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Markus Schneider :: RF group :: Paul Scherrer Institut

Status of the Injector 2 RF upgrade at PSI

10th Continuous Wave and High Average RF Power Workshop, 25 to 29 June 2018, Hsinchu, Taiwan

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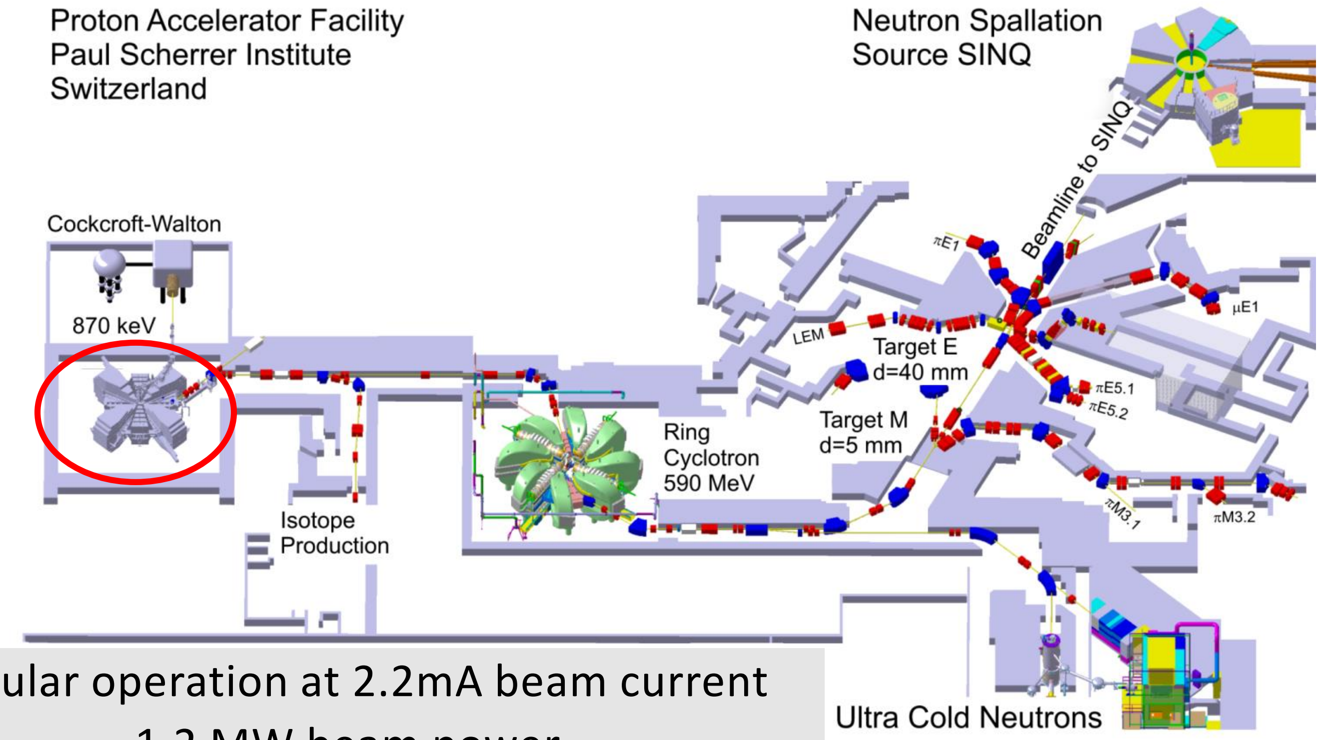
Agenda

- Overview HIPA and injector 2 cyclotron
- Project goals and milestones
- Shutdown 2018: installation of new 50 MHz resonator 2
- the new rf system
- Tests of new 50 MHz resonators:
  - Q_0
  - Radiation of rf in vacuum chamber
  - Measurement of bremsstrahlung
  - bridge between electrodes
  - tuner
  - coupler

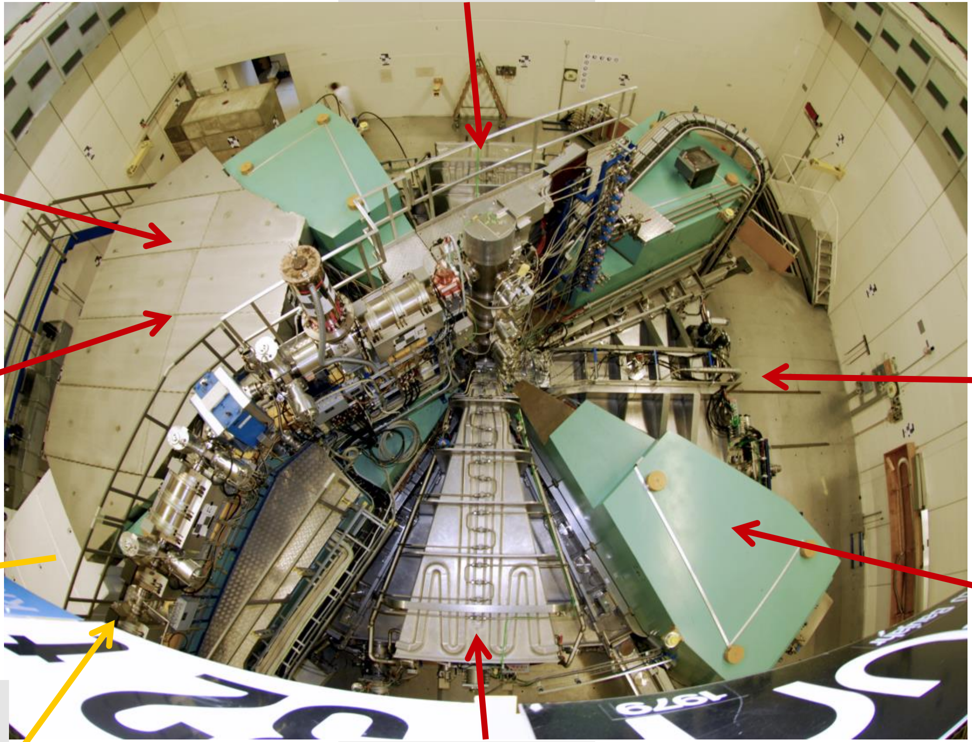
Overview High Intensity Proton Accelerator

injector 2 cyclotron



Regular operation at 2.2mA beam current
1.2 MW beam power
Tested up to 2.4 mA beam current

The injector 2 cyclotron



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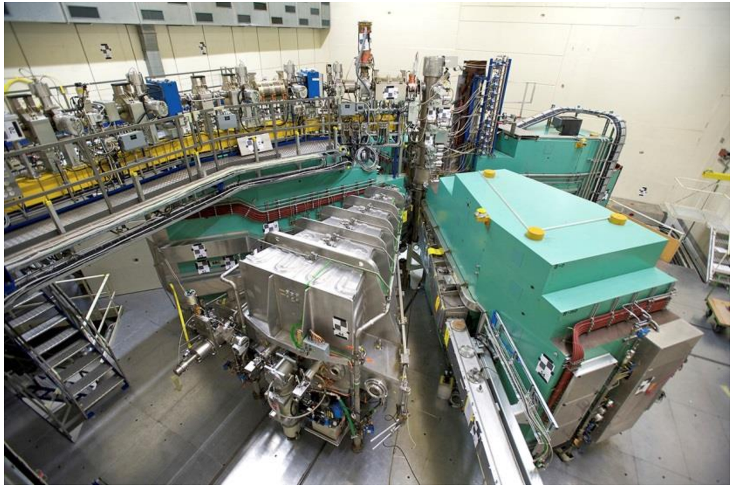
Injector 2 cyclotron



Injection energy: 870 keV
Extraction energy: 72 MeV
Number of turns: 83

Resonator	type	material	frequency	gap voltage	Wall losses in cavity	incident power @ 2.4 mA Beam
1 & 3	Double gap cavity	aluminum	50 MHz	~ 420 kVp	~ 150 kW	~ 225 kW
2 & 4	Flattop cavity	aluminum	150 MHz	~ 31 kVp	~ 5 kW	~ 14 kW
2 & 4 new	Single gap cavity	aluminum	50 MHz	~ 400 kVp @ extraction	~ 50 kW	~ 100 kW

Motivation for the injector 2 upgrade

project goal:

about 13 years ago:

dreams of **4+ mA beam current**	&	renewal of RF-systems

today:

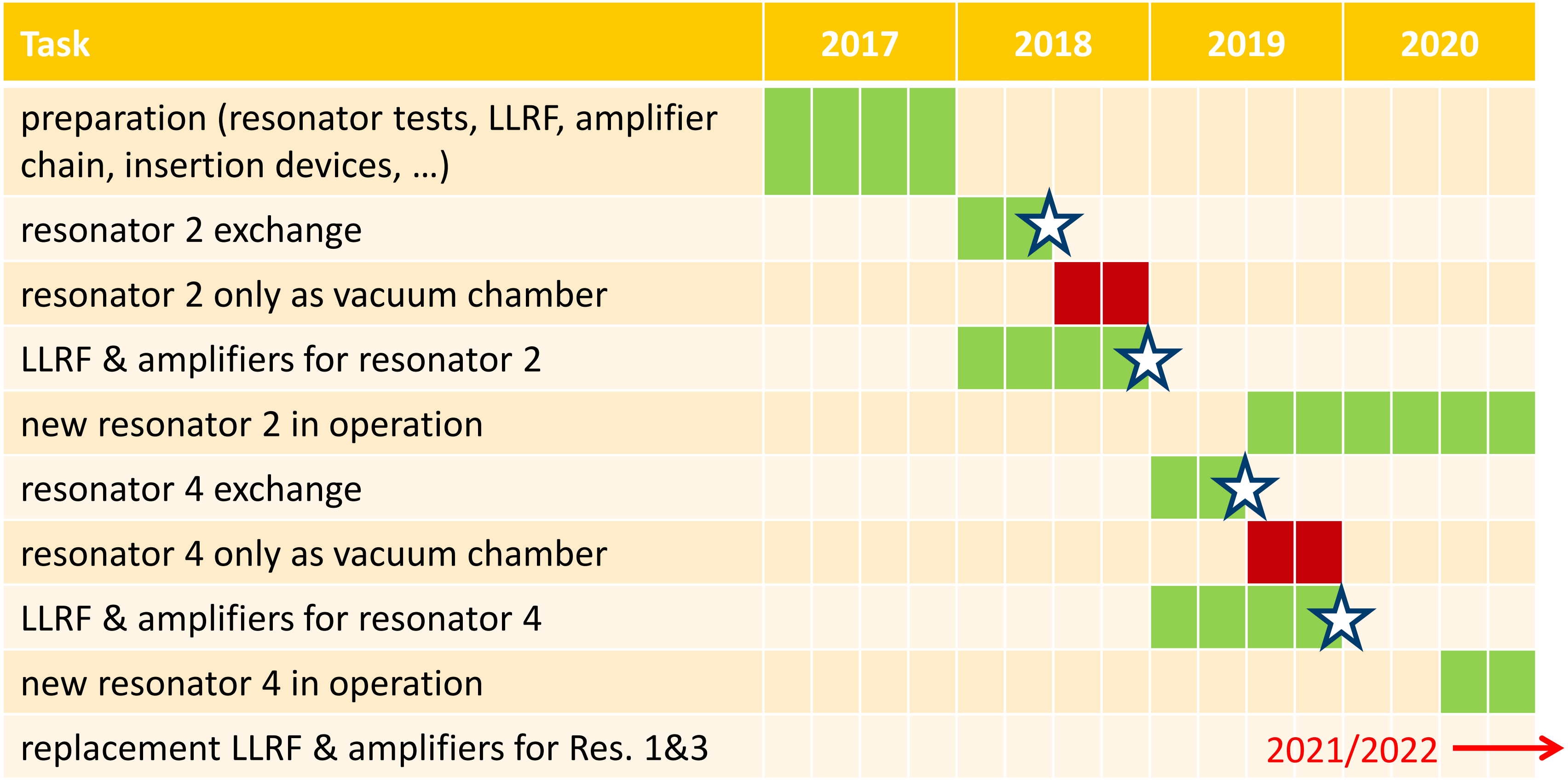
$\leq$ 3 mA beam current	&	**renewal of RF-systems**

