Evaluation of the SC characteristics of multi-layer thin-film structures of NbN and SiO_2 on pure Nb substrate

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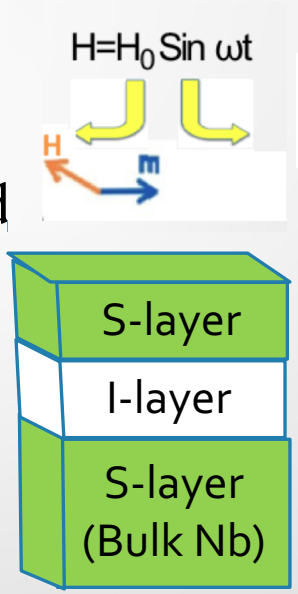
H.Ito (Sokendai, Ibaraki)

Introduction

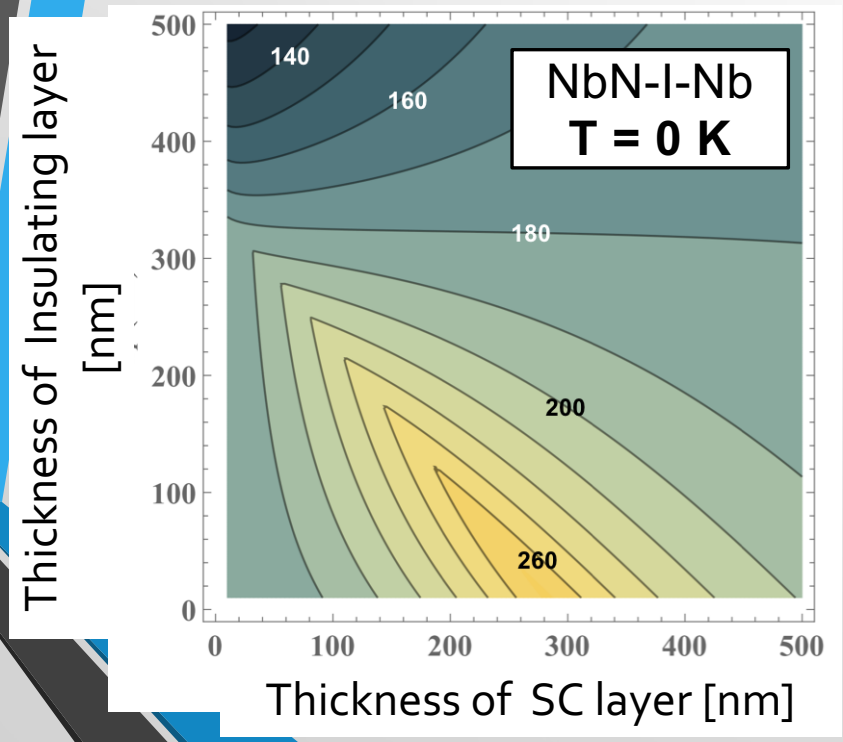
- The maximum accelerating gradient of superconducting cavity is limited by the magnetic field at which vortex avalanche occurs.
  - In this study, we calls such magnetic field as "**effective H_{c1}**", $H_{c1,eff}$.
- Recently proposed theory predicts that $H_{c1,eff}$ is pushed up by Superconductor-Insulator-Superconductor structure (**S-I-S structure**)[1][2][3][4].
- In order to verify this scheme, we are trying to make some experiments.



[1] A. Gurevich, Appl. Phys. Lett. 88, 012511 (2006).
[2] T. Kubo, Y. Iwashita, and T. Saeki, Appl. Phys. Lett. 104, 032603 (2014).
[3] A. Gurevich, AIP Adv. 5, 017112 (2015).
[4] T. Kubo, Supercond. Sci. Technol. 30, 023001 (2017).

Motivation of this study

- The proposed theory predicts an optimum set of the parameters to exhibit a good performances
  - We focused on NbN-Insulator-Nb structure.
  - Theoretical calculation of effective H_{c1} at 0 K is plotted below.
    - Note that Hc1 of pure bulk Nb is assumed to be 180 mT at 0 K in this calculation.



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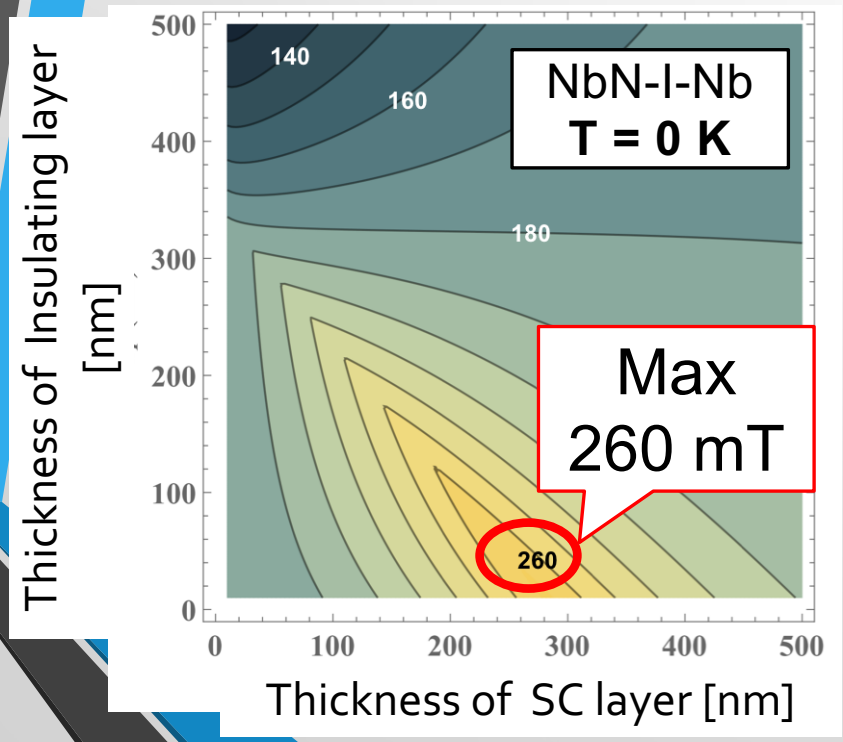

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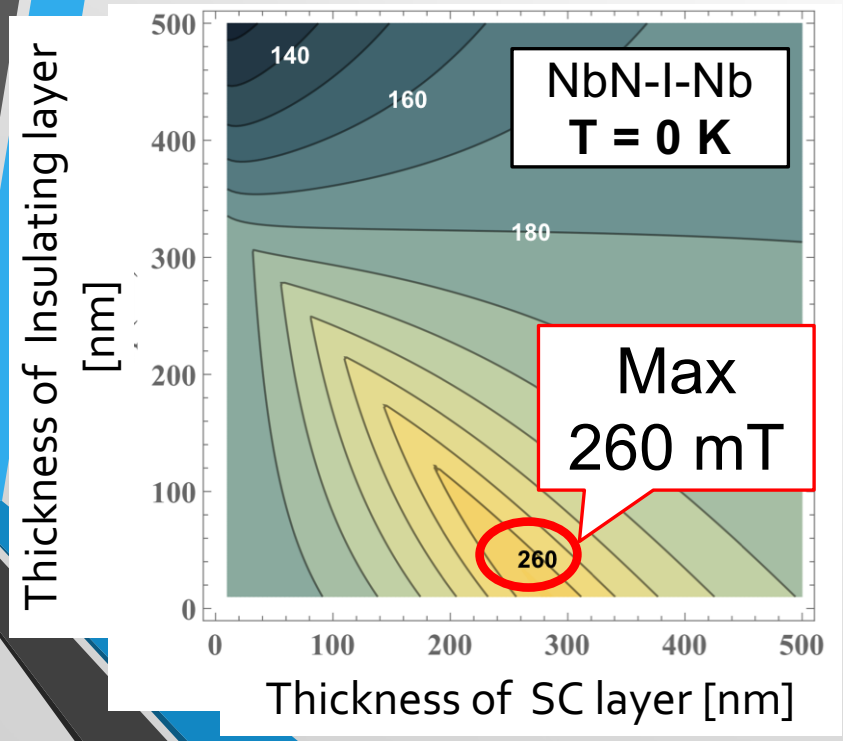

- In order to evaluate this scheme, we scanned parameter regions (red line).
  - NbN thickness: 50 - 800 nm
  - SiO_2 thickness is fixed to 30 nm.
- In this study, in order to determine effective Hc1, the third harmonic voltage method is used (explained in the following).

