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STATUS OF BERLINPRO

The European Laboratory Directors Group Meeting and Accelerator R&D Workshop

06/07/24,
Brookhaven National Laboratory

A. Neumann for the bERLinPro team @SEALAB

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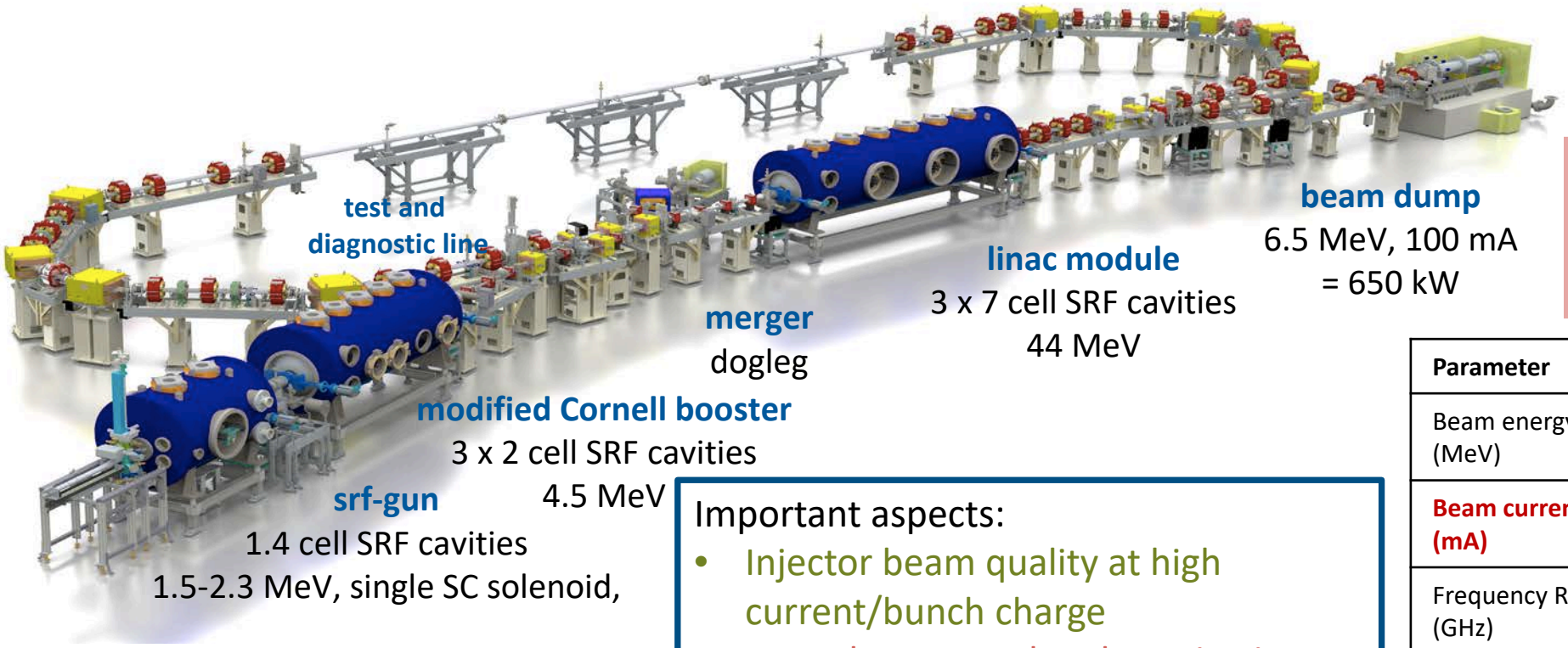
Evolution of bERLinPro

From 4th generation light source prototype (2011), via generic high intensity ERL prototype (2012-2020) towards *application driven* facility (today)



Single turn high intensity ERL
5 MW beam power
650 kW injector beam power

Important aspects:

- Injector beam quality at high current/bunch charge
- Beam loss control and monitoring → Radiation protection
- Beam break-up in main Linac
- Longitudinal control of beams for recovery process (low power margin)

Parameter	bERLinPro
Beam energy recirculator (MeV)	50
Beam current ERL mode (mA)	**100**
Frequency RF and Laser (GHz)	1.3
Normalized emittance (mm mrad)	**1 (< 0.6 in simulations)**
Bunch length (ps)	**< 2 (ERL mode), 100 fs @ 10 mA**
Beam losses	<< 10^{-5} @ 100 mA

Stages at bERLinPro

Presently installed facility

- Installed: 10-mA SRF gun + merger + recirculation + dump
- Installed: Proof-of-principle UED experiment

} CW photoinjector studies < 10 mA
Long-pulse injector studies < 100 mA

- Funded: Booster module. Produced but assembly required

— High-power beam studies (“long pulse”)

