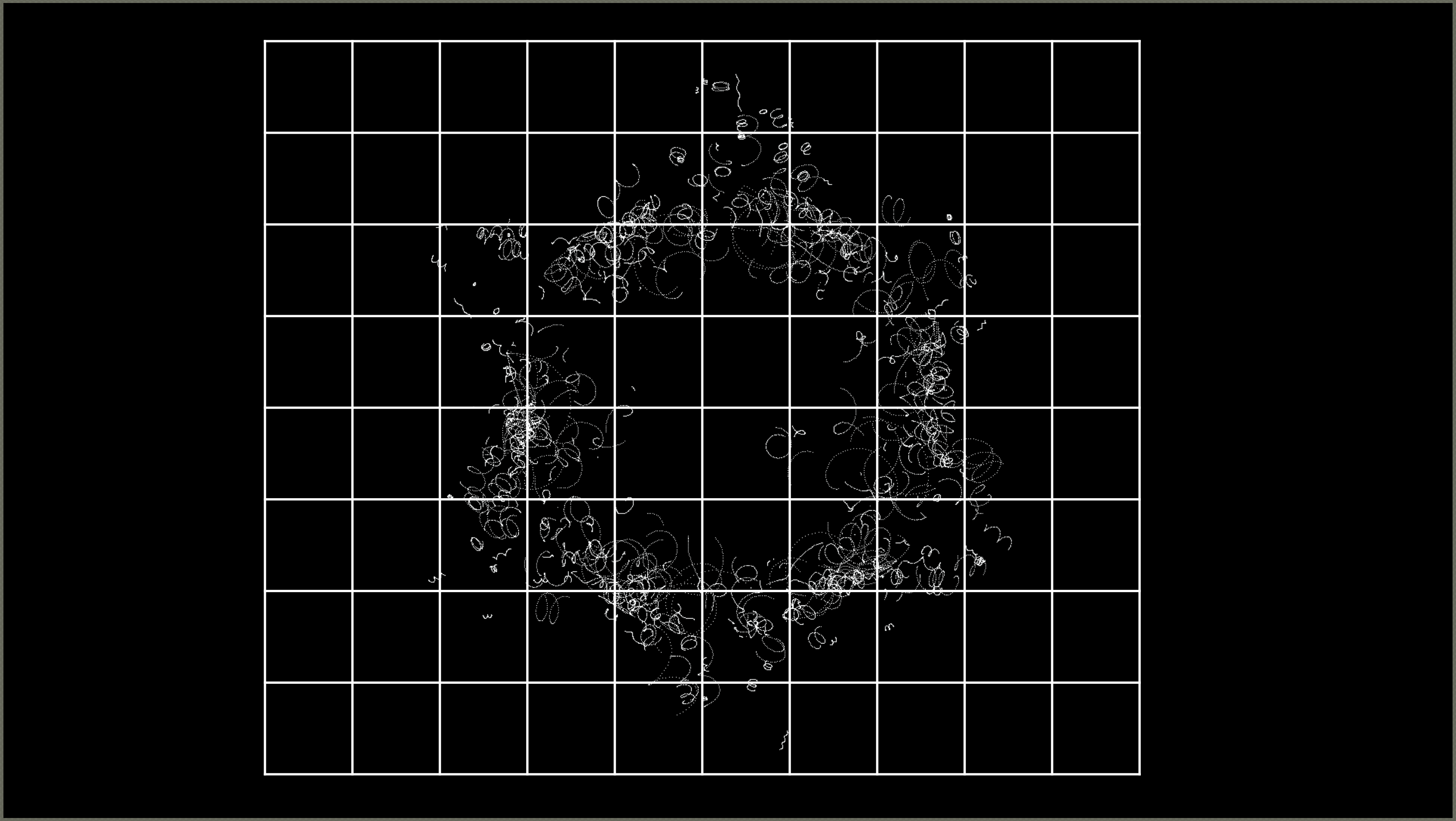
Study of ECRIS scaling laws with the Particle-in-Cell Code

V.E. Mironov
FLNR JINR Dubna

Outline

- Description of the model
- Basic responses: gas flow, RF power, spatial distributions
- Response to variations in the magnetic field (scaling laws)
- Conclusions

Particle-in-Cell



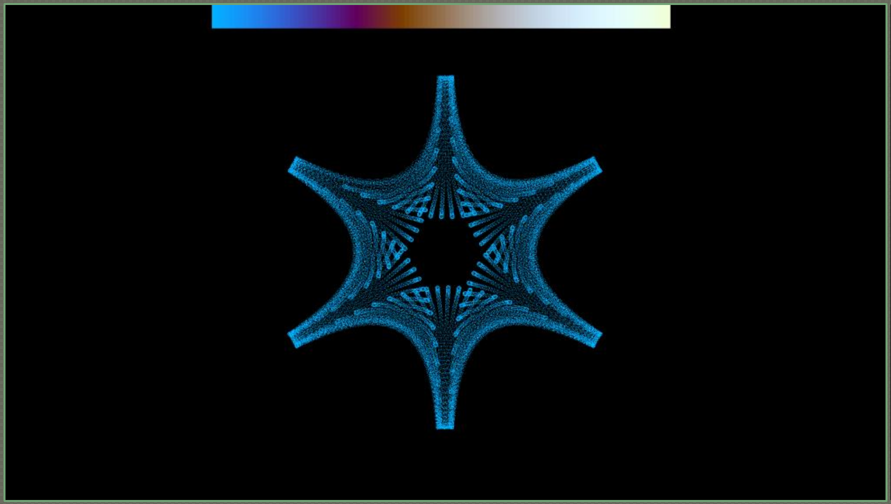
Monte-Carlo collisions

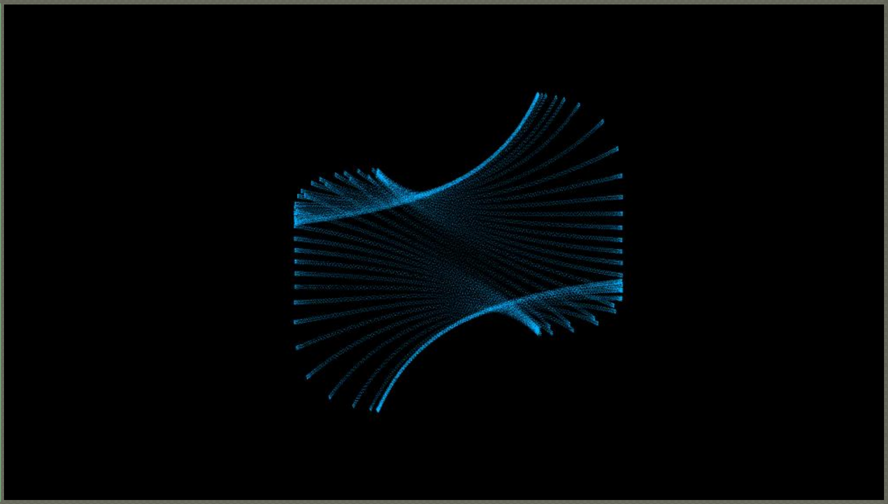
- Electron heating and ionization <– electron density from requirement of a quasi-neutrality
- Atomic processes: ionization, charge-change, recombination, neutralization in collisions with the chamber walls
- Ion-ion collisions: Takizuka-Abe model

Key assumption: mirror-confined volume

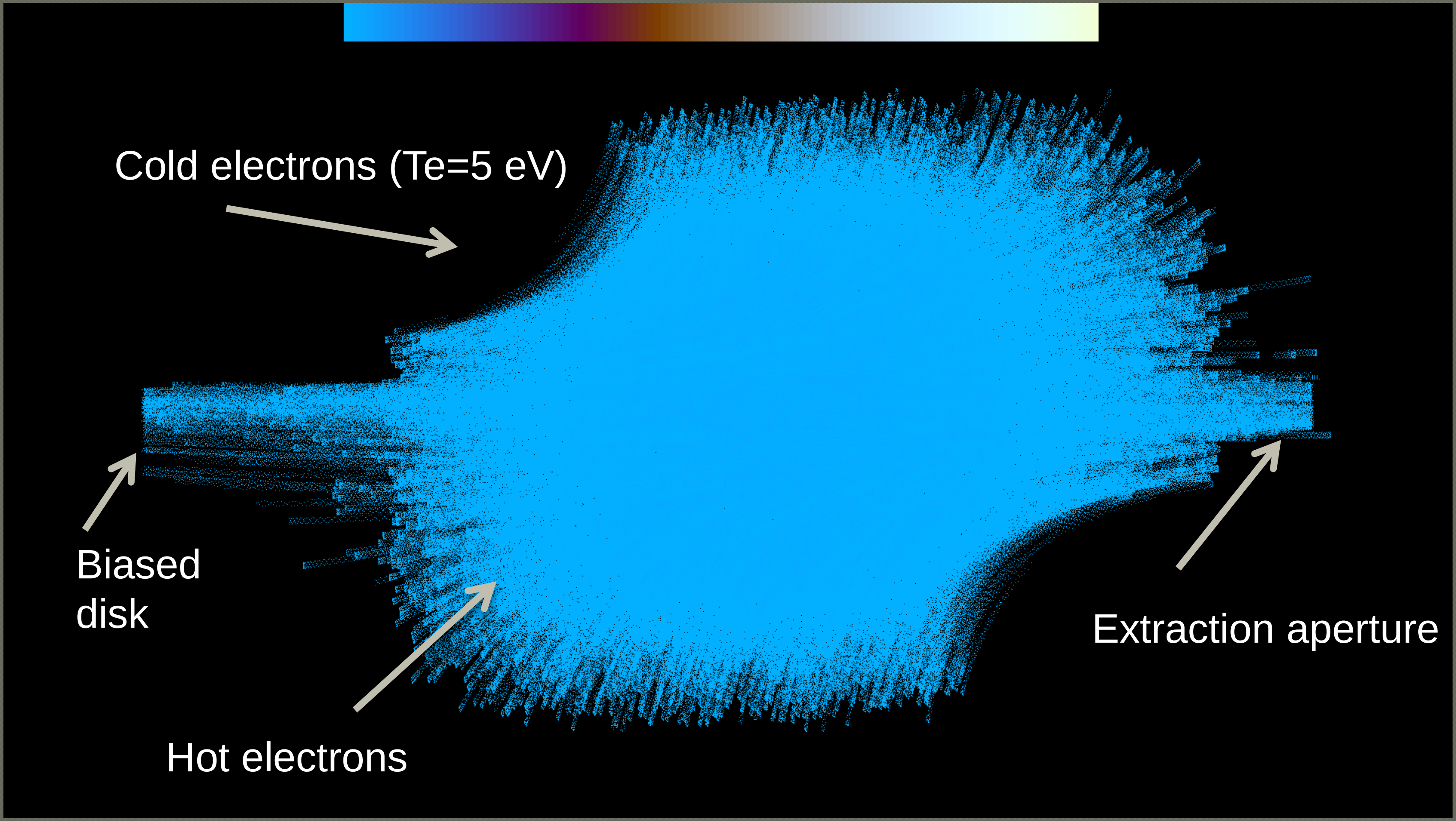
Electrons are drifting in the magnetic field of the source forming a set of closed orbits.

Grad-B drift $$\vec{v}_{\nabla B} = \frac{\epsilon_\perp}{qB} \frac{\vec{B} \times \nabla B}{B^2}$$

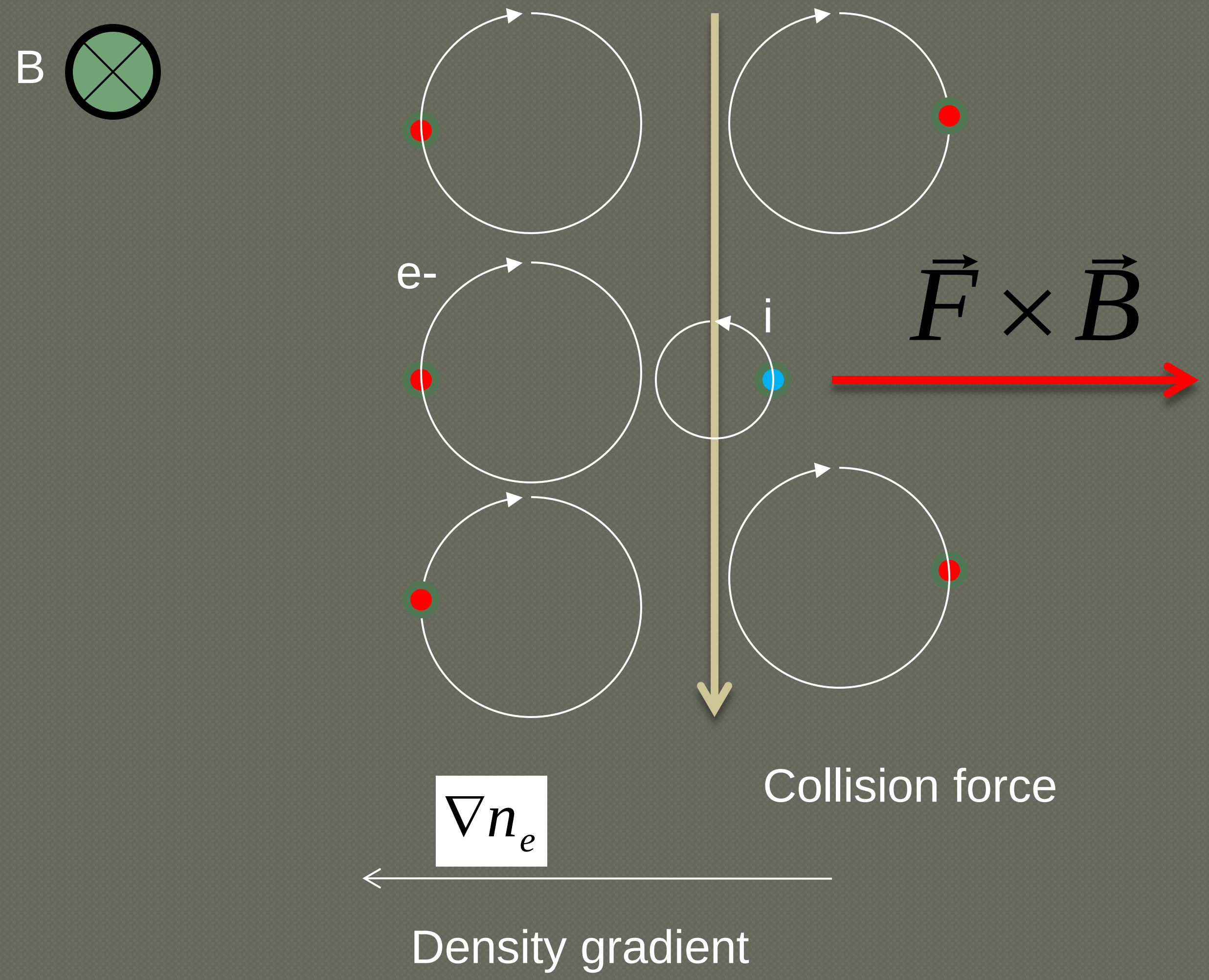




No electric fields in the volume except small regions close to the walls – in the sheath



