Two-dimensional simulation on the improvement of a spherical IEC device using magnetron discharge

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Objectives

Simple ion source using magnetron discharge → Lower pressure

Higher efficiency of the fusion reactions

2-dimensional simulation codes of particle trajectories:KUAD2

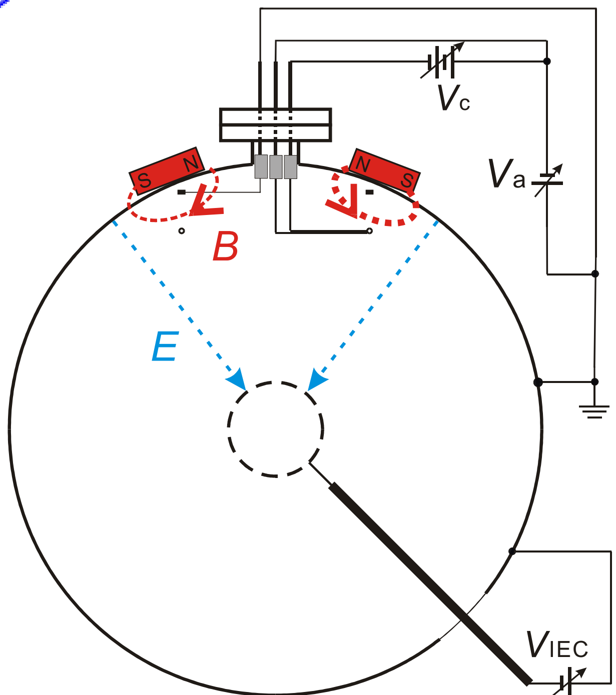
2-dimensional codes of magnetic field:KUSOS

· To find the optimal configuration of a spherical IEC device with magnetron discharge.

· Refinement of the code by considering collisions.

· To find out conditions for magnetron discharge.

Magnetron discharge



Magnetron discharge concept

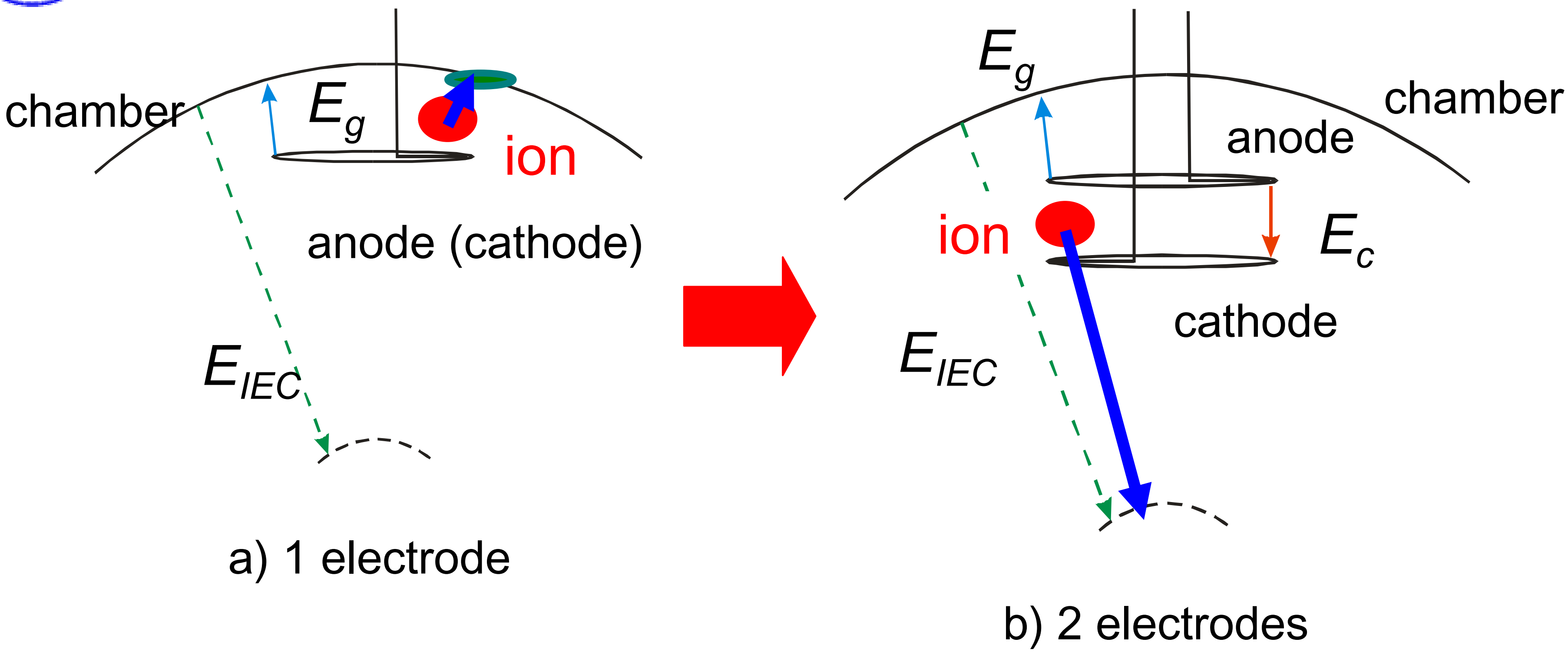
Electrons rotate spirally and are confined by $E \times B$ drift between the anode and the cathode for a long time.

The number of collisions increases so that high density plasma is obtained.

magnetron discharge

(P = 60 [mtorr], V_a= 1 [kV], V_c = 0 [V])

Schematic diagram of electrodes for magnetron discharge



In the case a), Ions are used for secondary electron generation.

↓

The extract efficiency of ions to the center is influenced.

↓

It is expected that the case b) is better.

Numerical methods

Simulation codes → · Cylindrical symmetry
· Static field

Magnetic field → Magnetic field is calculated by assuming surface current model.

