SECRAL Status and Future Challenge

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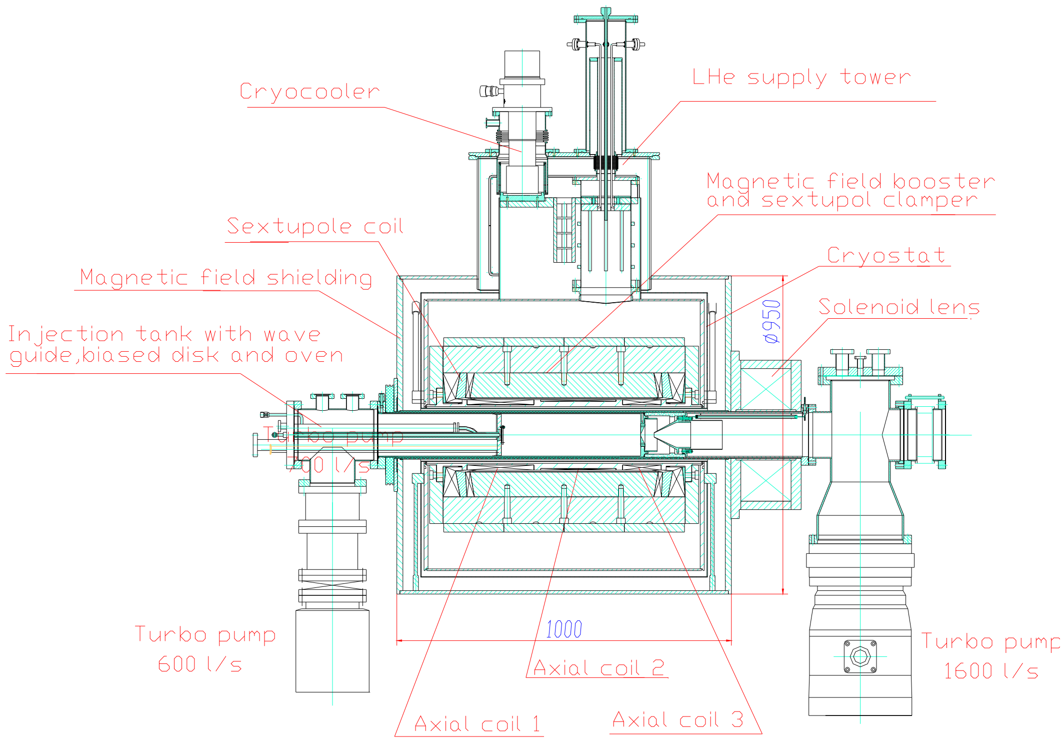
OUTLINE

SECRAL: **Superconducting ECR ion source with Advanced design in Lanzhou**

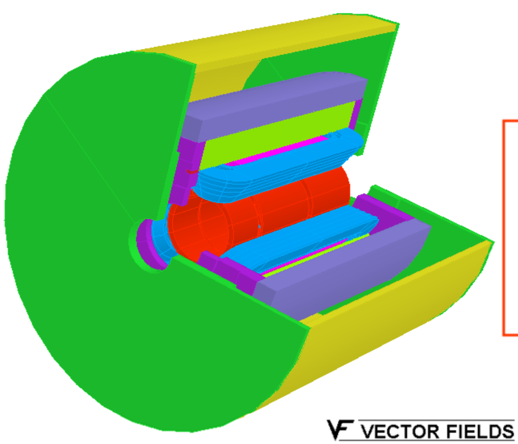
- **SECRAL performance at 24GHz**
- **SECRAL operation for HIRFL accelerator**
- **Considerations and challenge of the 4th generation ECRIS for IMP new project HIAF**

SECRAL Performance



SECRAL

- To achieve performance enhancement for HIRFL accelerator complex.
- Develop a compact fully superconducting ECRIS
- SECRAL is dedicated to highly charged heavy ion beam production
- SECRAL has been in routine operation for HIRFL since May 2007



Completely New Design!

- Solenoids-inside- sextupole
- Smaller plasma chamber

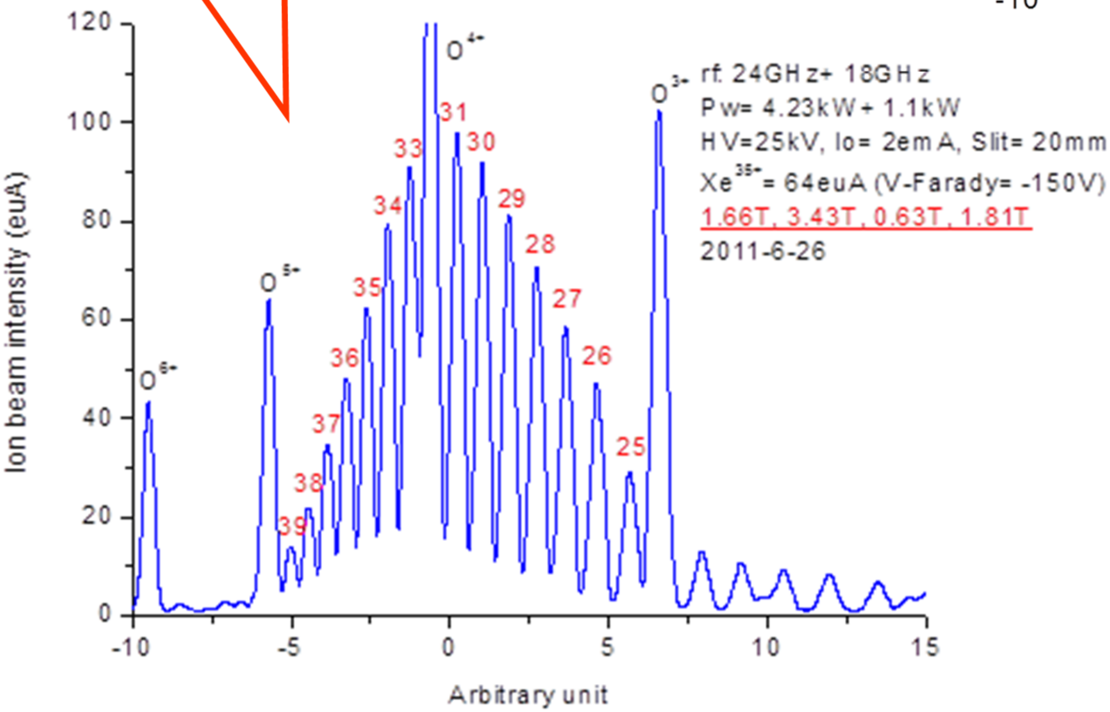
Achieved axial field: 3.7T, 2.2T
Sextupole at the wall: 2.0 T
RF frequency: 18-28 GHz
Plasma chamber: φ116-125
Extraction voltage: 20-30kV

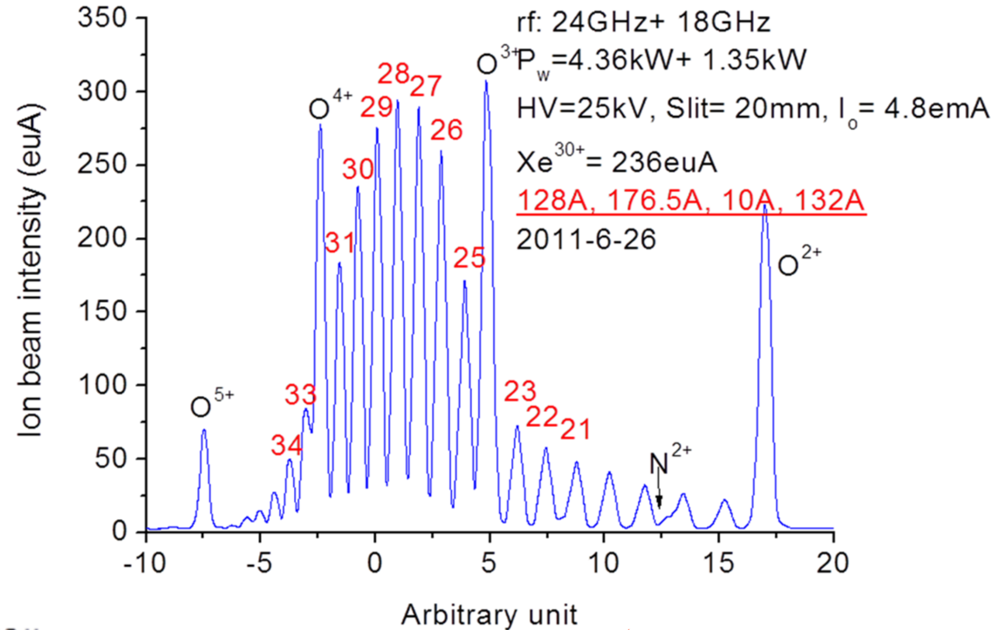
SECRAL with 24GHz/7kW Gyrotron System

SECRAL at 24GHz/2-5 kW

Highly charged Xe beams

- **SECRAL 24+18GHz, 4.2kW+1.1 kW**
- **Optimize Xe^{35+}, 64 eμA**
- **With Al chamber. 2011**



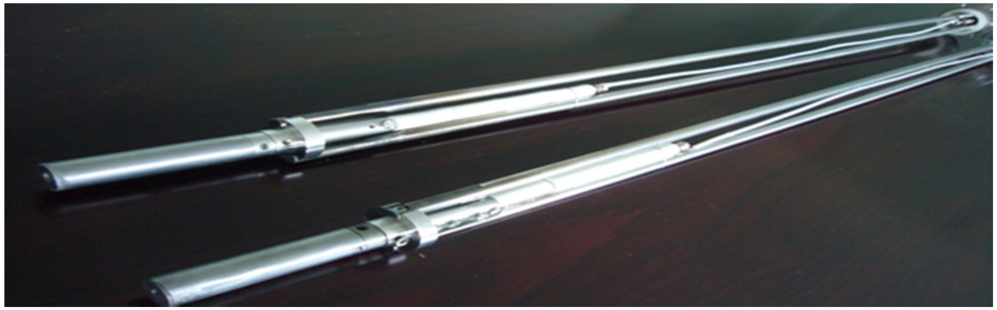


- **SECRAL 24+18 GHz, 4.36kW+1.35kW**
- **Optimize Xe^{30+}, 236eμA**
- **With Al chamber . 2011.**

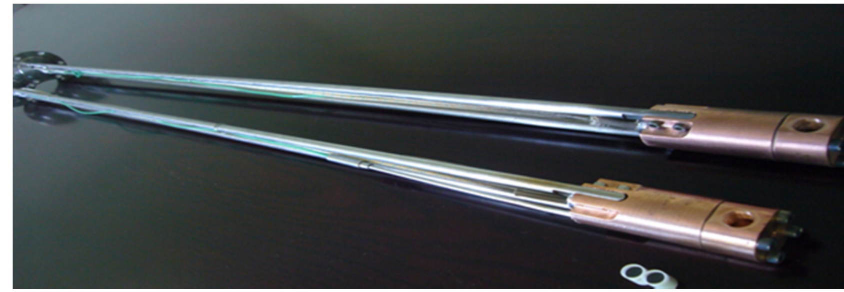
SECRAL 24GHz
Highly charged Xe beams

Xe IONS	SECRAL 18GHz <3.2kW (eμA) 2007	SECRAL 24GHz-SS <5kW (eμA) 2009	SECRAL 24+18GHz-Al <6kW (eμA) 2011
26+	410		
27+	306	455	
28+			
30+	101	152	236
31+	68	85	190
33+			
34+	21		
35+	16	45	64
36+			
37+			
38+	6.6	17	22.6
42+	1.5	3	

