Applications of the SRF photoinjector of SEALAB

Thorsten Kamps (Helmholtz-Zentrum Berlin, Humboldt-Universität zu Berlin)

presented at the ERL Workshop 2024, KEK, Tsukuba, Japan

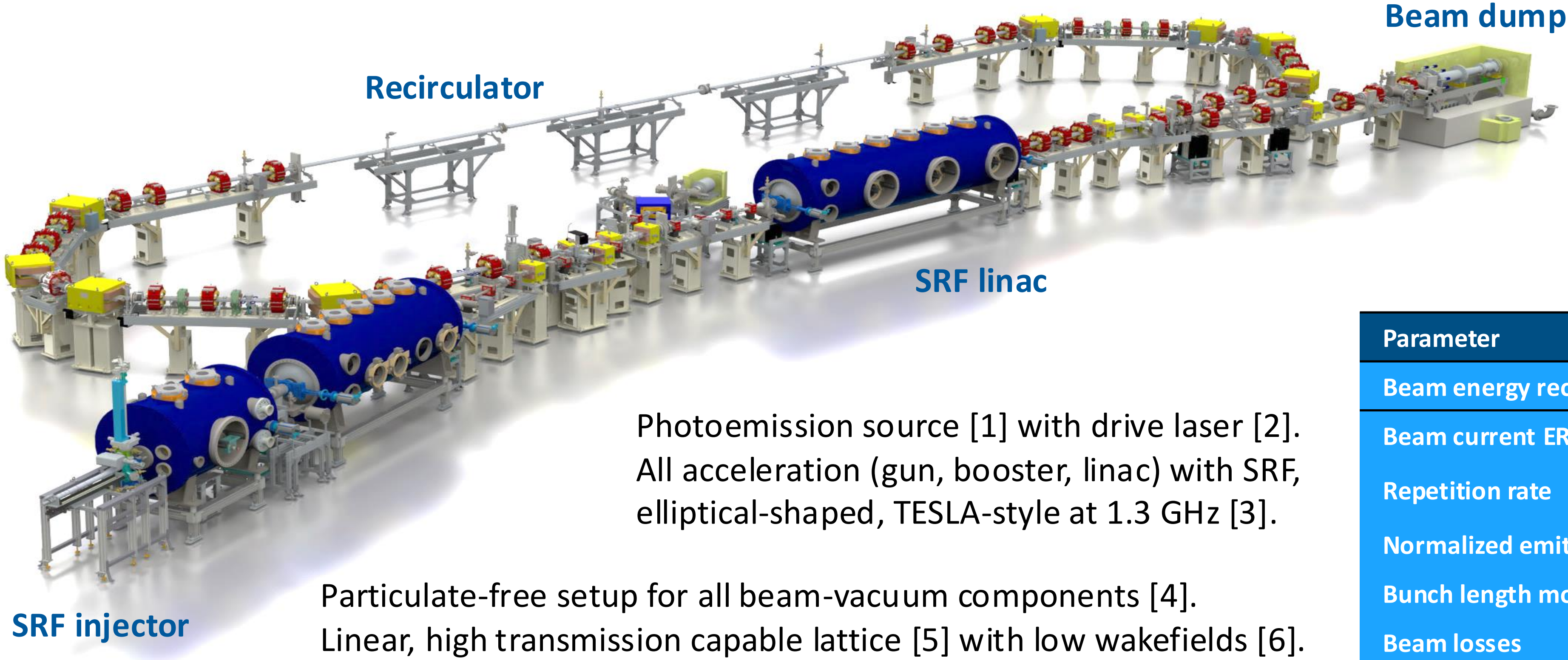
26.09.2024

brighter faster smarter


Helmholtz-Zentrum Berlin, Adlershof campus
MLS
Bessy II
SEALAB/bERLinPro


bERLinPro
ERL Science Factory
MESSER
HZB

bERLinPro – Aiming at high brightness, high average current beams



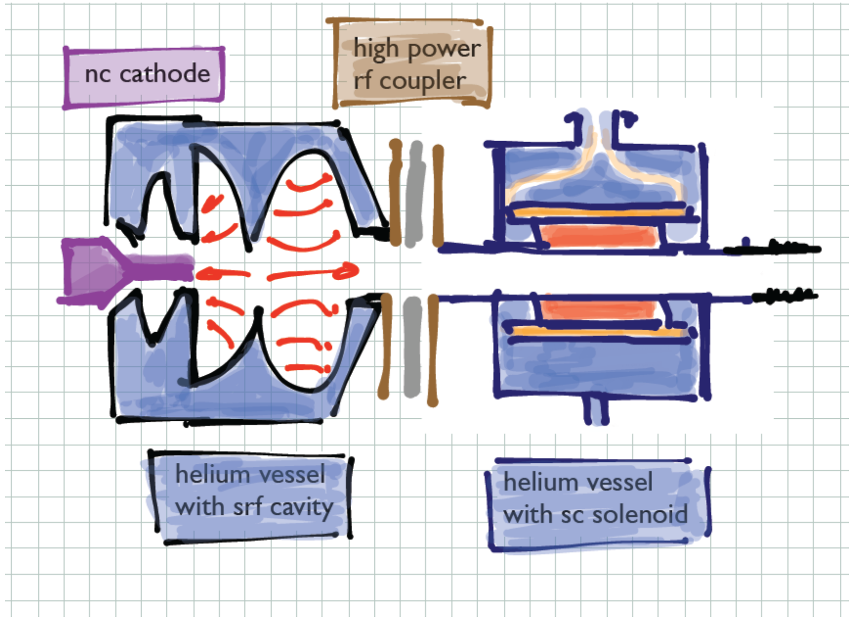
Photoemission source [1] with drive laser [2].
All acceleration (gun, booster, linac) with SRF, elliptical-shaped, TESLA-style at 1.3 GHz [3].

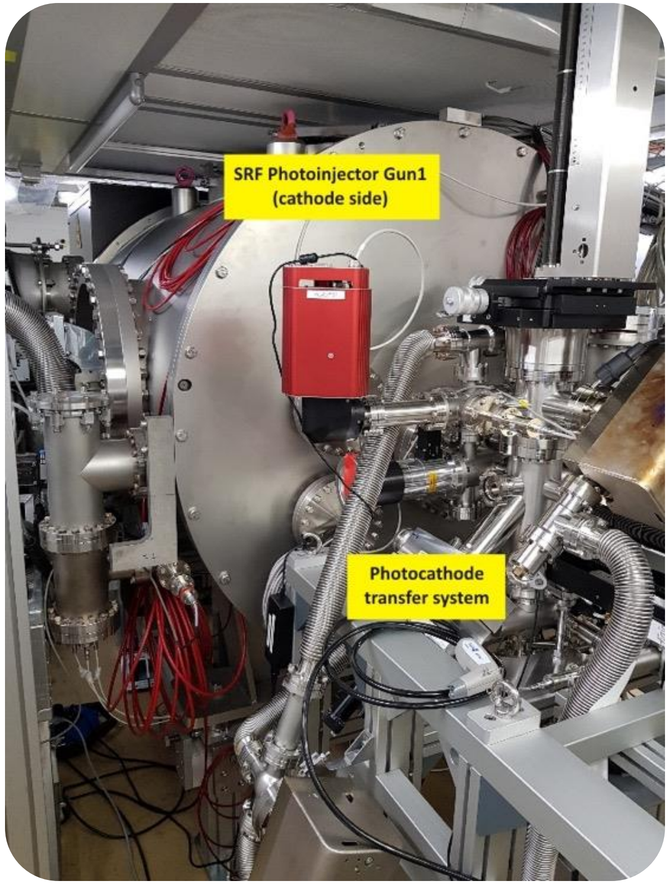
Particulate-free setup for all beam-vacuum components [4].
Linear, high transmission capable lattice [5] with low wakefields [6].
Diagnostics tools for long. and trans. phase space measurements [7]

Parameter	Goal
Beam energy recirculator	50 MeV
Beam current ERL mode I/II	5 mA / 100 mA
Repetition rate	1.3 GHz
Normalized emittance	1 µm
Bunch length mode I/II	100 fs / 2ps
Beam losses	<< 10^{-5} @ 100 mA

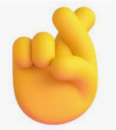
[1] M. A. H. Schmeisser, J. Kühn, S. Mistry, PRAB 21, 113401 2018
[2] G. Klemz, I. Will, in preparation
[3] A. Neumann, SRF 2015
[4] E. Sharples, et al., Operating SRF in a ‘dirty’ machine workshop, 2017
[5] M. Abo-Bakr, B. Kuske, A. Matveenko, IPAC 2013, IPAC 2018
[6] H.-W. Glock, IPAC 2015
[7] G. Kourkafas, LINAC 2019

