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PROTOTYPE ROOM TEMPERATURE QUADRUPOLE CHAMBER WITH CRYOGENIC INSTALLATIONS

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Abstract

The synchrotron SIS100 at FAIR accelerator complex at the GSI Helmholtzzentrum will generate heavy ion beams of ultimate intensities. As medium charge states have to be used, the probability for charge exchange in collisions with residual gas particles of such ions is much lager than for higher charge states.

In the last years, several measures have lowered the residual gas density to extreme high vacuum conditions. For example 55% of the circumference of SIS18 have already been coated with NEG, which provides high and distributed pumping speed. Nevertheless, this coating does not pump nobel and nobel-like components, which have very high ionization cross sections. A cryogenic environment at e.g. 50-80 K provides a high pumping speed for all heavy residual gas particles. The only typical residual gas particle that cannot be pumped at this temperature is hydrogen. With the pumping speed of an additional NEG coating in these areas, the pumping will be optimized for all residual gas particles.

The installation of cryogenic installations in the existing room temperature synchrotron SIS18 at GSI has been investigated. Measurements on a prototype chamber and simulations of SIS18 with cryogenic installations based on these measurements are presented.

INTRODUCTION AND MOTIVATION

The SIS100 synchrotron at the FAIR accelerator complex will provide high intensity heavy ion beams, with a goal of $5 \cdot 10^{11}$ [1] particles per pulse. To achieve this goal, medium charge states have to be used as this will shift the space charge to higher numbers of particles and avoids stripping losses. However the probability for charge exchanges of medium charge ions with the residual gas particles is much higher than for higher charge states. Ions with a different charge state than the reference ion will be deflected differently and hit the vacuum chamber wall at some point, see Fig. 1. At the impact location they will release gas particles into the vacuum chamber via ion impact induced desorption processes. This leads to a localized higher density of residual gas particles, resulting increase in charge exchanges in this area. As a result even more ions hit the vacuum chamber walls downstream. This self-amplification process is called dynamic vacuum and can evolve up to complete beam loss [2].

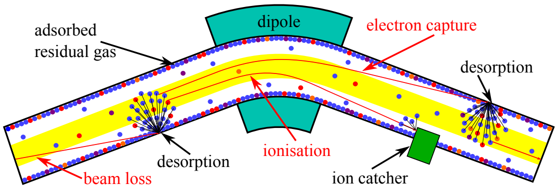

Figure 1: Principle of ionization loss and dynamic vacuum [2].

To avoid this process, several upgrade measures have been realized in the existing heavy ion synchrotron SIS18, at GSI [3]. Ion-catchers with low desorption surfaces have been installed to reduce the gas production by ionization beam losses. Furthermore to lower the residual gas density 65% of SIS18 vacuum chamber walls have been coated with NEG. This provides a high pumping speed for light residual gas particles like hydrogen. With these upgrades an improvement of the beam intensity was achieved [4]. However this current setup cannot reach the intensity goal for FAIR, as shown by different simulations of SIS18 [2]. Since the NEG coating only provides a high pumping speed for light particles and not for nobel and nobel-like gases, like argon and methane [5], which unfortunately have a high cross section for charge exchanges with U^{28+} [6], see Fig. 2, these particles have to be pumped differently to reduce the density of this residual gas particle species even further. However these can be pumped by cryogenic installations around 77 K. These pumps in combination with the already existing NEG coating can pump every residual gas component in SIS18 efficiently.

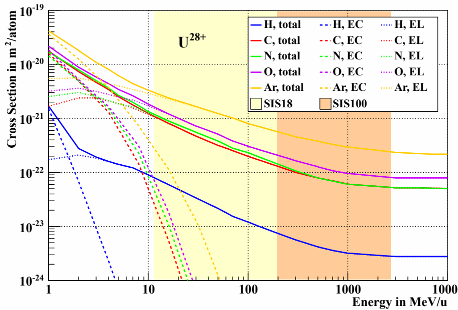

Figure 2: Cross sections for charge exchange of U^{28+} for different targets, distinguished for electron capture (EC), electron loss (EL) and total cross section. The energy regimes of SIS18 and SIS100 are marked [7].

PROTOTYPE TEST SETUP

To test the performance of cryogenic installations in a room temperature environment, a prototype quadrupole

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chamber is used. This prototype structure is similar to the set up of SIS18's quadrupole chambers.

