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# Screening Power of NbN Nanometric Layers

EuCARD² WP12.2 Thin Films

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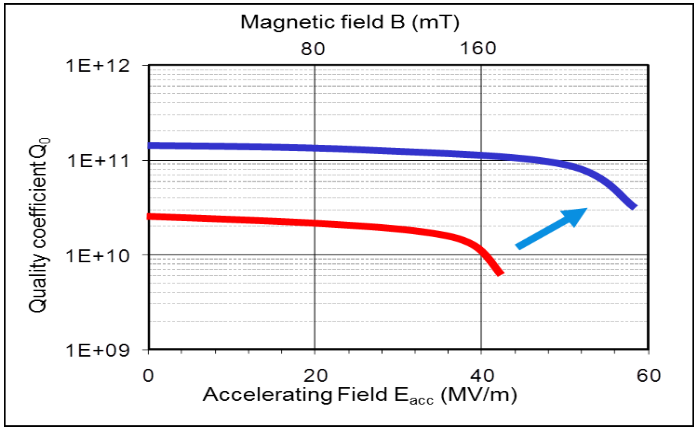
# Outline

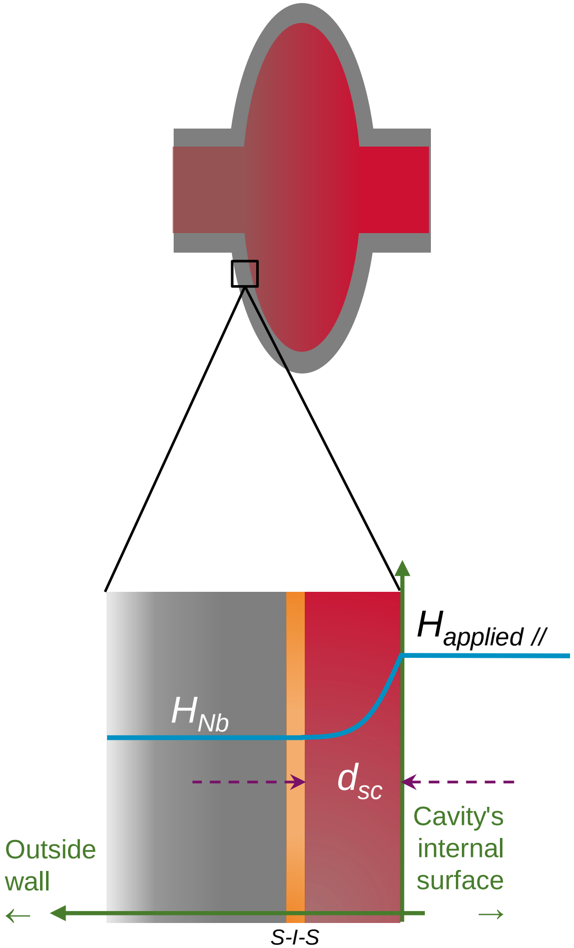
- Introduction
  - Why multilayers superconductors for SRF cavity?
  - Nb – Insulator – NbN model
- *$H_{c1}$* Measurement, a Local Magnetometer
  - Why a local magnetometer is necessary ?
  - How this magnetometer works ?
  - Behind every success, a lot of failures
- Screening Power of NbN Layer
  - 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 $T_c > T_c^{Nb}$
  - $R_s^{NbN} \approx \frac{1}{10} R_s^{Nb}$ => $Q_0^{multi} >> Q_0^{Nb}$



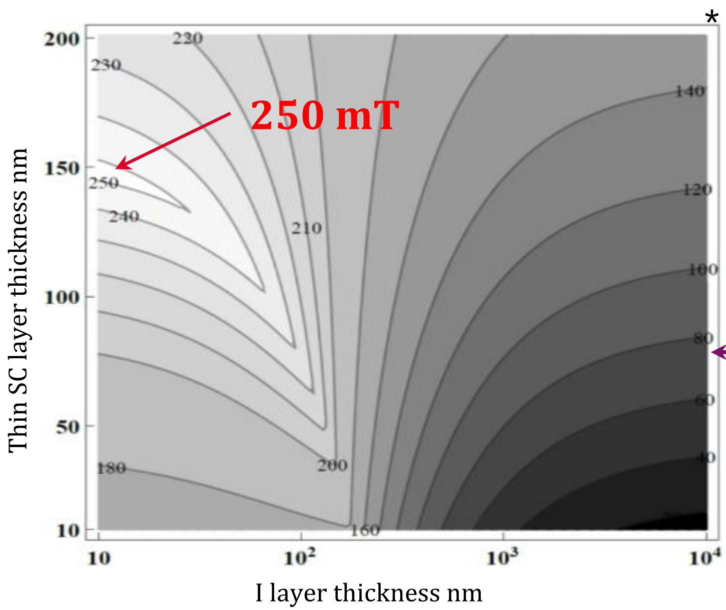

$$H_{Nb} = H_{appl} e^{-\frac{d}{\lambda}} \;*$$

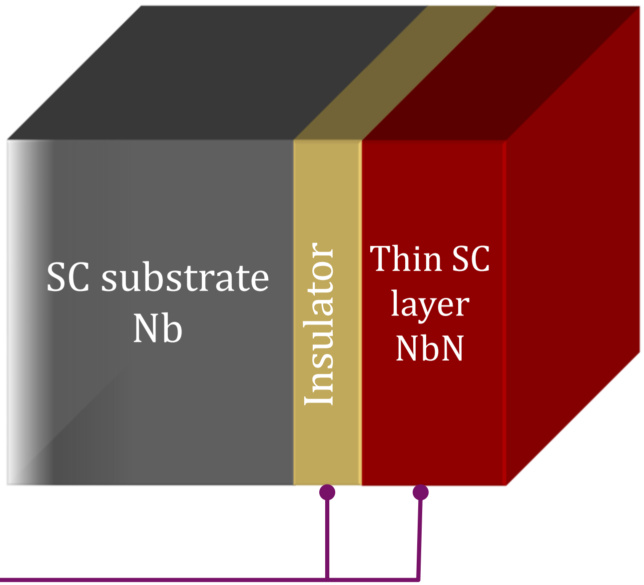
- Several superconductors are proposed :NbN, $MgB_2$, $Nb_3Sn$ or dirty Nb
- In this work, we will study the NbN coating effect on $H_{c1}$

[1]A. Gurevich, Applied Physics Letters 88,012511 (2006).

## Nb – Insulator – NbN model

- Nb – I – NbN with NbN ($T_C$ ~15K, $\lambda$ = 200 nm)
- Increasing the high-field performance by a NbN overlayer[2]
- Is there an optimum thickness of NbN layer which maximizes the breakdown field ?




**$H_{max}$ optimum ~250 mT which is higher than of thick Nb (170 mT)**

### Predictions

- T. Kubo (2014)[3] ~140 nm
- A. Gurevich (2015)[4] ~160 nm

### Our task

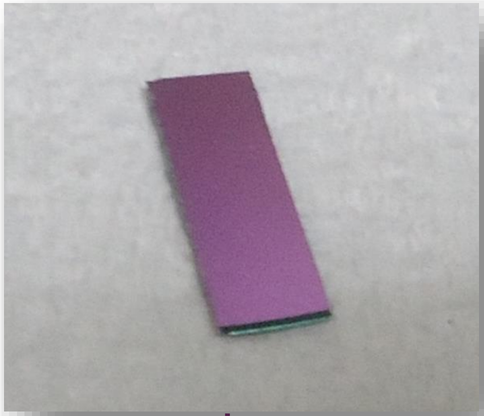
- Verifying the optimum thickness *d* for maximum $H_{max}$ which exceeds the superheating fields of both the layer and the substrate !

