STATUS OF THE MESA ACCELERATOR *

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Abstract

MESA will be operated as a superconducting multi-turn energy recovery linac (ERL), with the option to perform experiments with a windowless target with beam current of 1 mA which is to be increased towards 10 mA in a later stage of the project. Alternatively the machine can be used as a conventional c.w. accelerator with spin-polarized external beam at 150 MeV. We present the status of the design work.

INTRODUCTION

Figure 1 shows the underground areas which are available at our institution in Mainz. The existing accelerator cascade "MAMI-C" is foreseen to drive hadron physics experiments at the areas A1 and A2 for many years to come. On the other hand, the halt of the A4-experiments in autumn 2012 allows to make use of this space (see fig 1) in order to build a small "stand alone" machine, the **M**ainz **E**nergy recovering **S**uperconducting **A**ccelerator, MESA. In June 2012 the project received considerable funding by the German university excellence initiative within the cluster of excellence "PRISMA" (**PR**ecision experiments, fundamental **I**nteractions and **S** tructure of **MA**tter).

The feasibility of the ERL-concept was demonstrated at JLAB [1]. Such machines are widely known as possible drivers for future light sources of "fourth generation". We, however, try to use the ERL for electron scattering experiments, which relieves several of the requirements that plague the designers for light sources, such as operation in excess of 10 pC bunch charge. In this paper we describe the status of the accelerator design.

MESA LAYOUT

MESA will be installed in Hall 3 and in a part of the former MAMI-beamline tunnel (see fig. 1). Hall 4 will be employed for experiments, which gives the advantage that a high power beamdump is already available. The complex will be separated from the MAMI-accelerator and its remaining experiments (A1 and A2) by a 2 m thick heavy-concrete wall, for reasons of radiation protection. In the plane of the MAMI accelerator this shielding is increased additionally with at least 30 radiation length of material to protect against forward directed gamma-showers which could be created due to beam losses in MAMI-operation. MAMI experiments and the construction of MESA can therefore be performed independently. During the time of the conference the area of the beamline tunnel is about to be cleared, we expect the wall to be completed until summer 2014. The wall is a prerequisite to obtain permission from the authorities to work within the MESA Halls during MAMI operation. The main modification of infrastructure will be enlarging of the breakthrough between the beamline tunnel and hall 3.

Figure 2 demonstrates how the machine could be integrated into the existing building. Due to reasons which will be discussed below it is planned to erect the machine in two stages, the parameters for the stages can be found in table 1. If not mentioned otherwise, the discussion in this paper refers to stage-1 parameters.

The R.f.-operating frequency of MESA has still to be defined. A possible choice is 1300 MHz since a great number of superconducting accelerators around the world (e.g. E-XFEL, ALICE, ELBE, C-ERL) use this frequency. Advantages and disadvantages for a lower frequency are discussed below.

The superconducting main linac will allow for an energy gain of 50 MeV. Two recirculations are foreseen in conventional beam mode (external beam, EB-mode), leading to an output energy of the external beam of 150 MeV. This is presently considered as an optimum energy for the 'P2' experiment measuring the weak mixing angle [2]. The current foreseen for P2 is 150 μA with a polarization P≥0.85. The beam power of 30 kW will be released in the beam dump system which was in use for MAMI-C with similar beam powers.

In ERL operation the current is increased to 1 mA (unpolarized), corresponding to a bunch charge of 0.77 pC in c.w. operation. In the second recirculation at 105 MeV the beam orbit is directed towards the experimental hall 4 and passes a windowless target. In contrast to storage ring operation with an internal target the beam particles pass this "pseudo-internal target" (PIT) only once. This allows to achieve stationary beam conditions with minimized multiple and wall-scattering. The high beam power at the target (0.1 MW) allows for a luminosity in excess of $10^{35} cm^{-2} s^{-1}$ in spite of the low target density. Since energy straggling and Coulomb scattering are minimized in this set-up, emittance deterioration is negligible as far as RMS values are concerned. Of course long tails of the distribution exist which have to be collimated before the beam is redirected towards the accelerator. The long recirculation through hall-4 offers enough space for this. After passing the PIT the beam is redirected towards the MESA set-up where it re-enters the recirculation system.

