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STATUS OF THE MESA ERL-PROJECT*

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Abstract

MESA is a recirculating superconducting accelerator under construction at Johannes Gutenberg-Universität Mainz. It can be operated in either external beam or ERL mode and will be used for high precision particle physics experiments. The operating cw beam current and energy in EB mode is 0.15 mA with polarized electrons at 155 MeV. In ERL mode a polarized beam of 1 mA at 105 MeV will be available. In a later construction stage of MESA the beam current in ERL-mode shall be upgraded to 10 mA (unpolarized). Civil construction and commissioning of components like electron gun, LEBT and SRF modules have been started already. We will give a project overview including the accelerator layout, the current status and an outlook to the next construction and commissioning steps.

INTRODUCTION

The Mainz Energy-recovering Superconducting Accelerator (MESA) (layout see Fig. 1) will be a low energy continuous wave (cw) recirculating electron linac for particle and nuclear physics experiments. In the first phase of operation it will serve mainly three experiments.

The main experiment of MESA, run in external beam (EB) mode, where the beam needs to be dumped after being used, will be the fixed target setup P2 [1], whose goal is the measurement of the weak mixing angle (Weinberg angle) by measuring parity violation asymmetry with highest accuracy. Required beam current for P2 is 150 µA with spin-polarized electrons at a maximum energy of 155 MeV.

Additionally, a so called beam-dump experiment (BDX) is planned to run in parallel to P2 [2]. This experiment will be located outside of the accelerator hall in line with the beam dump and is dedicated for searching dark particles, which might be generated dumping the beam of the P2 experiment, benefiting from the massive radiation shielding of the dump, which reduces background to a minimum. The third experimental setup will be the high resolution two-arm spectrometer facility MAGIX [3], which uses a gas jet target [4] and can be run in ERL mode.

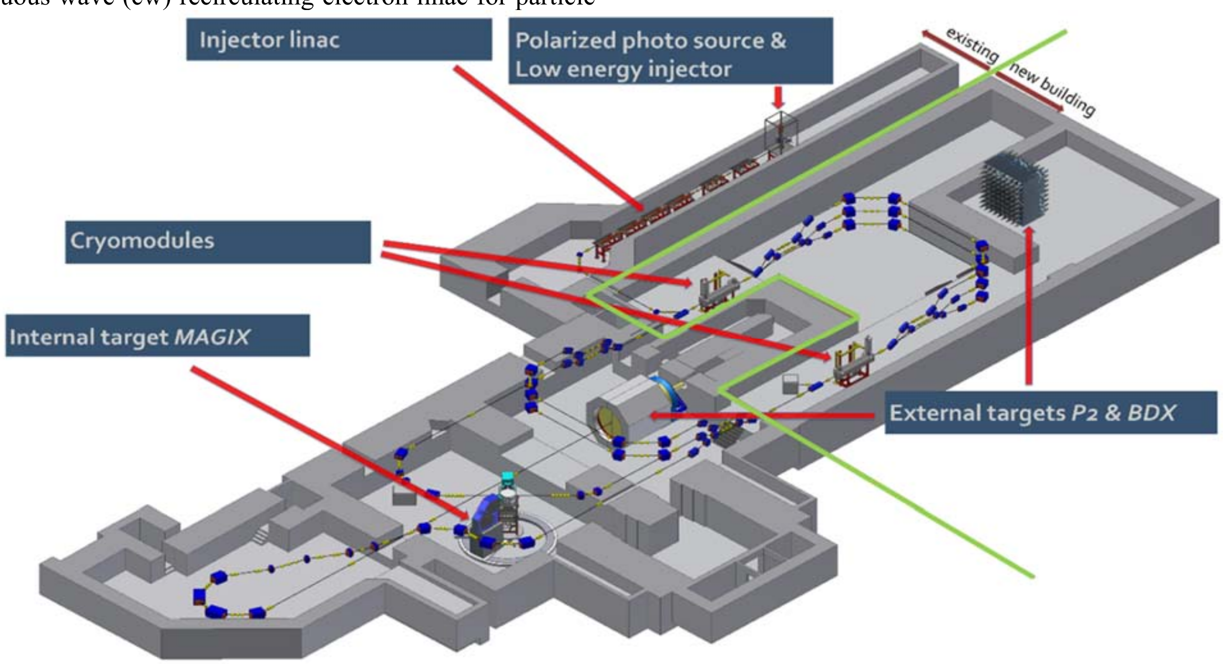

Figure 1: Layout of the MESA accelerator and the planned experimental setups. The accelerator will be located in existing and newly constructed underground halls. The boundary between the old and new parts of the building is marked by a green line. The injector will be constructed and commissioned first as it is located in an existing building part. Civil construction work for the new underground hall has started and will last until end 2021. Afterwards, construction of main linac and experiments will start as well (courtesy of drawing: D. Simon).

