

PROPOSAL FOR HIGH POWER CYCLOTRONS TEST SITE IN CATANIA

L. Calabretta, L. Celona, L. Cosentino, G. Gallo, D. Rifuggiato, Cui Tao, INFN-LNS, Catania, Italy
 J.R. Alonso, W. Barletta, A. Calanna, D. Campo, J.M. Conrad, MIT, Cambridge, MA 02139, USA
 R. Johnson, L.A.C. Piazza, BCSI, Vancouver, BC, Canada

Abstract

The IsoDAR and DAE δ ALUS experiments will use cyclotrons to deliver high-intensity (10 mA peak current) proton beams to neutrino-producing targets. Cyclotrons with similar high current but with lower energies are also useful to produce medical radioisotope. To investigate the feasibility of these very high beam current we proposed the construction of a dual cyclotron able to accelerate ions with $q/A=0.5$, in particular He^{++} , up to 7 MeV/A and protons up to 28MeV.

The application of this machine, the main characteristics and the planned activity of the project are presented.

INTRODUCTION

A small cyclotron with 700 mm extraction radius, able to accelerate ions with $q/A=0.5$ (H_2^+ ionized hydrogen molecule and He^{++}) up to the maximum energy of 7 MeV/A, is presented here. This cyclotron is based on the design of central part of a bigger cyclotron already studied in the context of the experiments DAE δ ALUS (investigation of CP-violation) and IsoDAR (to search for sterile neutrinos) [1, 2, 3].

One of the goals of the project is to check experimentally the acceleration of H_2^+ beams with current up to 5 mA. To achieve this goal, we need also a very powerful ion source able to supply H_2^+ current in the range 25-50 mA. Up to now our present ion source VIS [4] has been able to supply about 10 mA of H_2^+ . We planned to upgrade this source or to use other sources developed in other laboratories to supply the request current. Moreover, using this cyclotron it will also be possible to accelerate He^{++} beams up to a maximum energy of 28 MeV and or a deuteron beam up to 14 MeV. This cyclotron will be able to produce a helium beam current in excess of 0.5 mA when equipped with the AISHA ion source, under construction at INFN-LNS in Catania [4]. With this high-current He beam, through the reaction $^{96}\text{Zr}(\alpha, n)^{99}\text{Mo}$, we could produce enough ^{99}Mo to satisfy about 50% of the Italian needs. ^{99}Mo is the parent generator of ^{99}Tc , the most used radioisotope in the medical field. The production of ^{99}Mo inside a target of ^{96}Zr should simplify the purification of ^{99}Mo . The production of the ^{99}Mo radioisotope via accelerators is extremely interesting, building up an alternative way to the production by nuclear reactors that are at the end of their life. Using the helium beam we could also produce the ^{211}At radioisotope through the reaction of $^{209}\text{Bi}(\alpha, 2n)^{211}\text{At}$. Targets and procedures to prepare and separate these radioisotopes will be the charge of a private company that has already expressed interest in it.

Table 1: Cyclotron Parameters

R axial hole	29 mm	R pole	800 mm
N. Sectors	4	Hill width	$30^\circ \div 36^\circ$
Valley gap	1400 [mm]	Pole gap	60 [mm]
Diameter	2800 [mm]	Full height	1800 [mm]
Total weight	52 [tons]	Vacuum	10^{-5} Pa
Cavities $\lambda/2$	Double gap	Acc. Voltage	70 [kV]
Main Coil size	200x240 [mm ²]	2 nd Coil size	30x240 [mm ²]
Parameters for ions with $q/A=0.5$, H_2^+ , He^{++}			
E_{inj}	70 [keV]	E_{max}	7 [MeV/amu]
B_0	1.08 [T]	Bmax	1.90 [T]
RF Harmonic	4th	Freq.	32.5 [MHz]
Main coil curr. density	2.8 [A/mm ²]	2 nd coil curr. density	-1.1 [A/mm ²]
Parameters for proton beam			
E_{inj}	70 [keV]	E_{max}	28 [MeV]
B_0	1.12 [T]	Bmax	2.0 [T]
RF Harmonic	2 nd	Freq.	34.3 [MHz]
Cur. density Main coil	2.3 [A/mm ²]	Cur. density 2 nd coil	4 [A/mm ²]

A serious effort is dedicated to finding a design of the iron and of the coils of the cyclotron that allow the use of this cyclotron also to accelerate protons up to 28 MeV.

