H^- source developments at CERN

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Abstract

Future CERN programmes for LHC and ISOLDE require increasing the beam intensity and brightness from the PS Booster (PSB). This could be achieved by injection from a higher energy H^- linac. A new injector will require a high performance, high reliability, negative hydrogen ion source. This paper will present the requirements for such a source together with the first results for a prototype microwave driven source.

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1 Introduction

Present and future CERN programmes, like LHC[1], CNGS[2] or ISOLDE[3], require an intense and bright proton beam from the injector. The present combination of Linac2 and PS Booster (PSB) limits the performance of the whole complex (see Figure1). Different upgrade options are under investigation (for the complete list see [5]):

- modifications and optimization of existing machines (e.g. change of basic period)
- injection Linac4[6] into PSB (at an injection energy of 160 MeV)
- injection Superconducting Proton Linac (SPL)[7] into PS (at an injection energy of 2.2 GeV)

Common for several of the modifications is the need of a high performance, high reliability, negative hydrogen ion source. The source parameters for Linac4 and SPL are given in Table 1.

The developments are based on a microwave driven source due to the good and extensive experience with the ECR technology for the heavy ion physics programme. The first experiments are meant to investigate the behavior of the source and the extracted beam while changing different source parameters and certain other conditions.

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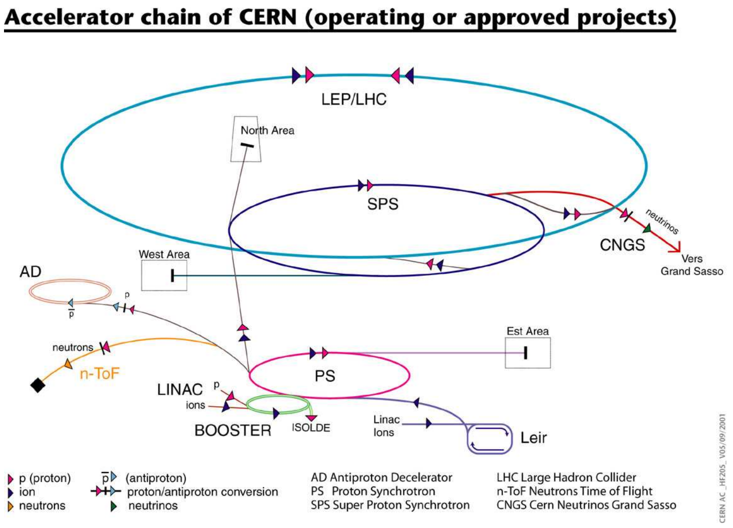

Figure 1: CERN accelerator complex[4].

	Linac4	SPL
Instantaneous current	50 mA	>40 mA
Pulse length	0.5 ms	2.8 ms[a]
Repetition rate	2 Hz	50 Hz
Extraction voltage	95 kV	95 kV
Emittance (rms normalized)[b]	0.25 π mm mrad	0.25 π mm mrad
Availability for tests	2007	2012
Assumed start of operational use	∼2008	∼2013
Further features (not essential but desired)	cesium free no antenna or filament in the plasma chamber high pulse-to-pulse stability mean time between failure: 100 days easy maintenance	

[a] 1.5 ms for the new SPL Layout (2005)

[b] Emittance at RFQ input

Table 1: Parameters of an H^- ion source for Linac4 and SPL.

2 Experimental set-up

The source body is a water-cooled plasma chamber of 10 cm inner diameter and 20 cm length. For the first experiments a configuration of 10 permanent magnets around the plasma chamber was used (see Figure 2). This provides a field of 0.21 T at the magnet position inside the plasma chamber.

The microwave of a frequency of 2.45 GHz and a maximum power of 1.5 kW (pulsed) is injected with a movable antenna (range of the antenna tip into the plasma chamber is $\lambda/4$).