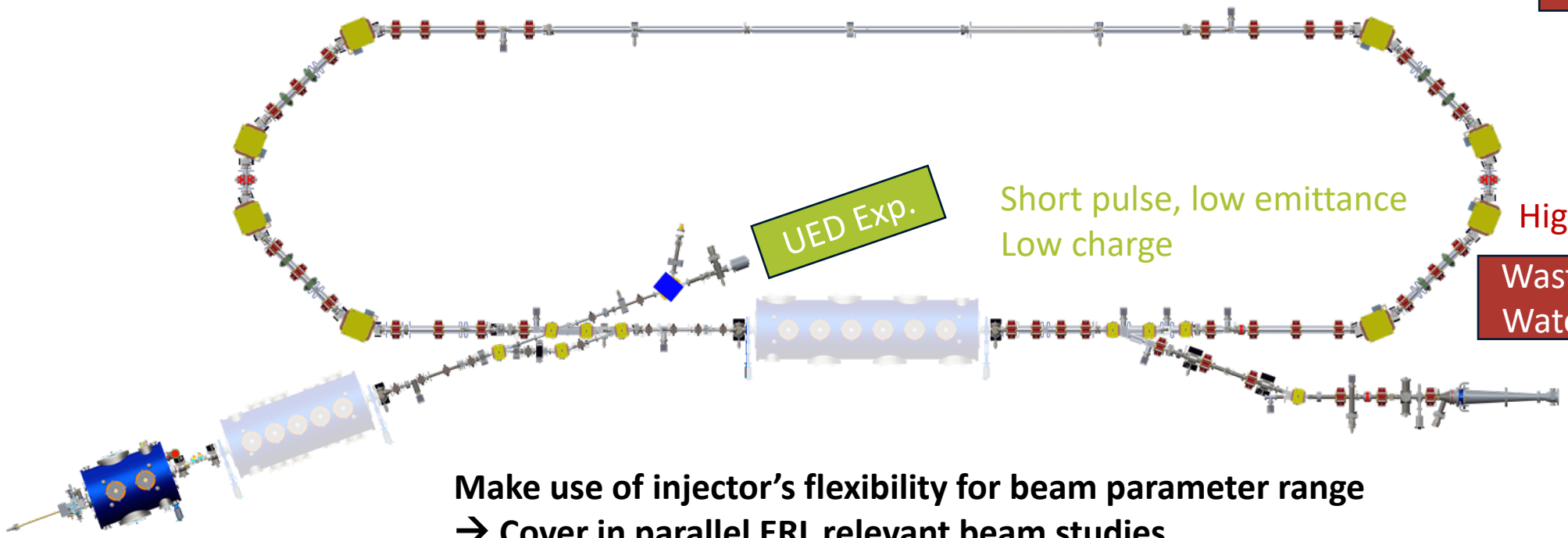
- Not funded: LINAC module
- Not funded: 100-mA class photoinjector

} High-power energy recovery
Energy-efficient RF operation

Stages at bERLinPro

Presently installed facility

Applications



Make use of injector's flexibility for beam parameter range
→ Cover in parallel ERL relevant beam studies

- Installed: 10-mA SRF gun + merger + recirculation + dump
- Installed: Proof-of-principle UED experiment
- Planned: Waste water treatment demonstrator
- Funded: Booster module. Produced but assembly required
- Not funded: LINAC module
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CW photoinjector studies < 10 mA
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High-power energy recovery
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Stages at bERLinPro

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Presently funded facility

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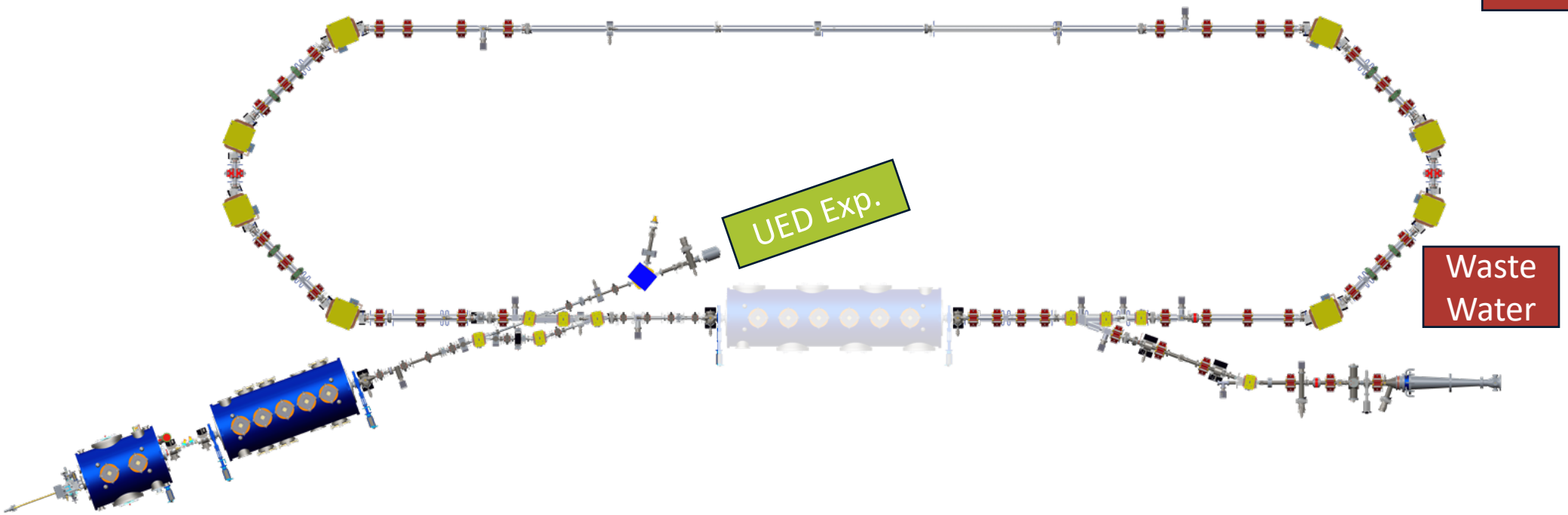

- Installed: 10-mA SRF gun + merger + recirculation + dump
- Installed: Proof-of-principle UED experiment
- Planned: Waster water treatment demonstrator
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- Not funded: LINAC module
- Not funded: 100-mA class photoinjector

