Status of the RF-System for the proton accelerator facility at PSI

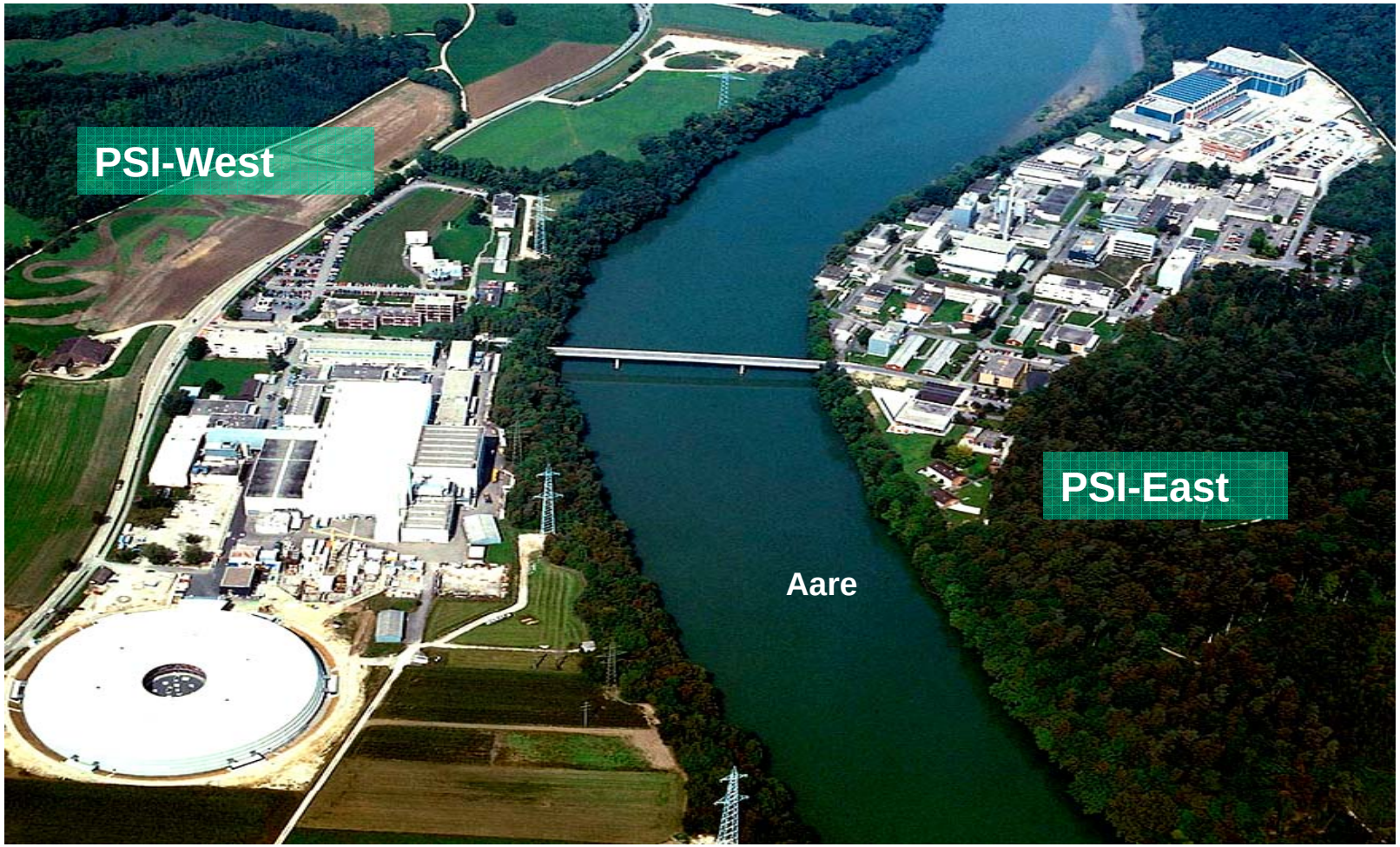
Markus Schneider, RF power amplifier

Status of the RF-System for the proton accelerator facility at PSI

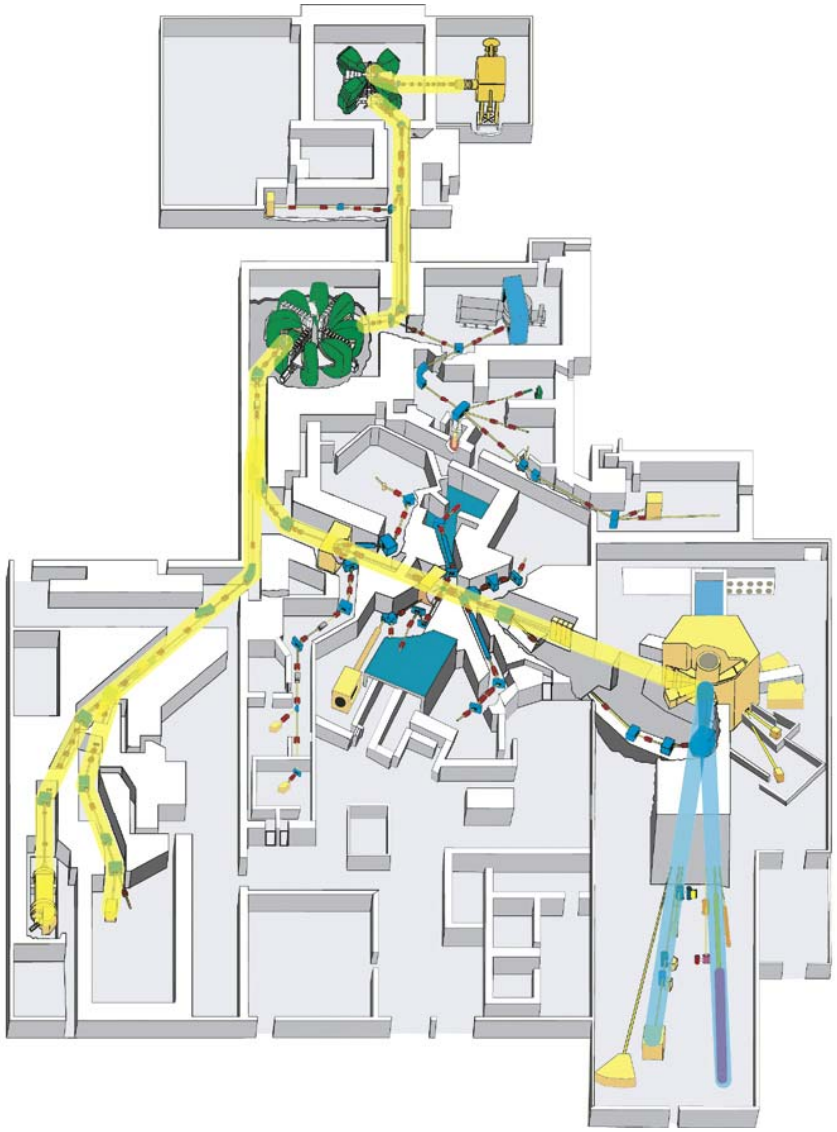
- **Overview of proton accelerator facility**
- **Upgrade of Ring cyclotron**
  new copper cavities
- **Superbuncher**
- **Upgrade of Injector 2 cyclotron**

Thanks to my colleagues of the RF-group

Paul Scherrer Institut



Proton accelerator facility



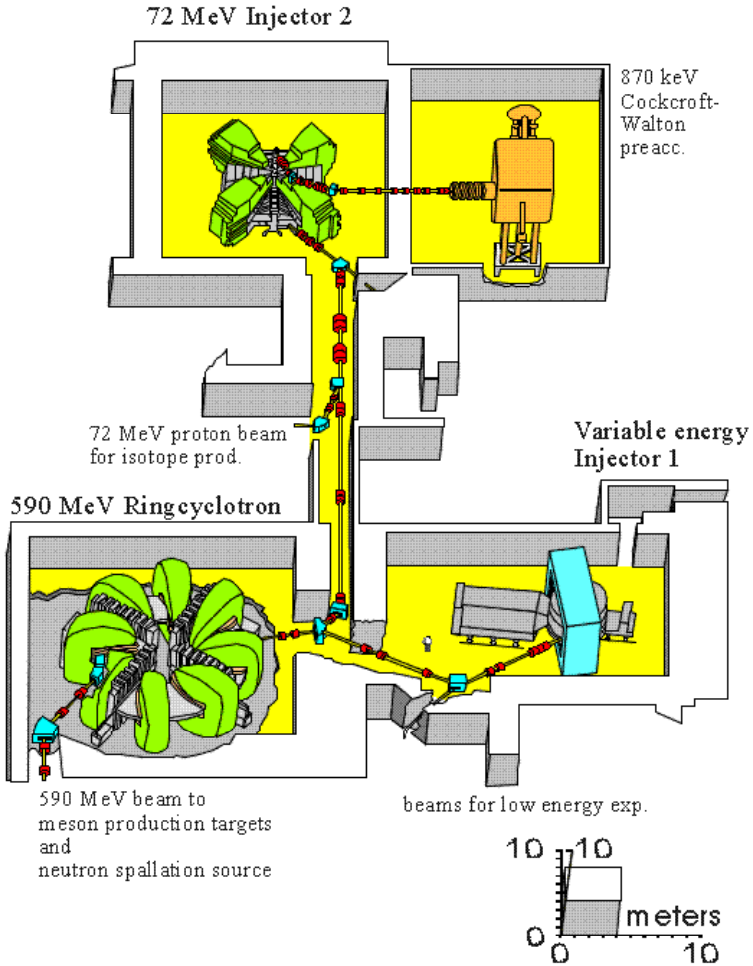
- 590 MeV proton beam
- 2 mA operational beam current
- 2.2 mA max achieved beam current

