UPGRADE OF THE LNS SUPERCONDUCTING CYCLOTRON FOR BEAM POWER HIGHER THAN 2-5 kW

L. Calabretta†, A. Calanna, G. D'Agostino, D. Rifuggiato, G. Cuttone, A.D. Russo,
INFN-LNS, Catania, Italy

Abstract

The LNS Superconducting Cyclotron has been in operation for more than 20 years. A wide range of ion species from Hydrogen to Lead, with energy in the range 10 to 80 AMeV, have been delivered to users. Up to now the maximum beam power has been limited to 100 W due to the beam dissipation on the electrostatic deflectors.

To fulfil the demand of users aiming to study rare processes in Nuclear Physics, the beam power has to be increased up to 2÷10 kW for ions with mass lower than 40 a.m.u., and extracted by stripping. This development has to maintain the present performances of the machine, i.e. the existing extraction mode for all the ion species allowed by the operating diagram.

To perform the extraction by stripping, a significant refurbishing operation of the Cyclotron is needed, including a new cryostat with new superconducting coils, a new extraction channel with a 60 mm vertical gap, additional penetrations to host new magnetic channels and new compensation bars.

Moreover, the vertical gap of the acceleration chamber is planned to be increased from the present 24 mm up to 30 mm by renewing the existing liners and trim coils.

A general description of the refurbishing project is presented.

INTRODUCTION

The LNS Superconducting Cyclotron (CS), designed by the Milano Group headed by F. Resmini, has been in operation since 1995 [1]. The CS was designed to be operated as a booster of a Tandem accelerator and to deliver beams for nuclear physics experiments mainly. The usual beam power stays around few tens of Watts.

After the year 2000, the CS was equipped with a central region to operate in stand-alone mode. Ion beams are now produced by ECR ion sources and injected into the cyclotron through the axial hole using a spiral inflector. The success of axial injection operation stimulated the development of the EXCYT project to produce radioactive ion beams on a thick target with the ISOL technique [2].

To operate the EXCYT project we pushed the CS to the maximum beam current, but it became clear that despite our efforts, the extraction system and in particular the two electrostatic deflectors (ED) were not able to deliver beam currents more than 150 W. This limit was mainly due to the extraction efficiency of the CS that stays around 50-60% and to the constraints of our ED. Although it is water cooled, can work with a maximum beam loss of 100 W. Recently some nuclear physicists proposed to use the magnetic spectrometer with large solid angle and large momentum acceptance "MAGNEX" to measure the nuclear matrix that is of relevant interest for the double β decay without neutrino emission [3,4]. This experiment, called NUMEN, needs mainly beams of Carbon, Oxygen and Neon with intensity up to 10^{14} pps. The required energies are in the range 15÷70 AMeV, which corresponds to a beam power in the range 1÷10 kW.

According to this relevant scientific interest, the management of LNS-INFN approved a program to upgrade the CS. This upgrade will be relevant also for experiments that use radioactive ion beams produced by in-flight fragmentation. In particular, a new dedicated beam line for the production and selection of the radioactive ion beams is under design. Moreover, the availability of light ion beams with medium power opens the opportunity also to produce radioisotopes of medical interest.

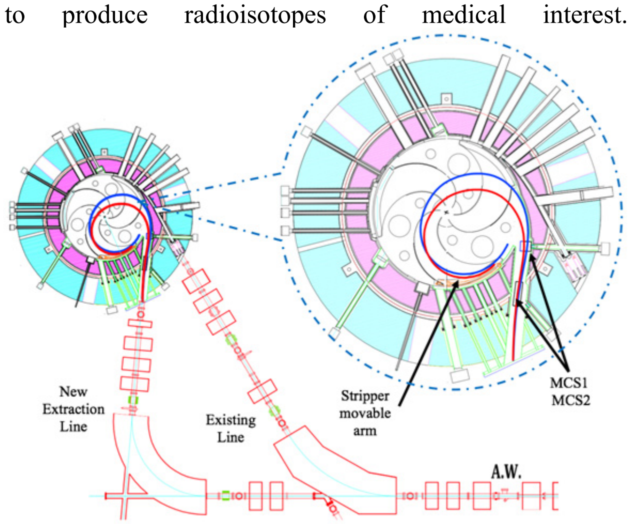

Figure 1: Layout of the Superconducting Cyclotron with the existing and the new extraction beam lines. Two extraction trajectories, in red and blue, are also shown.

