DESIGN OF THE BILBAO ACCELERATOR LOW ENERGY EXTRACTION LINES

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Abstract

The ESS-Bilbao linac will accelerate H^+ and H^- beams up to 50 MeV, which need to be transported to three laboratories, where different types of experiments will be conducted. This paper reports on the preliminary design of the transfer line, which is mainly performed based on beam dynamics simulations.

INTRODUCTION

The first stage of the ESS-Bilbao linac aims to accelerate a high current beam of light ions up to 50 MeV. Two ion sources will inject H^+ and H^- beams into a hybrid Low Energy Beam Transport (LEBT), which are then accelerated by the Radio Frequency Quadrupole (RFQ) up to 3 MeV. The particles are then transported by the Medium Energy Beam Transport (MEBT) into the 3–tank Drift Tube Linac (DTL), which accelerates them up to 50 MeV. The beams will be injected in the form of (up to) 2 ms long pulses, with 50 Hz (max.) of repetition rate and a duty cycle of 8 %, reaching a maximum peak current of 75 mA.

There are three main laboratories projected at this first stage of the project, which will make use of the ion beam to perform several types of experiments. Due to radiological protection reasons, as well as a maximal utilization of the space available in the projected building, the accelerator will be located in a tunnel at -10 m under the surface, together with one of the laboratories. The other two will be placed at ground level. Therefore, is is necessary to design and construct the transfer lines that will transport the beam from the output of the DTL to the three laboratories. This work reports on the preliminary development of said 50 MeV transfer lines.

50 MEV APPLICATIONS

The characteristics and location of the projected 50 MeV laboratories are explained bellow:

1. Material Irradiation Laboratory: This facility, codenamed P4M (*Protons for Materials*), will host experiments to evaluate radiation damage in materials aimed for fusion reactors [1]. Two different types of experiments will be able to be performed simultaneously: in-beam mechanical tests, to analyse the material during irradiation; and off-beam analysis, to study physical properties of the material after irradiation.

   The maximum required average intensity will not exceed 1 mA, applied continuously over several days. The beam spot size will be limited to 1 cm^2. The samples will be about 1 mm thick and made of Eurofer97 and other reduced activation steels. The irradiation will take place inside vacuum chambers.

2. Radiation Biology Laboratory: In this facility, codenamed P4B (*Protons for Bio*), the response of biological material (cells, tissues and organs) to ionising radiation will be studied. The experiments will be oriented to biomedical research on Proton Therapy [2].

   A maximum average current of 1 µm, applied over very short periods of time, is required for the applications conducted in the P4B laboratory, with a transverse beam size of 1–10 cm. Depending on the specific application, the beam energy may need to be degraded to values in the 10–50 MeV range.

3. Neutron Applications Laboratory: This facility will consist of a low intensity neutron source based in the Be (p, n) reaction, which enables experimentation with cold neutrons similar to that of LENS [3]. The configuration of the neutron production target will be based on a rotating disk of beryllium slabs perpendicularly facing the beam on one side, and a cryogenic methane moderator on the other, with the target–moderator system surrounded by a beryllium reflector.

In order to achieve an efficient location of the laboratories, the P4M facility will be placed at the same level as the linac (-10 m), whith the other two laboratories on the surface (0 m). The location of the P4M facility is depicted in figure 1.

Due to the fact that the laboratories are located at different vertical levels, the 50 MeV transfer tine needs to be split in two after some point, with one sub-line going horizontally into the P4M laboratory, and other sub-line ascending 10 m to the surface level, where it will be bent back into the horizontal direction before entering the upper facilities. The next section presents the preliminary transfer line design, based on beam dynamics simulations.

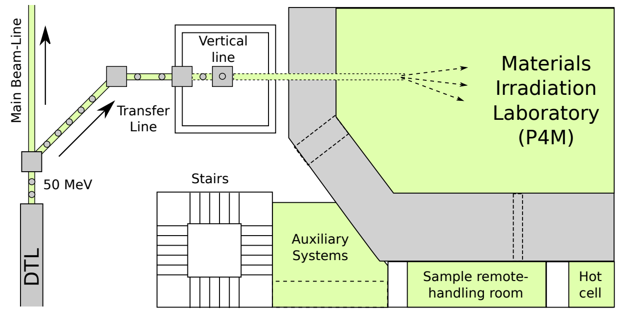

Figure 1: Schematic top view of the $-10\,\mathrm{m}$ level of the linac, depicting the first part of the 50 MeV transfer line, and the Material Irradiation Laboratory.

