Operation of the GTS-LHC ECR ion source in afterglow with varying klystron frequency

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Introduction

The GTS-LHC ECR ion source is based on the original Grenoble Test Source (GTS) and provides since 2005 the CERN heavy ion injector complex with ions [1]. Over the last years the source has delivered lead, argon and xenon ions for the two main clients - the fixed target experiments in the North Area of the Super Proton Synchrotron (SPS) and the experiments at the LHC.

The main 14.5 GHz microwave generator of the source was taken over from the predecessor source (ECR4) and was meanwhile more than 20 years old. As the old generator suffered from increasing failure rate and obsolete components it was decided to replace it.

Recent experiments with a travelling wave tube amplifier (TWTA) showed that for the lead ion of interest (Pb^{29+}) some increase of the beam intensity can be reached [2]. And as the frequency where this happens is covered by the new microwave generator it became of interest to study the ion beam production varying the frequency from the microwave generator and to see if a similar behaviour as with the TWTA can be reproduced. This would help to get a better understanding of the TWTA experimental results and in the positive case provide more beam for the users.

The characteristics of the Sairem microwave generator

type	Klystron based, remote channel and frequency selection
frequency range	14.0 ... 14.5 GHz
number of Klystron channels	20
bandwidth of each Klystron channel	25 MHz
step size of the synthesizer	1 kHz
nominal peak power	2.2 kW (for a matched load)
operation mode	cw or pulsed (via external timing)

Central frequencies/GHz

channel	frequency	channel	frequency
1	14.0125	11	14.2625
2	14.0375	12	14.2875
3	14.0625	13	14.3125
4	14.0875	14	14.3375
5	14.1125	15	14.3625
6	14.1375	16	14.3875
7	14.1625	17	14.4125
8	14.1875	18	14.4375
9	14.2125	19	14.4625
10	14.2375	20	14.4875

Experiments with varied frequency

Before the experiment the source was optimized using a frequency of 14.5 GHz. The source was always tuned on Pb^{29+}.

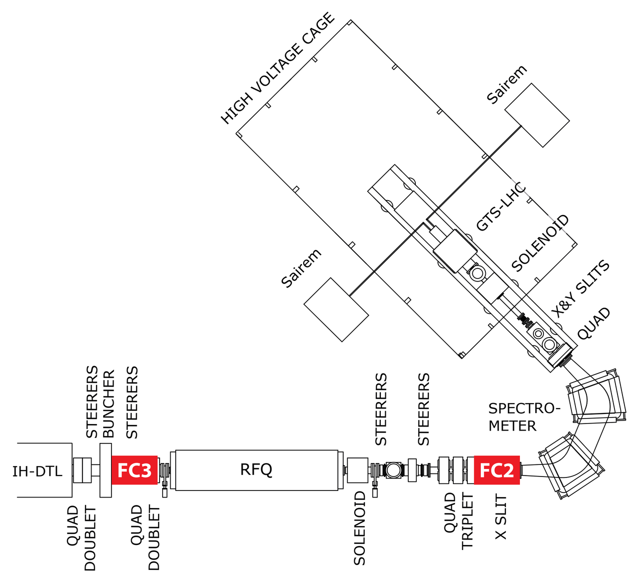
Experiences from the past show that especially for metal ion beams a proper source conditioning may take from several days up to some weeks to reach the full performance (stable and intense beam). Due to the limited time it was not possible to wait for the final optimum conditioning for each frequency step. Data were taken when a temporary stability was reached.

Source setting for the different frequency scans

	a)	b)	c)	d)
microwave power/W	1650	1700	1650	1000
bias disk/V	320	280	300	295
injection sol./A	1270	1270	1270	1270
central sol./A	180	200	150	220
extraction sol./A	1210	1200	1200	1185
gas/a.u.	9.780	9.710	9.740	9.755
extract. voltage/kV	18.89	18.89	18.89	18.89

The frequency scans

Multiple frequency sweeps were performed with different source settings. The beam intensity was measured in a Faraday cup (FC2) directly after the spectrometer and in a Faraday cup (FC3) after the Radiofrequency Quadrupole (RFQ).



Before each sweep the source and the Low Energy Beam Transport (LEBT) were optimized.

