QWR Nb sputtering

MoP04

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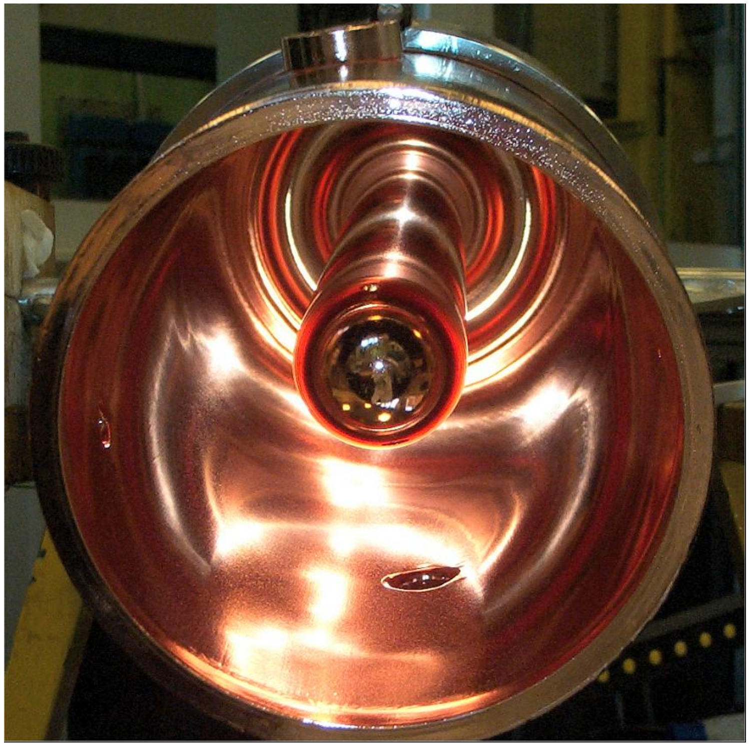
SC Quarter Wave Resonators

- SC QWRs were developed in the 70's to build independent phased superconducting linacs for heavy ions
- Their advantages are:
  - a very broad acceptance in velocity
  - An excellent mechanical stability
  - a shape simple to build, treat and clean
  - the absence of joints in high current regions
- Nowadays QWRs are proposed also as accelerating structures for high intensity beams



Superconducting QWRs

- QWR evolution:
  - Pb on Cu (Waizmann, Washington University, Stony Brook, Mumbay)
  - Nb Sheet+explosevely bonded Nb on Cu (Argonne, JAERY)
  - Full Nb double wall (Weizmann, Legnaro, TRIUMF...)
  - Double wall, Nb for the inner wall, SS for the outer wall (Argonne, New Delhi)
  - Nb sputterd on Cu (Legnaro, Peking University, Canberra)

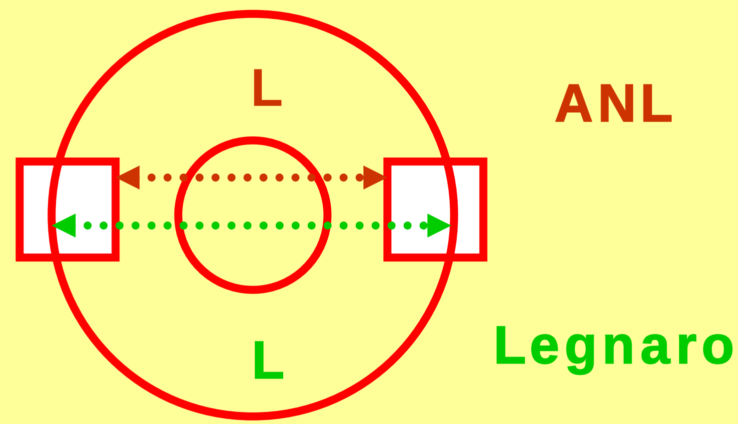
hand set tuner

Continuous frequency tuning

Fast tuner

Accelerating and surface fields

- **Accelerating field Ea:**
  $E_a = \Delta E_{max}/(q*L)$, with
  ΔE_{max} = max. Energy gain,
  q = state of charge,
  L = inner resonator length.
  But, pay attention:



