

# Observations of Impurity Hole in High Ion Temperature Discharge on LHD

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# Abstract

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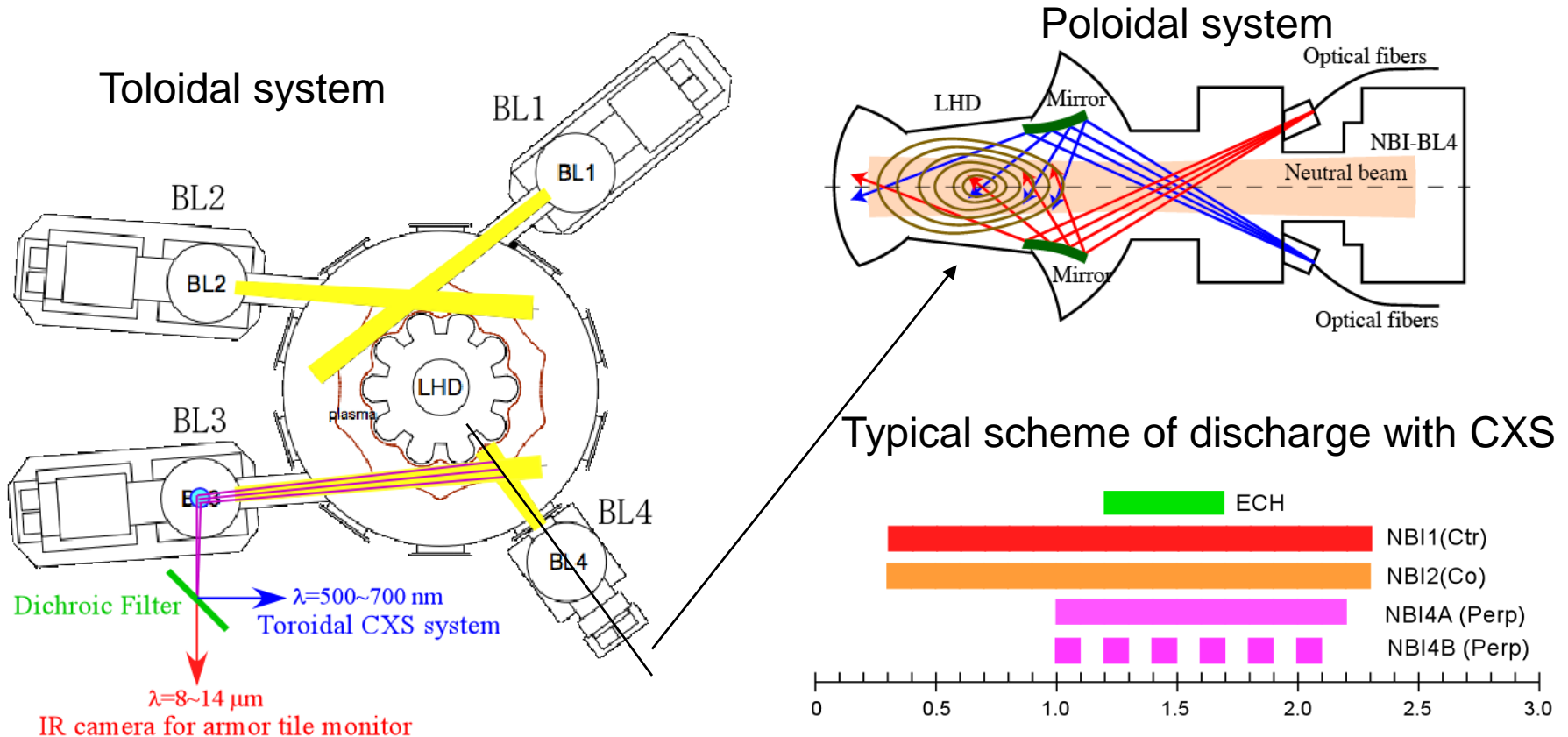
It is desirable for the fusion plasma that the hot plasma core is produced with less an impurity, because the impurity causes reduction of the fusion power density through an enhancement the cooling of the plasma by radiation and a dilution of the hydrogen fuel. And the profiles of impurities have been observed with keen interest while the transport and behaviors of impurities strongly affects on the characteristics of the plasma in magnetically confined fusion experiments.