Focal point SRF gun development

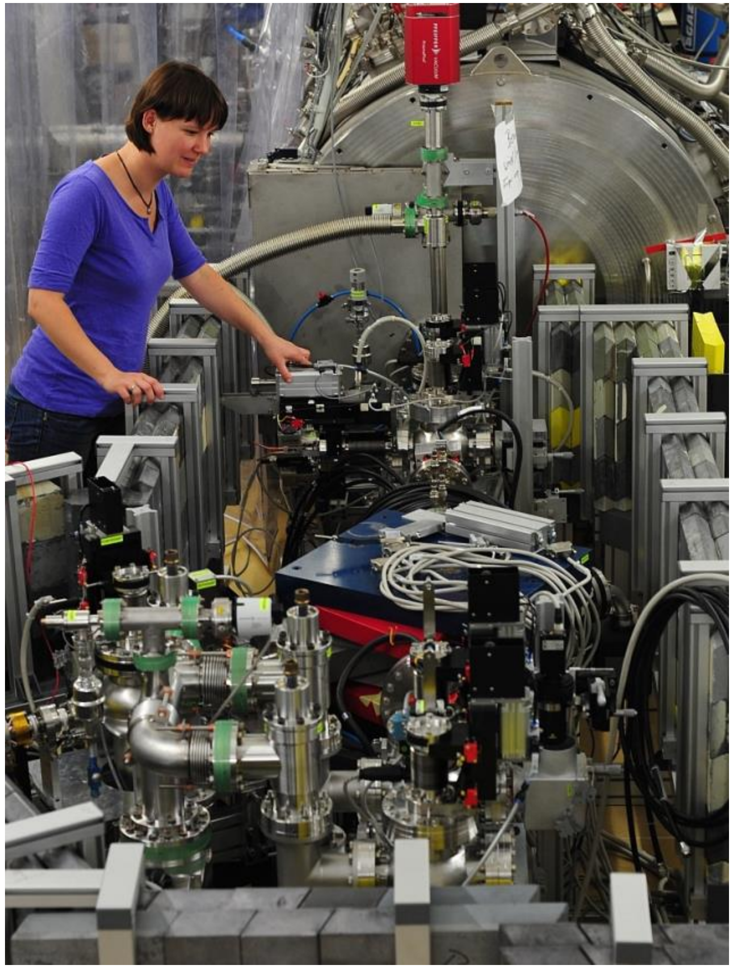




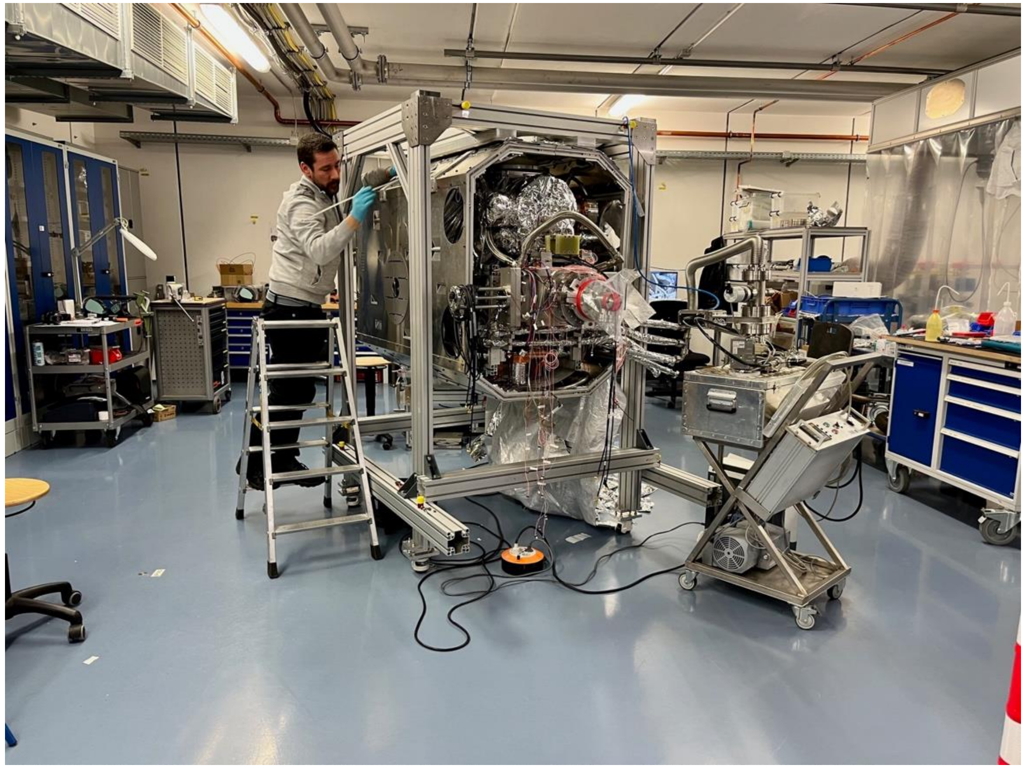
SRF gun development at HoBiCaT (first beam April 2011) and GunLab (first beam Dec 2018), now moving to SEALab (hope for Oct/Nov 2024)