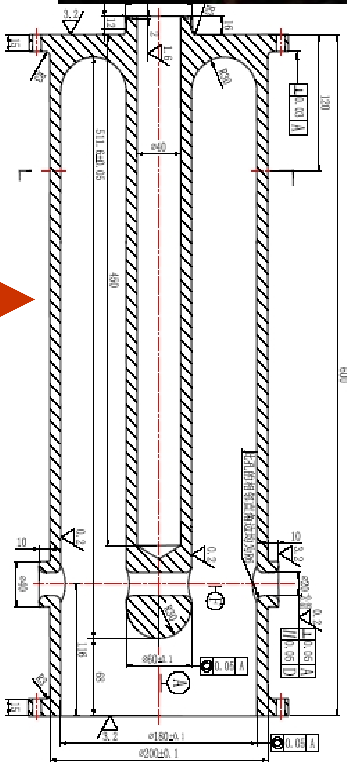
- **Electric surface field**. In QWRs Es/Ea ≈ ½ than in elliptical cavities, consequently the performance obtained in QWRs results comparable to the ones obtained in elliptical cavities in terms of electric surface fields Es.

QWR sputtering development at LNL

- 1988: a research project on QWR Nb sputtering started at LNL (Palmieri)
- 1991: first sputtered prototype;
- 1993: three prototypes reach 6 MV/m @ 7 W dissipated power
- 1995: Four high β resonators installed in ALPI (4 MV/m @ 7W); process improvements allowed reaching 7 MV/m @ 7W
- 1998: Four new cavities operate at 6 MV/m @ 7W in ALPI
- 1998: The substitution of Pb with Nb allowed to reach 4 MV/m in a medium β ALPI resonator
- 1999: The upgrading of medium β resonators began
- 2003 : All the 44 accelerating cavities had their Pb superconducting layer replaced by Nb, the average operational field is 4.4 MV/m

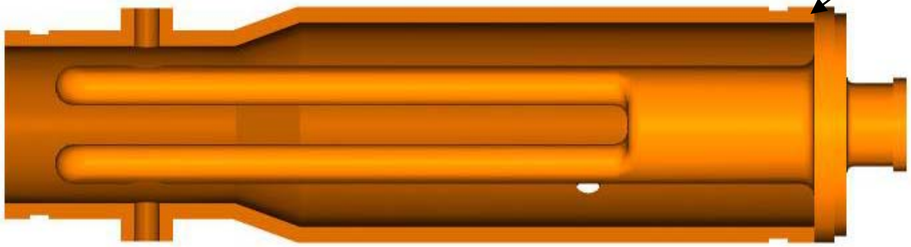
Others Nb/CU QWRs

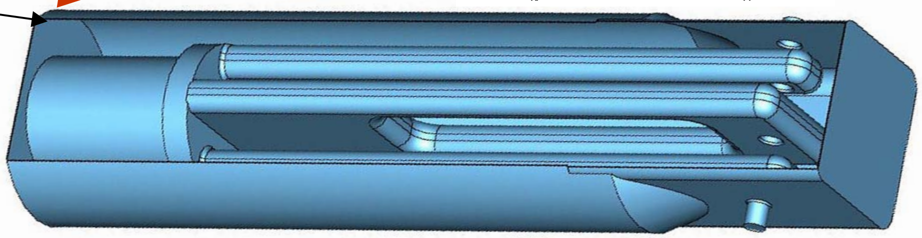
- The Institute of **Heavy Ion Physics in Peking** built, always by DC based Nb sputtering, a QWR for the booster of the Beijing Radioactive Nuclear Beam Facility. In spite of a not satisfactory coating on a substrate brazing joint, it overcame 5 MV/m. Further development is foreseen once new substrates will be available.
- At the **Australian National University** DC magnetron-sputtering configuration was developed for Nb QWR sputtering. Two resonators were produced and installed as superbuncher and time-energy lens in the ANU SC booster. Nb sputtering will be applied to the new accelerating structures developed.



