This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.

SupraLab: SRF Testing Facilities at HZB

From Samples to Beam Operation

Sebastian Keckert, HZB

Workshop on Vertical Cavity Testing

DESY, 15.09.2022

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ACCELERATOR AND MAGNET INFRASTRUCTURE FOR COOPERATION AND INNOVATION

HZB Helmholtz Zentrum Berlin

SupraLab

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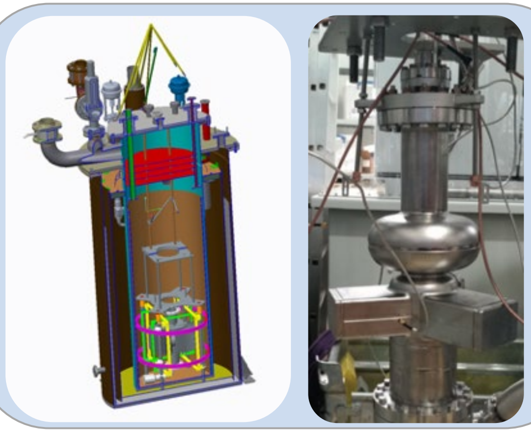
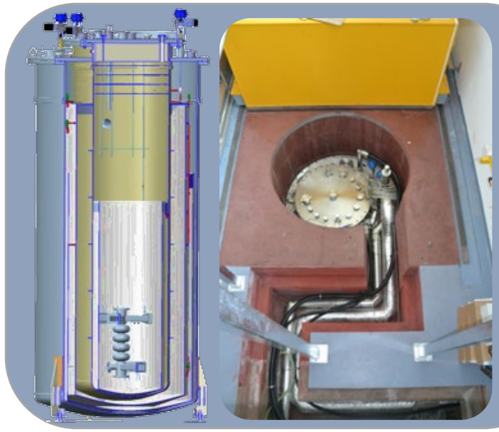
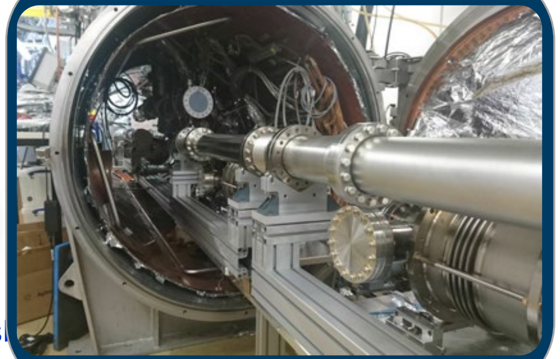
Development Cycle of SRF Systems

SRF Materials Characterization → Sample RF testing (QPR) → 1-cell prototype testing (SVTA) → Full cavity testing (LVTA)





Component Testing → Dressed system (HoBiCaT) → Full module tests (MTF) → Beam operation (SEALab)



SupraLab Philosophy

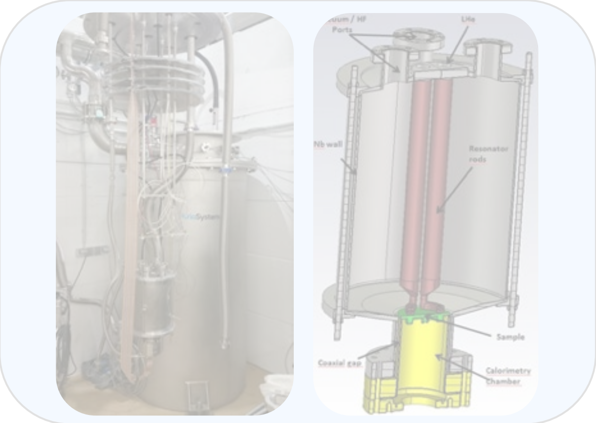
Link: SupraLab Website

- Key infrastructure designed for ARD/HZB research program
- Parts EFRE financed with the goal to open facilities for research laboratories and industrial partners
- Examples:
  - RI → 1.3 GHz, 80 kW CW coupler RF testing
  - Rossendorf: TESLA cavity testing, SRF gun HPR, SRF gun testing
  - DESY: Superconducting dark current measurement system, superconducting solenoid (planned)
  - IN2P3, JLab, Cornell: RF characterization of samples (→QPR)
  - Cryoelectra: SS RF transmitter operation with SRF systems (planned)
- Tests subject to resource limits and limited availability

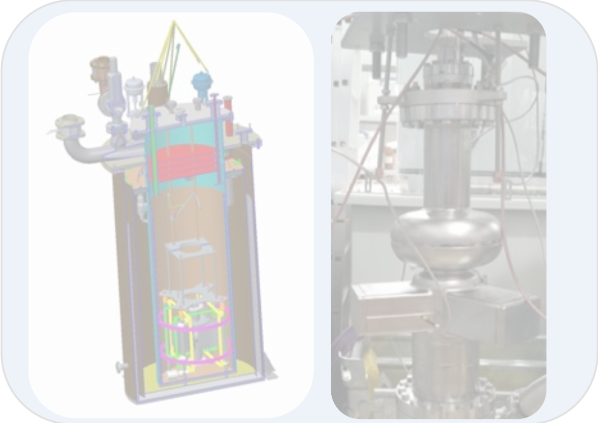
Development Cycle of SRF Systems

SRF Materials Characterization

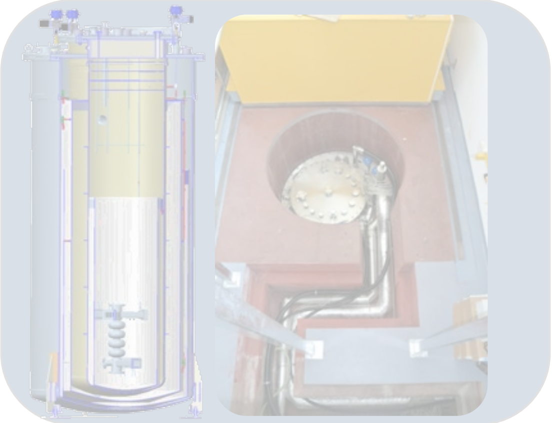
Sample RF testing (QPR)



1-cell prototype testing (SVTA)

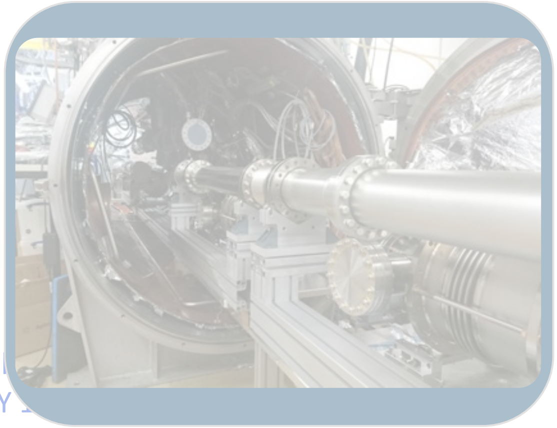


Full cavity testing (LVTA)



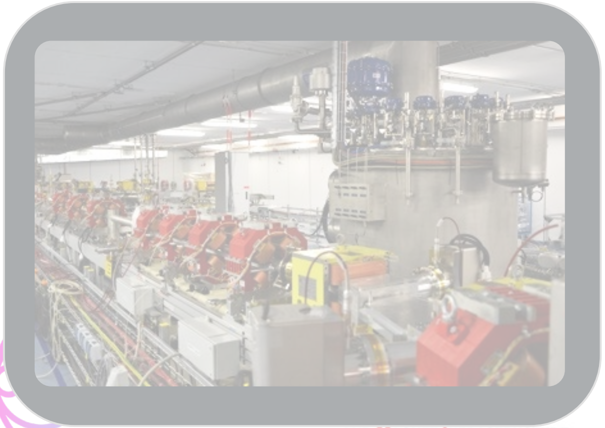
Component Testing

Dressed system (HoBiCaT)



Full module tests (MTF)

Beam operation (SEALab)



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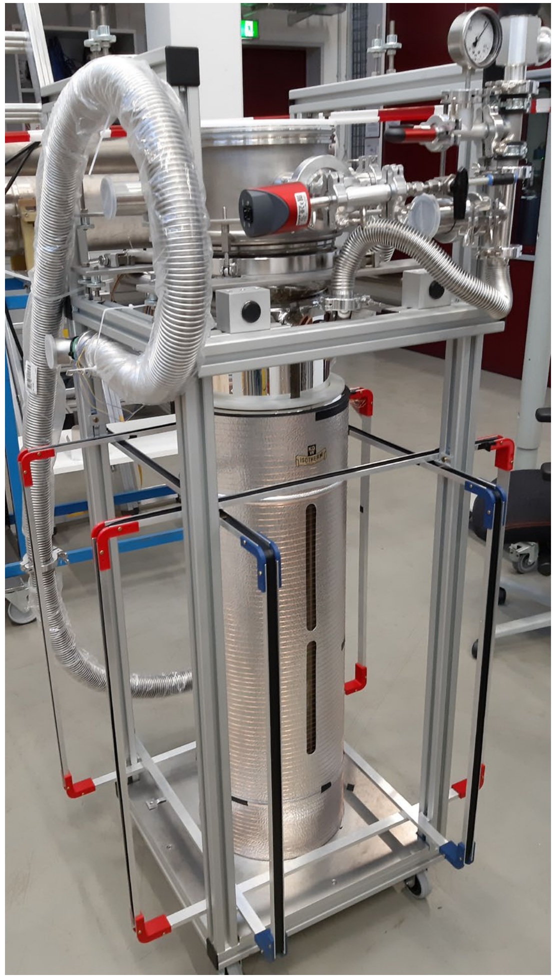
miniVTS – cryogenic material studies

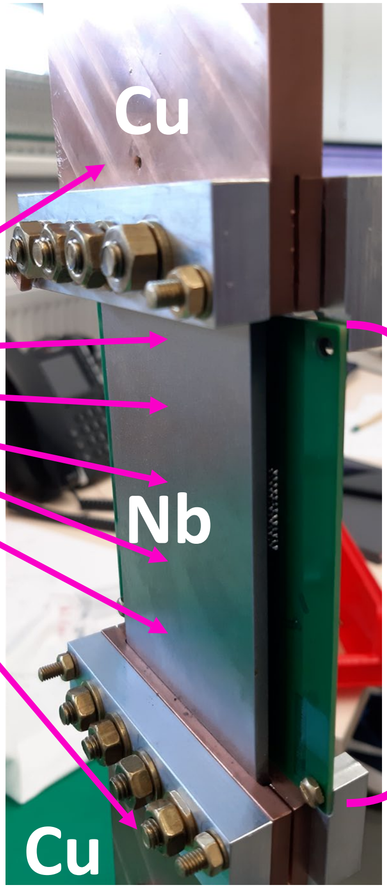
- Glass cryostat, very flexible, easily adapted
  - no radiation protection → low power RF only
- Fully manual operation
  - LHe and/or LN_2 from dewars
  - Turnaround time few hours
  - Slow/fast cool-down/warm-up, parking
- No mag. shield, active 3D Helmholtz coils
- Recent examples:
  - Cryogenic sensor tests (B.Sc.)
    → GMR, carbon resistors
  - Trapped flux in sc samples (Ph.D)
    → B- and T-mapping



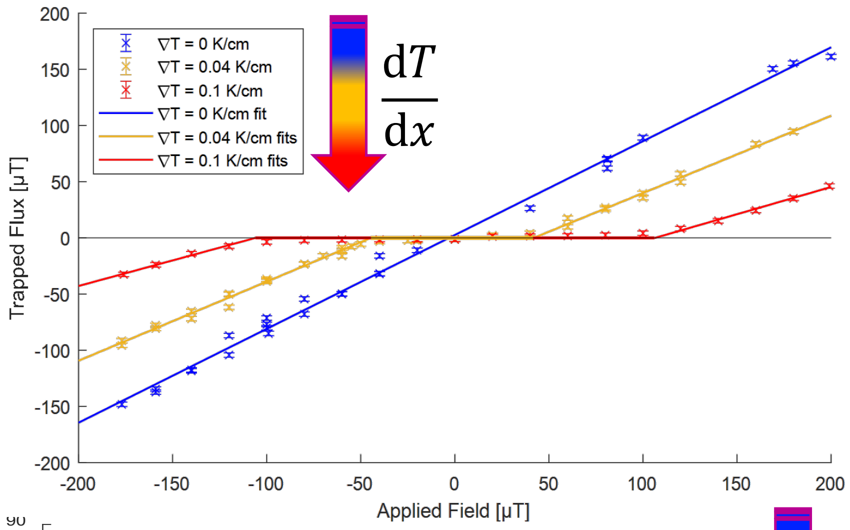
[F. Kramer, TUPOTK006, IPAC’22]