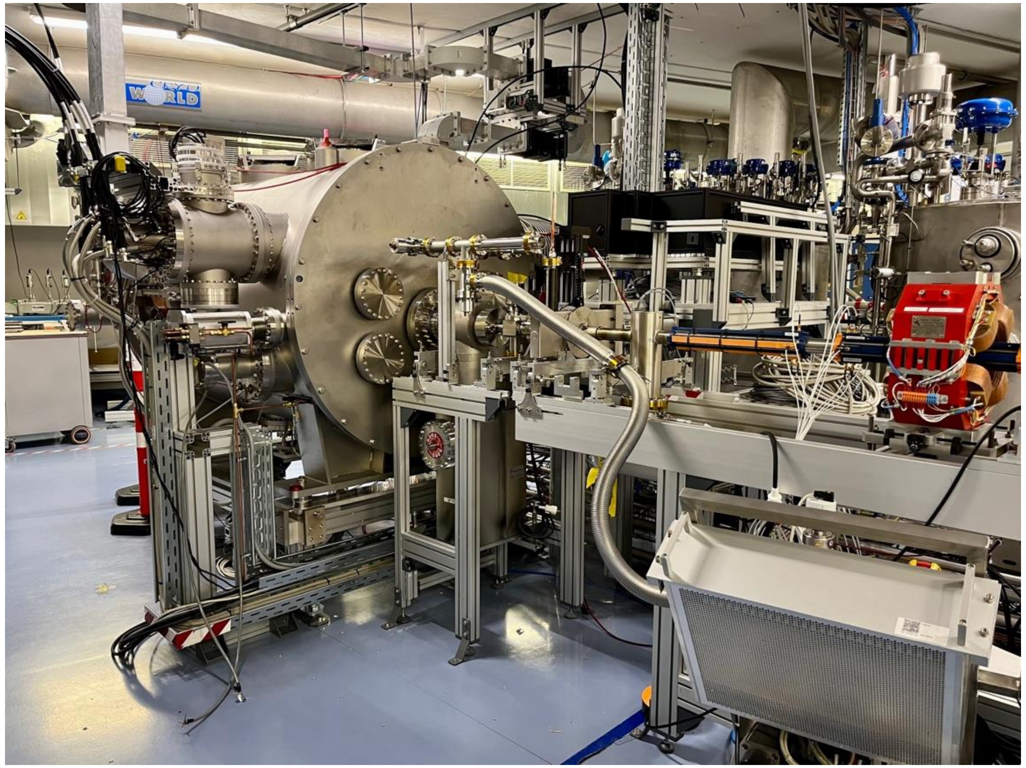


see IPAC 2023-TUPL160 and references therein

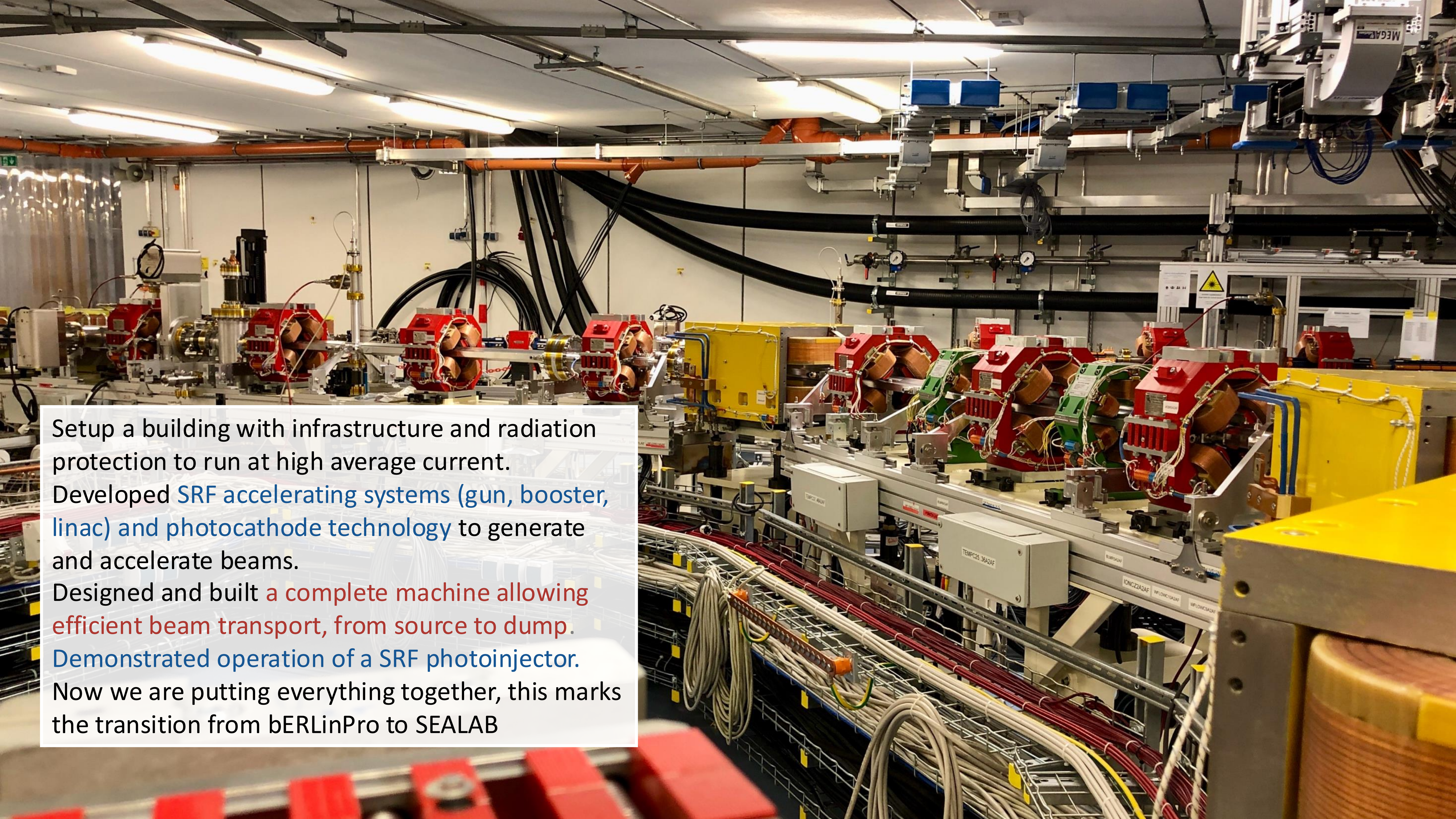


Setting up the SRF photoinjector in 2023





First cooldown in Oct 2023 ✓
SRF gun ready for operation in Sep 2024 ✓
First beam with SRF gun in Nov 2024
Complete SRF injector available in 2025



Setup a building with infrastructure and radiation protection to run at high average current.

Developed SRF accelerating systems (gun, booster, linac) and photocathode technology to generate and accelerate beams.

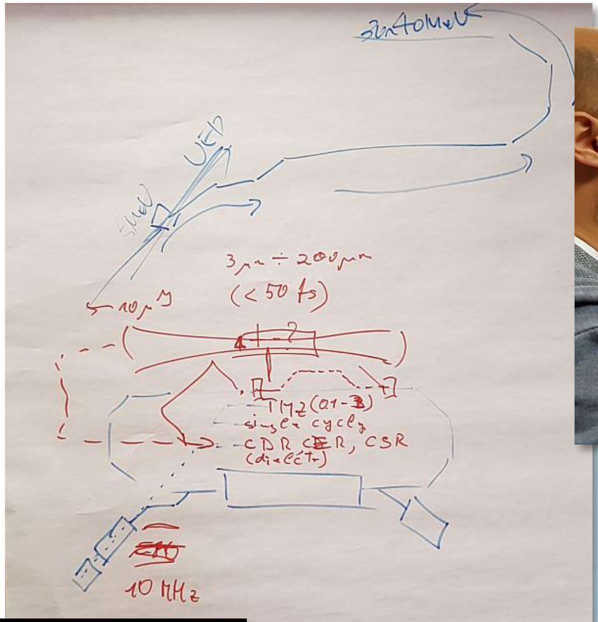
Designed and built a complete machine allowing efficient beam transport, from source to dump.

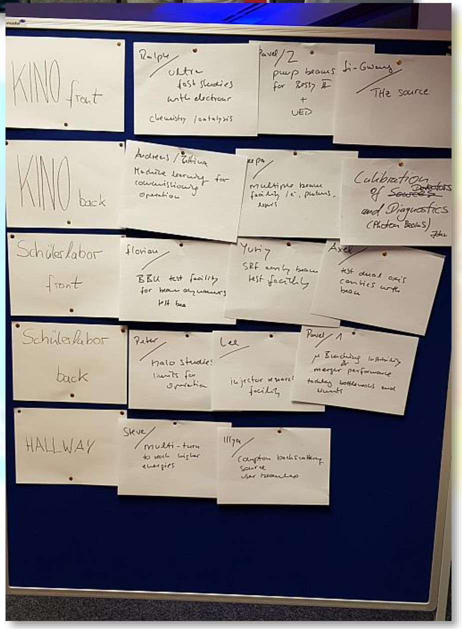
Demonstrated operation of a SRF photoinjector.

Now we are putting everything together, this marks the transition from bERLinPro to SEALAB

From **bERLinPro...**
ERL Science Factory

bERLinProCamp 2019 as satellite workshop to ERL 2019 in Berlin





arXiv:1910.00881v1 [physics.acc-ph] 2 Oct 2019

Scientific Opportunies for bERLinPro 2020+,
Report with Ideas and Conclusions from bERLinProCamp 2019

Thorsten Kamps,[1,2] Michael Abo-Bakr,[1] Andreas Adelmann,[3] Kevin Andre,[4] Deepa Angal-Kahn,[5] Felix Armborst,[1] Andre Arnold,[6] Michaela Arnold,[7] Raymond Amador,[2] Stephen Benson,[8] Yulia Choporova,[9] Illya Drebot,[10] Ralph Ernstdorfer,[11] Pavel Evtushenko,[6] Kathrin Goldammer,[12] Andreas Jankowiak,[1,2] Georg Hoffstätter,[13] Florian Hug,[14] Ji-Gwang Hwang,[1] Lee Jones,[5] Julius Kühn,[1] Jens Knobloch,[1] Bettina Kuske,[1] Andre Lampe,[15] Sonal Mistry,[1] Tsukasa Miyajima,[16] Axel Neumann,[1] Nora Norvell,[17] Yuriy Petenev,[1] Gisela Pöplau,[18] Houjon Qian,[19] Hiroshi Sakai,[16] Olaf Schwarzkopf,[1] John Smedley,[20] Yegor Tamachevich,[1] Sebastian Thomas,[14] Jens Völker,[1] Paul Volz,[1] Erdong Wang,[21] Peter Williams,[5] and Daniela Zahn[22]

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4) *CERN, Geneva, Switzerland*
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6) *Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany*
7) *Technische Universität Darmstadt, Darmstadt, Germany*
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11) *Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany*
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18) *Universität zu Lübeck, Lübeck, Germany*
19) *Deutsches Elektronen-Synchrotron, DESY, Zeuthen Site, Zeuthen, Germany*
20) *Los Alamos National Laboratroy, Los Alamos, New Mexico, USA*
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22) *Fritz-Haber Institut, FHI-MPG, Berlin, Germany*

(Dated: 3 October 2019)

The Energy Recovery Linac (ERL) paradigm offers the promise to generate intense electron beams of superior quality with extremely small six-dimensional phase space for many applications in the physical sciences, materials science, chemistry, health, information technology and security. Helmholtz-Zentrum Berlin started in 2010 an intensive R&D programme to address the challenges related to the ERL as driver for future light sources by setting up the bERLinPro (Berlin ERL Project) ERL with 50 MeV beam energy and high average current. The project is close to reach its major milestone in 2020, acceleration and recovery of a high brightness electron beam.

