HZB Helmholtz Zentrum Berlin

BESSY VSR

Microphonics Considerations for BESSY-VSR

Pablo Echevarria, on behalf of LLRF team

Second Topical Workshop on Microphonics
Brooklyn, NY
25-26 Oct. 2018

Outline

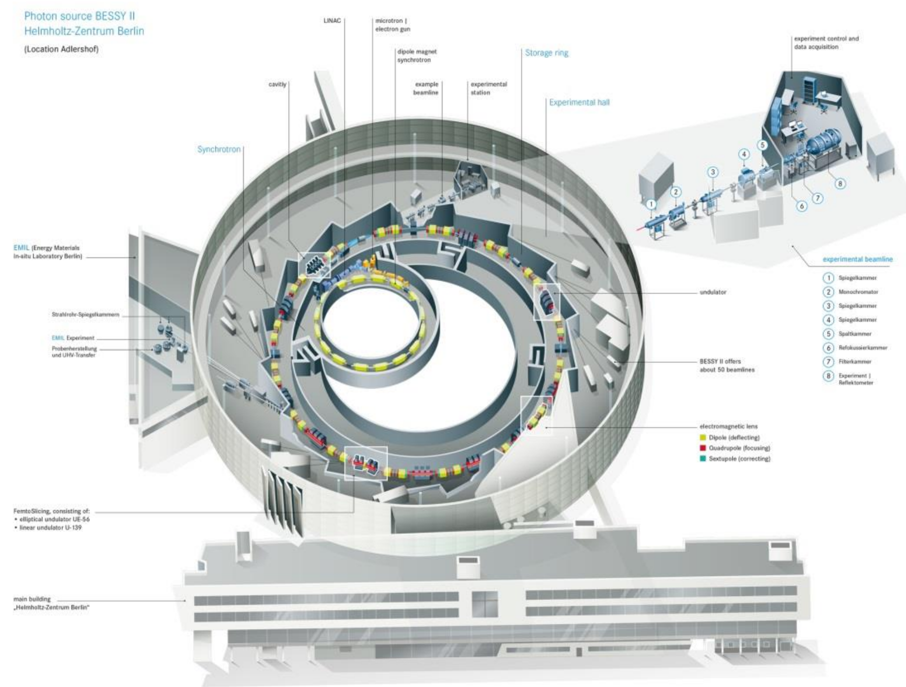
- The BESSY VSR concept
- LLRF challenges
- mTCA.4 single cavity control
- BESSY-VSR cavities and cryomodule

BESSY-II

- The SR BESSY II is a 1.7 GeV synchrotron radiation source operating for 20 years in Berlin

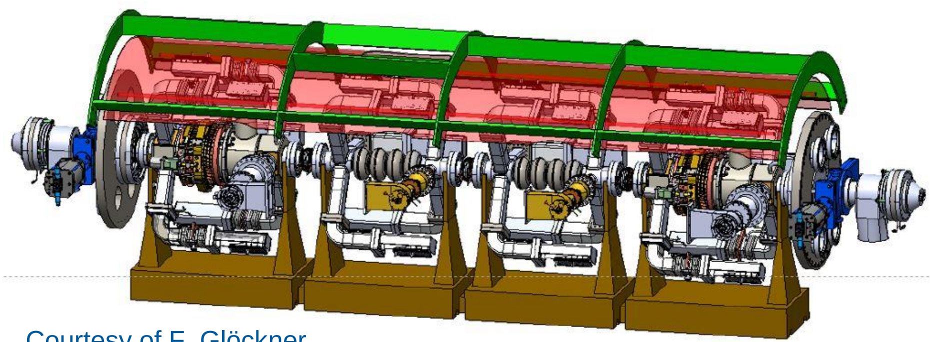
- BESSY II emits extremely brilliant photon pulses ranging from the long wave terahertz region to hard X rays
- Pioneer in offering low α operation with a comunity of users performing dynamic measurements in „functional materials“

In order to remain competitive among the international synchrotron sources a superconducting upgrade is undergoing



