ISBN: 978-3-95450-190-8 doi:10.18429/JACoW-ERL2017-MOPSPP007

BEAM DYNAMICS AND COLLIMATION FOLLOWING MAGIX AT MESA

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Abstract

The Mainz Energy-recovering Superconducting Accelerator (MESA) will be an electron accelerator allowing operation in energy-recovery linac (ERL) mode. After the beam hits the target at the MESA Internal Gas Target Experiment (MAGIX), the beam is phase shifted and recirculated back into the linac sections. These will transfer the kinetic beam energy back to the RF-field by deceleration of the beam and allow for high beam power with low RF-power input. Since most of the beam does not interact with the target, the beam will mostly just pass the target untouched. However, a fraction of the scattered electrons may be in the range outside the accelerator and detector acceptances and therefore cause malicious beam dynamical behavior in the linac sections or even damage to the machine. The goal of this work is to determine the beam behavior upon target passage by simulation and experiment and to protect the machine with a suitable collimation system. The present status of the investigations is presented.

MESA

An overview of MESA is given in [1]. MESA will supply the P2 experiment in external beam (EB) mode with a beam current of 150 µA at 155 MeV [1,2]. In EB mode, the whole beam is dumped after interaction with the target. A second beamline is set up for the ERL mode, where the beam passes the MAGIX target and is then phase shifted 180° to the RF and recirculated through the cryomodules for energy recovery. MESA will maintain a 1 mA beam current in the first stage and 10 mA after upgrade at 105 MeV.

MAGIX

ERL operation is possible since MAGIX provides a low density target and only a small fraction of the beam actually interacts with the gas. The target is designed as a gas jet of nearly homogenous density and allows to reach luminosities in the region of 10^{35} cm^{-2} s^{-1} [3]. The jet is of cylindrical shape with 4 mm in height and diameter [4]. The jet is produced by accelerating gas to supersonic speeds in a Laval nozzle perpendicular to the beam axis. A gas catcher is set up opposite to the Laval nozzle to collect the major part of the injected gas in order to keep vacuum conditions at a tolerable level. MAGIX is designed to operate with various elementary gases for fundamental physics experiments, e.g. the search for the dark photon as well as investigations on the proton form- and astrophysical S-factor [5]. The setup is shown in Fig. 1.

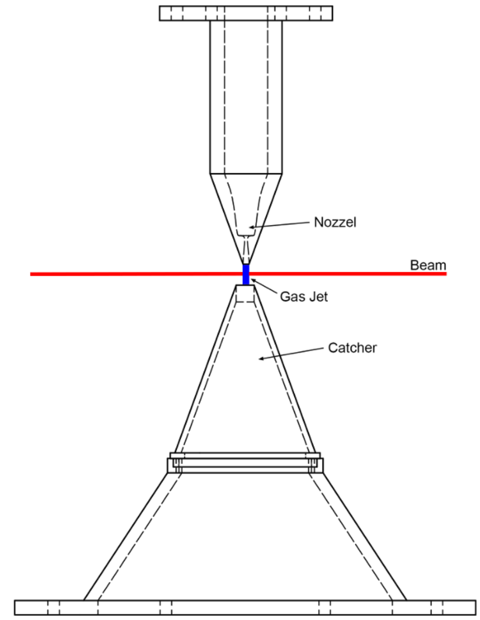

Figure 1: Schematic drawing of the MAGIX gas target [6].

Luminosity Limit Estimation

Target scattering and beam optics limit the luminosity of targets in ERL operation. Luminosity and target density limits for MAGIX can be estimated as presented in [7]. The luminosity limit then depends on beam and target properties as well as the beam power lost in the accelerator. It is therefore important to examine these parameters to ensure reliable ERL operation.

TARGET INDUCED HALO

Scattering on the gas target widens the angle and energy distribution of the electron beam in a way that a halo forms around the original beam cross-sectional area as shown in Fig. 2. The halo is therefore called "Target Induced Halo" (TAIL). TAIL might cause malicious beam dynamical behavior when passing the cryomodules, such as inducing Higher Order Modes (HOMs) in the cavity, or directly damage machine parts when electrons get dumped in the cavities and beam pipes. Radiation produced by dumping electrons may further lead to damage especially to electronic components and generate background noise in the detectors of the experiments reducing measurement precision. It is therefore crucial to carefully investigate on the effects originating from the beam passage of MAGIX and formulate a collimation approach downstream the target to encounter impacts on machine operation safety and reliability. The collimation contributes to power losses as described above and have to be minimized in order to maximize luminosity available for the experiment.

