CNAO

Introduction

The CNAO ("*Centro Nazionale di Adroterapia Oncologica*[1]") project is based on the experience of previous important projects (PIMMS[2], Oncology 2000 and TERA).
CNAO site is installed in PAVIA (ITALY), close to one of the hospitals of PAVIA (*San Matteo University Hospital*).
The vacuum chambers of the Storage Ring and several beam diagnostic components (about 70 meters of UHV line in total) were produced and tested by CECOM: the most relevant details about these UHV elements are described in this document.

Summary

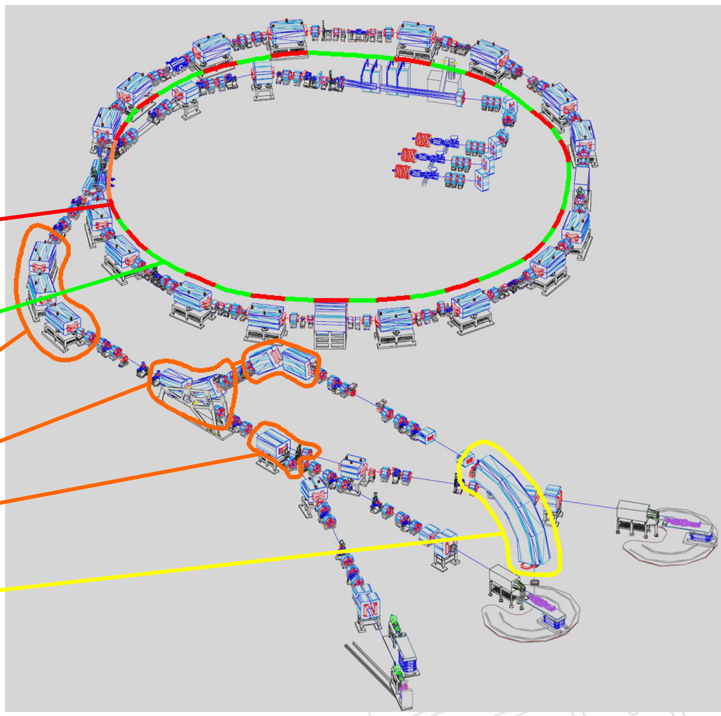
1 References

The references of contact persons for this work are available under request.

2 CECOM activities

CECOM carried out the following activities:

- Material purchase
- Manufacturing
- Assembling, welding and brazing
- Cleaning (for UHV application)
- Factory Acceptance Tests



[1] Translation from Italian: "NATIONAL CENTRE FOR ONCOLOGICAL HADRONTHERAPY"
[2] Proton Ion Medical Machine Study (CERN)

3 Scope of the CNAO project

One of the most important technical aspects of CNAO is the application of *hadron-therapy* with *protons and light ions (carbon ions)*.
As shown in the scheme in Fig. 1, the use of protons and light ions allows to concentrate the deposited energy in a very narrow range, along the particle path. Furthermore the use of charged particles allows the precise focusing of the beam by means of magnetic fields. In addition, in case of treatment of deep regions (with respect to the skin level) the dose deposited in the most superficial layers reached by the incident beam is minimized. Hence the released energy can be concentrated with high accuracy on the regions to be treated, allowing to achieve simultaneously the following results:

- Maximization of efficiency in the treated area
- Minimization of unwanted treatment of other regions

This level of precision and resolution can not be achieved with X-rays or with electrons, due to physical reasons related to the laws governing the interaction of radiation with the matter.

