FIRST BEAMS PRODUCED BY THE SPIRAL-2 INJECTORS

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Abstract

The SPIRAL-2 superconducting linac driver, which aims at delivering 5 mA, 40 MeV deuterons and up to 1 mA, 14.5 A.MeV q/A=1/3 heavy ions, has now entered its construction phase in GANIL (Caen, France). The linac is composed of two injectors feeding one single RFQ, followed by a superconducting section based on 88 MHz independently-phased quarter-wave cavities with room-temperature focusing elements. The first stages of the injectors have been fully built and are now operational. They have been partly commissioned with beam in Grenoble and Saclay in 2010. This paper describes the results obtained so far in this context.

INTRODUCTION

After a detailed design study phase (2003-2004), the SPIRAL2 project at GANIL (Caen, France) was officially approved in May 2005, and is now in its phase of construction, with a project group in which many French laboratories (CEA, CNRS) and international partners are participants. The SPIRAL2 facility is driven by a multi-beam linear accelerator (5mA/40MeV deuterons, 5mA/33Mev protons, 1mA/14.5 MeV/u heavy ions with A/q<3). In its phase I, it will deliver its beams in new experimental areas for nuclear and interdisciplinary physics, and for the production of high intensity neutron flux for irradiation and time-of-flight experiments. In its phase II, the beams will also be delivered to a new dedicated building for the production of radioactive ion beams by the ISOL method (the main process being the fission of a uranium carbide target); the existing cyclotron CIME will also be used for RIBs post acceleration.

The major parts of the SPIRAL-2 linac are presently under construction and test [1]. In particular, the machine injectors have been installed and already partly commissioned during year 2010 in LPSC Grenoble and CEA Saclay, as detailed here after. These injectors include two ECR sources (one for deuterons/protons and one for A/q<3 heavy ions) with their associated LEBT lines which merge before entering a 88 MHz RFQ, as showed in Figure 1. These injectors will be moved to the GANIL site end 2011 / 2012 as soon as the SPIRAL-2 accelerator building is achieved. The full commissioning of the whole SPIRAL-2 facility (phase I) should take place by the beginning of 2013.

THE DEUTERON INJECTOR

The 2.45 GHz ECR source for deuterons and protons, presently installed at CEA Saclay, is based on a permanent magnet design [2], and benefits from the long term development of the laboratory on high-intensity beams, with especially the 100 mA SILHI source. In 2005, this source demonstrated its capability to produce a very stable 6.7 mA, 40 kV deuteron CW beam with an emittance of about 0.1 π.mm.mrad norm rms. Then, a similar ECR source was constructed for SPIRAL-2, and tested end 2009 in proton mode either in pulsed or CW operation. The 20 keV extracted beam was collected just at the source exit a faraday cup equipped with an electron repelled electrode. A total CW beam of 12 mA has been extracted, without any characterization; in pulsed mode, an 8 mA beam of 200ms at 1 Hz has been obtained (see Figure 2)

The associated deuteron LEBT line is based on the use of a solenoid refocusing the source beam, followed by an achromatic double deviation that ensures an efficient separation of the deuteron beam from the main pollutants, while avoiding any beam degradation due to possible fluctuations of the source's voltage or of the bending magnets' field. The achromat is composed by one quadrupole triplet surrounded by two 45° sector magnets with 50 cm curvature radius and deviating the beam to the right side. This deuton/proton injector is presently installed (Figure 3) and in beginning of September, proton

