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Status Report on the AECR-U Ion Source at KVI-CART

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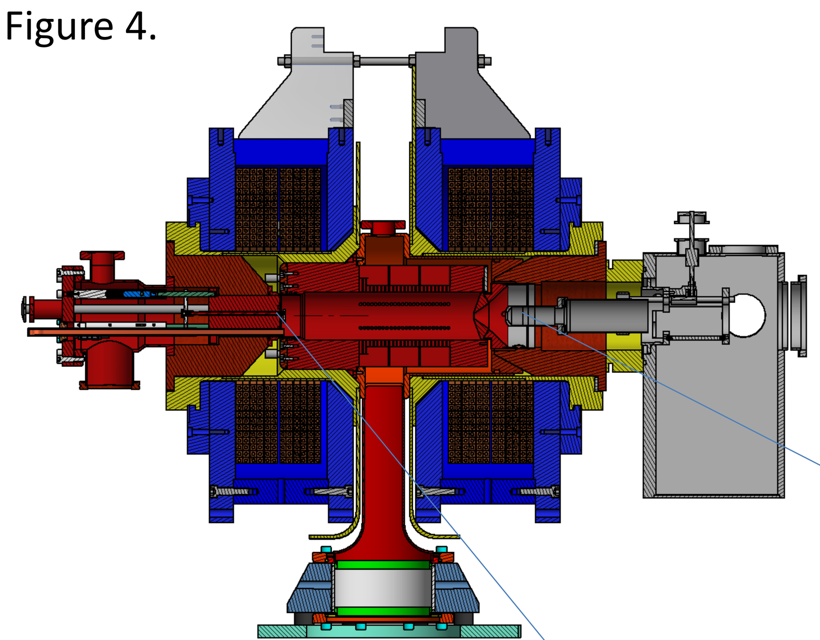
Motivation and challenges

Due to the demand for higher intensities of highly-charged heavy-ion beams at the AGOR accelerator facility, the hexapole of the AECR-U ion source has been replaced by an stronger hexapole with pole tip fields of 0.86 T at the wall. Optimally, following the scaling laws for ECR ion sources we should aim for 1 T radial magnetic field at the plasma wall $B_{rad} = 2 \times B_{ECR}$ [Ref.1]. However, 1 T is difficult to reach due to the pumping ports in between the bars required to provide a good background pressure.

Replacement of the hexapole

Figure 4.



Main Parameters:

- Freq RF 14 Ghz inject : 14.1 GHz
- Max Power 14 GHz : 1200 W
- Freq Range TWT : 11-13 GHZ
- Typical Power TWT : 450 W
- Max Extract voltage : 32.4 kV
- Base Vacuum : 5 x 10^{-8} mbar
- B_{ecr} : 0.49 T
- B injection : 1.8 T
- B extraction : 0.9 T
- B radial : 0.85 T
- B min : 0.42 T

Figure 1.