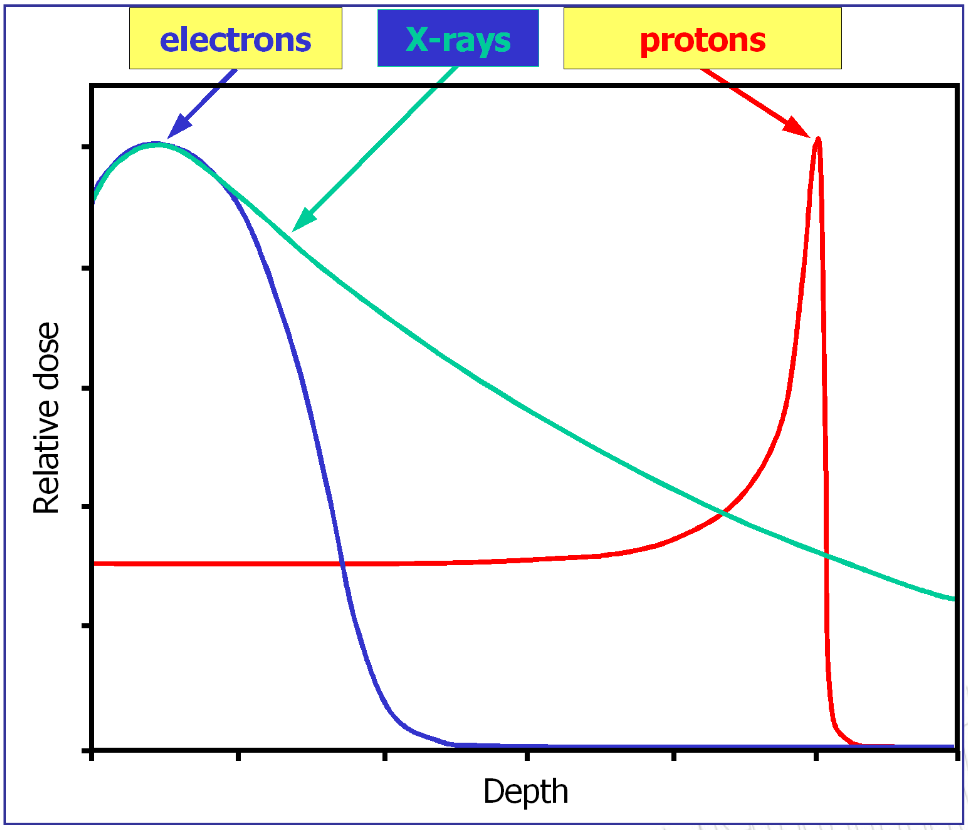


Fig. 1: Energy loss scheme for photons and for charged particles

In order to allow a precise 3-dimensional scan of the area to be treated, a great control of the beam is required, in terms of energy, intensity, focusing, and stability. This control can be achieved only if, during the production, a particular care is applied to machining tolerances, vacuum performances, guarantee of low magnetic permeability in all regions close to the magnetic fields used for the control of the beam.

The CNAO Storage Ring is installed in a complex 4300 m^2, including treatment rooms and services. The energy of accelerated particles will be [60 – 250] MeV for protons and [1440 – 4800] MeV for carbon ions.

4 CECOM and CNAO

CECOM has been one of the main collaborators during the development and construction of the CNAO Storage Ring.
In particular the following elements were manufactured and tested by CECOM:

- Chambers for the straight sections:
- UHV bellows with ceramic breaks
- Dipole thin chambers (for bending magnets)
- Pick-Up and chambers for diagnostics
- Chambers for the extraction of beam from the Storage Ring
- Injection Chamber

4.1 Chambers for the straight sections

The main purposes of these chambers is to allow the straight passage of the beam, without interacting with it. Since the beam is composed of charged particles, the vacuum chambers of the Storage Ring must not induce electro-magnetic disturbs: for this reason a low magnetic permeability is required, in order to prevent eventual distortions of magnetic fields.

In order to maintain the standard profile of the beam-pipe, special UHV edge-welded bellows were produced and installed on these chambers. Special "Diamond gaskets" were produced by CECOM for the UHV assembling of "racetrack" flanges.

Some pictures of these chambers are shown in Fig. 2.