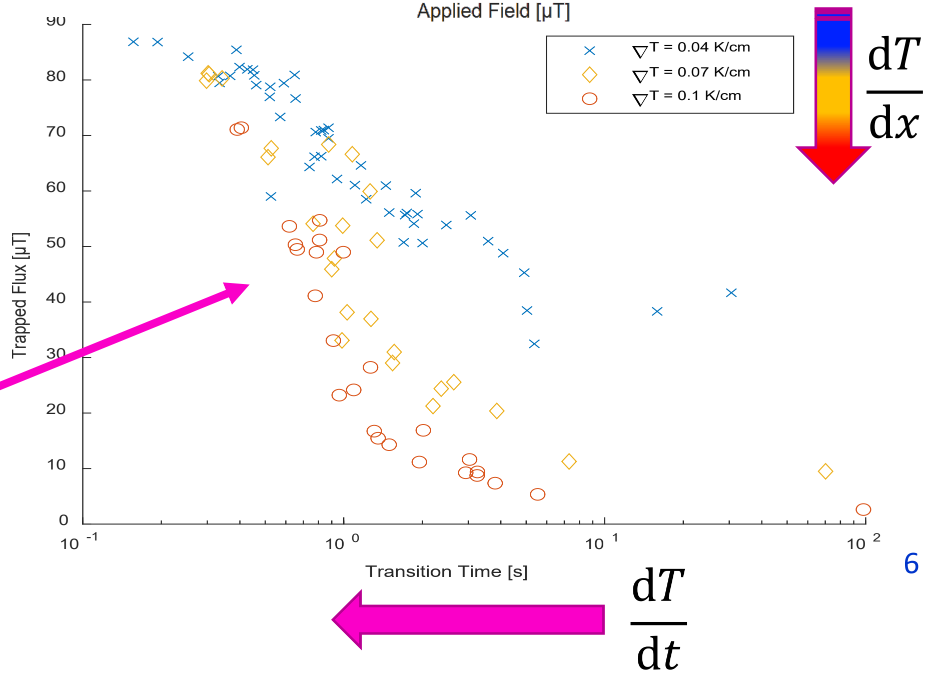
miniVTS – trapped flux in samples

8 Cernox sensors for T-mapping and active heater control



PCB with 5x3x3 AMR sensors





1 data point = 1 T_C cycle → ~100 cycles/day

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miniVTS @ HZB

No	Property name	Value	Unit	Comment
1	LHe volume	20	L	
2	Operating temperature	1.6 K up to RT	K	
3	Diameter / size	Ø = 0.2, H = 0.6	m	Usable height
4	Number of inserts	2		
5	RF frequency	Broad band		Low power, no interlock, no radiation
	Magnetic background	Earth's field, <15 nT with active 3D HHC compensation		
	Radiation protection	n/a		
	Max. pressure	1.2	bar	
6	Maximum incident power	Depends on DUT		
7	Additional instrumentation	3D HHC, B-map, T-map		
8	Typical testing rate (Vts / year)	many		
9	Possibility to test naked cavities	YES		

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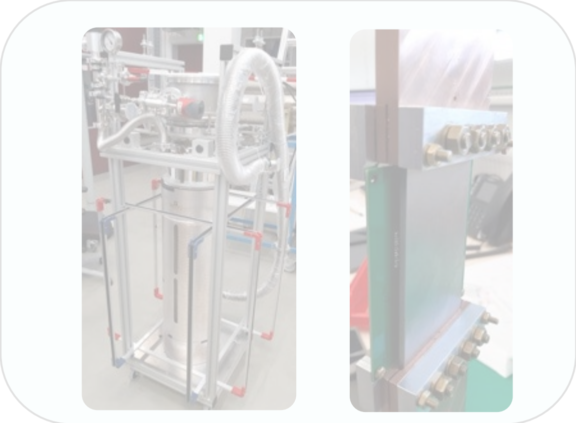
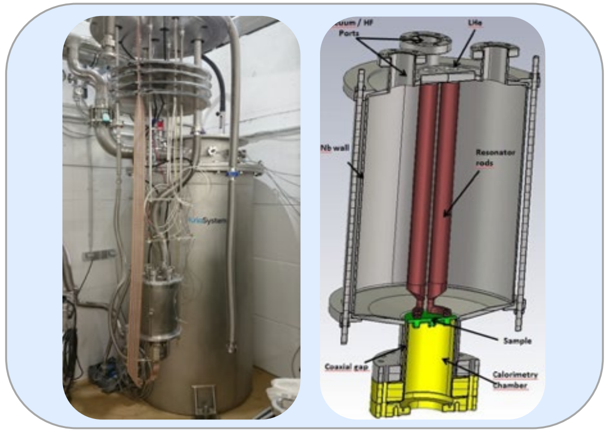
Development Cycle of SRF Systems

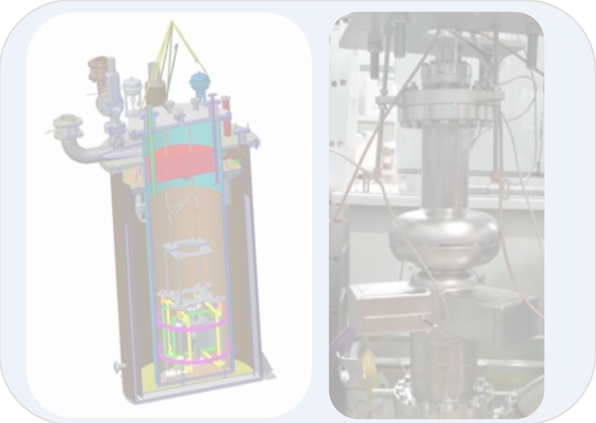
SRF Materials Characterization



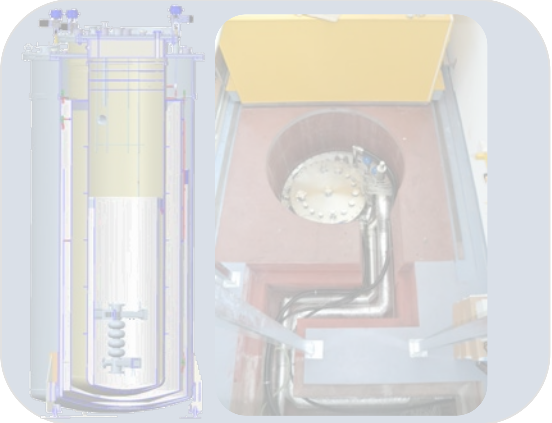
Sample RF testing (QPR)



1-cell prototype testing (SVTA)

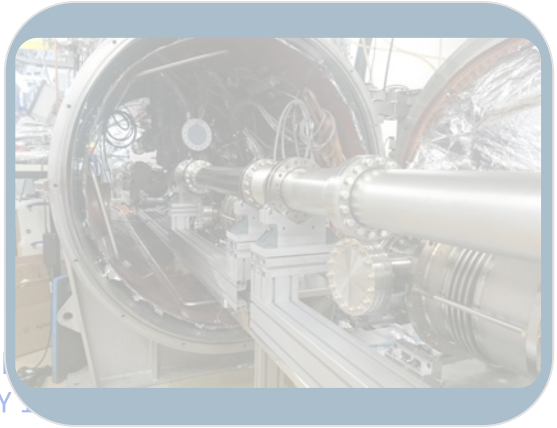


Full cavity testing (LVTA)



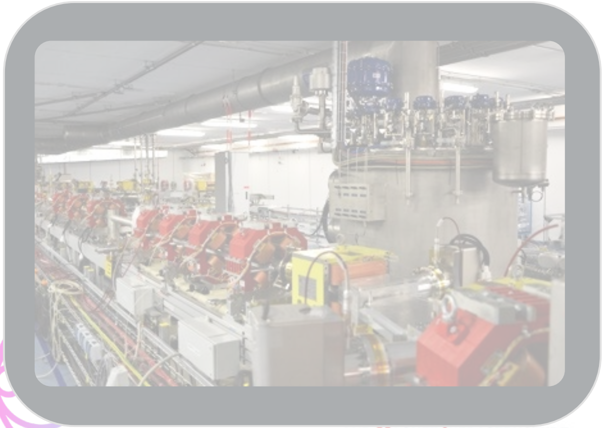
Component Testing

Dressed system (HoBiCaT)



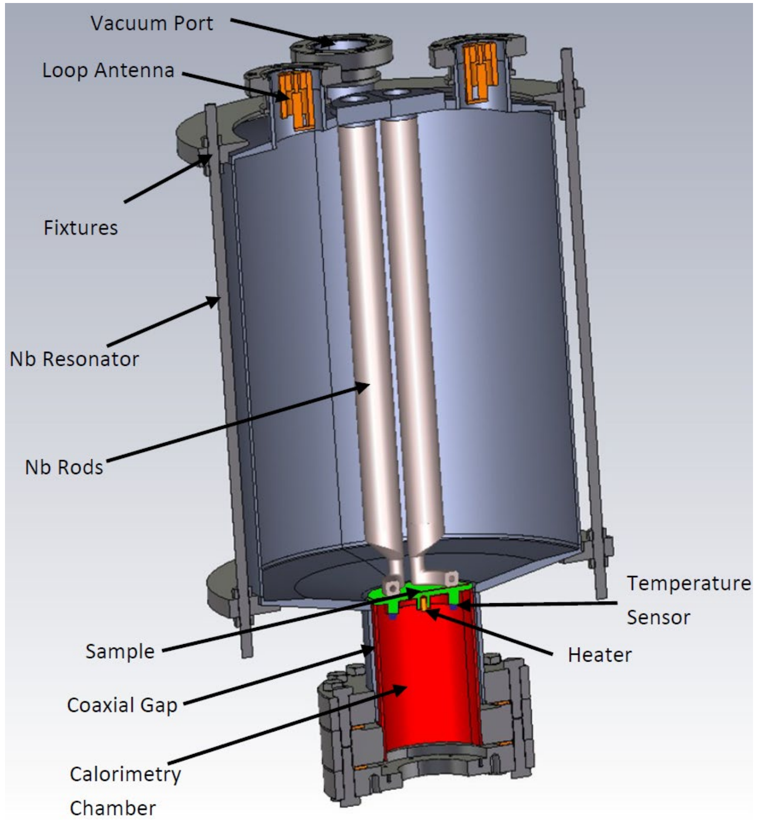
Full module tests (MTF)

Beam operation (SEALab)

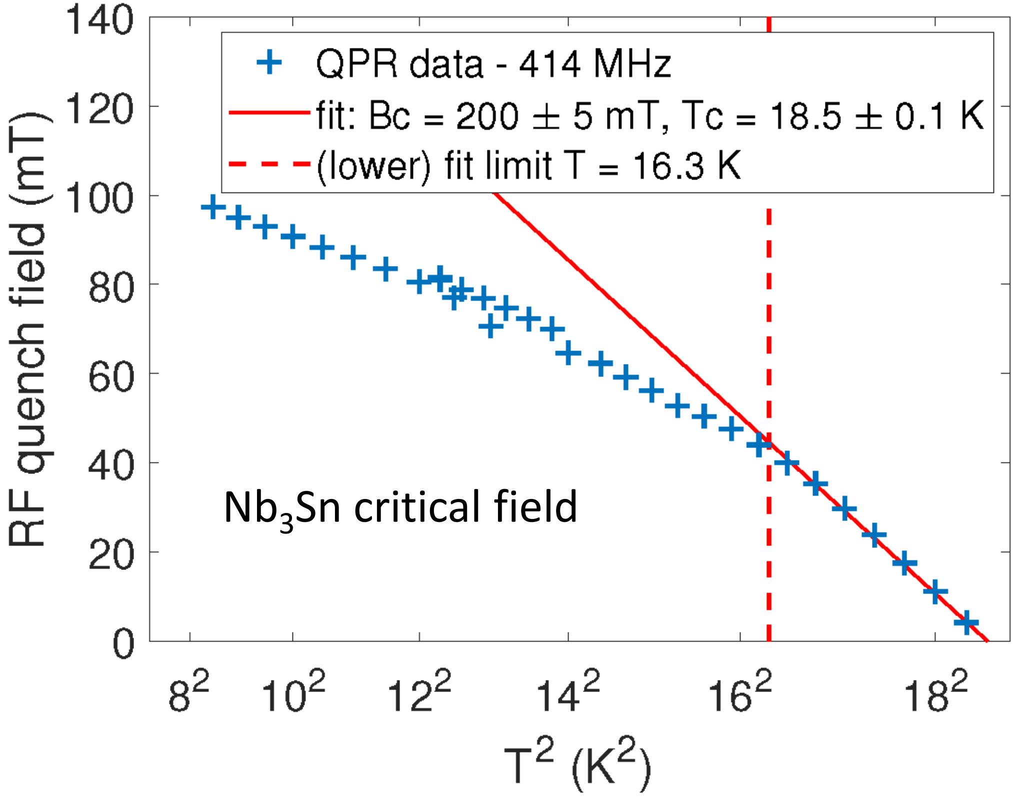


QPR – Characterizing SRF properties

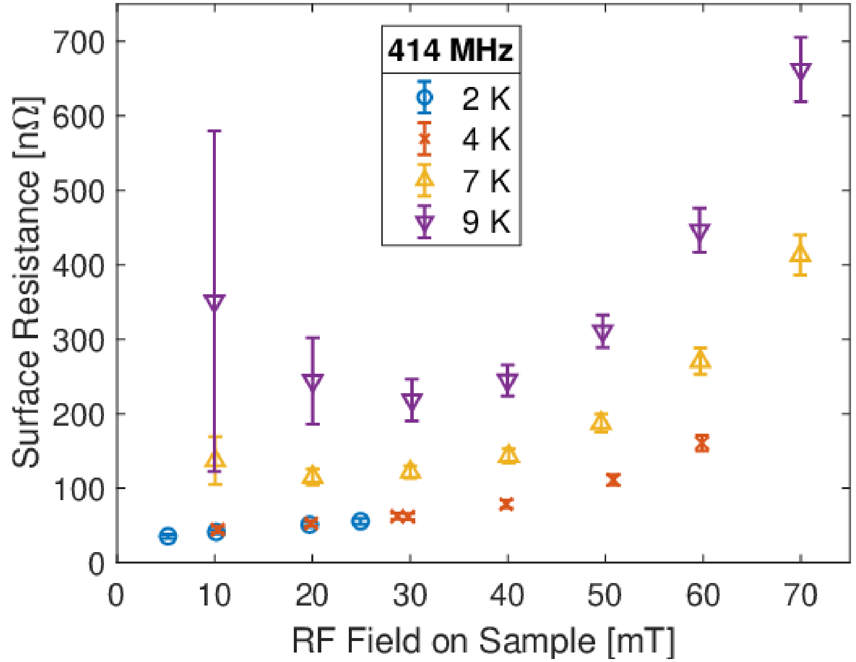
- Dedicated sample test cavity
  sample: Ø=75 mm, h≈100 mm
- 3 frequencies: 415, 850, 1290 MHz
- T_{sample} = 1.8 … > 20 K
- $B_{max} \approx$ 120 mT
  R_S meas. typ. limited by heating
- Measure R_S, B_{quench}, λ
  → T_c, Δ, κ, RRR

