PAUL SCHERRER INSTITUT

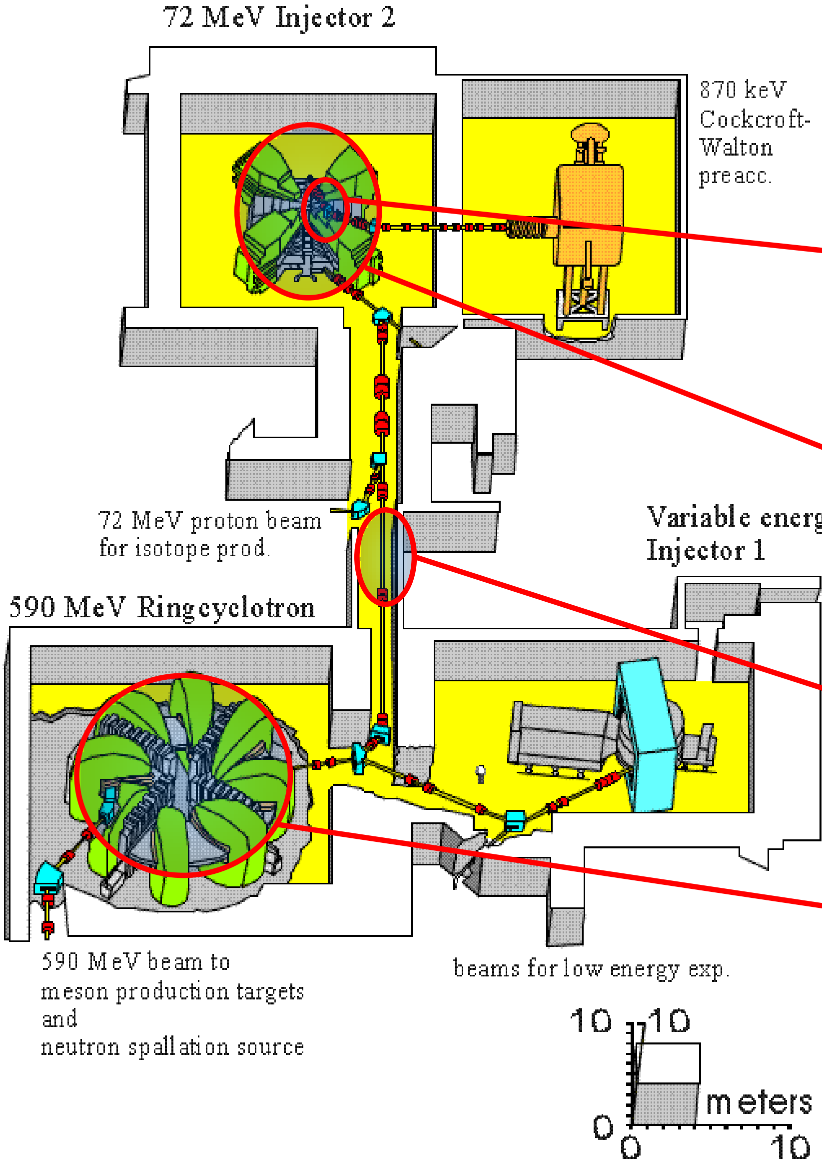
PSI

Wir schaffen Wissen – heute für morgen

Paul Scherrer Institut

Lukas STINGELIN for the PSI RF-group

High Power RF Systems and Resonators for Sector Cyclotrons



New RF-Components

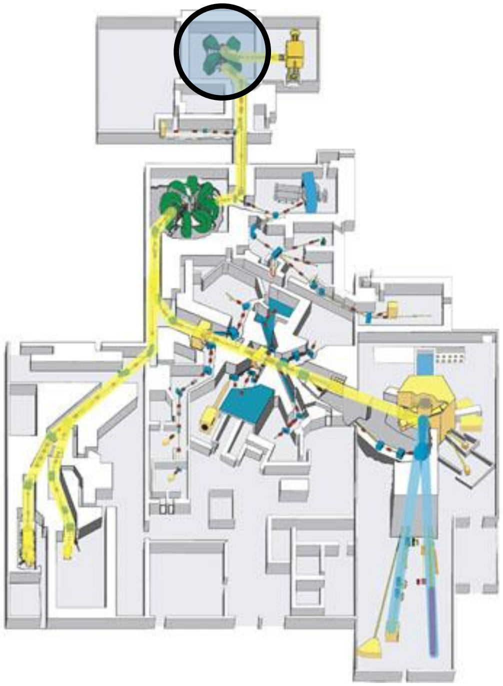
870 keV Line
New 150 MHz Buncher
50 MHz Buncher moved

Injector 2
New 50 MHz Resonators 2&4

72 MeV Line
500 MHz Buncher (Super-Buncher)

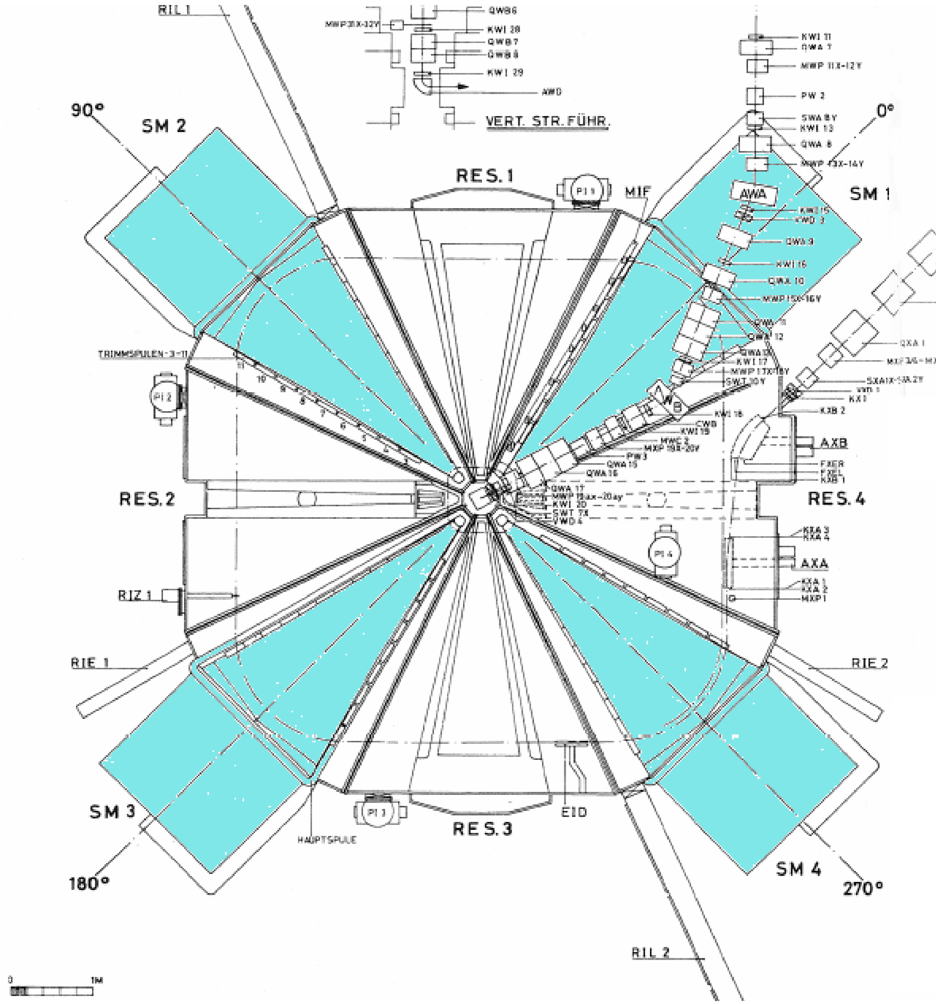
Ring
New 50 MHz Cu-Cavities

Injector 2



Injection energy:	**870 keV**
Extraction energy:	**72 MeV**
Accelerator frequency:	**50.63 MHz**