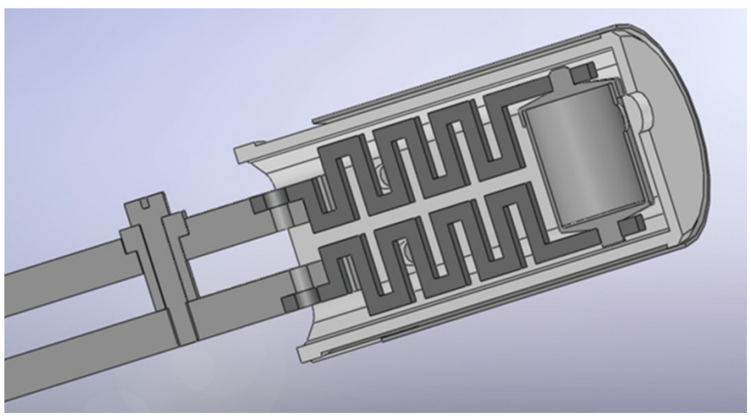
Metallic Ion Beam Production at SECRAL

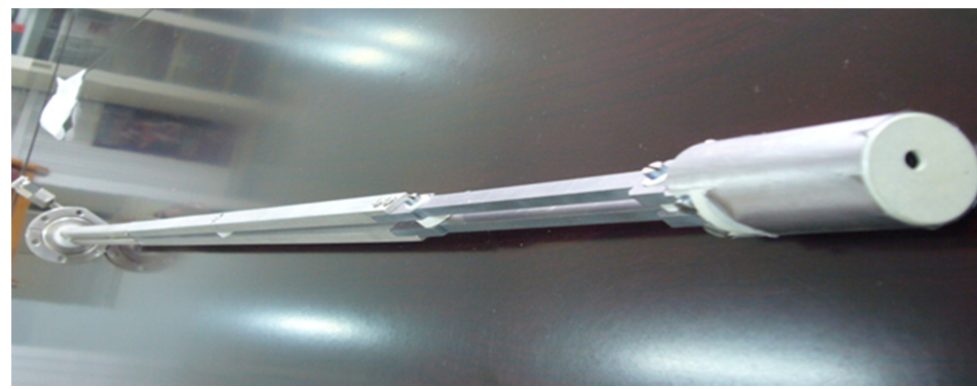


Conventional Ovens (1600 C),



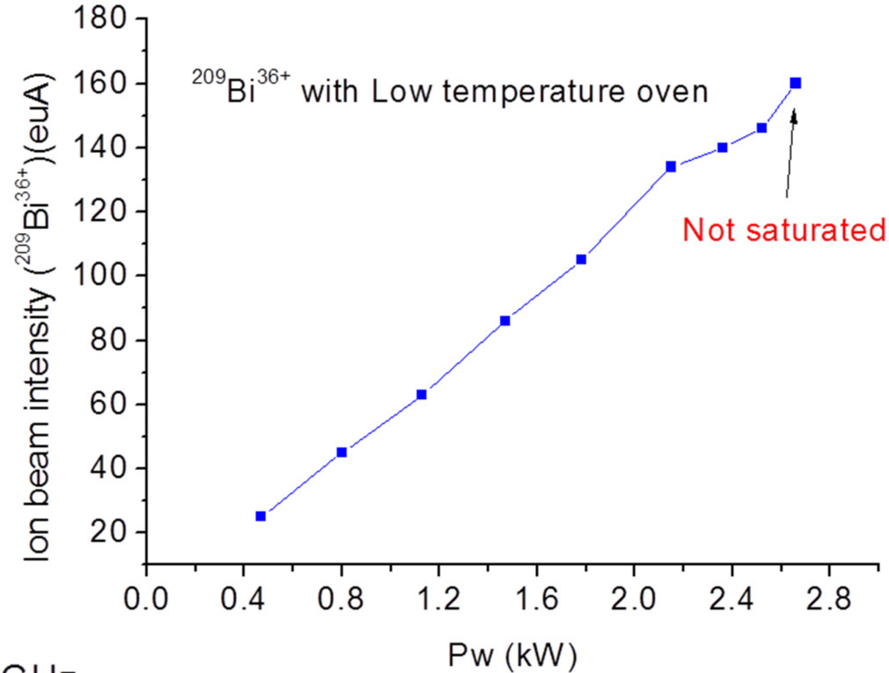
Lowe Temperature Ovens (700 C)

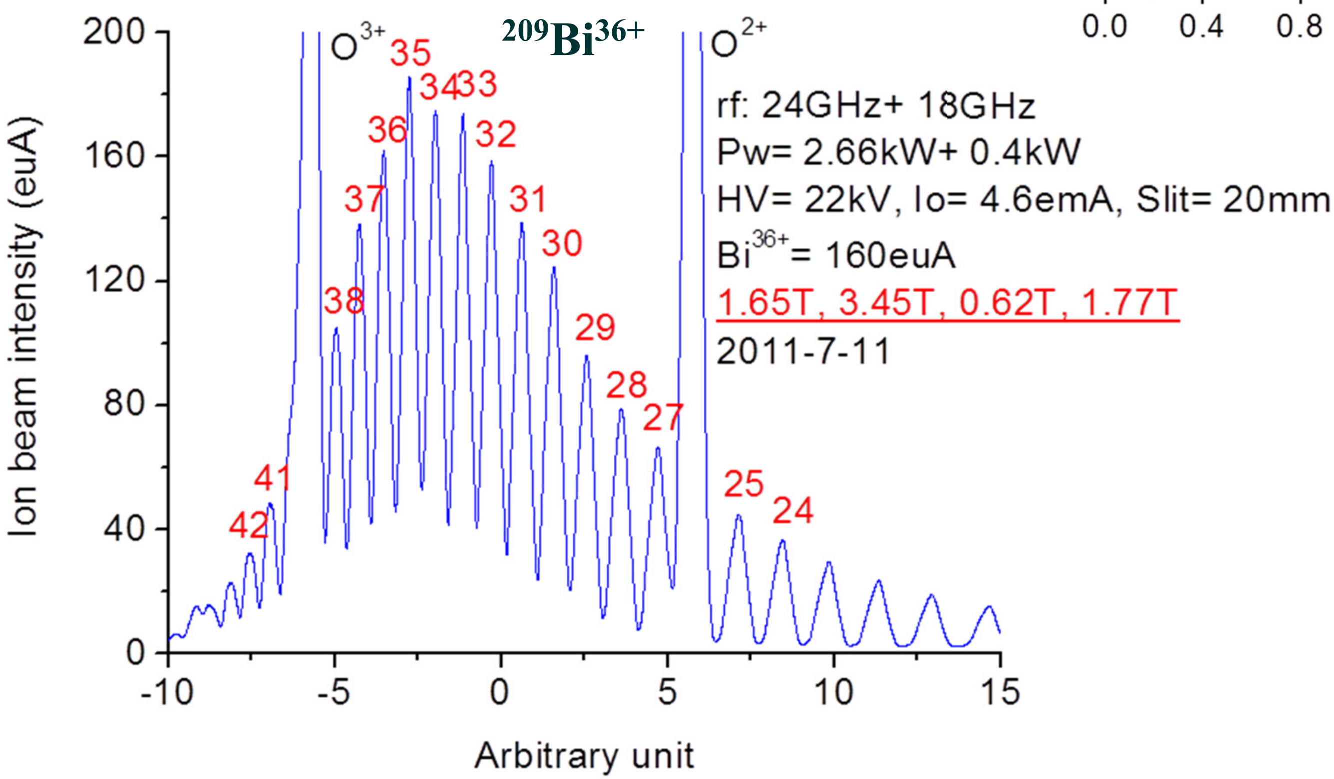




High Temperature Ovens (over 2000 C), long-term reliability needs to be tested because of high temperature. Not ready for U beam production

SECRAL 24GHz
Highly charged Bi beams

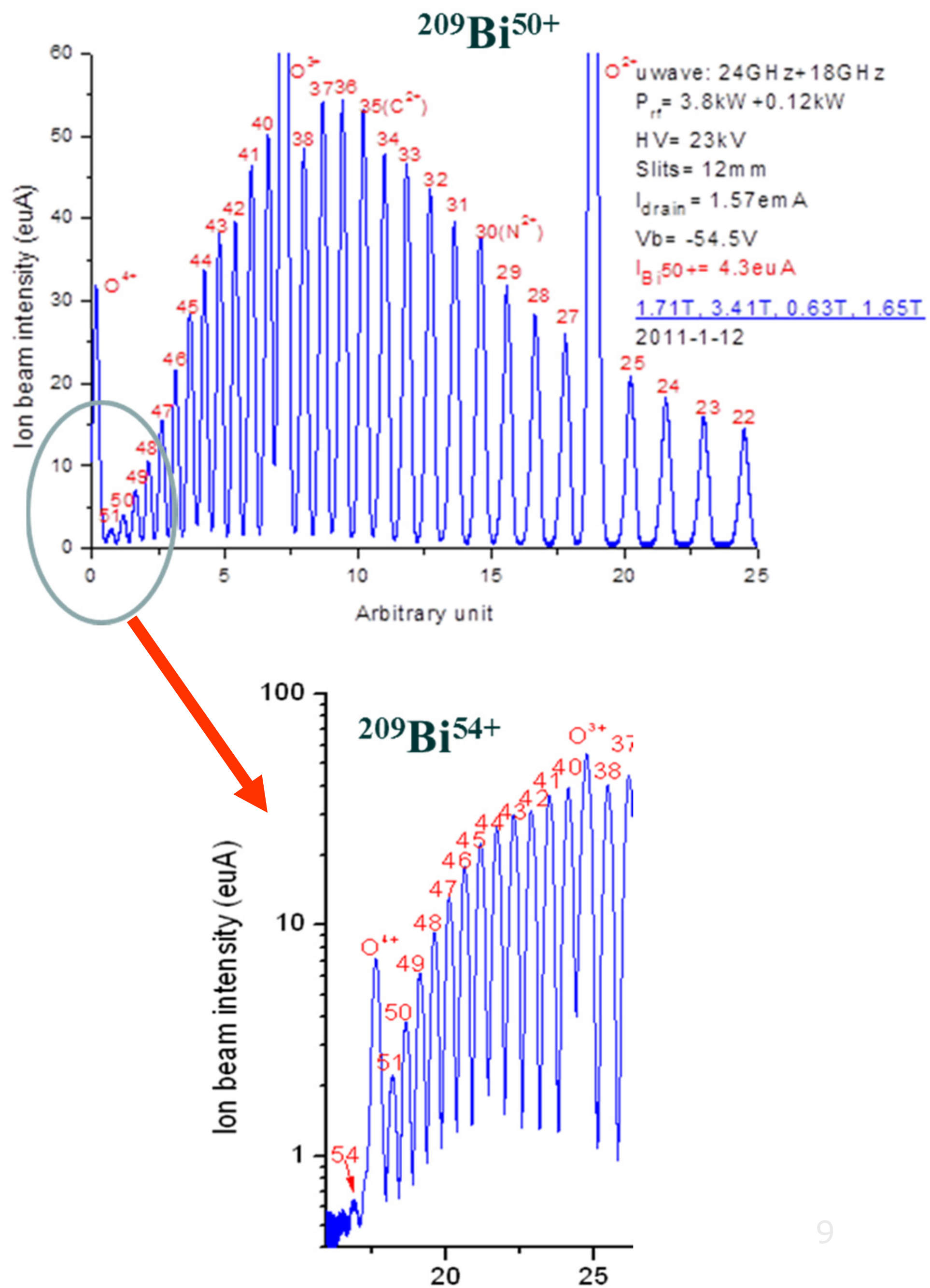




SECRAL at 24GHz

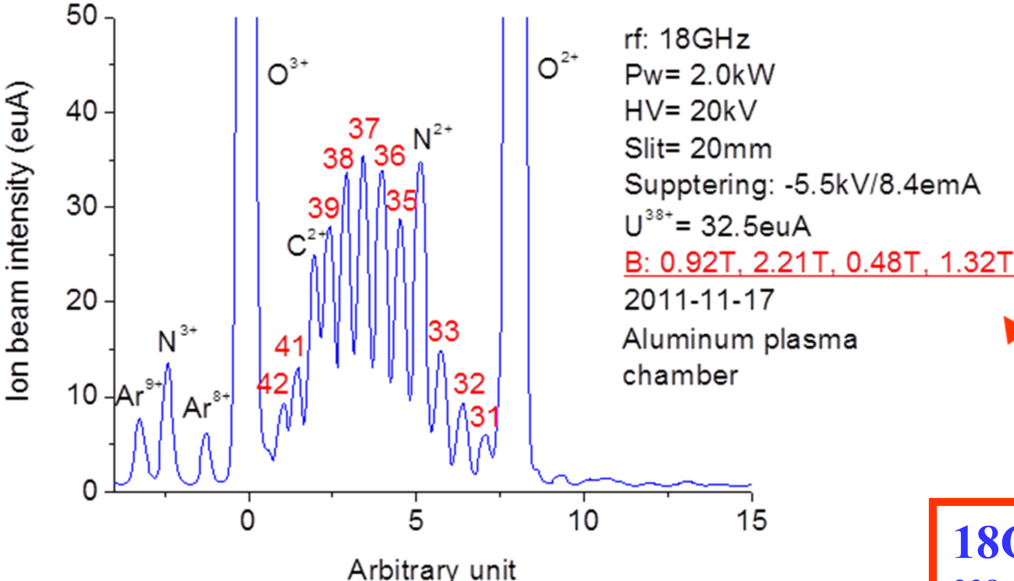
Highly charged Bi beams

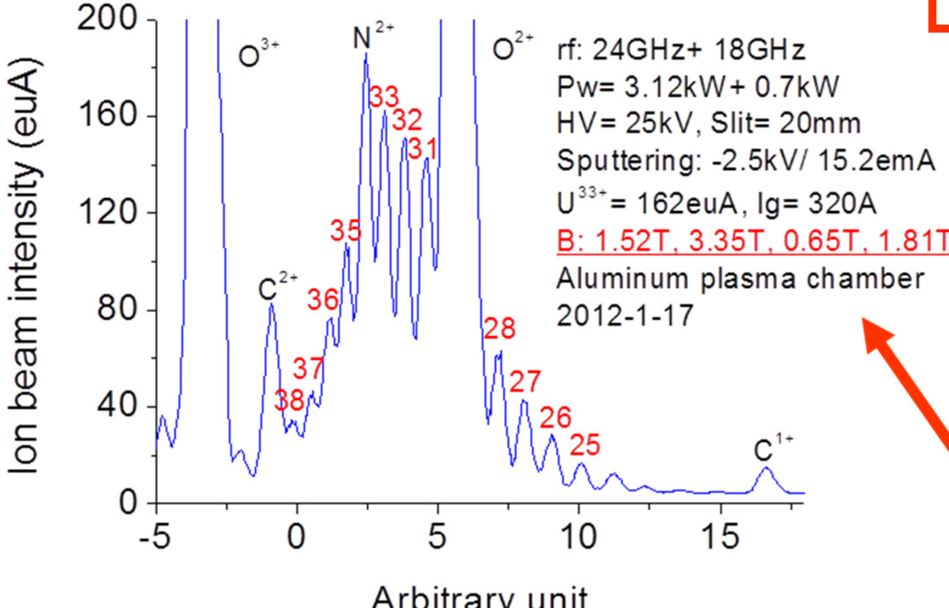
Q ^{209}Bi	SECRAL *18 GHz* *<3.2 kW* *eμA*	SECRAL 24+18GHz *3-5kW* *eμA*
28+	214	
31+	191	242
32+		
36+	62	160
41+	22	50
42+		
43+	17.3	38
44+	15	33
46+	10	
48+	4.2	11.5
49+	2.6	
50+	1.5	4.3
51+		2.3
54+		0.2

