PETRA III upgrade to PETRA IV

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Michael Ebert († 2021-03-06)

PETRA III upgrade to PETRA IV.

Overview

- Rough overview of how PETRA-IV will look like

What are the plans for the RF systems

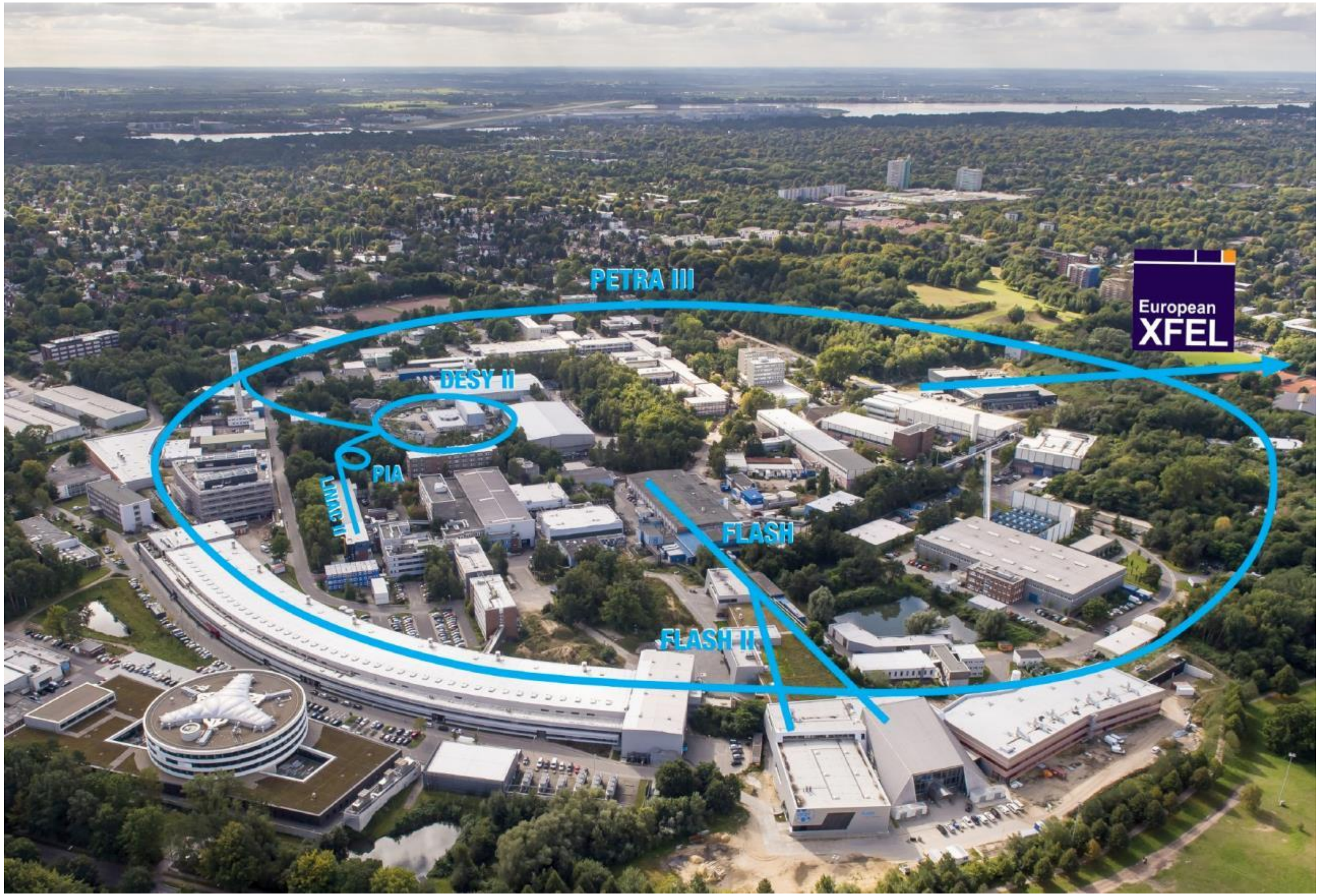
- The Fundamental-system: SSA-HOM-damped cavity, 500MHz
- The High Harmonic system: SSA- HOM-damped cavity, at 1,5GHz
- Alternative ideas for a 3rd harmonic cavity

Aerial View on the DESY Site

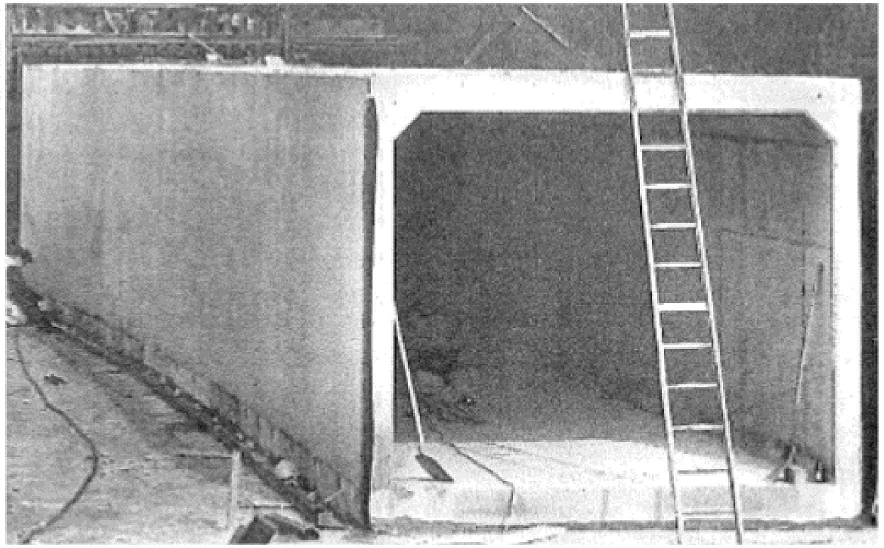
PETRA III and its related injectorm chain:
LINAC II, PIA and DESY II