- Planed to increase up to 3 mA

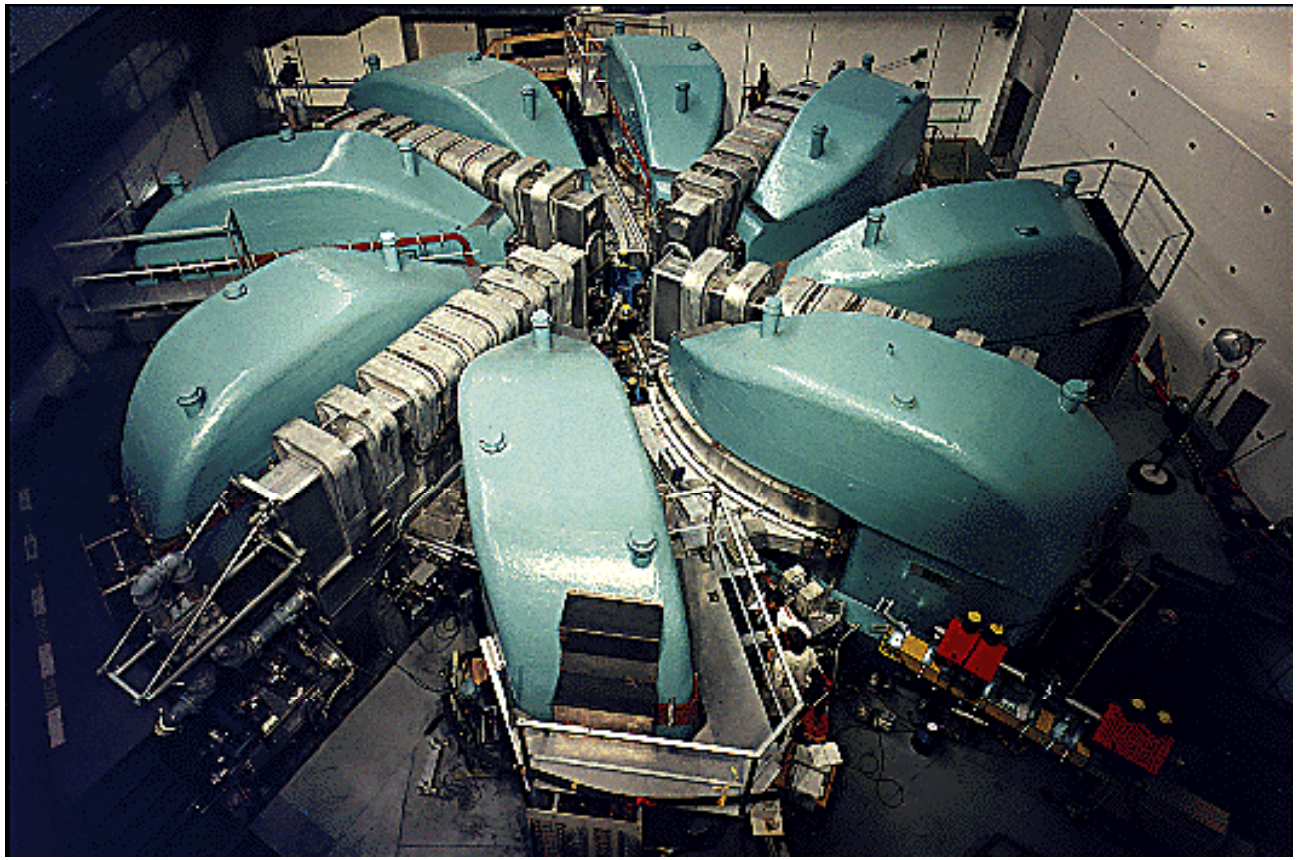
Protons beam

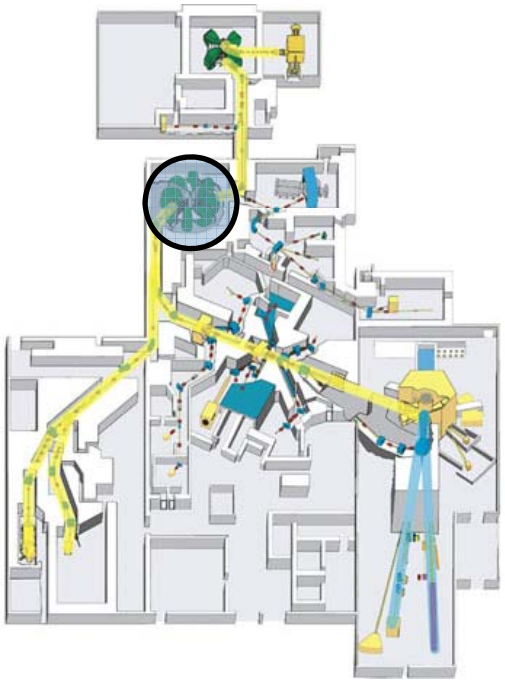
Neutrons beam

Proton accelerator facility



590 MeV Ring Cyclotron





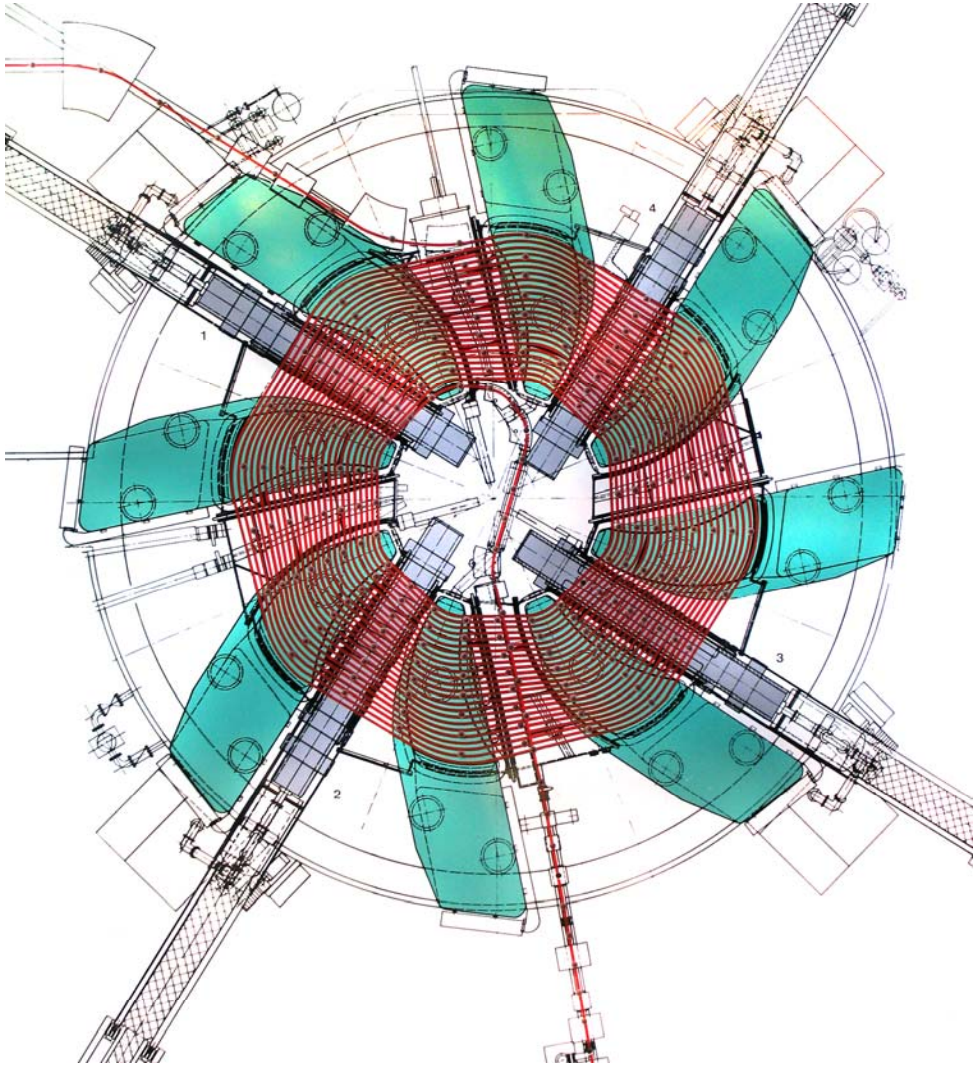
Separated Sector Cyclotron

590 MeV Ring Cyclotron

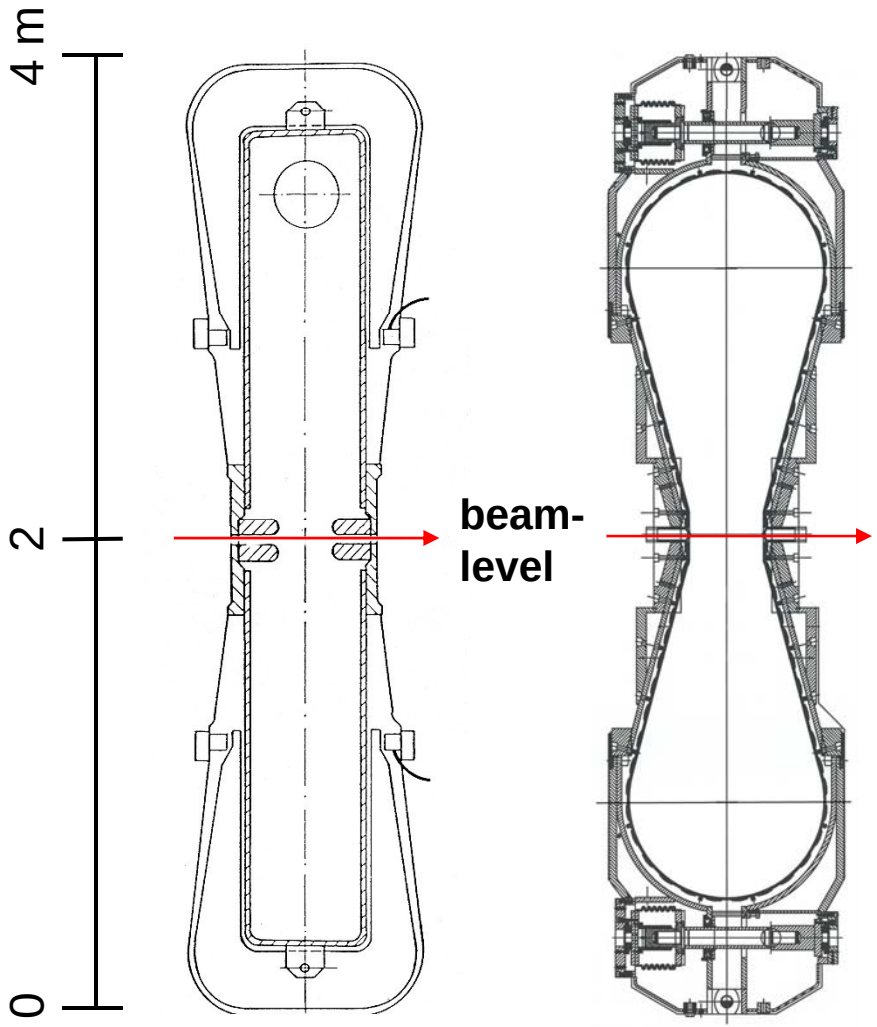
- 8 Sector Magnets	1 T
- Injection energy:	72 MeV
- Extraction energy:	590 MeV
- Accelerator frequency:	50.63 MHz
- 4 Accelerator Alu-Cavities:	730 kV
- Beam current:	2 mA
- Number of turns:	202

For 3 mA beam current

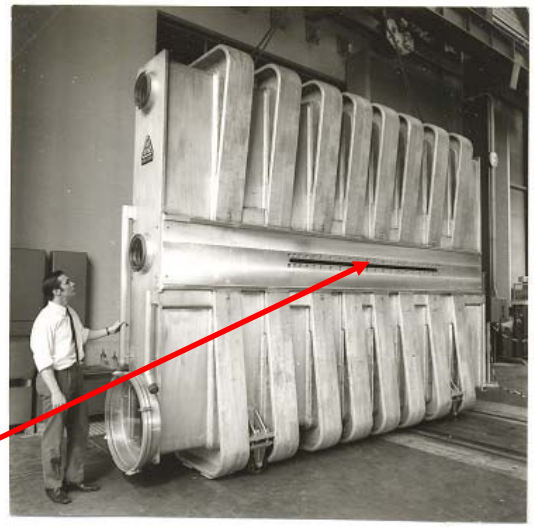
- 4 Accelerator Cu-Cavities:	~ 1 MV
- Number of turns:	~ 160



