BESSY VSR

HZB Helmholtz Zentrum Berlin

Status of the BESSY VSR Project

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for the BESSY VSR team

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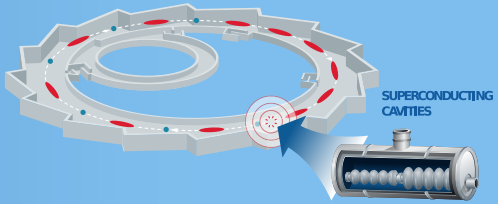
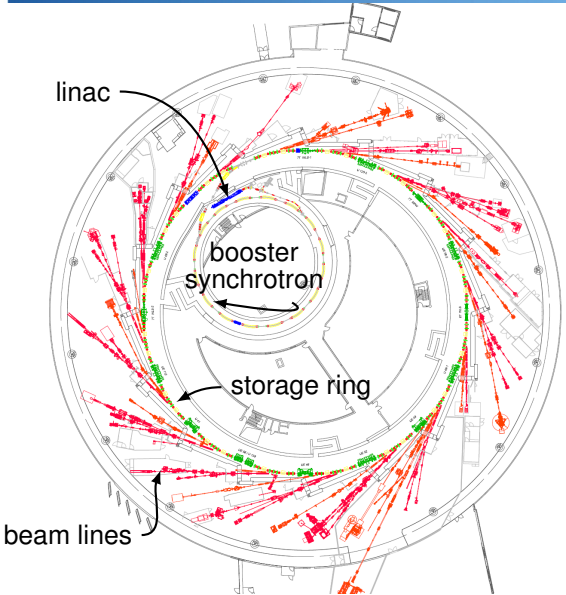


Advanced Low Emittance Rings Technology (ALERT) 2016 Workshop
ELETTRA, Trieste, Italy
14-16 September 2016

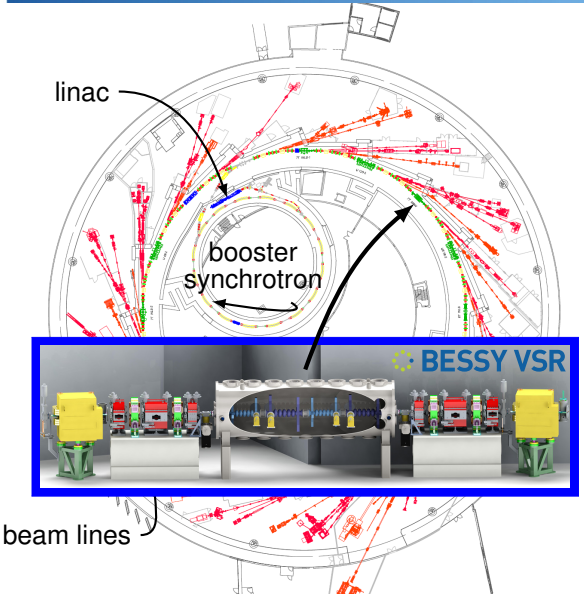
Outline

From BESSY II to BESSY VSR



Machine Parameters	
Circumference	240 m
Energy E	1.7 GeV
Horizontal emittance ϵ_x	5 nm rad
Total beam current I_{DC}	300 mA
Harmonic number	400
Mom. comp. factor α	7.3×10^{-4}
Synchrotron frequency f_{s}	8.0 kHz
RF voltage at 500 MHz	1.5 MV
Effective bunch length (rms)	15 ps

From BESSY II to BESSY VSR



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Effective bunch length (rms)	15 ps
RF voltage at 1.5 GHz	20 MV
RF voltage at 1.75 GHz	17 MV
Effective bunch length (rms)	1.7 ps

