A_RD_9
Effort Towards Improving Large Scale Production for Superconducting (SC) Cavities

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France-Japan-Korea
Associated Laboratories
2019 International Annual Workshop

May 8th-10th 2019, Jeju Island

CONTEXT

- ILC: ~8000 Superconductive Niobium cavities > 31.5 MV/m
  = cost driver
- Challenging performance
- Requires a worldwide effort

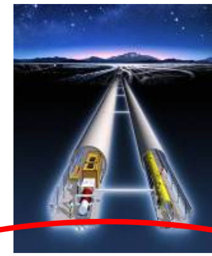
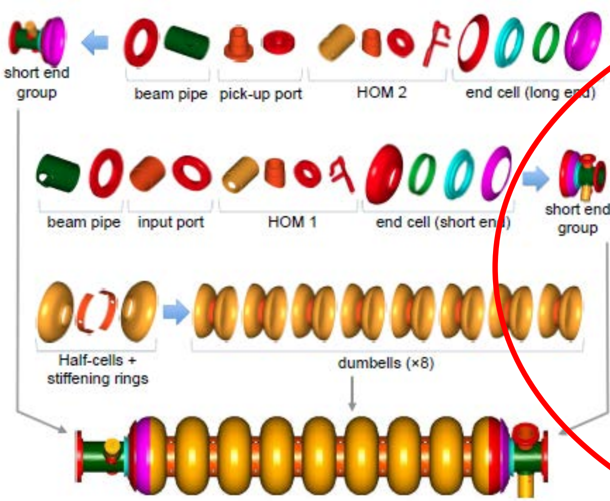
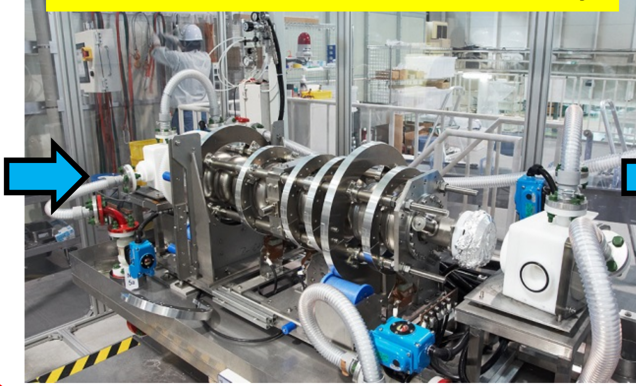


Table 2.1 The main goals and timeline for SCRF R&D established at the beginning of the Technical Design Phase

Year	2007	2008	2009	2010	2011	2012
S0: Cavity gradient at 35 MV/m in vertical test		→ yield 50%			→ yield 90%	
S1: Cavity string at average gradient of 31.5 MV/m in cryomodule		Global effort for string assembly and test				
S2: System test with beam acceleration including high- and low-level RF		FLASH at DESY, ASTA/NML at FNAL, STF2 at KEK				
Industrialisation: Study and preparation for industrial production of SCRF cavities and cryomodules			Production technology R&D			



Inner surface treatment of cavity



Horizontal Electro-Polishing (EP)

Cleanroom Assembly

- Requires perfect knowledge of SRF technology from cavity fabrication to cleanroom assembly
- Decrease the cost: increase the performances (Emax and Q) and VEP

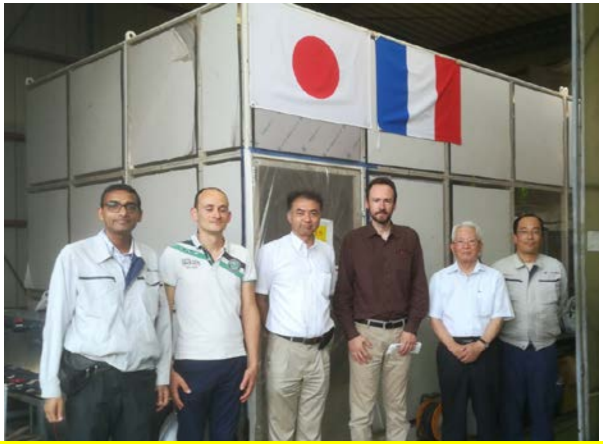
GOAL OF A_RD_09

- Develop process for the large scale cavity production
- From Cavity Fabrication, inner surface treatments, to RF performance Test (Vertical Test: VT)
- + Multilayer and surface Analysis.
- Thanks to advanced facilities: CFF/STF/COI at KEK, Supratech at CEA Saclay
- Thanks to motivated teams:

Concentrate in R&D of Vertical EP (cost-effective inner-surface treatment) and multilayer surface (advanced high-performance inner-surface) .

Please replace the red examples by the appropriate data in black

ID[1]:	Title: R&D on innovative treatments and characterization of SRF surface for future accelerators.					
	French Group			Japanese Group		
	Name	Title	Lab./Organis.[2]	Name	Title	Lab/Organis.[3]
Leader	T. Proslier	Dr.	Irfu	Takayuki Kubo	Dr.	KEK
Members	C. Madec	Dr.	Irfu	Hitoshi Hayano	Dr.	KEK
	C. Antoine	Dr.	Irfu	Shigeki Kato	Dr.	KEK
	S. Berry	Dr.	Irfu	Hideaki Monjushiro	Dr.	KEK
	C. Servouin		Irfu	Takayuki Saeki	Dr.	KEK
	F. Eozénou		Irfu	Ryo Katayama	Dr.	KEK
	A. Four		Irfu			



Collaboration with Marui Co. Ltd. (industry).

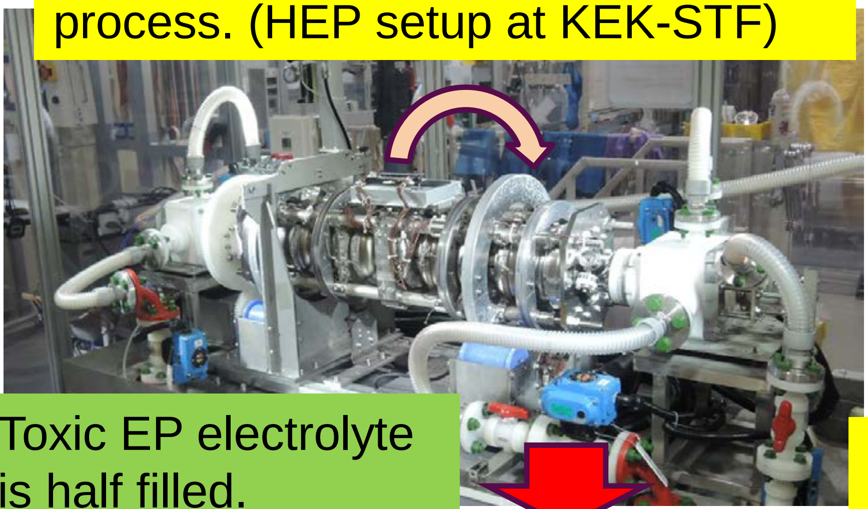
We will add a student in the members.
Hayato Ito (KEK Sokendai Univ.)

RECENT ACHIEVEMENTS

ELECTROPOLISHING (EP) AT KEK & MARUI

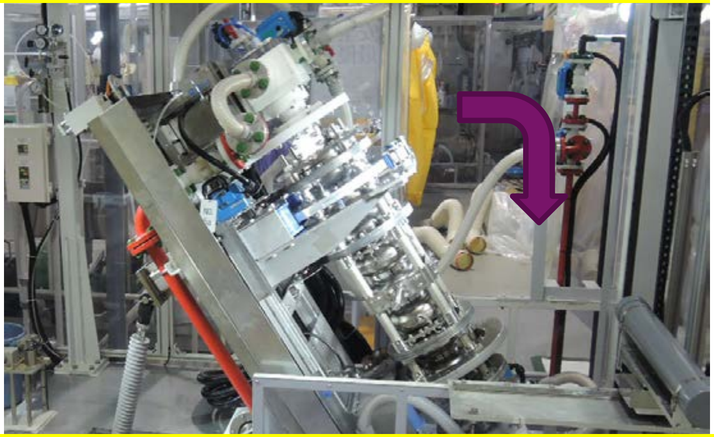
EP is the best method for inner surface treatment, but expensive.

Rotation of cavity in Horizontal EP process. (HEP setup at KEK-STF)



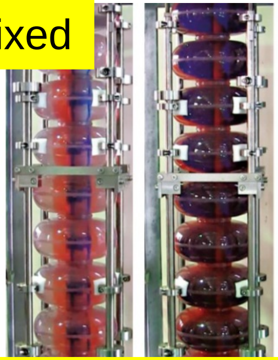
Toxic EP electrolyte is half filled.