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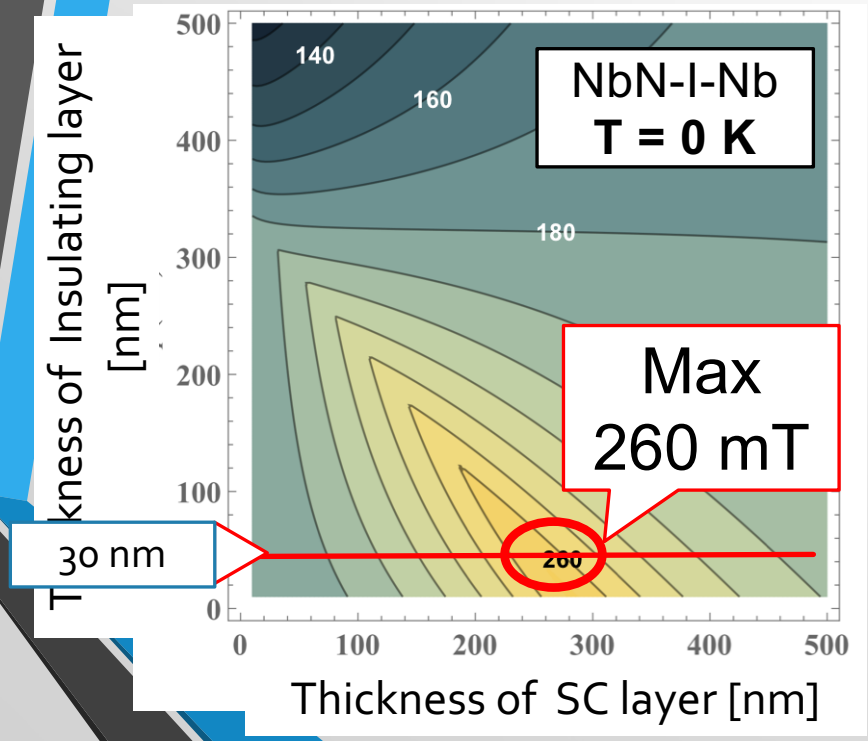

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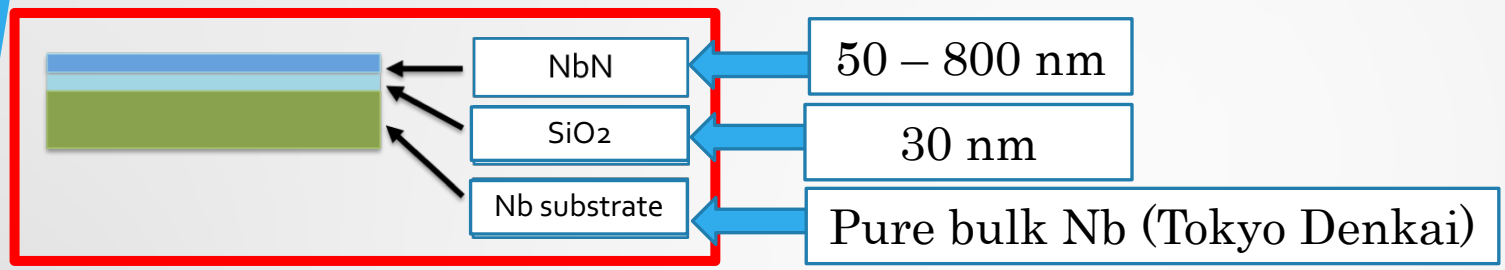
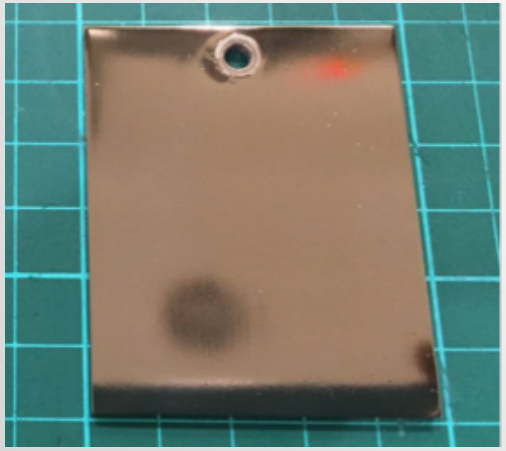
S-I-S' sample used in this study





- NbN/SiO_2 thin-film with various thicknesses is formed on pure bulk Nb [5].
- This sample is fabricated by ULVAC, Inc. with **DC magnetron sputtering**.

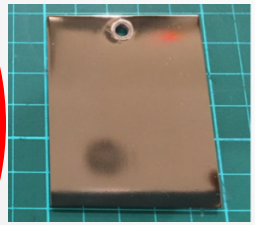
[5] R. Ito, T. Nagata, et al., LINAC 2018 Proceedings, TUPO050

Independent measurement and analysis

NbN/SiO2/Nb Multilayer samples are prepared

Kyoto Univ.

By Ryo Katayama



ULVAC, Inc.

KEK

By Hayato Ito

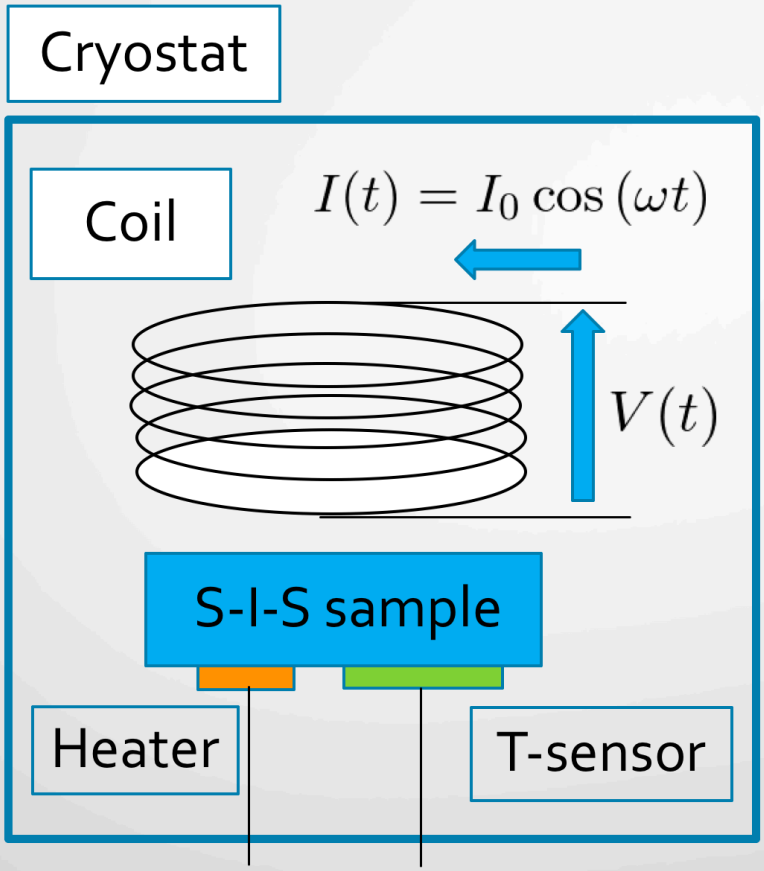
This presentation

TUPO78

We obtained consistent results at two independent setup!

In this presentation, I will report on the measurement and analysis results performed at Kyoto University.

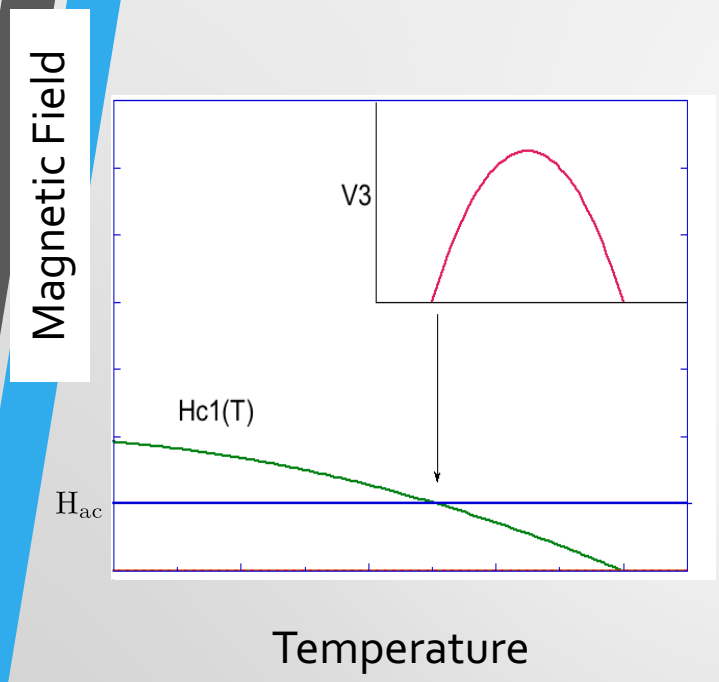
Setup of the third harmonic measurement



- **S-I-S sample** is installed in **Cryostat**.
- **Liquid Helium** keep the temperature of S-I-S sample at the cryogenic temperature.
- **Coil** set just above S-I-S sample, which can apply an AC magnetic field $H_{ac}\cos(\omega t)$.
- Temperature of S-I-S sample is monitored by **Temperature sensor**, and gradually increased by **Heater**.
- Coil voltage and current are detected and digitized by **V-A meters** installed outside.

We can control the temperature and the magnetic field

Measurement method



- H_{c1} satisfies the following empirical curve:
  - $H_{c1}(T) = H_{c1}(0)\times(1-(T/T_c)^2)$
  - T_c is the critical temperature
- **Third harmonic measurement**:
  - AC magnetic field $H_{ac}\cos(\omega t)$ is applied to a S-I-S sample by the coil.
  - In general, **the third harmonic voltage induced in the coil**, V_{3rd}, rises at the moment $H_{ac} > H_{c1}(T)$.
    - By changing the temperature and detecting the rise of V_{3rd} signal, we can determine H_{c1} at a certain temperature.
- By repeating measurements for different H_{ac}, we can clarify the temperature dependence of H_{c1}.

