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OPTICS OF A RECIRCULATING BEAMLINE FOR MESA

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Abstract

The Mainz Energy-recovering Superconducting Accelerator (MESA) is an Energy Recovery Linac (ERL) facility under construction at the Johannes Gutenberg-University in Mainz. It provides the opportunity for precision physics experiments with a 1 mA c.w. electron beam in its initial phase. In this phase experiments with unpolarised, high density ($\rho \approx 10^{19}$ atoms/cm^2) gas jet targets are foreseen at the Mainz Gas Internal Target Experiment (MAGIX). To allow experiments with thin polarised gas targets with sufficiently high interaction rates in a later phase, the beam current has to be increased to up to 100 mA, which would pose significant challenges to the existing ERL machine. Thus it is proposed here to use MESA in pulsed operation with a repetition rate of several kHz to fill a storage ring, providing a quasi c.w. beam current to a thin gas target. The optics necessary for this recirculating beamline are presented here.

MESA

MESA is a small-scale, multi-turn, double-sided recirculating linac with vertical stacking of the return arcs currently being built at the Johannes Gutenberg-University Mainz. The layout of the facility can be seen in Fig. 1. The accelerator features superconducting cavities of the TESLA type [1], housed in an ELBE type cryomodule [2] and operated at 1.3 GHz. The possible modes of operation are a thrice recirculating external beam mode (EB) with 150 µA current and 155 MeV particle energy or a twice recirculating energy recovering mode (ER) with 1 mA and in a later phase 10 mA current at a beam energy of 105 MeV, where 100 MeV of beam energy can be recovered from the beam and fed back into the cavities. Further information on the facility and the planned experiments can be found in [3–5].

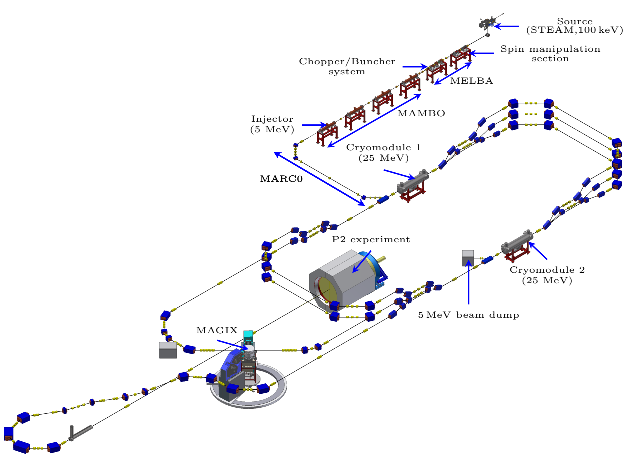

Figure 1: Rendering of the layout of the MESA facility. The injection beam line can be seen on the top right. The pseudo internal gas jet target of the MAGIX experiment is located in the fourth arc of the energy recovery mode on the bottom left.

RING BEAMLINE

The maximum achievable beam current in ERL machines is limited for example by the Beam Breakup (BBU) instability as was investigated for MESA in [6] or the heating of the Higher Order Mode couplers. Scattering experiments in search for rare processes however would benefit from an increase in luminosity. Since the density of the minimally invasive windowless gas target for MAGIX is limited, the remaining option is to increase the beam current to further increase the luminosity. This is especially true for polarised gas targets, with target densities of the order of 1×10^{14} atoms/cm^2 [7]. One way to circumvent the BBU limit is to use MESA as an injector for a ring beamline, where high intensity bunches would recirculate in quasi c.w. operation through the experiment multiple times and be dumped afterwards. In such a configuration ERL operation of MESA would not be needed and the accelerator would be used as a pulsed injector to fill the ring. The pulsed beam will then have to be extracted and dumped at 105 MeV but with a duty cycle of the order of 0.1 %.

In the area where the beamline has to be closed in order to loop back to the MAGIX experiment a lot of the infrastructure of the P2 Experiment is housed, consisting mainly of the superconducting solenoid, the backscattering detectors, the cryogenic infrastructure for the liquid hydrogen target and the helium distribution system for the solenoid. Several options are available to install an additional beamline. The simplest of them with a small vertical offset and a closed loop above of the P2 Experiment superconducting solenoid might face complications due to space constraints. However there is an alternate option passing over and behind the P2 Experiment superconducting solenoid, since the available vertical space is close to 6 m. The ring of option 1 has a circumference of 53.87 m, which is ≈234 times the radio frequency wavelength. At a repetition rate of 6 kHz and 210 buckets filled with $Q_{\mathrm{bunch}} = 77$ pC the average current in the ERL would be 0.1 mA, while the stored beam in the ring would provide 100 mA for the experiment. Each bunch train would be 0.153 µs long and would spend 167 µs in the ring, being stored for only 1000 turns. This is well below the estimated damping times ($\tau_i \approx 2$ s) of such a ring. Approximately 1.5 W are emitted as synchrotron radiation at 100 mA of stored beam. The first design goal of such a beamline was