A magnetic filter of two permanent magnets separates the source into the plasma and the

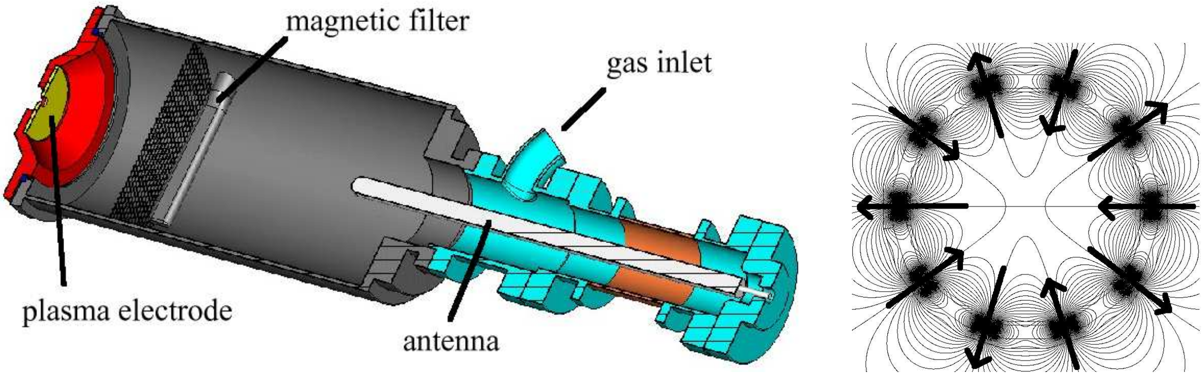

Figure 2: Schematic view of the source and the magnetic field.

production region. The field in the middle of the filter is ∼0.007 T. The filter is 7.8 cm away from the plasma electrode.
The extraction system consists of two electrodes. The experiments were done with 20 kV extraction voltage. The plasma electrode is insulated in respect to the plasma chamber and can be biased (see Section 4).

3 Microwave simulation and measurements

The response of the actual plasma chamber on microwave injection was studied with some simulations in MICROWAVE STUDIO[8]. Figure 3 shows the calculated S_{11} parameter of the plasma chamber and Figure 5 shows the distribution of the electrical field in the chamber for the frequency of 2.45 GHz.

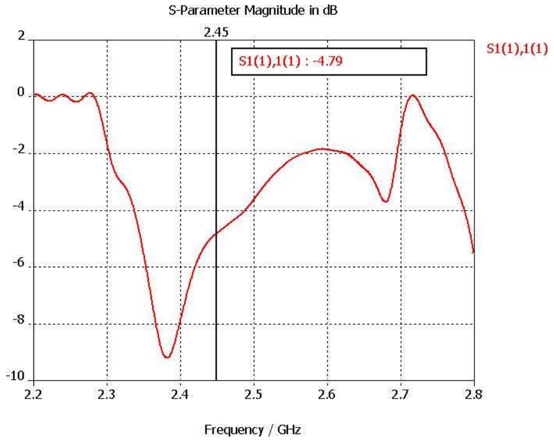

Figure 3: Simulation of the S_{11} parameter of the plasma chamber.

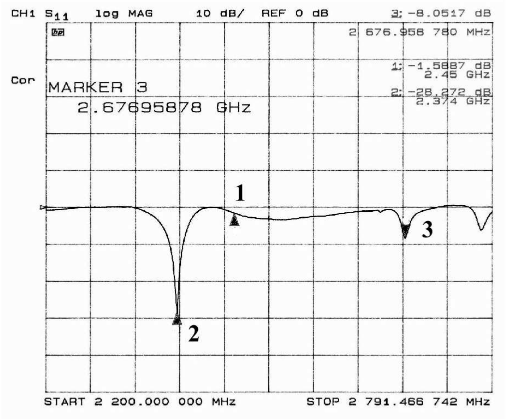

Figure 4: Measurement of the S_{11} parameter.

Measurements of the S_{11} parameter are shown in Figure 4. Marker 1 is at the generator frequency of 2.45 GHz, which is not an eigen mode, leading to a high reflected power. In Figure 5 a high field at the foot of the antenna indicates the bad matching. To improve the situation in the future the transition from the cable to the antenna will be modified with a taper.

