Higher Harmonic SRF Cavities for BESSY II Upgrade

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TESLA Technology Collaboration Meeting

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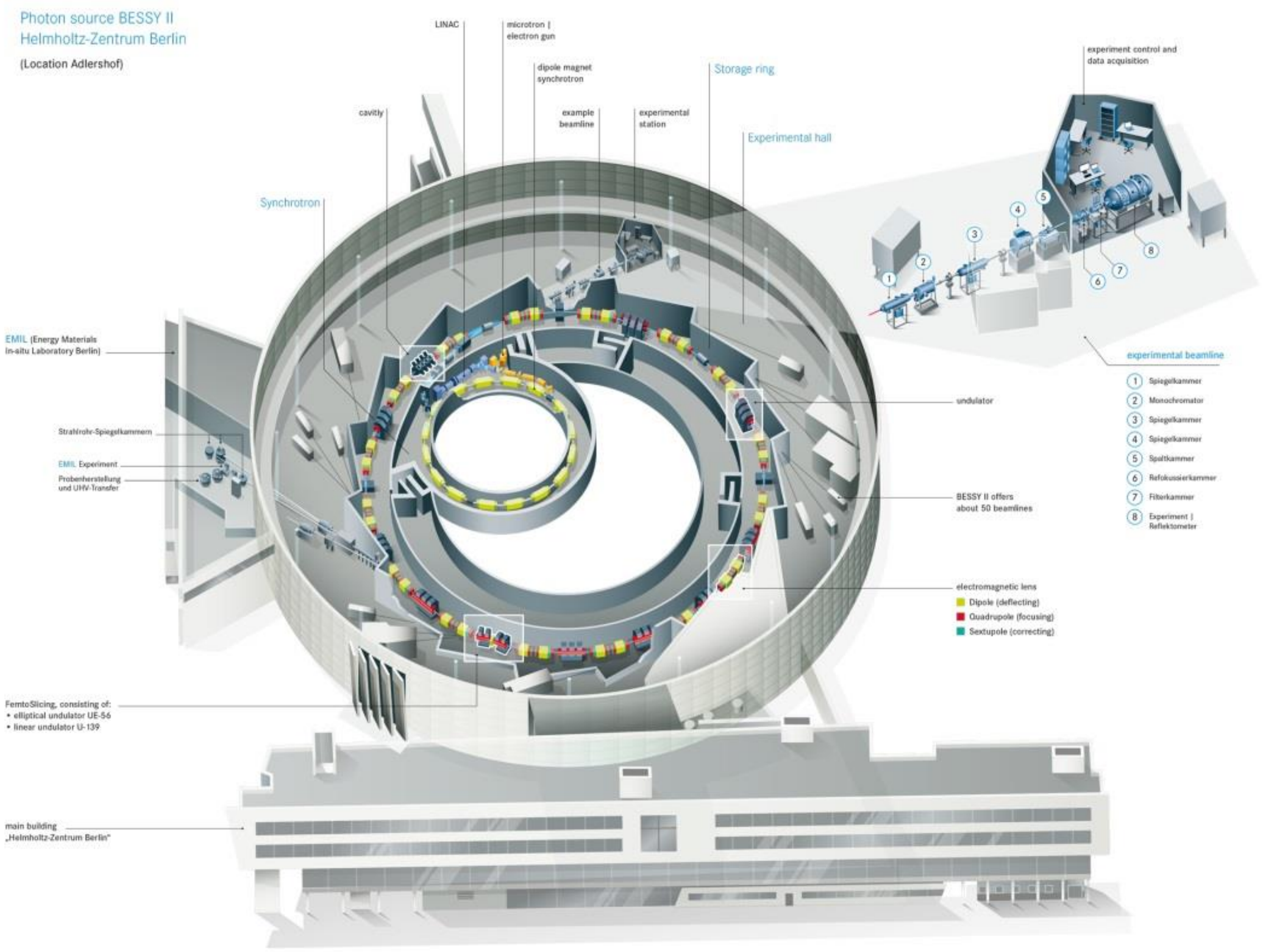
Milano, Italia

BESSY II Storage Ring

- BESSY II is a 1.7 GeV synchrotron radiation source operating for 20 years in Berlin
- Core wavelength in the range from Terahertz region to hard X rays



BESSY II Parameters	
Lattice	DBA
Circumference	240 m
Energy	1.7 GeV
Current	300 mA
RF Frequency	500 MHz
RF Voltage	1.5 MV
Bunch Length	15 ps
Emmitance	6 nm rad

The Concept of BESSY VSR

BESSY II @ present

Normal conducting cavity system

❖ Low alfa operation only 12 days/year (all beamlines) ------- Low flux

❖ Femtoslicing is continuously operated (only 1 beamline) -- Low flux

Can we design a system offering both possibilities simultaneously?

- Limited pulse length in storage ring

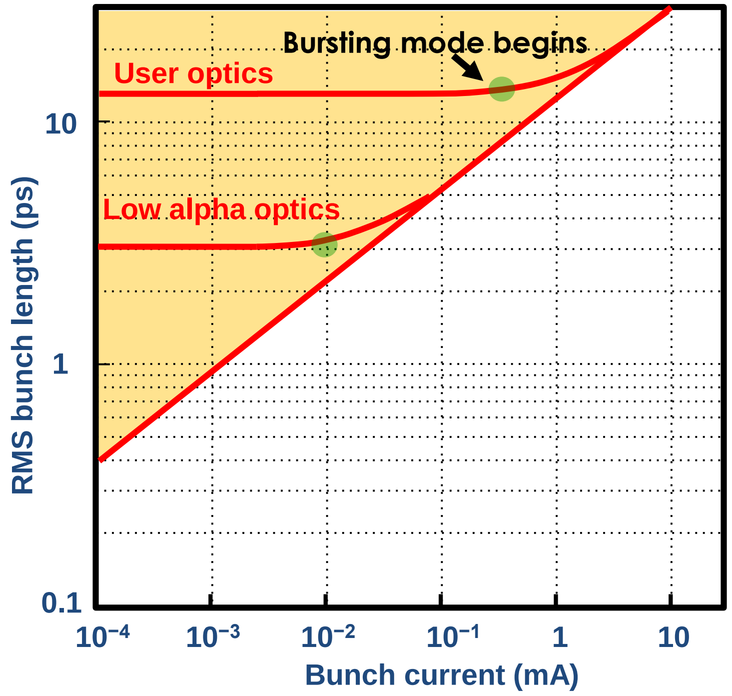
$$\sigma \propto \sqrt{\frac{\alpha}{\dot{V}_{\mathrm{rf}}}}$$

Machine optics

Hardware (RF cavities)

- At high current beam becomes unstable

- For ps pulses, flux is reduced by nearly 100



The Concept of BESSY VSR

BESSY II @ present

Normal conducting cavity system

> - Supply short pulses down to 1.5 ps (100 × more bunch current)
> - Low α permits few 100 fs pulses
> - Configure BESSY^{VSR} so 1.5 ps and 15 ps bunches can be supplied simultaneously for maximum flexibility and flux!