European XFEL

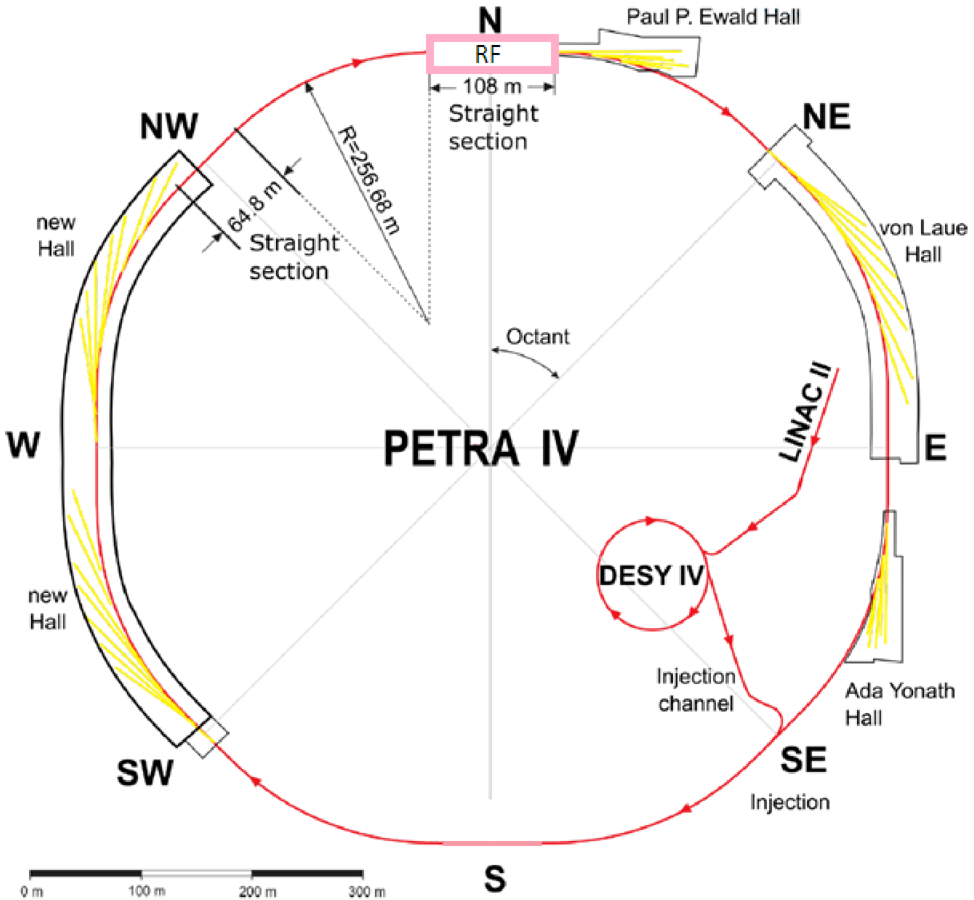
FLASH and FLASH II



PETRA IV Uses The PETRA III Tunnel



mostly reuse of the
old tunnel segments
of PETRA 1 from 1976



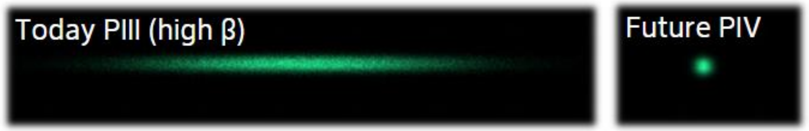
Thanks to
Michael Bieler

Some main parameters in comparison.

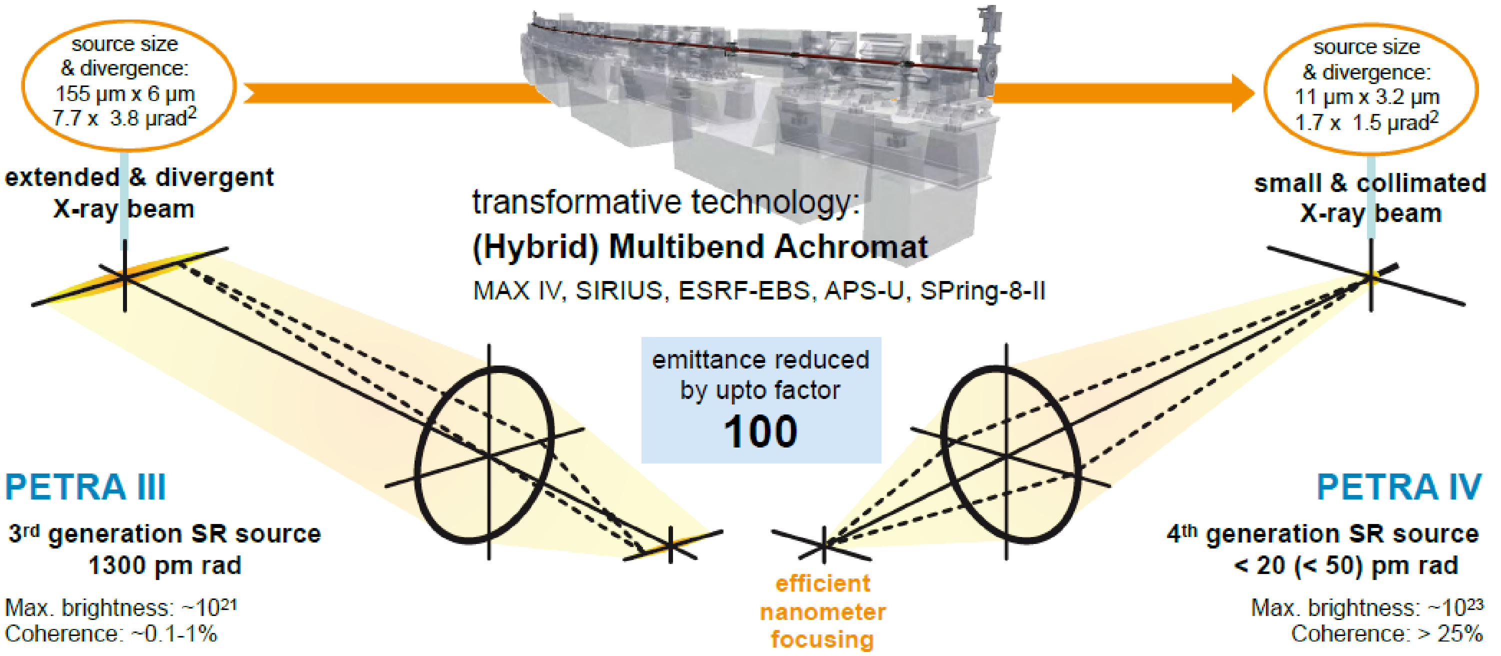
	PETRA III	PETRA IV (CDR)
Energy / GeV	6.0	6.0
Circumference / m	2304	2304
Revolution frequency / kHz	130.121	130.121
Beam lines	26	30
Number of bunches (timing-, brightness mode)	40, 480	80, 1600
Beam current / mA	100, 100	80, 200
Emittance (hor./vert.) / pm rad	1300 / 10	<50 / 10, <20 / 4
Energy loss (ID closed) / MeV per turn	5	4.024
Momentum comp. factor	0.001127	0.00001485
RF voltage / MV	20	8 + 2.3
Synchrotron frequency / kHz	6	0.421
RF frequencies / MHz	499.6	499.6 + 1500
Harmonic number	3840	3840

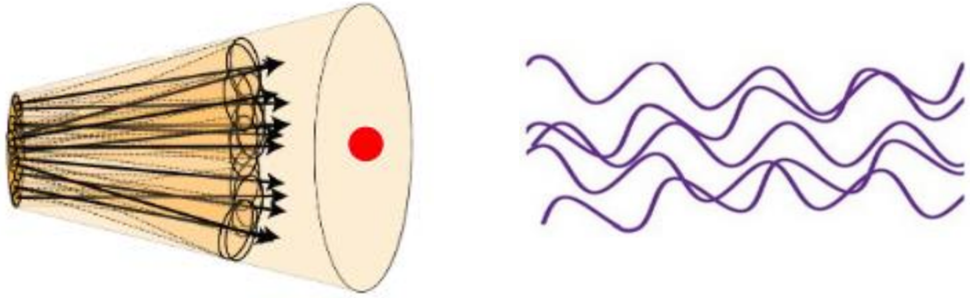
PETRA IV: The Ultimate Hard X-Ray Storage-Ring-Based Light Source

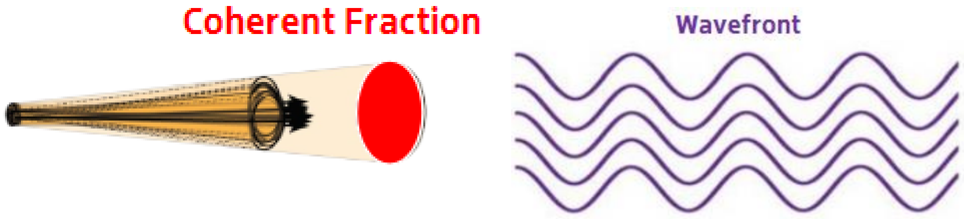
Preparing X-Rays in a Well-Defined State



