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Experimental Study of Magnetic-assisted Electrostatic Confinement

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Issues on IEC device

More Neutron Output!!

IEC Neutron Source
 $\sim 10^5$ [1/cm²/s]
 $\sim 10^8$ [n/s]



Cancer Therapy (BNCT)
 $> 10^9$ [1/cm²/s]

The Ways to Improve the Output

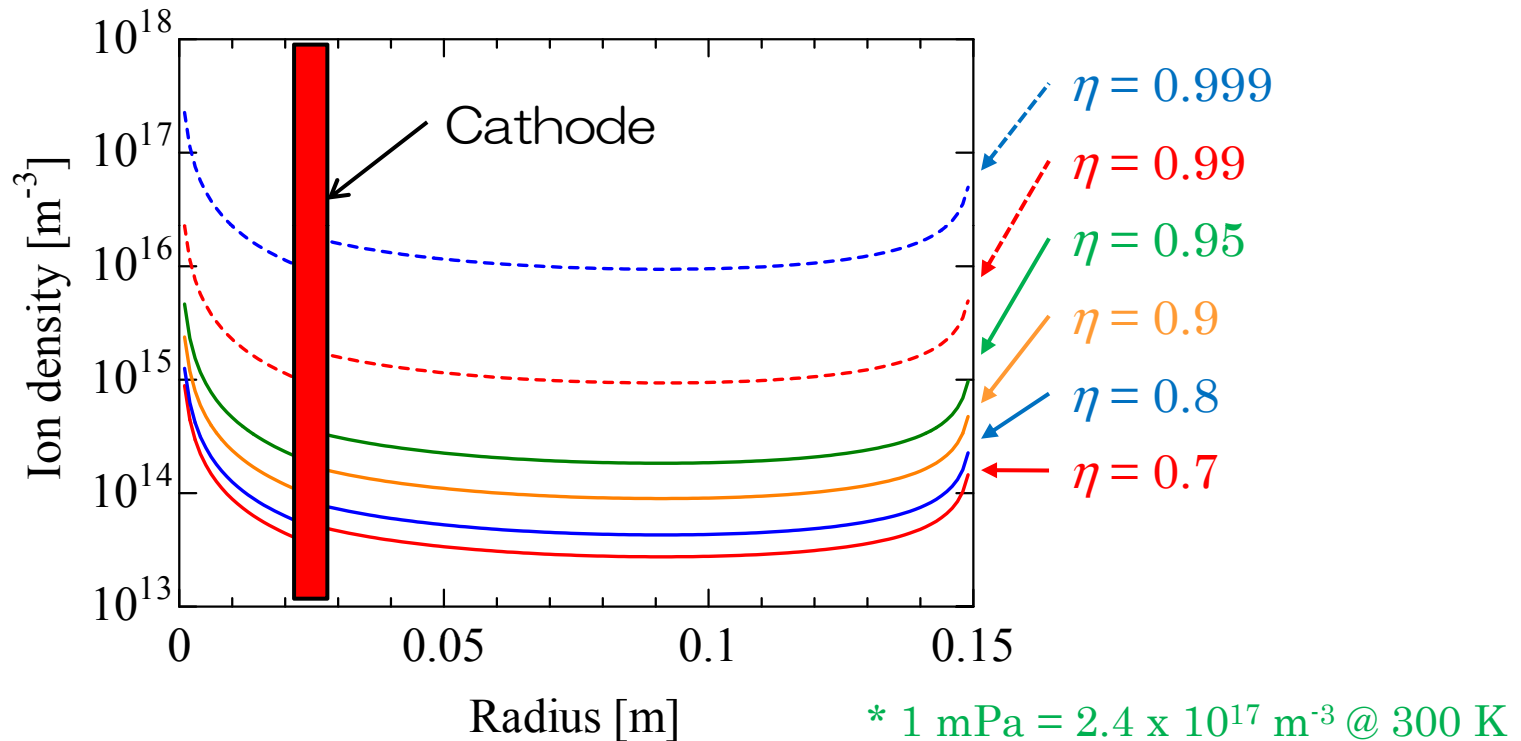
- Increase ion density
 - Not only the ion density but also cathode current increases.
 → Electrode MELTING
- Improve ion energy
 - Reducing pressure → Hard to increase ion current



- Both of the restrictions might be due to the grid system?
 - At least $(1-\eta)$ ions collide with the cathode every time they pass through it. η : Geometrical cathode transparency

