Activities on SRF Thin-Film study at KEK and Kyoto University

T. Saeki (KEK)

Y. Iwashita (Kyoto Univ.), H. Hayano (KEK), S. Kato (KEK), T. Kubo (KEK),
H. Oikawa (KEK / Utsunomiya Univ.)

Thin Film Workshop at Jlab

28 July 2016

Contents

Motivation for Thin Film R&D

- KEK and industries are working closer recently, and we constructed the Center-of-Innovation (COI) building to induce the innovation of SRF technology and to help industries produce the innovative products in SRF field.
- To realize the COI concept, we really need higher gradient and innovation in SRF. Thin-Film technology is very good subject to pursue in the COI concept and in the COI building.
- Japanese HEP community is pushing the Japanese government to host the International Linear Collider (ILC) in Japan.
- One of problem to realize the ILC is the huge cost of construction.
- If the thin-film technology can improve the accelerating gradient of SRF cavity, the cost of ILC might be reduced drastically.

Superconducting Accelerator Promotion Center / Center-of-Innovation (COI) Building at KEK

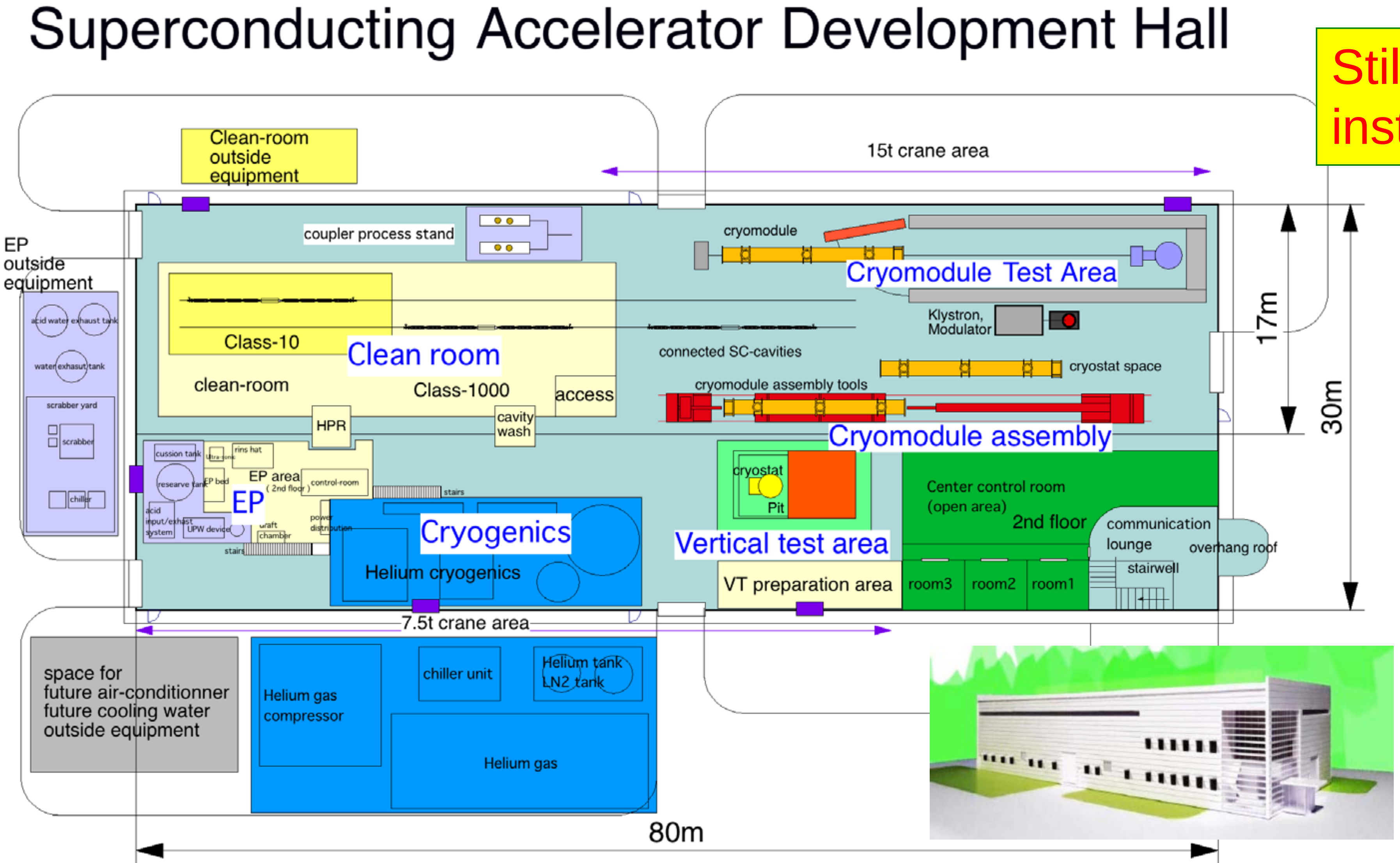
Construction was finished in Jan. 2015.

Promotion of KEK-industry collaboration to induce innovations in SRF technology

New SRF facilities : promotion of SRF accelerator utilization in industies

Facility lay-out plan of the new COI building (80m x 30m)

Still under installation

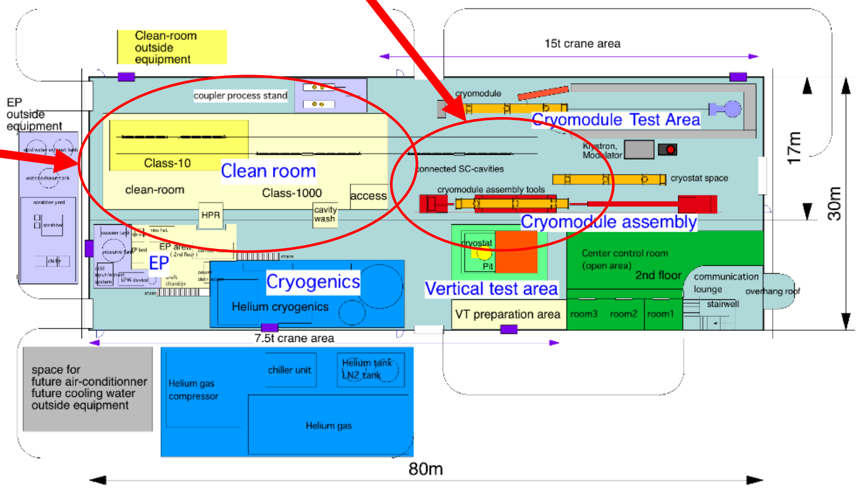


SC cavity inspection & process, vertical test, cryomodule assembly, cryomodule test

New SRF facilities for cryomodule assembly in COI building at KEK

Long cantilever rod was delivered for the 9-cavity cryomodule assembly.

Superconducting Accelerator Development Hall



Clean-room for cavity-string assembly with 2-rail system.

ILC Cost Breakdown (RDR)

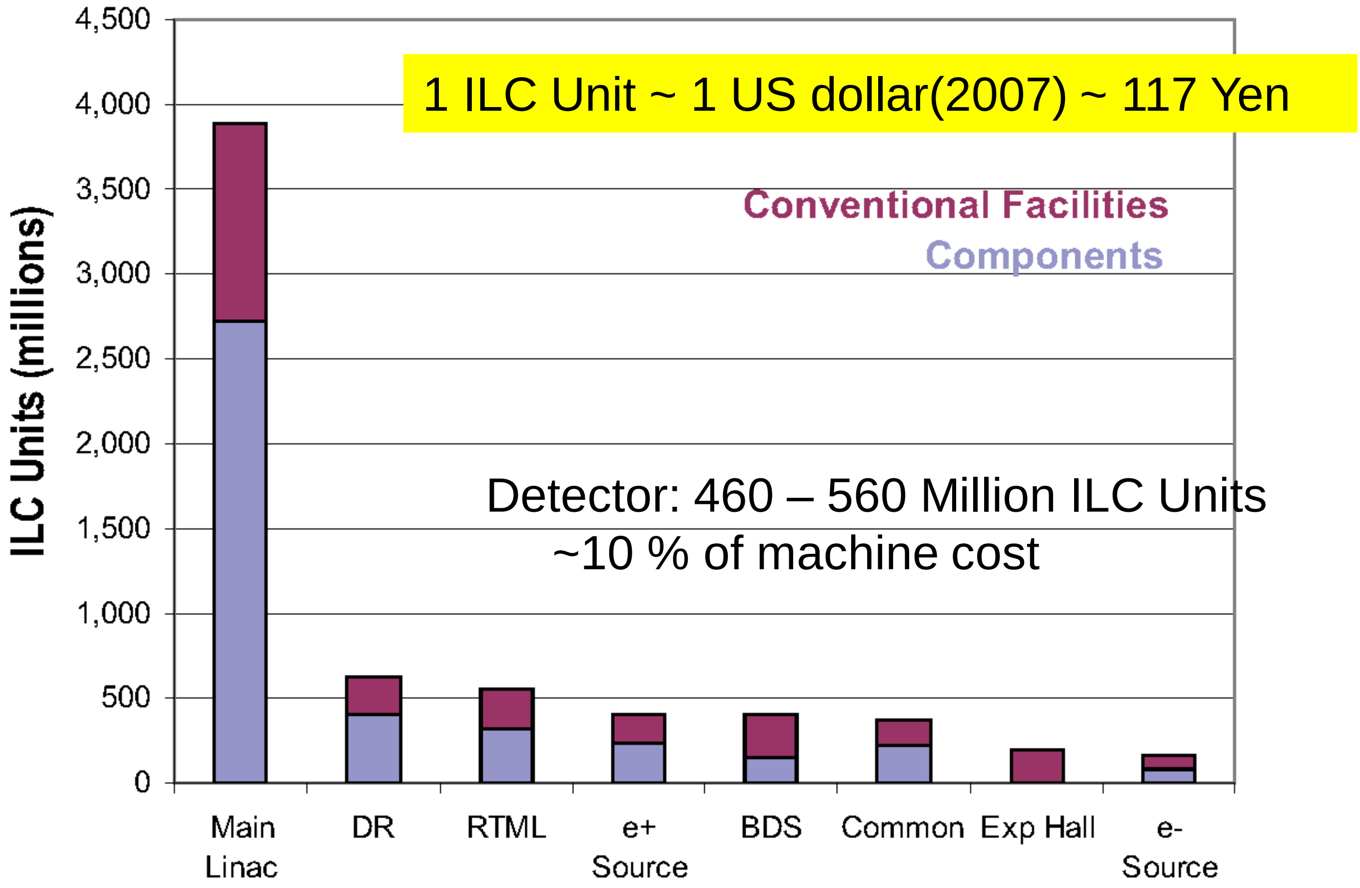
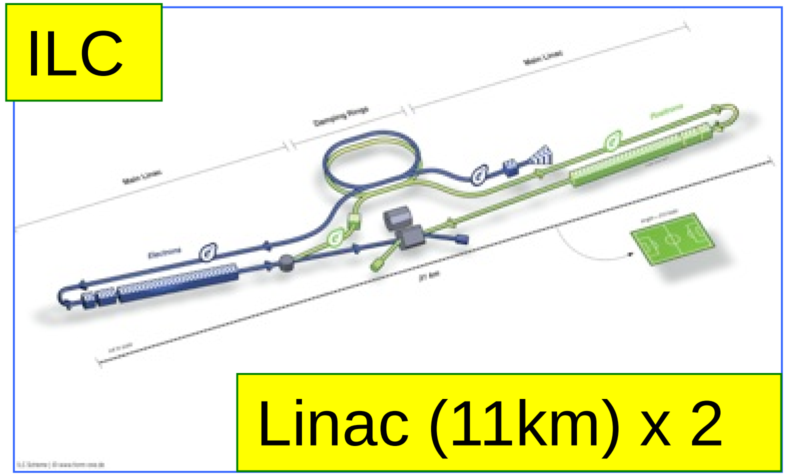


FIGURE 6.2-1. Distribution of the ILC value estimate by area system and common infrastructure, in ILC Units. The estimate for the experimental detectors for particle physics is not included. (The Conventional Facilities estimates have been averaged over the three regional site estimates.)