Classical flux



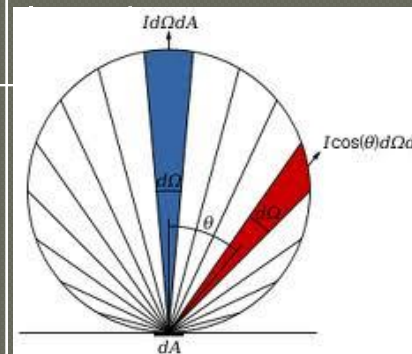
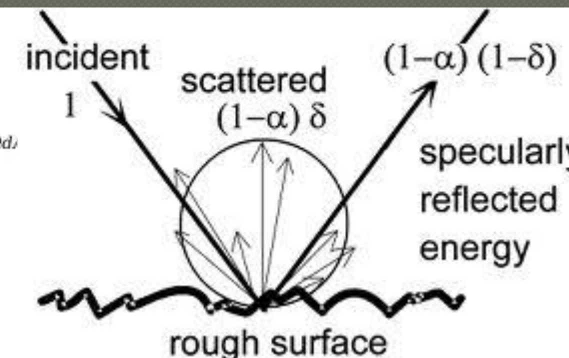
Classical fluxes

- Ion-ion collisions: higher charge states are pushed inward
- Electron-ion collisions: outward transport (ambipolar)

To model the e-i collisions: ions are kicked in a random direction with the corresponding dV.

Then, we make a small correction to direction of dV that depends on the density gradient and Larmor radius of electron.

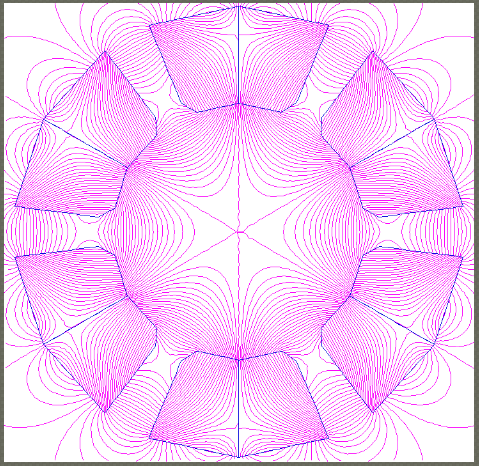
Gas temperature

When ion hits the chamber wall, it is neutralized	Fraction of the backscattered singly charged ions is
If not in extraction aperture, ion is scattered back with an angular distribution according to the cosine-law (diffuse scattering)	 
Energy distribution of neutralized atoms - room temperature, full accommodation	

Inputs

- Magnetic field: POISSON + analytical hexapole component (hard edge) – KVI AECRIS
- Coupled microwave power -> electron temperature
- Gas flow into the chamber = flow into the extraction aperture

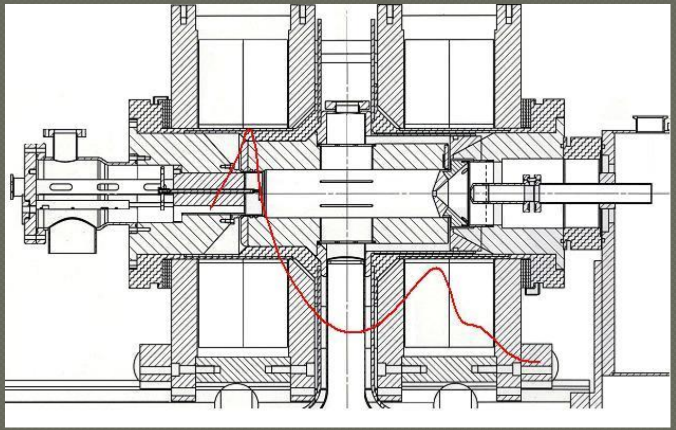
KVI A-ECRIS layout and performance



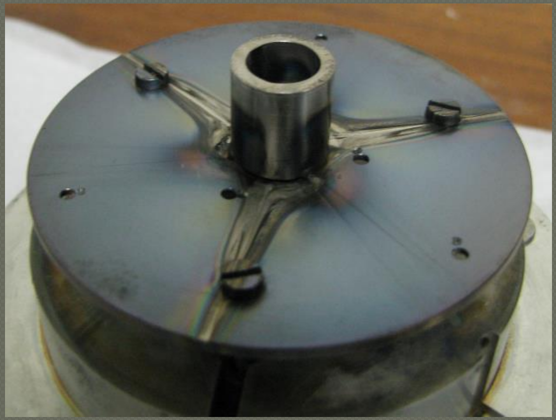
Al plasma chamber, hexapole with the slits for better pumping of the chamber.

RF frequency 14+(11-12.5) GHz

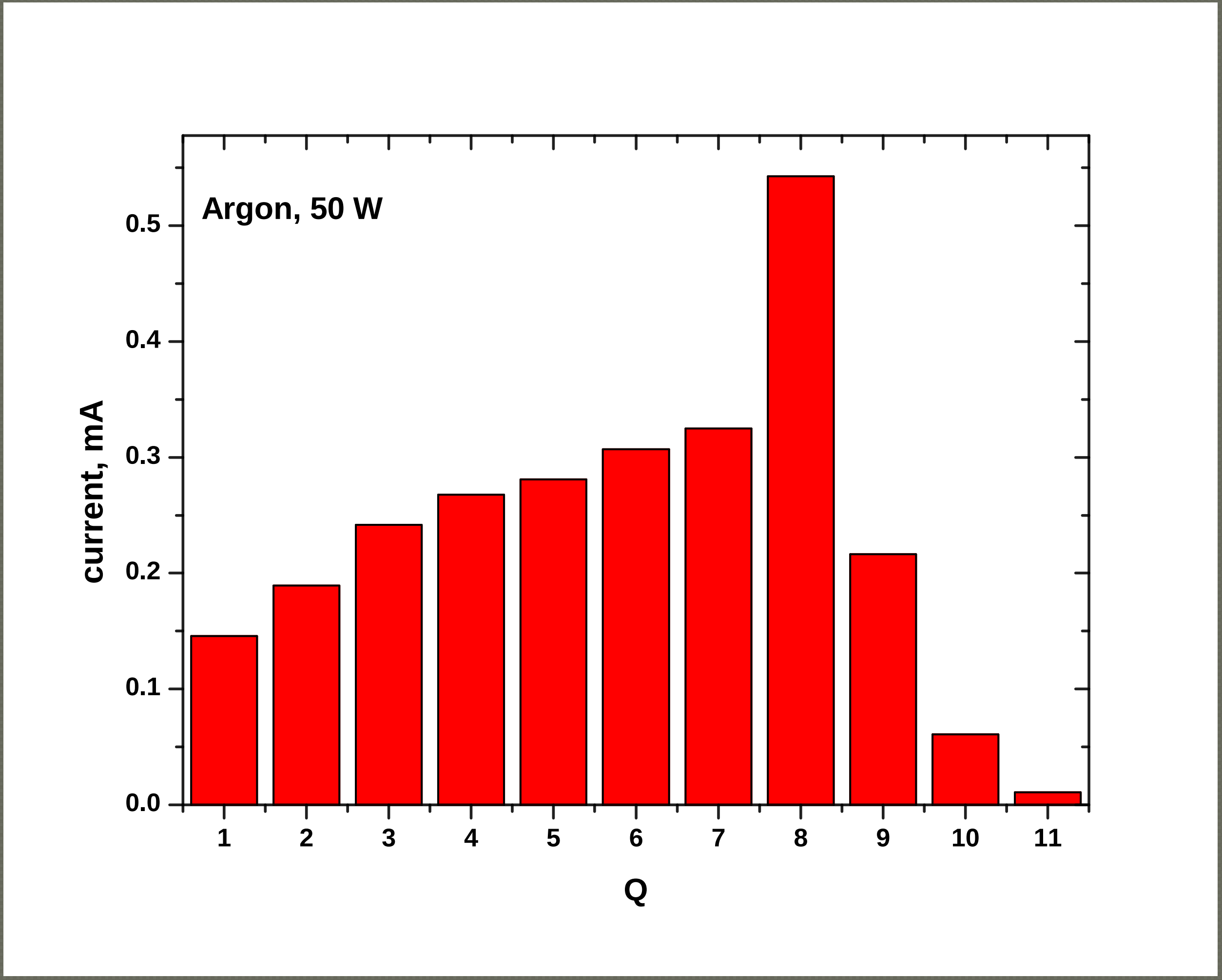
- B_{inj}=2.1 T, B_{min}=0.36 T
- B_{ext}=1.1 T, B_{rad}=0.85 T
- Chamber length 30 cm
- Chamber diameter 7.6 cm
- Extraction aperture 0.8 cm



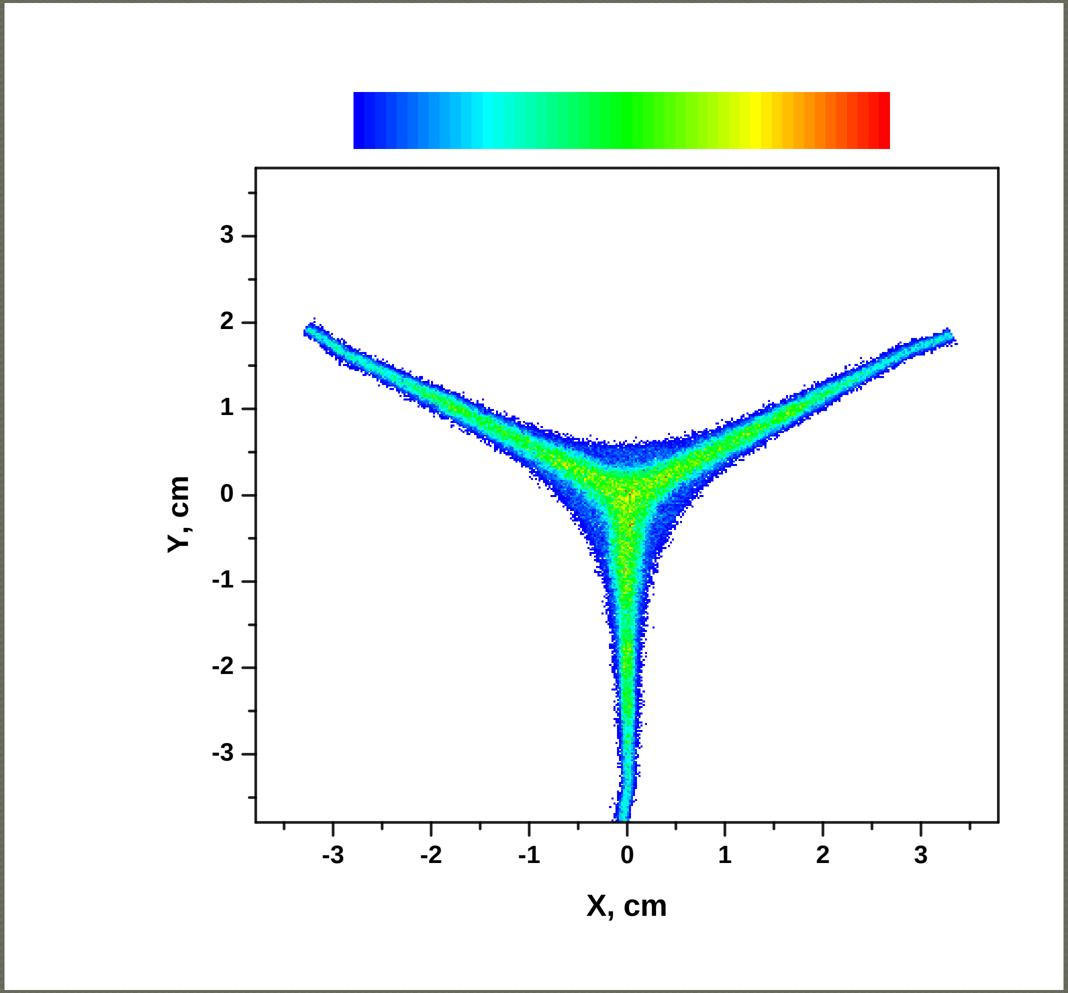
Q	C	O	F	Ne	Ar	Q	Pb
1	11		67	105	55	23	19
2	40		134	158	69	24	25
3	270		159	245	61	25	29
4	187	-	183	394	75	-	-
5	61		188	590	119	27	26
6	~5	700	107	446	174	28	19
7		110	55	224	275	29	16
8				87	488	30	9
9					250	31	5
10					-		
11					20		