Ion density vs. Cathode transparency

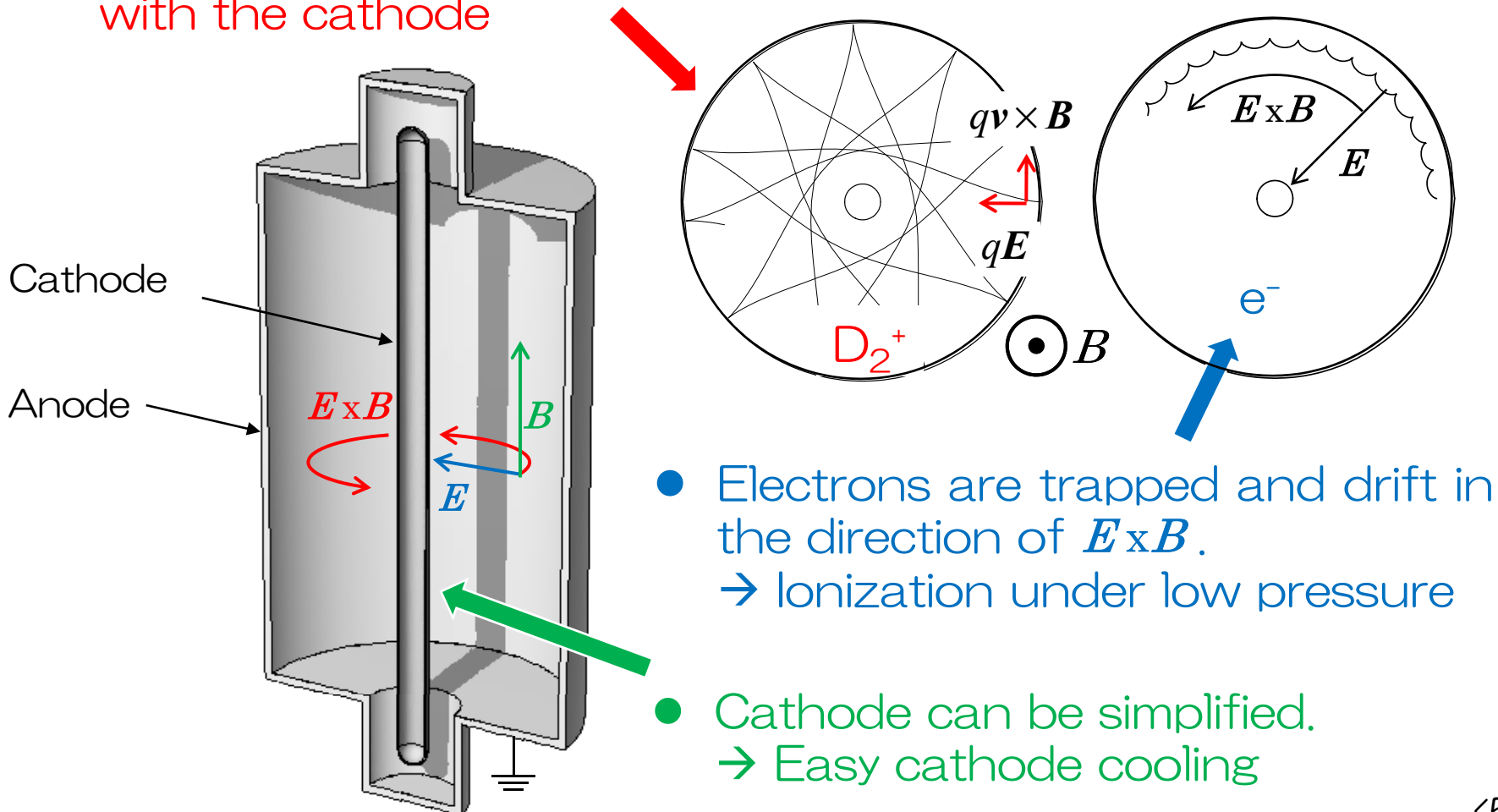
- Conditions : Vacuum potential, Cylindrical geometry, Ions only
 $I_c/h = 1.0 \text{ A/m}$, $V_c = -100 \text{ kV}$



- If the ions are controlled so that they do not hit the cathode ($\eta \sim 1$), ion density can be increased drastically even with low cathode current.

Magnetic-assisted Electrostatic Confinement

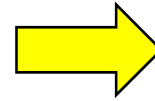
- Ion motion can be controlled by applying an appropriate axial magnetic field so that the ions can avoid colliding with the cathode



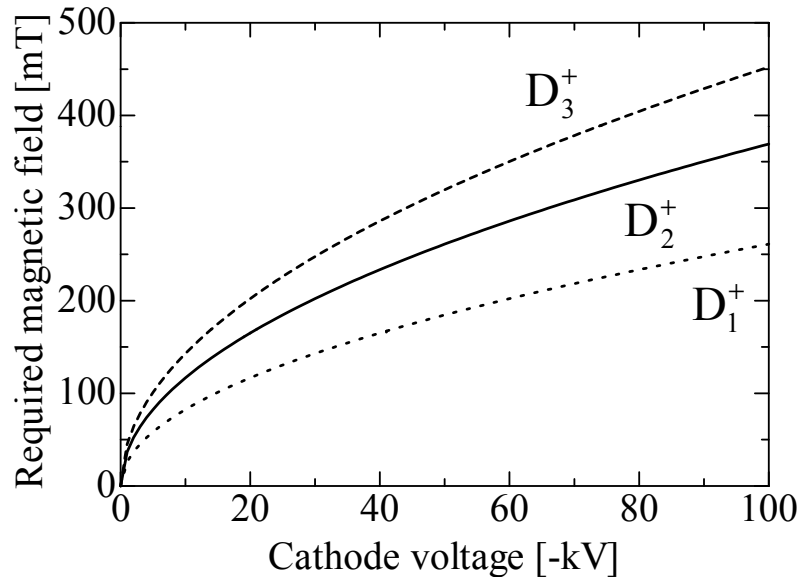
- Electrons are trapped and drift in the direction of $E \times B$.
→ Ionization under low pressure
- Cathode can be simplified.
→ Easy cathode cooling

