Intense Ion Beam Production with SuSI

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ECRIS 2010, 23-26 August 2010, LPSC-Grenoble, France

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Outlines

- ❑Typical features of SuSI
- ❑SuSI project timeline
- ❑SuSI upgrading
- ❑Production of Intense and HCI beams
- ❑Production of refractory metal beams
- ❑Next-step R&D on SuSI

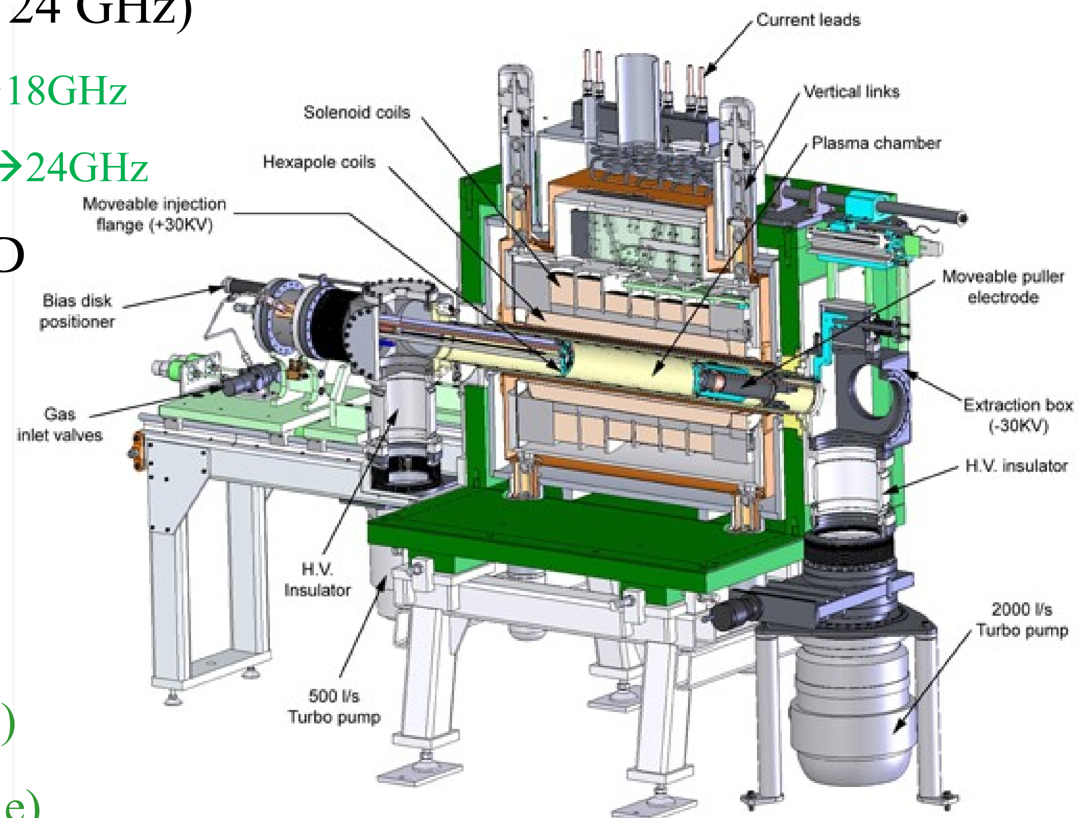
The Superconducting Source for Ions (SuSI)

- Fully Superconducting coils
- 18 GHz operating frequency (up to 24 GHz)

B_{inj}=2.6T, B_{ext}=1.4T, B_{min}=0.5T, B_{rad}=1.3T→18GHz

B_{inj}=3.6T, B_{ext}=2.0T, B_{min}=0.75T, B_{rad}=1.6T→24GHz

- Al Plasma chamber of ∅101 mm ID
- Extraction HV up to 27kV

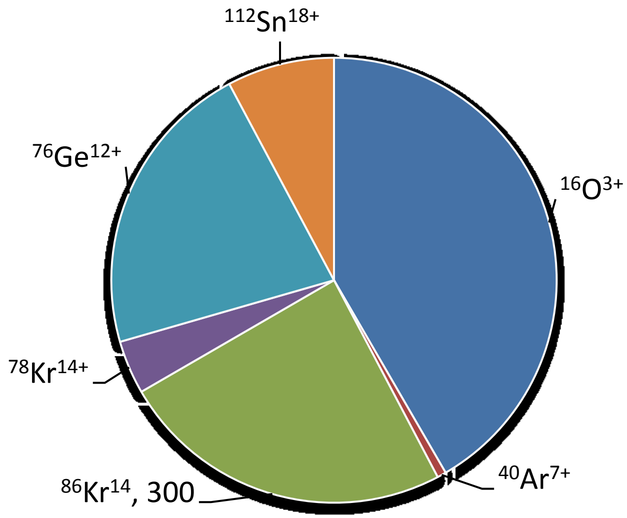


- <u>Specific Design features</u>
  - ✓6 solenoids coils
  - ✓Movable injection baffle (tunable)
  - ✓Movable extraction puller (tunable)

SuSI Project Timeline

Coils winding completed	September 2005
Tested and trained Individuals coils	November 2005
Coil assembly (Hexapole + Solenoids)	Early 2006
Coil assembly testing (Helium Dewar)	February 2006
Cryostat completed	September 2006
Yoke is installed	December 2006
Source complete and moved to SuSI test lab	January 2007
First Plasma with O, Ar and Xe beams	March 2007
No more Quench	November 2007
Ion source and beam line commissioning completed	June 2008
Relocated to ECR area, connected to CCF	September 2009
First beam from SuSI to CCF	November 2009

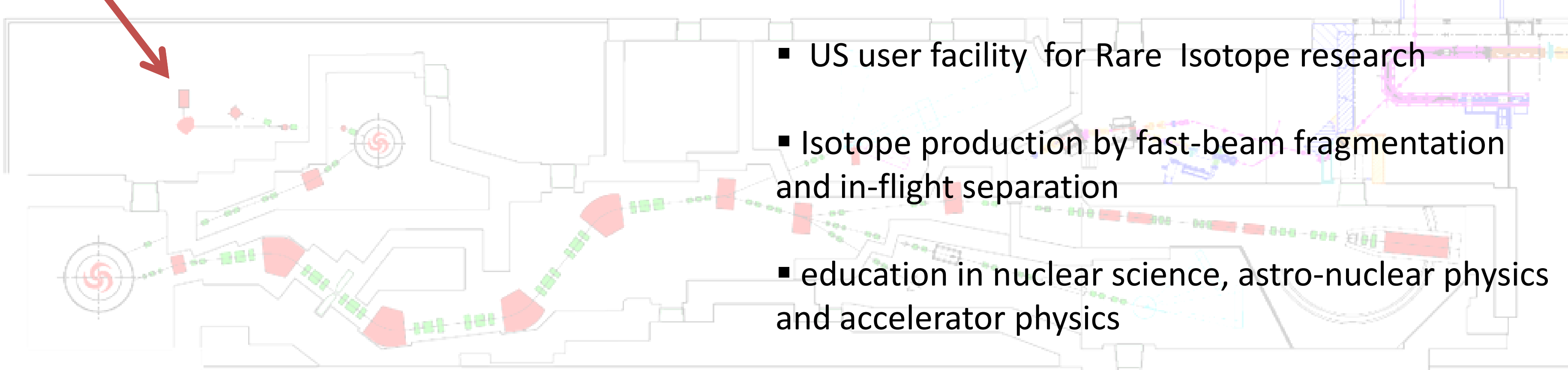
SuSI On-line Operation



✓More than 1200 hrs continuous operation for CCF;

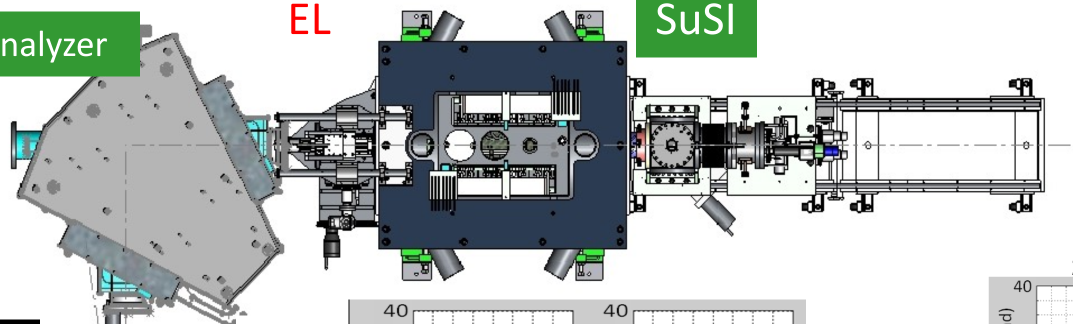
✓No quench during operation;

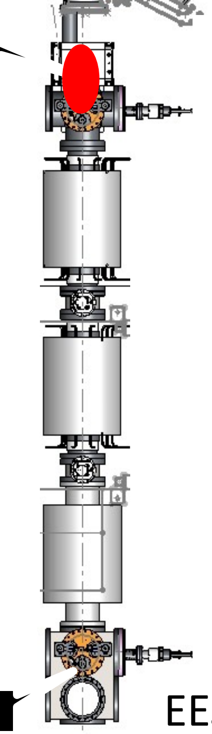
✓Good stability and reliability has been demonstrated with on-line operation.



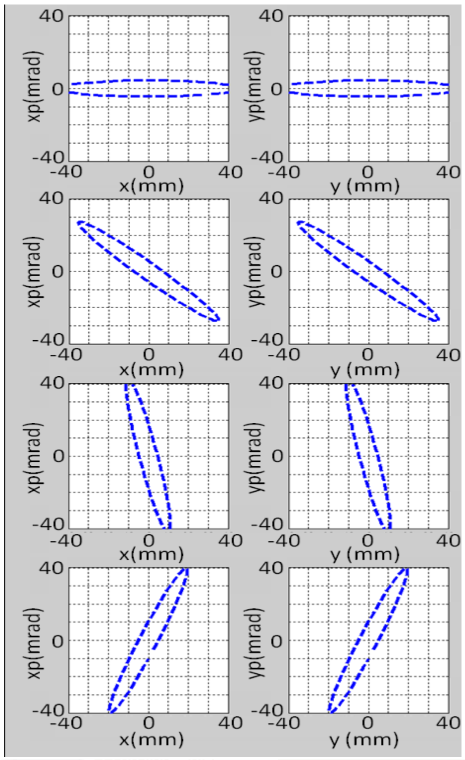
- US user facility for Rare Isotope research
- Isotope production by fast-beam fragmentation and in-flight separation
- education in nuclear science, astro-nuclear physics and accelerator physics

