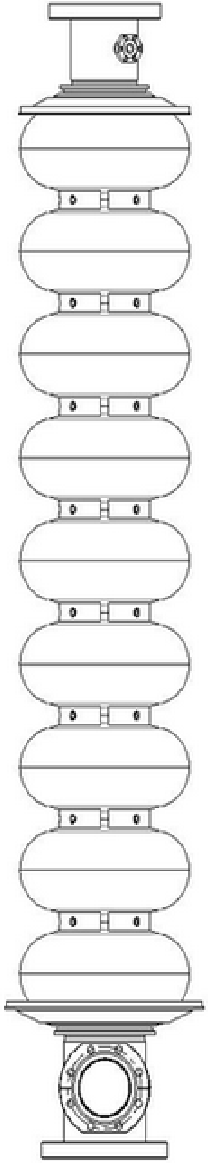
BESSY-VSR
A novel application of SRF for Synchrotron Light Sources

Adolfo Vélez*, A.Jankowiak, J.Knobloch, A. Neumann, M.Ruprecht,
H.W. Glock, G.Wüstefeld

SRF Conference 2015
Whistler CA
13-18 Sept. 2015

OUTLINE

- **BESSY VSR**
  - The BESSY VSR concept
- **BESSY VSR challenges**
- **SRF Systems**
  - Cavity design status
  - Module arrangement
  - Cryogenics
  - RF power
- **Prototypes and measurements**
- **Future work and Conclusions**



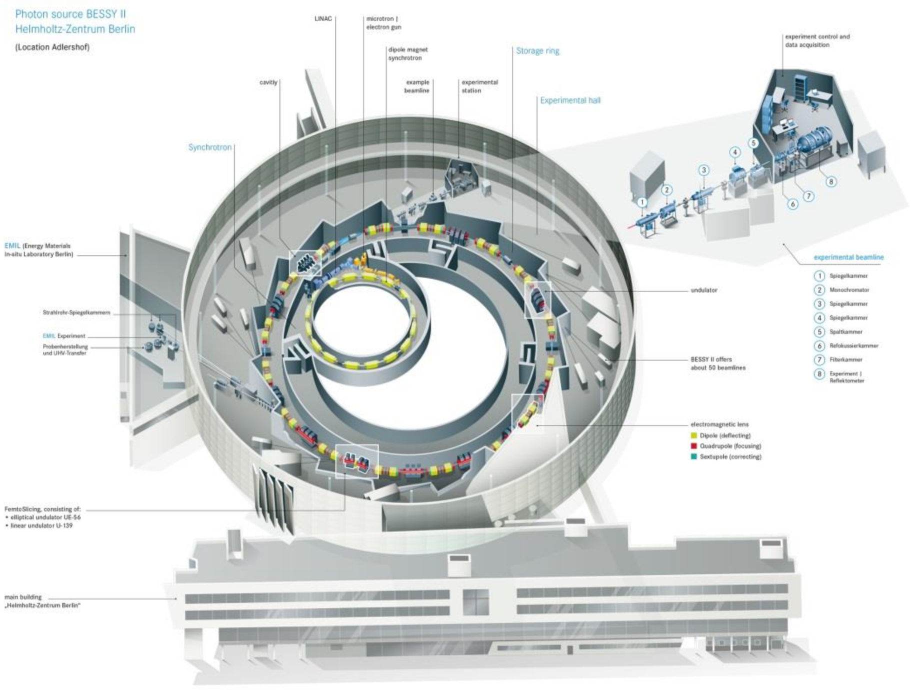
BESSY II

- 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 has ben developing a comunity of user performing dynamic measurements in ps and fs range „functional materials“
- Pioneer in offering low α and femtoslicing facility

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

⇩

BESSY III



Upgrading BESSY II

Third generation light sources move in the direction of minimizing beam emmitance

ESRF (Grenoble), Spring-8 (Japan), APS (USA) ⇒ **DLSR by multi-bend achromats (MBA)**

⇓

- Complete new ring
- New magnet/vacumm system
- Long dark time (1 year ESRF)
- Very expensive

⇐ Lifetime problems (radiation protection) ⇐ **Long pulses needed**

BUT ...

Short pulse experiments represent one of the strong fields at HZB (low-Alpha, femtoslicing).

Such a pitty to lose!

A complementary approach to DLSRs

BESSY VSR

The concept of BESSY $^{\mathrm{VSR}}$

BESSY II @ present

Normal conducting cavity system

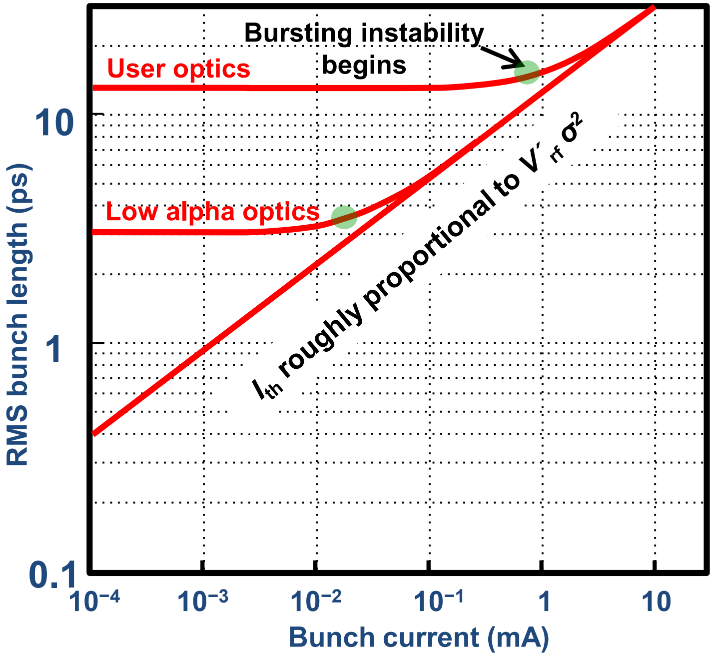
- Low alfa operation only 12 days/year (all beamlines) ------- Low flux
- Femtoslicing is continuously operated (only 1 beamline) ---------- Low flux

Can we design a system offering both possibilities simultaneously?

