Beam dynamics study of the vFFA electron model at Kyushu University

Kyosuke Adachi
Kyushu University

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KYUSHU UNIVERSITY

Outline

- Introduction
- Purpose
- Injection Simulation
- Measurement
- Summary

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Demands for high intensity and high energy hadron accelerators are strongly increasing in various fields recently.

Harmonytron[*1]

Fixed magnetic field
- ➢ Rapid cycle

Fixed rf frequency
- ➢ Continuous beam acceleration

Focusing system
- ➢ Strong focusing

Large turn separation
- ➢High efficiency for beam extraction

Our group is aiming to realize the Harmonytron that can efficiently accelerate high intensity hadron and muon.

*1 Y. Mori, Y. Yonemura and H. Arima : "A Proposal of Harmonictron", Mem. Fac. Eng. Kyushu Univ., Vol. 77, No. 2, pp. 1-13 (2017).

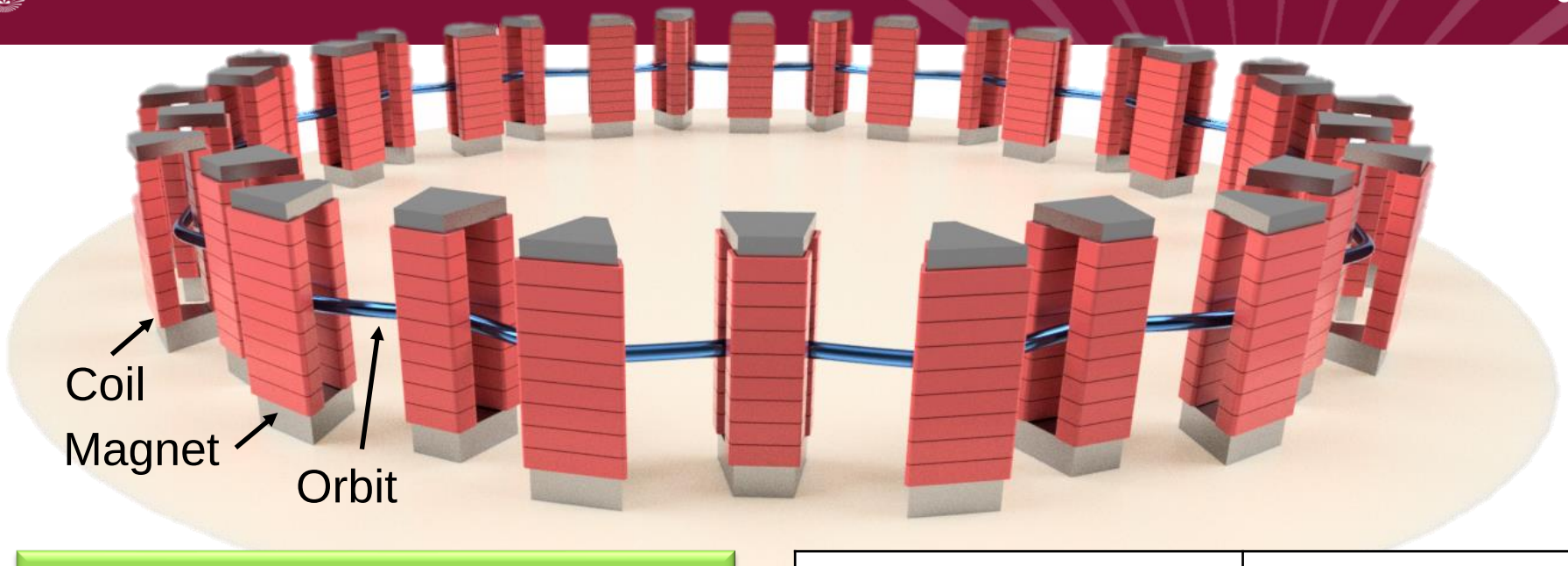
Harmonytron

- Acceleration method
  - Harmonic Number Jump
- Focusing system
  - Vertical FFA accelerator

A research of the vFFA has been carried out at various institutes.

At Kyushu university...

A design study and construction of the vFFA electron model aiming beam acceleration has been carried out.



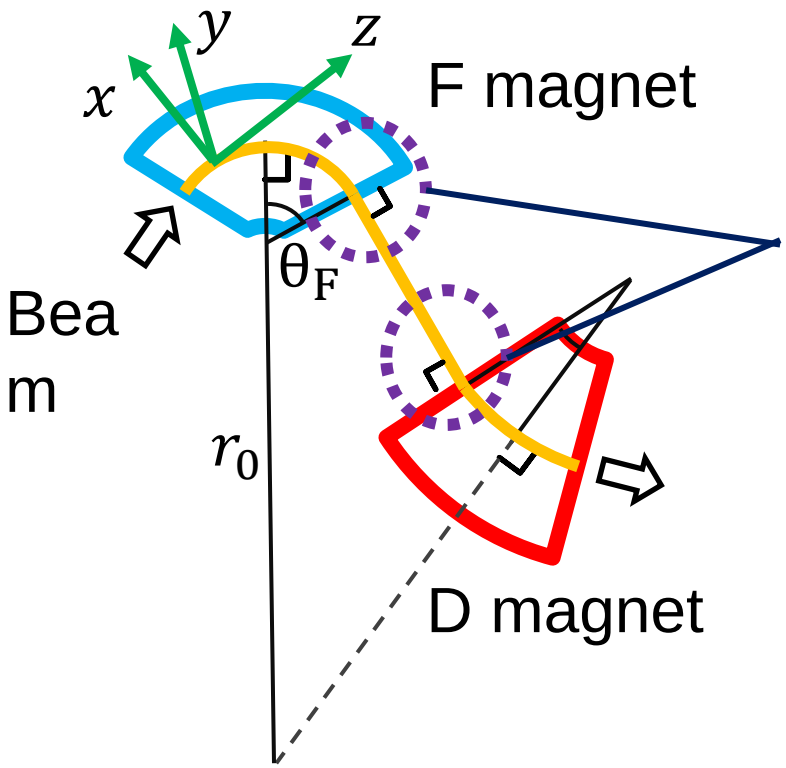
vFFA electron model

Focusing system	F-D Singlet
Number of cell	16
Magnet	Sector
Injection energy	20 [keV]
Maximum energy	40 [keV]
Radius	1.0 [m]

Development and Proof-of-Principle Experiment of the vFFA electron model is goal in our study.

