MESA - SKETCH OF AN ENERGY RECOVERY LINAC FOR NUCLEAR PHYSICS EXPERIMENTS AT MAINZ

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Abstract

We present the concept of a small superconducting CW accelerator with multi-turn energy recovery. This machine, the Mainz energy recovering superconducting accelerator (MESA), is intended to serve for particle physics experiments in the energy range 100-200 MeV.

OVERVIEW

The MESA accelerator [1, 2] is designed to serve two experiments (Ex1 and Ex2):

- Ex1 is a precision measurement of the Weinberg angle, which demands 150 μA CW polarised electrons at an energy of about 200 MeV
- Ex2 is dedicated to the search for dark photons, where up to 10 mA CW of unpolarised electrons at an energy of circa 100 MeV are intended.

For an efficient design, construction and commissioning MESA is relying on approved techniques and existing infrastructure: for instance the main linac is based on TESLA technology (2 Rossendorf like modules with 4 cavities) giving an energy gain of 50 MeV per pass. Our institute is presently setting up the infrastructure required for handling superconducting radio-frequency structures (SRF). A suitable He-liquefier is already available, clean room assembly facilities are planned within a new laboratory complex on our site to be completed before 2015. The MESA facility is going to be situated in the existing experimental caves of the A4-collaboration and the beam line tunnel that is connecting MAMI to the A4-experiment (fig. 1), providing heavily shielded areas, fully equipped with electrical and cooling infrastructure needed for accelerator operation and cranes for accelerator assembly.

MESA will be operated in two modes, an energy recovery (ER) mode for the unpolarised high current operation to sustain the 1 MW of beam power and an external beam (EB) mode for the low intensity polarised beam. In ER mode a windowless (pseudo) internal target (PIT) is inserted into the 100 MeV recirculation followed by a $\lambda/2$ chicane to provide the 180° phase jump to achieve energy recovery. Since the PIT is only introducing an energy spread of $< 10^{-4}$, highly efficient energy recovery seems feasible. Bypassing the chicane would result in further acceleration for the EB mode (see fig 2).

For the construction of MESA a staged approach is suggested: MESA is set into operation with reduced figures of merit to gain experiences with the accelerator, especially with the multi-turn energy recovery mode, and later upgrade to full performance. In stage-1 this results in an EB mode beam energy of approx. 150 MeV at 150 μA with only two recirculations, stage-2 will add a third recirculation, so 200 MeV will be available. In addition, the gun will be upgraded from 1 mA to 10 mA in ER mode (for parameters of both stages see table 1). Furthermore, the installation of HOM dampers has to follow to allow operation

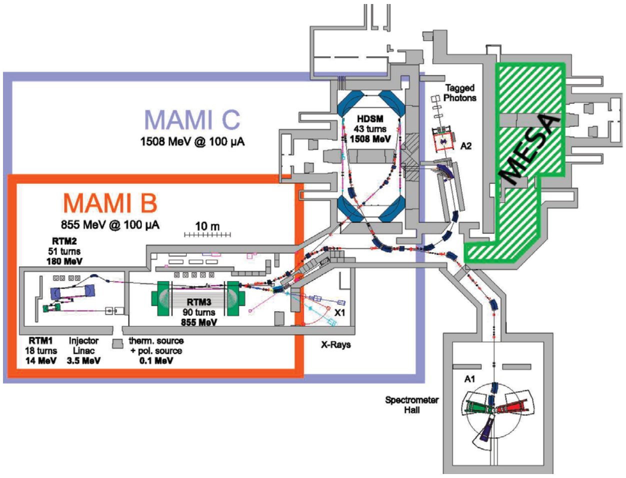

Figure 1: Floor plan of the caverns of the microtron facility MAMI at the IKPH in Mainz. The space intended for MESA and its experiments is marked in green.

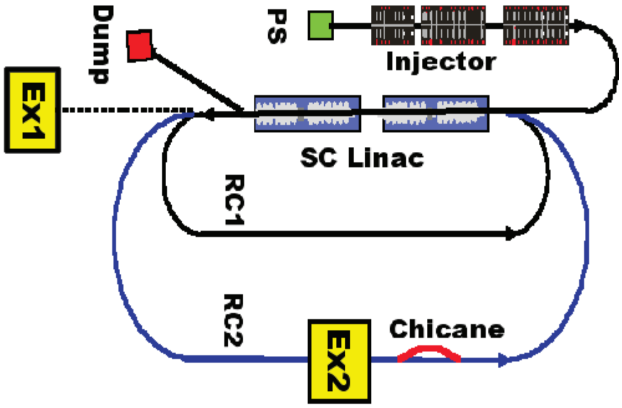

Figure 2: The basic idea of the MESA complex: running through the chicane (red) would switch MESA into ER mode, bypassing it would result in further acceleration to 150 MeV for EB mode. In stage-2 a third recirculation would be added resulting in 200 MeV for external beam.

