Emittance measurements for RIKEN 28GHz SC-ECRIS

Y. Higurashi (RIKEN)

1. Introduction

   RIKEN RIBF and RIKEN 28GHz SC-ECRIS

2. Emittance measurements

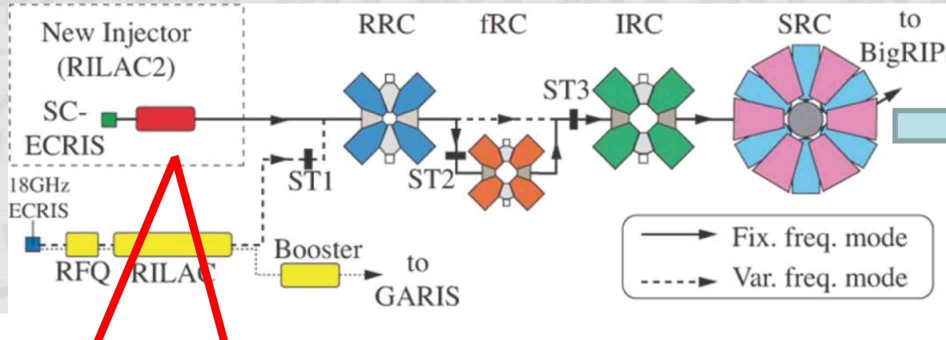
   1. Drain current (extraction current effect) (U ion beam)
   2. Extraction electrode position effect (U ion beam)
   3. Magnetic field distribution effect (18, 28GHz) (U ion beam)
   4. Magnetic field distribution effect (28GHz) (Kr, Xe ion beam)

3. Conclusion

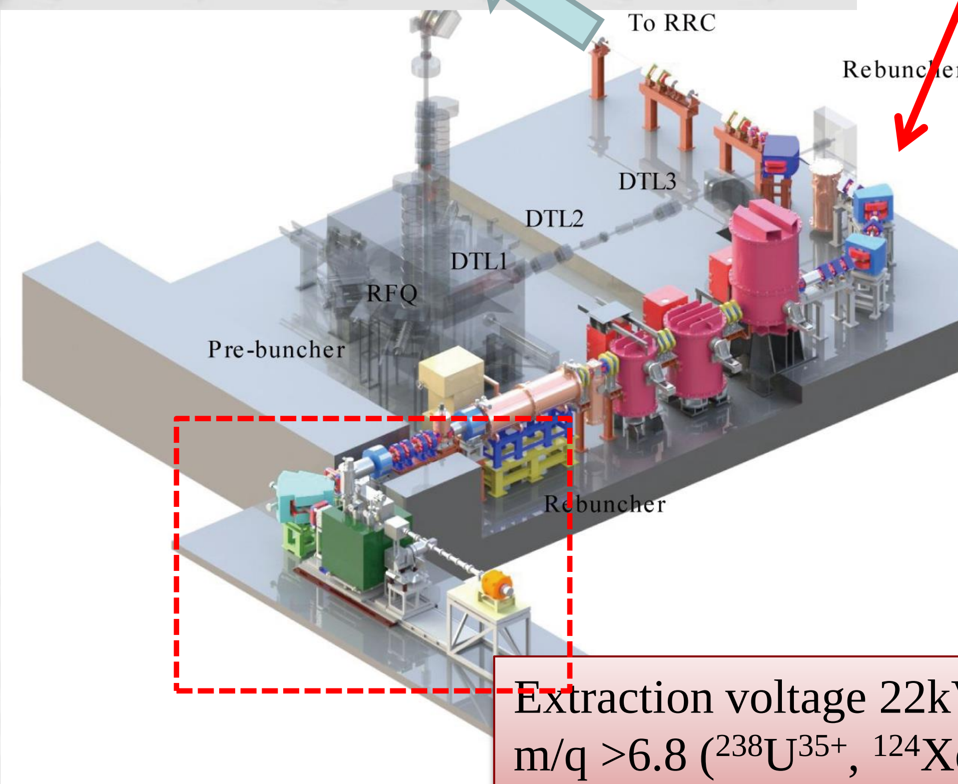
New injector (RILAC II)

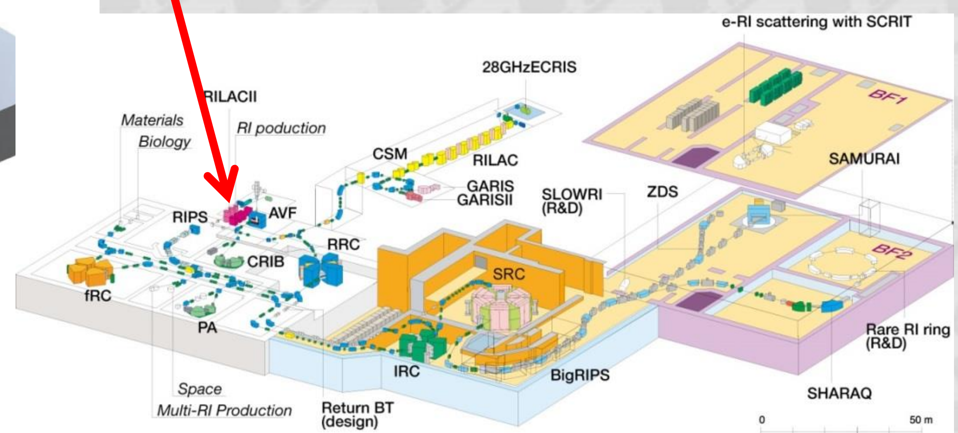
New injector system

~0.6MeV/u $^{238}U^{35+}$, $^{124}Xe^{19+}$



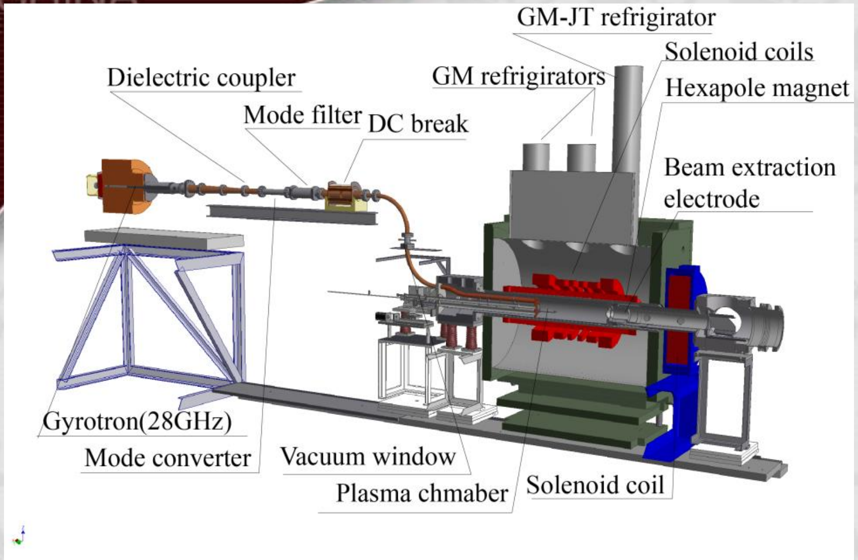
345MeV/u ^{238}U, ^{124}Xe

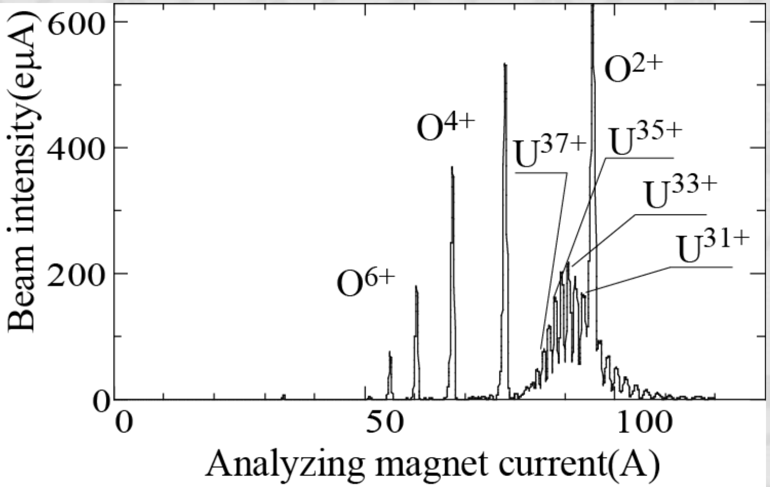




Extraction voltage 22kV
m/q >6.8 ($^{238}U^{35+}$, $^{124}Xe^{19+}$)

