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LIGHT IONS FROM THE GTS-LHC ION SOURCE FOR FUTURE PHYSICS AT CERN

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Abstract

Starting from 2028, physics programmes using ions at CERN have requested lighter ions than the lead usually produced. The Working Group on Future Ions in the CERN Accelerator Complex has been mandated to assess the feasibility of the production and operation of these new ion species. The ion beam production from two of the chosen elements, krypton and magnesium, was studied in the GTS-LHC ion source, and the preliminary results of beam intensity, stability and emittance will be presented, as well as proposed modifications to improve performance.

INTRODUCTION

The CERN accelerator complex was upgraded in 1994 to deliver heavy lead ions for the ion physics programme of the fixed target experimental area called North Area (NA) of the Superprotonsynchrotron (SPS) and since 2007 for the ion physics programme of the Large Hadron Collider (LHC). Some exceptions to the standard lead operation were indium (2003), oxygen (2005), argon (2015) and xenon (2017).

Recently a working group "Future Ions in the CERN Accelerator Complex" was created to define future ion operation needs based on the requests from the LHC and the fixed target experiments and their implications for the ion injector accelerator complex [1]. The aim is to find synergies between the different experiments to limit the number of different ion species, to study challenges and limitations in the ion accelerator complex and to make proposals to schedule tests of selected ion species.

Presently a limitation for the study of new ion species is the existence of only one ion source in the complex, the GTS-LHC ECR ion source [2], which has to be used for the operation of requested ion beams and the development of new ion beams.

The setup of the ion accelerator chain and the following physics period can be up to 6 months. This means, depending on the physics programme, only two ion species can be operated or studied per year. Only precise long-term schedule allows under this condition to serve all the needs of the ion community.

Due to these long operation periods it requires an excellent long-term stability over weeks or months of the source. This is more demanding than just reaching the target beam intensity, especially for metal ion beams based on oven operation.

For the LHC, the working group studied if by using different ions, the nucleon-nucleon luminosity could be increased. One candidate ion is krypton. With nobel gas ions the source conditioning time is usually shorter, and stable operation is reached within 2 weeks, so a short 3 week test with krypton before the start of the setup of the ion accelerator chain with lead was scheduled in the beginning of 2023.

For the fixed target physics the list of ions to be prepared for the next years could be limited to magnesium and boron. In the beginning of 2024 a 8 weeks test of magnesium was done. Boron has to be tested in one of the following years.

KRYPTON TEST

The aim of this test was to find the settings of the source for a reliable and stable operation, information about the charge state distribution, beam intensity and beam emittance. Due to the short time available the beam could be studied only in the Low Energy Beam Transport (LEBT) and in the following RFQ. The rest of the linear accelerator was not available at that moment. To transport the ion beam through the RFQ the extraction voltage has to be set to a value corresponding to a beam energy of 2.5 keV/u.

The linear accelerator Linac3 injects the ion beam into the Low Energy Ion Ring (LEIR) [3]. Depending on the ion species and the charge state available from the source the beam needs to be stripped at the end of the linear accelerator as only a limited range of charge-over-mass can be injected into LEIR. For the test isotopically pure ^{86}Kr was used (17.3 % abundance in natural krypton). A charge state around Kr^{22+} would have been a good option to avoid stripping.

The source was mechanically already set up for the following lead ion beam commissioning (to minimize the switch-over-time), i.e. the extraction gap was not adjusted for the low extraction voltages needed for the krypton ion beam. Oxygen was used as support gas.

In the first stage of testing a charge distribution peaking at Kr^{19+} could be achieved (see Fig. 1, FC2 is the Faraday cup directly after the separation spectrometer). But this charge state would have been too low for a direct injection into LEIR. After re-adjusting the source parameters a charge state distribution peaking at Kr^{22+} could be achieved (see Fig. 1).

After a couple of days of commissioning we achieved around 120 eμA of Kr^{22+} at an extraction voltage of 9.8 kV out of the source and around 80 eμA out of the RFQ (see Fig. 2). The stability of the ion beam was excellent compared to the standard lead ion beam.

