

ADVANCES IN THE PERFORMANCE AND UNDERSTANDING OF THE SNS* ION SOURCE

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Abstract

The ion source developed for the Spallation Neutron Source* (SNS) is a radio frequency, multi-cusp source designed to produce ~ 40 mA of H^- with a normalized rms emittance of less than 0.2π mm mrad. To date, the source has been utilized in the commissioning of the SNS accelerator and has already demonstrated stable, satisfactory operation at beam currents of 10 - 40 mA with duty-factors of $\sim 0.1\%$ for operational periods of several weeks. Ultimately the SNS facility will require beam duty-factors of 6% (1 ms pulse length, 60 Hz repetition rate). To ascertain the capability of the source to deliver beams at this duty-factor over sustained periods, ongoing experiments are being performed in which the ion source is continuously operated on a dedicated test stand. The results of these tests are reported as well as a theory of the Cs release and transport processes which was derived from these data. The theory was then employed to develop a more effective source-conditioning procedure and a new-concept, direct-transfer Cs collar which led to a considerable improvement in source performance.

* SNS is a collaboration of six US National Laboratories: Argonne National Laboratory (ANL), Brookhaven National Laboratory (BNL), Thomas Jefferson National Accelerator Facility (TJNAF), Los Alamos National Laboratory (LANL), Lawrence Berkeley National Laboratory (LBNL), and Oak Ridge National Laboratory (ORNL). SNS is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy.

I. INTRODUCTION

The Spallation Neutron Source (SNS) is a large multinational user facility dedicated to the study of the structure and dynamics of materials by neutron scattering and is currently under construction at Oak Ridge National Laboratory (ORNL) [1,2]. In order to meet the baseline requirement of 1.4 MW of beam power on target, the ion source must produce ~ 40 mA of H^- within a ~ 1.2 ms pulse at a repetition rate of 60 Hz (7% duty-factor). An ion source pulse of ~ 1.2 ms is required to make a flat beam pulse of 1 ms due to the characteristic overshoot of beam current from the source during the first 100-200 μs . To date, the ion source has been utilized in commissioning the SNS Front-End (FE) both at Lawrence Berkeley National Laboratory (LBNL) [3] and ORNL [4], the Drift Tube Linac (DTL) [5], the Coupled-Cavity Linac (CCL) [6], and most recently the Super Conducting Linac (SCL). During these campaigns ion source availability increased from 86% during FE re-commissioning to 95% during DTL commissioning and most recently to 99% during CCL and SCL commissioning. Much of this early improvement resulted from an increase in reliability of the Low Energy Beam Transport (LEBT) which matches the beam extracted from the source into the RFQ. This was accomplished by improving the design of the insulators holding the LEBT electrodes [7]. Although commissioning at LBNL and ORNL have briefly demonstrated operation at the design goal of 38 mA at the exit of the RFQ at large beam duty-factors, the vast majority of these commissioning periods were spent with the ion source operating at very low beam duty-factors of less than 1%.

Given the lack of performance data for the source operating at full duty-cycle over longer periods, we have performed 9 ion source and LEBT test runs at a duty-factor of 7.4% on our test

stand with interlocks allowing unattended operation [7,8]. During the course of these tests a novel source conditioning technique was developed which has led to a dramatic improvement in the persistence of the ion beam.

II. THE ION SOURCE

A schematic diagram of the H⁻ ion source is shown in Fig. 1. The source plasma is confined by a multicusp magnetic field created by 20 samarium-cobalt magnets lining the cylindrical chamber wall and 4 magnets lining the back plate. Pulsed RF power (2 MHz, 20-60 kW) is applied to the antenna shown in the figure through a transformer-based impedance-matching network. The plasma is sustained between pulses of the high-power RF by continuous application of ~200 W of 13.56 MHz power to the same antenna. A magnetic dipole (150-300 Gauss) filter separates the main plasma from a smaller H⁻ production region where low-energy electrons facilitate the production of negative ions. An air heated/cooled collar, equipped with eight cesium dispensers, each containing ~5 mg of Cs in the form of Cs₂CrO₄ mixed with elemental Al and Zr, surrounds this H⁻ production volume. The RF antenna is made from copper tubing that is water cooled and coiled to 2 1/2 turns. A porcelain enamel layer insulates the plasma from the oscillating antenna potentials [9]. More details of this source design can be found in reference 10.