**An extreme hollow profile of carbon impurity is observed in high ion temperature plasma on the large helical device (LHD).** The profiles of ion temperature, toroidal rotation velocity and carbon impurity are measured with charge exchange spectroscopy using the charge exchange line of fully ionized carbon.

The decrease of the carbon impurity is clearly observed on the high Z discharge for high ion temperature operation. The carbon pellet was used for the supplying of the high Z impurity into the core of the plasma. The electron density increases rapidly just after the pellet injection, and then decreases with the time scale of a few 100 msec. **The impurity profile suddenly changes to extreme hollow profile while the ion temperature grows higher in the decay phase of the electron density.**

# Line of Sights of CXS on LHD

Charge exchange spectroscopy measurement performed both with poloidal and toroidal line of sights.



40keV perpendicular injection NBI with positive ion source

To acquire the background signal, the p-NBI is modulated with 100msec ON and 100msec OFF.

# Advantage of CXS with Toroidal Line of Sights

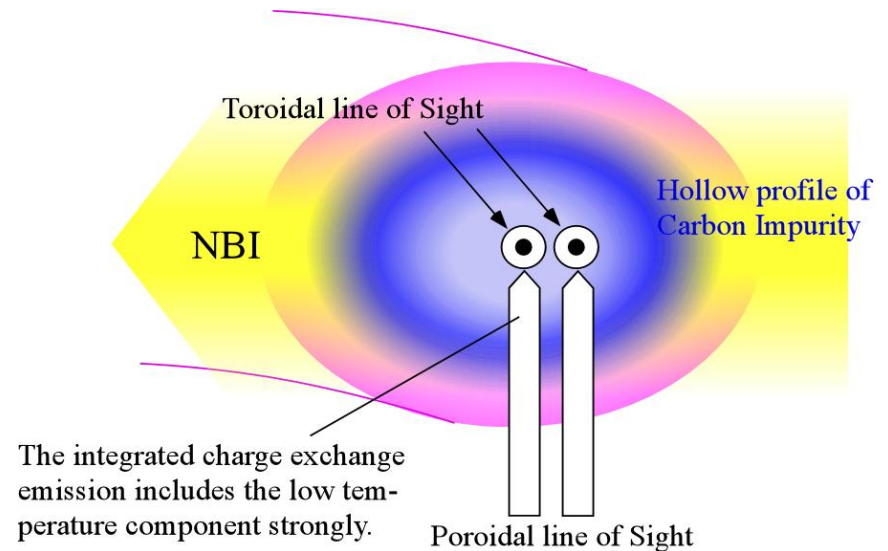
When there is the hollow profile of impurities caused by some outward flow of the impurities:

There is a difficulty on measurement of the ion temperature at the plasma center, because the strong emission from the off center of the plasma, where the ion temperature is lower, is dominant on the integration.



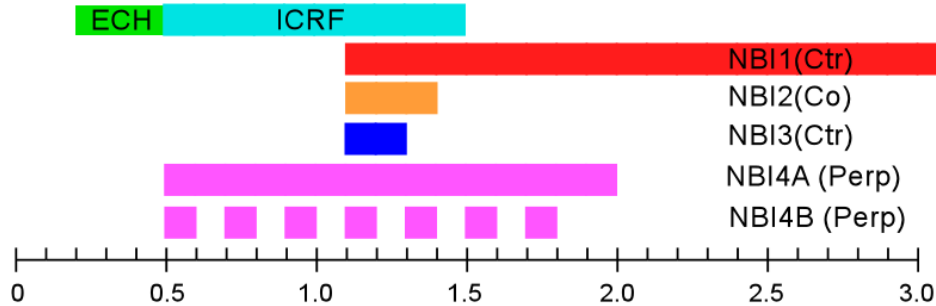
The CXS with toroidal line of sights can measure the parameters at the plasma center even while the impurity profile becomes hollow.

