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Incorporation of a MESA linac module into bERLinPro

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Abstract. bERLinPro is an Energy Recovery Linac (ERL) project, currently being set up at the Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin, Germany. bERLinPro is designed as - and for - experiments in accelerator physics and as a test bed for novel ERL components. MESA is an ERL project under construction at the Johannes Gutenberg-Universitt, Mainz, Germany. MESA is designed as a user facility to perform experiments in dark matter physics and precision measurements of natural constants. Despite the diverse goals, the main linac, providing the larger part of the particles energy, is fairly compatible. It is planned to test and run the MESA linac module in bERLinPro, prior to its usage in MESA. The goals and benefits of this unique cooperation for both projects are outlined in this paper. The necessary adaptions in bERLinPro, including hardware aspects, the new optics, and the scope of performance are described.

1. Introduction

The goal of bERLinPro is the production of high current, low emittance cw beams and to demonstrate energy recovery at unprecedented parameters, [1]. The three stage acceleration consists of an SRF photon gun, an SRF booster linac with an extraction energy of 6.5 MeV and an SRF main linac module equipped with three 7-cell HOM damped cavities. All magnets and the vacuum system of the low energy injector and dump line are installed, figure 1. Commissioning of the diagnostic line and the low energy part of the machine, i.e. gun / booster / linac replacement straight / dump line, is planed for spring 2020, figure 2. Many of the projects target parameters, as listed in table 1, can be shown with this setup already. Although the design bunch charge of 77 pC can be reached, the design current of 100 mA requests a further gun cavity with elaborate high power input couplers. The energy of 50 MeV can only be reached with a linac module designed for high current with adequate HOM dampers. Unfortunately, the design and construction of the main bERLinPro linac had to be postponed due to the prioritization of a parallel running project at BESSY II.

MESA is a 2-turn ERL project currently under construction at Mainz University, [2]. The target parameters of MESA are listed in table 2. It utilizes a 100 keV polarized DC photon gun, a normal conducting injector linac with an extraction energy of 5 MeV, and two superconducting linac modules equipped with two 9-cell TESLA/XFEL cavities and an energy gain of 25 MeV

Figure 1. Installation of bERLinPro in subterranean hall.

each, located in the straight sections of the racetrack type recirculating loops, figure 3. The different energy arcs are vertically stacked. Both main linac modules have been delivered to Mainz University, and module tests are ongoing. Due to the necessity of the extension of the existing subterranean halls, the installation of the modules at their final location had to be postponed to 2022. This opens up the gap for the planned collaboration.

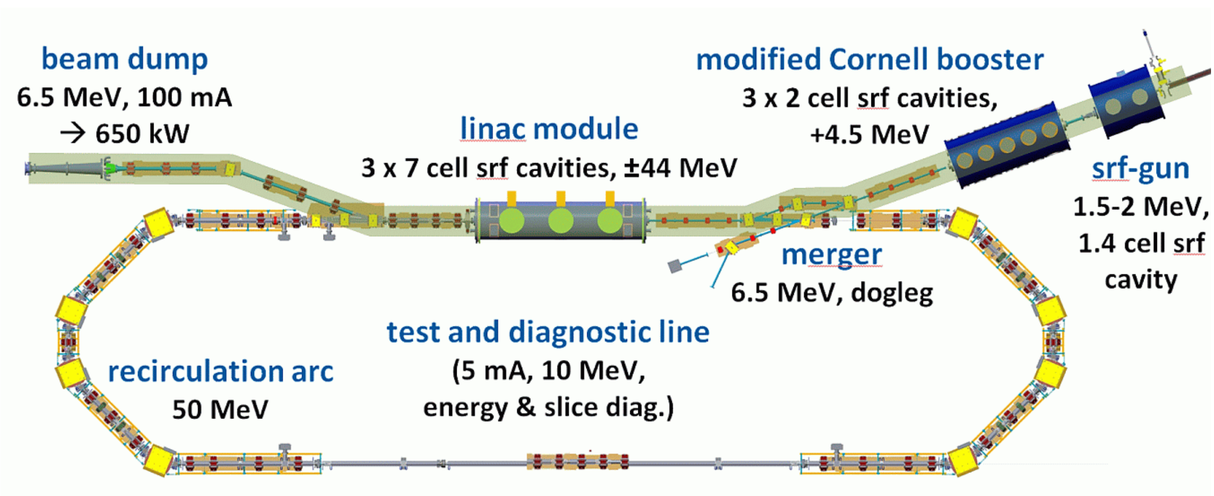

Figure 2. Layout of bERLinPro: The low energy part is highlighted in green.

