Design of the BESSY VSR Waveguide Damped Cavities & Ancillary Components for the Cold String

Dr. Andranik Tsakanian, on behalf of BESSY VSR Team

Helmholtz-Zentrum Berlin, Albert-Einstein-Str. 15, 12489 Berlin

ICFA Mini Workshop on HOMs in SRF Cavities

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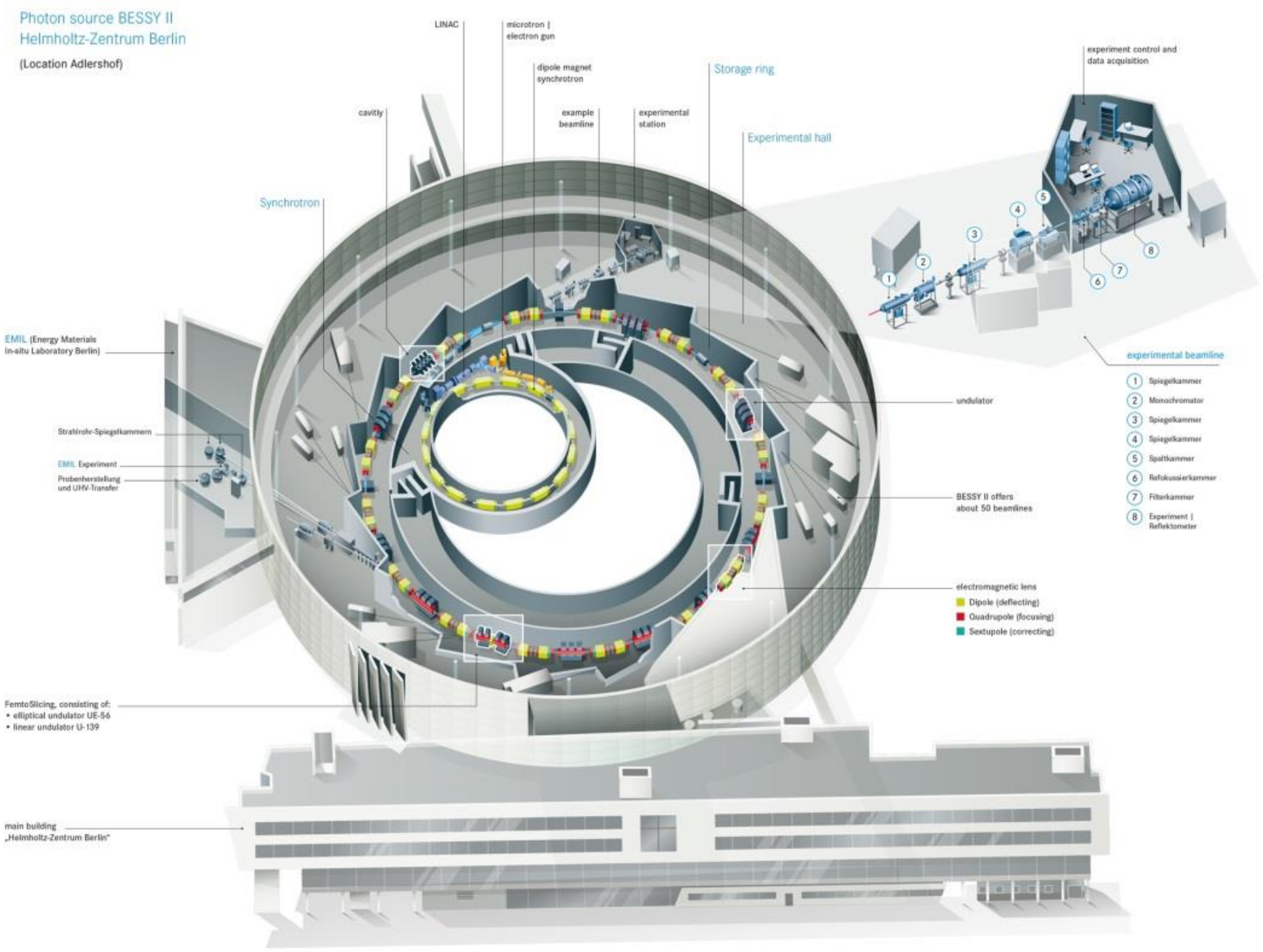
Ithaca, USA

Outline

- Introduction to BESSY II storage ring
- SRF Upgrade - BESSY VSR & Highlights
- SRF Cavity Specific Designs
- HOM Power Levels in SRF Module
- Ancillary Components for the Cold String
- HOM Power Levels in Cold String
- Outlook

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

- Limited pulse length in storage ring

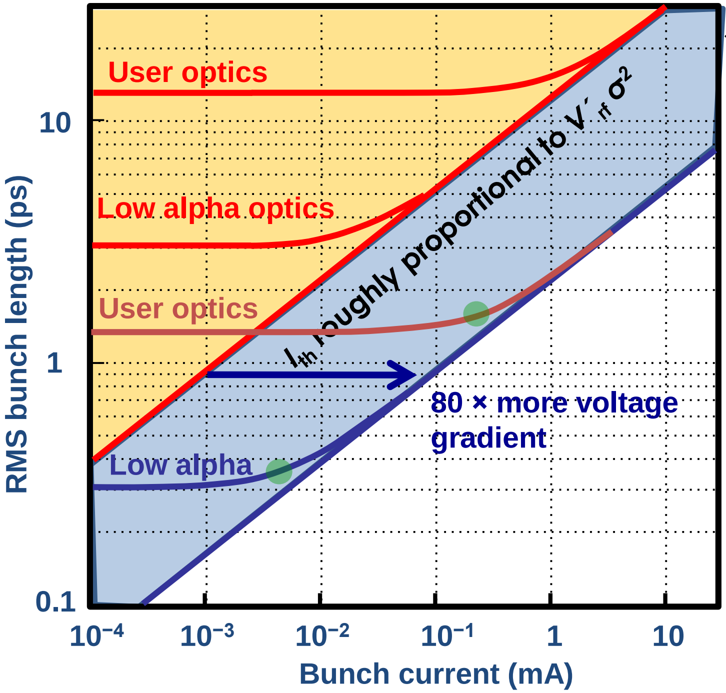
$$\sigma \propto \sqrt{\frac{\alpha}{\dot{V}_{\text{rf}}}}$$

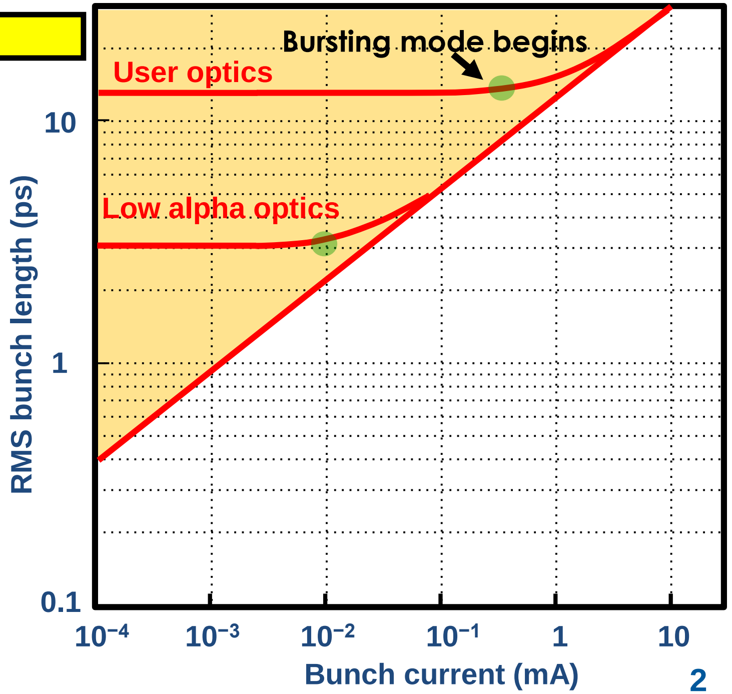
Machine optics

Hardware (RF cavities)

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

SC Upgrade



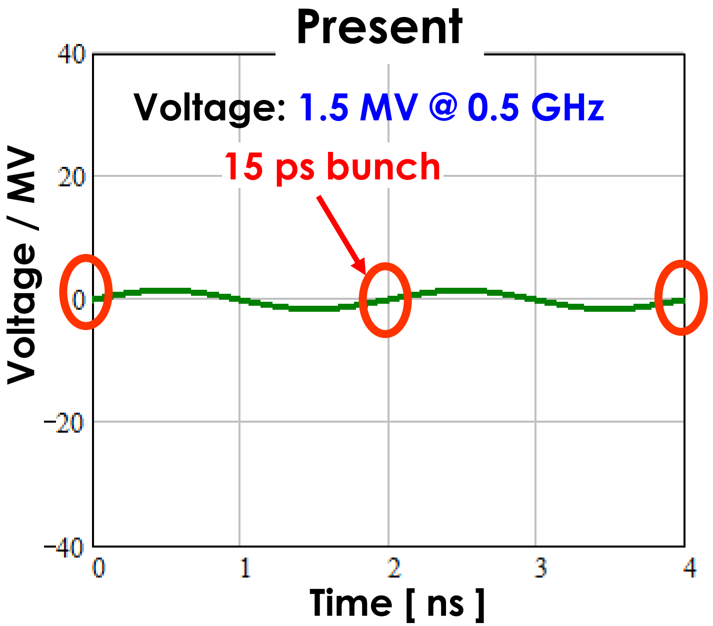


- ➢ **Supply short pulses down to 1.5 ps (100 × more bunch current)**
- ➢ **Low α permits few 100 fs pulses**
- ➢ **Configure BESSY$^{\text{VSR}}$ so 1.5 ps and 15 ps bunches can be supplied simultaneously for maximum flexibility and flux!**

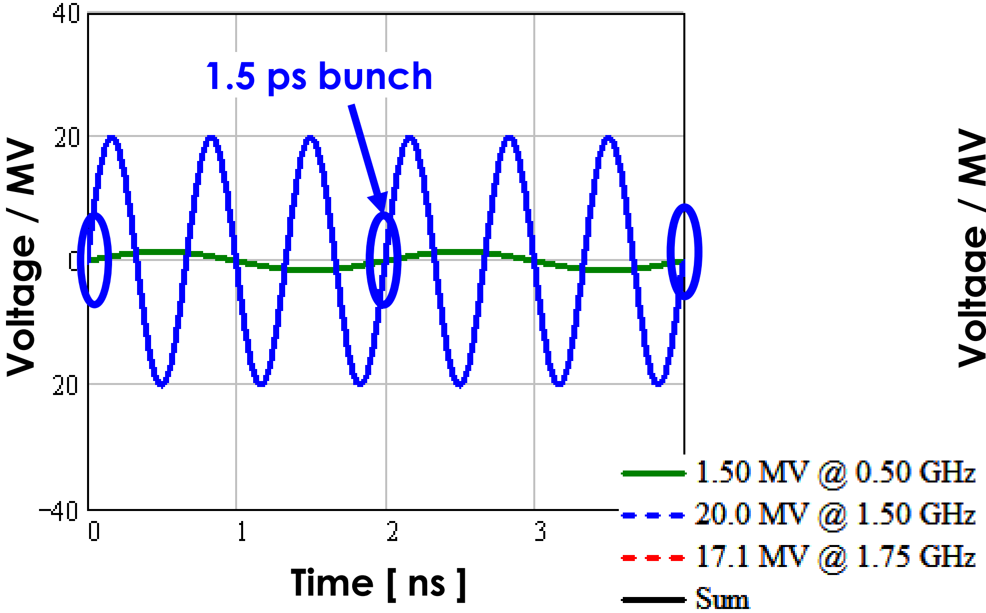
BESSY II, SC Upgrade – BESSY VSR

SC Upgrade

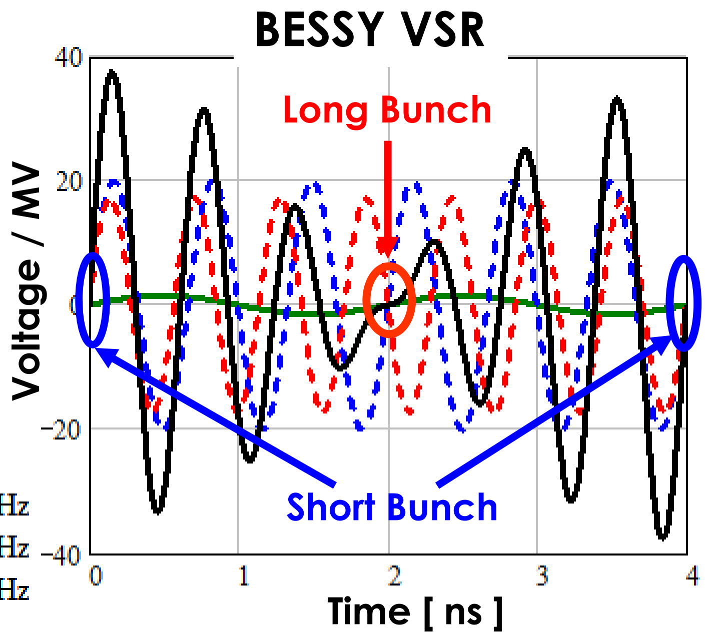
G.Wüstefeld et al. „Simultaneous long and short electron bunches in the BESSY II storage ring“ , IPAC2011



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



$$\dot{V} \propto V \times f_{rf} = 30\ MV \times GHz$$



$$\dot{V} \propto V \times f_{rf} = 60\ MV \times GHz$$

- 1.5GHz and 1.75GHz ---- RF beating
  (modulate RF focusing)
- Odd (voltage cancelation, 15 ps bunches)
- Even (voltage addition, 1.1 ps)

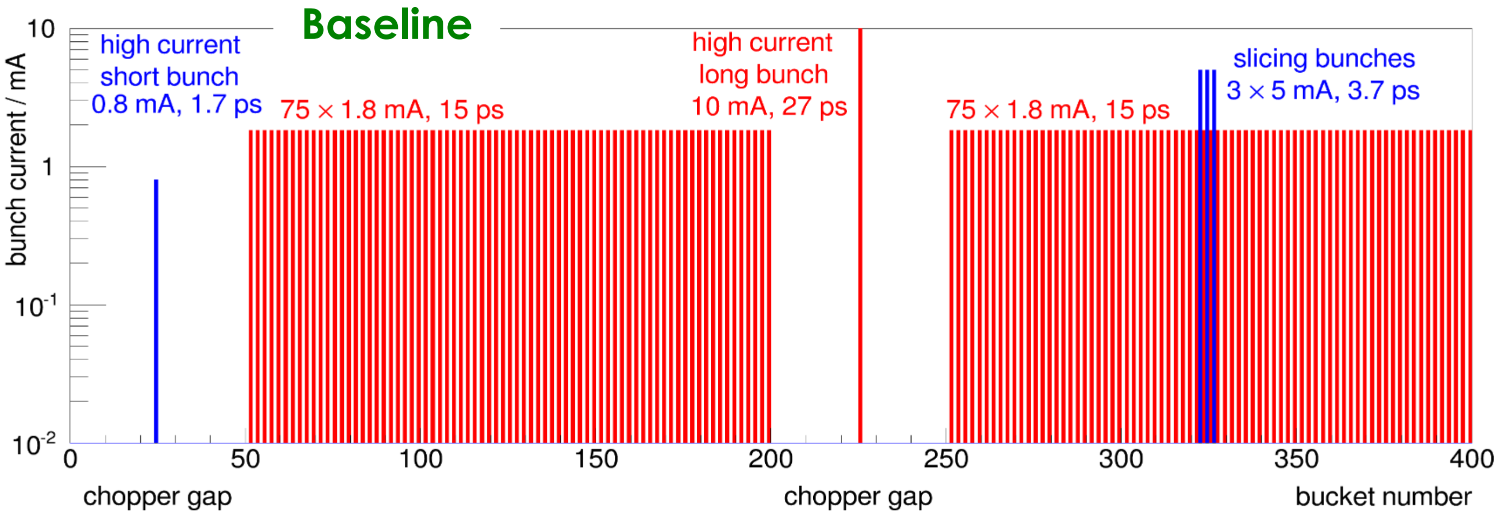
BESSY II, SC Upgrade – BESSY VSR

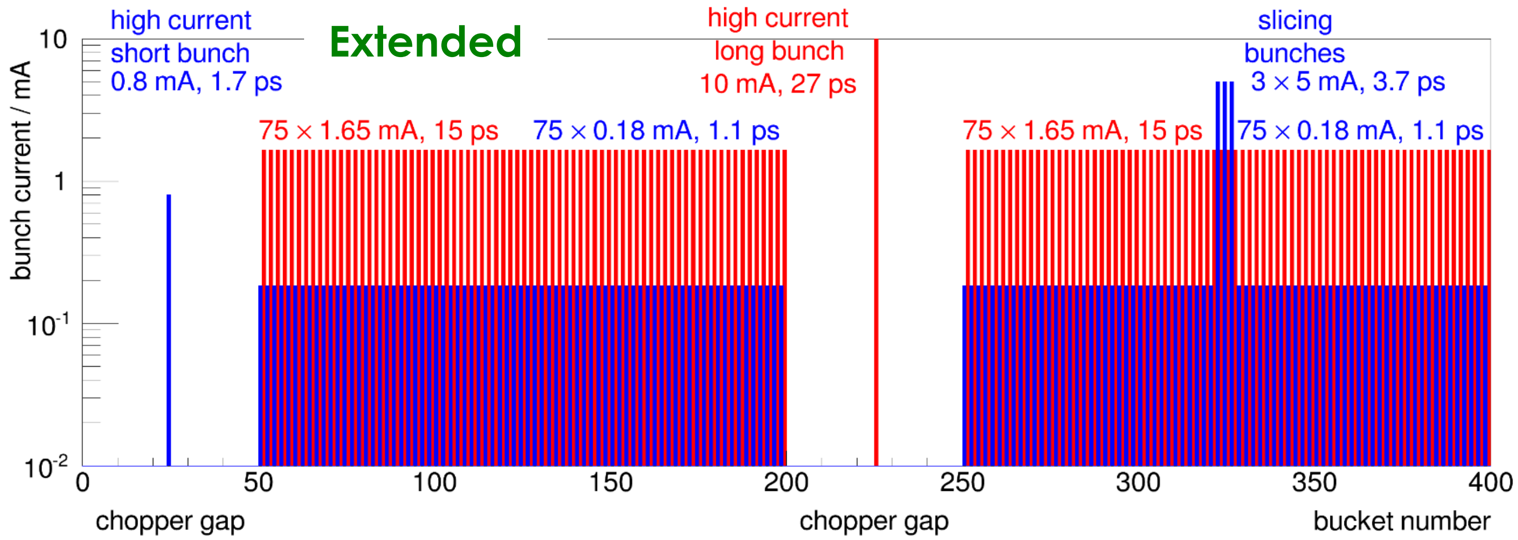
BESSY VSR Filling Patterns

- **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**





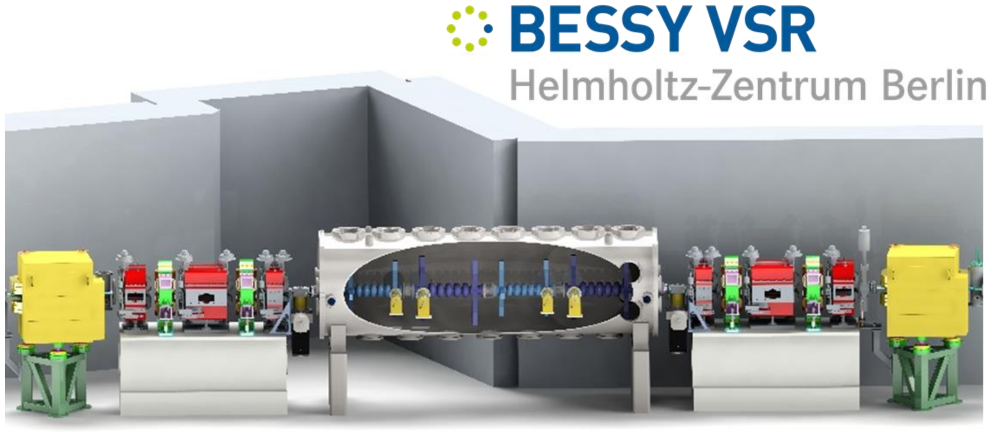
BESSY II SC Upgrade – BESSY VSR

- Simultaneous Store of long & short bunches

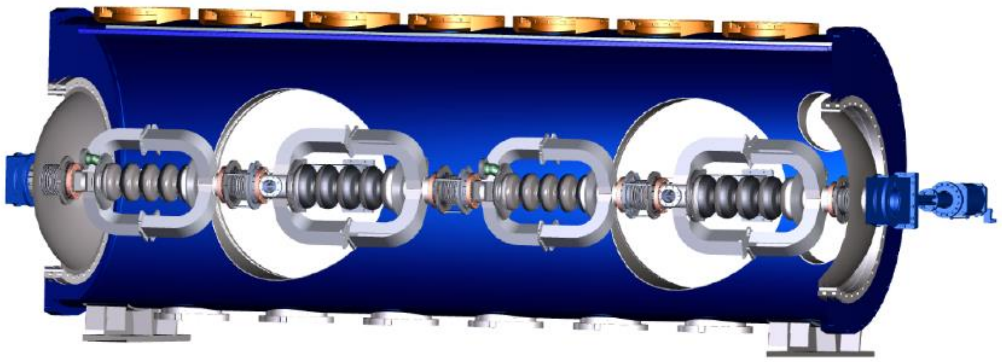
SC Upgrade

BESSY VSR

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



- **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.**

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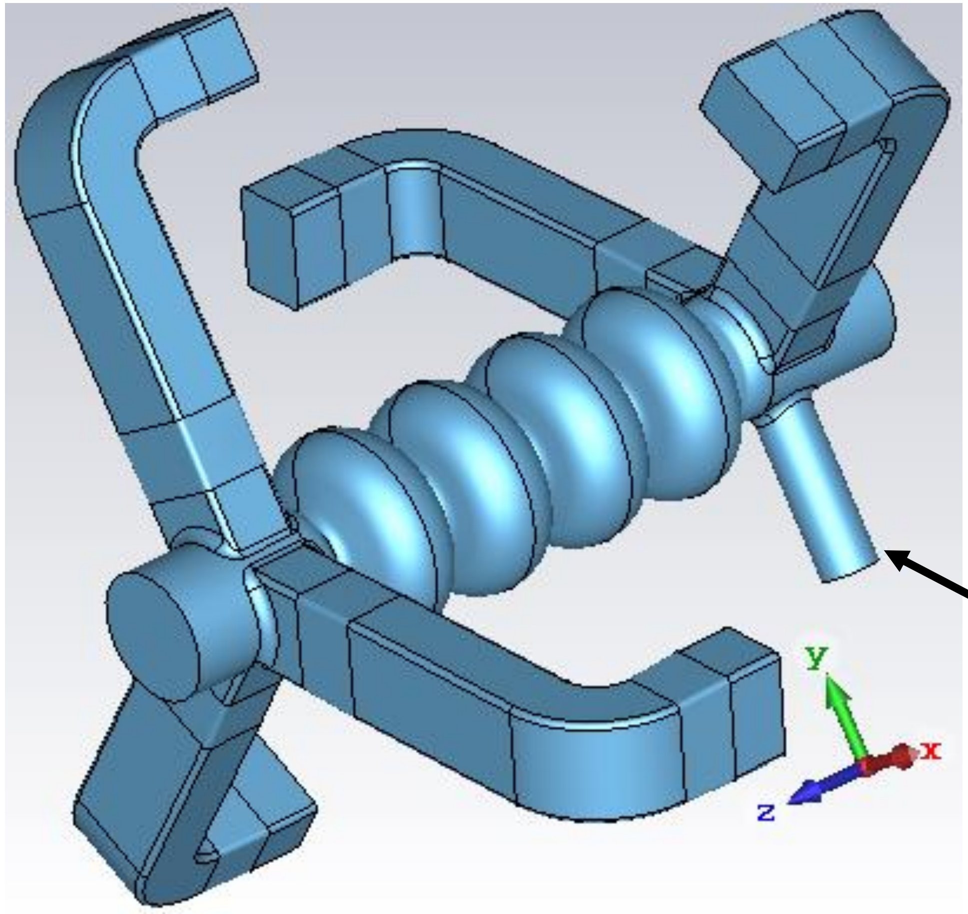
BESSY VSR SRF Cavity Designs

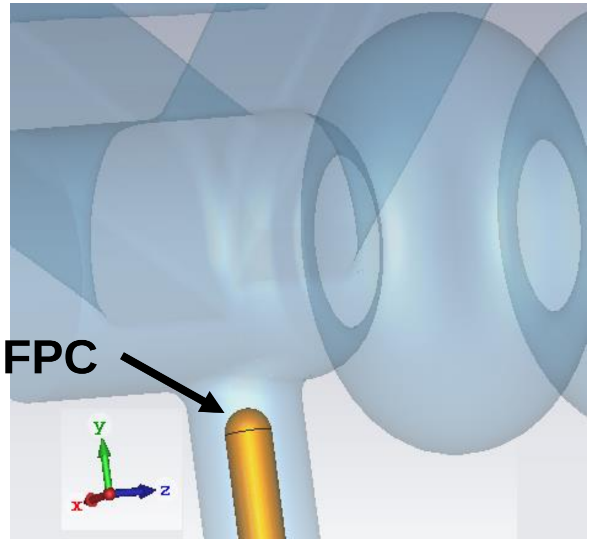
- Tune fundamental mode: field flatness, R/Q …
- Control cavity HOM spectrum (off-resonance condition) during the design.

