SPES
exotic beams for science

Thin film QWRs performance for ALPI-SPES upgrade at INFN-LNL: first results

G. Keppel, on behalf of SRF LNL groups

TESLA TECHNOLOGY TTC COLLABORATION

Link Station Hall Aomori

October 11-14, 2022

INFN
Istituto Nazionale di Fisica Nucleare

Outline

- Thin film QWR @LNL
  - Introduction: ALPI evolution over the years
  - The SPES Project @LNL
  - ALPI Upgrade for SPES project
  - The TANDEM – PIAVE – ALPI Complex
- QWR Status @LNL
  - Sputtering and Chemistry Facility Upgrade
  - Back extrusion cavities
  - Results
- Conclusion

Outlook - Introduction

- ALPI's design started **in 1990**
- ALPI started operation in **1994-98 with Pb/Cu** technology
- Meanwhile from 1993:
  - R&D on **low β** (0,055) 80 MHz bulk Nb resonators (thanks A. Facco)
  - R&D on **Nb/Cu medium β** (0,11) 160 MHz resonators (thanks V. Palmieri, S. Stark, A. Porcellato)

$$E_a = (2.7 \rightarrow 4.4)\, MV/m$$

Outlook - Introduction

- Nb/Cu resonators are definitively a mainstay of this facility, given the **performance and stability over the years**.
- We have faced a generation transition in the recent years, which has represented a new challenge

Outlook - Introduction

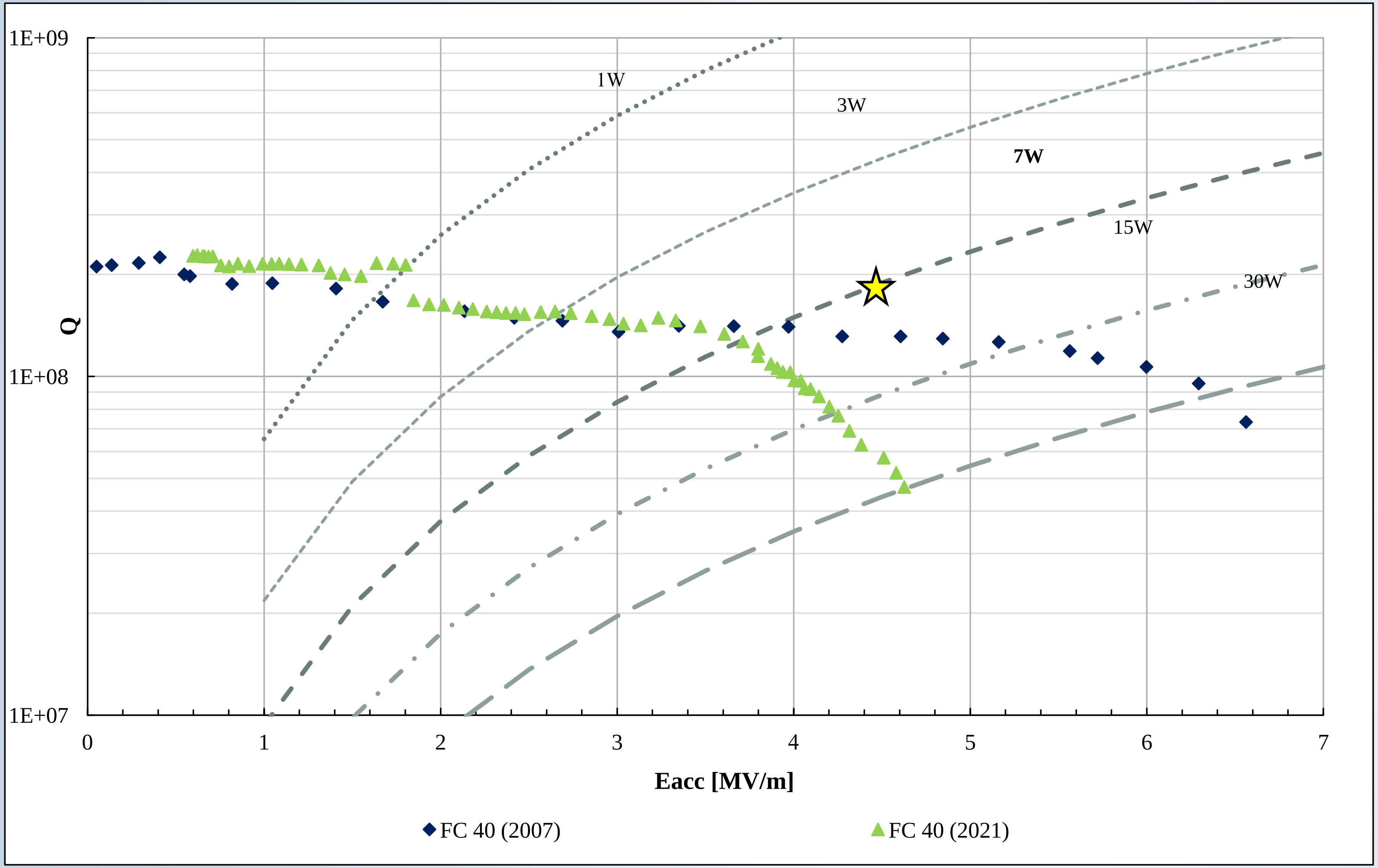
LNL Nb/Cu experience specially in terms of

- Reliability
- Repeatability
- Stability
- Cost Reduction
- Performance

Demonstrate the suitability of the technology for large-scale production

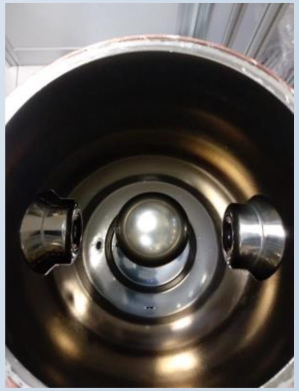
ISOLDE - CERN

Medium β cavity test 2007 -> 2021



FC 40 cavity from CR7 2007 vs. 2021

- Same Q_0
- Same RF performance
- Difference at high filed due to low conditioning in 2021



ALPI-SPES upgrade

Selective **P**roduction of **E**xotic **S**pecies

- ✓**Second generation ISOL facility for nuclear physics: Production & re-acceleration** of **exotic beams**
- ✓Research and Production of **Radio-Isotopes for Nuclear Medicine**
- ✓Accelerator-based neutron source (**Proton and Neutron Facility for Applied Physics**)

Cyclotron

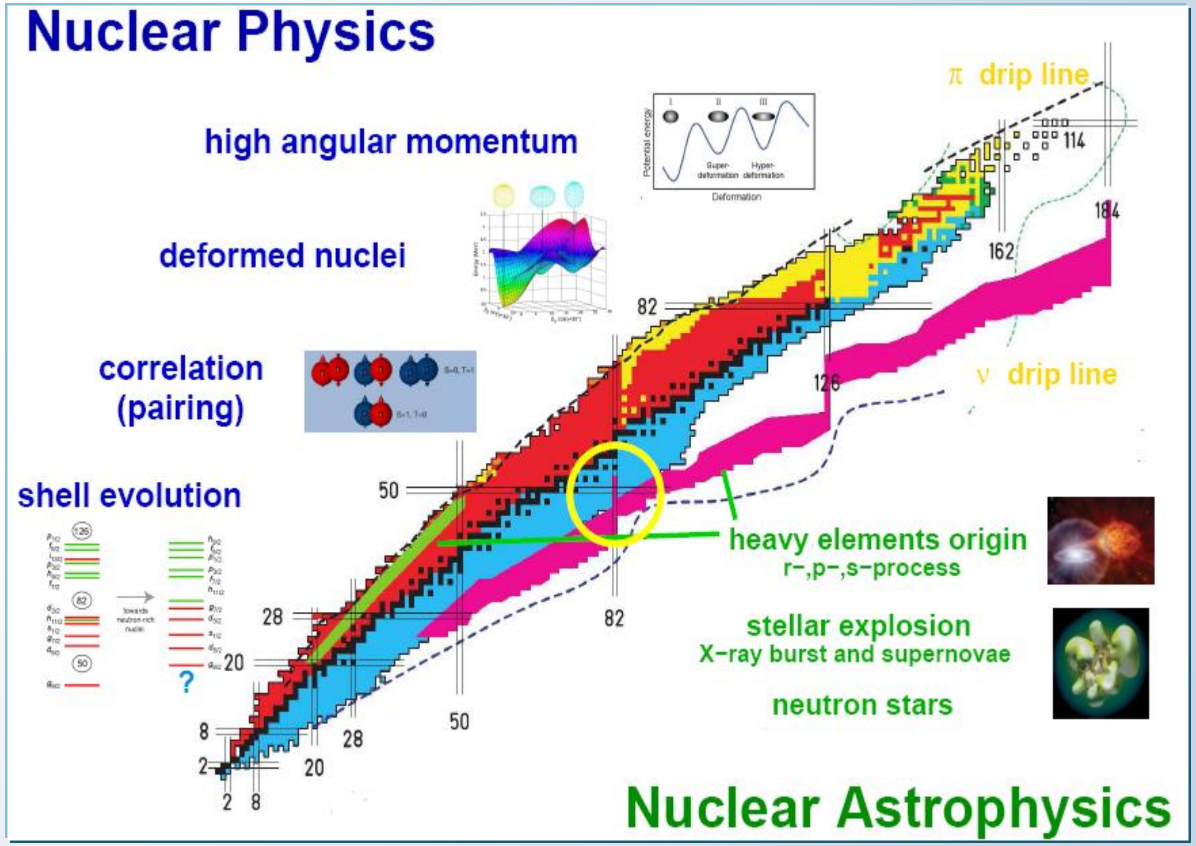
ISOL RIBs+ Post-Acc.

