First Commissioning Results of An Evaporative Cooling Magnet ECRIS-LECR4

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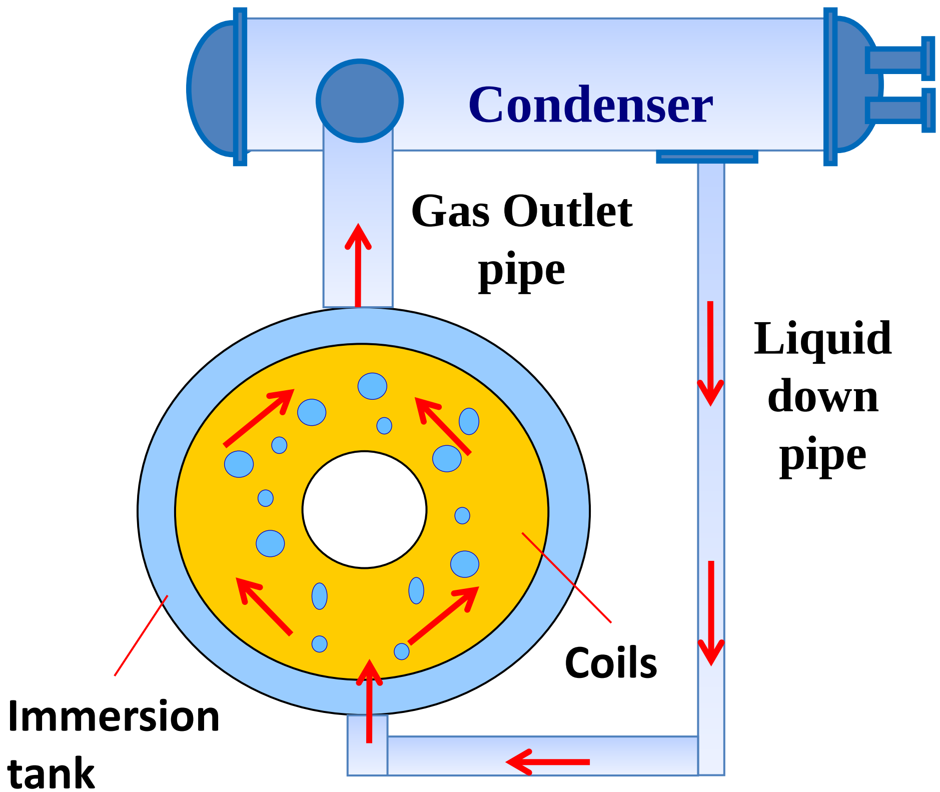
Evaporative Cooling Technology

Evaporative cooling technology (Developed by Institute of Electrical Engineering, Chinese Academy of Sciences- IEE, CAS):

It is based on the principle of phase change heat transfer; High insulating and room-temperature boiling point organic coolant is used to absorb the heat of electrical equipment.



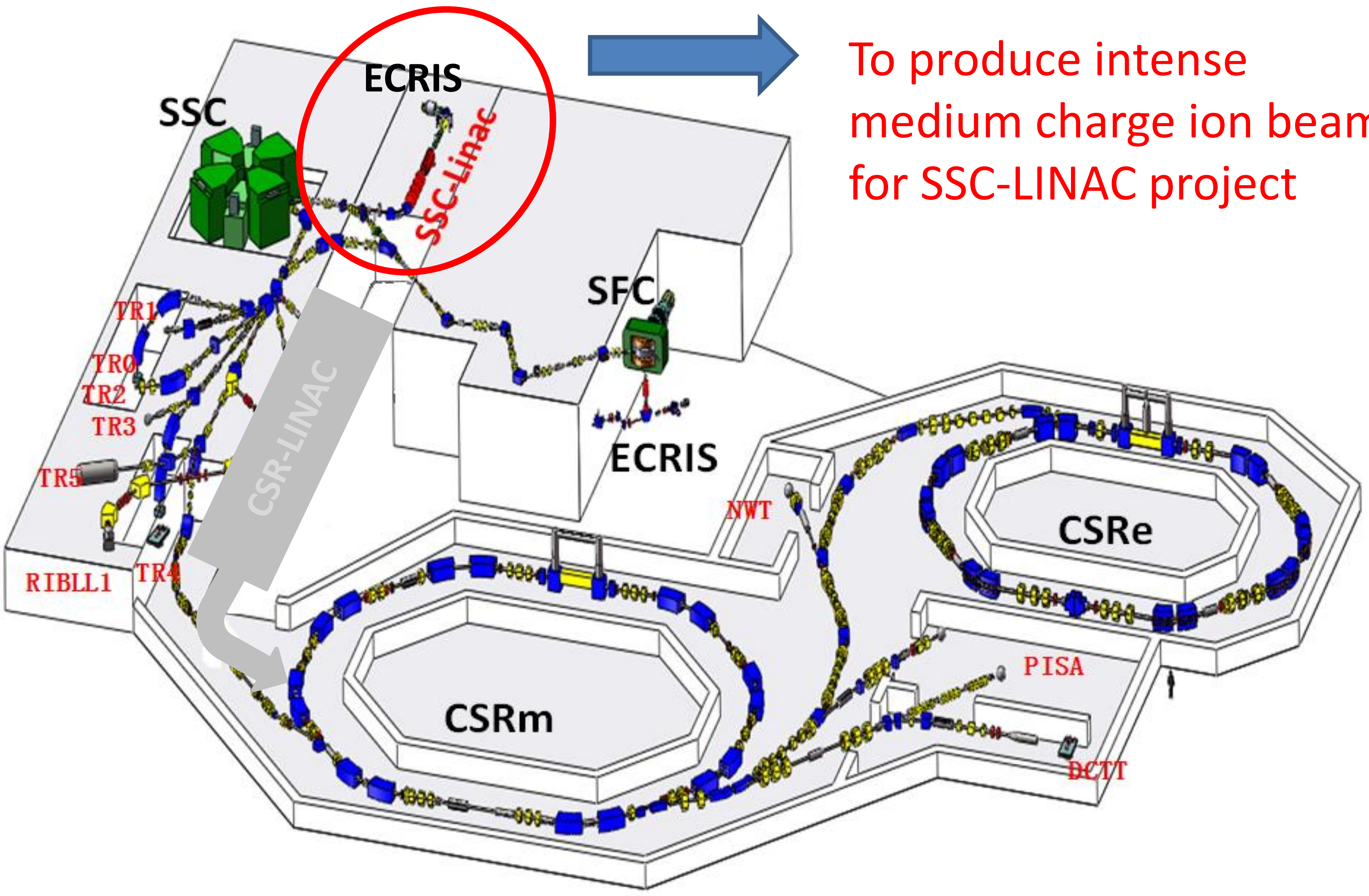
Is it possible to use this technology in an ECR ion source magnet?