Strong HOM Damped SRF Cavity Concepts

Cavity with HOM WG Dampers

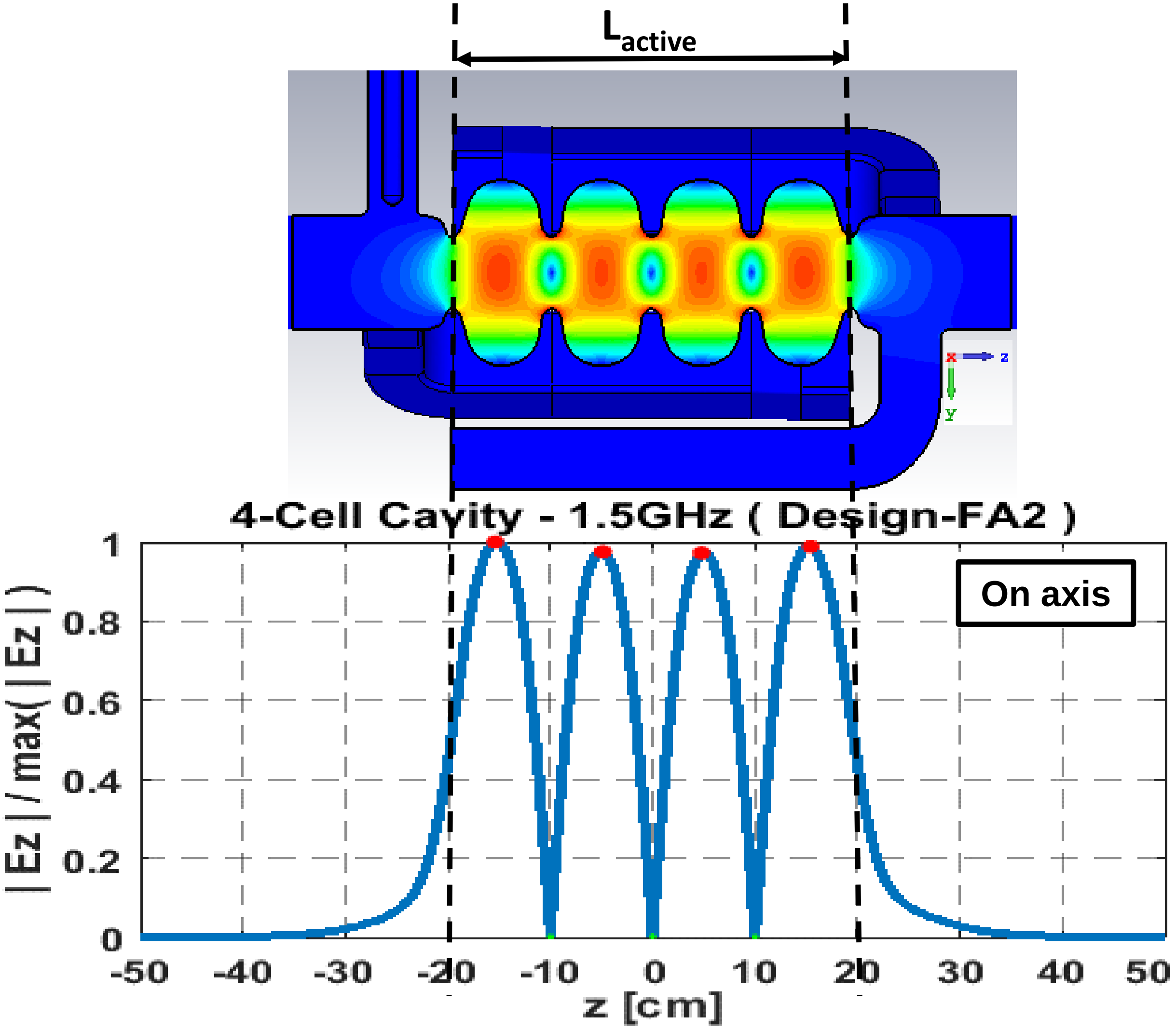


- 5 x Waveguide dampers, HOM loads (warm)
- Large beampipe radius – better HOM propagation
- Waveguides are below cutoff for fundamental → can be moved close to the cavity for heavy damping.



BESSY VSR SRF Cavity Designs

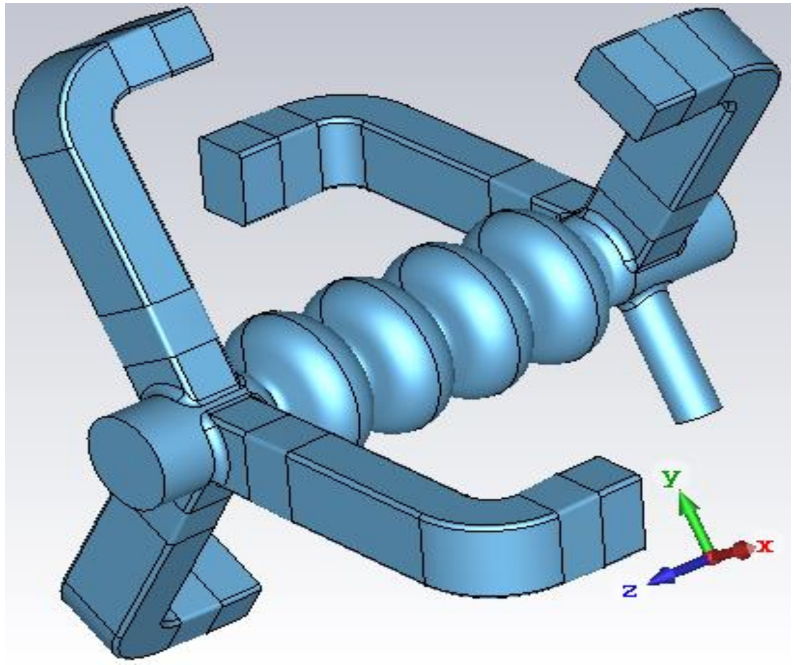
Simulation Results – for both Cavity (TM_{010} π-mode)			
	1.5GHz	1.75GHz	Design goal
Number of Cells	4		
L_{active}	0.4 m	0.344 m	
Frequency [GHz]	1.4990	1.7489	3th & 3.5th harm. of 499.65 MHz
Q_{ext}	$4.99*10^7$	$4.28*10^7$	
G [Ω]	277.63	275.42	
E_{pk} / E_{acc}	2.32	2.30	≤ 2.4
B_{pk} / E_{acc} [mT / (MV/m)]	4.98	5.13	≤ 5.3
R/Q [Ω]	386	380	≥ 90 per cell
Field Flatness - μ_{ff}	97%	99 %	≥ 95%

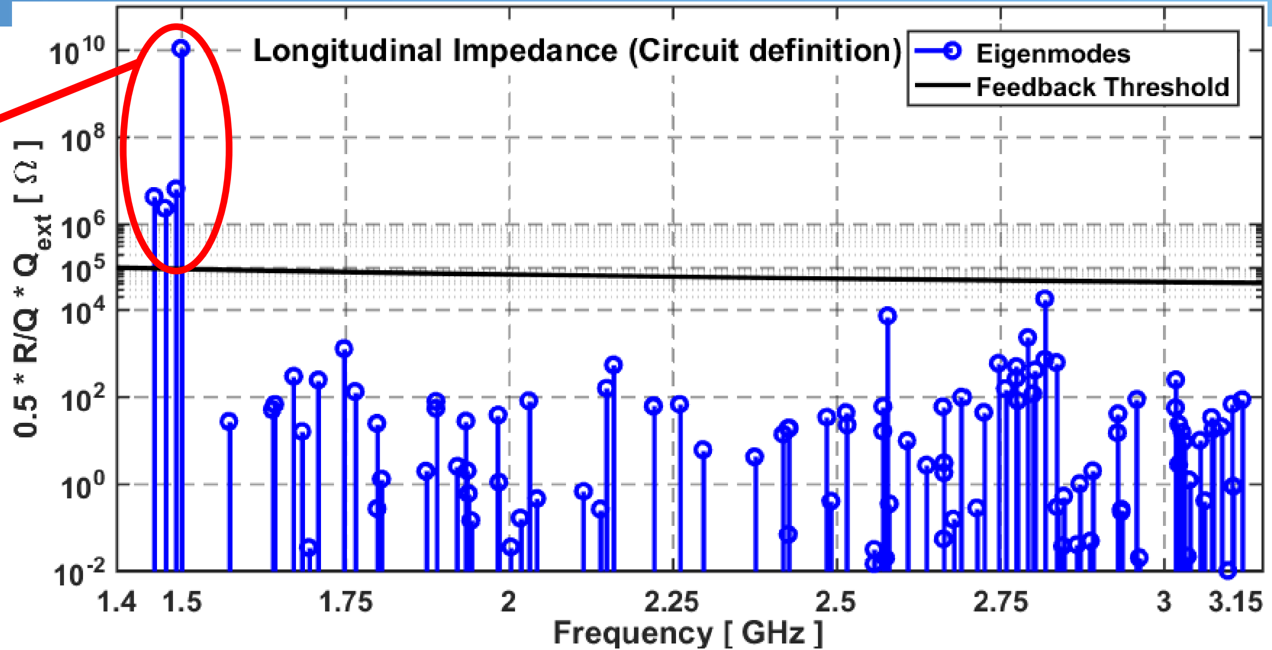


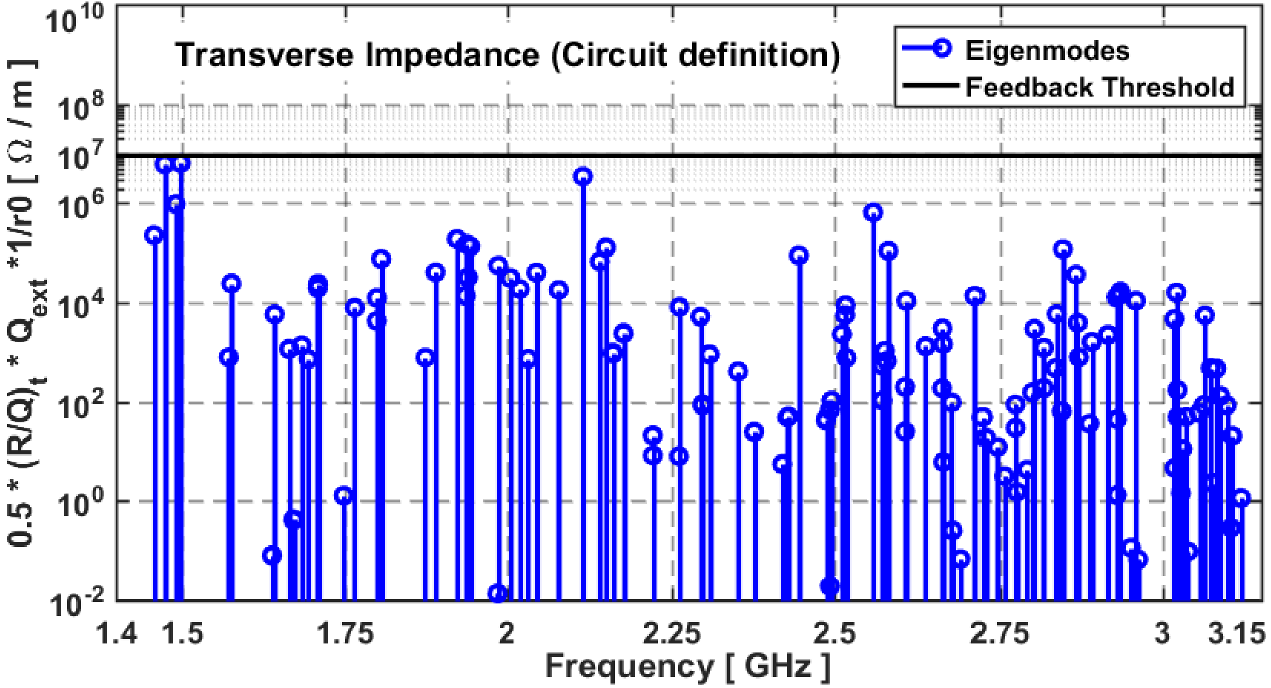
VSR 1.5GHz Cavity Impedances from Eigenmodes

Monopole Band

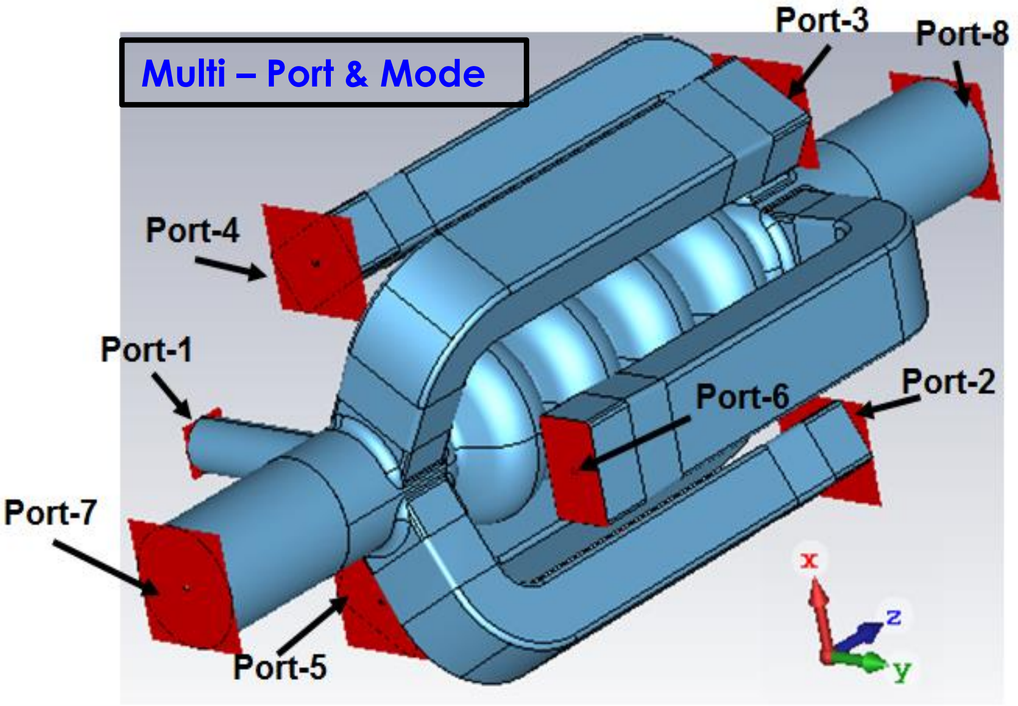
	Frequency [GHz]	R/Q [Ω]	Q_{ext}	Mode Type
1	1.49866	386	$5.00\cdot10^7$	π
2	1.49134	0.41	$2.98\cdot10^7$	2π/3
3	1.47424	0.09	$4.74\cdot10^7$	π/2
4	1.45785	0.05	$1.60\cdot10^8$	2π







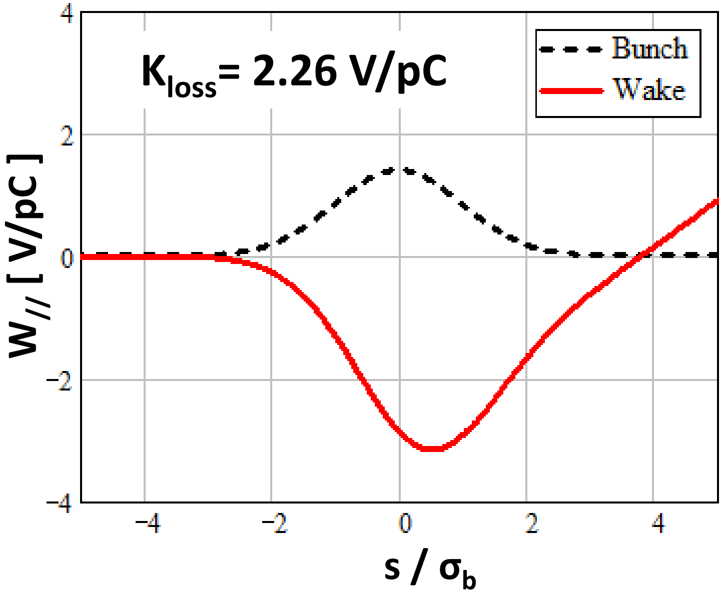
BESSY VSR SRF Cavity Designs

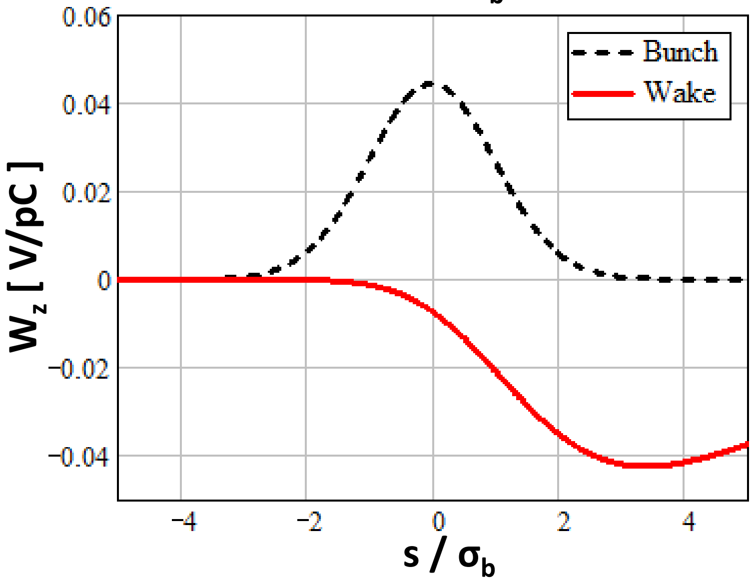


Setup Wakefield Solver

- 5 x WG ports – 15 mode
- FPC port – 10 mode
- 2 x Bmp – 40 mode

Shot Range Wakes





Simulation Consistency

- Energy loss in all ports ~ 1.46 µJ < 2.26 µJ (bunch loss). About 35% of EM energy still remains in fundamental mode.

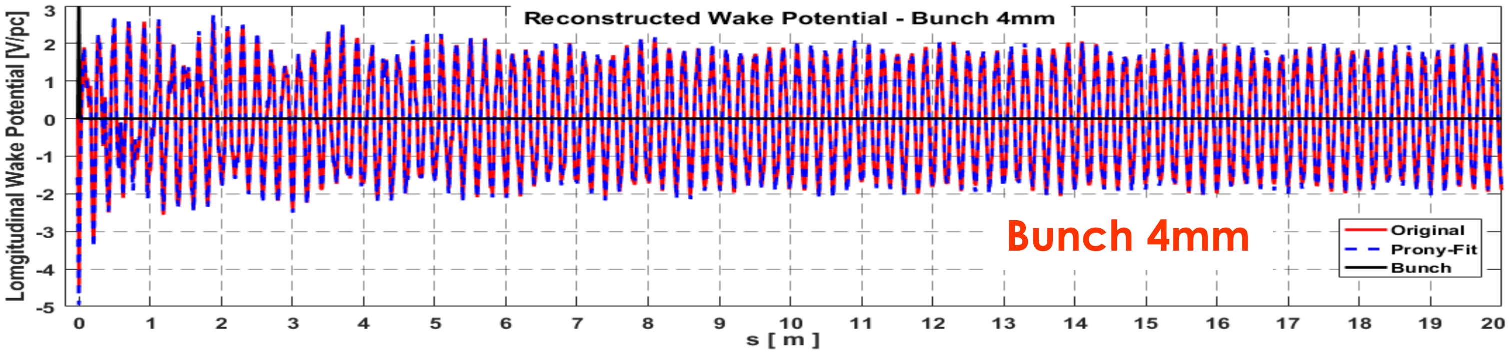
- The vertical kick of fundamental-power-coupler can be compensated by 180 degree rotation of second 1.5GHz Cavity.
- Horizontal kick is 10K times smaller than vertical.

