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PREPARATION FOR COMMISSIONING WITH BEAM OF THE ADVANCED DEMONSTRATOR MODULE WITH HEAVY ION BEAM

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Abstract

The integration of the accelerator components in to the cryogenic module prototype (Advanced Demonstrator) is a major milestone of the R&D for the superconducting heavy ion continuous wave linear accelerator **HE**lmholtz **LI**near **AC**celerator (HELIAC) at GSI. The HELIAC is a joint project of Helmholtz Institute Mainz (HIM) and GSI developed in collaboration with IAP Goethe University Frankfurt. This module is equipped with three **super****c**onducting (sc) **C**ross bar **H**-mode (CH) acceleration cavities CH0-CH2 and a sc rebuncher cavity, as well as two sc solenoids. The commissioning of the cryogenic module with Argon beam at GSI is scheduled for August 2023. In preparation for the beam test activities, the beam line, which connects the High Charge State Injector (HLI) with the testing area, has been installed. The beamline comprises a pair of phase probes for **T**ime **O**f **F**light (TOF) measurement of the incoming beam energy, quadrupole lenses and a 4-gap RF-buncher cavity. The beam diagnostics bench behind the cryo module is equipped with phase probe pairs, a slit grid device, a **B**unch **S**hape **M**onitor (BSM Feshenko monitor) for measurements of the longitudinal beam profile. The bench allows complete 6 d characterization of the ion beam.

INTRODUCTION

The design and construction of continuous wave (cw) high intensity Linacs is a crucial goal of worldwide accelerator technology development [1]. In the low- and medium-energy range, cw-Linacs can be used for several applications and user experiments, as **A**ccelerator **D**riven **s**ubcritical nuclear reactor **S**ystems (ADS) [2, 3], synthesis of **S**uper **H**eavy **E**lements (SHE) [4] and material science. In particular the increased projectile intensity, preferably in cw mode, would remarkably improve the SHE yield. The need for compactness and energy efficiency of such cw facilities requires the use of superconducting (sc) technology in modern high intensity ion linacs [5–9]. For this purpose the heavy ion **super****c**onducting (sc) cw linear accelerator HELIAC)is developed at GSI Helmholtzzentrum für Schwerionenforschung at Darmstadt and Helmholtz Institute Mainz (HIM)[10, 11] under key support of Institut für Angewandte Physik (IAP) of Goethe University Frankfurt (GUF) [12, 13].

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Table 1: General Characteristics of the HELIAC Accelerator

Property	Value
Frequency	108.408 MHz (216.816 MHz[1])
Mass-to-charge ratio	≤ 6
Repetition rate	Continuous wave
Beam current	≤ 1 mA
Output energy	3.5 MeV/u to 7.3 MeV/u
Injector energy	1.4 MeV/u
Normal conducting cavities	5
Superconducting cavities	12

[1] SC CH cavities operate at the second harmonic

Table 1 shows the key parameters of the HELIAC. Heavy ion beams with a mass-to-charge ratio up to $A/z = 6$ will be accelerated by twelve multi-gap CH cavities, operated at 216.816 MHz. The HELIAC should serve for physics experiments, smoothly varying the output particle energy from 3.5 to 7.3 MeV/u and simultaneously preserving high beam quality [14].

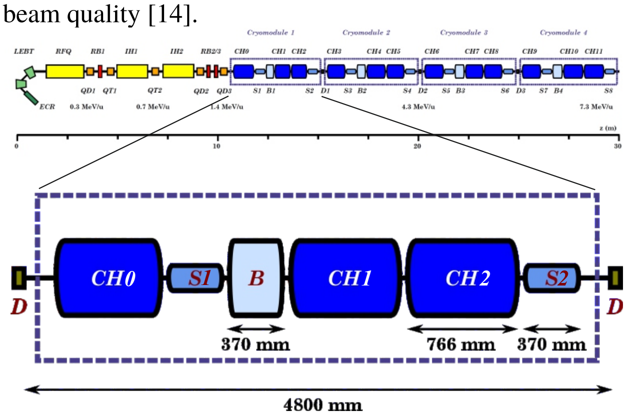

Figure 1: Layout of the HELIAC (top) and of the first cryogenic module i.e. "Advanced Demonstrator" (bottom).