OUTLINE

LECR4 (Former name DRAGON): Lanzhou ECR ion source No. 4

- Motivation of LECR4 ECR ion source
- LECR4 Structure & Features
- Preliminary Commissioning results
- Summary

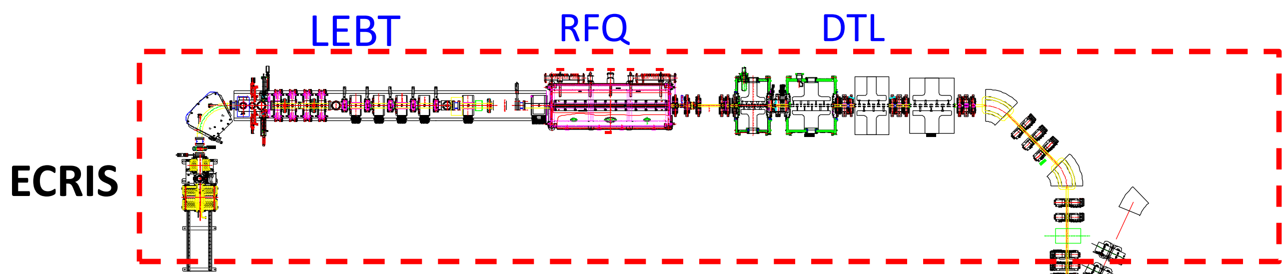
HIRFL Layout

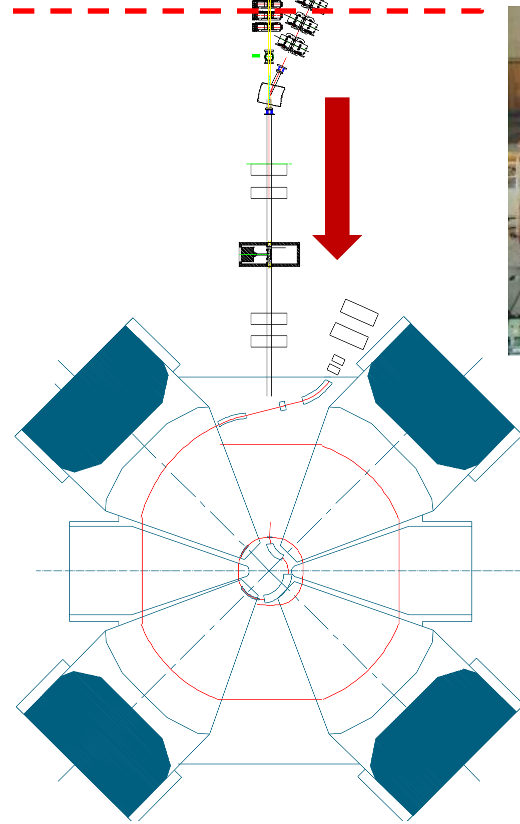


To produce intense medium charge ion beams for SSC-LINAC project

SSC-LINAC project: A new heavy ion injector for SSC cyclotron at IMP, Lanzhou

SSC-LINAC layout





SSC-LINAC:

- Ion Species: C-U, CW ion beam
- Input Energy: 3.728 keV/u
- Beam emittance: <150 π.mm.mrad

SSC

K=450 –100AMev

Injection Energy:

1 Mev/u-10 Mev/u

An ECRIS can meet the demand, include RT ECRIS, SC ECRIS, etc…

What type of ECRIS we need?

Lower cost and easy maintenance

→ **Room temperature ECRIS**

Higher current density & axial magnetic field
(Compared with LECR3, another RT ECRIS at IMP)

→ **Evaporative cooling technology**

Intense medium charge state ion beams

→ **Rf frequency: 18 GHz.**
Can produce O^{6+}, Ar^{9+}, Xe^{20+}, Bi^{28+}, etc…

LECR4 is a RT ECRIS with Evaporative cooling technology. (cooperated with IEE, CAS)

Magnetic Field Design

Parameters of SECRAL

	SECRAL 18 GHz	SECRAL 24 GHz
Operating Frequency (GHz)	18	24
Resonance Length (mm)	105	110-120
Plasma Chamber (mm)	Length: 420 Diameter: 126 Effective volume: ~5 L	
Axial Injection field (T)	2.5	3.7
Axial Extraction field (T)	1.4	2.2
Max. Chamber Radial field (T)	1.4	2.0

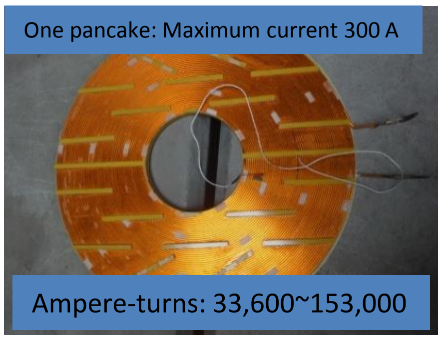
SECRAL, 18-24 GHz, IMP

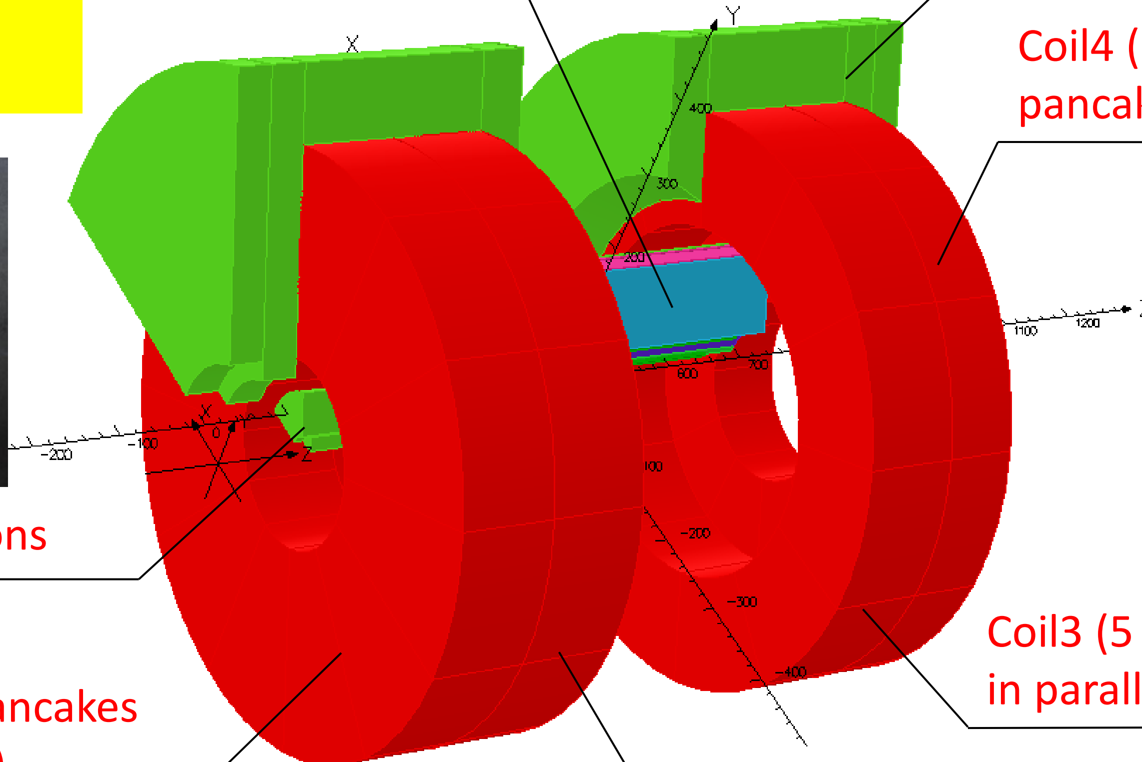
Performance of SECRAL at 18 GHz

		SECRAL
f (GHz)		*18*
^{16}O	6^+	2300
	7^+	810
^{40}Ar	11^+	810
	12^+	510
^{129}Xe	20^+	505
	27^+	306
	30^+	101
^{209}Bi	28^+	214
	30^+	191

Magnet Structure of LECR4

Features of magnet:
- Solid square copper wire
- Higher current density
- Axial field: 2.3, 1.3T