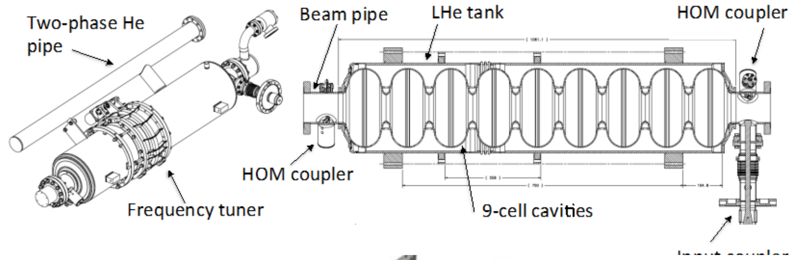
SCRF specification for ILC

Parameters	Value
C.M. Energy	500 GeV
Peak luminosity	1.5 x10^{34} $cm^{-2}s^{-1}$
Beam Rep. rate	5 Hz
Pulse duration	0.73 ms
Average current	5.8 mA (in pulse)
Av. field gradient	31.5 MV/m +/-20% Q_0 = 1E10
# 9-cell cavity	16,024 (x 1.1)
# cryomodule	1,855
# Klystron	~400

ILC



Linac (11km) x 2



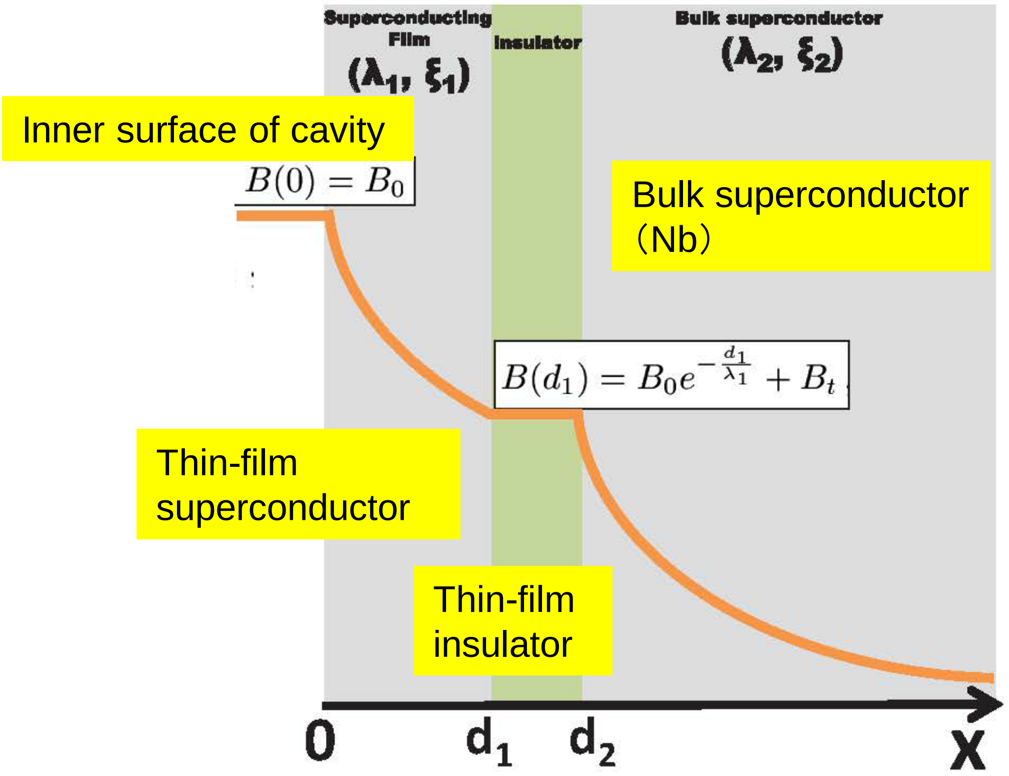
High quality

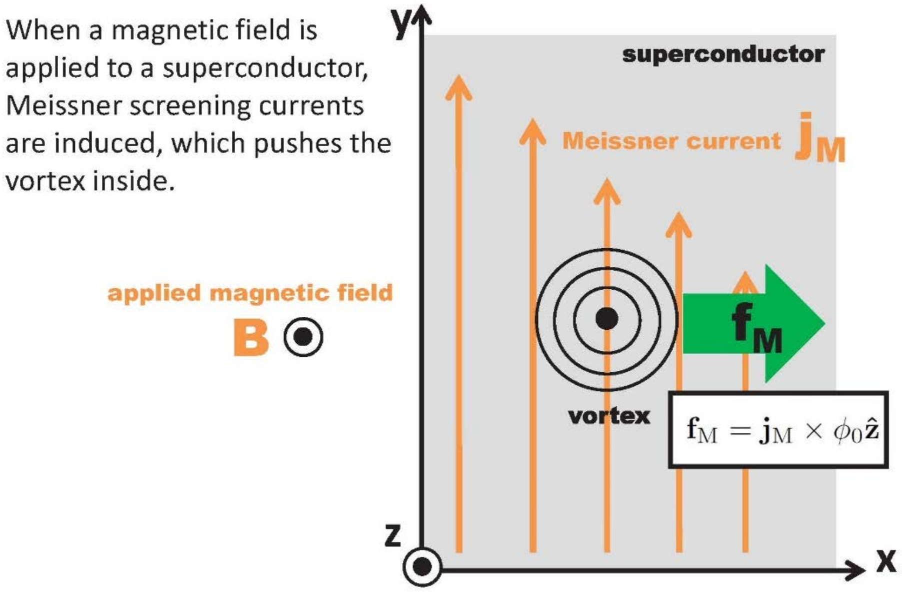
16024 x 1.1(Yield = 90%)
~ 17600 cavities of mass-production

Higher gradient by thin-film means less # of cavities / shorter tunnel.

Consideration on theory

We started from some consideration of theory to minimize the experimental efforts.





A. Gurevich suggested the possibility to achieve higher gradient by thin-film structure on the inner surface of SRF cavity.

Consideration on theory

APPLIED PHYSICS LETTERS **104**, 032603 (2014)

CrossMark

Radio-frequency electromagnetic field and vortex penetration in multilayered superconductors

Takayuki Kubo,[1,a)] Yoshihisa Iwashita,[2] and Takayuki Saeki[1]
[1]*KEK, High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan*
[2]*Institute for Chemical Research, Kyoto University, Uji, Kyoto 611-0011, Japan*

(Received 4 July 2013; accepted 9 January 2014; published online 23 January 2014)

A multilayered structure with a single superconductor layer and a single insulator layer formed on a bulk superconductor is studied. General formulae for the vortex-penetration field of the superconductor layer and the magnetic field on the bulk superconductor, which is shielded by the superconductor and insulator layers, are derived with a rigorous calculation of the magnetic field attenuation in the multilayered structure. The achievable peak surface field depends on the thickness and its material of the superconductor layer, the thickness of the insulator layer, and material of the bulk superconductor. The calculation shows a good agreement with an experimental result. A combination of the thicknesses of superconductor and insulator layers to enhance the field limit can be given by the formulae for any given materials. *© 2014 AIP Publishing LLC.* [http://dx.doi.org/10.1063/1.4862892]

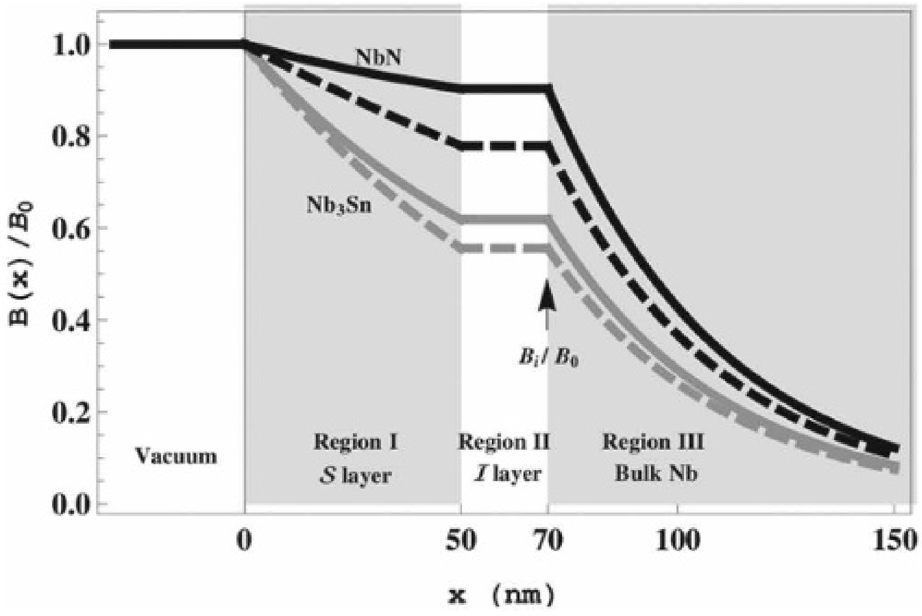


FIG. 1. Examples of the magnetic field attenuations in the multilayered structure. Solid curves show our formulae given above, and dashed curves show the naive estimates with $B = B_0 e^{-x/\lambda_1}$. Black curves and gray curves correspond to the material of the $\mathcal{S}$ layer: NbN ($\lambda_1 = 200\,\text{nm}$) and Nb_3Sn ($\lambda_1 = 85\,\text{nm}$), respectively. The bulk superconductor is assumed to be Nb ($\lambda_2 = 40\,\text{nm}$). The values of λ_1 and λ_2 are given in literature.[4] The thickness of the $\mathcal{S}$ layer and the $\mathcal{I}$ layer are fixed at $d_{\mathcal{S}} = 50\,\text{nm}$ and $d_{\mathcal{I}} = 20\,\text{nm}$.

Precise theory of H-max on thin-film is necessary to evaluate and compare the experimental results/data.