Increase energy gain per turn -> less turns -> better turn separation -> lower extraction losses	2010 Thales: End of production of smaller tetrodes -> last order in 2010 -> finite time of operation

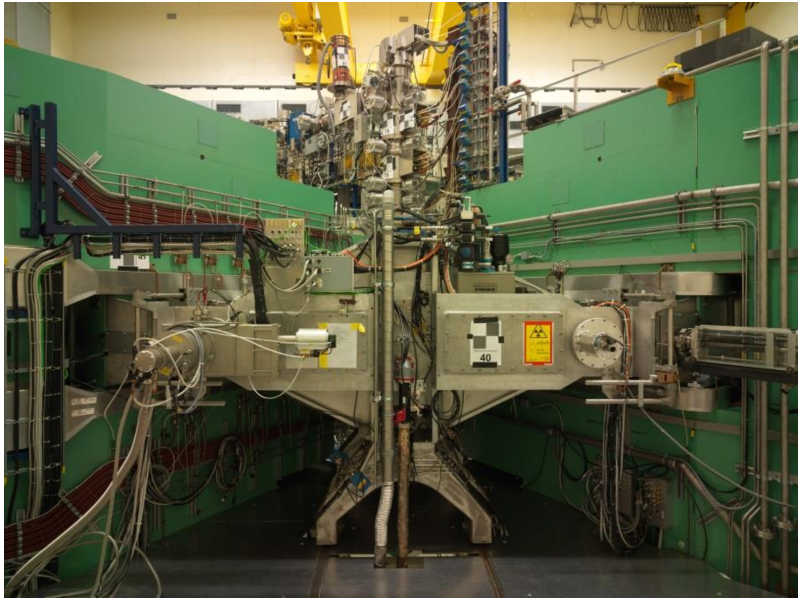
-> new rf-cavities **&** -> replacement of old amplifiers

REI2 -> Resonator Exchange Injector 2

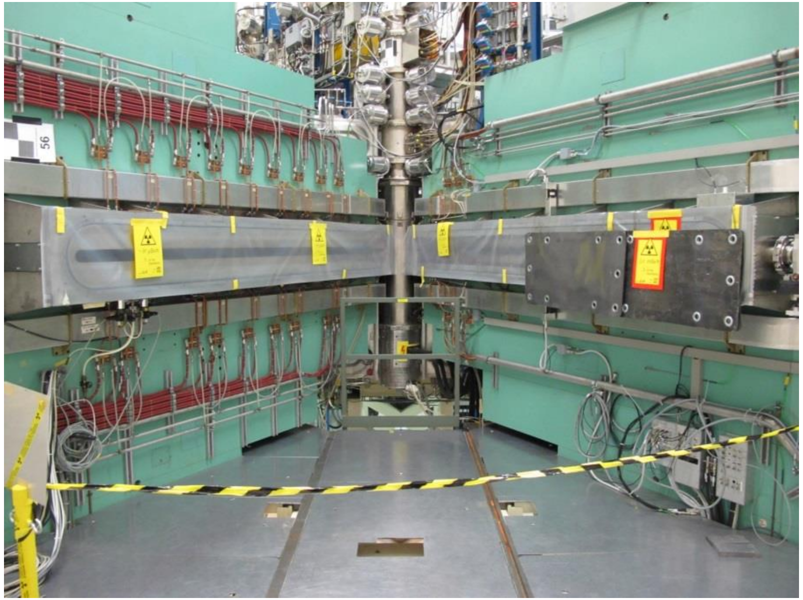
Project milestones



Replacement of old resonator 2



Old 150 MHz resonator 2



Open sector of the injector 2 cyclotron

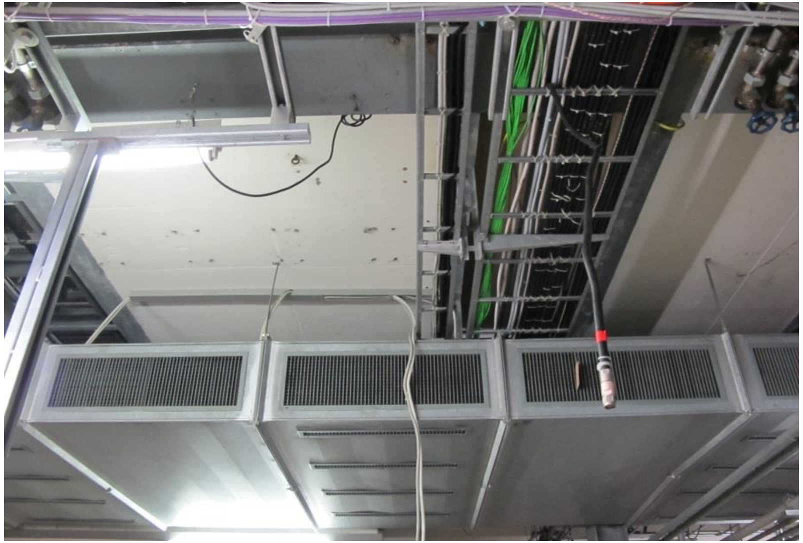
Dismantling of amplifiers for resonator 2

Rack of LLRF for resonator 2 and
1kW / 8kW amplifier chain including air cooling

Racks removed.
LLRF rack for resonator 4 still in use.

Dismantling of amplifiers for resonator 2

Matching network for
2 x 8 kW/150 MHz combining



rf-cables, $\lambda/4$ transformers and phase shifters were removed

Transportation of new resonator

On the crane in the experimental hall
(from the rf test bunker)

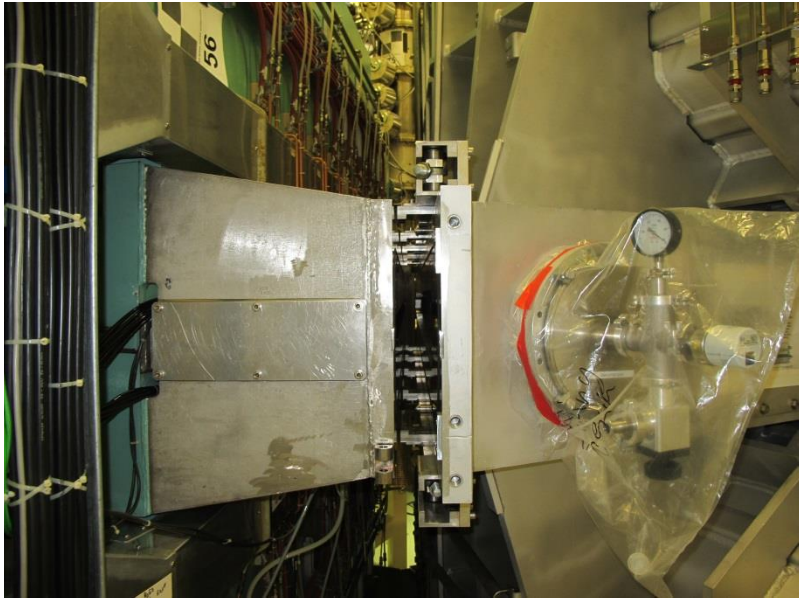
On the ground inside the PSI area

Bringing the new resonator into the injector 2 bunker

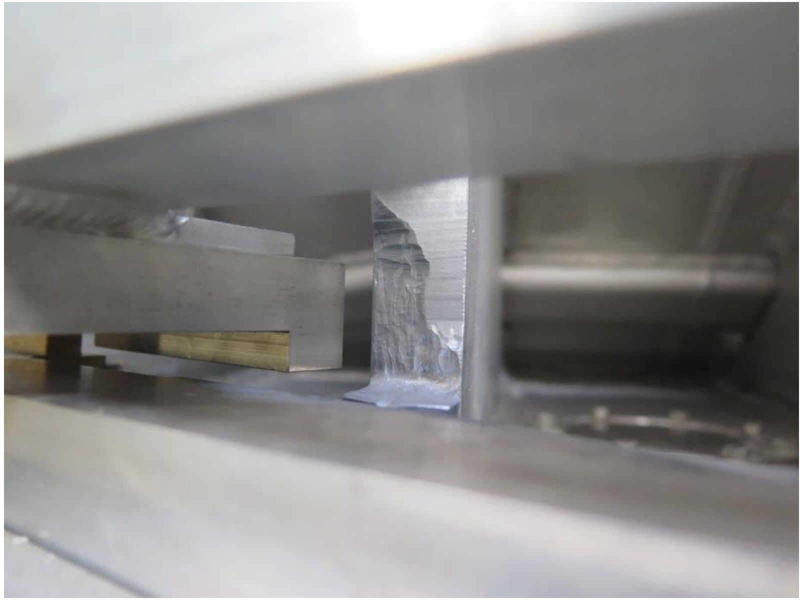
Bringing the new resonator into the injector 2 bunker

Passing trough the wall
(only about 10 cm left in height)

Installation of resonator 2 in the injector 2 cyclotron



Some misalignment in height with the quick fastener system.
Adjustment of resonator position and quick fastener system solved this issue.



