**ERL 2022**
**66th ICFA Advanced Beam Dynamics Workshop on Energy Recovery Linacs**


HZB Helmholtz Zentrum Berlin

# bERLinPro BECOMES SEALAB:

## STATUS AND PERSPECTIVE OF THE ENERGY RECOVERY LINAC AT HZB

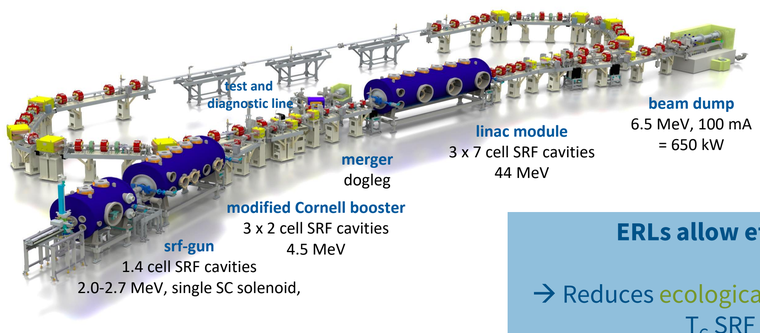
### A new perspective to combine Energy Recovery Linac and ultra-low emittance injector studies in a broad, multi-application parameter space

HIGHLIGHTS

- bERLinPro project accomplished in 2020, readiness of building, infrastructure, warm machine, diagnostics, cryo-plant and high-power RF stations
- Commissioning of SRF photo-injector on-going, high quantum efficiency cathodes preparation , Laser system, high-power RF conditioning of SRF Booster module couplers are on track to allow first beam from the injector first half of 2023
- Beam commissioning program in development to map the injector's parameter space from short pulse-low charge to, via medium average currents to high charge regime

## bERLinPro: AN ENERGY RECOVERY LINAC DEMONSTATOR

### A demonstration facility for ERL science and technology [1]




### Possible application

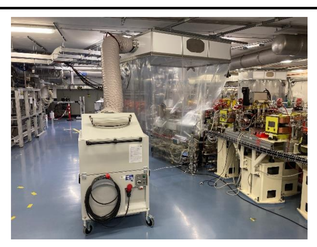
- Multi-user light source: XFEL oscillator, EUV source
- High energy electron cooling for proton/ion beams
- Ultra high luminosity electron-ion collider (EIC, LHeC) ERL roadmap initiative
- High energy, high luminosity e+e- collider
- Compact radiation source, nuclear physics

**ERLs allow efficient operation at high average brightness/luminosity with Linac class beam quality**
→ Reduces ecological footprint of large-scale science, especially when combining with higher $T_C$ SRF technology, vision of sustainable large-scale science driver

### New developments:

- Beam dynamics and manipulation: Merger, recirculation, beam break-up
- SRF Systems: Photo-injector, high power Booster, HOM damped LINAC
- Injector: High repetition rate laser, high QE cathode, high peak and average beam brilliance with high quality (low emittance, short pulse)
- Control of beam loss and radiation protection: Dark current suppression and Halo formation, high power beam dump
- High power continuous wave RF power sources
- Low impedance optimized machine
- Complete setup of the vacuum system under particulate free cleanroom conditions

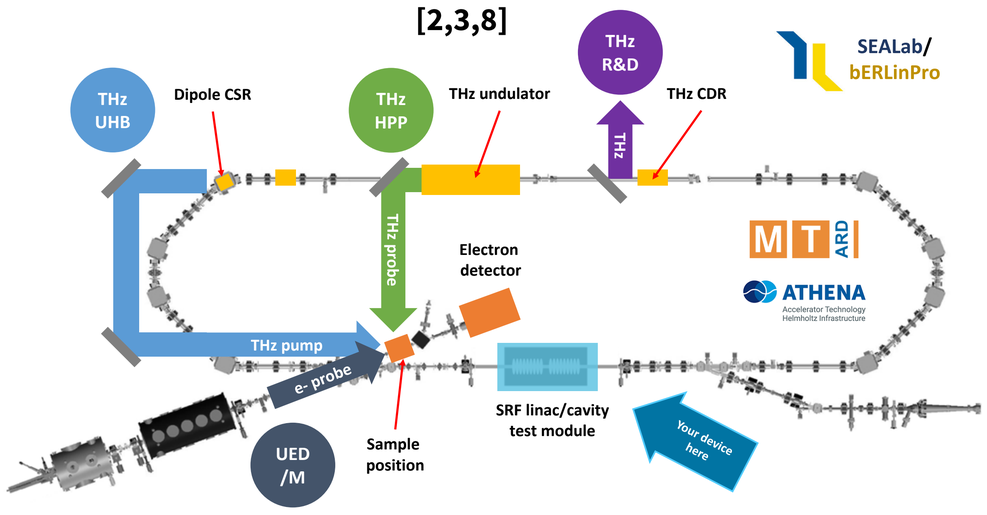
| Parameter | ERL | Injector/UED |
|---|---|---|
| Beam energy (MeV | 50 | 6.5-10/2 |
| $I_{avg}$ (mA) | 100 | 6-10/0.0025 |
| Laser freq. (MHz) | 1300 | 50, 1300 |
| RF freq. (MHz) | 1300 | 1300 |
| $\epsilon_{norm}$ (mm mrad) | 1 (0.6) | 0.6/0.03 |
| $\sigma_t$ (ps) | 2 (0.1) | 0.02-2 |
| Bunch charge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