- ➔ A study of carbon impurity profile **Impurity hole**
- ➔ A study of toroidal rotation



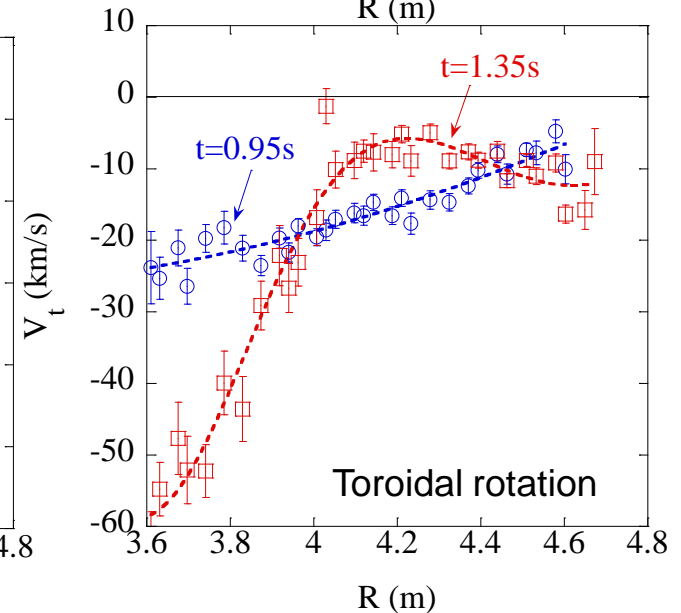
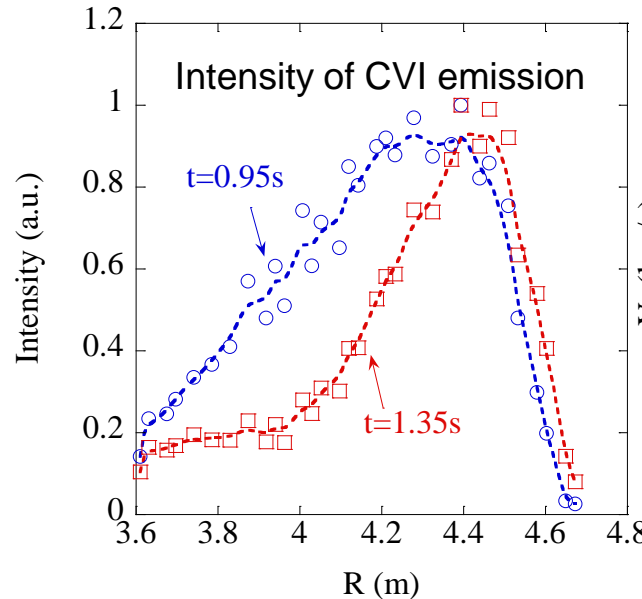
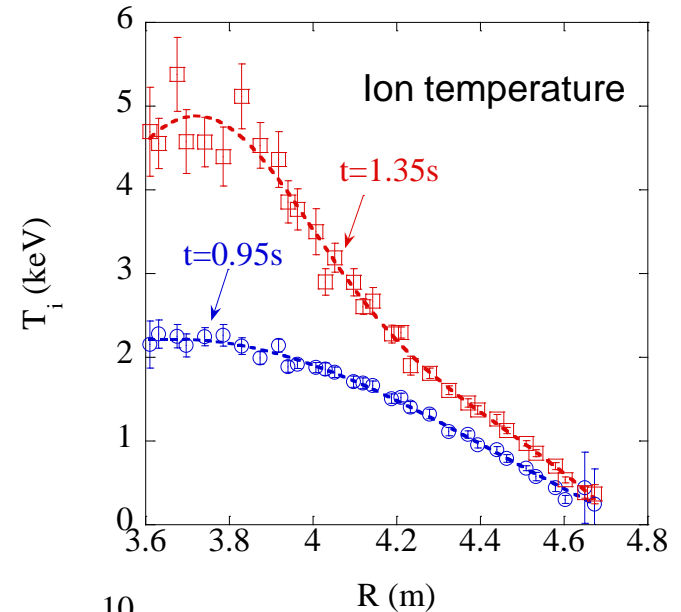
# Profiles in the case of Counter Injection