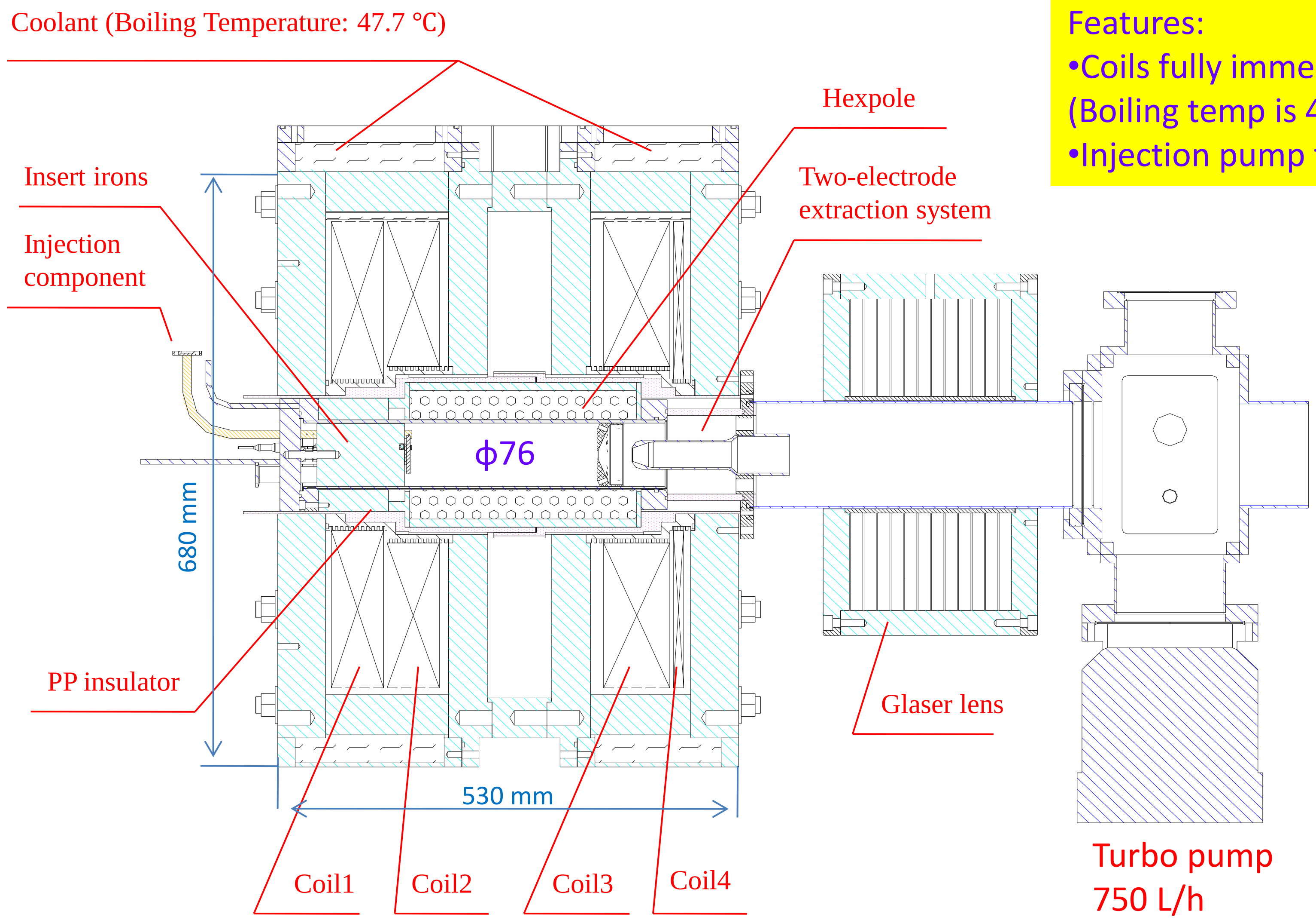


Current density: 11.85 A/mm^2 (slightly higher than LECR3)

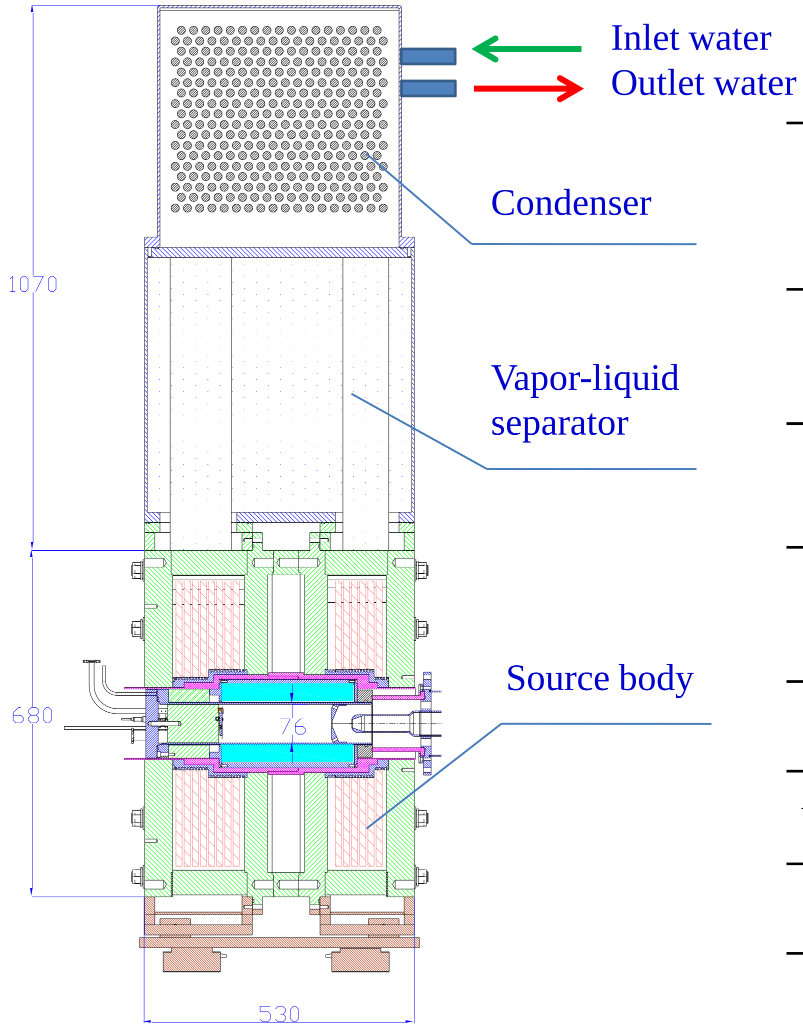
Maximum exciting current of Coil1, 2, 3 and 4: 1200 A, 1200 A, 1500 A and 300 A

Schematic View of LECR4

Features:
- Coils fully immersed in coolant (Boiling temp is 47.7 ^{0}C)
- Injection pump free



Designed Parameters



Weight: ~1.5 Tons

Parameters of LECR4

	LECR4	LECR3	SECRAL 18 GHz
Operating Frequency (GHz)	18	14.5	18
Resonance Length (mm)	18GHz: 118	14.5GHz: 86	105
Plasma Chamber (mm)	L: 220 ID: 76	L: 220 ID: 76	L: 420 ID: 126
Axial Injection field (T)	2.3	1.7	2.5
Axial Extraction field (T)	1.3	1.1	1.4
Max. Chamber Radial field (T)	1.0- 1.1	1.0-1.1	1.4
Total Power (kW)	195	100	-


DC-BREAK
WR62 waveguide
Injection component
Biased disk
Insulator and Hexpole
270 mm
SS plasma chamber
422mm
Allison Scanner
X & Y Slits
Pin valves
Faraday cup

In July 2013

First Magnet Test after Assembly at IMP

First Magnet Test after Assembly at IMP

Current =0

First Magnet Test after Assembly at IMP

Current =0 **30% Current**

First Magnet Test after Assembly at IMP

Current =0 | 30% Current | 100% Current

First Magnet Test after Assembly at IMP

Current =0 | **30% Current** | **100% Current** | **Temperature**

Safety operation requirements: $T_{Coil} < 120$ °C; $T_{warm\text{-}bore} < 80$ ℃.

