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# DOUBLE ACHROMAT SOLUTION WITH A DEDICATED COLLIMATION SYSTEM FOR THE MEBT-3 SECTION OF MYRRHA*

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*Abstract*

MINERVA (MYRRHA phase 1) aims at demonstrating the requirements related to the reliability and the fault tolerances of the MYRRHA accelerator-driven system (ADS) by the realization of a superconducting linac for 100 MeV, 4 mA proton beams. The reference scenario of injector reconfiguration and line switching has been defined [1, 2] with the maximal time for the procedure being 3 seconds. A universal tool for compensation of various failure scenarios in linacs has been developed [3].

The design and the performance of the Medium Energy Beam Transfer section (MEBT-3) of the accelerator are critical for the operation of the linac and the subsequent high energy beam lines towards the experimental facilities of MINERVA [4]. The purpose of the MEBT-3 is to fast-switch between the 16.4 MeV beams coming from the two injectors, thus to ensure a continuous injection of the proton beam into the main superconducting linac in case one of the injectors fails. The MEBT-3 was defined by beam dynamics calculations using TraceWin [5] by performing simulations with beam envelopes and with realistic particle distributions.

## THE MEDIUM ENERGY BEAM TRANSPORT SECTION OF MYRRHA

The MEBT-3 transport section connects the two injectors to the main linac (Fig. 1). It is divided into 8 subsections (4 in each injector branch) according to their purpose. The first subsection ①⑤ (collimation subsection) serves to fully characterize the beam after the CH-linac and accommodates a collimation system, the 2nd subsection ②⑥ (rebuncher subsection) includes a room-temperature rebuncher. The 3rd subsection ③⑦ (achromatic deviation subsection) consists of fast switching dipoles, which allow to send the beam from the active injector towards the linac and from the unused injector towards the beam dump subsection ④⑧ (DUMP-I).

### *Design Criteria*

The specifications of the MEBT-3 line are defined to satisfy the following criteria:

- Matched beam at the linac entrance
- Maximal beam transmission
- Double achromaticity
- Minimal emittance growth (at 4 mA)

### *Collimation Subsection*

The subsection contains a quadrupole triplet, numerous beam diagnostic elements, and a beam collimation system. The latter consists of three X/Y collimators positioned equidistantly along the line for intercepting the beam halo in both transverse planes. The main purpose of the collimation system is to protect the main linac.

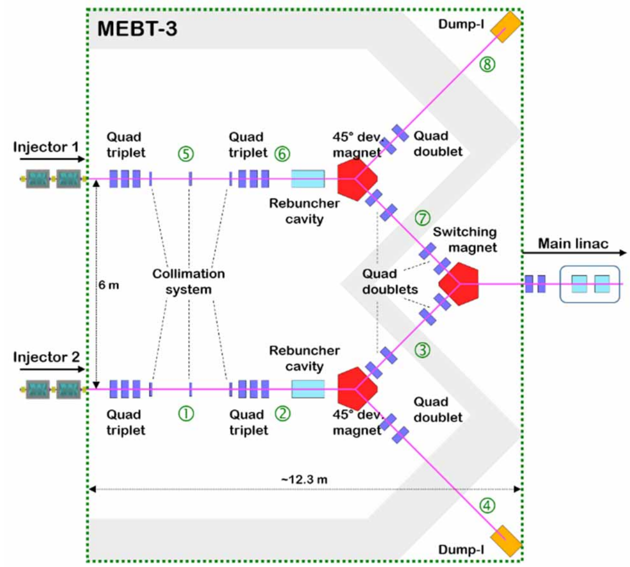


Figure 1: The MEBT-3 transport section with 8 subsections (4 in each injector branch) by their purpose – collimation system ①⑤, rebuncher ②⑥, deviation/achromat ③⑦, and beam dump ④⑧.

### *Rebuncher Subsection*

The second subsection contains a quadrupole triplet and non-accelerating, room-temperature rebuncher cavity for longitudinal phase matching at the linac entry. The quadrupole triplet serves for transporting the beam through the rebuncher and adjusting the beam for the desired entry into the deviation subsection, i.e. converging in the horizontal plane (X) and diverging in the vertical (Y).

### *Achromatic Deviation Subsection*

The achromatic deviation subsection contains two 45-degree bending dipoles and two quadrupole doublets. The quadrupole doublets are positioned and tuned symmetrically in the subsection and their exact positions are adjusted to guarantee that both the position dispersion $D$ and

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the angular dispersion *D'* are minimized simultaneously at the exit of the second switching dipole magnet. The latter allows connecting both injectors to the linac at the end of the MEBT-3 section.

