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INSTALLATION OF A NEW LOW ENERGY LINE (LEBTO3) AT CNAO*

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Abstract

CNAO is one the six centres all around the world able to treat patients affected from cancer by proton and carbon ions beams. Beams are produced by a synchrotron equipped with two sources. A third source has been recently installed in order to produce new species that will be interesting both for clinical and R&D purposes.

A new low energy line has been designed, installed and commissioned to transport beams from the new source to the accelerator (see Fig. 1). In this paper the new line, called LEBTO3, is presented.

INTRODUCTION

CNAO [1] uses two Supernanogan ECR sources. The systems for medical applications installed in a hospital environment, in addition to requiring ions with sufficient current intensity to minimize patient treatment times, also require high reliability, stability and reproducibility of the properties of the produced and accelerated beam. Furthermore, it is very important that the sources built for a hospital-type structure are simple to optimize and that maintenance is quick and easy. Fondazione CNAO decided to install a third source (named "AISHa") developed on the same concept by the INFN-LNS researchers, who built a design with improvements derived from over ten years of experience on this type of sources.

Figure 1: Installation of the new LEBT line.

These modifications have made it possible to significantly improve the characteristics of stability, reliability and expected average life of the source, also optimizing the ionization efficiency, the flexibility in easily varying the energy of the ion beam produced and the reproducibility of the characteristics of the beams, also after several on and off cycles.

The third source was built and installed in CNAO within the framework of a Call HUB Research and Innovation funding from the Lombardy Region.

CNAO has decided to produce with the new source the ion species present in Table 1. The intensity of the new ion species must ideally be such as to have the same dose rate of already accelerated protons and carbon ions, i.e. about 2 Gy/L in 1-2 minutes. As a first approximation, the intensity of each species can be obtained from that of carbon by scaling with Z^{-2}, where Z is the atomic number. Assuming the same carbon injection/acceleration/extraction efficiencies, the input current to the Linac can be calculated accordingly for the various species, as shown in the table. For iron, the stripping efficiency of 30% must also be taken into account. For iron, a clinical dose rate is not strictly necessary and significantly lower intensities can also be satisfied.

Table 1: New Ionic Species That Will Be Produced by AISHa

	He	**Li**	**C**	**O**	**Fe**
Z	2	3	6	8	26
A	4	7	12	16	56
q	2^+	3^+	4^+	6^+	19^+
I_Lebt[μA]	344	229	110	64	174
I_iso[p/s]	$2.5\ 10^9$	$1.1\ 10^9$	$4\ 10^8$	$1.6\ 10^8$	$4\ 10^7$

Species selection can be achieved if the ion species can be sufficiently separated to place a pair of slits in a position that allows one type of ion to pass through and stops unwanted particles on the slits itself. This capability is expressed by the ratio "dispersion/beam size" which is generally called resolution (R).

It is possible to estimate the resolution at the simulation level taking into account the dispersion introduced by the spectrometer and the beam size, using the formula:

$$R = \frac{D_x}{2\sqrt{\beta_x \varepsilon_x}}$$

Where D_x is the horizontal dispersion, and β_x, ε_x are beam horizontal twiss parameters.

Experimentally, the ability to distinguish two peaks, in the case of two species with magnetic rigidity $B\rho_1$ and $B\rho_2$, is expressed as follows:

$$R = \frac{\Delta x}{W} \Big/ \frac{B\rho_1 - B\rho_2}{B\rho_2}$$

where W is the peak width (at 2% of the width) of the species most present in the spectrum and Δx is the distance between the peaks. Figure 2 shows a spectrum for carbon

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obtained starting from a mix of CO_2 and He measured during the commissioning of AISHa in INFN-LNS [2].

The minimum resolution occurs when the distance Δx is at least equal to the width W, and therefore R_{min} is given by:

$$R_{min} = \frac{B\rho_2}{B\rho_1 - B\rho_2}$$

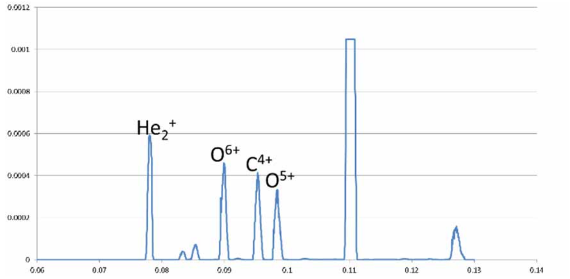

Figure 2: Carbon spectrum during commissioning at INFN-LNS.