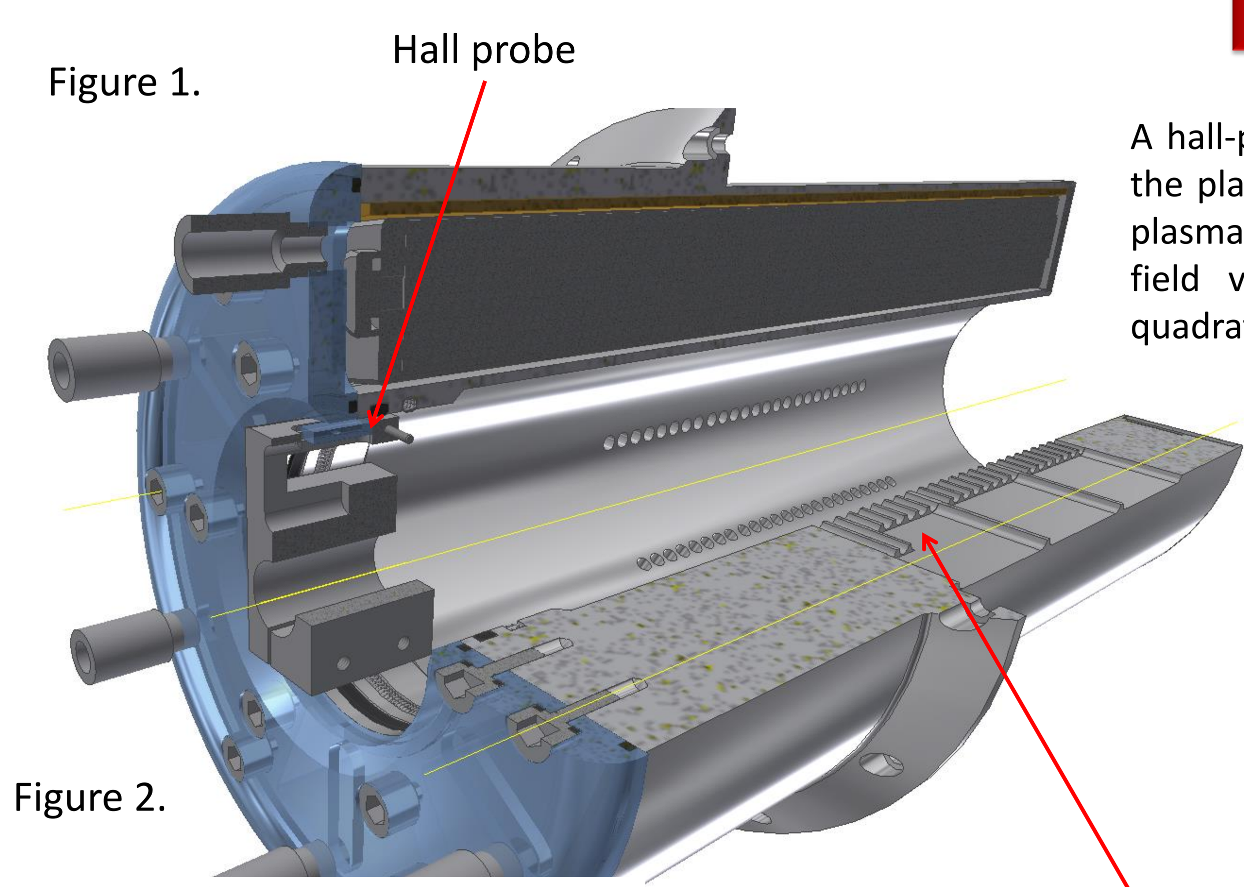
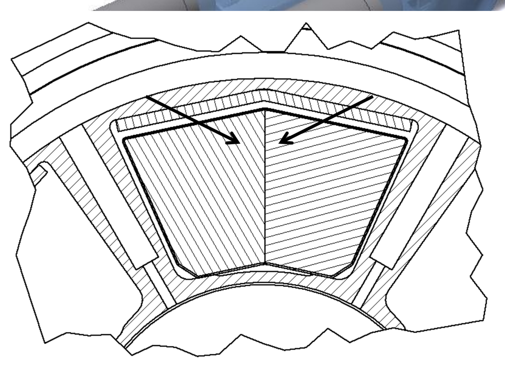
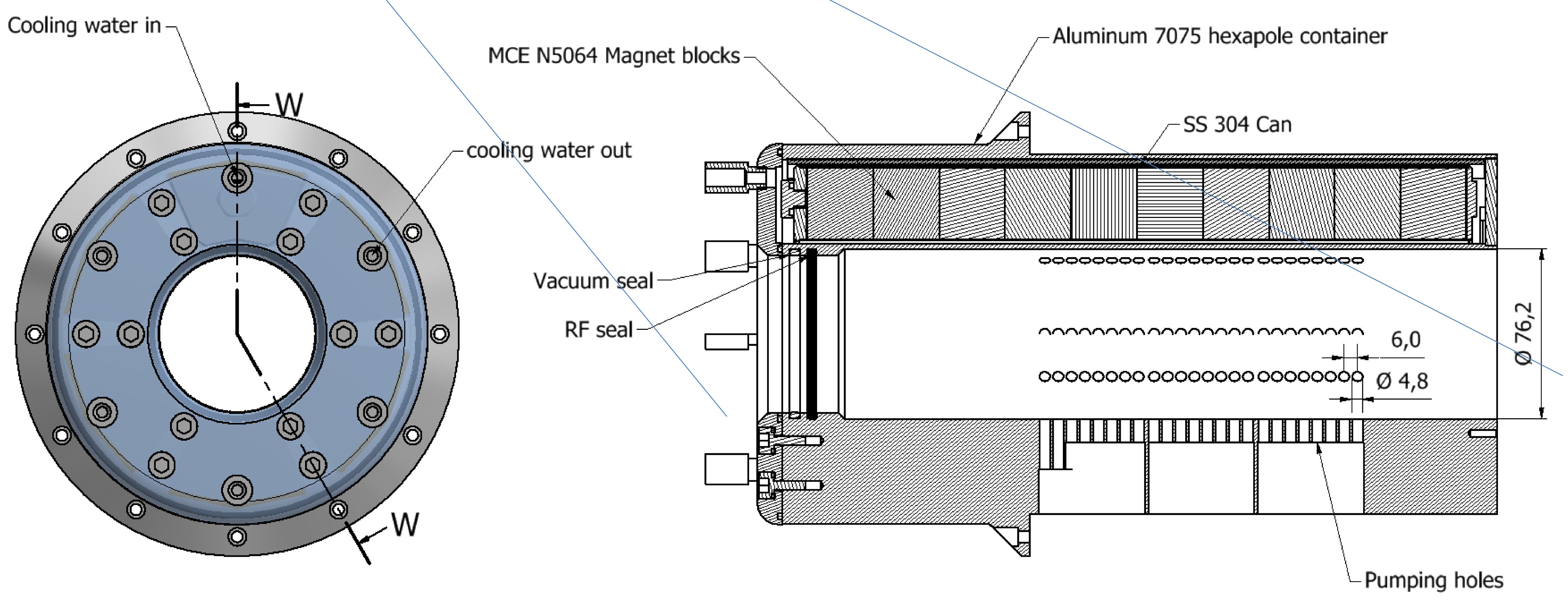


