中国科学院近代物理研究所
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LECR5 Development and Status Report

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Outline

- Design of LECR5
- Testing setup and Platform construction
- Commissioning for Ion Beams
  - Gaseous ion beams production
  - Metal ion beams production
- Summary

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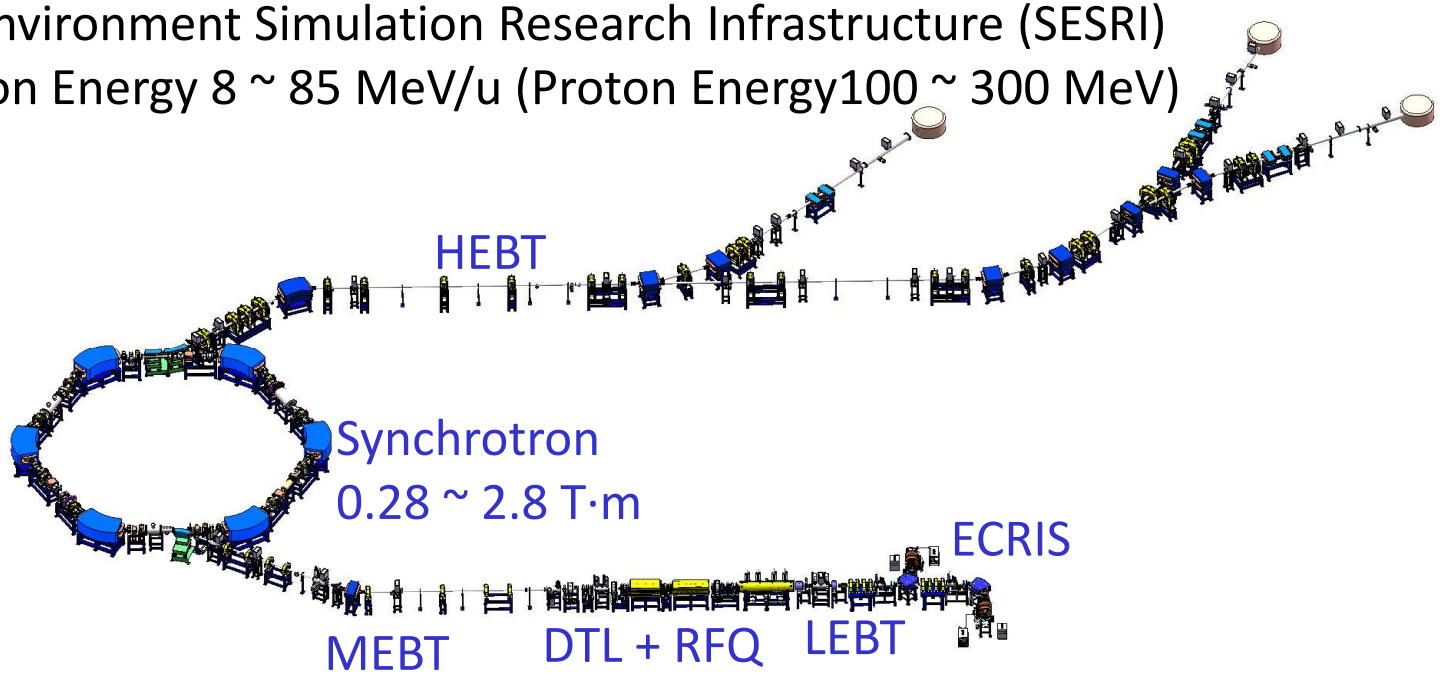
Background introduction

Space Environment Simulation Research Infrastructure (SESRI)
Heavy Ion Energy 8 ~ 85 MeV/u (Proton Energy100 ~ 300 MeV)



The requirement of the ECR ion source

Ions	Current	Ion energy	NRMS
H_2^+	≥250 euA	4 keV/u	≤0.2
$^4He^{2+}$	≥200 euA		≤0.15
$^{84}Kr^{18+}$	≥84 euA		
$^{209}Bi^{32+}$	≥50 euA		

Design considerations of ECRIS

Beam intensity produced by two types of typical ECRIS in IMP

Ions	Charged State	LAPECR2 (eμA)	LECR3-14.5 GHz (eμA)	LECR4-18 GHz (eμA)
^{40}Ar	8+	310	1100	1717
	9+	200	720	1075
	11+	105	325	503
^{209}Bi	28+	45	$^{207}Pb^{30+}$/18	118
	31+	20		70

- All permanent Magnet ECRIS and 14.5 GHz room temperature ECRIS can't meet the requirement of the bismuth ion beam.
- High performance 18 GHz room temperature ECRIS can meet all ion beam requirements.

Design parameters of LECR5

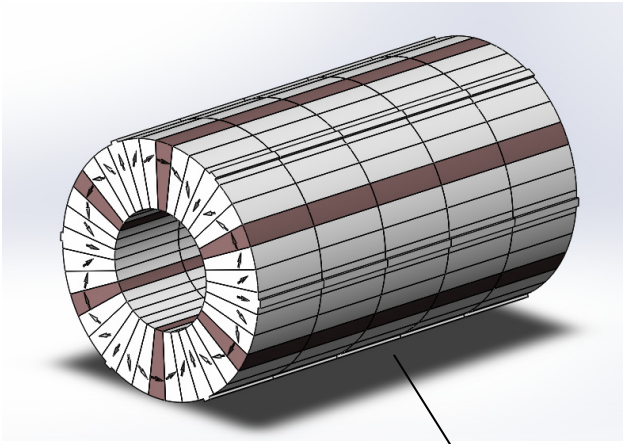
Design parameters in comparison of other ECRIS

	LECR5	LECR4	SECRAL(18 GHz)
f (GHz)	18	18	18
B_{inj} (T)	≥2.5	2.4	2.5
B_{min} (T)	0.33~0.53	0.53	~0.5
B_{ext} (T)	≥1.2	1.3	1.4
B_{rad} (T)	≥1.2 (r=40)	~1.0 (r=38)	1.4 (r=63)
Mirror length	340 mm	307 mm	420 mm
Plasma Chamber	80 mm	76 mm	126 mm

The magnetic field configurations of the LECR5 are similar for those of SECRAL operating at 18 GHz.

- Injection and radial magnetic field as high as possible.
- The minimum magnetic field in the middle can be adjusted.
- Plasma chamber as large as possible.

