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ECRIS2016, 28 August - 1 September, Busan, Korea

Design of new compact ECR ion source for C^{5+} production

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  - Present status of carbon-ion radiotherapy
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Clinical results of Carbon-ion radiotherapy

Carbon ion radiotherapy has 3 large advantage:

Publications
D. Schulz-Ertner and H. Tsujii, Journal of Clinical Oncology, 2, 953 (2007).
H. Tsujii *et al.*, New Journal of Physics 10, 075009 (2008).
H. Tsujii and T. Kamada, Jpn. J. Clin. Oncol. 42, 670 (2012).

A part of carbon ion radiotherapy has been covered by Japanese national health insurance since May 2016.

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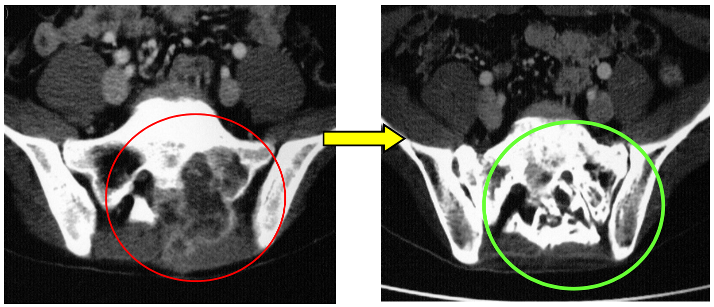
Clinical results of Carbon-ion radiotherapy

Carbon ion radiotherapy has 3 large advantage:

Better local control / survival ratios



before **5 years after**

5 years overall survival ratio in inresectable cases

46% (<500cc), 19% (>500cc)

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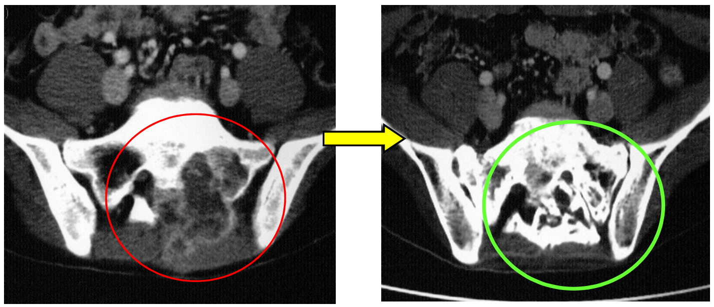

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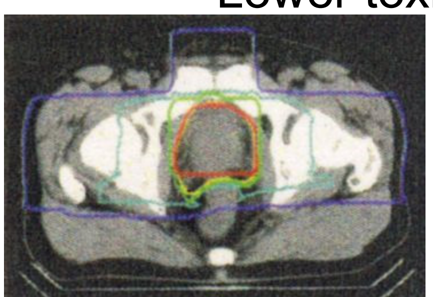
Lower toxicities



Delayed adverse reaction rate (>=G2)
- 0.3% (Rectum)
- 2.4% (Genitourinary system)

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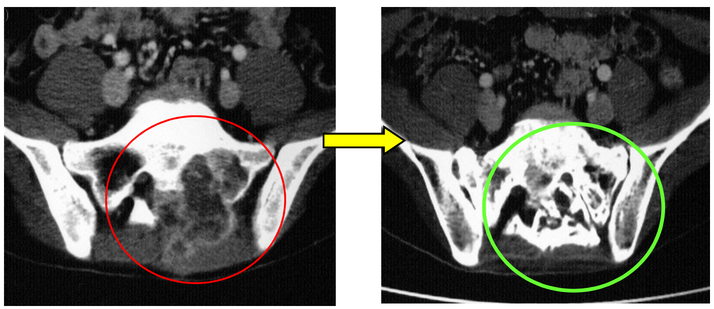


before **5 years after**

5 years overall survival ratio in inresectable cases

46% (<500cc), 19% (>500cc)

Hypo-fractionation:The treatment period can be shorten

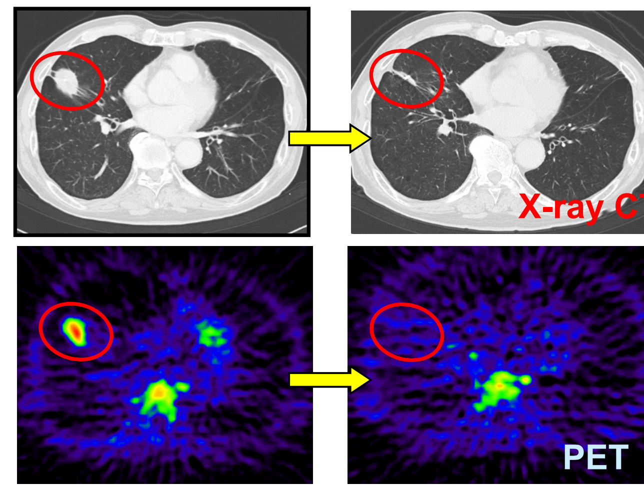
1 day treatment

1 fraction ~50.0GyE in 1 day

3 year Local control 83% (incl.28-50GyE)

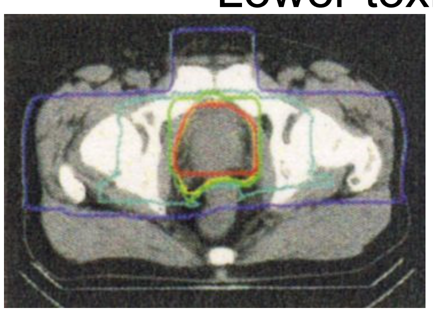
5 years survival 55% (mean age=73.9)

cause specific survival 73%



before **1 year after**

Lower toxicities



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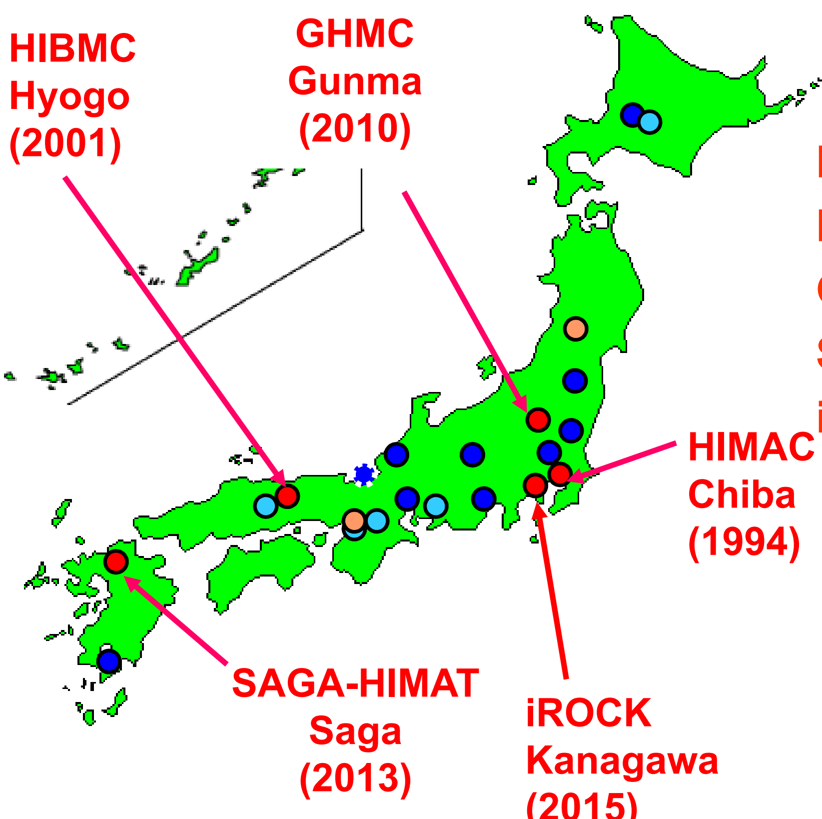
Carbon-ion radiotherapy in Japan



- Heavy ion
- Heavy ion (under construction)
- Proton (including shutdown)
- Proton (under construction)

Operation facilities:

	Period	Patients total	(in 2014)
HIMAC	(1994 – 2016.8)	10031	(794*)
HIBMC	(2005 – 2016.3)	2263	(241)
GHMC	(2010 – 2016.6)	2087	(501)
Saga-HIMAT	(2013 – 2016.7)	1492	(503)
iROCK	(2015.12 –)	-	(-)
	sum	15873	(2039)

*from Apr. to Mar.