Collision of quick fastener system with a fin of resonator.
Solved by some fine tuning.

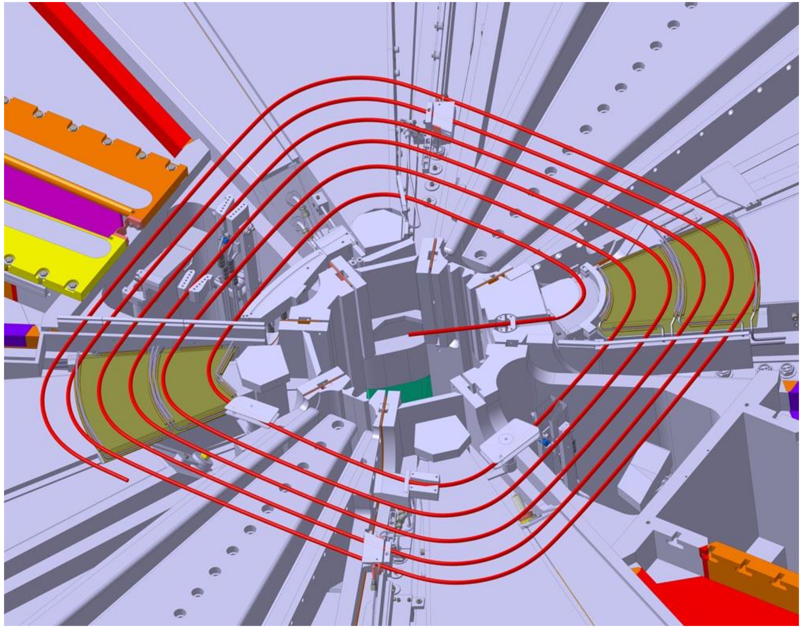
.... finally sitting in the right place

20.02.2018 first time new 50 MHz resonator 2 installed in the injector 2 cyclotron

Installation of central region components

Resonator 1

Resonator 2

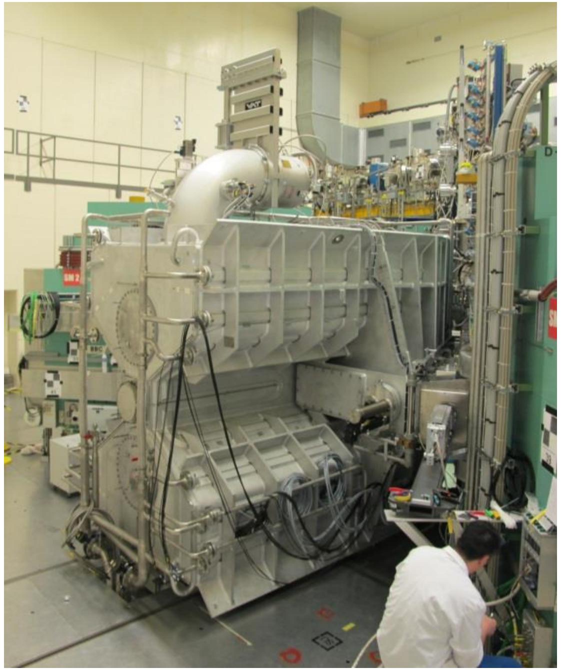


Resonator 3

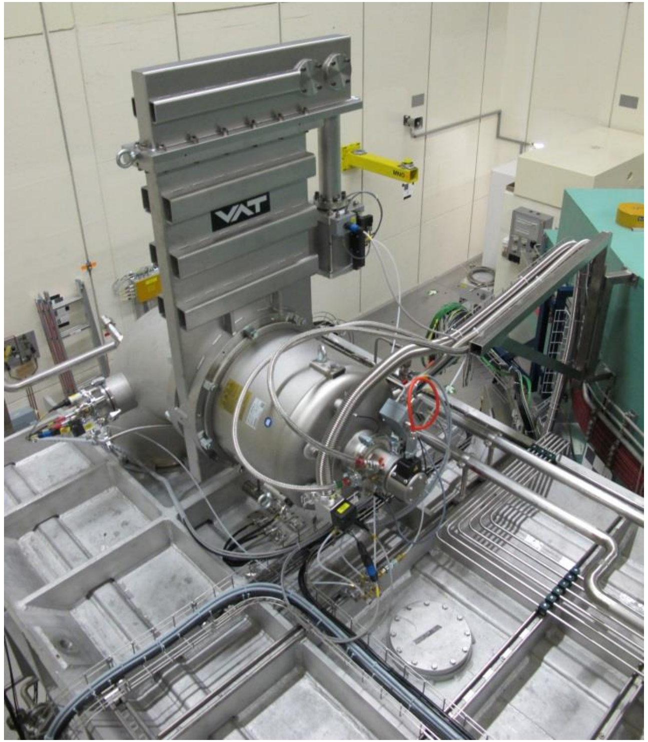
CAD model of central region with first few turns in the cyclotron

Collimators in the nose of resonator 2

Other installations

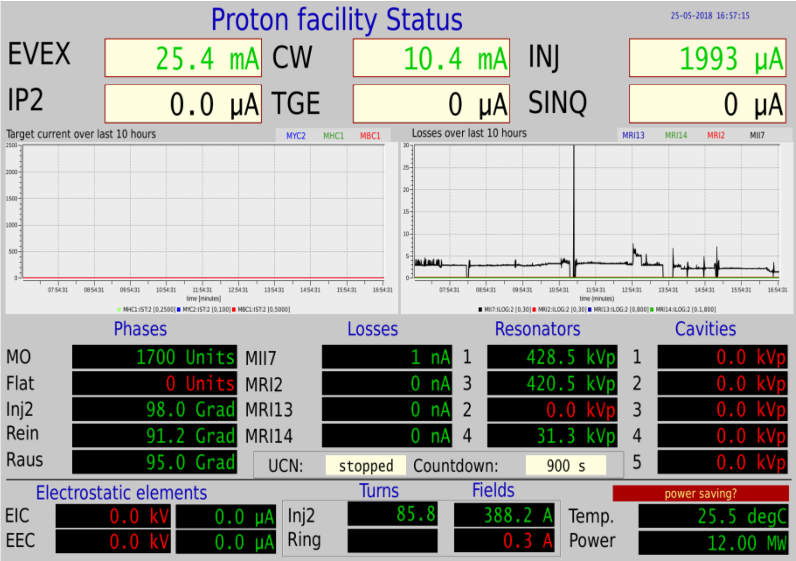


Cabling:
All cables from the bunker to outside were installed during shutdown 2018



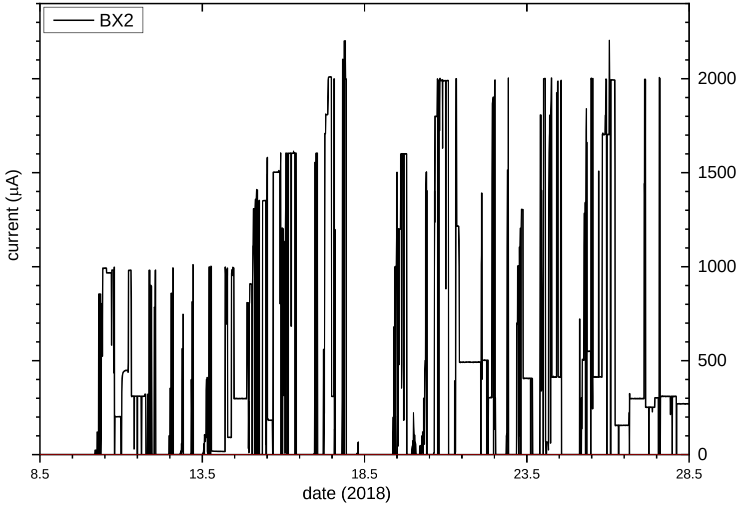
Vacuum pump for resonator 2

First tests with beam on 9th May 2018



Setup with 3 Resonators (1,3,4)

New 50 MHz resonator only installed as vacuum chamber.

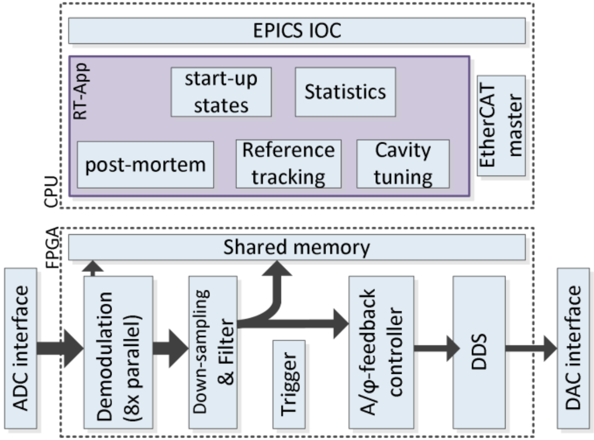


Beam current at the beam dump after the injector 2 cyclotron (BX2).

