# INSTALLATION AND STARTUP OF AN 18 GHz ECRIS FOR HIGHLY CHARGED METALLIC IONS AND GASES

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*Abstract*

This paper presents the technical improvements and experimental characterisation of a hybrid superconducting 18 GHZ Electron Cyclotron Resonance Ion Source (ECRIS) manufactured by Pantechnik. Since the last one manufactured in 2011, the source has undergone significant upgrades to enhance its performance and reliability for heavy ion beam production. Key improvements include optimisation of the magnetic confinement system, aiming to increase the production of highly charged ions while maintaining stable operation at high RF power levels. An extensive experimental campaign is currently underway at Pantechnik's facilities to characterise the source performance on a selection of ions (N, Al, Ar, Au, Pb) and the goal of demonstrating stable $Xe^{28+}$ and $Ta^{36+}$ beams.

## INTRODUCTION

Electron Cyclotron Resonance Ion Sources (ECRIS) are among the essential components of modern heavy-ion accelerator facilities, providing intense beams of highly charged ions for both fundamental research and industrial applications [1]. Operating at microwave frequencies matched to the electron cyclotron resonance condition, these devices sustain a magnetically confined plasma in which successive electron-impact ionisation events produce ions in progressively higher charge states. The trend towards higher operating frequencies—driven by the well-known frequency scaling laws predicting higher ion currents and charge states with increasing RF frequency—has motivated the development of third-generation, 18 GHz class machines [2]. Pantechnik has developed in the past and is currently commissioning again an 18 GHz source specifically designed for the production of highly charged metallic and gaseous ions required by accelerator injectors. This contribution describes the technical design improvements implemented in the source and reports on the ongoing experimental commissioning campaign on a range of ion species, including argon (Ar) and helium (He). The ultimate objectives of the campaign are the demonstration of stable $Xe^{28+}$ and $Ta^{36+}$ beams, representative of the demanding requirements of modern heavy-ion physics.

## SOURCE DESCRIPTION

The source under test is the second commissioned at Pantechnik and is described in detail in Ref. [3]. The source is designed to achieve optimum performance at 18 GHz RF frequency and was conceived to operate on a high-voltage platform with minor power consumption. The present campaign is conducted without the high-voltage platform used in the original installation.

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### *Mechanical Layout*

The source body, shown in Fig. 1, is approximately 1 m in length (including the injection system) with an external diameter of 0.7 m, for a total weight of approximately 1600 kg. The iron yoke incorporates the permanent magnet hexapole, the plasma chamber, and the cryostat. The plasma chamber is an aluminium cylinder of 82 mm inner diameter and 450 mm length. The outer diameter of the yoke is 680 mm with a length of 730 mm.

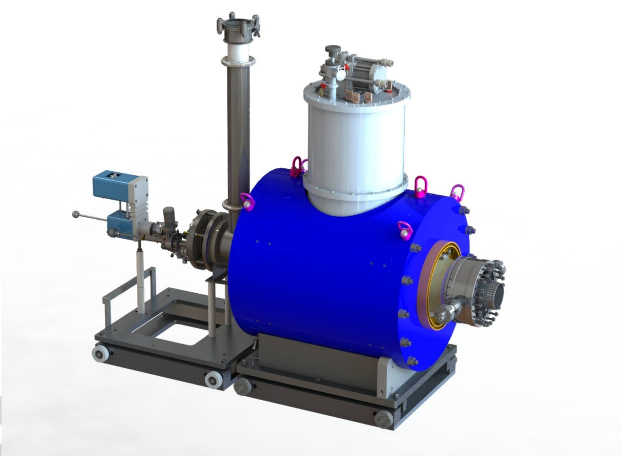

Figure 1: Schematic of the 18 GHz ECRIS ensemble.

### *Magnetic Confinement System*

The magnetic confinement of the ion source relies on a hybrid configuration combining superconducting axial coils with a multi-layer, multi-grade permanent magnet hexapole for the radial field [3].

