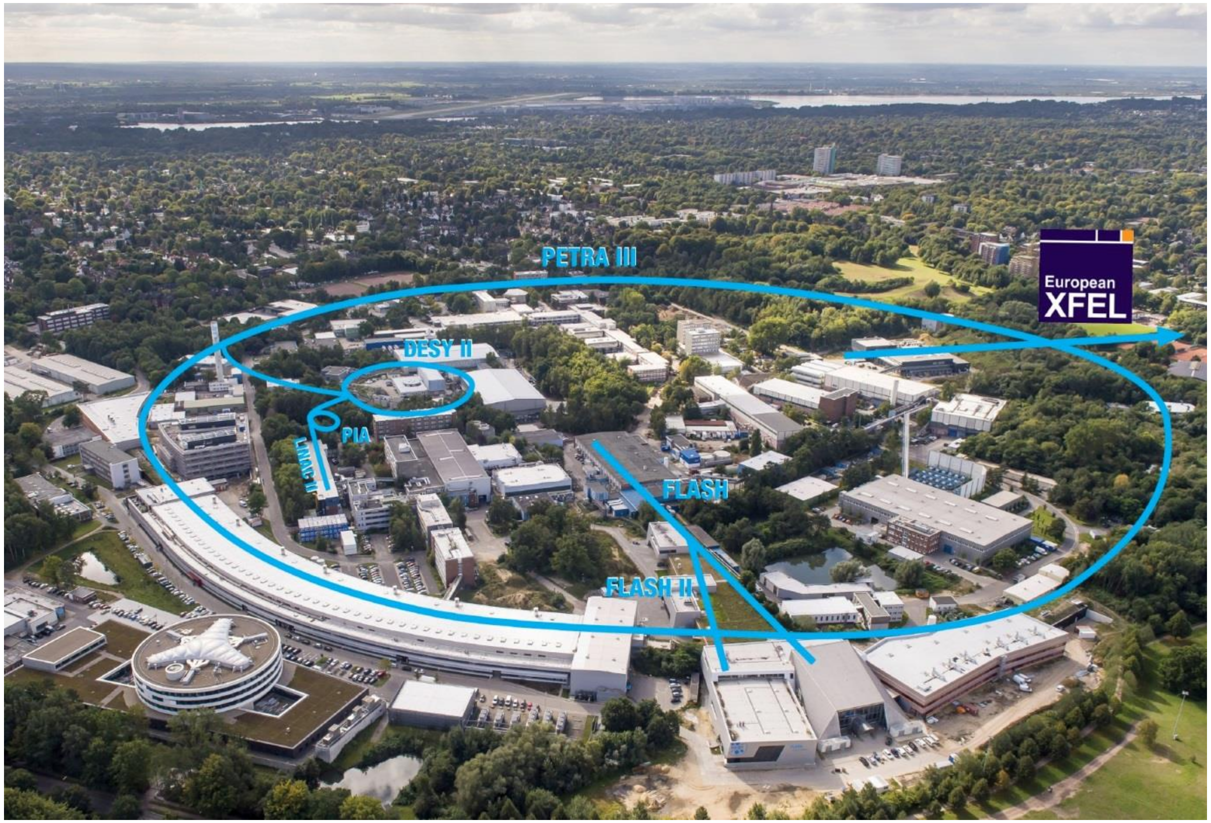
System design concept

❖Old and new machine
❖The Fundamental RF System
❖The Harmonic RF System

Google Streetview

PETRA III



Main parameters:

l = 2304 m

beam energy = 6.08 GeV

beam current: 100 mA (4.8 E12 e^-),

Top Up

emittance (hor.) = 1 nmrad

energy loss: ca. 5 MeV per turn
(ca. 65 % from damping wigglers)

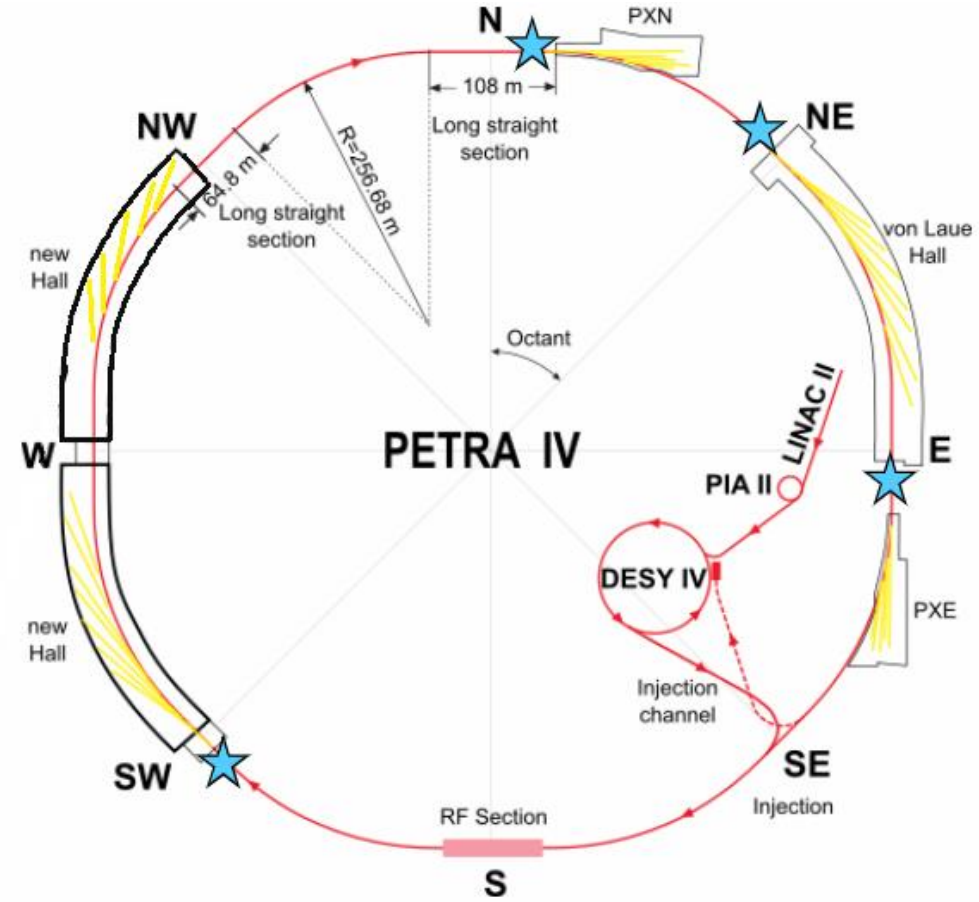
20 undulators

fill pattern:

- timing mode :
  - 40 bunches, 192 ns gap
  - 60 bunches, 128 ns gap
- continuous mode:
  - 480 bunches, 16 ns gap
  - 960 bunches, 8 ns gap

Plans for PETRA IV

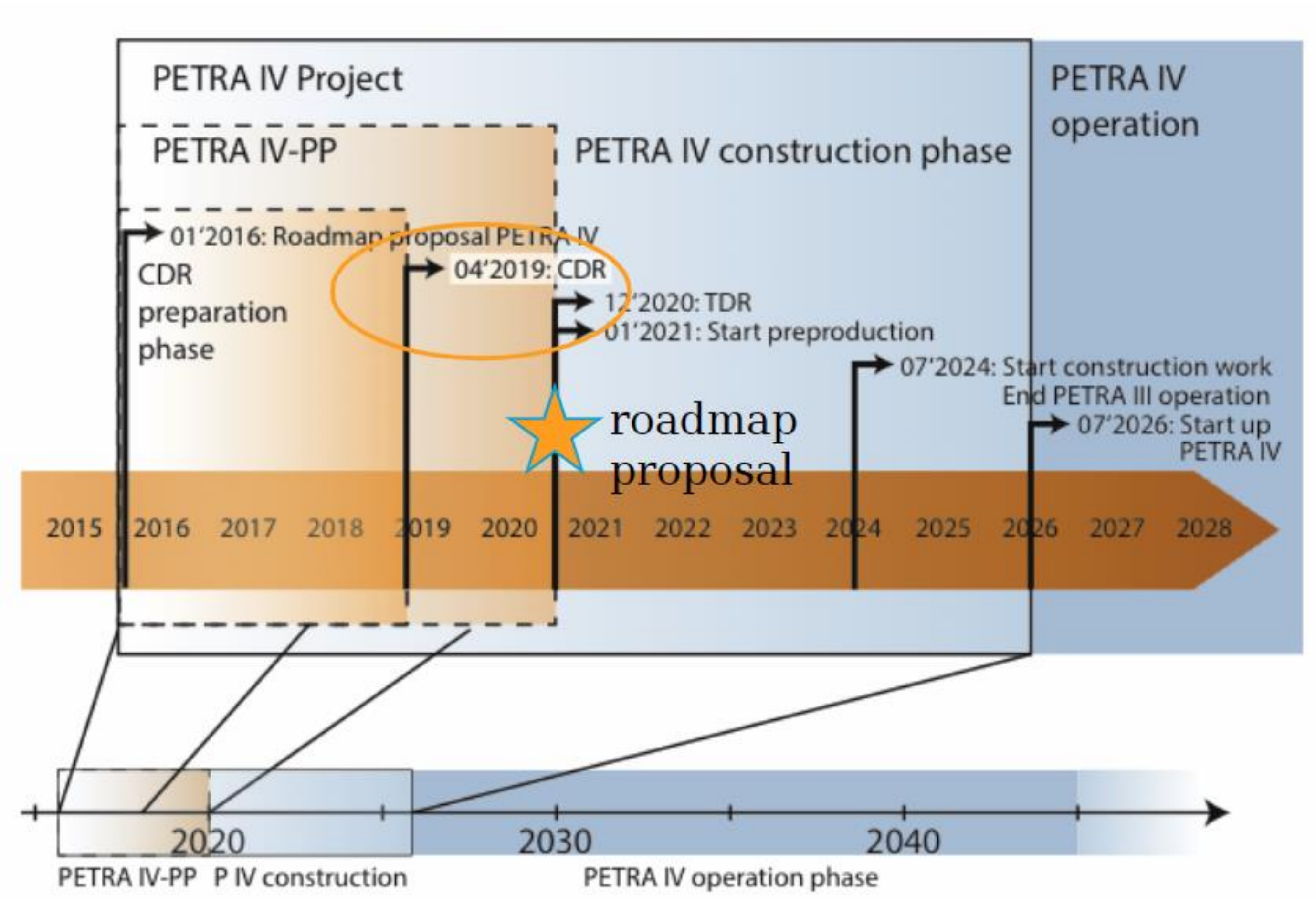
- 2 more experimental halls
- complete new pre-accelerator chain
- New injection scheme (no topup – but swap out part of beam and on axis injection



RF-Related PETRA IV Parameters

„H7BA“-Lattice with 26 IDs

		remarks
Energy	6.0 GeV	
RF frequency	500 MHz	
Circumference voltage	6 MV_{nom} (9 MV_{max})	Optimized for max. Touschek lifetime. Effect of 3. harm. syst. has not yet been considered
Beam current	200 mA	
Energy loss per turn	3.32 MeV	IDs included
Energy spread	$0.905 \cdot 10^{-3}$	w/o IBS
Momentum compaction factor	$1.43 \cdot 10^{-5}$	About 80 times smaller than PETRA III
Bunch length (1σ)	6.8 ps	
Long. damping time	16.2 ms	


PETRA IV Project
PETRA IV operation
PETRA IV-PP
PETRA IV construction phase
01'2016: Roadmap proposal PETRA IV
CDR
preparation
phase
04'2019: CDR
12'2020: TDR
01'2021: Start preproduction
07'2024: Start construction work
End PETRA III operation
07'2026: Start up
PETRA IV
roadmap
proposal
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2020
2030
2040
PETRA IV-PP
P IV construction
PETRA IV operation phase

rf- part of PETRA IV

Fundamental cavities

What options are there?