- Limited pulse length in storage ring

$$\sigma \propto \sqrt{\frac{\boxed{\alpha}}{\dot{V}_{\mathrm{rf}}}} \quad \begin{matrix} \leftarrow \text{Machine optics} \\ \leftarrow \text{Hardware (RF cavities)} \end{matrix}$$

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



The concept of BESSY ^{VSR}

BESSY II @ present

Supply short pulses down to 1.5 ps
100× more bunch current

Low *α* permits few 100 fs

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
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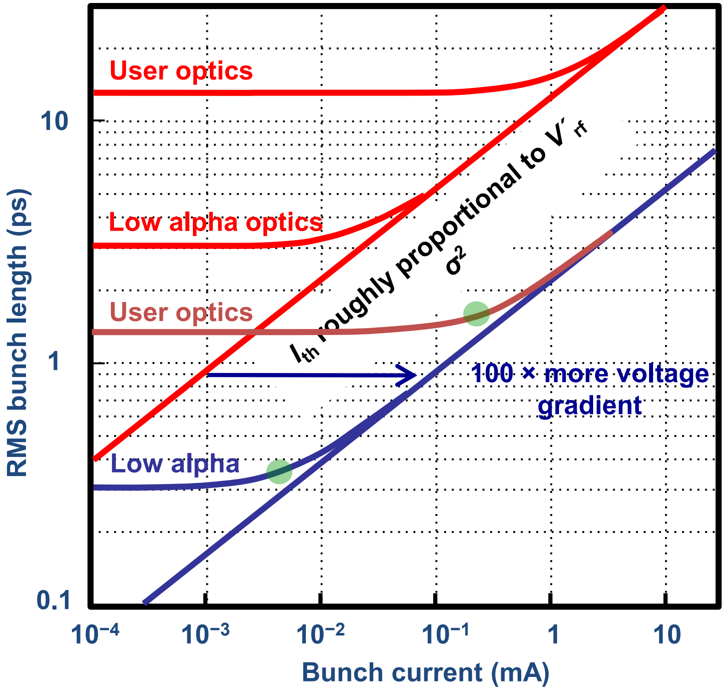
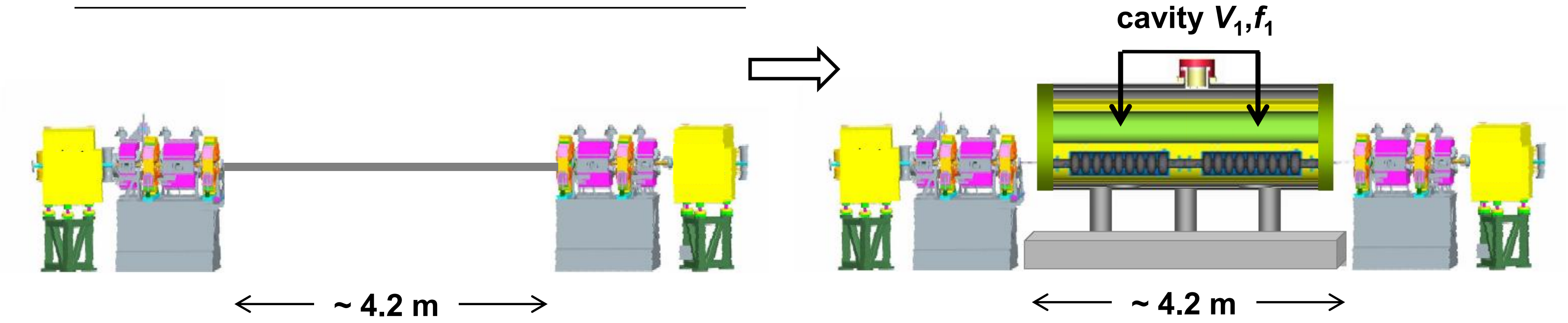


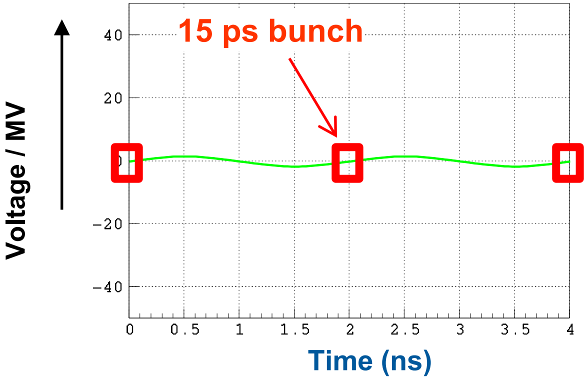
The concept of BESSY ^{VSR}

BESSY II , SC Upgrade



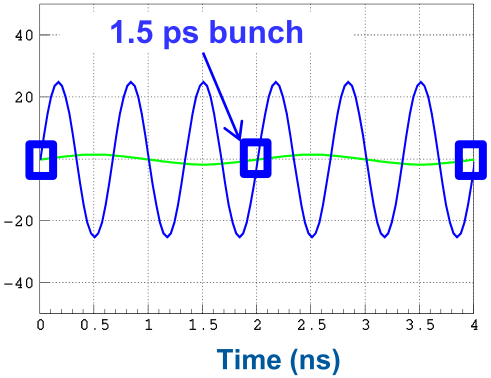
J.Feikes, P.Kuske and G.Wüstefeld.
„Towards Sub-picoseconds electron bunches: Upgrading ideas for BESSY II“
EPAC2006

Present



Voltage: 1.5 MV @ 0.5 GHz

Phase I



Voltage: 20 MV @ 1.5 GHz

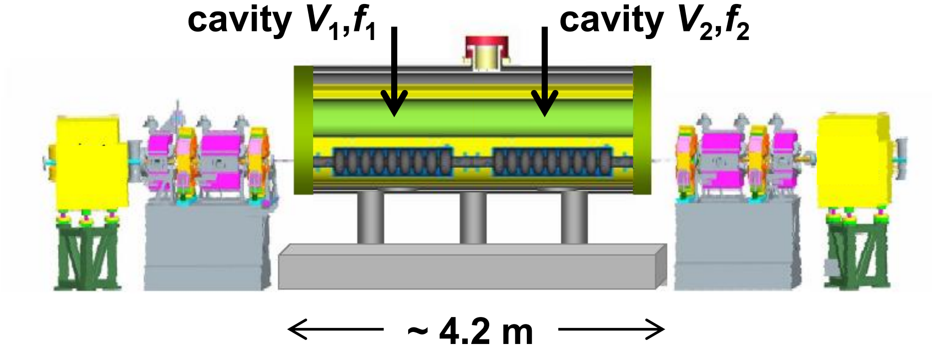
Impedance heating problems

Touschek lifetime issues

The concept of BESSY ^{VSR}

BESSY II , SC Upgrade

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

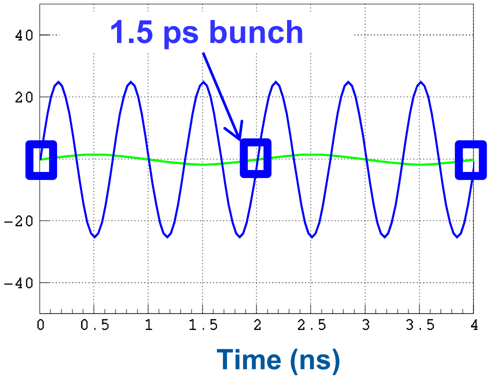


- 1.5GHz and 1.75GHz ---- RF beating (modulate RF focusing)
- Odd (voltage cancelation, 15 ps bunches)
- Even (voltage addition, long.focussing, 1.7 ps)

