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STATUS AND COMPUTER SIMULATIONS FOR THE FRONT END OF THE PROTON INJECTOR FOR FAIR

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Abstract

FAIR - the international facility for antiproton and ion research – located at GSI in Darmstadt, Germany is one of the largest research projects worldwide. It will provide an antiproton production rate of $7 \cdot 10^{10}$ cooled pbars per hour, which is equivalent to a primary proton beam current of $2 \cdot 10^{16}$ protons per hour. A high intensity proton linac (p-linac) will be built, with an operating rf-frequency of 325 MHz to accelerate a 70 mA proton beam up to 70 MeV, using conducting crossed-bar H-cavities. The repetition rate is 4 Hz with an ion beam pulse length of 36 µs [1]. Developed within a joint French-German collaboration - GSI/CEA-SACLAY/IAP – the compact proton linac will be injected by a microwave ion source and a low energy beam transport (LEBT). The 2.45 GHz ion source allows high brightness ion beams at an energy of 95 keV and will deliver a proton beam current of 100 mA at the entrance of the RFQ (Radio Frequency Quadrupole) within an emittance of 0.3π mm mrad (rms). To check on these parameters computer simulations with TraceWin, IGUN and IBSIMU of the ion extraction and LEBT (Low Energy Beam Transport) are performed.

INTRODUCTION

For the Accelerator Facility of Antiproton and Ion Research (FAIR) a proton linac is built within a joint CEA/GSI/IAP collaboration. The SILHI (Source d´Ions Légères a Haute Intensités) source matches the requirements for the new proton injection system. Measurements at the end of the SILHI-LEBT system in 2005 have shown that a proton current around 100 mA can be obtained inside an emittance of about 0.4-0.5π mm mrad (95 % rms). Emittance growth within the LEBT is dominated by space charge effects. These effects can be counteracted by enhancing the residual gas pressure [2]. The required specifications for the proton injector are listed in Table 1.

Table 1: Required Beam Parameters for the Injector

Proton beam energy	95 keV
Designed beam intensity	100 mA (at the RFQ entrance)
H^+ fraction	≥ 85 %
Duty cycle (ion source)	4 Hz/0.2 ms
Pulse length (chopper)	~36 µs
Emittance (rms. norm.)	0.3π mm mrad
Noise level	$< \pm 5$ %
Life time	months

Simulations for the performance, the extraction system and the LEBT, are done with several simulation programs like IBSIMU, TraceWin and IGUN. In 2015 the commissioning of the injector which is build up in France is planned. In this framework a crosscheck on emittance measurements and computer simulations is foreseen.

In this contribution, a general overview of the actual status and design of the ion source and for the LEBT proton linac, including the beam dynamics simulation is given.

PROTON LINAC

The new designed and developed pulsed proton linac serves as an injector into the existing heavy ion synchrtron (SIS18). In Fig. 1 the conceptual layout of the proton linac is shown. The FAIR proton linac comprising a proton source, LEBT, an RFQ, rebuncher for longitudinal beam matching and a Drift Tube Linac (DTL) based on 12 crossed-bar H-mode (CH) cavities will be accelerating the beam to its final energy of 70 MeV [3]. The main design parameters of the FAIR proton linac are shown in the Table 2 [3].

Table 2: Proton Linac Parameters

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

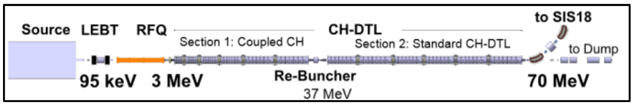

Figure 1: Layout of the proton linac.

ION SOURCE AND LEBT

The ion source is located on a 100 kV platform inside a Faraday cage and consists of a five electrode extraction system. RF power for operating the ion source in pulsed mode is produced by a magnetron (microwave generator) and injected into the plasma chamber via rectangular waveguide. This magnetron operates with a frequency of 2.45 GHz. The plasma chamber has a length of 100 mm and a diameter of 90 mm [4].

The H_2 injection in the plasma chamber leads to a pressure around $2.5 \cdot 10^{-3}$ Pa. The chamber is coated with two boron nitride discs in order to increase the proton fraction. The two solenoids with a magnetic field of 87.5 mT are used to reach the electron cyclotron resonance [5].