Continuing use of the existing 5- or 7-cell cavities

- ☺ Cheap
- ☺ High shunt-impedance
- ☺ Space-saving
- ☺ Decades of experience
- ☹ Unclear HOM spectrum with high impedances
- ☹ Hardly any possibilities for HOM damping

Developing a new cavity

- ☺ Cavity can be optimized for PETRA IV
- ☹ Need about 5 years from idea to the first prototype
- ☹ Childhood diseases are expected

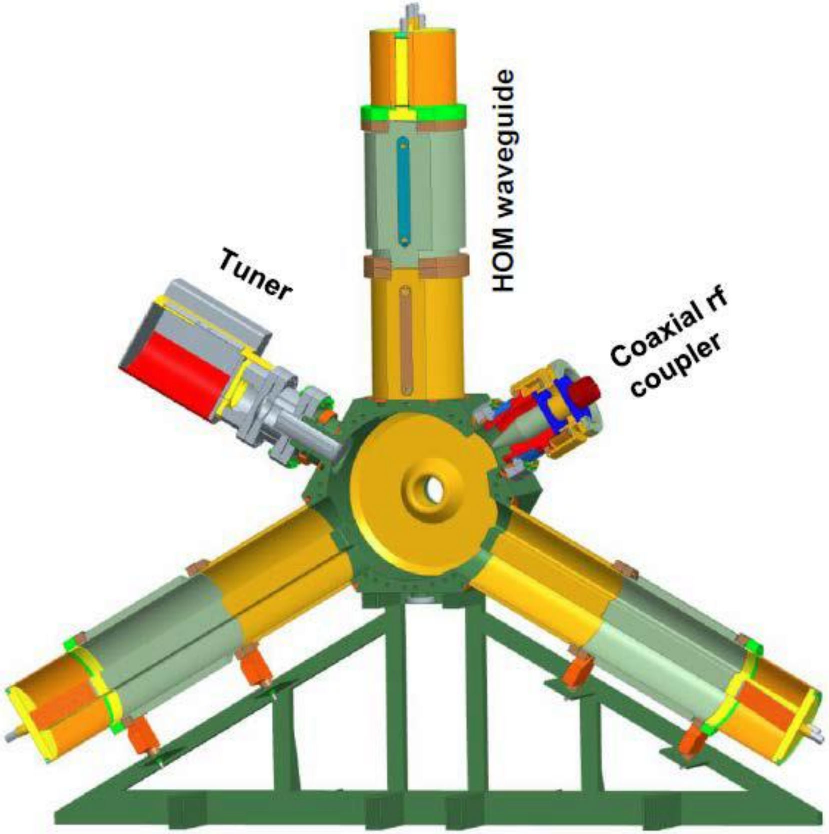
Using an existing and proved modern cavity design

- ☺ Operating experience available
- ☺ Childhood diseases are overcome
- ☹ Possibly not ideal for PETRA VI

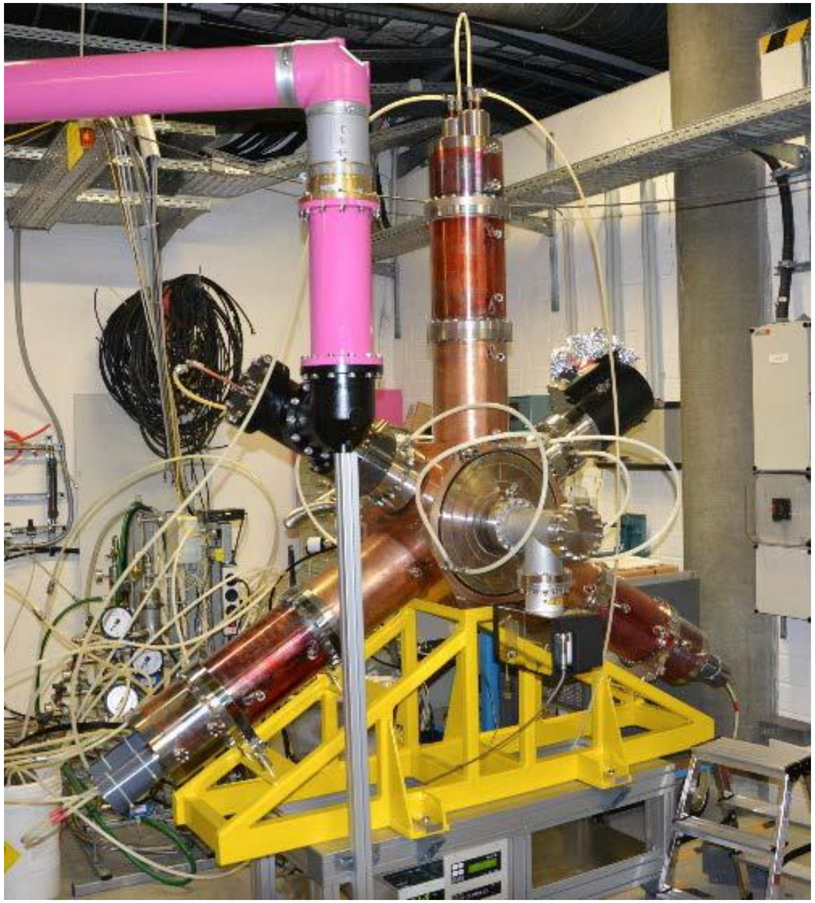
“*The MAC believes that it is mandatory to* ***replace the present RF cavities with HOM-damped*** *ones. Given the long lead time to develop such systems the MAC recommends to finalize a design based on* ***well-established solutions (e.g. BESSY cavities*** *or a rescaled version of the ESRF ones) and to start the construction of a prototype as soon as possible. The MAC would like to see a related fully resource-loaded plan.*”

HOM-Damped EU-Cavity

Existing and proved modern cavity design for synchrotron light sources



Courtesy of Ernst Weihreter, HZB



Courtesy of Wolfgang Anders, HZB

HOM-Damped EU-Cavity

Cavity Parameter	Design (2002)	Series (BESSY 2013)	
RF frequency	500 MHz	499.654 MHz	
Tuning range	not reported	2 MHz	
Shunt impedance	4 MΩ	3.4 MΩ (A10)	influenced by damper cut-off PETRA 7-cell cav.: 3.95 MΩ per cell
Cut-off frequency of HOM dampers	650 MHz	625 MHz	
Longitudinal HOM impedances	4 kΩ w/o E011	< 10.8 kΩ (*)	PETRA 7-cell cav.: 32 kΩ per cell
Transverse HOM impedances	< 170 kΩ/m	< 50 kΩ/m (*)	PETRA 7-cell cav.: 450 kΩ/m per cell
Quality factor	not reported	29.600 (A10)	
Maximum cavity voltage	895 kV	730 kV (A10)	
Maximum power dissipation	100 kW	78.4 kW (A10)	
Operational cavity voltage	-	500 kV (A17, B18)	**15 arcing trips per cavity and year (A17)** PETRA 7-cell cav.: 1.2 arcing trips per cavity and year (0.2 arcing trips per cell and year) @ 240 kV per cell
Insertion length	< 700 mm	500 mm	
Beam hole diameter	74 mm	74 mm	

(A10): ALBA, 2010
(A17): ALBA, 2017
(B18): BESSY 2018
(*): Data of the 2nd PT

HOM-Damped EU-Cavity

How many Cavities are required for PETRA IV?