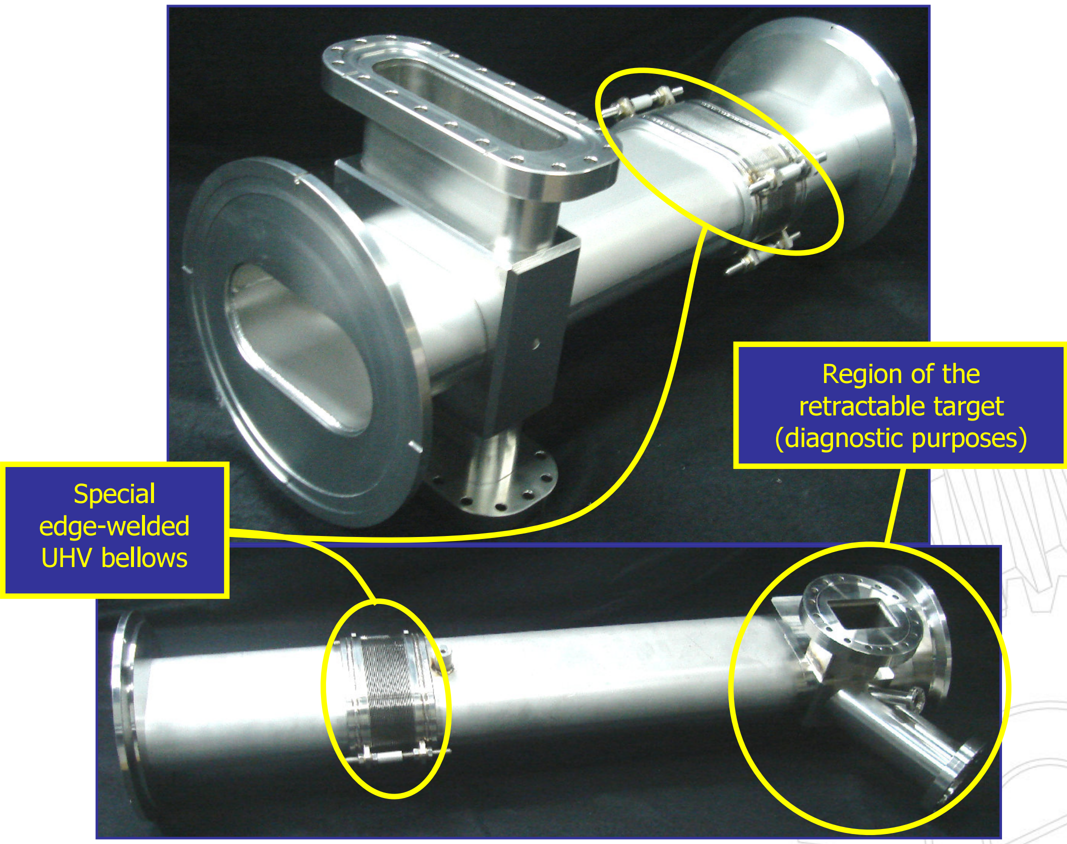


Fig. 2: Chambers for the straight sections

4.2 UHV chambers and bellows with ceramic break

In order to provide the required insulation between adjacent vessels of the Storage Ring, special edge-welded bellows assemblies were installed. These bellows includes vacuum brazed ceramic breaks, as shown in the following pictures.
All bellows assemblies are equipped with a manual locking system: the position of bellows convolutions can be set and locked by means of dedicated threaded bars.
Special UHV chambers with integrated edge-welded bellows and ceramic breaks were also produced.