Present

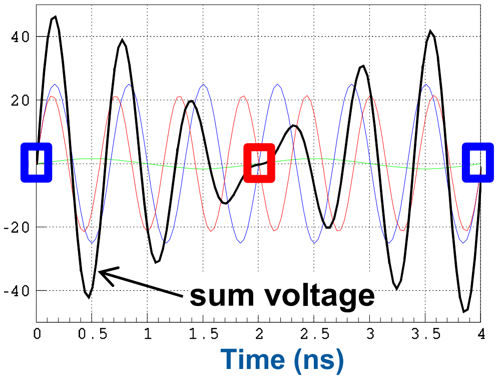
Voltage: 1.5 MV @ 0.5 GHz

Phase I



Voltage: 20 MV @ 1.5 GHz

Phase II



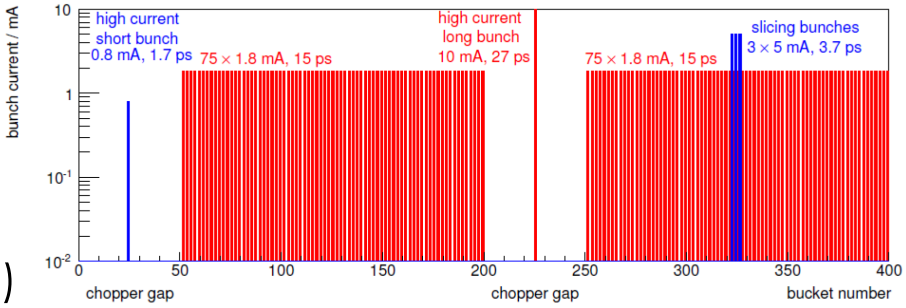
Voltage: 20 MV @ 1.5 GHz
+ 17.1 MV @ 1.75 GHz

The concept of BESSY ^{VSR}

BESSY II , SC Upgrade

BESSY VSR filling pattern

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



Present

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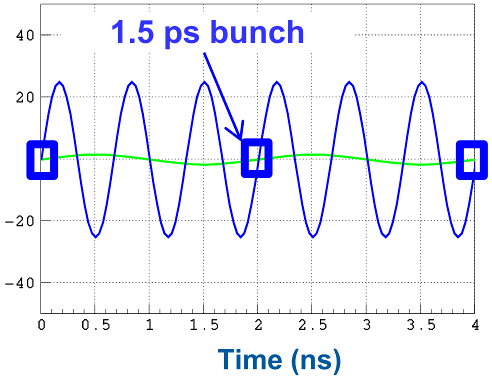

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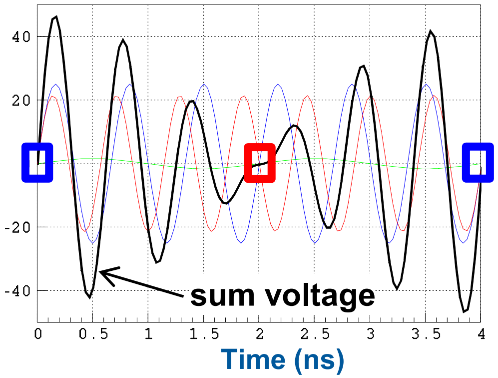
Phase II



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The concept of BESSY ^{VSR}

BESSY II , SC Upgrade

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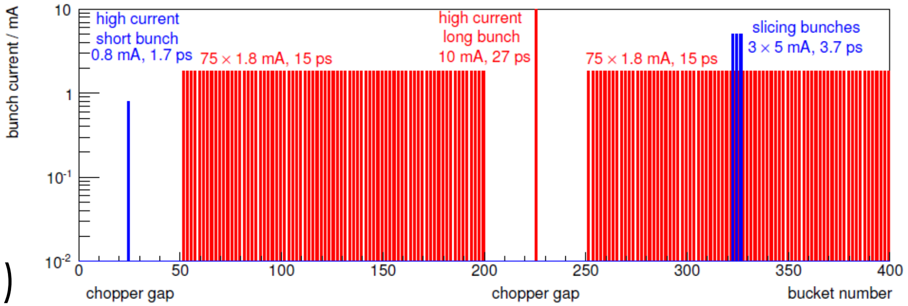
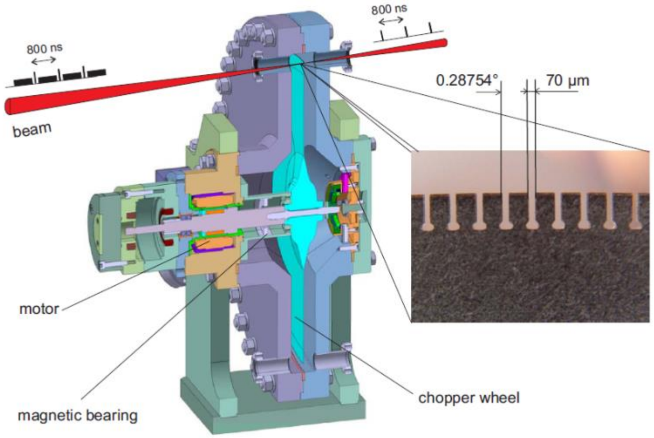


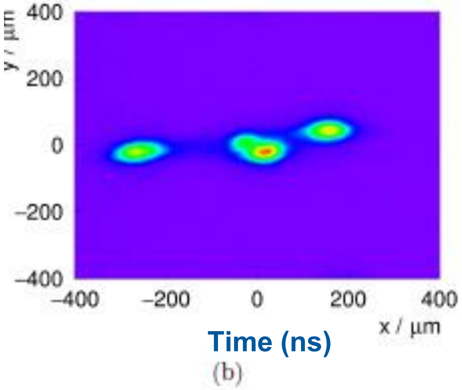
Chopper Wheel

Resonance Islands

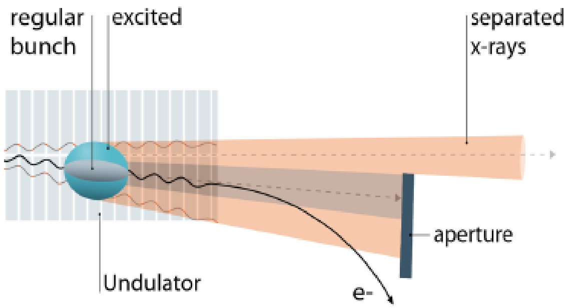
Incoherent excitation



M. Cammarata et al. “Chopper system for time resolved experiments with synchrotron radiation”. In: *Review of Scientific Instruments*