Nuclear Medicine

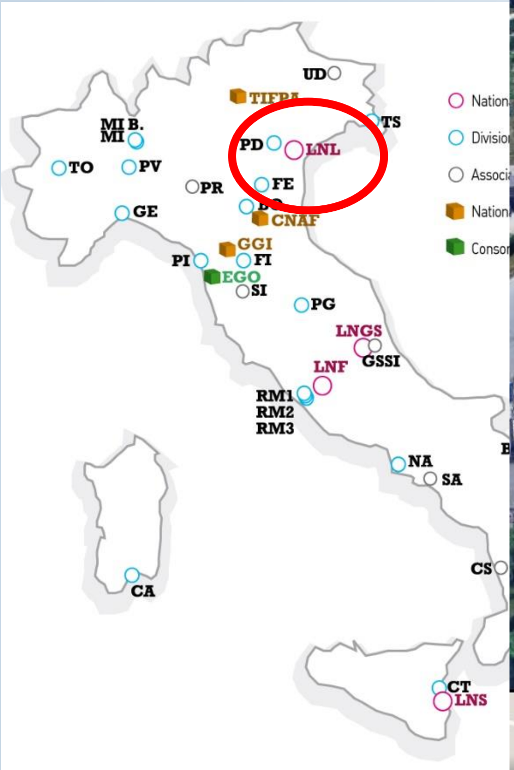
Nuclear Applications

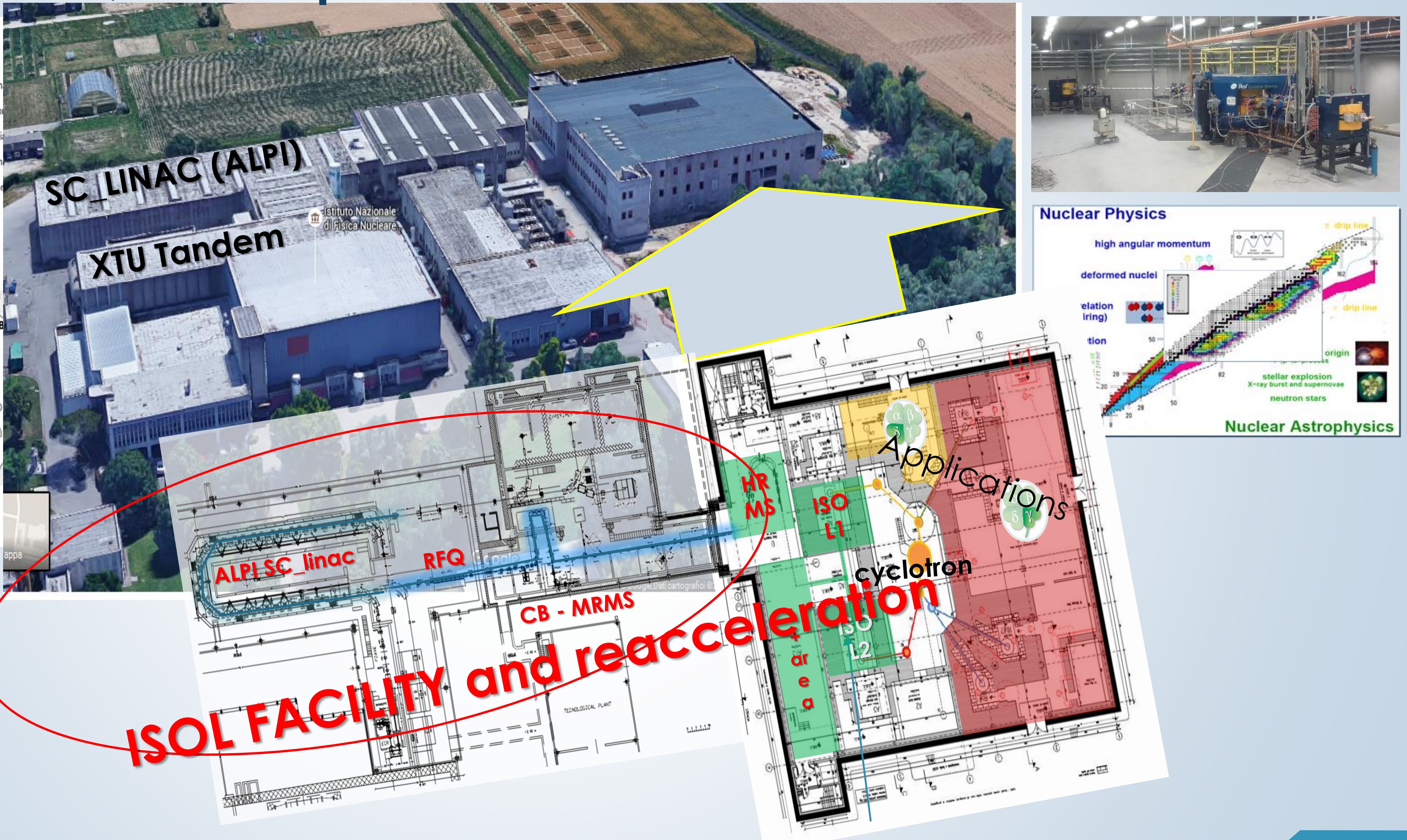
SPES Facility @ LNL

- **New High power compact CYCLOTRON 70 MeV 750 microA (BEST company)**
- **New configuration of High power ISOL System (8 kW Target ion source)**
- **ALPI superconductive LINAC (up-graded) for RIB's reacceleration**

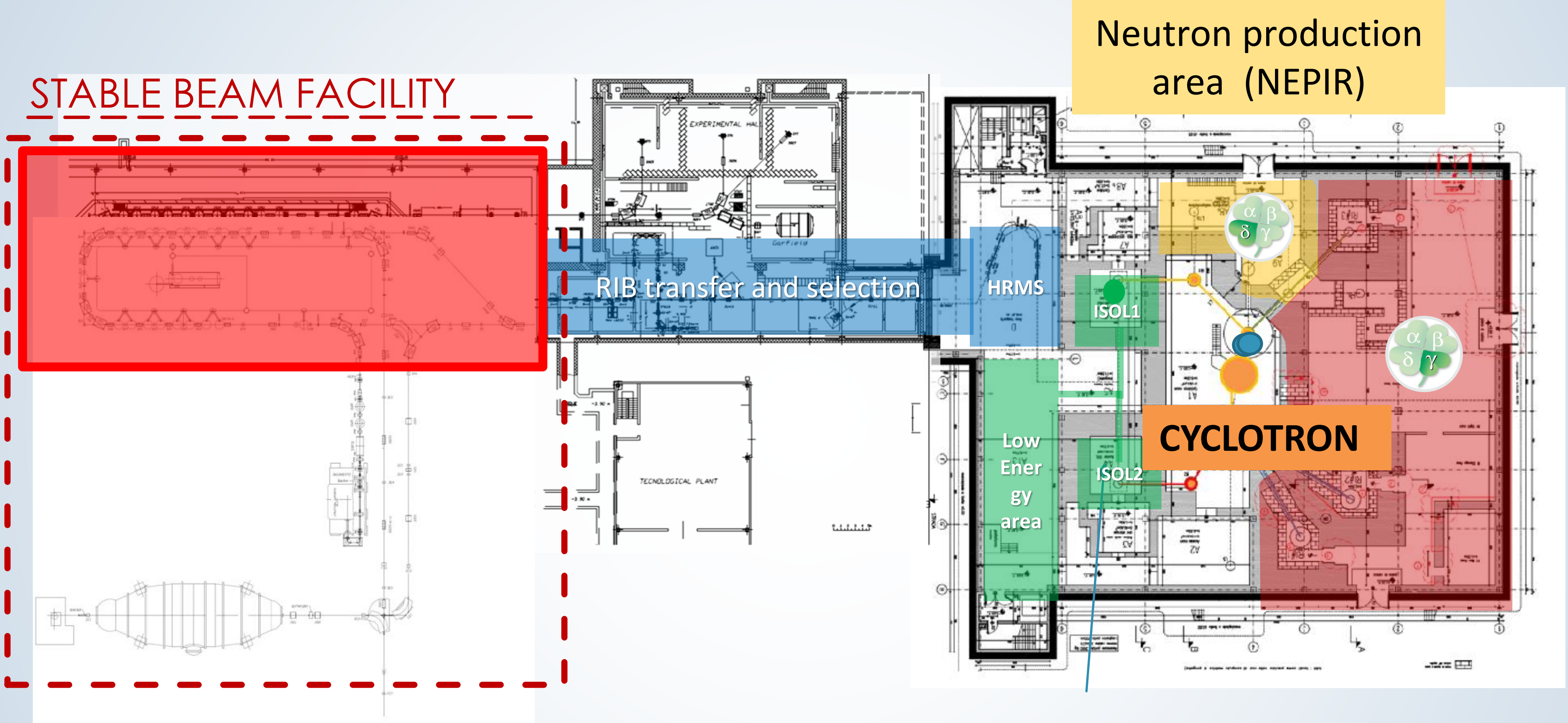


INFN-Legnaro: a lab for stable and presently unstable heavy ion beams, and RI production





SPES layout



RIB reacceleration:

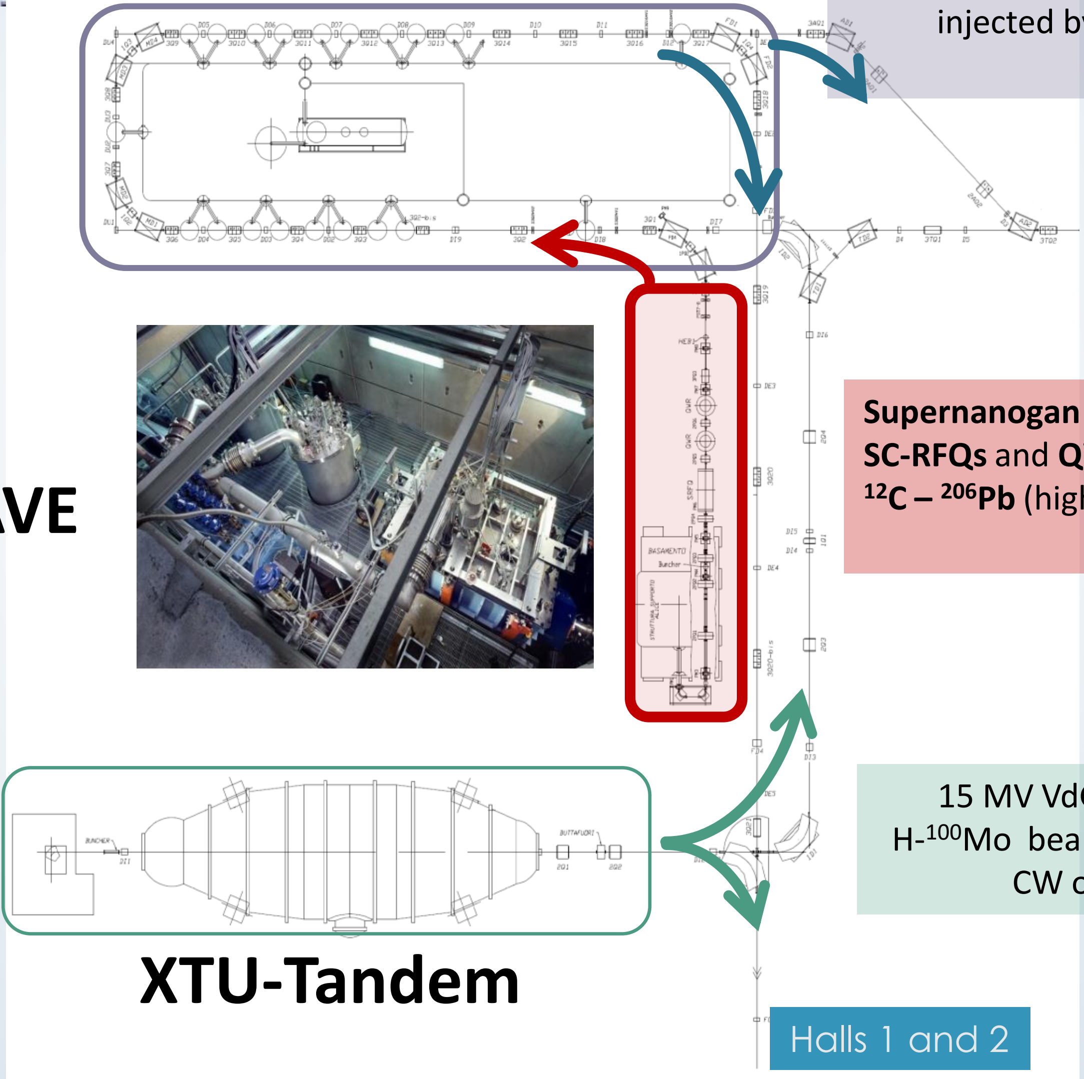
- New RT RFQ
- ALPI to 10 MeV/A

1/20.000 mass separator
(Beam Cooler + HRMS)
Elettrostatic beam transport
Charge Breeder (n+)
1/1000 mass separator

