SIMULATIONS OF THE FETS LASER DIAGNOSTIC

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Abstract

The Front-End Test Stand (FETS) aims to demonstrate clean chopping of a 60mA, 3MeV H- ion beam. Such high beam intensities require unconventional emittance and profile measuring devices such as the laserwire system that will be used on FETS.

A laser is used to neutralise part of the H- ion beam. The main beam is then separated from the stripped beam by using a dipole magnet. This paper presents tracking results of the laser diagnostic lattice using a simulated field map of an existing dipole magnet and investigates the possibility of laser stripping upstream of the dipole.

INTRODUCTION

The Front End Test Stand is an R&D project at the Rutherford Appleton Laboratory (RAL) with the aim to demonstrate a high power (60 mA, 3 MeV with 50 pps and 10 % duty cycle), fast chopped H- ion beam [1]. FETS consists of a high brightness ion source [2] and a magnetic three solenoid LEBT [3], both of which are operational, see Figure 1. The 4-vane 324MHz radio frequency quadrupole [4],

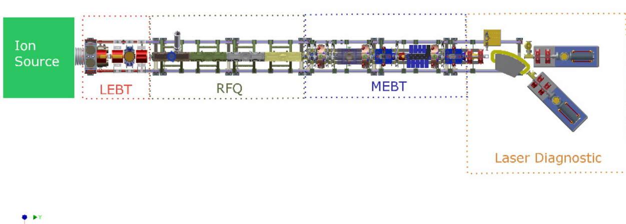


Figure 1: Layout of the Front End Test Stand.

which accelerates the beam from 65KeV to 3 MeV is manufactured and will be assembled and tested in the following months. Downstream of the RFQ is the medium energy beam transport (MEBT) [5], containing a high speed beam chopper [6] and non-destructive photo-detachment diagnostics. The MEBT is in the design phase; with the particle dynamics design finished and the transition to the mechanical design started. The diagnostics of high power particle beams is difficult, due to the power deposition on diagnostics elements by the beam, so non-invasive instrumentation is highly desirable. The laserwire emittance scanner is based on a photo-detachment process, utilizing the neutralized particles produced in the interaction between laser and H- beam for beam diagnostics purposes. The principle is appropriate to determine the transversal beam density distribution, as well as the transversal and longitudinal beam emittance downstream of the RFQ.

Previous studies of the FETS laserwire, see [7] and [8], were done with the laser stripping taking place within the dipole magnet to provide separation between neutrals within the beam and the H^0 particles produced by the laser interaction. The plan was to use a custom-built large aperture magnet and a vacuum vessel with three exit ports to allow scanning the laser over a distance of 40 mm to provide good emittance resolution. Since then it has been decided to use an existing dipole magnet and vacuum vessel and to investigate the possibility of stripping outside of the dipole magnet.

A model of the magnet was made to generate a field map which was then used to perform particle tracking simulations, including space charge effects, using General Particle Tracer (GPT) [9]. The aim was to adjust the optics of the laserwire quadrupoles to transport the beam but keeping the beam size large (around ±20 mm) at the stripping location in order to get good resolution at the detector and to have as large a beam size as possible on the dumps to keep the power density in the dumps as low as possible. The following sections give details of the magnet simulation and the tracking results for the quadrupole configuration that gives the required beam parameters at the stripping location and the subsequent transport of the stripped and unstripped beams to their respective dumps.

DIPOLE FIELD SIMULATION

The existing dipole magnet, see Figure 2, was modelled using CST Studio [10] to produce a magnetic field map that was used in the particle tracking simulations. Measurements of the yoke and coils were made and a 3D model of the magnet, see Figure 3. Here the magnet requires flipping to get a bend in the negative direction and will require mounting the existing magnet upside down. However, for the purposes of these simulations, this will not have any effect on the outcomes of the simulation results so the magnet was used in its current orientation. A 3D field map was generated using 100 A excitation current in the coils which gave 0.2475 T in the centre of the magnet. Figure 4 is a plot of the on-axis vertical field and shows that the fringe fields extend up to 300 mm from the entrance and exit faces of the magnet. Tracking a 3 MeV H^- ion, and ensuring it is on-axis at the entrance and exit faces, requires scaling the field by 0.894 to take into account the longer effective magnetic length due to the fringe fields.