P. Goslawski et al. *Bunch Separation with Resonance Island Buckets*. Conference Website. ESLS XXII Workshop.



The concept of BESSY ^{VSR}

BESSY II , SC Upgrade

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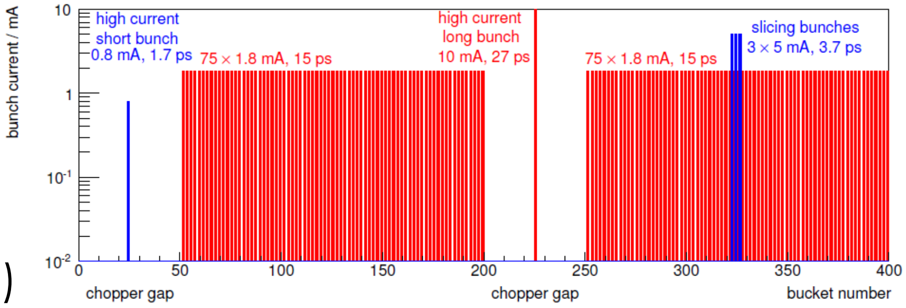


BESSY II is a low energy machine (1.7GeV)

The whole BESSY VSR installation fits into a single low β straight

No changes is the BESSY optics are needed !!

Project challenges

Bunch length: theory v. reality

- **Reality: bunch lengthening due to CSR-driven instabilities at high current**

High-gradient SRF cavities

- **20 MV/m CW operation**
- **Particulate free vacuum (10^{-10} mbar) in an otherwise "dirty" machine.**

Transparent "parking" of cavities in case VSR needs to be "switched off"

Coupled-bunch instabilities

- **Higher-order modes in SRF systems in relation to beam spectrum**
- **Very strong damping of HOMs**
- **Sufficiently strong bunch-by-bunch feedback to suppress instabilities**

Transient beam loading due to fill pattern & Robinson instabilities

- **RF and tuning control parameters for the cavities**
- **Proper choice of bandwidth and available RF power**
- **Changing bunch profile along bunch train**

Injection, top-up operation and lifetime issues

- **Injection of long booster bunches into short BESSY-VSR buckets**
- **Reduced Touschek lifetime**

Technical realization

- **Integration in a single straight**
- **Cryogenic installation**
- **Required infrastructure for system development and tests**

Technical design study

HZB. "BESSY-VSR: Variable pulse length Storage Ring Upgrade of BESSY II", Technical Design Report.DOI:10.5442/R000.http://dx.doi.org/10.5442/R0001

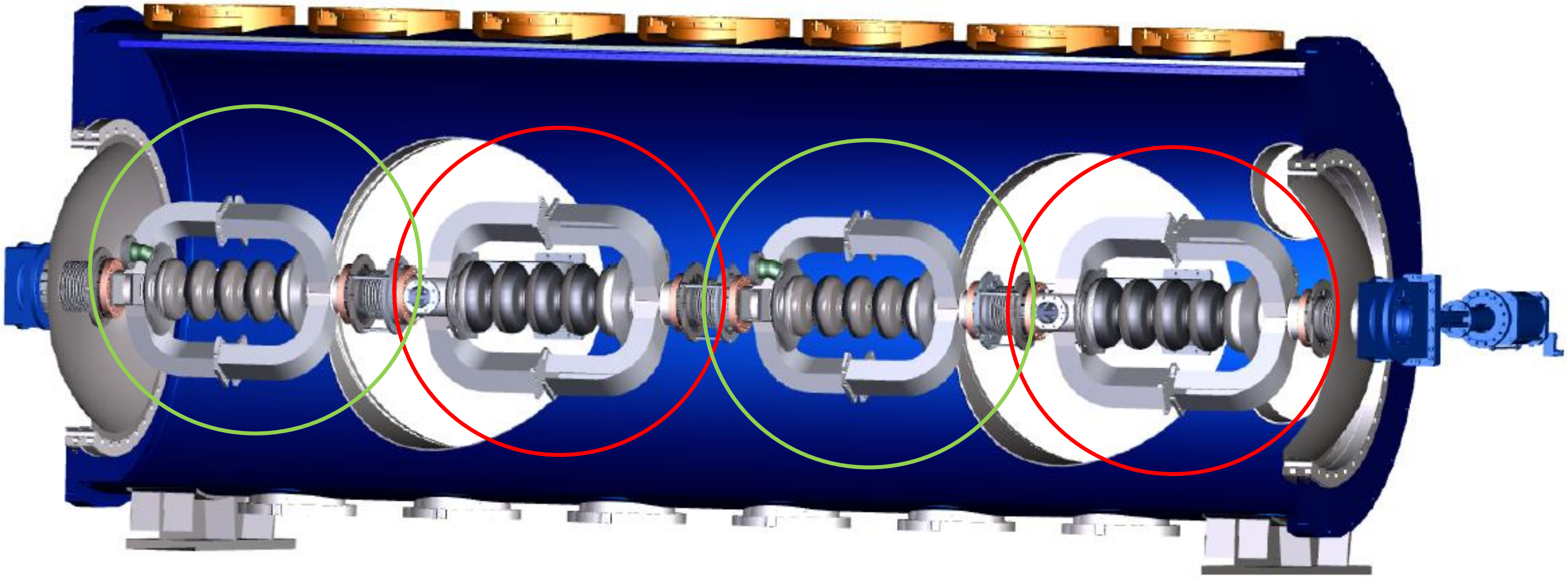
SRF Systems

SRF Systems challenges

- CW operation @ high field levels **E=20MV/m**
- On the edge field values on the surface (discharges, quenching)
- High beam current (**I_b=300mA**)
- Cavities must be highly damped (CBIs)
- Imposed design restrictions: iris diameter, beam-pipe diameter ...