Like the quadrupole chamber now installed in SIS18, this prototype is a thin-walled chamber with one turbo molecular pump (TM) on one side and an ion getter (IG) pump one the other side, Fig. 3. Lengthwise, there's a difference to the existing quadrupole chambers of SIS18 with the prototype's length being 3 m while the existing chambers covering more than 4 m. The thin-walled part is divided by thicker parts to install measurement gauges (measuring chambers). Four of them are installed along the prototype, to measure a pressure profile. In addition one residual gas analyzer (RGA) is mounted, to identify the residual gas species.

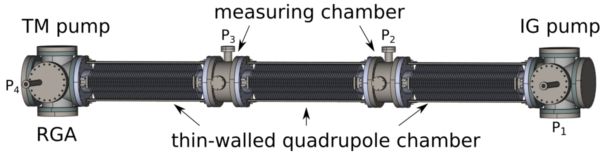

Figure 3: Sketch of the prototype quadrupole chamber with the positions of the pressure sensors p_i.

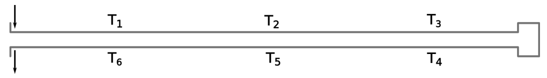

Figure 4: Sketch of the installed pipes with the positions of the temperature sensors T_i. The direction of the flow is marked.

Two pipes with a diameter of 8 mm are integrated into the chamber which can be cooled with liquid nitrogen or helium and can be used either in series as shown in Fig. 4 or independently of each other. Three sensors on each pipe measure the temperature, Fig. 4 shows their location.

In Fig. 5 measurements of the residual gas analyzer of the prototype chamber are presented. Both pipes were cooled with liquid nitrogen to about 80 K. The major masses of all common residual gas particles of SIS18 are plotted without the measurement of argon and molecular oxygen, which are present in SIS18 but were only detectable in insufficient amounts in the prototype. Some of the residual gas particles could only be presented together due to their major masses being indistinguishable. Furthermore to show the temperature of the pipes two sensors are included. These are the ones which will be cooled first (bright violet) and last (dark violet), respectively.

The results show that pumping of different residual gas particles with pipes at 80 K is not very effective. Furthermore only hydrogen (turquoise) did not get pumped, it seems that its amount rised during the measurement. In contrast water (bright blue) pumped most efficiently, as it was expected. Every other measurable common residue like nitrogen/carbon monoxide (red), methane/oxygen (blue) and carbon dioxide (green) are already pumped by the pipes at moderate temperatures. However this pumping is not effective enough to lower the residual gas density to extreme high vacuum conditions. As the pumping speed of cryogenic pipes scales with the temperature, one way to achieve this would be to cool pipes to even lower temperatures using for example liquid helium. Other measures would be to increase the surface of the pipes or to use a different coating.

In the near future the residual gas situation in SIS18 will be simulated by a gas inlet system with a dosing valve and additional argon. With this measure the cryogenic installation can be tested on all common residual gas particles. To maximize the pumping speed the system will be tested at lower temperatures with pipes cooled by liquid helium. In addition, saturation effects and capacity of the cryogenic installations are tested in order to evaluate the pumping performance of the prototype in the long term.