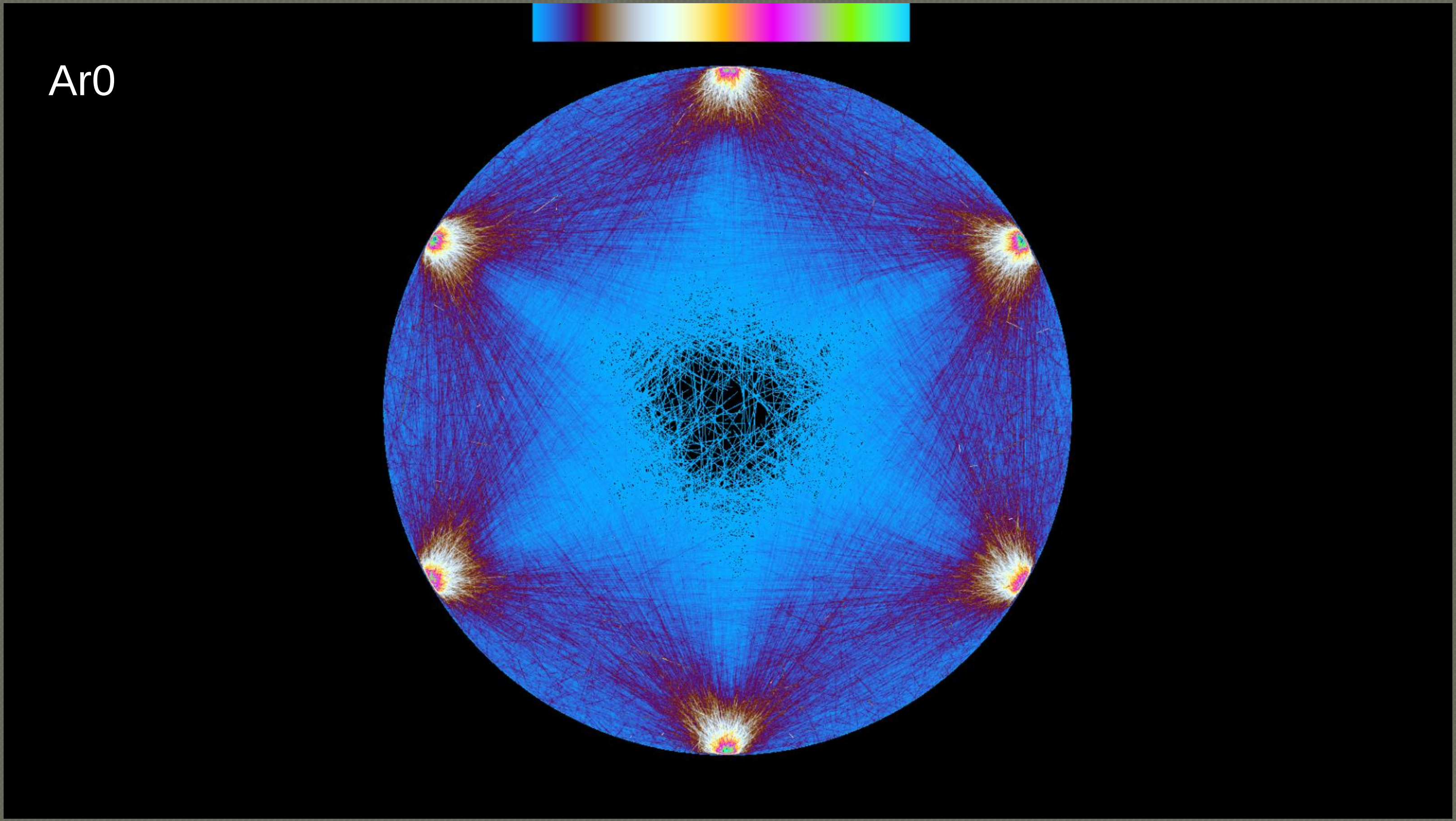
Typical spectrum (argon)