### *Beam Dump Subsection*

The deflected beam from the unused injector is transported towards a dedicated high-power beam dump (DUMP-I). The transverse size of the beam is adjusted by a quadrupole doublet, which allows to match the beam to the interception cone of the beam dump and to avoid unwanted high-power densities. The beam dump subsection is also equipped with dedicated diagnostics for the characterization of the beam arriving from the unused injector in order to prepare for the upcoming fast-switching between the injectors.

## BEAM TRANSPORT

To reach the desired specifications, the design and tuning of the MEBT-3 have been studied extensively by beam dynamics simulations with TraceWin [5]. The beam simulations have been performed with inclusion of space charge effects in both *Envelope* and *PARTRAN* modes with simulated particle distributions of more than 500 000 particles.

The MEBT-3 transport section includes magnetic quadrupoles for transverse focusing, magnetic dipoles for deviation, and a room temperature rebuncher for longitudinal phase space adjustments.

### *Beam Envelopes*

A quadrupole triplet is used for creating a double waist at the central collimator, which is a requirement for the collimation (Fig. 2). A second quadrupole triplet is used for transporting the beam through the rebuncher while entering the deviation with a horizontally converging and vertically diverging beam. The double achromaticity (X and X') is restored at the end of the deviation subsection by the use of two symmetrically placed and tuned quadrupole doublets (Fig. 2).

Various transverse and longitudinal beam diagnostics, such as beam profilers, beam position/shape/loss/current monitors, and emittance meters, have been defined and are foreseen for the commissioning of the section, as well as, for tuning and monitoring of the stable operation of the MEBT-3 section.

### *Emittance Growth*

At a proton beam current of 4 mA, the emittances after the deviation subsection are not restored to their initial values due to space charge effects and second order aberrations (Fig. 3). The latter can be minimized by modifying the shapes of the magnet poles. A dedicated design study of the magnets is foreseen and the present results of the beam dynamics simulations are going to be verified and eventually readjusted after the inclusion of the field maps for all magnetic elements.

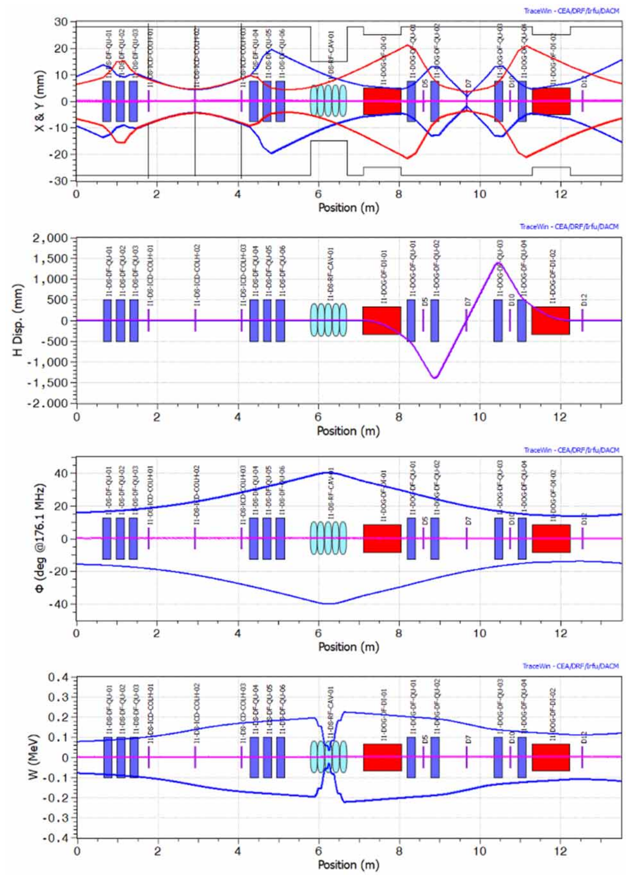


Figure 2: The top panel shows 6-σ envelopes in the two transverse planes (blue - horizontal, red - vertical). The second panel is showing the horizontal dispersion being minimized after the switching dipole and satisfying the double achromaticity condition. The lower two panels display the longitudinal beam envelopes along the MEBT-3 section.

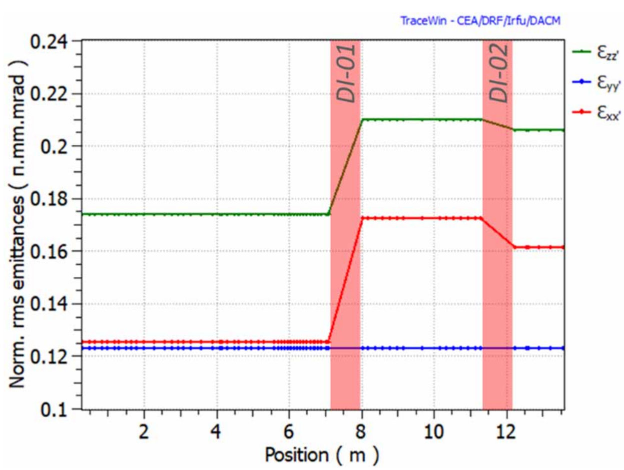


Figure 3: The plot displays the emittance growth in the deviation section. The green line corresponds to the longitudinal emittance and the two transverse emittances are shown by red (horizontal) and blue (vertical). The positions of the dipoles are displayed by red bands.

