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Validation of the Distribution of Stripping Loss Neutrals in the Accelerator of the Negative Ion Source

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NIFS

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Background

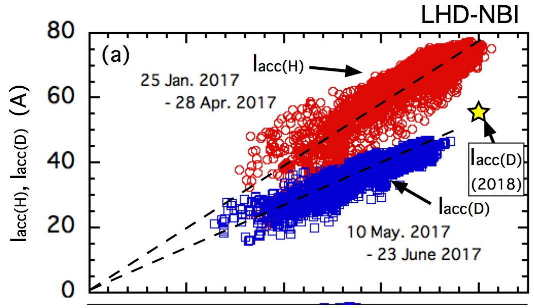
The N-NBI uses a **hydrogen-optimized negative ion source** and only the operating gas is changed to deuterium for deuterium beam injection in LHD in NIFS.

Negative ion current (by 2 ion sources)

Hydrogen : 80 A

Deuterium : 55 A

~ 70%

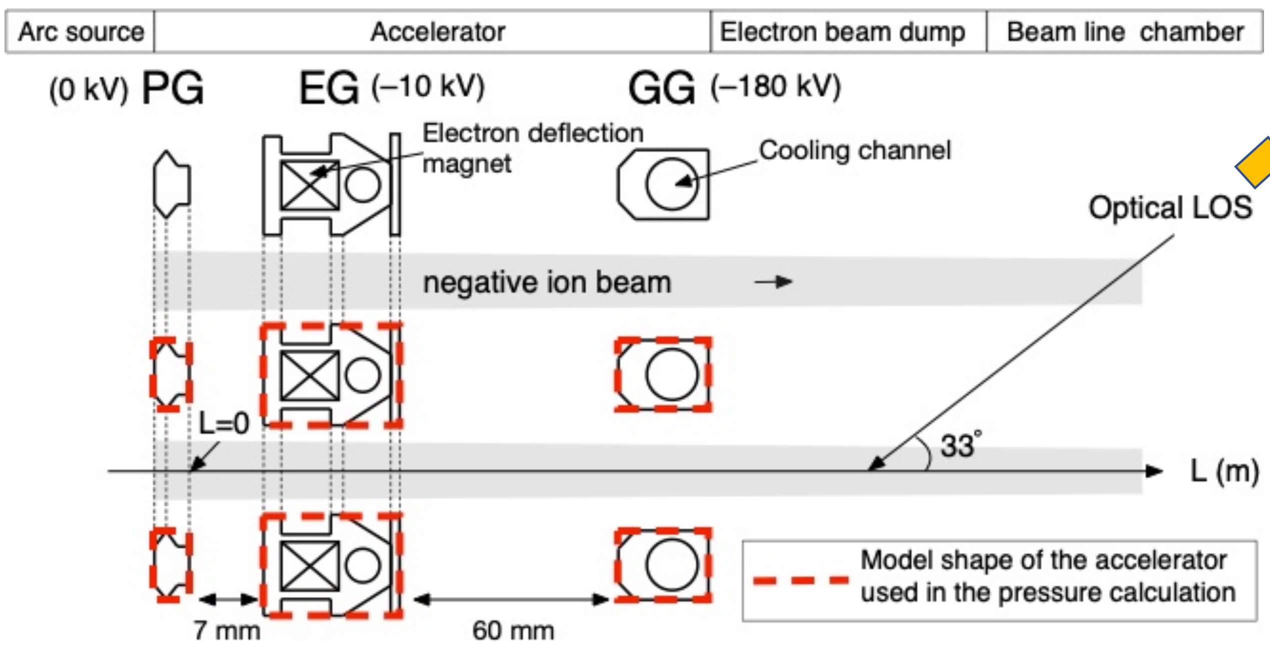


Stripping loss inside the accelerator is one of the reasons for the reduction of the ion current. Therefore, the **spatial and energy distributions** of the stripped neutral are discussed by beam emission measurements and stripping calculations using vacuum pressure.

