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Effect of light-mass ion species on plasma characteristics in NIFS-RNIS

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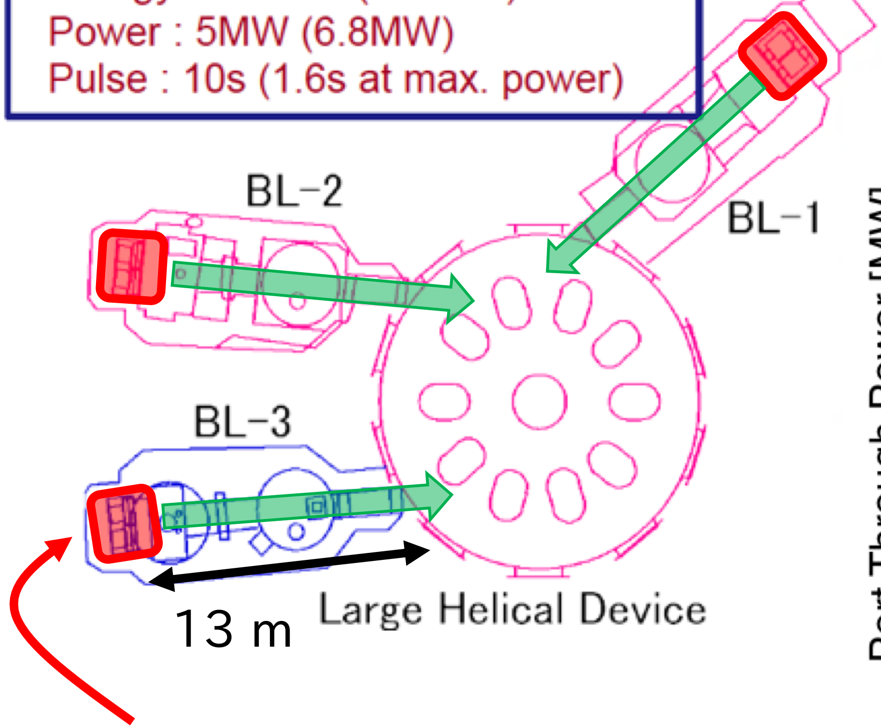
Outline

- Background and Objective
  - H and D Neutral Beam Operation in LHD
  - H_2 and He mixed H_2 discharge to imitate D_2 discharge
- Experimental Setup
  - NIFS-RNIS on NIFS-NBTS
  - Diagnostics in Source Plasma
- Experimental Results
  - H_2 and He mixed H_2 discharge
  - H_2 and D_2 discharge.
- Summary

First Deuterium Operation of Negative Ion Based Neutral Beam Injector (NBI) on Large Helical Device (LHD)

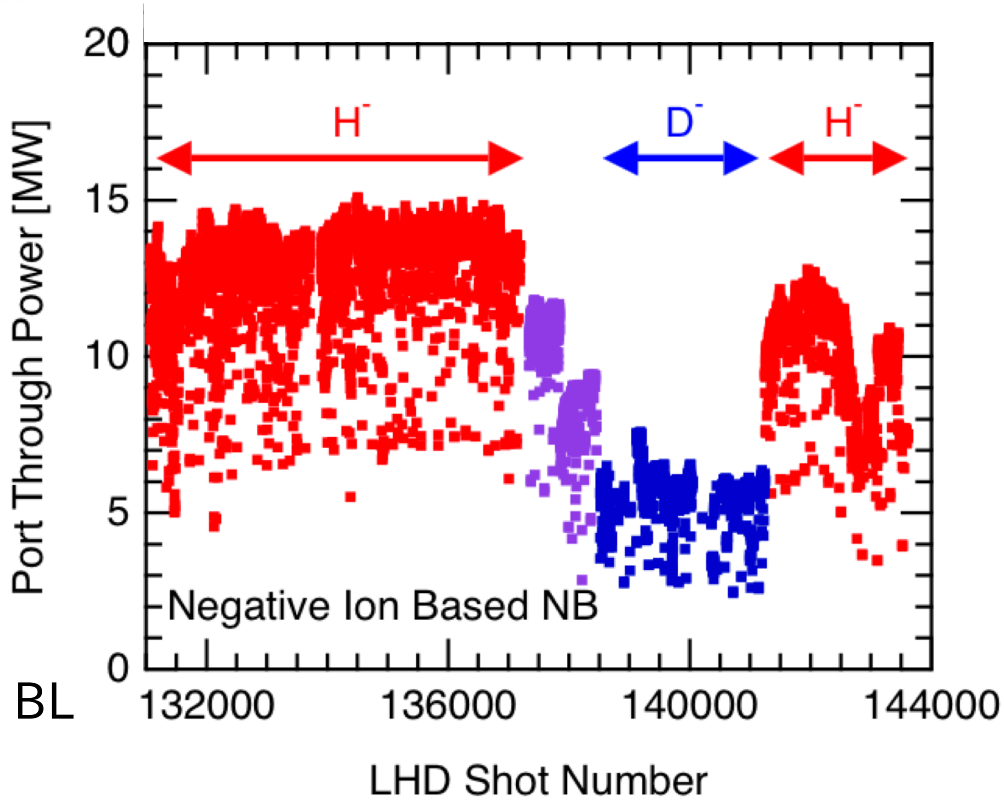
Hydrogen Operataion

Design (Achievements) for 1 injector
Energy : 180keV (190keV)
Power : 5MW (6.8MW)
Pulse : 10s (1.6s at max. power)



Two negative ion sources on each BL

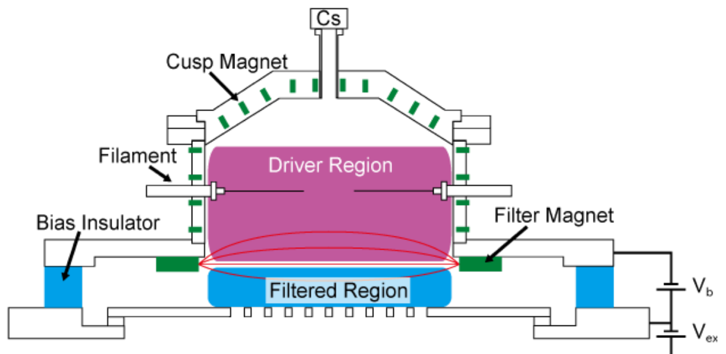
Total port through injection power by 3 BLs in first deuterium experiment campaign of LHD

