SRF ACTIVITIES AT CEA SACLAY

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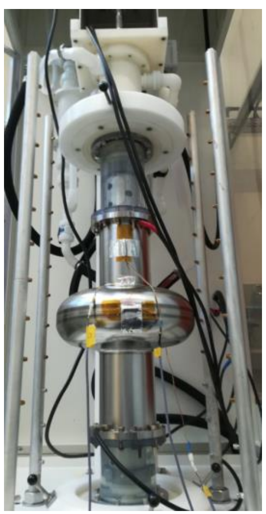
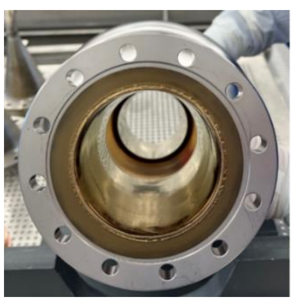
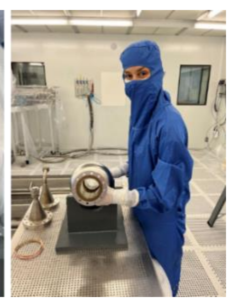
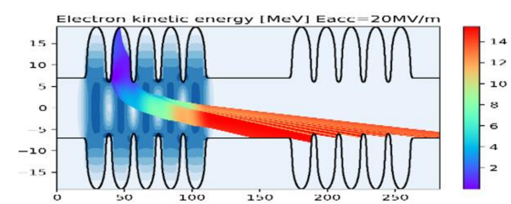
LCWS23, Accelerator: Superconducting RF
May 16th 2023



GOAL & OUTLINE

Continued effort for the improvement of SRF Cavities:

- Bulk Niobium: Vertical Electropolishing to reach ultimate performance
- Beyond Niobium: Multilayer superconducting structures for improvement of Q0 & Eacc
- Maintaining of the surface quality through the process: Cleanroom cleaning & assembly with a cobot
- Analysis of the tests: Diagnostics

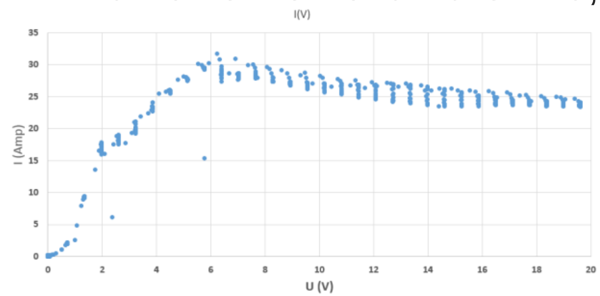
1. VERTICAL ELECTROPOLISHING

F. EOZENOU, E. CENNI

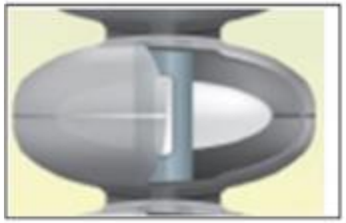
Vertical EP process at Saclay

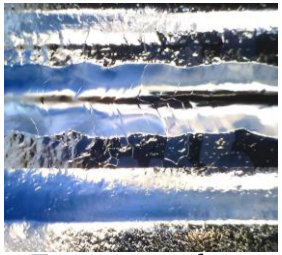
- VEP with rotating Ninja cathode
- External cooling of the cavity
- Better removal of H2
- Symetric removal
- But lower removal rate: ~ 0,1 µm/min

1-Cell cavity on VEP set-up

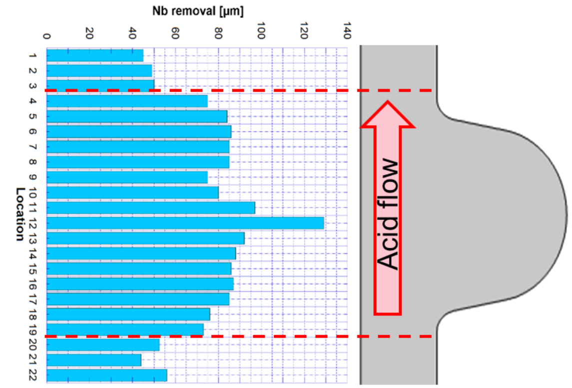


Standard diffusion 'plateau' on I(V) curve





Equator surface
(80µm average removal)



Nb removal along the cell

ROTATING TECHNOLOGY
'Ninja' Cathode by Marui Galvanizing company

Vertical EP Parameters (704MHz Case)

Treatments Parameters	Value
Acid temperature (in tank)	15 °C
External cool down water	12 °C
Acid flowrate	15-20 L/min
Voltage	19-20 V
Current	25 A
Removal rate	0.1 µm/min
Electrolyte	HF-H_2SO_4
HF acid mass concentration	0.5%
Ethanol rinsing (static)	60 h
Ninja Cathode Parameters	**Value**
Number of wings	4
Al cylinder diameter	70 mm
Cathode rotation speed	20 rpm
PVC ext cylinder diameter	114 mm
Cathode/cavity surface ratio	0.2

Working Parameters:

- U: 20V (Max voltage available)
- Acid flowrate: >15L/min
- T<15°C
- External Cooling of cavity wall
- Low HF concentration
- 20rpm rotation

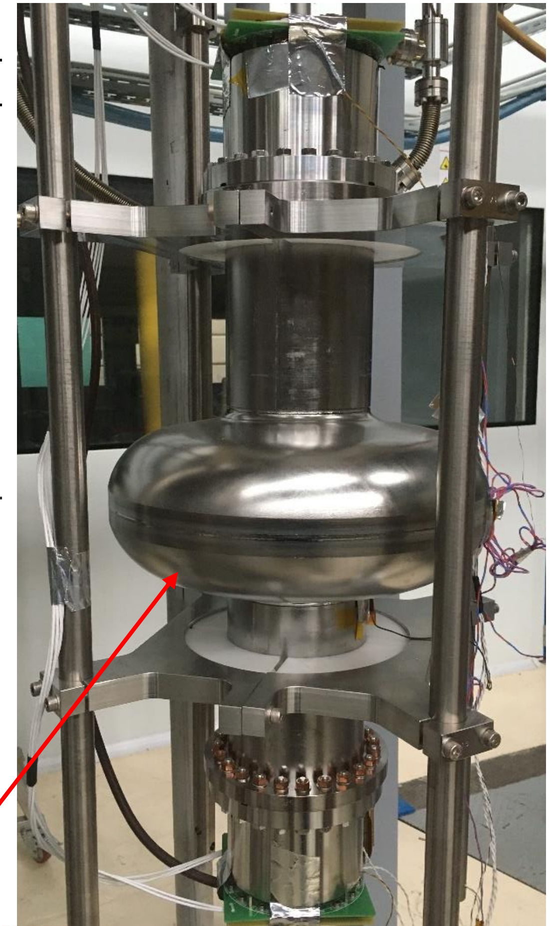
Strong sulfur odour after treatment.
→ Ethanol rinsing to avoid sulfur contamination

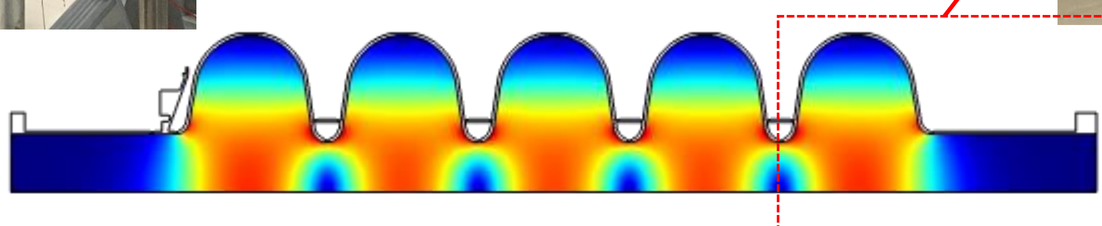
VEP Experiments with EH101 1C 704MHz cavity

