The RF of PETRA IV.

Stefan Wilke, DESY MHF-e
25th ESLS rf meeting Hamburg, 8th/9th nov 2021

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

We miss him so much.

Michael Ebert (+ 2021-03-06)

The RF of PETRA IV.

Overview

- Lots of activities at DESY

- Short view on the present RF-system at P3

- CDR P4

- main parameter of the machine
- RF parameter
- active 3rd harmonic RF

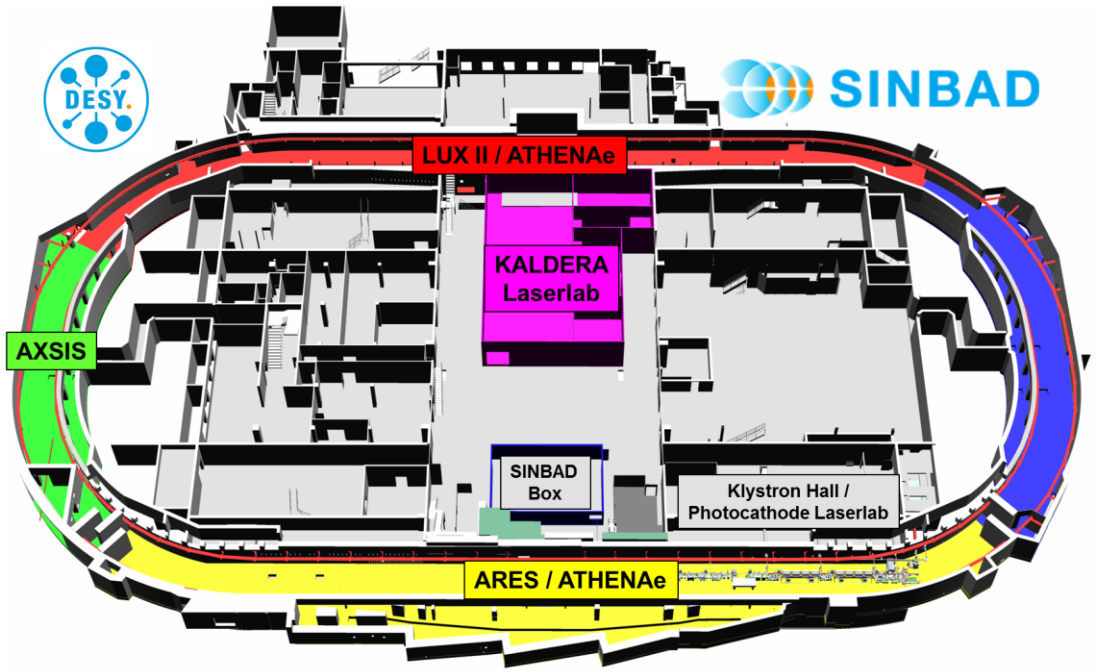
- RF at DESY IV

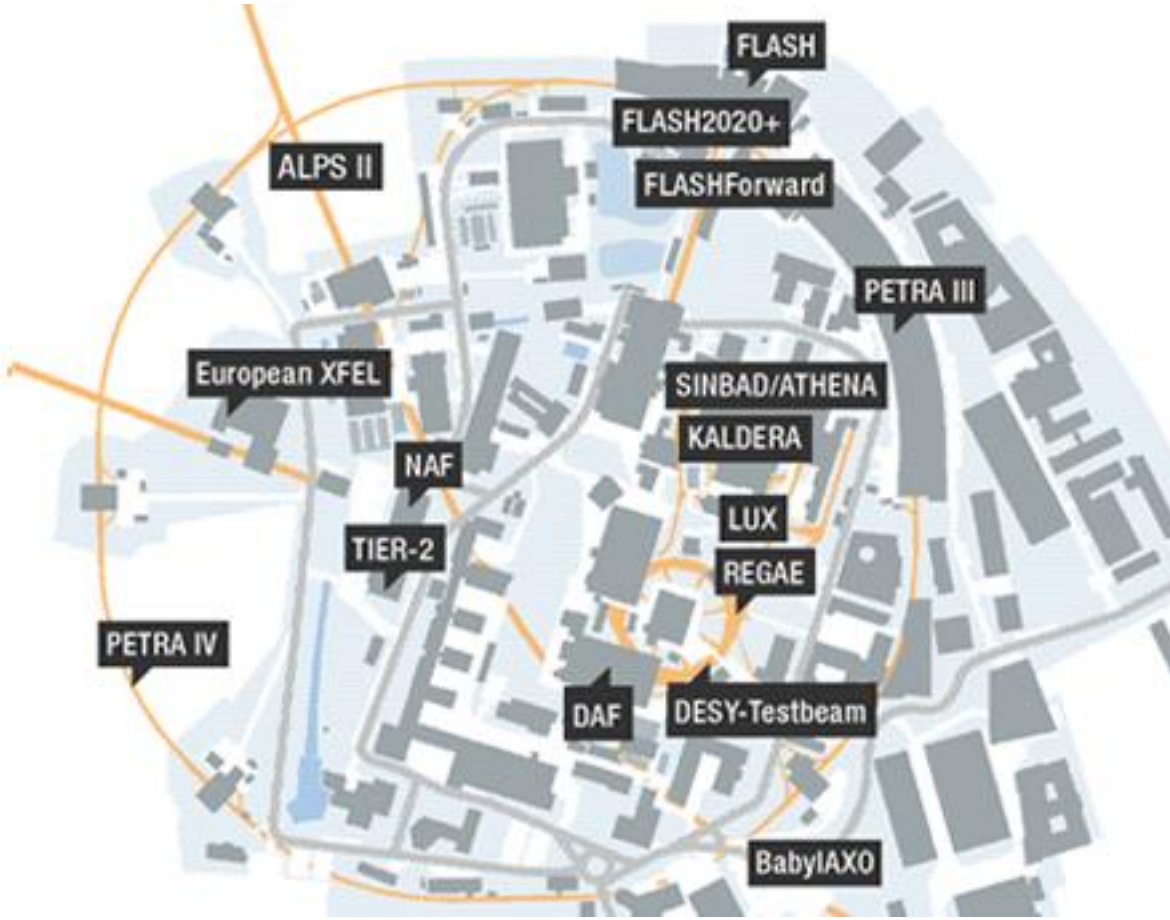
- Tests of P4 RF components in P3

Lots of activities at DESY.