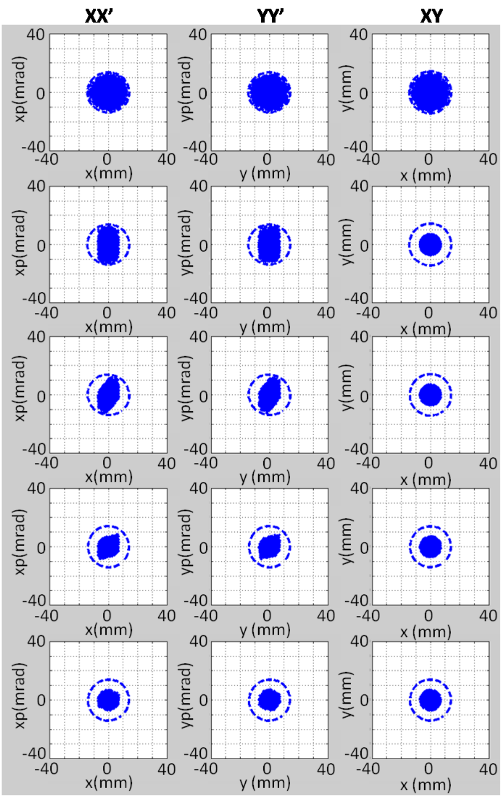
Beam Analysis Line





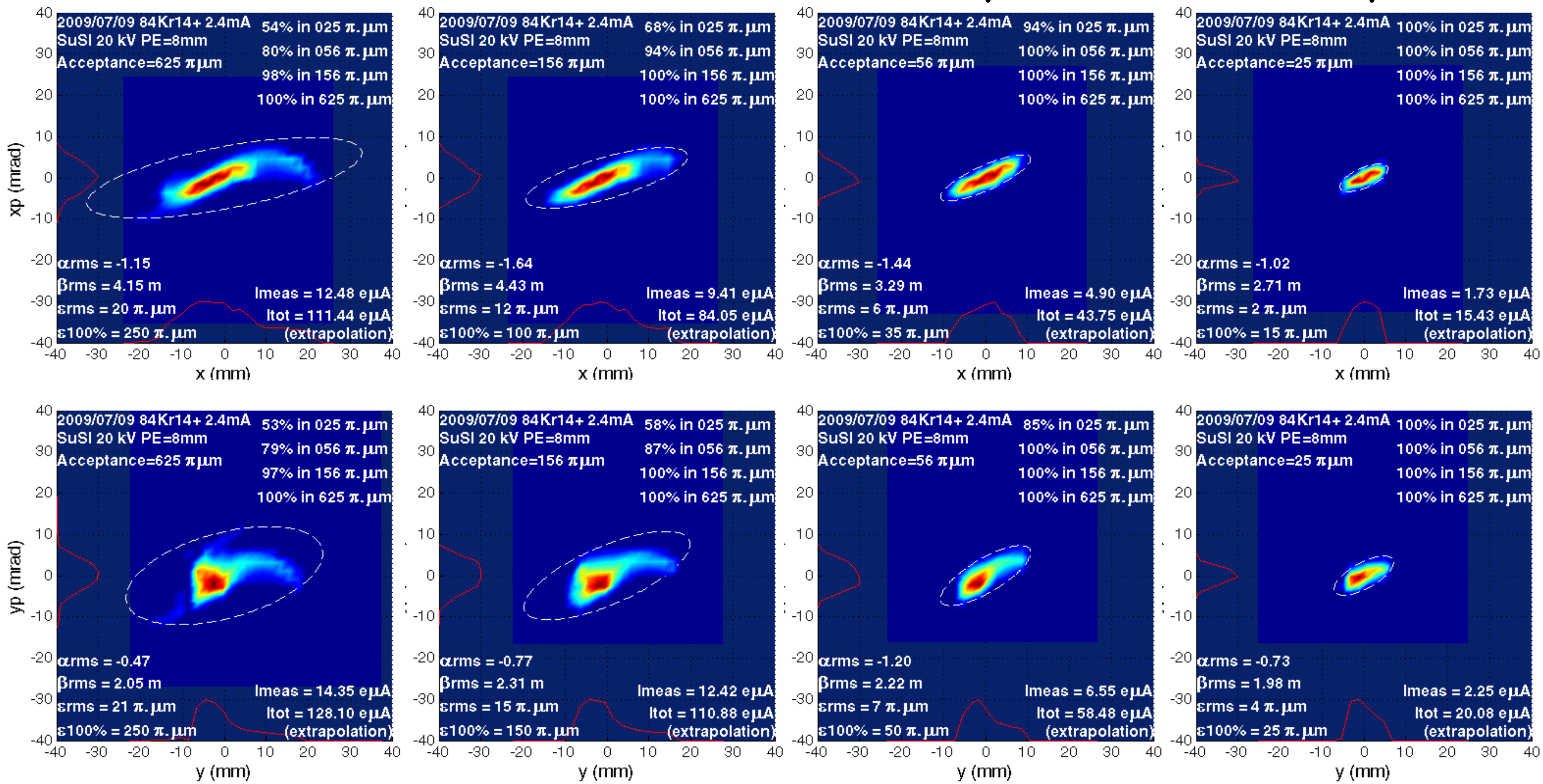
- Multiple-stage collimation with phase-space rotation in between;
- Possible to use solenoid lenses to do the phase space rotation;
- Design using 3 cells.





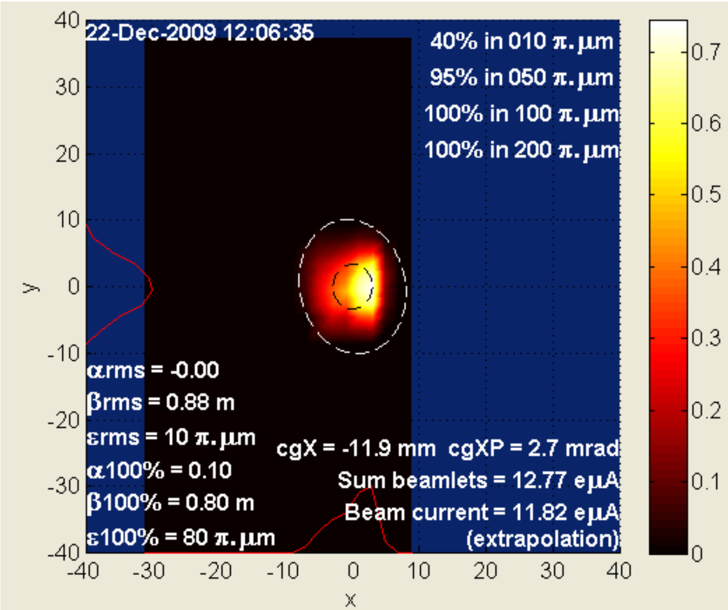
Kr^{14+} Beam Collimation

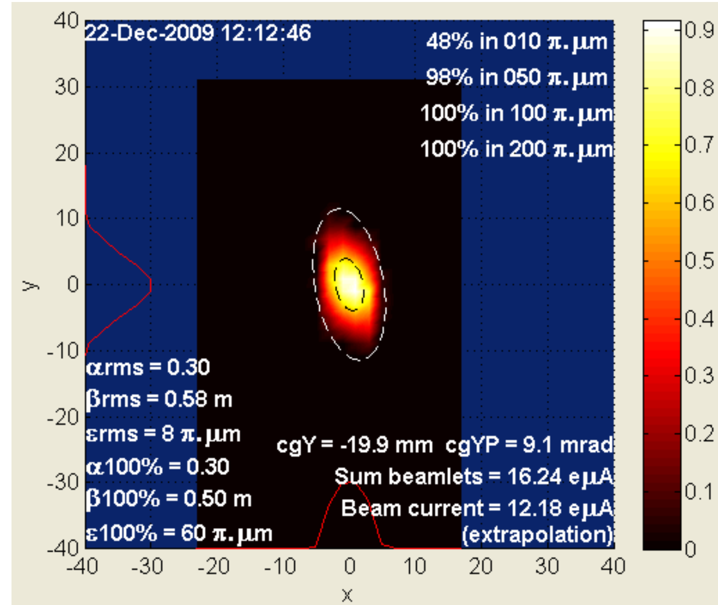
625 π.μm | 156 π.μm | 56 π.μm | 25 π.μm



FC: 138 eμA | 100 eμA | 55 eμA | 19 eμA

Application of Collimation Sys.

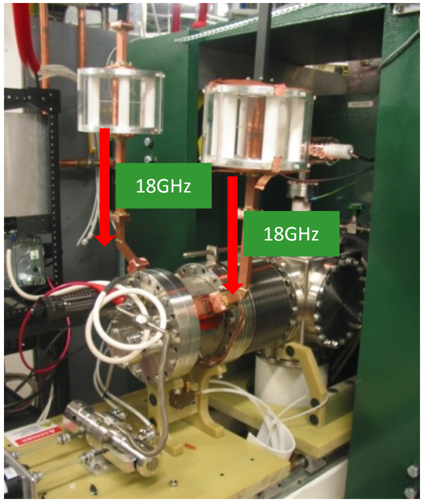




Extrapolation: K500 → 8300 enA & K1200 → 6000 enA ⇒ >2kW beam power vs. 1.4kW

Source	Beam	Intensity at the source (eµA)	Channel Acceptance (π.mm.mrad)	Current Extracted from K500 (enA)	K500 Extraction eff. (%)	Current Extracted from K1200 (ena)	Current Extracted from K1200 (pna)	K1200 Extraction eff. (%)	Beam List (pnA)
SuSI	$^{78}Kr^{14+}$	17.0	25	8300	80.2%	Ran Only from K500	Ran Only from K500	0.0%	25
ARTEMIS	$^{78}Kr^{14+}$	28.5	n/a	5600	80.0%	4200	123.5	82.0%	25

Upgrades on SuSI (2010)



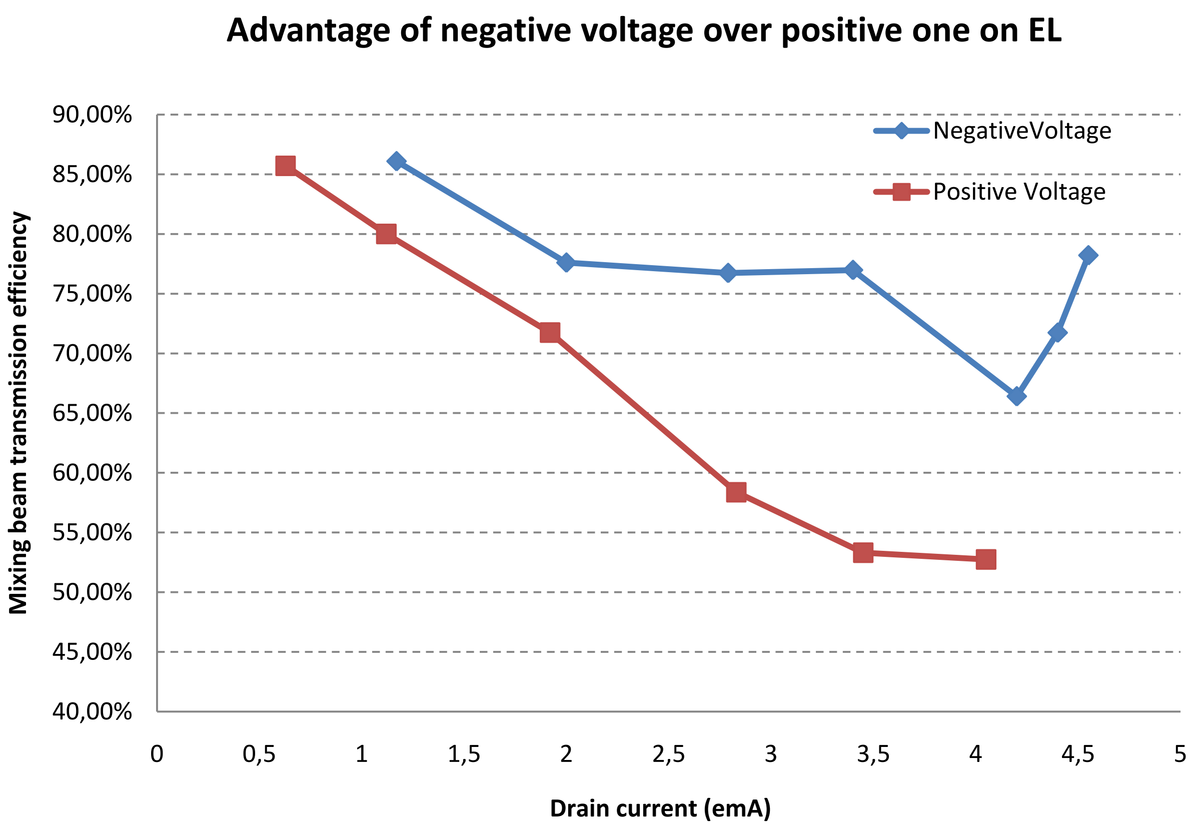
Two 18GHz klystron amplifiers that can provide up to 3.0 kW rf power into the 3.5L plasma chamber.

Good X-ray shield and proof that enables reliable long-term operation under high rf power.

Modified Einzel Lens that hold up to -30 kV with intense beam on, which helps intense beam transmission through the dipole

Enables the SuSI test at high power density to extract intense beams , especially good for the production of heavy beams.

EL: negative or positive voltage?