LAYOUT OF THE CYCLOTRON

The test site cyclotron consists of a four sectors cyclotron, mounted with median plane in the vertical direction, Fig.1. The iron return yoke has a large empty area at the position corresponding to the cyclotron's valley to allow easy access at the median plane. In Fig. 1 the main sizes of the cyclotron iron are shown. The cyclotron main features are presented in Table 1, in particular the different settings for acceleration of ions with $q/A=0.5$ and protons are also presented. To achieve the isochronous magnetic field, we use a double pair of coils mounted one on the other. The coil shown in Fig. 1 consists of a main coil and a second small coil that are fed independently. The two coils can be fed with current flowing in the same direction or opposite direction just to fit the isochronous magnetic

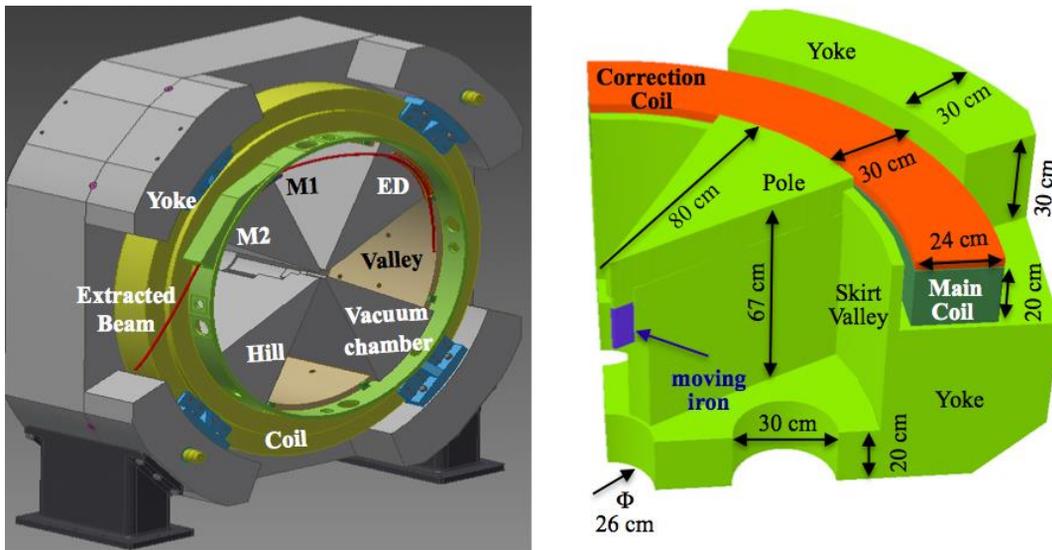


Figure 1: Layout of the Catania Cyclotron test site. The left side shows half part of the cyclotron coil, vacuum chamber and the extraction trajectory. The right side is a sector of the iron magnet with its sizes.

field for the ions with $q/A=0.5$ and for protons $q/A=1$, Table 1). The second coil is the most near to the median plane and the minimum distance between the two coils across the median plane is 130 mm. The iron configuration is optimized to accelerate the ions with $q/A=0.5$. To allow the acceleration of protons, it is necessary to change the harmonic operation mode from $h=4$ to $h=2$, and also change a little the operating frequency. Moreover, it is also necessary to introduce a piece of “moving iron” in the axial hole, see Fig. 1b.

The simulated average magnetic fields and the isochronism for the two cases are shown in Figs. 2 and 3, respectively.

Central Region

To achieve a true dual cyclotron a central region like the one designed by IBA [5] for the Nantes cyclotron is the straightforward solution. Unfortunately that central region is not optimized for acceleration of ions with $q/A=0.5$. The fast change of the beam from $q/A=0.5$ to proton is not mandatory for the first phase of the project. Indeed, the main challenge of our project is to demonstrate that acceleration of 5 mA of H_2^+ is feasible. Until now, only the central region for the acceleration of ions with $q/A=0.5$ has been studied, and it will be the same central region of IsoDAR cyclotron [3]. It will be finalized after the experimental test we are performing at the Best Cyclotron Systems Inc., in Vancouver [6].

It is also well known that for cyclotrons the injection is a crucial problem. To minimize the problem introduced by the spiral inflector, we like to investigate the use of a dipole magnetic inflector made by permanent magnet. Permanent magnets inside magnetic fields with direction perpendicular to their main field direction are successfully used in many ion sources.

RF System

The RF system consists of four RF cavities $\lambda/2$, double gap, operates in 4th harmonic and driven with the same phase when the cyclotron has to accelerate ions with $q/A=0.5$.

To accelerate protons the cavities will operate in 2nd harmonic; a couple of cavities will be driven with the same polarity (phase 0°), while the other couple are driven with inverse polarity (phase 180°). The full length of the cavities is 2.6 m, so the length of cavities exceeds of 40 cm from the two sides the cyclotron size. The expected power consumption driven at the maximum voltage of 70 kV is about 12 kW for each cavity. The cyclotron will be equipped with two RF Amplifiers of 50 kW each one. Each amplifier will feed a couple of cavities. These amplifiers will be able to supply enough power to operate the cyclotron with a beam current of 1 mA of He^{++} at 7 MeV/amu or 1 mA of proton at 28 MeV. Indeed for these ions the beam power is at maximum 28 kW. But to perform the acceleration and extraction of a high-intensity H_2^+ beam up to a maximum current of 5 mA, of interest for the IsoDAR experiment, we have to transfer about 70 kW to the beam. To perform this test we plan to use an additional amplifier with power of about 200 kW that will