→

The combination of **CW operation**, **high voltage** and **high beam current** in a storage ring make the design a challenging goal to achieve



2@1.5 GHz

2@1.75 GHz

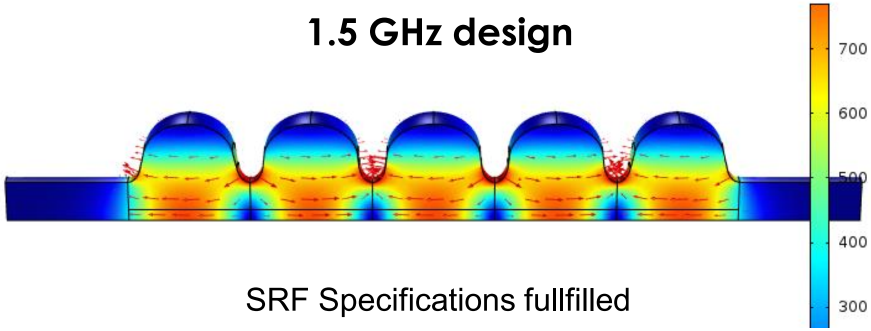
1.5 GHz Cavity design

Stage 1: Cavity geometry

Design specifications

Parameter	Target value
E_{acc}	$20\,\mathrm{MV/m}$
I_{beam}	$\leq 300\,\mathrm{mA}$
$E_{\mathrm{pk}}/E_{\mathrm{acc}}$	≤ 2.3
$B_{\mathrm{pk}}/E_{\mathrm{acc}}$	$\leq 5.3\,\mathrm{mT}\;/(\mathrm{MV/m})$
R/Q	$\geq 100\,\Omega$
K for TM_{010}	$\geq 3\,\%$
μ_{ff} for TM_{010}	$\geq 97\,\%$

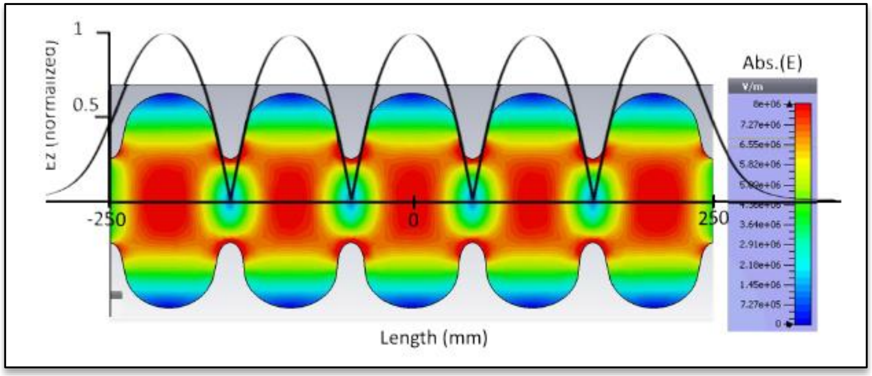
1.5 GHz design



SRF Specifications fullfilled

Cavity parameter	Design goal	HZB
$E_{\mathrm{pk}}/E_{\mathrm{acc}}$	≤ 2.3	2.29
$B_{\mathrm{pk}}/E_{\mathrm{acc}}$	$\leq 5.3\,\mathrm{mT}/(\mathrm{MV/m})$	$4.4\,\mathrm{mT}/(\mathrm{MV/m})$
R/Q	$\geq 500\,\Omega$	$525\,\Omega$
K for π-TM_{010}	$\geq 3\%$	3.3%
μ_{ff} for π-TM_{010}	$\geq 97\%$	98.2%

Operation problems derived from high field values prevented



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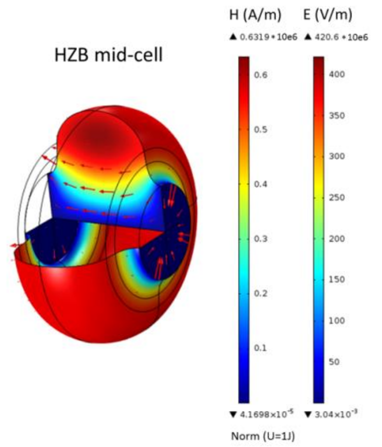


***HZB** optimized model*

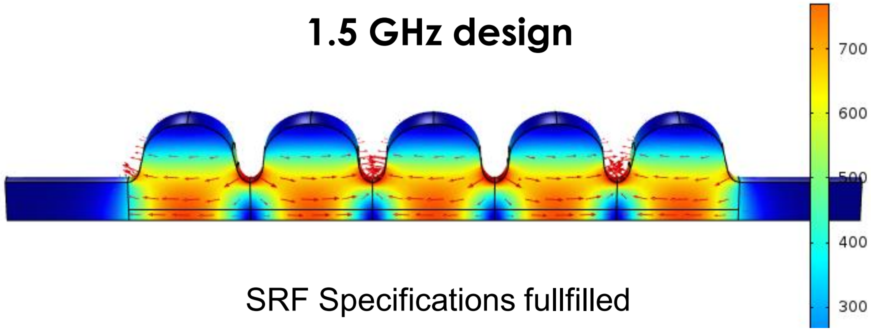
Base models

- Cornell 1.3 GHz (escaled)
- Jlab 1.497 GHz

Big iris diameter for high cell-cell coupling

Φ=71.34mm

1.5 GHz design



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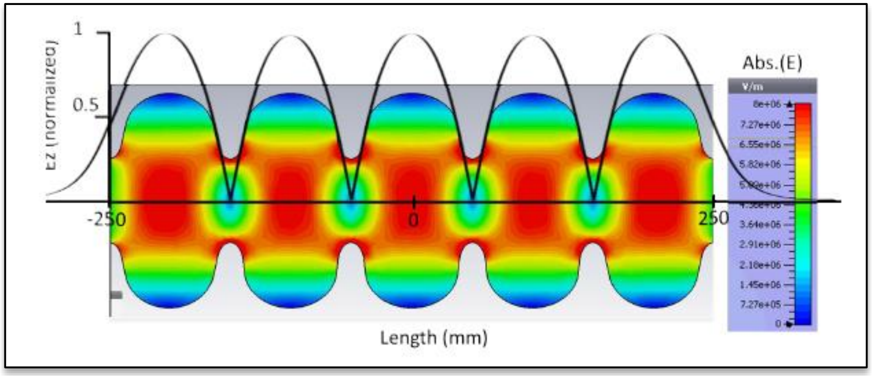

1.5 GHz Cavity design

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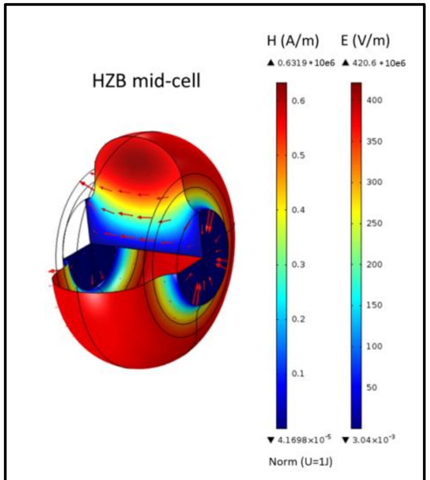