MAIN MODIFICATIONS

The extraction of 1÷10 kW beams is not feasible using the ED nor through the existing extraction channel. Indeed, the existing extraction channel allows to extract beams with a transversal size not larger than 8 mm, and this magnetic channel has no thermal shields to dissipate the beam power coming from haloes. So a solution based on extraction by stripping has been investigated [5]. According to Fig. 1, the ion beams are accelerated with a charge state q=Z-1÷Z-3 and after crossing a stripper foil the ions become fully stripped. The use of a stripper foil, placed at a proper position, allows the beam trajectory to escape from the region of the cyclotron pole and to come out through the new extraction channel. This extraction mode is currently used in the cyclotron of FLEROV laboratory [6]. The energies of our beams are enough high,

ISBN 978-3-95450-167-0

so that all the ions of interest, with mass <40 a.m.u., are fully stripped with efficiency higher than 99%. Beam losses well below 100 W are expected due to the stripping process also in the case of an extracted beam power as high as 10 kW.

The Fig. 1 shows the trajectories evaluated just for two ions of interest. More details about the stripping extraction trajectories are presented in another paper presented at this conference [7].

The mechanical study of the new extraction channel and the specifications for the new cryostat are also presented at this conference [8,9].

The main modifications of the new magnet are briefly presented in this paper.

Main Coils

The existing superconducting coils are wound with the so-called technique of the double pancake. This solution is very conservative but it is space consuming because a set of tie rods, beryllium made, are necessary to compress the two pairs of alfa and beta coil to prevent their radial movement.

The tie rods are room consuming both in radial and vertical direction, see Fig. 2. By having a little different coils size and higher current density, it is possible to reduce the vertical coils size and avoid the use of the vertical tie rods compressing, that are replaced by a set of springs placed on the top of the upper beta coil and on the bottom of the lower beta coils [10].

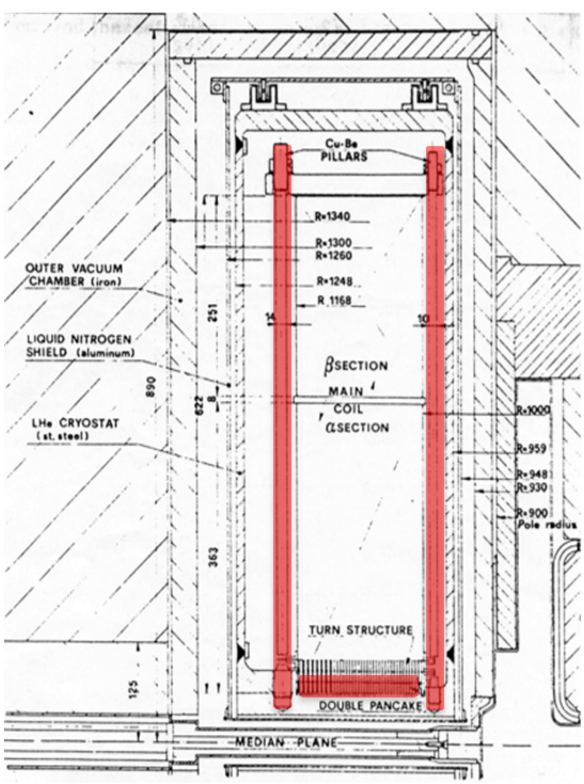

Figure 2: Cross section of the cryostat and of the existing alfa and beta coils. The Cu-Be and the two layers of the alfa coils that have to be removed are highlighted in red.