Turning the EP-bed for draining



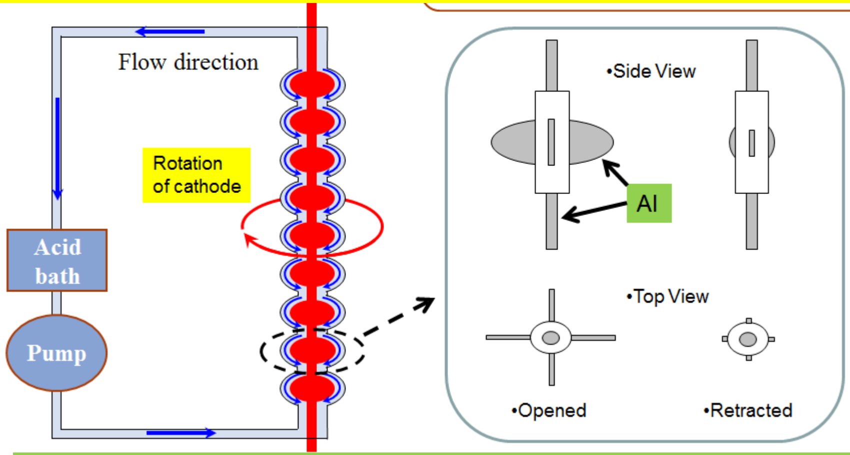
Massive and complicated system

Vertical EP (VEP) at Marui Galvanizing Co. Ltd. in collaboration with KEK



Cavity is fixed

Simple VEP is more cost-effective than HEP, but hydrogen-gas generation at cathode has a narrow way to escape at top and it is the main problem.



Special Ninja cathode by Marui Co. Ltd.

NINJA CATHODE VEP OF SINGLE-CELL CAVITY AT CEA-SACLAY IN 2017

VEP SET UP – CEA-Saclay

Ninja-cathod by KEK + Marui

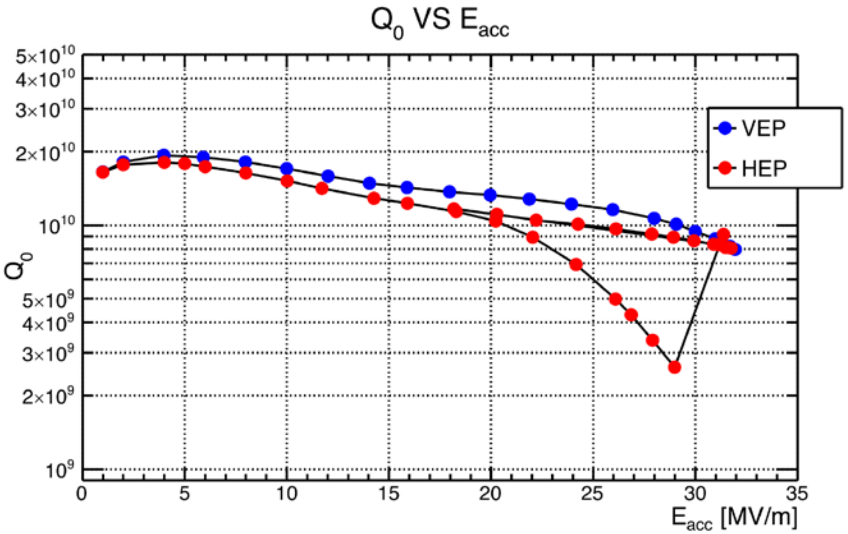
2017

VEP experiment at Saclay

Vertical EP conditions:

- Thickness removal 150 µm
- Acid Temperature in tank: 18°C
- Rotation cathode: 20 rpm.
- Voltage cathode: 17,3 V.
- Acid flow: 10L/min.

- 32MV/m (Q_0=8.0E9) was achieved.
- Accelerating gradient after VEP was almost same as achieved after HEP.



VEP SET-UP OF 9-CELL CAVITY AT MARUI

VEP setups of 9-cell cavity at Marui Co. Ltd.

Continuous improvement of the VEP set-up for 9-cell cavity at Marui Co. Ltd.:

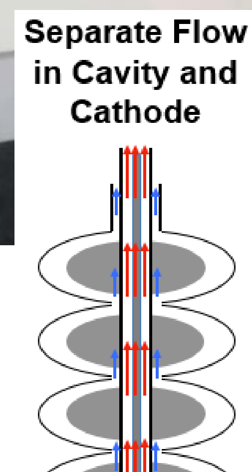
- Automation which makes it possible to test different flow configurations
- Cooling of the cavity
- Improvement of the acid tank with Teflon mesh to remove hydrogen bubbles

VEP SET-UP AT MARUI (II)

Acid reservoir with Teflon mesh to remove H2

Teflon filter on the acid line to remove H2

Top of the cavity: large chamber to separate acid & H2



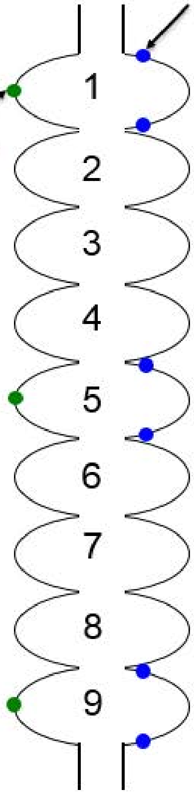
Separated flow (cavity & cathode)

Fully automated process

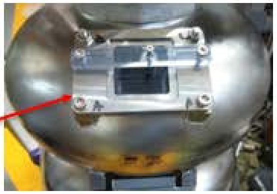
9-CELL 'COUPON' CAVITY TEST AT MARUI

Nb Coupon with view port

Nb Coupon



Coupon with Viewport near Iris



6 coupons near iris positions

Equator Coupon

3 coupons at the equator positions

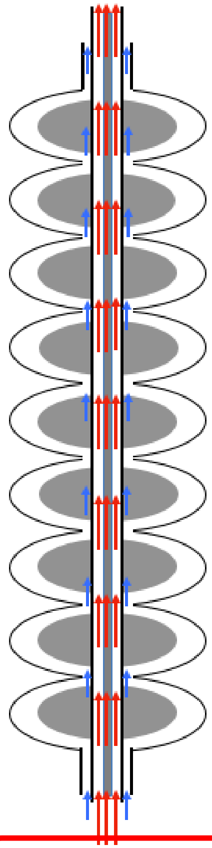
Coupon Cavity at VEP Stand

Dedicated to VEP studies. Powerful tool. Make it possible to achieve local studies along the cavity during process.

RESULTS ACHIEVED AT MARUI

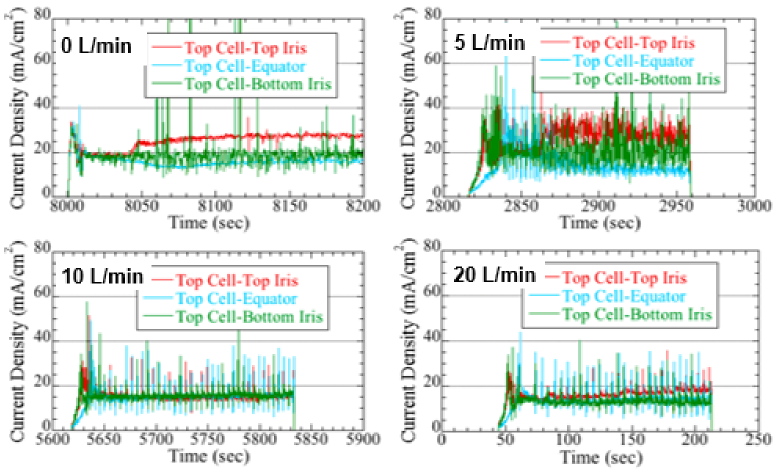
Separate Flow in Cavity and Cathode

- Removal of bubbles quickly from a multi-cell cavity to stop bubble accumulation in upper cells is difficult and challenging.