Basic equations

Equation of motion (ions, electrons)

$$\frac{d(\gamma_v \boldsymbol{u}_v)}{dt} = \frac{q}{m_0}(\boldsymbol{E} + \boldsymbol{u}_v \times \boldsymbol{B})$$

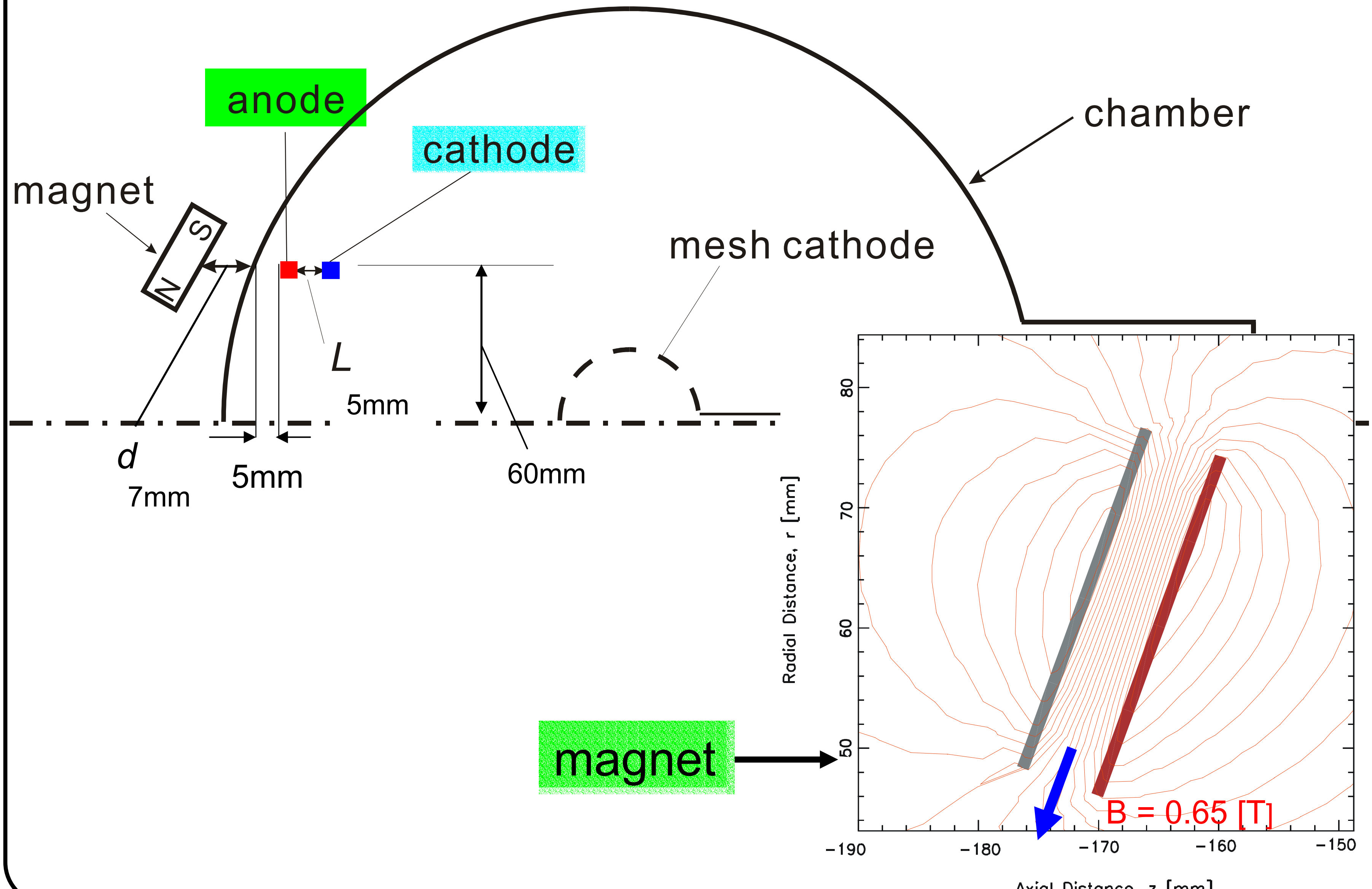
Poisson's equation

$$\nabla^2 \phi = -\frac{\rho}{\varepsilon}$$

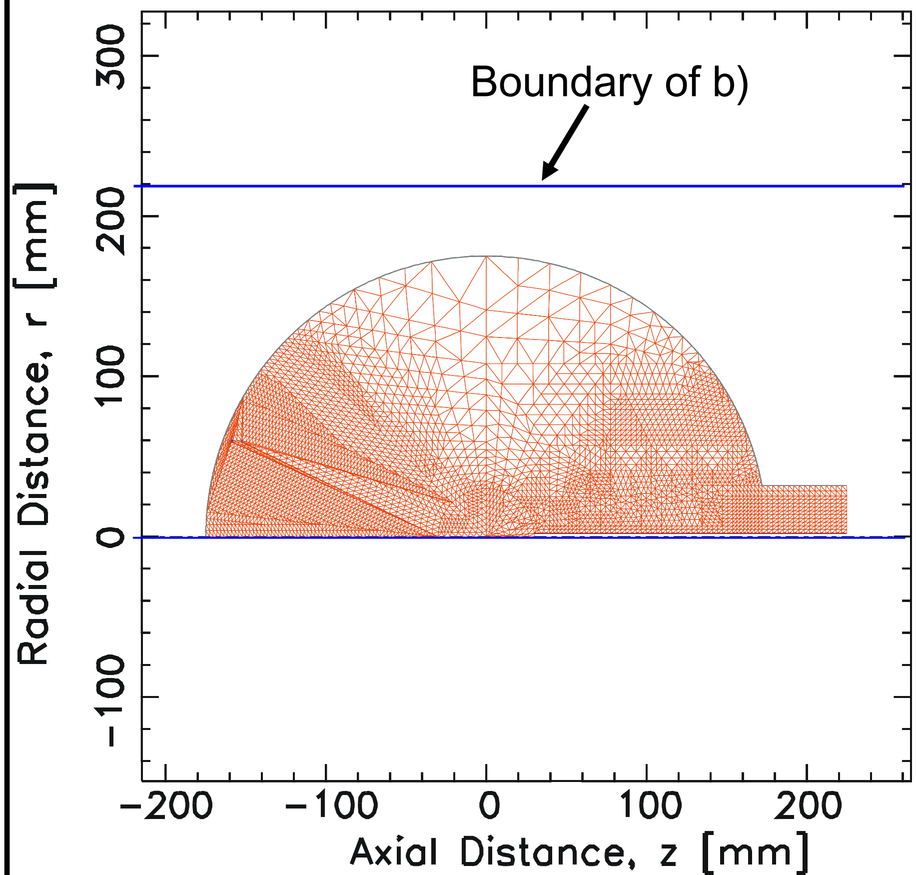
Magnetic field

$$\nabla \times \left(\frac{1}{\mu} \nabla \times \boldsymbol{A} \right) = \boldsymbol{J}$$