Required Magnetic field

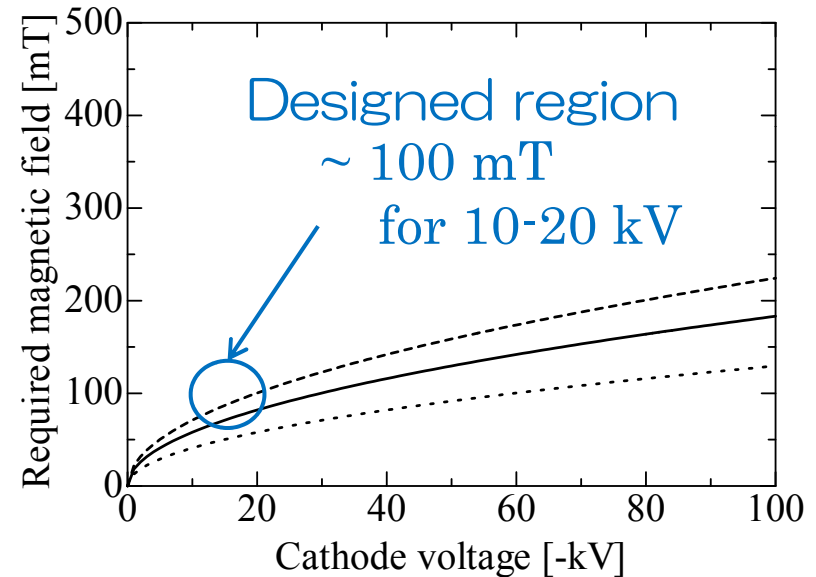
- Energy Conservation
- Canonical angular momentum conservation



$$B_{req} = \frac{r_c}{r_a^2 - r_c^2} \sqrt{\frac{8mV}{q}}$$



$r_c = 5.0 \text{ mm}, r_a = 50 \text{ mm}$



$r_c = 2.5 \text{ mm}, r_a = 50 \text{ mm}$

- Higher energy of ion, heavier ion (D_3^+), thicker cathode, and narrower anode requires higher magnetic field.