CW photoinjector studies < 10 mA
Long-pulse injector studies < 100 mA

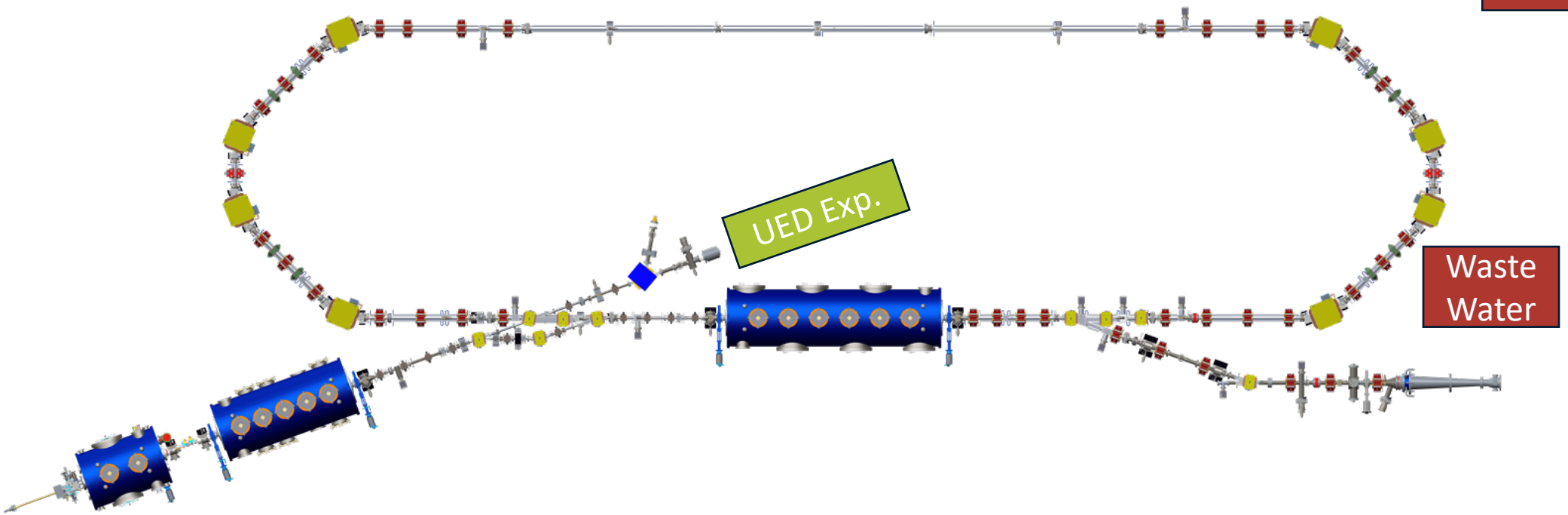
High-power beam studies (“long pulse”)

High-power energy recovery
Energy-efficient RF operation

Stages at bERLinPro

Full program (partially funded)

Applications



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Energy-efficient RF operation

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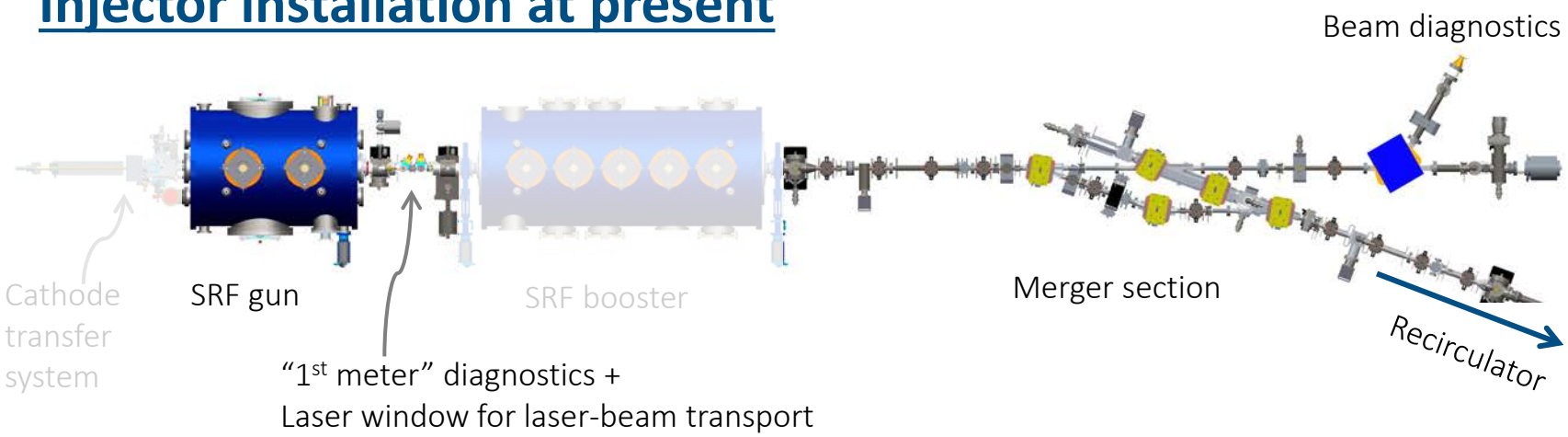
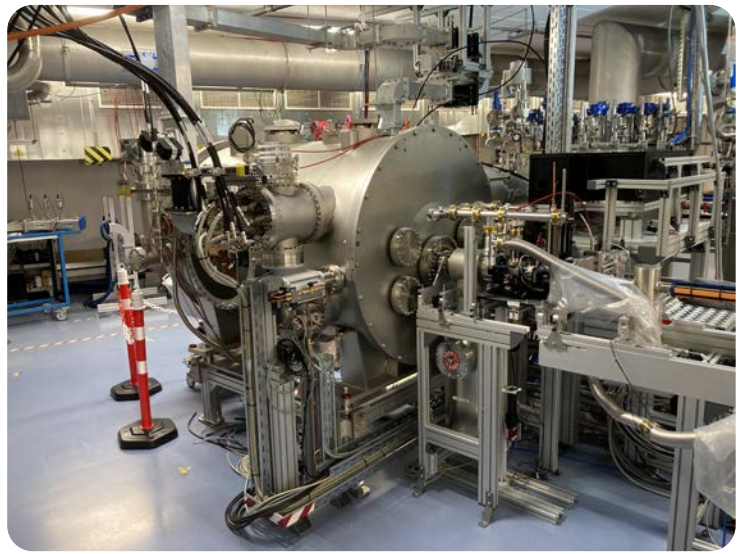
Status of bERLinPro@SEALAB