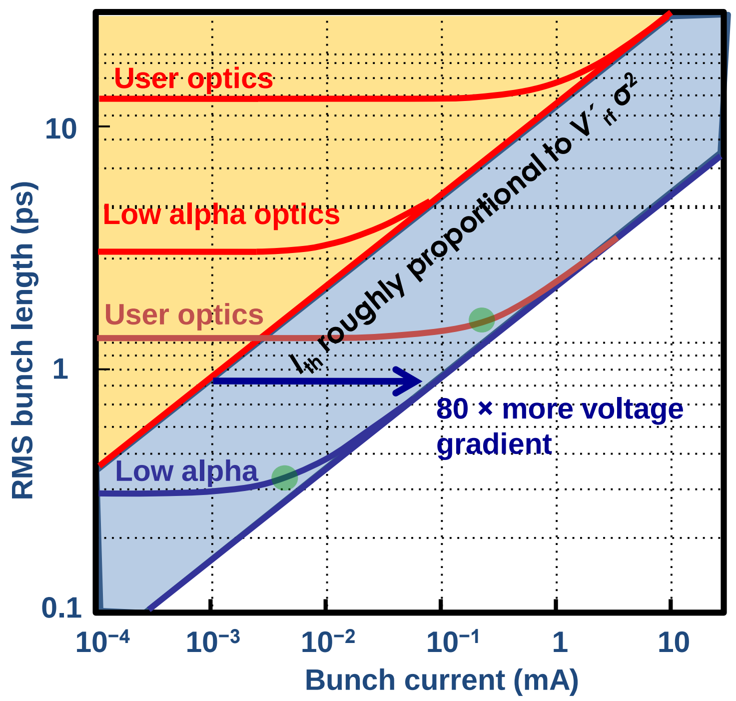
- Limited pulse length in storage ring

$$\sigma \propto \sqrt{\frac{\alpha}{\dot{V}_{\mathrm{rf}}}}$$

Machine optics

Hardware (RF cavities)

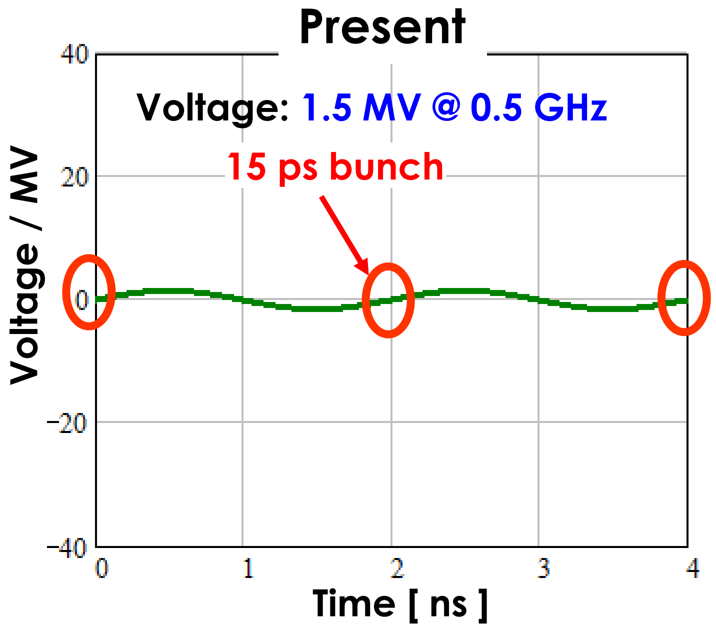
- At high current beam becomes unstable
- For ps pulses, flux is reduced by nearly 100



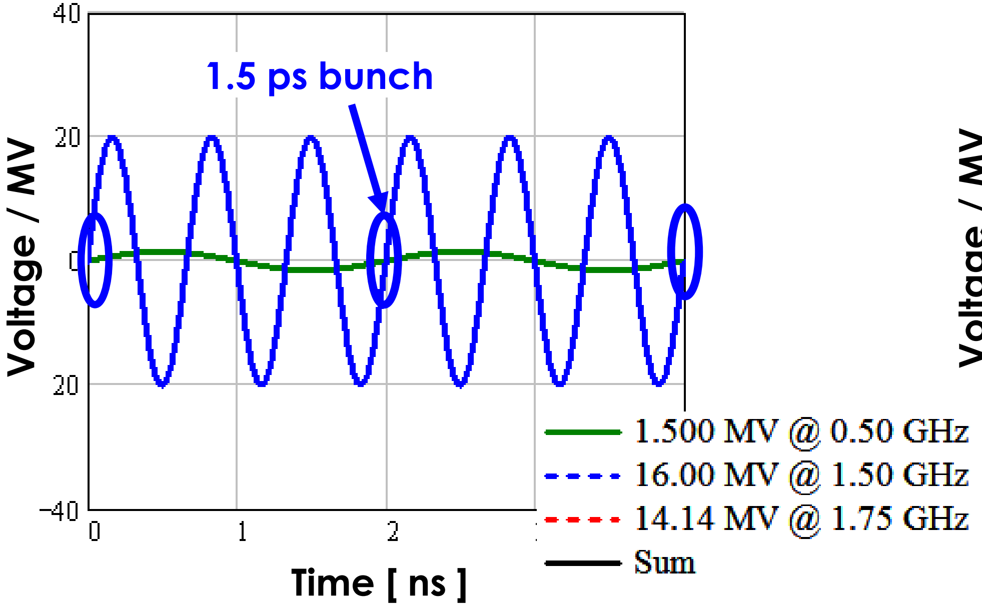
BESSY II, SC Upgrade – BESSY VSR

SC Upgrade

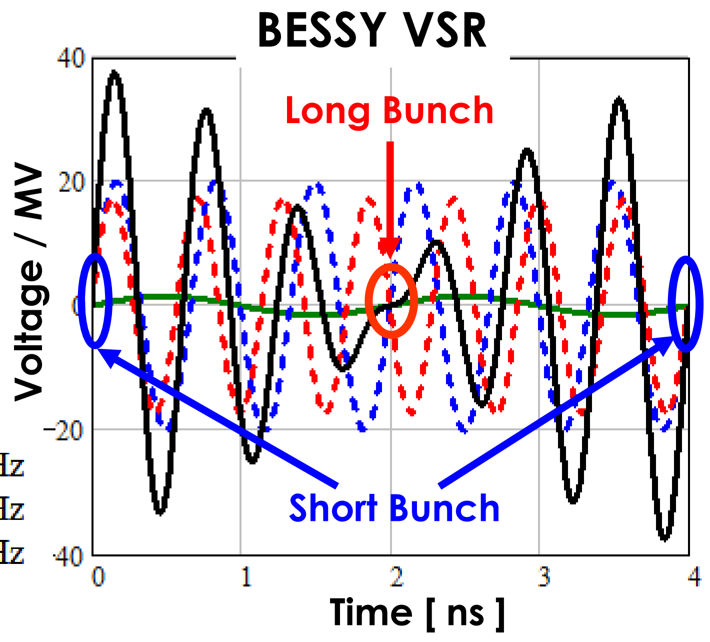
***G.Wüstefeld et al*. „Simultaneous long and short electron bunches in the BESSY II storage ring" , IPAC2011**



$$\dot{V} \propto V \times f_{rf} = 0.75\ MV \times GHz$$



$$\dot{V} \propto V \times f_{rf} = 24\ MV \times GHz$$



$$\dot{V} \propto V \times f_{rf} = 48\ MV \times GHz$$

- 1.5GHz and 1.75GHz ---- RF beating (modulate RF focusing)
- Odd (voltage cancelation, 15 ps bunches)
- Even (voltage addition, 1.5 ps)