ISOL bunkers
1/200 mass separator
low energy experimental area

Radioisotopes production area (LARAMED)

TANDEM – PIAVE – ALPI complex

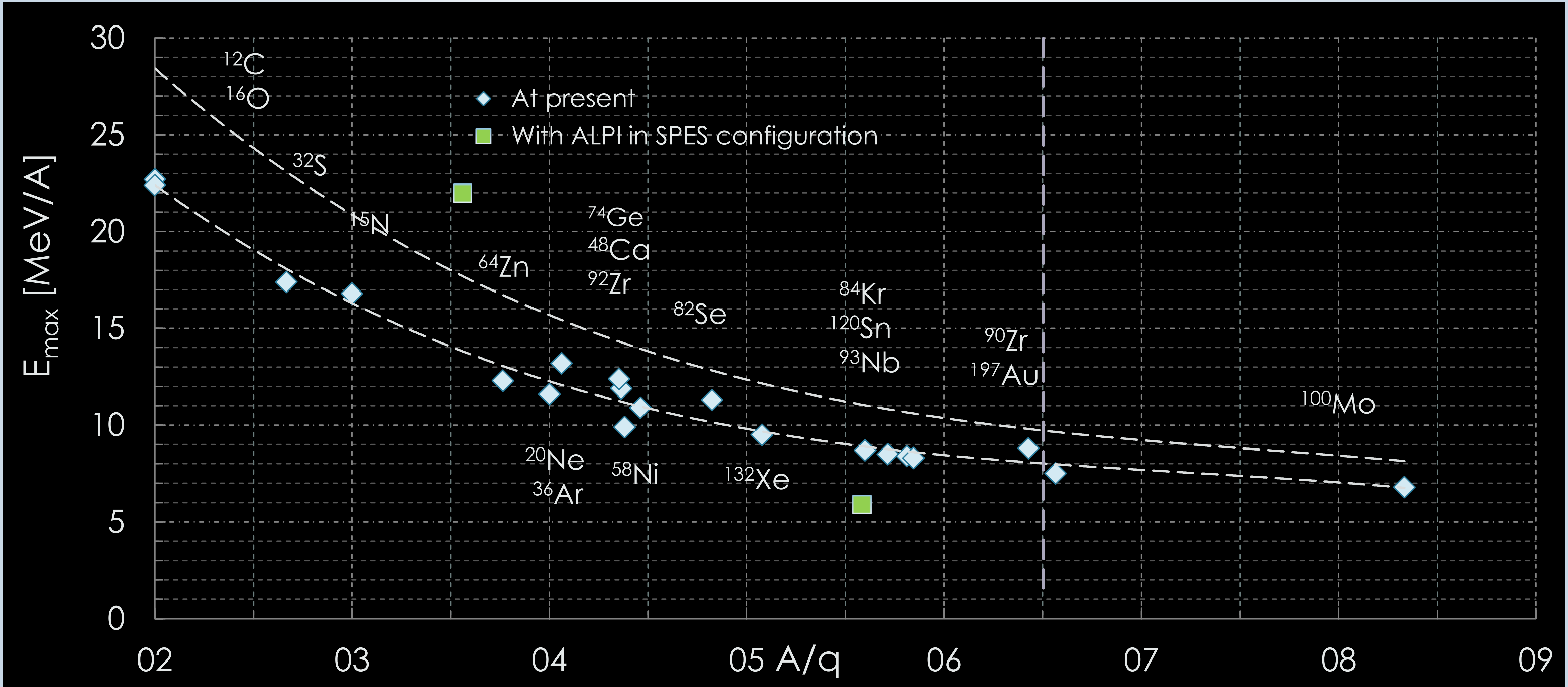


SC Linac with 68 **QWRs** (Nb, Nb/Cu) working @ 4,2 K in 19 cryostats $\mathbf{V_{eq}}$ **~ 48 MeV/q**, beams **from ^{12}C to ^{206}Pb**, injected by Tandem or PIAVE (**1994**)

Supernanogan ECR on 350 kV platform
SC-RFQs and **QWRs**, $\mathbf{V_{eq}}$ **~ 8 MV**
^{12}C – ^{206}Pb (higher q and I_{beam})
(**2006**)

15 MV VdG Tandem (HV Corp), H-^{100}Mo beams, E = **30 ÷ 1.5 MeV/A**, CW or pulsed (**1984**)

Beam Energies with full SPES Upgrade for Piave-Tandem-ALPI



Higher Energy (+2 cryostats), higher transmission (new QP), increased reliability (cryogenics)

Matching into ALPI SC linac

4,8 MV/m

6,5 MV/m

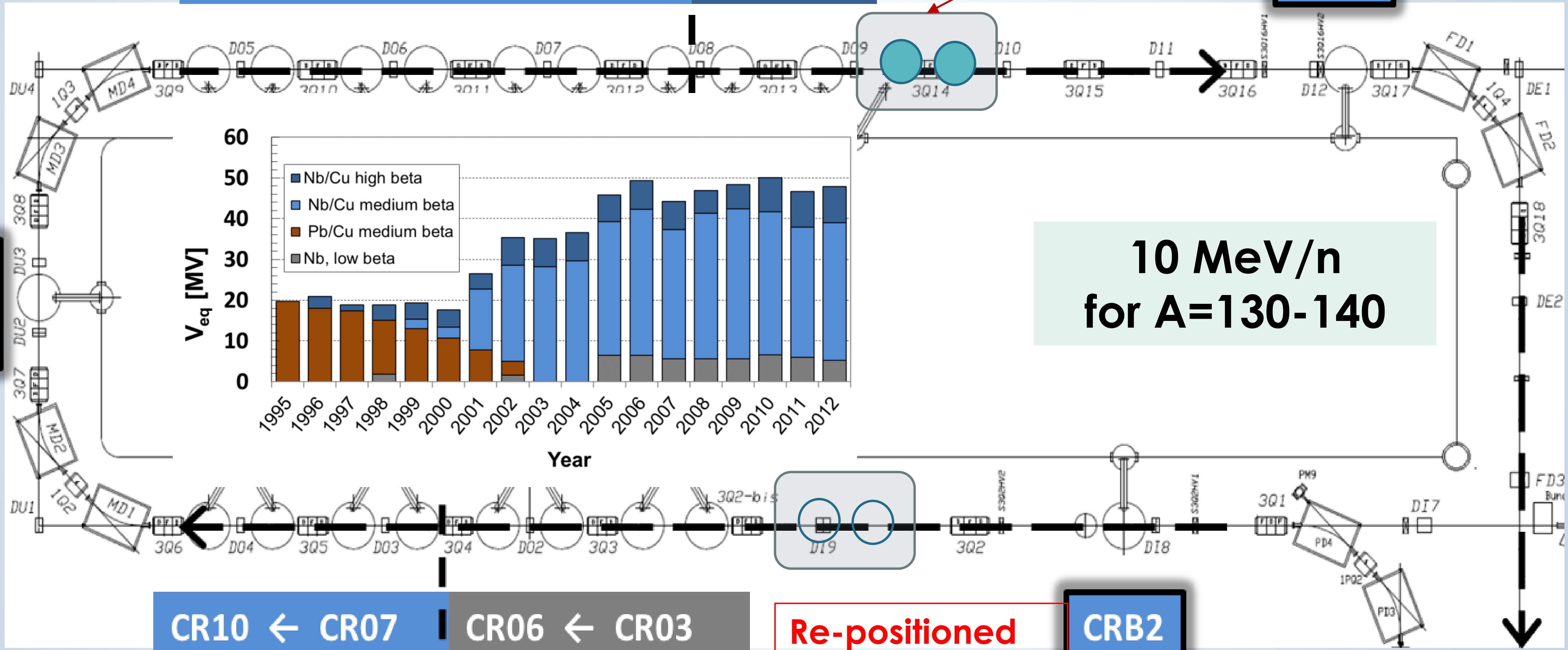
CR12 → CR18

CR19-20

Additional 8 cavities

CRB4

CRB3



10 MeV/n for A=130-140

CR10 ← CR07

CR06 ← CR03

Re-positioned low β cavities

CRB2

4,8 MV/m

5 MV/m

QWR Status @LNL

R&D activity for ALPI upgrade

After > 15 years Nb/Cu with a new team…

- **Vacuum systems refurbishing and upgrade**:
  - QWR and plates sputtering systems.
  - Cryostat for off-line test.

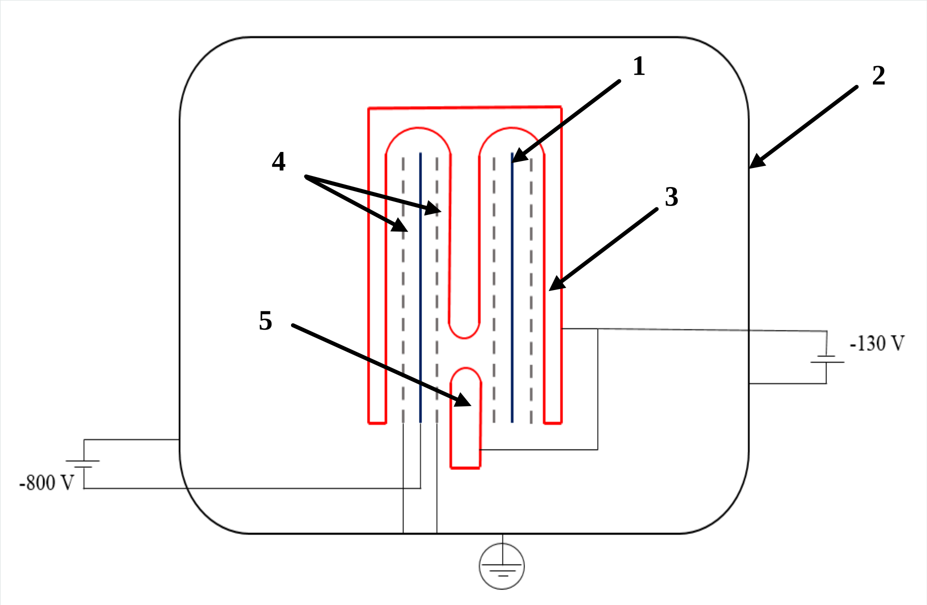
- **Re-definition on coating parameters** for Nb/Cu high-β QWRs and plates (for QWR and RFQ) due to:
  - Upgrade of the system (new pumps, mass flow implementation, software control, DC and BIAS power supplies etc.).

