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The AISHa ion source at INFN-LNS

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The AISHa ion source at INFN-LNS

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Abstract. The Advanced Ion Source for Hadrontherapy (AISHa) is an ECR ion source operating at 18 GHz, developed with the aim of producing high intensity and low emittance highly charged ion beams for hadrontherapy purposes. Due to its unique peculiarities, AISHa is a suitable choice for industrial and scientific applications. In the framework of the INSpIRIT and IRPT projects, in collaboration with Centro Nazionale di Adroterapia Oncologica (CNAO), new candidates for cancer treatment (including metal ion beams) are being developed. Moreover, within the IONS experiment, AISHa will be the test-bench for the development of an innovative active plasma chamber designed to increase plasma confinement by changing plasma fluxes. OES technique will be also used to refine techniques of non-invasive plasma diagnostics. Finally, a dedicated setup is under realization to provide impinging beams and detection systems for target production in nuclear physics experiments.

1. Introduction

The AISHa ion source has been designed to generate high brightness multiply charged ion beams for hadrontherapy and nuclear physics applications. AISHa is a compact electron cyclotron resonance ion source (ECRIS) [1] whose hybrid magnetic system consists of a permanent Halbach-type hexapole magnet and a set of independently energized superconducting coils. This allows to achieve high performances in a cost-effective way. AISHa has been already commissioned at 18 GHz operating frequency (see Ref. [2] for more information) and, in spring 2022, a second klystron amplifier operating in the 21 GHz band-1.5 kW, will be coupled to the source to carry out a two frequency heating mechanism, i.e. 21 + 18 GHz.

This final configuration will insert AISHa in an intermediate step between second generation ECRIS and third generation ECRIS as shown from the Golovanivsky plot (figure 1) [1].

The plasma chamber,able to hold a maximum power rate of 2 kW, the three electrodes extraction system and the waveguide DC break has been designed to permit reliable operation up to 50 kV.

The low energy beam transport (LEBT) consists of a focusing solenoid placed downstream of the source, a 90° bending dipole for ion selection, and two diagnostic boxes (fig. 2). The dipole supports the beam focusing by means of a double edge. Each diagnostic box consists of a Faraday Cup (FC), two beam wire scanners, and four slits. A beam viewer diagnostic system is being developed and its commissioning is foreseen in summer 2022.

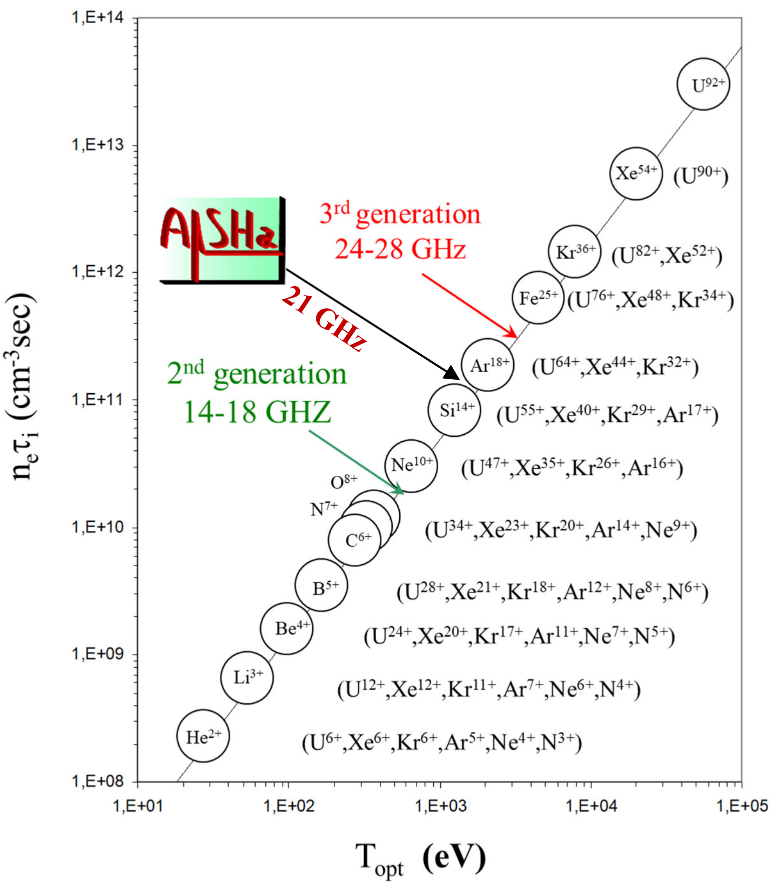

Figure 1. Position of the AISHa Ion source in the Golovanivsky diagram [1]