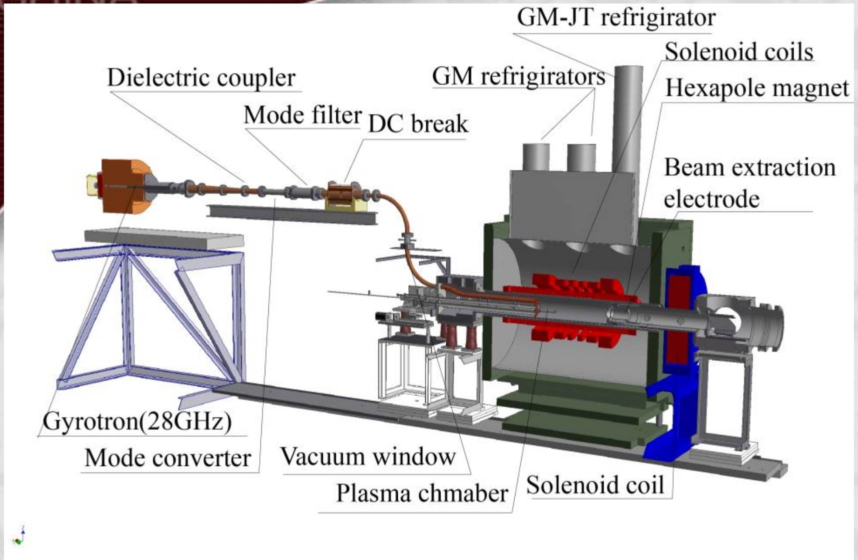
RIKEN 28 GHz SC-ECRIS

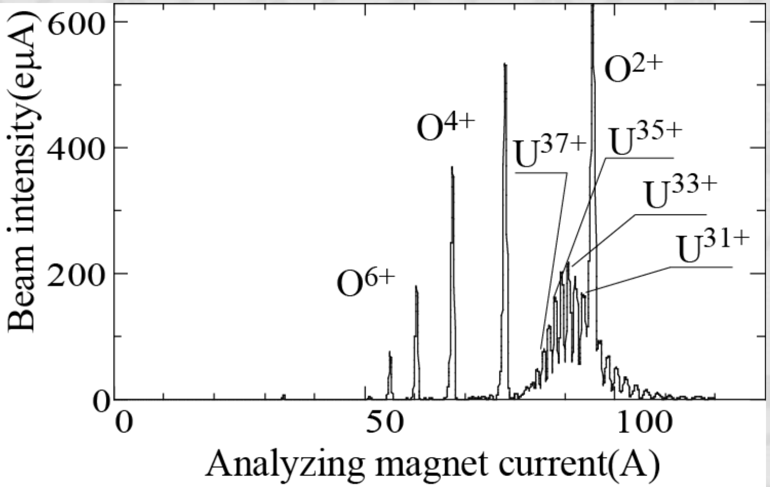


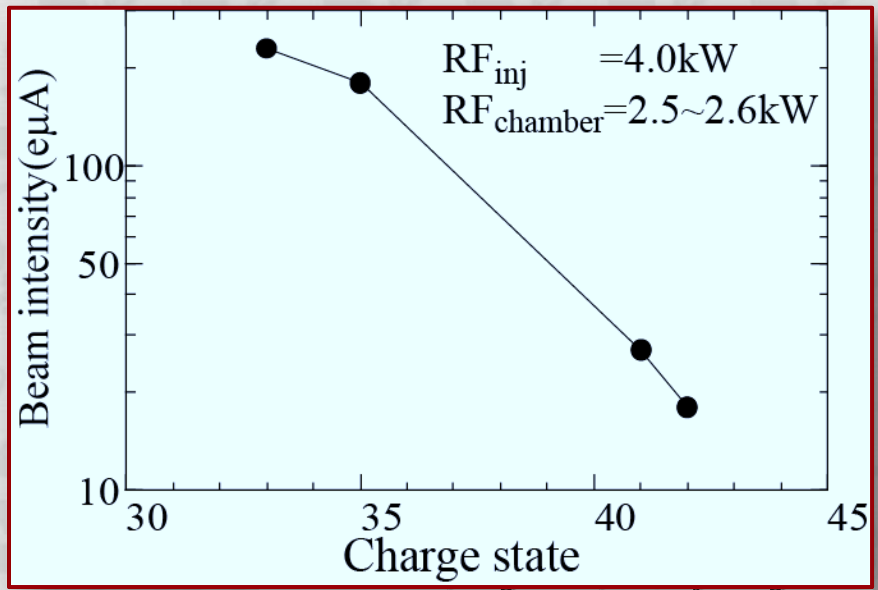


ECRIS-2014, Aug 24-28, Nizhny Novgorod

RIKEN 28 GHz SC-ECRIS







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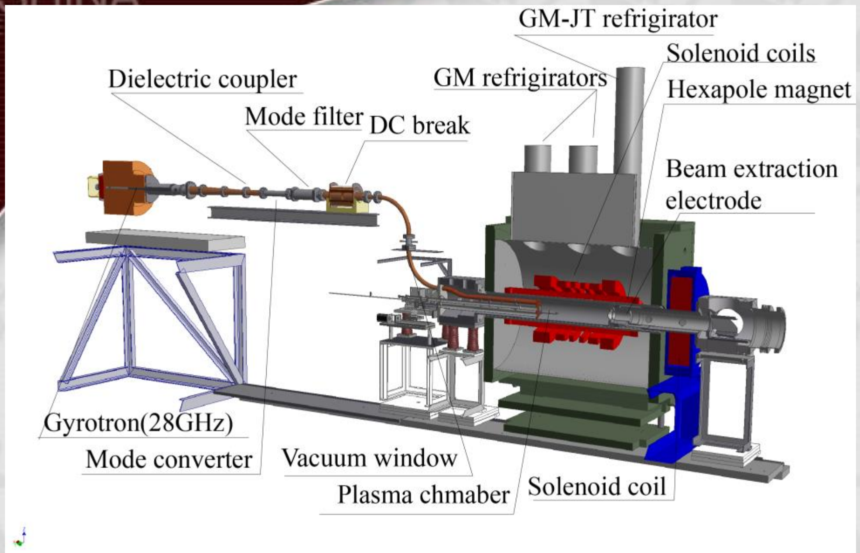
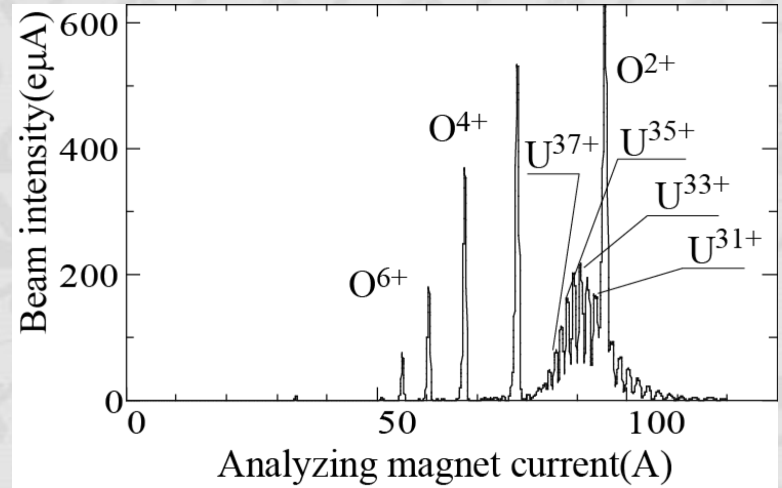
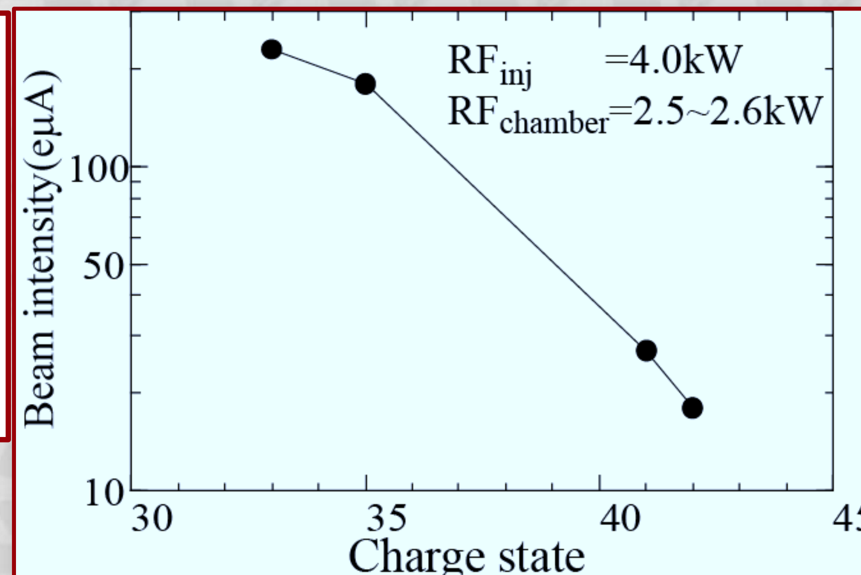




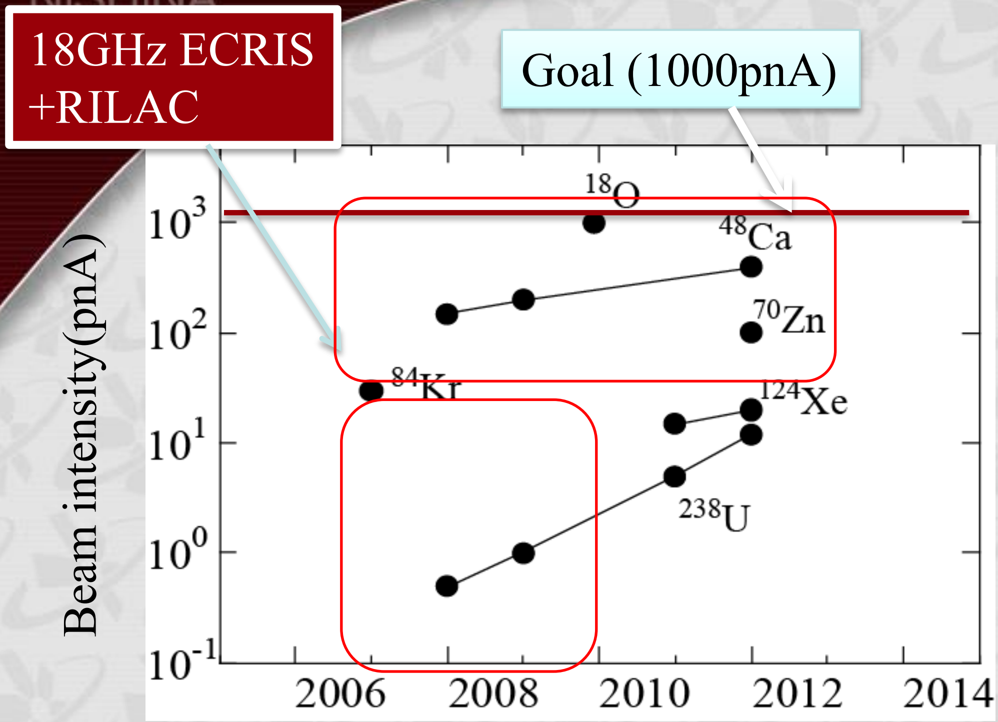
The RIKEN SC-ECRIS can be operated at flexible axial field distributions with six solenoid coils

It is possible to change the gradient of the magnetic field strength and the surface size of the ECR zone.

The RIKEN 28GHz SC ECRIS produced ~180eμA of U^{35+}, ~225 eμA of U^{33+} with the sputtering method at the injected RF power of ~4kW (28GHz).



Time evolution of the beam intensity (RIBF)



As an external ion source for heavy ion accelerator, it is obvious that the improvement of the beam quality, such as emittance and stability, is also important task. Especially, for RIKEN RIBF project, the production of intense beam from the accelerator is key issue to produce intense RI beam. For example, the total power of U ion beam (beam intensity of 1pμA) at the energy of 345MeV/u is 82kW. In this case, we have to minimize the beam loss to avoid the damage of the accelerator. It is obvious that the emittance of the highly charged U ion beam should be sufficiently smaller than the acceptance of the accelerators of the RIKEN RIBF for safety acceleration. Therefore, to minimize the emittance size for intense beam of U ions, we intensively studied the effect of the ion source parameters on the emittance.

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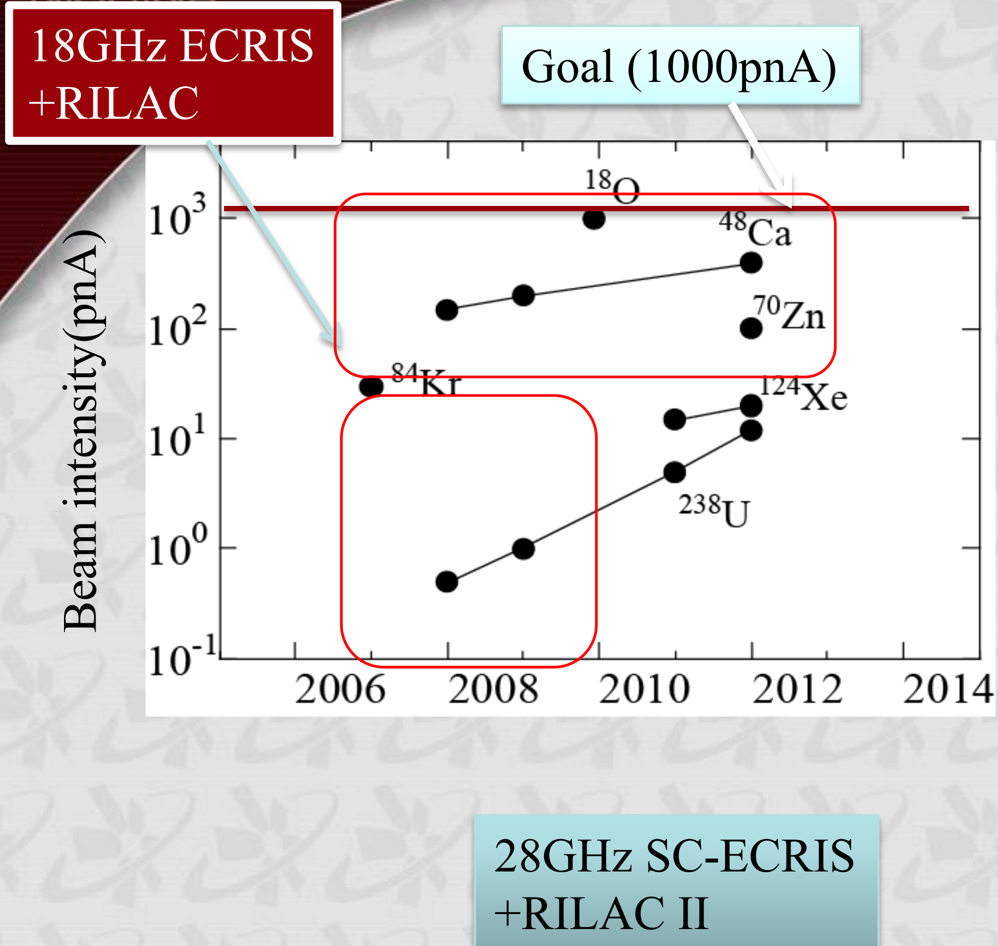

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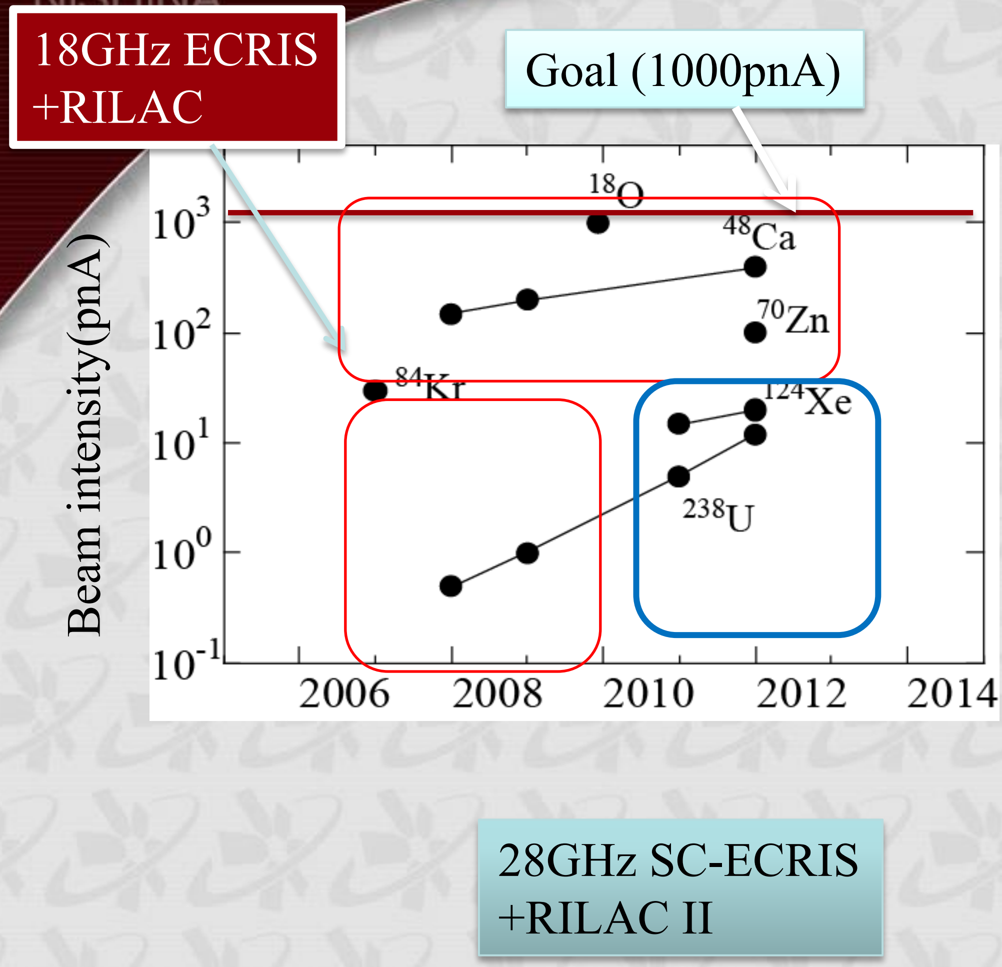

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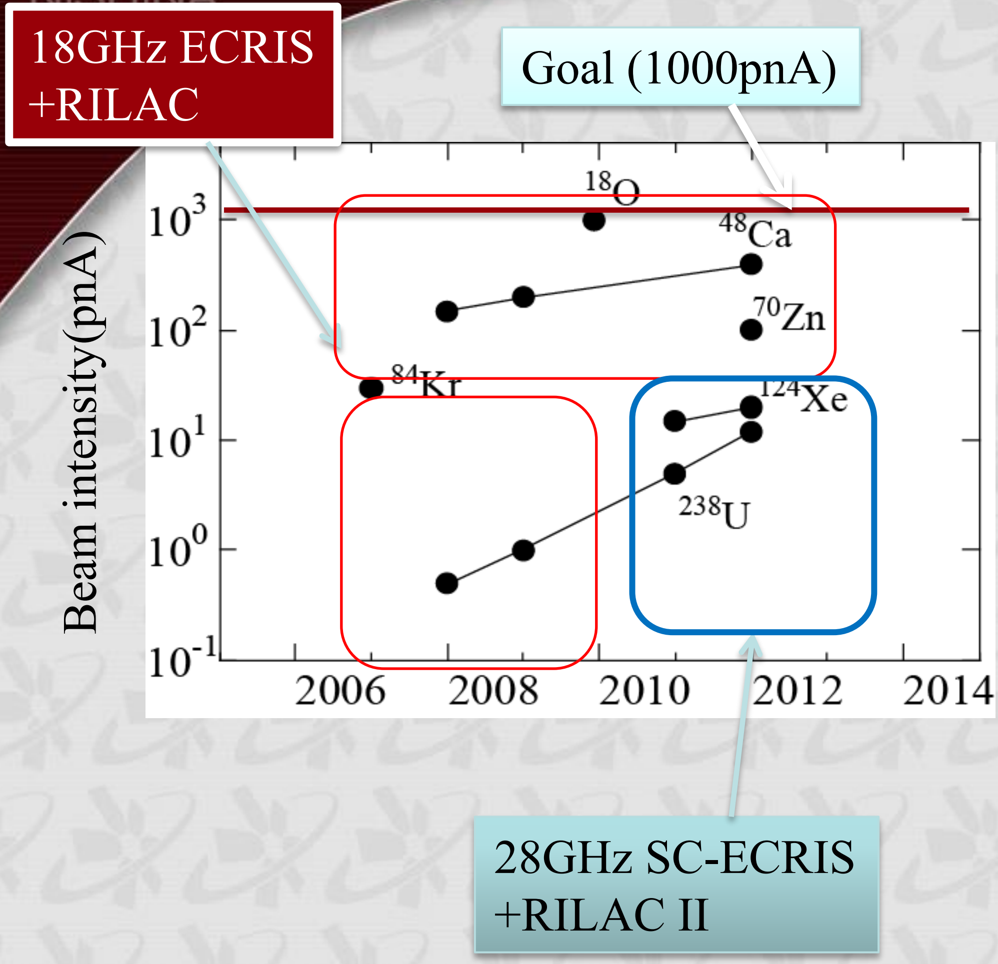