Magnet of vFFA electron model

Focusing system	F-D Singlet
Magnet	Sector

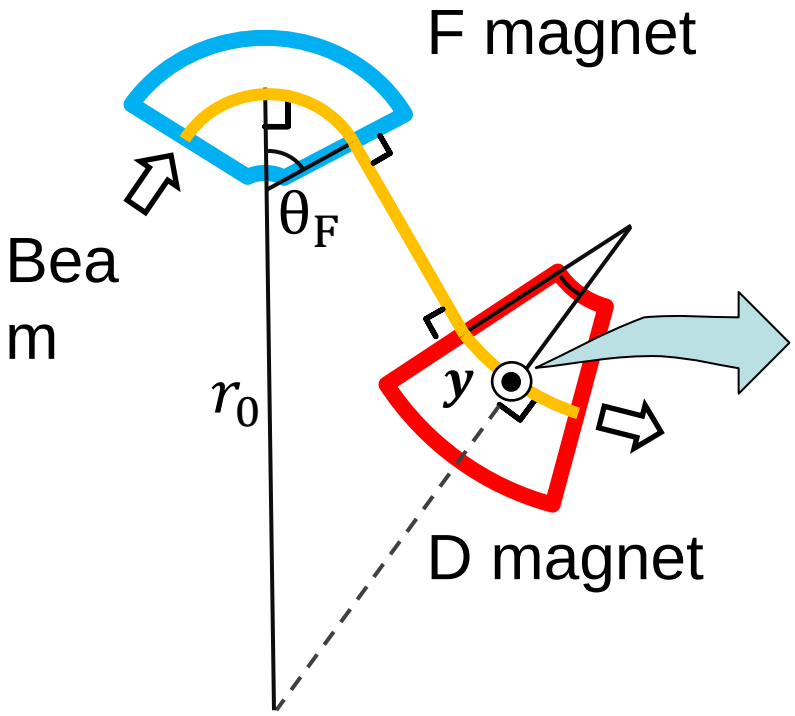


Advantage

1. Edge angle is 0.
2. Vertical kick is negligible.
   $\rightarrow B_x$ and B_z of fringing field = 0
3. Design orbit would be closed.

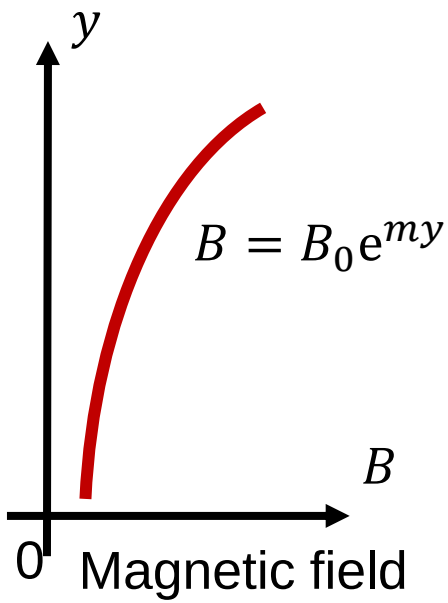
Magnet of vFFA electron model

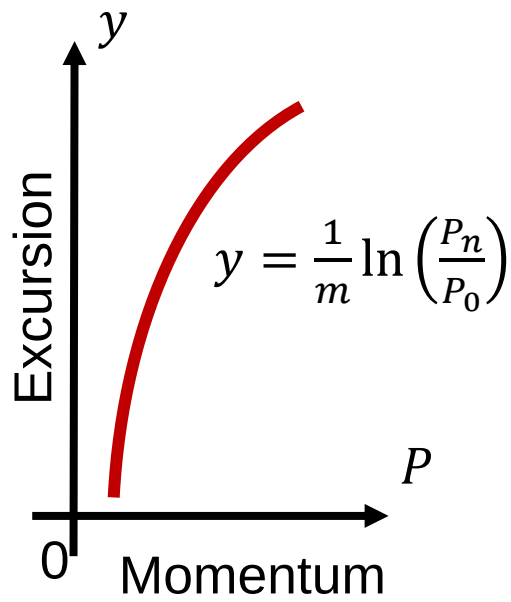
Focusing system	F-D Singlet
Magnet	Sector



Magnetic field of vFFA

$B = B_0 e^{my}$ m : field gradient





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Purpose

Beam injection using electron gun and acceleration

Simulation

- Calculation of beam emittance from electron gun with CST. *2
- Acceleration of the beam from electron gun.

Measurement

- Measurement of the performance of electron gun.

*2 CST Studio Suite, http://www.cst.com

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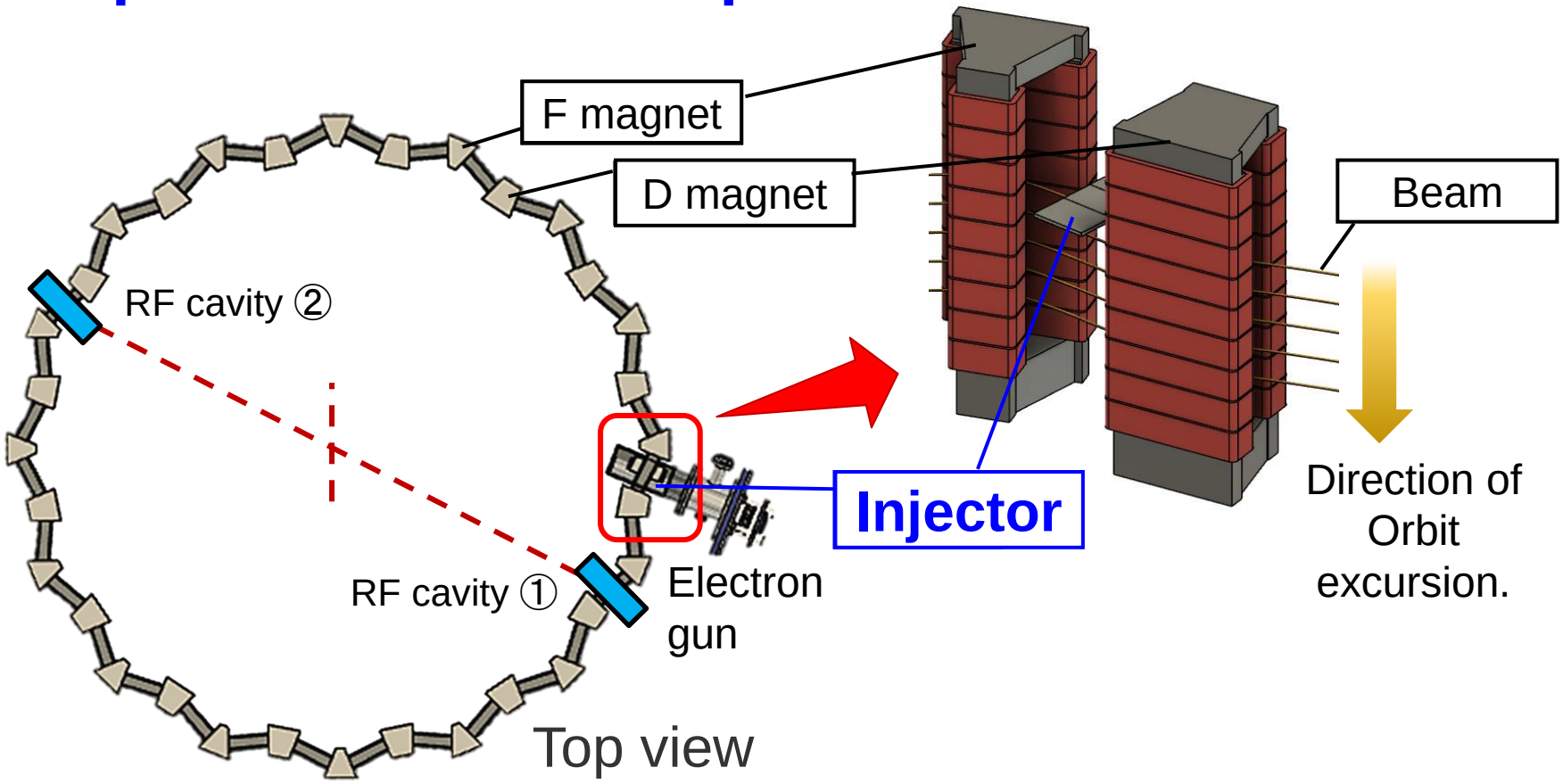
Development of each component