TRANSFER LINE DESIGN

Line Geometry Description

Figure 2 depicts the placement of the dipoles along the line (not to scale), which is divided in two main sections, depending on the direction of the bends.

A first pair of quadrupoles adjusts the beam that comes out of the DTL to enter the horizontal section of the line. This section starts with a $45°$ horizontal bending magnet (BM). The beam is transported by 5 quadrupoles to the second 45° horizontal BM. The dipoles are placed in a double bending achromat configuration (DBA) [4]. This first section leaves the beam oriented perpendicularly to the linac.

The next pair of quadrupoles match the beam into the vertical section. The first vertical bend is composed by two $45°$ bending magnets with a quadrupole in between. The beam is transported by 5 more quadrupoles along the vertical section, and is then deflected into the direction parallel to the ground by a second pair of vertical BMs of $-45°$ each, with a quadrupole in between. The vertical section of the transfer line follows an achromatic configuration, where each $90°$ bend is carried out by two BMs, for manufacturing simplicity.

The 17 quadrupoles to be used are $300\,\mathrm{mm}$ long, with an expected maximum field gradient is $10\,\mathrm{T/m}$. The bending radius of the 6 BMs is $1.2\,\mathrm{m}$, which implies a magnetic field lower than $0.9\,\mathrm{T}$. The foreseen apertures of all the elements should fit a beam pipe with an inner radius of $50\,\mathrm{mm}$.

The dipoles and the quadrupoles will be iron dominated, resistive magnets. The coils will probably require water cooled hollow conductors, with the yoke made of solid low carbon iron. Sector magnets will be used to design and fabricate the dipoles, which allows to reduce their size due to their high bending angle. H-type magnets are being preliminarily considered. All the dipole simulations will be made with COMSOL Multiphysics.

The quadrupoles will be designed and optimized using ROXIE, a well known CERN software for magnet design. The coils will be racetrack in order to simplify the fabrication process. The yoke could be made of solid iron or stacked low carbon iron sheets, depending on the costs. The coils will not fit inside the aperture, and therefore the yoke will be split in several parts for the coil assembly.

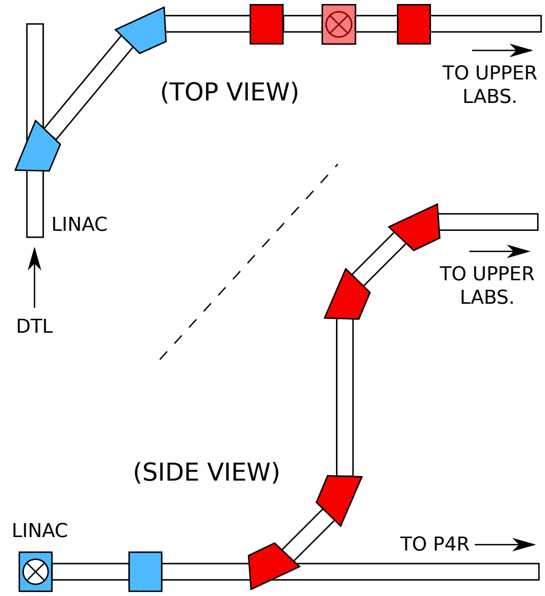

Figure 2: Top and side views of the transfer line geometry, including horizontal (blue) and vertical (red) dipoles.

Table 1: Beam Parameters at the Input and Output of the Transferline. β and ϵ_{nrms} are in π-mm-mrad units.

	Input			Output		
	α	β	ϵ_{nrms}	α	β	ϵ_{nrms}
x-x'	-4.24	2.97	0.27	-1.67	5.64	0.36
y-y'	3.11	2.14	0.29	5.26	3.24	0.58
z-z'	0.24	3.93	0.38	-31.87	564.50	0.67

Simulations

Two basic criteria were imposed to validate the magnetic quadrupole configuration of the line: a) The dispersion optical functions (D_x and D_y) should be made zero at the end of each section. Otherwise, the dispersion will grow continuously, since only bends in a certain direction can change the dispersion in that specific direction. Therefore, each section must contain an even number of bends. b) The beam envelope radius, calculated as [4],

$$r_u = \sqrt{5}\sqrt{\beta_u \epsilon_u + \left(D_u \frac{\Delta p}{p}\right)^2} \qquad u = x, y;$$

where β is the betatron function and ϵ is the emittance, should be smaller than the aperture radius of the focusing elements.