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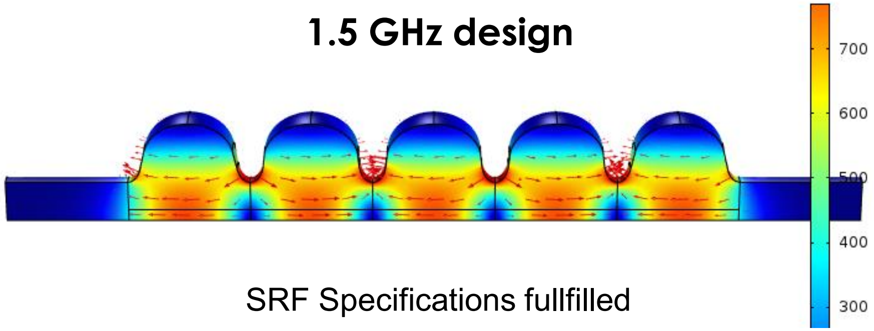

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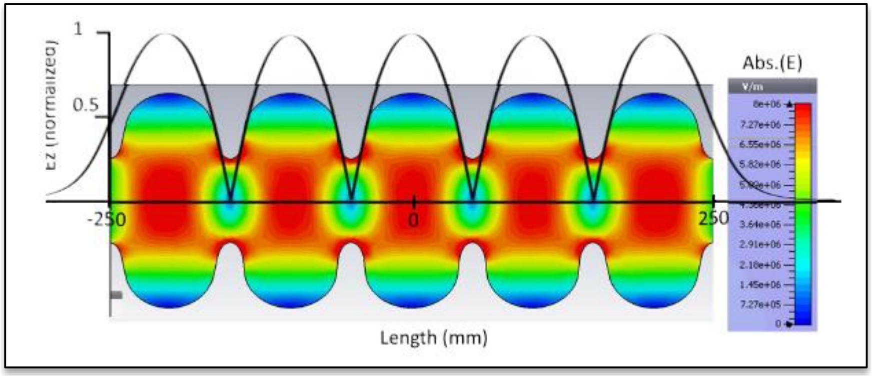
Stage 2: HOM damping

- Analyze HOM in relation to beam spectrum
- Provide strong HOM damping in order to avoid CBIs

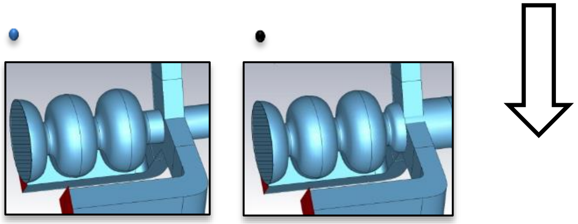


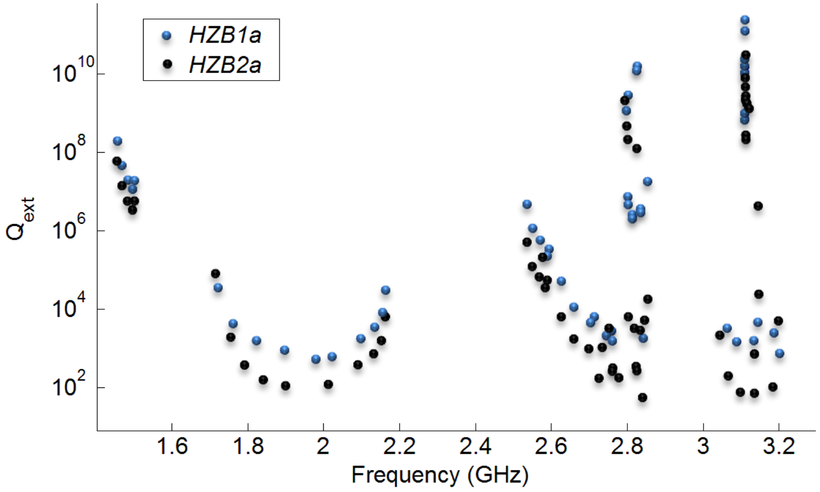
End-groups and Damping

Calculations show high HOM damping level required to avoid CBI's

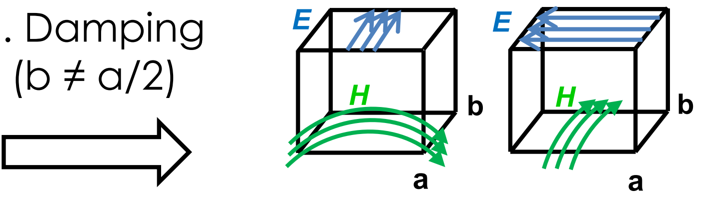
- **5e4 Ω**, longitudinal modes
- **1e7 Ω/m**, transverse modes

Enlarged beam-tubes





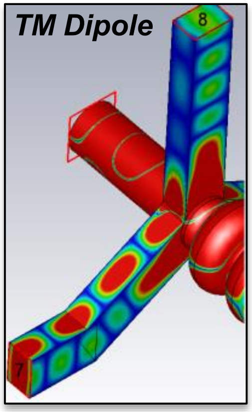
Modified
WG. Damping
(b ≠ a/2)

