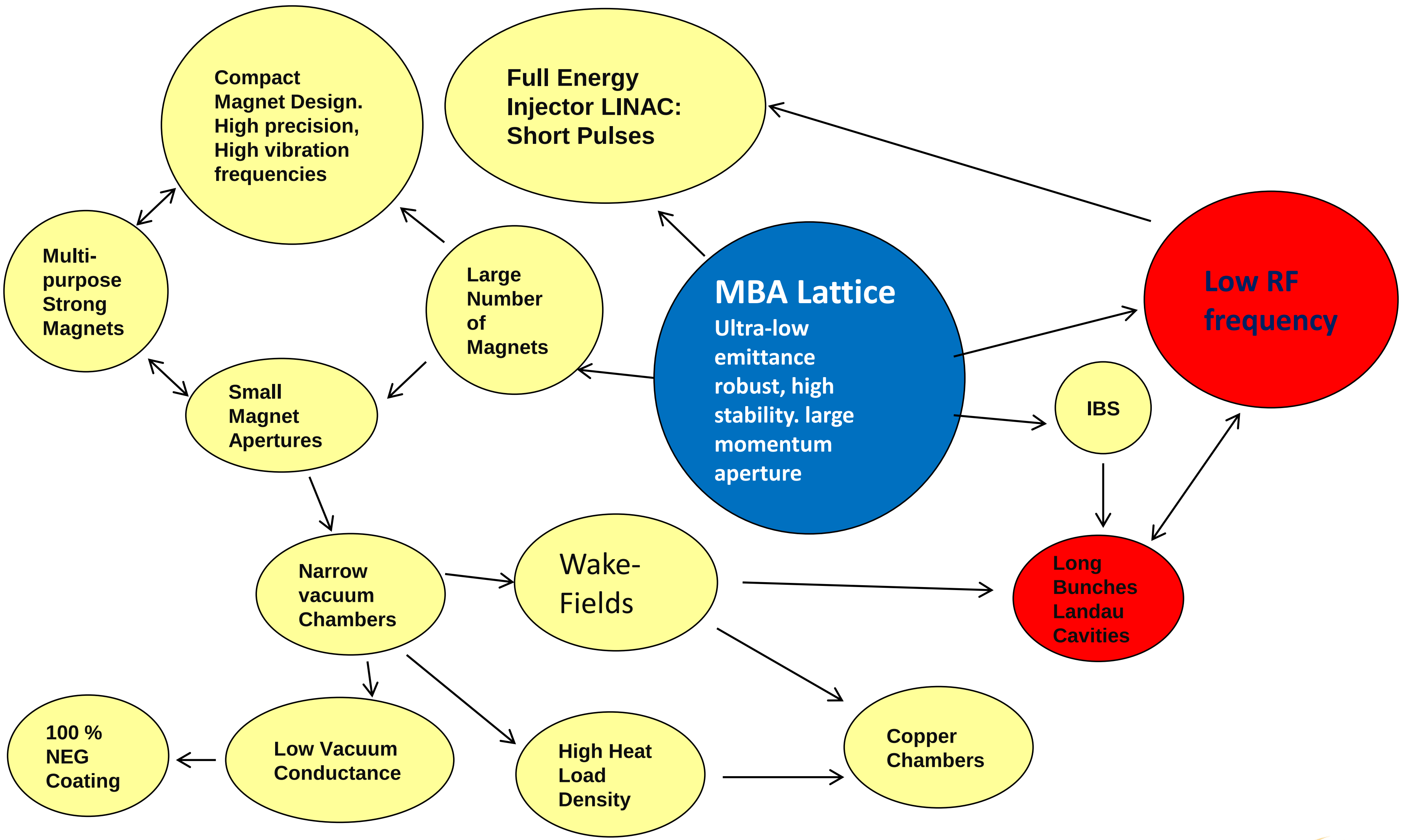
MAX IV RF Systems

Lars Malmgren
RF Group, MAX IV

Agenda

- MAX IV 3 GeV ring- An Integrated Solution
- MAX IV 3 GeV ring
- Main Cavity Design
  - Background
  - Final Design
  - Conditioning
- Harmonic Cavity Design
  - Final Design
  - Conditioning
- High Power Plants
- Digital Low Level RF

MAX IV 3 GeV ring- An Integrated Solution



MAX IV 3 GeV ring

- The Multi-Bend Achromat gives hor. emittance in the Intra Beam Scattering regime:

Main radio frequency [MHz]	99.931
Harmonic number	176
Circulating current [mA]	500
Circumference [m]	528
Horizontal emittance (bare lattice) [nm rad]	0.37 [0.326]
Horizontal emittance (with 4 d w and 10 in-vac. Und.) [nm rad]	0.23 [0.201]
Radiation losses per turn (bare lattice) [keV]	360
Radiation losses per turn (with 4 d w and 10 in-vac. Und.) [keV]	854
Natural energy spread (bare lattice) [%]	0.084 [0.077]
Natural energy spread (with 4 d w and 10 in-vac. Und.) [%]	0.094 [0.091]
Momentum compaction factor	3.0 x 10e-4
Required lattice momentum acceptance	± 4.5 %
Rms bunch length with Landau cavities [mm]	50
Vertical emittance [pm rad]	8

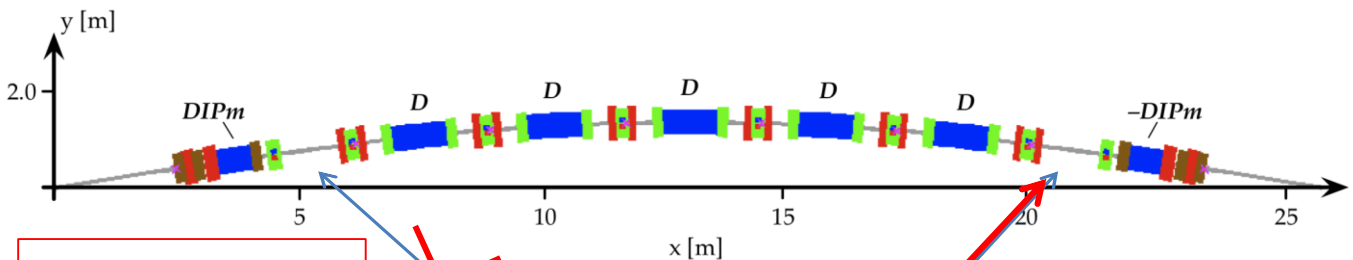
[ ] = without IBS

The difference in horizontal emittance with/without IBS is kept low by diluting the electron density in the bunches.

➔ Landau cavities are essential in order to reach the design horizontal emittance!

MAX IV 3 GeV ring

One of the 20 achromats in the 3 GeV ring



ID light cannot pass the cavity

None of the twenty SS is ”sacrified” for RF. Instead we use nine short matching straights upstream the SS.