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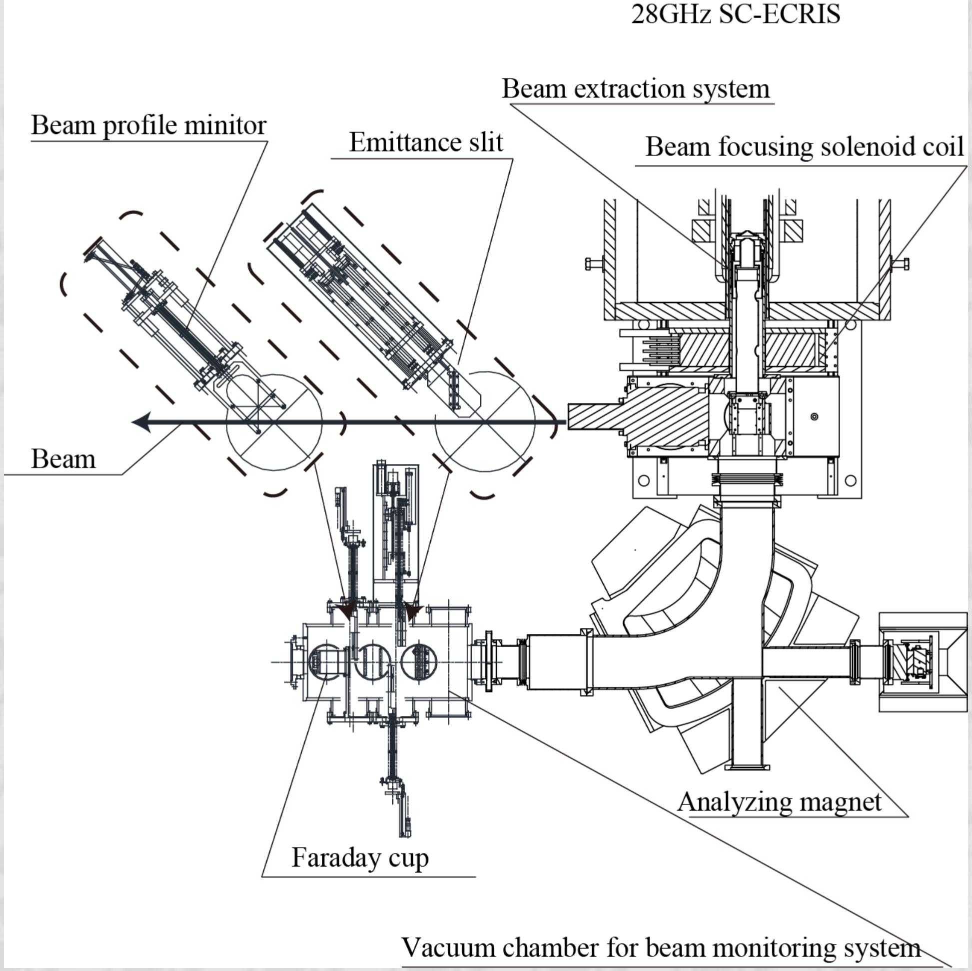
Emittance monitor

Figure shows the schematic drawing of the beam extraction of the ion source, and low energy beam line (analysing magnet and beam monitoring system). The emittacne was measured by using the emittacne monitor which consists of movable thin slit (emittance slit (slit width ~0.3mm) in fig) and wires (beam profile monitor in fig). We also installed the beam slit and faraday cup in the vacuum chamber for beam monitoring system.



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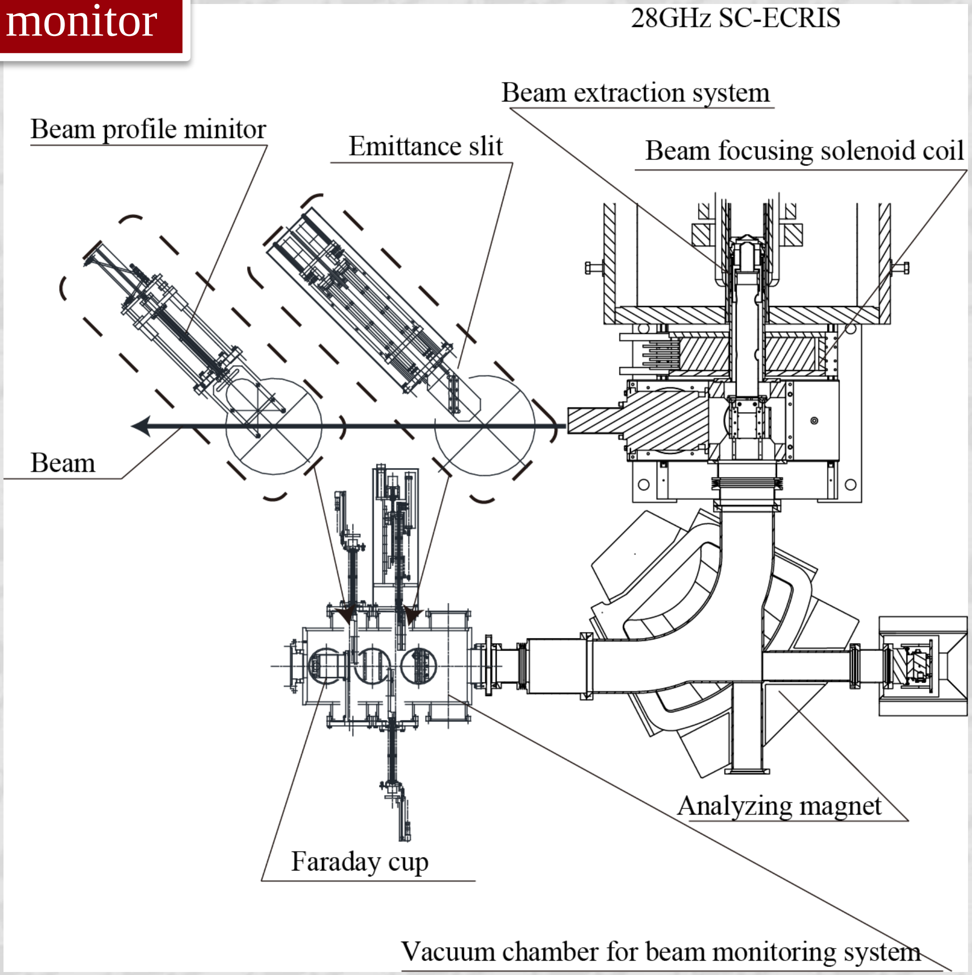

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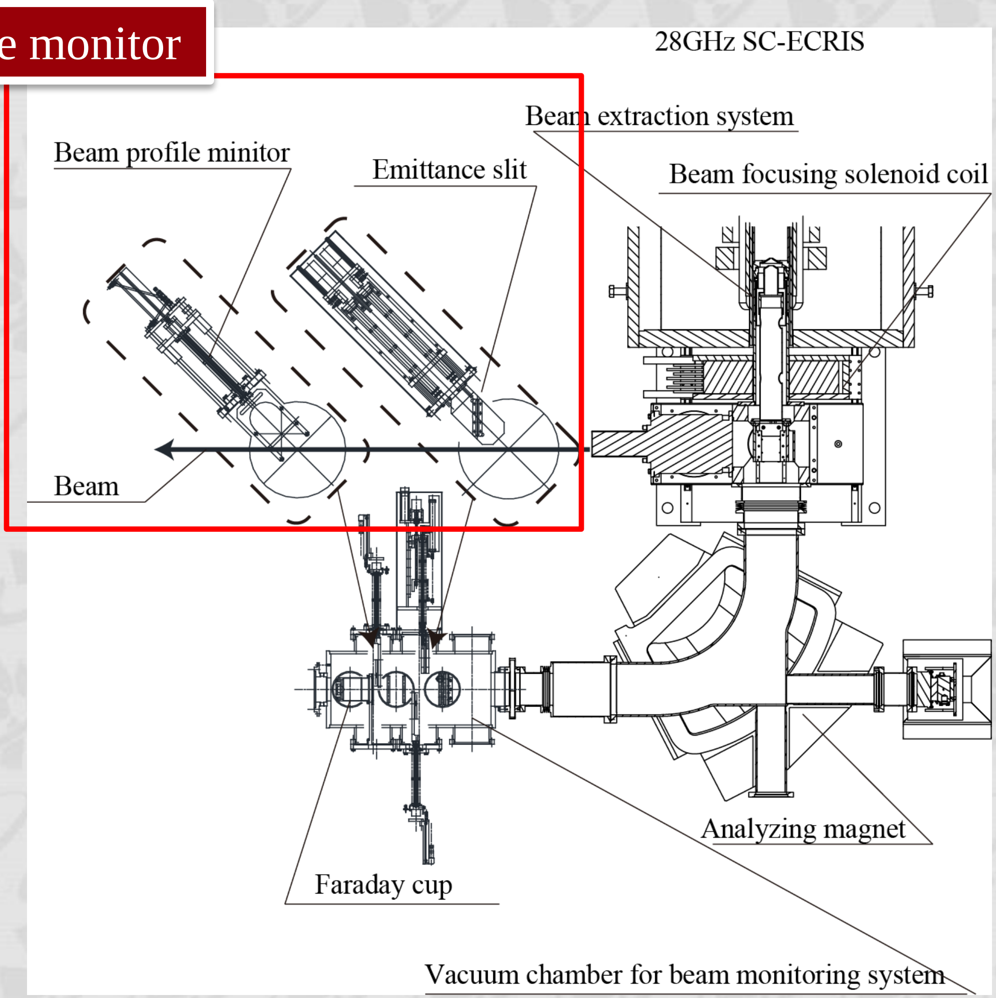
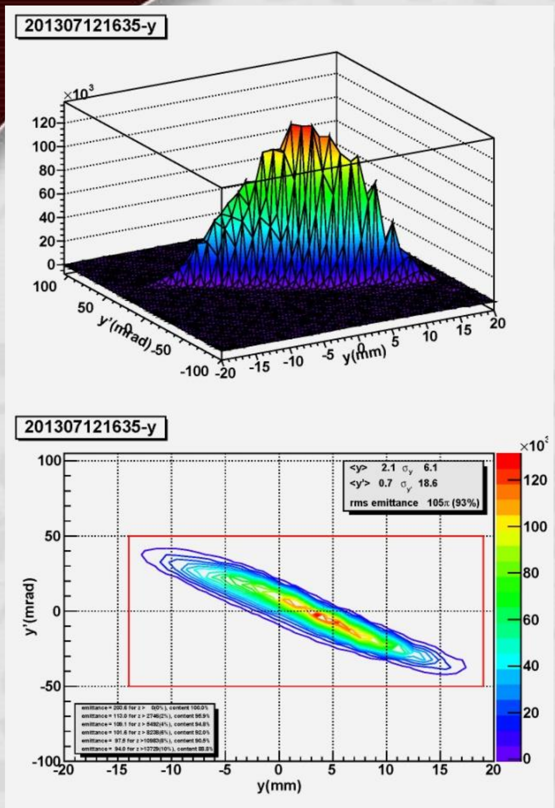


RMS emittance (threshold)



$$\varepsilon_{x-rms} = \sqrt{\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle^2}$$
$$\varepsilon_{y-rms} = \sqrt{\langle y^2\rangle\langle y'^2\rangle - \langle yy'\rangle^2}$$

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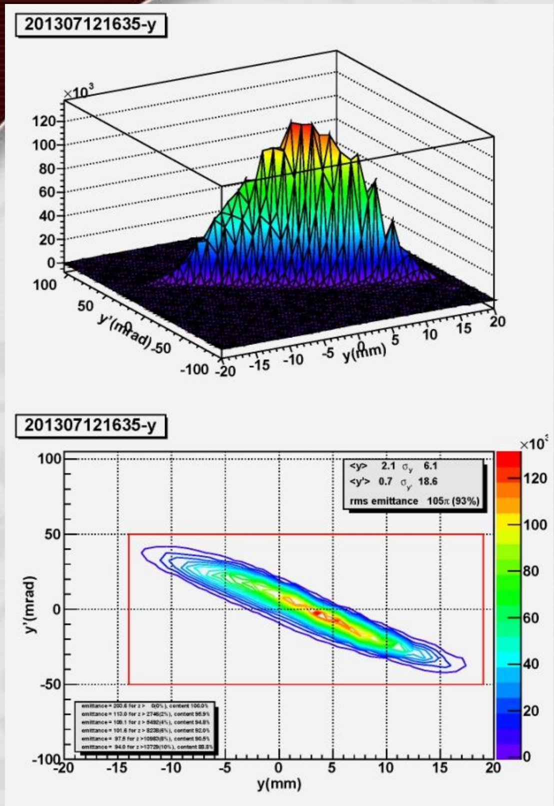

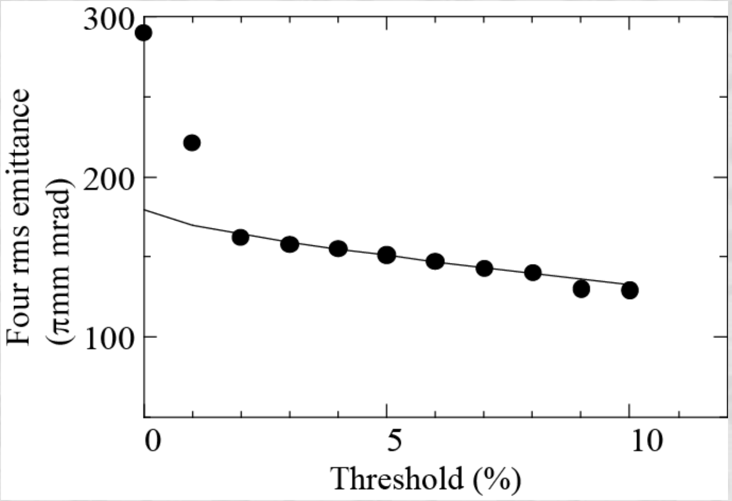

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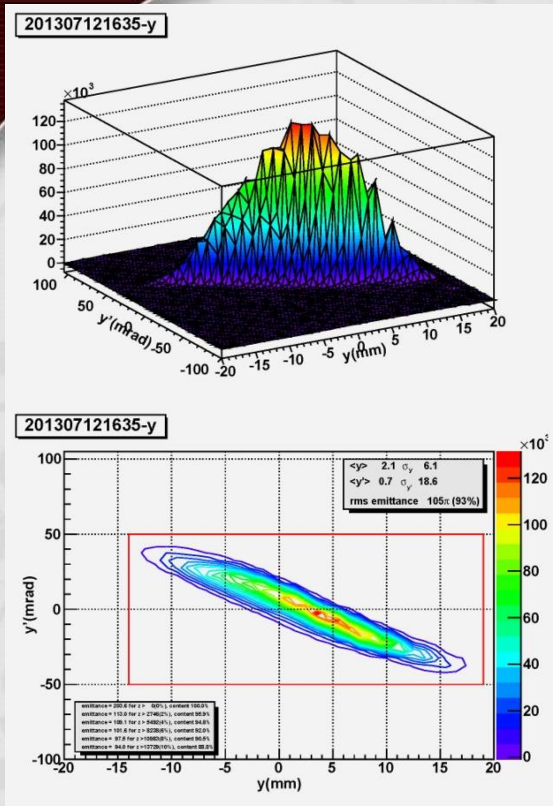