β= 0.1

Demountable RF joints





β= 0.05

Nb sputtering advantages

- Mechanical stability
- Frequency not affected by changes in the He bath pressure
- High thermal stability
- Stiffness
- High Q of the normal conducting cavity (helps during multipactoring conditioning)
- Absence of Q-disease
- Insensitivity to small magnetic fields
- Absence of vacuum joints
- No degradation with time after installation

The lower performance at high fields, due to the more pronounced Q-slope of Nb/Cu resonators, is not an issue in QWRs as it is in high β cavities, because beam dynamic constraints ask for limiting the accelerating gradient in the low β section of linacs to values well reachable by Nb sputtered resonators

QWR sputtering technology

- At present DC bias sputtering showed to be the most consolidate technology for large scale Nb sputtered QWR production.
- The crucial steps for producing good resonators are:
  - Resonator design
  - Substrate choice
  - Construction technology
  - Surface finishing and chemical treatment
  - Sputtering
  - Assembling and test
- Further development is possible also in magnetron sputtering, but it is not completely developed yet.

Resonator design

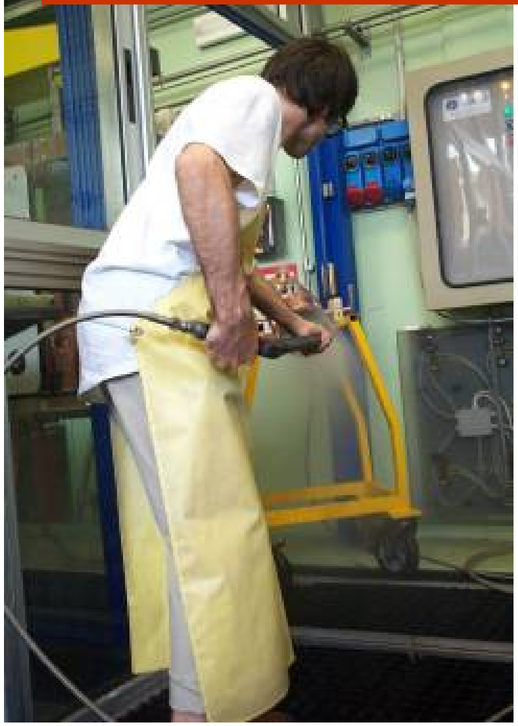
- Some constraints are mandatory:
  - To have the possibility of both the cathode and the grounding electrode inside the resonator
  - To assure a sufficient distance between cathode, grounding nets and resonator surface in order to allow the plasma discharge to take place.
  - To avoid any sharp angle and unnecessary holes in high current regions
- An optimum cavity shape can be find if the necessary constraints are kept in mind since the beginning of the cavity design.

The Substrate

- The substrate has :
  - To assure proper and uniform film cooling
  - To avoid impurity release on the sputtering chamber atmosphere and on the film
- Usually **Cu is used** and its purity, thermal conductivity, microstructure and porosity are crucial in reaching high performance. We got the best results using OFHC certificate grade Cu
- **Al could also be** used offering many advantages:
  - good thermal conductivity,
  - reduced cost,
  - easy construction technology
  - reduced activation risk due to a shorter life time of activated radioisotopes.

A cavity having Q_0 of $2.5x10^9$ has been produced, but the necessity to cool down the substrate during the sputtering process delayed the use of this material. A further difficulty is the necessity to optimize the chemical processes both for Al treatments and Nb stripping from the substrate.

