MACHINE PHYSICS STUDIES FOR THE MYRRHA PHASE 1 LINAC AT SCK CEN

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Abstract

At the Nuclear Research Center SCK CEN in Belgium, the first phase of the MYRRHA project (an accelerator driven system) is under construction. Included in MYRRHA Phase 1 are a normal conducting injector linac (RFQ + CH cavities) and a super conducting (SC) linac, providing a CW proton beam of 4 mA and 100 MeV. In this contribution the recent changes to the MYRRHA Phase 1 linac design and the associated machine physics studies are reported. First of all, the layout of the MYRRHA linac was changed from two identical injector linacs each including a dog leg to one straight injector (for the MYRRHA phase 1) and a (future) second injector with a dogleg. The beam dynamics studies of the straight linac and two options for the second injector are presented. Secondly, the impact of a detailed mechanical integration of the beam line elements, which is a compromise between the ideal theoretical layout and a realistic and pragmatic implementation, on the longitudinal and transverse phase space distributions are presented. Finally, the losses along the SC linac are compared for the new and old injector layout.

GENERAL OVERVIEW

The MYRRHA Phase 1 accelerator contains a Low Energy Beam Transfer line (LEBT) which is described in detail in contribution [1]. The main purpose of the LEBT is to match the continuous 4 mA proton beam into the Radio Frequency Quadruple (RFQ) which accelerates the beam from 30 keV to 1.5 MeV.

Following the RFQ, the proton beam is injected into a first matching section (ME1), consisting of 2 normal conducting re-bunching quarter-wave resonators with a quadrupole triplet in between them. Following the ME1 section, the beam is accelerated by 15 normal conducting CH cavities from 1.5 MeV to 16.6 MeV. After the first 7 CH cavities, around 5 MeV, a second matching and diagnostics section is installed with a doublet and 1 re-bunching CH cavity. All components from the source up to this point are referred to as the 'injector'. Selected machine physics details and studies related to the injector are presented in the following paragraph.

Before the beam is injected into the superconducting linac, it passes through another diagnostics section and sections dedicated to fast switching between 2 identical injectors. Different designs for the second injector are presented in the paragraphs below. Note that for MYRRHA Phase 1, only 1 injector will be constructed.

Finally, the beam is injected into a superconducting linac consisting of 30 lattice periods of 3.040 m. Each lattice period consists of a normal conducting quadrupole doublet and 1 cryomodule (QM) containing 2 superconducting single spoke cavities. The superconducting section is referred to as the "Low Beta" (LB) section. Subsequently, the beam is distributed to the user facilities PTF and FPF (see [2]) via the High Energy Beam Transfer Lines (HEBT) or the high energy beam dump.

THE NORMAL CONDUCTING INJECTOR

An Alternative Second Injector

Although a second identical injector will not be constructed during the MYRRHA Phase 1, it was nevertheless decided to change the second injector concept from two symmetric injectors which both inject into the super conducting (SC) linac via a dog-leg (see bottom part in Fig. 1) to a layout where the first injector is 'in-line' with the SC linac (i.e. a straight linac for MYRRHA Phase 1) and the second injector can inject into the SC linac with either a dog-leg or a septum-kicker.

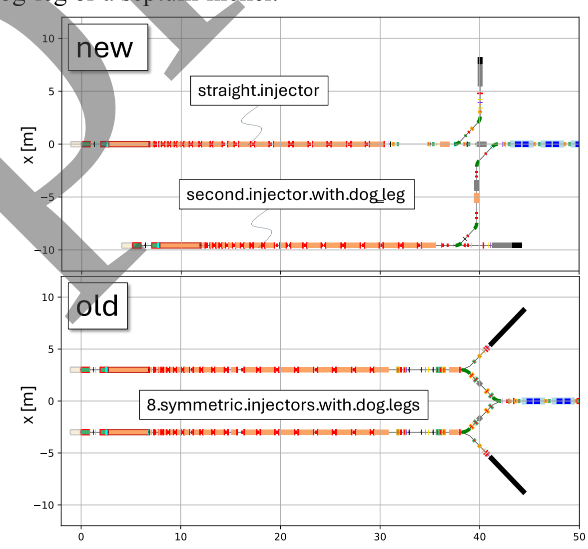

Figure 1: (bottom) The original concept of 2 identical injectors and the (top) the currently implemented solution.