RF system of Injector 2



Resonator 1 & 3

50 MHz

double gap resonator

Accelerating voltage 420 kV

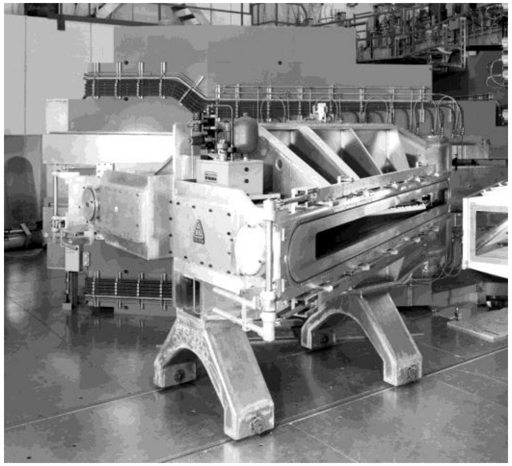
Power dissipation 150 kW

Resonator 2 & 4

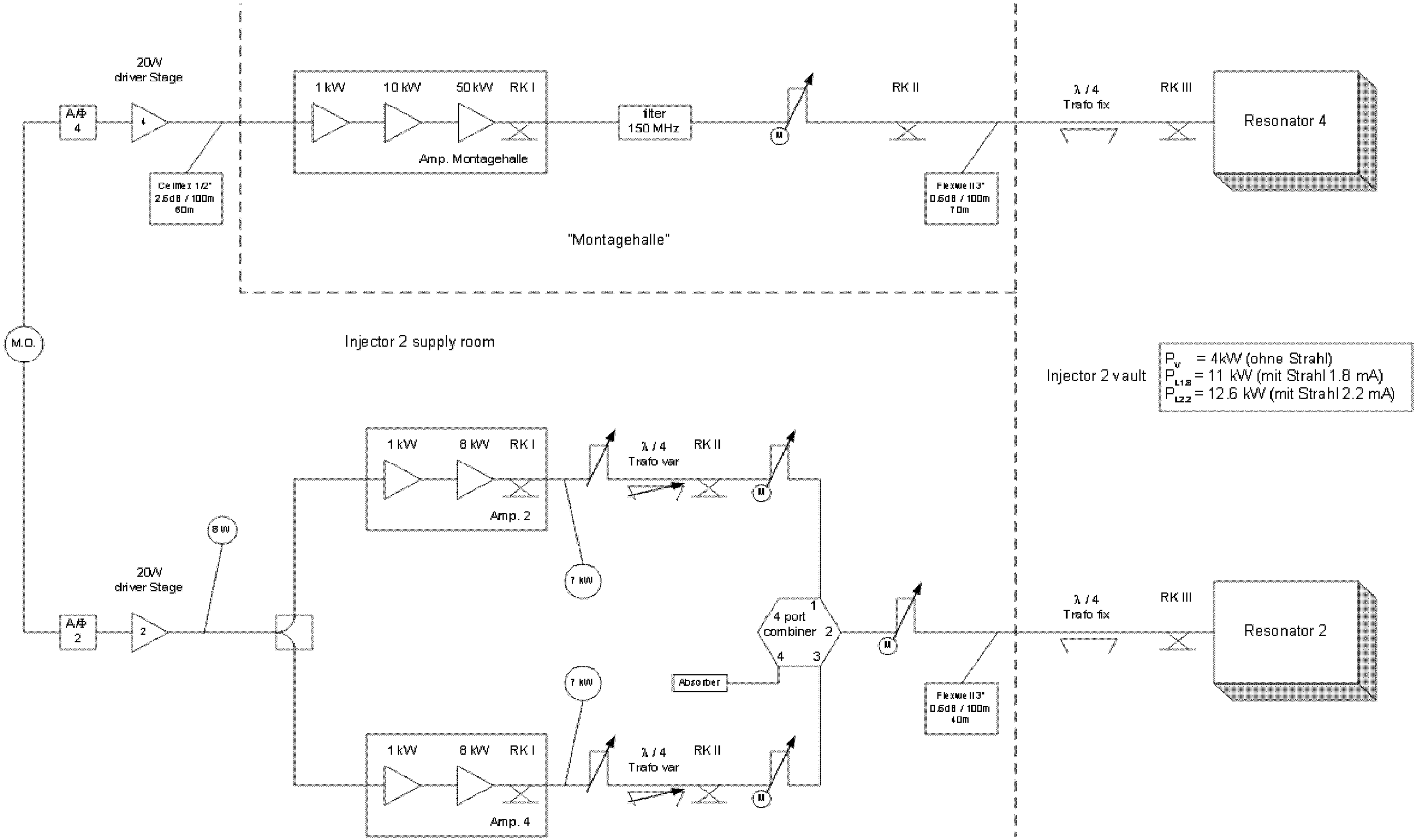
150 MHz resonator

Accelerating voltage 30 kV

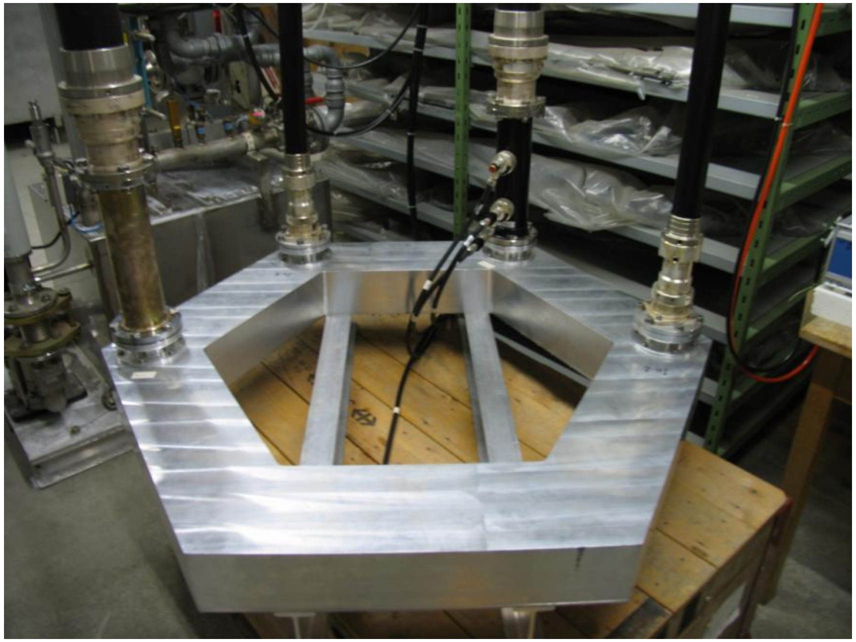
Power dissipation 3.5 kW



Inj. 2 Power upgrade 2003



Inj. 2 Resonator 2 Power upgrade 2003



Combiner

2 x 25 kW Load

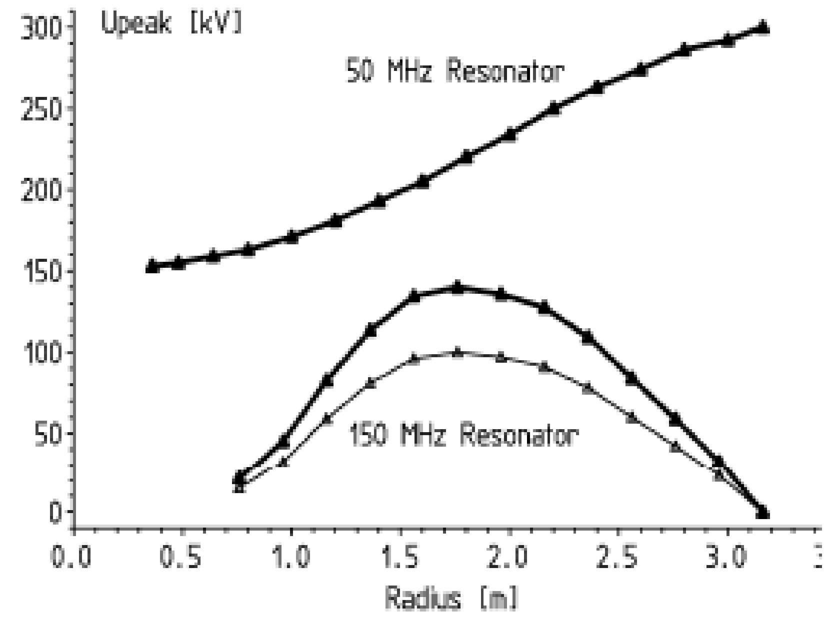
3 mA upgrade of Inj. 2

Number of turns:

Beam current 2mA	82
Beam current 3mA	~65

Higher energy gain per turn on outer radius

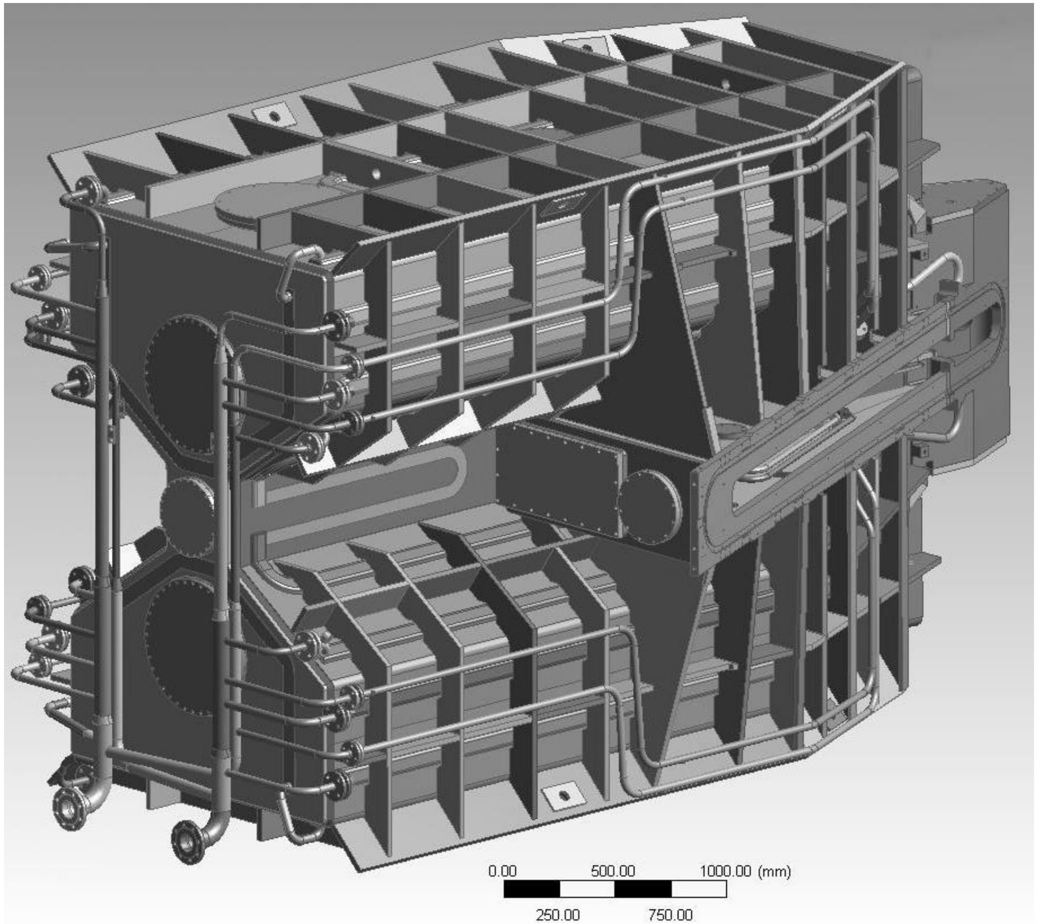
Replacement of resonator 2 and 4
(150 MHz by 50MHz)
including new amplifier chain and low level RF
Resonator 2 planned before 2013
Resonator 4 planned before 2014



Gap voltage versus Radius of existing resonators

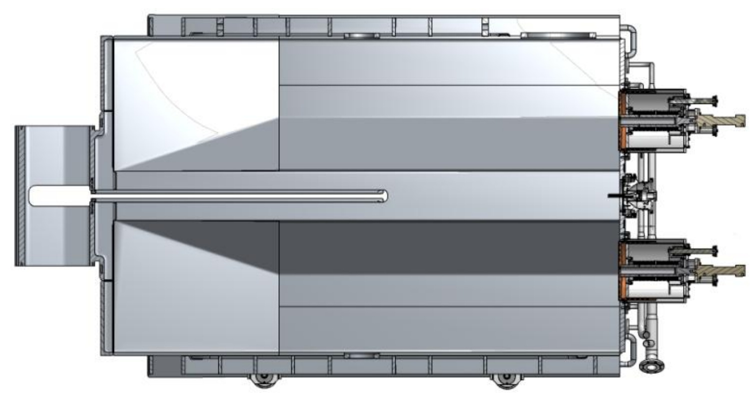
Later replacement of amplifier chain and low level RF of resonator 1 and 3
Using same system as for resonator 2 and 4