The transverse emittance in front of the RFQ was measured using tomographic reconstruction [4] from beam profile measurements on a profile grid, as a function of current in a upstream quadrupole magnet. The results show that

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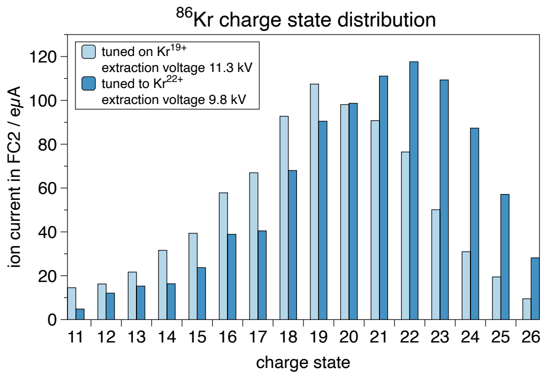

Figure 1: Charge state distributions of the krypton ion beam optimized for two different peak charge states. FC2 is the Faraday cup after the spectrometer.

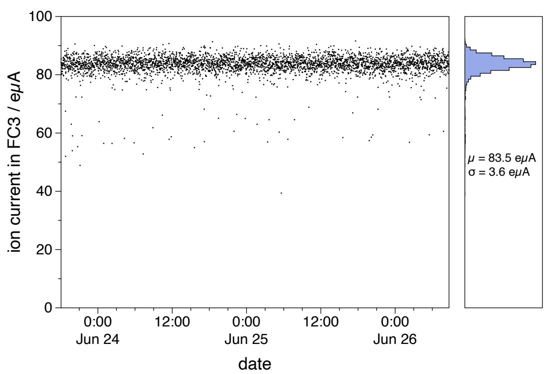

Figure 2: Beam stability of the krypton ion beam out of the RFQ over a period of 48 hours. FC3 is the Faraday cup directly after the RFQ.

the emittance of the krypton ion beam is clearly bigger than the lead ion beam at this location (see Fig. 3). The not well adapted extraction gap may be the reason for this behaviour. Further studies, to better understand this, are needed.

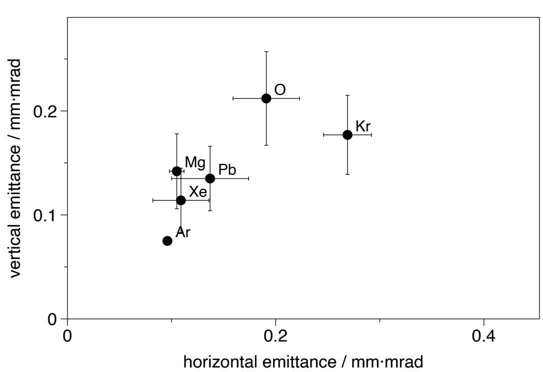

Figure 3: Horizontal and vertical emittances (normalized RMS emittance) of different ion beams in the LEBT. The values are averaged over several measurement campaigns. The error bars represent the rms values. For argon only one measurement was available.

The experiment was very successful. Source and LEBT settings and beam performance values were recorded. No show stoppers could be identified.

MAGNESIUM TEST

The aim of this test was as well as for the krypton test to find the settings of the source for a reliable and stable operation, information about the charge state distribution, beam intensity and beam emittance. Magnesium ions bring the additional challenge of finding suitable parameters for the evaporation and measuring consumption from the micro-oven.

Magnesium consists of three stable isotopes. But as ^{24}Mg has an abundance of 79 % we performed the first test with chemical pure, natural magnesium. The source has two ovens that can be installed in parallel. Each oven could be filled with around 250 mg of magnesium.