Observation of Beam Emission

- Negative ions are produced on the plasma grid (PG) surface. These ions are extracted and accelerated by the extraction grid (EG) and the grounded grid (GG), respectively.
- Observing the emission from neutral particles generated inside the accelerator using the Doppler effect

Structure of the accelerator for the negative ion source



Observation system

Total resolution : 0.21 nm

Spectrometer

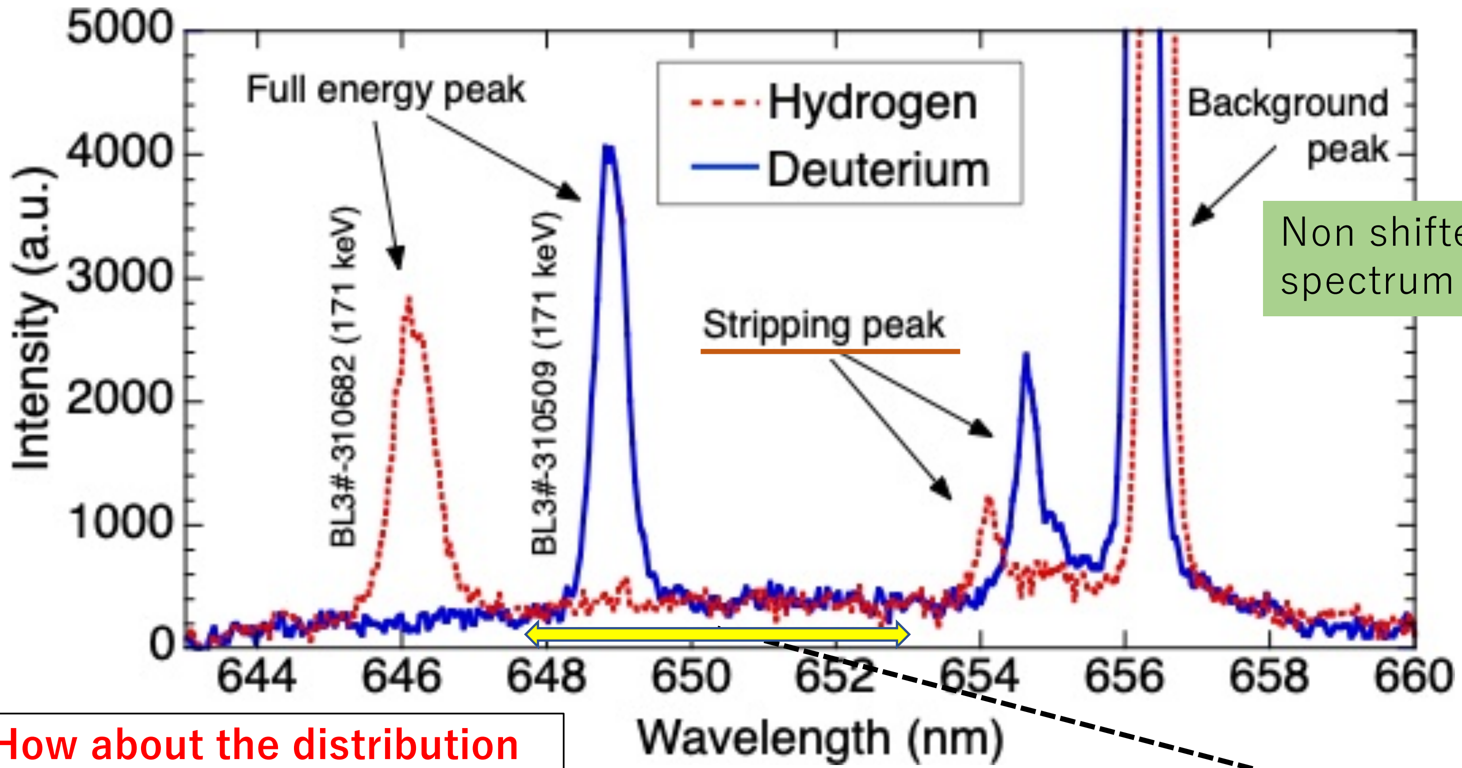
Optics: Czerny-Turner
Focal length : 25 cm
Grating : 1800 lines/mm
Braze : 500 nm

ICCD

Model : Andor DH720–18F-03
Photo cathode : W
Phosphor : P43
CCD : 1024 x 256 pixels
A/D resolution : 16 bit

Beam emission spectrum (H & D)

Two beam emission signals were observed at the blue shift side of the Balmer-α line.



Non shifted Hα and Dα spectrum from arc discharge.

Hα = 656.3nm
Dα = 656.1nm

Difference ~ 0.2nm

Low energy peak signals were observed near the source peak.

Stripping signal in the middle region was small.

How about the distribution of stripping neutrals in the accelerator ?

Calculation of beam stripping

(Pressure & conductance)

1) **Estimation the vacuum** inside the accelerator using the modeled accelerator structure and the measured vacuum during beam operation.

(σ_n) (σ_r) (σ_e)

2) Deriving **neutralization**, **re-ionization** and **emission cross-sections** inside the accelerator by using the cross-section database.

(Energy distribution & spectrum)

3) **Determining energy distribution** of neutral particles by the neutralization and reionization reactions of negative ions. Furthermore, the Doppler shifted spectrum is estimated by the emission cross-section.