Figure 2.

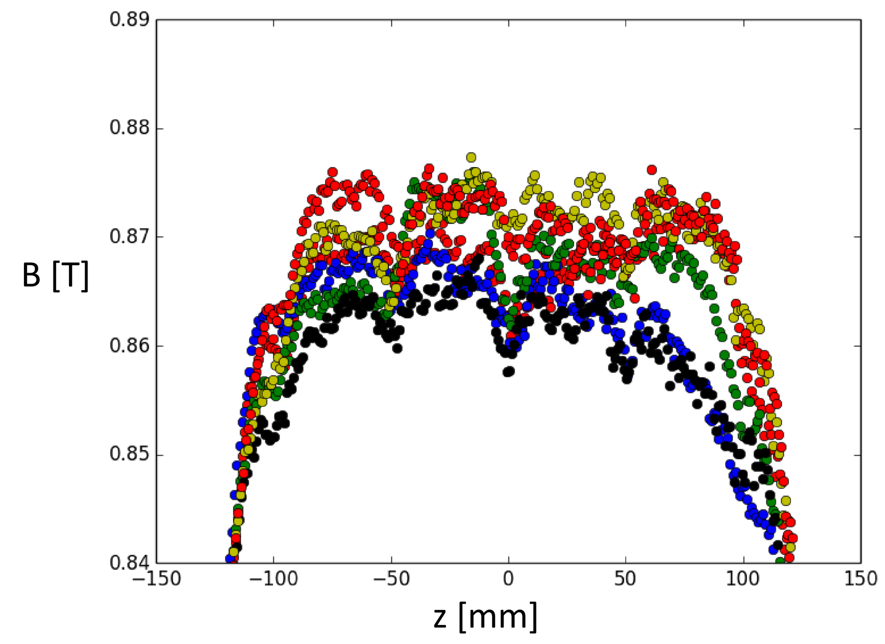




Magnetic field measurements

A hall-probe (LPT-141-10s), centered in front of a pole, is moved along the plasma wall on a radius of 32.92 mm (Fig.1). The inner bore of the plasma chamber has a radius of 38.1 mm. Measured radial magnetic field values are multiplied by $(38.1/32.9)^2$ as the magnetic field quadratically increases as a function of the radius.

Figure 7.



The radial magnetic field is measured over 300 mm with steps of 1mm. The glue spots are identified by small dips in the magnetic field (<1.5%) as can be seen in figure 7.

Measured Radial magnetic field at the wall is 0.865+/-0.05 (6%)

Highly-Charge Heavy-Ion beams

Measurement of the maximum intensities for 129 xenon before (March 2017) and after the replacement of the hexapole (April 2018) are presented in table 1.
Conditions for both datasets are same:

- A conditioned ion source; the ion source runs for two weeks, 6 hours a day on oxygen, to remove mainly the carbon contaminants.
- For two weeks the ion source is optimized for xenon, which is sufficient to reach the optimal conditions.
- Operational pressure is < 10^{-7} mbar.
- Oxygen is used as a mix gas.
- The bias disk voltage ranges from -10 V to -60 V
- Double frequency injection ranges from 11.5 to 12.3 GHz.
- The beam current was measured by a collimated Faraday cup (Ø6 mm) in the image plane of the magnet.

Table 1.

Ion	Date measurement	FC aperture [mm]	RF [W]	29	30	31	32	33	34	35
^{129}Xe	April 2018	6	500	3.3	2.7	1.7		0.44*	0.2	0.07
^{129}Xe	March 2017	6	800	3.3	1.5	0.7		0.053		

* See measured charge state distribution

Conclusion: Charge state $^{129}Xe^{+33}$ increased with a factor 8.

Beam on Target: Intensity, LET, Purity, Switching

KVI-CART provides 30 MeV/u to 90 MeV/u highly-charged heavy–ion beams for the scientific community and commercial users. An in-air set-up for carbon to xenon at 30 MeV/u allows for easy access of the irradiation facility as the device under test (DUT) does not need to be placed in a vacuum chamber.

