Beam Extraction Results with KAERI 14.5 GHz ECR Ion Source

Byung-Hoon Oh[1*], Chang Seog Seo[2], Dae-Sik Chang[1], Cheol Ho Lee[1], Jeong-Tae Jin[1], Tae-Seong Kim[1], Sang-Ryul In[1], Kwang-Won Lee[1], Seung-Ho Jeong[1], Churl-Kew Hwang[1], and Eun-San Kim[2]

[1]*Korea Atomic Energy Research Institute, Daejeon, Korea*

[2]*Institute for Basic Science, Daejeon, Korea*

KAERI 한국원자력연구원 Korea Atomic Energy Research Institute

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- Short introduction on my another today's POSTER
- Fabricated KAERI 14.5 GHz ECR ion source
- ECR plasma characteristics with hard X-ray spectrum
- Beam experimental results
- Upgrade plan and Summary

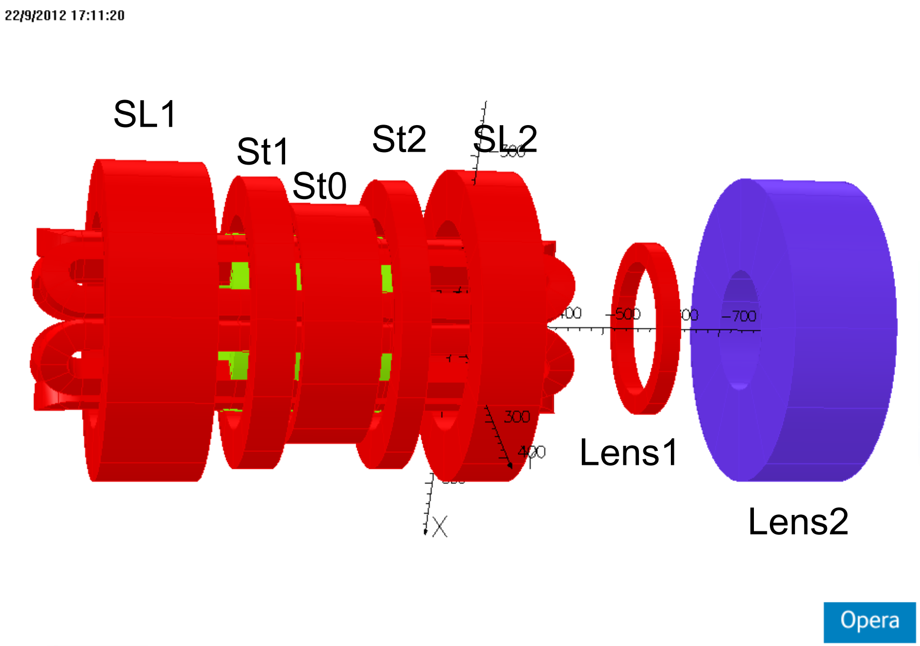
Conceptual Design of 28 GHz ECR Ion Source

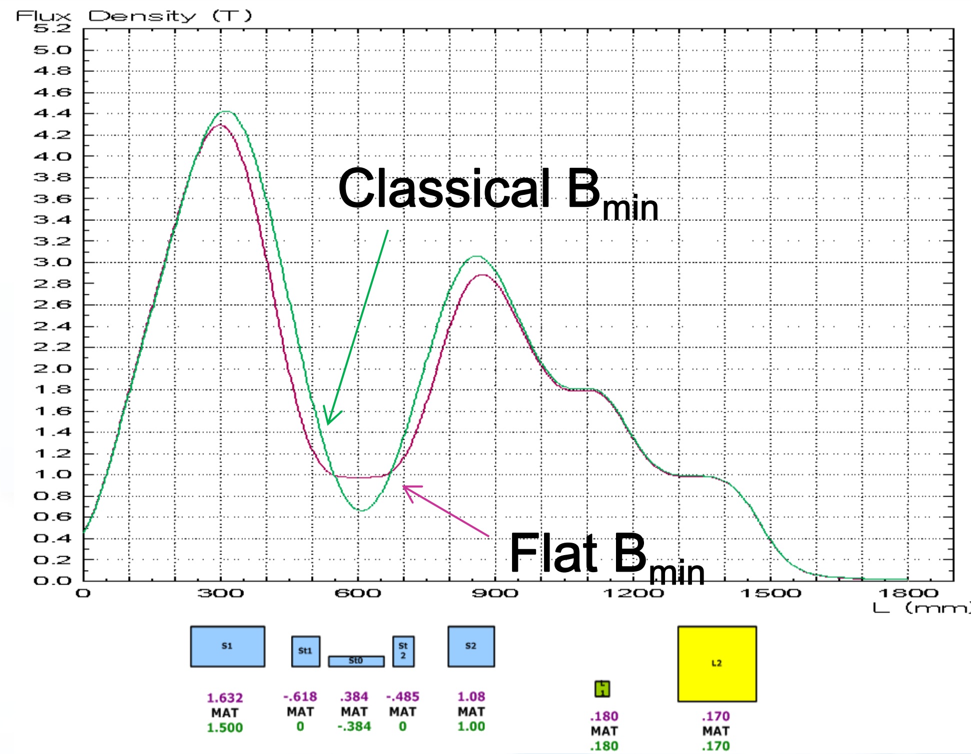
- A heavy ion accelerator project is launched in Korea to produce wide range of rare isotopes, and for this accelerator a superconducting ECR ion source will be developed.

- Based on the proven technology, a 28 GHz superconducting ECR ion source has been conceptually designed to produce wide range of different ion beams from proton to uranium in high quality and high current beam.

- Main parameters
  - beam current: $U^{34+} + U^{35+}$ > 400 μA (conservative)
  - $B_{z,entrance}$/ B_r/ $B_{z,exit}$: > 4.0T/ 2.2T/ 3.0T
  - beam extraction voltage: 30 keV

Designed ECRIS magnets and field structure





- Five solenoids for B_{min} control
- Saddle type winding for Sextupole
- Two solenoid lens
  - one in cryostat
  - the other is outside

- The graph shows two axial field configuration
  - one for classical B_{min} mode
  - the other for flat B_{min} mode

- Today's POSTER on this design is TUPP16;

  "The conceptual design of 28 GHz superconducting ECRIS for Korea Rare Isotope Accelerator"

- Please give your comments especially on
  - double solenoid lens system
  - five solenoid coils for B_{min} layer control
  - X-ray heat loads
  - and any other points.