Under construction:

Osaka (plan 2018 –)

Yamagata (plan 2019 –)

Other plans:

Gifu, Okinawa, …

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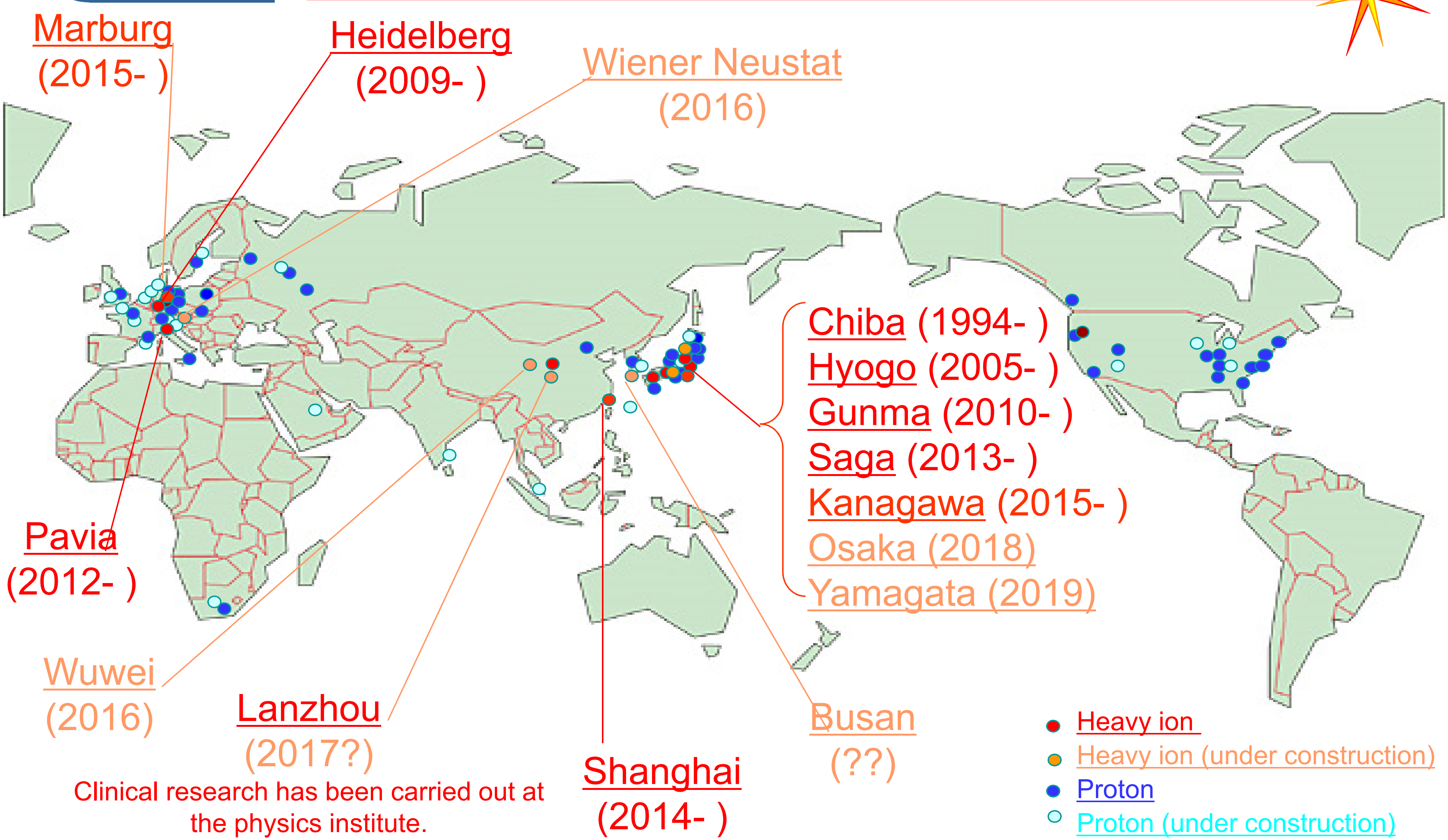
Charged particle radiotherapy worldwide



Study of new Carbon-ion radiotherapy facility

In order to reduce the cost of the injector Linac,

Lower RF power (tube -> semiconductor amp.)

Manufacturing of cavity (reduce the initial cost)

-> Ion source produces the highly charged ions (5+, 6+).

However, it is difficult to separate C^{6+} from other ions (nitrogen and oxygen).

-> Production of C^{5+} ion.

Requirement and design concept of compact ECR ion source for carbon therapy

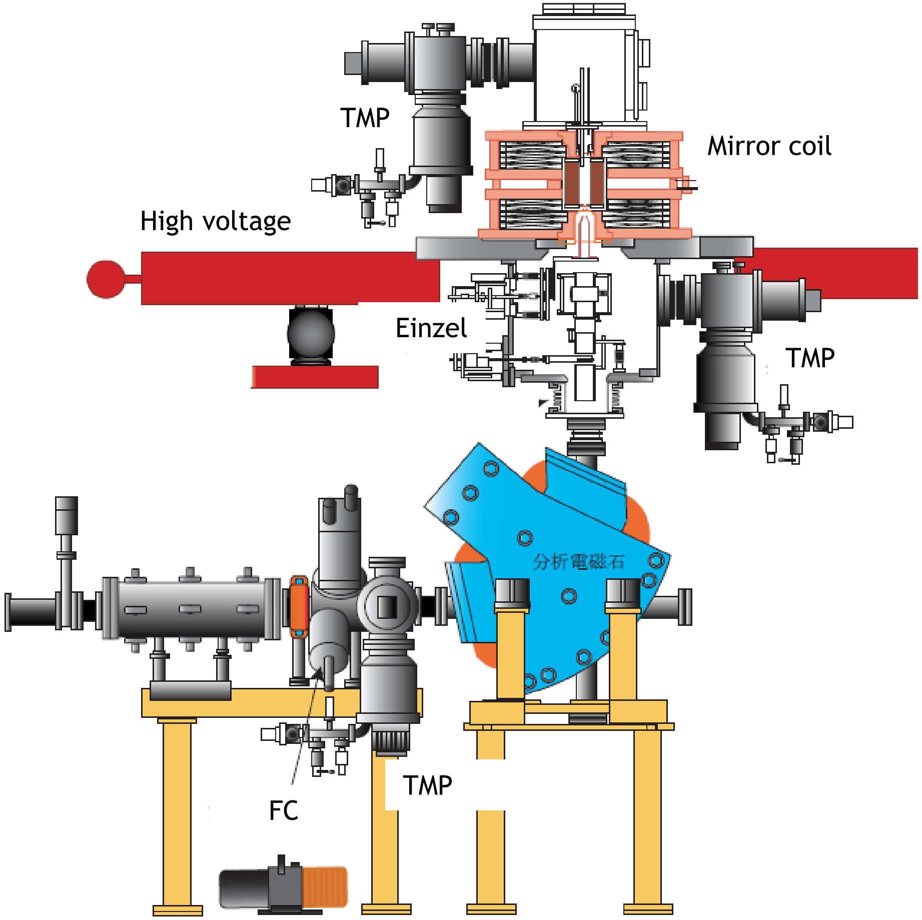
Design concept of compact ECR ion source for medical facility

