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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/cm^2/s]

$\times 10^4$ →

Cancer Therapy (BNCT)
$> 10^9$ [1/cm^2/s]

$\sim 10^8$ [n/s]

The Ways to Improve the Output

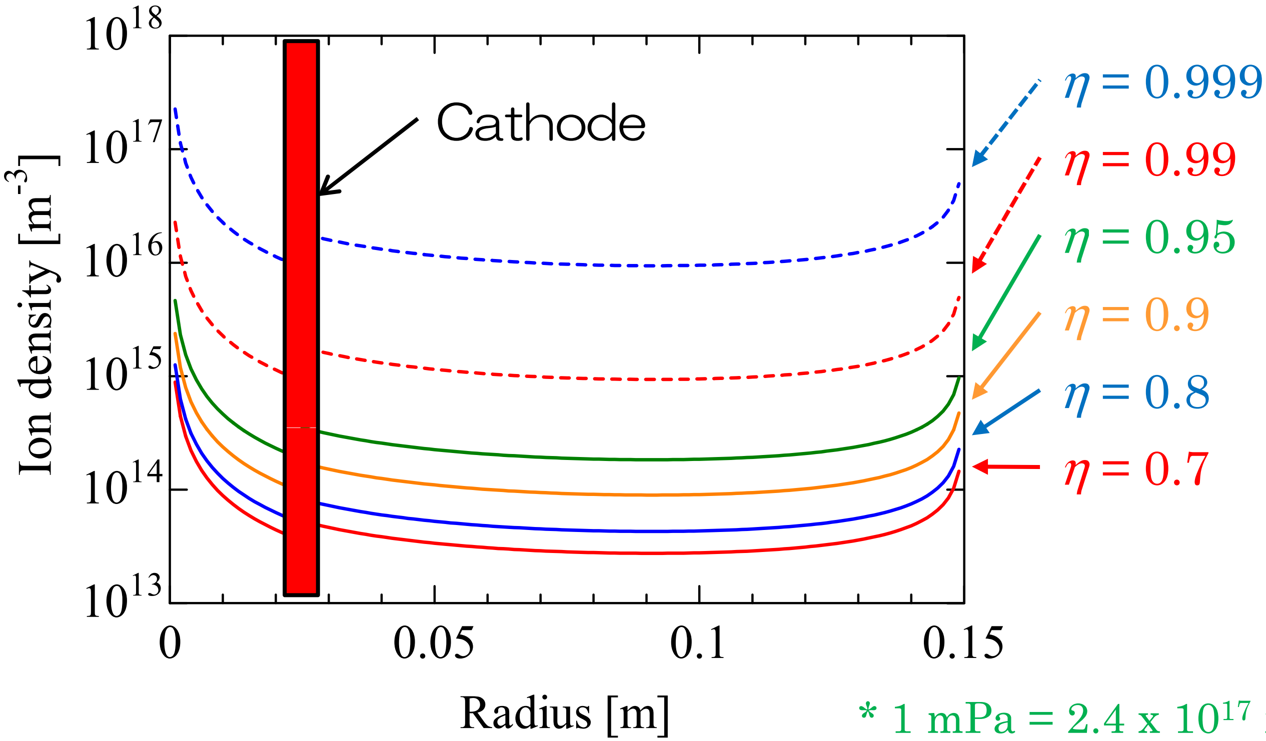
- Increase ion density
  - Not only the ion density but also cathode current increases.
    → Electrode MELTING
- Improve ion energy
  - Reducing pressure → Hard to increase ion current

↓

- 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
  $I_c / h = 1.0$ A/m, $V_c = -100$ kV

