Discharge Simulation of IEC with the ion source

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- Purpose of Study
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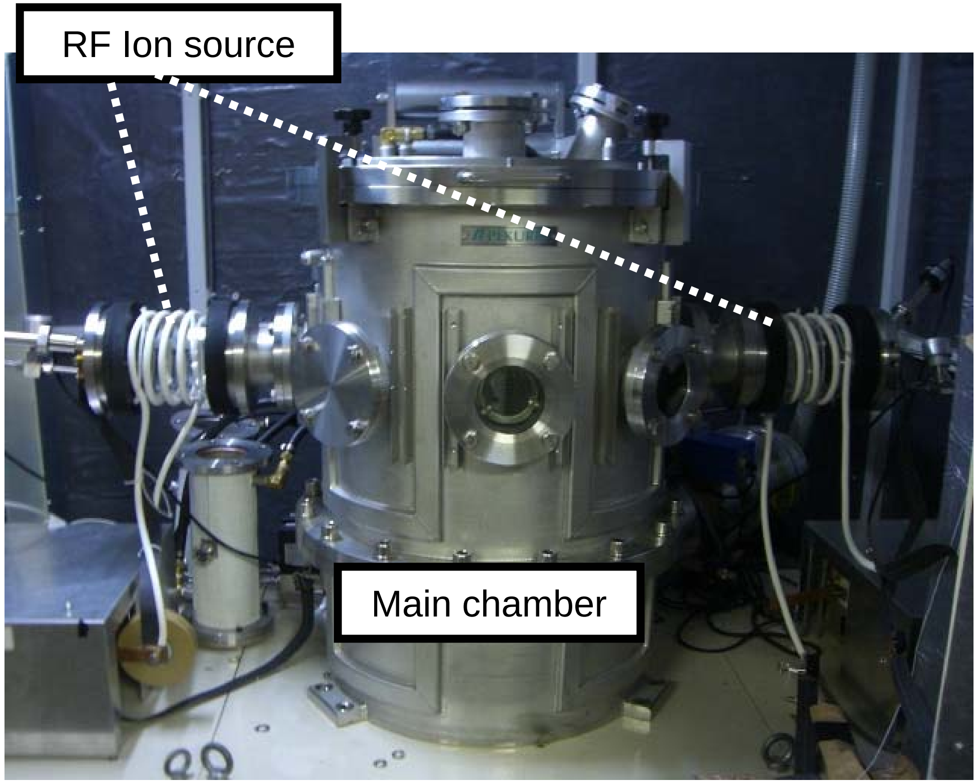
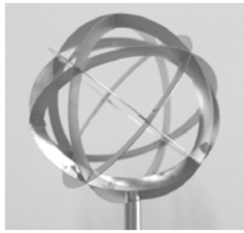
- Space Distribution
- Increase of Charged Particle
- Discharge Characteristics
- Rate of Each Collision Processes
- Neutron Production Rate
- Conclusions

Experimental Setup of Kansai U.

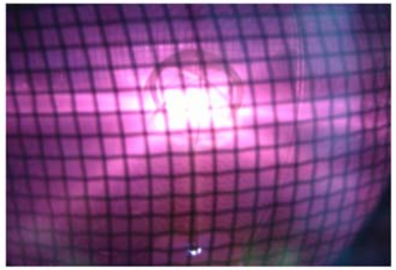


Experimental setup

Mesh Anode



6ring-Cathode



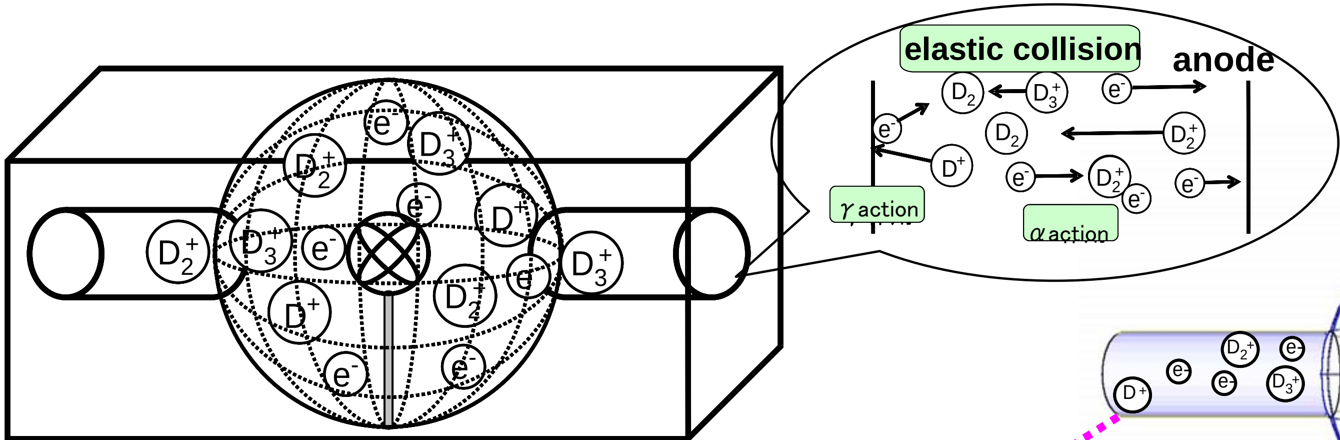
Discharge mode

Reason of using ion source for IEC

- The density of ions is increased
- Differential pumping is done between ion source and main chamber
- Gas pressure of main chamber can be lower
- Mean Free path of the ion is prolonged

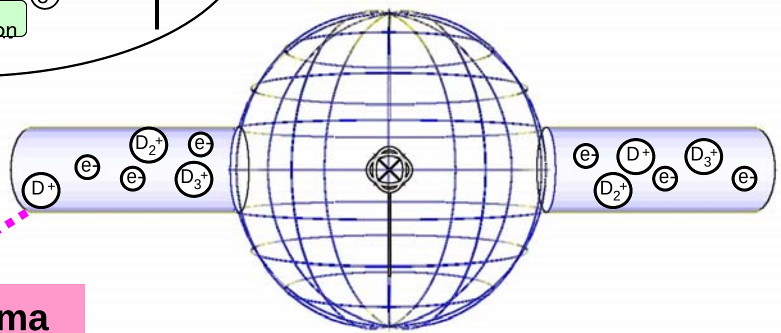
Purpose of Study

This study is to investigate for discharge characteristic, neutron production rate with ion source or without ion source by numerical simulation.