Experimental device

Electromagnet

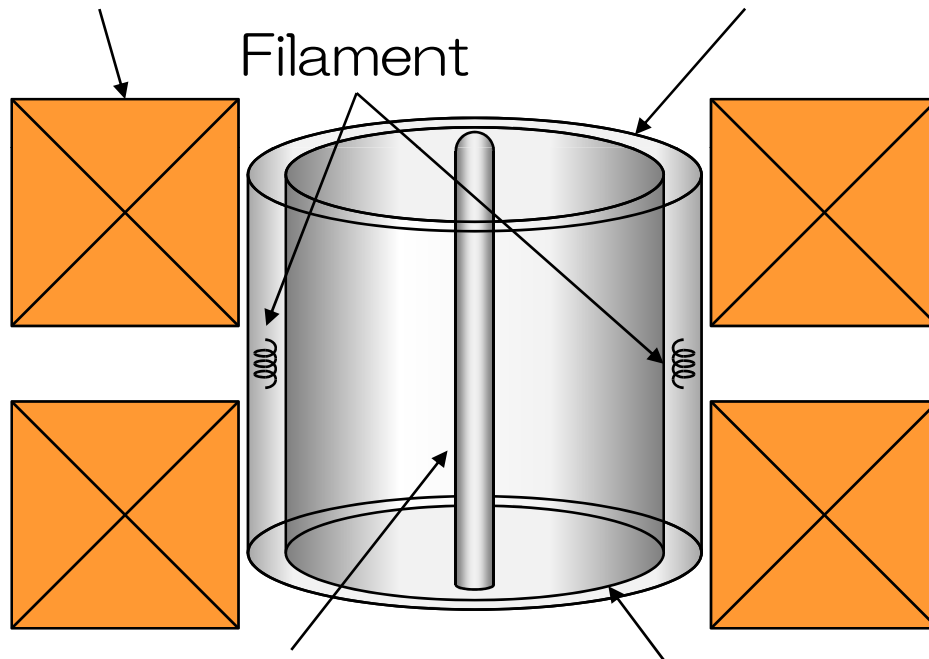
800 Turns x 10 A

→ $B_z \sim 100$ mT

Vacuum chamber

h 100 mm

ϕ 120 mm



Cathode

h 120 mm

ϕ 5 mm

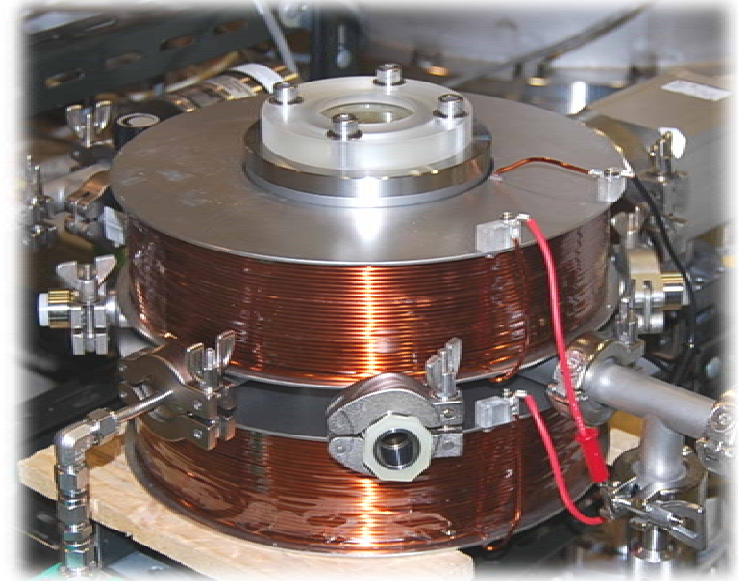
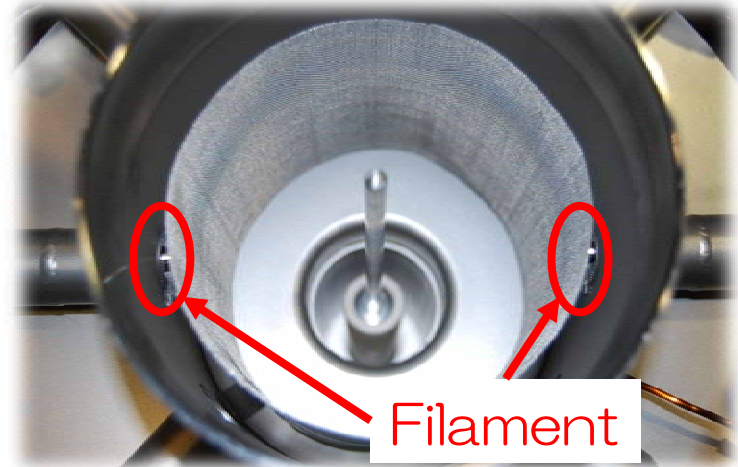
$V_c \sim -20$ kV