Single cell cavity, geometry from ESS high beta (β=0.86) end cell

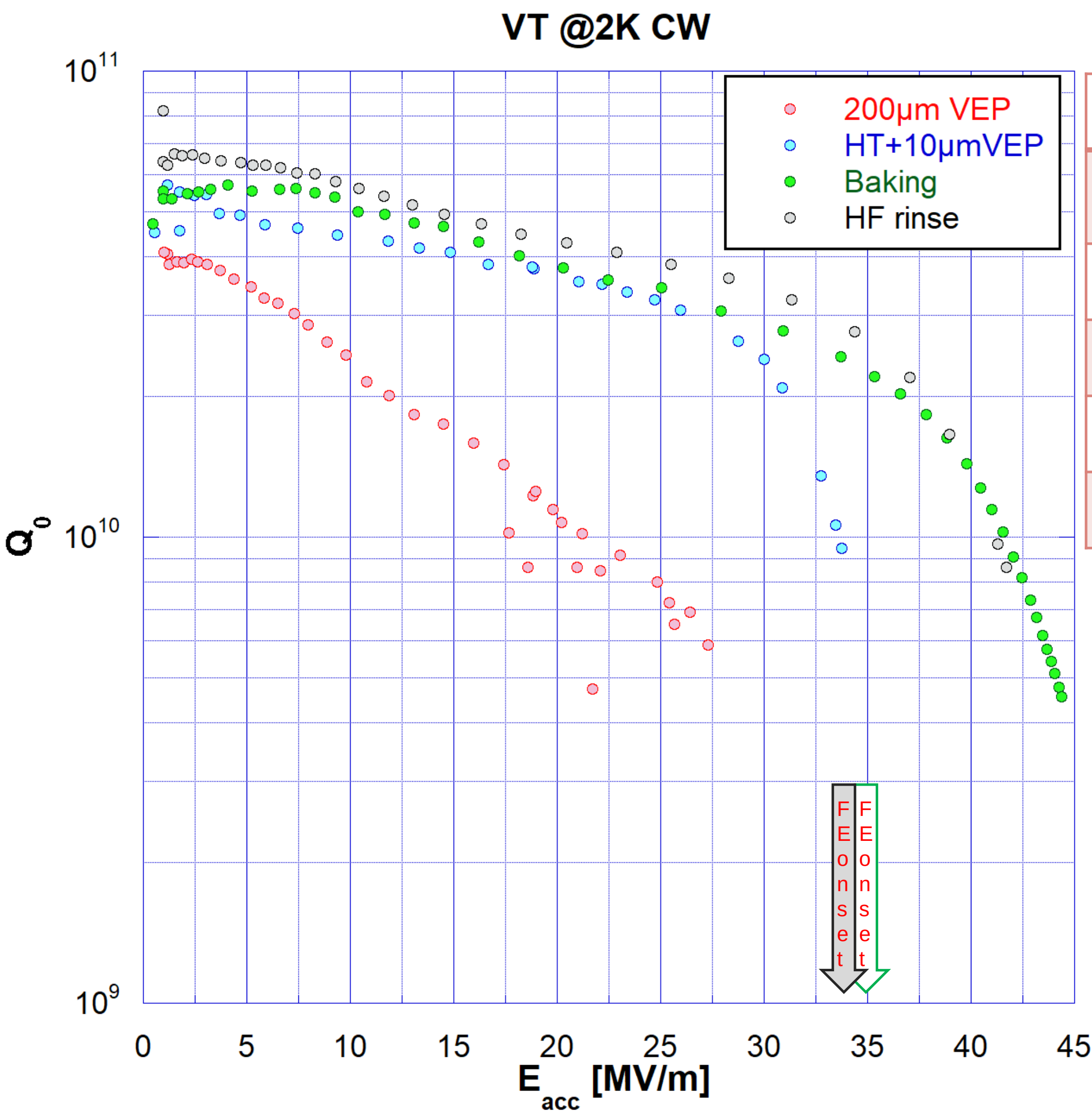
Design parameters	Value
G [Ω]	250
R/Q [Ω]	113
E_{pk}/E_{acc}	1.88
B_{pk}/E_{acc} [mT/(MV/m)]	3.86
Inner surface [m²]	0.55
Nb RRR	>300
Nb Supplier	Tokyo Denkai
Cavity manufacturer	Zanon R&I

Beam tube extension

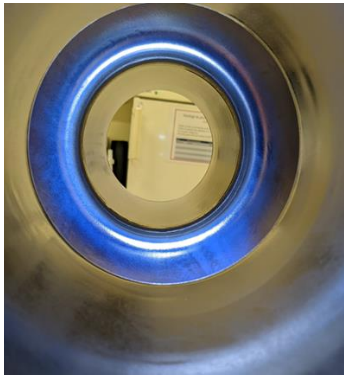




Vertical tests Results for EH101 1C 704MHz cavity

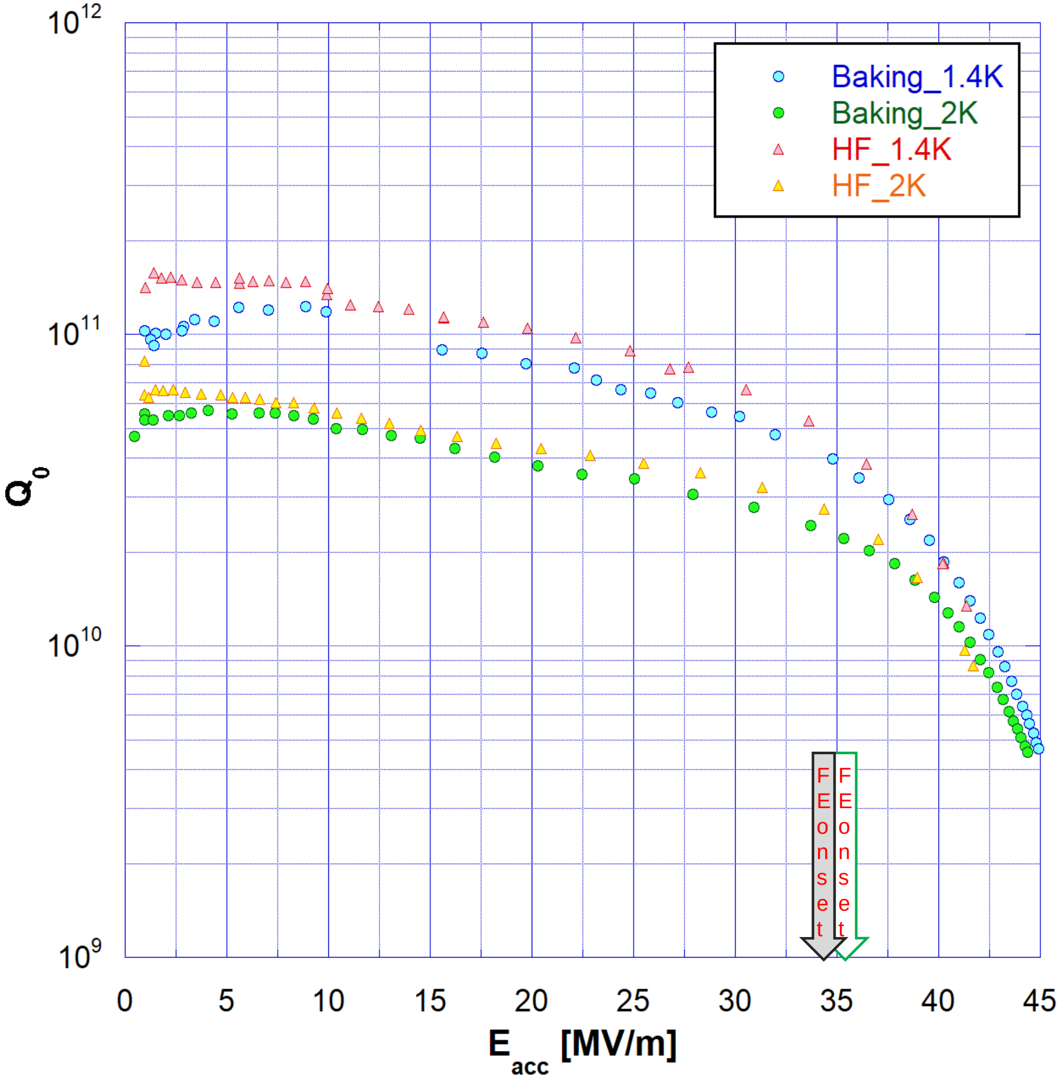


CW@2K				
VT#	Max E_{acc} [MV/m]	Max Q_0 [$/10^{10}$]	E_{acc} @10^{10} [MV/m]	Limit
1	27.3	4.09	20.2	Quench
2	33.8	5.7	33.5	Admin.
3	**44.4**	**5.7**	**41.5**	**Power**
4	41.7	6.4	41.3	Admin.



See also
- THPOGE23 @ LINAC 2022
- E. Cenni’s talk at TTC 2022

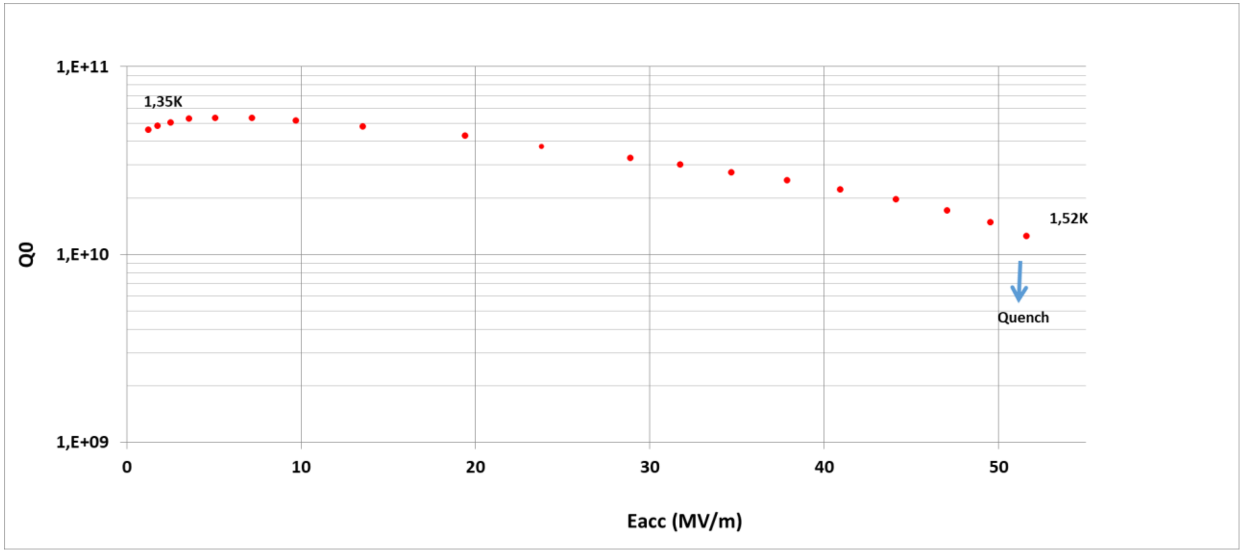
Results @ 1.4K CW



CW@1.4K			
VT#	Max E_{acc} [MV/m]	Max Q_0 [$/10^{10}$]	Q_0 Max field [$/10^{10}$]
Baking	**44.9**	**12.3**	**4.7**
HF rinse	41.4	15.7	1.34

