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Titolo

CNAO Beams Description for Requirements Collection

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Referente

Parole chiave

Riassunto

This note has been written to be distributed together with a questionnaire in order to collect the needs of the future users of the CNAO experimental room. The scope of this note is to illustrate the beams available at CNAO and to give a first description of the infrastructure.

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1 Introduction

One of the goals of the CNAO Foundation is scientific research. The CNAO center has been conceived since the beginning with three treatment rooms and an "experimental room" where research can be carried on without hindering the clinical activity.

Such an experimental room shall be designed to be "general purpose", to be used for research in different fields. Possible activities could be, as an example, irradiation of cells, test of beam monitors, development of in-beam monitoring devices or radiation hardness studies.

This note has been written to be distributed together with a questionnaire in order to collect the needs of the future users of the CNAO experimental room. The scope of this note is to illustrate the beams available at CNAO and to give a first description of the infrastructure. The details and the functional specifications of the experimental room and line(s) will be defined when the survey will be completed taking into account the answers collected with the questionnaires.

1.1 Building Layout

The experimental room already exists, but it is not yet equipped. Figure 1-1 shows the high-tech area of the CNAO with the experimental room in evidence. A preliminary drawing of the beam line has been sketched in blue in Figure 1-1 to illustrate a possible geometry.

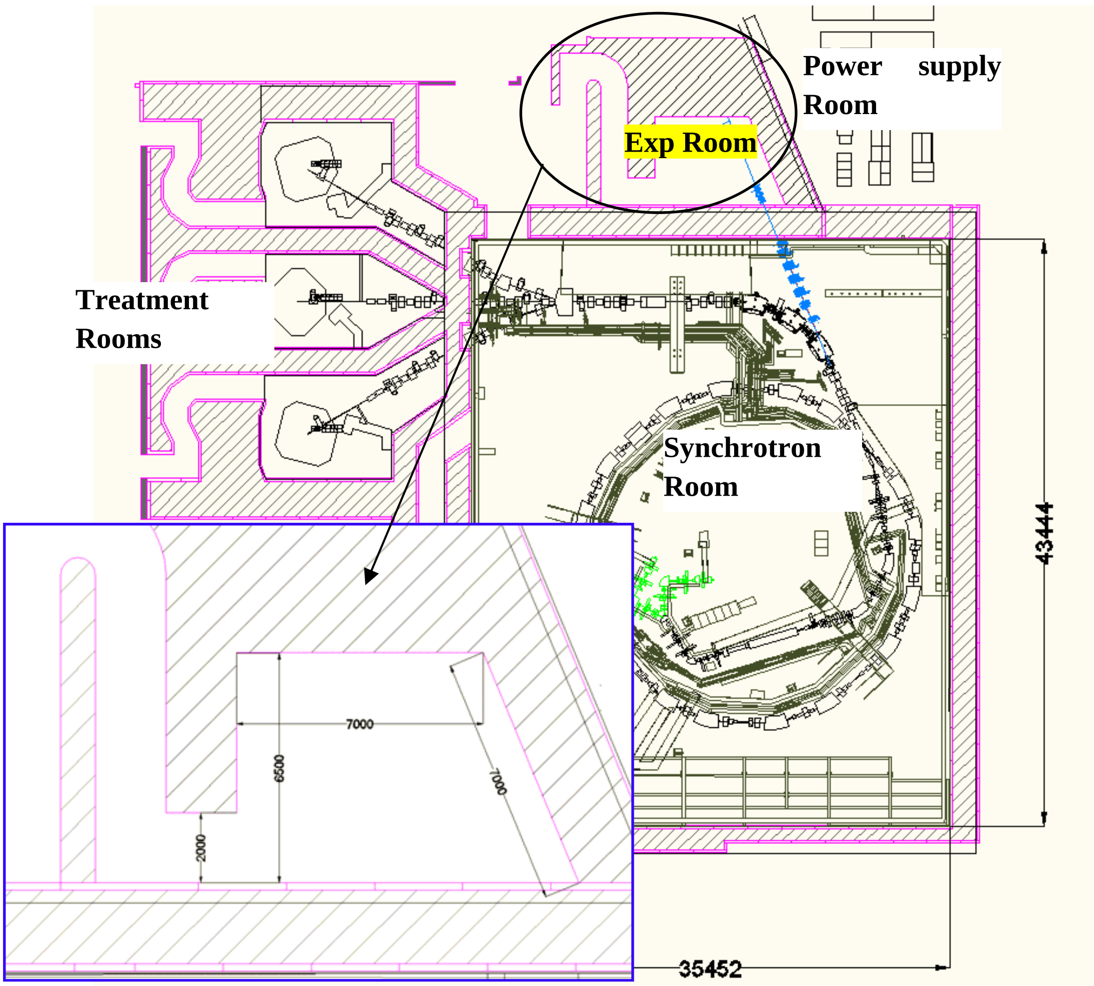

Figure 1-1. CNAO accelerators rooms (dimensions in mm). The experimental room with a few quotes has been zoomed in the in the lower – left blue frame. The shaded areas represent the shielding walls.

