Status for beam and perspectives for applications at the SRF photoinjector of the SEALab facility

Thorsten Kamps (HZB, HU Berlin)

New Scientific Opportunitites at the TRIUMF ARIEL e-linac

May 25-27, 2022

Vancouver, Canada

brighter
faster
smarter

Acknowledgements and Partners

HZDR

MAX-BORN-INSTITUT

DESY

CORNELL UNIVERSITY FOUNDED A.D. 1865

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HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION

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The Andrzej Soltan Institute for Nuclear Studies
PL-05400 Otwock-Świerk
Poland

TESLA TECHNOLOGY
T T C
COLLABORATION

HUMBOLDT-UNIVERSITÄT ZU BERLIN

Universität Potsdam

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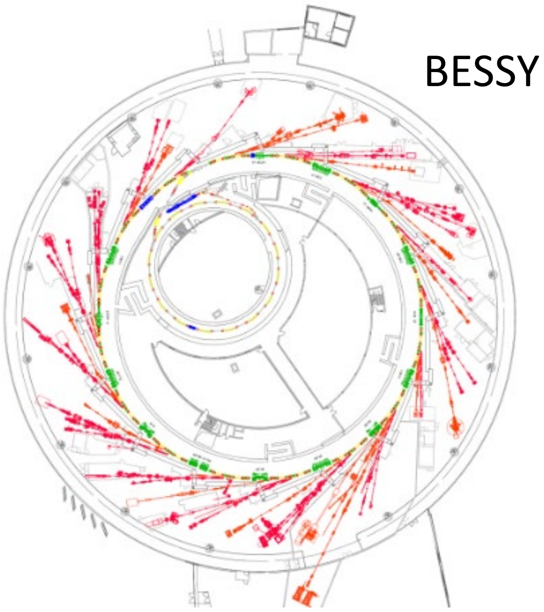
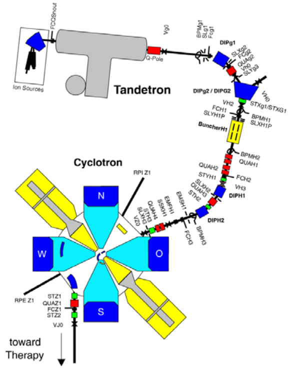
BESSY II





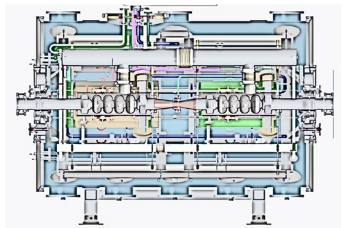
Cyclotron and proton therapy complex

BESSY III & MLS2

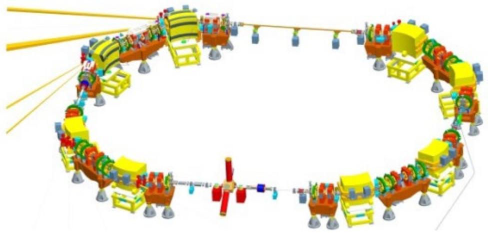
PTB

SupraLab@HZB

VSR DEMO



Metrology Light Source



PTB

LEAPS League of European Accelerator-based Photon Sources

Digital LEAPS – ML, AI, Data
PerMaLic – permanent magnets

MT ARD

ATHENA Accelerator Technology Helmholtz Infrastructure

SEALAB/ bERLinPro

We develop, operate, maintain and modernize our accelerators to provide unique research opportunities

SEALab

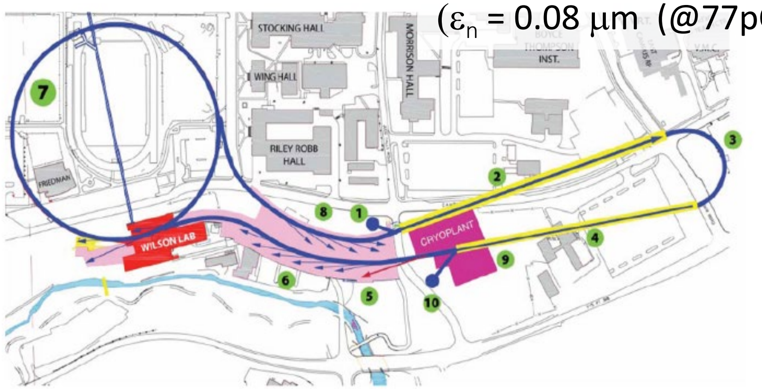
Accelerator + Applications + ERL Science Factory

The ERL concept promises high energy efficiency and high beam quality

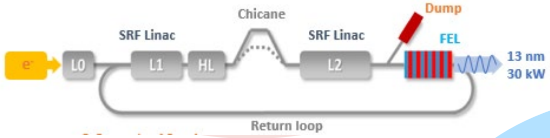
- **10 years ago people were thinking BIG and throught the ERL could replace the storage ring (SR) as next generation light source [1].**
- **Nowadays the ERL concept occupies niches both the SR and the FEL find hard to reach.**
- **Demand for high brightness at high average current, short pulses, demanding intra-beam target or radiation process**

Cornell ERL [1]

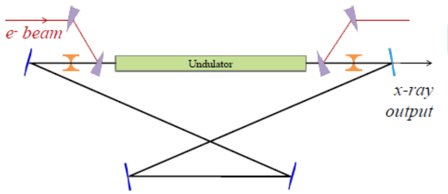
5 GeV, 100mA, ε = 8 pm rad
(ε_n = 0.08 μm (@77pC) , 2ps)



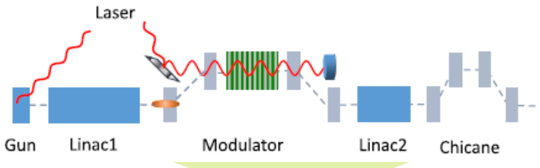
EUV FEL lithography [2]



XFEL-O [3]