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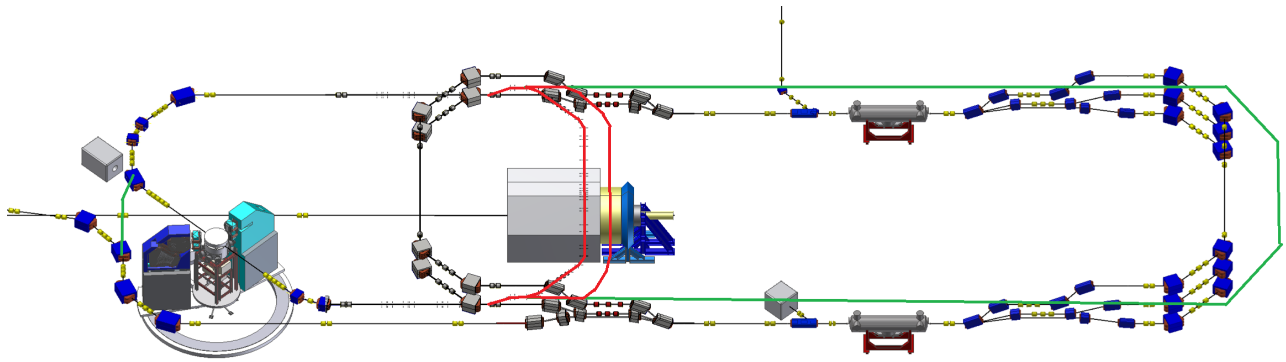

Figure 2: Illustration of possible changes to the beamlines for a recirculating setup. Green line: biggest option with possibility for additional compton scattering experiments on the far right side and additional injection option via the MESA 155 MeV beamline. Red lines: Options by- or overpassing the P2 experiment, for which optics have already been calculated, see Figs. 3 and 4.

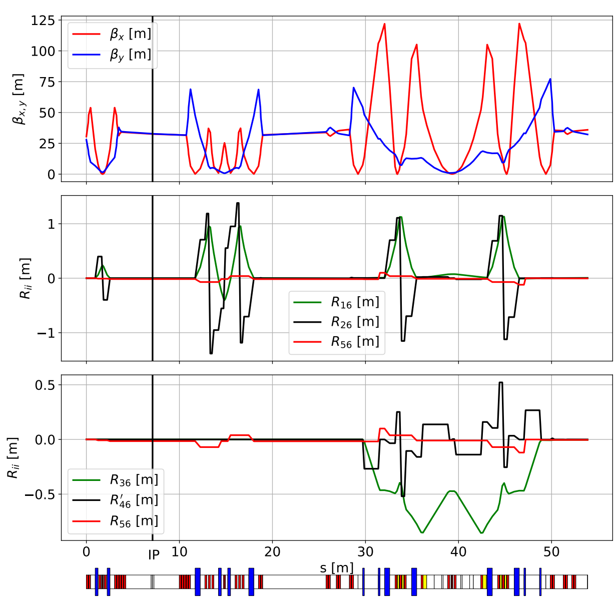

Figure 3: Optics layout simulation option 1. Simulations performed with MAD-X [8]. The layout below the graphs depicts the optical elements. Dipole magnets are blue, quadrupole magnets are red and sextupole magnets are yellow. The black line indicates the interaction point (IP) where the experiment is located.

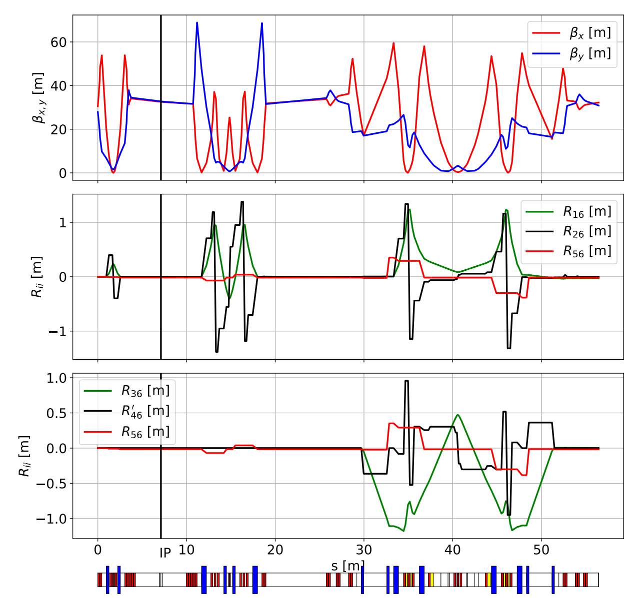

Figure 4: Optics layout simulation option 2. Compared to option one a larger vertical shift is necessary to get above and behind the superconducting P2 magnet. The beamline is roughly 0.5 m more vertically displaced compared to option 1, resulting in larger vertical dispersion along the way.

to achieve 1000 recirculations without significant particle loss. Due to radiation protection issues not more then 100 W of beam loss are allowed. The beam loss should stay well below that number since additional beam loss will occur from the interaction with the target. For option 1 the beam loss over 1000 turns with an aperture of 36 mm is 8.4 W. Additionally a vertical offset was included, since elements of the P2 experiment have to be bypassed. In the second option the layout of the P2 Experiment was considered and it was aimed to bypass the superconducting solenoid completely and stay well above any parts of the P2 experiment. This resulted in an increase of the vertical displacement. Dispersion can still be controlled in first order, but additional studies have to be performed to evaluate and refine option 2.

