SECRAL Status and Test Operation at 24GHz

H.W.Zhao, *W.Lu, L.T.Sun, X.H.Guo, X.Z.Zhang, Y.Cao, H.Y.Zhao*

Institute of Modern Physics (IMP), Chinese Academy of Sciences, Lanzhou, 730000, China

D.Z.Xie

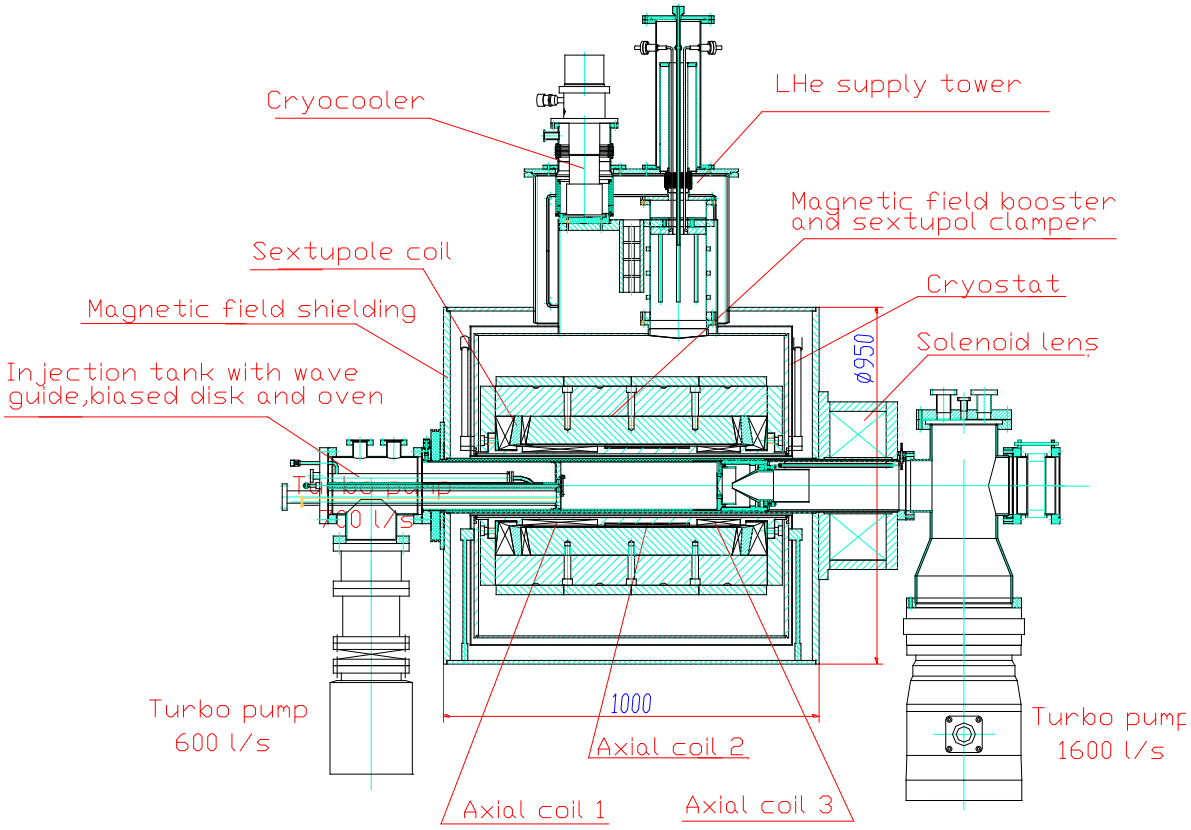
IMP Visiting Physicist

OUTLINE

SECRAL: Superconducting ECR ion source with Advanced design in Lanzhou

- **Introduction**
- **Test Results at 24GHz**
- **SECRAL operation for HIRFL accelerator**
- **SECRAL beam quality study**

SECRAL



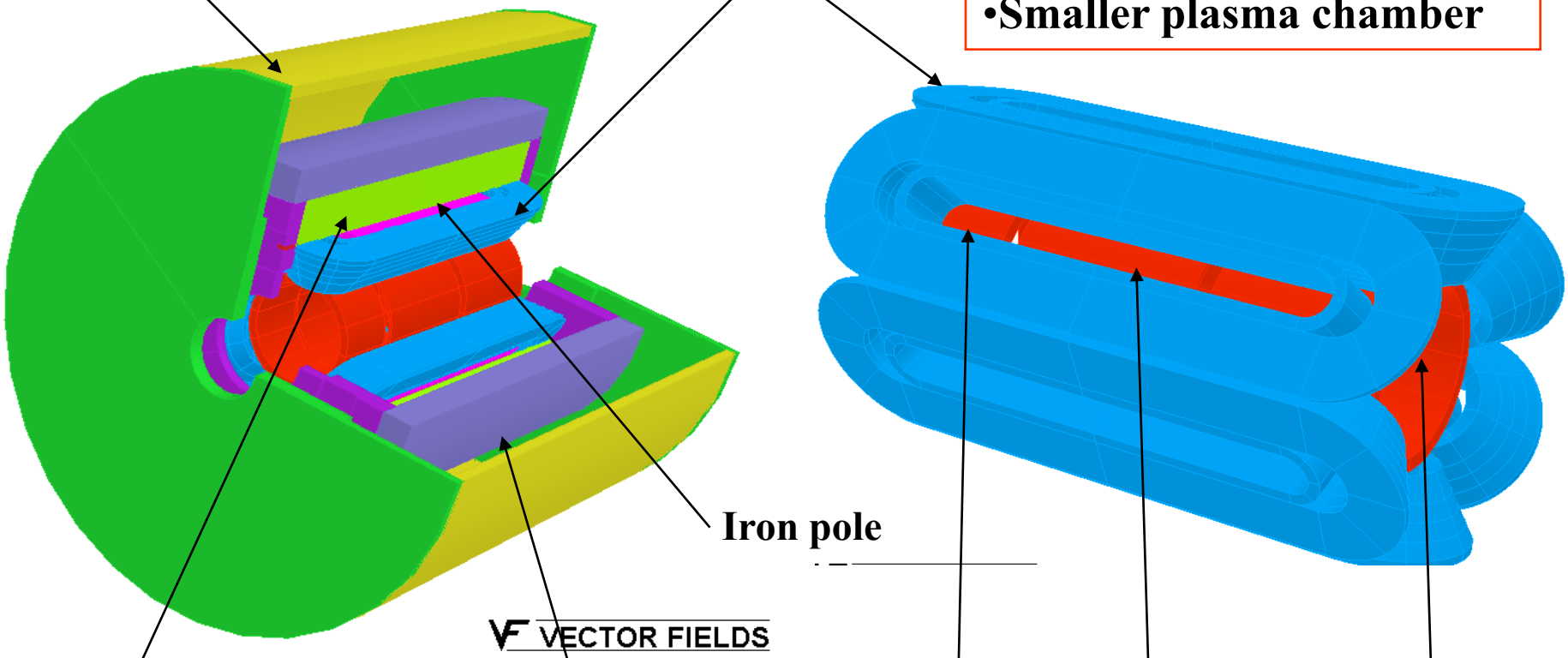
SECRAL Motivation

- To achieve performance enhancement for HIRFL accelerator complex.
- Develop a compact fully superconducting ECRIS
- SECRAL is dedicated to highly charged heavy ion beam production

Achieved axial field: 3.7T, 2.2T
Sextupole at the wall: 2.0 T
RF frequency: 18-28 GHz
Plasma chamber: φ125-116
Extraction voltage: 20-30 kV

SECRAL Magnet Concept and Superconducting Coil Configuration

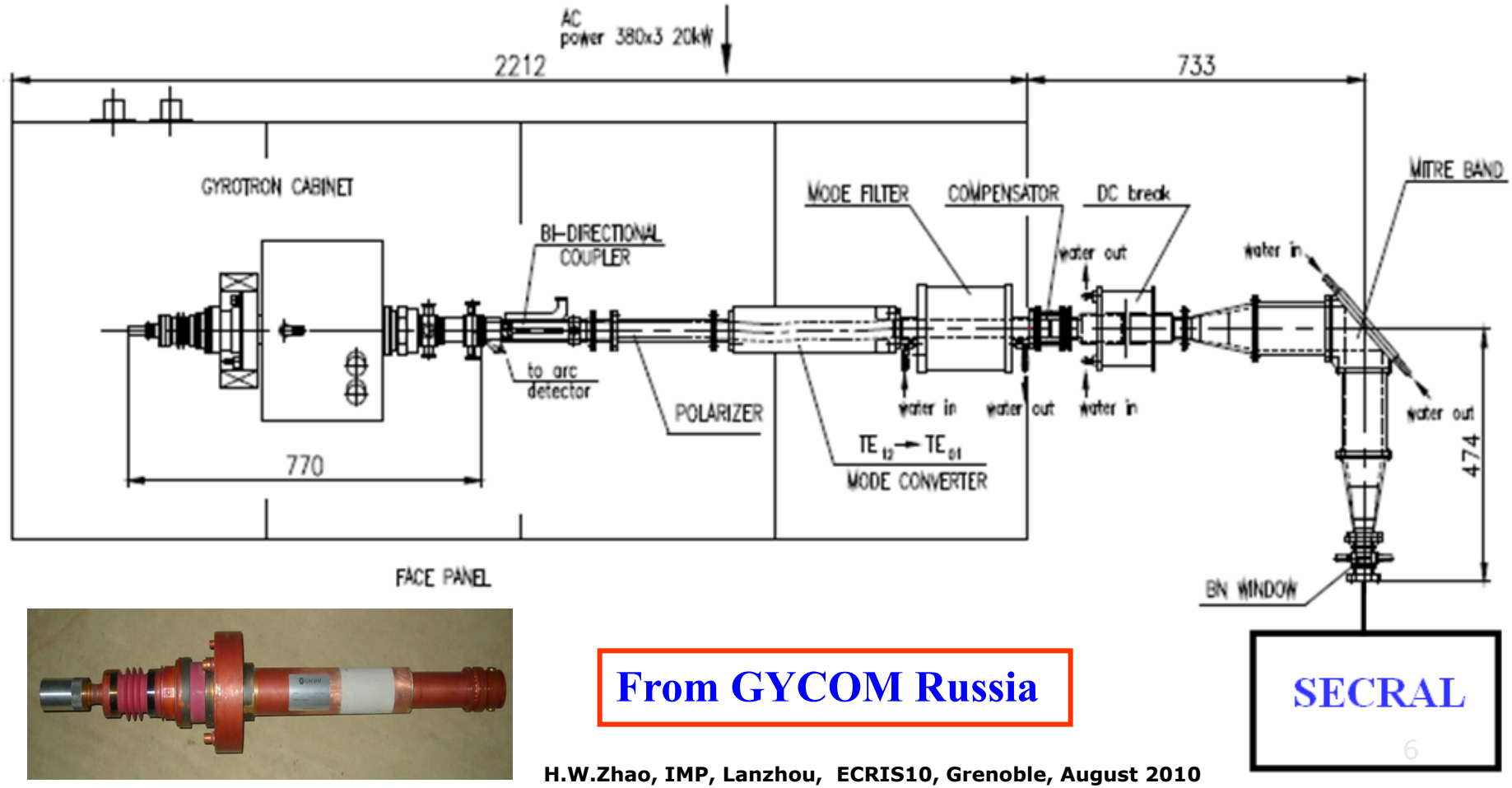
Completely New Design!
- **Solenoids-inside- sextupole**
- **Smaller plasma chamber**



Test Results at 24GHz

SECRAL 24GHz/7kW Gyrotron System

- Reason for choice 24GHz: 24+18GHz better than 28+18GHz;
- 24GHz RF coupling to SECRAL similar to that of SERSE and VENUS at 28GHz;
- All components at 24GHz transmission line are water cooled and as compact as possible