Layout structure of LECR5



Φin=88 mm

Φout=188 mm

Hexapole Magnet
(Halbach-36 blocks)

L: 620 mm

Insert Iron for B_{inj}

D: 640 mm

Injection Coils

Extraction Coils

Middle Coils for B_{min}

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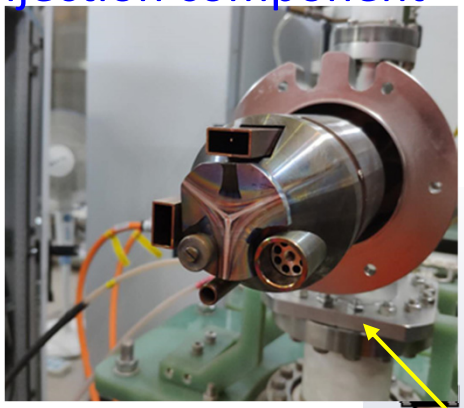
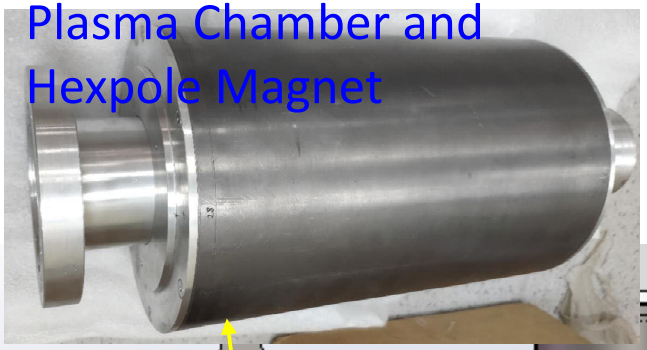
Source Assembly of LECR5

