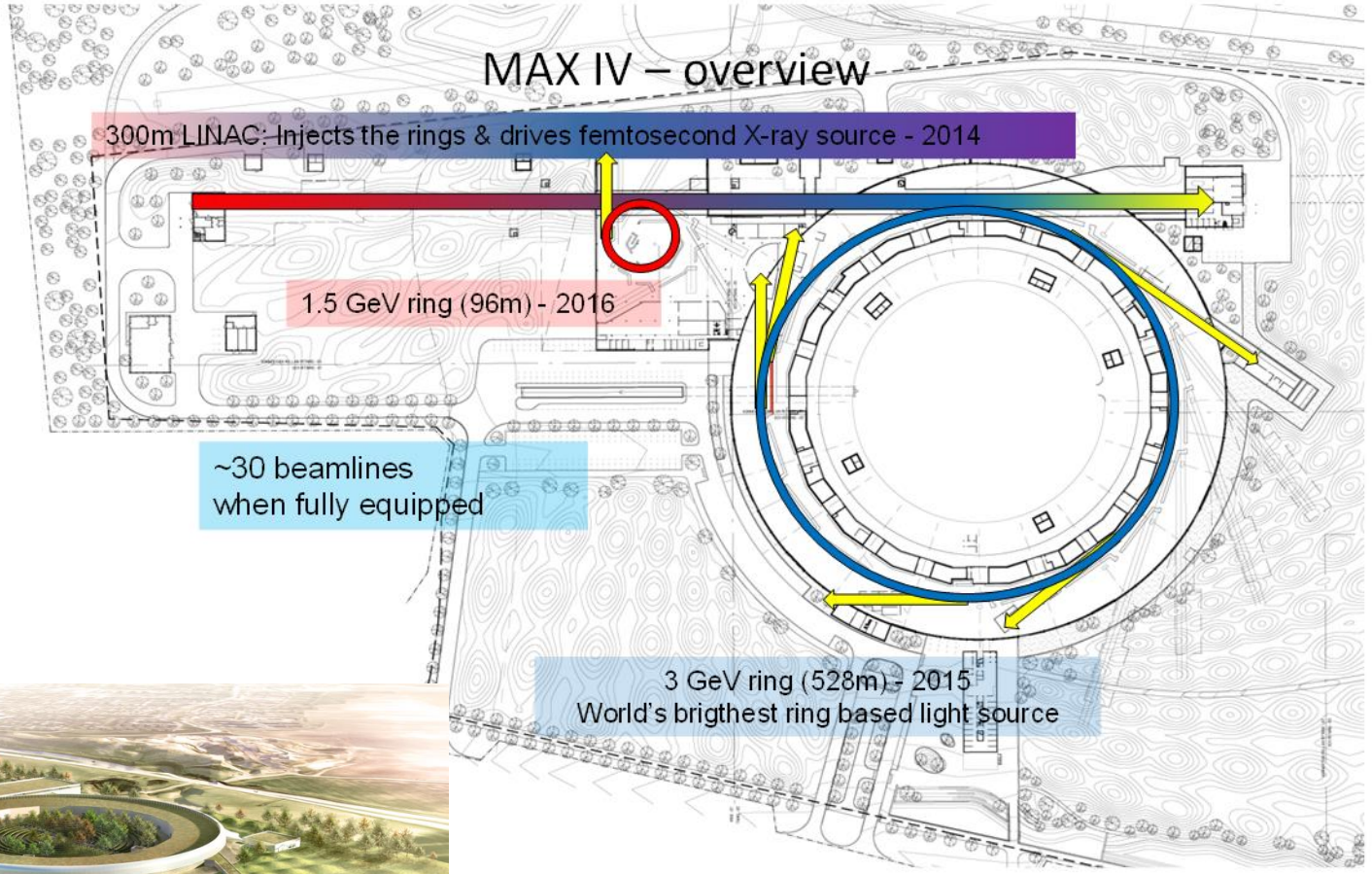
Status of the MAX IV RF systems

Outline

- MAX IV overview
- MAX IV - Linac
- MAX IV - Ring RF system
- Ring RF – Cavities
- Ring RF – Power plants
- Digital low level RF
- Chopper for ring injection