$B_t=2.85T$   $R_{ax}=3.6m$   $\gamma=1.254$   $Bq=100\%$



High Ion temperature ( $\sim 4.5\text{keV}$ ) obtained in NBI sustained plasma with electron density  $n_e \sim 1.5 \times 10^{19} \text{m}^{-3}$ .

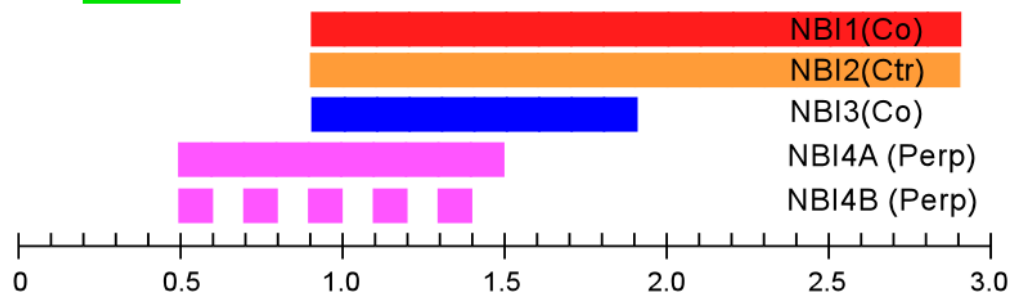
Strong toroidal rotation is observed in the core region of the plasma and its direction is consistent with the direction of NBI injection .