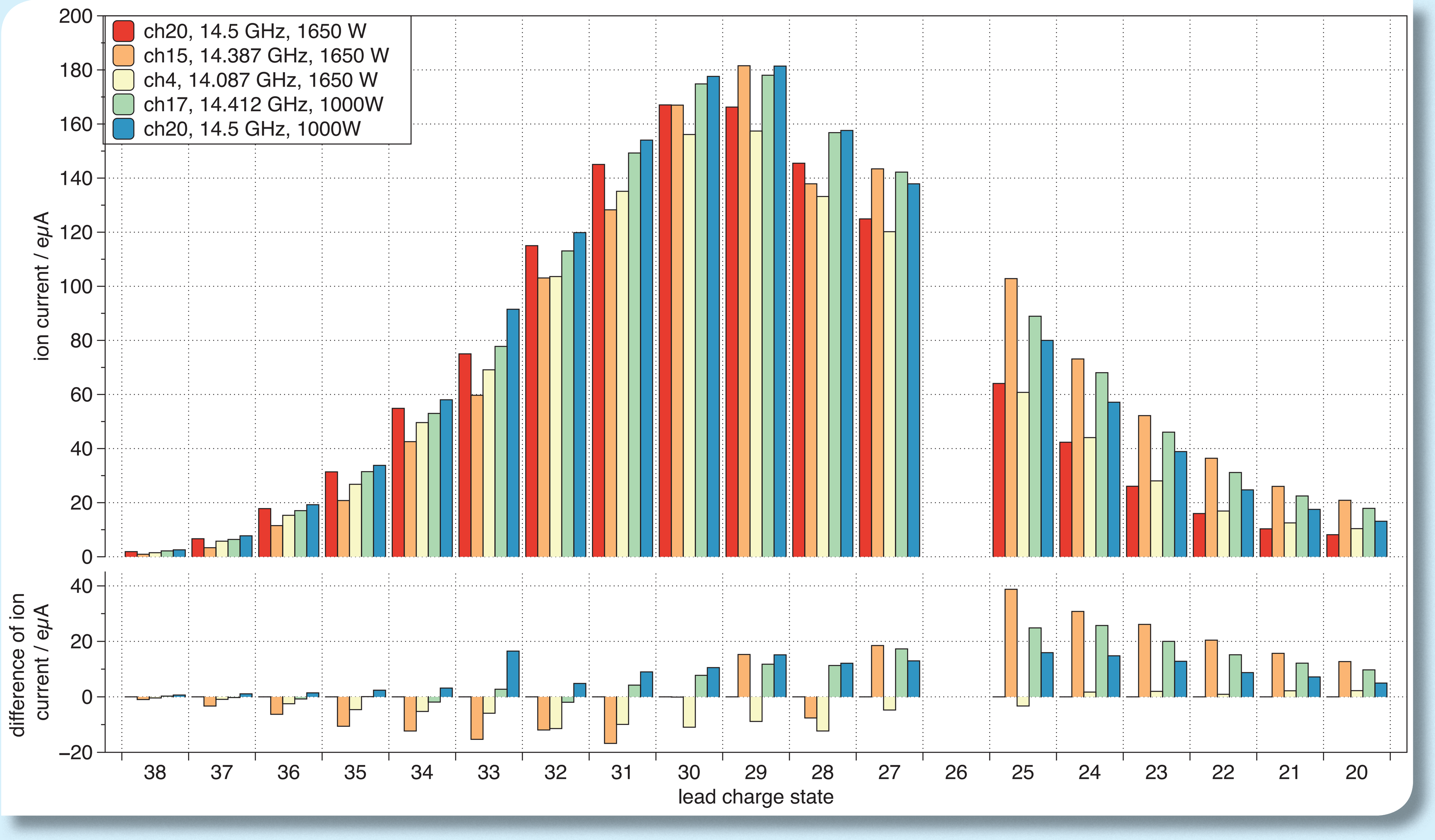
In the sweeps the center frequencies of each channel were used, except for channel 20. For this the center frequency and the highest available frequency (14.5 GHz) were measured. For the cases a) to c) it seems that the starting point was also the point with the highest beam intensity in FC2 (sweeps a) and b) were started at channel 20 (14.5 GHz) and sweep c) was started at channel 15 (14.3625 GHz)). For case d) the sweep started at channel 20 (14.5 GHz) and the highest beam current was recorded at channel 17 (14.4125 GHz). All scans went from high to low frequency.