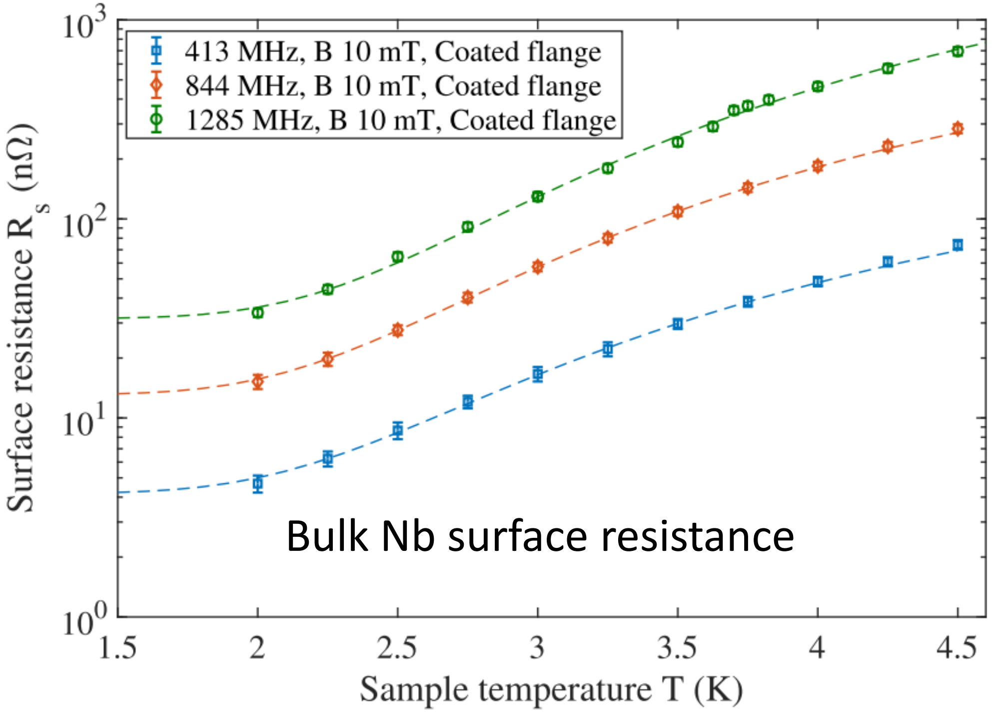


QPR – Examples



Nb_3Sn





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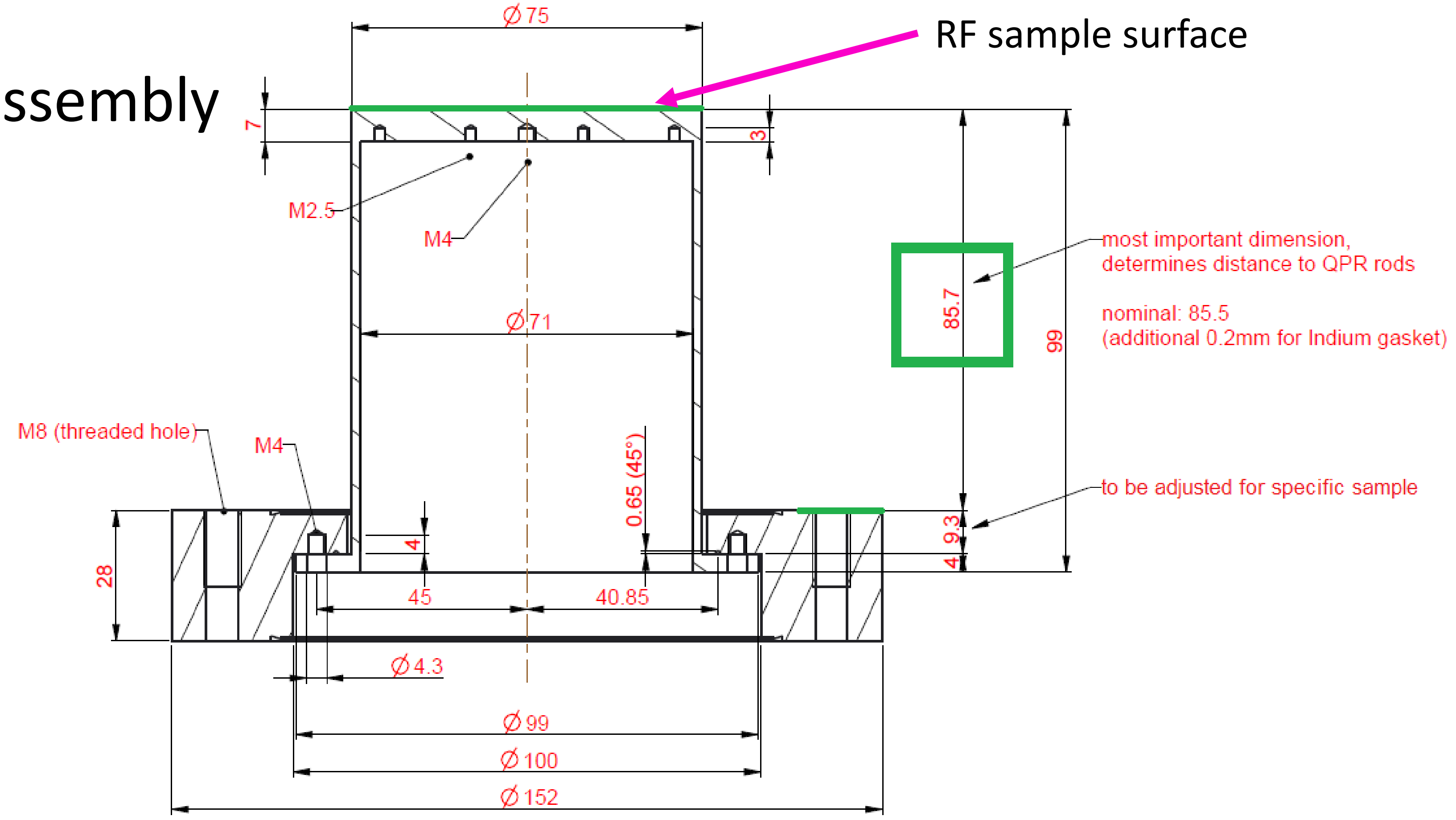
QPR Samples – Interface Definition

- ‘naked’ sample or assembly with DN 100 CF flange (double sided)
- Final height: 85.5 mm



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Development Cycle of SRF Systems

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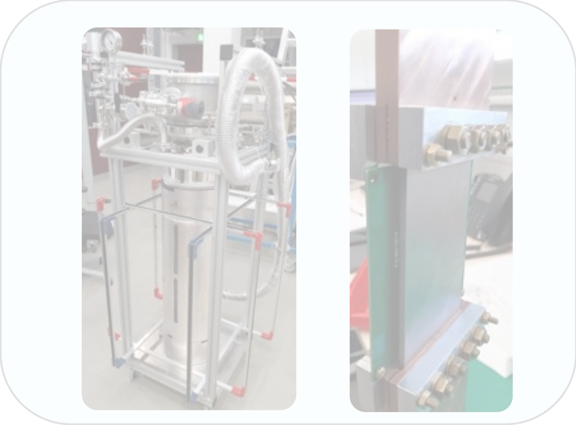
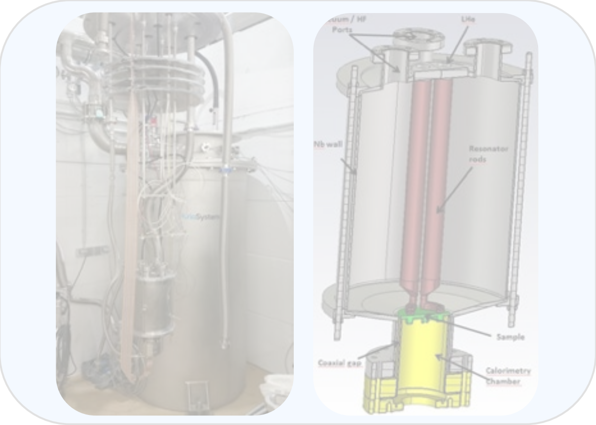
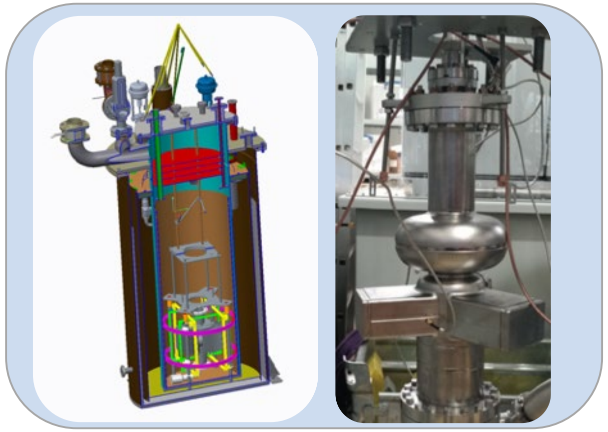
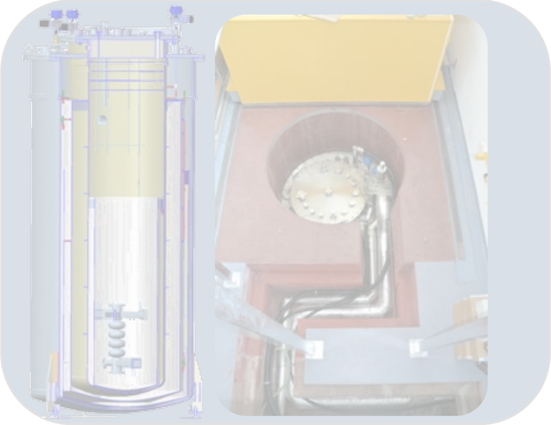
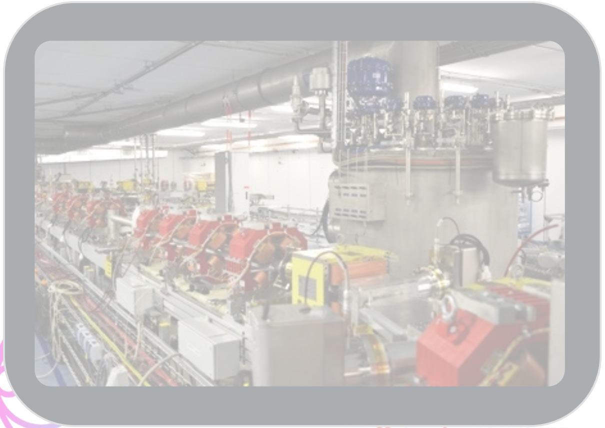


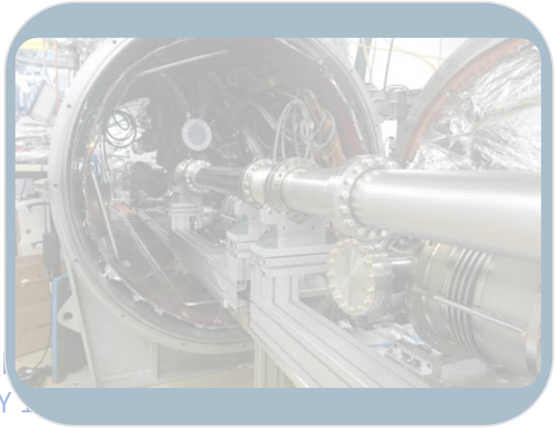






Beam operation (SEALab) ← Full module tests (MTF) ← Dressed system (HoBiCaT) ← Component Testing