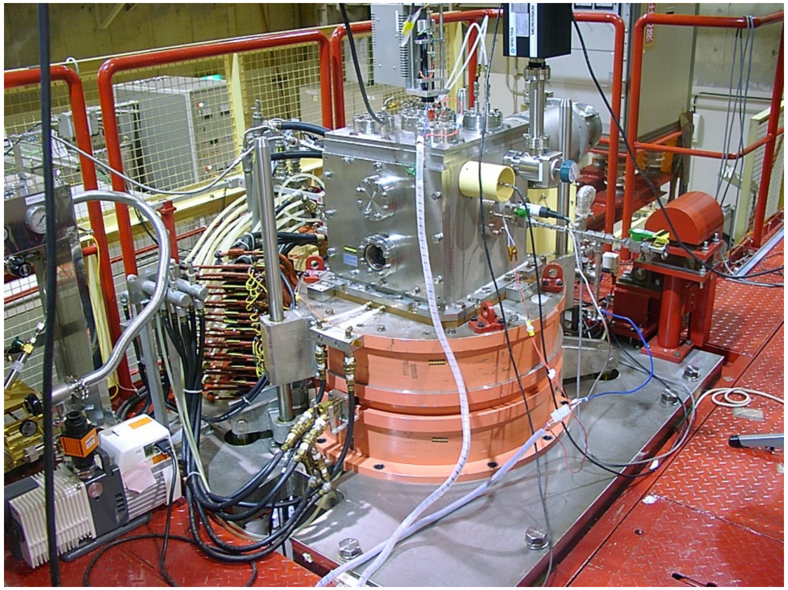
1. Enough C^{5+} intensity for medical use
2. Long lifetime and good stability
3. Easy operation and easy maintenance
4. Compactness

Requirement values of ion source for medical facility

1. Beam intensity: 300 eμA, C^{5+}
2. Emittance: 1.0 π mm mrad (normalized)
3. Lifetime: one year
4. Stability: less than 10% (beam fluctuation)

18 GHz NIRS-HEC



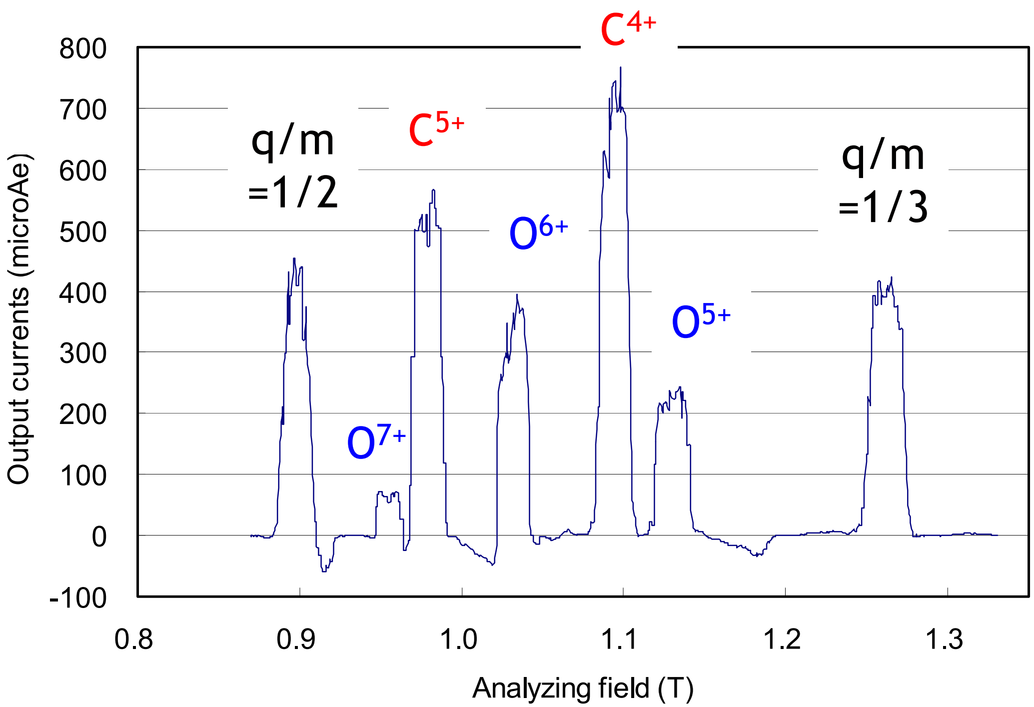


KPA: 18 GHz, 1400 W

TWTA: 17.10 – 18.55, 1200 W

Extraction voltage : 60 kV max.

18 GHz operation for Carbon ions



<u>Operation parameters</u>

optimized C^{5+} at after-grow

t_{mw} =20ms

f_1=18.00GHz, P_1=1050W

f_2=17.843GHz, P_2=1200W

B_{inj}=1.21T, B_{ext}=0.72T

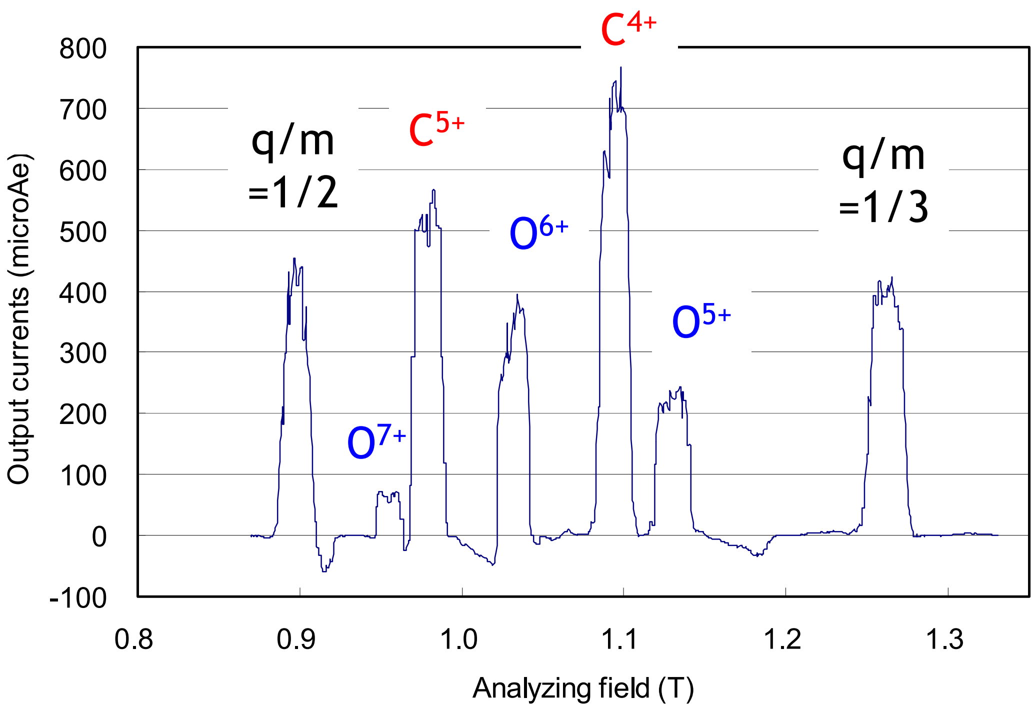
V_{ext}=30kV, d_{ext}=18mm

S_{CH4}=0.070cc/min atom

P_{inj}=5.0x10^{-5}Pa

Peaks of oxygen appeared due to residual gas from the previous measurement. This was not suitable condition for highly charged carbon ions.