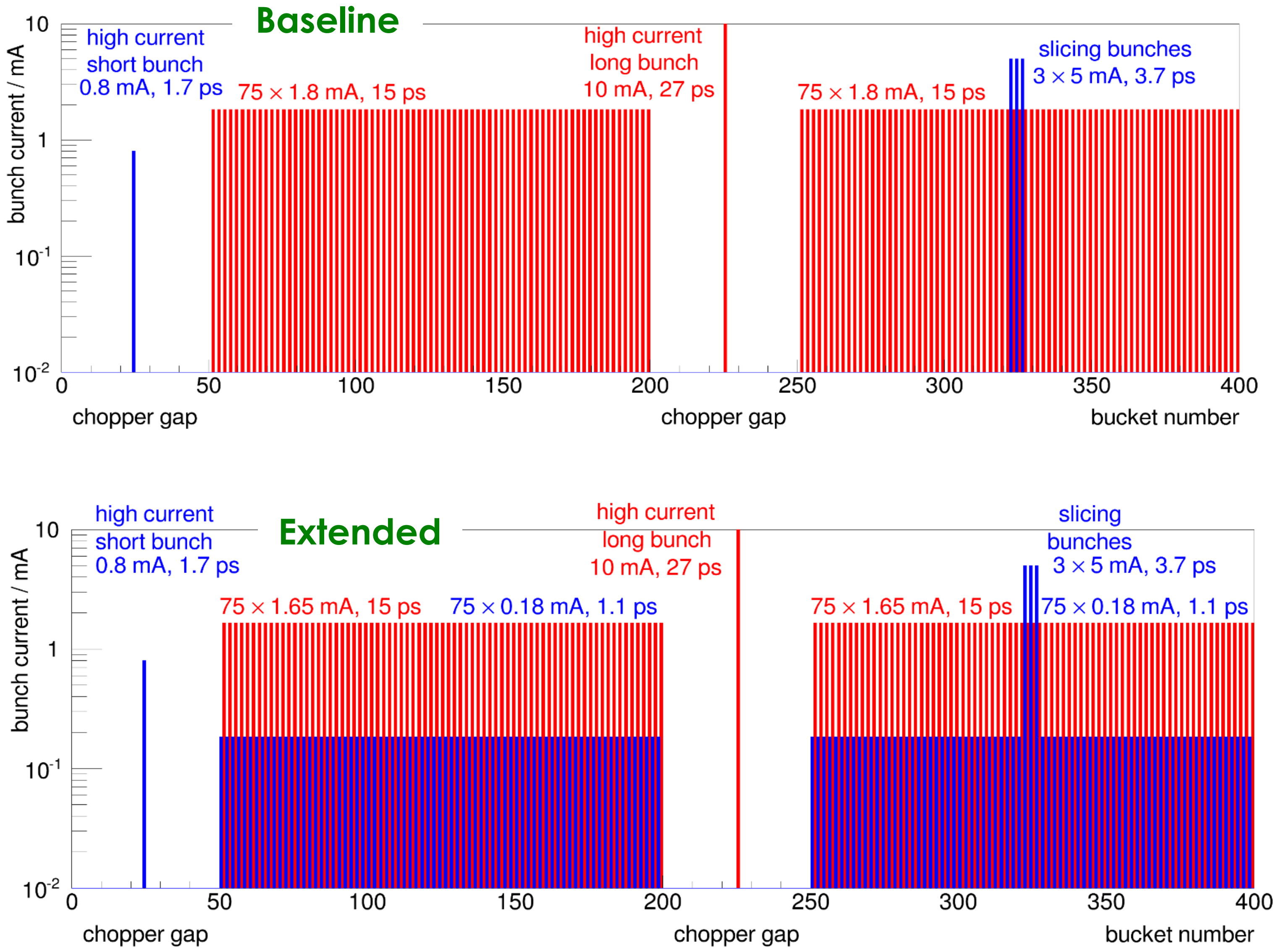
BESSY II, SC Upgrade – BESSY VSR

BESSY VSR Filling Patterns

- High concentration of long bunches populated with high current
  (flux hungry users)
- Few high current - short bunches
  (slicing bunches …)

More short bunches (Extended)

- High Population of long & short bunches at the same time



BESSY II SC Upgrade – BESSY VSR

- Simultaneous Store of long & short bunches

SC Upgrade

BESSY VSR
Variable pulse length **S**torage **R**ing

BESSY VSR
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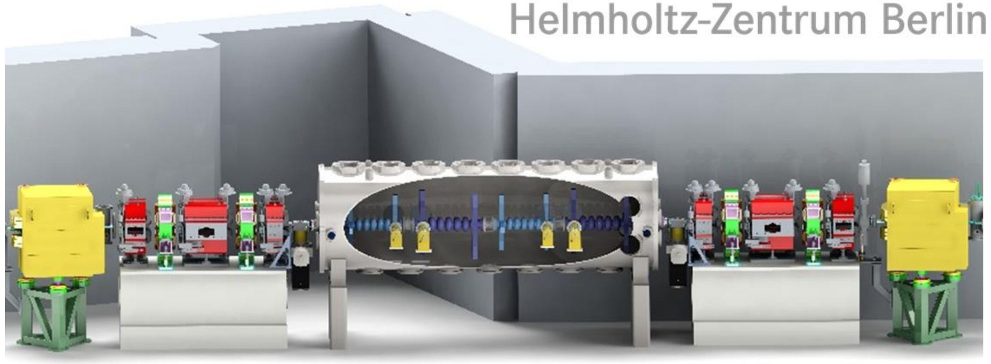
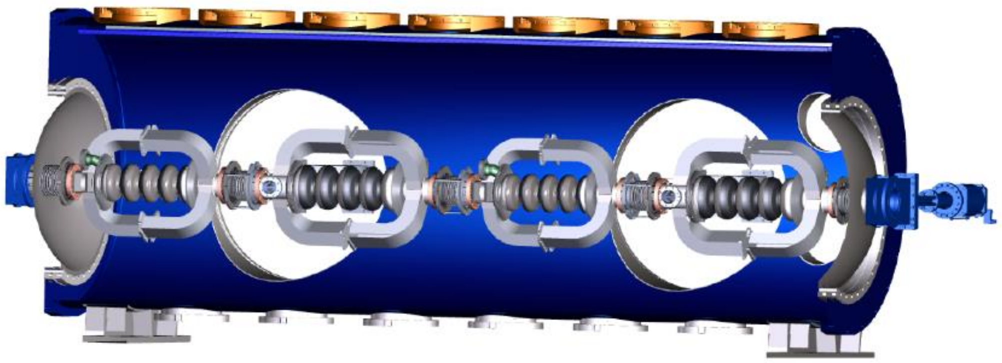


- **SRF SYSTEM:** 2@1.5 GHz & 2@1.75 GHz



CHALLENGES

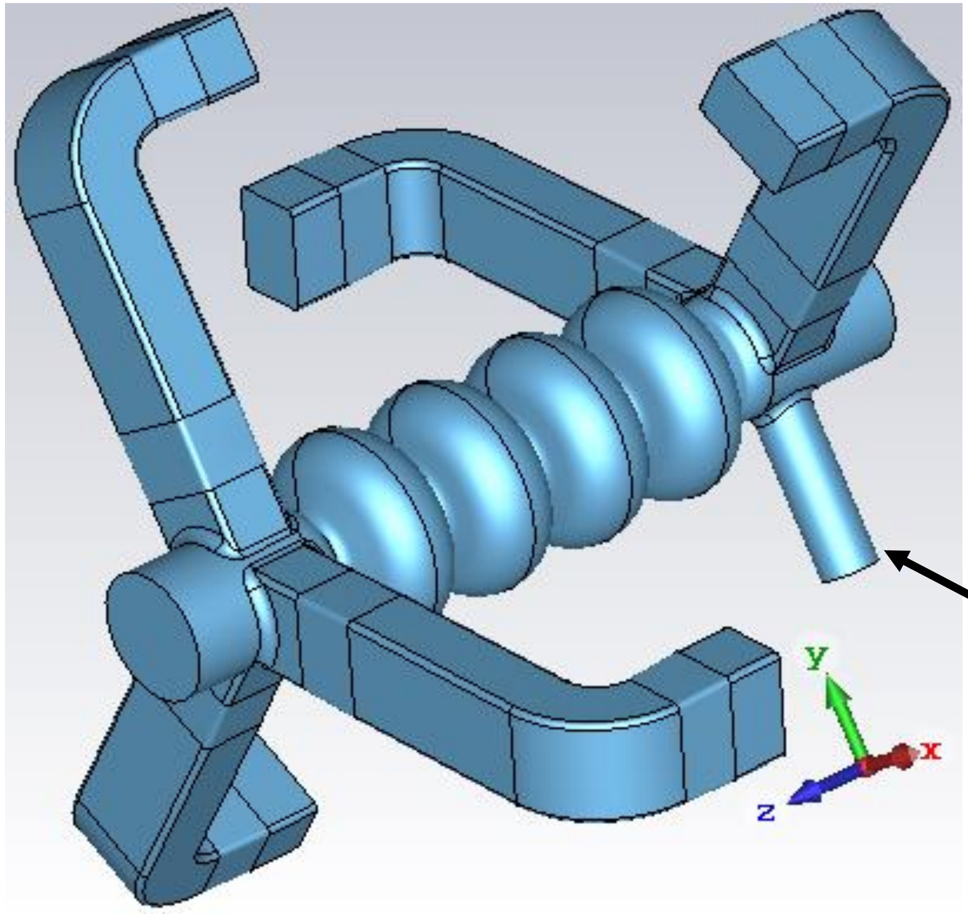
- **CW operation @ high field levels E=20MV/m**
- **Peak fields on surface (discharges, quenching)**
- **High beam current (Ib=300mA),**
- **Cavity HOMs must be highly damped (CBIs)**
- **Exotic cavity design (damping end-groups)**
- **Integrating in existing storage ring**
- **Transparent Parking of SRF Module.**

BESSY VSR SRF Cavity Designs

- Tune fundamental mode: field flatness, R/Q …
- Control cavity HOM spectrum (off-resonance condition) during the design.