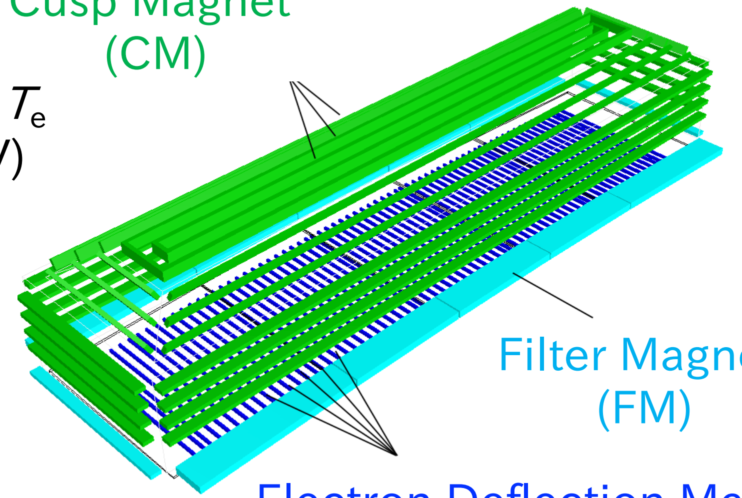


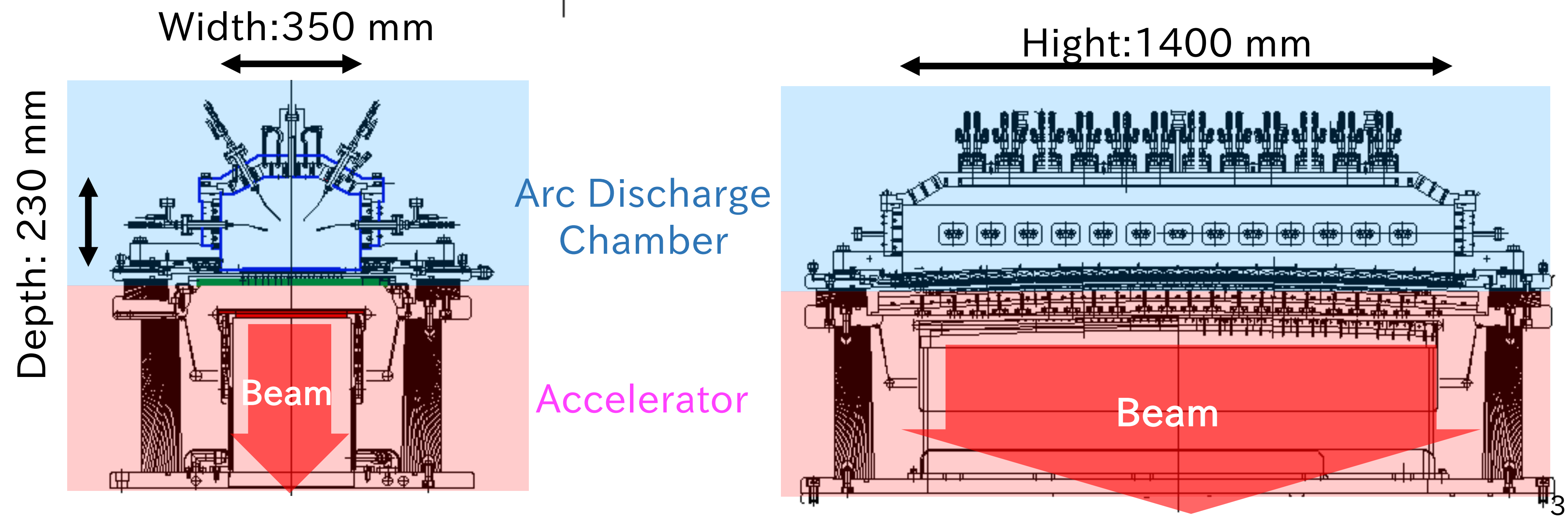
- The total port-through (PT) power of H beam reached 15 MW nominal total power.
- However, the PT power of D beam decreased less than half of that of H beam.

Negative Ion Source for LHD-NBI

- Cesium seeding filament-arc aource
- Three types of magnets is installed; CM, FM EDM.
- FM separates the ion source plasma into the high T_e (a few eV) discharge (driver) and the low T_e (<1 eV) extraction (filtered) regions.







Comparison between Hydrogen (H) and Deuterium (D) Operations

<Comparison Experiment>

Gas Species	Pressure [Pa]	Discharge Power (P) [kW]	Bias Voltage [V]	Extraction Voltage [kV]	Acceleration Voltage [kV]
H_2	0.25	165	3	6.6	112
D_2	0.25	149	3	6.6	112
	Fixed		Fixed		

Gas Species	Electron Beam Current (I_e) [A]	Negative Ion Beam Current ($I(H^-)$, $I(D^-)$) [A]	$I_e/I(H^-)$, $I_e/I(D^-)$
H_2	9.3	24.6	0.38
D_2	22.6	16.5	1.37
Current ratio normalized by Discharge Power $\frac{[I(D)/P_{dis}(D)]}{[I(H)/P_{dis}(H)]}$	~3	0.7 $(\sim 1/\sqrt{2})$	

What is the difference between H and D plasmas?

Parameter	Hydrogen		Deuterium
Ion/atomic mass, M	Light (1)	<	Heavy (2)
Space Potential (V_s) in the vicinity of PG	Low ?		High?
Electron density (n_e) in the vicinity of PG (∝ electron beam current, I_e)	Low ?		High ?
Cs Sputtering	Low?		High?
Negative ion generation efficiency (Work function of PG surface)	Low (High) ?		High (Low) ?
Negative ion density, $n(H^-)$, $n(D^-)$	same ?		same ?
Negative ion flux to PG, nv (∝ negative ion beam current, $I(H^-)$, $I(D^-)$)	High	>	Low

What mechanism is provided for the difference of the ion source performance between H and D operations?

Measure the ion source plasmas in H and D discharges

~~LHD-NBI~~

However, we need time to pass some procedure for getting the permission to start to use D_2 gas and cannot extract D beam in the test facility at NIFS.

Objective

Helium (He)

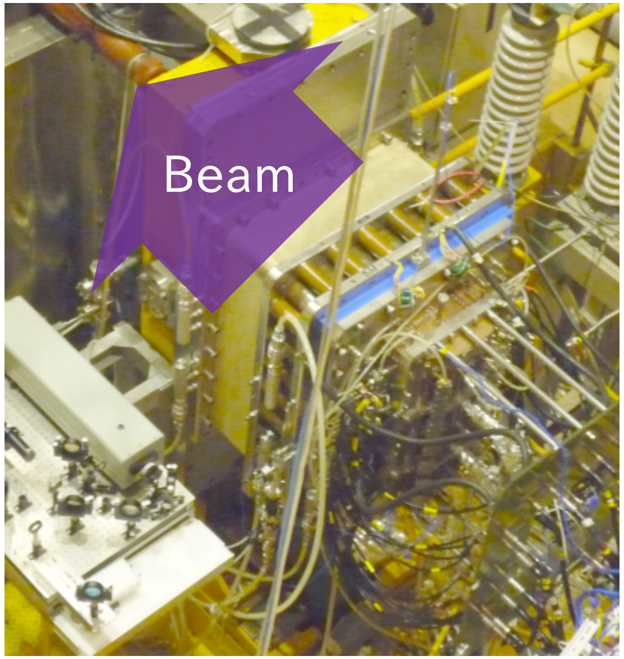
- The lightest mass particle except H.
- NOT much amount of negative ion generation.
- Cryo-sorption pump does not evacuate He much.
  - It is difficult to use much amount of He gas frequently.

There is a possibility that the He mixed H_2 gas discharge simulates the higher effective M and n_e plasma such as the D_2 discharge plasma.

- **He mixed H_2 discharge**
  - Property of He mixed discharge plasma
  - Difference between H_2 and He mixed plasmas.
  - Negative ion and cesium behavior in plasma with different average-ion-mass number : 1x(H_2 gas ratio) + 4x(He gas ratio).
    e.g. He(30%) → 0.7+4x0.3 =1.9.
- **D_2 discharge**
  - Comparison with H_2 and D_2 discharge.

