R&D

High Gradient Cavities

F. Eozenou

French IRFU Collisioner Days. CEA Saclay, November 27-29th 2013

OUTLINE

- Context
- ILC/S0 achievements
- Worldwide R&D activities
- High gradient R&D activities at CEA/IRFU

CONTEXT

- ILC: ~16000 Superconductive Niobium cavities > 31.5 MV/m
  = cost driver
- Challenging performance
- Requires a worldwide effort

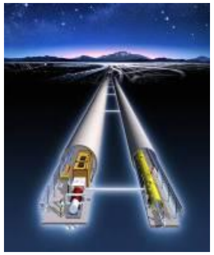
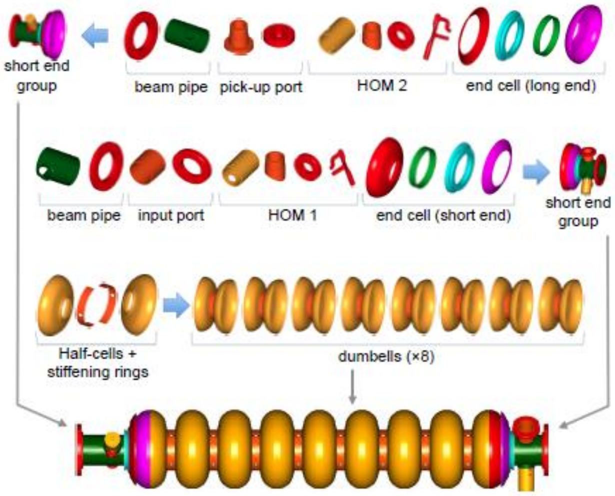
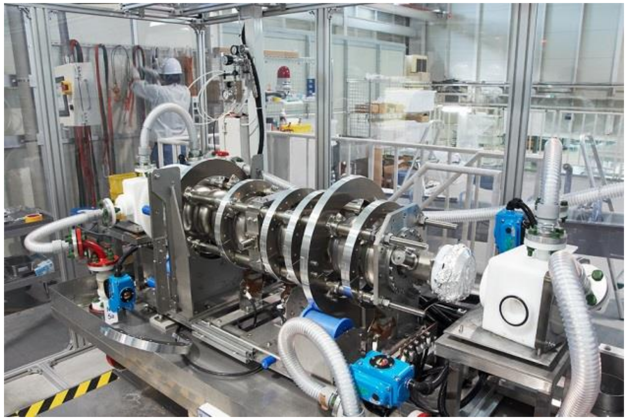


Table 2.1
The main goals and timeline for SCRF R&D established at the beginning of the Technical Design Phase

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			

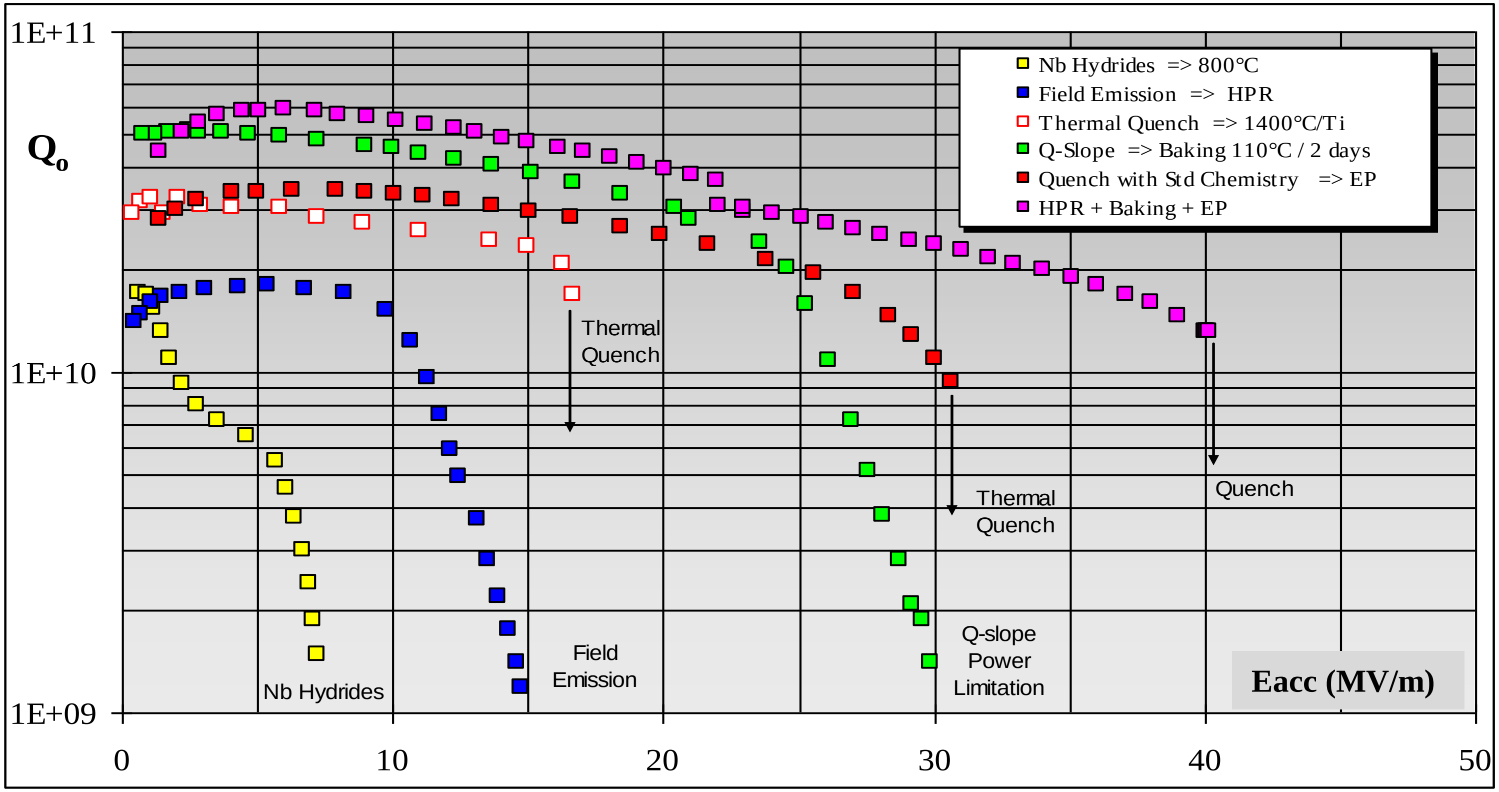



Horizontal EP set-up at KEK


Cleanroom Assembly at CEA/IRFU

Requires perfect knowledge of SRF technology from cavity fabrication to cleanroom assembly

BULK NIOBIUM CLOSE TO ITS ULTIMATE PERFORMANCES



Main breakthroughs in the 90's for performance improvement:

- Hydride cure (800°C heating)
- Cleaning (High Pressure Rinsing)
- Baking (120°C)
- Electropolishing

ILC STANDARD RECIPE

- Light chemical etching (10µm)
- Heavy electropolishing (EP) (100-120µm) ~ 7h
- Cleaning
- 800°C x 2h degassing
- Tuning
- Light EP (25µm) ~ 1h30
- Cleaning
- High Pressure Rinsing (HPR) (2x6h)
- Cleanroom assembly
- HV Baking 120°Cx48h

= Time Consuming

EP and Baking set-up @ KEK

HPR= UP water sprayed at 100 bars for cleaning

Nb Polishing: Removing of the damaged layer/surface smoothening

Cleaning: Removing of chemical residuals

Baking: Degassing of niobium, Q_0 cure, higher gradients

FOCUS ON ELECTROPOLISHING PROCESS

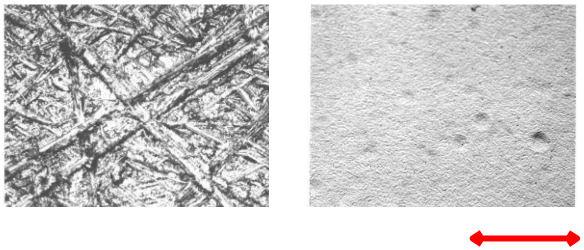
Process

- Nb polished internally with an electrolyte
- (concentrated H_2SO_4 - **HF** mixture) under constant voltage
- Cavity = Anode & Cathode is an Al pipe inside the cavity

Chemical reactions

- \- Anode: Niobium oxidation
- $2\ Nb + 5\ H_2O \leftrightarrow Nb_2O_5 + 10\ H^+ + 10\ e^-$
- \- Cathode: H_2 generation
- $2\ H^+ + 2\ e^- \leftrightarrow H_2$ (Teflon net to prevent H contamination)
- \- HF: dissolution of oxide Nb_2O_5 layer
- \- H_2SO_4: forming of a viscous layer