QWR diode sputtering re-engineering

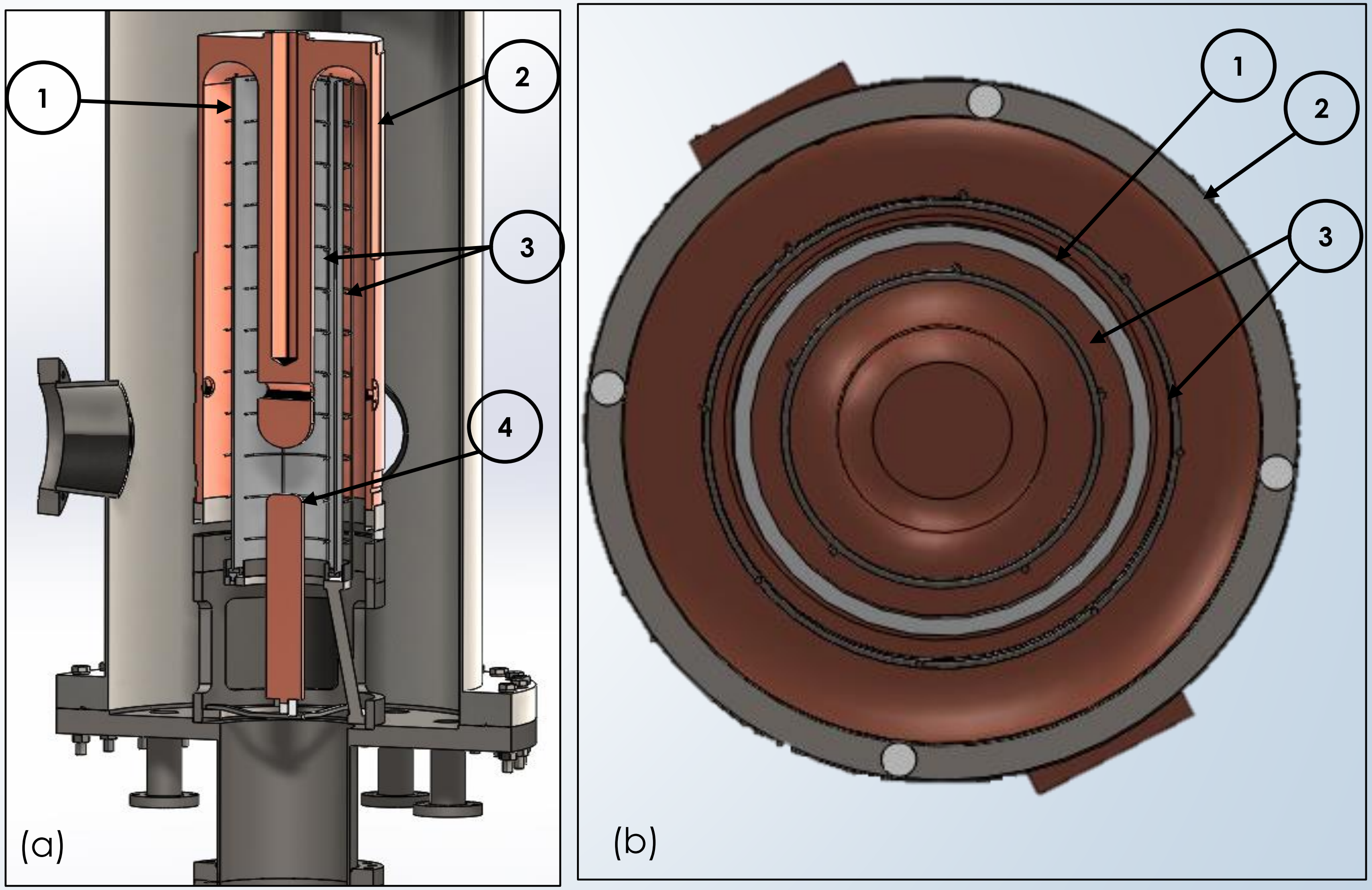
Nº	System compound
1	Niobium cathode
2	QWR cavity
3	Titanium ground nets
4	Copper counter electrode

Upgrades started from facility re-modelling using 3D software
Re-engineering of:

- Vacuum system.
- Vacuum electric connections.
- Thermocouple design and connection.
- Process gasses.
- Control system.



Scheme of the QWR diode sputtering system.

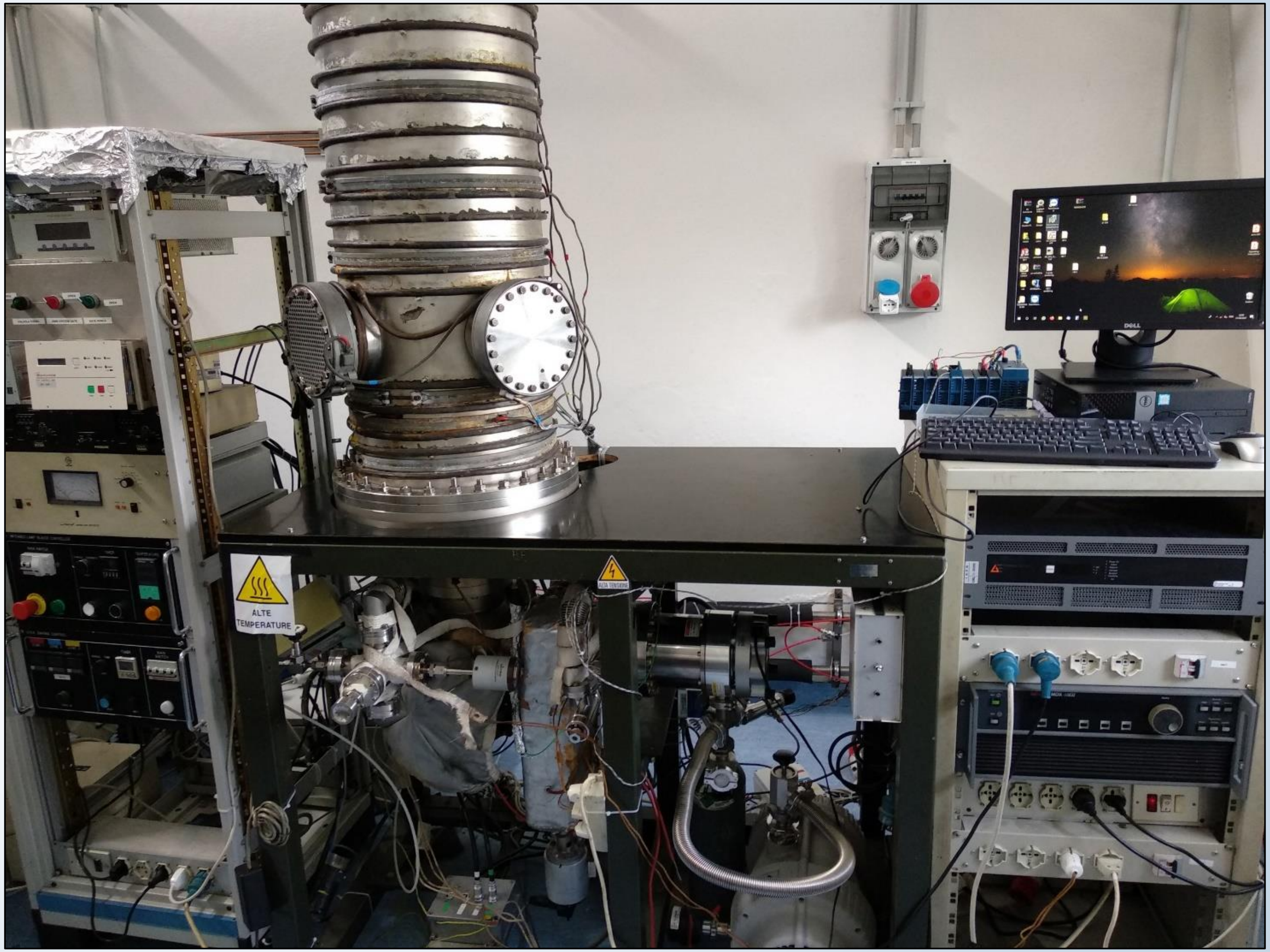


3D model of the QWR sputtering system: (a) – side view, (b) – bottom view.

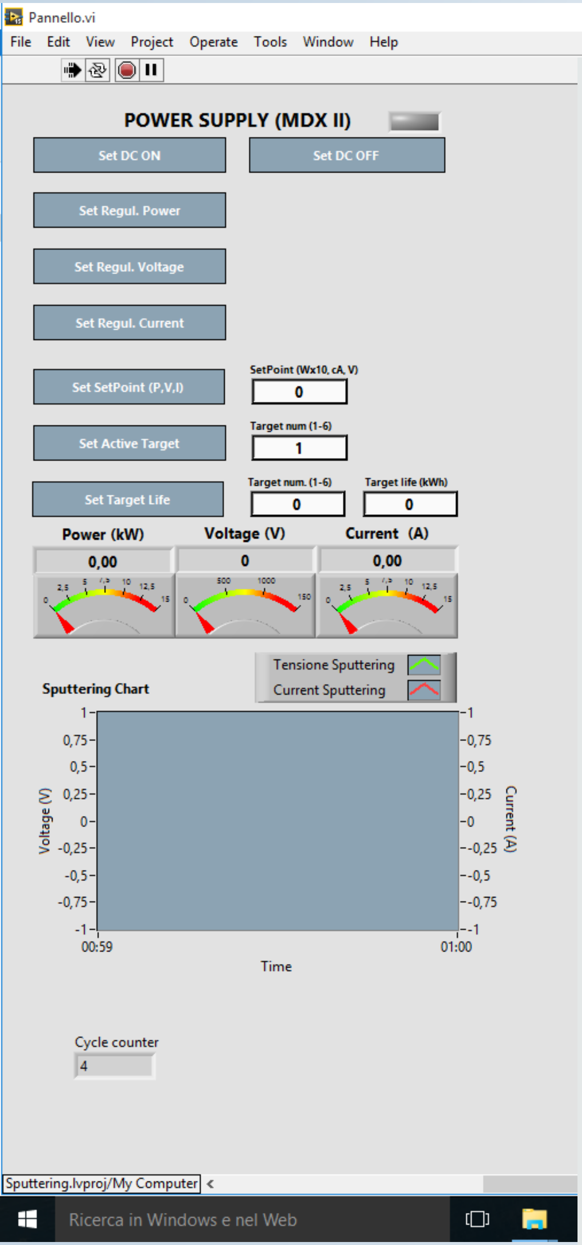
QWR diode sputtering system upgrade

Refurbishing of LNL QWR coating system. Major upgrade on:

- **Vacuum pumps**
- **Ar Mass flow controller**
- **Power supplies (sputtering and BIAS)**
- **Backing controls and cavity heating**
- **NI PLC-PC control System**