Photon source size – ideal imaging capabilities





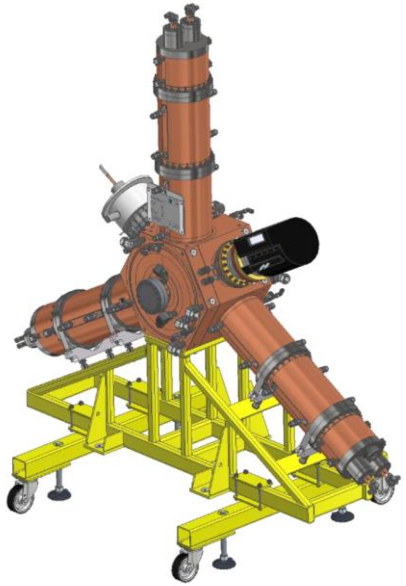


PETRA IV RF

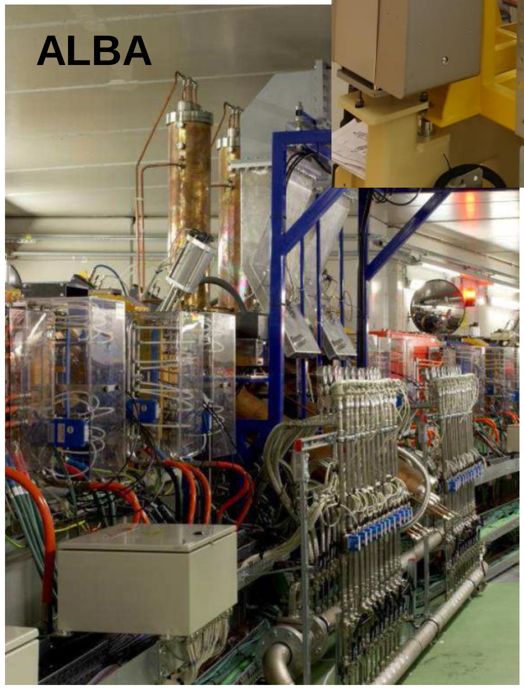
The 500 MHz fundamental RF system

Parameters for the PETRA IV fundamental RF system:

Main (fundamental) RF frequency	499.65 MHz
Total voltage main RF	8 MV
RF voltage per cavity	476 kV
Transit Time Factor	0.7
RF voltage per cavity seen by the electrons	333 kV
Cavity wall loss	16.3 kW
Power to the beam	37,4kW
Quality factor (unloaded)	29600
Cavity coupling factor	3.3
Shunt impedance $R_s=V^2/(2P)$	3.4 MΩ
Loaded quality factor	6900
Number of main RF cavities	24
Synchronous phase	34.2°
Nominal transmitter power per RF station	120 kW
Beam tube aperture	74 mm
Length of cavity (flange to flange)	500 mm

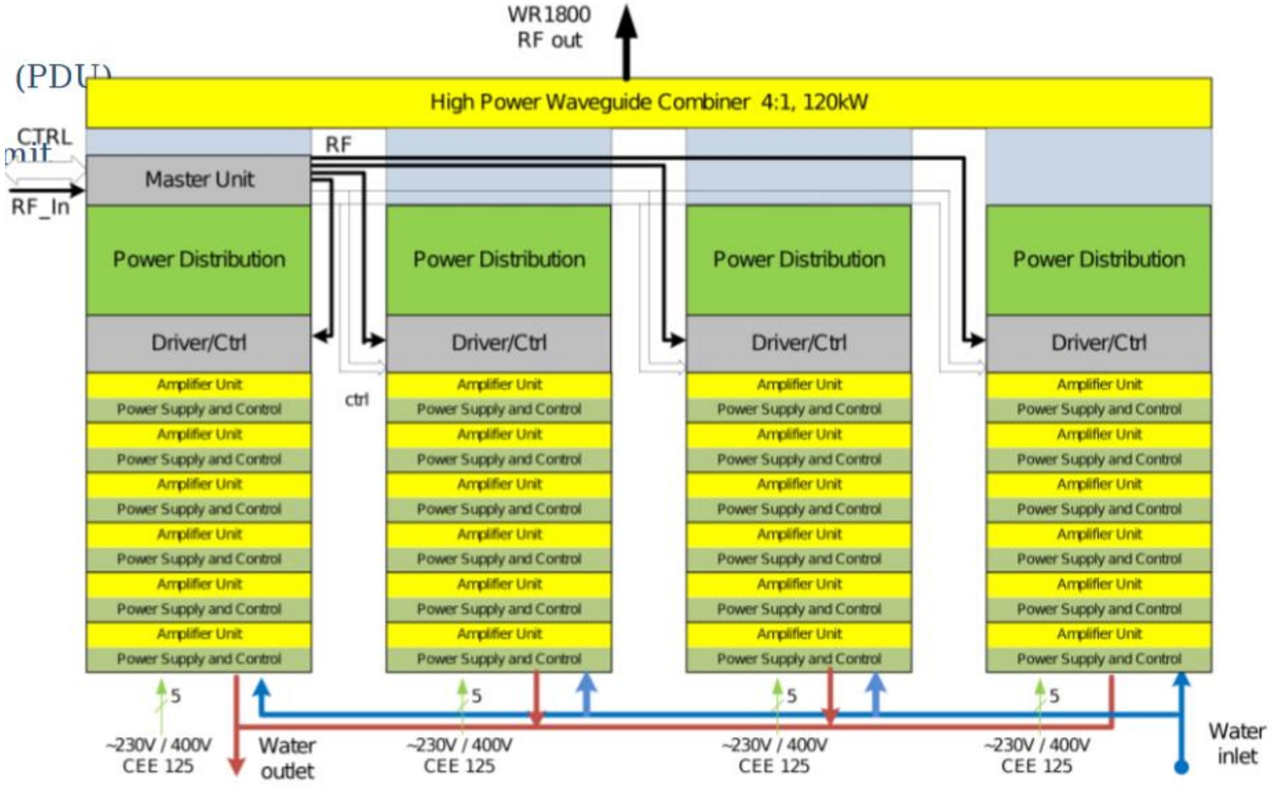


New Design
HOM-damping capabilities are optimized
(Cavities in operation at:
- ALBA
- BESSY
- DELTA
- Diamond
- ESRF)



PETRA IV RF

The Prototype 500 MHz, 120 kW SSA



Two frequencies

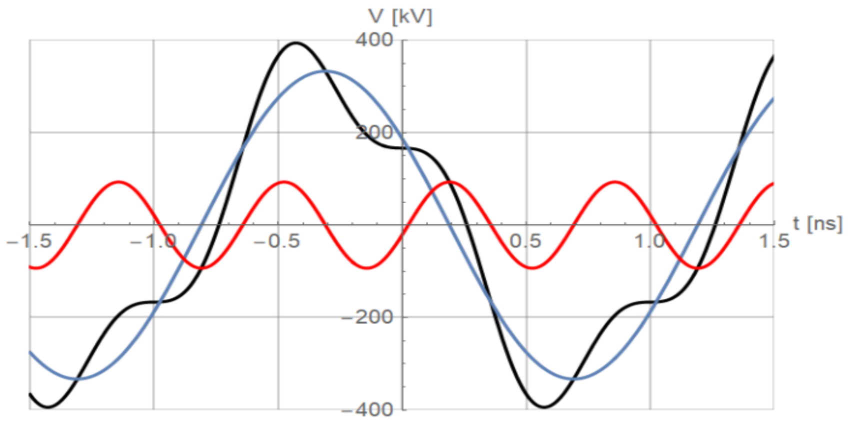
Lengthen the bunch with a second active RF-system

$$V(t) = V_{01}\sin(\omega t + \phi_{s1}) + V_{02}\sin(n\omega t + \phi_{s2})$$

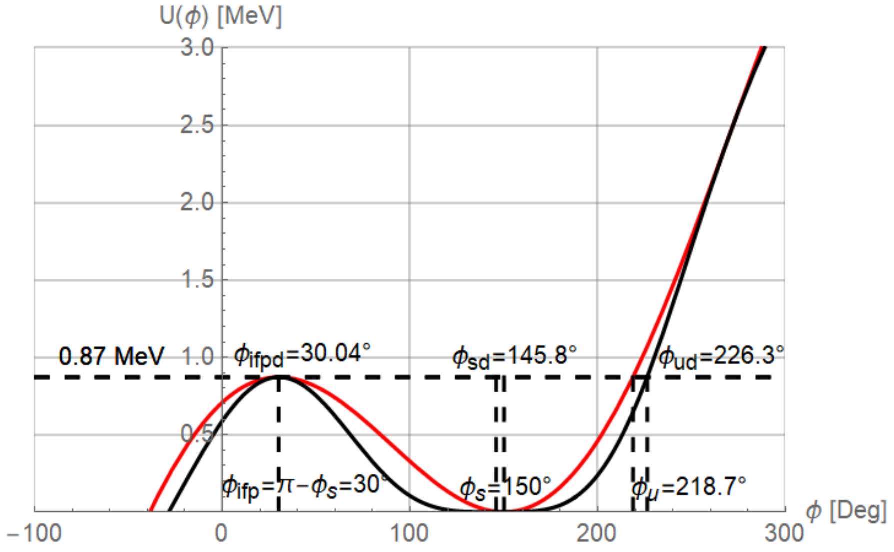
Bunch length:

- without a 2nd RF-system: 23 ps (7 mm)
- with an additional RF-system (n=3): 60 ps (18 mm)
- So the single bunch current could be increased
- The required harmonic RF voltage for a flat potential and the required synchronous phase is:
- V_{02}= 2.26 MV.
- ϕ_{s2} = -12.8°

The calculated parameters for the dual harmonic rf system (500MHz and 1,5GHz)				
ϕ_{s1}	ϕ_{s2}	k	V_{01}	V_{02}
145,8°	-12,8°	0,28	8MV	2,24MV



The 500MHz-voltage (blue), the 1,5GHz-voltage (red) and the resulting voltage (black)



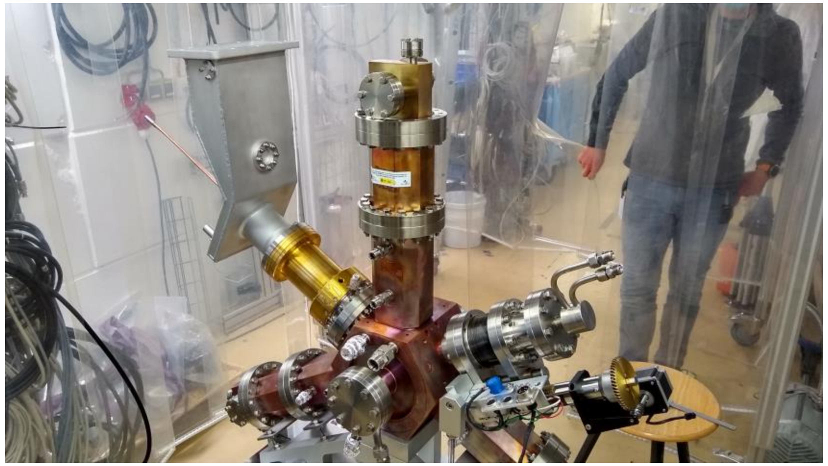
The single-harmonic- (red) and the dual harmonic bucket (black) in comparison.

PETRA IV RF

The high harmonics RF system

Parameters for the PETRA IV third-harmonic RF system:

3rd harmonic RF frequency	1498.995 MHz
Total RF voltage	2.3 MV
RF voltage per cavity	93 kV
Cavity wall loss	3 kW
Quality factor (unloaded)	17000
Loaded quality factor	4250
Cavity coupling factor	3
Shunt impedance $R_s=V^2/(2P)$	1.5 MΩ
Number of RF stations (cavity/SSA)	24
Nominal transmitter power per RF station	10 kW
Beam tube aperture	46 mm
Length of cavity (flange to flange)	313.6 mm



Courtesy of A. Matveenko, BESSY II

Courtesy of Beatrice Bravo, ALBA

RF System Design

How to group the RF-systems

Each cavity of the complete rf system is powered by its own Solid State amplifier (SSA)

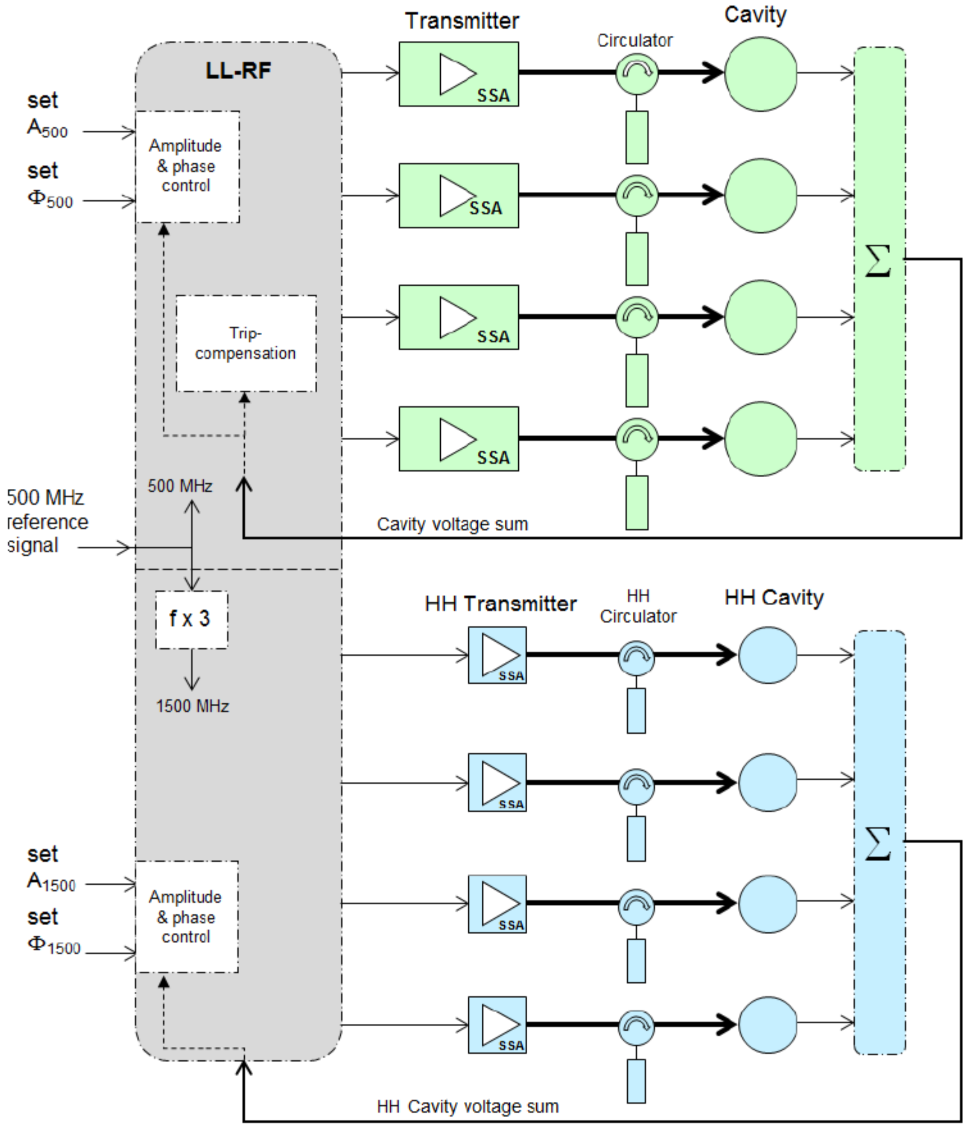
The complete rf system is divided into 6 groups

Each group is composed of
- 4 * 500 MHz systems
- 4 * 1,5 GHz high harmonic systems