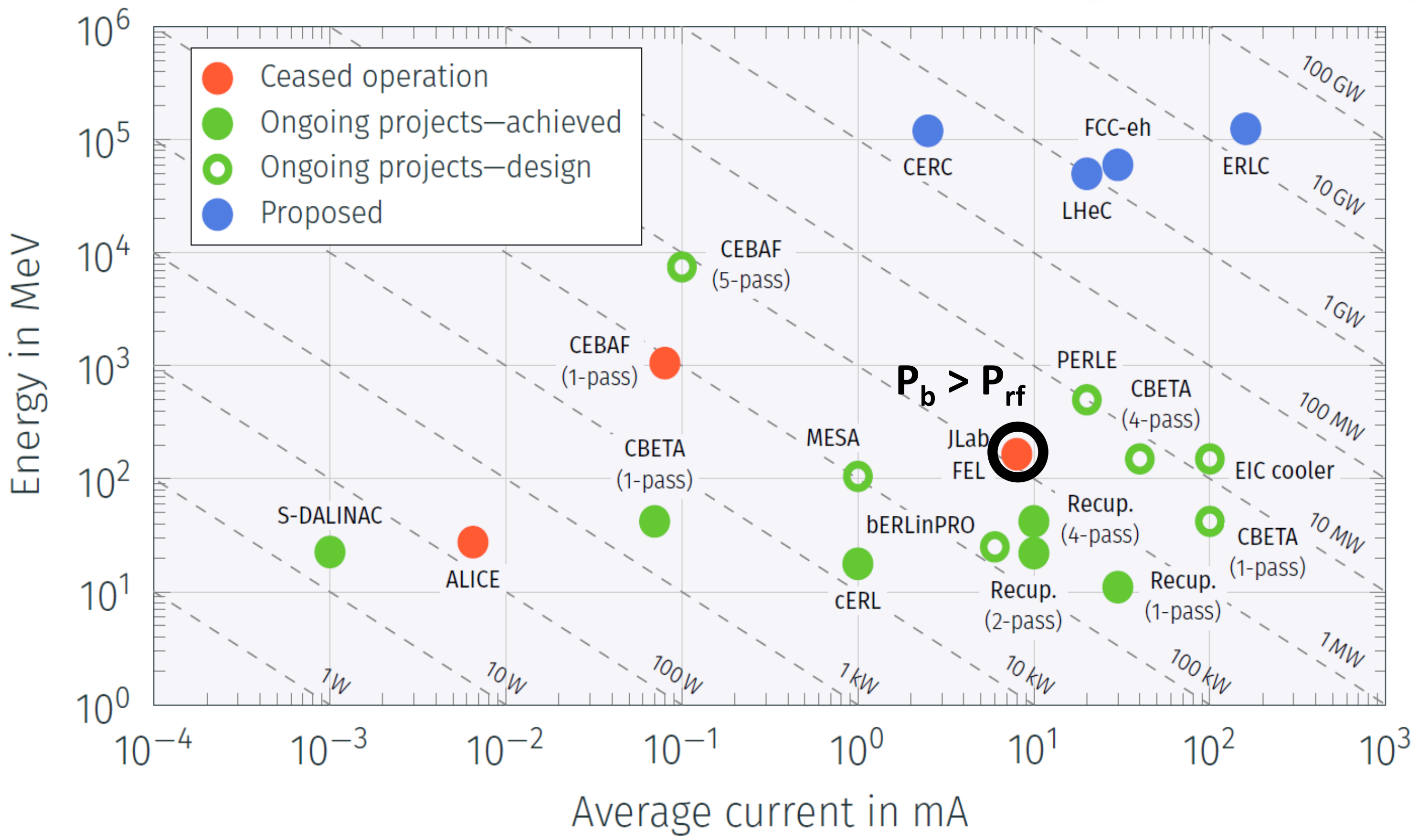
THz Source [4]



High energy physics applications [5]

[1] https://www.classe.cornell.edu/Research/ERL/PDDR.html
[2] M. Venturini, G. Penn, NIM A 795 (2015) 219-227
[3] for example K.J. Kim, et al., XFELO at LCLS-II
[4] Z. Zhang, et al., PRAB 20, 050701 (2017)
[5] European Strategy for HEP – Accelerator R&D Roadmap, 2022

Where are we with the ERL concept?



Plot from A. Hutton, presented at ERL 2021 Symposium, courtesy C. Tennant and M. Bruker
See also M. Abo-Bakr and M. Arnold, ERL 2019