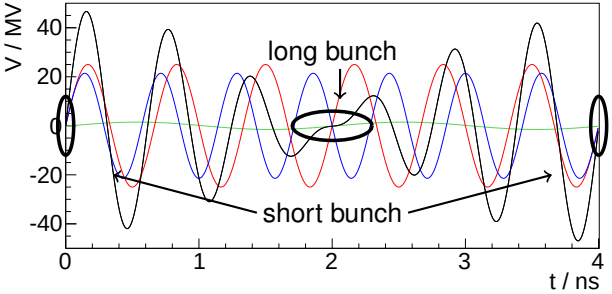
From BESSY II to BESSY VSR: Upgrade Concept

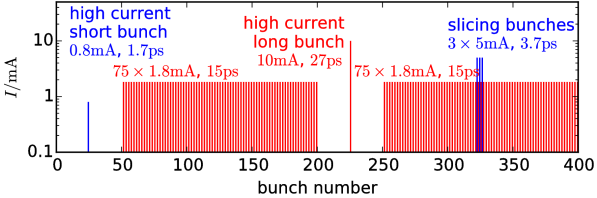
- Bunch length:

$$\sigma_0 \propto \sqrt{\left|\frac{\alpha}{V'}\right|}, \quad I_{\mathrm{CSR}} \propto \alpha$$

f	V	$V' = \frac{\mathrm{d}V}{\mathrm{d}t}/2\pi$
500 MHz	1.5 MV	0.75 MV GHz
1.5 GHz	20 MV	30 MV GHz
1.75 GHz	17.1 MV	30 MV GHz

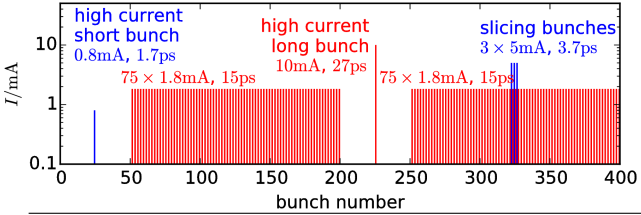
- short, stable, high intensity bunches (1.7 ps, 0.8 mA)
- 300 mA basic operation maintained
- impedance heating / Touschek losses mitigated



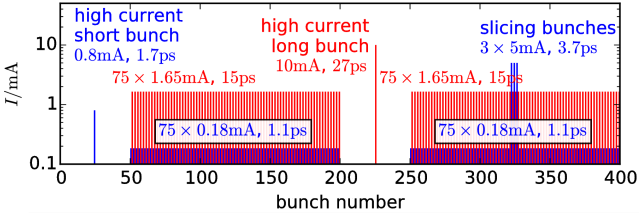


From BESSY II to BESSY VSR: Upgrade Concept

Possible BESSY VSR operations



baseline fill pattern



high rep rate short pulses / THz ($\approx$ 5 kW)

low-α short bunch: $I \approx 0.04$ mA, $\sigma \approx 0.3$ ps (rms)

Timeline:

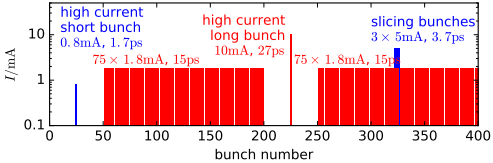
since 2013	VSR Science Workshops
03/2015	Technical Design Study completed
04/2015	successful review TDS BESSY VSR
06/2015	application to Helmholtz Association submitted (strategic investment, 19 Mio€ + 10 Mio€ HZB)
10/2015	scientific evaluation of application, result: “outstanding” project
2016/17	ranking of all applications from all research fields, decision about funding, available budget heavily “overbooked”
2018	first tranche of “fresh” Helmholtz money expected
2020/21	start of full user operation

http://dx.doi.org/10.5442/R0001

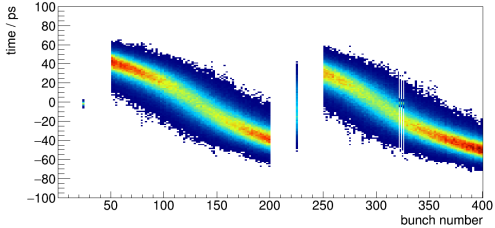
- Two R&D projects started (total 3 Mio€ / 3a) + 15 FTE for the full project: SRF cavity + auxiliary prototyping / bunch resolved diagnostics
- preparatory phase = 1.5 GHz module @ BII planned for 2018/19

