MESA - AN ERL PROJECT FOR PARTICLE PHYSICS EXPERIMENTS*

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Abstract

The Mainz Energy-recovering Superconducting Accelerator (MESA) will be constructed at the Institut für Kernphysik of the Johannes Gutenberg University of Mainz. The accelerator is a low energy continuous wave (CW) recirculating electron linac for particle physics experiments.

MESA will be operated in two different modes serving mainly three experiments: the first is the external beam (EB) mode, where the beam is dumped after being used with the external fixed target experiment P2, whose goal is the measurement of the weak mixing angle with highest accuracy. The required beam current for P2 is 150 µA with polarized electrons at 155 MeV. Additionally a so called beam-dump experiment (BDX) is planned to run in parallel to P2.

In the second operation mode MESA will be run as an energy recovery linac (ERL). The experiment served in this mode is a (pseudo) internal fixed target experiment named MAGIX. It demands an unpolarized beam of 1 mA at 105 MeV. In a later construction stage of MESA the achievable beam current in ERL-mode shall be upgraded to 10 mA.

Within this contribution an overview of the MESA project will be given highlighting the latest accelerator layout and the challenges of operation with high density internal gas targets.

INTRODUCTION

The MESA accelerator has been planned since approx. 2009 [1] and has undergone several design changes during that time as the layouts and requirements of the experiments have been refined as well [2,3]. MESA is planned to be constructed inside of existing underground halls formerly used by one experimental setup (A4) at the microtron MAMI [4]. Since A4 has been decommissioned the existing halls are free now and can be used by MESA. MAMI nevertheless will continue operation in parallel. In

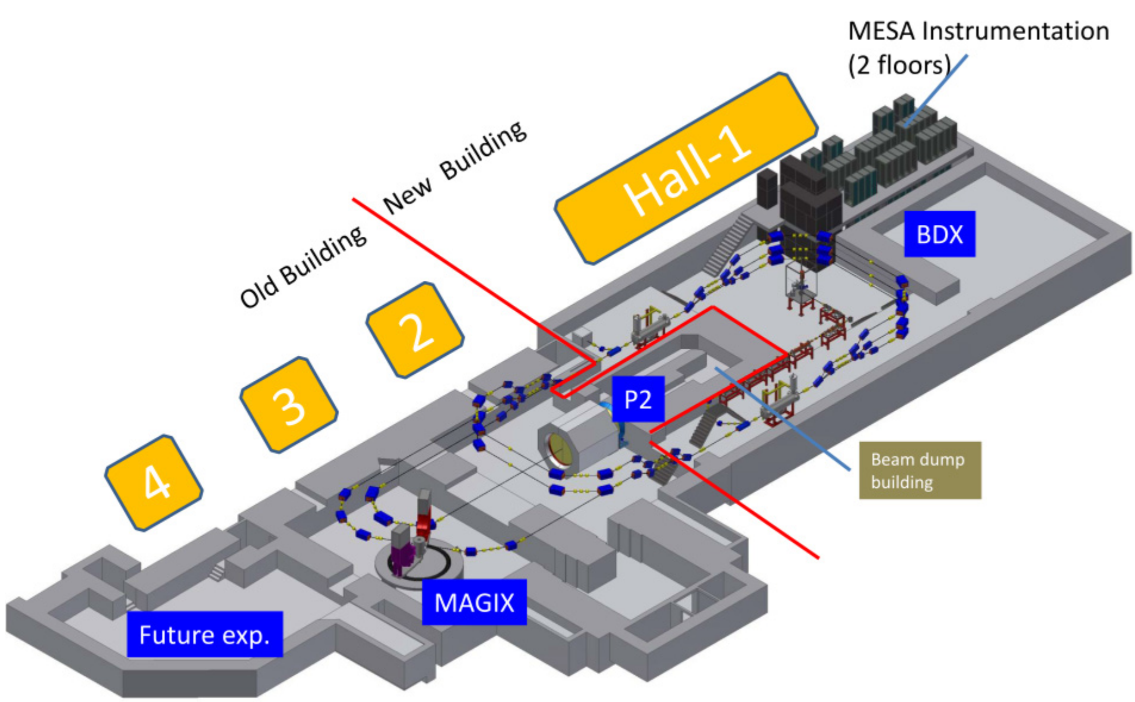

Figure 1: Layout of the MESA accelerator and planned experiments. The accelerator will be located in two existing (No. 2&3) and one new (No. 1) underground halls. The boundary between the old and new part of the building is marked by a red line. Hall 4 can be used at a later stage for additional experiments if needed. Construction of new Hall 1 will start in 2018.

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June 2015 the German research foundation DFG funded the erection of an additional experimental hall adjacent to the halls used by A4 so far, which will enlarge the underground area for the accelerator as well as for the experiments. This new hall provides large benefits for the setup of the machine but on the other hand required another change of MESA design. The latest layout, which is now defined as the final one, is given in Fig. 1.

The MESA accelerator will consist of a polarized inverted dc photogun [5] followed by a low energy beam transport containing spin manipulation and chopper-buncher sections as well as transverse matching into the accelerating structures of the injector. Afterwards the electrons will be preaccelerated by a normal conducting injector linac to energies of up to 5 MeV and beam currents of up to10 mA [6,7]. Leaving the injector the beam is transferred into the main linac through a 180° bend. 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 TESLA/XFEL 9-cell SRF-cavities mounted in two modified ELBE cryomodules [8]. Each cavity will provide 12.5 MeV energy gain.

MESA OPERATION MODES

MESA will allow two operation modes, an external beam mode and a multi-turn ERL mode. In external beam mode the beam is recirculated three times and transported to a fixed target experiment, while in ERL mode the beam is recirculated twice, hits an internal target and is decelerated again.