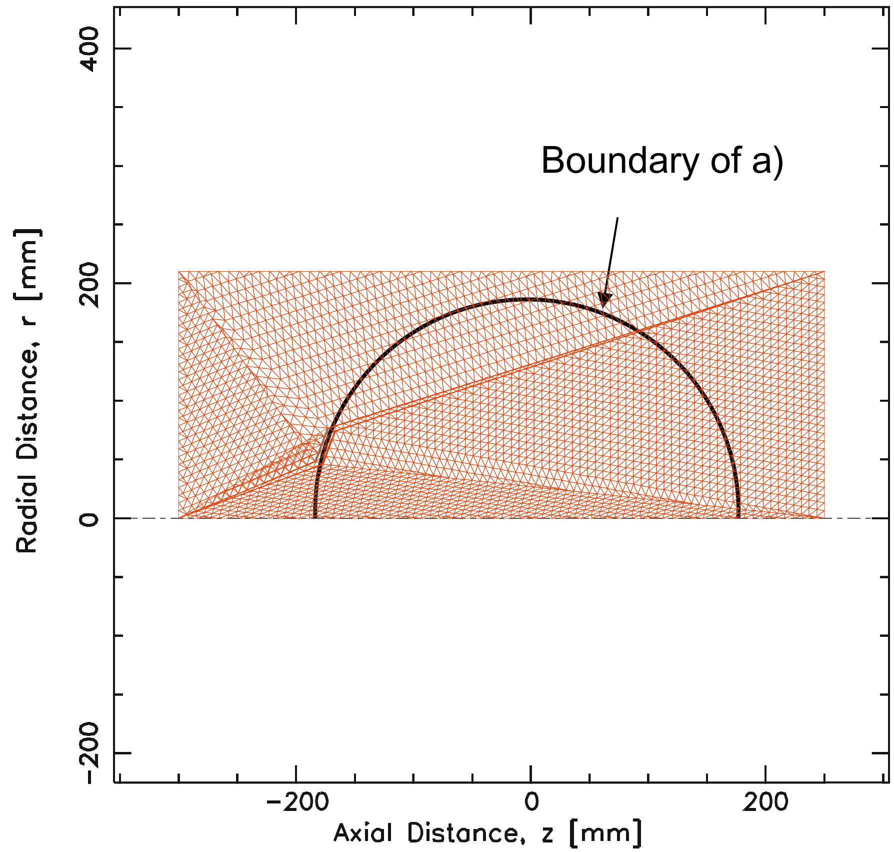
Definition of parameters



Elements in the Finite Element method

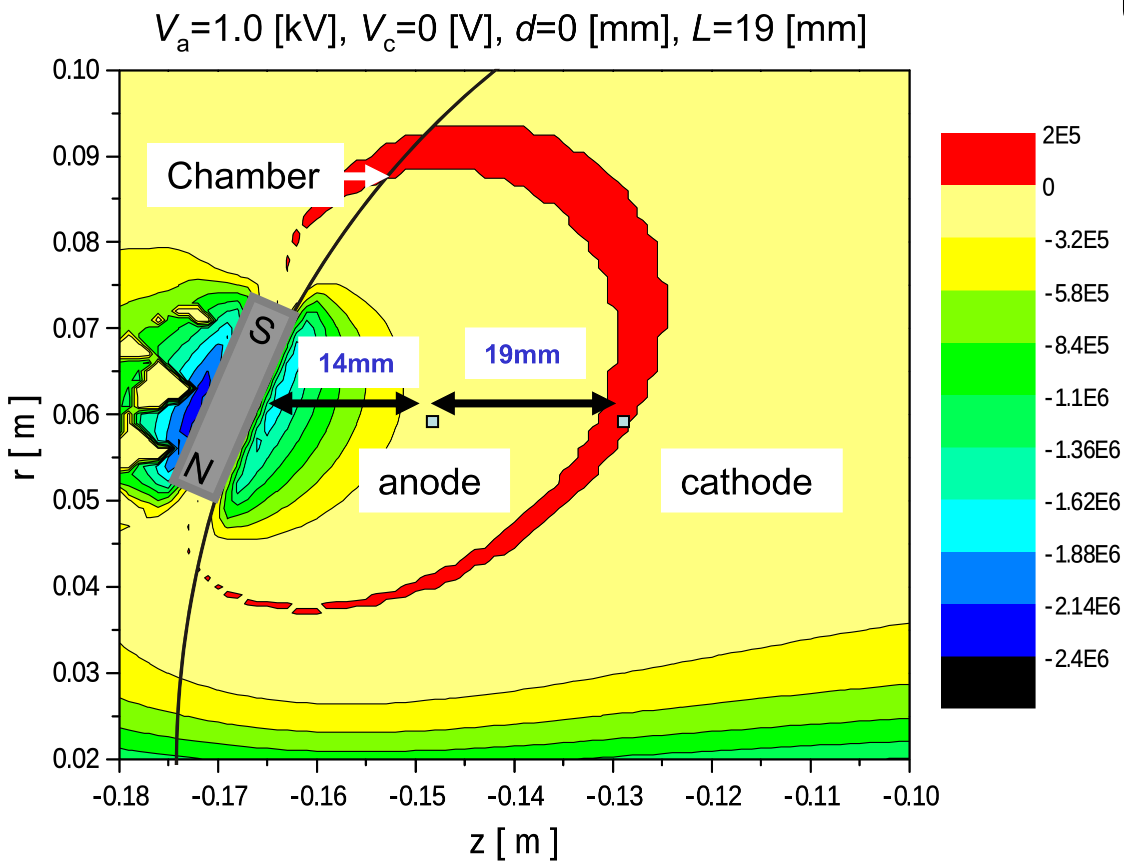


a) meshes to solve electric field



b) meshes to solve magnetic field

Universal potential in magnetron discharge



universal potential

$$u = \frac{1}{2mq}\left(\frac{P_\theta}{r} - qA_\theta\right)^2 + \phi$$

$$P_\theta = const.$$

$$\frac{1}{2}m\left(v_z^{\,2} + v_r^{\,2}\right) + qu = const.$$