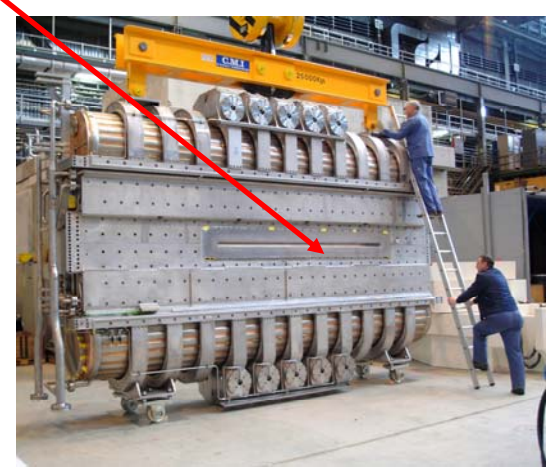
“old” Alu-cavity **New Cu-cavity**



beam-slit

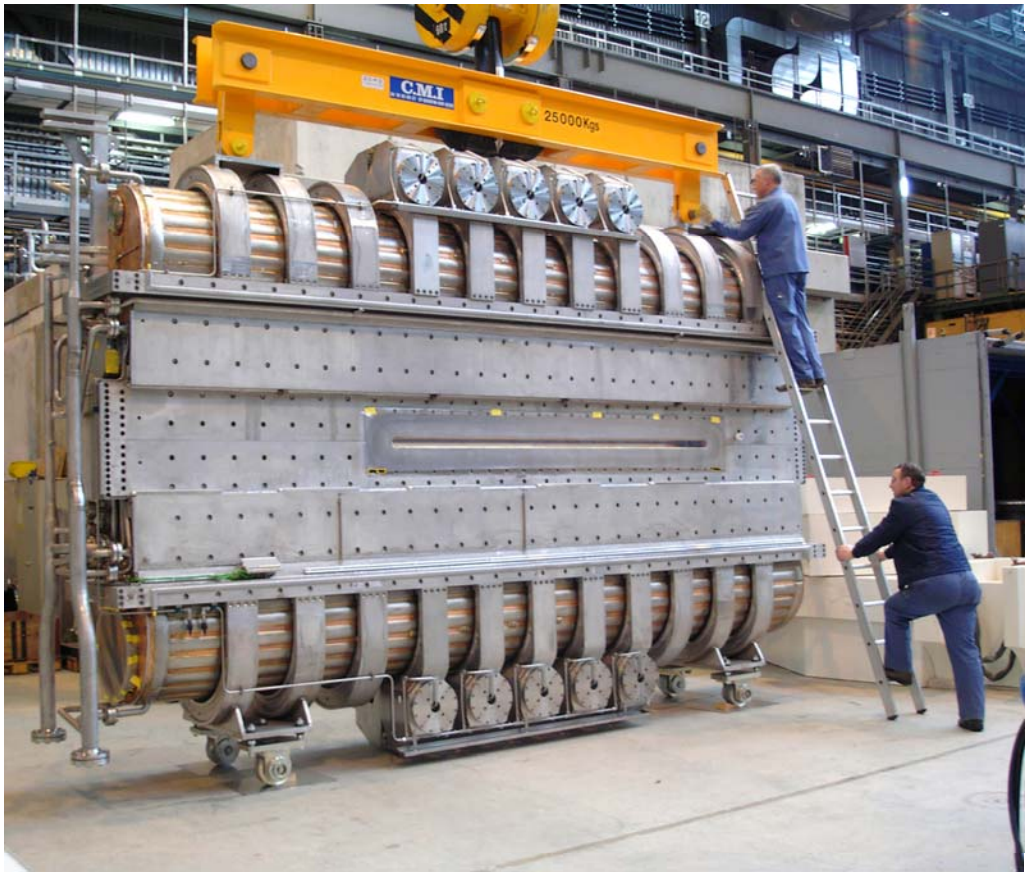


50 MHz Alu-Cavity, Ring



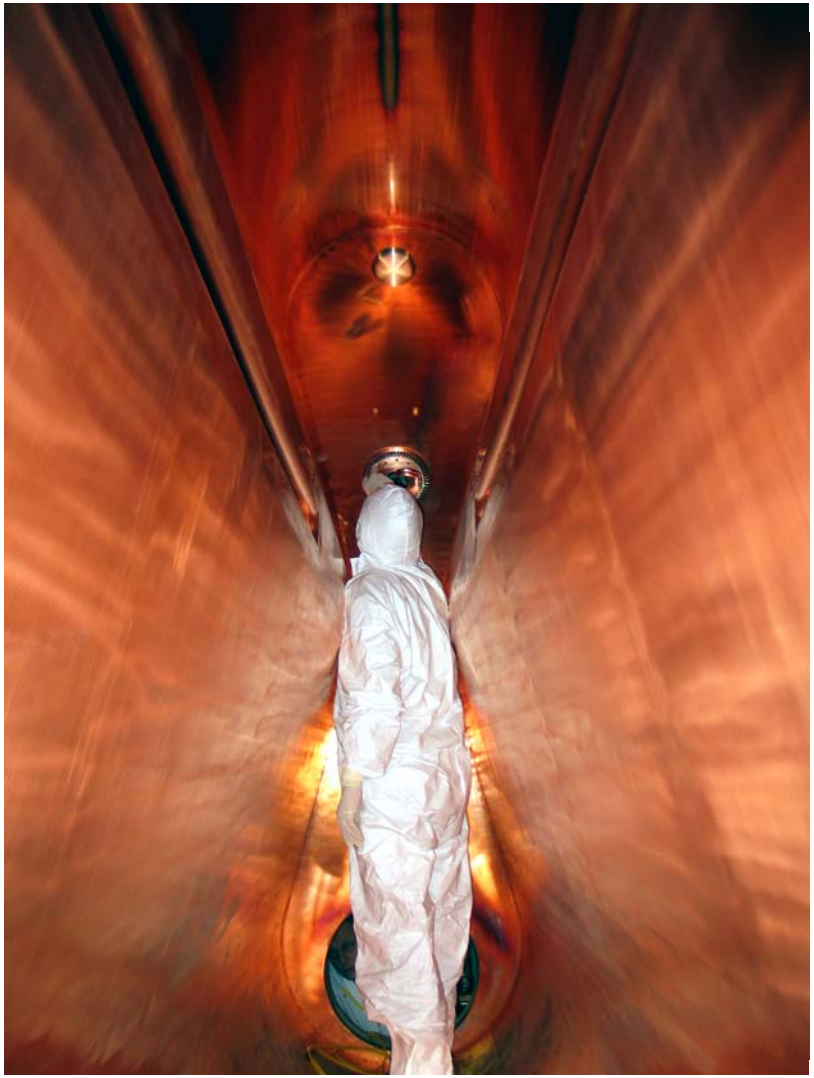
New 50 MHz Cu- Cavity, Ring

The New 50 MHz Ring Cyclotron Cavity

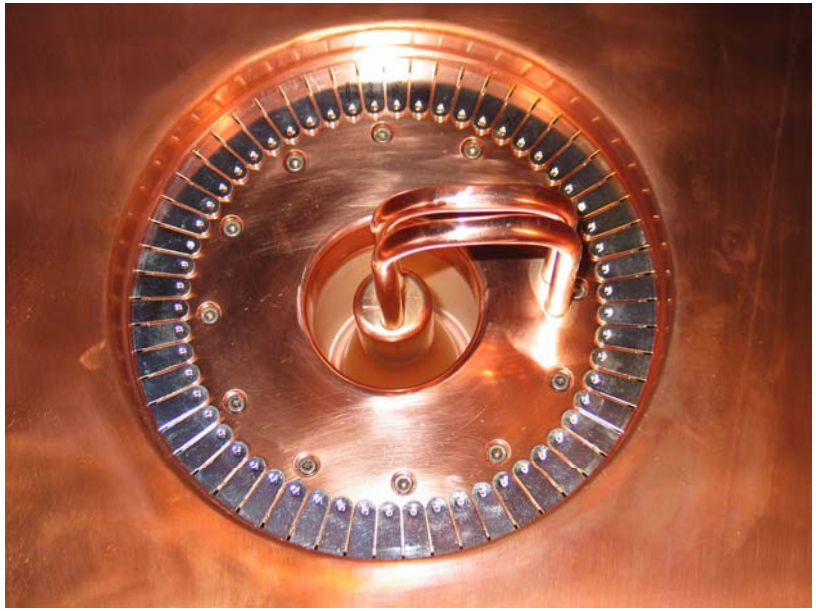


Specification

Resonance frequency:	**50.6328 MHz**
Accelerating voltage:	**1.4 MV**
Dissipated power:	**500 kW**
Q value:	**45‘000**
Tuning range:	**540 kHz**
Cavity wall:	**Cu-OFHC**
Support structure:	**316LN**
Vacuum pressure:	**1e-6 mbar**
Cooling water flow:	**34 m3/h**
Dimension:	**5.6x3.9x0.95 m**
Weight:	**25'000 kg**



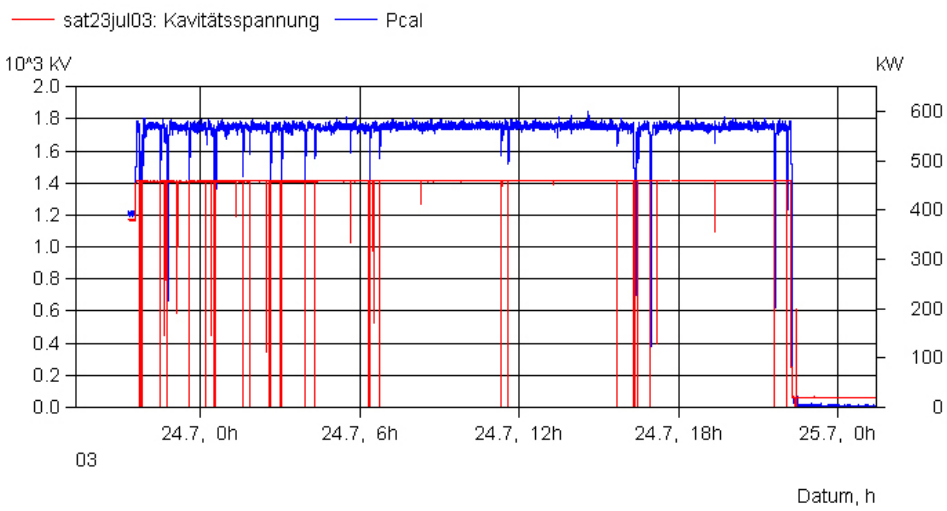
Inside the Cavity



Coupling loop

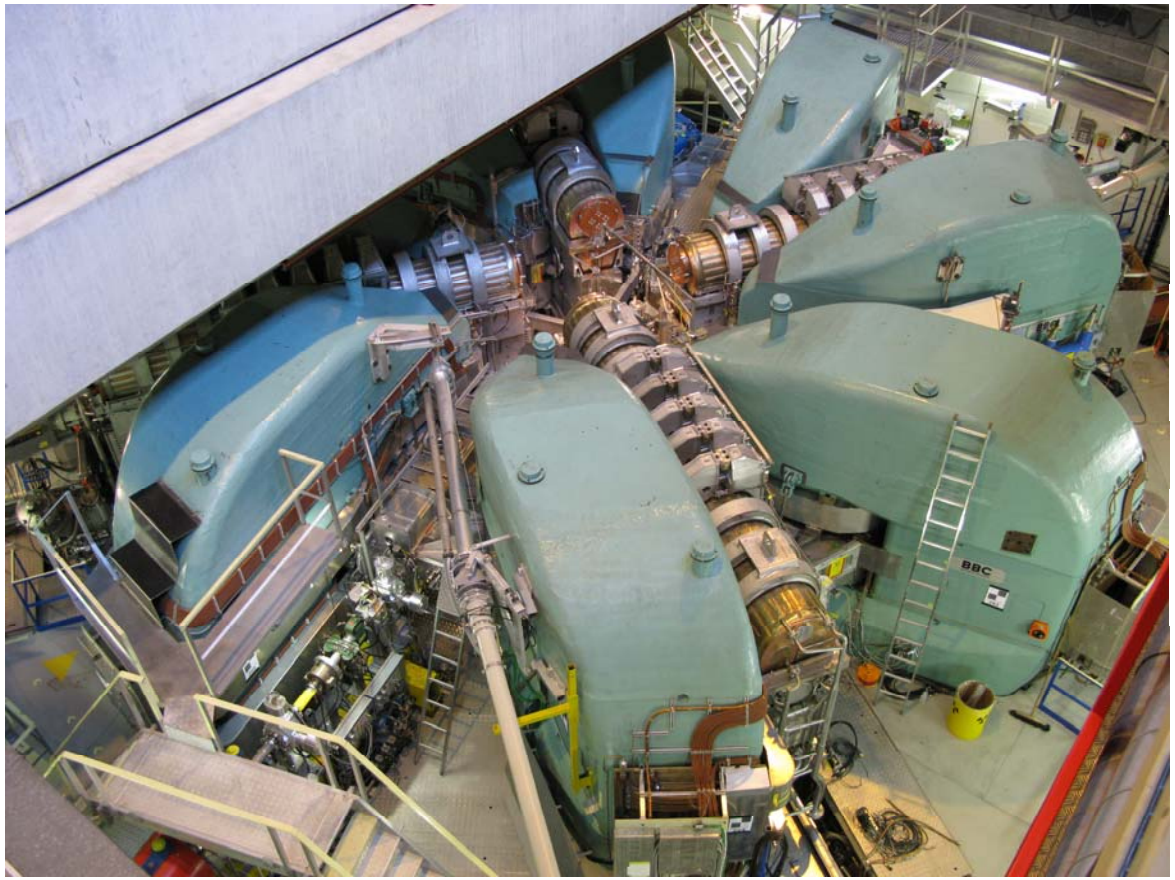
Site Acceptance Test

Each cavity 24h test run at nominated power



To achieve full power about 1 day of conditioning was needed

Replacement of 50 MHz Ring Cyclotron Cavities



SD 2004

Cavity 3 replaced

SD 2006

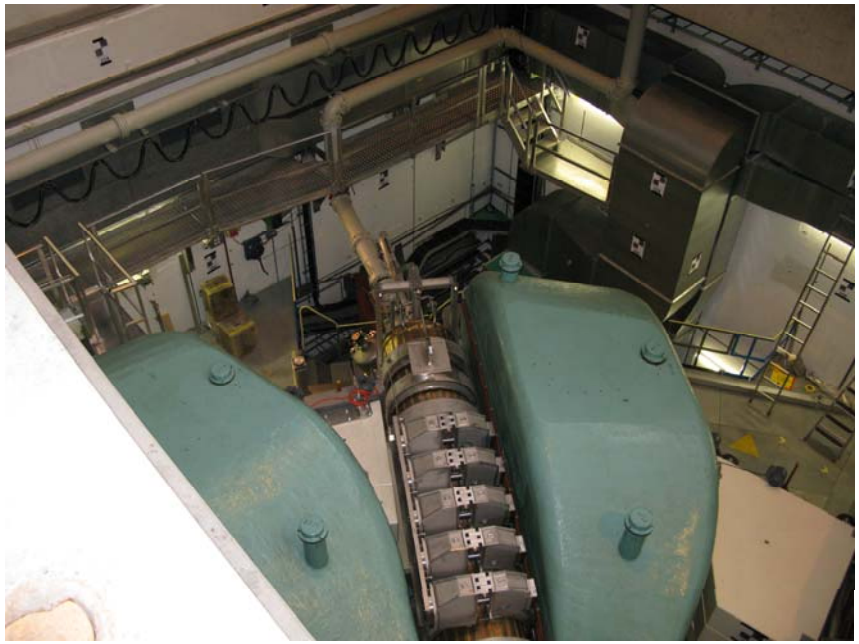
Cavity 1 replaced

SD 2008

Cavity 2 & 4 replaced

Start of operation with beam in April 2008

Burned finger contacts in transmission line 2007



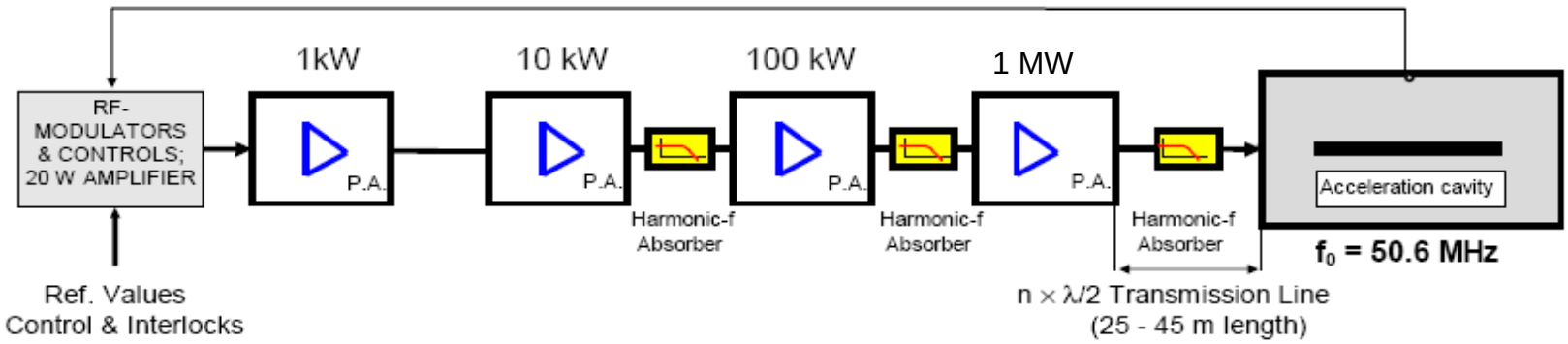
100 – 230 RL transmission line to Cavity 1

Burned finger contacts of spherical joint

Reasons:
- Sphere in wrong position
- Angle of elbow out of tolerance (83° instead of 90 +/- 5°)