III. INITIAL ION SOURCE RUNS

A series of 7 experimental runs were performed in which a thoroughly cleaned ion source was mounted on a test stand, conditioned, brought to full duty-factor and optimized for maximum beam current. The source was then run continuously for ~1 week while recording the

each run we observe relatively constant light emission from the plasma using the spectrometer, suggesting plasma conditions, and therefore volume ionization, remain essentially constant over time. We therefore suspect the decreased beam intensity is related to a decrease in surface H⁺ production, caused by degradation of the Cs coating on the ionization surface. Following the arguments developed in reference [12] we further suspect that this process is driven by the degradation of the rate at which Cs is released from the dispensers. A detailed discussion of the thermochemical reactions occurring within the Cs dispenser involving the mixture of Cs₂CrO₄, Al and Zr can also be found in reference 12. Briefly, Cs is released primarily through these reaction pathways.



Theoretically, there is enough Cs loaded in each source to support ~700 standard cesiations, which should supply an ample surface coating for periods of time much longer than these experiments. It is therefore more likely these reactions are limited by the availability of Zr and Al rather than Cs₂CrO₄. Computational thermodynamic analysis reveals that at temperatures greater than ~250 C, Zr and Al will spontaneously react and form stable compounds with residual gases evolved from the source during initial out-gassing. Employing the residual gas analyzer, we observe that significant quantities of CO₂, O₂, N₂ and H₂O are released into the vacuum chamber during each increase in source duty-factor. Therefore, it is clear that the Cs

beam current exiting the electrostatic LEBT monitored by a toroidal Beam Current Monitor (BCM). If the beam current exceeded 30 mA the run period was extended.

The following conditioning / operating procedure was employed as recommended by LBNL: the source was started with a low-duty-factor plasma ($\sim 0.1\%$) and the Cs collar was heated to $\sim 300\text{C}$. After several hours of conditioning in this state, the duty-factor of the source was increased to $\sim 3\%$ and air flow to the Cs collar was terminated allowing the collar temperature to reach $\sim 550\text{C}$ injecting Cs into the source. This condition was held for ~ 30 min. and then heated air flow was restored, returning the collar temperature to its nominal operating range of $\sim 300\text{C}$. The source was then ramped to full duty-factor by increasing the RF pulse length and repetition rate. Once high-duty factor operation was established, the RF power was adjusted to give maximum beam current, typically 40-60 kW. This Cesium procedure was repeated as needed to keep the beam intensity high.

Fig. 2 shows the beam currents for the three best performing experimental runs of the seven which employed the original conditioning technique. The average beam current across the droop-corrected pulse as measured by the BCM is plotted. Notice the beam current only exceeds 30 mA for periods of several hours. The spikes extending upward from the baseline show the effects of cesiations on the beam current. Cesiums were performed 3-4 times during each run. The spikes extending downward to zero are system trips which could not be reset during periods of unattended operation. A detailed account of experimental runs 1-4 can be found in reference 7.

IV. ANALYSIS

It is well known that Cs-enhanced, multicusp ion sources produce H^- in both in the plasma volume and on Cs-coated surfaces which are subjected to plasma bombardment [11]. During

collar must be maintained at temperatures below 250C, ideally as cold as possible, until the source has been conditioned (out-gassed) to full duty-factor before heating the Cs collar.

V. LATER ION SOURCE RUNS

Prior to beginning experimental runs 8 and 9, the source was conditioned at full duty-factor and RF power for several hours while maintaining the Cs collar temperature below 100C using cooling air. The residual gas analyzer was used to verify that out-gassing was complete. The source was then cesiated and operated in the same manner described for the earlier experimental runs. Experimental runs 8 and 9 are shown in Fig. 3 and both exhibit an extraordinary beam persistence with time: mean beam attenuation rate decreased from an average of 5 mA/day (runs 1-7) to 0.4 mA/day (runs 8 and 9) as a result of implementation of the new conditioning technique. Fig. 3 shows beam currents in excess of 30 mA were maintained for 16 days of continuous operation at full duty-factor. The run was terminated due to a puncture through the ion source antenna. Reference 13 presents a survey of different Cs systems employed in negative ion sources and discusses their performance.