## TRANSITION FROM BERLINPRO TO SEALAB

Open the facility to Acclerator Research and Development (ARD) through Athena, pursue SRF research through Supralab and enable pilot experiments with external partners and industry.

### Accelerator test facility with pilot application experiments [2,3,8]

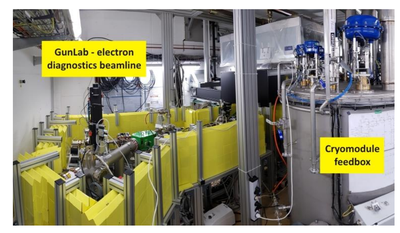



### Contribute to the European ERL Roadmap [9], PERLE collab.

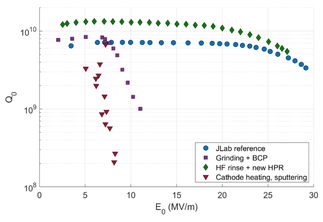
- ERL injector studies including high charge plus high current macro-pulse studies
- Development for an efficient SRF Linac: Ferro-electric fast reactive tuner studies [10]: Saving RF power + detuning compensation
- Possibility to operate at 4K and above, reserve a cavity in the Linac for higher temperature operation

## SELECTED RESULTS

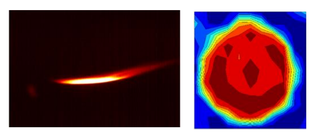
### Operation and recovery of SRF Photo-injector Cavity




Gunlab installation to characterize the SRF photo-injector for bERLinPro and test cathode transfer procedures

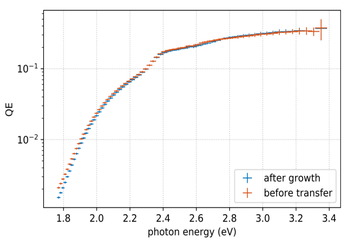


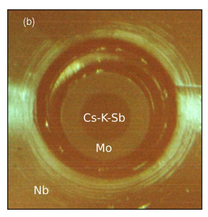

Development of Nb cavity recovery after accident during treatment at manufacturer [3]



First beam signal on viewscreen[4] (left). Right: QE map of Cu cathode in proof of principle experiment at Gunlab [5]

### High QE photo-cathode production [6,7]




16.8% at 515 nm (2.4eV) with Cs-K-Sb type cathode on Mo substrate plug.

Cathode plug in Nb cavity backwall

## PERSPECTIVES

- Open up the machine for internal and external applications within Helmholtz ARD program and beyond:
  - Completion of the injector and linac/dump lines: Commissioning Injector with beam (up to 5-10 mA, up to few 100 pC, up to 6.5 MeV)
  - Support and contribute to UED pilot experiment at SEALab [8]
  - Offer the injector as a testbed to test and commission AI/machine learning techniques, digital twins
  - Map the complete attainable injector phase space for many applications: From FEL, UED to HEP[9]
  - Testing of new diagnostics, acceleration concepts and controls, beam test facility at Linac position
  - Collaborate with external partners for a 100 mA compatible Linac module in most efficient design,

    e.g. fast reactive tuners, optional 4K operation of single cavity in module of three (ERL initiative for HEP[9]) → sustainable Linac for ERL

## REFERENCES

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