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

SPINNEREI

Low Level Electronics
1 kW & 10 kW amplifier
PLC for 100 kW & 1 MW amplifier

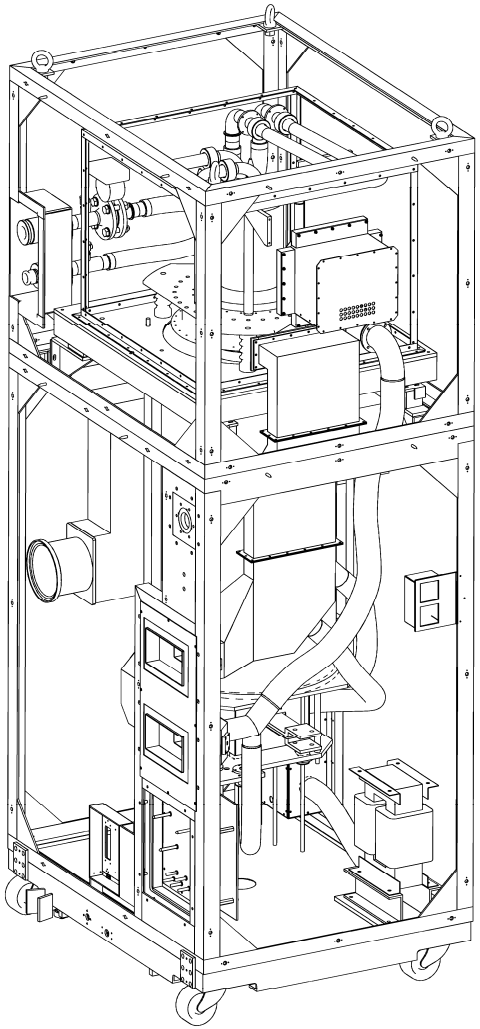
5 x 50 MHz 100 kW Amplifier
Tube box from Siemens

FRIES

Final stages:

4 x 1MW 50 MHz
1 x 150 / 220 kW 150 MHz
Air cooling, trombones
2 spare amplifiers

Potential problems for 3mA at the Ring cyclotron



- Limit of RF-power coupler unknown
- Water cooling system for tubes at power limits

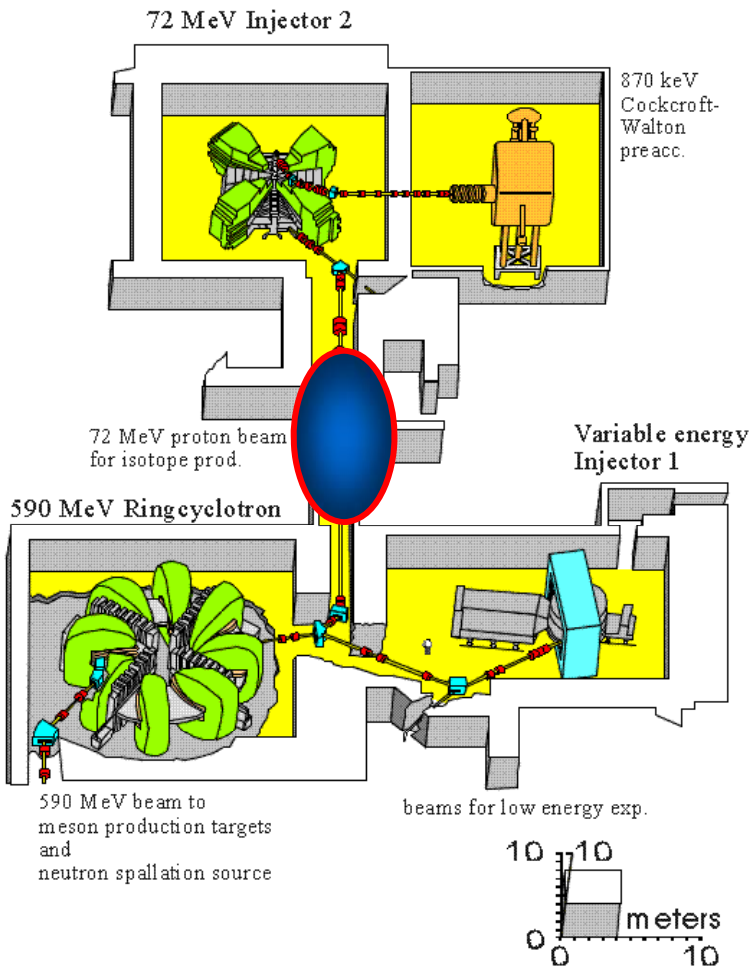
now	Inlet 55°C	Outlet 80°C
PA=500kW	Inlet 45..50°C	Outlet 80°C

- Heavy beam loading

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

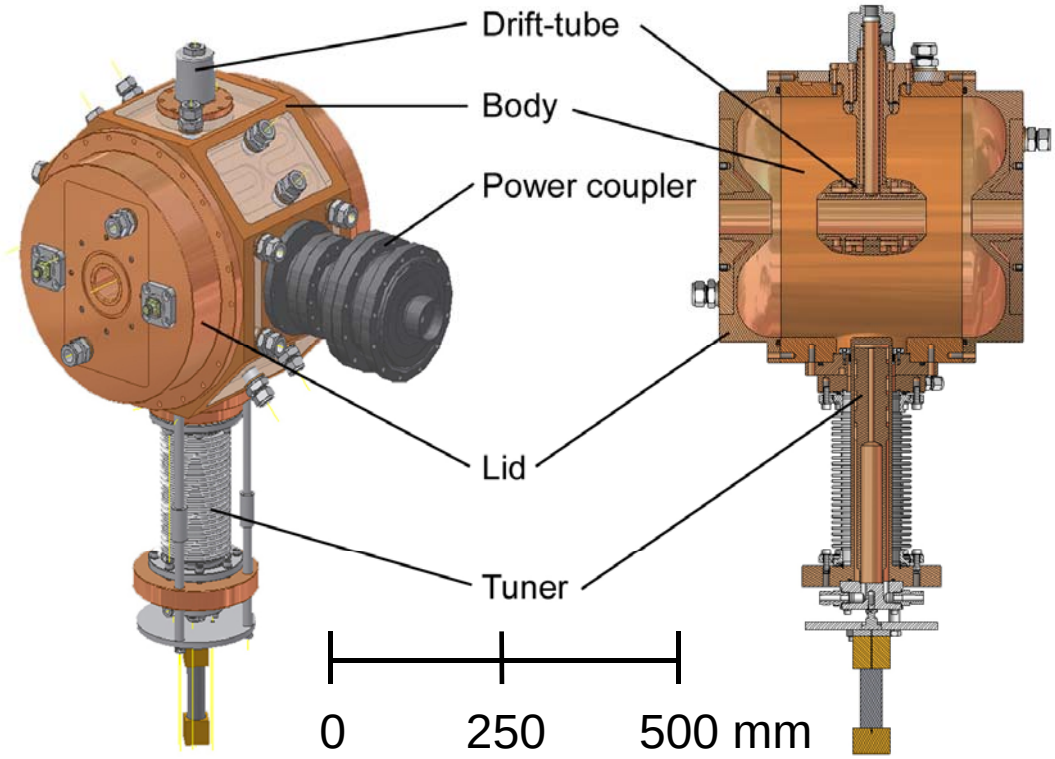
- Amplifiers pushed to limits
  -> reliability
  -> lifetime of tubes?
- Flattop system is working on the limits
  Cavity, transmission line, amplifier
- With Superbuncher flattop voltage might be reduced

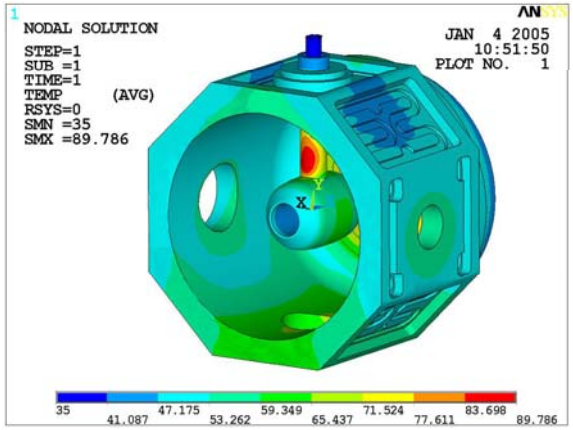
Buncher between Inj. 2 and Ring

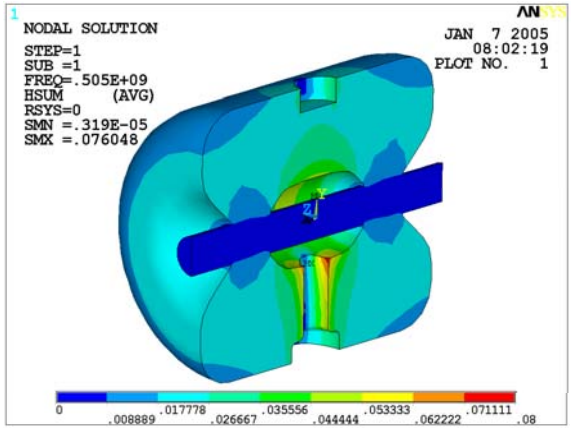


- proton bunch length at the exit of Injector 2 is about 6 cm
- increases up to about 20 cm at the end of the 58 m injection line for the ring cyclotron due the energy dispersion and space charge repulsion
- Buncher between Inj. 2 and Ring
- Design studies on 150 MHz and 500 MHz
- 30 kW tetrode amplifier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

500 MHz Buncher, between Inj. 2 and Ring

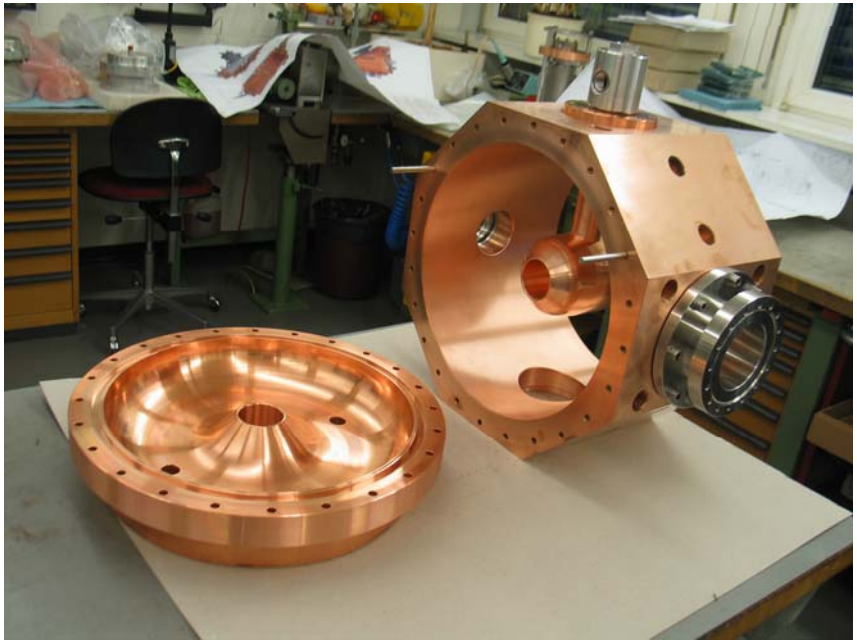




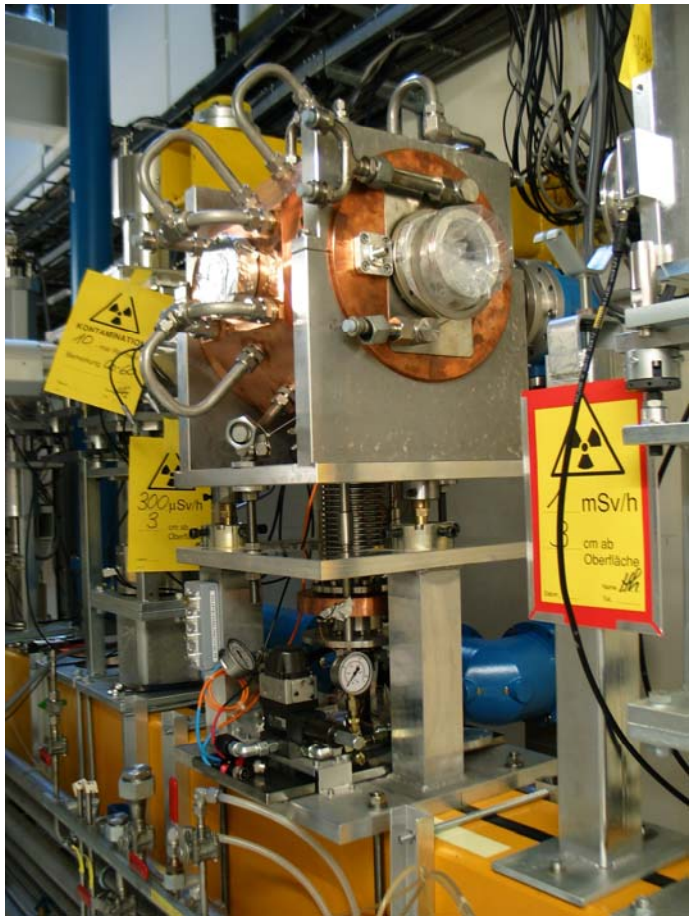


Resonance frequency:	506.328 MHz
Gap voltage:	218 kV
Quality factor:	34’000
Dissipated power:	10 kW, max 30 kW
Hydraulic tuning system range:	2.34 MHz
Cavity wall:	Cu-OFHC