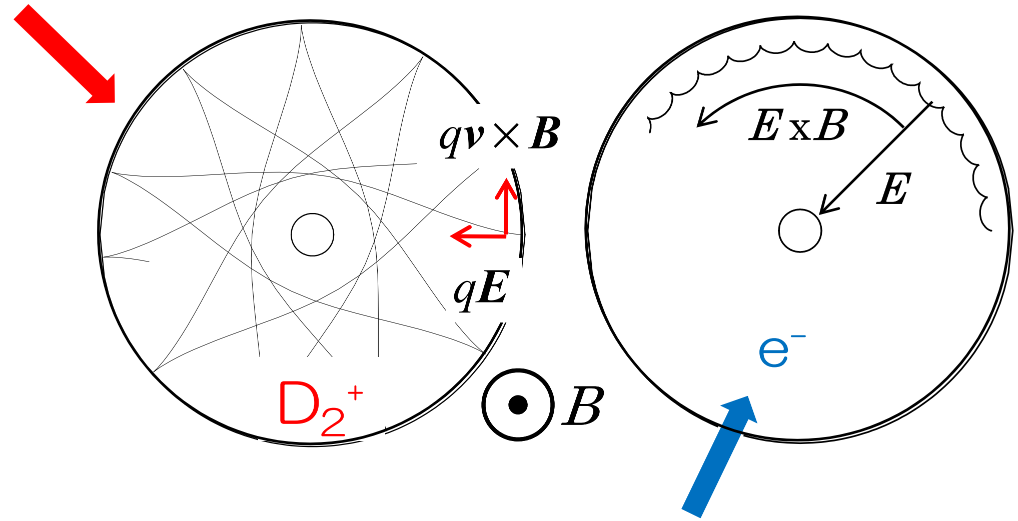


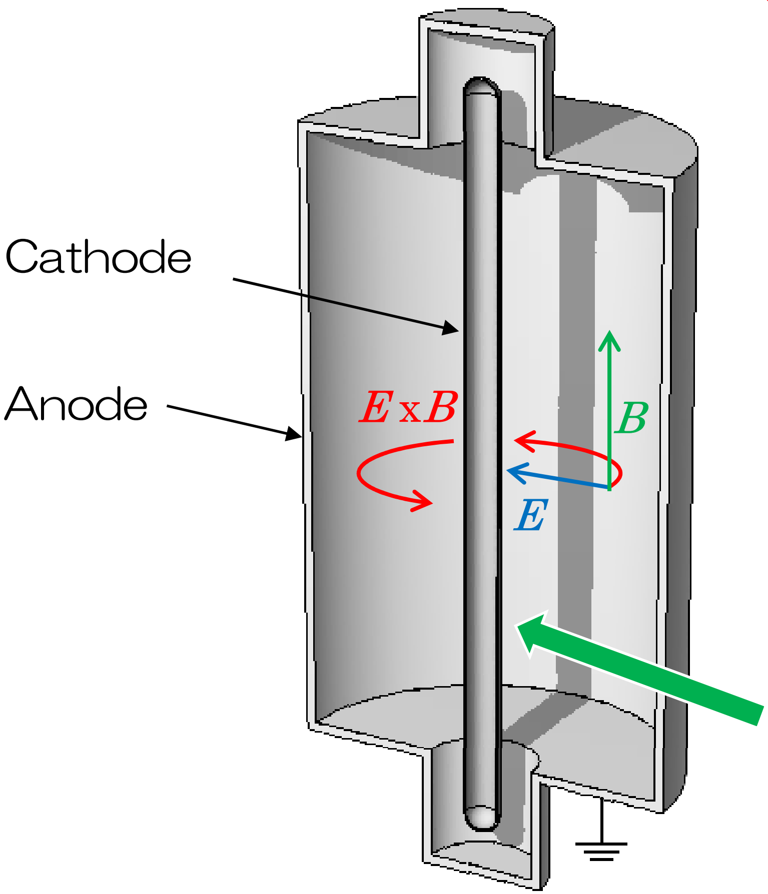
* 1 mPa = 2.4 x 10^{17} m^{-3} @ 300 K

- If the ions are controlled so that they do not hit the cathode (η~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