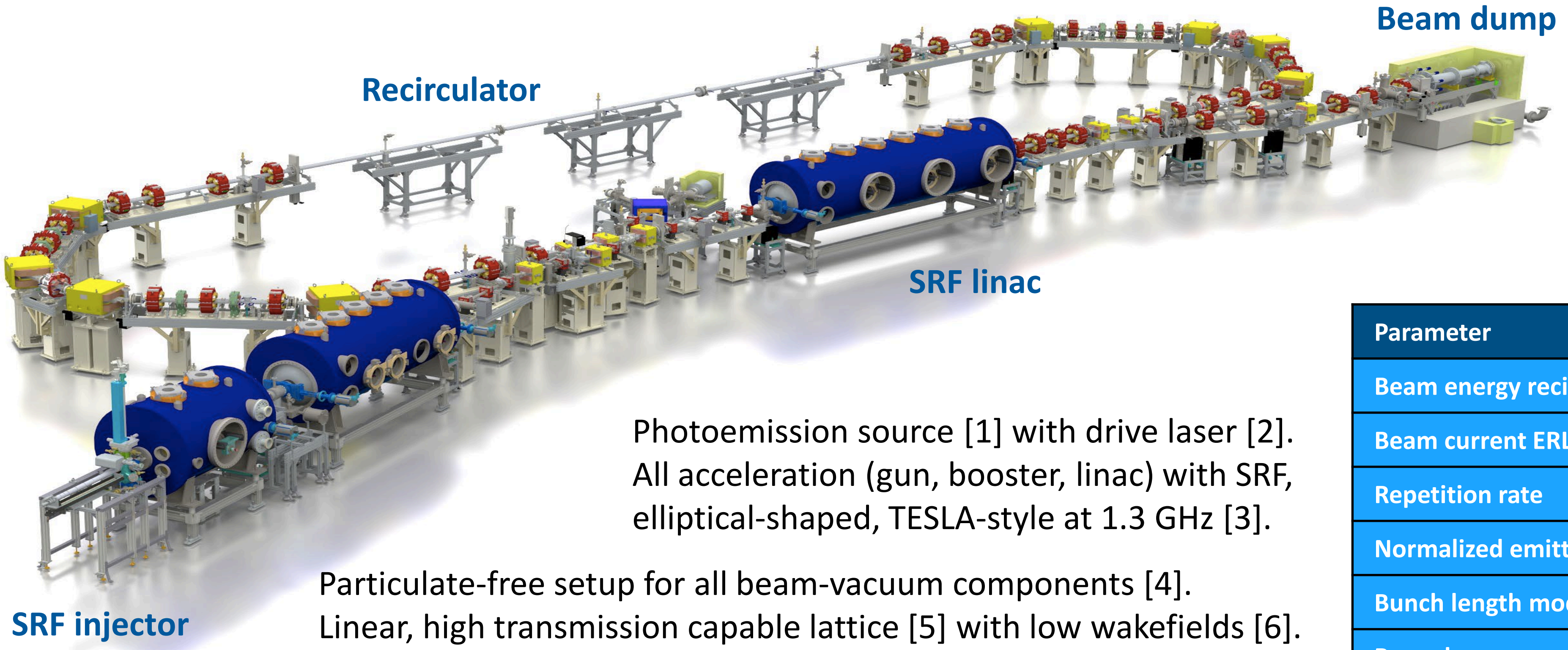
HZB Helmholtz Zentrum Berlin

Lessons learned from 10 SRF ERLs approaching $P_{beam} > P_{RF}$ [1]

SRF	• ALICE never ran CW because of dark current from field emission in **unclean SRF cavity modules** • ALICE was limited by **LLRF control and RF power overhead** for beam current transients
Longitudinal beam dynamics	• HEPL and CEBAF-FET had **limited longitudinal acceptance** (large dispersion) to transport used/disrupted beam • Both had also issues with **energy spread induced by wakefields**
Halo losses	• All JLAB Erls suffered from **halo and losses**, mitigated by careful tuning • cERL stages were **loss limited at each stage,** radiation protection
Tech	• CEBAF-FET, CEBAF-ER and S-DALINAC **are injector/gun performance limited** to $P_{beam}<P_{RF}$ • CEBAF-ER **magnetic-field limited** for recovered beam at low beam energy

[1] Discussion with D. Douglas and P. Williams

bERLinPro – Aiming at high brightness, high average current beams



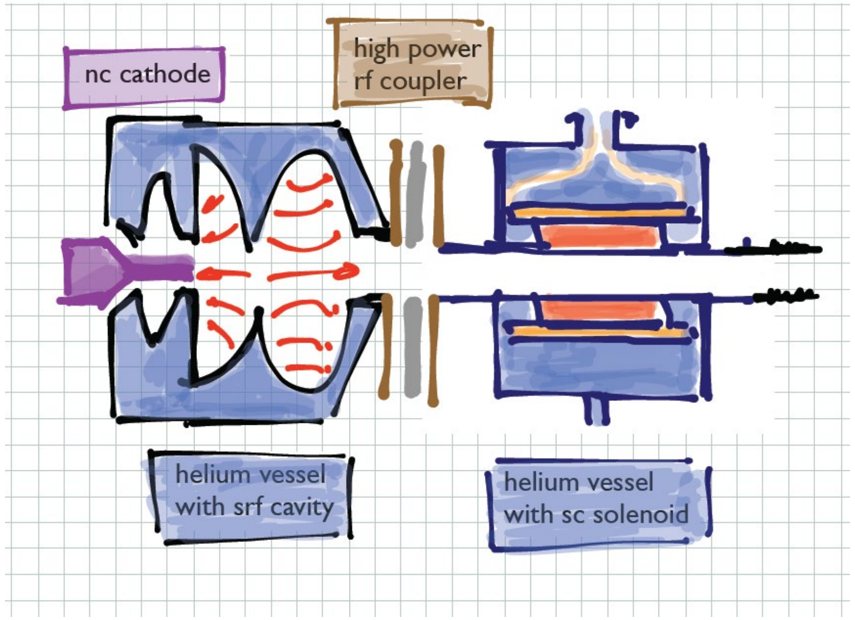
Parameter	Goal
Beam energy recirculator	50 MeV
Beam current ERL mode I/II	5 mA / 100 mA
Repetition rate	1.3 GHz
Normalized emittance	1 µm
Bunch length mode I/II	100 fs / 2ps
Beam losses	<< 10^{-5} @ 100 mA

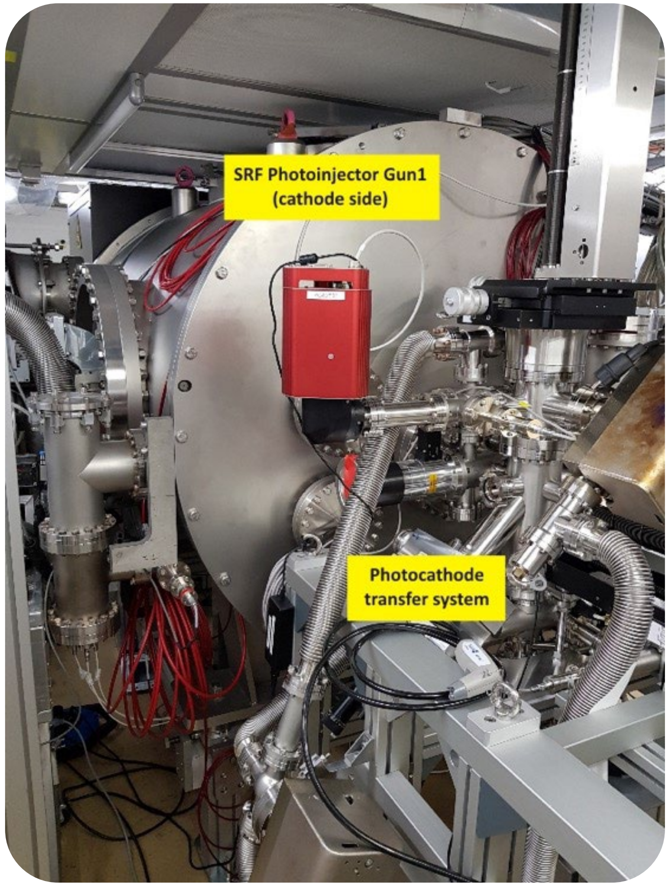
Photoemission source [1] with drive laser [2].
All acceleration (gun, booster, linac) with SRF, elliptical-shaped, TESLA-style at 1.3 GHz [3].

