# B*ERL*inPro - A COMPACT DEMONSTRATOR ERL FOR HIGH CURRENT AND LOW EMITTANCE BEAMS

A. Jankowiak*, M. Abo-Bakr, W. Anders, T. Kamps, J. Knobloch, B. Kuske, O. Kugeler, A. Matveenko, A. Meseck, A. Neumann, T. Quast, J. Rudolph
Helmholtz-Zentrum Berlin für Materialien und Energie (HZB), Berlin, Germany

*Abstract*

The HZB (previously BESSY) was the first institution in Germany to build and operate a dedicated synchrotron light source (BESSY I). About 10 years ago BESSY II, a third generation synchrotron light source, was commissioned and is very successfully running since that time. Due to its expertise in development and operation of accelerator facilities HZB is ideally suited to realize new accelerator concepts. Therefore HZB is proposing to build a demonstrator ERL facility (B*ERL*inPro) that will realize high current and low emittance operation at 100 MeV. B*ERL*inPro is intented to bring ERL technology to maturity. This paper presents an overview of the project and the key components of the facility.

## GOALS OF THE B*ERL*inPro: ADDRESSING THE CHALLENGES OF ERLS

ERL specific issues revolve primarily around the fact that an ultra-low-emittance beam must be generated at storage-ring-level currents that then is accelerated to full energy without emittance dilution. It must also be demonstrated that efficient energy recovery is possible, even when the beam's energy spread is increased. Nearly all components along the linac are impacted by these unique operating conditions. While not all aspects can be covered exhaustively, the following are key areas which the B*ERL*inPro program will concentrate on.

### *CW SRF Cavity System*

The high average current in an ERL requires a CW machine operation. Together with the need for a high gradient in the RF cavities superconducting accelerating technology is a key aspect for ERLs. The basic superconducting linac technology has been developed and demonstrated with great success in facilities such as FLASH, which uses pulsed TESLA technology [1]. For several years, extensive studies at HZB/BESSY with HoBiCaT [2] have already served to adapt this to CW operation [3]. Other institutes, such as Cornell University, FZ Dresden-Rossendorf and Daresbury Laboratory have also been modifying various aspects of TESLA technology for CW linacs. It will therefore also provide the baseline for B*ERL*inPro.

**Electron source** A variable ERL source must be able to provide an average current of order 100 mA, with approximately 50-100 pC bunch charge at a GHz repetition rate and a normalized emittance better than 1 mm mrad. SRF photoinjectors have the greatest potential and flexibility, as they are able to operate at 100% duty factor and can generate significantly higher fields than (CW-operated) normal conducting RF and DC systems. One of the primary goals of the B*ERL*inPro facility will therefore be to demonstrate that a high brightness, high-average-power electron beam can be generated and maintained by a photo-driven SRF gun. Main challenges are the cathode system and its implementation in the gun cavity, cathode lifetime and handling and the achievement of highest accelerating fields by employing appropriate treatment techniques.

**Injection System** The injection linac is a short acceleration section that boosts the beam energy from the gun to approximately 5-10 MeV. This beam energy is not recovered. Consequently, the booster module must provide the full beam power (500-1000 kW at 100 mA), placing stringent boundary conditions on the SRF hardware and the beam dynamics. The voltage provided by each cavity is limited by the average RF power that can be coupled to the beam, rather than the achievable peak field. Thus suitable high-average-power RF sources must be developed as well as an RF input coupler system capable to handle the large thermal loading, operating with more than 100 kW RF power per cavity.

**SRF Main Linac** The SRF main linac does not only accelerate the electrons but also decelerates them after "usage" for energy recovery, so that the effective beam loading is negligible.

Common to the booster, the cavities must handle a large current. For ps long bunches higher order mode (HOM) power in the order of 100 W/m can be generated, with a frequency spectrum out into the 100 GHz range. Optimizing the cavity shape and number of cells is an important method to reduce the HOM power in the first place. The remaining HOM power must be extracted with specialized HOM absorbers in the cryostat, guaranteeing the efficient power extraction with minimum beam disruption.

The main linac of an X-ray ERL represents by far the dominant cryogenic load and hence is a significant cost driver both in terms of capital investment and operating costs. For the feasibility of future ERL facilities, it must be demonstrated that lowest-loss (high Q-factor) cavities can be produced and operated over the long term in an ERL system.