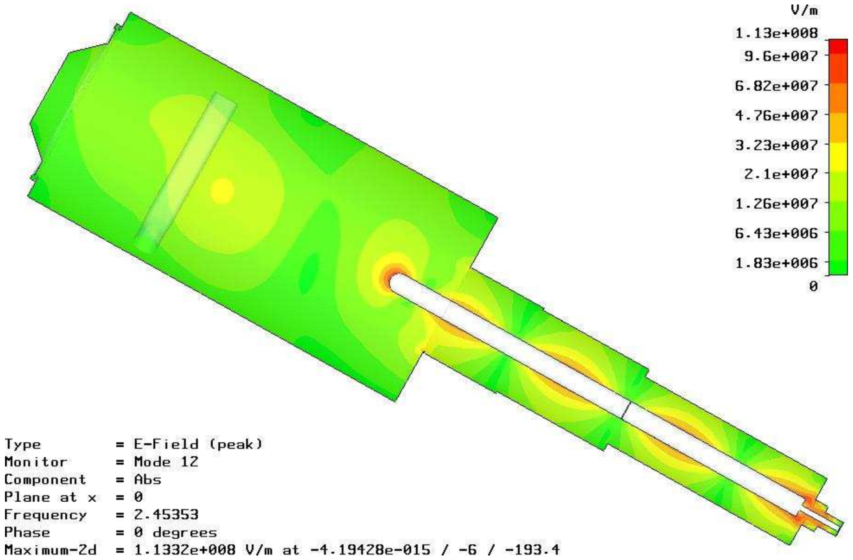

Figure 5: Simulation of the absolute value of the electric field at the frequency of 2.45 GHz.

The simulations and the measurements were done with an empty plasma chamber, i.e. without a plasma. The behavior with plasma is expected to be different.

4 Measurements

Many parameters of the source were varied and for all measurements the H^- current, the electron current, the pressure in the extraction tank and the reflected power were recorded (experimental setup see Figure 6, RF setup see Figure 7).

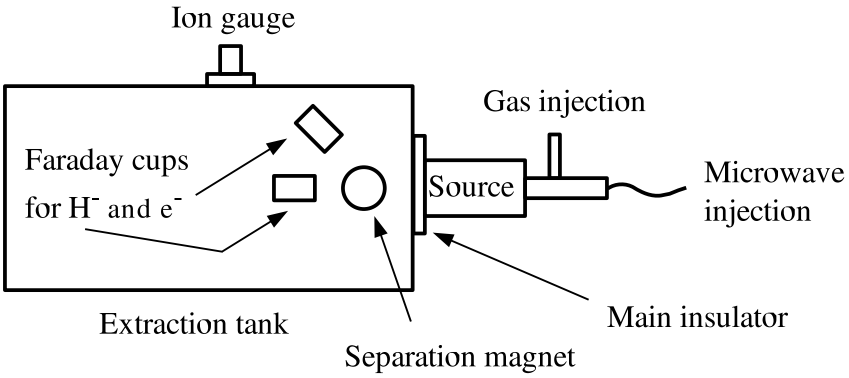

Figure 6: The experimental setup.

First the influence of the RF power, the gas flow and the position of the antenna were studied (Figures 8 and 9).

The influence of the gas was difficult to obtain because there is no differential pumping between the extraction tank and the source. An increase of the pressure in the source resulted in an increase of the pressure in the extraction tank as well. Due to the sensitivity of the H^- ion to higher pressures the results for high gas flow rates are most likely too low (see top right corner in Figure 8).

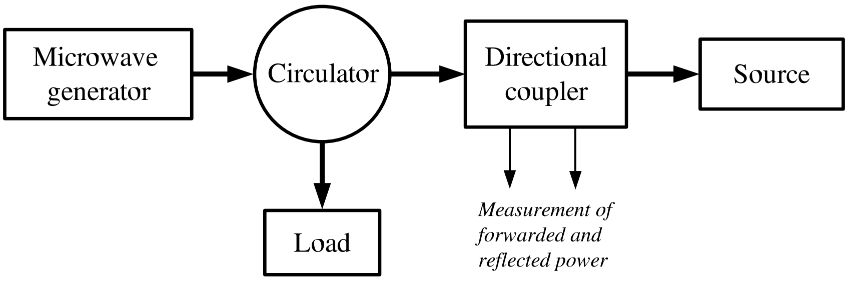

Figure 7: The setup of the RF components.