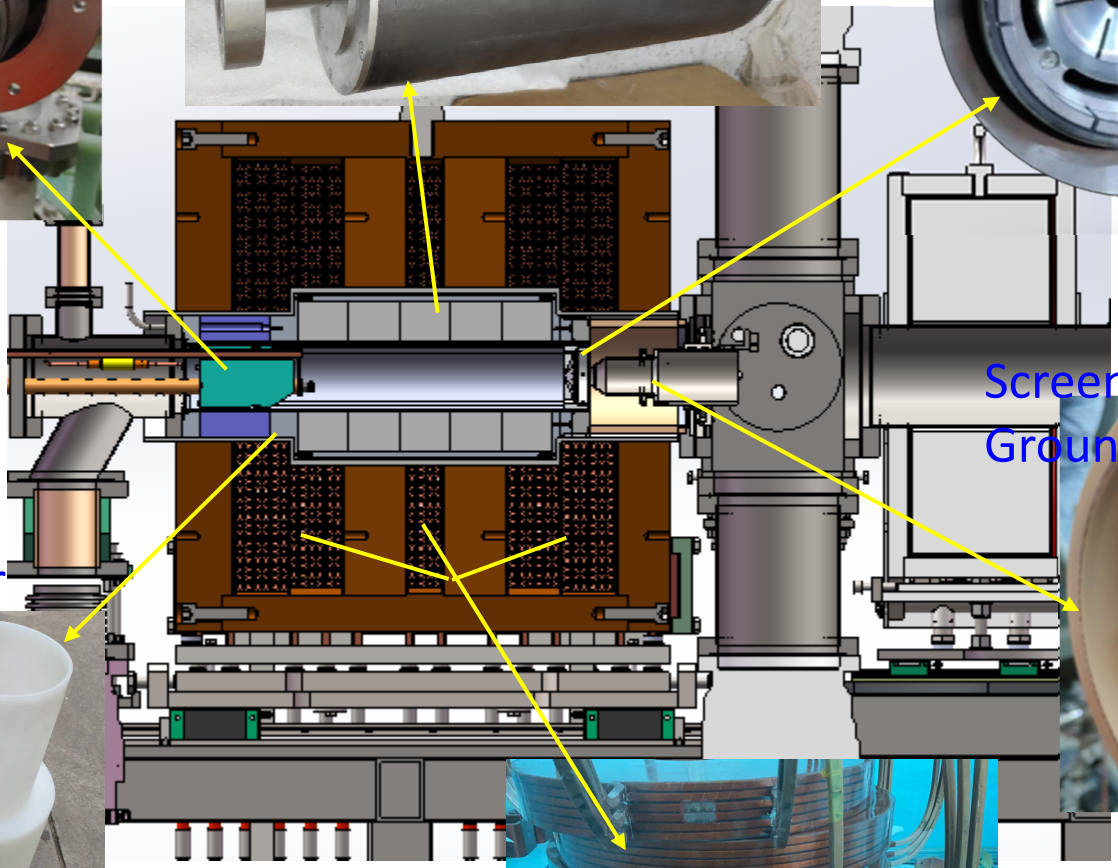
Injection component



Plasma Chamber and Hexpole Magnet



Plasma Electrode

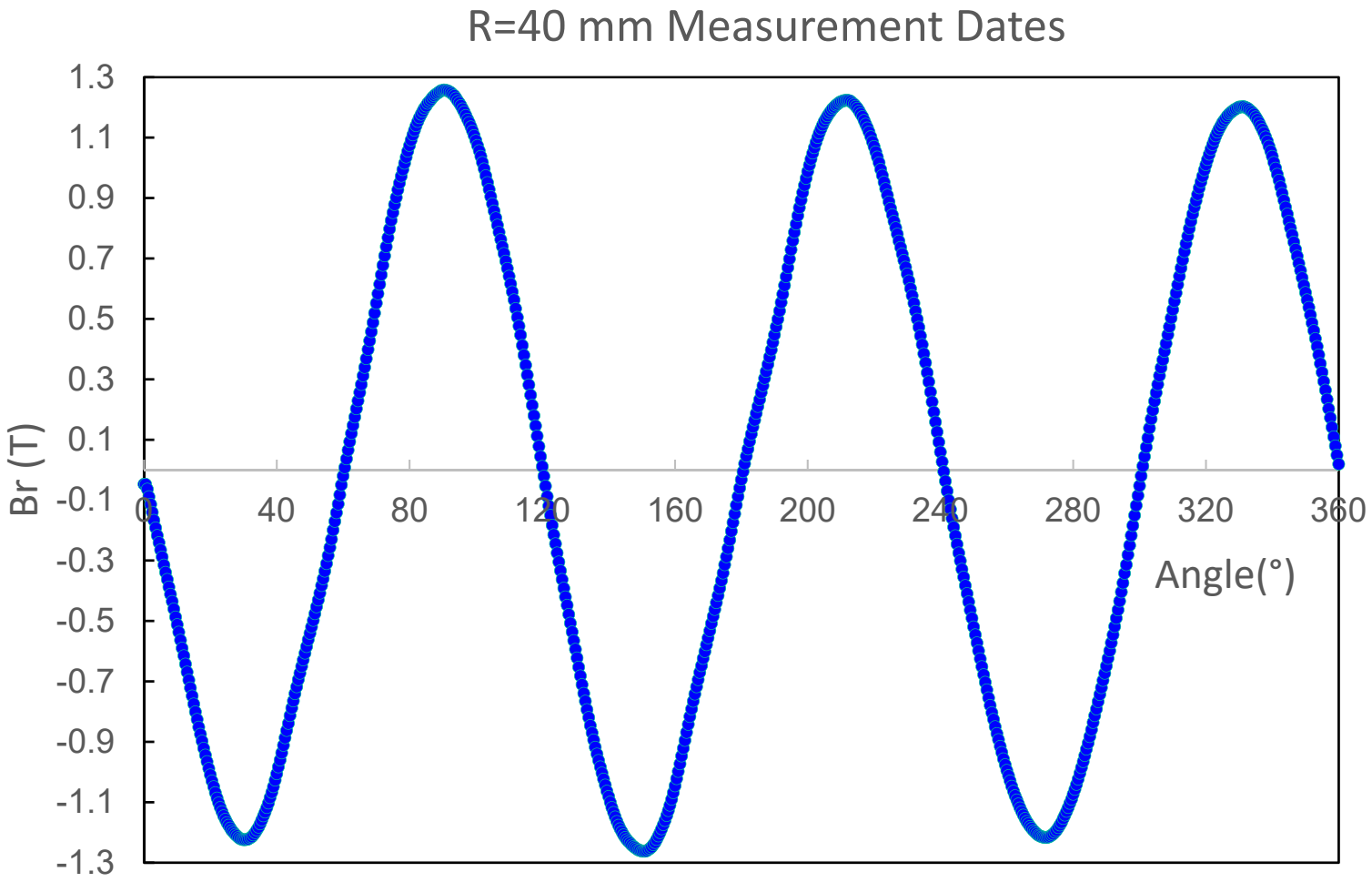


Screening Electrode and Ground Electrode

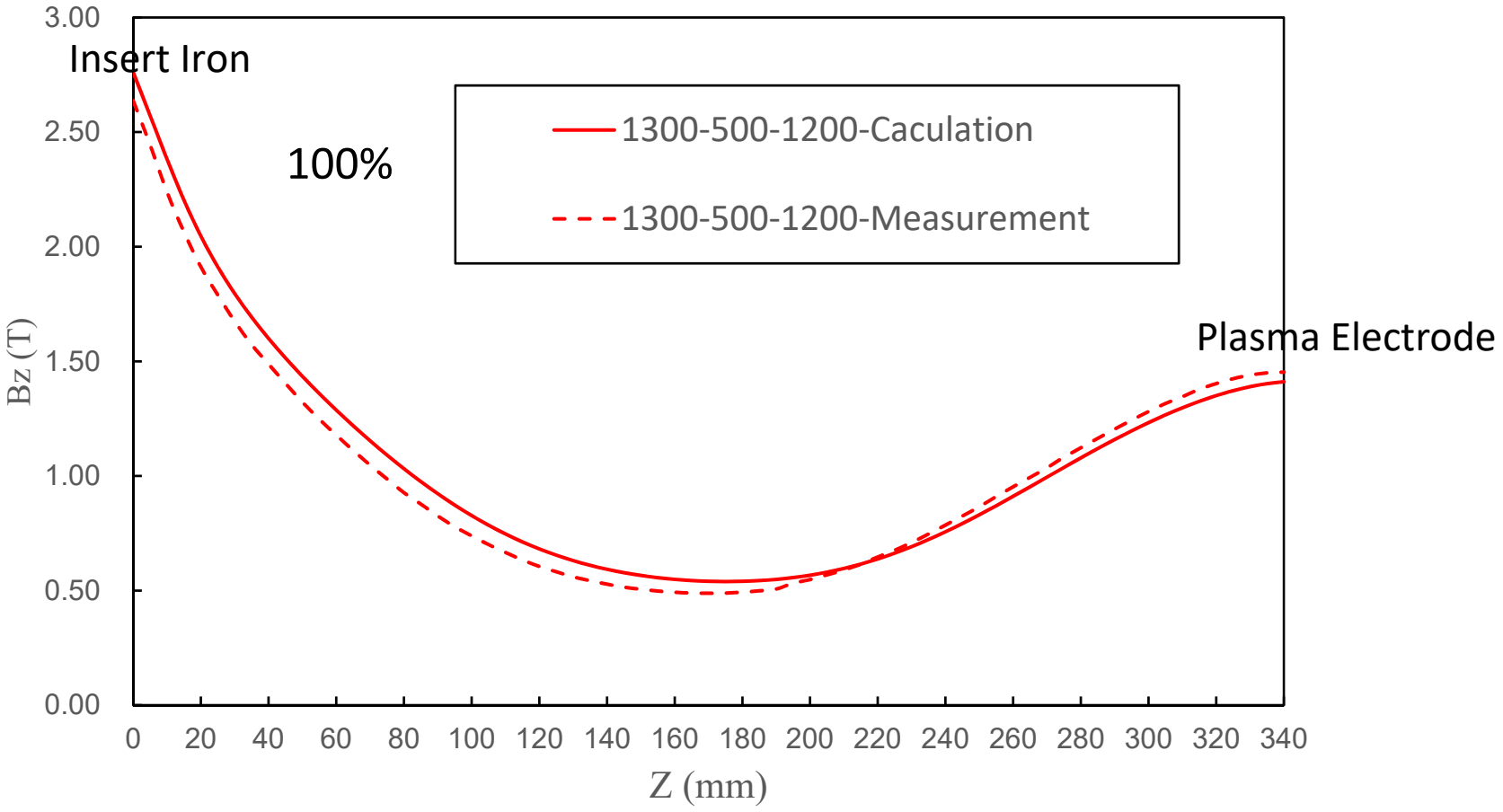
Insulating Layer

Axial Coils

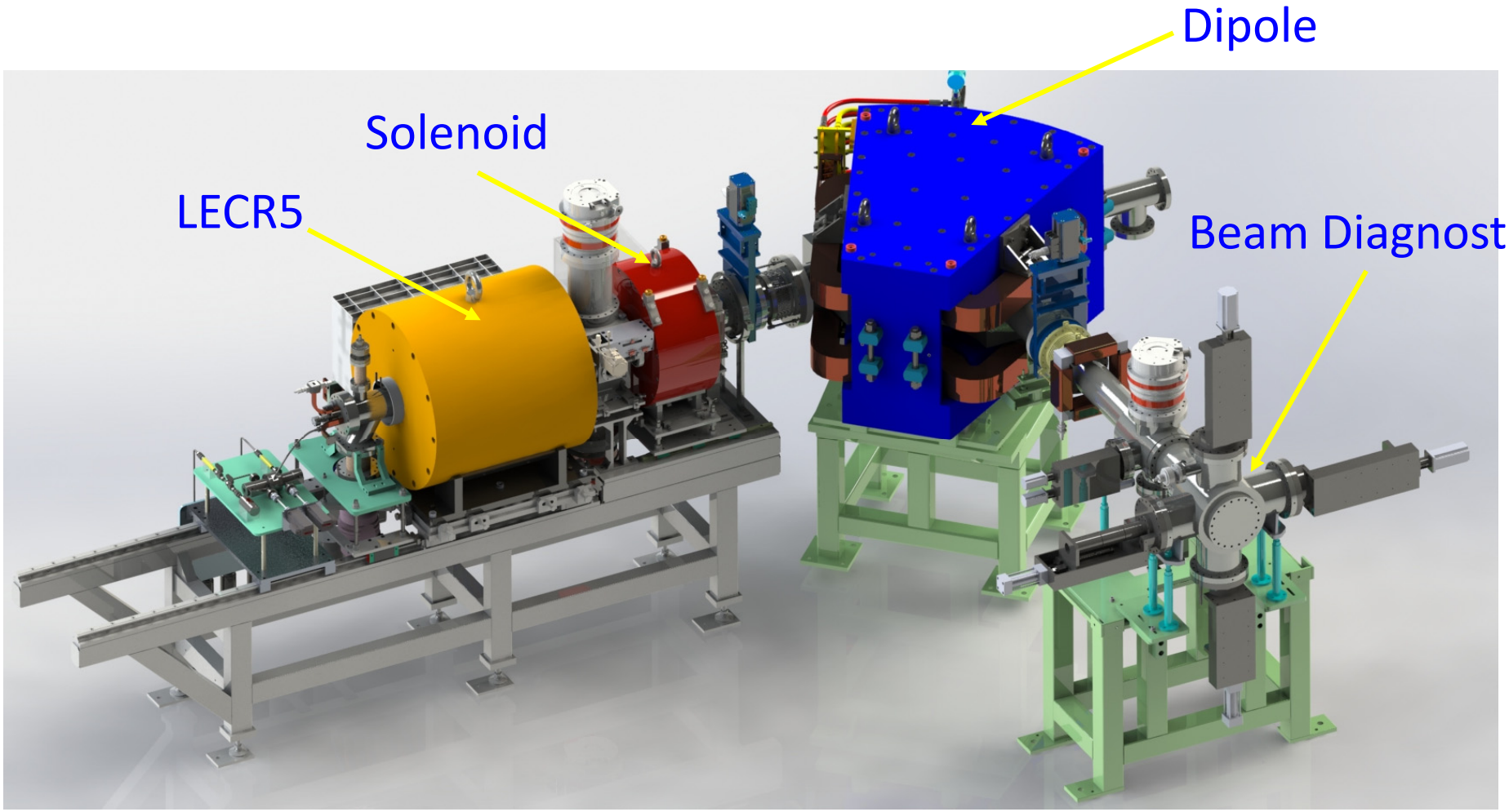
Radial magnetic field of LECR5



Axial magnetic field of LECR5



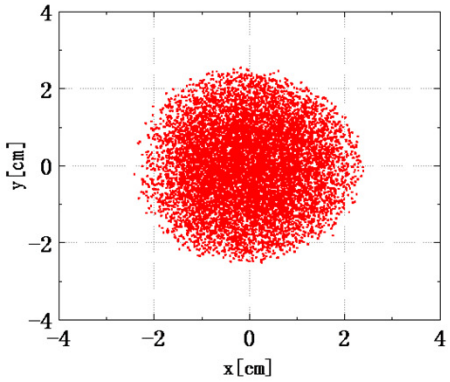
Testing Platform of LECR5



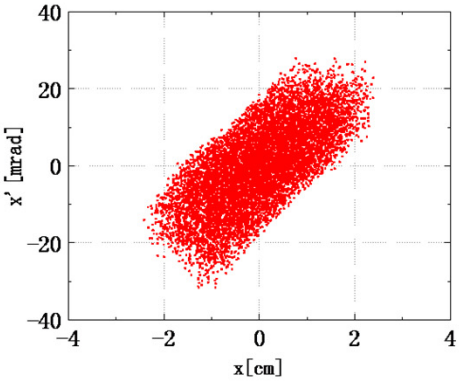