### *Beam Dynamics*

One of the ERL's advantages is the fact that emittance and bunch length do not arise from an equilibrium condition like in storage rings but are defined by the source and

* contact: Andreas.Jankowiak@helmholtz-berlin.de

by bunch manipulation techniques. Therefore the challenge is to generate, accelerate and transport an electron beam of ultra high density from the source through the accelerator to the place of the beam experiment.

**Emittance** To reach smallest emittances an 'emittance compensation scheme' for the entire injection path, from the gun through booster and merger to the entrance of the linac, has to be developed. Especially the merger with space charge dominated beam transport trough a dispersive section is challenging. Although the energy is higher, reducing the space-charge effects, also for the ERL recirculator potential emittance dilution sources have to be carefully investigated. Coherent synchrotron radiation gains in importance due to the strong dipoles and short pulses. Nonlinearities in beam transport and acceleration needs to be studied and compensated when required.

**Bunch Length** A great strength of ERLs is the operation with ultra-short bunches. Bunch compression at B*ERL*inPro will primarily be performed in the recirculator to avoid emittance growth in the low-energy beam transport and to minimize HOM excitation in the main linac. Conventional dipole chicanes and compression in the recirculator's return arcs are approaches currently studied. Modest velocity bunching in the booster and compression in the merger is also considered.

**Energy Recovery** The key point for operating an ERL with high average current is a maximum recovery of the invested energy. A very low loss rate during recirculation, requiring a large longitudinal and transverse acceptance as well as good vacuum conditions, is a necessary condition for this. Options for path length adjustment have to be foreseen to ensure the optimal phase on the decelerating linac passage.

**Collective Effects** At high currents several collective effects can disturb or even cause complete beam loss in the ERL. The Beam Break-Up (BBU) instability arises from the resonant excitation of higher order modes in the linac cavities that kick the beam out of the axis. Ion trapping in the electron beams potential over the whole ERL adds extra focusing and nonlinear forces, and increases the residual gas pressure seen by the beam. Both effects have to be investigated to find a design offering sufficient stability also at highest currents.

## DESCRIPTION OF THE B*ERL*inPro FACILITY

As shown in Figure 1, B*ERL*inPro will be located in an extension of an existing assembly hall (Schwerlasthalle). The main B*ERL*inPro parameters are listed in Table 1.

The Schwerlasthalle also houses the HoBiCaT facility which already is used extensively for off-line cavity and subsystem testing in collaboration with DESY, FZD, Cornell, CEA-Saclay and INFN Milano. Recently HoBiCaT was extended by 7 m to provide sufficient room to set up an SRF photoinjector test stand to enable electron source development prior to the construction of B*ERL*inPro. An

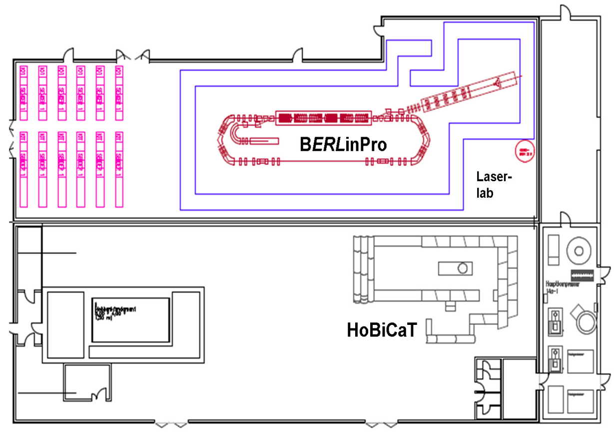


Figure 1: Layout of B*ERL*inPro in the extension to the existing Schwerlasthalle.

upgraded cryogenic plant has been installed next to the Schwerlasthalle to provide sufficient helium liquefaction to operate B*ERL*inPro. An important first stage of the B*ERL*inPro program will be the in-depth development of an optimized layout. An SRF photoinjector will serve as the beam source. A combination of RF focusing and solenoidal field provides the first stage of the emittance compensation scheme, which continues through a booster module. The beam must then be inserted into the main linac at a small angle, which is accomplished with a merger section consisting of several bending magnets. The main-linac acceleration to 100 MeV is provided by a 1.3 GHz superconducting module to be developed. Recirculation is done in a race-track configuration through optics with a high degree of flexibility to configure B*ERL*inPro for the various studies. Finally the beam is extracted after deceleration into a high power beam dump. Importantly, the B*ERL*inPro site is chosen in such a manner, that a second recirculation arc can be implemented in a future upgrade of the facility.