The major benefit of the new injector layout is the improved matching at the entrance of the SC linac. As can be seen from Fig. 2, the longitudinal matching has improved considerably. The 'red' highlighted protons, which are lost at higher energy in the SC linac and are related to longitudinal halo from the injector, have completely disappeared. For the second injector, the beam parameters can be monitored and validated continuously very close to the injection.

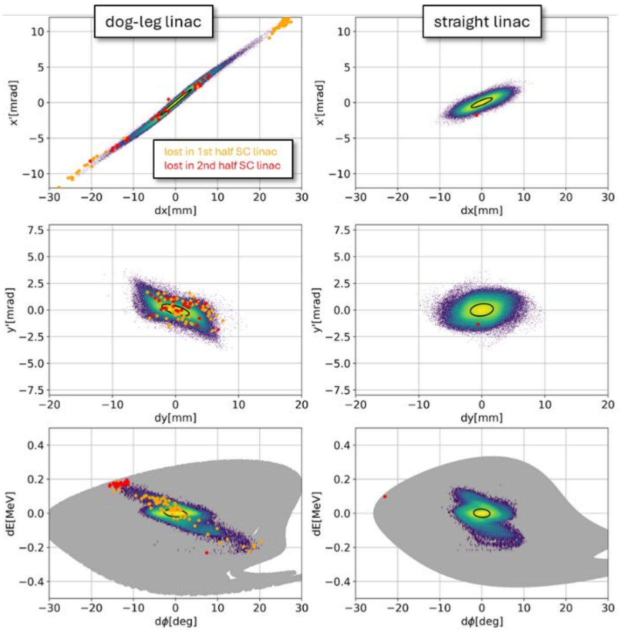

Figure 2: The transverse and longitudinal beam distribution at the entrance of the SC linac for the old (left) and new (right) injector layouts. The orange and red highlighted protons are again protons which are lost in the first and second half of the SC linac.

Several options for injecting from the 2nd injector to the SC linac are currently being investigated and are shown in Fig. 3. The first option is similar to the initial concept consisting of a dog-leg with a fast-switching dipole (within a few seconds). The two other options use a septum-kicker option, which allows for considerably faster switching between injectors.

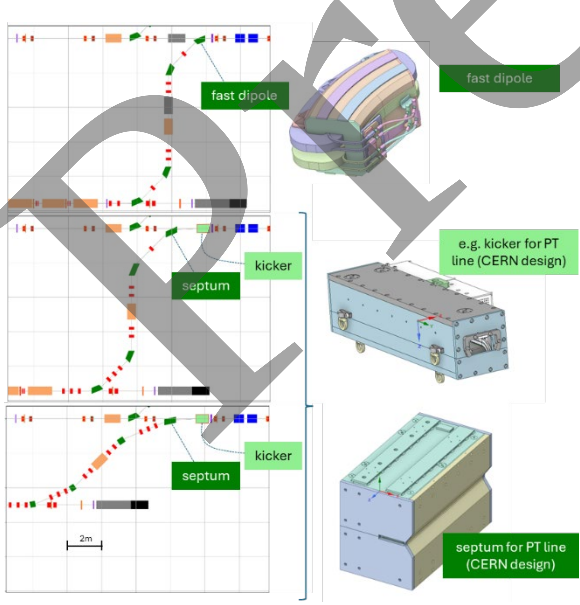

Figure 3: Options for injecting from the 2nd injector to the SC-linac.