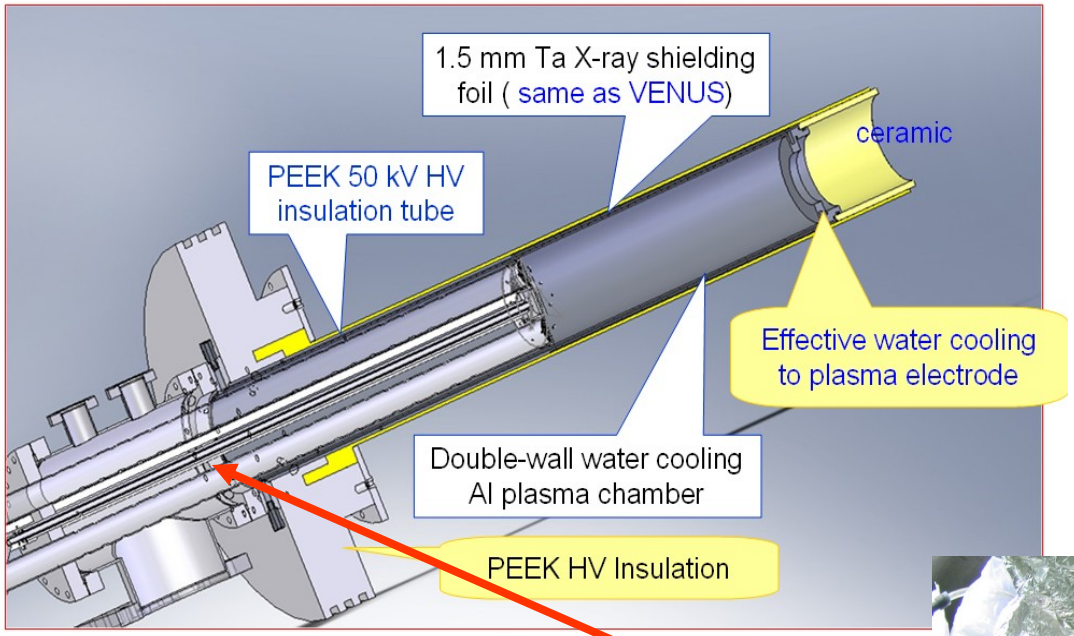


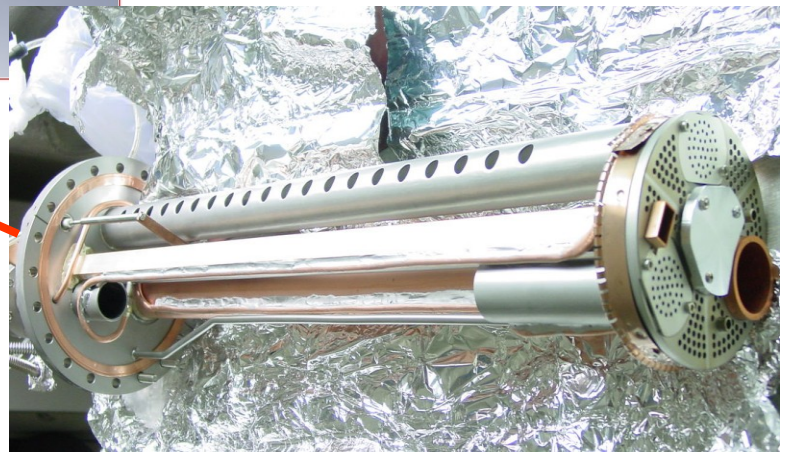
From GYCOM Russia

SECRAL with 24GHz/7kW Gyrotron System

SECRAL Components at 24GHz

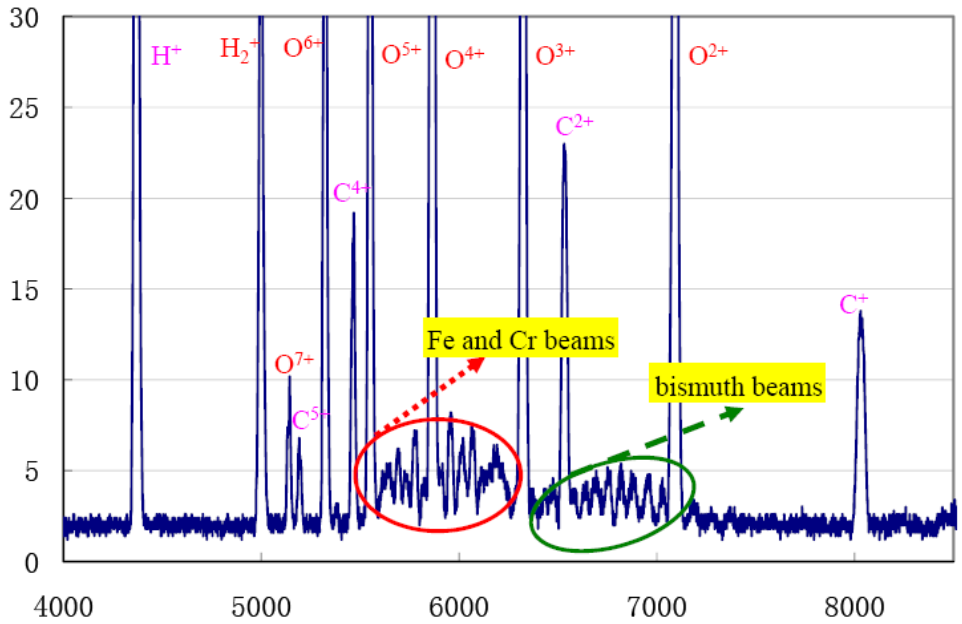
Two plasma chambers for both 18GHz and 24GHz:
Al chamber: Ø116mm, L890 mm
Stainless Steel chamber: Ø120mm, L890 mm

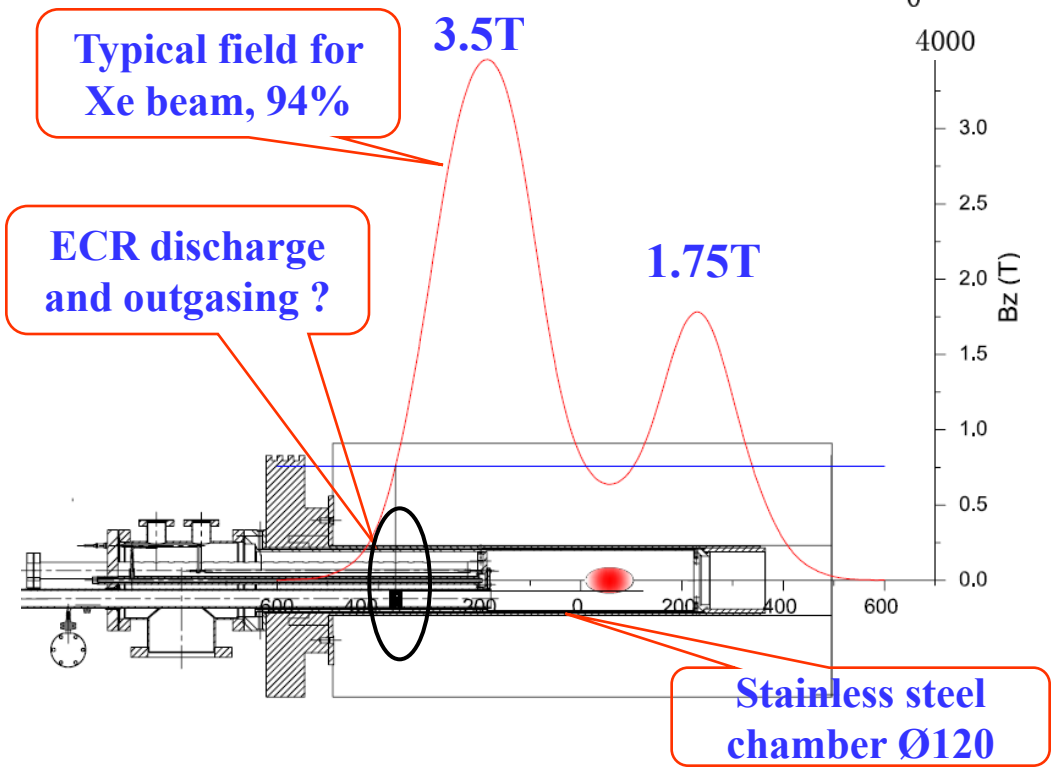




SECRAL First Beam Tests at 24GHz

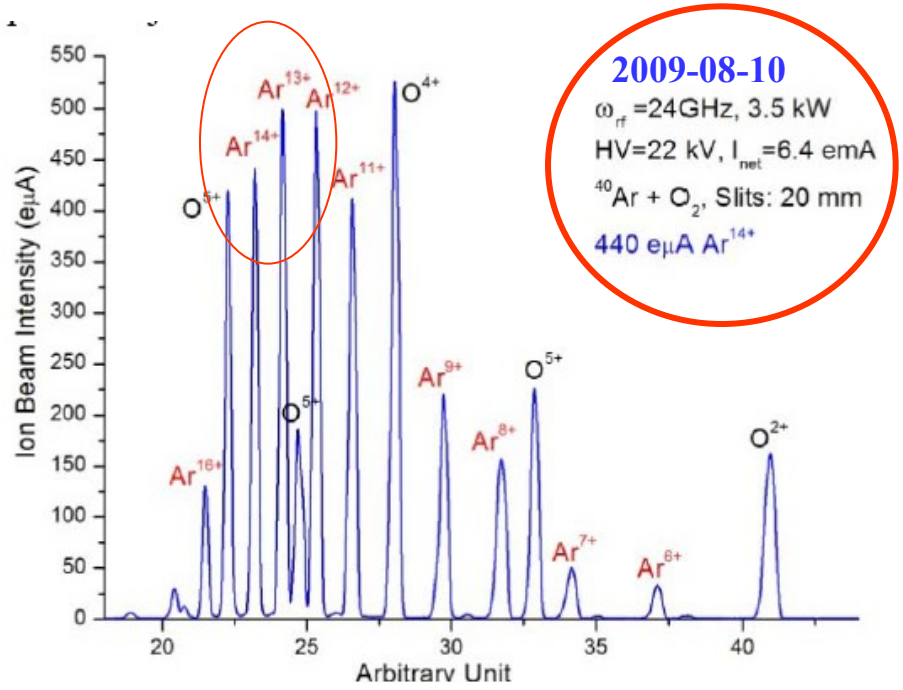
Ar and Xe beams were tuned with a stainless steel chamber started in 08/2009. SECRAL was set at 90- 95% maximum field.