Experimental Setup

NIFS-RNIS on NIFS-NBTS

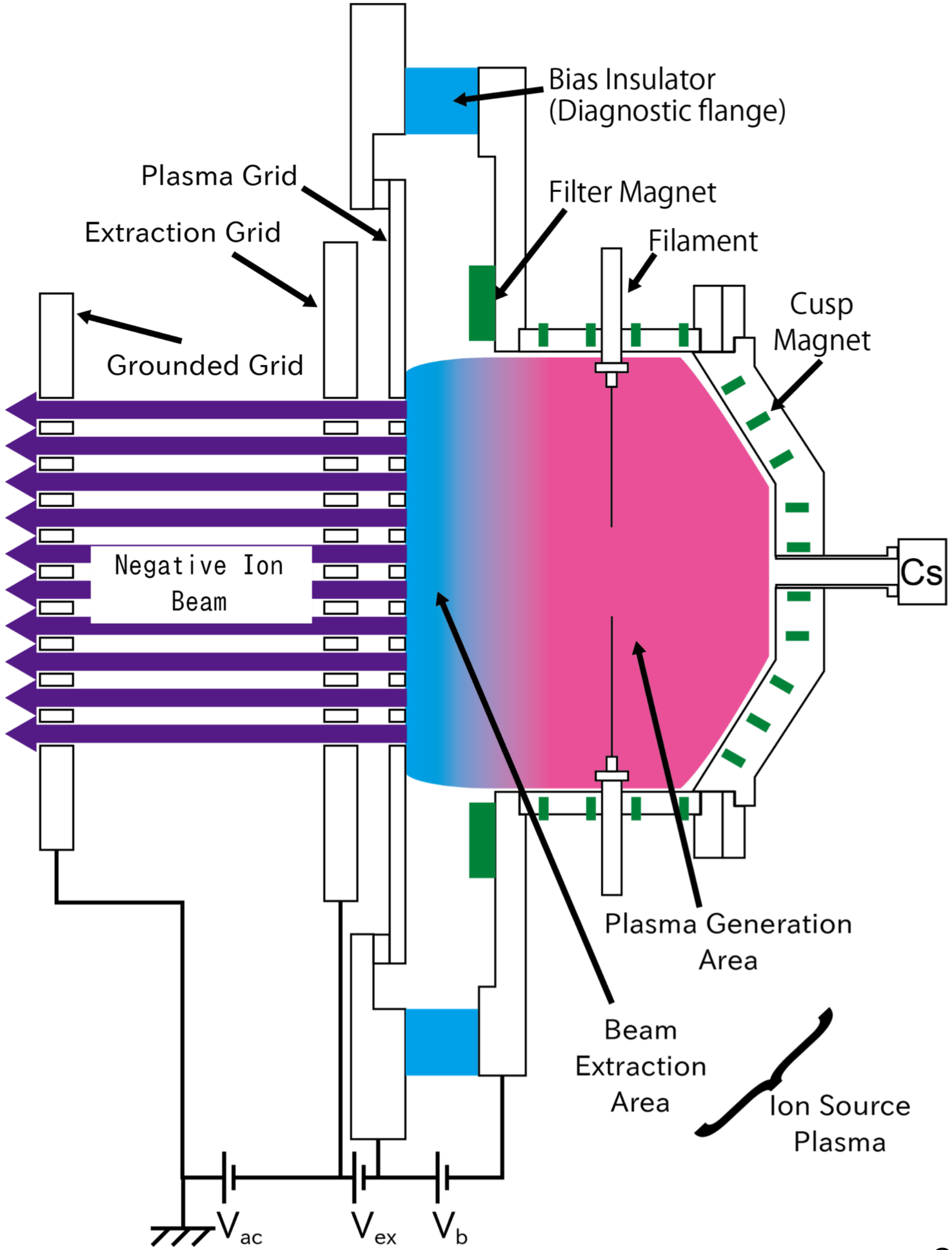


NIFS-NBTS:

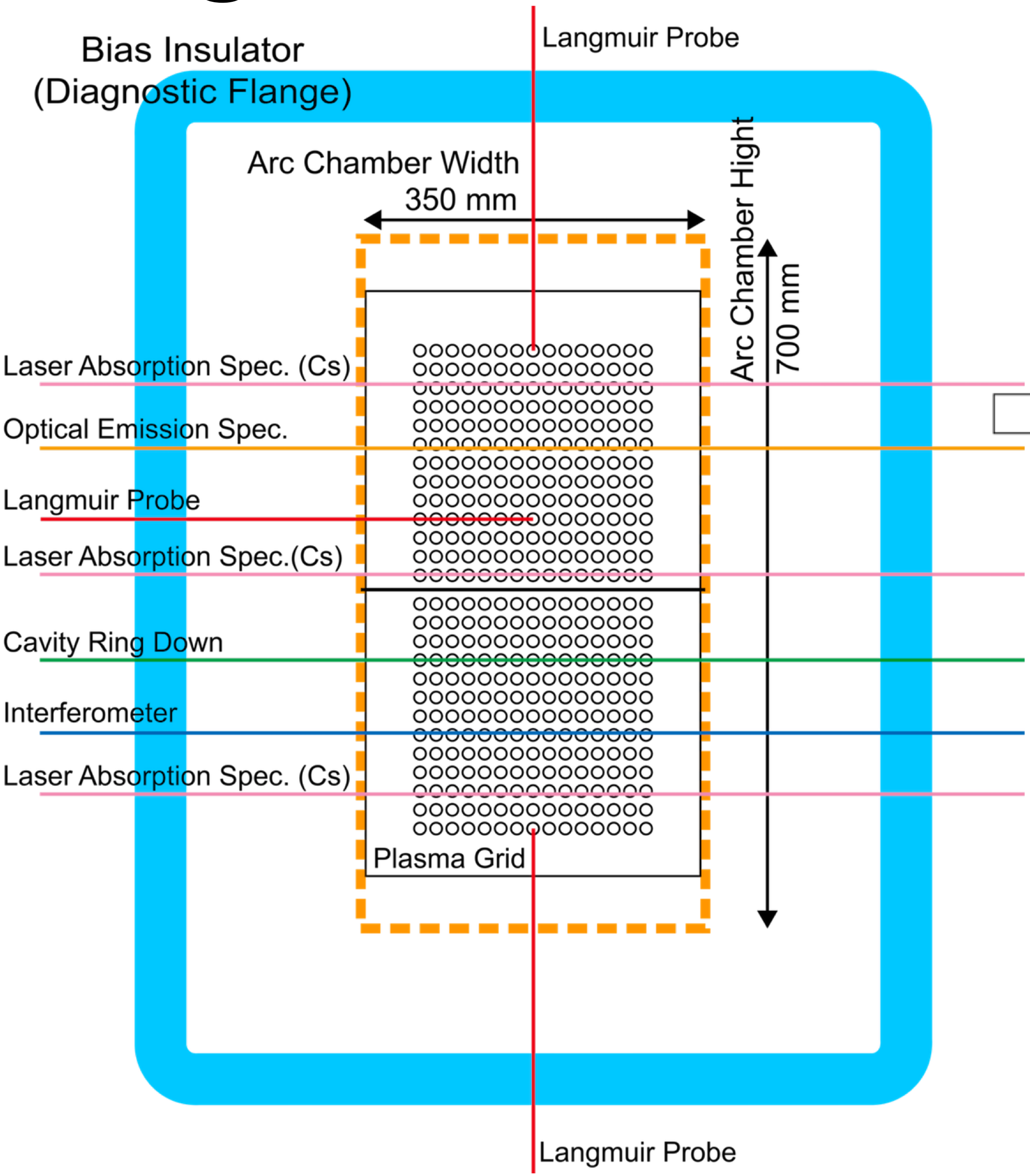
- Real scale beam line of LHD-NBI.
- No high energy D beam extraction.
  (The NIFS-NBTS is not in the LHD hall where neutron generation is permitted in NIFS.)

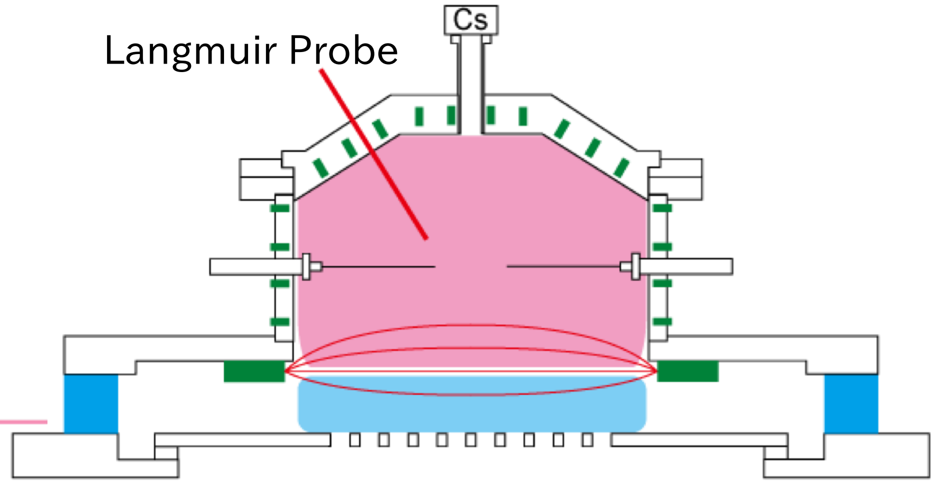
NIFS-RNIS:

- Filament-arc source the same type as the negative ion source for LHD-NBI.
- Half discharge volume of actual negative ion source for LHD-NBI.
- Many diagnostics are installed on the bias insulator and discharge chamber.