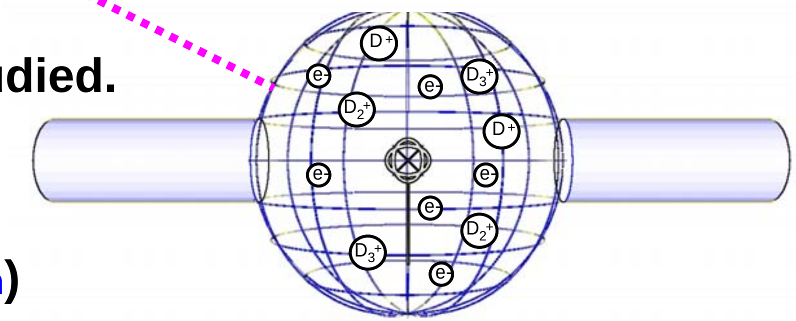


Schematic of the IEC device

Initial position of plasma



Discharge with ion source



Discharge without ion source

The behavior of the particles in the device is studied.
Those particles are e^-, D^+, D_2^+, D_3^+, D^0, D_2^0

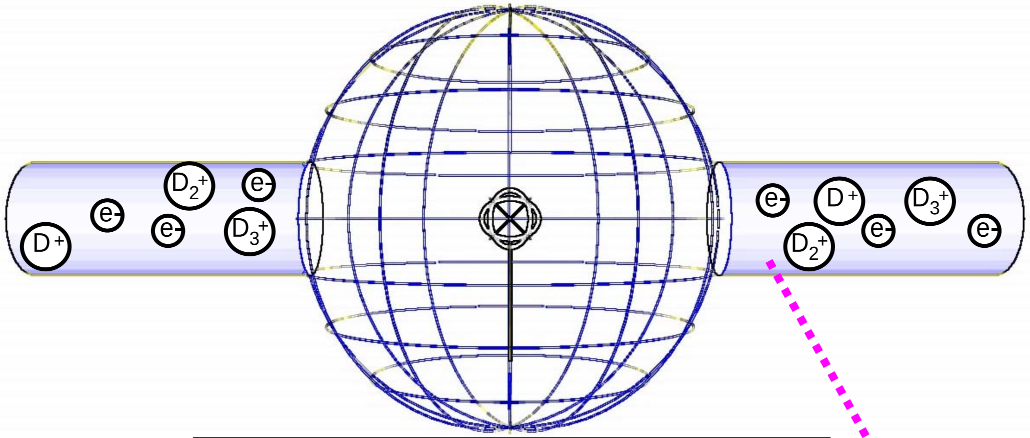
→This code is including the atomic process
(ionization , dissociation , charge-exchange , elastic collision)

Method of particle simulation

- The three-dimensional Monte Carlo particle in cell code including the atomic processes is used
- The finite difference method with the 1 mm mesh is used
- The initially 1000 particles of each kind of ions (D^+,D_2^+,D_3^+) and 3000 electrons are distributed uniformly within the area of the ion source or within the anode .
- The trajectory of each particle is followed by the Runge-Kutta method.
- The atomic and molecular collisions and the elastic collisions are considered.
- When the total number of ions becomes more than 50000, it is recognized that 'discharge' is occurred in this simulation.

Parameter of Simulation

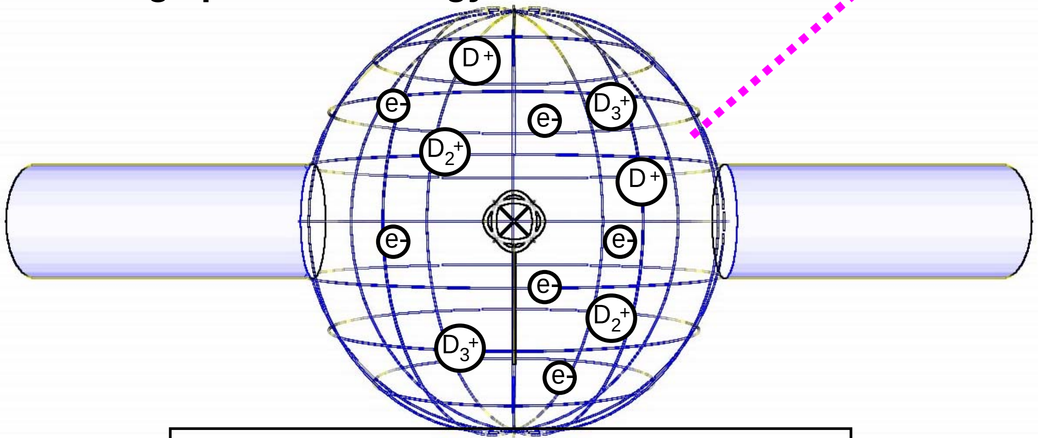
Average potential energy of ions→ 79.2kV