BESSY II , SC Upgrade

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



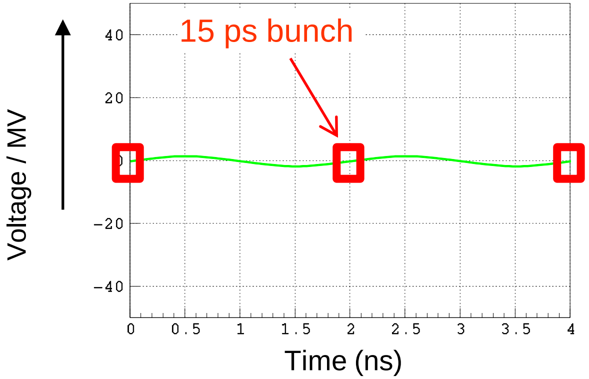
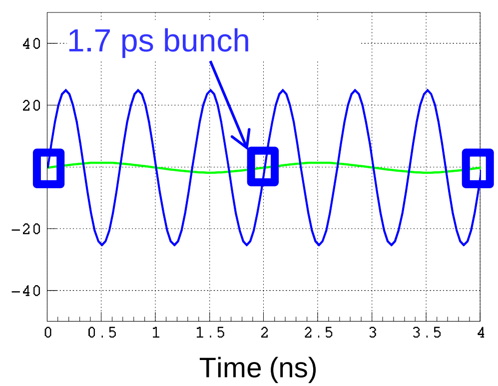
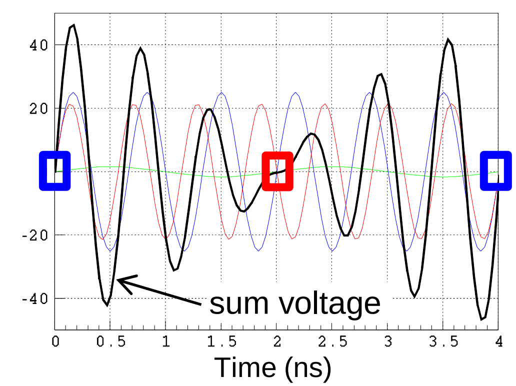
Courtesy of F. Glöckner

- 1.5GHz and 1.75GHz ---- RF beating
- Odd (voltage cancelation, 15 ps bunches)
- Even (voltage addition, long.focussing, 1.7 ps)

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

← **Machine optics** (α)

← **Hardware (RF cavities)** ($\dot{V}_{\mathrm{rf}}$)

Present	**Phase I**	**Phase II**
		

Voltage: 1.5 MV @ 0.5 GHz

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

Voltage: 20 MV @ 1.5 GHz

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

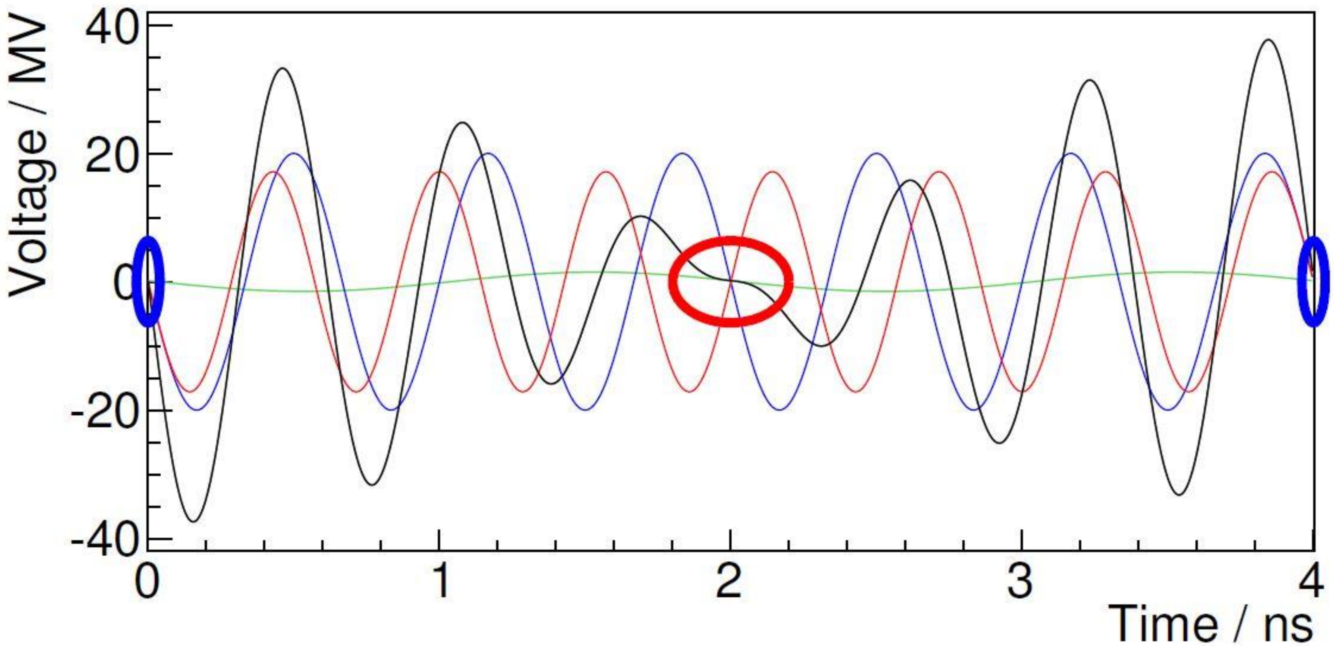
Voltage: 20 MV @ 1.5 GHz
+ 17.1 MV @ 1.75 GHz