Figure 1 shows the schematic layout of HELIAC, it comprising of ECR source, warm injector LINAC [15, 16] and four cryogenic modules [17].

Following the successful beam test of the first cavity cavity (CH0) within the Demonstrator [6, 10, 18] research project, the next step towards realization of HELIAC is the development, manufacturing and operation of the first cryogenic module (CM1) within the "Advanced Demonstrator" project [18]. As shown in Fig. 1 it contains the demonstrator cav-

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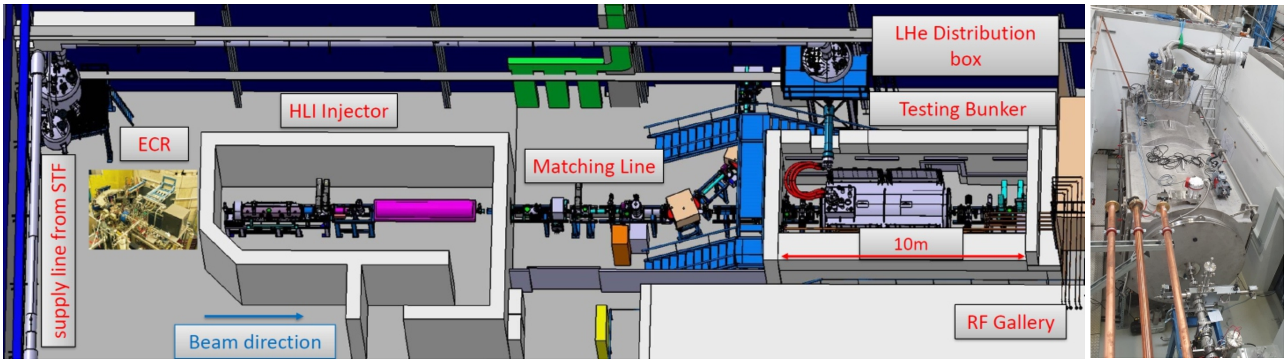

Figure 2: 3d Model of the testing area at GSI (left) and photograph of cryostat installed in testing area.

ity CH0 [19] , two identical CH1 & CH2 cavities [20], a two-gap re-buncher cavity (B) [21, 22] and two identical sc solenoids S1 & S2).

CRYOGENIC MODULE TESTING AREA AT GSI

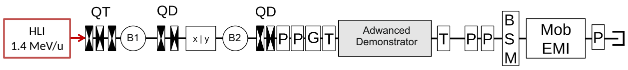

Figure 3: Schematic layout of matching line and beam diagnostic test bench.

For stable 4 K operation of the entire cw-Linac HELIAC a cryo plant with 240 W total cooling power@4K is required. The cryo plant of the GSI-Series Test Facility (STF) has a cooling capacity of 700W and is already in operation for testing of superconducting SIS100 dipole magnets for FAIR project. After the magnet testing will be finished, the cryo plant is foreseen to supply mainly the HELIAC. Figure 2 (left panel) shows a 3d model of Helium transfer lines and the distribution boxes in the testing area. The LHe distribution box supplies the test area with liquid Helium. The commissioning of the He-supply infrastructure has been accomplished in the 3rd quarter of 2020. In preparation for further beam test activities, the beamline, which connects the "GSI-**H**och**l**adungs**I**njektor" (HLI) with the testing area, was installed. Figure 2 (right panel) shows the installed cryostat within the radiation protection shelter.