Mechanical Integration and Longitudinal Halo

In recent years, the detailed design of the injector components (cavities, quadrupoles, BPM's, etc.) has been performed, necessitating a detailed mechanical integration of the injector. During this process, compromises have to be found between mechanical feasibility and impact on beam optics for the new design. During this process it has become clear that increased distances between the first few CH cavities (at low energies) have a severe impact on the creation of a tail in the longitudinal distribution, as illustrated in Fig. 4. Protons which will be lost in the first and second half of the following SC linac are tagged in orange and red, respectively. Protons lost in the second half of the SC linac are mainly related to the longitudinal tail (halo) from the injector. Since these are higher energy protons and deposit higher power, this tail should be avoided. Protons lost in the first half of the SC linac are related to protons at the transverse edges of the beam and can be removed by collimators before the SC linac.

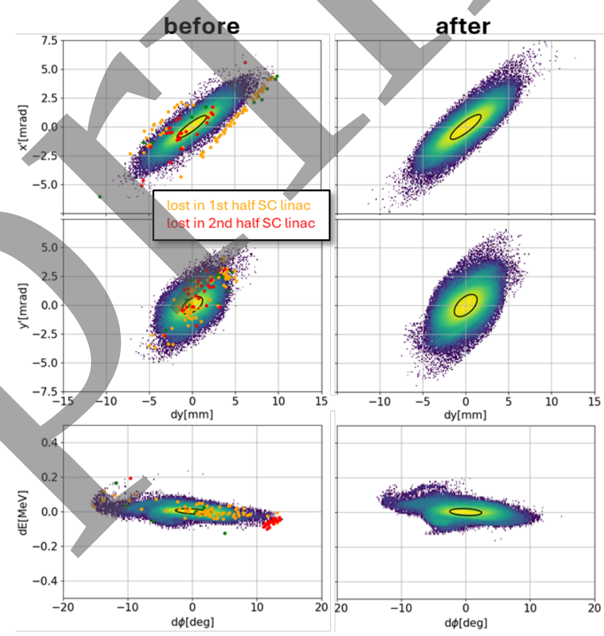

Figure 4: Phase space distributions taken at the end of the last CH cavity, "before" (left) and "after" (right) optimizing the CH mechanical integration for optimal longitudinal tuning.

THE SUPERCONDUCTING LINAC

Figure 5 compares the transverse and longitudinal envelopes of the 'old' accelerator layout (with a dog-leg between injector and SC linac) and the 'new' (straight) accelerator layout. The dashed lines in the transverse envelopes indicate the maximum excursion of a proton. The new layout reduces the horizontal maximum size considerably. The impact of the change to a straight linac on the longitudinal distribution was illustrated at the start of the SC linac in Fig. 2 (better matching and less halo). This results in a much cleaner beam at the end of the SC linac longitudinally as is shown in Fig. 6.

Figure 7 shows the energy of the beam along the SC linac and the dots represent the position and energy of the protons which are lost along the way. Protons which are below the nominal beam energy have dropped out of the longitudinal bucket already at the start of the SC linac and are lost transversally mainly in the second half of the SC linac. Clearly these losses have been reduced due to the better longitudinal match at the start of the SC linac and the reduction of the longitudinal tail from the mechanical integration of the injector. Proton which are on the nominal energy curve are protons which reside in the transverse halo. Note that these protons could be removed by collimators before the SC linac in the 'old' injector design. In the new design, even without collimators, these transverse halo protons are not present anymore.