[2]C.Z. Antoine, et al. APL 102, 102603 (2013). [3]T. Kubo et al, Appl. Phys. Lett. 104, 032603 (2014). [4]A. Gurevich, AIP Advances 5, 017112 (2015).

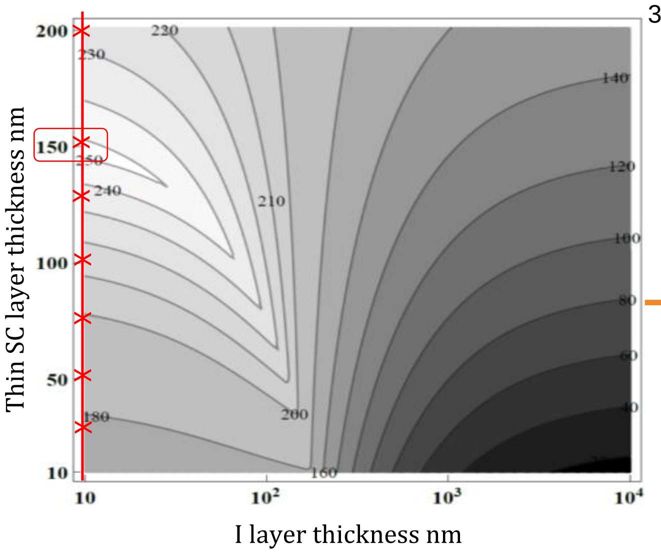
## Nb – Insulator – NbN model

- Series of Nb - MgO - NbN samples (*Collaboration of CEA-Inac Grenoble*)

| N° | Nb (nm) | MgO (nm) | NbN (nm) |
|---|---|---|---|
| 1 | 500 | 10 | 25 |
| 2 | 500 | 10 | 50 |
| 3 | 500 | 10 | 75 |
| 4 | 500 | 10 | 100 |
| 5 | 500 | 10 | 125 |
| 6 | 500 | 10 | 150 |
| 7 | 500 | 10 | 200 |



**NbN coating by Magnetron Sputtering**

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Calculations[3] obtained by the assumption that:

- SC thin layer : **NbN**
  $B_c$ (NbN) = 230 mT and $\lambda$ (NbN) = 200 nm
- SC thick layer : Clean **Nb**
  $B_{max}$ *(Nb) =* $B_{c1}$ *(Nb) = 170 mT and* $\lambda$ (Nb) = 40 nm

[3]*T. Kubo et al, Appl. Phys. Lett. 104, 032603 (2014).*

# Introduction

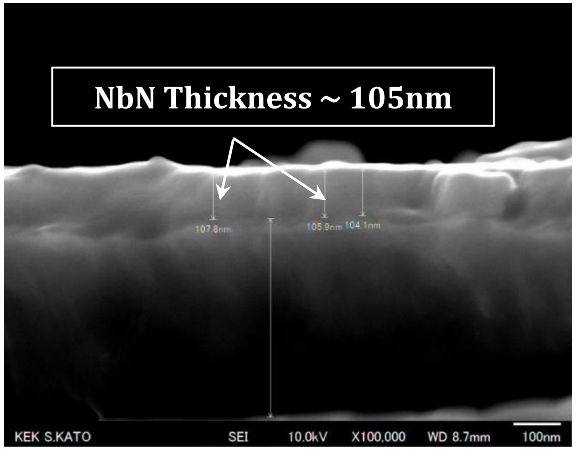
## Nb – Insulator – NbN model

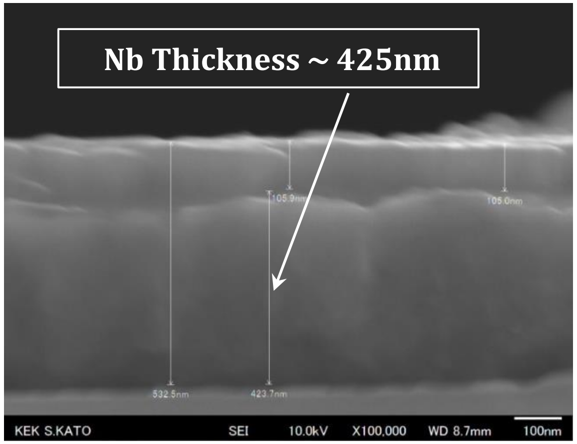
- Samples characterization (*Collaboration of KEK Japan*)
- SEM-EDX Analysis
- Depth profile by XPS

> - 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**



# Introduction

## Nb – Insulator – NbN model

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

- Superconductivity of samples by PPMS

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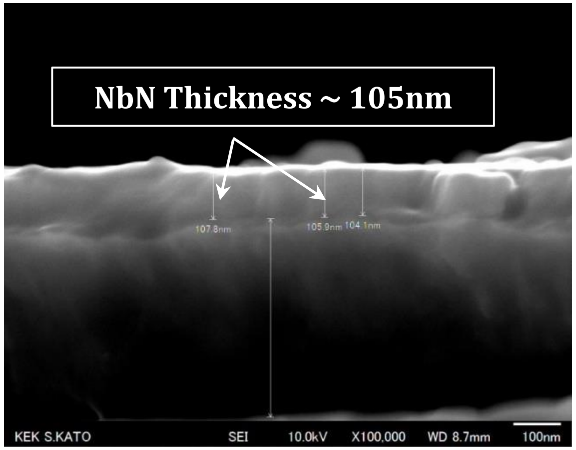


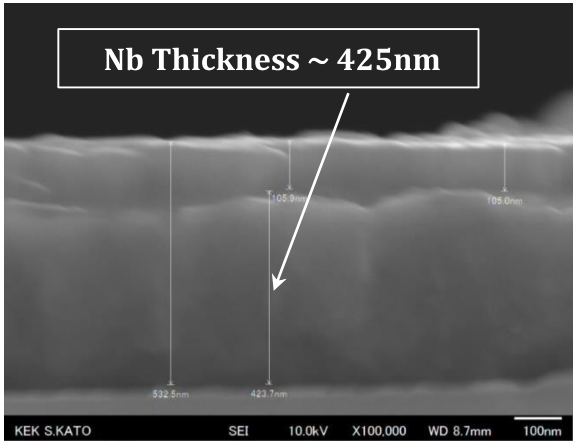

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  - SEM-EDX Analysis
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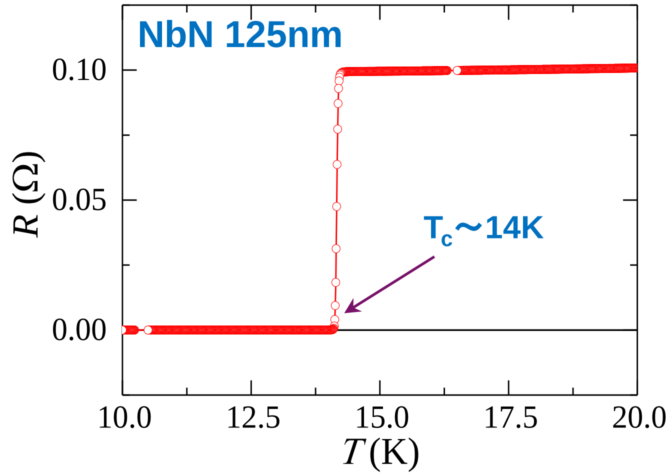
**Improvement of NbN deposition is required or use alternative techniques (ALD, CVD, … )**