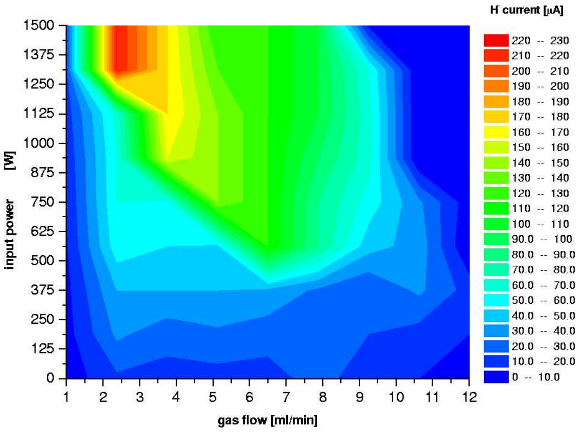

Figure 8: Dependency of the H^- current (in μA) from RF power and gas flow (bias voltage +30 V, antenna position $z = 25$ mm).

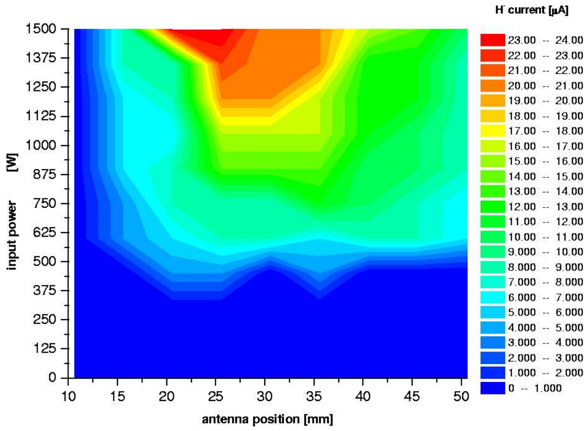

Figure 9: Dependency of the H^- current (in μA) from RF power and antenna position (bias voltage 0 V, gas flow 3 ml/min).

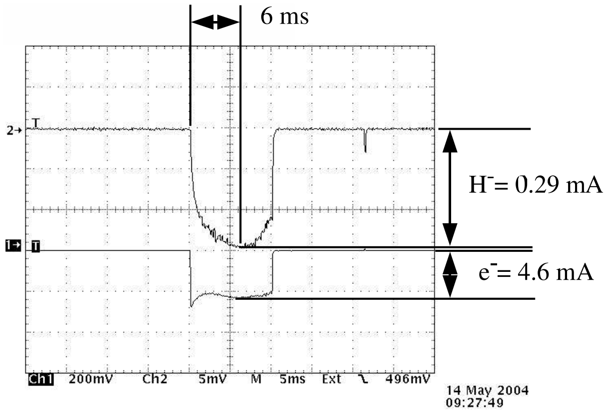

Figure 10: Oscillogram of the H^- (top trace) and the e^- (bottom trace) beam.

Figure 10 shows the maximal H^- current measured up to now ($I_{H^-} = 0.29$ mA, $I_{e^-} = 4.6$ mA, $e^-/H^- = 15.9$). The rise time of the beam is 6 ms. The drop at the end of the pulse is due to the per pulse limited power available from the RF generator.

The plasma electrode is insulated and can be biased in respect to the plasma chamber. With the bias the beam current could be increased by about a factor 10 and there is also a big influence on the e^-/H^- ratio (see Figure 12). This ratio was for the most of the

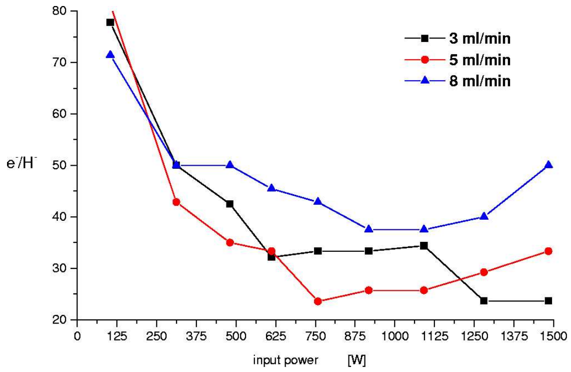

Figure 11: The ratio e$^-$/H$^-$ as dependence from the RF power (bias voltage +30 V, antenna position $z = 25$ mm).

