STATUS REPORT ON THE CENTRO NAZIONALE DI ADROTERAPIA ONCOLOGICA (CNAO)*

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Abstract

The *Centro Nazionale di Adroterapia Oncologica* (National Center for Oncological Hadrontherapy, CNAO) is the Italian center for deep hadrontherapy. It will deliver treatments with active scanning both with proton and carbon ion beams.

The accelerator complex is based on a 25 m diameter synchrotron capable of accelerating carbon ions up to 400 MeV/u and protons up to 250 MeV.

Four treatment lines, in three treatment rooms, are foreseen in the first stage. In one of the three rooms a vertical and a horizontal fixed beam lines are provided, while in the other two rooms the treatment will be administered with horizontal beams only.

The injection chain is positioned inside the synchrotron ring itself, to save space and to better exploit the two non-dispersive regions in the synchrotron. The injection chain is made by a 8 keV/u Low Energy Beam Transfer line (LEBT), a RFQ accelerating the beam to 400 keV/u, a LINAC to reach the injection energy of 7 MeV/u and a Medium Energy Beam Transfer line (MEBT) to transport the beam to the synchrotron.

This report describes the design and the performances of the CNAO complex, and reports about the status of the commissioning of the machine.

INTRODUCTION

The origin of the Italian hadrontherapy center dates back to 1991, when the first proposal was made [1]. In the same year the ATER experiment was launched by INFN.

In 1996 CERN, Med-Austron and TERA started the Proton Ion Medical Machine Study (PIMMS) [2] in collaboration with GSI and Onkologie-2000 joined later the study group. The study lasted approximately four years and resulted in a green-field conceptual design, with a particular attention to the theoretical aspects.

With the financial law of 2001, the Ministry of Health created a non-profit organization, named CNAO Foundation, to build and subsequently run the National Center for Hadrontherapy.

Since then the CNAO has been designed and its components have been engineered, specified, tendered and built. Buildings and plants are now almost finished. The accelerators are being assembled and the first tests have started. At present the ECR sources and the Low Energy Beam Transfer line are under commissioning.

BUILDINGS

The site, evidenced in Figure 1, is close to the internal highway of Pave and thus it is well connected by communication means. It is also located nearby the sites of three hospitals (San Matteo, Maugeri and Mondino) and the university campus and thus well placed to profit of clinical and research synergies that will be fundamental for the success of the CNAO initiatives. The buildings construction started in autumn 2005 and is now almost completed. To complete the construction there are only a few steps left: sewer, some functional and performance tests of the various plants and the external part (garden, fences and so on)

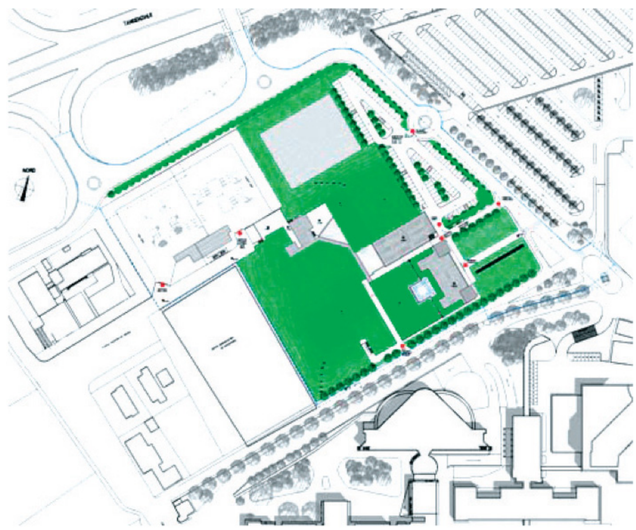

Figure 1: Location of the CNAO site (in green at the centre of the picture). Bottom right: area occupied by San Matteo hospital; top right: parking area; top left: part of the highway contouring the city of Pave.

The CNAO design is based on the following assumptions:

- the Centre will be devoted to the treatment of deep seated tumours with light ion beams (proton, carbon ions and others) and to clinical and radiobiological research;
- the full-size CNAO will have 5 treatment rooms (3 rooms with fixed beams and 2 rooms in case with gantries) and one experimental room. For the first phase 3 treatment rooms will be equipped with 4 fixed beams, three horizontal and one vertical, and an experimental room will be available;
- at regime, on a double shift operation, five days per week and 220 days per year, the CNAO will deliver about 20 thousands sessions per year of hadrontherapy.

The overall number of patients will obviously depend by the fractionation schemes adopted. The actual dimensioning of spaces and fluxes for patients, personnel and people are adequate for about 3000 patients per year.

The site of the CNAO allows the future expansion of the facility, both in the direction of the extracted beam channel and also to add a new research and clinical building close to the centre. The expansion in the direction of the extracted beam is potentially adequate to host two rooms for carbon ions, each approximately the same size of the present Heidelberg gantry.

The present layout of the building is shown in Figure 2.