18 GHz operation for Carbon ions



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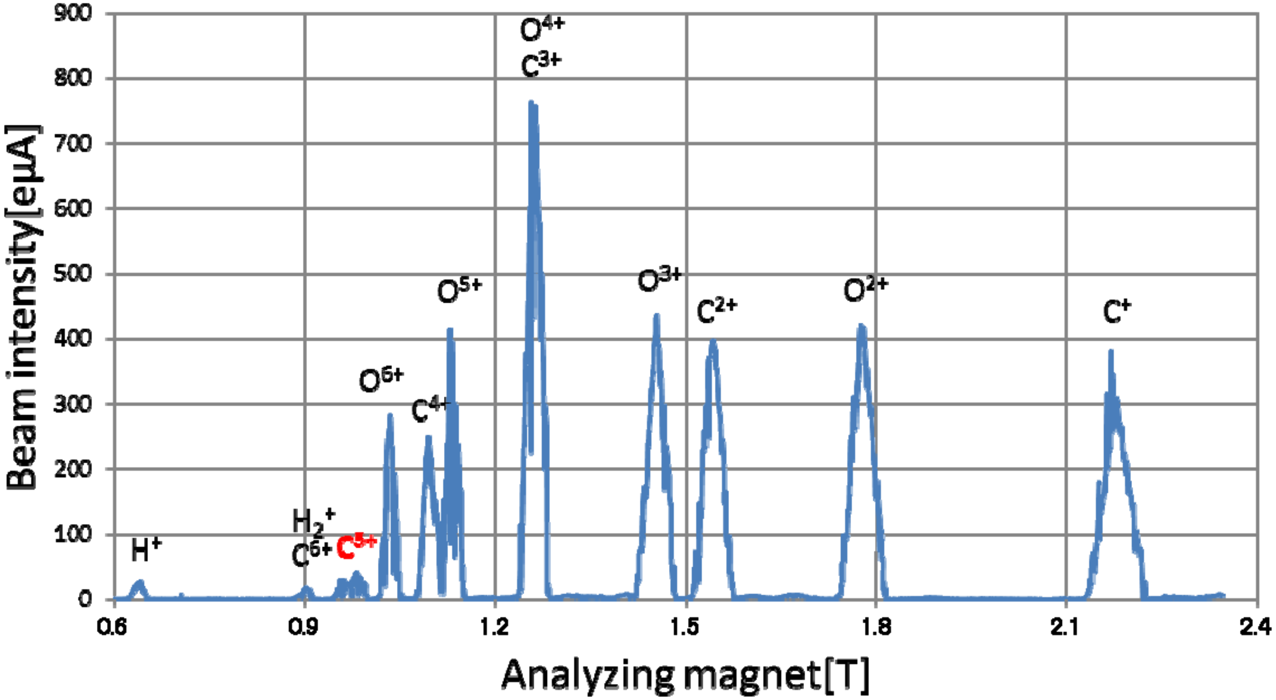
Optimization of the mirror field for C^{5+} production at 18 GHz NIRS-HEC

Operation parameters

- Gas (CO_2, CH_4)
- Microwave frequency: 14 - 15.02 GHz
  Microwave power: 5 - 300 W
- Upstream coil current : 610 - 840 A
- Downstream coil current : 360 - 660 A
- Microwave Operation mode : pulse, 2.4 Hz, 10 msec
- Extraction voltage: 30 kV

Charge state distribution (CO_2)



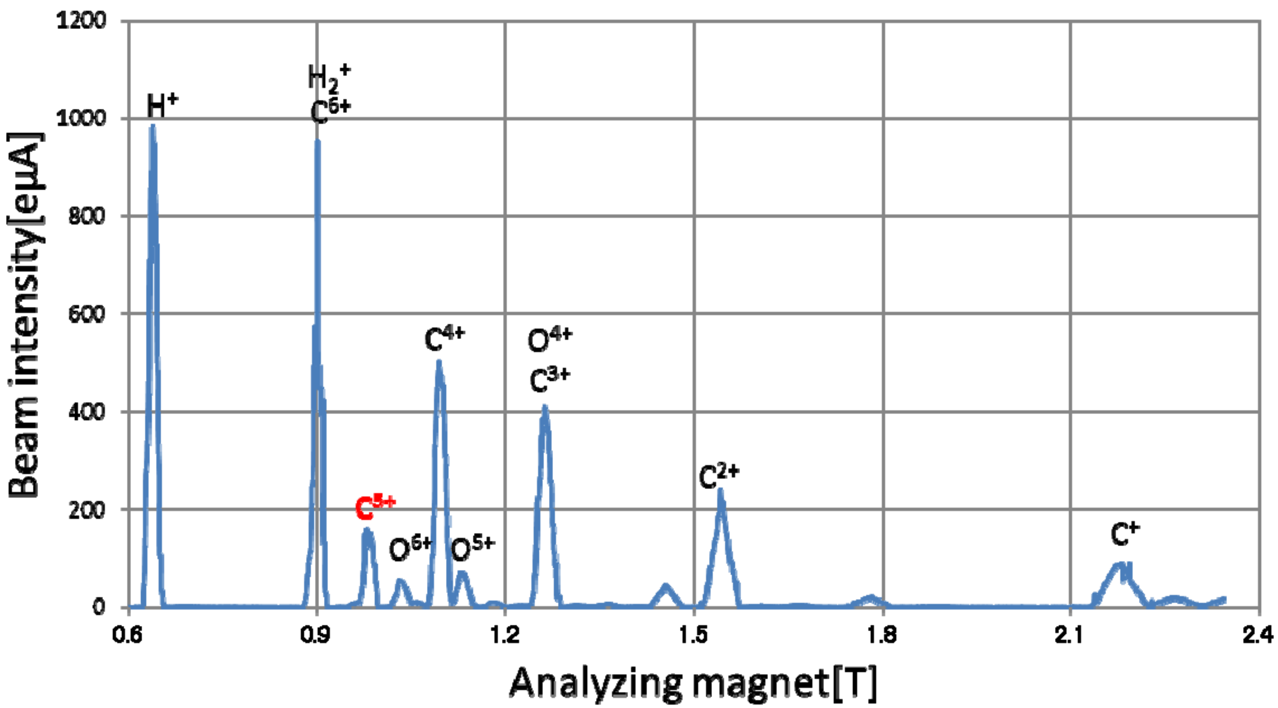
Gas: CO_2
Vacuum pressure (inj): 7.4E-5 Pa
Vacuum pressure (ext): 5.2E-5 Pa