500 MHz Buncher, between Inj. 2 and Ring

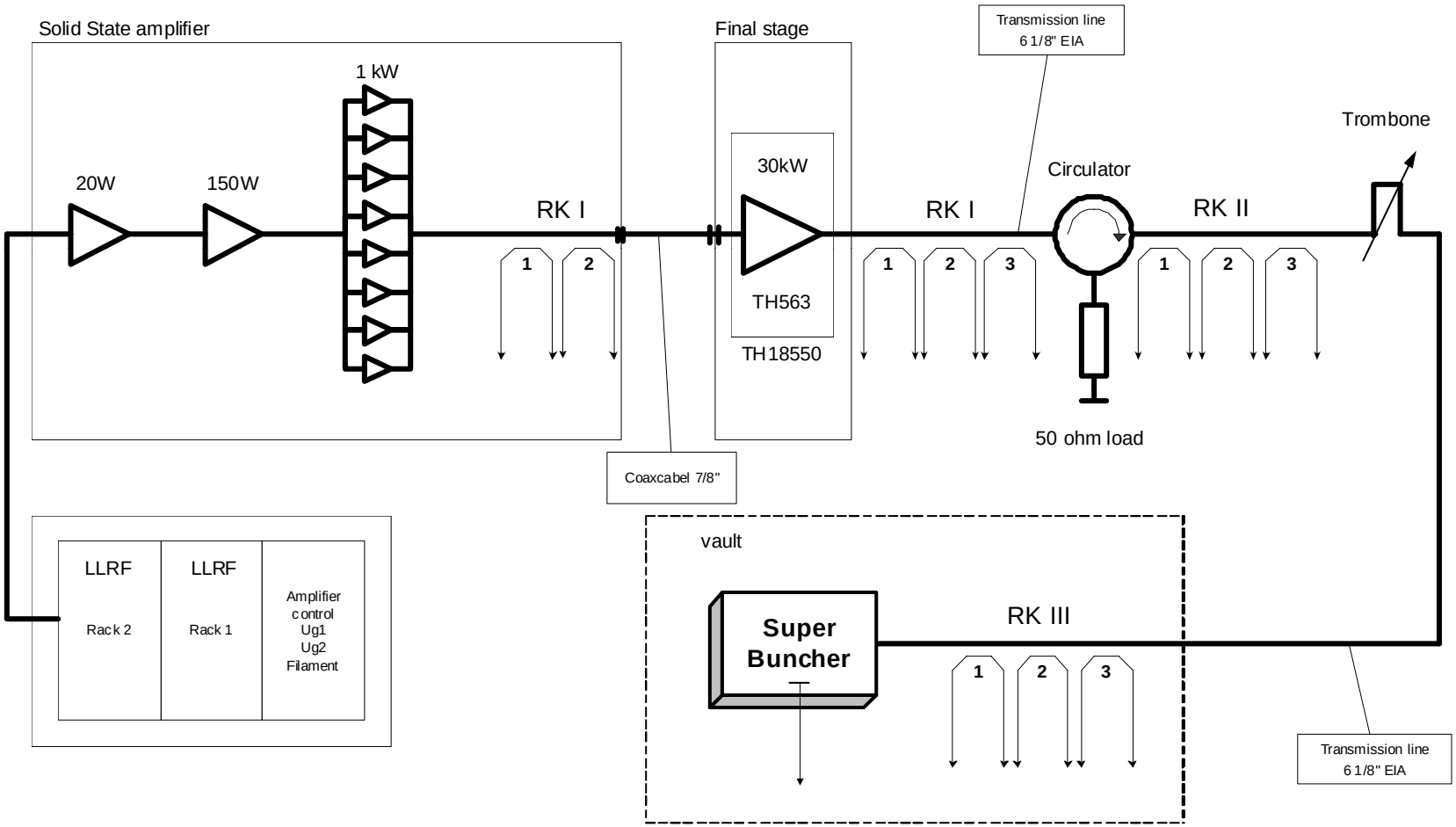


Assembling of buncher



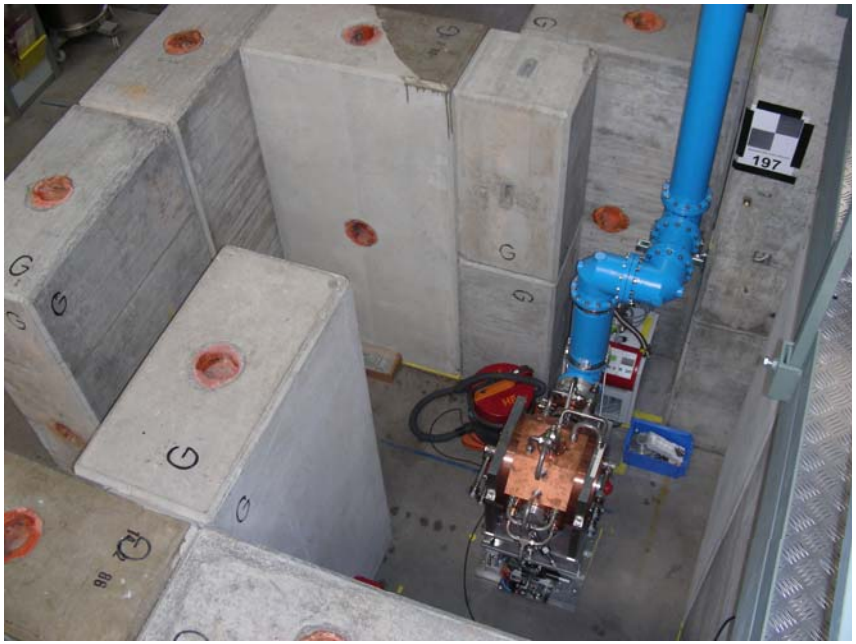
Test installation in beam line

RF-System of 500 MHz Superbuncher



Test facility Superbuncher

RF-station 506 MHz / 30kW



Test vault

Solid state amplifier 506 MHz / 1 kW

Power supplies

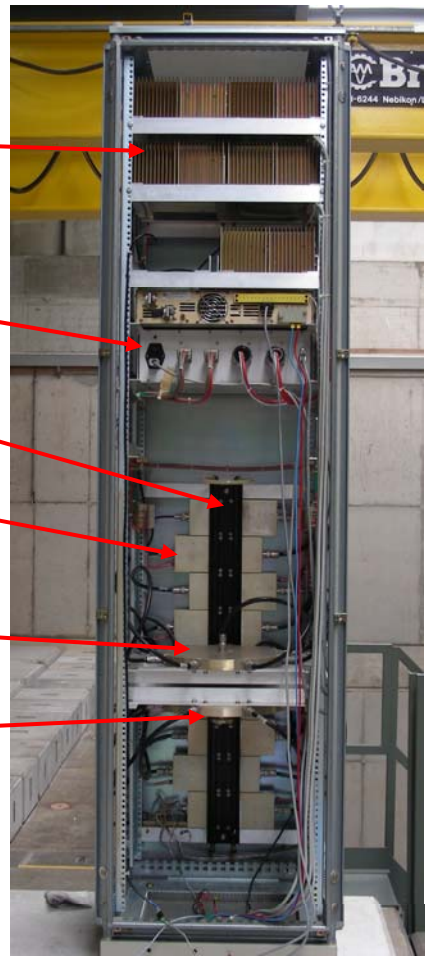
Measurement

Cooling bar

Solid state modules

Splitter

Combiner



- Driver stage 8 x 120 W solid state amplifiers combined
- Till now driver module failed due to bad soldering contact. Repaired, but transistor destroyed. Module will be replaced by PSI design of Marcos Gaspar.
- Only one spare module from Lure left
- Maybe whole solid state amplifier will be replaced by PSI design.

Amplifier 506 MHz / 30 kW

- Coaxial cavity amplifier TH18550 from Thales
- Thales tube Tetrode TH563

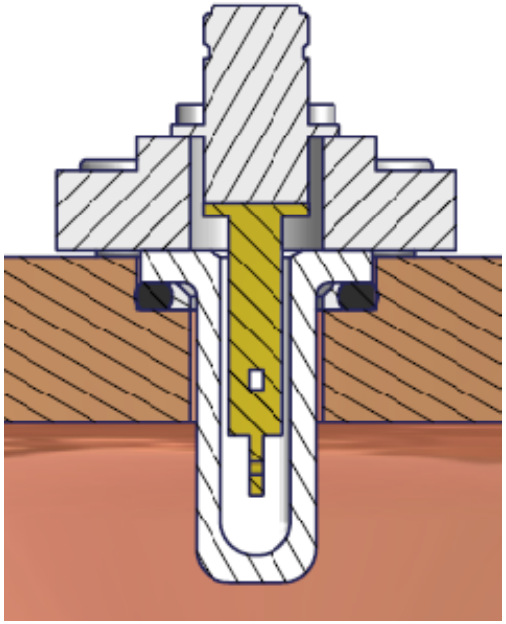
Commissioning of Superbuncher

- Low level measurements
- Amplifier tested on dummy load up to 20 kW
- Tests on Superbuncher:

  a lot of multipactoring
- At 2 kW dissipated power

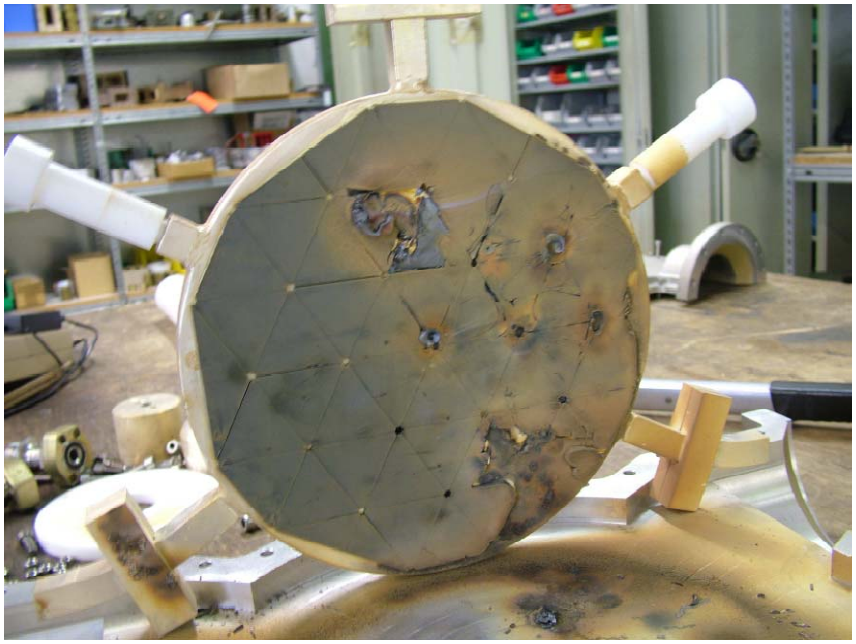
  ceramic tulip for RF-pickup broken
- At 5 kW dissipated power