Consideration on theory

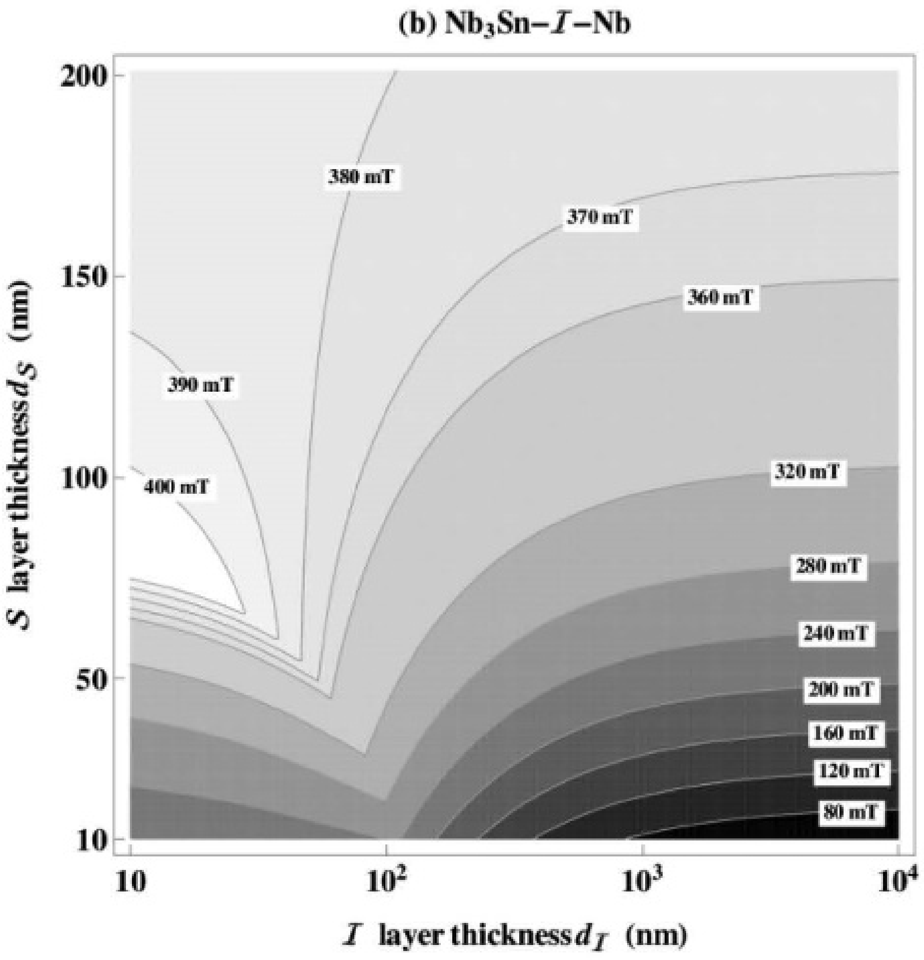


FIG. 3. Contour plots of the maximum achievable peak surface-field without vortex dissipations, $B_v^{(ML)}$. The abscissa represents the $\mathcal{I}$ layer thickness $d_{\mathcal{I}}$ and the ordinate represents the $\mathcal{S}$ layer thickness $d_{\mathcal{S}}$. Values written in the plot area are $B_v^{(ML)}$ in the unit of mT. The top and bottom figures correspond to materials of the $\mathcal{S}$ layer. (a) NbN ($\lambda_1 = 200\,\mathrm{nm}$, $\xi_1 = 5\,\mathrm{nm}$) and (b) Nb_3Sn ($\lambda_1 = 85\,\mathrm{nm}$, $\xi_1 = 5\,\mathrm{nm}$), respectively. The bulk superconductor is assumed to be Nb with $\lambda_2 = 40\,\mathrm{nm}$ and $B_v^{\rm bulk} = 200\,\mathrm{mT}$.

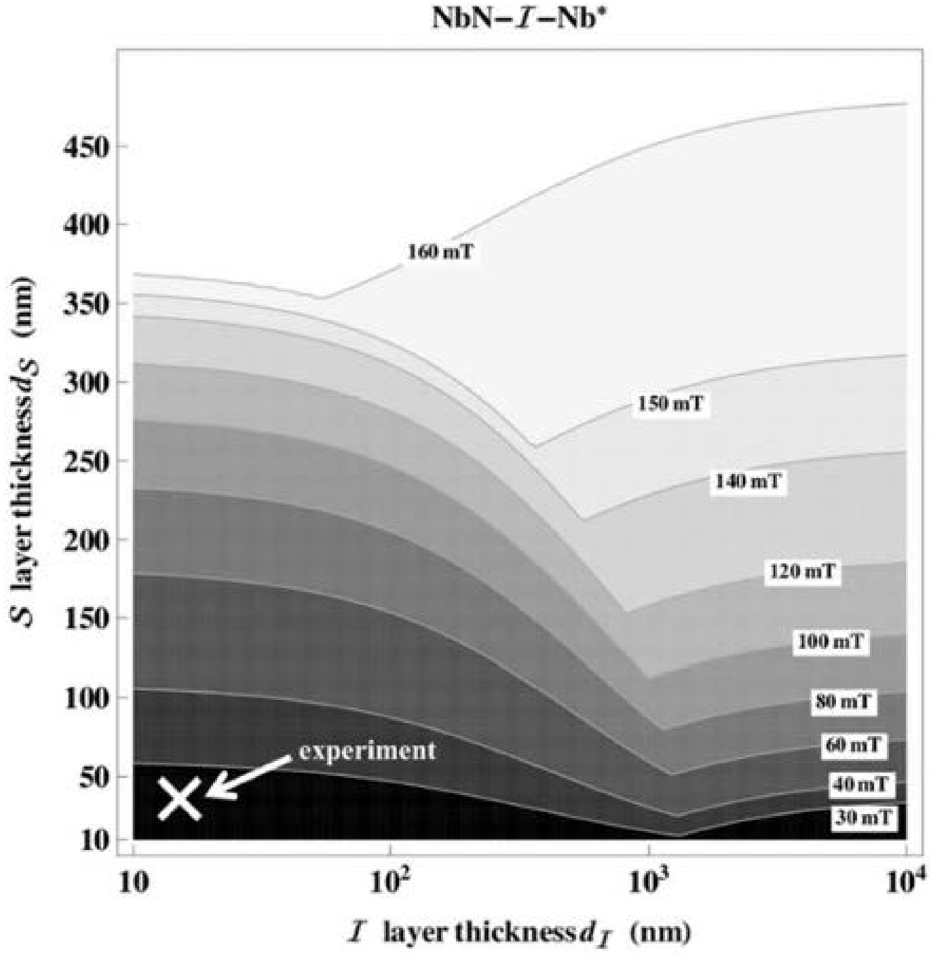


FIG. 4. A Contour plot of the maximum achievable peak surface-field without vortex dissipations, $B_v^{(ML)}$. The abscissa represents the $\mathcal{I}$ layer thickness $d_{\mathcal{I}}$ and the ordinate represents the $\mathcal{S}$ layer thickness $d_{\mathcal{S}}$. Values written in the plot area are $B_v^{(ML)}$ in the unit of mT. Materials of the $\mathcal{S}$ layer and the bulk superconductor are assumed to be NbN ($\lambda_1 = 200\,\mathrm{nm}$, $\xi_1 = 5\,\mathrm{nm}$) and magnetron sputtered Nb ($\lambda_2 = 300\,\mathrm{nm}$ (Ref. 12) and $B_v^{\rm bulk} = 20\,\mathrm{mT}$ (Ref. 13)), respectively. A cross shown at the lower left indicate a parameter set used in an experiment.[13]

Creation of thin-film samples by IBS

Proceedings of SRF2015, Pre-Press, Whistler, BC, Canada TUPB062

EVALUATION OF SC PROPERTY COATED ON A SURFACE

Y. Iwashita, Y. Fuwa, ICR, Kyoto U., Kyoto, Japan
M. Hino, KURRI, Kyoto U., Osaka, Japan
T. Kubo, T. Saeki, KEK, Ibaraki, Japan

Abstract

Depositions of thin superconducting materials on a substrate are investigated for improvements of performance on superconducting cavity such as higher accelerating field gradients. Some trial depositions of thin superconducting material on a substrate are performed by ion sputtering method. In order to evaluate the deposition method, surface properties are measured. Some results on measurements at DC and a preparation status toward RF measurement are reported.

INTRODUCTION

Multilayer coating techniques of thin superconducting (sc) films seem promising to enhance sc cavity performances [1]. Recently, a guide to investigate the idea becomes available by the self-consistent analysis of such configurations [2]. In order to start the experimental study, the thin film deposition technique had to be established.

Two sets of deposition trials have been performed so far, where each trial is followed by a measurement at DC.

Next section describes the deposition technique and the following sections describe the trial results at DC.

PHYSICAL VAPOR DEPOSITION

As the physical vapour deposition, we adopted the ion beam sputtering method that was developed for supermirror for neutrons [3]. A supermirror has a structure of multilayers to reflect neutrons with smaller incident angles. There are two kinds of PVD coating systems for fabrication of such neutron optical devices at the KURRI. One is based on a vacuum deposition

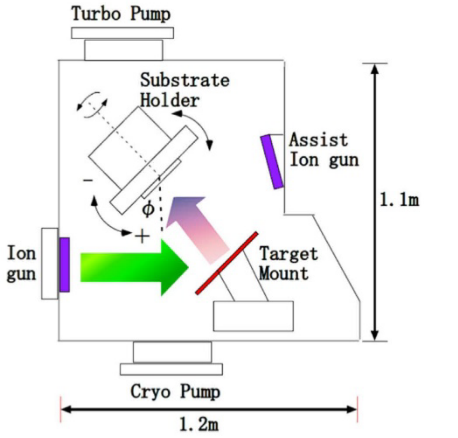


Figure 1: Schematic view of the Ion Sputtering System.

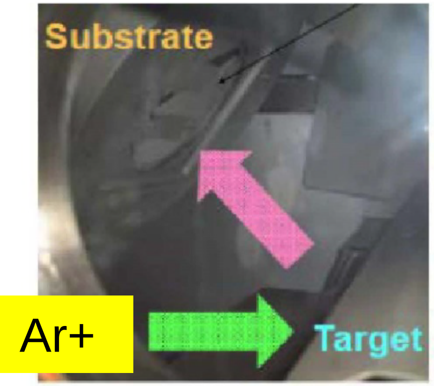


Figure 4: First samples.