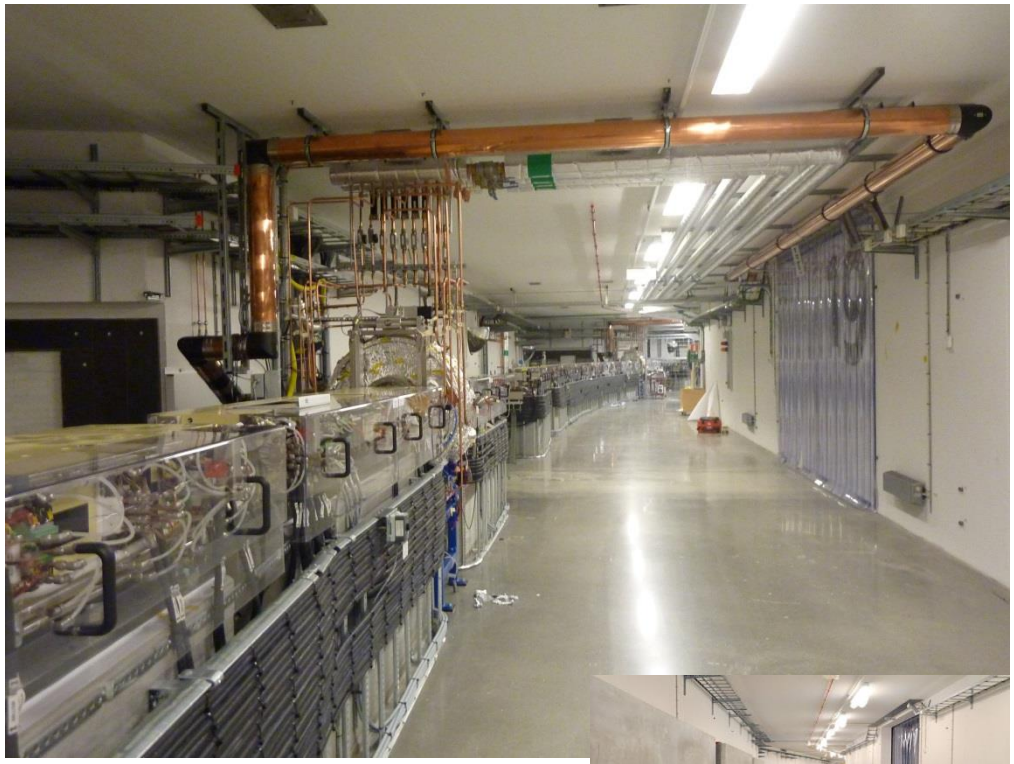


Inauguration June 21, 2016

Aerial View of the MAX IV Site

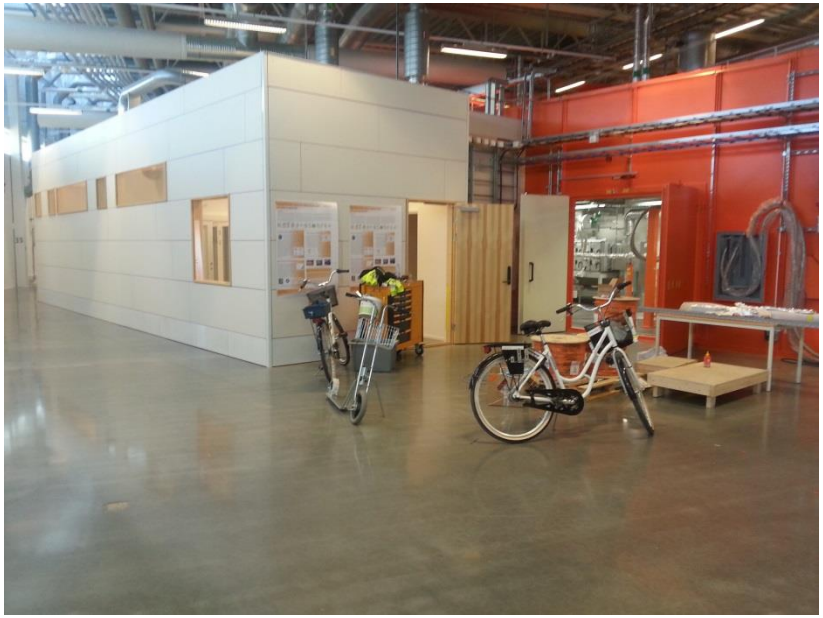
Photo Perry Nordeng

Inside the 3 GeV building



Ring tunnel

20150928



The experimental hall with one of the beamlines experimental hutches. Seven is already funded.

Photo Annika Nyberg 140828

MAX IV Linear Accelerator

Klystron gallery

Photo Annika Nyberg

Linear accelerator

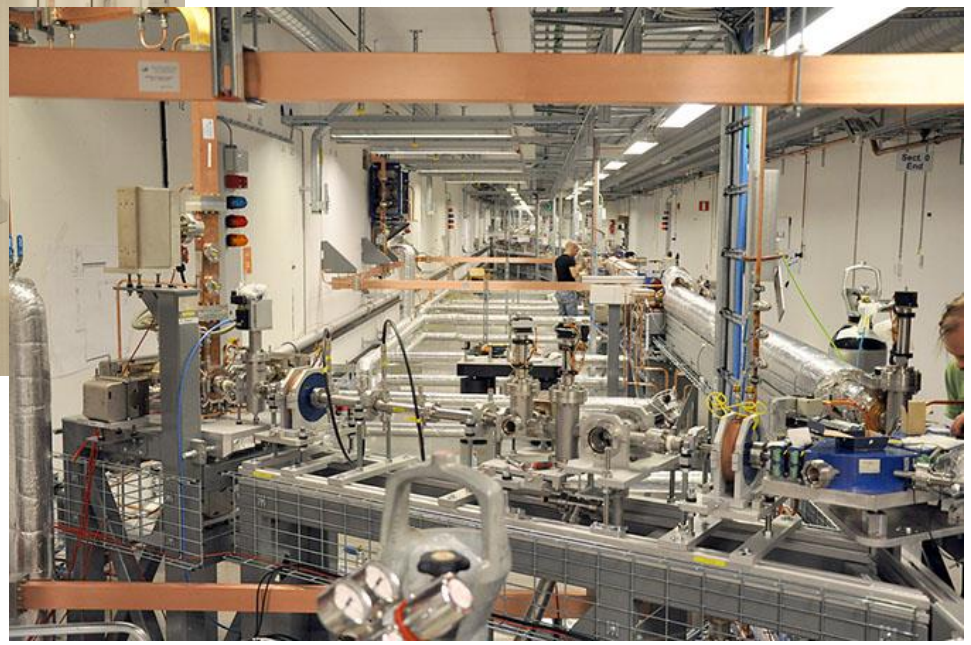


Photo Annika Nyberg

The status of the S-band high power linac components will be covered by the talk of Dionis Kumbaro

MAX IV Linac

The linac should be used as an injector for both the 1.5 and 3 GeV storage rings and the SPF (Short Pulse Facility)

- **18 klystrons**
- **18 SLEDS**
- **39 linac structures**

  Operating frequency 2998.5 MHz
  Maximum rep. rate 100Hz
  Maximum RF power 35 MW
  RF pulse length 4.5µs
  Linac length 250 m

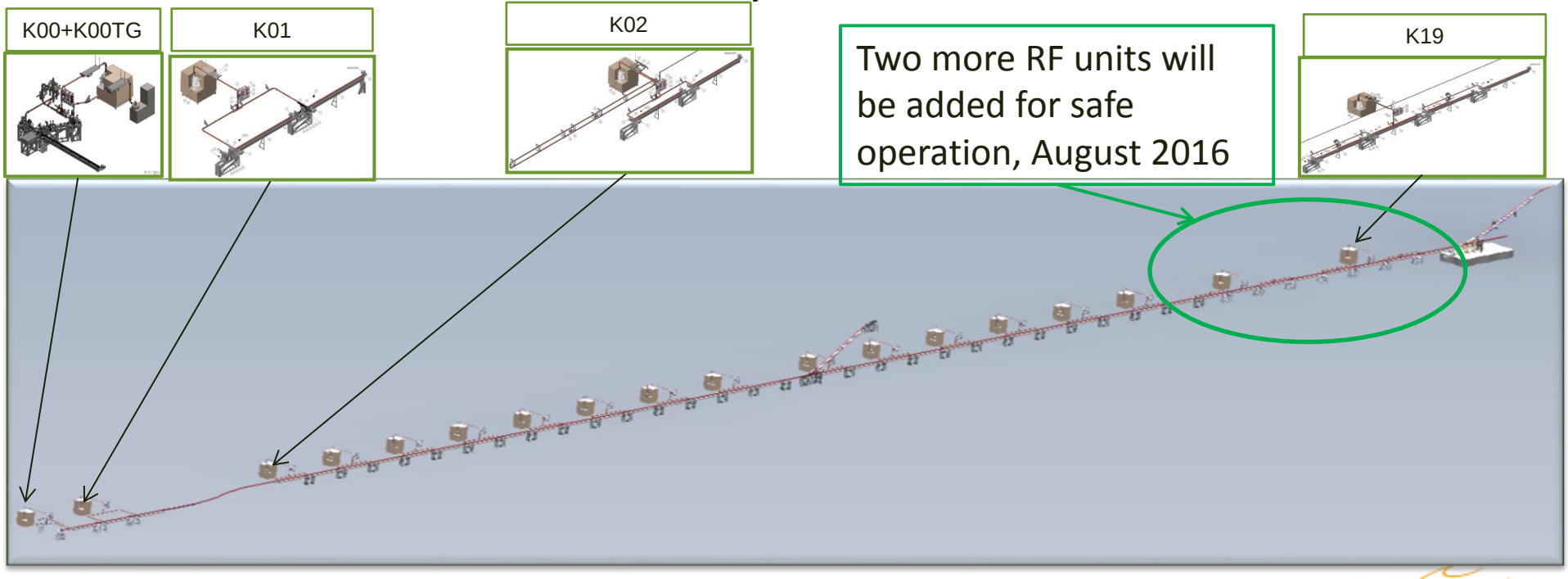
- **Two Electron sources**
  1. **One klystron (7.5MW) feeding a thermionic RF gun used for ring injections**
  2. **A photo cathode gun for the SPF fed from the first linac klystron**