Liquid Nitrogen Shields

Removing the tie rods, the LHe vessel can be radially smaller. More than 10 mm became available at the inner and outer side of the liquid Helium vessel, which allows the installation of a larger and more reliable Liquid Nitrogen shield. The larger size of the Liquid Nitrogen shield allows to feed it with Liquid Nitrogen flowing with a natural convection mode. This solution should reduce significantly the present liquid nitrogen consumption.

Larger Vertical Gap for the Extraction Channels

The beginning of the alfa coil is planned to stay at around 90 mm from the median plane (the present distance being 62 mm) and allows to increase the vertical gap of the extraction channel up to 60.5 mm vs the present value of 30.5 mm and also to have some extra room of about 10 mm for the liquid nitrogen shield.

PRESENT LIMITS AND PROBLEMS

Some components of the CS are suffering from few problems after 22 years of operations. The liquid nitrogen shield, made by an aluminium made roll bond plate, consists of three main components: the inner wall, the outer wall, the bottom and the top. Unfortunately, the pipeline cooling the inner wall is having serious leaks and has been closed for more than 6 years. The pipeline cooling the outer wall is also having some small leaks towards the cryostat vacuum. These leaks are not critical, but about once per years we are forced to warm up the cryostat up to 100 K to allow the frozen nitrogen to evaporate and to restore the working vacuum pressure in the cryostat. It is evident that this is a serious problem for the future operation of the cryostat, especially if the leaks in the nitrogen shields should increase.

Another problem is related with the vacuum of the acceleration chamber that is slowly worsening. The walls of our vacuum chamber are the internal wall of the cryostat and the two copper made liners, that cover the upper and lower poles, see Fig. 3. The liners separate the vacuum of the acceleration chamber from the vacuum volume trapped among the liners and the poles, the so called "dirty" vacuum. The residual pressure in the acceleration chamber is increasing along the years. The main reason of this worsening are the leaks through the welds of the liners. Indeed, some recent tests in the acceleration chamber showed a strong correlation of the measured residual pressure with the so called dirty vacuum. The worsened vacuum in the acceleration chamber increases the amount of beam losses along the acceleration path and produces additional sparking problems at the RF cavities and in the perspective of higher beam currents the amount of beam losses should became higher. These problems are reducing the reliability of our cyclotron.

FURTHER MODIFICATIONS

The replacement of the cryostat and of the main coil gives us the opportunity to replace also the existing cop

ISBN 978-3-95450-167-0

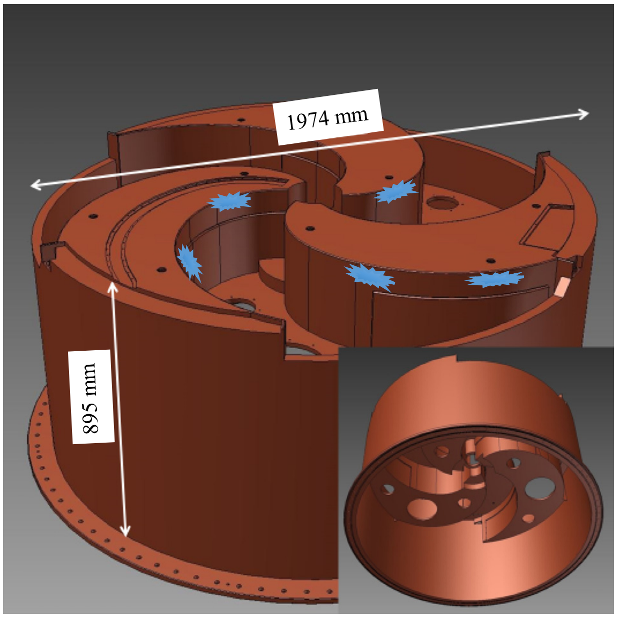

Figure 3: View of one of the two copper made liners. The blue sparking clouds indicate the regions of the possible leaks.

per made liners with new ones. We believe that today it is feasible to realize the new liners with safer welds.