$$m\frac{\partial v_r}{\partial t} = -\frac{\partial u}{\partial r}$$

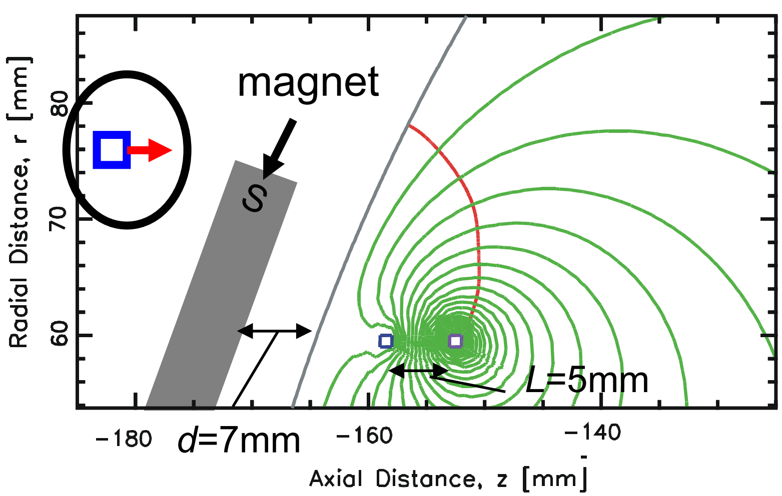
$$m\frac{\partial v_z}{\partial t} = -\frac{\partial u}{\partial z}$$

u; The potential contour in z-r plane

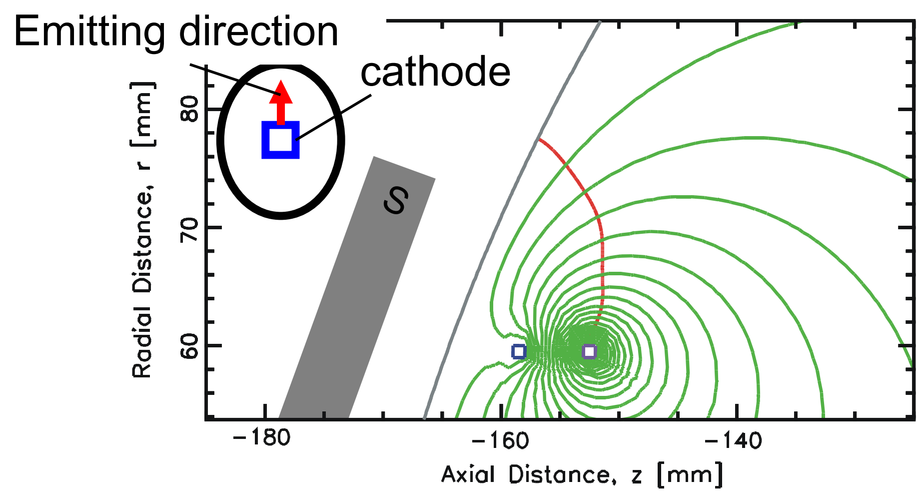
An electron from the cathode can move in the red zone.

Electron trajectory dependence on emitting direction

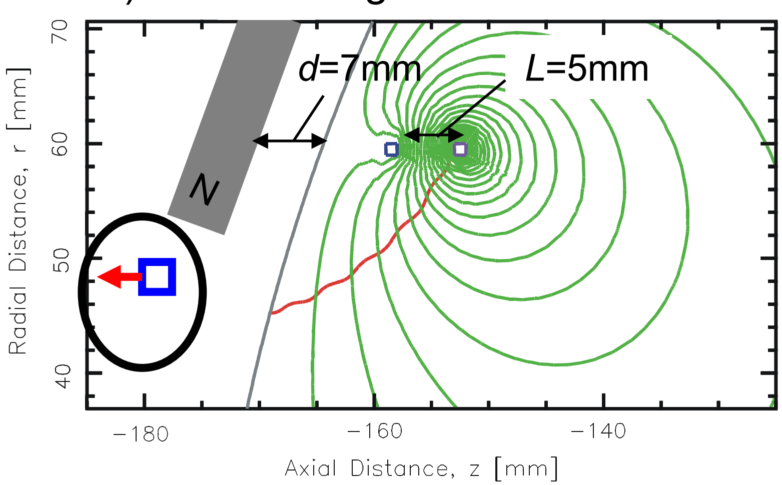
emit position change (d=7 [mm], L=5 [mm], V_a = 0 [V], V_c = -1.5 [kV], K_{init} = 1[eV])