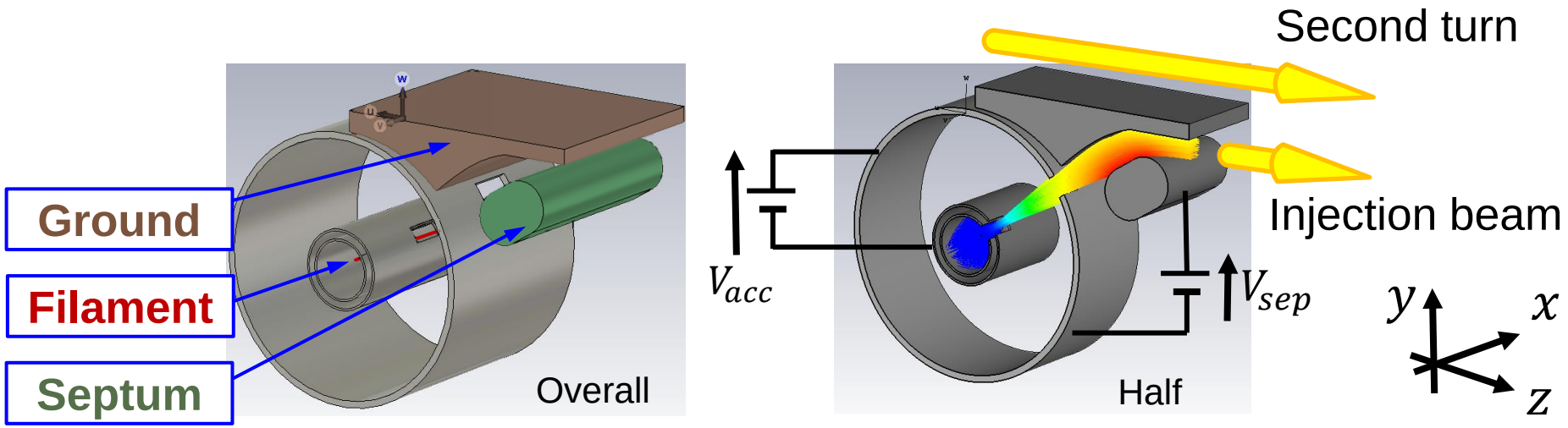


- The beam vertically moves downwards with acceleration in the vFFA electron model.
  →The m-value means negative.

Injector (Electron gun)

- Filament material is tungsten or tantalum.
- Target emission current is 100μA.
- V_{acc} represents the acceleration voltage.
- V_{sep} represents the septum voltage.
- Consists of filament, ground and septum electrodes

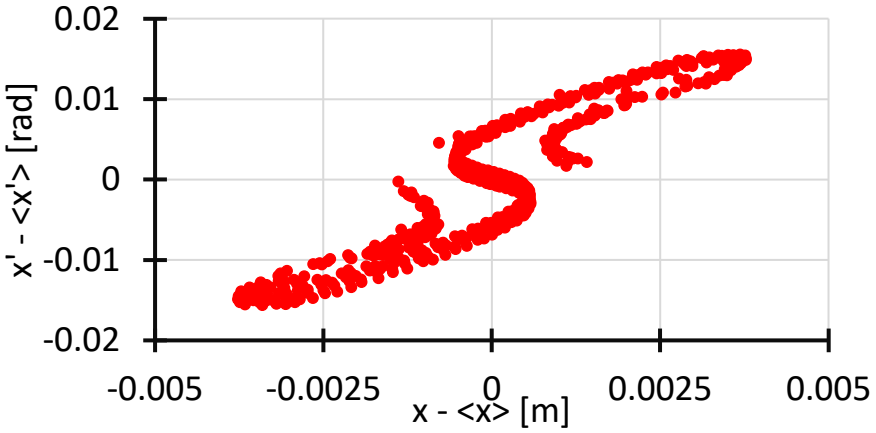
Type	Thermionic electron emission
Filament	W or Ta ($\Phi 0.3$ wire)
Current	100 μA
Temperature	~2000 K
Energy	20keV