**Axial field** The axial mirror field is generated by three independent NbTi/Cu superconducting coils (INJECTION, CENTRE, EXTRACTION) wound on a single-piece aluminium former and epoxy-impregnated, each powered by an independent bipolar supply (100 A, 5 V). The nominal operating current is ≈86 A with a total stored energy of ≈143 kJ. The field is tuned to the 18 GHz resonance condition ($B_{ECR}$ = 0.648 T), with injection and extraction field variable up to 2.1 T and 1.5 T respectively, and $B_{min}$ independently adjustable between 0.4 T and 0.6 T. The axial magnetic field measurements were performed with the HIRST Magnetic Instrument Gaussmeter (GM08). The Gaussmeter was connected to a cylindrically shaped triaxial Hall probe. Results of the measurement, shown in Fig. 2 point out a really good agreement with the simulated value.

**Radial field** The radial confinement is provided by a multi-layer, multi-grade permanent magnet hexapole assembly, achieving a maximum radial field of 1.32 T at the wall

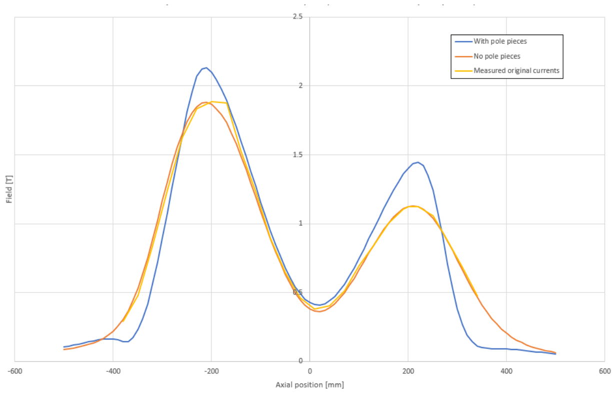


Figure 2: Comparison between simulated Axial field and experimental one, with and without pole pieces.

of the 82 mm diameter plasma chamber [3]. The hexapolar structure is designed to withstand strong demagnetising fields from the axial coils and to operate up to 135 °C. Special attention was paid tothe design of the plasma chamber cooling circuit to manage the heat load from electrons lost on the wall, which also provides good protection to the hexapole magnets. Magnetic measurements confirmed close agreement with the calculated radial field profile. The main parameters of the source are listed in Table 1.

Table 1: Main Parameters of the 18 GHz ECRIS [3]

| **Parameter** | **Value** |
| --- | --- |
| RF Frequency | 18 GHz |
| $B_{\mathrm{inj}}$ (max) | < 2.1 (var.) T |
| $B_{\mathrm{ext}}$ (max) | < 1.5 (var.) T |
| $B_{\mathrm{min}}$ | $0.4 < B < 0.6$ (var.) T |
| $B_{\mathrm{rad}}$ (wall) | 1.32 T |
| RF Power (max.) | 2.4 kW |
| Chamber diameter | 82 mm |
| Chamber length | 450 mm |
| Total weight | ≈ 1,600 kg |
| Insulation voltage | 30 kV |
| Neutral input | Gas, oven (<1400 °C), sputtering |

### *RF Injection System*

The 18 GHz RF power is delivered via a direct WR62 waveguide, isolated from the RF amplifier by a 40 kV/2 kW DC breaker. A DC-bias moving disc facing the plasma on the injection side allows fine tuning of the plasma heating. Up to 2.4 kW of RF power is available.

### *Metallic Ion Injection and Sputtering*

Metallic species can be injected into the plasma chamber via two methods. A resistive oven, installed at 5° with respect to the source axis, heats the target material up to 1400 °C and introduces metal vapour into the plasma volume. An axial sputtering system, mounted on the axis of the source, is also available for elements that are difficult to evaporate. Measurements will be performed with solid-material oven injection for gold and lead. Stable Au beams will hopefully be obtained after optimisation of the oven temperature.