Experiments with External Beam

In external beam mode the beam can be accelerated to a maximum energy of 155 MeV and a beam current of 150 µA. The main experiment in external mode will be P2, which aims at a precise determination of the electroweak mixing angle (Weinberg angle), by measuring parity violation asymmetry [9,10]. For that purpose polarized electrons are needed. The polarization of the beam is flipped with a frequency of 1 kHz [11]. In order to reach the precision needed for that experiment an active stabilization of beam position is needed [12].

A second experiment in external beam mode will be the beam dump experiment BDX. It can run whenever P2 is receiving a beam. The goal of BDX is the search for dark matter particles which could be generated inside the beam dump and penetrate the massive shielding of the hall.

Experiments with ERL Beam

In ERL mode a maximum beam energy of 105 MeV and a maximum beam current of 1 mA can be reached. In a later construction stage of MESA this beam current can be increased to a maximum of 10 mA. For these high beam currents no polarization of the beam is planned due to a very short lifetime of photocathodes at such high currents. The experimental setup for measurements with ERL beam is the high resolution spectrometer facility named MAGIX [13]. Experimental goals of MAGIX are for example the search for dark photons and the measurement of the proton radius. Nevertheless the spectrometer facility can be used for many purposes in future. In ERL modes internal gas targets are used [13].

PSEUDO INTERNAL TARGET

Possible Target Layouts

One unique feature of an ERL is the possibility to achieve high luminosities with a nevertheless thin and windowless gas target. High target densities can be still used with only modest influence to the efficiency of the energy recovery of the accelerator. For MESA basically two types of targets are investigated for this purpose, a tube target and a jet target [13].

In a tube target a simple T-shaped target cell can be used with a low pressure constant gas flow to the accelerator vacuum. This design achieves only moderate target densities, however with the possibility of using a polarized gas source, e.g. via a laser-pumped polarization cell or a polarized atomic beam source. Such polarized gas targets would allow double polarization measurements.

A complementary approach is to use a supersonic jet target, where a gas jet is produced with high pressure and high gas flow. This design can easily reach gas densities where the luminosity is only limited by the acceptable multiple scattering contribution for the energy recovery mode of the accelerator, however the required high gas flow cannot be achieved with polarized gas. Nevertheless, the density of the target is still low enough to detect low energetic nuclear recoil particles with high resolution, making the target ideal for high statistics and high resolution precision measurements.

Challenges on Beam Operation

An ERL offers improved experimental conditions compared to a storage ring with an internal target. This is due to the fact that electrons only have to pass the target once which allows for stationary beam conditions even if the target has much higher areal density than those used at storage rings so far. To distinguish this device from the established technique we call it "pseudo-internal" target [14]. This experimental technique has not been realized before, its specific advantage may be found in the investigation of rare processes at low energy where the suppression of target induced background imposes limitations to conventional set-ups [15]. Figure 2 shows a GEANT-IV simulation for the distribution of intensity with respect to the scattering angle for a hydrogen target with an areal density of $5{\cdot}10^{18}$cm^{-2}.

With the anticipated MESA-intensity of up to 1 mA (~$6{\cdot}10^{15}$ electrons/s) this yields a luminosity of $3{\cdot}10^{34}$cm^{-2}s^{-1}. The results indicate that only a fraction of about $1.2{\cdot}10^{-4}$ is scattered into angles larger than 0.5 mrad, so only a tiny fraction of the overall beam would be scattered outside the acceptance of the

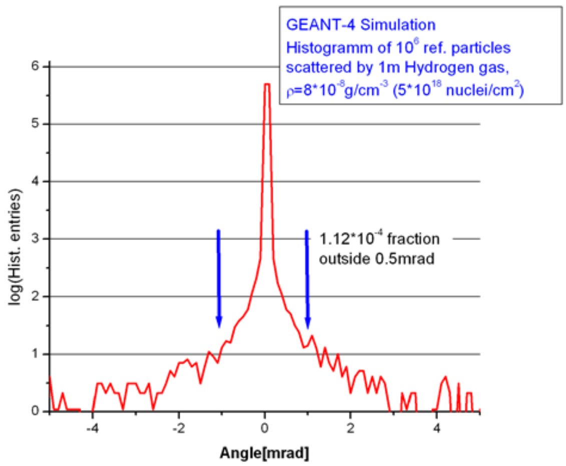

Figure 2: GEANT-4 simulation of electron scattering in a pseudo-internal hydrogen target.

accelerator. The uncorrelated energy loss inside the target is also much smaller than the inherent energy width of the beam. However, besides the particles that are used for the detection of the interesting scattering reactions there is always a fraction which is located in an 'intermediate' angular region, i.e. larger than the acceptance but smaller than the lowest detection angle. This fraction – the so-called TArget Induced haLo, TAIL – must be treated with great care, both, the desire of the experiment for low background as well as the potential deterioration of accelerator operation have to be taken into account.

SUMMARY & OUTLOOK

MESA will be a multi-turn ERL for particle physics at the university of Mainz. It will be constructed in two existing as well as one new underground hall. As the planning for the building is finalized by now the accelerator layout can be finalized as well. A general layout has been developed already. The new design can rely on much of the existing one like on the vertical spreaders [16] and the double sided layout. However the detailed beam dynamics, which already existed for the old layout including start-to-end simulations [16], have to be revised again and in parts to be calculated newly in the future months.

One challenge at the MESA ERL will be the operation with internal gas targets. Here detailed investigations are going on including estimations for collimation needed after the target in the final setup.

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