"+" vs "-"

"+" Pros:

- Effective with low voltage setting
- Effective at low beam intensity transmission

"+" Cons:

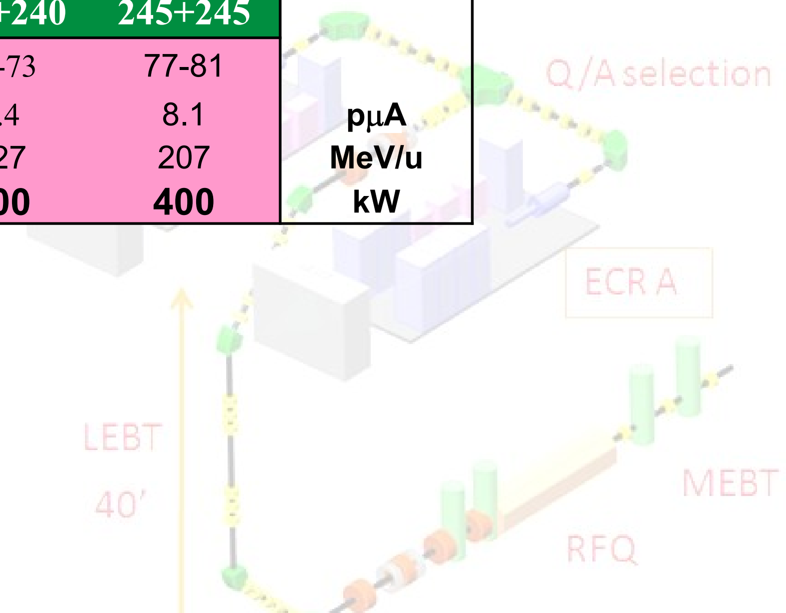
- Fail to work well with intense beam transmission
- Not suitable for I_0> 4 emA beam transmission

FRIB requirements for ECRISs

BEAM	Ion	O	Ar	Kr	Xe	Bi	U	
	Z	8	18	36	54	83	92	
	A	18	40	86	136	209	238	
ECR	Q	6	8	14	20	29+30	33+34	
	I_p	103	47.3	23.6	18.5	14.2	12.7	pμA
	I_e	618	378	331	334	**419***	**424***	eμA
	ε_{FRIB}	0.9	0.9	0.9	0.9	**0.6***	**0.6***	π.mm.mrad
ECR-max.#	I	700	420	380	410	**240+240**	**245+245**	
TARGET	Q	8.0	18.0	34-36	47-51	69-73	77-81	
	I	73.0	33.7	17.5	12.5	8.4	8.1	pμA
	KE	305	297	265	235	227	207	MeV/u
	P	**400**	**400**	**400**	**400**	**400**	**400**	kW

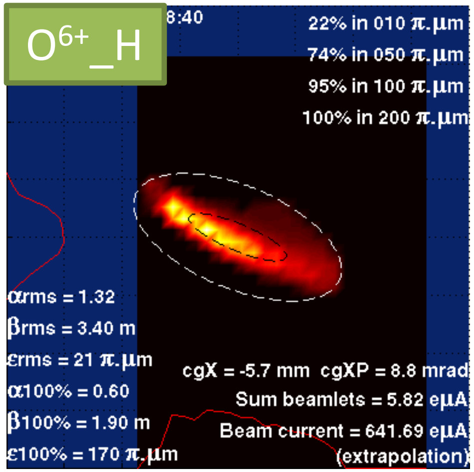
* Emittances per charge state;   # with 10~15 % redundancy

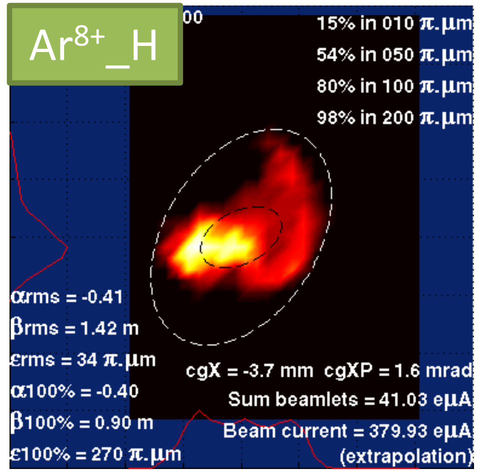
ECRIS on HV platform [1+1] - generate ~400 eμA 12 keV/u ion beams (oxygen to uranium)
Achromatic charge selection system [1+1] – select charge state(s)
LEBT – transport beam, form beam emittance and time structure
RFQ – accelerate beam to 300 keV/u
MEBT – match beam to SRF driver linac



See G. Machicoane' s talk: MOCOBK01

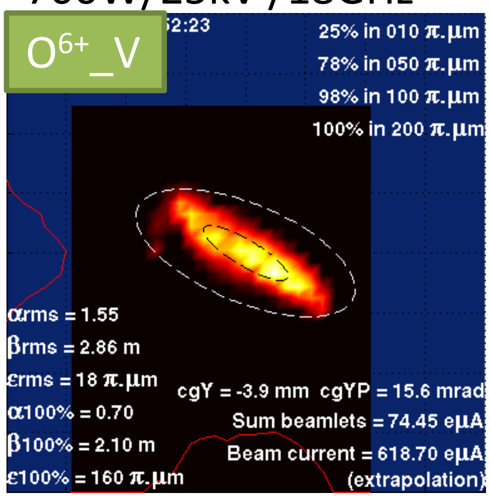
Light Gaseous Ion Beams

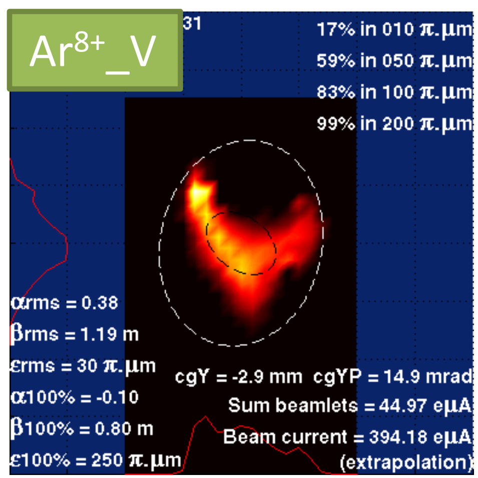




700W/25kV /18GHz

900W/25kV /18GHz





Sufficient brightness is easily achieved for light ion beams. Even higher beam intensity within the collimation channel acceptance is still available: like ~1emA O^{6+} or more than 0.5emA Ar^{8+}.

	O^{6+}	Ar^{8+}
FRIB ε_{6rms} (25kV)	200 π	275 π
ε_H	170 π	270 π
ε_V	160 π	250π

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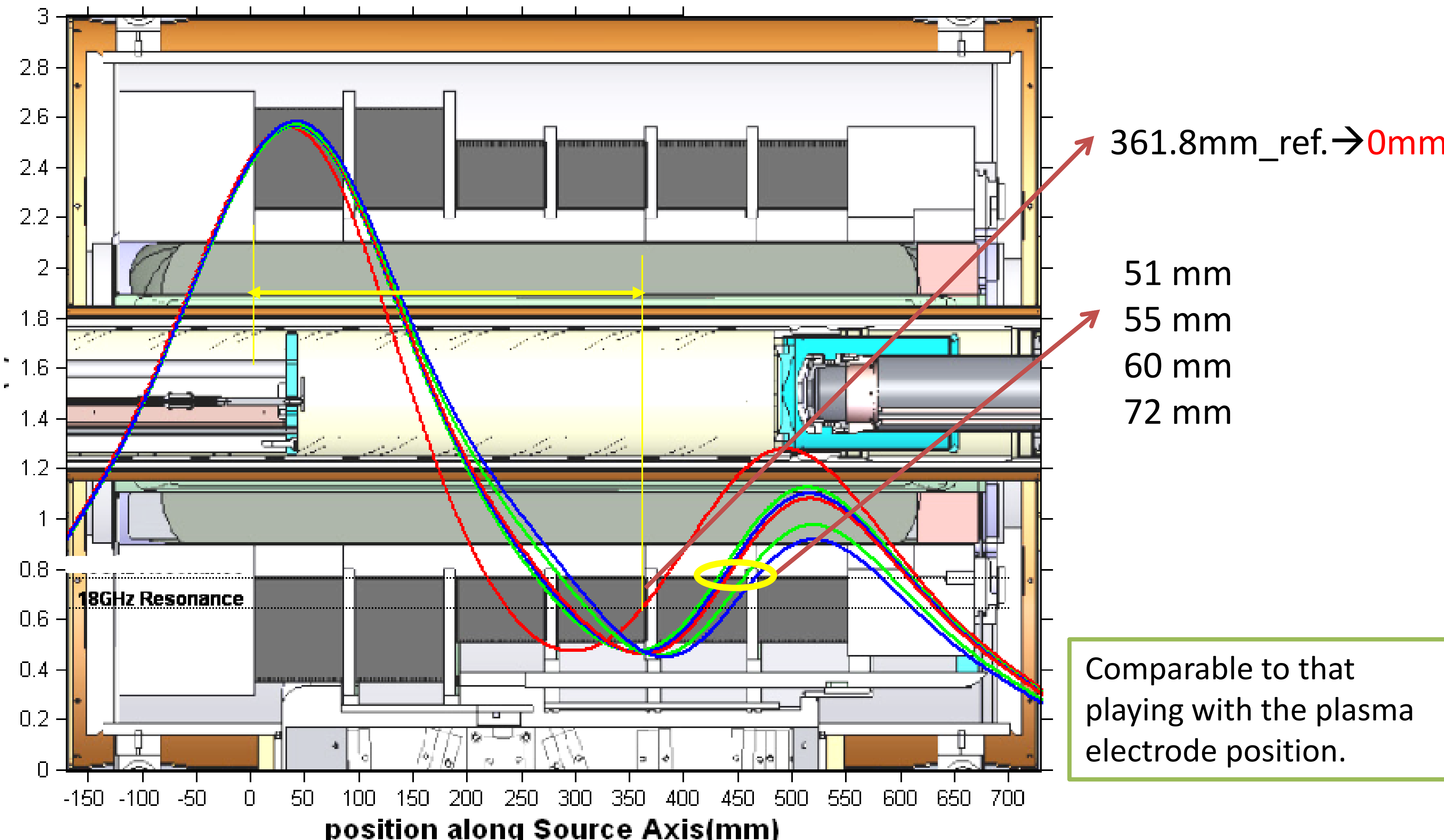
Moving ECR Zone Position_to make more beam (1)



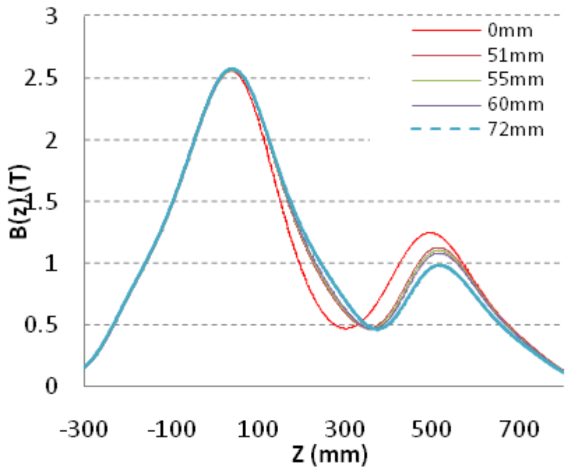
Comparable to that playing with the plasma electrode position.

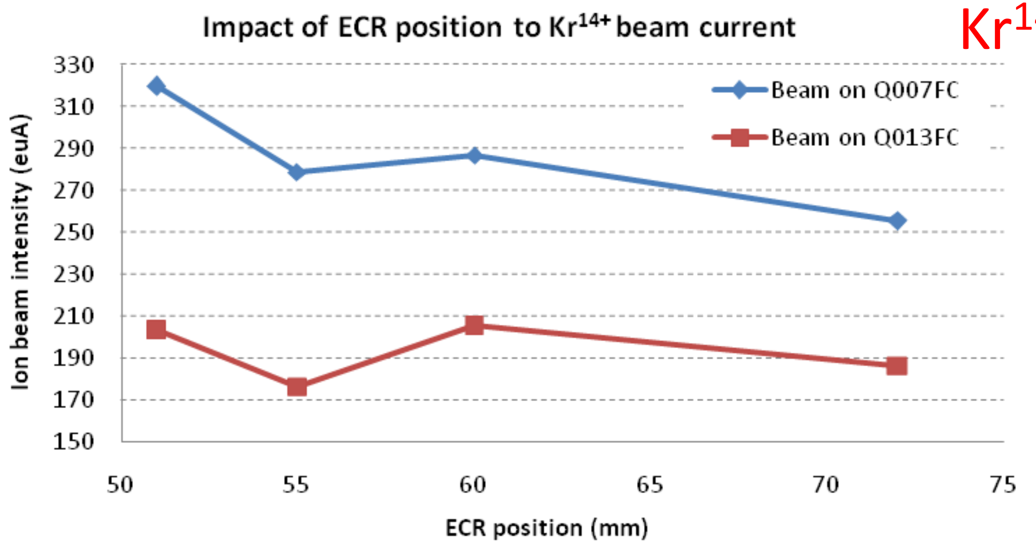
Also the Flat-B test, See T. Ropponen's talk: WECOAK04