Injector installation at present





- SRF photo-injector and diagnostics ready for commissioning
- Final preparation of cathode-laser beam transport
- 1.3 GHz laser demonstrated 23 W CW → sufficient for 100 mA @ 2.5% QE
- **1st Cool-down in Jan. 2024** → prerequisite for rad. permit application for RF operation
- **RF test of photoinjector Q2 2024** → prerequisite for rad. permit application for beam operation
- Cathode-transfer unit ready for installation following RF test
- **Beam operating permit expected Q3 2024 → First beam from SRF Gun around 10-11/2024**
- Start of Booster assembly H1/2024 (all parts in house)

Six+ month delay due to severe HZB cyber attack

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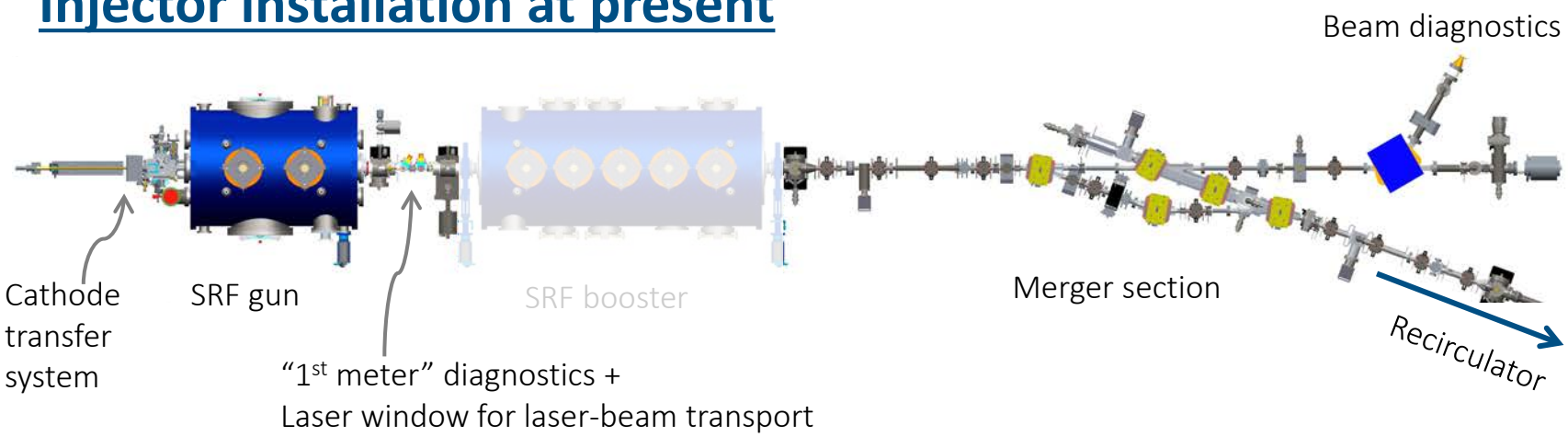

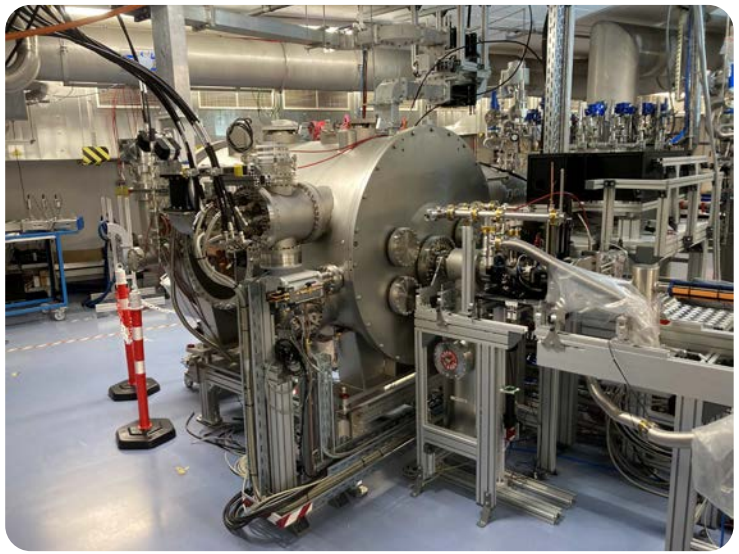

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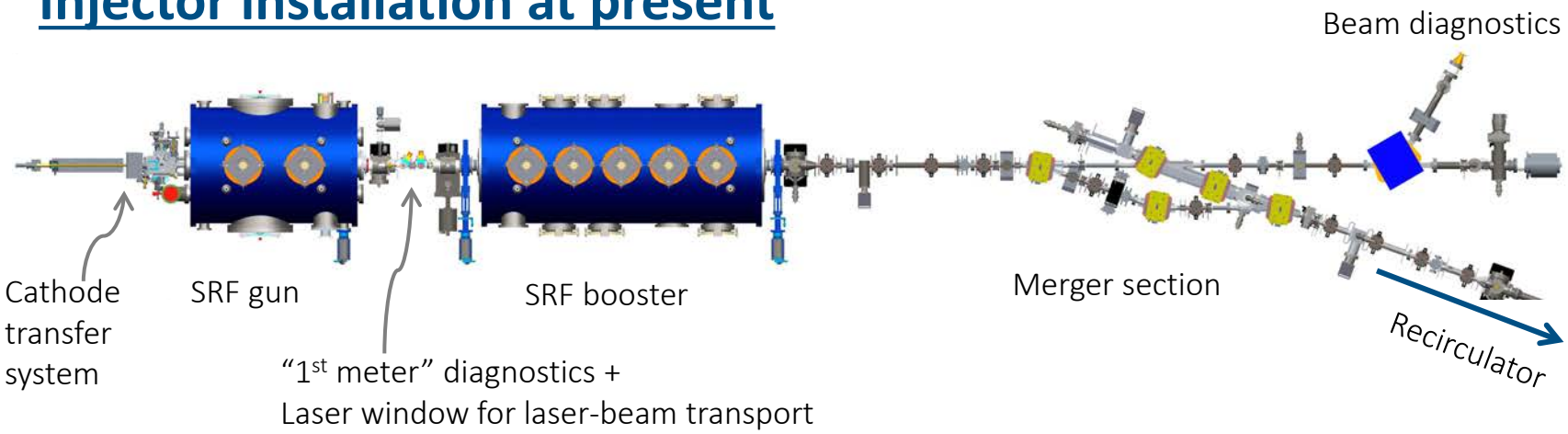