OPTICAL STUDIES

The MADX code was used for the study of the optics of the existing lines and of the new branch of the LEBT (Low Energy Beam Transfer line). The beam extracted from the source was simulated, starting from the emittance measurements carried out at the diagnostic tank placed after the spectrometer and then back tracking through the model of the existing line. As regards the new section of line (LEBTO3), we started from the measurements made after the spectrometer in the Catania line, which has already installed the AISHa source.

Table 2 shows the optical parameters obtained for Carbon, Helium and Oxygen beams:

Table 2: Twiss Parameter at Source Exit

Parameter	C	He	O
$\beta_x\ (m)$	4.54	10.46	9.75
α_x	20.52	40	41
$\beta_y(m)$	1.43	4.28	3.34
α_x	6.63	16.55	14.67
$5\varepsilon_{RMS}(\pi\ mm\ mrad)$	380	325	220

The settings of the various magnets were then calculated to obtain the correct optical parameters at the RFQ input and a resolution higher than the minimum one. Figure 3 and Fig. 4 show the optics found for Helium.

To exclude further possible criticalities, an analysis of the residual distortion of the orbit was also carried out after correction on a set of 500 cases of random alignment and field errors. Figure 5 clearly shows the ability to correct large deviations of the orbit from its nominal value.

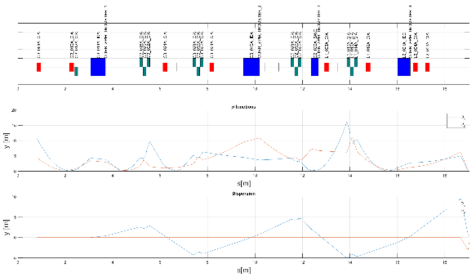

Figure 3: Trend of the Beta functions and of the dispersion along the LEBTO3 line.

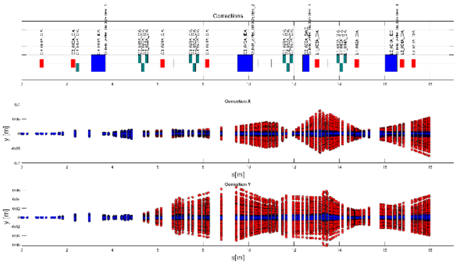

Figure 4: Residual orbit distortion (blue) after correcting over a set of 500 random alignment and field errors (red).

LEBTO3 INTEGRATION

The new line has been designed to fit into the current layout, minimizing the impact on the time dedicated to treatments.

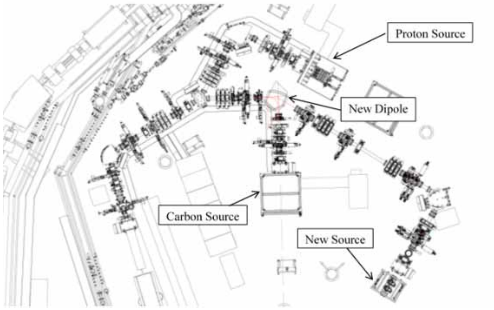

Figure 5: Layout of the CNAO LEBT with the new source and dipole installed.

As can be seen from Fig. 5 the third line is inserted at the level of the spectrometer of the Carbon source (O2 source). A two-input magnet was therefore designed (using the commercial software OPERA 3D): it has for the carbon source the same magnetic behaviour as the existing spectrometer (now used as spectrometer of the O3 source) and for the O3 source a bending angle of 33° and a radius of curvature of 1150mm (see Fig. 6, Fig. 7 and Table 3).

Table 3: Dipole Characteristics

	O2	O3
Deflection	90°	33°
Bending radius	400mm	1150mm
Entrance edge angle	26.6°	10°
Exit edge angle	26.6°	26.6°
Integrated field quality	$\leq\pm3\ 10^{-3}$	$\leq\pm6\ 10^{-3}$

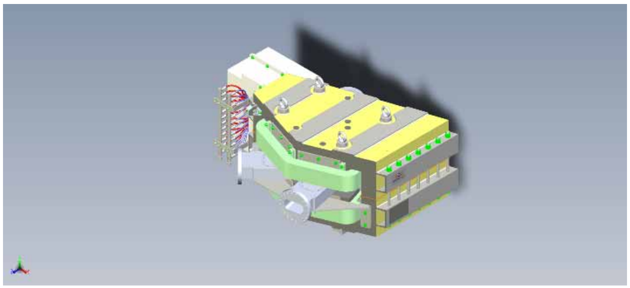

Figure 6: The new two input bending dipole.