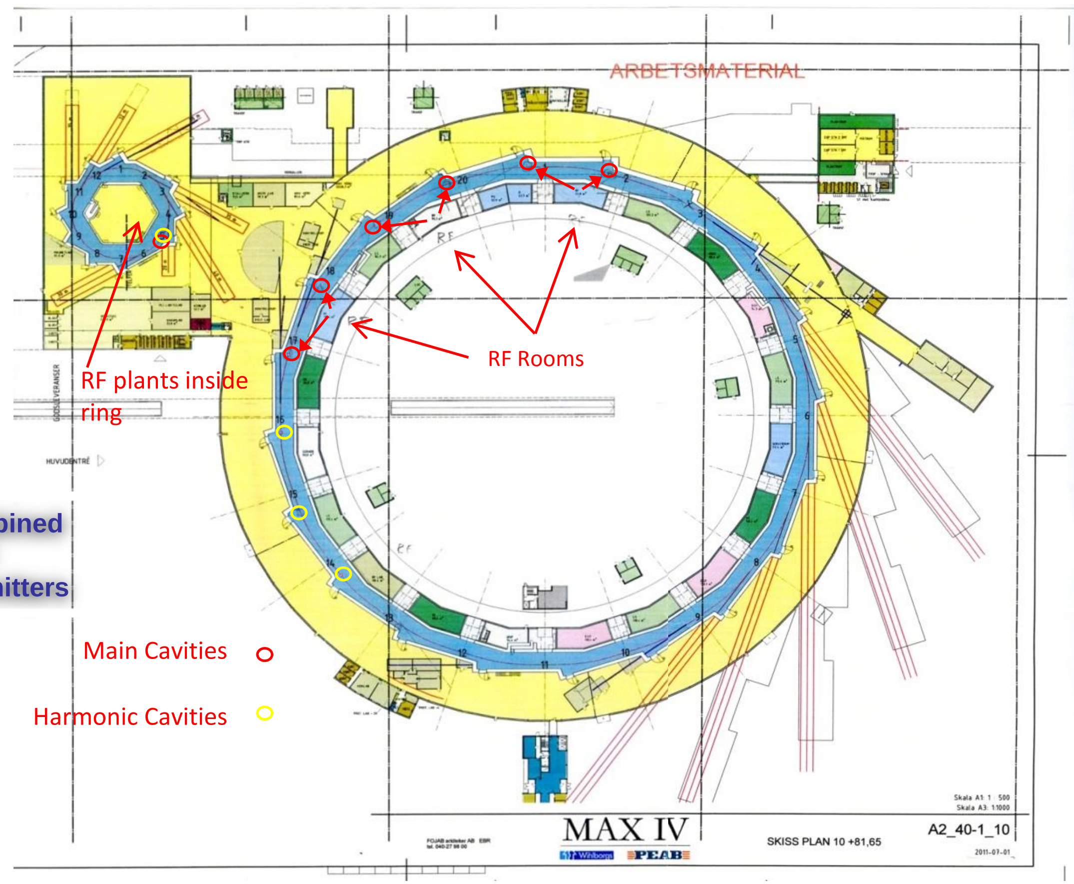
MAX IV 3 GeV ring

Storage Rings Parameters

Energy	1.5 GeV	3.0 GeV
RF	99.931 MHz	99.931 MHz
Circumference	96 m	528 m
Harmonic number	32	176
Current	500 mA	500 mA
No of cavities	2	6
RF station power	60kW	120kW
Cavity voltage	280kV	300kV
Coupling (beta)	2.3	4.0

2 combined 60 kW transmitters

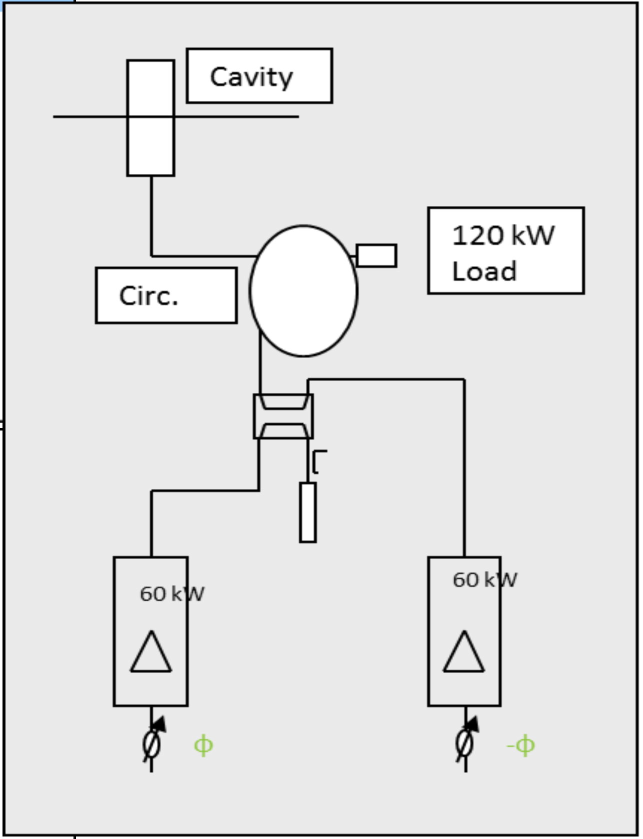
1 single 60 kW transmitters



MAX IV 3 GeV ring

Alternative	I	II
Energy loss with Ids	756keV	1020keV
Circulating current	0.5A	0.5A
Total beam power	378kW	510kW
Total RF voltage	1.5MV	1.8MV
Number of cavities	6	6
Cavity shunt impedance	3.2Mohm	3.2Mohm
Cu losses	117kW	169kW
Total RF power needed	495kW	679kW
Nr of RF stations	6	6
Nr of transmitters	12	12
Transmitter power	41.5kW	56kW
Power to cavity	83kW	113kW
Cu losses/cav	20kW	28kW
Coupling (beta)	4.2	4.0
Cavity voltage	250kV	300kV
Cavity gap	4cm	5cm
Bucket height	4.5 %	4.5 %

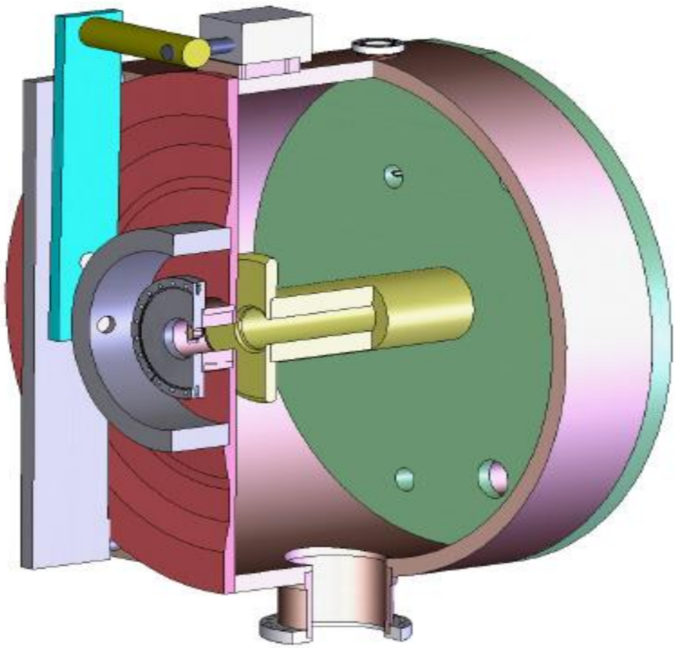
Chosen!

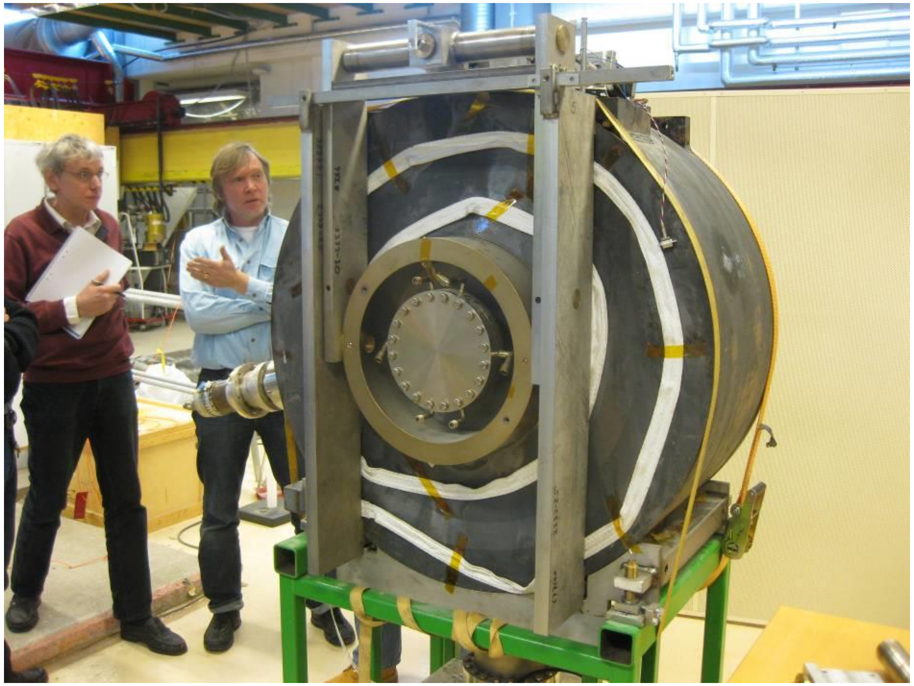


Alt I: Represents a solution for a 60% ID equipped ring, with the MAX II/ MAX III cavities.
Alt II: Represents a solution for a fully ID equipped ring, with slightly modified MAX II/MAX III cavities.