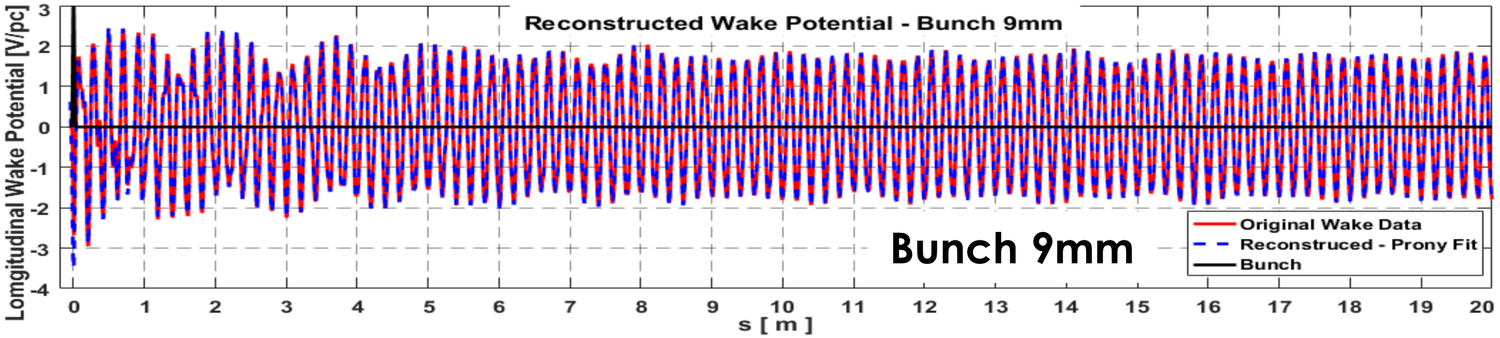
Resonant Mode Extraction from Wakes : Pole-Fitting

Bunch Path -off axis XY=2.1mm

$$W(s) = \sum_{\nu} 2\, K_\nu \cos\left(\frac{\omega_\nu}{c} s\right) e^{-\alpha_\nu s}$$

$$\alpha_\nu = \omega_\nu /(c\ 2\ Q_{loaded})\ ,\ R/Q[\Omega] = \frac{4\, K_\nu\, [V/pC]}{\omega_\nu\, [GHz]} 10^3 \quad (Linac)$$





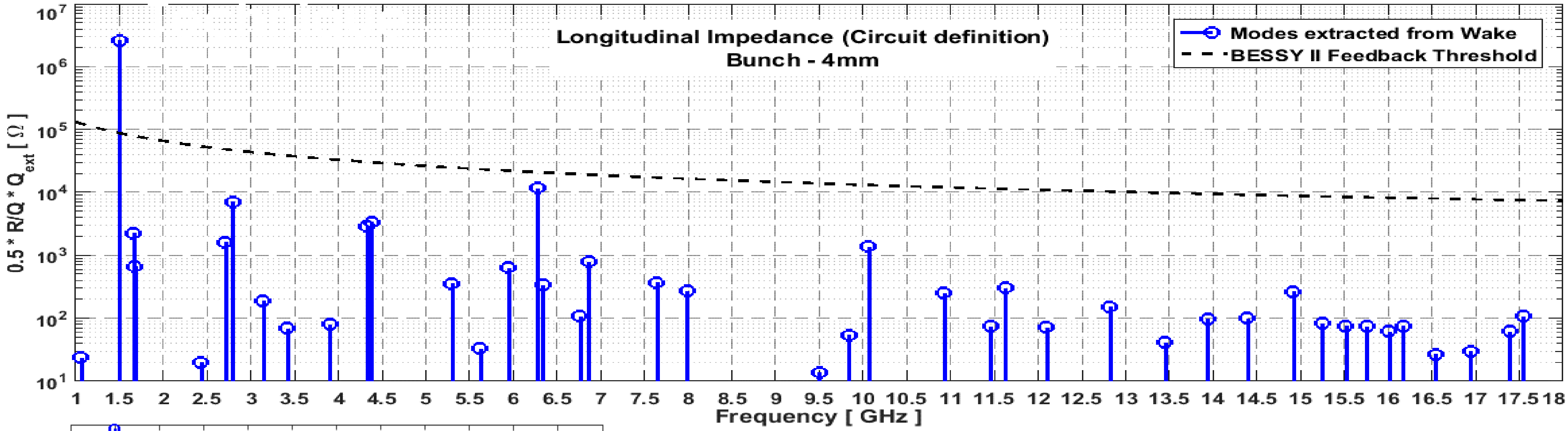
Prony-Pisarenko Fit

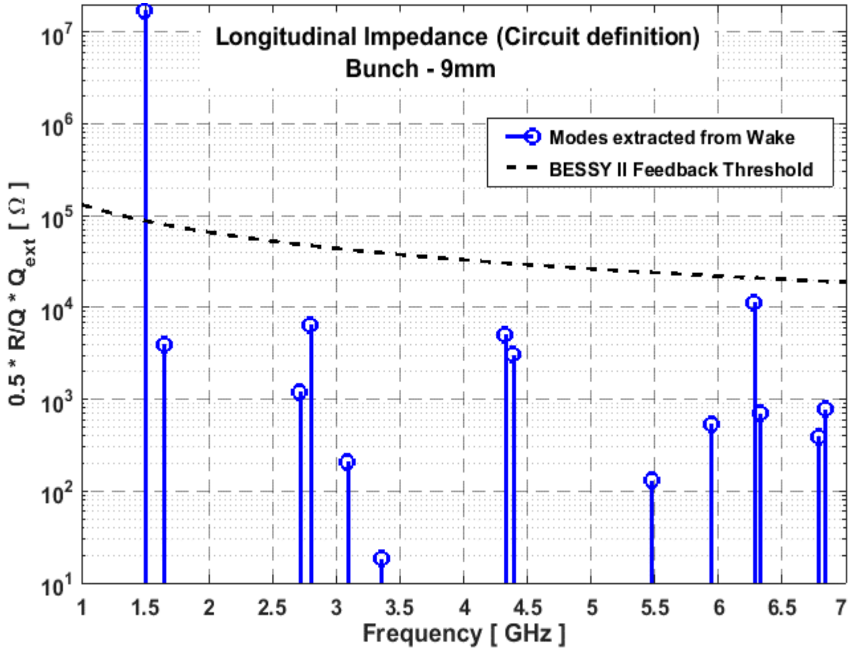
Circuit definition

N	Freq. [GHz]	R / Q [Ω]	Q_{loaded}	$0.5 \cdot R/Q \cdot Q_{loaded}$ [Ω]
1	1.499 1.499	386.46 420.44	8.97e+4 1.25e+4	1.73e+7 2.64e+6
2	1.649 1.657	17.877 26.45	4.46e+2 1.69e+2	3.99e+3 2.24e+3
3	2.713 2.709	7.05 7.047	3.4e+2 4.61e+2	1.2e+3 1.62e+3
4	2.794 2.793	130.0 143.02	1.0e+2 9.85e+1	6.5e+3 7.04e+3
5	4.326 4.330	7.535 10.65	1.34e+3 5.5e+2	5.05e+3 2.92e+3
6	4.385 4.384	21.19 25.39	2.87e+2 2.65e+2	3.04e+3 3.36e+3
7	5.941 5.944	3.939 5.233	2.76e+2 2.42e+2	5.43e+2 6.32e+2
8	6.280 6.278	9.88 10.12	2.3e+3 2.32e+3	1.13e+4 1.17e+4
9	6.324 6.339	3.713 8.960	3.79e+2 7.43e+1	7.04e+2 3.33e+2
10	6.836 6.863	3.815 4.128	4.04e+2 3.79e+2	7.72e+2 7.82e+2

- Pole-fitting gives quantitative estimate on the resonances of the system (Mode type undefined).
- For the fundamental mode Qext=5e7 should be used, because the wake length 20m is too short to extract such high Qext.
- The search for best fit is done manually, it depends on frequency range & filter settings in the algorithm.

Resonant Mode Extraction from Wakes : Pole-Fitting

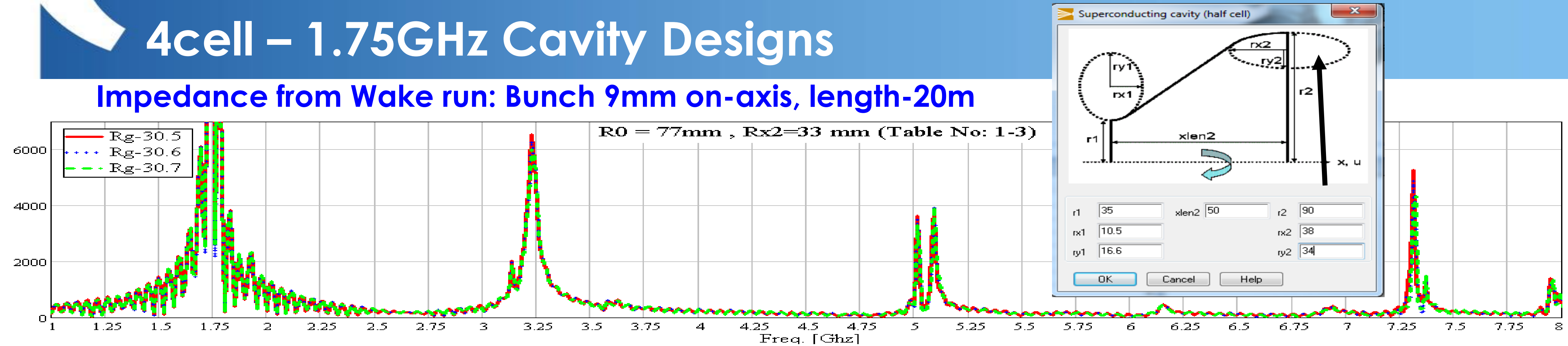




- The discrepancy at high frequencies - above 5GHz , is because of simulation accuracy, i.e. the time signal in 4mm bunch simulation contains this part of the spectrum & have better accuracy.
- Pole fitting is a fast estimate of the resonances in the system (low resolution).
- Eigenmode analyses is required (High resolution). At high frequencies >4GHz is very time consuming & requires huge hardware resources.

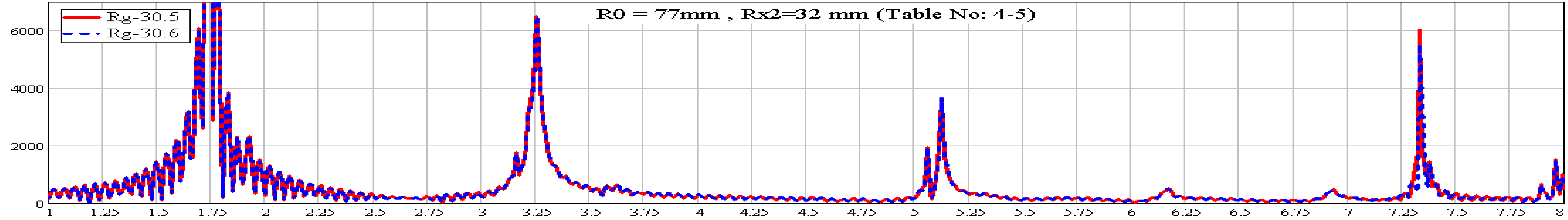
4cell – 1.75GHz Cavity Designs

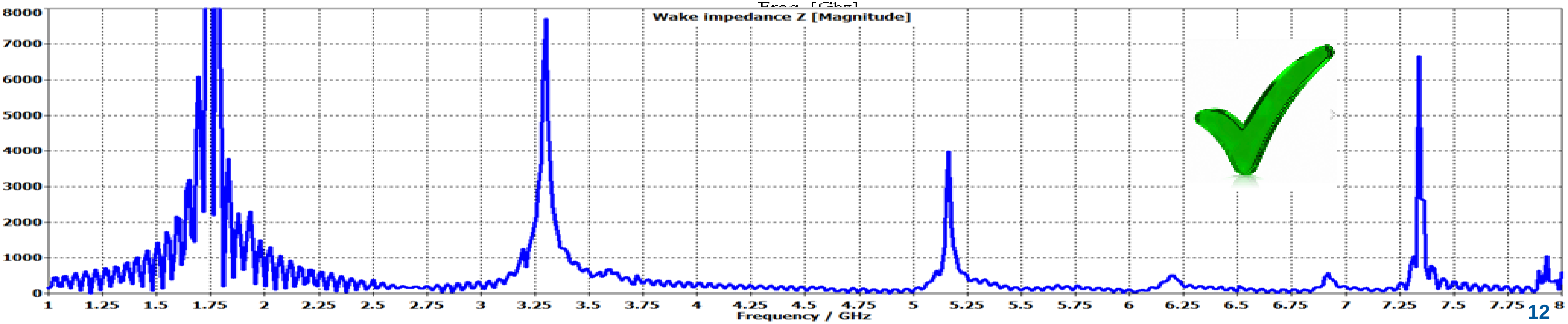
Impedance from Wake run: Bunch 9mm on-axis, length-20m



Superconducting cavity (half cell)

r1 35
xlen2 50
r2 90
rx1 10.5
rx2 38
ry1 16.6
ry2 34

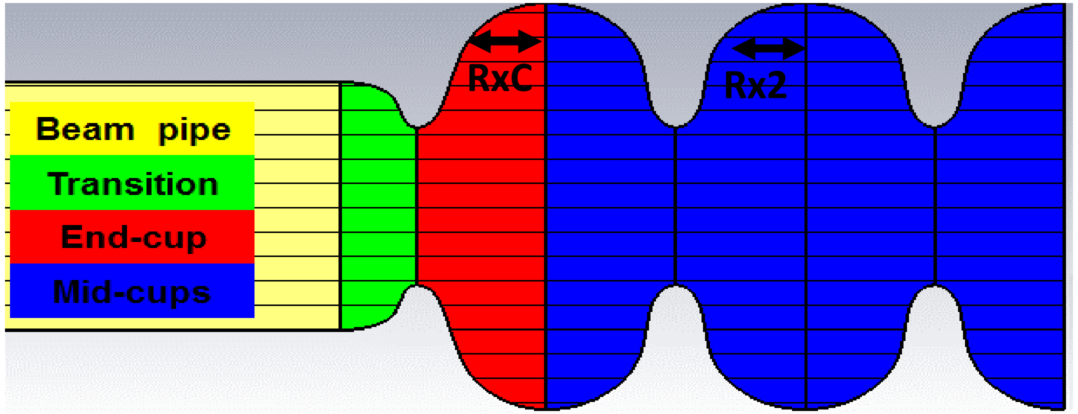


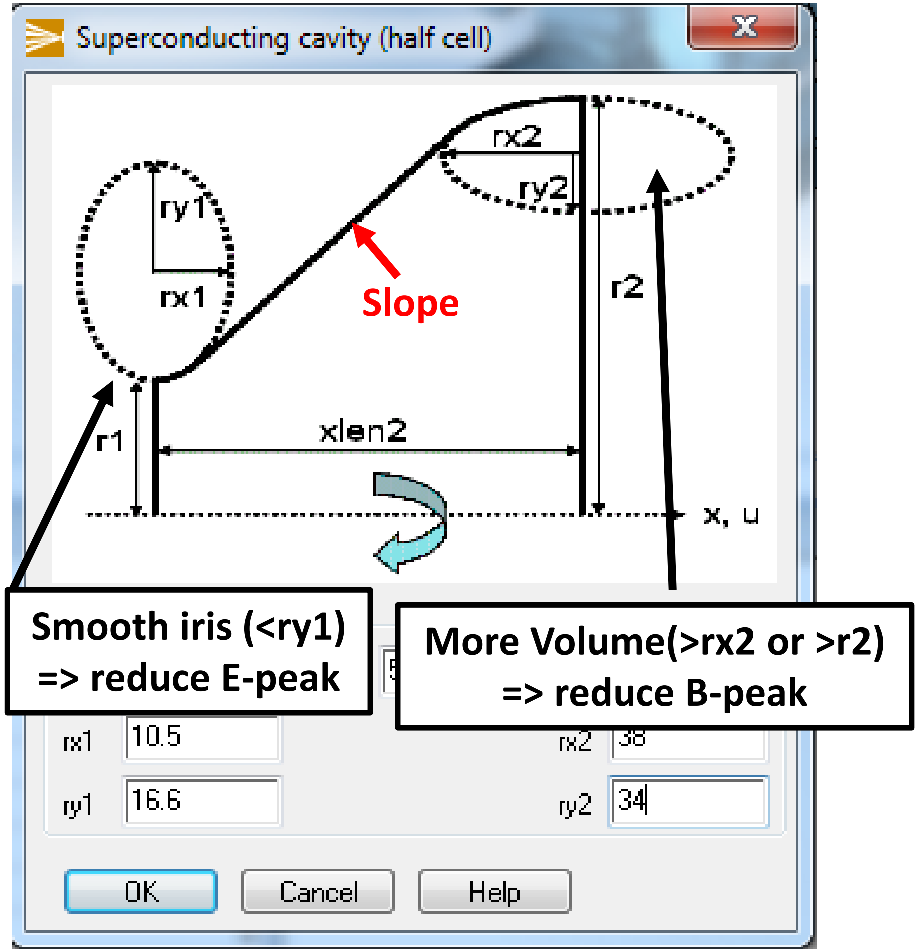


BESSY VSR SRF Cavity Designs

Geometry Parameters for Accelerating Mode & HOM Control

- **Rx2/RxC** – field flatness (not sensitive on other parameters)
- **HOM spectrum shift is sensitive on cell-slope**
  (for tuned fundamental)
- **Design:**
  1. Fix iris radius (Shunt impedance)
  2. Ensure field flatness >95% (Rx2/RxC , fixed slope)
  3. Tune fundamental frequency by r2, check B-peak.
  4. Check HOM spectrum



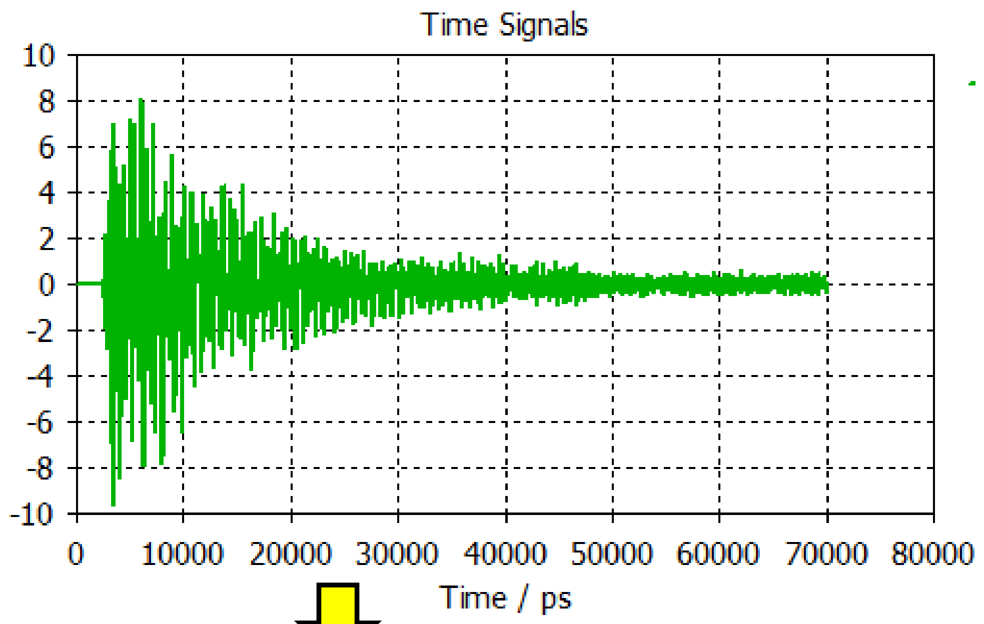


rx1 10.5
ry1 16.6
rx2 38
ry2 34

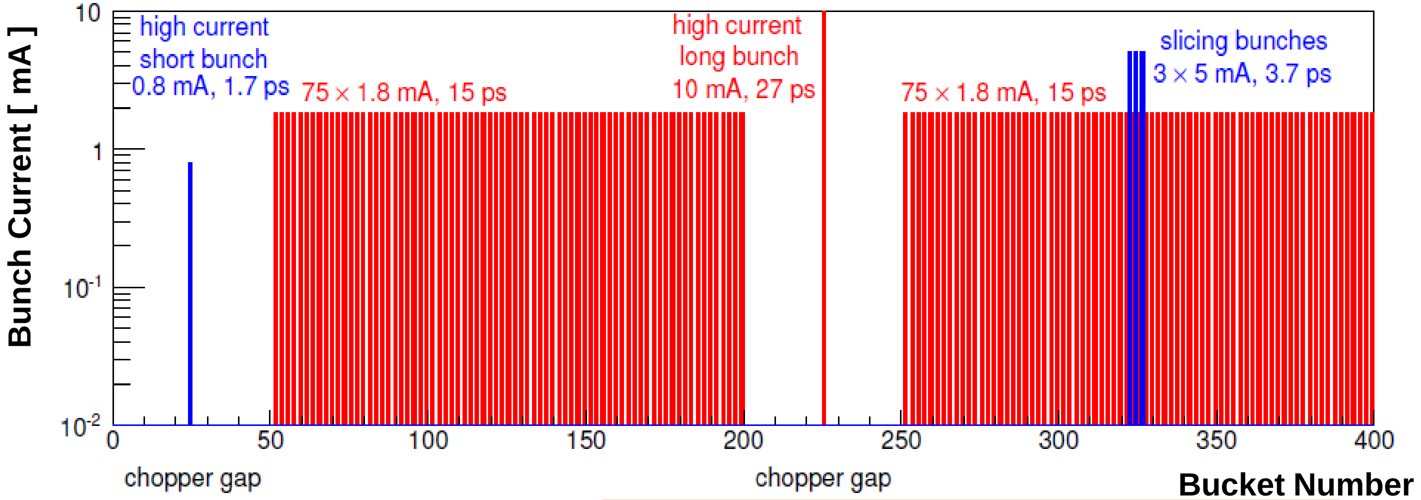
Smooth iris (<ry1)
=> reduce E-peak

More Volume(>rx2 or >r2)
=> reduce B-peak

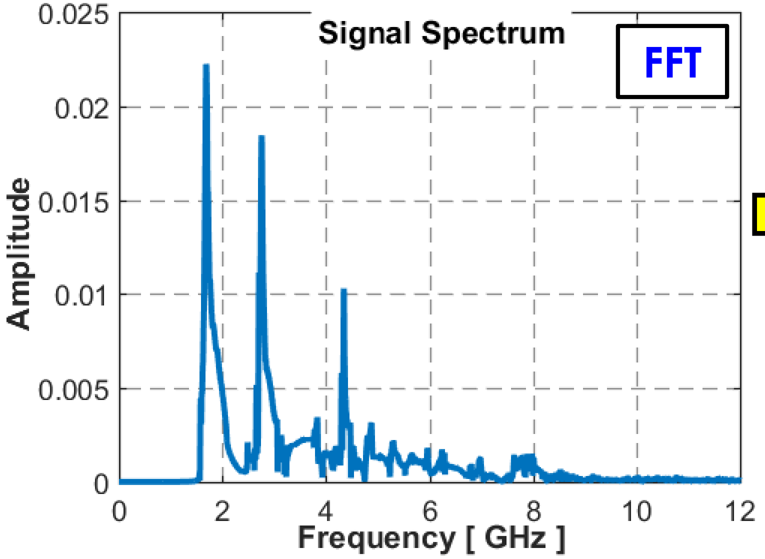
Signal Spectral Weighting Technique



Bunch Train - Baseline



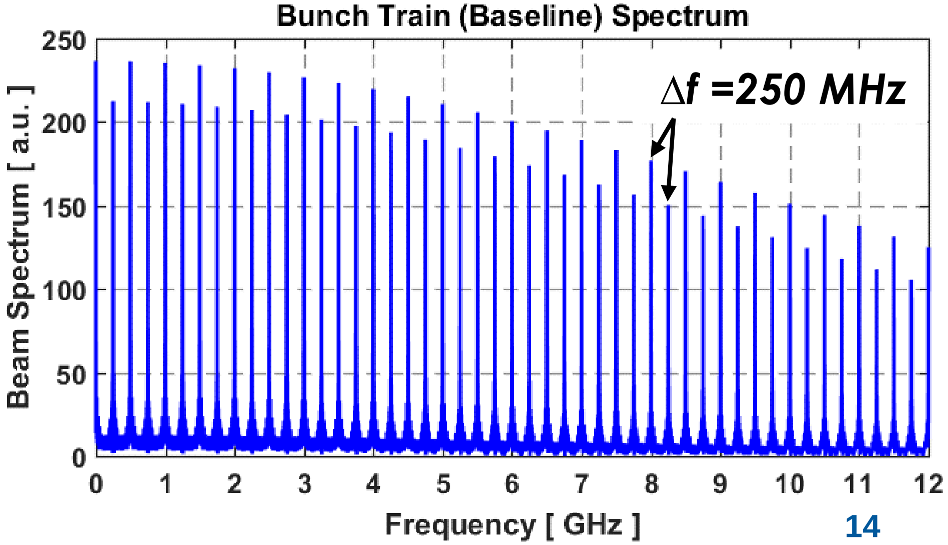
$$\tilde{I}_b(\omega) = f_{rev} \sum_n q_n \cdot e^{-0.5 \cdot \omega^2 \sigma_n^2} \cdot e^{j\,\omega\, t_{0,n}}$$



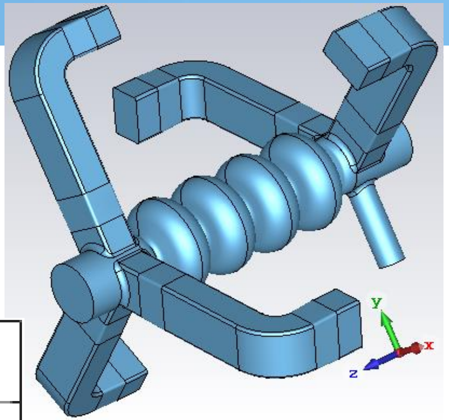
Spectral weighting of port signal & Power per freq. bins (FFT)

$$P(\omega) = \left| \frac{\tilde{I}_b}{\tilde{I}_0} \mathcal{F}(\omega) \right|^2$$