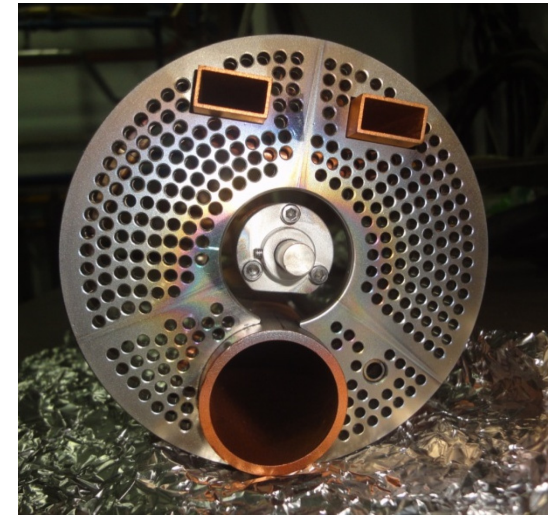


SECRAL at 18 GHz and 24GHz

Highly charged U beams







Sputtering method
the first ^{238}U beam test

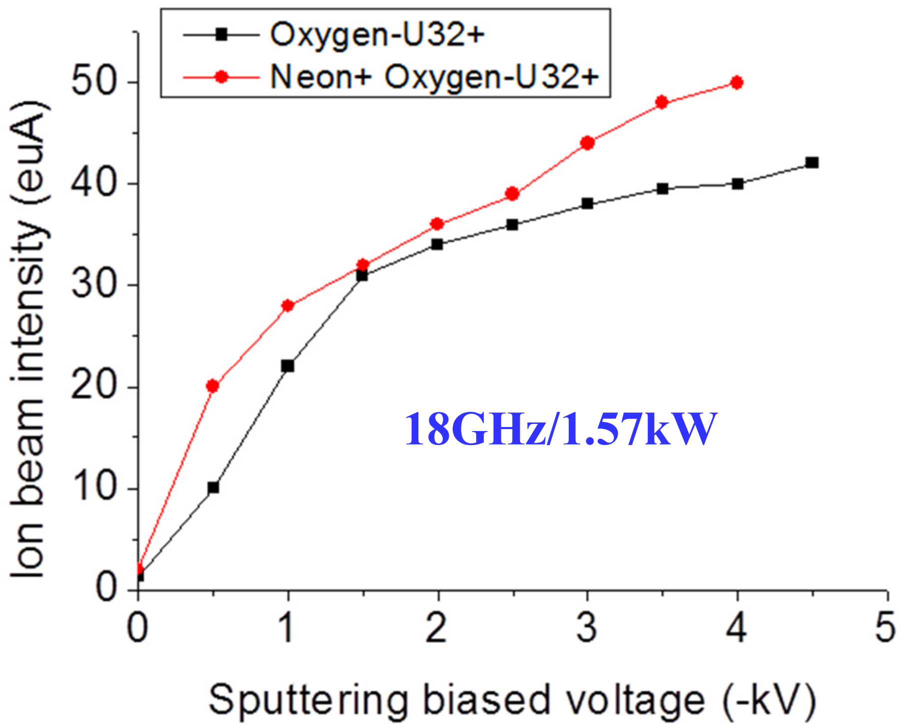
18GHz/2kW, 11.2011
$^{238}U^{32+}$ 82eμA, $^{238}U^{35+}$ 64 eμA, $^{238}U^{38+}$ 32eμA

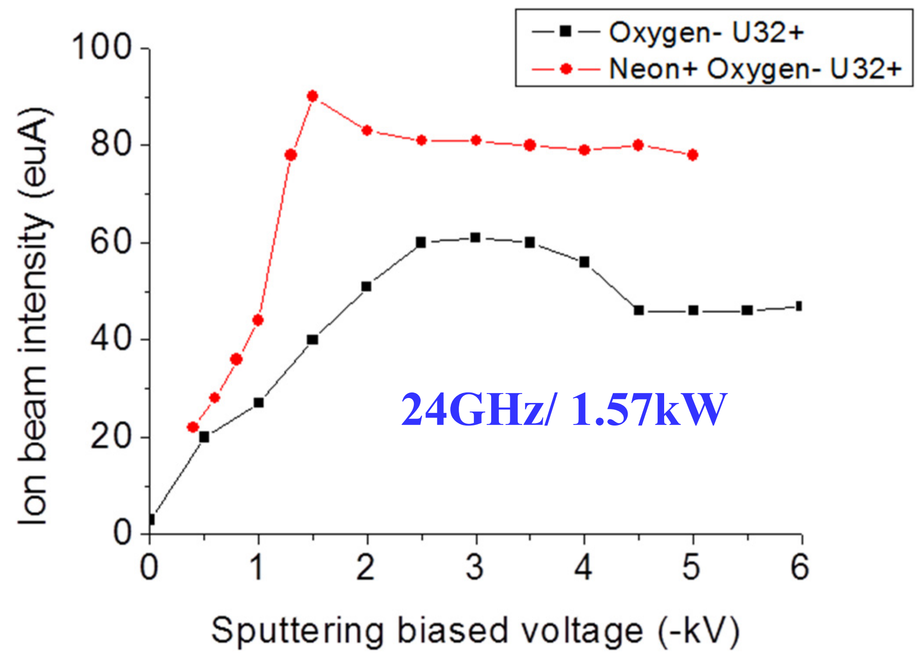
$^{238}U^{32+}$ was delivered to HIRFL Accelerator for about four weeks at 18 GHz in 9-10/2011

24GHz+18GHz, 3.1kW+0.7 kW, 1.2012
$^{238}U^{32+}$ 107 eμA, $^{238}U^{33+}$ 164eμA

Preliminary !

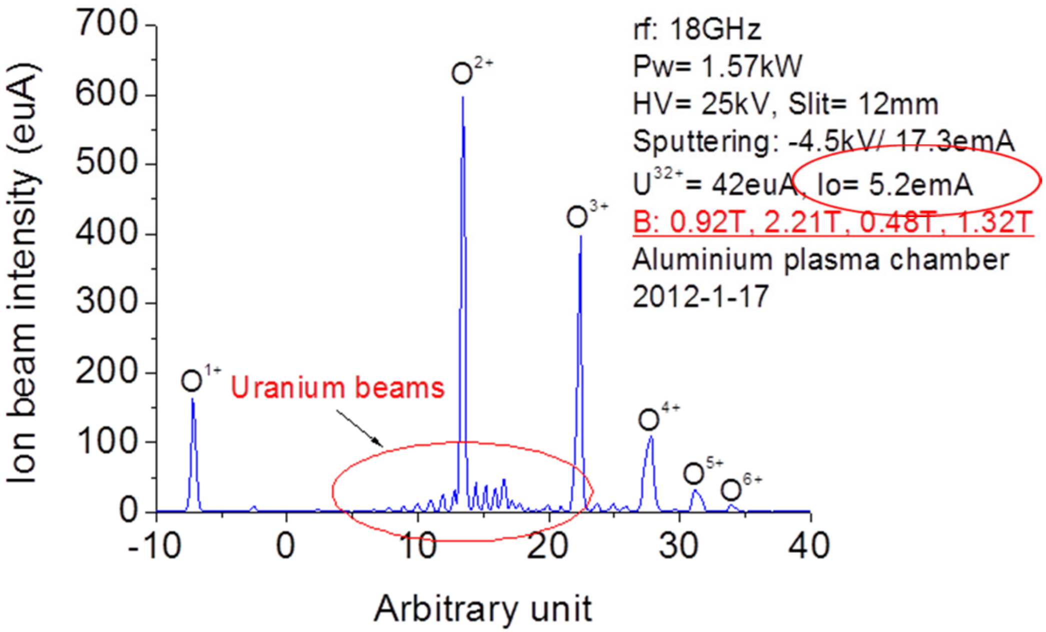
$^{238}U^{32+}$ beam intensity at 18 GHz/1.57 kW and 24GHz /1.57 kW with different sputtering voltage and support gas

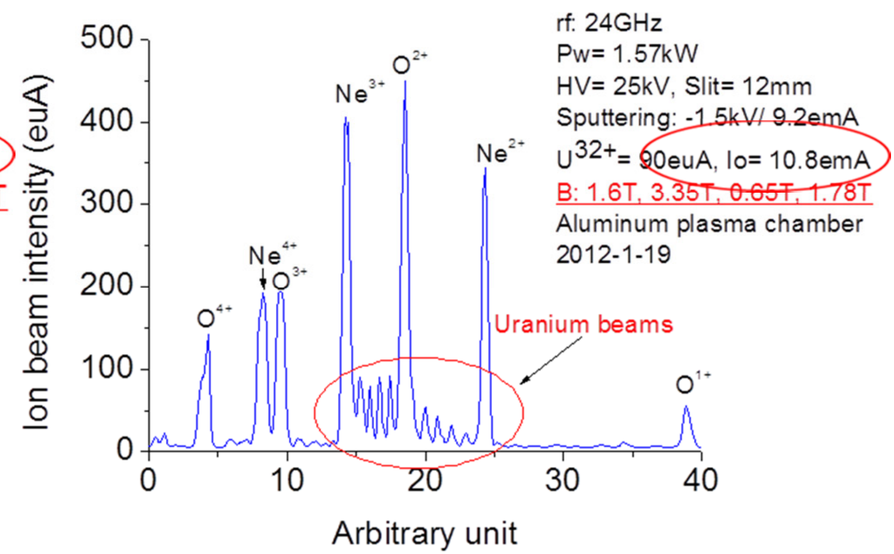




- Neon +Oxygen is better than oxygen as support gas for U beam with sputtering
- Optimized sputtering voltage could be much different for different source conditions.

Surprise! Very low transmission efficiency for U beam!