These data points are fitted with the above empirical curve.

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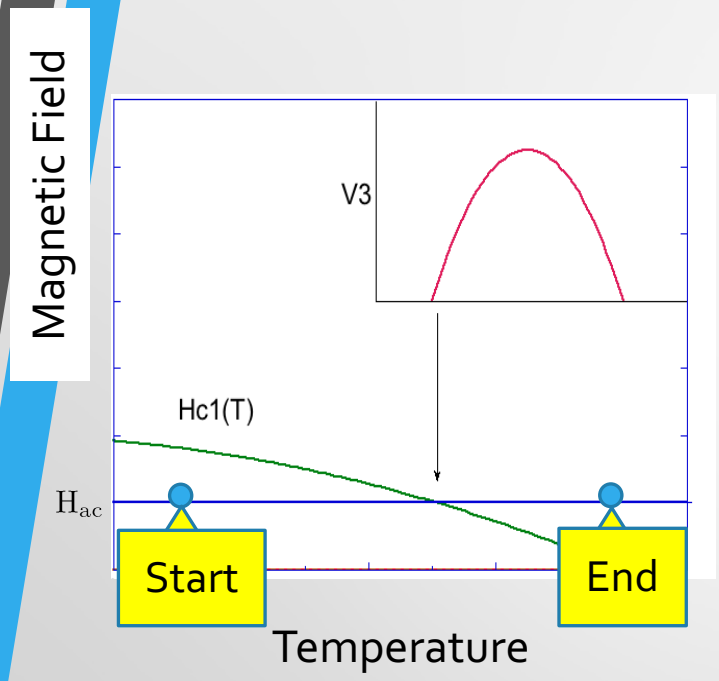

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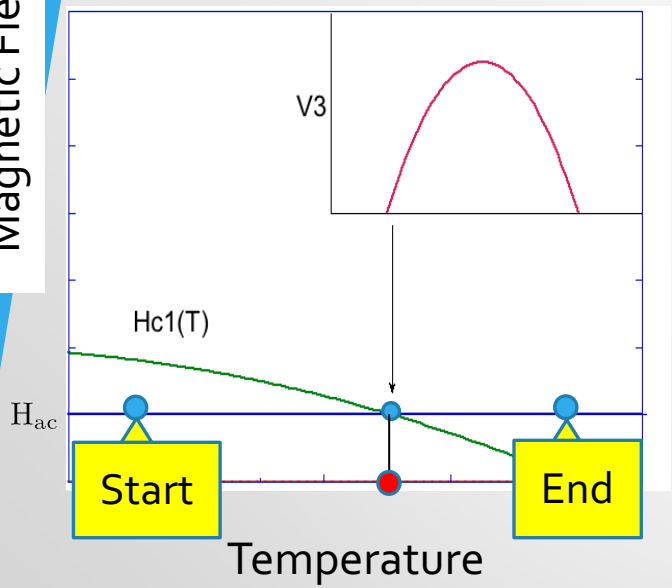

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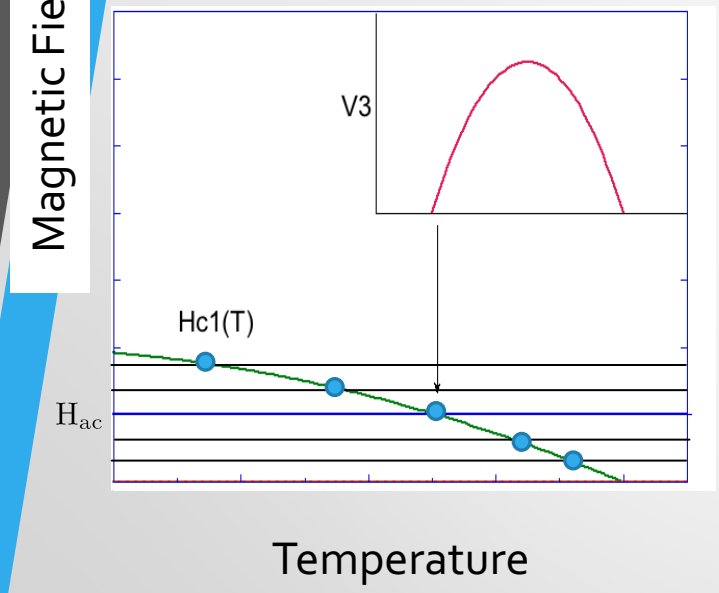

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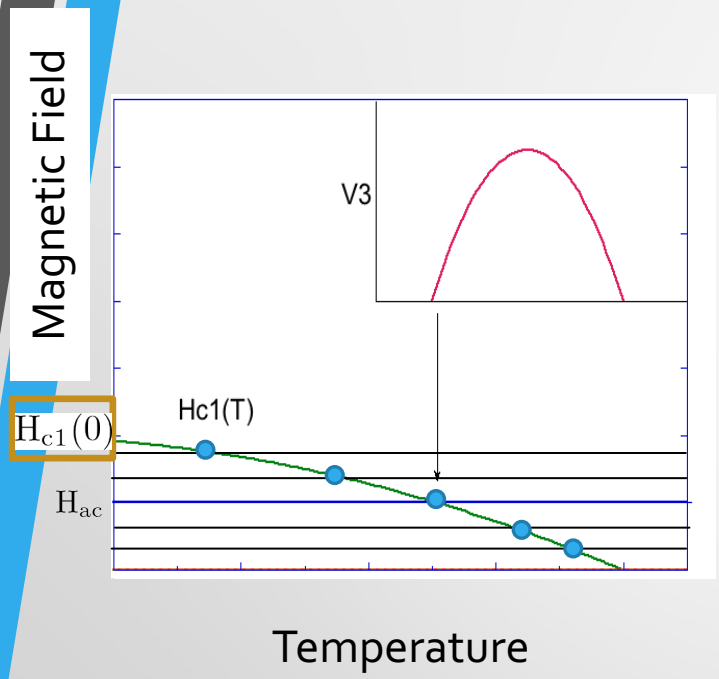

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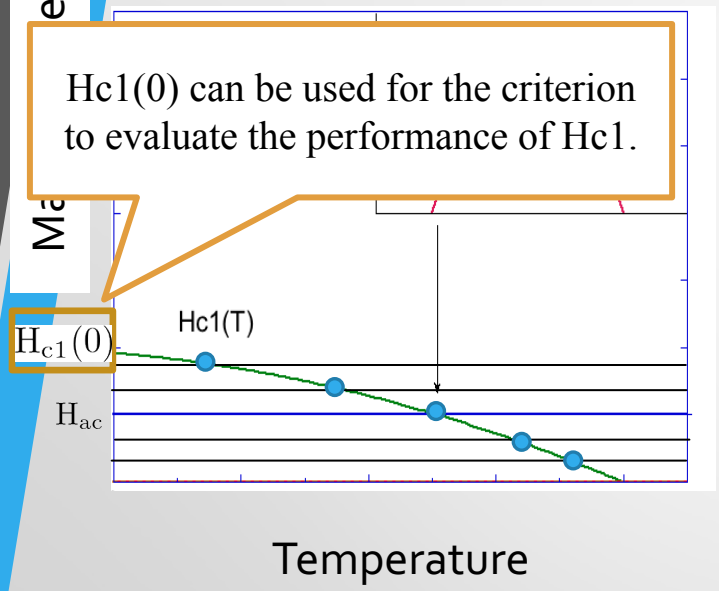