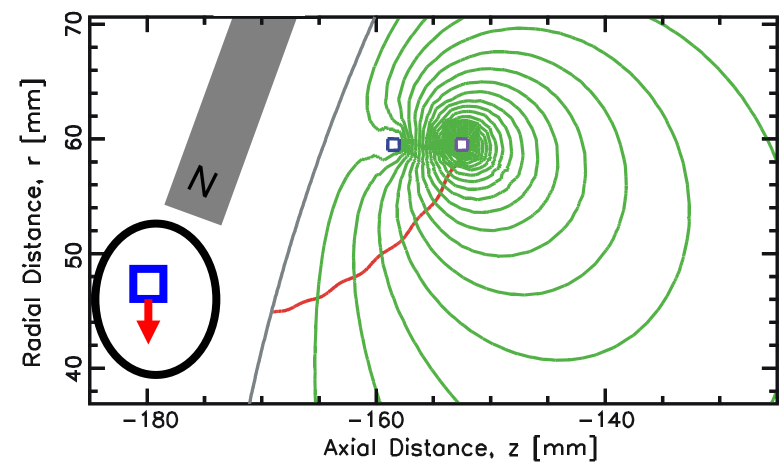
1) emit from right side of the cathode



2) emit from up side of the cathode



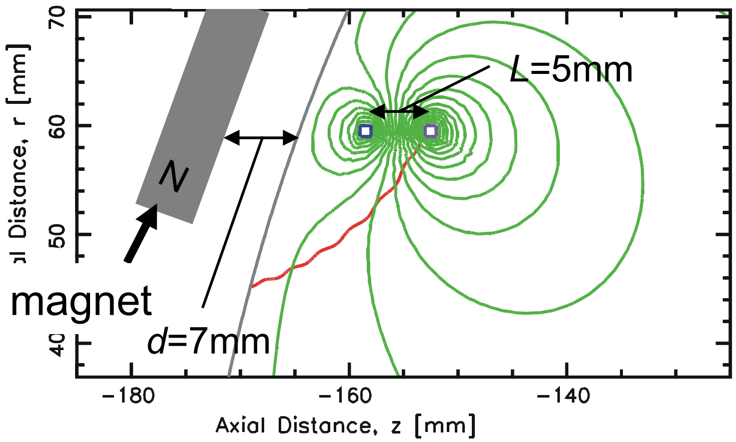
3) emit from left side of the cathode



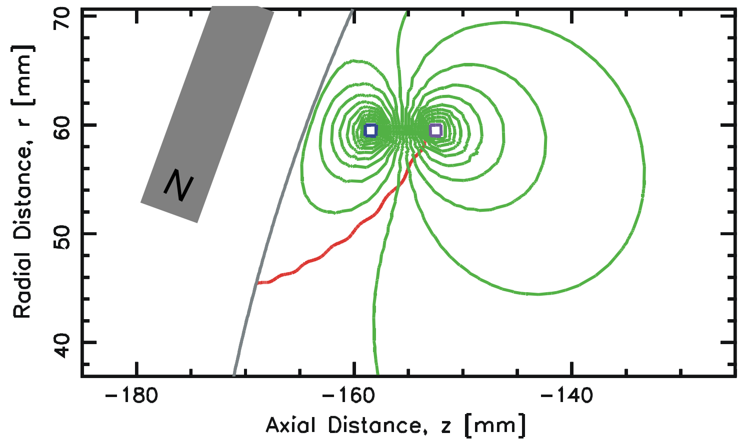
4) emit from down side of the cathode

Dependence on anode and cathode voltage

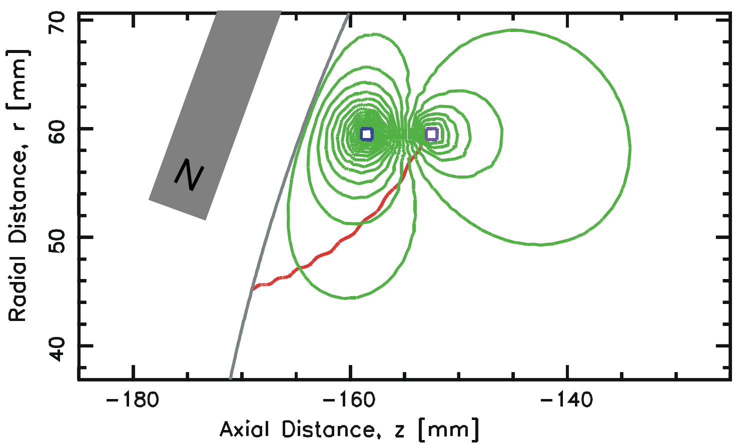
anode and cathode voltage change(d=7 [mm], L=5 [mm], K_{init} = 1[eV], V_a - V_c=1.5[kV])



1) V_a = 0.5 [kV], V_c = -1.0 [kV]



2) V_a = 0.7 [kV], V_c = -0.8 [kV]

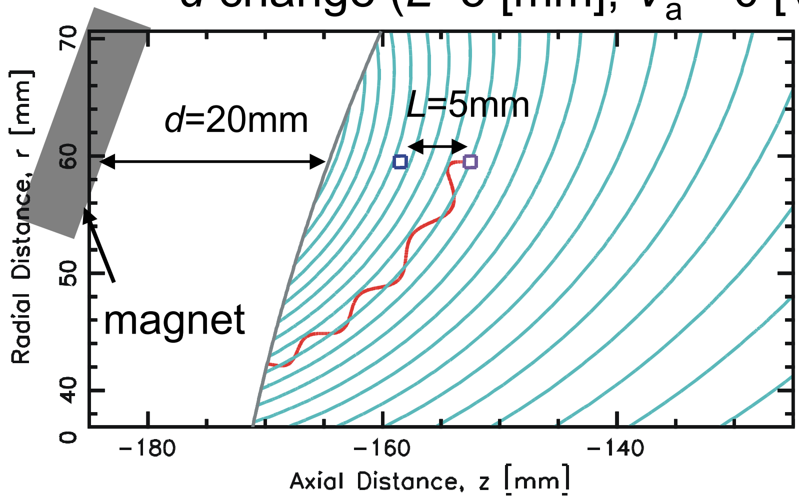


3) V_a = 1.0 [kV], V_c = -0.5 [kV]

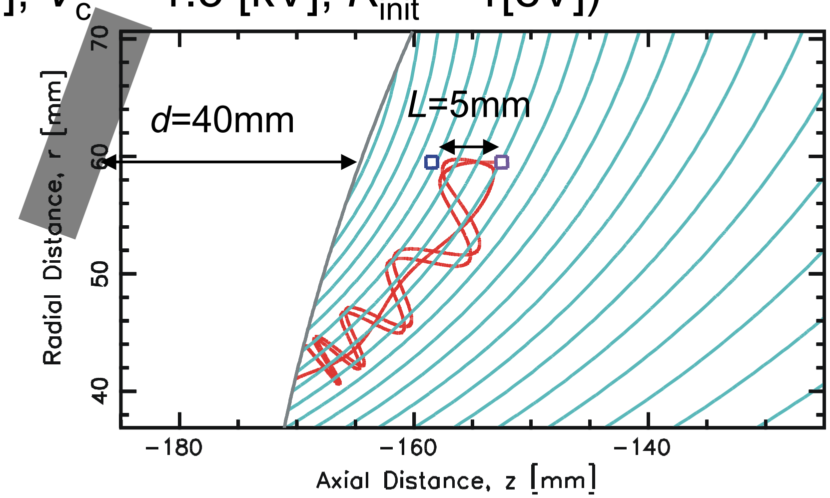
In the case of V_a, V_c change ($V_a - V_c$=const.), there is no significant difference.

Dependence of electron trajectory on E and B strength

d change (L=5 [mm], V_a = 0 [V], V_c = -1.5 [kV], K_{init} = 1[eV])

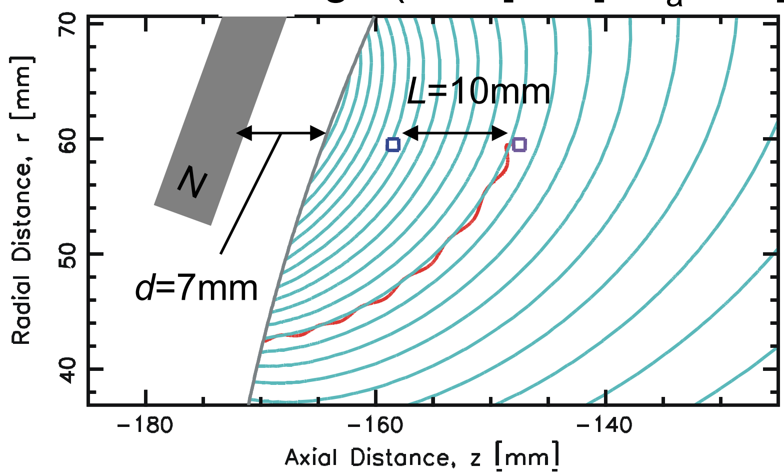


1) d = 20 [mm]