ALBA:
<15> arcing trips per cavity and year

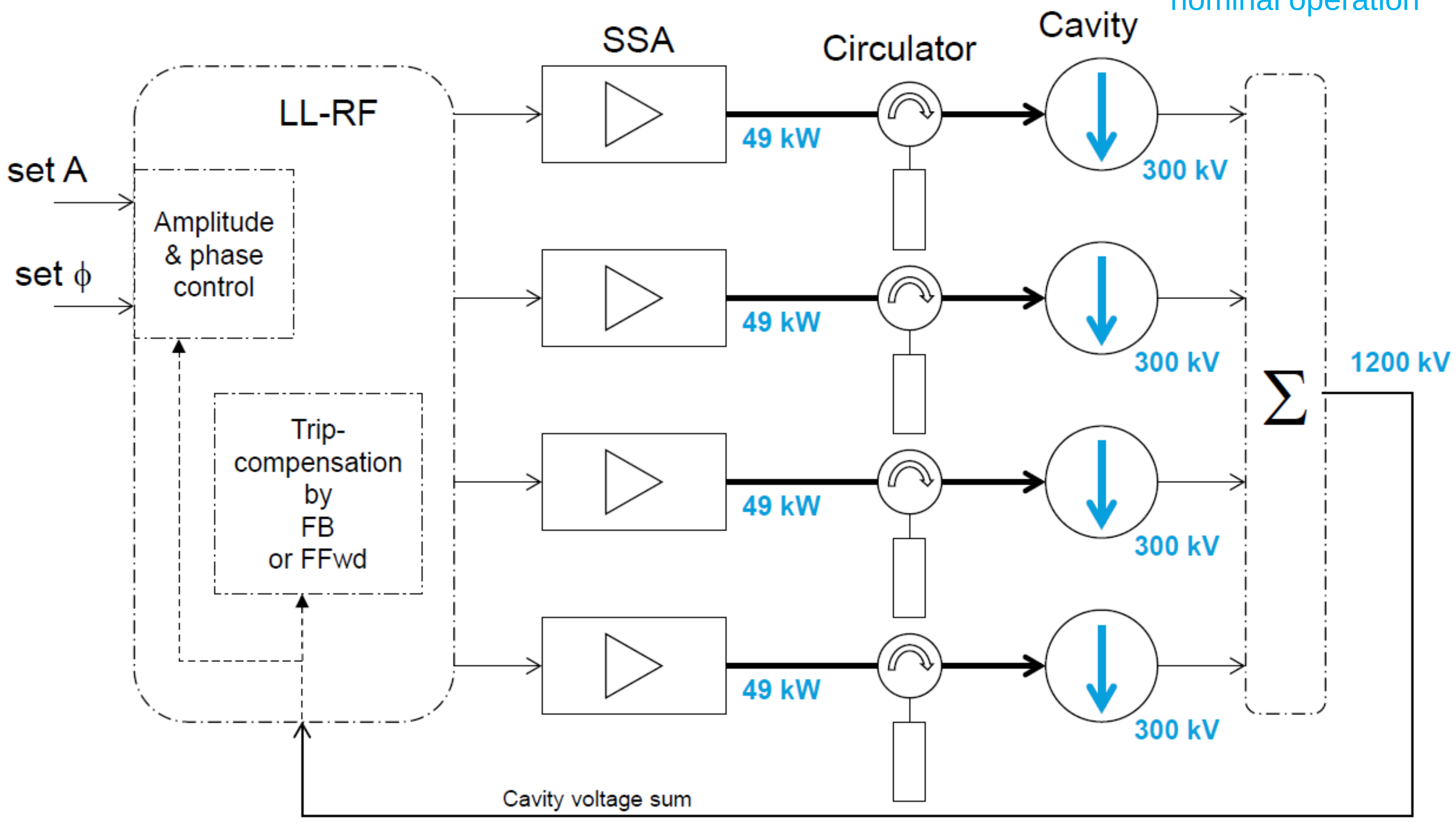
PETRA III:
<1> arcing trip per cavity and year @ 0.80 MV/m

Circumference voltage	6 MV	6 MV	9 MV
Number of Cavities	12	**20**	20
Operational cavity voltage	500 kV	**300 kV**	470 kV
Cavity voltage gradient	1.67 MV/m	**1.00 MV/m**	1.57 MV/m
Power dissipation per cavity	36.8 kW	**13.2 kW**	29.8 kW
Power to beam per cavity	55.3 kW	**33.2 kW**	33.2 kW
Coupler power	92.1 kW	**46.4 kW**	63.0 kW
5% transmission loss	4.6 kW	**2.3 kW**	3.1 kW
Coupling factor	2.5	**3.5**	2.1
Total rf power consumption	1160 kW	**975 kW**	1325 kW
Installed rf Power (20% reserve included)	12 x 115 kW	20 x 60 kW	**20 x 80 kW**