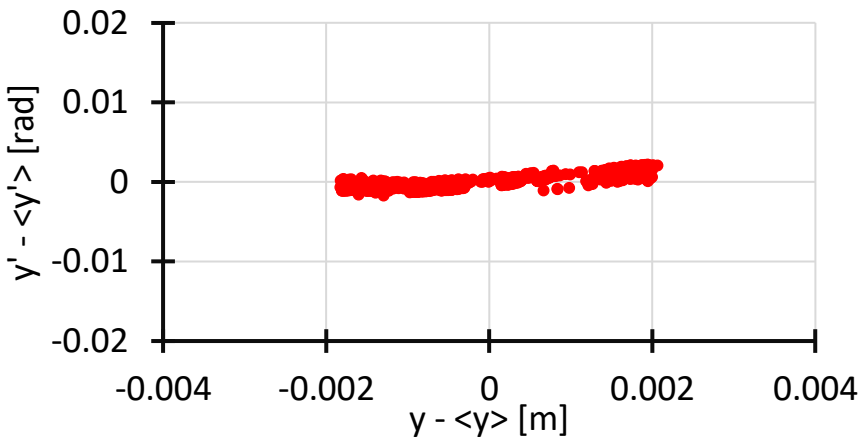


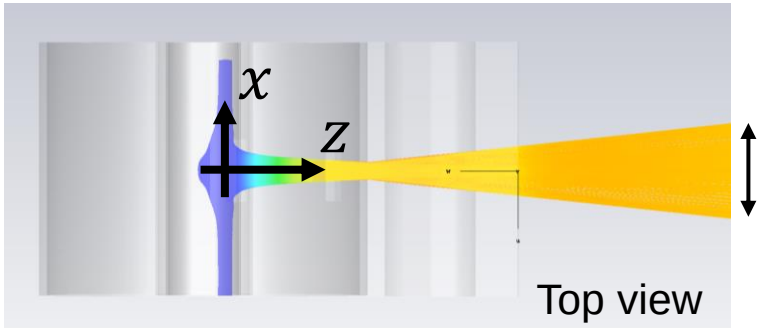
Schematic of electron gun and beam orbit

Injection beam emittance

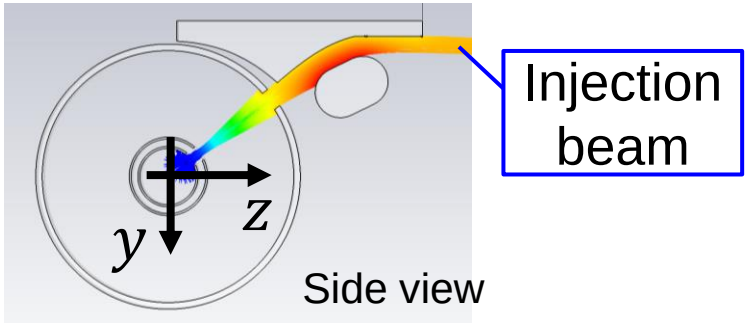
- The emittance of the injection beam obtained using CST is shown below.







Horizontal (x)



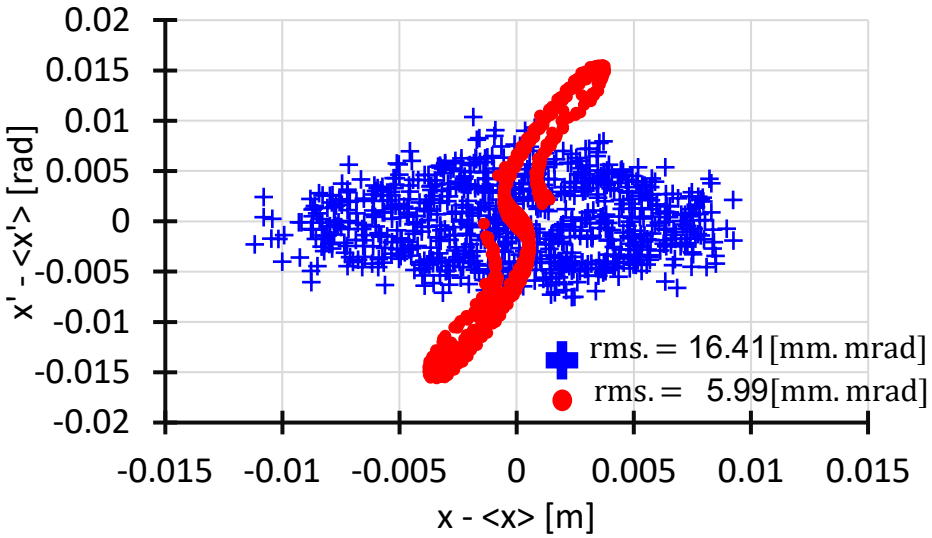
Vertical (y)

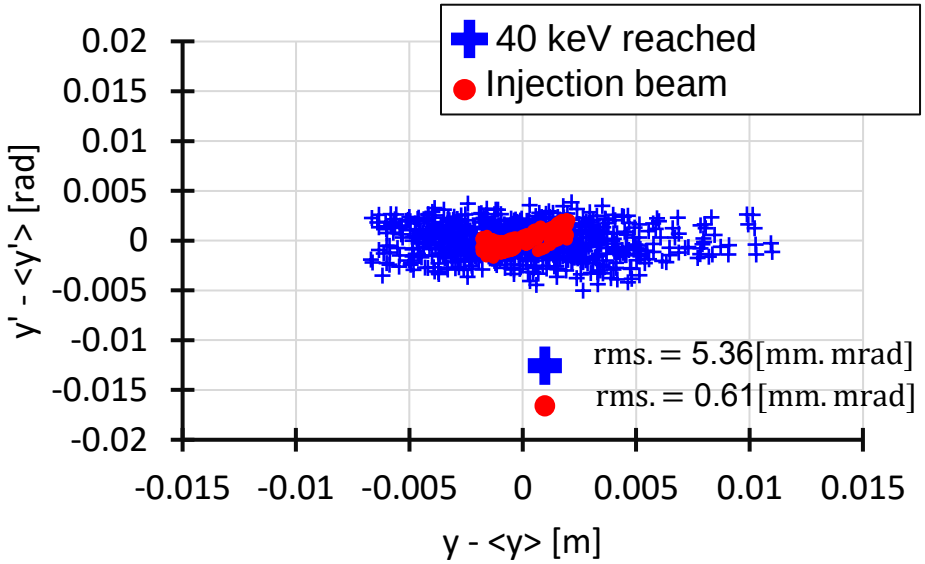
Characteristics

- Large horizontal spread and small vertical spread beam
- The beam has a width of 4mm for y-direction.

Comparison

- The injection beam emittance was compared with the acceptance of electrons that can reach up to 40 keV.