New digital LLRF system

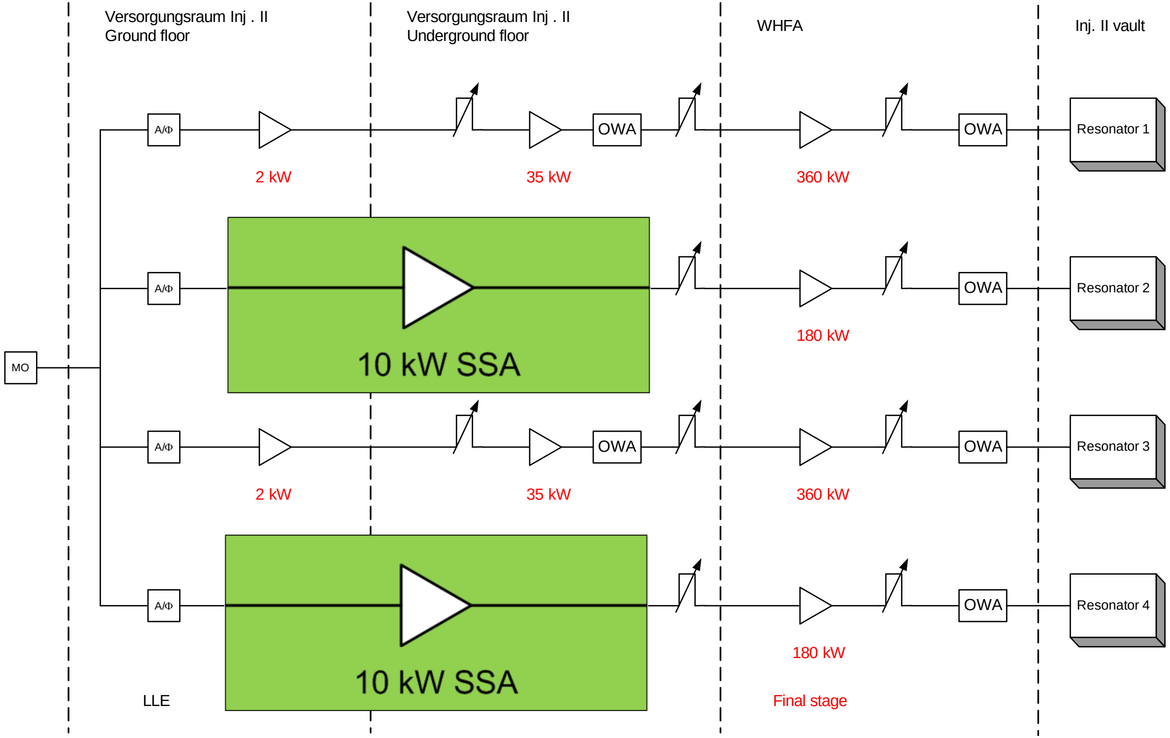
Installation for new LLRF system

- Replacement of 30 years old analog LLRF system (amplitude & phase loop, tuning system)
- New LLRF based on VME processing platform as used in the SwissFEL facility
- RF frontend for signal conditioning
- Direct sampling of rf at 50 MHz



signal processing

Amplifier chain



Phase 1: 10 kW SSA of the shelf. Sufficient power for 2.4 mA for Res. 2 & 4

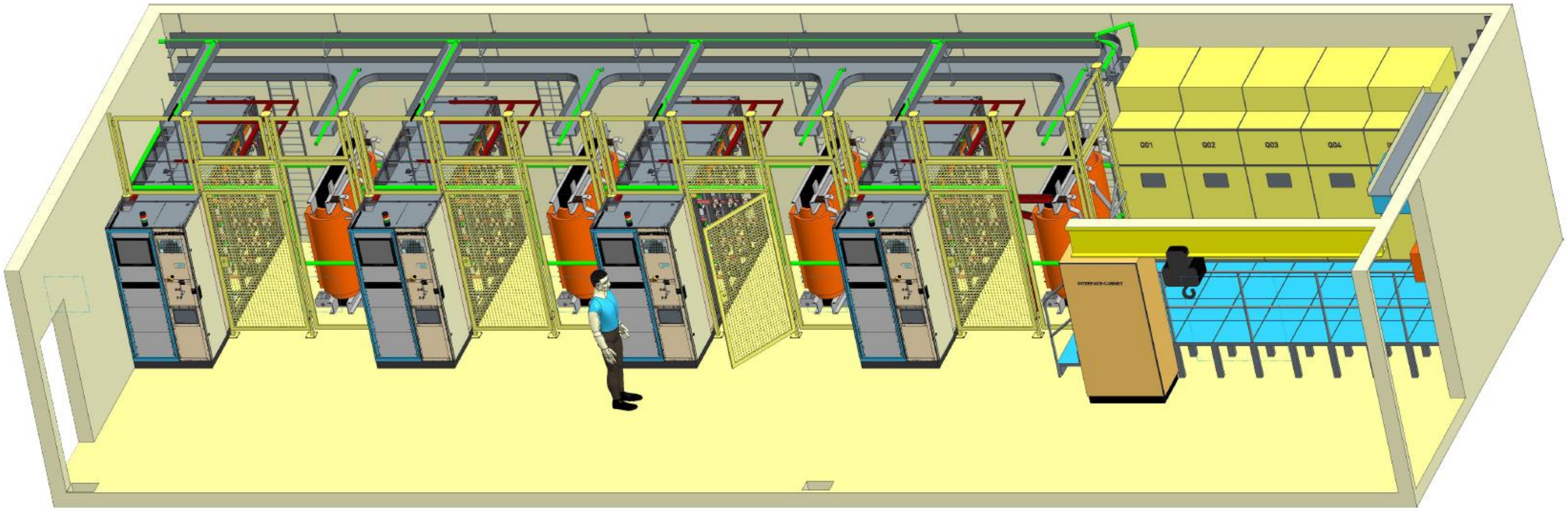
New power amplifiers for the injector 2

Power amplifiers installed on ground floor WHFA

- 4 + 1 spare 50 MHz 1MW tetrode based coaxial cavity amplifier running on a reduced power level. Working point adapted to needed power.
- Tetrode RS2074HF, Thales
- In house design
- Size of amplifier trolley 1m x 1m x 3m. Can be replaced within 3 hours.
- Same design as used for ring cyclotron. Amplifiers are useable on both machines.

First floor WHFA (Anode power supplies)

16kV-main Distribution



4 x Anode power supplies 15kV, 40 A

Supplier:	Ampegon
Technology:	PSM9
Efficiency:	96%

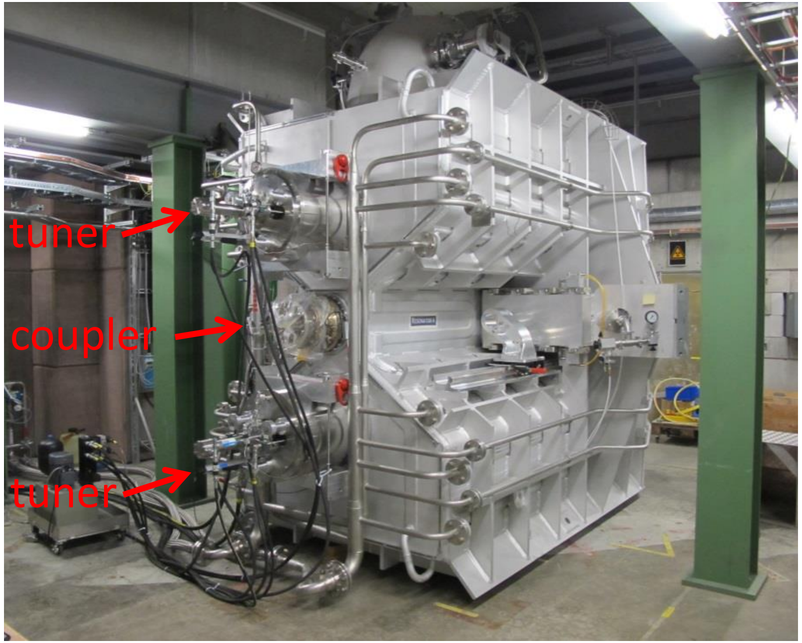
4 similar power supplies
crowbar less system

First floor WFHA (16kV-main distribution)

Double floor for 16kV switch gears
with interface cabinet, 48V power supply

FAT of 16kV switch gears (17./18. May 2018)
5 x ZS8.4 from ABB
Delivery and installation at PSI in July

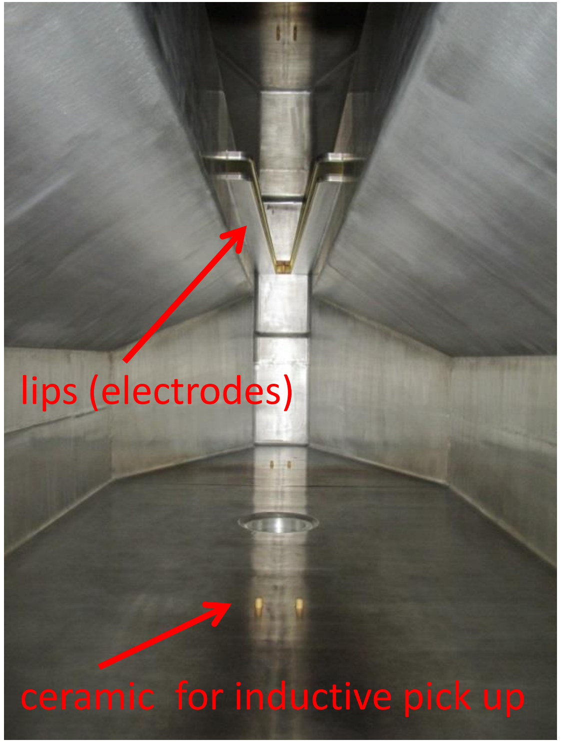
The new 50MHz resonator



Resonator 4 in test bunker

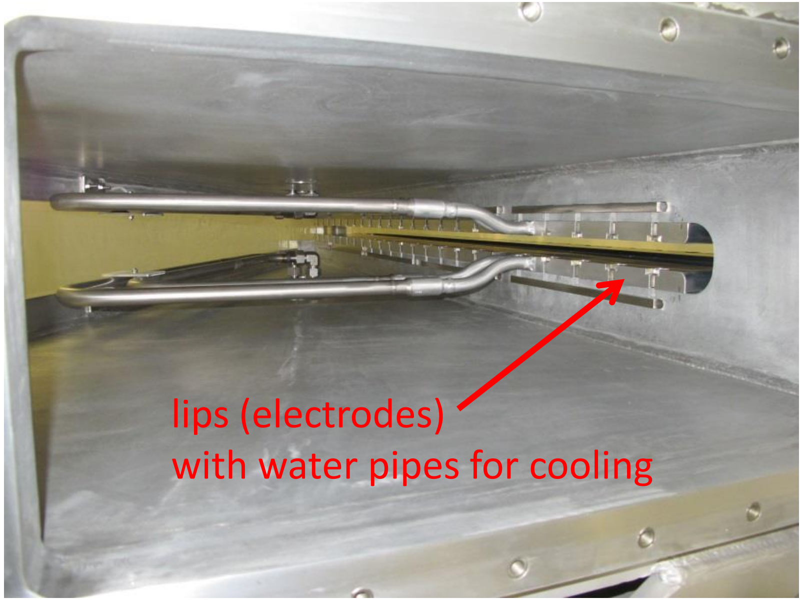
resonance frequency	50.6328 MHz
accelerating voltage	400 keV @ extraction radius
dissipated power	45kW @ 400 kVp
Tuning range	200 kHz
material cavity RF-wall	EN AW 1050
material structure	EN AW 5083
cooling water flow	15 m^3/h
dimension	5.6 x 3.3 x 3 m
weight	7000 kg

Inside resonator 2



Pictures taken at inspection of resonator 2 after power tests. View towards nose.