Some major competitions to PETRA IV

- 24/7 operating of XFEL, PETRA3, DESY2, FLASH
- FLASH2020+: new undulators, new rf-modules
  Operation from 2025
- KALDERA: A high-power laser for plasma accelerators. Operation from 2026





The existing RF system. One half of the current PETRA III rf system

PETRA III

RF parameters

frequency:
499.664 MHz

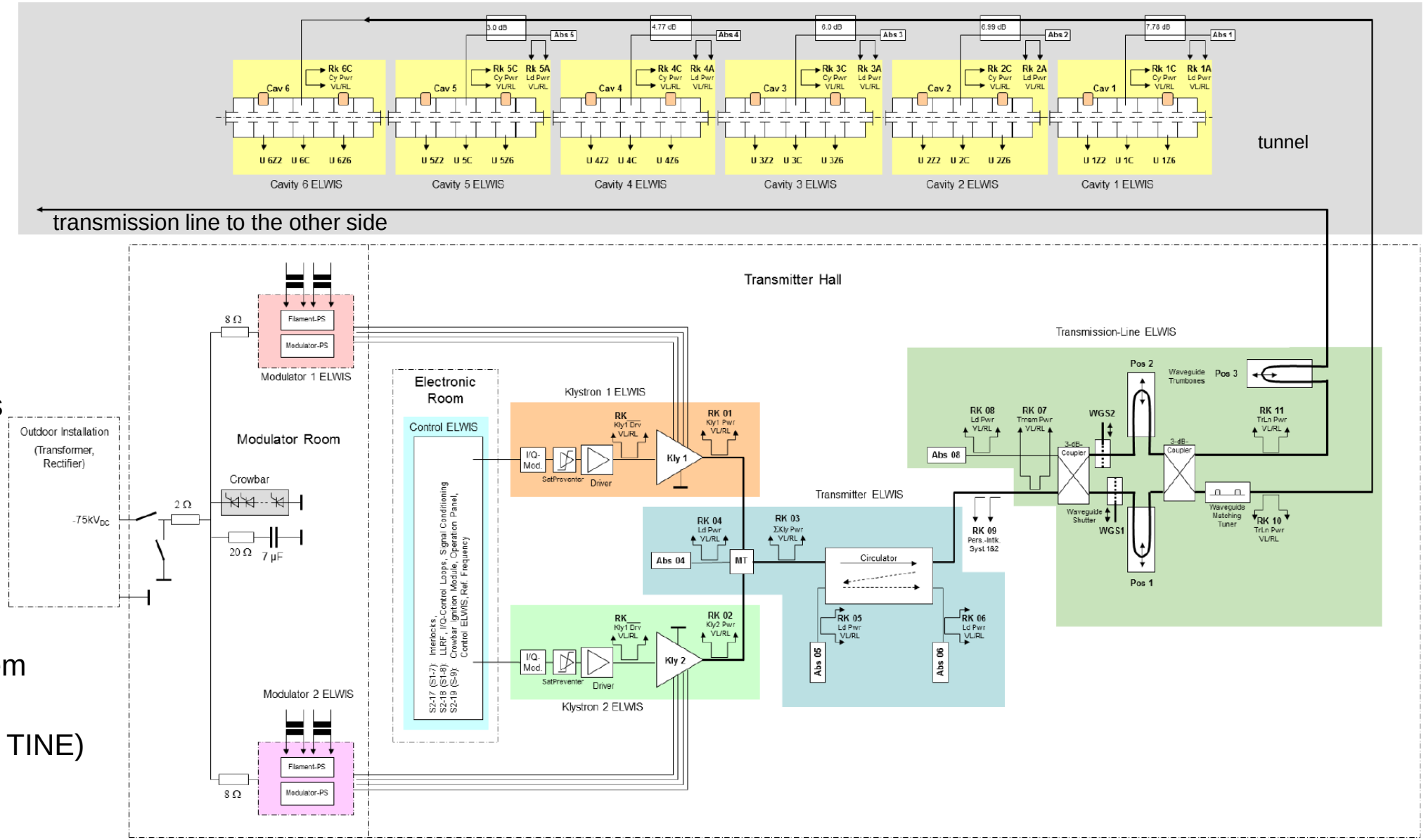
harmonic number:
3840

20 MV cavity voltage

12 × 7 cell nc cavities

RF power:
up to 4 × 800 kW
(2 Thales and
2 Philips klystrons)

ELWIS:
modular control system
based on PXI crates
(Windows, LabVIEW, TINE)