Automatic sputtering control and data acquisition



SetPoint (Wx10, cA, V): 0

Target num (1-6): 1

Target num. (1-6): 0

Target life (kWh): 0

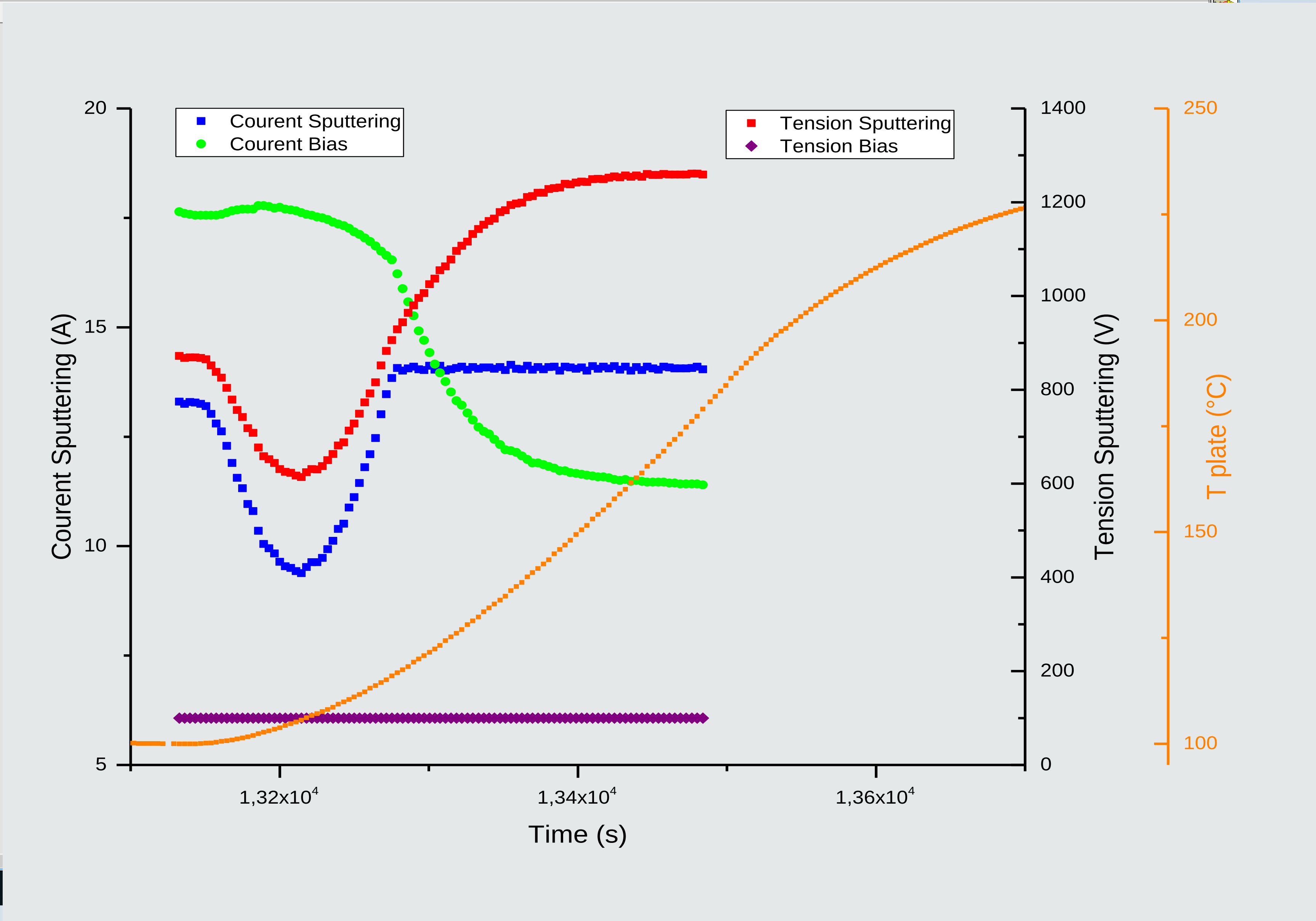
Power (kW): 0,00

Voltage (V): 0

Current (A): 0,00

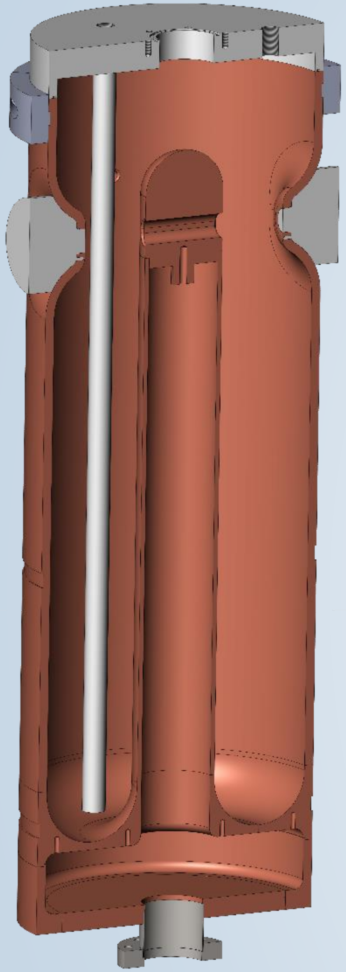
Cycle counter: 4

Sputtering.lvproj/My Computer

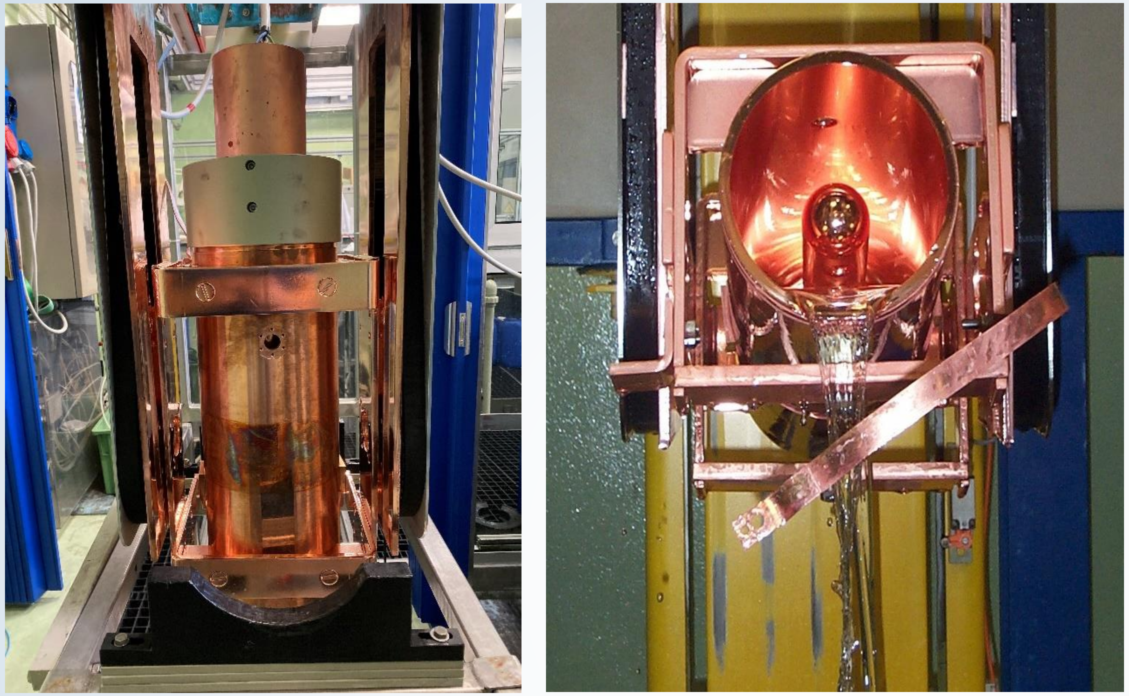


Tumbling and Chemistry plant upgrade

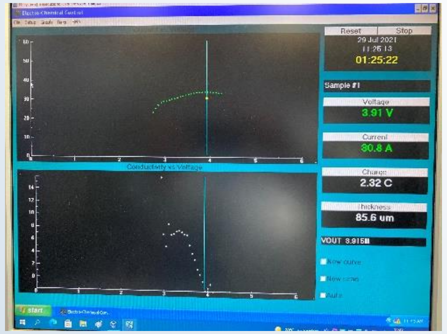
- Tumbling system maintenance
- Chemistry plant upgrade (new PLC control system)
- New stripping facility



Nb stripping tools

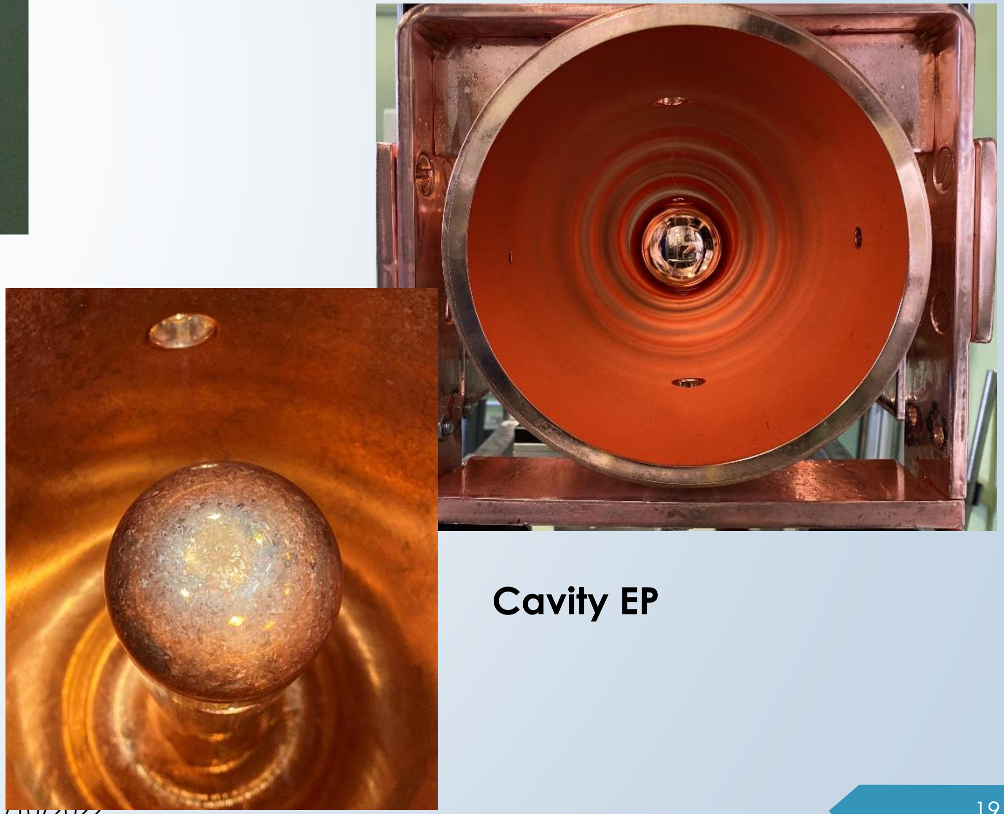


EP facility



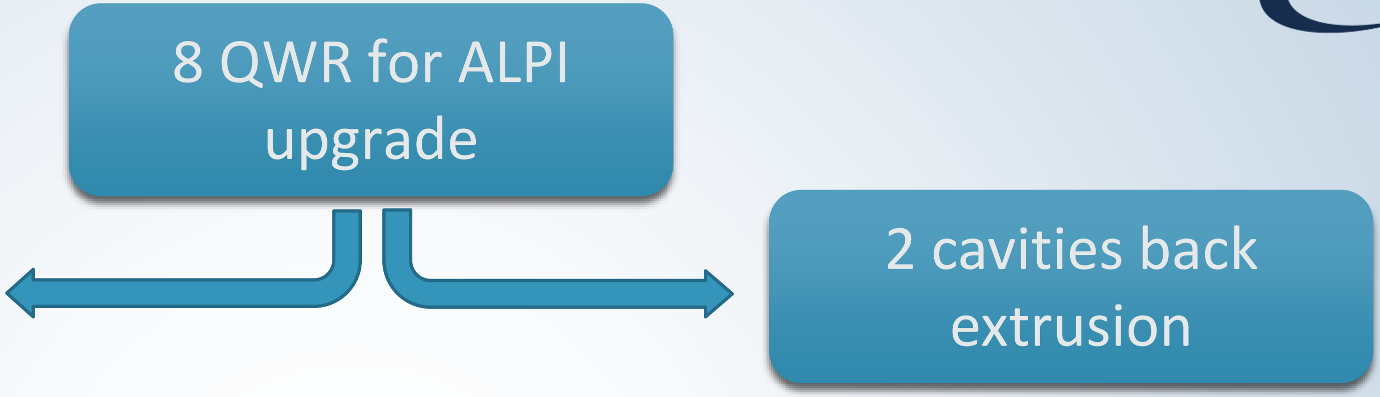
29 Jul 2021
11:25:13
01:25:22
Sample #1
Voltage 3.91 V
Current 30.8 A
Charge 2.32 C
Thickness 85.6 um
VOUT 8.915