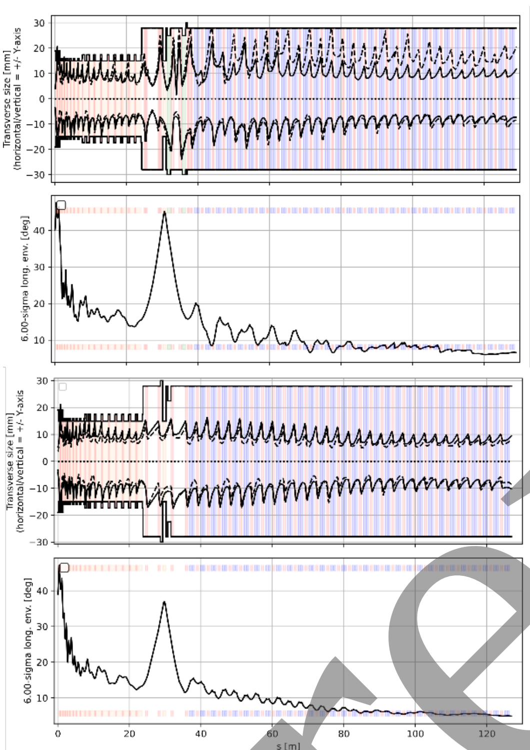

Figure 5: The transverse and longitudinal 6-σ envelopes for the 'old' design (top, with a dog-leg after the injector) and for the 'new' design (bottom, the 'straight' linac).

CONCLUSION

A better longitudinal and transverse matching at the start of the SC linac has been achieved for the MYRRHA Phase 1 construction phase thanks to the change to an injector in a straight line with the SC linac and due to a careful mechanical integration of the CH cavities in this injector. Options for the second injector are still open, but clearly a dog-leg or a septum-kicker option are identified as valid choices.

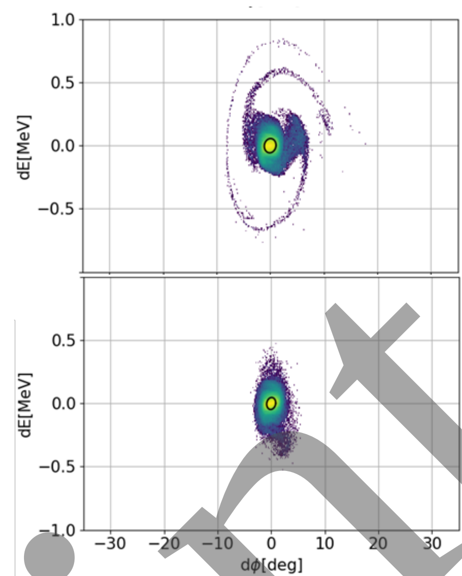

Figure 6: Longitudinal distribution at the end of the SC linac for the old (top) and new (bottom) accelerator layout.

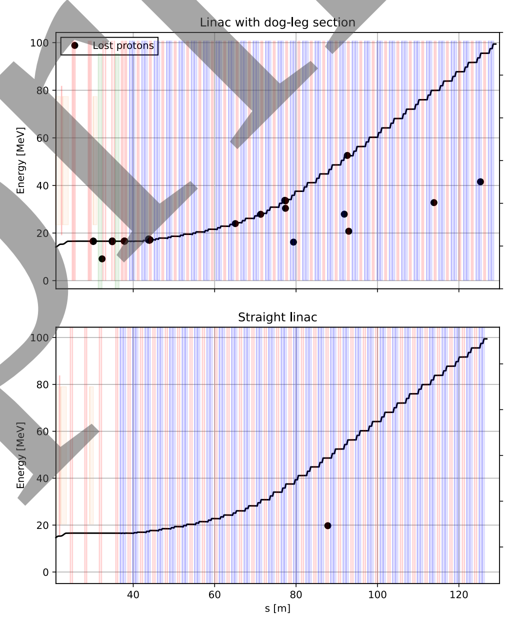

Figure 7: Energy along the SC linac with the black dots representing the position and energy of the protons which are lost along the way.

REFERENCES

[1] L. De Keukeleere, U. Dorda, J. Hustings, E. Tanke, and J. Van De Walle, "The Low Energy Beam Transfer (LEBT) line and RFQ for the MYRRHA Phase 1 facility", presented at the IPAC'26, Deauville, France, May 2026, paper THP4057, this conference.

[2] L. Perrot *et al.*, "Detailed design studies of the high energy beam transport line of the Minerva Project at SCK CEN", in *Proc. IPAC'23*, Venice, Italy, May 2023, pp. 69-72. doi:10.18429/JACoW-IPAC2023-MOPA011