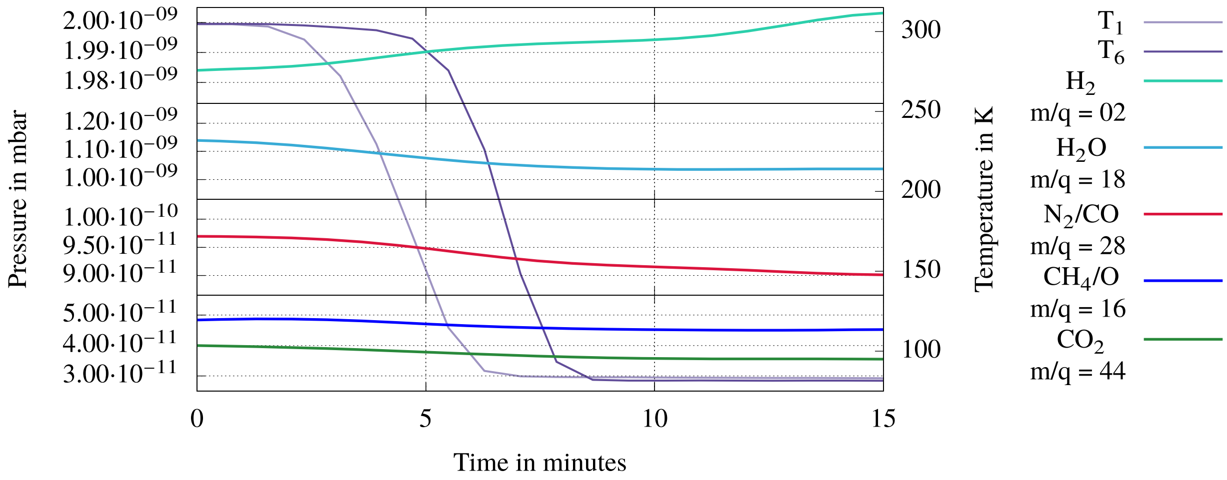

Figure 5: Residual gas analyzer measurement with both pipes cooled to ≈80 K. Presented are the main masses of the most common residual gas particle of SIS18 except argon and molecular oxygen. The position of the sensors can be seen in Fig. 3 and 4. All Curves have been smoothed.

SIMULATION OF U^{28+} IN SIS18 WITH CRYOGENIC INSTALLATIONS

To simulate the effect of cryogenic installations in SIS18 the software StrahlSim is used. This program is developed at GSI and is a unique code to simulate dynamic vacuum effects in circular accelerators.

The simulations presented here concentrate on two different types of cryogenic installations. The first one consists of two pipes like in the prototype quadrupole chamber. The second one features cryogenic surfaces close to the outer walls of the entire chamber. For a prototype chamber with such an installation see [8] of this conference. SIS18 is simulated with both of these installations in quadrupole and ion catcher chambers.

The SIS18 is simulated in the so called booster mode. This is the mode for injection of particle beams into the SIS100 at FAIR. Its consist of four individual cycles, a so called super cycle, following by a short break.

Presented are the number of extracted particles of U^{28+} per pulse as a function of the number of injected intensities and cycle frequencies for different scenarios. The simulation parameters can be found in Table 1. The following figures compare the operating SIS18 as it is now, blue line, with different options of cryogenic installations. The first option are pipes in the quadrupole, red line, and ion-catchers chambers, dark green. The second one are surfaces in the ion-catchers chambers, bright green. Thirdly a combined option with pipes in the quadrupole and surfaces in the ion-catcher chambers are simulated, purple line.

Table 1: Simulation Parameters for the Shown Simulations in Fig. 6 and 7.

Number of injected particles	3 to $20 \cdot 10^{10}$ U^{28+}
Ramp rate	10 T/s
Cycle frequency	1 to 2.7 Hz
Temperature of installations	15 K
Injection losses	5%

Figure 6 shows the simulation results with the highest cycle frequency of SIS18 at 2.7 Hz, although simulations with lower frequencies have been done. At first the number of extracted particles rises with increasing number of injected particles, however after reaching a maximum, the correlation inverts. This effect is a result of the dynamic vacuum. The results in Fig. 6 show that cryogenic installations will not only lead to higher number of extracted particles, but also shift the limit for a positive correlation between number of injected and extracted particles to higher numbers. The limit of this positive correlation could be shifted from $6.5 \cdot 10^{10}$ at room temperature to 10^{11} particles of U^{28+} with the combined cryogenic options. The results show that cryogenic installations in the ion-catcher chambers could shift the number to higher number of injected particles while cryogenic installations in the quadrupole chambers only resulted in higher numbers of extracted particles.

In Fig. 7, the maximum number of extracted particles per cycle frequency are presented. This figure shows that cryogenic installations rise the number of extracted particles for every cycle frequency, but also that the ion loss is getting bigger with rising cycle frequency. However, by calculating the average intensity of extracted particles per second from the results shown in Fig. 7, one can see that the resulting particle numbers increases with higher frequencies.

The simulation results predict that the peak intensity in SIS100 could be created from a super cycle of pulses from SIS18 using cryogenic pipes and surfaces in the quadrupole chambers and ion-catcher chambers respectively employing a cycle frequency of 1 Hz. The number of injected U^{28+} particles from SIS18 in SIS100 per pulse could be increased with cryogenic installations from 2.71 to $3.27 \cdot 10^{11}$. By using the same cooling scheme at a cycle frequency of 2.7 Hz the average intensity per second of extracted U^{28+} particles would increase from 1.13 to $1.65 \cdot 10^{11}$. Although the FAIR intensity of $5 \cdot 10^{11}$ U^{28+} per pulse could not be reached, cryogenic installations are a basis for further optimization.

