COMMISSIONING OF THE PROTON-LINAC ECR SOURCE FOR FAIR

J. Fils†, R. Berezov, R. Hollinger, GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany
B. Bolzon, N. Chauvin, O. Delferrière, O. Tuske, Y. Gauthier, Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA), IRFU, 91191 Gif-sur-Yvette, France

Abstract

The Facility for Antiproton and Ion Research (FAIR) presently built in Darmstadt, Germany, will be dedicated to physics of unstable nuclei and antiprotons. The antiproton program at FAIR needs for various experiments the delivery of $7x10^{10}$ pbar/h beams. Consequently, the acceleration chain composed of a proton-Linac and two synchrotrons, SIS 18 and SIS 100 has to deliver $2x10^{16}$ protons [1]. To this purpose, a 75 mA/ 68 MeV proton-Linac (p-Linac) is under construction. Its injector is composed of an Electron Cyclotron Resonance (ECR) ion source, a Low Energy Beam Transport (LEBT) line, a 3 MeV Radio-Frequency Quadrupole (RFQ) and a Drift Transport Line (DTL) using Cross-bar H-mode cavities (CH). The CEA/Saclay is in charge, in the framework of a French-German collaboration, of designing, constructing and commissioning the proton-Linac injector composed of both the ECR proton source and the LEBT with dedicated diagnostics [2]. The on-axis species repartition of the proton beam is measured with a Wien Filter (WF), and the 2D-emittance with an Allison Scanner (AS) [3]. The targeted specifications are a proton beam current of 100 mA for an energy of 95 keV at the entrance of the RFQ within an emittance of 0.3π mm.mrad (rms norm). We present in this paper the latest results obtained with the injector in view of commissioning.

PROTON LINAC

At FAIR, the primary proton beam for the antiproton production is delivered by the p-Linac at an energy of 68 MeV and a repetition rate of 4 Hz (Fig. 1). Its main parameters are listed in Table 1.

Table 1: Proton Linac Parameters

Parameter	Value
Beam Energy	68 MeV
Maximum design current	70 mA
Current at SIS18-injection	35 mA
Proton per pulse	$7.9\ 10^{12}$
Beam pulse length	36 µs
RF-frequency	325.224 MHz
Repetition rate	≤ 4 Hz
Emittance (norm)	≤ 2.1 mm.mrad
Momentum spread (tot., norm)	$\leq \pm 10^{-3}$
Overall length	43 m

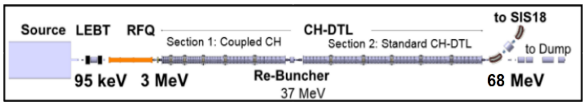

Figure 1: Schematic of the future p-Linac.

The proton injector being commissioned at CEA/Saclay is composed of the proton source and the LEBT until the entrance of the RFQ (Fig. 2).

PROTON INJECTOR

The proton source, acceleration column and LEBT presently under construction and test at CEA/Saclay has been designed according to the SILHI model and the IPHI deuteron injector.

General Layout

The injector has to deliver a proton-beam at 95 keV with a proton beam intensity of 100 mA at the entrance of the RFQ. All general requirements are listed in Table 2. Its general layout is represented in Fig. 1. Different parts are described more precisely in following sections.

Table 2: Proton Injector Parameters

Parameter	Value
Beam Energy	95 keV
Beam Intensity	100 mA (H^+)
Repetition rate	4 Hz
Energy spread	< 60 eV
Final emittance	≤ 0.33 π mm.mrad
Pulse length	≥ 36 µs
α Twiss parameter	0.27 ≤ α ≤ 0.59 mm/π.mrad
β Twiss parameter	0.037 ≤ β ≤ 0.046 mm/π.mrad

Ion Source and Extraction System

Its design was taken from the SILHI high intensity light ion source [4] developed at CEA. The cylindrical plasma chamber, 90 mm wide and 100 mm long, is put on a 100 kV-platform in a Faraday cage. H_2 gas is injected through a capillary. Its flow is tuned by a mass flow controller. To occur, the ECR condition needs the presence of an axial magnetic field produced by two coils, independently power-supplied and tuned in order to reach a constant on-axis magnetic field value of 0.875 T, possibly as close as possible to the ridge output concentrating the 2.45 GHz RF-wave from the magnetron. Electron density is increased thanks to two boron nitride disks inside the plasma chamber.

---

† j.fils@gsi.de

ISBN: 978-3-95450-196-0 doi:10.18429/JACoW-ECRIS2018-TUP04

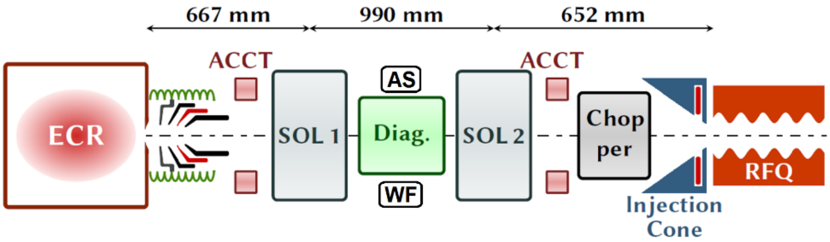

Figure 2: Layout of the proton injector including the ECR proton source, the acceleration column, the solenoids 1& 2, the diagnostic chamber, two ACCT devices, the chopper chamber and the injection cone before the RFQ line.