## EXTRACTION AND LEBT SIMULATIONS

Beam extraction simulations were performed using the IBSimu code [4]. The resulting beam phase space at the exit of the extraction system was then used as input for LEBT simulations, carried out with the TraceWin code [5]. Xenon was chosen as the reference species, as $Xe^{28+}$ represents one of the most demanding cases in terms of space-charge budget and optical matching among the ions targeted by this source.

### *Extraction System*

The extraction system consists of three electrodes in an accel-decel configuration. The electrode geometry and inter-electrode voltages were optimised in IBSimu for an extraction voltage of 12 kV, minimising beam aberrations and halo formation at the plasma meniscus. Figure 3 shows the simulated ion trajectories in the extraction region for a Xenon beam, in the case of a fully compensated beam.

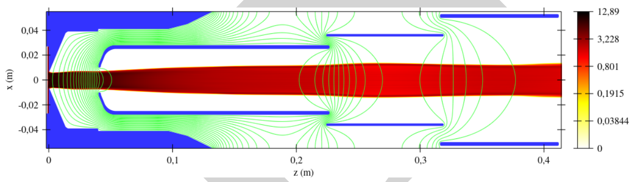


Figure 3: IBSimu simulation of the accel-decel extraction system for $^{129}Xe^{28+}$ at 12 kV (full compensation). Electrode contours are shown in blue.

### *LEBT Optics*

The LEBT downstream of the extraction system is composed by a first solenoid (S1), a pair of steering dipoles for transverse beam correction, a dipole (D1), a second solenoid (S2) for re-focusing, and a diagnostic tank containing an emittance metre and a Faraday cup. This configuration is designed to transport the beam from the source exit to the measurement station while controlling transverse emittance growth driven by space charge. TraceWin simulations of the full LEBT were carried out for the $Xe^{28+}$ beam, using the phase-space distribution exported from IBSimu at the exit of the extraction system as the input distribution. The two solenoids were matched to deliver a convergent, symmetric beam at the entrance of the diagnostic tank. Steering dipoles were included to compensate residual transverse offsets arising from the fringe fields of the source magnet. Space-charge compensation by residual gas was accounted for in the TraceWin model. Figure 4 shows the simulated transverse RMS beam envelope along the LEBT.

The simulated normalised RMS emittance at the emittance meter is $\varepsilon_{n,\mathrm{rms}} = 0.17\,\pi$ mm mrad. These results provide the reference optical settings for the experimental commissioning of the LEBT and will be directly benchmarked against the measured emittance once the data are available.

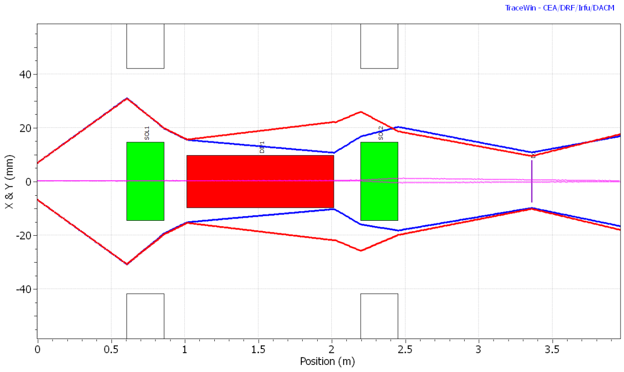


Figure 4: Simulated transverse RMS beam envelope along the LEBT for $^{129}Xe^{28+}$. Positions of the solenoids (S1, S2), dipole (D) and the Faraday cup (continuous line) are indicated.