1.3GHz 1C cavity:
Test of the ‘2-step Baking’ recipe at Saclay

- This baking recipe was successfully tested on 1AC3 1300MHz 1-cell cavity,

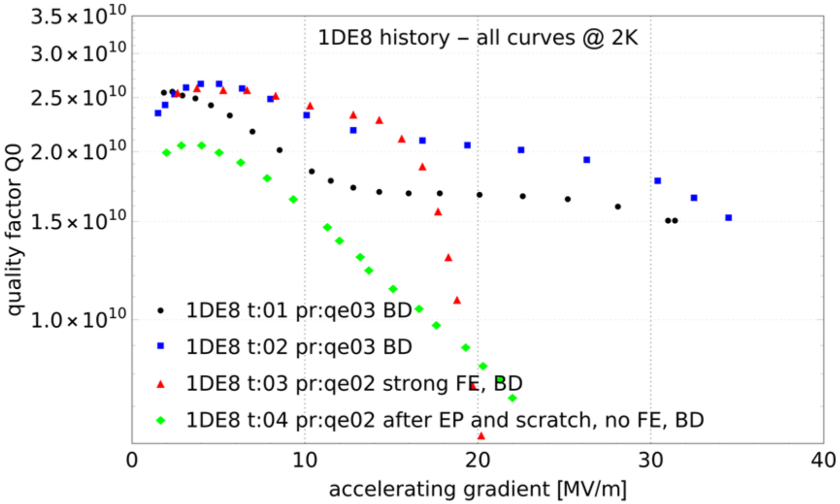


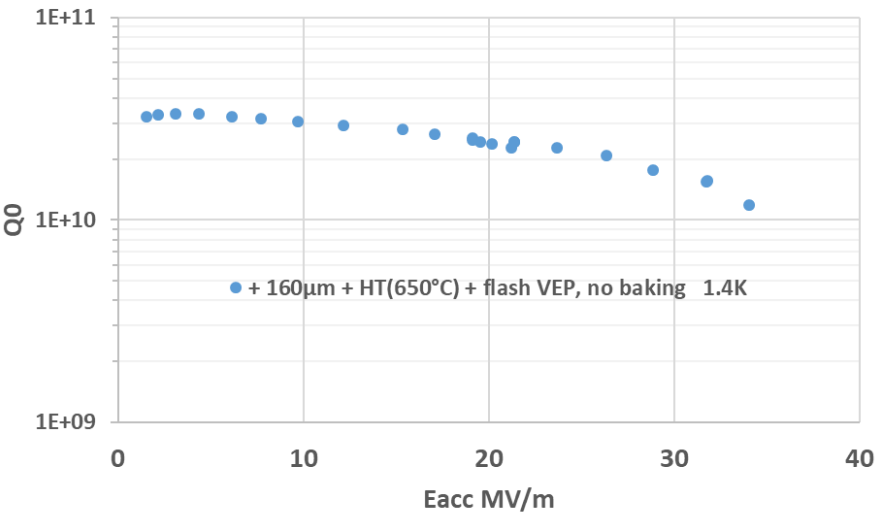
Excellent RF Peformance after VEP including ‘2-step baking’ (FERMILAB recipe)
at 75°C-120°C on Tesla 1300MHz single-cell cavity

See also

- THPOGE23 @ LINAC 2022

1.3GHz 1C cavity:
No High Field Q-Slope observed in some cases





1DE8 1-Cell TESLA: Loan from DESY
Limited performance due to scratches
→ bulk VEP to recover

No clear HFQS after VEP. Eacc=34MV/m
Field Emission due to residual scratches

OUTLOOK

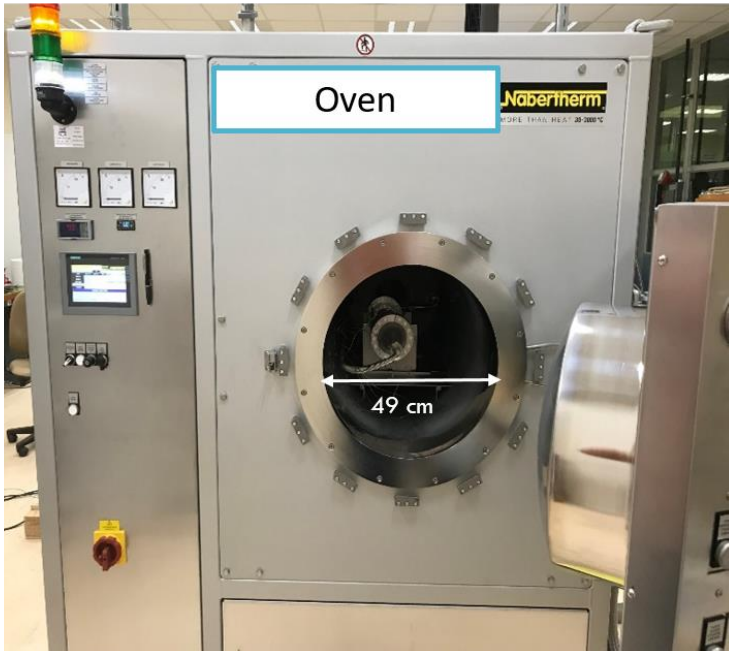
- Apply the 2 step baking recipe on EH101 704MHz cavity
- Transfer of the process to 5Cell 704MHz cavity
- Study of HF concentration on a dedicated 1300MHz pristine single cell cavity
- Study of the effect on HFQS