In Figure 1-1, the hatched part represents the shielding walls and in the frame is shown a zoomed view of the experimental room with a few quotes.

The control room, where the users can work during data acquisition and where the signals from the experimental room will be collected, is located next to the entrance.

2 Description of the beams available in the treatment rooms

The CNAO synchrotron has been designed for particle therapy which requires energies up to 400 MeV/u for *carbon ions* (corresponding to a Bragg peak depth of up to 27 cm in water) and up to 220 MeV for *protons* (corresponding to a Bragg peak depth of up to 30 cm in water). The maximum proton energy available is 250 MeV, included in the initial CNAO specification for an hypothetic passive system. The minimum extraction energies are 60 MeV and 120 MeV/u for protons and carbon respectively. All the intermediate energies are possible and are distributed in steps of 1 mm range rather than in fixed energy steps.

The intensities needed for therapy are relatively low, up to 10^{10} protons/spill (p/spill) and up to 4×10^{8} Carbon ions/spill (C/spill), with spills one second long every three to five seconds, as illustrated in Figure 2-1.

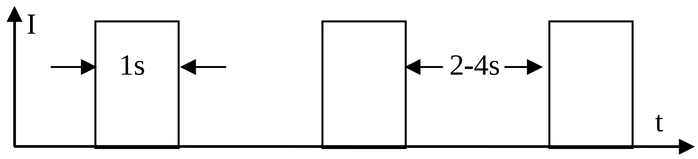

Figure 2-1. Time structure of the CNAO beam.

In the treatment rooms, the beam is distributed into the patient, but into any target as well, with an *active beam delivery system*. To explain what this means, consider the tumour inside the patient and subdivide it in *iso-range slices*. The beam energy is at first set such that the Bragg peak is in the first slice. The beam is displaced with two *scanning magnets* to paint the slice in order to deliver the planned dose to every spot, as illustrated in Figure 2-2.

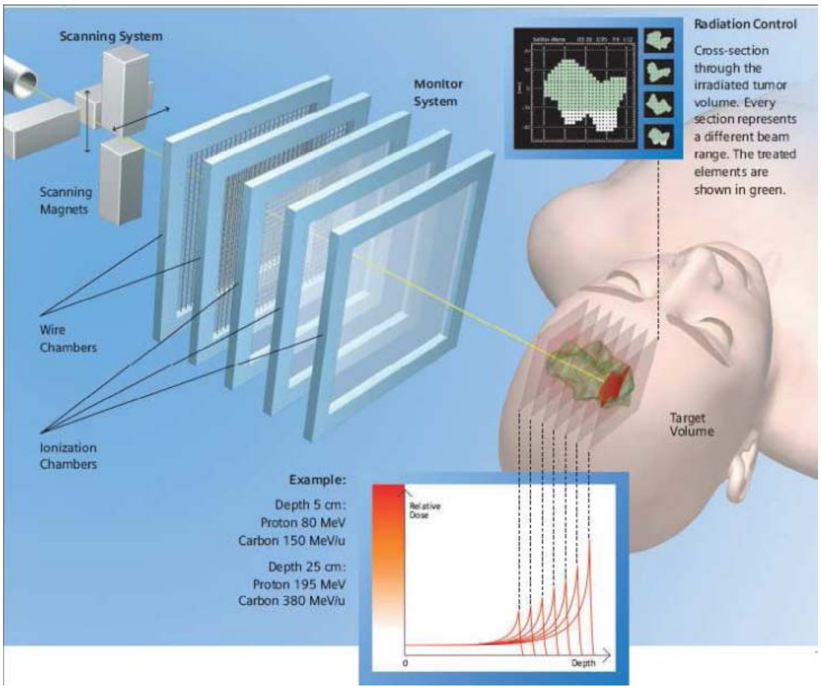

Figure 2-2. Illustration of the active scanning system (courtesy of Siemens medical).