SVTS – Vertical Testing of Small Cavities

- ‘standard’ vertical bath cryostat
  - Ø = 0.56 m, H = 1.35 m
  - Double magnetic shielding, B < 1 µT
  - $T_{min} \approx 1.5$ K
    80 W @ 1.8 K available
- Diagnostics
  - Thermometry (2 ms for entire map)
  - 3D B-mapping (2 ms for entire map)
  - Second sound

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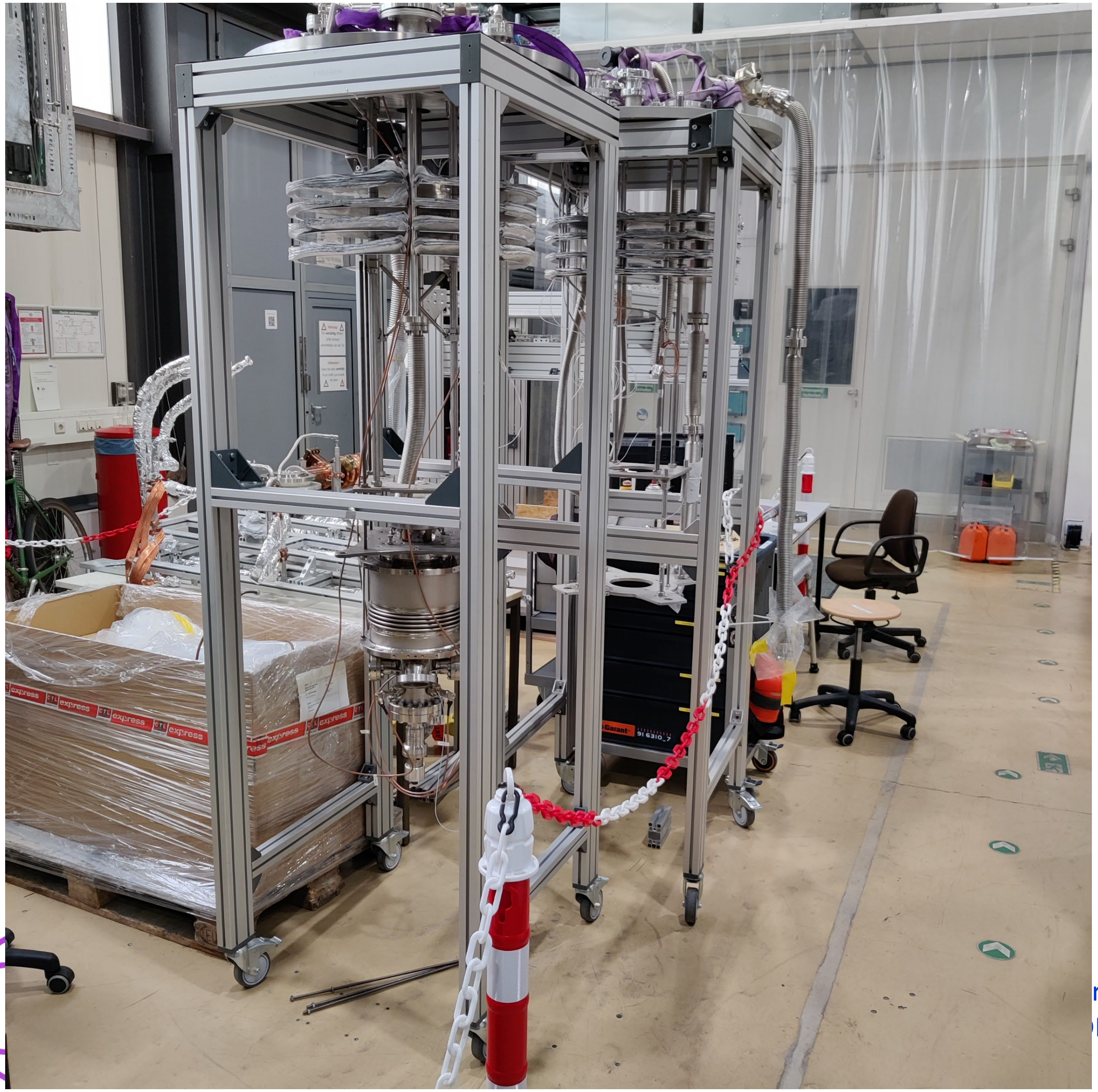
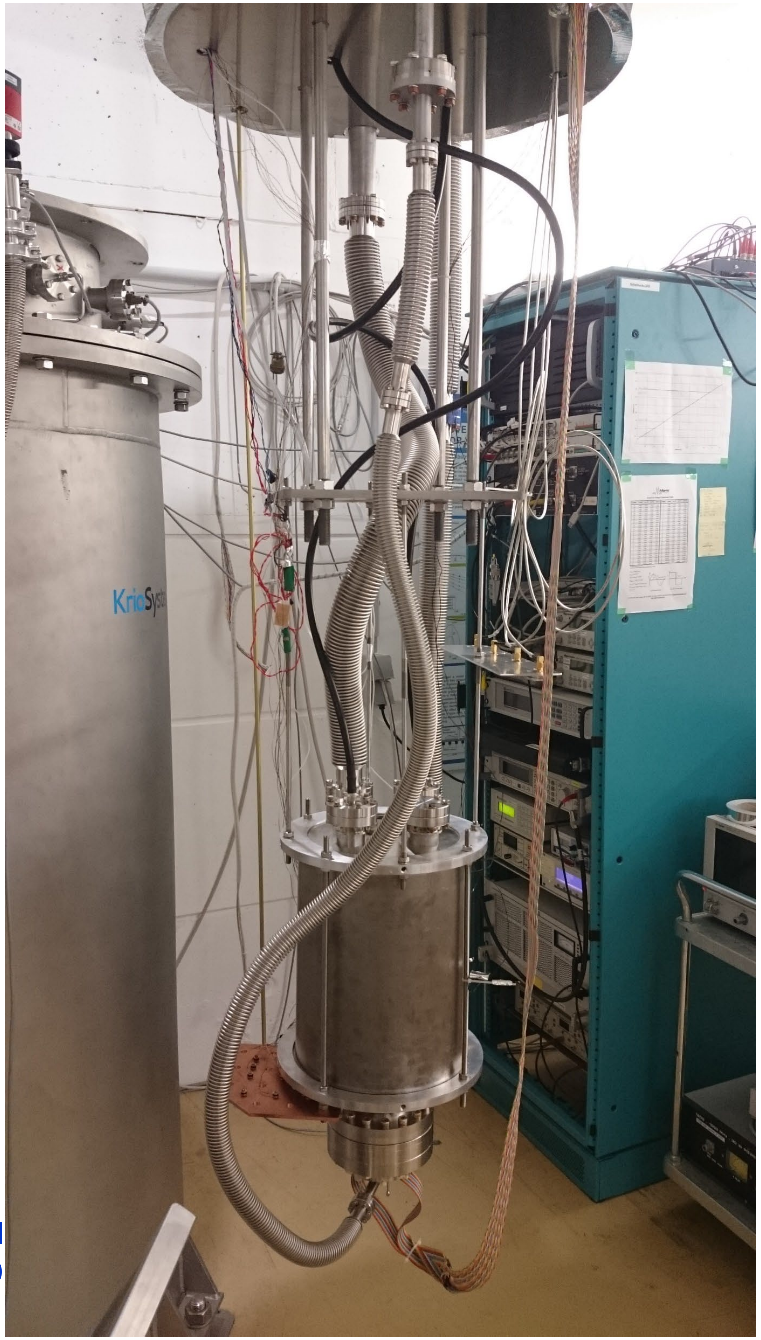
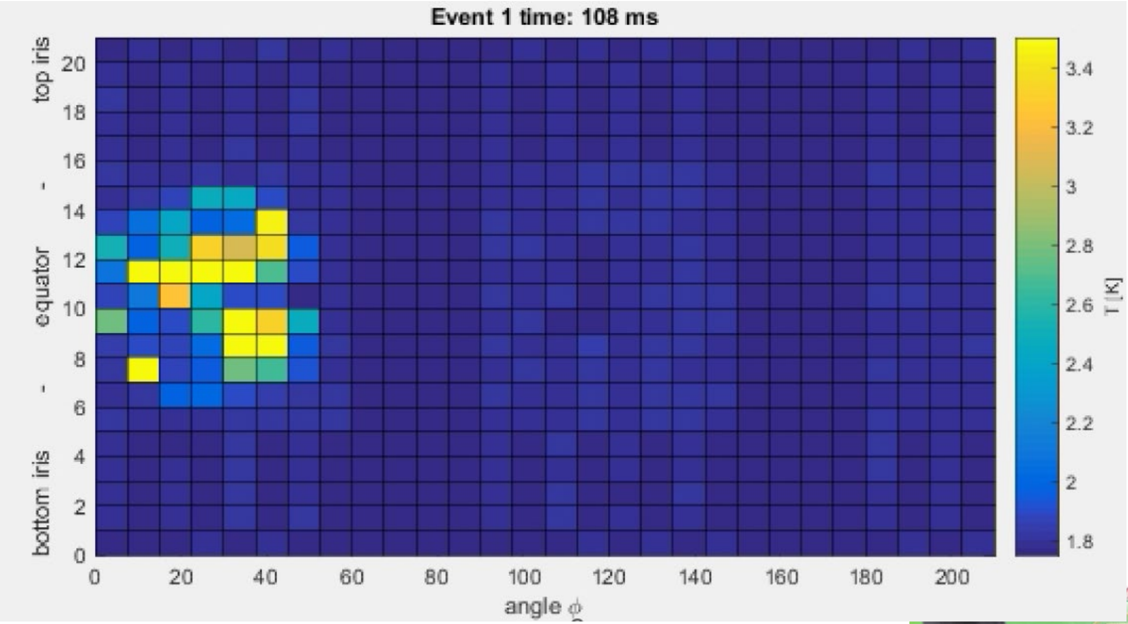
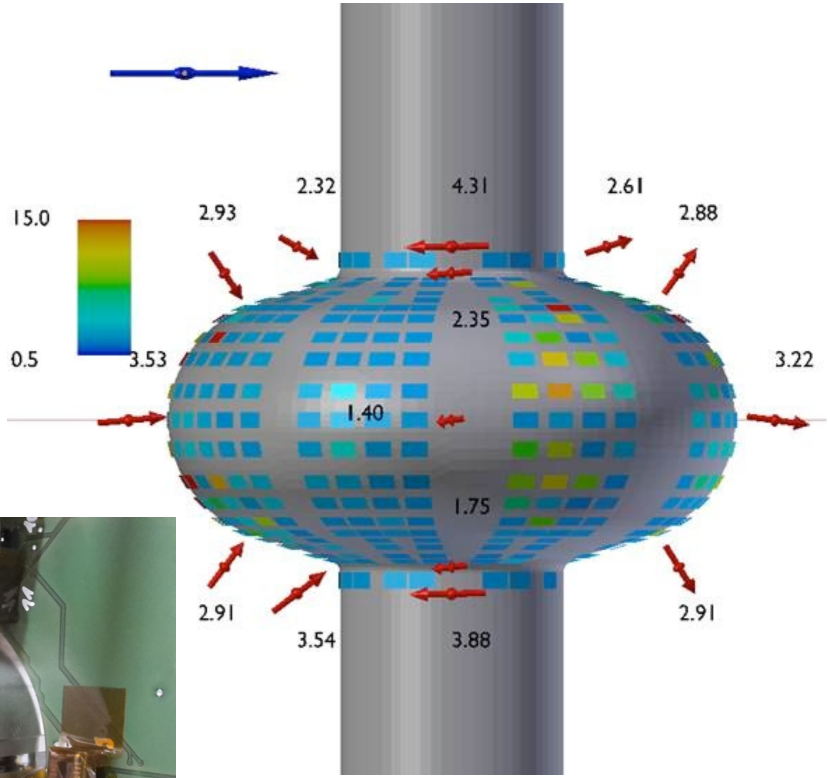
SVTS Inserts (3)



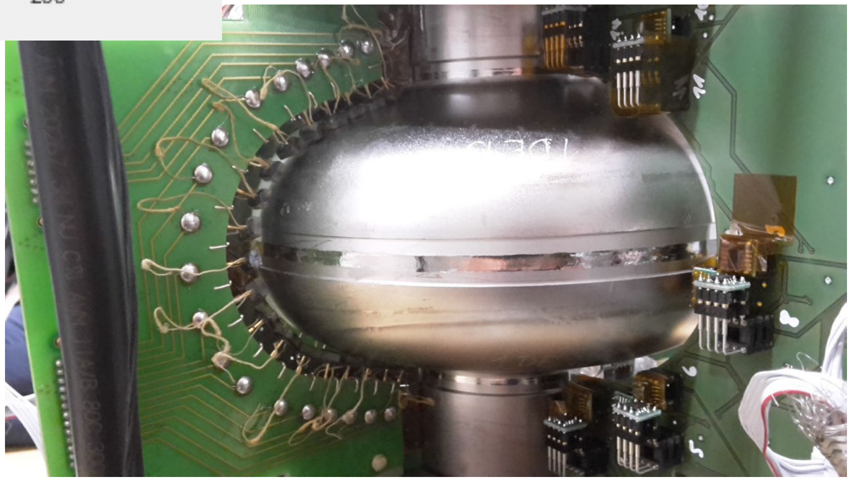


T-map and B-map (not only for SVTS)