The groups are independent of each other
They are spatially separated

Each group has its own
- Water supply
- Power supply
- Air cooling

The top priority of the design is redundancy and reliability



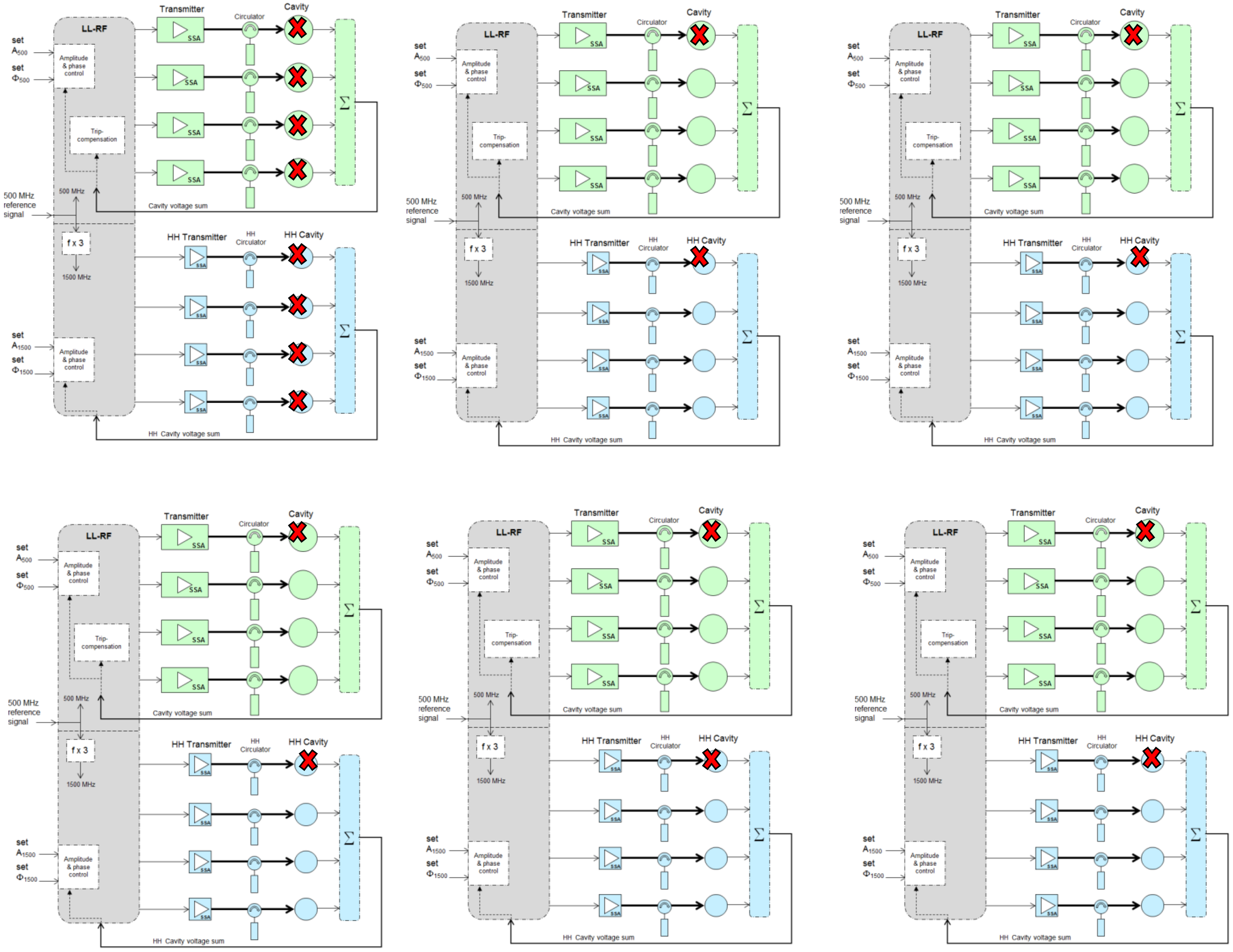
1.5 Trip compensation, what does that mean?

- The RF system has a high redundancy
- Continuous RF operation without beam loss is still guaranteed when:

1) A complete group has failed or is in service.
2) 1 fundamental- and 1 high harmonics rf system is in service in each of the remaining groups.

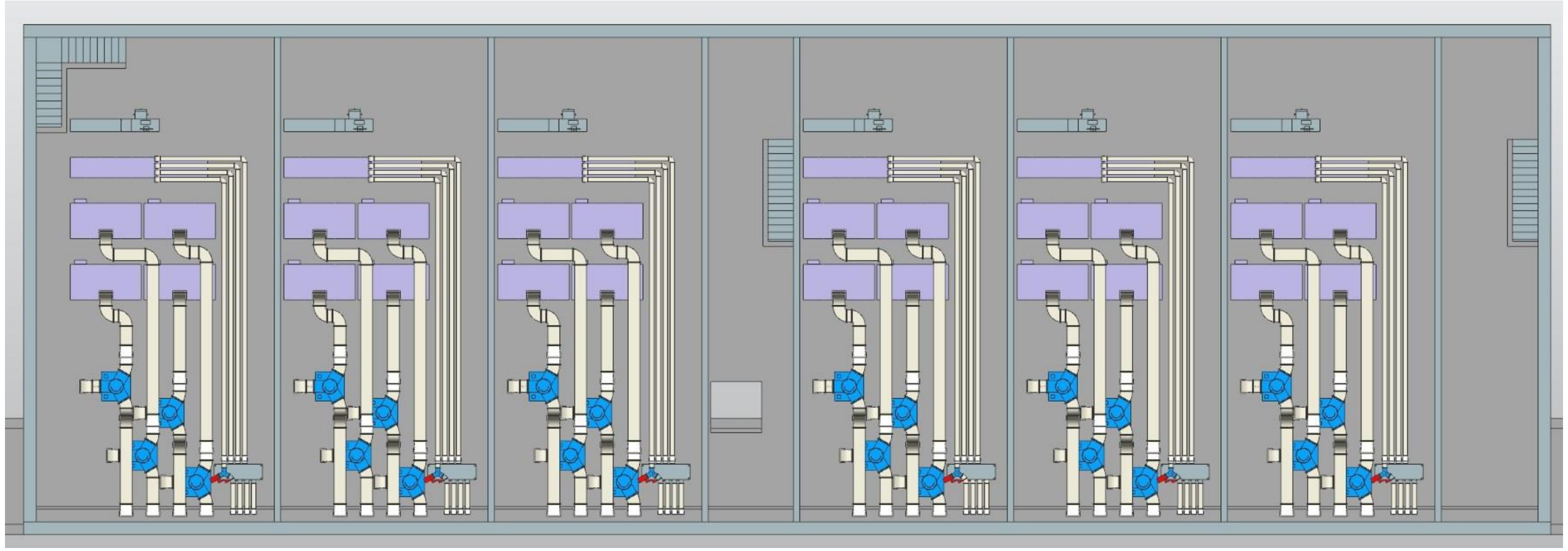
Trip compensation in the worst case would bring the cavities as well as the SSA's to their limits.

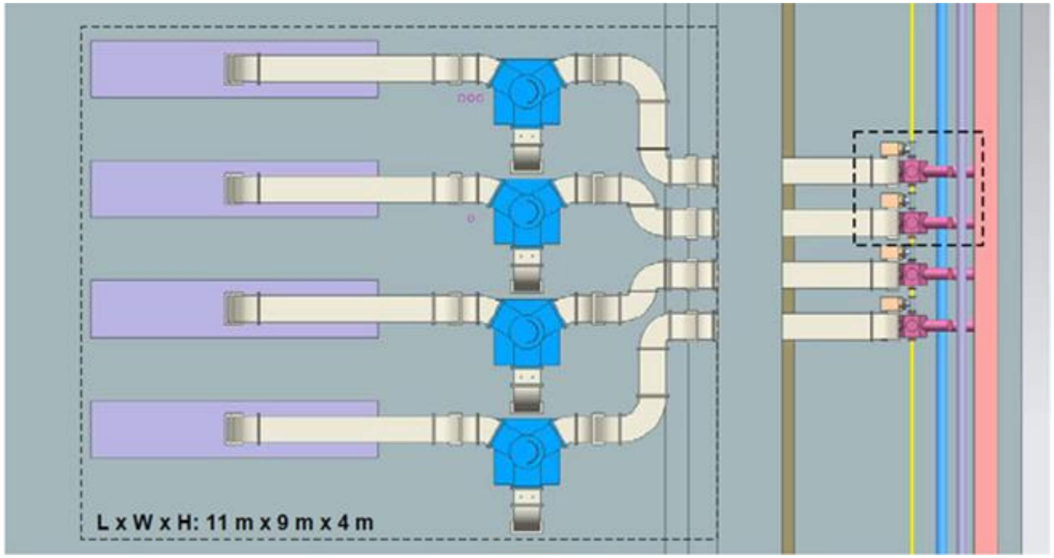
Requirements for the worst case Trip compensation on the 500MHz rf-system	
V_C	533kV
P_W	42kW
P_B	60kW
Power from the SSA	107kW