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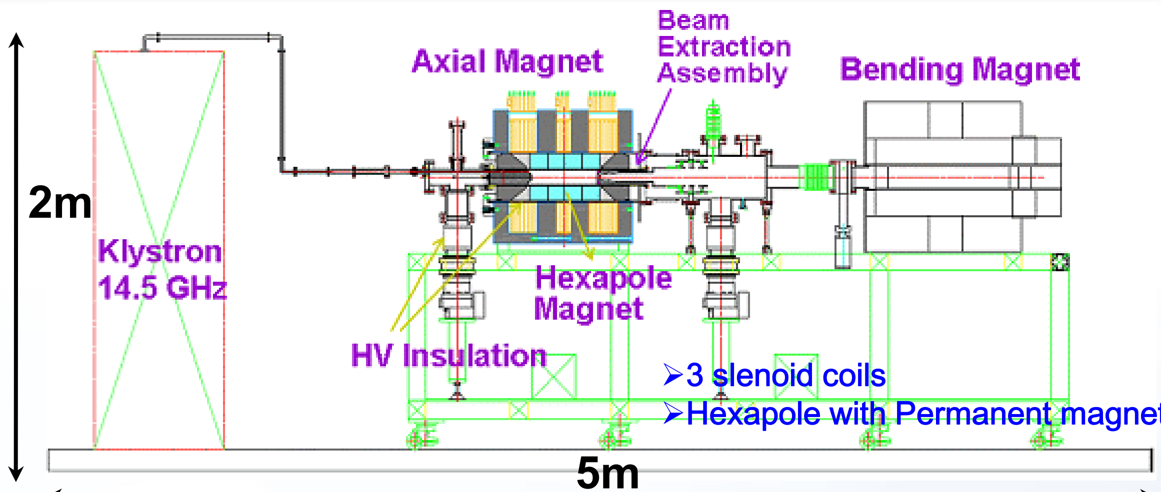
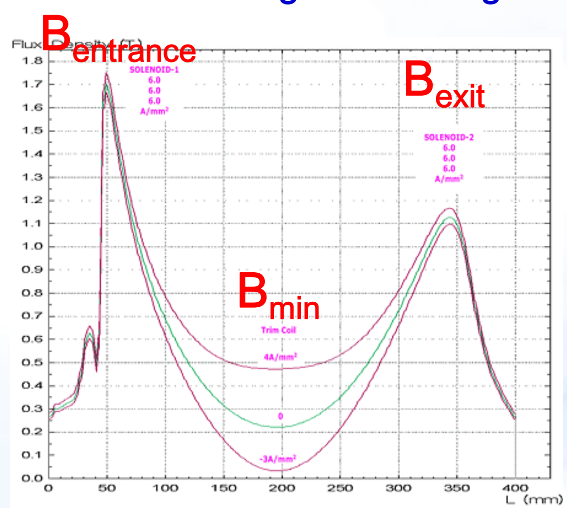
Designed and Fabricated KAERI 14.5 GHz ECRIS

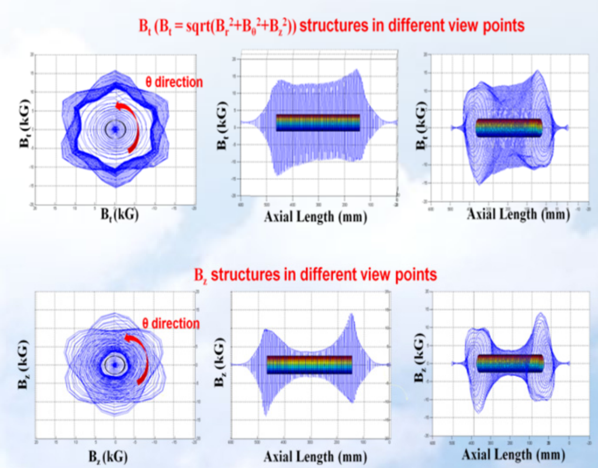
Device Parameters	EM-type
Frequency	14.5 GHz
Power	2.0 kW
B_{ECR}	0.52 T
$B_{entrance}$	1.7 T
B_{exit}	1.1 T
$B_{r,\,max}$	1 T
L_{ECR}	90 mm
V_{plasma}	85 cm^3
$ID_{chamber}$	68 mm
$L_{chamber}$	320 mm
D_{ext}	8 mm
V_{ext}	20 kV
I_{C6+}	20 eμA