VI. ONGOING ION SOURCE DEVELOPMENT

At full duty-factor (7.4%), the new source conditioning procedure has resulted in an order-of-magnitude improvement in beam persistence, allowing delivery of beams in excess of 30 mA for ~16 days. We are now much closer to meeting the SNS operating goal of 40 mA for 21 days. To insure that this goal can be met, as well as the future SNS power upgrade requirement of ~75 mA at comparable pulse and emittance specifications [14], an aggressive ion source R&D program is in place. The program is focused on improving the basic LBNL ion source shown in Fig. 1 by

developing (i) enhanced Cs collars [15] (ii) external antennas [16, 17] (iii) enhanced extraction and electron suppression systems and (iv) helicon plasma generators.

Recently, as part of this program, initial tests were performed on the direct-transfer Cs collar shown in Fig. 4. The original Cs collar from LBNL operated at a single temperature which prohibited Cs from being simultaneously released and collected on an ionization surface, resulting in an uncontrollable and inefficient process [12]. The direct-transfer collar, on the other hand, features two air cooling/heating loops which allow independent control of the temperature of the Cs dispensers T_1 and the ionization surface T_2 over a range 30-650 C. Thus Cs can be transferred directly from the dispensers to the ionization surface at a controllable rate without requiring re-evaporation (uncontrollable) from the ion source walls. Initial tests of this system show that for $T_1=585$ C and $T_2=211$ C, approximately 50 mA of 1.2 ms H^- pulses can be produced. This result was achieved in spite of a damaged antenna, suggesting high beam current would be possible from an undamaged system. Further tests are underway to quantify lifetime.

¹ www.sns.gov

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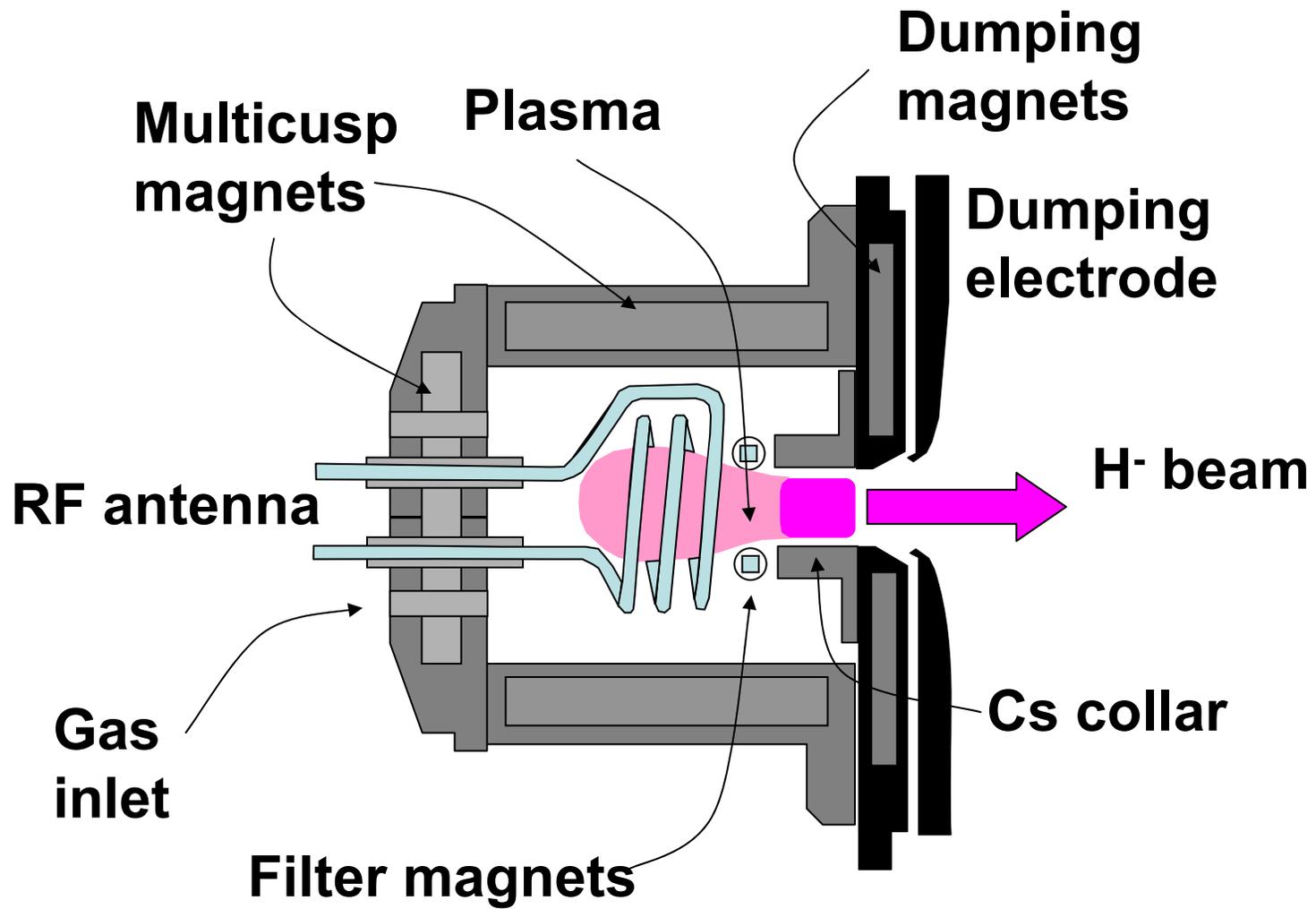