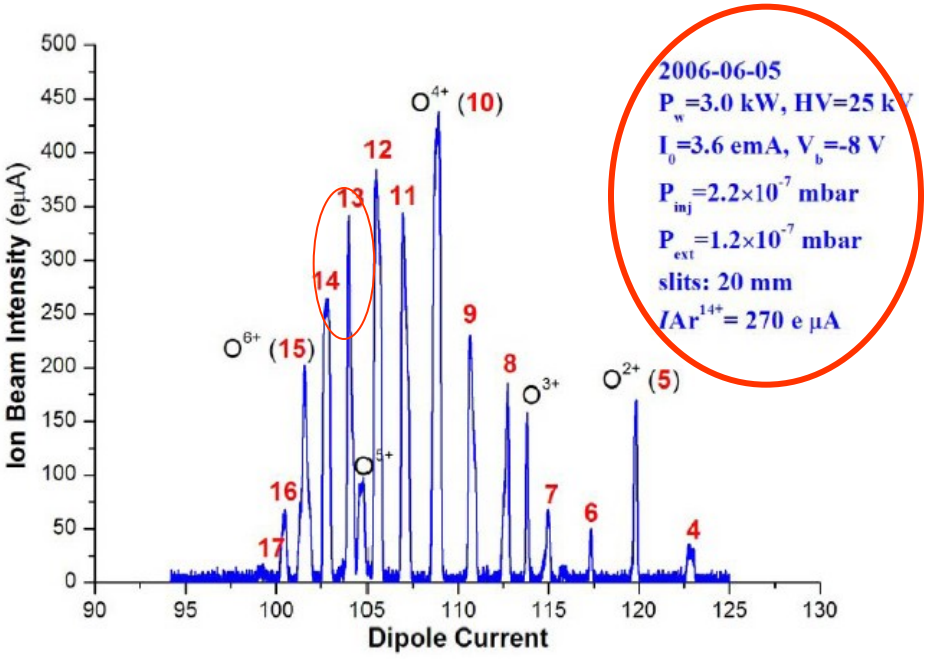


- Conditioning and outgasing take longer time at 24GHz;
- Stable operations for medium and high Q need very different parameters optimization;
- X-ray much stronger at 24GHz;

Test Results of SECRAL at 24GHz – Ar beam



Spectrum to optimize Ar^{14+} at 3.5kW/24GHz



Spectrum to optimize Ar^{14+} at 3kW/18GHz

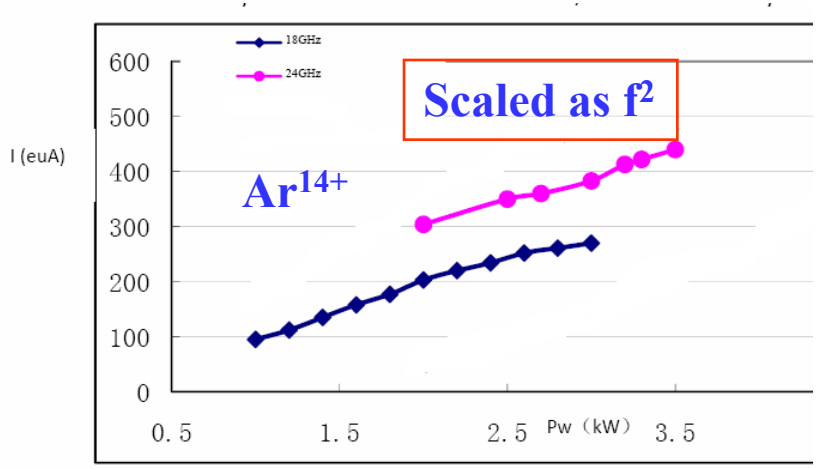
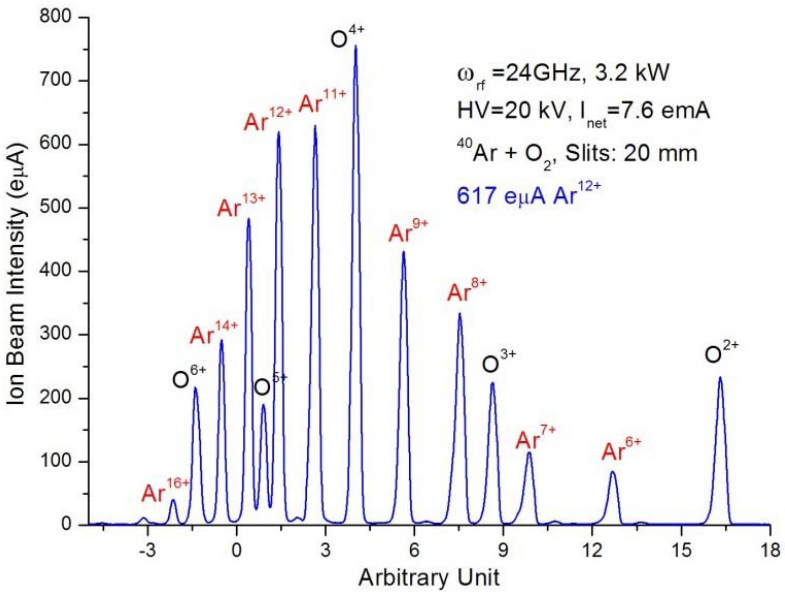
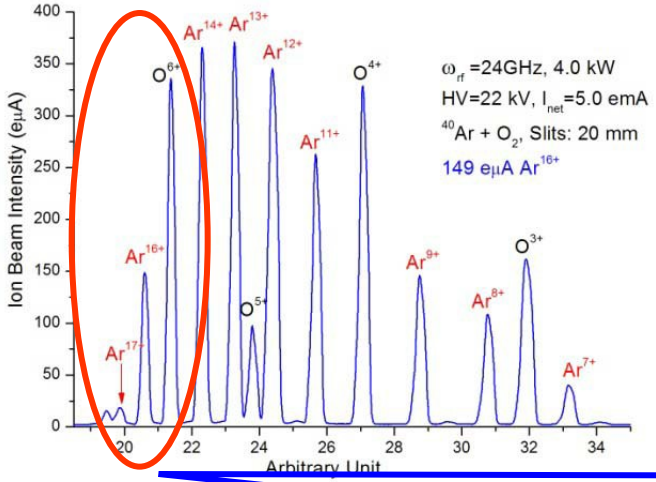


Fig. 6 Power evolution of Ar^{14+} beam intensity.

- At 24GHz, more mixing gas O_2 is needed?
- At 24GHz, spectrum moves to higher Q.
- Beam intensity is increasing with rf power.
- Results achieved with one week conditioning.

Test Results of SECRAL at 24GHz – Ar beam



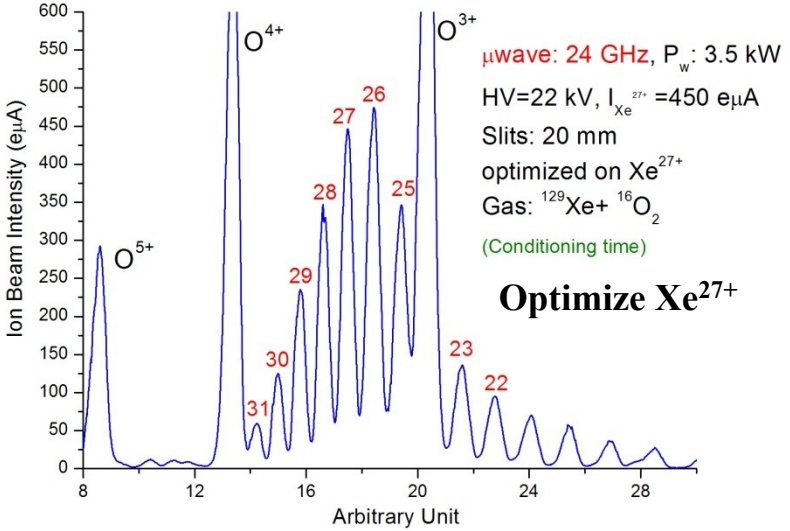


IONS	SECRAL 18GHz 3kW (eμA)	SECRAL 24GHz 3-4kW (eμA)
Ar 12+	510	650
14+	270	440
16+	73	149
17+	8.5	14

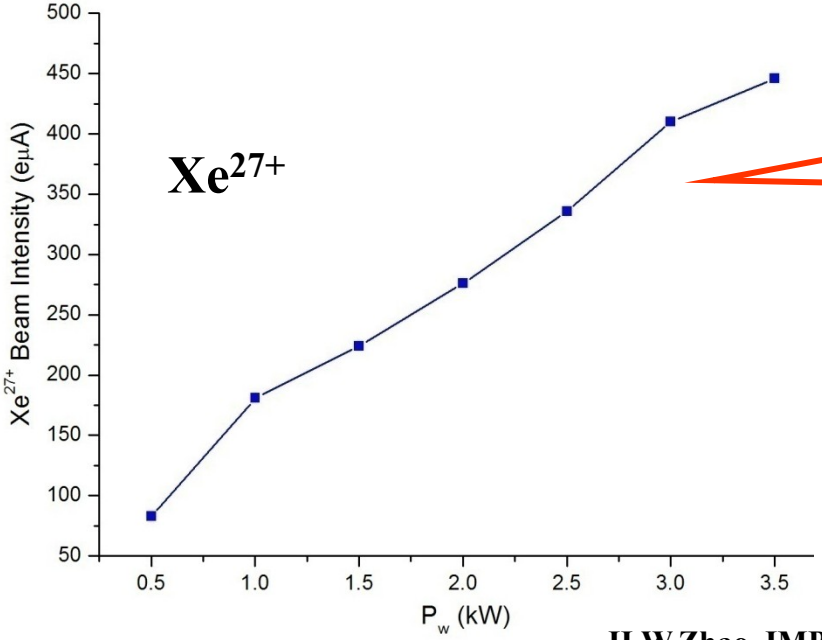
20-22 kV, 24GHz,3-4 kW, B_{inj}=3.3 T, B_{rad}=1.7T

To optimize Ar^{16+}, Ar^{17+}, need a lot mixing gas O_2. Optimum condition has not been found for 16+, 17+,18+. Probably Al chamber is needed.

Test Results of SECRAL at 24GHz—Xe beam



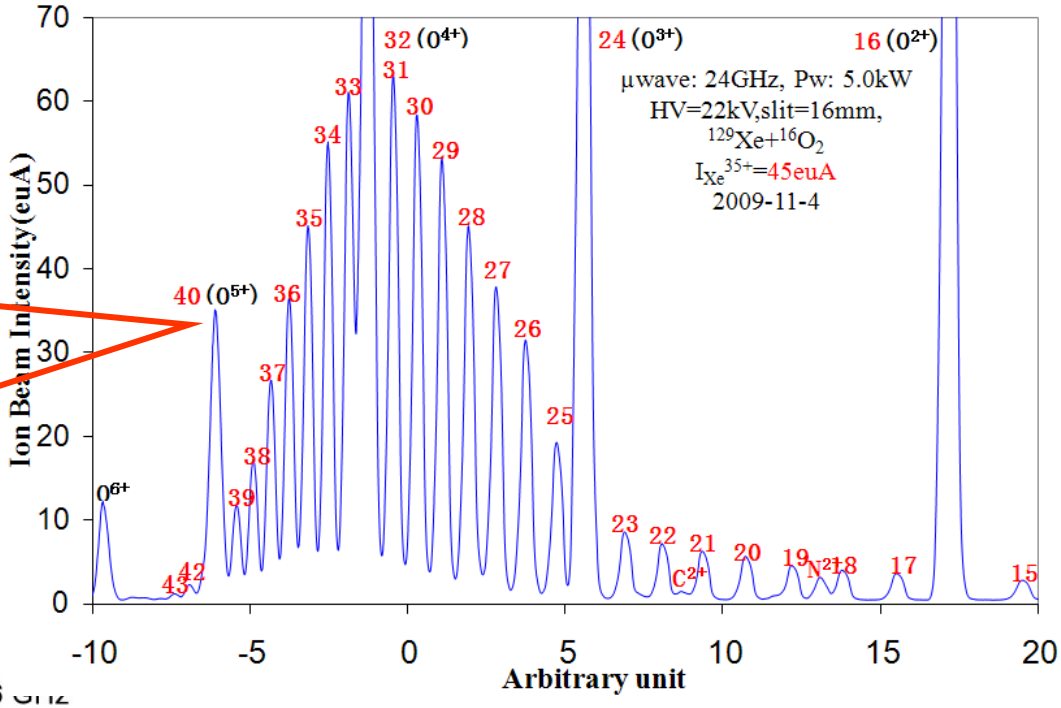
22kV extraction 24GHz , 3.5 kW, magnet 94%, B_{inj}=3.5 T, B_{rad}=1.75T