Operating beam energy 3 GeV
Max. on-crest beam energy 3.6 GeV

44% RF power redundancy. Part of this has been reduced due to arcing at some of the RF Power Units at high power. For safe operation two RF units will be added in August 2016. The linac tunnel is prepared for this change.

MAX IV linac

- RF conditioning did take longer time than anticipated despite that everything except the waveguides is preconditioned by RI. Problems with the subsystems have limited the time for conditioning
- The first three RF stations are fully conditioned uppdateras
- Only minor impact on the Linac commissioning time schedule. The personal safety system PSS was changed so that it is possible to accelerate electrons up to the first bunch compressor while RF conditioning could continue in the rest of the linac.
- **3 GeV was reached for the first time February 9, 2015**



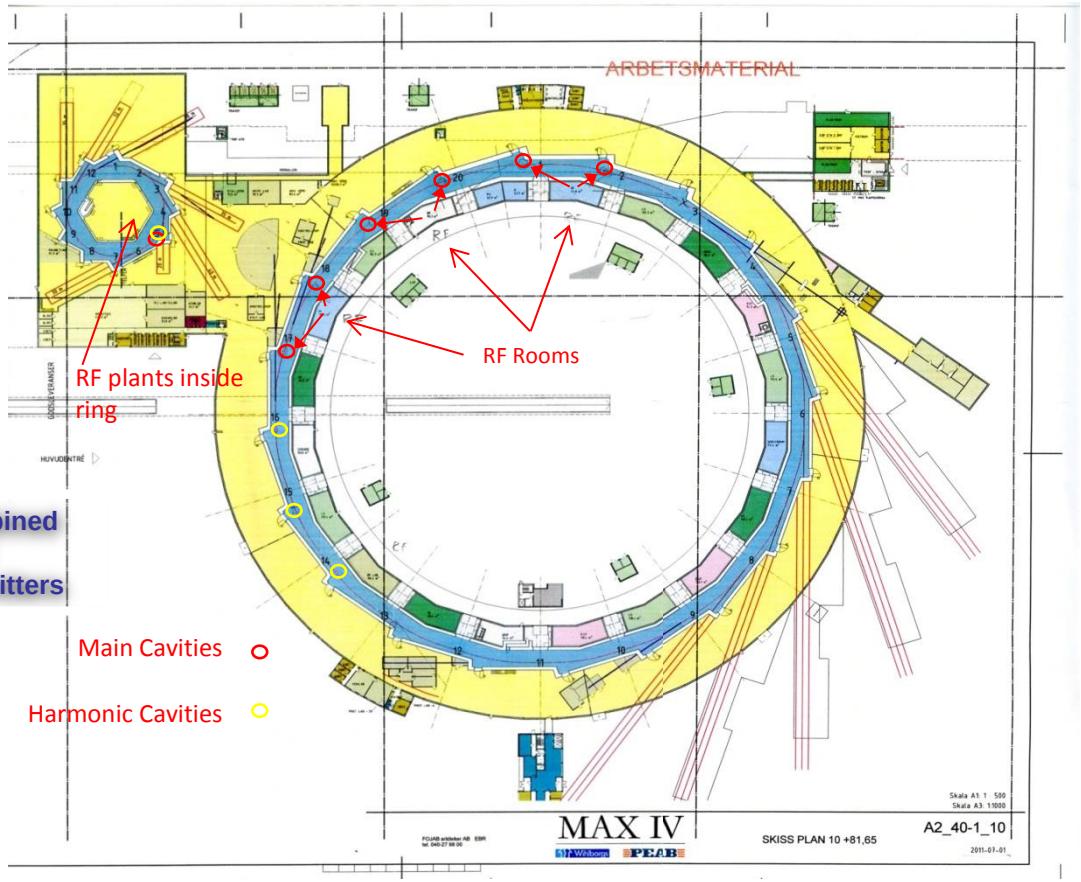
MAXIV Ring RF System

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

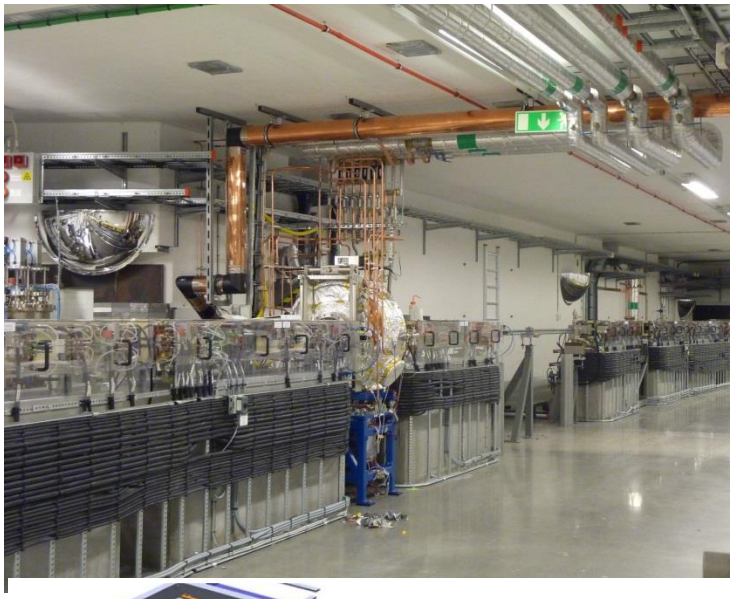
2 combined 60 kW transmitters

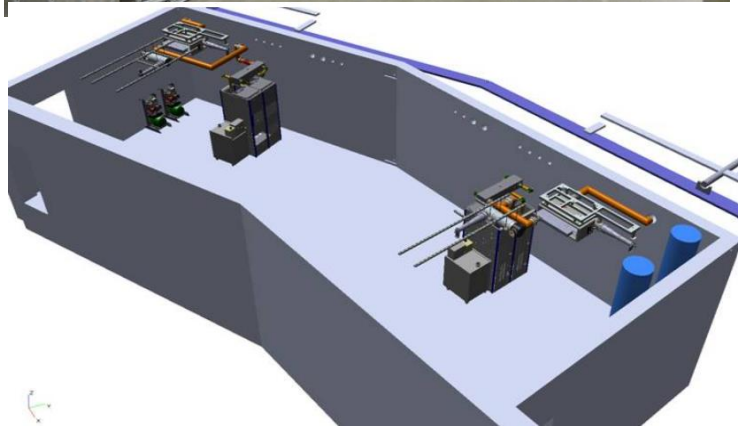
1 single 60 kW transmitters



Ring RF System - 3 GeV Ring RF

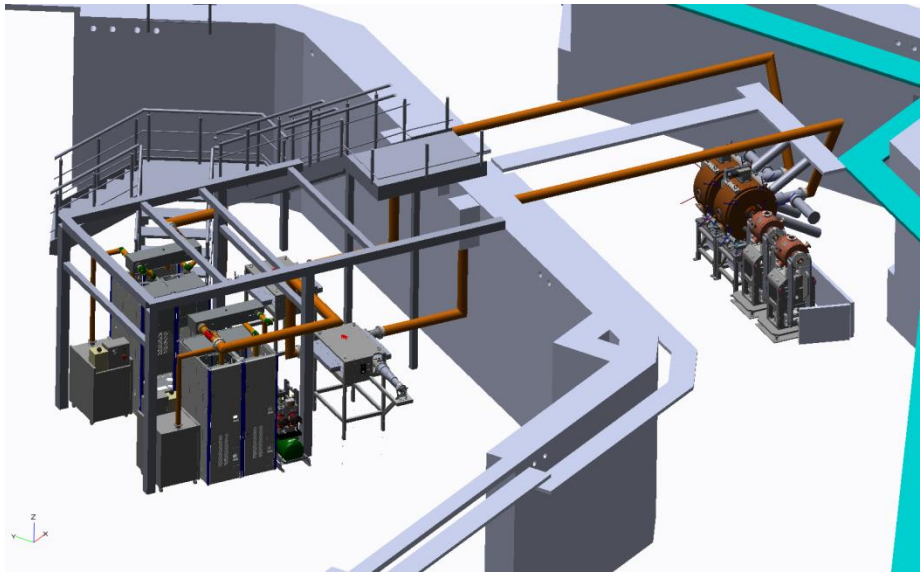
- The main cavities are placed in the second short straight section of six consecutive achromats.
- Each RF-room contains two RF power plants.





Ring RF System - 1.5 GeV Ring RF

- Two Main Cavities and two Harmonic Cavities occupy one straight section
- Two 60 kW Power Plants are placed inside the ring.



Ring RF System - Cavities

