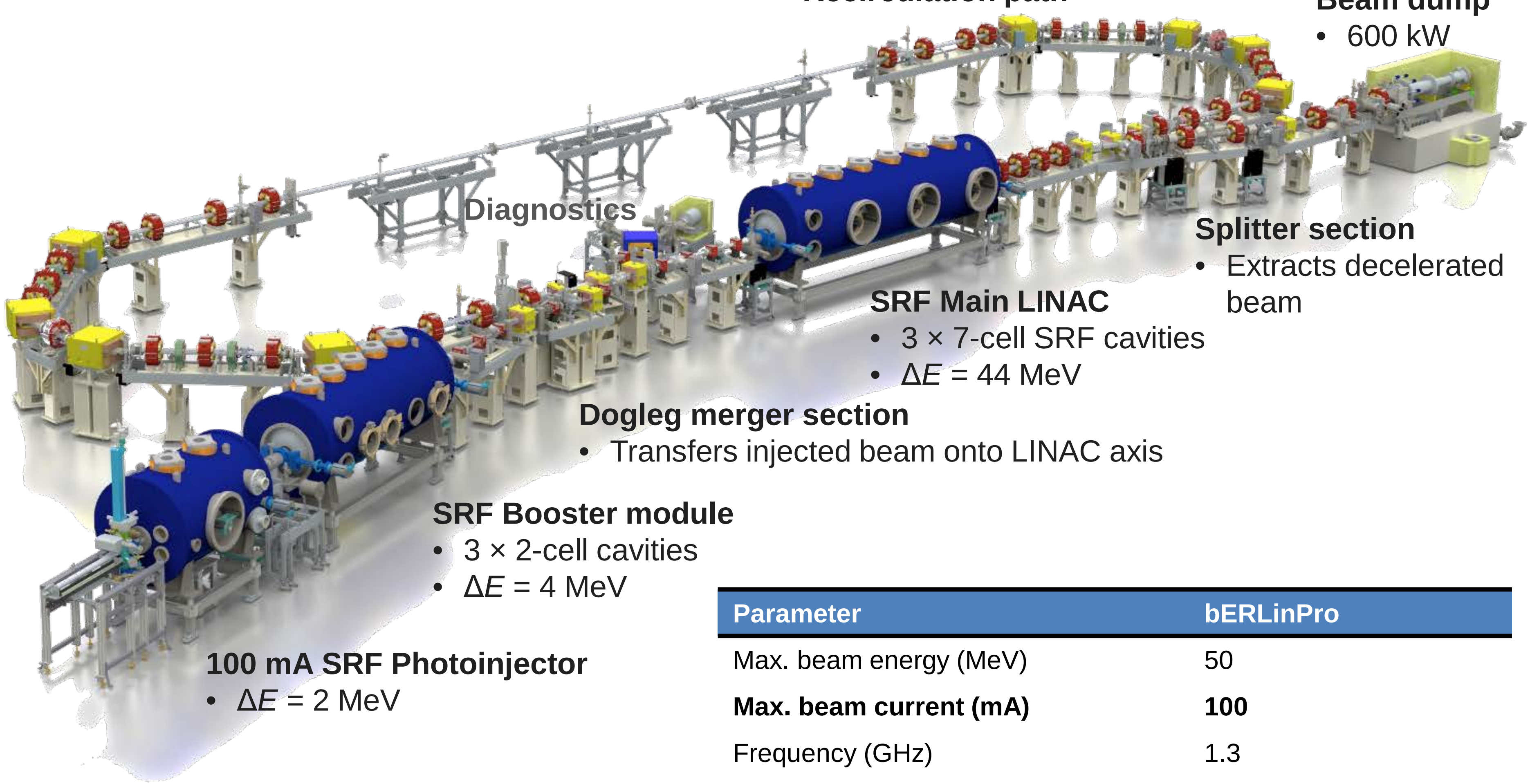
bERLinPro & BESSY VSR @ HZB

Status, Plans, Perspectives

Andreas Jankowiak
on behalf of the HZB accelerator team
Helmholtz-Zentrum Berlin

7th ARD ST3 Annual Meeting
GSI / FAIR campus
16.10.2019

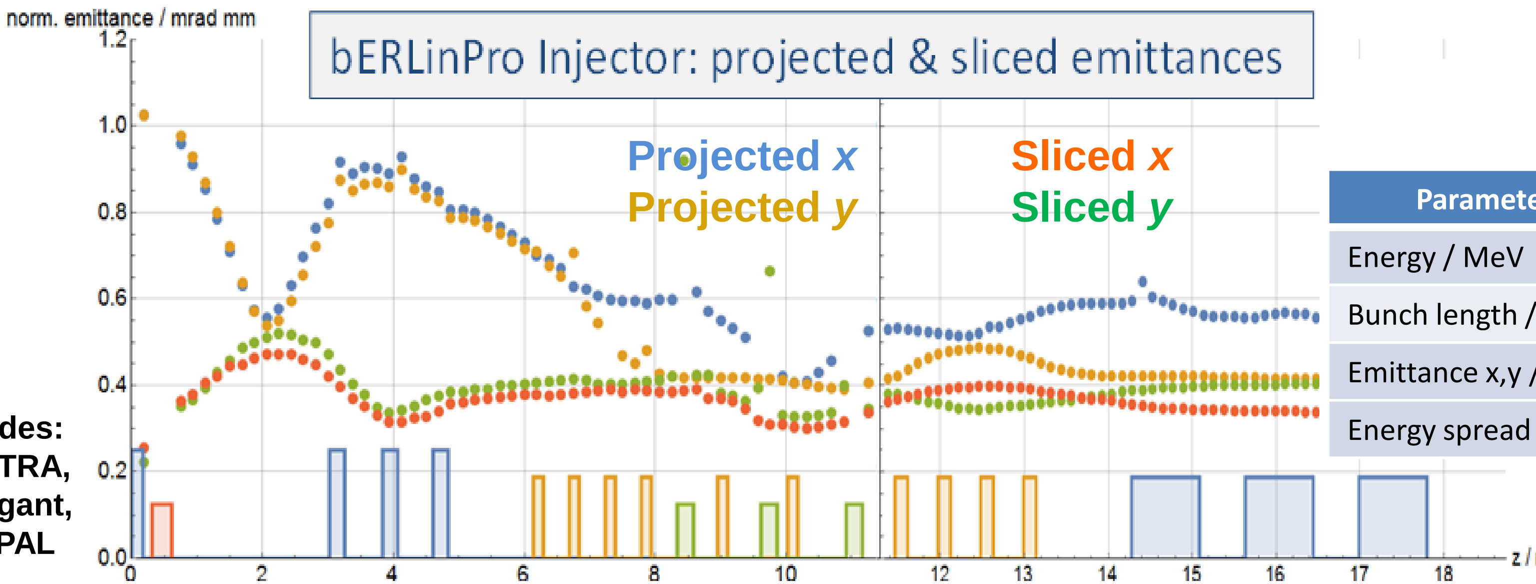


Parameter	bERLinPro
Max. beam energy (MeV)	50
Max. beam current (mA)	**100**
Frequency (GHz)	1.3
Normalized emittance (mm mrad)	**1 (< 0.6 in simulations)**
Bunch length (ps)	**< 2 ps (100 fs @ 10mA)**
Beam losses	<< 10^{-5} @ 100 mA

- project start 2011
- fully funded

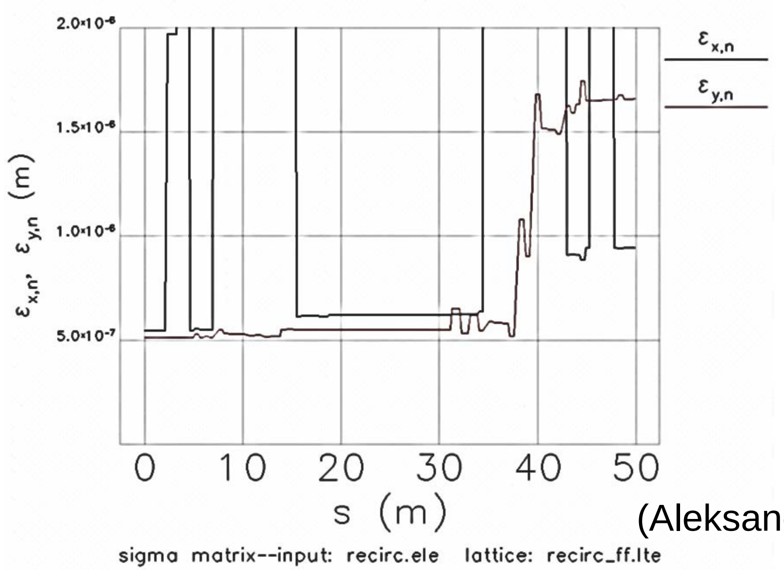
Low emittance / short bunches

codes: ASTRA, elegant, OPAL

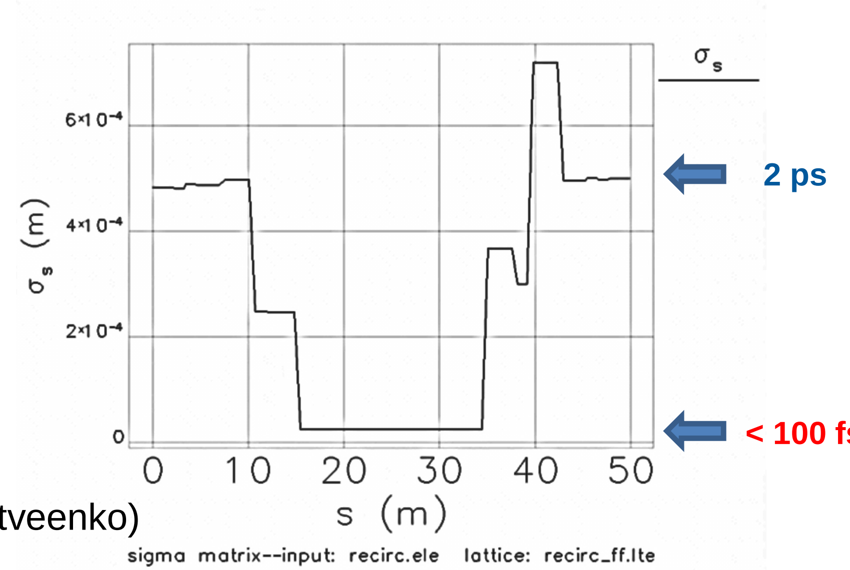


Parameters at LINAC exit	
Energy / MeV	50.1
Bunch length / ps	4.65
Emittance x,y / µm	**0.58/0.41**
Energy spread / keV	254