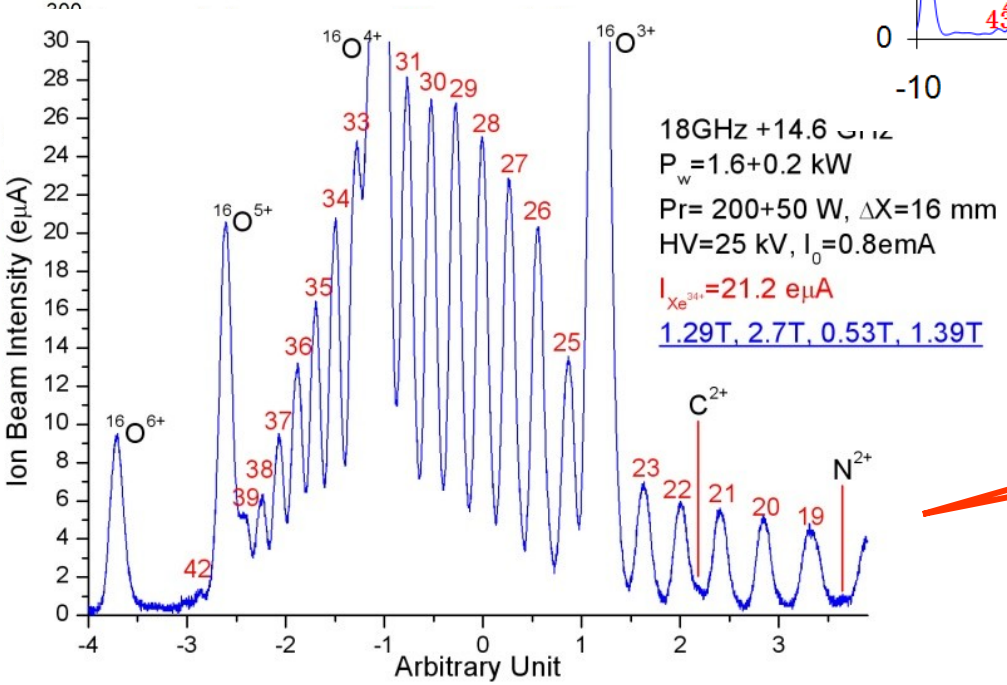


Xe^{27+} keep increasing with 24GHz rf power, not saturate

SECRAL 24GHz –Xe Beam

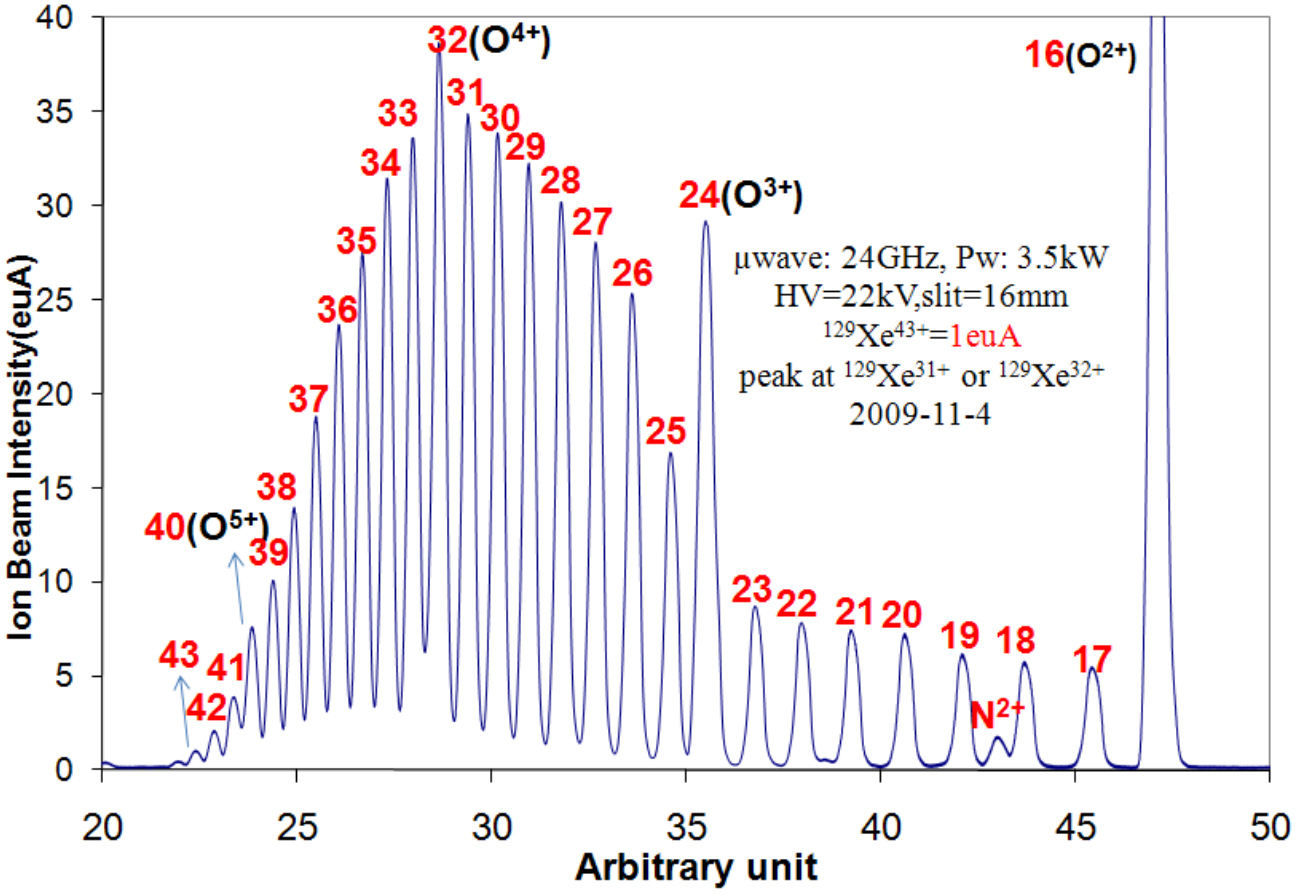
- SECRAL 24GHz, Xe HCI
- Optimize Xe^{34+}, Xe^{35+}at 3-5kW.
- With stainless steel chamber.
- Source conditioning more important and complicated.





SECRAL 18+14.5GHz
Optimize Xe^{34+} at 1.8 kW.
With Al chamber.

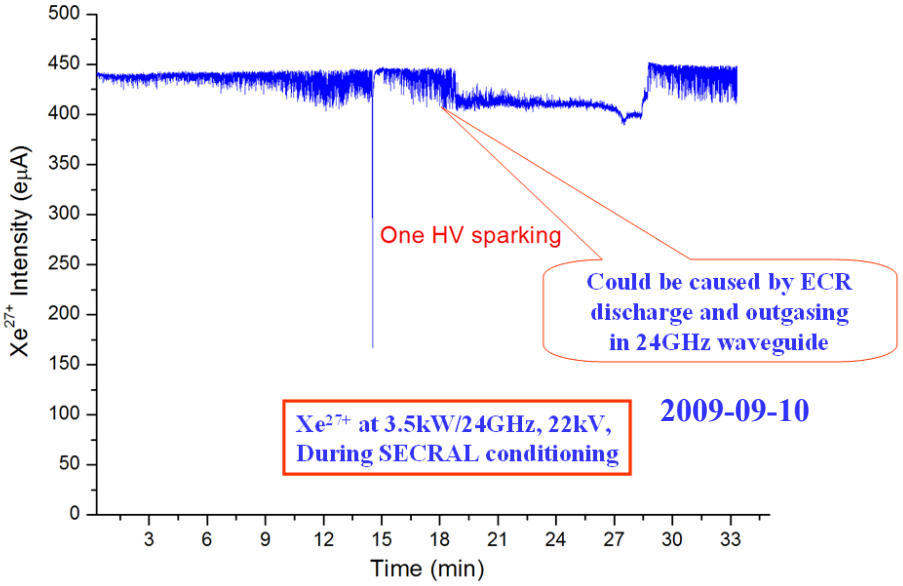
For Xe beam Q>40, at 3-5 kW, optimum condition still has not been found. Maybe more source tuning is needed and better results for Q>40 should be achieved with Al chamber and 24+18 GHz which will be tested.

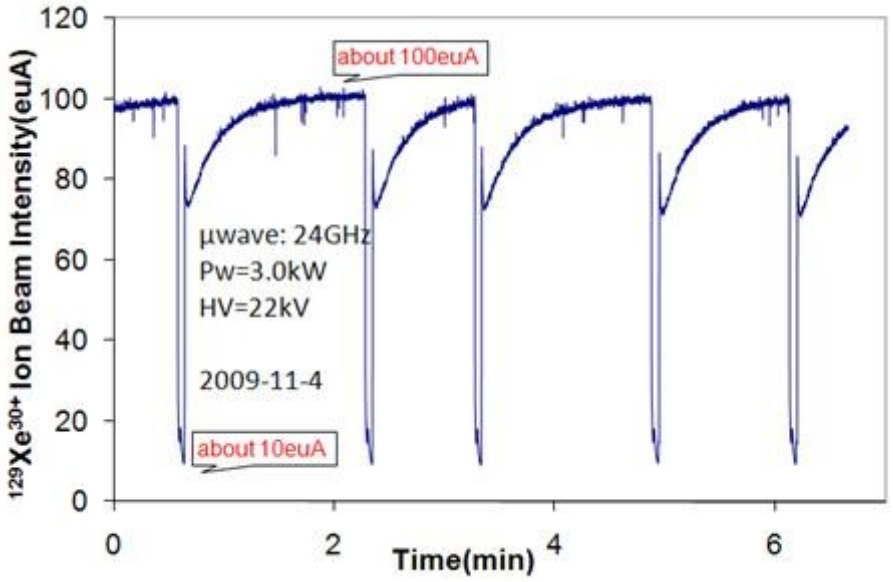


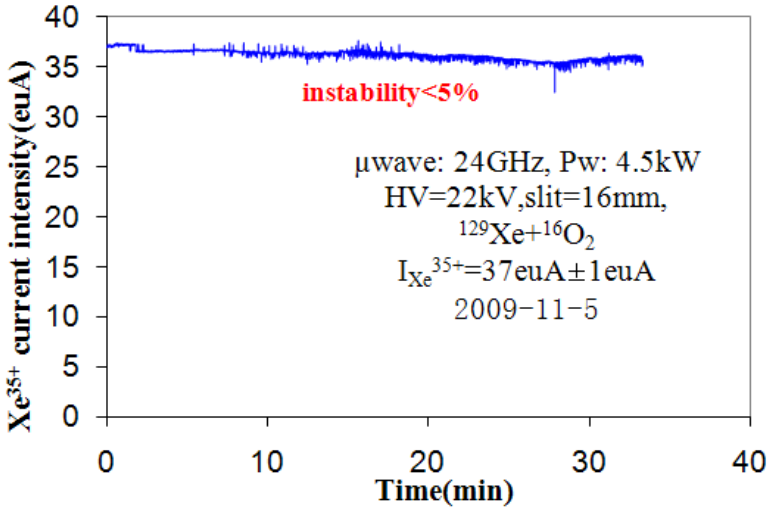
SECRAL Xe beam at 18GHz and 24GHz

IONS	SECRAL 18GHz <3.2kW (eμA)	SECRAL 24GHz <5kW (eμA)	VENUS 28GHz or 28+18GHz >6kW (eμA)
Xe 26+	410	480	290
27+	306	455	270
28+		350	222
30+	101	152	116
31+	68	85	67
34+	21	60	
35+	16	45	28
38+		17	7
42+	1.5	3	0.5