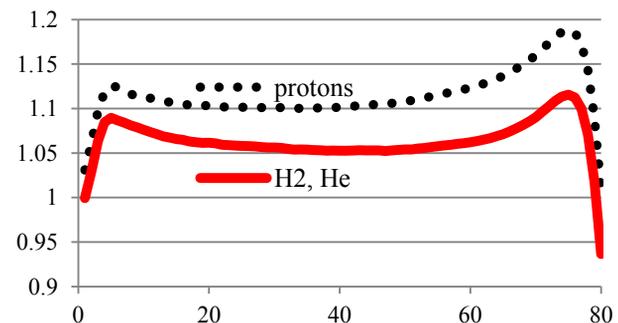


Figure 2: Simulated average fields for $q/A=0.5, 1$.

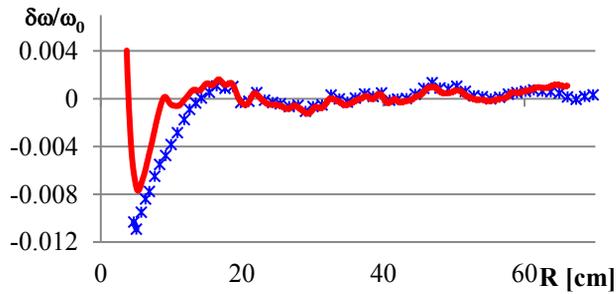


Figure 3: Isochronism for ions with $q/A=0.5$ (\times) and for protons, continuous line.

be not only a check of the central region ability to accelerate high H_2^+ current but also of the performance of the amplifier.

Vacuum Plant

The vacuum chamber of the cyclotron has a simple design. It consists of the magnet steel as the vacuum vessel with a tank wall just outside the pole radius. The tank wall is divided into two asymmetric cylinders. The larger cylinder is 36 cm in height while the smaller is only 24 cm in height. Through the larger vacuum tank the hole for the extraction channel, four vacuum pumps, four trimming capacitors for the RF cavities, and two diagnostic probes are drilled. Metallic O'ring seals the contact surfaces between the two vacuum tanks and the surfaces of the iron pole. A Viton O'ring seals the contact surfaces of the two cylinders, 6 cm offset from the median plane. To minimize the exposed surface area the pole and hill will be a single piece. The beams arrive at extraction radius after only 26 turns, so a vacuum of 10^{-5} Pa is enough to maintain the beam losses due to interaction with the residual gas below 100 W in the worst case of acceleration of 5 mA of H_2^+ . To achieve the request vacuum, two cryogenic and two turbo pumps will be installed on the outer side of the tank. Another couple of cryogenic and turbo pumps will be installed on the two opposite sides of the axial hole to achieve a good vacuum along the injection line and in the central region.

BEAM EXTRACTION

The low mean field and the use of four RF cavities allow a separation among the last turns of about 15 mm. Using a 1st harmonic precession, the turn separation at extraction can be increased up to 25 mm. So extraction efficiency near to 100% can be achieved also using an Electrostatic Deflector (ED). The ED is placed on a hill, Fig. 1. The expected maximum voltage will be about 50 kV and the gap of ED is 18 mm, enough to accept a beam with a normalized emittance of 13.4π mm.mrad. This large value, about 40 times the beam emittance of ion the source [7], was chosen to take into account nonlinear effects along the inflector and space-charge effects that increase the emittance. The ED produces a quite well separated extracted trajectory that at the position of the

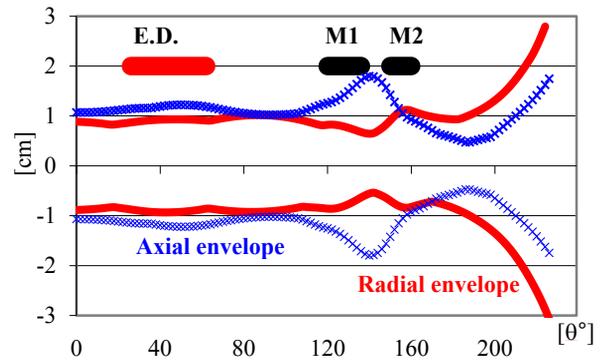


Figure 4: Radial (continuous line) and axial (\times) beam envelope along the extraction path.

first magnetic channel MC1 is about 40 mm outer the last accelerated orbit. The beam envelopes for the extraction trajectories are presented in Fig. 4. The beam envelope along the extraction path is quite small in both the radial and axial plane and along the trajectory. The introduction of energy spread of $\pm 0.2\%$ does not broaden the beam significantly along the ED.

FINAL REMARKS

The funds for the construction of this cyclotron have already been requested and we are waiting for the official approval in the coming months. The proposal has been supported by many international scientific institutions and also by a private company. The preliminary design is finished, and we are waiting for the project approval to start the final design.

This project will enhance LNS-INFN infrastructure in the field of high-intensity cyclotrons and radioisotope production.

ACKNOWLEDGMENT

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