Simplified accelerator model

PG (14x11) x 5 = **770 apertures**

D=14mm
L=4mm

EG (14x11) x 5 = **770 apertures**

D=10mm
L=14mm

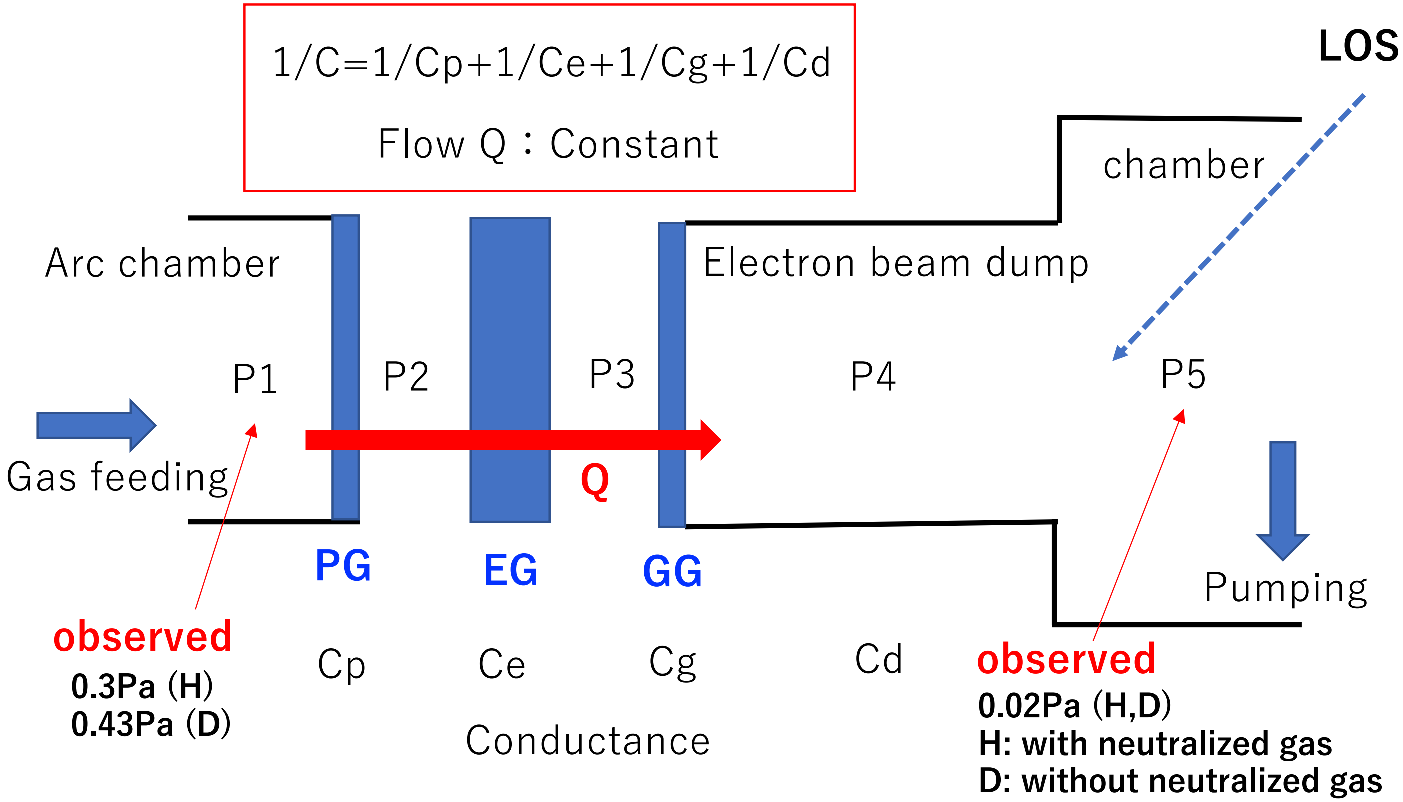
GG 11 x 5 = **55 Slots**

a=260mm
b=4mm
L=10mm

Electron beam dump

265x1190mm
L=1900mm

One-dimensional estimation of vacuum pressure in the accelerator



Pressure distribution

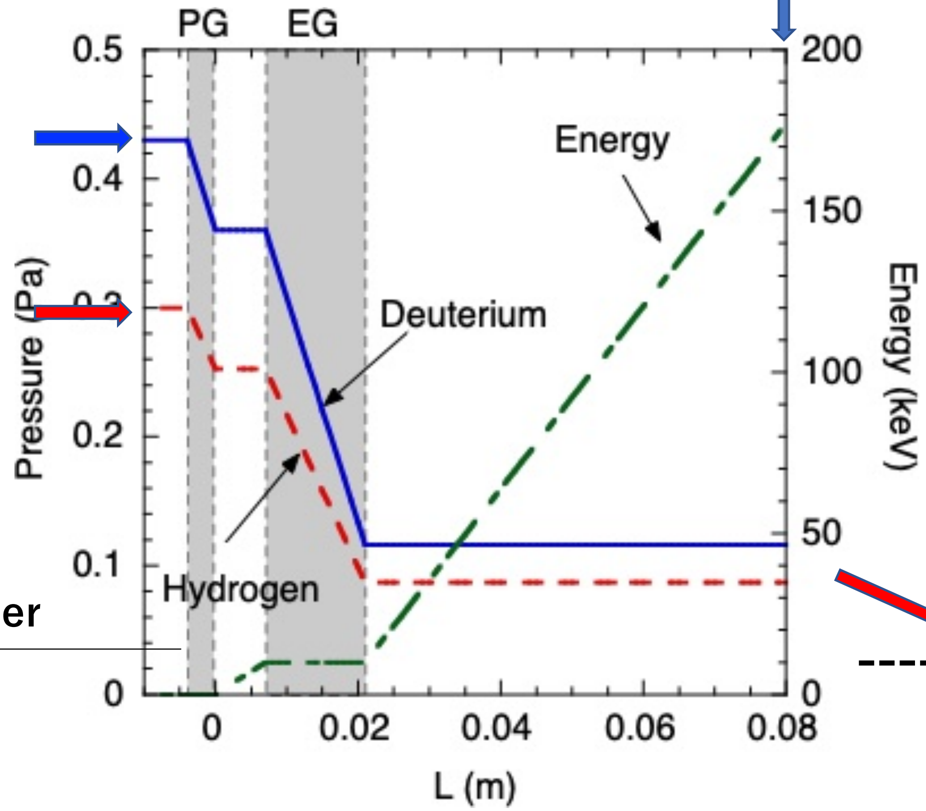
Pressure distribution was obtained from the accelerator structure and 1D analysis