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The maximum beam energy in ERL mode is limited to 105 MeV as up to two recirculations can be used only in contrary to the external mode with up to three recirculations. Nevertheless, the beam current in ERL mode is not limited by rf power installed at the superconducting main linac anymore and is planned to be 1 mA in the beginning of MESA operation Later, this current shall be upgraded to 10 mA, which is the maximum available current from the normal-conducting injector linac MAMBO [5]. The MAGIX facility can be used for different experiments on gas targets in ERL operation. Highlights will be the precise measurement of the proton radius at low momentum transfer or the search for dark photons, both on a Hydrogen gas jet target. In addition, the experiment can be run in an external mode as well, then restricted to lower beam current comparable to P2.

MESA LAYOUT

Underground Halls

The MESA accelerator has been designed since approx. 2009 [6] and its construction was funded in 2012 in course of the cluster of excellence "PRISMA". Since that date, it has undergone several design changes as the detailed layouts and requirements of the experiments have been optimized as well [7-9]. By now the layouts of both, MESA floorplan and experimental sites, have been finalized. The latest version is presented in Fig. 1. MESA will be constructed partly inside of existing underground halls, which have been used by one experimental setup (A4) at the microtron cascade MAMI [10]. Since A4 has been decommissioned, the existing halls are available now and can be used by MESA. MAMI nevertheless will continue operation in parallel. In addition, the German research foundation DFG funded the erection of an additional experimental hall adjacent to the existing halls in June 2015. Construction of the new hall, which will enlarge the underground area for the accelerator as well as for the experiments, started already. In course of the construction work the existing halls will be refurbished as well. Until start of the refurbishment of the existing underground halls in August 2019, a test setup for the polarized electron gun STEAM [11,12] and the low energy beam transport system MELBA [13] has been located there and produced first low energy electron beams for MESA.

Accelerator Layout

The MESA accelerator will consist of a polarized dc photogun on an extraction voltage of 100 kV followed by a low energy beam transport system (MELBA) containing a spin manipulation system and a chopper-buncher section for longitudinal matching into the normal-conducting booster linac MAMBO. In addition, the LEBT is used for transverse matching into the accelerating structures of the injector and for extensive beam diagnostics. In MAMBO the electrons can be further accelerated by four normal-conducting injector cavities to energies of up to 5 MeV and beam currents of up to10 mA (cw) [5,14]. After the injector the beam is transferred into the main linac through a 180° arc, which can be used as a bunch compressor to reach shortest possible bunches at the position of the first SRF cavity of the main linac [15,16]. The recirculating main linac follows the concept of a double sided accelerator design with vertical stacking of return arcs. Acceleration is done by in total four SRF cavities located in two cryomodules [17]. In the following sections we will present experimental results from the injector test setup (Fig. 2) and give an outlook to the timeline of MESA construction and commissioning. The status of beam optics and cryomodules are presented in [18,19] and will not be discussed in this contribution.