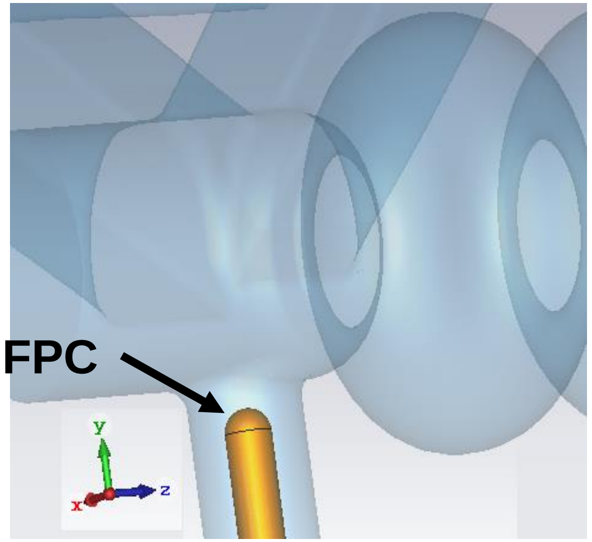
Strong HOM Damped SRF Cavity Concepts

Cavity with HOM WG Dampers

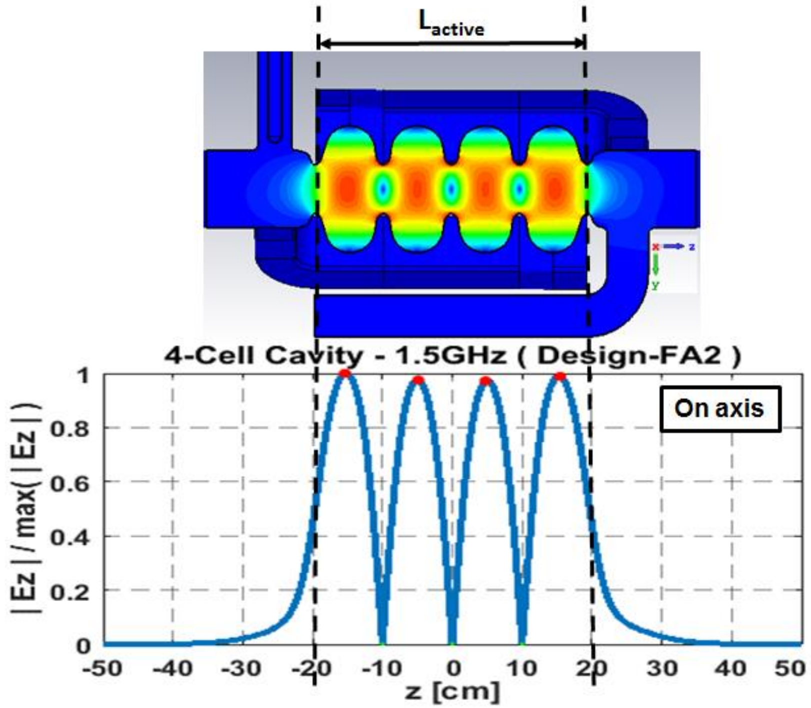


- 5 x Waveguide dampers, HOM loads (warm)
- Large beampipe radius – better HOM propagation
- Waveguides are below cutoff for fundamental → can be moved close to the cavity for heavy damping.

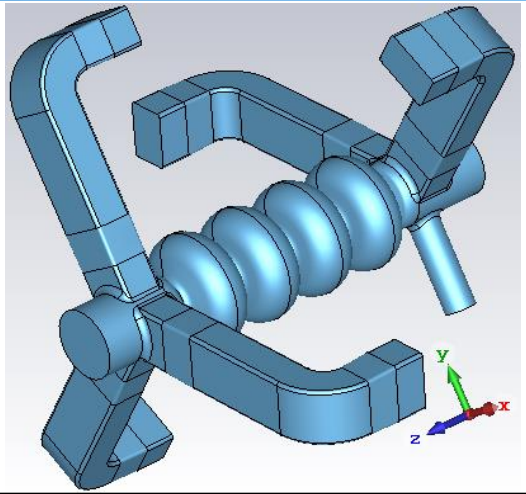
FPC

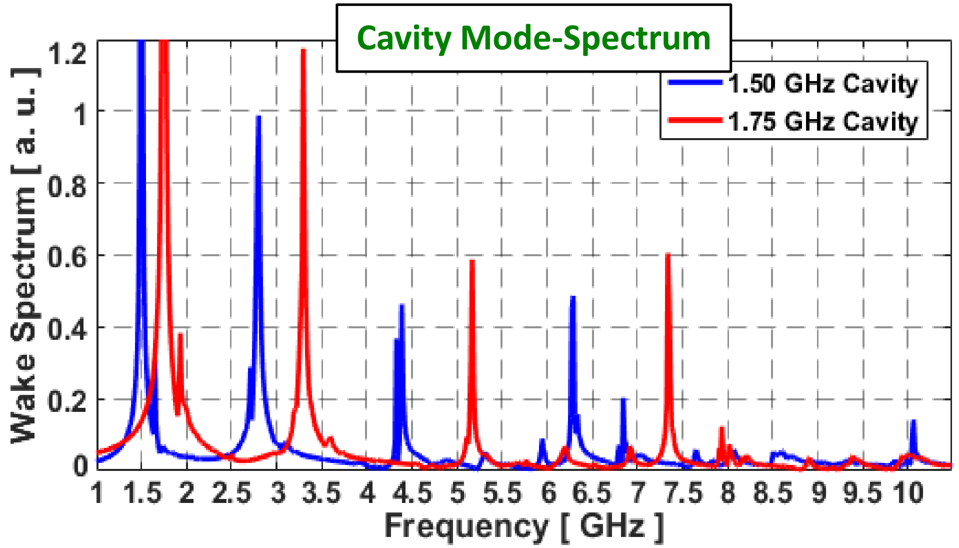


BESSY VSR SRF Cavity Designs



Simulation Results – for both Cavity (TM_{010} π-mode)			
	1.5GHz	1.75GHz	Design goal
Frequency [GHz]	1.4990	1.7489	3th & 3.5th harm. of 499.65 MHz
Q_{ext}	4.99*10^7	4.28*10^7	
G [Ω]	277.63	275.42	
E_{pk} / E_{acc}	2.32	2.30	≤ 2.4
B_{pk} / E_{acc} [mT / (MV/m)]	4.98	5.13	≤ 5.3
R/Q [Ω]	386	380	≥ 90 per cell
Field Flatness - μ_{ff}	97%	99 %	≥ 95%



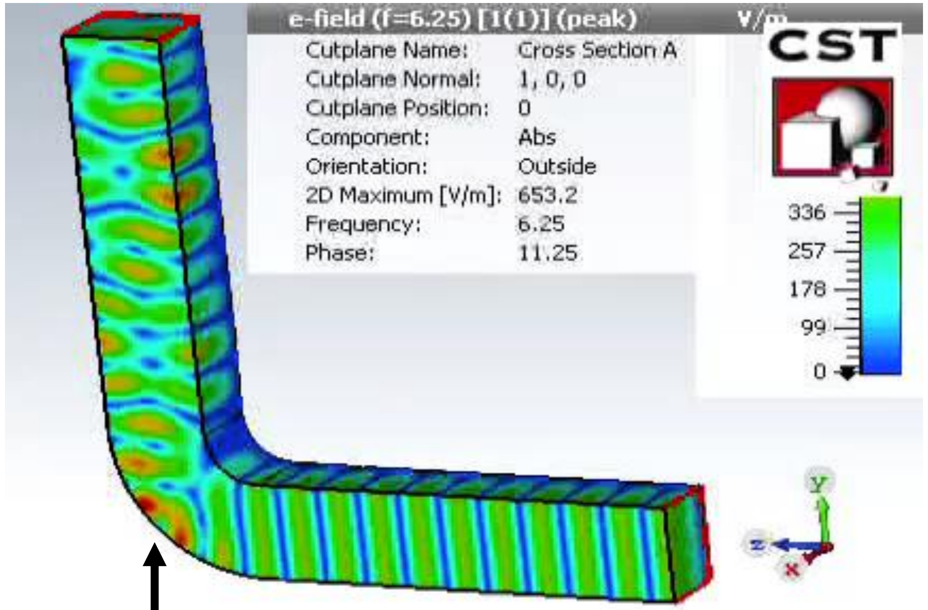


Spectrally Weighted with "Baseline" pattern

Cavity Type	1.5GHz	1.75GHz
Port No.	HOM Power [W]	
1 – FPC(1)	37.9	33.8
2 – WG(1)	105.3	154.7
3 – WG(1)	103.8	151.4
4 – WG(2)	88.5	108.3
5 – WG(2)	90.2	109.8
6 – WG(2)	90.6	111.6
7 – BmP(Upstream)	235.4	200.5
8 – BmP(Downstream)	327.1	275.9
Total Coherent	**1079**	**1146**
None-Coherent	**1293**	**1300**