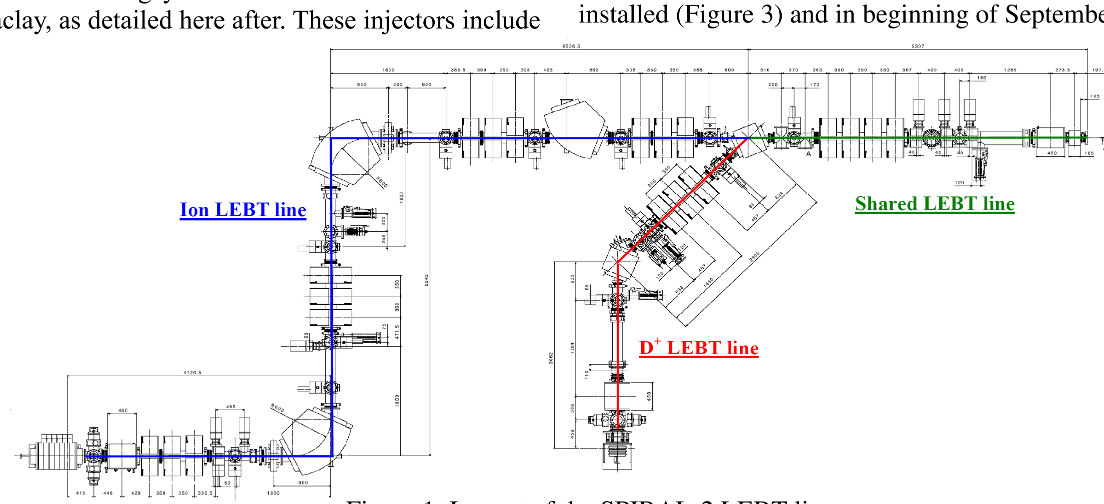

Figure 1: Layout of the SPIRAL-2 LEBT lines.

transport has been performed up the end of the first dipole. First beam characterization is planned before the end of 2010 including profile and emittance measurements. The complete beam transport up to the end of the full LEBT is expected during 2011.

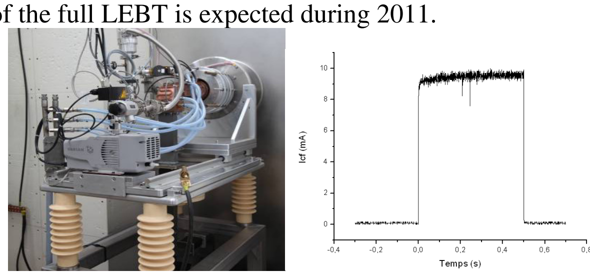

Figure 2: First characterization of the light ion ECR source in pulsed proton mode.

Figure 3: The light ion LEBT2 line installed at CEA IRFU/Saclay.

THE HEAVY ION INJECTOR

The goal of SPIRAL2 is also to produce a large diversity of heavy ions with intensities up to 1mA: noble gases like Ar or Xe, and metallic ions like Cr, Ni and Ca are required. Such beams will be produced in a first step by the 18 GHz PHOENIX V2 ECR source, developed by the LPSC laboratory (Grenoble), which demonstrated in 2004 its capability to produce up to 1 mA of O^{6+} at 60 kV with emittances of 0.2 π.mm.mrad norm. rms [3].

The LEBT line associated to this ion source aims at separating efficiently the different masses and charge states. For this purpose, a double-focusing 90° dipole is used, with 60 cm curvature radius and 26.565° edge angles. One solenoid and 3 quadrupoles are used to match the beam to the dipole by creating the object point at 1.2m before the bend entrance, and the image point at 1.2 m after the bend exit, where the slit system is located for the ion selection. An associated hexapole located before the dipole is used to minimize the non-linearities induced by such large beam extensions inside the bend. After the selection slit, 3 quadrupoles and a second 90° dipole and its associated hexapole complete the achromatic left/right double-deviation.

The assembly of the ion injector has been performed in Grenoble between June 2008 and end 2009 (Figure 4). It is equipped with 2 Faraday cups, 3 beam profilers, a couple of Allison-type emittance-meters, and is operated through an EPICS-based control/command system. The tuning of the magnetic elements is performed with the help of automated optimization algorithms developed from the TraceWin code [4] [5] and directly linked to the EPICS system. Such a tool allows us to optimize very easily the beam optics, by asking for either the smallest size on the profiler located near the separation slit, or the highest current on the corresponding Faraday cup.