New 50 MHz Resonator 2&4, Injector 2



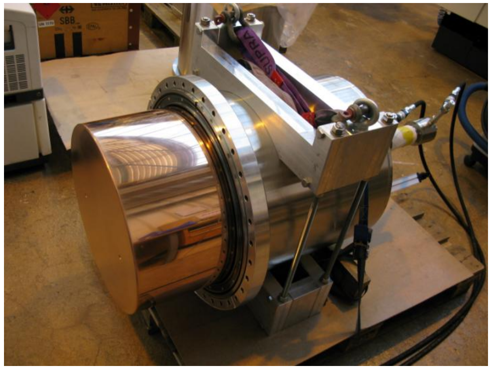
Specification

Resonance frequency:	**50.6328 MHz**
Accelerating voltage:	**400 keV**
Dissipated power:	**45 kW@400kV**
Tuning range:	**200 kHz**
Cavity RF-wall:	**EN AW 1050**
Structure:	**EN AW 5083**
Vacuum pressure:	**1e-6 mbar**
Cooling water flow:	**15 m3/h**
Dimension:	**5.6x3.3x3.0 m**
Weight:	**7‘000 kg**



New 50 MHz Resonator 2&4, Injector 2

At SDMS

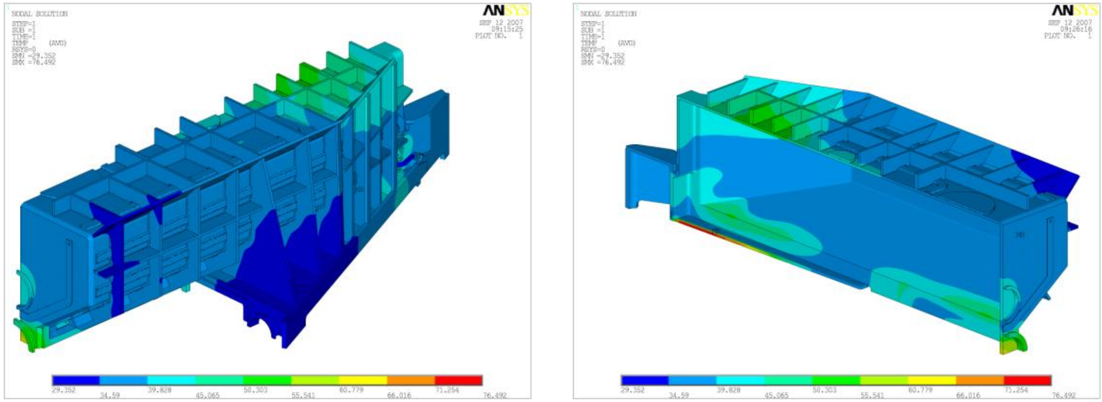


Status

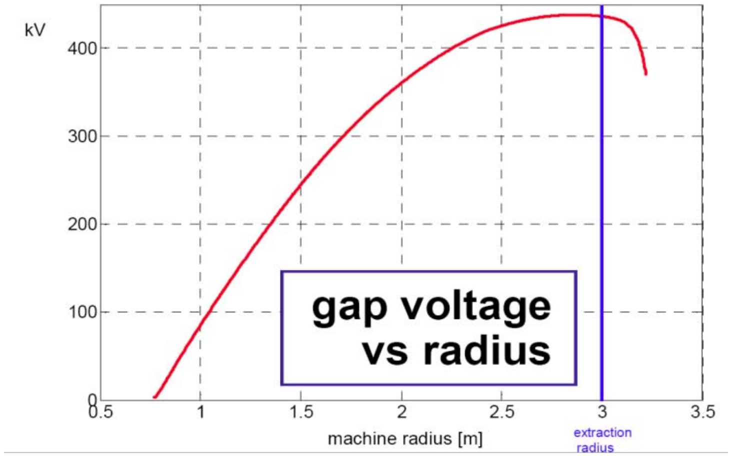
Delivery of Res. 2 to PSI:	**June 2009**
Tuner (PSI Workshop):	**Mid June**
RF-Power tests:	**fall 2010**
Manufacturing Res. 4	**13 Month**

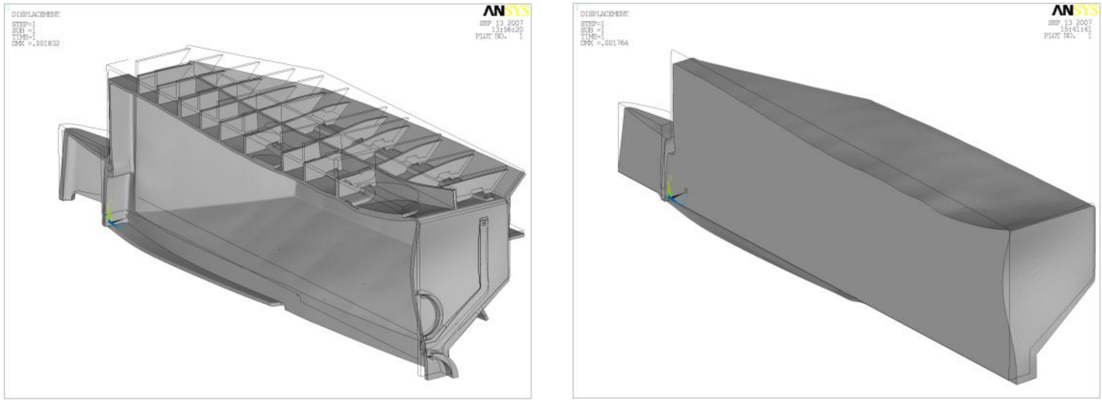
Simulation and measurement results 50 MHz Resonator 2&4

	Simulation	Measured
Qo	28'159	24'814
Tuning range	190kHz	197.6kHz
Vacuum drift	-59.2kHz	-65.5kHz
Thermal drift	-32.6	-30.4



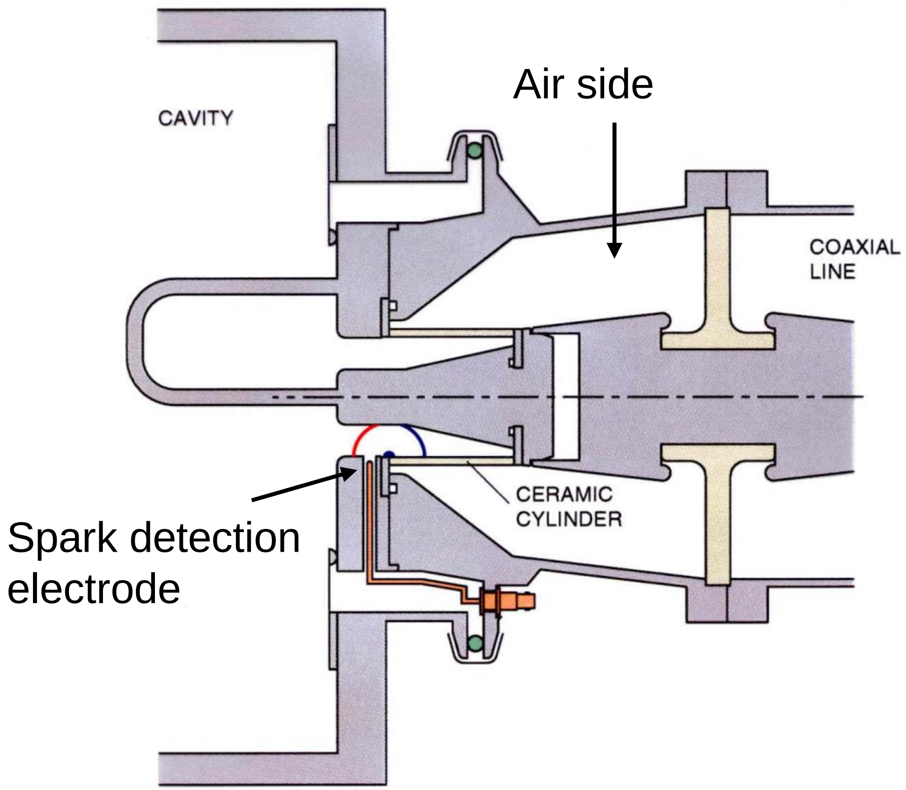
Temperature distribution, Design case 100kW