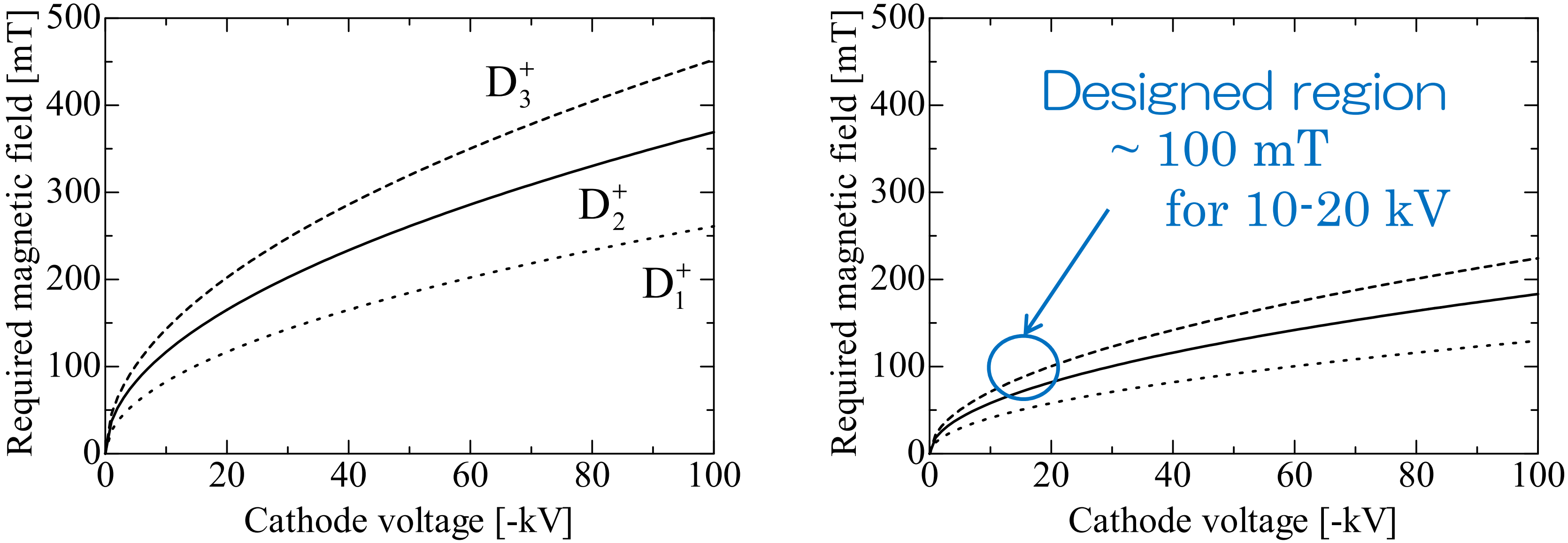
- Electrons are trapped and drift in the direction of $\boldsymbol{E}\times\boldsymbol{B}$.
  → Ionization under low pressure