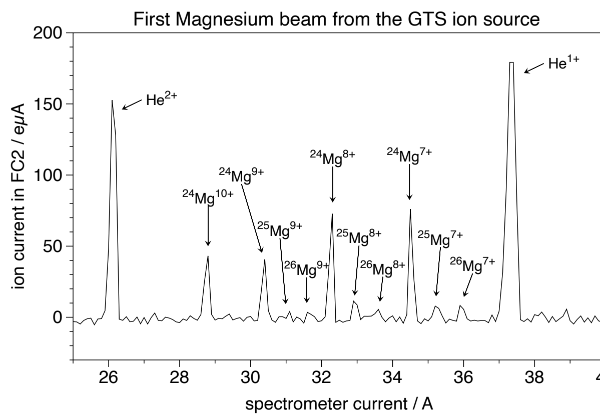

Figure 4: Charge state distribution of the magnesium ion beam. All three magnesium isotopes are visible, the ratio of the intensities roughly correspond to the natural abundance ratios. The peak of He^{1+} is cut due to saturation. FC2 is the Faraday cup after the spectrometer.

Out of the source up to 75 eμA of $^{24}Mg^{7+}$ (see Fig. 4) could be measured (routinely 30-40 eμA). The charge state 7+ was chosen, as with this charge state no stripping before injection into LEIR is needed. Out of the RFQ the intensity was around 20 eμA and at the end of the linac we measured 10-15 eμA. During the final two days of the test the intensity could be increased to 20 eμA, which would be sufficient for the operation of LEIR. The beam stability over shorter periods was excellent (see Fig. 5). Over periods more than one or two days the stability suffered due to the high material consumption.

As shown in Fig. 3 the emittance for the magnesium ion beam is in the same range as the emittance of the lead ion beam. The transmission through the RFQ was significantly lower than what was observed for other ion species, this is currently not understood (at least not in terms of transverse emittance).

As mentioned earlier 250 mg of material could be installed per oven. Oven operation was limited to 2-5 days with

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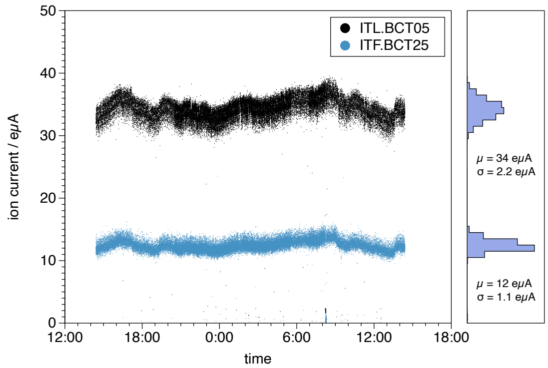

Figure 5: Measurement of the magnesium ion beam stability over a period of 24 h. ITL.BCT05 is the beam transformer in the LEBT in front of the RFQ, ITF.BCT25 is the beam transformer at the end of the linac.

250 mg of Mg installed, which results in an average consumption of 2.7 mg/h over the whole test period. Due to this the ovens had to be regular refilled and there were periods were the source was running with low magnesium input. As a result, the conditioning of the source and the beam stability suffered. The peak performance of the source could only be reached by the end of the test while pushing the oven operation to higher oven power.

For this test source settings and settings for the linear accelerator and beam performance values were recorded. The oven operation was identified as the main performance-limiting factor. No other show stoppers could be found.

CONCLUSIONS AND FUTURE PLANS

Both tests, krypton and magnesium, can be counted as success. Both tests showed that the required charge states and beam intensities can be provided by the source.

During the krypton test the beam could be sent only through a part of the linear accelerator. A follow-up test is needed to send the beam through the whole ion injector chain to study the performance and limitations along the accelerator chain.

For the next test it is also planned to improve the gas injection system to allow the flow rate of the two simultaneously injected gases to be better controlled.

The source extraction gap should be shortened compared to the initial krypton test to see if this lowers the emittance and improves transmission.

The next test with magnesium is scheduled during the Long Shutdown 3 (LS3) period (2026–2028). As the material consumption was the main issue in the present test the installation of a hot screen inside the plasma chamber is foreseen [5]. To achieve similar operation periods per oven as for lead (around 30 days) the magnesium consumption needs to be reduced to values below 0.5 mg/h.

If this test does not show the required results an experiment with magnesocene is foreseen as a fallback solution.

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