# Profiles in the case of Co Injection

$B_t = -2.769T$   $R_{ax} = 3.575m$   $\gamma = 1.254$   $Bq = 100\%$

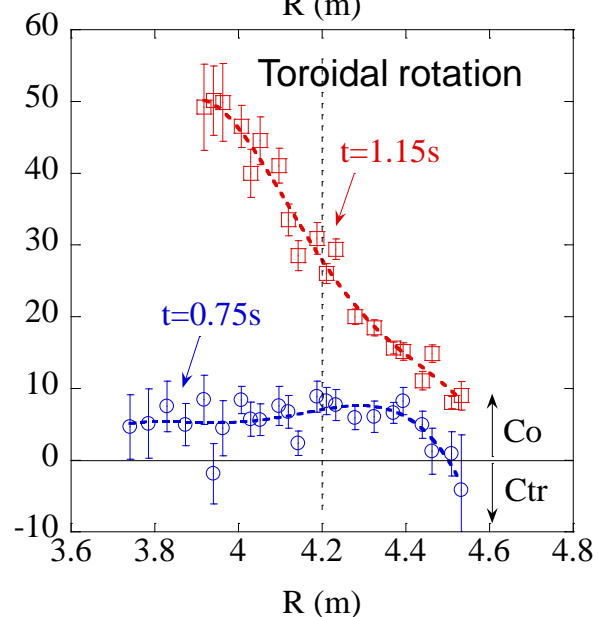
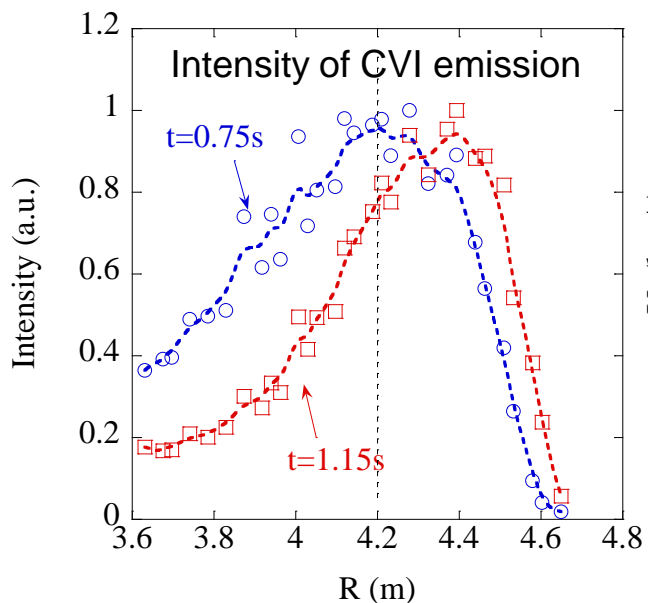
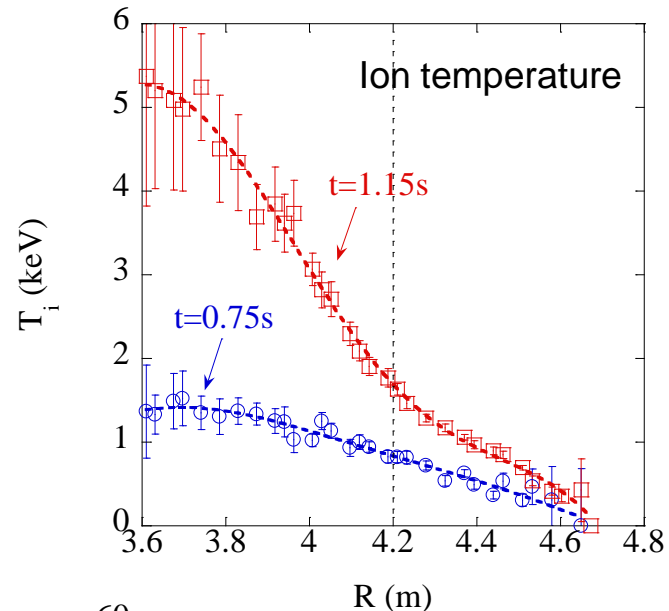
ECH



High Ion temperature ( $\sim 5\text{keV}$ ) obtained in NBI sustained plasma with electron density  $n_e \sim 1 \times 10^{19} \text{m}^{-3}$ .