Ext. =10 keV
Acc. = 170 keV

GG

D : 0.43Pa

H : 0.3Pa



Arc chamber

In deuterium operation, the filling gas pressure (0.43 Pa) is higher than that of hydrogen operation (0.3 Pa) **in order to suppress the co-extracted electron current.**

No neutralization D-gas was used to maintain the neutralization efficiency in the neutralization cell.

Same pressure

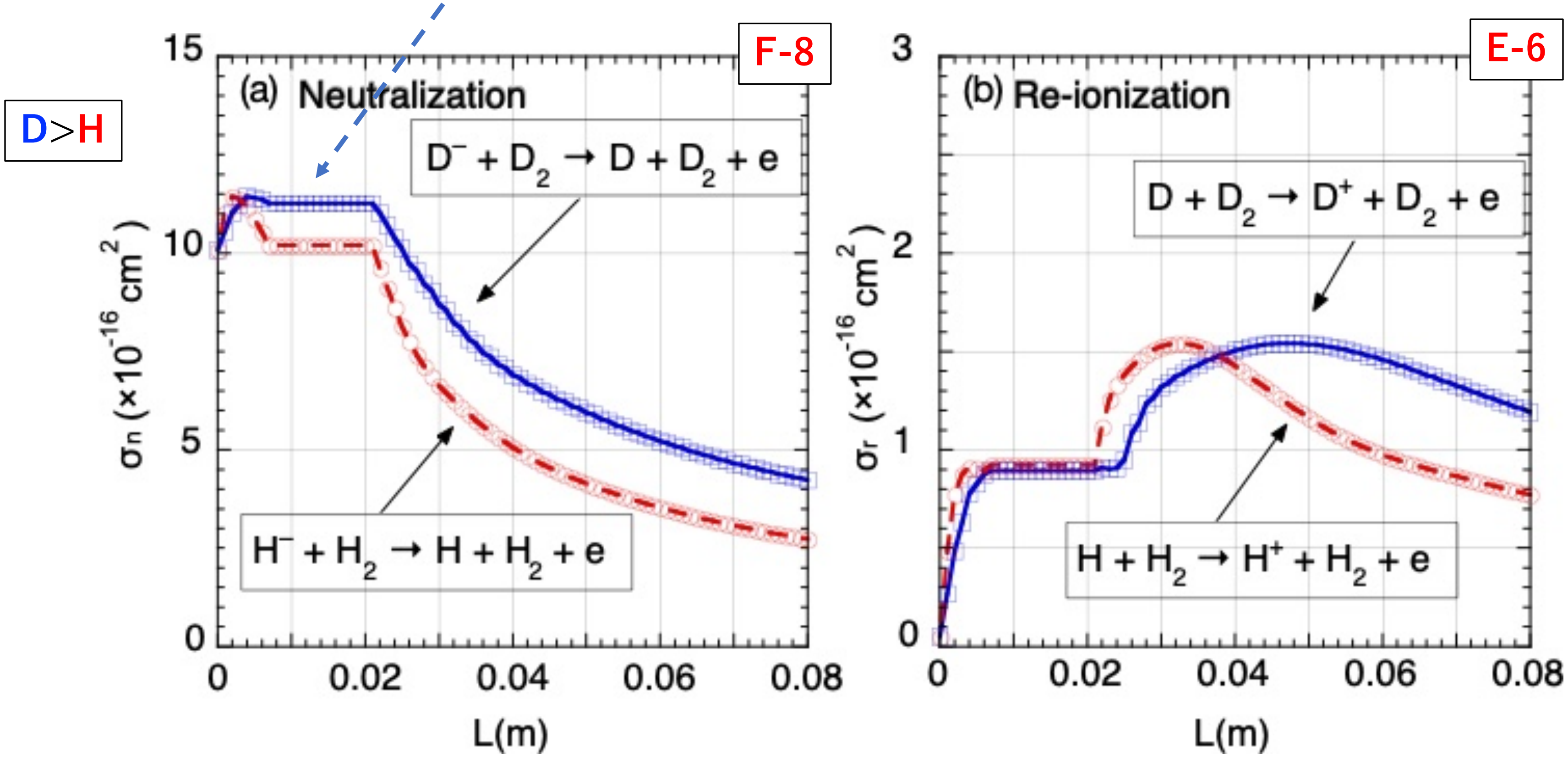
0.02Pa (H,D)
H: with neutralizing gas
D: without neutralizing gas