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

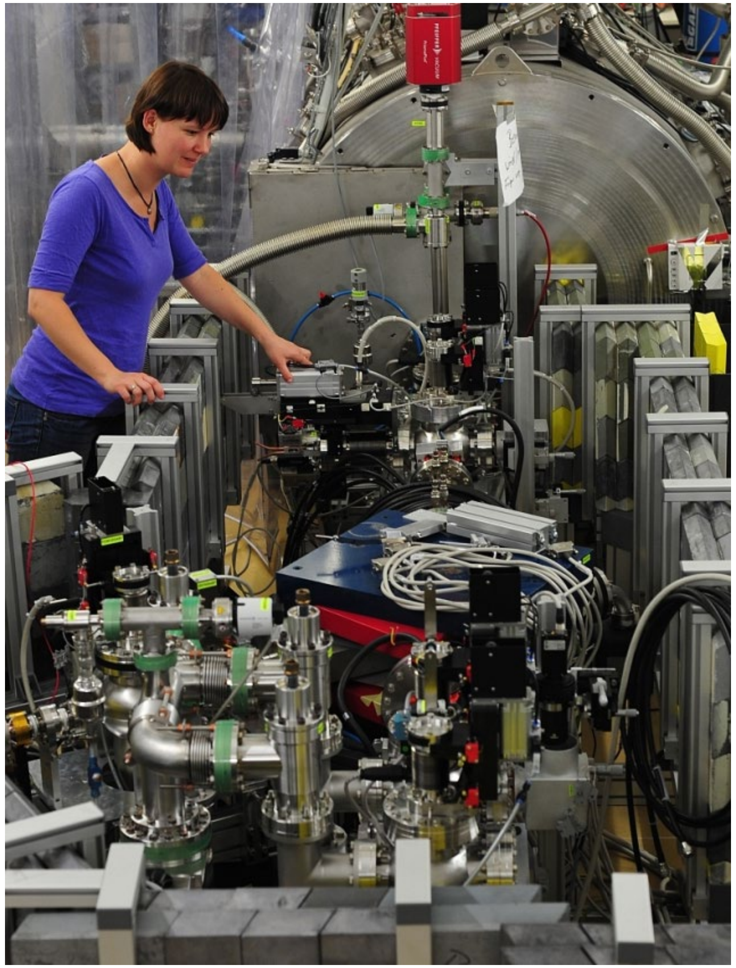
[1] M. A. H. Schmeisser, J. Kühn, S. Mistry, PRAB 21, 113401 2018
[2] G. Klemz, I. Will, in preparation
[3] A. Neumann, SRF 2015
[4] E. Sharples, et al., Operating SRF in a 'dirty' machine workshop, 2017
[5] M. Abo-Bakr, B. Kuske, A. Matveenko, IPAC 2013, IPAC 2018
[6] H.-W. Glock, IPAC 2015
[7] G. Kourkafas,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

Focal point SRF gun development





SRF gun development at HoBiCaT and GunLab, now moving to SEALab

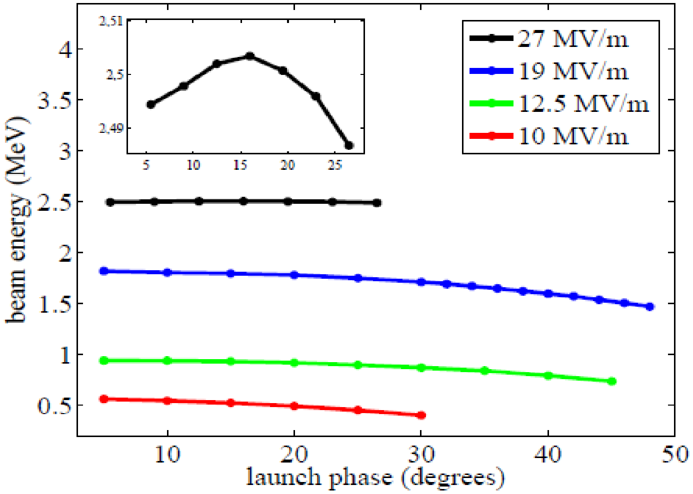


Focal point SRF gun development

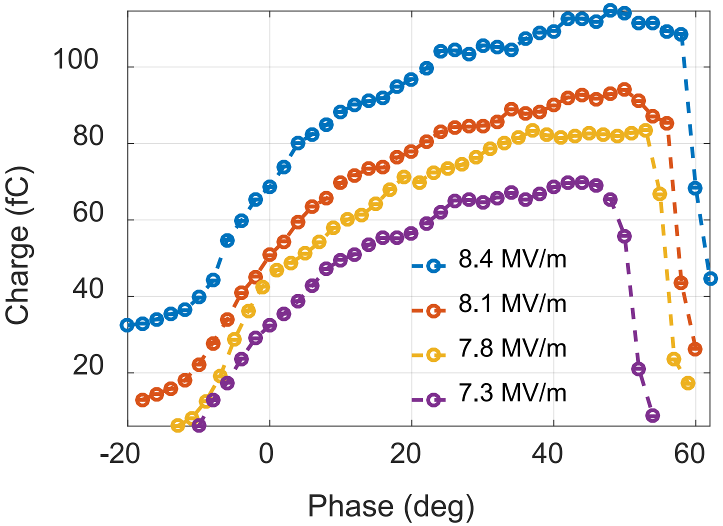
Spec / Demo	ERL spec I	Demo	System
Repetition rate	1.3 GHz	12 kHz	1.0
Emittance	0.5 µm	1.8 µm	0.2
Bunch charge	77 pC	0.1 pC	1.0
Average current	5 mA	50 nA	0.2
Gradient at cathode	30 MV/m	27 MV/m	0.2
Accelerating gradient	16 MV/m	15 MV/m	1.1
Photocathode / Drive laser	CsK2Sb/ Green	Pb, Nb, Cu / UV	0.2, 1.0
Beam kin. Energy	2.5 MeV	2.5 MeV	0.2, 1.0

Gun0.1 and 0.2: Designed, build and tested an all superconducting SRF gun [1,2] with Pb cathode [3]
Gun1.0 and 1.1: Optimized SRF gun cavity design [4] to incorporate a normal-conducting multi-alkali photocathode [5,6]