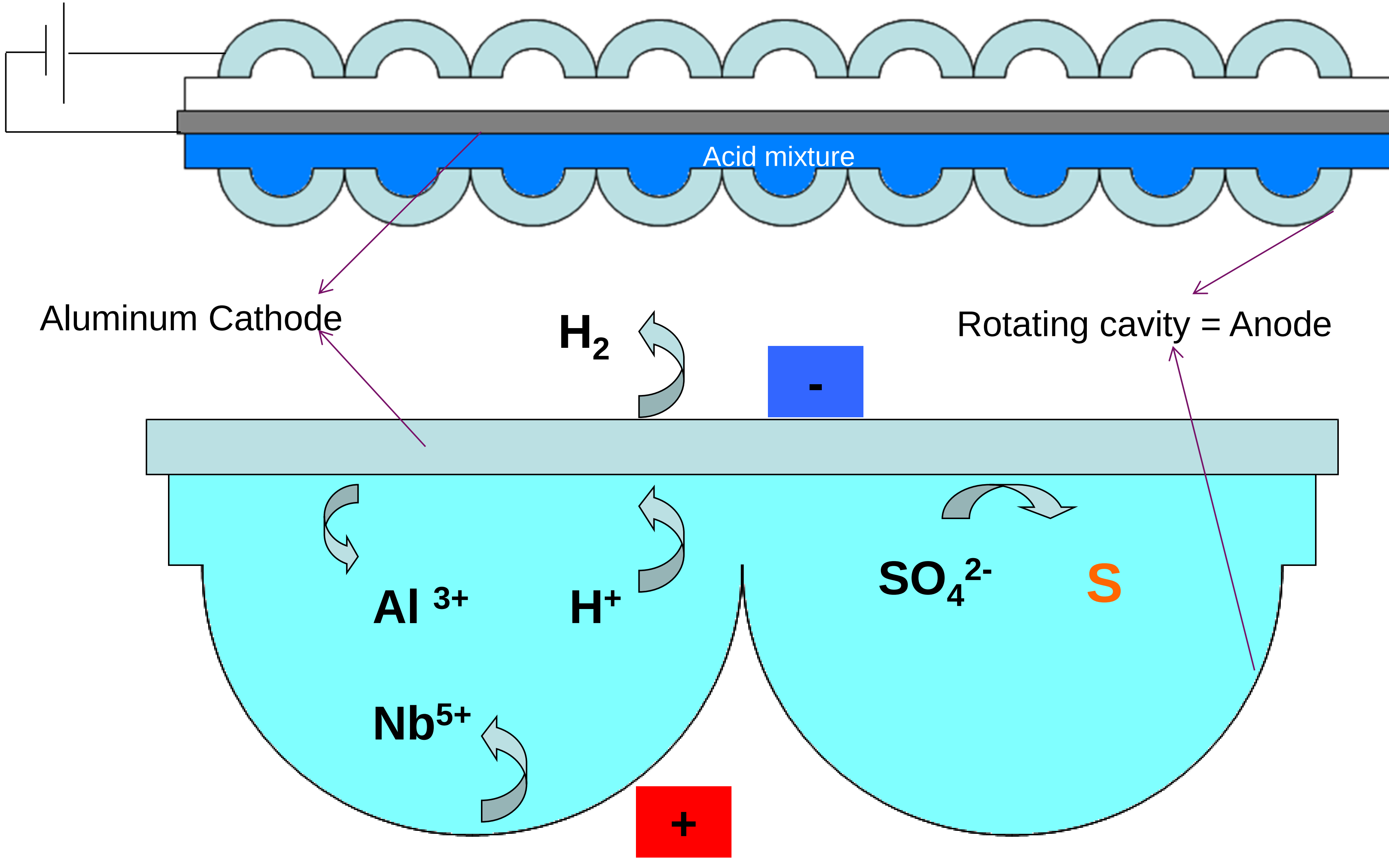
Raw material EP'ed



100 µm

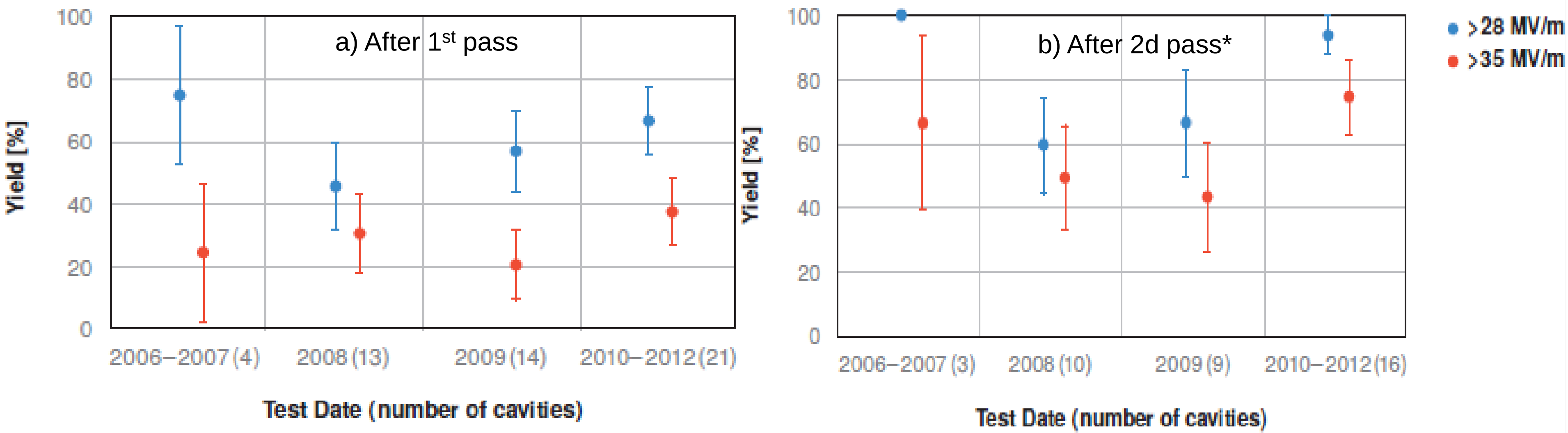
Obtention of law roughness 0.1µm

DETAILS OF NB ELECTROPOLISHING



Improve the yield of the cavity gradient:

Goal of S0 program: reaching 90% yield above 35MV/m

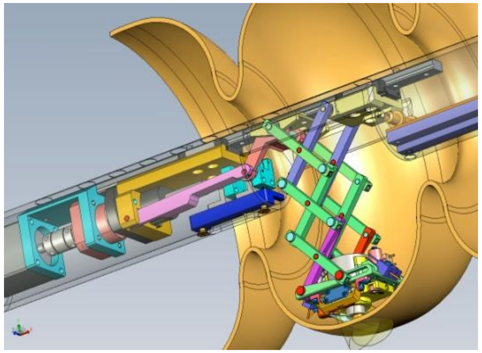


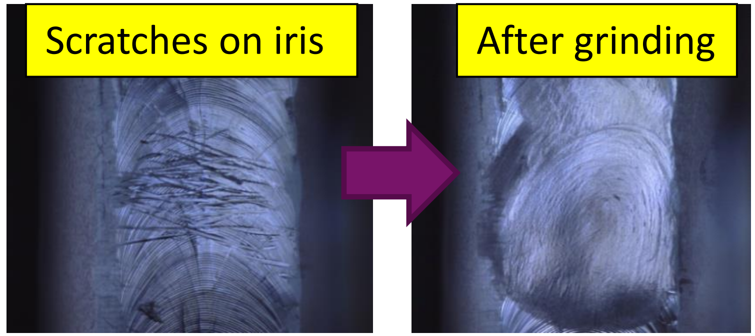
*2d pass = Re-EP or Re-HPR

From ILC TDR report

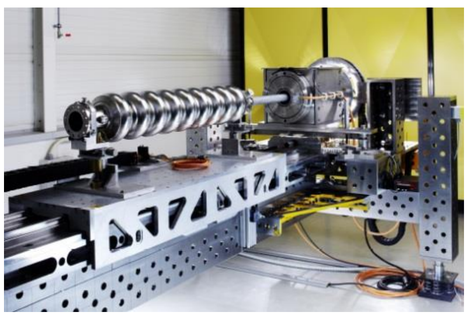
- 75% (±11%) above 35MV/m and 94% (±6%) above 28MV/m in 2010-2012.
- development of repairing techniques, inspection of cavities, etc.