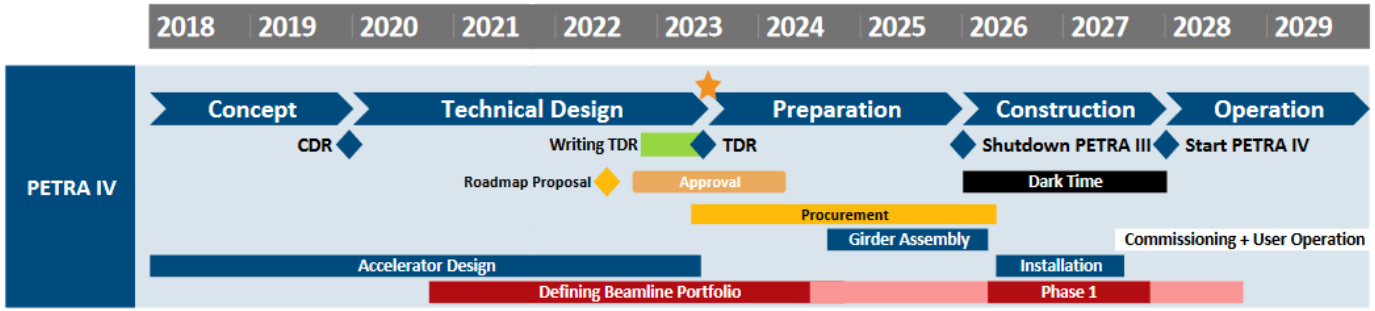


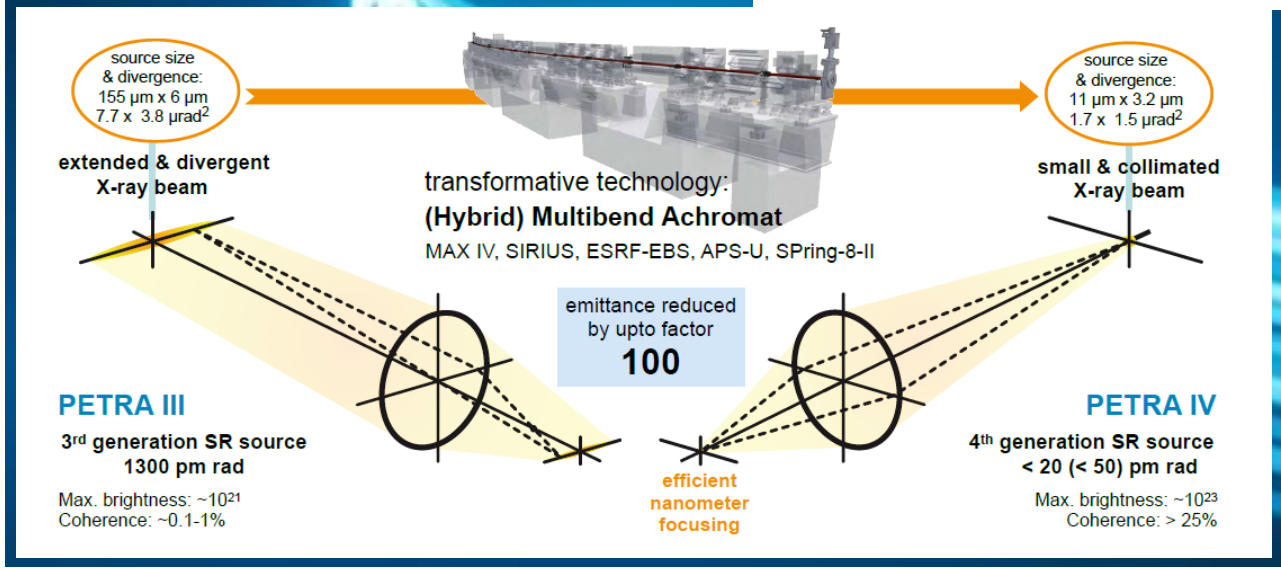
PETRA IV.