- Horizontal
  - Region of large angles is outside the blue region
  - Significantly affects injection efficiency
- Vertical
  - Exists within the blue region

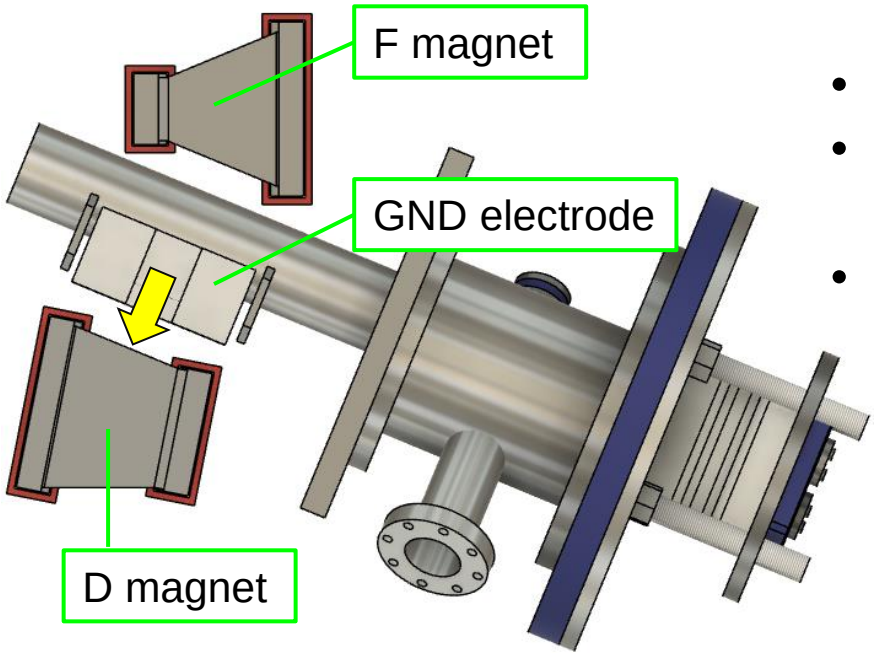
Acceleration

Injection conditions

Energy	20 keV
V_{acc}	-19.0 kV
V_{sep}	6.3 kV
position	On the closed orbit

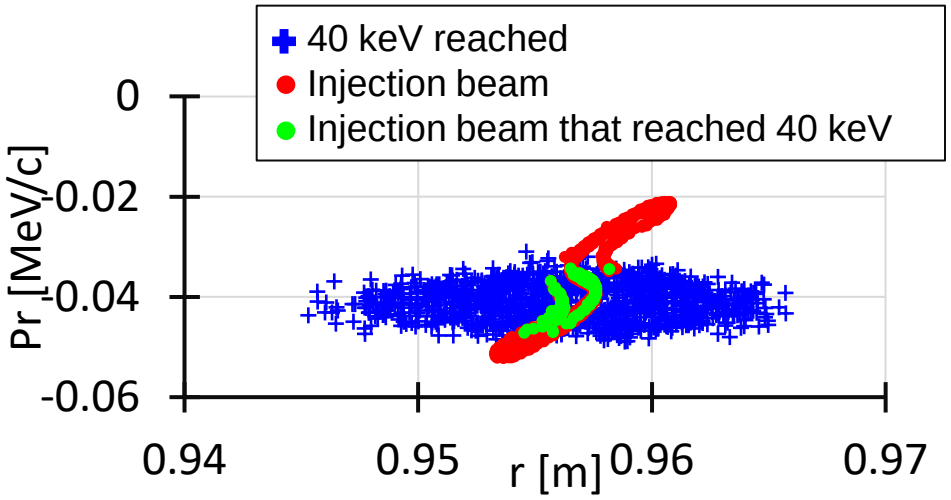
RF cavity conditions

V_g	200 V/cavity
Φ_s	30 deg.
accelerate	20→40 keV

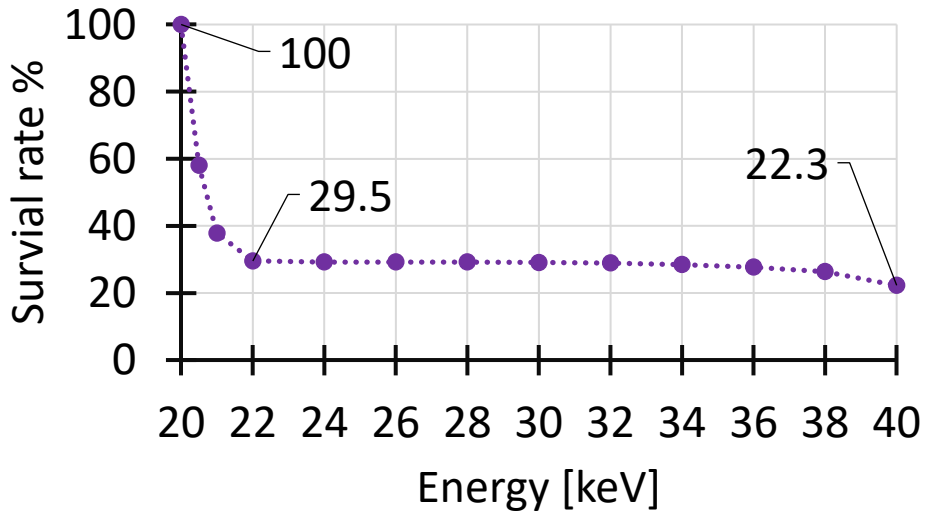


- The average energy is set to be 20 keV.
- The injection position is the same as the 20 keV closed orbit position.
- ↙ represents a direction of injection beam.

Result of acceleration



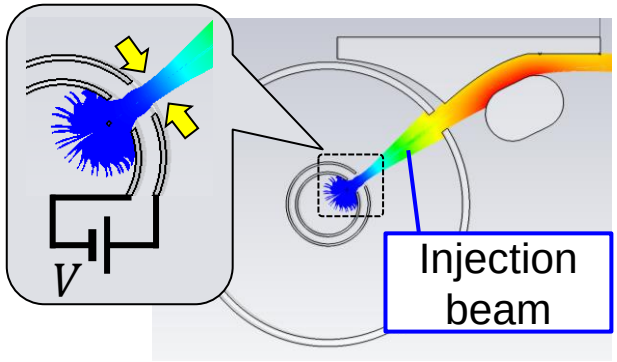
- Plot of injection emittance overlaid on blue region.
- Green marker shows particles that reached to 40keV.
- These particles exist within only the blue marker area.