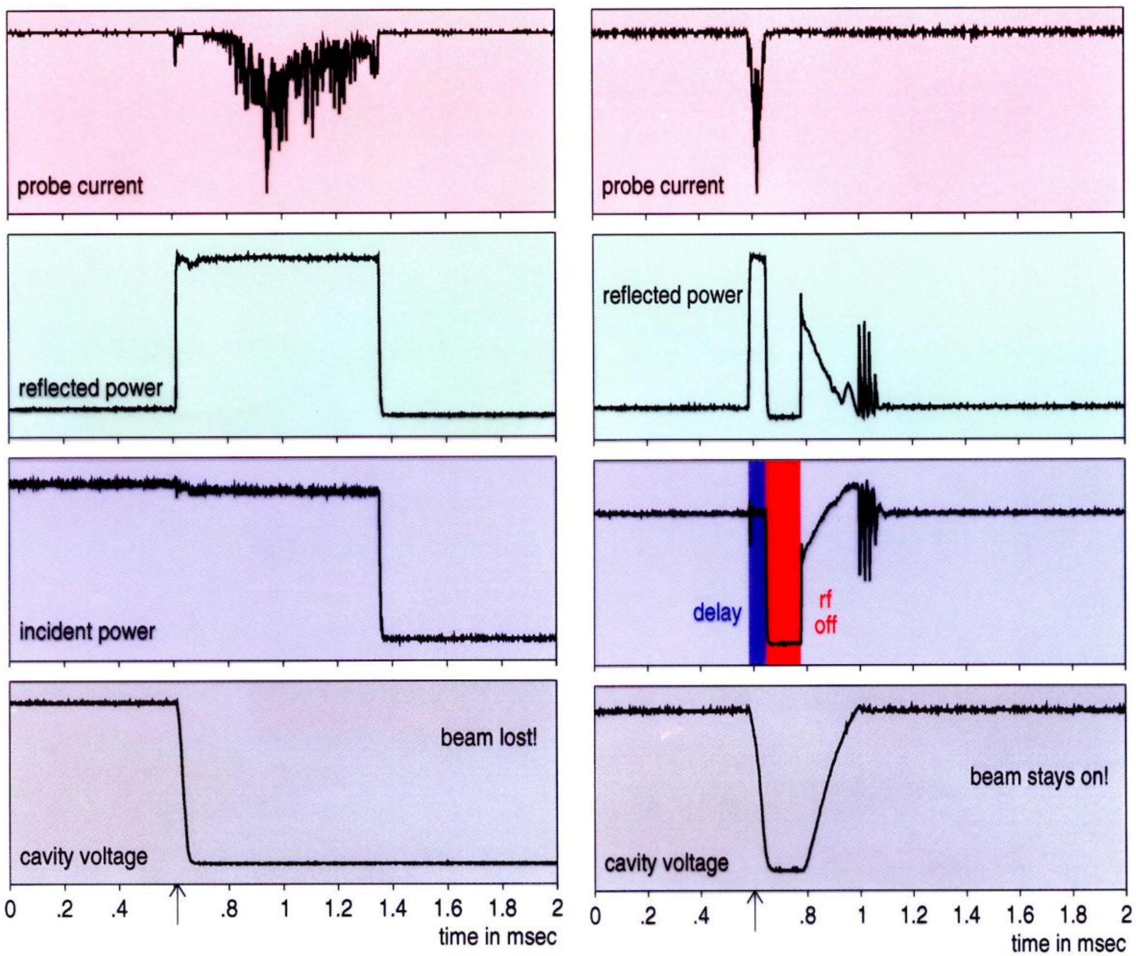


Deformation, atmospheric pressure, RF-Power

The Coupling Loop



Spark Detection by the Coupling Loop

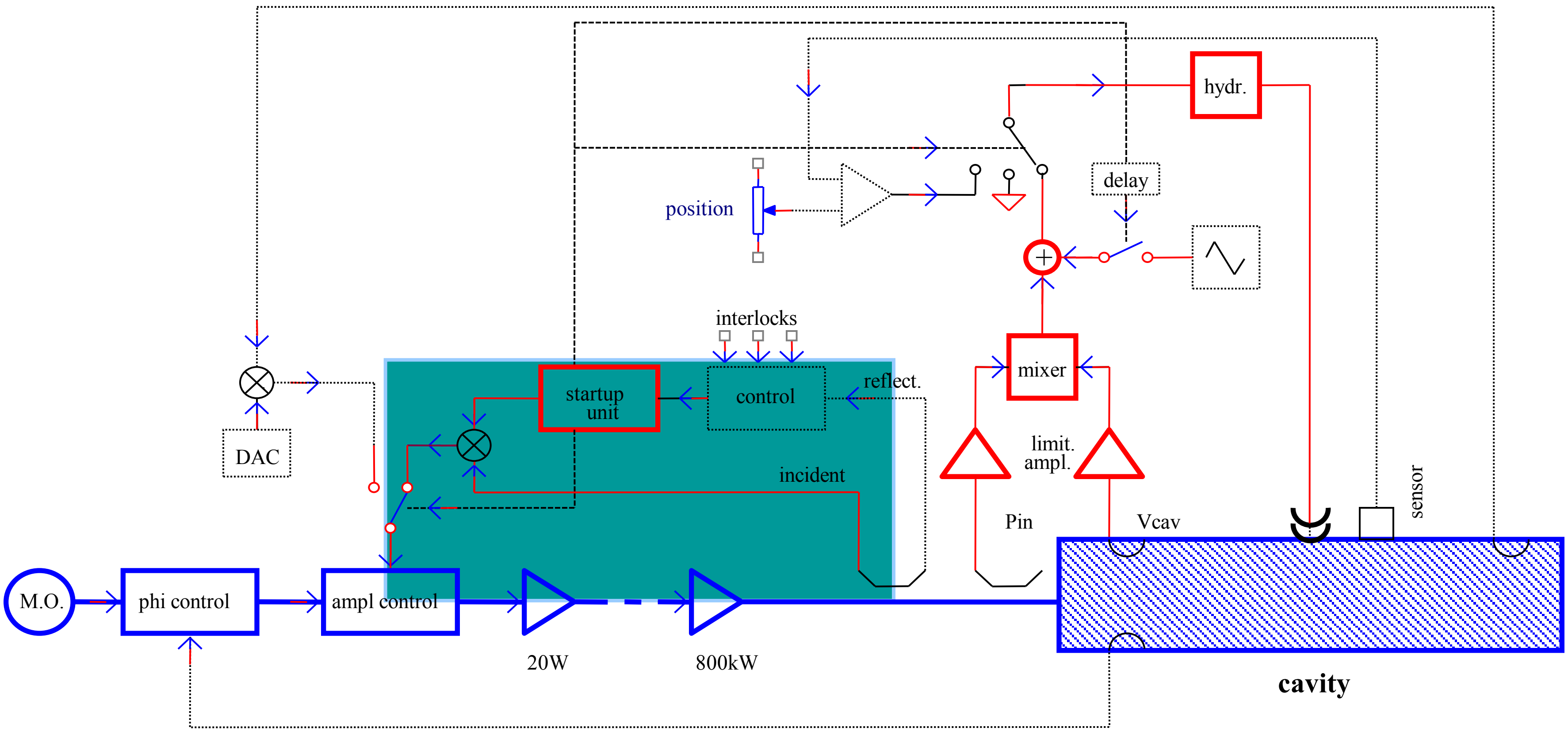


Without blanking With blanking

The RF is blanked for about 100μs in case of spark detected at the coupling loop.

This is enough time for the ions cloud to vanish.

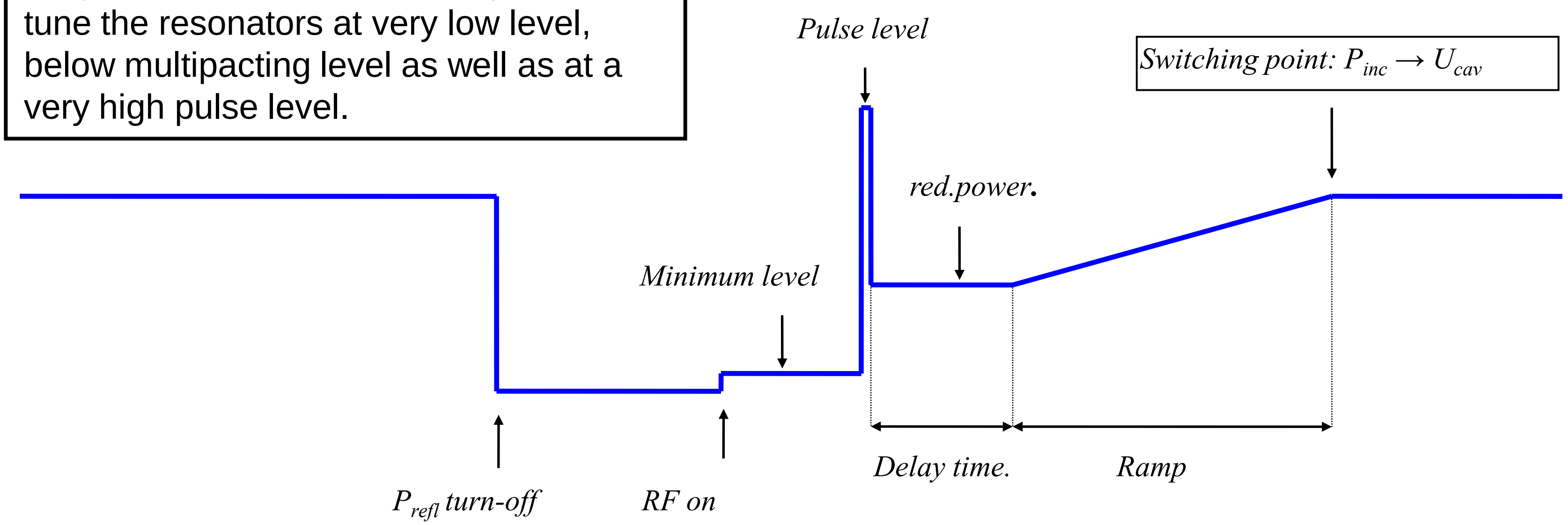
Block Diagram of the LLRF



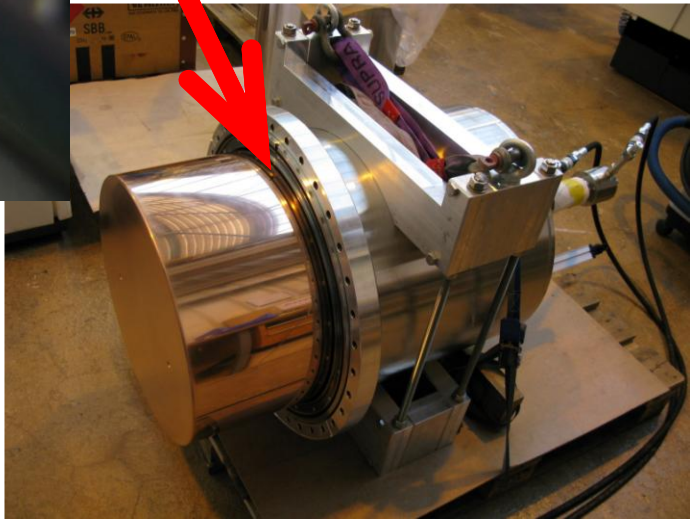
Block diagram of the pulsing startup and interlock control circuitry

Philosophy of the RF Turn-on

Using limiting amplifiers with an operating range of more than 60dB, it is possible to tune the resonators at very low level, below multipacting level as well as at a very high pulse level.



Bent RF contacts after test

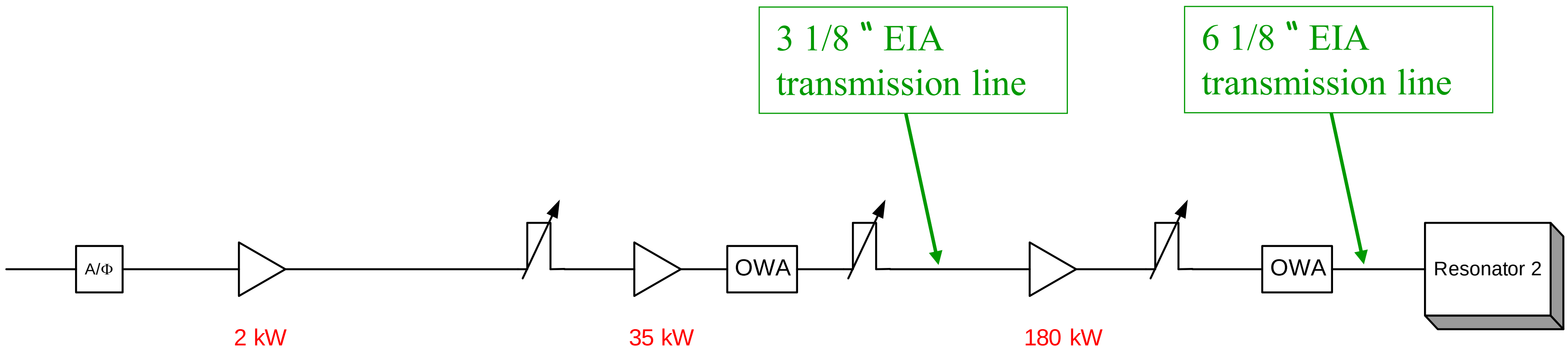


After successful high power tests, it was discovered that several RF contacts were bent.