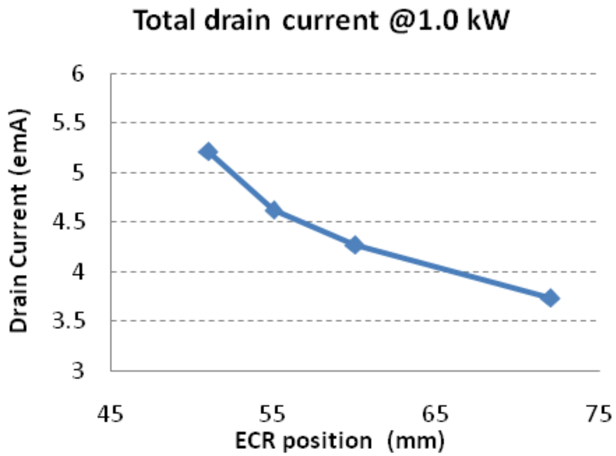
To make Intense Ion Beams

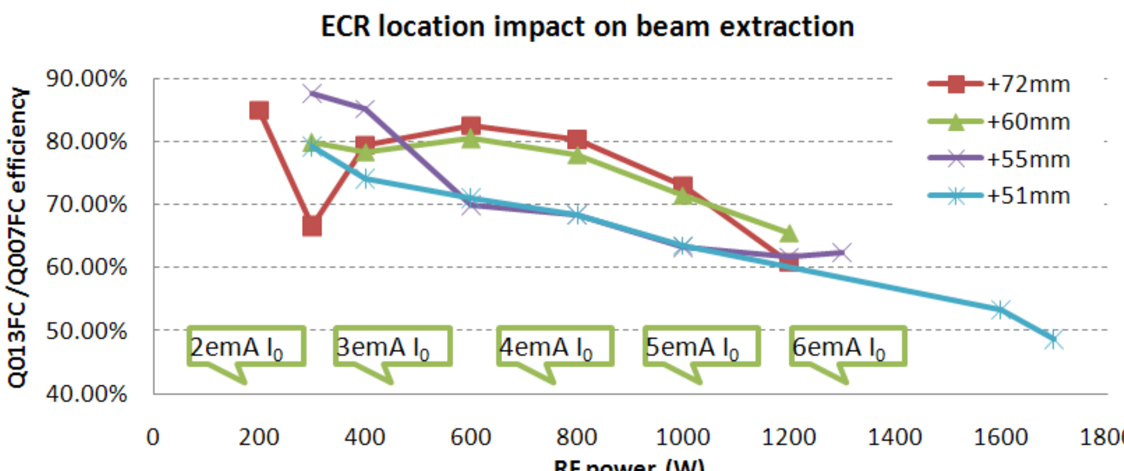
__ECR position & B_{ext} changed

Kr14+









Also the Flat-B test, See T. Ropponen's talk: WECOAK04

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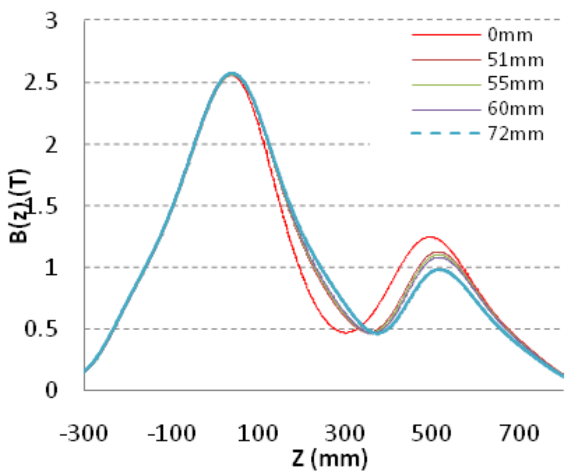
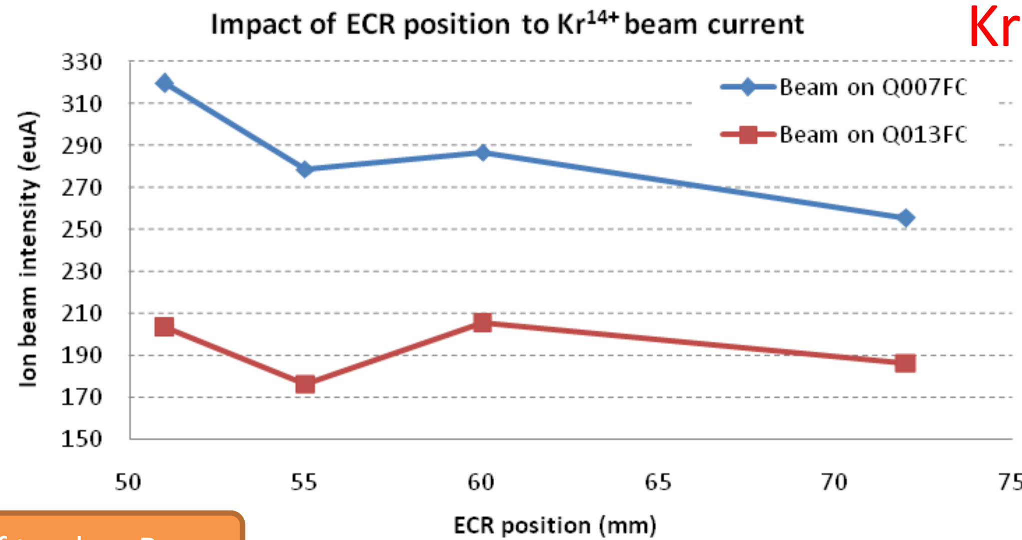
To make Intense Ion Beams

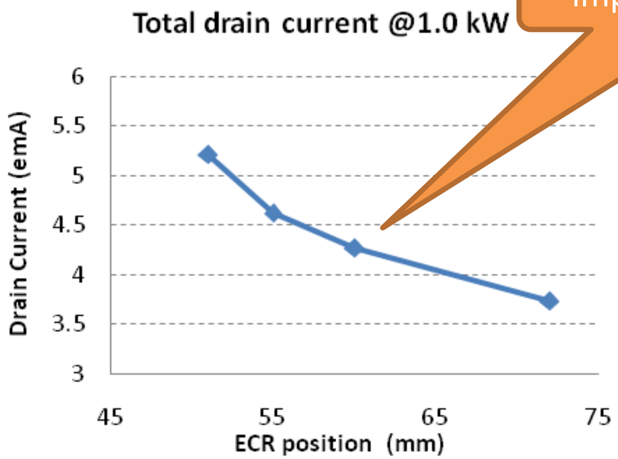
__ECR position & B_{ext} changed

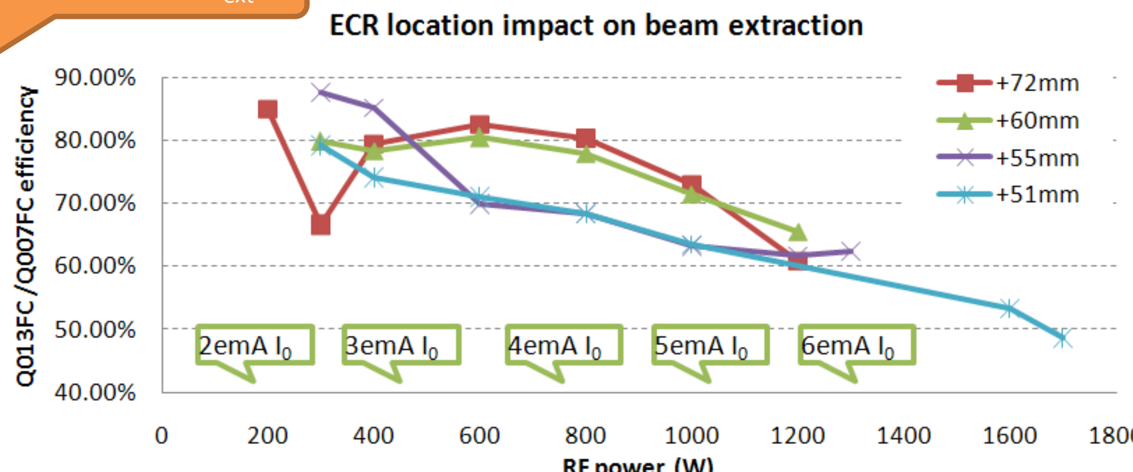


Kr^{14+}



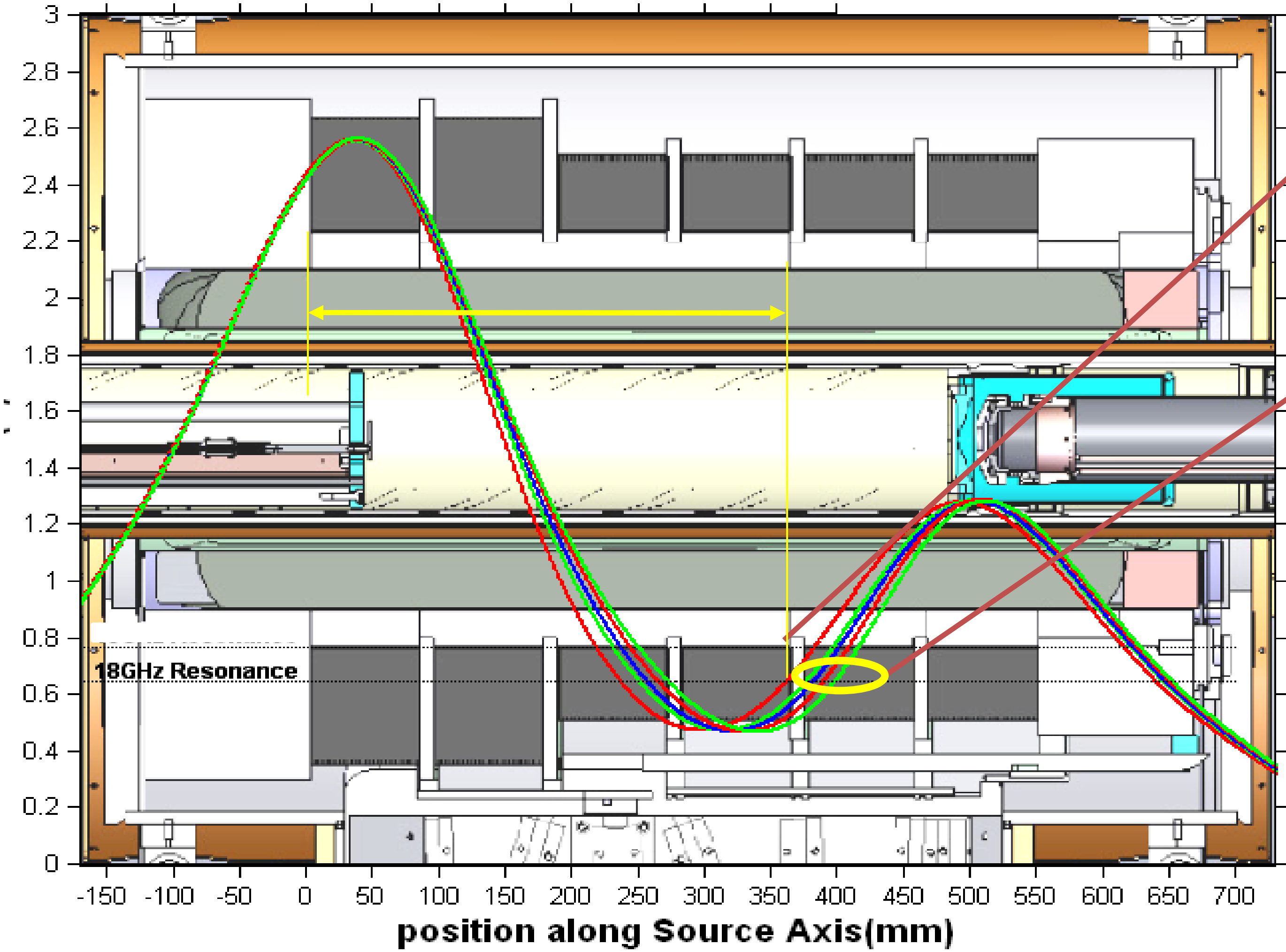
impact of too low B_{ext}





Also the Flat-B test, See T. Ropponen's talk: WECOAK04

Moving ECR Zone Position_to make more beam (2)