First Magnet Test after Assembly at IMP

Current =0 | **30% Current** | **100% Current** | **Temperature**

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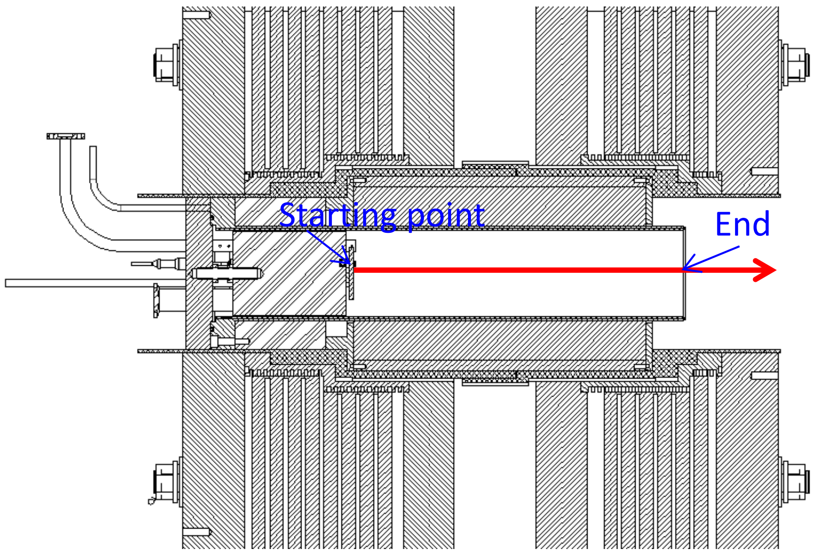
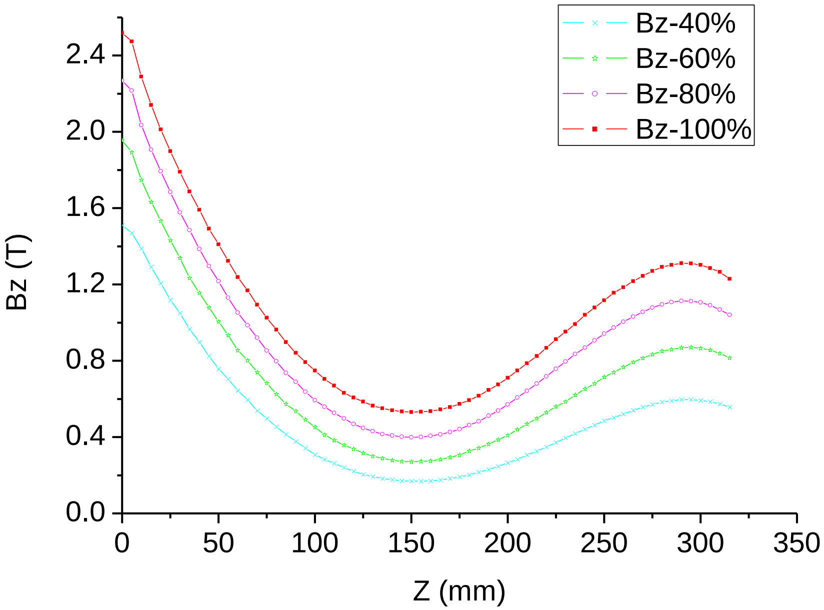
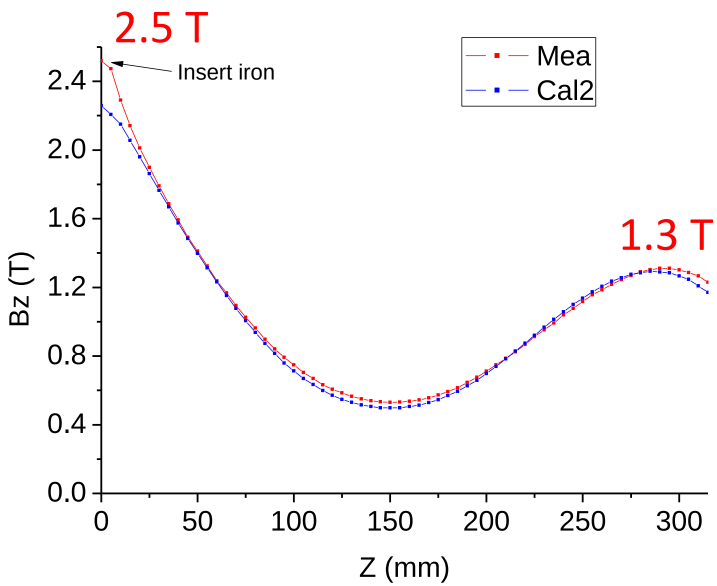
Axial Field Mapping







The measured field distribution agrees well with the calculated result!

Unique Features of LECR4 ECR ion source

LECR4– Room Temperature ECR Ion Source with New Coil Cooling Technique !

✓ Axial solenoids cooled with evaporative cooling medium

- Higher axial magnetic field is possible
- High-pressure de-ionized water free

✓ Injection pump free

- Very simple injection part: easy maintenance and installation
- More compact and lower cost

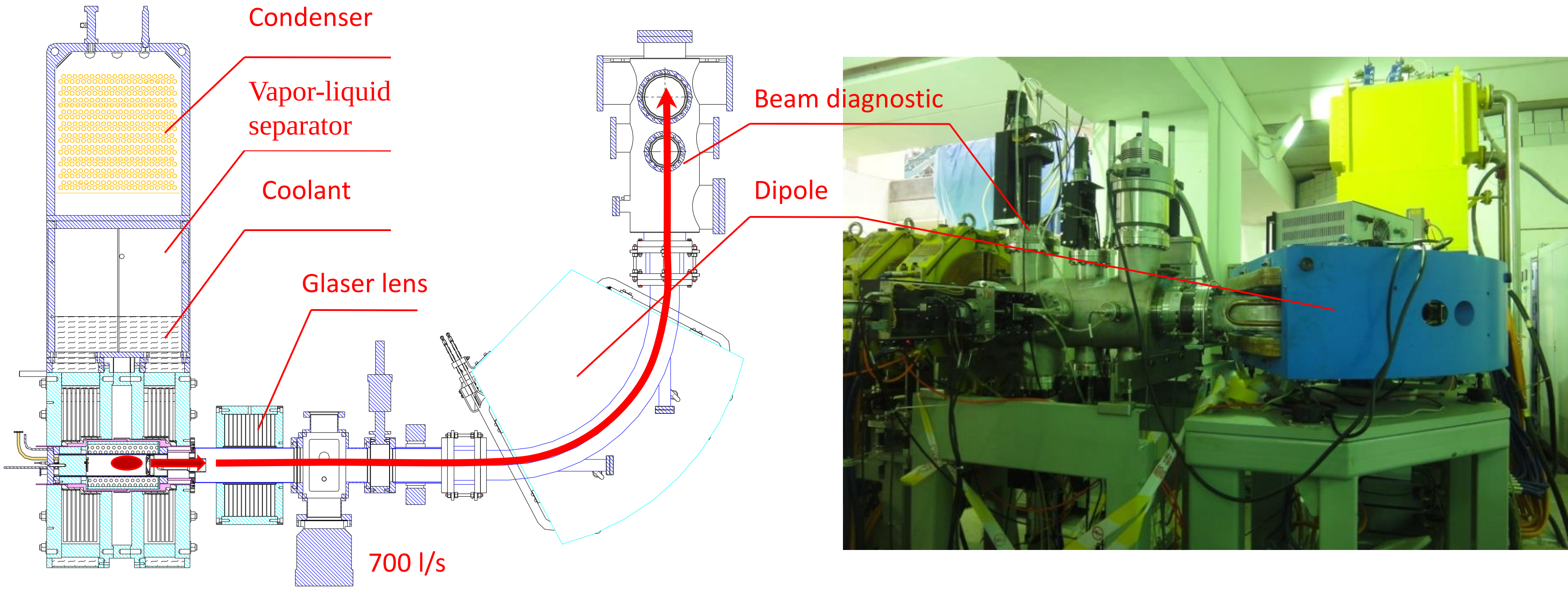
➢ Disadvantage:

- **Big magnet size**

LECR4 Milestone and Status

- **01. 2010 – Project approved.**
- **07. 2010 – Preliminary concept design finished, called DRAGON**
- **10. 2010 – DRAGON Coil1 prototype reached current 280A, but local temperature in the coils exceed 150 degree.**
- **08. 2011 – DRAGON Coil1+Coil2 prototype reached current 100% (300A), maximum temperature in the coils is 83 degree.**
- **09. 2012 – Final concept design finished, called LECR4**
- **07. 2013 – LECR4 overall assembly at IMP**
- **10. 2013 – Axial magnetic filed reached 100% of its design field.**
- **02. 2014 – LECR4 First Analyzed Beam at 18 GHz.**
- **03. 2014-06.2006 — LECR4 Commissioning for intense highly charged beam**
- **03. 2014 & 05. 2014 — One week's RFQ experiment using LECR4 beam**

Beam Transport Line



Dipole magnet:

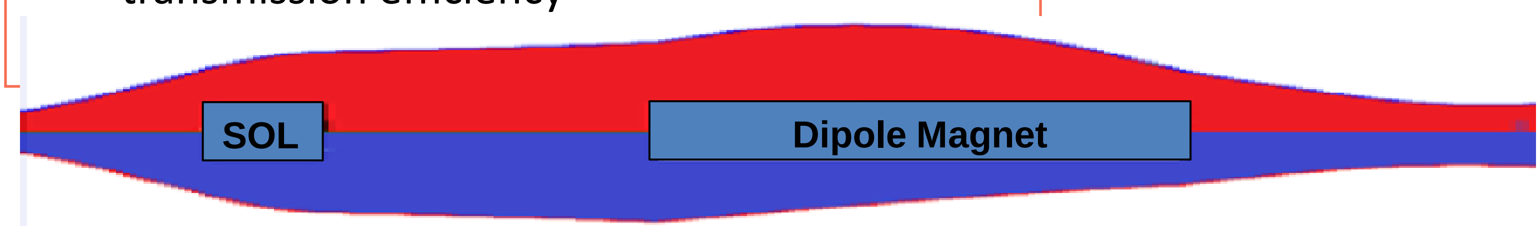
Bending angle: 90 degree

Bending radius: 600 mm

Pole gap: 130 mm

Main Design Issues:

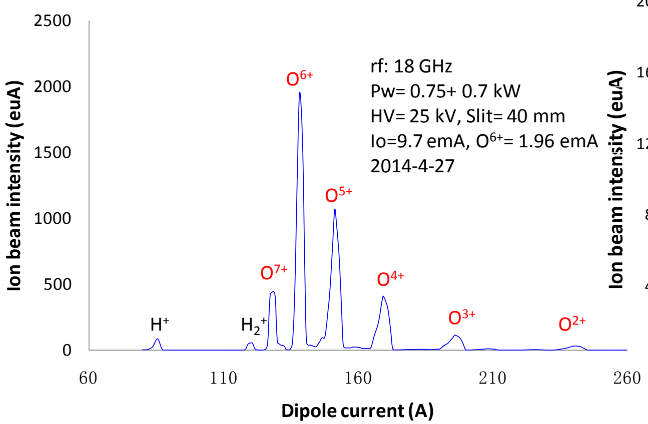
1. Solenoid close to the source body
2. Large acceptance dipole magnet & high transmission efficiency

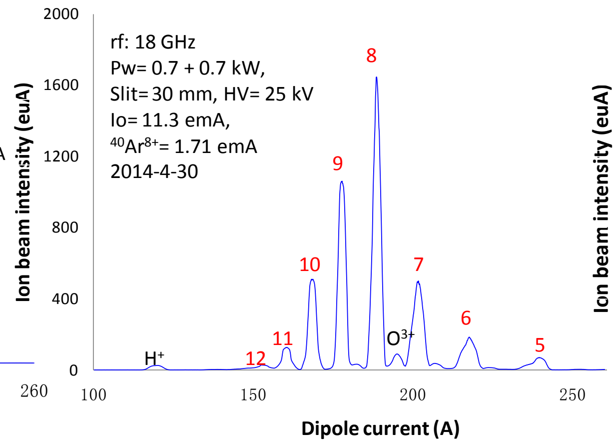


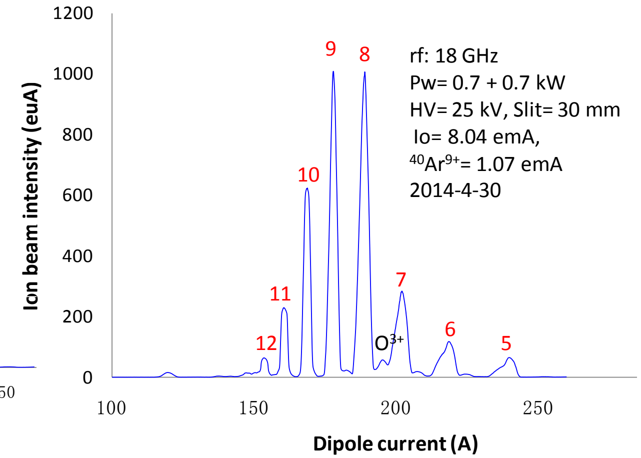
LECR4 Tuning Conditions

- Plasma Chamber: Stainless steel, ID： Ø76 mm
- RF Frequency: 18 GHz
- Maximum RF Power: 1.6 kW
- Extraction High Voltage: 15~25 kV
- Plasma Electrode Aperture: Φ10 mm
- Puller Electrode Aperture: Φ16 mm
- FC Negative Biased Voltage: -150 V
- X-Slits: 16 mm~40 mm
- Ion Species: Oxygen, Argon, Xenon, Bismuth

Gaseous Ion Beams Production







O^{6+}: 1960 eμA (1.45 kW, 25 kV)

B_r1.0T, B_{inj} 2.5 T, B_{ext}1.01T, B_{min}0.45 T

Ar^{8+}: 1710 eμA (1.40 kW, 25 kV)