Cross-section in the accelerator

Database

C. F. Barnett, et al., Atomic data for Fusion Vol 1, ORNL – 6086/V1 (1990)

Large cross-section in low energy region **Neutralization >> Re-ionization**



Cross-section energy dependence

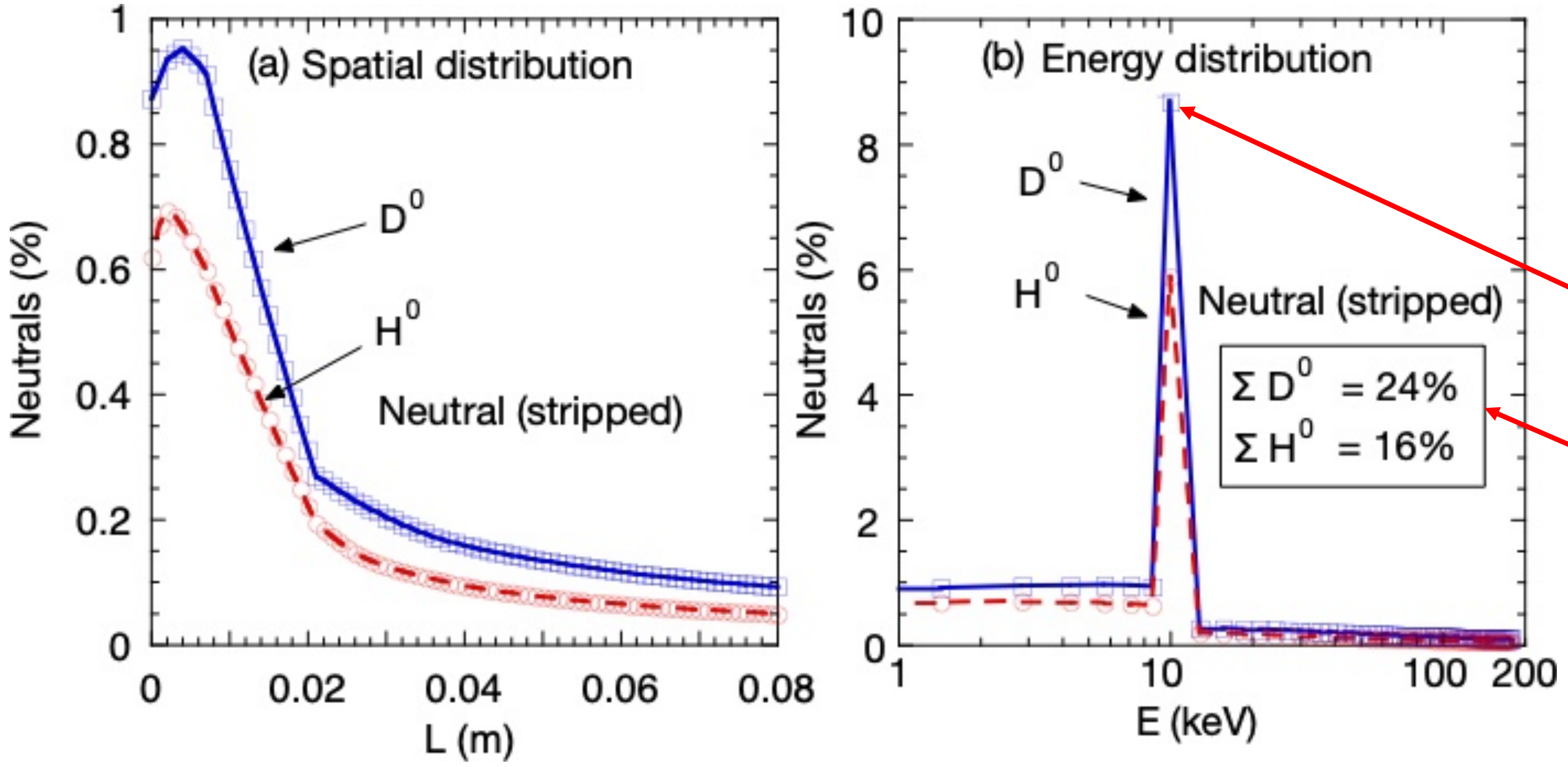
convert

Spatial distribution

Distribution of stripping neutrals