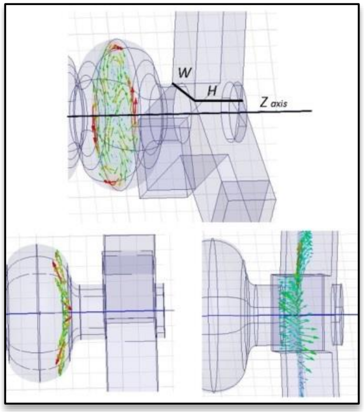


f = 2.755 GHz

4xTE$_{01}$

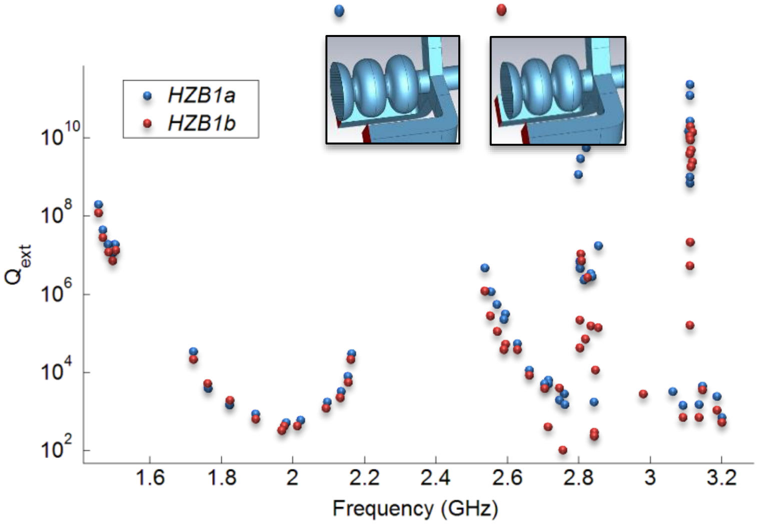
2xTE$_{10}$





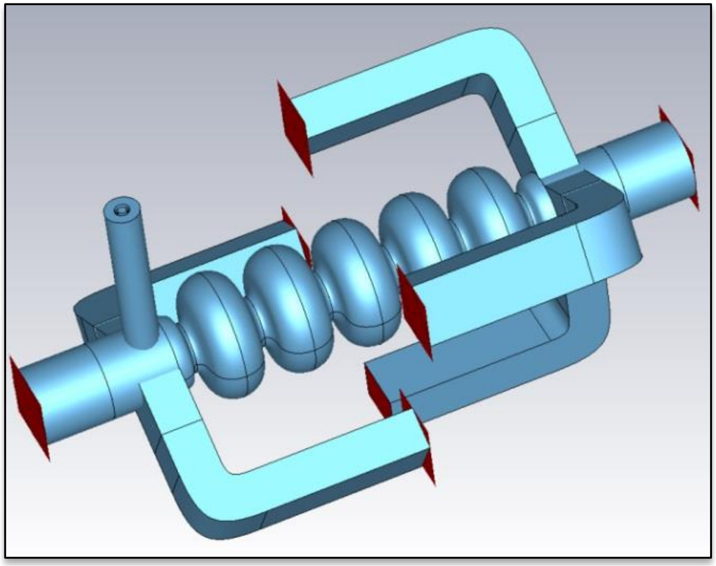
A.Velez et al.
WEPMA013
IPAC15

A.Velez et al.
MOPP071,
LINAC'14



End-groups and Damping, adding a coaxial coupler

Heavily damped 1.5 GHz prototype (with FPC+WG dampers)



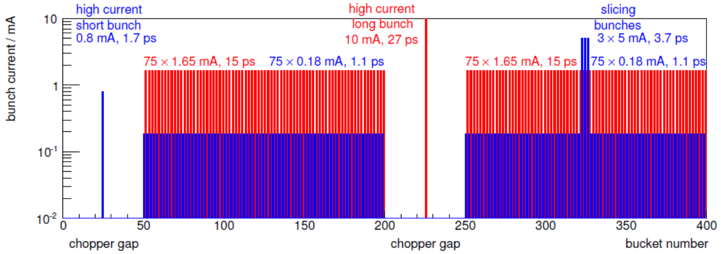


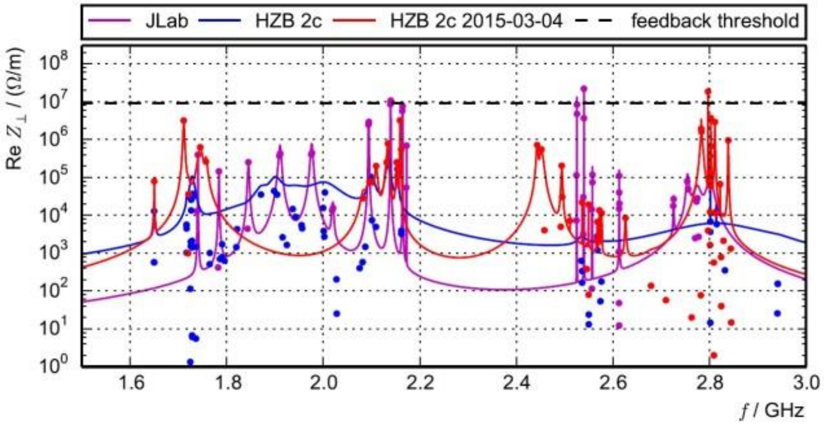
Table 1: BESSY VSR filling pattern with calculated loss factor for the different bunch δ

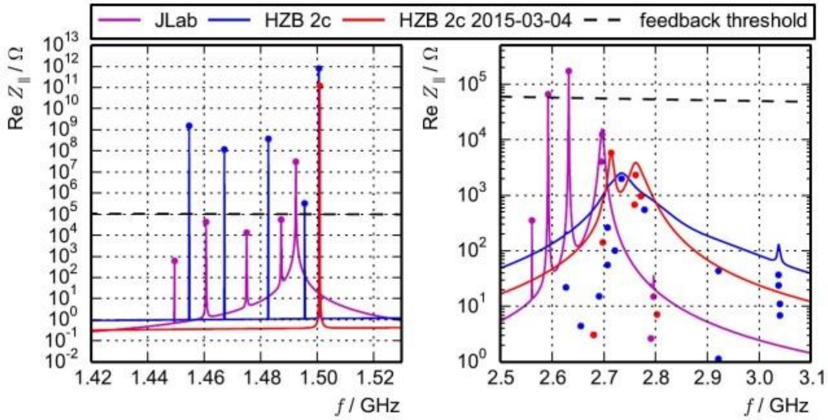
n	I(mA)	δ(mm)	k//, a=4/3	k//, a=0.59
1	0.8	0.51	48	13
150	1.65	4.5	2.6	3.55
150	0.18	0.33	85.8	16.9
1	10	8.1	1.21	2.45
3	5	1.11	17	8.18

Table 2: Calculated HOM power for different scaling of the loss factor (k) for the BESSY VSR filling pattern

∑n	∑I	∑(pC)	P_{HOM},a=4/3	P_{HOM},a=0.59
305	300.3	2.4e5	1.2kW	0.98kW

All analyzed modes except 1 are below the Impedance threshold (with feedback)



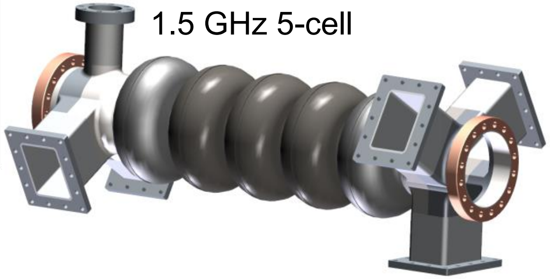


Courtesy of M.Ruprecht

HOM power of 1 KW need to be damped with the most possible compact design (module length limitation)