The goal of bERLinProCamp 2019 was to discuss scientific opportunities for bERLinPro 2020+. bERLinProCamp 2019 was held on Tue, 17.09.2019 at Helmholtz-Zentrum Berlin, Berlin, Germany. This paper summarizes the main themes and output of the workshop.

CONTENTS

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

Exotics
Dark matter search
Isotope production
EUV facility tests

Training and education for accelerator physics and technology

Compact accelerator for high power electron beam treatment

ERL / Gun test acc for beam tests with impedance sections, undulators, …

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

...to **SEALab**

SustainablE Accelerator and applications Lab

HZB Helmholtz Zentrum Berlin

HELMHOLTZ MT ARD

ATHENA

Hi ACTS

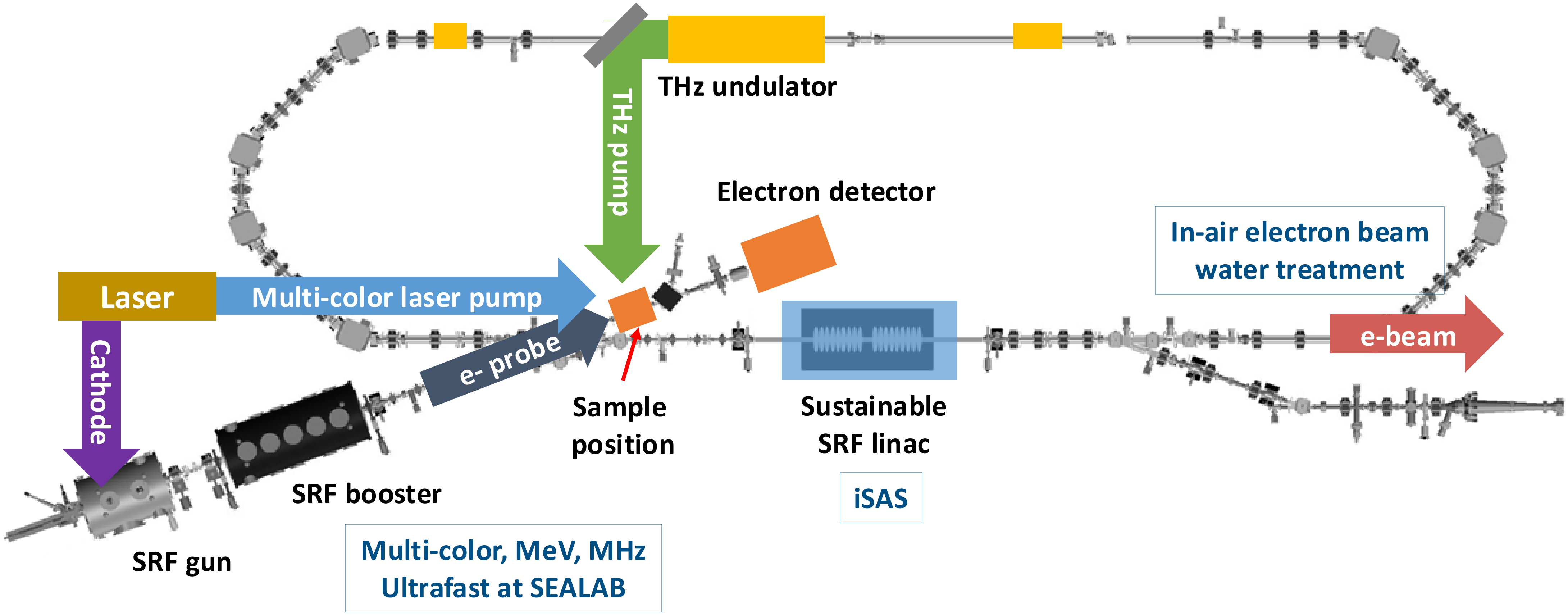
iSAS

DFG Deutsche Forschungsgemeinschaft

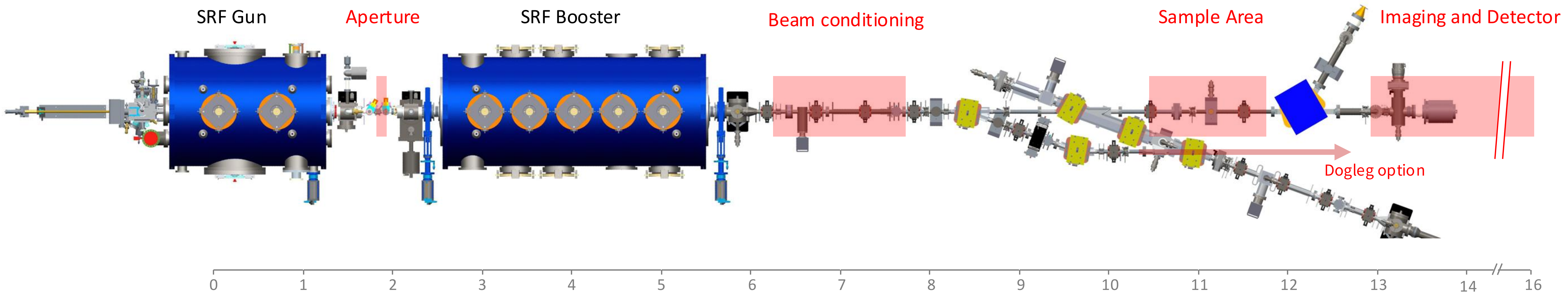
BERLIN

Accelerator test facility with pilot application experiments, a multi-science factory

T. Kamps et al., arXiv:1910.00881v2 [physics.acc-ph] 8 Jan 2020
J.-G. Hwang et al., J. Korean Phys. Soc. 77, 337–343 (2020). https://doi.org/10.3938/jkps.77.337
A. Neumann et al., IPAC 2022



Ultrafast scattering experiments with the SEALAB photoinjector



Capabilities of the photoinjector:
1 to 6.5 MeV beam energy with **variable** bunch charge (1 fC to 100 pC), pulse length (1 fs to 6 ps) and spot size (10 to 100s μm), **high stability at MHz repetition rate.**

Very **flexible accelerator/lens system**: one gun cavity and three booster cavities, many quadrupoles, done optimization for bunching/diffraction/imaging schemes,

Ultrafast science drivers:
fs thermometer for the lattice – study of functional materials, solar cells, protein imaging

Enabling **multi-modal capabilities** with integration into large scale facility. Availability of THz sources, sample handling and data analysis workflows.

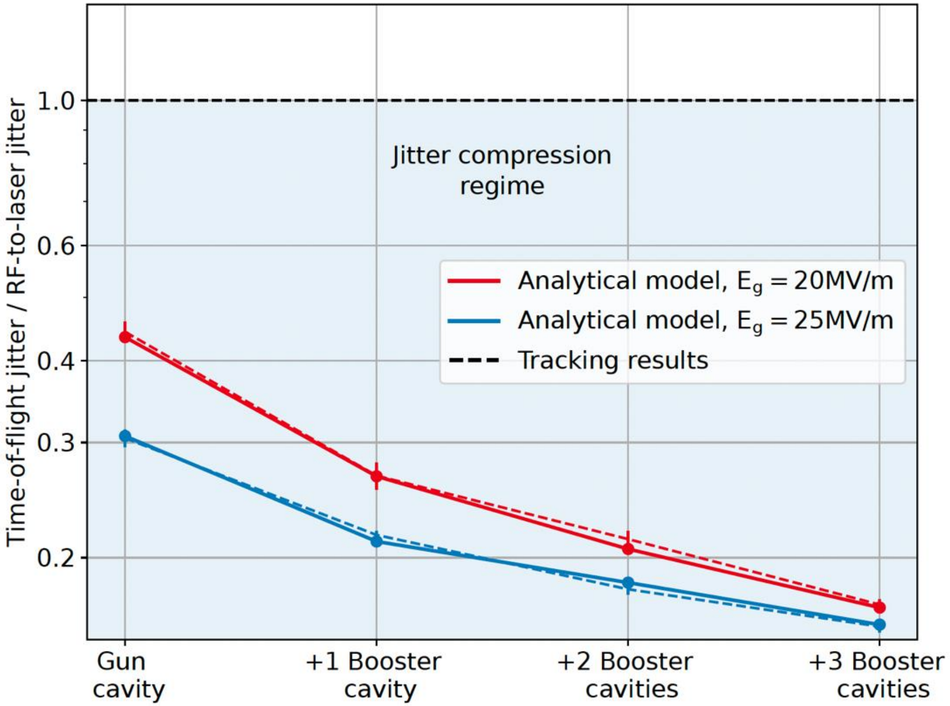
T. Kamps, B. Alberdi Esuain, S. Barg, A. Neumann, C. T. Kocj, H. Seiler, R. Ernstorfer