Discharge with ion source

Initial position of plasma

Average potential energy of ions → 72.7kV

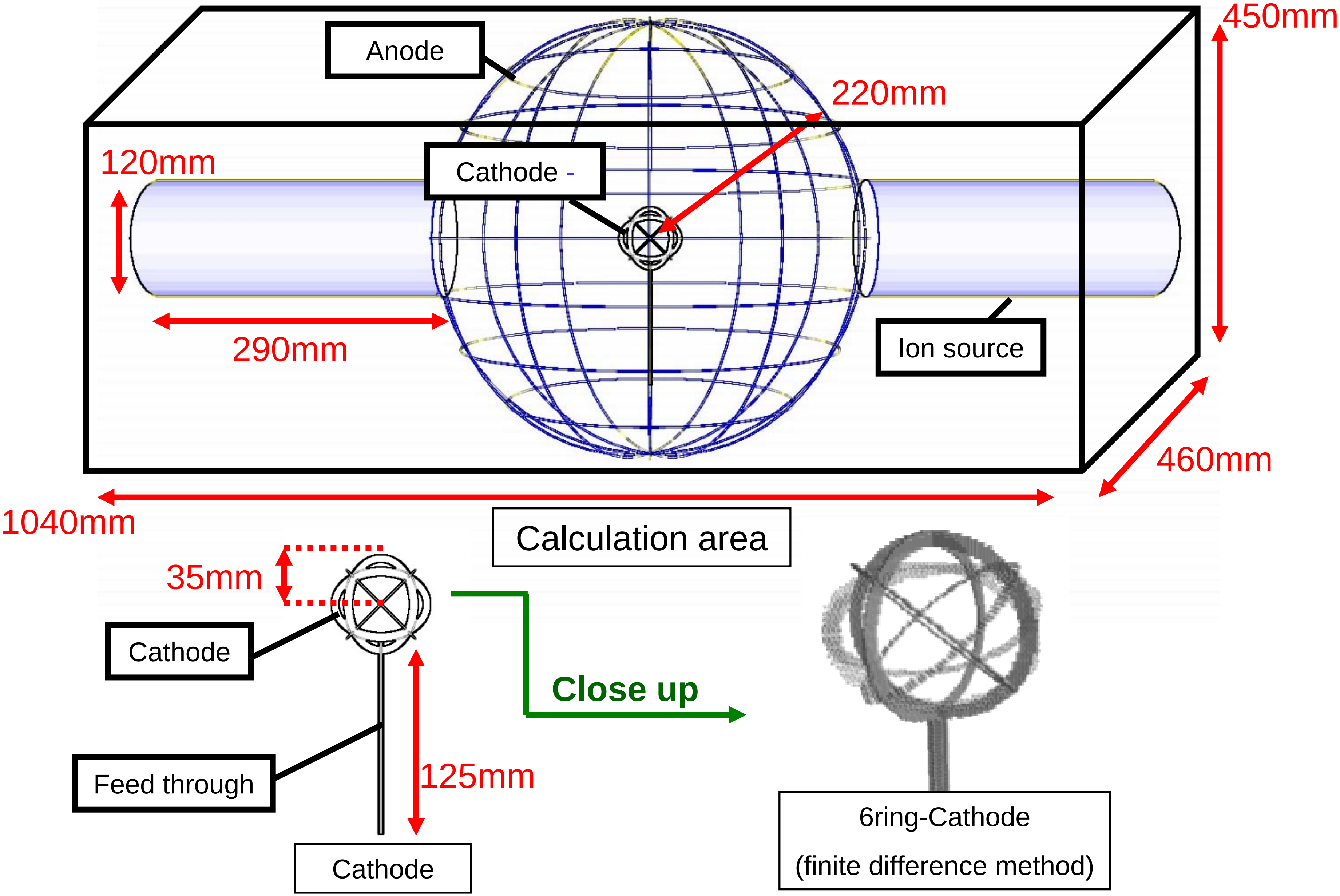


Discharge without ion source

Anode Radius [m]	0.22(Φ440mm)	
Cathode Radius [m]	0.035(Φ70mm)	
Feed through Radius [m]	0.003	
Material of ion source wall	glass	
Calculation lattice	520×450×230	
Time step [sec]	1.0×10^{-12}(1.0psec)	
Simulation time [sec]	6.0×10^{-6}(6.0μsec)	
Initial number of super particle	e^-	3000
	D^+	1000
	D_2^+	1000
	D_3^+	1000
The number of super particle as 'discharge'	50000	
Range of gas pressure [Pa]	0.5～2.0	
Range of voltage [kV]	0.1～80	

●The particle moves only the ion source area and the anode area,
●And the electric field calculation is the whole calculation area.

Calculation Area



Ion-molecule Collision Process

24 kinds of ionization , dissociation , charge-exchange ,elastic collision are considered

$\mathbf{D^+}$

$$D^+(beam) + D_{2(back)} \rightarrow D^0(beam) + D_2{}^+(slow) \quad \mathbf{(1)}$$

$$D^+(beam) + D_{2(back)} \rightarrow D_2{}^+(slow) + D^+(beam) + e^- \quad \mathbf{(2)}$$

$$D^+(beam) + D_{2(back)} \rightarrow D^+(slow) + D^+(beam) + D^0(slow) + e^- \quad \mathbf{(3)}$$

$\mathbf{D_2{}^+}$

$$D_2{}^+(beam) + D_{2(back)} \rightarrow D_2{}^0(beam) + D_2{}^+(slow) \quad \mathbf{(4)}$$

$$D_2{}^+(beam) + D_{2(back)} \rightarrow D_2{}^+(beam) + D_2{}^+(slow) + e^- \quad \mathbf{(5)}$$

$$D_2{}^+(beam) + D_{2(back)} \rightarrow D^+(beam) + D^0(beam) + D_{2(back)} \quad \mathbf{(6)}$$

$$D_2{}^+(beam) + D_{2(back)} \rightarrow D_3{}^+(slow) + D^0(beam) \quad \mathbf{(7)}$$

$\mathbf{D_3{}^+}$

$$D_3{}^+(beam) + D_{2(back)} \rightarrow D_2{}^0(beam) + D^+(beam) + D_{2(back)} \quad \mathbf{(8)}$$

$$D_3{}^+(beam) + D_{2(back)} \rightarrow D^0(beam) + D_2{}^+(beam) + D_{2(back)} \quad \mathbf{(9)}$$

Fast Neutrals-Molecule , Electron-Molecule Collision Process

$$D^0{}_{(beam)} + D_{2(back)} \rightarrow D^+{}_{(beam)} + D_{2(back)} + e^- \quad (10)$$

D^0

$$D^0(beam) + D_{2(back)} \rightarrow D^0(beam) + D_2{}^+(slow) + e^- \quad (11)$$

$$D^0(beam) + D_{2(back)} \rightarrow D^0(beam) + 2D^+(slow) + 2e^- \quad (12)$$

$$D^0(beam) + D_{2(back)} \rightarrow D^0(beam) + D^+(slow) + D^0(slow) + e^- \quad (13)$$