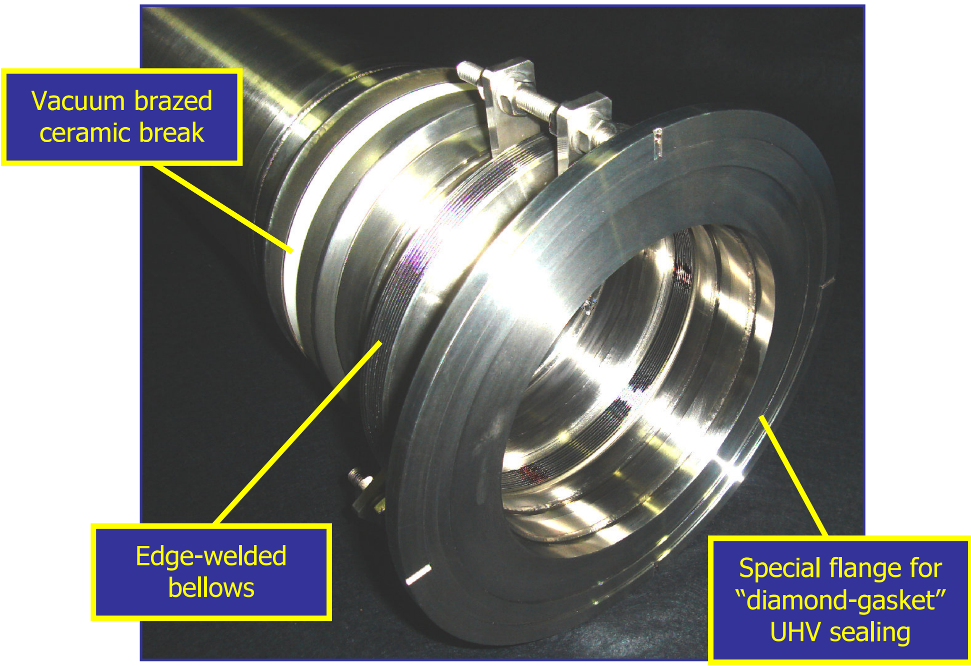


Fig. 3: UHV chamber with edge-welded bellows and ceramic break

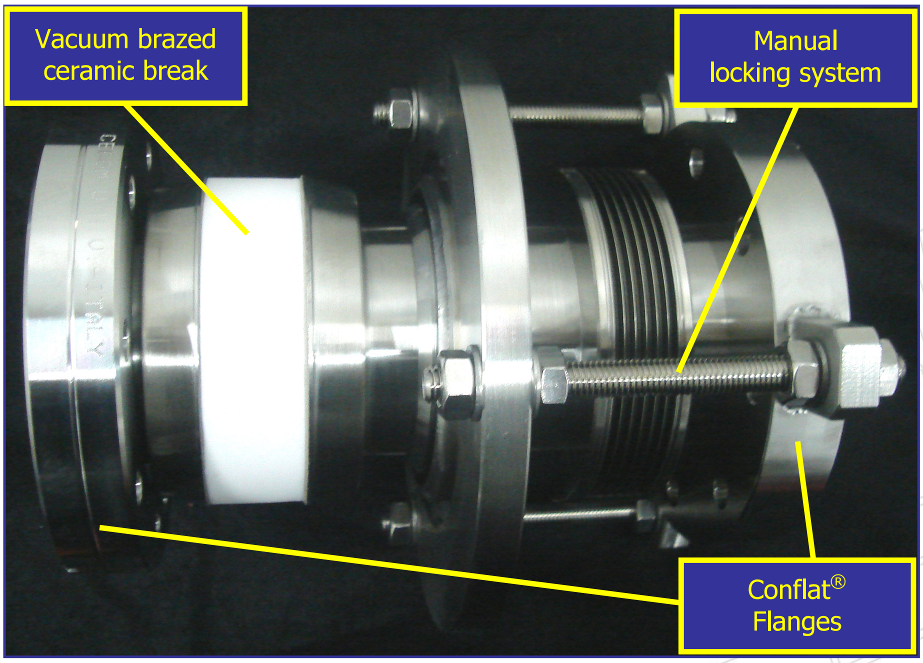


Fig. 4: UHV bellows assembly with ceramic break

4.3 Pick-Up and chambers for diagnostics

The "Pick-up" are very important for the beam diagnostics, allowing the beam position monitoring in several sectors of the Storage Ring. In order to guarantee the required UHV, electrical and mechanical performances, a special production and assembling process was applied.
The inner electrical components (Electrodes, connections and ceramic insulators) were assembled with a precision of the order of 10 µm.
One side of the assembly is equipped with a support for the survey reference structure. All marks and supports for survey fixtures were machined and assembled with reference to inner components, in order to allow a reliable fiducialization.