The future from 2028

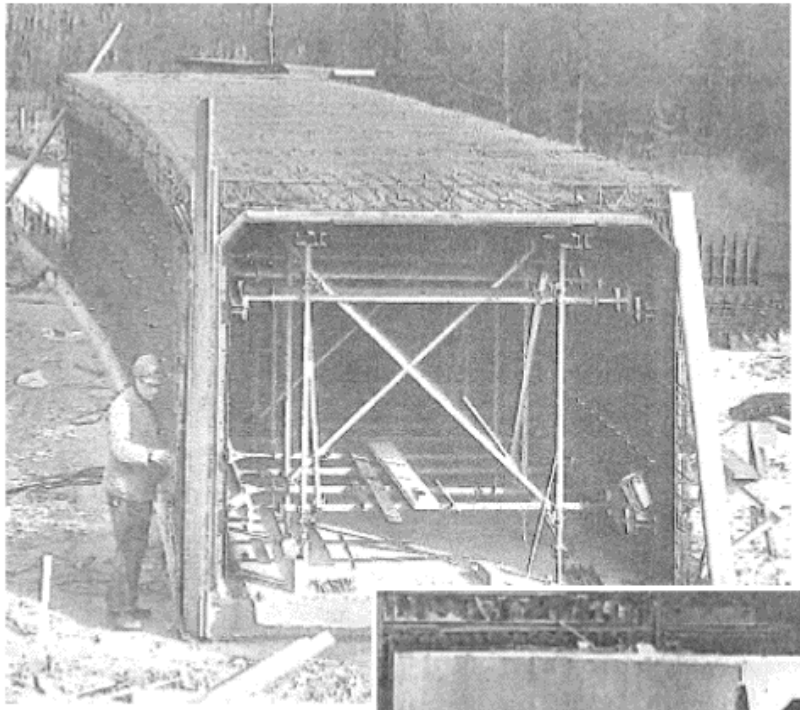
Timeline of the PETRA IV Project

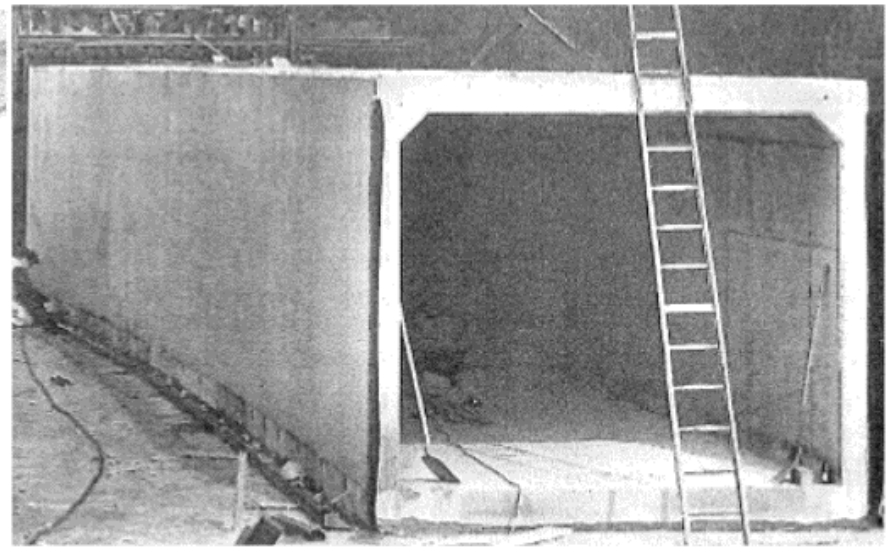
Overview





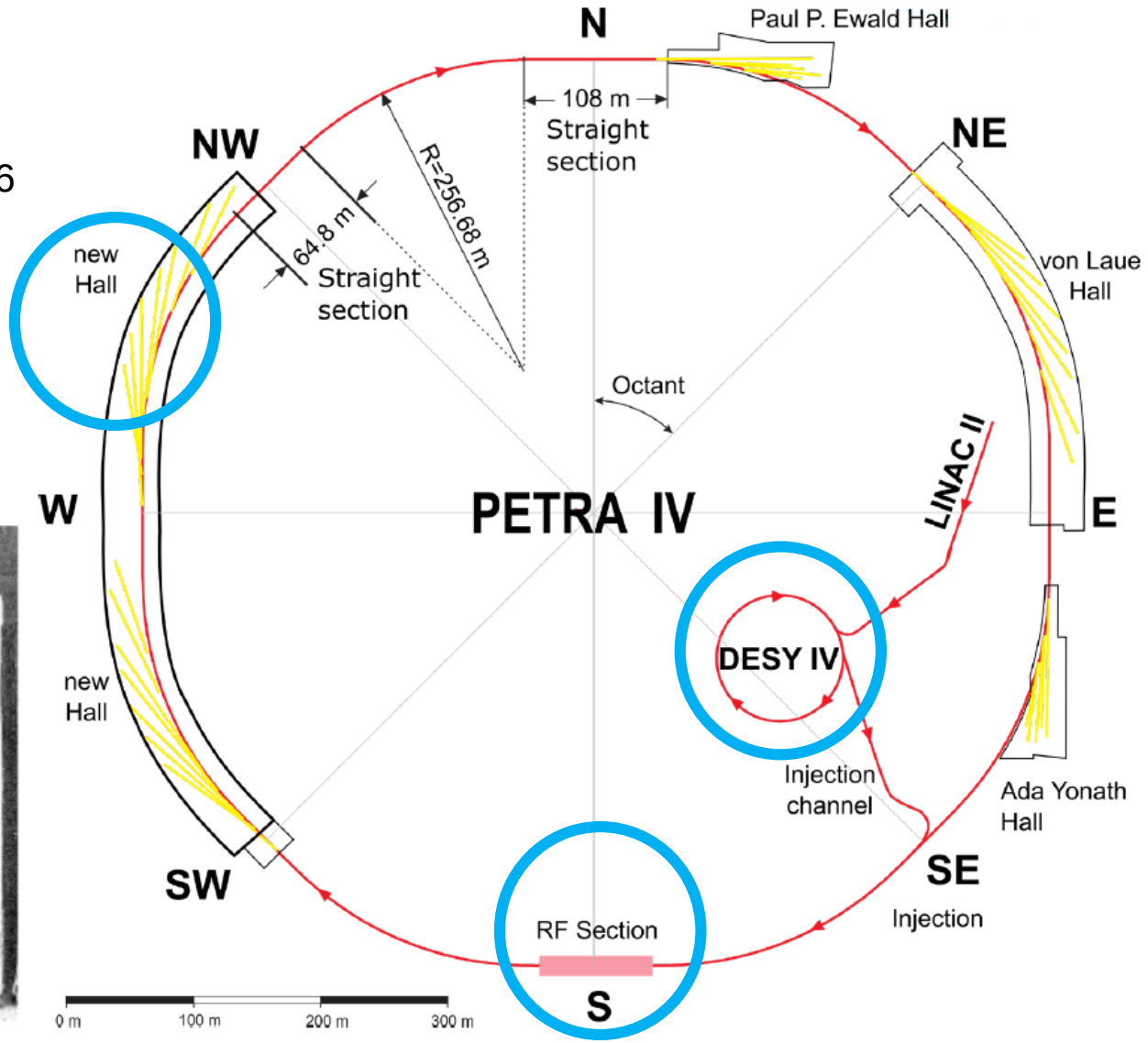
PETRA III vs PETRA IV.





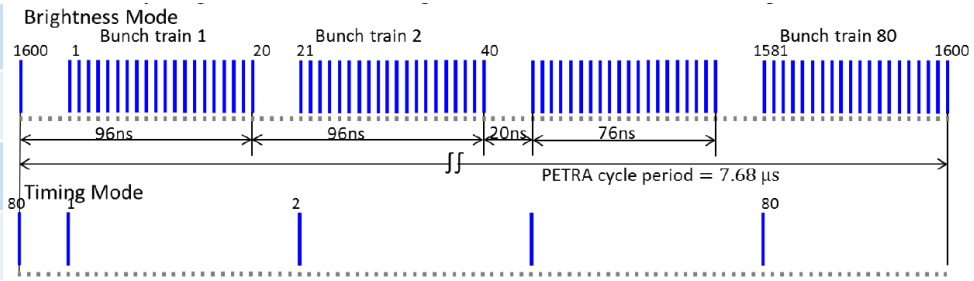
mostly reuse of the
old tunnel segments
of PETRA 1 from 1976

Thanks to
Michael Bieler



Some main parameters in comparison.

	PETRA III	PETRA IV (CDR)
Energy / GeV	6.08	6.08
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, 120	80, 200
Bunch current / mA	2.5, 0.25	1, 0.125
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 + 2.4
Synchrotron frequency / kHz	6	0.421
RF frequencies / MHz	499.6	499.6 + 1500
Harmonic number	3840	3840



PETRA IV RF.

fundamental

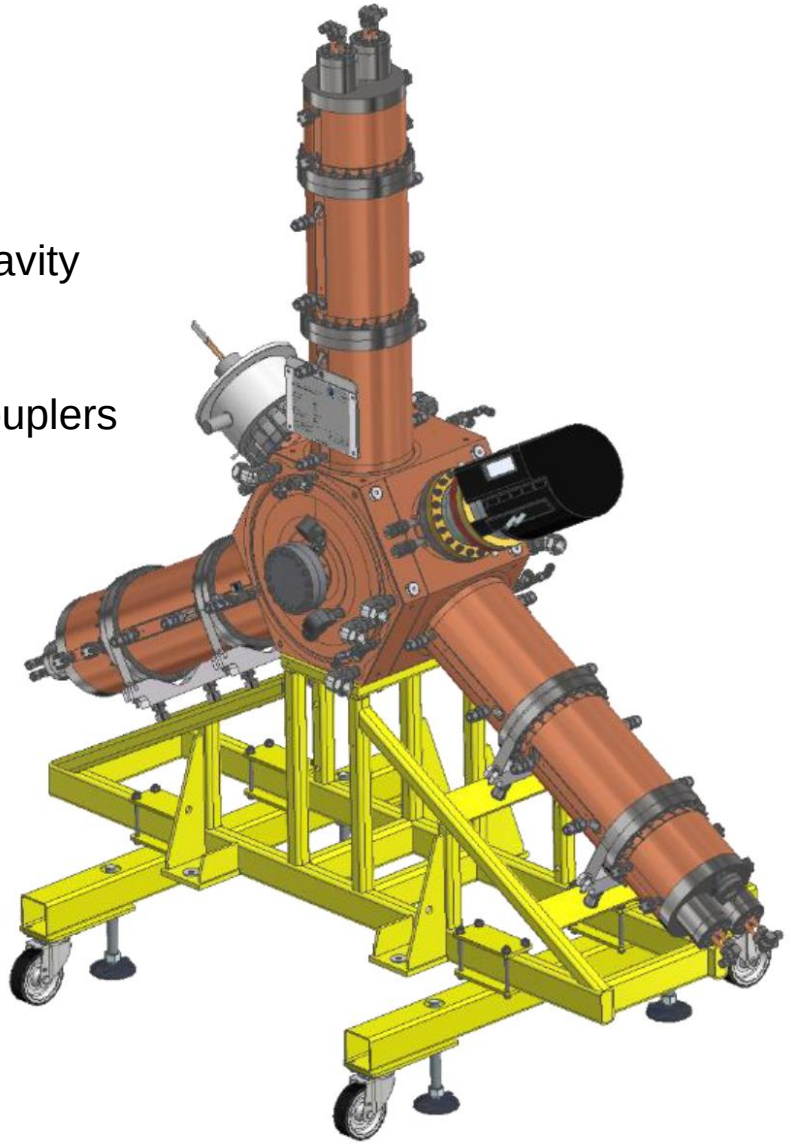
Parameters for the PETRA IV fundamental RF system:

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	
Quality factor (unloaded)	29600	
Cavity coupling factor	3.0	
Shunt impedance $R_s=V^2/(2P)$	3.4 MΩ	
Loaded quality factor	7400	
Number of main RF cavities	24	⇦
Synchronous phase	30.2°	
Synchrotron frequency	421 Hz	
Total wall loss in cavities	392 kW	
Total beam loading power	800 kW	
Nominal transmitter power per RF station	110 kW	⇦
Beam tube aperture	74 mm	
Length of cavity (flange to flange)	500 mm	

500 MHz single cell nc cavity
HOM damped

reuse of plungers and couplers

see presentation
‚Plunger Refurbishment‘
(Nils-Oliver Fröhlich)



two frequencies.

lengthen the bunch with a second active RF-system

Bunch length: corrected: 23 ps (7 mm)
- without a 2nd RF-system: 5 ps (1.5 mm)
- with an additional RF-system (3rd harmonic): 65 ps (ca. 20 mm)
So the single bunch current could be increased

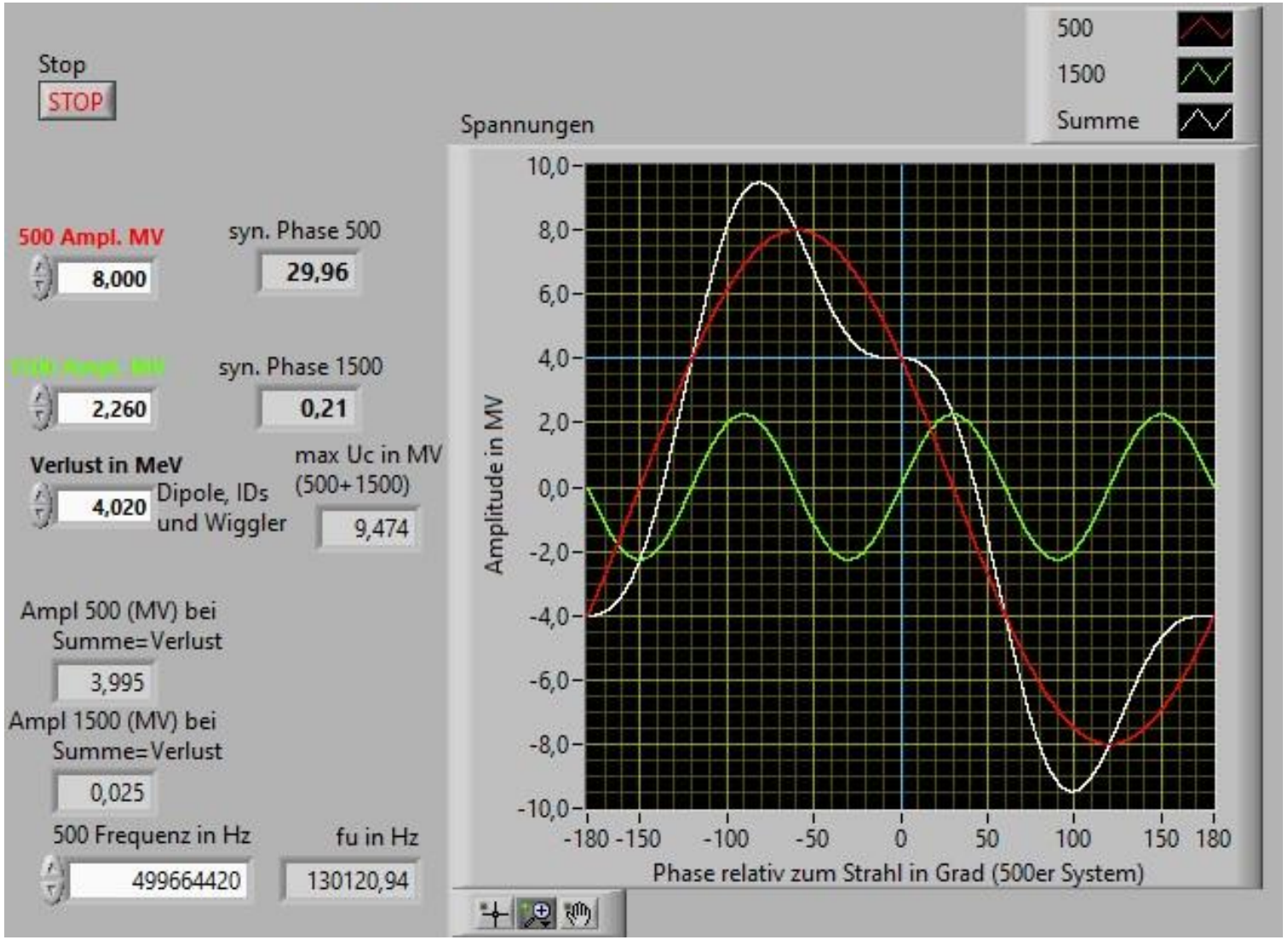
corrected: 60 ps (18 mm)

The required harmonic RF voltage for a flat potential at the bunch transition is

$$V_{HHC,\,opt.} = Vr_f \sqrt{\frac{1}{n^2} - \frac{1}{n^2 - 1} * \left(\frac{U_0}{qe\ Vrf}\right)^2}$$

n: order of the harmonic (PETRA IV: 3)
U_0: energy loss per turn (4.0 MeV)
V_{rf}: voltage of the fundamental RF system (8.0 MV)
q_e: elementary charge ($1.602 * 10^{-19}$ C)

This gives an optimum value for the harmonic voltage of $V_{HHC,opt.}$ = 2.26 MV.
With some safety margin, the system is designed for V_{HHC} = 2.4 MV.