$D_2{}^0$

$$D_2{}^0(beam) + D_{2(back)} \rightarrow D_2{}^+(beam) + D_{2(back)} + e^- \quad (14)$$

$$D_2{}^0(beam) + D_{2(back)} \rightarrow 2D^+(beam) + D_{2(back)} + 2e^- \quad (15)$$

e^-

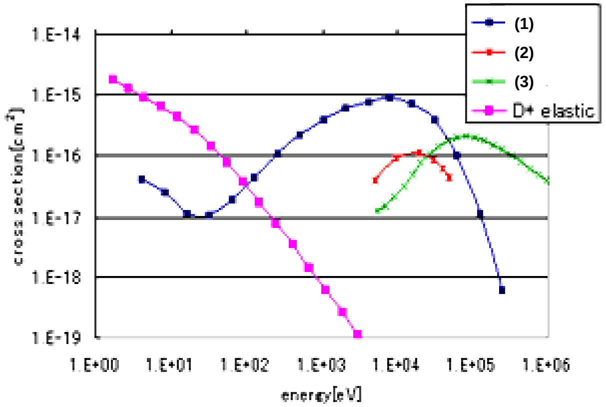
$$e^- + D_{2(back)} \rightarrow D_2{}^+(slow) + 2e^- \quad (16)$$

$$e^- + D_{2(back)} \rightarrow 2D^0(slow) + e^- \quad (17)$$

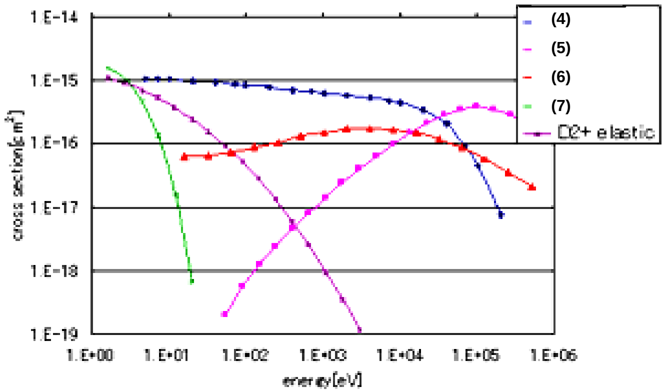
$$e^- + D_{2(back)} \rightarrow D^+(slow) + D^0(slow) + e^- \quad (18)$$

Elastic collisions **(19)-(24)**

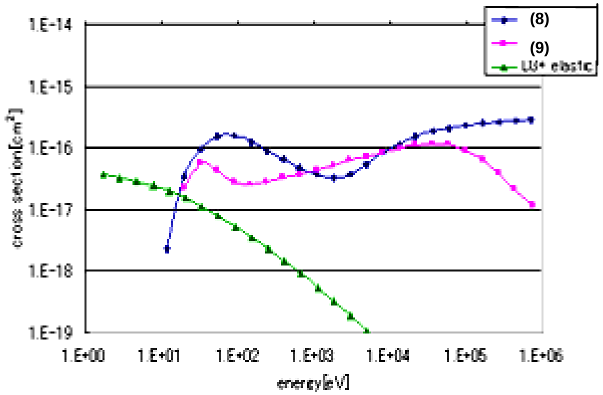
Date of Cross-Section



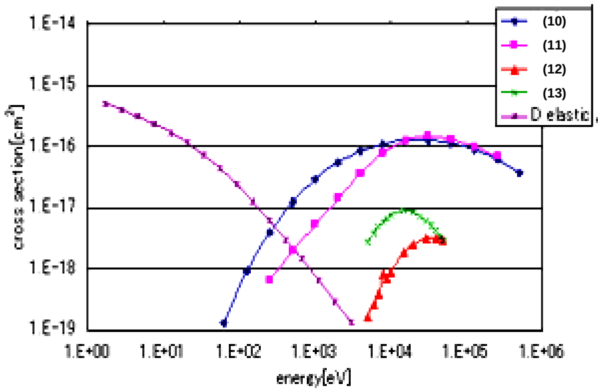
D^+ (1)～(3)



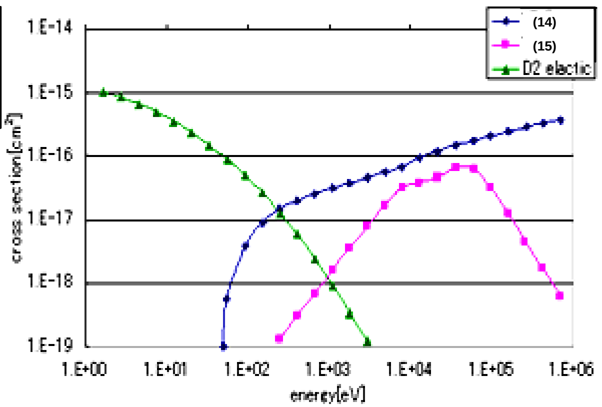
D_2^+ (4)～(7)



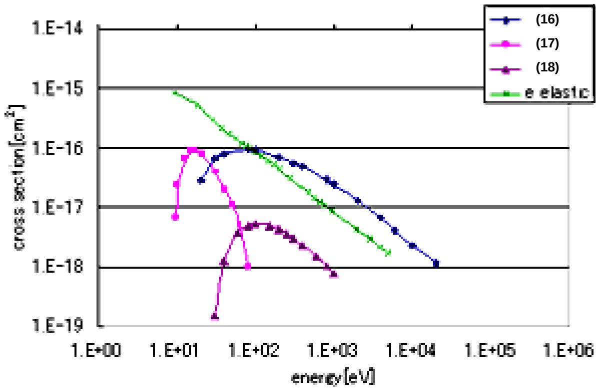
D_3^+ (8)～(9)



D^0 (10)～(13)