  circulator broken



Inductive pickup
with ceramic tulip

6 1/8 “ EIA Circulator for Superbuncher



Disk with ferrites

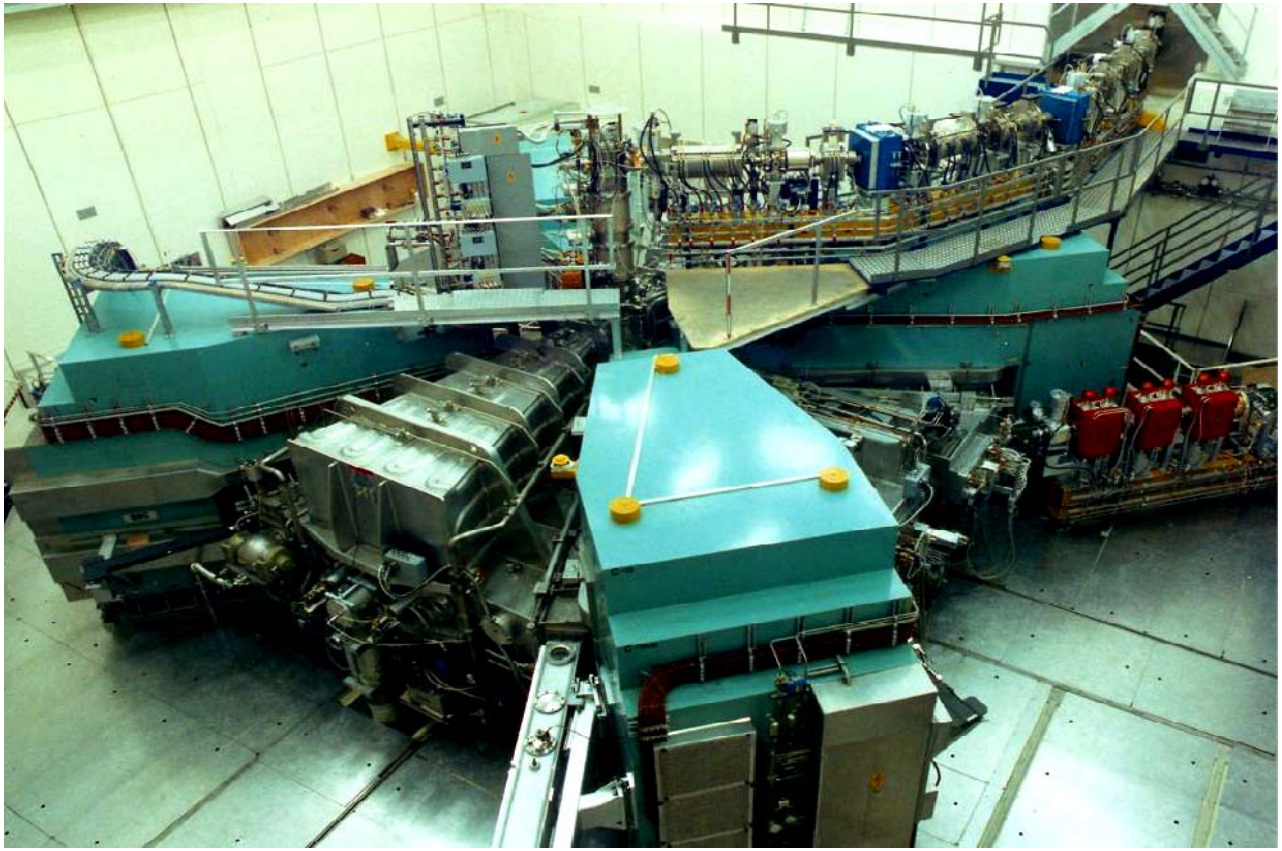
Outer conductor of circulator

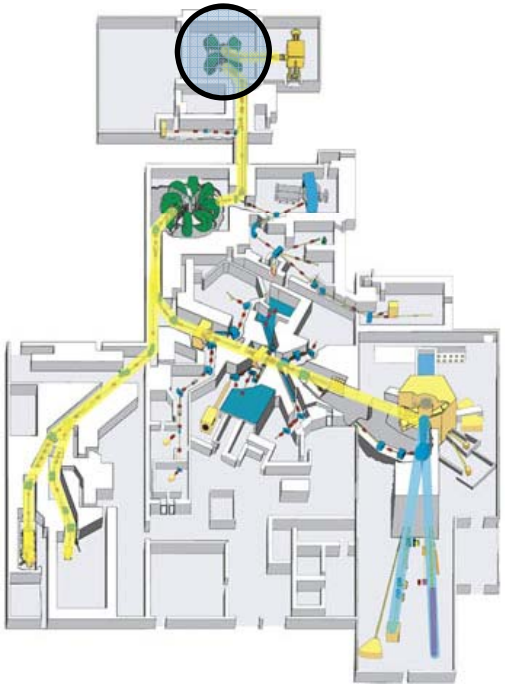
Circulator in repair till April 2008 -> Circulator will be equipped with ARC-detector