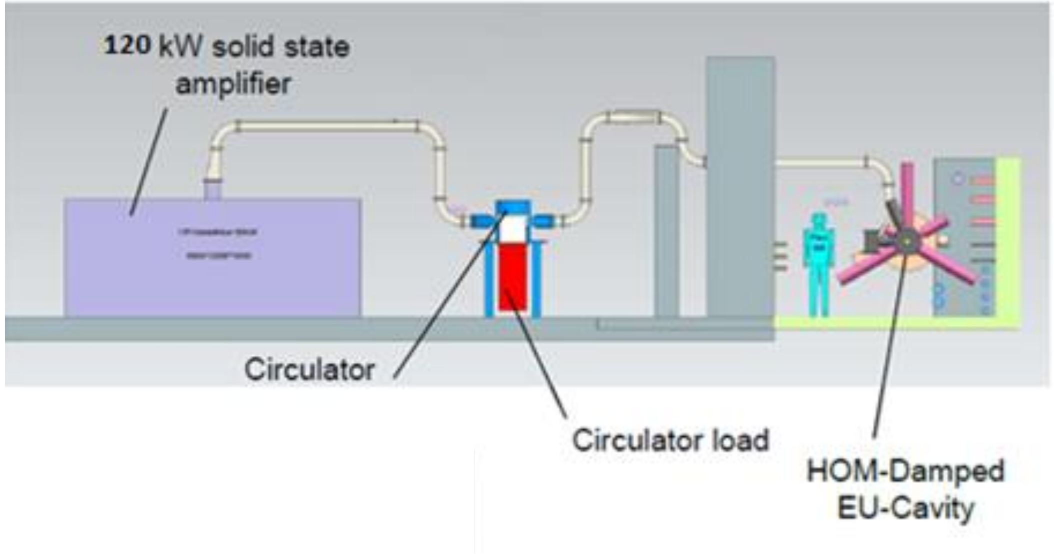


How To Arrange Six Independent Groups In A Building

The RF-building was shifted from the South to the North







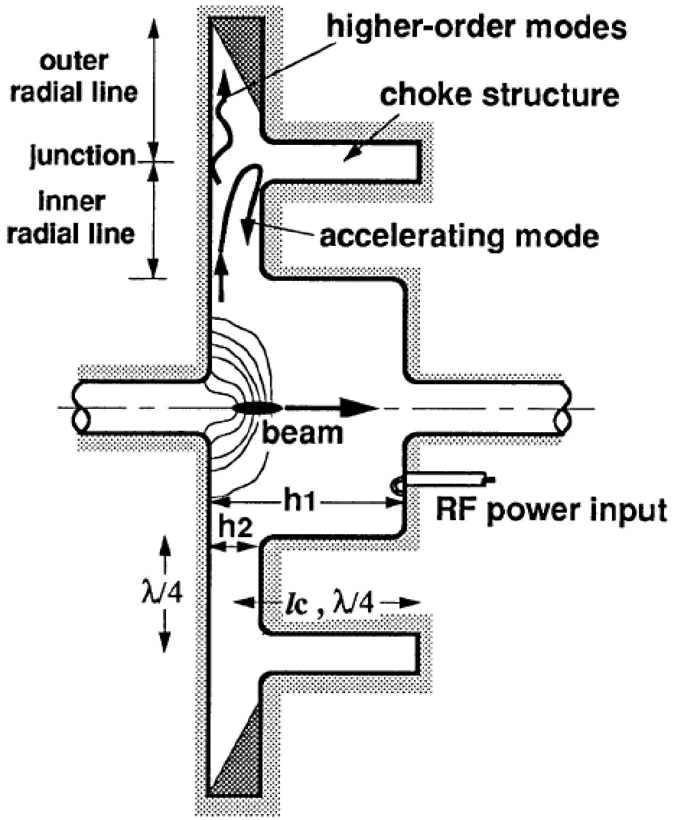
An Alternative Cavity Design For The High Harmonics Cavity

Motivation for an alternative

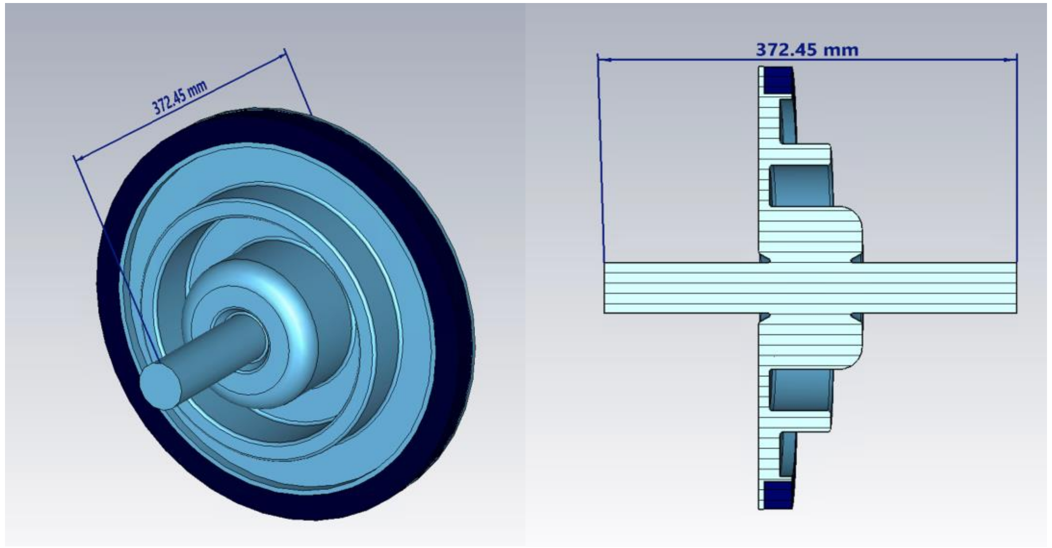
- HH-rf-system needs a frequency of 1.5GHz, the 500MHz BESSY-HOM-damped cavity was downsized by a factor of 3. Fabrication is extremely expensive
- Simply downsizing is mechanically not an easy task. Cooling circuits of the cavity are a nightmare.
- longitudinal loss factor $k_l \sim f$
- transversal loss factor $k_\perp \sim f^2$
- increased HOM damping capabilities for the HH-rf-system would be desirable!
- Driven by the arguments we have started to look for other cavity concepts which have to fulfil the following requirements:

1) The concept has to be mechanically very simple and cost saving.
2) The HOM-damping capabilities must be more effective compared to the downsized BESSY-cavity.