Drawing of the designed KERI ECR ion source

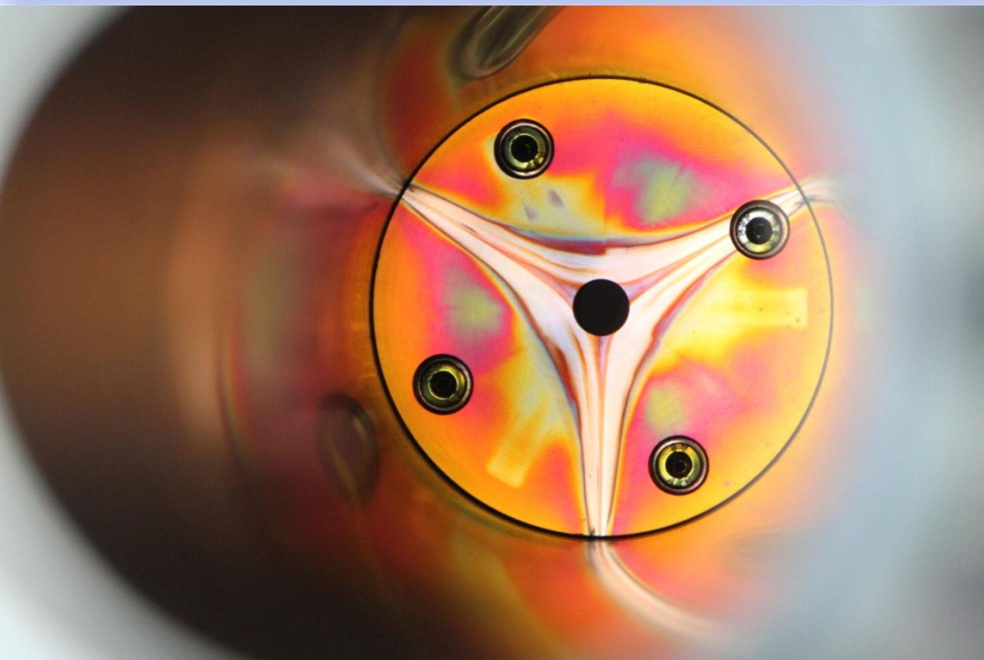


B_{min} control by trim coil current



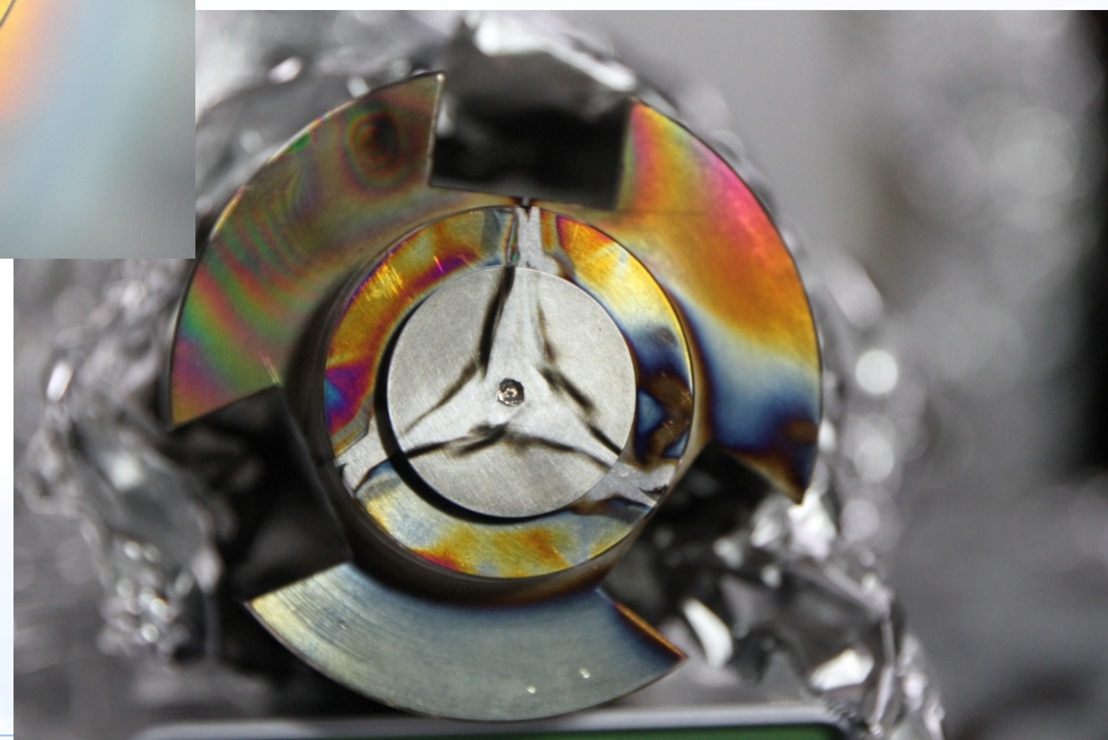
Measured magnetic field structure

Footprints inside the KAERI 14.5 GHz ECRIS chamber

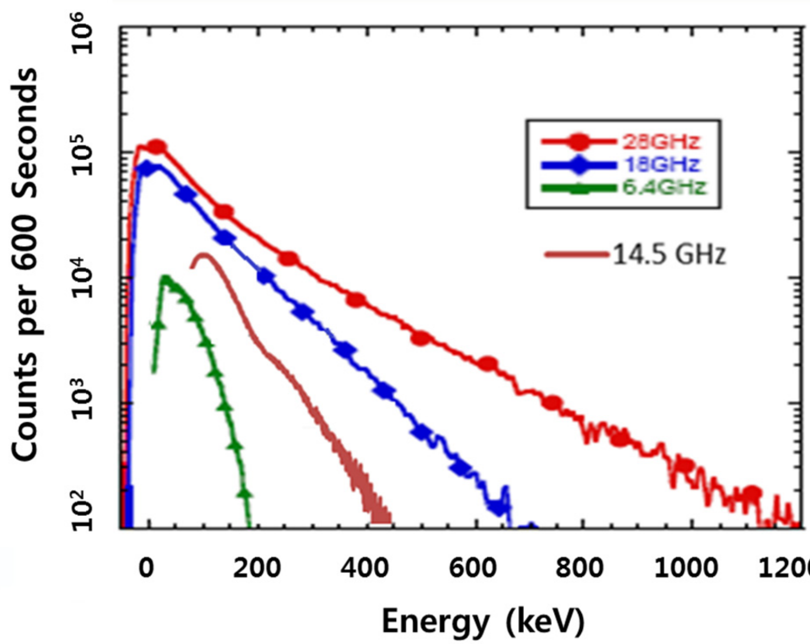


At the beam extraction plug

At the RF input plug



Compared X-ray spectrum with other machines



- The slope of the hard X-ray energy spectrum in log scale from ECR plasma is closely related with electron temperature.
- USA team has reported the above X-ray spectrums from VENUS and other 6.4 GHz ECR ion source, and I added my 14.5 GHz data on this graph.
- KAERI source spectrum, gathered at the outside of the source and therefore most of the low energy X-rays be absorbed at the source structure, shows a good performance as a 14.5 GHz ECR ion source.

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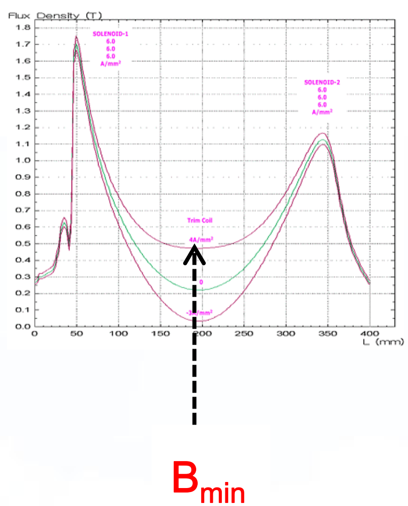
- Even though the tools to measure the plasma characteristics of an ECR ion source is very limited, X-ray spectrum is one of them.

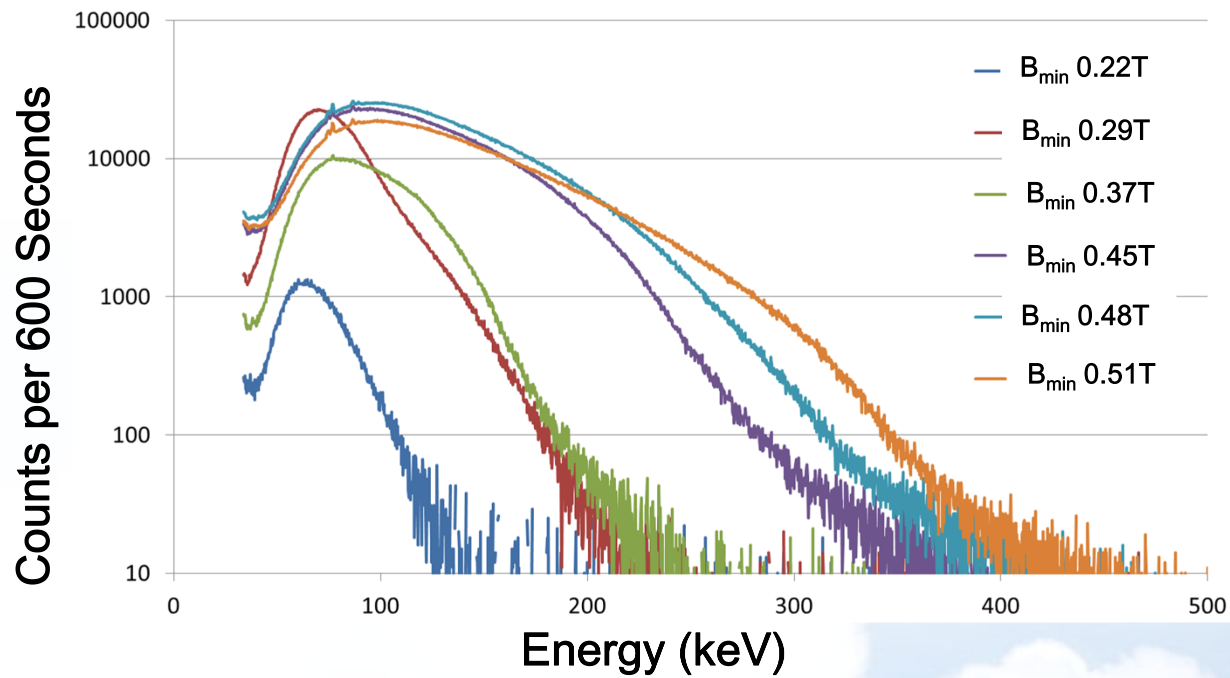
- The X-ray spectrums depending on different operation condition could tell us something on ECR plasma characteristics of the ion source.