Optics (Short Bunch Mode, 10 pC): Bunch size & Emittance

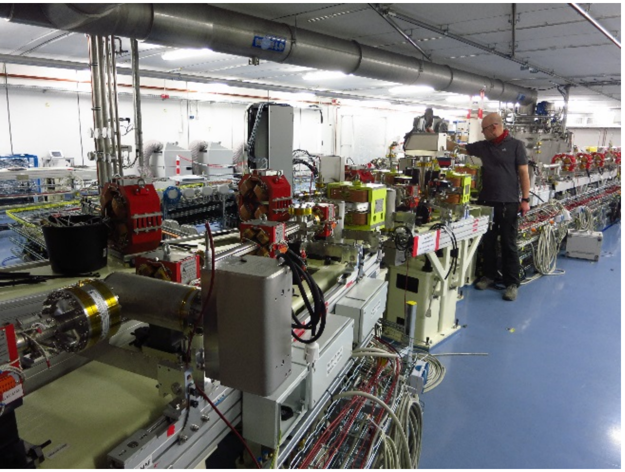


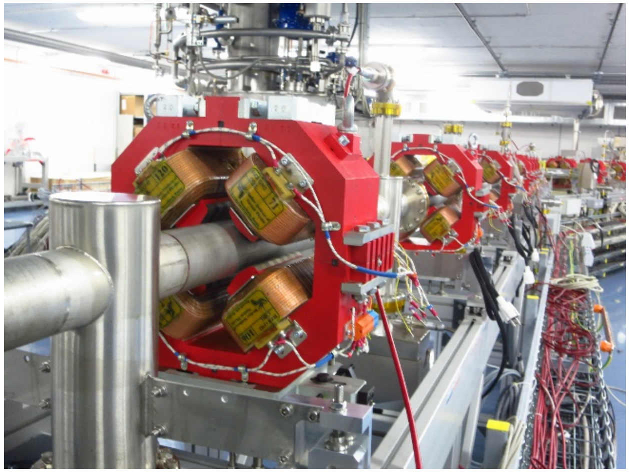
(Aleksandr Matveenko)

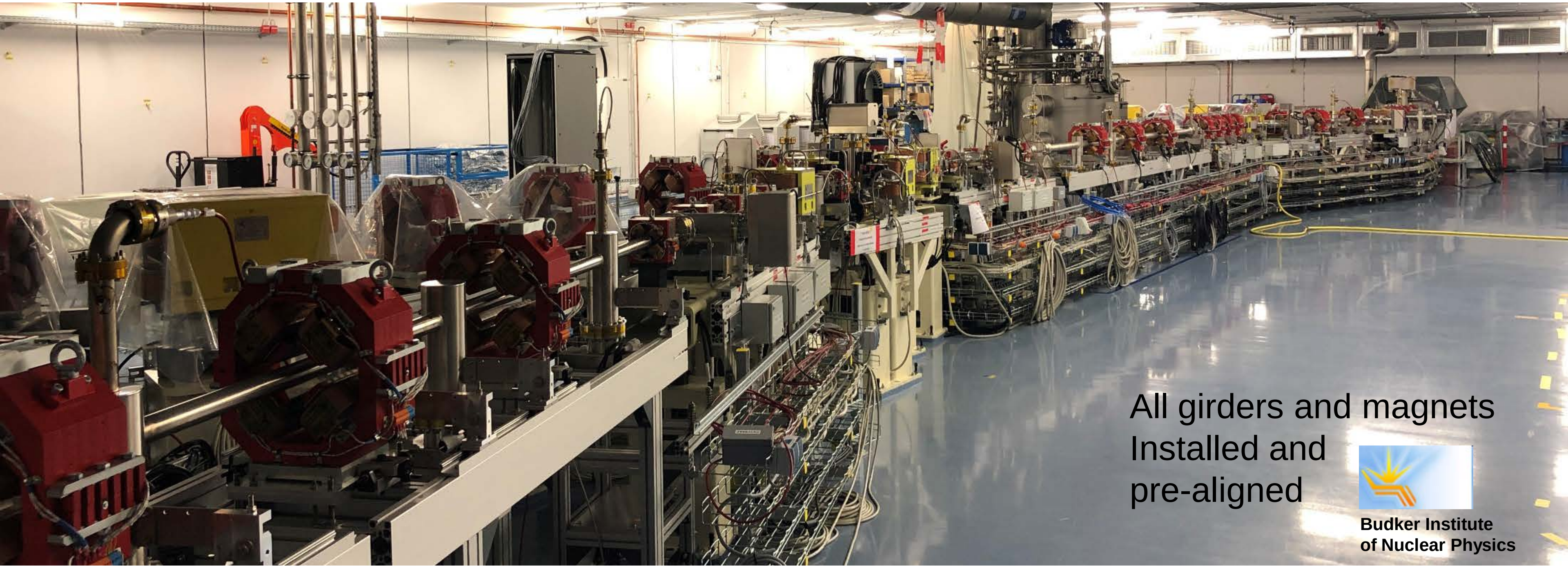


bERLinPro – building + technical infrastructure nearly finished

Underground accelerator hall – machine installation in full swing





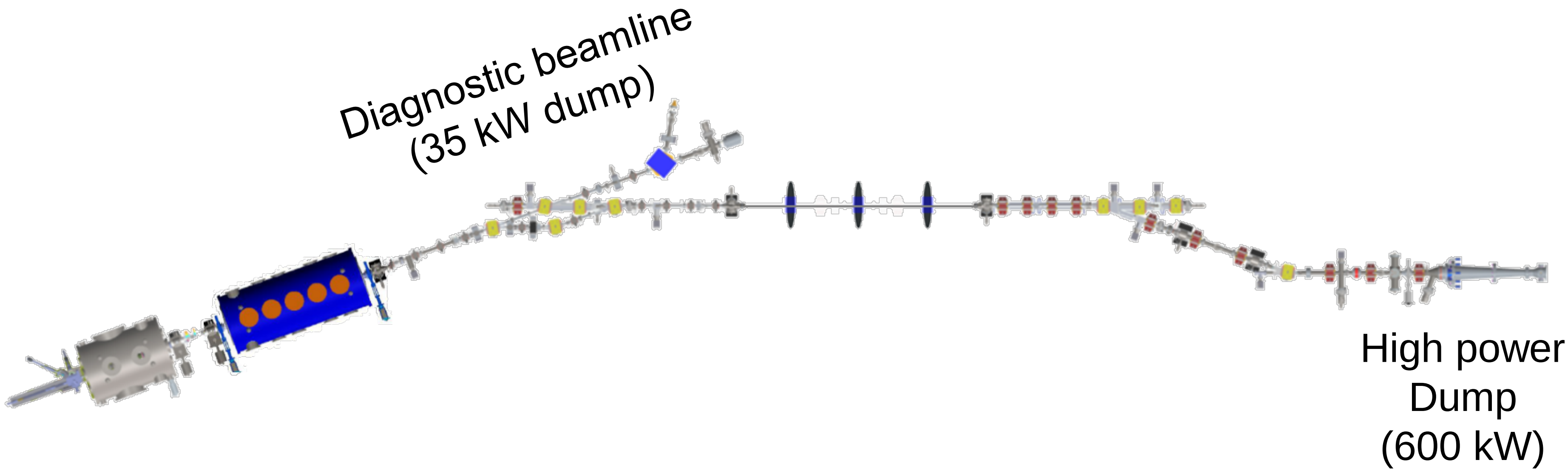


All girders and magnets
Installed and
pre-aligned

Budker Institute
of Nuclear Physics

Stepwise startup foreseen

to separate challenges / for load balancing / to get early scientific output



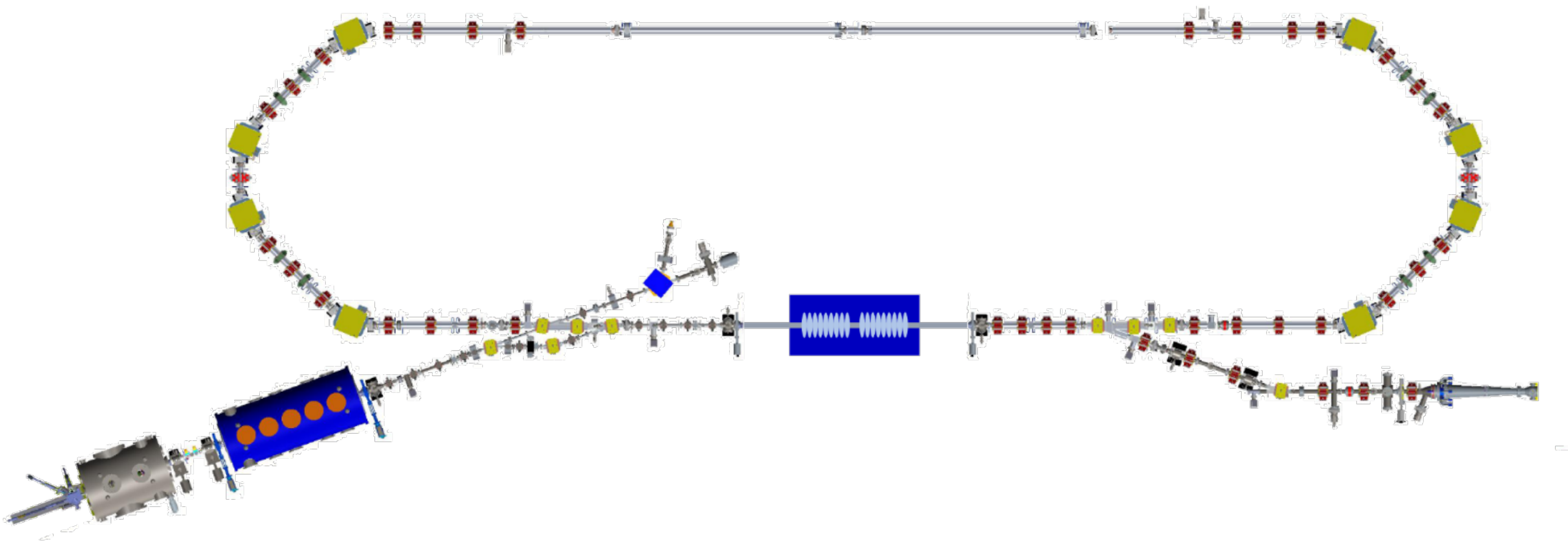
(1) First beam Gun1 in bERLinPro building (2019)

medium power, up to 5 mA → diagnostic beamline

(2) Add booster module (2020)

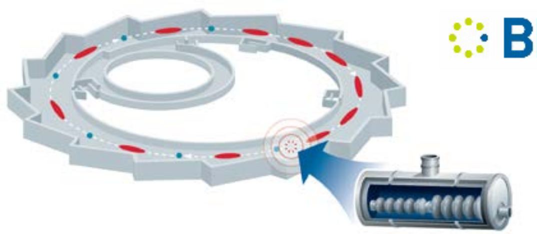
up to 5 mA → diagnostic beamline & high power dump

Commissioning plan bERLinPro (as it was) – Stage 3/4



(3) Add HOM damped linac module and demonstrate recirculation and energy recovery (2021)
medium power (5 mA, 50 MeV) → recirculation

(4) Replace Gun1 by Gun2 and go for high power recirculation (202?)
up to 100 mA, 50 MeV → recirculation

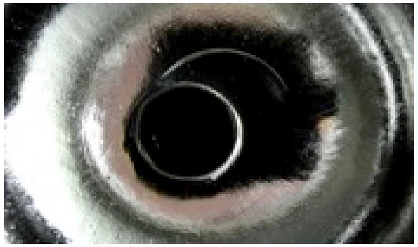


BESSY VSR

BESSY VSR upgrade (2017 – 2026) has higher priority than bERLinPro
→ no Gun2 module, no linac module

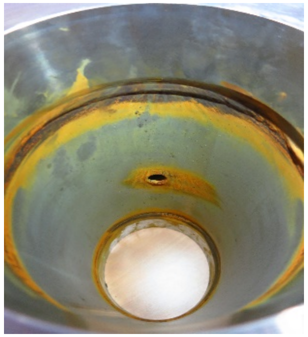
Cold parts of booster HPC were delayed, warm parts even more severe (need to be re-manufactured)