Main cavity design Background

- MAX II & MAX III main cavity



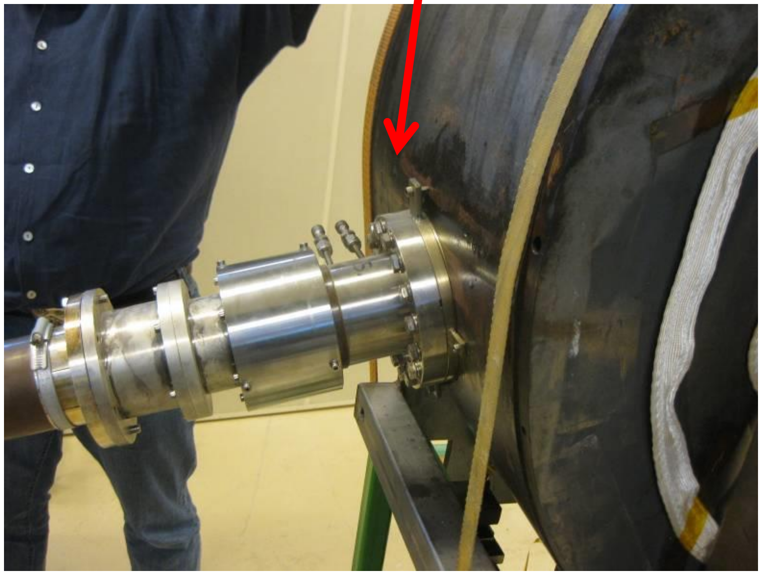


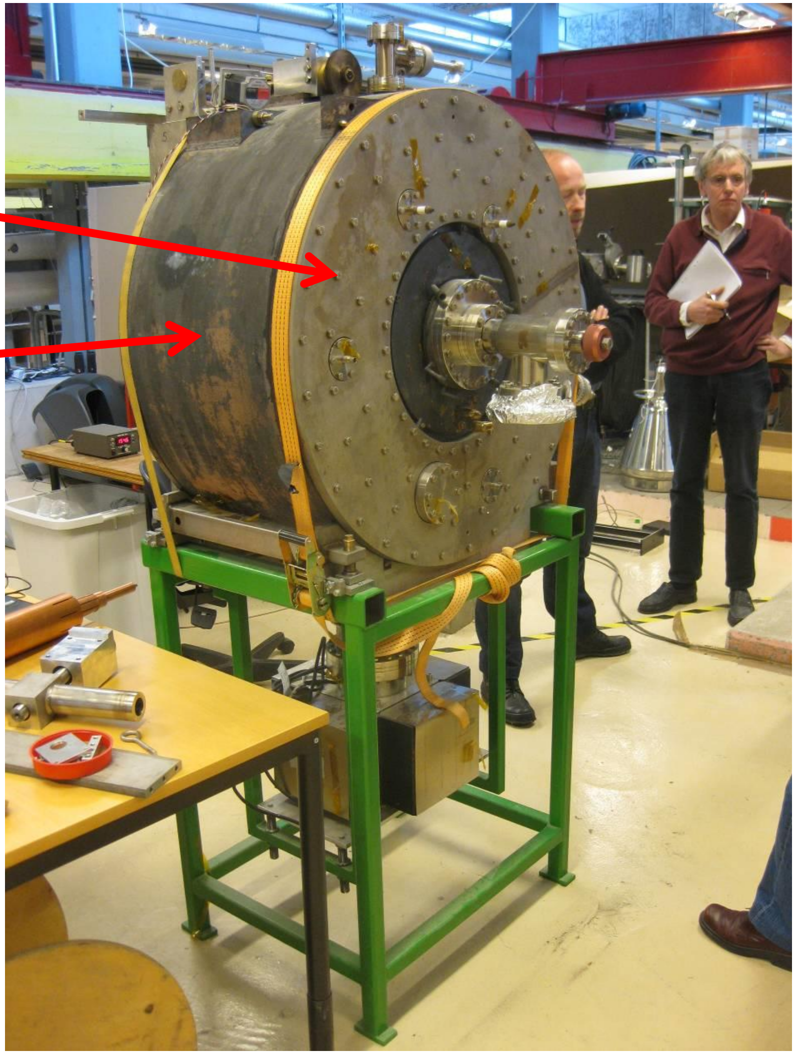
Mechanical design:
Leif Thånell, MAX-lab (retired)

ESLS-RF Trieste, September 29-30, 2010. Åke Andersson

Main cavity design background

- <u>What we need to do better</u>!
- Cu became too soft after soldering
- An ”in air” weld of the shell (Ø 82 cm) had leaks.
- Water cooling of the shell





MAX IV

Main cavity design background

Electron Beam Welding EBW seems to be the solution, but we need to learn:

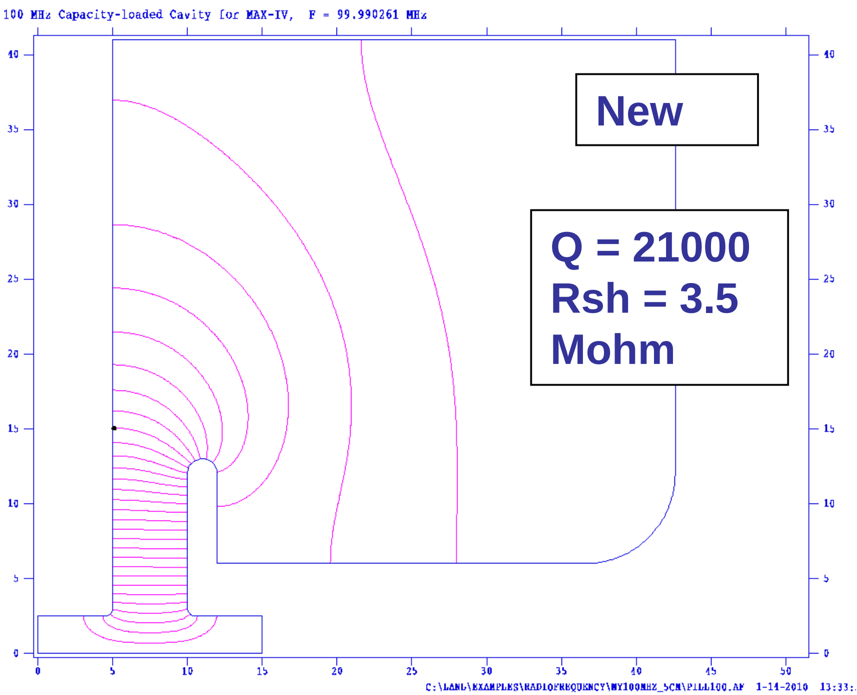
- **How stiff OFHC copper can we excpect to get for the end plates, from industry?**
- **How much does an EBW soften the material around the weld?**
- **Do we really need to stay in the elastic region when we tune the cavity?**
- **Can we safely construct the shell out of two half shells?**

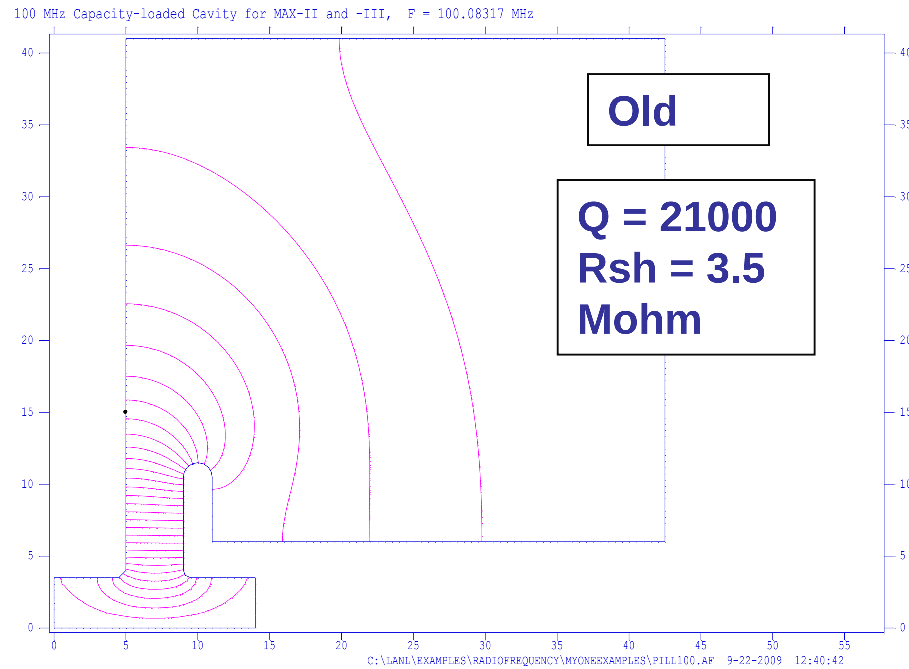
For the final weld:
What is the weld shrinkage?
Do we get a decent inner RF contact at the weld stop?