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

Slide courtesy of A. Velez

BESSY-VSR‘s LLRF challenges

- BESSY-VSR: two superposing voltages at 1,5GHz and 1,75 GHz → Beating of voltage to create RF buckets for long and short bunches
- Zero-crossing operation for focussing/defocussing

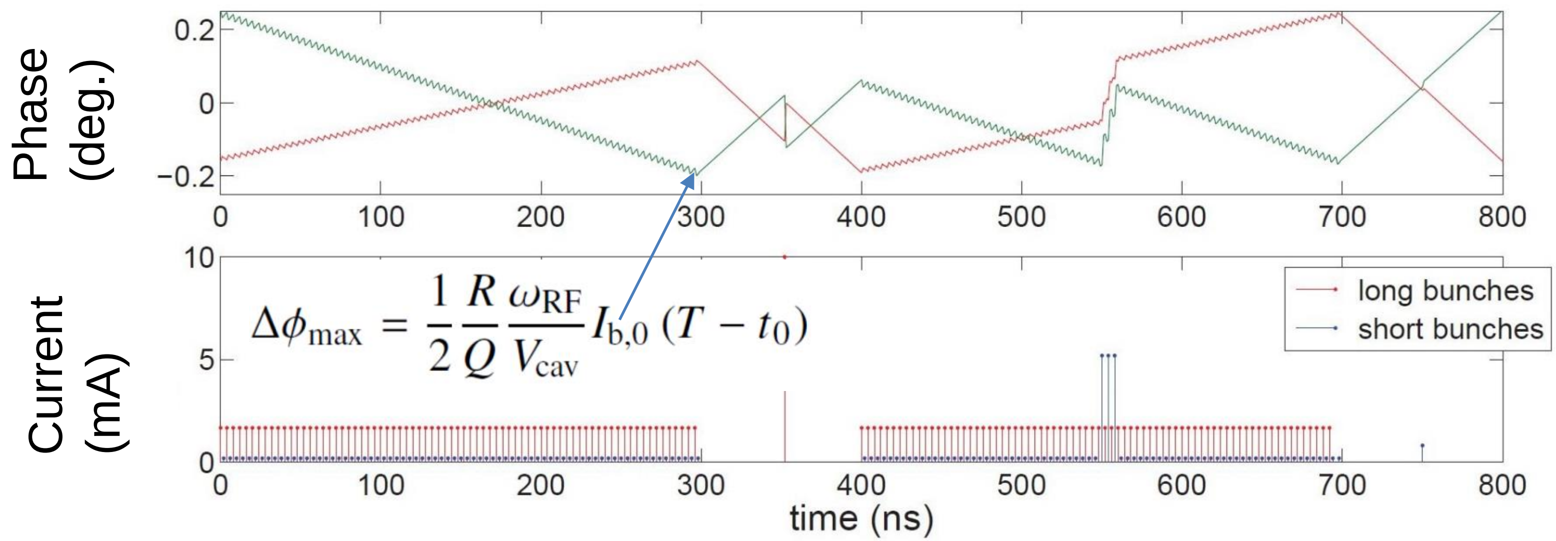


Long bunches lay in opposite slopes→ cancellation two large voltages

→ any deviation from nominal is magnified

BESSY-VSR's LLRF challenges

- Non uniform bunch train induces a **transient beam loading → Different zero crossing for each bunch! →** unwanted shorter bunches + lifetime