Table 1. bERLinPro Target Parameters

max. beam energy		
gun / booster / recirc.	2.5 / 6.5 / 50.0	MeV
max. avarage current	100	mA
norm. emittance	<1.0	pi μrad
bunch length	2.0	ps
repetition rate	1.3	GHz

Table 2. MESA Target Parameters

max. beam energy		
gun / booster / recirc.	0.1 / 5 /105-155	MeV
max. avarage current	0.15-1.0	mA
norm. emittance	<1.0	pi μrad
bunch length (rms)	1	ps
repetition rate	1.3	GHz

As bERLinPro is designed to show energy recovery for high current (100 mA) beams, the damping of higher order modes in the SRF linac is demanding and led to a new design of the HOM-couplers [3]. MESA is planned for 1 % of the bERLinPro current, with a possible upgrade to 10 mA. For the HOM-damping the same technology as used at ELBE or XFEL is in operation. Nevertheless, with the MESA linac module, recirculation of the beam at 32 MeV and some mA can be demonstrated at bERLinPro, and many valuable studies can be performed for cw beams and down to single pulse operation: Excitation and damping of higher order modes for different bunch patterns, beam currents, accelerating fields and electron pulse conditions; limitations of beam current, such as heating of the HOM antenna; the response of the cavities to current changes and to ramping up and down the ERL mode; transverse and longitudinal beam-break up (BBU); test and improvement of the LLRF systems; halo and beam emittance studies, to mention just a few.

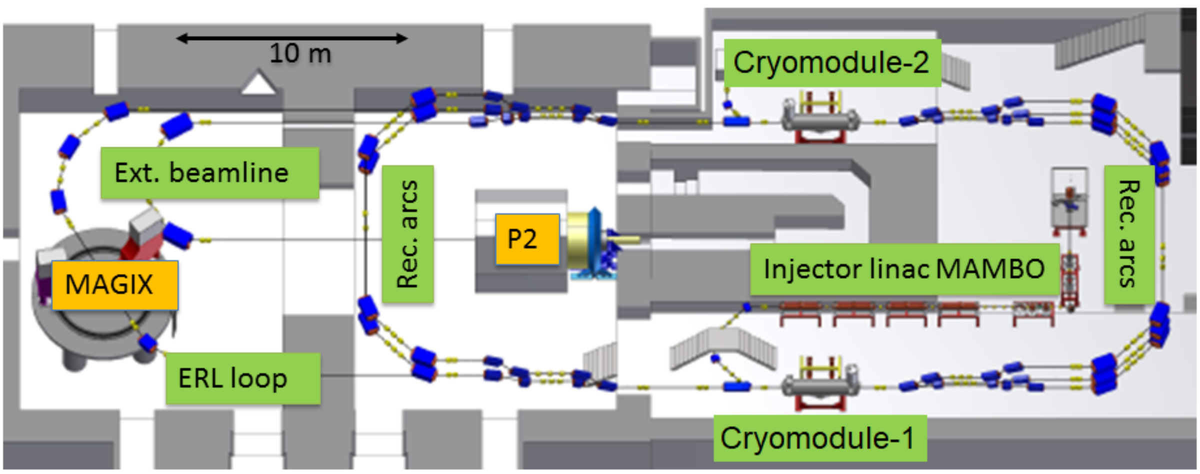

Figure 3. Layout of MESA.

2. The MESA LINAC MODULE

The MESA module is produced by industry and based on the design of the Rossendorf SRF linac module, figure 4, [4]. It hosts two 9-cell Tesla cavities. Compared to the Rossendorf module, several improvements have been implemented. The improved HOM-dampers consist of a notch-filter and a coupling antenna. The out-coupled HOM power is transferred to the outside of the module by a cable and dumped afterwards. Quenching of the antenna is considered as the limiting factor of this system. For that reason an improved thermal connection of the antennas to the 1.8 K Helium-vessel has been developed using sapphire-feedthroughs for the antennas as well as a copper strip line for direct cooling of the inner conductor [5, 6]. In addition, studies investigating the estimated BBU limits for MESA have been carried out resulting in BBU threshold currents in the 10 mA-range [7, 8]. Therefore, HOMs will most probably limit the maximally achievable current in the planned experiments at bERLinPro, either by BBU or by HOM-antenna heating. Furthermore, the tuning system has been equipped with additional piezo controllers for fast tuning of the resonant frequency of the cavities. Therefore the XFEL/Saclay tuner is used for MESA which combines a spindle lever system for slow tuning with an additional piezo actuator support. Two cryomodules have been fabricated for MESA and are under test at Mainz at the moment. In vertical test all cavities exceeded the design gradient of 12.5 MV/m reaching up to 35 MV/m [6]. In MESA operation the gradient is mainly limited by cryogenic losses. The input couplers can sustain 15 kW of forward power in cw operation and the forward coupling is fixed to $Q_L = 1.38 \cdot 10^7$. This would allow much higher gradients than planned for MESA in the presented bERLinPro experiment, as there is much more cryogenic power available at Berlin.