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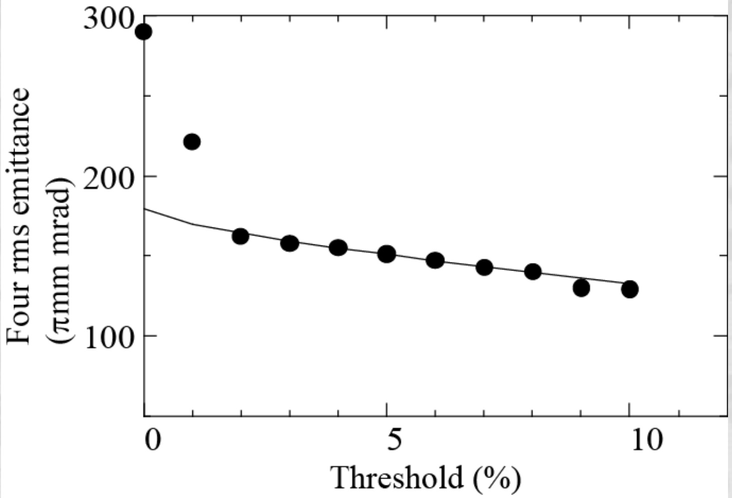
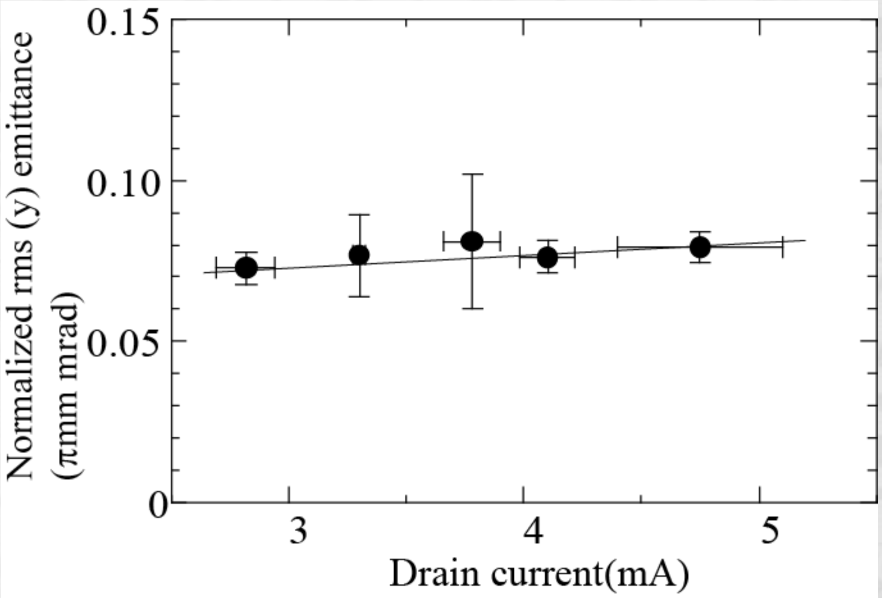


Figure shows the Four RMS emittance as a function of the threshold. The mittance dramatically increased with decreasing the threshold below 2%. This is mainly due to the effect of the detector noise.

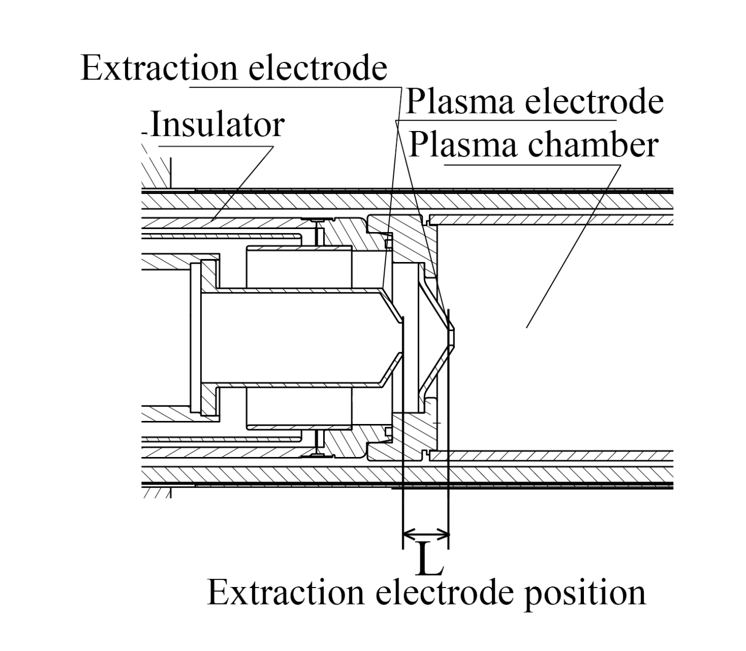
To minimize the noise effect, we set the threshold of 5% of the maximum height of the peak value of the spectrum

Drain (extraction) current effect

Figure shows the size of the rms emittance as a function of the drain current of the ion source, which is proportional to the extraction current. The error bar (emittance spread) shows the standard deviation. It seems that the emittance slightly increased from 0.07 to 0.08 π mm mrad with increasing the drain current from ~2.5 to ~4.7mA. It may conclude that the space charge mostly compensates in this experiment.



Extraction electrode position effect (I)



Left figure shows the schematic drawing of the beam extraction side. The position of the extraction electrode (L) is defined in fig.3. The magnetic field distribution was fixed as B_{inj}~3.1T, B_{min}~0.65T, B_{ext}~1.78T and B_r~1.82T. Right figure shows the normalized rms y-emittance of U^{35+} ion beam as a function of extraction electrode position (L). We observed that the effect of electrode position was very weak and the emittance slightly increased with decreasing L.

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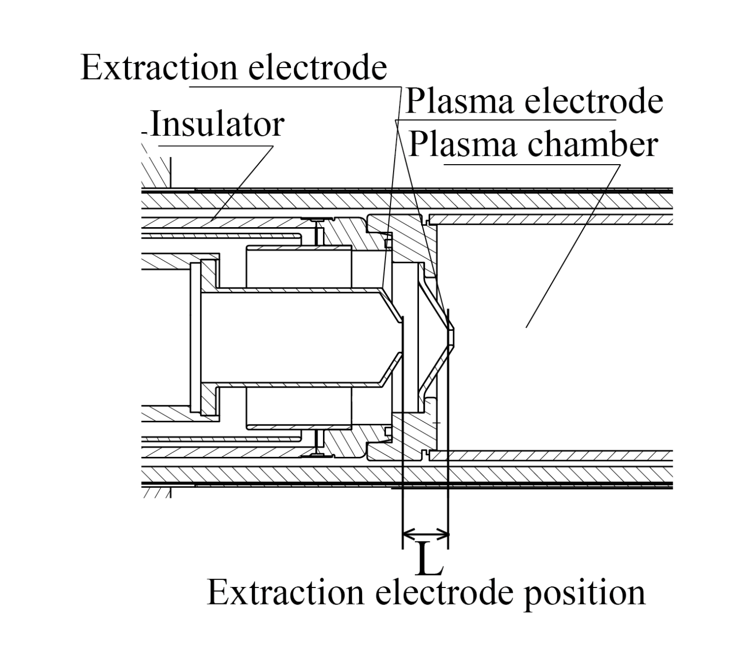

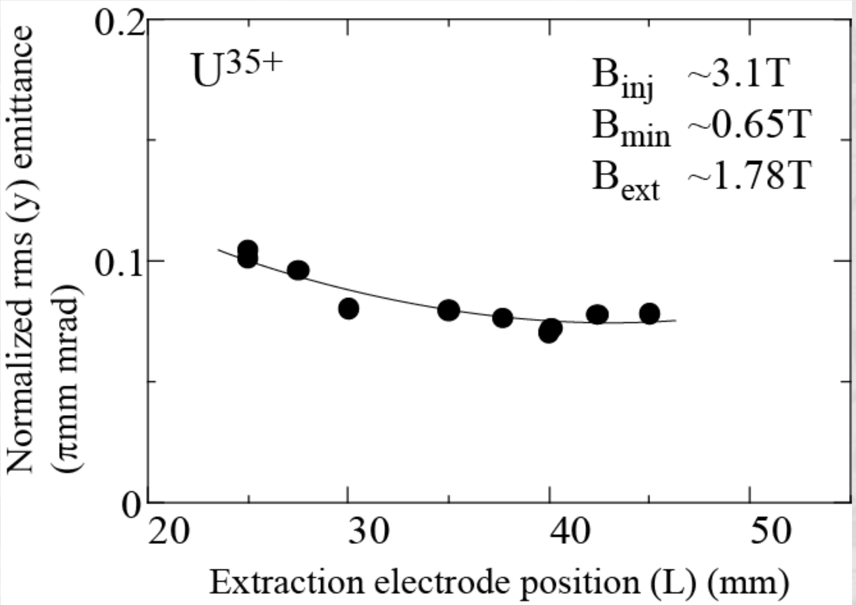

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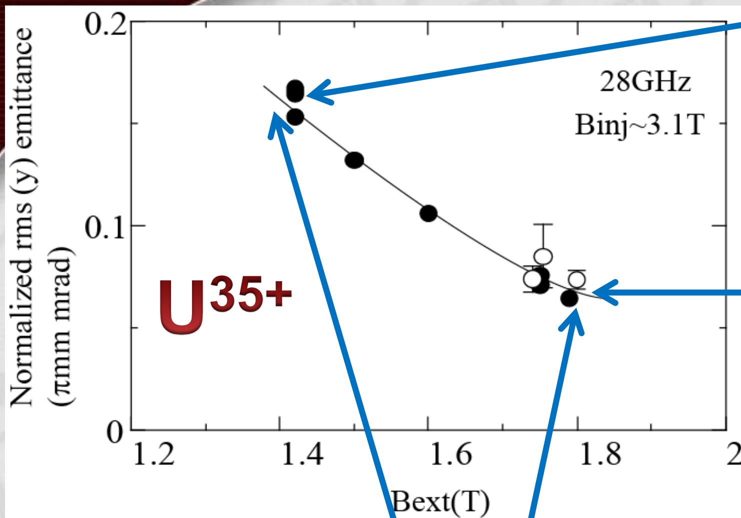
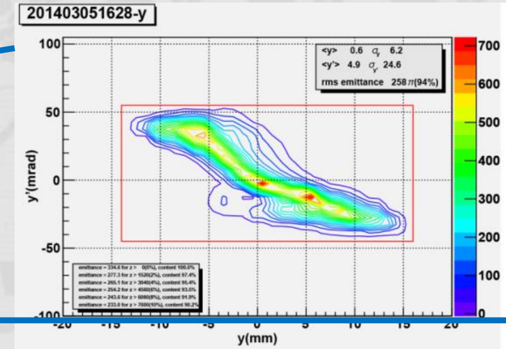
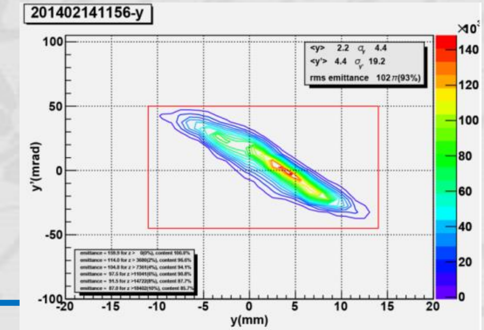
B_{ext} effect (28GHz)







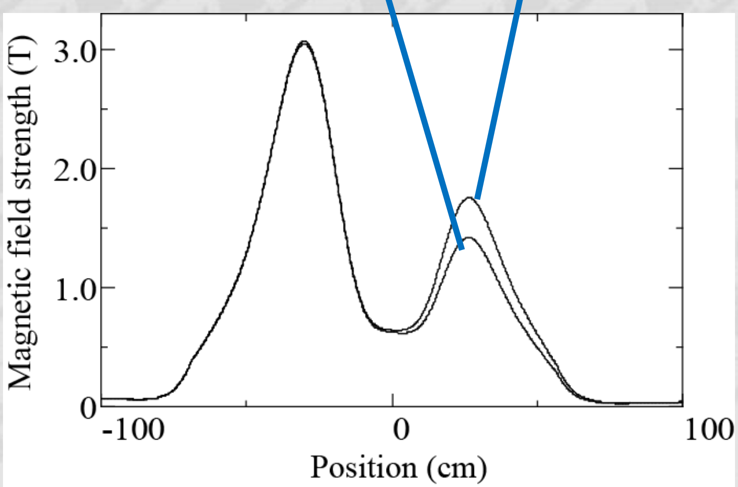
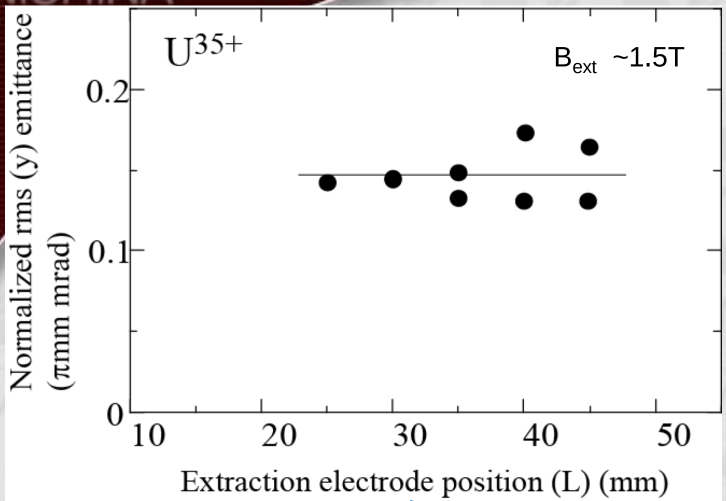
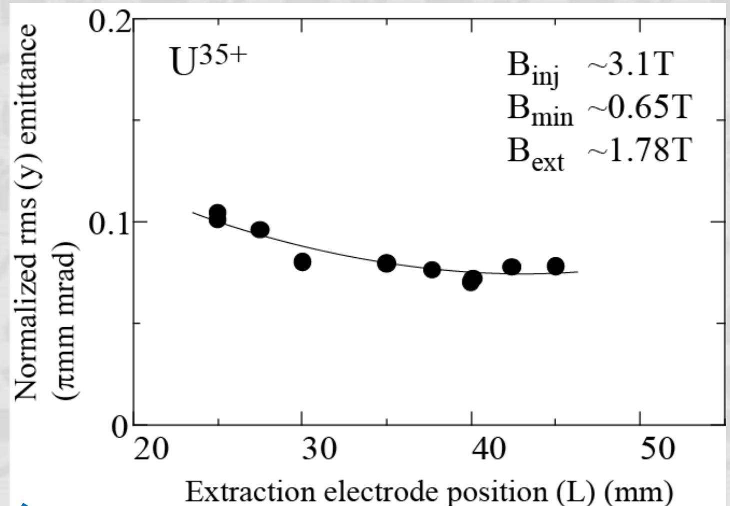
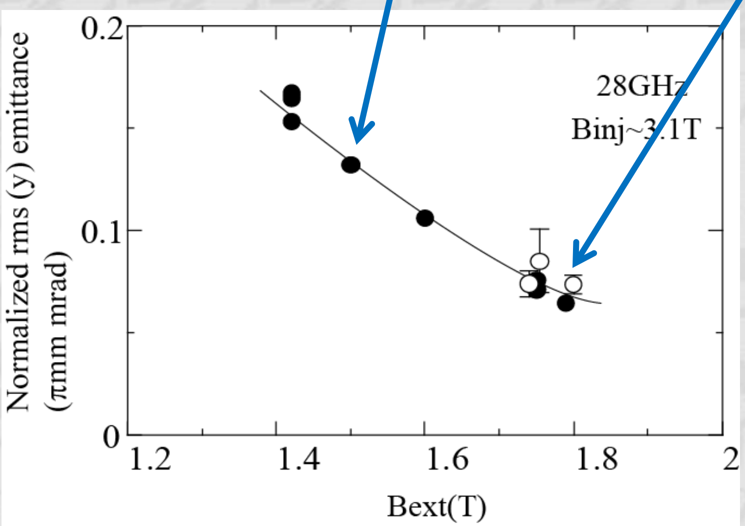


Figure shows the magnetic field distribution for investigating the B_{ext} effect with 28GHz. The B_{ext} was changed from **~1.8 to ~1.4T**, while keeping the other magnetic field strength **(B_{inj}~3.1T, B_{min}~0.65T and B_r~1.8T)**. The RF power and extraction voltage were ~1.5 kW and 22kV, respectively. Figure 6 shows the normalized rms y-emittance as a function of B_{ext}. **The emittacne drastically changed from ~0.07 to ~0.17 π mm mrad with decreasing the B_{ext} from ~1.8T to ~1.4T.** The beam intensity was also dependent on the B_{ext}. It was changed from ~60 to 40 eμA with decreasing B_{ext} from ~1.8 to ~1.4T.