$\tilde{I}_0$ - Simulated single bunch

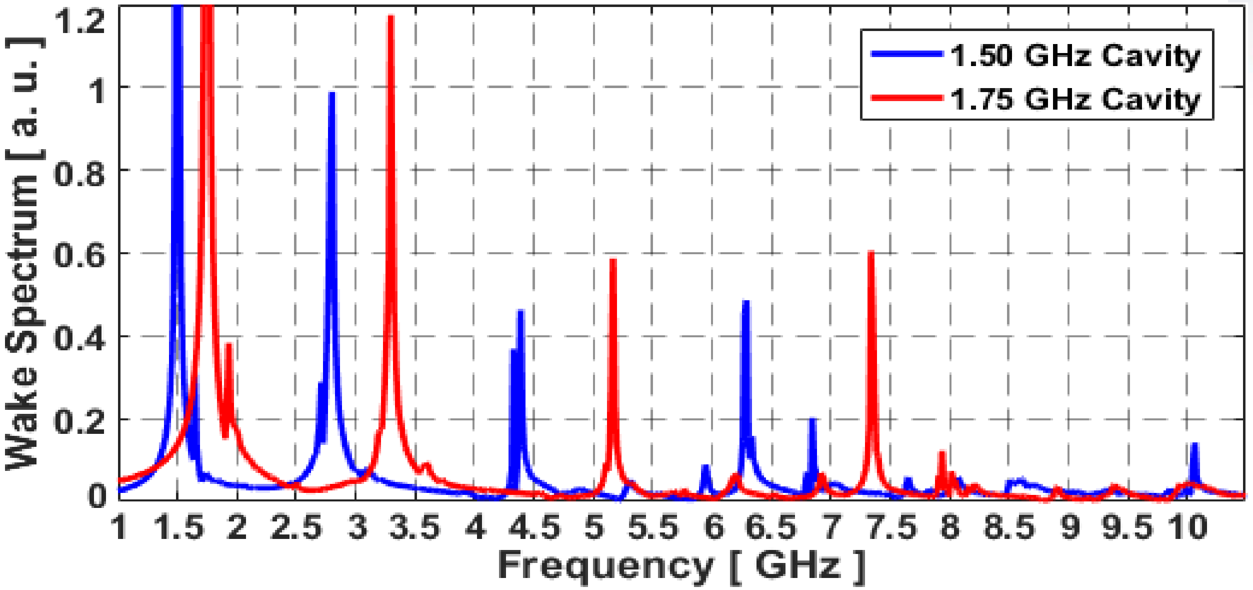


HOM Power of Single Cavity – VSR Baseline beam



Spectrally Weighted with "Baseline" pattern

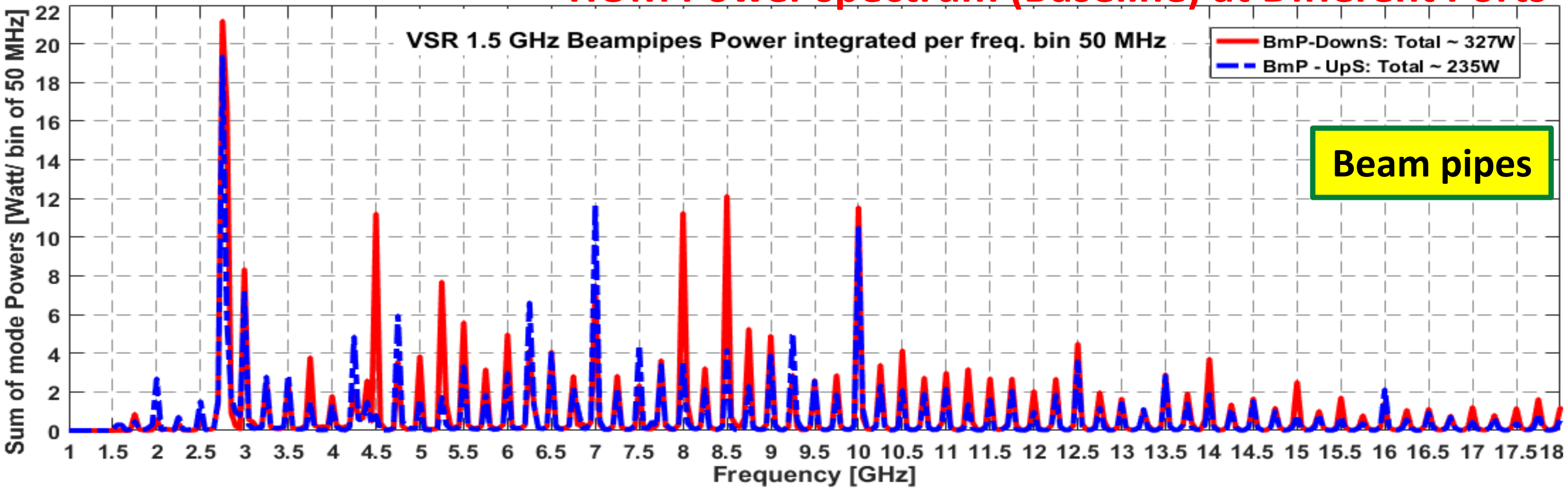
Cavity Type	1.5GHz	1.75GHz
Port No.	HOM Power [W]	
1 – FPC(1)	37.9	33.8
2 – WG(1)	105.3	154.7
3 – WG(1)	103.8	151.4
4 – WG(2)	88.5	108.3
5 – WG(2)	90.2	109.8
6 – WG(2)	90.6	111.6
7 – BmP(Upstream)	235.4	200.5
8 – BmP(Downstream)	327.1	275.9
Total Coherent	**1079**	**1146**
None-Coherent	**1293**	**1300**



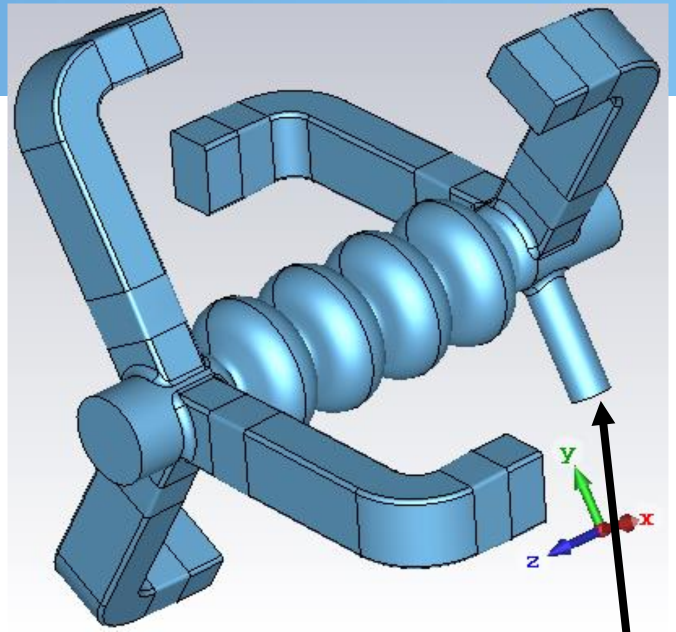
- **Both cavities are not hitting any of beam resonances that are multiple of 250MHz (Coherent and none-coherent powers are at the same level).**
- **Cornell's ERL cavities are designed to run at about 100-200W HOM Power.**

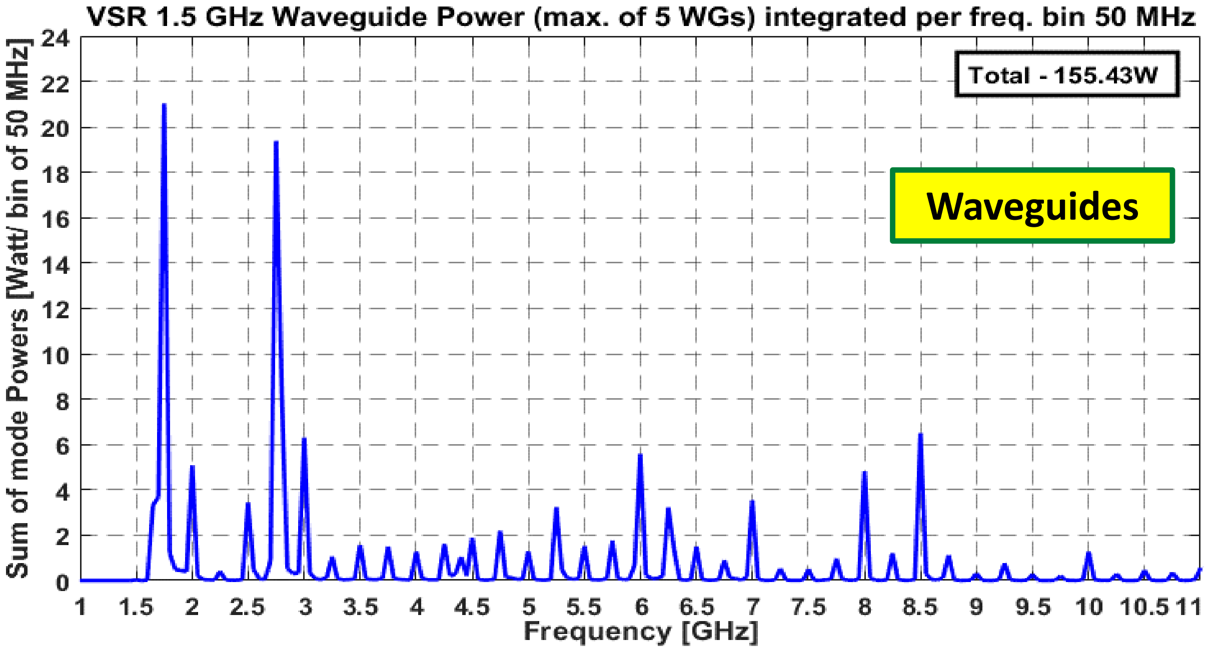
HOM Power of Single Cavity 1.5GHz

HOM Power spectrum (Baseline) at Different Ports

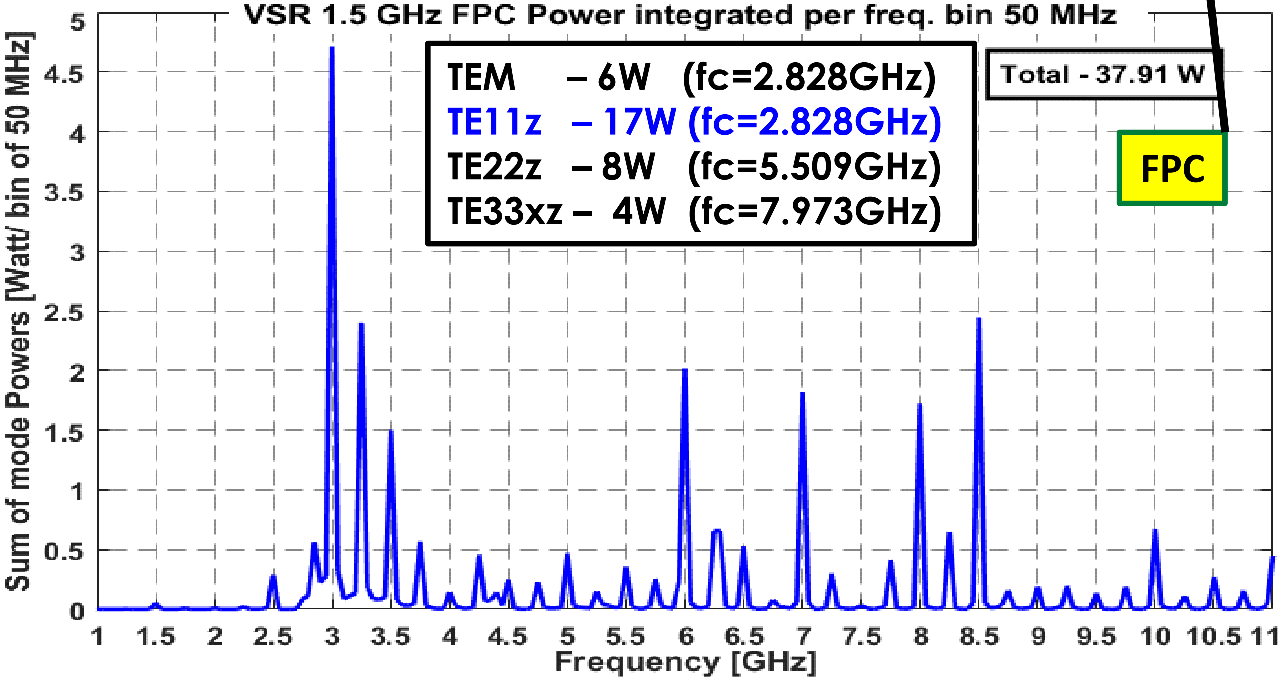

VSR 1.5 GHz Beampipes Power integrated per freq. bin 50 MHz

Beam pipes




VSR 1.5 GHz Waveguide Power (max. of 5 WGs) integrated per freq. bin 50 MHz

Waveguides


VSR 1.5 GHz FPC Power integrated per freq. bin 50 MHz

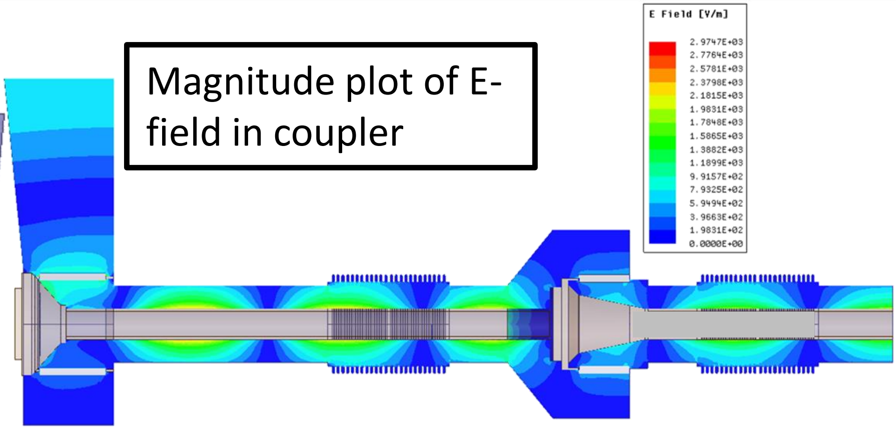
TEM – 6W (fc=2.828GHz)
TE11z – 17W (fc=2.828GHz)
TE22z – 8W (fc=5.509GHz)
TE33xz – 4W (fc=7.973GHz)

FPC

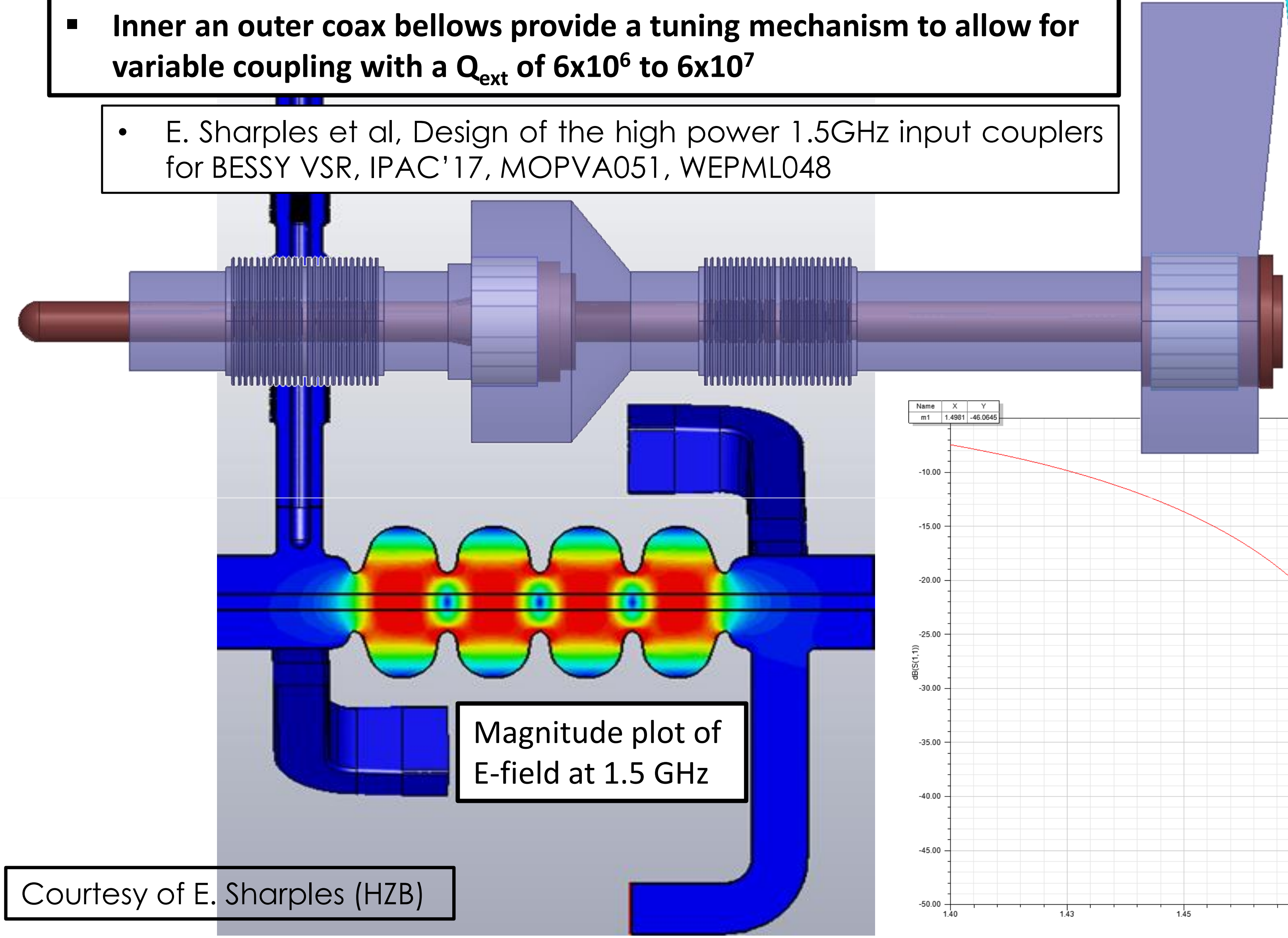
Design of the 1.5 GHz BESSY VSR coupler

- **Coax coupler diameters: 49 mm x 20 mm.**
- **Two ceramic windows to maintain vacuum.**
- **Inner an outer coax bellows provide a tuning mechanism to allow for variable coupling with a Q_{ext} of $6x10^6$ to $6x10^7$**

- E. Sharples et al, Design of the high power 1.5GHz input couplers for BESSY VSR, IPAC'17, MOPVA051, WEPML048



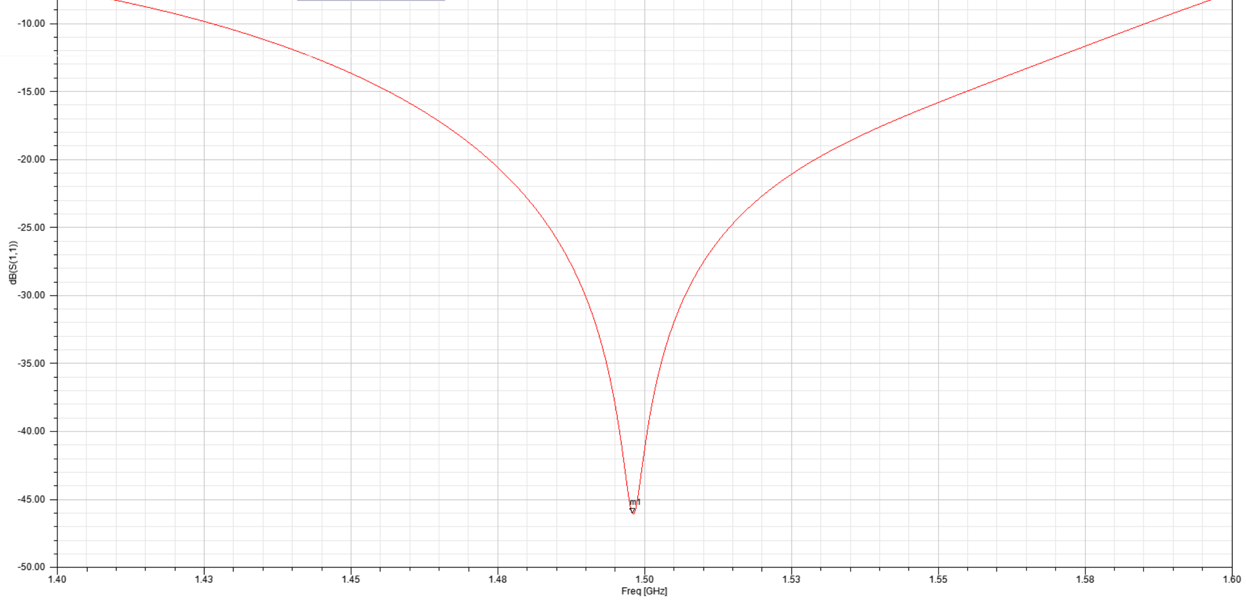
Magnitude plot of E-field in coupler



Magnitude plot of E-field at 1.5 GHz

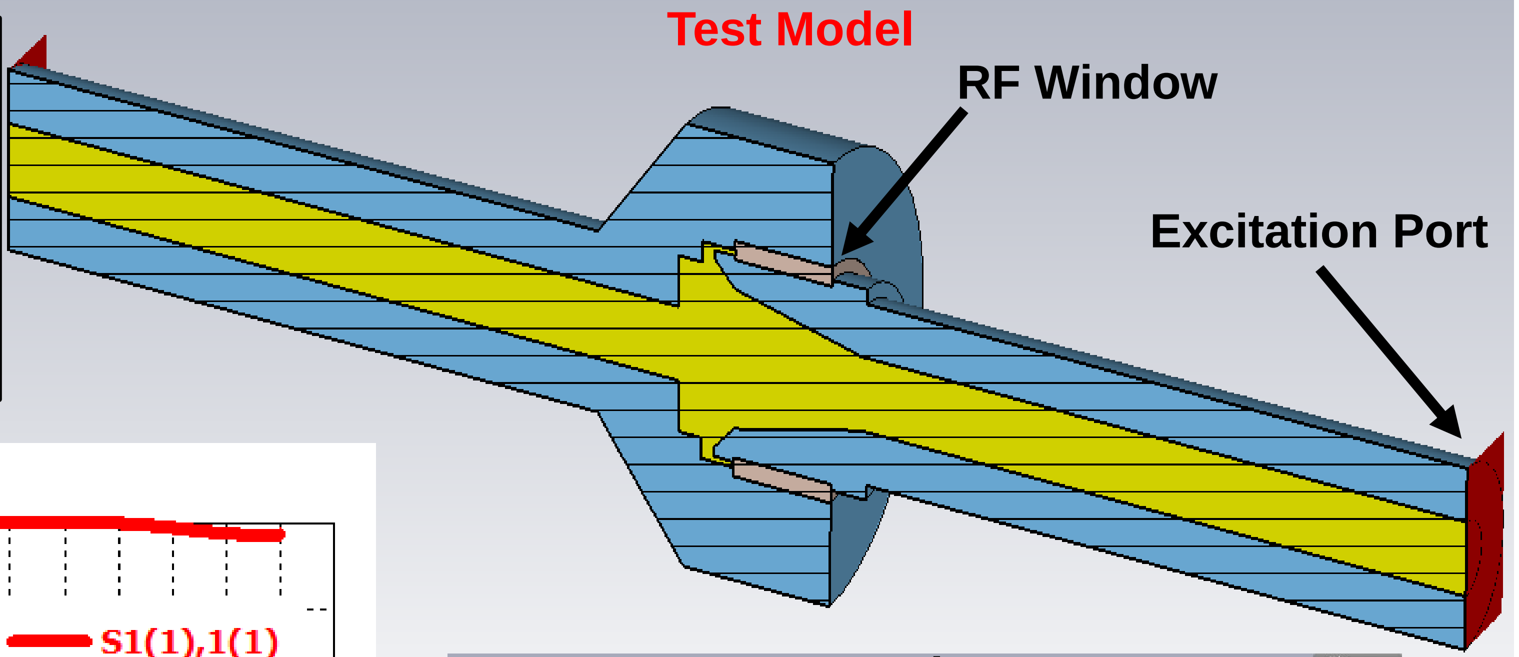
Courtesy of E. Sharples (HZB)

S11 Plot
Magnitude of -46 dB at 1.498 GHz



FPC characteristics for HOMs

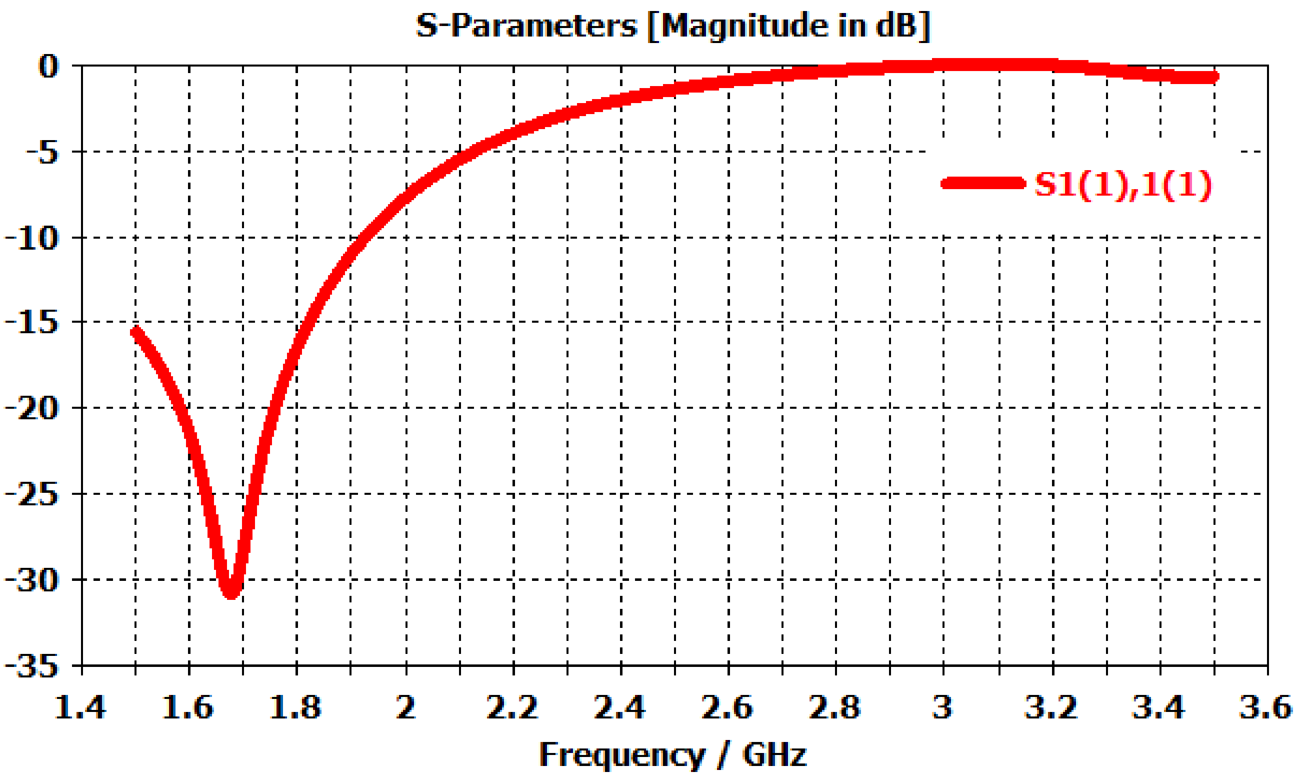
- In FPC at higher frequencies (HOMs) the EM waves are mainly reflected back from first RF windows – forms standing wave. True for all coax modes – TEM, TE11 …
- One should include the first half of the FPC in wake & Eigenmode simulations – to analyze how this fact reflects on HOM power balance & to avoid possible trapped mode in end-group.