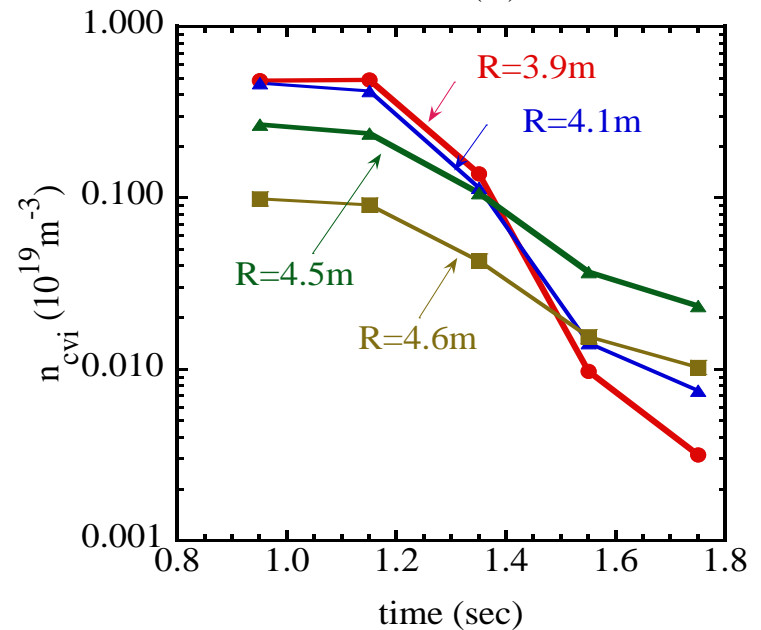
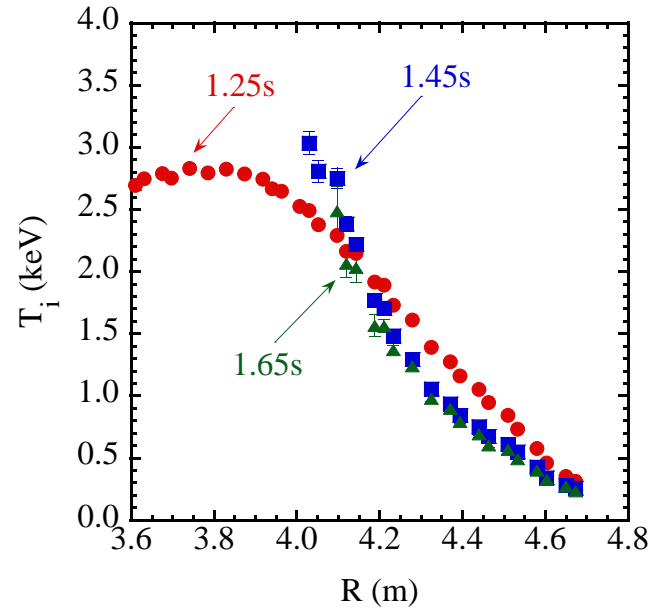
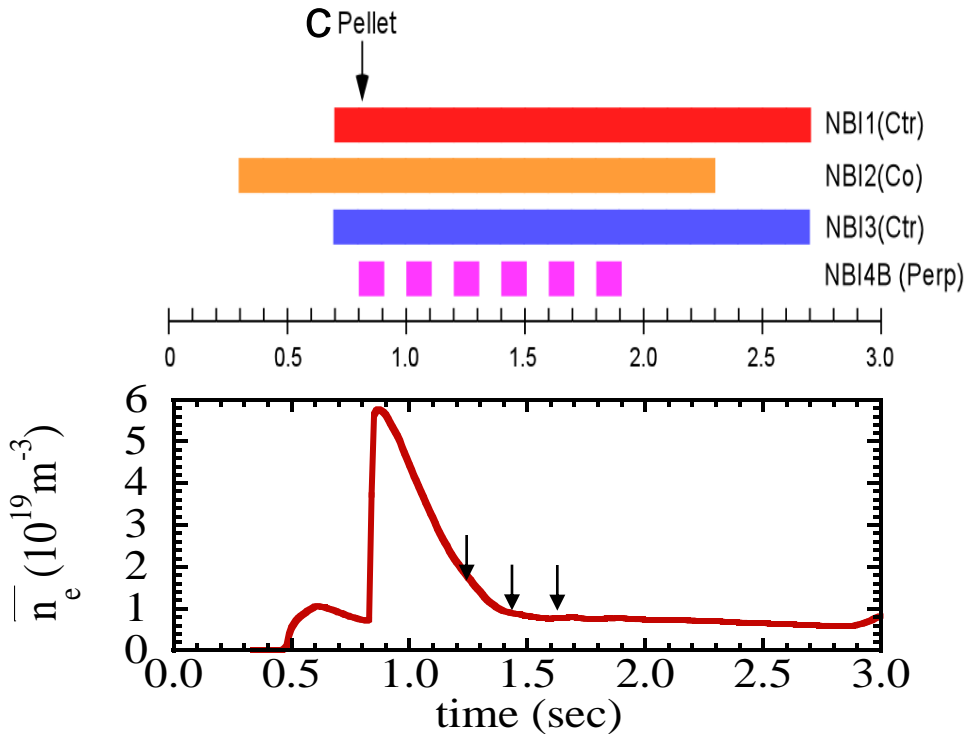
The CXS intensity profile shows that the profile of carbon impurity is strongly hollowed when the  $T_i$  becomes high.