- Cathode can be simplified.
  → Easy cathode cooling

Required Magnetic field

- Energy Conservation
- Canonical angular momentum conservation

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



$r_c = 5.0$ mm, $r_a = 50$ mm

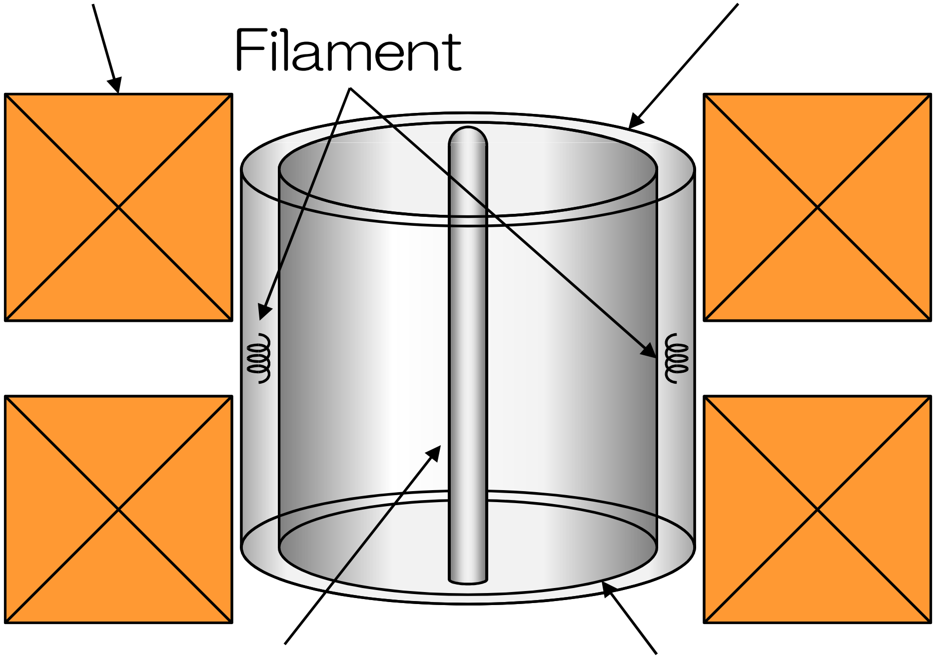
$r_c = 2.5$ mm, $r_a = 50$ mm

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

Experimental device

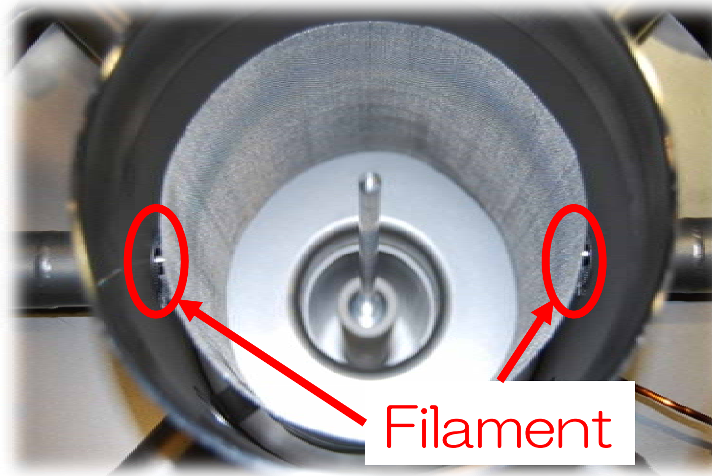
Electromagnet
800 Turns x 10 A
→ $B_z \sim 100$ mT

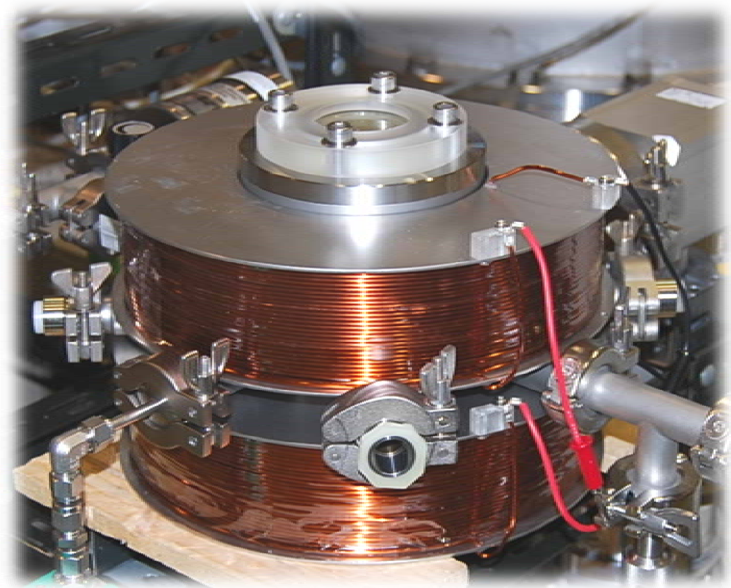
Vacuum chamber
h 100 mm
ϕ 120 mm



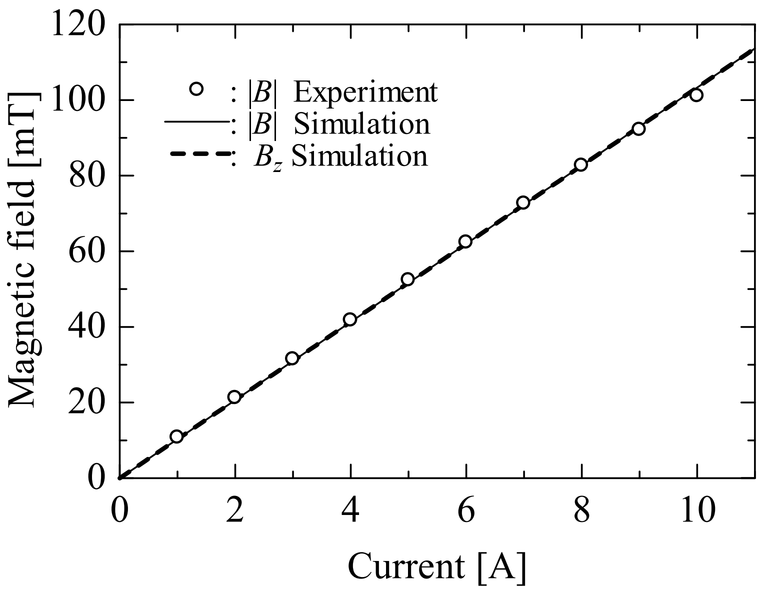
Cathode
h 120 mm
ϕ 5 mm
$V_c \sim -20$ kV