PETRA IV RF.

third-harmonic

Parameters for the PETRA IV third-harmonic RF system:

3rd harmonic RF frequency	1498.995 MHz	
Total RF voltage	2.4 MV	⇦
RF voltage per cavity	100 kV	⇦
Cavity wall loss	3.3 kW	
Quality factor (unloaded)	17000	
Loaded quality factor	2700	
Total wall loss in cavities	71 kW	
Cavity coupling factor	5.3	
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	

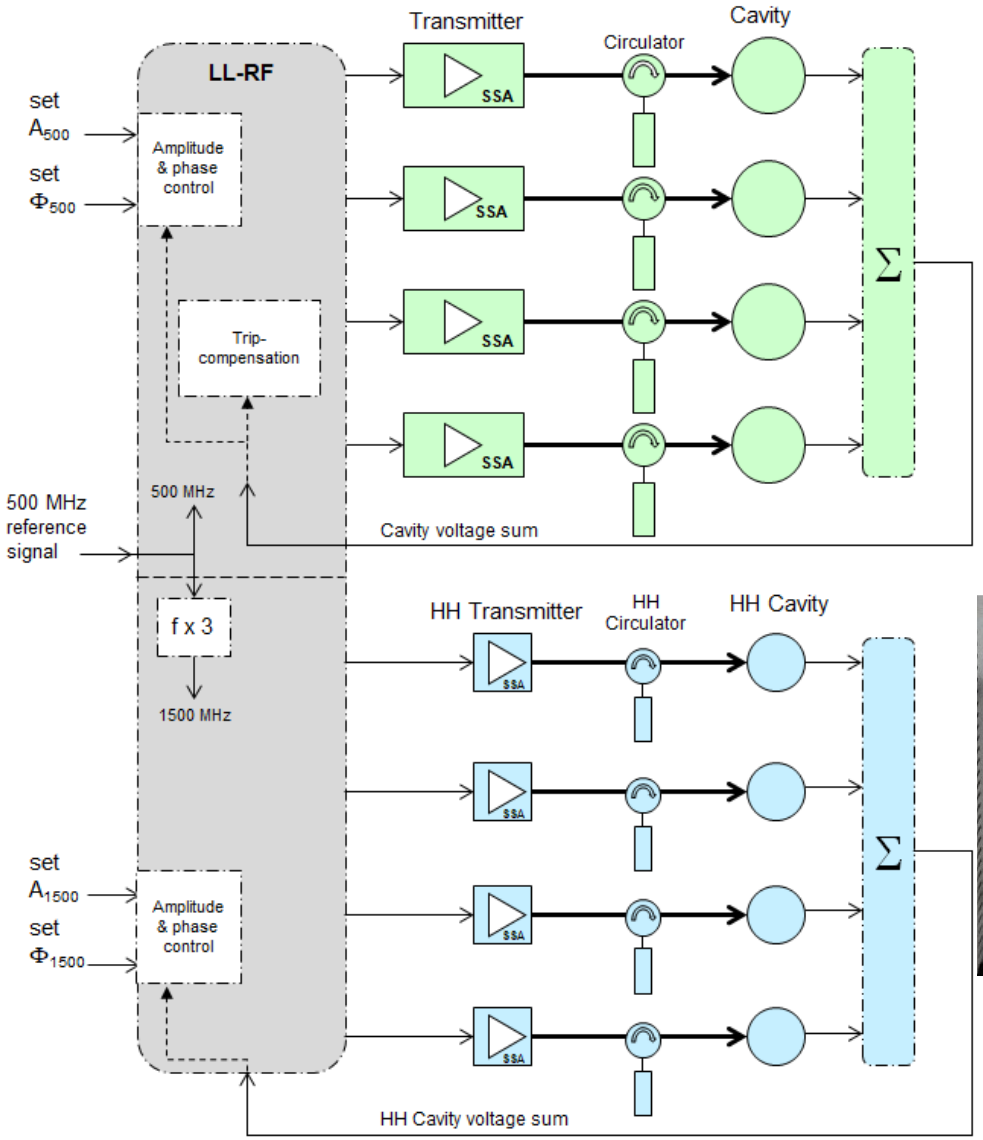
Collaboration ALBA/HZB/DESY
Development of a 3rd harmonic HOM damped cavity
1/3 scaled and optimize from 500 MHz
see presentation tomorrow (Jesús Ocampo)

In addition there are some ideas of alternatives
see presentation of Peter Hülsmann

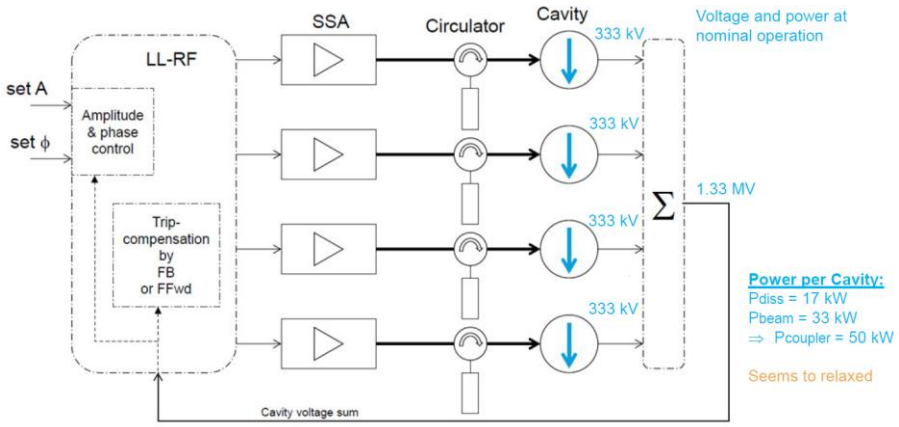
RF System Design.

One of six RF systems

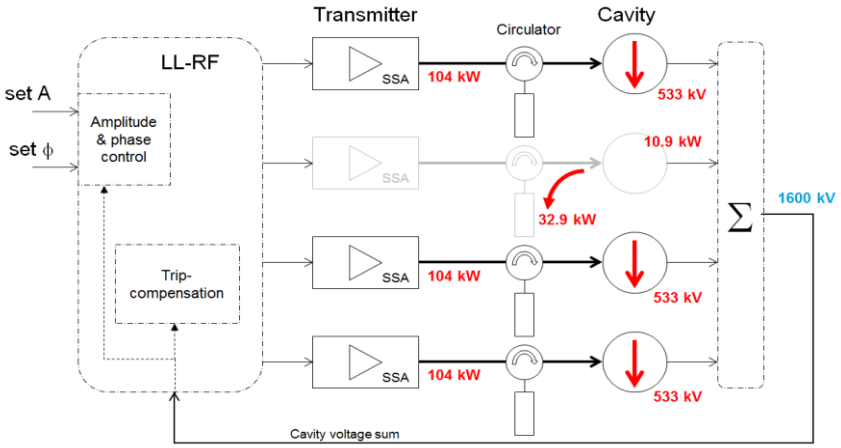
Each of the 24 cavities is powered by its own Solid State Amplifier (SSA) and we want to control them in 6 groups of 4 pairs of cavity/SSA.



normal operation:



A worst case scenario (200 mA beam current):
Only 5 of the 6 systems (each a group of 4 SSA/Cav) running and in addition a failure of one sub-system (SSA/Cav).
This brings the cavities to their limit.