Surface finishing and chemical treatments

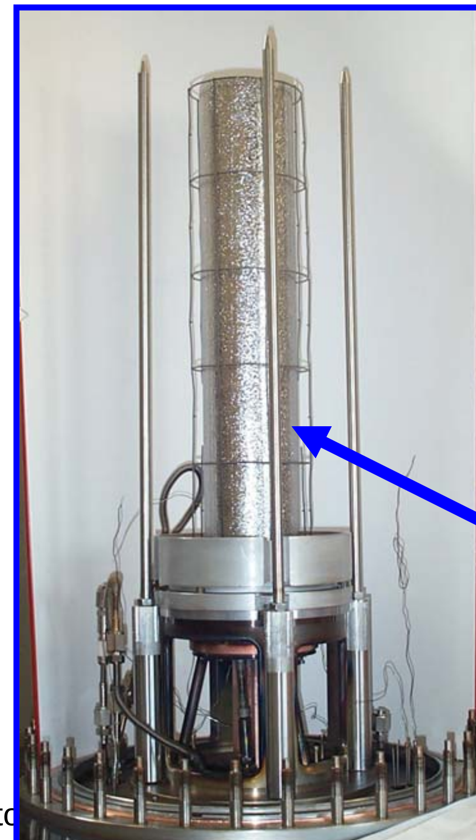


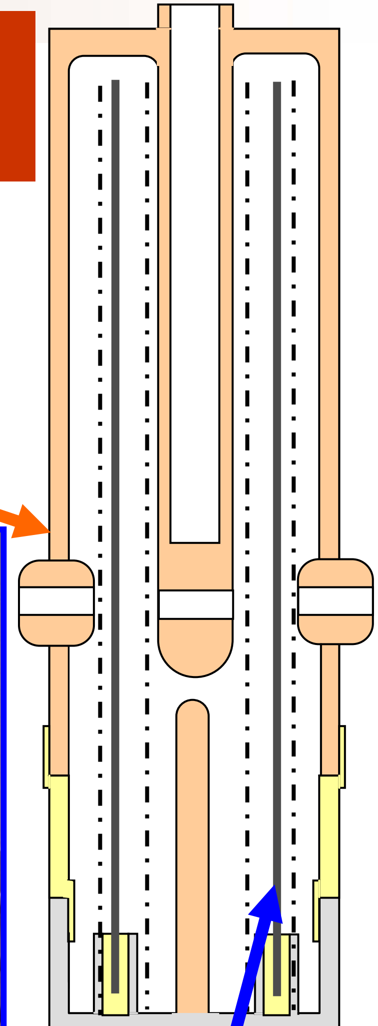
- **Electropolishing** (20μm, 2 hours, phosphoric acid+butanol, computer controlled)
- **Rinsing** (water, ultrasonic water bath, HPR)
- **Chemical polishing** (10μm, 4 min, SUBU5)
- **Passivation** (sulphamic acid)
- **Rinsing** (water, ultrasonic water bath, HPR)
- **Drying** (ethanol, nitrogen)

QWR Nb sputtering

Sputtering chamber

Cu base





Cathode:
Nb tube

- Good vacuum
- No discharges
- High substrate temperature

The sputtering process

The sputtering parameters

- Argon pressure: 0.2 mbar
- Substrate temperature: 300-500°C
- Cathode voltage: 1KV
- Power sustained by discharge: about 5 KW
- Bias: - 120 V

Average film thickness:
about 2 μm

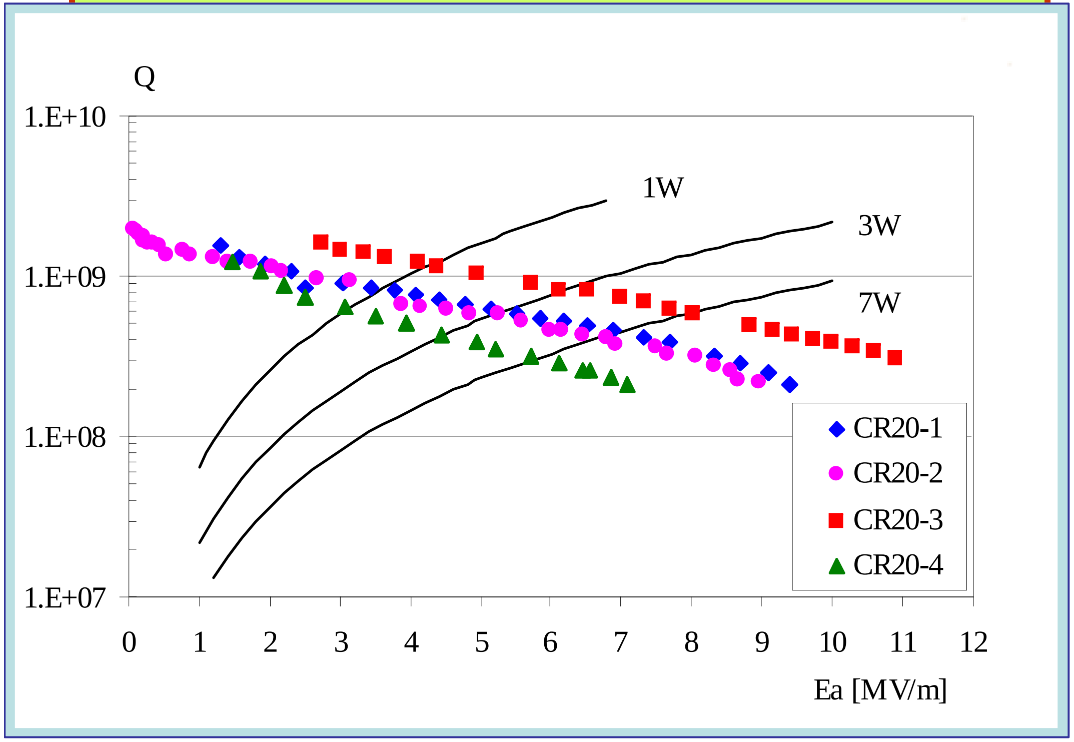
The cavity end plate is also Nb sputtered in a devoted chamber, set up for producing PIAVE SRFQs end plates