2. MULTILAYERS

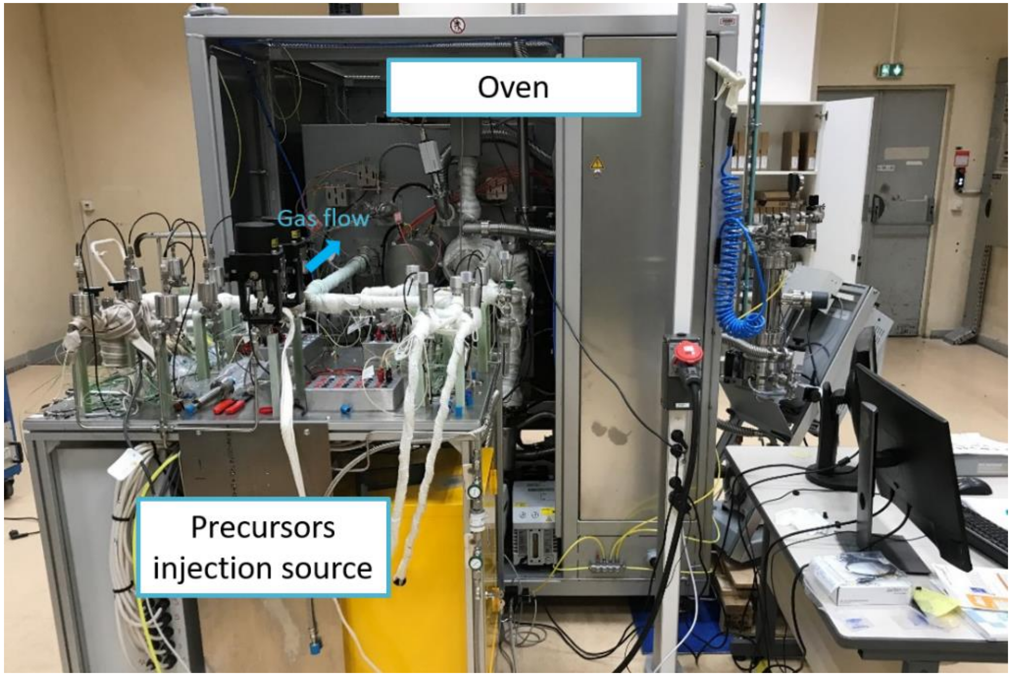
Y. KALBOUSSI, T. PROSLIER

Freshly-built ALD system for cavity coating at CEA

Front



Back

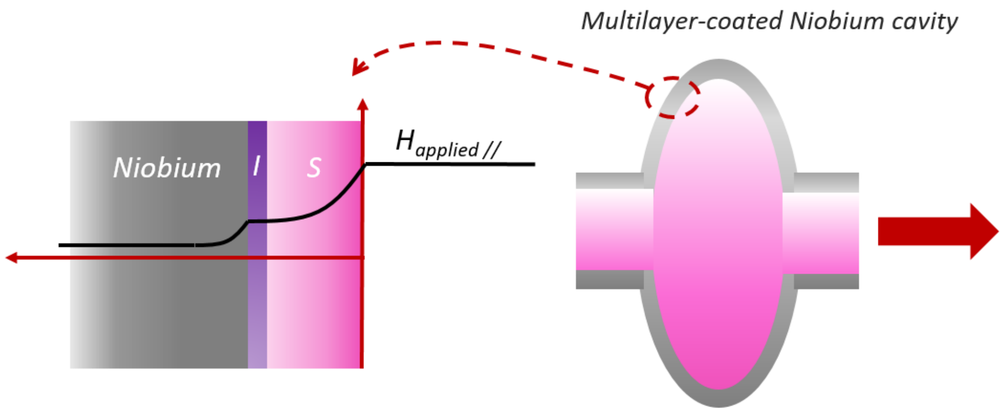


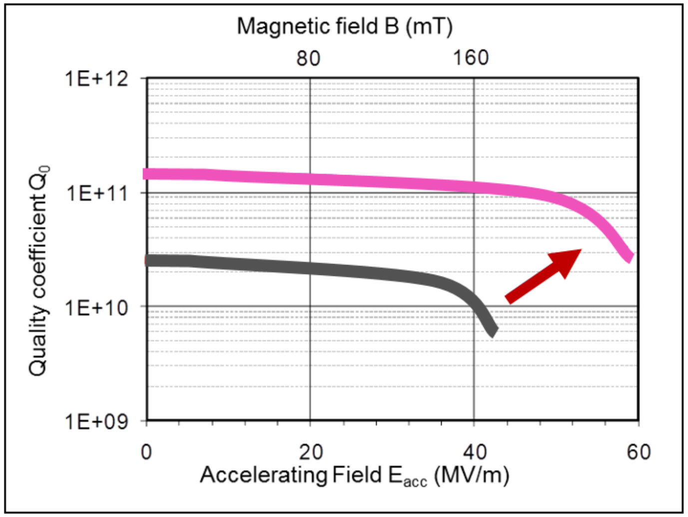
- High vacuum oven:
  - 650°C – 10^{-6} mbar / 900°C 1bar N_2
  - Volume retort: Φ = 49 cm, L= 110 cm (1.3, 0.7 GHz cavities)
- Interface and control:
  - Labview program of ALD system and Oven.
  - Automatic synthesis parameter control (overnight dep.) and monitoring.

Ongoing R&D activies

- Multilayer coating on Nb cavities
- Doping
- Multipacting mitigation

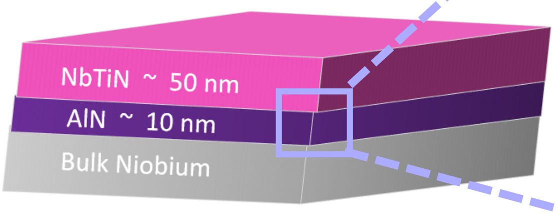
Multilayer structure





- A theoretical approach proposed by A. Gurevich (2006) to improve RF cavities through depositing a superconducting multilayer to screen the magnetic field.
- The thickness of the superconductor must be lower than its penetration depth.
- The superconducting layer must have higher T_c than Nb.

Multilayer structure by ALD

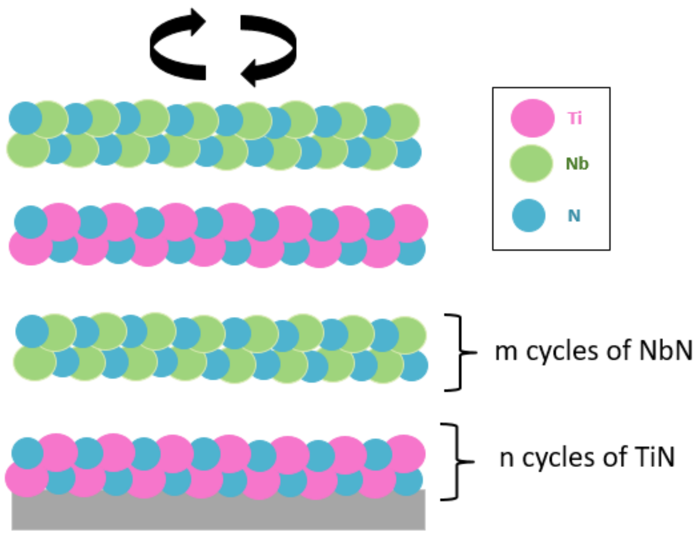


- NbTiN has good superconducting performances (T_c = 17 K) and a low resisitivity.
- AlN is a good dielectric layer and has a good chemical stability.

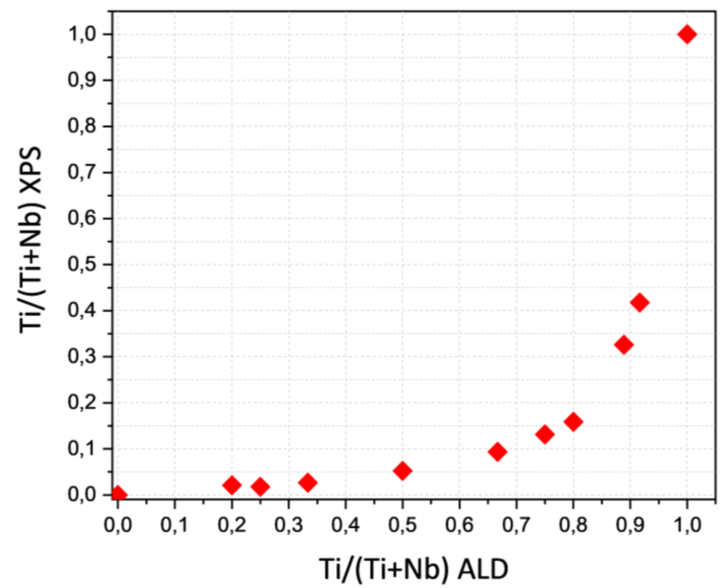
Chemistry: Thermal ALD @ 450°C + Annealing @ 900°C

- AlN was deposited using *$AlCl_3$* + NH_3
- NbTiN was deposited using a combinaison of TiN and NbN cycles