The length of the (second) recirculation in ERL-mode - with PIT - is adjusted to a half integer number of wavelengths so that the electrons get decelerated in the main

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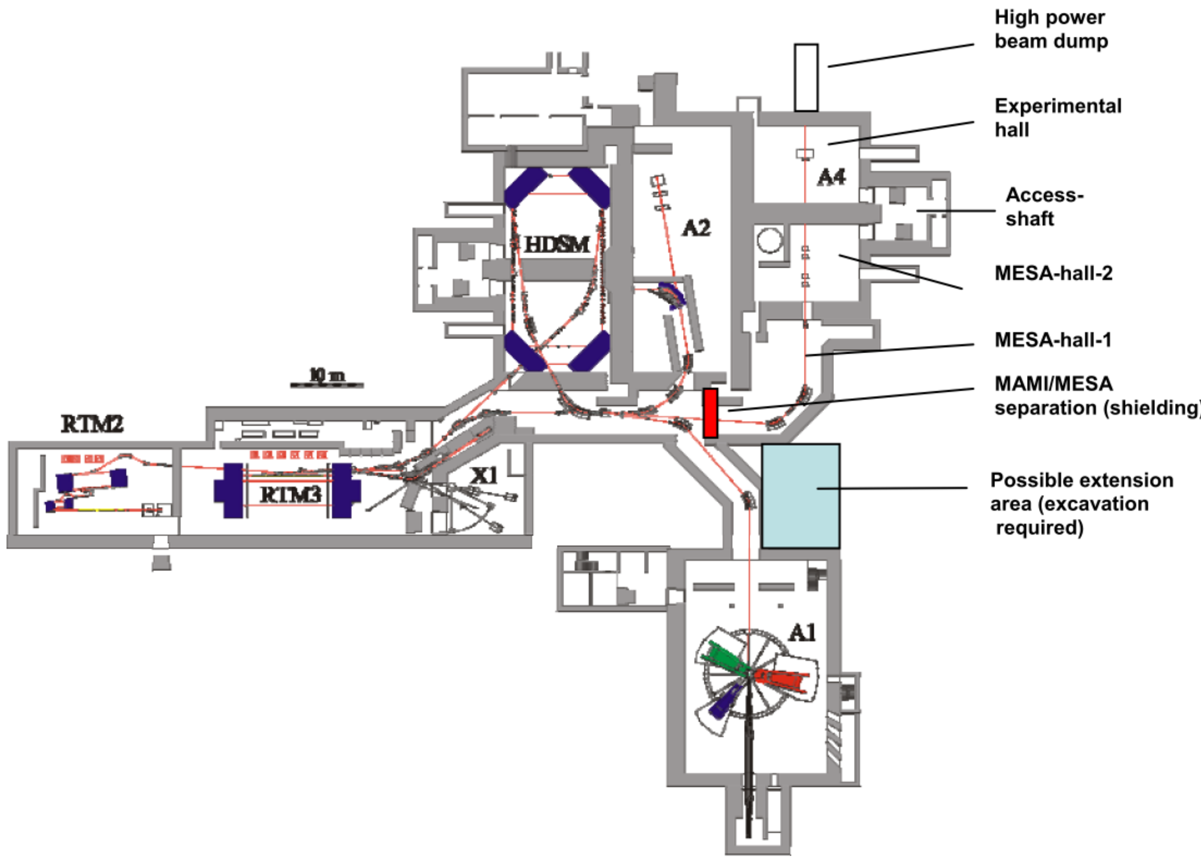

Figure 1: MAMI-C floor plan with experimental halls. The former beamline tunnel (Mesa-Hall-1) and the former Halls 3 (MESA-Hall-2) and Hall 4 (A4) will be available for the installation of MESA and its experiments.