Microwave : 14.6 GHz, 300 W
Operation mode:
pulse, 2.4 Hz, 10 msec
Upstream coil: 840 A
Downstream coil: 530 A

Disk voltage: -800 V
Extraction voltage : 30 kV

36 eμA @ C^{5+}

Charge state distribution (CH_4)



Gas: CH_4

Vacuum pressure (inj): 8.7E-5 Pa

Vacuum pressure (ext): 6.5E-5 Pa

Microwave : 14.6 GHz, 300 W

Operation mode:

pulse, 2.4 Hz, 10 msec

Upstream coil: 840 A

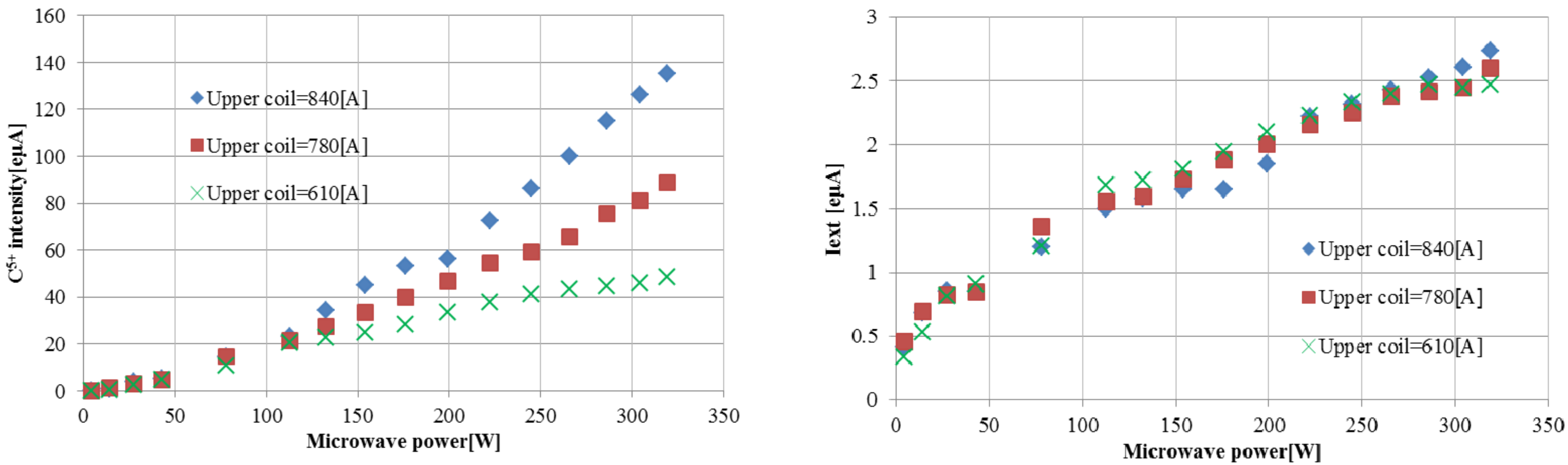
Downstream coil: 500 A

Disk voltage: -550 V

Extraction voltage : 30 kV

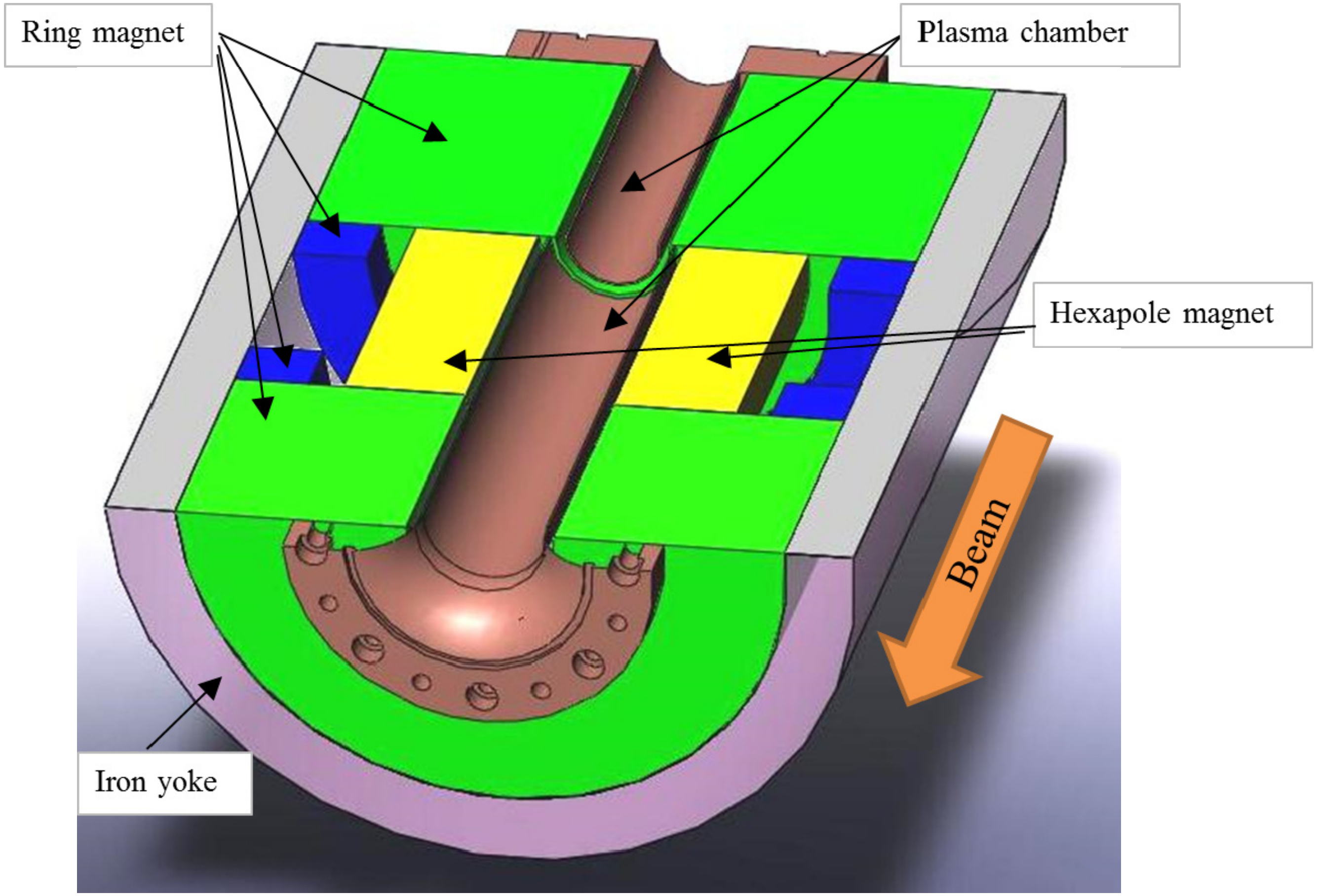
160 eμA @ C^{5+}

Microwave power dependence



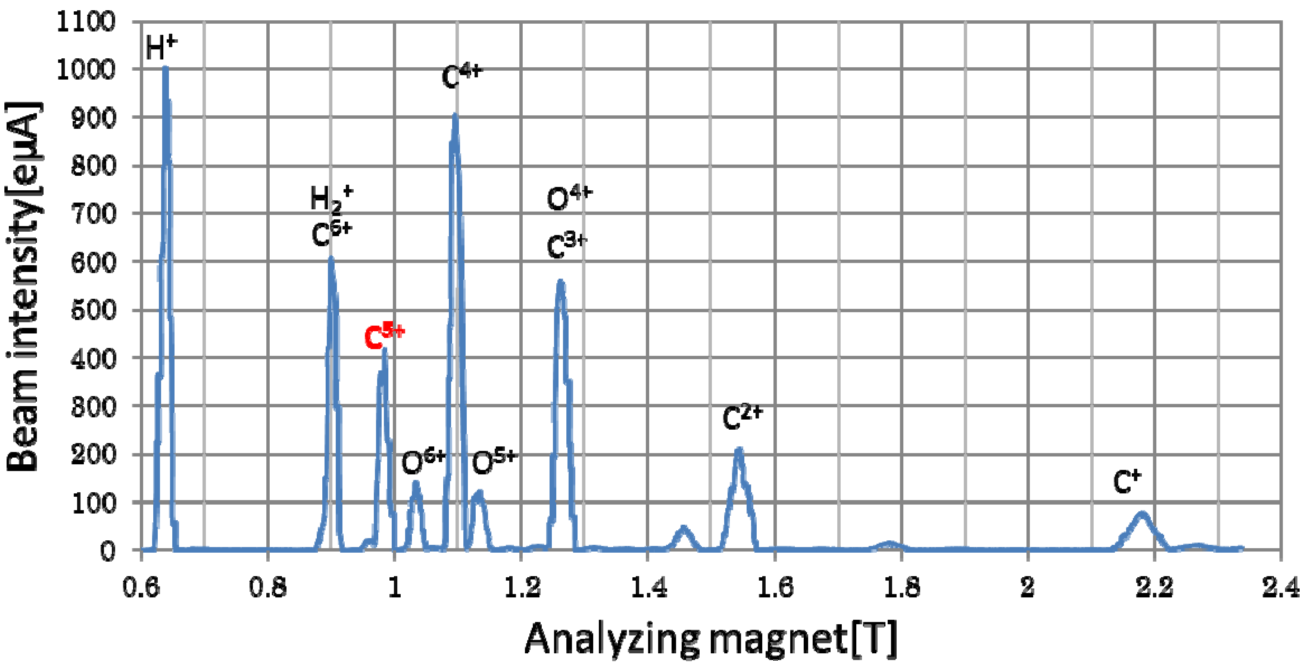
Higher magnetic field is better for C^{5+} production
Not enough microwave power (300 W)
We have to take other dependences under the high power.
->14.0 – 14.5 GHz, 600 W, TWTA

Design of permanent magnets



Coil current of 840(inj), 500(ext) A