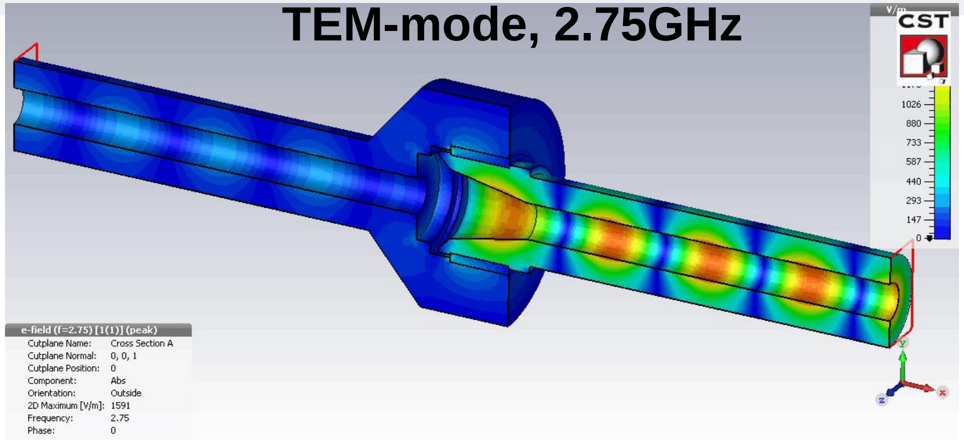


Test Model

RF Window

Excitation Port

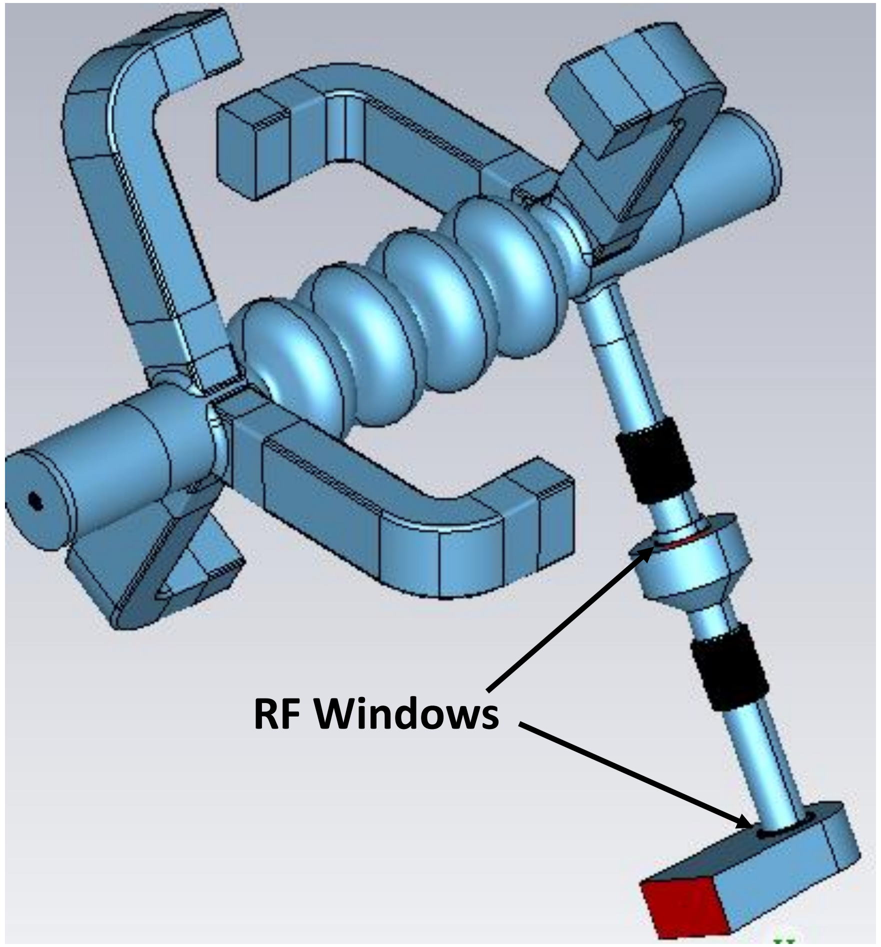




TEM-mode, 2.75GHz

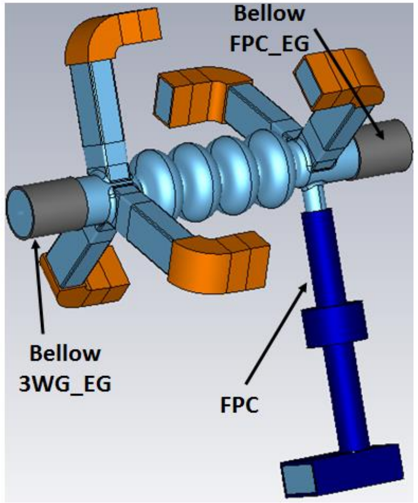
e-field (f=2.75) [1(1)] (peak)
Cutplane Name: Cross Section A
Cutplane Normal: 0, 0, 1
Cutplane Position: 0
Component: Abs
Orientation: Outside
2D Maximum [V/m]: 1591
Frequency: 2.75
Phase: 0

HOM Powers for 1.5GHz Cavity Full-Model (incl. FPC)



Dielectric losses are included in Wake simulation

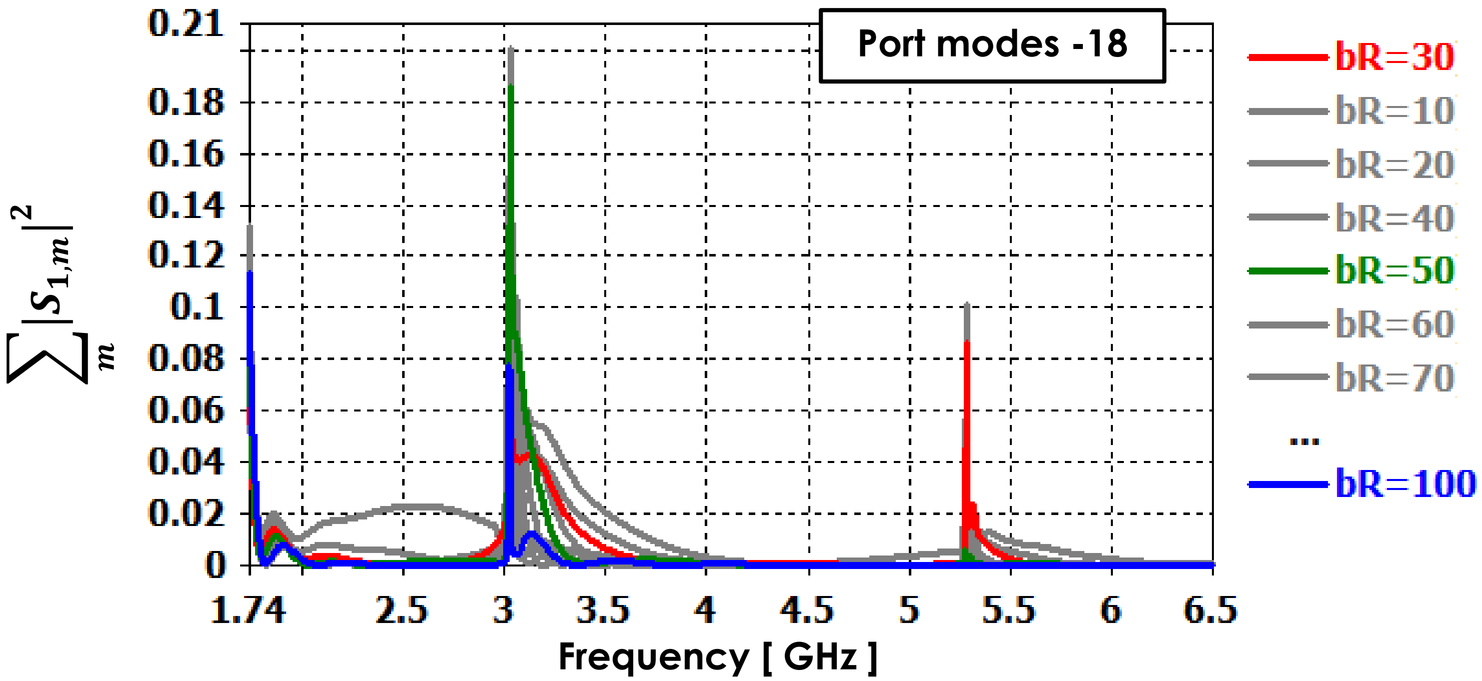
HOM Power Levels & Distribution for Baseline-FP (Wake Simulation - Bunch=9mm onAxis)		
Ports	**Model mit FPC**	**Model ohne FPC**
FPC(1)	**2.89 ↓**	**25.86**
WG(1)	**93.78 ↑**	**91.62**
WG(1)	**93.78 ↑**	**91.62**
WG(2)	**87.35**	**87.94**
WG(2)	**87.35**	**87.94**
WG(2)	**97.00**	**98.26**
BmP(1)	**213.11 ↑**	**205.58**
BmP(2)	**269.97**	**270.79**
Sum	**945.24**	**959.62**



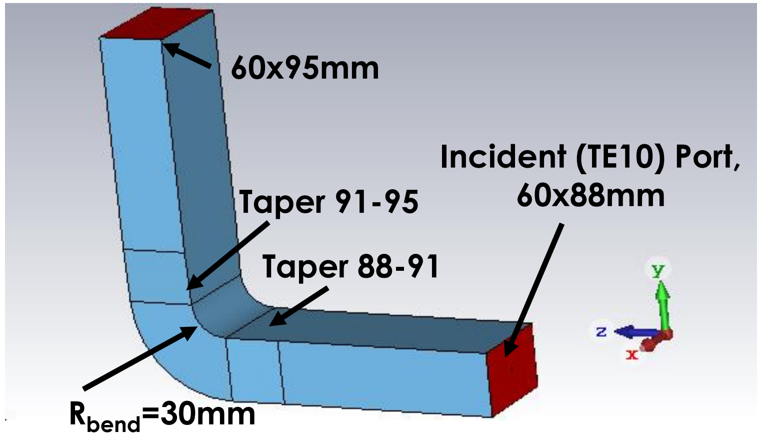
- With full coupler model the HOM power in FPC is reduces significantly.
- This HOM power is redistributed into the closest ports, i.e. 2 x HOM waveguides of corresponding end-group & beam pipe.

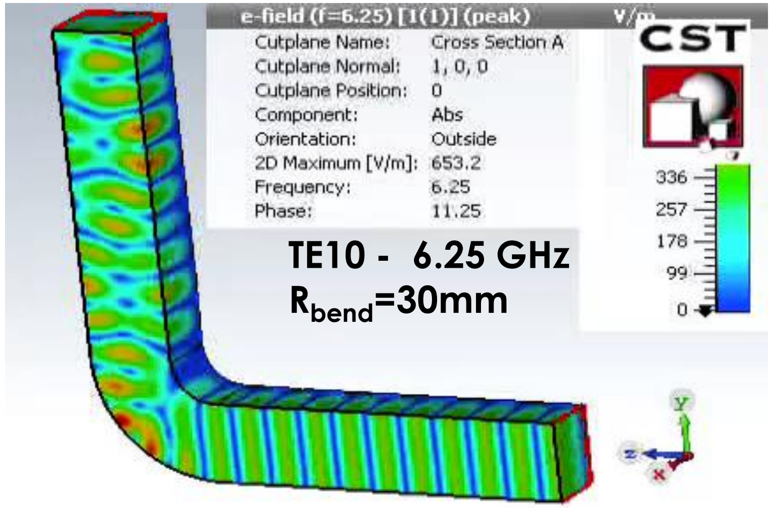
Waveguide Bend Broadband Characteristics

Reflection Broadband Behavior for TE10 Mode



WG Tapered 60 x 88_91_95mm




e-field (f=6.25) [1(1)] (peak)

Cutplane Name: Cross Section A
Cutplane Normal: 1, 0, 0
Cutplane Position: 0
Component: Abs
Orientation: Outside
2D Maximum [V/m]: 653.2
Frequency: 6.25
Phase: 11.25

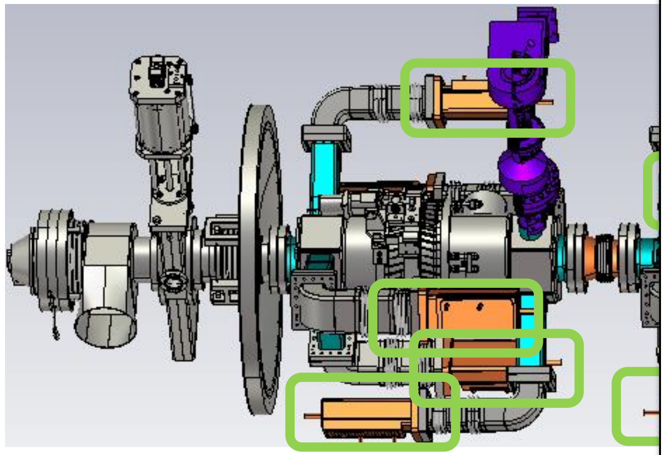
TE10 - 6.25 GHz
R_{bend}=30mm

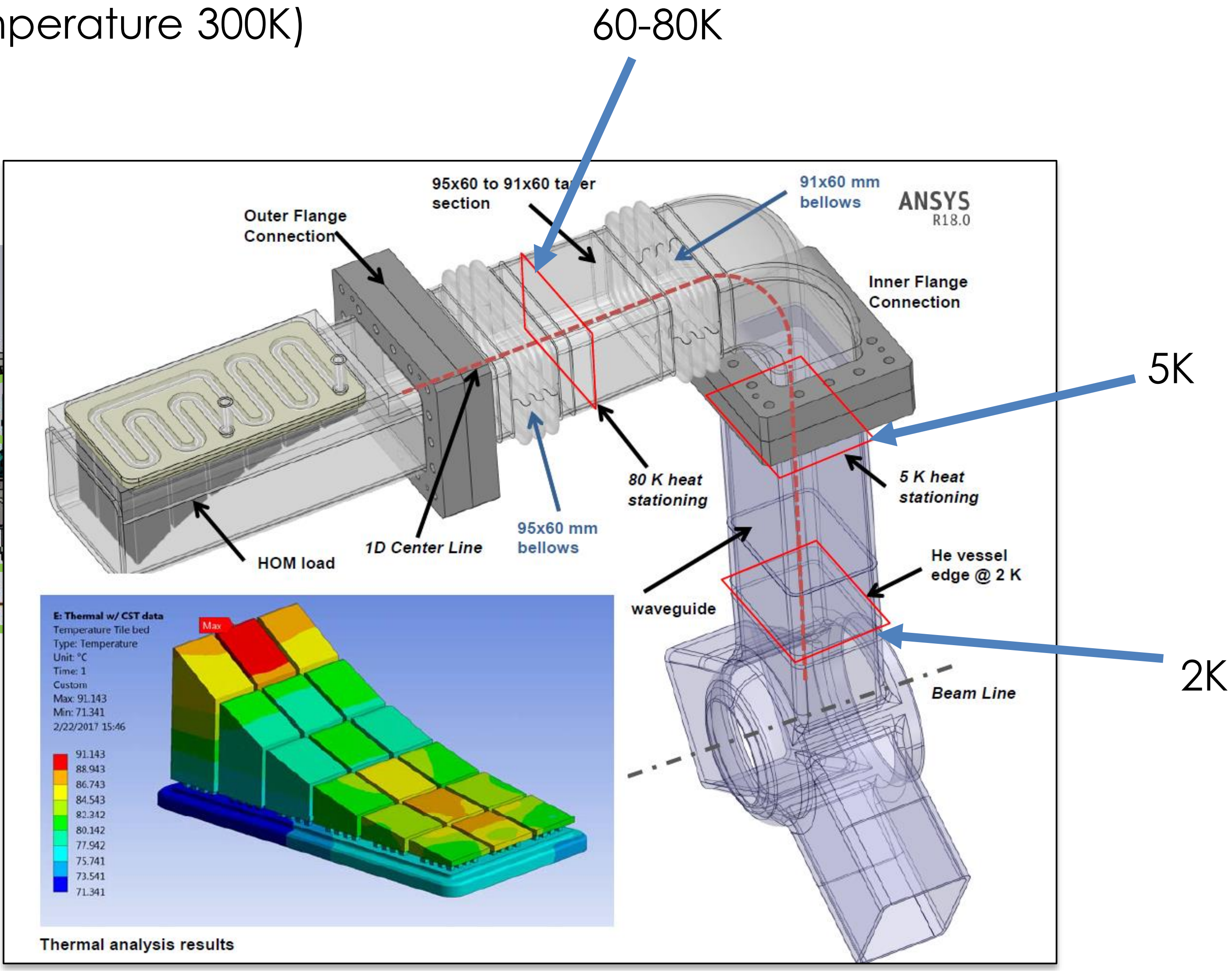
- Low reflection (broadband) from the WG bend is for bending radius = 30mm or bR ≥ 100mm.

- 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.

BESSY VSR HOM Loads

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





Thermal analysis results

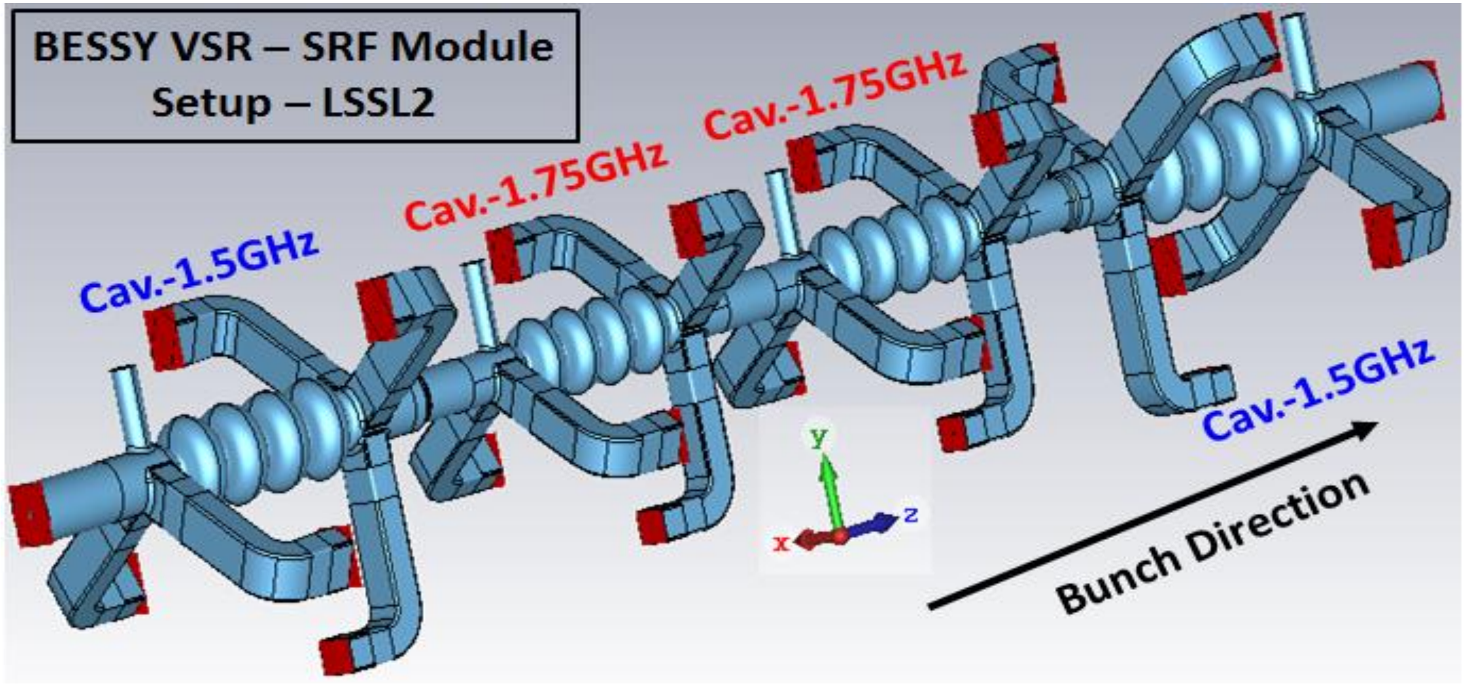
- L. Guo et al, Development of waveguide HOM loads for BERLinPro and BESSY-VSR SRF cavities, IPAC'17, MOPVA130

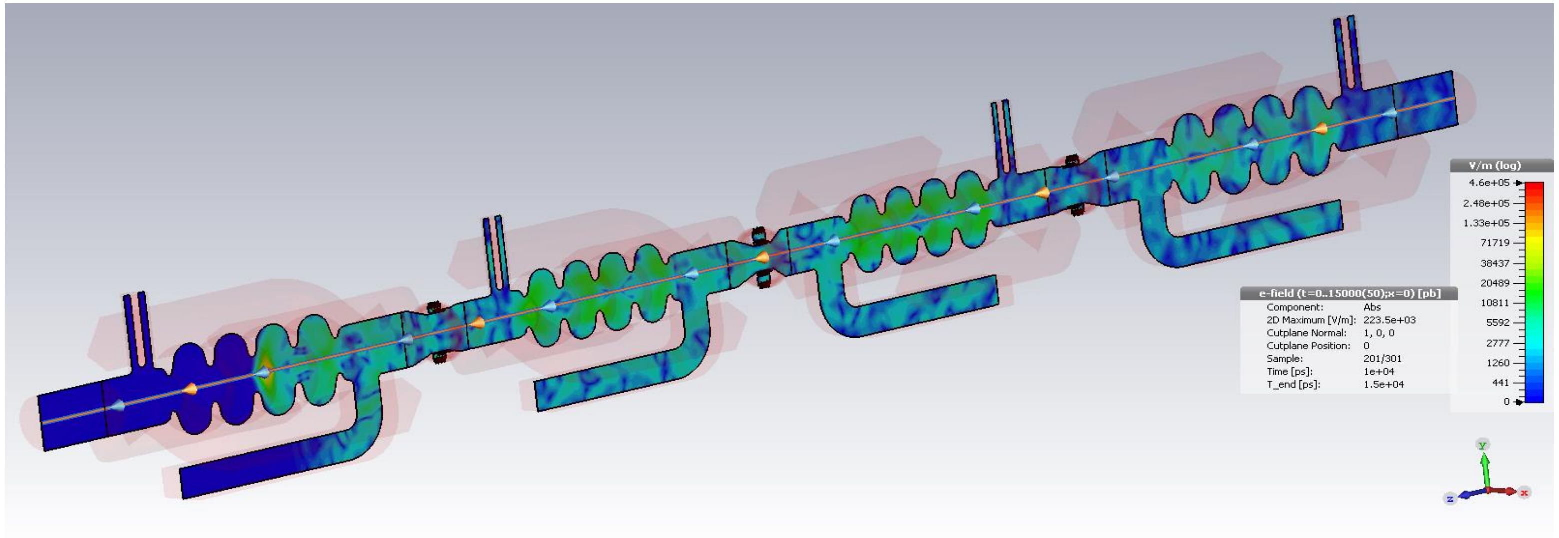
Courtesy of Jefferson Lab

Outline

- Introduction to BESSY II storage ring
- SRF Upgrade - BESSY VSR & Highlights
- SRF Cavity Specific Designs
- **HOM Power Levels in SRF Module**
- Ancillary Components for the Cold String
- HOM Power Levels in Cold String
- Outlook