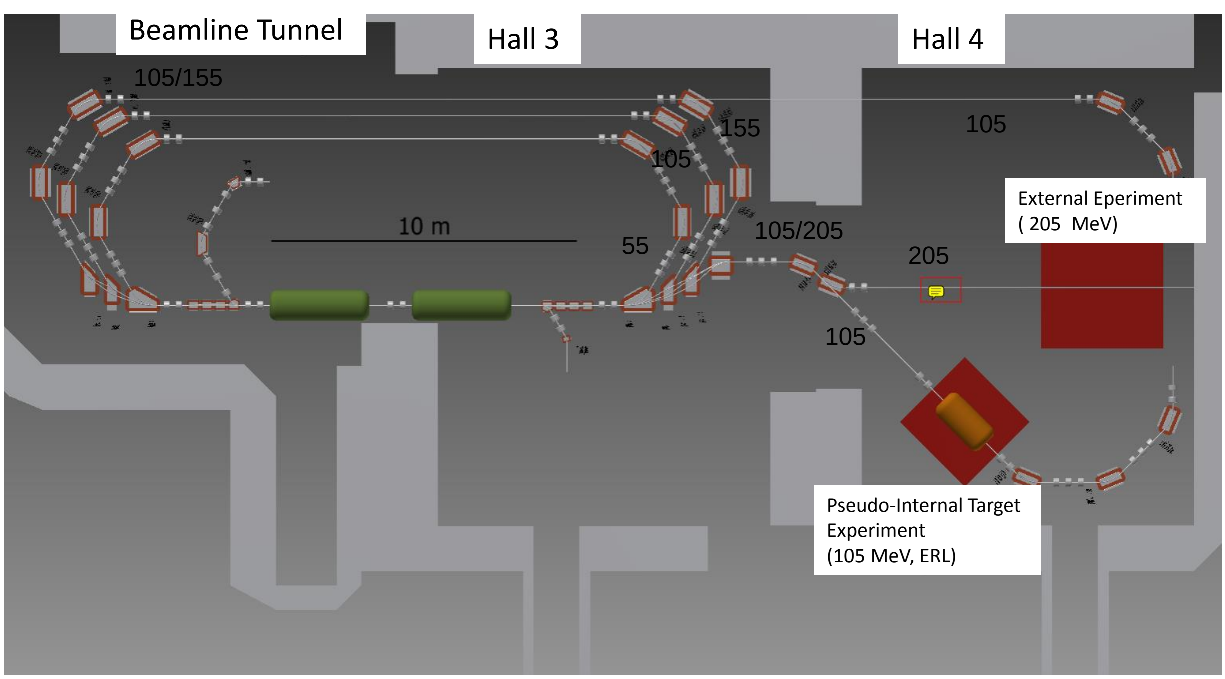

Figure 2: Integration of MESA inside the existing building. Shown is a three fold recirculating flat lattice (stage-2) which would allow for 205 MeV in EB mode. In ERL-mode the beam is deflected in the second recirculation into a loop through experimental hall 4. Numbers are beam energies in MeV on the orbits in ERL or EB mode.

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linac. After this the beam propagates into the first recirculation orbit which has an integer number of wavelengths, so that the arrival phase is not changed at the next passage, leading to another deceleration of the beam. Then, the beam leaves the main linac at the injection energy (5 MeV). MESA would represent the first superconducting multi-turn ERL - a normal conducting system exists at the NOVOFEL facility at Budker institute in Novosibirsk [3].

CRYOMODULES

Parameter	**stage-1** (EB/ERL)	**stage-2** (EB/ERL)
Beam energy, MeV	155/105	205/105
Bunch charge, pC	0.15/0.77	0.15/7.7
norm. emittance, μm	0.2 / <1	0.2/< 1
Beam polarization, %	>0.85/n.a.	>0.85/n.a.
Recirculations	2	3
Beam power at exp., kW	22.5/100	31/1000

Table 1: Parameter set for MESA in stages 1 and 2.

Cryoplant

Our institute already possesses a cryoplant with a liquefaction capacity of 140 l/h. This capacity can be doubled by using liquid Nitrogen precooling. We estimate that about 40% of the enthalpy of evaporation of the liquified Helium will be available for cooling the main linac, corresponding to a cooling power of ≈ 90 Watt at 2 K.