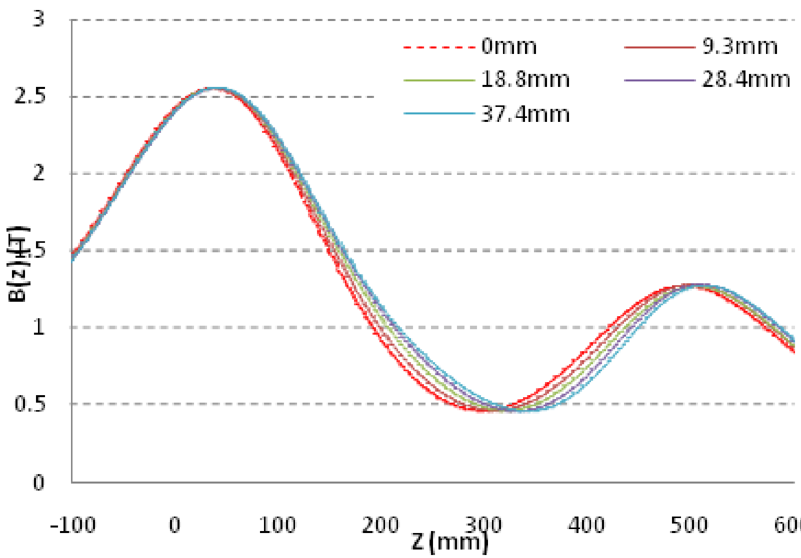
361.8mm_ref.→0mm

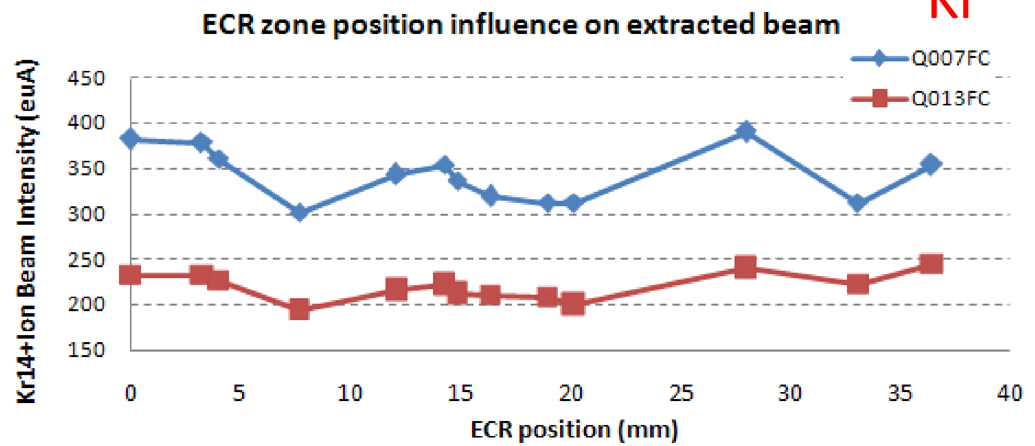
9.3 mm
18.8 mm
28.4 mm
37.4 mm

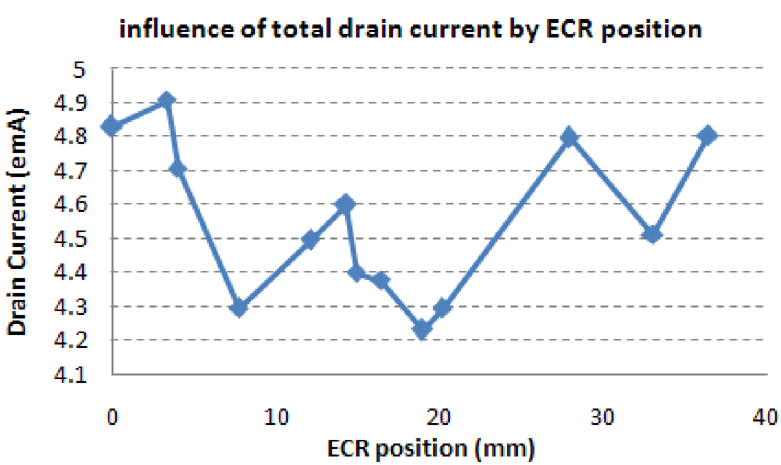
To make Intense Ion Beams

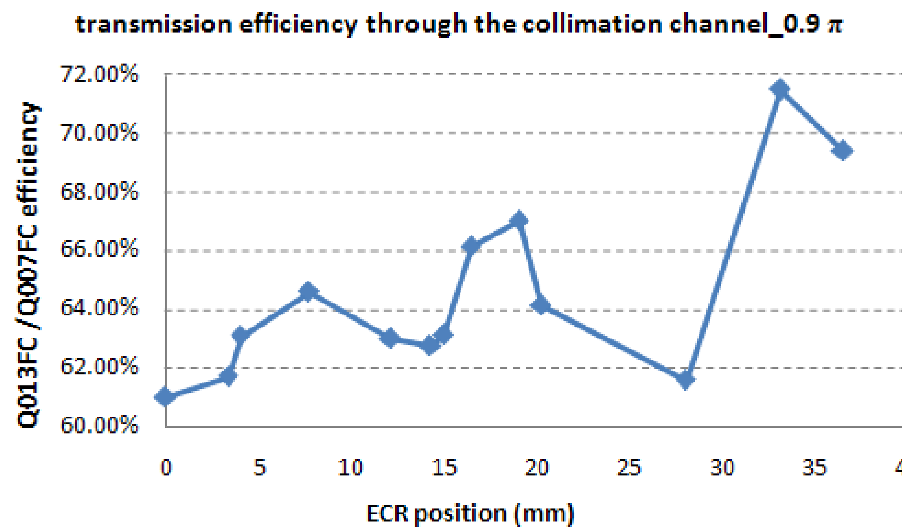
__ Only ECR position changed

Kr^{14+}





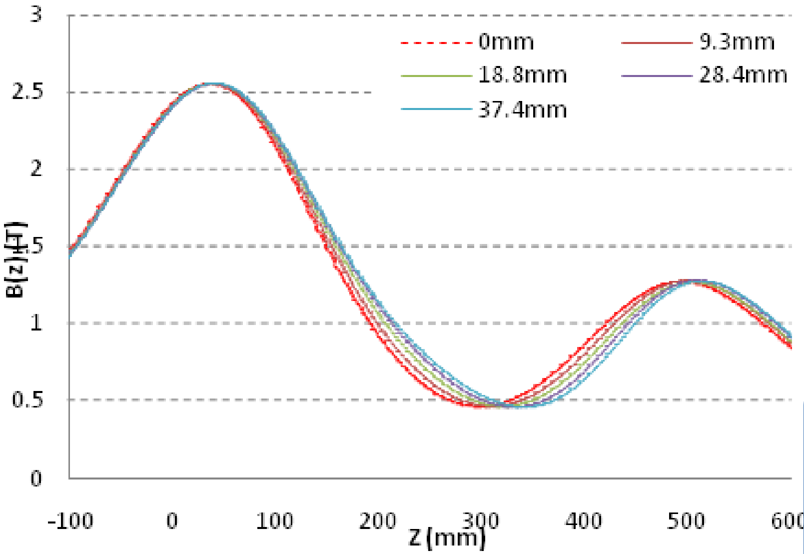


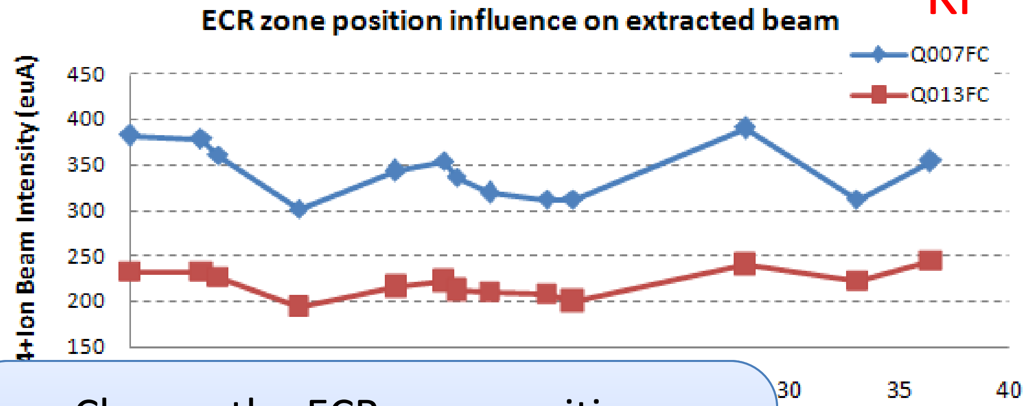


To make Intense Ion Beams

__ Only ECR position changed

Kr^{14+}



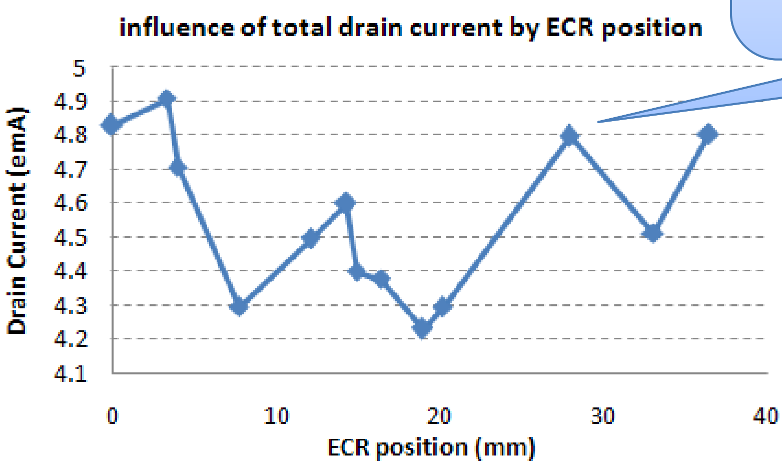


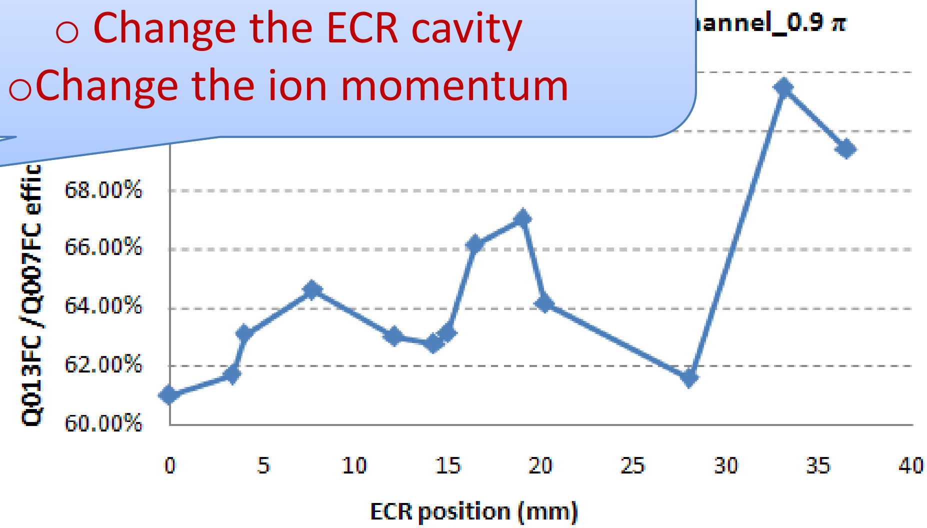
Change the ECR zone position:

○Change the ECR confinement

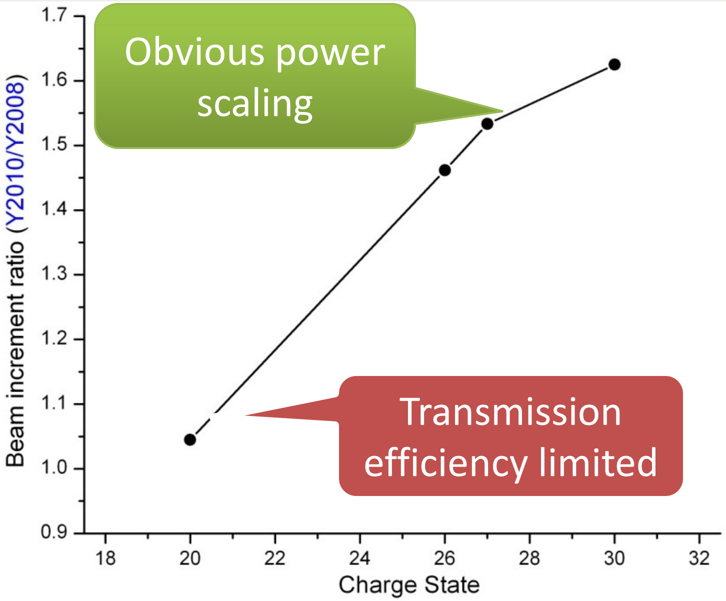
○ Change the ECR cavity

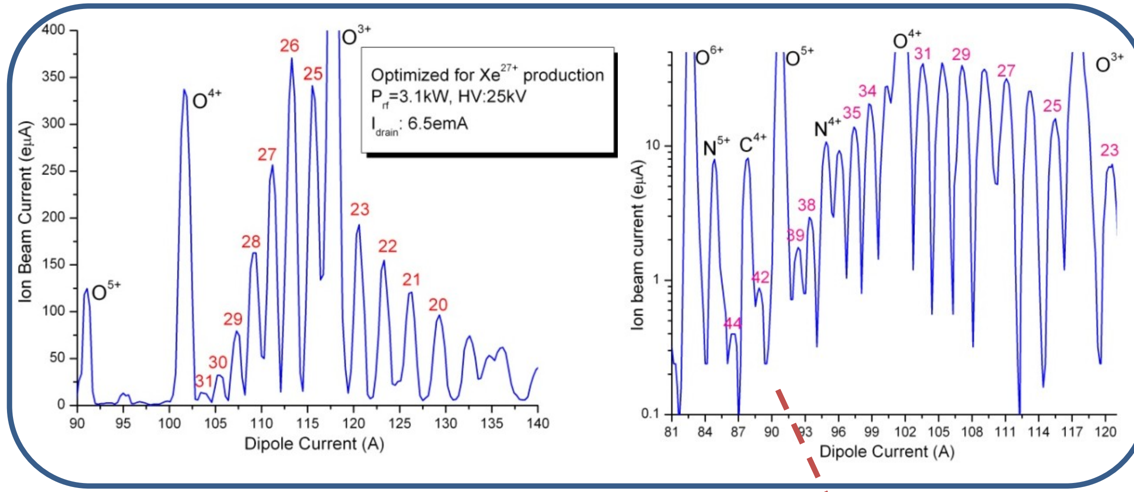
○Change the ion momentum



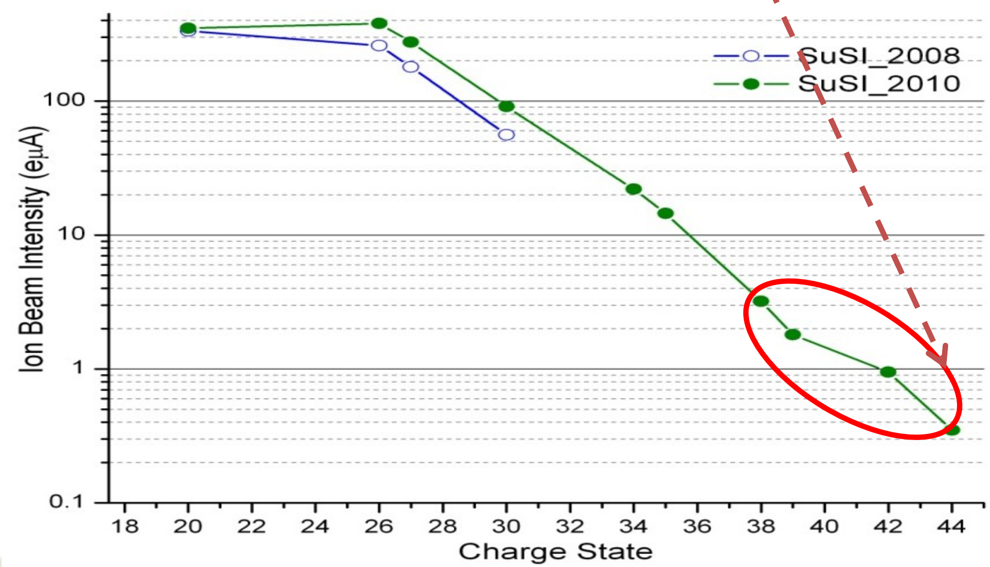


Xenon Beams

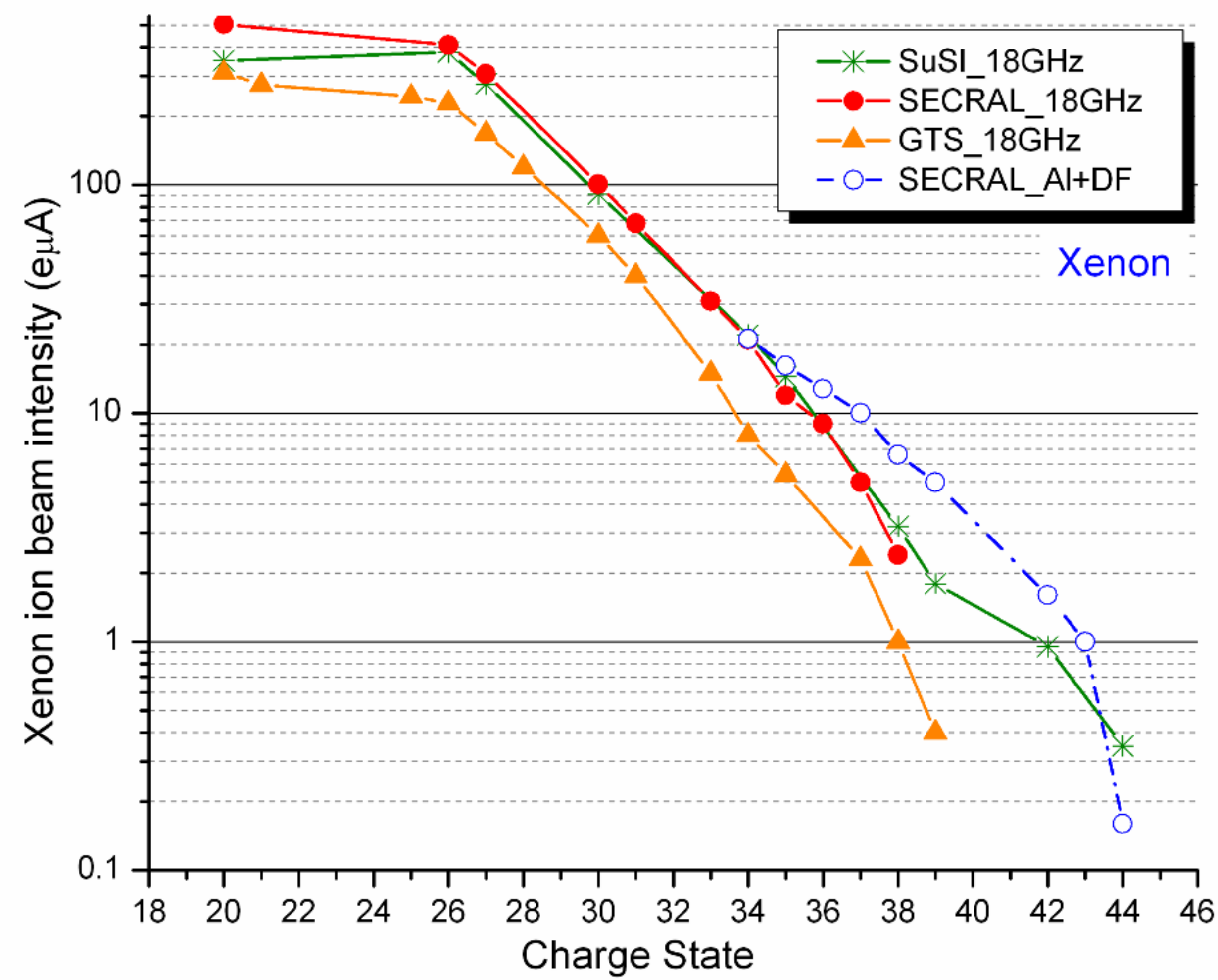




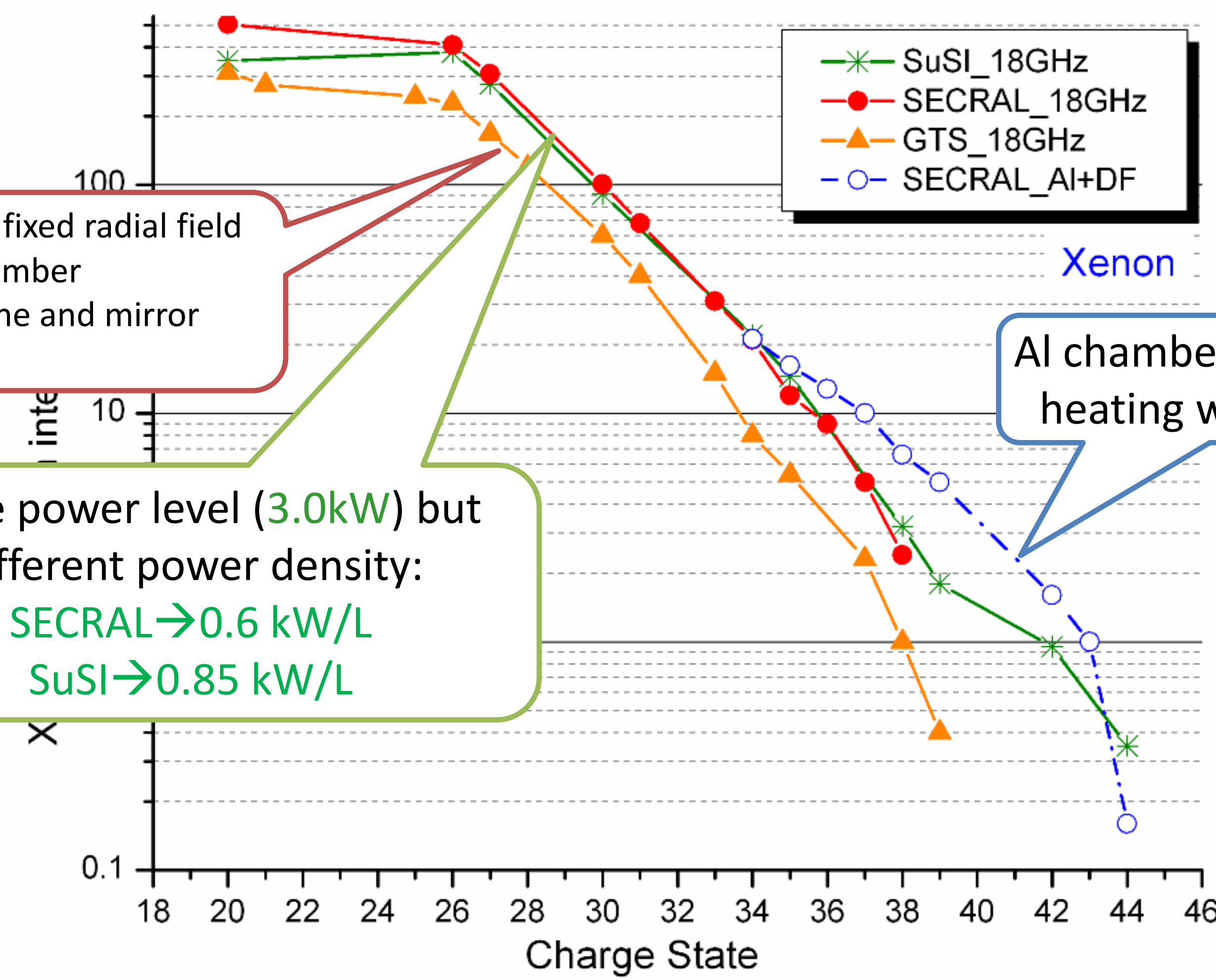
Power density scales the extracted beam intensity, especially for the higher charge state ion beams: ~0.5 kW/L (2008)→~0.85kW/L (2010)→1.7 times power density



Power or Power Density?



Power or Power Density?