The five electrodes extraction system consists of a plasma electrode (plasma chamber potential), a puller electrode (50 kV), screening electrode (5 kV) and two ground electrodes. The aperture is 8mm.

Space charge compensation behind the extraction area is ensured by the negative biased screening electrode. The extraction system, shown in Fig. 2 allows for full beam currents of 130 mA and energies of 100 keV.

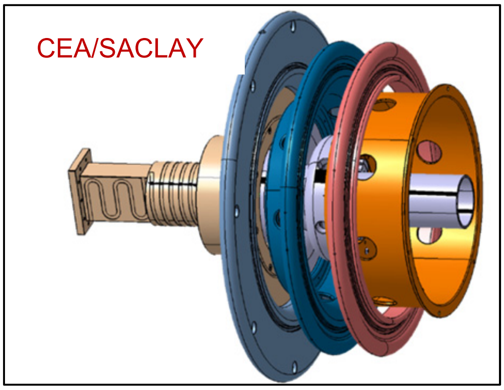

Figure 2: Schematic view of the wave guide, plasma chamber and extraction system.

Pulsed mode operation of the ion source leads to a longer lifetime and reduces the requirements for the cooling system. The low energy beam transport (LEBT) consists of two 31 cm long solenoids with a maximum induction of 500 mT. Steerers are integrated in the solenoids to adjust the horizontal and vertical beam position. The diagnostic chamber between the two solenoids is equipped with the following devices: Wien filter, Allison scanner, SEM, profile grid, IRIS, 4-grid analyzer and beam stopper. The diagnostic chamber is shown in Fig. 3. There are two alternating current transformers (ACCT) in the LEBT for the measurements of the ion beam intensity behind the extraction system and at the end of the LEBT. Overall the compact LEBT has a length of almost 2.3 m.

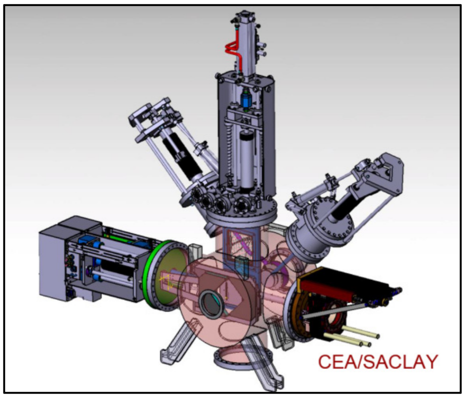

Figure 3: Diagnostics chamber.

DIAGNOSTIC CHAMBER

The emittance measurements will be performed with an Allison scanner build at CEA/Saclay. The scanner is moved stepwise through the ion beam while the voltage of the plates is varied at each step to determine the divergence and the intensity distribution of the beam and its location. The diameter of length of the slit is 80 mm, the diameter of the slit is 0.1 mm. The Allison scanner is shown in Fig. 4.

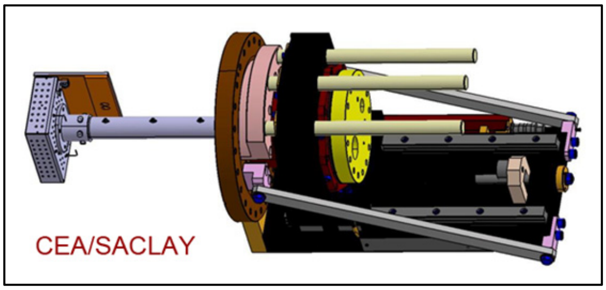

Figure 4: Schematic view of the Allison scanner.

The proton fraction will be checked with a Wien filter. It consists of a permanent magnetic field and an adjustable electric field. For the direct determination of the beam position a secondary emission grid (SEM grid) will be used. It is also planned to install a 4-grid analyzer to the diagnostics chamber to measure the space charge compensation.

Mainly the 4-grid analyzer consists of four metal grids. The first grid is grounded and prevents from any disturbance within the probe and the beam and is on ground potential. The second grid is used to screen secondary emission electrons from the beam. The third grid is for separating the ions. Only ions with a higher kinetic energy than the potential on the grid can pass through. The fourth grid is again needed to screen secondary electrons from the Faraday cup. The schematic drawing seen in Fig. 5 shows the basic setup of the 4-grid analyzer.