- During cavity design additional to standard parameters (peak fields, field flatness …), HOM spectrum should be controlled to avoid any resonances with circulating beam harmonics.
- Both cavities are not hitting any of beam resonances that are multiple of 250MHz.
- Cornell's ERL cavities are designed to run at about 100-200W HOM Power.

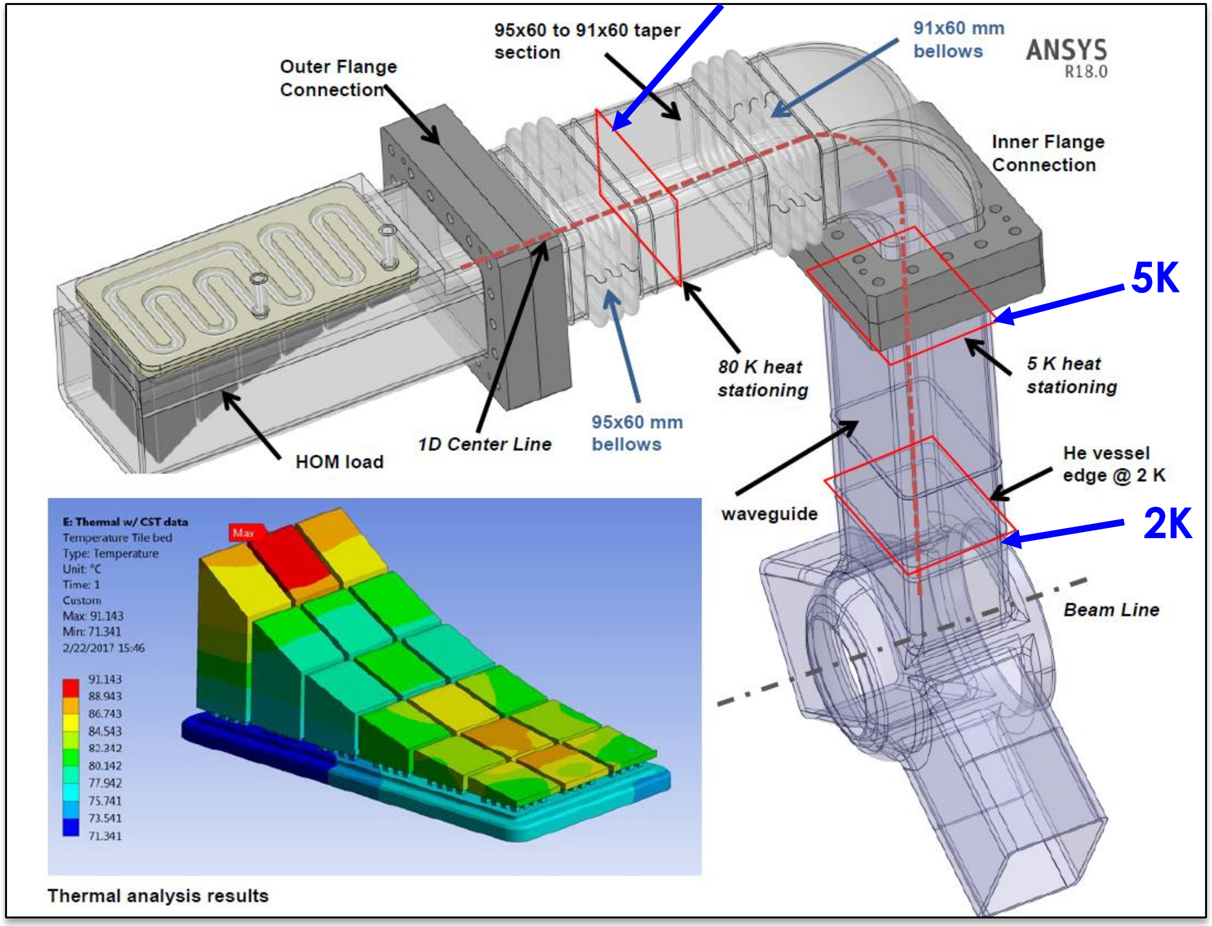
Waveguide Bend Broadband Characteristics & HOM Loads



- Low reflection (broadband) from the WG bend is for bending radius = 30mm or bR ≥ 100mm.

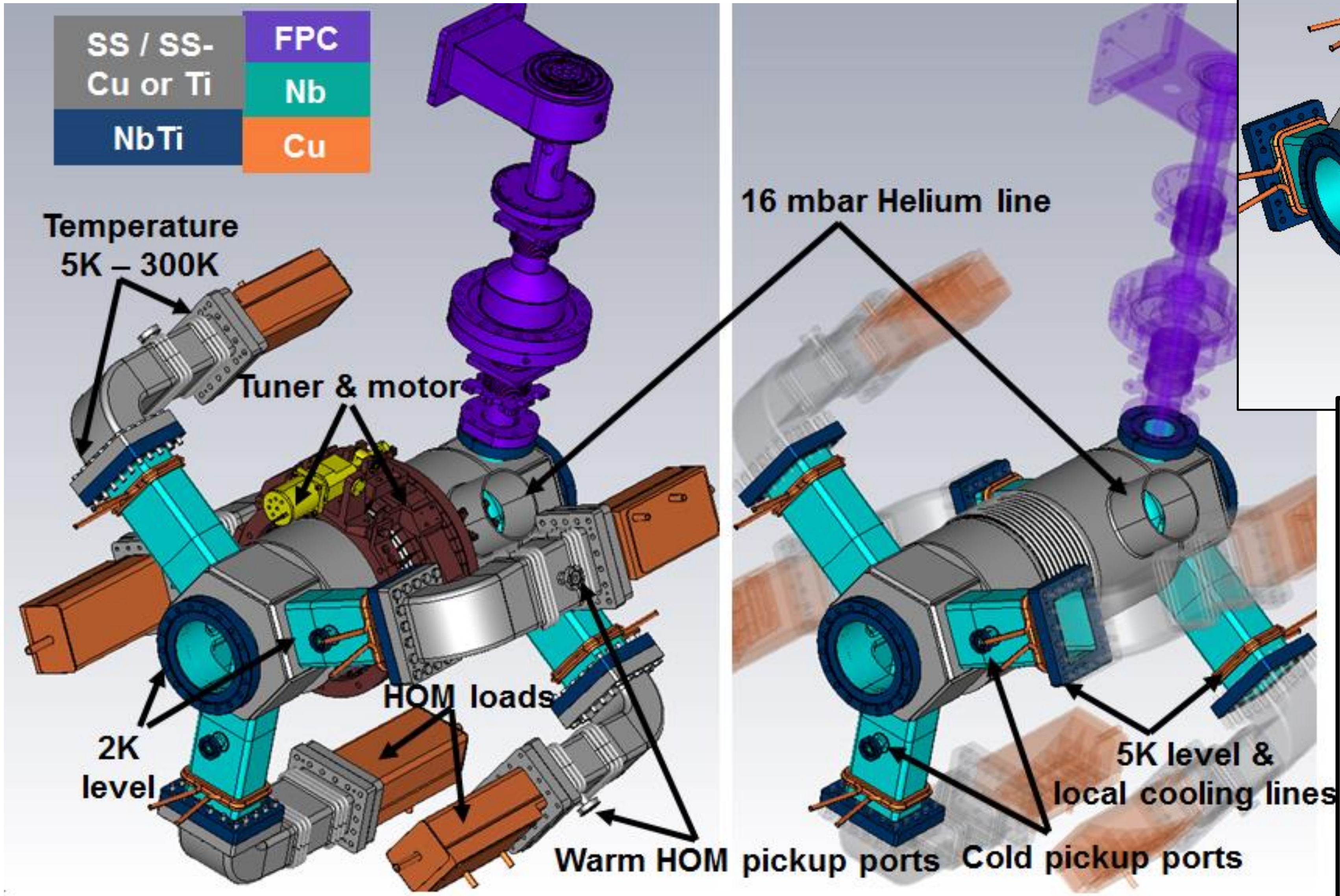
- TE10 mode couples into different modes after bend: TE10, TE11, TM11…, depending on excitation frequency & the cutoff of each WG mode !
- At high frequencies the TE10 is scattered from the bend into several modes, i.e. acts as mode mixer.
- At optimized 30mm inner bending radius the reflection is minimal in broadband frequency sense.