Trip Compensation

Many cavities make a big trip-potential

Voltage and power at nominal operation

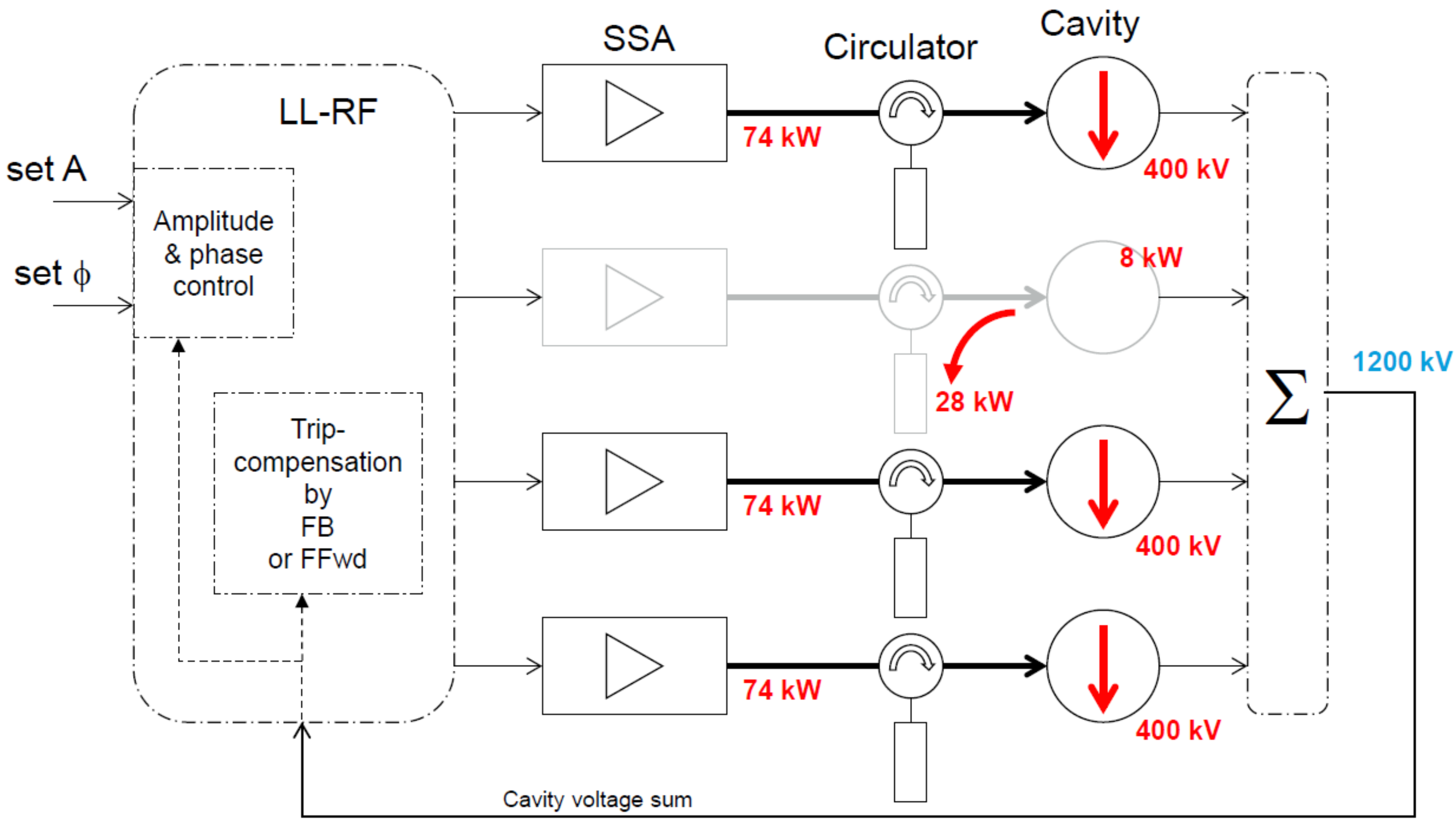


Trip Compensation

Voltage and power at nominal beam operation with one system tripped

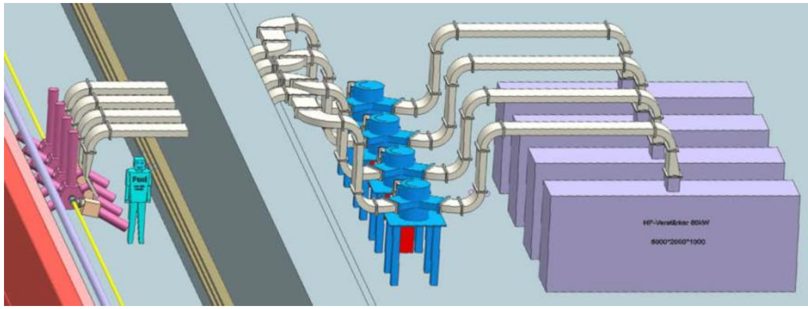
Synchronous phase changes by 2° from 33.6° to 35.6°