- Robinson instabilities → Not fulfilled by 1,75GHz cavities → Stability scales with the LLRF loop gain.

- Low beam-loading allow operation at high Q_L ($5x10^7$) → **Microphonics!**

Δl = 1 nm ←→ Δf = 0.6 Hz ←→ $\Delta\Phi$ = 1,14° for BESSY-VSR Cavities

BESSY-VSR's LLRF challenges

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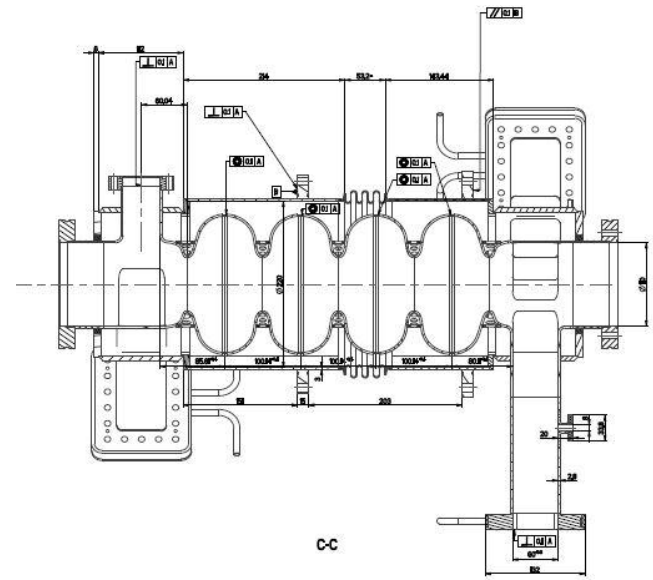
Parameter per cavity	1.5 GHz	1.75 GHz
E_{acc} (MV/m)	20	20
Q_L	$5x10^7$	$5x10^7$
φ_{acc} (degrees)	90	-90
Δf for beam loading (kHz)	11,25	15,3
Average Pf (kW)	1,49	1



$$P_f = \frac{V_{cav}^2}{\frac{R}{Q} Q_L} \frac{1}{4} \left\{ \left(1 + \frac{\frac{R}{Q} Q_L I_{b0}}{V_{cav}} \cos\varphi_{acc}\right)^2 + \left(\frac{\Delta f}{f_{1/2}} + \frac{\frac{R}{Q} Q_L I_{b0}}{V_{cav}} \sin\varphi_{acc}\right)^2 \right\}$$

resistive

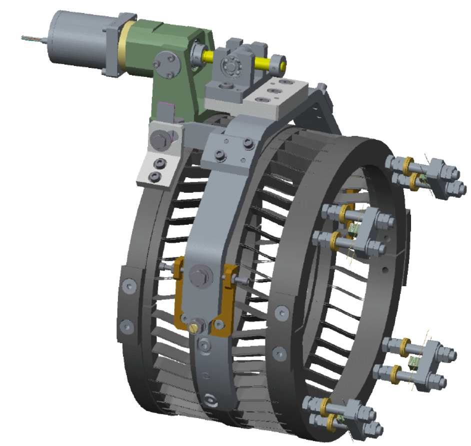
reactive

$$\Delta f = -\frac{R}{Q} \frac{f_{rf} I_{b0}}{2 V_{cav}} \sin\varphi_{acc}$$

15 kW SSA → RF overhead for:

- 60 Hz peak detuning or
- Current jump of 1.5 mA

BESSY-VSR's LLRF challenges

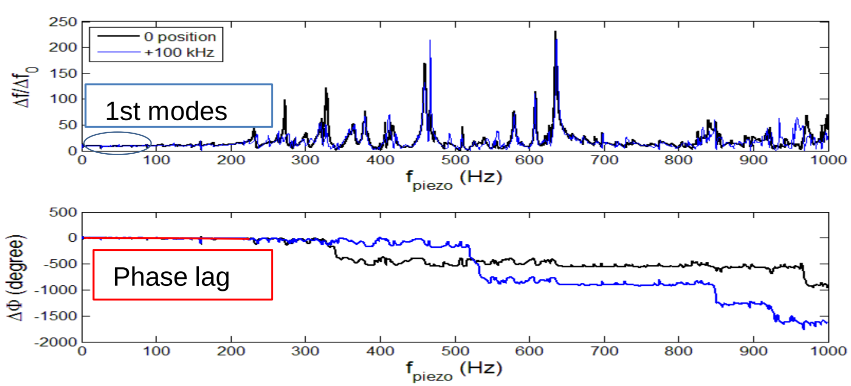


Blade tuner: motor + piezos

Several detuning control strategies:

- Classical PID +
- FIR filter + LMS learning algorithm. — A. Neumann, PRST 2010
- **Kalman filtering + adaptive control** — **A. Ushakov, yesterday**

"Iterative process that uses a set of equations and consecutive data inputs to estimate the true value of the object being measured, when the measured values contain unpredicted or random error, uncertainty, noise or variation or when the physical description is not complete"