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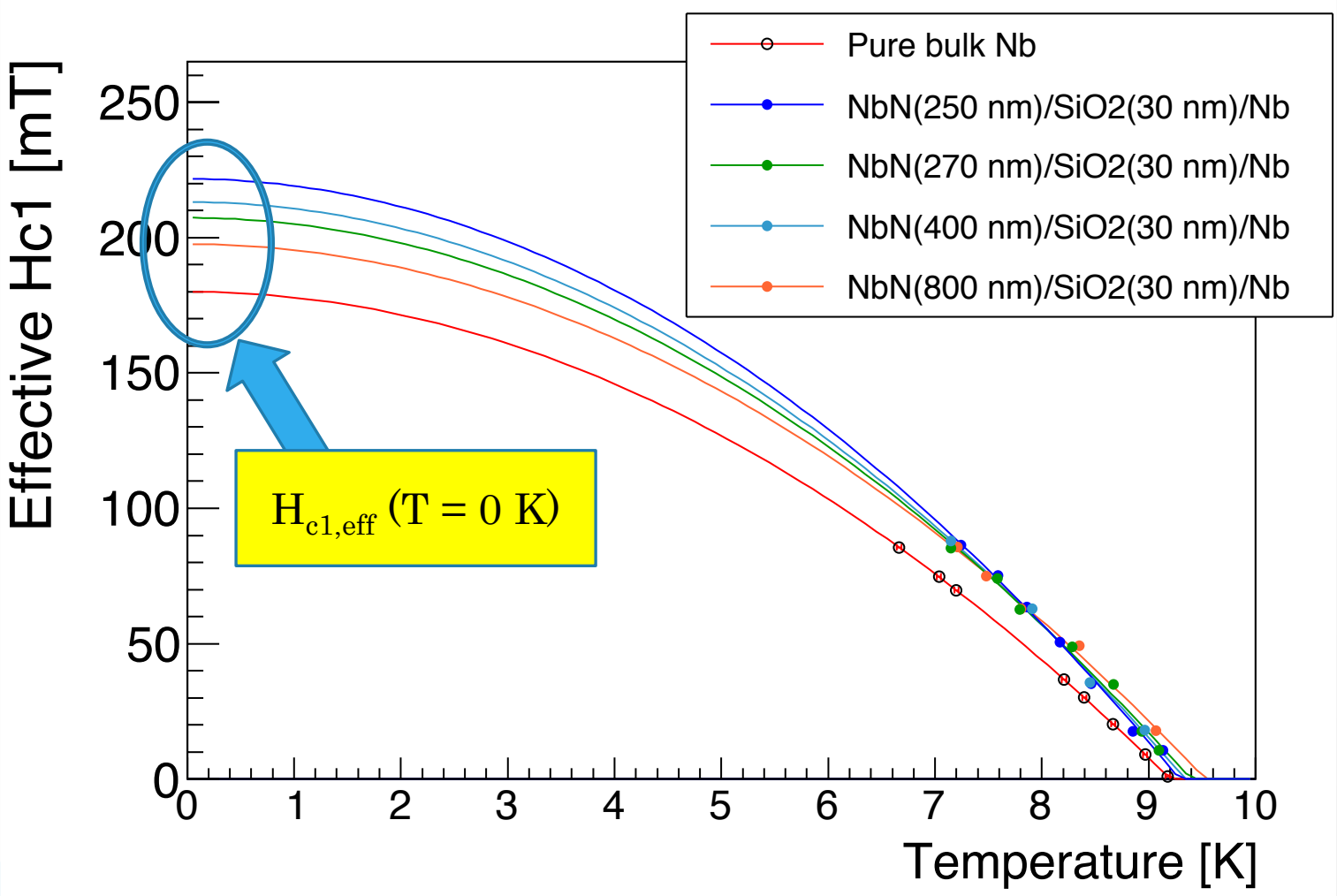
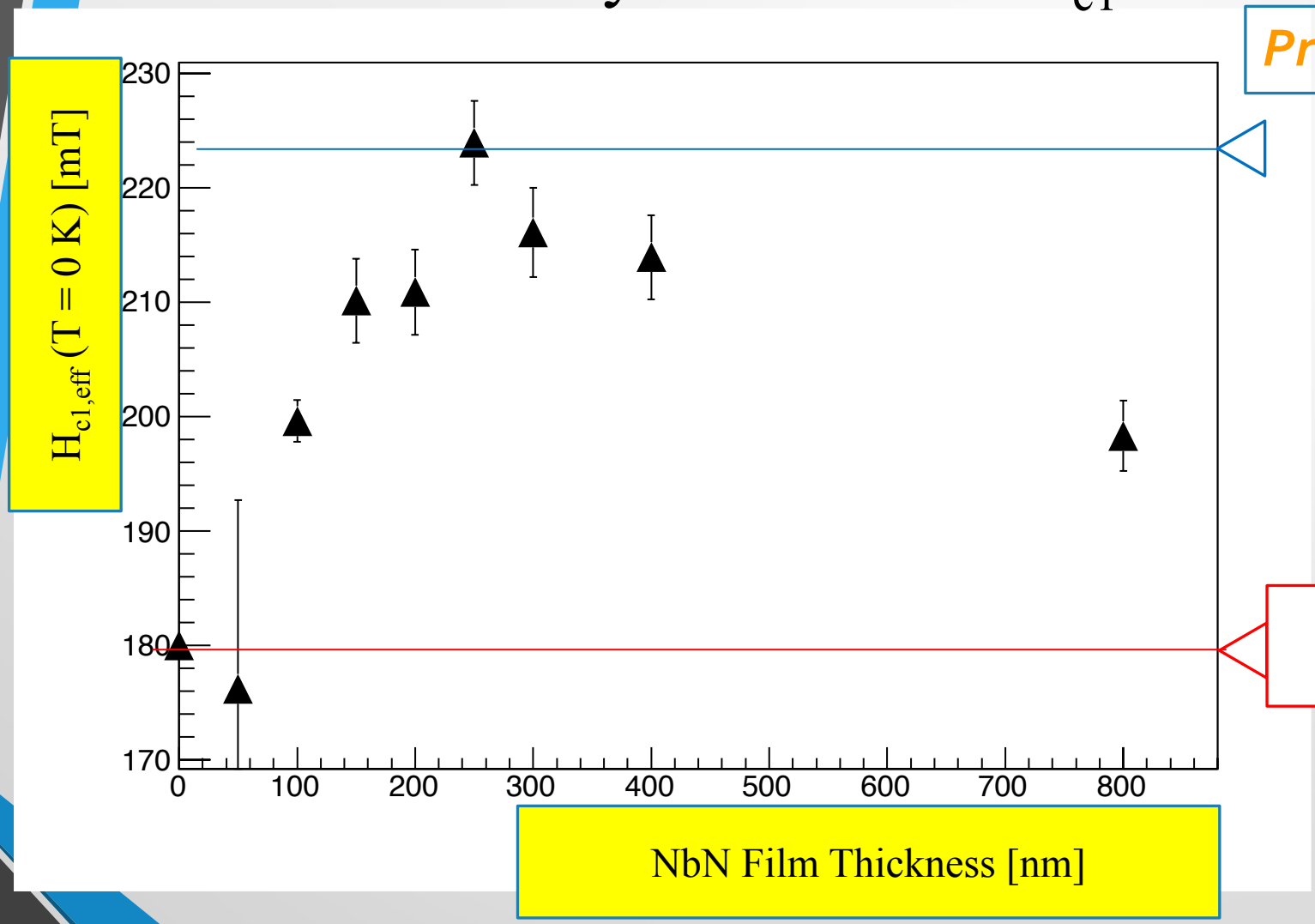
The measurement result of the effective Hc1



Analysis Result of H_{c1}



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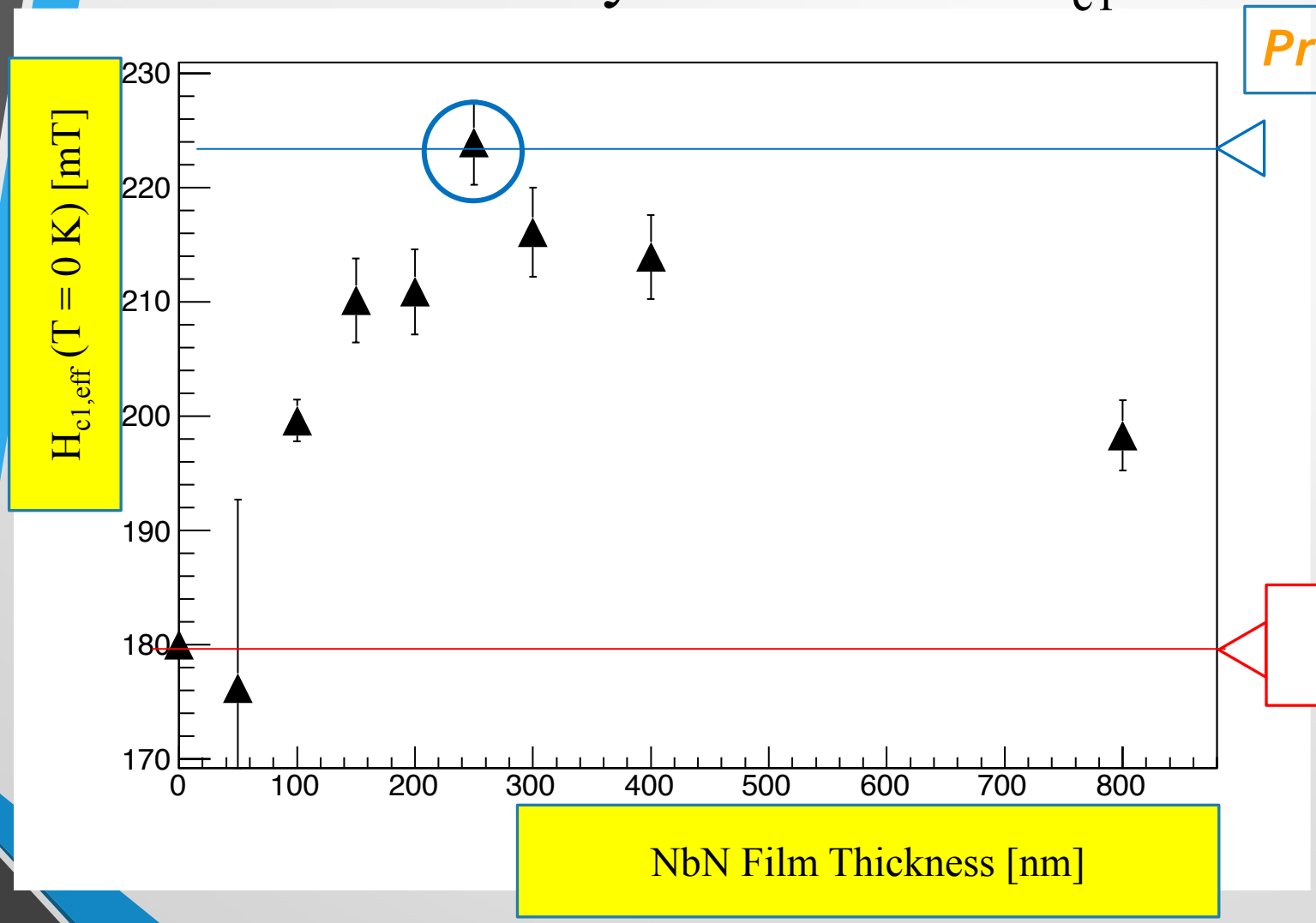