Figure 3 displays the schematic layout of the matching line between HLI and cryogenic module testing area. The beamline comprises current transformers, a pair of phase probes for TOF measurement of the incoming beam energy, quadrupoles and two steering magnet pairs enabling transversal matching and two 4-gap RF-buncher cavities for longitudinal matching. Furthermore, new collimating slits (in horizontal and vertical plane) in front of the test area were installed in order to enable for beam-based alignment of the cryogenic module . The slits cut out the beam halo and potentially can produce a pencil like beam. The beam diagnostics bench behind the cryostat is equipped with phase probe pairs, a slit-grid device, a **b**unch **s**hape **m**onitor (BSM-Feshenko monitor)[23] for measurements of the longitudinal beam profile. This setup allows complete 6d characterization of the ion beam. In 2021 two test beam times were successfully accomplished. During the first run the BSM was commissioned. The measured longitudinal profiles for different rf-amplitudes of two bunchers could be used for the reconstruction of the 2d longitudinal distribution [24] at the exit of HLI. The projection of the reconstructed distribution shows excellent agreement with measurements of another BSM monitor, installed temporary at the exit of HLI. Additionally, the longitudinal profile has been measured with a novel fast Faraday cup; the agreement with the BSM monitor measurement [25] is excellent as well.

The second run was dedicated to the commissioning of cryostat and the sc solenoids. Among others a key criteria for successful site acceptance test of the cryostat is the fidelity of transversal positioning with respect to the beam axis of the accelerator components during evacuation of the isolation vacuum and during the cool down phase. Prior beam test the position of temporarily installed cross hair targets - fixed on entrance and exit of both solenoids – could be measured during evacuation and cool down with a dedicated telescope equipped with a CMOS camera. The analysis shows a movement of components during evacuation and cool down in transversal plane less than 0.1 mm, which is within the cryostat specification. After removal of the target, the cryostat has been integrated into the beam line and could

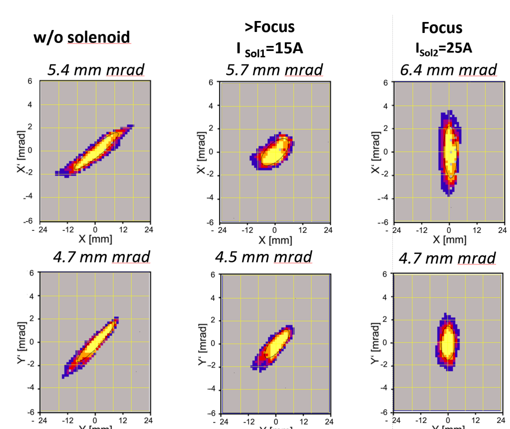

Figure 4: Transverse beam emittance.

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be cooled down again. The electrical functionality of both solenoids and their current leads were proven by ramping up to the maximal design current of 100 A. The beam was successfully focused on the profile grid behind the set up. Under the influence of the solenoids, the beam was only slightly displaced. It was possible to compensate the offset by gentle excitation (<1 A) of the steering coils, integrated in the solenoid. Figure 4 shows the measured emittance of an Ar^{8+} beam behind the cryostat without and with subsequently excited solenoids. The measured emittance growth is negligible, so that the functionality and quality of the solenoids is fully validated.