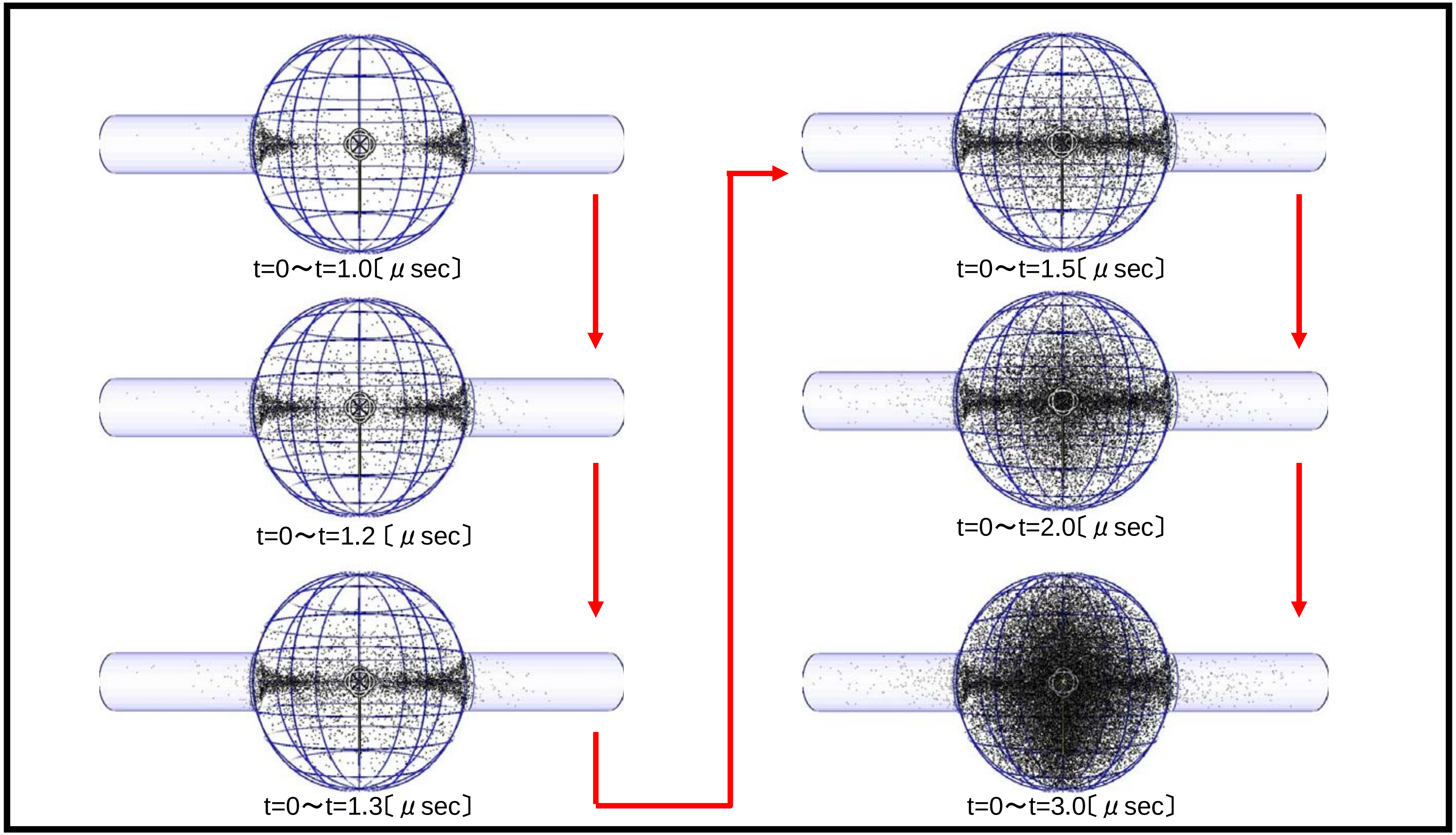
D_2^0 (14)～(15)



e^- (16)～(18)

- ●Each number is according to the number of process at previous slide.
- ●These graphs are referred to the data of the Red Book of the oak Rich University.

Space Distribution of Collision (4)