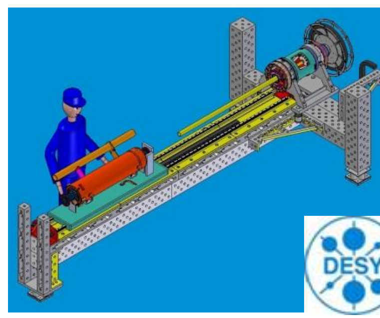
TECHNICAL DEVELOPMENTS DURING S0 PROGRAM





Repairing technique:
Local grinding





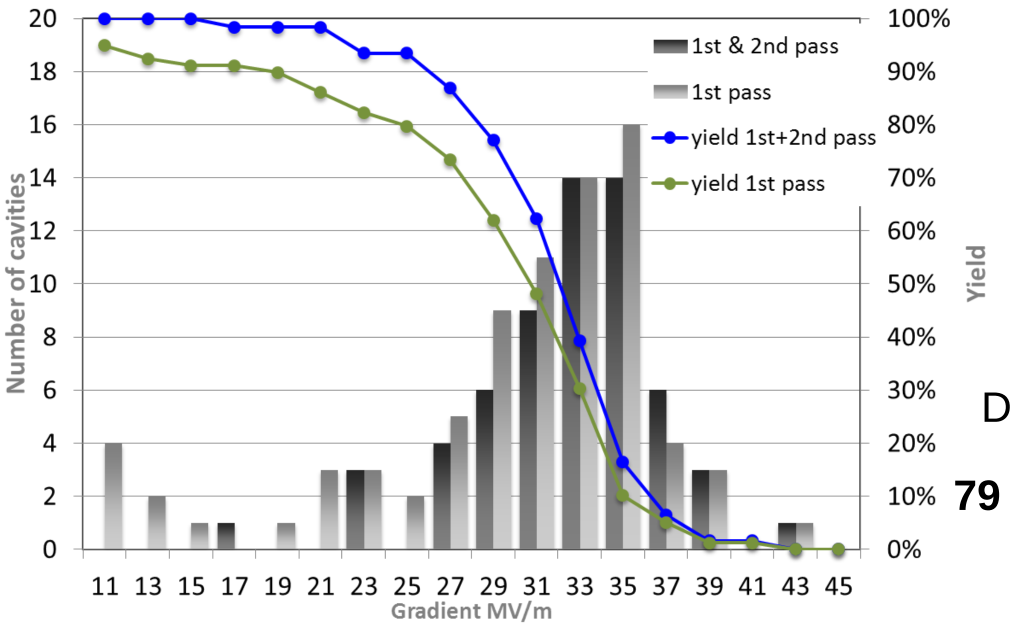
Improved inspection techniques: OBACHT (Desy) and Kyoto Camera (Kyoto U./KEK)

Temperature mapping systems, measurements by 2^d sound, etc.

OBJECTIVE OF THE R&D (II)

Transfer of the technology to industry for large scale production.

Paramount importance of the cavity production for the XFEL linac:
- Similar cavity vs. ILC
- Similar treatment recipe
- Large scale production (800 cavities, ILC/20)



D. Reschke, THIA01, SRF 2013

79 cavities received from 2 vendors (RI, Zanon)

Average maximum gradient: (30.9 ± 4.9) MV/m after 2d pass.

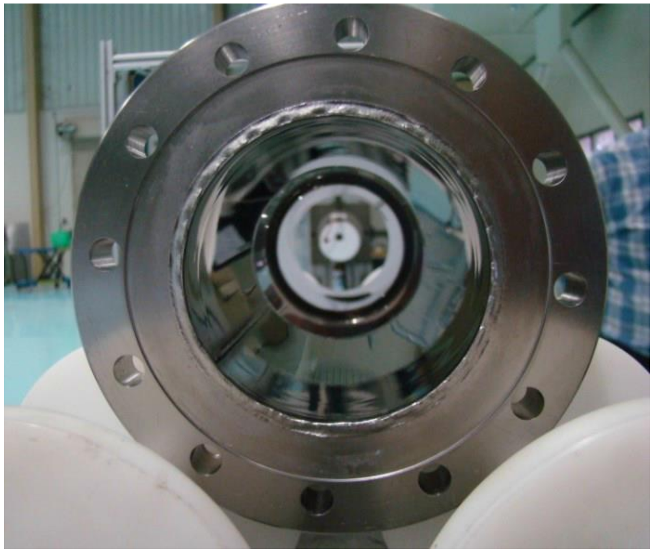
OBJECTIVE OF THE R&D (III)

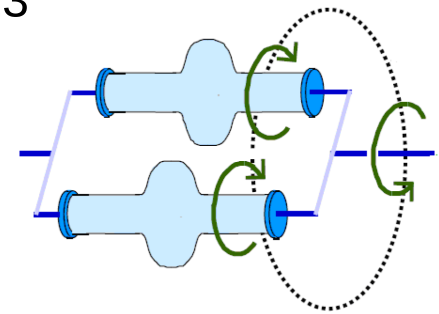
- Develop simpler process
- Develop safer process (HF-free recipe)
- Improve Q_0

R&D for Safer Processes

CAVITY TUMBLING (I)
AKA 'CENTRIFUGAL BARREL POLISHING' CBP

A.D. Palczewski, TUIOB01,SRF 2013



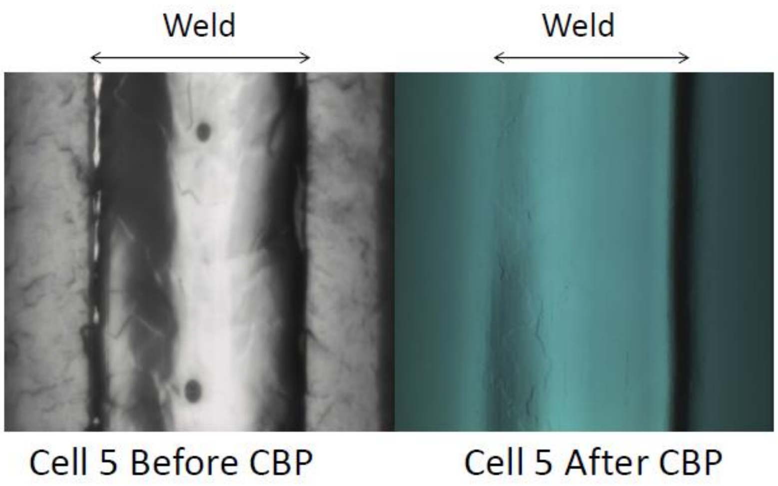


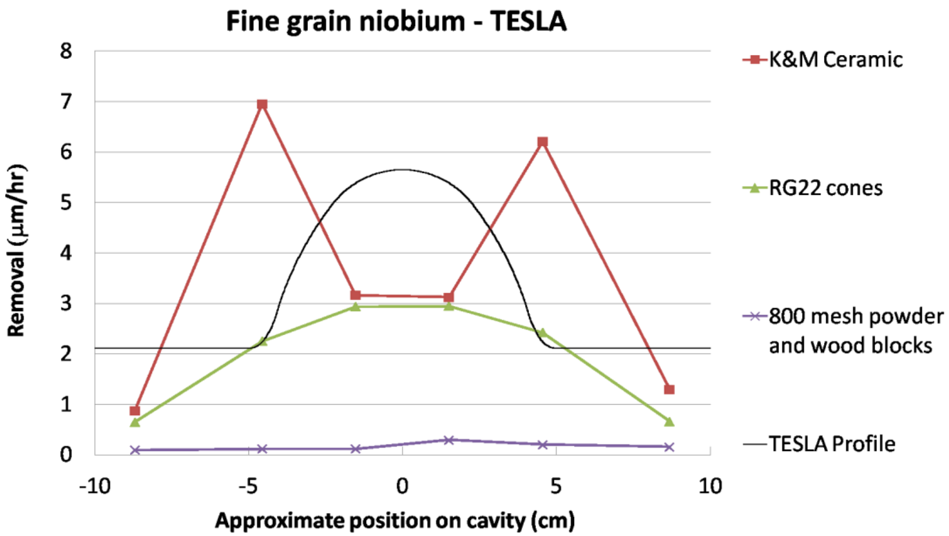
1-cell CBP at RRCAT

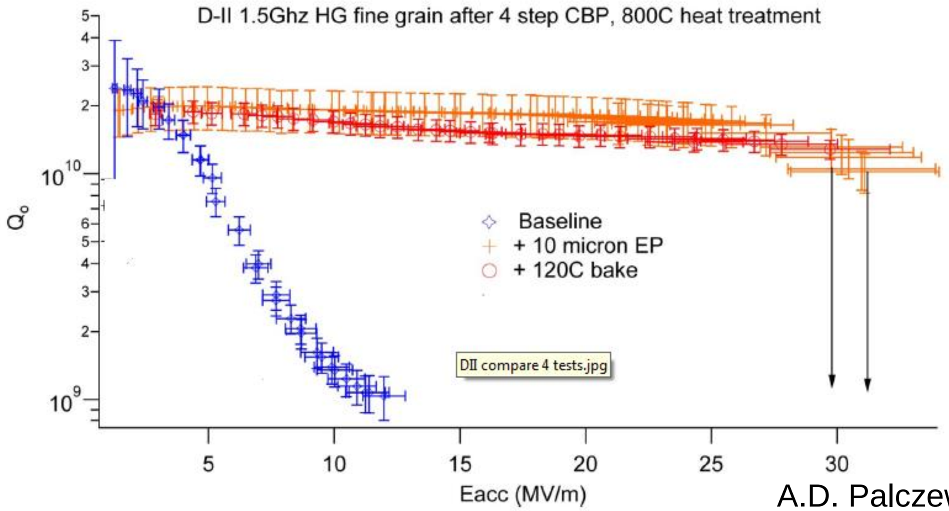
9 mm stone

Decreasing abrasive size

- The cavity is mechanically polished
- It is filled with abrasive components and rotated
- Different steps are necessary with decrease in abrasive size
- Mirror-like final surface finishing
- Developped at FNAL, JLAB, KEK, RRCAT, DESY, INFN