When the slice is "finished", the beam is stopped and a new beam is accelerated to the energy corresponding to the second slice, which is also "painted" according to its own shape. The process is iterated until the completion of the planned treatment.

The transverse *beam size* in the treatment rooms is approximately 10 mm Full Width at Half Maximum (FWHM) and the beam can be scanned over a 200 x 200 mm^2 area (*field size*).

The typical slice thickness is 2 mm, which can be increased to 4 mm with a *ripple filter*.

During normal operation, the beam intensity and position are measured in real time with a set of ionization chambers placed just after the vacuum window next to the "*isocenter*", the treatment position. The beam delivery is "*dose driven*", which means that the beam is displaced to the next spot when the desired dose in the present spot is reached.

When the "slice" is completed, or when the next spot is not adjacent to the present one, the beam is turned off by a fast device called "HEBT Chopper" that directs the beam onto a dump until the system is ready to irradiate the next spot.

3 Irradiation position, field size and space available

The beam distribution system used in the experimental line will be the same used in the treatment rooms.

The distance between the center of the last scanning magnet and the isocenter in the treatment rooms is 5460 mm; if the same distance is applied in the experimental room to get the same scanned field, the isocenter ends up very near to the wall (370 mm).

If the irradiation position is withdrawn so to leave a space of 2 m from the end wall, as illustrated in Figure 3-1, the scanned region for the maximum energy carbon ions reduces from 200 to 135 mm. Lower energy particles can be scanned to larger positions in proportion to their magnetic rigidity.

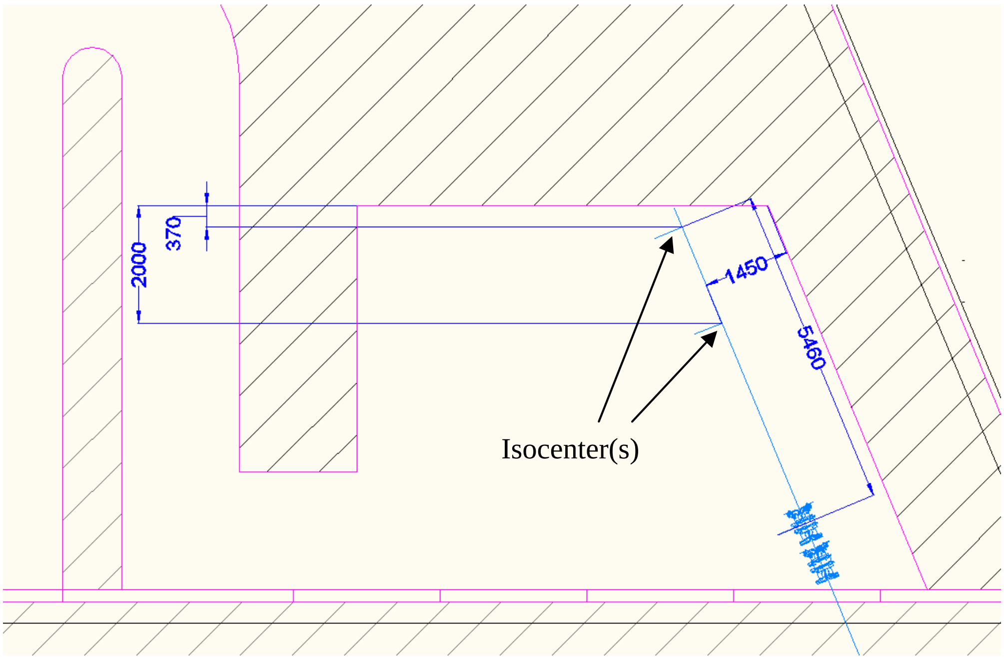

Figure 3-1. Experimental room; two positions for the irradiation position are shown corresponding to a larger space around the irradiation position or a larger irradiation surface.

Thus depending on the size of the samples to be irradiated, one position or the other (or any other position in between) might be more convenient. The position of the irradiation point will be chosen according to the needs in terms of samples area and experimental equipment requirements around the irradiation point.

4 Additional ion species

Despite the fact that only protons and carbon ions can presently be accelerated at CNAO, there is an interest both on the medical side and on the experimental side in using other ion species.

As an example, He ions have radiobiological properties similar to protons but they feature a smaller scattering and their use has already been suggested in literature.