HOM Power Levels in SRF Module





e-field (t=0..15000(50);x=0) [pb]

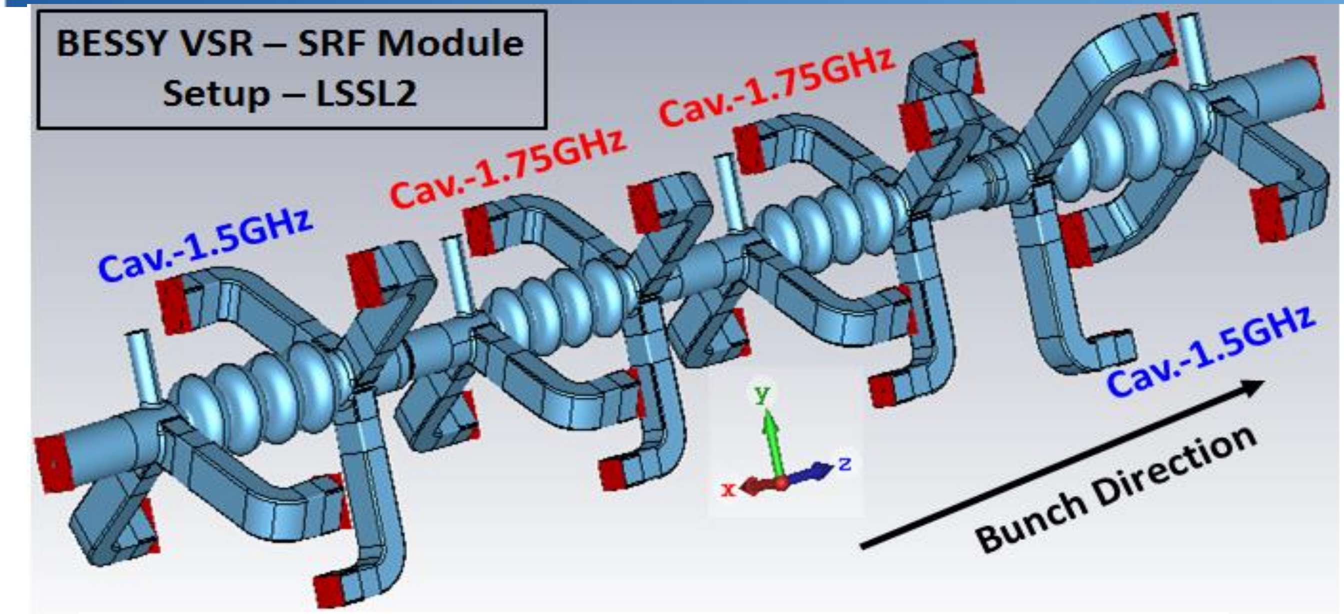
Component: Abs
2D Maximum [V/m]: 223.5e+03
Cutplane Normal: 1, 0, 0
Cutplane Position: 0
Sample: 201/301
Time [ps]: 1e+04
T_end [ps]: 1.5e+04

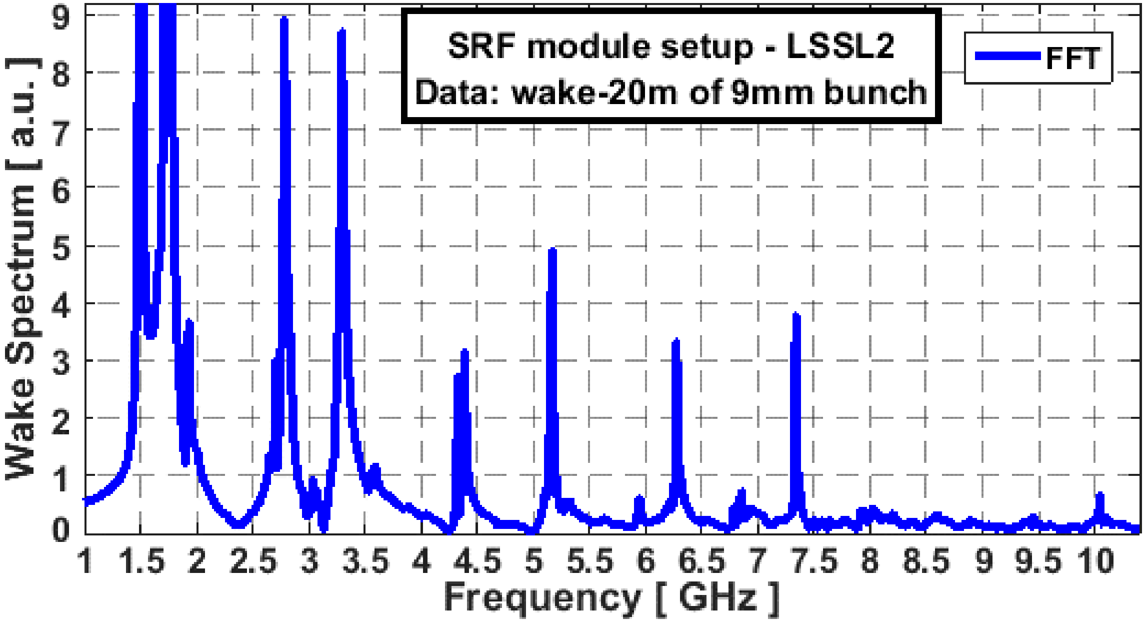
Wakefield Simulations

- 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

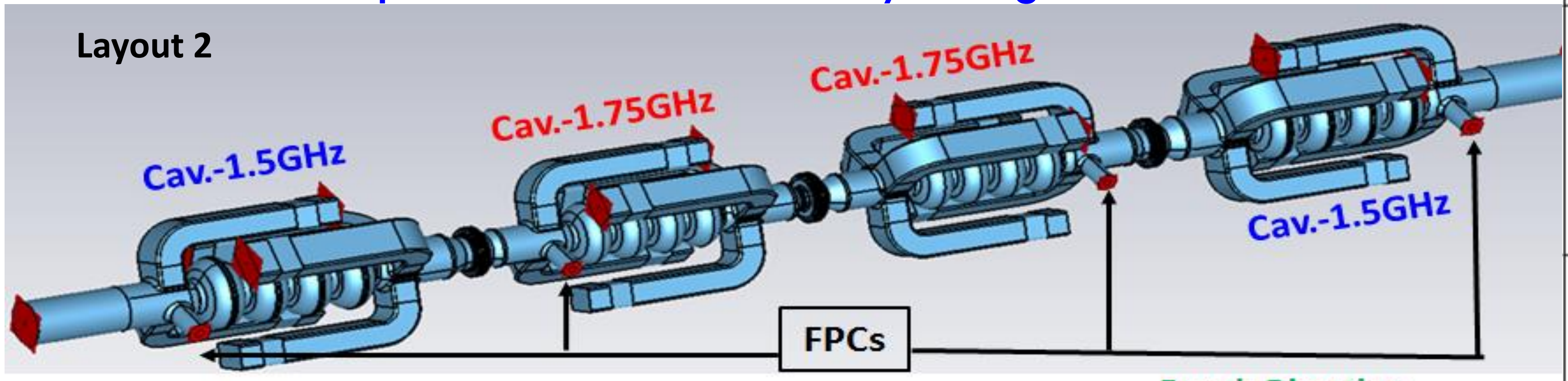
1.75 GHz Cavities

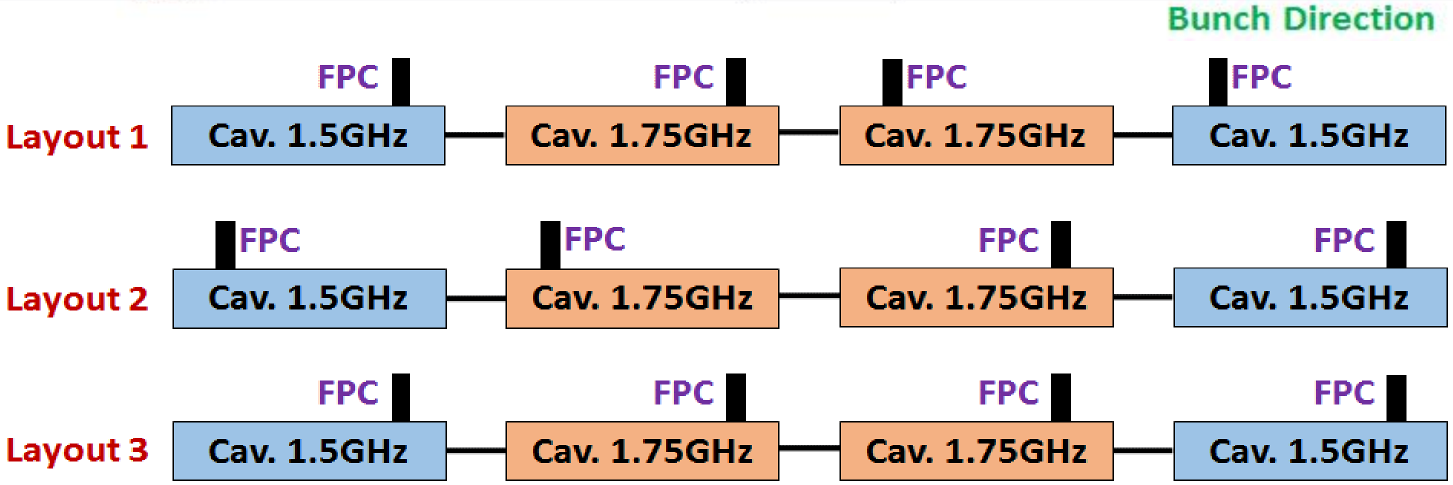
1.5 GHz

Beam pipes

HOM Power Levels in SRF Module

Different FPC positions of the 4-cell cavity arrangement in SRF module





- Layout 2 is the optimal setup in terms of equally distributed HOM power portions along the SRF module.
- Low HOM power at FPC to protect RF windows.
- Technically difficult to achieve due to the limited space in the low-beta straight of the ring.

Component	Port	HOM Power [W]		
		Layout 1	Layout 2	Layout 3
Cavity 1.5 GHz Upstream	FPC(1)	25	28	61
	WG(1)	115	107	206
	WG(1)	115	107	206
	WG(2)	136	157	74
	WG(2)	136	157	74
	WG(2)	172	193	90
Cavity 1.75 GHz Upstream	FPC(1)	66	67	73
	WG(1)	267	265	305
	WG(1)	267	265	305
	WG(2)	204	187	179
	WG(2)	204	187	179
	WG(2)	243	213	220
Cavity 1.75 GHz Downstream	FPC(1)	107	72	114
	WG(1)	314	261	316
	WG(1)	314	261	316
	WG(2)	171	245	171
	WG(2)	171	245	171
	WG(2)	203	282	211
Cavity 1.5 GHz Downstream	FPC(1)	59	25	74
	WG(1)	208	112	203
	WG(1)	208	112	203
	WG(2)	74	143	80
	WG(2)	74	143	80
	WG(2)	90	184	83
BmP	Upstr.	230	300	230
	Downstr.	363	380	290
Total		4534	4693	4515

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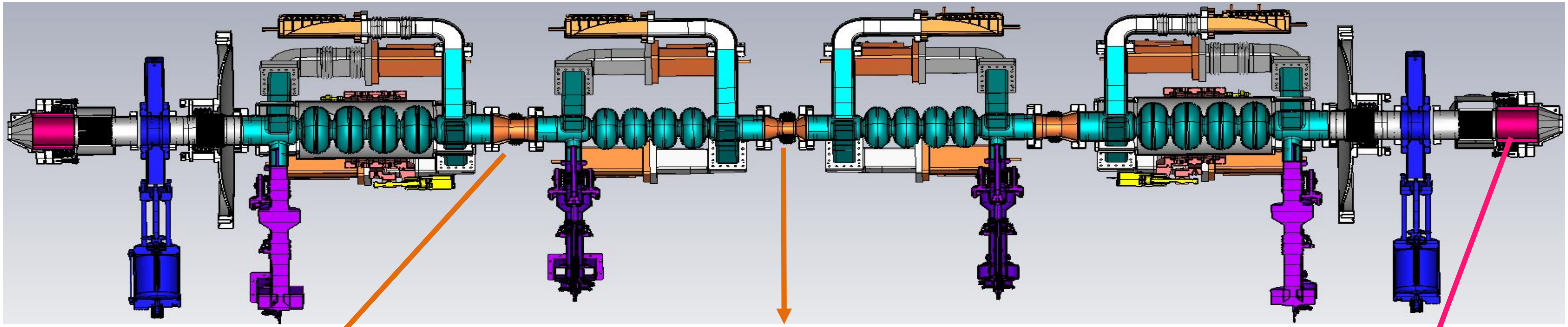
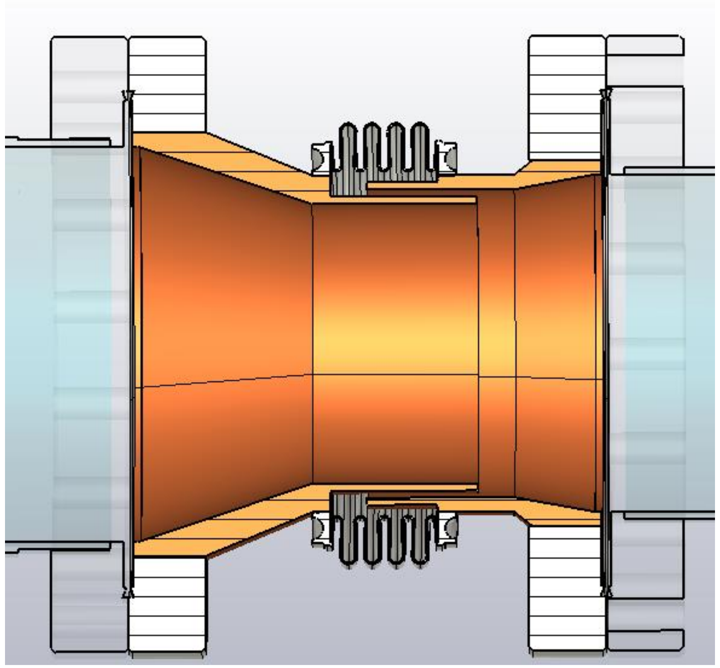
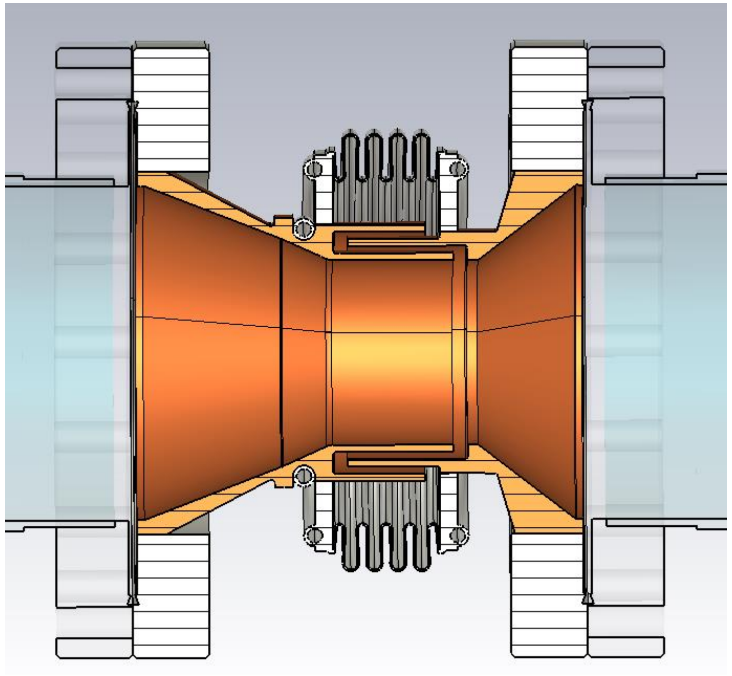
Ancillary Components for the Cold String



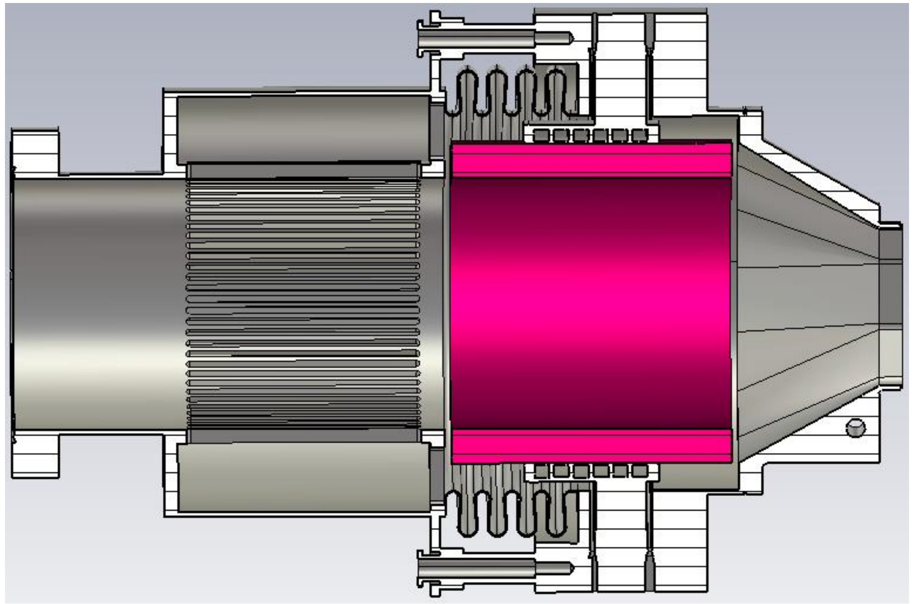
Shielded Bellow



Collimating Bellow



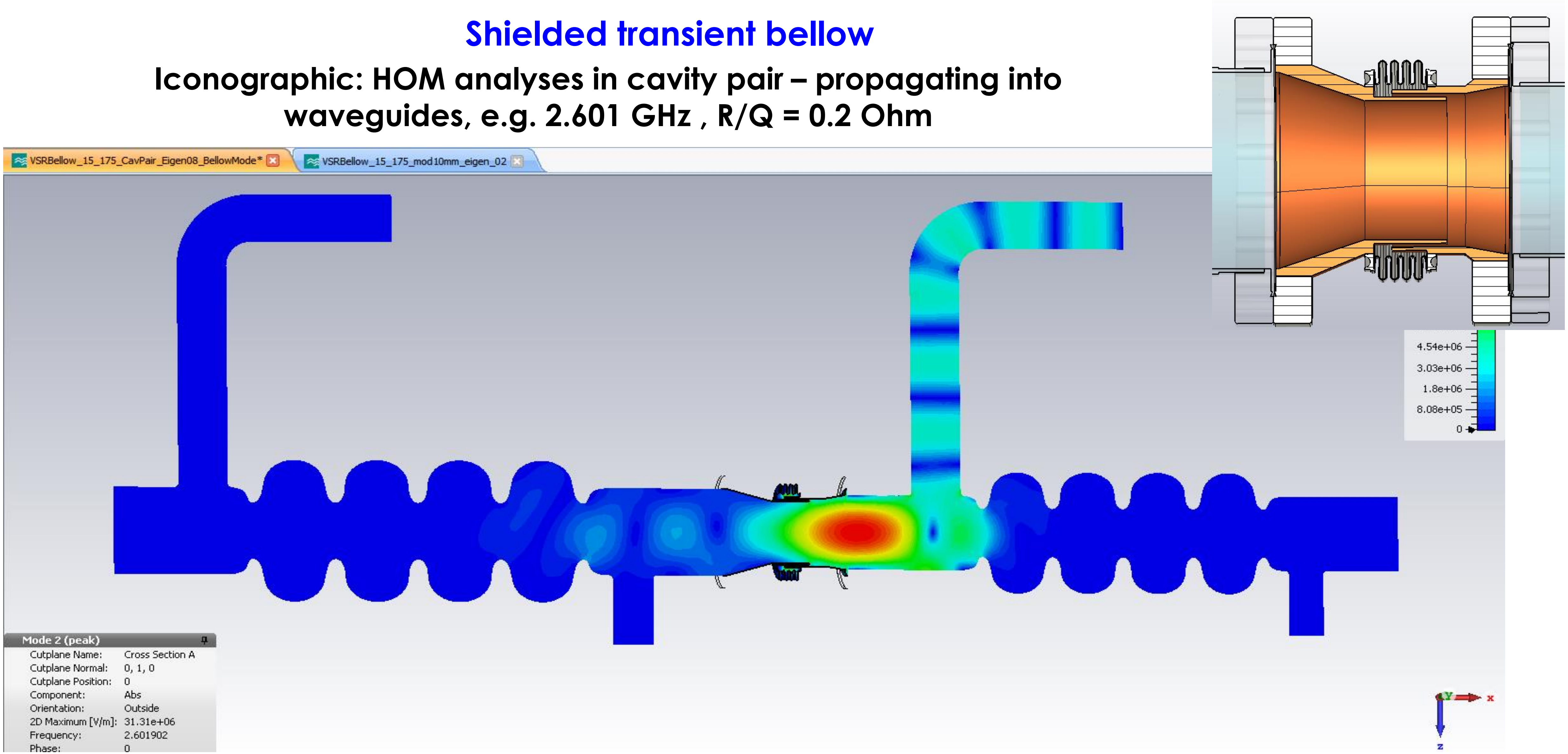
Beampipe Absorber & Pumping Dom



Shielded Transient Bellow

Shielded transient bellow

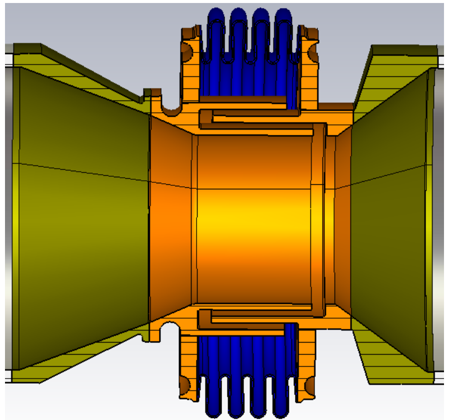
Iconographic: HOM analyses in cavity pair – propagating into waveguides, e.g. 2.601 GHz , R/Q = 0.2 Ohm



Mode 2 (peak)
Cutplane Name: Cross Section A
Cutplane Normal: 0, 1, 0
Cutplane Position: 0
Component: Abs
Orientation: Outside
2D Maximum [V/m]: 31.31e+06
Frequency: 2.601902
Phase: 0

- H.-W. Glock et al, Design of the beamline elements in the BESSY VSR cold string, IPAC'18, THPMF033

Collimated Shielded Bellow



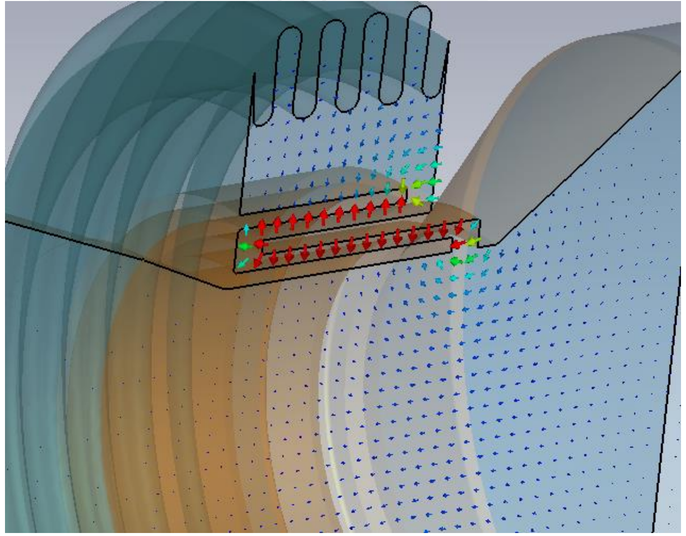
Collimated shielded bellow: Length dependency of parasitic modes