Extraction electrode position effect (II)

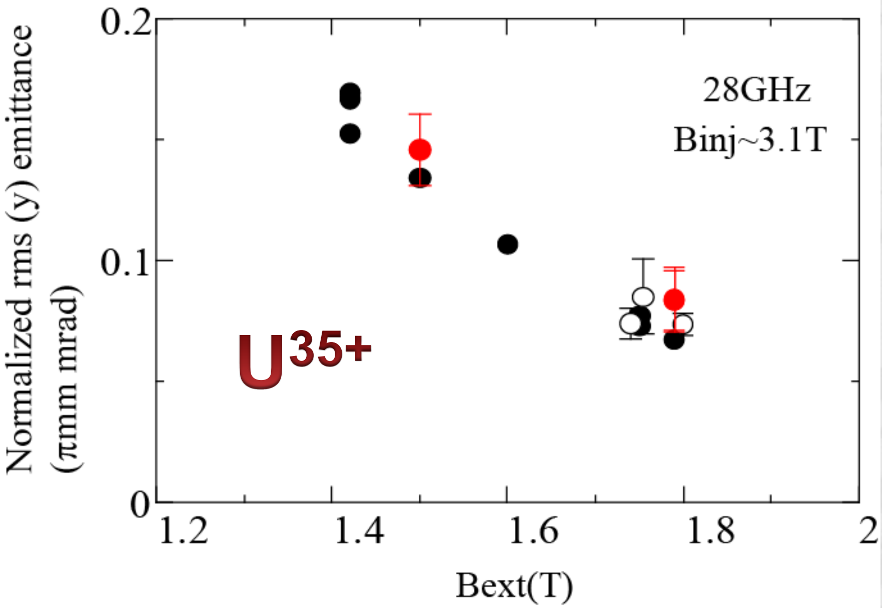






Figures show the extraction electrode position effect. The emittance was almost constant and independent on the position. Therefore, we may conclude that the emittacne size for U^{35+} ions was not dependent on the extraction electrode position for the magnetic field distribution in these test experiments.

B_{ext} effect (28GHz) (II)



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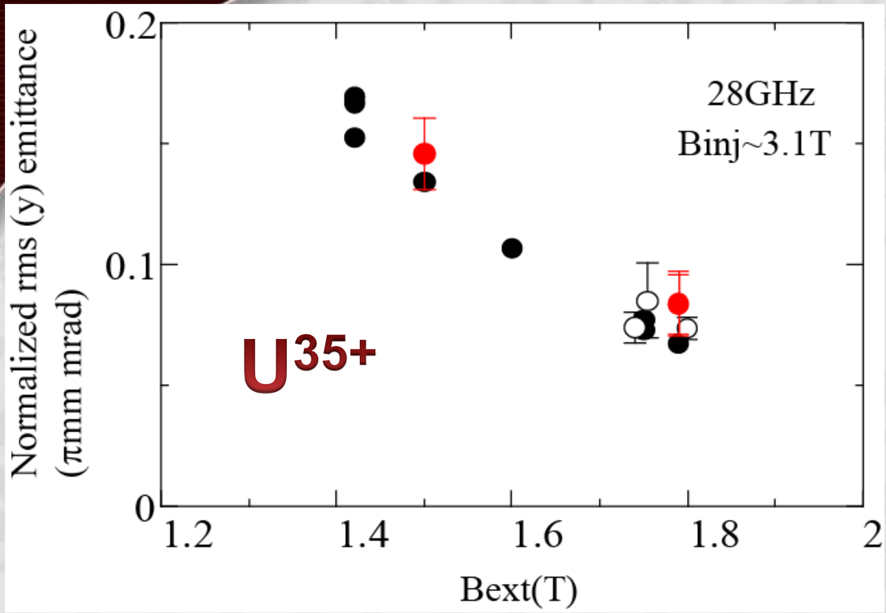

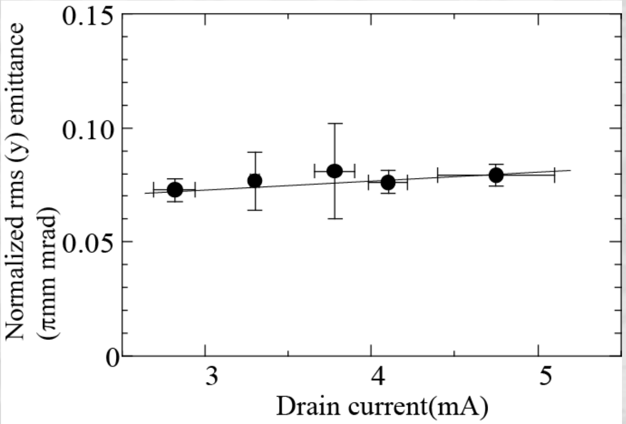

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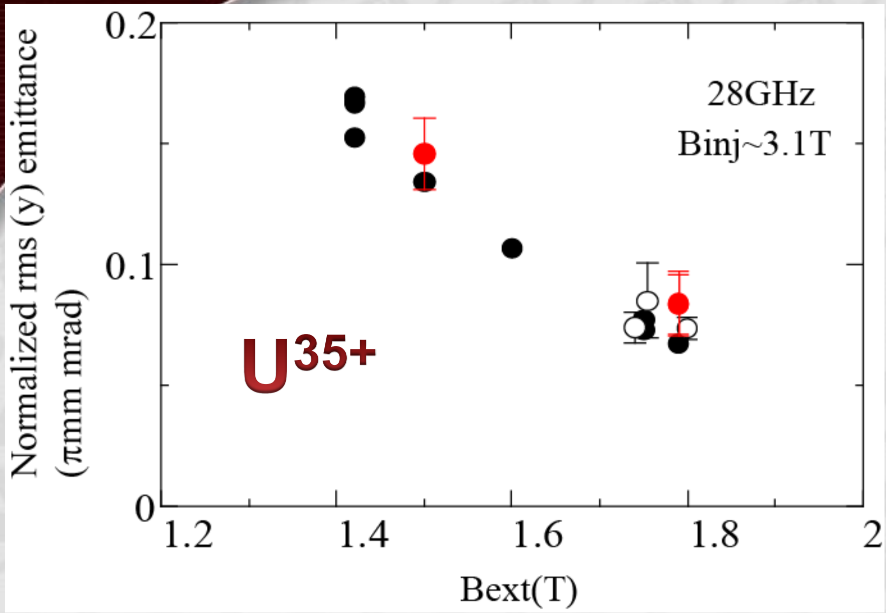

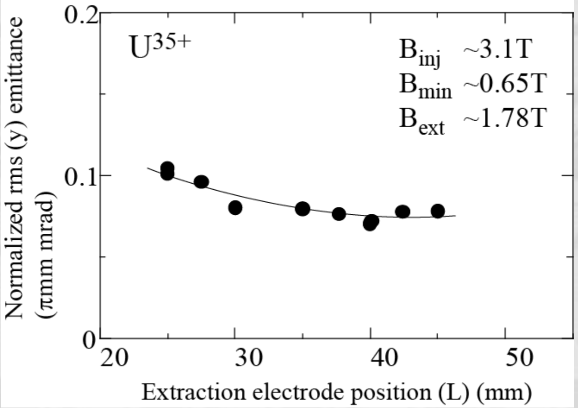

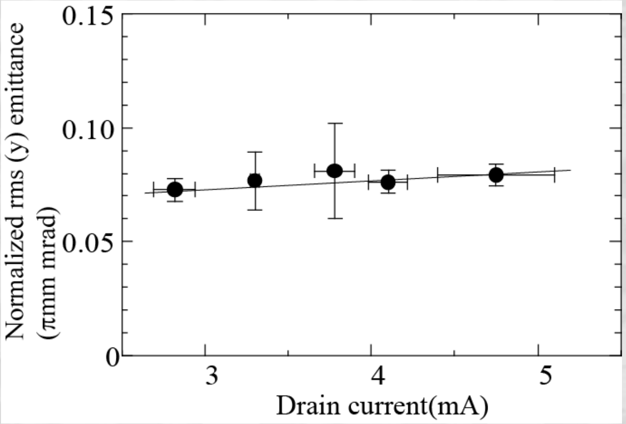

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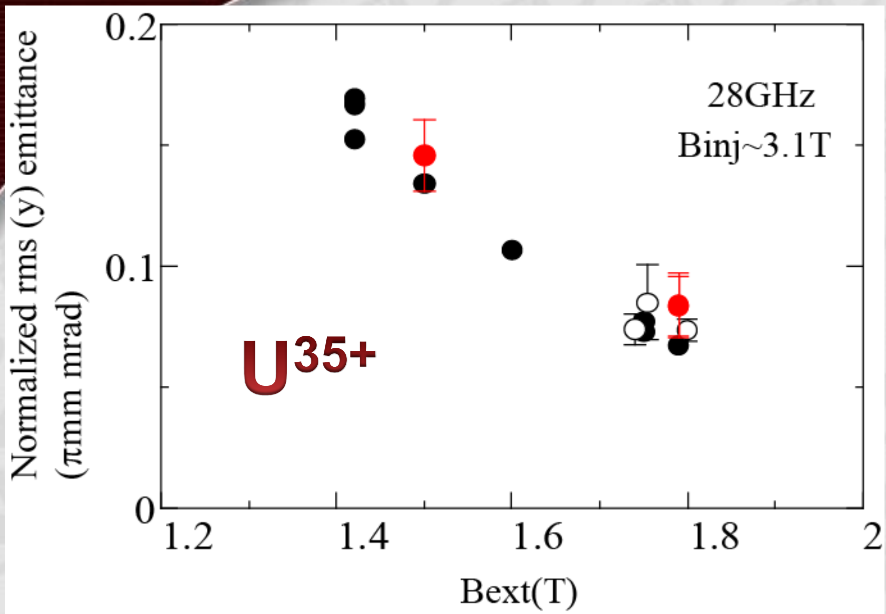

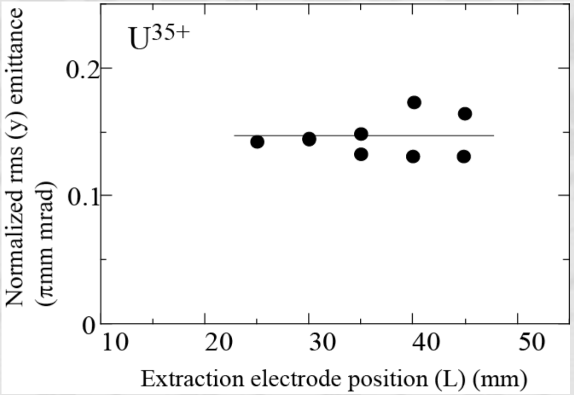

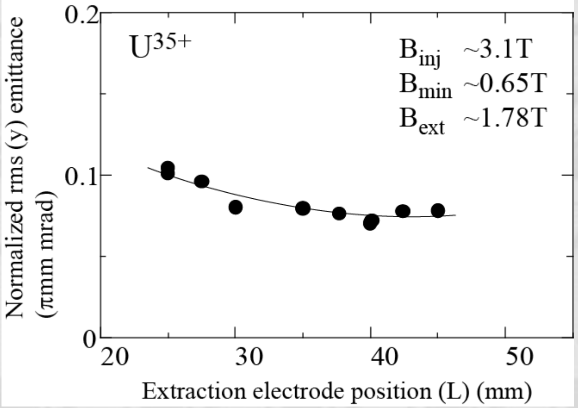

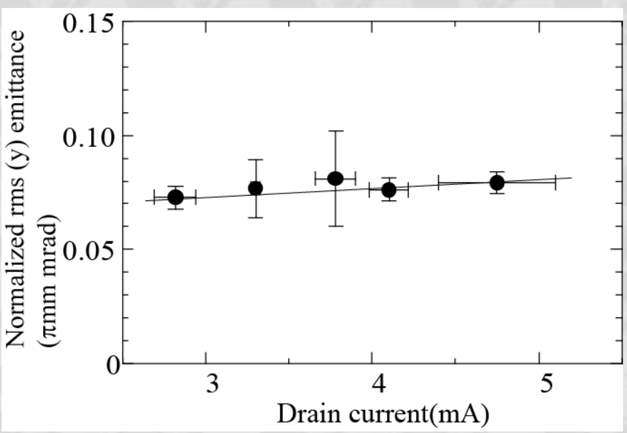

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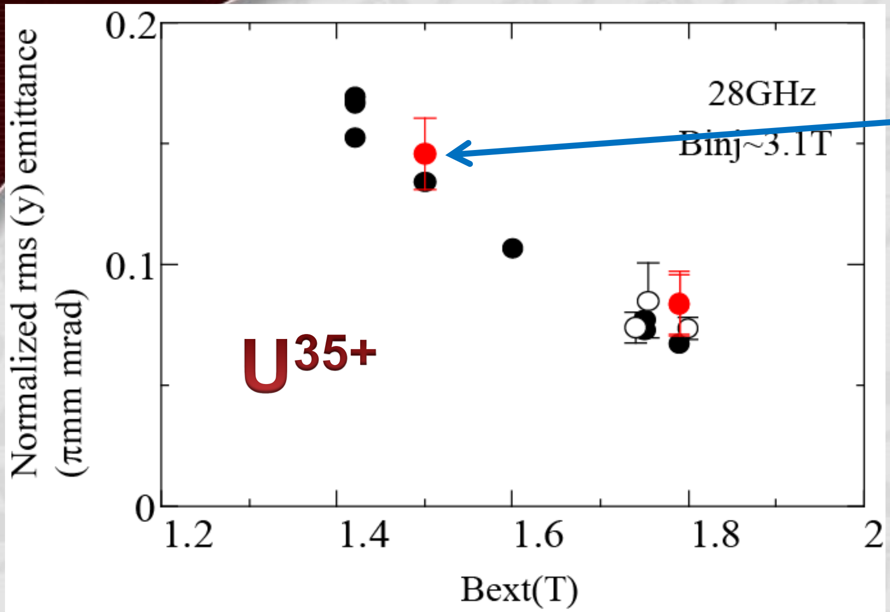