SPACE CONSTRAINTS

While the MESA facility is small and a lot of the available space is already taken by the experiments, the opportunity to implement a recirculating beamline is promising to further broaden the scientific prospects and longevity of the machine, while adding just a small amount of magnets and diagnostics to the existing machine. A third even more sophisticated option would be to extend the beamline further into the existing halls, closing the loop behind the recirculating arcs of MESA, depicted by a green line in Fig. 2, opening

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the possibility to install a Compton scattering experiment in addition. However for this last option a way has to be found to by- and/or overpass the cryomodules and their respective liquid helium supply systems and waveguides for the RF. The potential gain is another source for experiments at MESA using a 105 MeV electron beam in a compton scattering experiment. See for example C. Loreys paper in this conference [9].

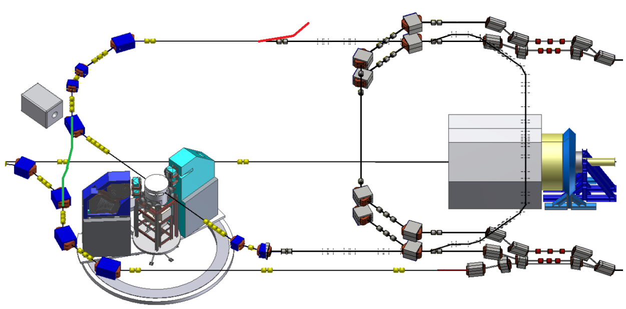

Figure 5: Sketch of the recirculating beamline option 1, for which the optics layout can be seen in Fig. 3. This option does not completely fit with the existing space demands of the P2 experiment not completely shown in this CAD model. The locations and sizes of various elements of the P2 experiment have to still be finalised. The green line shows a possible injection scheme using part of the existing 155 MeV beamline for P2. The red line depicts a possible beamline to a small beam dump.

RING OPTICS

The preliminary linear optics layout can be seen in Fig. 3. It is simulated and optimised using MAD-X. The existing internal beamline of MESA was extended with the aforementioned option 1, extending the beamline over the P2 experiment superconducting solenoid. In this additional beamline 6 Sextupoles are foreseen as well as optional collimators to control beam losses that might occur due to scattering with the gas target. Space for diagnostic elements has to be planned as well. Six additional quadrupoles are currently not used but available to create a smaller focus at the interaction point to adapt to the experimental needs. The optics were then translated to ELEGANT [10], which allows to calculate for example the damping times or to approximate the effect of the beam target interaction by a scatter element in a first approach. The damping times of the ring are $\tau_x = 2.24$ s, $\tau_y = 2.11$ s and $\tau_z = 1.02$ s, clearly showing that equilibrium states will not be reached in the planned configuration. Results for scattering on the high density ($\rho = 10^{19}$ atoms/cm^2) hydrogen jet target have been simulated in the ring. As can be expected, severe beam loss is experienced when such a high density target is introduced to the beam. While the effect on the single pass ERL beam is minimal, after thousand turns in the ring nearly all particles are lost. The effect of a lower density polarized gas target can be approximated by using a scatter element with overall smaller amplitudes for the induced beam perturbations. These simulations were performed by linearly scaling the scatter element leading to a small increase in lost beam of 1.1 W, making for a total of 9.5 W of beam power lost with the scaled approximated target interaction. See [11] for more information on the beam target interaction.

INJECTION AND EXTRACTION

The space constraints described are also challenging for injection and extraction. While the beam can be safely dumped on a relatively low power beam dump (10 kW), since the duty cycle is only below 0.1 % with this high bunch charge. Special care is necessary for the injection into the recirculating beamline. A possible option stems from the fact that the P2 Experiment beamline that is optimised for 155 MeV is also able to accept beams of lower energy, by changing the configuration of the whole machine. It might thus be possible to use the P2 experiment beamline also for dedicated injection into the recirculating beamline, bypassing a lot of the problems in the splitter section, see Fig. 5. Injection and extraction optics will be calculated in the future.

CONCLUSION AND OUTLOOK

Several options for a MESA recirculating beamline have been presented as well as beam optic designs for two of the three options. While the available space is limited, it can be seen that with a few additional optical elements the option to implement a ring into the facility seems feasible. The different optics are still being optimised to have the least impact on the existing machine but provide further upgrade paths in the future. Final optics for injection into the ring and extraction of spent beams have to be developed and integrated into the existing facility.

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