Design of RF contacts still has to be improved.

(No problem of rf-current, but mechanical tribology)

Amplifier chain for Resonator 2 / 4



LLE	Predriver (2 kW)	Driver stage (35 kW)	Final stage (180 kW)
	Solid state amplifier	Tetrode Amplifier	Tetrode Amplifier
		Thales RS 2048 CJC	Thales RS 2074 HF
		New design by PSI	Copy of 1MW design Reduced power supply

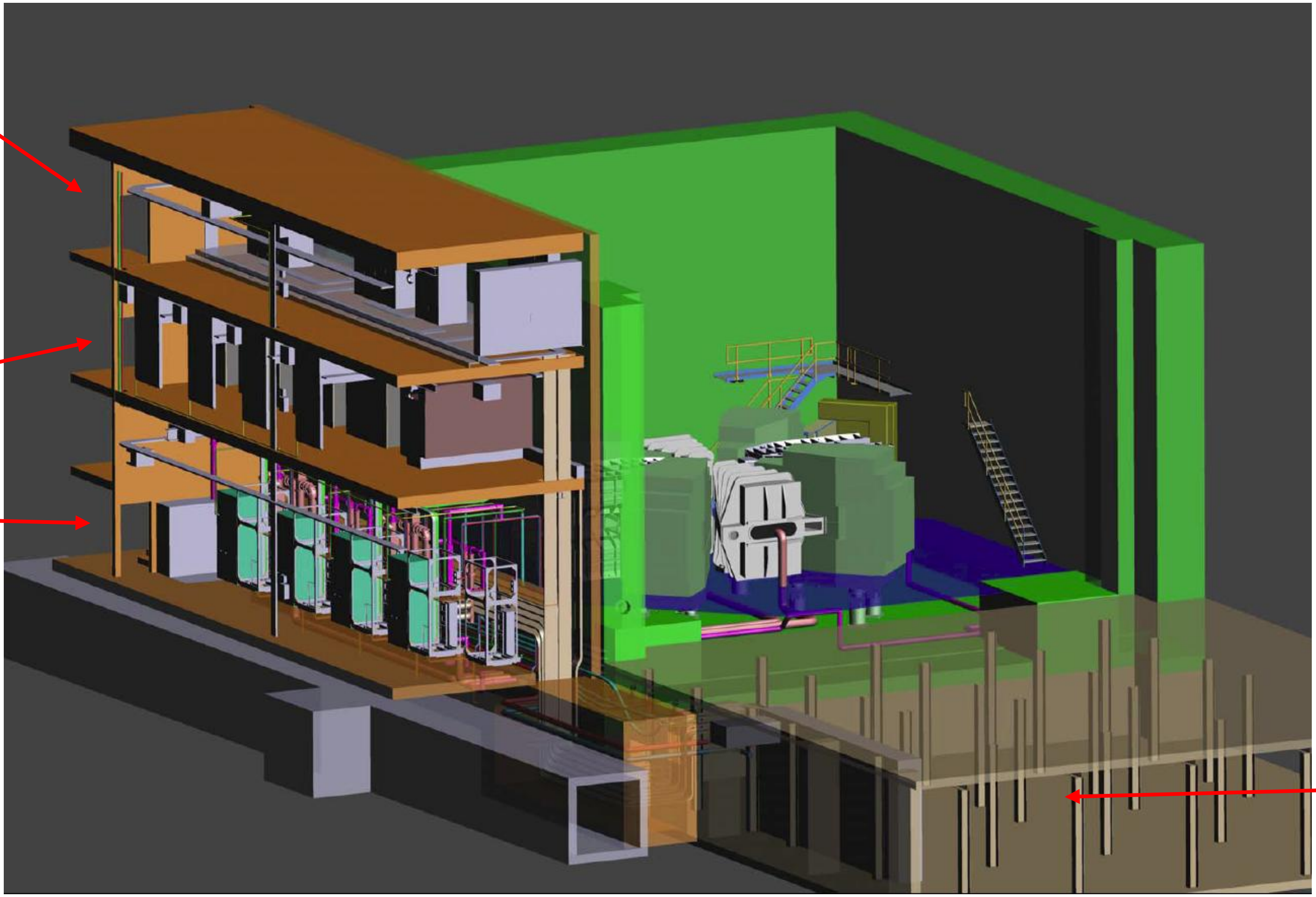
OWA Higher harmonic absorber

Inj. 2 vault and WHFA

power supplies

Plate power supplies

Amplifiers



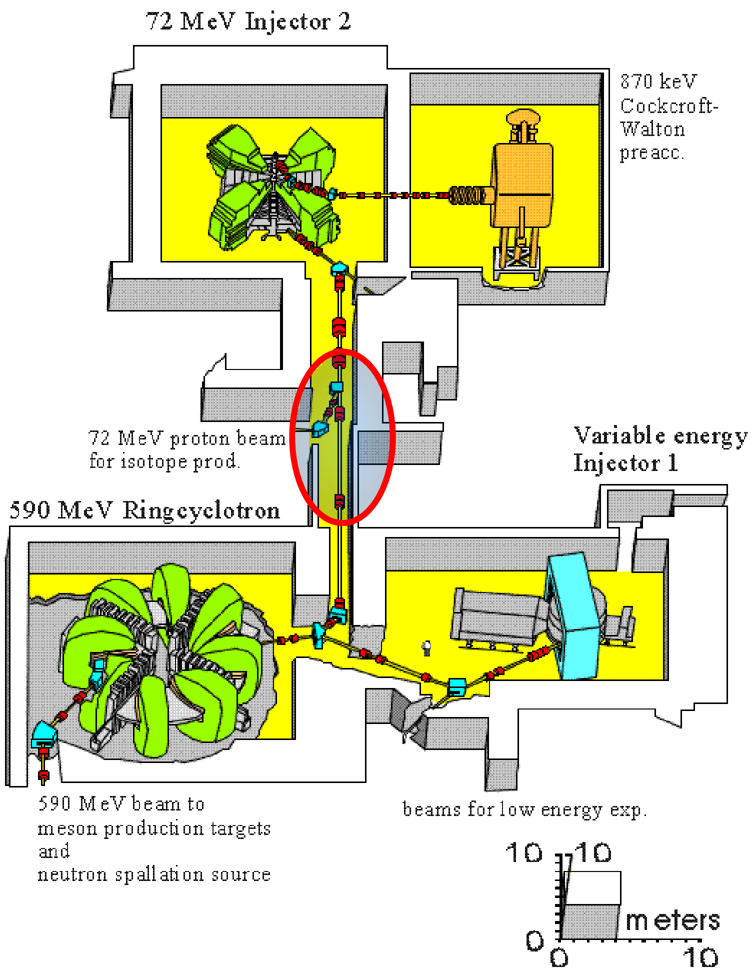
Driver stages

New building WHFA

End of 2007

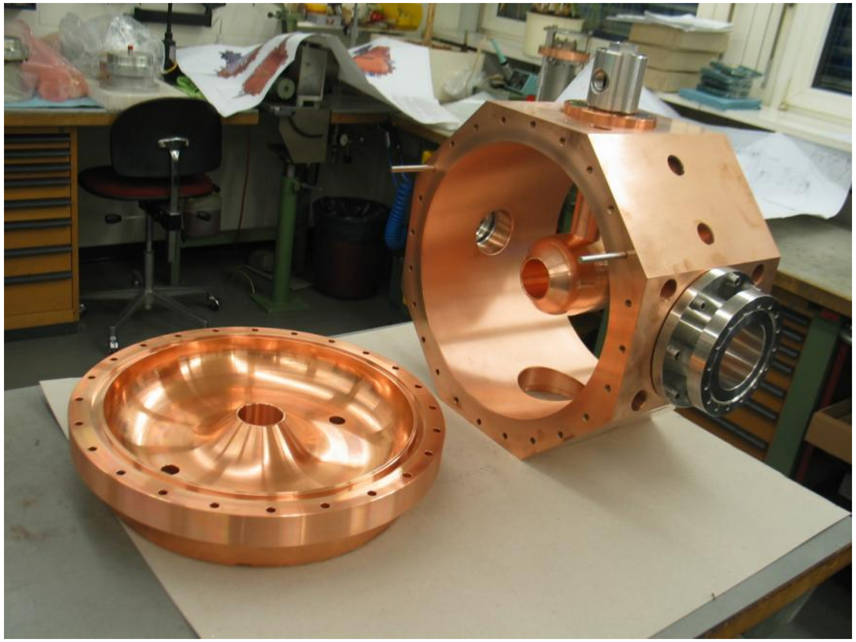
End of March 2008

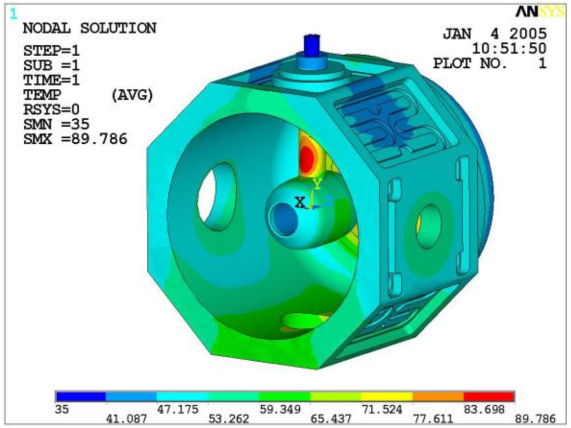
Buncher between Inj. 2 and Ring

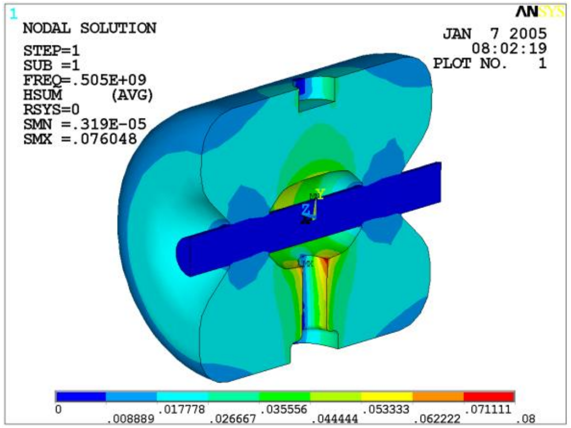


- proton bunch length at the exit of Injector 2 is about 6 cm
- increases up to about 20 cm at the end of the 58 m injection line for the ring cyclotron due the energy dispersion and space charge repulsion
- Buncher between Inj. 2 and Ring
- Design studies on 150 MHz and 500 MHz
- 30 kW tetrode amplifier at 500 MHz from LURE