- We measured the energy spectrums depending on different operation conditions such as;
  - Trim coil current or B_{min}
  - RF input power
  - Gas pressure
  - Solenoid coil current or $B_{entrance}$

- These data are very helpful in finding out the optimum operation conditions of the ECR ion source.

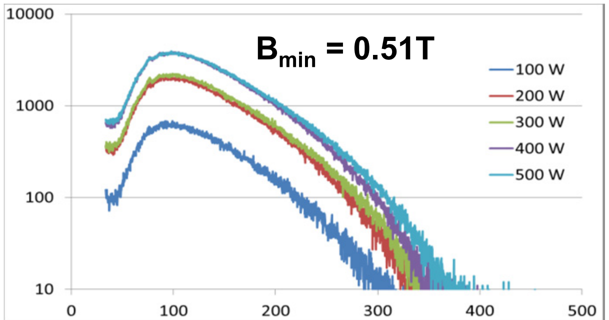
The X-ray energy spectrum depending on B_{min}

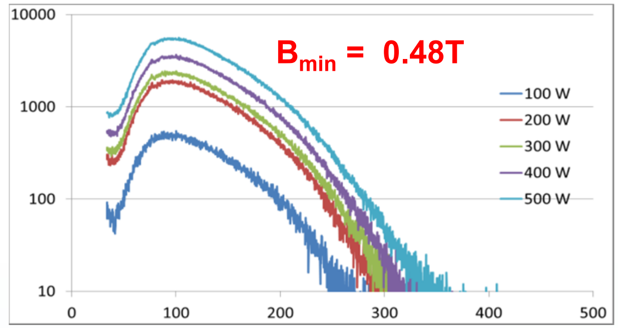


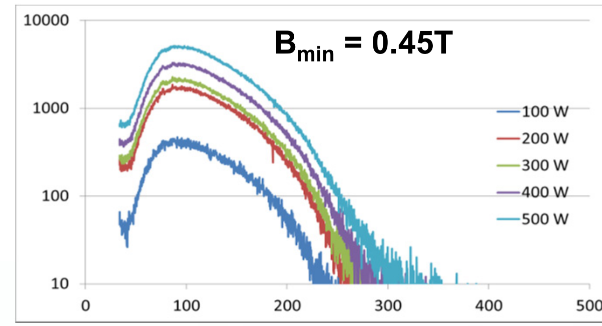


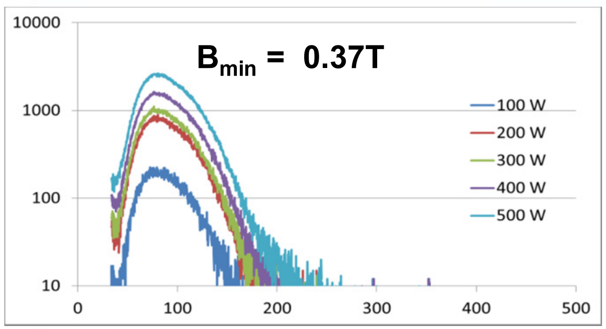
- As B_{min} approaches to B_{ECR}, the energy spectrum is broaden and total counting rate increases, and in some high energy region the increasing rate is very high.
- It means that effective electron heating could be made when B_{min} is controlled near B_{ECR}.

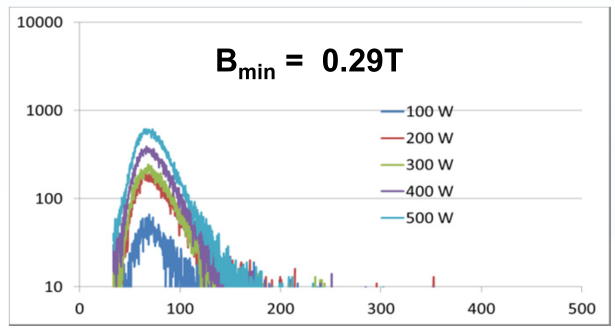
The X-ray energy spectrum depending on RF input power