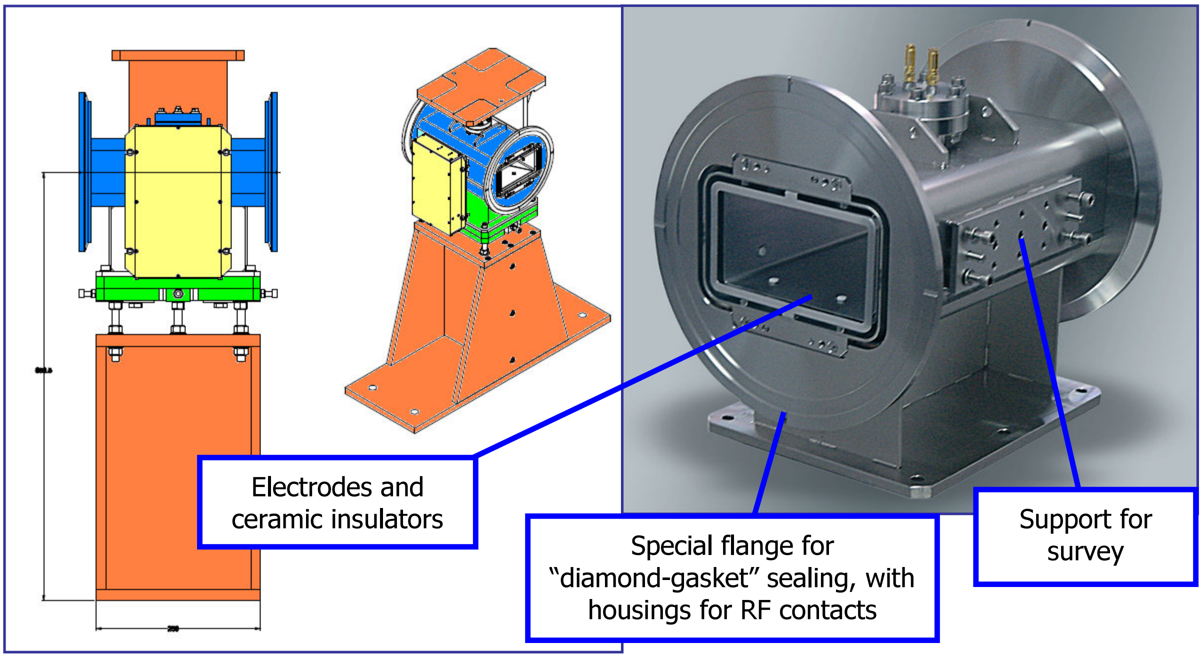


Fig. 5: Pick-up (diagnostics)

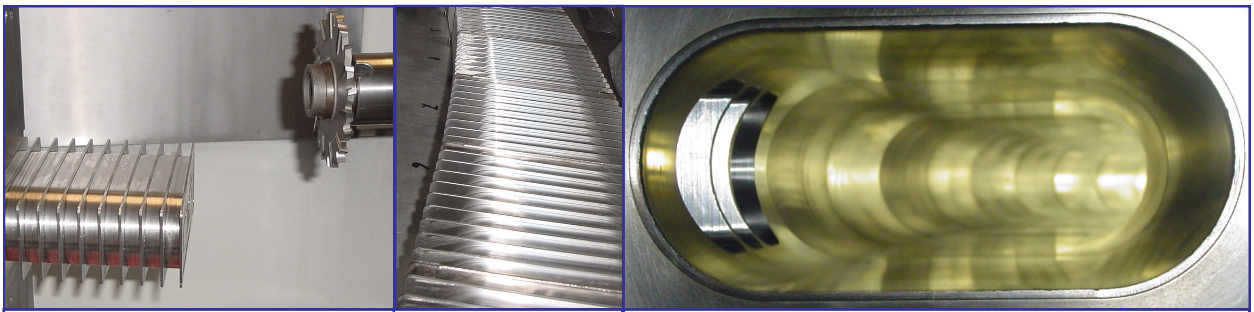
Fig. 6: Electrodes and ceramic insulators of the pick-up chamber

4.4 Dipole chambers (for bending magnets)

Dipole chambers are directly installed between the poles of dipole bending magnets, hence two very important technical aspects involved with the production of these chambers are the reduction of Eddy currents and the absence of influences on the electro-magnetic field. From the mechanical point of view, this required a thickness of 0.3 mm for the beam pipe along the whole length of each UHV chamber, and the selection of the raw material for the production (AISI 316L).

The technical solution we choose for the production was to obtain the bended chambers by joining (TIG welding) twelve sectors. Each sector was machined internally and externally from a unique block of stainless steel (forged AISI 316L), by means of wire eroding machining and milling machining respectively. This allowed to achieve a great result, with a high accuracy of the profile shape, high UHV and structural performances (cleanliness, tightness and stiffness).

Some pictures of these chambers are shown in Fig. 7.