Cavity 0.2



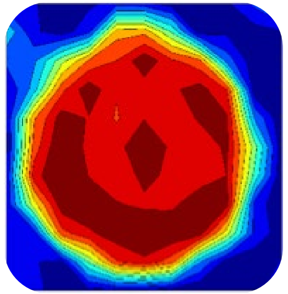
Schottky scans with cavity 1.0



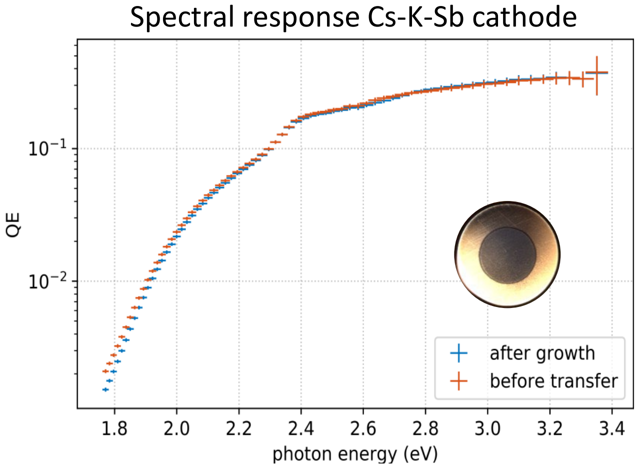
[1] J. Sekutowicz, TESLA-FEL Report 2005-09
[2] A. Neumann, SRF 2009, 2RF 2011, SRF 2013
[3] R. Barday, PRAB 16, 123402, 2013
[4] A. Neumann, SRF 2015, IPAC 2018
[5] M. A. H. Schmeisser, J. Kühn, S. Mistry, PRAB 21, 113401 2018
[6] J. Kühn, IPAC 2018, ERL2019

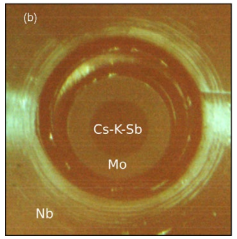
Focal point SRF gun development

Commissioning of Gun1.0 at GunLab in 2017/2018



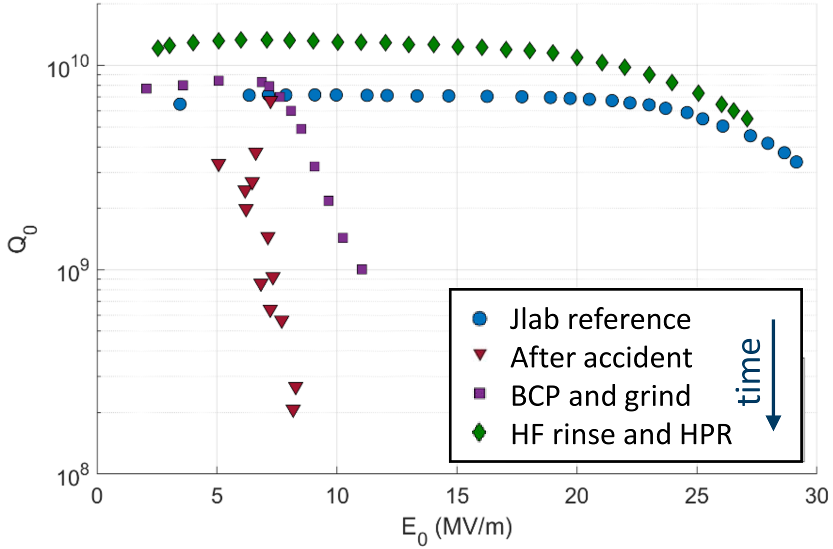
First beam, QE mapping, and dark current from Cu cathode