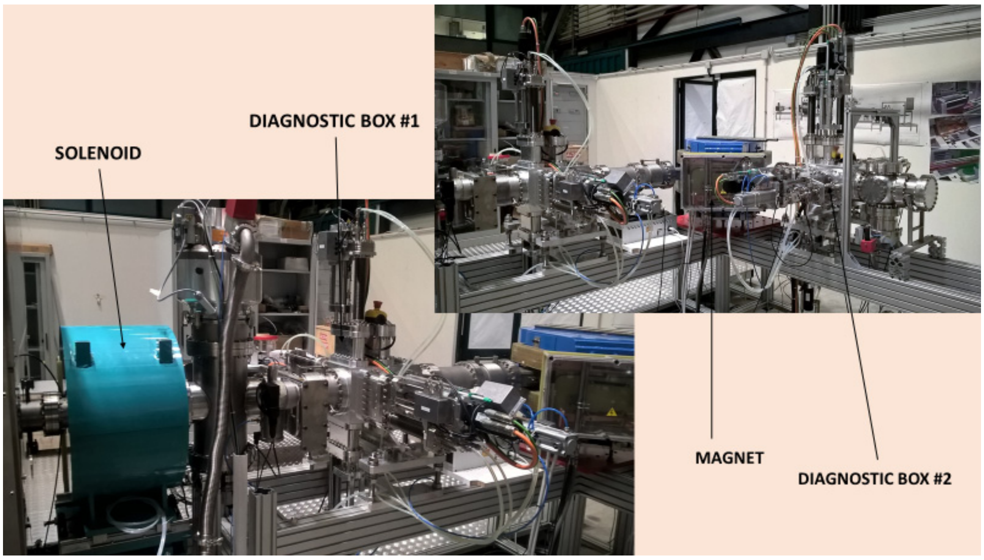

Figure 2. LEBT of AISHA @ INFN-LNS

2. Experimental activities

Peculiarities and characteristics of the AISHa ion source make it a suitable choice not only for medical purposes but also for industrial and scientific applications. In the following, the main activities that involve the AISHa ion source and the relative challenges are presented.

AISHa will be mainly used as a testbench to develop instrument and technologies to apply to the ECRIS for daily use.

The R&D program is funded by the Fifth National Commission of INFN under the IONS experiment and aims to the following main goals:

1) To project, develop and test an active plasma chamber able to decrease, by an opportune biasing, the radial ion losses induced by the Simon diffusion mechanism [3].
2) To develop a non - invasive diagnostics tool, based on optical Emission Spectroscopy to investigate the Electron Energy Distribution Function and ion densities in plasma during ECRIS operations.
3) Investigate wave to plasma coupling at 21 GHz.

The physical principle that has driven the R&D of the so called "active plasma chamber" is the well-known Simon diffusion mechanism: in a magnetized plasma, diffusion is anisotropic, electrons are mainly lost along the magnetic field while ion are mainly lost across the magnetic field. Therefore, the typical magnetic configuration of ECRIS causes electrons to be mainly lost axially and ions to be mainly lost in lateral walls [4, 5]. The reduction of electron and/or ion loss fluxes should improve plasma confinement, with positive consequences on ECRIS performances.

According to this principle, a negative bias is usually placed in the injection flange of ECRIS to reduce electron losses and improve the production of highly charged ion (HCI) beams [6]. At the same time, it was clearly proven that positively biased lateral electrodes decrease the ionic losses leading to higher HCI currents [7]. However, several technological limitations forbidden the daily use of this technology until now. The IONS project proposes to use a set of aluminium tails inserted into a support chamber. Each sector is insulated from the support to make possible a positive differentiated polarization. Each sector will then be connected to ground by means of an I-V measurement circuit, permitting the measurement of the plasma leakage currents based on an axial segmentation and thus enabling the optimization of the wall polarization to minimize radial losses and to optimize the plasma parameters. Figure 3 shows a lateral and front view of the system of tails together with a detail.

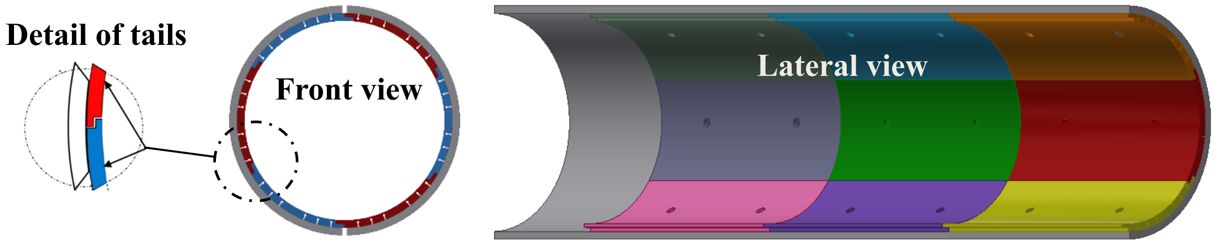

Figure 3. Lateral and front view of the aluminum ensemble of tails and a detail of the tails overlap.

The first prototype is foreseen to be tested in the second half of 2022 and in the same period we planned to start the operations of the Optical Emission Spectroscopy (OES) setup.