Inspection of resonator 2 after power tests

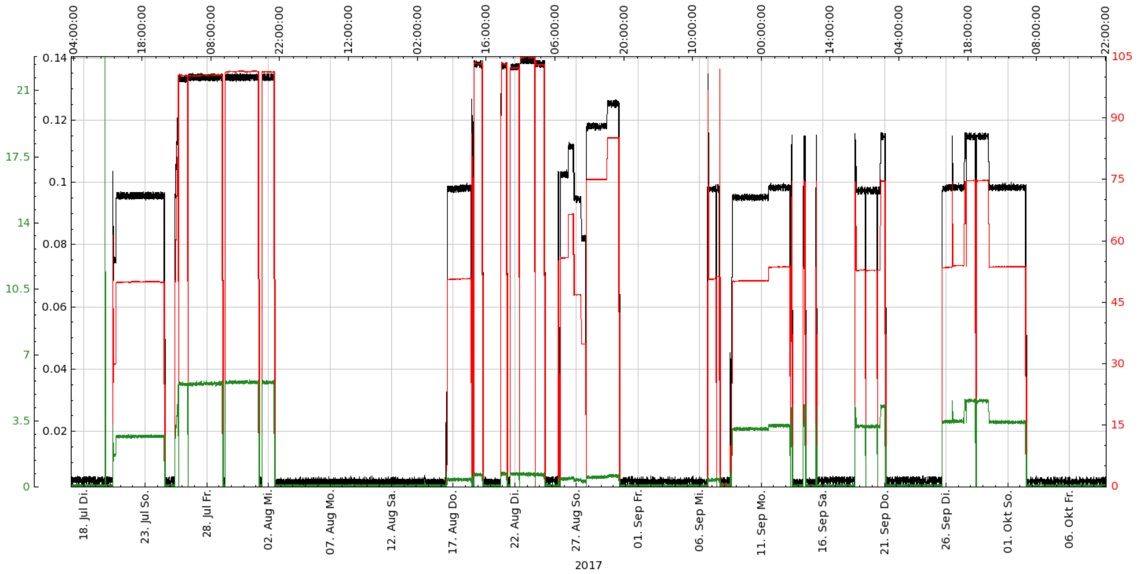


Wing of resonator at beam entrance side

Wing of resonator at beam exit side

Resonator 2

Resonator 2 nose: view from centre



Power tests of resonator 2

- Voltage on pick up
- Forward power
- Reflected power

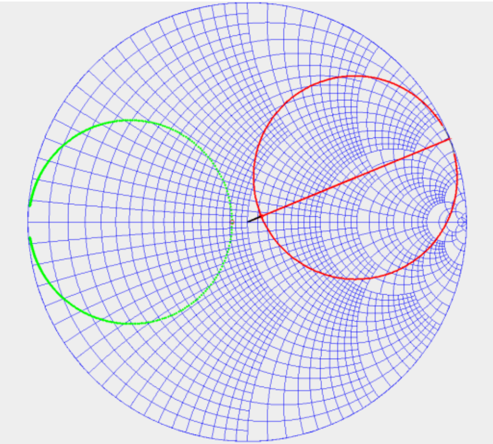
Measurement of Qo

plunger position	Resonance frequency	Q_0	tuning range
fully moved in	50.77920 MHz	24300 +/- 40	Δf = 197.2 kHz
fully moved out	50.58198 MHz	24738 +/- 43	

Plunger

fully moved in

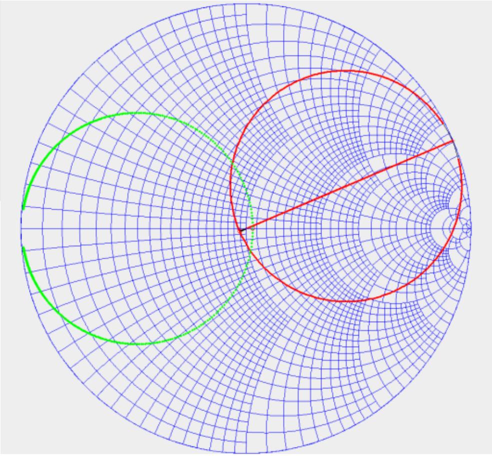
Z_{in} = 43.5Ω



Plunger

fully moved out

Z_{in} = 53.2Ω



Measurements taken with vacuum applied in resonator

Reduction of rf radiation into vacuum chamber

Capacitive pickup in resonator wing to measure the rf radiation out of the beam slit

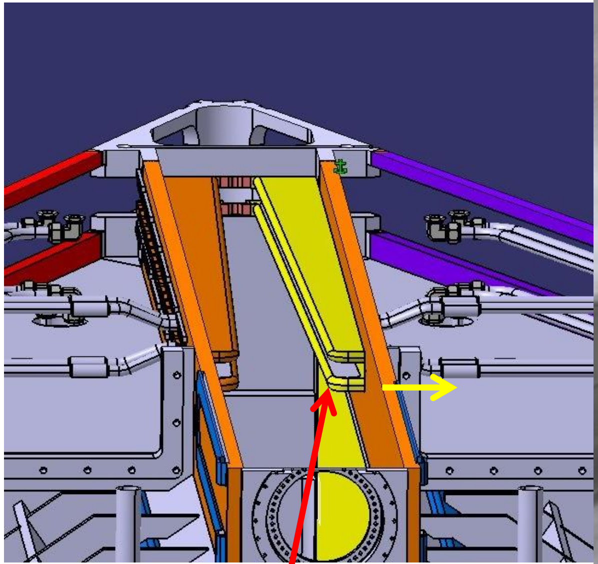
	rf power	before shifting	after shifting
Pickup in wing Beam exit side	50 kW	233.5 mV	22.2 mV
Pickup in wing Beam exit side	70 kW	271.8 mV	25.1 mV
Pickup in wing Beam entrance side	50 kW	41.7 mV	25.0 mV
Pickup in wing Beam entrance side	70 kW	33.3 mV	30.4 mV

By shifting the lower right electrode at the outer radius of 1.45 mm the measured signal on the pickup was reduced by 20dB.

The radiation on both sides is now symmetrical.

Coupling between power coupler and pickup is -96 dB.

Reduction of rf radiation into vacuum chamber



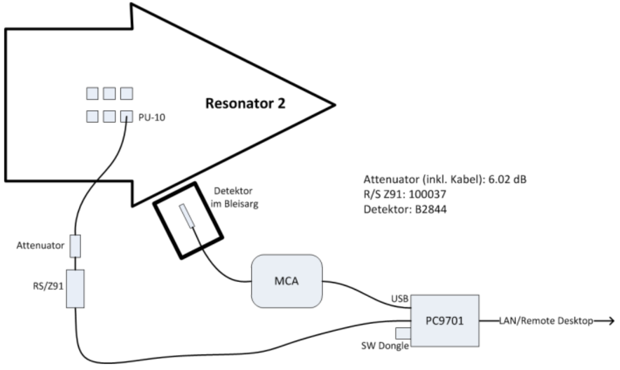
Shifting end of lower electrode by 1.45mm towards wing.

Measurement of electrode position inside resonator.

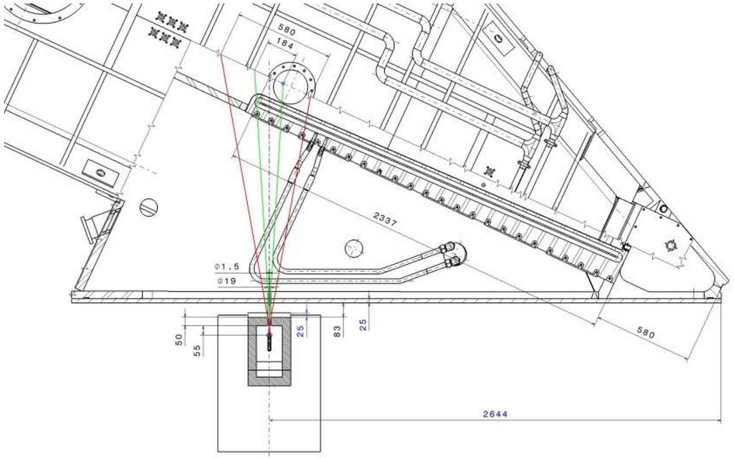
- By shifting the electrodes the radiated rf power into the wings to the measurement pickup was reduced. On both sides the same value was measured.

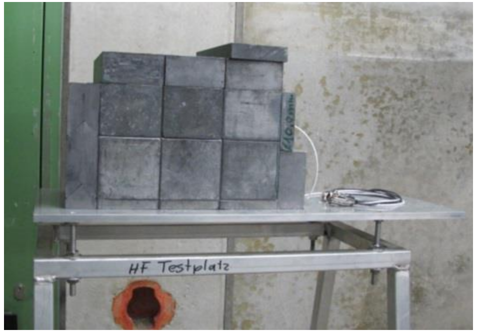
- Asymmetric tuning of plungers had no effect of 50 MHz radiation into the wings.

Calibration of gap voltage



Measurement setup

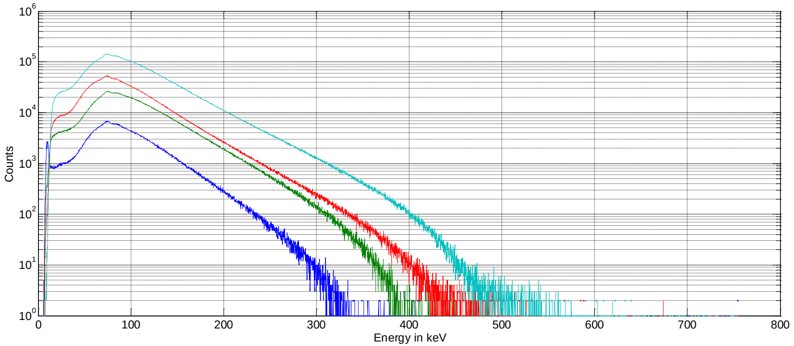




Lead housing holding the SPEAR^{TM}-detector (CZT-detector) of kromek

Positioning of detector
Two different hole in lead housing (∅19 mm, ∅1.5mm)
-> different aperture angle of detector

