ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB217

A STORAGE RING 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 ($\rho \approx 1 \times 10^{19}$ 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. For this purpose the existing optics need to be extended and adapted, a suitable injection and extraction scheme is necessary and beam target interaction has to be investigated. First considerations on these topics 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].

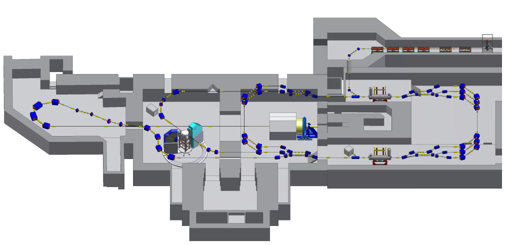

Figure 1: Rendering of the layout of the MESA facility. The injection beam line can be seen on the top right. The pseudo internal gas jet target is located in the fourth arc of the energy recovery mode.

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STORAGE RING

The maximum achievable beam current in ERL machines is limited by for example 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 reachable density of minimally invasive windowless gas targets is limited, the remaining option is to increase the beam current to further increase the luminosity. This is especially true for polarised gas targets. One way to circumvent the BBU limit is to use MESA as an injector for a multi pass beamline / storage ring, where high intensity bunches would recirculate through the experiment multiple times and be dumped afterwards, see Fig. 2.

The beamline is 48.54 m long, which is 210 times the radio frequency wavelength. With a repetition rate of 6 kHz and 200 buckets filled with $Q_{\mathrm{bunch}} = 77$ pC the average current in the ERL would be 0.1 mA, while the stored beam 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 1 000 turns. This is well below the estimated damping times ($\tau_i \approx 2$) of such a ring. Approximately 1.5 W are emitted as synchrotron radiation at 100 mA of stored beam.

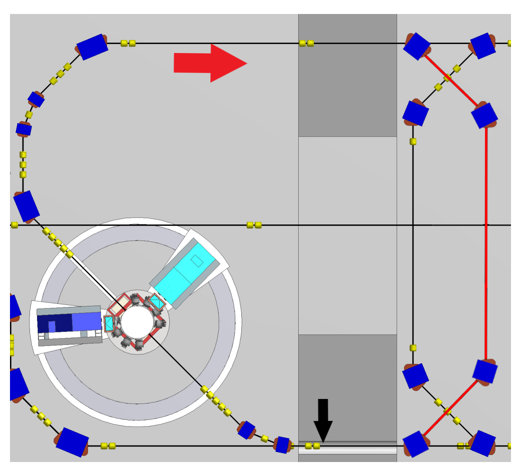

Figure 2: Top view of the planned recirculation line layout. The red line marks the beamline, that has to be built to close the ring, the black arrow marks the start of the simulation line and the red arrow marks the beam direction.

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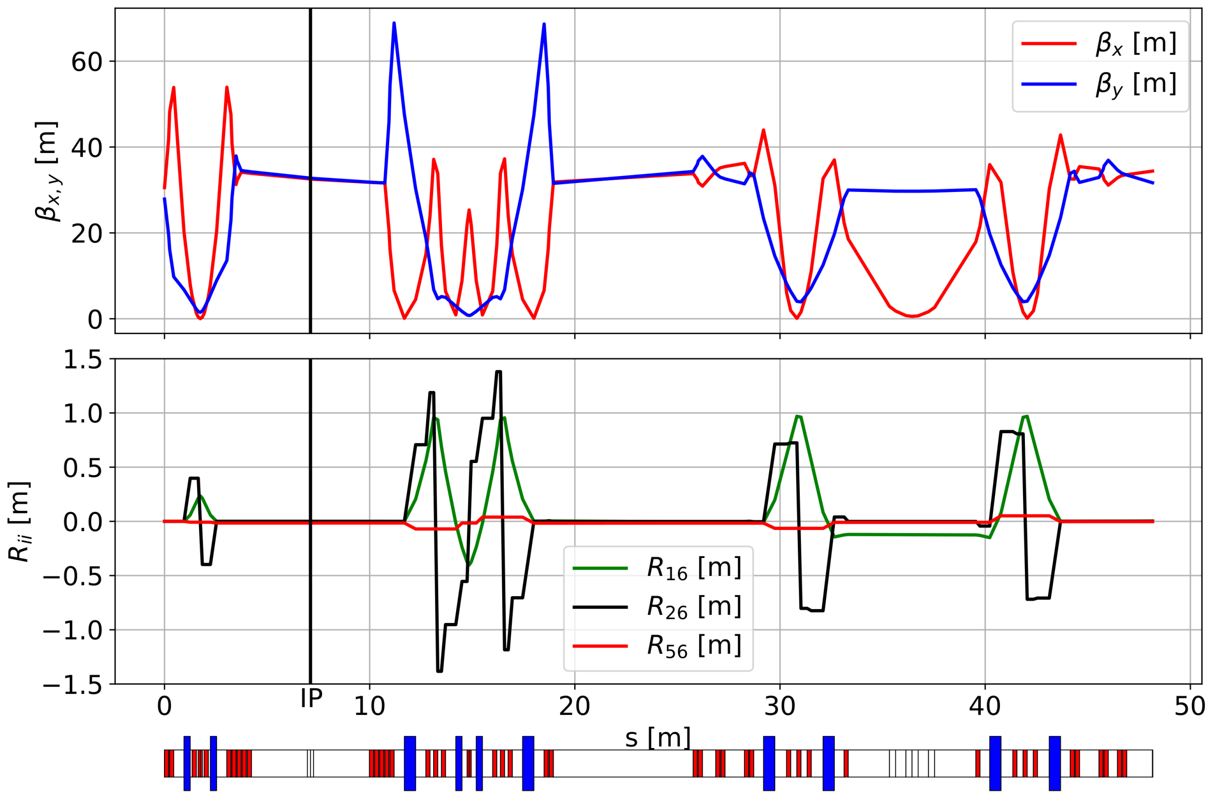

Figure 3: Simulations performed with MAD-X [7]. The layout below the graphs depicts the optical elements. Dipole magnets are blue and quadrupole magnets are red. The black line indicates the interaction point (IP) where the experiment is located.