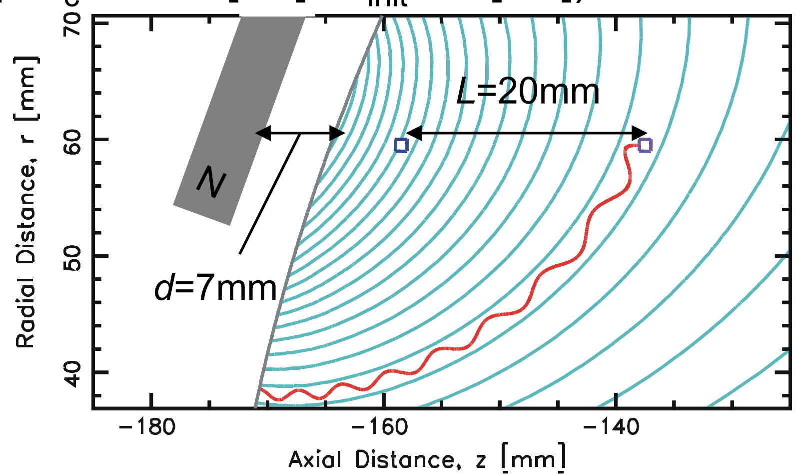


2) d = 40 [mm]

L change (d=7 [mm], V_a = 0 [V], V_c = -1.5 [kV], K_{init} = 1[eV])

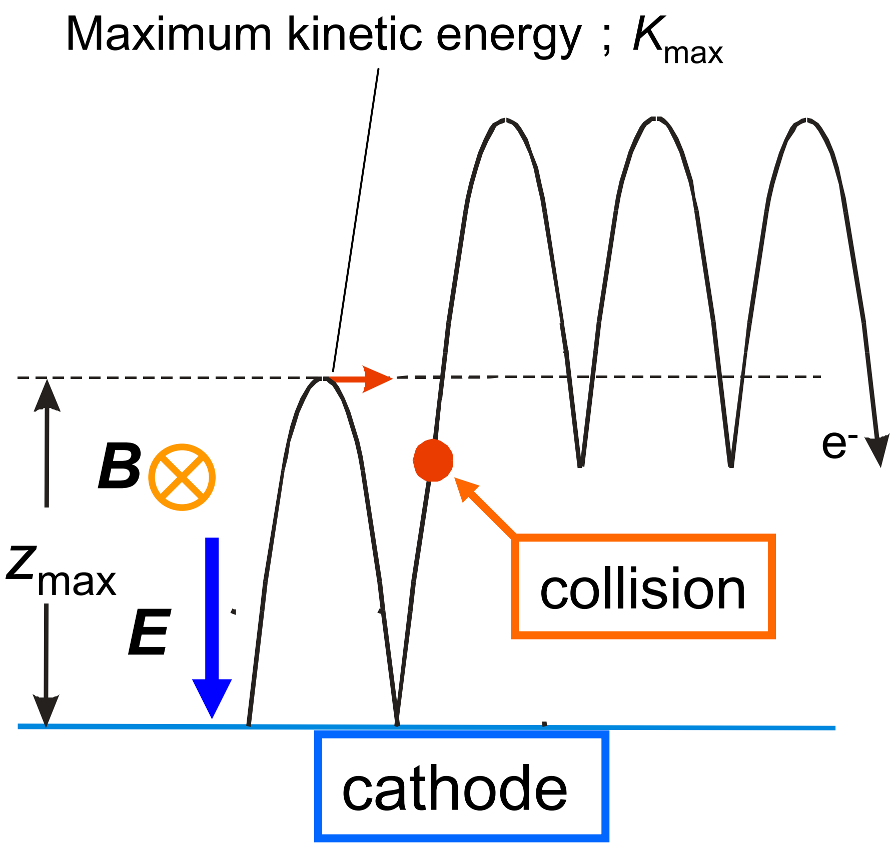


1) L = 10 [mm]

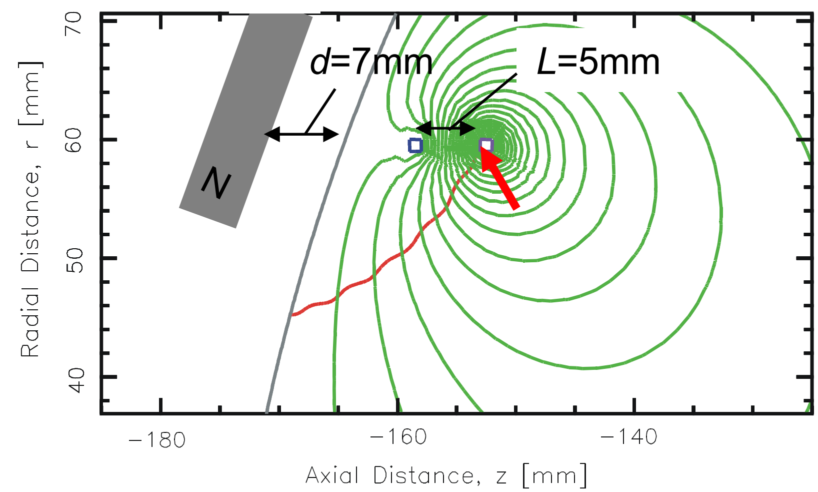


2) L = 20 [mm]