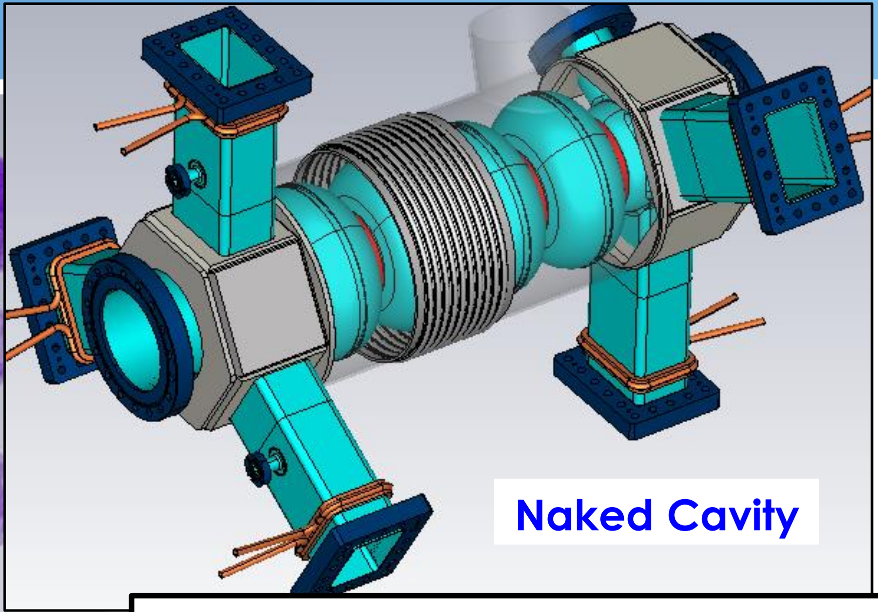
- Water-cooled HOM loads (room temperature 300K)
- Specifications: 460W per load
- Design, fabrication and tests @ JLab



Courtesy of Jefferson Lab

BESSY VSR SRF Cavities

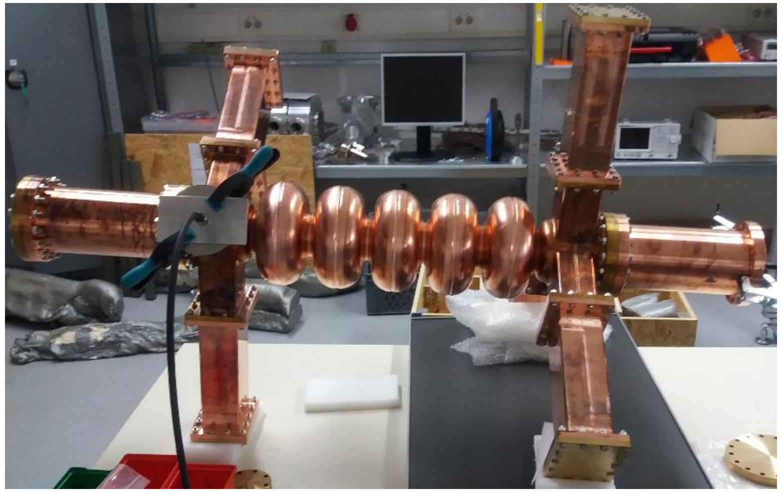


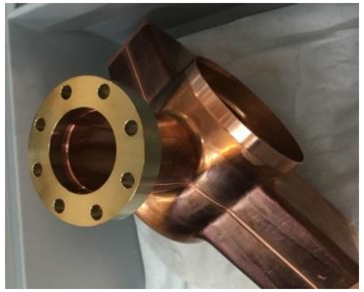


- Baking temperature ~ 700^{0}C, because of Helium-vessel parts.
- Nb inner surface removal ~ 200µm total is planned with BCP. The homogeneity of removal in HOM dampers should be checked.
- In waveguide NbTi flanges VATSEAL gaskets will be used – cold test is planned. At all other flanges – diamond gaskets.
- Looking solutions for cooled WG-flange concept.