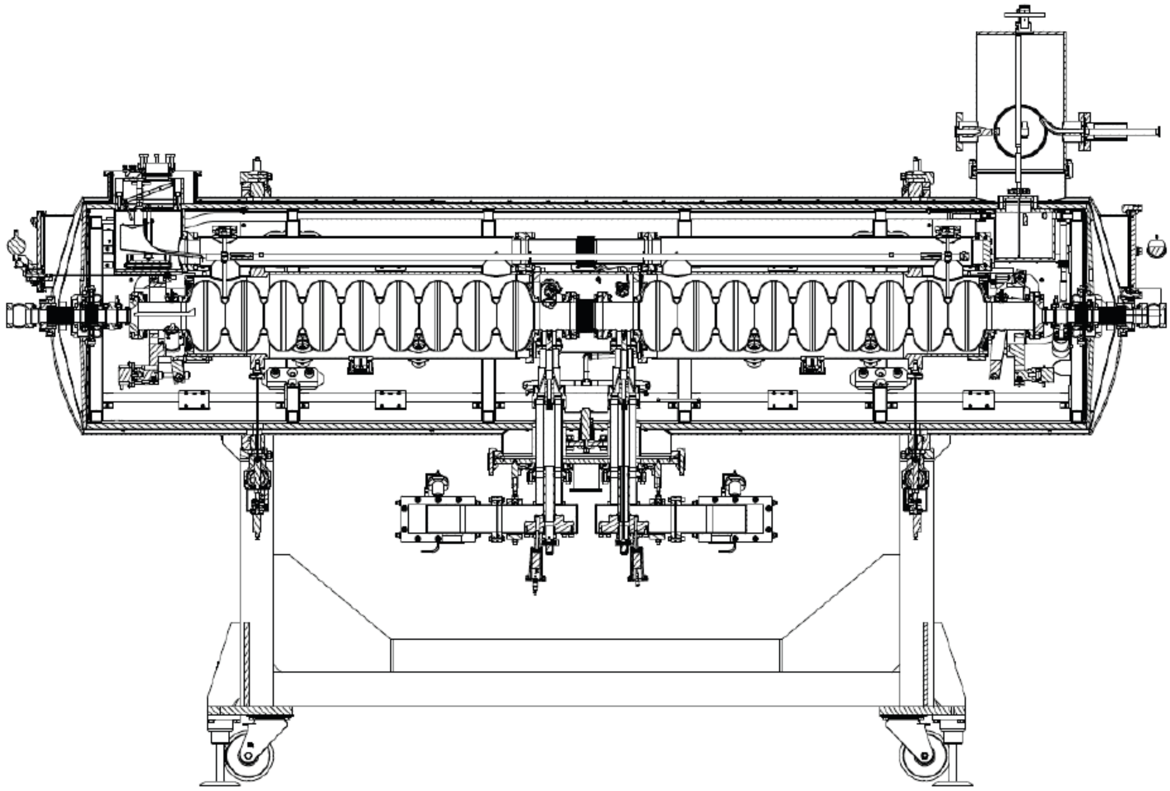

Figure 4. Sketch of the MESA module. Geometric dimensions: 3.45 m, 2.675 m (height, including LN_2 valve), 1.05 m (maximum width of girder). Beam height: 1.4 m.

3. INSTALLATION ASPECTS

3.1. Module

The straight section for the integration of the linac module extends over 5.77 m, enough space for the 3.45 m long module. Due to the different heights of beamlines (1.2m bERLinPro, 1.4m MESA), a new girder for the module is needed. The reduced anticipated peak field on axis of the MESA cavities of 23.1 MV/m, compared to 34.6 MV/m for bERLinPro leads to a strong reduction of the RF focusing strength, which can be corrected for by smaller optics changes.

3.2. Cryogenics

The cryogenic power consumption of the MESA module is lower than what is planned for bERLinPro and therefore is of no concern. No permanent LN_2 supply is available in the bERLinPro hall, but is need for the LN_2 shield of the MESA module. With an LN_2 inventory of 20 liter, the losses are <100 liter/day, so manual refilling is feasible. Losses to the LHe bath in cw operation amount to <46 watt at 12.5 MV/m. The MESA RF test stand for horizontal module tests utilizes a 350 liter dewar for refilling the MESA module from the top. The liquid Helium supply at HZB will be realized by a feedbox from the side, so cryogenic multi-transfer lines have to be adapted to feed the MESA module. The difference in the security pressure limits of the two modules needs to be taken care of by additional security elements in the transfer lines; interfaces have to be defined.