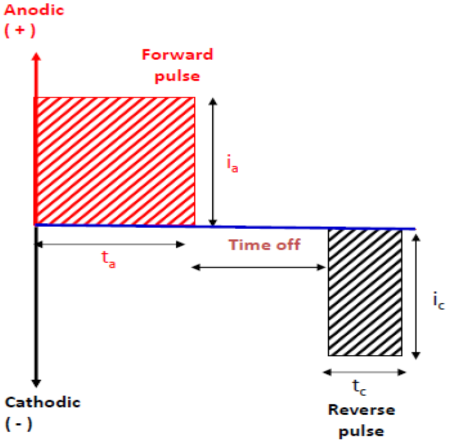


- Promising results on cavity
- Smooth surface
- Repairing technique

- Low removal rate
- Multi-step process

A.D. Palczewski et al., IPAC2012,WEPPC094

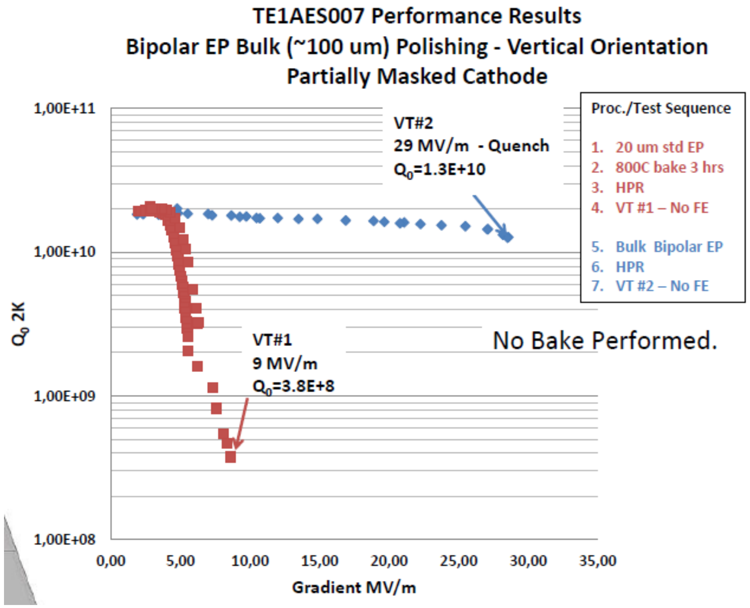
HF-FREE RECIPE:BI-POLAR ELECTROPOLISHING

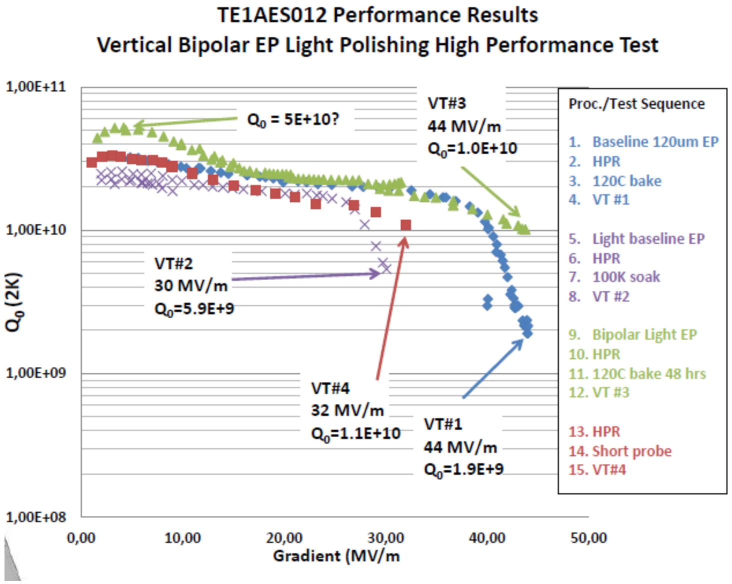


Fermilab

A. Rowe, SRF 2013, TUIOC02

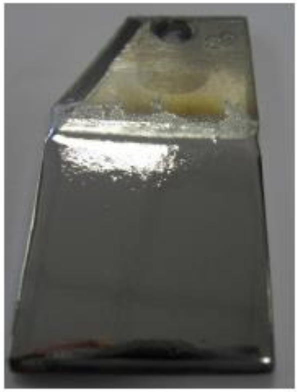
- EP in diluted H_2SO_4 electrolyte
- Non-constant voltage: reverse pulse for de-passivation
- Collaboration FERMILAB-Faraday Technology INC.
- Promising results on cavities but low removal rate: 1.5µm/hr





HF-FREE RECIPE: EP WITH IONIC LIQUID @ INFN

Choline Chloride : Urea	1 : 4
Sulfamic acid, g/l	97
Material cathode	Nb
Temperature,°C	Higher then 120
Current density, A/cm²	0,3



V.B. Pastushenko, SRF 2013, TUIOC03

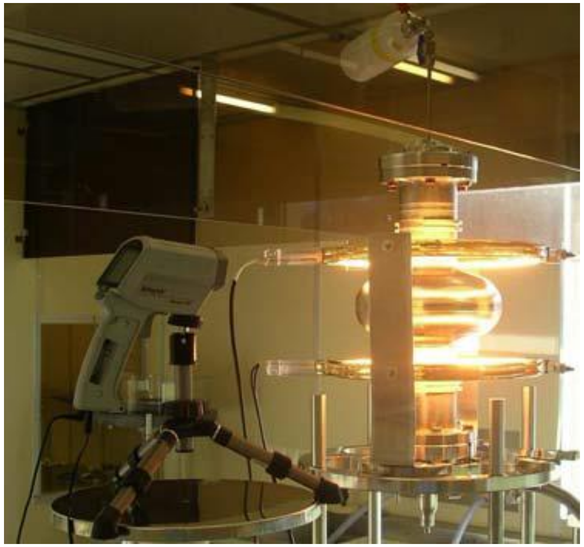
6GHz cavity after treatment in vertical position

6GHz half-cavity after treatment in horizontal position

- The recipe has been optimized for samples
- Improvements for cavity treatment
- High temperature treatment

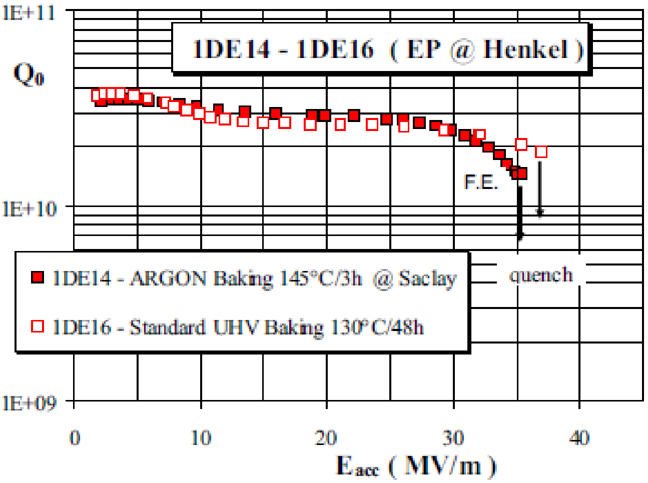
Decreasing Processing Time

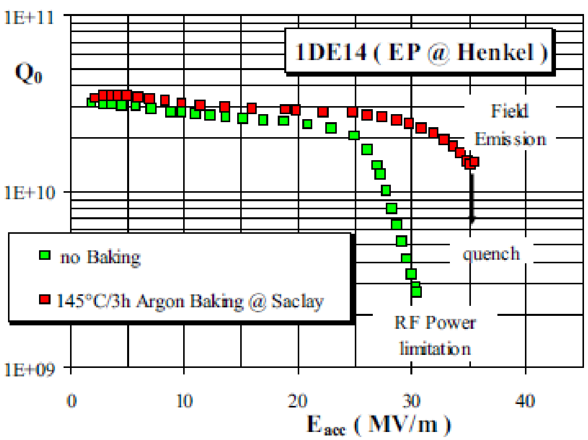
REDUCTION OF BAKING TIME



Fast Baking technique developped at CEA Saclay:

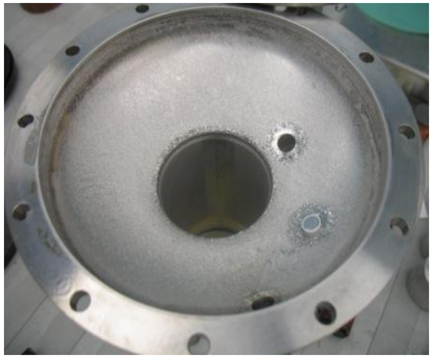
Baking under Argon at higher T: 3h baking.