Beam Stability at 24GHz/3-5 kW

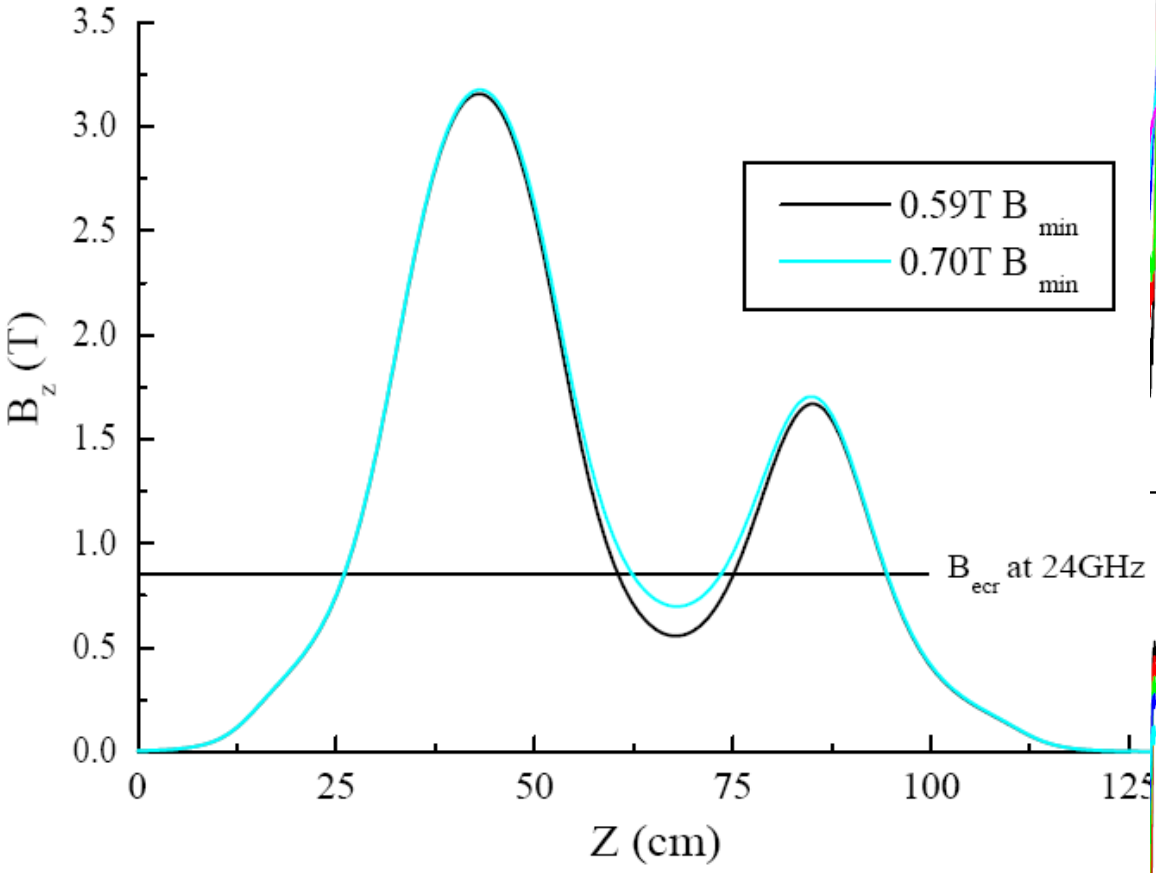


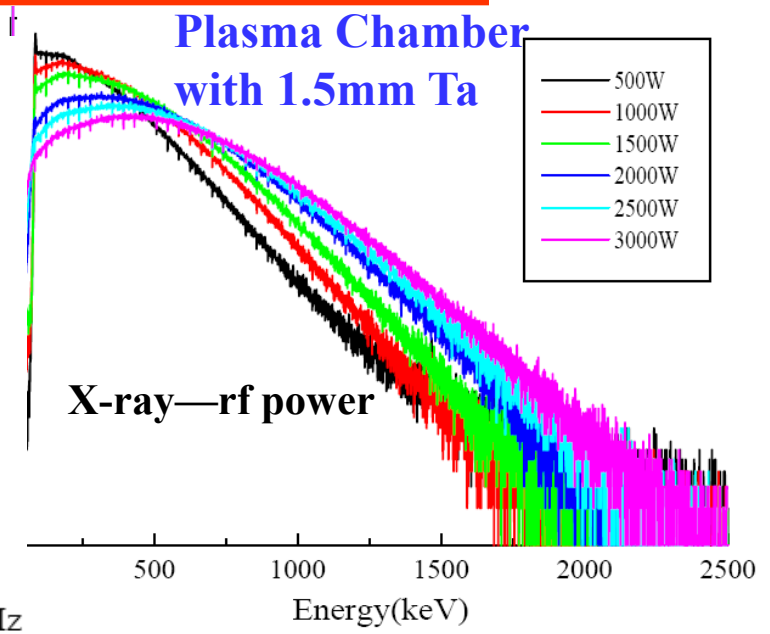


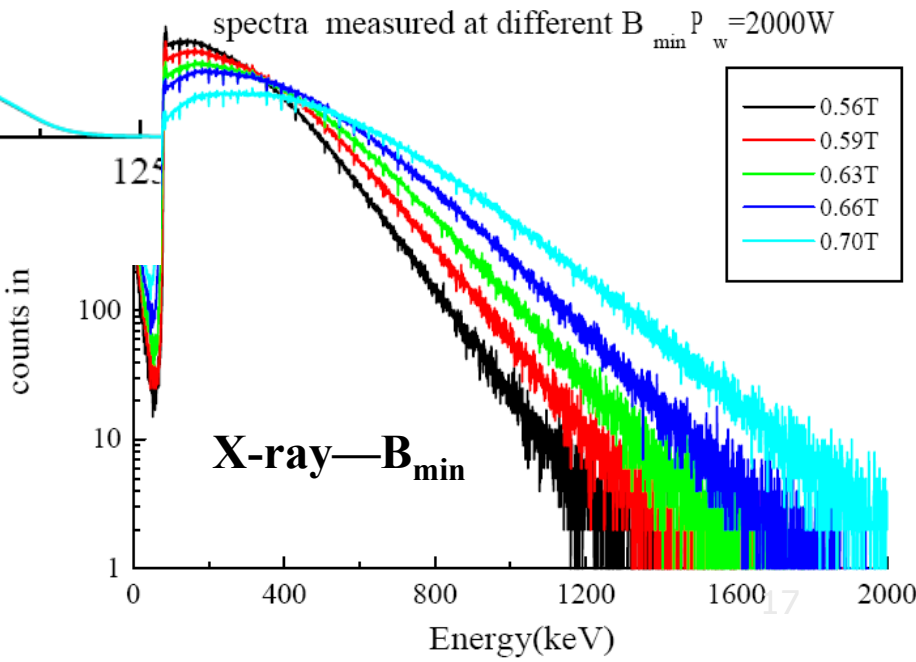


Beam long-term stability at 24GHz/3-5 KW is not as good as that at 18GHz/3kW. Reasons need to be studied.

SECRAL Bremsstrahlung Measurements at 24GHz



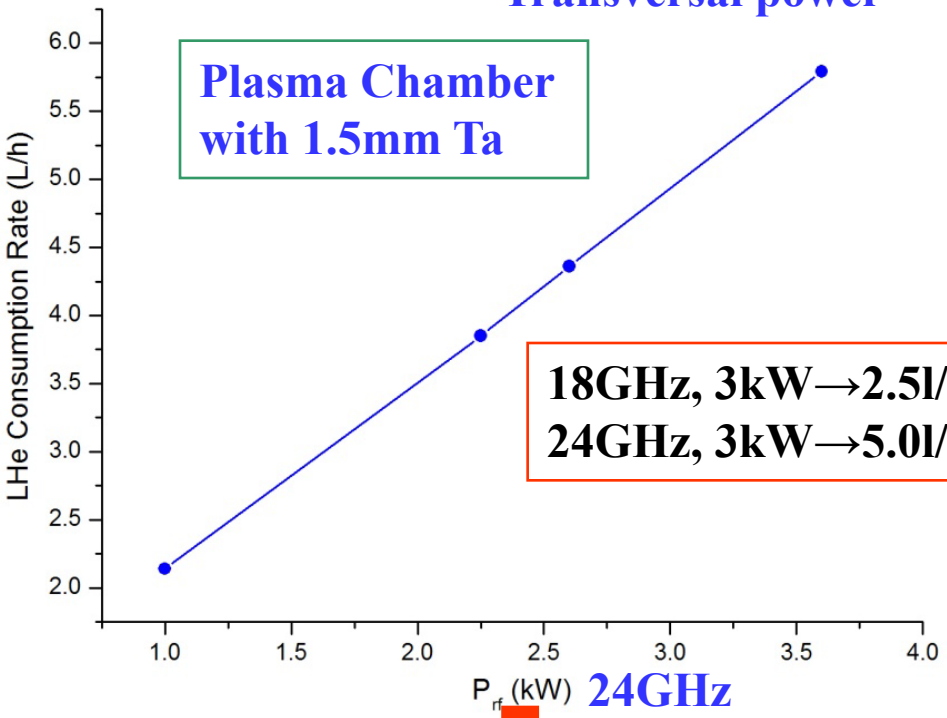




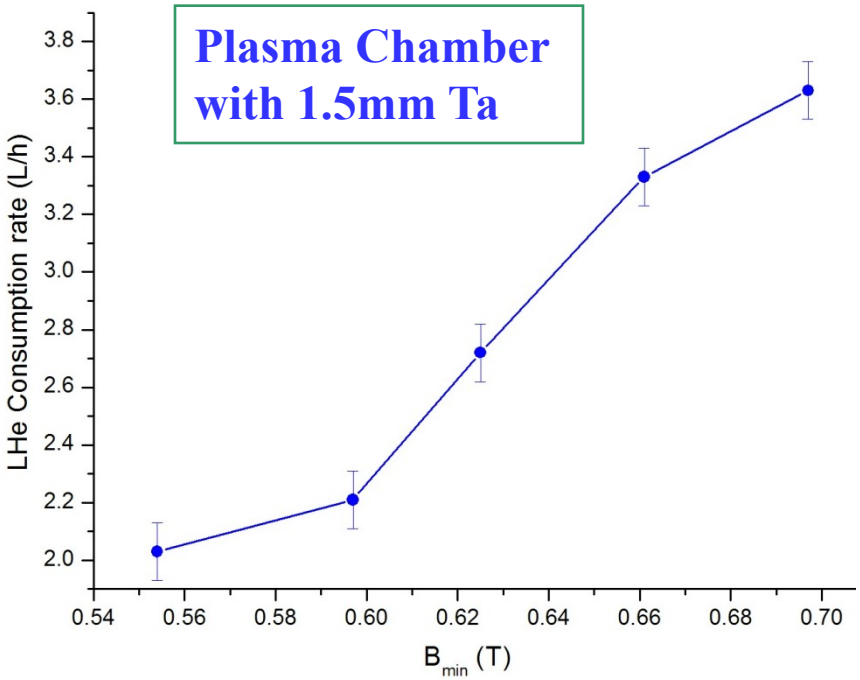
- Results are similar to those from VENUS;
- X-ray is much stronger with higher frequency, higher rf power and higher B_{min}
- High energy tail is much larger.