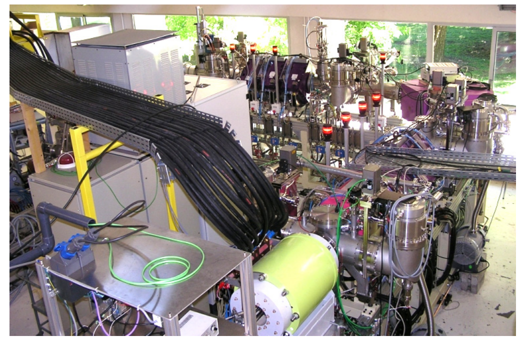

Figure 4: The heavy ion ECR source and LEBT1 line installed at LPSC/Grenoble

The injector is presently being fully commissioned: first beam have been produced like Oxygen, Argon, Xenon and Calcium, up to a voltage of 47 kV. In all cases, a very good beam transmission is reached, while keeping ultra high vacuum conditions (2.10^{-8} mbar in the whole line) even at high currents [6].

First experiments have been performed in March 2010 using a 0.4 mA beam of Oxygen 6+ at 32 kV. Very good agreements between simulations and real measurements have been reached, and emittances of about 0.25 pi.mm.mrad norm. rms have been measured in both transverse planes. Figure 5 illustrates for example the effect on the beam horizontal emittance of the hexapole tuning that is used to compensate second order aberrations created by the bending magnet.

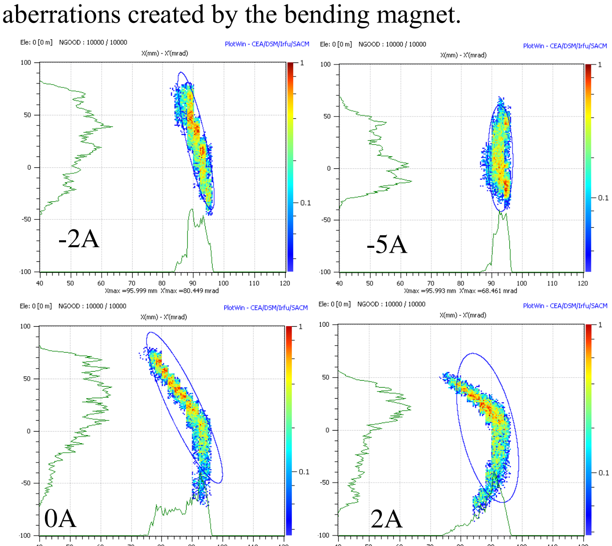

Figure 5: Effect of the hexapole tuning on the horizontal emittance ($^{16}O^{6+}$, 32kV, March 2010).

In June 2010, tests have been performed with a 0.13mA beam of Argon 12+ at 40 kV. Very nice emittances of 0.3

and 0.25 pi.mm.mrad norm rms have been measured in the horizontal and vertical planes respectively. Moreover, very good stability and reproducibility of the beam behavior have been reached, especially between CW and pulsed source mode, as showed on Figure 6.

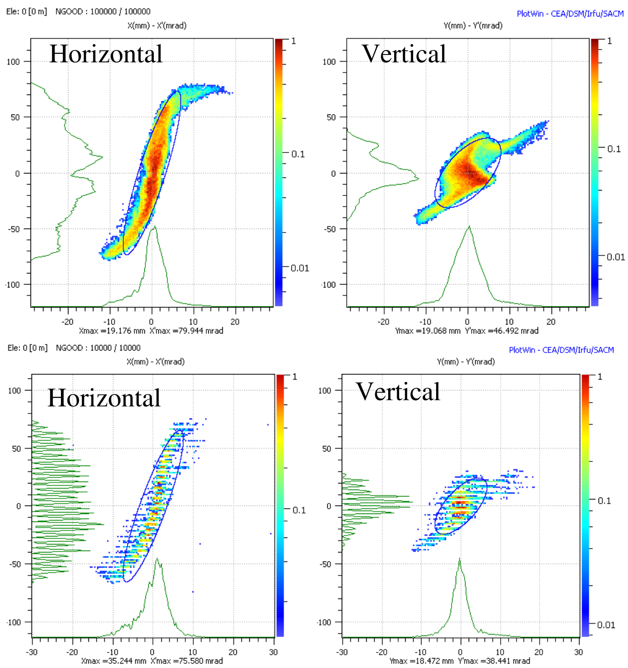

Figure 6: Emittance measurements in CW (up) and pulsed (bottom) source mode ($^{40}Ar^{12+}$, 40kV, June 2010).