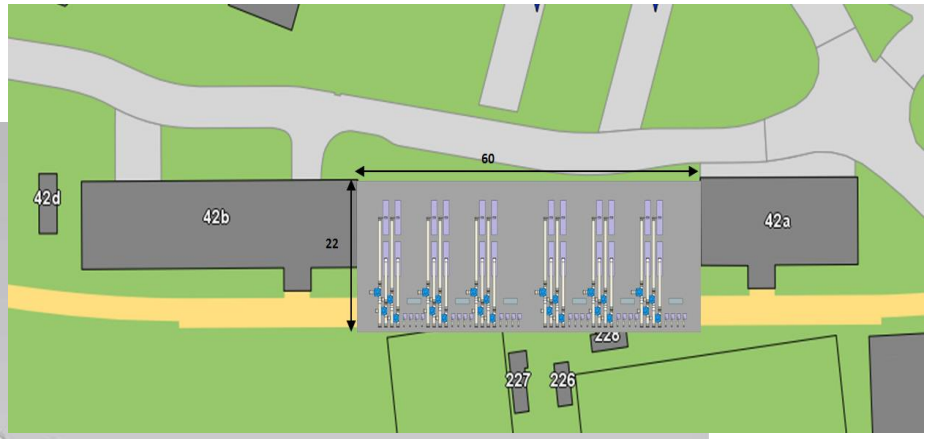


µTCA crate

More details see presentations tomorrow (Frank Maschewski, Arvid Eislage)

RF implementation in PETRA IV.

new tunnel segment and new hall: 24 + 24 cavities and 24 + 24 SSA



DESY IV.

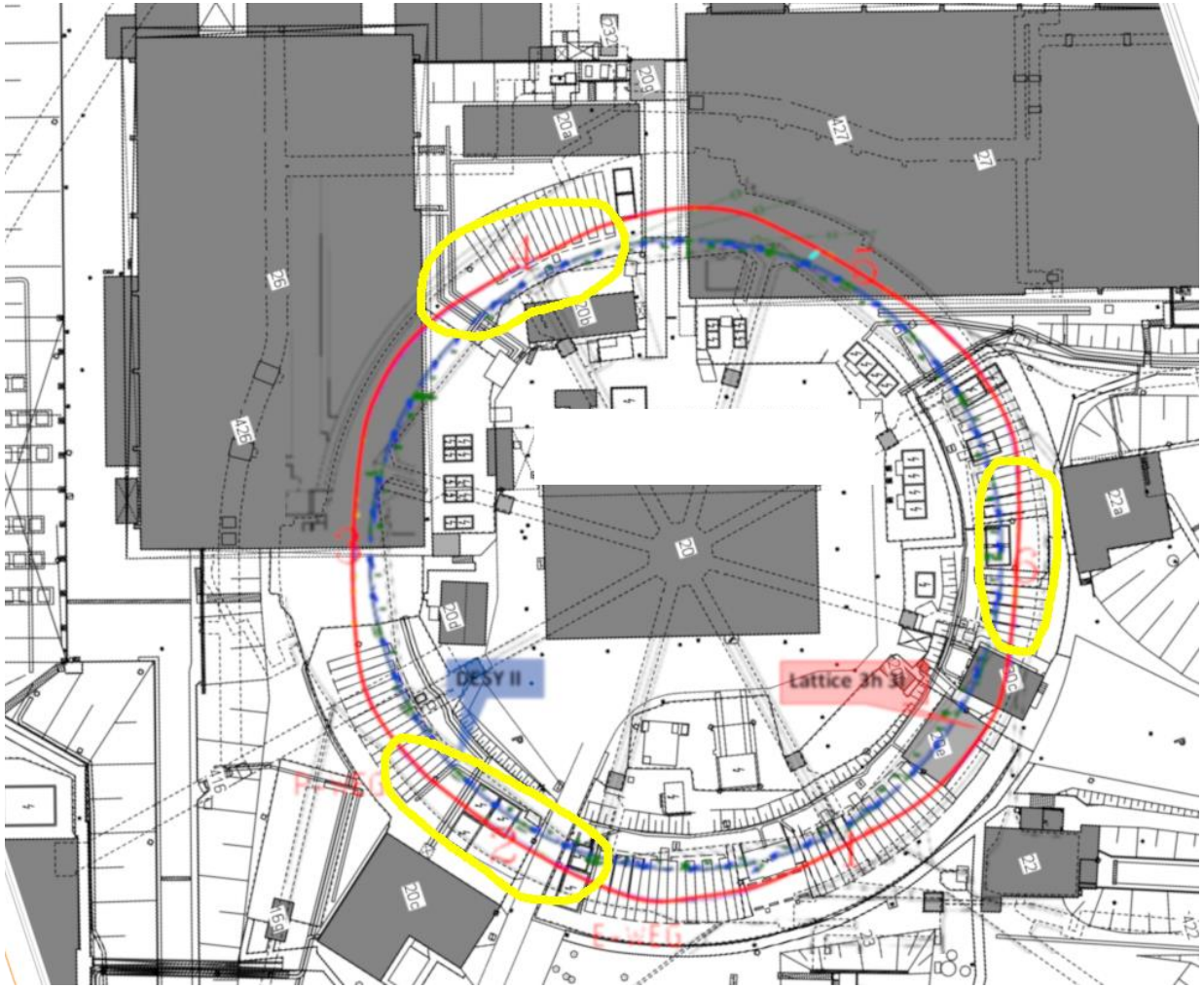
Booster parameters:
Circumference: 316.8 m
Harmonic number: 528
Repetition rate: 2 Hz to 5 Hz
Momentum compaction: 3.30 × 10−3

Beam energy at	6 GeV	700 MeV
Energy loss per turn	4.04 MeV	0.748 keV

A new machine (DESY IV) in the same tunnel as the existing and remaining DESY II.