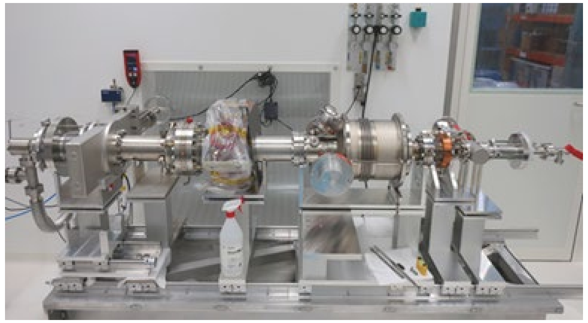




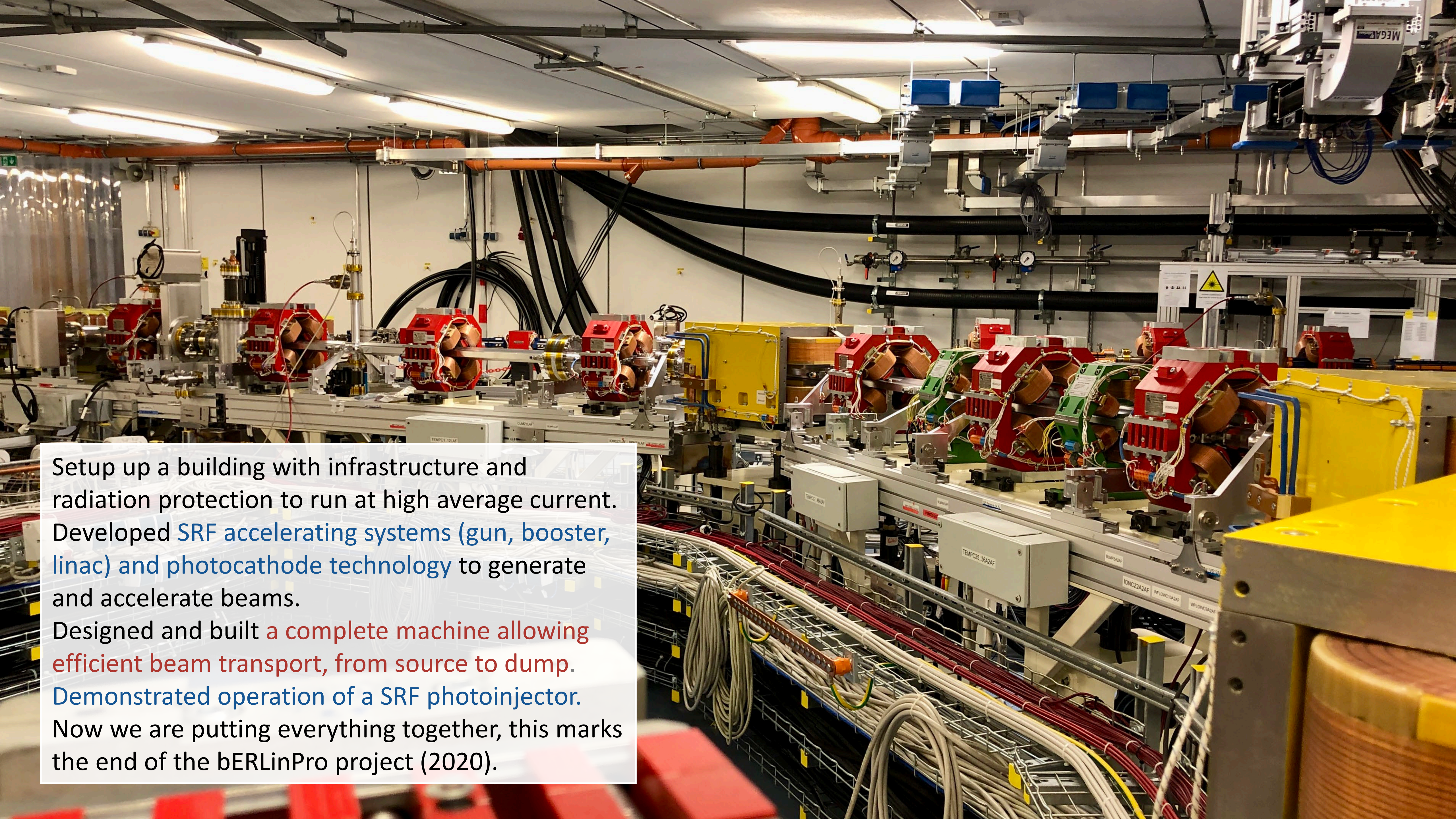
Inside SRF gun

Recovery of Gun1.0 at GunLab in 2021 [1]



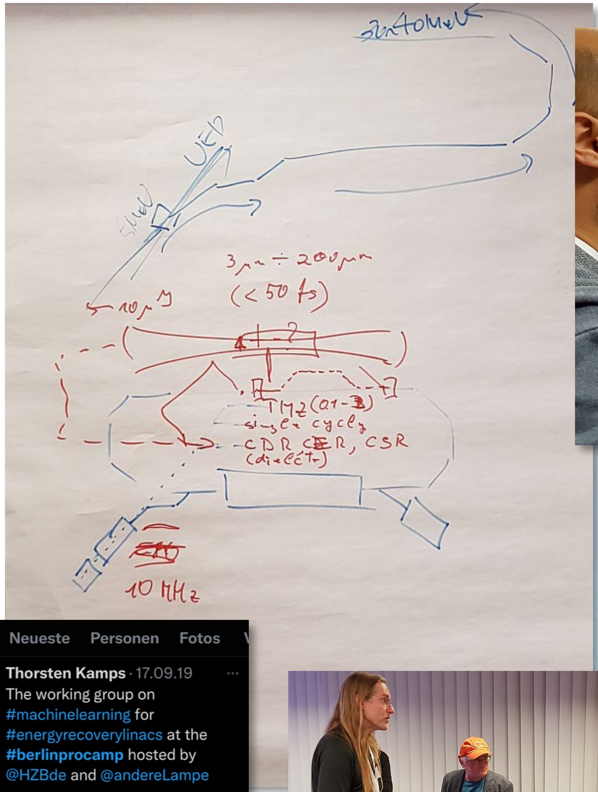


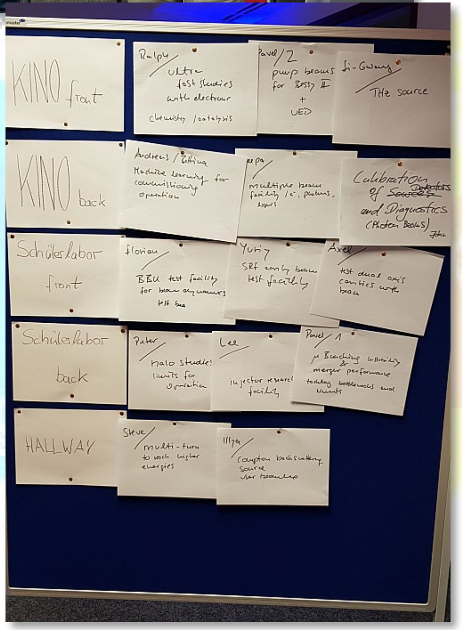
[1] Y. Tamashevich, Proc. of SRF 2021



Setup up 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 end of the bERLinPro project (2020).

bERLinProCamp 2019





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]

1) *Helmholtz-Zentrum Berlin, Berlin, Germany*
2) *Humboldt-Universität zu Berlin, Berlin, Germany*
3) *Paul Scherrer Institut, Villingen, Switzerland*
4) *CERN, Geneva, Switzerland*
5) *ASTEC Daresbury Lab, Warrington, UK*
6) *Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany*
7) *Technische Universität Darmstadt, Darmstadt, Germany*
8) *Jefferson Laboratory, Newport News, Virginia, USA*
9) *Budker Institut for Nuclear Physics, Novosibirsk, Russia*
10) *INFN LASA, Milano, Italy*
11) *Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany*
12) *Reiner Lemoine Institut, Berlin, Germany*
13) *Cornell University, Ithaca, New York, USA*
14) *Johannes-Gutenberg Universität Mainz, Mainz, Germany*
15) *@andrelampe, Berlin, Germany*
16) *High Energy Accelerator Research Organization, KEK, Tsukuba, Japan*
17) *SLAC National Accelerator Laboratory, Menlo Park, California, USA*
18) *Universität zu Lübeck, Lübeck, Germany*
19) *Deutsches Elektronen-Synchrotron, DESY, Zeuthen Site, Zeuthen, Germany*
20) *Los Alamos National Laboratrory, Los Alamos, New Mexico, USA*
21) *Brookhaven National Laboratory, Brookhaven, Long Island, USA*
22) *Fritz-Haber Institut, FHI-MPG, Berlin, Germany*