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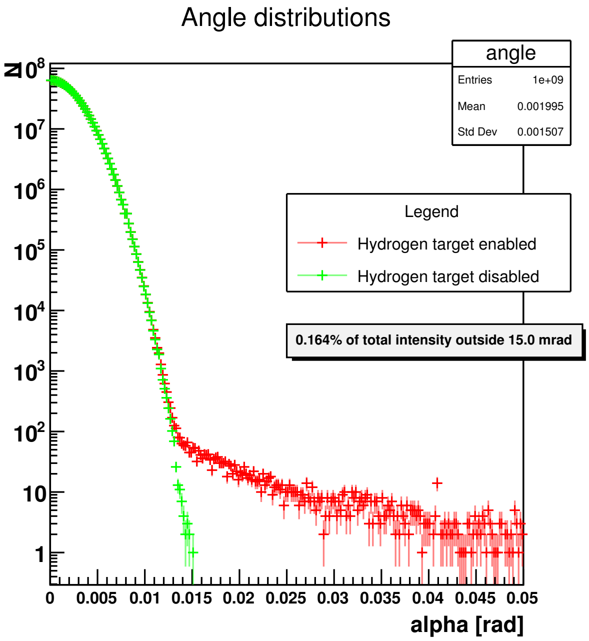

Figure 2: Geant4 simulation of the angle distributions with (red) and without (green) a hydrogen target as designed for MAGIX. TAIL region starts at 15 mrad.

Simulation of the MAGIX target

Statistical scattering models such as the Moliere distribution in practice quickly get complicated to evaluate owing to the degree of idealization on which these models are based. Simulating the target hence is a key part in understanding the formation of the TAIL. The Open Source simulation toolkit Geant4 is used for this purpose since it offers the greatest flexibility, high precision and high performance in simulating passage of particles through matter. The simulation is developed on an Intel Core i7 workstation providing four cores and eight threads allowing to run simulations in multi-threaded mode to reduce runtime significantly. By now the design parameters of the MAGIX target are not finalized, hence the development process has concentrated on performance optimization and automation rather than generating results. The simulation program is capable of processing beam, target and analysis configuration input on runtime and therefore improve the performance of the simulation routine when setup parameters are available. Furthermore efficient data handling and analysis is possible with the utilization of the ROOT analysis framework, which allows writing universal evaluation routines for popular scenarios.

Preliminary results

Although there are no final results, some qualitative statements on beam-target interaction can be made. Atomic hydrogen (H_2) with a particle density of 10^{19} cm^{-2} is used in this scenario. The beam transverse profile is modeled as an rotationally symmetrical 2-dimensional gaussian with $\sigma = 100\,\mu$m in width. Beam energy and angle distributions are gaussian with $E = 105$ MeV, $\sigma_E = 100$ keV and $\sigma_\alpha = 2.5$ mrad respectively. The beam RMS emittance is $0.25\,\pi$ mm mrad.

Angle distribution The impact of target passage on the angle distribution is shown in Fig. 2. A mentionable broadening of the distribution is visible starting from ~ 14 mrad to higher angles. The region outside 15 mrad is identified with the TAIL region. A fraction of 1.64 ‰ of the total intensity is scattered into this region in the case of a hydrogen target, which corresponds to losses of 172 W with 1 mA total beam current. These effects are expected to enlarge with higher mass target gases.

Energy distribution Energy distributions before and after target passage have been extracted to investigate on the effects on the energy distribution. The distributions were fitted with gaussian distributions yielding no net widening of energy deviation in the region of the initial beam design energy. The scattering process yet produces low energy electrons potentially reaching downstream accelerator sections as shown in Fig. 3. By now there is no correlation analysis between energy and angle available to get a clearer picture of the properties of TAIL electrons.

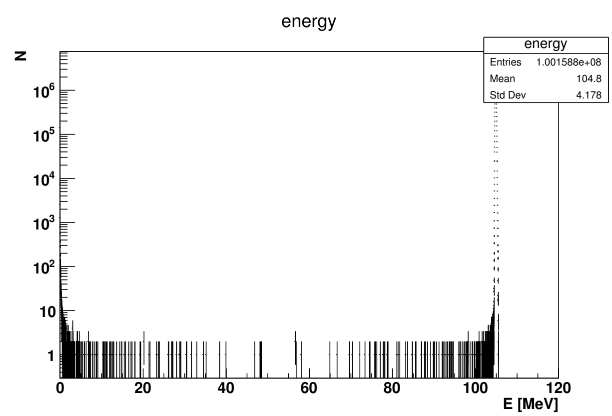

Figure 3: Electron energy spectrum after target passage. At beam energy are no visible changes, while few low energy particles are produced through scattering.

Phase space Transverse phase spaces before and after target passage were extracted and RMS emittance ellipses fitted in ROOT as shown in Fig. 4. The fit parameters show that no net RMS emittance growth is observable at such low target densities. The effect of more dense gases has to be investigated.