Nb can be sputtered on the Si wafer

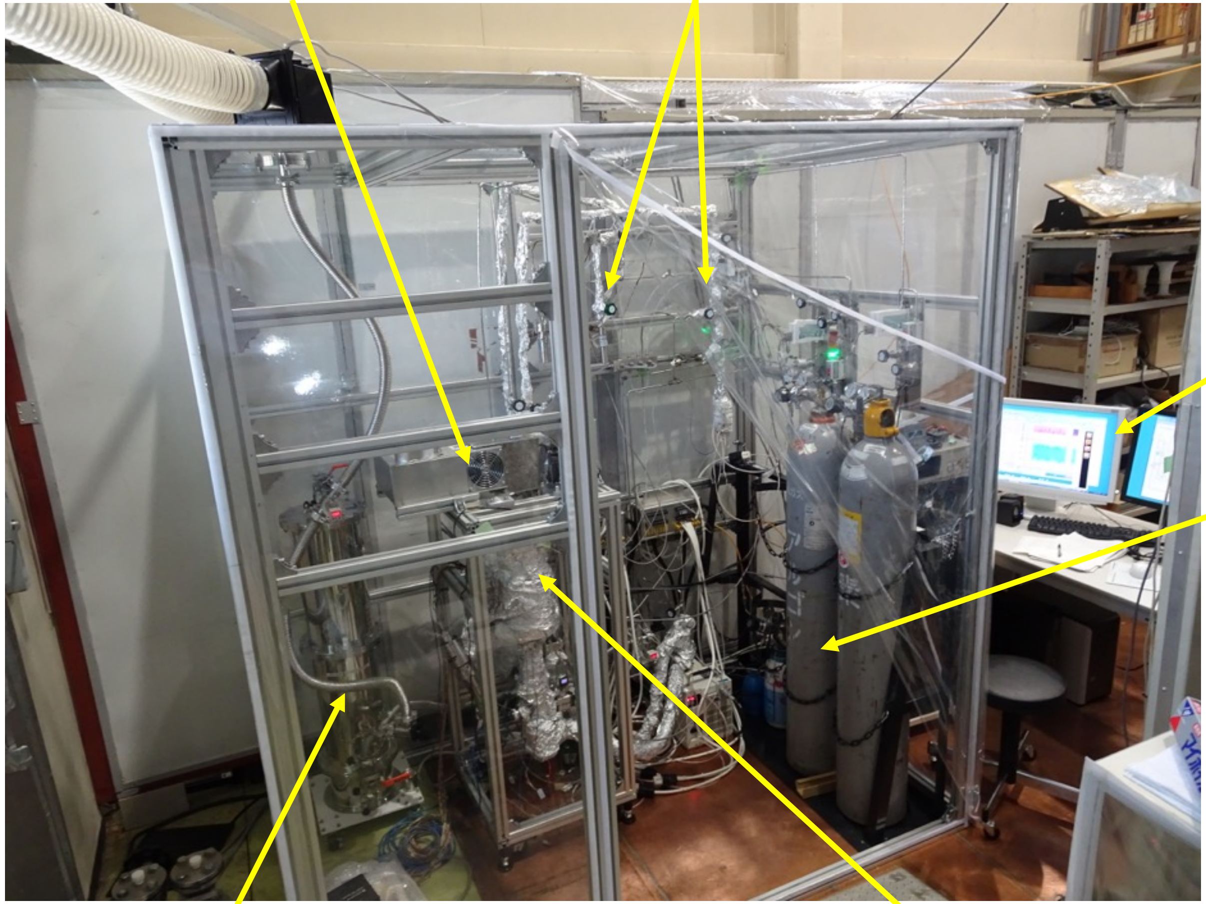
Ion Beam Sputtering (IBS) method to make thin-film samples

Thin-film R&D by Atomic Layer Deposition (ALD) at KEK

KEK ALD device is now under development

Plasma exciter

Precursor Gas



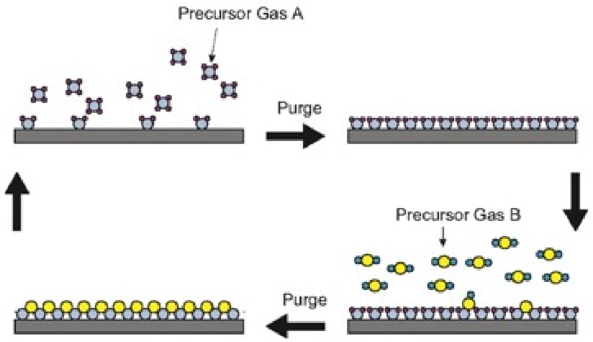
Control PC

Purge Gas: Ar, N

Detoxifying apparatus

Sample deposition chamber with heater

Thin-film by Atomic Layer Deposition



Almost ready to make film.

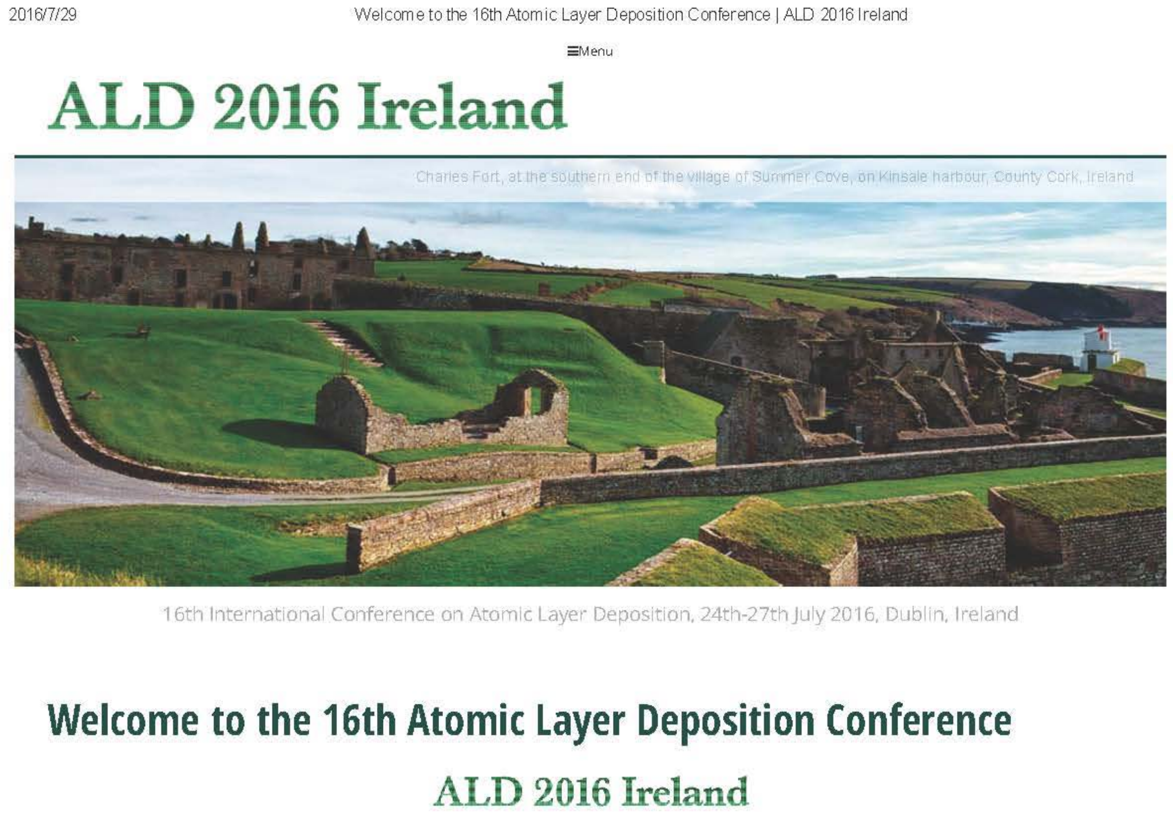
NbN ALD on Si-wafer, at first.

http://ald2016.com

P-02-019 Development of plasma-enhanced ALD system for SRF cavity

Shigeki KATO*1, Tsuneyuki NOGUCHI1, Hitoshi HAYANO1, Kentaro TOKORO2, Kensaku KANOMATA2, Fumihiko HIROSE2

1 Accelerator Laboratory, High Energy Accelerator Research Organization (KEK), Japan,
2 Graduate School of Science and Engineering, Yamagata University, Japan



Collaboration between KEK and ULVAC for Thin Film R&D

- **KEK is already collaborating with ULVAC for production of high-RRR Nb ingot and Nb sheet for a few year.**
- **KEK has less experiences on the thin-film creation. On the other hand, ULVAC has a long history of thin-film business. If KEK collaborates with ULVAC, synergy is expected.**
- **ULVAC might create thin-film samples and KEK might evaluate the SRF characteristics of the thin-film samples.**
- **KEK will start collaboration with ULVAC for the R&D of SRF thin-film from August 2016.**

ULVAC PRODUCTS

Search ULVAC GLOBAL NETWORK ULVAC

EQUIPMENT

From the homepage of ULVAC

Top > 装置

製品別カテゴリ

- スパッタリング装置
- CVD装置
- 真空蒸着装置
- 蒸着重合装置
- アッシング装置
- エッチング装置
- イオン注入装置
- アニール装置
- 真空炉
- 巻取り装置
- 凍結真空乾燥装置
- 真空蒸留装置
- ヘリウムリークテスト装置
- その他

アルバックは真空技術を核とする基盤技術とその周辺技術を結合し、半導体、電子部品、薄型テレビ、太陽電池、自動車、医薬・食品・科学など多岐にわたる産業向け製造装置を提供しています。