Figure 1

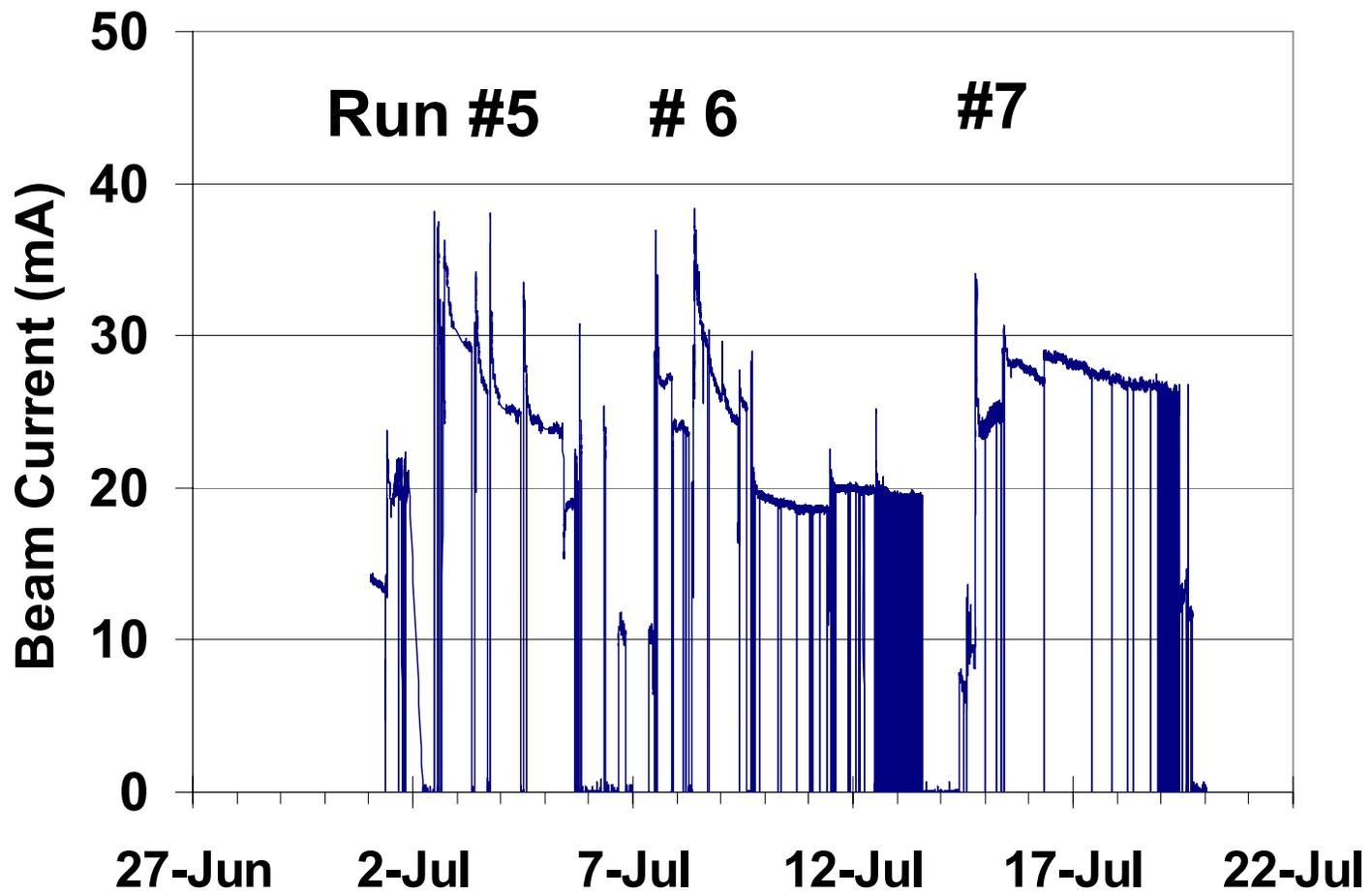