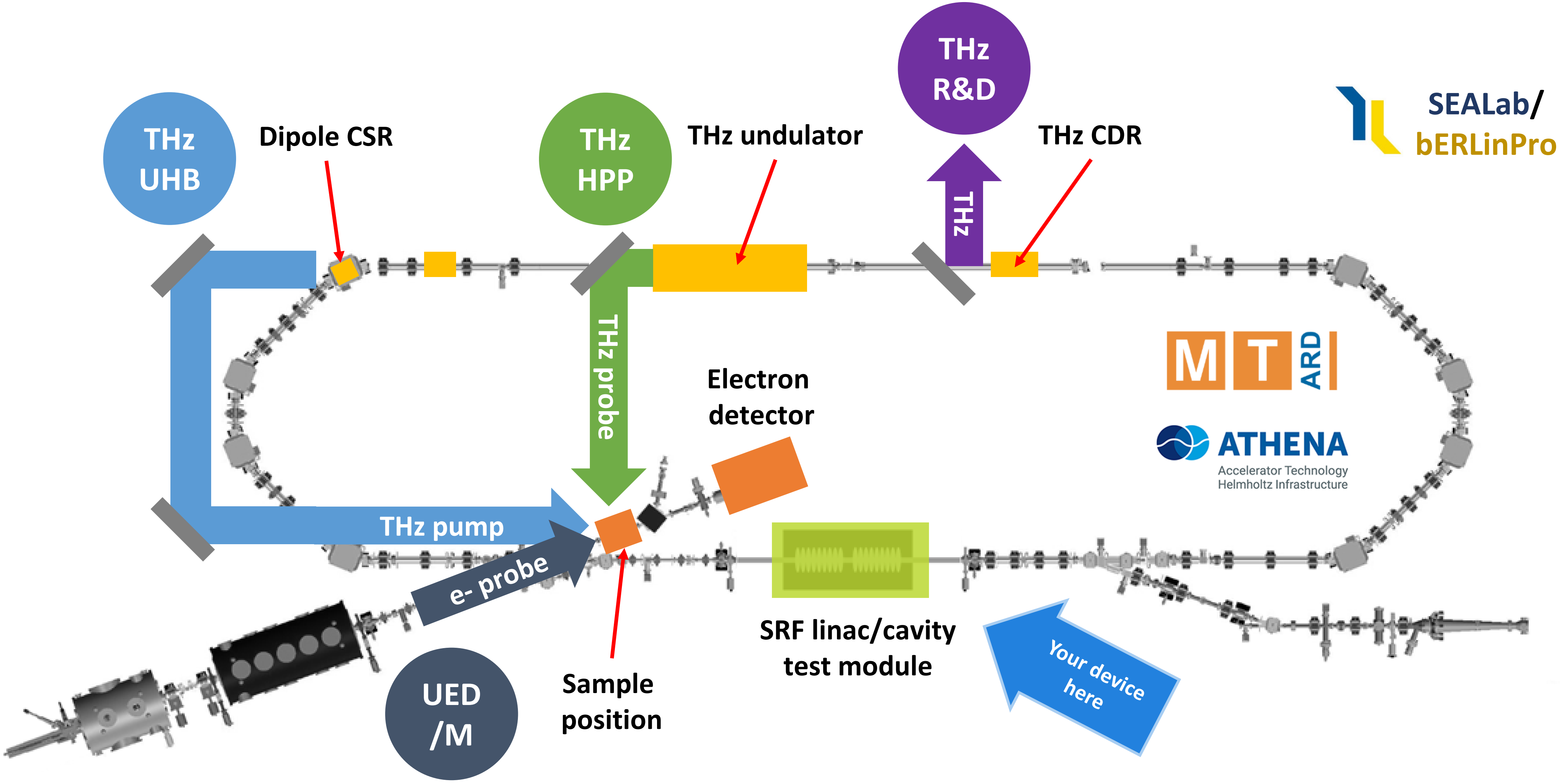
(Dated: 3 October 2019)

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.

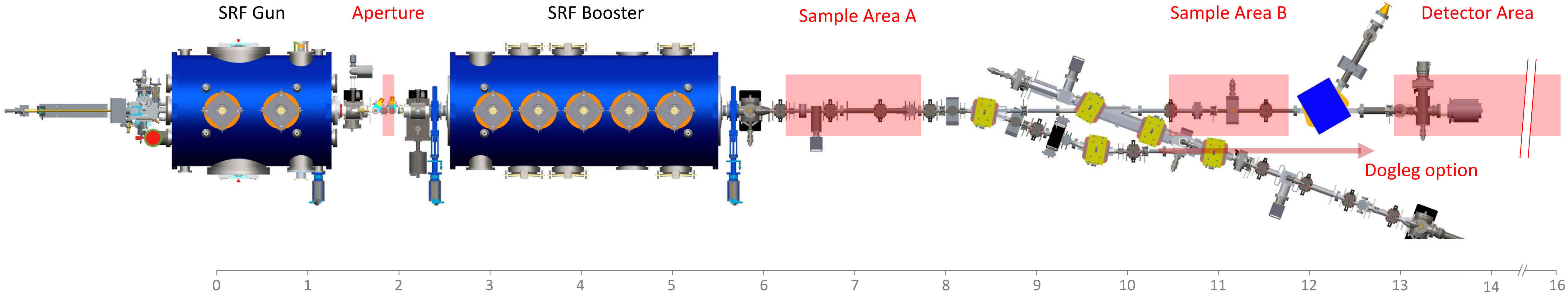
The goal of bERLinProCamp 2019 was to discuss scientific opportunities for bERLinPro 2020+. bERLinProCamp 2019 was held on Tue, 17.09.2019 at Helmholtz-Zentrum Berlin, Berlin, Germany. This paper summarizes the main themes and output of the workshop.

CONTENTS

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



Ultrafast experimental station at the SEALab photoinjector



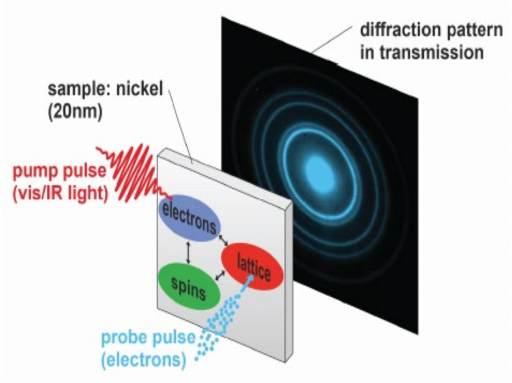
- **1 to 3.5 MeV beam energy with variable bunch charge (1 fC to 100 pC), pulse length (10 fs to 6 ps) and spot size (10 to 100s µm), high stability**