- 1-cell combined T and 3D B-map
- Capture movies with 2 ms resolution



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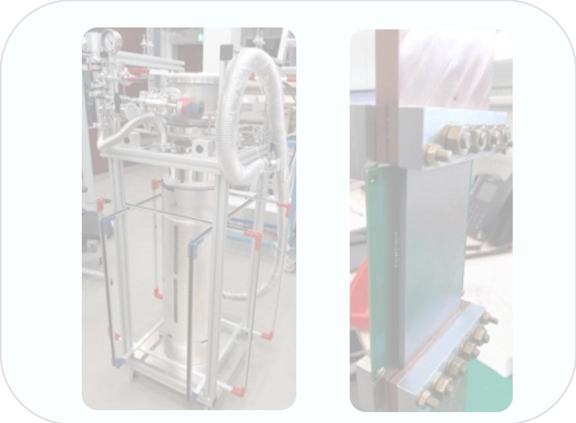
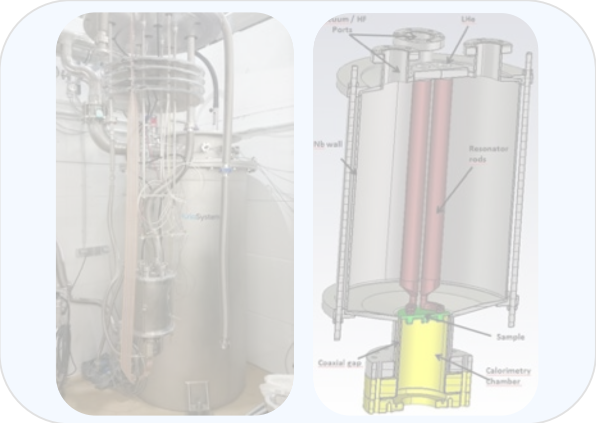
SVTS @ HZB				
No	Property name	Value	Unit	Comment
1	LHe volume	380	L	
2	Operating temperature	1.8 typ. 1.5 – 4.2	K	±30 µbar at T<2.2 K 80 W at 1.8 K
3	Diameter / size	Ø = 0.56, H = 1.35	m	Usable height
4	Number of inserts	3		1 for QPR only
	Magnetic background	< 1	µT	
	Radiation protection	≤ 5	Sv/h	
	Max. pressure	1.5	bar	
5	RF frequency	→ see 		
6	Maximum incident power			
7	Additional instrumentation	T-map, B-map, second sound		
8	Typical testing rate (Vts / year)	15 tests in 2021 (mostly QPR tests)		
9	Possibility to test naked cavities	YES		

Development Cycle of SRF Systems

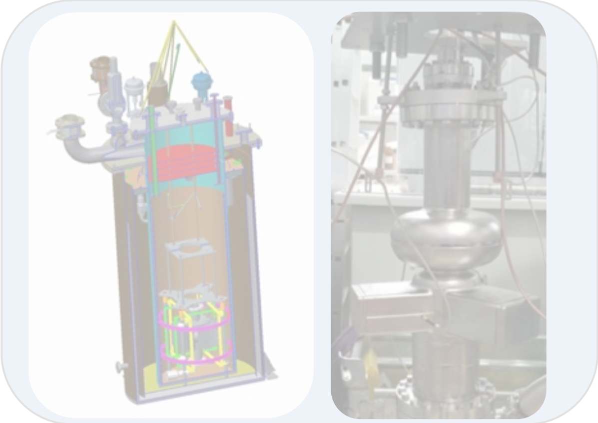
SRF Materials Characterization



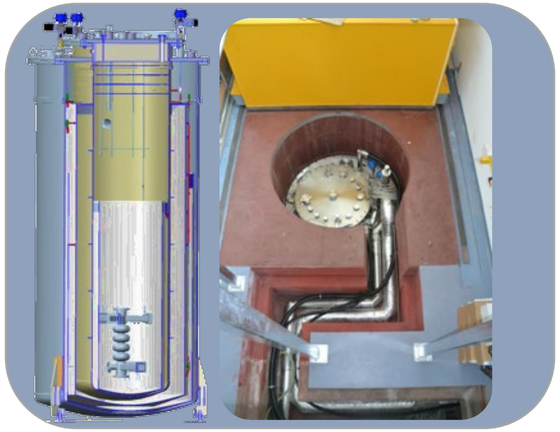
Sample RF testing (QPR)



1-cell prototype testing (SVTA)

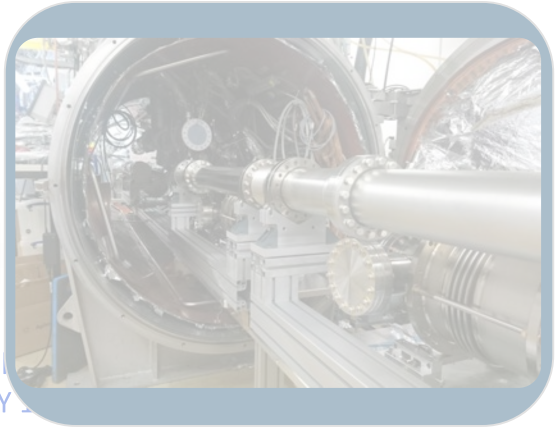


Full cavity testing (LVTA)



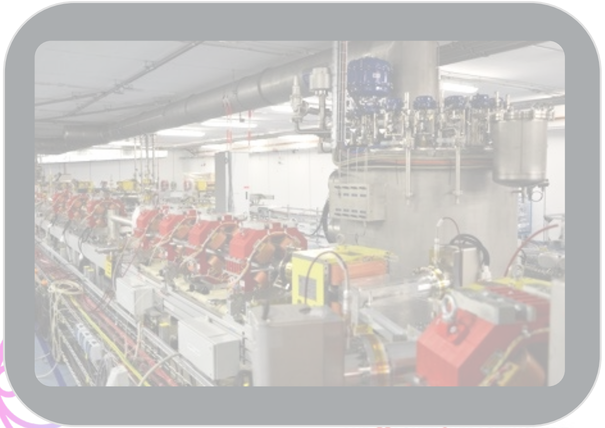
Component Testing

Dressed system (HoBiCaT)



Full module tests (MTF)

Beam operation (SEALab)



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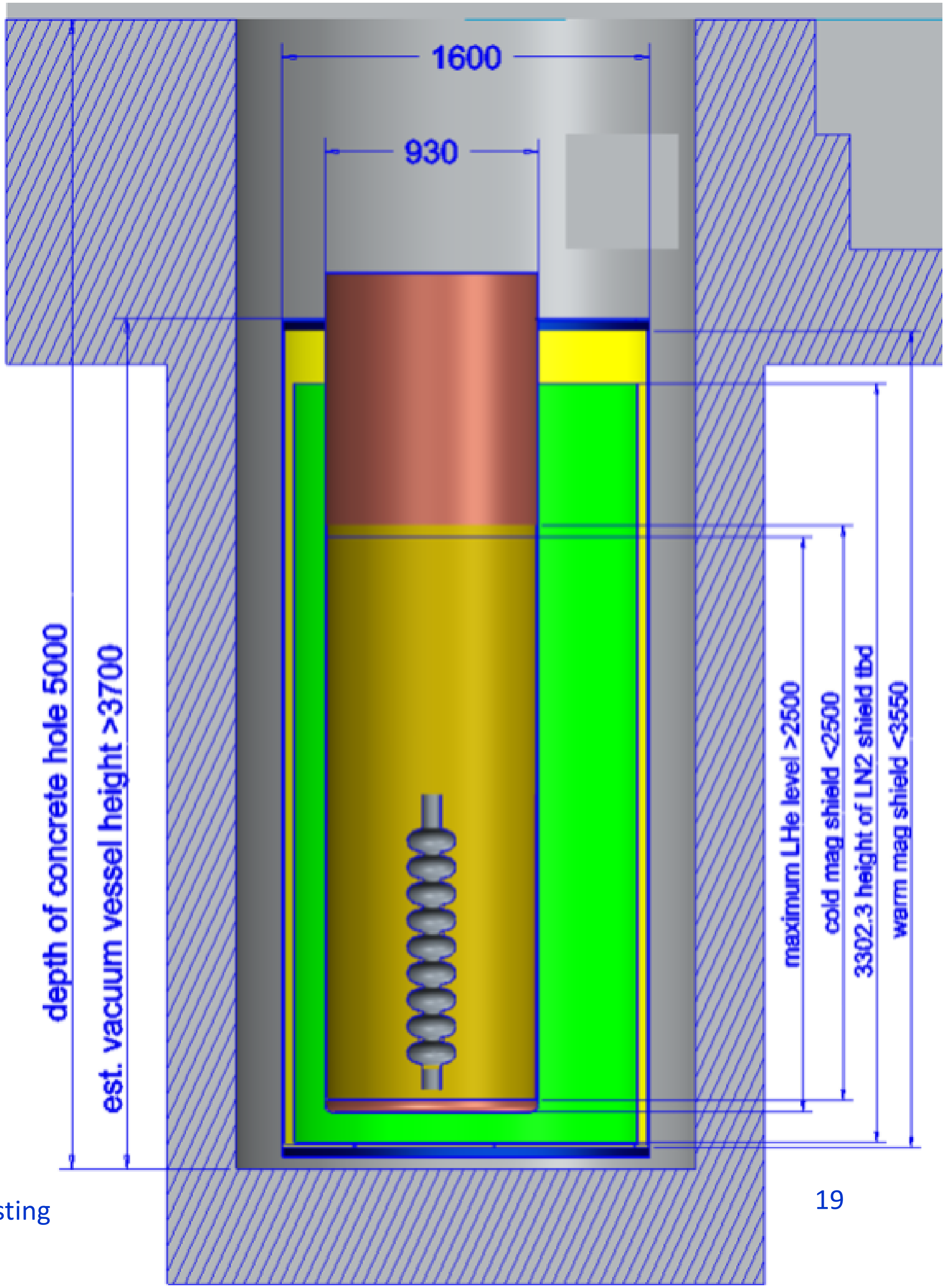
LVTS – Testing Large/Long Cavities

- Availability high, but large volume of helium required
  - Costs
  - Turnaround time several (?) weeks (currently only 1 insert available)
- JT-valve for operation with constant LHe level
- Pump stand mounted on insert
- Start in 2023

LVTS

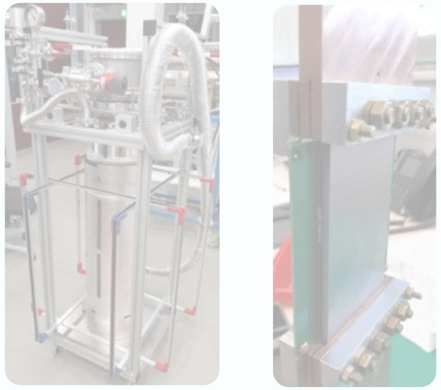
- Availability high, but large volume of helium required
  - Costs
  - Turnaround time several (?) weeks (currently only 1 insert available)
- JT-valve for operation with constant LHe level
- Pump stand mounted on insert
- Start in 2023



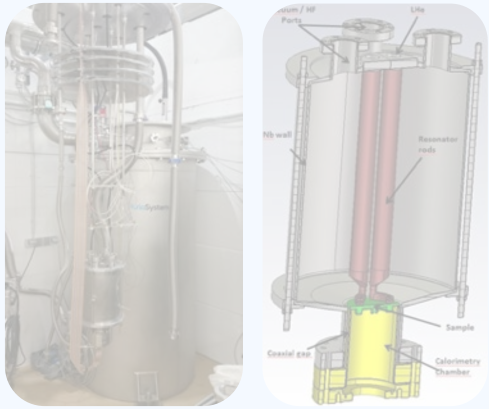
LVTS @ HZB				
No	Property name	Value	Unit	Comment
1	LHe volume	2000	L	
2	Operating temperature	1.8 typ. 1.5 – 4.2	K	±30 µbar at T<2.2 K 80 W at 1.8 K
3	Diameter / size	Ø=0.93, H=2.5	m	2.5m usable height
4	Number of inserts	1		
	Magnetic background	< 1	µT	
	Radiation protection	≤ 5	Sv/h	
	Max. pressure	3.2	bar	
5	RF Frequency	0.69 – 3.2	GHz	PLL only 1.3 + 1.5 GHz
6	Maximum Incident power	300	W	
7	Additional instrumentation	T-map, B-map, second sound		
8	Typical testing rate (Vts / year)	Currently in commissioning		
9	Possibility to test naked cavities	YES		