Diagnostics for Source Plasma





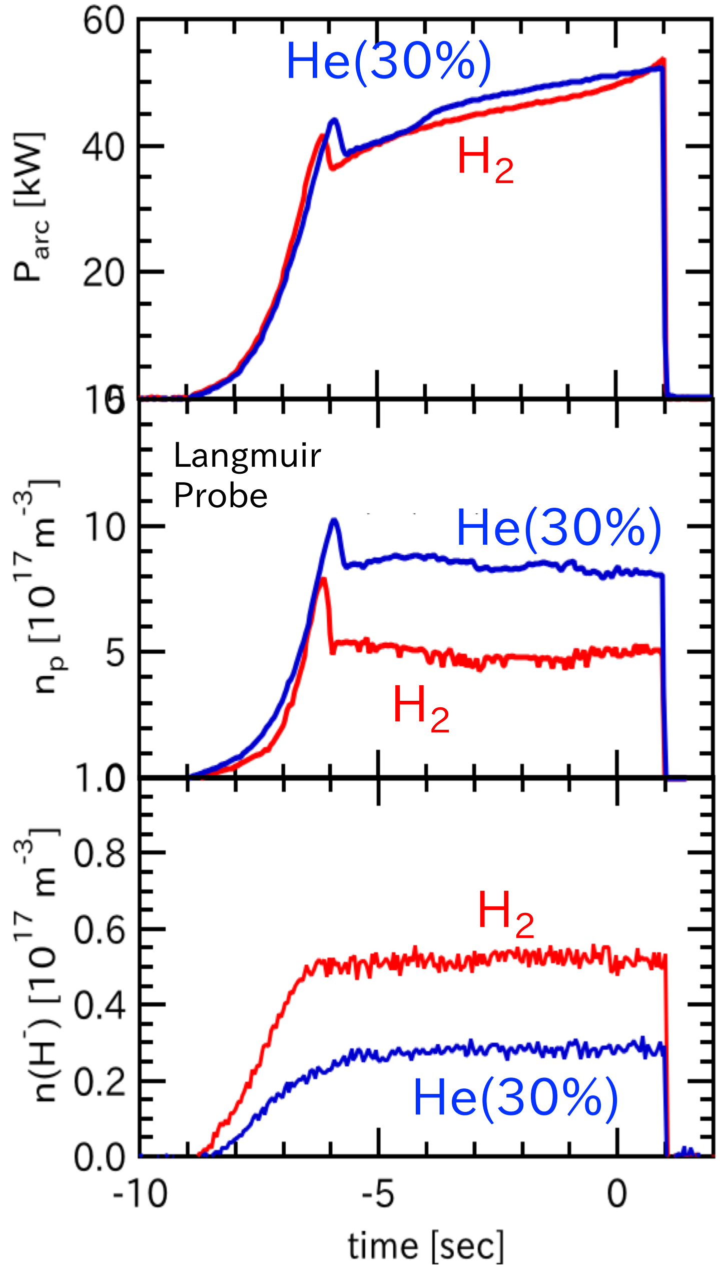
- Langmuir Probe (LP):
  n, T_e, V_s, I_{is}, I_{es} & their profiles
- Cavity RingDown (CRD):
  $\langle n(H^-) \rangle$
- Interferometer:
  $\langle n_e \rangle$
- Laser Absorption Spectroscopy (Cs):
  $\langle n(Cs^0) \rangle$
- Optical Emission Spectroscopy:
  $H\alpha$, $H\beta$, $H\gamma$, Cs I, He I

Measure position of the diagnostics on the bias insulator is 1 – 30 mm.

Experimental Results

～He mixed H_2 Discharge～

H_2 and H_2+He(30%) Discharges without cesium seeding



Pressure : 0.3 Pa

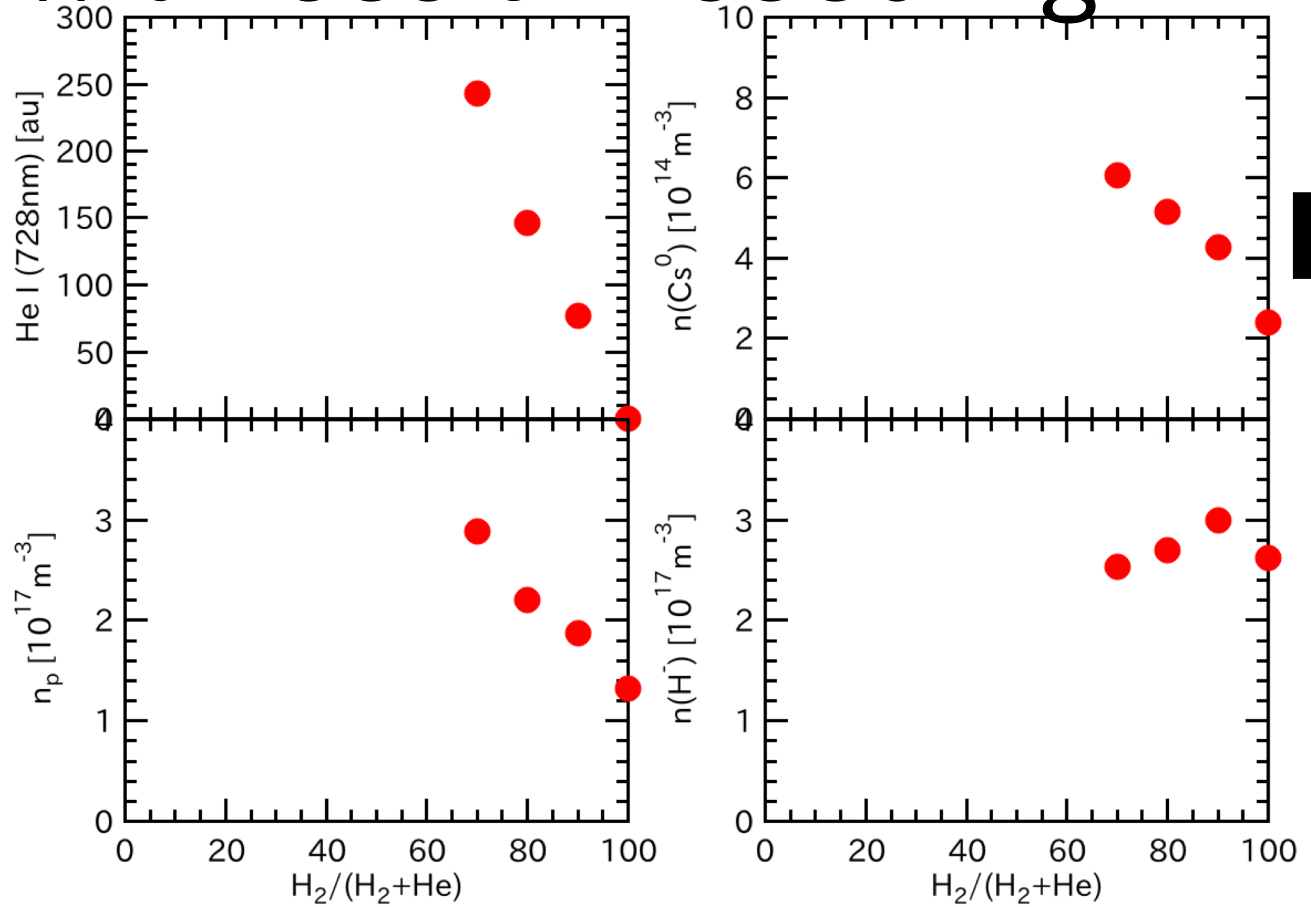
Discharge Power : 50 kW

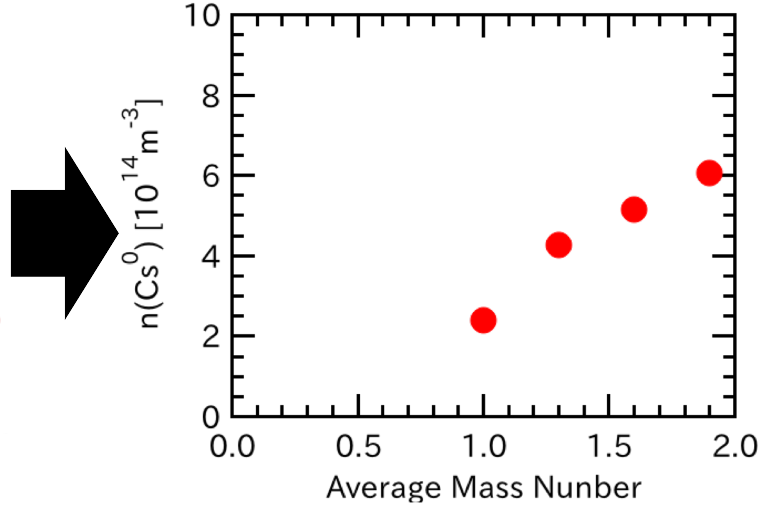
Bias Voltage : 2.4 V

- Not only electron but also plasma density (n_p) in the vicinity of the PG in He(30%) mixed plasma was approximately 1.6 times higher than that in H_2 plasma.
- $n(H^-)$ decreased to approximately 53% of the H_2 plasma.