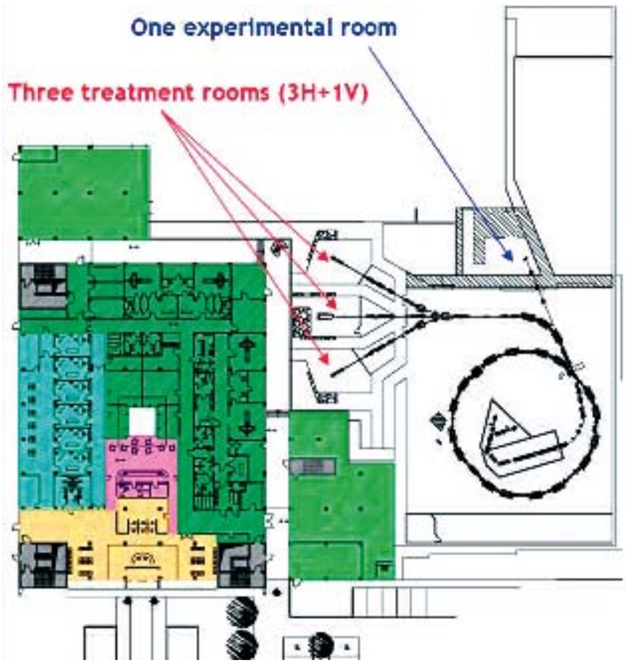

Figure 2: Floor -1 (accelerator level) at CNAO.

ACCELERATORS

General description

The CNAO has been conceived to perform treatment of deep seated tumours with beams of ions with Z in the range 1 to 6 (eventually Oxygen, but with a reduced range). The beam shall be capable of delivering up to 2Gy in 2l in 2-3 min and to deposit the dose up to a depth of 27 g/cm2. To reach this depth with carbon ions a total kinetic energy of 4800 MeV is needed.

The CNAO main accelerator is a synchrotron of about 25 m diameter. The CNAO synchrotron is made by two symmetric achromatic arcs joined by two dispersion free straight sections. The dispersion free sections host the injection/extraction region, the resonance driving sextupole and the RF cavity.

The total bending of 360° has been divided in 16 identical dipoles powered in series. The focusing action is provided by 24 quadrupoles grouped in three families and the horizontal and vertical chromaticities are controlled by four sextupoles grouped in two families. A fifth sextupole is used for resonance excitation.

Orbit correction is guaranteed by 20 steering magnets (11 H + 9 V).

Multi turn injection is foreseen in order to relax the requirements on the source intensity. After injection at 7 MeV/u, the beam is scraped to the nominal emittance and then accelerated to the extraction energy in less than one second. The beam is then slowly extracted till when the iso-energy slice is completely irradiated and finally is destroyed on an internal dump during the standardization cycle of the magnets.

The injection chain comprises two 8 keV/u Low Energy Beam Transfer lines (LEBT), a RFQ accelerating the beam to 400 keV/u, a LINAC to reach the injection energy of 7 MeV/u and a Medium Energy Beam Transfer line (MEBT) to transport the beam to the synchrotron.

At the other side of the synchrotron, four High Energy Beam Transfer lines (HEBT) transport the extracted beam to the three treatment rooms. All the lines are equipped with a pair of scanning magnets which allow delivering the dose to the tumour by scanning over an area of 200 mm x 200 mm.

The extracted beam distribution is strongly asymmetric because of the slow extraction process. To cope with this beam, CNAO has adopted the “empty ellipse” approach [3] but has abandoned the modular structure in order to keep the layout as compact as possible.

The layout of the whole accelerator complex is shown in figure 3.

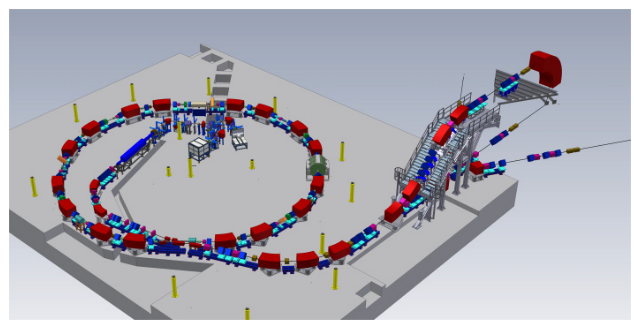

Figure 3: bird view of the CNAO accelerator complex.

Work progress

The LEBT is now installed (see Figure 4) and under commissioning. RFQ and LINAC have been built and are at CNAO waiting to be installed at the end of the LEBT commissioning. MEBT magnets are at CNAO and will be installed in the next future.

Synchrotron quadrupoles and sextupoles are already in position and connected to their power supply and to the water cooling system. Synchrotron dipoles have already been built and are being measured and shimmed. Synchrotron vacuum chambers and beam diagnostics are at CNAO ready to be installed when needed.

The RF cavity and the special magnets (septa, bumpers and kickers) are already in their position in the ring.

Concerning the extraction lines, magnets have been built and are under measurement. Patient handling systems have been ordered and the installation in the treatment rooms is foreseen in the next weeks.