OES [8] has already demonstrated to be a reliable tool to investigate plasma parameters of a Hydrogen plasma discharge in a non-invasive way [9]. Moreover, opportune 0-dimensional model can be used to relate plasma parameters to beam parameters [10]. The goal of the IONS project is to relate the emission lines of some test element (such as hydrogen, Helium and Neon) to the plasma parameters. This result can be achieved by using databases concerning the emission characteristic lines in the optical domain for any charge state as a function of density and temperature. The CHIANTI database [11] has been identified as the most complete and appropriate for this purpose. Figure 4 shows a sketch of the envisaged optical coupling system which focus the light emitted by a 1.6° cone of view to an optical fiber by means of a system of collimators and lenses. Finally, the optical fiber leads the light towards a 15.000 resolving power (λ/Δλ) monocromator operating in the wavelength domain 350-700 nm.

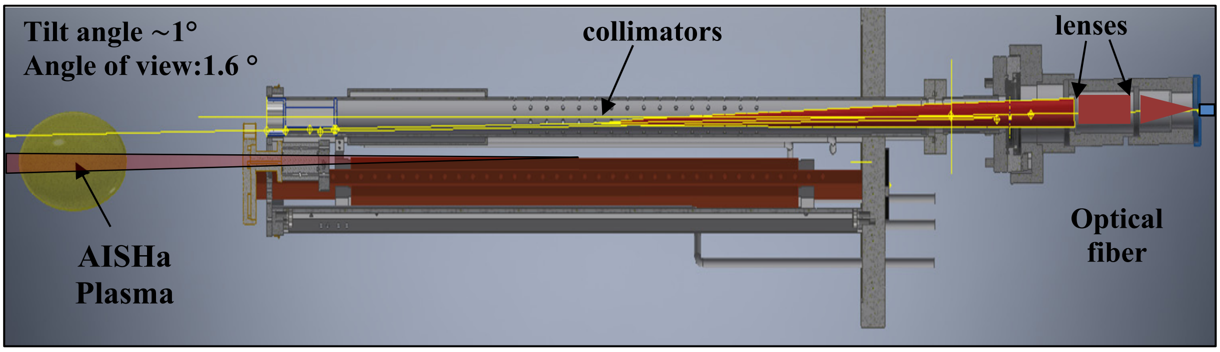

Figure 4. sketch of the optical coupling system that will be installed in the AISHa ion source for plasma diagnostics via OES.

The availability of high intensity beams and the scientific interest in precision nuclear physics experiments pushes the requests for demanding targets, able to resist at high intensity ion fluxes while maintaining its characteristics

In this framework, AISHa will be the test-bench for a feasibility study concerning the production of solid noble gas targets by implantation.

In particular, test will focus on some isotopes that are candidates for the Neutrinoless double beta decay, such as ^{136}Xe [12]. Implantation should take place in a surface quite small (5-10 mm^2) on a material able to resist to the high beam powers (up to 10 kW), such as Highly Oriented Pyrolitic Graphite (HOPG). High implantation uniformity is required to ensure the energy resolution during nuclear physics experiments. For this purpose, a rotating target support has been implemented. A sketch of the target support within the diagnostics box is shown in figure 5.

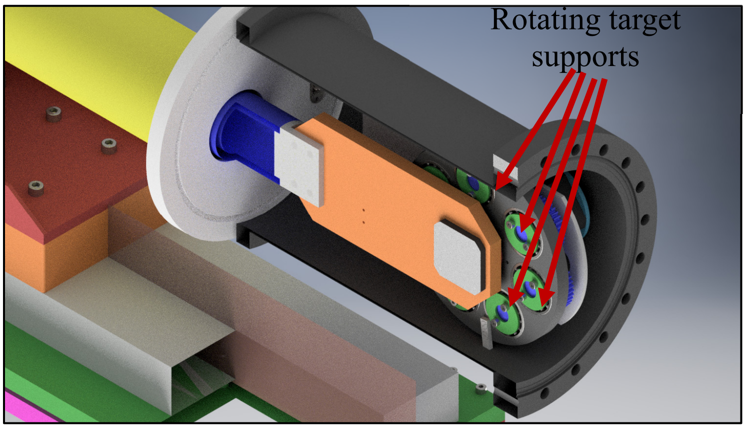

Figure 5. Sketch of the target support within the diagnostics box

3. Conclusion and Perspectives

The AISHa source is a LHe free compact ECR ion source adapt to work in hospital environment as well as for research purposes. Its use at INFN-LNS will enable some R&D activities playing a key role in the optimization of the ECR on sources for daily operation. Moreover, in the framework of the INSpIRIT project, funded by the Lombardy Region, a copy of the AISHa ion source is going to be installed at the Centro Nazionale di Adroterapia Oncologica (CNAO) in Pavia (Italy). The installation of a third ion source at CNAO will increase the beam availability both in terms of intensity and of ion species that can be produced. Helium and Lithium ions will be studied for their better lateral dose distribution with respect to protons, Oxygen is also considered due to its energy deposition characteristics [13]. Finally Iron beams will be also developed for space radiation research.

Acknowledgments
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