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Table 1: Table of Beam Parameters of the 1st and 2nd Stage of MESA.

Parameters	Stage 1	Stage 2
Beam energy ER/EB [MeV]	105 / 155	105 / 205
Photo source ER/EB	DC 100 keV, pol./unpol	+ 500 keV, unpol.
Bunch charge ER/EB [pC]	0.77 / 0.115	7.7 / 0.115
Beam polarization (EB)	> 0.85	
Norm. emittance ER/EB [mm]	<1 / 0.15	<2 / 0.15
Beam recirculations	2	3
Beam power at exp. ER/EB [kW]	100 / 22.5	1000 / 31
RF operating mode	1.3 GHz, CW	
RF power installed [kW]	120	160
Main linac energy gain/gradient [MeV], [MV/m]	50 / 13	50 / 16

at such high currents.

PARTICLE SOURCES

MESA is going to be equipped with a 100 keV GaAs photo source for polarised and unpolarised beam. The source has the well proven design used at MAMI for some years [3]. The restriction to 100 keV is due to the easier spin measurement and manipulation at lower energy. In stage-2 the bunch charge will be increased 10-times, to 7.7 pC. In order to minimize emittance growth, it is desirable to double the cathode electric field and potential of presently 1 MV/m at 100kV. Such values are achievable in a very practical manner by the 'inverted' gun design [4]. A beam energy of 500 keV can be achieved with a subsequent 300 kV electrostatic stage as it was in use at the MIT Bates injector [5]. Such a system is comparatively conservative in comparison to a 500 kV electrostatic diode [6] or a an SRF-gun [7]. The injection point for the high charge gun would be behind the first ('graded-β') section of the stage-1 arrangement.

INJECTOR

The injector linac for MESA will provide an end energy of 5 MeV at a maximum current of 10 mA. Two approaches are followed:

1. a normal conducting bi-periodic standing wave structure in $\pi/2$-mode. This configuration resembles the MAMI injector linac [8, 9] scaled to 1.3 GHz. The first accelerating structure is a graded-β ranging up to $\beta = 0.885$ followed by three constant-β structures with $\beta = 0.947$, 0.985 and 0.995. The phase slip is chosen that a longitudinal FDDF-focussing is achieved. With an accelerating gradient of 1 MV/m the overall ohmic losses of the structures will be of the order of 50 kW.
2. a superconducting linac with two TESLA-type 9-cell cavities at 5 MV/m. Because of the difficult beam dynamics at the low injection energy of 100 keV, the same graded-β as in the first approach is preceding the superconducting resonators resulting in a hybrid inject.

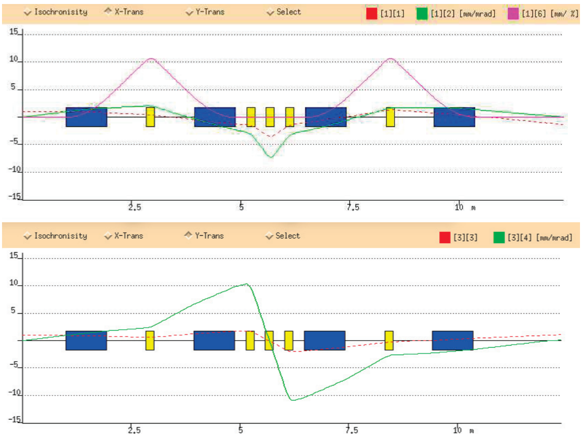

Figure 3: Linear beam optics of the MESA arcs for 45° bending angle. With the matrix elements R_{11} in red, R_{12} in green and R_{16} in magenta. The upper plot shows the optics in x direction, the lower in y direction.

Both configurations have been simulated with PARMELA [10], for the design of the graded-β section the omitted PARMELA routine "DESIGN" has been reprogrammed with ROOT [11].

Although the hybrid injector is a technologically interesting option, it is not clear whether this option is compatible with the needs of the parity violation experiment. In addition with budget considerations, the normal conducting injector is favoured at the moment, but the hybrid option will be investigated alternatively.