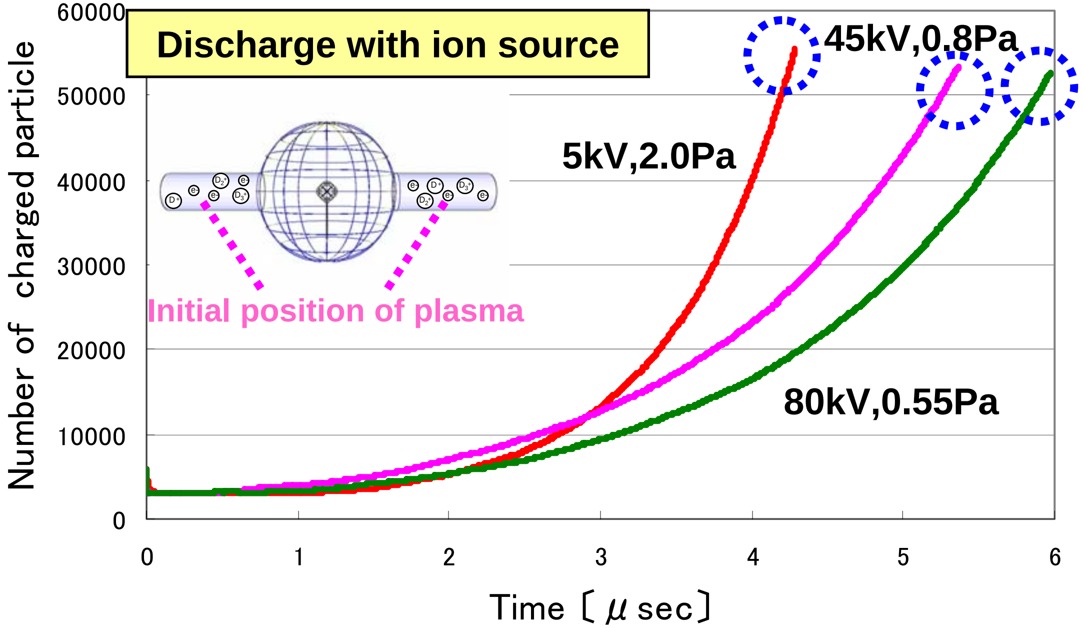


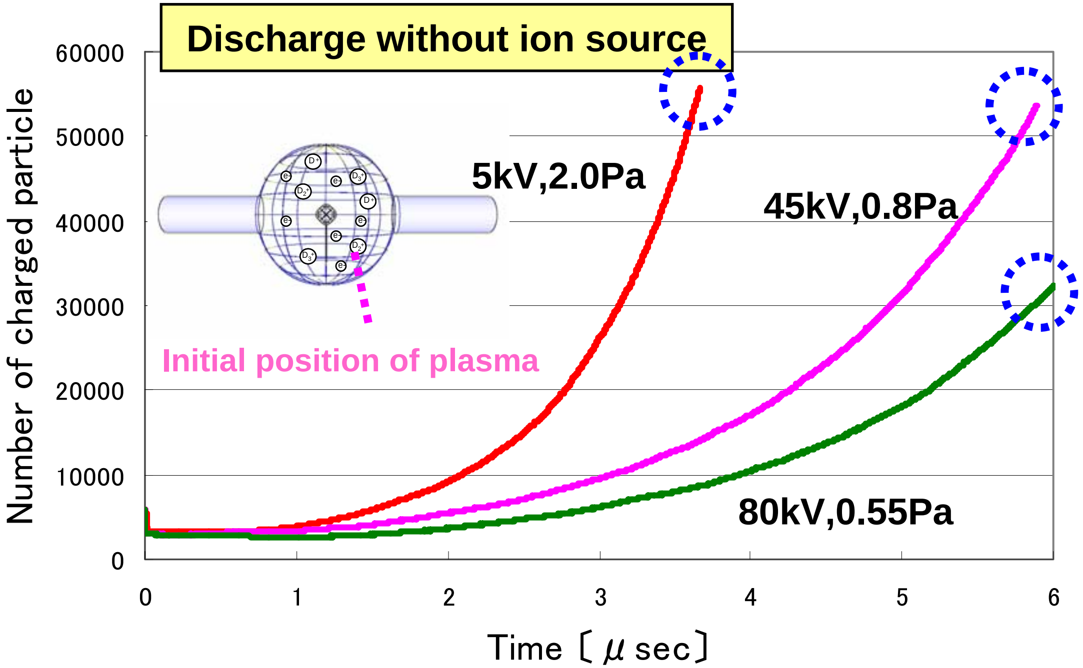
Voltage	−10kV
Gas pressure	1.6pa

Those figures is the space distribution of collision process (4).

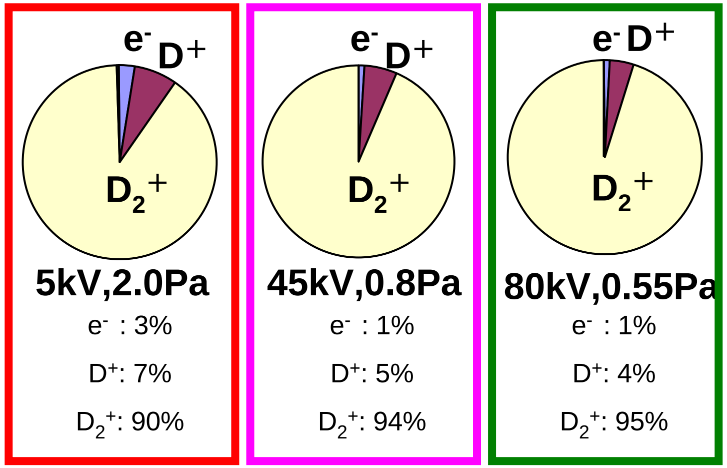
$$D_2{}^{+}{}_{(beam)} + D_{2(back)} \rightarrow D_2{}^{0}{}_{(beam)} + D_2{}^{+}{}_{(slow)} \quad (4)$$