Mesh Anode
h 100 mm
ϕ 100 mm
$V_a \sim -1$ kV

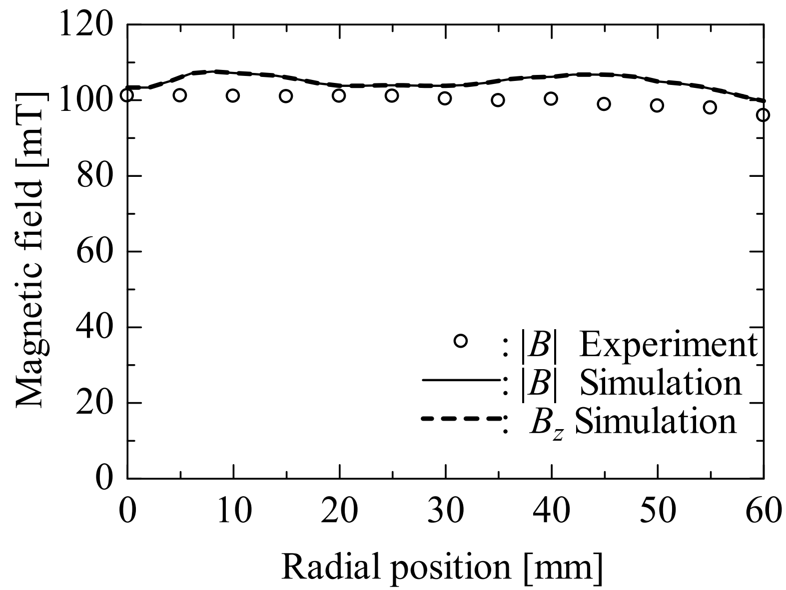




Confirmation of Magnetic field



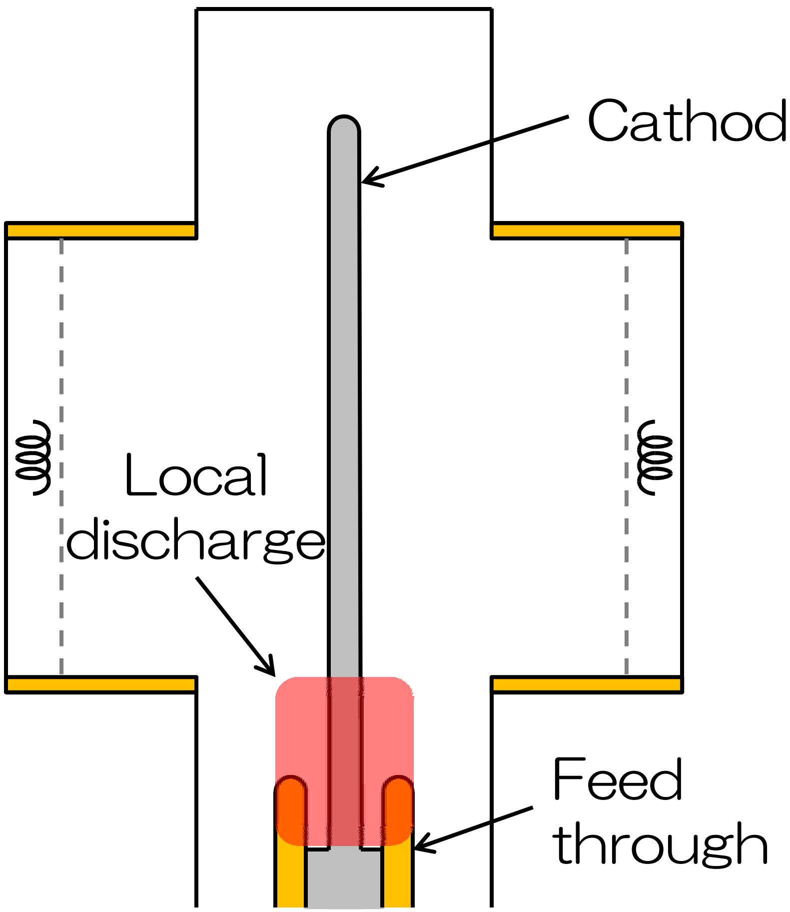
Magnetic fields vs. Coil current
($z = 0, r = 0$)



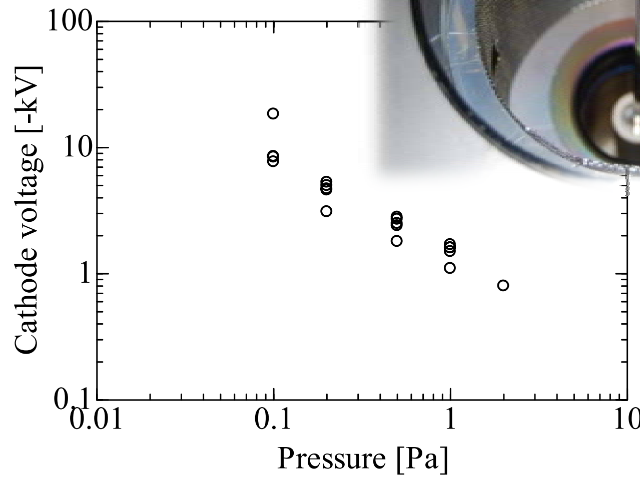
Radial distribution
($z = 0$)