ESLS-RF Trieste, September 29-30, 2010. Åke Andersson

Main cavity design backgrond

- Cavity profile modification for 250 kV ➔ 300 kV



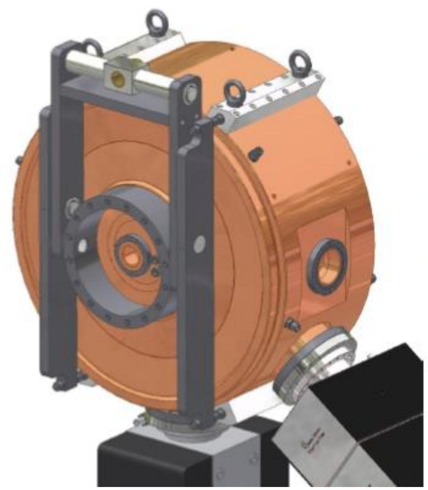


5 cm gap instead of 4 cm ➔
sligthly larger capacitor plate ➔
We want to improve the cooling of the plate.

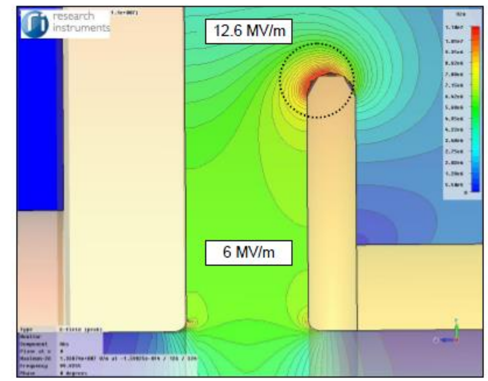
➔ **Difficult to avoid water-to-vacuum joints! OK, or not?**

Main cavity design

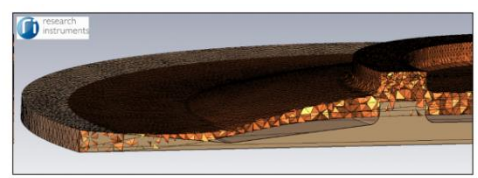
- Tuning by a small deformation of the left endplate
- A deformation of ±1.0 mm is equivalent to ±540 kHz
- The profile of the endplate is optimized to minimize the imposed stress (max. <100 MPa)
- Endplates are electron beam welded onto the cavity body
- Tuning can be kept in the elastic range
- Maximum electric fiels is 12.6MV/m (1.106 Kilp.)
- The manufacturing was contracted to Research Instruments GmbH



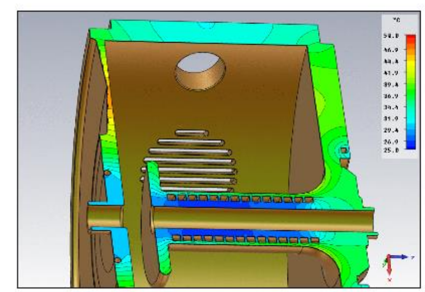
Tuning Mechanism



RF



Tuning plate

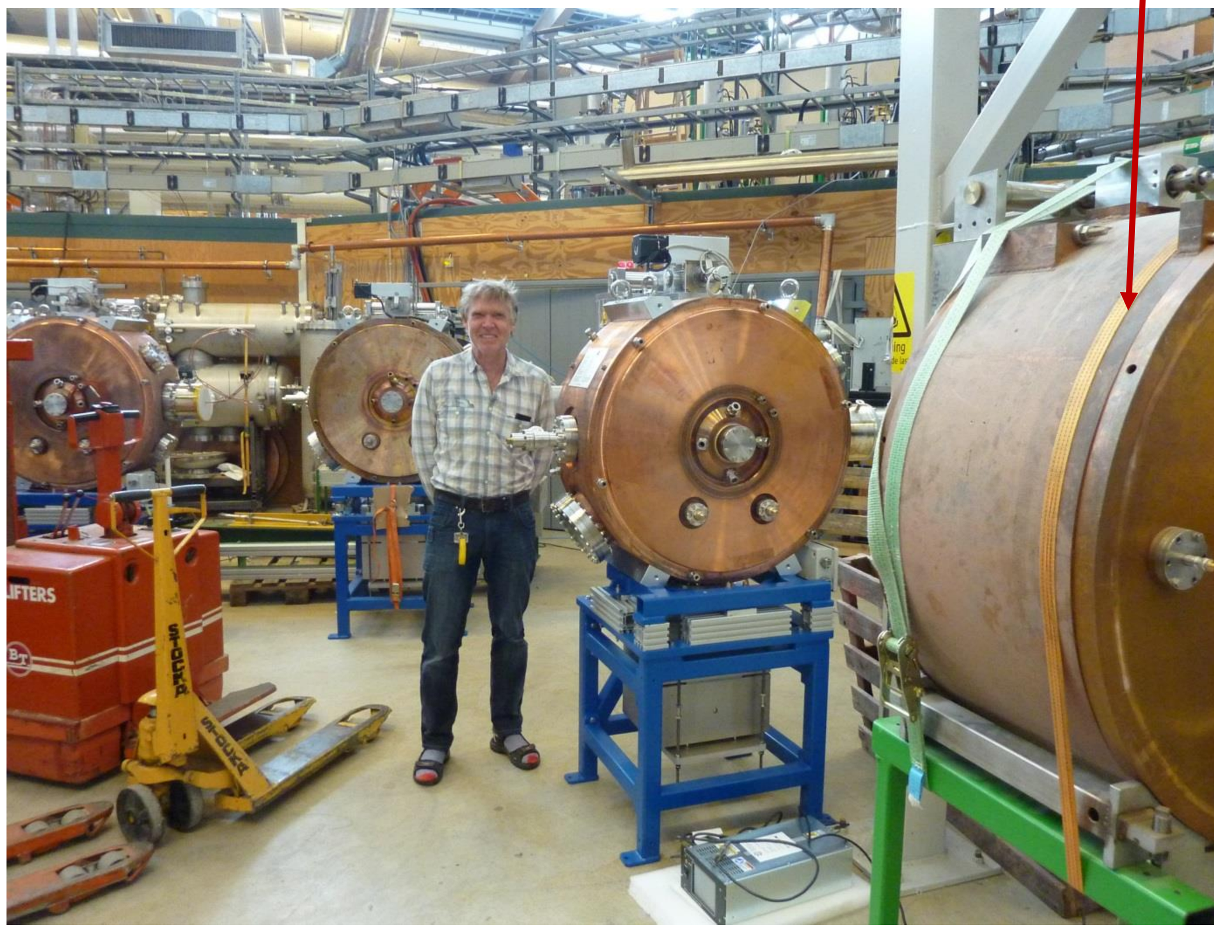


Thermal

Main cavity design

- All main cavities including two for Solaris Poland was delivered October – December 2013

Old spare cavity for MAX-II & MAX-III



Main Cavities - Conditioning

- Ten Main (two for Solaris) and five Harmonic Cavities have been conditioned at the old MAX-lab.

Main Cavities - Conditioning

- Ten Main (two for Solaris) and five Harmonic Cavities have been conditioned at the old MAX-lab.

100 MHz Tetrode tube transmitter for conditioning

300 MHz Harmonic Cavities

MAX IV

Main Cavities - Conditioning

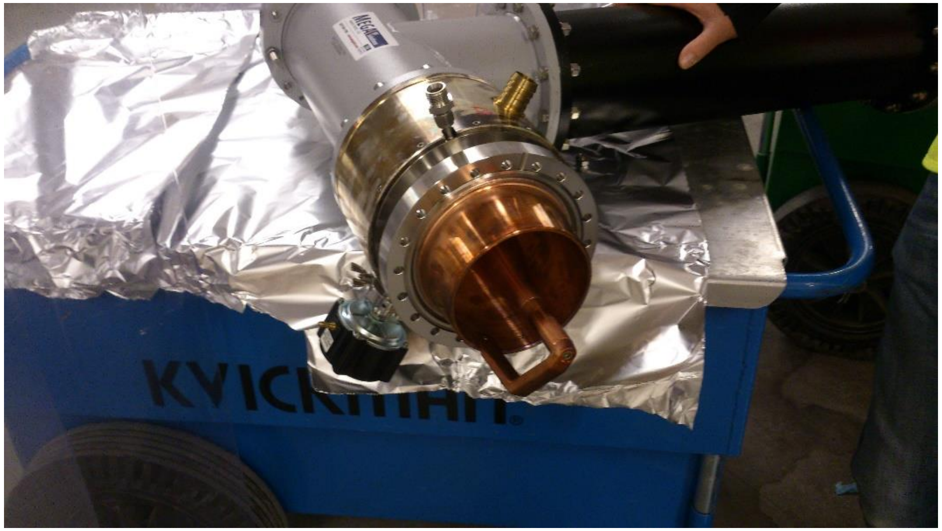
- The cavities were delivered baked (3 days, 120 degree), with power coupler attached ($\beta = 1$).
- A 600 l/s ion pump is attached. All cavities in the low 10^{-10} mbar range.