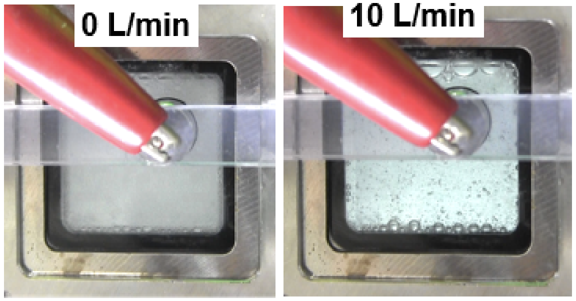


Separate Acid Flow in Cathode and Cavity

Coupon currents at 5 L/min in Cavity & Different Flow Rates in Cathode Housing



Viewport (Top Cell) at 0 and 10 L/min in Cathode Housing



Filled with bubbles **With reduced bubbles**

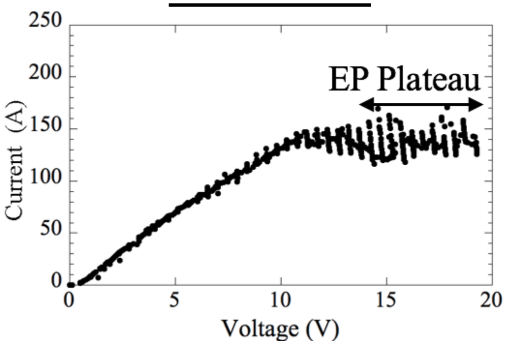
Adequate acid flow rates:
Cathode housing ~ 10 L/min & Cavity ~ 5 L/min

Separate acid flow in the cavity and cathode housing reduced bubble accumulation in the cavity cells.

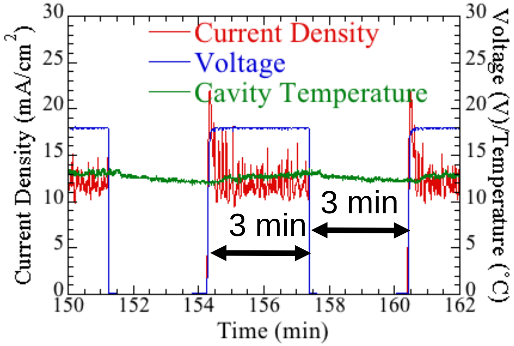
VEP WITH DUAL-FLOW STREAMS AT MARUI

Flow rate: Cathode housing-10L/min, Cavity-5L/min

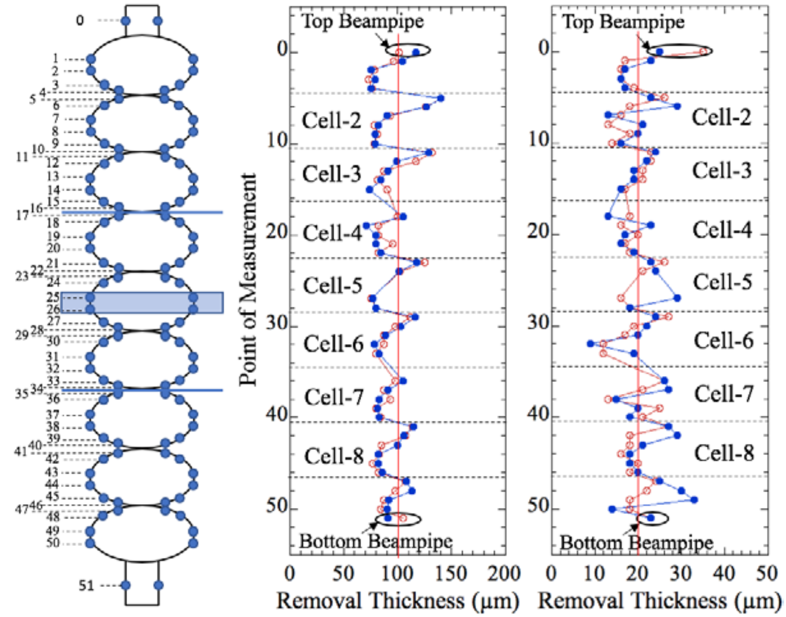
I-V Curve



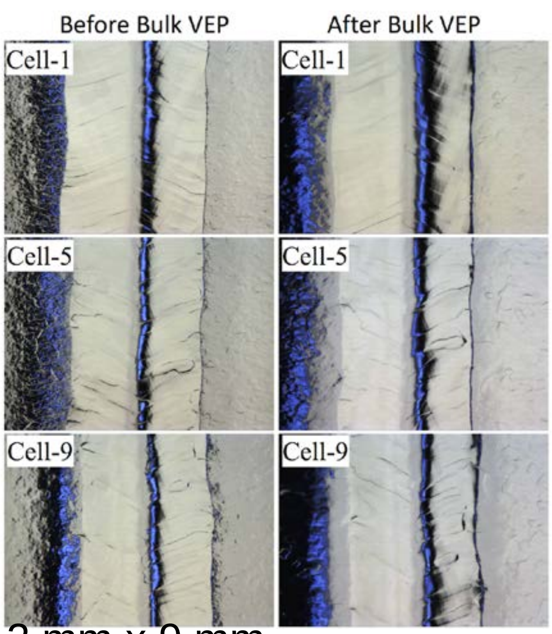
On-Off voltage cycles



VEP for 100 µm **VEP for 20 µm**



On-Off cycles were selected to reduce circulating bubbles from the acid tank to cavity



12 mm x 9 mm

- Removal asymmetry significantly reduced.
- Surface was smooth in all the cells.

RF TEST AFTER BULK REMOVAL OF 9-CELL CAVITY AT KEK

Horizontal EP (baseline RF test)