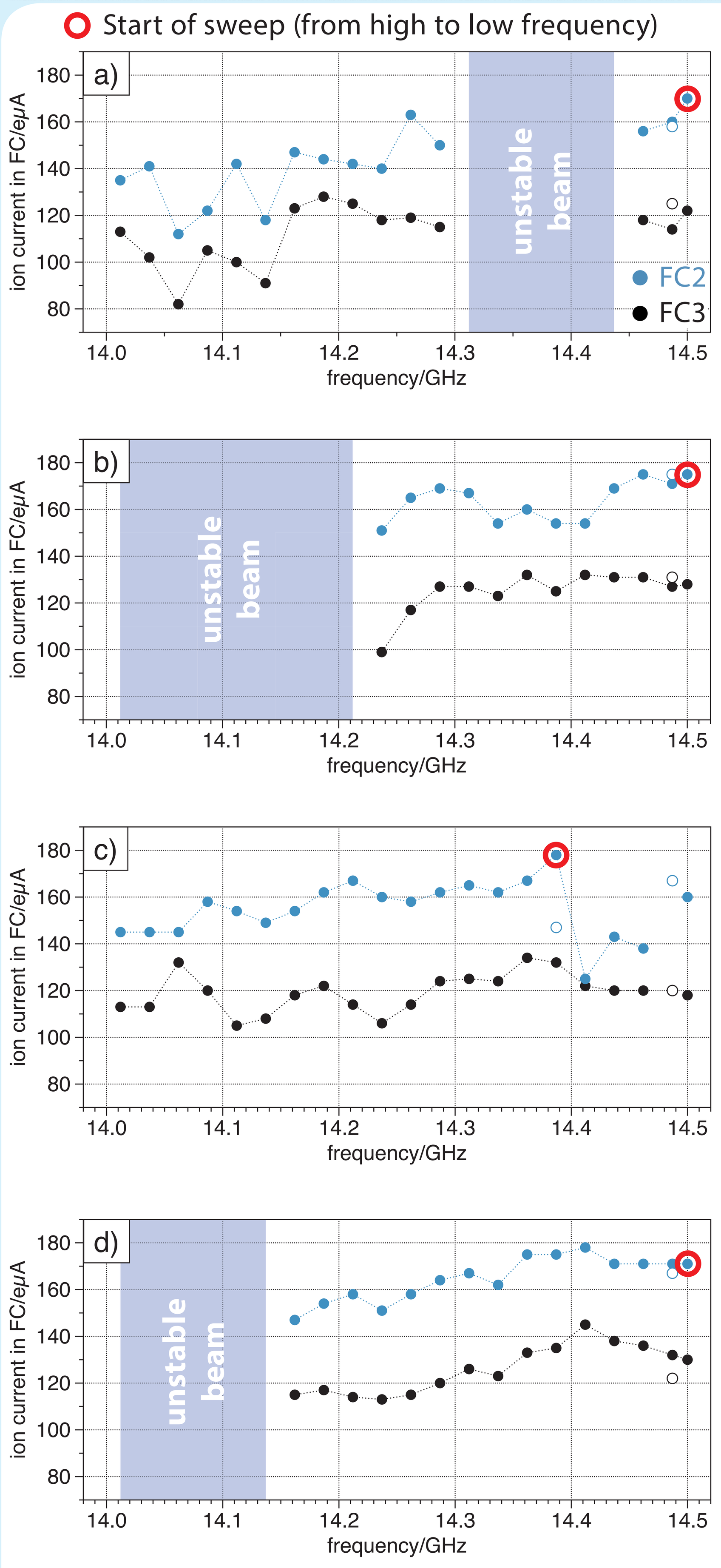
As a general trend one can observe that on average the beam currents seem to increase towards higher frequencies. This could be due to the global frequency scaling effect. On top of the global current increase a fine structure was observed with frequency. But a reproducible, stable pattern independent of the other source parameters could not be identified. Based on the present results one cannot draw a clear conclusion if the fine structure is caused by out-gassing or by improved/degraded ionization conditions due to the varied microwave conditions, or microwave coupling issues.

For some combinations of source setting and frequency it was impossible to stabilize the extracted beam (grayed out regions). The position and width of these regions vary in dependence of the source settings. No improvement of these beams could be observed over time compared to more out-gassing related instabilities.

Although the source was well conditioned at 14.5 GHz before the experiment started a significant out-gassing was noticed while changing to some of the lower frequencies. Running the source for a while at these specific frequencies lead to a recovery of the vacuum conditions. The reason for this behaviour could be that with the lower frequencies parts of the plasma chamber gets bombarded with particles which do not see any or only a limited number of particle interactions at the reference frequency of 14.5 GHz.

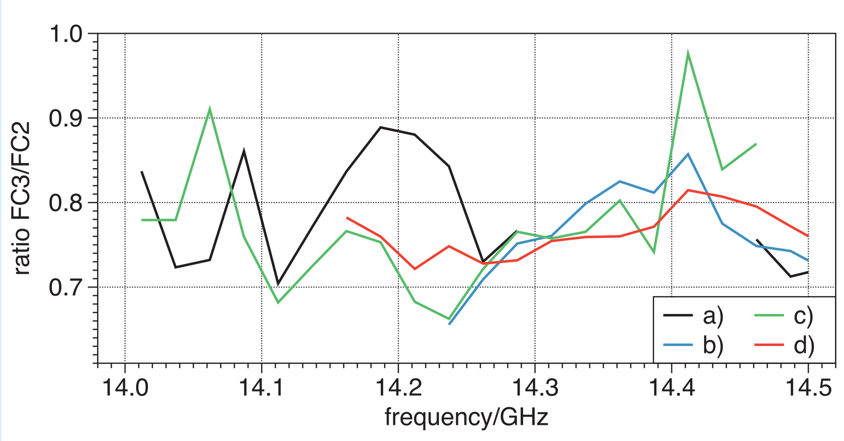
In general one can say that the tuning of the source influences clearly frequency response.