3.3. RF

The RF infrastructure is existing at HZB and can be adapted to the MESA module. Only some coaxial RF-lines need to be adjusted.

3.4. Optics

Generally, single particle optics are independent of the particles energy to first order, except for the scaling of gradients. When introducing the MESA module into the bERLinPro optics, differences do arise in the strength of the RF focusing in linac cavities and in the strength of the edge focusing of the splitter and the merger chicane dipoles. Here the field is set by the injection/dump energy of (6.5 MeV) while the deflection angle is determined by the energy after acceleration. To compensate for the lower RF focusing, the field of the quadrupoles between booster and splitter chicane was slightly increased ($\approx$ 1 %). To compensate for the stronger edge focusing in the splitter magnets, the vertically focusing quadrupoles behind the splitter and in the first arc where reduced in strength. With few further adaptions, the beam could be recirculated and dumped.

The traveling time through the recirculator has to ensure a phase advance of 180 at the re-entrance to the linac for complete energy recovery. The path length is energy dependent in the particle velocity and the deflection of the beam in the chicanes. The total decrease in the path is 7.68 mm for 32 MeV , within the reach of the path length correction chicane. The maximal displacement in the chicanes is 55 mm out of 80 mm good field region.

The optics and the beam parameters at the center of the straight section are shown in figure 5 and table 3. Compared to the bERLinPro optics, the emittance decreases horizontally by 12 % while it increases vertically by 14 %, still well below the 1 pi mm mrad design goal. The bunch length decreases by 5 %. It is noticed, that, different to the original 50 MeV optics, the beam is now space charge effected through the complete machine. Ongoing CSR studies indicate an increase of the horizontal emittance due to CSR losses, that diminishes with increasing energy and is not observed for the bERLinPro optics.

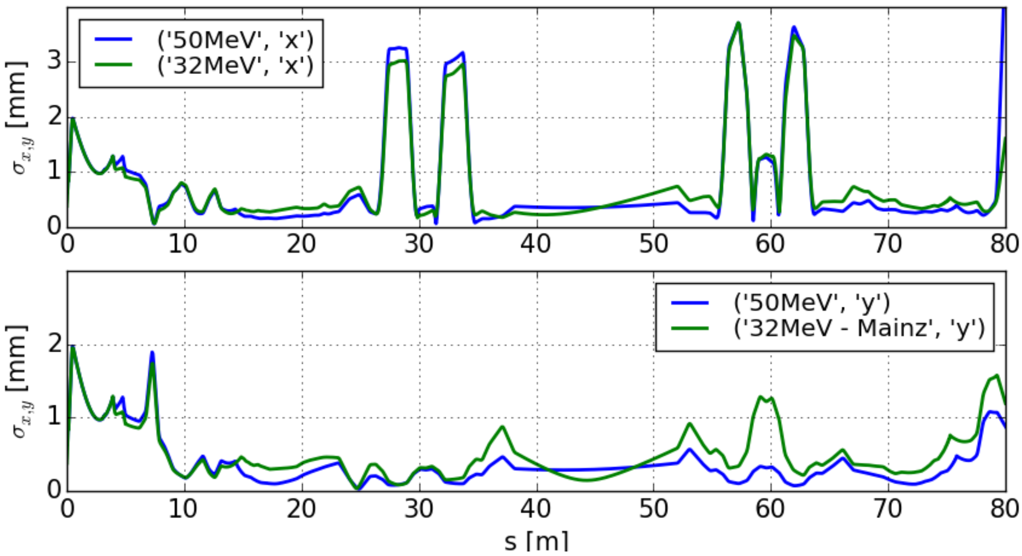

Figure 5. Comparison between the bERLinPro optics (blue) and the new optics using the MESA module (green). The performance is quite comparable.

Table 3. bERLinPro Parameters using the MESA module

max. beam energy		
gun / booster / recirc.	2.5 / 6.5 / 32.0	MeV
max. avarage current	5	mA
norm. emittance	0.65	pi μrad
bunch length	1.9	ps

4. CONCLUSION

The unique collaboration between the Johannes Gutenberg-Universitt in Mainz and the HZB is outlined. It consists of installing the MESA main linac module for a period of ≈2 years in the bERLinPro machine. While Mainz's interest in the collaboration is to test the module for a variety of beam patterns and currents, including investigations on HOM antenna heating, BBU in ERL operation and improvement of LLRF systems for high current operation, bERLinPro is enabled to show energy recovery, although at lower beam currents than planned, and start with the commissioning program much earlier than expected. bERLinPro is designed as an experiment and a test facility in accelerator physics. This testing of the MESA module perfectly suits this intention. bERLinPro utilizes an unprecedented option for the community to test diverse equipment under realistic beam conditions.

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