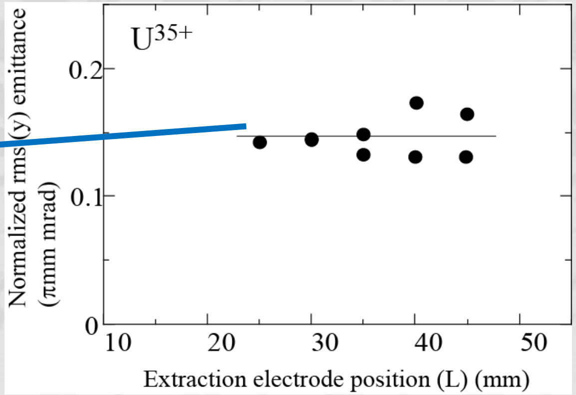

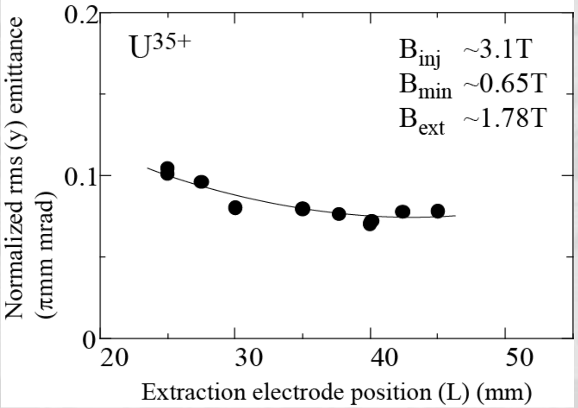

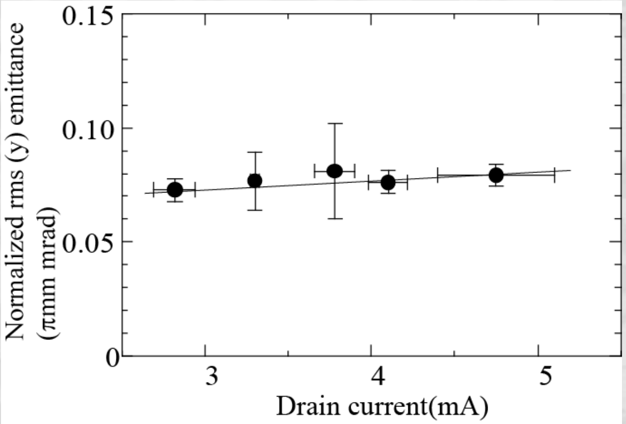

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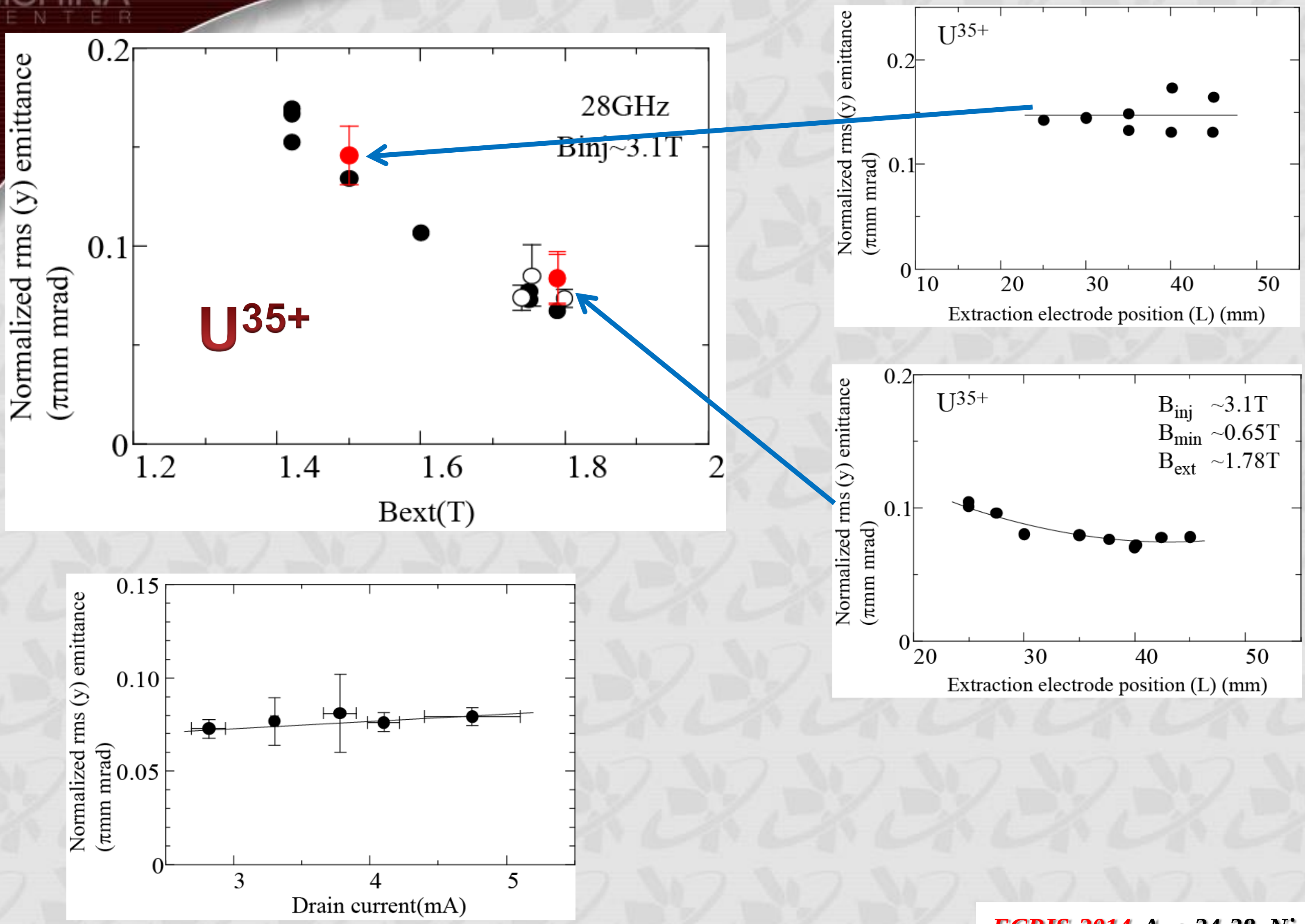

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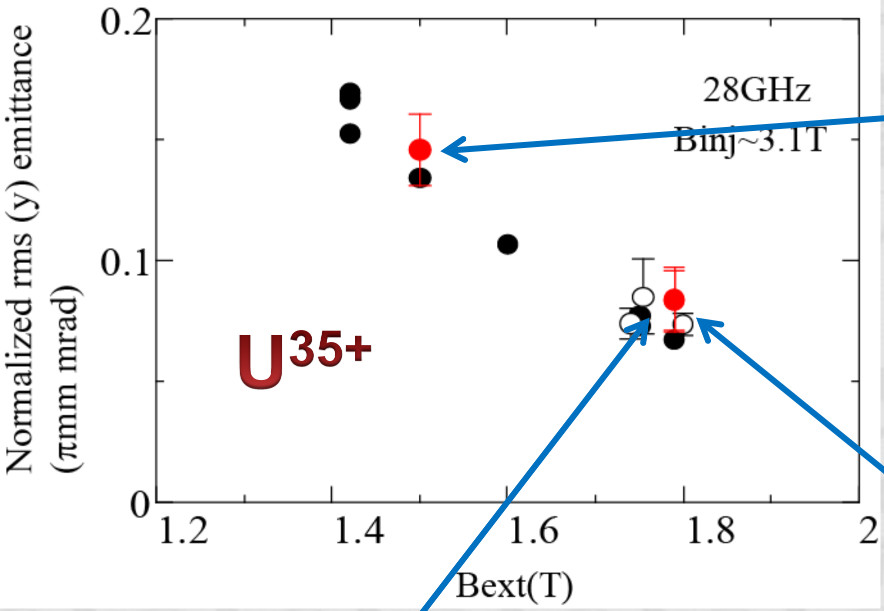
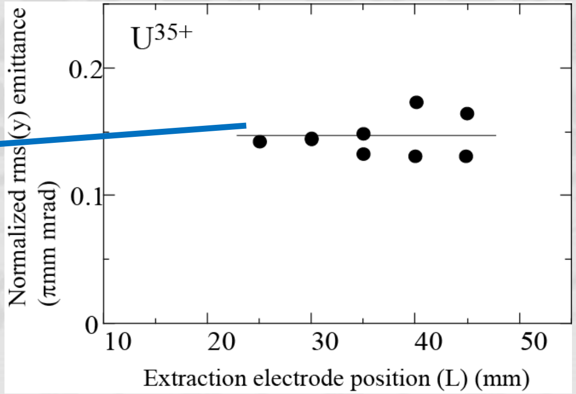
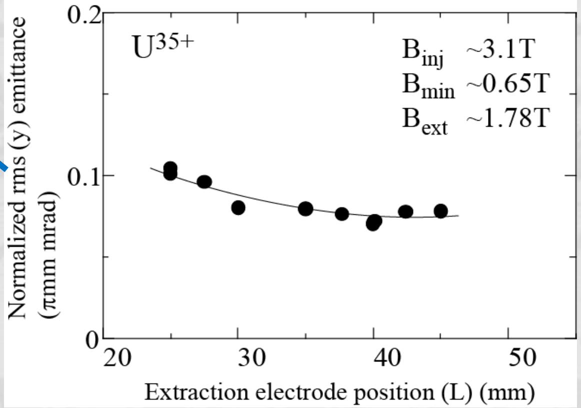
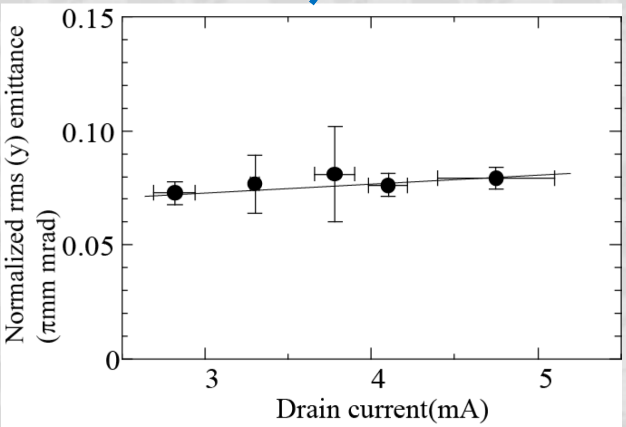
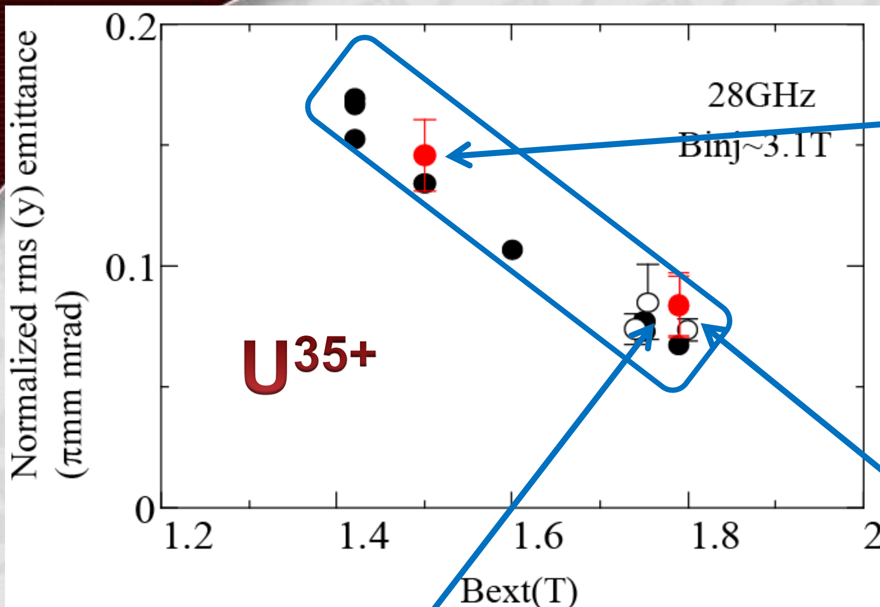


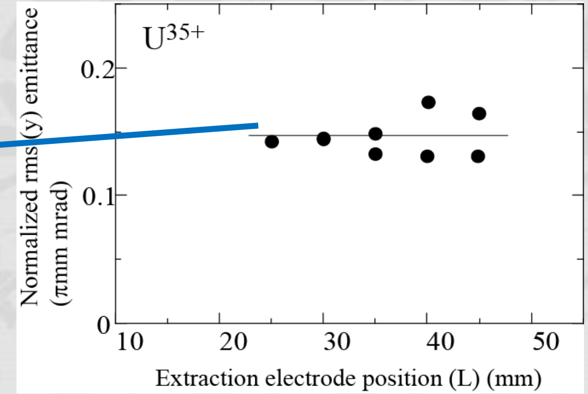


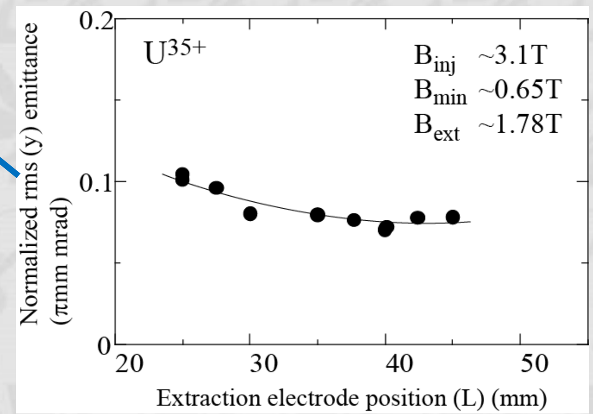


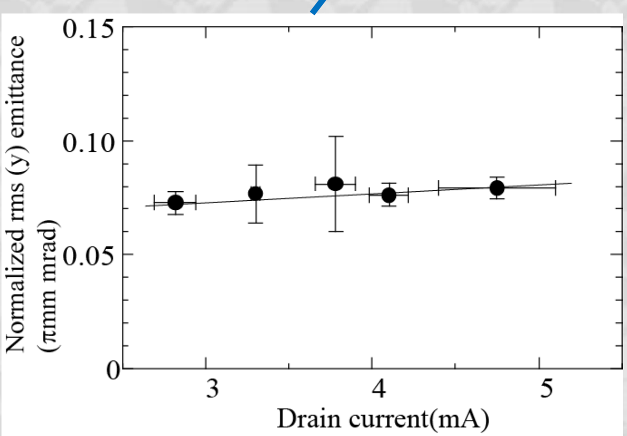


B_{ext} effect (28GHz) (II)