The variation by He mixed H_2 discharge qualitatively corresponds to expected one.

He mixed H_2 Discharges with cesium seeding

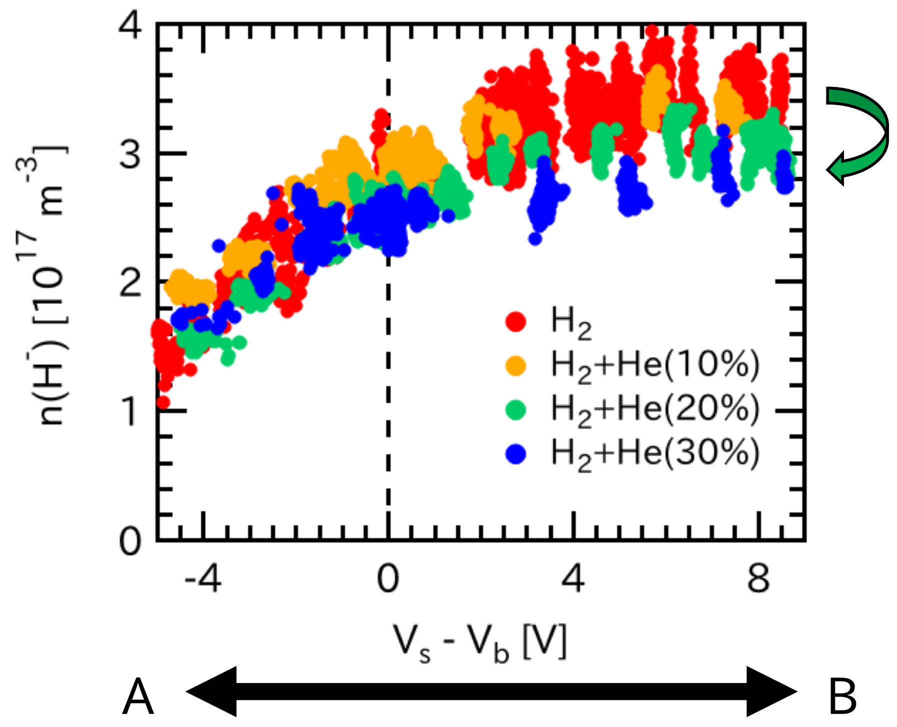


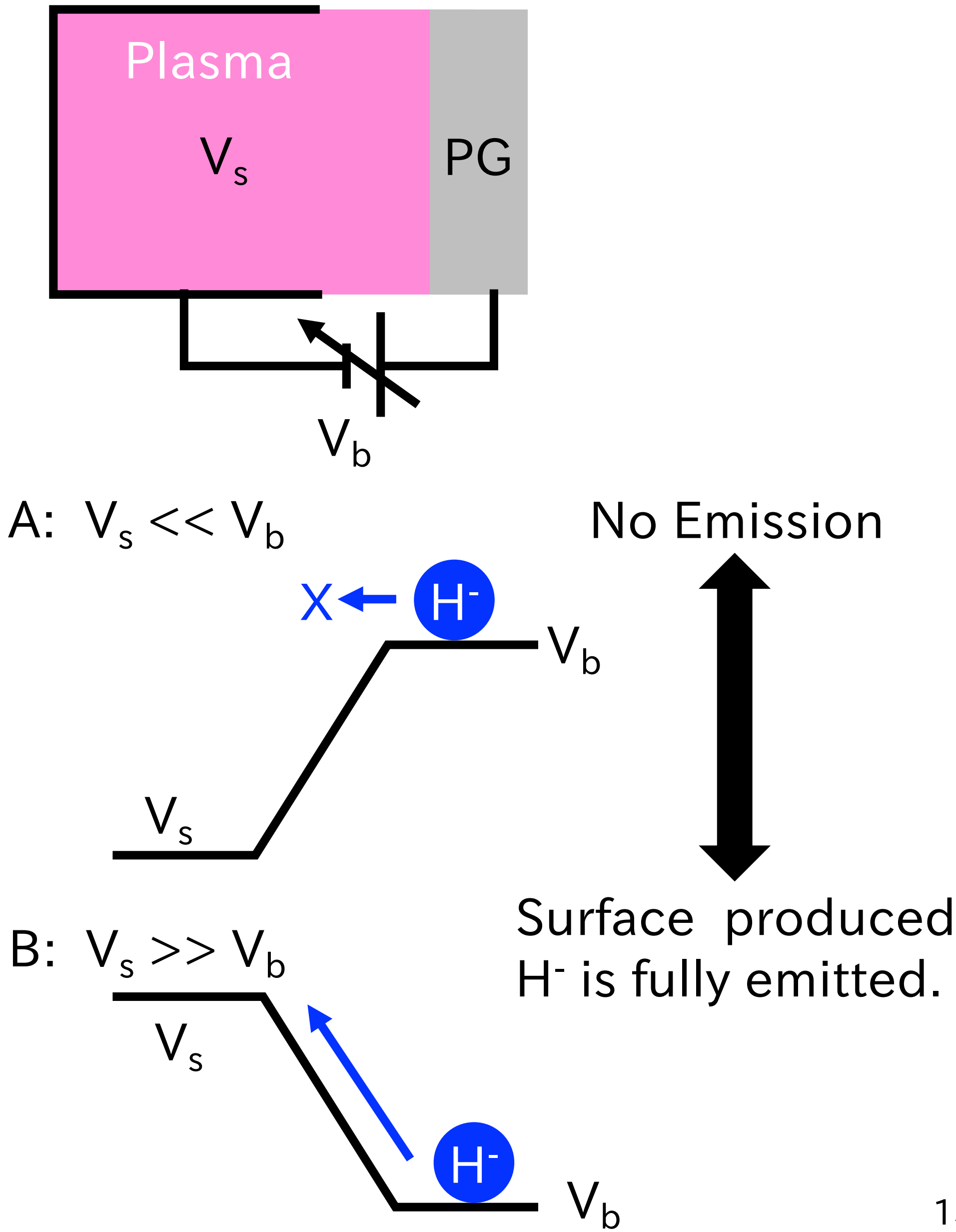


Pressure : 0.3 Pa
Discharge Power : 50 kW
Bias Voltage : 2.4 V

- He I intensity increased with He ratio (decreasing with H_2 ratio).
- Plasma density (n_p) in the vicinity of the PG decreased with H_2 ratio.
- $n(Cs^0)$ decreased with the H_2 ratio. Massive particle effectively sputter cesium on the chamber surface. This case the sputtering mechanism is the physical sputtering.
- $n(H^-)$ does not change comparing to the n_p variation.