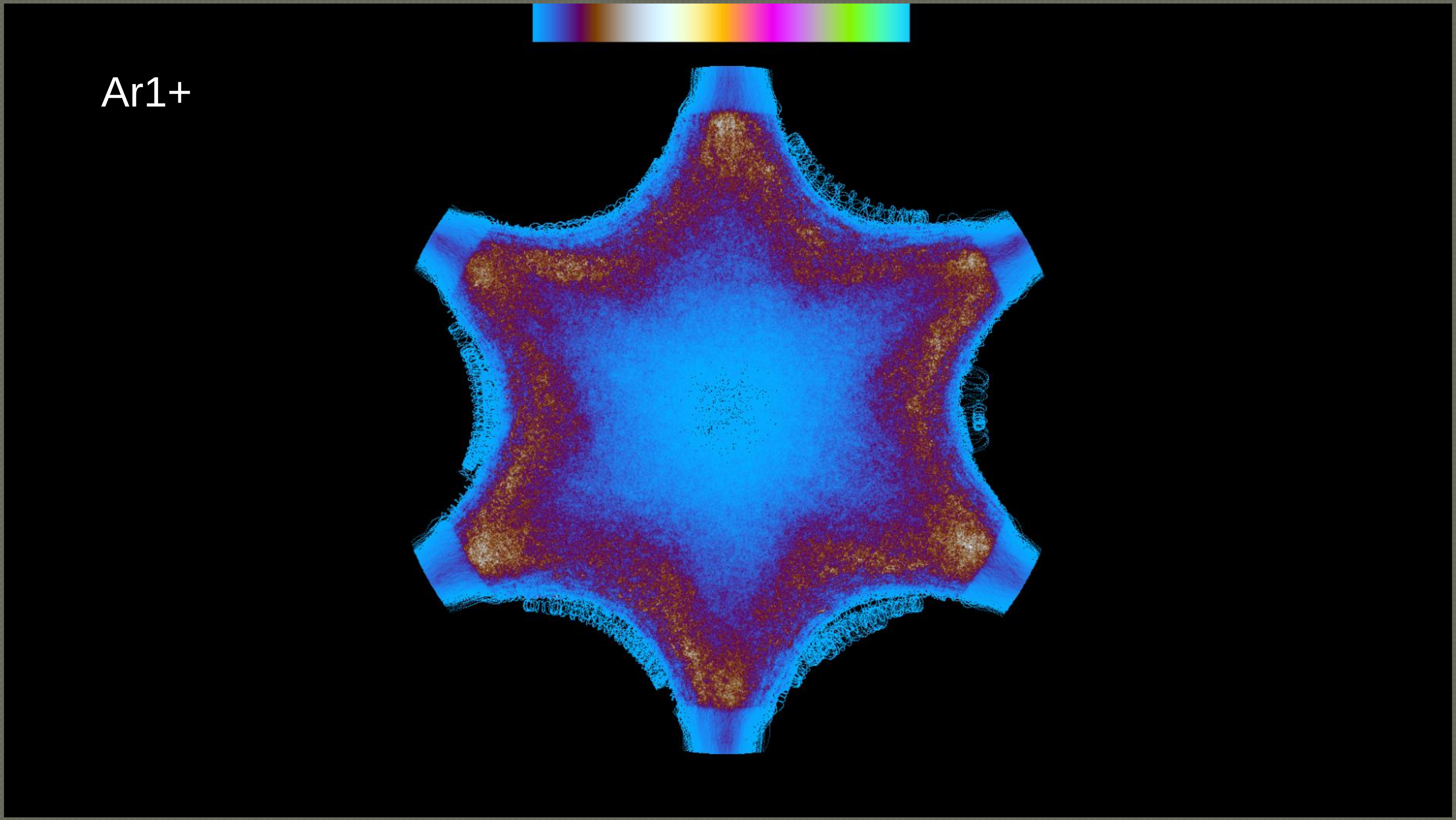
Ions at the extraction electrode



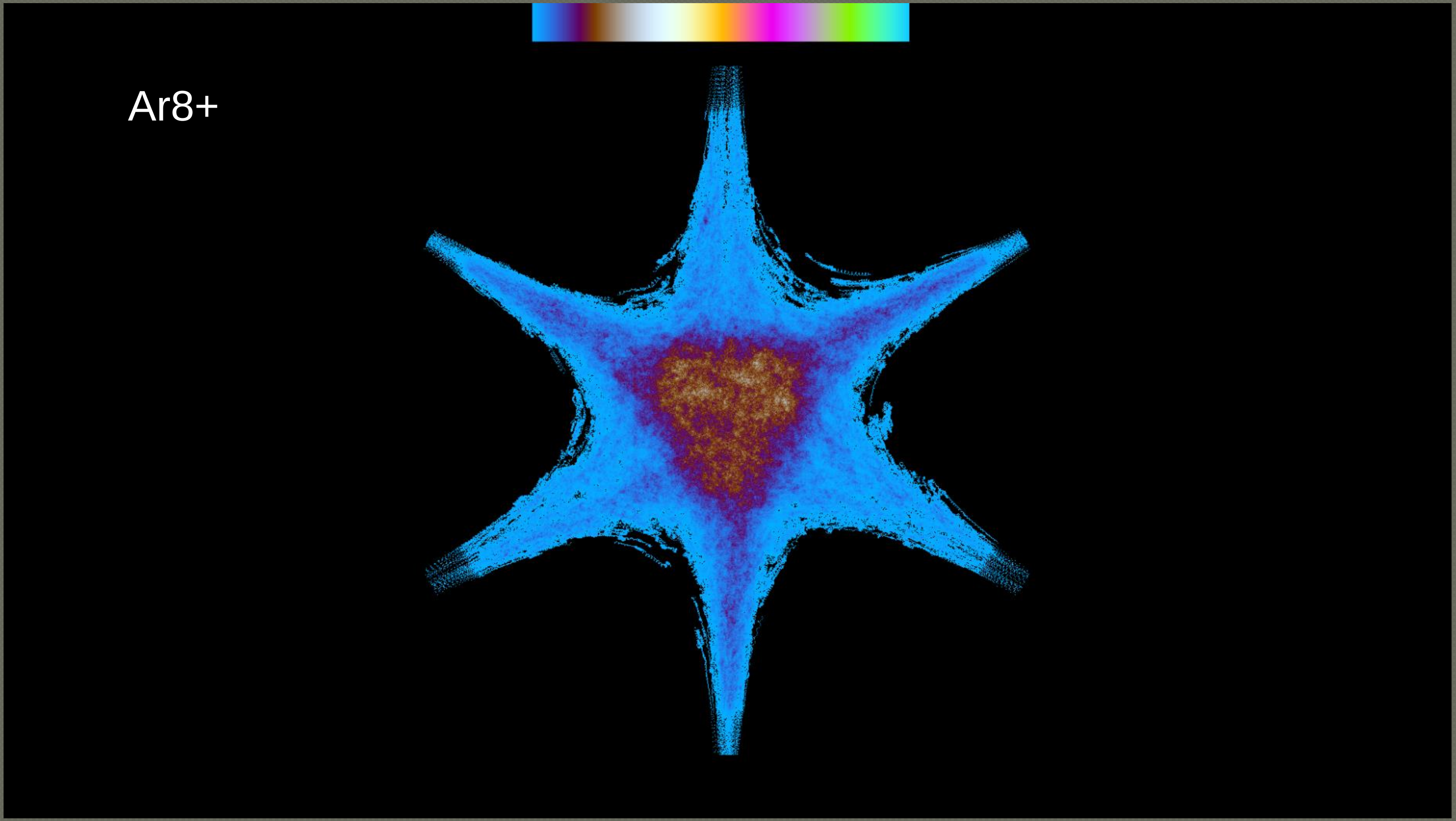
Gas density at the center



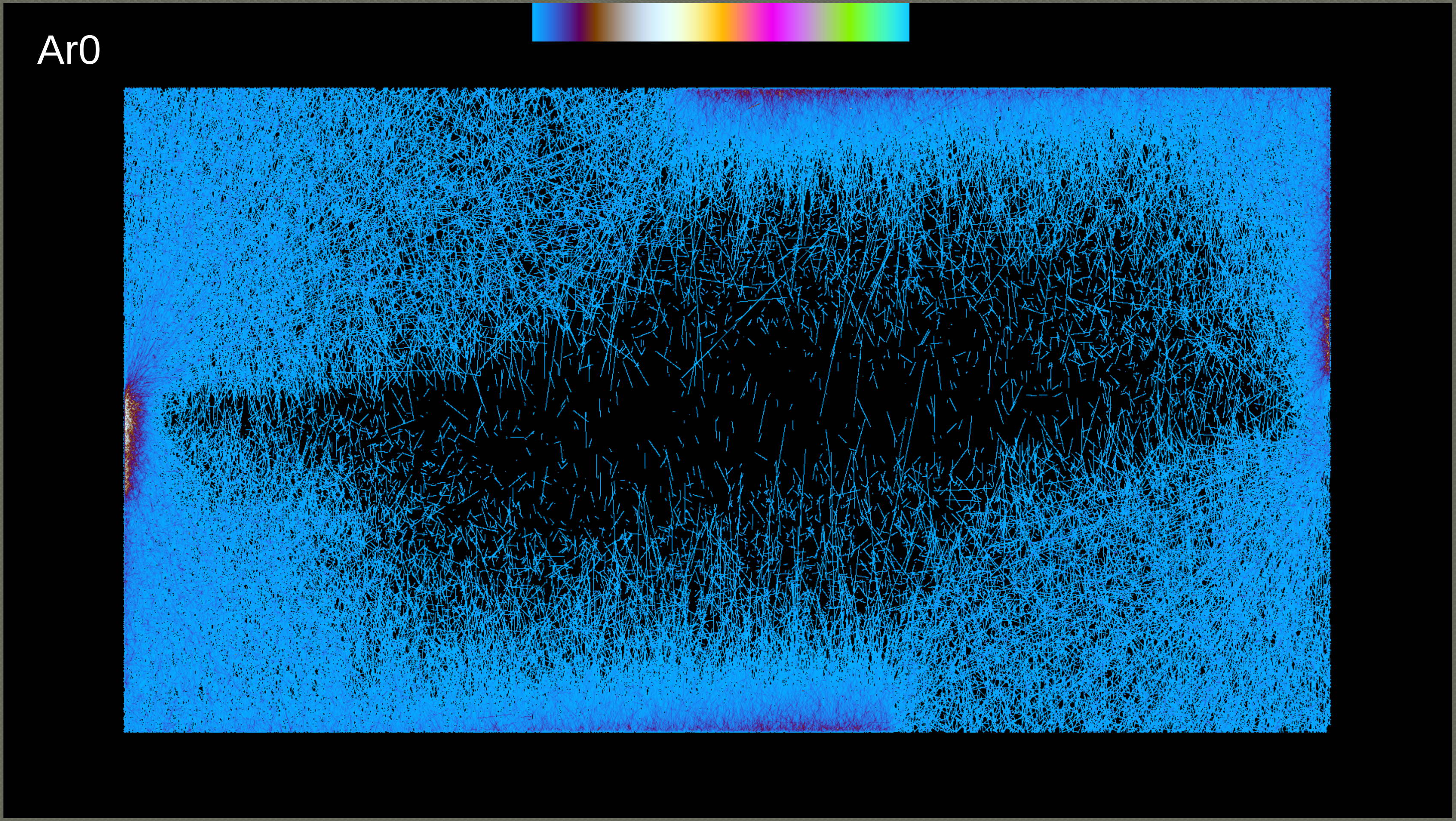
Ion density at the center



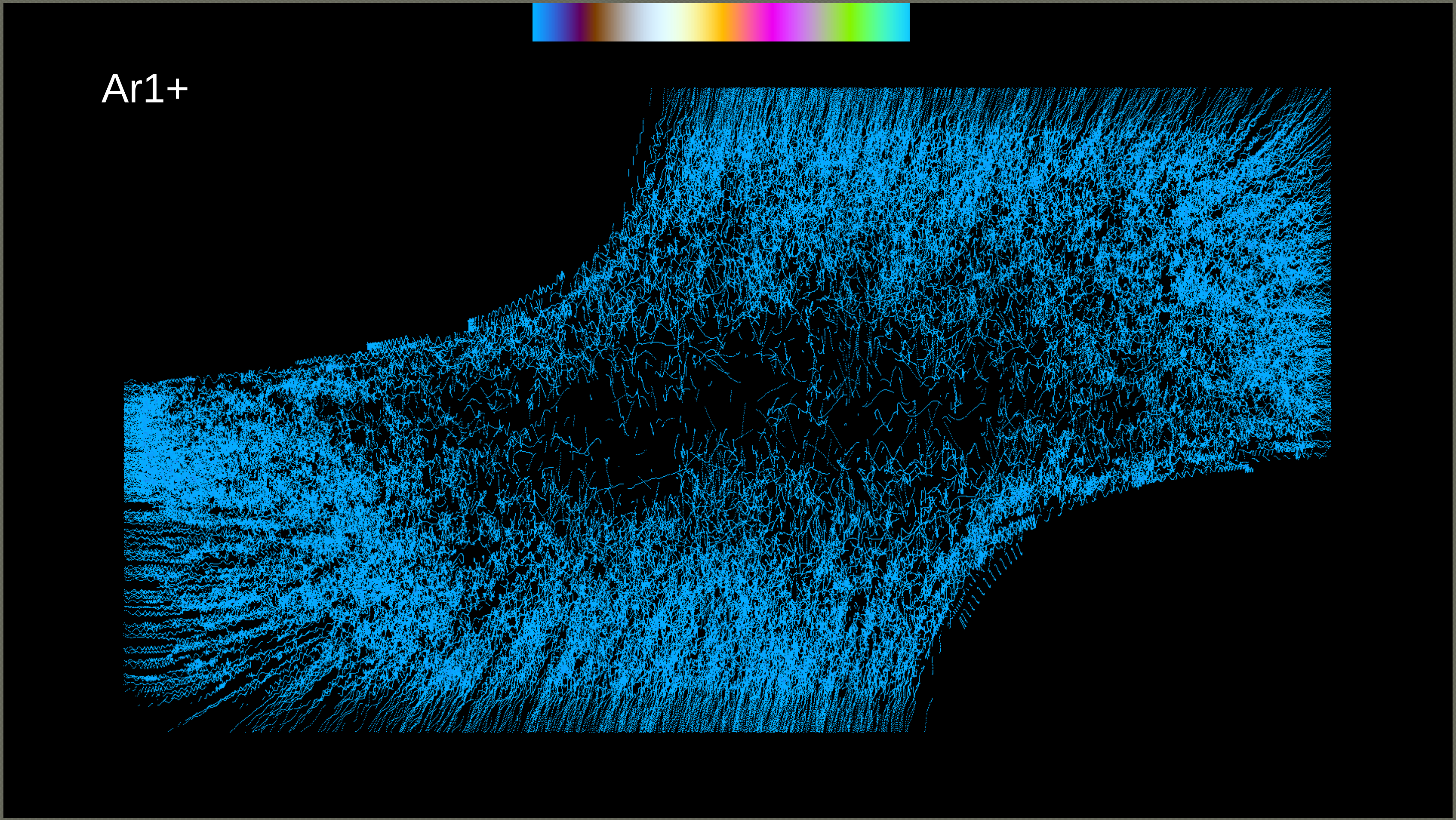
Ion density at the center



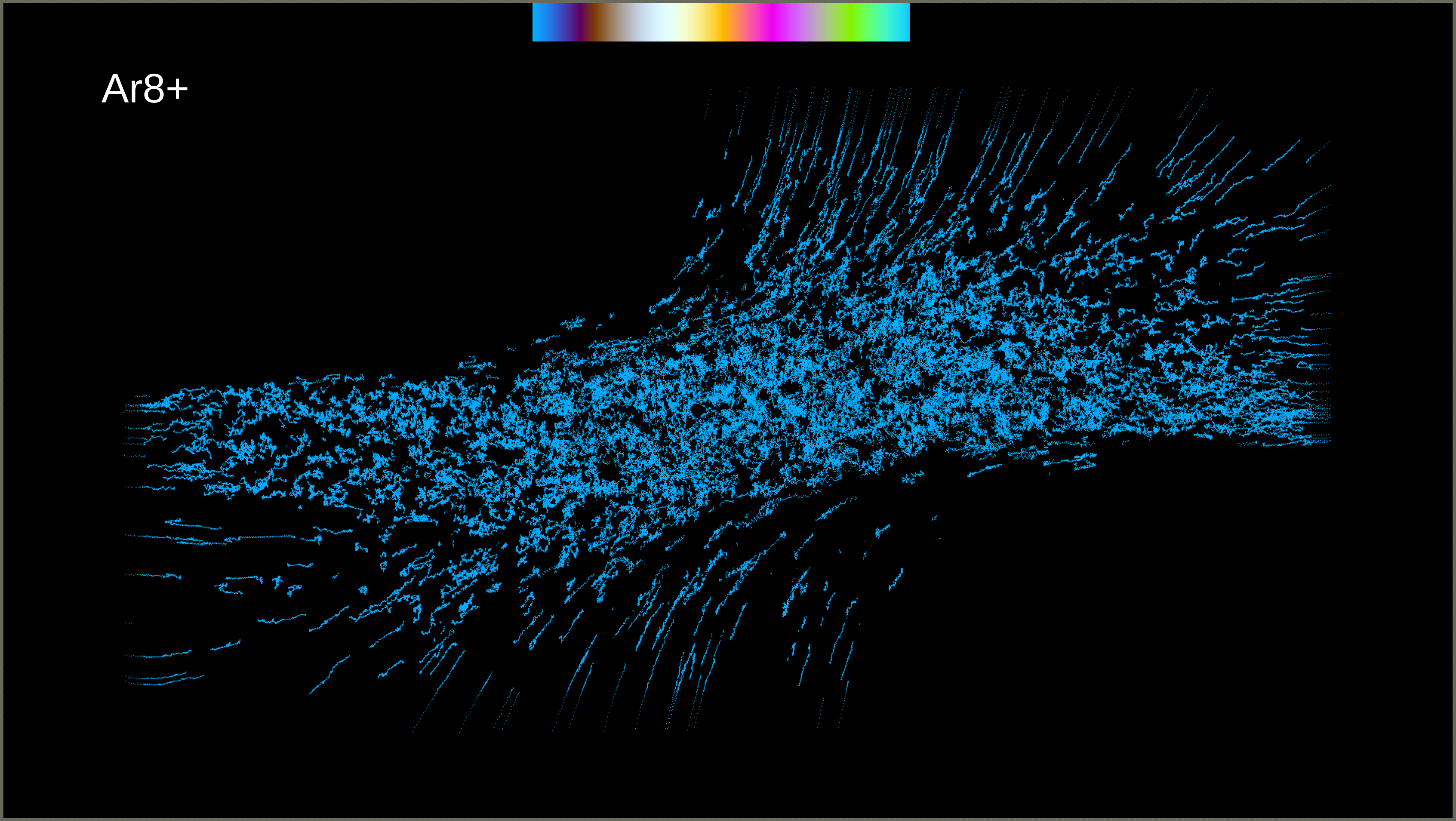
Gas density in x-y plane



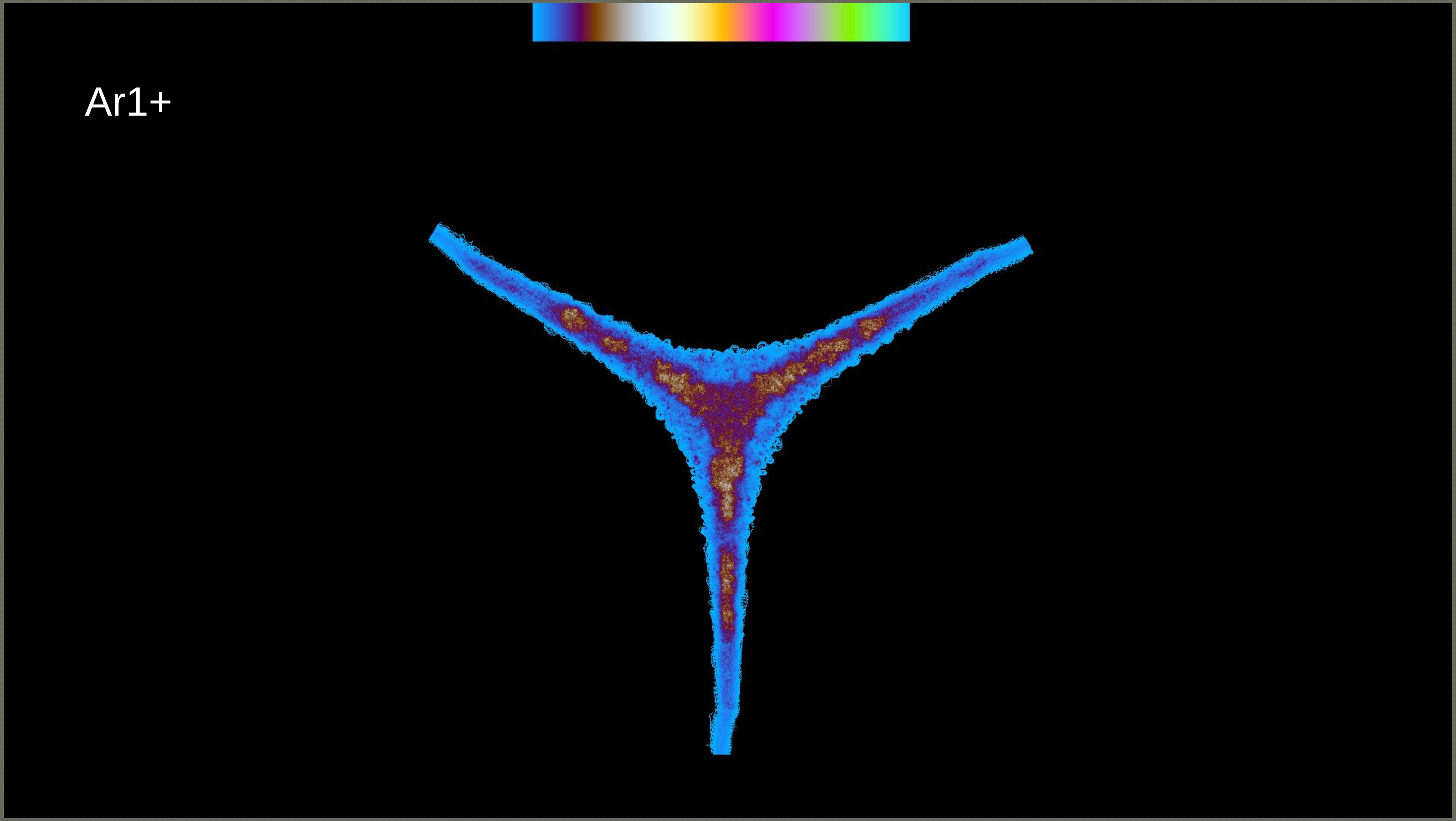
Ion density in x-y plane



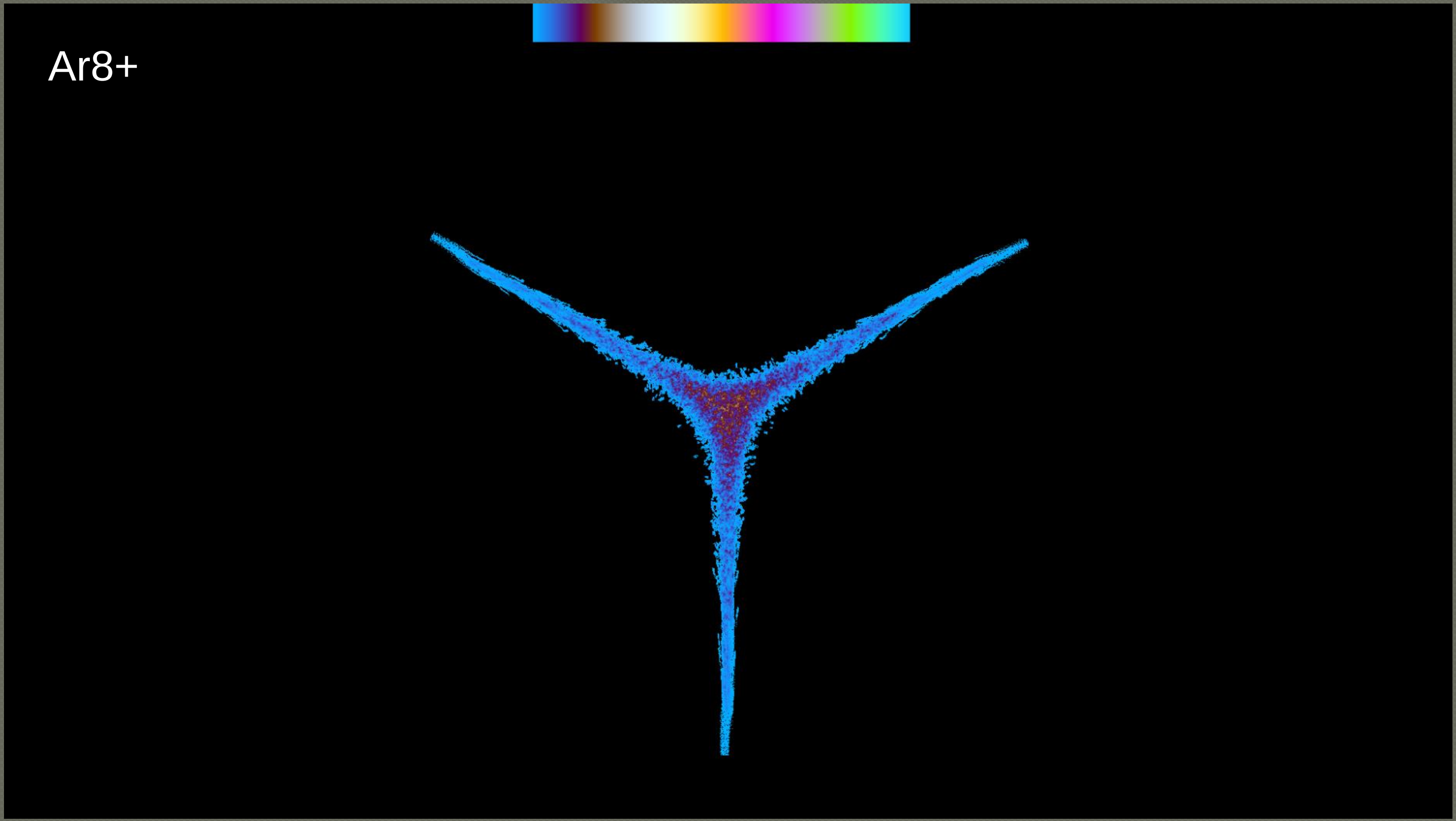
Ion density in x-y plane



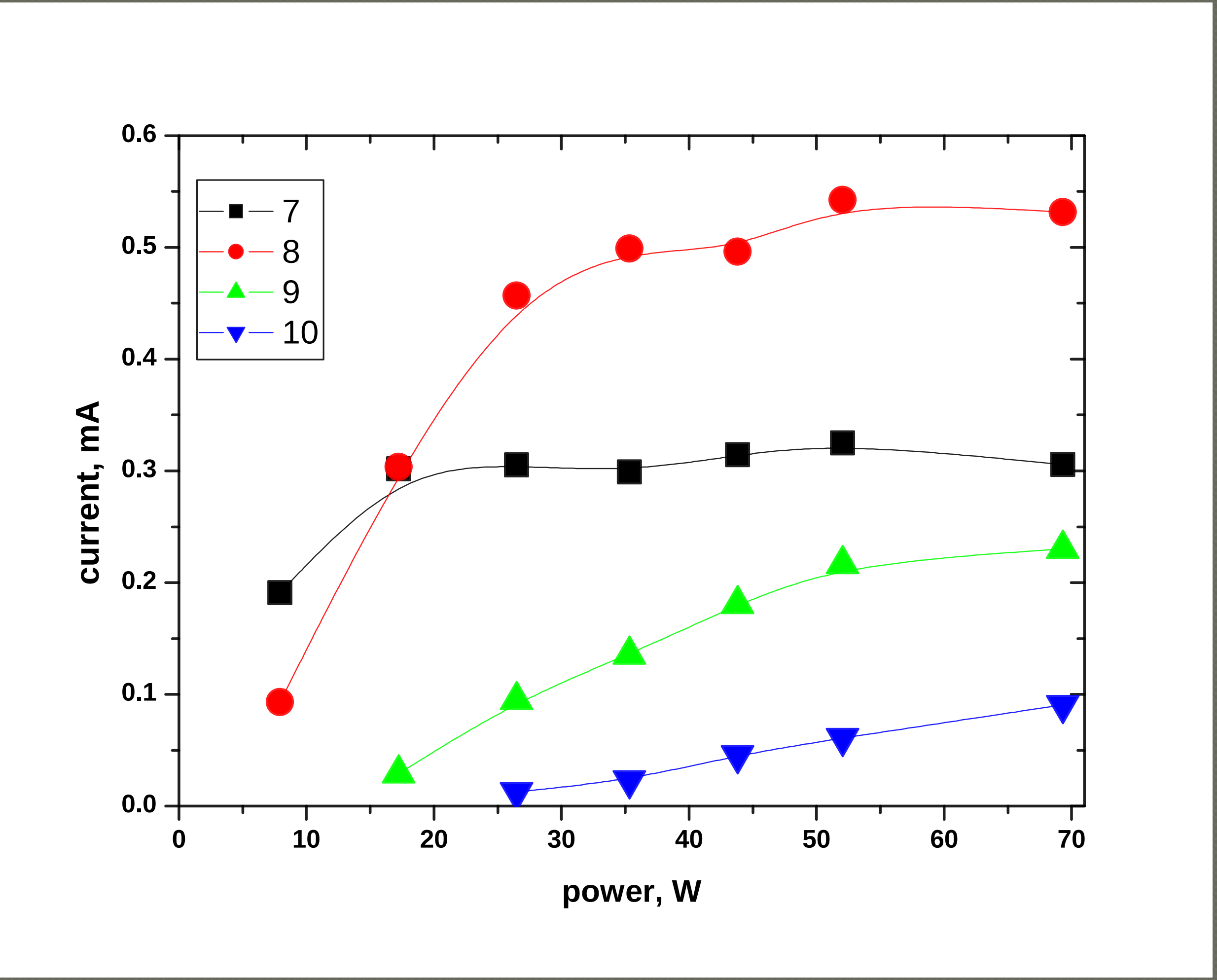
Ion density at extraction



Ion density at extraction