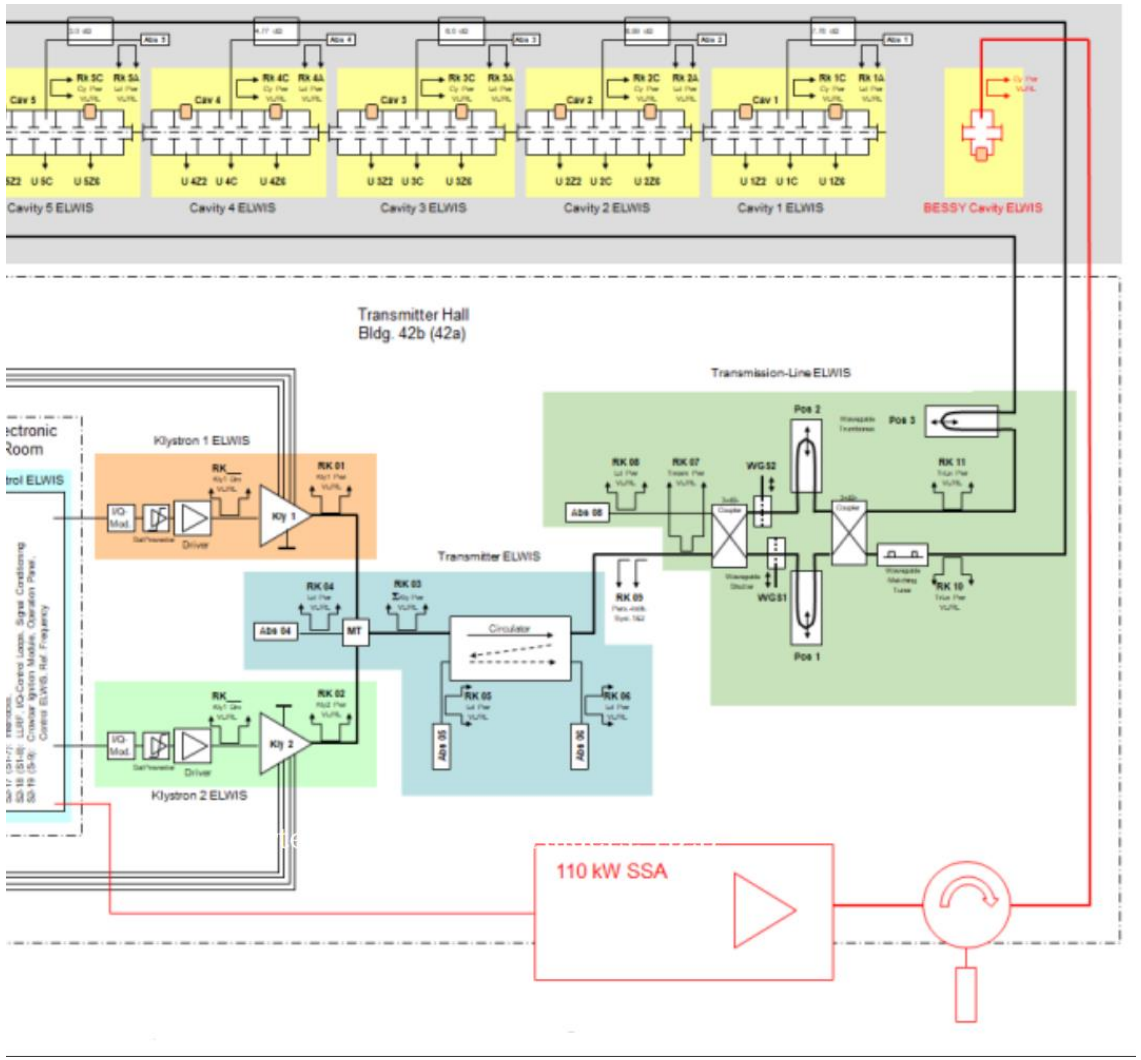
RF:
9 (grouped in 3 locations) 5-cell 500 MHz nc cavities each powered by a SSAs

Frequency	499.65 MHz
Total RF voltage	12 MV
RF voltage per cavity	1.3 MV
Cavity wall loss	59 kW
Quality factor (unloaded)	29500
Cavity coupling factor	nyd
Shunt impedance $R_s=V^2/(2P)$	15 MΩ
Number of RF 5-cell cavities	9
Beam tube aperture	120 mm
Cavity length (flange to flange)	1800 mm

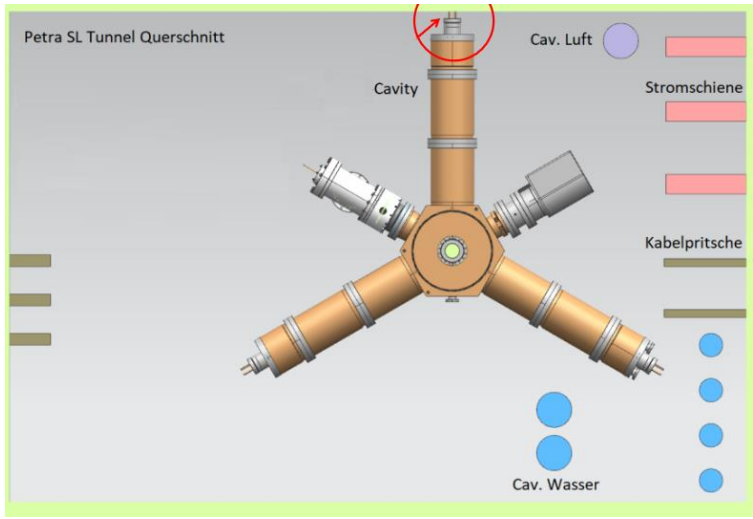


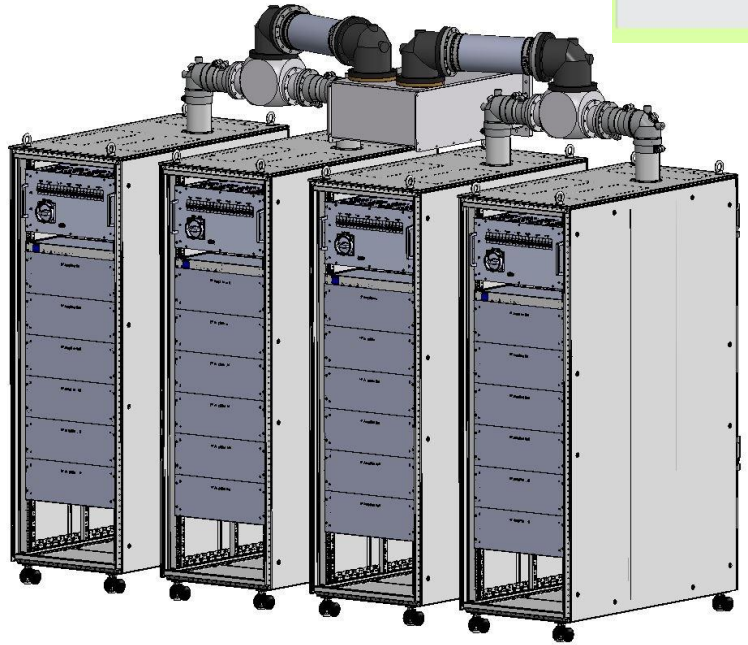
Tests of P4 RF components in P3.

One prototype SSA and one prototype HOM damped 500 MHz single cell cavity



Delivery SSA: July 2022
Delivery cavity: March 2022





Thank you for lending your ears.

Additions or questions?

Sailing vessel (four-masted barque) „Peking“ back in Hamburg 2020-09-07

Contact

DESY. Deutsches
Elektronen-Synchrotron

www.desy.de

Stefan Wilke
DESY, MHF-e
stefan.wilke@desy.de
049/40/8998-1836