What's New

2015/3/24 EQUIPMENT 世界初、CMOSへ搭載可能な圧電MEMSデバイス向け量産用低温PZTスパッタリング技術を開発
→プレスリリース

Sputtering | CVD | Deposition in vacuum | Deposition Polymerization

スパッタリング装置

CVD装置

真空蒸着装置

蒸着重合装置

XPS/AES/SIMS for surface and x-section observation of thin-film samples at KEK

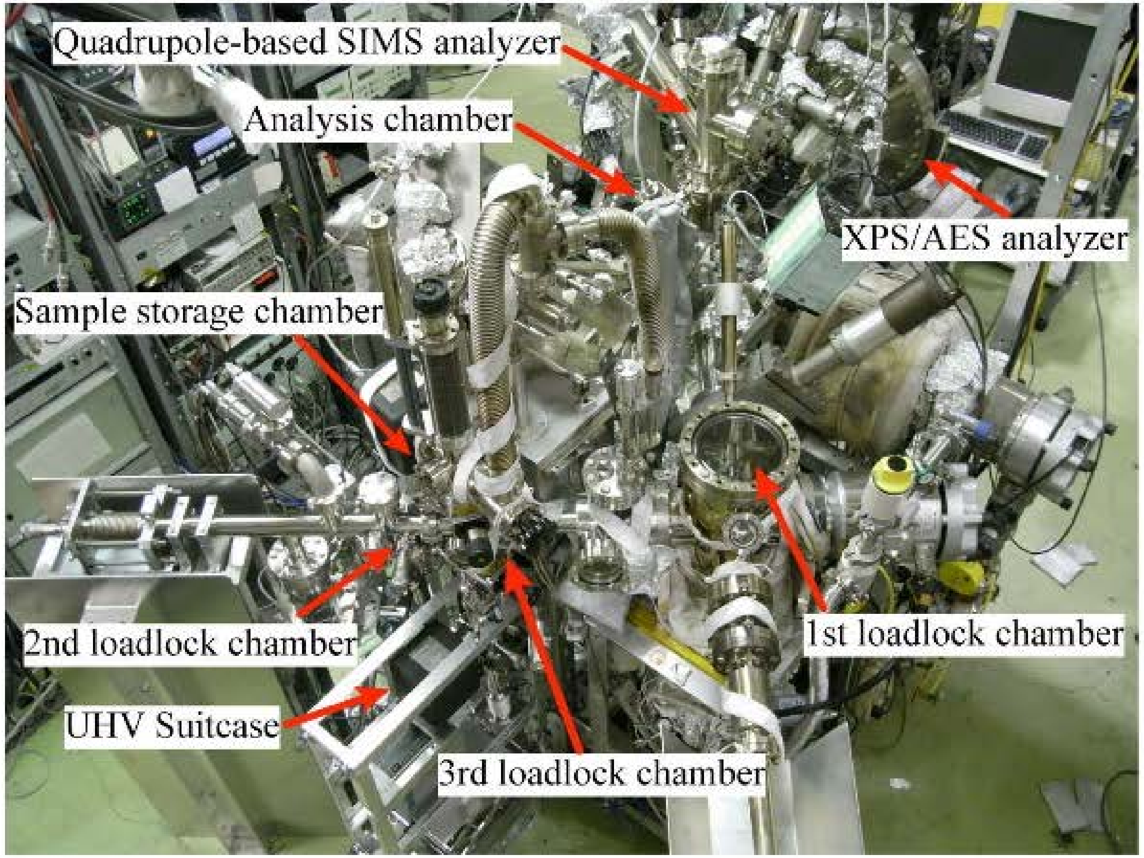
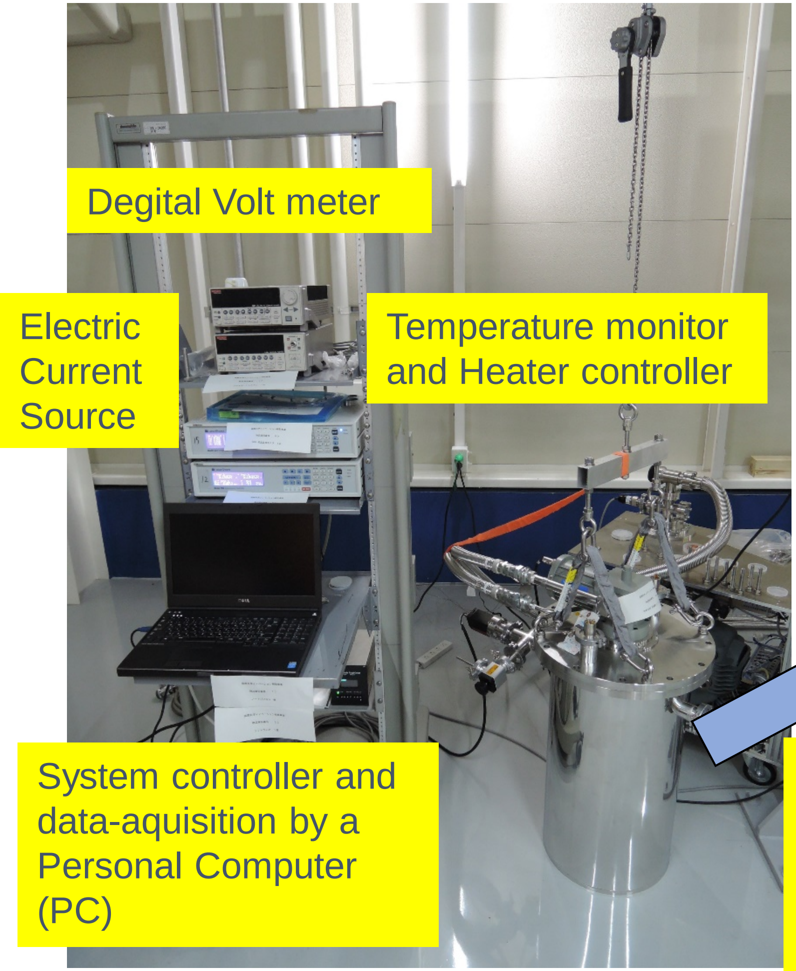


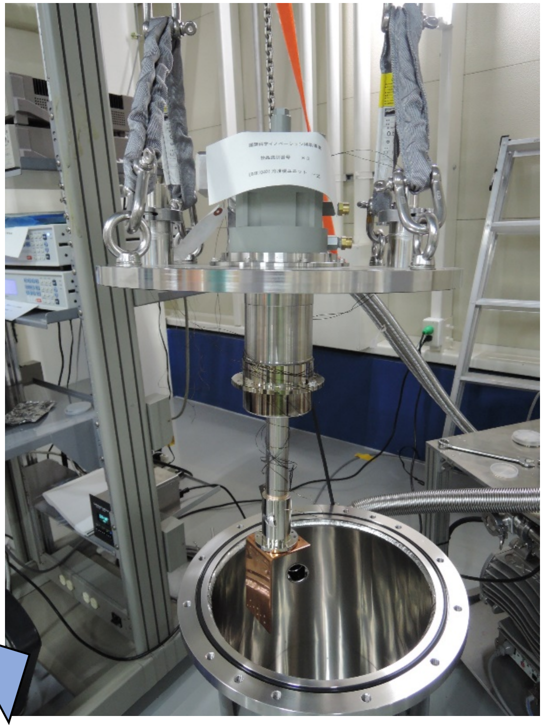
Figure 3: Overview of the XHV surface analysis system. The system equipped with XPS/AES/SIMS analyzers and the loadlock chambers to transfer the sample coupons without air exposure. The base pressure in the analysis chamber is in the order of 10^{-9}Pa.

SURFACE STUDY USING NIOBIUM SAMPLE COUPONS FOR SUPER CONDUCTING RF CAVITY

M. Nishiwaki[#], H. Hayano, S. Kato, T. Saeki, M. Sawabe, KEK, Tsukuba, Ibaraki, Japan,
P. V. Tyagi, GUAS, Tsukuba, Ibaraki, Japan, T. Noguchi, KAKEN Inc., Mito, Ibaraki, Japan

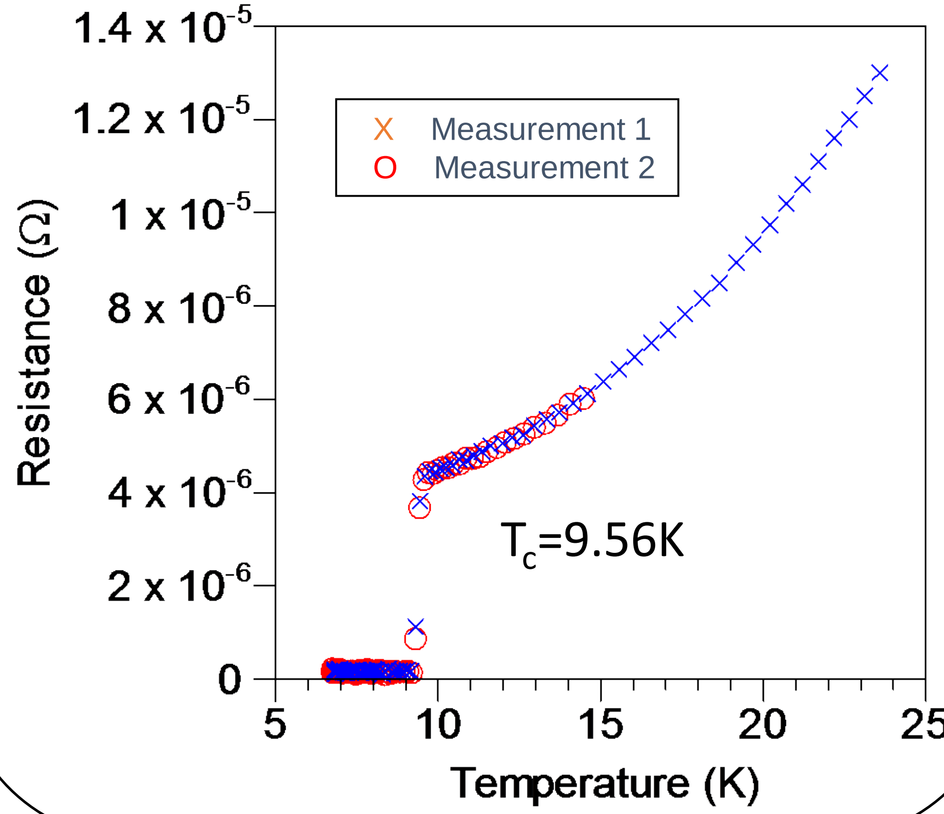
Small-sized Cryostat with a Compact Refrigerator for Measurements of SC Samples (Tc, RRR, etc. / DC)





Refrigerator is fixed in the center of top-flange. A cupper L-angle stage is attached on the top of rifrigerator head. Samples are fixed on the cupper L-angle stage.

Nb sample: 2.8 x 5 x 150 (mm^3)
Resistance measurement with electric current = 50 mA



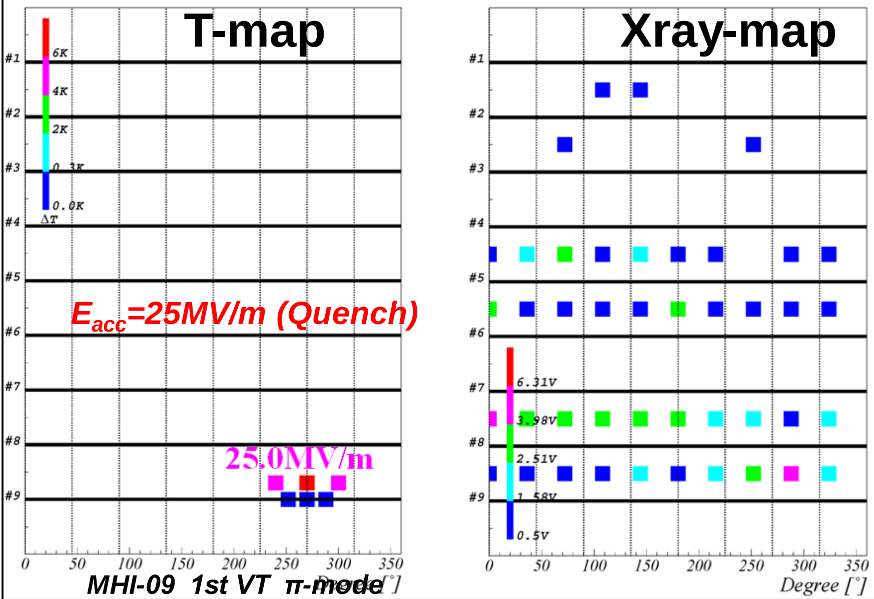
Small-sized Cryostat with a Compact Refrigerator for Measurements of SC Samples (Tc, RRR, etc. / DC)

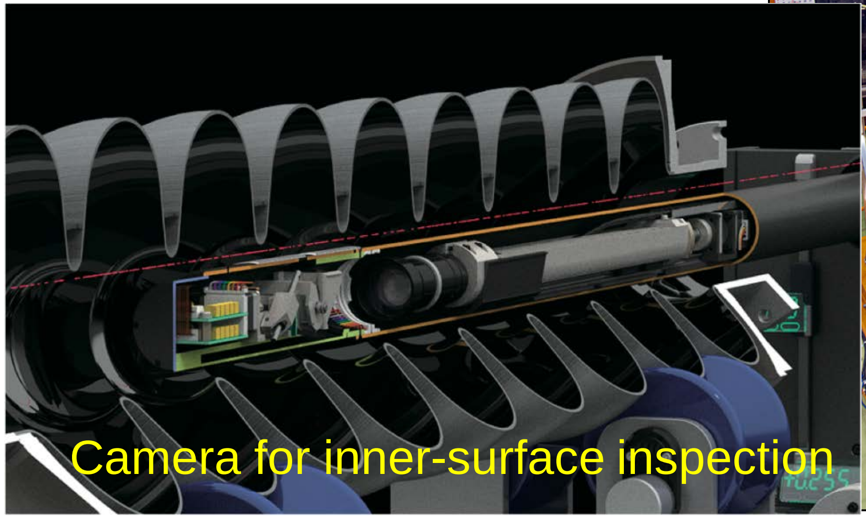
- Compact system to measure the SC characteristics of thin-film samples.
- Handling of the system is easy because no need of complicated liquid-He operation. The refrigerator starts cooling just by switching-on. (After measurements, warming up is done without complicated He-gas operation.)
- The history log of 8 temperature-sensors (CERNOX) are recorded.
- The temperature of samples can be controlled by a heater and a controller.
- Data acquisition and the temperature controlling can be done by a Personal Computer (PC).