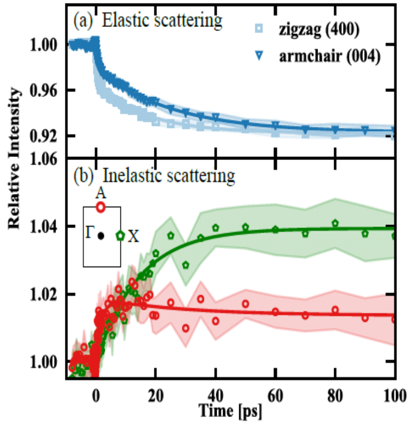
➢ **Very flexible longitudinal accelerator/lens system: one gun cavity and three booster cavities, done optimization for velocity bunching scheme and for transverse coherence length [1]**

[1] B. Alberdi, et al., 2022

Science case for MeV MHz ultrafast scattering experiments with electrons

Solids



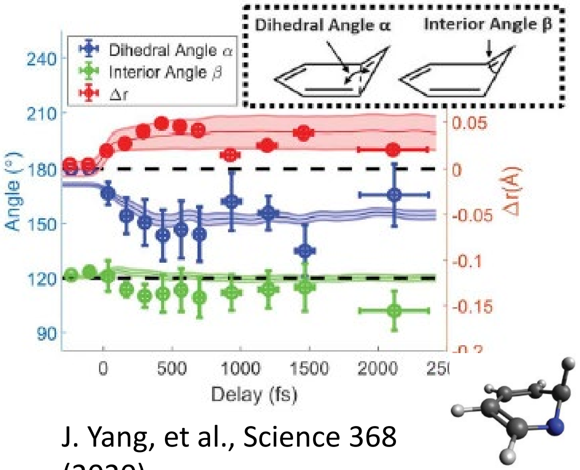


0.1 fC, 150 fs, 70 keV

D. Zahn, et al., arXiv:2008.04611 (2020)

H. Seiler, et al., arXiv:2006.12873 (2020)

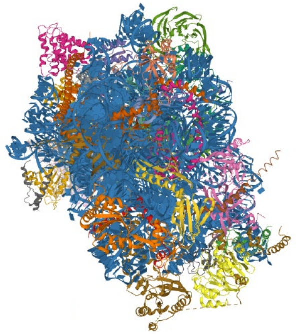
Gases



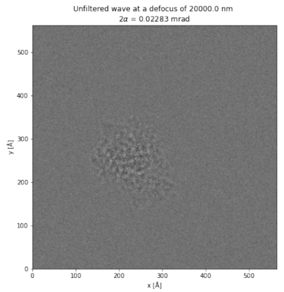
J. Yang, et al., Science 368 (2020)

Liquids

Ribosome 6em1



Wavefunction image



S. Barg, C.T. Koch, in preparation, 2022

fs thermometer for the lattice
Temporal resolved ARPES

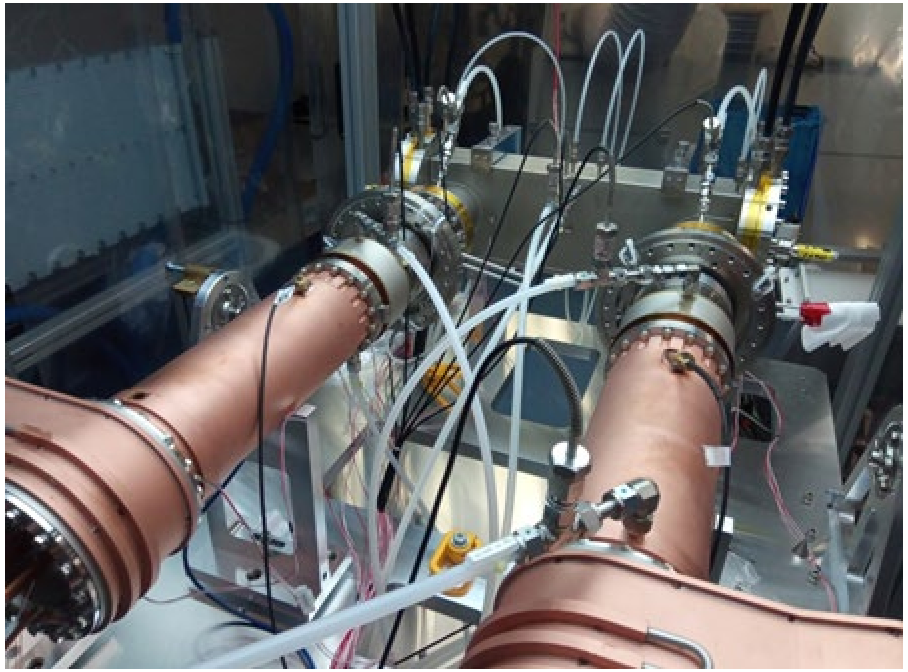
Diffraction camera
for molecular movies

Imaging macromolecular
structures

→ complementary to synchrotron radiation and FEL light sources
→ multi-modal capabilities (Bessy III)

Industrial partnerships: Consulting and joint test campaigns for Lighthouse project

- Lighthouse (RI + many partners) constitutes the industrial use of **high-power linear accelerator based on SRF technology**, to establish a sustainable method for Mo-99 production for medical diagnostics.
- **HZB consults** RI on photocathodes, drive laser, beam dynamics →applying results from bERLinPro/SEALab R&D phase
- **HZB cooperates on testing** of SRF components → applying SRF infrastructure **SEALab/Supralab**.



SRF collaboration for MESA/VSR/HEP module test at SEALab

- The goal: test the MESA linac module with SEALab/bERLinPro. Find out operational limits (HOMs, BBU) prior setup in MESA complex [1,2].
- MESA linac module: ELBE-type, industry produced, two TESLA 1.3 GHz cavities, added XFEL piezo tuners and modified HOM dampers and feedthroughs -> good for several mA average beam current
- Played through integration of the module: looks doable. Need some modifications to vacuum, cryo (availability of specific coolants at SEALab) and LLRF control. But no funding available.

[1] S. Thomas, ERL 2019
[2] for example: F. Hug, ERL 2019

Perspectives

- bERLinPro project accomplished in 2020, readiness of building, infrastructure, warm machine, diagnostics, cryo-plant and high-power RF stations
- From now as SEALab: Commission the SRF photoinjector and demonstrate versatility.
- Demonstrate UED mode, sustainable operation of the injector, and grow collaboration for potential ultra-fast beam applications.
- Involve ARD labs, universities, industry in future opportunites.