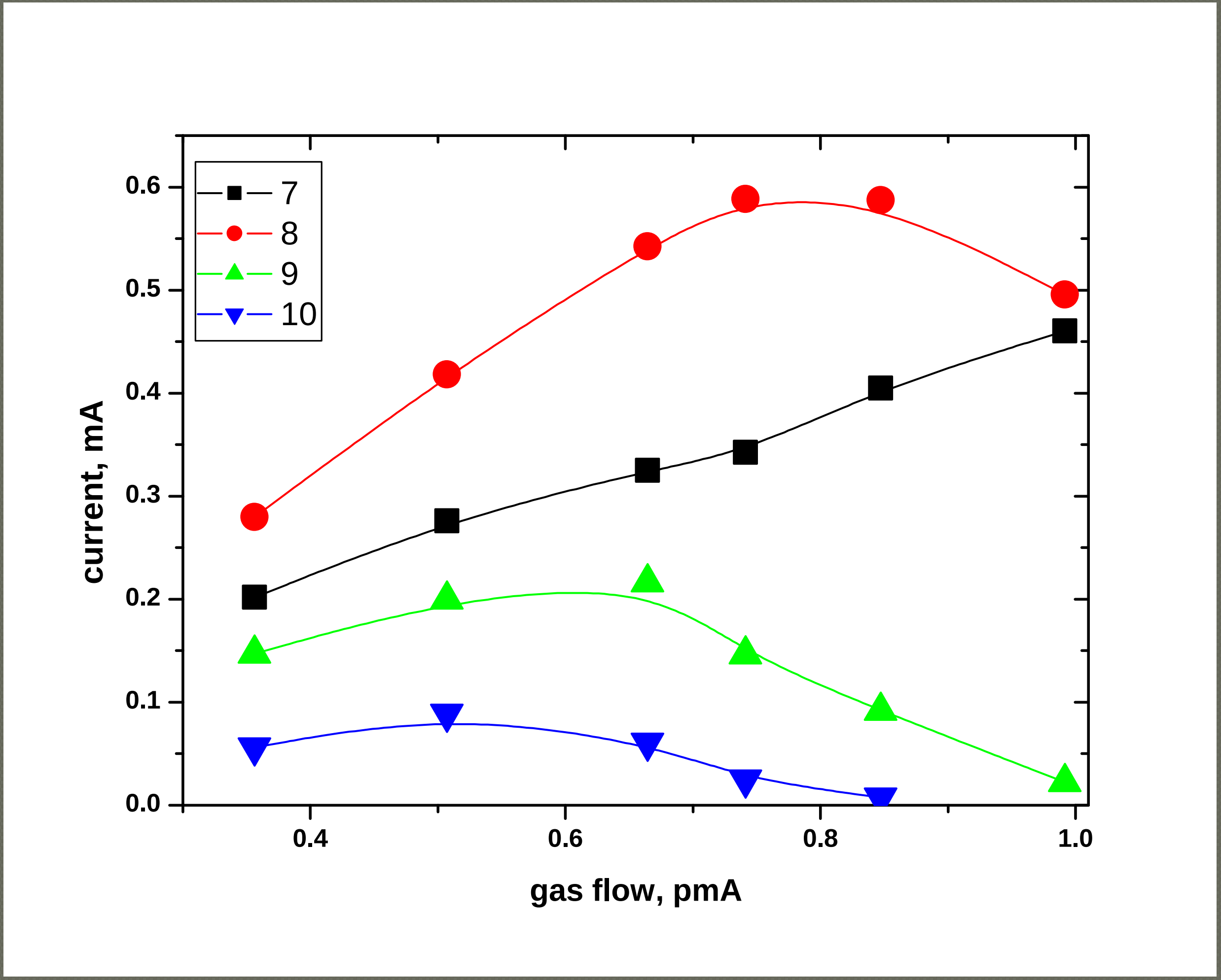


RF power@ the same gas flow

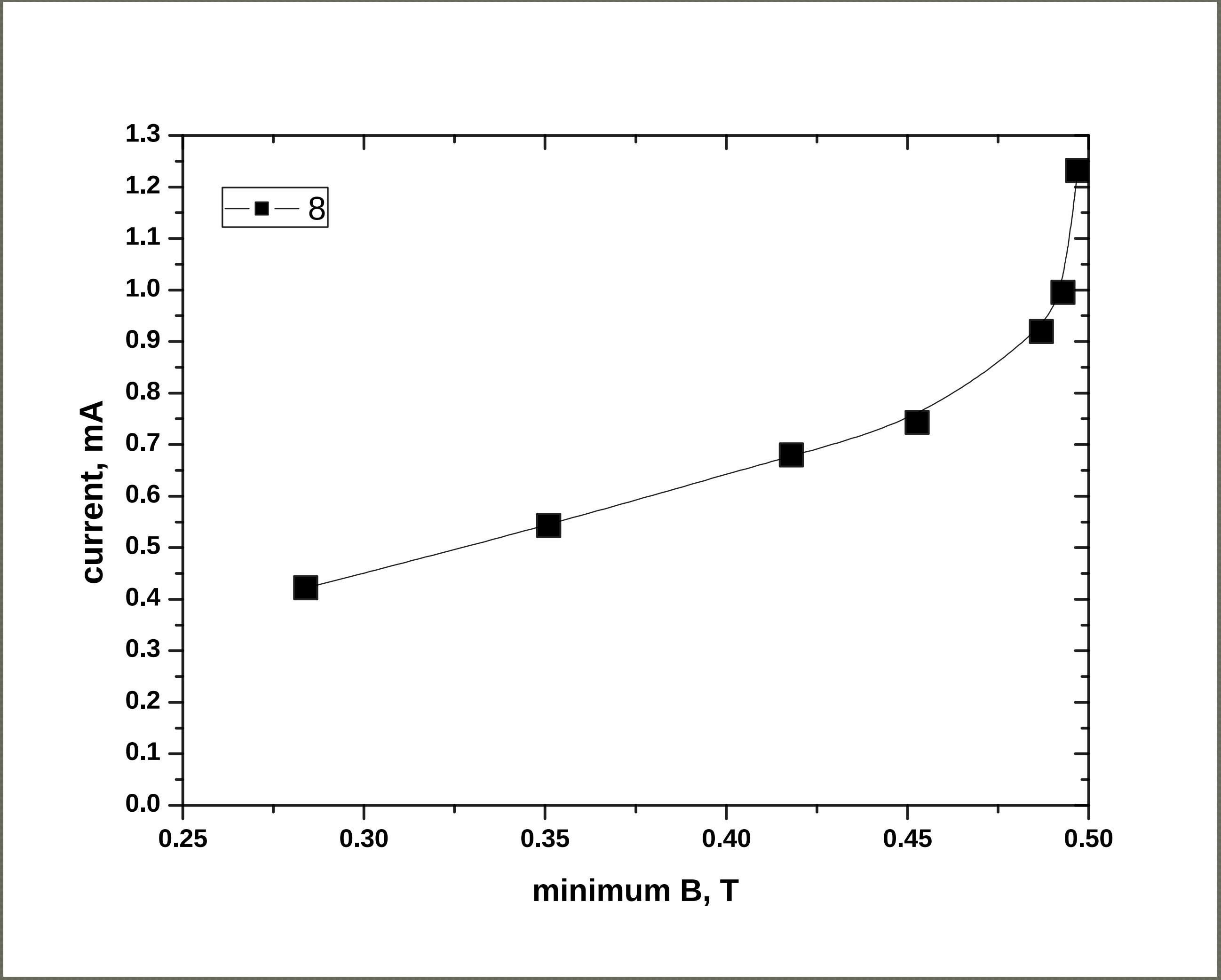


Gas-flow @50 W of RF

Argon 50 W



Minimum field



Minimum field

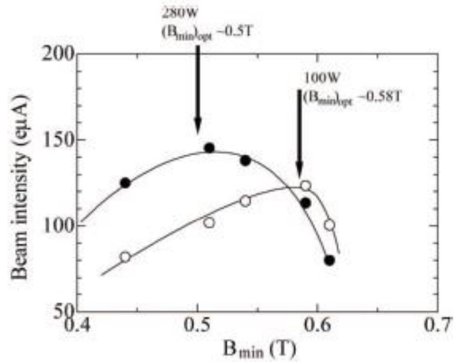


Fig. 3. Beam intensity of Ar^{9+} as a function of B_{min} at the RF power of 100 and 280W.

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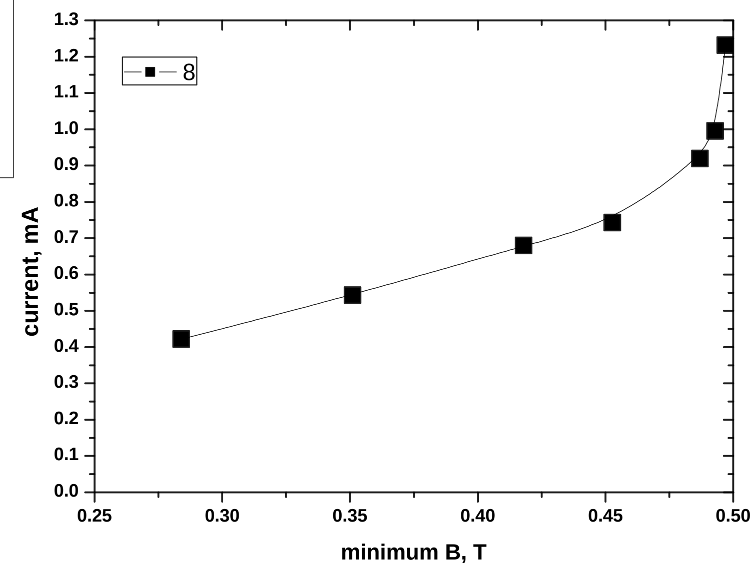
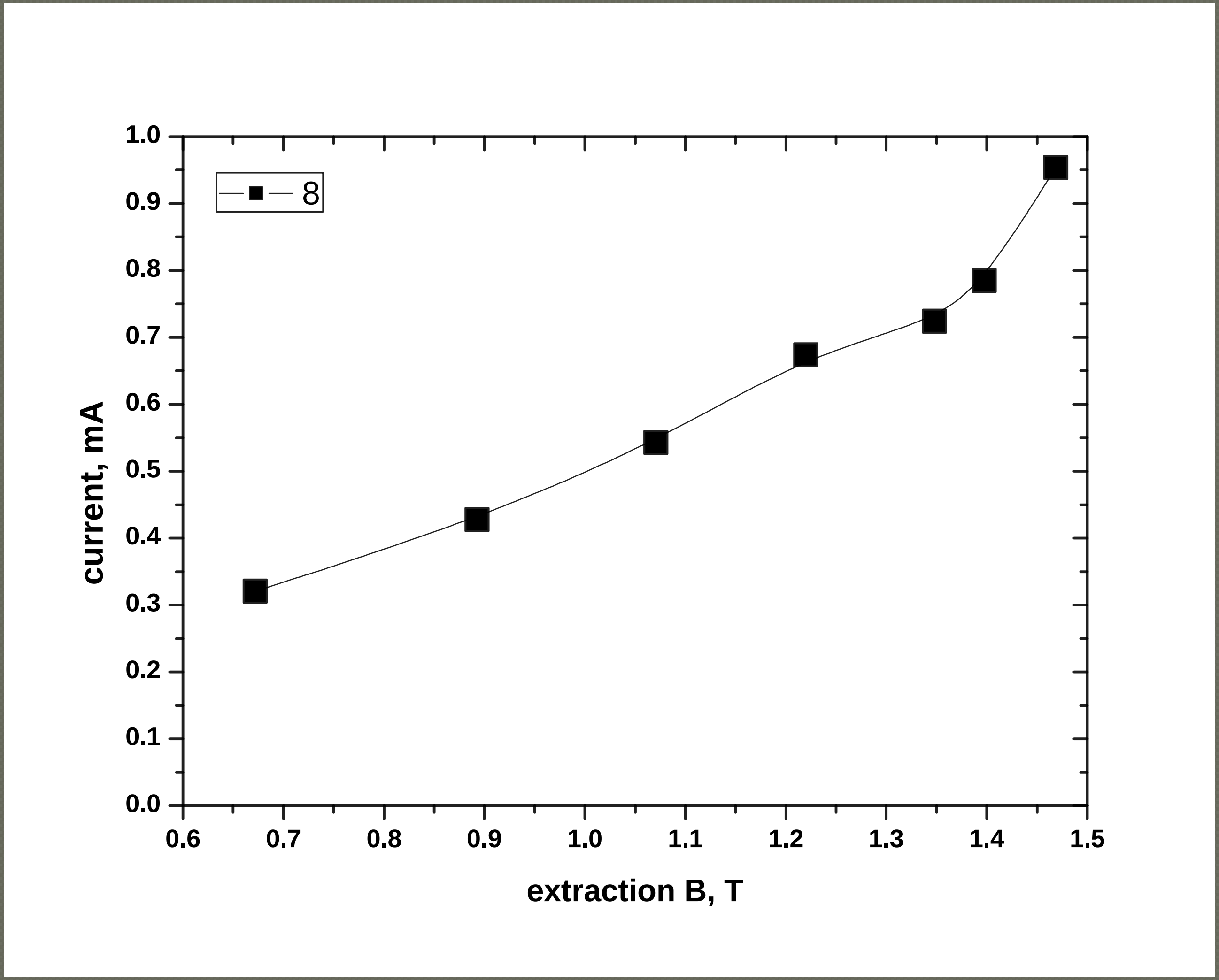
2007 年 7 月 HIGH ENERGY PHYSICS AND NUCLEAR PHYSICS Jul., 2007

Magnetic Field Configuration Effect and New ECRISs for RIKEN RIBF Project