  $n\ (TiCl_4 + NH_3) + m\ (NbCl_5 + NH_3) = Nb_{1-x}Ti_xN$



NbTiN film composition

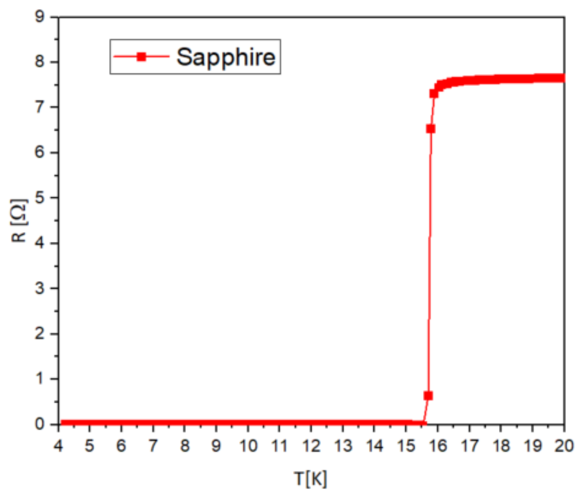


- Thermal ALD results in precise control of the NbTiN film chemical composition

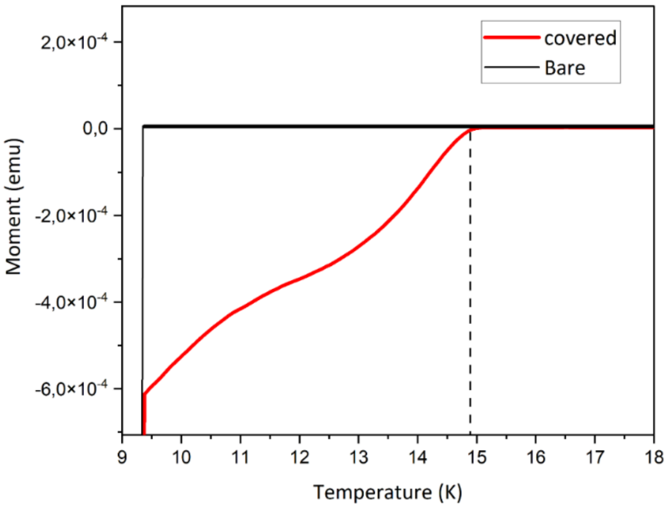
T.Proslier & Y.Kalboussi

Multilayer structure by ALD

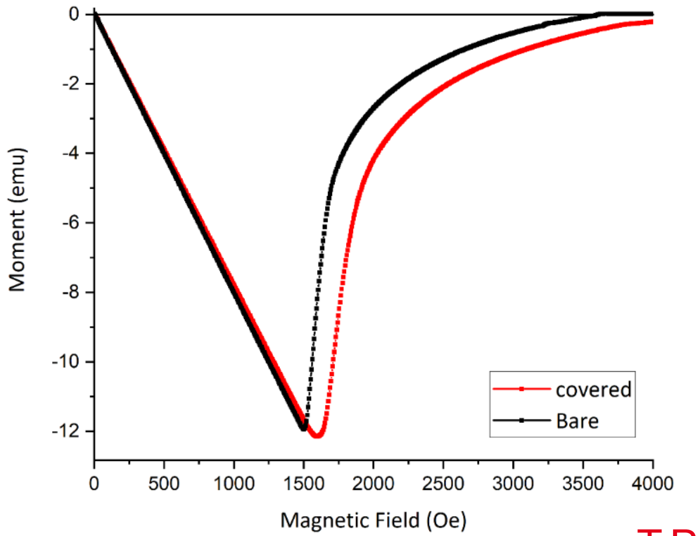
NbTiN (45 nm) –AlN (10 nm) – Sapphire



NbTiN (45 nm) –AlN (10 nm) – Niobium



- T_c similar on Niobium and sapphire substrates (around 15 K)

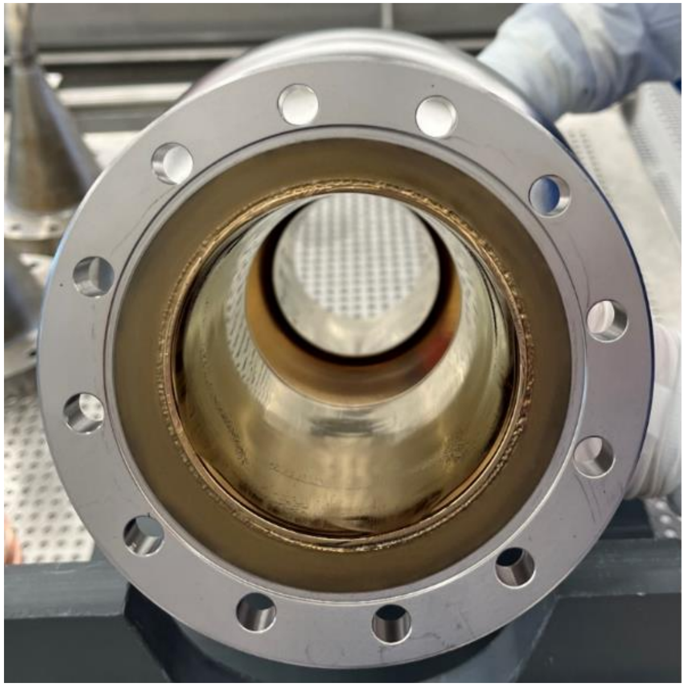


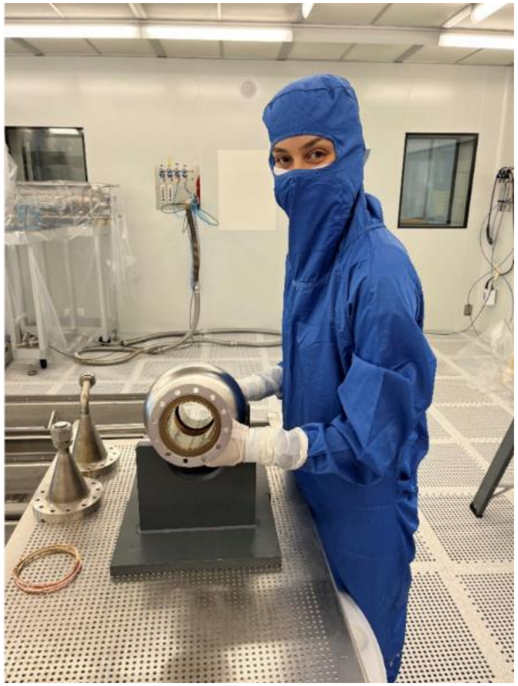
- The first vortex penetration field is enhanced by 13.4 mT after NbTiN (45 nm) – AlN (10 nm) coating which can lead to an increase of 3 MV/m (1.3 GHz Tesla shape)
- The NbTiN thickness needs to be increased for optimal screening efficiency.

First attempt of NbTiN-AlN coating on 1.3 GHz Nb cavity

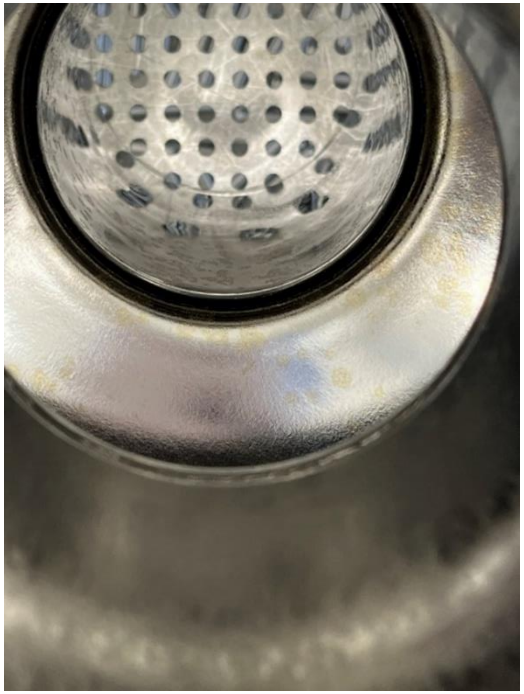
- The Niobium cavity was coated with NbTiN (45 nm) - AlN (10 nm) bilayer.

Before annealing





After annealing



- Vacuum degradation during the annealing step.
- Observed delamination in the beam tubes.
- The coated cavity showed overall degraded performances.

➢ More coating tests are ongoing to optimize the coating + annealing step …

3. CLEANROOM ASSEMBLY COBOT DEVELOPMENT

S. BERRY, C. SERVOUIN

Cea Production Cobot: nitrogen cleaning for ESS cavity strings (~20/30)