500 MHz Buncher, between Inj. 2 and Ring





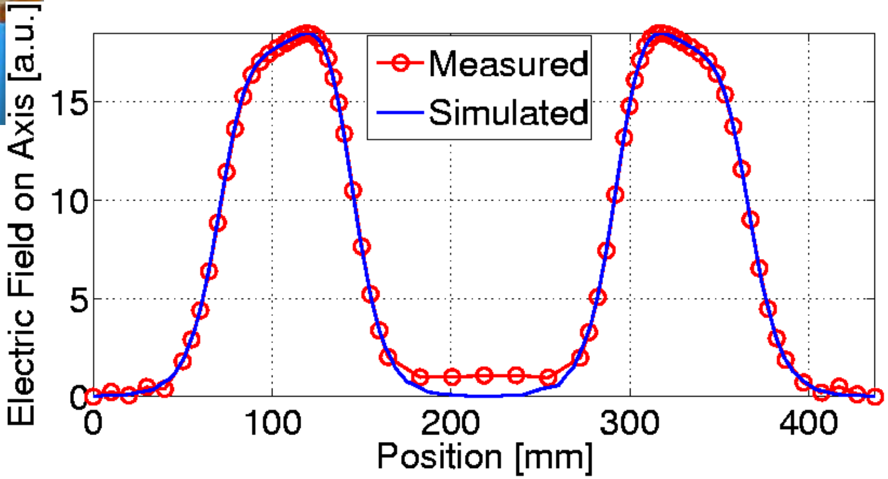


Assembly of buncher

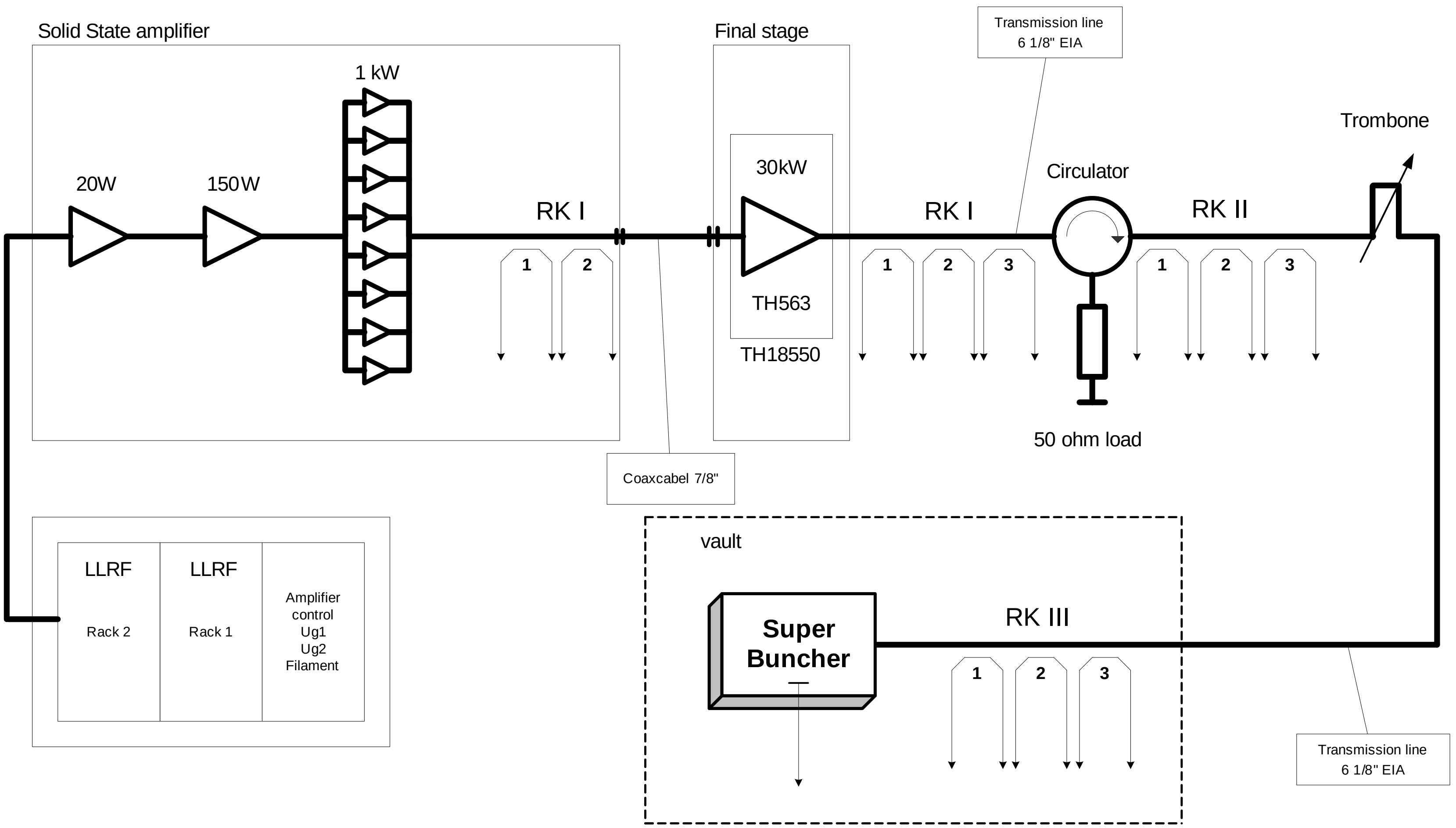
Resonance frequency:	506.328 MHz
Gap voltage:	218 kV
Quality factor:	34’000
Dissipated power:	10 kW, max 30 kW
Hydraulic tuning system range:	2.34 MHz
Cavity wall:	Cu-OFHC

Super-buncher bead-pull measurement

	Simulation	Measured
Qo	34’000	30’340
Tuning range	2.34MHz	2.3MHz
Vacuum drift	-127kHz	-120kHz
Thermal drift	-270kHz @30kW	-260kHz @20kW

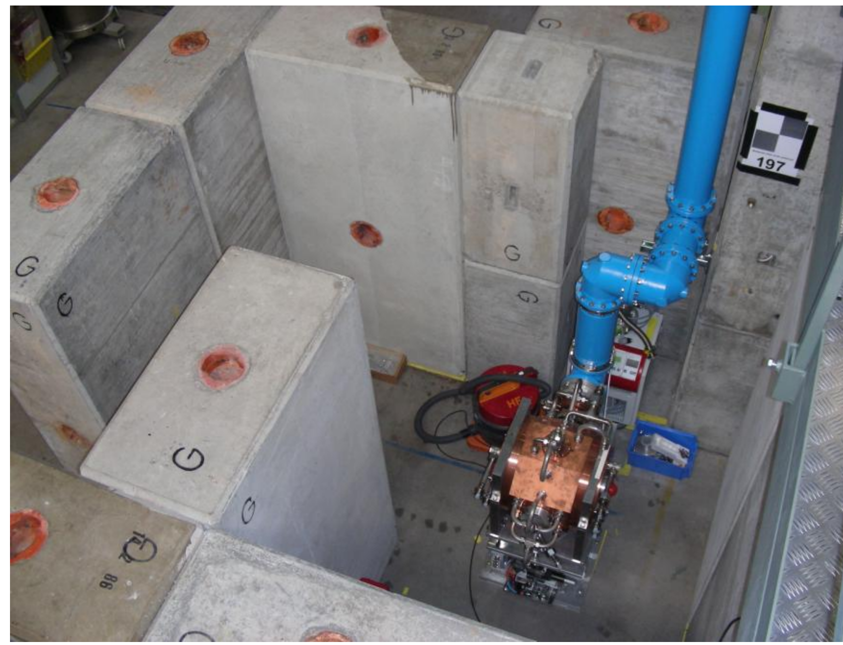


RF-System of 500 MHz Superbuncher



Test facility Superbuncher

RF-station 506 MHz / 30kW



Test vault

Commissioning of Super-buncher

Low level measurements

Amplifier tested on dummy load up to 20 kW

Tests on Superbuncher:

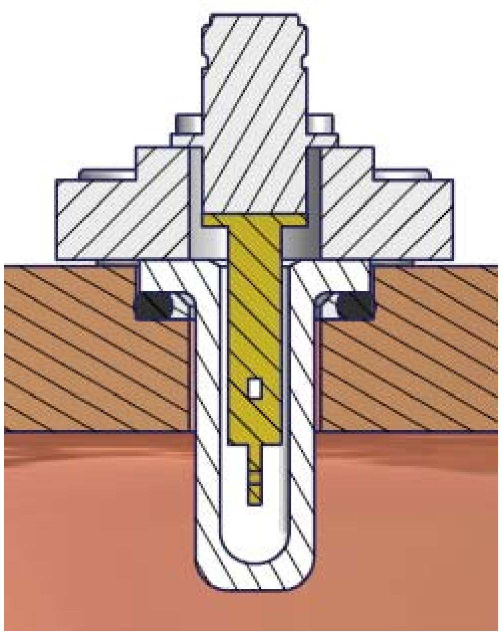
a lot of multipactoring

At 2 kW dissipated power

ceramic tulip for RF-pickup broken

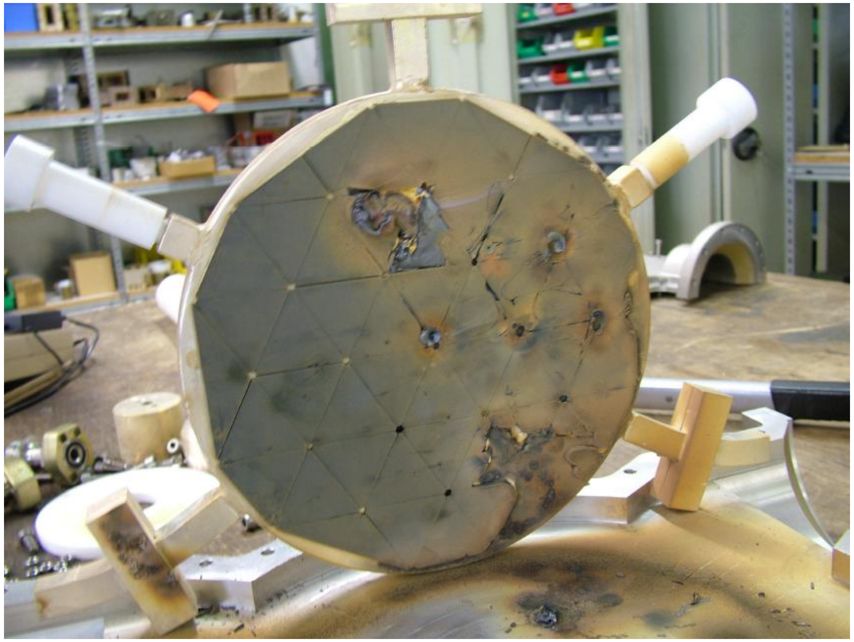
At 5 kW dissipated power

circulator broken



Inductive pickup
with ceramic tulip

6 1/8 “ EIA Circulator for Superbuncher



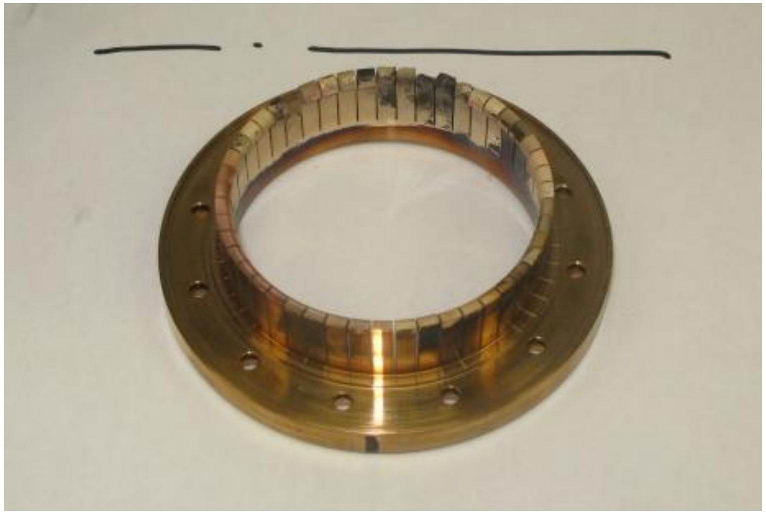
Disk with ferrites

Outer conductor of circulator

Circulator in repair till April 2008 -> Circulator equipped with ARC-detector

3rd device killed, contact finger burned

Tuner



Contact fingers

After 6 hours @ 10kW (nominal power)

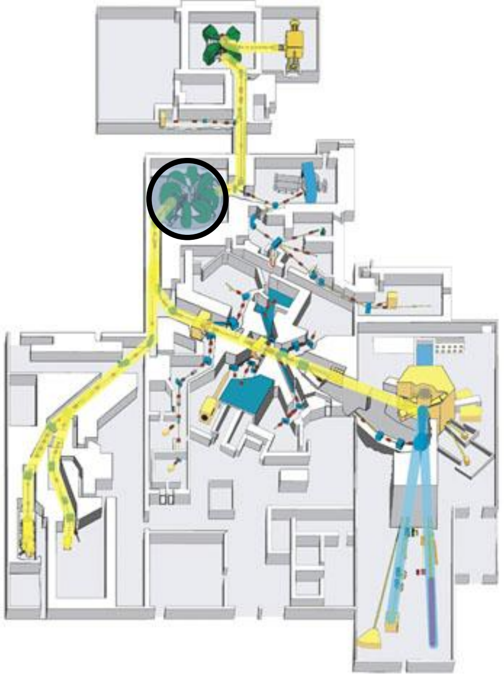
Contact ring Ag plated

Contact force increased

Inspection of the Plunger after 15kW Tests

Contact surface of the plunger had then been plated with hard-gold and contact force slightly reduced.
Since then, no hardware faillure of the Super-buncher system.

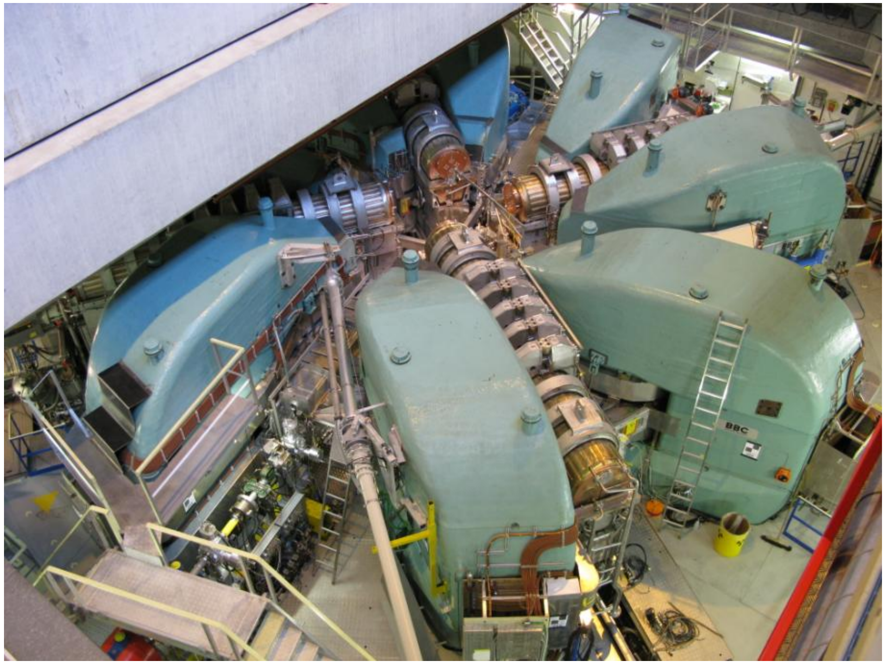
590 MeV Ring Cyclotron

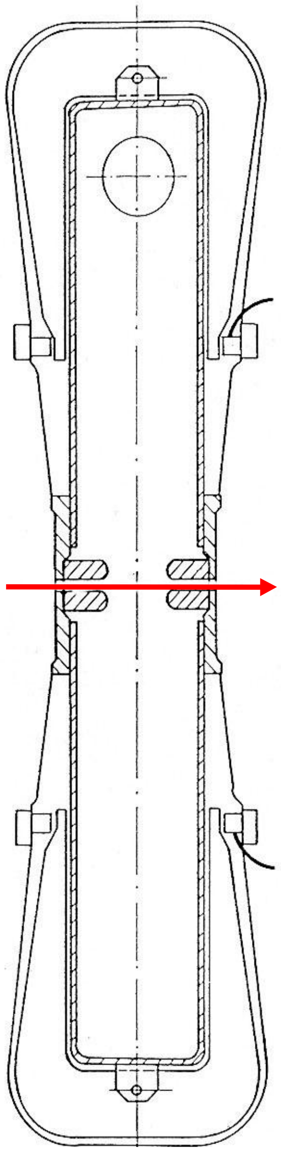


- 8 Sector Magnets 1 T
- Injection energy: 72 MeV
- Extraction energy: 590 MeV
- Accelerator frequency: 50.63 MHz
- 4 new Cu-Cavities: 850 kV
- Beam current: 2.2 mA

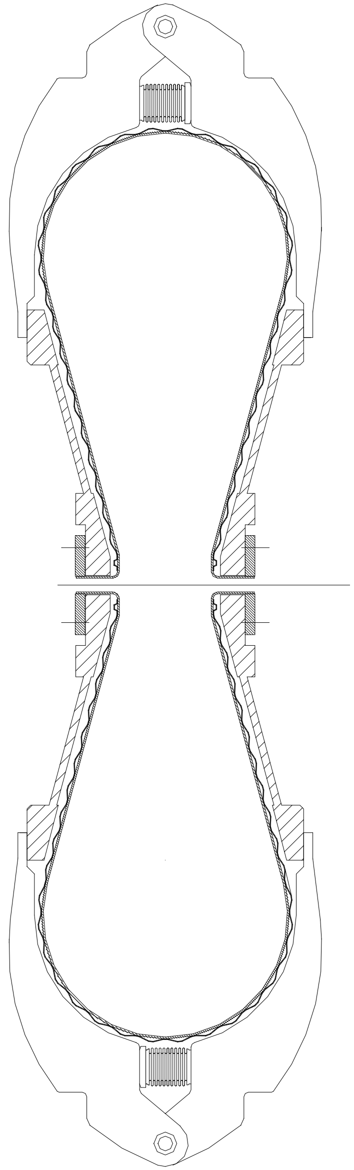
For 3 mA beam current

- 4 Accelerator Cu-Cavities: ~ 1 MV
- Number of turns: ~ 160





Al-Cavity

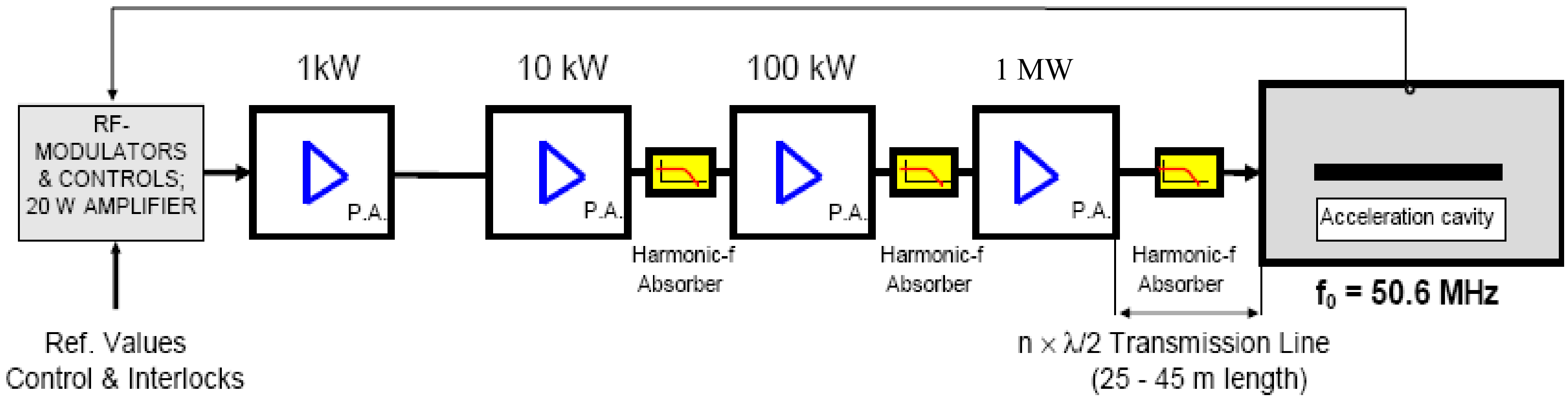


Cu-Cavity

	Al-Cavity	Cu-Cavity
Frequency	50.6 MHz	50.6 MHz
Voltage	750 kV_p	>1 MV_p
Dissipated Power	300 kW	500 kW
Q-value	28‘000	45‘000
Bandwidth	1.8 kHz	1 kHz
Tuning Range	240 kHz	560 kHz