Massive Copper

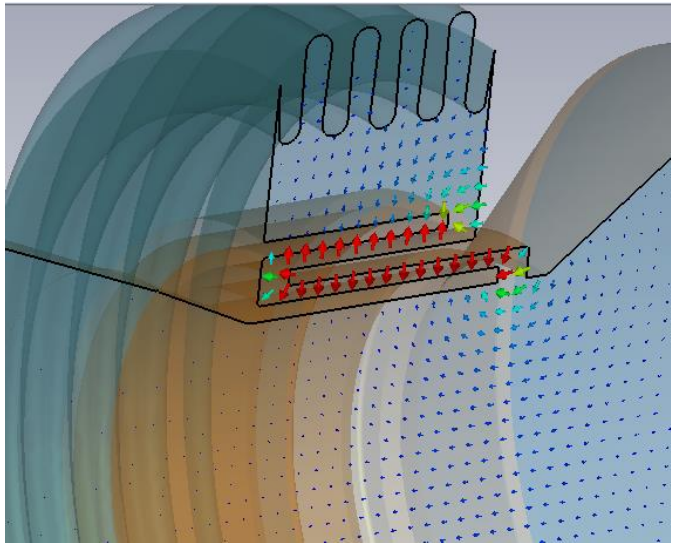
Stainless Steel

SS with Cu coating

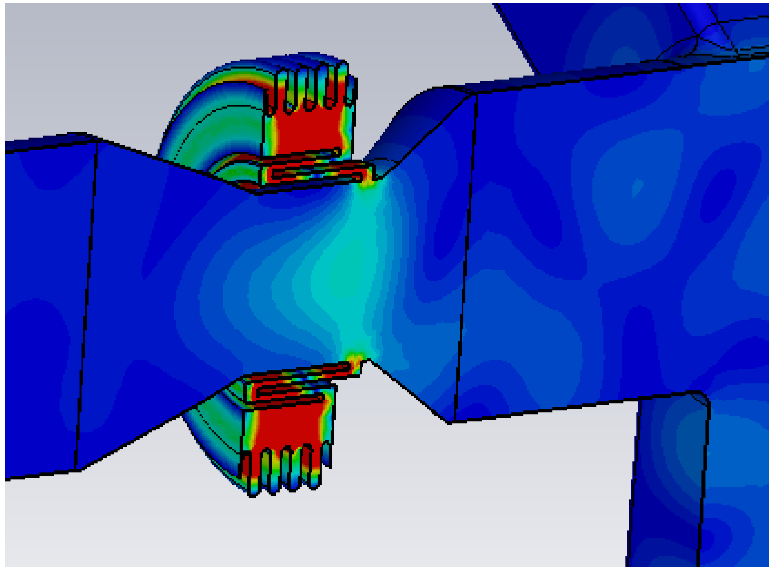
- ➢ No issues from stretching / shortening
- ➢ Not necessarily monotonous dependency



-2 mm	± 0	+ 2mm
415.8 MHZ	422.1 MHz	423.0 MHz
14.3 Ω	15.8 Ω	17.1 Ω



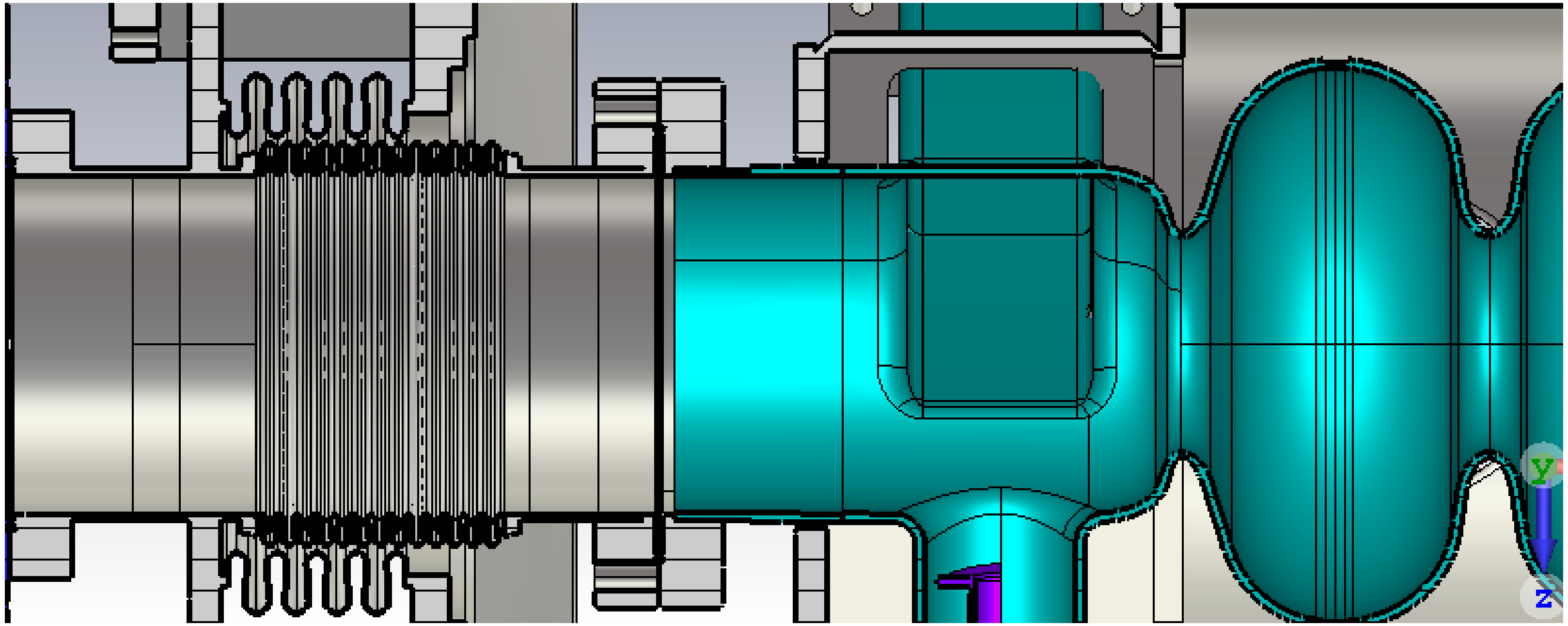
-2 mm	± 0	+ 2mm
2125.1 MHz	2154.8 MHz	2135.4 MHz
4.3 Ω	4.2 Ω	4.2 Ω



-2 mm	± 0	+ 2mm
3976.4 MHz	3928.0 MHz	3784.4 MHz
5.2 Ω	2.2 Ω	2.2 Ω

Computation and pictures courtesy of H.-W. Glock

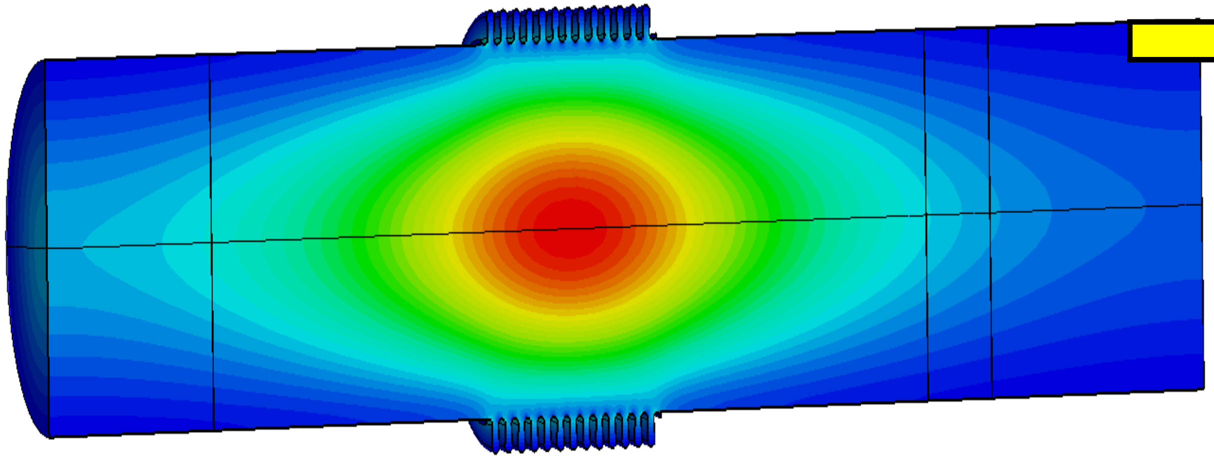
Module End-Bellow



Module end-bellows demands

- *Longitudinal and transversal compensation of cold string and tank tolerances*
- *Lateral compensation of exterior cavity's shrinkage*
- *Compensation of space requirements during mounting procedure*
- *Thermal isolation 300 K ⇔ 1.8 K; accommodate thermal intercept*
- *Least beam interaction, esp. no localized modes @ multiples of 250 MHz*

Module End-Bellow

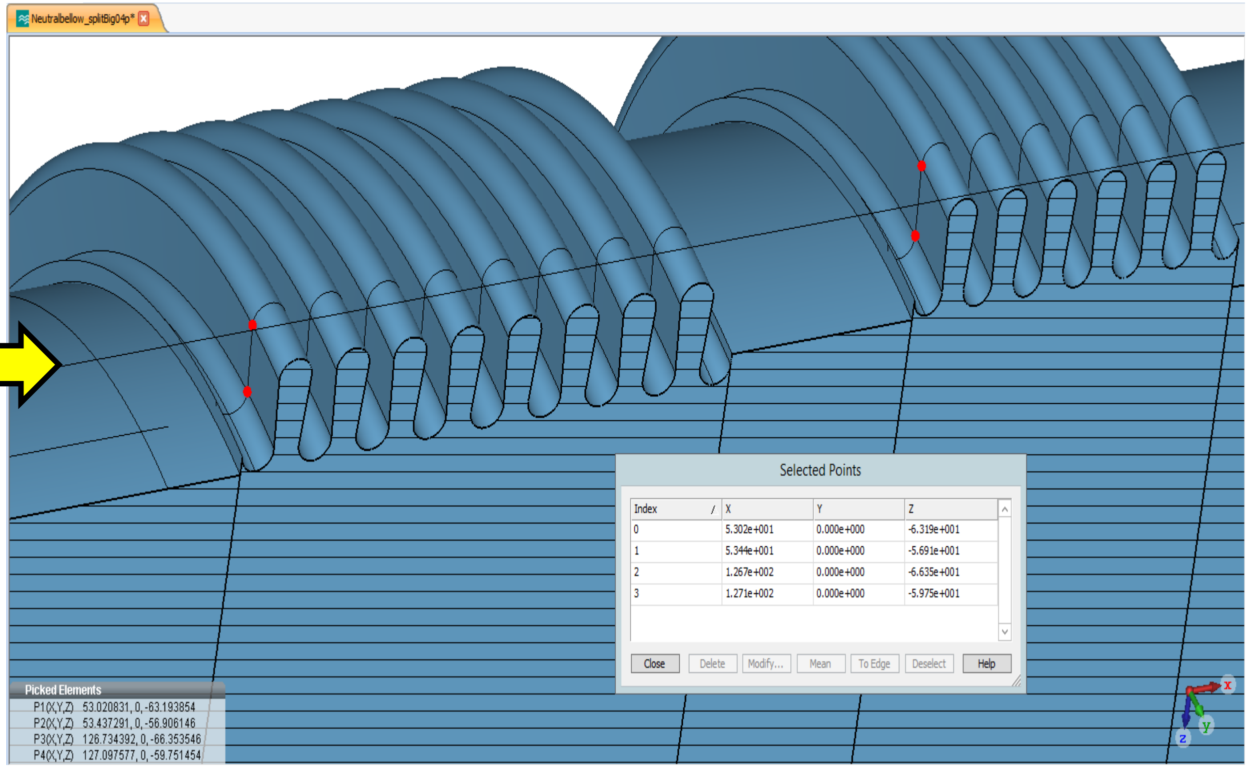


Module-end-bellows draft design

- *Layout following mechanical and thermal considerations*
- *Revealed single localized mode @ 2.023 GHz, R/Q = 1.61 Ω, Q ~ 2600, …*
- *… which is considered as dangerously close to 2.00 GHz in view of mechanical softness*

Concept of tunable split bellow

- **Section diameter of second part raised by 5% (final design subject of production limits)**
- **Intermediate short straight to accommodate thermal intercept**
- **Position of intermediate straight adjusted by active tuner within ± 3 mm**



Selected Points

Index	X	Y	Z
0	5.302e+001	0.000e+000	-6.319e+001
1	5.344e+001	0.000e+000	-5.691e+001
2	1.267e+002	0.000e+000	-6.635e+001
3	1.271e+002	0.000e+000	-5.975e+001

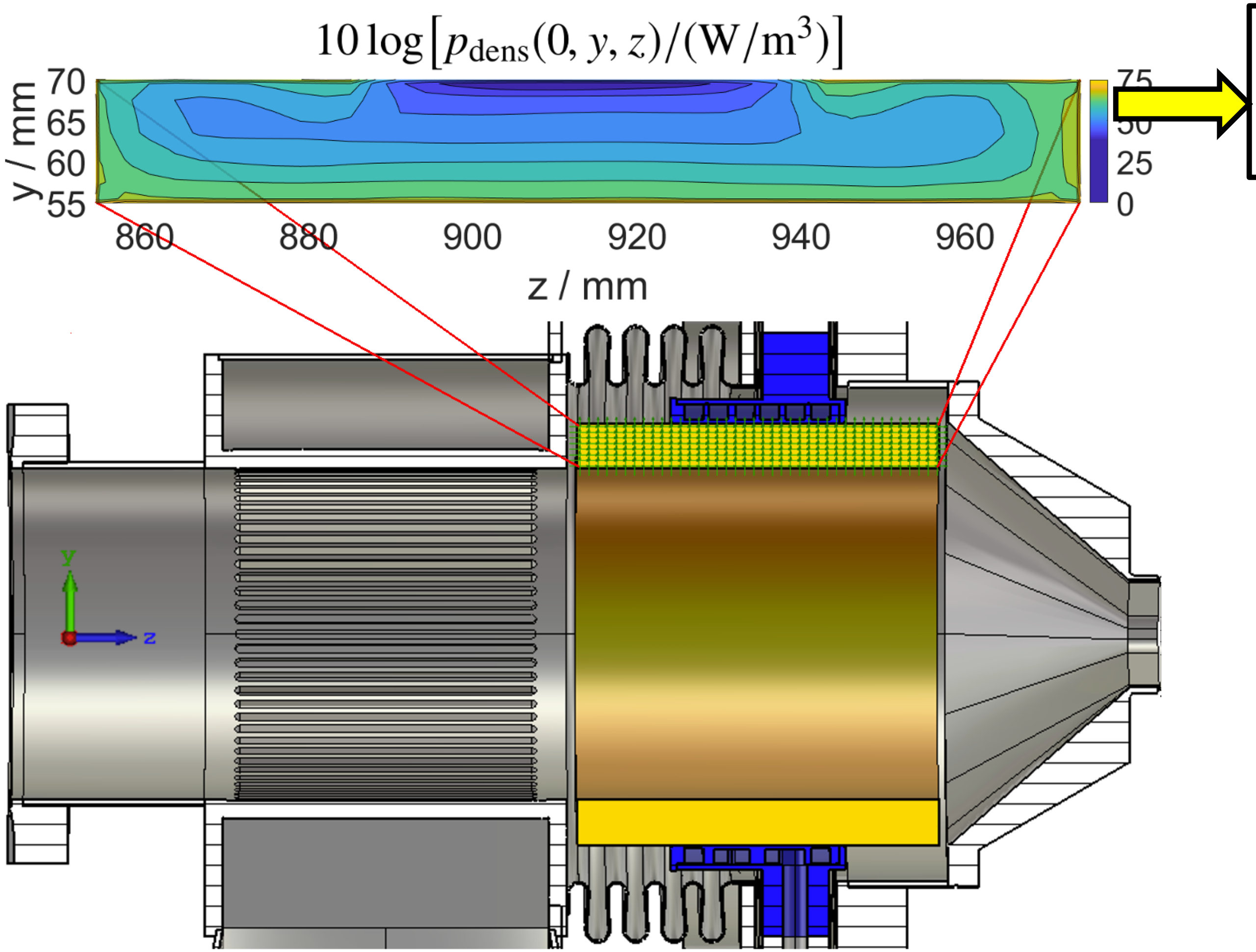
Picked Elements

P1(X,Y,Z) 53.020831, 0, -63.193854
P2(X,Y,Z) 53.437291, 0, -56.906146
P3(X,Y,Z) 126.734392, 0, -66.353546
P4(X,Y,Z) 127.097577, 0, -59.751454

Computation and pictures courtesy **of H.-W. Glock**

Beampipe Absorber

HOM powers in beampipe absorber



- HOM power dissipation is strongly concentrated close to surface.
- With contingency we expect ~ 2 kW per absorber.

HOM power losses in dielectric absorber

$$p_n = \iiint\limits_{\Omega_{\mathrm{abs}}} \frac{1}{2}\omega_n\,\varepsilon''(\omega_n)\,|\mathbf{E}_n(\mathbf{r})|^2\,\mathrm{d}V$$

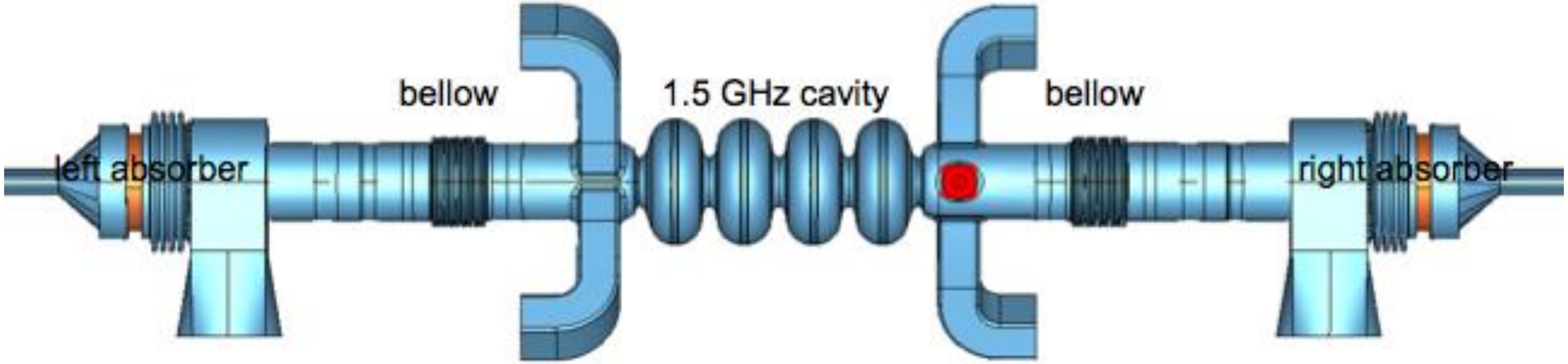
$$= \pi \int_{y_{\min}}^{y_{\max}} \int_{z_{\min}}^{z_{\max}} r\,\omega_n\,\varepsilon''(\omega_n)\,|\mathbf{E}_n(\mathbf{r})|^2\,\mathrm{d}y\mathrm{d}z$$

Approximaton for Spectral- & spatial-distributed dielectric wake loss for periodic beams.

***Computation and pictures courtesy* of T. Flisgen**

- T. Flisgen et al, Estimation of Dielectric Losses in Beam Pipe Absorbers, IPAC'18, THPAF084
- H.-W. Glock et al, Design of the beamline elements in the BESSY VSR cold string, IPAC'18, THPMF033

Beampipe Absorber



	σ / mm	f_{max} / GHz	N_{mesh}	T_{comp}
Model 1	14	7.3136	426,809,958	2 d 20 h 12 min
Model 2	10	10.2391	1,075,099,752	7 d 3 h 11 min

- **112 2D port modes**
- **320 field probes for E_x, E_y, E_z per beampipe absorber**
- **Transverse offset of the bunch XY = 2.1 mm**

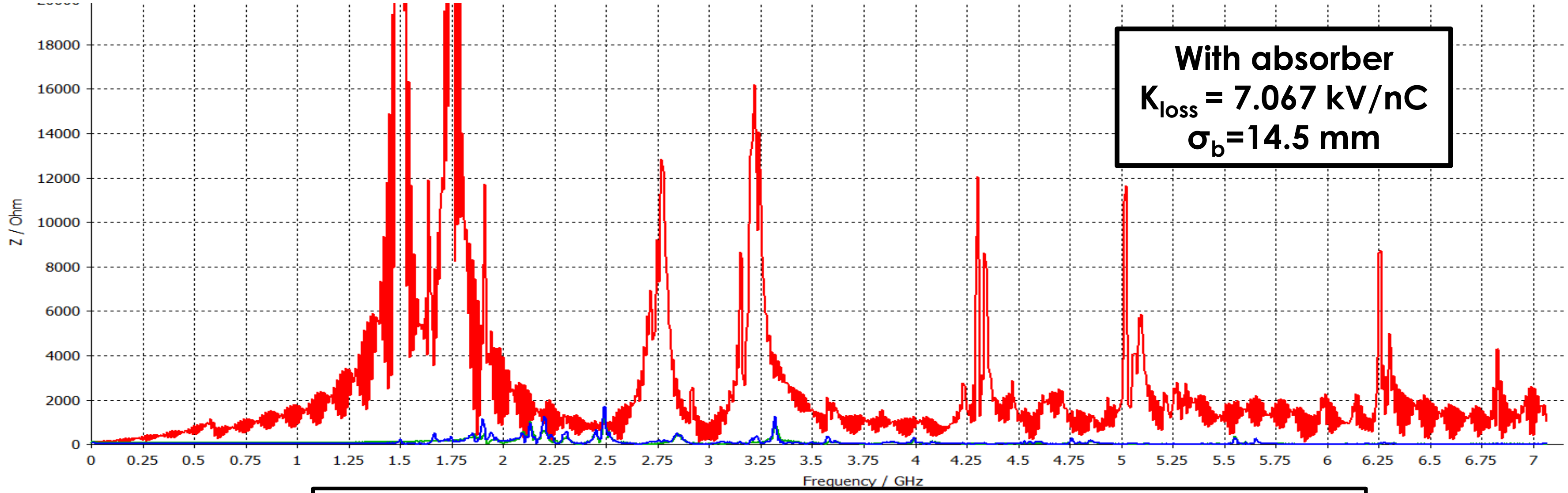
Total absorbed HOM powers for BESSY VSR filling patterns

Filling Pattern	Power Left Absorber	Power Right Absorber
baseline	801 W	1371 W
extended	716 W	1250 W

- ➢ **Losses are in the expected order, but depend heavily on the considered frequency range.**
- ➢ **Losses in in the right absorber are ~ 1.7 higher than in the left absorber.**

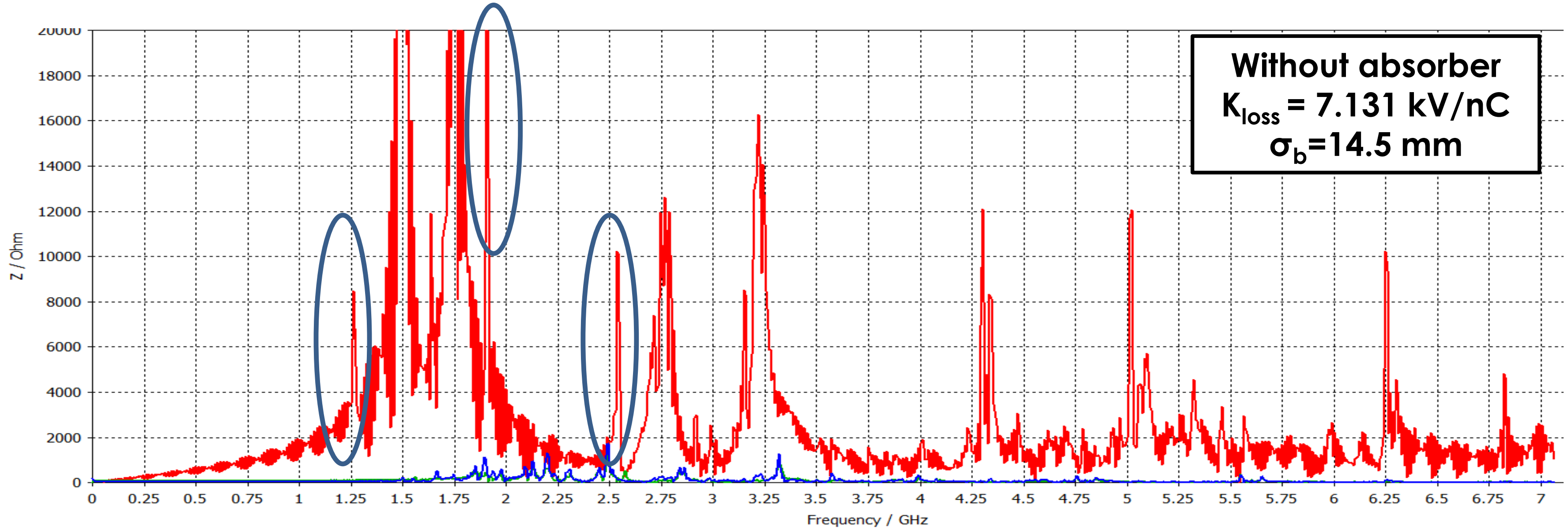
***Computation and pictures courtesy* of T. Flisgen**