The full 3D field map from this simulation was used in the tracking simulations described in the following section.

ISBN 978-3-95450-176-2

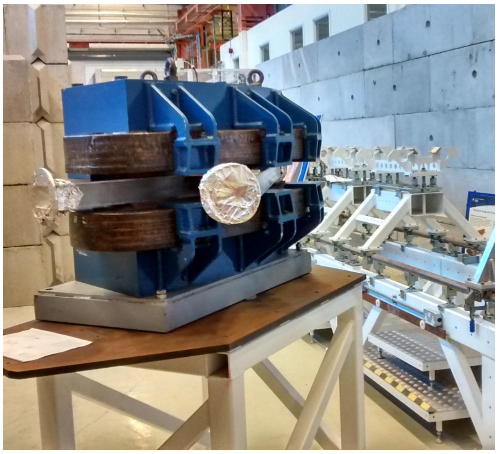


Figure 2: Picture of the existing dipole that can be used for the laserwire beam line.

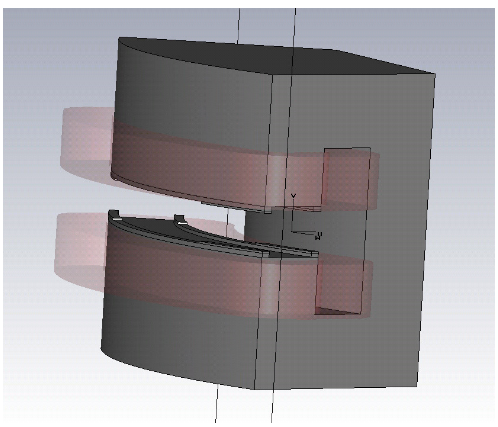


Figure 3: 3D model of the magnet in CST Studio.

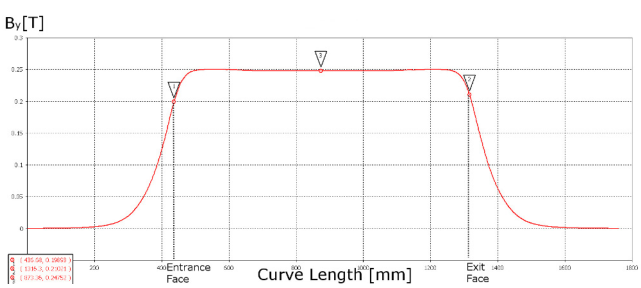


Figure 4: On-axis field from the CST Studio simulation. The markers indicate the field at: 1) the entrance face; 2) the exit face; 3) the centre of the magnet.

PARTICLE TRACKING SIMULATIONS

The main aim of these simulations was to demonstrate the feasibility of using the existing dipole and to perform stripping upstream of the dipole. Figure 5 shows the CAD drawing of the laserwire lattice, the main components being the 45° sector-bend dipole magnet, the six quadrupole magnets (two upstream and two downstream in each direction), the laser feedthrough and the beam dumps. The beam at the exit of the RFQ (10k particles) was tracked through the final version of the MEBT lattice (using the latest fields maps

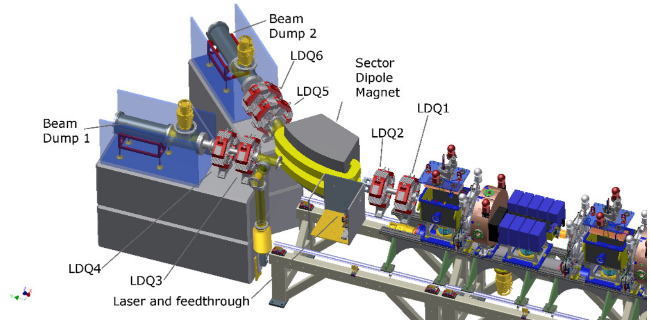


Figure 5: CAD model of the laserwire lattice showing the six quadrupoles (LDQn), the 45° sector-bend dipole magnet, the laser feedthrough and the beam dumps.