COLLIMATION STRATEGY

Collimation should take place after the first dipole downstream from MAGIX as shown in Fig. 5. The dipole allows to filter low energy electrons and dispersion. Movable collimators in both transverse directions are planned to account for the use of several gases at MAGIX. Further studies on

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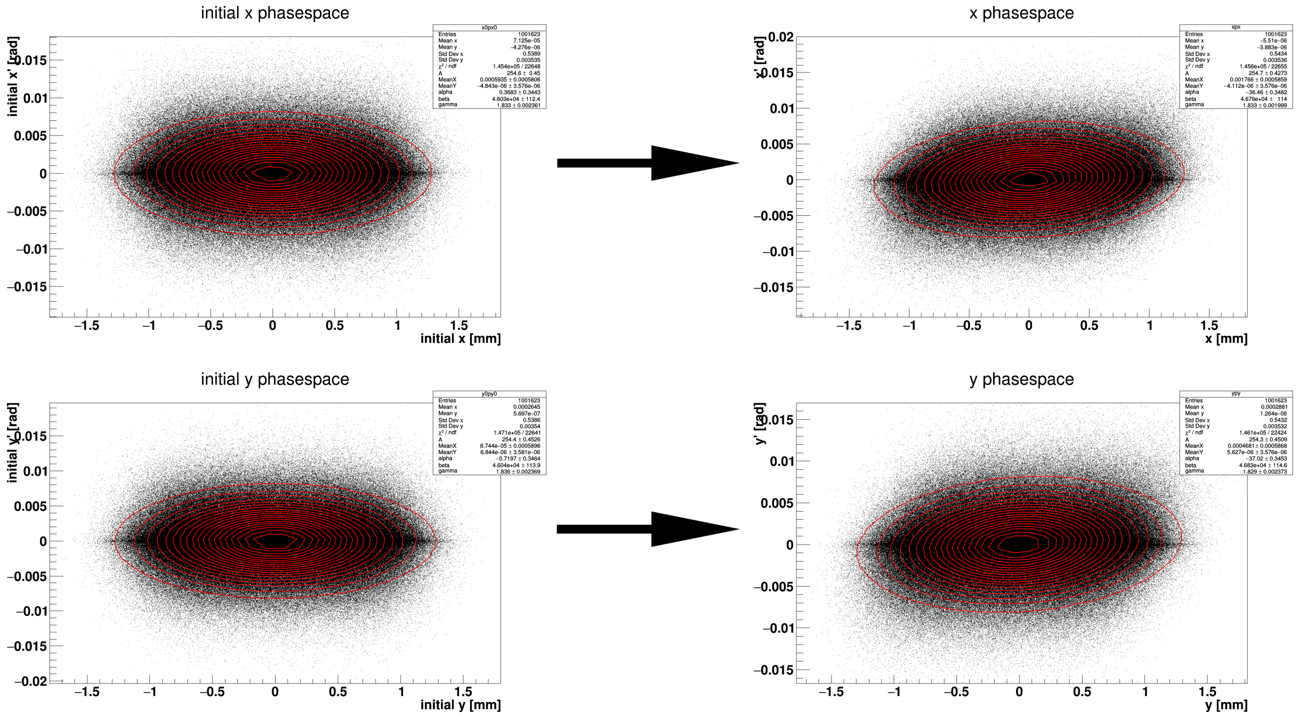

Figure 4: Transverse phase spaces before (left) and after target passage (right). The red RMS ellipses are fitted and show no RMS emittance growth.

the impact of different target gases have to be conducted to formulate a precise design of the collimation elements.

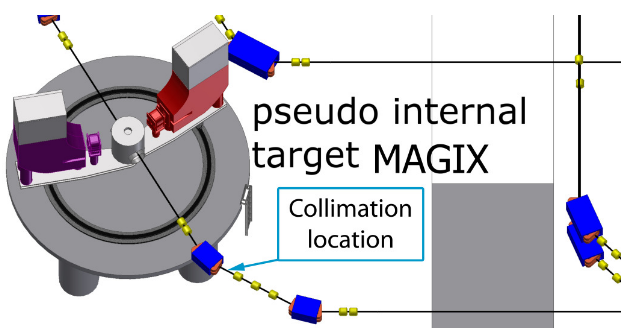

Figure 5: The region behind the first of the two foreseen deflection magnets seems to be favorable for collimation, lying neither in the direct line of sight to the target nor the cryomodules [1].

CONCLUSION

Simulation development as basis for this thesis has reached production level and rough statements on beam-target interaction could be made. The simulation process allows automated simulation routines to be run time efficient to prepare for when final design parameters are available for input. TAIL leads to significant beam losses potentially limiting the luminosity available for MAGIX, especially when operating with higher mass gases. When machine development is approaching the final design, more studies will be conducted to start collimation design. Collimator construction will be accompanied with simulations of radiation levels caused by the collimation process. Collimation experiments are intended to be conducted at the Mainz Microtron (MAMI) before MESA is commissioned.

ACKNOWLEDGEMENT

We thankfully acknowledge the funding for this project by the DFG through GRK 2128 "AccelencE".

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