↓

VEP for 100 µm

↓

750ºC bake

↓

VEP for 20 µm

↓

750ºC bake

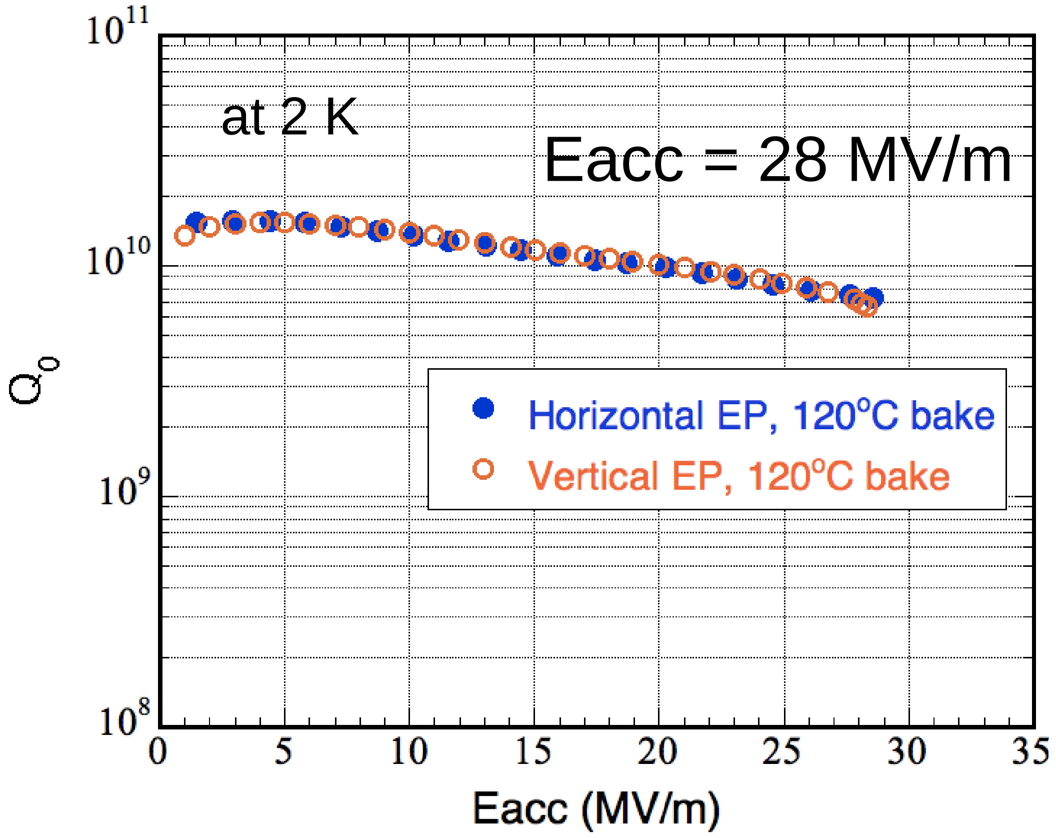
↓

VEP for 10 µm and 120ºC

↓

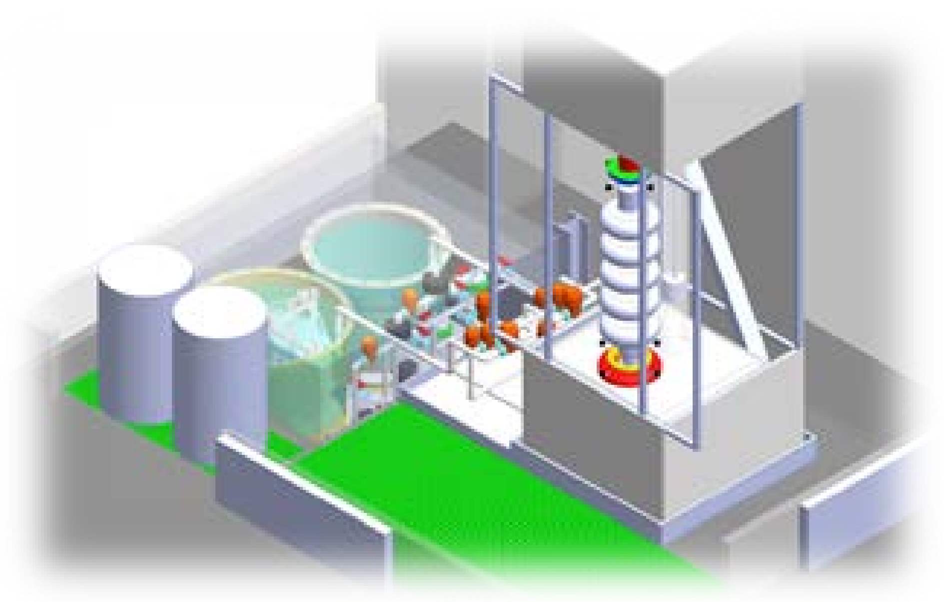
RF Test

Eacc = 28 MV/m



Cavity performance after VEP is the same as achieved after HEP.

VEP SET-UP AT CEA SACLAY

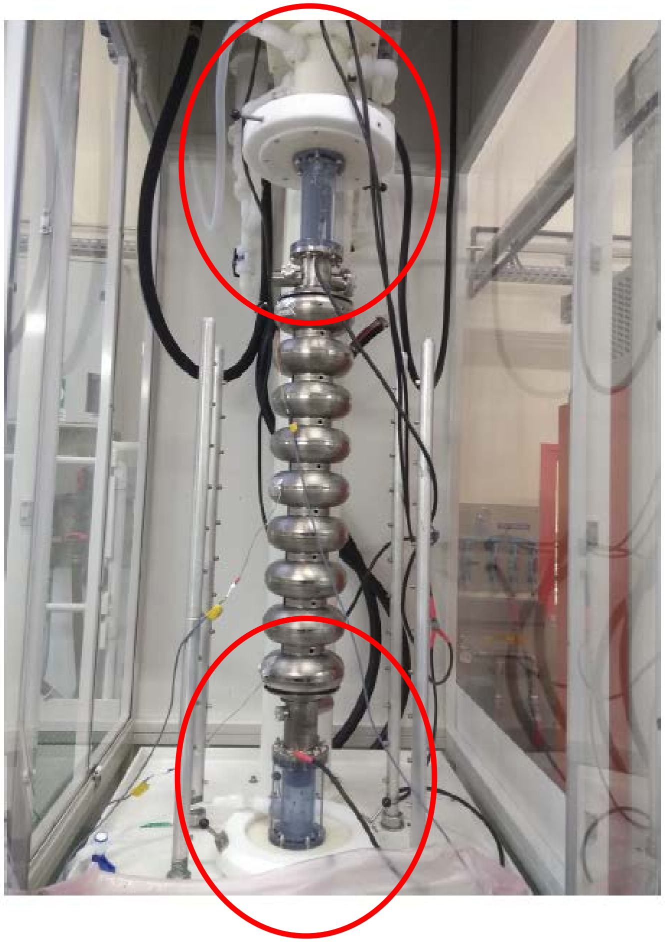


- Designed for large cavities
- Circulating acid
- Injected from bottom
- 300L acid capacity
- Cooling system (heat exchanger in acid tank)
- Emptying/draining by gravity
- Nitrogen blowing in top of cavity/acid tank
- Cathode inserted in horizontal position

SPL Cavity insertion in the cabinet

Set-up at Saclay has a larger acid reservoir (300L capacity). It makes it possible to VEP big cavities and to tackle the H2 problem.

ADAPTATION OF NINJA TECHNOLOGY TO SACLAY

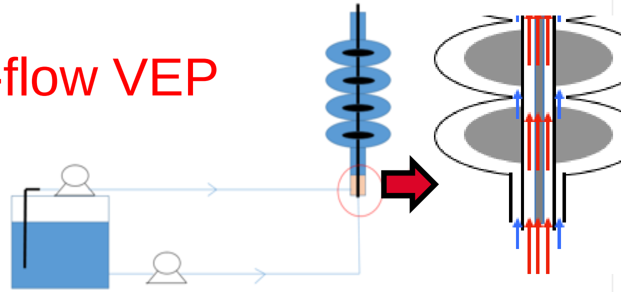


Mechanical fittings were necessary to use the Ninja Technology at Saclay

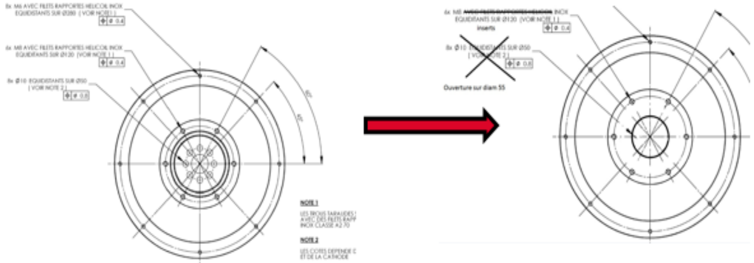
CEA has modified set-up for Marui/KEK experiments:

-Additional pump to feed the external area (cavity) with acid (lower flowrate)

Applied 2-flow VEP

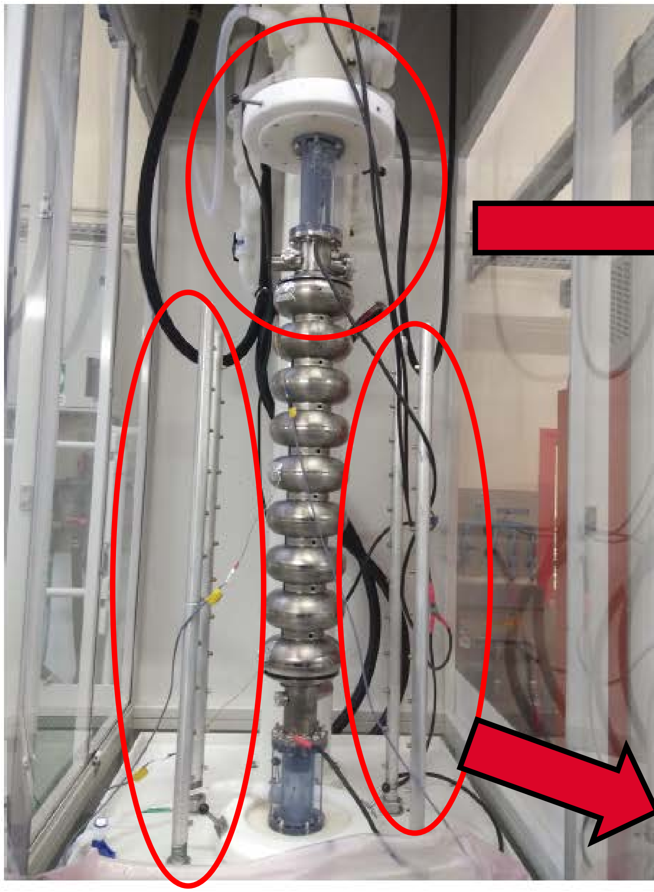


-Modification of upper plate for better H2 removal (tested with water test).