Development Cycle of SRF Systems

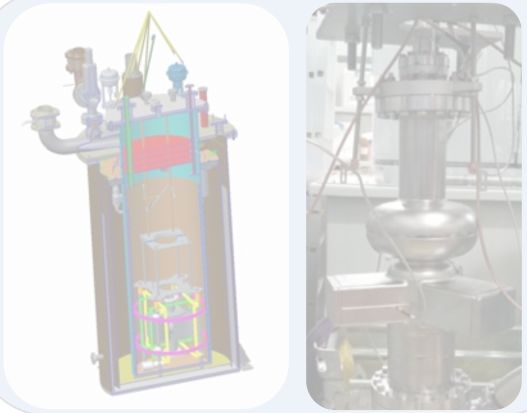
SRF Materials Characterization



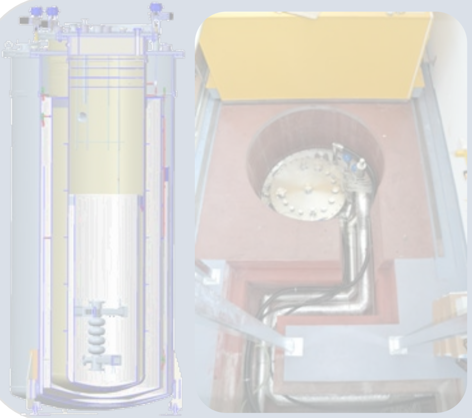
Sample RF testing (QPR)



1-cell prototype testing (SVTA)

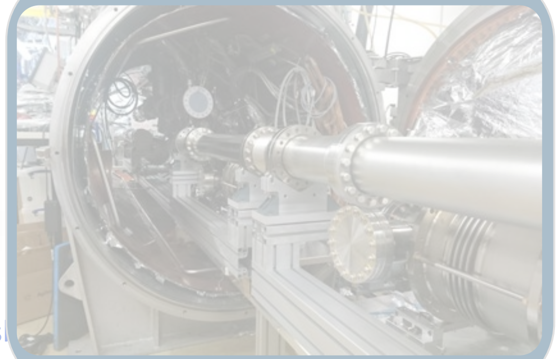


Full cavity testing (LVTA)



Component Testing

Dressed system (HoBiCaT)



Full module tests (MTF)

Beam operation (SEALab)

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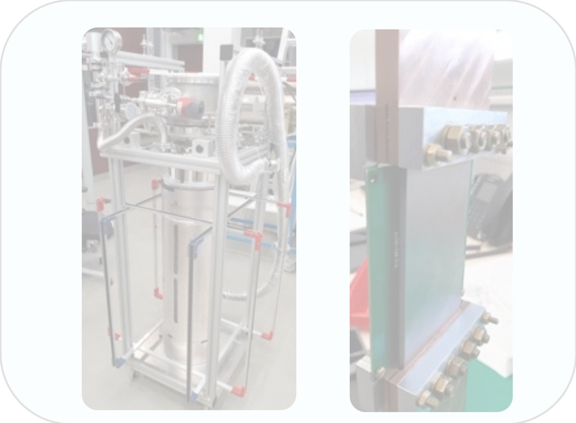
Component Testing

- Coupler testing and conditioning
- RF power capabilities
  - 80 kW at 500 MHz
  - 250 kW CW at 1.3 GHz
  - 15 kW CW at 1.3 GHz, 1.5 GHz, 1.75 GHz
- Virtual cavity
  - FPGA-based system mimics a real cavity → LLRF debugging

Development Cycle of SRF Systems

SRF Materials Characterization



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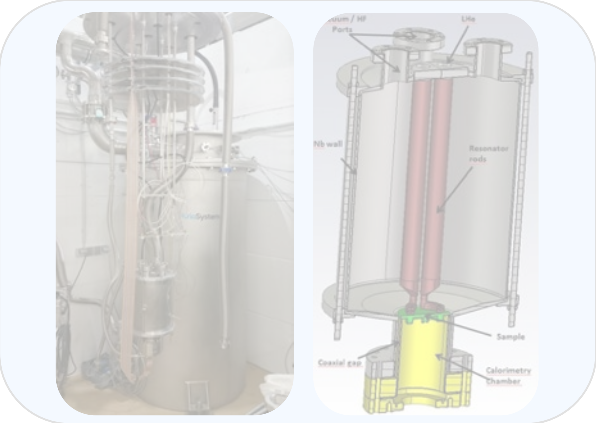

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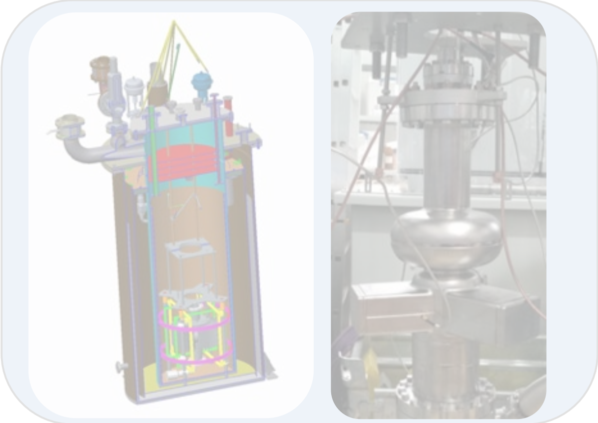
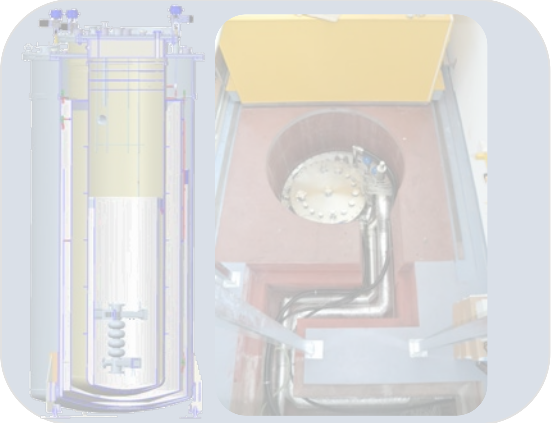


Full cavity testing (LVTA)



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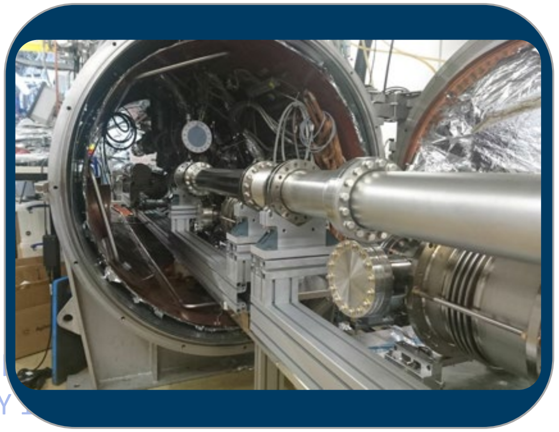

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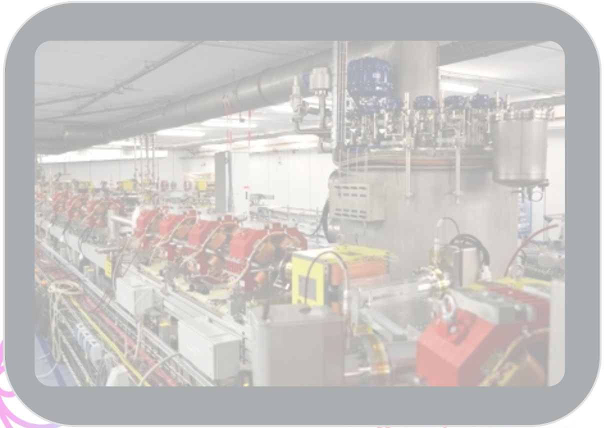

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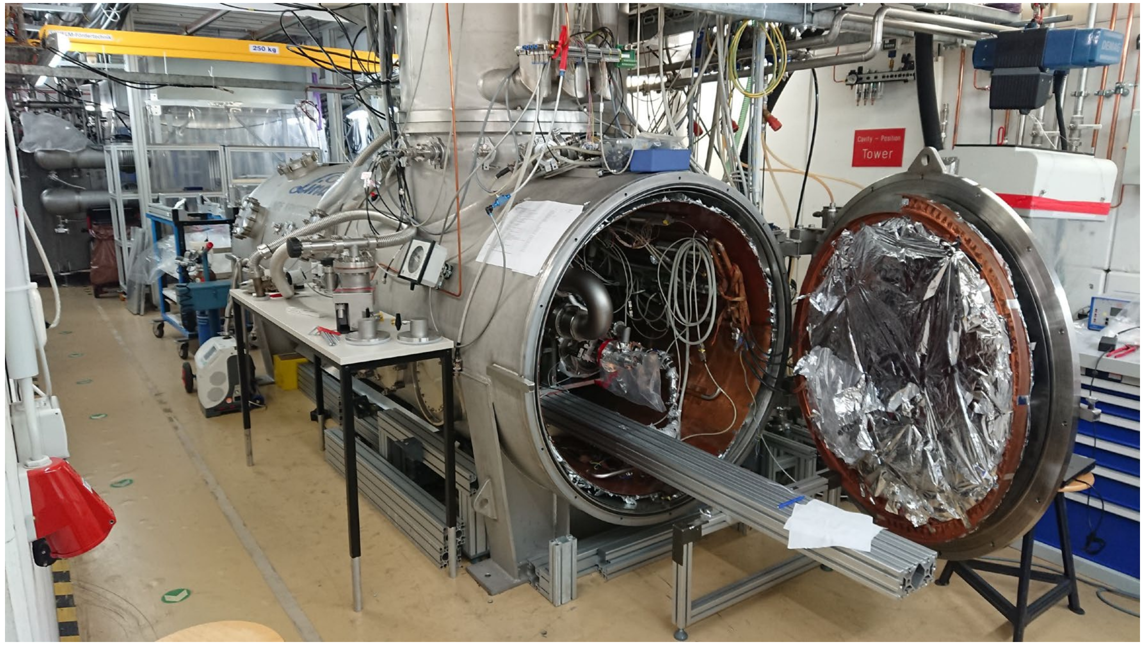
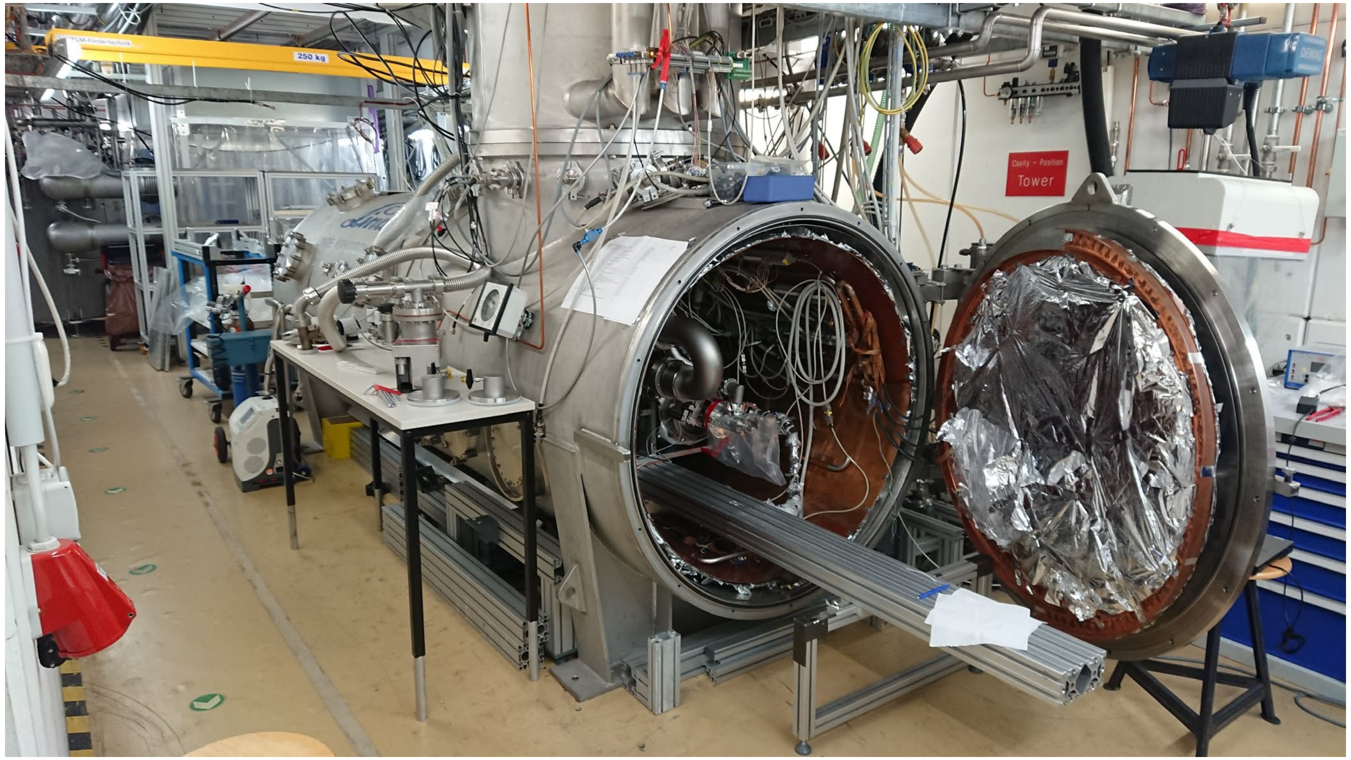
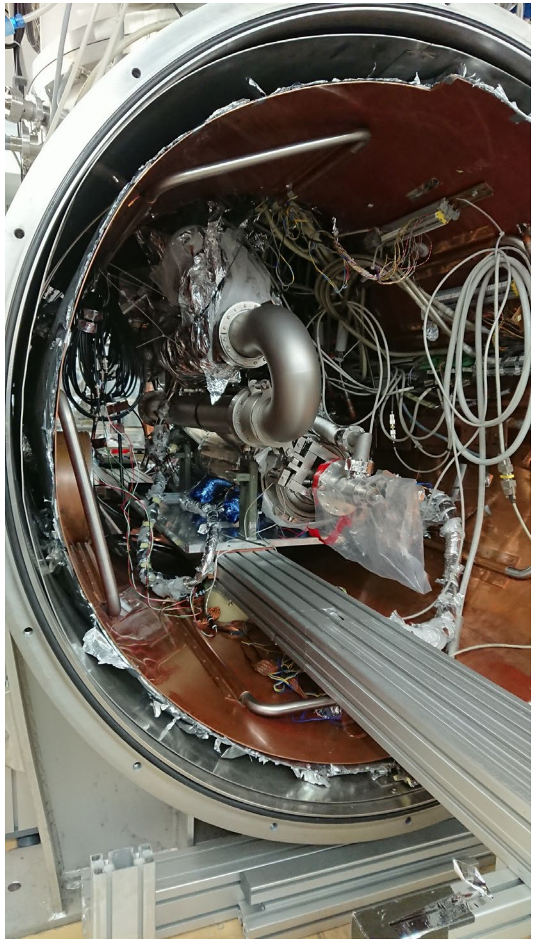
HoBiCaT – Dressed Cavity Testing