1.75 GHz Cavity design

1.75 GHz 5-cell

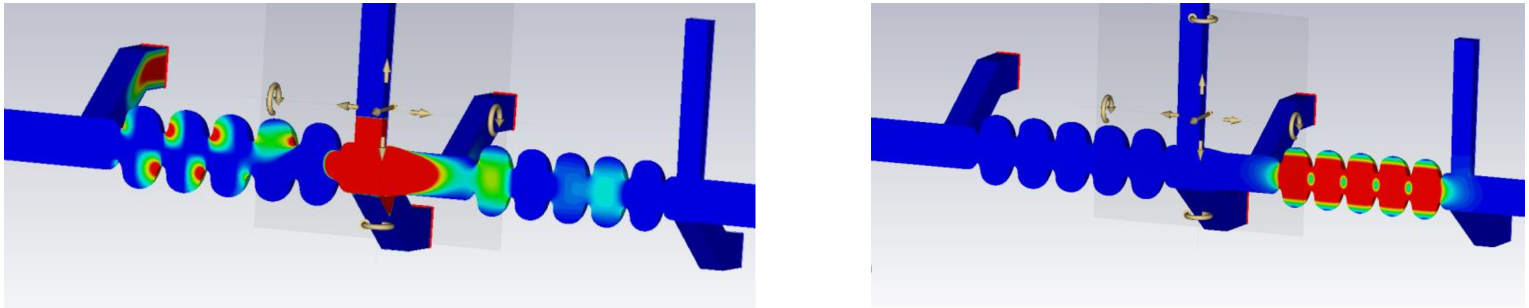


1.5 GHz 5-cell

1.75 GHz Cavity design

- Design work started with a scaled version of the 1.5 GHz 5-cell cavity.
- The RF and HOM damping techniques developed on the 1.5 GHz cavity can be implemented in order to fine tune the design (if needed).

1.75 GHz Cavity design



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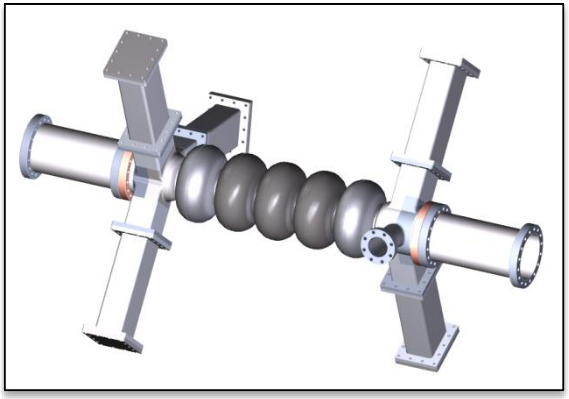
Concatenation of cavities

- Different iris sizes. Tapered transitions are needed to avoid modal overlaping between cavities and fundamenta power leakage (TM_{010}).
- Possible high Q trapped modes generated in the tappered transitions (CBIs).
- Limited module space (4.2m).
- Possible heating on belows, HOM dampers ...
- In case higher damped needed beam-tube dampers might not be feasible.
- Concatenation studies currently undergoing

T. Flisgen et al.
IPAC2014 TUOAB01 (2014)

Prototypes and Measurements

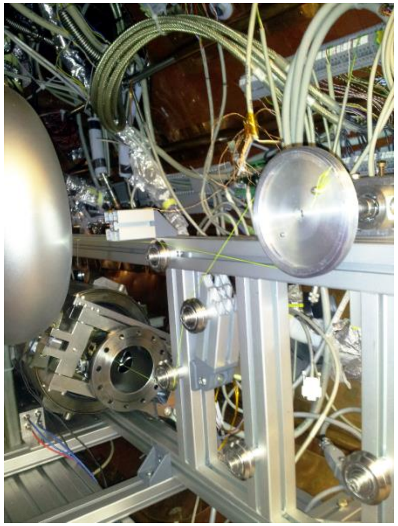


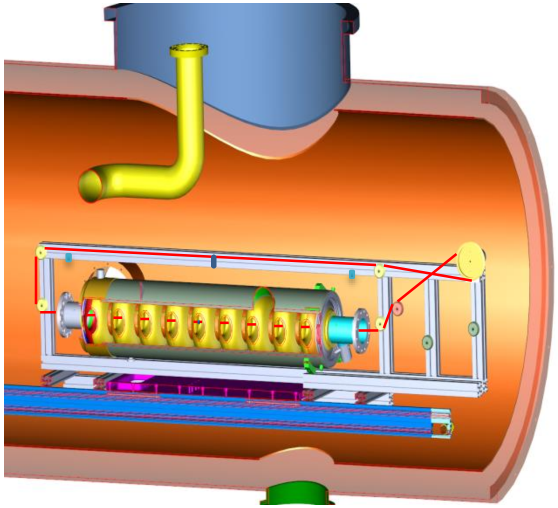
Copper prototype (1.5GHz)
(5 WG+1 FPC) with Rotary mechanical flanges

To be measured in standard bead-pull test-bench

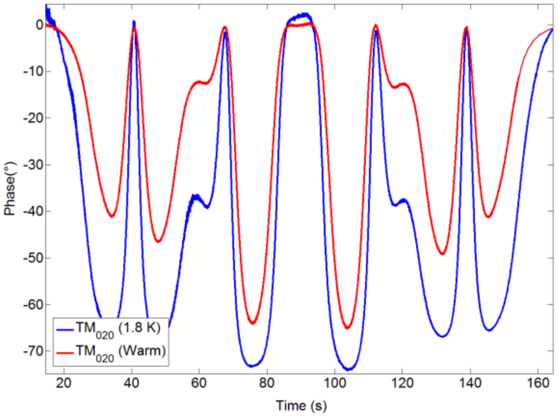
A new cold-bead-pull test stand has been developed by HZB in order to **measure field characteristics** of Nb prototypes in ***SUPERCONDUCTING STATE*** at HoBiCat

First results obtained from 1.8K measurements of a 9 *cell Tesla* Cavity





A.Velez et al,
TUPB078, this proceedings



Future work and conclusions

Work in progress ...

- Study effects of undamped energy propagated throug the beam-pipes to the ring. Heating issues.
- Concatenation studies . Cavity-cavity coupling, energy damping and impedances.
- Thermal studies (waveguides, flanges...).
- Studies on tunning HOMS
- FPC Coupler design.
- Multipacting on transitions (iris-damper, damper-B.P)
- Fabrication of prototypes.

Poster

TUAA03

Thank you for your attention

BESSY VSR