As shown in Figure 4 (top and middle), the dispersion in both horizontal and vertical planes are made zero at the end of each of the bending sections. The beam $\sqrt{5}$–envelope

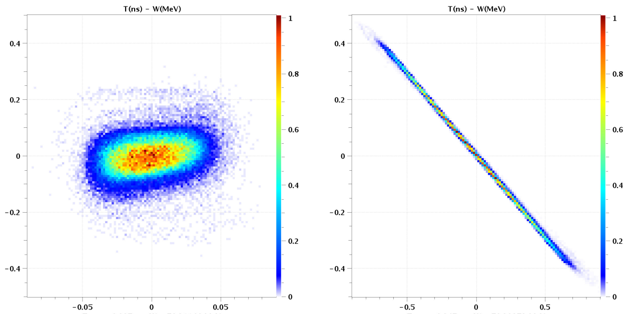

Figure 3: Longitudinal phase-space distributions of the input beam (left) and transported output beam (right), represented as ΔT vs. ΔW.

aperture remains bellow half of the pipe aperture at the widest point (Figure 4, bottom plot). Multiparticle simulations show that no beam loss is noticeable. The momentum dispersion ($\Delta p/p$) growths smoothly along the transfer line, but stays below $0.5\,\%$.

The output beam parameters, listed in Table 1, show a 50% and 100% increase in the transverse emittances. Figure 3 shows an 10-fold bunch time-length increase and a 2-fold energy spread growth. This is due to the fact that no re-bunching cavities have been used in the line, since the calculated beam longitudinal distribution is suitable for the applications presented in the first section of this paper.

CONCLUSIONS

We have presented a preliminary design for the ESS-Bilbao 50 MeV transfer line, showing promising results. However, the work is still in progress, and will probably be subjected to later modifications depending on the final design of the previous elements of the accelerator.

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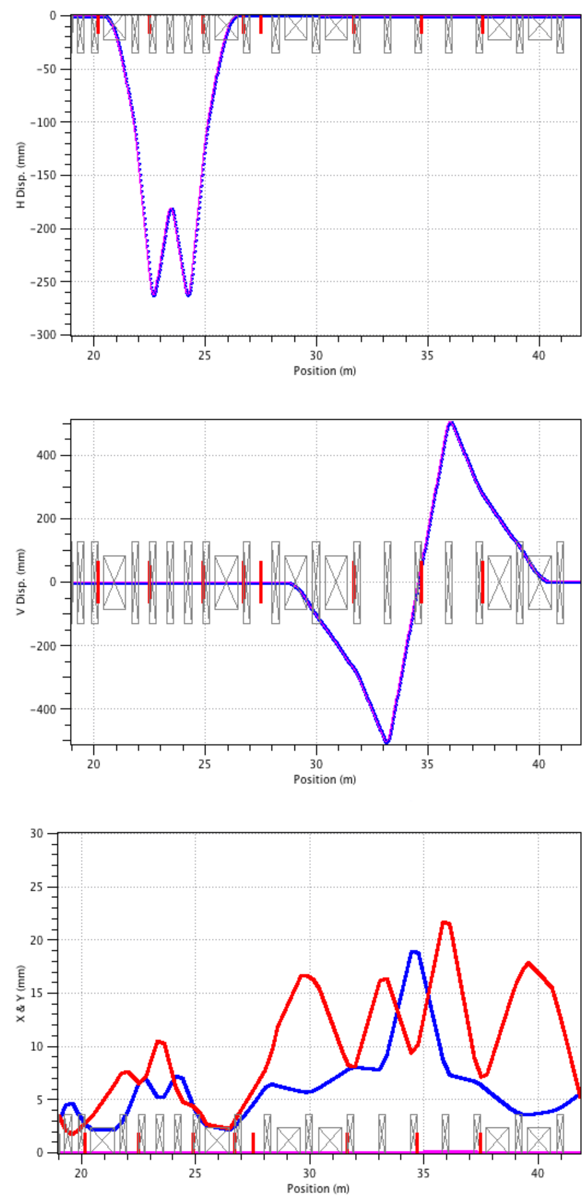

Figure 4: Top: horizontal dispersion. Middle: vertical dispersion. Bottom: Beam $\sqrt{5}$-envelope in horizontal plane (blue) and vertical plane (red).

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