It is therefore intention of CNAO to add new species and a third ion source will be added to the two present ones.

The order of magnitude of the intensities of the new ion species will be such to deliver approximately the same dose rate considered for protons and carbon, that is in the order of 2 Gy in one litre in 1-2 minutes. Smaller volumes correspond to higher dose rates. With a rough approximation, this can be obtained by scaling the number of ions per spill as Z^{-2}, where Z is the atomic number. The intensities obtained with this approximation, are summarized in Figure 4-1 for the range H to O.

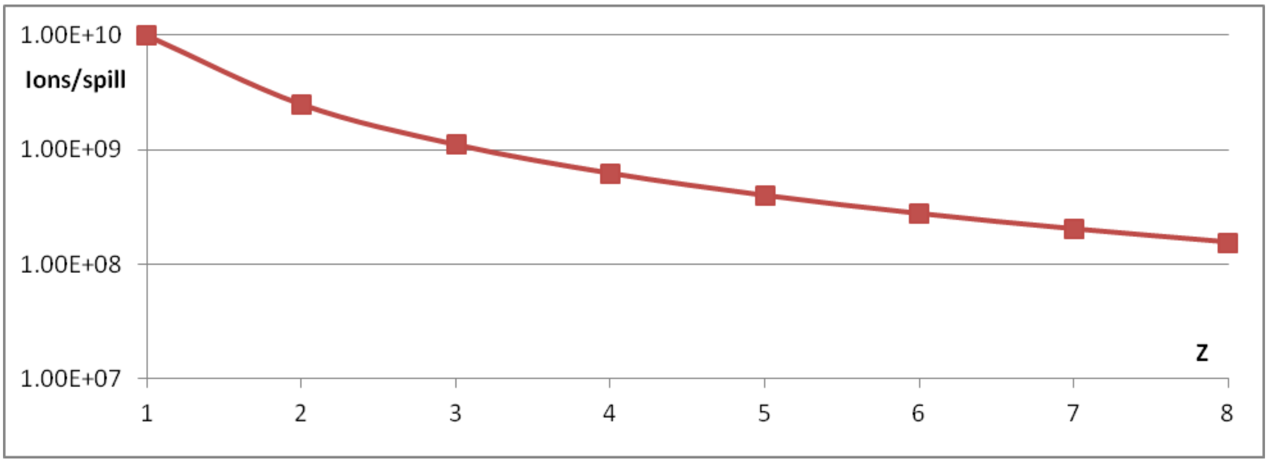

Figure 4-1. Intensities foreseen for the ion species with 1 < Z < 8.

The energy necessary to reach the maximum range useful for therapy depends on the ion species, but already for Lithium, such an energy is of the order of 300 MeV/u. Thus it can be assumed as a first guess that the maximum energy available in the experimental room is 400 MeV/u, the maximum that can be produced by the accelerator.

Figure 4-1 includes only the light ions generally considered for clinical applications, but for experimental reasons the use of other ions might be conceived.

For experimental reasons other currents and other ion species can be considered. The requirements on the ion species and currents will be taken into account in defining the specifications of the new ion source.

5 Availability of a 7 MeV beam

Considering the operation of the synchrotron, it appears that only a few microseconds per machine cycle of LINAC beam are required for injection and most of the time the LINAC is idling. It is therefore conceivable that the LINAC beam could be used in parasitic mode with a large availability.

If a MEBT line (Medium Energy Beam Transfer[1]) were built to make that beam available, the ion specie in use for the patient treatment would be available for experiments. Thus when a patient is being treated with protons, a proton beam could be used in the experimental room and when a patient is being treated with carbon ions, a carbon ion beam would be available for experiments.

The beam energy would be 7 MeV/u and typical currents are 600 μA for protons and 90 μA for C, in 50 μs pulses with a repetition rate of 10 Hz, as illustrated in Figure 5-1.

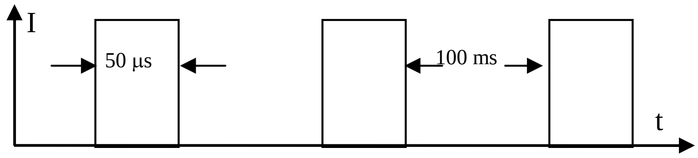

Figure 5-1. Time structure of the CNAO LINAC beam.