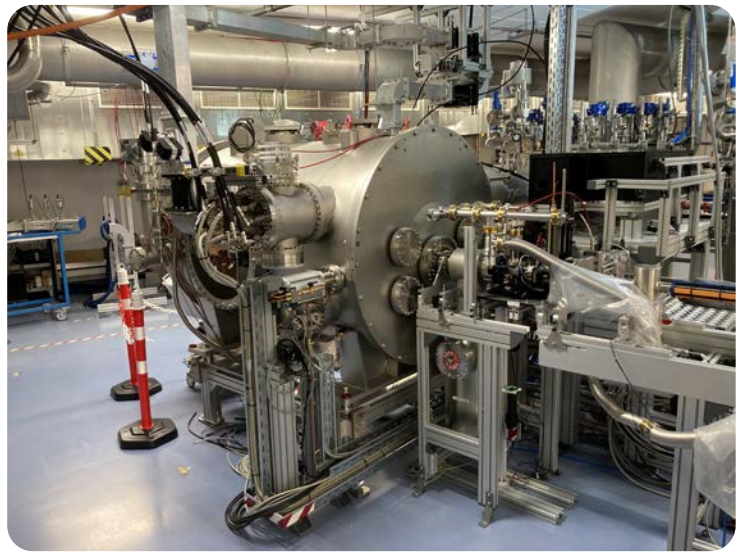

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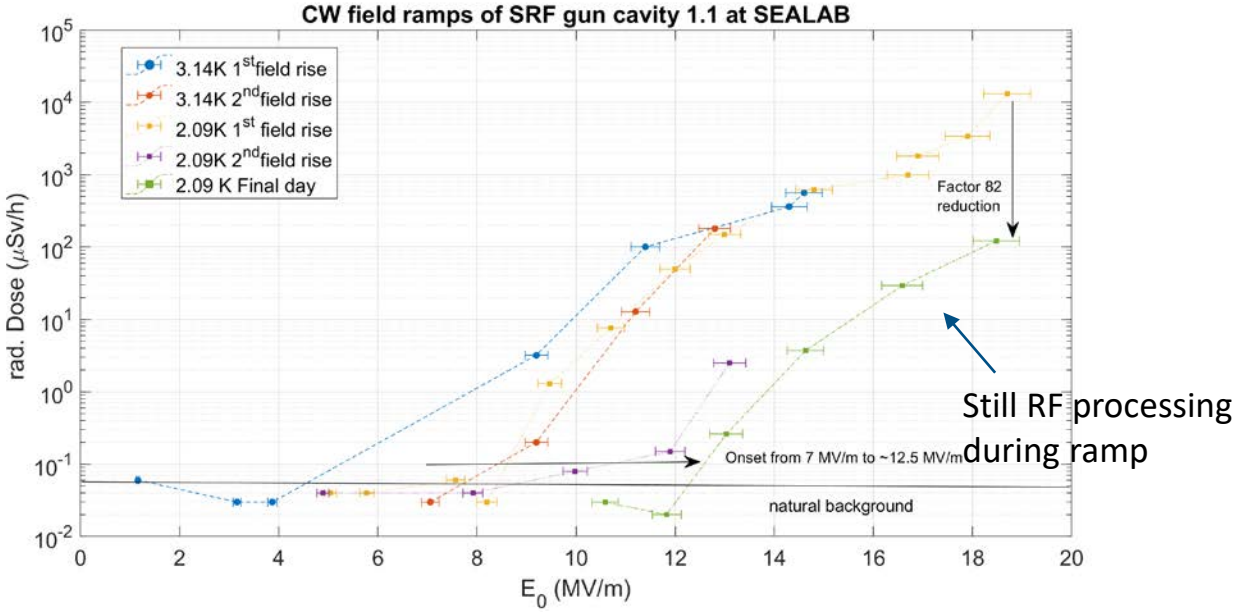
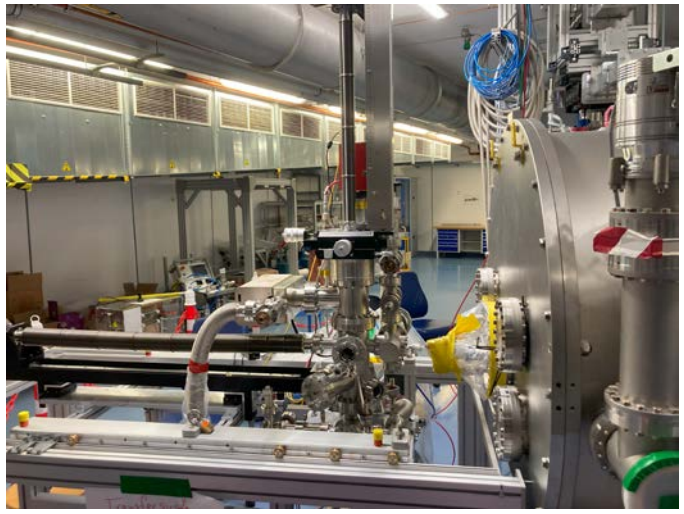
Current activities