Limits for temporal resolution – can compress dominant jitter by factor 3

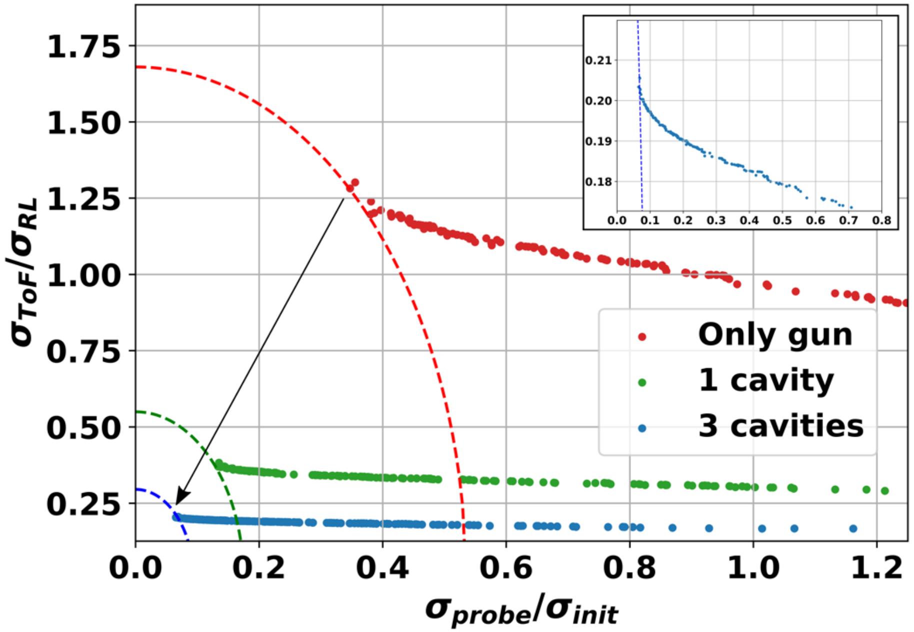
Temporal resolution of our setup is limited by **longitudinal beam dynamics** (compression) of the probe beam at the target and the **synchronisation** system between laser and RF (arrival time jitter)

Parameter	Value
Laser arrival	300 fs
RF phase	0.05 deg
Rf amplitude	1*10^-4 V

Limited by bERLinPro/ERL legacy timing and synch system



B. Alberdi et al., Sci. Rep. 12, 13365 (2022)



$$\sqrt{\sigma_{probe}^2 + \sigma_{TOF}^2} \leq 100 \text{ fs}$$

Capabilities of spatial resolution

Spatial resolution is limited by **transverse beam dynamics** (emittance manipulation), ability to focus and image the beam, and **methods to generate contrast**

Preparatory phase modificaitons

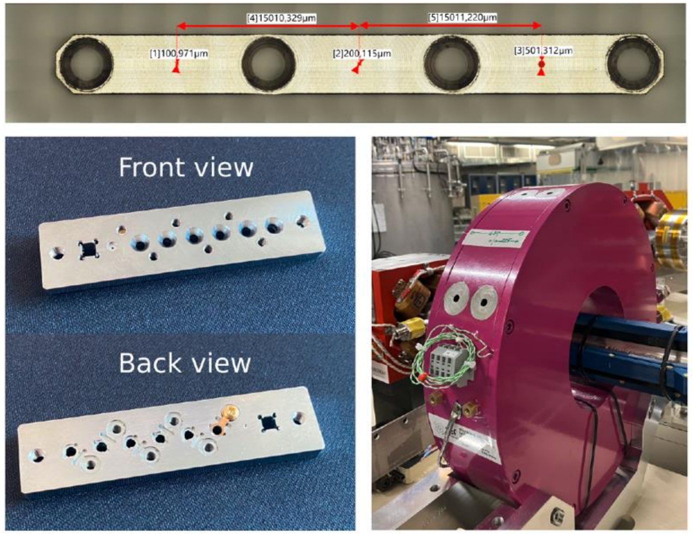
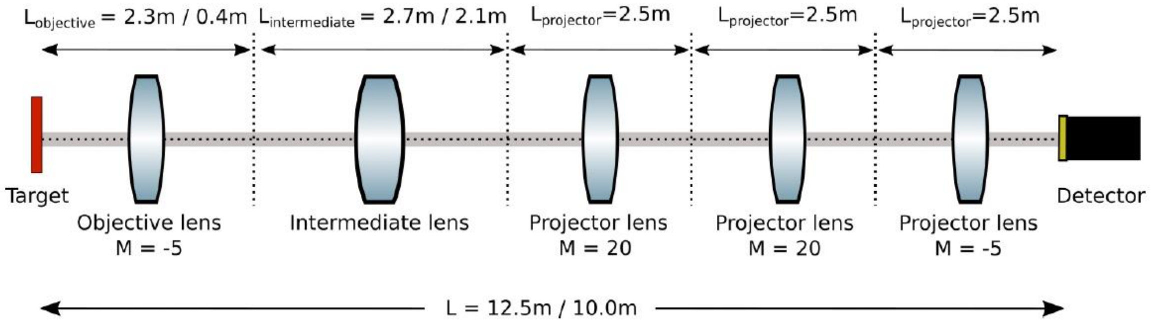
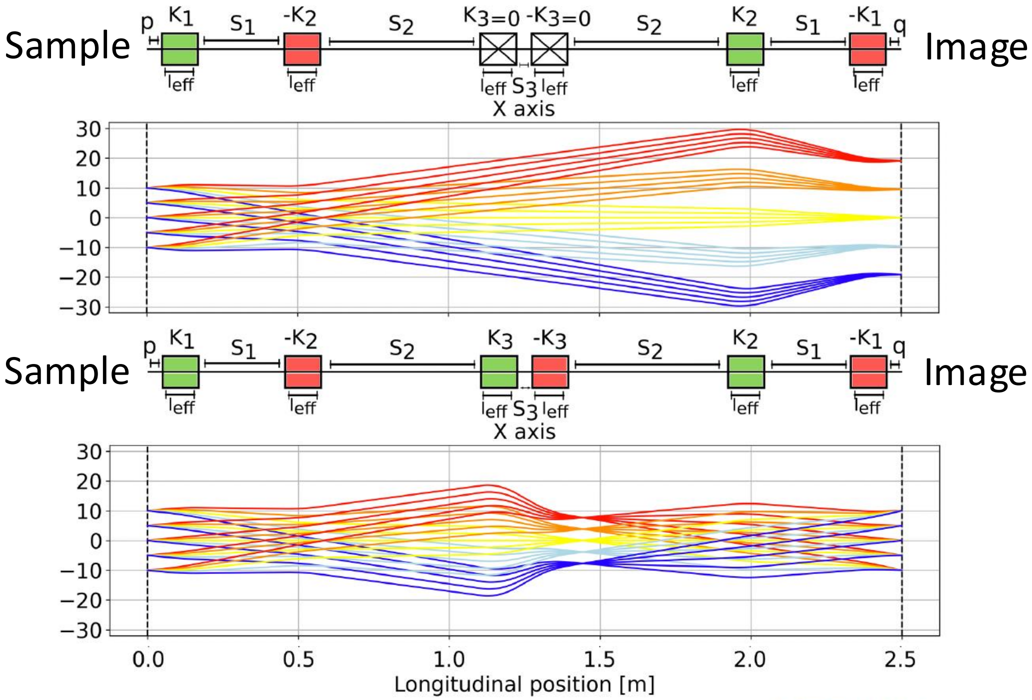


Figure 4.5: Collage of the pictures of the new beamline elements. Top side: the image of the aperture plate with the three aperture holes signaled with red arrows. On the lower left: front and back views of the sample holder plate. On the lower right: the normal conducting solenoid installed in the beamline.