Charge state distribution (C_4H_{10})



Gas: C_4H_{10}

Vacuum pressure (inj): 1.3E-4 Pa

Vacuum pressure (ext): 5.3E-5 Pa

Microwave : 18.0 GHz, 1050 W

Operation mode:

pulse, 2.4 Hz, 10 msec

Upstream coil: 840 A

Downstream coil: 500 A

Disk voltage: -600 V

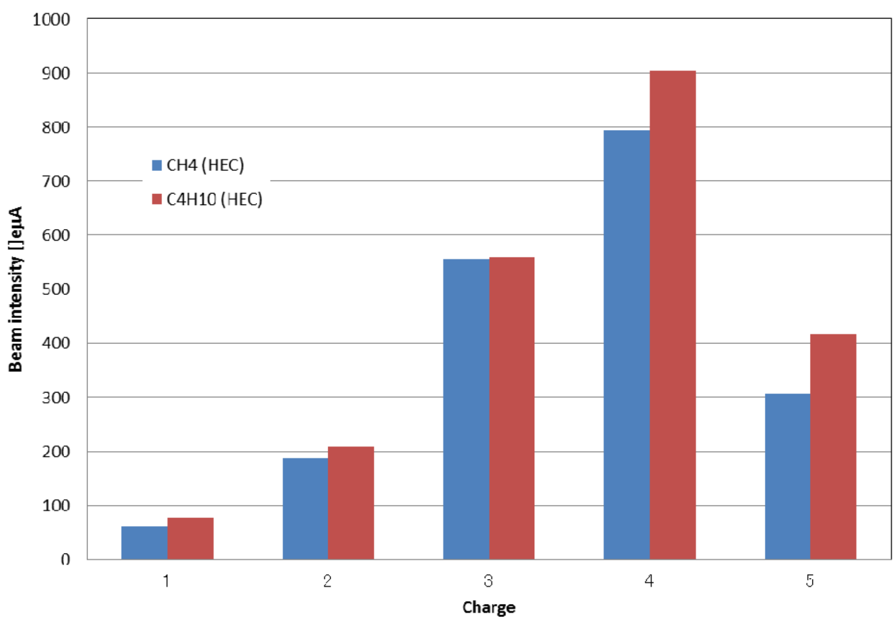
Extraction voltage : 30 kV

410 eμA @ C^{5+}

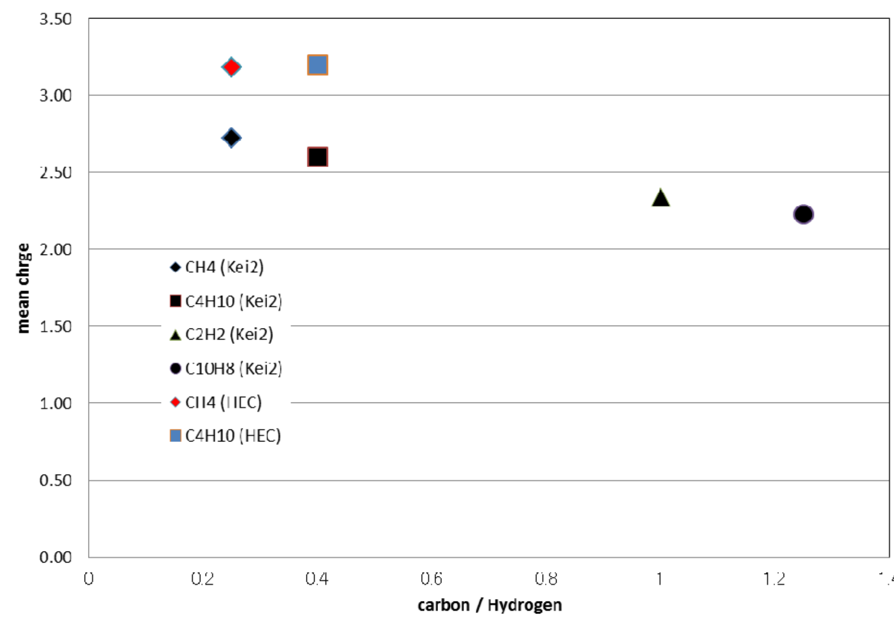
CSD and mean charge (18 GHz)

CH_4 is used for medical use at C-ion RT facility
-> C_4H_{10}

CSD of carbon



Mean charge



Conclusion and next step

Conclusion

- Beam intensity was 160 eμA (14.6 GHz, 300 W, CH_4)
- Microwave power of 300 W was not enough
- Maximum intensity of C^{5+} was 410 eμA (18 GHz, 1050 W, C_4H_{10})

Next step

- Same dependences at higher microwave power (next week)
- Design of permanent magnet
- Long run test (C_4H_{10} at Kei2)
- Other gas (C_2H_2)