ASSEMBLY OF COLD STRING IN CLEAN ROOM AT HIM

The recent build laboratory of the **H**elmholtz **I**nstitute **M**ainz (HIM) comprises amongst other things a **c**lean**r**oom (CR), which is dedicated as part of the infrastructure for the SRF projects at GSI in Darmstadt and Johannes-Gutenberg University (JGU) in Mainz [26]. The clean room without further equipment and other auxiliary installations was already put into operation in November 2015. It features a heavy duty aluminum double floor, capable for up to 5 tons per square meter and a rail system through its different zones in order to roll out a complete cold-string. In the basement of the HIM building a water treatment plant with a 5000 L storage tank provides 2500 L/h ultra pure water with a resistivity of 18 MΩ cm) supplying the clean room. Besides different locks the clean room is mainly divided into two parts: a 42 m^2 ISO-class 6 area (CR1) for cleaning and preparation, and a 43 m^2 ISO-class 4 (CR2) area, designated for drying and assembly. The CR1 contains an ultrasonic bath with a volume of 1 m^3 and a conductance rinse bath of the same volume. The High Pressure Rinsing cabinet has been installed in the dividing wall between the CR1 and CR2. Besides those large permanent installations the clean room is equipped with additional smaller tools such as ionized nitrogen spray guns, other smaller US baths, a clean room dishwasher, particle counters, wet and dry CR-vacuum cleaners and two lift trolleys, used to lift and transport heavy objects, besides perforated stainless steel tables, shelves and trolleys.

Figure 5 shows 3d model of the cold string for CM1 as to be assembled in clean room. The main components of the cold string i.e. the cavities, solenoids and vacuum valves subassembly are supported with trolley stands and should be successively assembled together. The main components,

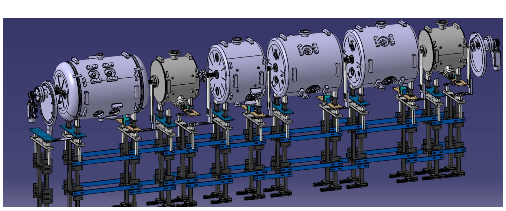

Figure 5: 3d Model of cold string assembly in clean room.

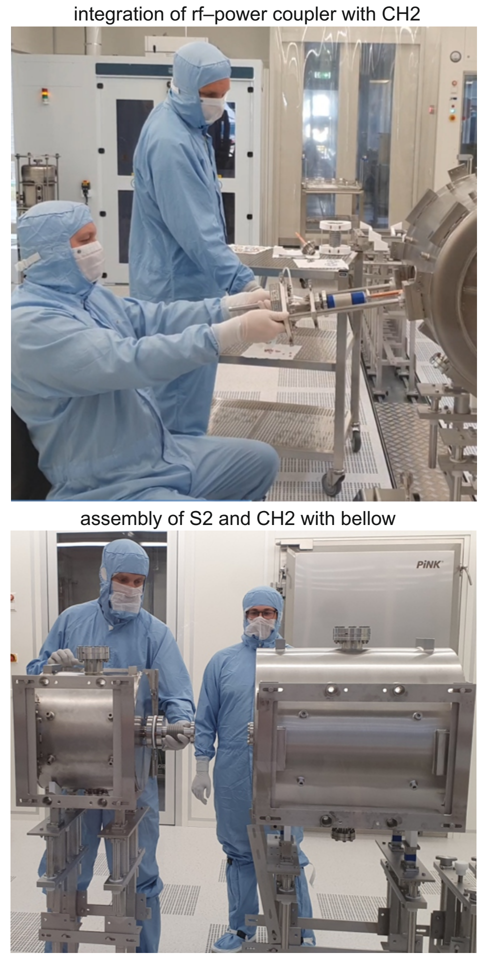

Figure 6: Integration of rf-power coupler into CH2 cavity (top panel) and interconnecting the CH2 and S2 with bellows (bottom panel) in clean room CR2 .

bellows and fastener are cleaned just in time in preparation for the next step, intrinsically the stockpiling of the cleaned components leads to contaminations with particulates.

The upper panel of Fig. 6 shows the integration of the rf-power coupler [27] into the CH2 cavity, the bottom panel displays the interconnection of CH2 cavity and vacuum below with the solenoid S2.