Machining	Welding	Result (inner view)

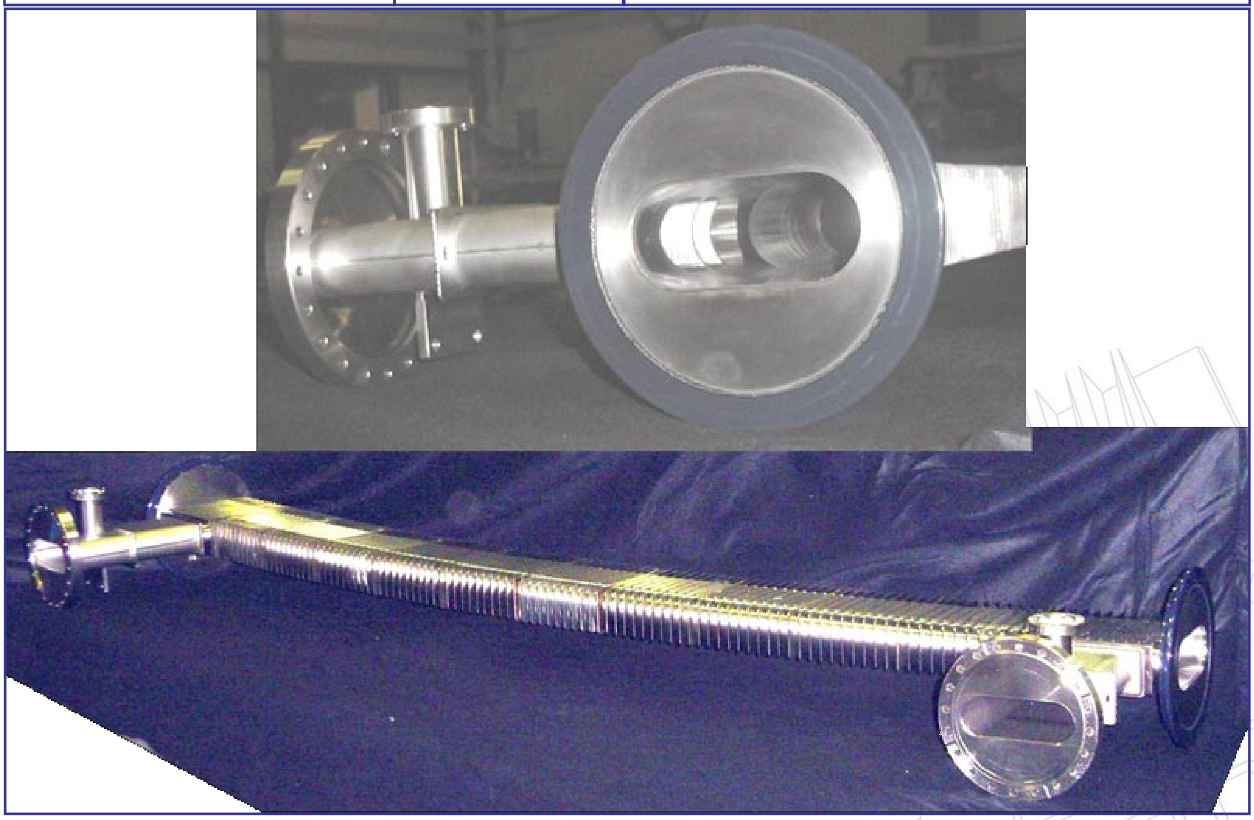


Fig. 7: Dipole thin chambers for the Storage Ring

4.5 Chambers (2-way and 3-way) for the extraction of beam from the Storage Ring

Special Aluminium UHV chambers were produced for the beam extraction sections.
Two-way and three-way chambers were obtained by welding longitudinally the respective halves: this allowed to achieve a high mechanical accuracy for all dimensions and a very low roughness of inner machined surfaces. In addition, several bending magnet aluminium chambers were also produced.

Fig. 8: Beam extraction chambers (2-way and 3-way), and bending magnet chambers

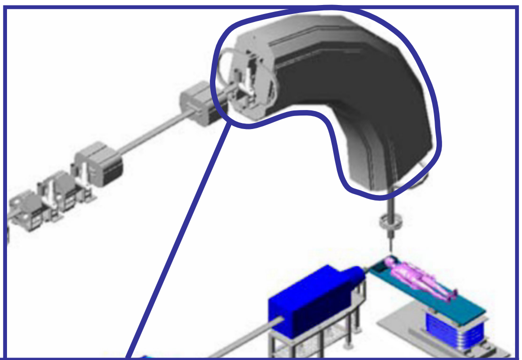
4.6 Dipole Chamber

The total length of this UHV chamber is about 6.7 meters.
The dipole chamber, completely in Aluminium, was obtained by welding together eight sectors, each of them machined in two halves and welded longitudinally.
The final UHV cleaning and all welds (TIG) were executed in CECOM by our qualified personnel, and the complete chamber was tested for UHV leak tightness after a bakeout at 120 °C (leak rate lower than 10^{-10} mbar·l/s with an evaluated outgassing rate lower than 10^{-12} (mbar·l)/(s·cm^2).