Beam optical design of Testing Platform

HV=8 kV, I_0= 1.5 emA, H_2^+=500 euA, SSC=70%

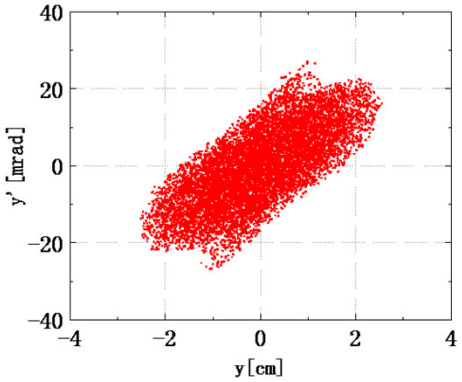
Beam spot size



X emittance

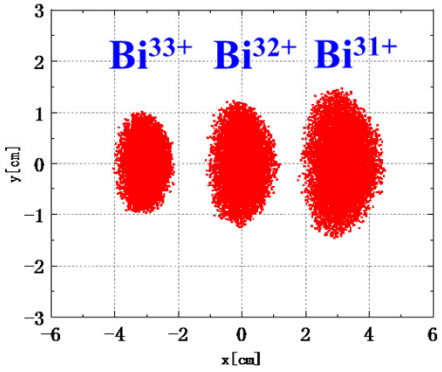


Y emittance

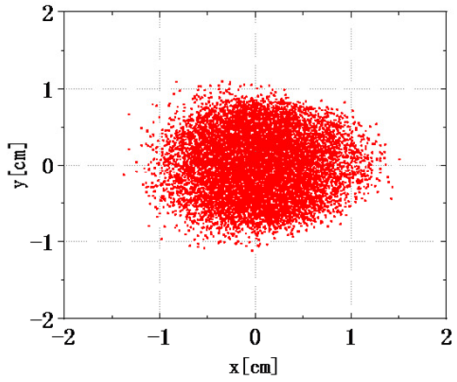


HV=26.125 kV, I_0= 5.0 emA, Bi^{32+}=65 euA, SSC=70%

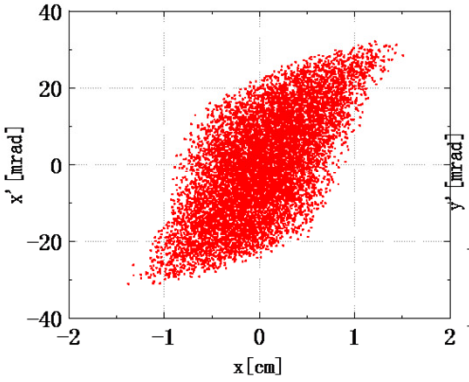
Beam spots position



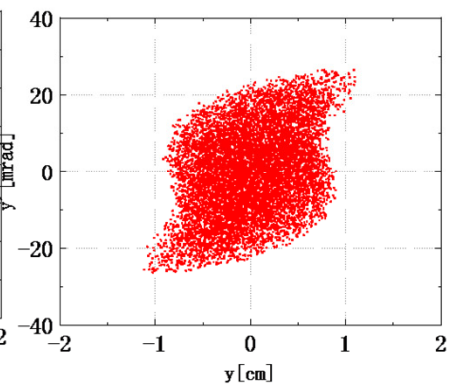
Beam spot size



X emittance

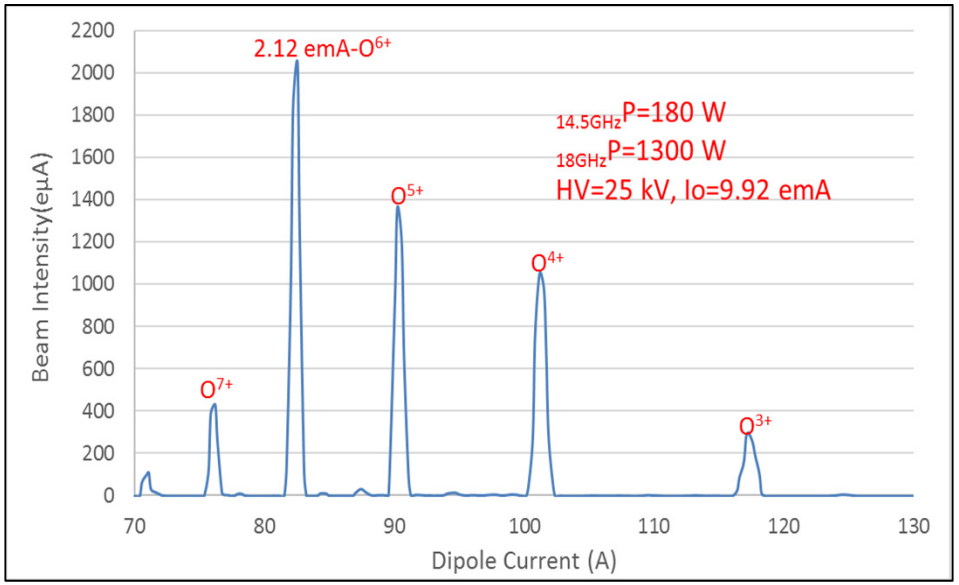