Beam Dynamics: Transient beam loading and lifetime

BESSY-VSR hybrid fill with two 100 ns gaps:



Phase transient and bunch length simulation:



Transient beam loading:

- Changes in beam current result in phase change that cannot be compensated by the RF (insufficient power, limited bandwidth)
- Focusing gradient (and hence bunch length) of long bunches varies along the bunch train, short bunches are nearly unaffected.

→ Long bunches are shortened: **Increased Touschek losses**

- Possible solution are investigated: Separation by resonant island buckets, optimization of fill pattern, ...

- R&D project bunch resolved diagnostics addresses challenges of complex fill pattern

Beam Dynamics: Booster

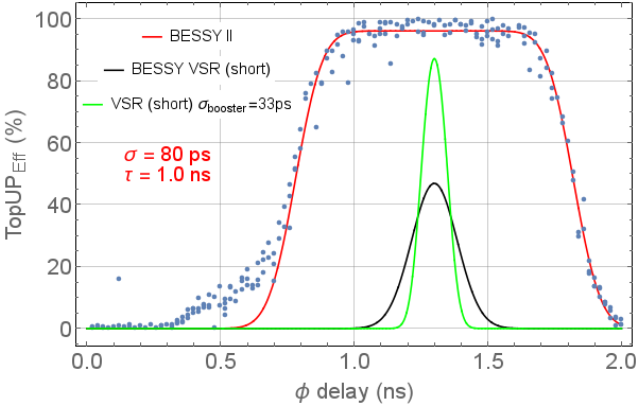
Status:

- Bunches from booster rather long (80 ps)
- Low injection efficiency into short buckets expected

Ongoing booster studies (T. Atkinson):

- Low-α? (requires splitting)
- Cavity upgrade? (extra focusing)
- Longitudinal stability
- Diagnostics improvements

Injection efficiency; measurement and expectations: (courtesy T. Atkinson)



Status R&D SRF Cavities: Overview

The following slides are based on:
Adolfo Vélez (HZB G-ISRF), “R&D of SRF cavities for BESSY VSR”, TTC Meeting at Saclay, July 5 - 8, 2016.

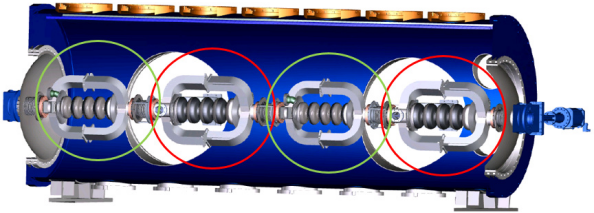
HZB SRF R&D project (budget: 2.5 M€):

- Design, fabrication and testing of fully dressed 1.5 GHz Nb cavities
- Development of HOM loads, tuners and necessary ancillaries
- Fabrication of copper and niobium prototypes to validate the proposed RF design techniques
- Design and fabrication of high power couplers
- Development of RF sources for cavity operation
- Prototype testing and commissioning: HoBiCaT and testing hall vertical test stand.