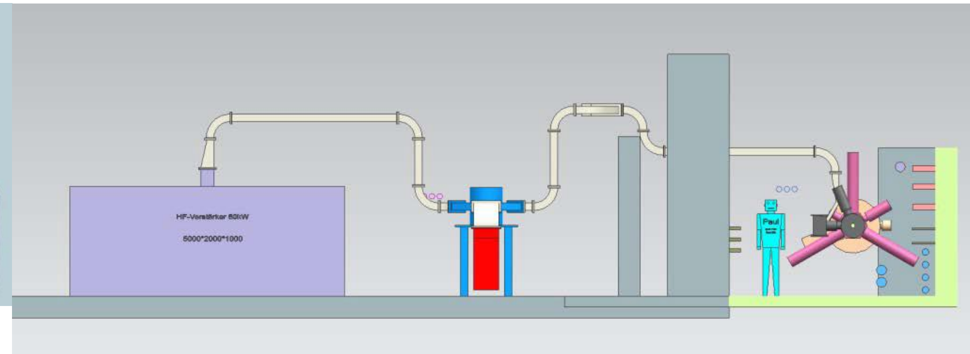
Many cavities make a big trip-potential

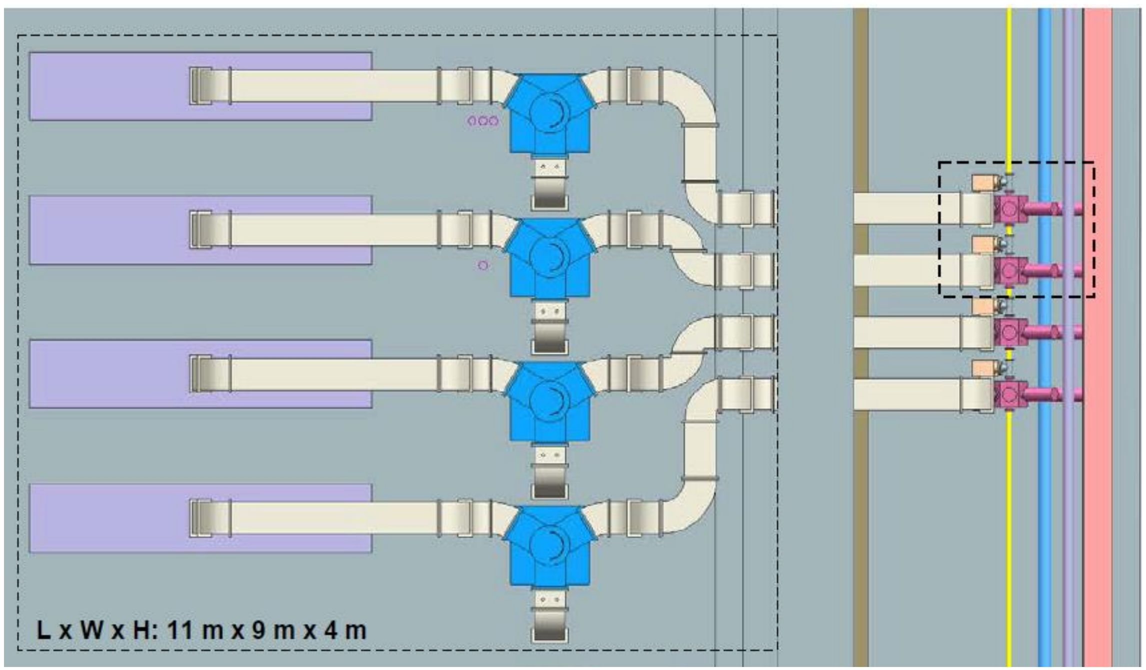


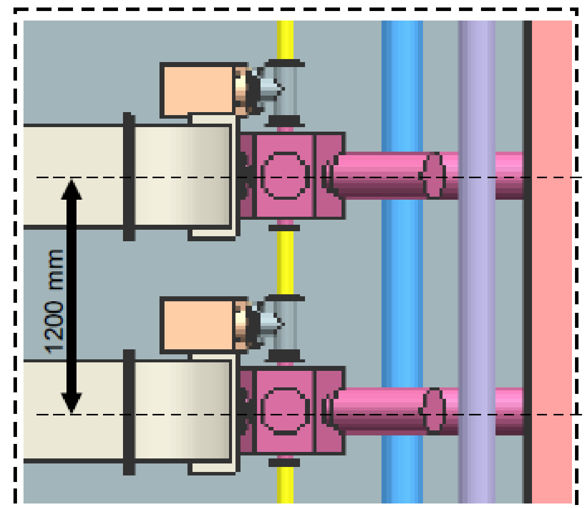
RF System Structure (fundamental)

5 groups with 4 cavities

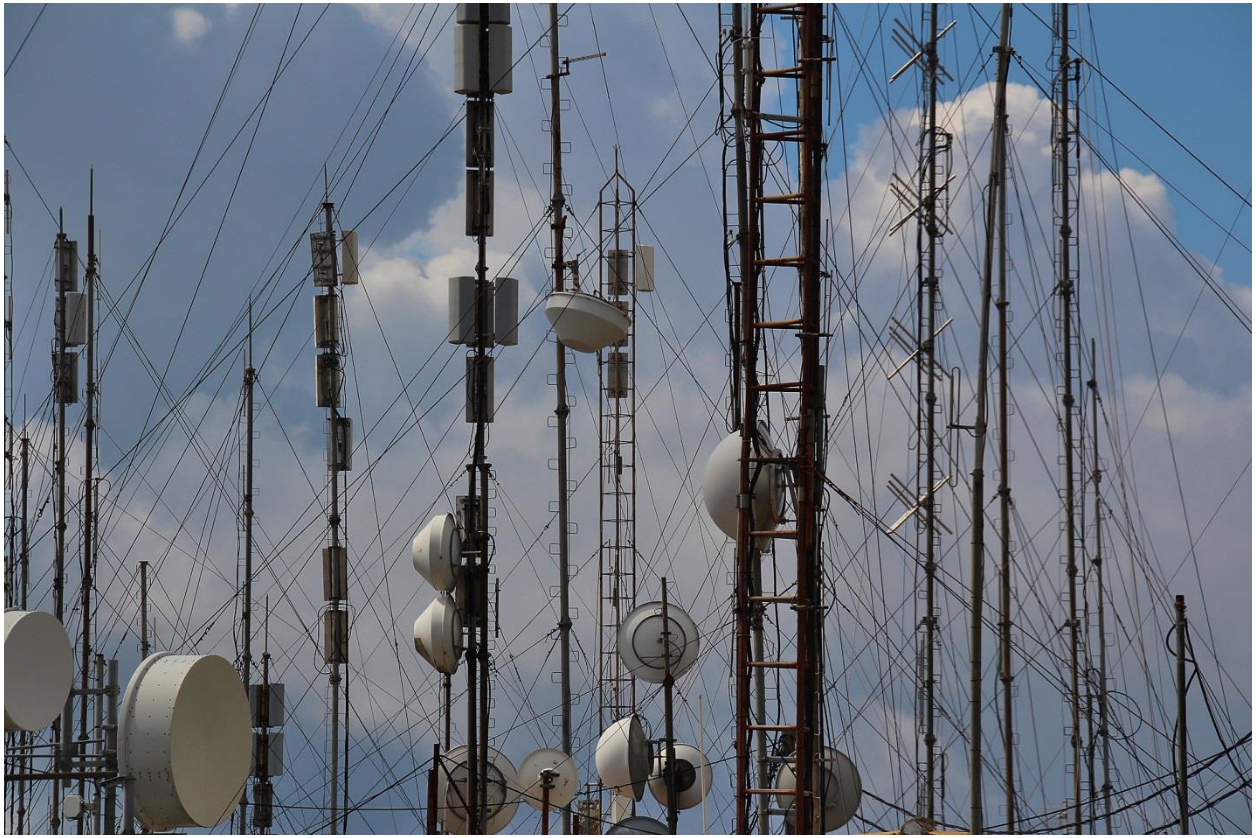








Harmonic RF- system



How can a Harmonic RF System be realized

Three different designs are common used

- The simplest case is just a **passive copper cavity**. The harmonic voltage is induced by the beam itself. V_{HHC} or φ_{HHC} can be adjusted by tuning the resonance frequency.
- Something more complex is an **active system**. The cavity is fed by a RF power source like the fundamental RF system.
- Even more complex is the use of a **superconducting cavity**. It makes sense for example if high V_{HHC} is required, but the space for a corresponding number of copper cavities is not available.