- 9 main cavities (7 for MAX-IV, 2 for Solaris) have been conditioned to ~ 25 kW.
- Prototype: ~ 1 year (!)
- 2nd Cav # 11: ~ 3.5 months
- 3rd Cav # 08: ~ 3 months
- The following 5 cavities: ~ 5 * 1 month (now a computer code was used! Robert Lindvall)
- 9th cavity # 06: 2 weeks
- 10th cavity #09: was only conditioned to ~ 3 kW (lack of time)

- When all surrounding systems work OK, ~ 3 weeks of conditioning is sufficient.
- ~1 week up to 50 W (!). Pressure raises up to $5*10^{-6}$ mbar!
- ~1 week to pass multipacting regime 3-5 kW. Sometimes a need to attach a turbo!
- Finally ~1 week to reach 25 kW stable operation, without more than 1 ”glitch” per day.
- ”Glitch” = Sudden high reflected power, however self extinguishing after ~ 60 µs.

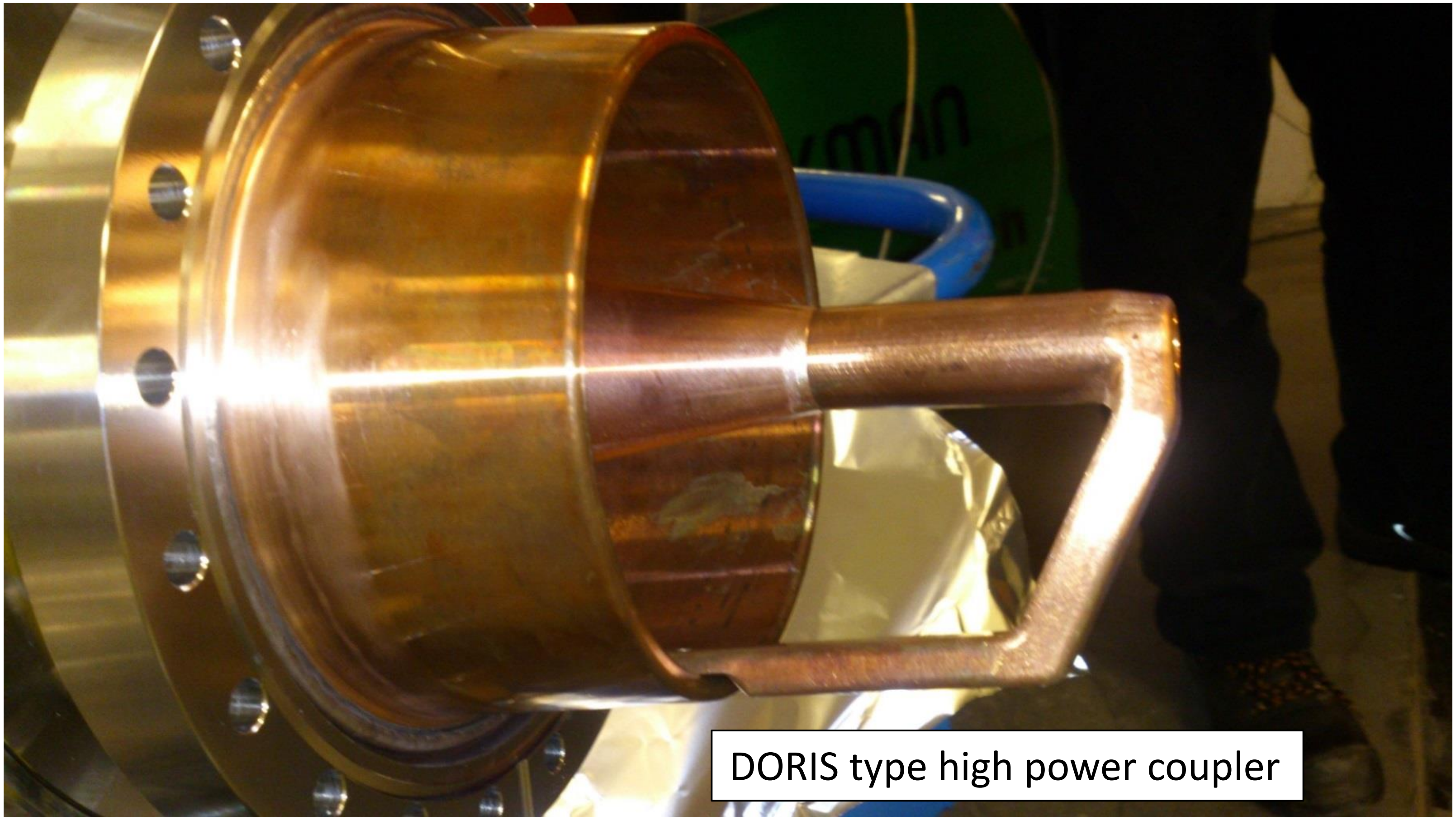
Main Cavities - Conditioning

- Multipacting problem origin: Coupler or Cavity body?



MAX IV

Main Cavity – Coupler loop



Main Cavities - Conditioning

After conditioning we vented and turned coupler to β = 2 for installation.
We then measured f_r and Q_0 carefully (by turning coupler to β = 0) :

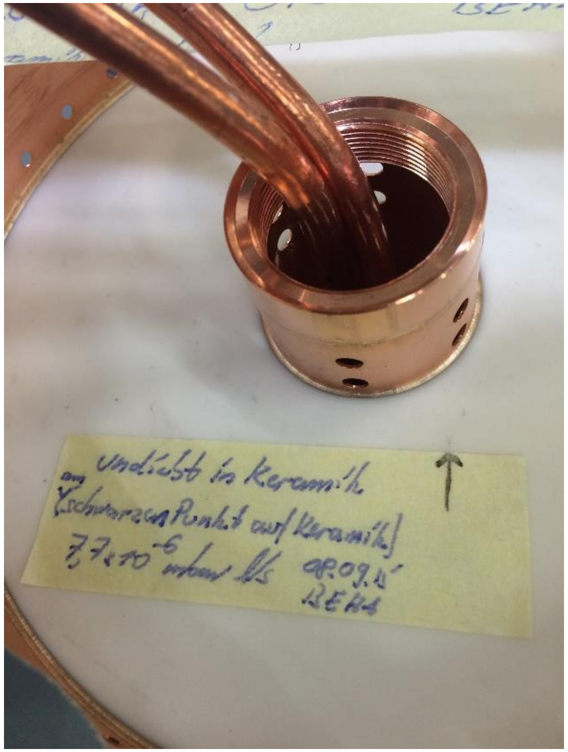
Achromat #	16	17	18	19	20	1	
Resonant freq. N2-Vented & Force free [MHz]	100,112	100,019	99,93	100,13	99,973	100,042	
Difference compared to FAT [MHz]	-0,084	-0,001	0,014	-0,043		0,038	
Unloaded Q	20500	20400	20400	20250	20450	19700	Theory cyl-symm: 20923
Degradation due to Ports & Surfaces [%]	2,1	2,5	2,5	3,2	2,3	5,8	
Shunt Impedance (linac def.) [MΩ]	3,45	3,43	3,43	3,41	3,44	3,32	Theory cyl-symm: 3,52 MΩ
Required power to reach 300 kV [kW]	26,1	26,2	26,2	26,4	26,2	27,1	

The two cavities for the 1.5 GeV ring: Unloaded Q were 20100 and 19300.
(The last Q-value was surprisingly low, indicating a 7.6 % surface degradation.)