- Superconductivity of samples by PPMS

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

**But how we can measure $H_{c1}$ ?**

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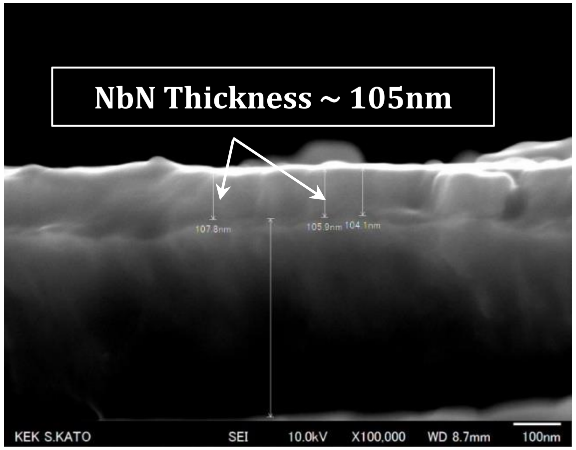
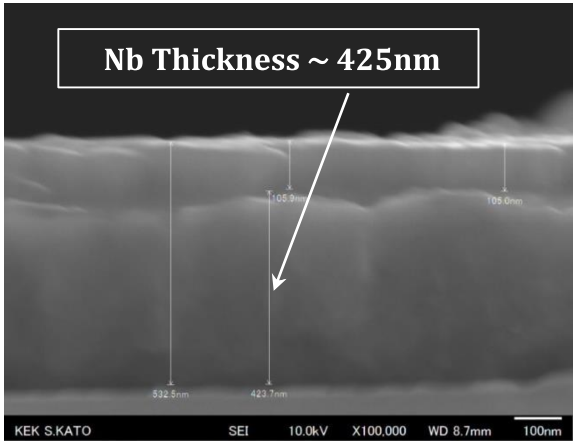


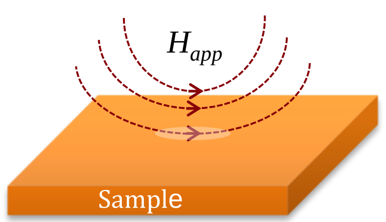



# $H_{c1}$ Measurement, a Local Magnetometer

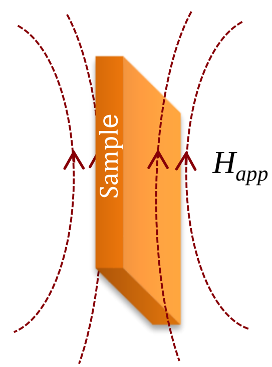
## Why a local magnetometer is necessary ?

- Conventional Magnetometer (SQUID) gives ambiguous results:
  - Uniform field around the sample
  - Orientation, edge and shape effects
  - Demagnetization effects
  - Samples exhibit a strong transverse moment
  - Exact local field configuration not known

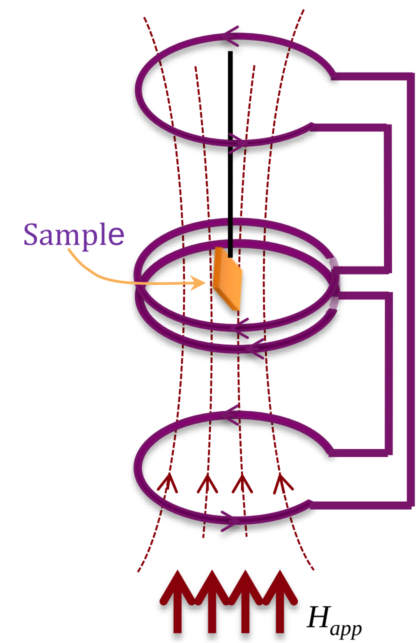
- Development of local magnetometer necessary:
  - Magnet size << sample size (infinite plane approx.)
  - Measurement of $H_{c1}$ on sample without edge/demagnetization effect
  - Explorer new SCs multilayers at higher fields




Local magnetometer principle



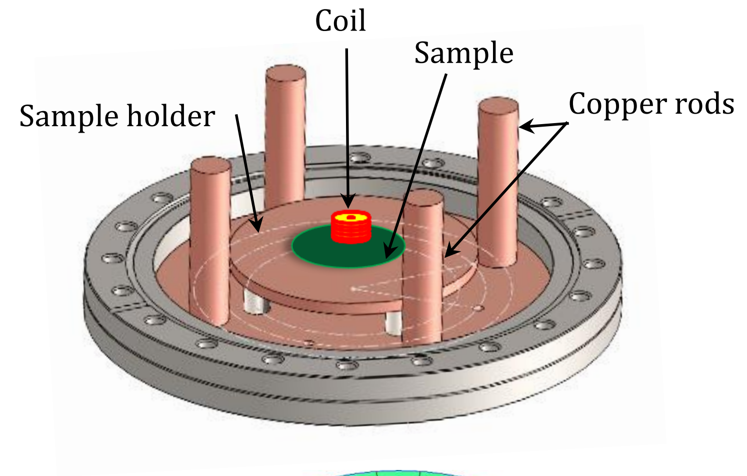

SQUID magnetometer principle

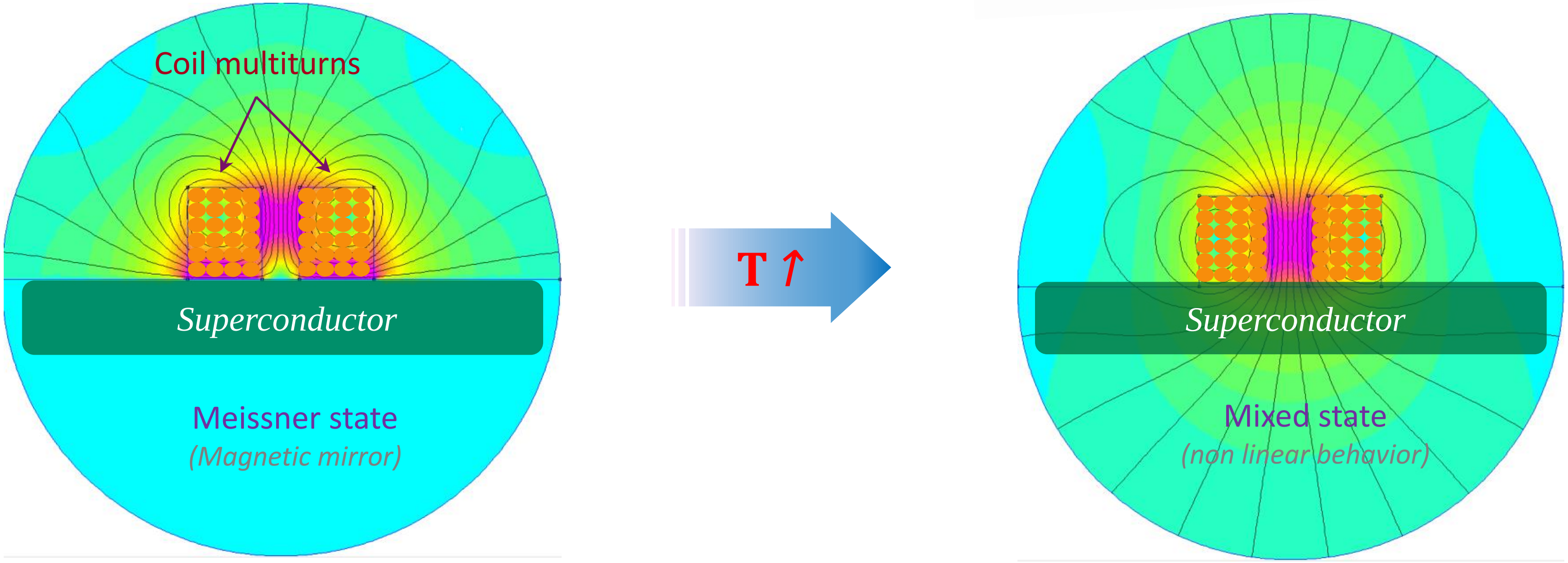


# $H_{c1}$ Measurement, a Local Magnetometer

## How this magnetometer works ?

- 3rd harmonic measurement of $Hc_1$
  - Excitation / Detection coil ($R_{coil} << R_{sample}$)
  - Field decreases quickly away from the coil
  - *ZFC* of the Sample
  - $I_0 cos(\omega t)$ in the coil => $b_0 cos(\omega t)$ on the sample
  - Slow temperature rise
  - Meissner state : sample "*perfect magnetic mirror*" [5]
  - At $Hc_1$ , $V_3$ appears (non linear behavior)