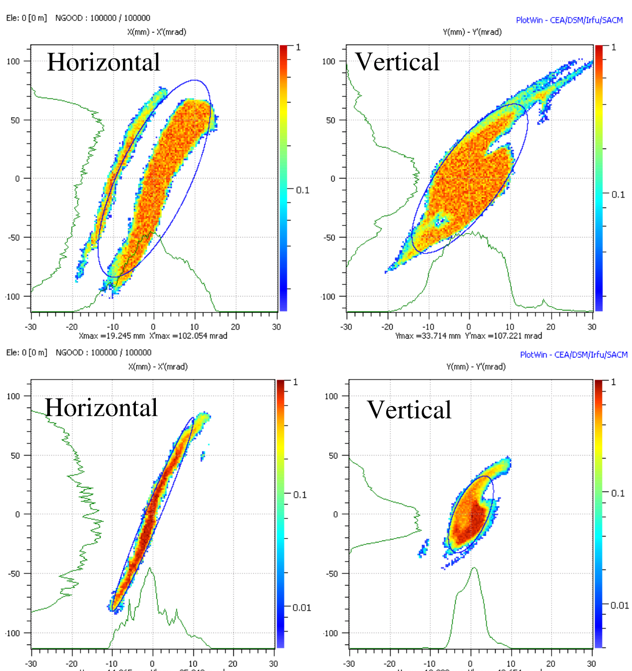

Figure 7: Test of the separation power with Xe at 40kV (up) slits fully opened: $^{132}Xe^{25+}$ & $^{16}O^{3+}$ are visible; (bottom) slits opened at ±5mm, only $^{132}Xe^{25+}$ remains.

The separation power of the optical system has been validated using a Xenon beam. The design value $(d(q/A)/(q/A)\leq 1/100)$ was reached by clearly separating $^{132}Xe^{25+}$ from $^{16}O^{3+}$, as shown on the emittances measurements (Figure 7).

The most recent beam test was performed in July 2010. A beam of more than 1mA of $^{16}O^{6+}$ was obtained at 45kV (see Figure 8) with emittances lower than 0.3 pi.mm.mrad norm rms. During this last campaign, a first metallic beam of Calcium has also been produced at 20 kV, using a large capacity oven from GANIL. More than 100μA of $^{40}Ca^{11+}$ was reached easily, which is a very promising result.

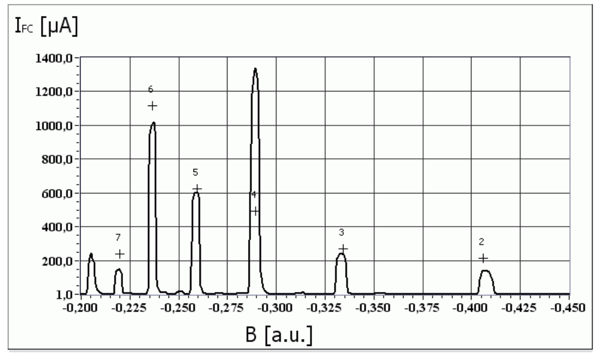

Figure 8: Oxygen Spectrum (45kV, July 2010).

The beam tests will continue up to mid 2011, with a special focus on the increase of the source voltage up to the nominal 60kV value, and on the production of metallic ions. In parallel, the new 18-28GHz ion source "A-PHOENIX" [7], which is a compact hybrid ECRIS with high-temperature superconducting (HTS) coils (3T axial magnetic field) and a permanent-magnet design (1.6 to 2T hexapolar field), has been re-started and is under beam tests on a dedicated beam line. This new source, that is designed to approach nearer to the 1 mA intensity level for a $^{40}Ar^{12+}$ ion beam, could replace the present PHOENIX V2 one on the SPIRAL2 injector.

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