Increase of Charged Particle

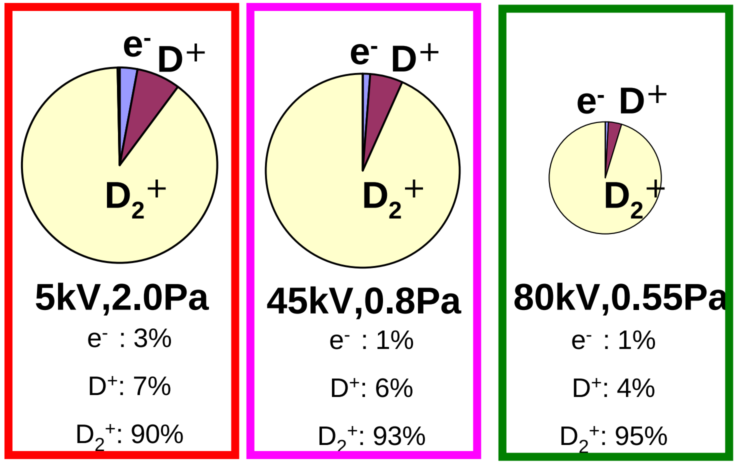




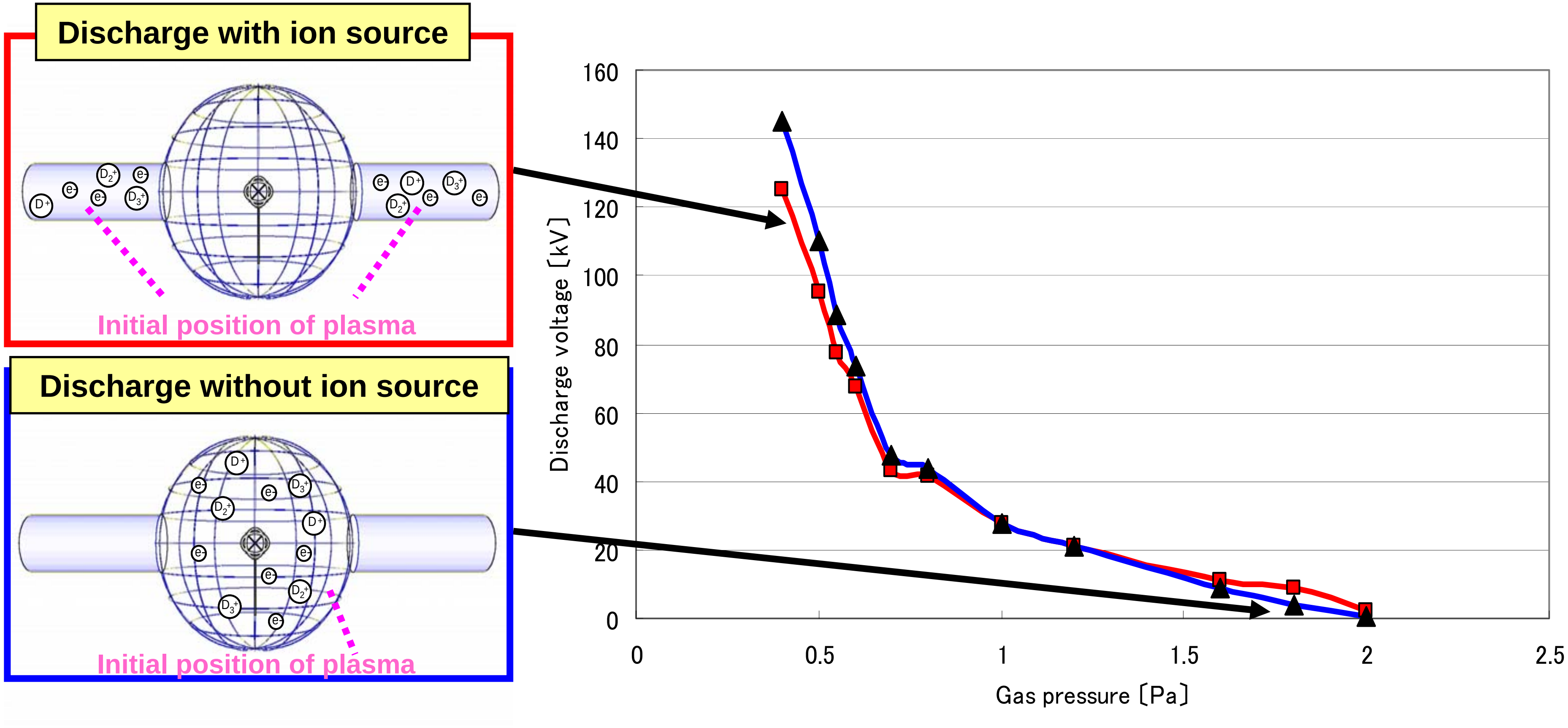
Existing rate of the particles



- ●The number of charged particle is increased proportionately to the gas pressure.
- ●The dependence to the gas pressure with ion source is not so strong .
- ●The rate of charged particle with ion source and without ion source are almost same.
- ● The rate of D2+ is highest at all condition.



Discharge Characteristics



The discharge characteristic with ion source and without ion source is almost same.

Rate of Each Collision Processes

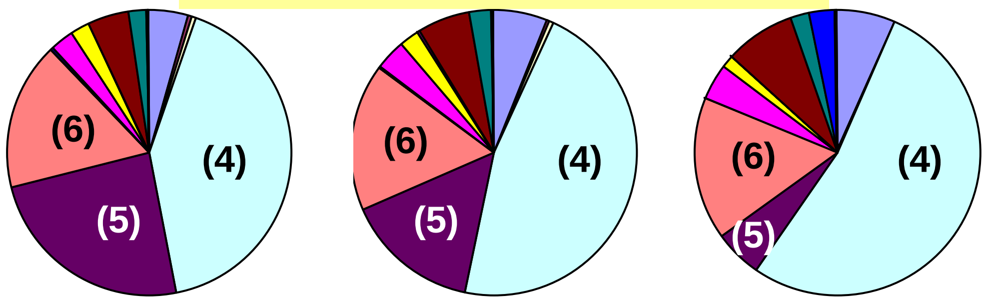
$$D_2^{+}(beam) + D_{2(back)} \rightarrow D_2^{0}(beam) + D_2^{+}(slow) \quad (4)$$

$$D_2^{+}(beam) + D_{2(back)} \rightarrow D_2^{+}(beam) + D_2^{+}(slow) + e^{-} \quad (5)$$

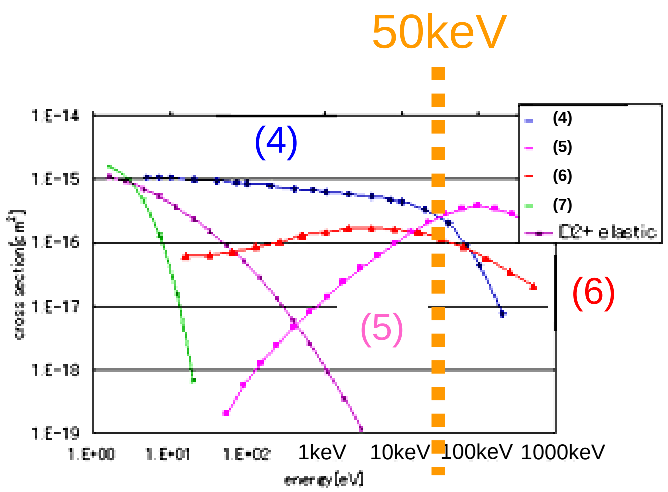
Self-multiplication reaction

$$D_2^{+}(beam) + D_{2(back)} \rightarrow D^{+}(beam) + D^{0}(beam) + D_{2(back)} \quad (6)$$