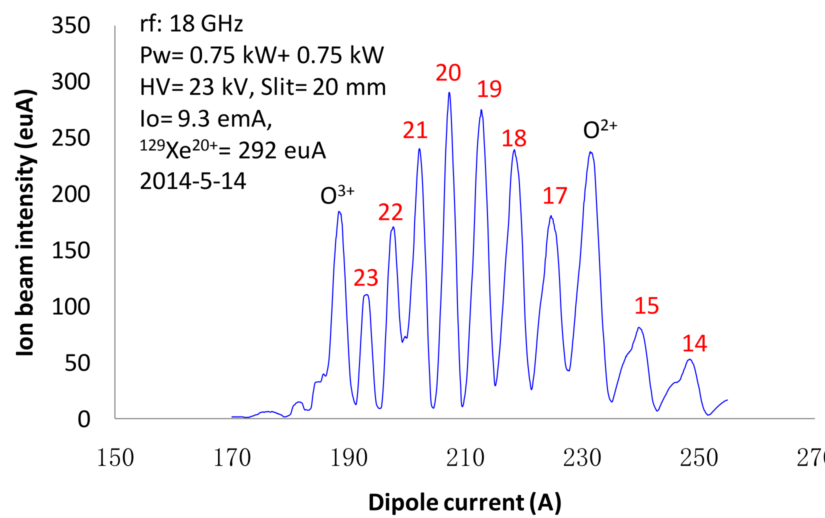
B_r1.0 T, B_{inj} 2.5 T, B_{ext} 0.9 T, B_{min}0.4 T

Ar^{9+}: 1070 eμA (1.40 kW, 25 kV)

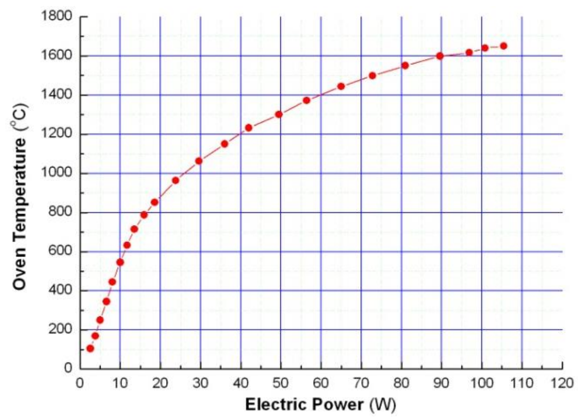
B_r1.0 T, B_{inj} 2.5 T, B_{ext} 0.95 T, B_{min} 0.4 T

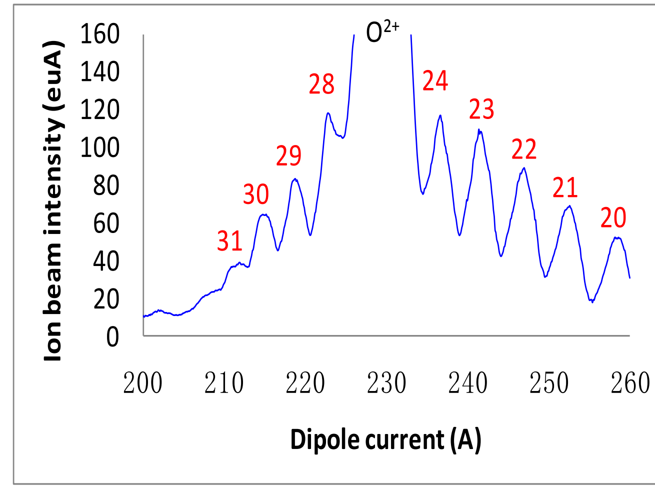
Xe^{20+}: 292 eμA (1.50 kW, 25 kV)

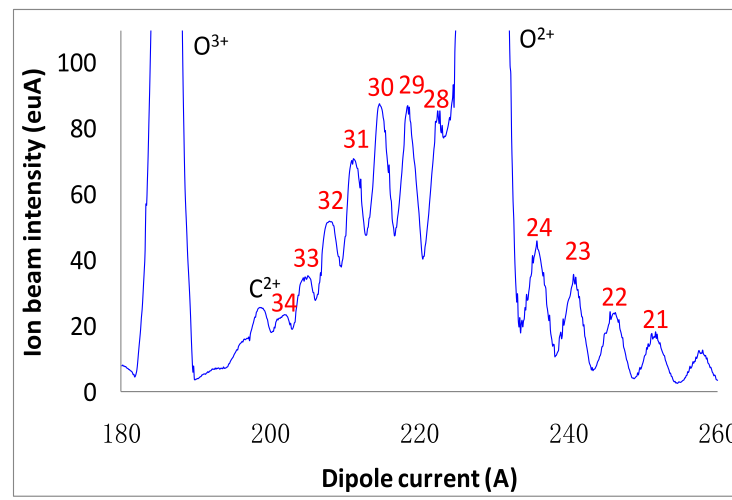
B_r1.0 T, B_{inj} 2.5 T, B_{ext}1.0 T, B_{min} 0.43 T



Preliminary Test of Metallic Beam



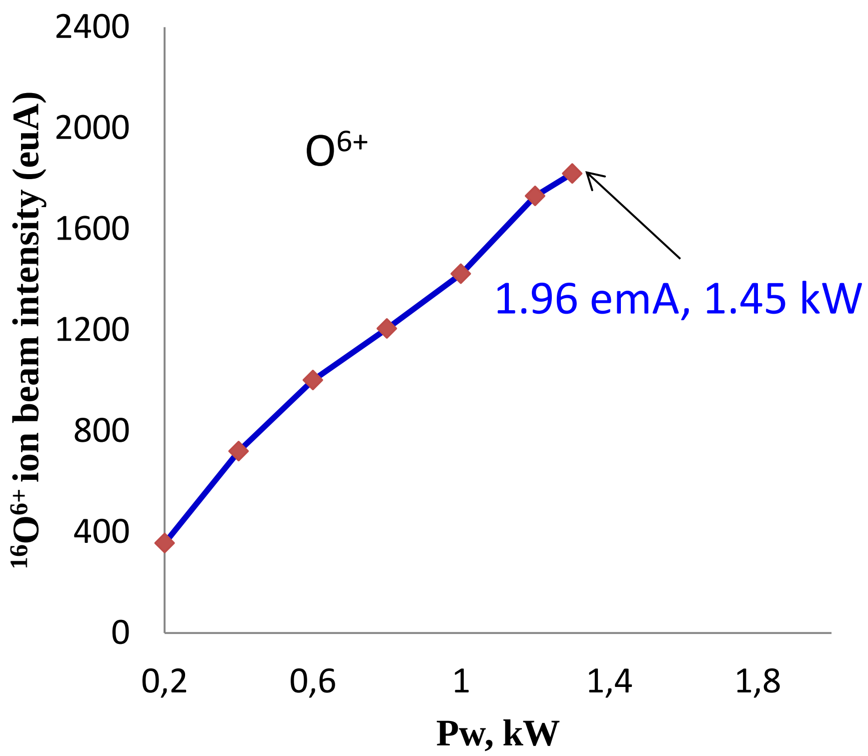


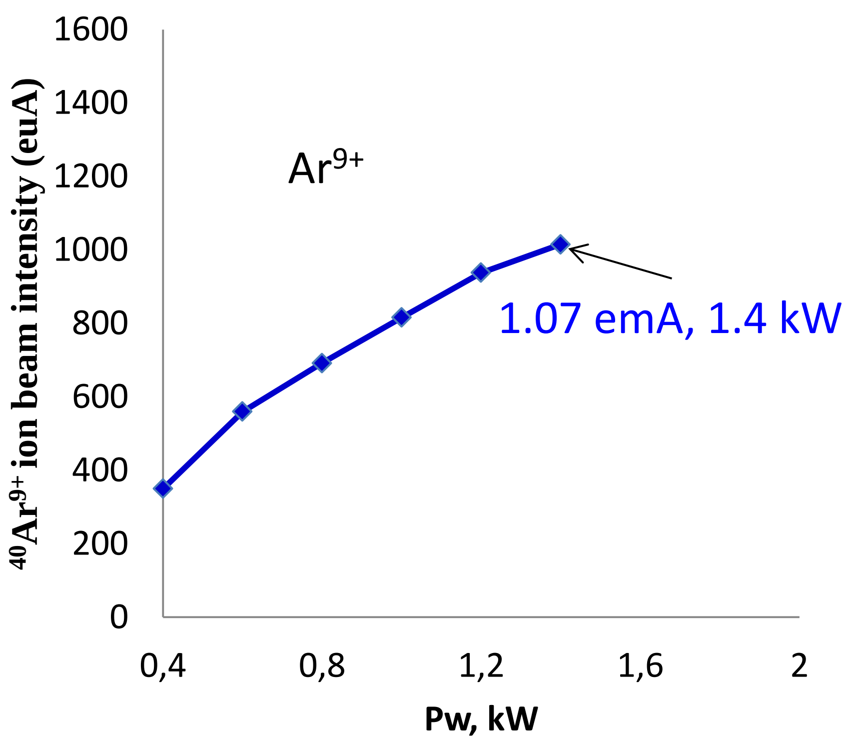


With maximum P_{rf} =1.6 kW, some preliminary but very promising metallic ion beams were produced:

118 eμA Bi^{28+}, 89 eμA Bi^{29+} , 78 eμA Bi^{30+},
70.5 euA Bi^{31+} , 23 euA Bi^{34+}

Beam Intensity Evolution vs. RF Power

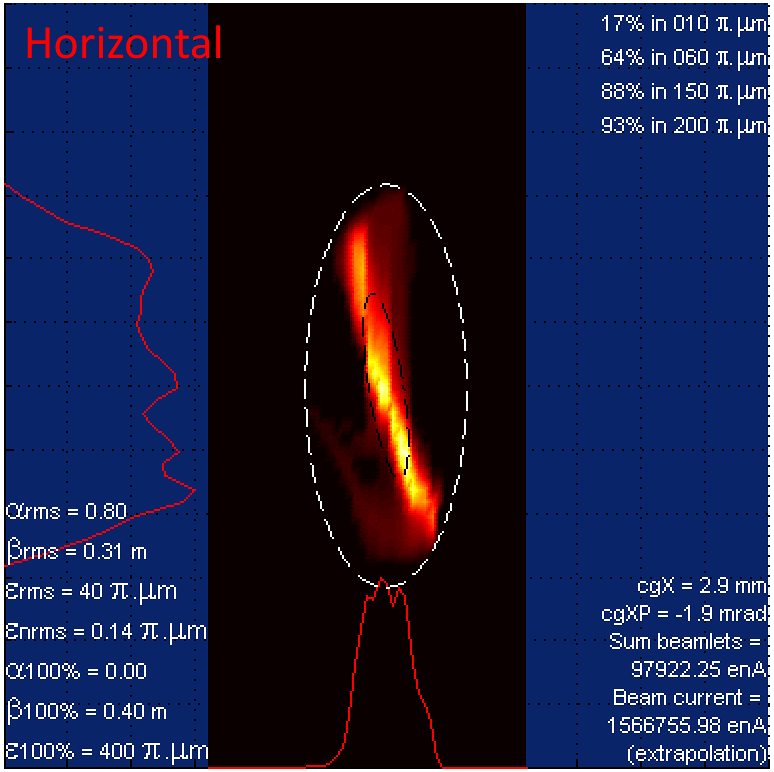


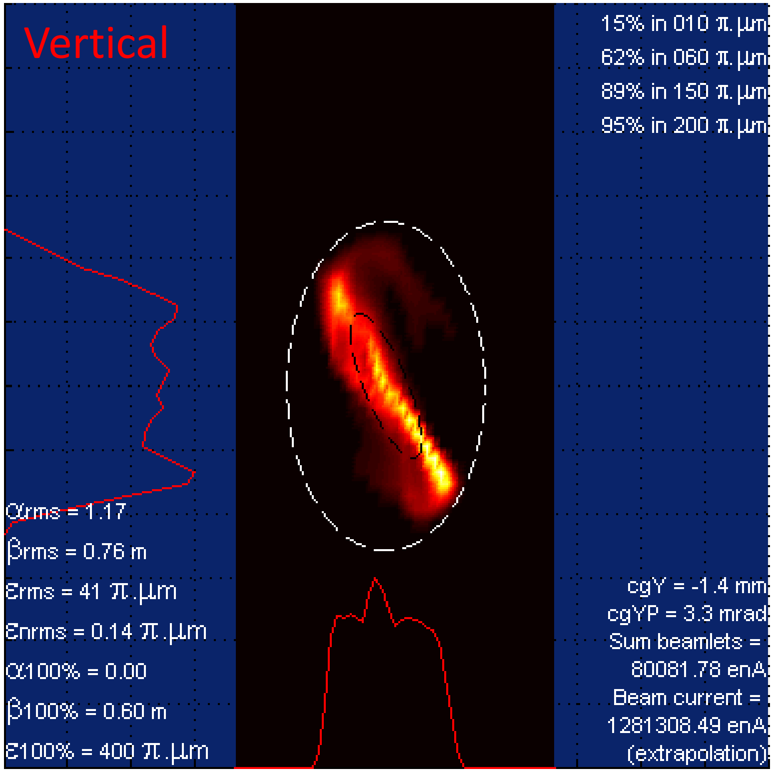


- Ion beam intensities are not saturated
- To input more power, long tuning time is needed.