- Up to 2x 9-cell dressed TESLA cavities (or 3x 2-cells)
- Flexible system also for component testing (closed LHe system!)
  - Tuner, piezos, SC solenoids
  - Cold bead pull
  - Second sound
  - …
- Several helium circuits available
  - 2 K with JT-valve
  - 4 K



HoBiCaT – Dressed Cavity Testing





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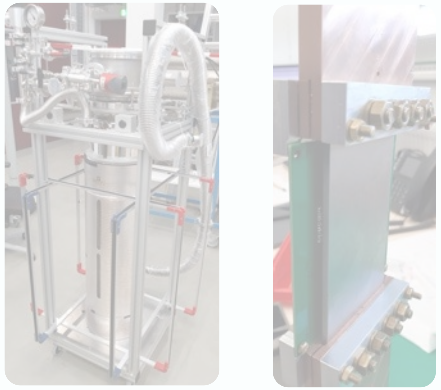
HoBiCaT @ HZB

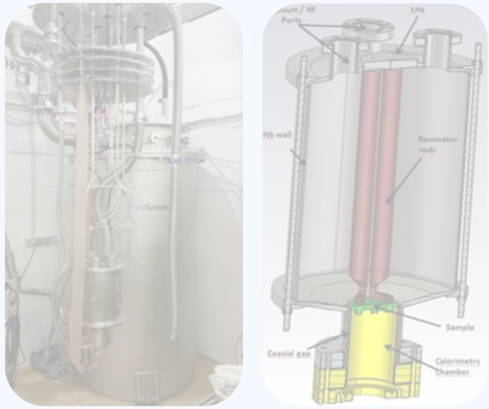
No	Property name	Value	Unit	Comment
1	LHe volume	few	L	
2	Operating temperature	1.8 typ. 1.5 – 4.2	K	$\pm$30 µbar at T<2.2 K 80 W at 1.8 K, 10 W static losses
3	Diameter / size	Ø ≈ 1	m	2x 9-cell TESLA
4	Number of inserts	n/a		
	Magnetic background	< 5	µT	plus shield of DUT
	Radiation protection	≤ 5	Sv/h	
5	RF frequency	→ see 		
6	Maximum incident power			
7	Additional instrumentation	second sound, cold bead pull, …		
8	Typical testing rate (Vts / year)	< 10		
9	Possibility to test naked cavities	NO		

Development Cycle of SRF Systems

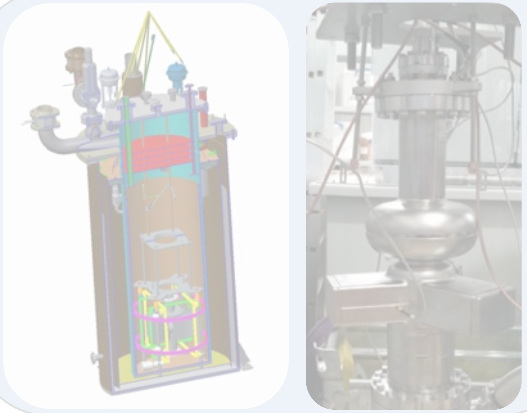
SRF Materials Characterization



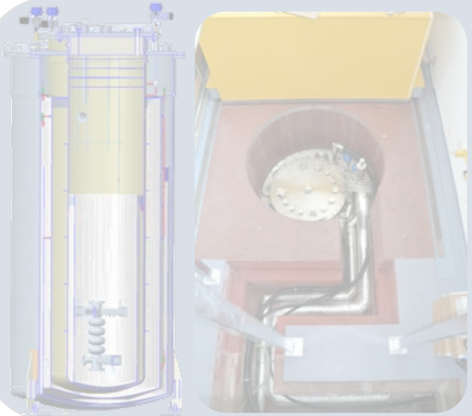
Sample RF testing (QPR)



1-cell prototype testing (SVTA)

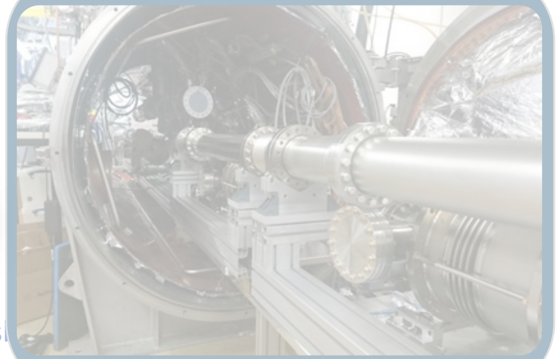


Full cavity testing (LVTA)



Component Testing

Dressed system (HoBiCaT)



Full module tests (MTF)

Beam operation (SEALab)

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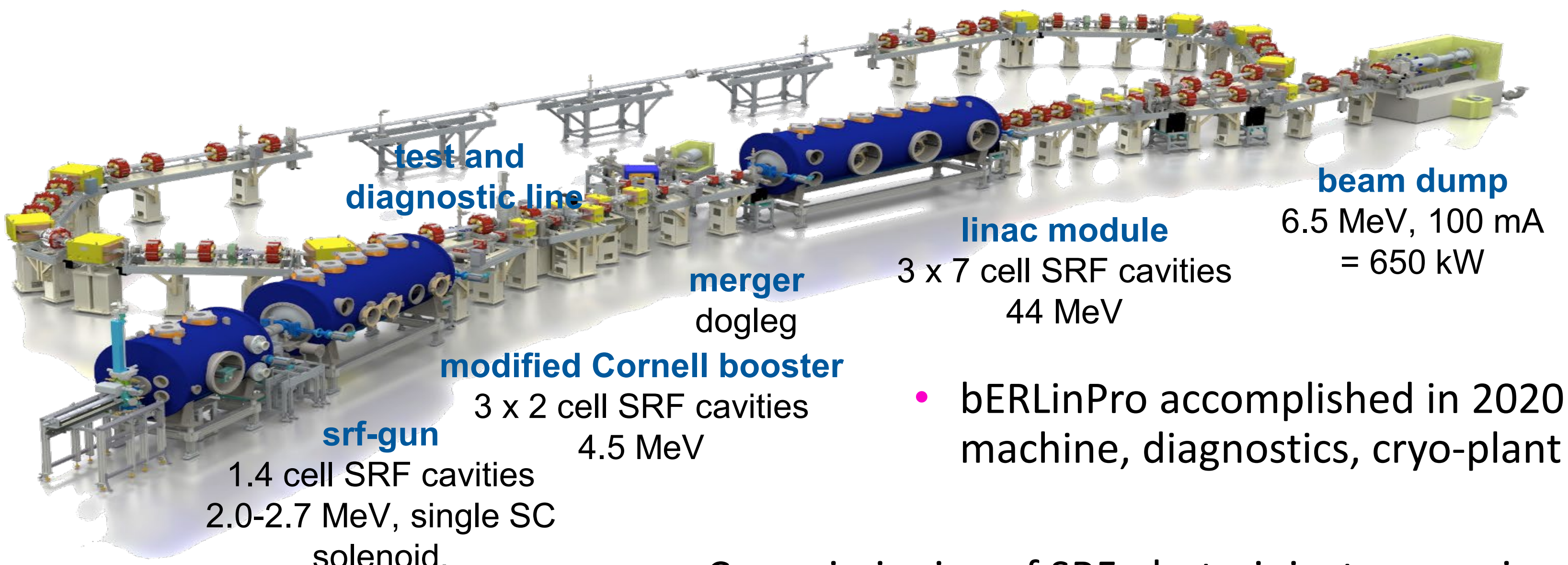
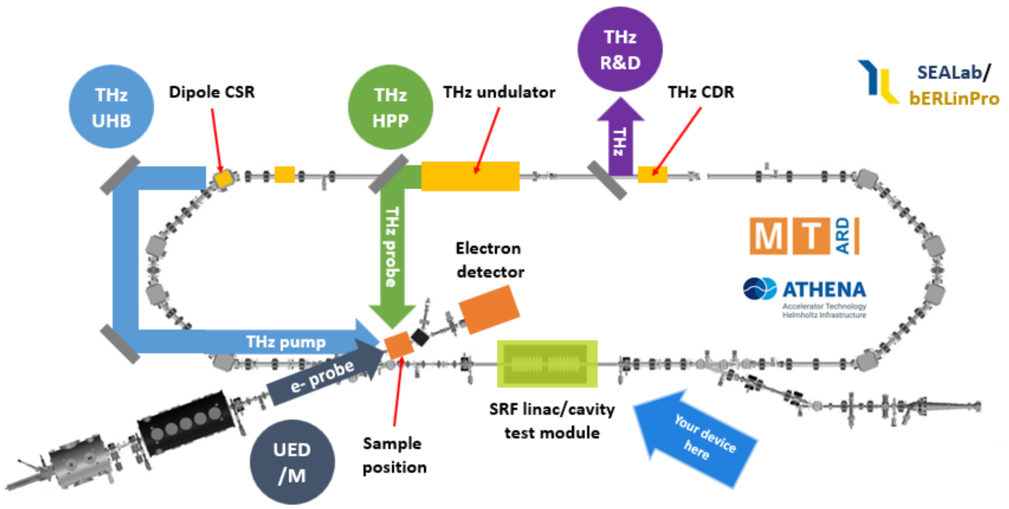
SEALab – Putting the Full System to the Test



bERLinPro becomes SEALab: an ERL and more…

- bERLinPro accomplished in 2020: Building, infrastructure, warm machine, diagnostics, cryo-plant and high-power RF stations ready
- Commissioning of SRF photo-injector ongoing, high-QE cathode, laser system, high-power SRF booster coupler conditioning on track → first beam from injector in spring 2023
- Beam commissioning program in development to map out the injector‘s parameter space from short pulse-low charge via medium avg. current to the high charge regime
- Machine open for additional applications, contributes to the European ERL stragegy for HEP

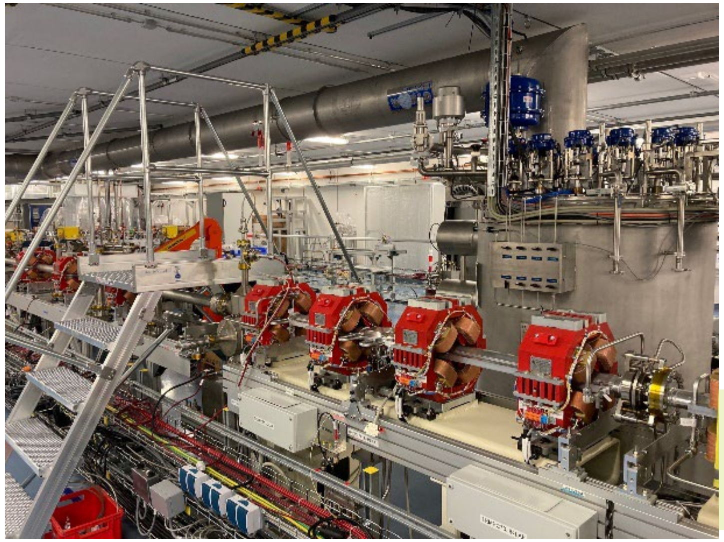
SEALab – Putting the Full System to the Test