Mesh Anode

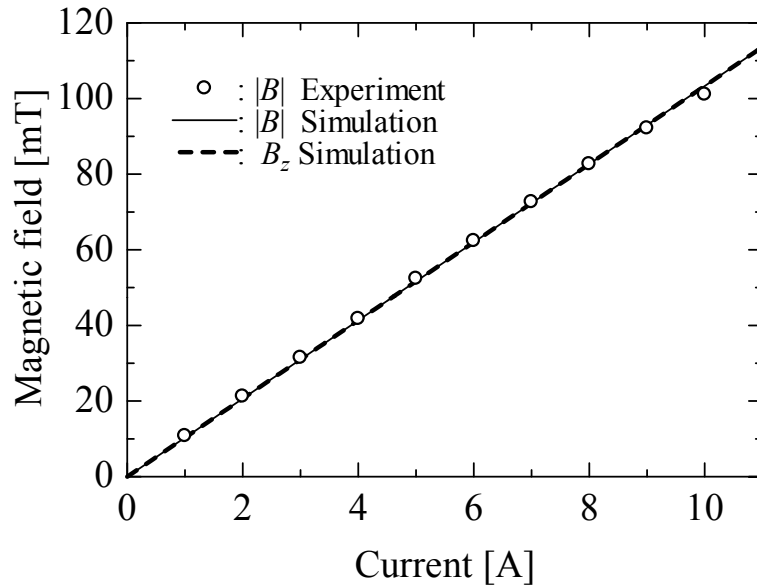
h 100 mm

ϕ 100 mm

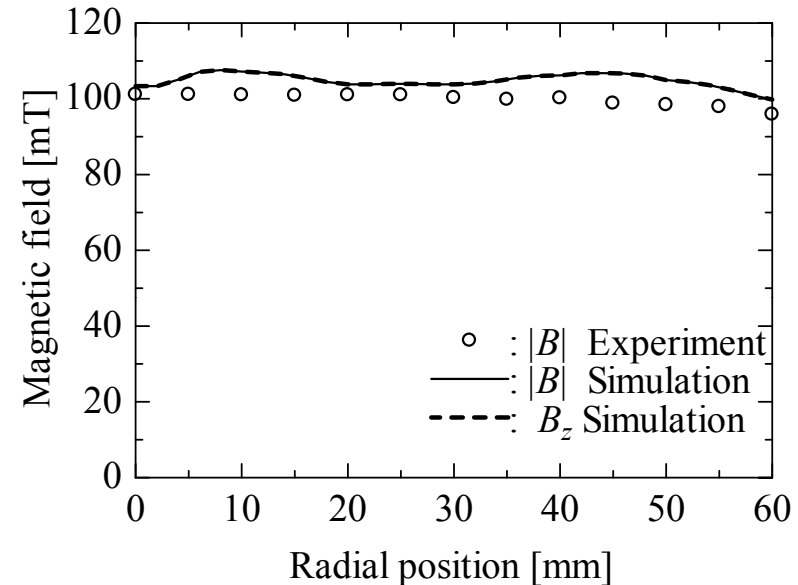
$V_a \sim -1$ kV



Confirmation of Magnetic field



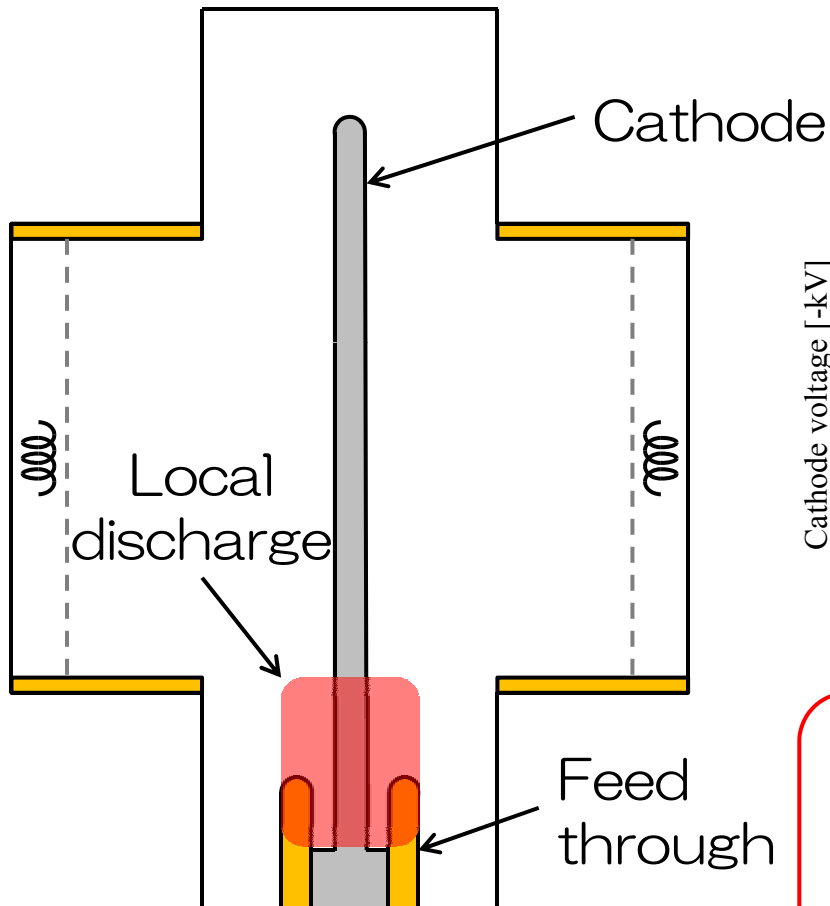
Magnetic fields vs. Coil current
($z = 0, r = 0$)



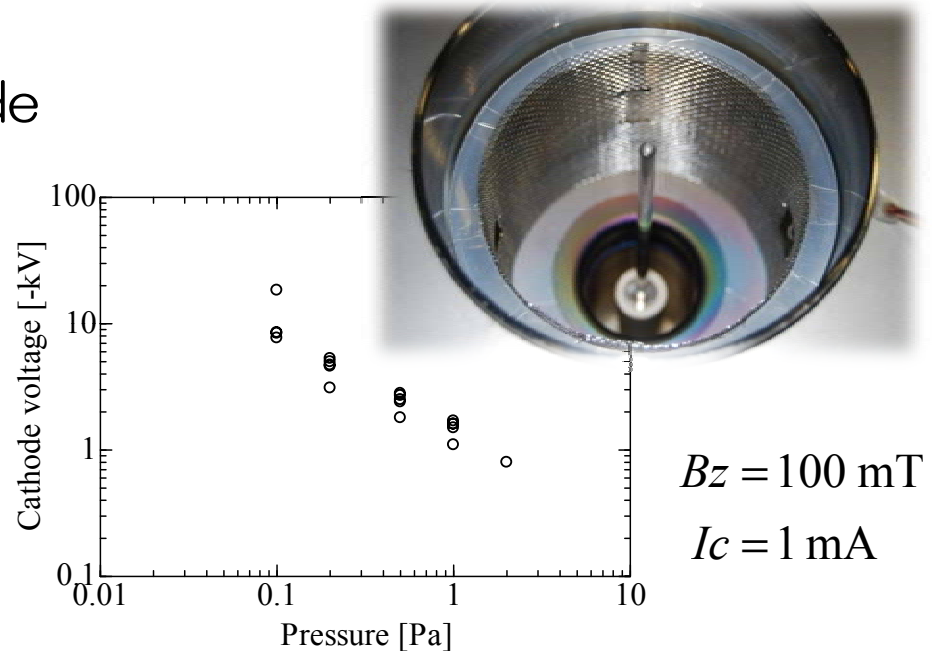
Radial distribution
($z = 0$)

- Intended magnetic field strength and distribution was obtained.
- Due to the heat of the coil (~ 540 W at 10 A), operating time is limited within 30 minutes.