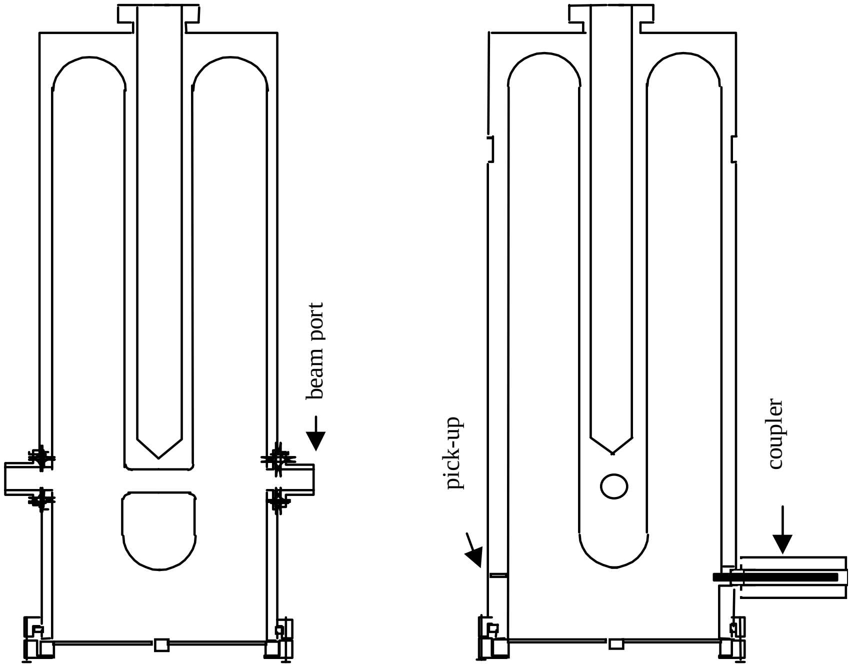
Operation sequence

- Mounting the resonator in the sputtering chamber
- Pumping the vacuum chamber
- Resonator bake-out, at about 500°C for a couple of days
- The sputtering process: in 12 steps of about 15 minutes each
- Cooling the resonator at room temperature in vacuum
- The sputtering cycle of a QWR requires 9 days