Pros and Cons of Different Designs

Incomplete selection

Passive copper cavity

- ☺ simplest set-up
- ☹ optimum operation only possible at one beam current
- ☹ Gap in the fill pattern induces a strong modulation of the V_{HHC} and φ_{HHC} which limits the effect
- ☹ operation on the Robinson unstable slope, generating a Robinson growth rate

Active copper cavity

- ☹ RF power source required
- ☺ allow operation near optimum V_{HHC} and φ_{HHC} for any I_{beam}
- ☹ Gap in the fill pattern induces a strong modulation of the V_{HHC} and φ_{HHC} which limits the effect
- ☹ operation on the Robinson unstable slope, generating a Robinson growth rate

Superconducting cavity

- ☹ Cryogenic system required
- ☹ Because of the narrow cavity bandwidth, difficult to achieve ideal φ_{HHC} and V_{HHC} at the same time.
- ☺ Passive operation down to very low currents
- ☺ less sensitive to transients (filling gap)
- ☺ less sensitivity to the Robinson instability due to small BW and detuning near 90°

Harmonic RF System for PETRA IV

Consideration of a 3rd harmonic system using downscaled HOM-Damped EU-Cavities

The formula gives the required ratio

$k_{fp} = V_{HHC}/V_{RF}$

The subscript *fp* stands for *flat potential*

$$k_{\mathrm{fp}} = \sqrt{\frac{1}{n^2} - \frac{1}{n^2-1}\left(\frac{U_0}{e_0 V_{\mathrm{rf}}}\right)^2}, \qquad (11)$$

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 17, 064401 (2014)

Equilibrium bunch density distribution with passive harmonic cavities in a storage ring

Pedro F. Tavares, Åke Andersson, Anders Hansson, and Jonas Breunlin

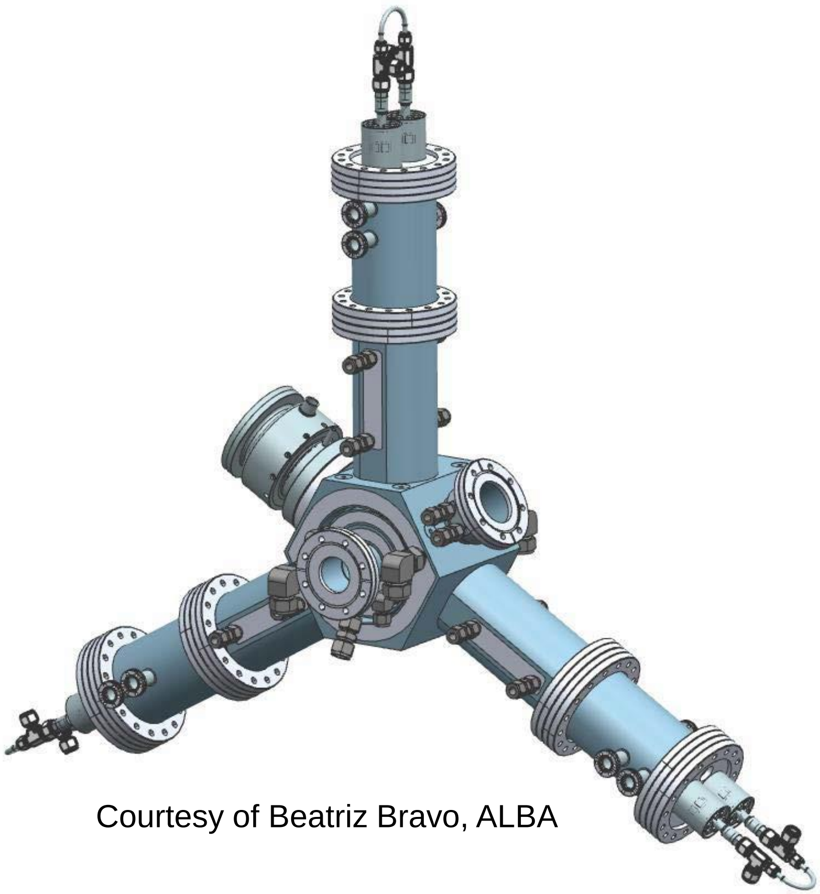
Required Voltage
U_0 = 3.32 MeV
V_{RF} = 6 MV
n = 3 (1,5 GHz)

$\Rightarrow k_{fp}$ = 0.27
$\Rightarrow \Sigma V_{HHC}$ = 1.62 MV

Required number of cavity cells
Limiting parameter is the voltage gradient

VRF /cell length ≤ 1 MV/m
cell length = 10 cm

$\Rightarrow V_{HHC} \leq$ 100 kV
$\Rightarrow N_C \geq 16$
chosen
NCC = 20
for higher reliability



Courtesy of Beatriz Bravo, ALBA

Harmonic RF System for PETRA IV

Consideration of a 2rd harmonic system using old PETRA 6-cell cavities

The formula gives the required ratio
$k_{fp} = V_{HHC}/V_{RF}$

The subscript *fp* stands for *flat potential*

$$k_{\mathrm{fp}} = \sqrt{\frac{1}{n^2} - \frac{1}{n^2 - 1}\left(\frac{U_0}{e_0 V_{\mathrm{rf}}}\right)^2}, \qquad (11)$$

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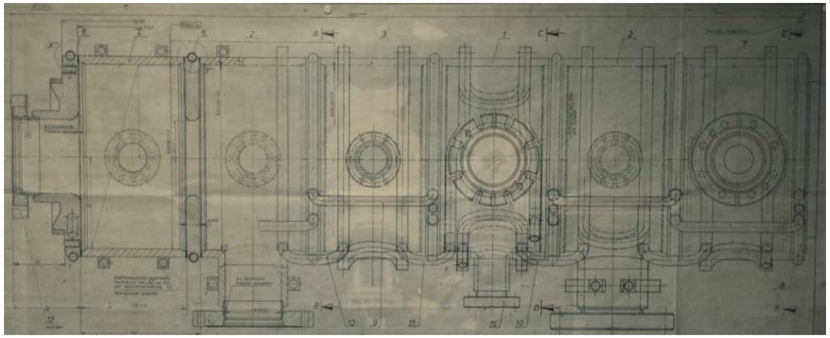
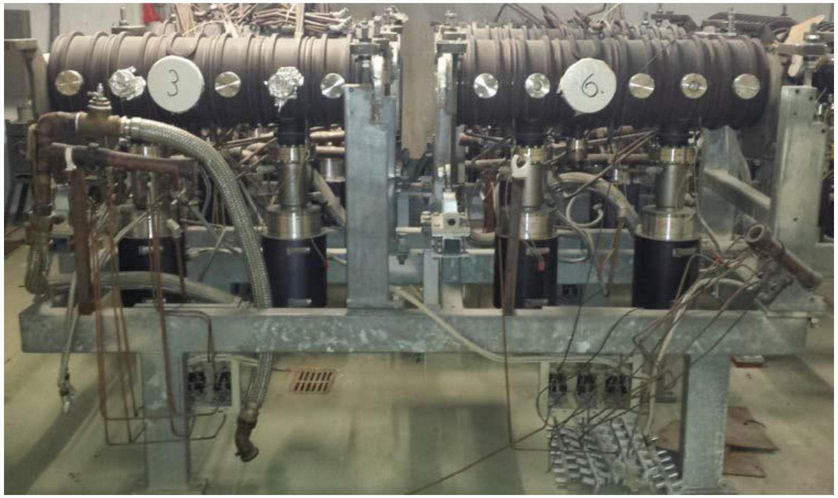