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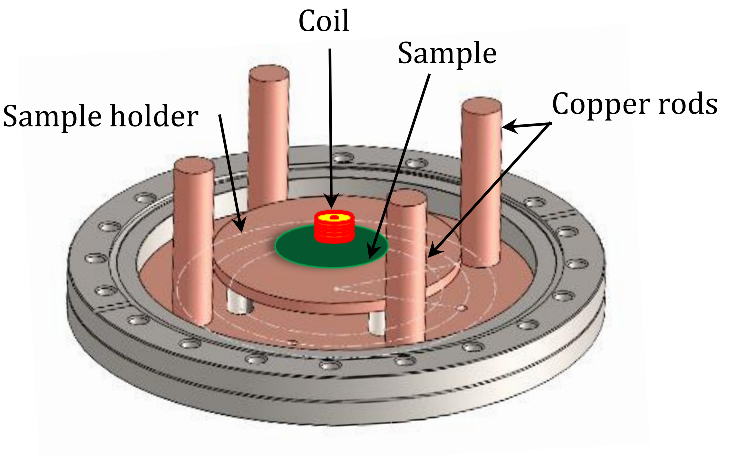
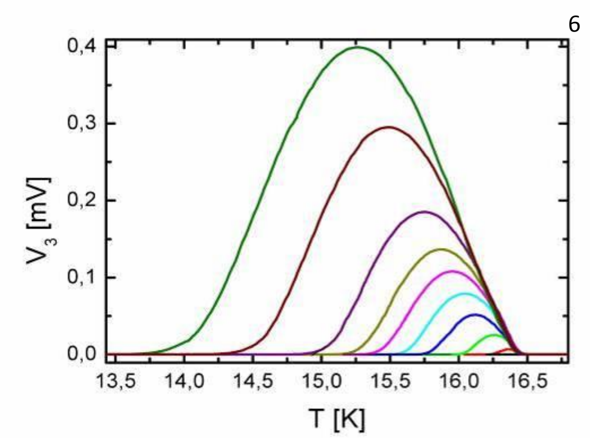
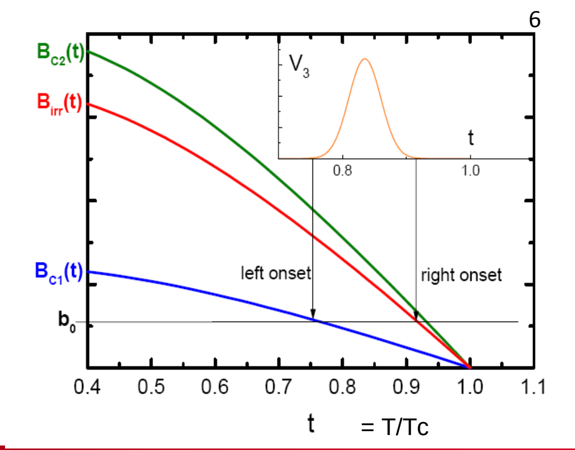



- Building a setup ~operating conditions for SRF (2K-20K; *H* >> 150 mT) : (tbc existing facilities[6] : > 4,5 K or 70 K and $B_{max}$ ~15-20 mT)

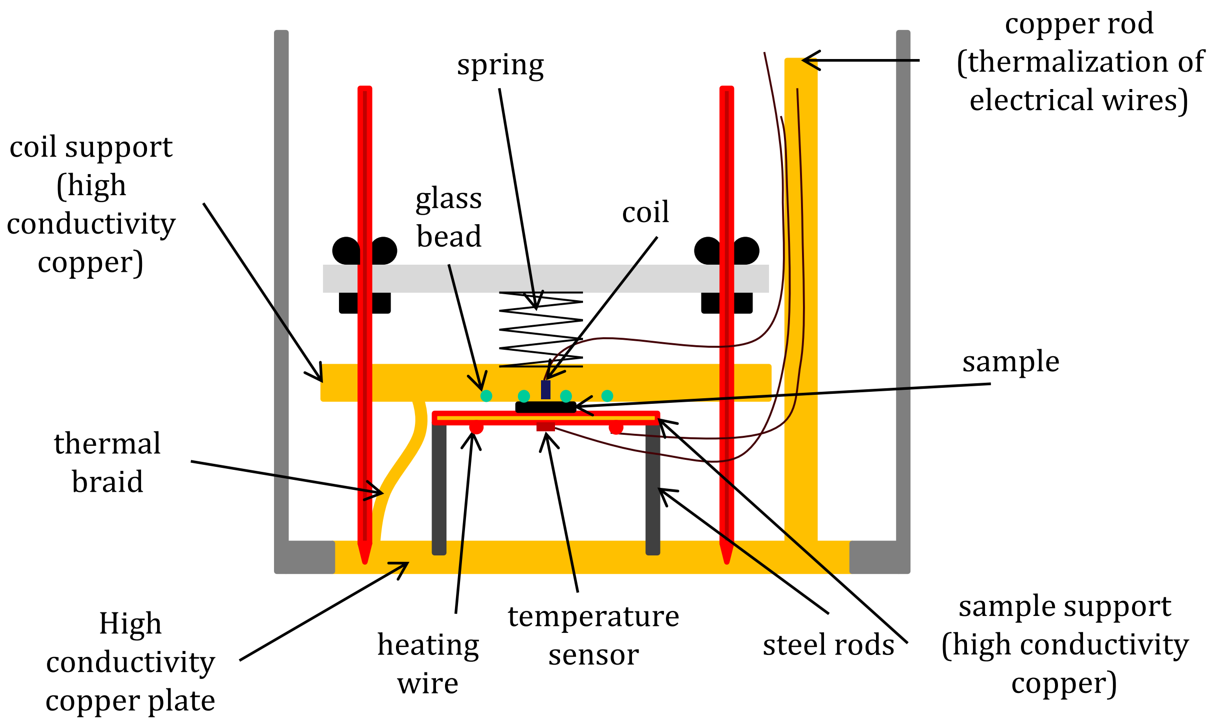


# $H_{c1}$ Measurement, a Local Magnetometer

## How this magnetometer works ?

- Works have been beginning in 2010




**Schematic of local magnetometer**

# $H_{c1}$ Measurement, a Local Magnetometer



## How this magnetometer works ?

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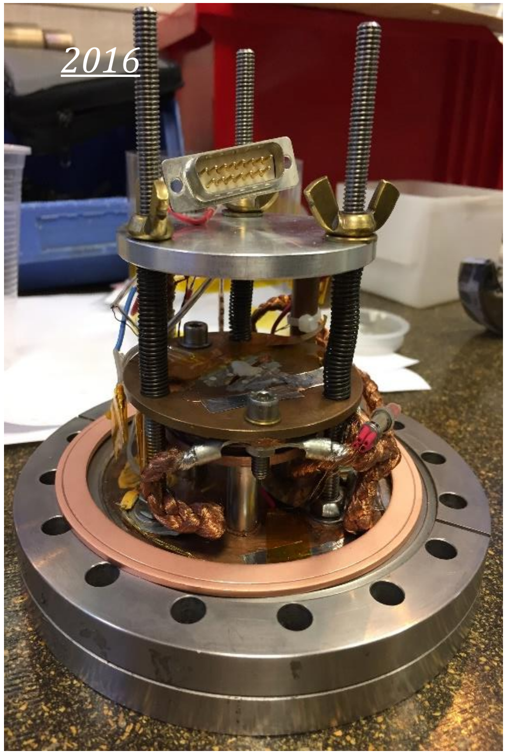