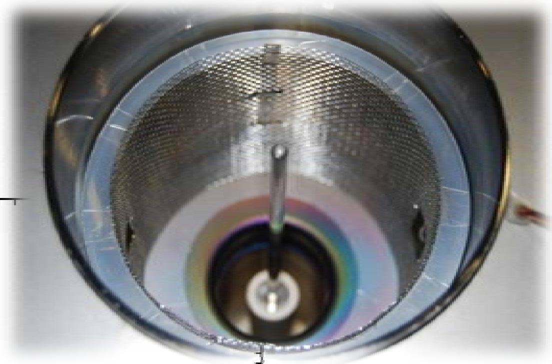
- Intended magnetic field strength and distribution was obtained.
- Due to the heat of the coil (~540 W at 10 A), operating time is limited within 30 minutes.

Discharge mode (A)



Electrode structure (A)



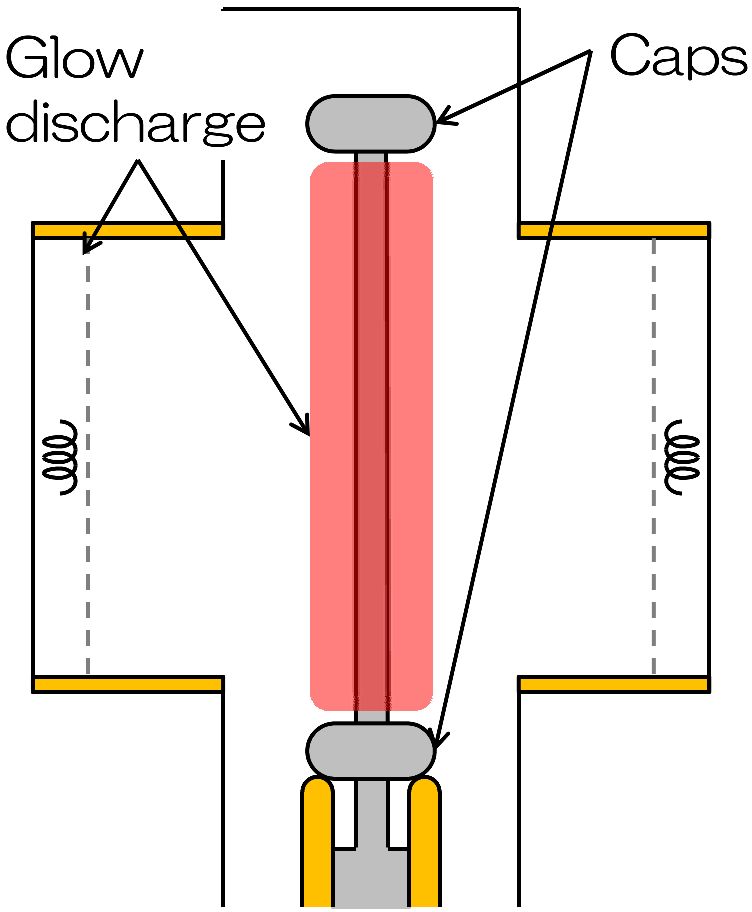


$Bz = 100$ mT

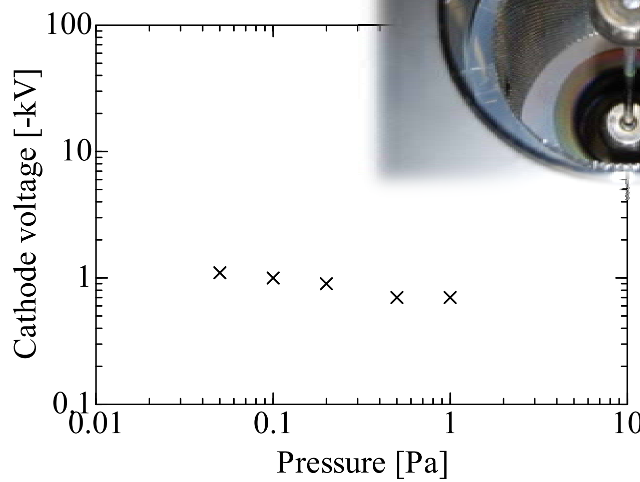
$Ic = 1$ mA

- 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)