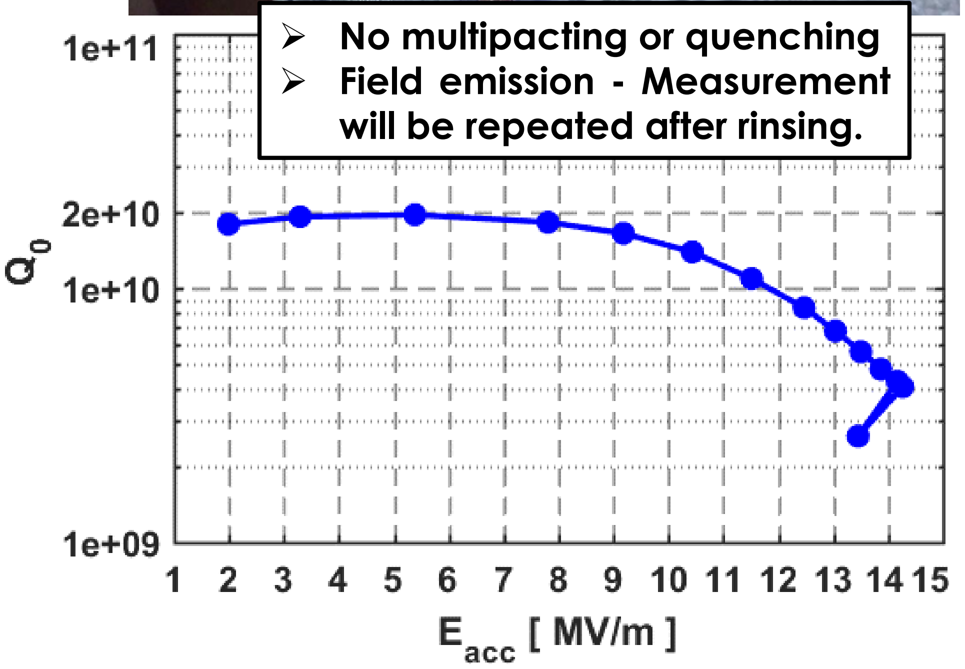
BESSY VSR: Cavity Prototypes

1.5 GHz 5-cell Copper prototype

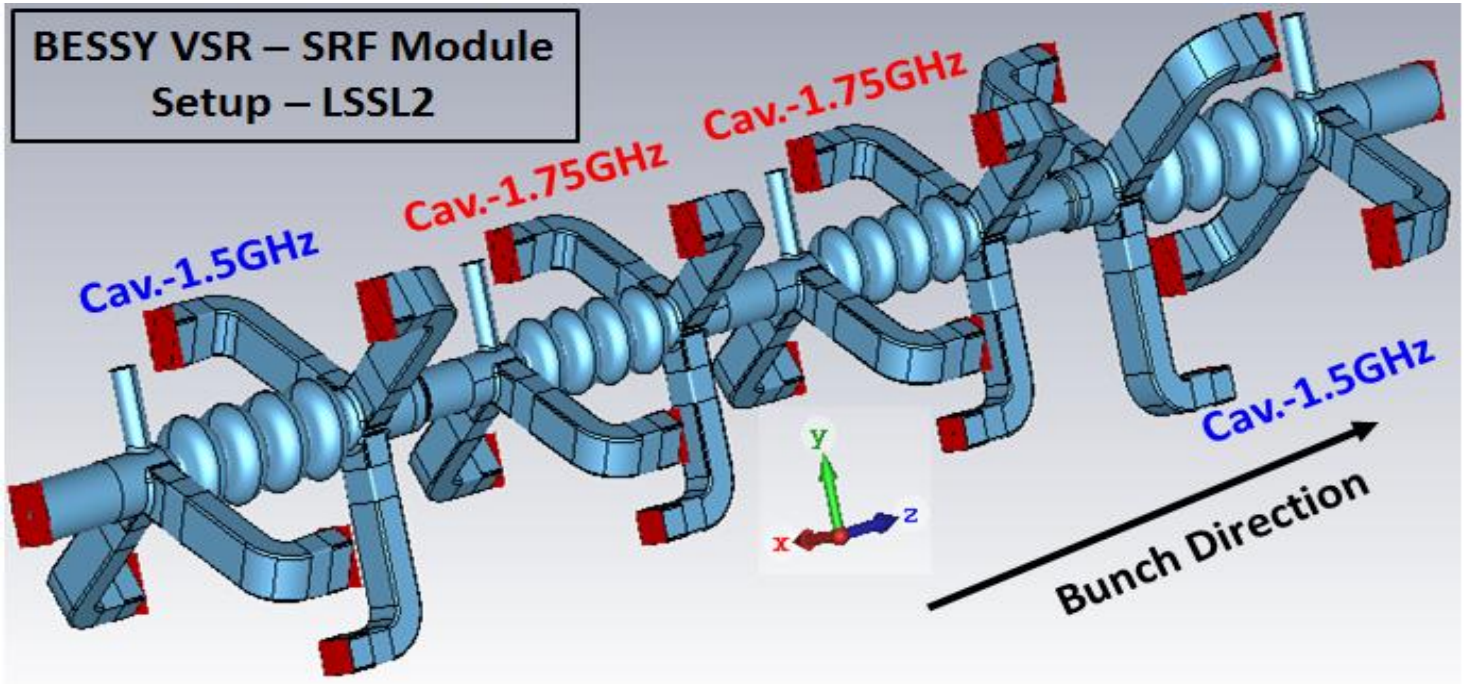


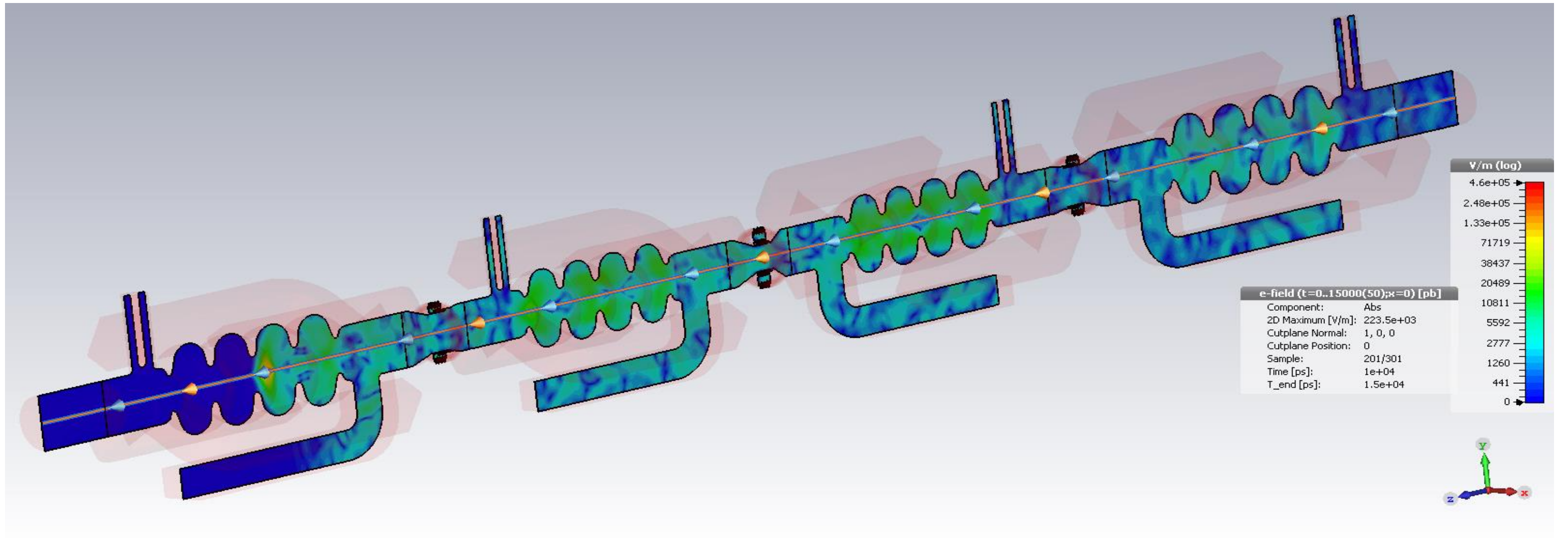


1.5 GHz Single-cell Nb prototype



HOM Power Levels in SRF Module



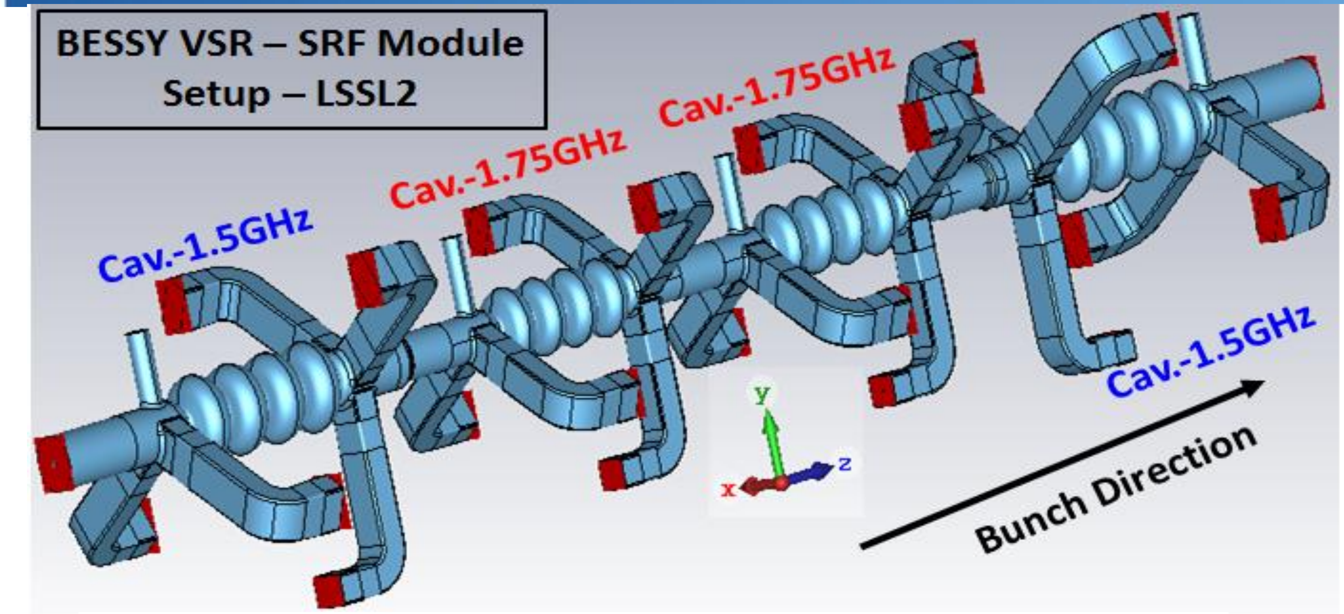


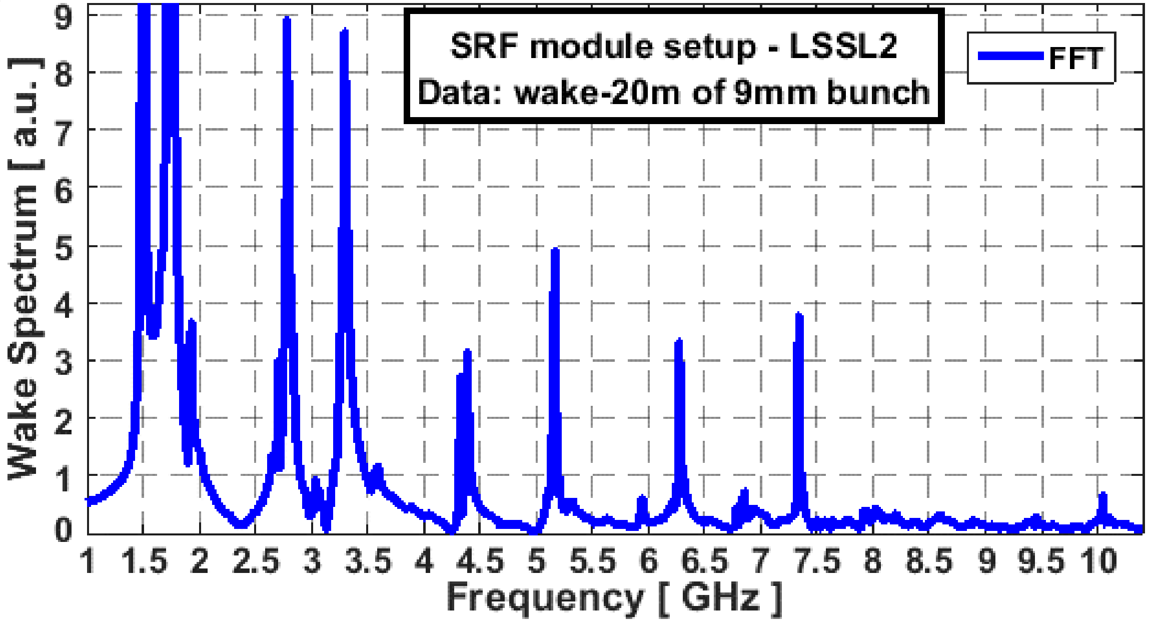
Wakefield Simulations

- Long Range Wakes~ 20m
- Spectral Weighting of all Port Signals with Beam Spectrum
- Expected HOM Power Levels & Spectrum
- Efficiency of HOM Damping

- ➢ Analyze different cavity arrangements in the module to reach optimal operation conditions with equally distributed power portions in warm HOM loads.
- ➢ Study on different FPC locations (Upstream - Downstream) to minimize the flown HOM powers & redirect to wavguide dampers. (RF window issues)

HOM Power Levels in SRF Module





VSR Module Power Levels: Baseline Filling Patern

HOM Power [W]

Port	LSSL1	LSSL2	SSLL1	SSLL2
1	28,9	28,9	102,2	58,6
2	102,2	102,1	216,0	217,4
3	102,2	102,1	216,0	217,4
4	157,0	157,1	178,7	179,0
5	157,0	157,1	178,7	179,0
6	195,6	195,5	204,6	231,7