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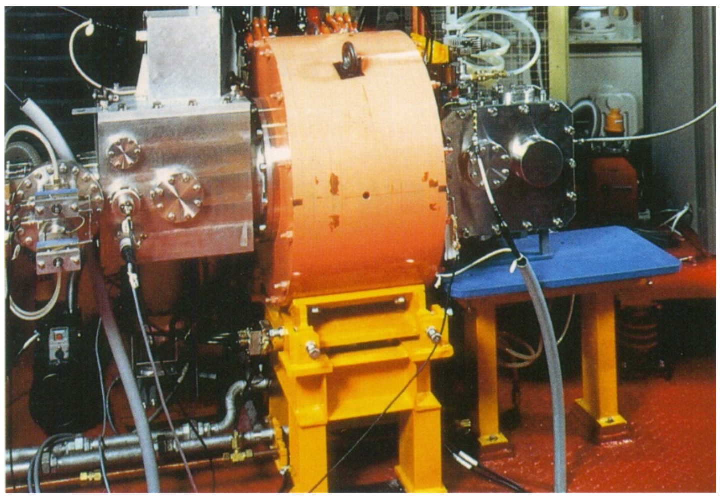
Thank you

Design of the mirror field for C^{4+} production

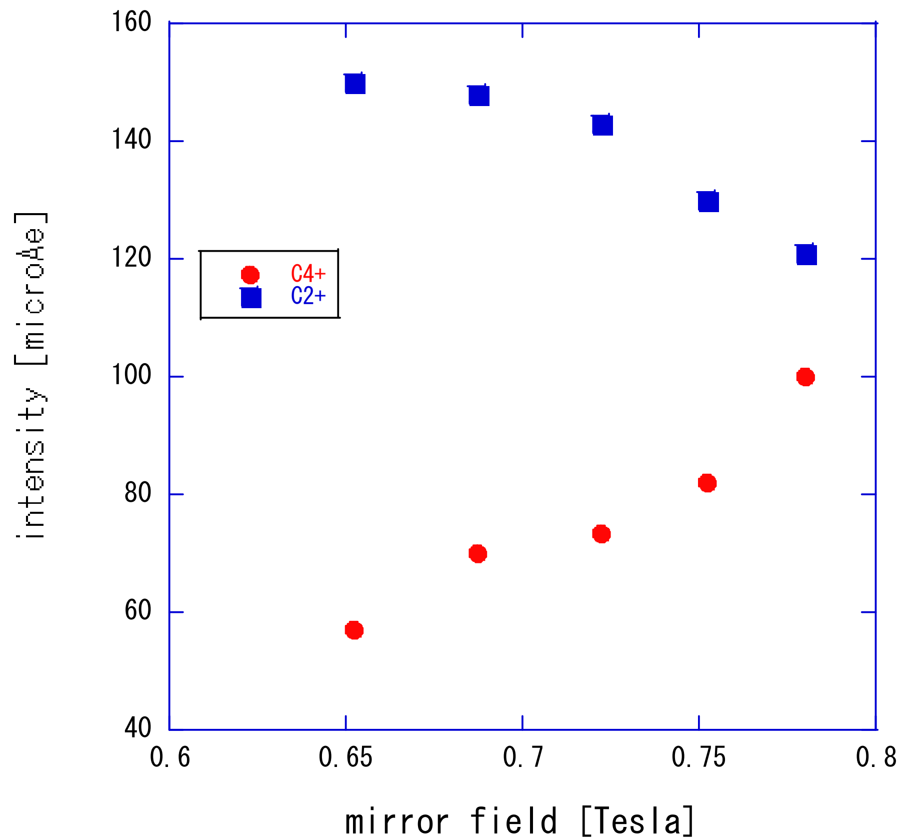
Optimization of the mirror field for C^{4+} production at 10 GHz NIRS-ECR



Gas : CH_4

RF : 10 GHz, 300 W

Extraction voltage : 22 kV



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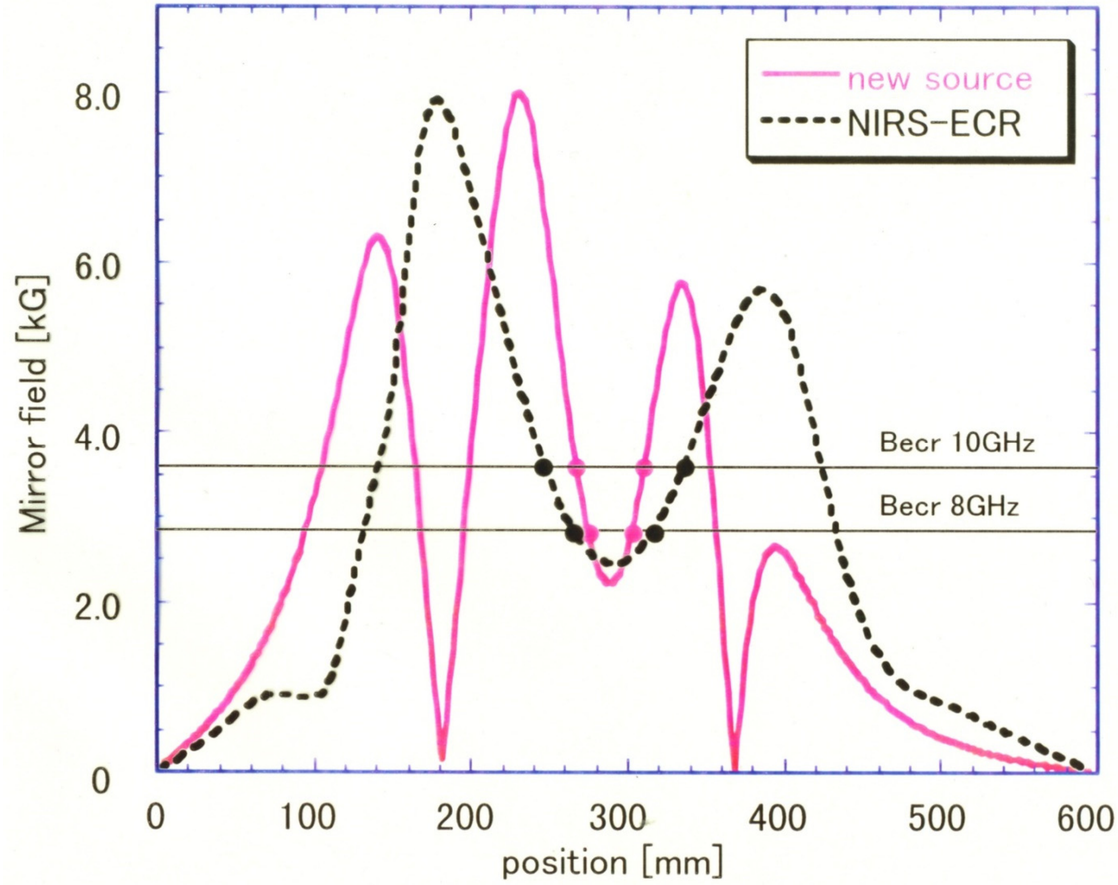
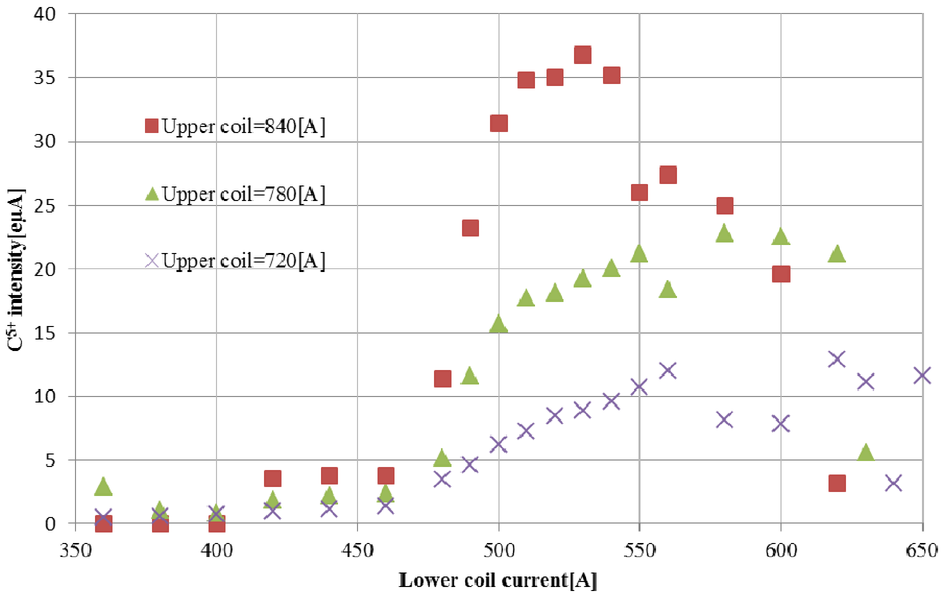
Mirror field for Kei2



