductors multilayers at higher fields.
- Sample deposited onto bulk Nb to be tested soon



SPARES

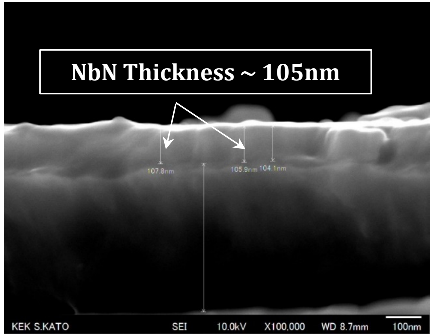
Nb – Insulator – NbN model

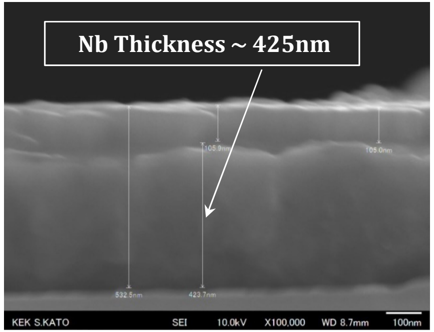
- Samples characterization (*Collaboration of KEK Japan*)
- SEM-EDX Analysis
- Depth profile by XPS

  - Thicknesses of NbN are largely dependent on their position on the samples
  - Generally, Thickness of NbN are thinner than the targeted thicknesses
  - The thickness of MgO is approximately uniform

- Superconductivity of samples by PPMS

N° 4 : NbN 100nm





Nb – Insulator – NbN model

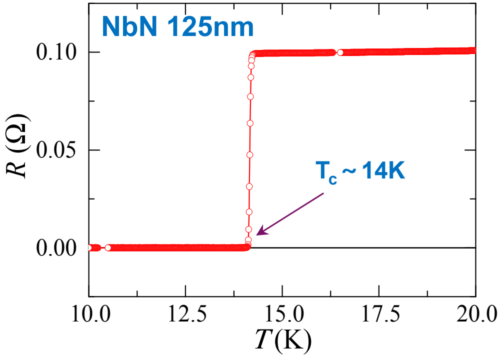
- Samples characterization (*Collaboration of KEK Japan*)
- SEM-EDX Analysis
- Depth profile by XPS

Improvement of NbN deposition is required or use alternative techniques (ALD, CVD, …)

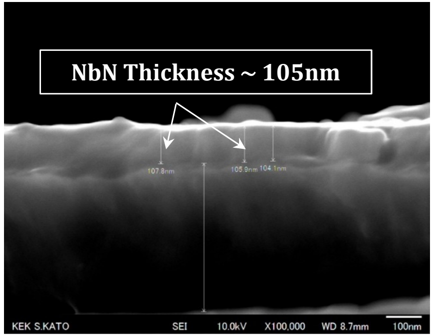
- Superconductivity of samples by PPMS

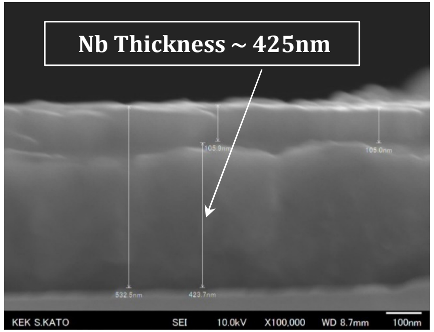
Our measurements indicate that $Tc \sim$ 14,3K

But how we can measure H_{c1} ?