9-cell cavity (TSB01) was provided from KEK

VEP TREATMENT WITH TSB01 CAVITY AT SACLAY

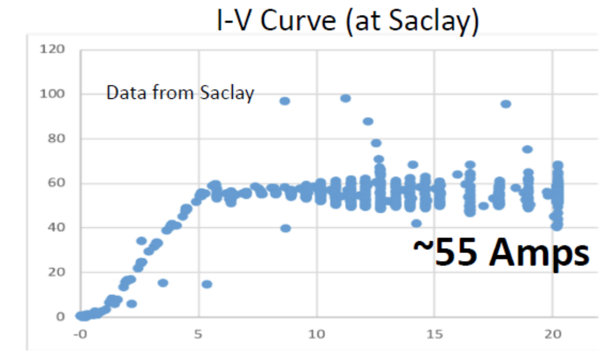


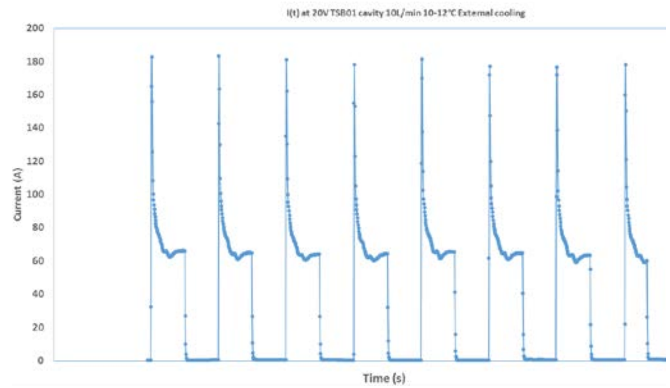
Issue: Coupler

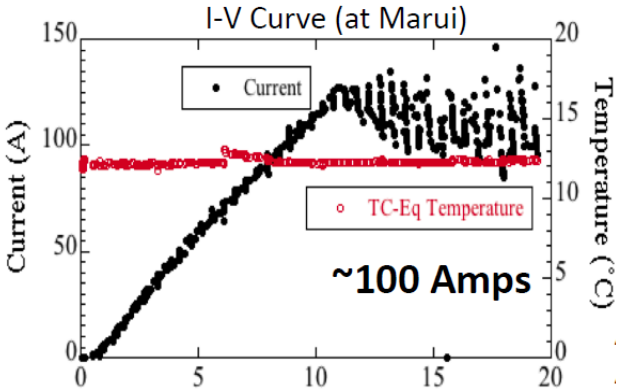
External cooling of cavity surface by applying water spray.

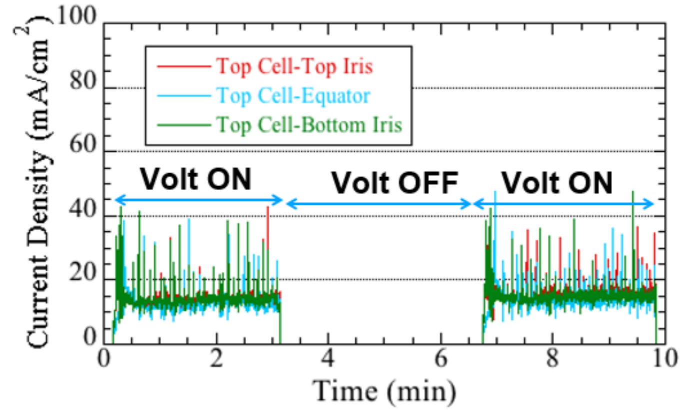
- 30µm removed at Saclay on TSB01, previously VEP’ed at KEK/Marui.
- The cavity will be tested at Saclay in May 2019.

COMPARISON OF RESULTS BETWEEN SACLAY AND KEK/MARUI









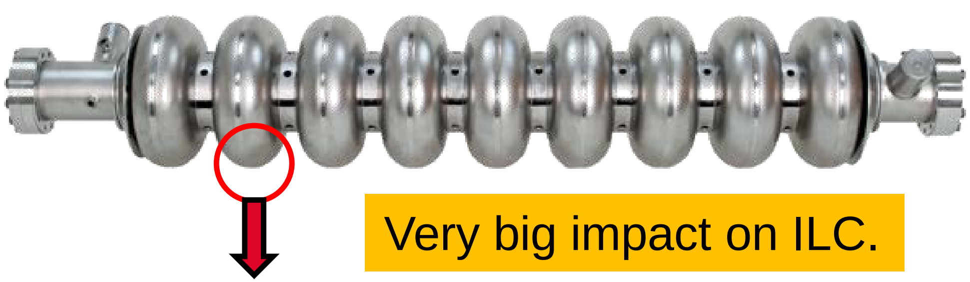
- I(V) curves have been recorded, as well as I(t) curve.
- On/off (3' – 3') sequences were applied during VEP.
- The EP 'plateau' is wider at Saclay. It might be attributed to a light difference in acid concentration (HF 40% - Vs HF 55%).
- The cavity will be tested at Saclay in May 2019.

COLLABORATION IN ILC CONTEXT

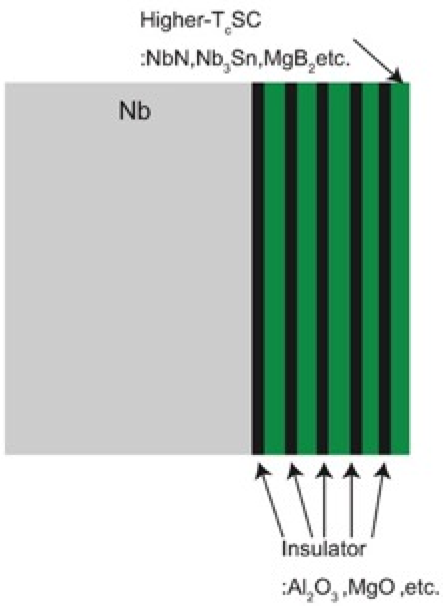
Joint-Experiment was broad-casted on a local Iwate TV channel. (Iwate is the Japanese ILC-site)

STUDIES OF MULTILAYER-SC

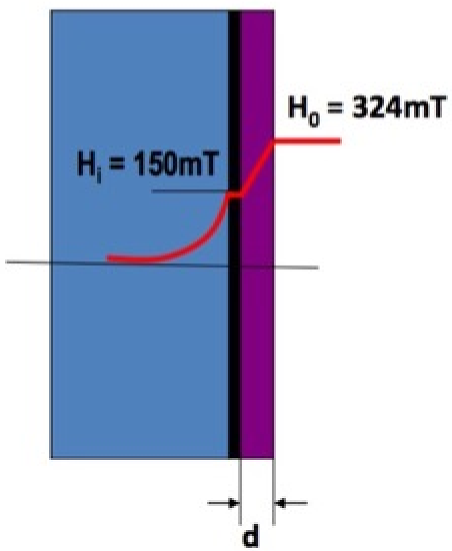
Higher Hc of thin-film on Nb → Higher quench field
(Cavity of higher gradient)



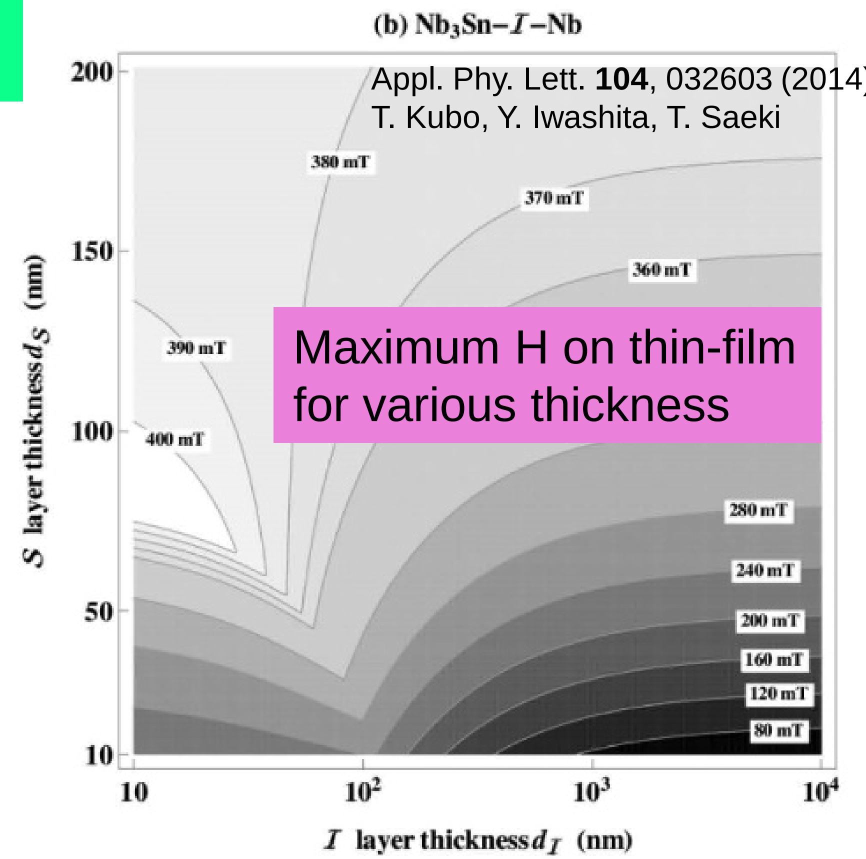
Very big impact on ILC.