- Successful RF test, beam energies up to 2.1 MeV → there is room for progress
- Laser system, diagnostics, beam transport optics, beam loss monitoring (several systems) installed and ready
- Cathode transfer system ready



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bERLinPro@SEALAB injector studies

Parameter	Injector / UED	ERL
Beam energy (MeV)	6.5 – 10 / 2	50
Max. average current (mA)	10 / 0.0025	100
Bunch charge (pC)	0.05 – 400	77
RF Frequency (MHz)	1300	1300
Norm. Emittance (mm mrad)	0.6 / 0.03	1 (0.6)
RMS bunch length (ps)	0.02 – 2	2 (0.1)

Funded: SRF gun/booster ops & UED mode

Not funded: 100-mA CW gun cavity + couplers + LINAC module (existing design)

Medium-power gun (20kW) / booster program

- Explore full parameter space of SRF injector @ I_b < 10 mA
- 100 mA can be potentially studied in long-pulse* regime
- Bunch charge up to 0.5 nC with a high QE cathode
- Proof of cathode exchange concept, test of more robust cathode materials: Replace Cs by Na
- Studies of beam loss scenarios by dark current or beam halo formation by bunch tails
- Propagation of beam and unwanted beam from injector to dump
- Beam loss monitoring and machine protection concepts
- High dynamic range diagnostic concepts for low-current start-up to high-power operation (< µA → mA → 100 mA*)
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Improve efficiency of ERLs

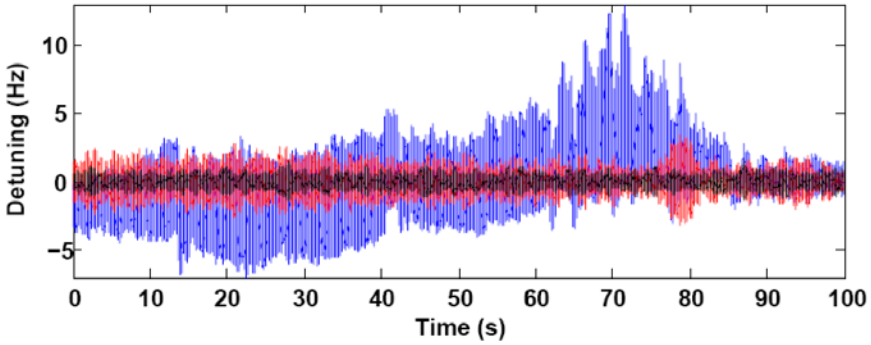
iSAS

Funded: Demonstrate efficiency gains with cavity in HoBiCaT test cryomodule

Funded: Integrate into bERLinPro LINAC module design

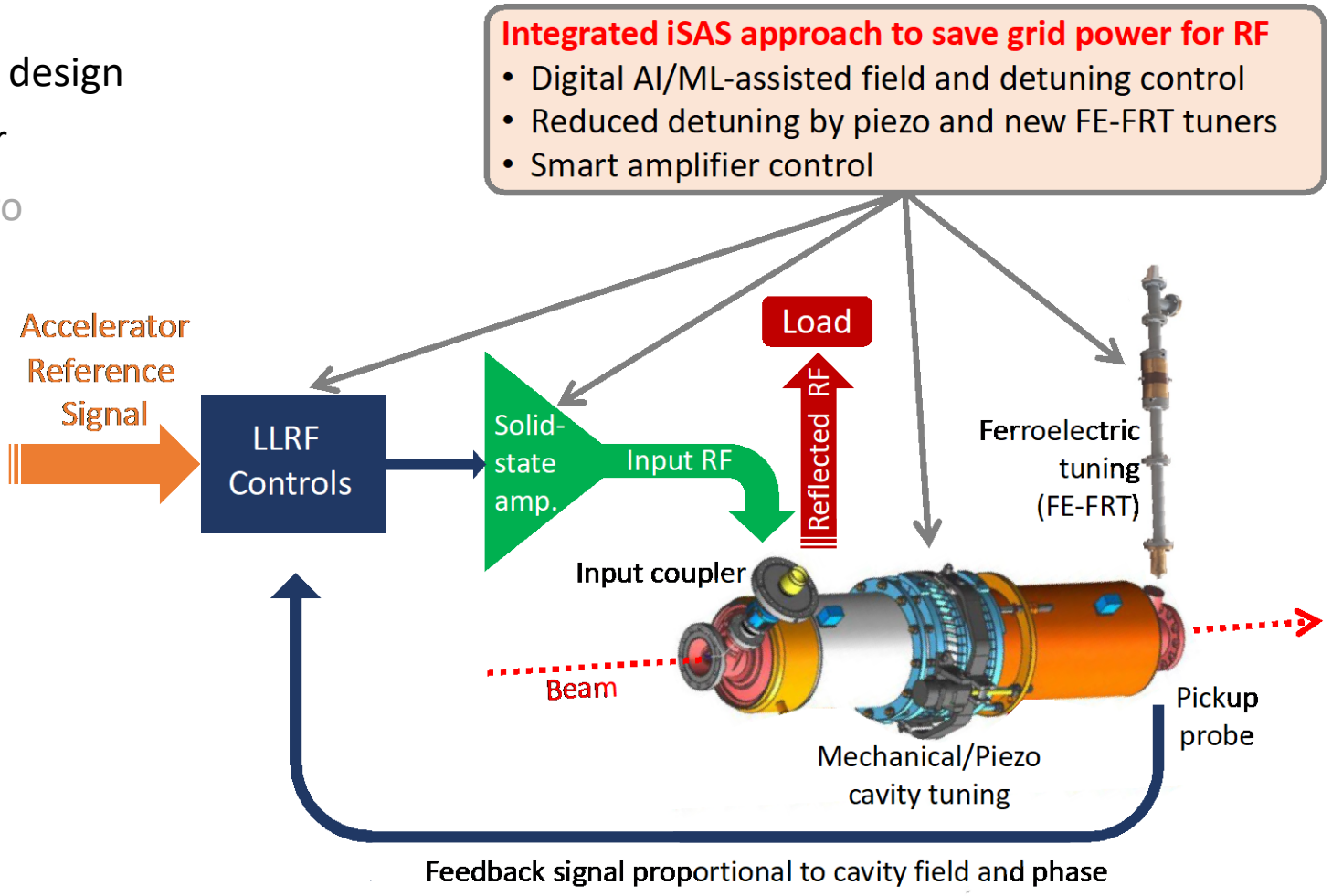
Funded: LLRF (AI/ML) tests at bERLinPro injector