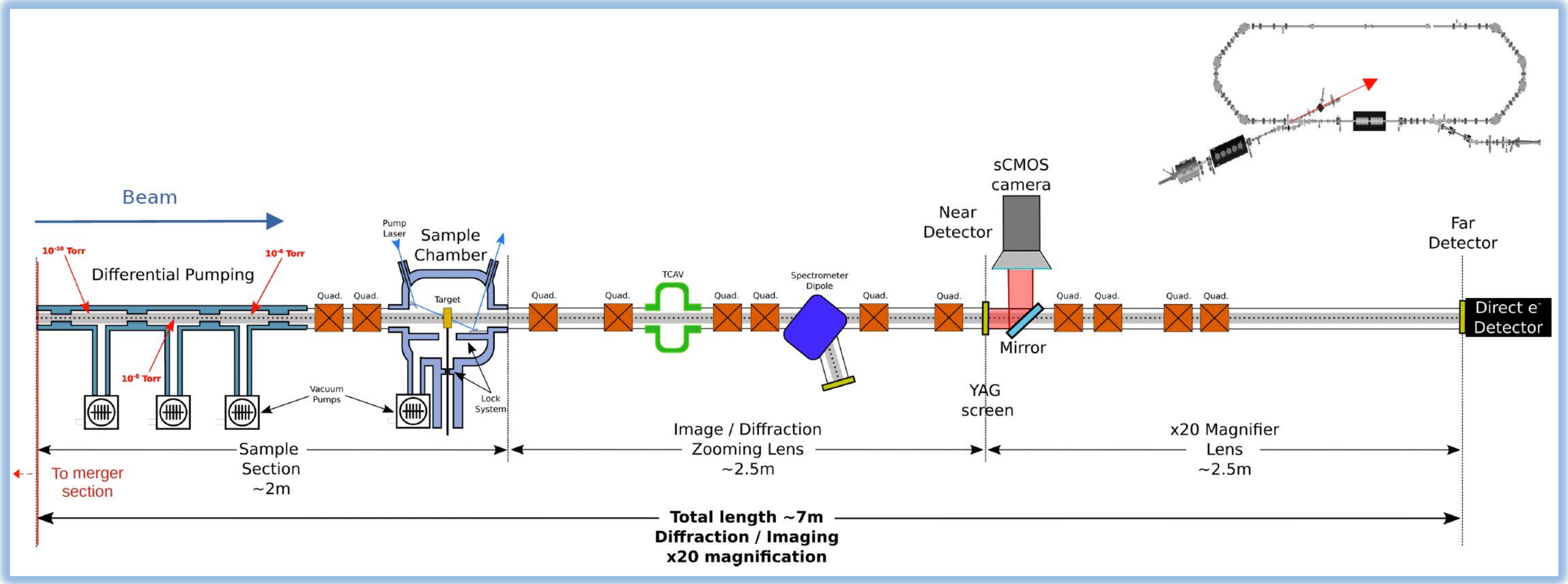
Ideas for pilot phase





B. Alberdi et al., IPAC 2023 and PAHB 2023

Implementation of diffraction and imaging modalities: a pilot UES beamline



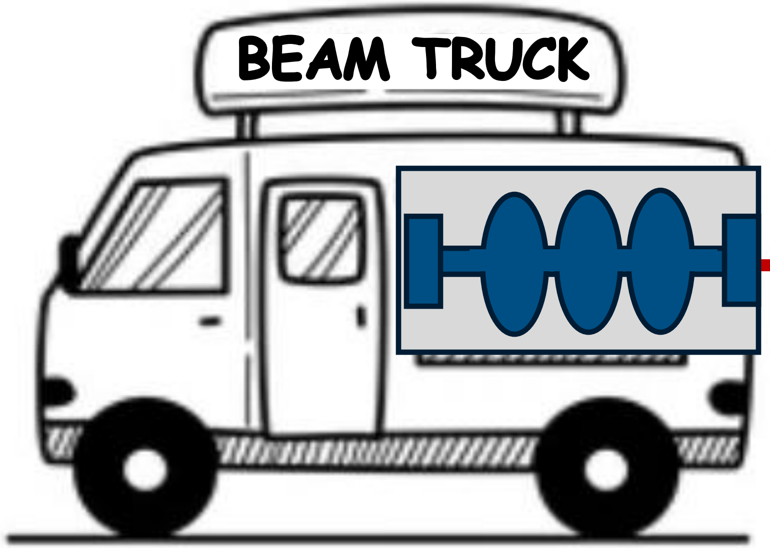
B. Alberdi-Esuain, S. Barg, T. Kamps, C. Kalus, V. Dürr, C. Koch

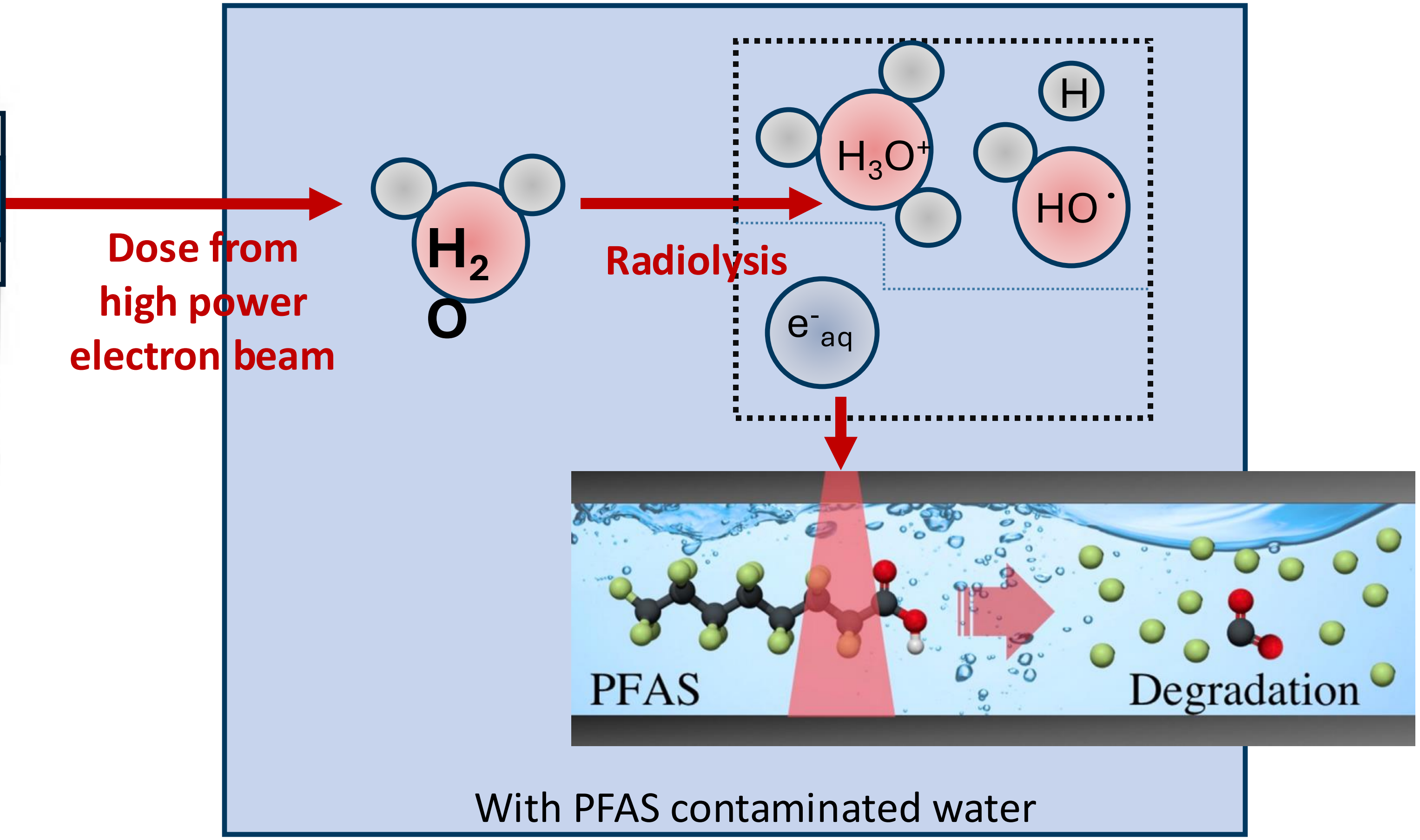
The New York Times

PFAS 'Forever Chemicals' Are Pervasive in Water Worldwide, Study Finds

A global survey found harmful levels even in water samples taken far from any obvious source of contamination.