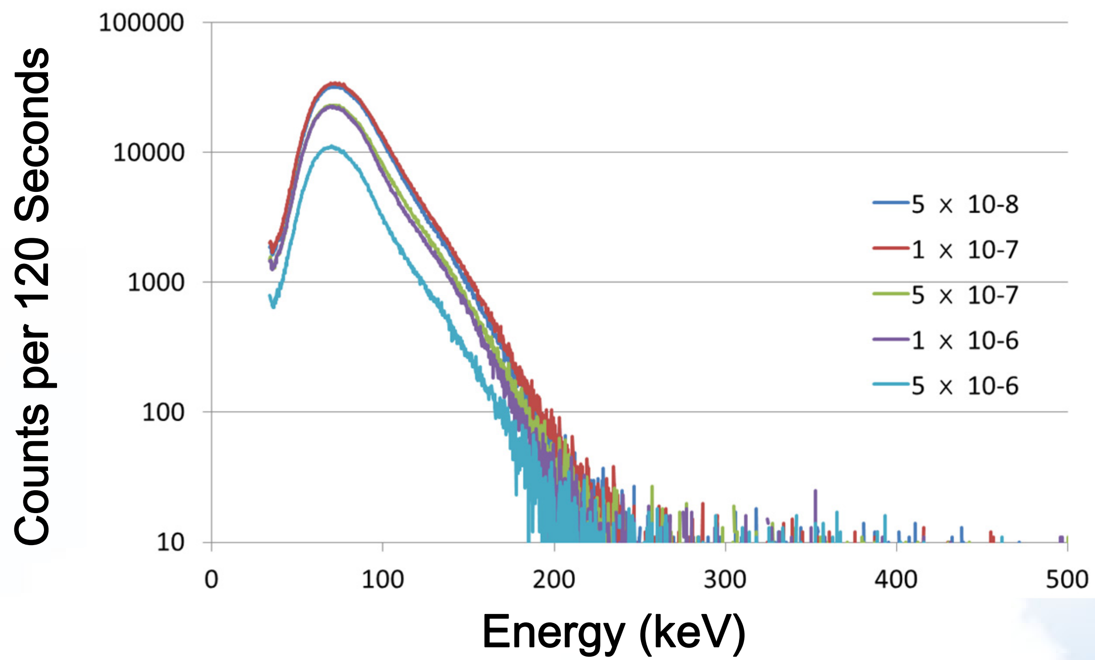






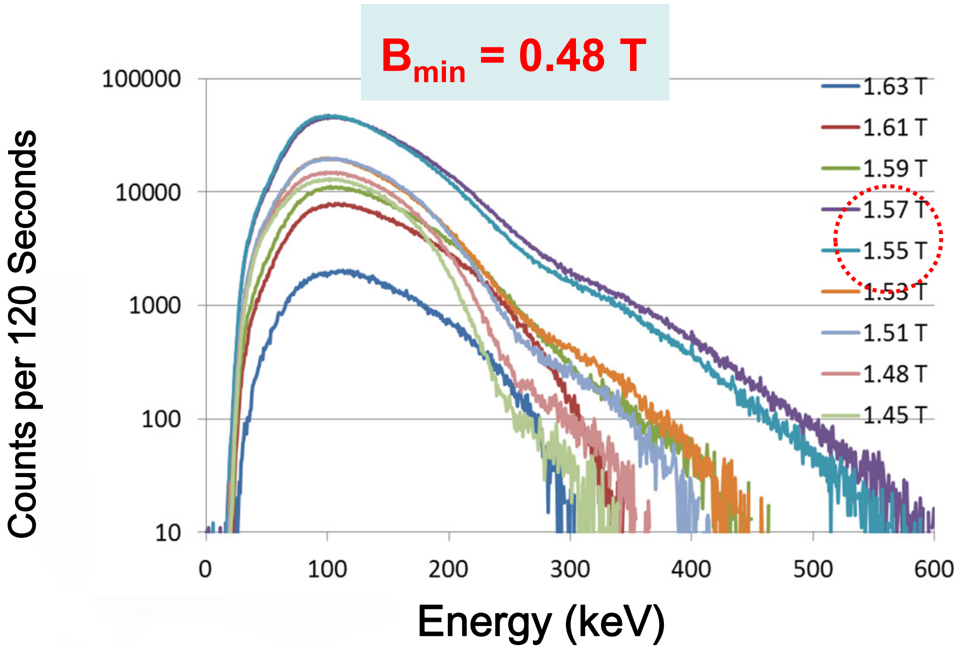
- As RF power increases, the X-ray spectrum is broaden and total count rate increases.
- But the overall shape of the distribution of the spectrum at high energies does not change much with RF power.
- It is expected that to get high energy electrons as much as possible, RF power should be matched to the plasma as much as possible.

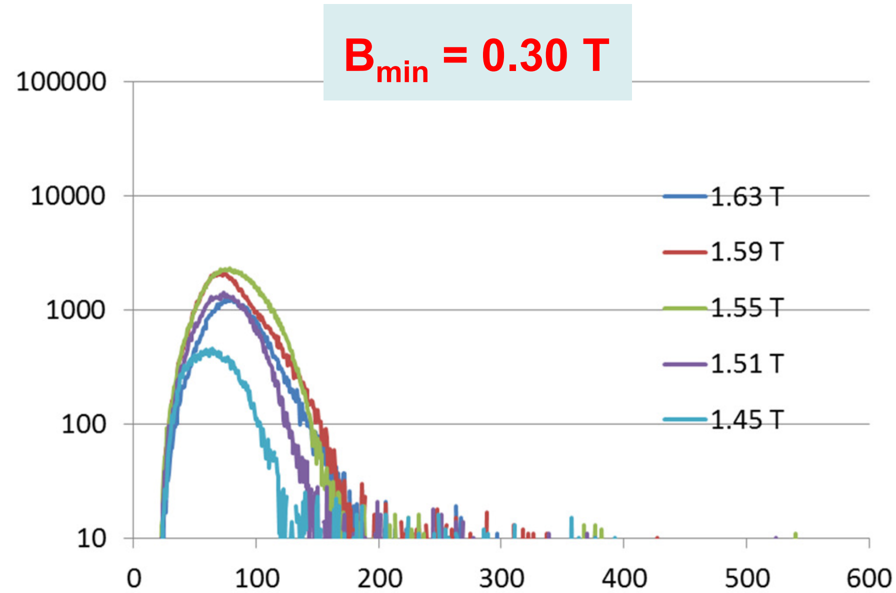
The X-ray energy spectrum depending on gas pressure



- As gas pressure decreases, the X-ray spectrum is broaden and total count rate increases.
- It is expected that to get high energy electrons, the operation pressure should be controlled as low as possible.
- But the overall shape of the distribution of the spectrum is not changed depending on pressure.

The X-ray energy spectrum depending on $B_{entrance}$





- The first graph show that there is an optimum value of $B_{entrance}$ for the effective electron heating of the ECR ion source.
- The highest energy spectrum and the highest counting rate could be get when
  $B_{entrance}$, = 1.57 T, B_{min} = 0.48 T.
- The second graph shows that if B_{min} is below 0.3 T it is impossible to make high energy electrons and high-charge-state ions.

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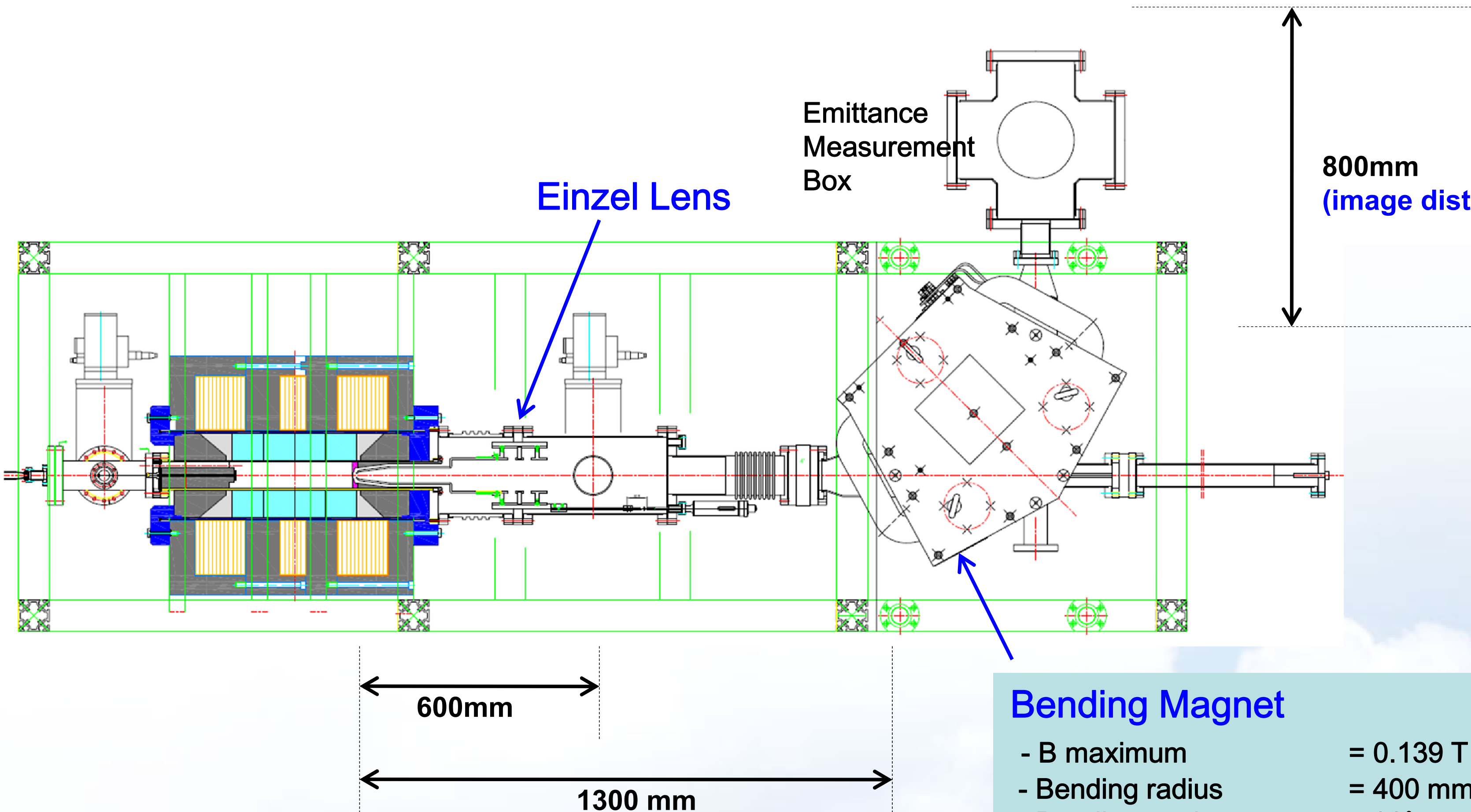
Beam Transport and Measurement System