Collaboration partners

- Helmholtz Association POF-III Topic “Accelerator Research and Development”
- External: Jefferson Lab (USA), TU Dortmund and Uni Rostock

Status R&D SRF Cavities: Cavity Design Specifications and Challenges



2 x 1.75 GHz 2 x 1.5 GHz

Cavity specifications

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

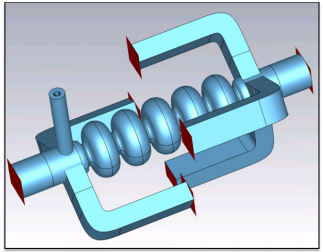
Cavity parameter	1.5 GHz	1.75 GHz
Frequency	1.5 GHz	1.75 GHz
Number of cells	5	5
Number of cavities	2	2
Voltage	20.0 MV	17.14 MV
Accelerating field	20.0 MV/m	20.0 MV/m
Cavity length	0.5 m	0.43 m
(R/Q)	$525\,\Omega$	$525\,\Omega$ *
G	$280\,\Omega$	$280\,\Omega$ *
Q_0 at E_{acc} ($R_{res} = 23\,\mathrm{n}\Omega$)		
@1.8 K	8.56e9	7.86e9
@2.0 K	6.1e9	5.2e9
@4.4 K	1.66e8	1.26e8
Dynamic losses per cavity		
@1.8 K ($R_{res} = 23\,\mathrm{n}\Omega$)	22.3 W	17.8 W
@2.0 K ($R_{res} = 23\,\mathrm{n}\Omega$)	31.2 W	26.9 W
Total gradient	60.0 MV GHz	
Module electrical length	1.86 m	

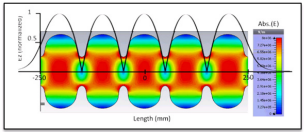
Cavity design challenges:

- CW operation at high field levels E = 20 MV/m
- Edge field values on the surface (discharges, quenching)
- High beam current (300mA), reactive beam loading
- High HOM damping (CBIs)
- Cavity fabrication processes not mature

Status R&D SRF Cavities: Cavity Design Specifications and Challenges

Basic design:





Cavity parameter	Design goal	HZB
E_{pk}/E_{acc}	≤ 2.3	2.29
B_{pk}/E_{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_{tt} for π-TM_{010}	$\geq 97\%$	98.2%

Damping Technique

Choice for Waveguide Dampers:

- High power capabilities
- Natural cut-off
- Damping efficiency
- Long distance to loads (dust contamination)
- Compact option

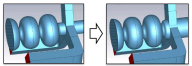
Gernal constraints:

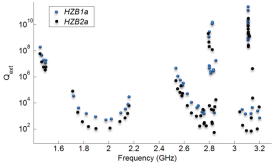
- High HOM damping level required to avoid Coupled Bunch Instabilities (CBIs)

Status R&D SRF Cavities: Cavity Design Specifications and Challenges

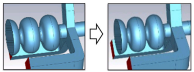
Major steps towards high HOM damping:

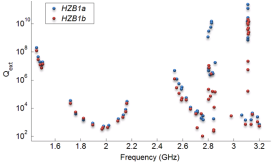
- Enlarged beam tubes



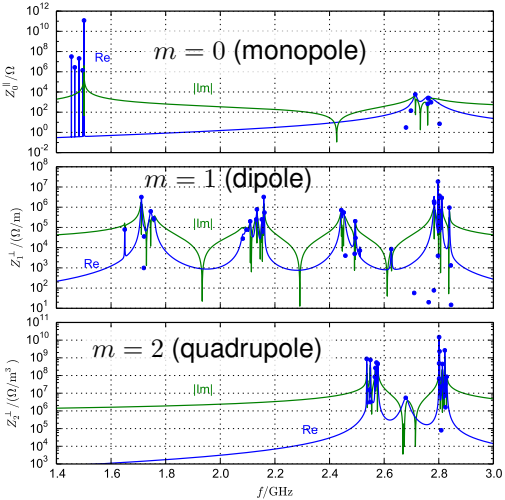


- Modified wave guide cross sections





Resulting impedance spectrum



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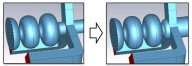