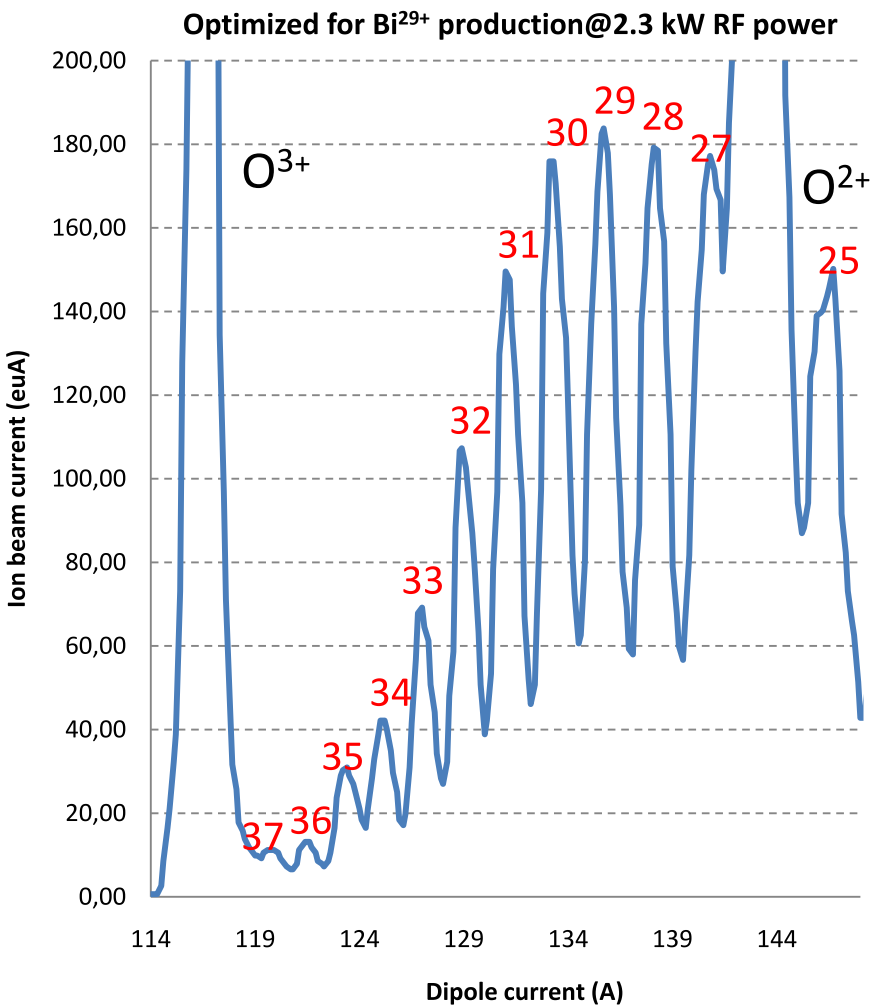


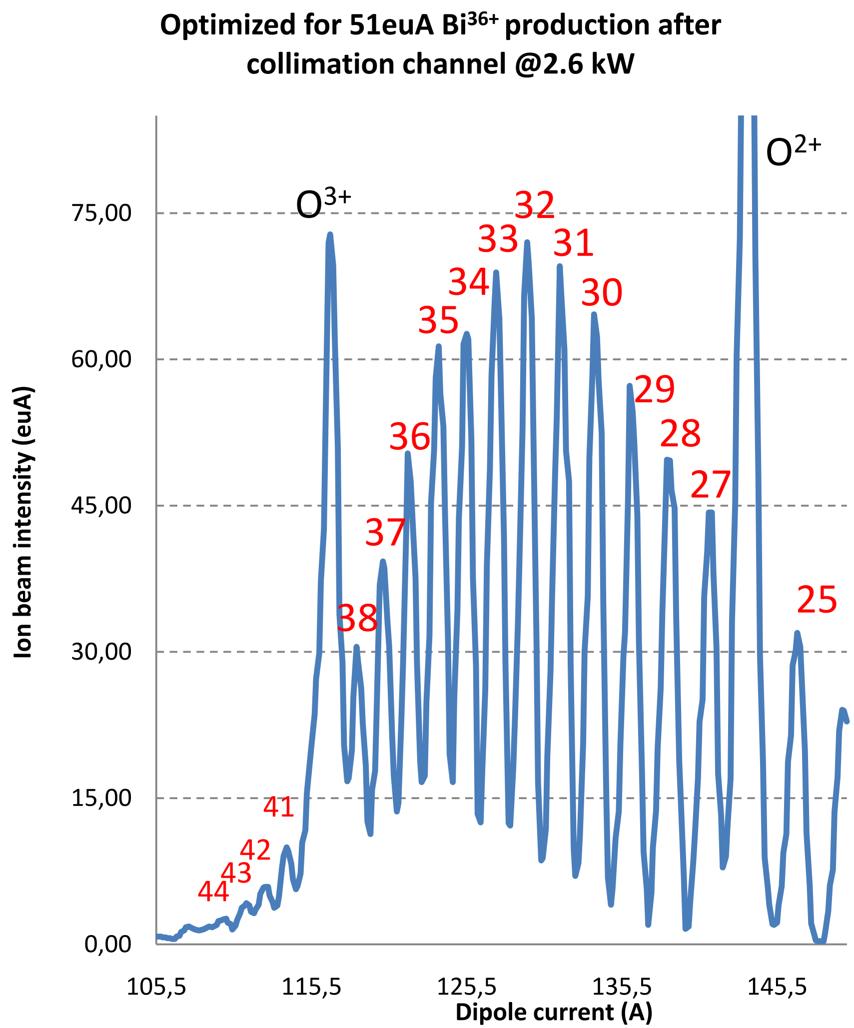
- RT source with fixed radial field
- ∅78mm ID chamber
- Smaller ECR zone and mirror length

Same power level (3.0kW) but different power density:
SECRAL→0.6 kW/L
SuSI→0.85 kW/L

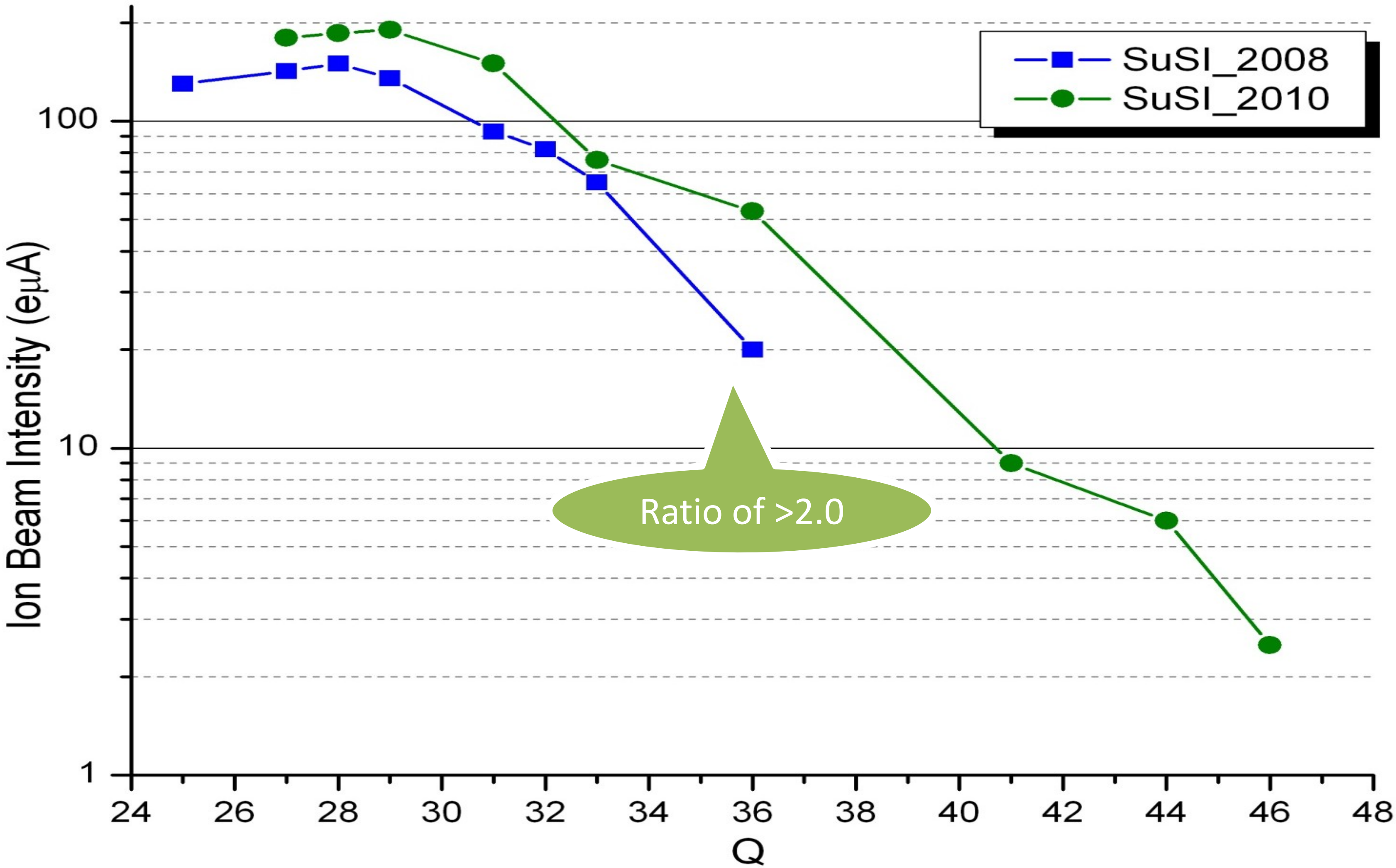
Al chamber+2-frequency heating with 0.3 kW/L