The repetition rate is set up to 4 Hz and is operated by the pulsed injection of the RF-signal. The extracted beam is set longer than the desired one at the RFQ entrance: the chopper will cut off rising and falling beam profile parts.

The extraction system is composed of 5 electrodes. Due to the low duty cycle, they are not water-cooled:

- The plasma electrode has a ø9-mm aperture hole.
- The intermediary or *puller* electrode is tuned downwards relatively to the 95 kV-platform. As we see later, its value influences the beam parameters.
- The 3rd and 5th are put to the earth potential.
- The 4th, called *repeller*, is set to a negative value to hinder electrons to go upstream into the plasma chamber and consequently to ensure a space charged compensation of the beam.

LEBT and RFQ-injection

Imaging and propagation are assured by two solenoids on the model of IFMIF setup, independently tuned up to 450 A [5]. Two magnetic steerers are integrated into both solenoids to realign in both directions the proton beam. The diagnostic chamber is placed between them.

Deviation plates forming a *chopper* will cut the proton beam down to a minimum of 36 µs with sharp edges. It is coupled to a thungsten cone that intercepts cut proton beam as well as remaining off-axis undesired species. A negatively charged *repeller* plate is located before the RFQ-entrance to block upstream electrons.

All measurements shown in this article were performed with 5 ms-long pulses, which is the upper duration limit of expected proton beams.

Beam Diagnostics

Two Alternating-Current Current Transformers (ACCT) before and behind 1st and 2nd solenoids measure the proton beam time profile and intensity. This last value is compared, only for the commissioning phase, to the current measured with Faraday cup at final beam stop.

On diagnostic chamber are installed:

- a Wien Filter to measure the species fraction
- an Allison Scanner, either vertically or horizontally set up, to measure emittance
- a Secondary Electron emission grid (SEM-grid) will also be installed at GSI.
- also installed at GSI a diamond-shaped slit to reduce the proton beam size.

MEASUREMENTS & RESULTS

As defined in [6], the commissioning at Saclay is divided in 3 different phases. We will present here results for:

- Phase 1: beam intensity, emittance and species proportions from the source directly measured behind the acceleration column with a ø9-mm aperture.
- Phase 2: same diagnostics are put in the diagnostic chamber directly behind the 1st solenoid.

At the Source Output

H^+ proportion is represented in Fig. 3. It was measured with WF for different total beam current and different magnetic configuration given by coils intensity. It is given here with couple currents B1 / B2 in A.

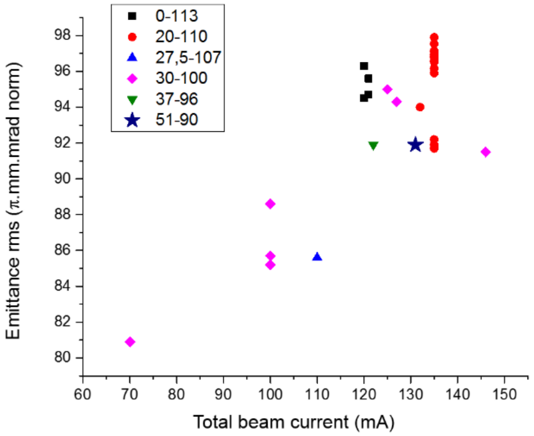

Figure 3: proportion of H^+ in extracted beam for different coil configurations vs. total beam current

Even if measurement noise is present, yielding ± 4% for the (20/110) configuration, a strong trend can be extracted: the higher the total beam current, the higher the proportion of H^+. A maximum total extracted current of 147 mA was obtained in the (30/100) configuration.

At the RFQ entrance, the normalized *rms* emittance has to be lower than 0.33 π mm.mrad (straight line in Fig. 4). We measured it at source exit for different coil configurations and different total output current by varying the puller voltage. Plots of a series (same magnetic configuration and total beam intensity) are included in a same curve. The dotted line binding plots for the 20/110 case indicates that measured values were data-processed to compensate the acquisition resolution discrepancies with the value represented encircled. This last one was measured with the same resolution as the other data bound with solid lines.

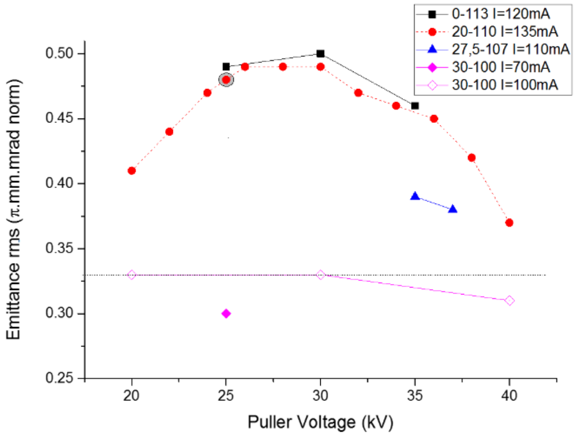

Figure 4: Emittance vs. puller voltage for different coils configurations and total beam current.