MAX IV

Main Cavities - Conditioning

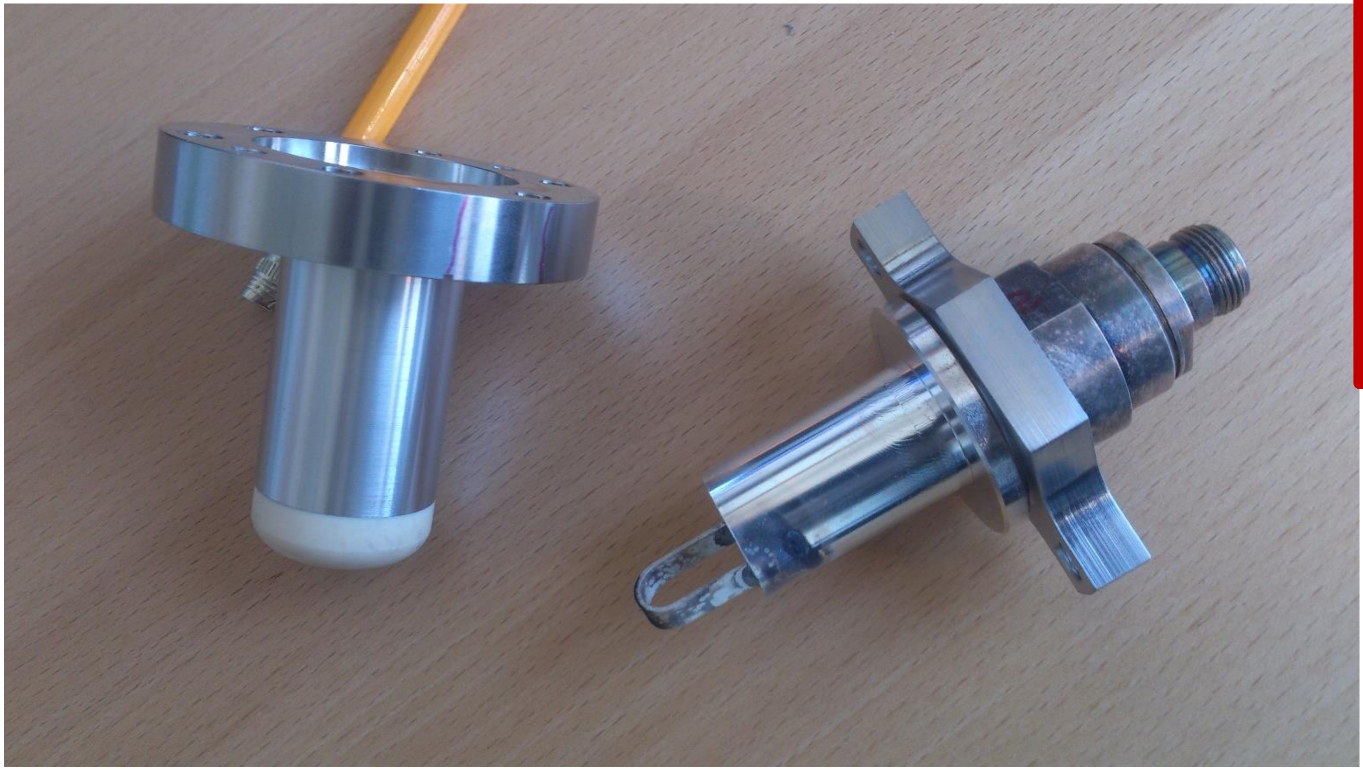
A tiny defect in the ceramic window caused a leak ➔ p ~$1*10^{-8}$ mbar



Main Cavities - Conditioning

Three probe loop ceramics (out of 16) have started leaking.
Only those we forgot to 50 Ω terminate! Heating problem?

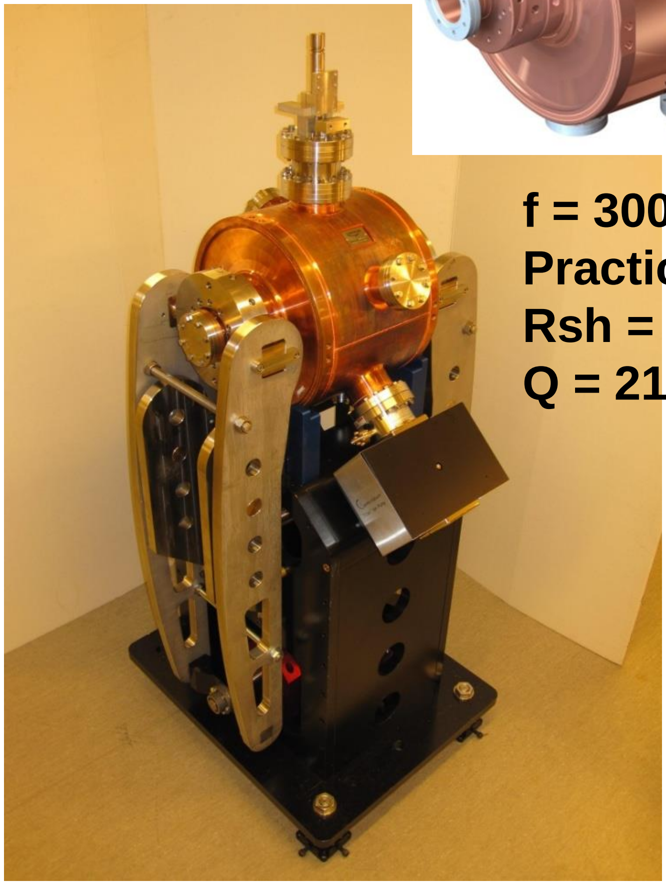
The last half year, more leaks have appeared, even though terminated properly!!!



Main Cavity – Transport to site

Harmonic Cavities - Design

- The third harmonic Landau cavities are also of the capacity-loaded type
- Tuning by a small deformation of both endplates
- A deformation of ±0.25 mm per end plate is equivalent to ±550 kHz (max. stress < 60MPa)
- Both endplates are electron beam welded onto the cavity shell and centre rods
- RI have manufactured five 300 MHz Landau cavities from drawings supplied by MAX-lab.



f = 300 MHz
Practice:
Rsh = 5.6 Mohm
Q = 21000

Harmonic Cavities - Conditioning

- The 7 series cavities (5 MAX-IV, 2 Solaris) were delivered non-baked, only leak tested.
- We performed ourselves the bake-out, with an Århus-coupler at $\beta = 1$ attached.
- Each cavity has two 100 l/s ion pumps. All cavities in the low 10^{-10} mbar range.

- So far, 5 harmonic cavities have been conditioned to ~ 4 kW.
- Prototype: Is situated in the MAX-III ring since ~ 4 years. Used only at ~ 0.5 kW.
- The following 5 cavities: ~ 5 * 2 weeks (manual conditioning from a 300 MHz transm.)

- ~1 week up to 50 W. Pressure raises up to $5*10^{-7}$ mbar!
- ~1 week to pass multipacting regime 0.5-2 kW.
- 4 kW without problems, and without ”glitches”.
- ”Glitch” = Sudden high reflected power, however self extinguishing.