1. Alternative: The „Choke Mode Cavity“ from T. Shintake

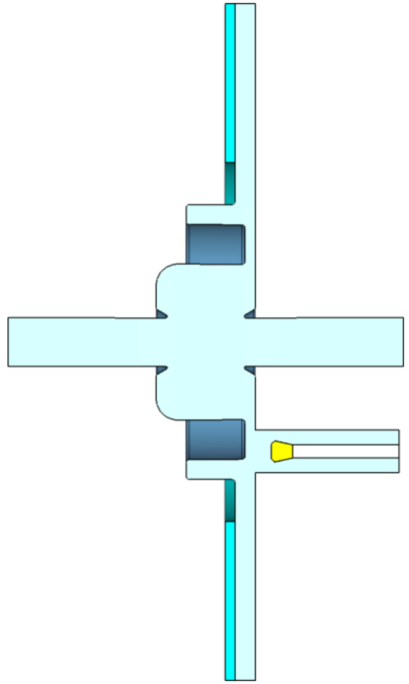


A cut view through the “choke mode cavity”. The cavity is azimuthally symmetric. (Picture: T. Shintake [1])



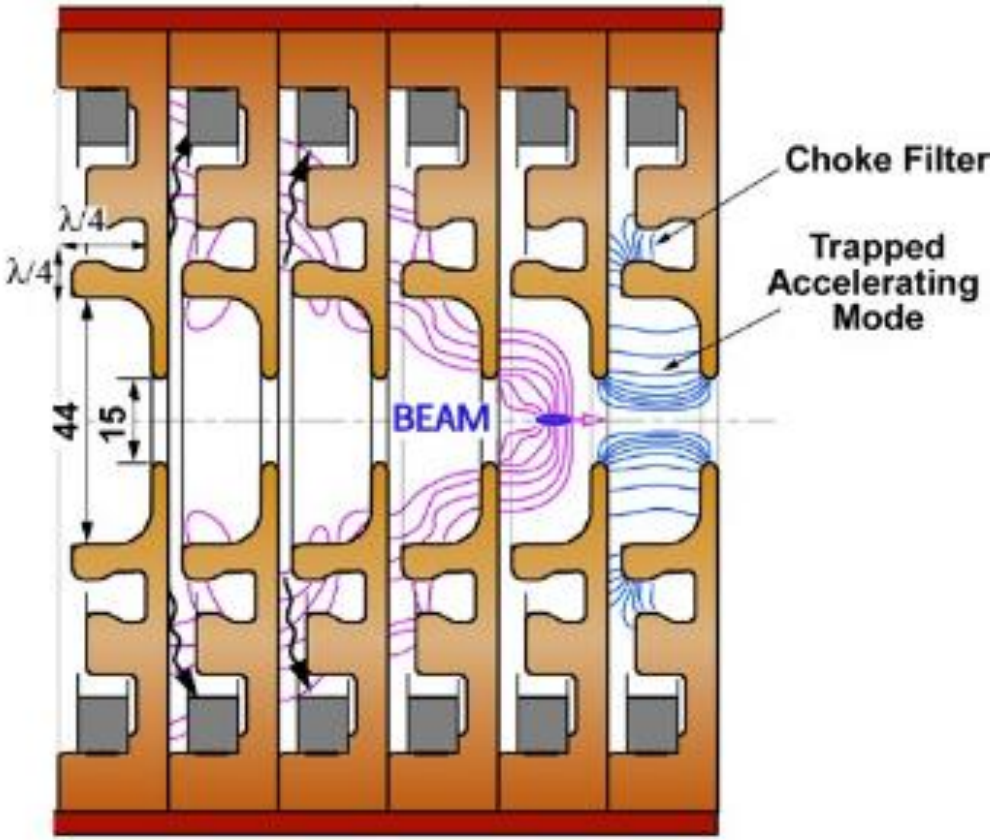
Our final design of the “choke mode cavity” with a ring shaped HOM-absorber made of silicon carbide (ring in dark blue) (Picture: S. Karau (DESY MHF)).

frequency	f_0	1,5GHz
shunt impedance (CST)	R_S	1,7 MΩ
unloaded quality factor	Q_0	19.000
	R_S/Q_0	88Ω



High power input coupler was chosen to be a capacitive coupler. Coupling factor β is adjustable from 0 up to 5 (XFEL-coupler) (Picture: S. Karau (DESY MHF))

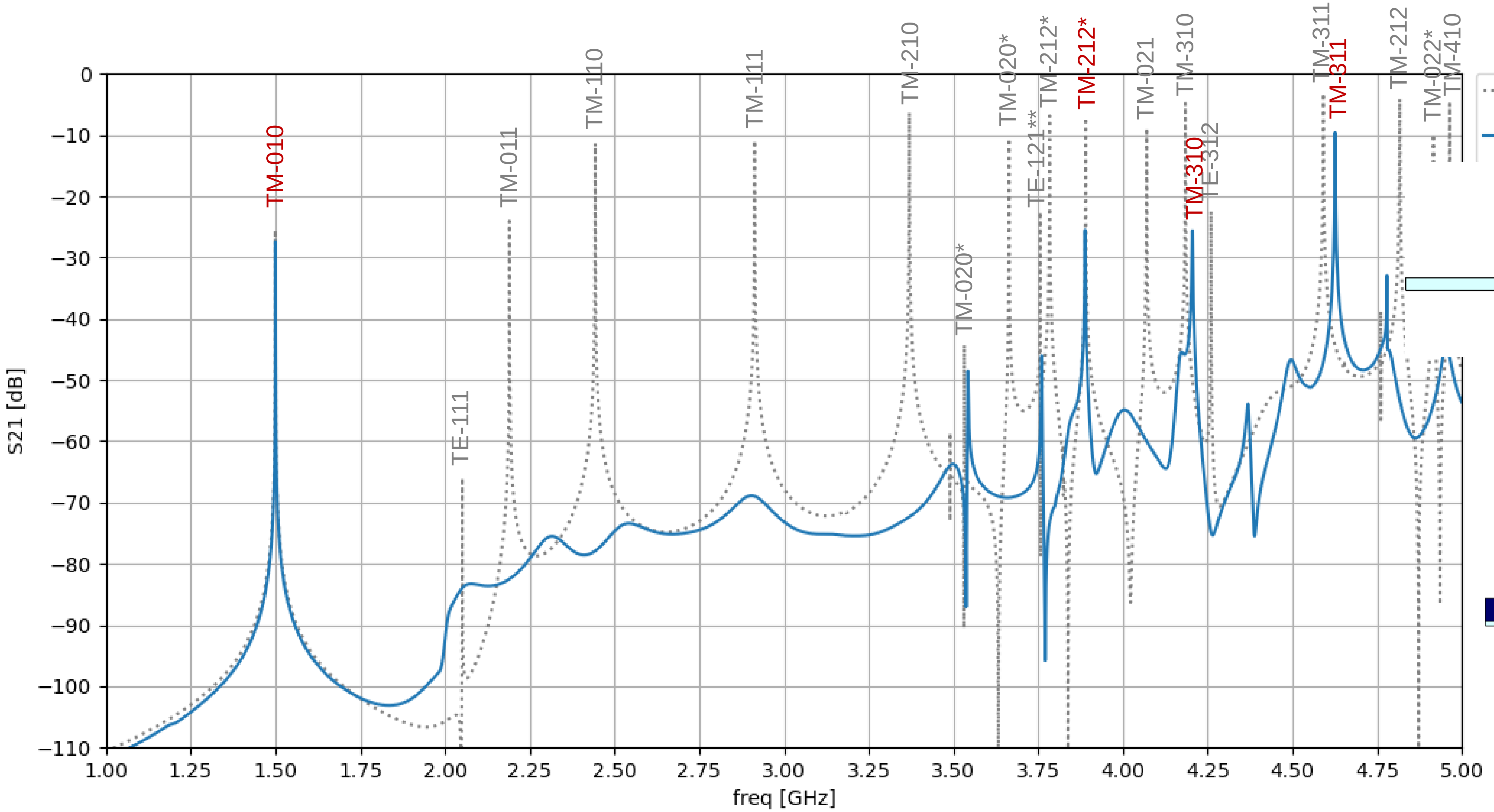
An application of the choke mode cavity

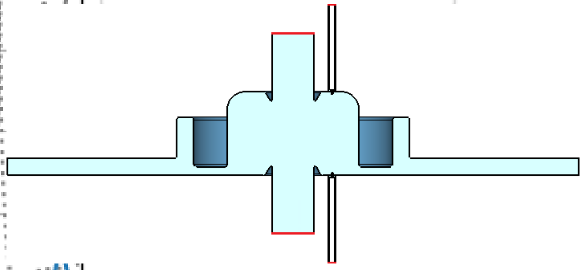


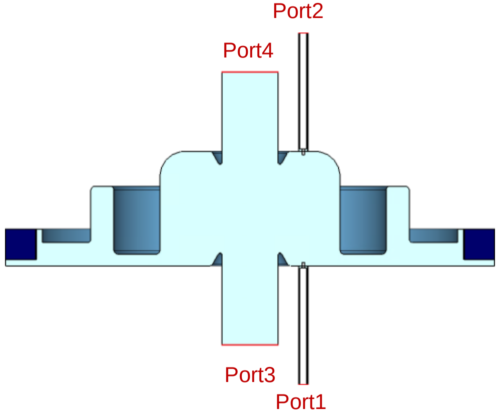
The choke mode cavity in a LINAC application. The individual choke mode disks are stacked to form a LINAC. This is a C-band LINAC for a compact X-ray free electron laser facility. The HOM-damper-material is a simple ring made of Siliconcarbide