**Experimental setup**

# $H_{c1}$ Measurement, a Local Magnetometer

## How this magnetometer works ?

- Works have been beginning in 2010

Insert

Cryostat

Measurement devices

# $H_{c1}$ Measurement, a Local Magnetometer

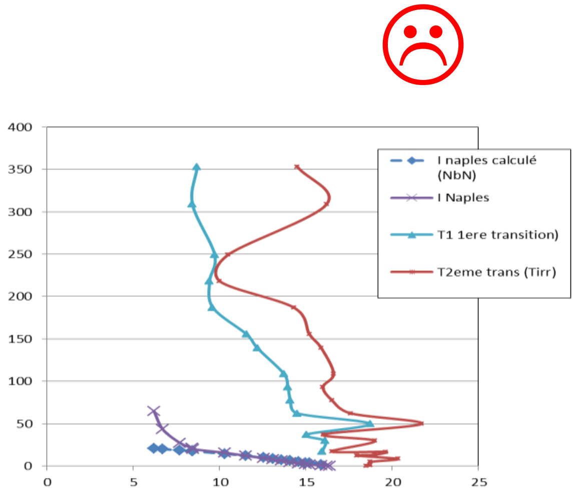
## Behind every success, a lot of failures

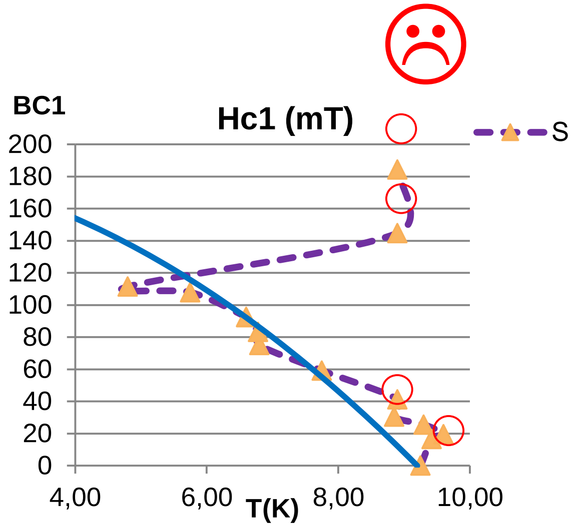
- Many efforts were achieved to overcome some difficulties

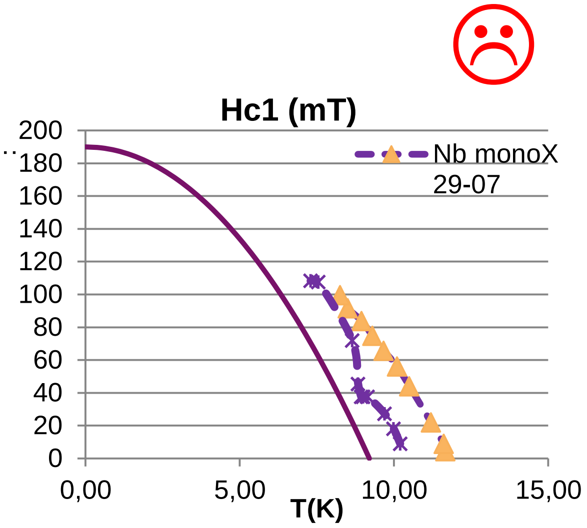
**Problems !**

**Thermal stabilizations**

**Calibration (important shift)**



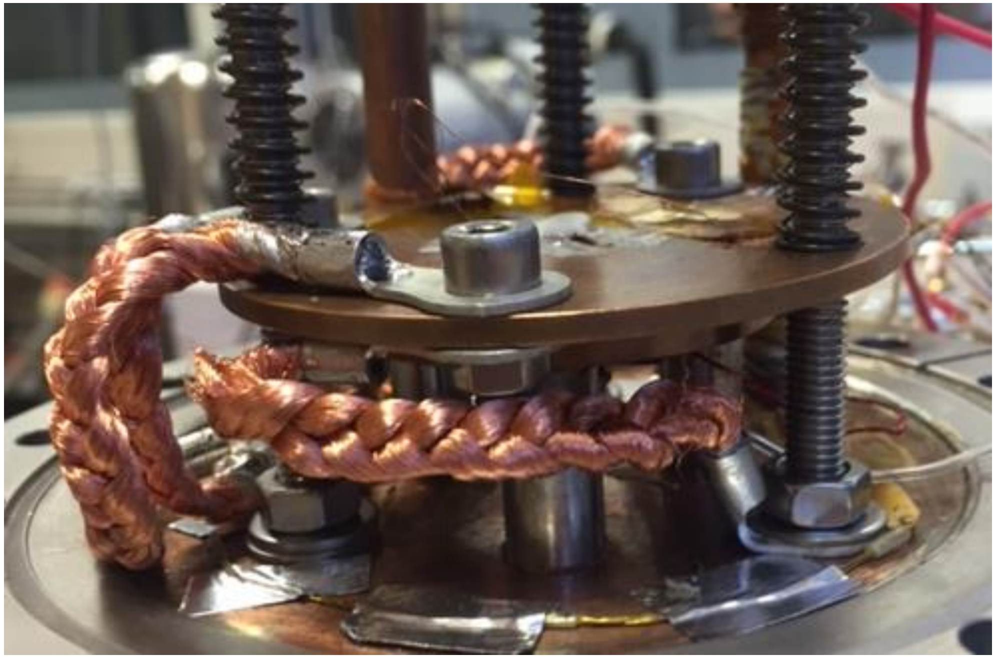

Calibration with a monocrystalline Nb

# $H_{c1}$ Measurement, a Local Magnetometer

## Behind every success, a lot of failures

- Many efforts were achieved to overcome some difficulties

| Problems ! | Modifications |
| --- | --- |
| Thermal stabilizations | Add some copper braids |
| Calibration (important shift) | |

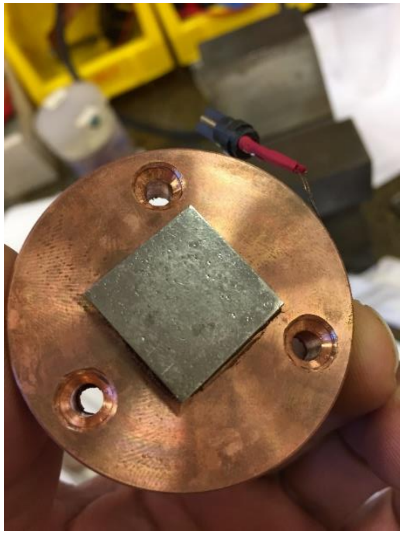


# $H_{c1}$ Measurement, a Local Magnetometer

## Behind every success, a lot of failures

- Many efforts were achieved to overcome some difficulties

| Problems ! | Modifications |
| --- | --- |
| Thermal stabilizations | Add some copper braids |
| Calibration (important shift) | The sample holder |