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## COLLIMATION SYSTEM

The collimation system is designed to protect the elements downstream in the MEBT-3 and the main linac during beam transients and in case of element failures in the injectors. A double waist is required at the second collimator *COL2*. This allows to form a converging beam at the collimator *COL1* and a diverging beam at *COL3* (Fig. 4). The distance between the three collimators has been selected to guarantee particle interceptions from every direction of the transverse phase space of the beam. A double focusing quadrupole triplet allows achieving a symmetric, converging beam at the first collimator, a double waist at the central collimator, and a diverging beam in the third one.

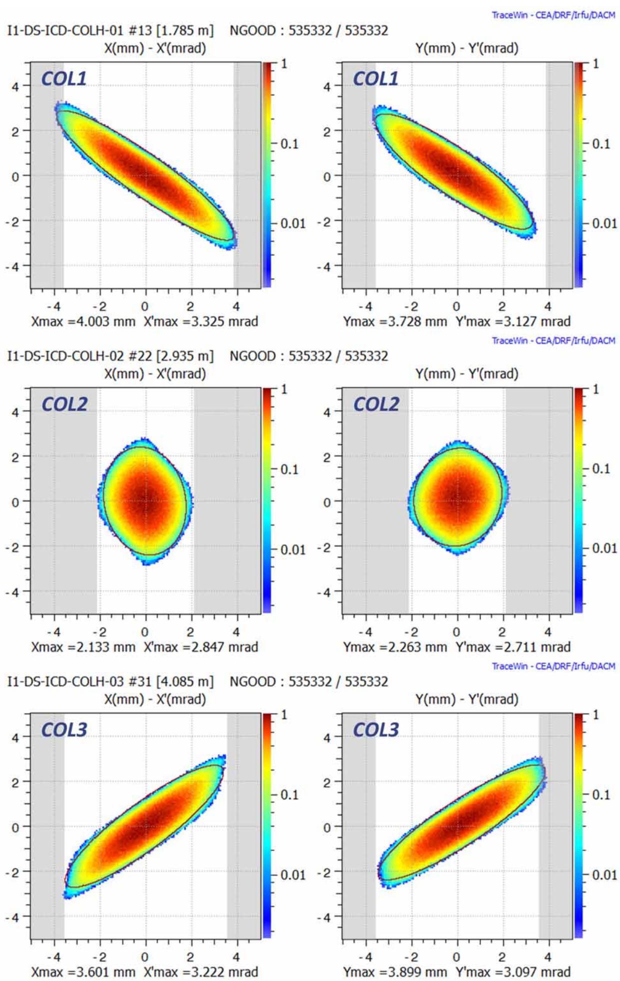


Figure 4: Transverse distributions at the three interception positions of the collimation system in MEBT-3. The beam is converging at COL1, reaching a double waist at COL2, and diverging at COL3. The grey rectangles represent the effect of the collimation on the phase space at the three collimation positions. The selected collimator configuration fully covers the transverse phase space of the beam.

## BEAM DUMP-I

DUMP-I, the beam dump of MEBT-3, contains a quadrupole doublet for adjusting symmetrically the size of the beam to the desired dimension. The preliminary configuration with a quadrupole doublet allows to reach a large range of beam spot sizes at the DUMP-I (Fig. 5). The exact beam specifications will be determined by thermal simulations.

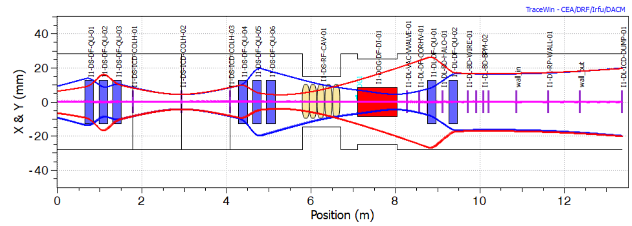


Figure 5: Transverse envelopes towards DUMP-I. The displayed example is for 6-σ size of 20 mm at the beam dump.

## CONCLUSION

The MEBT-3 transport section have been studied extensively by simulations in the past several years. The section evolved, going through several modifications, since the original lattice. The new additions, such as using only one room-temperature rebuncher and dedicating a subsection for the collimation system, have been incorporated into the lattice and the main design criteria are fulfilled. The type and specifications of all optics elements, as well as the necessary diagnostics and their positions, have been defined.

The work on several aspects is still ongoing, such as the design of the dipoles and the inclusion of their field maps into the optics simulations for verification of the obtained results.

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