High stripping losses occur in the low energy region due to large cross-section and high pressure.

The energy of stripping neutrals is concentrated in the extracted energy.



Particles in peak energy is 9% for D, and 6% for H.

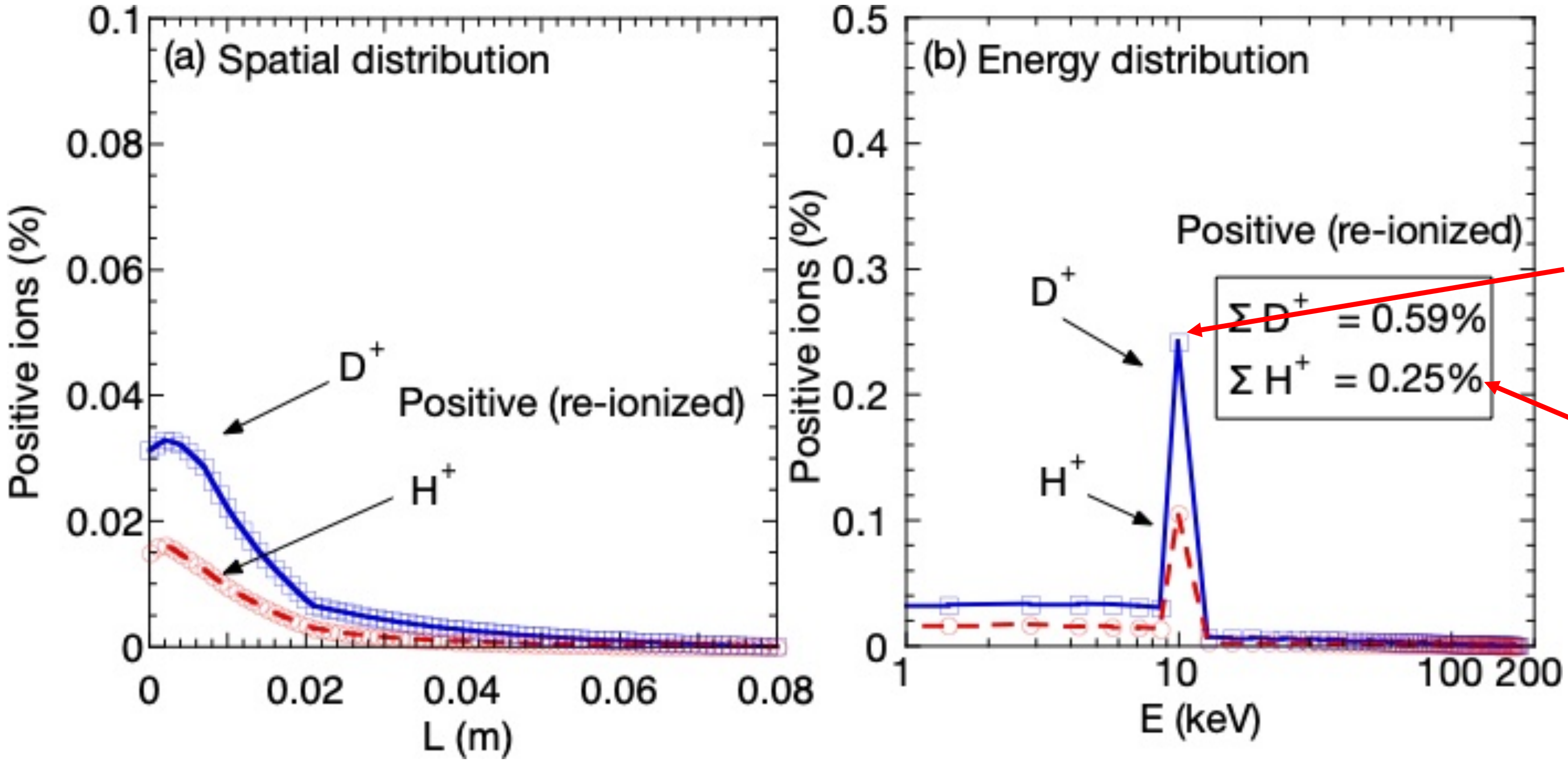
Stripping loss for D is 1.5 times larger than H.