Y emittance



Performance Testing of LECR5

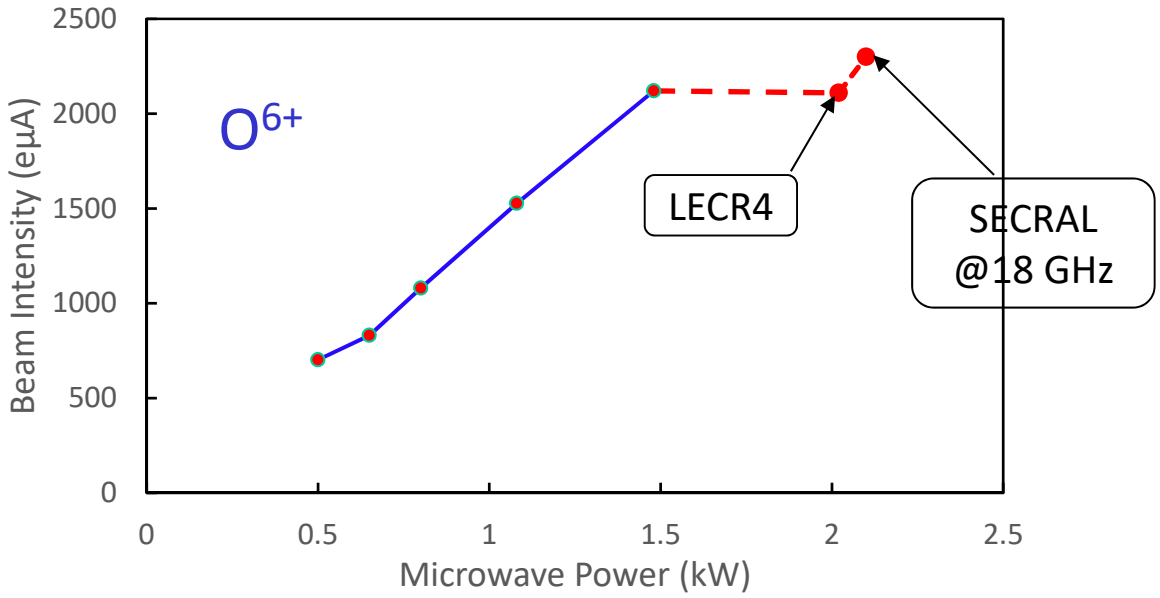
Data:01-18-2020



Testing conditions:

- Heating frequency: 14.5 +18 GHz
- Plasma chamber material: Stainless steel
- Plasma Electrode Aperture: Φ8 mm
- Screening Electrode Aperture: Φ16 mm
- FC Negative Biased Voltage: -150 V

✓ LECR5 has demonstrated its performance.



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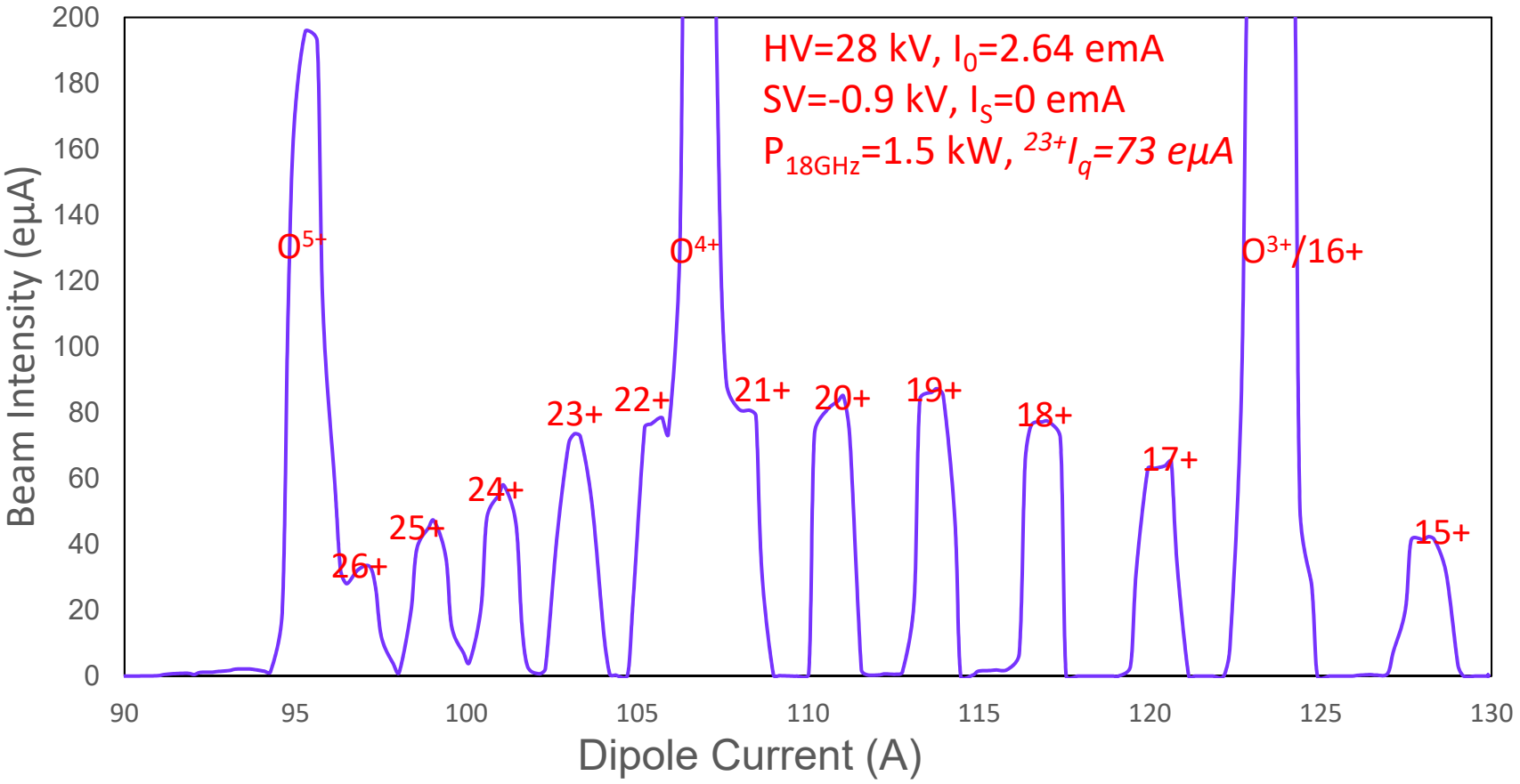
Gaseous Ion Beams Production