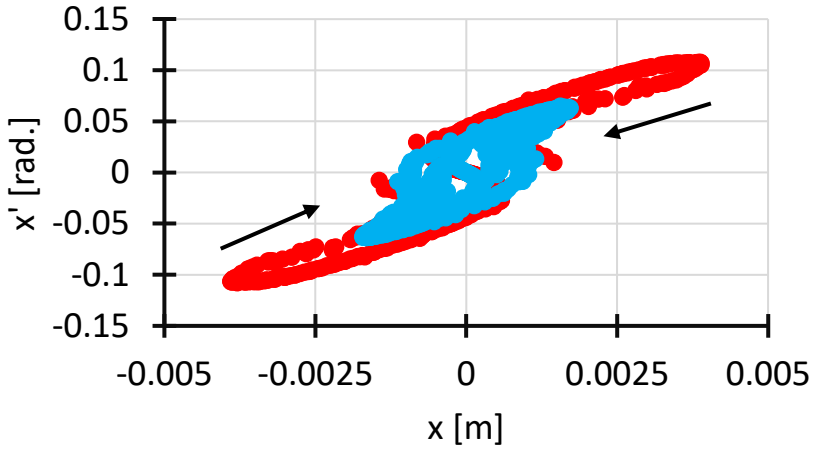


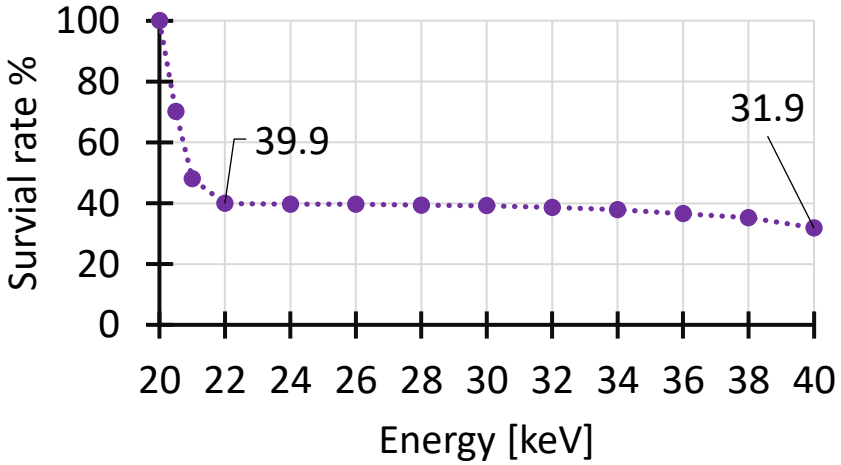
- The survival rate is calculated with the number of particles at the time of injection at 100%.
- Survivability decreases at 20-22keV and 38-40keV.
  → Large decrease at 20-22keV
- The cause is considered to be the large radial direction spread and size of dynamic aperture.

Beam matching

- Generates an electric field with the effect of a lens「⇨」in the path of the beam inside the electron gun.
- Calculated as $V = -400V$.







- The radial angular spread is suppressed.
- In survival rate, overall improvement was observed (22.3→31.9%).

- Further improvement is future tasks.
  → Injection conditions, Dynamic aperture, …

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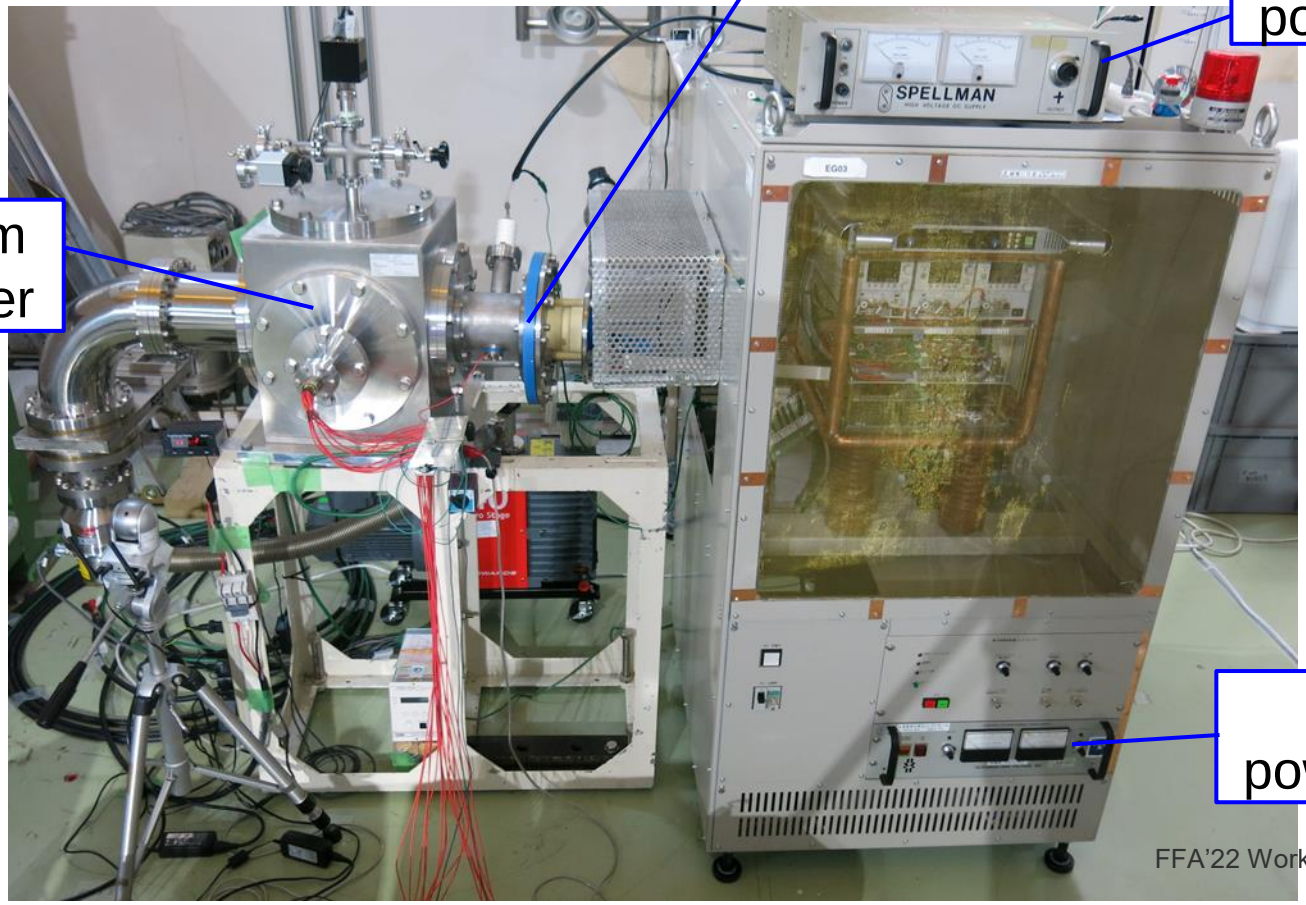
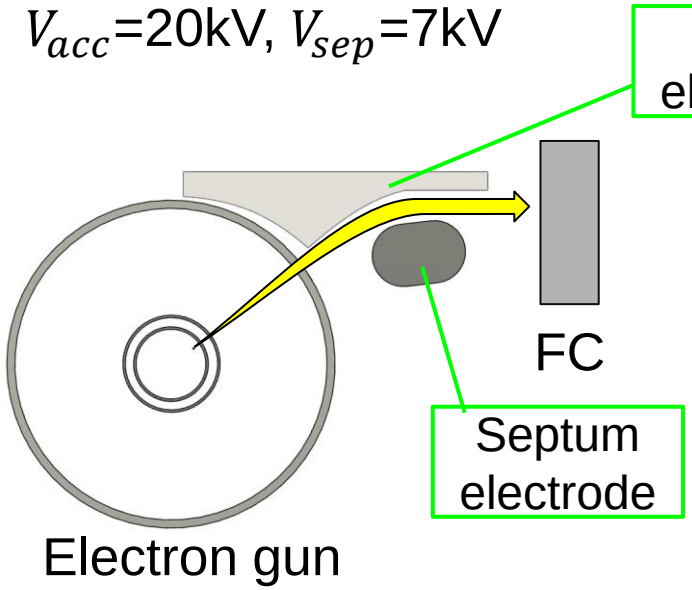
Measurement