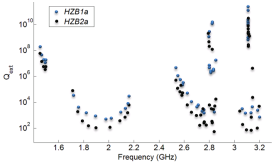

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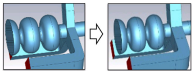
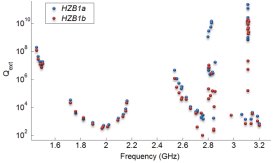
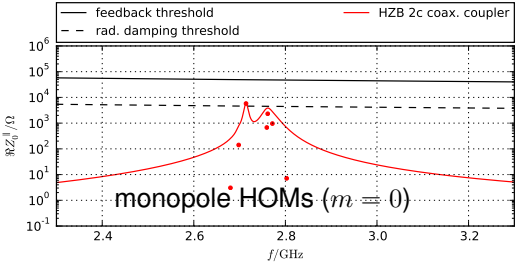
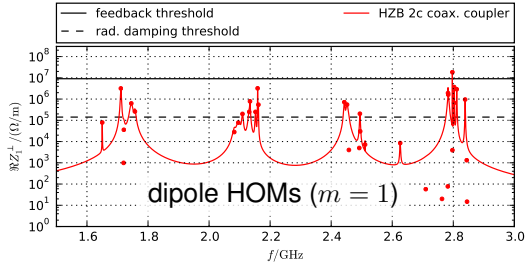




Coupled bunch instability thresholds

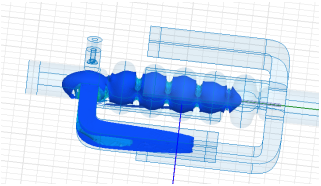


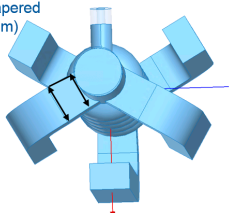


Status R&D SRF Cavities: End-groups and HOM Power

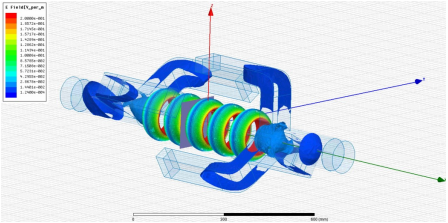
End-group design considerations:

- Long waveguide needed in order to avoid Q droping (> 400 mm)
- Waveguide tapered to reduce a localized end-group mode

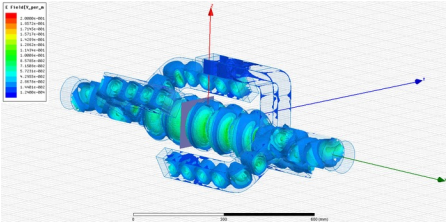




$\mathrm{TM}_{010}\pi$ mode:



Dipole HOM:

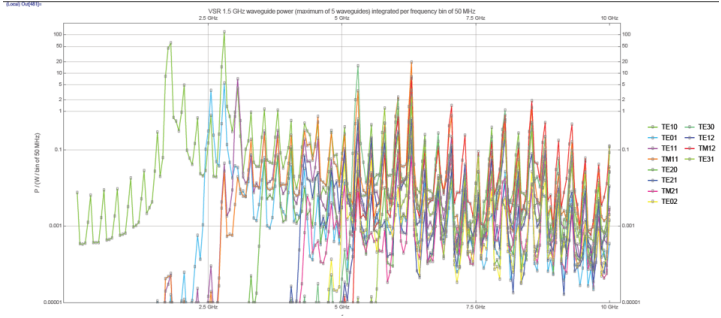


Status R&D SRF Cavities: End-groups and HOM Power

Energy going to HOMs:

- HOM power = 1.3 kW (5 waveguides) + 800 W (up/downstream)
- Maximum power on load = 300 W

Waveguide power:



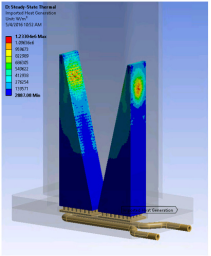
Status R&D SRF Cavities: End-groups and HOM Power

HOM dampers:

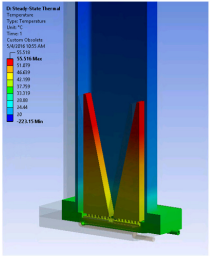
- Specifications scaled to max. values on WG + BP power (460W per load)
- Water-cooled
- Collaboration with Jefferson Lab

- 3 prototype loads (Q4 2016) + series of 15 (2017)
- Dust production test (particle counting)
- Low power + High Power tests @ JLab

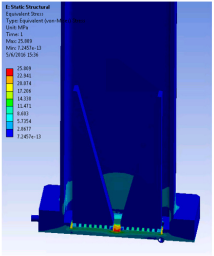
First load designs for bERLinPro



Imported RF power losses mapped to the absorber



Thermal analysis results

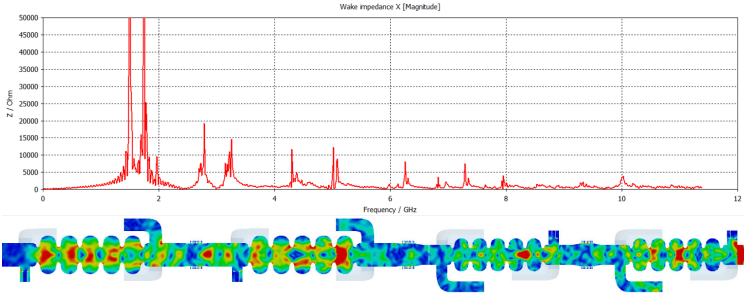


Structural analysis results

VSR design ongoing: Stronger cooling, single plate with ferrit tiles

Status R&D SRF Cavities: Concatenation Studies

First power calculations of complete cold string (very preliminary) 1.5 GHz + 1.75 GHz:



Challenges:

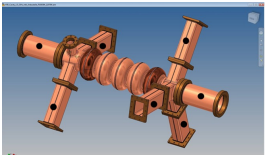
- Limited length
- Different frequencies, different sizes
- Extra beam pipe absorbers needed?

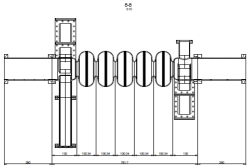
Tasks:

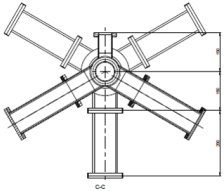
- Confirm HOM load specifications
- Validate impedance budget
- Coupler kicks, orientation

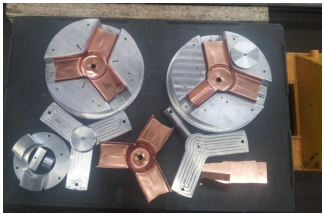
→ work in progress!

Status R&D SRF Cavities: Prototypes





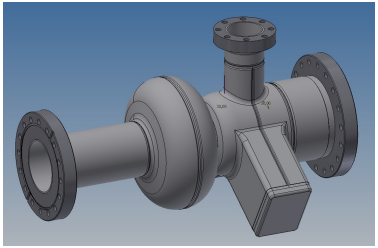




WG loaded cavity with copper WG extensions

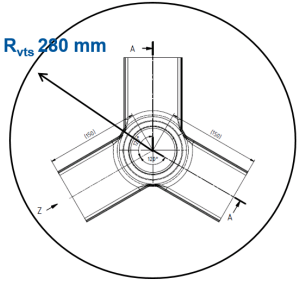
- Under fabrication by Research Instruments (RI)
- To be delivered by October 16
- Validate fabrication techniques, relatively new development (deep drawing, spring backs, weld shrincage)
- Validate EM design
- 1.75 GHz prototype foreseen

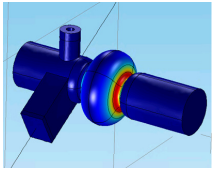
Status R&D SRF Cavities: Prototypes



Niobium single-cell with one sided WG end-group loaded with 2 WG + 1 FPC + 100 mm beam-pipe extension