Picture: T. Iganaki, C. Kondo, H. Maesaka, T. Ohshima, Y. Otake, T. Sakurai, K. Shirasawa and T. Shintake: “High-gradient C-band linac for a compact x-ray free-electron laser facility”, Physical Review special topics-Accelerators and Beams, 17, 080702 (2014)

HOM-Damping Capabilities Of The Choke Mode Cavity

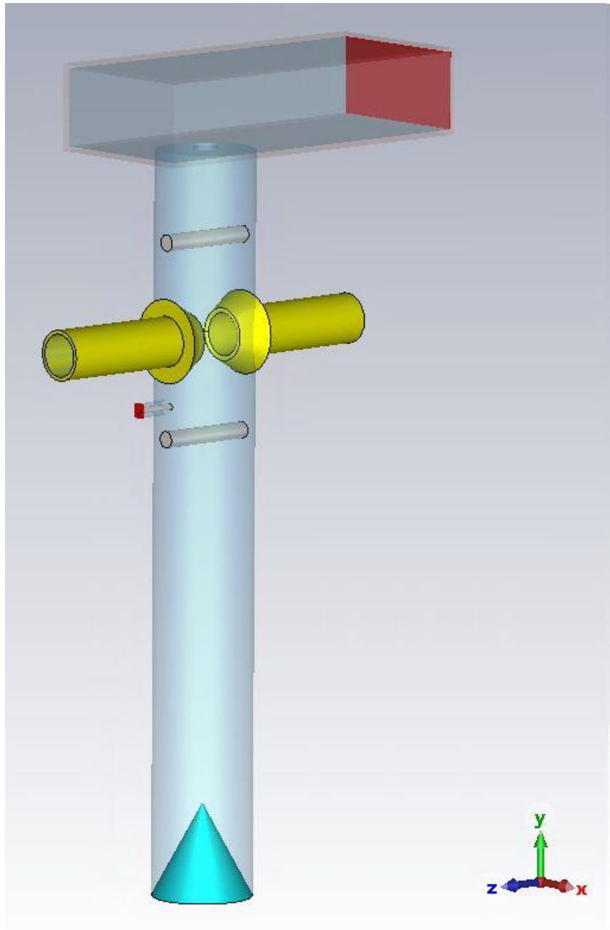


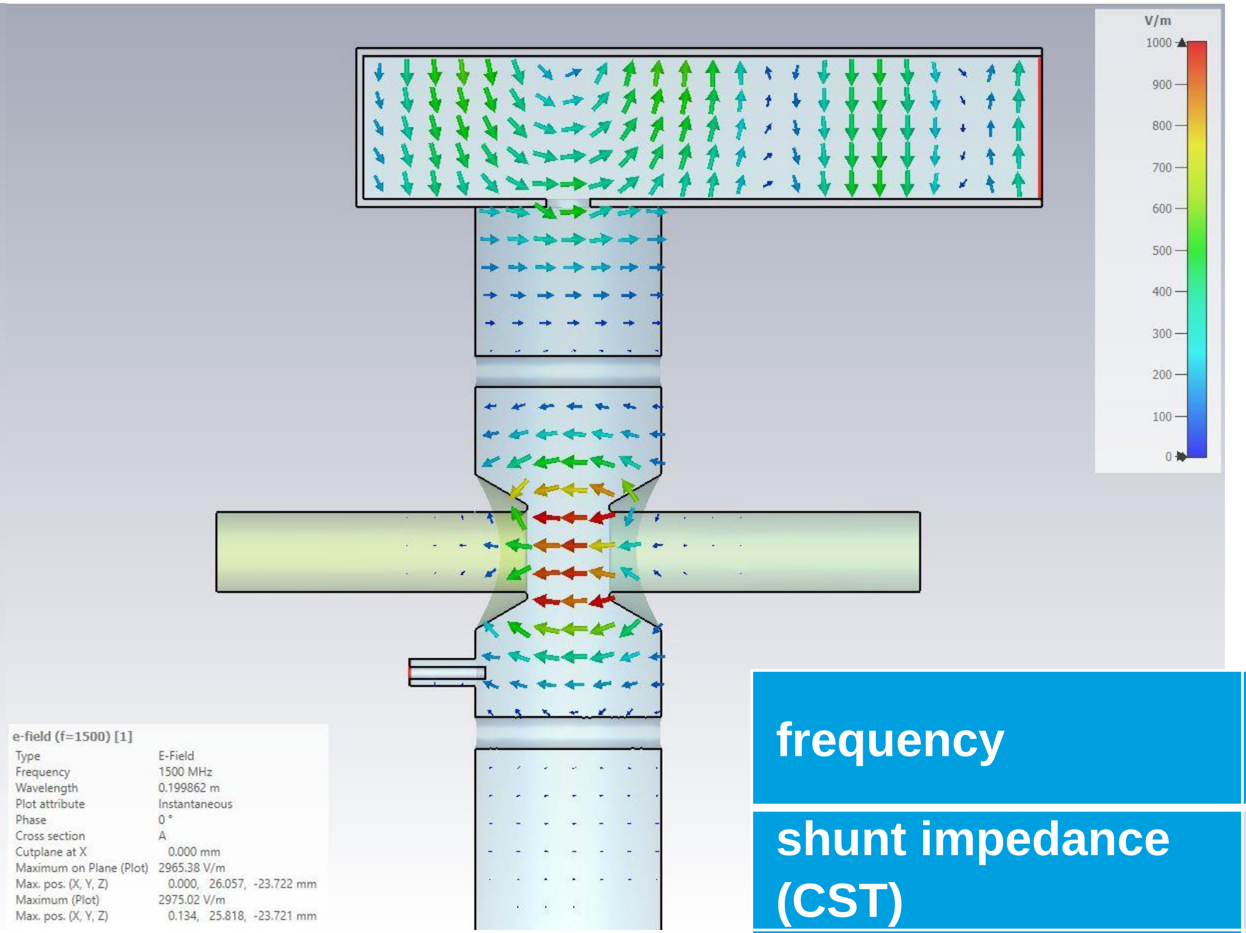




The pictures are provided with kind permission of Simon Karau (DESY MHF)

2. Alternative: The „Herminghaus" Single Mode Structure





frequency	f_0	**1,5GHz**
shunt impedance (CST)	R_S	1,4 MΩ
unloaded quality factor	Q_0	16.100
	R_S/Q_0	87Ω

The pictures are provided with kind permission of Kathrin Cottel (DESY MHF)

Summary

- A concept for the PETRA IV RF system was presented:
  1) Fundamental RF: 24 x 500MHz HOM damped cavies plus 24 x 120kW SSA
  2) High Harmonics RF: 24 x 1,5GHz HOM damped cavities plus 24 x 10kW SSA

- The main focus of the concept is: redundancy and reliability

- Hence the large numbers of cavities with relatively moderate voltages

- There is currently a discussion at DESY ongoing: How much redundancy and reliability we should allow ourselves to have.

- Are there cavity alternatives which are simple to manufacture and with enhanced HOM damping capabilities?

- Currently we are investigating two single mode cavities: The Choke Mode Cavity and the Herminhaus Cavity.

Thank you for lending your ears.

- Additions or questions?

Contact

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