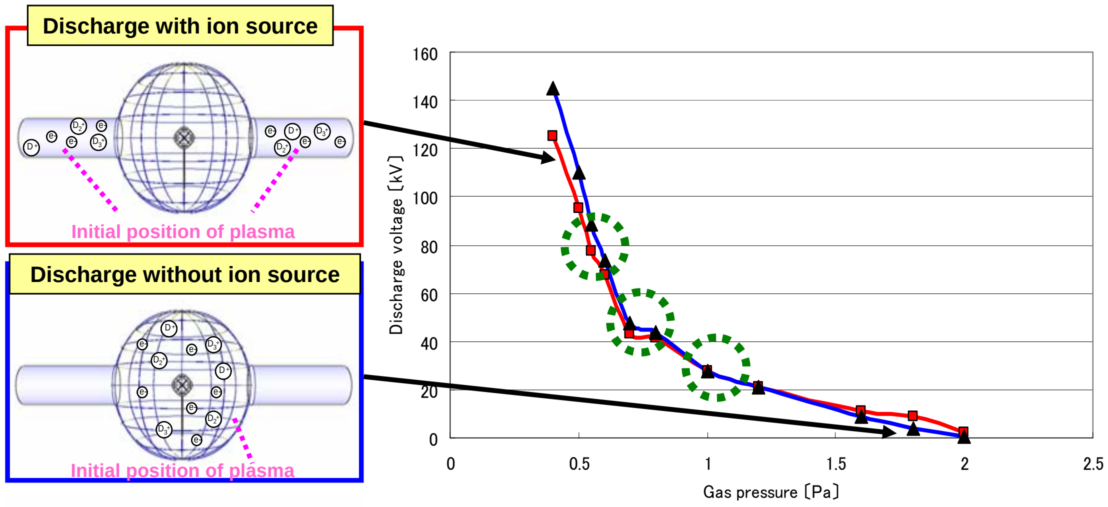
Rate of each collision process



80kV,0.55pa **45kV,0.8pa** **22.5kV,1.2pa**



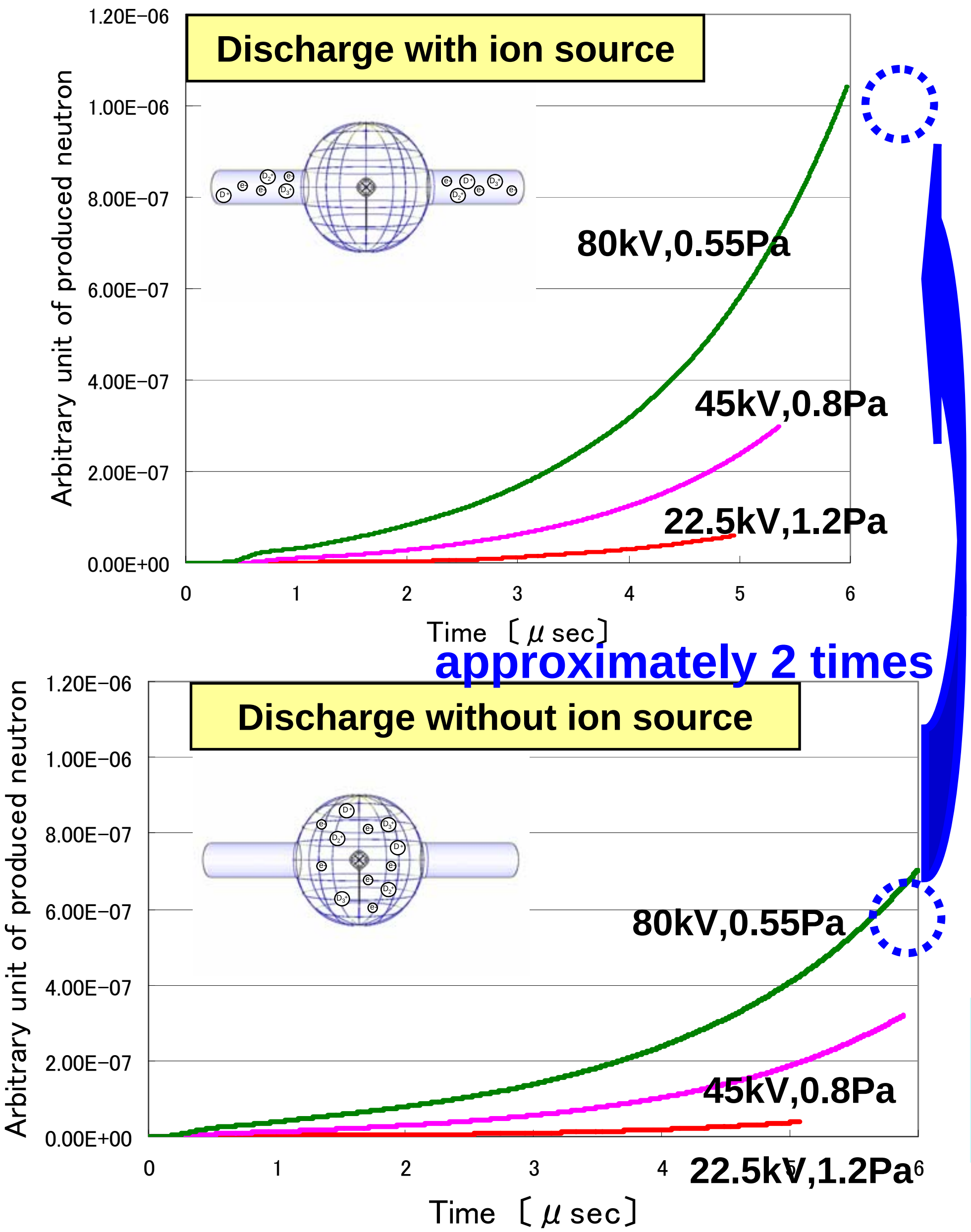
Cross-section of D_2^{+} ion V.S D_2 neutrals



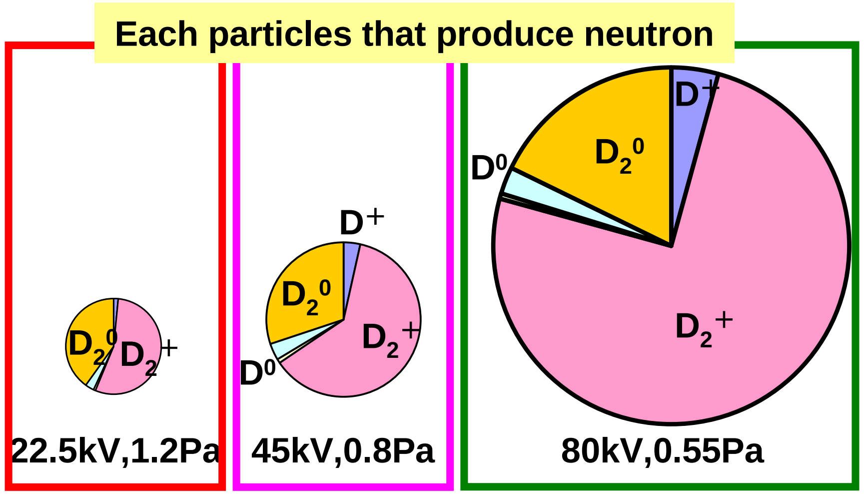
●Because rate of this reaction of (5) is high at low gas pressure, it is predicted that D2+ are multiplies efficiently.

●Though there are little number of the charged particles at low gas pressure ,D2+ increases neutron production rate must be high.

Neutron Production Rate



●In both situations , the initial plasma density is assumed as same in this simulation.
●However, in the experimental results, the plasma density become high when the ion source is used.
●Therefore, it is expected that the effect of the ion source appears more than this calculation result.



●From previous slide, D2+ is domain particles.
●Therefore there are many neutron production by D2+ .
●Those pai charts are almost same in both situation.

Conclusions

- The number of charged particle is increased proportionately to the gas pressure. The dependence with ion source is not so strong.
- The discharge characteristics with ion source and without ion source are almost same.
- 90% of charged particle is D_2^+ with or without ion source.
- The atomic process (5) which is self-multiplication of D_2^+ ion is make important role at the discharge of lower gas pressure.
- 75% of neutron is produced by D_2^+ ion , 25% of neutron is produced by D_2^0 fast neutral at 80kV, 0.55Pa.
- The neutron production rate with ion source is almost 2 times higher than one without ion source.