→ conditioning not before Q2/2020, delay of booster module



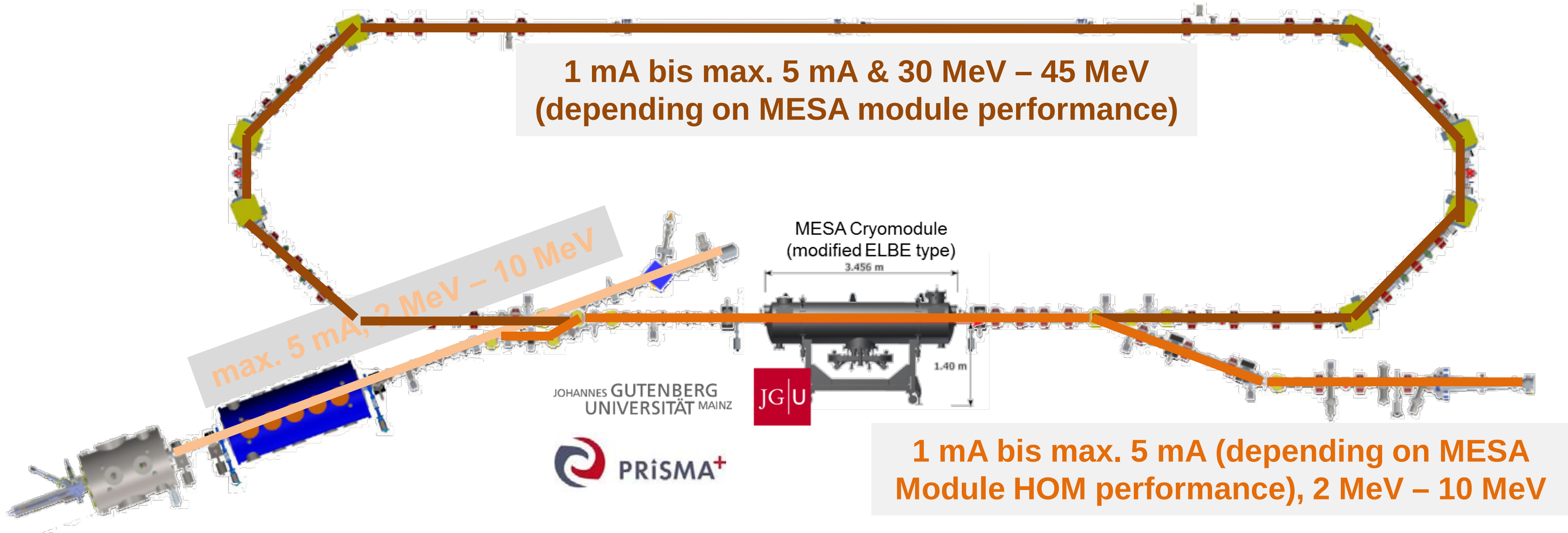
- Gun1.0 cavity not usable in bERLinPro due to “drop” of cathode in cavity (etc.)
- Gun1.1. cavity got scratch during final HPR at manufacturer

→ attempt to repair by grinding ongoing, delay (min. 5 months) of Gun module



Rust in de-ionized water cooling circuits of bERLinPro, nearly complete system needs to be exchanged
→ delay in commissioning cryo-system, coupler tests, …

Present planning – no contingency / still some uncertainties



09/2020 Gun1 cool down and RF commissioning (no beam tests)

10/2020 start installation of re-circulator vacuum (to be finished 03/2021)

12/2020 booster module installed

01/2021 MESA module installed (collaboration JGU Mainz, 2 x 9 cell)

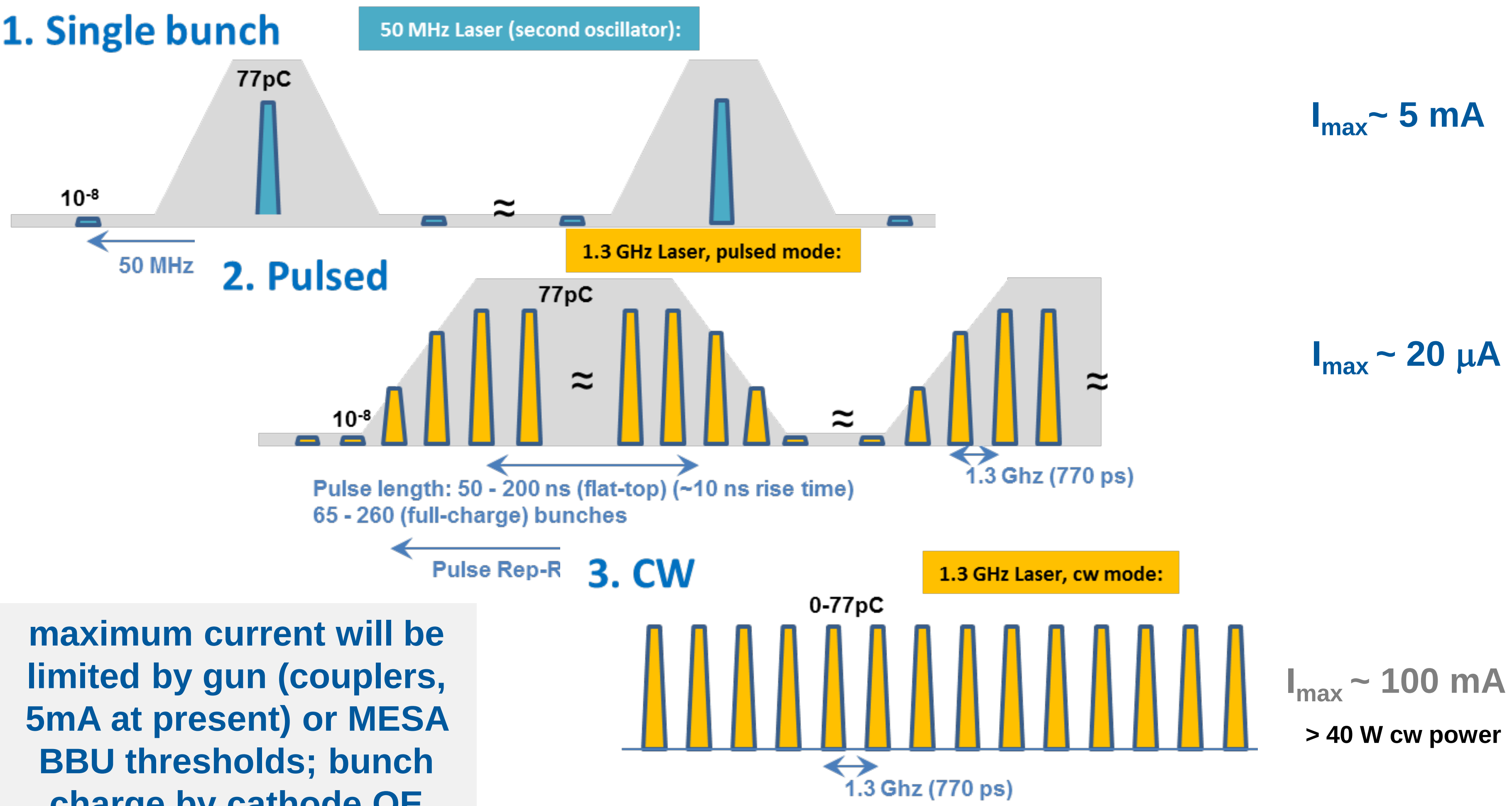
06/2021 First beam possible, with subsequent re-circulation + recovery

Re-circulation test period limited, as MESA module back to Mainz 07/2022
and start of VSR module tests in bERLinPro hall ca. 09/2022.
Funding for 2000 h / a of operation secured till end of 2022.

Operational modes – pulse patterns

Pulse Pattern Options

- 2 laser systems by MBI: 50 MHz & 1.3 GHz, 510 – 540 nm, extinction ration 10^{-8}

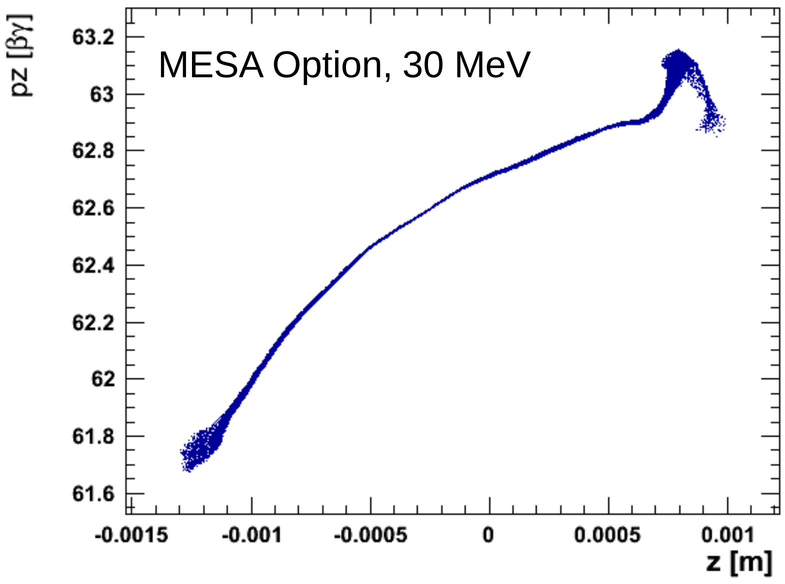


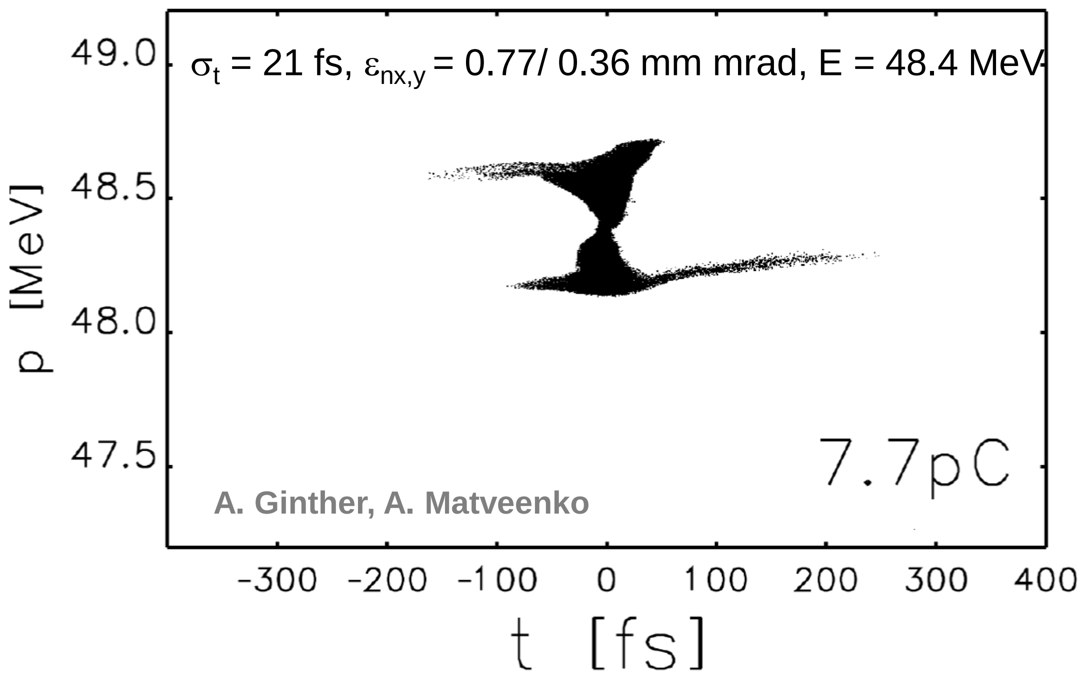
maximum current will be limited by gun (couplers, 5mA at present) or MESA BBU thresholds; bunch charge by cathode QE

pulse length: adjustable 3 ps – 12 ps (rms), 7 ps (rms) baseline,

Short pulses

- standard operation: σ_t = 2 ps @ Q_b = 77 pC
- dedicated short puls mode: σ_t ~ 100 fs @ reduced bunch charge