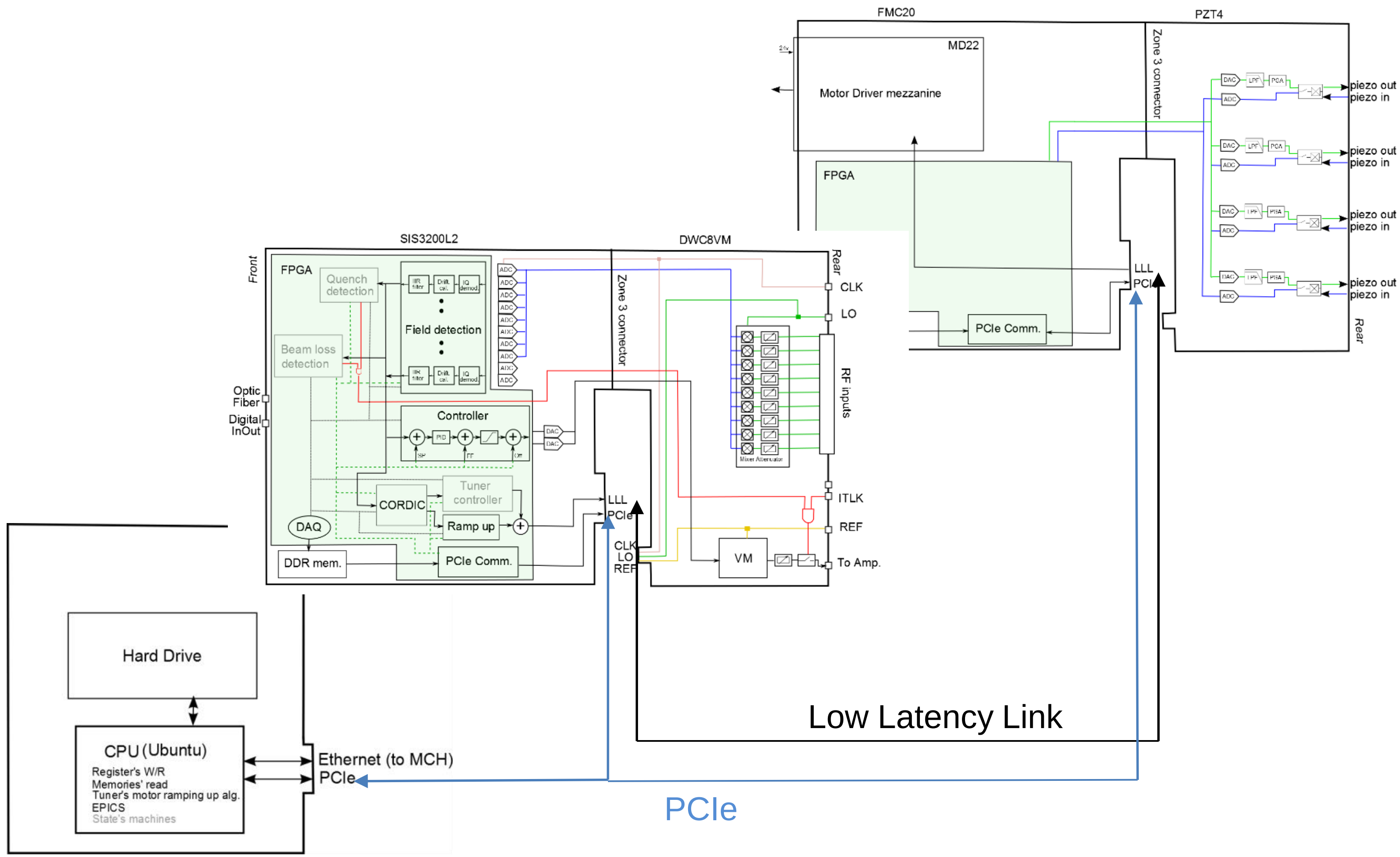
Measured mechanical response

Discretized state-space model

$$\begin{pmatrix}x_1\\x_2\end{pmatrix}_{n+1} = \begin{pmatrix}1 & \Delta t\\ -\omega_m^2\Delta t & 1-\frac{\omega_m}{Q}\Delta t\end{pmatrix}\begin{pmatrix}x_1\\x_2\end{pmatrix}_n + \begin{pmatrix}0\\ \pm k2\pi\cdot\omega_m^2\end{pmatrix}E_{acc}^2(t)$$