OUTLOOK

The assembly of the cold string and integration into the cryostat is scheduled for Q4 2022, the installation at GSI-testing area and cryogenic commissioning for Q1 of 2023, followed by rf conditioning and commissioning of the low level rf system. The CM1 commissioning with beam is scheduled for Q3 of 2023. A variety of different activities for the realization of the HELIAC project is still ongoing: R&D on 18 GHz ECR ion source, prototyping of a cw capable RFQ, manufacturing of an APF cw IH-DTL [15, 16], specification of cw capable high power rf-amplifiers for warm injector linac, purchasing of CM2&3 -cavities, manufacturing of the CM2 cryostat, preparation of the linac tunnel, final layout of the beam transfer line to experimental area, detailed specification of beam line magnets and power supplies.

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REFERENCES

[1] C. R. Prior, "Overview of high intensity accelerator projects," in *Proc. HB'10*, Morschach, Switzerland, 2010, pp. 6–10.

[2] Z.-J. Wang *et al.*, "Beam commissioning for a superconducting proton linac," *Phys. Rev. Accel. Beams*, vol. 19, p. 120 101, 12 2016. doi:10.1103/PhysRevAccelBeams.19.120101

[3] S. M. Polozov and A. D. Fertman, "High-energy proton beam accelerators for subcritical nuclear reactors," *Atomic Energy*, vol. 113, no. 3, pp. 192–200, 2013. doi:10.1007/s10512-012-9616-4

[4] J. Khuyagbaatar *et al.*, "^{48}Ca +^{249} Bk fusion reaction leading to element $Z = 117$: Long-lived α-decaying ^{270}Db and discovery of ^{266}Lr," *Phys. Rev. Lett.*, vol. 112, p. 172 501, 17 2014. doi:10.1103/PhysRevLett.112.172501

[5] I. Mardor *et al.*, "The Soreq Applied Research Accelerator Facility (SARAF): Overview, research programs and future plans," *EPJ A*, vol. 54, no. 5, p. 91, 2018. doi:10.1140/epja/i2018-12526-2

[6] W. Barth *et al.*, "First heavy ion beam tests with a superconducting multigap ch cavity," *Phys. Rev. Accel. Beams*, vol. 21, p. 020 102, 2 2018. doi:10.1103/PhysRevAccelBeams.21.020102

[7] N. Sakamoto *et al.*, "Construction Status of the Superconducting Linac at RIKEN RIBF," in *Proc. LINAC'18*, Beijing, China, 2018, pp. 620–625. doi:10.18429/JACoW-LINAC2018-WE2A03

[8] P. Ostroumov *et al.*, "Accelerator Physics Advances in FRIB (Facility for Rare Isotope Beams)," in *Proc. IPAC'18*, Vancouver, BC, Canada, 2018, pp. 2950–2952. doi:10.18429/JACoW-IPAC2018-THYGBF4

[9] Z. Conway, B. Guilfoyle, H. Guo, M. Kedzie, M. Kelly, and T. Reid, "Progress Toward 2 K High Performance Half-wave Resonators and Cryomodule," in *Proc. SRF'17*, Lanzhou, China, 2018, pp. 692–694. doi:10.18429/JACoW-SRF2017-WEYA05

[10] W. Barth *et al.*, "Superconducting CH-cavity heavy ion beam testing at GSI," *J. Phys. Conf. Ser.*, vol. 1067, p. 052 007, 2018. doi:10.1088/1742-6596/1067/5/052007

[11] S. Yaramyshev *et al.*, "Advanced approach for beam matching along the multi-cavity SC CW linac at GSI," *J. Phys. Conf. Ser.*, vol. 1067, p. 052 005, 2018. doi:10.1088/1742-6596/1067/5/052005

[12] H. Podlech, U. Ratzinger, H. Klein, C. Commenda, H. Liebermann, and A. Sauer, "Superconducting CH structure," *Phys. Rev. ST Accel. Beams*, vol. 10, p. 080 101, 8 2007. doi:10.1103/PhysRevSTAB.10.080101

[13] M. Schwarz *et al.*, "Beam dynamics simulations for the new superconducting CW heavy ion LINAC at GSI," *J. Phys. Conf. Ser.*, vol. 1067, p. 052 006, 2018. doi:10.1088/1742-6596/1067/5/052006