- Cavities (100 and 300 MHz)
- All main cavities including two for Solaris Poland
  - **Was Delivered October - December 2013**
- Eight main (two for Solaris) and four HC has been conditioned at Maxlab. Two main and one HC cavities for the 1.5 GeV remains to be conditioned.

Ring RF System – Main Cavities

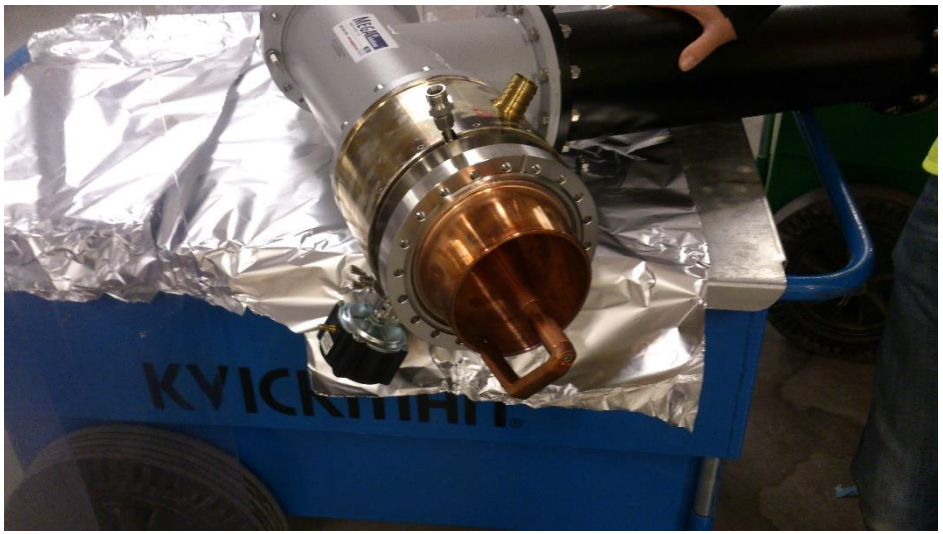
- The cavities were delivered baked (3 days, 120 degree), with power coupler attached (β = 1).
- A 600 l/s ion pump is attached. All cavities in the low 10^{-10} mbar range.

- So far, 8 main cavities (6 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)

- 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.

Ring RF System – Harmonic Cavities

- Multipacting problem origin: Coupler or Cavity body?



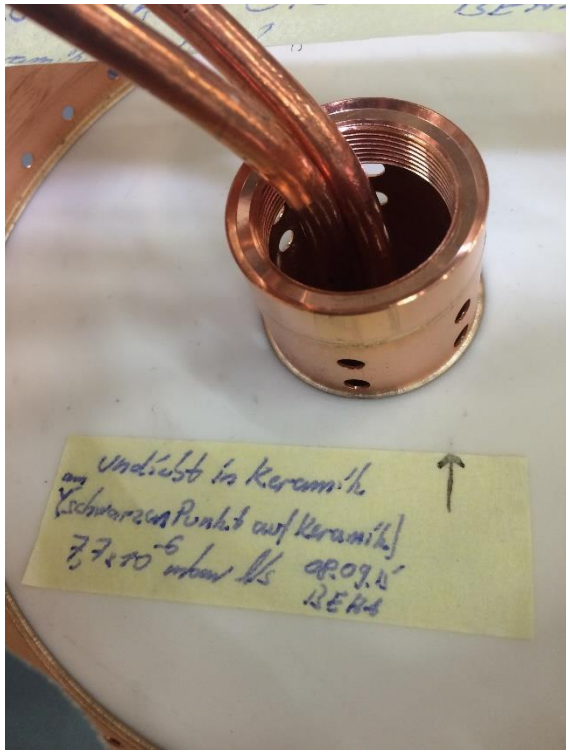
Ring RF System – Main Cavities

After conditioning we vented and turned coupler to β = 2.
We then measured f_r and Q_0 carefully:

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	2450	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	

Ring RF System – Main Cavities

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



Ring RF System – Main Cavities

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

Ring RF System – Harmonic Cavities

- 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 β = 1 attached.
- Each cavity has two 100 l/s ion pumps. All cavities in the low 10^{-10} mbar range.

- So far, 4 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 4 cavities: ~ 4 * 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.