The existing upper and lower liners consist each one of 3 copper plates, 14 mm thick, that cover the hills and 3 thick plates that cover the valleys. These hills and valleys plates are joint by a copper made 3 mm thick wall, that is wrapped around the side of the hills and around the poles, see Fig. 3.

To achieve a better welding between the thin sides of the liners that wrap the hills and the top and bottom plates of liners, we plan to increase the thickness of the copper sides from the present value of 3 mm to 5 mm. This will be quite easily feasible if we replace also the set of 20 trim coils wrapped around each hill of our cyclotron. The cable of the present trim coils has a size of 6.25×6.25 mm and an inner hole of 4.76 mm. The existing trim coil cable has a minimum thickness of about 0.75 mm and this is one additional reason that suggests us to replace the trim coils, to prevent the collapse of some of these 120 trim coils. We plan to replace this cable with a new one with size 6.25×5.00 mm and inner hole with size 4.25×3.00 mm. This new cable has a minimum thickness of 1 mm. Moreover, the reduction of the cable size of 1.25 mm in one direction allows to increase the total gap of the vacuum chamber of 5 mm. Indeed, the trim coils are wound in two turns on each hill and are symmetric vs. the median plane, therefore 2×2×1,25 mm is the full increased gap of the vacuum chamber due to replacement of the trim coils. Reducing the thickness of the copper plates of liners from the present 14 mm down to 13 mm the vertical gap of the vacuum chamber in the region of the hill will increase from the present value of 24 mm up to 31 mm. With the great advantage to minimize the beam loss due to beam halo striking on the liner surfaces and to increase the vacuum conductance.

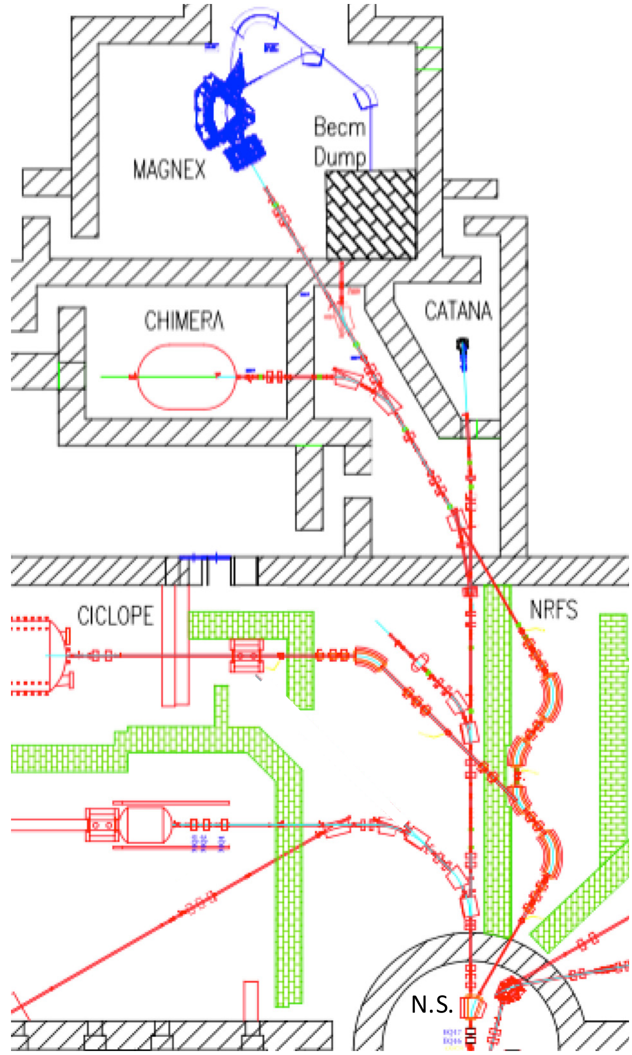

Figure 4: beam transport line of LNS with the proposed New Recoil Fragment Separator (NRFS).