$Bz = 100$ mT
$Ic = 1$ mA

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

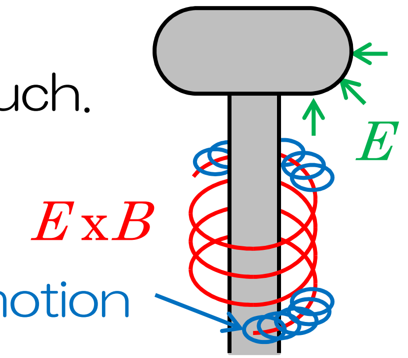
Discharge mode (A, B)

- The electrons are expected to be reflected at the caps.
  - ☐ Electrons drift in ExB (azimuthal) direction.
  - ☐ Electrons do not move in radial direction so much.

    Larmor radius ~ 0.74 mm

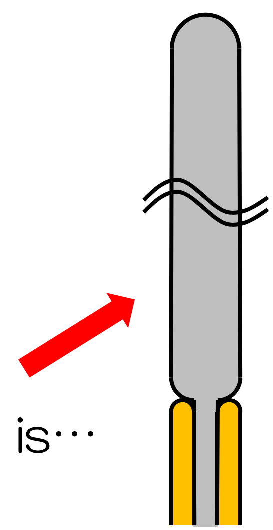
    ($E_r = 1.3 \times 10^6$ V/m (near cathode), $B_z = 0.1$ T)
  - ☐ Electrons drift in axial direction.

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

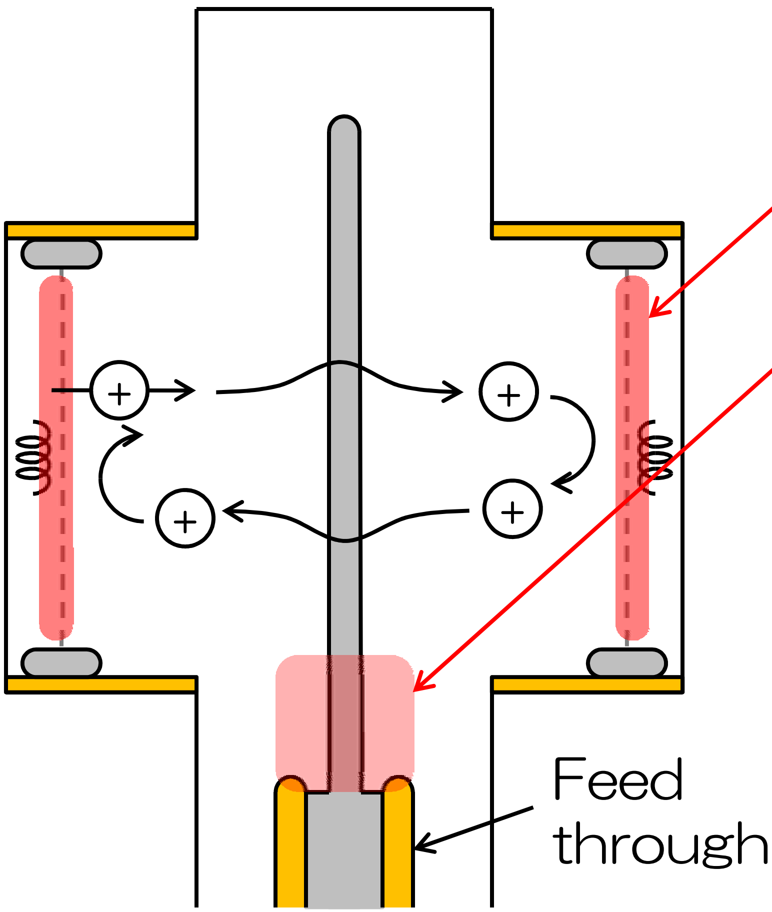


- The obtained glow (magnetron) discharge is not preferable since the ions produced there will hit the cathode immediately.