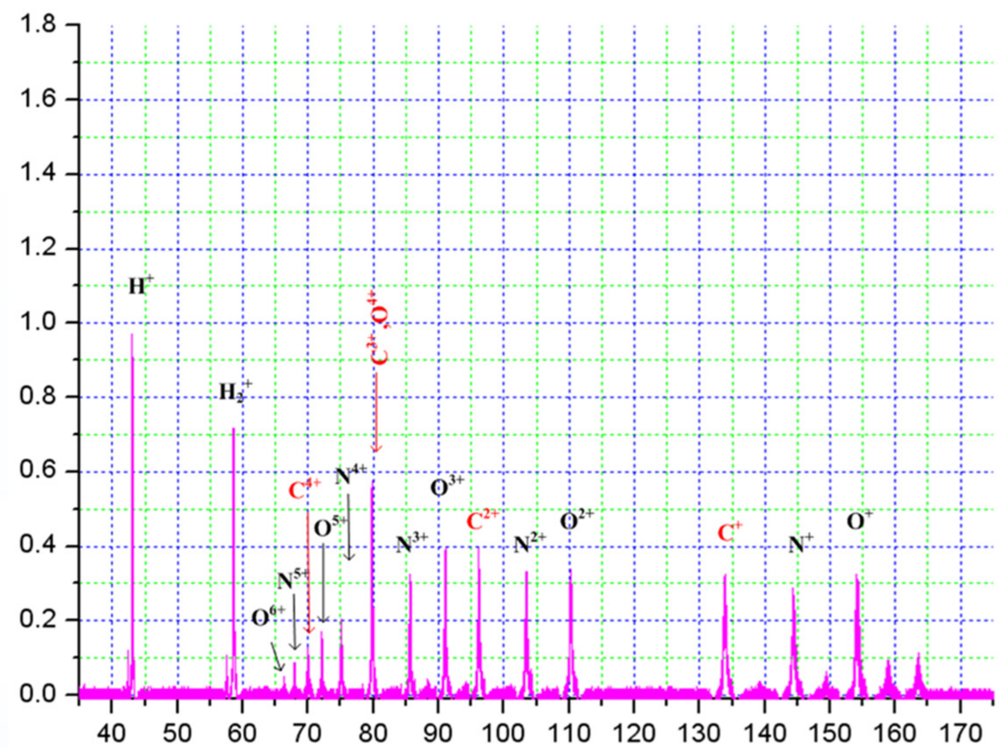


Bending Magnet

- B maximum	= 0.139 T
- Bending radius	= 400 mm
- Bending angle	= 90˚
- Entrance/Exit angle	= 26.6˚
- pole gap length	= 45 mm
- vertical acceptance	= 37 mm

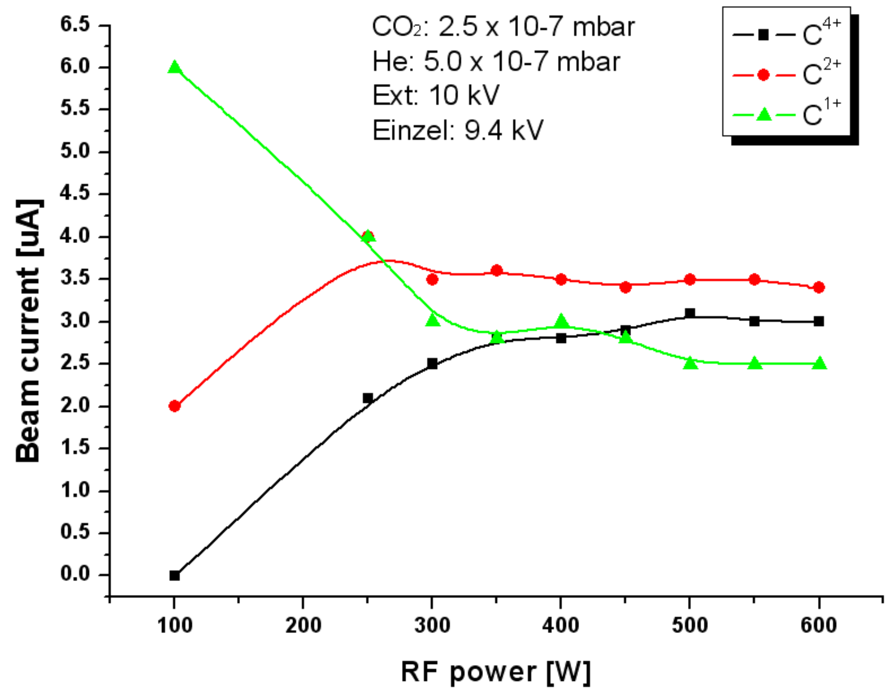
Beam production and separation result with CO_2 gas