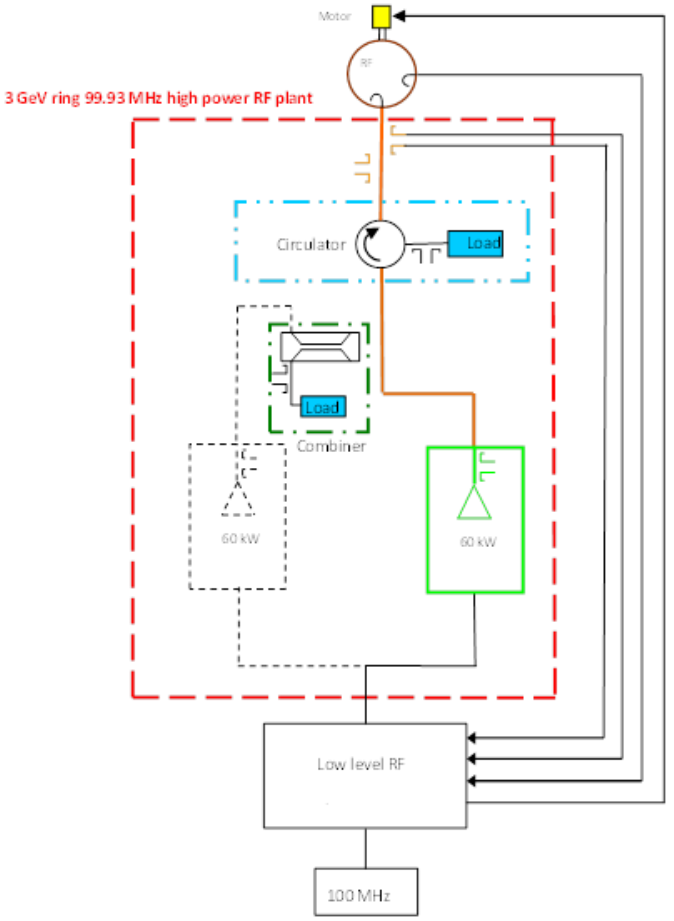
Ring RF System – Harmonic Cavities

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

Ring RF System – High Power Plants

- Contracts signed for
  - High power amplifiers (Electrosys, Italy). The delivery time was delayed because of severe financial problems in the company. The risk was too large to continue so the contract was canceled (June 2014). **A new contract has been signed** (September 2014)for delivery of 60 kW liquid cooled solid state power amplifiers (Rohde & Schwarz, Germany)
  - Circulators (AFT, Germany)
  - Transmission Lines and Integration Work (Exir Boadcasting AB, Sweden)
- **Delivery of high power amplifiers: Two in December 2014 (January 2015) for test of circulators, two in February 2015 , two in March and finally two in June 2015 (1.5 GeV).**



Ring RF System – 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 × 600 mm × 1100 mm (HxWxD)
- Coolant: glycol/water

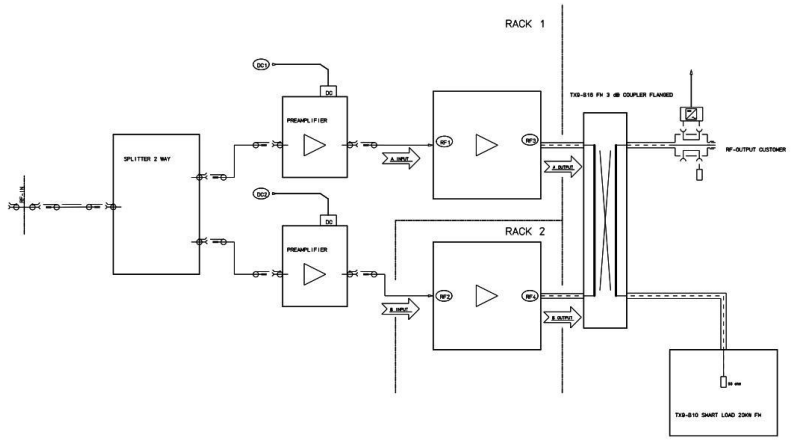
One pump unit and heat exchanger per rack

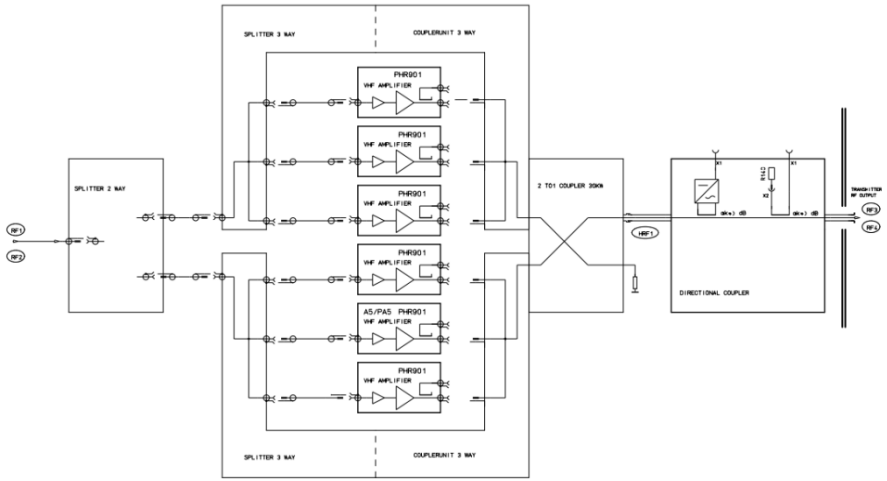
Ring RF System – High Power Plants

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

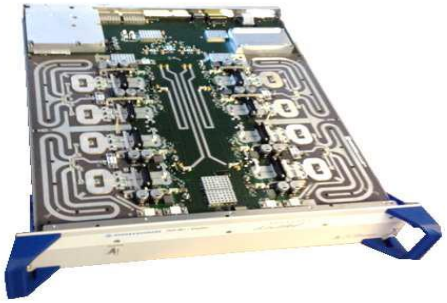
- Few changes from off-the-shelf product means lower price
- Modified from constant output power to constant gain

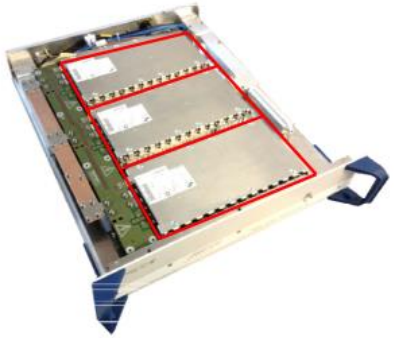
- Efficiency values where measured in the FAT:
  - Overall efficiency at full power 60,2 %
  - Overall efficiency at -3 dB power level 45,3 %
- With new software with possibility to change the DC voltage of the amplifiers:
  - Overall efficiency at full power 66,1 %
  - Overall efficiency at -3 dB power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