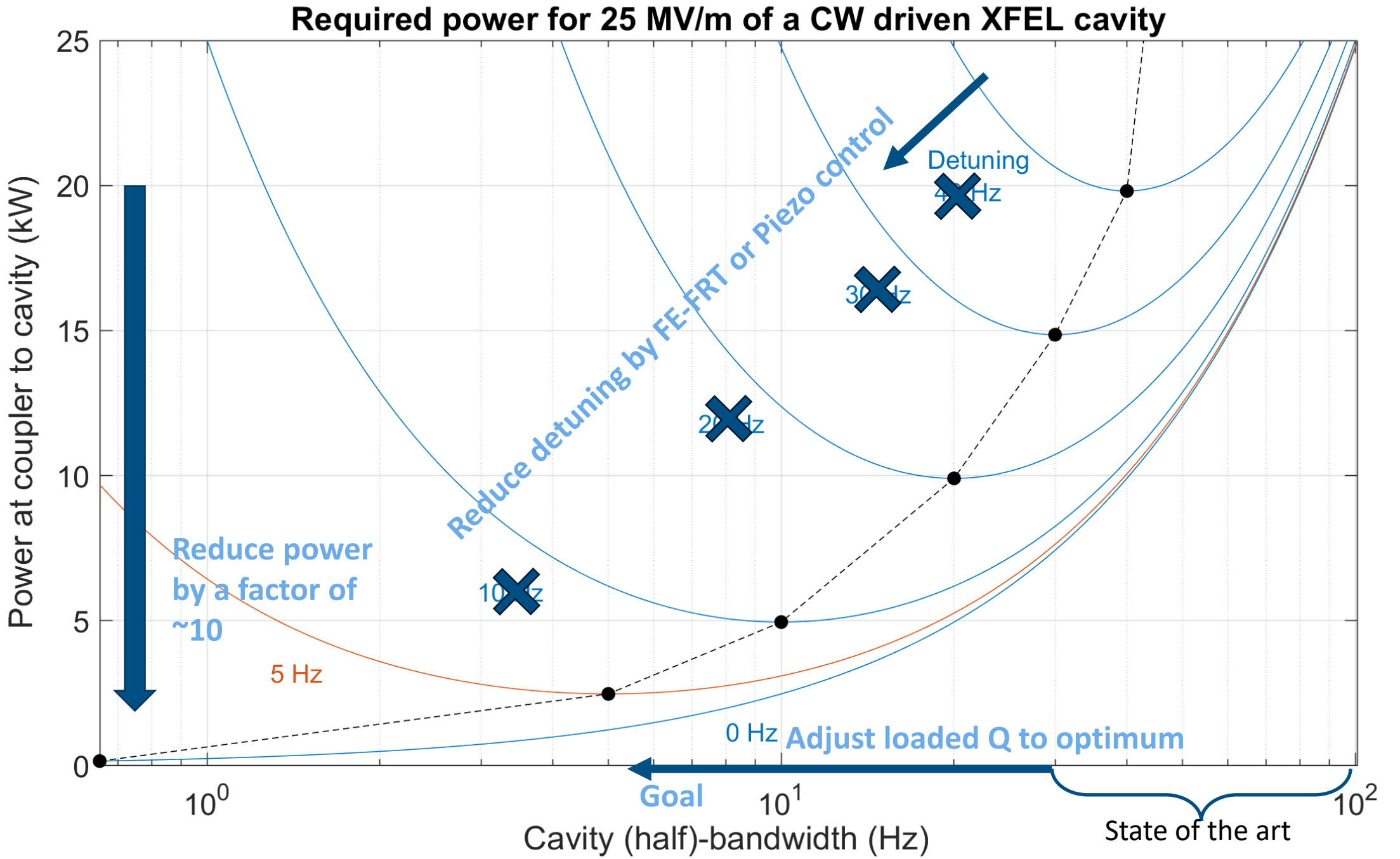
Not funded: Demonstrate operation in bERLinPro



From A. Neumann et al.,
Phys. Rev. ST Accel. Beams **13**, 082001 (2010)

Compensation of disturbances in the acoustic frequency regime




Required power for 25 MV/m of a CW driven XFEL cavity
Power at coupler to cavity (kW)
25
20
15
10
5
0
10^0
10^1
10^2
Cavity (half)-bandwidth (Hz)
Detuning
Reduce detuning by FE-FRT or Piezo control
Reduce power
by a factor of
~10
5 Hz
0 Hz
Adjust loaded Q to optimum
Goal
State of the art