Optimizing the production of highly charged krypton ion beams

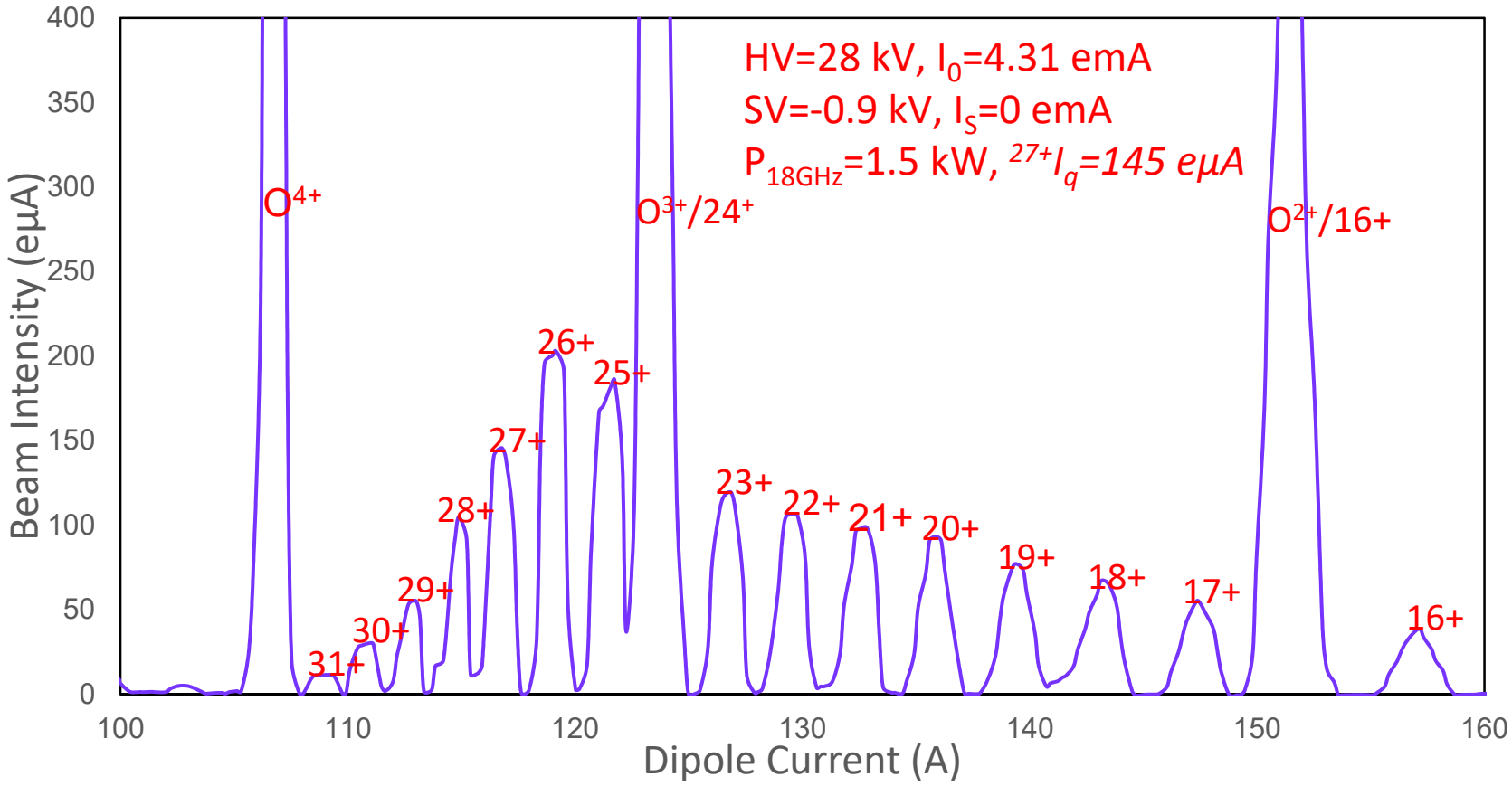


Tuning Conditions:

- Heating frequency: Single 18 GHz
- Plasma chamber material: Stainless steel
- Plasma Electrode Aperture: Φ8 mm
- Screening Electrode Aperture: Φ16 mm
- FC Negative Biased Voltage: -150 V

Gaseous Ion Beams Production

Optimizing the production of highly charged xenon ion beams



Tuning Conditions:

- Heating frequency: Single 18 GHz
- Plasma chamber material: Stainless steel
- Plasma Electrode Aperture: Φ8 mm
- Screening Electrode Aperture: Φ16 mm
- FC Negative Biased Voltage: -150 V

Gaseous Ion Beams Production

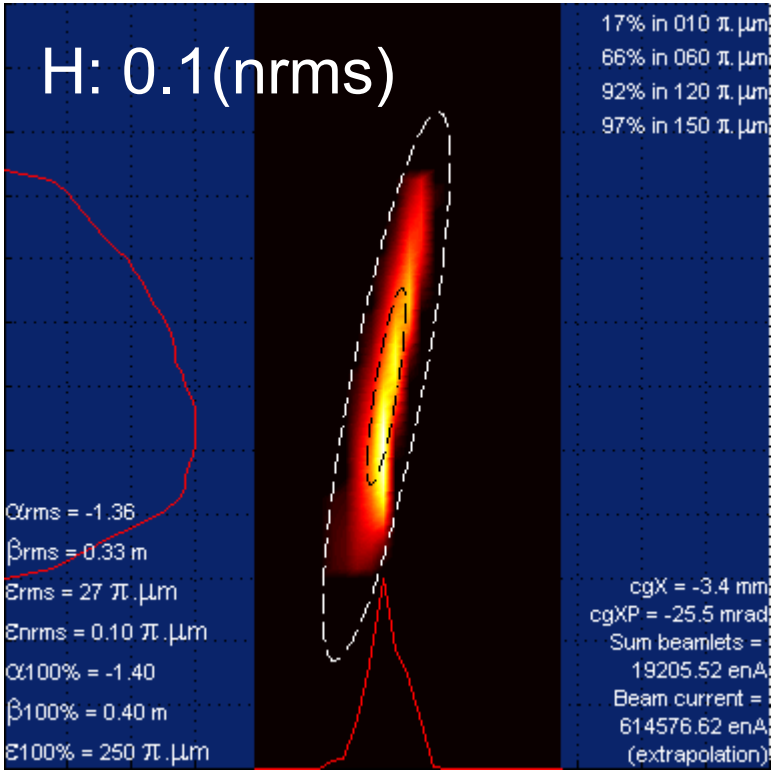
Gaseous ion beam results of LECR5 in comparison with other ECR ion sources