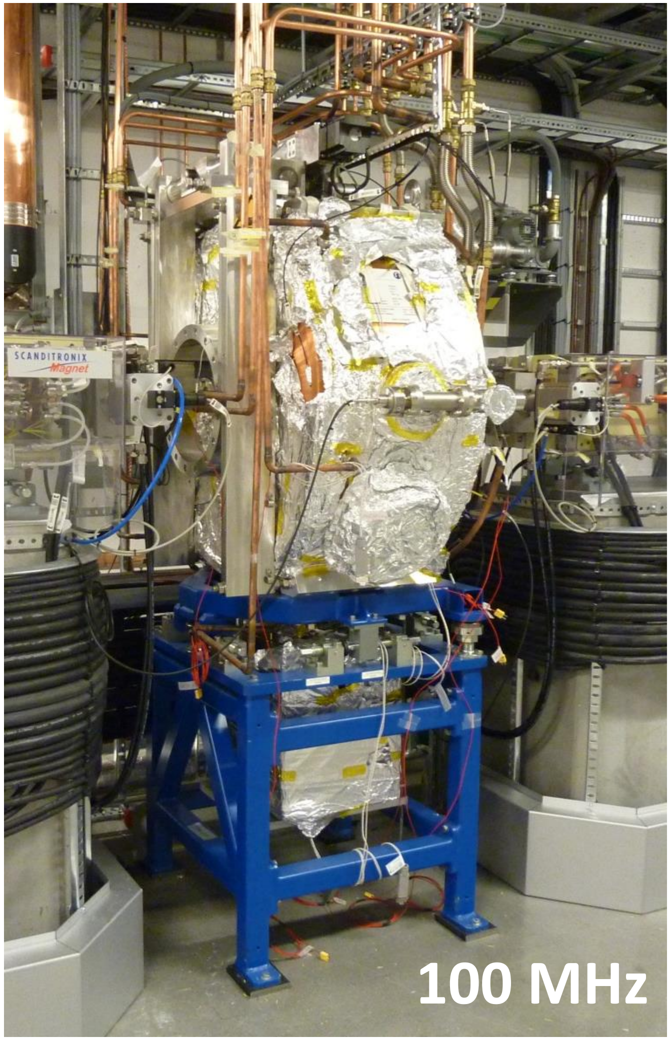
MAX IV

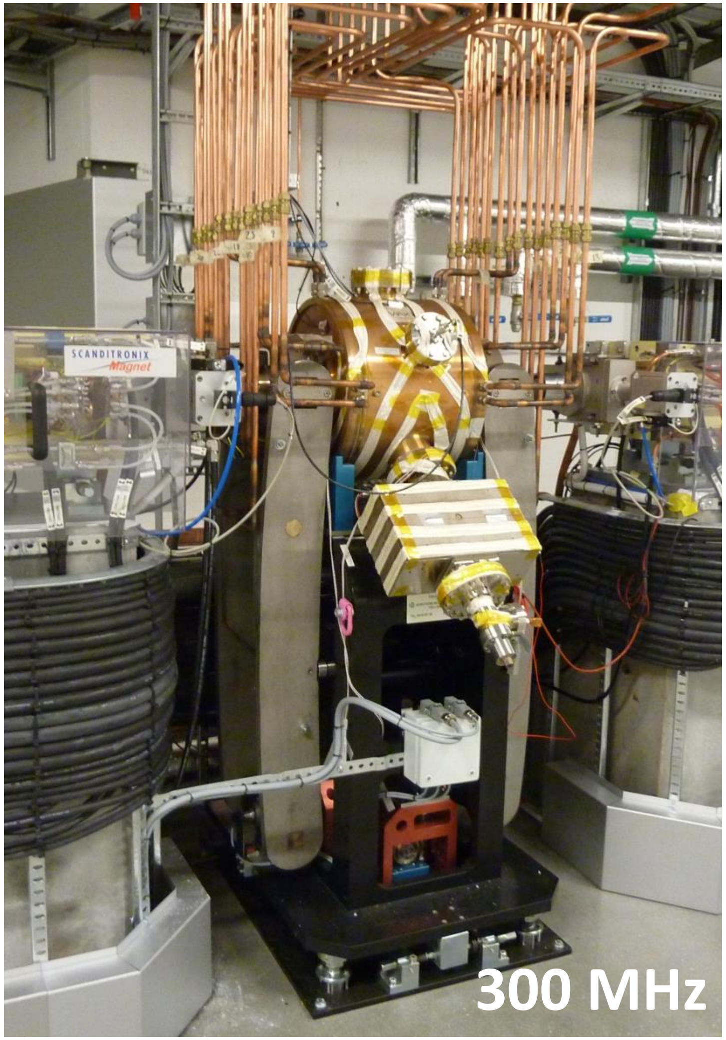
Harmonic Cavities - Conditioning

After bake-out, conditioning, removal of coupler, and installation we measured f_r and Q_0. A Δf_r = 140 kHz is expected.

Achromat #	13	14	15				
Resonant freq. @ FAT [MHz]	299,89	299,749	299,575				
Resonant freq. Pumped & Force free [MHz]	299,766	299,561	299,44				
Unloaded Q	20800	20800	21000				Theory cyl-symm: 21656
Degradation due to Ports & Surfaces [%]	3,95	3,95	3,03				
Shunt Impedance (linac def.) [MΩ]	5,32	5,32	5,37				Theory cyl-symm: 5,54 MΩ

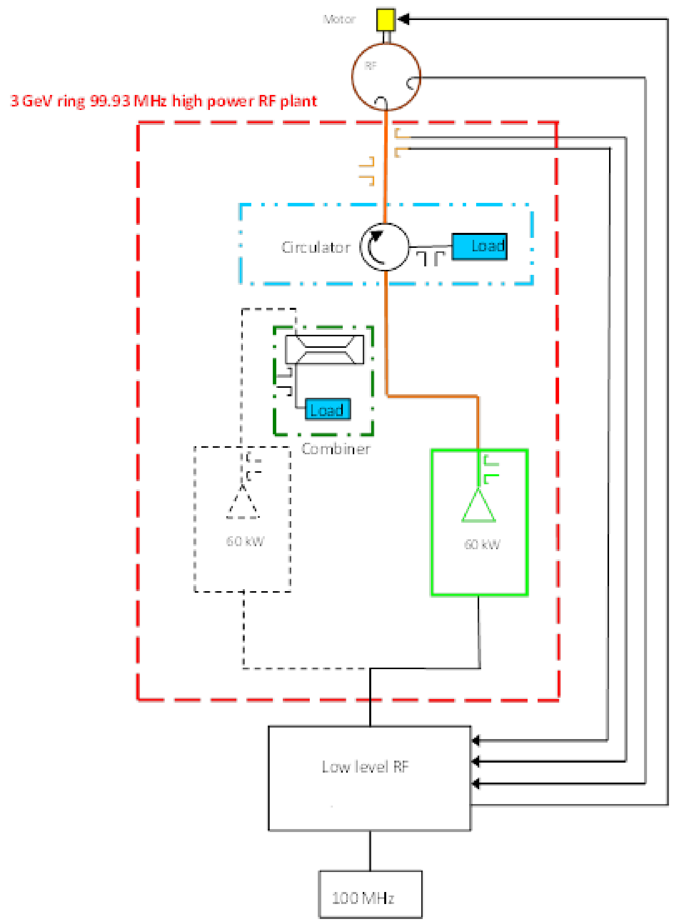
Installed and baked in 3 GeV ring





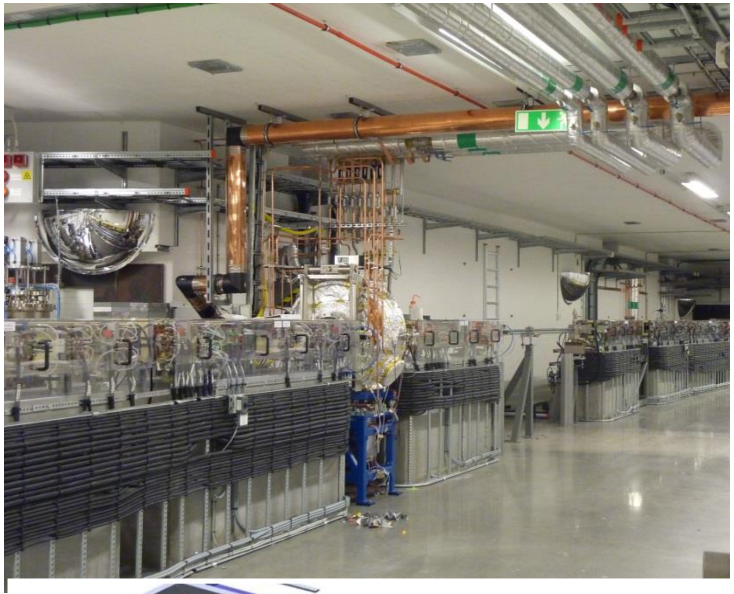
High Power Plants

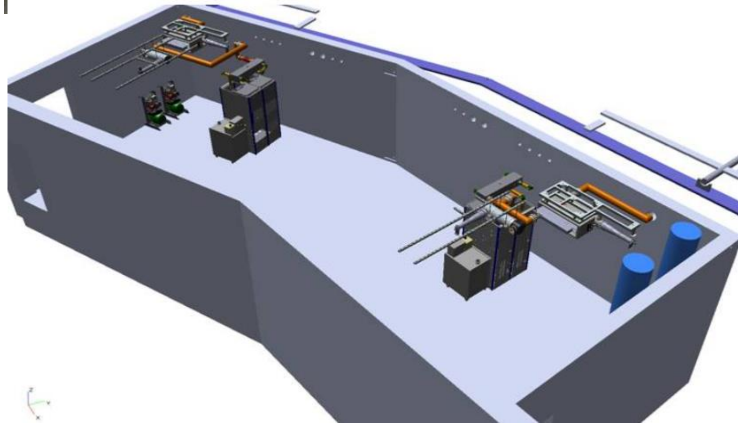
- 120 kW RF power needed when fully equipped with ID´s
- Currently 60 kW
- Another 60 kW SSPA are added when needed
- Combiner already installed but not connected
- Singel high power (120 kW) circulator from AFT at the output
- 6 1/8” rigidline transmission lines from Exir Broadcasting, Sweden, who also was contracted for integration and installation



High Power Plants

- The main cavities are placed in the second short straight section of six consecutive achromats.
- Each RF-room contains two RF power plants.