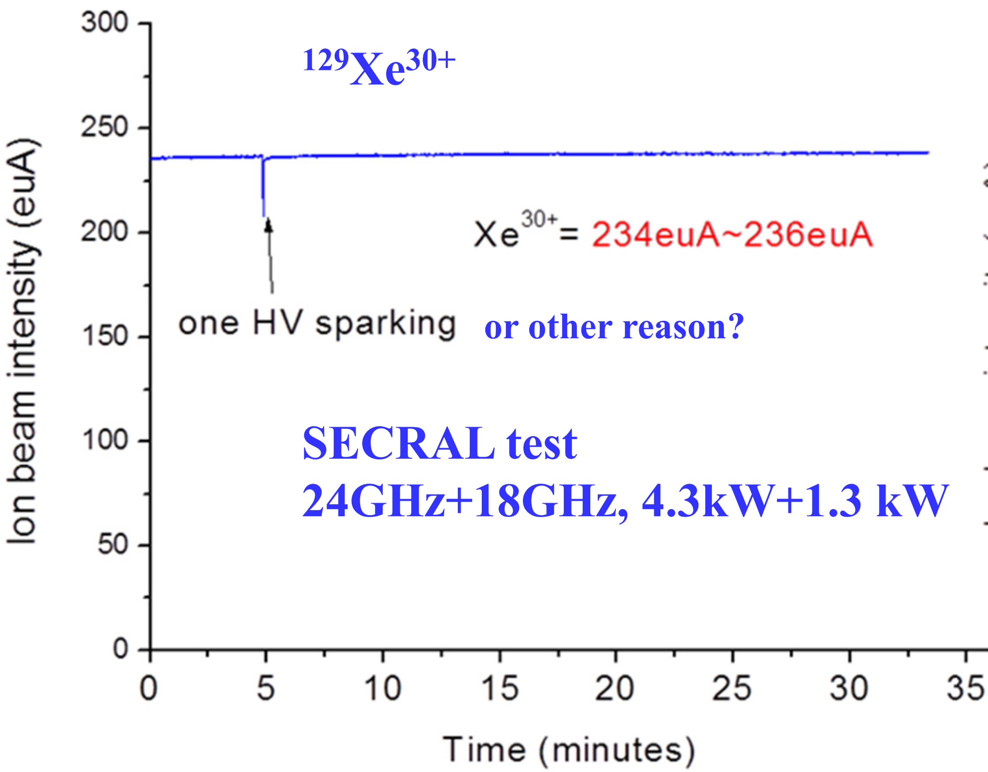
18GHz/1.57kW: $^{238}U^{32+}$ 42eμA

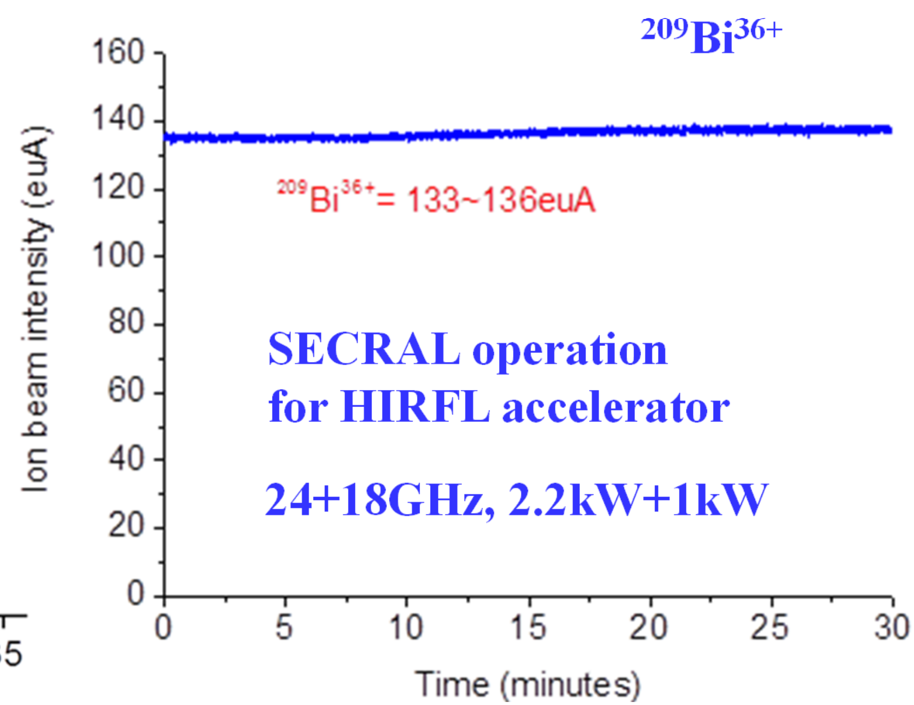
$\eta = I_{total}/(I_{drain} - I_{leakage}) \approx$ 41%

24GHz/1.57kW: $^{238}U^{32+}$ 90eμA

$\eta = I_{total}/(I_{drain} - I_{leakage}) \approx$ 24%

SECRAL Beam Stability at 24GHz/2-5 kW

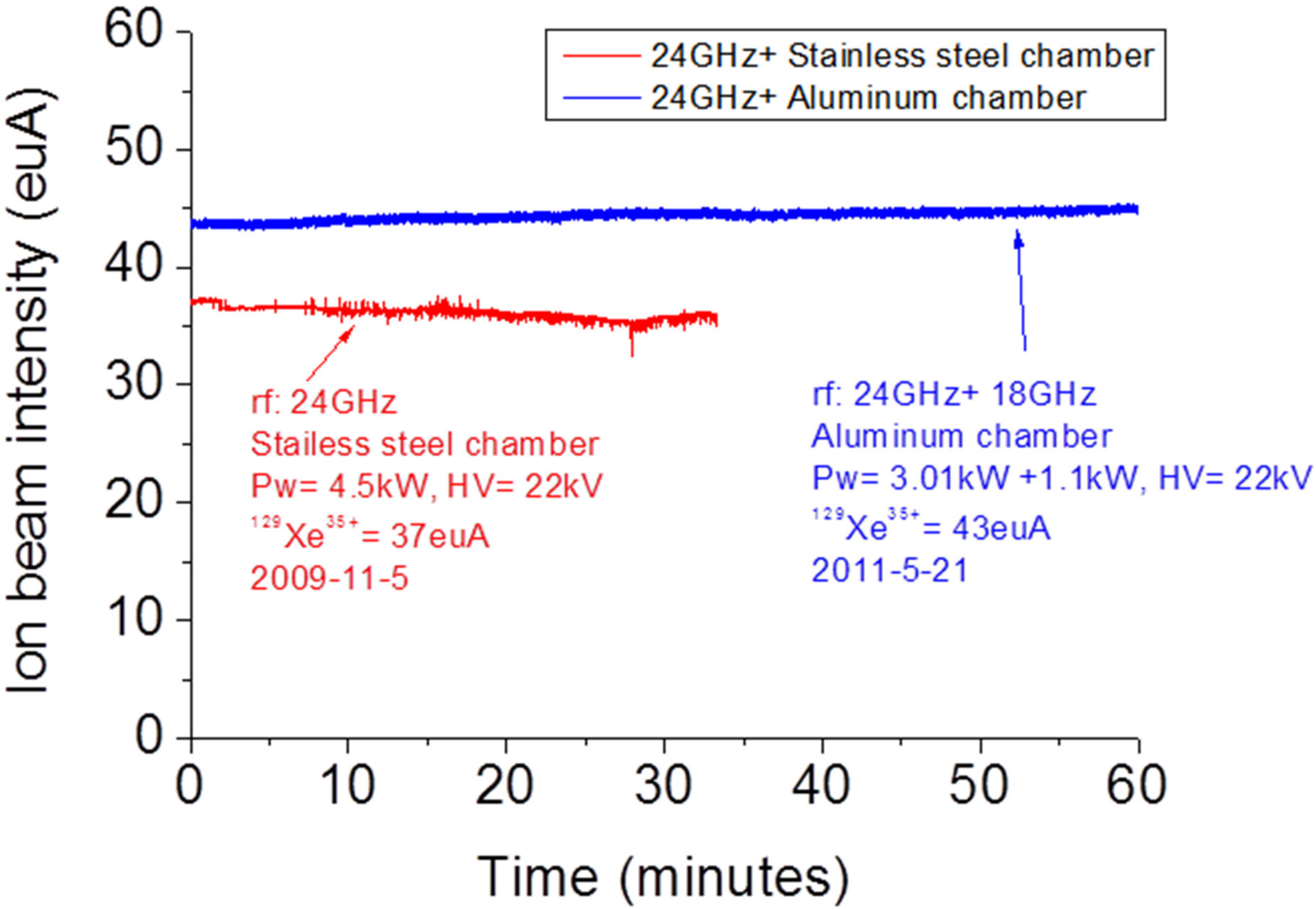




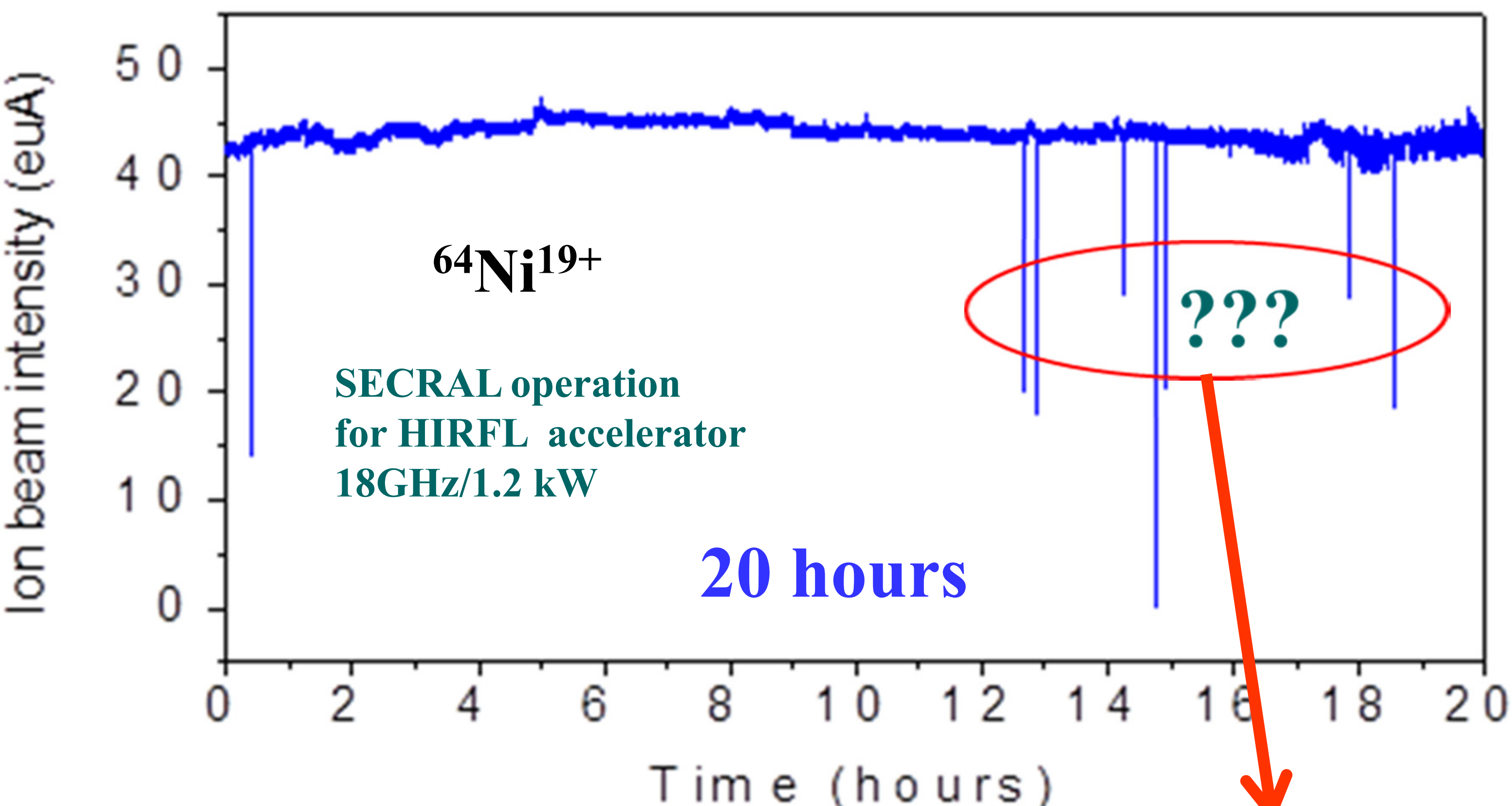
Looks nice, but for hours,days and weeks??