- Ordered at RI, delivery expected in December
- 150 mm extended beam-pipe on the other side (same diameter as copper model)
- Fabrication drawings based on the existing copper model
- Chemical surface treatment
- WG flanges closed with an Nb sealing (space constraint in vertical test stand)





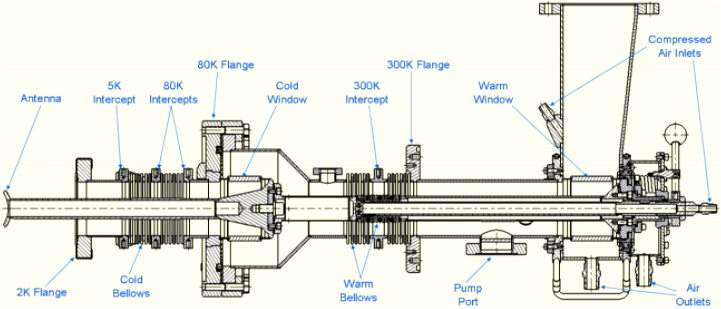
Primary goals:

- Validate multipacting
- Validate Nb fabrication process

Status R&D SRF Cavities: High Power Couplers

16 kW CW couplers @ 1.5 GHz

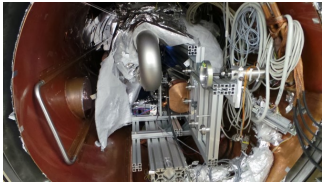
- Close to 0 beam loading expected, high $Q_{\text{ext}} > 10^7$ with low power < 10 kW
- Adjustable coupling is required due to parking (different temperature) and impedance control (within power budget)
- Design based on the Cornell 60kW injector coupler



→ Work in progress!

Status R&D SRF Cavities: Testing, Bead Pulls and Infrastructure

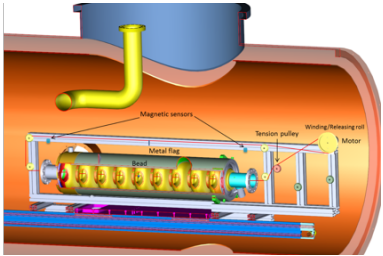
Warm bead-pull



Cold bead-pull:

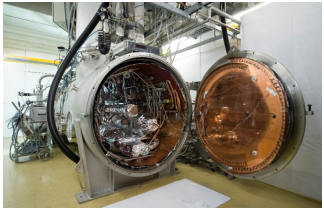
- Novel design
- Inside HoBiCaT (horizontal test module)
- Evaluates field profile of cavities in SC state
- Commissioned with a 9 cell Tesla cavity
- Able to characterize HOMs
- Results to be published (Adolfo Vélez)

Cold Bead-Pull installation in HOBICAT



Status R&D SRF Cavities: Testing, Bead Pulls and Infrastructure

Summary of planed tests



1.5 GHz and 1.75 GHz 5-cell Copper Cavites:

- To be tested in new RF Lab (Schwarzschildstraße)

1.5 GHz Single-cell Niobium Cavity:

- To be tested in small VTS, minor modifications

1.5 GHz 5-cell Niobium Cavities

- Undressed cavities: To be tested in large VTS, Testing Hall 1 in operation by Q2 2017
- Dressed cavities: To be tested in HoBiCaT (horizontal)
- Low power tests: 500 Watts broadband Amp @1.5 GHz+1.75 GHz
- High power Tests: 16kW transmitter, SSA. RF infrastructure: WGs, circulator, water loads etc. Installation in HoBiCaT

Summary BESSY VSR

Concept:

- Combines high brilliance with short pulses
- Opens a new regime for storage ring operation
- Is the ideal and cost effective upgrade of BESSY II

Status:

- Two R&D projects started:
  - SRF cavity and auxiliary prototyping
  - Bunch resolved diagnostics
- Application process for full funding ongoing

HZB Helmholtz Zentrum Berlin

BESSY VSR

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