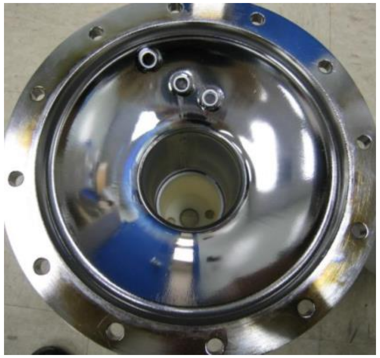




B. Visentin, SRF 2007, TUP69, pp. 304-307

ALTERNATIVE ELECTROLYTE





Buffered EP developped at J-Lab and PKU:

- Mixture of Lactic-HF-Sulfuric acids
- Very low roughness achieved
- Very high removal rate: up to 10 µm/min

Cathodes tested at J-Lab during BEP studies

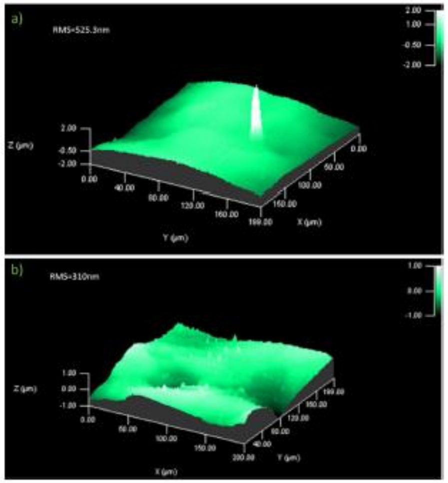


Fig. 18. Typical Profilometer images of the surfaces of the button samples from the demountable cavity treated by EP process with a scanned area of (200 × 200) µm². (a) Sample 1 and (b) sample 3.

EP

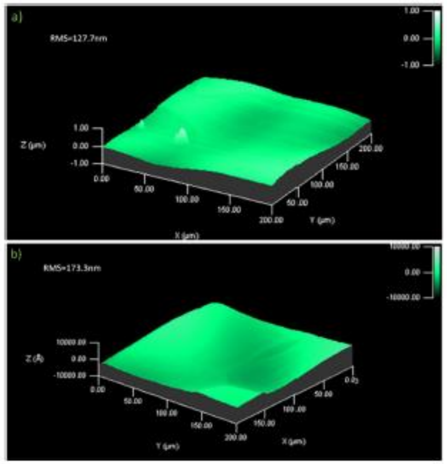


Fig. 19. Typical Profilometer images of the surfaces of the button samples from the demountable cavity treated by BEP process with a scanned area of (200 × 200) µm². (a) Sample 1 and (b) sample 3.

BEP

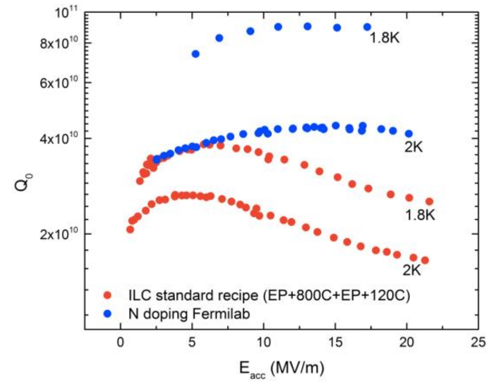
S. Jin et al. / Applied Surface Science 280 (2013) 93–103

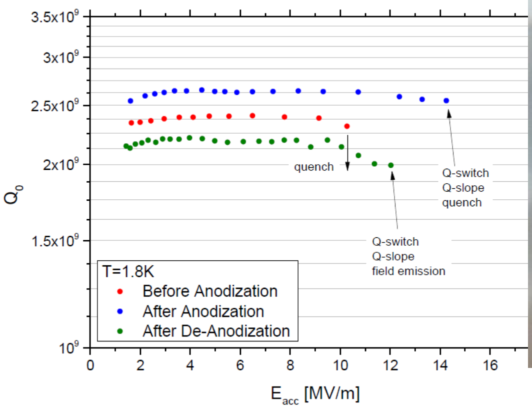
High Q_0 Research

SEEK FOR HIGHER Q0 (SEE SRF 2013)

- Doping with impurities as N

A. Grasselino, TUIOA03



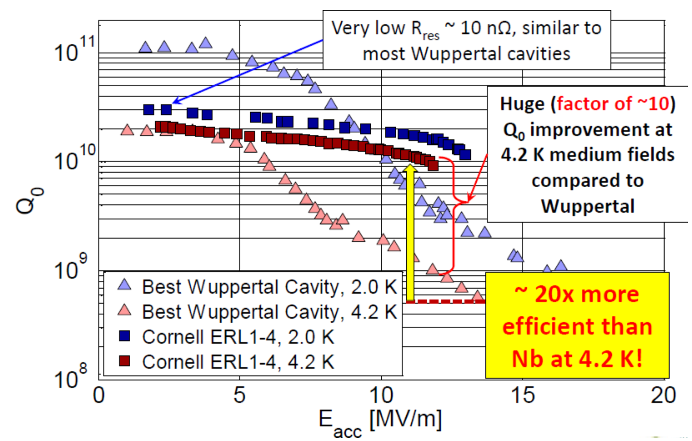


Treatment of external surface of the cavity

V. Palmieri, MOIOCO1

- Optimization of cooling

J.M. Vogt, TUIOA02



- Deposition techniques: Nb3Sn

M. Lieppe, S. Posen, WEIOA04

Vertical Electropolishing (VEP)

MAIN VEP FACILITIES IN THE WORLD

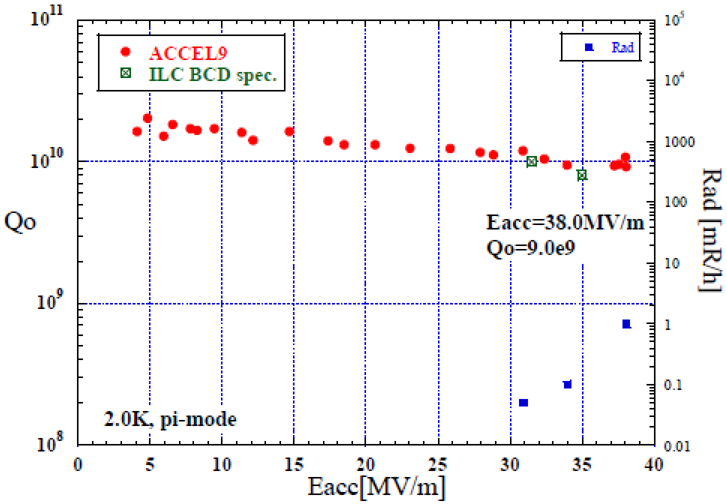
Cornell

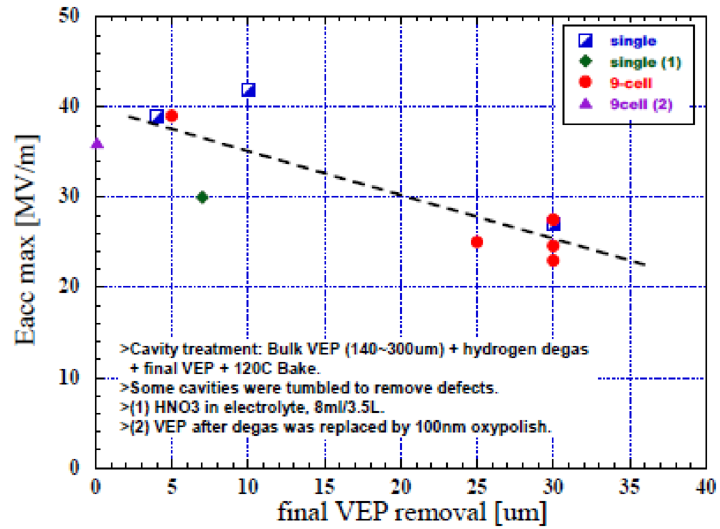
CEA/IRFU

CERN

F. Furuta, IPAC 2012, TUPPR045 & SRF 2013, TUIOC01
F. Eozenou et al. PRST-AB, 15, 083501 (2012) & SRF 2013, TUP046
S. Calatroni et al. LINAC 2010, THP032, pp 824-826 & SRF 2013, TUP047

VERTICAL ELECTROPOLISHING





F. Furuta, IPAC 2012, TUPPR045

- High gradient demonstrated at Cornell but:
- Final VEP removal should be thin to avoid decrease in Eacc

→ Proposal at CEA Saclay IRFU for a set-up with circulating acid

HORIZONTAL VS VERTICAL

Pros:

- Good evacuation of gases (cavity half filled)
- Demonstrated efficiency
- Large range of parameters

Cons:

- Complicated process
- Rotary seals
- Switching of the cavity
- Low removal rate

Pros:

- Simple process
- Low floor surface
- Improved safety
- Higher removal rate

Cons:

- Sensitive to fluid dynamics
- Proper parameters to be determined…

…Voltage and fluid velocity

HIGH GRADIENT ACTIVITIES IN FRANCE

JAPAN-FRANCE TYL COLLABORATION (PREVIOUSLY LIA) 2007-…

FRANCE-JAPAN PARTICLE PHYSICS
TOSHIKO YUASA LAB.