Bismuth Beams



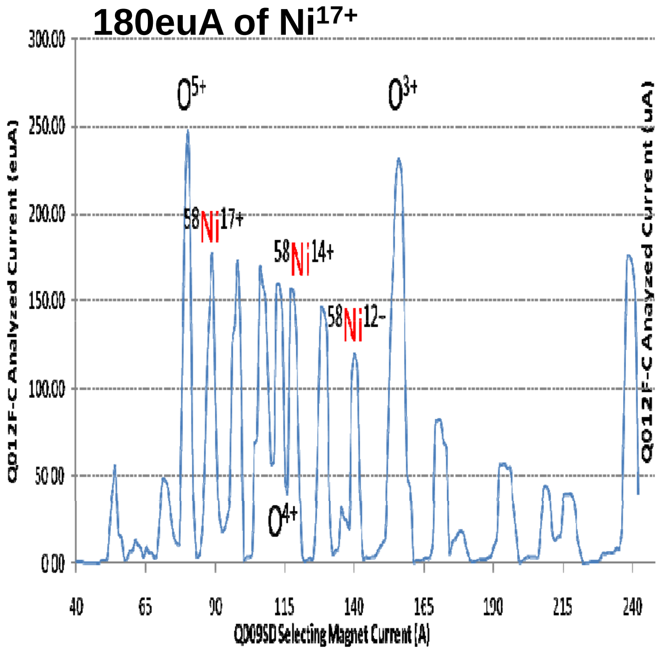


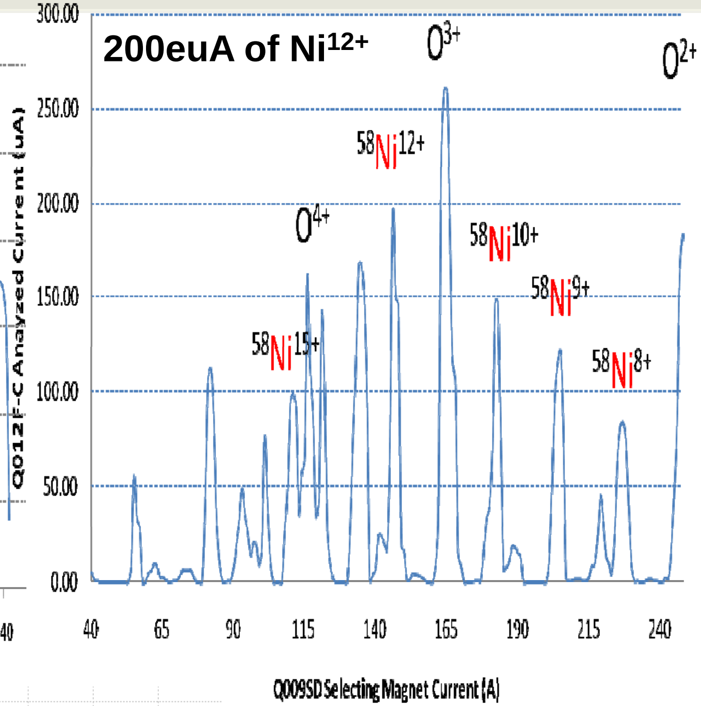
Bismuth Beams

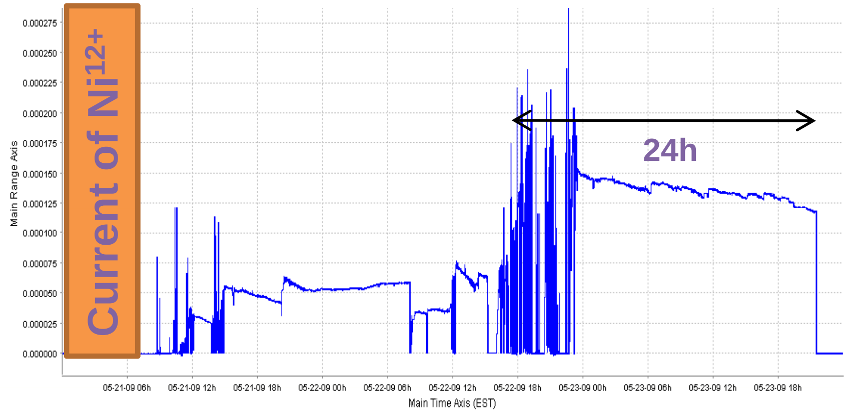


Refractory Metal Beams_2009

Stable inductive heating oven for refractory metal vapor production: Ni, Ge…



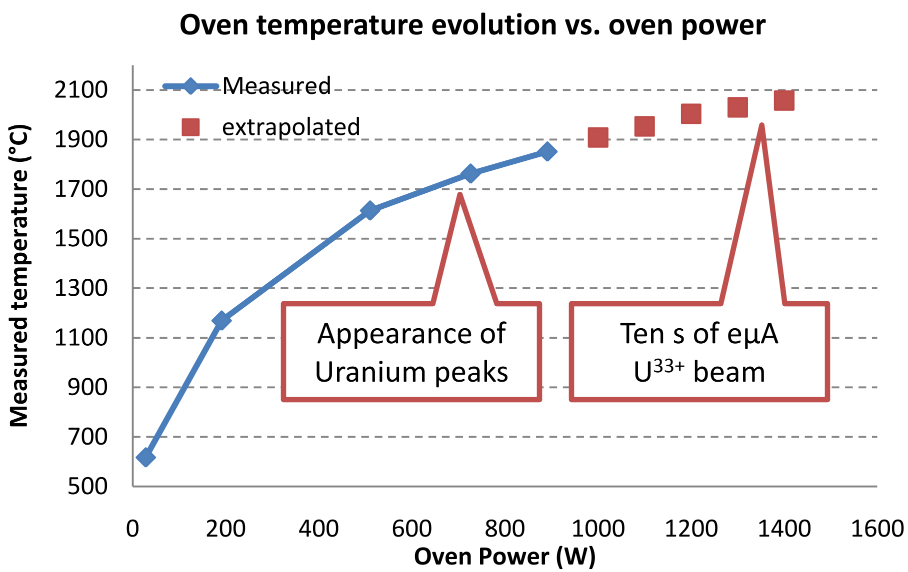


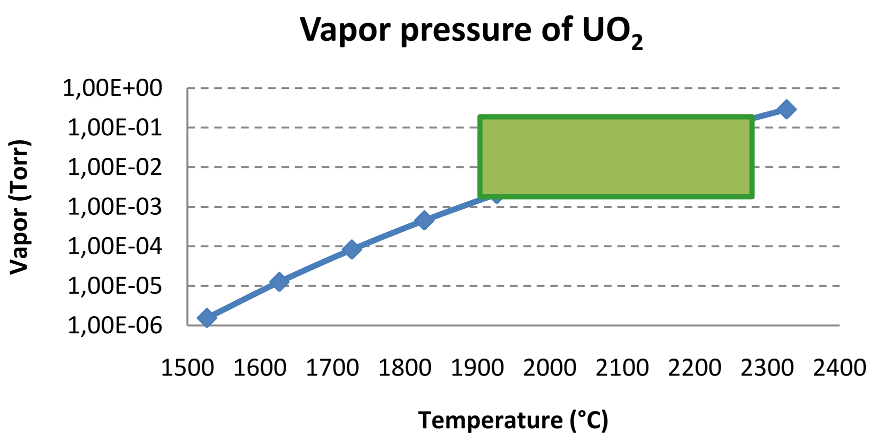


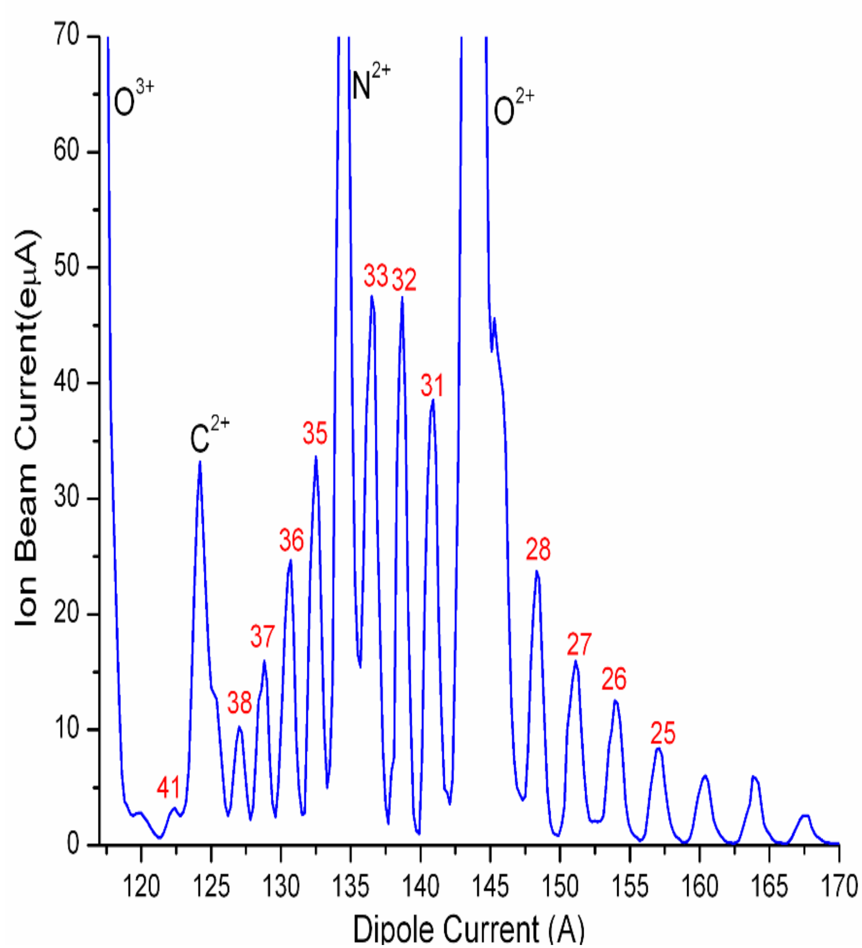
Consumption: 410 mg
60euA 24 hrs
140euA 24 hrs

Average: 6.83mg/hr

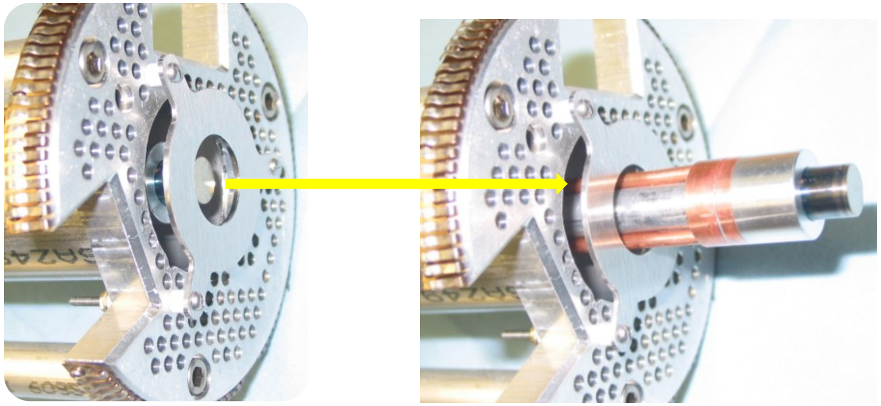
Uranium beam production with oven

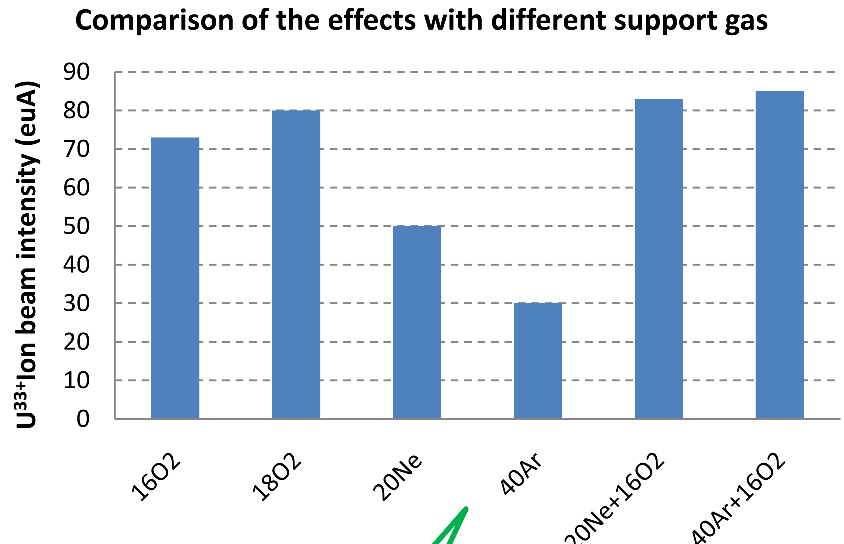






Intense Uranium Beam with Sputtering Method

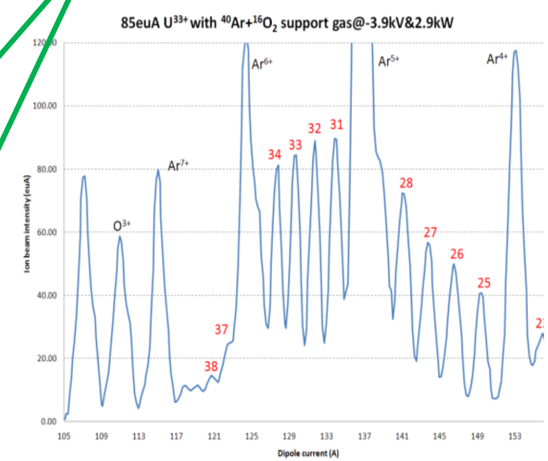




New setup features:

- ✓Injection axis centered
- ✓Axially movable 50mm
- ✓Water cooling
- ✓Bigger sample ∅10mm
- ✓Tested on SuSI

- ▪>85eμA U^{33+} has been detected;
- ▪Heavier support gas has better sputtering efficiency;
- ▪While oxygen is better for HCI production;
- ▪Typical 55%~60% transmission efficiency may account for huge beam loss.



See D. Cole's poster: MOPOT16

Conclusion and Future Plans

Conclusion

- SuSI ion source has demonstrated its reliability ;
- SuSI performances benefit from its many flexible features;
- SuSI performances are still challenging the limits of 18GHz results ;
- Power density is a big issue for large ID sources while power coupling efficiency should also be considered;
- UO_2 has been tested to produce U beams with SuSI.

Future plans

- Follow power scaling: a third 18GHz klystron amplifier to be connected to boost the power density up to 1.3kW/L;
- Follow frequency scaling: a 24GHz/10kW gyrotron amplifier project is under going;
- Improve beam transmission especially for I_0>5emA;
- Reliable beams with required brightness for FRIB.

Max. beam intensities from SuSI*

^{86}Kr	Q	I (eμA)	^{58}Ni	Q	I (eμA)
	14	500		12	200
^{129}Xe	20	350		17	180
	26	380	^{209}Bi	27	180
	27	276		28	190
	30	91		29	150
	34	22		31	76
	35	14.5		33	53
	38	3.2		36	9
	39	1.8		41	6
	42	0.95		46	2.5
	44	0.35	^{238}U	31	95
				32	95
				33	88

*Optimized for beam intensities

NSCL Support

- **Accelerator**
  M.Doleans, O.Kester, F. Marti,
  E. Pozdeyev, X. Wu, Q. Zhao

- **Mechanical Design**
  B.Arend, R. Fontus,
  D.Lawton, J. Ottarson

- **Operation**
  All Cyclotron operators: G. Humenik,
  P. Miller, D. Poe, J.Stetson

- **Ion Source Physicists**
  D. Cole, G. Machicoane,
  T. Ropponen, L. Tobos

- **Students**
  C. Zhang

- **Electronics**
  J. Brandon, K. Davidson,
  K.Holland, D Morris,
  C.Supangco, J.Vincent

- **Fabrication and assembly**
  J. Pline, J.Wagner,
  Electricians, Machinist

- **Facilities**
  S. Chouhan, J. DeKamp,
  S. Hitchcock, J. Yurkon, A. Zeller