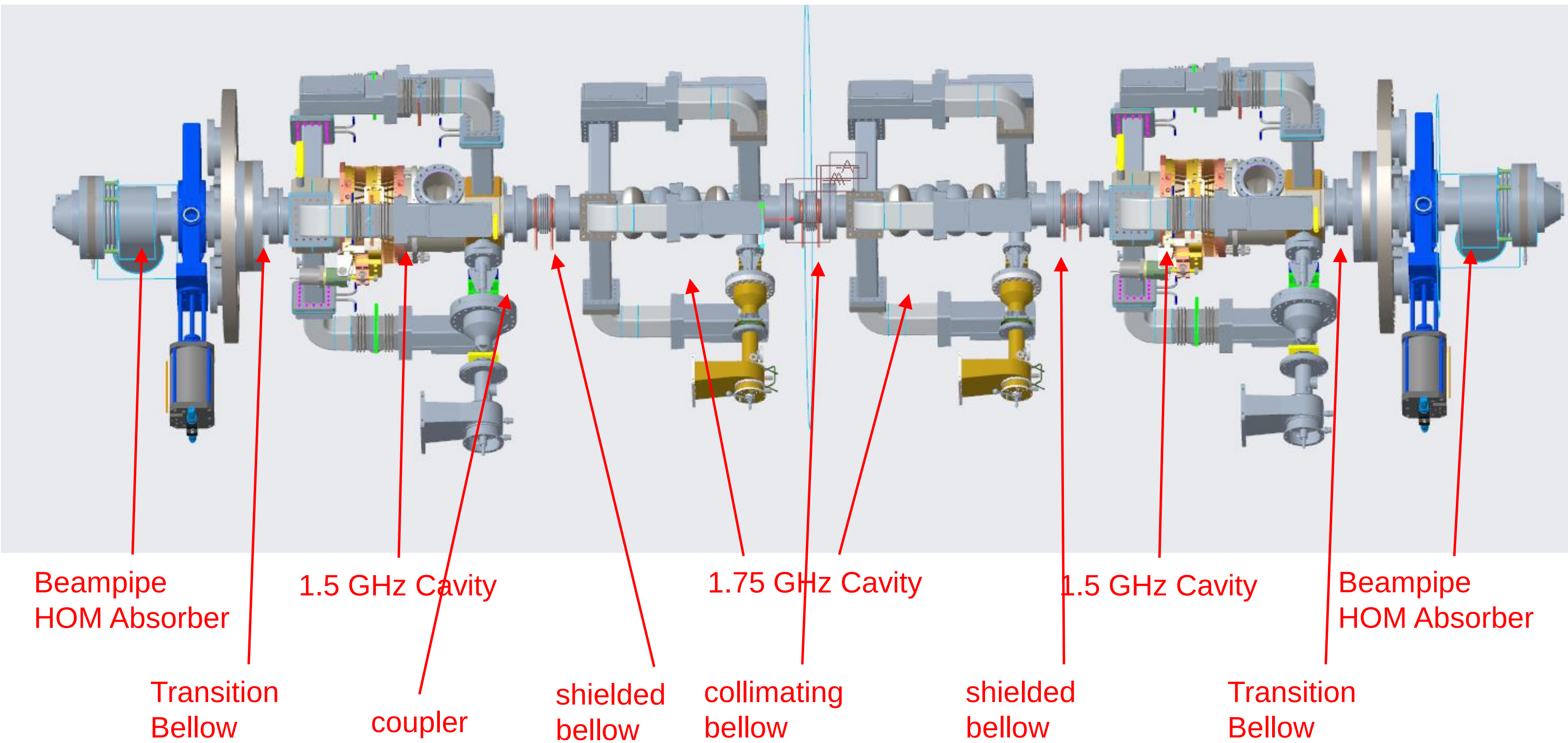
mTCA.4 single cavity control

- 1 RF amplifier per cavity → no Vector Sum needed
- Used in EXFEL's gun and ELBE
- Around 600ns of latency



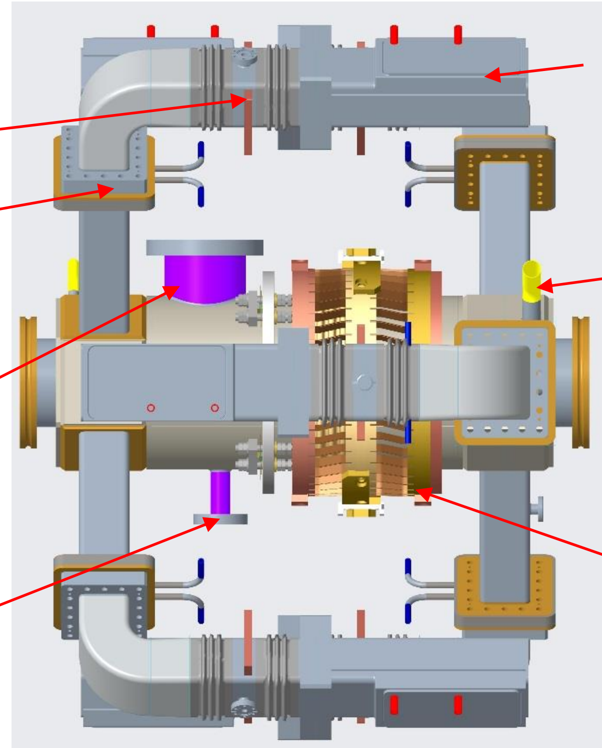
P. Echevarria, Microphonics Workshop 2018, Brooklyn.