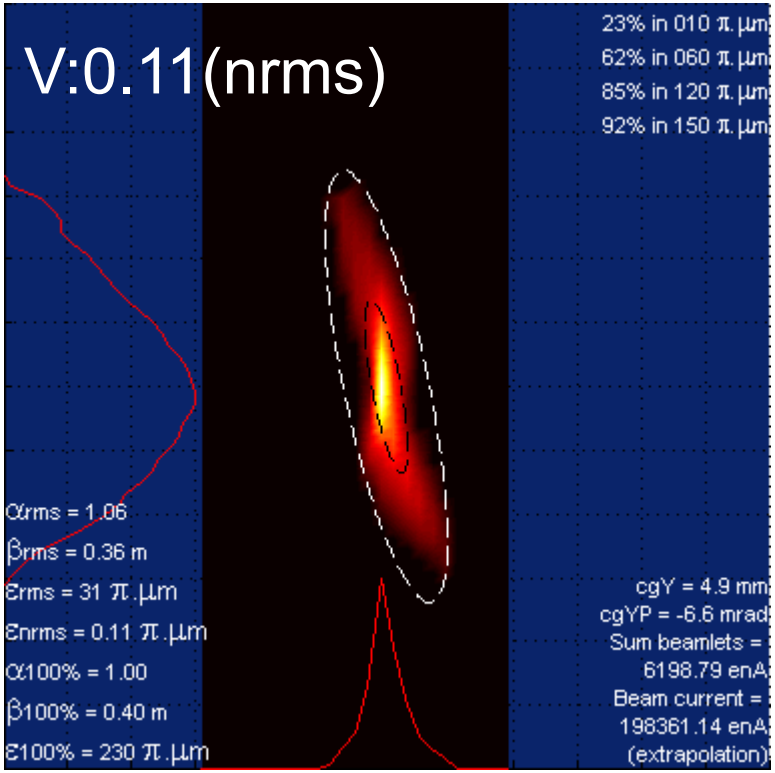
Ions	Charged State	LECR5(eμA) 18 GHz＜2 kW	LECR4(eμA) 18 GHz＜2 kW	SECRAL(eμA) 18 GHz ＜3.2 kW
^{16}O	6+	2120	2110	
	7+	458	560	
^{16}Ar	11+	521	620	
	12+	385	430	510
	14+	121	185	270
	16+	**25**	23	73
^{86}Kr	18+	220		
	20+	120		
	23+	73		
	26+	32		
^{209}Xe	20+	338	430	505
	23+	263	275	
	26+	**200**	205	410
	27+	**145**	135	306
	28+	**104**	92	

- LECR5 has the potential to produce intense highly charged ion beams.

Intense highly charged Ion beam Emittance

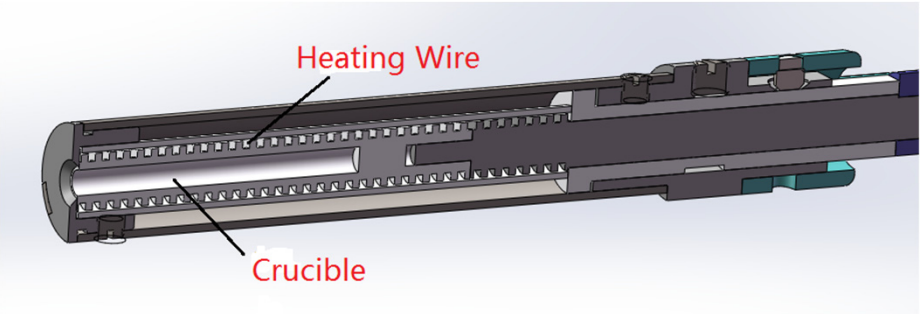
HV=28 kV, I_o=4.31 emA, $^{129}Xe^{27+}$=145 eμA





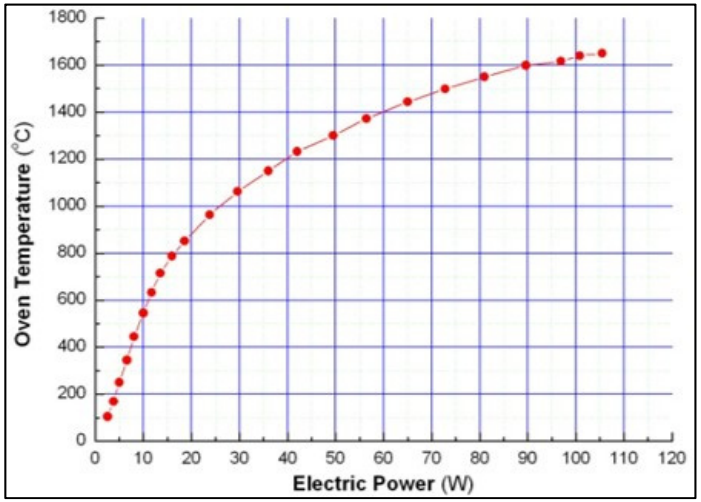
Metal Ion Beams Production

Micro-Oven 2D Section



Micro-oven

Off-line test results

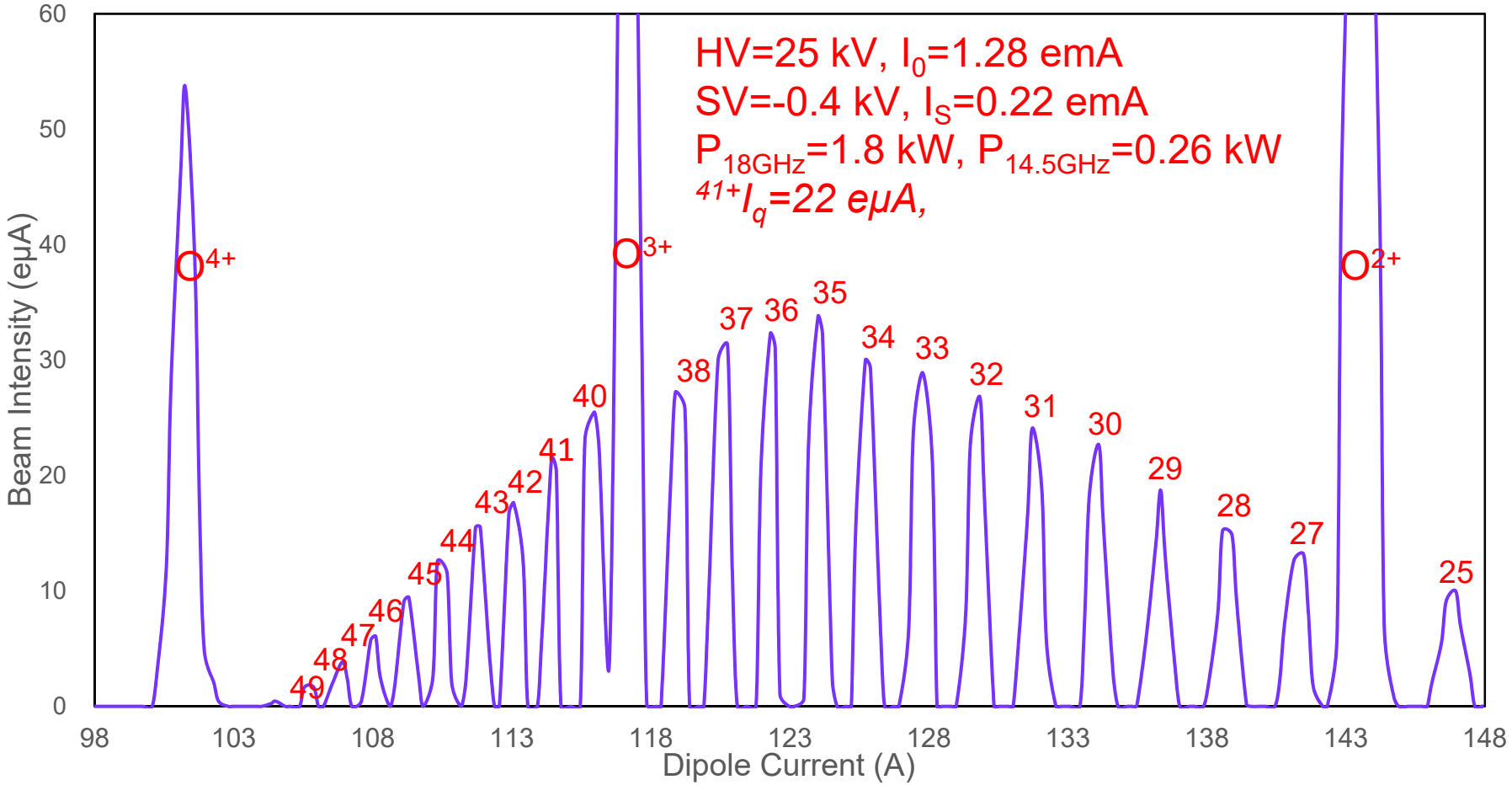


Tuning Conditions:

- Heating frequency: 14.5 +18 GHz
- Plasma chamber material: Aluminum
- Micro-oven port Aperture: Φ4 mm
- Plasma Electrode Aperture: Φ8 mm
- Screening Electrode Aperture: Φ16 mm
- FC Negative Biased Voltage: -150 V

Metal Ion Beams Production

Optimizing the production of highly charged bismuth ion beams



- LECR5 can produce highly charged heavy ion beams.

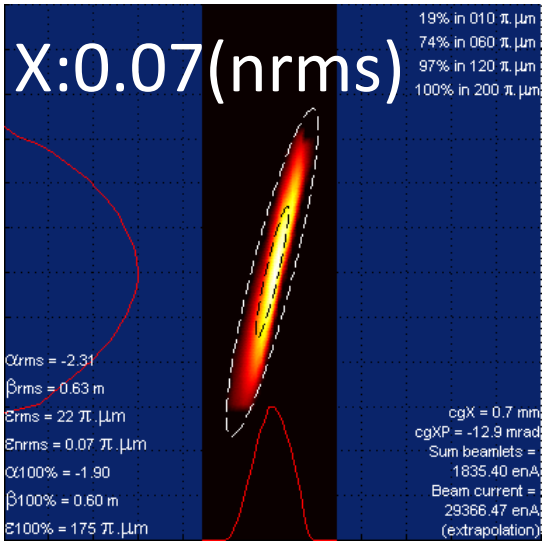
Metal Ion Beams Production

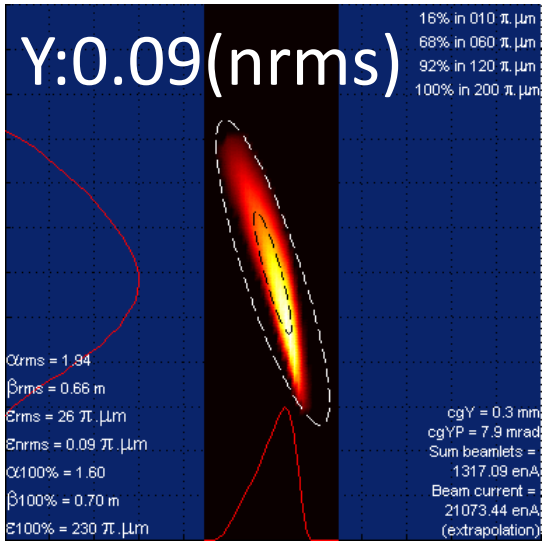
Ion Beam Spots with different charged state.

Metal Ion Beams Production

Bismuth ion beam results of LECR5 in comparison with other ECR ion sources

Ions	Charged State	LECR5(eμA) 14.5+18 GHz＜2.2 kW	LECR4(eμA) 18 GHz＜2 kW	SECRAL(eμA) 18 GHz ＜3.2 kW
^{209}Bi	30+	119		191
	31+	101	92	150
	32+	81	63	
	41+	22		22
	45+	12.5		15
	50+	3.8		1.5

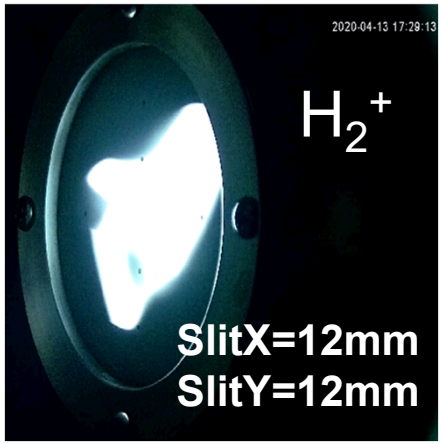


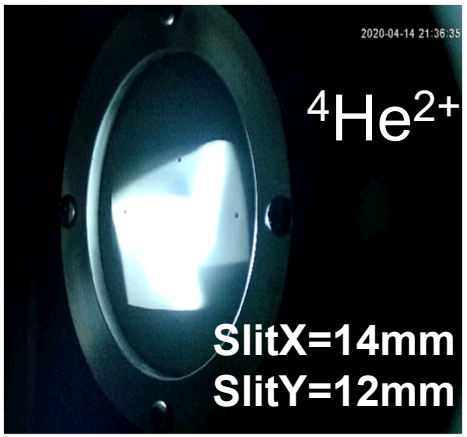


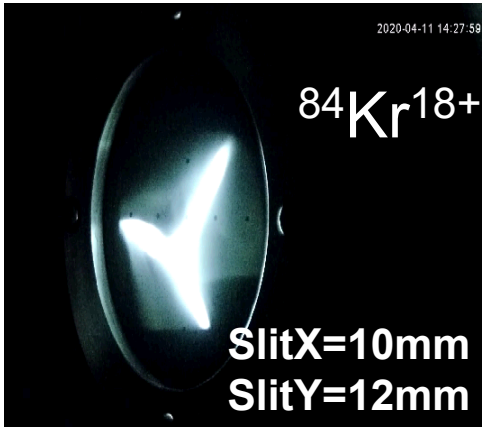
Commissioning for project requirements

Results of ion beams commissioning in comparison with requirements

Ions	Intensity （eμA）	X (nrms)	Y (nrms)
H_2^+	266＞250	0.14＜0.2	0.15＜0.2
$^4He^{2+}$	204＞200	0.15 ≤ 0.15	0.14＜0.15
$^{84}Kr^{18+}$	88＞84	0.09＜0.15	0.11＜0.15
$^{209}Bi^{32+}$	51＞50	0.05＜0.15	0.05＜0.15







LECR5 Milestone and Status

- 02. 2016 – Project proposed, called LECR5-SESRI.
- 07. 2018 – Final Overall design finished.
- 07. 2019 – Overall assembly and first beam analyzed at IMP.
- 04. 2020 – LECR5-SESRI commissioning for intense highly charged ion beams.

Next: Ready to transport to Harbin, Commissioning with RFQ.

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Summary

1. A high performance 18 GHz room temperature ECR ion source was successfully constructed.
2. Some outstanding results of highly charged ion beams have been produced.
3. Excellent quality of intense heavy ion beam has been obtained.

✓ Better results will be obtained by further optimizing conditions:

   1. Multi-frequency heating.
   2. Higher microwave power up to 3 kW.

谢谢！

Thanks for your attention!