Nb/Cu QWR performance in properly designed and built substrates

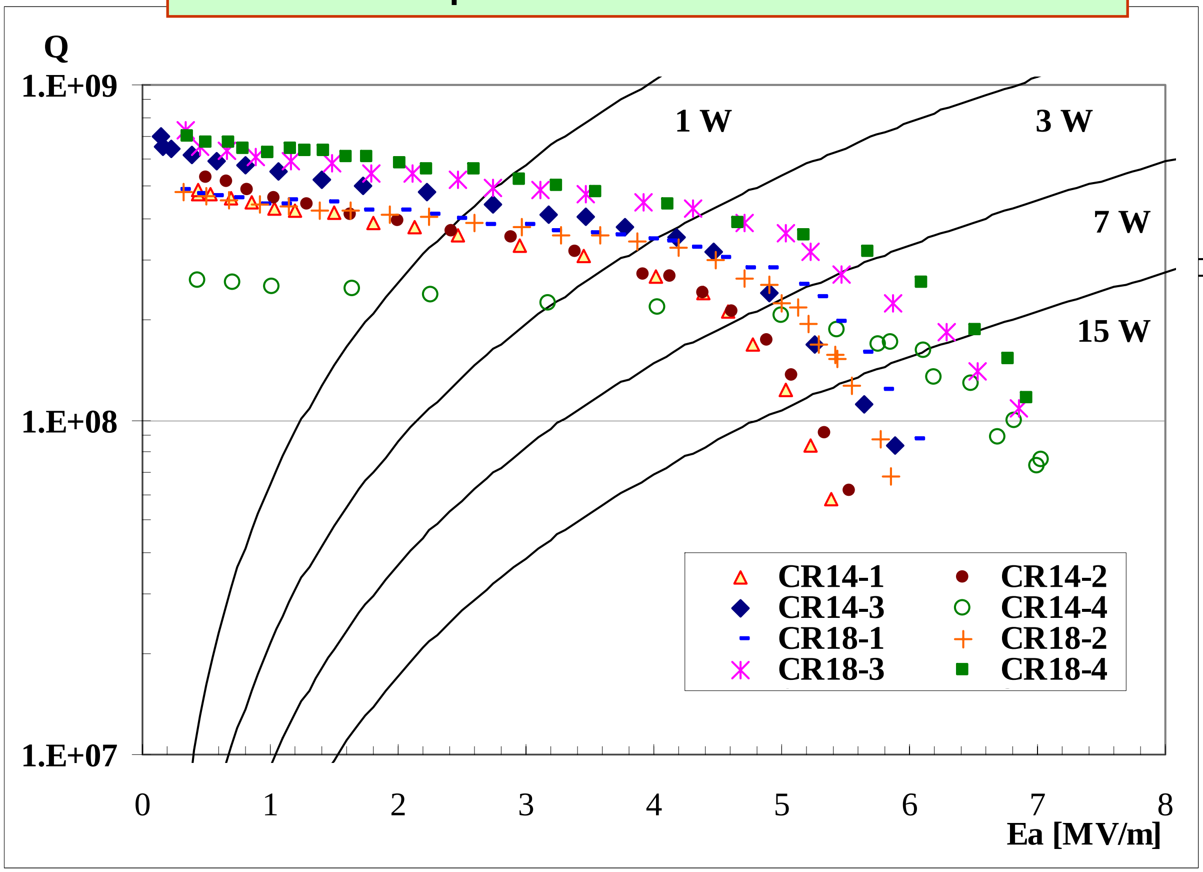
- ALPI β=0.13, 160 MHz
- The cavity has no brazed joints
- The shorting plate is rounded
- The coupler is capacitive
- The beam ports are jointed by indium gaskets