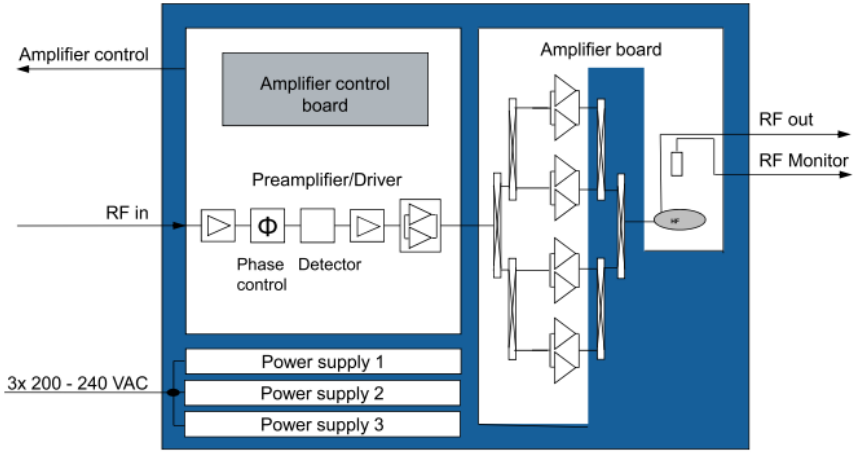


Ring RF System-PA moduls





- 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



High Power RF Systems Installation

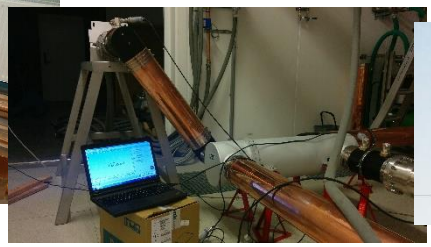
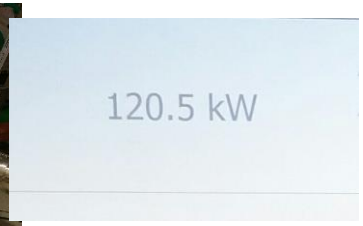
- High Power Amplifiers
- 120kW Circulators
- 120 kW 3dB Couplers
- 6 1/8” EIA Coaxial Lines





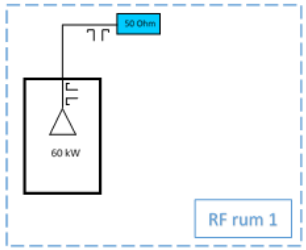


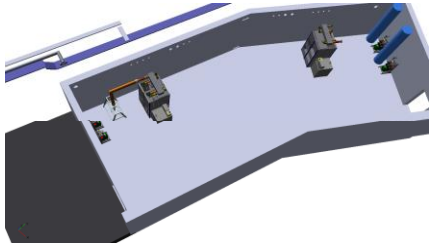


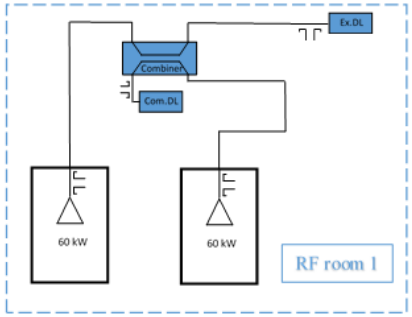

Ring RF Systems – SAT of the High Power Plants and Circulators

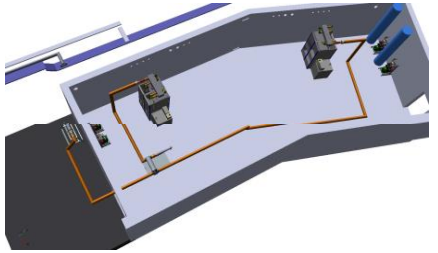
- One High Power Amplifier
  60 kW to load



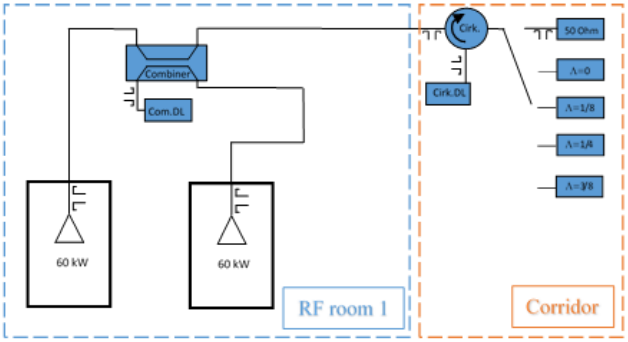


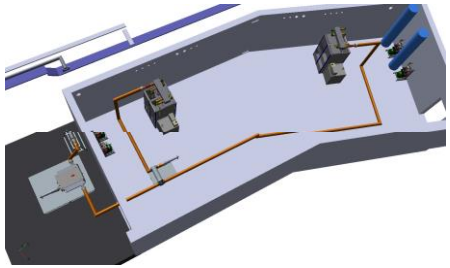
- Two combined HPAs
  120 kW to load





- 120 kW circulator Port 2 connected to :
  -50 Ohm water load
  -EIA 6 1/8”-Short via coax waveguide length 0, 1/8, ¼, 3/8 …lambda





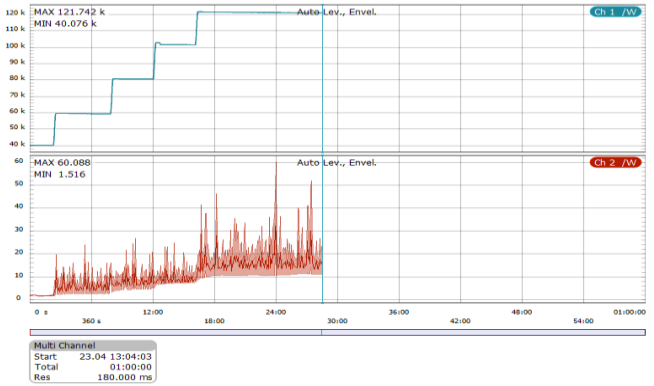
Ring RF System – SAT of Circulators

- FAT/SAT and retuning of TCU was performed on 8 units

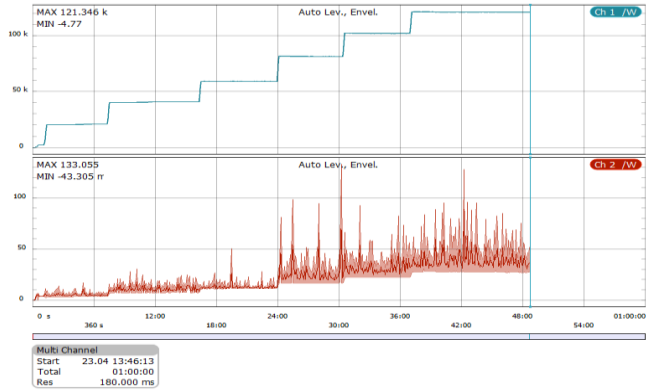
- Two test conditions with regards to the termination at port 2:
  (1) matched water load and
  (2) short circuit of variable phase .