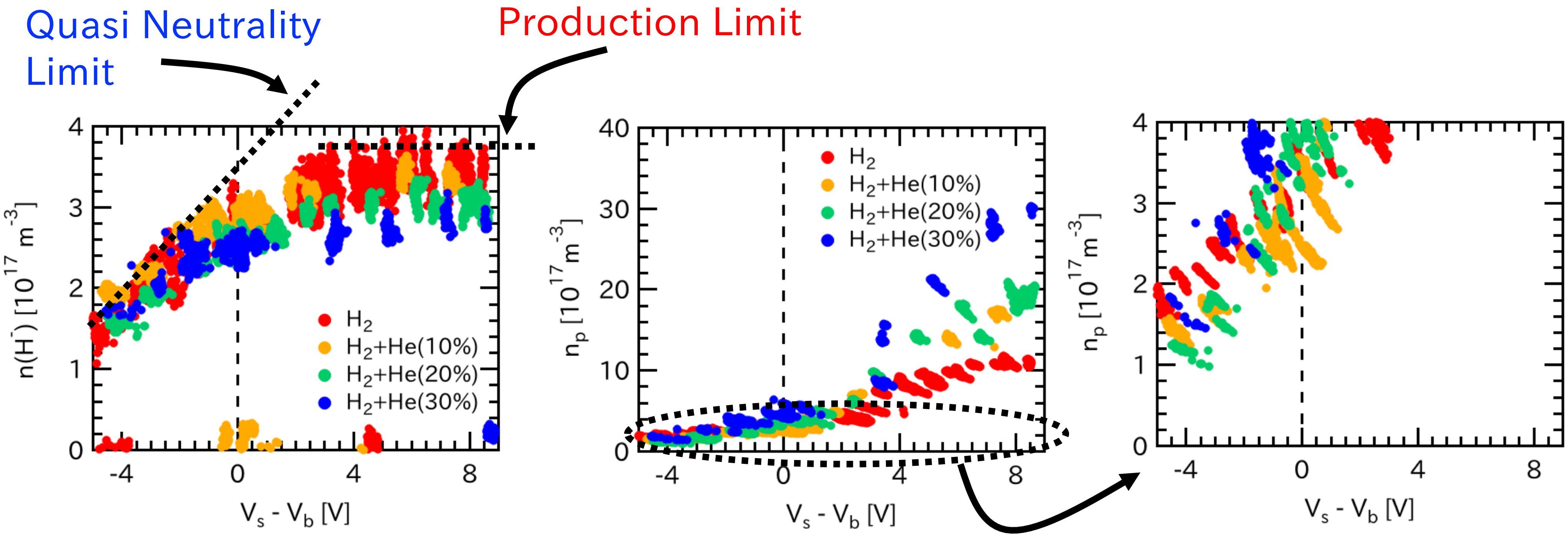
Bias Voltage Dependence of H_2 and He mixed H_2 plasmas





In large V_s-V_b, $n(H^-)$ changes with H_2 ratio. Here, $n(H^-)$ difference between different H_2 ratio is reflected by the differences of H^- production amount on the PG, that is, by the number of the parent particle incidence to the PG. → Production Limit

Production and Quasi-Neutrality Limits



Production Limit

In large $V_s - V_b$, maximum $n(H^-)$ is limited by production amount.

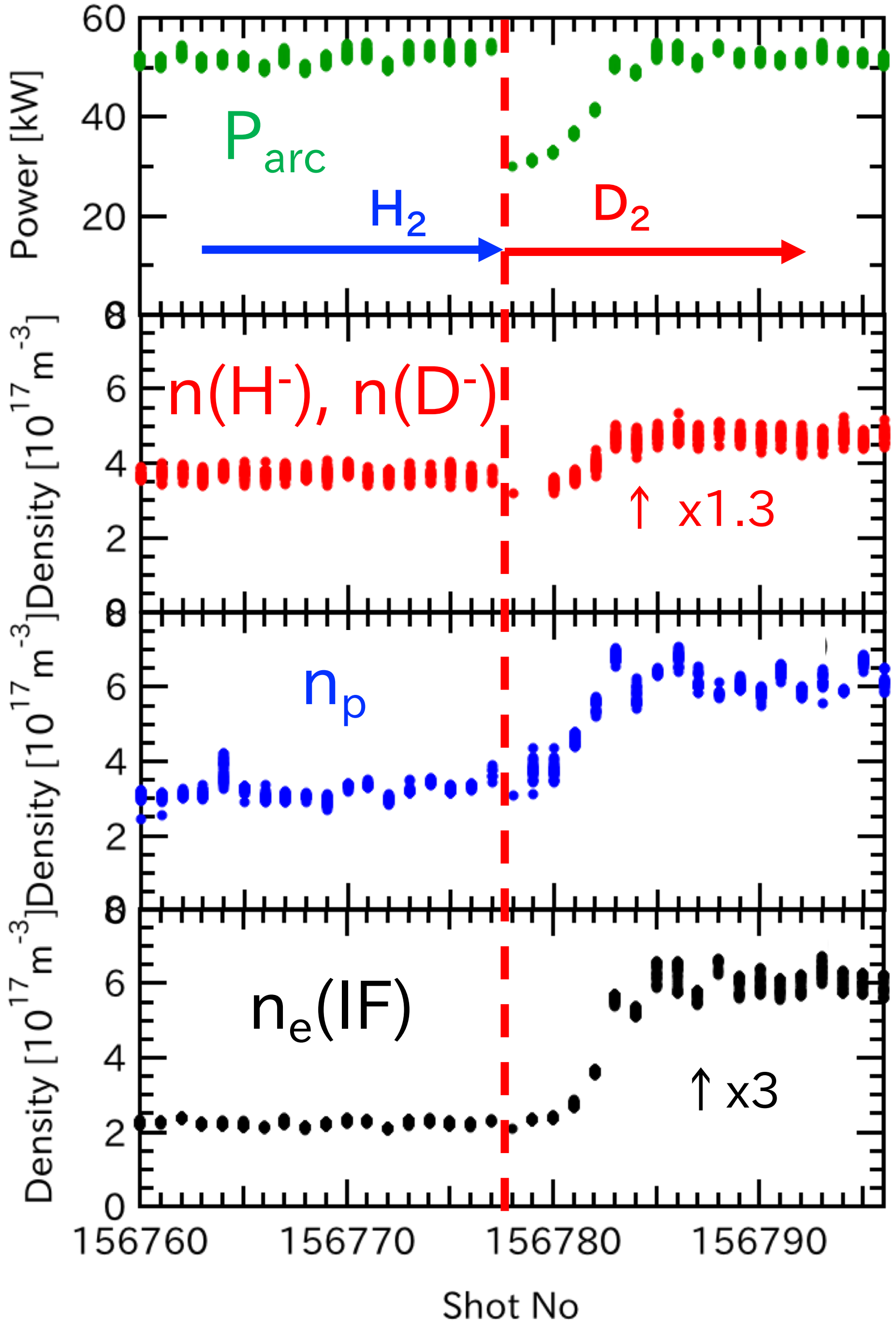
Quasi Neutrality Limit

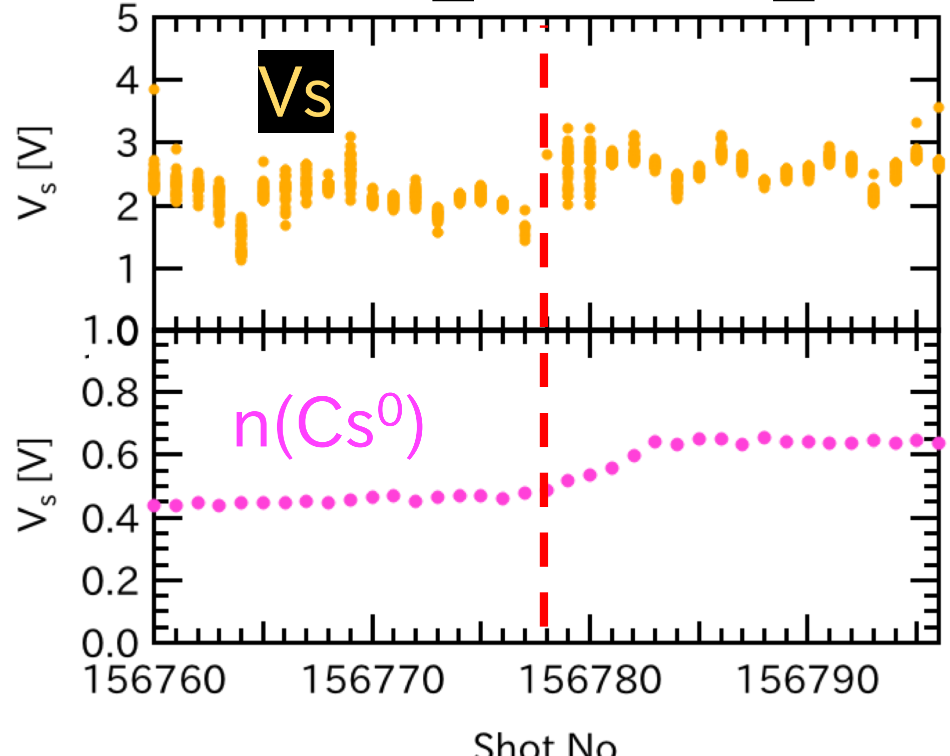
In low $V_s - V_b$, n(H-) is limited by the plasma density in the vicinity of the PG.