Discharge mode (A)

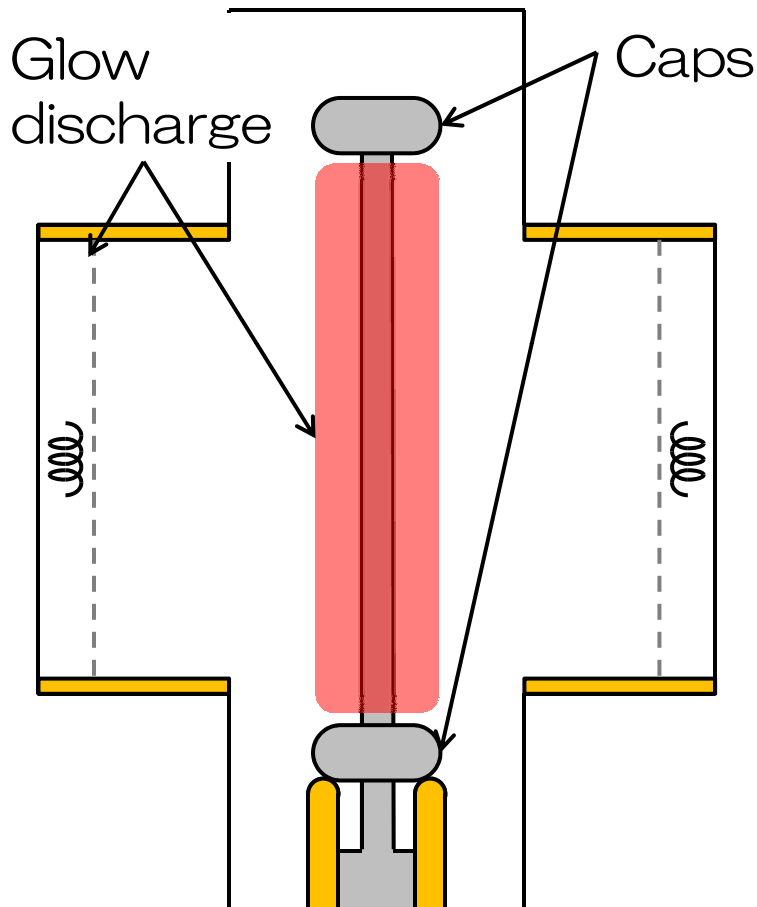


Electrode structure (A)

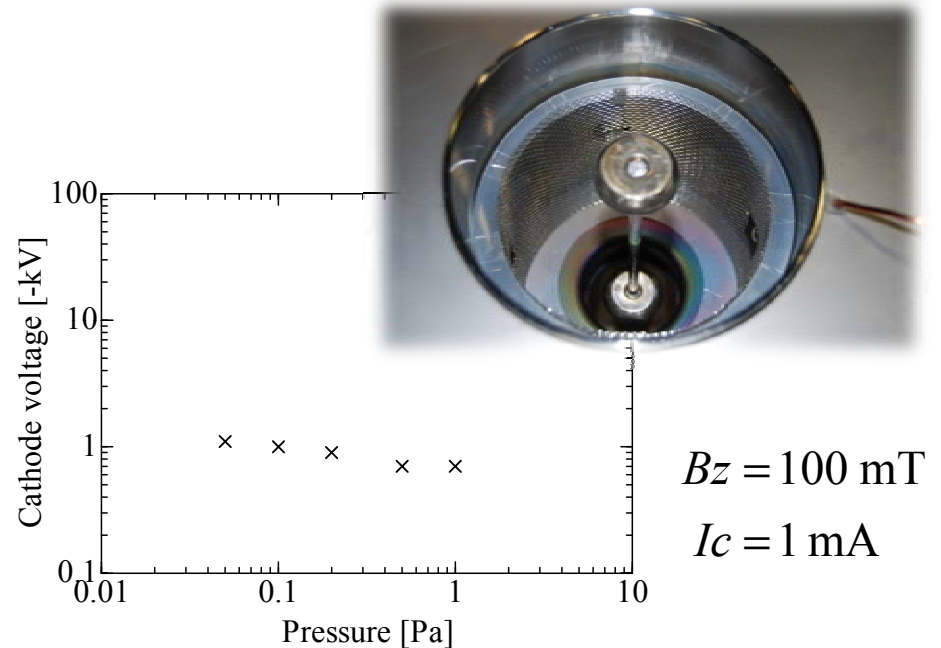


- Local glow discharge near the cathode feed-through
- Low cathode voltage to sustain the discharge
- Feed-through and cathode edge might affect the discharge

Discharge mode (B)



Electrode structure (B)
(with caps)



- Stable discharge around the whole cathode
- Lower cathode voltage to sustain the discharge

Discharge mode (A, B)

- The electrons are expected to be reflected at the caps.
 - Electrons drift in $E \times B$ (azimuthal) direction.
 - Electrons do not move in radial direction so much.