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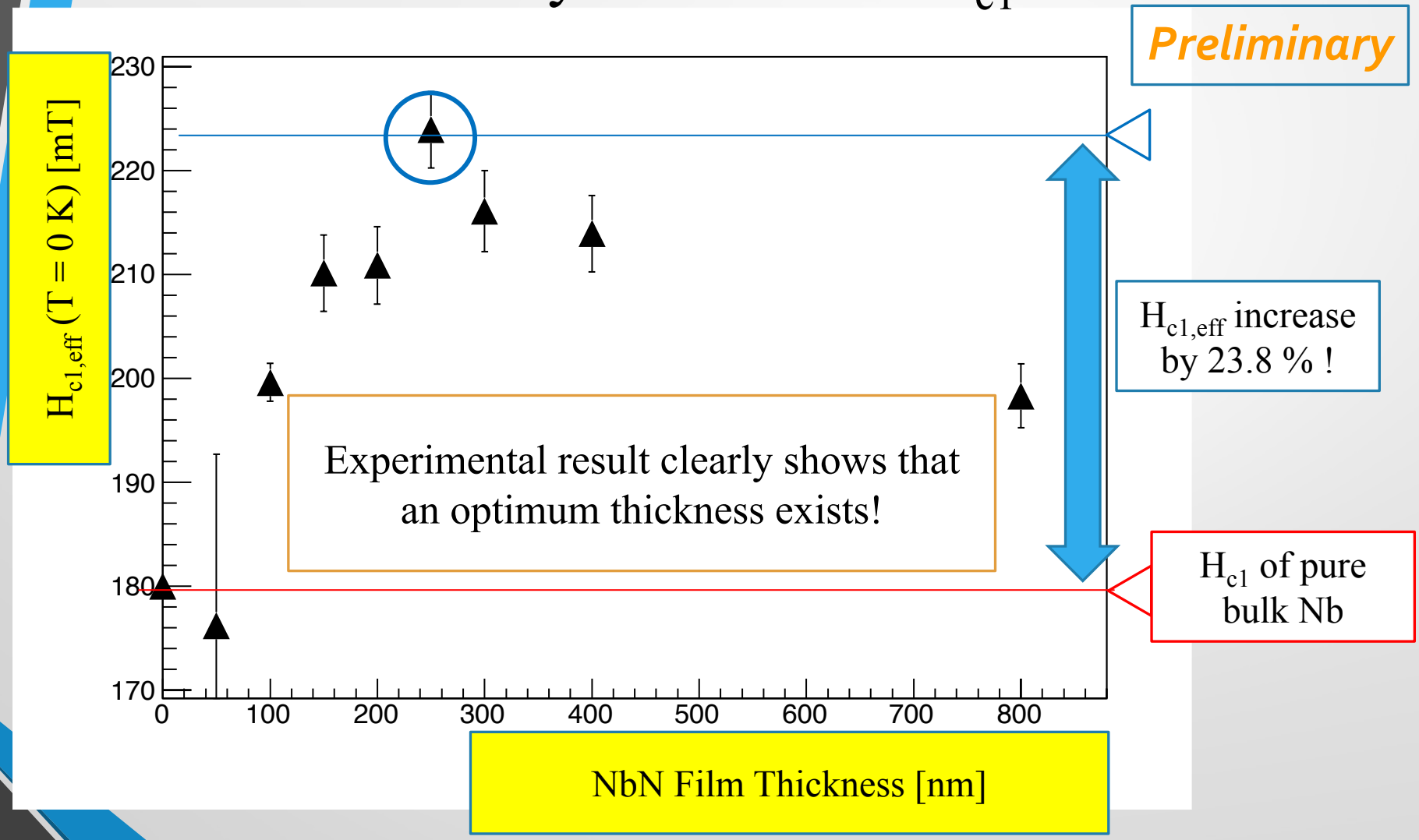
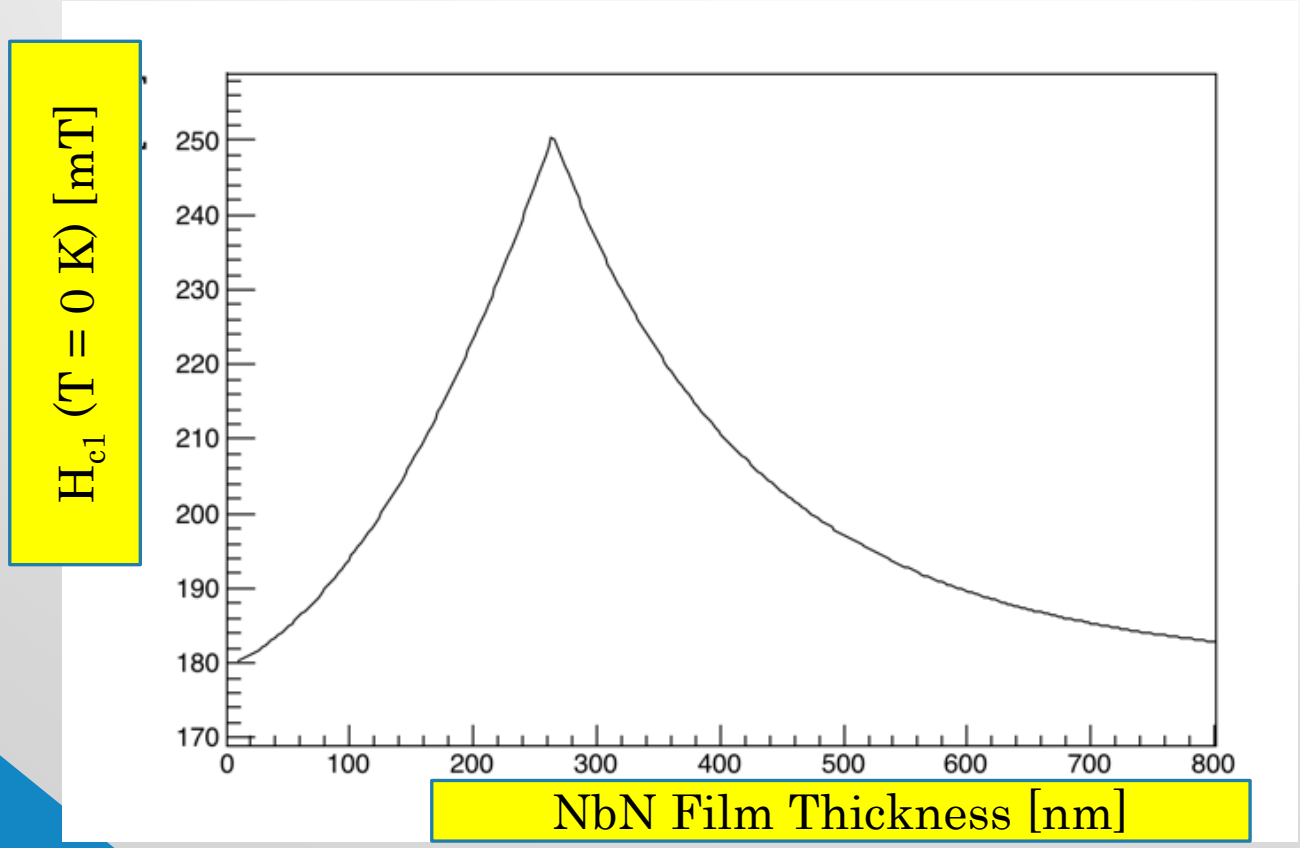


Theory

- Theoretical calculation ($H_{c1,eff}$ vs NbN thickness) is plotted below:
  - Optimum thickness exists, which is the same as experiment.
  - London penetration depth λ of NbN film is calculated by the electrical resistivity ρ and the critical temperature T_c.
  - H_c of NbN is taken from literature (C Geibel et.al, (1985) J. Phys. F: Met. Phys. 15 405).