Xe^{35+} beam stability at 24GHz/4kW

with Al chamber and stainless steel chamber

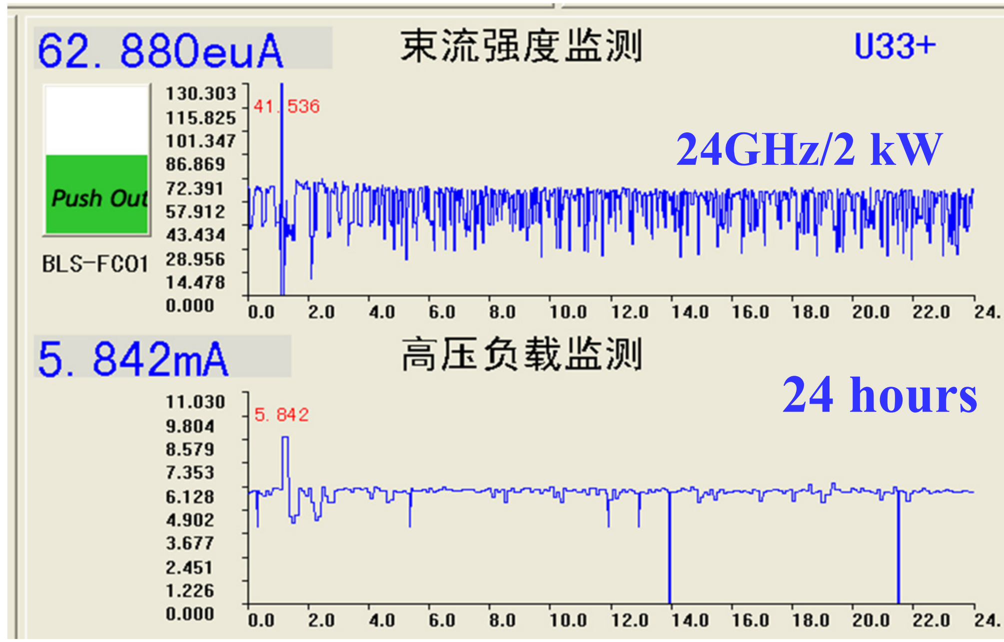


$^{64}Ni^{19+}$ beam stability at 18GHz/1.2W during operation



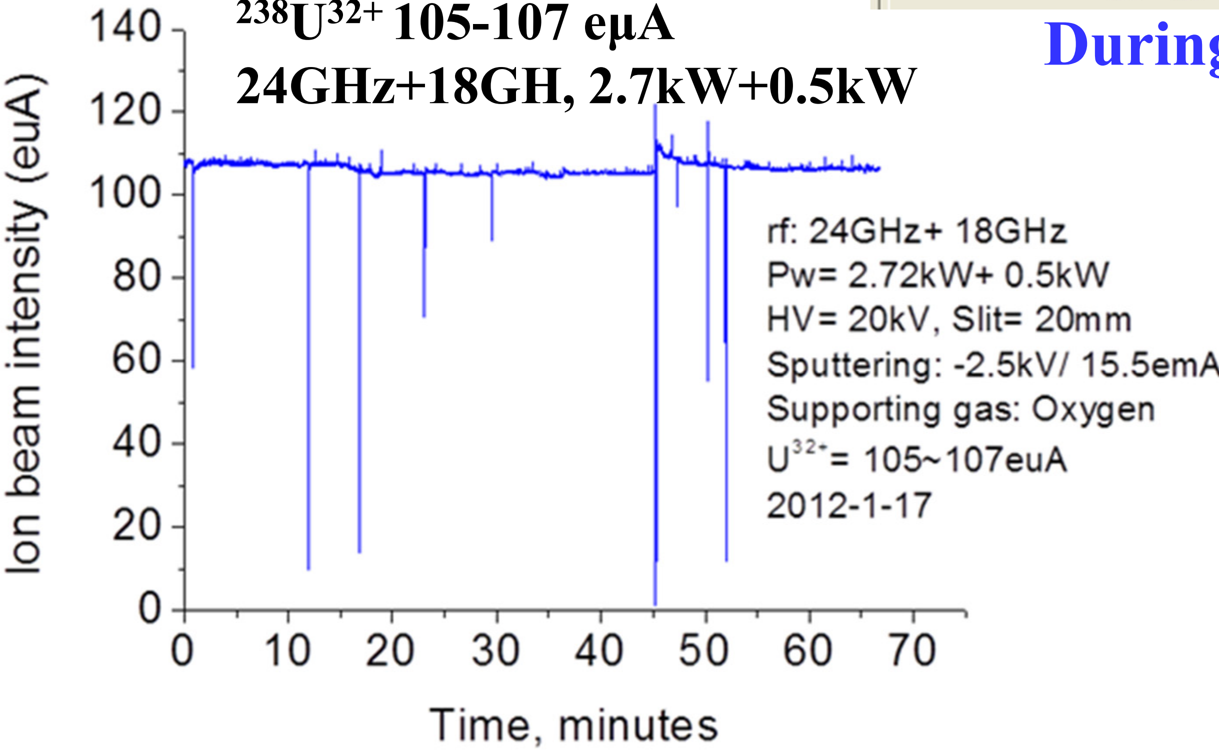
Why? It is spark or wall effect?
Usually happened for metallic beams !

SECRAL U Beam Stability with sputtering

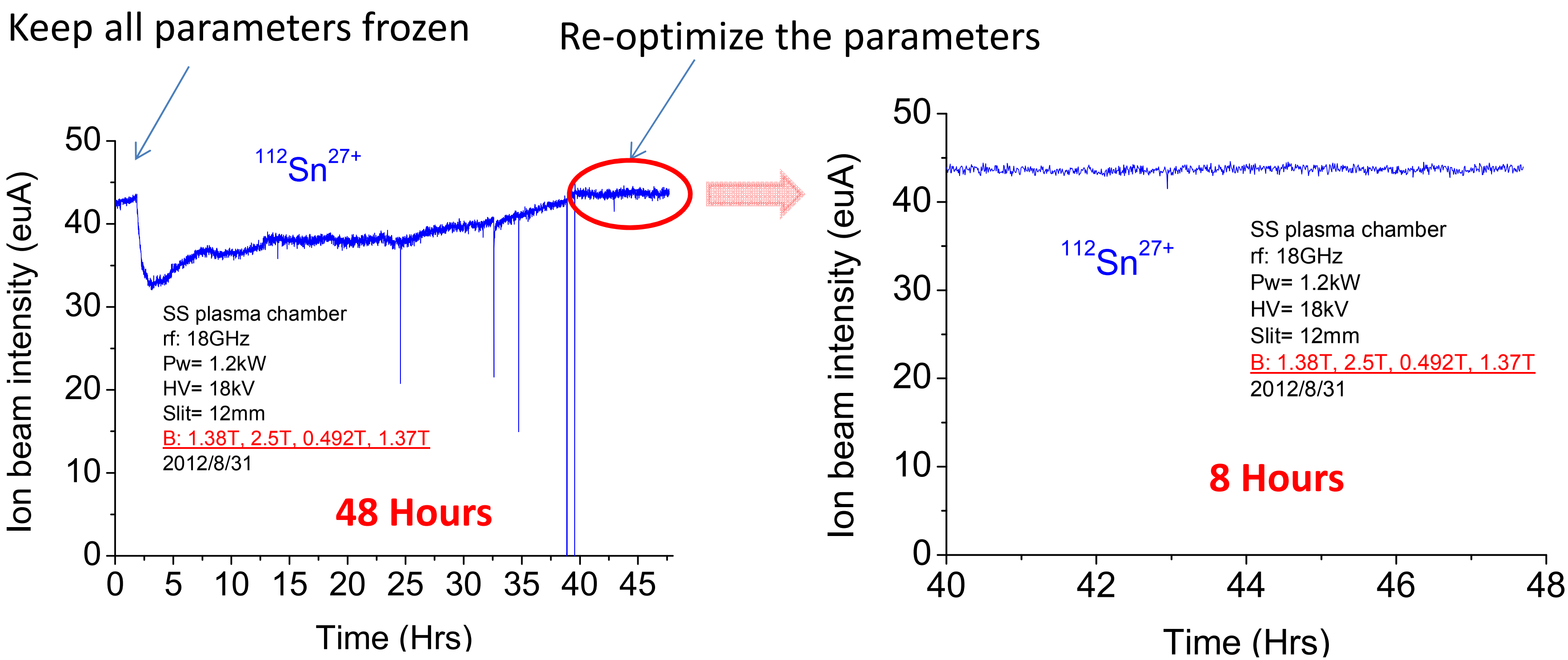


During U beam conditioning

$^{238}U^{32+}$ 105-107 eμA
24GHz+18GH, 2.7kW+0.5kW



Long-term stability test at 18GHz/1.2 kW for $^{112}Sn^{27+}$ preparing for beam operation



Stainless steel plasma chamber (ϕ120.5mm)

Questions

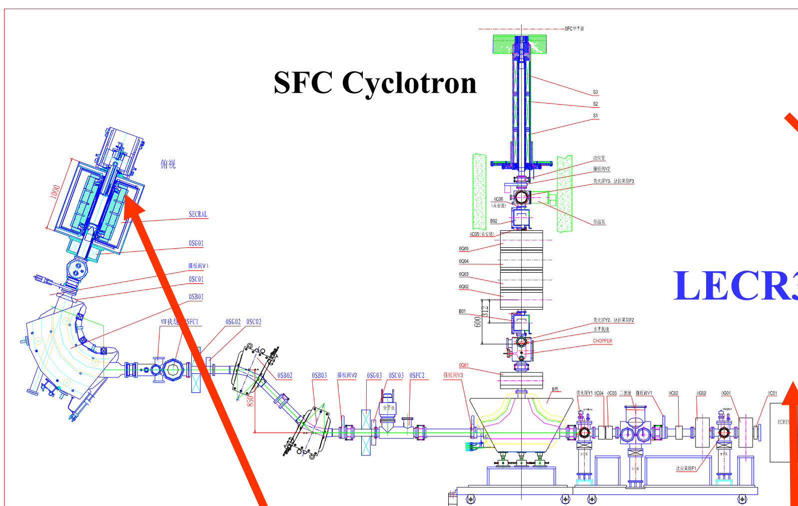
No. 1: Can SECRAL be able to operate at >5 kW/24GHz for days and weeks to deliver intense beams for accelerator with good long-term stability?

No. 2: Did any 3rd generation ECRIS ever run at >5kW/18-28GHz continuously for days and weeks to deliver intense beams with good long-term stability? VENUS ?

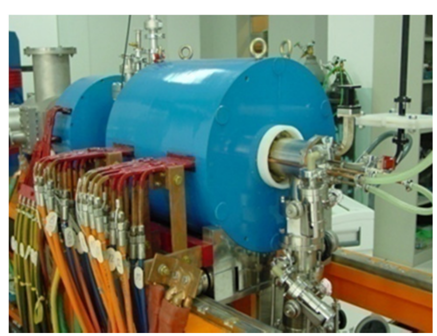
SECRAL Operation for HIRFL Accelerator

SECRAL is dedicated only for operation of highly charged heavy ion beams. Without SECRAL CSR would not be able to run heavier ion beam than Kr such as Kr, Xe, Bi and U because of energy and intensity issue

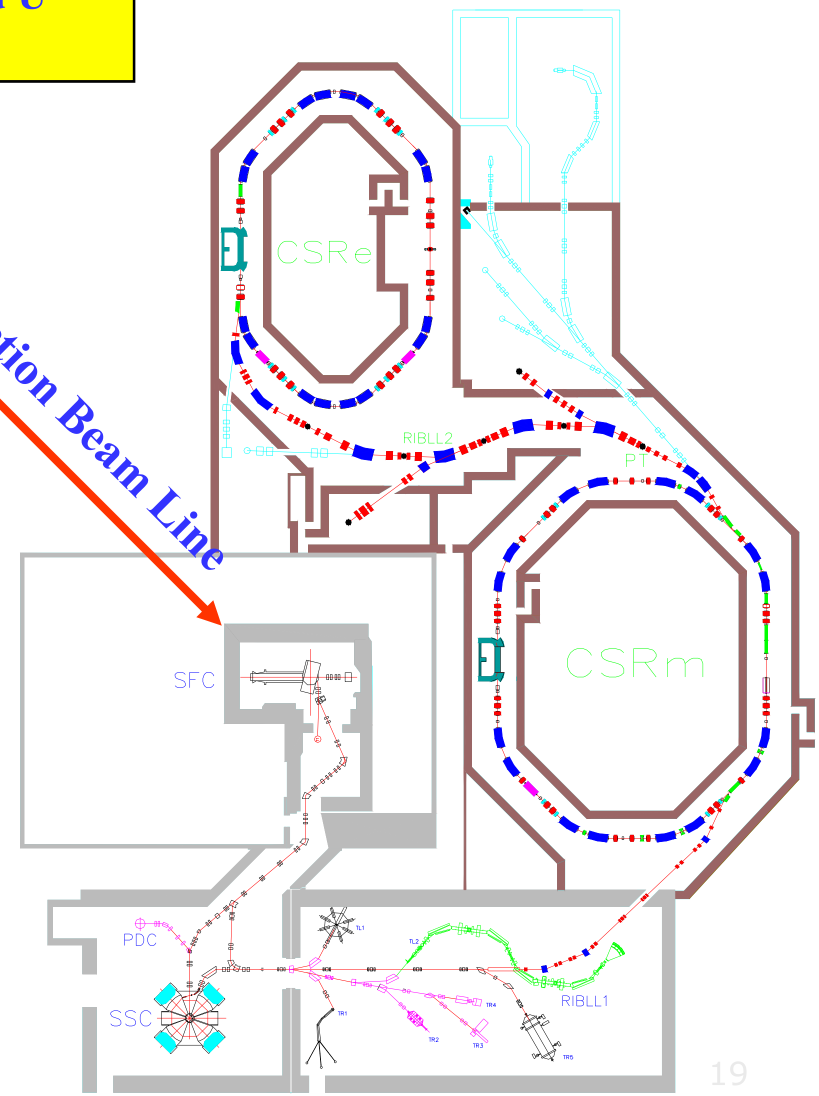
HIRFL Accelerator Complex
At IMP lanzhou