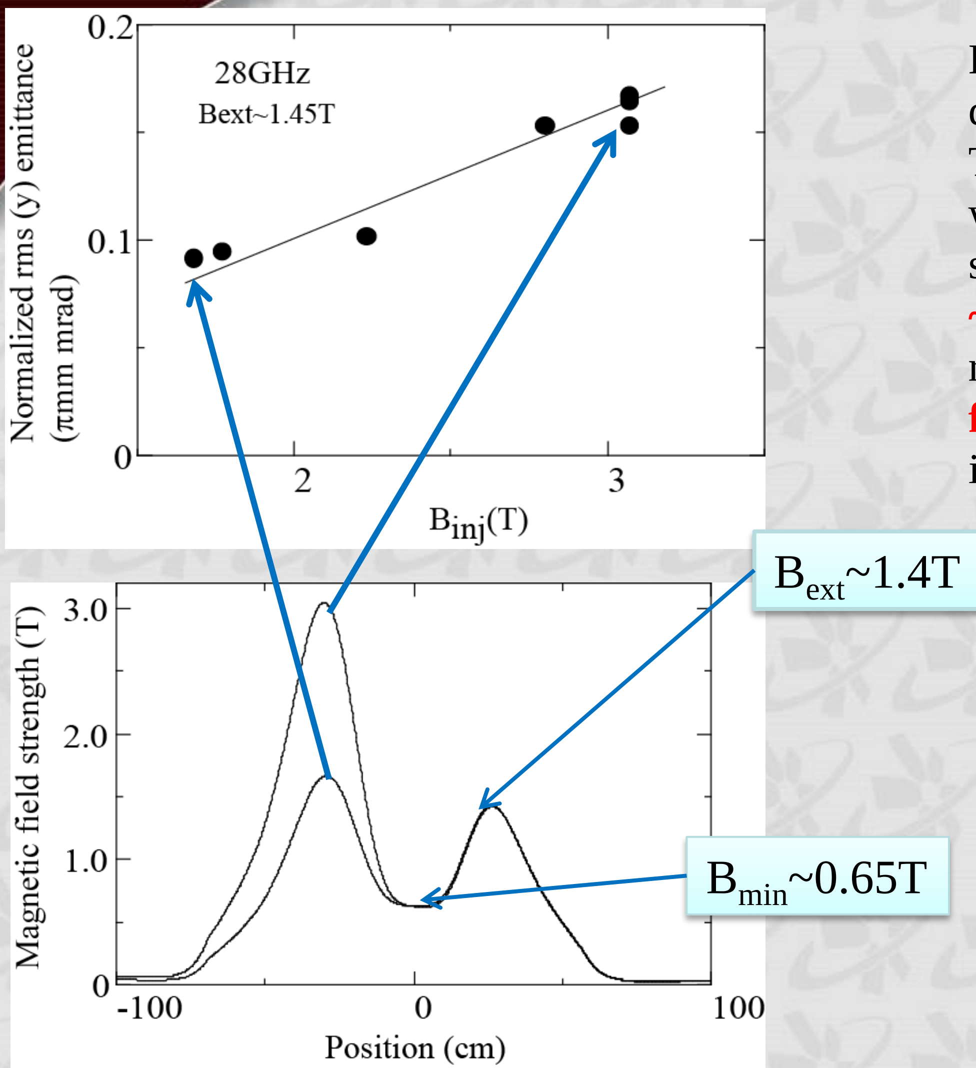








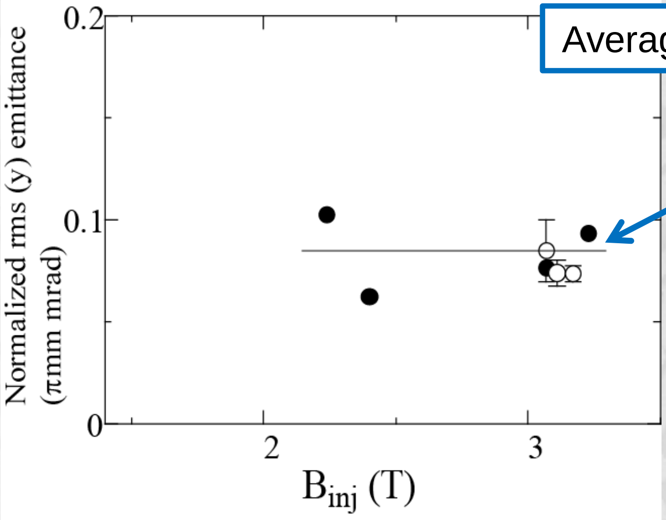
B_{inj} effect(28GHz) (I)



Lower figure shows the magnetic field distribution for investigating the B_{inj} effect. The B_{inj} was changed from ~1.5 to 3.1T, while keeping the other magnetic field strength (**B_{ext} ~1.45T, B_{min} ~0.65T, B_r ~1.8T**). Upper figure show the results of rms y-emittance. The emittance **increased from ~0.09 to ~0.17 π mm mrad** with increasing the B_{inj}.

It is noticed that the B_{ext} in this figure was much lower than that the usual magnetic field strength (so-called “high B mode operation”) to produce intense beam of highly charged heavy ions.

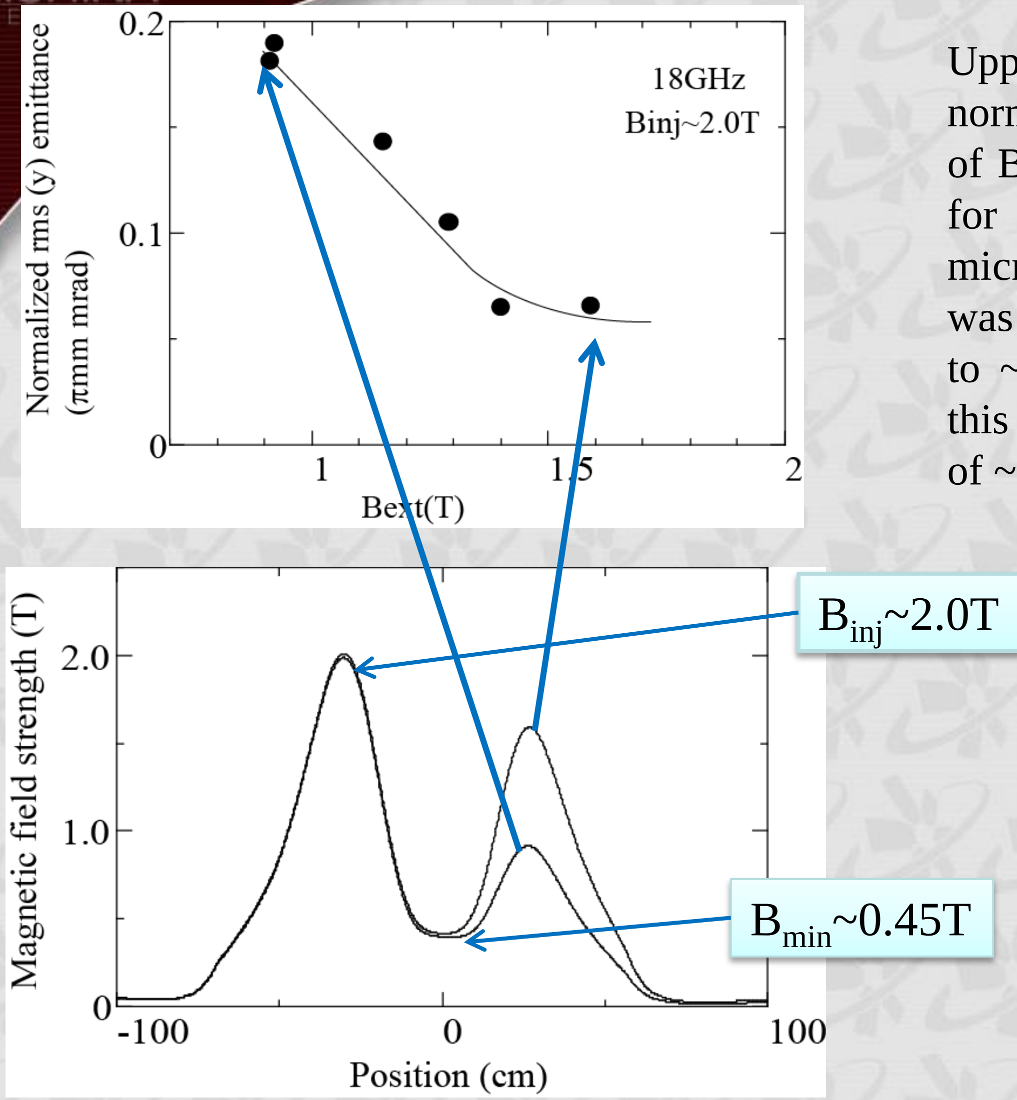
B_{inj} effect(28GHz) (II)



Averaged rms emittance was 0.08π mm mrad

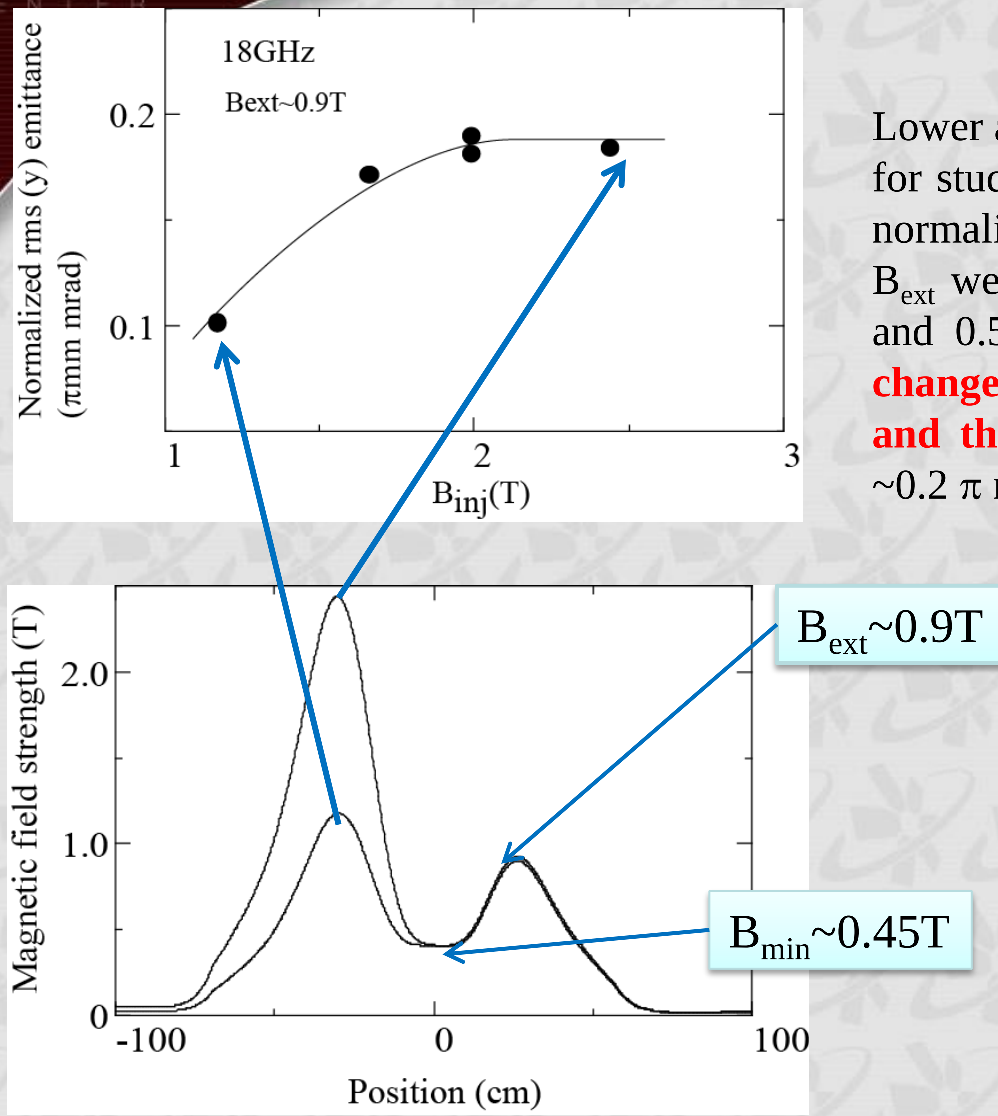
If we take **High B mode operation (B_{inj}~3.1T, B_{min}~0.65T, B_{ext}~1.75T, B_r~1.83T)**, the emittance was almost constant and independent on the B_{inj}. In this figure, open circles are averaged emittance for B_{ext}~1.75T. The error bar (emittance spread) is the standard deviation.

B_{ext} effect (18GHz)



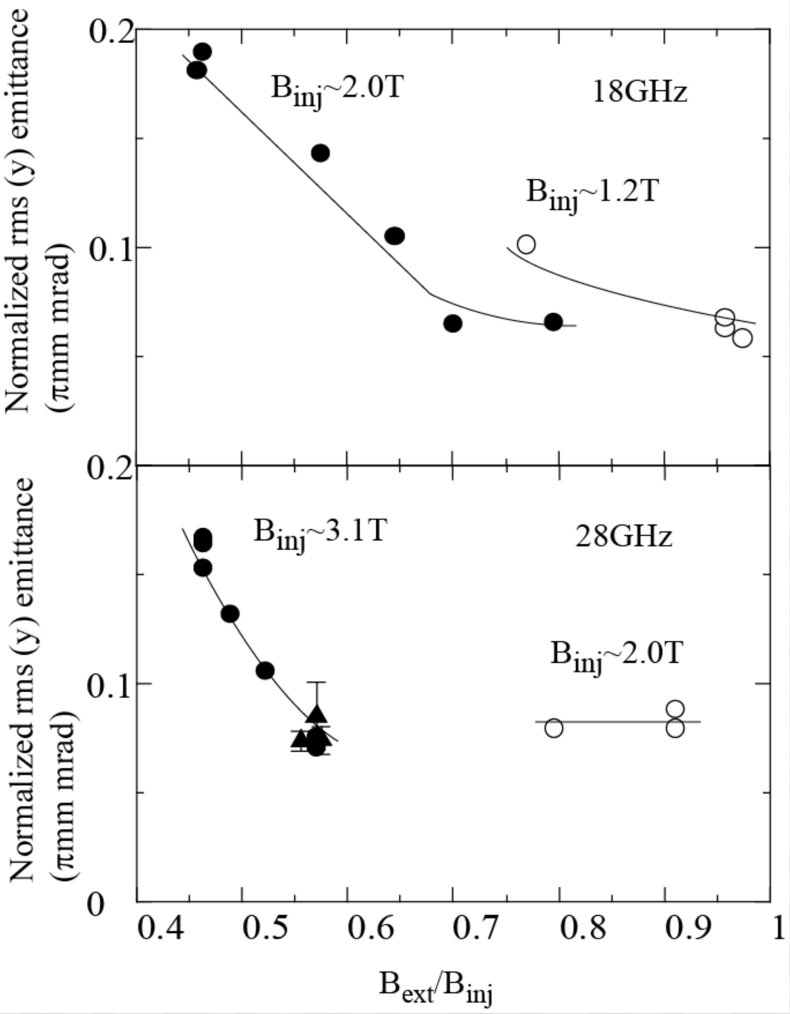
Upper and lower figures show the normalized rms y-emittance sa a function of B_{ext} and the magnetic field distribution for studying the B_{ext} effect with 18GHz microwaves, respectively. The emittance was decreased with increasing the B_{ext} up to ~1.4T and saturated above ~1.4T. In this experiment, the minimum emittance of ~0.06p mm mrad was obtained.