Firstly, the higher the total intensity beam is, the higher the emittance, which can be explained by space charge. Secondly, the emittance reaches a maximum around 29 kV of puller voltage. This was already observed on IFMIF [7]. It seems that the puller voltage for these scan values influences the emittance measurement.

Behind 1st Solenoid

Emittance measurements were performed in the diagnostic chamber by varying the current value of 1st solenoid for two different beam total current, 130 mA and 90 mA (Fig. 5). The AS was put horizontally and vertically to check the hypothesis of the beam rotation symmetry.

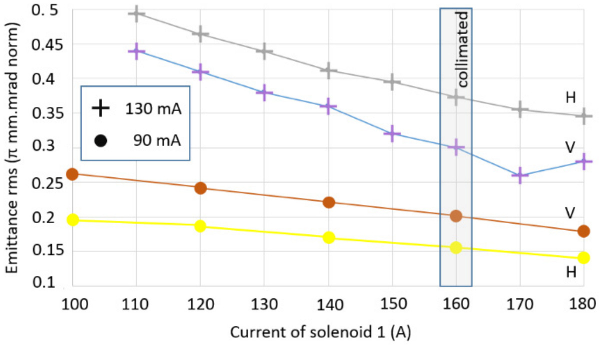

Figure 5: Vertical and Horizontal emittances vs. solenoid current for different total beam current

The tendency to reduce the emittance by increasing the convergence effect of 1st solenoid observed, as well as by reducing the total beam intensity, possibly due to space charge compensation. On the other hand, differences between vertical (V) and horizontal (H) emittances are less easy to interpret: the upper values H or V are not the same according to the total beam current. The ideal would be to dispose of two perpendiculars AS in the diagnostic chamber to compare both without the necessity to open the beam line between horizontal and vertical measurements which modify the measurement conditions.

We analysed the influence of the puller voltage value on the emittance (Fig. 6) in case of a parallel beam. The same tendency occurs as in (Fig. 4): the puller acts as a kind of *condenser* on the beam without changing focusing as shows the inserted emittance figure for 11 kV voltage. Measurement errors should be longer investigated.

Finally, we compared measurement of H$^+$ proportion obtained with two methods, one with WF, the other one by analysing the emittance figures with a software developed at CEA [8].

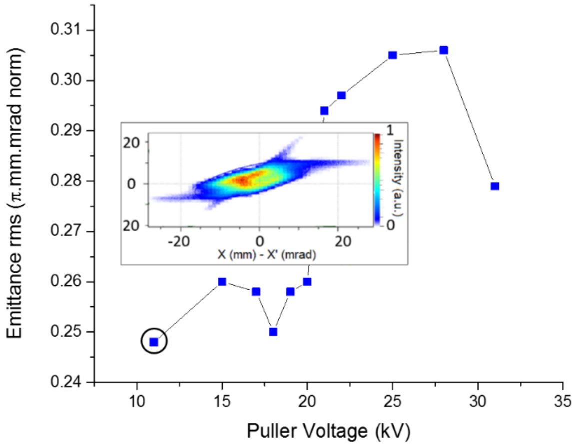

Figure 6: Emittance vs. puller voltage for a total beam current of 90 mA. The insert is the figure for encircled data.

H$^+$ proportion is measured for a total beam current of 90 mA. The WF gives 93.5% while the software analysis gives 84.9%. It may be that WF only see the beam centre whereas the software takes into account the whole beam. A same discrepancy was already observed with spectroscopic measurements [6].

Conclusions

First results of emittance value, proton energy and beam current just at the source exit and behind the 1st solenoid show that targeted parameters at the RFQ input are reachable. It has to be confirmed by direct measurements behind the 2nd solenoid in a next step.

REFERENCES

[1] L. Groening *et al.*, *Proceedings of LINAC2012,* THPB034

[2] R. Berezov *et al.*, *Rev. Sci. Instrum.* vol. 87, p. 02A705 (2018)

[3] C. Ullmann *et al.*, *Proceedings of IPAC2014,* TUPRO043

[4] R. Hollinger *et al.*, *Proceedings of LINAC2006,* TU3001

[5] N. Chauvin *et al.*, *Proceedings of LINAC2014,* THPP015

[6] O. Tuske *et al.*, *Rev. Sci. Instrum.* vol. 89, p. 052303 (2018)

[7] R. Gobin *et al.*, *Rev. Sci. Instrum.* vol. 87, p. 02A726 (2016)

[8] B. Bolzon *et al.*, *Fusion Engineering and Design* (2018), doi: 10.1016/j.fusengdes.2018.04.128