- RF power: 500W   - Gas pressure 2.35×10^{-6} mbar



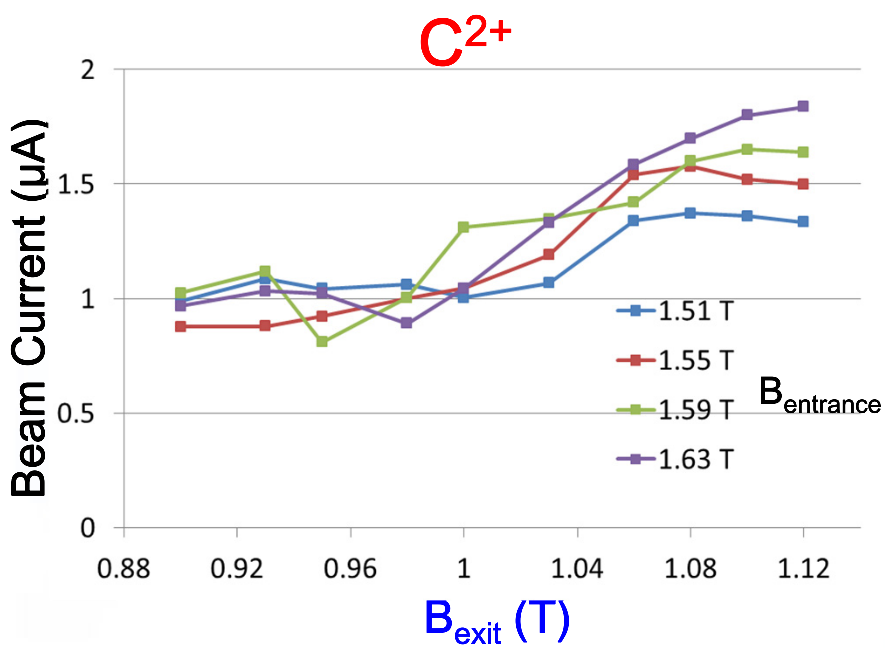
➢ Single charge beam components could be depressed by tuning the operation conditions.

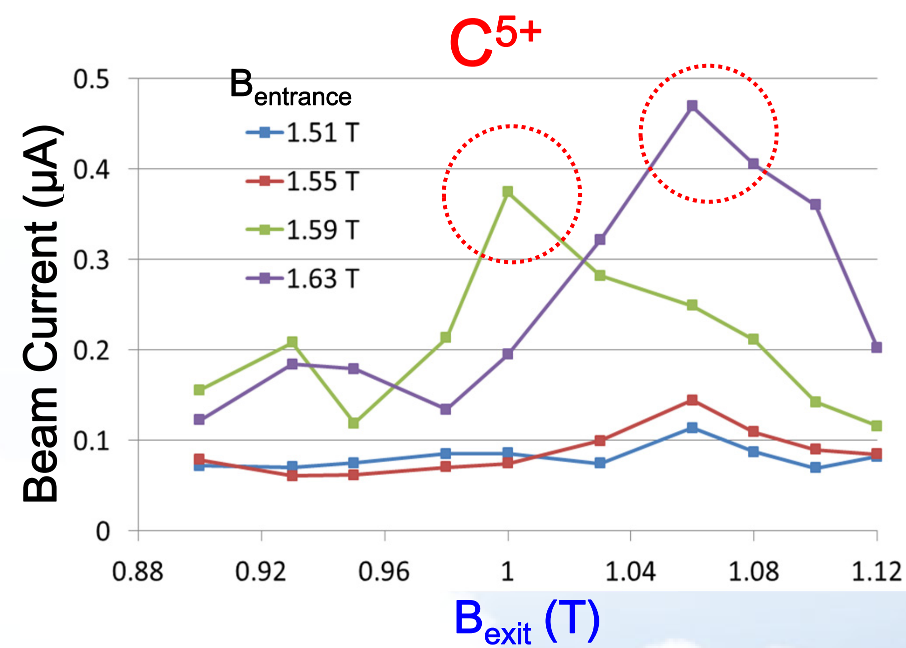
Carbon beam(C^{4+}, C^{2+}, C^{1+}) currents depending on RF power



- There are different optimum RF input powers for different charge state beam.
- The graph shows that to get high current beam with C^{5+} and C^{6+} ions, higher RF power more than 500 W is necessary.

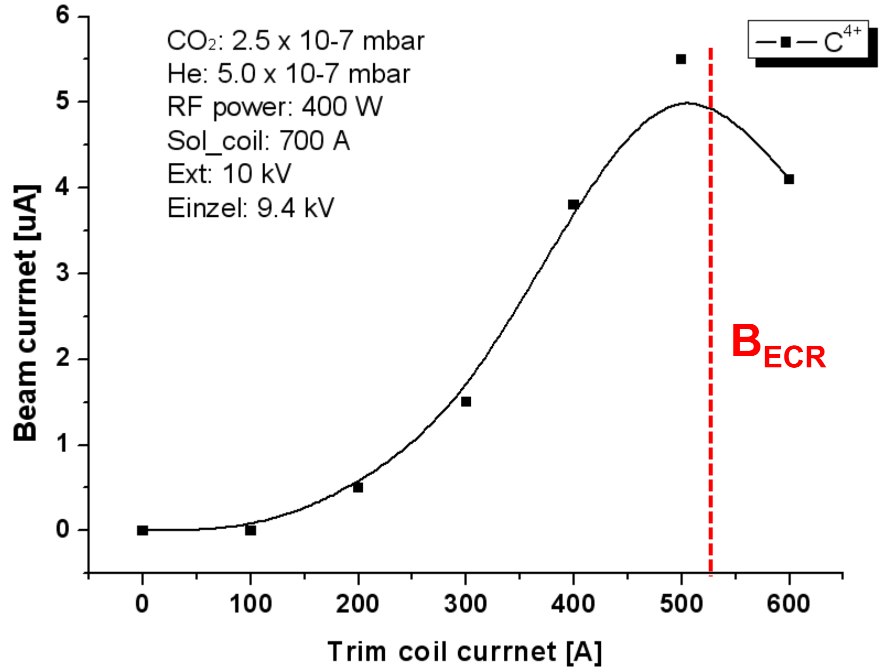
Beam Current Depending on B_{exit}





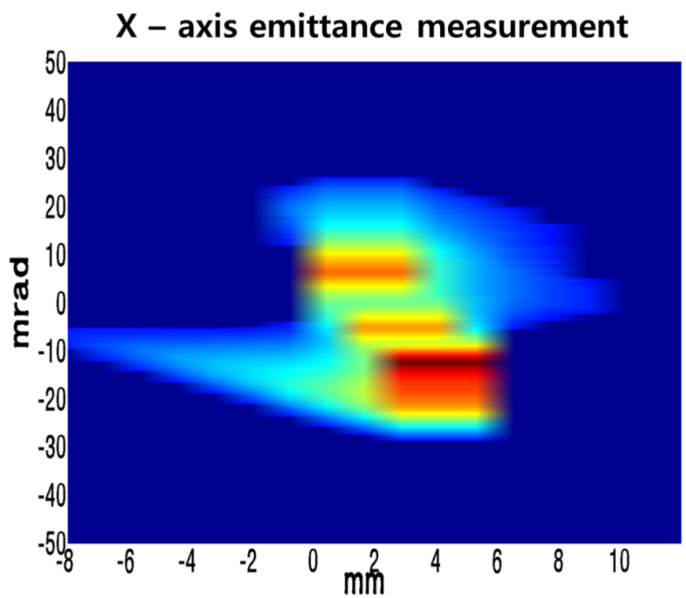
- These graphs show that high charge state beam is more sensitive to B_{exit} , and high $B_{entrance}$ and well tuned B_{exit} is necessary to get high current of C^{5+} beam.
- It looks like high-charge-state ions are concentrated at the center region, and therefore they are more sensitive to the mirror field strength of loss cone.