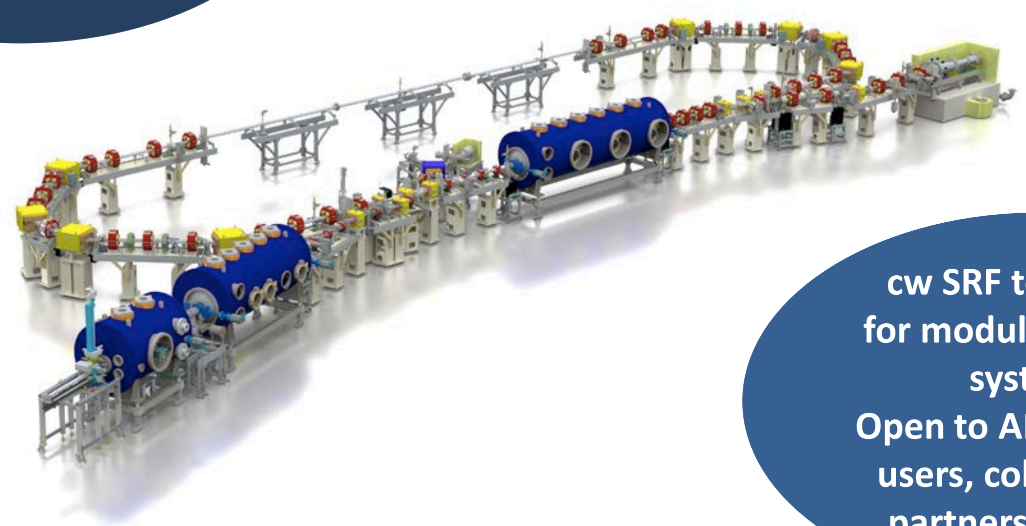




bERLinPro as an R&D test facility in the future ...

THz pilot facility, High quality, high power radiation schemes (THz, X-rays, e- pump/probe)

Exotics
Dark matter search
Isotope production
EUV facility tests



cw SRF test facility for modules, cavities, systems.
Open to ARD, external users, collaboration partners, industry.

ERL / Gun test accelerator, test bed for undulators, impedance tests, ...

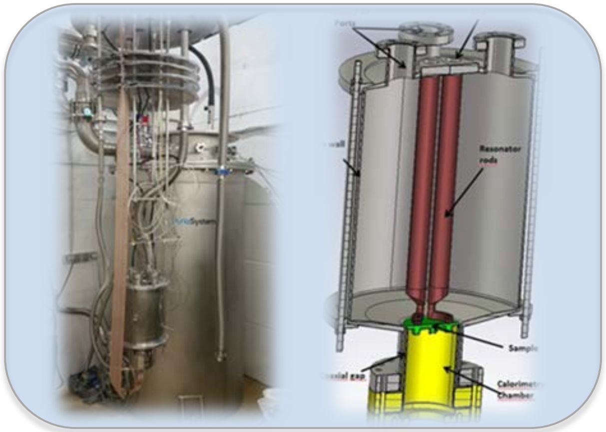
Teaching and education

SupraLab@HZB – Facilities for cw SRF development & tests

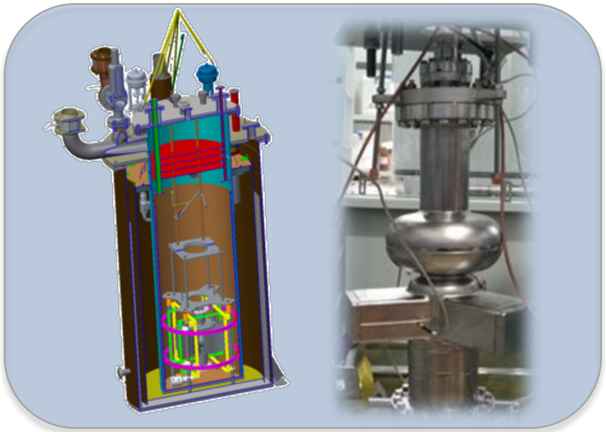
A one stop shop for the full CW SRF development chain

- From new characterization of new materials, to prototypes (cavities, modules), to beam tests in bERLinPro

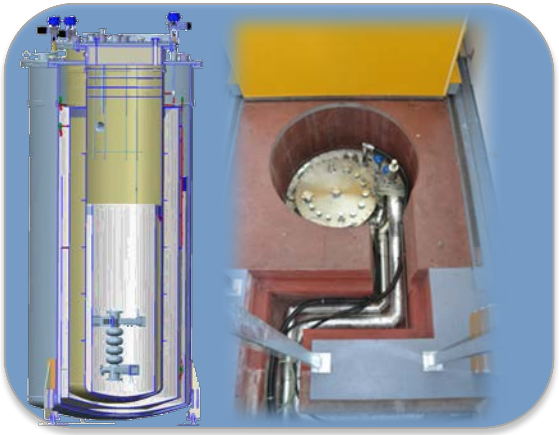
Sample testing (QPR)



1-cell prototype testing (SVTA)

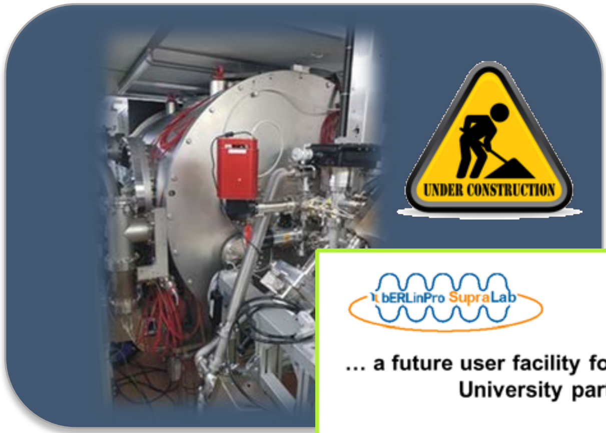


Full cavity testing (LVTA)



Dressed system (HoBiCaT)

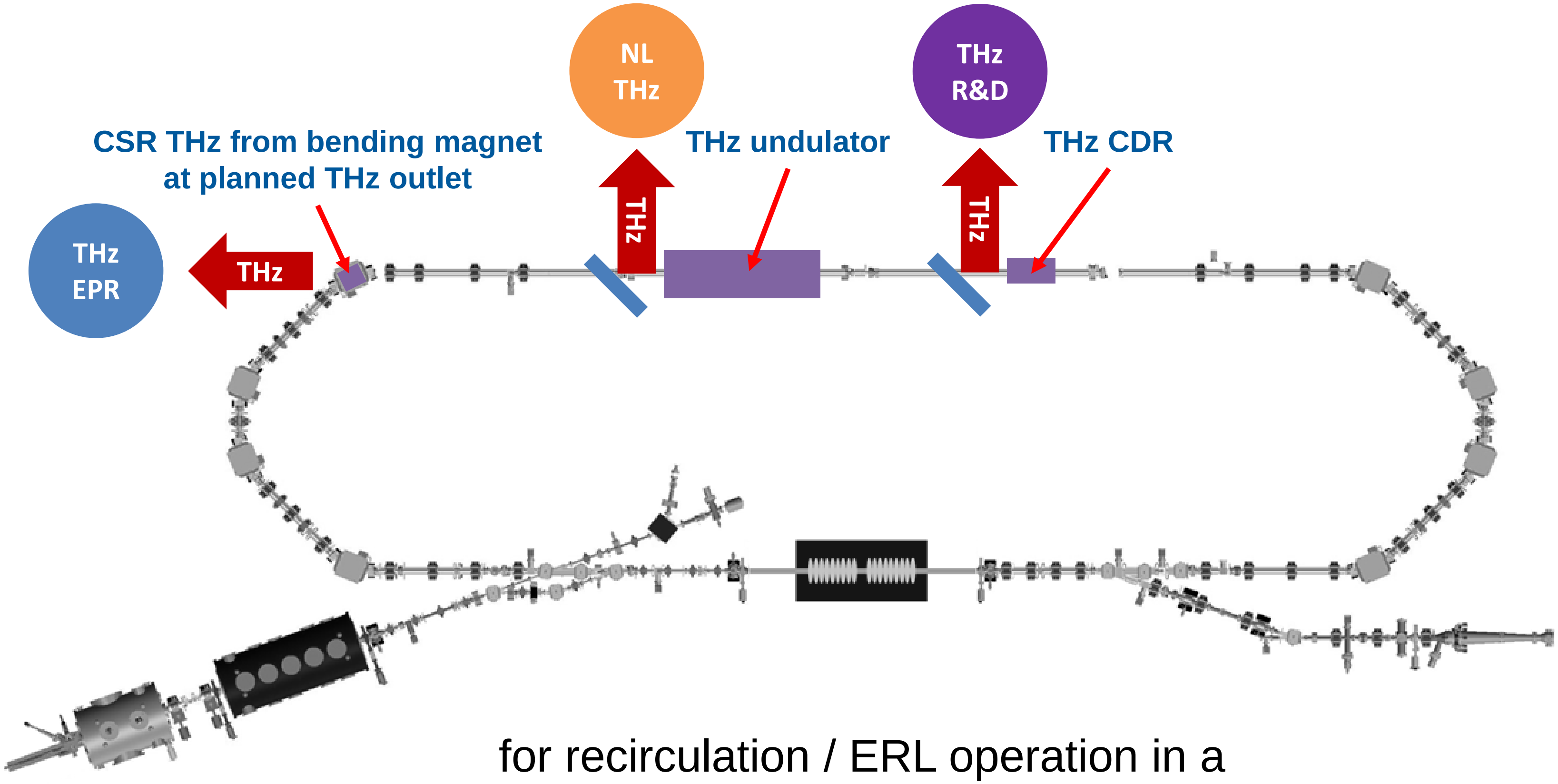
Full module tests (MTF)