Larmor radius ~ 0.74 mm

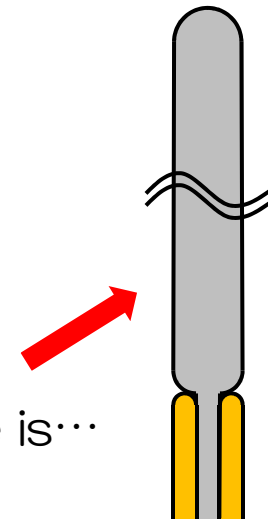
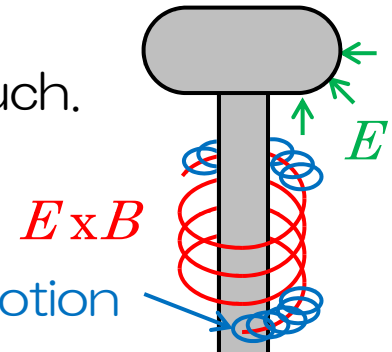
($E_r = 1.3 \times 10^6$ V/m (near cathode), $B_z = 0.1$ T)

- Electrons drift in axial direction.

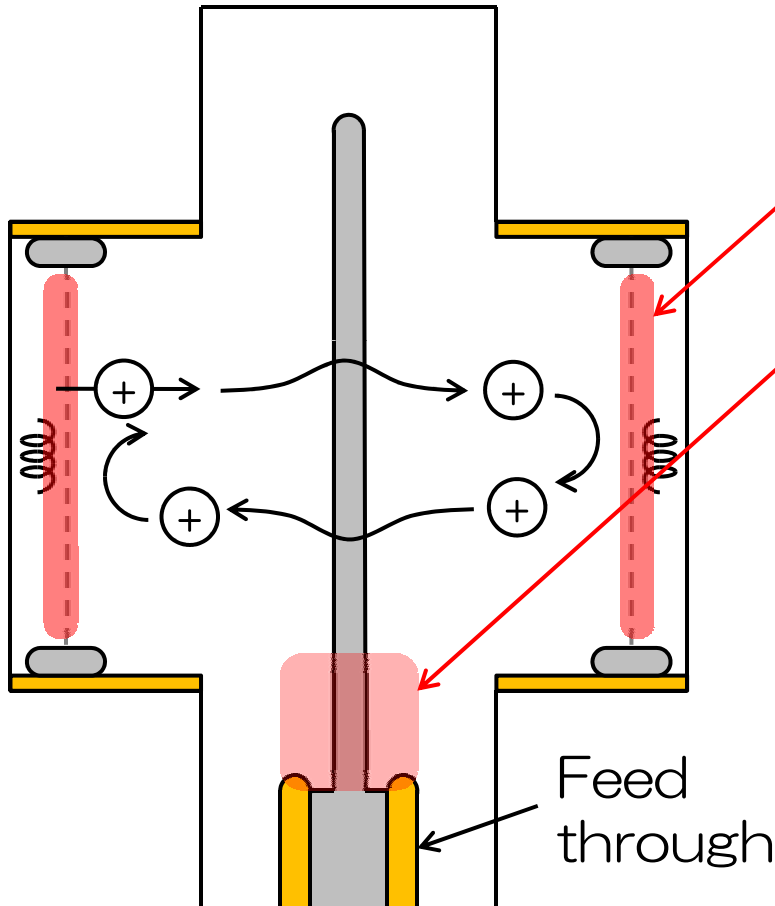
Then they are reflected at the caps (by electric field).

- The obtained glow (magnetron) discharge is not preferable since the ions produced there will hit the cathode immediately.

- Preferable cathode and feed-through structure to suppress the glow discharge around the cathode is...

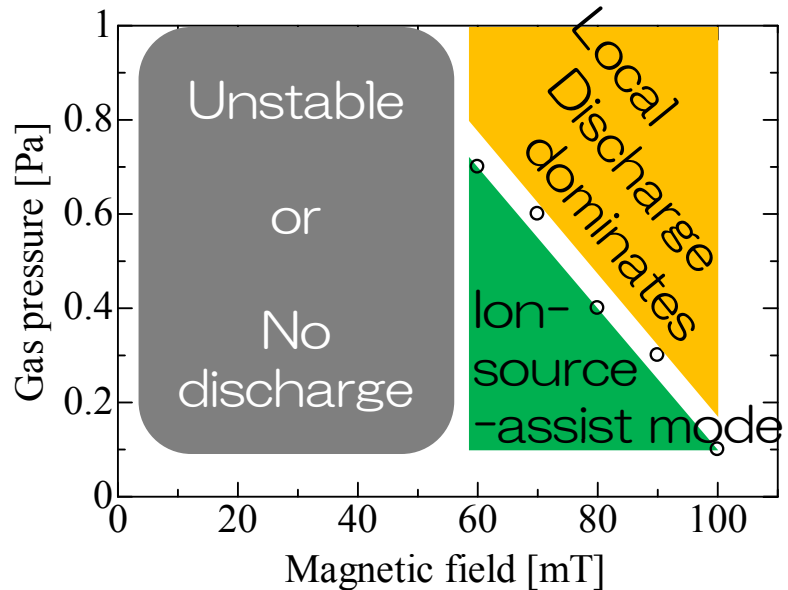


Discharge mode (C)