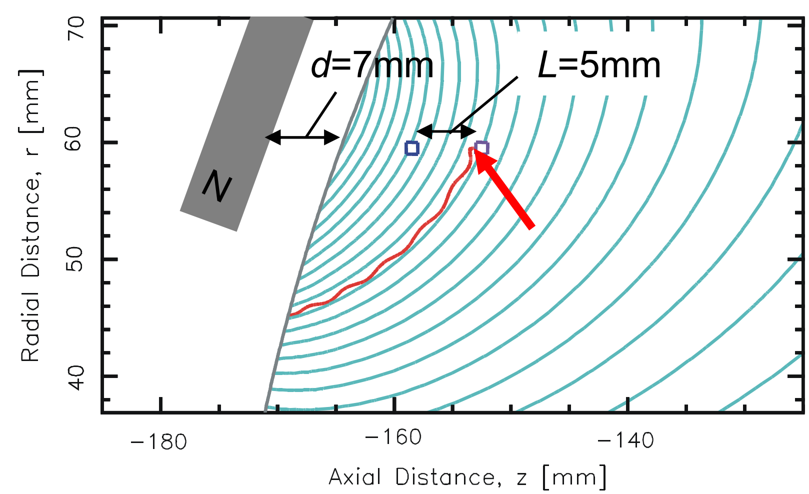
Maximum kinetic energy near the cathode



$$K_{max} = \frac{2mE^2}{B^2} \qquad z_{max} = \frac{2mE}{eB^2}$$



1) Potential contour

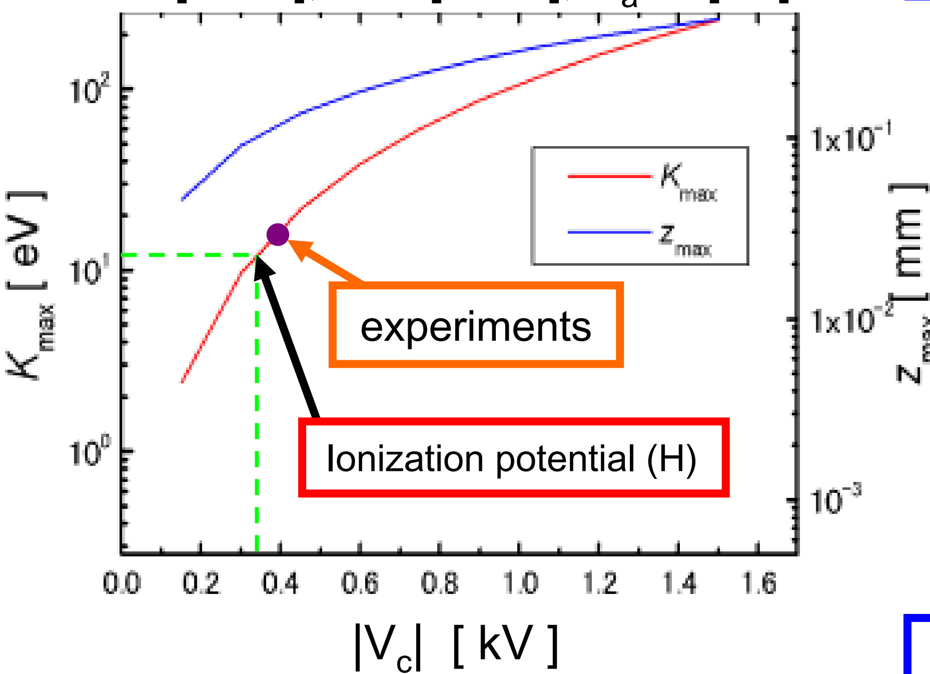


2) Magnetic flux line

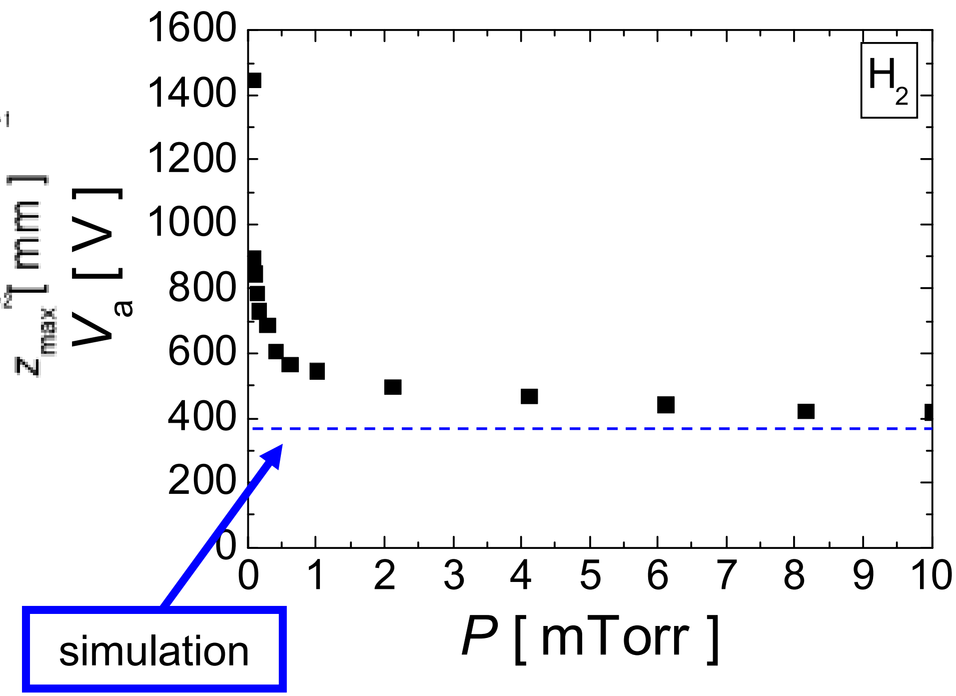
Magnetron discharge Ignition

K_{max} , z_{max} - $|V_c|$

d=7 [mm], L=5 [mm], V_a=0 [V]



Magnetron discharge Ignition (experiment)



Values of E and B are on the cathode.(↖)

almost agree with a experimental result

Treatment of collision

Kinetic energy of an electron

> 1.0 [eV] + Ionization potential (H; 13.6 [eV])

↓

An electron loses kinetic energy by collision.

Assumption

An electron which collided

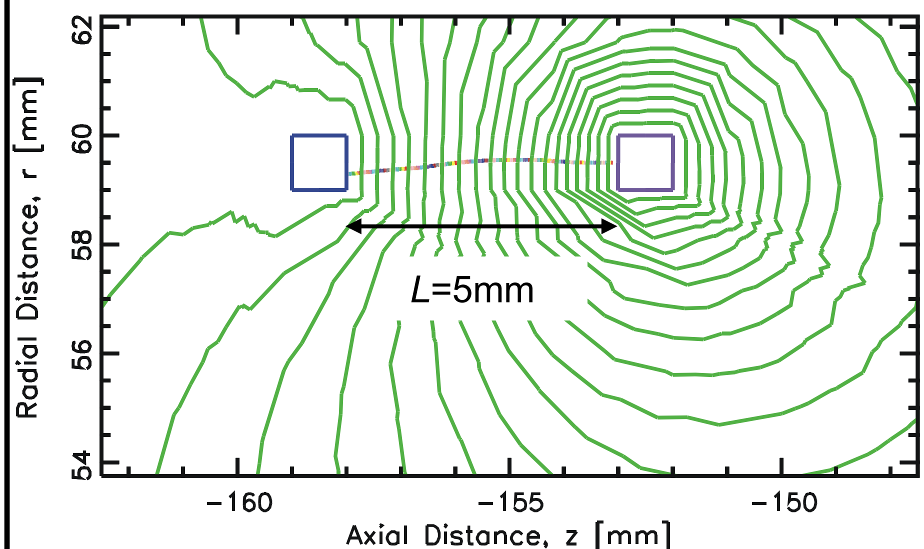
After colliding, it begins to move again with kinetic energy of 1.0 [eV].