Concerning the irradiation area, a compromise will be necessary between the thickness of the vacuum window and its surface. When traversing the vacuum window, the low energy ions suffer a considerable energy loss. On the other side, the larger the vacuum window, the larger its thickness has to be in order to withstand the atmospheric pressure. As an example a 10 mm diameter Havar vacuum window can be made 2.5 μm thick, which corresponds approximately to 20 μm in water. 7 MeV/u Carbon ions have a range of ~200 μm in water, thus the aforementioned window would already correspond to ~10% of their range. In case heavier ions were used, the relative range loss would be correspondingly more important. Large samples would probably have to be irradiated under vacuum.

On the other hand with such a low energy a microbeam, that is a beam with size in the order of microns generally obtained by collimation, would be possible. This kind of beams is often used in radiobiology.

5.1 Space allocation

In case the 7 MeV line were built, the space in the experimental room should be shared between the needs of the high energy beam and those of the low energy one. As an example a 2 m wide corridor has been left free, in order to allow access to the High Energy Experimental Line isocenter, in Figure 5-2.

In the example shown, a space of 1.5 m is assumed downstream the irradiation point of the low energy line for detectors, supports and other instrumentation to be installed around the irradiated sample.

All the quotes shown in Figure 5-2 refer to the example considered and will change when the final design will be made. They shall be considered as indicative.

[1] At CNAO Energy is defined Low in the lines between sources and LINAC, Medium between LINAC and synchrotron and High after the synchrotron.

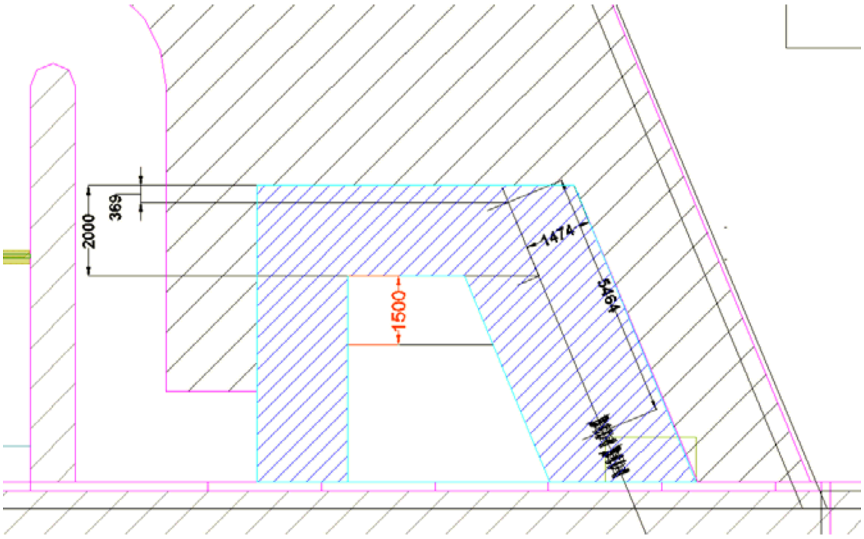

Figure 5-2. Space allocation for the Medium Energy Experimental Line. The blue shaded corridor is 2 m wide and should be left free to allow access to the High Energy Experimental Line isocenter.

6 Glossary/summary

Beam size: transverse beam dimension; the FWHM is generally used. Typical beam size is 10 mm.

Field size: area over which the beam is scanned. The maximum field size in the treatment rooms is 200 mm x 200 mm.

HEBT: High Energy Beam Transfer line. The beam energy in the HEBT ranges between 60 and 250 MeV for protons and between 120 and 400 MeV/u for carbon ions.

Isocenter: position in the treatment room where the tumor is placed for irradiation.

LEBT: Low Energy Beam Transfer line. The beam energy in the LEBT is 8 keV/u

MEBT: Medium Energy Beam Transfer line. The beam energy in the MEBT is 7 MeV/u.

MeV/u: it is a energy per nucleon measurement unit frequently used in the hadrontherapy community; it corresponds to the total ion energy expressed in MeV divided by its mass expressed in amu.

QA: Quality Assurance; the activities performed periodically in order to verify the correct parameters of the beam delivered in the treatment rooms.

Ridge filter: passive element used to increase the energy spread of the beam. It is made by a slab with a series of undulations that is inserted on the beam path such that some particles cross a high thickness and some others cross a low thickness creating a residual range spread in the beam.

Ripple filter: passive element used to increase the energy spread of the beam. It is made by a slab with a series of undulations that is inserted on the beam path such that some particles cross a high thickness and some others cross a low thickness creating a residual range spread in the beam.