SECRAL Heat Load to the Cryostat from Strong Bremsstrahlung

Transversal power



18GHz, 3kW→2.5l/h
24GHz, 3kW→5.0l/h



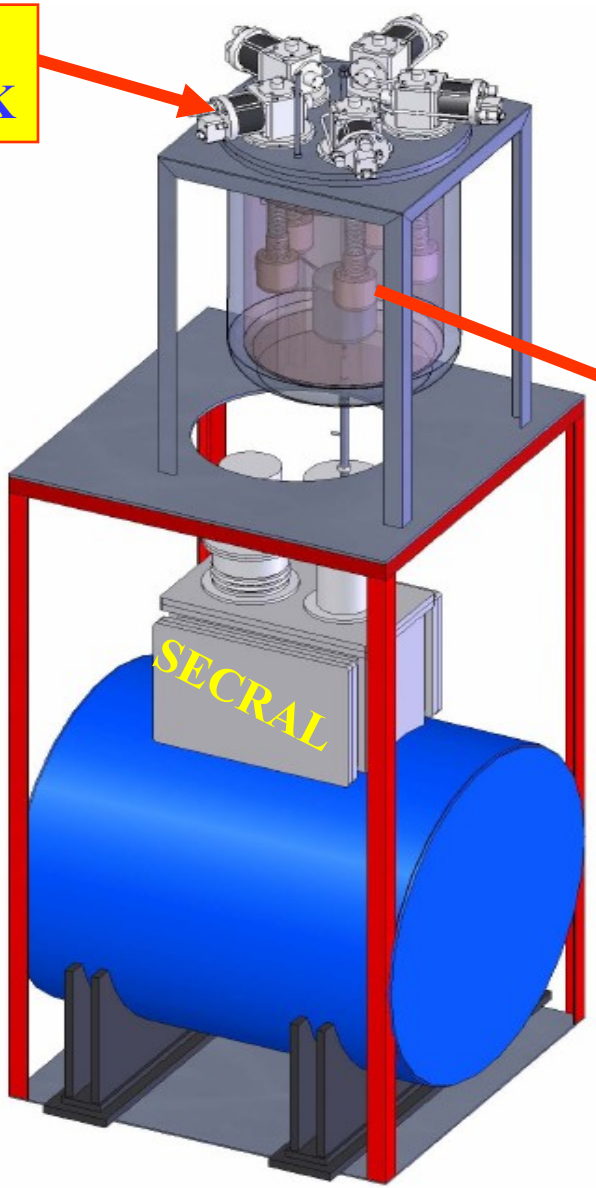
1 kW rf power → 1W heat load, Almost same as that of VENUS

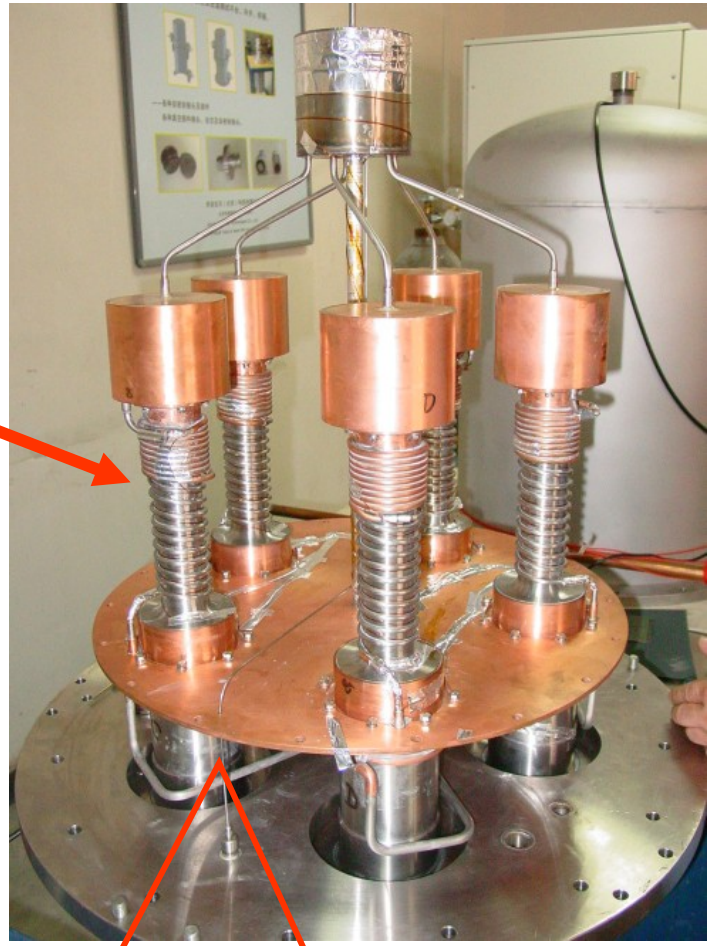
From point view of reducing heat load to the cryostat, it is better to run SC-ECRIS with double frenq heating at lower B_{min}.

Without close-loop LHe supply system or Cryocoolers, impossible to run SC-ECR!

Modify SECRAL with Cryocoolers for Operation without LHe Consumption

Cryocooler 1.5W@4.2K





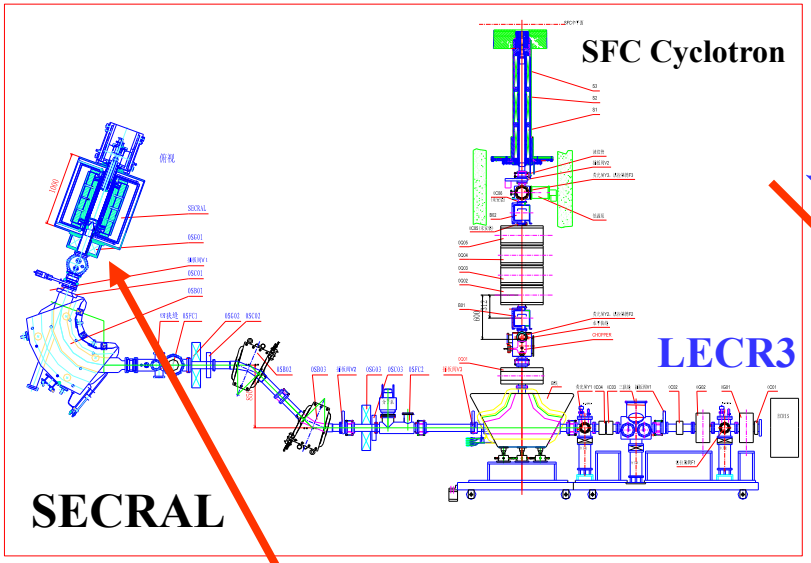
Off-line test with warm He gas, total LHe rate 3-4l/h. Has been operated for more than 7 months at SECRAL.

Operation status of additional cryostat with 5 cryocoolers

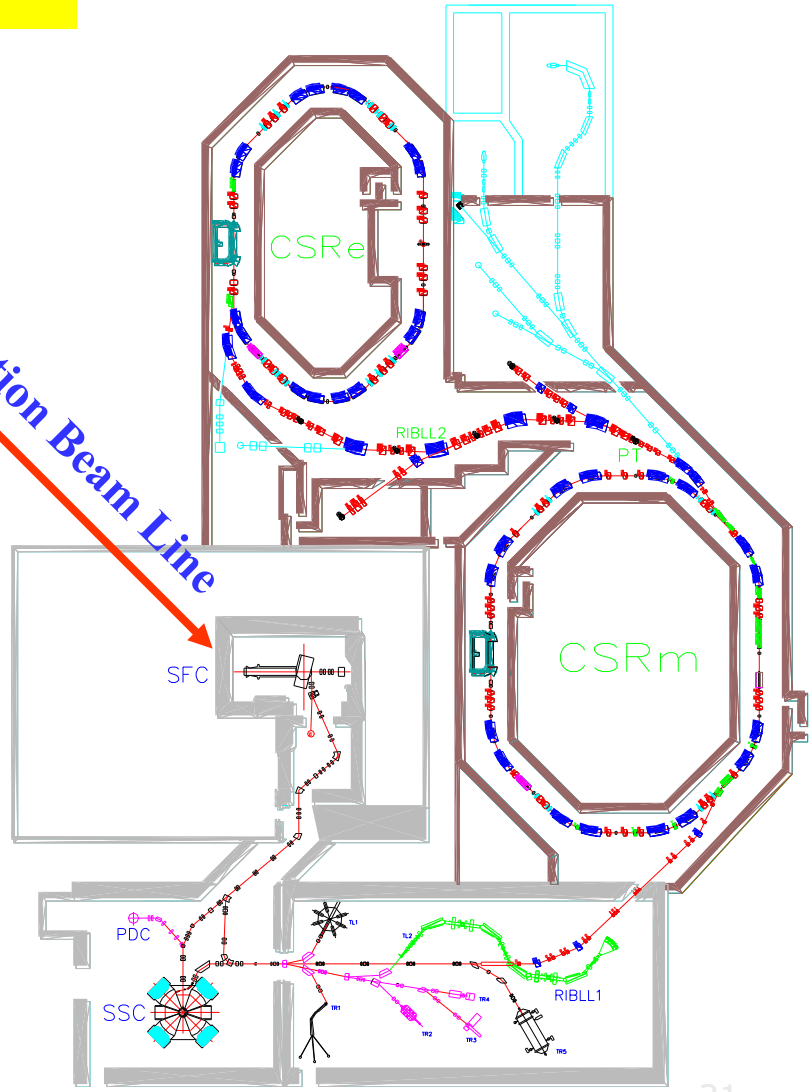
- It has been operated since 12/09.
- The best operation: 2 weeks without LHe refilling.
- Still some problems to be solved. Modification!
- Goal: no LHe refilling at 18GHz/3 kW,
  Refilling LHe(50 l) /3-4 days at 24GHz/3kW

SECRAL Operation for HIRFL Accelerator Since May 2007

SECRAL is dedicated only for operation of highly charged heavy ion beams.



HIRFL Accelerator Complex At IMP lanzhou



SECRAL Operation for HIRFL Accelerator

- Beams operated for HIRFL accelerator:
  $^{209}Bi^{31+}$, $^{129}Xe^{27+}$, $^{78}Kr^{19+}$, $^{58}Ni^{19+}$
  At 18GHz, typical rf power 1.3-2.0 kW, extraction voltage 10-22kV
  Beam intensity during operation:
  100-150 eμA for Xe, Kr , 50-70 eμA for, Bi^{31+}, Ni^{19+}(9.8kV)

- **One month continuous operation, $^{78}Kr^{19+}$ in Oct.09 and $^{209}Bi^{31+}$ in Jul. 10**

- **Total beam time from SECRAL for HIRFL: >3500 h**

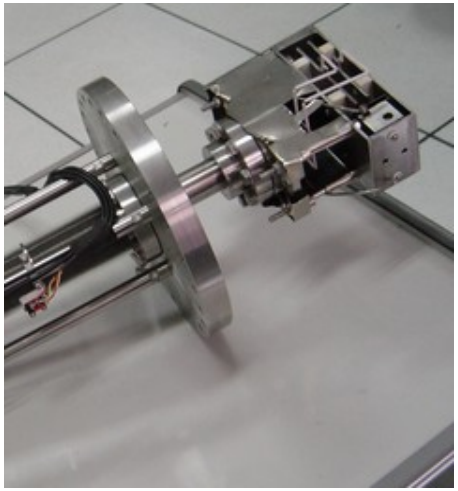
- **With ^{78}Kr beams at CSRe, 9 new nuclides (^{63}Ge,^{65}As,^{67}Se...) were identified firstly in the world with $\Delta m/m=10^{-6}$**

Problems of SECRAL operation for HIRFL accelerator

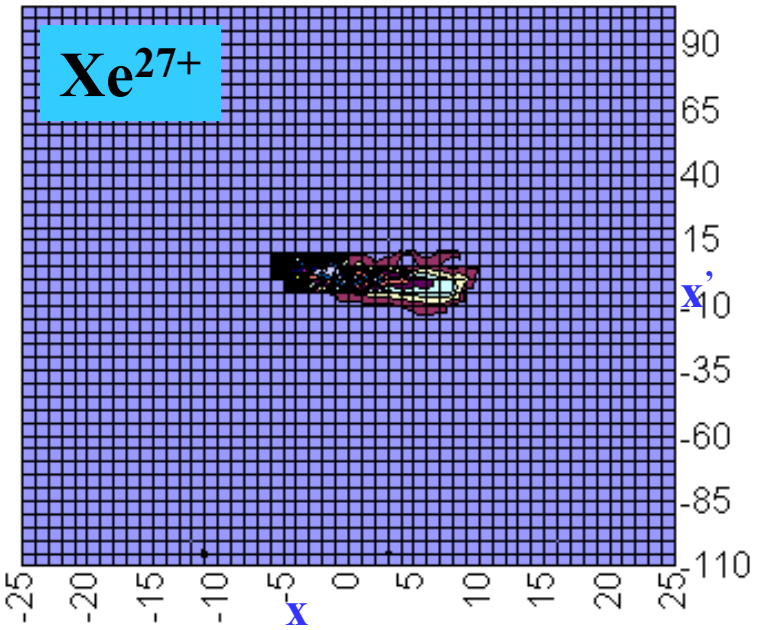
- Low extraction voltage (<15kV for high Q heavy ions)
- Cyclotron beam very sensitive to the plasma conditions due to variations of beam extraction, emittance and image.
- Need to refill LHe if the additional cryostat is not operated normally
- Control board of the CPI 18GHz rf generator sometimes broken if there is spark
- The long term stability of beam $^{209}Bi^{31+}$ and $^{129}Xe^{27+}$ is not as good as that of last year due to micro-leakage at the extraction insulator and one cooling tube in the injection component.