Calibration of gap voltage



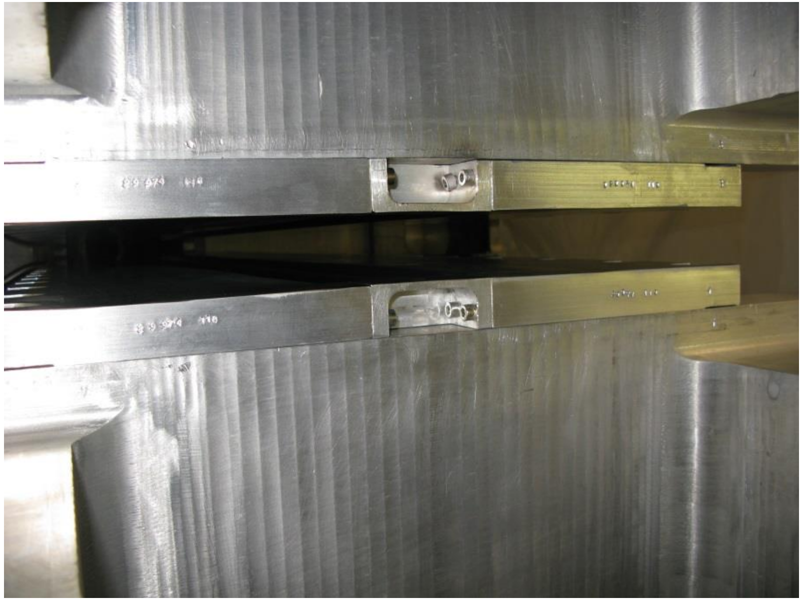
Measured bremsstrahlung spectrum on resonator 2 at different power levels

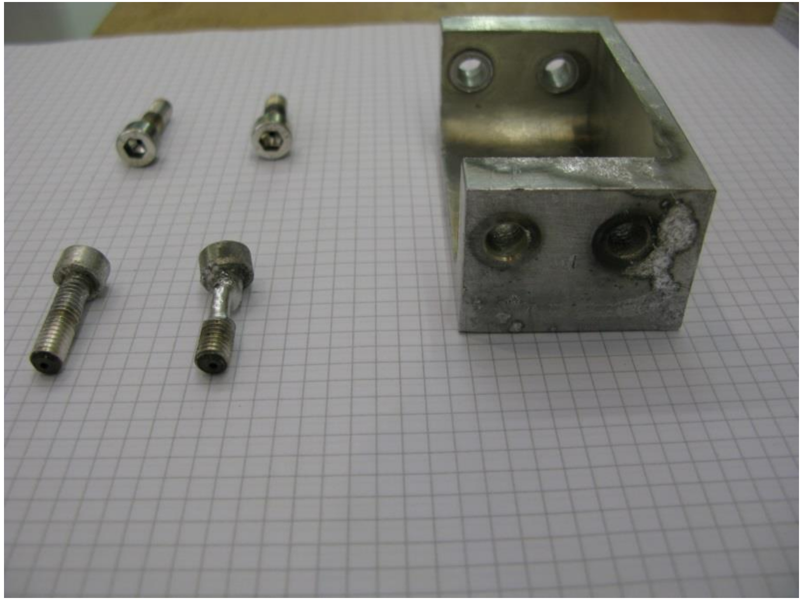
rf power	voltage on reference pickup	zero crossing in bremsstrahlung spectrum
35 kW	2.936 V	323 keV
46 kW	3.402 V	382 keV
56 kW	3.714 V	422 keV
66 kW	4.040 V	467 keV
75 kW	4.280 V	483 keV
85 kW	4.560 V	500 keV

Simulation cavity: 400 kpV -> 45 kW

Bremsstrahlung: 400 keV -> 50.3 kW

First bridge between the lips in central region

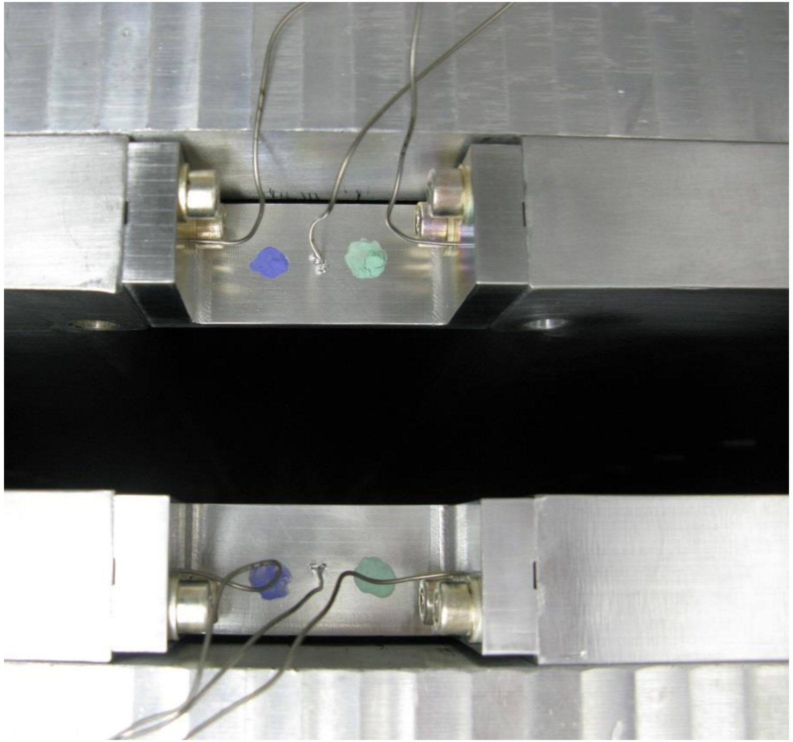




First bridge was not designed by an RF engineer. RF current flowed over screws.

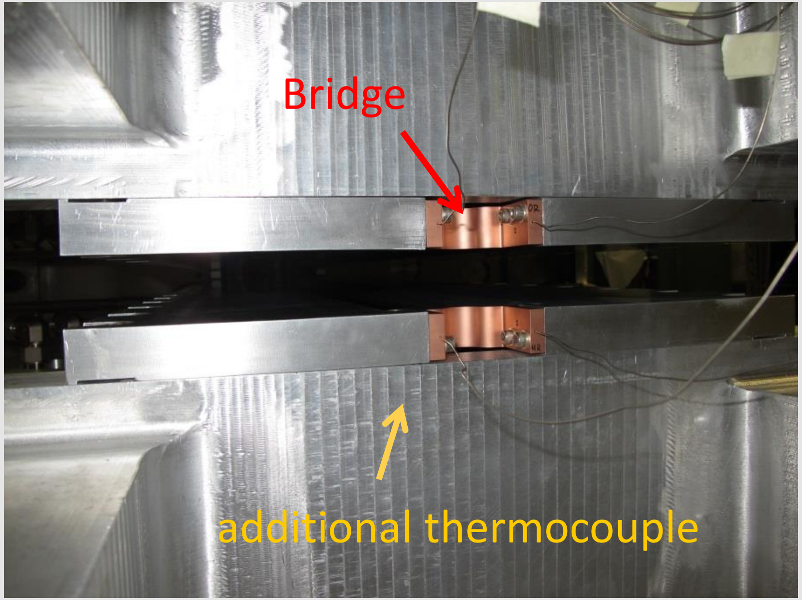
Very strong forces of lips on bridge.

Second bridge between the lips in central region



- New design of aluminum
- Including surrounding edge for defined rf contact from bridge to electrode.
- Temperature measurement added for tests. Still getting very high temperatures.
- Screw were not anymore tighten after rf power tests.

Third bridge between the lips in central region



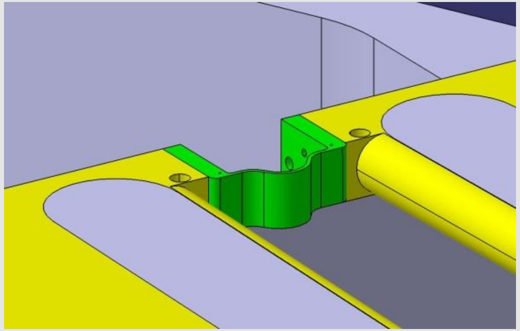
For better diagnostic additional thermocouple needed in wall of resonator but attention there are cooling channels……

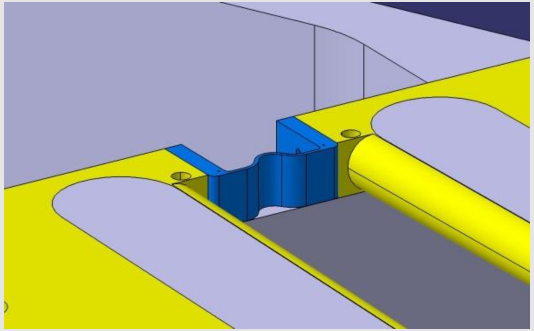
Wrong reading of a distance and drilling the hole 5 mm to low…

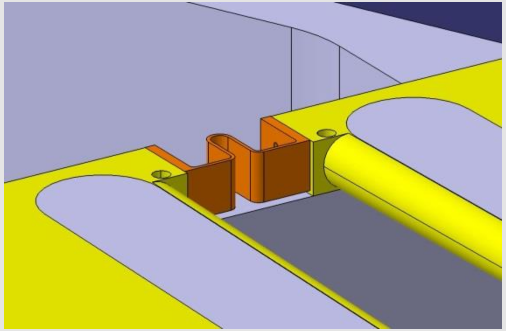
water leak into the vacuum chamber

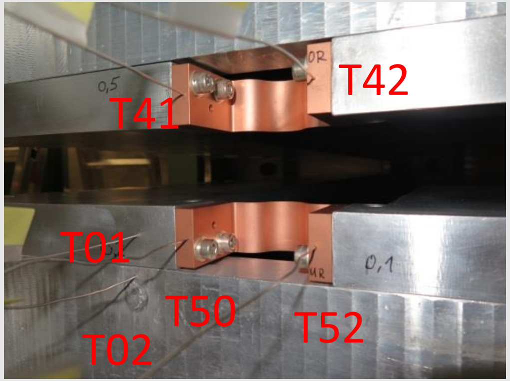
Draining all the water out, welding and testing helium leakage rate.