COBOT: CO*llaborative ro*BOT human can work nearby

Articuled Robot Vehicule – Ingeliance Solutions

Cart dimension : 1250mm x 785mm height:865mm

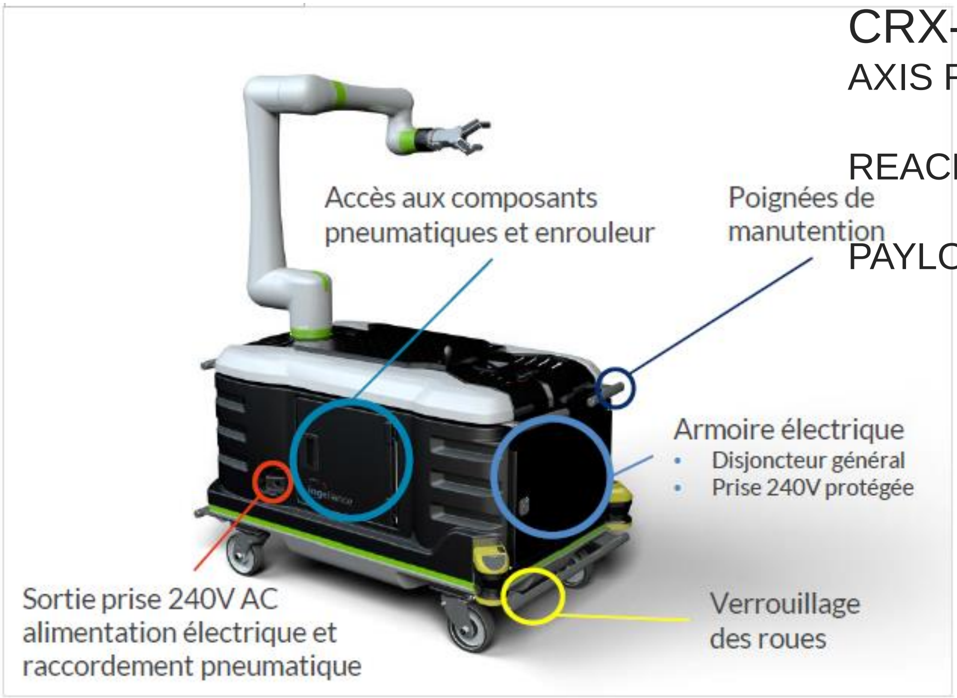
Total weight: 190kg

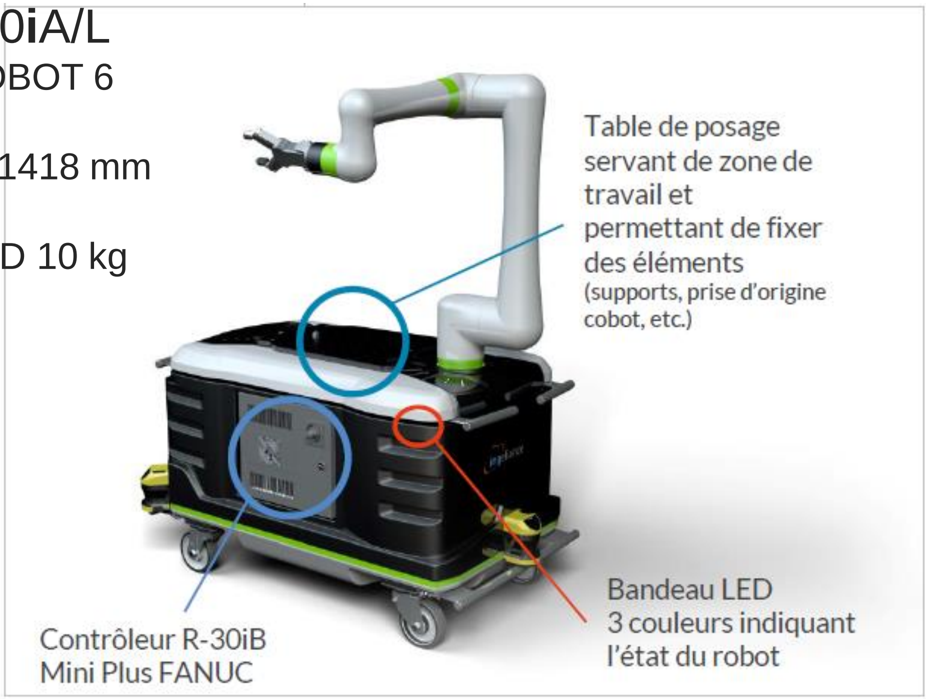
CRX-10**i**A/L

AXIS ROBOT 6

REACH 1418 mm

PAYLOAD 10 kg





FANUC CRX-10**i**A/L on an ARVIS cart (bought to Ingeliance company):
4 month to prepare, 5 days installation and commissioning, about 2 years production (starting May 2022)

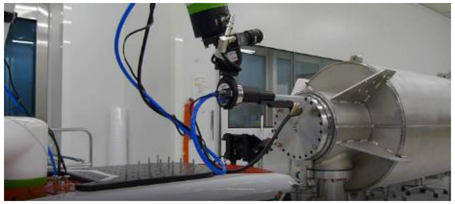
Cobotisation : from cleaning to assembly

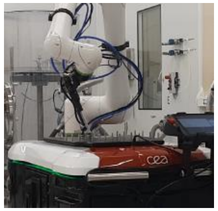
First issue addressed: reduce effort and hardship of flange cleaning

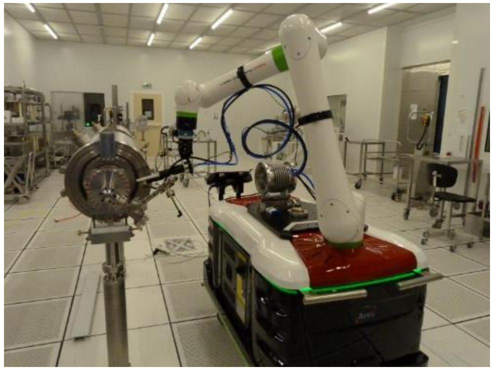
Feasibility study: with CEA/DRT, SYB3 prototype (sept17-oct18)

Flanges cleaning with Nitrogen blowing, CEA/DRT : commercial cobot (janv 20-mars 21)

Commercial cobot order and installation sept.21-mai 22







Robot commissioning

B&S feed-back leads to program reliability improvement

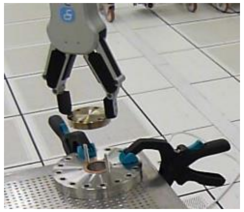
1st quarter 2022 → 2nd quarter 2022 → 3rd quarter 2022 → 4th quarter 2022 → 2023

Robot use by B&S subcontractor for ESS

Programming knowledge reinforcement

New programs

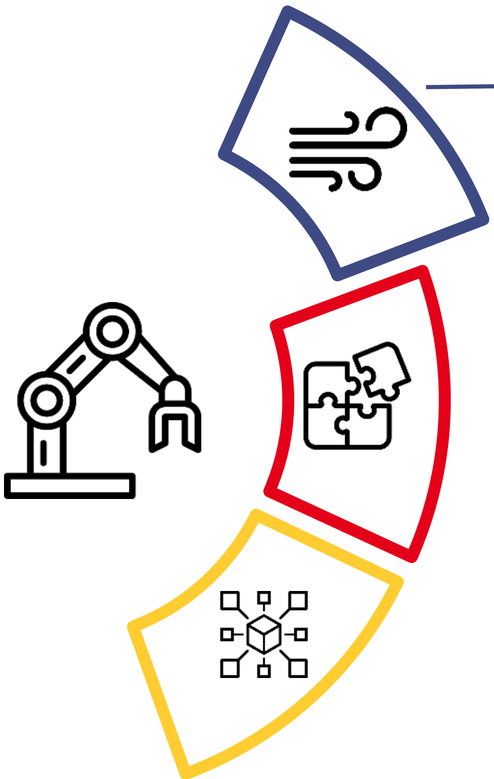
- ESS Bellows Cleaning
- Bellows to cavity assembly
- PIP-II programs with Mock-Up



Start assembly work

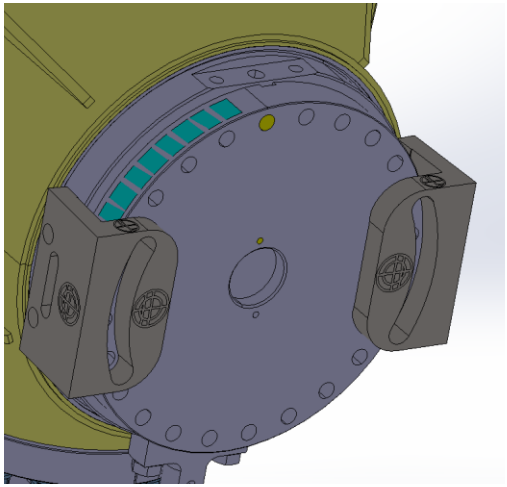
New gripper (delivered Dec 2022)

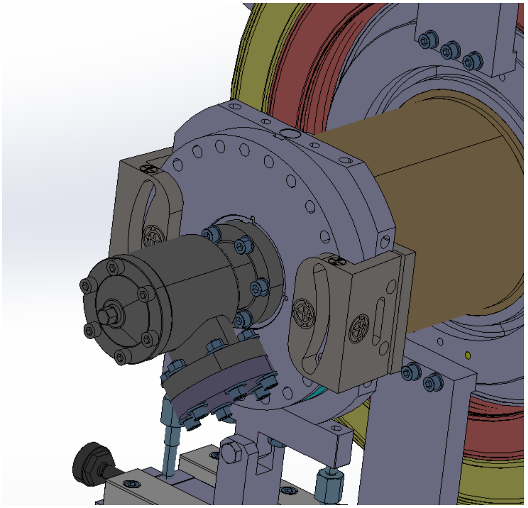
Development road map



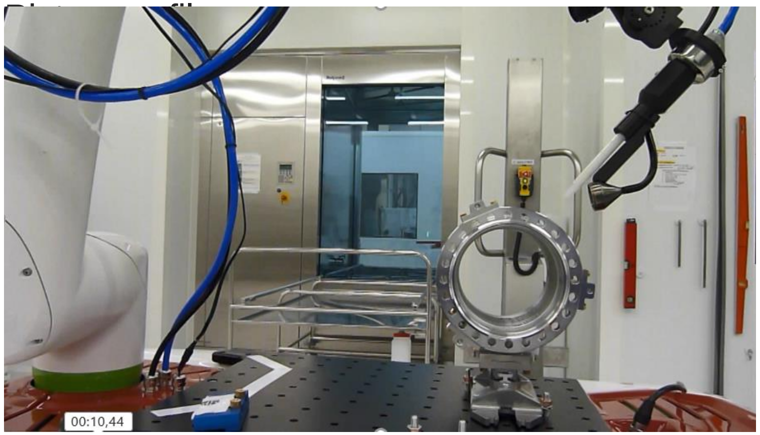
Compressed air blowing (painfull reduction & reliable cleaning process)

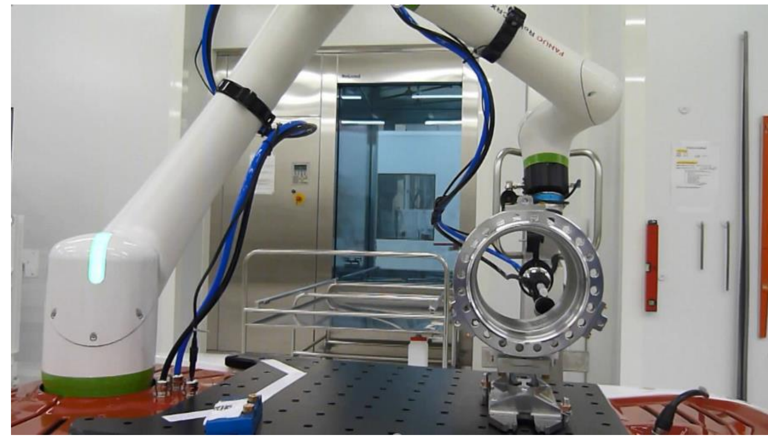
- ESS production program adjustment (late 2022)
- new programme : bellows cleaning (early 2023) next slide
- ESS beam flanges clamps on cavities (late 2023) below