- Previous collaboration within A_RD_5 program: Surface treatment
- New equipments at KEK & Irfu
- Extension of our expertise from cavity fabrication to Vertical Test
- Involvement of industrial partners

→ A_RD_9: Effort towards improving large scale production of SC cavities

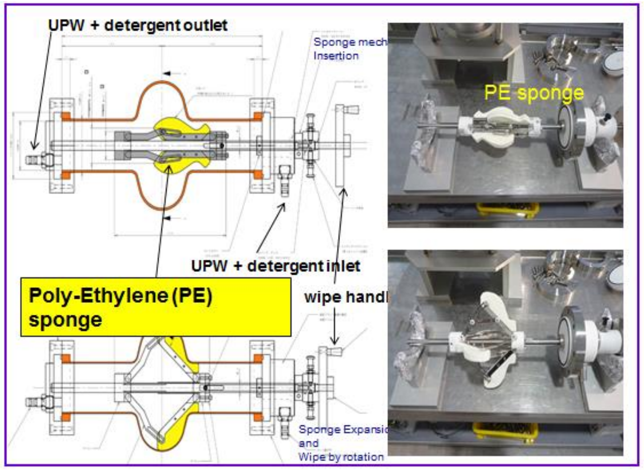
Collaboration KEK – CEA and industrial partner: Marui Galvanizing Co. Ltd.

Since 2012, additionnal collaboration KEK-IRFU: A_RD_7:

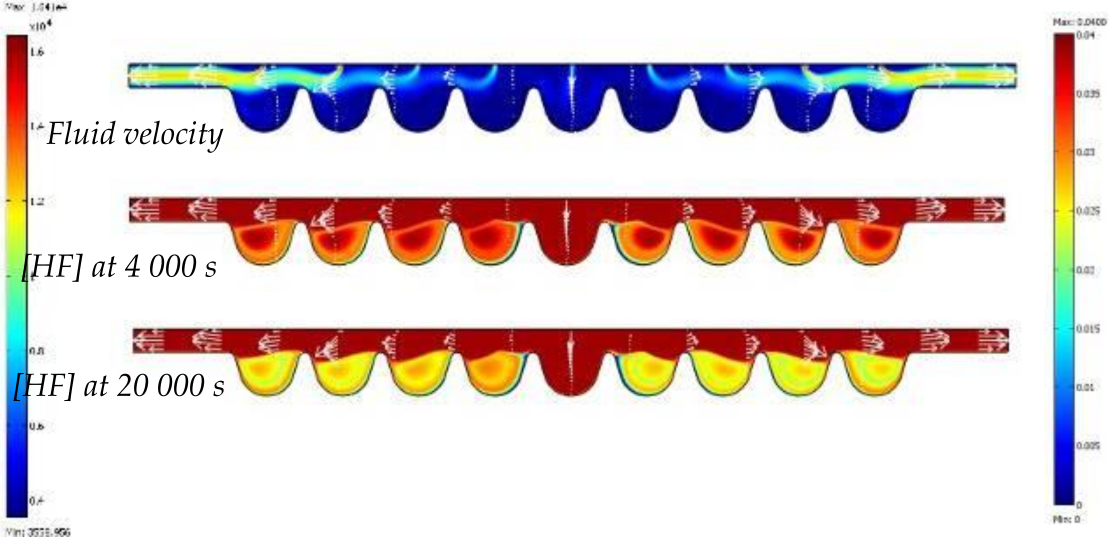
Study on the magnetic sghielding for SC cavities (M. Mazusawa, J. Plouin)

ACHIEVEMENTS WITHIN A_RD_5 (I)

- Improvement of cleaning recipes, ie:
  - Sponge cleaning technique
  - Improvement of rinsing after EP



- Modelling of EP, understanding of field flatness deterioration after EP



Modelling with COMSOL:
- Fluid dynamic
- Acid concentration

EP should be considered as an asymetric process

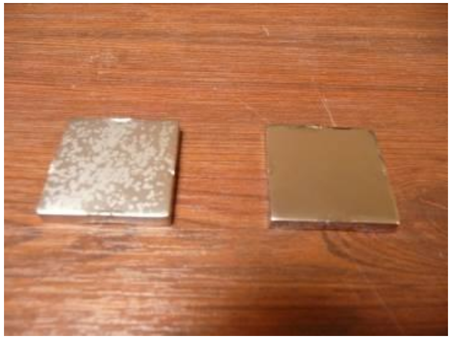
ACHIEVEMENTS WITHIN A_RD_5 (II)

- Study of contamination related to chemical treatments: high voltage and high current EP are likely to generate sulfur compounds

Sample A, 20 Volts:

9.18g removed

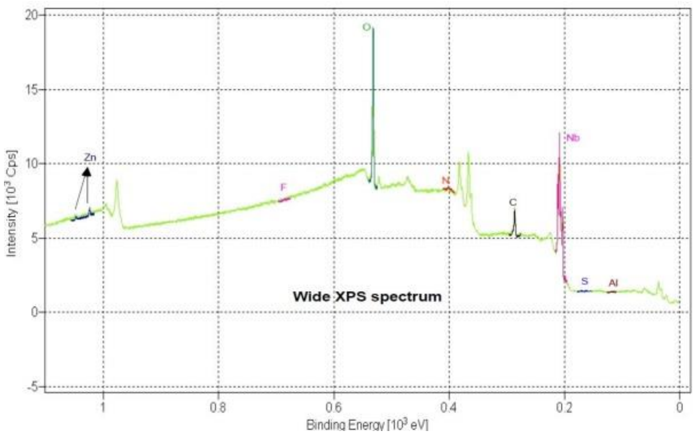
51 hours EP



Sample B, 5 Volts:

9.11g removed

115 hours EP



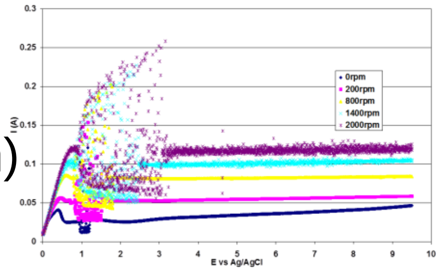
Example of XPS Analysis at KEK

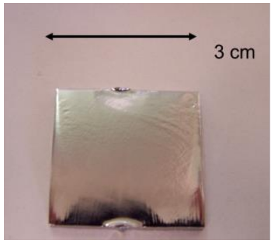
- Succesful evaluation of repairing technique such as grinding

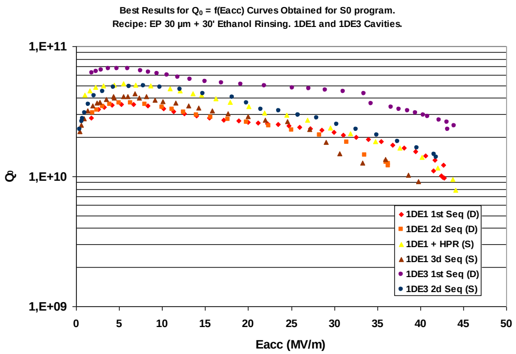
ELECTROPOLISHING AT IRFU: 2004-2013

EP on samples (CARE program): 2004-…

- Parameters optimization
- Understanding of the process (F^- diffusion)
- Study of the aging of electrolytes
- Sulfur contamination







1-Cell Horizontal EP: 2006-2009

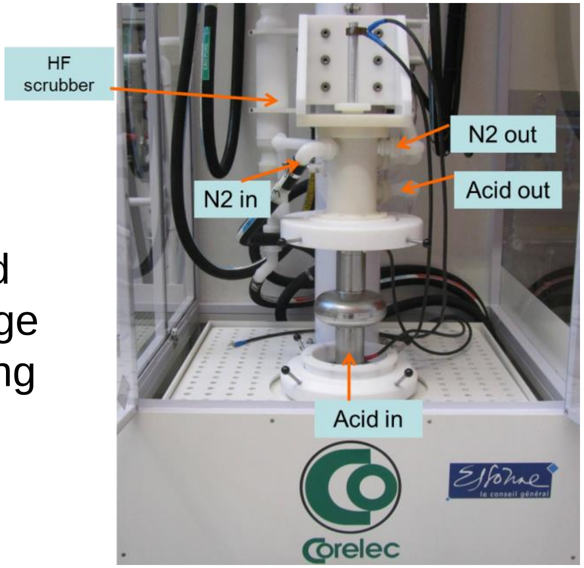
- Achievement of high gradients
- Alternative recipe tested
- Achievement of high Q_0
- Low voltage EP