N° 4 : NbN 100nm

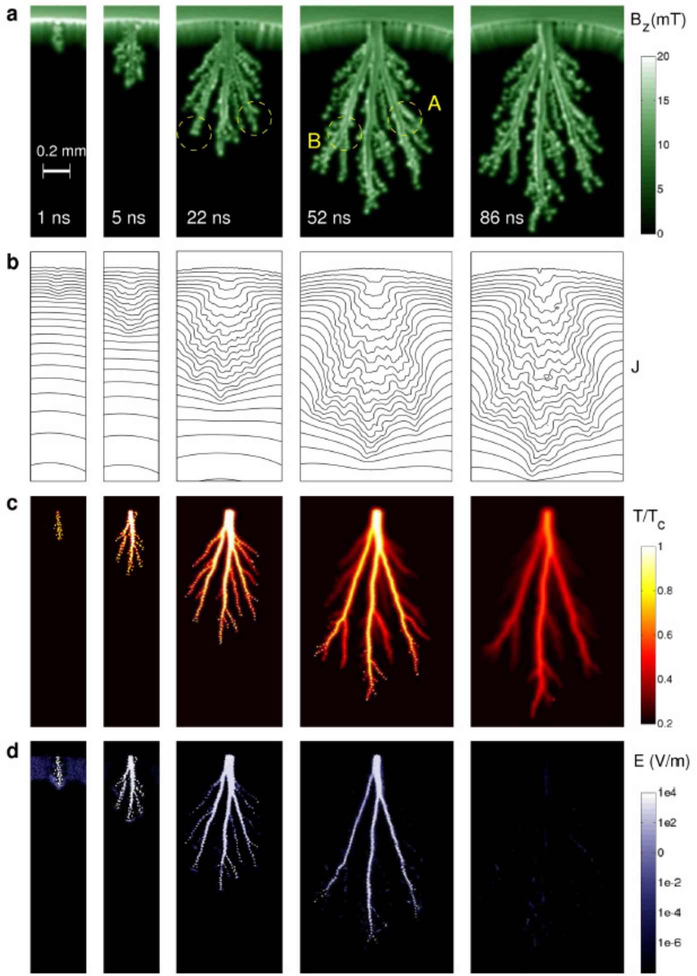




VORTICES:
AVALANCHE PENETRATION

⊗

$\overrightarrow{H}_{appl}$



- ~100 µm in 1 ns (~RF period) !!!
- Compare with λ (field penetration depth)
  - Nb : ~ 40 nm
  - MgB_2 ~ 200 nm

Here MgB_2 example
http://www.nature.com/srep/2012/121126/srep00886/full/srep00886.html?message-global=remove&WT.ec_id=SREP-20121127

H_{c1} Measurement, a Local Magnetometer

A

- A

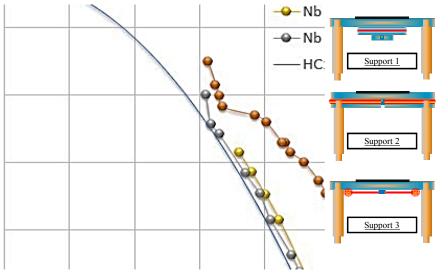
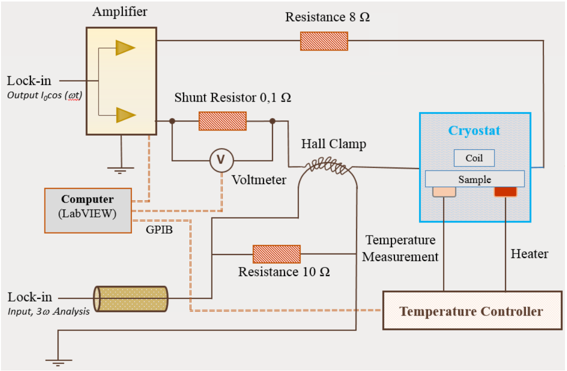
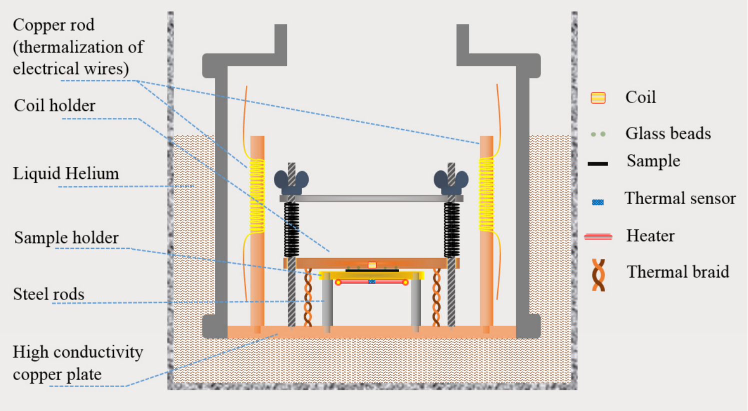
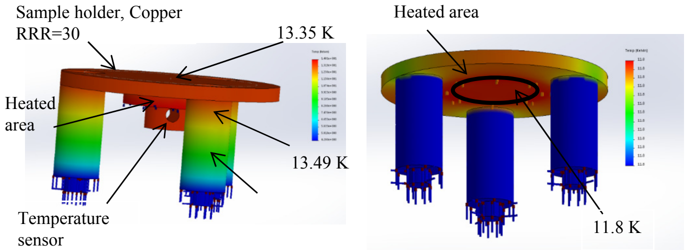


Figure 9: Several improvements for sample holder to achieve good calibration with Nb RRR =300.





Schematic of local magnetometer



first sample holder design 0.05W at 180s