Beam operation in bERLinPro

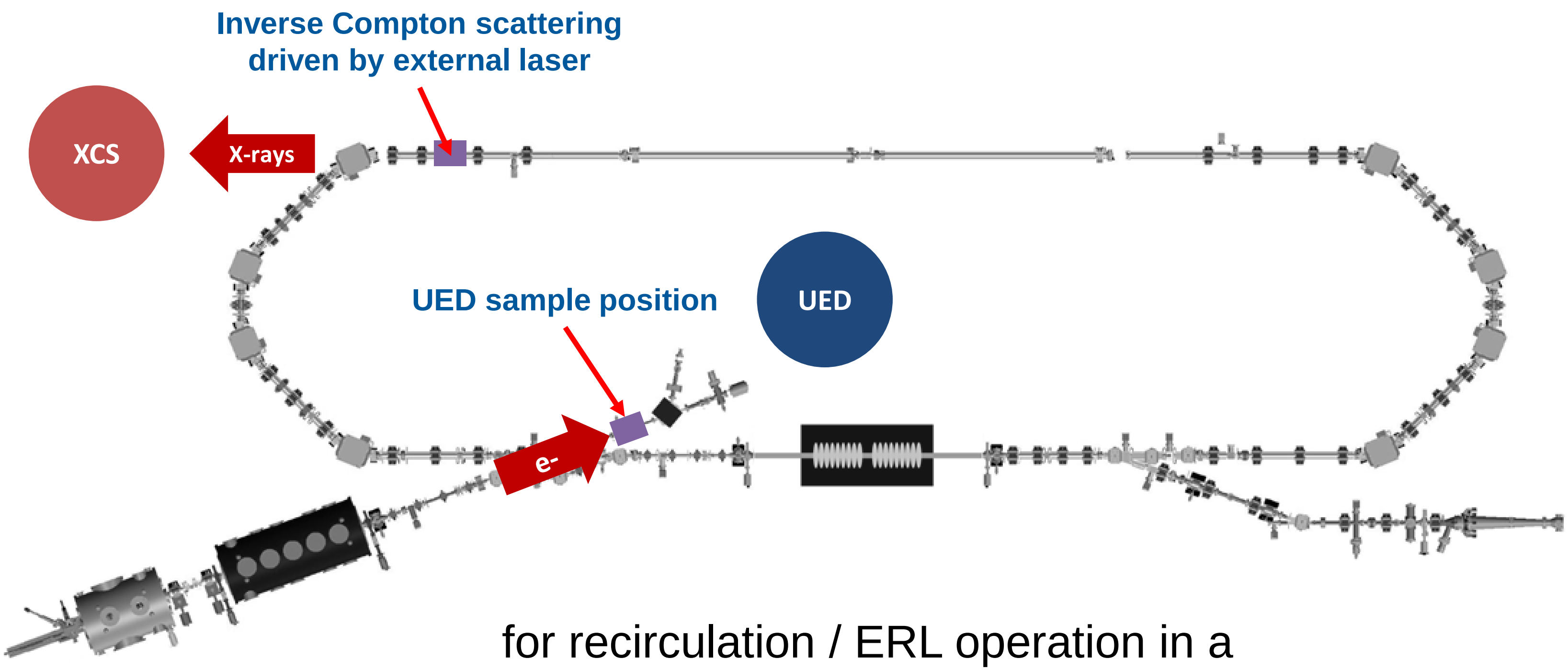
… a future user facility for Helmholtz partners, external collaboration partners, University partners, as well as industry (e.g. LightHouse)

Some first ideas - THz opportunities at THz@SupraLab/bERLinPro



for recirculation / ERL operation in a
"post MESA@bERLinPro time" (from 2022/23 on)
we need a "linac module"

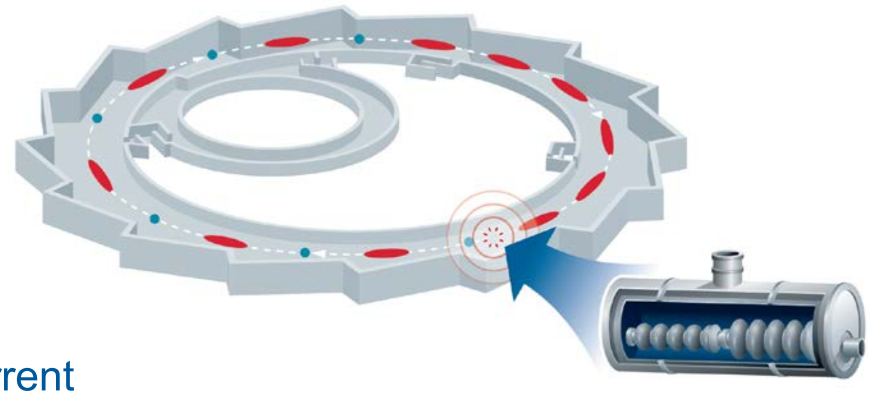
Some first ideas – X-ray / e- opportunities at THz@SupraLab/bERLinPro



for recirculation / ERL operation in a
“post MESA@bERLinPro time” (from 2022/23 on)
we need a “linac module”

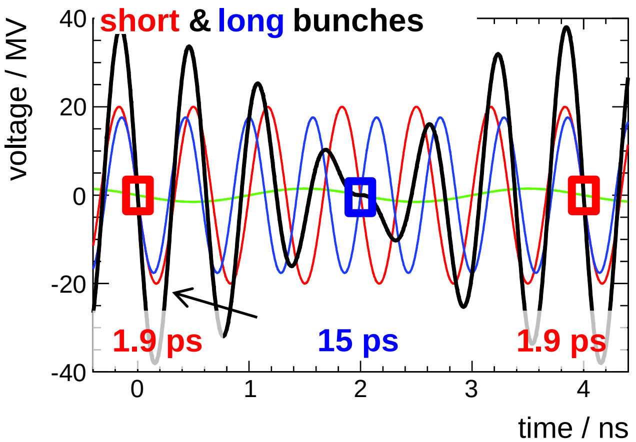
BESSY-VSR – short & long electron pulses simultaneously

$$\sigma \propto \delta_0 \sqrt{\frac{E_0}{\omega_0} \cdot \frac{\alpha}{\omega_{rf} V_{rf}}} \qquad I \propto \alpha$$



high voltage (20 MV/m) cw multi-cell SC cavities allow to increase the total voltage gradient by two orders of magnitude
→ ca. 1/10 bunch length @ constant bunch current

Combining two RF systems with different frequencies (1.5 GHz & 1.75 GHz) generates long and short buckets, which can be filled individually to generate optimized fill pattern.



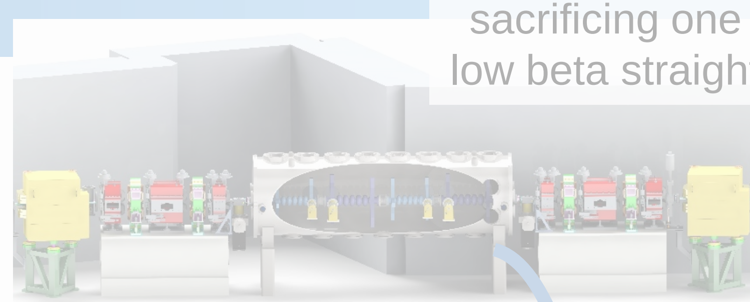
1.5 MV @ 0.5 GHz
16 MV @ 1.5 GHz
14 MV @ 1.75 GHz

J. Feikes, P. Kuske, G. Wüstefeld, EPAC2006
G. Wüstefeld, A. Jankowiak, J. Knobloch, M. Ries, IPAC2011

VSR – variable pulse length storage ring

Technical realisation

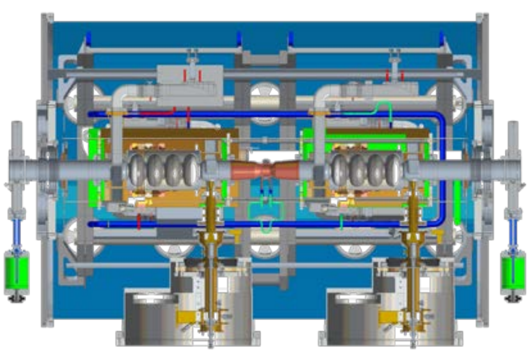
sacrificing one low beta straight

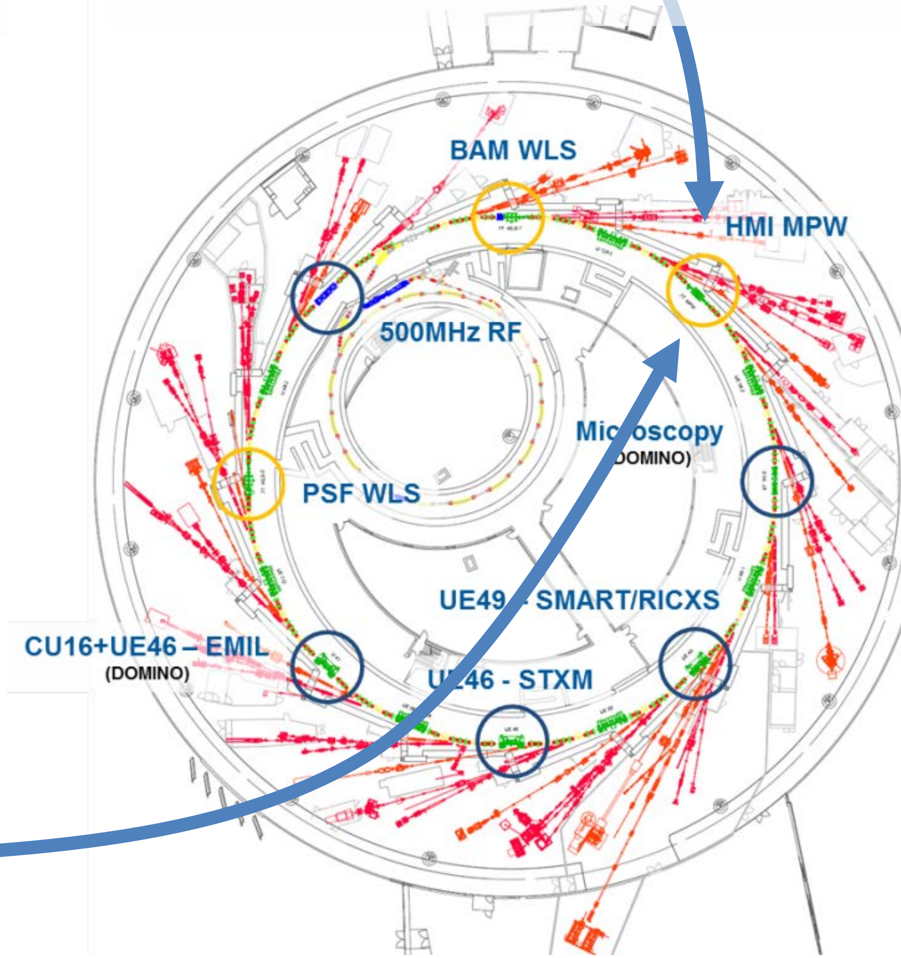


One cryo-module with:
2 x 4 cell @ 1.5 GHz & 2 x 4 cell @ 1.75 GHz
operating at **1.8 K LHe** temperature
active length: **1.50 m** with **20 MV/m**
total gradient: **2π 50 MV×GHz (x 60 increase)**