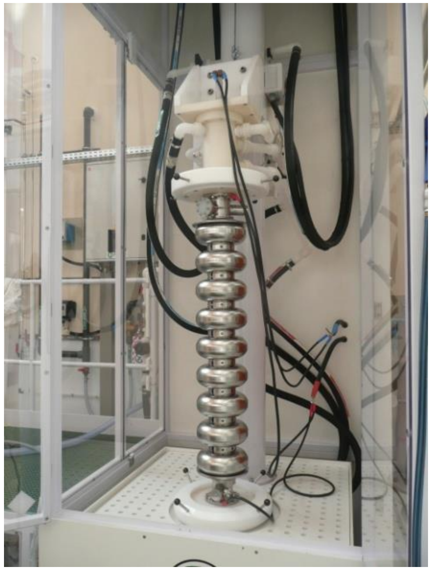
Design of a new VEP system: 2009-…

- Operating since 2011
- Optimization on 1-Cell cavities
- Operation with ILC and SPL cavities

VEP AT CEA SACLAY

- Circulating acid
- Constant voltage
- Nitrogen blowing





Fermilab
TB9RI025 cavity
Prior to VEP

- VEP of 1-Cell and 9-Cell cavities
- Focus on parameters: low voltage (~ 6V) – high acid flow (25L/min)
  - Improved degassing (H_2 , O_2)
  - Lower heating
- Four 1-Cell cavities and one 9-cell cavity prepared by VEP

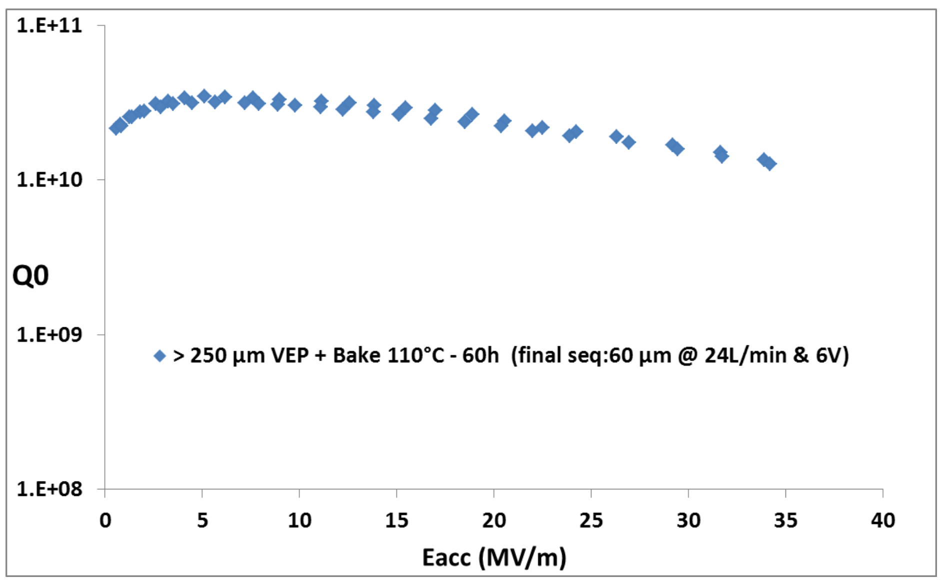
LOW VOLTAGE VEP: 1ST RESULT

VEP of cavity with low surface quality (pits)

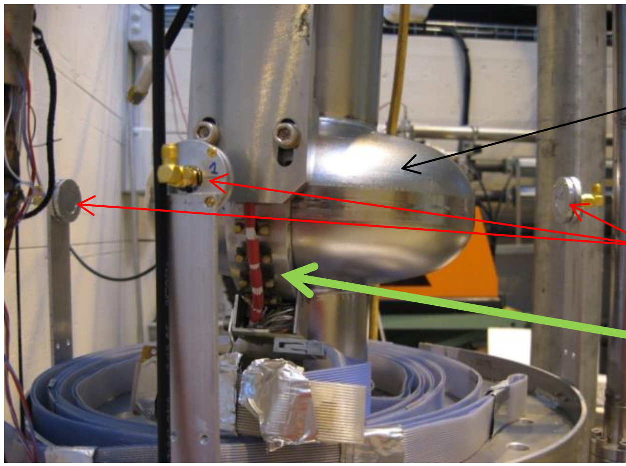
- ❖ Better surface achieved
- ❖ Pits partially removed
- ❖ In spite of pits, the cavity is tested

→ Quench at 34MV/m at the pit area

(Standard Q-Slope before baking)



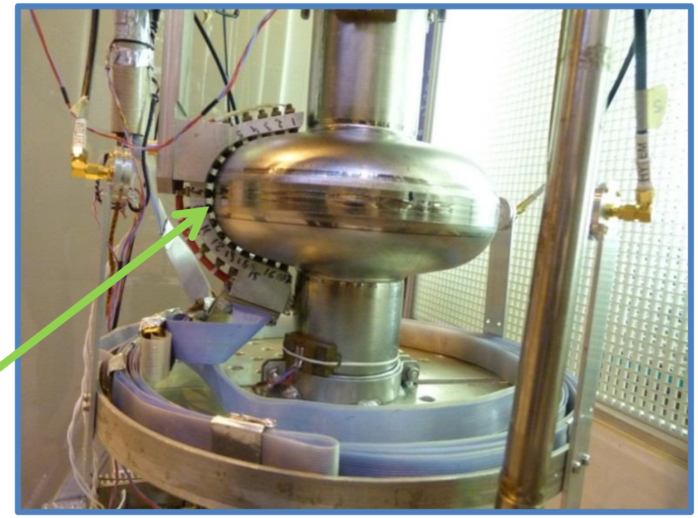
VEP EXPERIMENTS COMBINED WITH RESEARCH OF QUENCH BY 2D SOUND



Monocell cavity 1,3 GHz

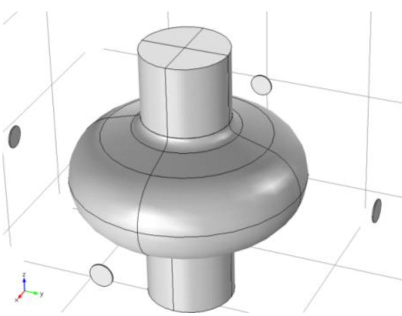
OSTs

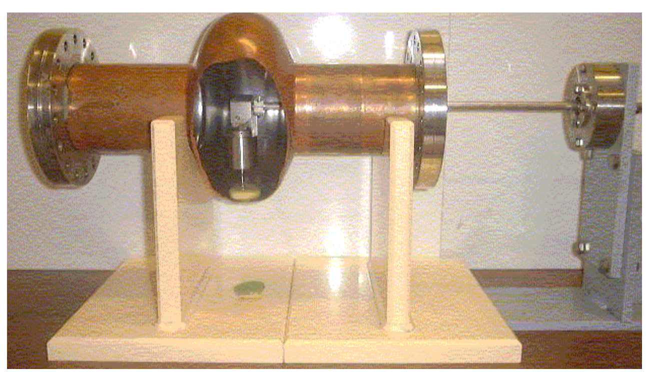
Temperature mapping



4 OSTs are placed around the cavity, in the equator plane

Presented by J. Plouin at TTC 2012, JLab.





→ Study of the quench morphology by replica technique.

S. Berry et al.
SRF 2003, THP04, 591-595

→ Quench located at the pit area

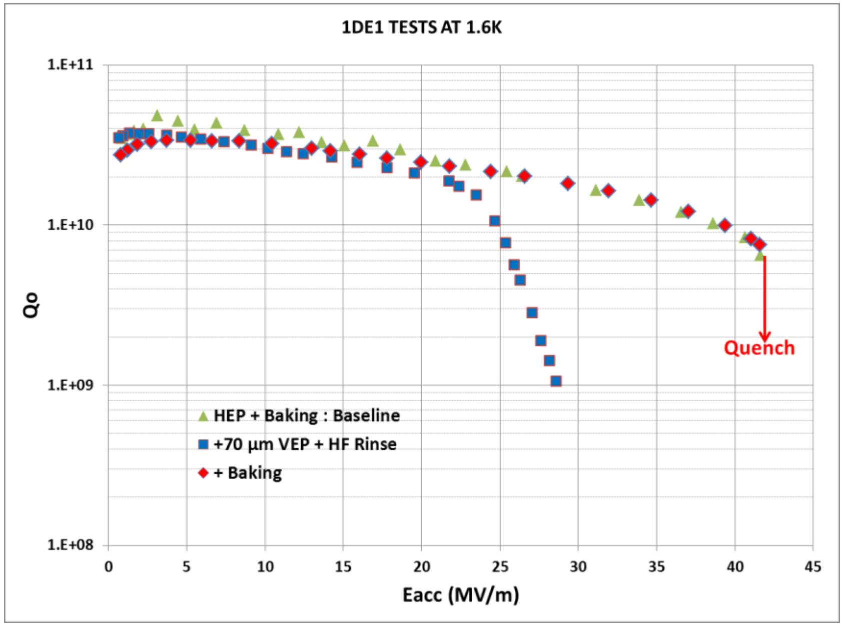
Eacc > 41 MV/m on 1Cell Cavity with Parameters:

Low Voltage – High Acid Flow

1DE1: Horizontal EP + 70 µm VEP

- Parameters: 6V & >24L/min
- Bright and smooth surface

- Performance before/after baking similar to HEP
- High gradient maintained after VEP



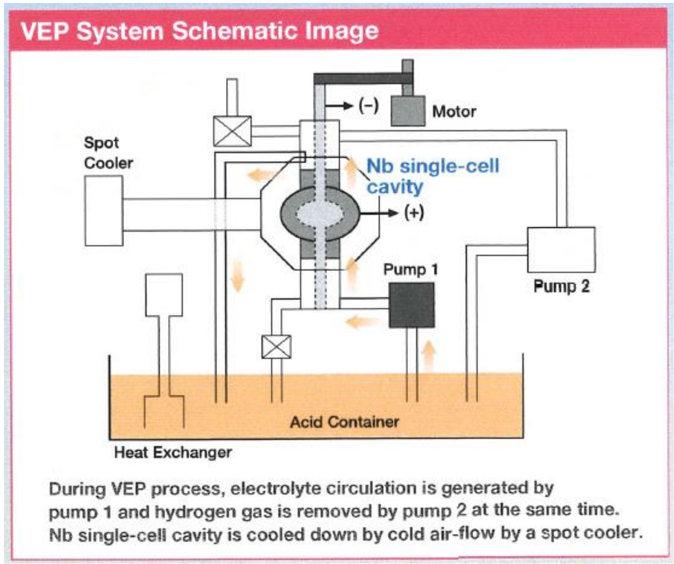
1DE1 after HEP + 70 µm VEP

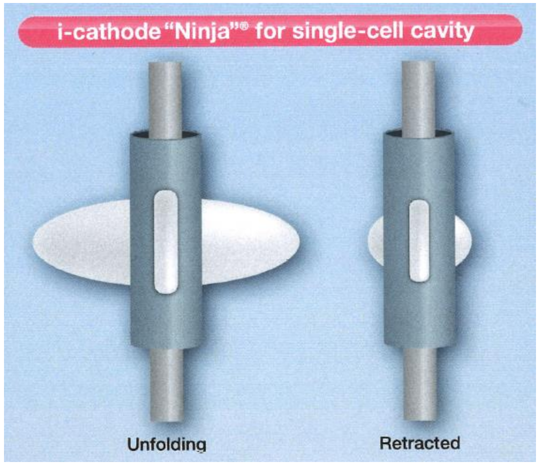
Aspects to improve:

- Low removal rate at 19°C: 0.2µm/min
- asymmetry: removal rate higher in the upper part of the cell (x 3)

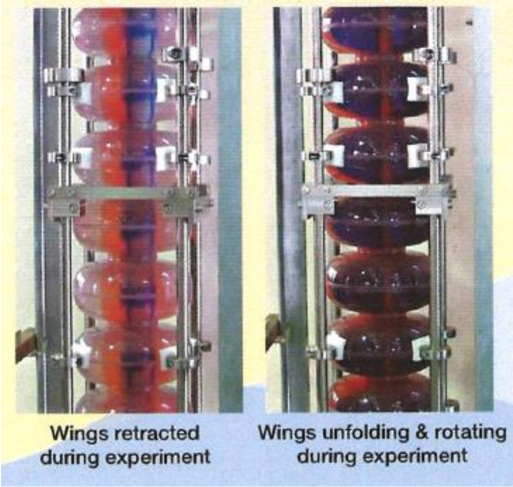
TECHNICAL PROPOSAL BY MARUI CO LTD

Use of a cathode with a specific shape: i-Ninja® cathode





SRF 2013, TUP052

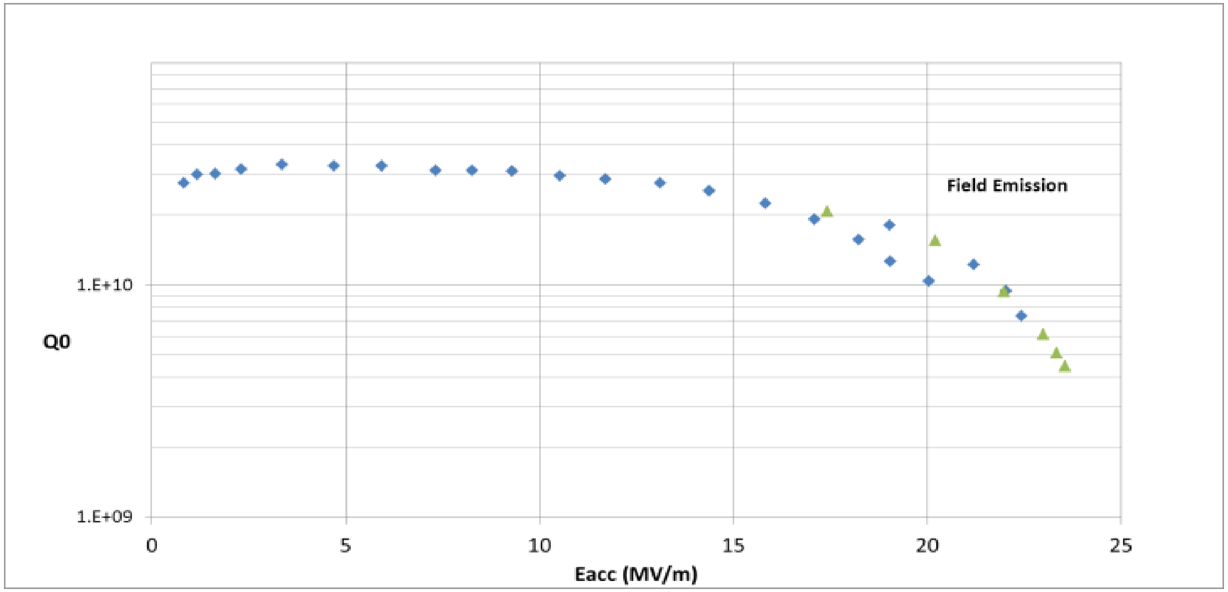


Improved fluid distribution with unfolded cathode.

- Rotating Cathode with retractable wings
- Uniform anode-cathode distance
- Better hydrogen removal

1-Cell cavity exchange programm within TYL.

RESULTS ON 9-CELL ILC CAVITY AT IRFU



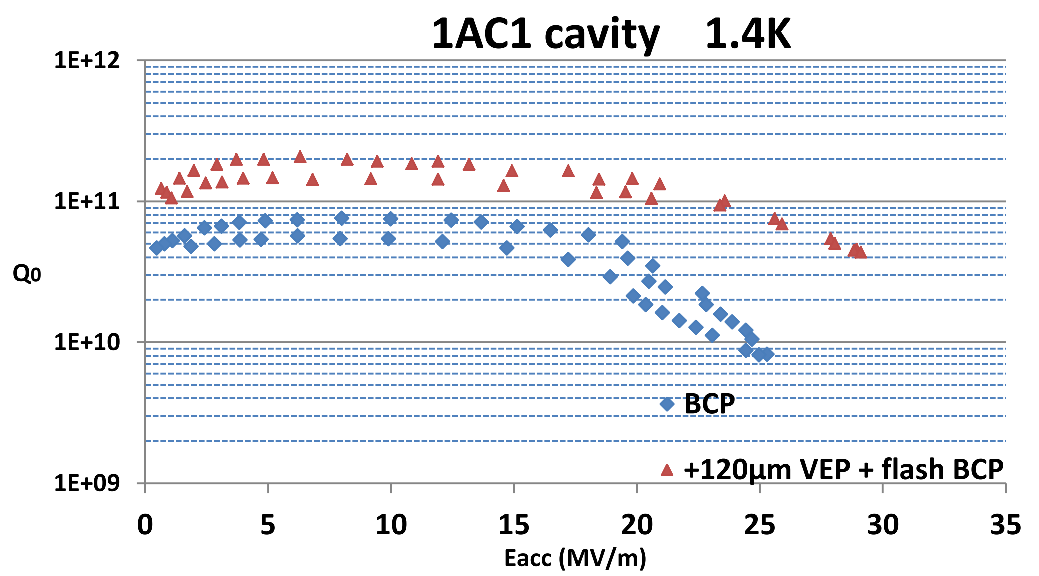
RF results for ILC TB9R1025 cavity at 1.6 - 1.9K after HEP + 50µm VEP at 6V.
Fermilab

- Results limited by field emission
- New cleanroom in construction will make possible a better assembly of the cavity

OUTLOOK

- Recent result: Q_0 2^E11 after VEP on 1-Cell cavity (without baking)

→ Experiments on 1-Cell cavities to be continued



- Full treatment of 9-Cell cavities from ilc higrade

CONCLUSION

- Technical maturity: Results close to ultimate performance

- Improvement of the yield during ILC TDP phase

- Technology succesfully applied in XFEL project

- R&D is going on

    - Simpler process
    - Cost reduction
    - Safer process
    - Higher Qo

- Vertical Electropolishing developed at CEA/IRFU

THANK YOU FOR YOUR ATTENTION