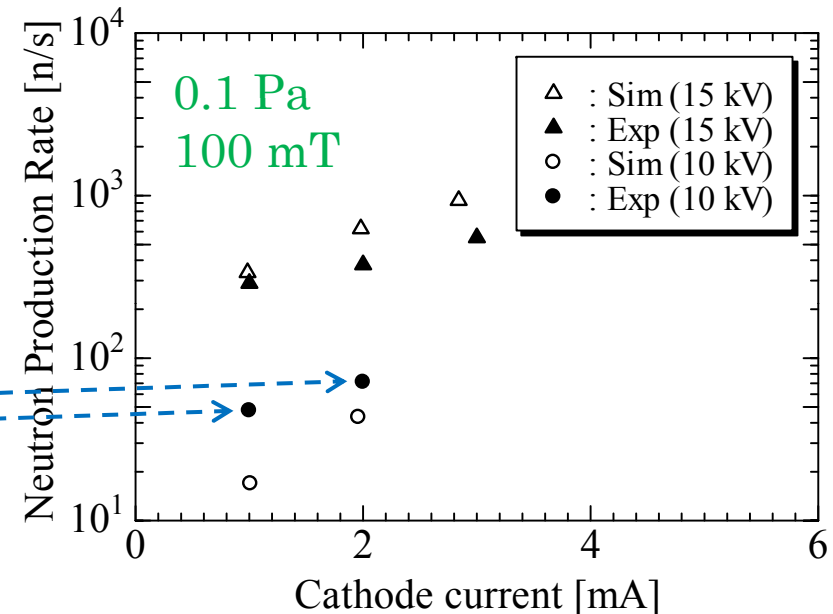
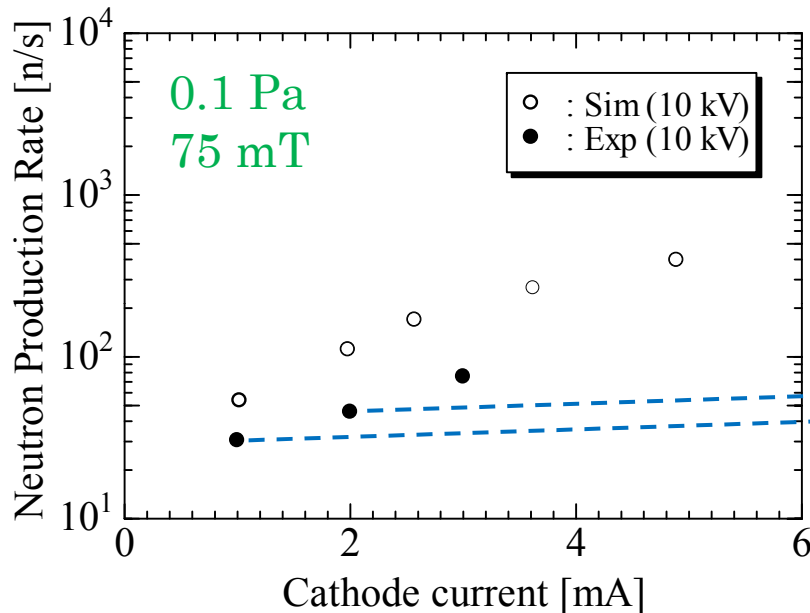


Electrode structure (C)

- By placing the rings at top and down of the anode, stable discharge was obtained.
- By reducing the pressure, local glow discharge near the feed-through was suppressed.
- Ion-source-assist operation was obtained.



Neutron Production Rate



- The obtained results are in the same order of those by simulation code.
- Local discharge is expected to deteriorate the production rate.
- Higher B might be preferable since electron energy is reduced.
→ Ion production near the cathode is suppressed.

Summary

- Experimental device for Magnetic-assisted Electrostatic Confinement was constructed.
- It was confirmed that the intended magnetic field strength and distribution can be obtained.
- Several cathode structures were examined in order to obtain a preferable operation.

Then ion-source-assisted operation was obtained.

- Preliminary measurement of the neutron production rate was carried out, and the obtained results were in the same order of those by the PIC simulation.

Future Plan

- New cathode and feed-through is examined.
→ Local discharge will be suppressed.
- Lower pressure region (< 0.1 Pa) is investigated.
→ Pressure dependence will be clarified.