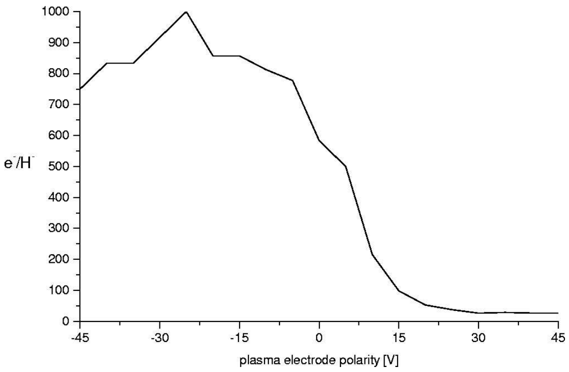

Figure 12: The ratio e$^-$/H$^-$ as dependence from the plasma electrode voltage (RF power 1500 W, antenna position $z =$ 25 mm, gas flow 3 ml/min).

measurements (positive bias of the plasma electrode) in the range 20–80 (see Figure 11). Several recipies for ion improvement were copied from other sources.

The group at CEA/Saclay had improved the ion currents after installing a grid between the plasma and the production chamber [9]. The idea is to prevent microwave heating in the production chamber. Introducing a grid in the CERN source, reduced the H$^-$ current significantly. This may be an effect of a too low electron density. In the present scenario the additional heating in the production region is useful. This may change for other magnetic configurations.

Several groups reported a positive effect of tantalum in the source [9]. This was tested in two ways. First a tantalum sheet was placed inside the plasma chamber. Second a collar made out of tantalum was used.

The tantalum sheet did not improve the output on H$^-$ significantly, but it reduced the reflected power and changed the optimal plasma electrode bias to lower voltages. The reduction of the reflected power could be a result of the change of the inner diameter of the plasma chamber due to the foil. This “tunes” the cavity and the resonances move.

Three different lengths of the collar have been tried: 78 mm (up to the magnetic filter), 39 mm and 20 mm. They were electrically connected to the plasma electrode and could so be biased as well. No improvement was found. The H$^-$ current was rather reduced to 50 % for the shortest collar and to less than 5 % for the longest collar.

Bacal et al. [10] reported some success improving the H$^-$ density in the source by using a small argon addition. At the CERN source the use of argon destroyed the H$^-$ current.

5 Conclusion and future plans

In the next step the permanent magnets will be replaced by two solenoids (Figure 13). The stronger magnetic field (Figure 14) should result in a higher electron density and therefore in a higher H$^-$ beam current. Optimization of all the above parameters will then be performed.

A small additional experiment is to place a disk of boron nitride at the end of the plasma chamber and to set the magnetic field onto the disk to a value corresponding to the

Figure 13: The source body with the new solenoids.

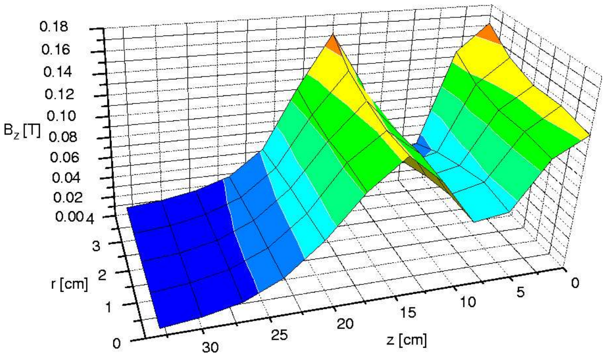

Figure 14: The field of the solenoids.

electron cyclotron resonance (2.45 GHz → 0.0875 T). This method showed good results in the ECR H^- source at CEA/Saclay.
On the basis of all the experiences made with the present experimental setup it is planed to design a new source. This work will start at the end of this year and will go in parallel with the design of the Low Energy Beam Transport (LEBT) of Linac4.

6 Acknowledgments

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