A dedicated support structure was designed and produced in order to allow the following activities:

- assembling
- handling
- UHV testing (including bakeout)
- Transportation

Some pictures related to the production of this chamber are shown in Fig. 9.



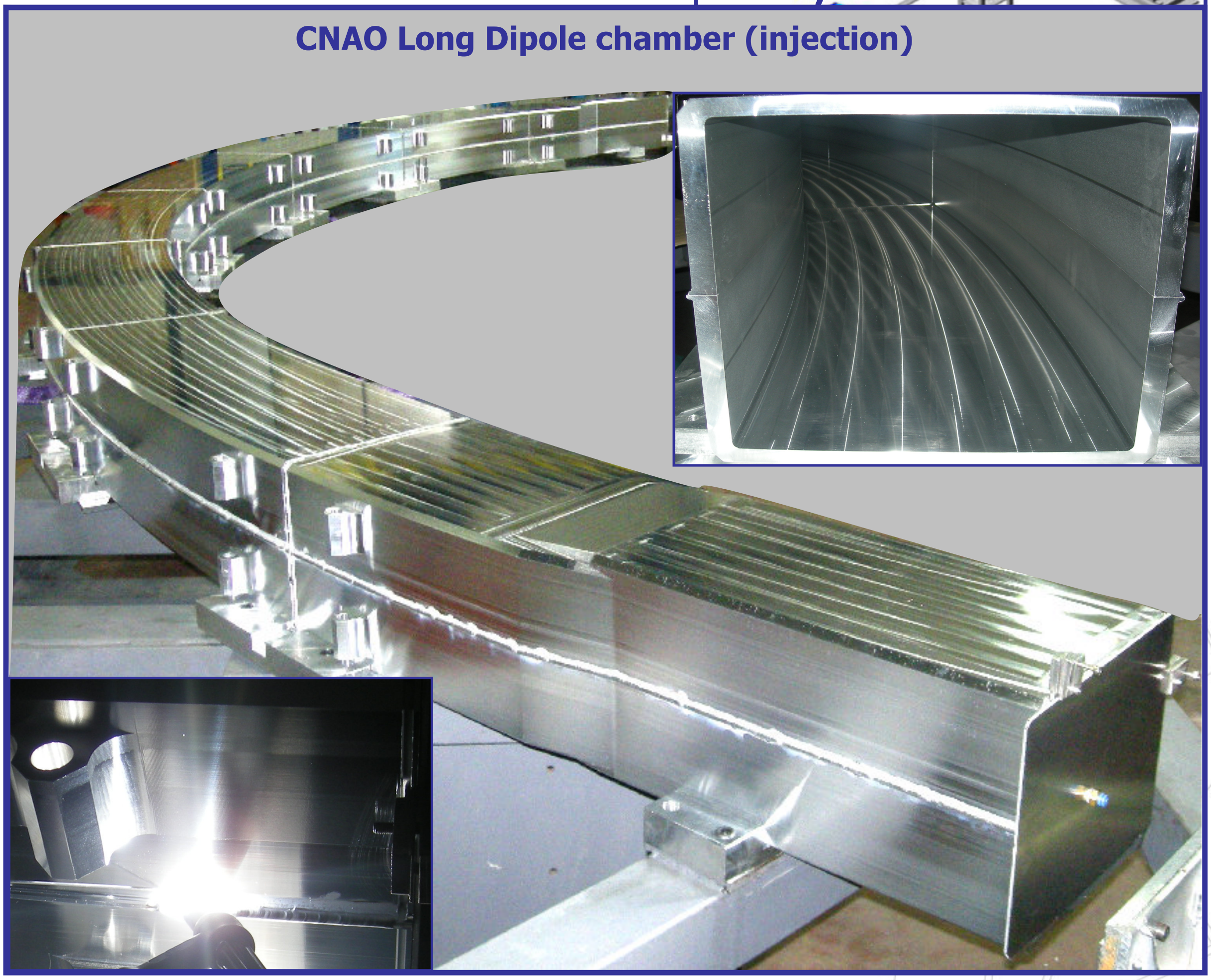


Fig. 9: Dipole chamber