Impurity Hole



# Impurity Hole

High  $T_i$  experiment with a carbon pellet injection

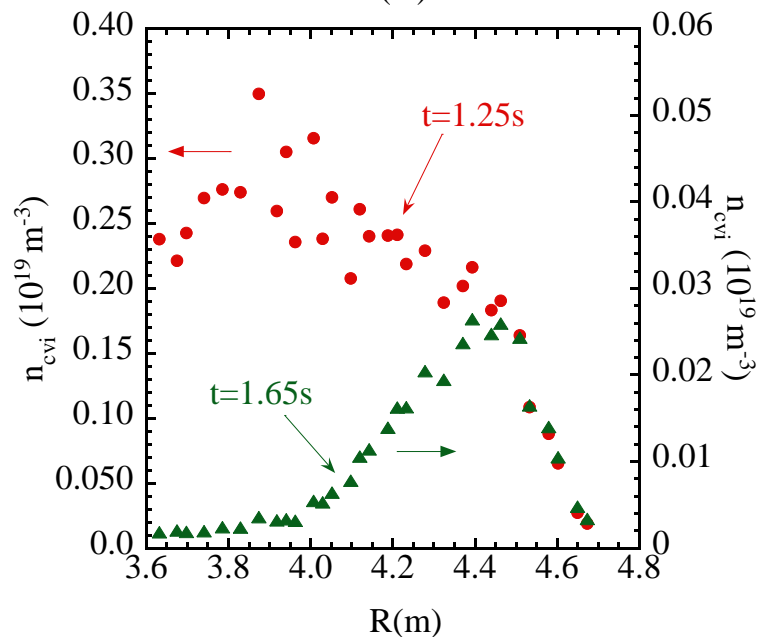
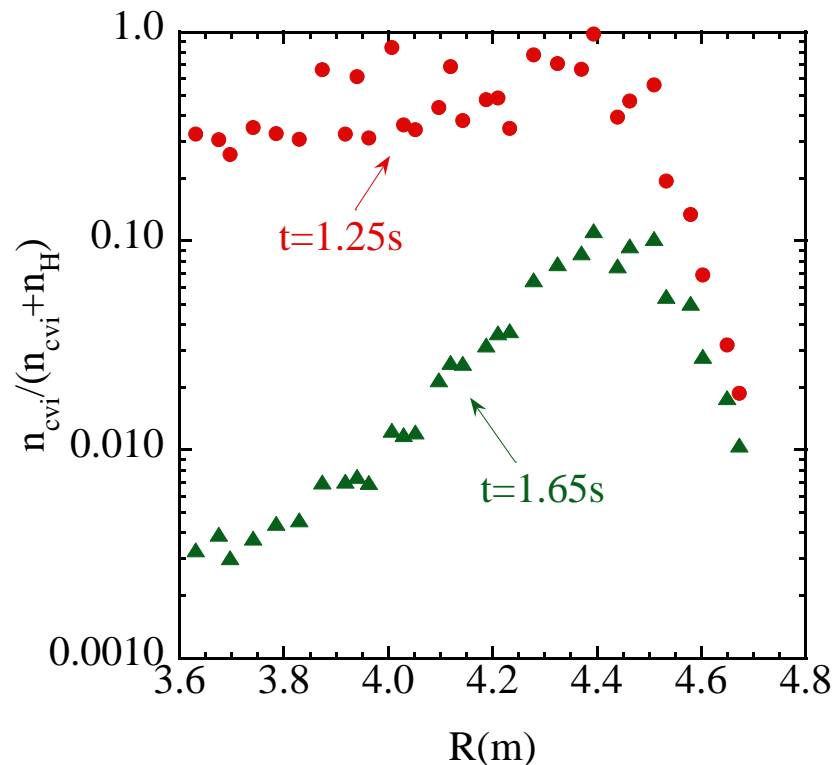
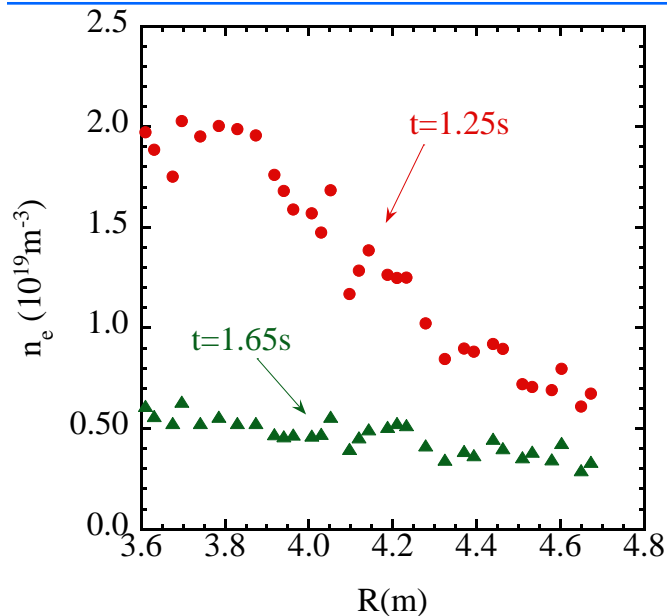