Beam transmission

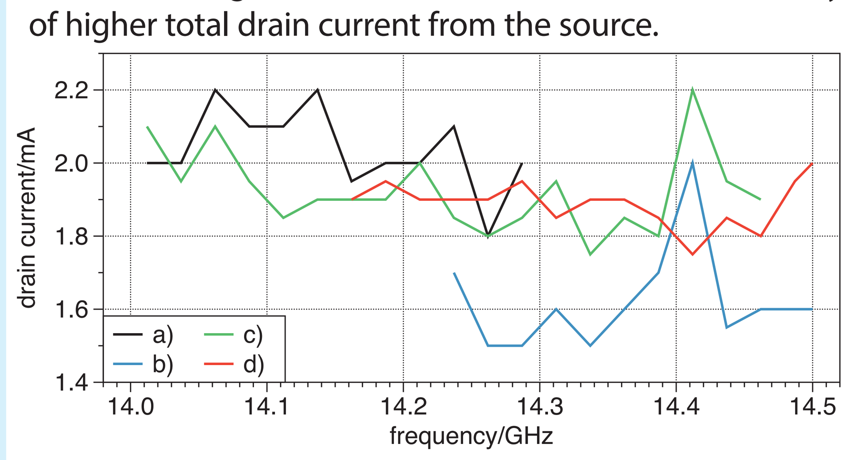
Assuming an intensity independent transmission through the RFQ (at least in a certain intensity range) one would expect a constant ratio of the ion beam intensity between FC2 and FC3. But as one can see in the figure below this is not the case.



This seems to indicate that the beam emitted from the source occupies a different volume (size and/or shape) in phase space for the different microwave frequencies It was not possible to measure the emittance directly. It is known that the transmission through the LEBT and the RFQ is sensitive concerning changes of the beam energy.

The charge state distributions

Comparing the charge state distributions of some special cases (see above) one can clearly see the enhancement of the beam intensity for lower charge states. The distributions seem to be broadened towards the lower charge states. This is also reflected in a tendency of higher total drain current from the source.



Looking at Pb^{29+} one can see some gain for medium frequencies (channel 15 and 17) and also for the reference frequency at lower power. Especially the last case points towards the issue of insufficient conditioning for all the different settings as normally at this low power the beam intensity is also much lower compared to a nominal microwave power of around 1700 W.

If one assumes that the varying frequency alters the exact location of where the plasma particle flux interacts with the chamber wall this shift in performance could be caused by the enhanced recirculation of the lead from the plasma chamber walls and in this case one would expect this to be only a temporary phenomenon.

Discussion and Conclusions

In previous measurements using a TWTA [2] some enhancement of beam intensity around a frequency of 14.2 GHz was observed. A similar behaviour could not be reproduced with the Klystron driven generator. This suggests that the observed effects with the TWTA were caused by the combined influence of the klystron and the TWTA, which were operated in double frequency mode, and the same conditions can not be achieved with only a single microwave source.

Even more the measurements seem to show that there is no clear preferred frequency. The source behaviour found suggests that the frequency becomes a tuning parameter as all the other settings of the source.

This suggests that the observed fine structure is not defined by e.g. the plasma chamber geometry or other fixed properties of the source, but is rather the result of dynamic processes taking place in the plasma volume. This result is in line with observations presented in Ref. [3] showing that the frequency structure defined by the chamber disappears in the presence of plasma.

In general it must be stated that the other source settings were not tuned for the different frequencies during the experiments and it was observed that the source condition was clearly altered after performing the frequency sweeps. This makes it difficult to draw strong final conclusions based on these results. Longer runs in the future on selected frequencies will clarify these issues and allow a better assessment of the early findings presented here.

References

[1] C.E. Hill et al., "Experience with the GTS-LHC ion source", 3rd LHC Project Workshop: 15th Chamonix Workshop (2006), pp. 239–241.

[2] V. Toivanen et al., "Effect of double frequency heating on the lead afterglow beam currents of an electron cyclotron resonance ion source", Phys. Rev. Accel. Beams 20, 103402 (2017).

[3] V. Toivanen et al., "Electron cyclotron resonance ion source plasma chamber studies using a network analyzer as a loaded cavity probe", Rev. Sci. Instrum. 83, 02A306 (2012).

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