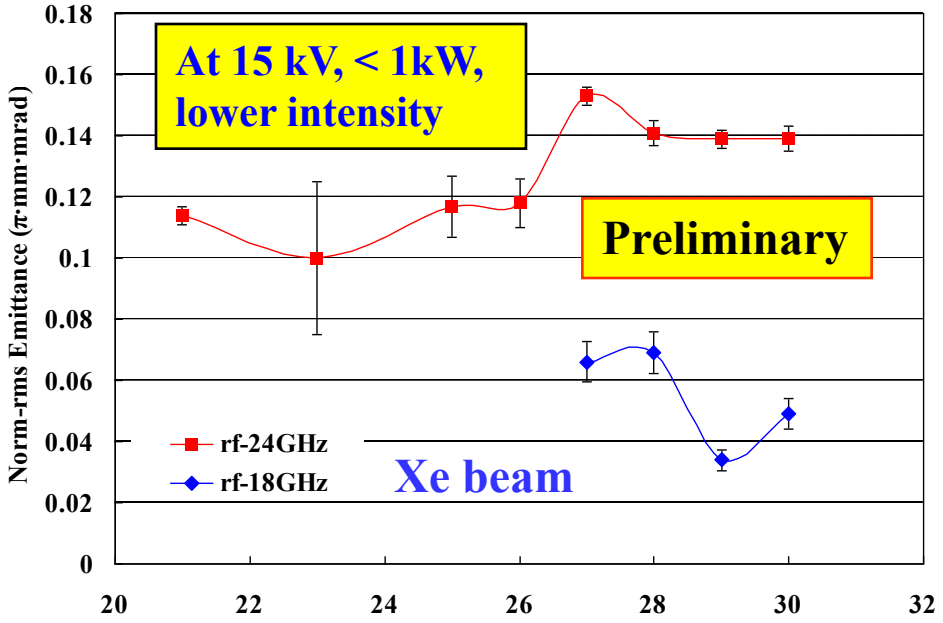
Beam quality study at SECRAL

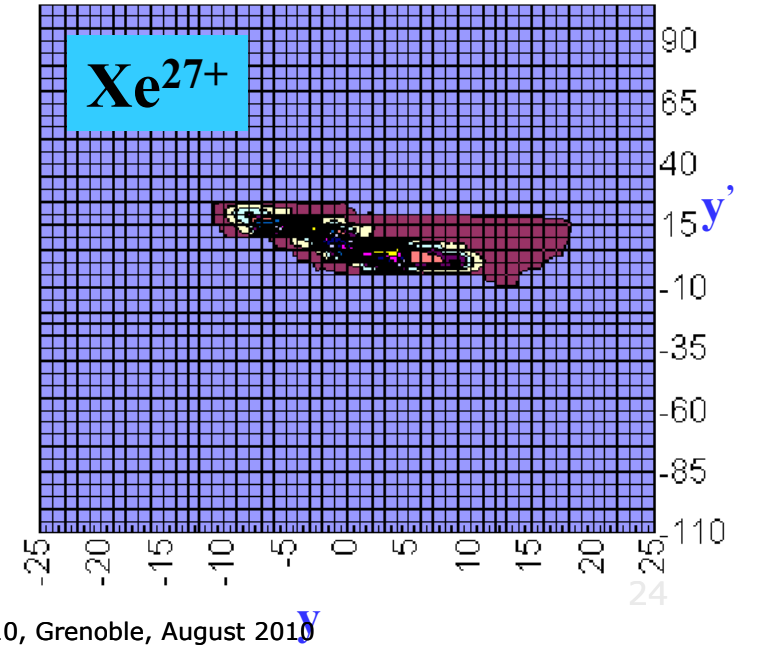
Use M. Stockli's code to process data



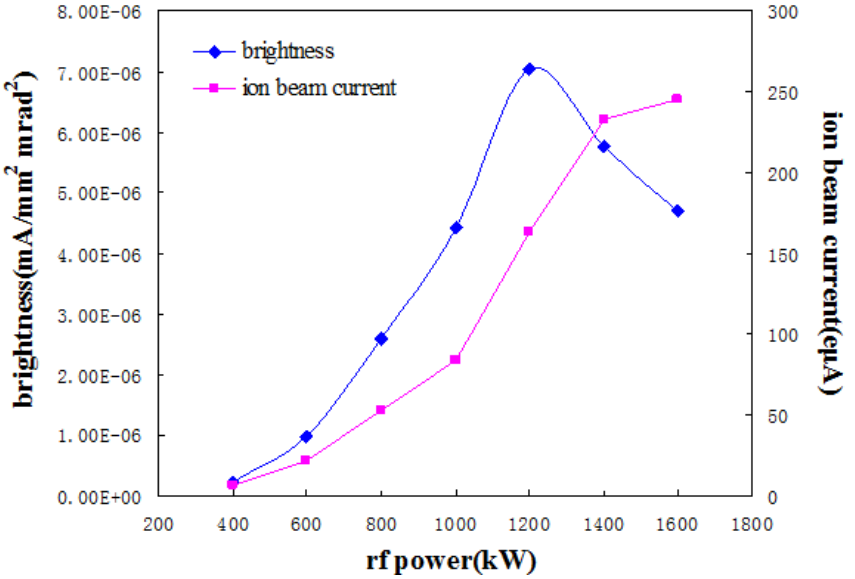
IMP Allison-type emittance scanner.
Located after the analyzing magnet