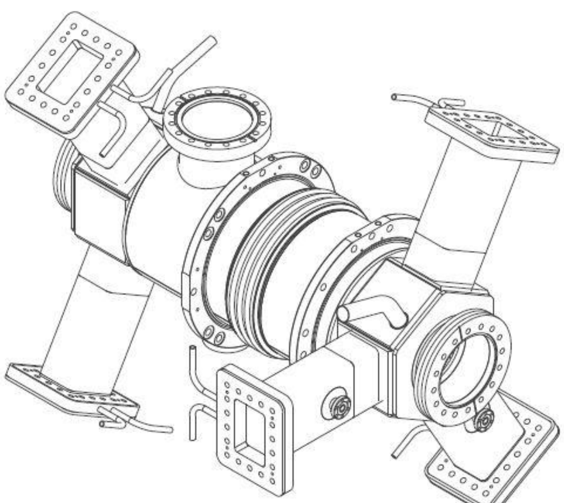
BESSY-VSR cavities and cryomodule

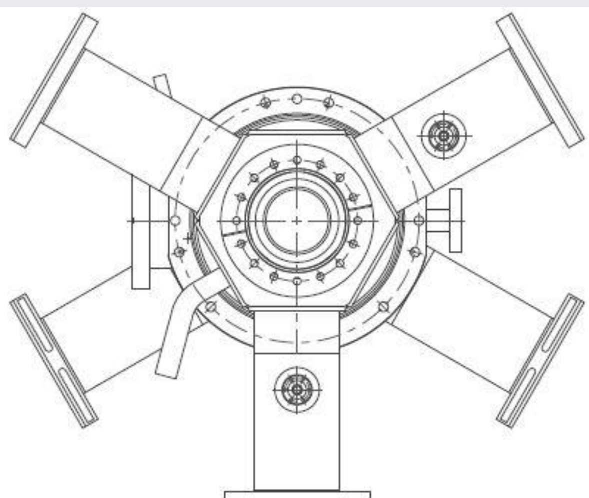


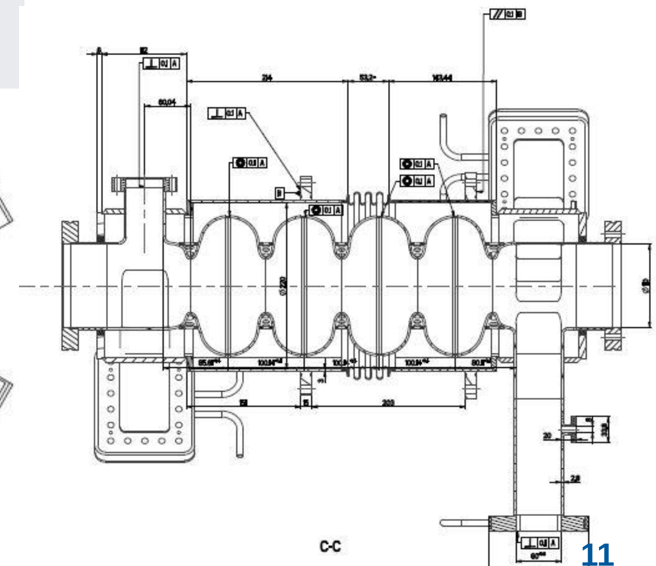
Courtesy of F. Glöckner

BESSY-VSR cavities and cryomodule









Courtesy of N. Wunderer and F. Glöckner

BESSY-VSR mechanical vibrations

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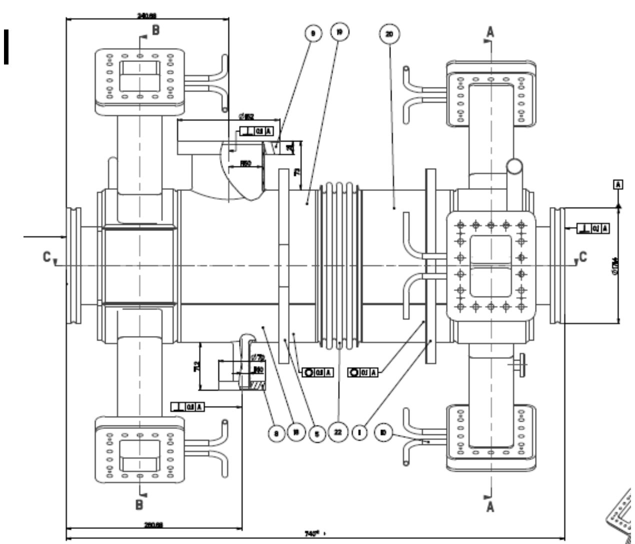
- Currently designing the cyomodule. Paying attention to:
    - Water cooling of HOM loads
    - Helium gas cooling of the wave guide flanges
- Vibration analysis of the string to be done. ANSYS is useful to determine mech. modes. Is there any software to simulate responses to excitation signals?
- Determine possible capacitive sensors which can go to the module without harming the RF operation of the cavity.
- Measure the excitation spectrum in the BESSY tunnel
- After construction a modal analysis will be done:
    - Hammer impact test?
    - Reasonable locations for input and output measurement need to be determined.
    - Cold/warm tests?



Courtesy of N. Wunderer

THANKS FOR YOUR ATTENTION!