Required Voltage
U_0 = 3.32 MeV
V_{RF} = 6 MV
n = 2 (1,0 GHz)

⇒k_{fp} = 0.385
⇒ΣV_{HHC} = 2.31 MV

Required number of cavity cells

Limiting parameter is the power dissipation per cell
P_{diss}/cell ≤ 3 kW

⇒V_{HHC} ≤ 86 kV
⇒N_C ≥ 27

chosen
N_{CC} = 30 (5 cavities)
for higher reliability

≈20 cavities are available

Harmonic RF System for PETRA IV

Comparison of PETRA 6-cell cavity and downscaled HOM-Damped EU-Cavity

Harmonic Number	2	2	3	3
Cavity type	Passive PETRA 6-cell Cavity	Active PETRA 6-cell Cavity	Passive downscaled HOM-Damped EU-Cavity	Active downscaled HOM-Damped EU-Cavity
Number of HHC-cells	30	30	20	20
R/Q per HHC-cell	45 Ω (1) (56.7 Ω (2))	45 Ω (1) (56.7 Ω (2))	88 Ω (3)	88 Ω (3)
R_S per HHC-cell	1.22 MΩ (1) (1.53 MΩ (2))	1.22 MΩ (1) (1.53 MΩ (2))	1.50 MΩ (3)	1.50 MΩ (3)
Operational HHC voltage per cell	77 kV	77 kV	81 kV	81 kV
Operational HHC voltage	2.31 MV	2.31 MV	1.62 MV	1.62 MV
HHC voltage gradient	513 kV/m	513 kV/m	810 kV/m	810 kV/m
Bandwith	37 kHz	74 kHz	88 kHz	176 kHz
HHC-detuning	80.9° 116 kHz	71.6° 116 kHz	82,2° 320 kHz	74.3° 320 kHz
Power dissipation per HHC-cell	2.43 kW	2.43 kW	2.19 kW	2.19 kW
Power dissipation of all HHC-cells	72.9 kW	72.9 kW	43.7 kW	43.7 kW

(1) The experimental study of a higher harmonic rf system in PETRA, Kohaupt, PAC1983_2525
(2) B. Dwersteg –MHC- 27.06.1983
(3) 1.5 GHz CAVITY DESIGN FOR THE CLIC DAMPING RING AND AS ACTIVE THIRD HARMONIC CAVITY FOR ALBA, May 2017

fin

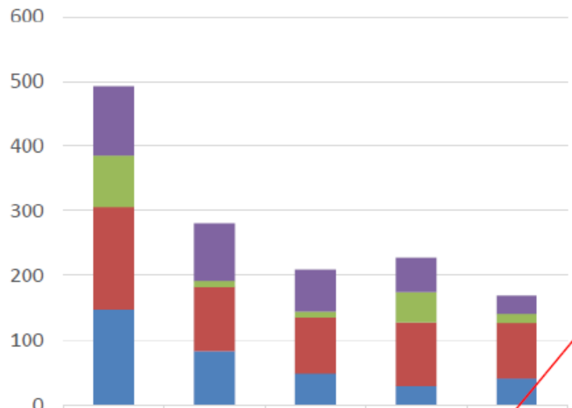
Thank you, for Your attention

Annex / HOM-Damped EU-Cavity

ALBA RF Statistics

Evolution since 2013

RF interlocks



	2013	2014	2015	2016	2017
Other	107	89	66	53	28
Cooling	81	9	8	45	13
Arcs	158	99	87	99	87
IOT	147	84	49	30	41

IOT Arcs Cooling Other

Cooling interlocks greatly reduced

IOT interlocks similar t year, even though 6 ne IOT's have been instal

Arc interlocks similar to l year, despite the voltage beam current increase

J. Ocampo | ALBA RF status 2017 | 15/11/2017

Due to fast phase and voltage compensation only about 5% of the trips leading to beam loss

6 Cavites
~ 90 cavity trips/year
~ 4…5 beam losses due to cavity arcing per year

PETRA-III
12 Cavites
~ 14 cavity trips/year
~ 14 beam losses due to cavity arcing per year

Annex / HOM-Damped EU-Cavity

ALBA RF Statistics

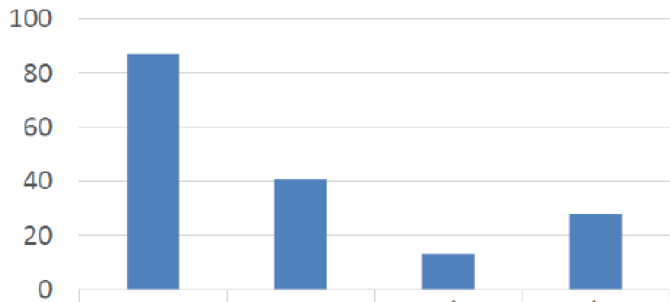
Statistics 2017

8

Operation mode: Top-up 150mA → 200mA (since October)

450kV/cavity → 500kV/cavity

2017 RF interlocks



Arcs	IOT	Cooling	Other
87	41	13	28

Total: 169 interlocks

Only 13 beam losses (7,7%)

8,3 hours downtime (0,2%)

75% of cavity arcs after increasing voltatge from 450kV to 500kV

75% of IOT interlocks in newly installed L3 IOT's. They disapear in ~ 2 months

J. Ocampo | ALBA RF status 2017 | 15/11/2017