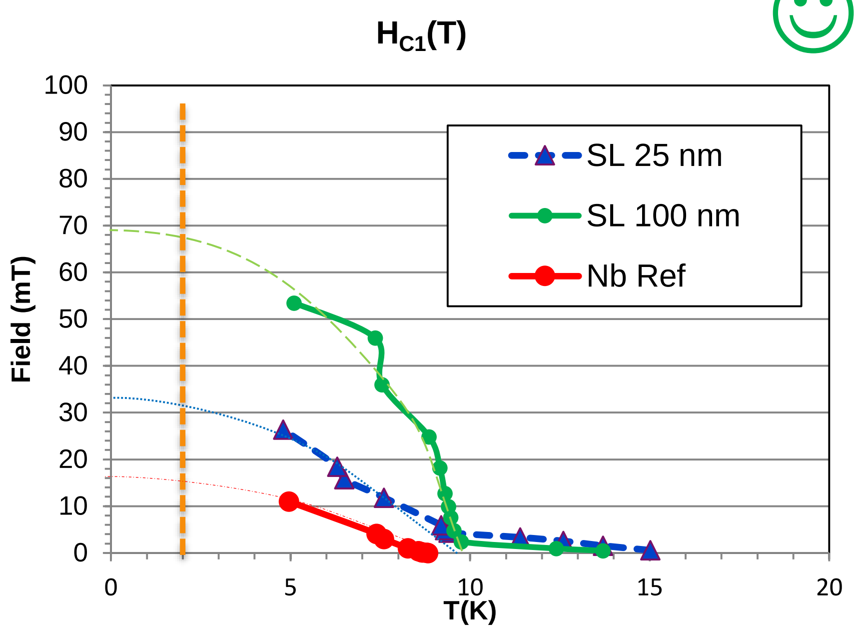


# $H_{c1}$ Measurement, a Local Magnetometer

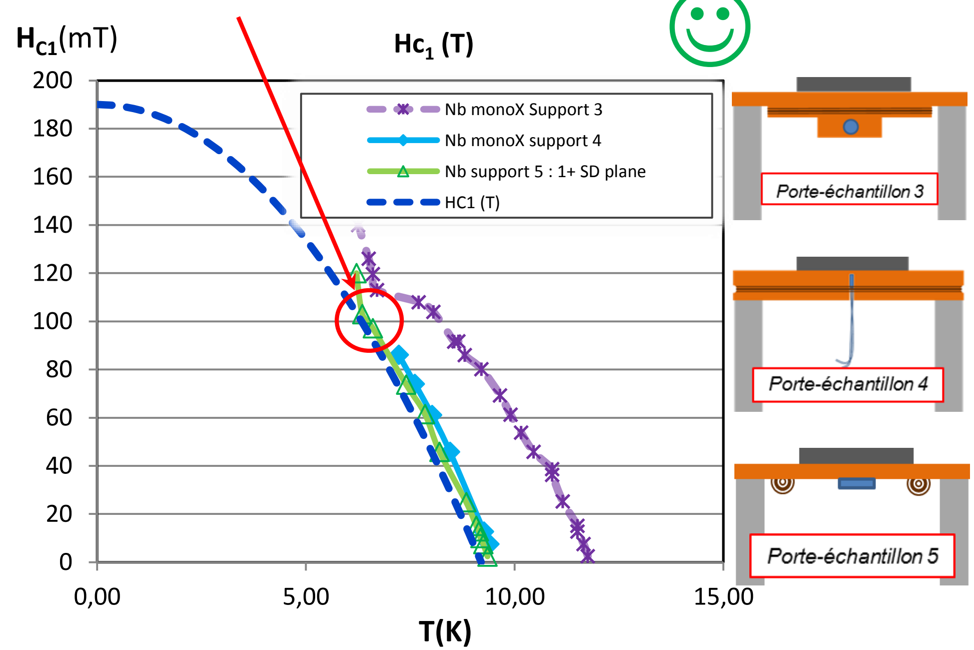
## Behind every success, a lot of failures

- Many efforts were achieved to overcome some difficulties
- End of 2016, first successful measurement

**Finally, a measurement done correctly until ~100mT**




First acceptable results



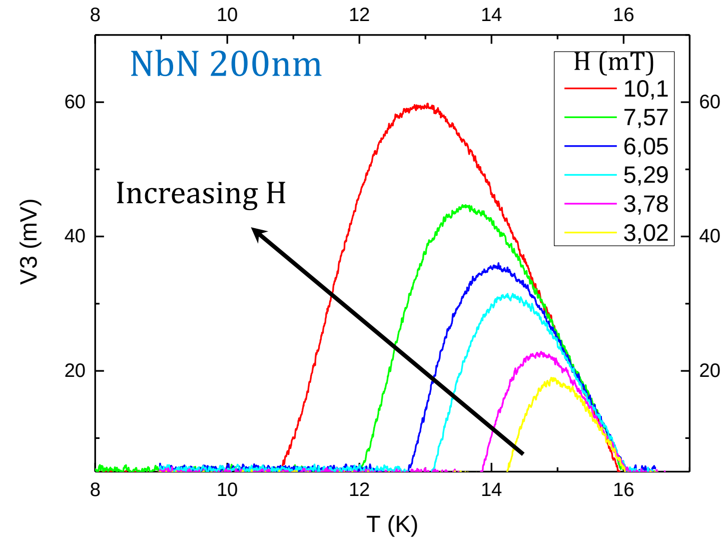

Calibration with a monocrystalline Nb

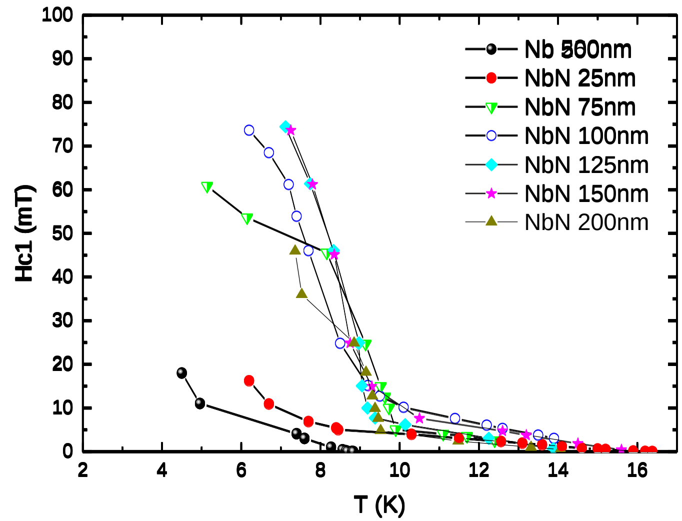
# Screening Power of NbN Layer

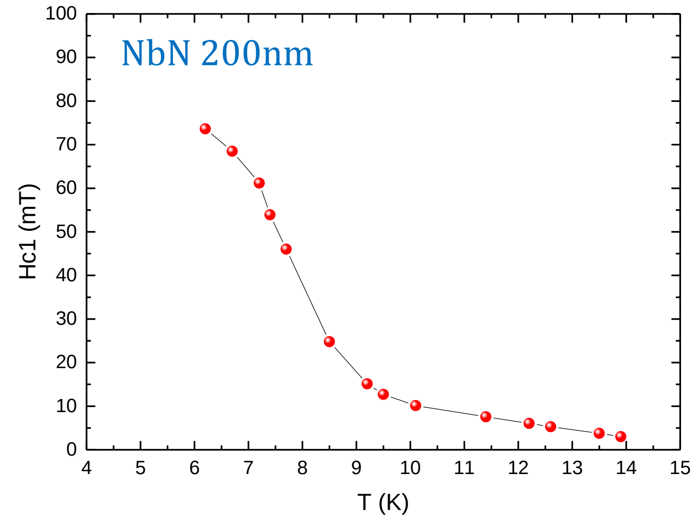
## Last results and discussion

- Series of Nb - MgO - NbN samples
  - January 2017, beginning of measurements
  - Generally, 1 sample/week
    (*Mounting + cooling + manipulation + warming up*)