EP software



Cavity EP

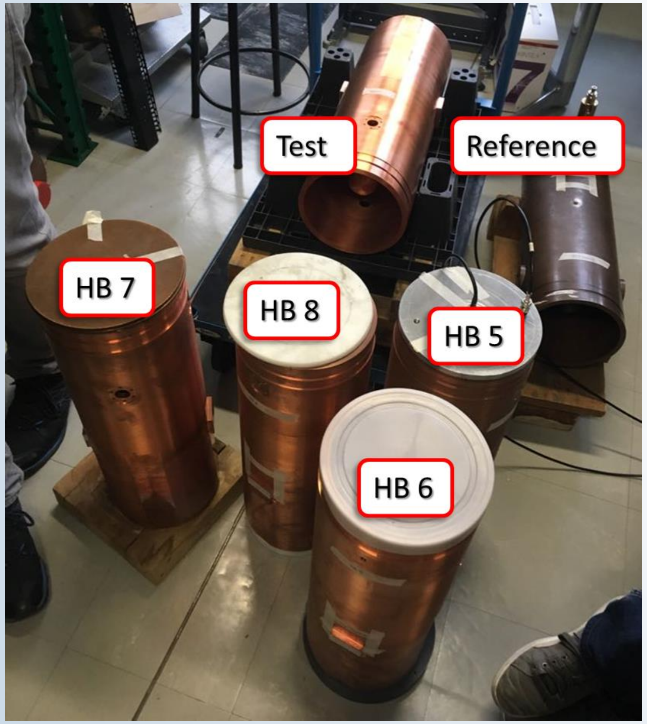
QWR Production for CR21 and CR22



8 QWR for ALPI upgrade

4 cavities machined from bulk Cu

2 cavities back extrusion

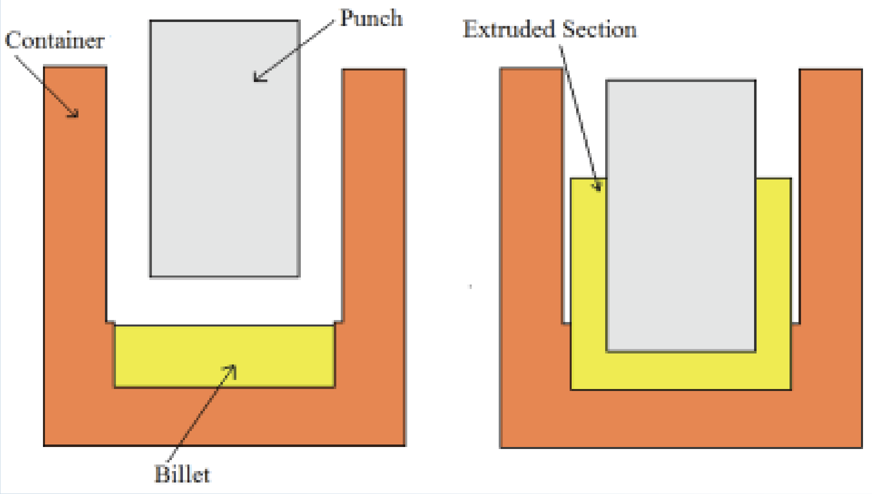


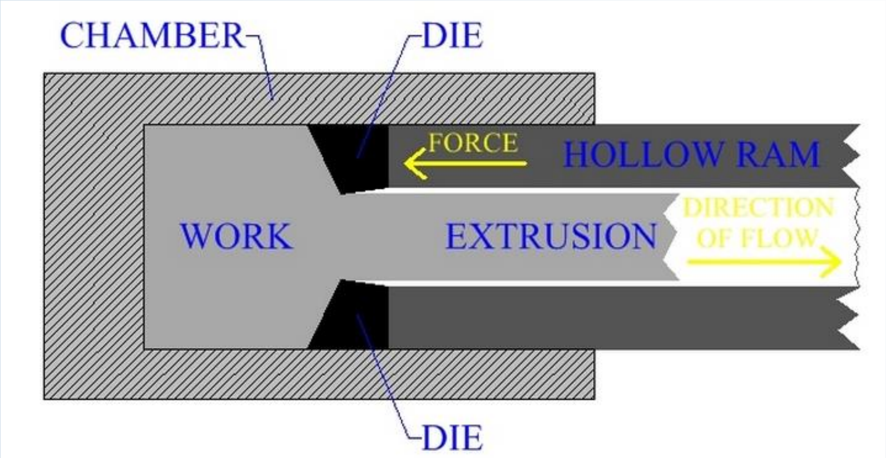
Classical production tecnology

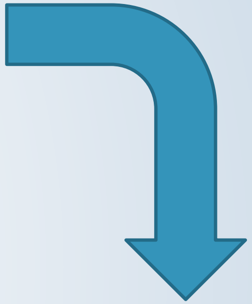
	f_0 [MHz]	Δ f_0 [MHz]
Reference	159.390	
HB5	159.388	0.005
HB6	159.335	0.055
HB7	159.328	0.062
HB8	159.330	0.063
Test (DD0)	159.455	0.205

Innovative approach

Cold back extrusion applied to QWR resonators







QWR preformed ready for machining

- **DD0 test cavity and DD1 produced with this technique**

Cold back extrusion applied to QWR resonators

Back extrusion techniques advantages:

- Reduction on copper usage
- Surface finishing close to EP finishing
- Cheaper machining procedure
  - Machining of top and inner part of antenna
  - Machining of beam ports
- Good material performance

Back extrusion observed disadvantage:

- Imperfection on cavity bottom

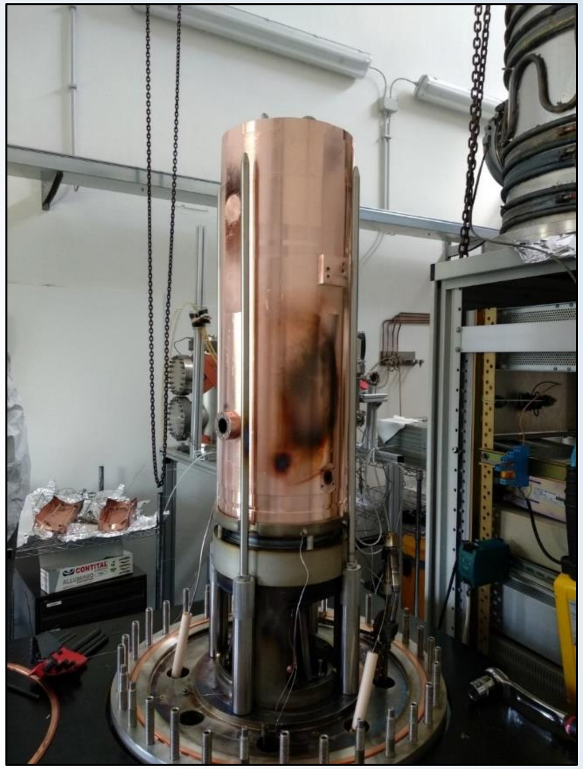
Cavity Coating

Baking procedure	
Chamber temperature [°C]	120 - 220
Substrate temperature [°C]	400
Baking time [h]	48 - 96

Sputtering procedure	
Sputtering pressure [mbar]	0,08 – 0,2
Cycle time [min]	15
Number of cycles	16 – 20
Cathode current [A]	3,25 – 3,5
Bias voltage [V]	-130

Coated Cavity

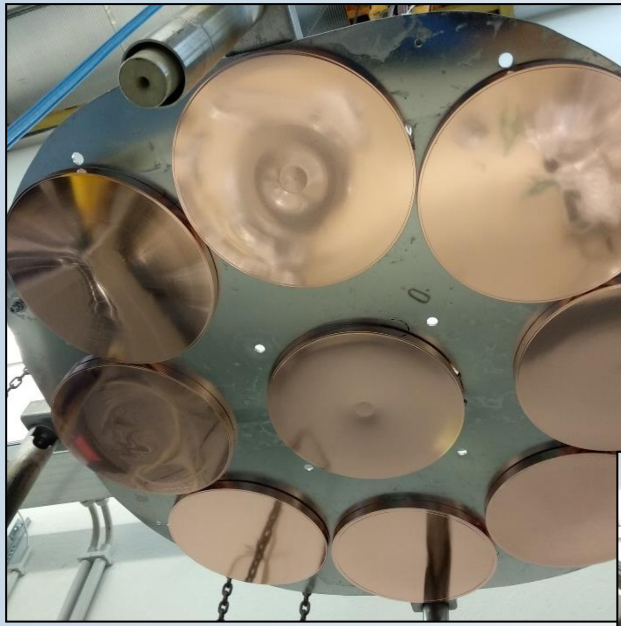
System maintenance



Cavity assembled on coating system

Nb cathode plasma cleaning

Cavity Plates coating



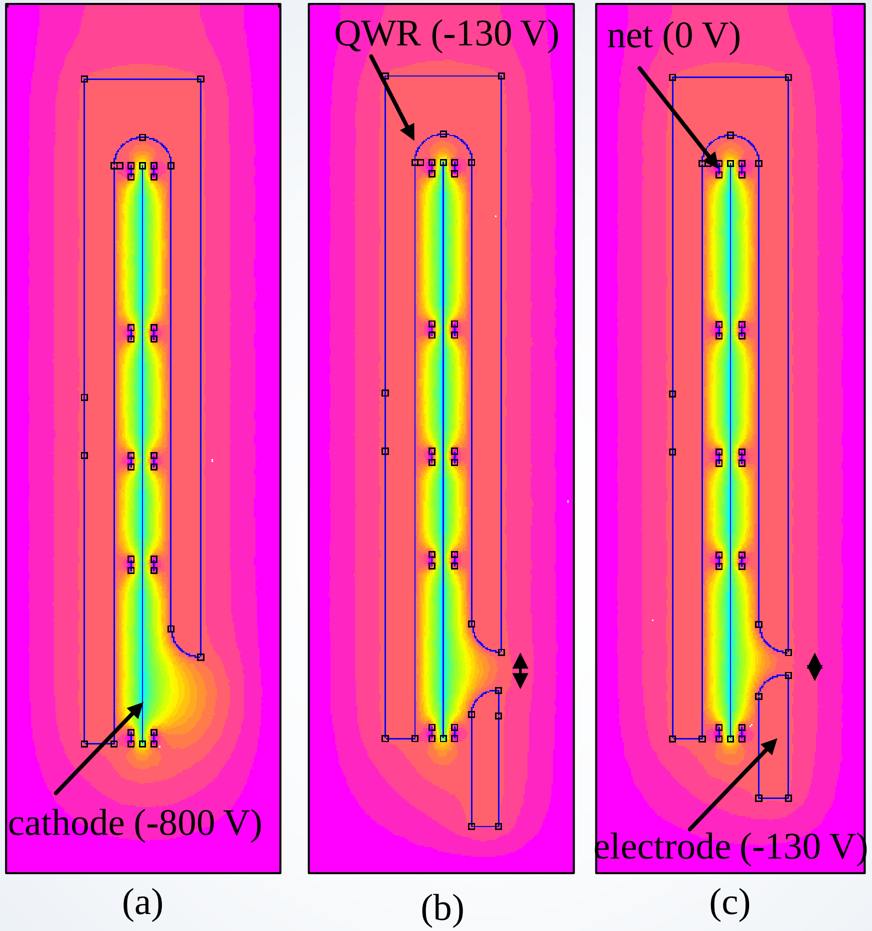
QWR plates before coating

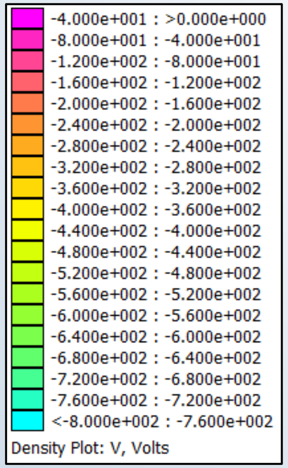
Coated Plates

Procedure	Parameters
Chemical preparation	
Ultrasound cleaning	In soap solution at 60 °C for 60 min;
Surface activation	In $(NH_4)_2S_2O_8$ solution at 20 °C for 20 min;
SUBU	SUBU at 72 °C for 4 – 6 min.
Passivation	H_3NO_3S for 5 min.
Water rinsing, drying, packaging.	
Deposition process	
Baking	Chamber temperature: 100 – 120 °C; Substrate temperature: 300 °C; Time: 48 – 96 hours.
Sputtering	Argon pressure: 0,2 mbar; Cycle time: 6 min; Number of cycles: 10; Substrate temperature: 200 °C; Cathode current: 12 A; Bias voltage: -130 V;

QWR antenna delamination

- Correct positioning of the electrode uniforms electric field distribution in the top antenna area;
- Optimal QWR – electrode distance to avoid delamination seems between 30–40 mm.