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

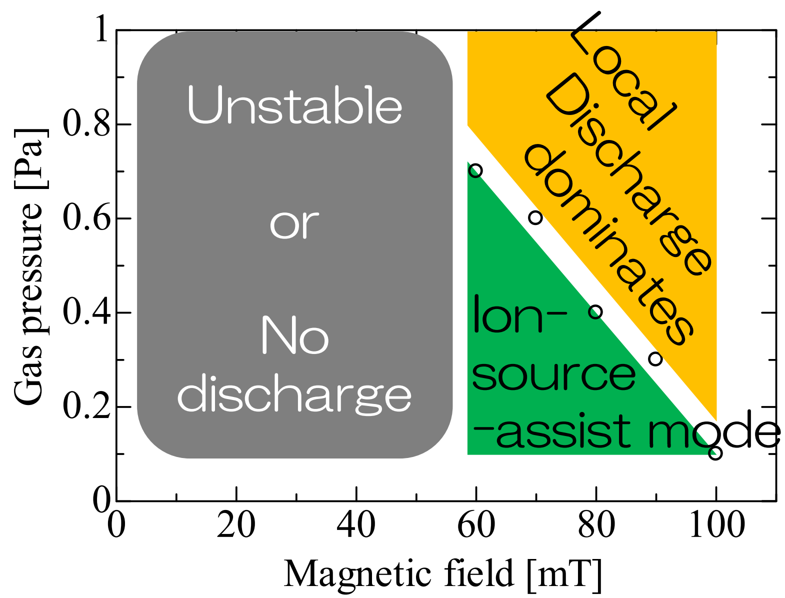


Discharge mode (C)

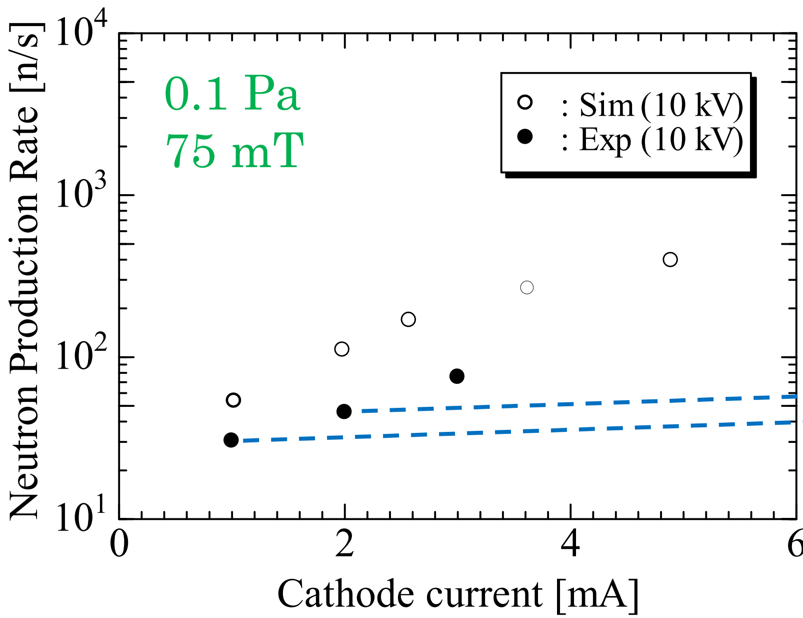


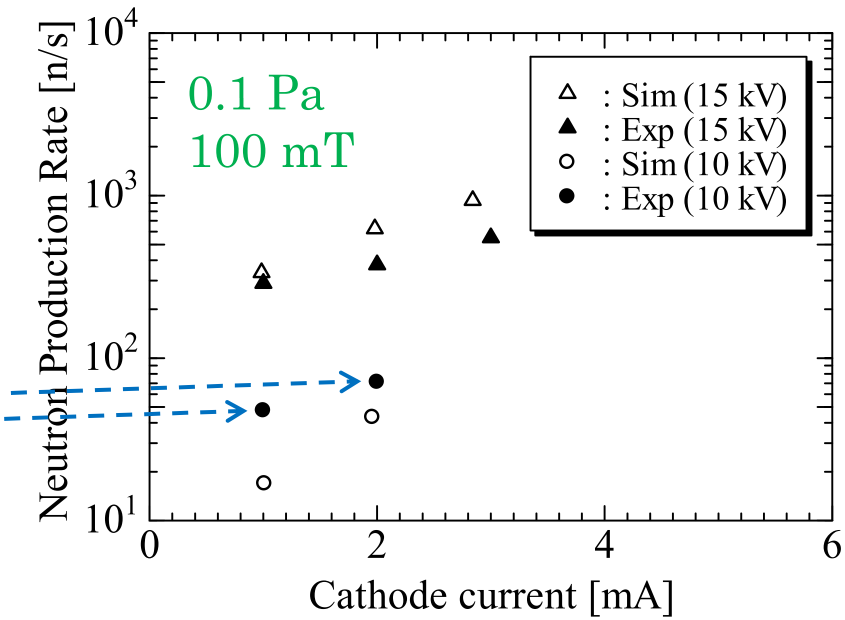
Electrode structure (C)

- 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.