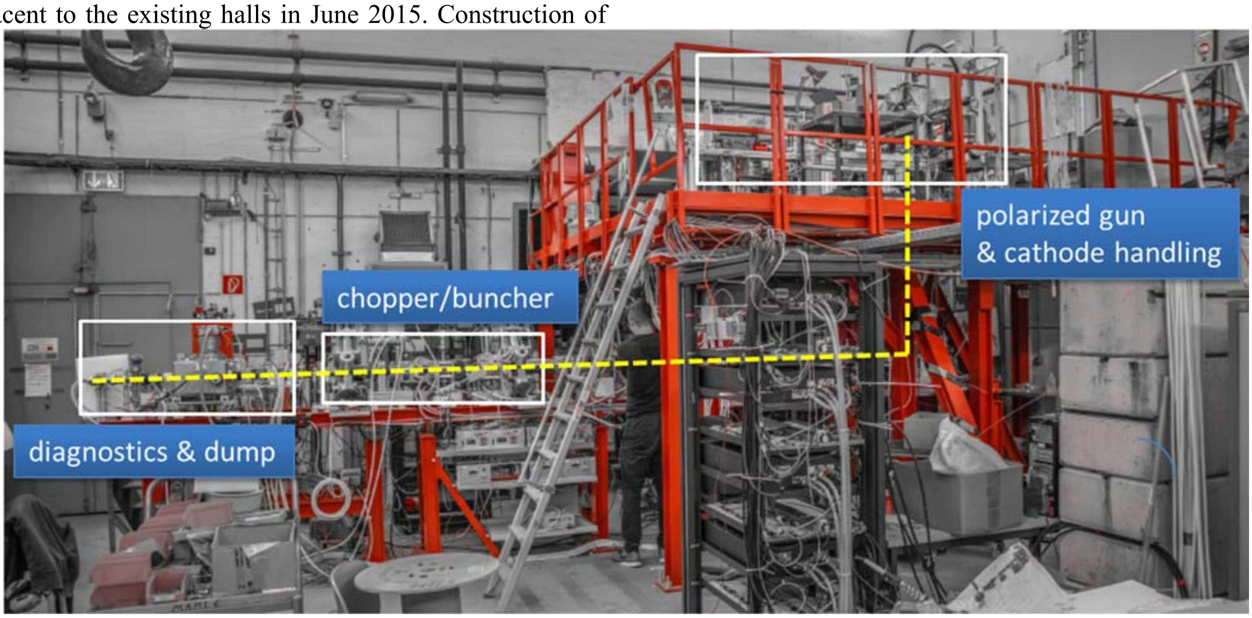

Figure 2: Injector test setup as run until July 2019. The test beamline consisted of the polarized inverted dc gun STEAM and parts of the MELBA LEBT system (chopper, buncher and beam transport). Extensive longitudinal and transverse diagnostics have been set up and used for beam characterization. The way of the electron beam along the beamline is illustrated by the yellow dashed line (photography: MELBA group).

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INJECTOR TEST RESULTS

MELBA

The low energy part of the injector has been tested successfully already producing the first MESA beams at 100 keV (and up to higher energies >150 keV for testing reasons) [12,13]. The setup (see Fig. 2) could be used for first tests of the crucial components and for extensive beam diagnostics. During the operation of the MELBA test setup the performance of the dc photo-gun and of the bunching system could be investigated. In addition, a new bunch length diagnostic device [20] and a cavity for future beam stabilization at P2 [21] could be qualified as well. It was possible to demonstrate the extraction of 10 mA beam current from the gun, which already satisfies the goal for MESA stage 2. The results of emittance measurements performed during the beam tests are shown in Fig. 3. Even though the measured emittance deviates from simulations depending on the type of laser used, the required transverse emittance for the 150 µA external MESA beam has been achieved already [13].

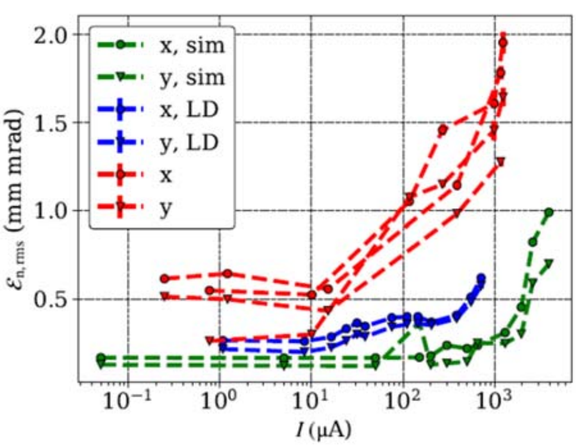

Figure 3: Measurement of beam emittance at different extracted beam current produced by different lasers and compared to simulation results [13]. The emittance goal for the external beam experiment P2 could be achieved already.

MAMBO

The 5 MeV booster linac MAMBO consists of two main components: four normal-conducting cavities, the first one β-graded, and four solid state amplifiers providing the required rf power. For qualifying the cw solid state technology at the MESA operation frequency of 1.3 GHz, a prototype has been produced by industry and tested successfully at HIM [22]. This prototype amplifier could be used for the cryomodule acceptance tests as well [19]. The design of the normal-conducting linac cavities follows the MAMI linac design but needed to be adapted for frequency and for suppressing multipacting in presence of longitudinal magnetic field needed for space-charge compensation at the high current MESA beam. Therefore, a prototype was ordered and tested at Helmholtz Institut Mainz (HIM, see Fig. 4). Both parts performed well and the design of the booster cavities could be verified. The four cavities for the complete MESA booster linac have been ordered from industry and will be delivered to Mainz in fall 2020. Right afterwards the injector construction can start, as the injector will be located in an existing building part and can be constructed independently from the civil construction work of MESA underground halls.

Figure 4: Photography of the MAMBO test cavity inside of the HIM rf test bunker. (photography: R. Heine).

CONCLUSION AND TIMELINE

The MESA accelerator under construction at JGU Mainz will serve nuclear and particle physics experiments with cw electron beams. The experiments are planned and will be run within the framework of PRISMA^{+}. Civil construction work for MESA underground halls is ongoing and planned to be finalized until end 2021. Afterwards accelerator construction and commissioning can start. Nevertheless, important parts of the accelerator have been designed already and tested successfully. In this contribution we concentrated on results of test measurements for the normal-conducting injector at MESA. The dc photogun and LEBT system worked properly and the experimental results gathered in the testing runs will be very useful for beam commissioning of the final injector. The rf tests on the normal-conducting booster cavity prototype using the newly developed solid state amplifier could verify the simulation results.

The timeline for completing the MESA facility is mainly determined by the civil construction work on the underground building. Therefore, construction start of the MESA main accelerator and of the experiments is postponed to end 2021. Construction and commissioning of the injector will start much earlier, as the injector will be located in an existing building part. It is envisaged to have the injector set up and start commissioning before construction of the underground halls is finished. First beam to the experiments is expected in 2023.

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