Test of Superbuncher at nominated power

Installation in beam line on maintenance days summer 2008

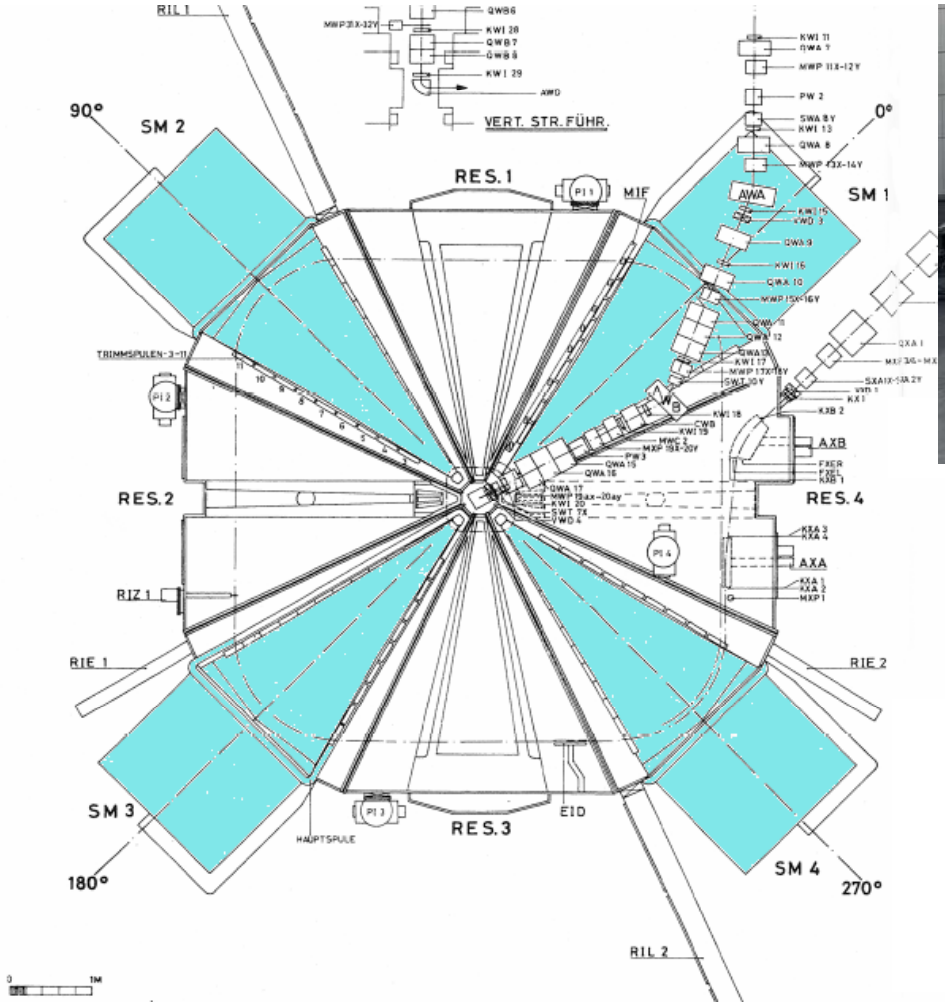
Injector 2





- **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

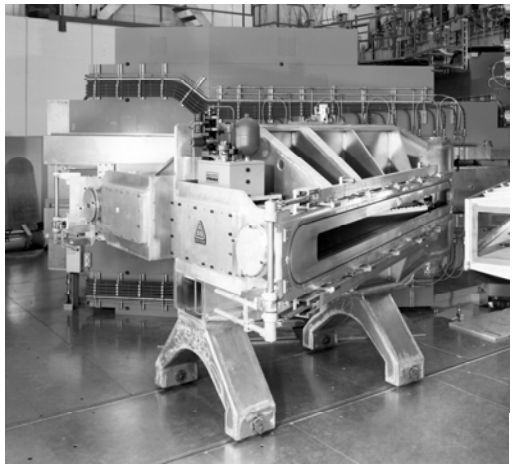
Power dissipation 150 kW

Resonator 2 & 4

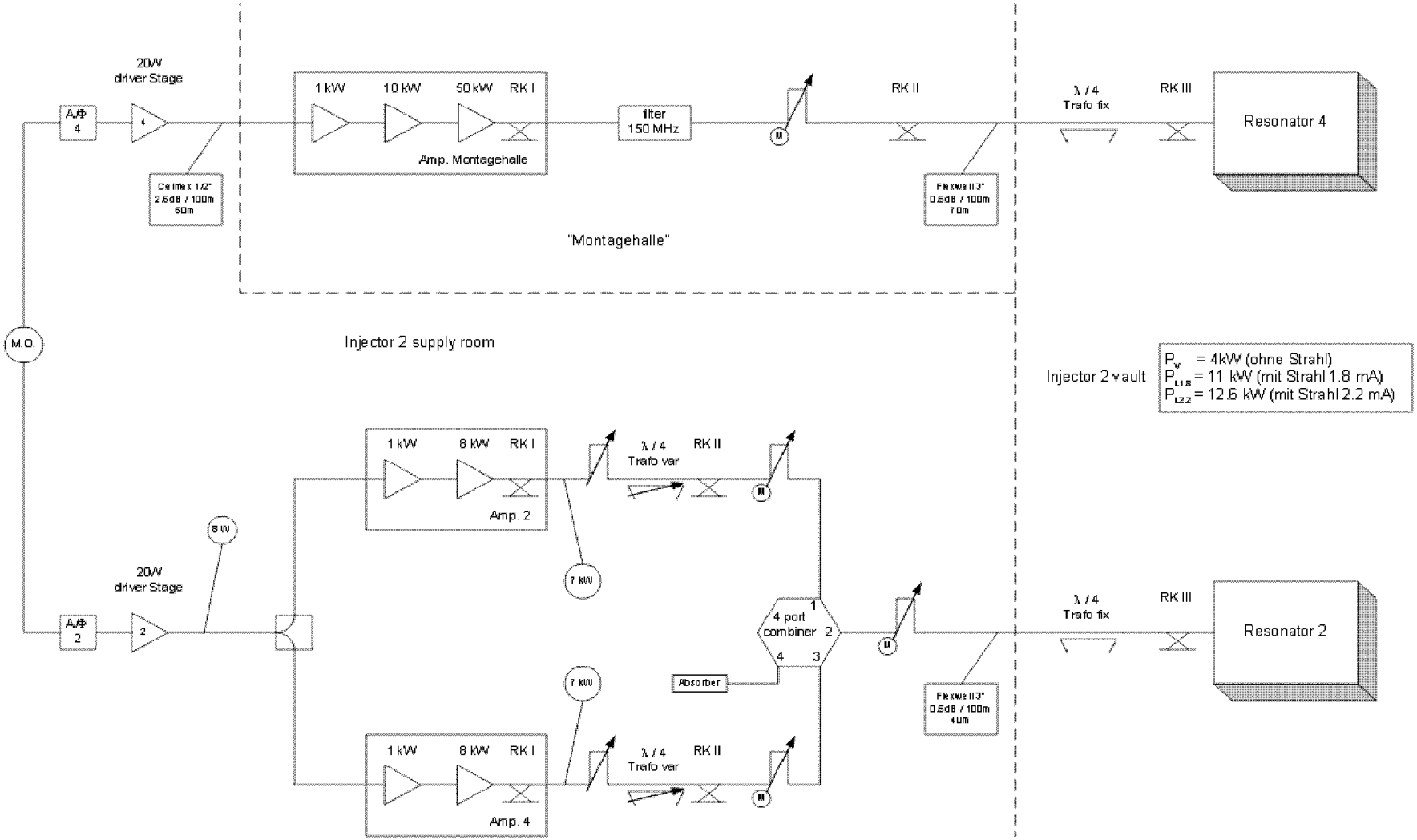
150 MHz resonator

Accelerating voltage 30 kV

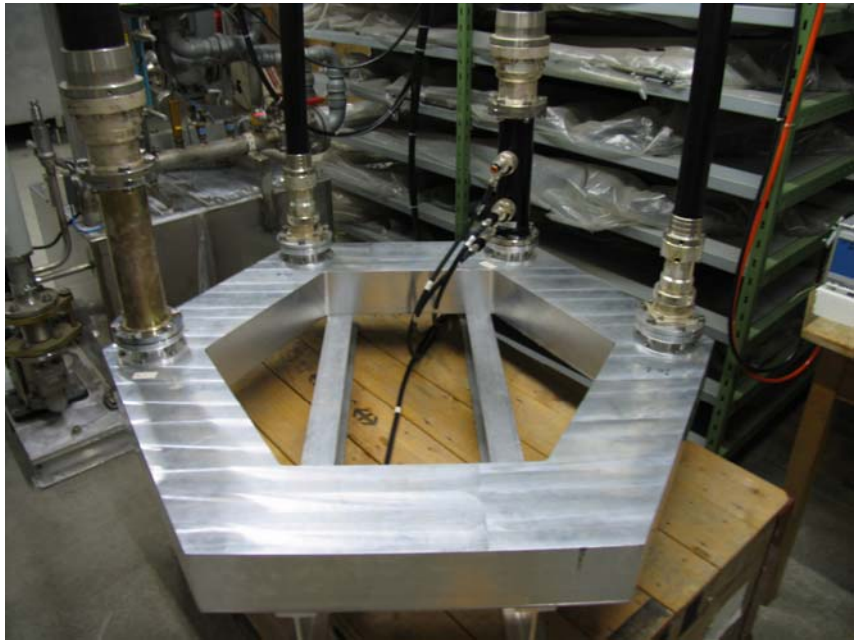
Power dissipation 3.5 kW



Inj. 2 Power upgrade 2003



Inj. 2 Resonator 2 Power upgrade 2003



Combiner

2 x 25 kW Load

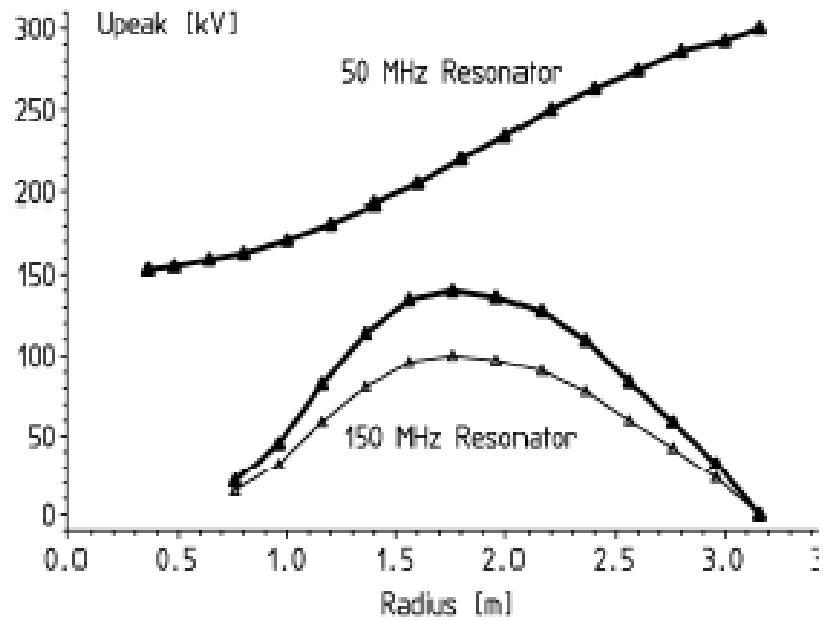
3 mA upgrade of Inj. 2

- Number of turns:
  Beam current 2mA 82
  Beam current 3mA ~65

- Higher energy gain per turn on outer radius

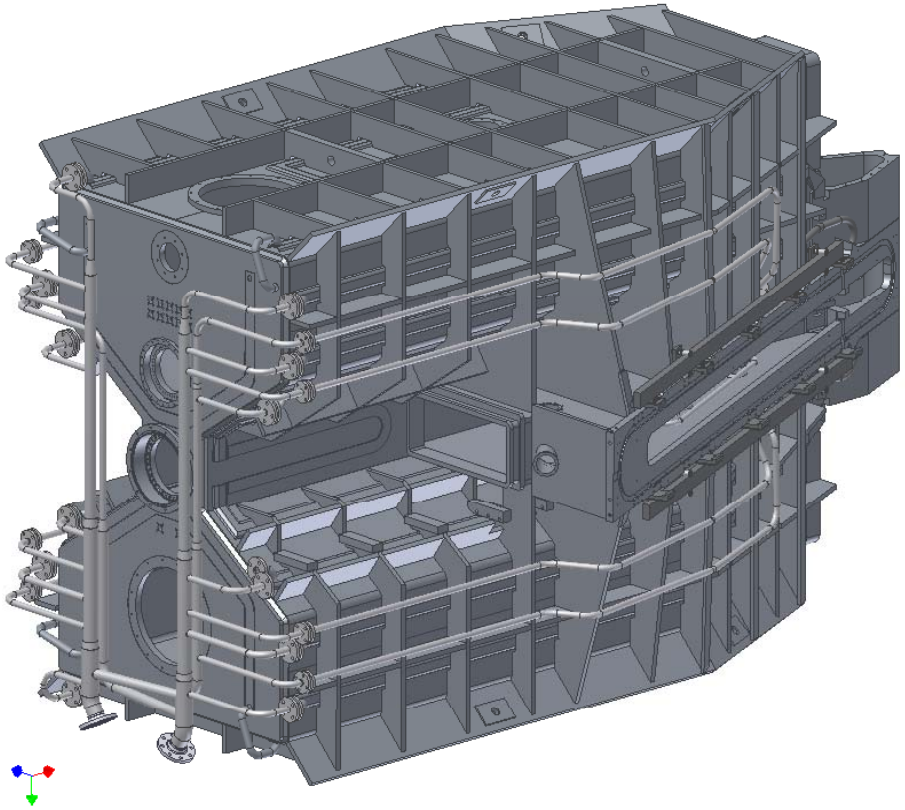
- Replacement of resonator 2 and 4
  (150 MHz by 50MHz)
  including new amplifier chain and low level RF
  Resonator 2 planned in SD 2010 ??
  Resonator 4 planned in SD 2011 ??

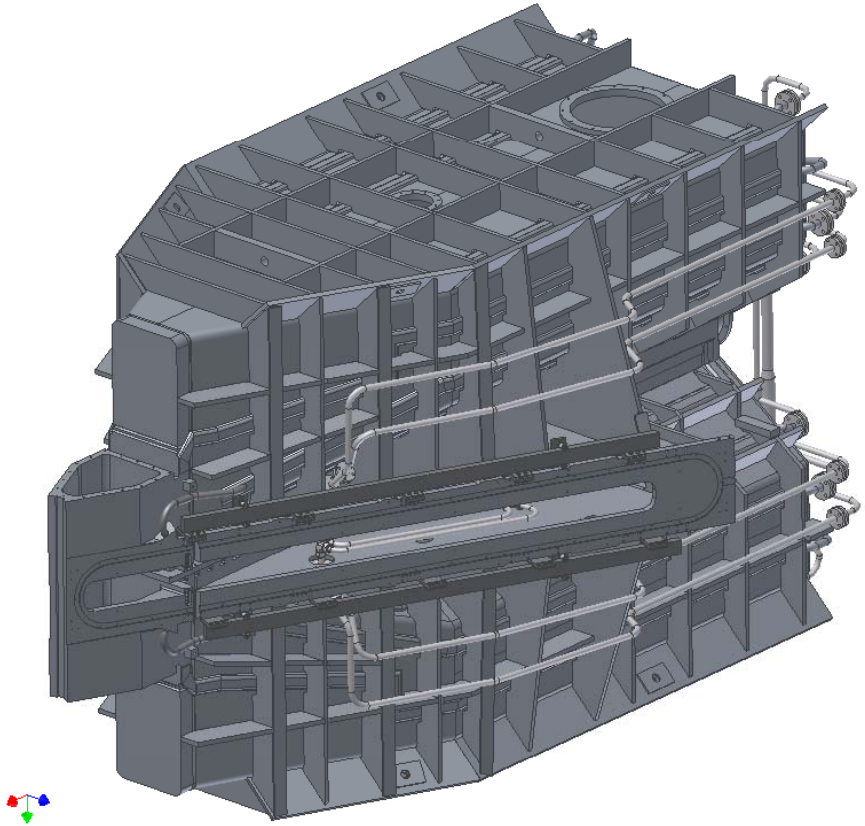
- Later replacement of amplifier chain and low level RF of resonator 1 and 3
  Using same system as for resonator 2 and 4



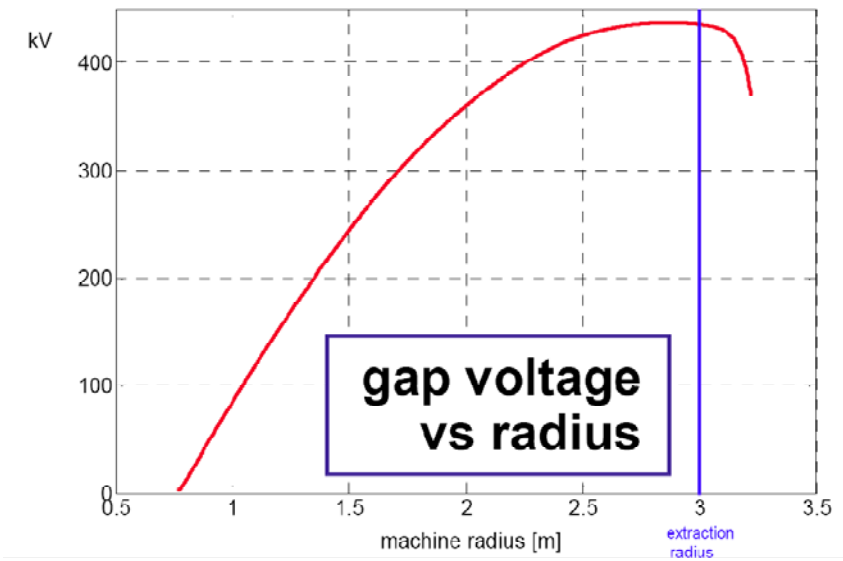
Gap voltage versus Radius of existing resonators

New 50 MHz Resonators 2 & 4 Injector 2





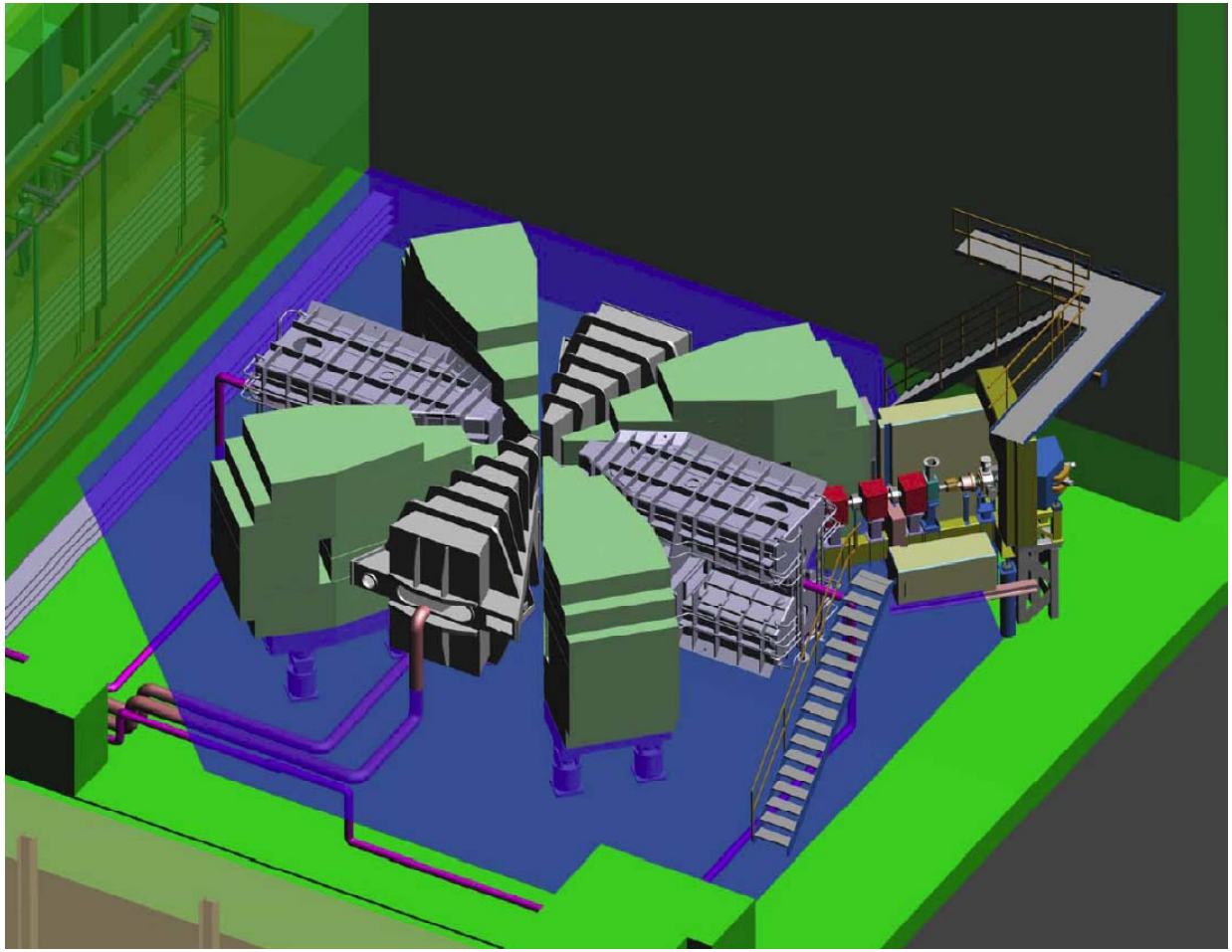
Specification:



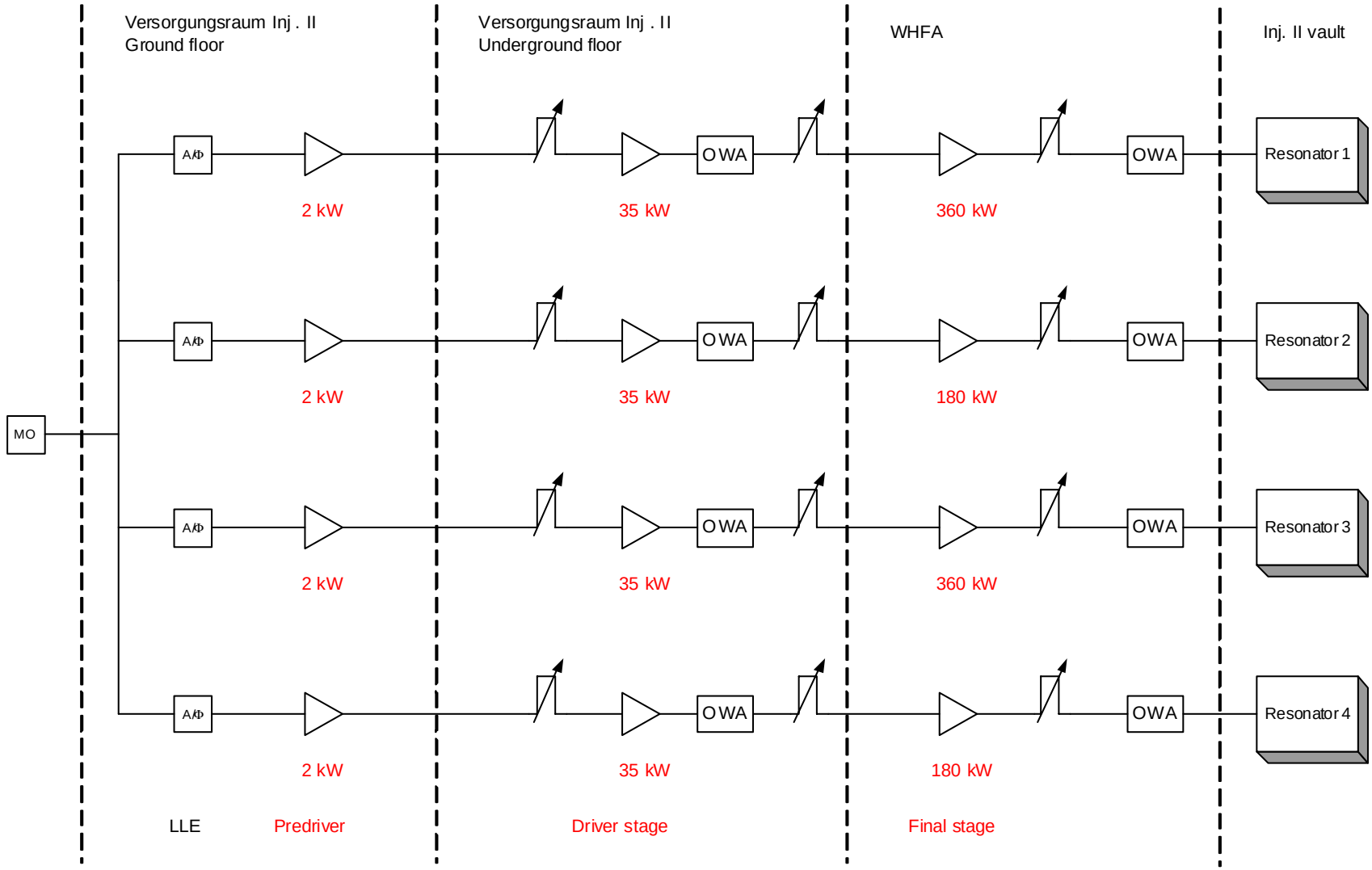
Resonance frequency:	**50.6328 MHz**
Gap voltage:	**400 kV**
Power dissipation:	**45 kW @ 400kV**
Tuning range:	**250 kHz**
Materials:	**EN AW 1050, EN AW 5083**
Vacuum:	**1e-6 mbar**
Flow of cooling water:	**15m3/h**
Size:	**5.3m x 3.3m x 3.0m (LxWxH)**
Weight:	**6 to**