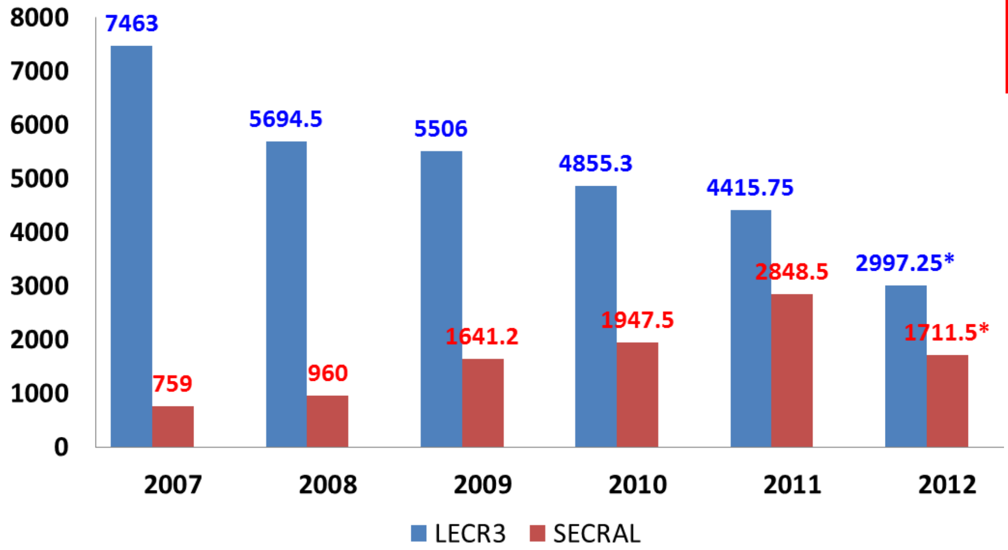
LECR3



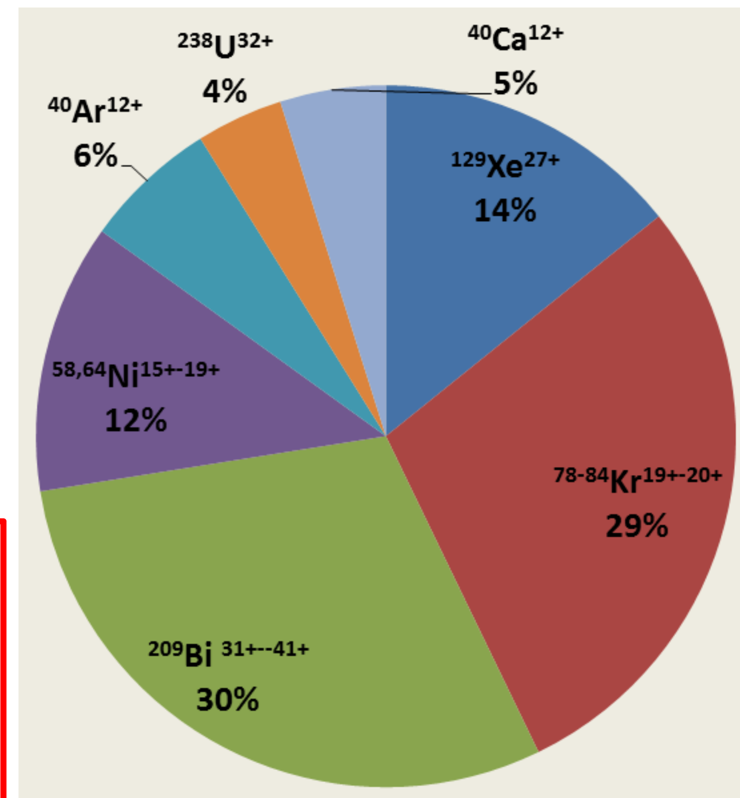
Axial Injection Beam Line



SECRAL operation statistics for beams and time



Up to this week the total beam time from SECRAL since May 2007: >10000 hours



- SECRAL is operated at 18GHz in most cases
- Only for very high charge state, SECRAL is operated at 24GHz, such as $^{209}Bi^{36+}$, $^{209}Bi^{41+}$
- $^{209}Bi^{36+}$ and $^{209}Bi^{41+}$ were provided at 24+18GHz.
  $^{209}Bi^{36+}$ 80-90 eμA, 10 days continuously
  $^{209}Bi^{41+}$ 20-25 eμA, 2 days continuously

Nuclear Physics Results

Mass measurement for short-lived nuclides

PRL 106, 112501 (2011) PHYSICAL REVIEW LETTERS week ending 18 MARCH 2011

Direct Mass Measuremen
Th

X. L. Tu,[1,2] H. S. Xu,[1,*] M. Wa
J. W. Xia,[1] G. Audi,[7] K. Blaum,[3]
R. S. Mao,[1] B. Mei,[1] P. Shuai,[8]
T. Yamaguchi,[10] Y. Yamagu

[1]Institute of Modern P
[2]Graduate Universi
[3]Max-Planck-
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burst model calculatic
passes through ^{64}Ge v

DOI: 10.1103/PhysRevL

PRL 109, 102501 (2012) PHYSICAL REVIEW LETTERS week ending 7 SEPTEMBER 2012

Mass Measurements of the Neutron-Deficient ^{41}Ti, ^{45}Cr, ^{49}Fe, and ^{53}Ni Nuclides: First Test of the Isobaric Multiplet Mass Equation in fp-Shell Nuclei

Y. H. Zhang,[1] H. S. Xu,[1] Yu. A. Litvinov,[1,2] X. L. Tu,[1] X. L. Yan,[1,3] S. Typel,[2] K. Blaum,[4] M. Wang,[1,4,5] X. H. Zhou,[1]
Y. Sun,[6,1] B. A. Brown,[7]
R. S. Mao,[1] B. Mei,[1]

[1]Institute of Mo
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Isochronous
HIRFL-CSR f
^{41}Ti, ^{45}Cr, ^{49}F
test for the firs
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NUCLEAR ASTROPHYSICS

Star bursts pinned down

One of the main uncertainties in the burn-up of X-ray bursts from neutron stars has been removed with the weighing of a key nucleus, ^{65}As, at a new ion storage ring.

Philip Walker

Understanding how the chemical elements formed in stars, and how their formation is related to observable astrophysical phenomena, requires close cooperation between those astrophysicists who study the ways that stars burn and the nuclear physicists who study interactions between atomic nuclei. A fertile area of common interest is the nature of X-ray bursts — flashes of intense radiation that can last from tens to hundreds of seconds. These come from binary star systems, where material falls from the less dense companion star onto the surface of a collapsed neutron star.

Energy is generated by a rapid succession of proton captures by nuclei, but eventually any given nucleus can hold no more protons, and it must wait to beta-decay — a relatively slow process, because it depends on the weak nuclear interaction. Consequently, these 'waiting point' nuclei assume a key role in determining the time evolution of the radiation burst. Yet, in some cases, it is simply not known whether or not a nucleus can keep hold of another proton. By measuring the mass of the arsenic nucleus ^{65}As — a so-called proton-unbound nucleus, in which a captured proton remains unbound or only loosely bound to the nucleus — Xiaolin Tu and colleagues[1] have now shown that the germanium isotope ^{64}Ge is most likely not, after all, a waiting point in the evolution of X-ray bursts.

There is a long history of laboratory experiments being used to help understand

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Figure 1 | A new facility for nuclear physics: the cooler storage ring, now in operation at the Institute of Modern Physics, Lanzhou, in western China.

PRL 106,112501 (2011)

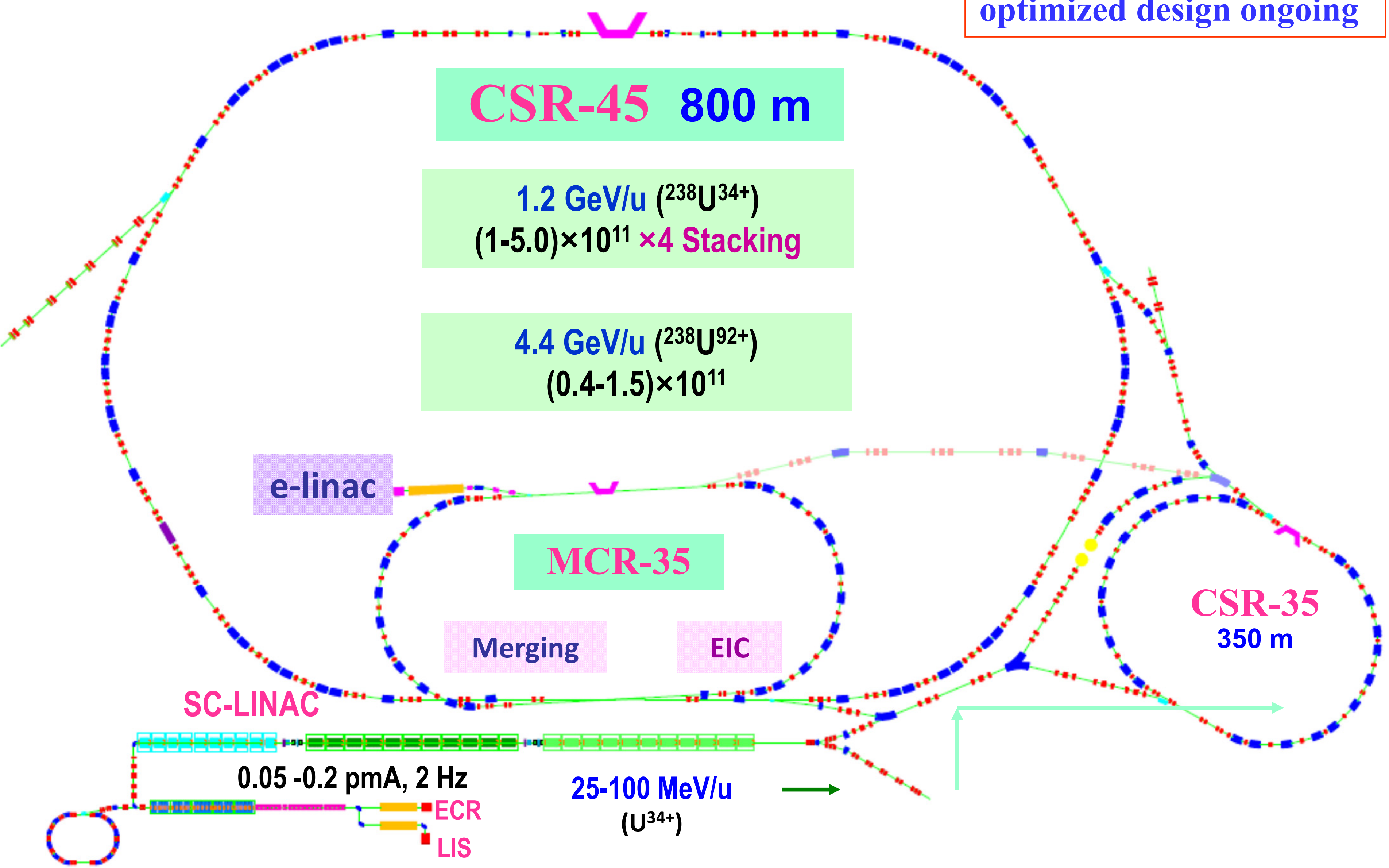
PRL 109,102501 (2012)

Nature Physics 7(2011) 281-282

Considerations and challenge of the 4th generation ECRIS (50-60GHz) for IMP new project HIAF

Concept Design of HIAF--IMP future project

Preliminary design and optimized design ongoing



HIAF Beam Intensity Requirement to ECRIS

$^{238}U^{34+}$, CW beam, 850 eμA (0.025 pmA)

Pulse beam, 1.7emA (0.05 pmA)

Energy: ≥60xQ

VENUS test result for U^{34+}

CW:0.4 emA

ECRIS at least should produce:

$^{238}U^{34+}$, CW beam, 1.2 emA (0.035 pmA)

Pulse beam, 2.4 emA (0.07 pmA)

Energy: ≥60xQ

- Only an 4th generation ECRIS might meet the requirements
- Keep one point in mind: Deliver stable beams to accelerator

The most difficult task for the 4th generation ECRIS

- **Frequency scaling $I \propto \omega_{rf}^2/m$ for 50-60 GHz??**
- **How 50-60 GHz microwave power be efficiently coupled into the ECR plasma and at what power level (10kW or 20 kW) ?**

The first two questions need to be answered seriously

↓

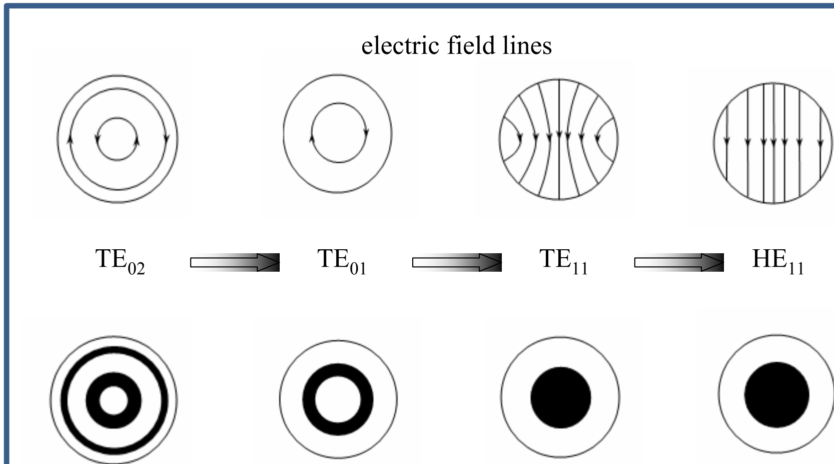
Plasma chamber size and RF power level

↓

SC magnet structure and its cooling

RF coupling: Corrugated wave-guide
Optical coupling?
Microwave mode: TE_{01}, TE_{11}, HE_{11} ?