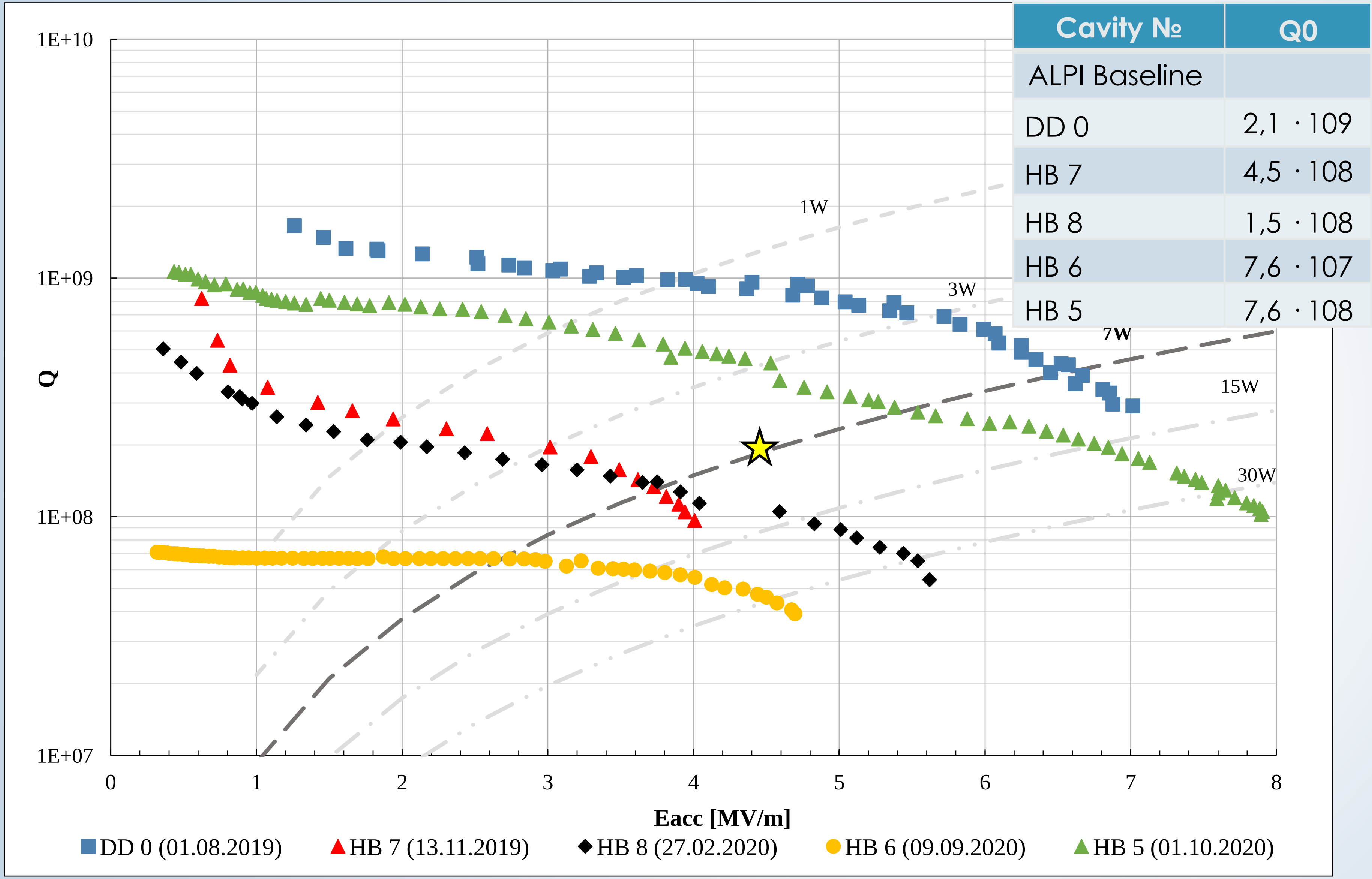


Electric field simulation with QWR – electrode distance: (a) – without electrode; (b) – 40 mm.; (c) – 30 mm.

Delaminated cavity

No delamination

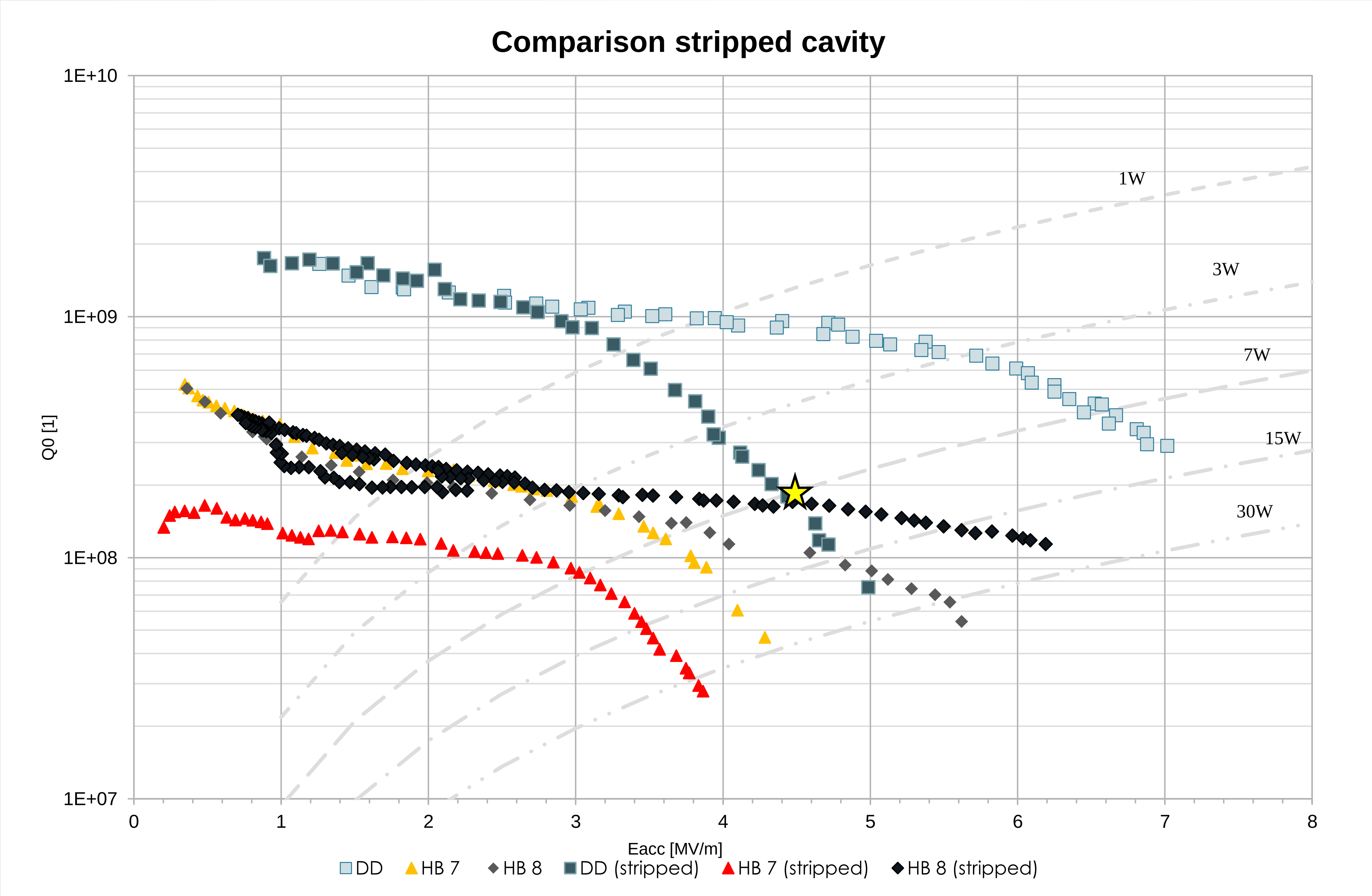
LNL cavity performance – 160 MHz @4.2K



Cavity №	Q0	Q [7W]	E_{acc} [7W], MV/m	Rs, [nΩ]
ALPI Baseline		$\geq 1 \cdot 10^8$	≥ 4,5	
DD 0	2,1 · 109	$4,3 \cdot 10^8$	6,5	14
HB 7	4,5 · 108	$1,4 \cdot 10^8$	3,7	90
HB 8	1,5 · 108	$1,4 \cdot 10^8$	3,8	195
HB 6	7,6 · 107	$6,7 \cdot 10^7$	2,6	383
HB 5	7,6 · 108	$1,8 \cdot 10^8$	5,5	38