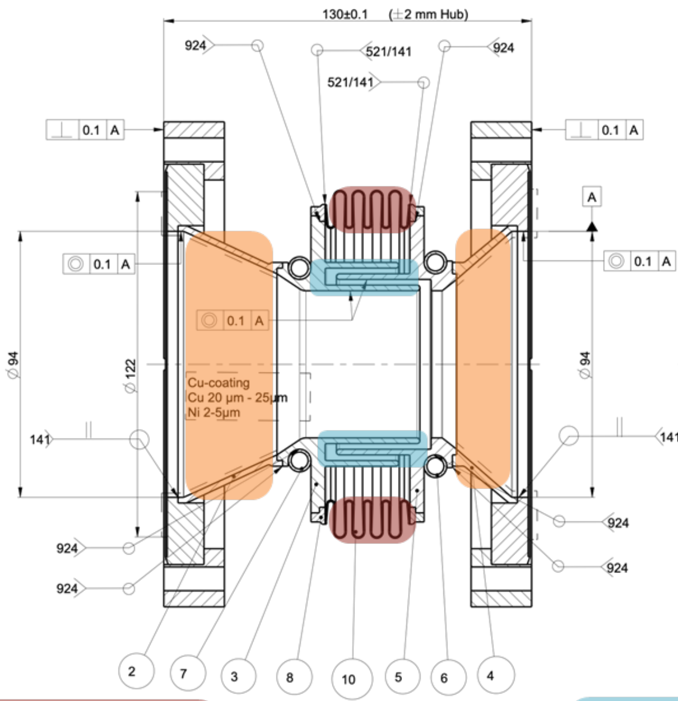
A. Velez, A. Neumann, H.-W. Glock, V. Dürr,
F. Pfloksch, N. Wunderer, F. Glöckner, J. Knobloch et al. HZB

Prep. Phase module
(demonstration of reliable operation of a high-gradient, multi-cell, sc cavity in a high current storage ring) with:
2 x 4 cell @ 1.5 GHz
operating at **1.8 K LHe** temperature
active length: **0.8 m** with **20 MV/m**
total gradient: **2π 24 MV×GHz (x 30 increase)**





Collimating shielded bellow (CsB) – most inner part of VSR module



acts as:

- *compensation for cavity shrinkage during cool-down*
- *compensation for cavity manufacturing tolerances*
- *mechanical decoupling between cavities (tuning, microphonics)*
- *synchrotron light collimator with active cooling in the 5 … 8 K circuit*
- *constructed in view of severe length restriction while still preserving fundamental mode Q*
- *impedance-aware design, esp. avoiding lower 250 MHz-beam harmonics*

– st. st. bellow

– copper coated st.st. taper parts

– copper coaxial shielding labyrinth

Lfd.Nr.	Benennung	Einheit	Menge	Zeichnungsnummer	Werkstoff / Halbzeug
9	Flange DN130-CF (VSR_MCA_6213_CF130_R_HF_ID_94)	ASSEMBLY	2	R-MV-8011/0.000 VSR_MCA_6213_CF130_R_hf	1.4429 ESU rotatable blank
8	Anschlußteil DN96-105 (ANSCHLUSSTEIL_B_BORD_DN96_ID105)	PART	2	VSR-MCA-6213/0.001	316 LN-ESU
7	Intercept 68 (VSR_MCA_6213_5K_INTERCEPT_68_EN)	PART	1	VSR-MCA-6213/0.002	CU SE
6	Intercept 72 (VSR_MCA_6213_5K_INTERCEPT_72)	PART	1	VSR-MCA-6213/0.003	CU SE
5	Schild (VSR_MCA_6213_94_SHIELD)	PART	1	VSR-MCA-6213/0.004	CU OF
4	Taper 94 (VSR_MCA_6213_TAPER_94_1_1)	PART	1	VSR-MCA-6213/0.005	316 LN-ESU
3	Schild 3 (VSR_MCA_6213_SHIELD_3_2)	PART	1	VSR-MCA-6213/0.006	CU OF
2	Taper 94-3 (VSR_MCA_6213_TAPER_94_3_1)	PART	1	VSR-MCA-6213/0.007	316 LN-ESU
1	5K D8 Cu-SS-Anschweißstutzen (VSR_6110_5K_CU_SS)	PART	4	VSR-MCA-6213/0.008	316 LN

Stückliste

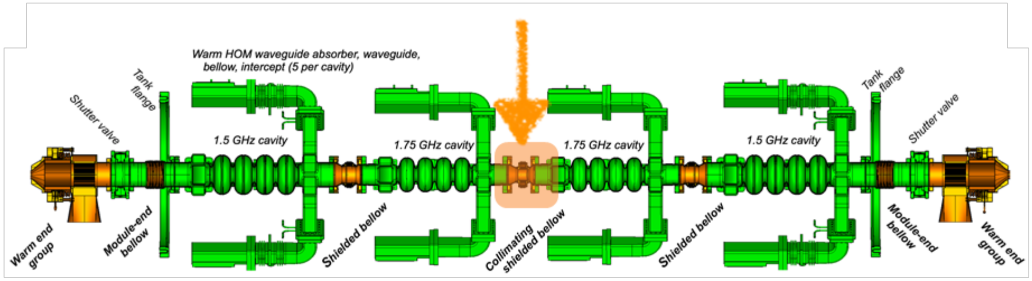
Dateiname des Zeichnungsobjektes: VSR_MCA_6213_BELLOW_2 | Rev. A.5 | Dateityp: ASSEM | Rev. A.1 | Format: A2

HZB Helmholtz Zentrum Berlin | Allgemeintol. DIN ISO 2768-m | Werkstückkanten DIN ISO 13715 | Maßstab 1:1 | Gew.:

Bear. 11-Jul-17 Glöckner | Benennung: Bellow 2

Zeichnungsnummer: VSR-MCA-6213/0.000 | Blatt 1 | 1 Bl.

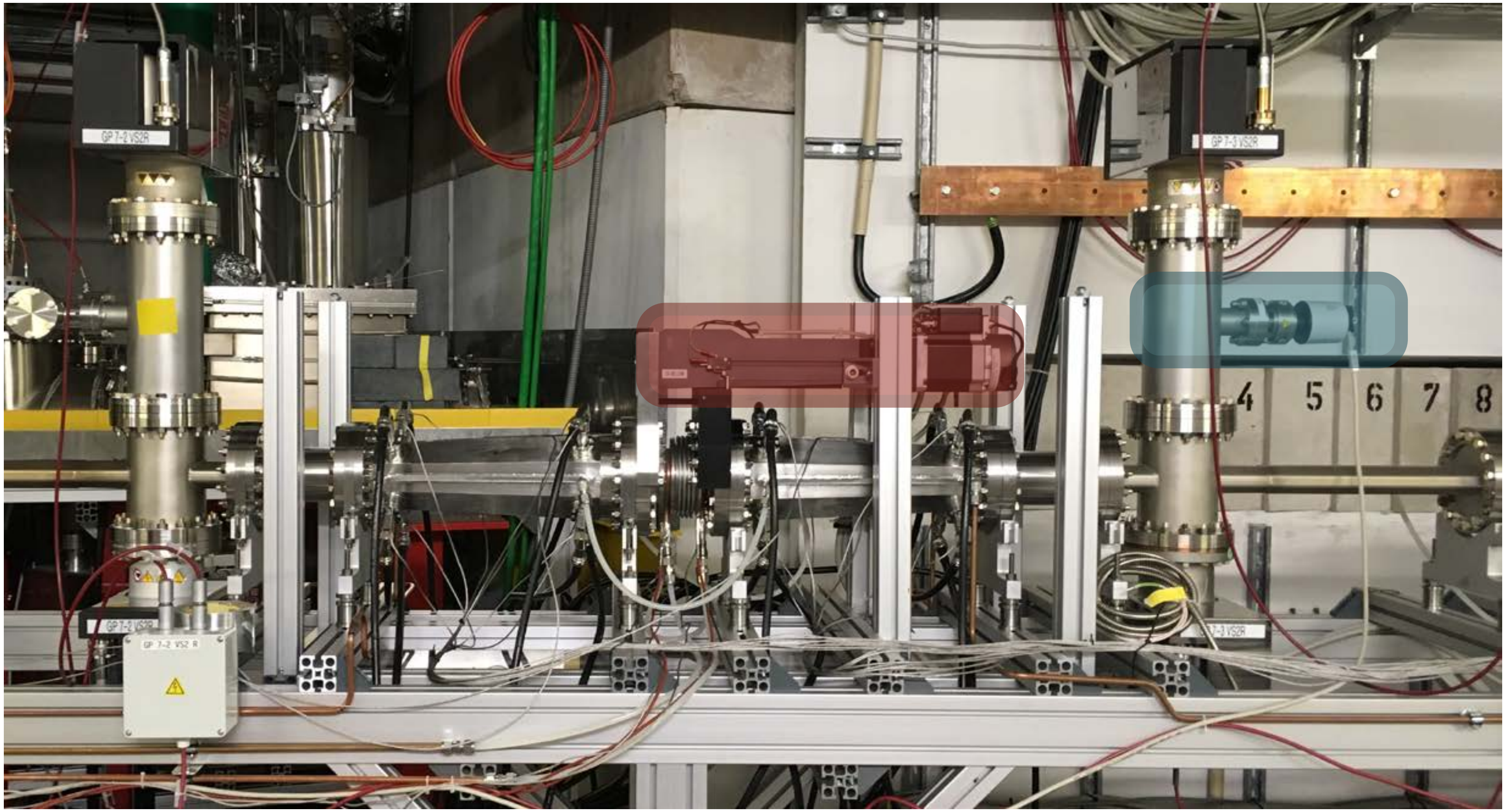
VERTRAULICH - ALLE RECHTE VORBEHALTEN



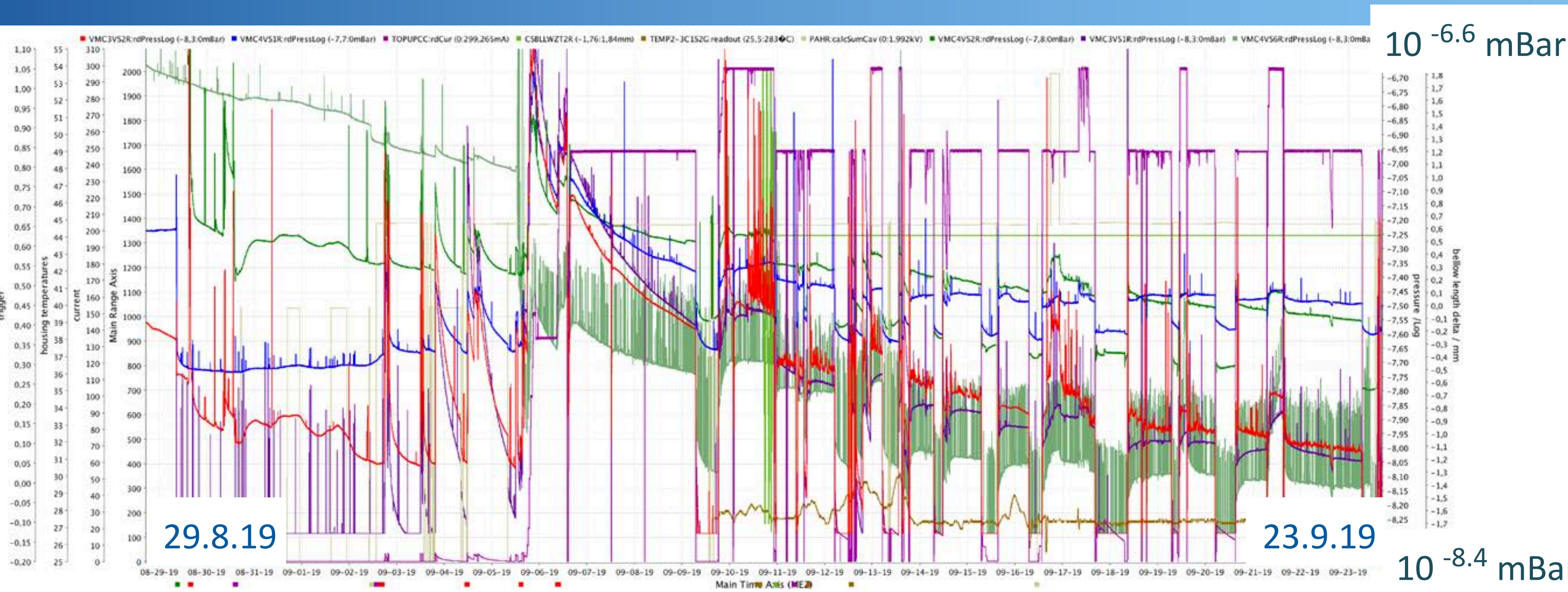
H.-W. Glock, V. Dürr, F. Glöckner, B. Kuner, M. Ries, M. Tannert, D. Wolk et al.