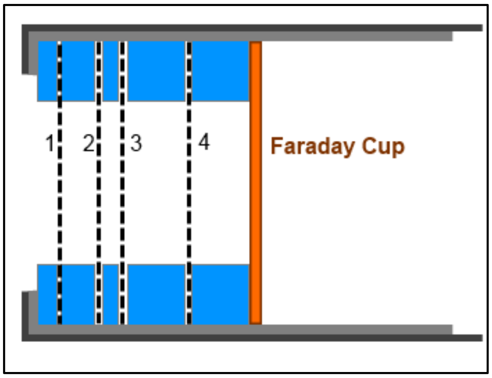

Figure 5: Schematic view of the 4-grid analyser.

1. Floating attenuation grid
2. Electron repelling grid
3. Retarding ion filtration grid
4. Secondary electron suppression grid

An iris as a beam diaphragm is required for transversal beam limitation. For chopping the beam an electrostatic chopper will be placed behind the second solenoid in front of the RFQ entrance. To match the acceptance of the RFQ a beam waist is formed before the injection of the beam to the RFQ. For preventing the electric field from migrating from the RFQ through the LEBT a screening electrode is placed as close as possible to the RFQ entrance to repel the neutralizing and to minimize the uncompensated zone.

SIMULATIONS AND OUTLOOK

Beam dynamic simulations are performed with several programs and still ongoing. Simulations of the extraction system are performed with IGUN. A simulation is presented in Fig. 6. The simulations are only 2D, so no steering effects and misalignment can be taken into account. They will be compared to the simulations performed with IBSIMU.

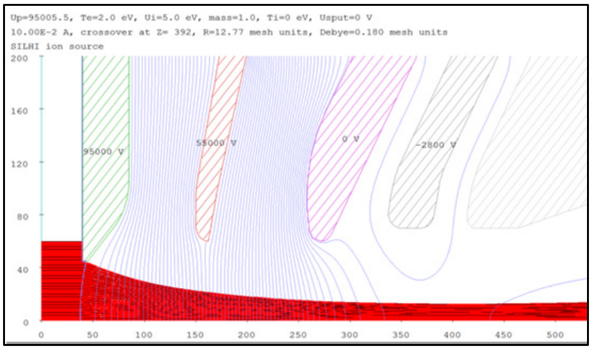

Figure 6: 2D simulation of the pentode system with IGUN.

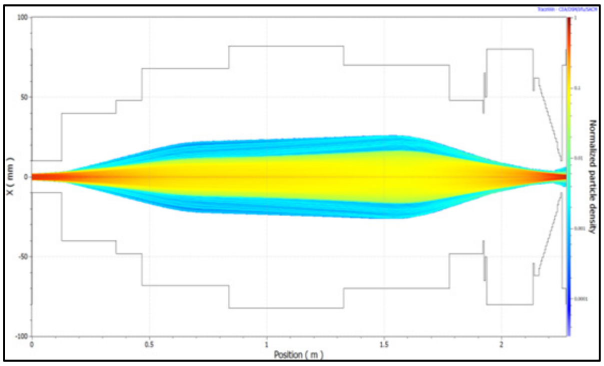

Figure 7: Particle distribution animation in the FAIR p-linac nominal LEBT.

TraceWin [6] simulations are presented in Fig. 6. The simulation shown starts 35 mm after the electrode extraction. The distribution follows the chamber through Solenoid 1 with 0.2852 T and Solenoid 2 with 0.3035 T. The Twiss parameters in the beam focus are α= 0.46 and β= 0.04 mm/π mrad. Thus the rms- emittance is ε= 0.15 π mm mrad. Several other scenarios are simulated and compared to each other to proof how the magnetic field matches the requirements of beam focusing.

The code for an optimal simulation of the proton beam is under development. IBSIMU is an optical computer simulation package for ion optics, plasma extraction and space charge dominated beams. The code is build up as a C++ library and open source to use it for simulations and further development.

Simulations done during 2014 will be checked on the emittance measurements done at the commissioning of the proton injector in 2015.

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