### *Electron Source*

For B*ERL*inPro an SRF photo-electron gun will be developed in a staged approach [4]. Design parameters for the final gun will be an energy gain of up to 1.5 MeV, an average current of 100 mA and a beam emittance of lower than 1 mm mrad at 77 pC bunch charge. Beyond these requirements, issues such as dark current and long-term reliability are critical to the success of an ERL facility.

The first stage of the gun development aims to the design of an all-superconducting, high-brightness SRF gun with

Table 1: Main Parameters of B*ERL*inPro

| | |
|---|---|
| maximum beam energy | 100 MeV |
| maximum beam current | 100 mA |
| nominal bunch charge | 77 pC |
| maximum repetition rate | 1.3 GHz |
| normalized emittance | $<$ 1 mm mrad |
| cryogenic load at 1.8 K | 240 W |

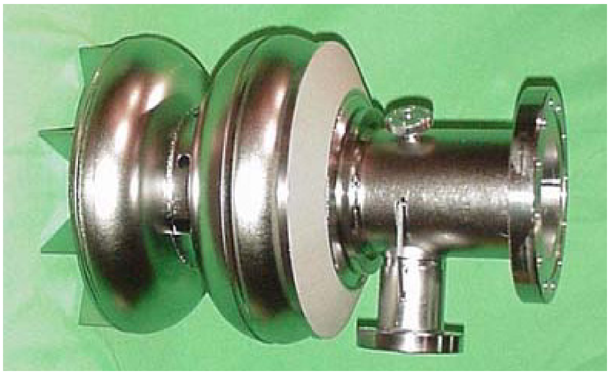

Figure 2: The Pb coated gun cavity.

an average current below 1 mA. This gun contains a 1.6 cell 1.3 GHz SRF gun cavity. The back wall has a small area coated with Pb used as the photocathode (see Figure 2).

For the next stage a SRF gun cavity with NC cathode insert is foreseen. There a CsK2Sb cathode will be employed to reach an average current of 10 mA. For the final stage RF couplers for 150 kW average power level will be added to the gun design opening the door to operate at 1.5 MeV with 100 mA average current.

### *Booster RF System*

Cornell University recently developed a booster module for 5-10 MeV operation [5]. First beam tests are under way [6] and this system will likely be adopted for B*ERL*inPro. Five 2-cell 1.3 GHz cavities, fed by two input couplers each, deliver 750 kW to the beam. Both the booster and photoinjector RF systems are currently limited by the capability of the 75 kW input couplers.

### *Main Linac Acceleration Module*

First steps in developing CW capable systems have already been performed by HZB in developing the BESSY-FEL modules [7, 8], although these were designed for low-current operation.

Plans now call for a collaborative development of a high-current, low-beam-loading module. Universität Rostock, Universität Dortmund and HZB recently started a collaborative work on cavity designs based on multiple waveguide absorbers for HOM damping. The Jefferson Lab high-current design is serving as a baseline [9]. Studies for the reduction of cryogenic losses have been started, concerning the optimization of the cavity shape, the trapped magnetic flux and the employment of better magnetic shields. For many of these investigations, HoBiCaT is used for off-line tests on the complete cavity units. The cavities will operate at less than 20 MV/m for 100 MeV beam energy. As measurements in HoBiCaT have shown, Q-factors in the order of $3 \cdot 10^{10}$ are possible in this case [10].

The required peak and average RF power budget is determined by the expected microphonic detuning of the cavities. It has been demonstrated at HoBiCaT that the detuning can be compensated by active means (fast piezo-electric stacks incorporated in the tuner) [11]. While a robust and automated system still needs to be developed, we are confident that such a system will be sufficient to ensure that all cavities can be operated at less than 20 Hz peak detuning with a peak RF power of 5-10 kW. The RF system will consist of individual solid state transmitters for flexibility, reliability and narrow-bandwidth operation.

BESSY-II's cryogenic system has sufficient capacity on the 4.2 K level for B*ERL*inPro. For cooling to 1.8 K an additional sub-cooling unit will be installed, consisting of a combination of warm and cold compressors.

## OUTLOOK

A first prototype of an SRF gun is currently being installed at the HoBiCaT facility and will be commissioned starting at the end of this year. Depending on funding decisions the realization of the project will start in 2011. First beam recirculation is planned for the end of 2015.

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