Figure 2

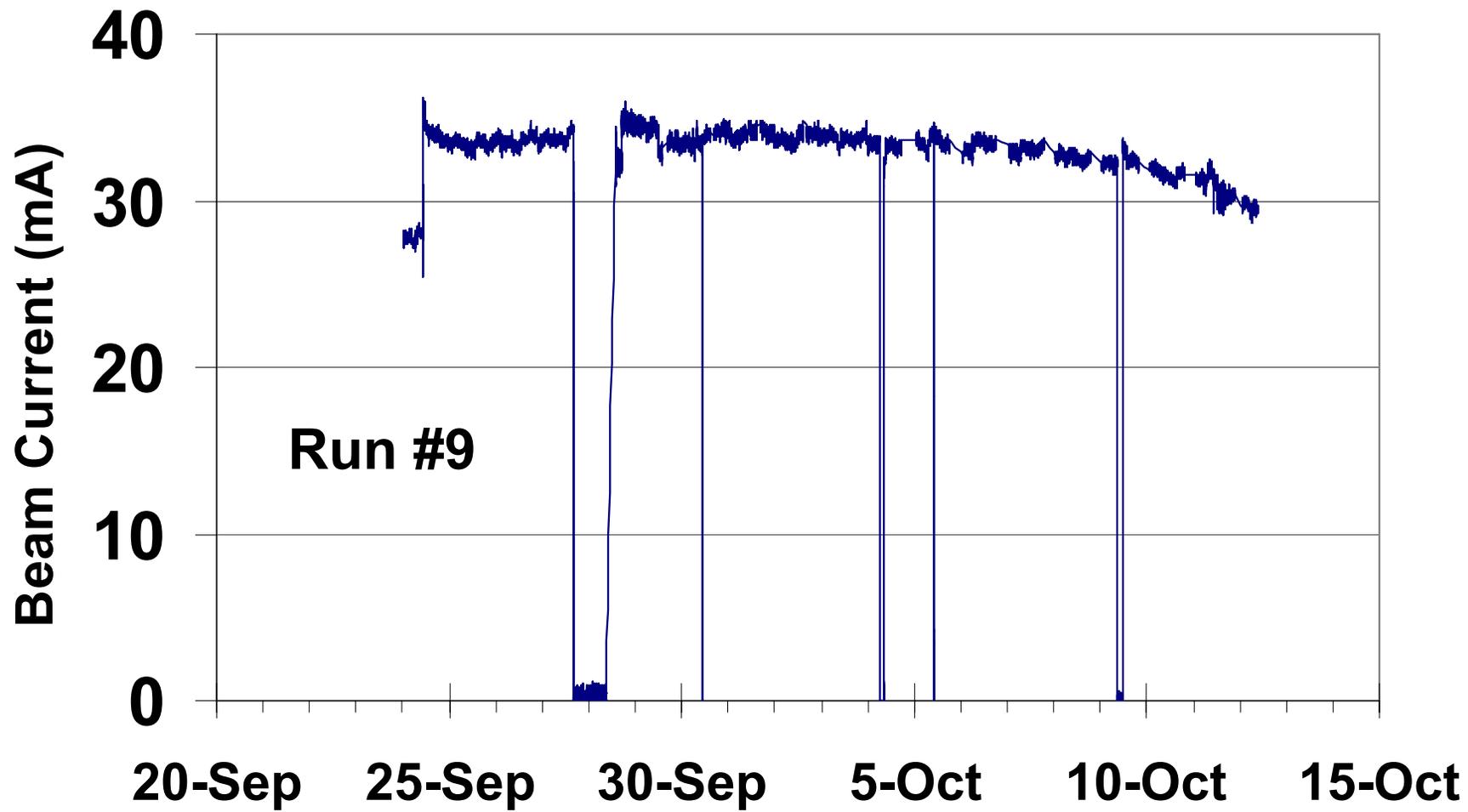


Figure 3