Vertical Test (VT) facility for cavity measurement at KEK

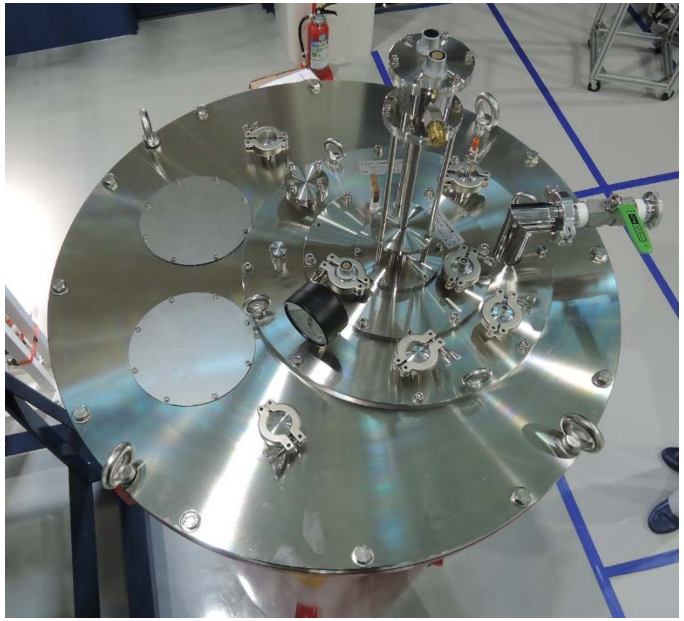
Temperature and X-ray maps of cavity are obtained during each test.

T-map & Xray-map,
together with pass-band
mode measurement,
location of quench is identified.
Inspection camera visualize
what's happen inside.

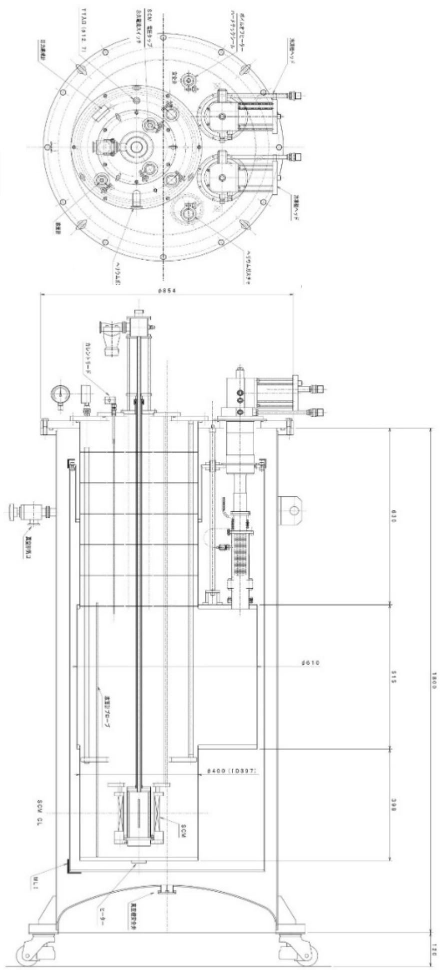


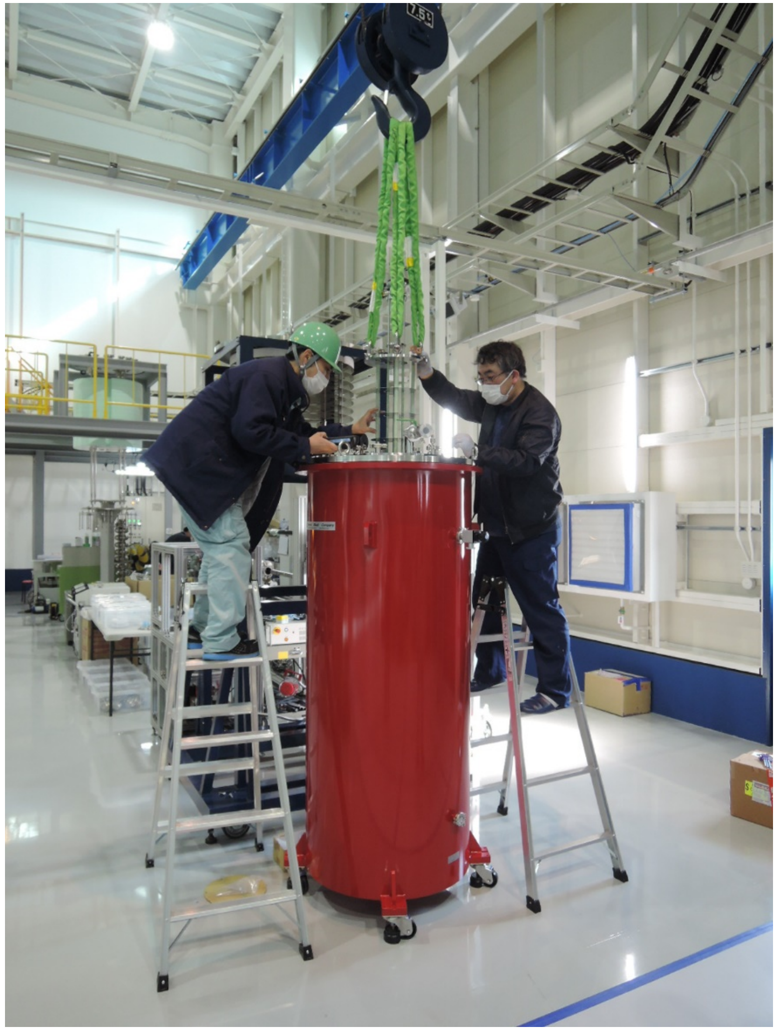


Middle-sized cryostat for the evaluation of thin-film samples.

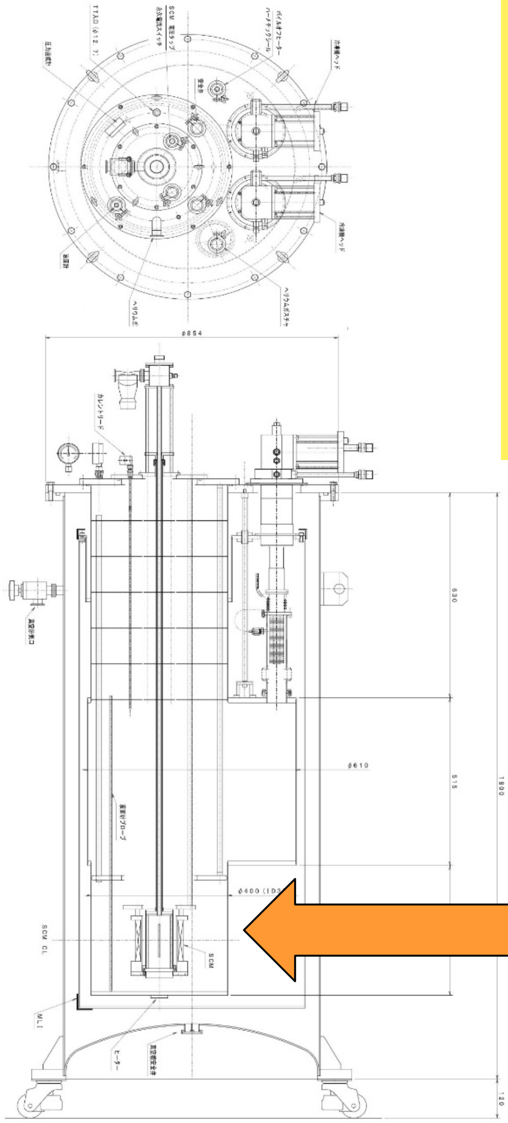


Top-flange is flexible and compatible for various setups.



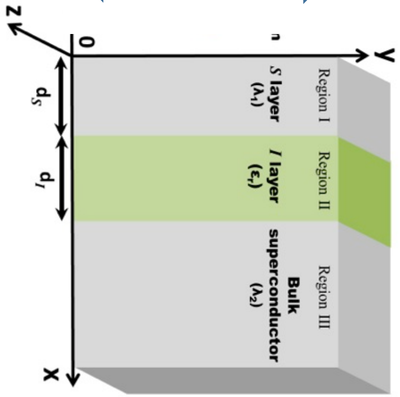


Middle-sized Cryostat for Hc1 AC(~kHz) Measurement

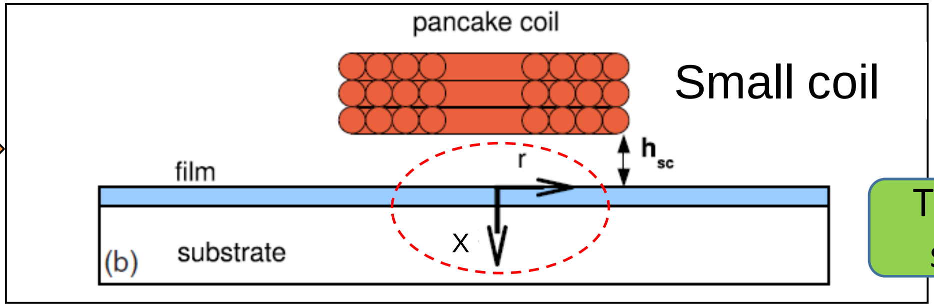


Oscillating voltage at ~ kHz is applied to the small coil and magnetic field at ~ kHz is created on the thin film sample. The voltage of the small coil is measured. Third harmonics of the voltage corresponds to the amount of penetrating magnetic field into the sample and the Bc1 is measured. The measurement of Hc1 is repeated by changing the temperature T.

Magnetic filed at ~ kHz by a small coil.