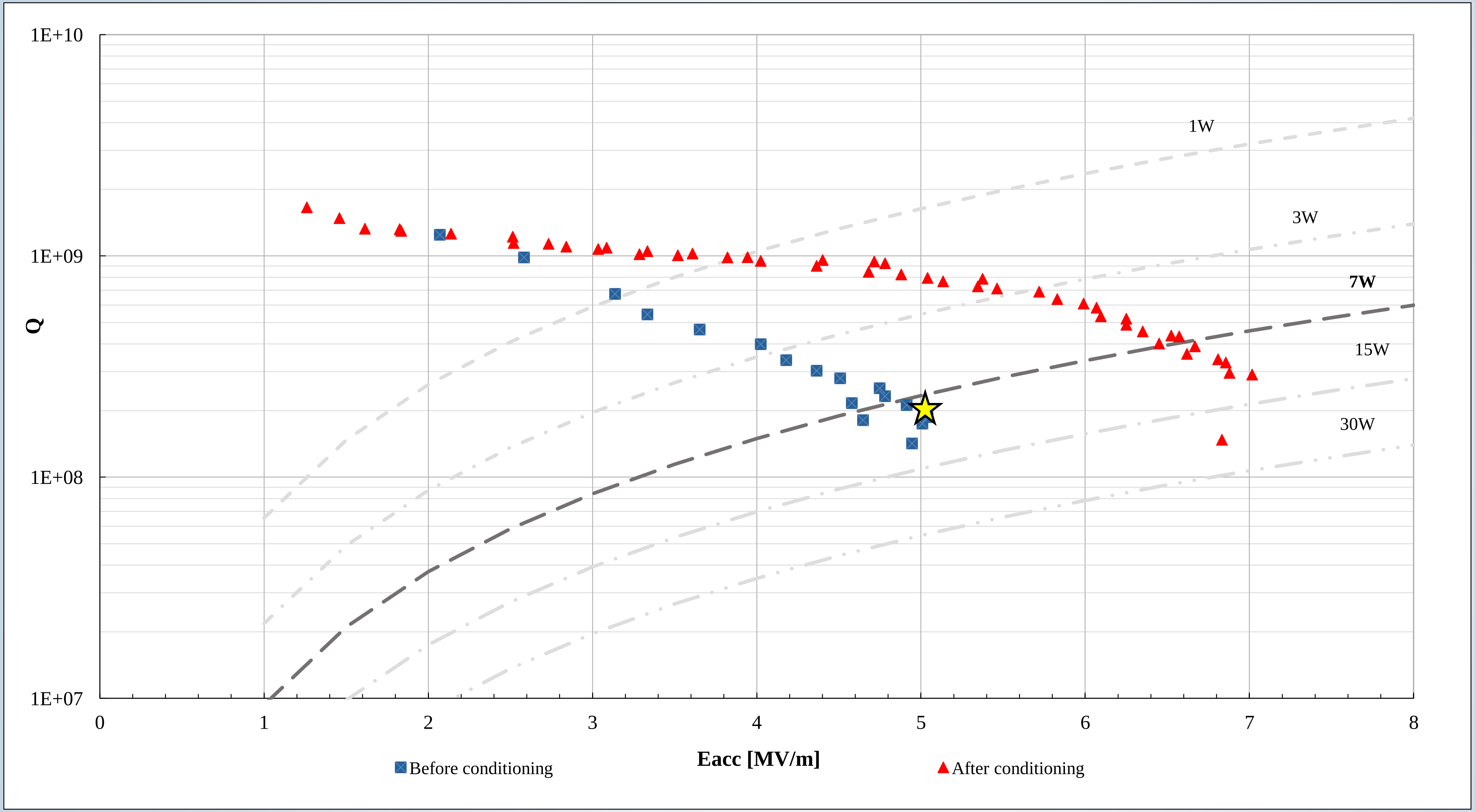
First cycle RF cold test measurements result.

LNL cavity performance - 160 MHz @4.2K

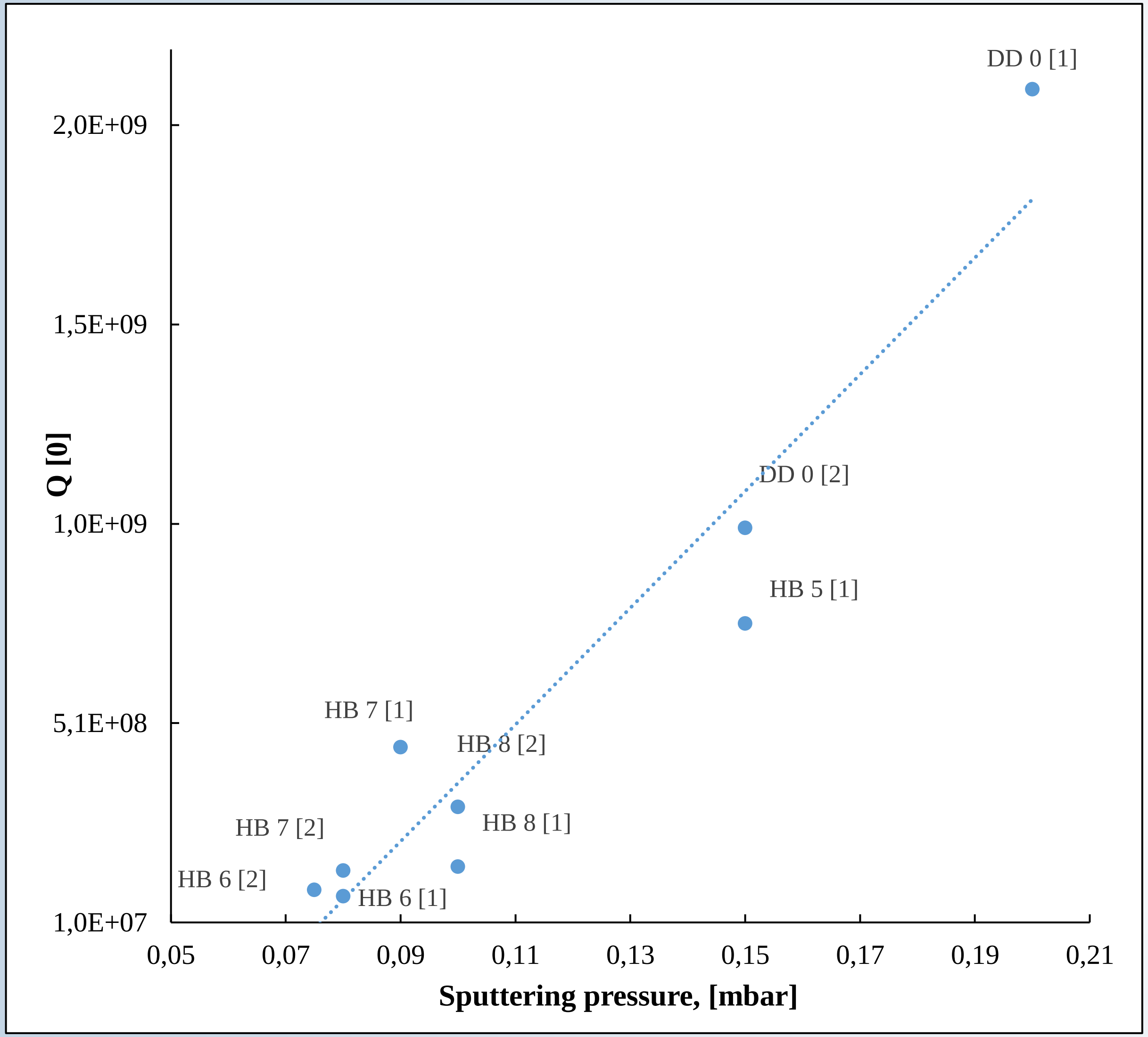


after stripping

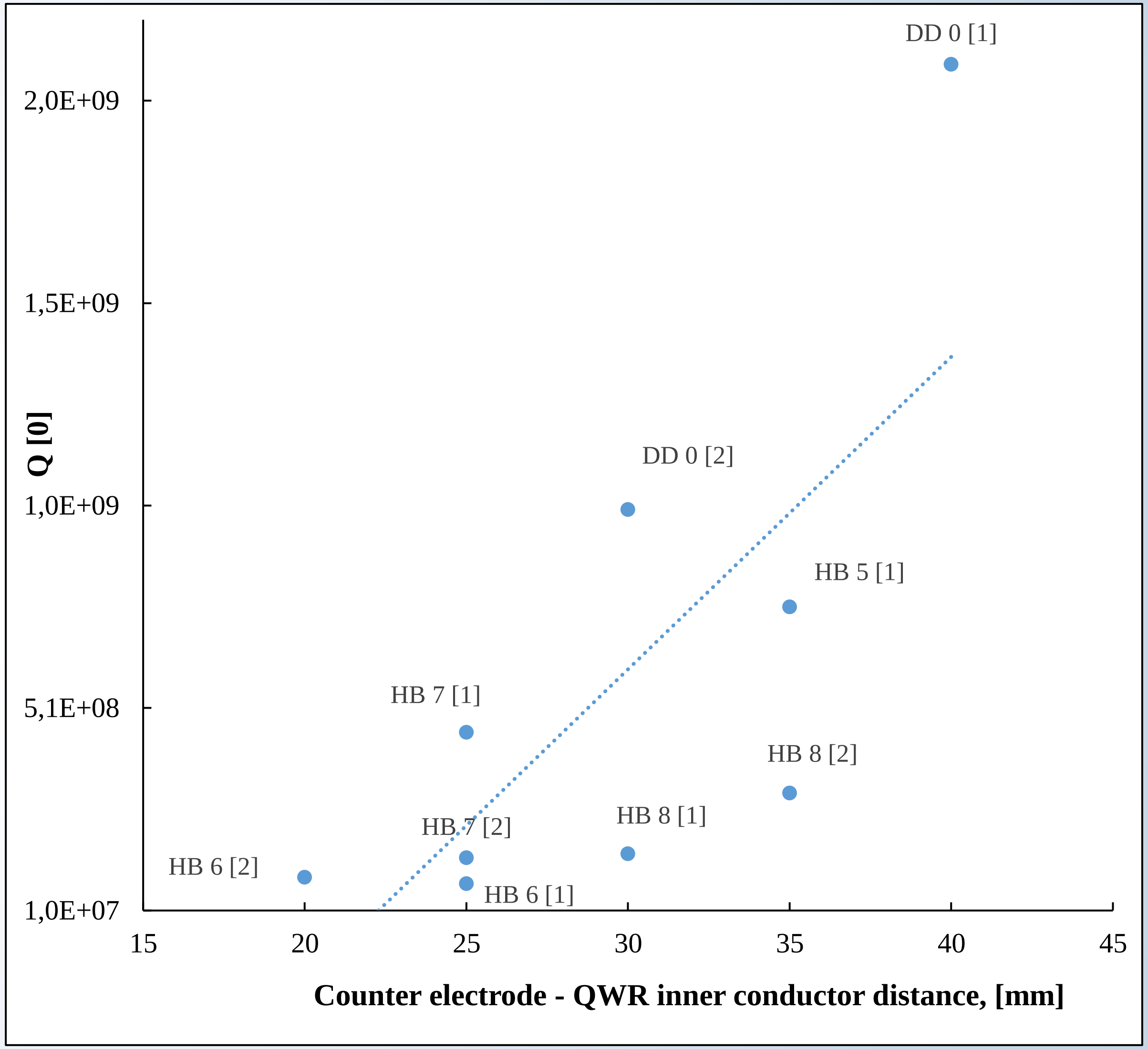
DD back extruded cavity – 160 MHz @4.2K



Sputtering parameters vs QWR performance



Q vs. sputtering pressure



Q vs. electrode distance

Conclusions

- A **major refurbishment** of the sputtering systems and cavity tests facility were carried out at LNL.
- **Improvements and upgrades** were made in substrate preparation (mechanical and chemical).
- **Intense R&D** was carried out so to redefine the deposition parameters necessary to obtain cavities respecting ALPI requirements.
- **3 cavities** (of the 8 needed) were ready to be installed in the cryostats
- the **back extrusion** technique for cavity production was explored and proved to be efficient, cost-effective and promising.

Special thanks

… to the LNL coating group and RF LNL service: O. Azzolini, G. Bisoffi, D. Bortolato, E. Chyhyrynets, E. Fagotti, E. Munaron, C. Pira, F. Stivanello, A. Tsymbaliuk.

Thanks for your attention

keppel@lnl.infn.it

SPES
exotic beams for science

INFN
Istituto Nazionale di Fisica Nucleare