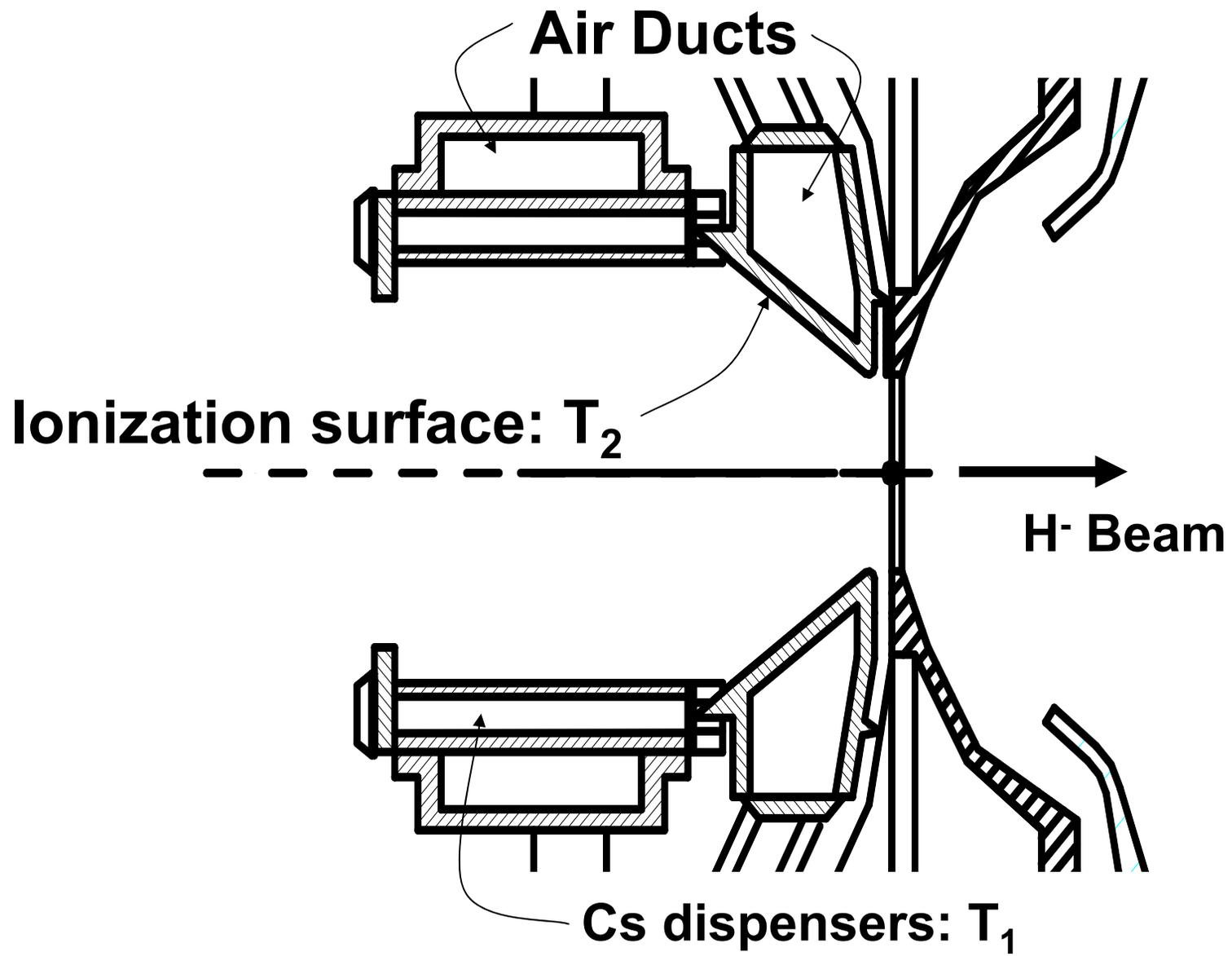


Figure 4