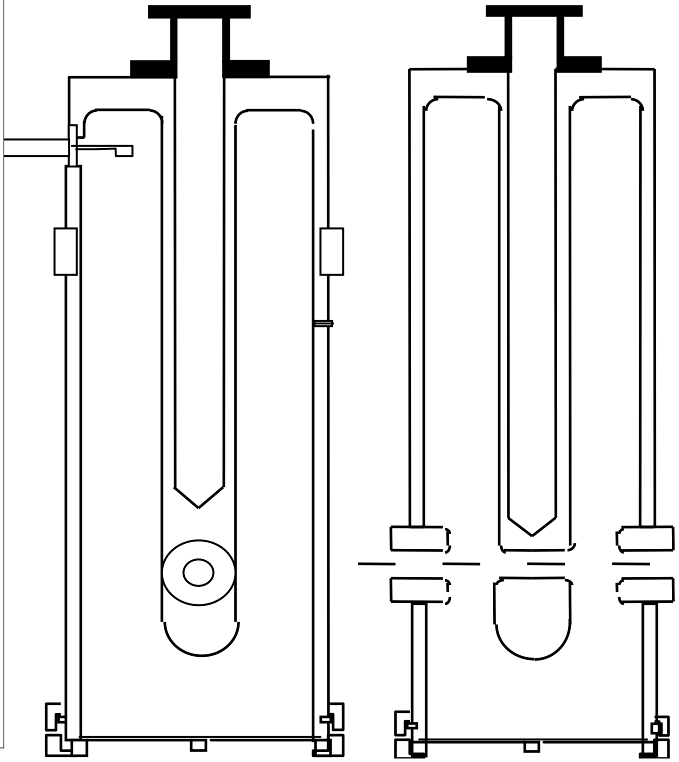




QWR Upgrading by Nb sputtering

- ALPI β=0.11, 160 MHz
- Many brazed joints
- Holes in high current regions
- The shorting plate is flat
- The coupler is inductive