Multi-layer-thin-film



Single-layer-thin-film

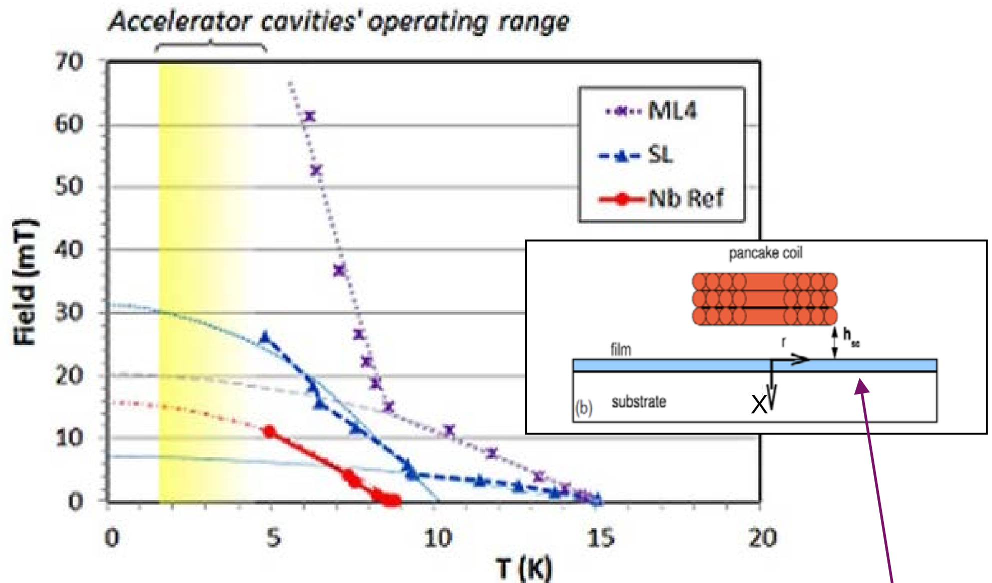


Appl. Phy. Lett. **104**, 032603 (2014)
T. Kubo, Y. Iwashita, T. Saeki

Maximum H on thin-film for various thickness

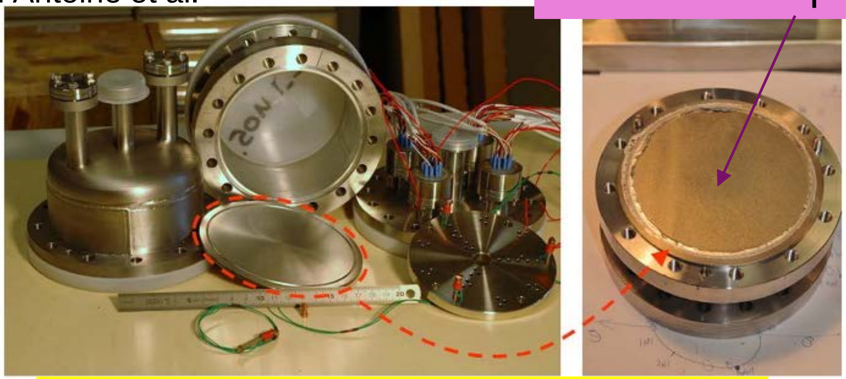
Optimized thicknesses of SC and Insulator layers are calculated.
T. Kubo. et al. (KEK)

STUDIES OF MULTILAYER-SC



Appl. Phy. Lett. **102**, 102603 (2013)
C. Z. Antoine et al.

Thin-film samples

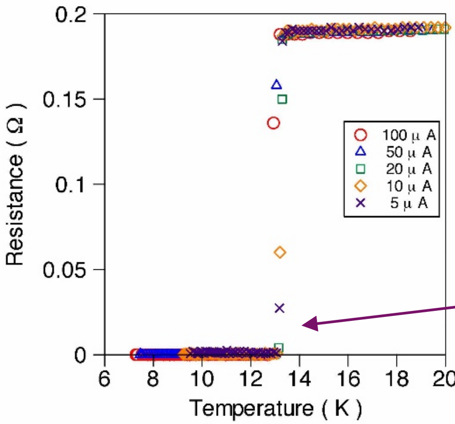


CEA/Saclay has lots of experiences for experiments of thin-film samples.

Proc. of IPAC2016
T. Saeki et al.
ID = WEPMB021

KEK experiments for thin-film samples.

Thin-film sample NbN (200 nm)



(Tc of NbN = 16.2 K)

Measured Tc = 13.3K

Collaboration for thin-film subjects

THIN-FILM PAPER WAS ACCEPTED BY JOURNAL: SUPERCONDUCTOR SCIENCE AND TECHNOLOGY.

ACCEPTED MANUSCRIPT

Optimization of tailored multilayer superconductors for RF application and protection against premature vortex penetration.

Claire Z. Antoine[1], Muhammad Aburas[2], Aurelien Four[2], Francois WEISS[3], Y Iwashita[4], Hitoshi Hayano[5], Shigeki Kato[6], Takayuki Kubo[5] and Takayuki Saeki[5]

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Abstract

Superconducting radiofrequency (SRF) cavities for accelerators is the unique superconductivity application that operates in the Meissner state. For decades bulk niobium, which exhibit the highest 1st critical field among all known superconductors, has been the only material able to achieve high performances in terms of high accelerating field (proportional to the RF field at the Nb surface) together with quality factor (inversely proportional to surface resistance). A better understanding of the peculiarities of SRF physics (comparatively much less explored than the mixed state of high κ superconductors) led to the proposal of specific nanostructures tailored for SRF applications, in the form of superconducting/Insulating/superconducting (S-I-S) multilayers which could improve SRF performance. In this paper we present the study of a series of NbN/MgO/Nb trilayers, including standard material characterization and specific superconducting characterization (local magnetometry), along with a comparison to the theoretical modeling available up to date for this kind of structures.

Thin-film experiment at Saclay

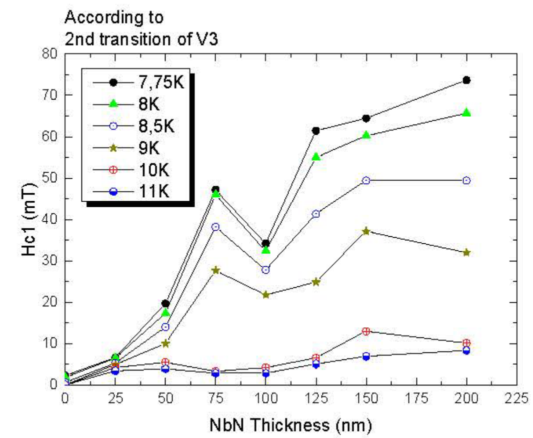


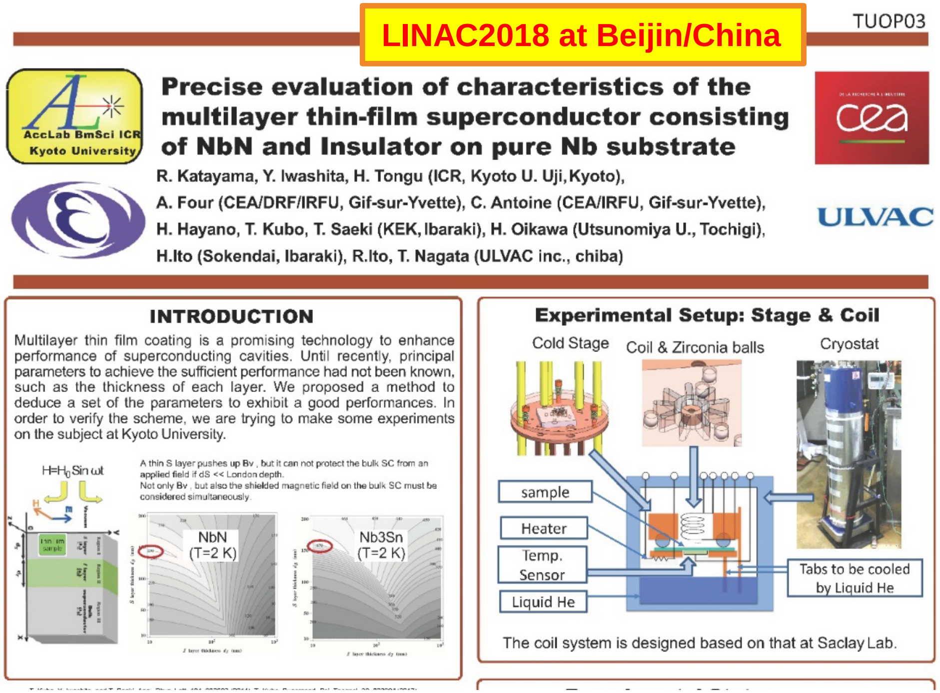
Figure 12. $\mu_0 H_{C1}$ as functions of NbN thickness for the series of NbN/MgO/thick-Nb trilayers at various temperature. The improvement seems indeed to saturate above 150 nm. However, thicker films need to be explored. Note that the 100 nm sample appears to be more defective than the rest of the series.