50 MHz 1 MW amplifier chain for Ring cyclotron

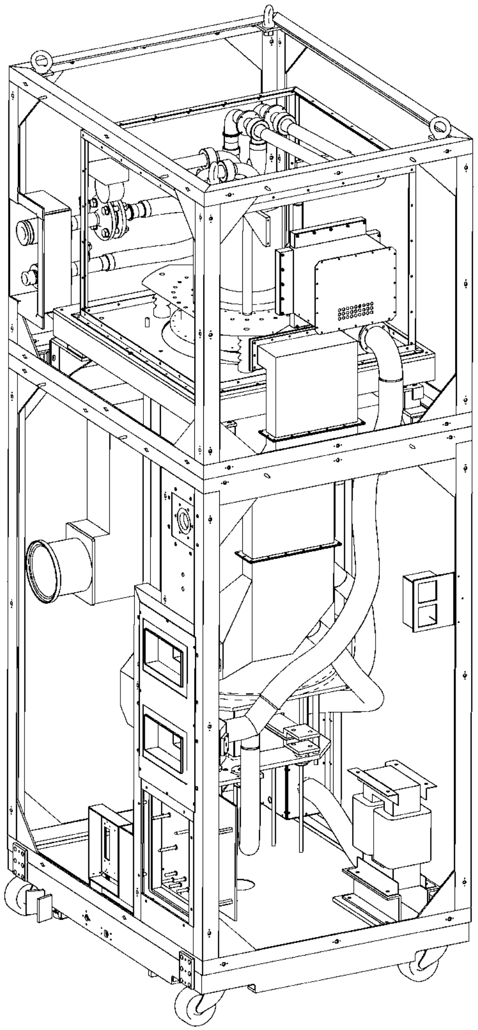
4- STAGE POWER AMPLIFIER CHAIN, EMPLOYING POWER TETRODE TUBES



Tube Types:	**YL 1056**	**RS 2022 CL**	**RS 2074 HF**	**RS 2074 HF**
Cooling Method:	forced air	forced air	water	water

Setup	Power dissipated in Cavity (no Beam)	Beam power at 2 mA beam current	Beam power at 3 mA beam current	Total Power
Alu cavity 202 turns	350 kW	300 kW		650 kW
Cu cavity 202 turns	250 kW	300 kW		550 kW
Cu cavity 160 turns	400 kW		450 kW	850 kW

Potential problems for 3mA at the Ring cyclotron



Limit of RF-power coupler unknown (1MW?)

Water cooling system for tubes at power limits

now	Inlet 55° C	Outlet 80° C
PA=500kW	Inlet 45..50° C	Outlet 80° C

Heavy beam loading

no beam	P = 400 kW	Zin ~ 85 Ohm
3 mA	P = 850 kW	Zin ~ 40 Ohm

Amplifiers pushed to limits
-> reliability
-> lifetime of tubes?

Flattop system is working on the limits
Cavity, transmission line, amplifier

With Super-buncher flattop voltage might be reduced

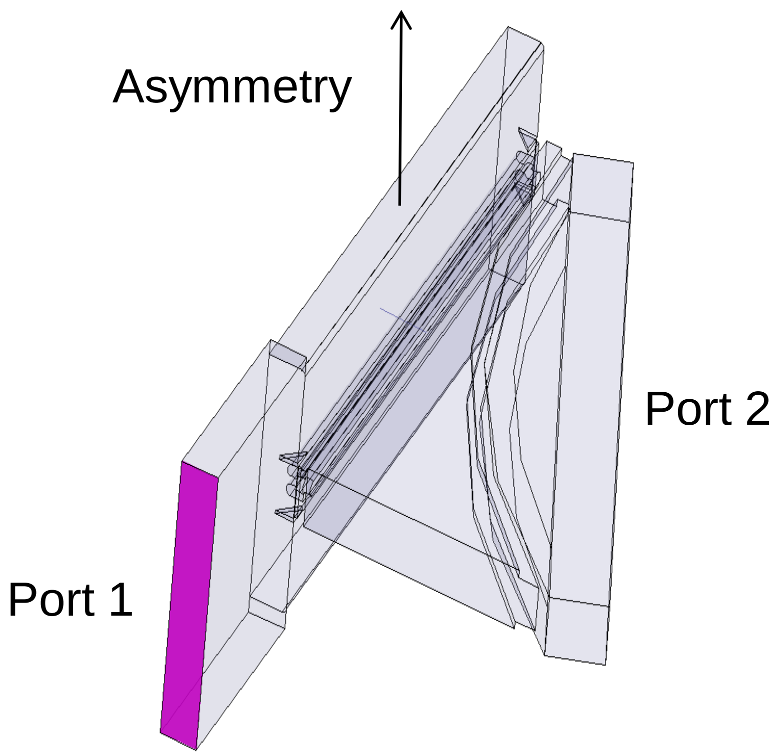
Conclusions:

…Upgrade is delayed by at least 3 years.

…Power tests of new Resonators for Injector II are promising. RF contacts have to be improved.

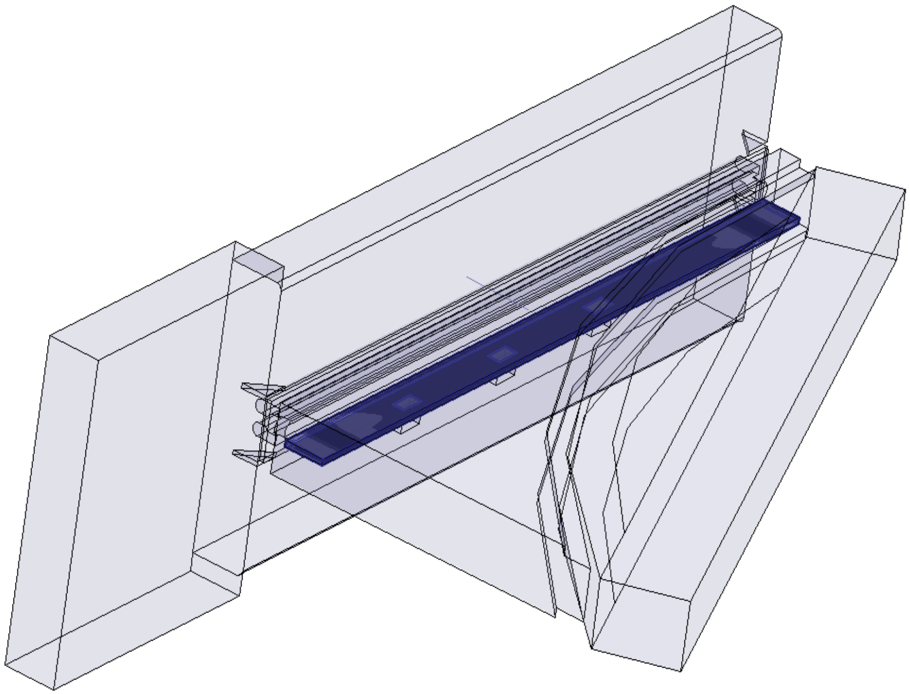
…RF stray fields should be investigated further. Reduction might lead to improved availability and performance.

Simulation Model without Absorber



- Up-down asymmetry: Cavity top wall moved up by 2mm
- Left-right symmetry assumed to reduce model size
- Power input from Cavity side-wall (Port 1) and attenuation recorded at waveguide extension attached to intermediate vacuum chamber (Port 2)
- Simulation method produces same fields in cavity, with the advantage to avoid narrow bandwidth simulation.

2.57m x 0.15m long Graphite Absorber



Almost no change in total radiated power, only mode-pattern at port 2 changes.

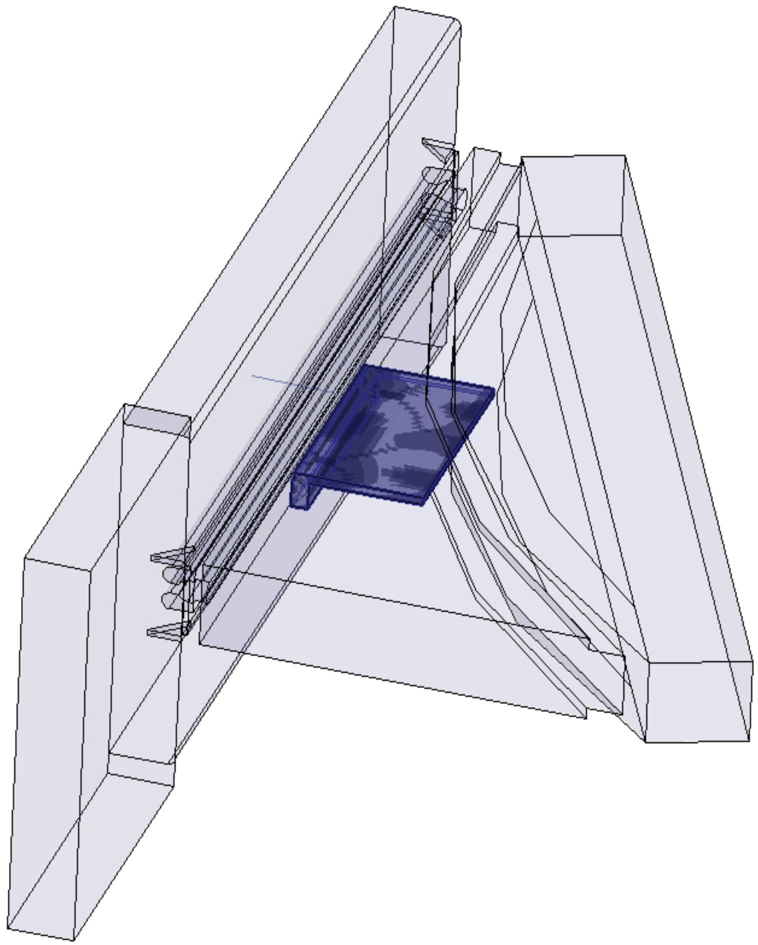
No impedance-step from sector magnet taken into account

Only limited simulation domain, (Simulation is more accurate if absorber is more efficient…)

Simulation in driven frequency domain by HFSS. Graphite with 7000S/m modeled as 0.2mm thick layer with 0.1 micro meter roughness.

Graphite plate 2cm thick, ends 2cm below beam plane

λ/4 absorbing Resonator: preliminary Results



Comparison of attenuations to case without absorber:
→S(2:1,1:1) gets 5dB lower
→Flattop-Voltage could be almost doubled for same radiated power