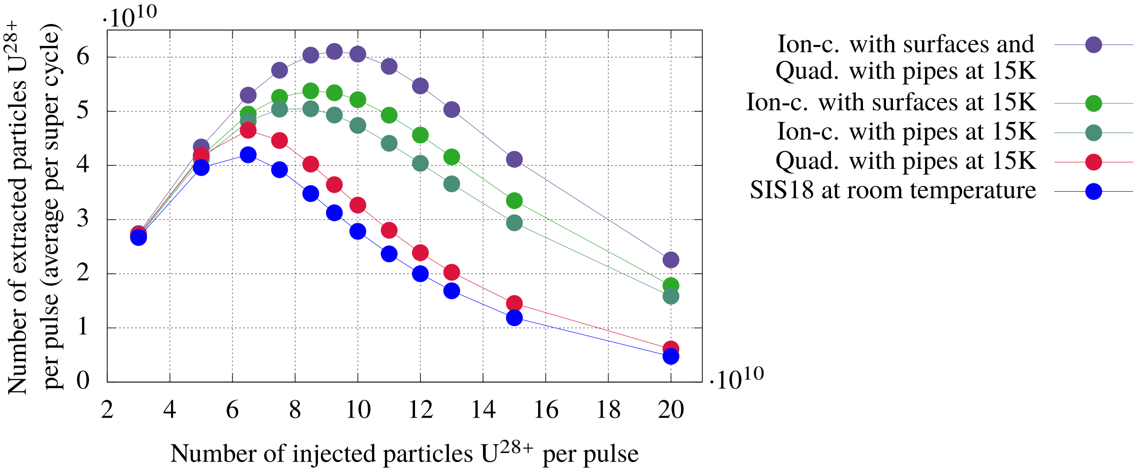

Figure 6: Results from simulations with cryogenic installations in the quadrupole and ion-catcher chambers at 15K with a cycle frequency of 2.7 Hz. More parameters are shown in Table 1.

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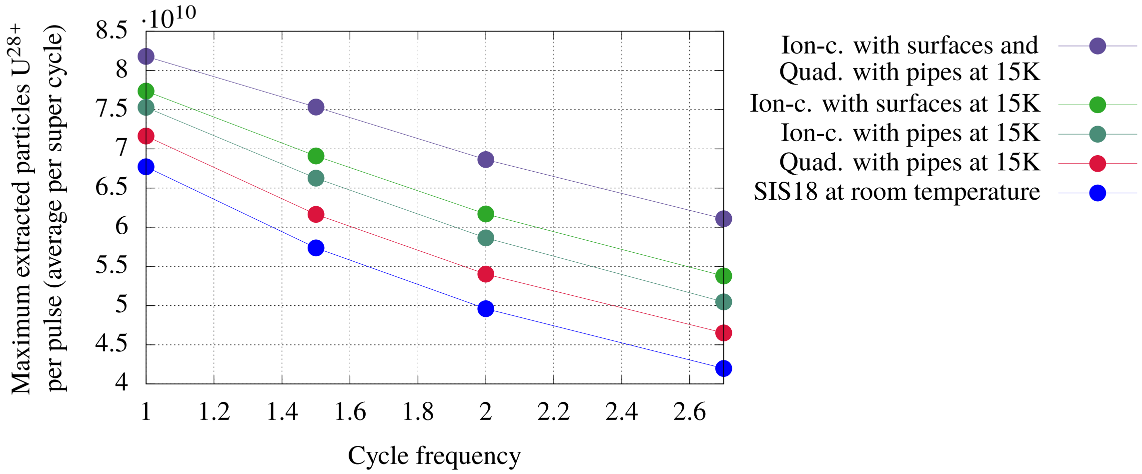

Figure 7: Maximum number of extracted particles U^{28+} from simulations with cryogenic installations in the quadrupole and ion-catcher chambers at 15 K. More parameters are shown in Table 1.

SUMMARY AND OUTLOOK

The quadrupole prototype chamber could be used successfully to show that every measurable common residual gas particle in SIS18 except for hydrogen can be pumped with cryogenic installations at 80 K. However, the measurements also showed that the achievable pumping speed is not very effective. To lower the residual gas density to extreme high vacuum conditions, for example lower temperatures have to be used. This will be tested in near future along with other measurements such as saturation effects.

Simulations of SIS18 with cryogenic installations at lower temperature have been done. They have shown the cryogenic installations could effectively lead to higher number of extracted particles and also shift the limit for a positive correlation between the number of injected and extracted particles to higher numbers of injected particles.

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