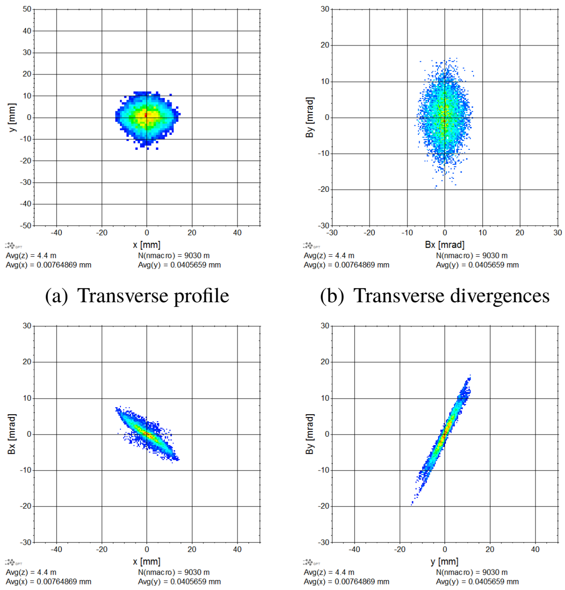
for the quadrupole magnets and rebunching cavities) to the location 4.4m downstream of the RFQ exit, which is the start of the laserwire lattice. The beam distribution at this location, see Figure 6, was used as the input beam for the laserwire lattice. Tracking of particles through the laserwire lattice was done in three separate stages: tracking of the H^- ion beam with the dipole switched off (this is the normal operating mode); with the dipole switched on and tracking H^- ions through to dump 2; and taking the beam distribution at the stripping location and drifting it (i.e. track with zero charge to simulate H^0) to dump 1.

The positions of the first two quadrupole magnets in the laser diagnostic beam line were adjusted such that there is no overlap of the magnets' fringe fields and to have a region of zero magnetic field before the dipole where laser stripping can take place. To get the best resolution at the detector it is better to have a beam size close to the maximum size of the detector. So the quadrupole strengths were adjusted to give a beam size around 40 mm in diameter at the detector location while ensuring the beam envelope stays within the aperture of the quadrupole magnets, i.e. ±30 mm and is large over the length of the beam dumps. The chosen set of quadrupole settings transports the beam without going through focal points and so a large beam size is maintained throughout the lattice. Figure 7 shows the trajectories in the x-z and y-z planes of the particles with the dipole switched off. This is the normal operating mode with the full beam going through to dump 1. The density profile of the beam at dump 1, see Figure 8, shows that the beam is well spread out.

With the dipole on the beam is deflected to dump 2. Figure 9 shows the trajectories in the x-z and y-z planes for the beam when the dipole is on. The bottom two plots are in the coordinate system of the exit face of the magnet (i.e. the z-axis is perpendicular to the exit face) and give a clearer indication of the beam envelope through LDQ3, LDQ4 and dump 2.

The density of the beam at dump 2, see Figure 10, shows the beam is well spread out but shows some distortion, which is currently under investigation.

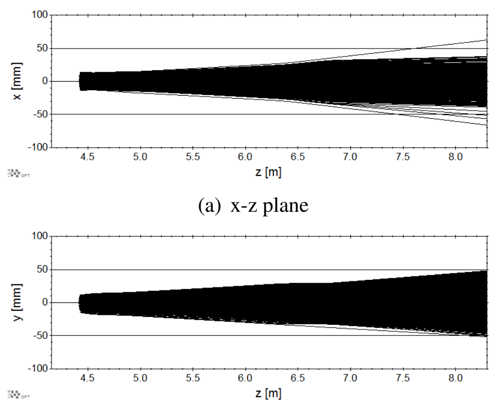
The particle distribution is read out at the stripping location, which is 300 mm before the entrance face of the dipole,



(a) Transverse profile (b) Transverse divergences

(c) x Emittance (d) y Emittance

Figure 6: Phase space distrbution of the input beam used in the tracking simulations.