Intense Ion Beam Emittance- Argon

HV=25 kV, I_o=8.04 emA, Ar^{9+}=1.07 emA





88% in 150 π.mm.mrad

89% in 150 π.mm.mrad

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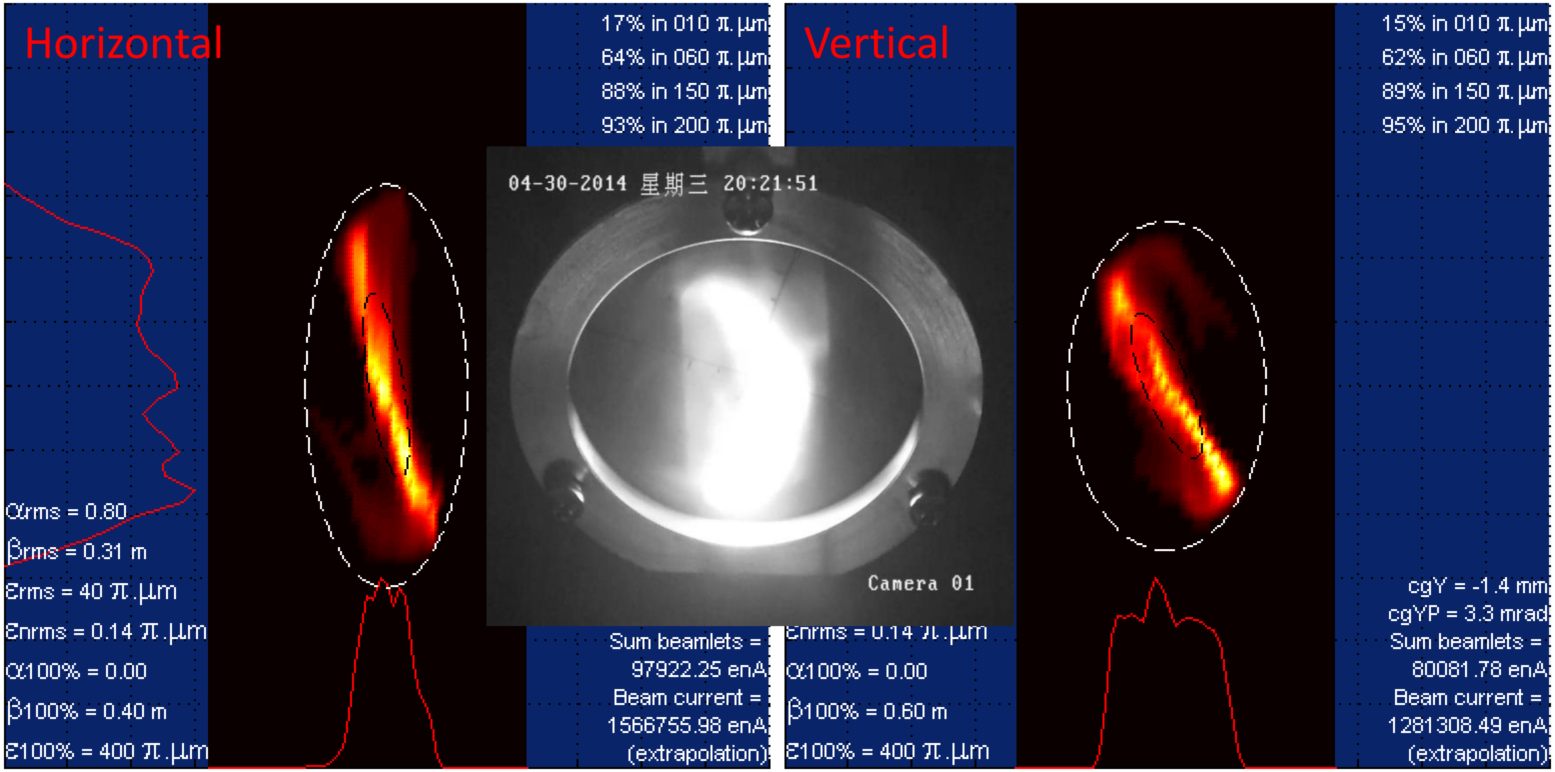
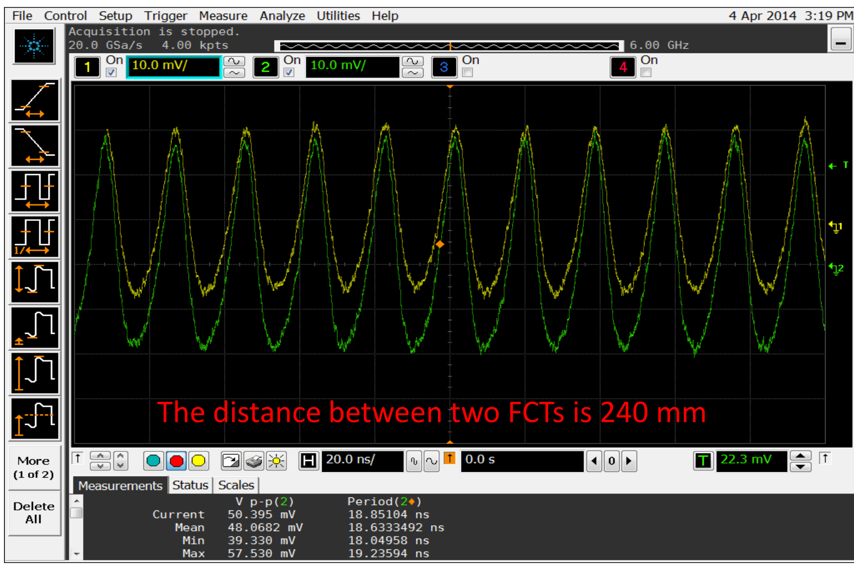


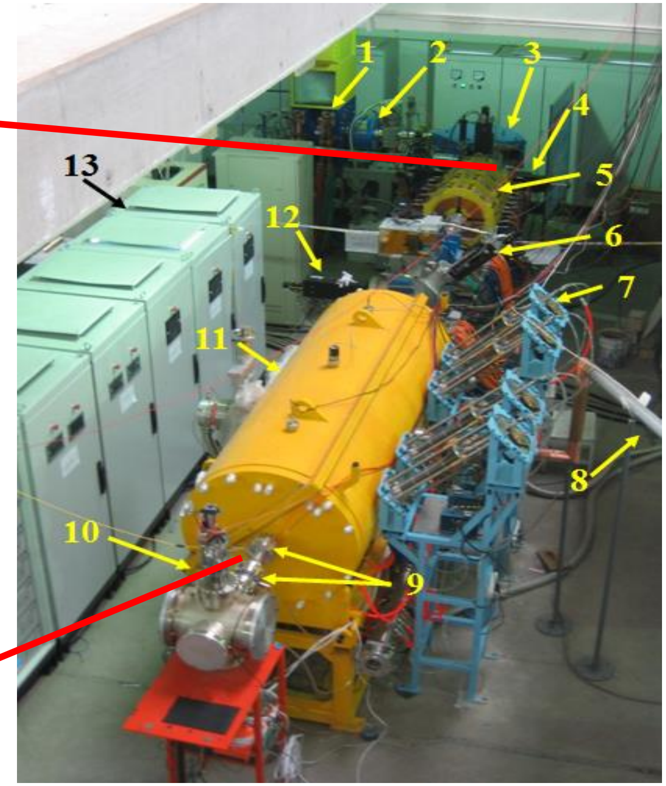
88% in 150 π.mm.mrad

89% in 150 π.mm.mrad

Commissioning with RFQ

Ion species: O^{5+}, Ar^{8+}
Intensity: ~200 euA
Extraction HV: 11.92 kV, 18.6 kV
Pw< 200 W (Only one generator needed)
Normalized rms emittance:
εx= 0.07 π.mm.mrad (Ar^{8+})
εy= 0.13 π.mm.mrad (Ar^{8+})





Final Energy=143 keV/u
Transmit Efficiency of RFQ> 90%

In about one week' s commissioning, the heavy ion beams delivered from LECR4 have been accelerated to the design energy successfully!

1: ion source, 3: bending magnet, 5: double doublet, 11: RFQ, 9: two FCTs

Latest Performance of LECR4

		SECRAL[1]	GTS[2]	LECR3[3]	LECR4
f (GHz)		*18* *<3.2 kW*	*18* *>2 kW*	14 &18	18 <1.6 *kW*
^{16}O	6^+	2300	1950	780	1970
	7^+	810		235	438
^{40}Ar	8+		1100	1100	1717
	9^+	1100	920	720	1075
	11+	810	510	325	503
^{129}Xe	20+	505	310	160	293
	23+			130	143
^{209}Bi	28+	214			118
	30+	191			78
	32+				51.5

1, H.W. Zhao *et al*, RSI, 79, 02A315 (2008).
2, D. Hitz *et al*, RSI, 75, 1403 (2004).
3, Z. M. Zhang et al, AIP Conf. Proc. 749, 238 (2005)

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Room temperature ECRISs

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Summary

Summary

- ✓ **The first room temperature ECR ion source using evaporative cooling technology--LECR4 has been developed successfully**
- ✓ The performance of LECR4 is promising:
  - Design without injection pump tested working fine
  - High beam intensity
  - Reasonable beam quality
- ✓ Successful RFQ commissioning with stable O^{5+} & Ar^{8+} ion beams from LECR4.
- ✓ Total operation time of LECR4> 1000 Hours

Acknowledgement

- Thanks the following colleagues from IEE,CAS for their nice work on building a nice magnet:

  Lin Ruan, Bin Xiong, Shuqing Guo,…

- Many thanks go to the following colleagues for their kind help and fruitful discussions during design and commissioning of LECR4:

  Dan.Xie, Peter Spaedtke,…

- Thanks for your attention!