Improve efficiency of ERLs

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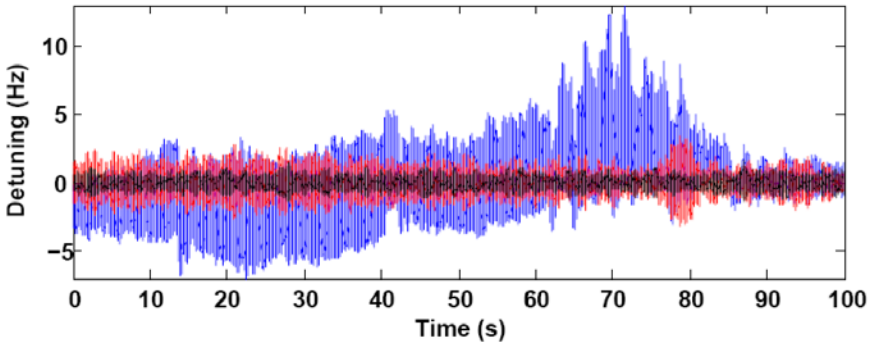

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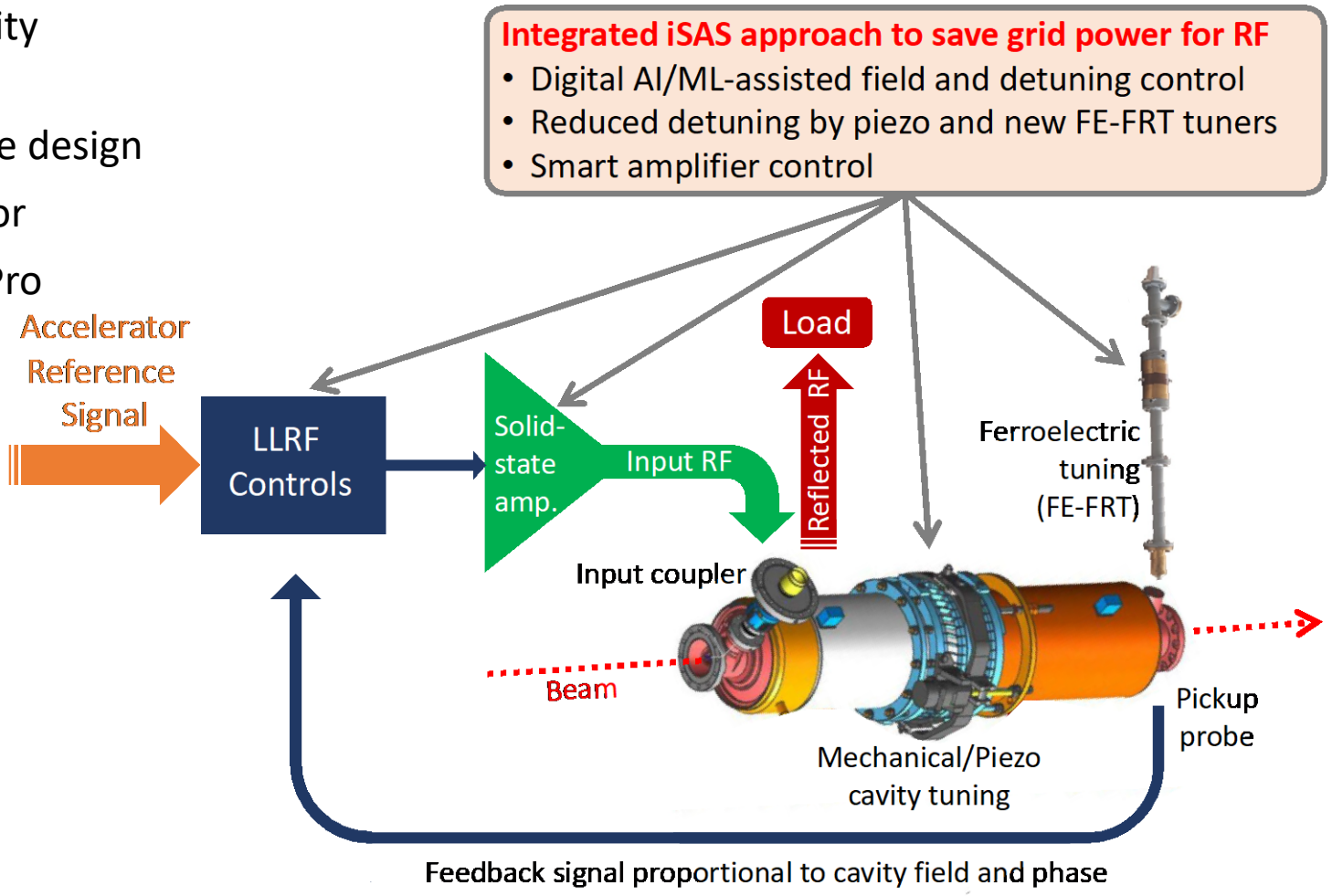

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement No 101131435

A rough 2024 schedule

RF operation permit

Cooldown 2K

RF test 2K

Dry run injector

January | February | March | April | May | June

- Setup Laser
- Setup transfer system
- Check for beam condition: FOMS, magnets,…

- LLRF ready
- High power RF ready
- Cryo ready
- Module diagnostics
- PSI operational
- Tcav ready

- Readiness cathode transfer system, cathode laser
- Beamline magnets, steerer magnets
- Diagnostics: FOMs, Faraday Cups Camera tools, beam loss monitoring
- Control system fully implemented for needed devices, MPS functional

Ongoing

Beam operation permit

Beam operation injector

July | August | September | October | November | December

- Commissioning program beam ready, first measurement applications

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Thank you!

If there is time left, questions are welcome or contact me at

Axel.Neumann at helmholtz-berlin.de

Thanks and acknowledgements to all partners, who contributed to this project

BROOKHAVEN NATIONAL LABORATORY
cnrs
ISAS
MAX-BORN-INSTITUT
Jefferson Lab
Thomas Jefferson National Accelerator Facility
Universität Rostock Traditio et Innovatio
KEK
HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION
JOHANNES GUTENBERG UNIVERSITÄT MAINZ
The Andrzej Sołtan Institute for Nuclear Studies
PL-05400 Otwock-Świerk
Poland
CERN
technische universität dortmund
Fraunhofer IIS
HZDR

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