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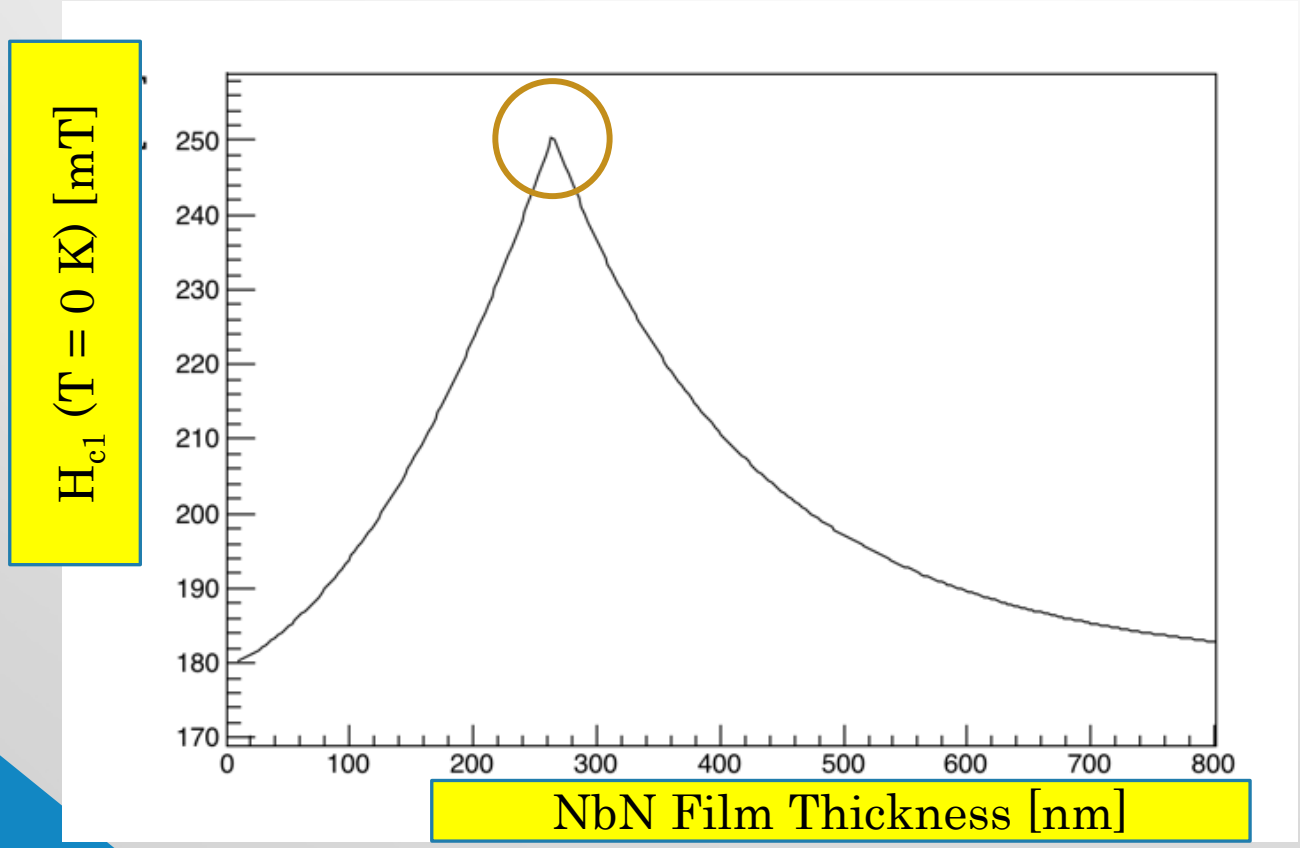

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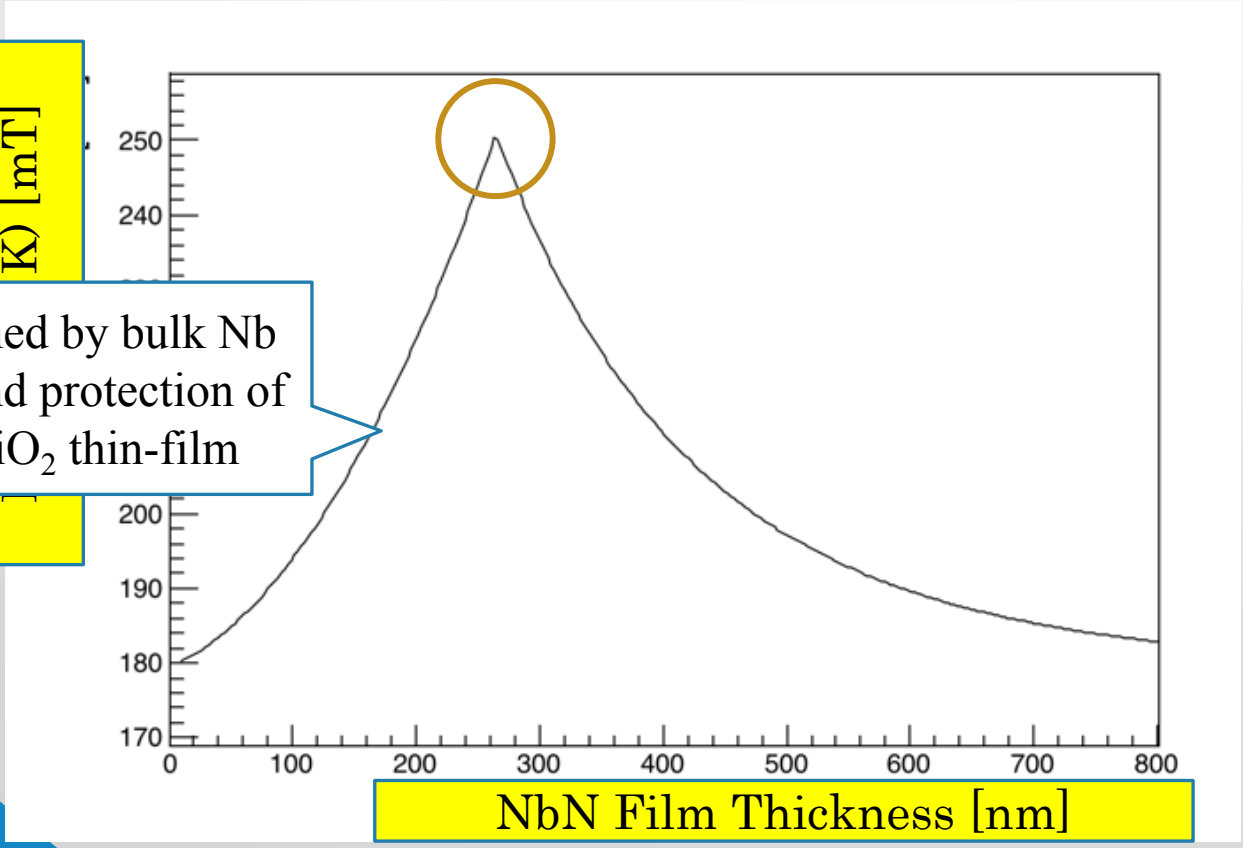