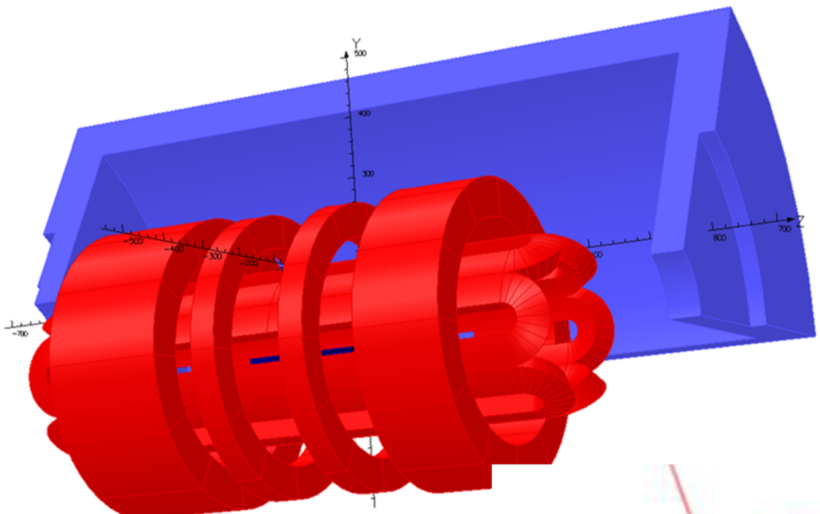
To be tested at SECRAL

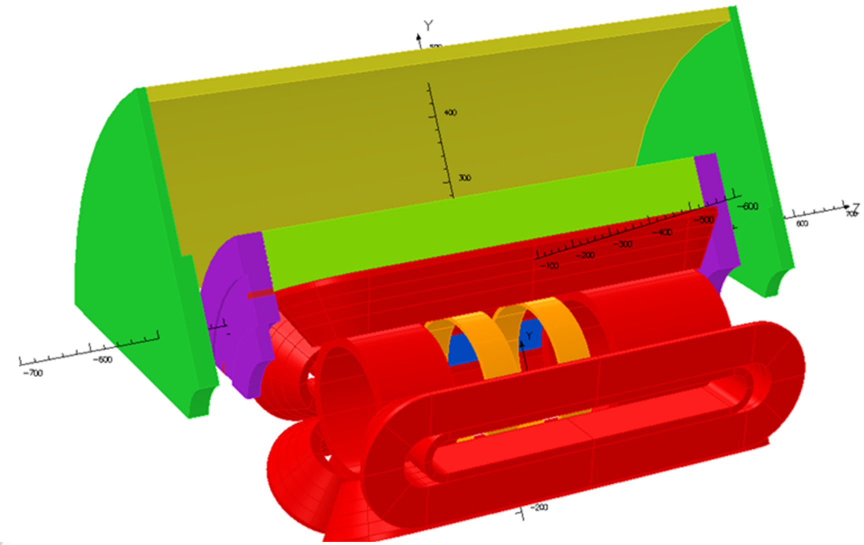


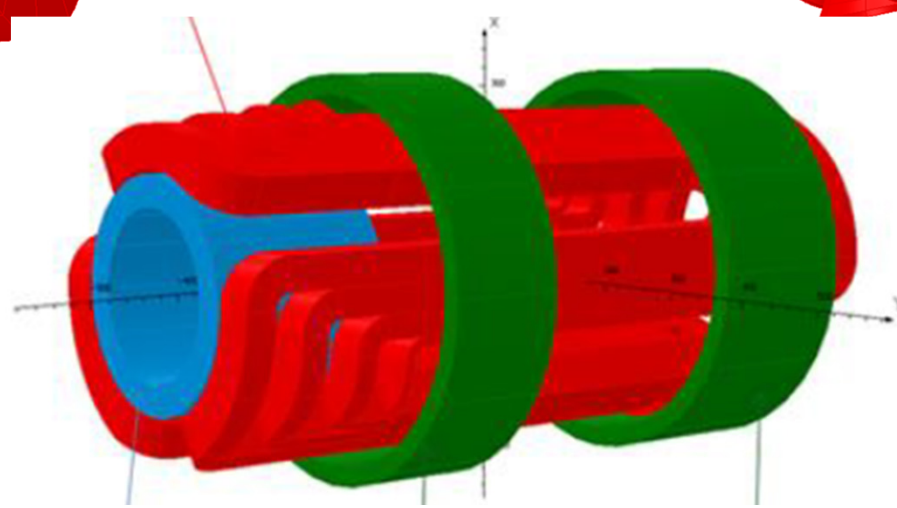
D.Hitz ECRIS2006

The most challenging for the 4th generation ECRIS

SC-magnet with the max field at the coil 14-16 T and the huge interaction forces between the solenoids and the sextupole (B_{inj} 7-8T, B_r 4-5 T).



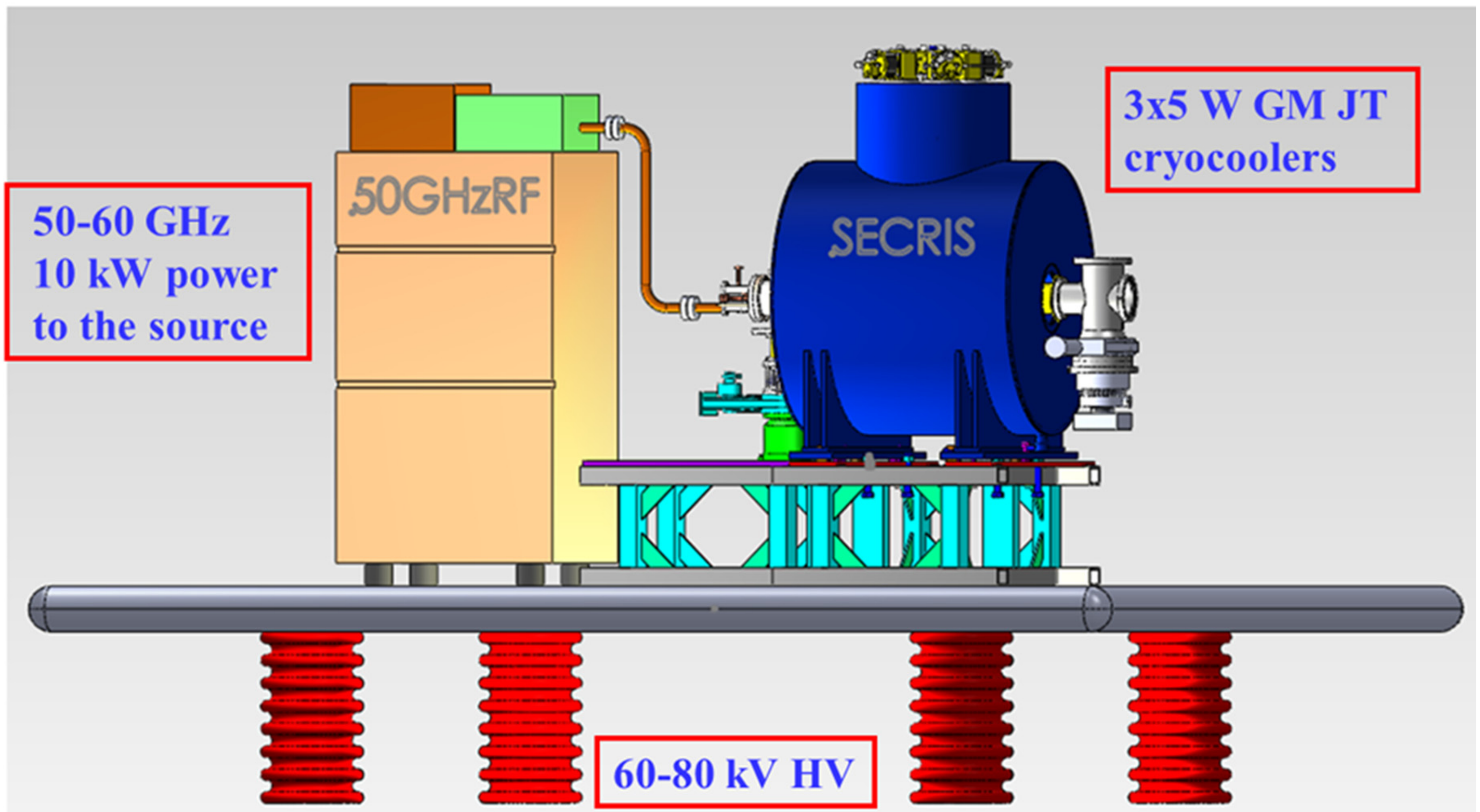


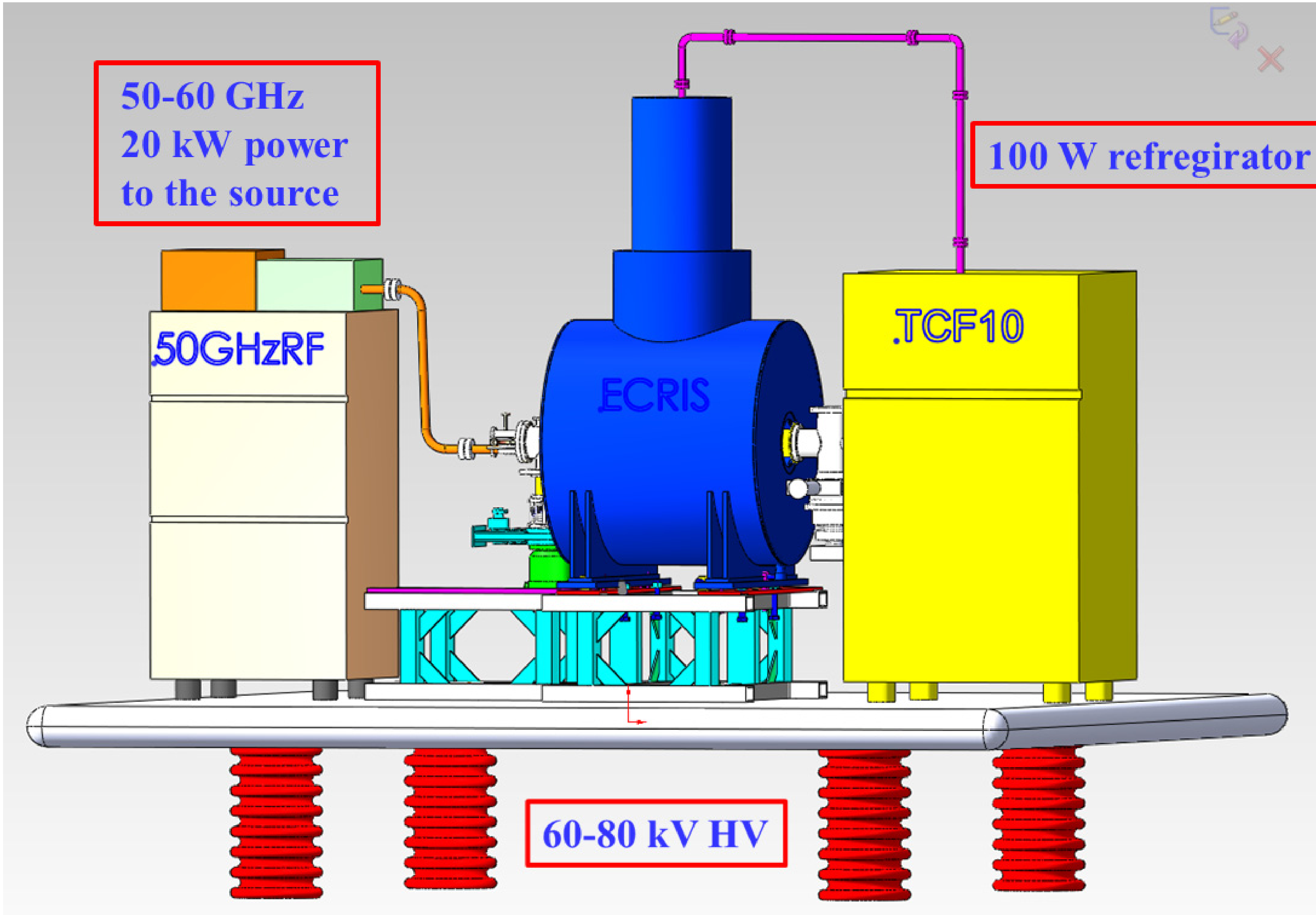


The most critical for the 4th generation ECRIS

- RF power: 10kW or 20 kW?
- 1 kW rf power → 1W heat load
  Still valid for 50-60 GHz?
  Maybe more heat load?