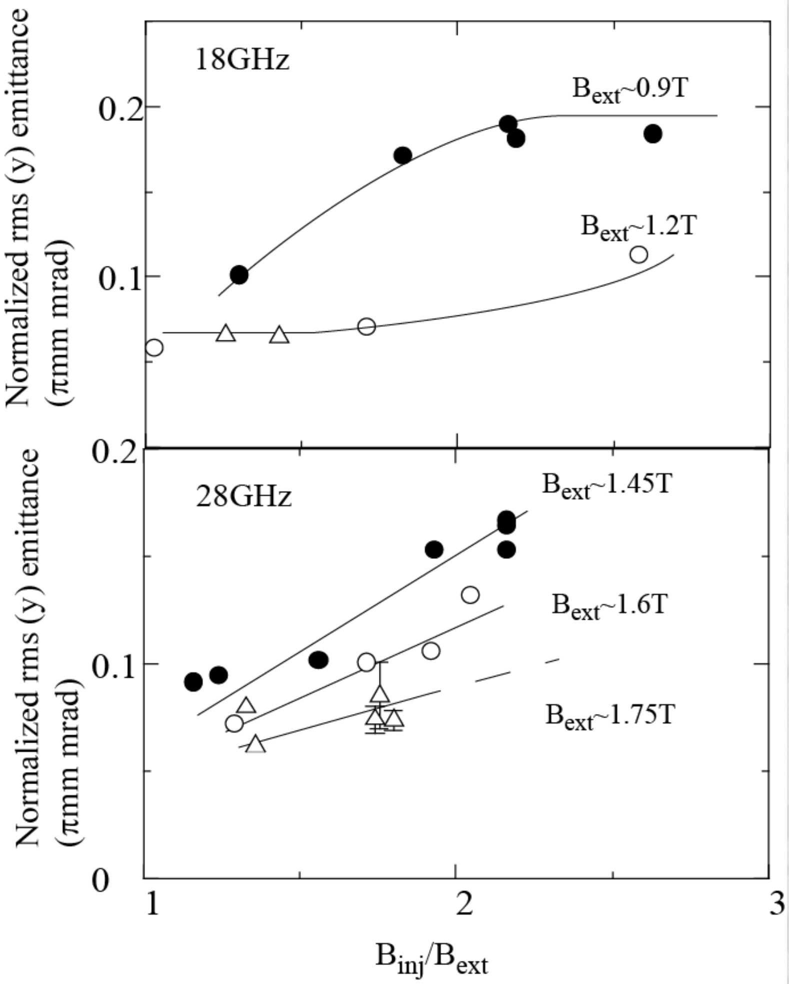
B_{inj} effect(18GHz)



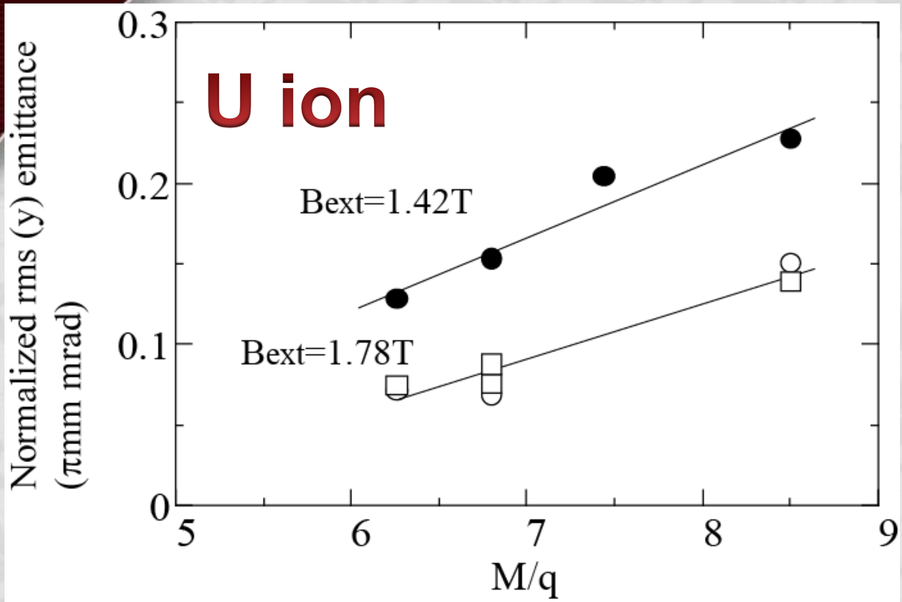
Lower and upper show the magnetic field distribution for studying B_{inj} effect with 18GHz microwaves and normalized rms y-emittance as a function of B_{inj}. The B_{ext} were fixed to 0.9T. The B_{min} was chosen to 0.4 and 0.5T for this experiment. **The emittance was changed from ~ 0.1 to ~0.2 π mm mrad up to 2T and then saturated.** The maximum emittance was ~0.2 π mm mrad.

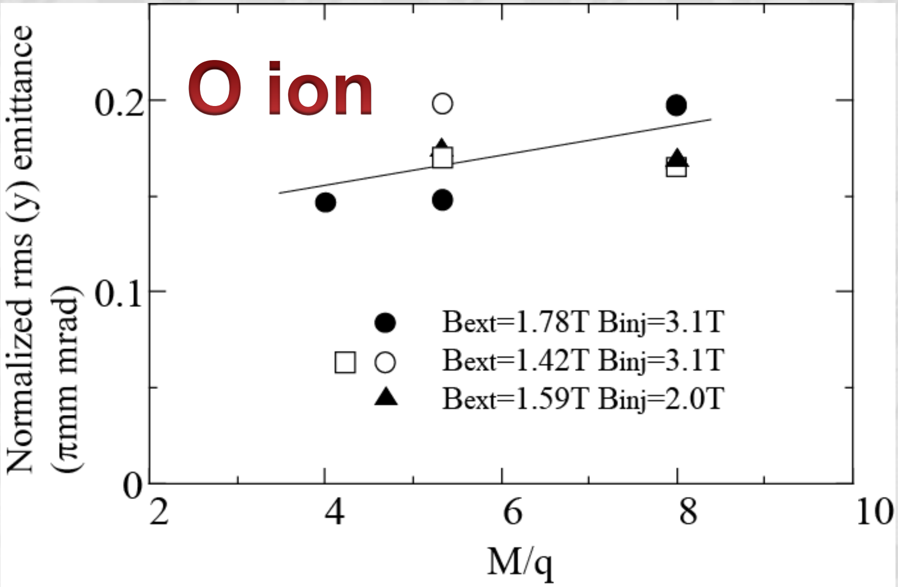
Summary (magnetic field effect)



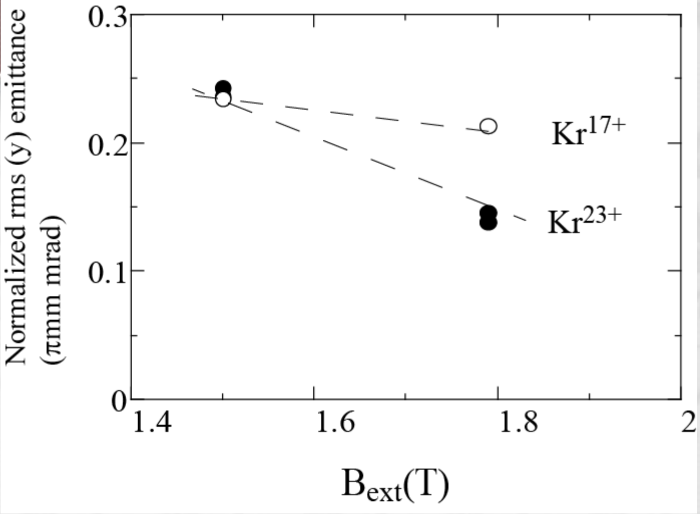


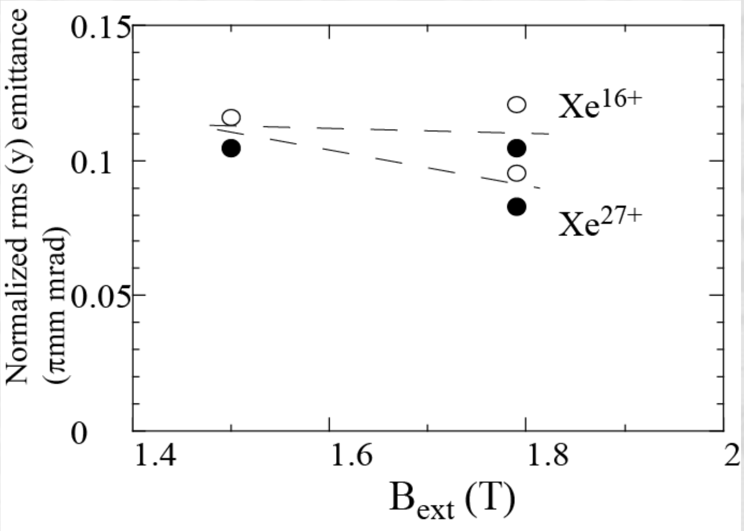
Emittance of highly charged U ion beam





Other ion species (preliminary)





In order to study the effect of magnetic field distribution on the emittance, we measured it for O, Kr and Xe ion beams. Figure 13 shows preliminary results of the normalized rms y-emittance for Kr ions as a function of B_{ext}. The B_{inj} and B_{min} are kept at ~3.1 and ~0.65T, respectively. The RF power and extraction voltage were ~1.5Kw and 22 kV, respectively. It seems that the emittance was slightly dependent on the B_{ext} for higher charge state Kr ions. Figure 14 shows the results of Xe ions. The tendency was almost same as that for Kr ion beams. We also measured the emittance of the oxygen ions. The emittanc was not dependent on the magnetic field distributions. We did not observe the strong effect of the magnetic field distributions for Kr and Xe ions.

Conclusion

1. The emittance of U^{35+} ion was not dependent on the drain current and extraction electrode position

2. The emittance of U^{35+} was strongly dependent on the magnetic field distribution
   The emittance increased with decreasing the B_{ext} for fixed B_{inj}
   The emittance increased with increasing the B_{inj} for fixed B_{ext}

3. For high B mode operation, the magnetic field effect was rather weak

4. The same tendency can be seen for other charge state of U ion beam (25+ ~38+)

5. For lighter heavy ions, such as Xe, Kr and O ions, preliminary experimental results did not show the strong effect of the magnetic field distributions like U^{35+} ion beam.

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To understand this phenomenon, We need further investigation.

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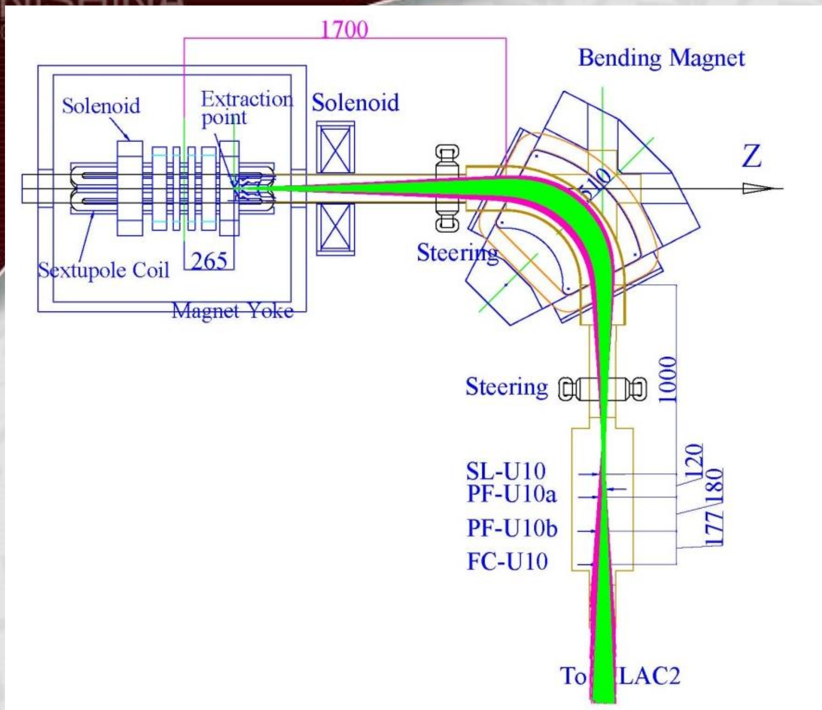
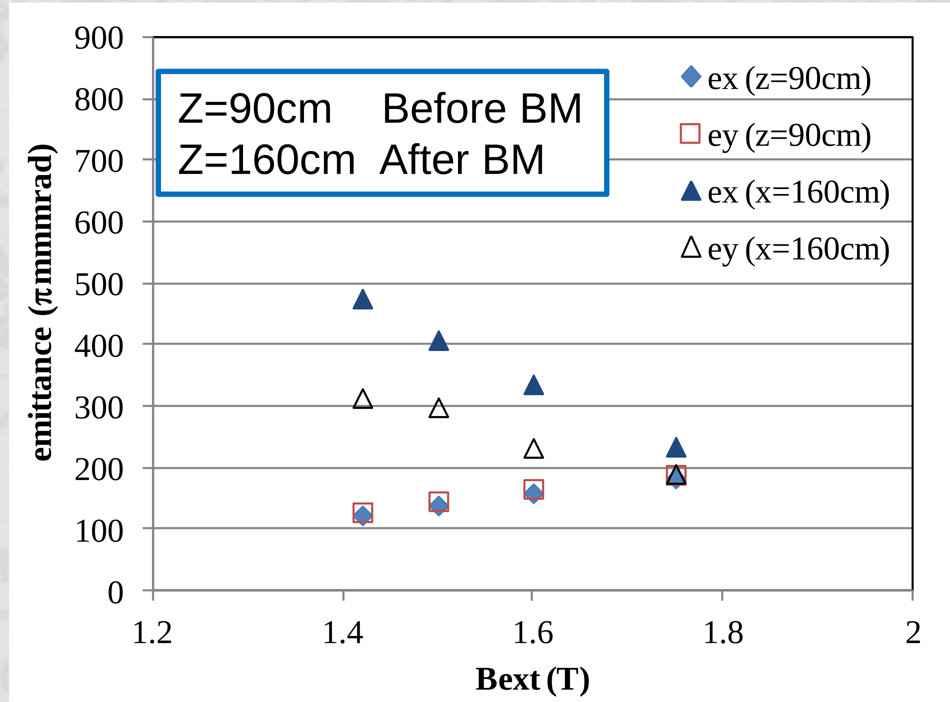
Thank you for your attention!

Simulation (preliminary)





	O^{2+}	O^{3+}	O^{4+}	U^{34+}	U^{35+}	U^{36+}
μA	300	300	300	100	100	100

OPERA3D SCALA
Include Space charge effect

Aberration of BM enlarge the emittance.