Distribution of positive ions

Prediction of the back-streaming ion

High re-ionization occur in the low energy region followed by the distribution of stripping neutrals.

The energy of re-ionized ion is also concentrated in the extracted energy.



Particles in peak energy in 0.25% for D, 0.1% for H.

Total re-ionized ion is less than 1%

Back-streaming energy to be twice of the peak energy. (20 keV)

Comparison of beam emission spectrum

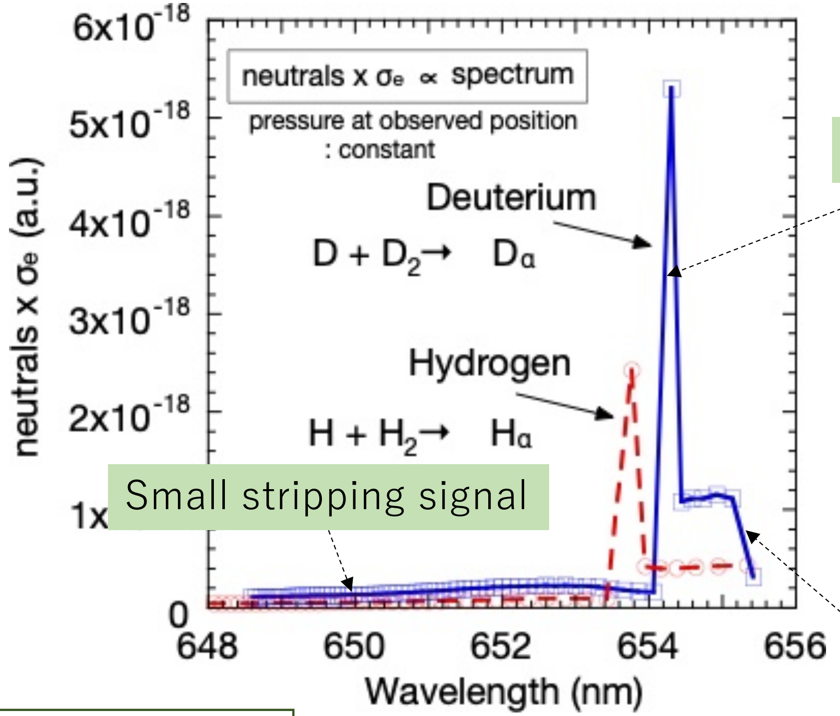
C-12 *C. F. Barnett, et al., Atomic data for Fusion Vol 1, ORNL – 6086/V1 (1990)*

Intensity = σ (emission) x n(neutral) x n(~~molecular~~)

H=D=constant

Emission intensity proportional to neutrals x σ (emission)