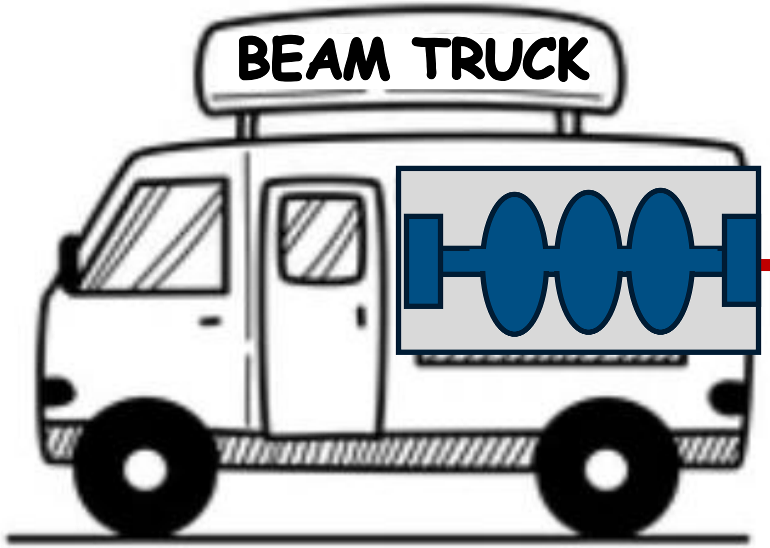
Electron beam treatment with higher power beam from compact SRF accelerator for water treatment of forever chemicals (PFAS)

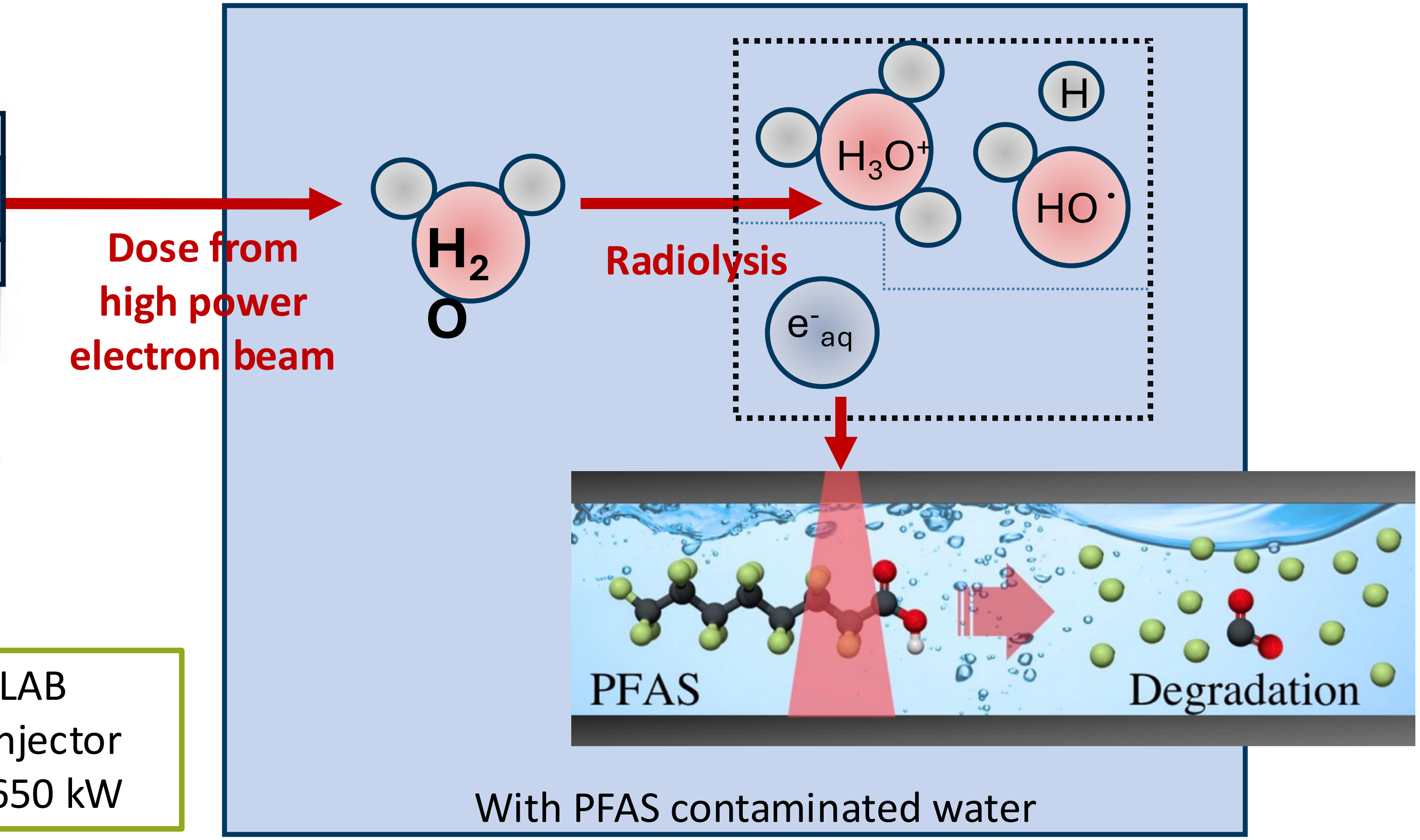




Water delivery system

Electron beam treatment with higher power beam from compact SRF accelerator for water treatment of forever chemicals (PFAS)





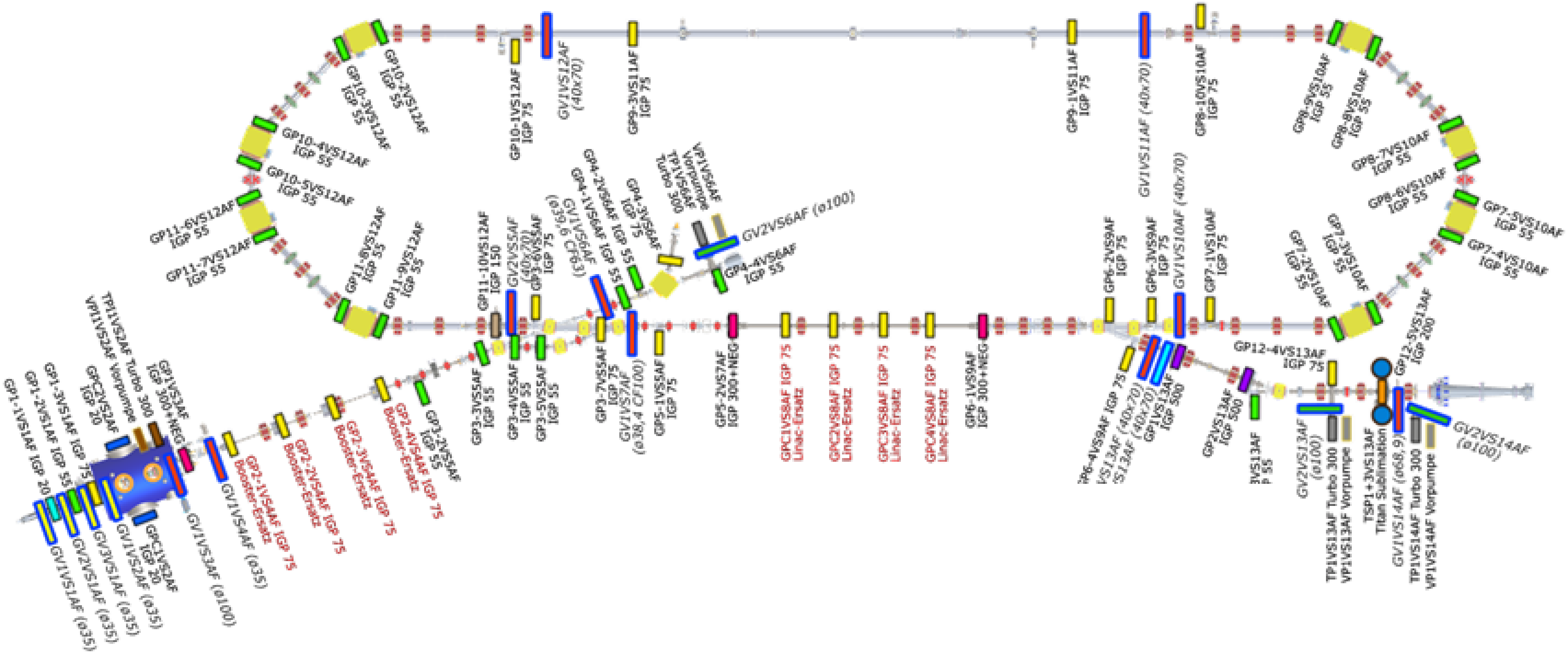
Water delivery system

High-power, energy-efficient electron accelerator → The SEALAB SRF Photoinjector delivering 650 kW

Electron beam treatment with higher power beam from compact SRF accelerator for water treatment of forever chemicals (PFAS)

Many open points: What is the right **dose**? What are suitale **beam parameters**? How can we fit the SRF injector of SEALAB into a **Beam Truck**?

Detailing now a **beam experiment with a new in-air beamline at SEALAB** to work on the dose and beam parameters.