MAIN ACCELERATOR

The main accelerator is intended as a multi-turn non-isochronous recirculating linac, which will in stage-1 be equipped with four TESLA 9-cell cavities in CW operation providing 50 MeV energy gain per turn (13 MV/m). In stage-2 they shall be replaced by HOM-damped 7-cell cavities at $\approx$16 MV/m (e.g. [12]) to cope with the higher beam current. Non-isochronous operations is preferred, because longitudinal focussing gives higher energy stability and a smaller energy spread [13, 14].

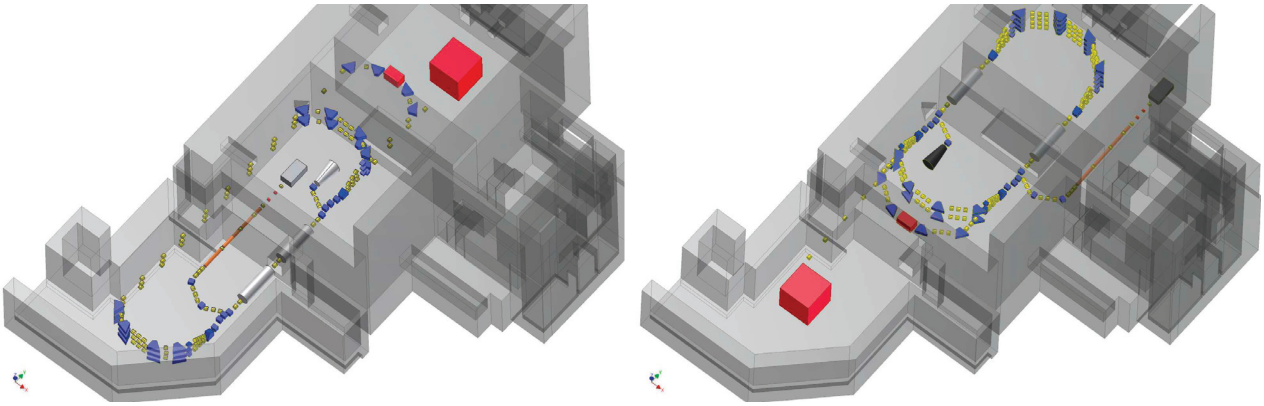

Figure 4: A 3D sketch of MESA in SSD (left) and DSD (right) inside the A4 halls (hatched area in fig. 1). The major semi-axis of both accelerators without the PIT arc is circa 27 m and 21 m respectively. The red cubes illustrate the positions of the experiments.

The fact that MESA is going to have the PIT in the 2nd arc suggests vertical stacking instead of horizontal for lattices with more than two recirculations. This has also the advantage of a more compact design and straight forward leads to identical optics in each arc by just scaling fields.

For the arcs lattices with bending angles of $30°$, $45°$ and $60°$ were investigated, where the $45°$ option (see fig. 3) turned out to be the most flexible one permitting to switch quite easily between non-isochronous and isochronous operations, if necessary. The fact that this optics is also dispersion free in the middle of the arc allows to put the PIT there, so it is possible to place the RF sections on both straights generating a more compact double sided design (DSD) lattice compared to a single sided design (SSD) (see fig. 4). The downsides of a DSD are:

- an additional arc is needed to gain the same end energy as with a SSD,
- both long straight sections are common for all energies, so the space for optical elements that act only on the optics of individual recirculations is very limited and some flexibility is lost,
- for the ER mode the maximum energy gain for all modules is limited by the weakest module,
- there is no space for a chicane in the 2nd straight, the path elongation has to be achieved in the corresponding arc, e.g. by moving the bending magnets of that arc similar to the procedure used at S-Dalinac [15].

FUNDING & TIMELINE

The MESA concept has been evaluated within the German university-excellence initiative, the funding decision will take place in summer 2012. In case of a positive outcome the accelerator can start operation for the experiments in 2017.

SUMMARY

This paper described a multi-turn recirculating linac that can be run in external beam mode as well as in energy recovery mode. It was outlined how such a project can be realised within an university environment by the use of established technologies and existing infrastructure, so more attention can be paid to the aspect of multi-turn energy recovery. This project will complement the experimental possibilities of the existing facility MAMI, so a wider parameter range can be investigated at the IKPH. Further this facility can be used as a test bench for upcoming larger facilities as e.g. LHeC or for new developments in SRF or particle sources research.

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