T. Nakagawa[1] M. Kidera[1] Y. Higurasi[1] J. Ohnishi[1] T. Kageyama[1] T. Aihara[2] A. Goto[1] Y. Yano[1]
1 (Nishina Center for Accelerator Based Science, RIKEN, Hirosawa 2-1, Wako, Saitama 351-0198, Japan)
2 (SAS Ltd, Ohsaki 1-17-6, Sinagawa-ku, Tokyo, 141-0032, Japan)



Extraction field



Extraction field

Gammino *et al.*

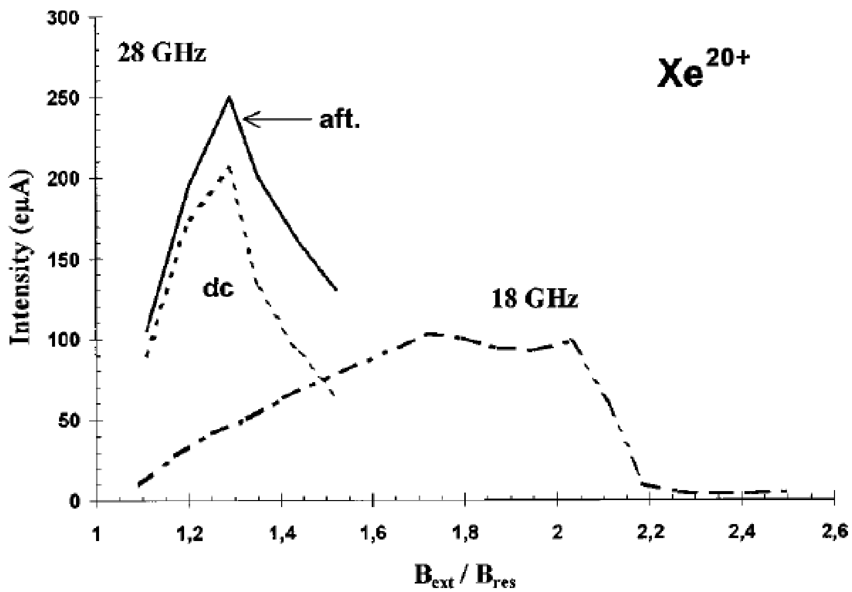
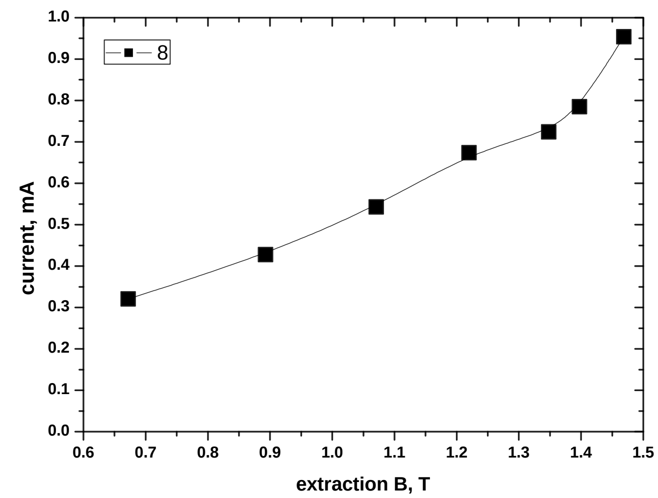


FIG. 12. Evolution of Xe^{20+} with the extraction magnetic field at different frequencies.



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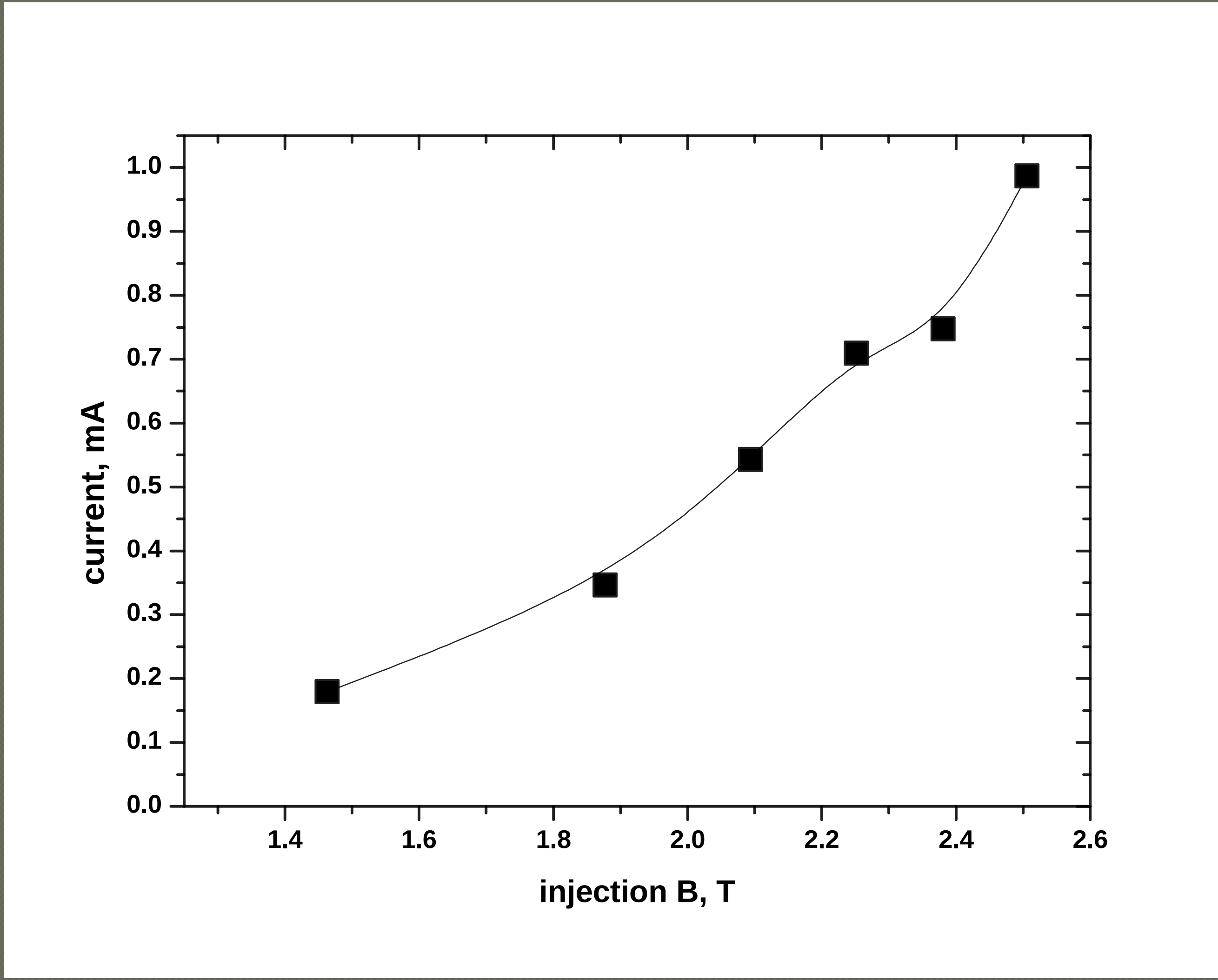
Injection field