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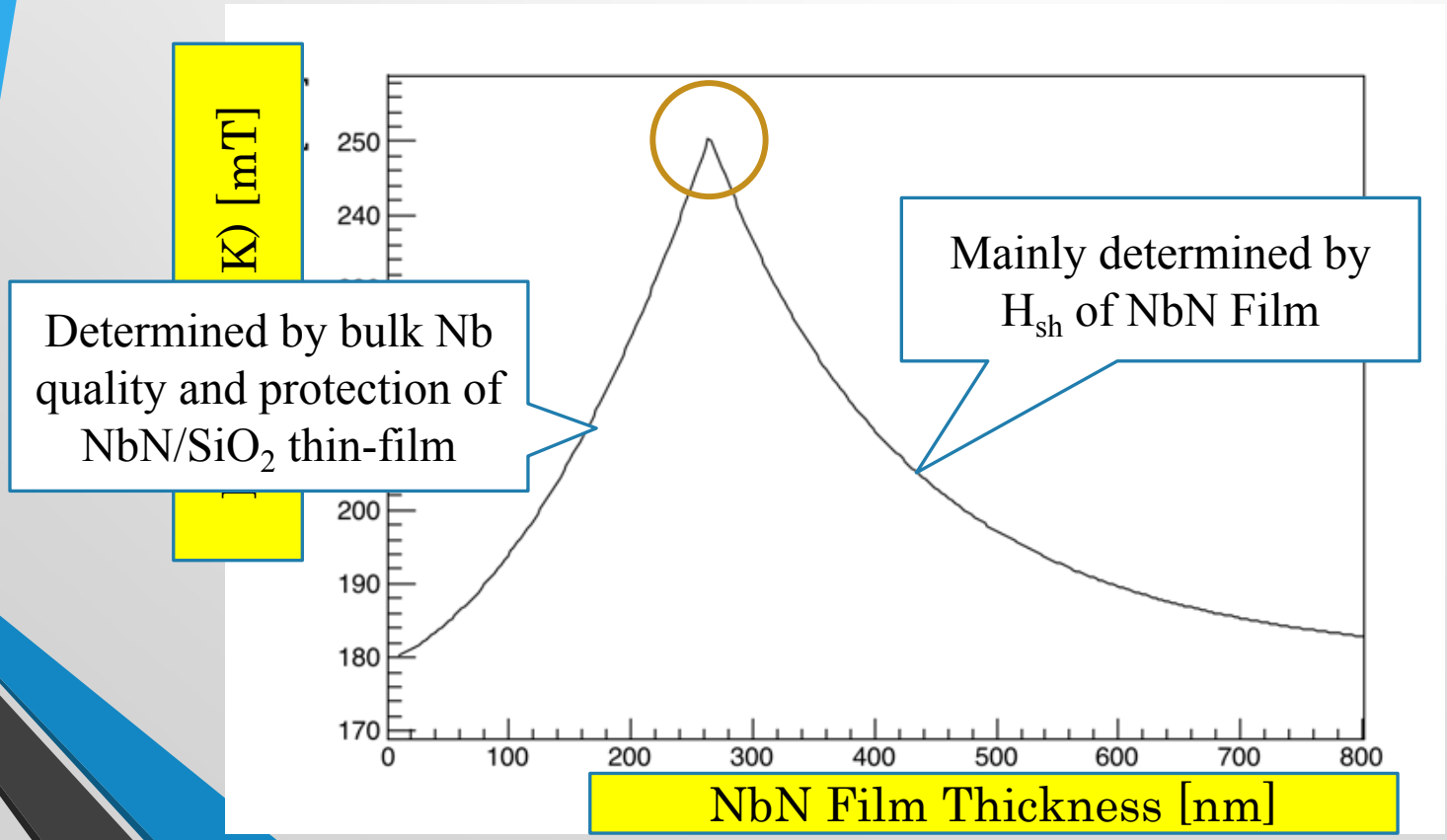
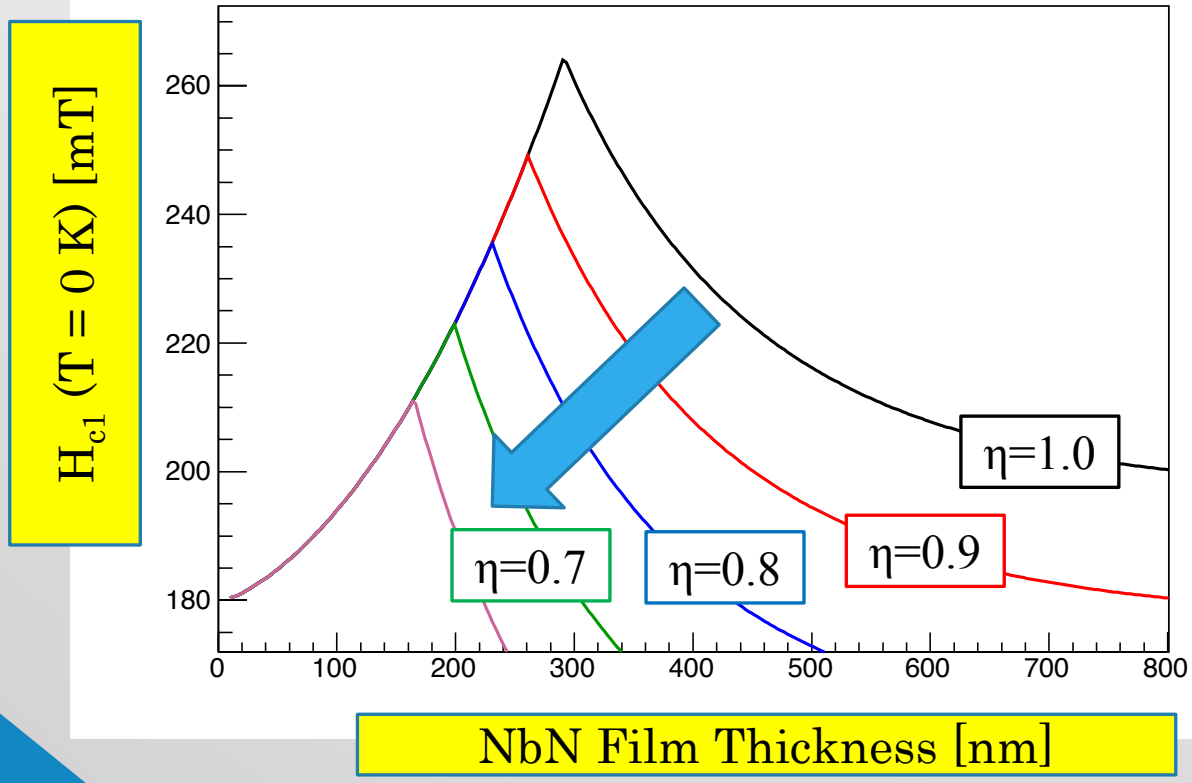


Theory

- The performance of NbN film deteriorates due to the effect of the imperfect surfaces such as surface defects and roughness and so on.
- This effect is included as the parameter η [6][7].
  - η =1 (Black line) is the ideal case, while η < 1 (other colors) is not so.



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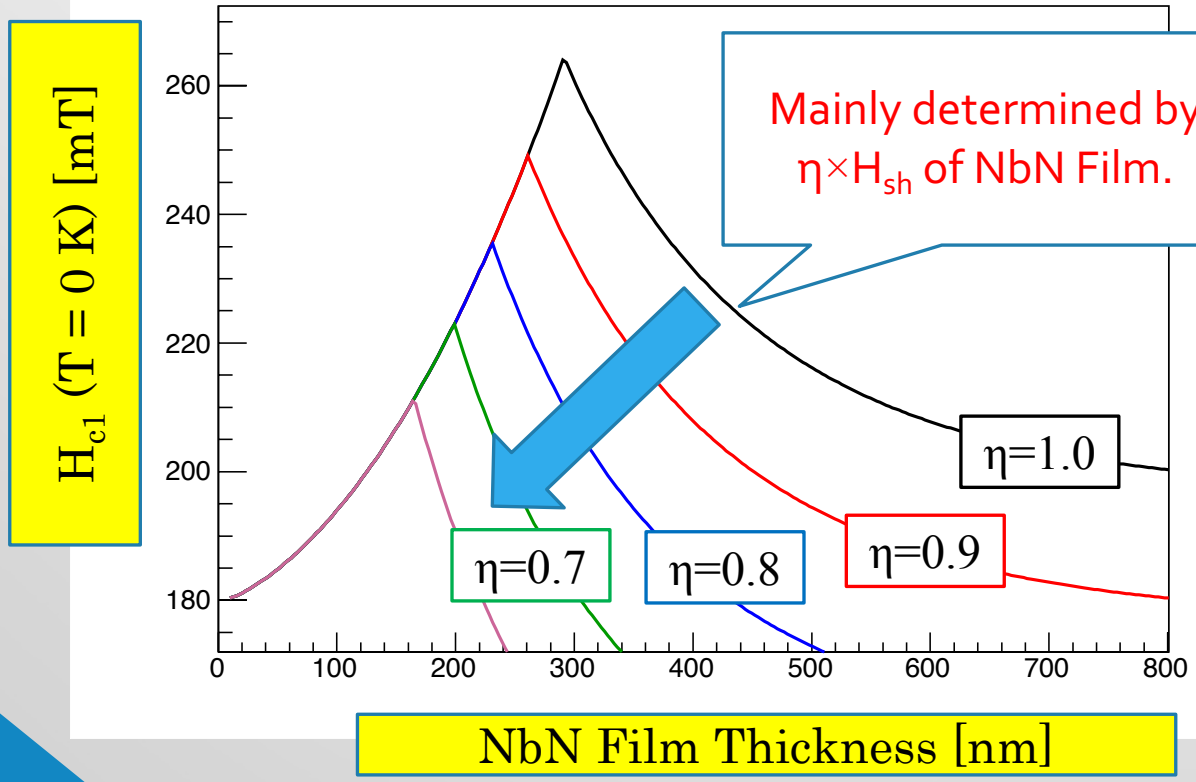

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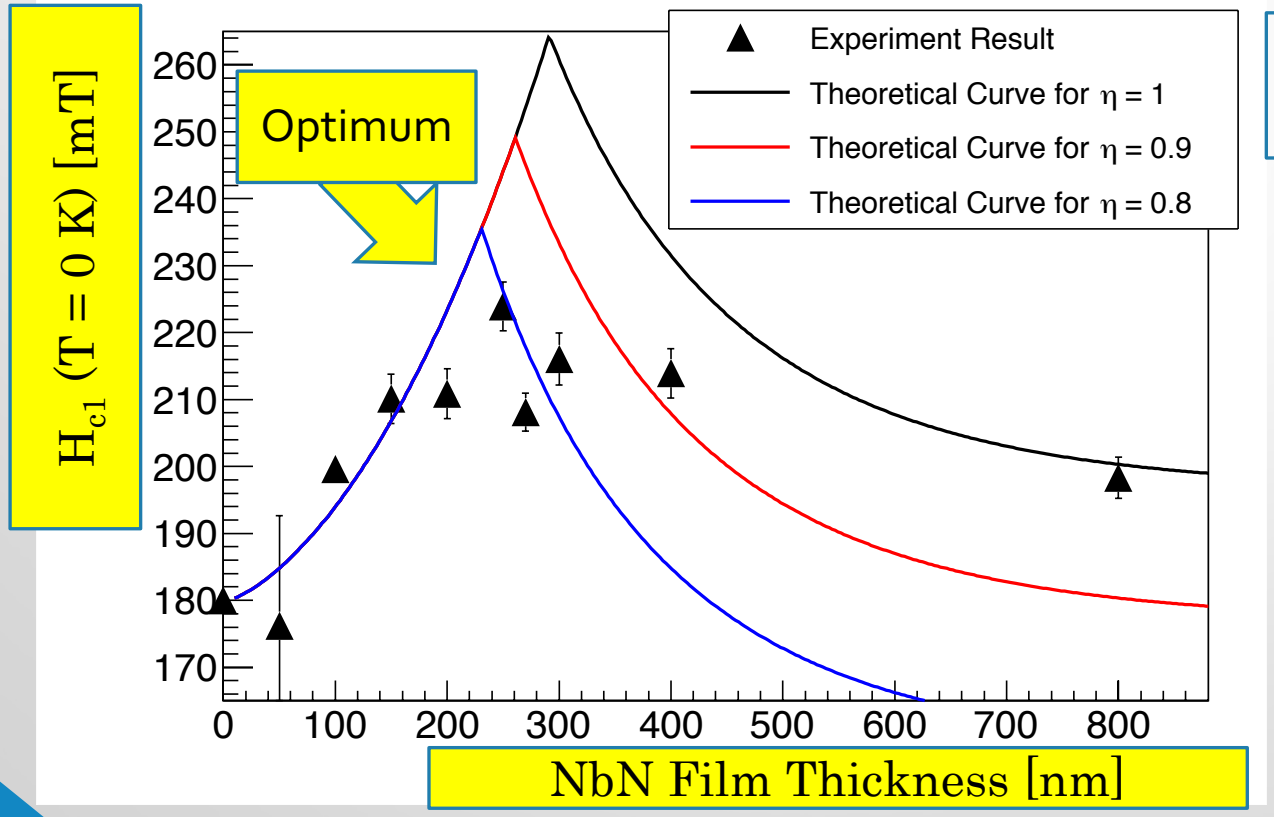
Comparison of data and theory