Third bridge between the lips in central region


Bridge A


Bridge B


Bridge C

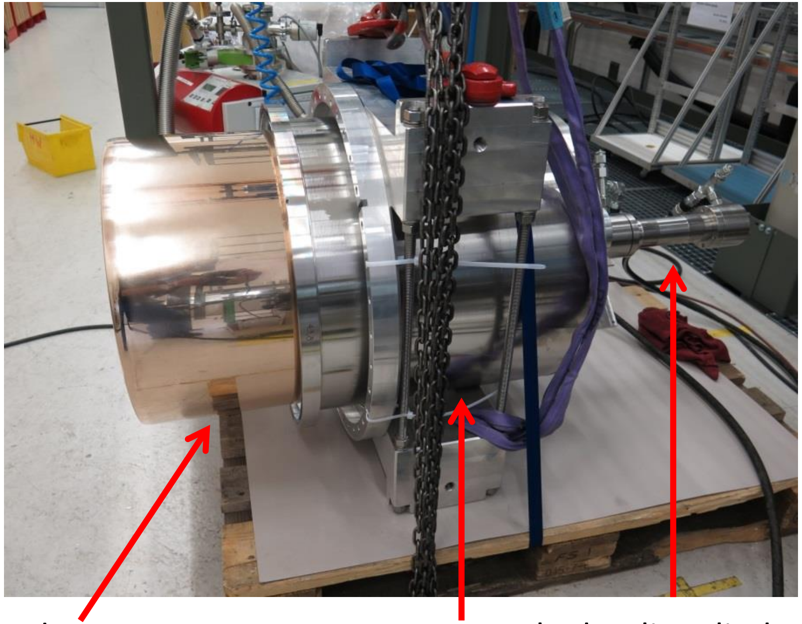


3 designs of copper were tested.
With the version B the lowest temperatures were measured.
At 50 kW incident power the temperatures were:

T02	36 °C
T01	61 °C
T41,T42,T50,T52	86…90 °C

final design version B

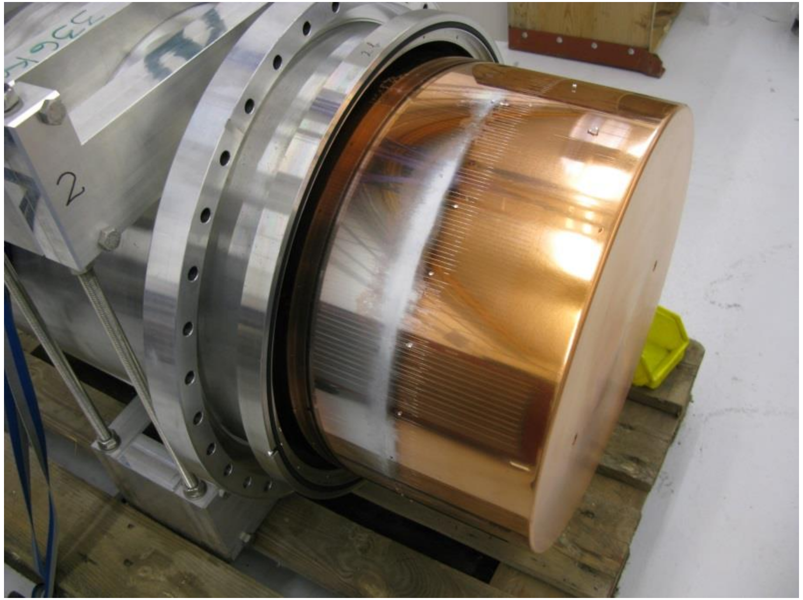
Tuning system for resonator



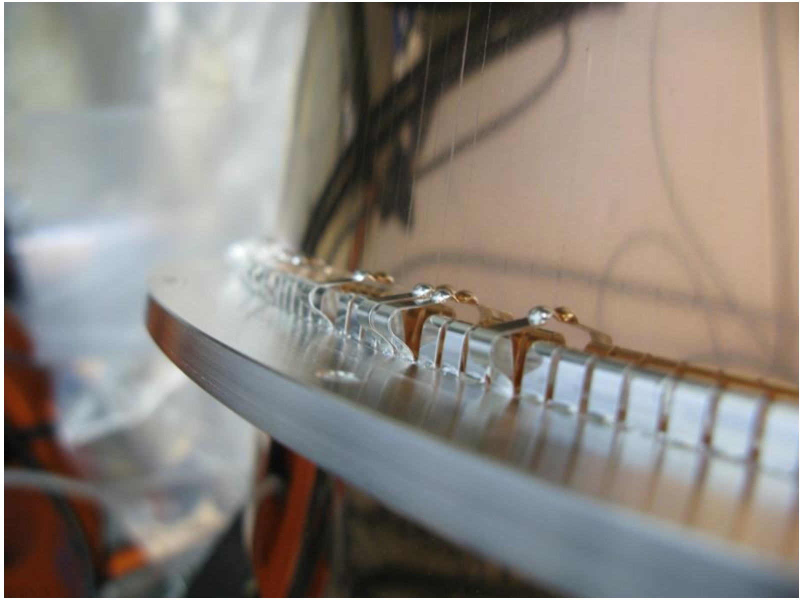
tuning range	200 kHz
moving range	200 mm
diameter of plunger	508 mm
speed of plunger	10 mm/s
current density on finger contacts	15 A/m
cooling	water

Master/slave tuning system:
Position of master controls the slave position.
Slave moves slower than master.

Development of finger contact

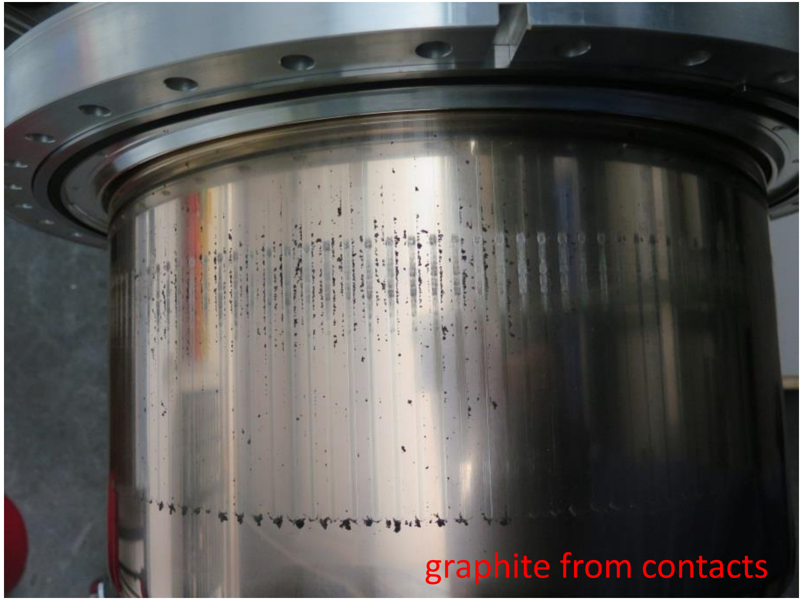


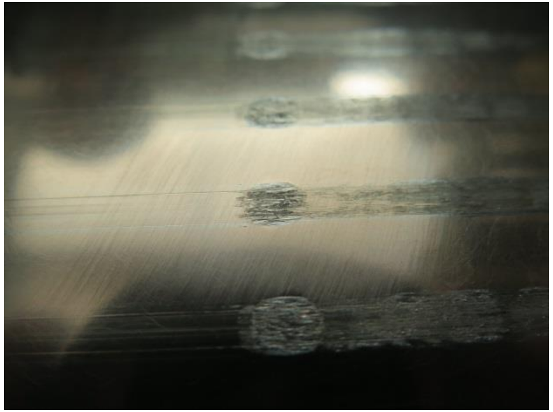
Plunger made of copper after meltdown of finger contacts



Tiny finger contacts bent because of wrong distance between contact head and pluger.

Development of finger contact





scratches in hard gold

strong abrasion of contacts

Plunger: copper with 4µm hard gold plating

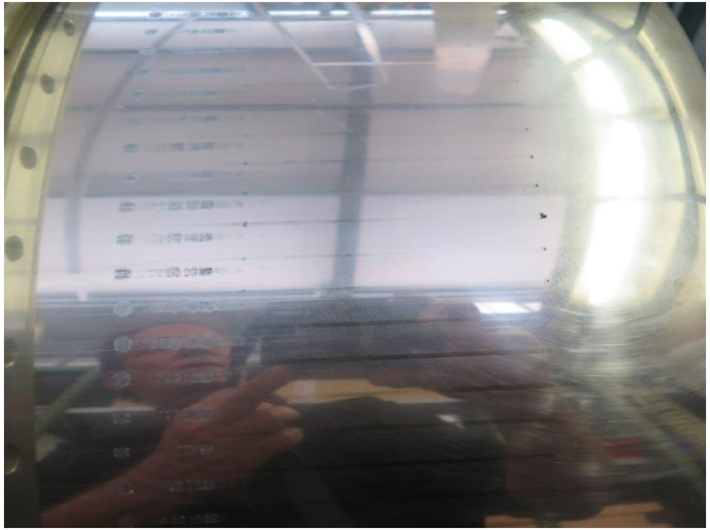
Finger contacts from: Sumitomo Heavy Industries, Ltd, Japan
(Material: silver and graphite, 97/3)

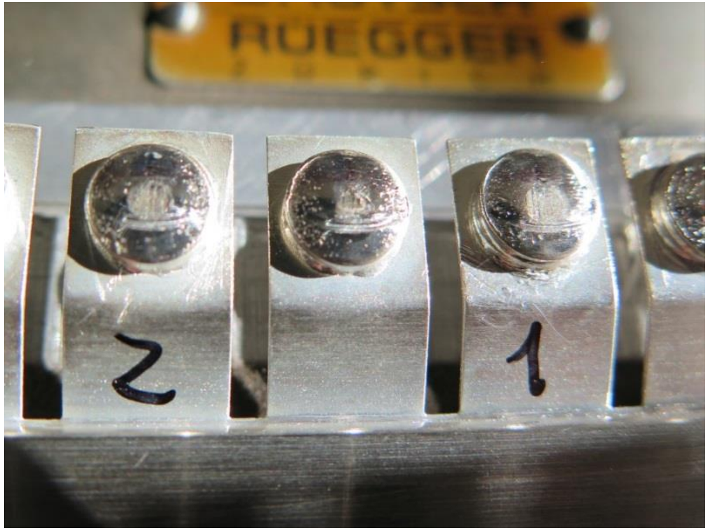
To strong force of each finger (**2kg / 1mm way**)