Fast RF feedback control

Port 2 Mached Load

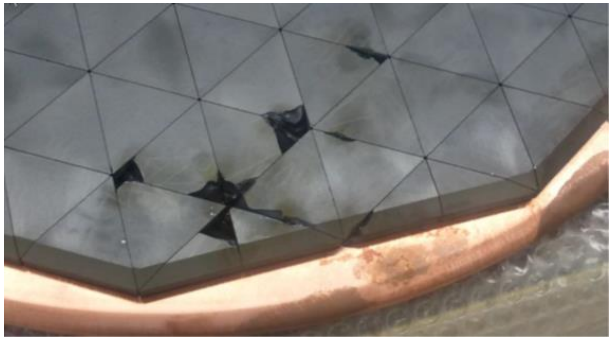


Port 2 Short Λ=0



Ring RF System – SAT of Circulators

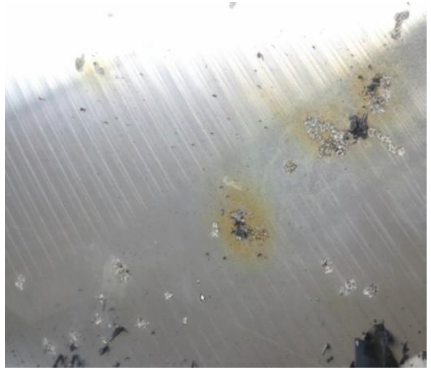
- Fifth circulator in row for test expiried arc att 100kW in configuration to matched load.
- Circulator returned to AFT
- Damage is visible at ferrite close to port 1. Bottom side of cooling disc with ferrites shows massive arcing damages. Bottom side of circulator housing shows arc traces on the aluminum surface. Probably very small ferrites chips or local contamination caused arcing at lower power levels already.



Ferrites are damaged severely.

- 1: Remove damaged ferrites, clean cooling disc, replace ferrites by new ones.
  2: Clean surface of inner housing. Rework surface of inner housing.
  3: Reassembly of Circulator, all mech. & physical testing
  4: Electrical retuning of Circulator, TCU calibration

Ferrite chips and burning marks close to port 1.

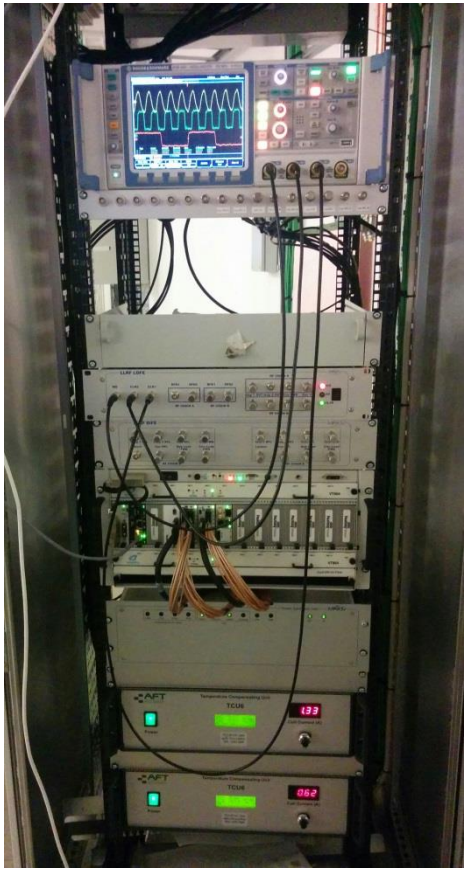


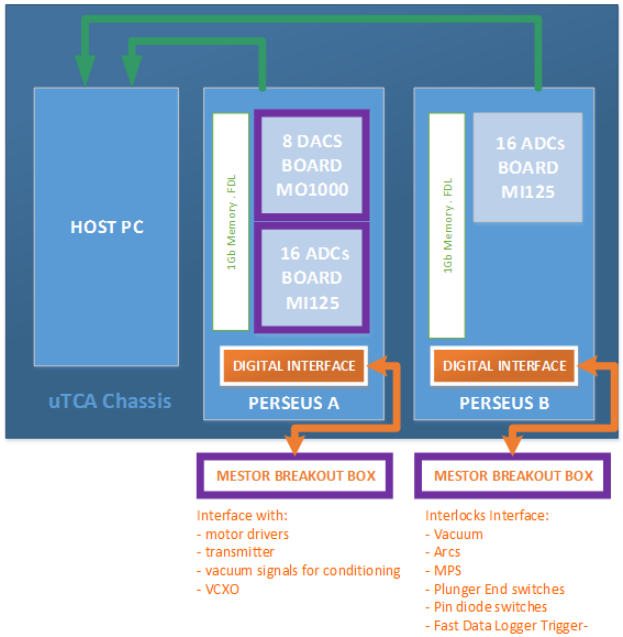
Aluminum surface of the house is damaged by arcs.

Digital Low Level RF

Design by Angela Solom
GUI by Antonio Milan

- 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 will be taken into operation soon.
- It is possible to implement two independent loops besides the tuning loop. One controlling the amplitude of the cavity field and one the phase of the forward power. Either I / Q or polar loops can be selected.
- It has a fast data logger for post-mortem analysis.