Main linac

Losses in the superconducting cavities are $\propto U_{acc}^2/Q_0$, where eU_{acc} is the energy gain of the linac and Q_0 is the quality factor of the accelerating cavity. We assume to have an active cavity-length of about 4 meters. Then, in order to achieve the objective of $U_{acc} = 50\,MV$ with the given cryoplant it is necessary to have $Q_0 > 10^{10}$. Values of $Q_0 > 1.5 \cdot 10^{10}$ at 1.8 K have been reported for 9 cell cavities of the TESLA type [4] even at accelerating fields of more than 25 MV/m. At the ELBE facility, TESLA cavities have been installed in cryomodules that have been modified for c.w. operation. These “ELBE”-cryomodules comprise two TESLA cavities. At a not too ambitious c.w. field of $13 MV/m$ two cryomodules would allow to achieve the envisaged energy gain of 50 MeV. The ELBE modules are commercially available.

However, TESLA cavities have not been intended for high current c.w. operation, especially not for recirculating operation. The chain of 9 coupled superconducting cavities can be exited in different, so called higher order modes (HOM’s). HOM’s with deflection properties (similar to TM_{110}-modes) may be excited by the beam. Such modes deflect particles with deviations from the axis. In particular, in recirculating systems a positive feedback can occur since a small misalignment of the beam excites the deflecting mode which in turn increases the misalignment. The excitation is proportional to the bunch charge or, equivalently, the beam current. Under simplifying assumptions a compact formula may be given which defines the threshold current for this, so-called beam blow up (BBU) instability [5].

$$I_{th} = \frac{2c^2}{e(R/Q)_{HOM} Q_{HOM} \omega_{HOM}} \frac{1}{T_{ij} sin(\omega_{HOM} t_r)} \quad (1)$$

T_{ij} stands for the transfer of deviations through the recirculations for the longitudinal and transverse coordinates, especially in the transverse plane this means the transfer of an angular deviation into a position deviation after the recirculation. These matrix elements can be varied by a suitable design of the recirculating lattice.

In this formula $(R/Q)_{HOM}$ and Q_{HOM} are separated for the following reason: R/Q is a geometry factor which is fixed by the shape of the cavity. Q_{HOM} is the actual (external) quality factor of the HOM which may be reduced for instance by extracting the power to the outside world by suitable antennas. Such antennas, so-called higher order mode couplers (or dampers) must not change Q_0 of the fundamental mode. Though two HOM couplers are foreseen in the TESLA cavity they are very probably not sufficient to allow for reasonably high threshold for MESA stage-2 parameters. Ongoing investigations must reveal if – or if not – TESLA cavities are suitable at least for MESA stage-1 parameters.

The time window for the decision which type of cryomudule should serve for MESA is still open, we guess that a 2 year period from ordering a module until delivery is not unrealistic. This sets the latest date for ordering to the end of 2014, if timely completion of MESA (before end of 2017) shall prevail.

802 MHZ AS ALTERNATIVE FREQUENCY

The choice of TESLA cavities with its limited HOM damping properties implies that, in order to achieve stage-2 parameters, new cryomodules would have to be acquired. Since the modules are one of the most expensive parts of the accelerator, this is not an attractive perspective. We are thinking of alternative schemes. This means finding suitable new cryomodules with improved HOM damping.

Optimized HOM damping is foreseen in many ongoing ERL projects. Usually the number of resonators is reduced (typically 5 or 7) and stronger damping (with adequate cooling of absorbers) is foreseen . It is evident that cryomodules with optimized cavities are potentially better suited for MESA but tests of such advanced cryomodules have only just begun in places such as BNL or SFTC [6], [7]. The fabrication and operation of such advanced modules is even more demanding than ELBE/TESLA, which will increase the costs and make the timeline longer. Since our institution does not have the resources to perform the necessary design work for an adaptation to our needs we cannot embark into such a project without additional part-

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ners. The absence of such a collaboration at the time of the funding proposal was the main argument why the project objectives were reduced towards stage-1 parameters.