7	46,3	45,8	25,7	25,4
8	230,3	230,1	140,2	140,1
9	230,3	230,1	140,2	140,1
10	163,2	163,7	165,5	165,9
11	163,2	163,7	165,5	165,9
12	221,8	221,3	225,7	223,6
13	52,6	53,0	53,1	52,4
14	249,6	247,2	254,2	251,8
15	249,6	247,2	254,2	251,8
16	185,2	163,9	195,2	171,1
17	185,2	163,9	195,2	171,1
18	240,9	199,9	263,6	207,6
19	96,2	24,2	59,7	23,7
20	201,5	115,1	210,2	116,2
21	201,5	115,1	210,2	116,2
22	86,0	159,5	90,0	167,6
23	86,0	159,5	90,0	167,6
24	97,3	202,8	96,5	208,5
25	246,6	246,1	227,6	225,0
26	269,4	330,2	299,0	357,7
Total	4245 W	4225 W	4457 W	4432 W

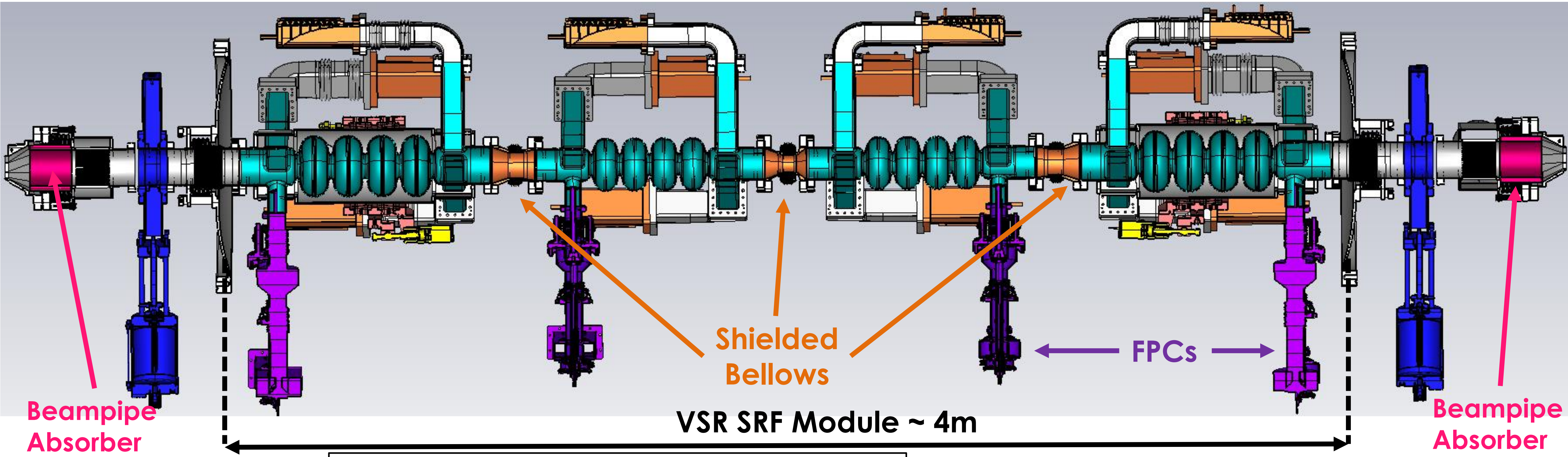
1.5 GHz

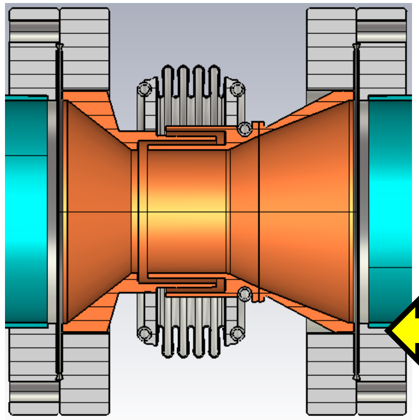
1.75 GHz Cavities

1.5 GHz

Beam pipes

Outlook





- Shielded bellows are required due to the cavity fundamental mode losses.
- Beampipe-Absorbers for more HOM damping, especially excited by interaction with warm components.
- Synchrotron light collimating bellow is required at module center.

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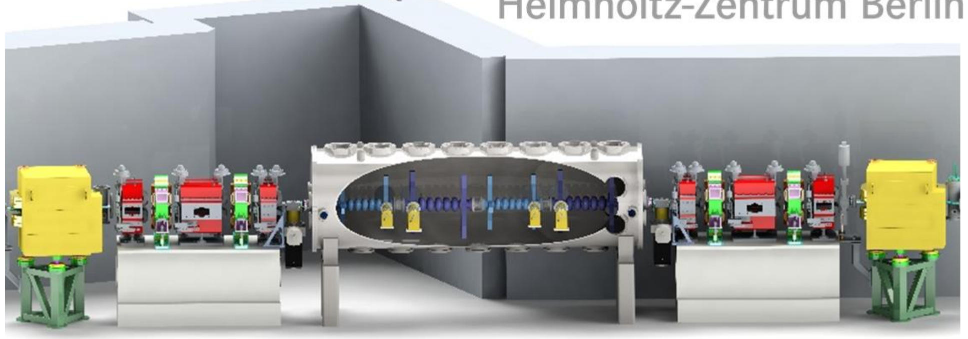

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