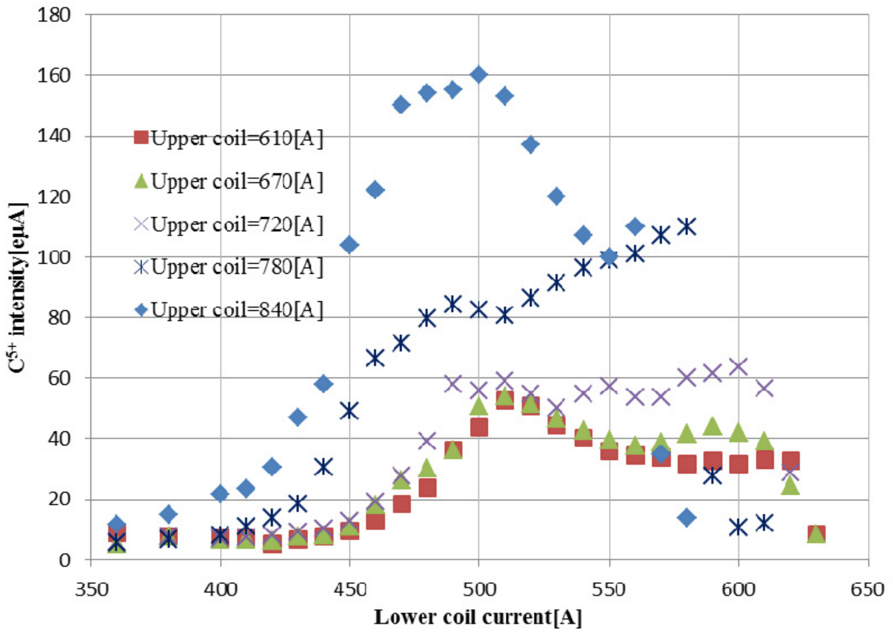
Mirror field dependence

CO_2



840 A and 530 A

CH_4



840 A and 500 A

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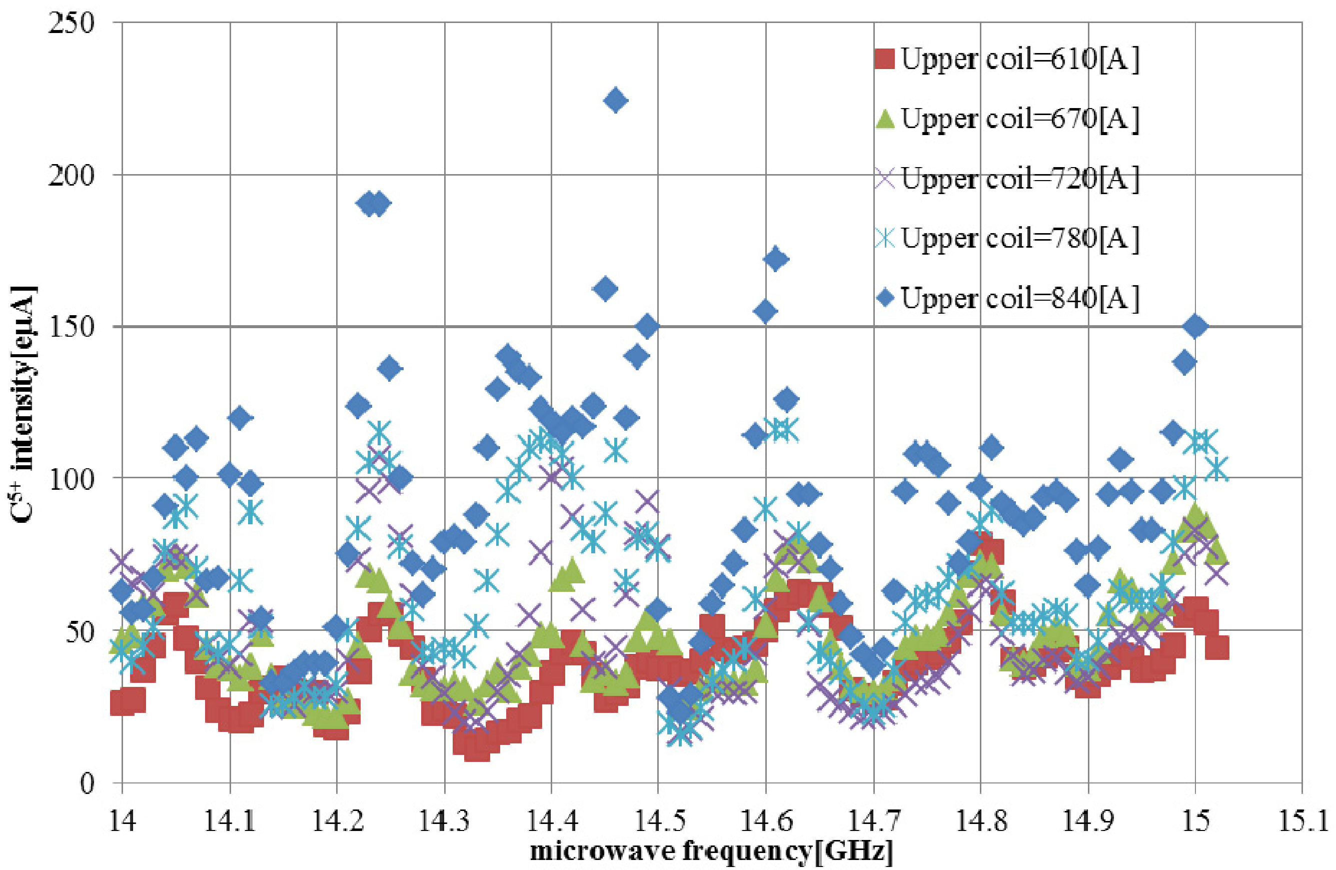
Microwave frequency dependence



Gunma University Heavy Ion Medical Centre (GHMC)