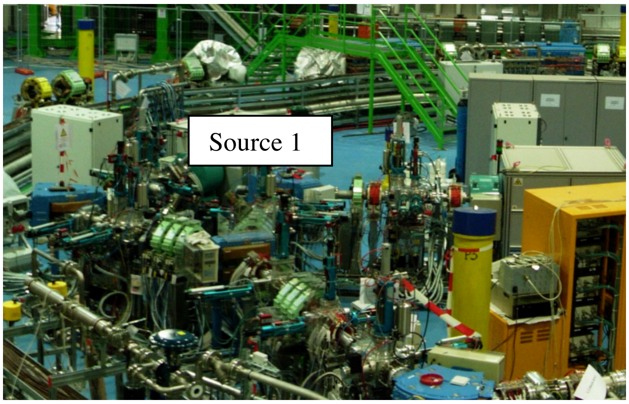

Figure 4: Sources and LEBT.

SOURCES COMMISSIONING

At present, commissioning has started at CNAO. The two ECR sources (Supernanogan from Pantechnik) are under test and the beams are measured in the first part of the LEBTs. Each analysis line, as illustrated in Figure 5, comprises:

- a solenoid;
- a 90° dipole that has the function of spectrometer;
- two measurement tanks;

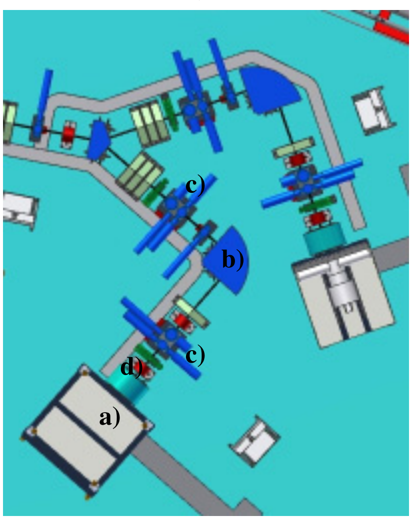

Figure 5: The initial part of the LEBT is used to analyse the beam and comprises: a) source, b) spectrometer, c) diagnostic tanks and d) solenoid.

The beam produced by the sources contains many particle species and charge states, as shown in Figure 6, showing the spectrum of the C^{4+} source.

The measurement tanks include horizontal and vertical slits, horizontal and vertical profile monitor and a Faraday cup. It is thus possible to measure beam current, beam position, beam profile and even beam emittance.

The required current for carbon is 200 μA and is achieved without problems. The 90% normalised beam emittance, see Figure 7, is approximately 1 π mm mrad.

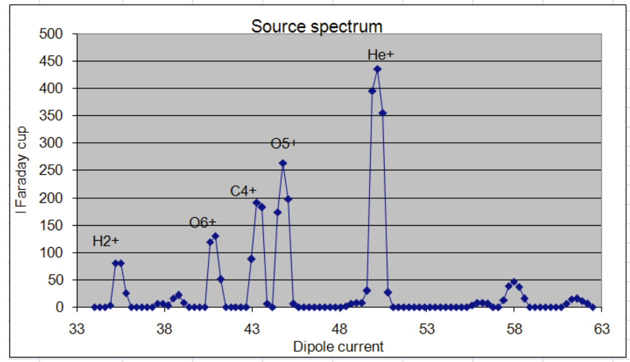

Figure 6: Spectrum of the carbon source. 200 μA of C^{4+} are produced

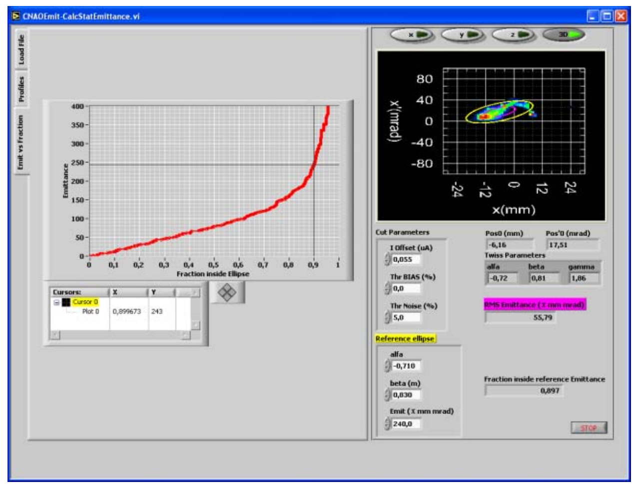

Figure 7: Emittance of the C^{4+} beam. The total current was 220 μA

The second specie of ions used in the LEBT, is H_3^+. The required current is 700 μA, which has been reached with a 90% normalised emittance of 0.75 π mm mrad.

CONCLUSIONS

CNAO construction is almost finished and the commissioning of the LEBT has started with success.

REFERENCES

[1] U. Amaldi, G Tosi, "Per un centro di teleterapia con adroni", TERA 1-1 (91).

[2] P.J. Bryant et al., "PIMMS, Proton-Ion Medical Machine Study", CERN 2000-006, ISBN 92-9083-166-9

[3] M. Benedikt, P. Bryant, M. Pullia, "A NEW CONCEPT FOR THE CONTROL OF A SLOW EXTRACTED BEAM IN A LINE WITH ROTATIONAL OPTICS", CERN/PS 99-008 (OP), Nuclear Instruments and Methods in Physics Research A430, 523-533, 1999.