(a) x-z plane

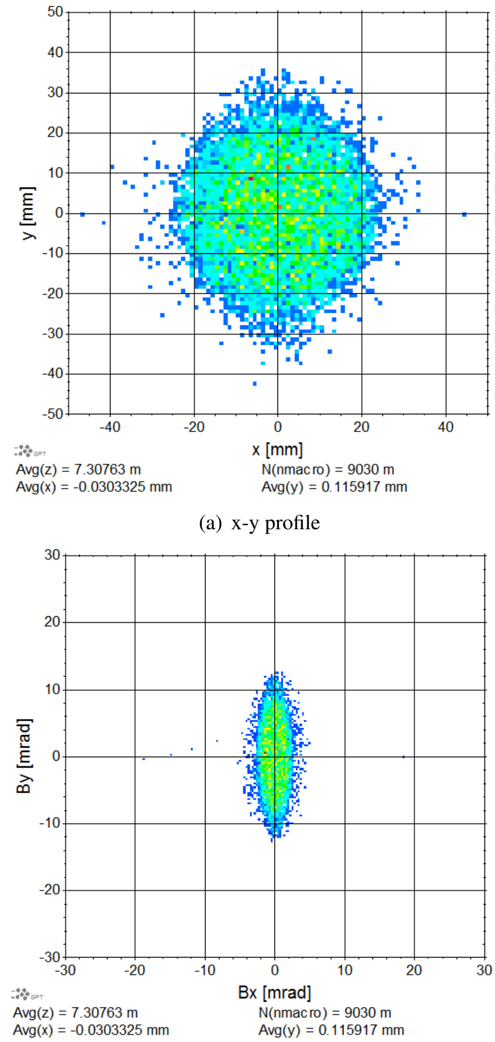
(b) y-z plane

Figure 7: Particle trajectories with the dipole switched off.

see Figure 11. The charge is set to zero for this particle distribution. These are then drifted (using the mass of the H^0) to the detector location, see Figures 12.

CONCLUSION

The simulation results show that the existing dipole is suitable for use as the bending magnet for the FETS laserwire emittance measurement device. The quadrupole settings have been adjusted to provide the required beam parameters at the stripping location in order to give good coverage over the full area of the detector, thus maximising the measurement resolution. The laserwire lattice has the flexibility to test different methods for the emittance measurement, including the options to scan the laser outside of the dipole field and in all transverse directions. Further work will focus on defining the set of measurements to be performed with



(a) x-y profile

(b) x-y divergences

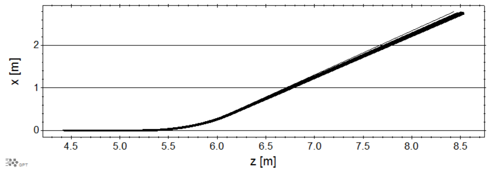
Figure 8: Beam at the entrance face of dump 1.

this configuration and investigate the best emittance resolution achievable by using different laser configurations and detectors.

ACKNOWLEDGMENT

The authors would like to thank Scott Lawrie for the quadrupole field map and Morteza Aslaninejad for the MEBT simulation and assistance with GPT.

ISBN 978-3-95450-176-2



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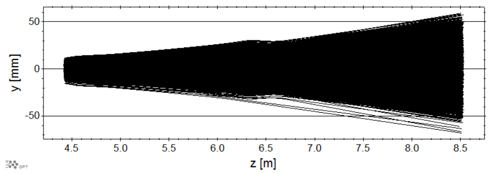
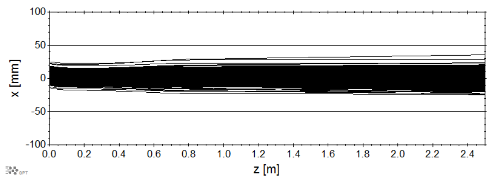
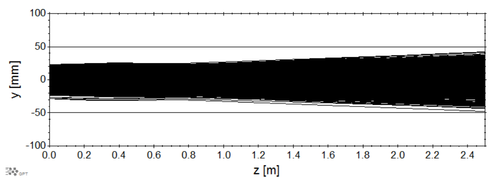


(b) y-z plane

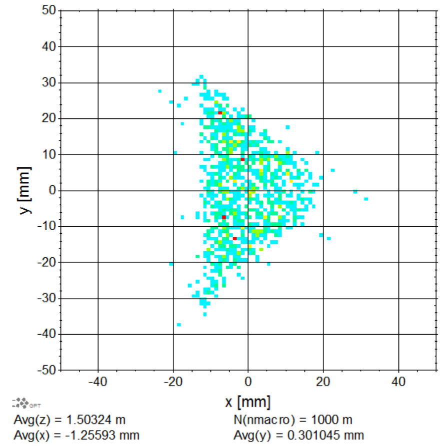


(c) x-z plane in the coordinate system of the exit face of the dipole.