$v_\theta = 0$

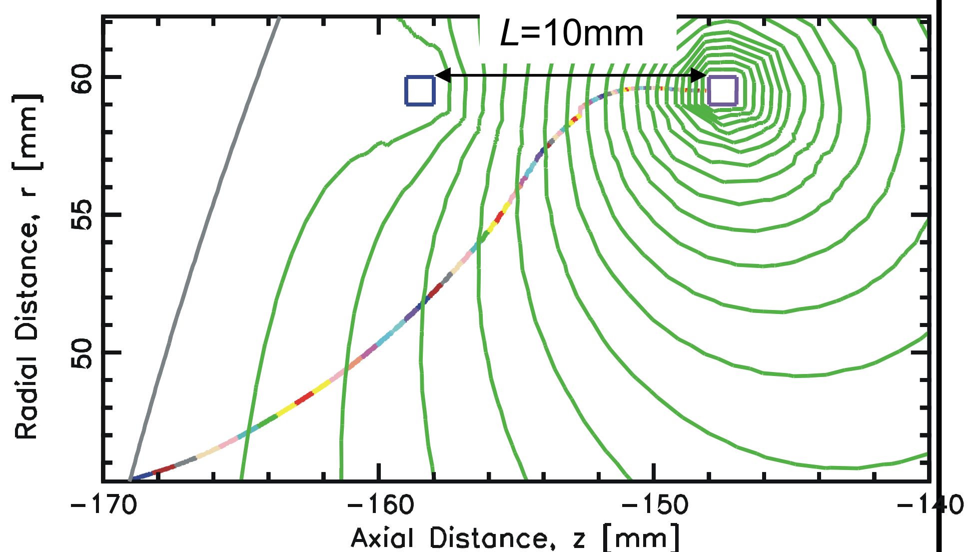
Electron trajectory including collision

Initial conditions

d = 7 [mm], V_a= 0 [V], V_c= -1.5 [kV], V_{IEC} = 0 [V]



1) L = 5 [mm]



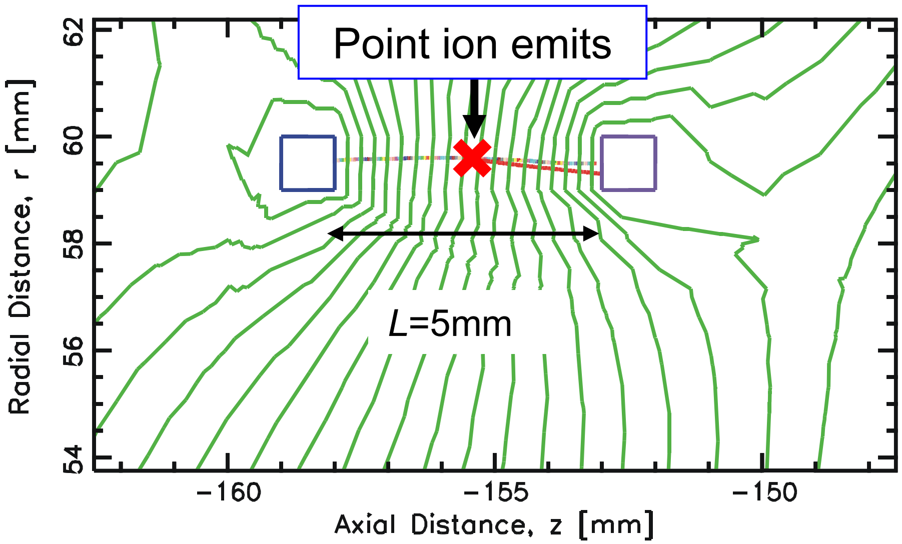
2) L = 10 [mm]

In the case 1), considering a collision, the electron which reaches the anode exists.

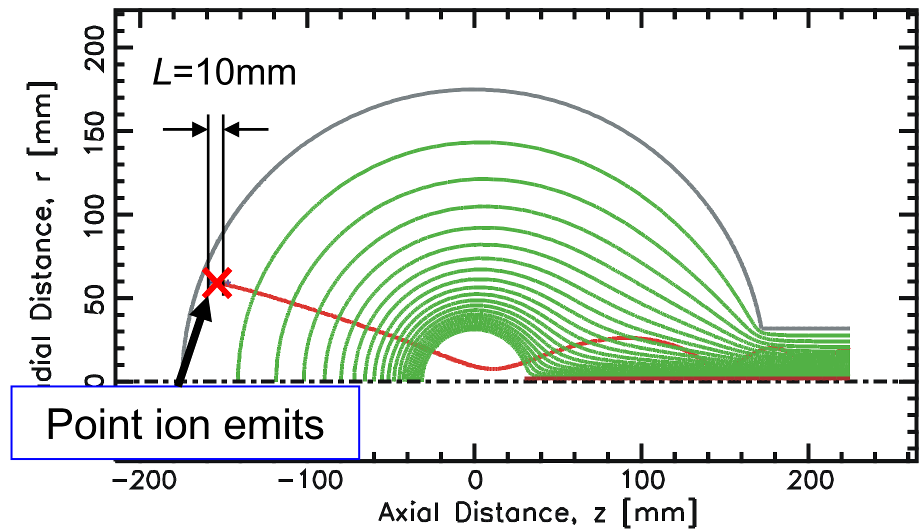
Ion trajectory

Initial conditions

d = 7 [mm], V_a= 0 [V], V_c= -1.5 [kV], V_{IEC} = -60 [kV]



1) L = 5 [mm]



2) L = 10 [mm]

Preservation of P_θ

1) Ion cannot reach the original potential.

2) Ion cannot go to the center.

Summary

1) Preliminary code for magnetron discharge was made and trajectories of ions and electrons were calculated.

2) Since electric field is relatively small compared with magnetic field, magnetron discharge hardly takes place.

→ Suitable values of parameters are required in order for magnetron discharge to take place.

Future works

1) Needs to consider collisions more precise

2) Comparison with experiments

3) Optimal design of E and B field distribution