Beampipe Absorber

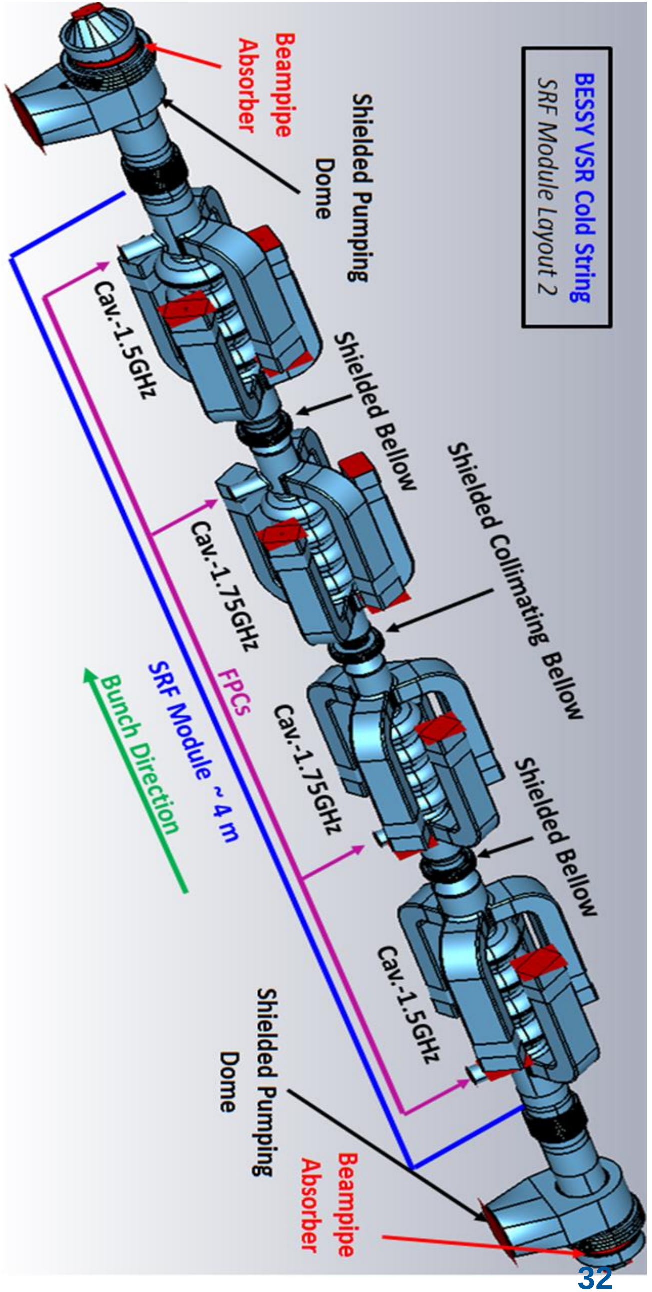


With absorber
K_{loss} = 7.067 kV/nC
σ_b=14.5 mm

- ➢ Transition without absorber prone to localized modes
- ➢ Absorber in total slightly reducing the loss factor



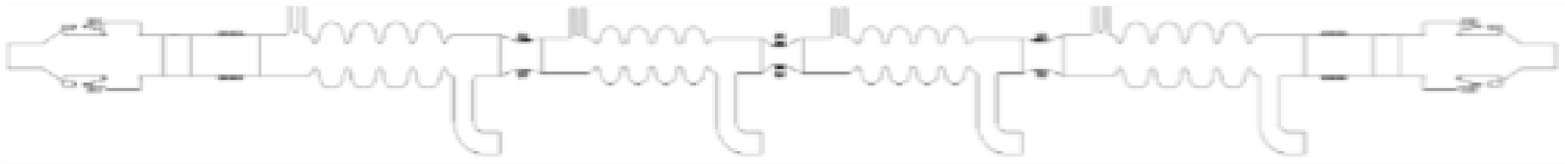
Without absorber
K_{loss} = 7.131 kV/nC
σ_b=14.5 mm

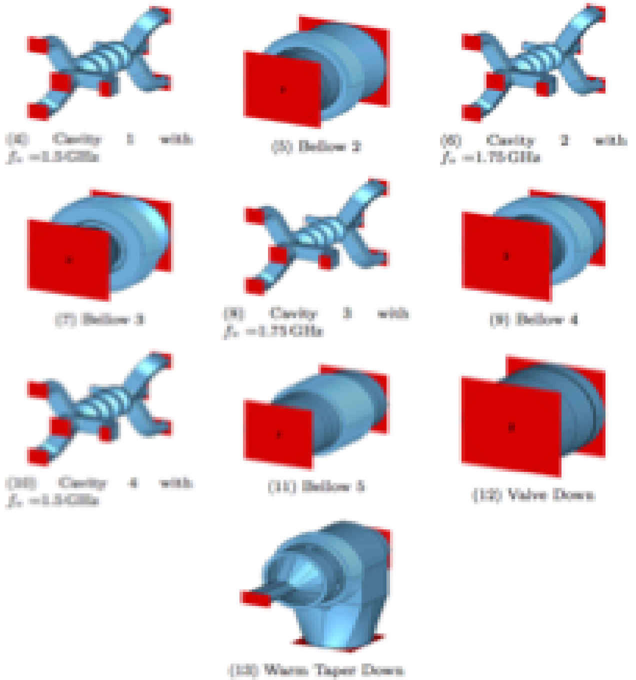


Eigenmodes in Big Structures: SSC Technique

Eigenmodes in rather big structures: State-Space-Computation (SSC)

Computation and pictures courtesy J. Heller, U. van Rienen, University Rostock





(4) Cavity 1 with $f_c = 1.5\,\mathrm{GHz}$

(5) Bellow 2

(6) Cavity 2 with $f_c = 1.75\,\mathrm{GHz}$

(7) Bellow 3

(8) Cavity 3 with $f_c = 1.75\,\mathrm{GHz}$

(9) Bellow 4

(10) Cavity 4 with $f_c = 1.5\,\mathrm{GHz}$

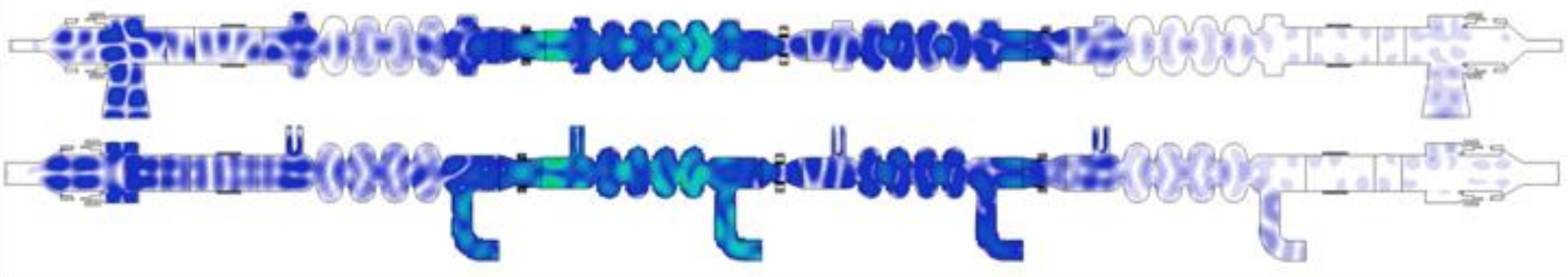
(11) Bellow 5

(12) Valve Down

(13) Warm Taper Down

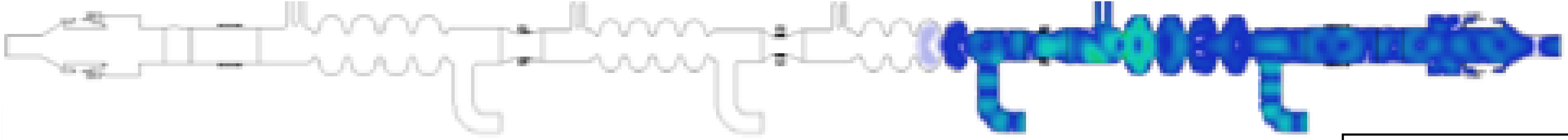
**decompose complex structure into smaller components;
provide coupling in terms of waveguide mode interactions
full-module eigenmode atlas up to 3.6 GHz computed**

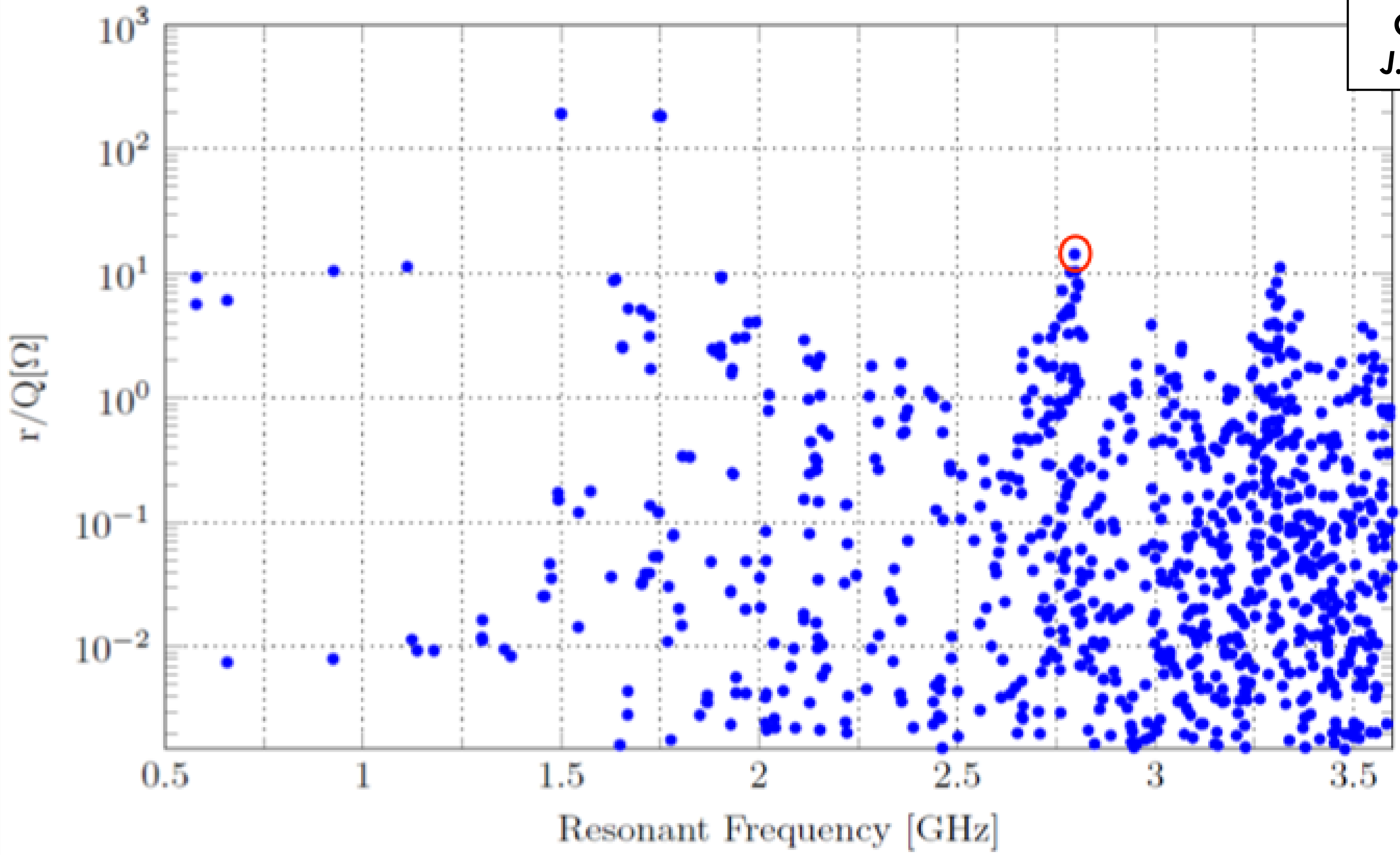
Example: Mode index 1221, f = 3.2877 GHz, R/Q = 3.86 Ω



Eigenmodes in Big Structures: SSC Technique

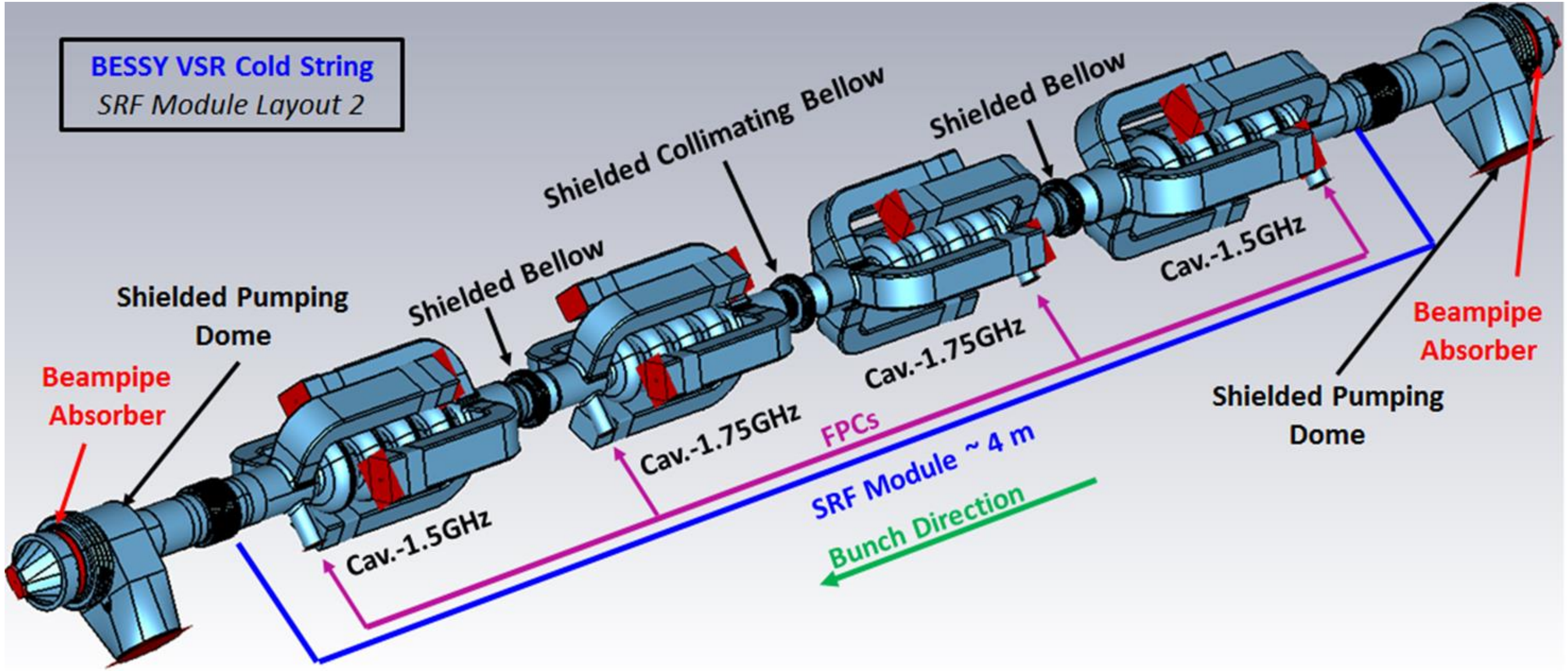
SSC Application on the BESSY-VSR cold string





Computation and pictures courtesy
J. Heller, U. van Rienen, Univ. Rostock

HOM Power Distribution in Cold String

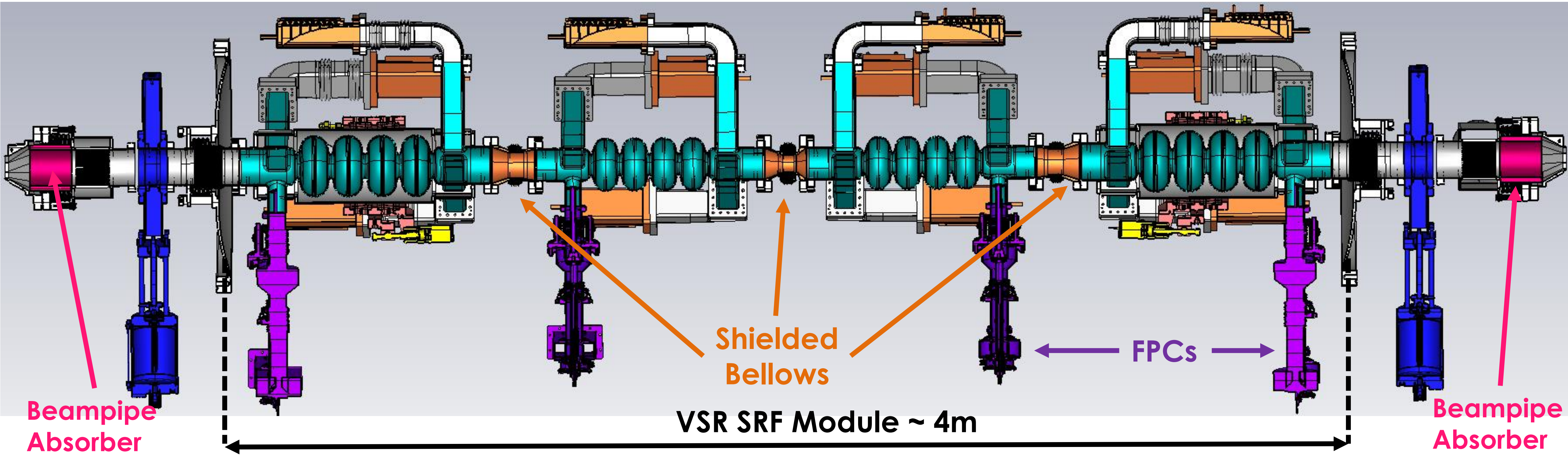


- The HOM power at FPC end-groups of 1.5GHz cavities located at both ends of the module are significantly increased due to the warm components – outside of the module.
- The power levels & balance inside the module is unperturbed.
- The beam pipe absorber losses are underestimated, because of sparse field-probe sampling in dielectric. More accurate simulations are foreseen & 1-2kW power dissipation in two absorbers is expected (see ref.).

- A. Tsakanian et al, HOM power levels in the BESSY VSR cold string, IPAC'18, WEPML048
- T. Flisgen et al, Estimation of Dielectric Losses in Beam Pipe Absorbers, IPAC'18, THPAF084

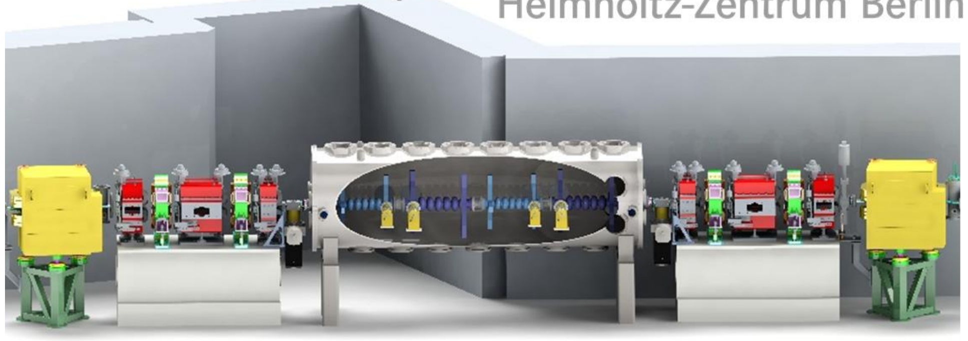
Component	Port	HOM Power [W]		
		Baseline 300mA	Extended 300mA	Single 30mA
Cavity 1.5 GHz Upstream	FPC(1)	↑ 62	57	30
	WG(1)	↑ 197	170	139
	WG(1)	↑ 197	170	139
	WG(2)	166	145	133
	WG(2)	166	145	133
	WG(2)	202	180	137
Cavity 1.75 GHz Upstream	FPC(1)	66	62	40
	WG(1)	255	231	148
	WG(1)	255	231	148
	WG(2)	183	168	134
	WG(2)	183	168	134
	WG(2)	206	192	134
Cavity 1.75 GHz Downstream	FPC(1)	69	67	50
	WG(1)	258	228	180
	WG(1)	258	228	180
	WG(2)	249	229	123
	WG(2)	249	229	123
	WG(2)	284	260	125
Cavity 1.5 GHz Downstream	FPC(1)	↑ 33	31	26
	WG(1)	↑ 151	126	134
	WG(1)	↑ 151	126	134
	WG(2)	140	124	106
	WG(2)	140	124	106
	WG(2)	176	156	110
BmP	Upstr.	54	47	16
	Downstr.	143	126	46
Pump. Dome	Upstr.	20	18	7
	Downstr.	17	15	8
BmP Absorber	Upstr.	273	241	185
	Downstr.	367	320	247
Total		5170	4611	3357

Outlook

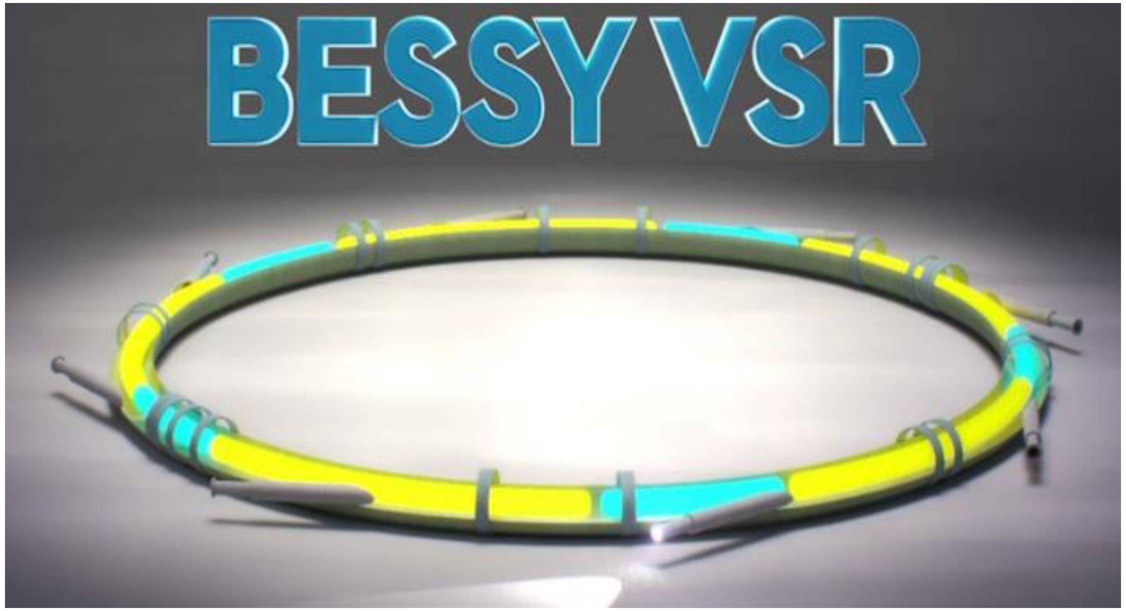


- Shielded bellows are required due to the cavity fundamental mode losses.
- Beampipe-absorbers for more HOM damping, especially excited by interaction with warm components.
- Synchrotron light collimating bellow is required at module center.
- Every component is optimized to fulfil off-resonance condition with respect to circulating beam.

BESSY VSR
Helmholtz-Zentrum Berlin



Outlook



Thank You for Your Attention !