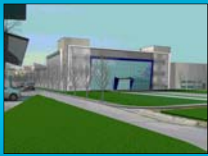

# The Chopper Faraday Cup Monitor

## A "NOT-interceptive" Faraday Cup!

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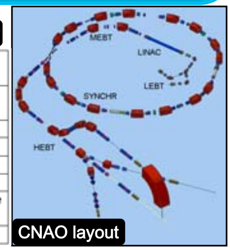
## INTRODUCTION

The Centro Nazionale di Adroterapia Oncologica (National Center for Oncological Hadrontherapy, CNAO), which will be the first Italian center for deep hadron therapy, is presently under construction in Pavia. It will be based on an evolution of the PIMMS synchrotron design, and will be capable of accelerating carbon ions up to a kinetic energy of 400 MeV/u, and protons up to 250 MeV/u. These energies are necessary to treat deep seated tumors. The beam is injected into the synchrotron from the inside, to allow positioning all the injection chain inside the synchrotron ring itself. The injection chain consists of a 8 keV/u Low Energy Beam Transfer line (LEBT), an RFQ to accelerate 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. Four High Energy Beam Transfer (HEBT) lines deliver the beam to the three treatment rooms.

The Chopper Faraday Cup (CFC) is installed in the LEBT line, just after the Chopper.

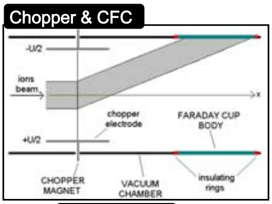
### Beam Parameters @Chopper

| | |
|---|---|
| H3+ Current Intensity at Chopper | 0.70mA |
| C4+ Current Intensity at Chopper | 0.15mA |
| Beam Current Stability | ±1.5% |
| Beam Current Ripples | <±2% |
| Beam Energy | 8keV/u |
| Beam before the Chopper | continuous |
| Beam after the Chopper | 100usec pulse at 0.5Hz |
| LEBT Vacuum Pressure | $10^{-8}$-$10^{-8}$ torr |




CNAO layout

### Chopper & CFC




## PRINCIPLE & SCOPE

A Chopper Magnet is an electrostatic deflector. When the Chopper electrodes (one left, one right of the beam trajectory) are polarized (up to ±5kV), the beam experiences a transverse electric field that deflects the charged particles into the vacuum chamber in order to minimize the beam lost at the RFQ entrance. It follows that the vacuum chamber section, just downstream the Chopper, is normally in the path of the deviated beam.

The CFC key idea consists of insulating this vacuum chamber sector and measuring the electric charge it collects, per unit time. So it measures the full beam intensity while the Chopper is on. This results a monitor based on the Faraday Cup principle, but not intercepting the beam directed to the synchrotron.

The CFC is a good way to monitor continuously source ripples and stability, even during treatments, without affecting the beam delivered to the synchrotron.

## MECHANICS

A Faraday Cup is constituted by a body, collecting the charge to be measured, and a device, aiming to push back into the body the secondary emitted electrons, produced by the beam-to-body interaction, whose escape would affect the measurement.

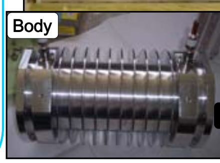
The CFC body is the section of the vacuum chamber where the beam is expected to be absorbed. It is defined by inserting two insulating rings, at the extremities of the region. CFC length and diameter are optimized for Chopper kick range and beam rigidity.

The repelling field, to send back electrons into the body, is produced by a cylindrical metallic grid, inserted into the CFC tank. The grid is set at a negative potential with respect to the body.

Many discussions with the mechanical designers were needed to define a grid support, leaving free the region hit by the ions, but strong enough to avoid grid deformation by overheating.

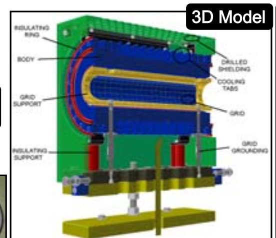
| | Material | Length | Inner Diam |
|---|---|---|---|
| Grid | INOX | 360mm | 80mm |
| Grid Support | Al | 360mm | 65mm |
| Body | Al | 360mm | 90mm |
| Insulating Ring | Viton | 3.53mm | 156mm |

Grid

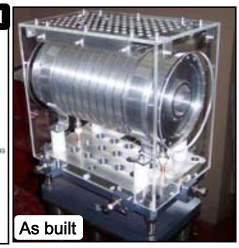


Body

Insulating ring



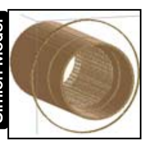

3D Model



As built

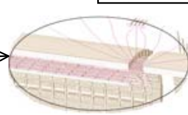

Grid Polarized

$V_{grid}$=-100V
$V_{tank}$=GND



Simion Model

$V_{grid}$=GND
$V_{tank}$=+100V



Tank Polarized

## Grid & Polarization

In order to optimize grid layout and polarization, we have simulated (SIMION 3D v.7.0) the electrostatic field the grid generates. Grounding the tank and polarizing the grid at a negative voltage perturbs the beam. When grounding the grid, and polarizing the tank at a positive voltage (+100V/+1000V), the residual field on the 8keV/u ions path is negligible, but….this requires the electronics to be kept at a floating potential.

Grid mesh design should optimize field flatness and, at the same time, grid transparency factor, with respect to the hitting beam. A good compromise, is achieved using a grid made up of 0.2mm diameter wires, with 3mm x 3mm mesh. This results in a transparency factor of 87%, and a secondary emission probability of around 100-200% at this energy.

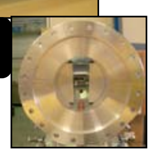
## Heating

As the beam entering the Chopper is continuous, and is onto the CFC for 99% of the time, grid and tank overheating must be taken into account.

Large cooling fins on the outside of the CFC tank improve air-cooling efficiency. Due to the choice of polarizing the tank to capture electrons, for safety reasons, the tank has all round Plexiglas shielding to avoid risk of electrocution. The shielding and tank support have holes to allow air-flow.

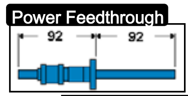
Two power feedthroughs (OFHC Copper, 1 pin, 9.5mm diameter) are used to ground the grid and allow heat transfer.

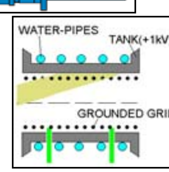
Overheating tests are in progress. A fall-back solution, based on water-cooling is ready, but this is not a preferred solution, because of tank H.V. polarization.



Heating Test Tools

Power Feedthrough



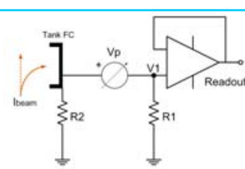




Water Cooling

## ELECTRONICS

**General Issues:**

- Good connection of the repelling grid to ground
- Leakage currents
- High Voltage Floating Power Supply: insulation transformer, "low" ripple , voltage control, safe installation




- Nominal Polarization Voltage 100V
- R1=1kOhm
- Insulation rings resistance R2=100MOhm
- With Ibeam=200µA V1=200mV

## CONCLUSIONS

An innovative application of the Faraday Cup principle is presented in this work. The detector is presently under mechanical tests and the electronics system is under study. The CNAO project is evolving in a framework of various collaborations; a large effort for the realization of the chopper Faraday Cup comes from INFN-LNF (Laboratori Nazionali di Frascati) and CERN (European Centre for Nuclear Research). CNAO LEBT commissioning is planned for beginning 2007.