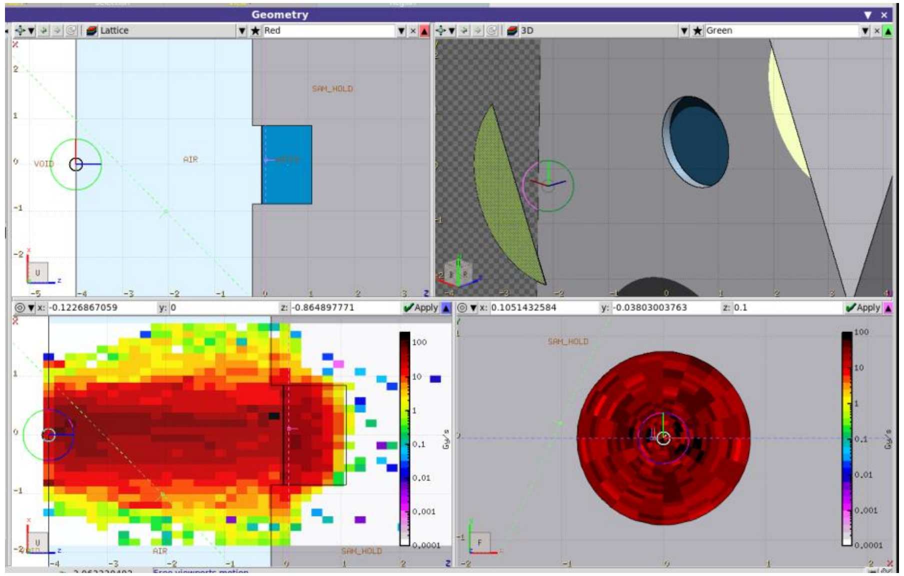
T. Spohr, T. Kamps, B. Alberdi Esuain, J. Knobloch, A. Neumann, P. Menzenes, B. Schröder, S. Specks, C. Walter, S. Lederer, V. Dürr, H. Huck

Electron beam treatment with higher power beam from compact SRF accelerator for water treatment of forever chemicals (PFAS)

Assume that we need 1000 kGy source for a Beam Truck, **what can do with our injector beam at low current?**

With diagnostics beam scenario of 2.5 MeV and 0.5 μA -> **generate dose rates of $\dot{D}$ = 0.2 kGy/s, good for tests!**

Establish water pipeline for contaminated water and water analysis with partners at TU Berlin (C. Walter, P. Menzenes) and Berliner Wasserbetriebe.



FLUKA simulation for dose depostition for 2.5 MeV energy beam on Ti window and into water container. Combined with thermal analysis (Courtesy T. Spohr)

HiACTS TU berlin

T. Spohr, T. Kamps, B. Alberdi Esuain, J. Knobloch, A. Neumann, P. Menzenes, B. Schröder, S. Specks, C. Walter, S. Lederer, V. Dürr, H. Huck

Sustainable SRF technology for future accelerators

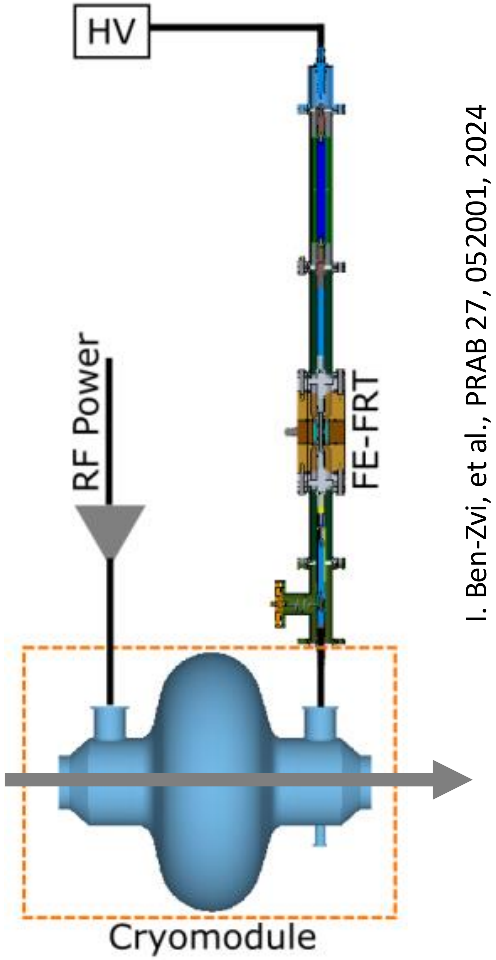
SRF technology as found in SEALAB and many other accelerator has a large sustainability potential for future accelerators.

iSAS sets out to unlock this potential and implement innovations in SRF and cryogenics.

Saving by power by beam, ERL at PERLE.

Solutions to RF power by de-tuning control. Include smart LLRF control and fast reactive tuner technology -> see poster session and talk by Nic Shipman later today.

Should be tested under high power beam conditions, at SEALAB.



I. Ben-Zvi, et al., PRAB 27, 052001, 2024

A. Neumann, J. Knobloch, N. Shipman

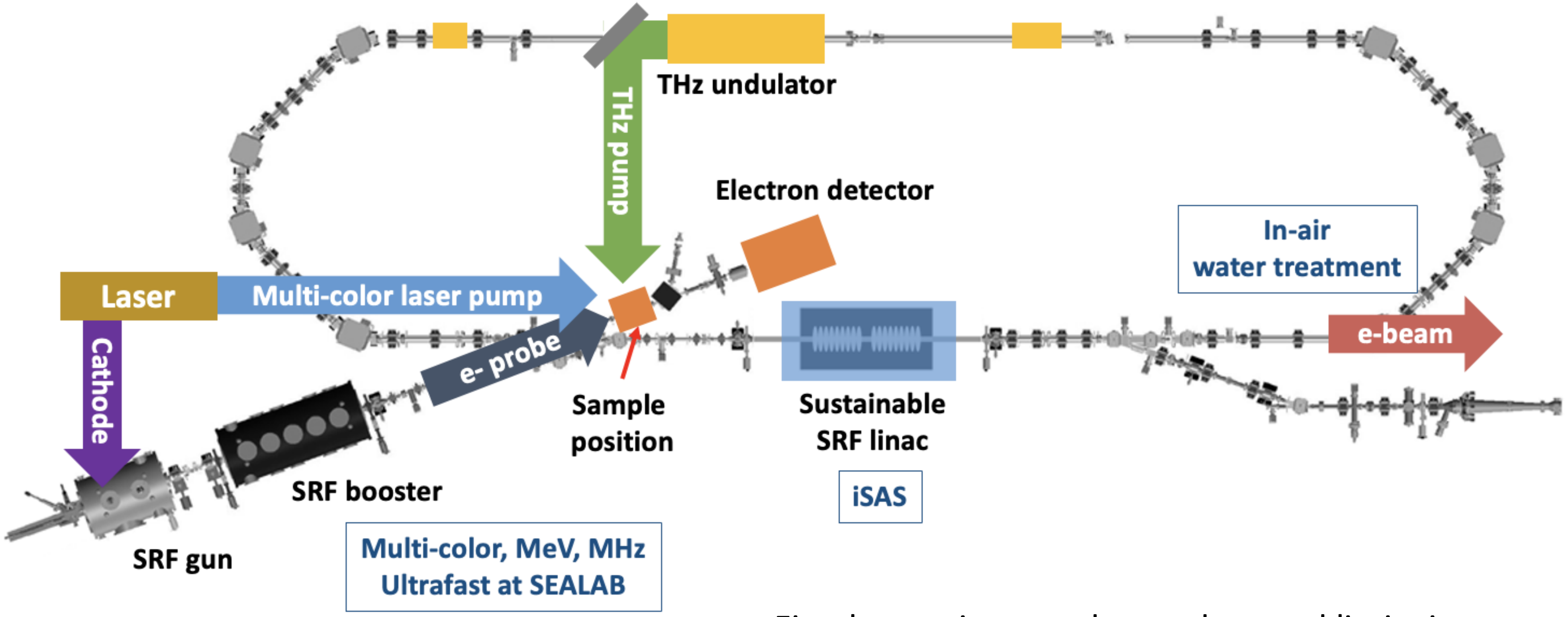
The future of SEALAB is bright, smart and ultrafast

The SRF gun of SEALAB starts operation in Oct/Nov 2024.

First beam time used to understand limits in parameter space. Demonstrate **versatility in various operation modes** for ERL with sustainable SRF, ultrafast (UED), and electron beam water treatment (EBWT).

素晴らしいワークショップをありがとう。

The future of SEALAB is bright, smart and ultrafast: Accelerator test facility with pilot application experiments, a multi-science factory



The SRF gun of SEALAB starts operation in Oct/Nov 2024.

First beam time used to understand limits in parameter space to benefit from versatility in various operation modes for ERL with sustainable SRF, ultrafast (UED), and electron beam water treatment (EBWT)