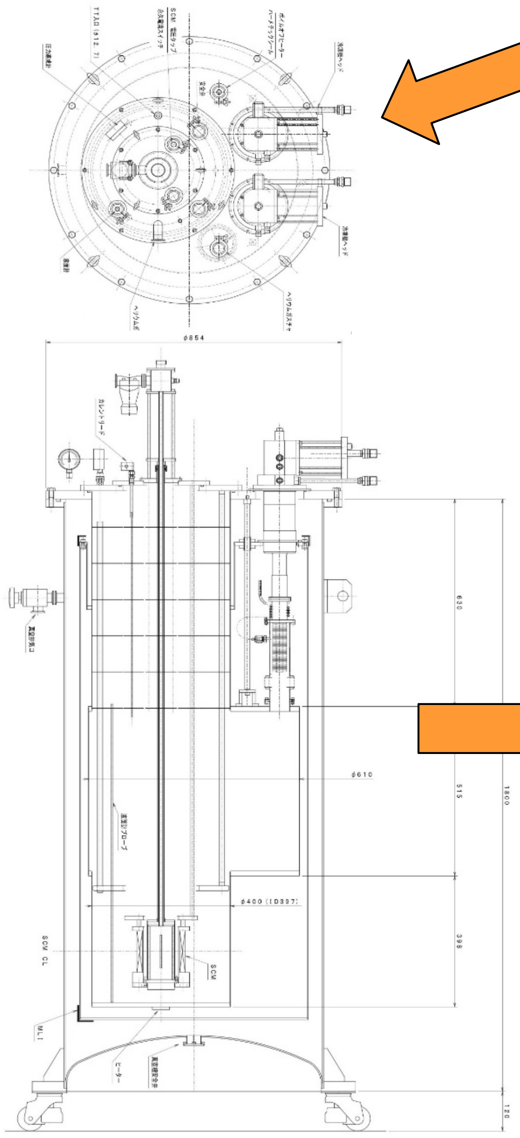


Thin Film sample

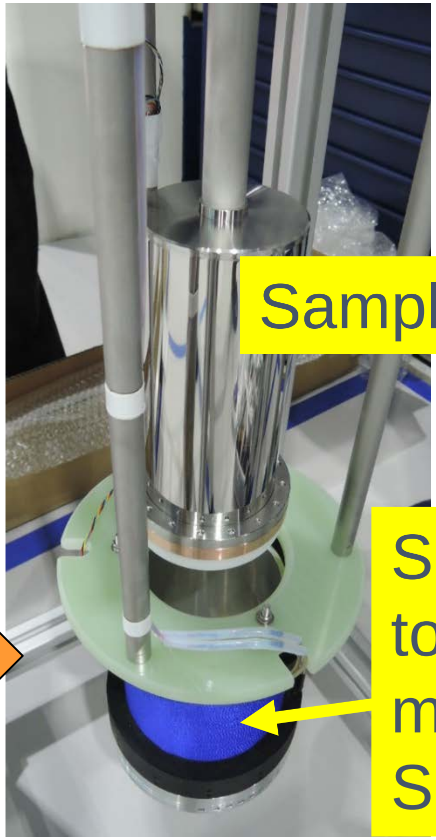


Thin Film sample

Middle-sized Cryostat for Hc1 DC Measurement



Top-flange is flexible and compatible for various setups.

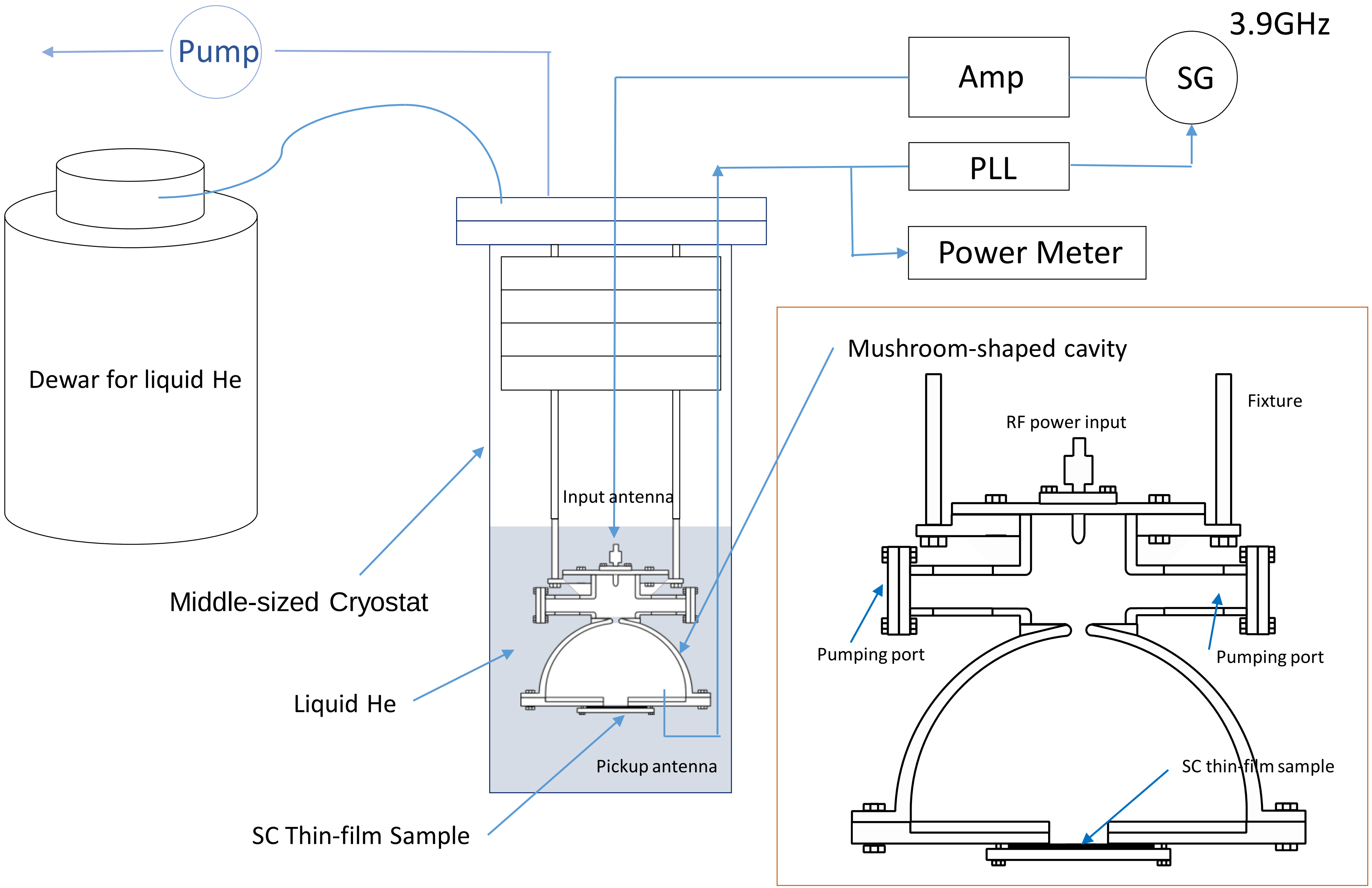


Sample-chamber

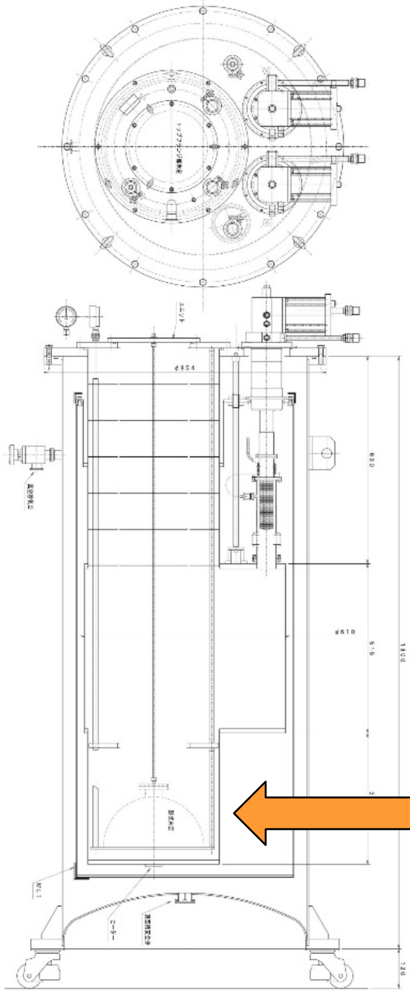
SC solenoid (5T) to create external magnetic field for SC samples.

Magnetization measureament (Hc1 by DC field)

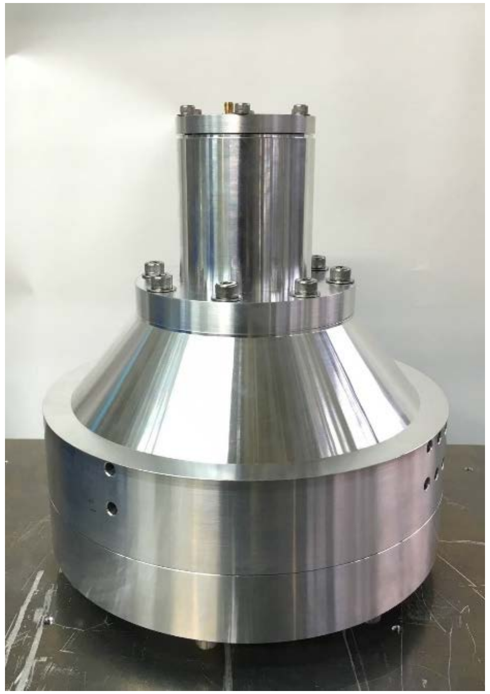
Setup to measure the RF critical magnetic field (Hc1)



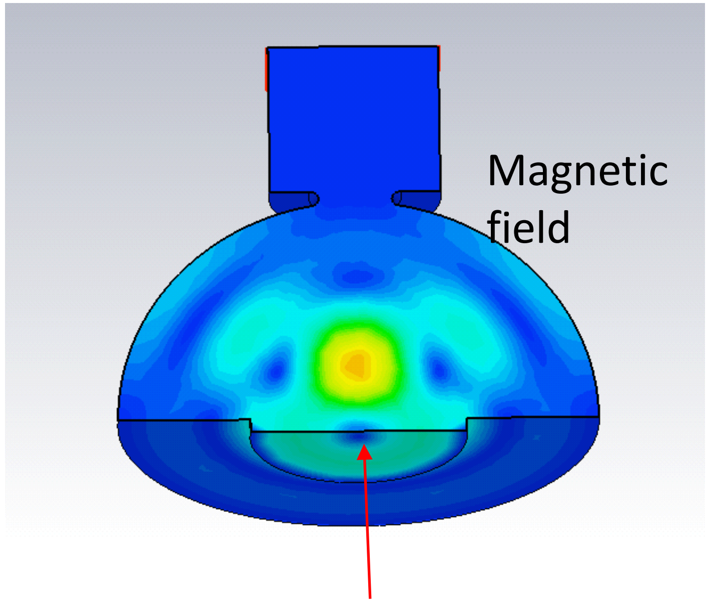
Middle-sized Cryostat for Hc1 RF Measurement



Al-model of mushroom-shaped cavity for RF test at Room Temperature (RT).