Injection field

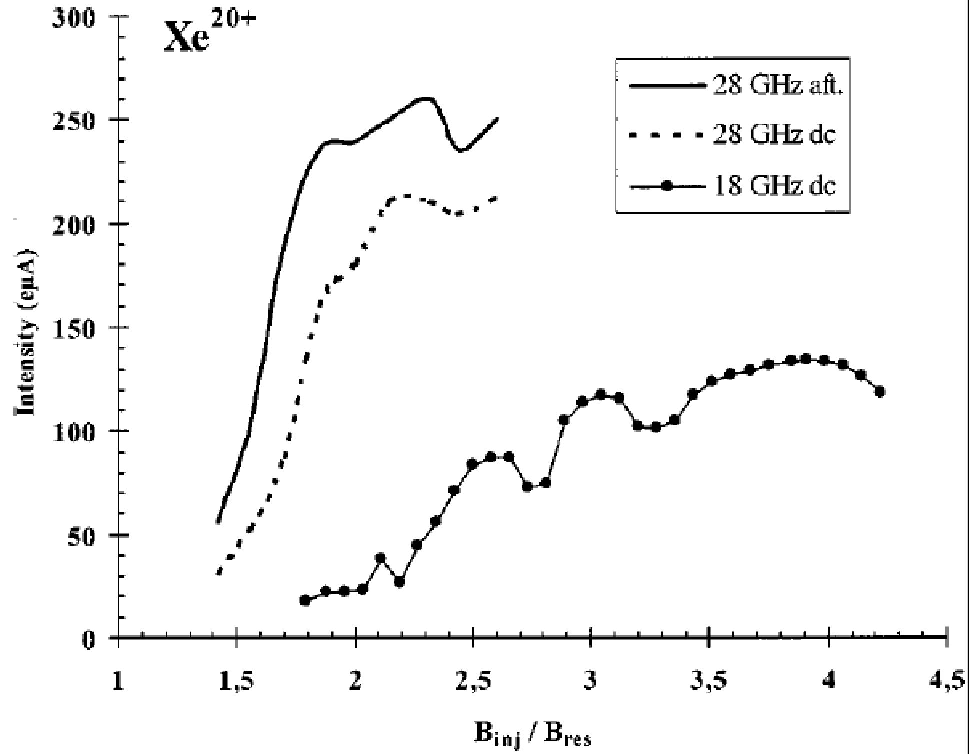
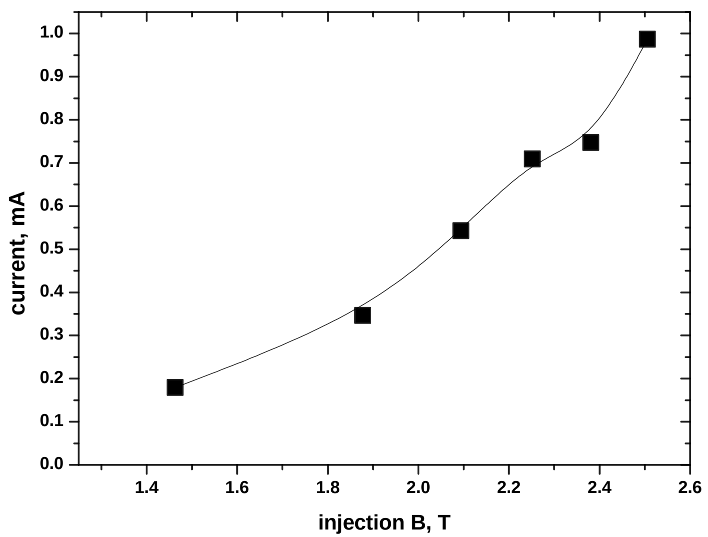
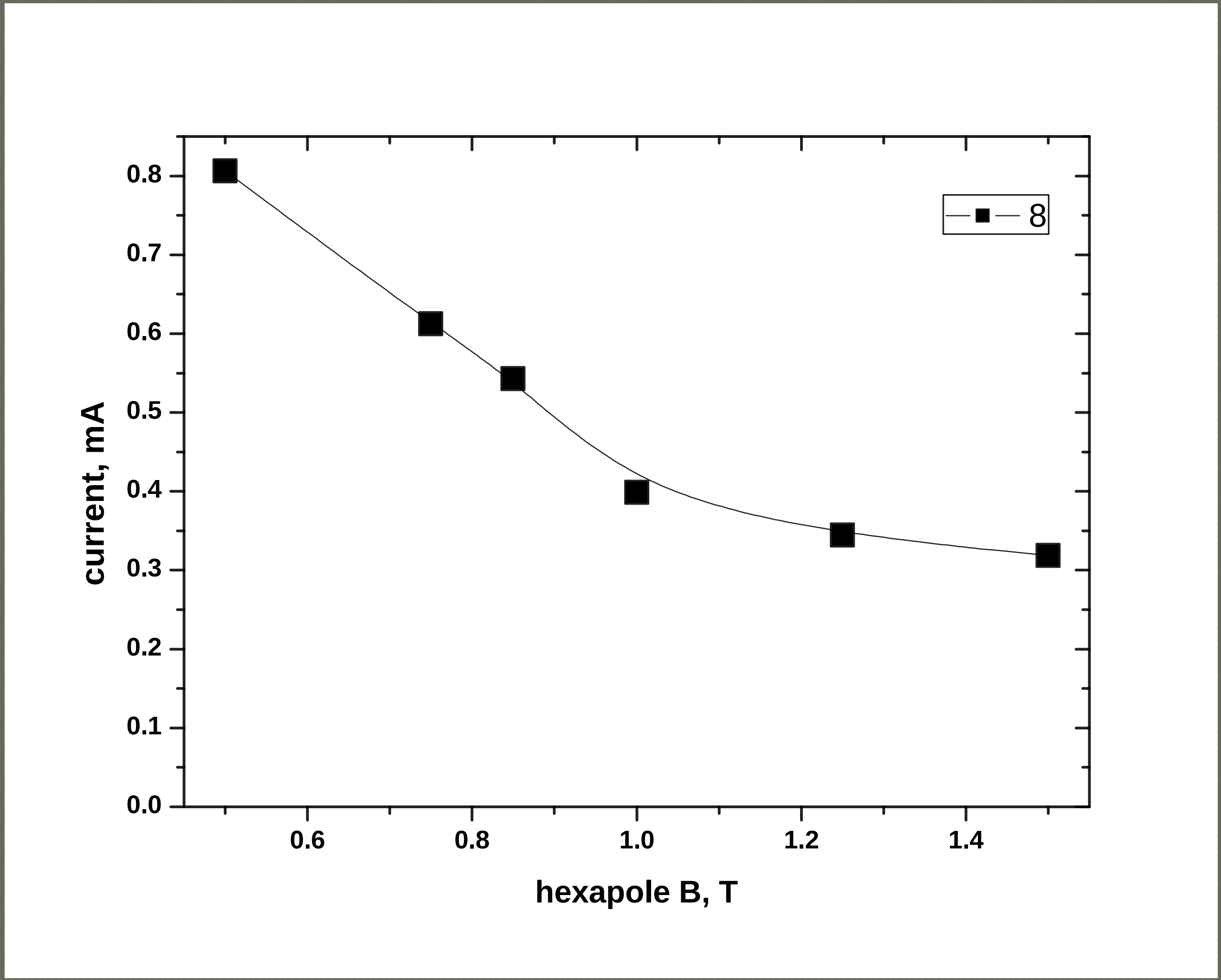


FIG. 11. Evolution of Xe^{20+} with the injection magnetic field.



Hexapole field



Hexapole field

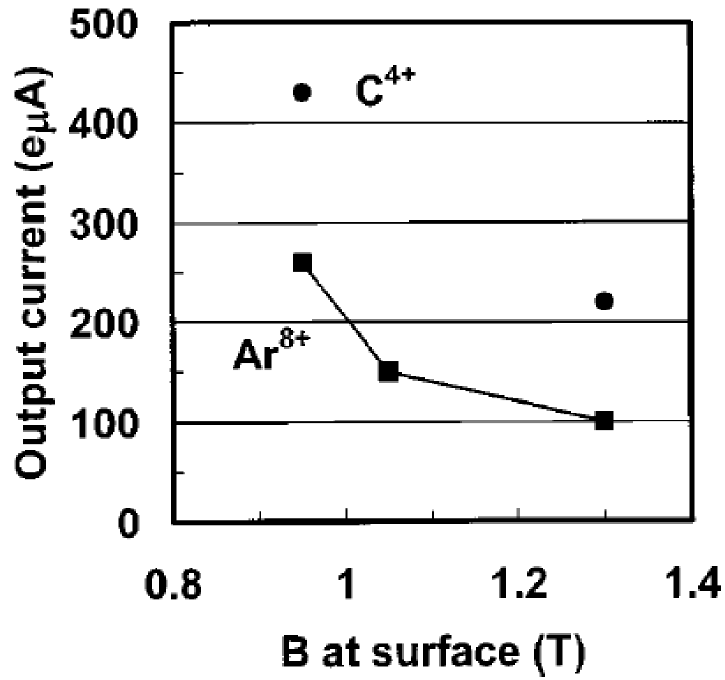
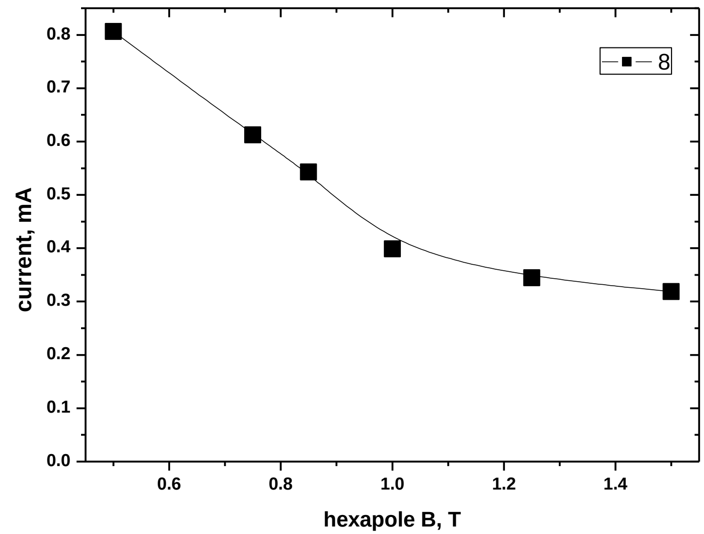


FIG. 4. Output currents of Ar^{8+} and C^{4+} for 10 GHz NIRS-ECR with radial magnetic fields $B_r = 0.95$, 1.05, and 1.3 T.