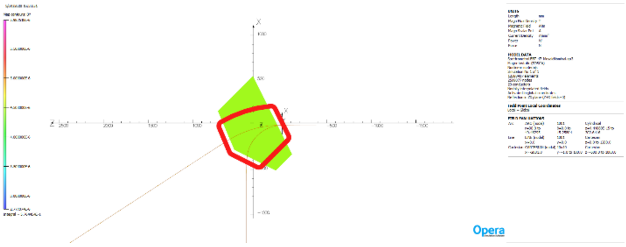

Figure 7: Calculated trajectories for the beams coming from O3 and O2 sources.

LEBTO3 COMMISSIONING

The commissioning of the new source has currently been carried out only for helium and up to the spectrometer output.

In the next few months, the helium will be transported up to the isocenter (end point of CNAO transfer lines where patients are positioned during treatments) and subsequently we will proceed with the other ionic species.

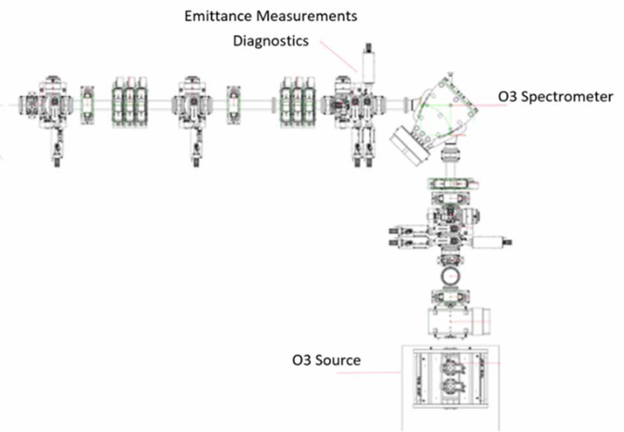

Figure 8: LEBTO3 Layout: magnets and diagnostic tank are showed.

For the commissioning of the LEBTO3 line, we performed the following steps: first we found the correct 90°dipole current by performing a spectrum measurement which allowed us to identify the peak of the desired species (He^{2+}).

In Fig. 9 the spectrum measurement is reported.

An emittance measurement was than performed using the slits and wire scanners present in the diagnostic tank downstream of the dipole (Fig. 8).

Figure 10 and Table 4 show the emittances and twiss parameters measured.

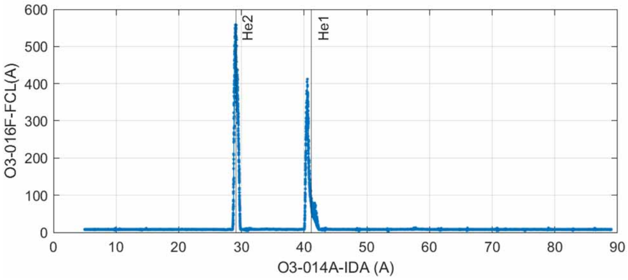

Figure 9: Measured helium spectrum.

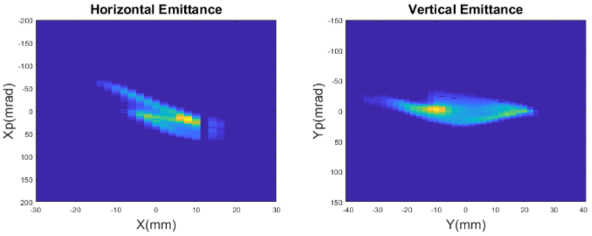

Figure 10: Emittance measurements.

Table 4: Emittance Measurements Results

	Horizontal	Vertical
ε (πmmmrad)	101.02	145.84
α	-1.108	-0.291
β	0.356	1.133
γ	6.255	0.958

CONCLUSION

The first phase of the commissioning of the new low-energy line of the CNAO has been successfully concluded. In the next months we will proceed to transport and characterize the beam at the isocenter to make it available for treatments. In a second step we will characterize the other ionic species.

ACKNOWLEDGEMENTS

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