Mushroom-shaped cavity for RF measurements of a thin-film sample

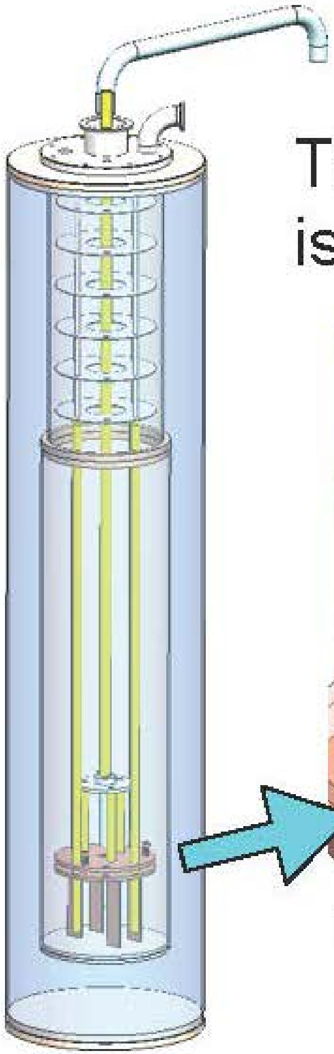


Magnetic field on thin-film sample

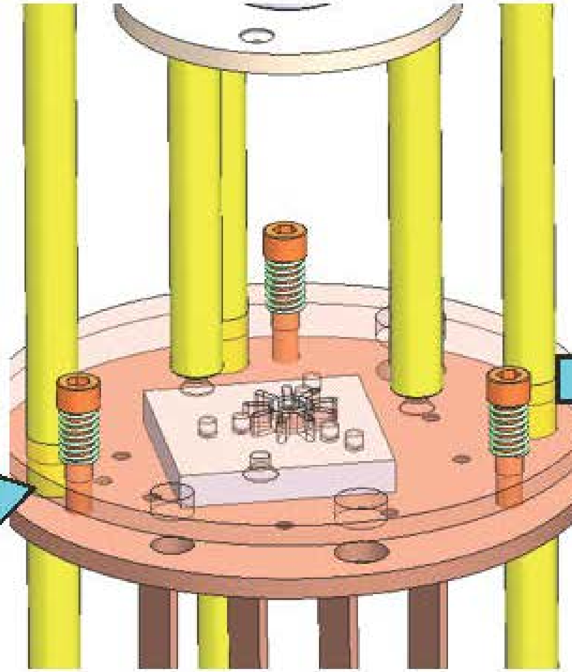
Hc1 measurement for RF field

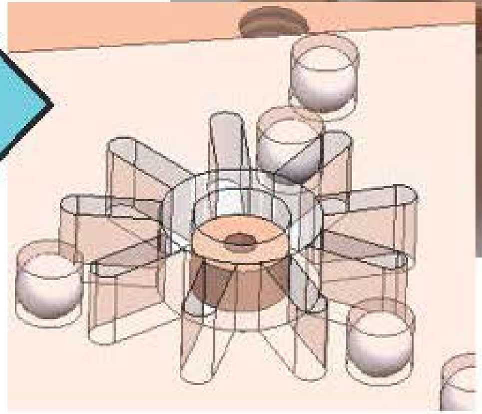
Superconducting sealing is still under discussions

Third Harmonic Test at Kyoto U.



Third harmonic test system is under construction.





Coil Holder with flux return slots

Waiting for arrivals of some parts.

Third Harmonic Test at Kyoto U.

He gas warming heat exchanger.

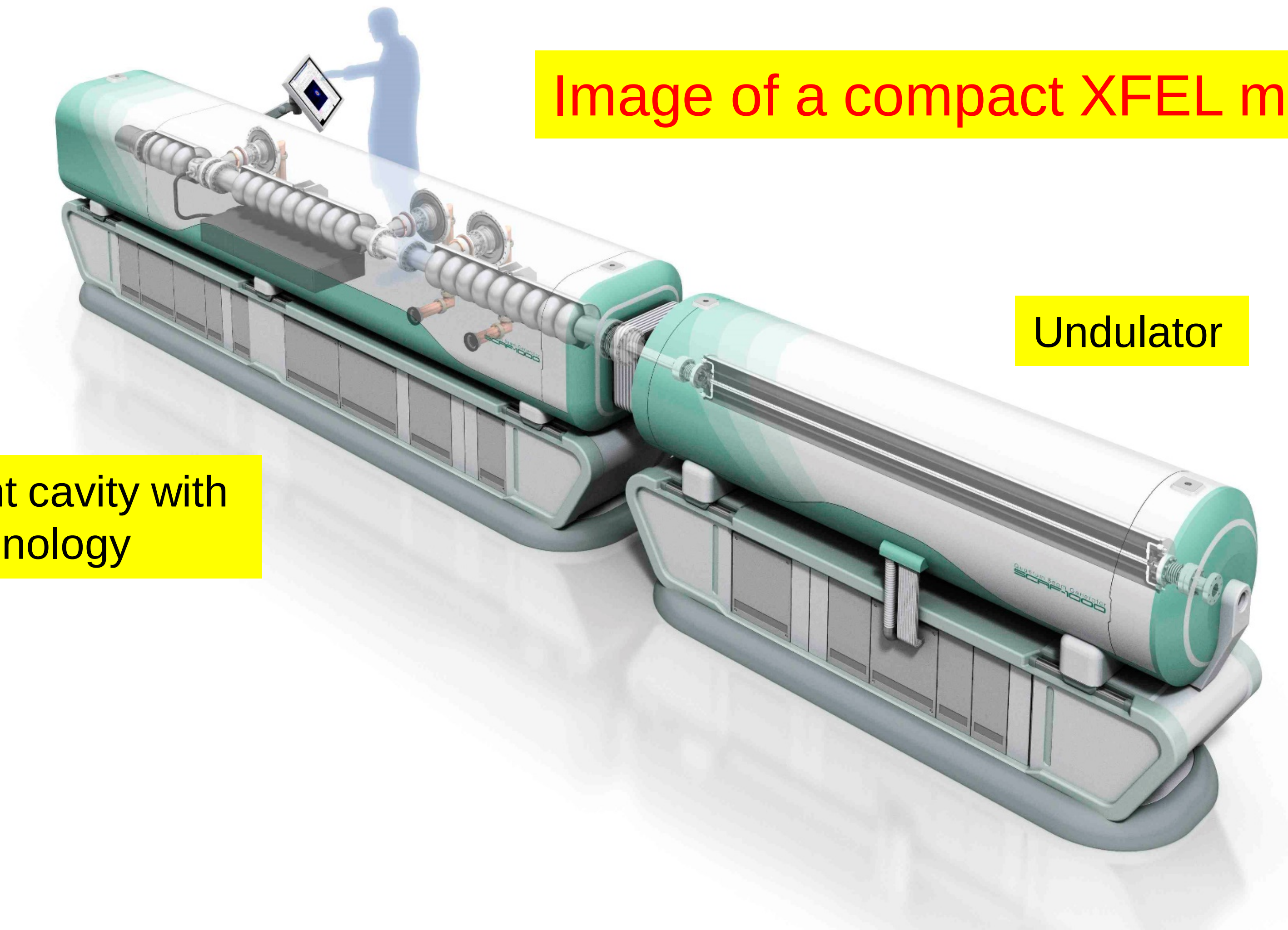
He gas return system is prepared.

Summary

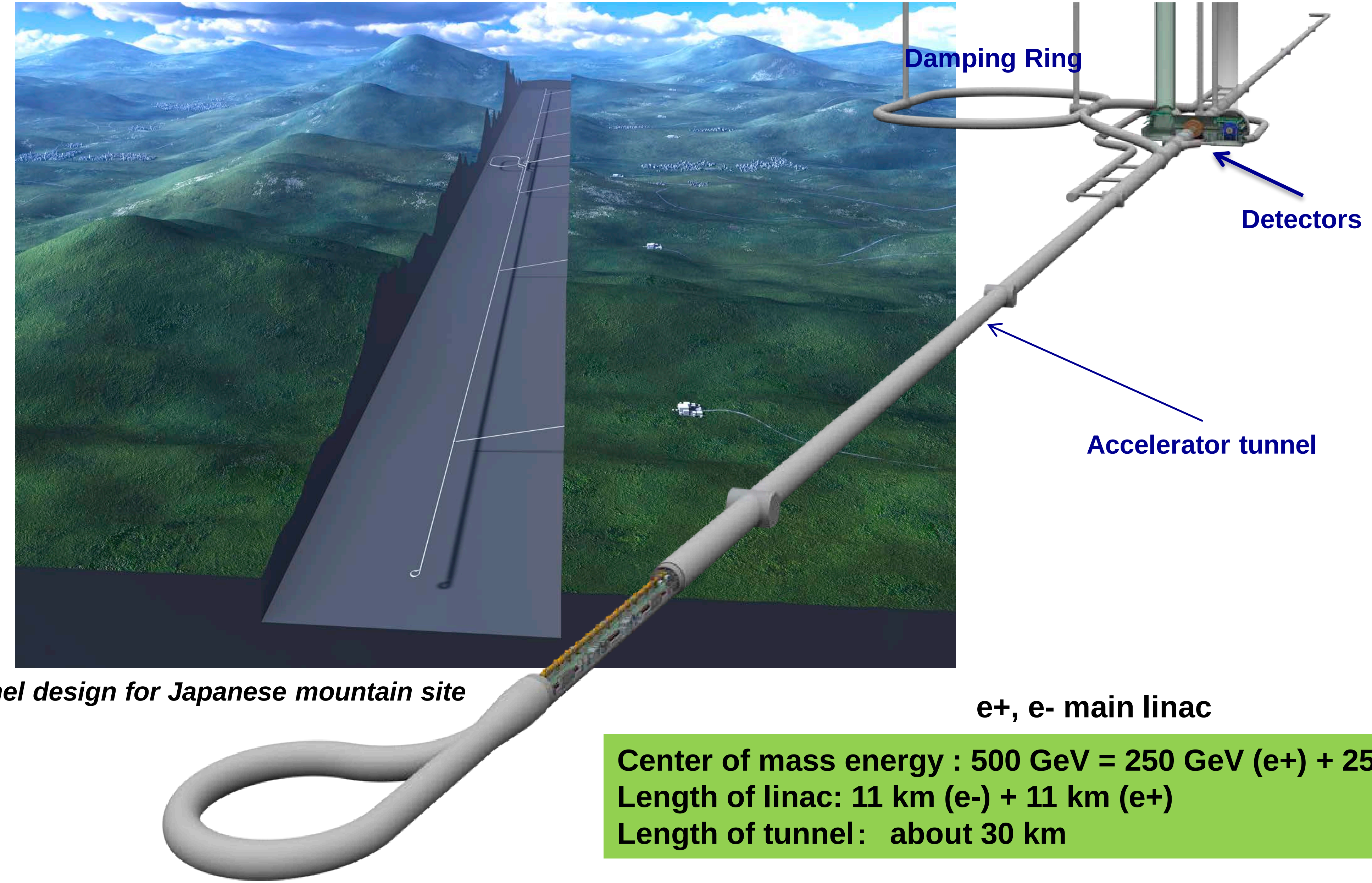
- Motivation of thin-film R&D is to produce compact SRF accelerators for industries and the cost reduction of ILC.
- Theoretical consideration is done firstly to effectively use the limited experimental resources.
- The experimental setups for thin-film creation are at Kyoto Univ. (IBS) and at KEK (ALD). KEK-ULVAC collaboration started for thin-film creation.
- A small-sized cryostat with a compact refrigerator is successfully installed at KEK (Tc, RRR, etc.).
- The middle-sized cryostat is used for the measurements of Hc1 for SC samples by DC, AC, and RF fields.
- The Al-model of mushroom-shaped cavity for 3.9 GHz RF field is fabricated for RF test at Room Temperature (RT).
- Preparation of third harmonic measurement is ongoing at Kyoto Univ.

Backup slides

R&D of thin-film technology is matching the concept of Center-of-Innovation (COI) KEK-industry collaboration



International Linear Collier (Technical Design Report)



Tunnel design for Japanese mountain site

Center of mass energy : 500 GeV = 250 GeV (e+) + 250 GeV (e+)
Length of linac: 11 km (e-) + 11 km (e+)
Length of tunnel： about 30 km