Resonator 2 ordered
Delivered to PSI beginning of 2009
Test in Summer 2009

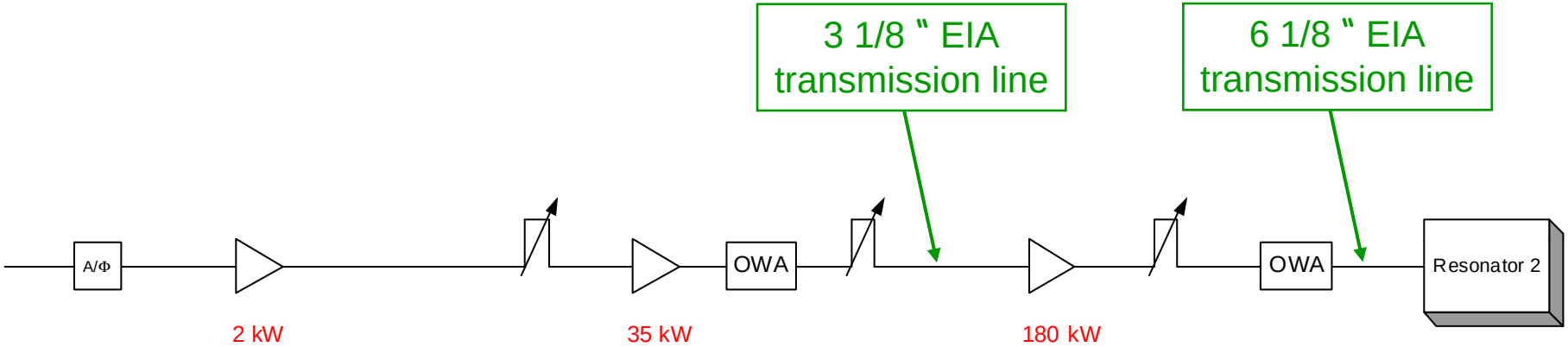
Injector 2 with new Resonators 2 and 4



Schematic new RF-system Inj. 2



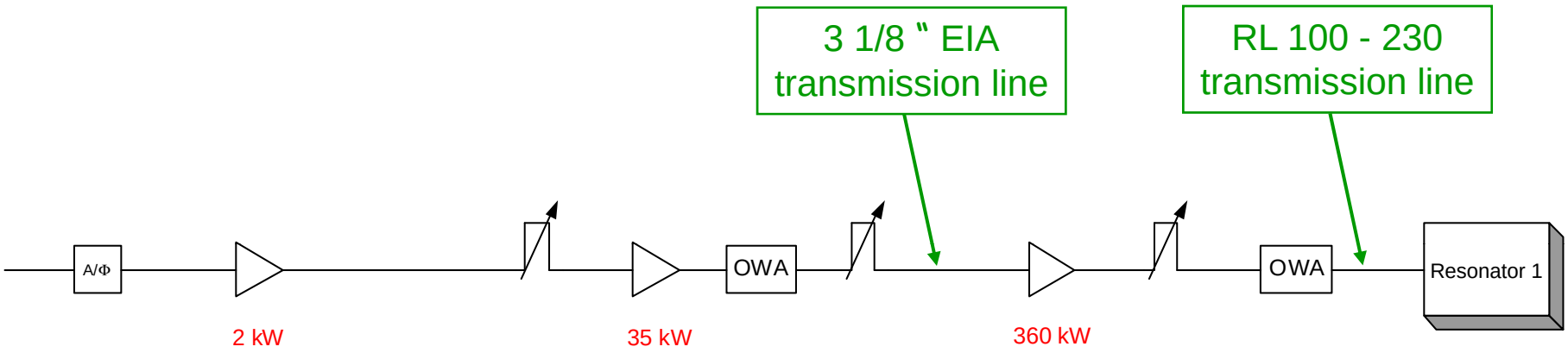
Amplifier chain for Resonator 2 / 4



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

OWA Higher harmonic absorber

Amplifier chain for Resonator 1 / 3



LLE	Predriver (2 kW) Solid state amplifier	Driver stage (35 kW) Tetrode Amplifier Thales RS 2048 CJC New design by PSI	Final stage (360 kW) Tetrode Amplifier Thales RS 2074 HF Copy of 1MW design Reduced power supply

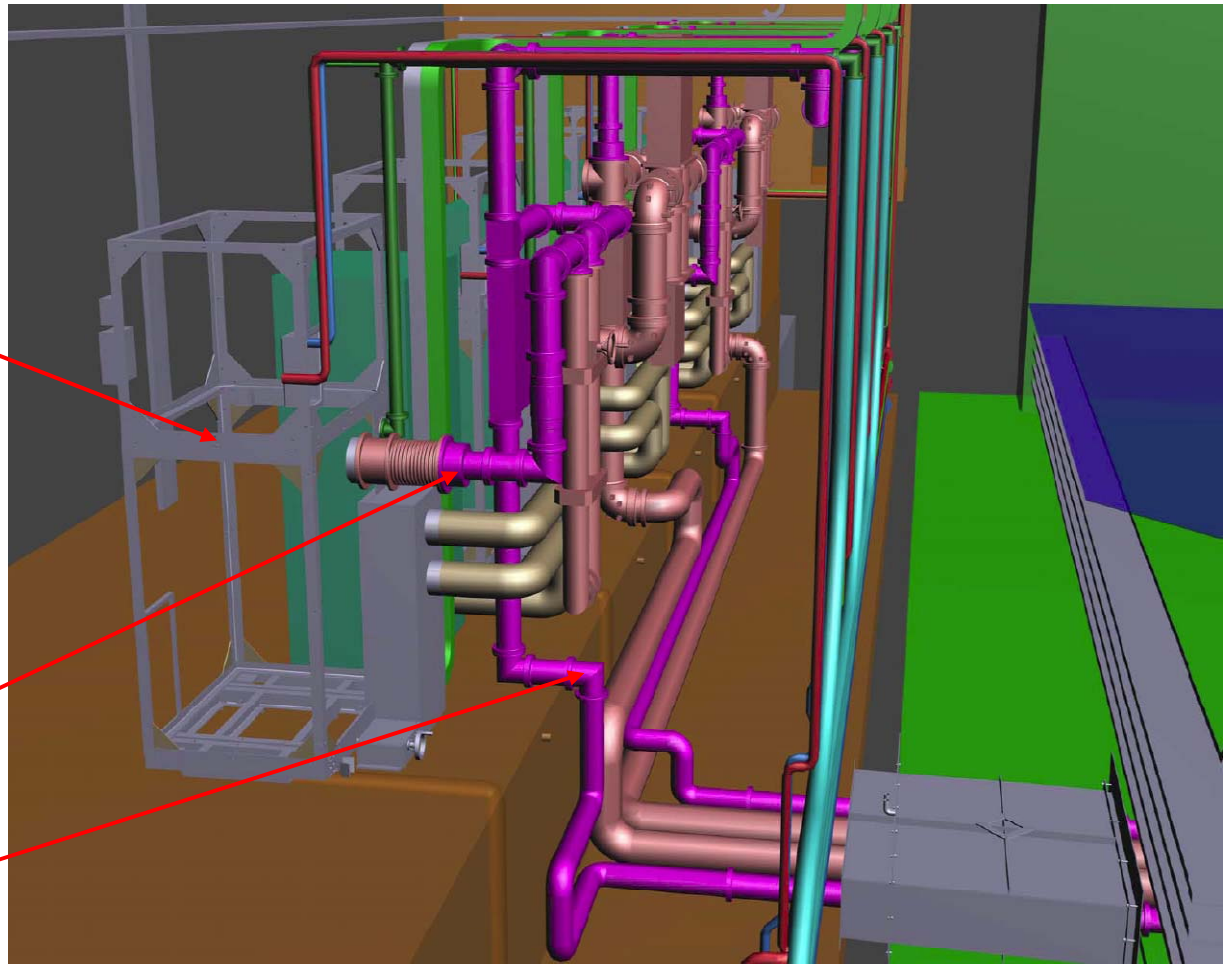
OWA Higher harmonic absorber

Layout of final stages for Inj.2 in WHFA

Amplifier

Reduction to
6 1/8 “ EIA

6 1/8 “ EIA
Transmission line



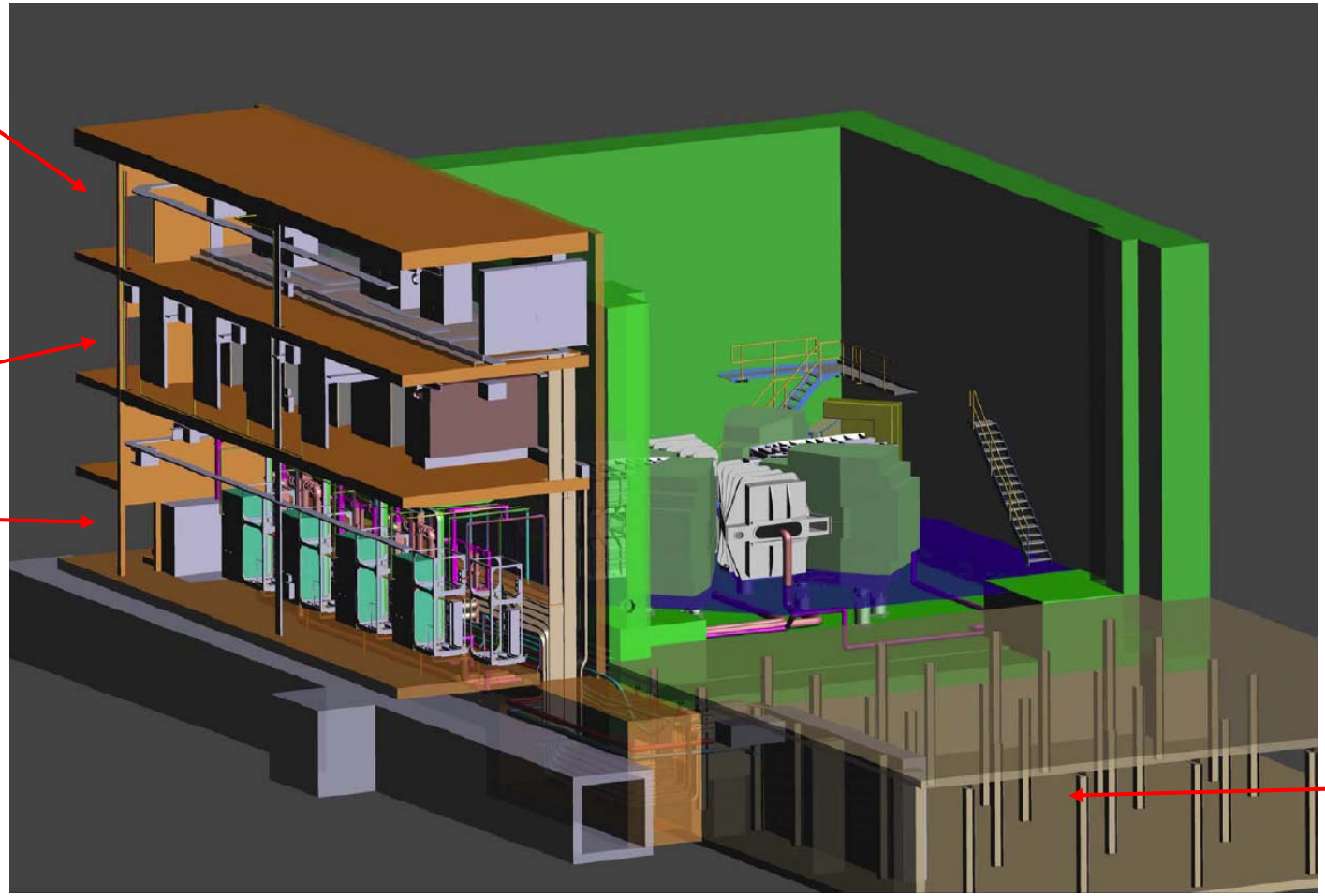
Inj. 2
vault

Inj. 2 vault and WHFA

power supplies

Plate power supplies

Amplifiers



Driver stages

New building WHFA

End of 2007

End of March 2008