[14] W. Barth *et al.*, "A superconducting cw-linac for heavy ion acceleration at gsi," *EPJ Web Conf.*, vol. 138, p. 01 026, 2017. doi:10.1051/epjconf/201713801026

[15] S. Lauber *et al.*, "An alternating phase focusing injector for heavy ion acceleration," *Nucl. Instrum. Methods A*, vol. 1040, p. 167 099, 2022. doi:10.1016/j.nima.2022.167099

[16] M. Basten *et al.*, "Continuous wave interdigital h-mode cavities for alternating phase focusing heavy ion acceleration," *Rev. Sci. Instrum.*, vol. 93, no. 6, p. 063 303, 2022. doi:10.1063/5.0094859

[17] M. Schwarz *et al.*, "Reference beam dynamics layout for the sc cw heavy ion heliac at gsi," *Nucl. Instrum. Methods. Phys. Res. A*, vol. 951, p. 163 044, 2020. doi:10.1016/j.nima.2019.163044

[18] M. Miski-Oglu *et al.*, "Beam commissioning of the demonstrator setup for the superconducting continuous wave HIM/GSI-linac," *J. Phys. Conf. Ser.*, vol. 1350, no. 1, p. 012 089, 2019. doi:10.1088/1742-6596/1350/1/012089

[19] F. Dziuba *et al.*, "Development of superconducting crossbar-H-mode cavities for proton and ion accelerators," *Phys. Rev. ST Accel. Beams*, vol. 13, p. 041 302, 4 2010. doi:10.1103/PhysRevSTAB.13.041302

[20] M. Basten *et al.*, "Cryogenic Tests of the Superconducting $\beta = 0.069$ CH-cavities for the HELIAC-project," in *Proc. LINAC'18*, Beijing, China, 2019, pp. 855–858. doi:10.18429/JACoW-LINAC2018-THPO072

[21] M. Gusarova, W. A. Barth, S. Yaramyshev, M. Miski-Oglu, M. Basten, and M. Busch, "Design of the two-gap superconducting re-buncher," *J. Phys. Conf. Ser.*, vol. 1067, p. 082 005, 2018. doi:10.1088/1742-6596/1067/8/082005

[22] F. Dziuba *et al.*, "A superconducting 217MHz single spoke cavity for thehelmholtz linear accelerator at gsi," presented at the 31st International Linear Accelerator Conference (LINAC'22), Liverpool, UK, Aug. 2022, paper MOPOGE21, this conference.

[23] S. Gavrilov, A. Feschenko, and D. Chermoshentsev, "Bunch shape monitors for modern ion linacs," *Journal of Instrumentation*, vol. 12, no. 12, P12014–P12014, 2017. doi:10.1088/1748-0221/12/12/p12014

[24] S. Lauber *et al.*, "Longitudinal phase space reconstruction for a heavy ion accelerator," *Phys. Rev. Accel. Beams*, vol. 23, p. 114 201, 11 2020. doi:10.1103/PhysRevAccelBeams.23.114201

[25] R. Singh *et al.*, "Comparison of Feschenko BSM and Fast Faraday Cup with Low Energy Ion Beams," in *Proc. IBIC'21*, Pohang, Rep. of Korea, 2021, paper WEPP16, pp. 407–411. doi:10.18429/JACoW-IBIC2021-WEPP16

[26] T. Kürzeder *et al.*, "Cleanroom Installations for SRF Cavities at the Helmholtz-Institut Mainz," in *Proc. IPAC'19*, Melbourne, Australia, 2019, pp. 2830–2833. doi:10.18429/JACoW-IPAC2019-WEPRB015

[27] J. List *et al.*, "Test and commissioning of the heliac power coupler," presented at the 31st International Linear Accelerator Conference (LINAC'22), Liverpool, UK, Aug. 2022, paper MOPOPA18, this conference.