- SC magnet cooling ⟺ RF power
- Extremely strong X-ray flux
- High voltage platform (60-80 kV)





50-60 GHz
20 kW power
to the source
100 W refregirator
.50GHzRF
.ECRIS
.TCF10
60-80 kV HV

The other challenging tasks for the 4th generation ECRIS

- Laboratory available 50-60GHz /10-20 kW gyrotron system operated at both CW and pulse mode. Long-term stability and reliability are crucial.

- 40-60 mA mixed highly charged ion beam extraction and transmission issues.

- Beam quality produced by 10-20 kW/50-60GHz ECR. Emittance, beam image.

- Uranium beam production. Long-term stability at high power?

Need R&D and technology prototyping

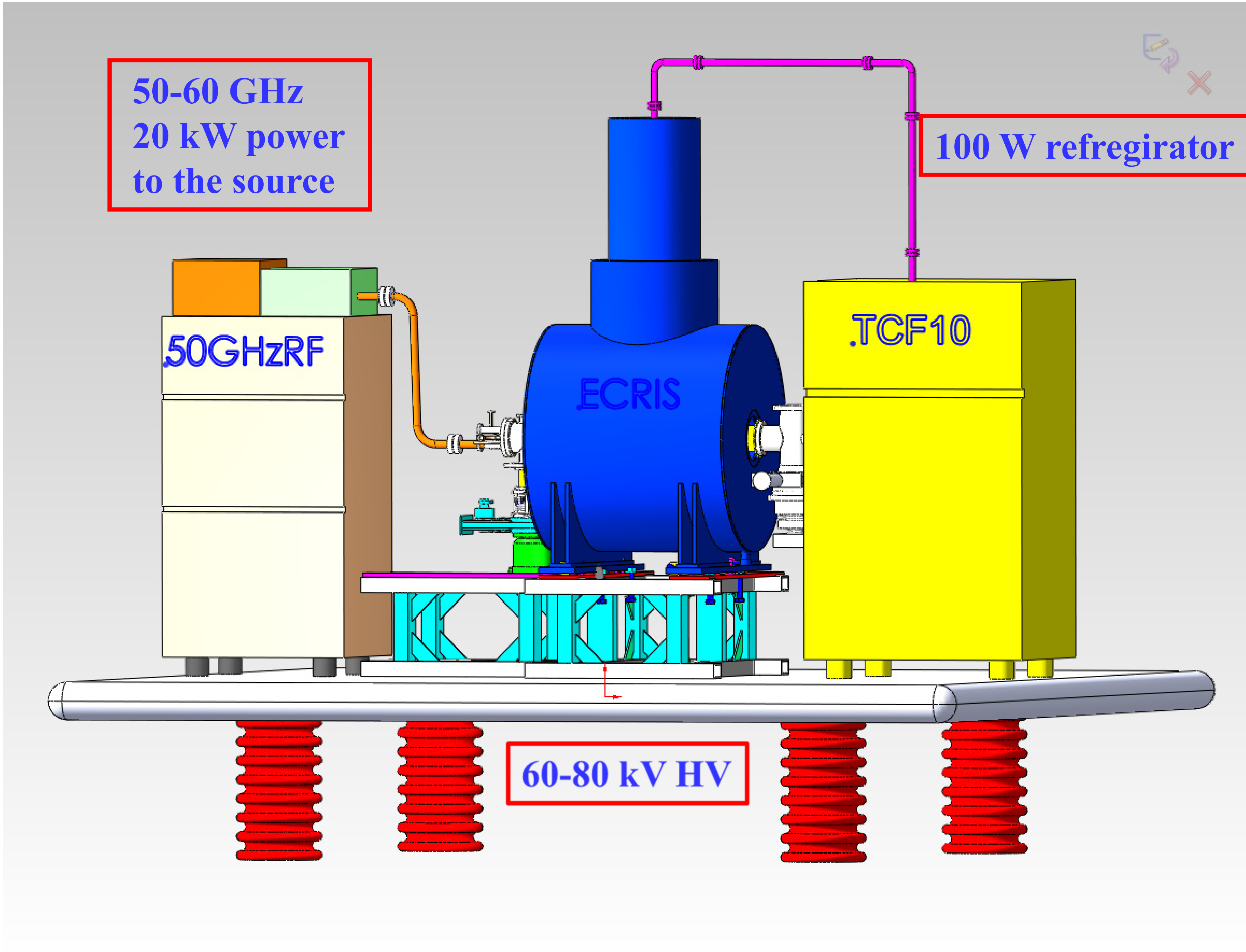
Conclusions

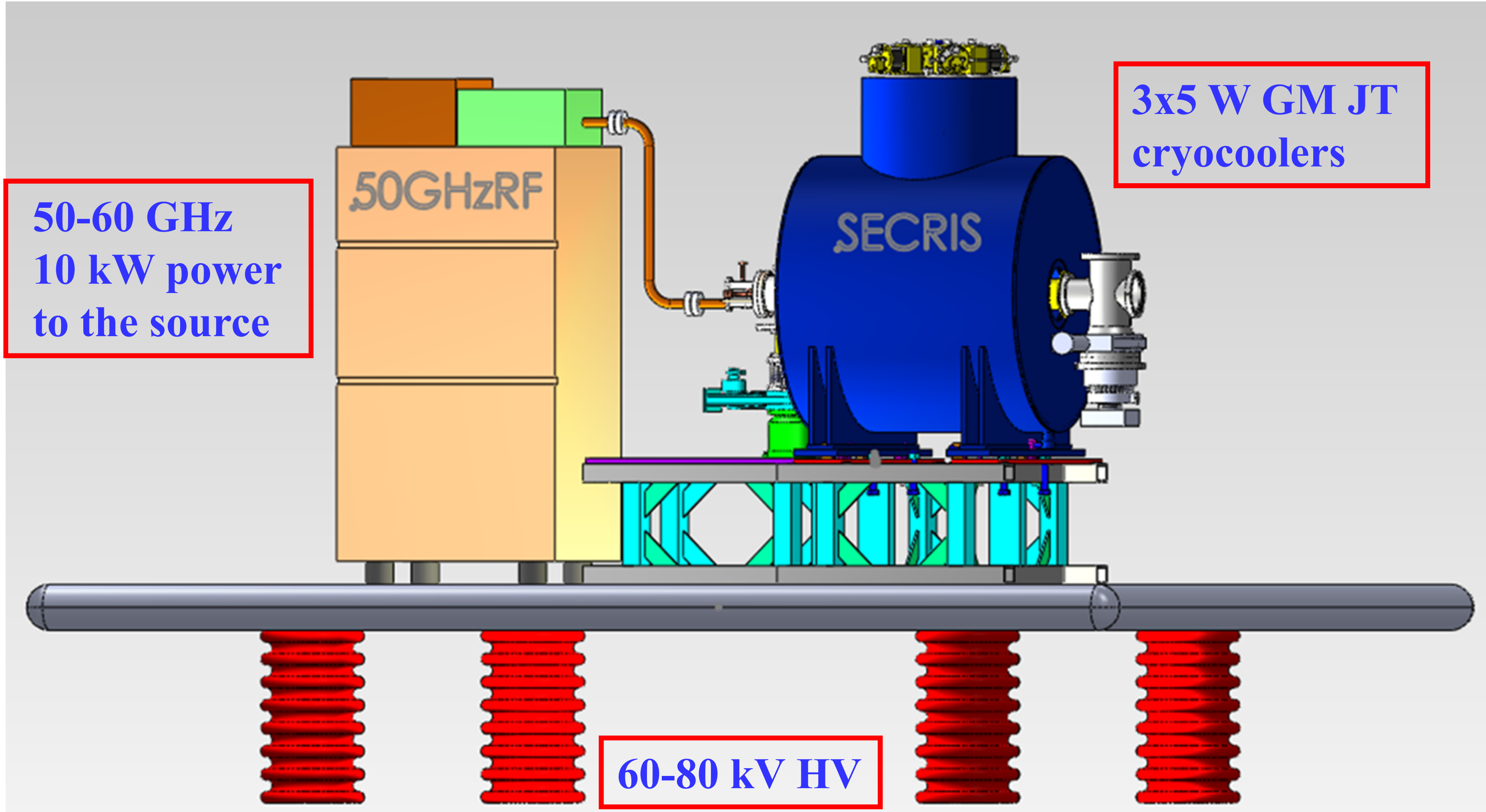
- SECRAL operating at 24GHz and 24GHz+18GHz double frequency heating has achieved excellent performance and quite nice stability. $^{29}Xe^{35+}$ 64 eμA, $^{129}Xe^{42+}$ 3 eμA, $^{09}Bi^{41+}$50eμA, $^{209}Bi^{50+}$4.3eμA ,$^{209}Bi^{54+}$0.2eμA and $^{238}U^{33+}$ 162 eμA.

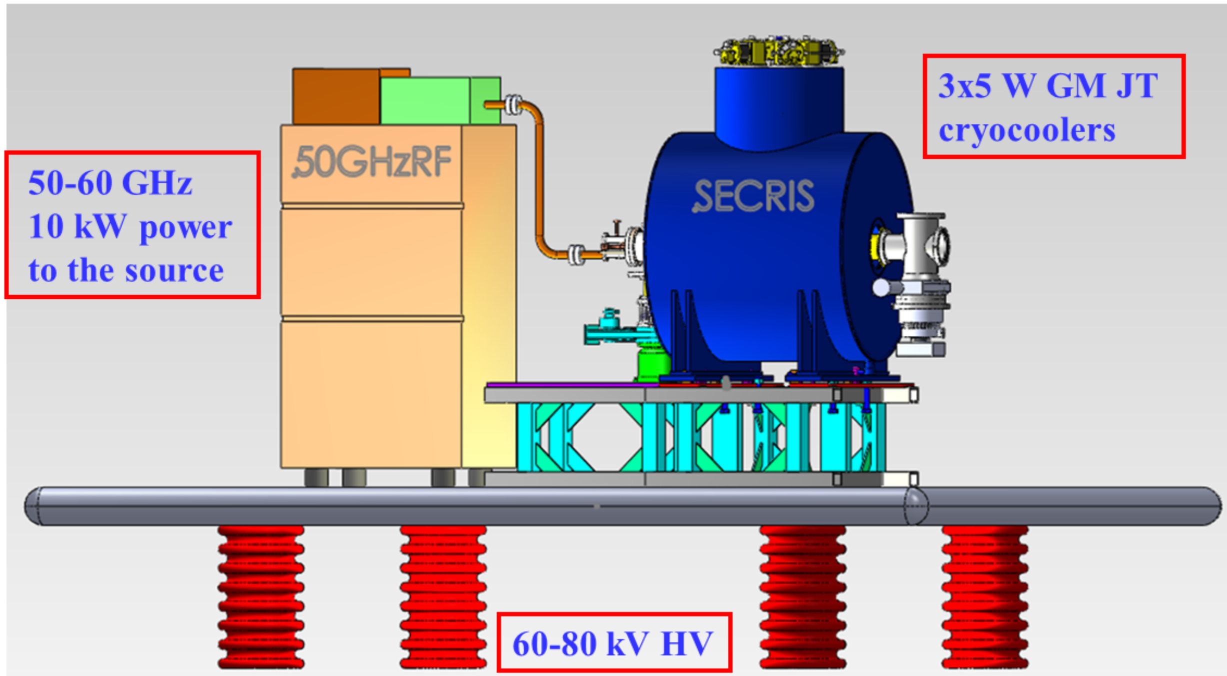
- SECRAL has been operated at 18GHz and 24GHz to provide highly charged heavy ion beams for HIRFL accelerator since May 2007. Total beam time provided by SECRAL is more than 10,000 hours up to Sept. 25th 2012. Beams delivered to HIRFL: Ar, Ca, Ni, Kr, Xe, Bi, U.

- An 4th generation ECRIS is being planed for IMP new project HIAF. Much more challenges and technical issues should be studied, tested and prototyped in advance before final decisions would be made.

THANKS for your attention !


50-60 GHz
20 kW power
to the source
100 W refregirator
.50GHzRF
ECRIS
.TCF10
60-80 kV HV


50-60 GHz
10 kW power
to the source
50GHzRF
SECRIS
3x5 W GM JT
cryocoolers
60-80 kV HV



3x5 W GM JT
cryocoolers
50-60 GHz
10 kW power
to the source
50GHzRF
SECRIS
60-80 kV HV