Experimental Results

～D_2 Discharge～

Changing Gas Species $H_2 \rightarrow D_2$





Pressure : 0.3 Pa
Bias Voltage, V_b : 2.4 V
Arc Discharge Power: 50 kW

- Not only plasma and electron density but also negative ion density increased by changing gas species from H_2 to D_2 .
- Space potential slightly increased (ΔVs ~0.5 V).
- $n(Cs^0)$ increased by the change.

Comparison between plasma parameter in NIFS-RNIS and operation parameter of the negative ion source for LHD-NBI.

<NIFS-RNIS>

- [[Condition]] Pressure : 0.3 Pa, V_b = 2.4 V, P_{arc} = 50 kW
- $n(D^-)/n(H^-) = 4.6 \times 10^{17}\ m^{-3} / 3.6 \times 10^{17}\ m^{-3} = 1.3$
- $V(D^-)/V(H^-) = 1/\sqrt{2} \sim 0.7$

$$I_{\text{Ion Beam}} \propto n\,v \;\longrightarrow\; \frac{n(D^-)v(D^-)}{n(H^-)v(H^-)} \sim 0.9$$

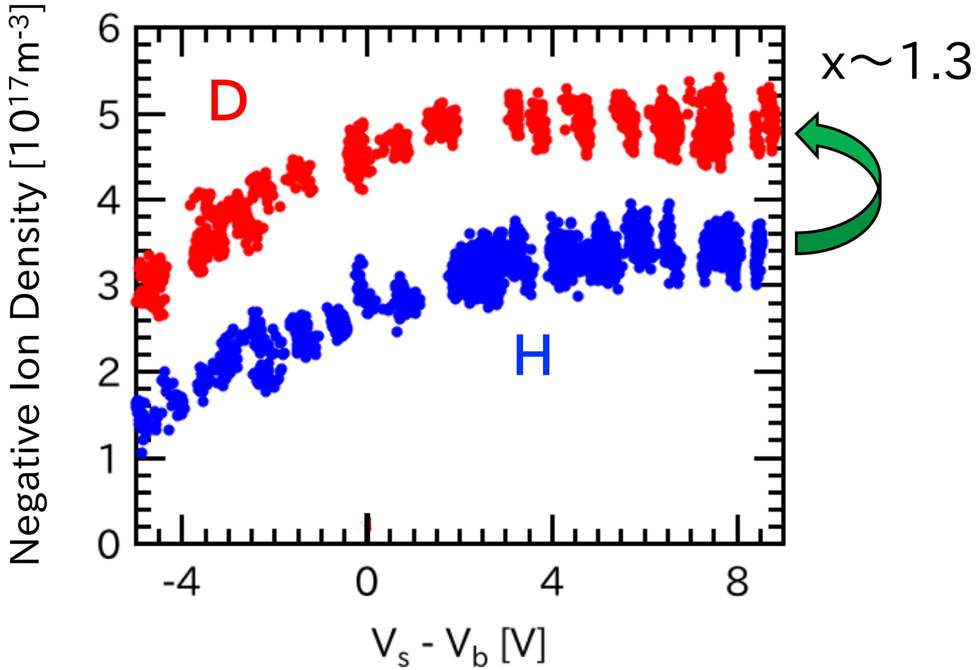
- $n_e(D) / n_e(H) = 6.3 \times 10^{17} m^{-3} / 2.2 \times 10^{17} m^{-3} \sim 3$

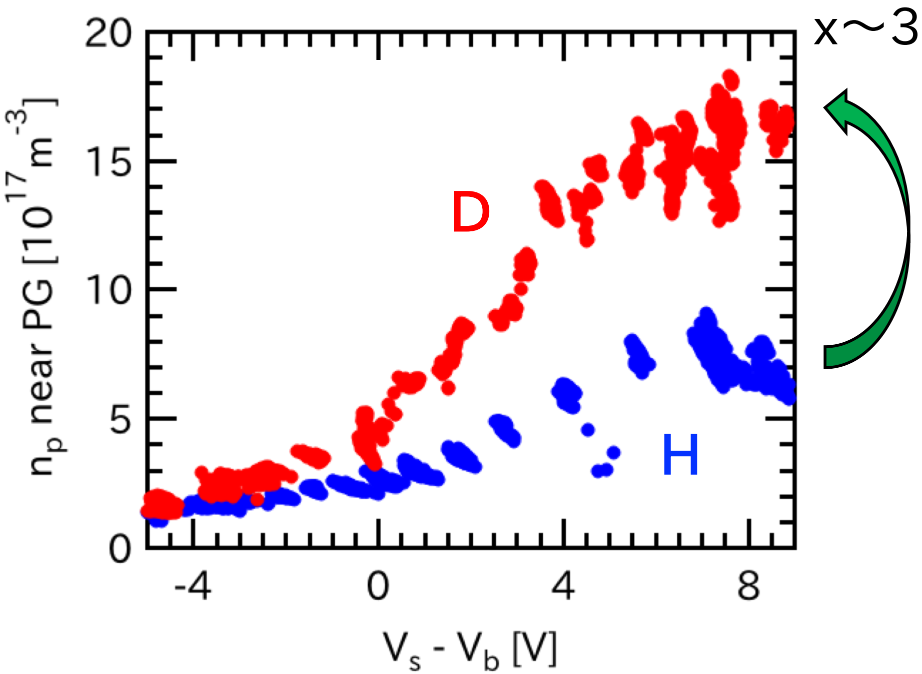
<LHD-NBI>

Gas Species	Electron Beam Current (I_e) [A]	Negative Ion Beam Current ($I(H^-)$, $I(D^-)$) [A]	$I_e/I(H^-)$, $I_e/I(D^-)$
H_2	9.3	24.6	0.38
D_2	22.6	16.5	1.37
Current ratio normalized by Discharge Power $\frac{[I(D)/P_{dis}(D)]}{[I(H)/P_{dis}(H)]}$	~3	0.7 $(\sim 1/\sqrt{2})$	

The increment factor of electron density corresponds to that of electron beam current of the negative ion source of LHD-NBI.