NEW BEAM LINES

As shown in Fig. 1, an additional beam extraction line has to be built to transport the beam extracted through the new extraction channel to the existing beam lines. The main elements of this line are: a steering magnet, three large quadrupoles, a 95° bending dipole and an additional quadrupole doublet. This beam line has to produce an achromatic beam waist at the common point position, labelled “AW” in Fig. 1.

A further mandatory modification is to replace the existing switching magnet with a smaller one with larger gap labelled “NS” in Fig. 4.

Moreover, a New Recoil Fragment Separator (NRFS) able to operate with a primary beam with power up to 2 kW is proposed. The NRFS can be used to deliver radioactive ion beams to three experimental room. The NRFS could be also used to clean the high beam power to be transported to MAGNEX spectrometer to reduce the en-

ISBN 978-3-95450-167-0

ergy spread of the beam extracted by stripping from the intrinsic value of $\pm 3\times 10^{-3}$ down to $\pm 1\times 10^{-3}$.

CONCLUSIONS

The call of tender for the construction of the new cryostat including the superconducting coils will be published before the end of this year. The new magnet is expected to be ready not before the middle of 2019. Since the expected time to dismount and to assemble the cyclotron is about 18 months, we expect the restart the cyclotron in the 2021. In the meanwhile, some crucial parts of the existing beam line will be optimised to ensure a beam transmission as high as 99%.

REFERENCES

[1] L. Calabretta et al., "Commissioning of the K800 INFN cyclotron", in *Proc. 14th Int. Conf. on Cyclotrons and their Applications (ICCA'95)*, Cape Town, South Africa, October 1995, pp. 12-19

[2] L. Calabretta et al., "The progress of the EXCYT facility at INFN-LNS", in *Proc. 7th European Particle Accelerator Conf. (EPAC'00),* Vienna, Austria, June 2000, pp. 2597-2599

[3] C. Agodi et al., "Heavy-ion double charge exchange reactions: A tool toward 0νββ nuclear matrix elements", in Proc. Of Neutrino Oscillation Workshop (NOW2014), Conca specchiulla, Otranto, Italy, September 2014, Nuclear and Particle Physics Proceedings 265-266, 2015, pp. 28-30

[4] F. Cappuzzello et al, "Heavy-ion double charge exchange reactions: A tool toward 0νββ nuclear matrix elements" European Phy. Journal, Vol. 51, pp. 145, 2015

[5] A. Calanna et al., "Proposal to increase the extracted beam power from the LNS-INFN Superconducting Cyclotron", in *Proc. 13th Int. Conf. on Heavy Ion Accelerator Technology (HIAT'15)*, Yokohama, Japan, September 2015, pp. 23-26

[6] G.G. Gulbekyan et al., "Extraction by stripping of heavy ion beams from AVF cyclotrons", in *Proc. 18th Int. Conf. on Cyclotrons and their Applications (ICCA'07)*, Giardini-Naxos, Italy, September 2007, pp. 308-313

[7] G. D'Agostino et al., "Extraction by Stripping for Intensity Upgrade of the INFN-LNS Superconducting Cyclotron: Beam Dynamics Studies and Major Modifications", in *Proc. 21st Int. Conf. on Cyclotrons and their Applications (ICCA'16)*, Zurich, Switzerland, September 2016, TUC03, this conference

[8] G. Gallo et al., "Mechanical Aspects of the LNS Superconducting Cyclotron Upgrade", in *Proc. 21st Int. Conf. on Cyclotrons and their Applications (ICCA'16)*, Zurich, Switzerland, September 2016, THP09, this conference

[9] F. Noto et al., "Status and Upgrade of the Cryogenic Plant of the LNS Superconducting Cyclotron After 25 Years of Operation", in *Proc. 21st Int. Conf. on Cyclotrons and their Applications (ICCA'16)*, Zurich, Switzerland, September 2016, THP10, this conference

[10] A. Radovinsky et al. "Design of a Superconducting Magnet for the LNS Cyclotron", IEEE Transactions on Applied Superconductivity, Vol. 26, Issue 4, 2016

ISBN 978-3-95450-167-0