  - Accepted results
  - Thermal stabilization
  - Correct transitions



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  - January 2017, beginning of measurements
  - Generally, 1 sample/week
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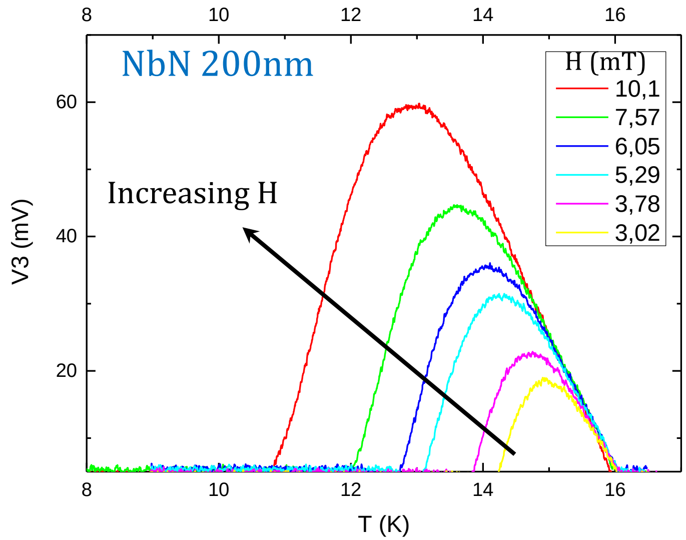
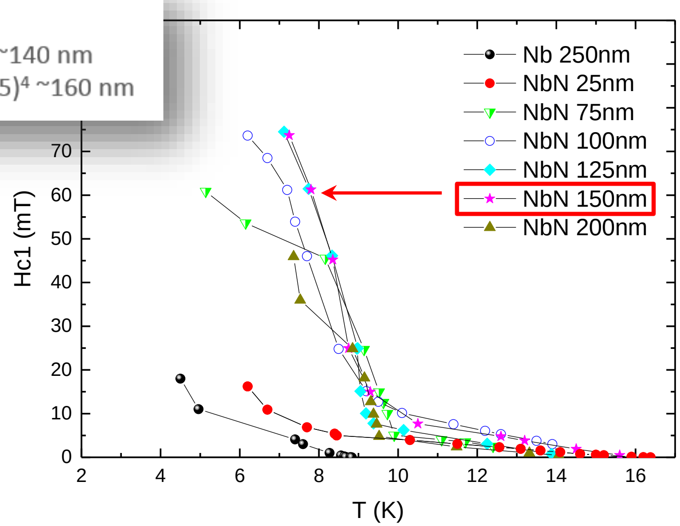
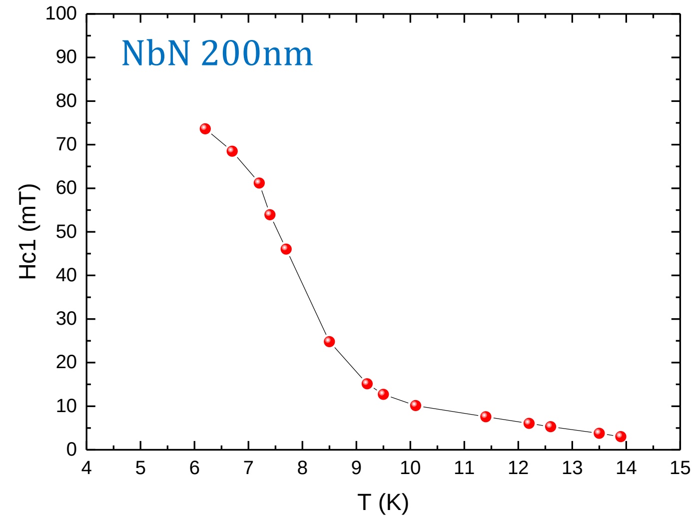
  - Accepted results
  - Thermal stabilization
  - Correct transitions
  - Good agreement with the predictions of Kubo - Gurevich




- **Predictions**
  - T. Kubo (2014)[3] ~140 nm
  - A. Gurevich (2015)[4] ~160 nm