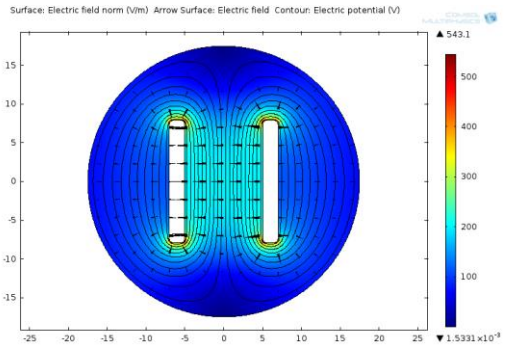




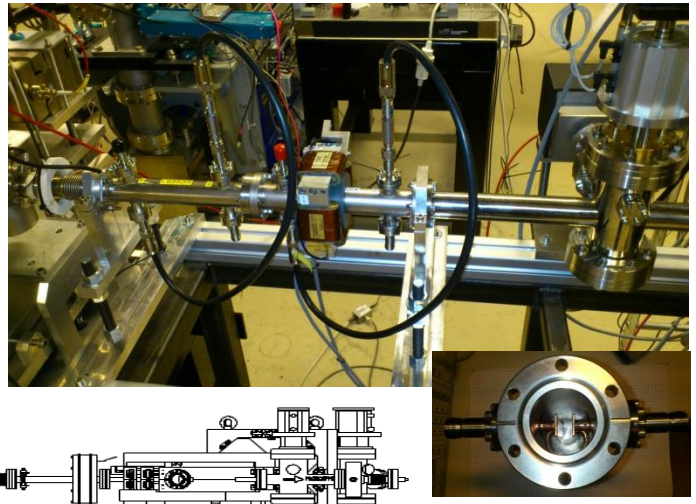
Chopper for Ring Injection

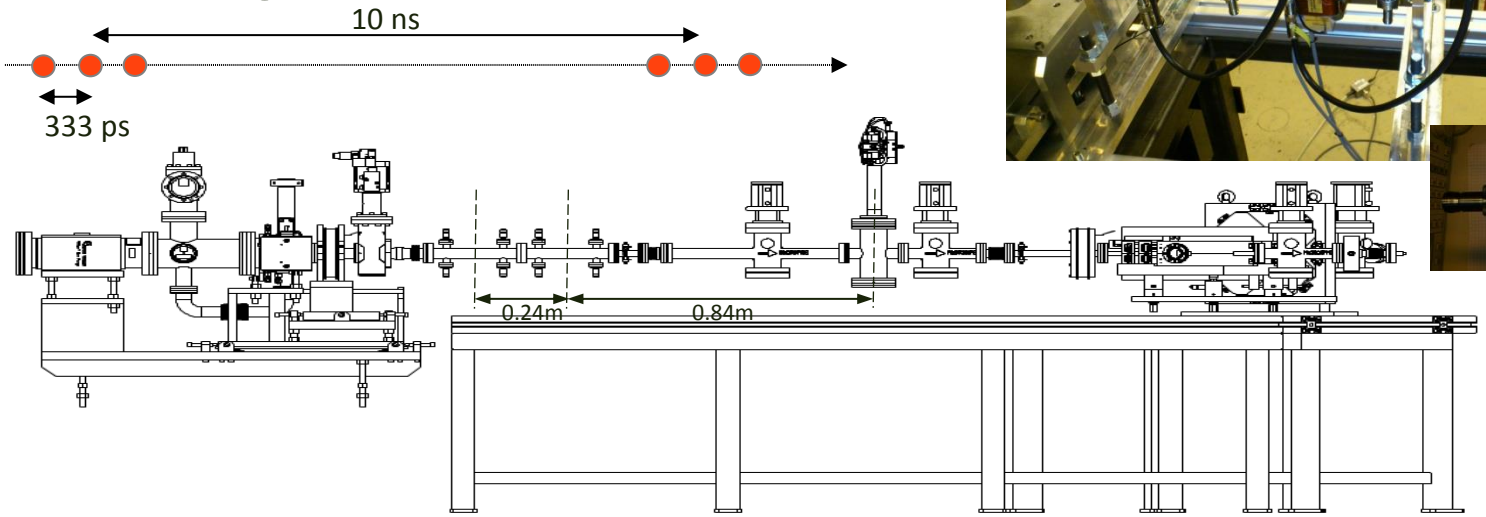
- Has two identical vertical kickers.
- The kickers consist of a 15 cm long stripline pair with a characteristic impedance of 50 Ω for odd TEM modes.
- Both electrodes are fed by RF
- An aperture is located downstream. The unwanted bunches will be dumped here.
- The aperture can be selected so the wanted bunches either passes a 1 mm iris, a 2 mm iris, or over an edge.

2 D design

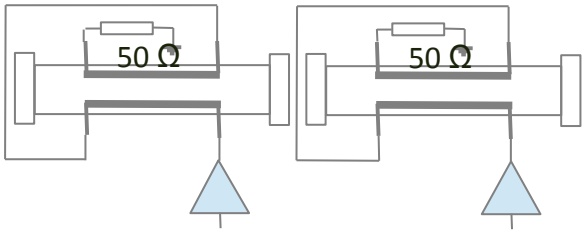


If $\phi_1=-\phi_2 \rightarrow$ Zo=49.9Ω
If $\phi_1= 0 \rightarrow$ Zo=63.8Ω
If $\phi_1= \phi_2 \rightarrow$ Zo=88.2Ω



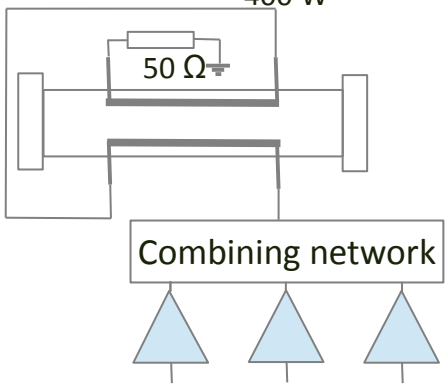


Kicker system for ring injection



300 MHz
~400 W

100 MHz
~1 kW

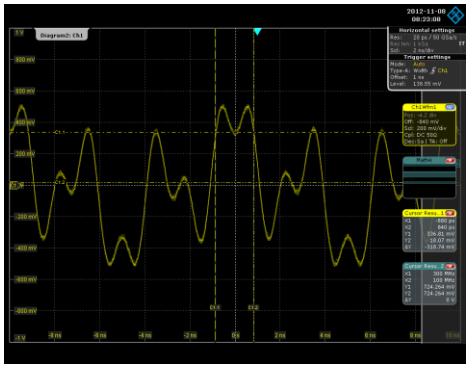


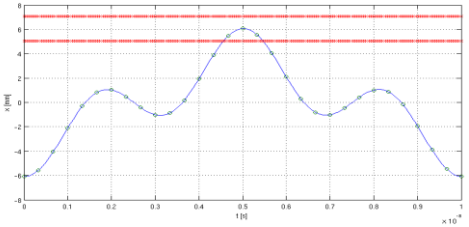
Crosstalk <-31db

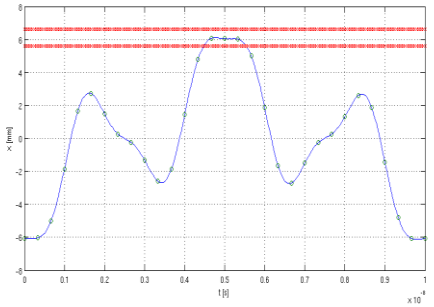
100 MHz
~400 W

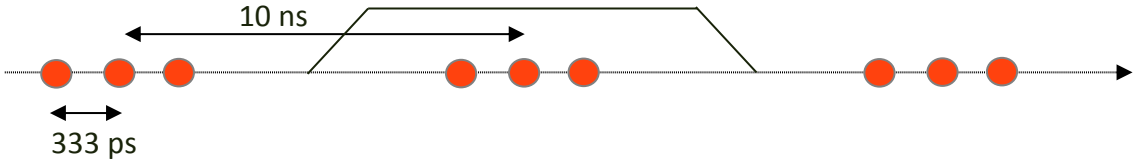
300 MHz
~1 kW

700 MHz
~300 W









The MAX IV thermionic pre-injector will be covered by the talk of David Olsson

Thanks for your attention
Questions?

No aperture

With aperture