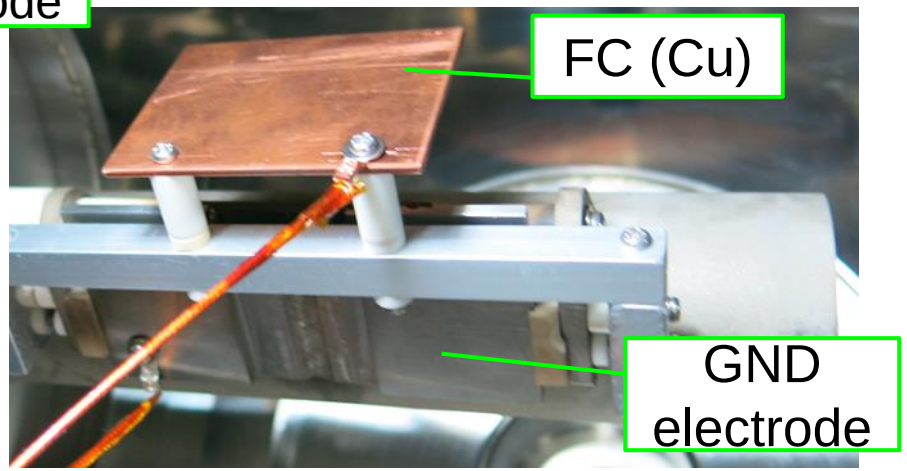
- Performance evaluation experiments on the electron gun have been carried out.
  ① Measurement of emission current values
  ② Beam profile
  ③ Emittance measurements

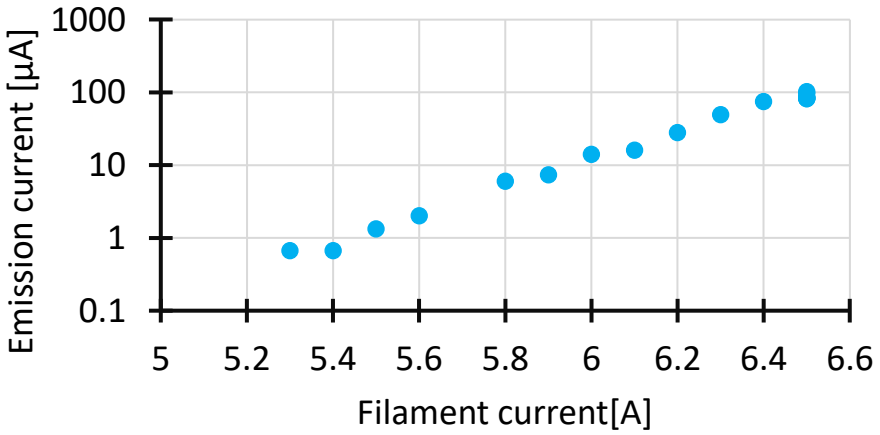


Measurement of emission current values

- Faraday Cup (FC) was installed at the electron gun exit and the current value at the exit was measured.
- V_{acc}=20kV, V_{sep}=7kV



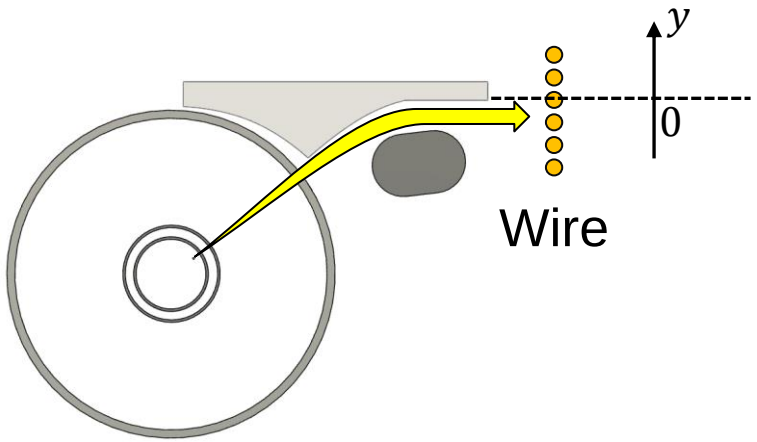


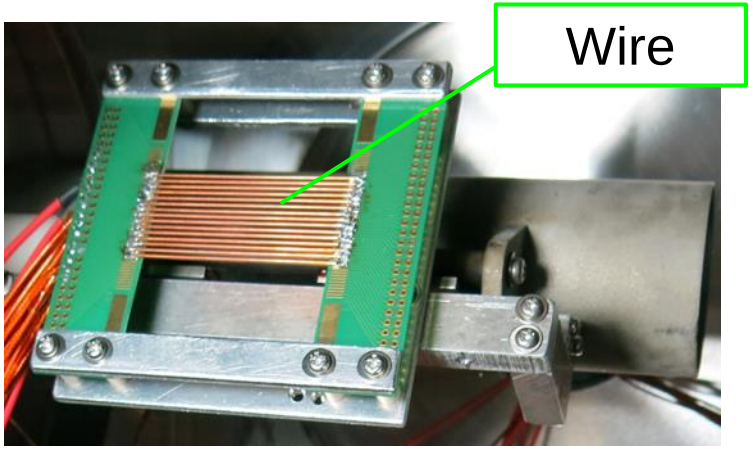


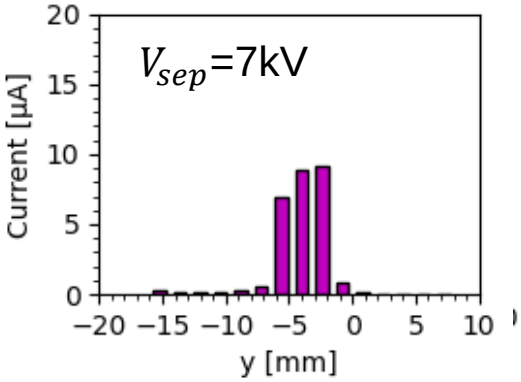
- Setting the filament current value to around 6.4 A resulted in the target emission current value of 100 μA.