- Experimental result and theoretical curve are superimposed below.



Preliminary

Quite similar result is also experimentally obtained by an independent measurement at KEK.

Please refer TUPO78

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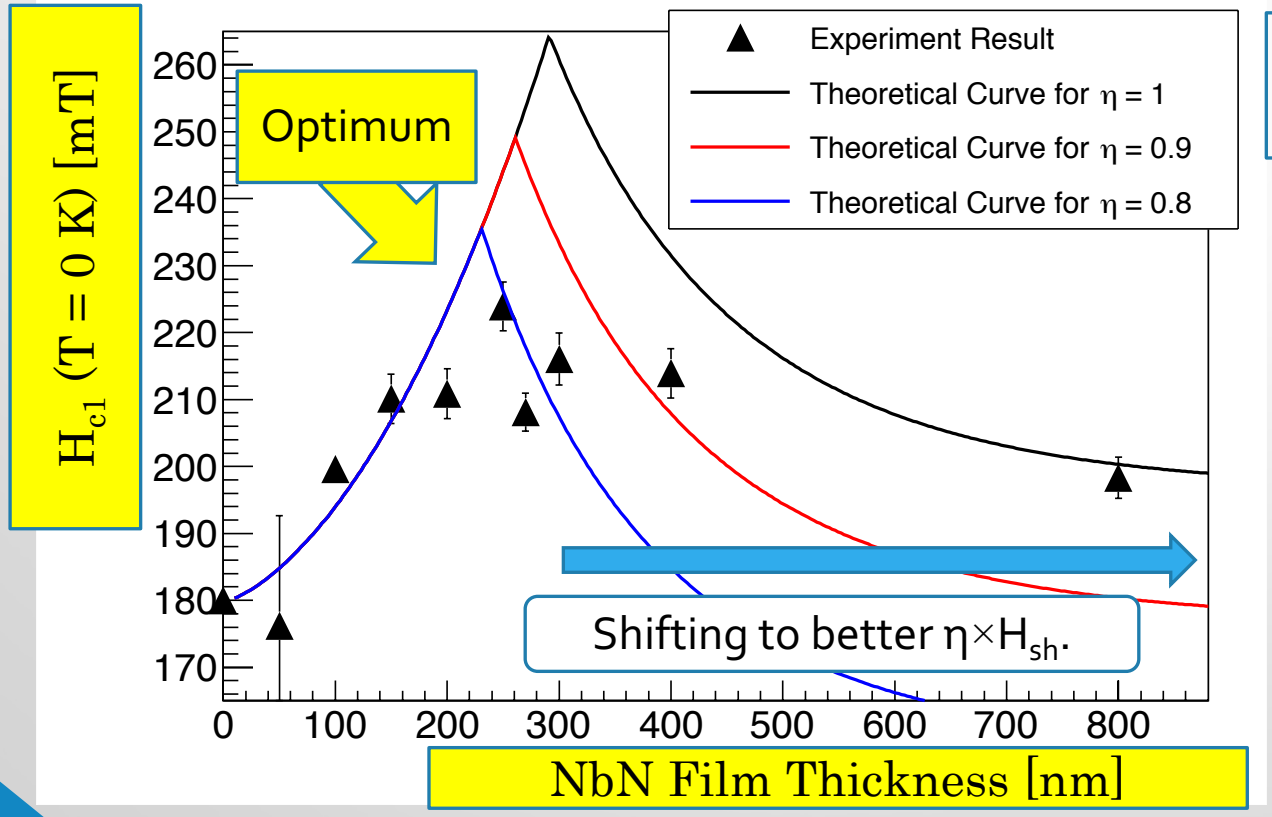

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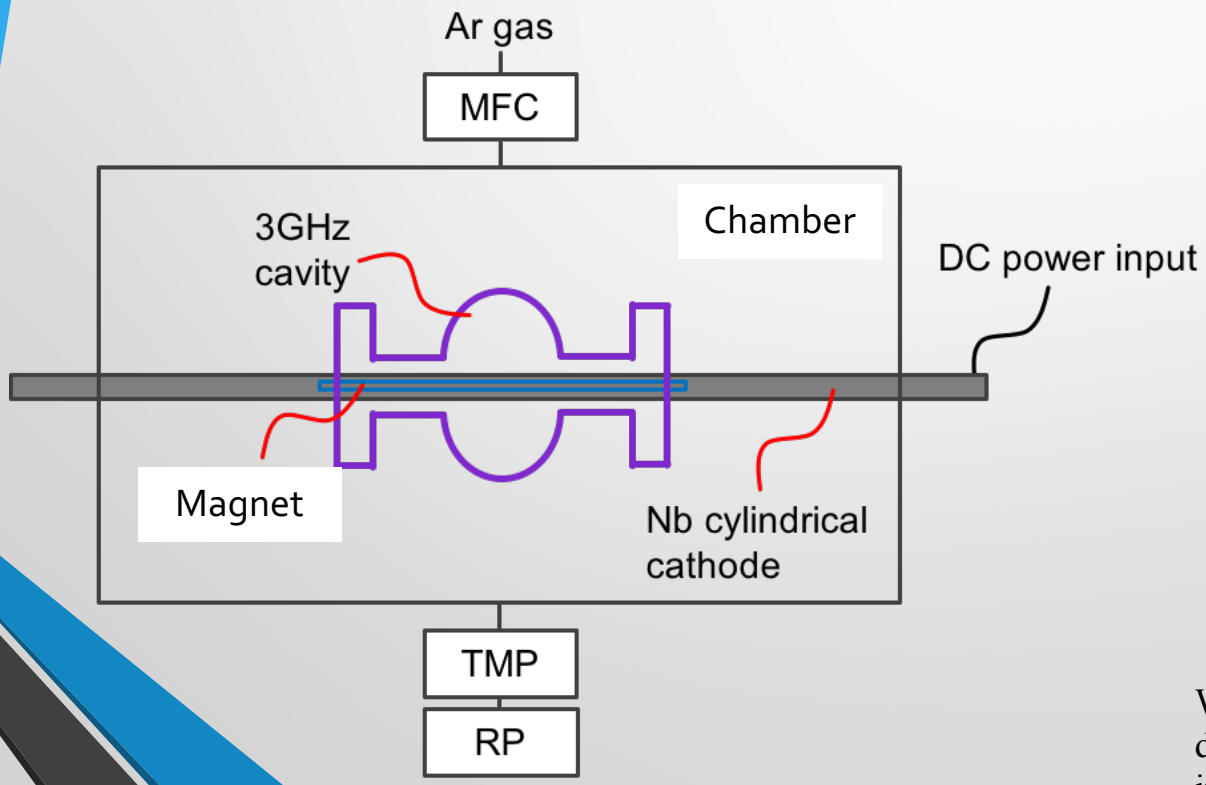
Future Prospect

- An apparatus that can deposit Nb or NbN thin-film on Cu or Nb cavity is being prepared in collaboration with ULVAC, Inc..



We have already successfully deposited Nb thin-film on the inner wall of Cu tube (Φ35mm).

Conclusion

- We measured the effective Hc1 of NbN/SiO2/Nb multi-layer sample by using the third harmonic measurement at Kyoto University.
- NbN thicknesses is 50, 100, 150, 200, 250, 300, 400, 800 nm and SiO2 thickness is 30 nm, being created on pure bulk Nb.
- An optimum thickness exists for multilayer thin-film structure to achieve the highest performance.
- Optimum sample showed 23.8 % increase of the effective Hc1 at 0 K (180 mT → 223 mT) compared to that of pure bulk Nb.
- The experimental result is qualitatively consistent with the prediction of theory.
- The theory will guide the production of optimum thin-film structure.
- This shows the possibility of getting high-performance SRF cavities with thin-film technology in mass-production consistently.