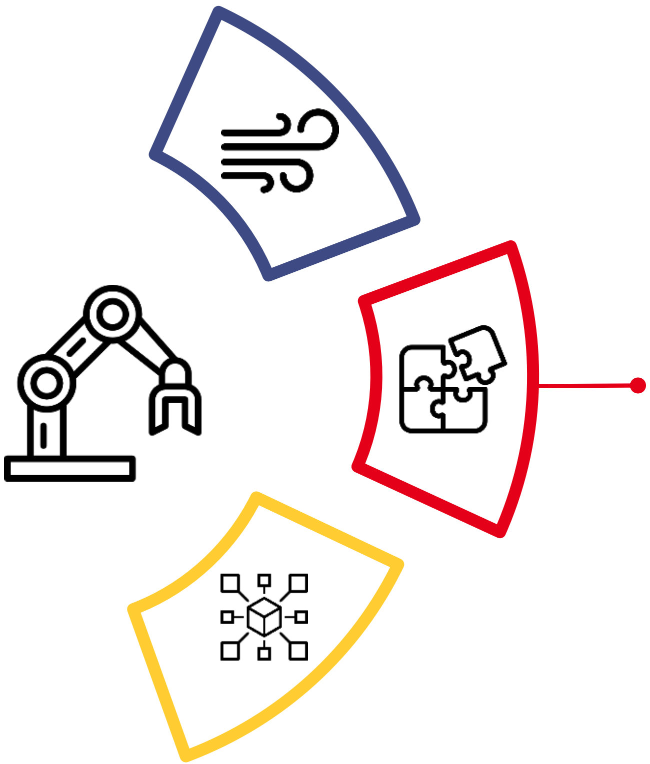


ESS Bellows Cleaning (used in production)





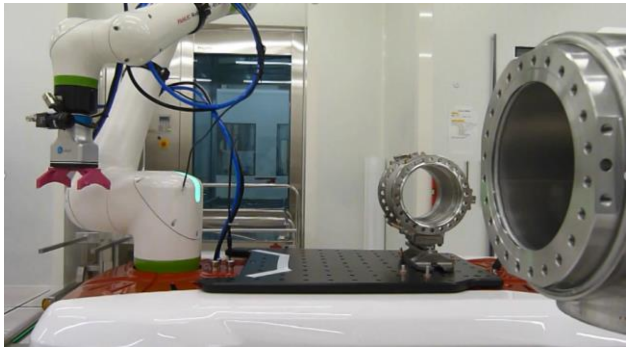
Development road map

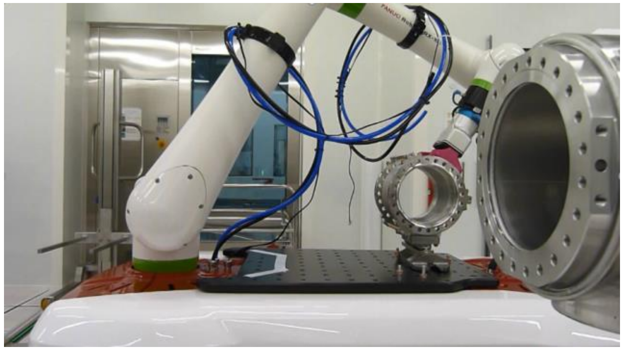


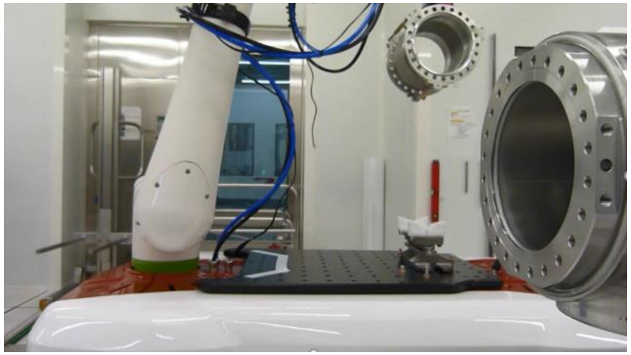
Assembling (quality improvment)

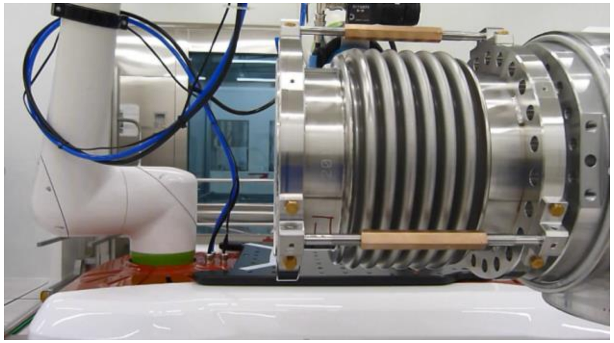
- Installation / Removal of a flange on/from a cavity
- Intercavity bellows to cavity assembly

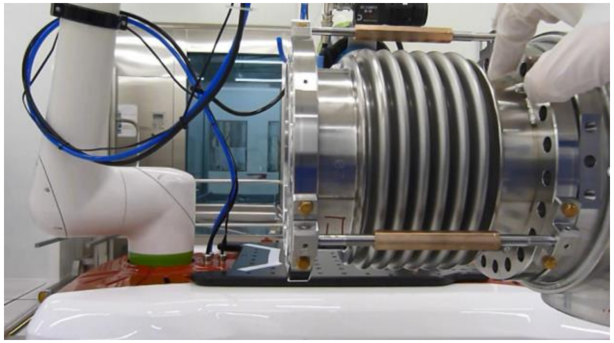
ESS Bellows assembly (under development)



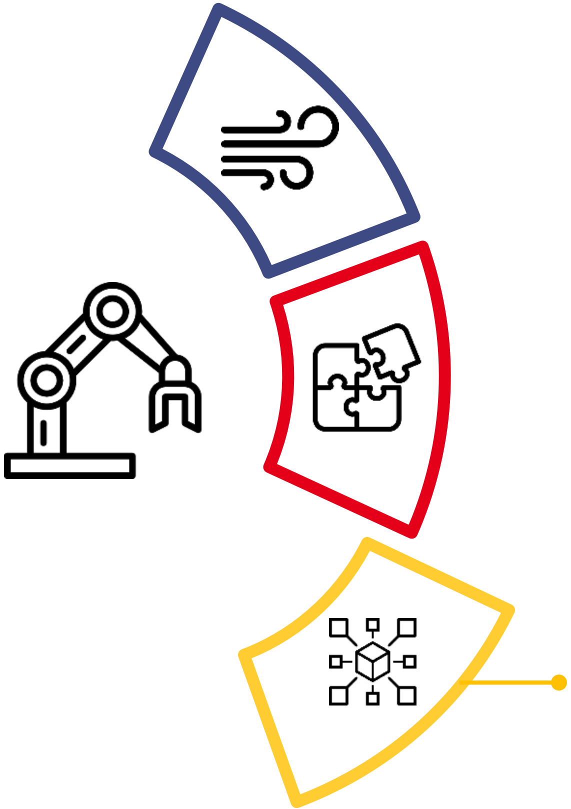








Development road map



Combine program blocks

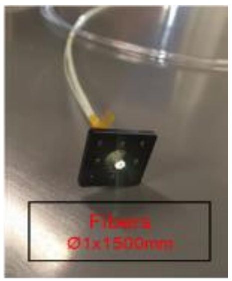
- PIP2 Project: must be developed

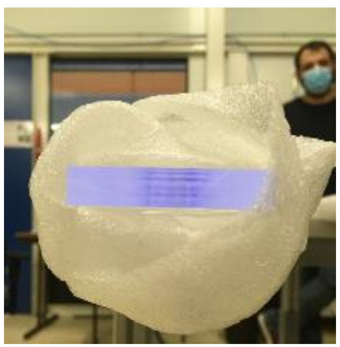
4. DIAGNOSTICS

E. CENNI, G. DEVANZ, J. PLOUIN

γ–Diagnostic system for high performance cavities and cryomodule (1/2)