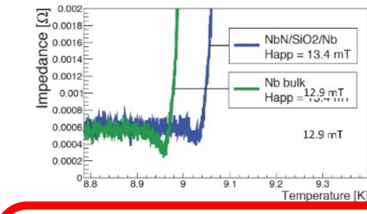
Fig. 12 clearly demonstrates the improvement of the transition field with layer thickness. Although this improvement appears to saturate above 150 nm, there is still room for improvement with thicker layers. This option will be explored in the near future.

Systematic measurements of Hc1 to show the denpendence on multilayer thickness (for the first time in the world).

Thin Film / Coupon-sample measurements on Japanese side

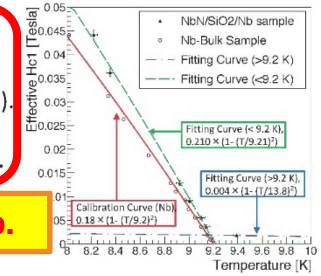
LINAC2018 at Beijin/China



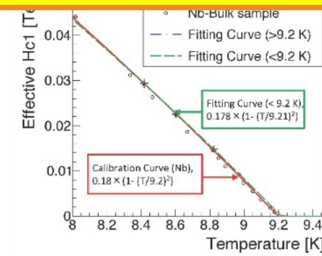


- Third harmonic signals are compared between Bulk pure Nb (Green) and NbN/SiO2/Nb (Blue).
- Significant difference exists between two results.

- Effective Hc1 are compared between Bulk pure Nb (circle) and NbN (200 nm)/SiO2/Nb (black triangle).
- Effective Hc1 for T < 9.2 K is **(0.210±0.007)x(1-(T/(9.21±0.02))²).**



17% higher Hc1 than bulk-Nb.



- Preliminary result of Effective Hc1 for NbN(50 nm)/SiO2/Nb is shown in the left figure.
- Effective Hc1 for T < 9.2 K is **(0.176±0.16)x(1-(T/(9.21±0.06))²),** Hc1(0) of which is consistent with that of Bulk pure Nb.

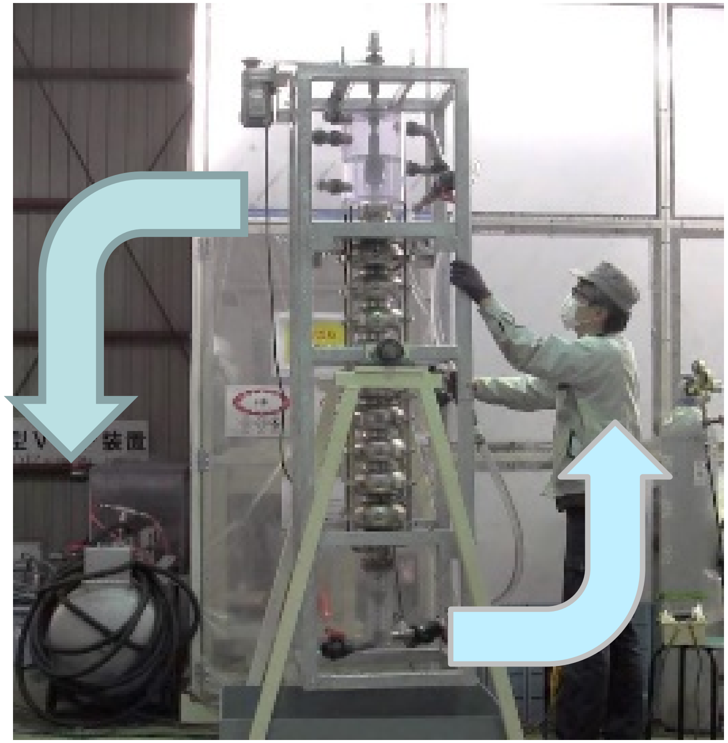
SRF characteristics (Hc) of NbN thin-film samples was measured by Katayama (KEK member) at Kyoto University. Hayato Ito (student of Sokendai-KEK) measured Tc of thin-film sample at KEK, and Hc measurement setup at KEK was also done.

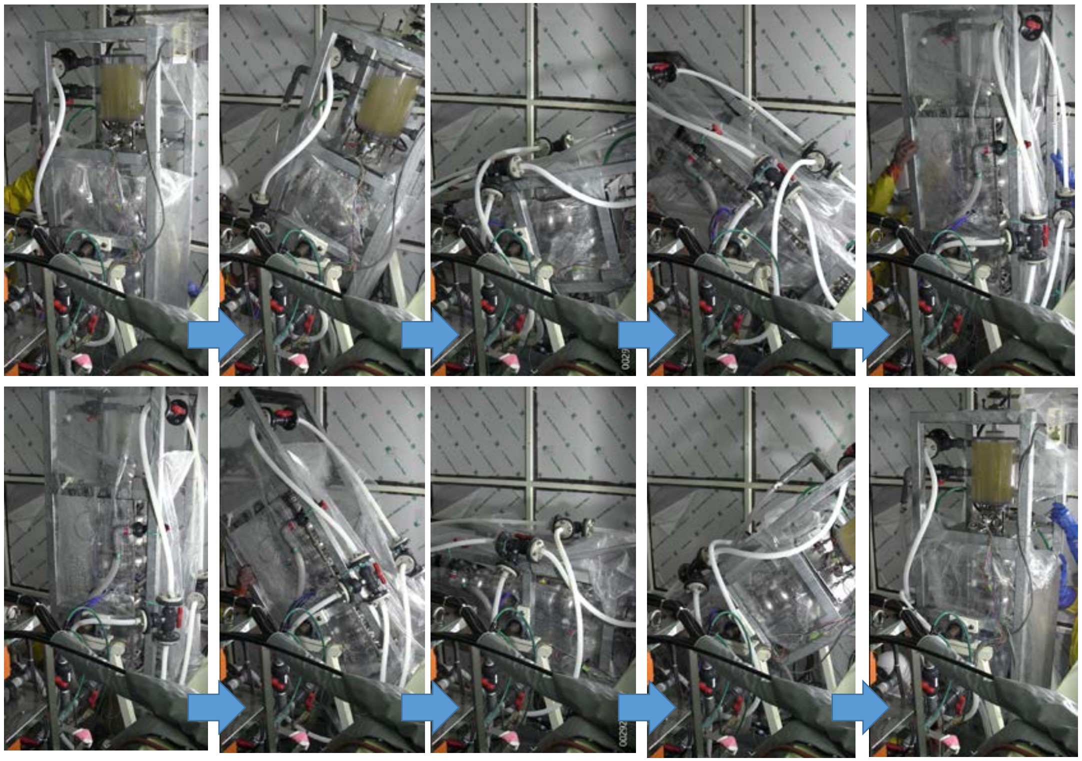
PROPOSAL FOR FY 2019-2020

R&D of 2-flow VEP
R&D of cavity flipping VEP system at Marui/KEK

- Continue the 2-flow VEP of 9-cell cavity to achieve Eacc > 35 MV/m at Marui/KEK and Saclay