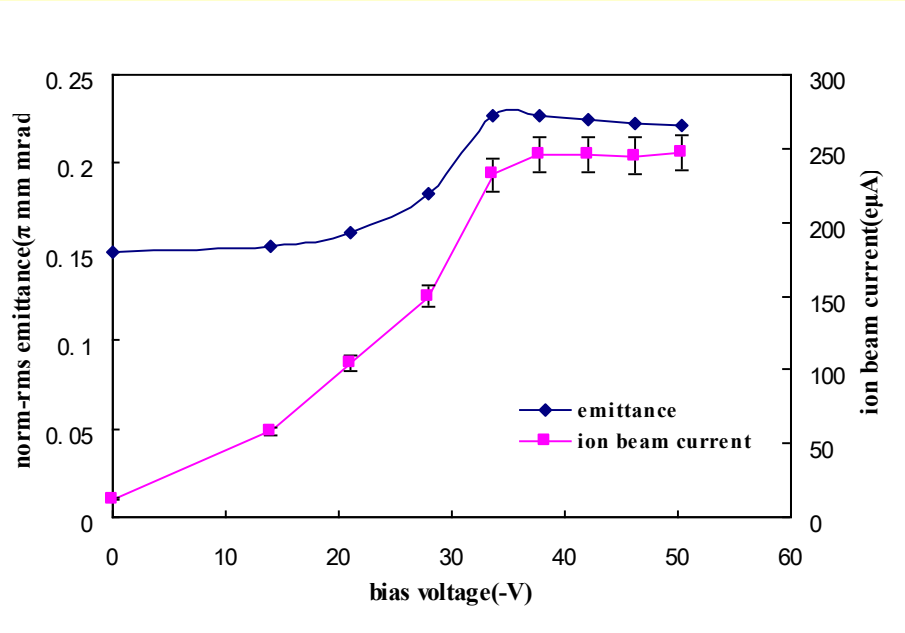


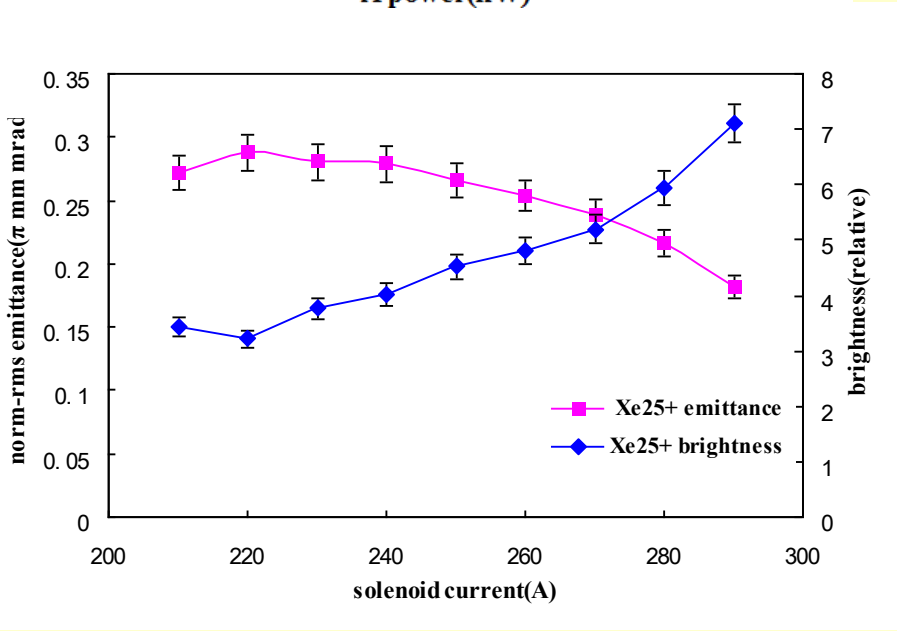




Emittance/Brightness VS RF power, bias voltage, solenoid lens current

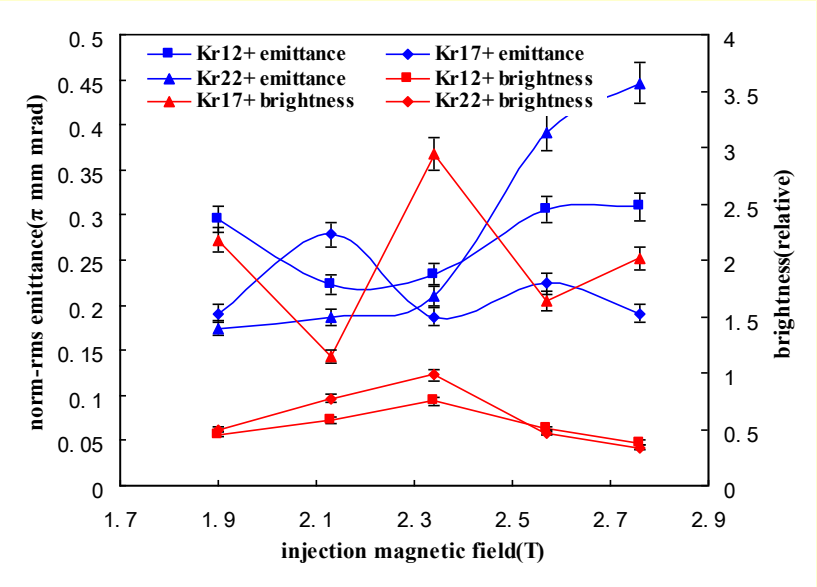


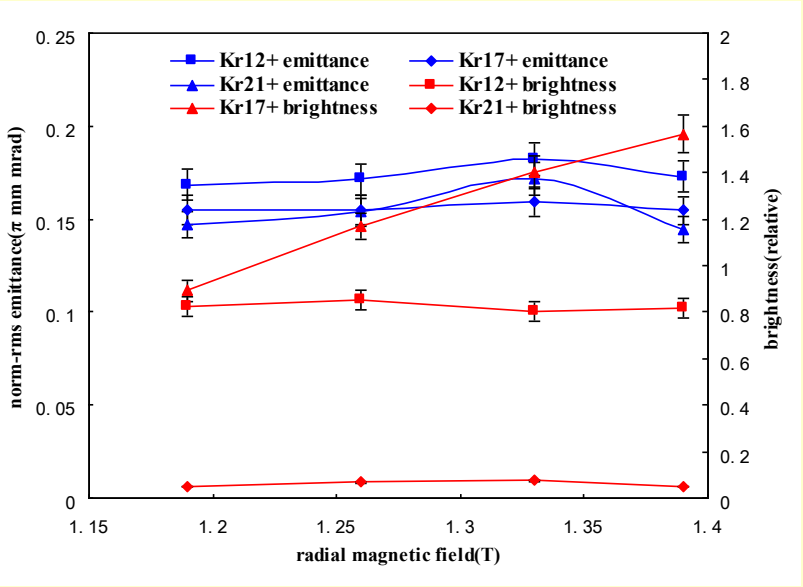


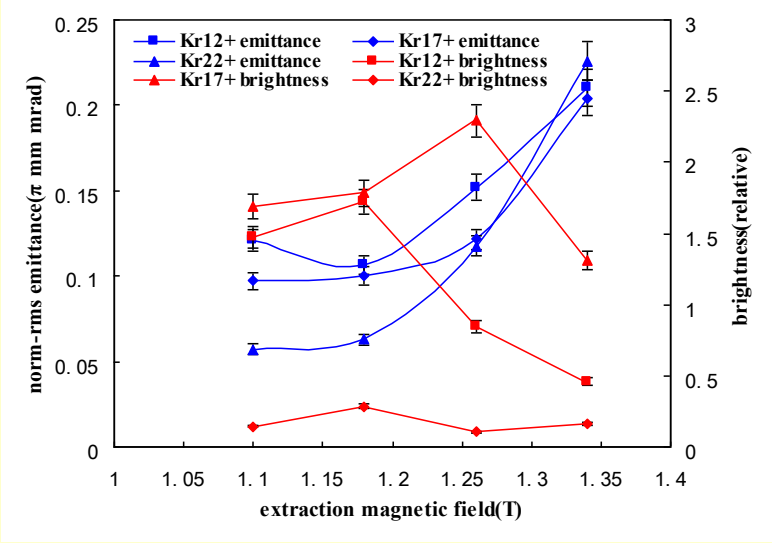


Xe^{25+} optimized, rf frequency: 18GHz, HV: 22kV, drain current: 5.04emA, beam current: 245eμA , slitX: 20mm.

Emittance/Brightness VS magnetic fields







Kr^{17+} optimized, rf :18GHz, 1.5kW.
HV: 15kV, beam current: 100eμA,
drain current: 3.1emA

Summary

- SECRAL was tested at 24GHz and results are promising. Beam test at 24GHz has not been conducted since last November due to failure of the gyrotron power supply system .

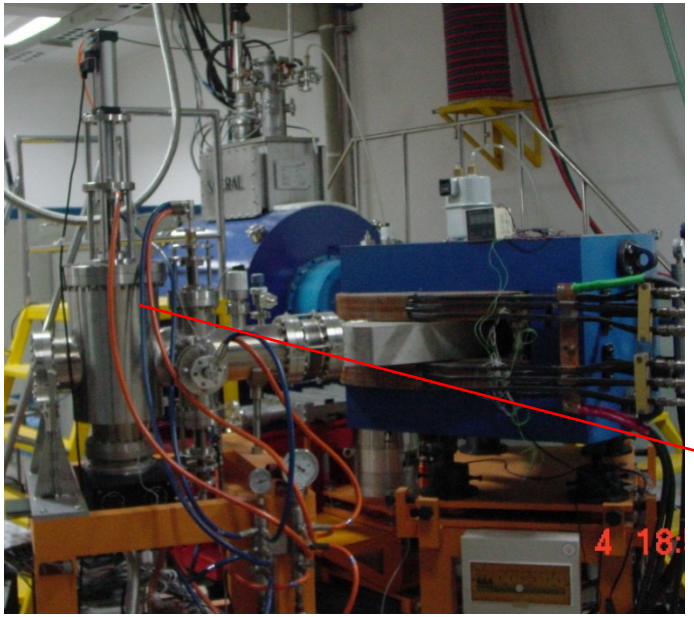
- Beam time from SECRAL for HIRFL accelerator has been more than 3500 h at 18GHz operation. But beam quality and long-term stability at high RF power need to be studied carefully.

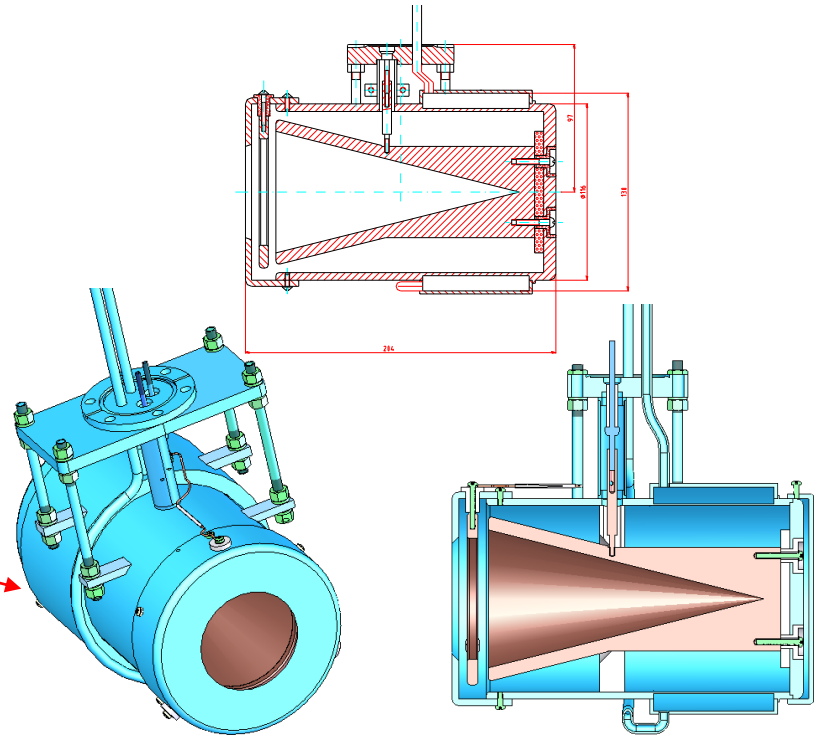
- SECRAL beam test and operation at 24GHz will continue and better results should be coming up. U beam test will be conducted with a new HT oven. A new SC-ECRIS is under design at IMP .

	Q	SECRAL *18 GHz* *<3.2 kW* *μA*	SECRAL 24GHz *3-5kW* *μA*	VENUS *28 GHz* *5-9kW* *μA*
^{16}O	6+	2300		2860
	7+	810		850
^{40}Ar	12+	510	650	860
	14+	270	440	514
	16+	73	149	270
	17+	8.5	14	36
^{129}Xe	20+	505		320
	27+	306	455	270
	30+	101	152	116
	31+	68	85	67
	34+	21	60	40
	35+	16	45	28
	38		17	7
	42+	1.5	3	0.5
	43+	1		
^{209}Bi	28+	214		240
	30+	191		225
	41+	22		15
	44+	15		7.7
	48+	4.2		1.4
	50+	1.5		0.5

THANKS for your attention !

Faraday-cup to measure beam current

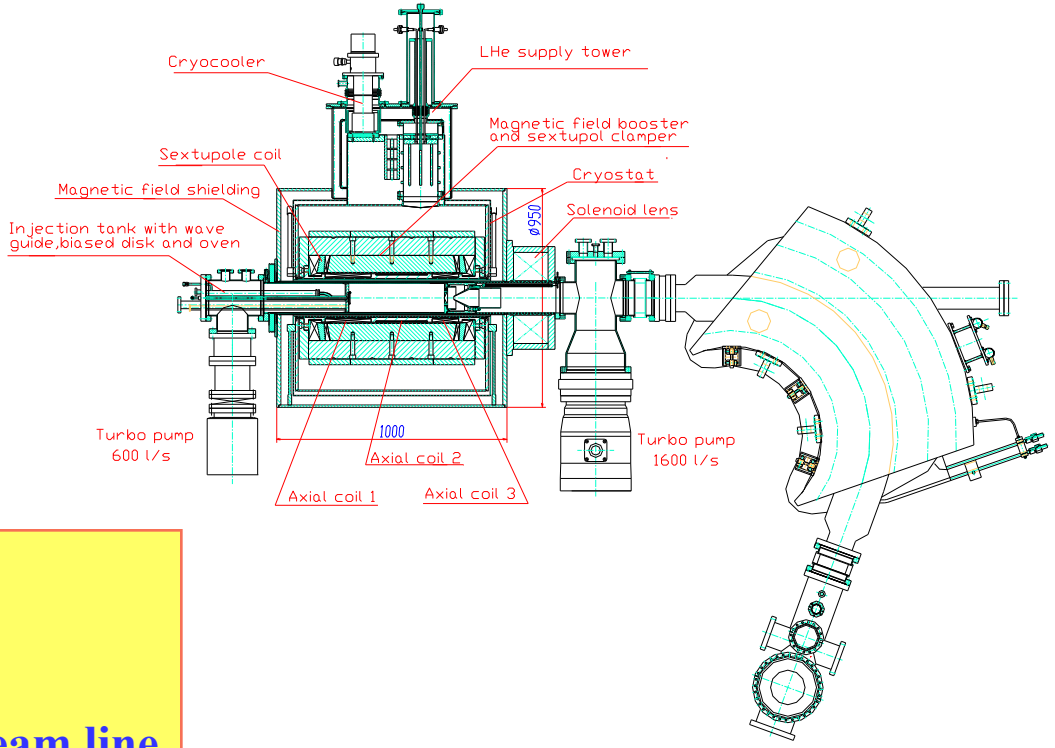




- Good shielding to the ground.
- Water cooled down through BeO.
- Suppressor electrode -150 ~-200 V.
- Cone-shape cup prevents from electrons coming out.

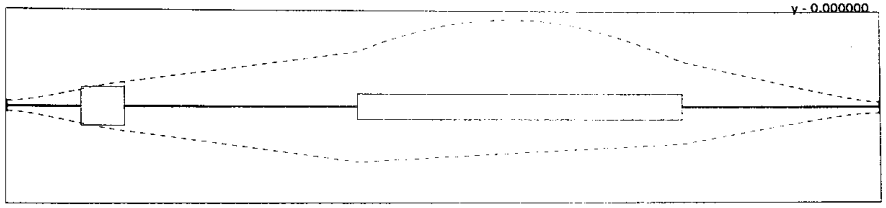
SECRAL Beam Transport Line

Designed for 15-20 mA total beam transmission at 20-30 kV extraction



Main Design Issues:

1. **High transmission efficiency**
2. **High mass resolution (1/100)**
3. **Match with the axial injection beam line**



Analyzing magnet:
Bending angle: 110 degree
Bending radius: 600 mm
Pole gap: 120 mm