Table 3.

Ion Species	Maximum Flux ion cm^{-2} s^{-1}	Energy at DUT in air (SRIM 2013) MeV/u	LET at DUT in Air (SRIM 2013) MeV/(mg/cm²)	Max LET degraded beam MeV/(mg/cm2)	Contamination Ions per beam ion	Time to switch ion species				
						O	Ne	Ar	Kr	Xe
$^{16}O^{4+}$	1E6	27.93	1.1	4.5	<1E-5	x	15m	15m	30m	<1h
$^{20}Ne^{5+}$	1E6	26.9	1.8	7.8	<1E-5	15m	x	15m	30m	<1h
$^{40}Ar^{10+}$	1E6	26.3	5.7	16.6	<1E-5	15m	15m	x	30m	<1h
$^{84}Kr^{21+}$	1E6	24.6	20	40	<1E-5	30m	30m	30m	x	<1h
$^{129}Xe^{32+}$	~1E6	25.5	42	65	<1E-5	<1h	<1h	<1h	<1h	x

Oxygen beams maximum intensities

Un-collimated Faraday cup (Ø40 mm) measures a factor of 3 more (see Table 2). Unfortunatly, this beam never get transported through the beam line and injected into the AGOR cyclotron. Ultimate transmission through the analyzing magnet is 50%.

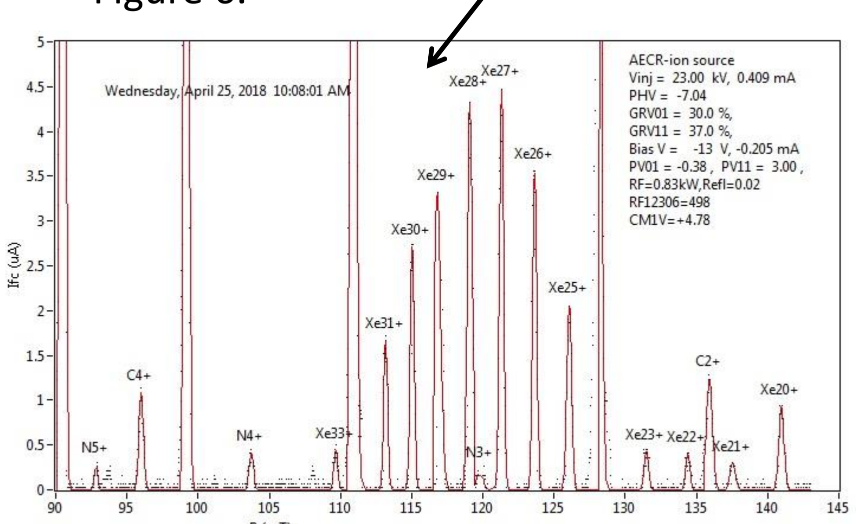
Table 2. Measured beam currents in eμA for different charge states of oxygen for two collimations

Ion	FC aperture [mm]	2	3	4	5	6	7
^{16}O	40	120	225		480	705	123
^{16}O	6	97	107		162	241	46

Ambitious plans of KVI-CART

(1) Implementation MIVOC/ oven technology for the production of ^{48}Ca and ^{64}Ni beams. due to a grant from the European Research Council (ERC)
(2) Higher radial magnetic fields up to 1.2 T pole tip fields , increase plasma volume
(3) Dual frequency injection with 2.5 kW 18 Ghz and 2 kW 14 Ghz.
(4) Stronger longitudinal magnetic fields up to 2.5 T at injection and 1.2 T at extraction side.
(5) Improved analyzing section: gap of 120 mm

Figure 6.



Summary

At KVI-CART, the hexapole of the AECR ion source has been replaced by a stronger hexapole with pole tip fields of 0.865 T on the plasma wall. The stronger radial magnetic field led to an overall improvement of performance of the AECR ion source. A factor of 8 increase in intensity was seen for $^{129}Xe^{33+}$ (see CSD figure 6) .
In the near future an einzel lens will be installed between the extraction aperture and the analyzing magnet to increase the overall beam intensities even further. Simulations show that a factor of 2 to 3 can be expected.

References

[1] D. Hitz, A. Girard, G. Melin, S. Gammino, G. Ciavola, L. Celona, Results and interpretation of high frequency experiments at 28 GHz in ECR ion sources, future prospects, Rev. Sci. Instrum. 73 (2002) 509–512.
[2] Conference proceedings ICIS 2017, H.R. Kremers , J.P.F. Beijers, S. Brandenburg and B.N. Jones, Highly Charged Xenon Beams at KVI-CART, T3_MO-62.

Acknowledgment

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 654002 and ENSAR FP7 contract No 262010 . Furthermore, it is also financed by the Netherlands Organisation for Scientific Research (NWO).

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