Plasma parameter in the vicinity of the PG



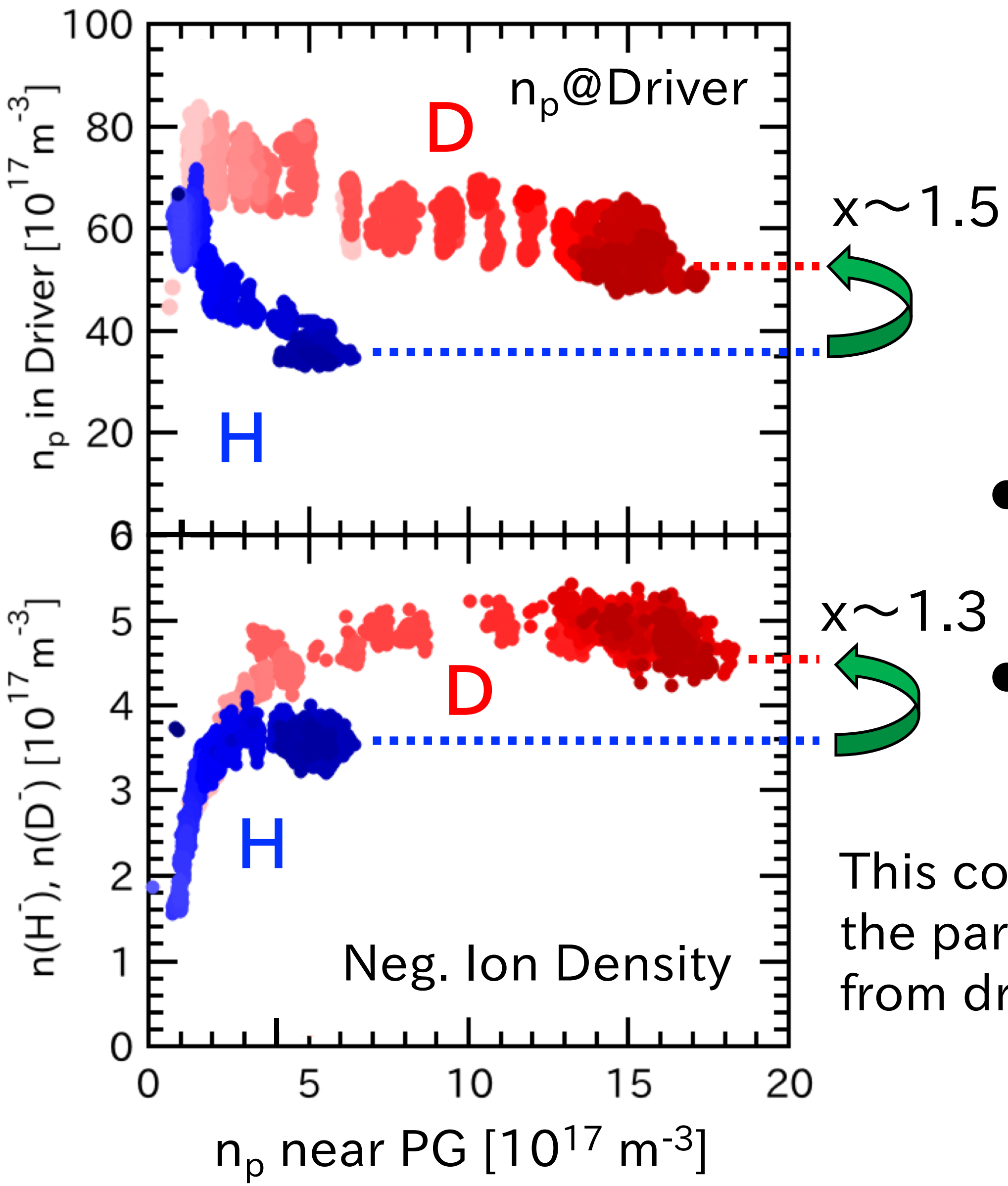


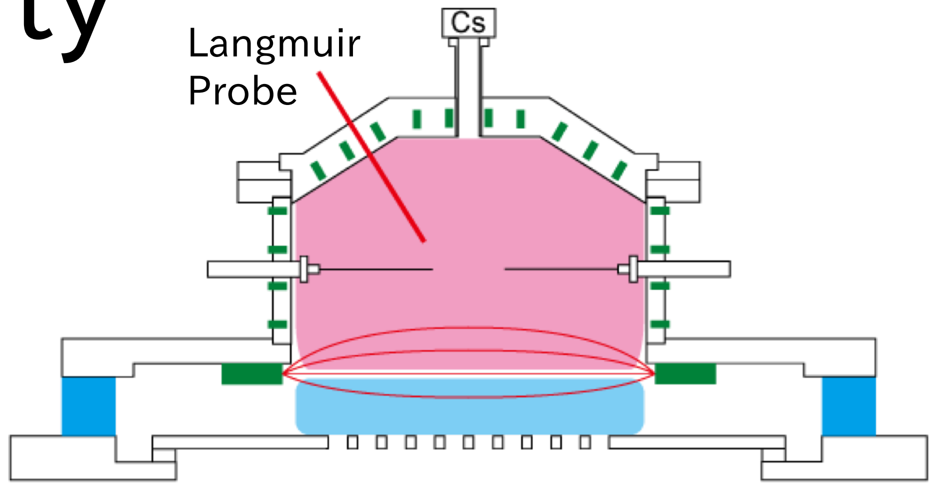
- Plasma density of D_2 discharge in larger $V_s - V_b$ is third times higher than that of H_2 discharge. However, $n(D^-)$ is only 1.3 times higher than $n(H^-)$.
- The reason of the large increase of the electron beam current in D operation is this different increase factors.

Why is the $n(D^-)$ higher than $n(H^-)$?

Why is the factor ～1.3 ?

Driver Plasma Density and Negative Ion Density



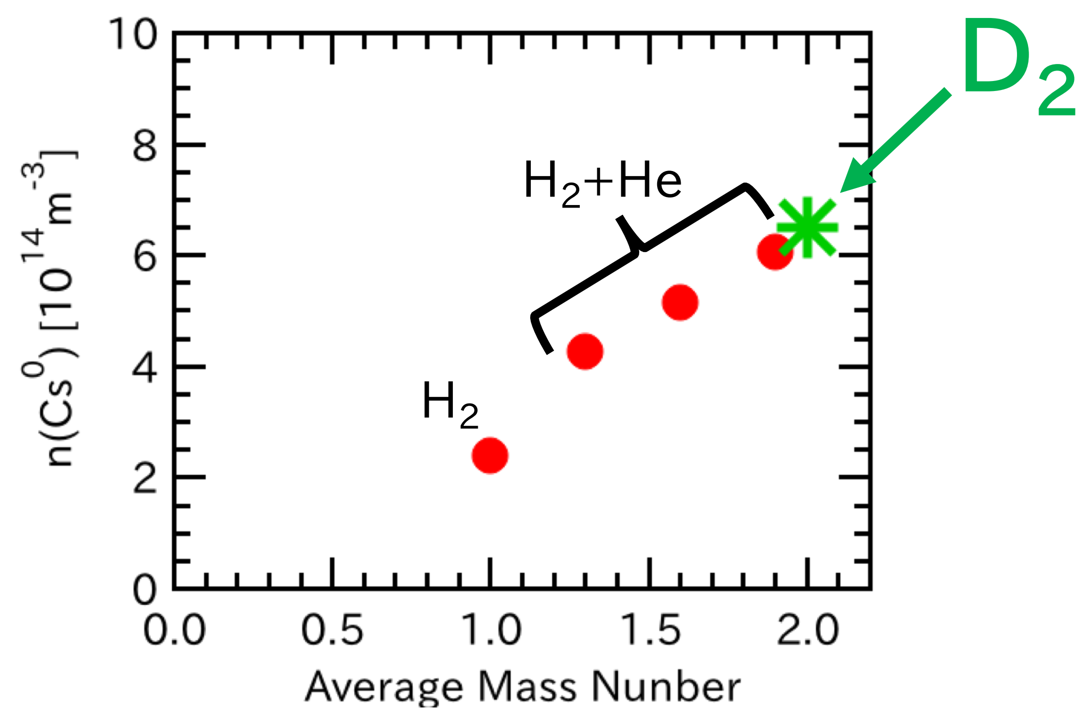


- The factor of the plasma density increase in driver region from H_2 and D_2 discharge is 1.5.
- This factor is similar to the increment factor of the negative ion density.

This correspondence indicates a possibility that the parent particle of the negative ion comes from driver region to the PG surface.

$n(Cs^0)$ increases by ***physical sputtering*** in H_2 and D_2 discharges.

Pressure: 0.3 Pa
Bias Voltage : 2.4 V
Discharge Power: 50 kW



In D_2 discharge, $n(Cs^0)$ increases by increasing physical sputtering by D_2.

Summary

He mixed H_2 Discharge

- He mixed H_2 discharge without Cs seeding.
  - Expecting decrement of volume production H^- was observed.
- He mixed H_2 discharge with Cs seeding.
  - Negative ion production limit and quasi-neutrality limit were demonstrated in the bias voltage dependence of negative ion density.

D_2 Discharge

- First D_2 discharge was performed in NIFS-RNIS on NIFS-NBTS.
- Increase of the negative ion density was observed in D_2 discharge. However the plasma density increment is larger than the negative ion density one.
- The increment factor of electron density is corresponding to that of electron beam current of the negative ion source of LHD-NBI.
- The increment factors of the driver plasma and negative ion density in the vicinity of the PG is similar value which indicates the parent particle comes from the driver region.
- Cesium neutral density in the space increases by the physical sputtering.