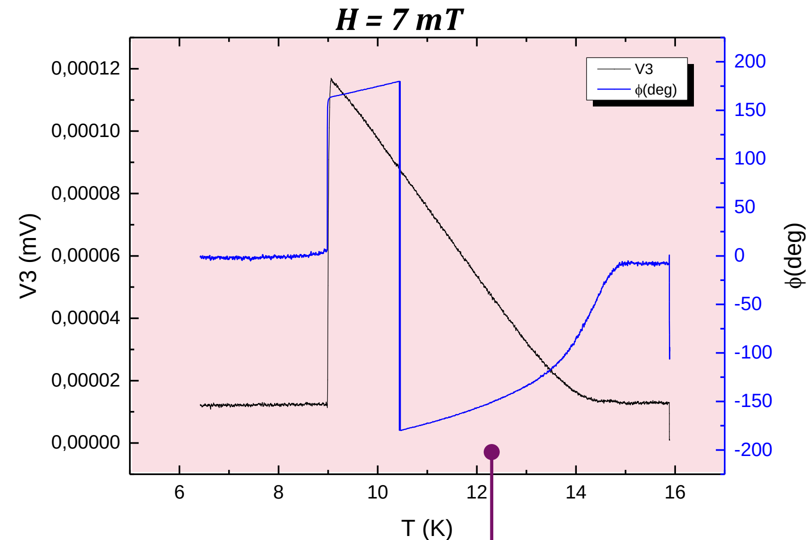



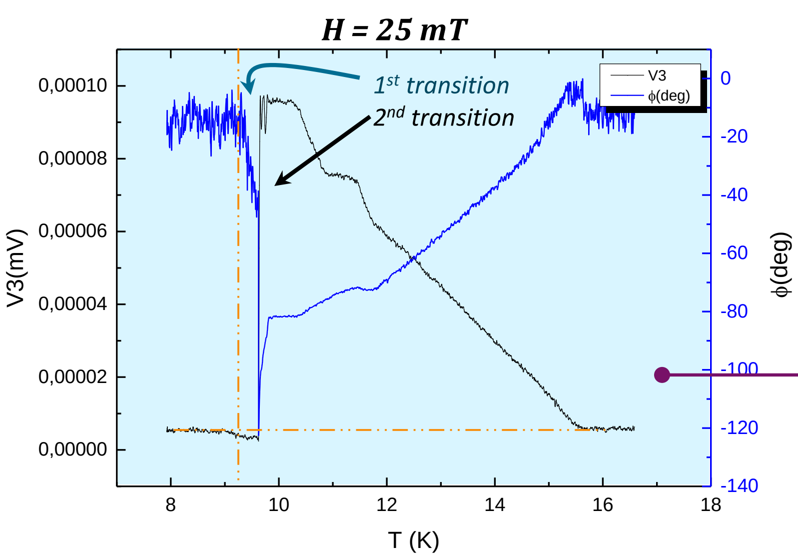
# Screening Power of NbN Layer

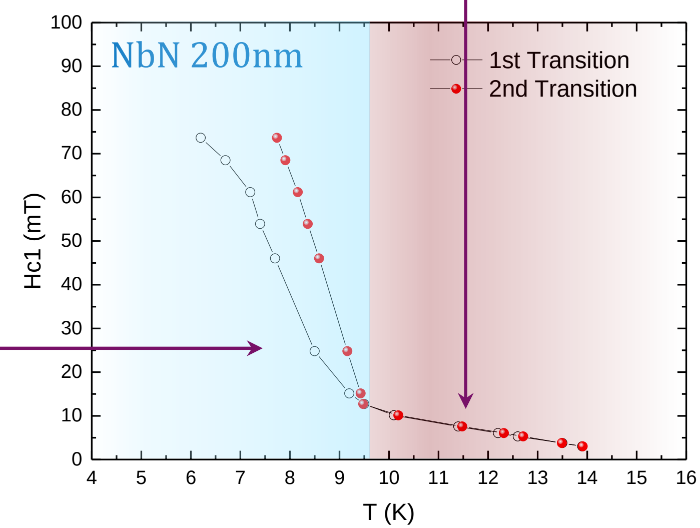
## Last results and discussion

- Determination of $H_{c1}$
  - Low field => one transition
  - High field => two transitions
  - 1st transition with low dissipation
  - 2nd transition very clear with high dissipation

- Why we have two transitions ?



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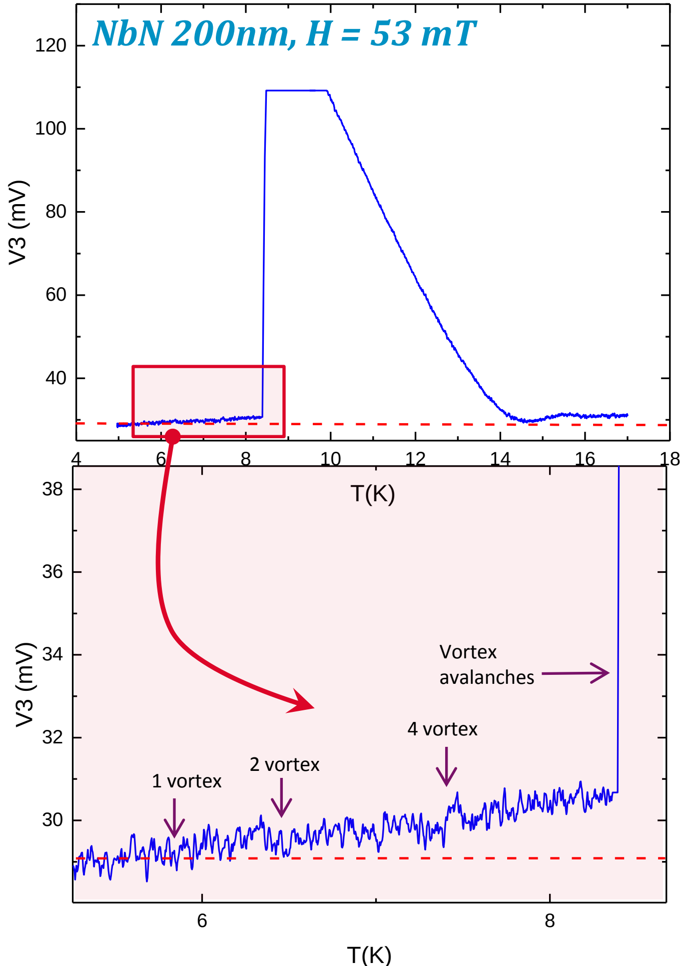
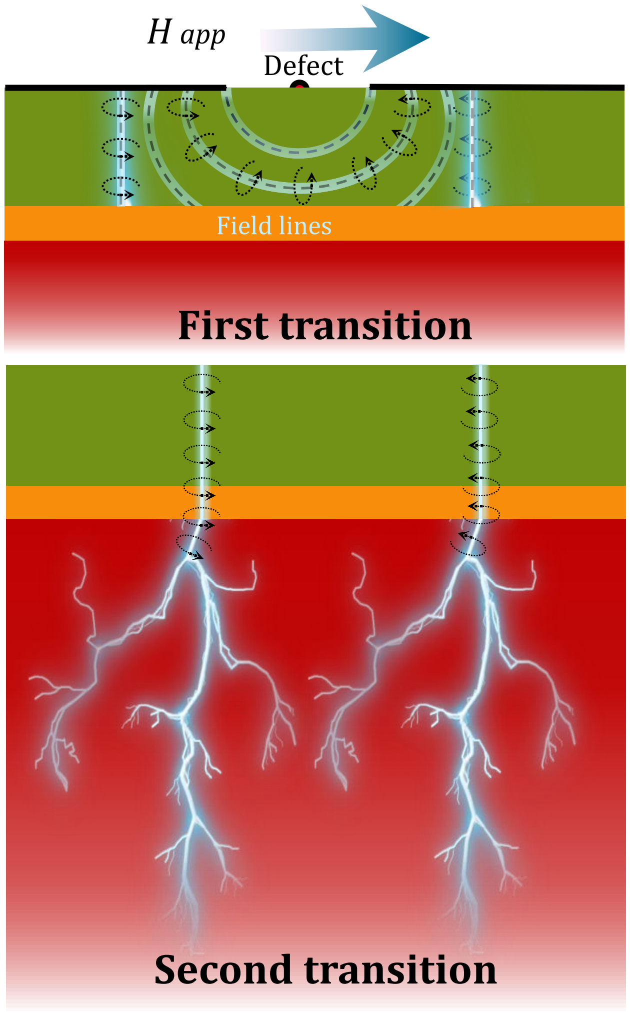



- Thin SC layer NbN
- Insulator MgO
- Thick SC layer Nb

- *H* // surface => surface barrier[7]
- 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.

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

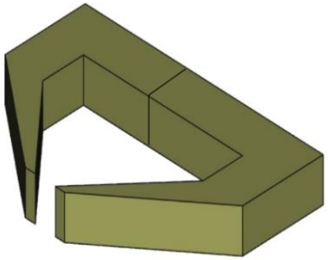
# Conclusion and Perspectives

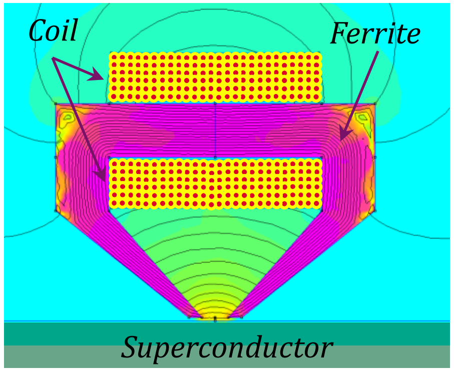
## Conclusion

- A local magnetometer has proven to be effective at measuring vortex penetration in conditions close to cavities operating condition.
- We have shown a very promising behavior of NbN layers
- S-I-S multilayers provide best protection of cavities against local penetration of vortices
- Overcome Nb monopoly by higher $H_{c1}$ superconductors multilayers is possible
- Sample gives results close to theory : optimization can 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.





# Thank you for your attention

*Claire ANTOINE*

*Muhammad ABURAS*

*Aurelien FOUR*

*Special thanks go to everyone participated in this work*