CsB beam (impedance) tests @ BESSY II (Summer 2019)

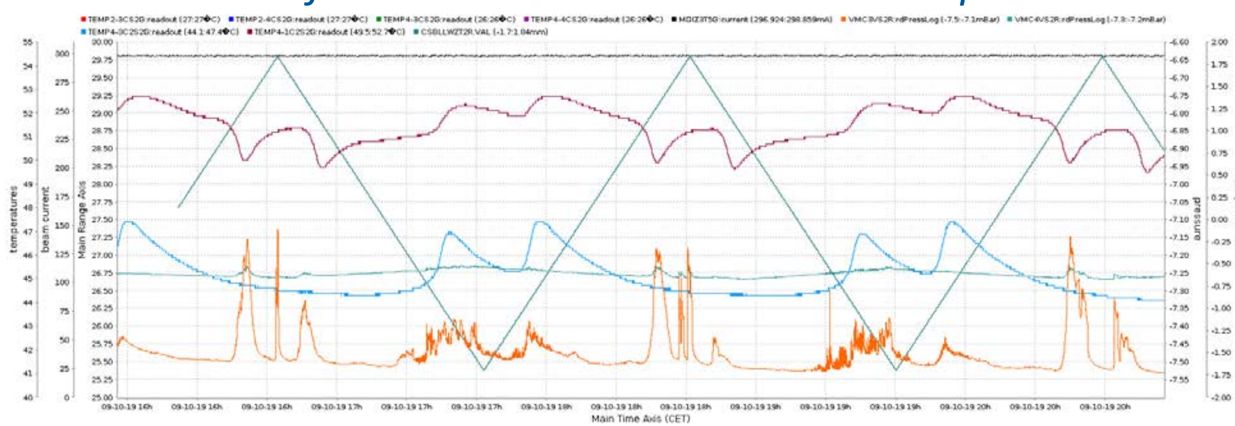
- *beam pipe cross section tapering (polygonal ⟺ circular D94; not wanted, but needed)*
- *each taper with 4 stripline-like two-port couplers mainly for „HOM-damping" / signal extraction*
- *linear mover for ± 2 mm compression/elongation of bellow; thermal sensors on each port, taper*
- *vacuum pressure measured at two close-by-positions*



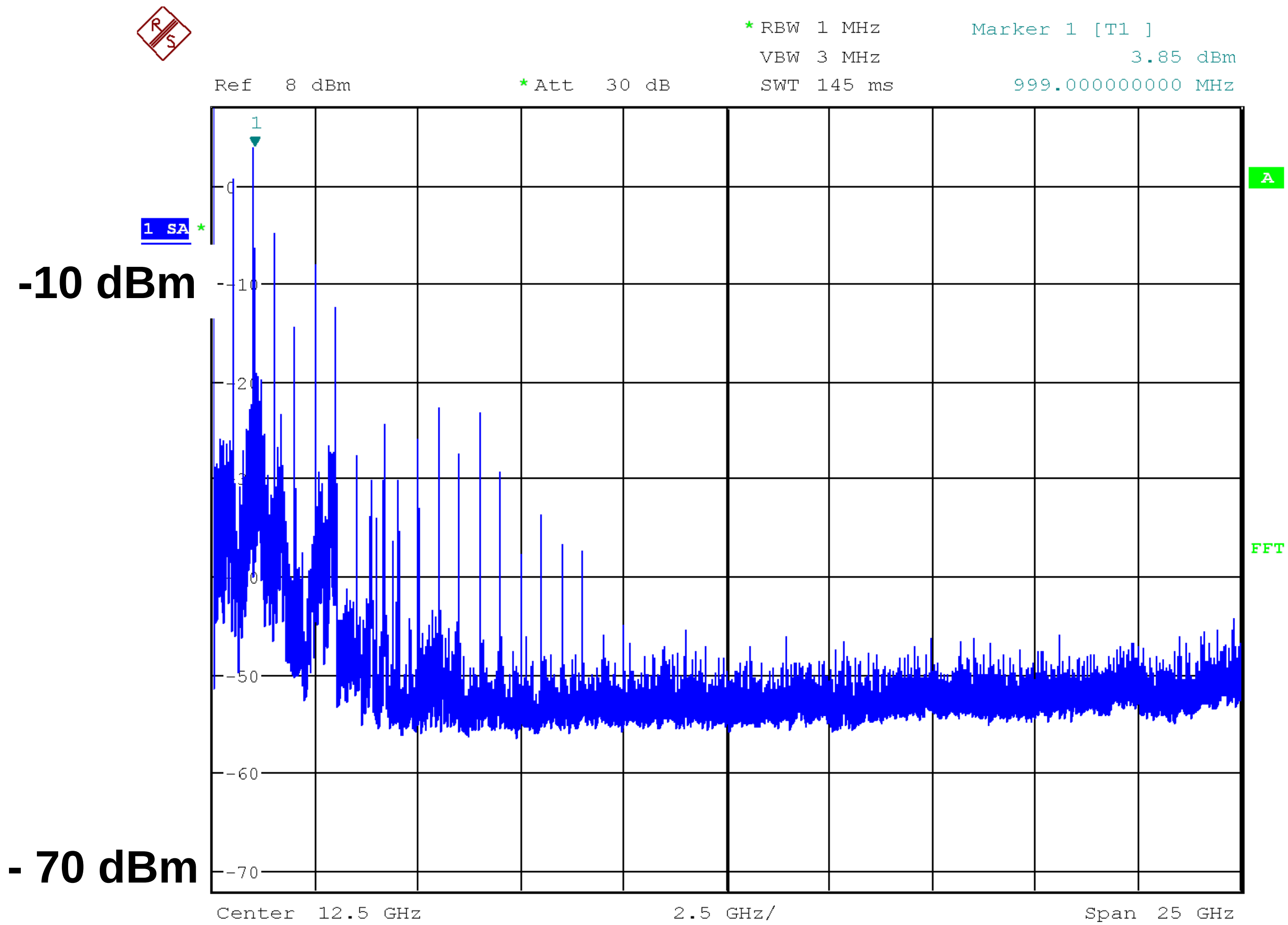
CsB long-term vacuum conditioning



- *– … goes on, but takes time*
- *– is interrupted by bursts mostly triggered by known changes in beam conditions, sometimes without clear correlation of burst incidence and exterior temperatures to bellow length:*



Signal spectra examples (300 mA standard fill pattern, 25 GHz)

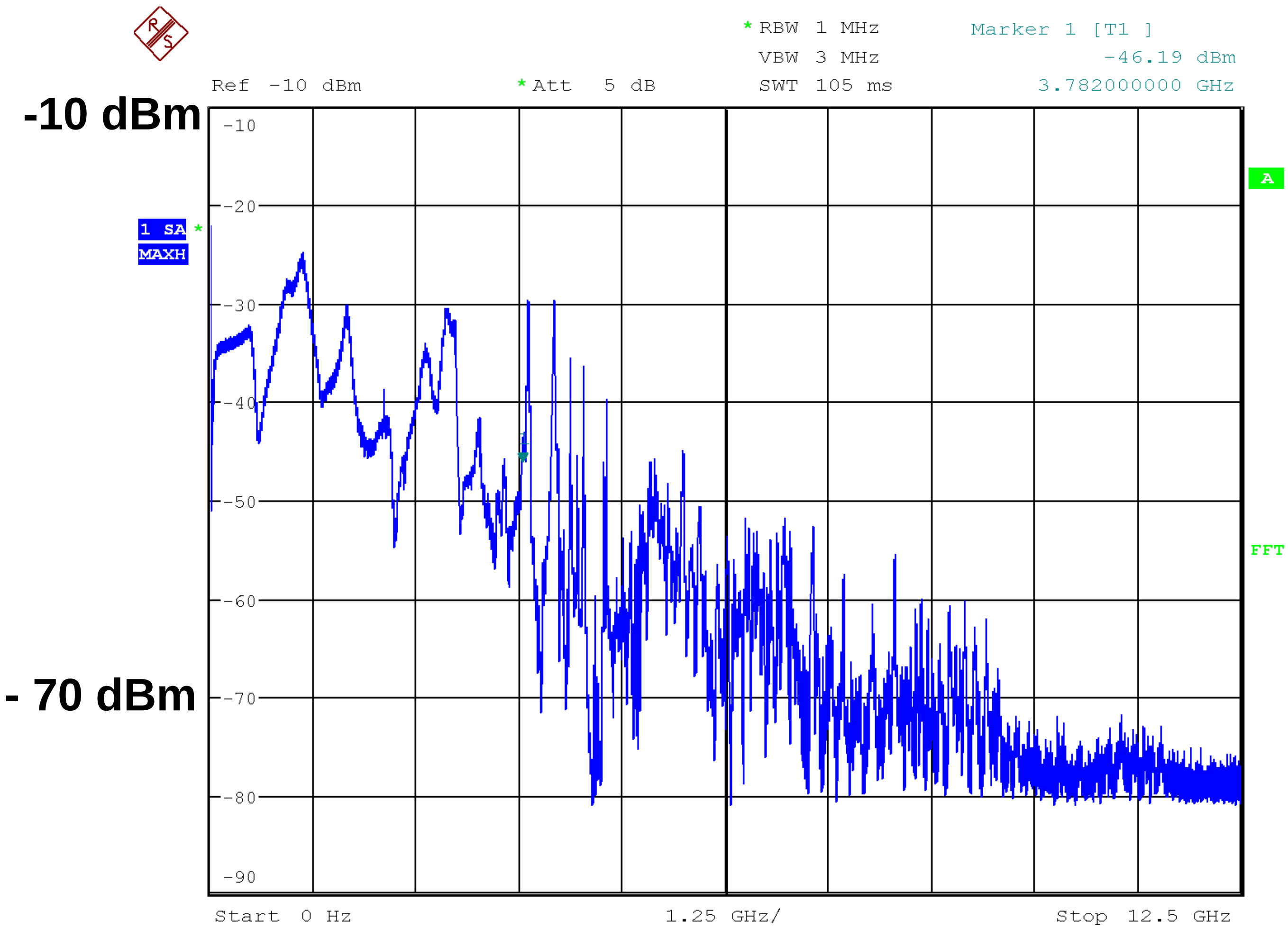


– *dominated by 500 MHz harmonics*

– *„envelope“ given by f $^{(-1/2)}$- cable damping, linear in log representation*

– *no disturbance of beam / no excessive heat dissipation on device*

Signal spectra examples (6 mA single bunch, 12.5 GHz)