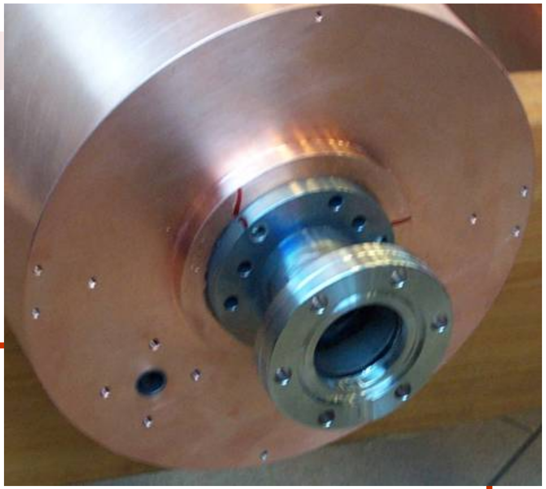




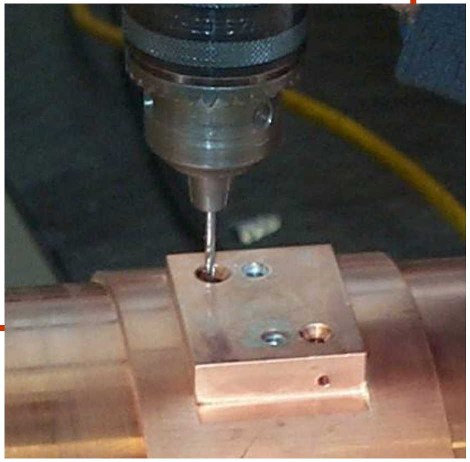
ALPI medium β cryostat

ALPI

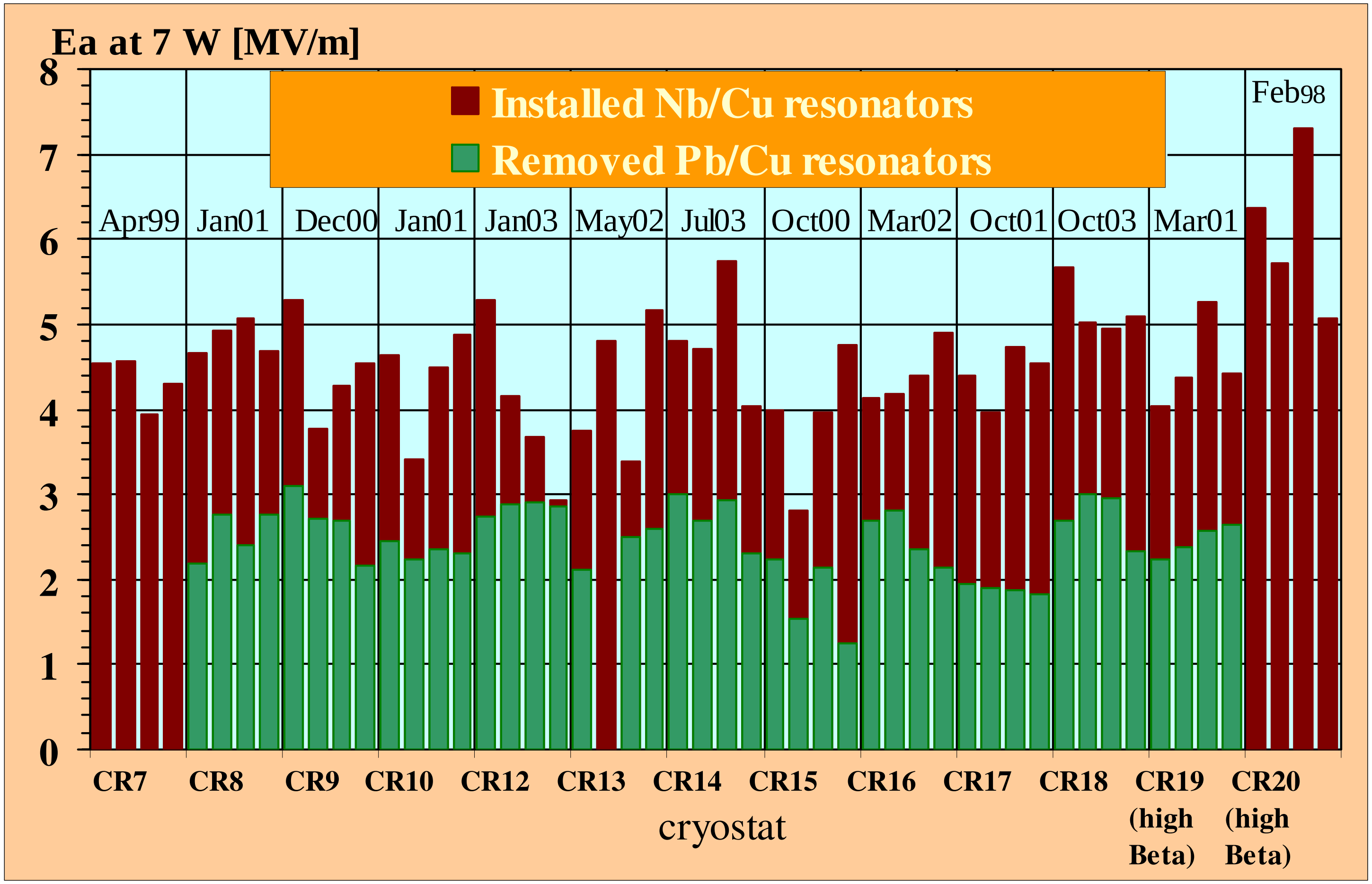
ALPI upgrading results



- 46, previously Pb electroplated, QWRs were upgraded by Nb sputtering.
- The obtained performance is lower than that obtained by sputtering on new substrates, but the gap both in Q and Ea has been improving with time. Q_0-value of 7×10^9 and Ea of 6 MV/m at 7 W were obtained in the last produced resonators.
- The average E_a in ALPI is however limited to 4.4 MV/m at 7 W, due to the lower E_a of resonators produced in between 1999 and 2001, when we had only bad substrates available and a very tight production schedule.
- The upgrading of medium β ALPI resonators gave a substantial increase in ALPI performance being the average Ea value of previously installed Pb/Cu resonators limited to 2.4 MV/m.



ALPI QWR upgrading by Nb sputtering



- On line accelerating field values of ALPI Nb/Cu QWRs before and after the upgrading process. The resonators of CR12,CR13,CR16 need further HP RF conditioning

Sputtered QWRs at work

- We have installed in ALPI 54 Nb sputtered QWR in between 1995 and 2003.
- All of them, but one having the feeding line interrupted, are operational in ALPI.
- The cavities do not show any sign of degradation with time
- Frequency feedback is not necessary because the resonators are insensitive (<0.01 Hz/mbar) to pressure fluctuations of the He cooling bath (up to 200 mbar in ALPI).
- The resonators are generally set for beam acceleration at the accelerating field sustained at 7 W dissipated power. They operate slightly over-coupled in a self excited loop, locked in field and phase.
- Once locked in amplitude and phase, the cavities remain locked for weeks without necessity of any adjustment, making their operation easy and reliable.

Conclusions

- The Nb sputtering technology shows to be very effective in producing reliable resonators, which have high performance, are very steadily phase locked and are easy to put into operation.
- Even better results can be obtained using suitable substrates.
- The high number of produced and operational resonators and the reliability of the sputtering process (rejection rate less than 10%) demonstrate that the technology is mature and very competitive and can be industrially applied.

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Thanks for your attention