Parameter	ERL	Injector/UED
Beam energy (MeV)	50	6.5-10/2
I_{avg} (mA)	100	6-10/0.0025
Laser freq. (MHz)	1300	50, 1300
RF freq. (MHz)	1300	1300
ϵ_{norm} (mm mrad)	1 (0.6)	0.6/0.03
σ_t (ps)	2 (0.1)	0.02-2
Bunch charge (pC)	77	0.05-400

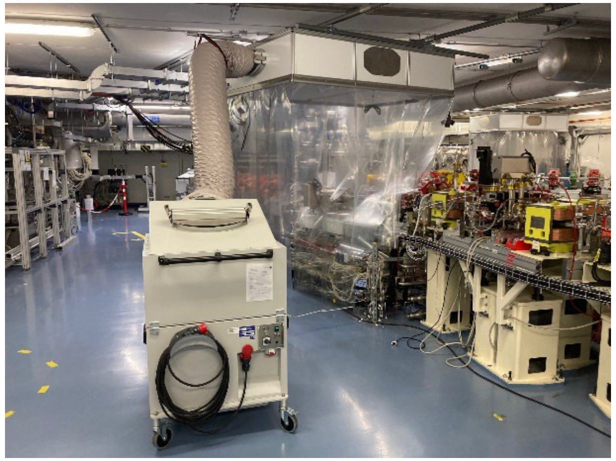
- SEALab offers potentially a large range of beam parameters due to its two photo-cathode laser systems (50 MHz, 1.3 GHz) and their macro-pulse capabilities
- As long as there is no Linac installed within the ERL reciculatory, this can be used as a passive beam (no effective acceleration) test stand
- Adaption to the existing cryogenic installations and particulate free installations are key for the success

SEALab – Putting the Full System to the Test

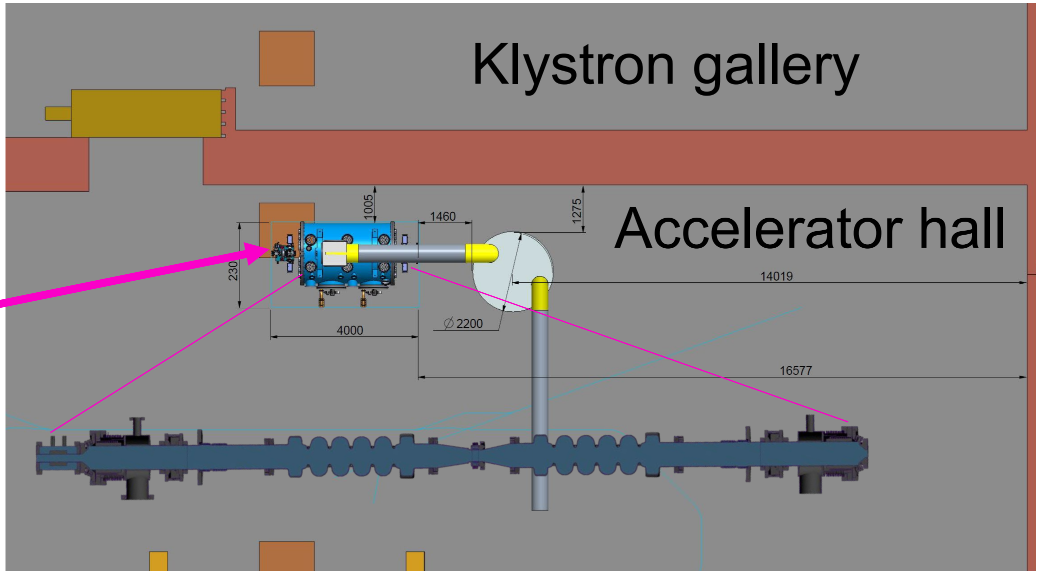


Linac location with Cryo coldbox

Example of local cleanroom for beam vacuum system



Site for RF only module teststand, currently VSRdemo



2x 4cell 1.5 GHz VSR Cavities equipped with power coupler, operated by 15 kW solid state RF transmitters

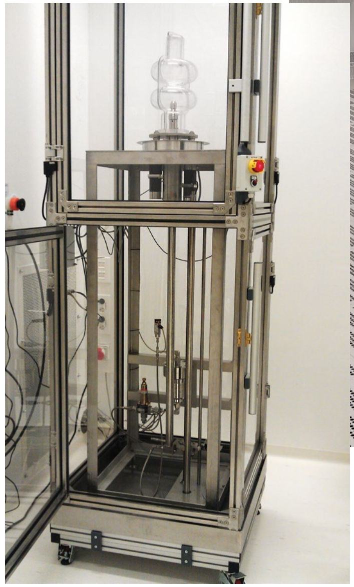
RF Infrastructure

- SVTS, HoBiCaT
  - 400 – 450 MHz, 500 W CW
  - 690 – 3200 MHz, 300 W CW
  - 1.3 GHz, 15 kW CW
  - 1.5 GHz, 15 kW CW
- LVTS
  - 690 – 3200 MHz, 300 W CW
- Coupler tests, nc cavity tests, SEALab
  - 500 MHz, 80 kW CW
  - 1.3 GHz, 15 + 250 kW CW
  - 1.5 GHz, 15 kW CW
  - 1.75 GHz, 15 kW CW

- Mobile devices
  - 2.5 – 6.0 GHz, 90 W CW
  - VNA up to 20 GHz
  - …
- PLL systems
  - 420, 850, 1300 MHz → QPR
  - 1.3 GHz
  - 1.5 GHz coming soon

Supporting Infrastructure

- 2 clean rooms available
  - 100 m² (18m x 5.5m) with 63 m² ISO-4 (9m x 7m)
  - 44 m², with 23 m² ISO-5 (5.1m x 4.4 m)
  - HPR, US-bath for large cavities
- Mobile pump stations for automated slow clean pumping and venting
- SRF Materials Lab
  - Laser Scanning Microscope
  - Optical Microscope
  - BCP setup
    (only small volumes and very limited availability)
  - Machines for sample cutting and grinding
  - Quartz tube furnace (1100°C, Ø=190mm, hot zone ~500 mm, total 2 m)



Key Issues

- Small interventions are possible, but limited by available personnel
- SVTS and HoBiCaT share the same rad. prot. bunker
- SVTS, LVTS, HoBiCaT: LHe cannot be pumped in parallel (upgrade work ongoing for more flexibility)
- "Standard Tests" that require no modification are fairly easy… but slots are limited by the availability of infrastructure
- Non-standard tests: Interface definition is key
  - Ideally, "user" comes with plug-and-play system pre-configured to interface with the existing system
  - e.g. coupler testing for RI

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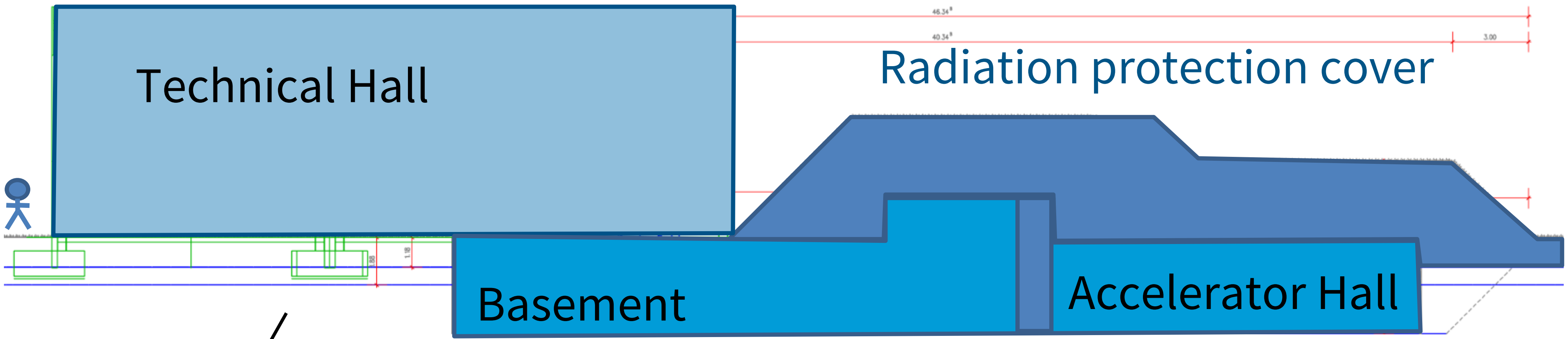
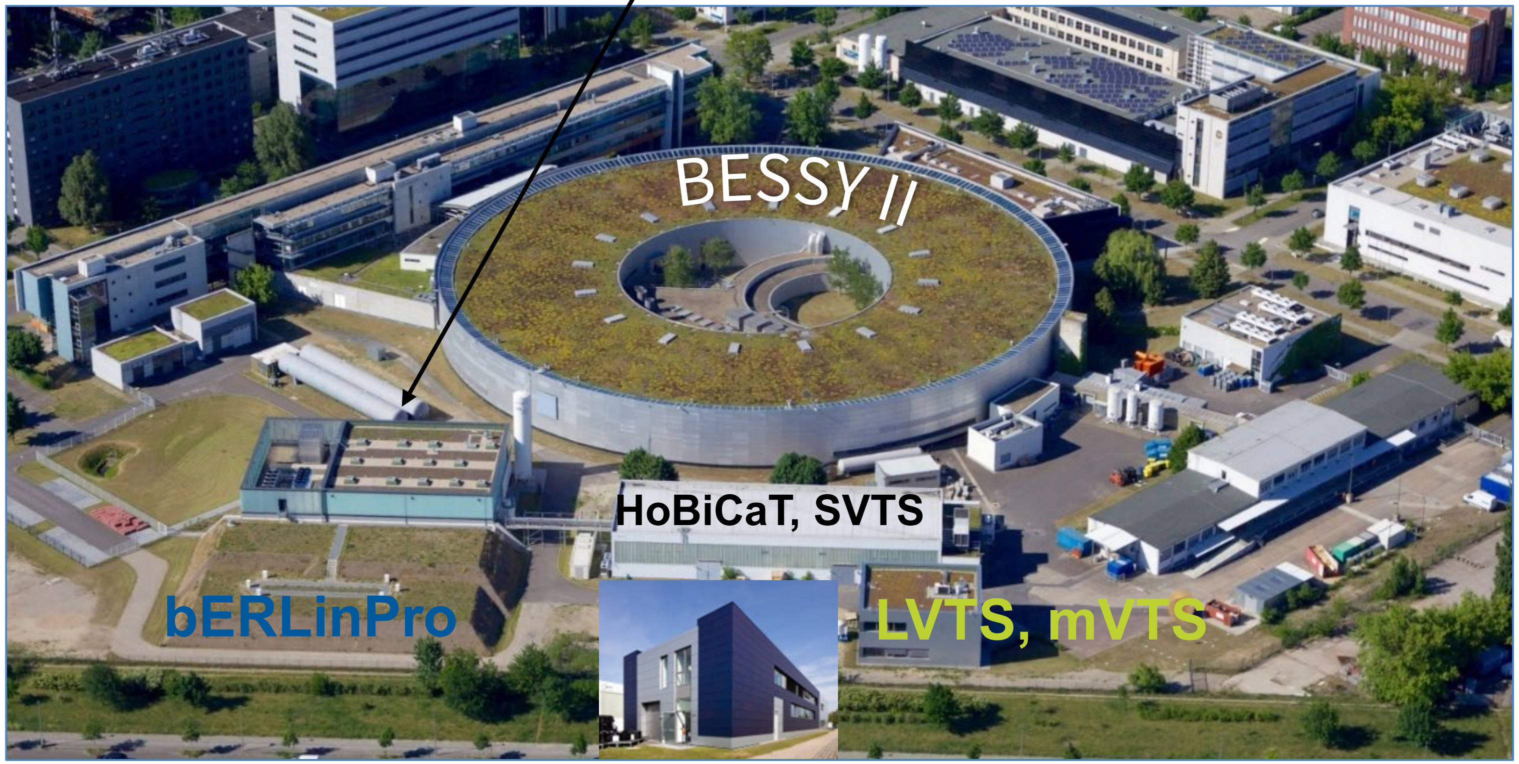
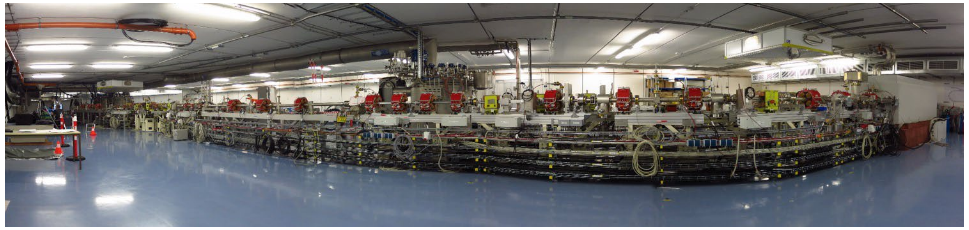
Thank you for your attention!

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.

bERLinPro/SEALab: A quick orientation







- bERLinPro is located in a sub-terranous radiation protection shelter
- All technical infrastructure, besides the klystron and some cryogenic installations are above ground in a technical hall