MAX IV

High Power Plants

- Rohde & Schwarz 60 kW CW solid state liquid cooled amplifiers based on two 30 kW transmitters/amplifiers with additional power combiner
- >64% overall power efficiency
- High MTBF
- Compact: 2000 mm × 1200 mm × 1100 mm (HxWxD)
- Coolant: glycol/water

One pump unit and heat exchanger per rack

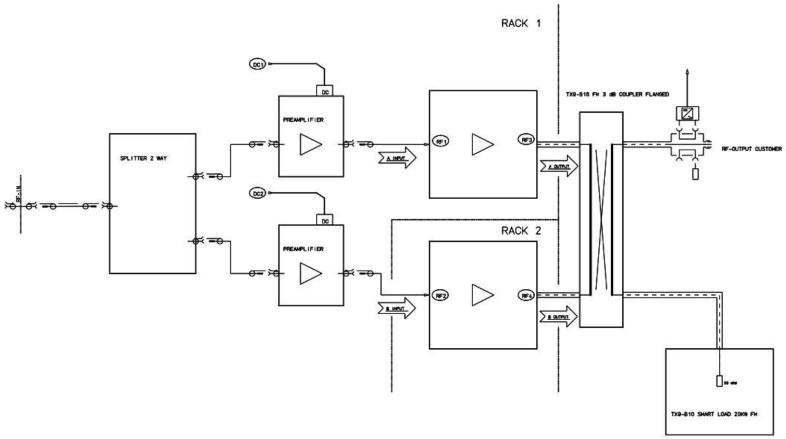
MAX IV

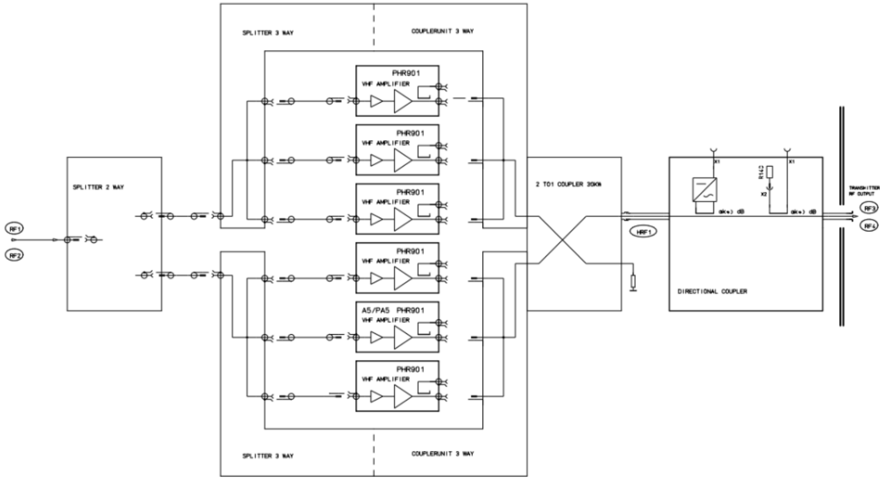
High Power Plants

- 12 PA units in two racks
- 5 kW per PA
- Redundant Liquid cooling system
- Freq. range from 87.5 MHz to 108 MHz

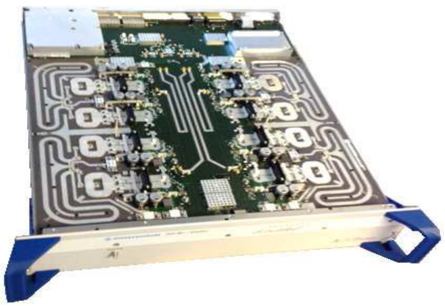
- Few changes from off-the-shelf product means lower price
- Modified from constant output power to constant gain

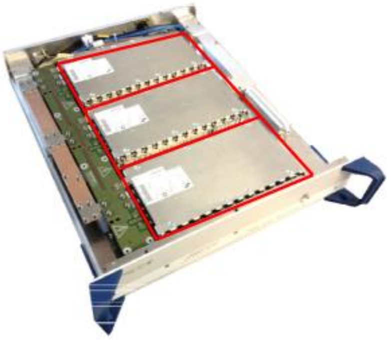
- Efficiency values where measured in the FAT:
  - Overall efficiency at full power 60,2 %
  - Overall efficiency at -3 dB power level 45,3 %
- With new software with possibility to change the DC voltage of the amplifiers:
  - Overall efficiency at full power 66,1 %
  - Overall efficiency at -3 dB power level 59,1 %



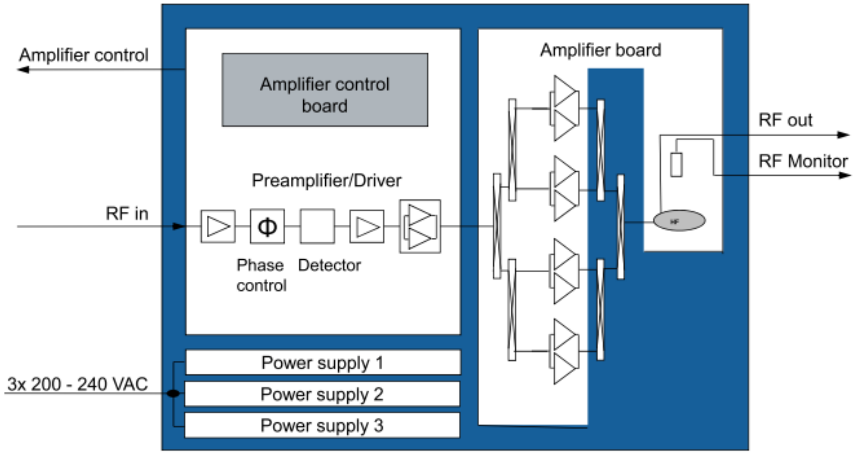


PA moduls





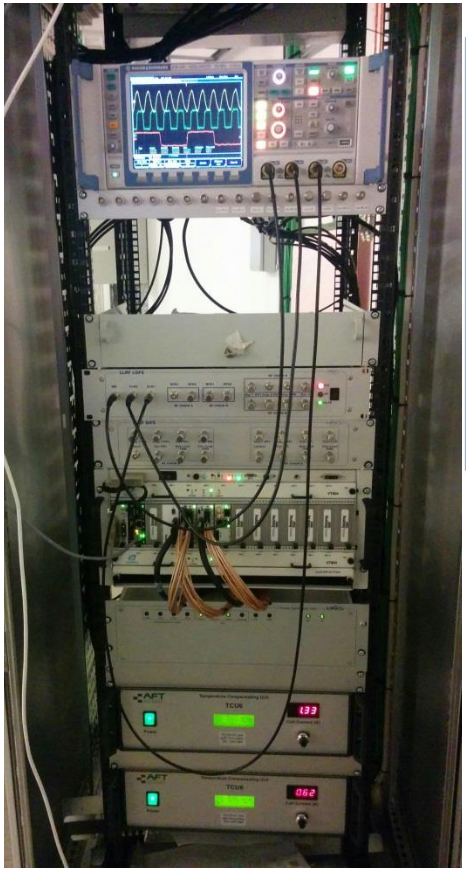
- Nominal power 5.0 kW Constant Gain mode
- Controlled via CAN bus
- Integrated harmonics filter
- Voltage 3 x 230 V AC ± 15% / 47 .. 63 Hz
- Transistor 50V LDMOS Freescale MRFE6VP61K25H
- 8 Finale Stage transistors
- 3 single-phase power supply units
- 90% of nominal output power with 2 PS
- Harmonic attenuation up to 1 GHz at Pnom > 85 dB

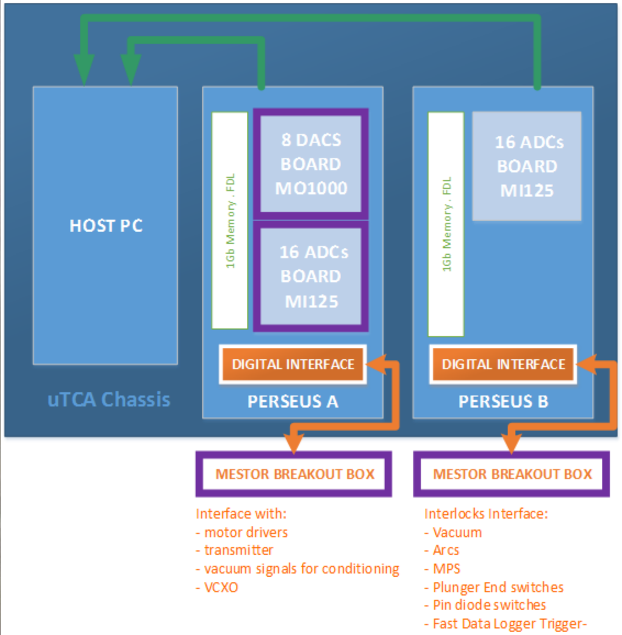


Digital Low Level RF

Design by Angela Solom
GUI by Antonio Milan
Hardware: MAV IV RF team

- The DLLRF is based on the Perseus FPGA platform from Nutaq. Two units is in operation in the 3 GeV ring controlling two cavities each. The third is in operation in the 1.5 GeV ring.
- Besides the tuning loop the amplitude of the cavity field and the phase of the forward power can be controlled independently, polar loops. For the I/Q loops phase and amplitude are linked and can either act on the forward power, or the cavity field.
- It has a fast data logger for post-mortem analysis.





MAX IV

Thanks for your attention
Questions?