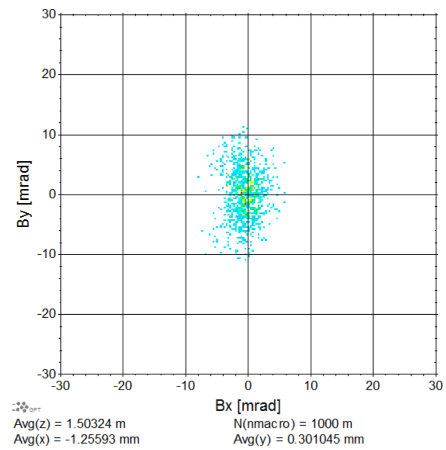


(d) y-z plane in the coordinate system of the exit face of the dipole.

Figure 9: Particle trajectories with the dipole switched on.

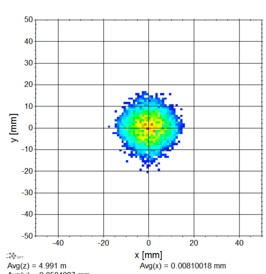


(a) x-y profile

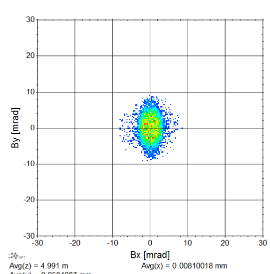


(b) x-y divergences

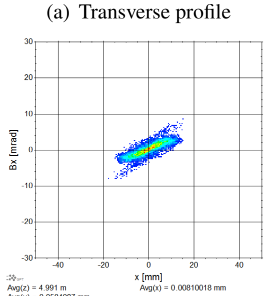
Figure 10: Beam at the entrance face of dump 2.



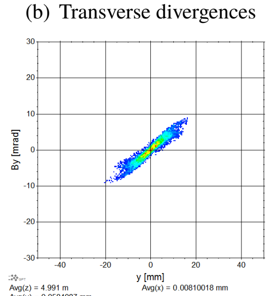
(a) Transverse profile



(b) Transverse divergences

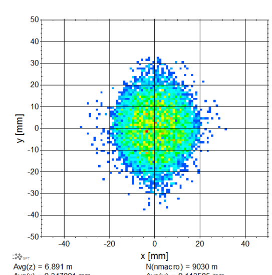


(c) x Emittance

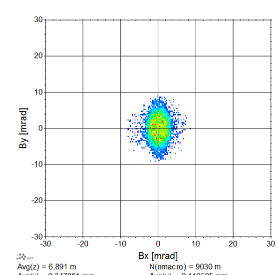


(d) y Emittance

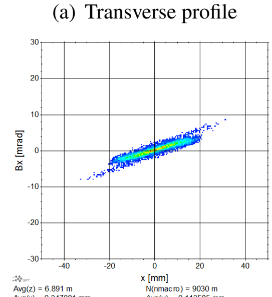
Figure 11: Phase space distrbution of the stripped beam used as the input beam for tracking neutrals to the detector.



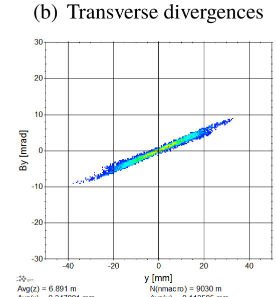
(a) Transverse profile



(b) Transverse divergences



(c) x Emittance



(d) y Emittance

Figure 12: Phase space distrbution of the beam of neutrals at the detector location.

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ISBN 978-3-95450-176-2