Since spring 2013 we consider designing a 802 MHz cryomodule together with the RF group of CERN. CERN accelerator scientists discuss the LHeC collider project. This linac-ring collider [8] will enable high luminosity collisions of polarized electrons with protons from LHC. The so-far unresolved issues of multi-turn ERL operation at the multi-10 GeV range require the construction of a test-facility, which is foreseen to be build on the same timescale as MESA. The beam current foreseen for LHeC is also similar to the one needed for MESA, creating the same needs regarding the module design, in particular HOM damping. 802 MHz is a harmonic of the LHC frequency and offers considerable technical advantages as far as high power Rf-sources are considered. The collaboration with CERN would compensate for our own limitation in resources. Furthermore, we envisage to double the active length of the modules with respect to the stage-1 plan. This will not only reduce the power loss at 2 K but also the reduced gradient will lead to more reliable operation and to a larger tolerance of the system in case of a cavity which is not performing according to the specifications. A further advantage would be that the increased active length would allow to increase the energy gain per turn towards 100 MeV, hence doubling the available output energies. We will decide if we join a collaboration with CERN with the objective to design and build such cryomodules before end of 2013.

OPTIONS FOR RECIRCULATING LATTICES

A first priority for MESA is to provide beam for particle and nuclear physics experiments, the P2 experiment being of particular importance. P2 requires a beam energy of 150 MeV and a very good control of the beam parameters. A necessary condition for this is very high stability of the accelerator. Multi turn acceleration is necessary due to the restrictions in space and budget. There exist several options how to realize the multi-turn recirculation. Though a flat recirculation with independent orbits is shown in figure 2 we presently favor a CEBAF-style lattice with two axis acceleration, i.e. the two cryomodules would be placed parallel to each other. The orbits are vertically separated and good compensation of vertical dispersion can be achieved. Such an approach needs twice the number of spreaders if compared with the single axis recirculation shown in fig 2. This additional effort can be tolerated. We have already achieved a reasonable solution for the lattice functions in both ERL and EB mode in this double axis set-up [9].

An independent orbit recirculator offers high flexibility especially if one is concerned with the dependence of eq. 1 on the matrix elements T_{ij}. However, if sufficient HOM-damping could be provided, we can also investigate a polytron approach which would allow to increase the number of recirculations in order to save costs. Such a polytron lattice consist of 2*N segment magnets, where N is the order of the polytron. We presently investigate a polytron of second order. The device would have an energy gain 25 MeV per turn by a single cryomodule. The single axis acceleration is a difference to the canonical ”double sided microtron”, we therefore call the lattice an ’asymmetric polytron of second order (AP-2)’. Such a lattice has the following advantages if compared to the independent orbit recirculator:

- Considerably reduced investment for cryomodules, cavities and cryogenic infrastructure
- Strong longitudinal focusing allows inherently for very stable beam conditions and also comparatively long bunches.
- sufficient transverse focusing is possible due to techniques which were applied during the design of MAMI-C [10].
- The number of components (bending magnets, quadrupoles) is much smaller if compared to an independent orbit recirculator.
- considerably reduced size is a very important feature for our given space restrictions

These advantages make the AP2 a very tempting alternative to conventional lattices. However there also disadvantages:

- In a polytron the matrix elements are not very varianble. Fixed parameters T_{ij} may imply low threshold currents, especially since the stored currents in the module are doubled for a given current.
- In order to obtain sufficient transverse focusing inhomogeneous fields are applied in the bending magnets. These lead to large phase slips during the recirculations. In order to maintain the synchronous phase, chicanes are needed to compensate for these shifts.

CONCLUSION

MESA is an interesting accelerator project that offers unique conditions for several experiments in particle and hadron physics and especially parity violating electron scattering. The compact size and favorable conditions regarding infrastructure and staff make the realization of MESA within the given constraints of budget and infrastructure conceivable. Future work will concentrate on detailed design studies to be completed within the next two years. We believe that the MESA accelerator could start to operate by the end of 2017.

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