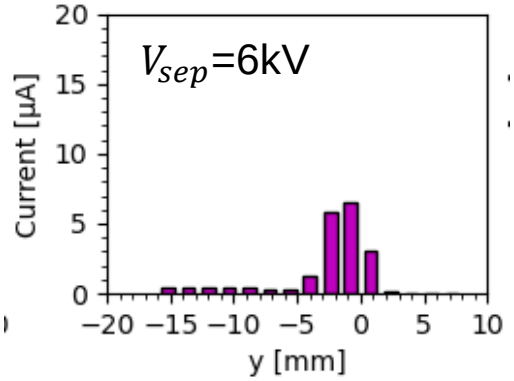
Beam profile

- Beam profile was measured in the y-direction (x-direction not measured)
- 15 points were measured at a pitch of 1.6mm using a wire of Φ1.0.
- The lower part of the ground electrode is set to y=0.





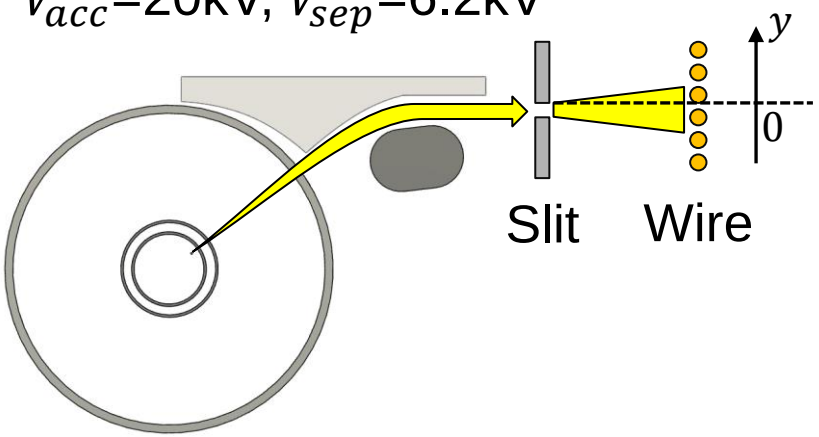


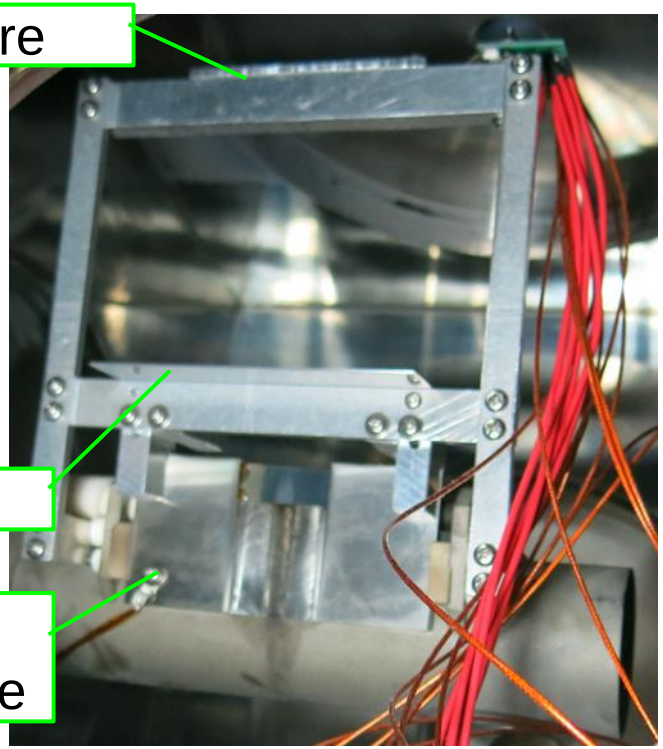


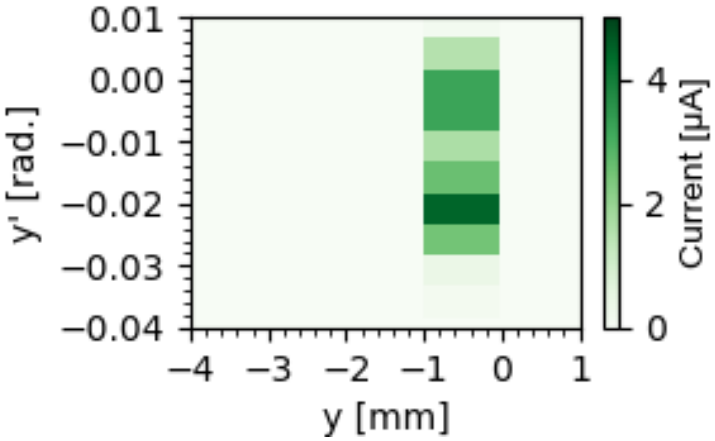
- The beam has a width of about 4mm for y-direction.
- Injection angle can be changed by changing septum voltage.

Emittance measurements

- Measurements using the single-slit method are in progress.
- The slit width was set to 1mm for the test.
- V_{acc}=20kV, V_{sep}=6.2kV







- 15 wires were arranged at a pitch of 0.5 mm.
- Distribution of 'y' was obtained.

- Plan to re-measure with narrower slit width

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Summary

Beam injection and acceleration

- ✓ Beams injected from the electron gun could be accelerated to 40 keV.
- ✓ The horizontal beam from the exit of the electron gun has a larger angular spread, causing a reduction in injection efficiency.
- ✓ By suppressing the radial spread of the incident beam, the injection efficiency can be improved.

Measurement

- ✓ Setting the filament current value to around 6.4 A resulted in the target emission current value of 100 μA.

Future plan of experiments

- ①Field measurement
  - F magnet, D magnet and Straight section.
- ②Beam transport
  - 4-cell electromagnet arrangement.
  - Injection energy range is 20 to 40 keV.
  - Measurement of beam position and Courant-Snyder parameters.