REVIEW OF SCIENTIFIC INSTRUMENTS VOLUME 73, NUMBER 2 FEBRUARY 2002

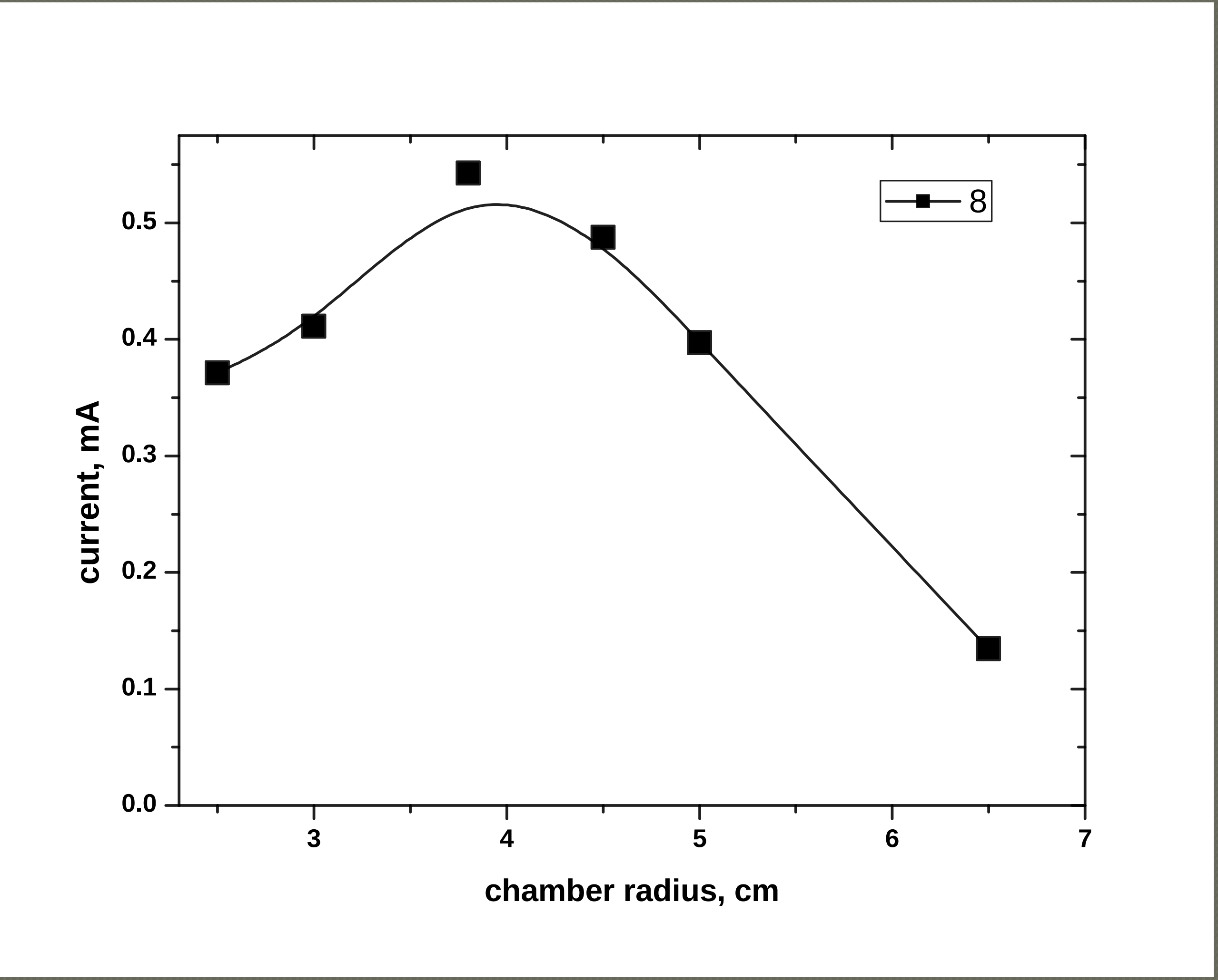
Study of the extracted beam and the radial magnetic field of electron cyclotron resonance ion source at HIMAC

A. Kitagawa,[a] M. Muramatsu, M. Sasaki, and S. Yamada
National Institute of Radiological Sciences, 4-9-1 Anagawa, Inage, Chiba 263-8555, Japan

S. Biri
Institute of Nuclear Research (ATOMKI), H-4026 Debrecen, Bem ter 18/C, Hungary

K. Jincho, T. Okada, T. Sakuma, W. Takasugi, and M. Yamamoto
Accelerator Engineering Corporation, 2-10-14 Konakadai, Inage, Chiba 263-0043, Japan

Chamber size



Chamber size

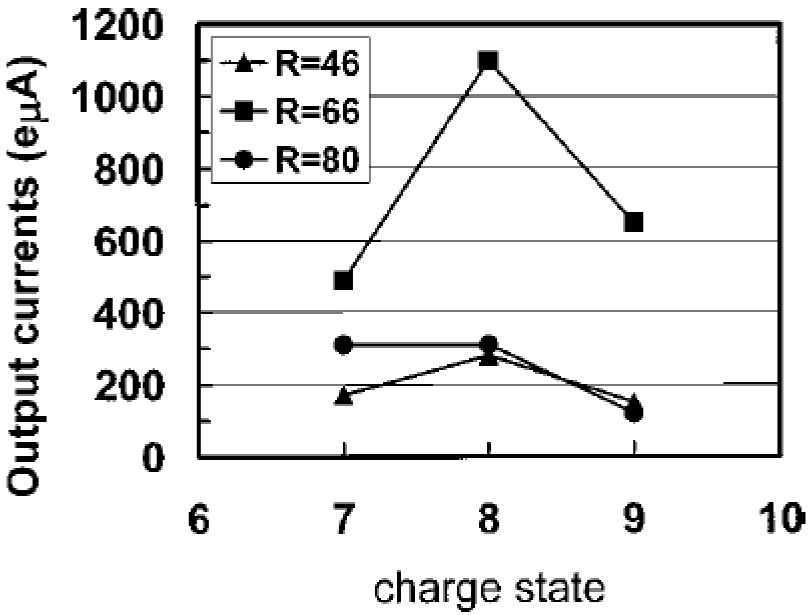
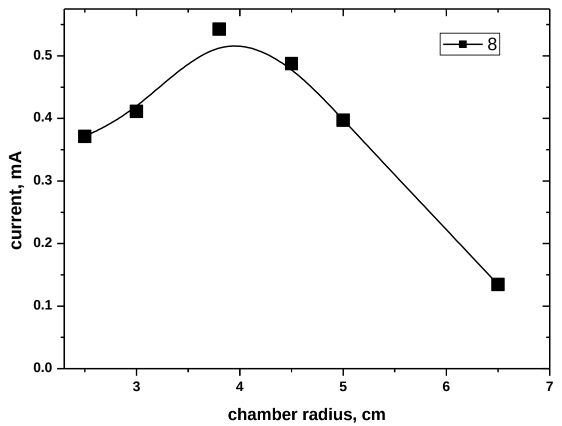
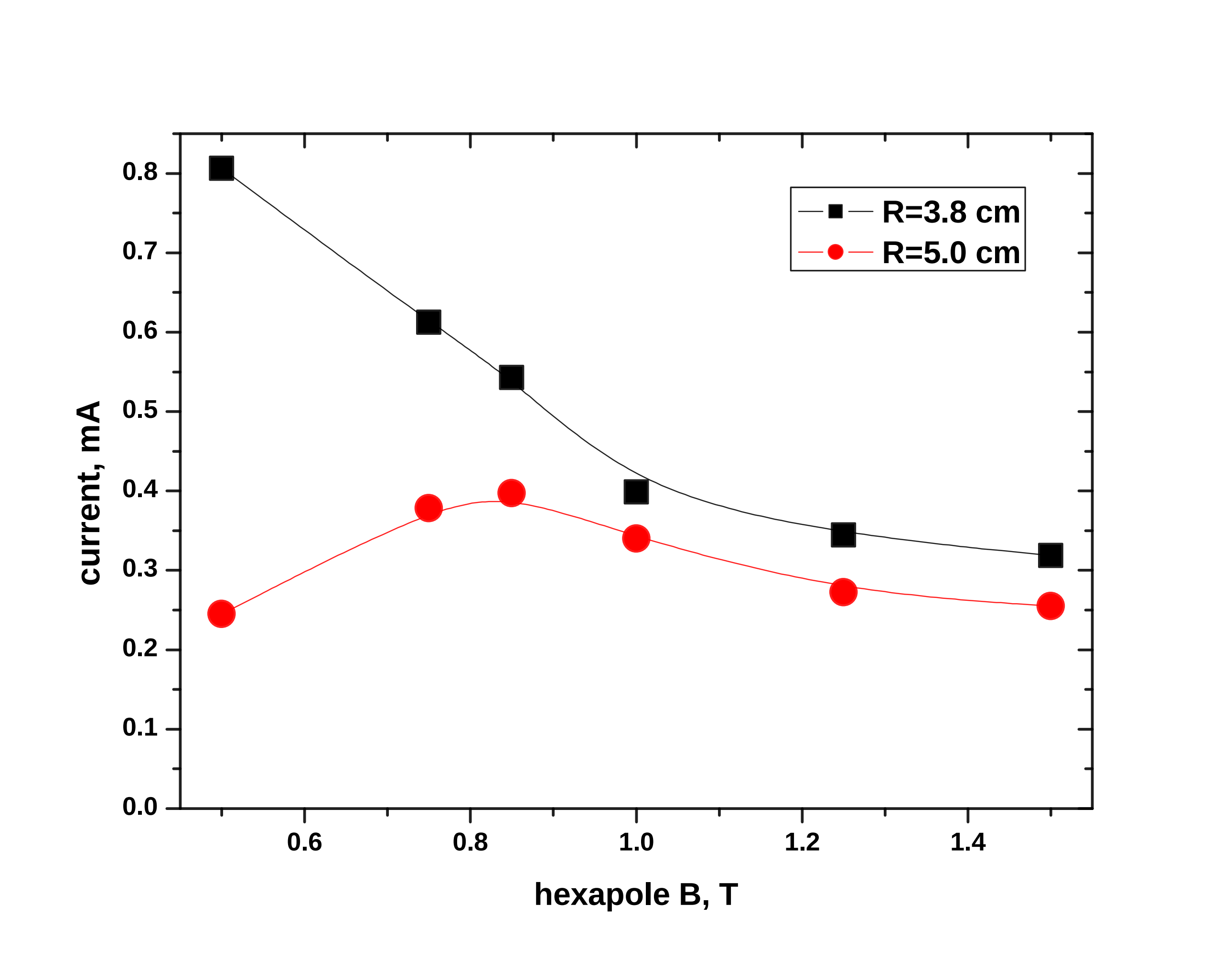


FIG. 3. Output currents of Ar^{7+}, Ar^{8+}, and Ar^{9+} for 18 GHz NIRS-HEC with $R = 46$, 66, and 80 mm.



R stays for a diameter here!

Chamber size: hexapole field



Chamber size: hexapole field

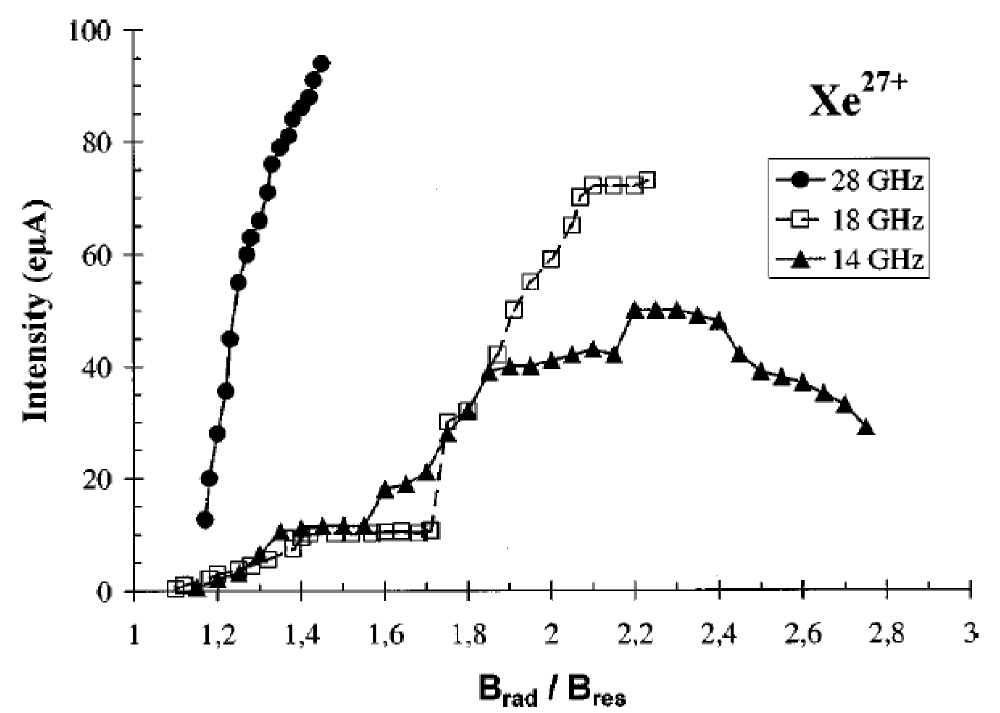
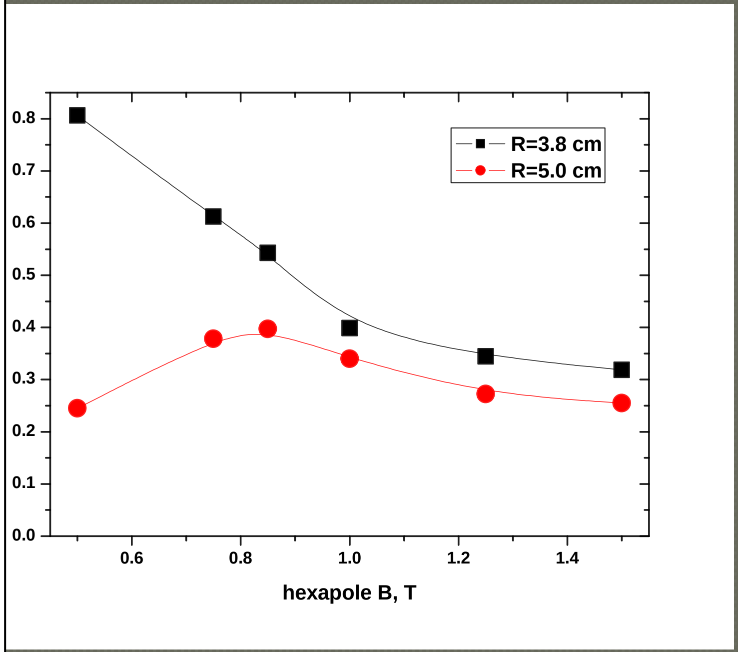


FIG. 10. Evolution of Xe^{27+} with the radial magnetic field.



Conclusions

- General behavior of the source is reproduced (gas flow, RF power, magnetic field)
- Hexapole field can be too strong
- Plasma chamber can be too large
- Minimum B – this is a good idea to tune Bmin, preferably by using the flat profile
- Gas temperature – the higher, the better.