RING OPTICS

The preliminary linear optics layout can be seen in Fig. 3 and was simulated and optimised using MAD-X. For symmetry reasons the simulation starts at the position marked with a black arrow indicated in Fig. 2. Higher order optics have to be further optimised and the need for sextupole magnets to correct chromaticity has to be investigated. 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 [8], 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 $\tau_x = 2.3\,\mathrm{s}$, $\tau_y = 2.2\,\mathrm{s}$ and $\tau_z = 1.1\,\mathrm{s}$, clearly showing that equilibrium states will not be reached in the planned configuration. Up to this point only results for scattering on the high density ($\rho = 1 \times 10^{19}$ 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. For a simple approximation scaling the high density target down by a factor of 1 000 allows a first glance at thin targets, as shown in Fig. 4. Without the scatter element

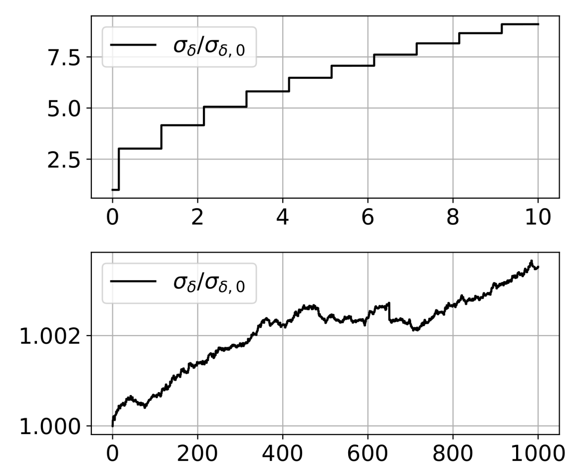

Figure 4: Comparison of the relative change in energy spread for the high density gas jet target simulated for 10 turns (top) with the scaled low density target simulated for 1 000 turns (bottom).

99.8 % of the particles are stored for 1000 turns. The optics will be further optimised in the future. Introduction of a polarised gas target also requires a solenoid magnet to maintain target polarisation. The effect of this magnet has to be accounted for in the ring optics.

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INJECTION AND EXTRACTION

A dipole chicane provides a simple scheme to inject into the ring. An additional fast kicker is then required to extract the beam either to the MAGIX beam dump or back into the accelerator. In the latter case energy recovery of the beam is possible, however additional changes have to be made to accommodate this option in MESA. As accelerating and decelerating beams have to arrive in one cavity at the same time for energy recovery, in pulsed operation symmetric path lengths of the return arcs have to be realised. Up to date this has not been foreseen since for c.w. operation the arrival time requirement is always fulfilled.

BEAM TARGET INTERACTION

The beam is subject to halo formation through Coulomb scattering at the target and the resulting halo distribution depends largely on the target properties and requires additional collimation. Studies with 4 mm long unpolarised gas targets with particle densities of $1{\times}10^{19}$ atoms/cm^2 projected along the beam axis at MESA were recently published in [9] and demonstrate that a tolerable amount of subsequent losses is limited by radioactive protection regulations. This limitation of beam losses then also dictates limits for the achievable luminosity at the experiment. In the aforementioned studies the maximum achievable luminosity for a proton target has been determined to be approximately $7.6 \times 10^{35}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, corresponding to beam currents of just below 12 mA. While for unpolarised targets the possibility to store the target gas under high pressure enables reaching high gas densities and correspondingly short target lengths, it is necessary to significantly reduce the target gas pressure for polarised targets to conserve polarisation. At the HERMES experiment a maximum polarised target density of $1.4{\times}10^{14}$ atoms/cm^2 was achieved [10]. Assuming that the projected scatter center density is reduced from $1{\times}10^{19}$ to $1{\times}10^{15}$ atoms/cm^2, the effective target scatter center density seen by the beam in 1 000 recirculations is $1{\times}10^{18}$ atoms/cm^2, which implies that beam currents in the region of 100 mA are compatible with the luminosity limit for polarised proton targets. For such experiments at MESA however, tube targets of 30 cm length have been proposed in [11] (HERMES: 40 cm [12]). The substantially increased target length is expected to consequently cause largely deviating halo characteristics and possibly require an adapted collimation setup. It is therefore envisaged to account for the discussed experiment configuration with dedicated simulations of target induced halo.

CONCLUSION AND OUTLOOK

Preliminary ring optics for a MESA storage ring upgrade have been presented and will be optimised by including nonlinear effects and chromaticity. Experimental needs have to be further clarified to adjust the ring optics accordingly, e.g. correct for the target magnet field and fulfil the beam requirements in the interaction region. A first concept of possible injection and extraction schemes was presented and has to be investigated. Limited space is available for the injection, which has to be resolved. Limitations imposed by interaction of the beam with the internal gas jet target has been simulated for the initial phase of MESA operation. Additional simulations are envisaged to account for the changed configuration of the target in the ring.

ACKNOWLEDGEMENT

This work is supported by the DFG excellence initiative PRISMA+. We are grateful for the support of the DFG through GRK 2128 Accelence.

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