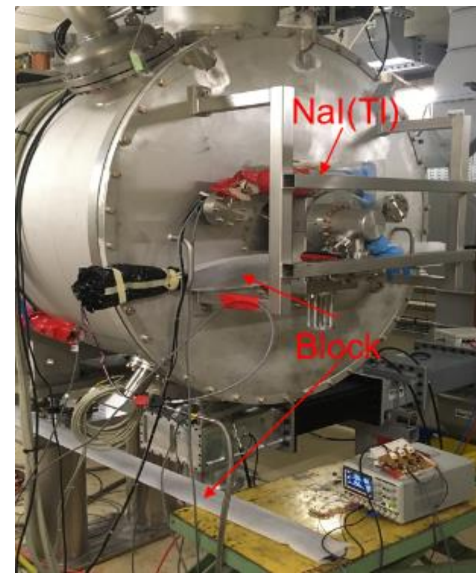
- We are interested in versatile and large-area coverage detectors:
  - Plastic scintillators can be shaped in different forms
  - Reasonably cheap with respect to the area coverage
  - Largely used in particle physics (e.g. Sci-Fi Tracker in LHCb)
- We started by testing a plastic block (10x50x1500mm) and fibers (Ø1x1500mm) as a proof of concept
- We are developing dedicated Geant4 applications for cryomodule and cavity testing allowing us to optimize detectors with respect to the radiation emerging from the cavities





Base plastic is Polyvinyl toluene (PVT)

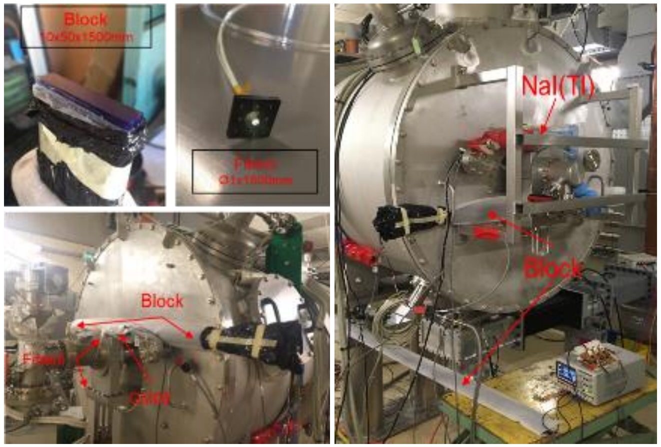
ESS cryomodule installed in the test stand at Saclay



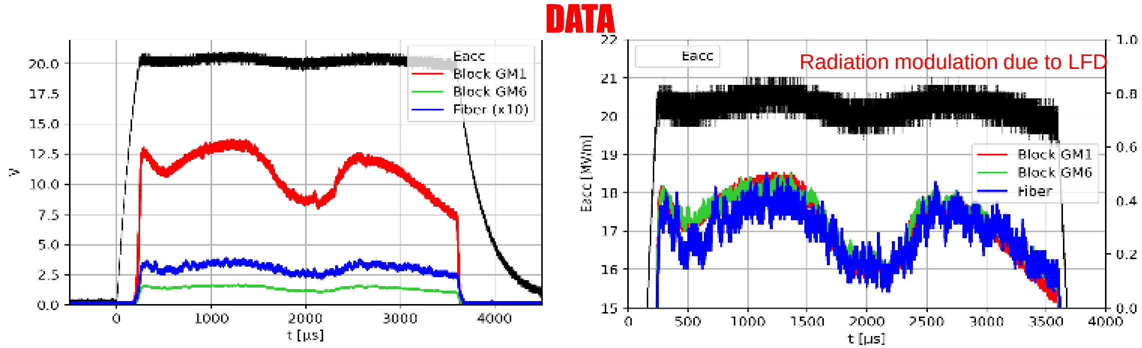
Scintillator block installed on ESS cryomodule during power test in Saclay, close to a NaI(Tl) scintillator.

- <u>Detectors are at room temperature (easy to install and change configuration)</u>
- <u>Possibility to study field emission radiation pulse by pulse, with time resolution within the pulse (*next slide*)</u>

γ–Diagnostic system for high performance cavities and cryomodule 2/2

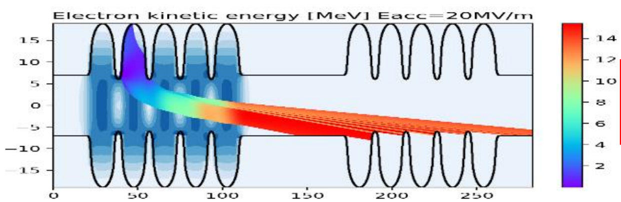


Proof of concept during ESS cryomodule test in CEA and Lund



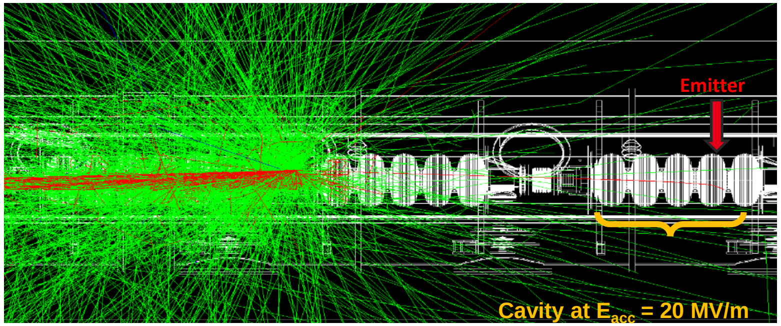
CAV1 excited with **nominal pulse**, the maximum Eacc is about 21.2MV/m (black), radiation detected by block at GM1 position, close to cavity (red), radiation detected by block (green) and from fiber (blue). *Right: zoomed and normalized view of the same pulse where it is possible to appreciate closely the change in the radiation amplitude due to Lorentz force detuning.*

Particle tracking code



Single emitter trajectories calculation with one cavity powered (CAV4) while the adjacent is off (CAV3). Trajectory colours are determined with respect to the electrons kinetic energy. All the impact on the beam tubes and adjacent cavity have energies between 12 and 15MeV.

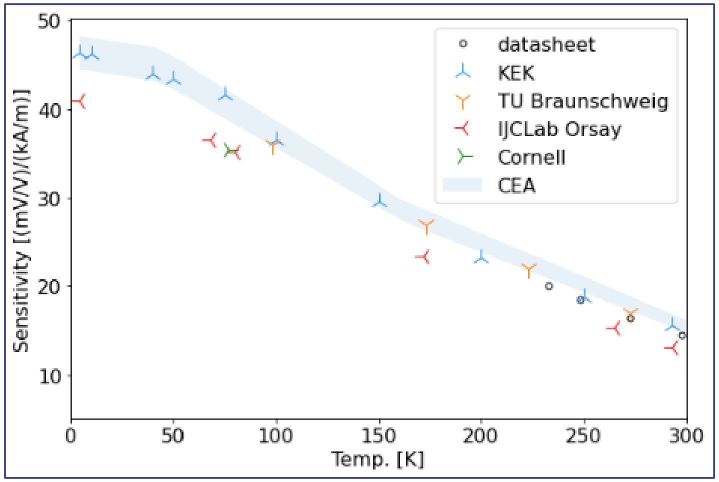
- ✓ Time-resolved radiation detection pulse by pulse



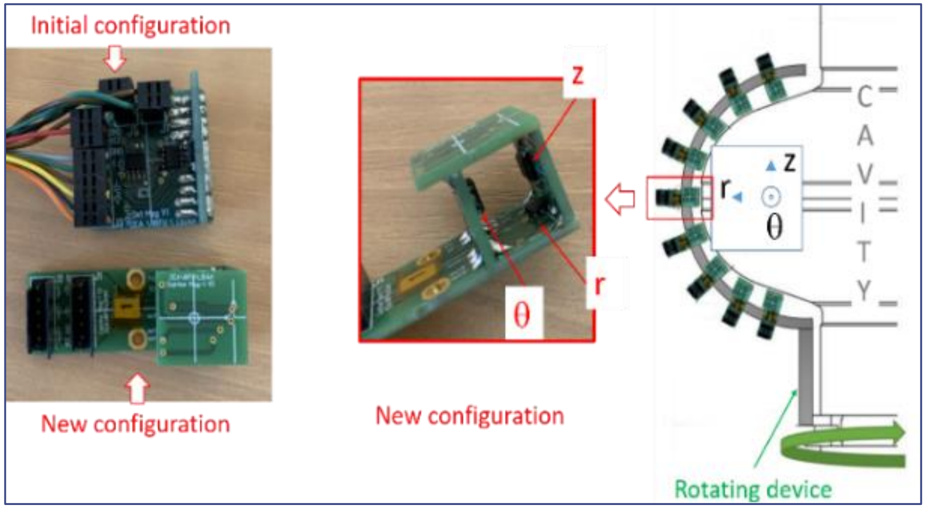
- ✓ 2D axial symmetry dedicated particle tracking code
- ✓ Customizable particle-matter interaction application

Magnetic sensors (AMR) for SRF cavities

- Studying flux expulsion during superconducting cavities test increases the need for exhaustive magnetometric cartography.
- The use of Anisotropic Magneto Resistance (AMR) sensors, much cheaper than commercial fluxgates, allows the use of tens of sensors simultaneously.



Sensors calibration at CEA, comparison with other labs



Sensors (developed) and sensors arrays (in development) at CEA

J. Plouin, E. Cenni, L. Maurice, "AMR sensors studies and development for cavities tests magnetometry at CEA", in SRF2021 proceedings.doi:10.18429/JACoW-SRF2021-TUPCAV009

THANK YOU FOR YOUR ATTENTION