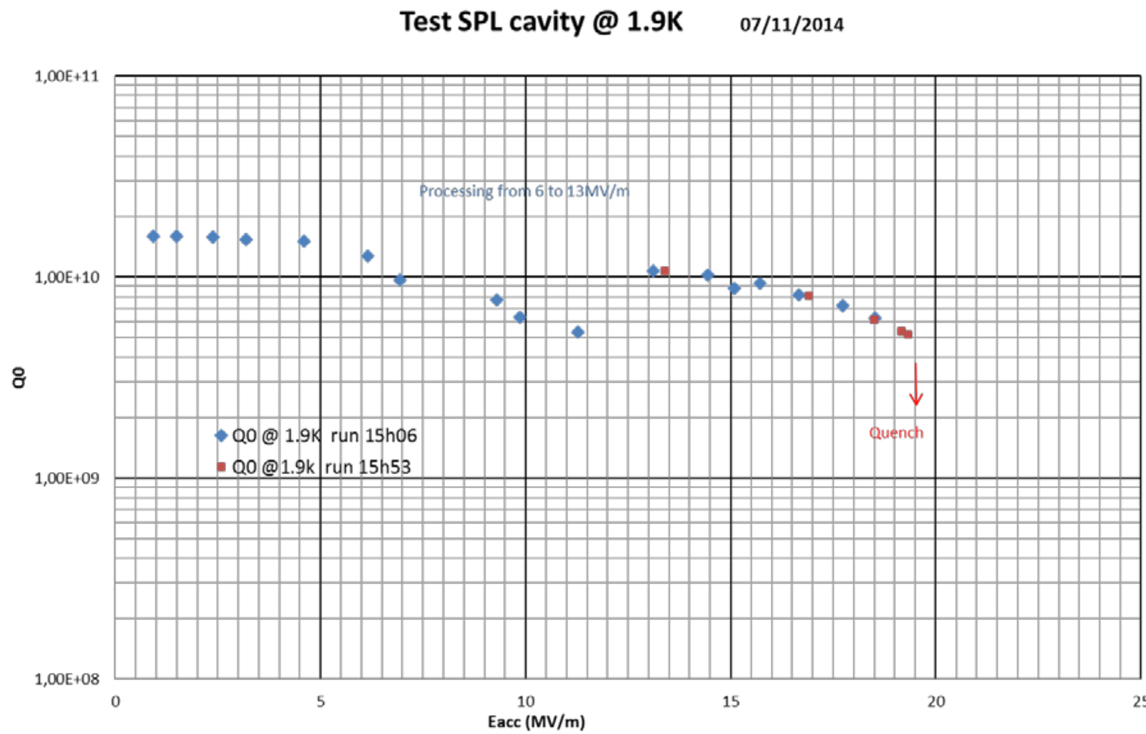
- In the VEP, the small asymmetry of the removal thickness in the cells has been a remaining problem.
- In order to solve this problem, we proposed and experimented “cavity flipping (rotation) VEP”.

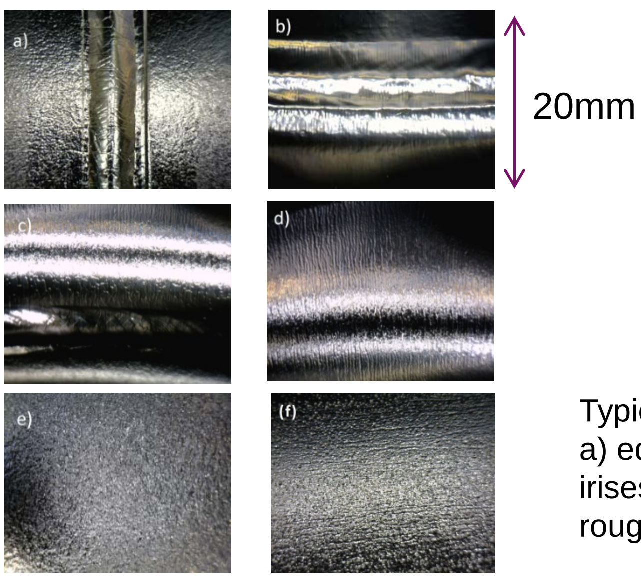

Cavity flipping (rotation) system


Cavity flipping (rotation) procedure

VEP OF 704MHZ CAVITY. PREVIOUS EXPERIENCE WITH SPL CAVITY

- 200 µm average removal by VEP
- Test stopped because of radiation level
- Test carried out at higher power until reaching quench at 20 MV/m

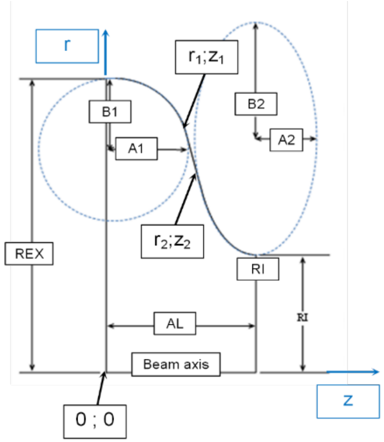




Typical surface morphologies after >100µm VEP at different locations. The weldings at a) equators, and b) irises are smooth. Bubbles stripes are observed at the proximity of irises c) and d). In the areas between equators and irises e) and f), the surface is rougher. Some pitting due to the uncontrolled EP sequence

PROGRAM FOR VEP OF ESS GEOMETRY 1-CELL CAVITY

1st step:
- Fabrication of single-cell β=0.86 cavity
- VEP at Saclay with dedicated VEP cathode by Marui
- VT (before/after baking)



2d step:
- Atomic Layer Deposition on the cavity
- VT

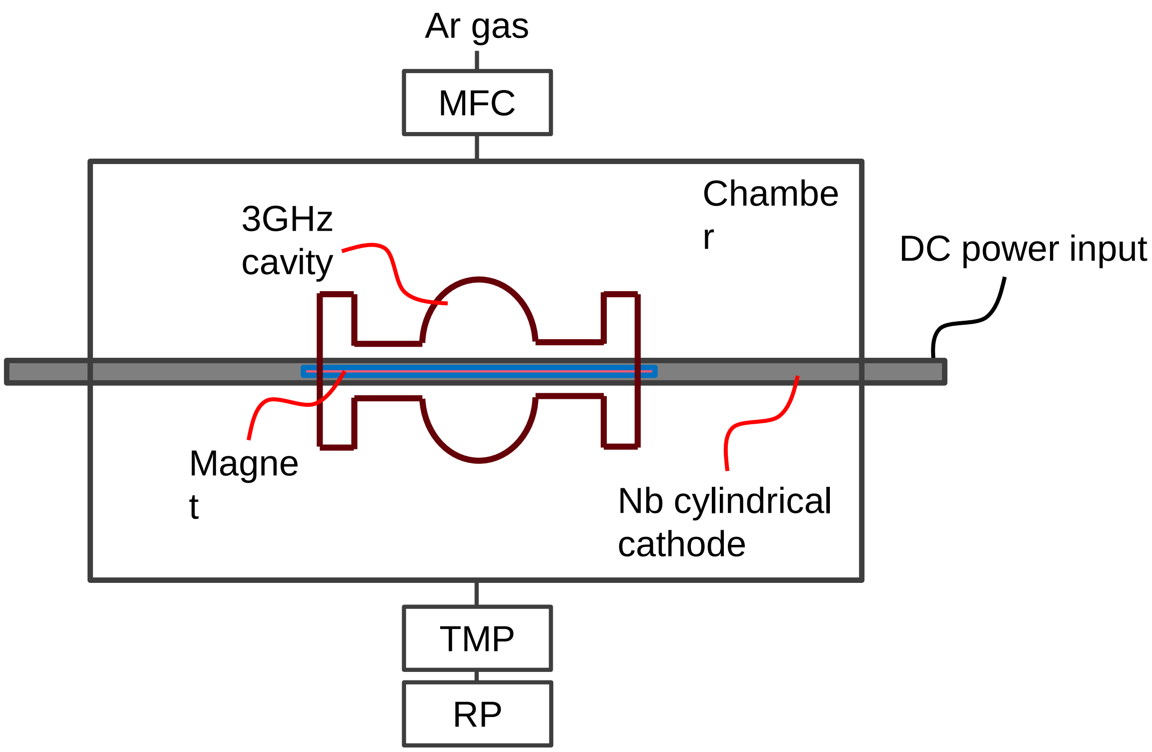
IF SUCCESSFUL, IT WILL BE ADAPTED TO 5-Cell CAVITY CONFIGURATION.


Figure 2: Medium beta cavity.

Current BCP treatment of ESS cavity at Saclay → R&D of VEP with ESS cavity by Ninja cathode

Thin-film R&D plan: Inner sputtering of cavity

We are setting up an apparatus that can deposit Nb or NbN thin-film on Cu or Nb 3GHz cavity in collaboration with ULVAC (industry).



Nb thin film deposited on the inner wall of Cu tube (Φ35mm).

Inner sputtering at ULVAC (Industry)

SUMMARY

Funding Request from France				
Description	**€/unit**	**Nb of units**	**Total (€)**	**Requested to[4]:**
Travel to Japan	1000	2	2000	Irfu
Visit to Japan	150/day	12	1800	Irfu
Shipping of cavity and samples	1300	1	1300	Irfu
Total			5100	

Funding Request from KEK				
Description	**k¥/Unit**	**Nb of units**	**Total (k¥)**	**Requested to:**
Travel to France	250	2 travels	500	KEK
Visit to France	20/day	10 days	200	
Travel to TYL-WS at Jeju/Korea	100	1 travel	100	
Visit to Jeju/Korea	20/day	3 days	60	
Total			860	

Picture at Himeji in Japan.

THANK YOU FOR YOUR ATTENTION

BACKUP

VEP SET-UP AT MARUI (III)

The set up is further being improved with mechanical development for the flipping of the cavity