– *fully populated, device-specific resonances*

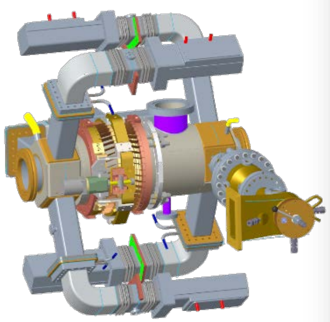
– *„envelope" given by f $^{(-1/2)}$- cable damping, linear in log representation*

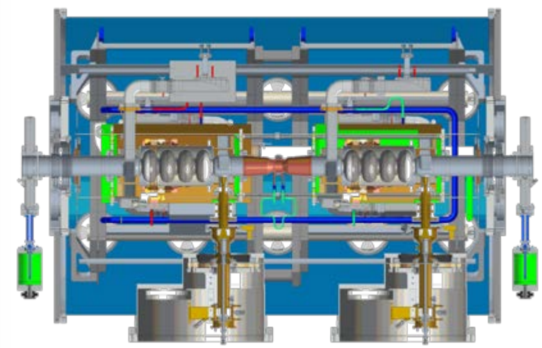
– *no disturbance of beam / no excessive heat dissipation on device*

4 cell, 1.5/1.75 GHz waveguide damped HOM cavities **(based on bERLinPro designs)**

1.8K cryo plant

Module design & system integration





2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025

tendering
cavities &
SSA transmitter &
couplers

installation &
commissioning
cryo-plant

prep. phase cryo-module
2 x 1.5 GHz
(assembly, module test, beam test)

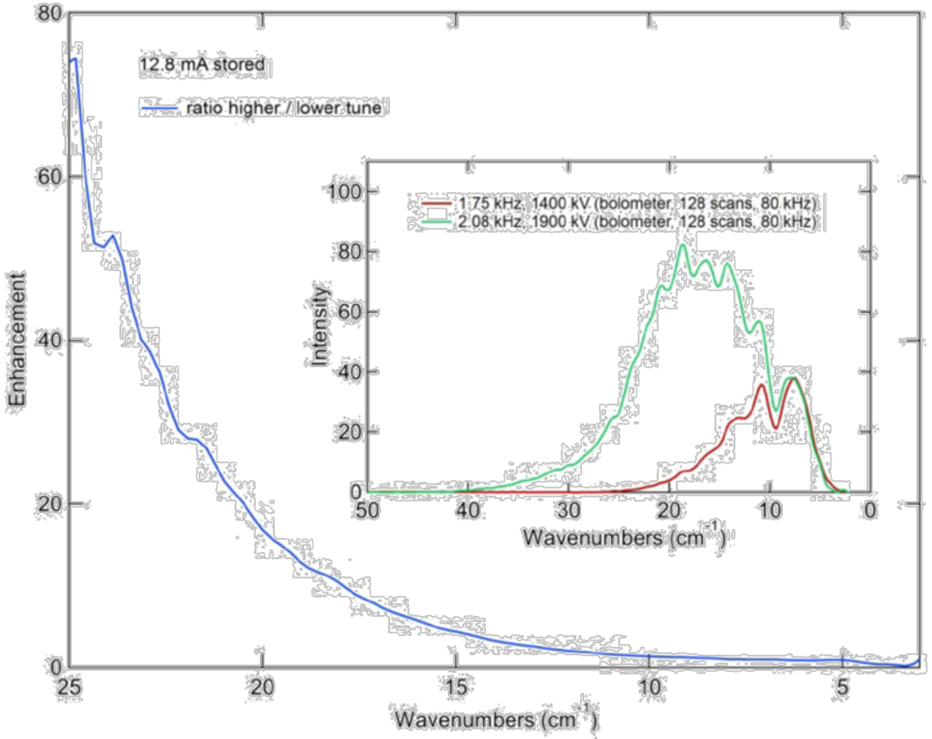
full BESSY VSR
2 x 1.5 GHz & 2 x 1.75 GHz
(assembly, test, user operation)

Installation of 2 x 4 cell 1.5 GHz cavity = 16 MV @ 1.5 GHz = 24 MV GHz
→ max. x 32 increase in gradient!

$$\sigma \propto \delta_0 \sqrt{\frac{E_0}{\omega_0} \cdot \frac{\alpha}{\omega_{rf} V_{rf}}} \qquad I \propto \alpha$$

max. reduction in pulse length → $^1/_{\sqrt{32}} = {}^1/_6$

e.g. 04/2018: BESSY II low-alpha test with 1.9 MV instead 1.4 MV ($\sqrt{^{1.4}/_{1.9}} = 0.85$)



BESSY VSR preparatory phase module can be used **in low-alpha mode** to dramatically improve performance.
3.4 ps rms → 0.6 ps rms

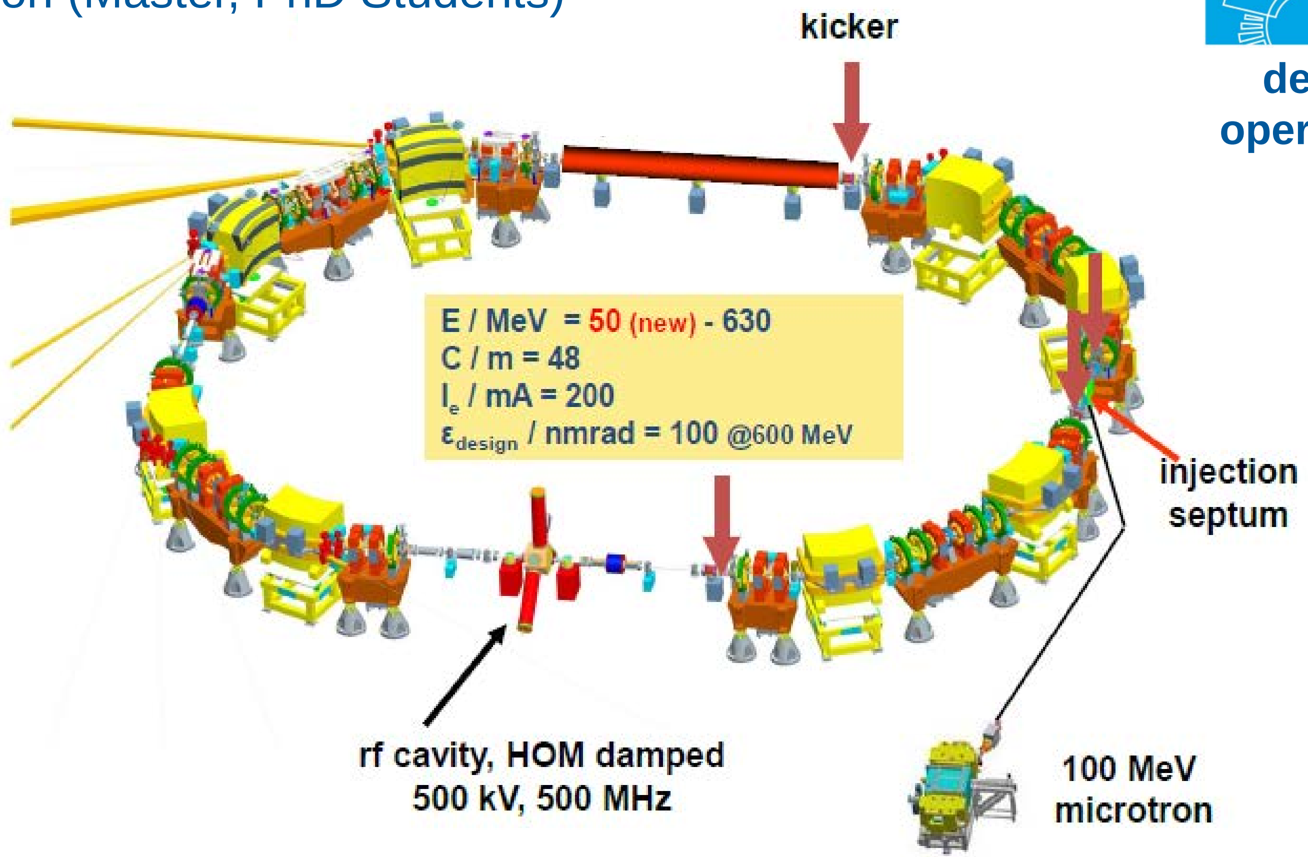
BESSY VSR preparatory phase module can be used to provide **~ ps pulse lengths** comparable to low-alpha operation, but **in standard user-optics.**

Metrology Light Source (MLS)

important test-bed for accelerator R&D
and education (Master, PhD Students)

owned by PTB

developed and operated by HZB

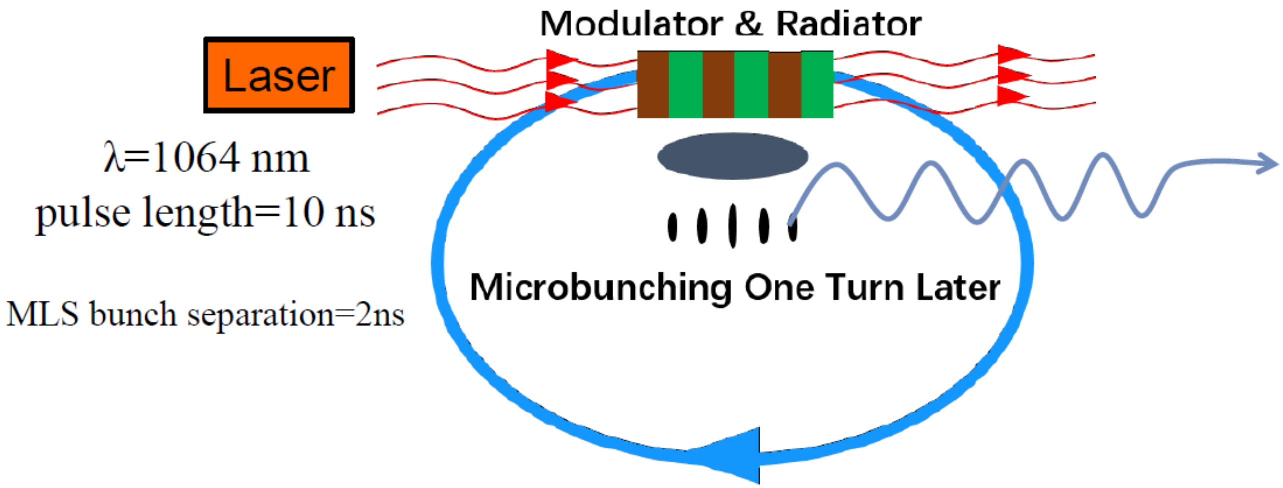


- metrology in the UV-EUV
- optimised for low-alpha operation
  (IR / THz generation)
- EUV reflectometry
  (next generation EUV lithography)

e.g. Proof of Principle Experiments
Steady State Microbunching schemes (SSMB)
SLAC, Tsinghua University, HZB, and PTB

Steady State Micro-Bunching = SSMB *(Daniel Ratner, Alex Chao)*

- Single pass microbunching or modified coherent harmonic generation:



we want to proof experimentally that **micro structures** generated by a **Laser driven energy modulation** inside an undulator at a resonant wavelength of 1064 nm lead to enhanced **coherent radiation** on the same undulator **one turn** (160 ns) **later**

First promising results achieved at MLS by a team of Tsinghua University, PTB and HZB. Publication under preparation.

Jörg Feikes, Ji Li, Aleksandr Matveenko, Yurij Petenev, Markus Ries / HZB
Deng Xiujie, Lixin Yan, Alex Chao / Tsinghua University
Arne Hoehl, Roman Klein / PTB

Thank you for your attention.