## EXPERIMENTAL SETUP AND MEASUREMENT METHODOLOGY

All measurements will be conducted at Pantechnik's test facility in Bayeux, France. The ion beam extracted from the ECRIS is accelerated through a puller electrode at a potential of up to 35 kV, passes through two solenoids and a 90° analysing magnet, and is detected with a Faraday cup (see the scheme in Fig. 5. The charge state distribution is obtained by scanning the magnet current and recording the Faraday cup signal as a function of the corresponding $q/A$ ratio. Beam emittance measurements are performed using an emittance metre positioned downstream of the analysing magnet, in the diagnostic tank.

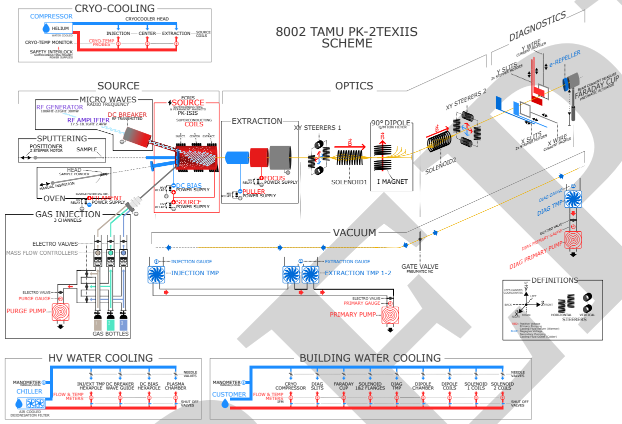


Figure 5: Schematic of the 18 GHz ECRIS test beamline at Pantechnik, Bayeux. The beam is focused via two solenoids, analysed via a 90° dipole magnet and collected on a Faraday cup (FC).

## ONGOING RESULTS : SYSTEM STARTING AND HV CONDITIONING

The ion source test phase is currently underway: the primary and turbo pumps have been connected and started, and the cryogenic system launched. The current status is shown in Fig. 6: we expect the temperature to decrease to optimal test values in two more days. Meanwhile, the ion source has recently been tested for HV to uphold the extraction potential of 35 kV. No major issues have been detected. The gas injection system has been validated, together with the RF system.

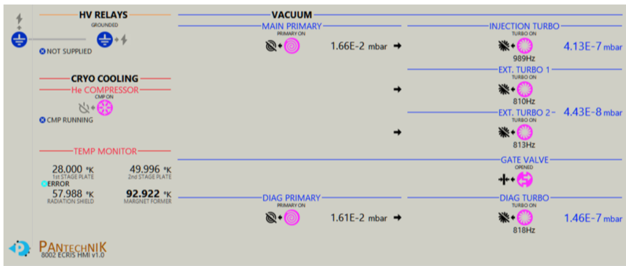


Figure 6: Command and control interface : current status of the cryogenic system and vacuum.

## OUTLOOK AND FUTURE WORK

Initial commissioning measurements will focus on gaseous species that provide a clean and reproducible plasma composition. Argon has been selected as the primary benchmark ion, given the extensive literature on Ar charge state distributions in 18 GHz ECRIS [6]. Helium will additionally be measured to characterise the source behaviour at lower atomic mass. The ongoing commissioning campaign will then proceed with measurement of gold(Au) and the demonstration of the target charge states for $Xe^{28+}$ and $Ta^{36+}$. These species represent the most demanding operational conditions in terms of plasma charge state and metallic vapour management, and their successful extraction will validate the readiness of the source for deployment at user facilities.

Following factory acceptance tests, systematic measurements of beam emittance, energy spread, and long-term stability will be performed, providing a comprehensive performance database for the ion source community. The operational experience and data acquired at Pantechnik's facility will support the commissioning of future ECRIS systems at accelerator laboratories worldwide.

## CONCLUSION

An 18 GHz ECRIS manufactured by Pantechnik will soon be characterised in an extensive experimental campaign at the manufacturer's facilities. Technical upgrades to the magnetic confinement system and RF injection will hopefully demonstrate improved performance for heavy ion beam production. These results will represent an important step in the advancement of high-frequency ECRIS technology for accelerator and industrial applications.

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