C^{4+} beam current depending on B_{min}

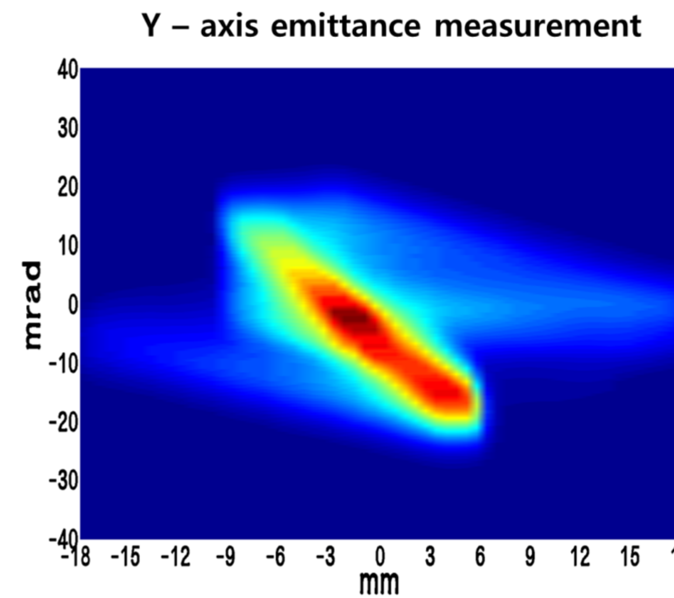


- C^{4+} beam current becomes maximum near B_{ECR}.
- The maximum beam current for C^{4+} is 15 μA at this moment, and large mount of the extracted beams are lost during the transport to the bending magnet.
- This bad beam transmission problem comes from long beam line and small acceptance of the bending magnet.

Emittance Measurement Result



Nor. rms emittance = 0.11 π ·mm·mrad
(90 % Fraction)



Nor. rms emittance = 0.12 π ·mm·mrad
(90 % Fraction)

- We setup the emittance measurement process using Allison type scanner.
- The condition of the above measurement is C^{2+}, 10 kV, 10 μA beam.

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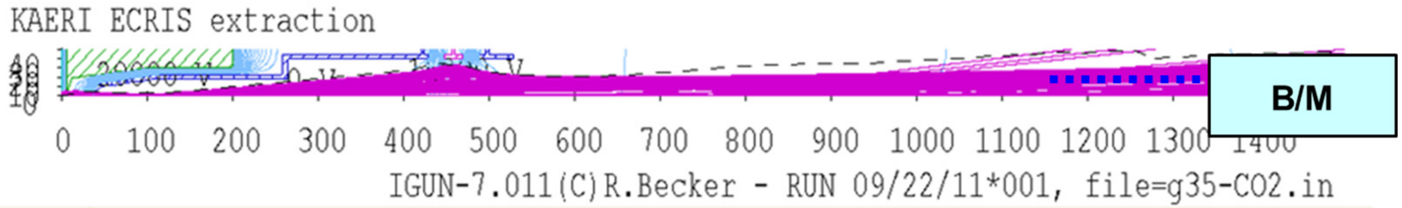
Upgrade Plan

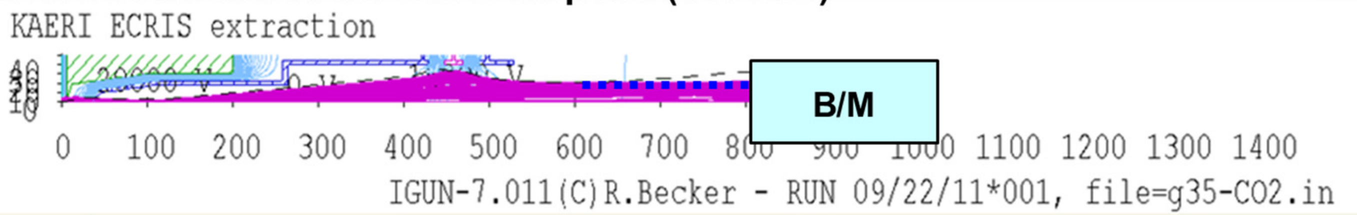
- High quality of ECR plasma is certified by X-ray characteristics. But large beam loss is made because of long beam line and small acceptance of the bending magnet.
- After installing a large acceptance bending magnet, we will do the experiments to increase the current of multi-charged carbon beam.
- Also for the uranium beam experiment in the future, we are going to start metal ion beam experiments with this source.

Upgrade plan of beam line optics

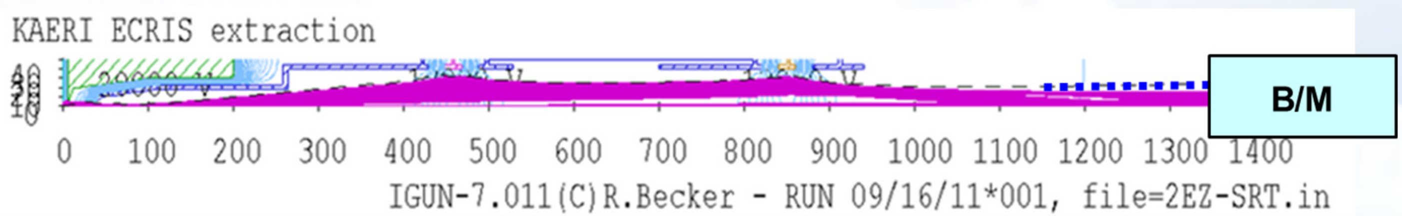
Present beam line



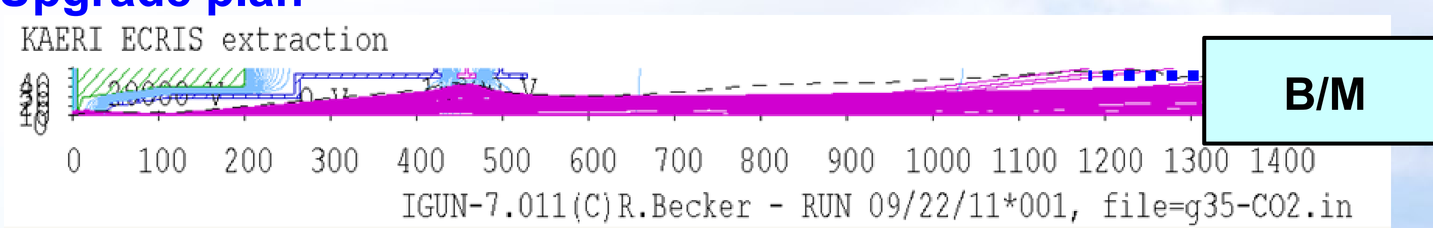
Shorten beam line to the BM focal point (800 mm)



Two-Einzel beam line



Upgrade plan



Summary

- We have checked the performance of the developed 14.5 GHz ECR ion source by hard X-ray spectrums from the ECR plasma.
- We have an upgrade plan to install a big acceptance dipole magnet for high current and high charge beam experiments.
- The energy spectrums of the hard X-rays depending on different operation condition of the ECR ion source show us the ways how to make high energy electrons.

Thank you very much for your attention.