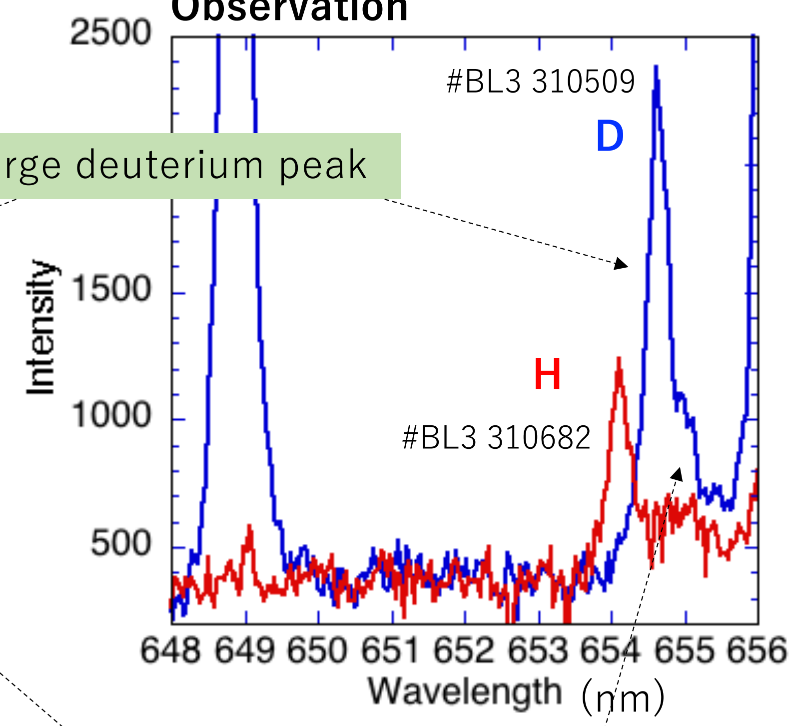
Calculation



Small stripping signal

Large deuterium peak

Observation



$$\lambda = \lambda_0 \frac{1 - \frac{v}{c} cos\theta}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Converted by Relativistic Doppler effect

The asymmetrical tail on the redshift side is appearing.

Discussion of stripping and back streaming

Large stripping loss in the EG aperture

Same energy neutrals make a peak spectrum

Thin EG might reduce stripping loss.

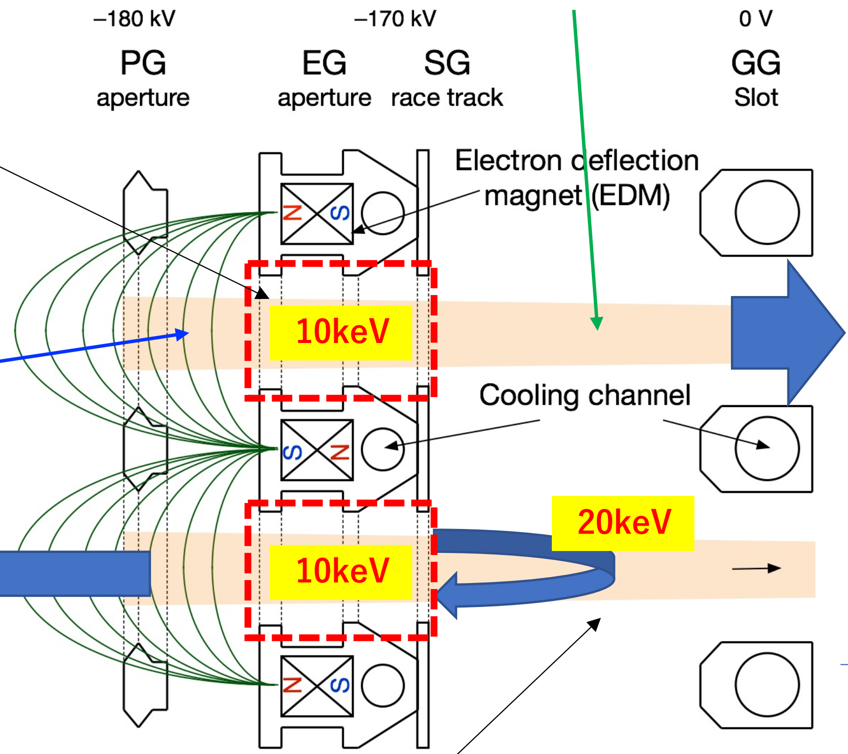
PG-EG：Low energy tail at the red shift side

Low operating pressure might reduce low energy stripping neutrals.

Back streaming (20keV peak)

The peak energy in the backstream ions increase twice as high as the stripping neutrals.

EG-GG：Small stripping loss



10 keV re-ionized positive ion turn at 20 keV position

Rough estimation of output current

	H	**D**
Source factor	1	1~1.2
Extraction factor	1	0.7
1-stripping loss	**0.84**	**0.76**
	0.84	0.53 ~0.63

D/H = 0.63 ~ 0.76

Summary

- Beam emission spectroscopy shows that the **intense peak** was appeared in the energy band of the **extraction voltage**, and no strong signal was observed in the acceleration region.
- The peak of the extraction energy is good reproduced by the stripping calculation from the pressure distribution in the accelerator
- The **stripping loss** inside the accelerator increases from **16% in H** to **24% in D**. This is largely due to the neutralization reaction cross section at low energy region.
- The energy peak of the re-ionized ions is also the same as that of the stripping neutral, and the backstream beam energy in the source is expected to be twice energy.