Development of finger contacts

from last test

Only small amount of graphite



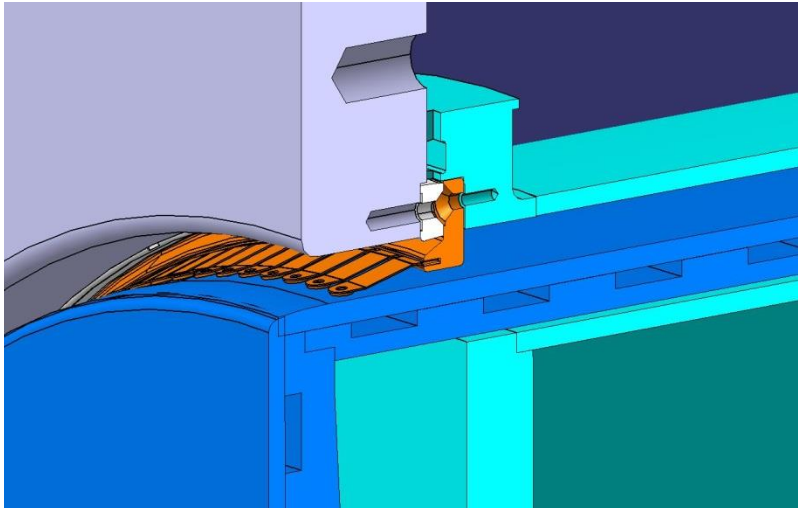


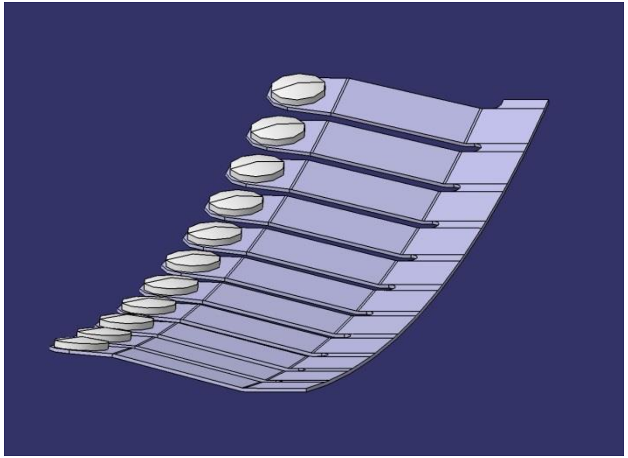
Plunger: copper with 4μm hard gold plating

Finger contacts from: Sumitomo Heavy Industries, Ltd, Japan
(Material: silver and graphite, 97/3)

Reduced force of each finger (**0.3kg / 0.3mm way**).

Development of finger contact

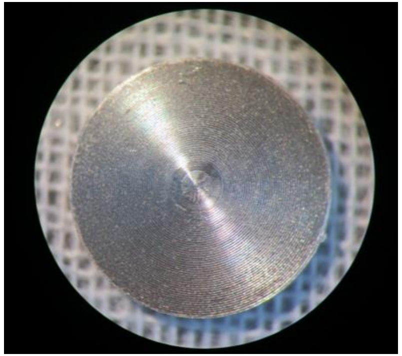




Plunger: copper with 4µm hard gold plating

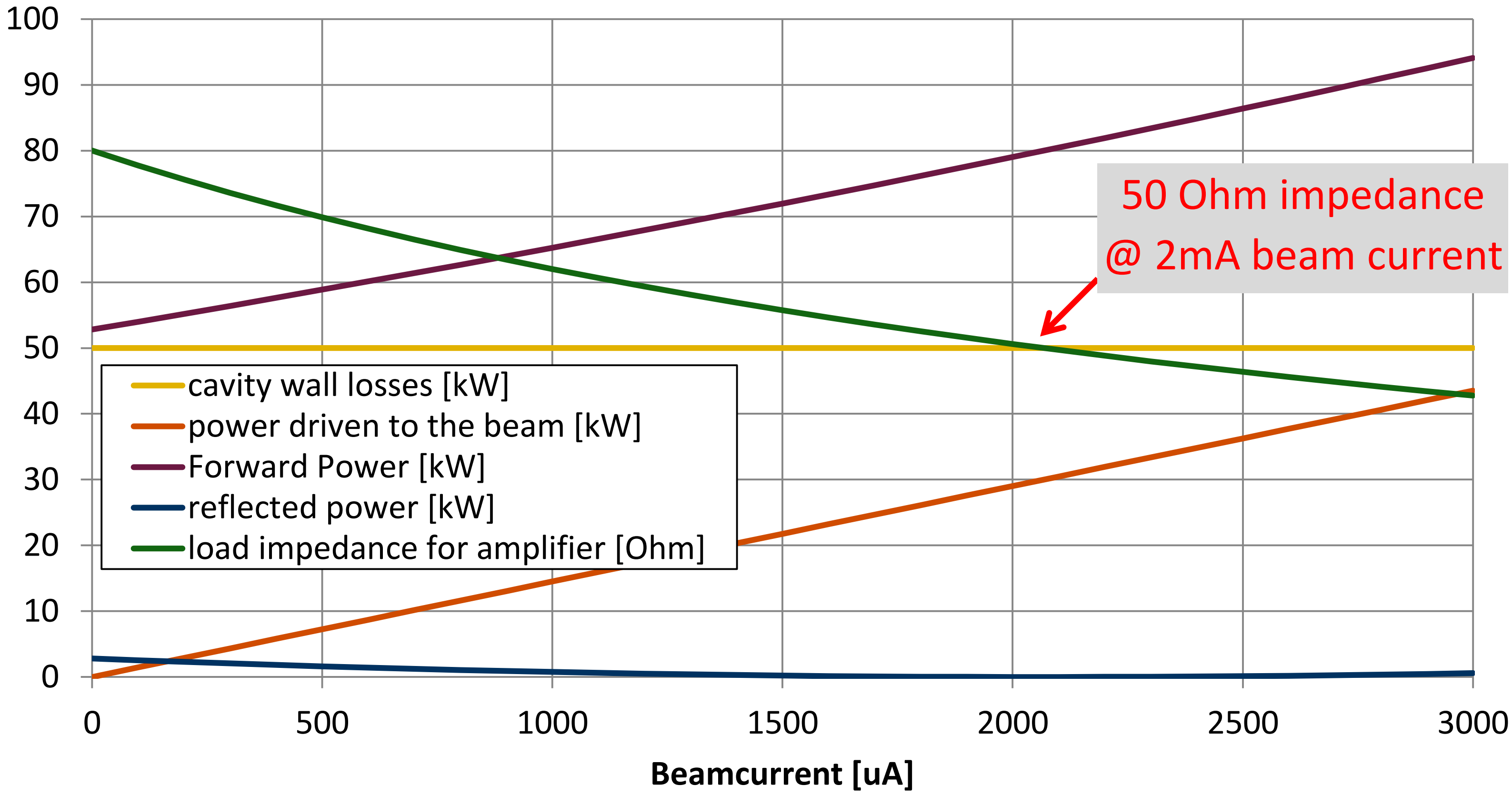
Finger contacts: in house design and production
reduced force of each finger
(**0.3kg , > 1mm way**).

In production, next test fall 2018

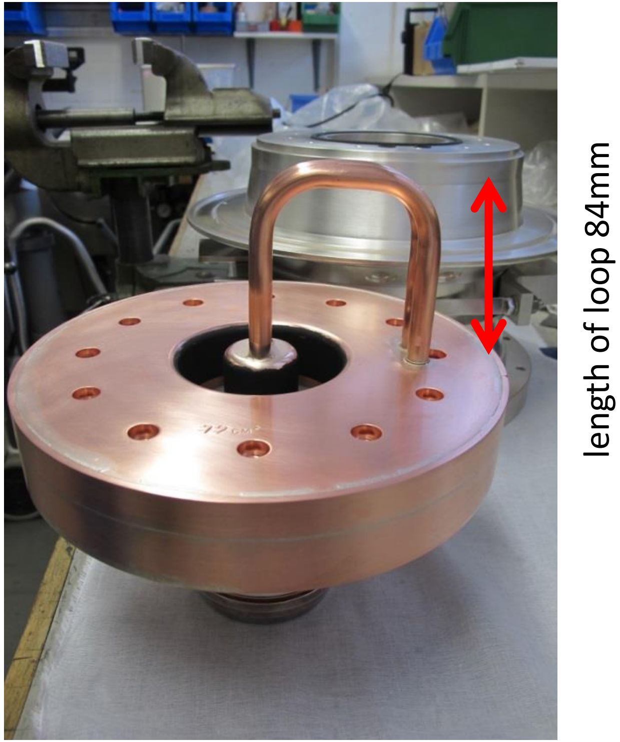


Ag/C3 contact pad
∅6.45 mm, height 1.2mm
from DODUCO
after machining

Coupler (calculation of input impedance)



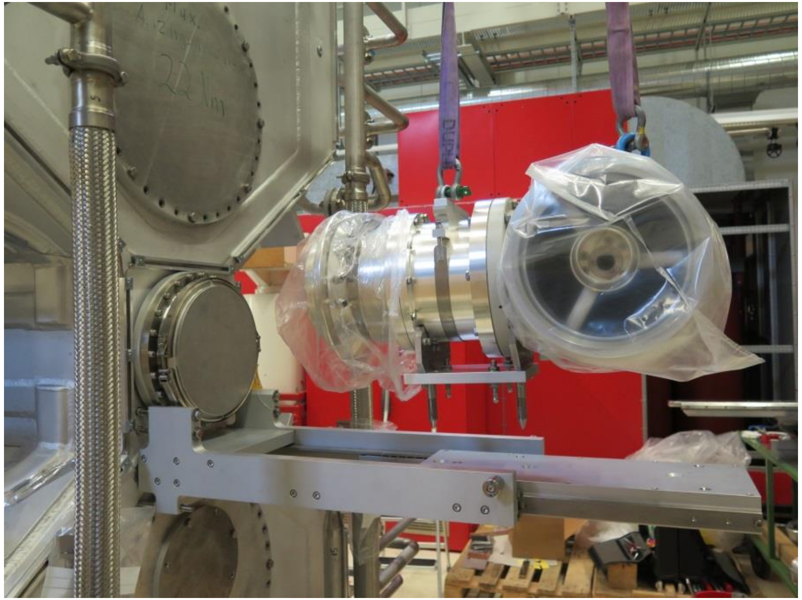
Coupler (measurement of different loops)



Coupler with soldered coupling loop
Impedance 81 Ohm

length of loop 84mm

Coaxial line



Test of coaxial line to coupler and support structure on resonator
Coaxial line RL100-230 produced by Spinner, Germany
Adaptor to coupler produced in house

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Summary

- The new resonator 2 was successfully tested and installed in the injector 2.
- Radiated rf power into the vacuum chamber was reduced.
- Bridge between electrodes works
- Finger contacts for tuners: working solution found, improved version in production.

- The new LLRF and amplifiers must be installed and tested until the end of 2018
- The resonator 4 must be tested until end of 2018

- In the next shutdown 2019 the resonator 4 will be replaced and new resonator 2 will go in operation.

….many challenges to get burnt or destroyed equipment for the next CWRF workshop.

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