A carbon pellet (a size of  $1.4 \times 1.4$  mm) is injected at  $t=0.8$  sec.

Ion temperature grows higher in the decay phase of the electron density.

$B_t = -2.676 \text{ T}$   $R_{ax} = 3.7 \text{ m}$   $\gamma = 1.254$   $B_q = 100\%$

# Profiles before and after of forming Impurity Hole

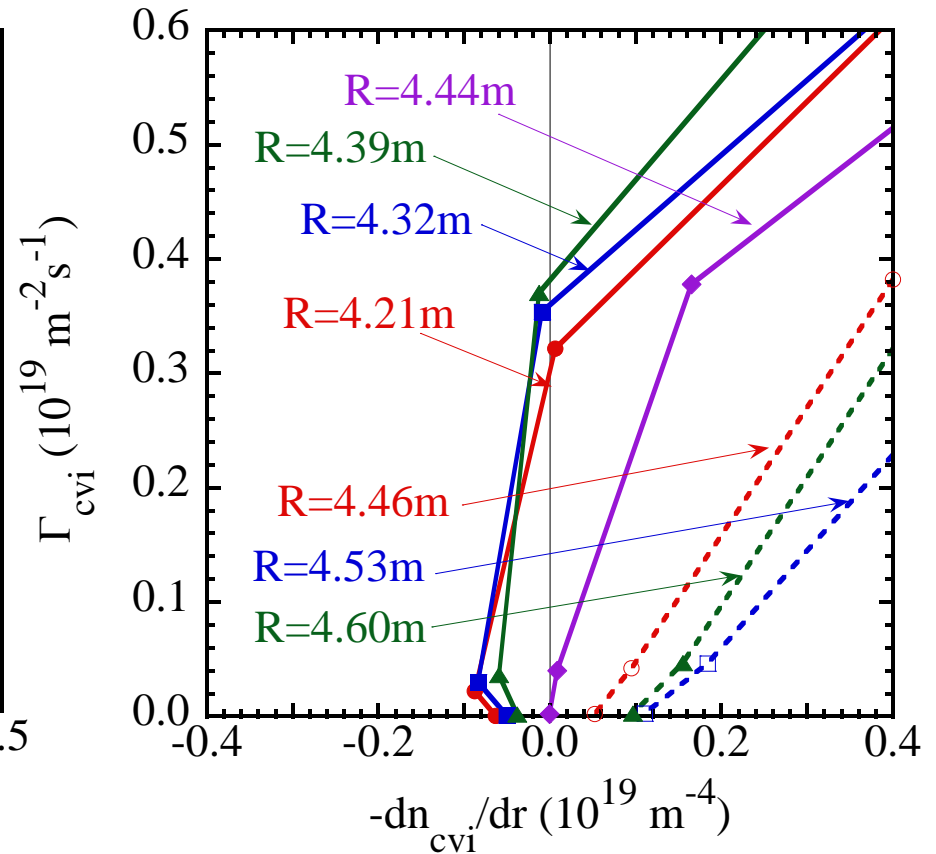
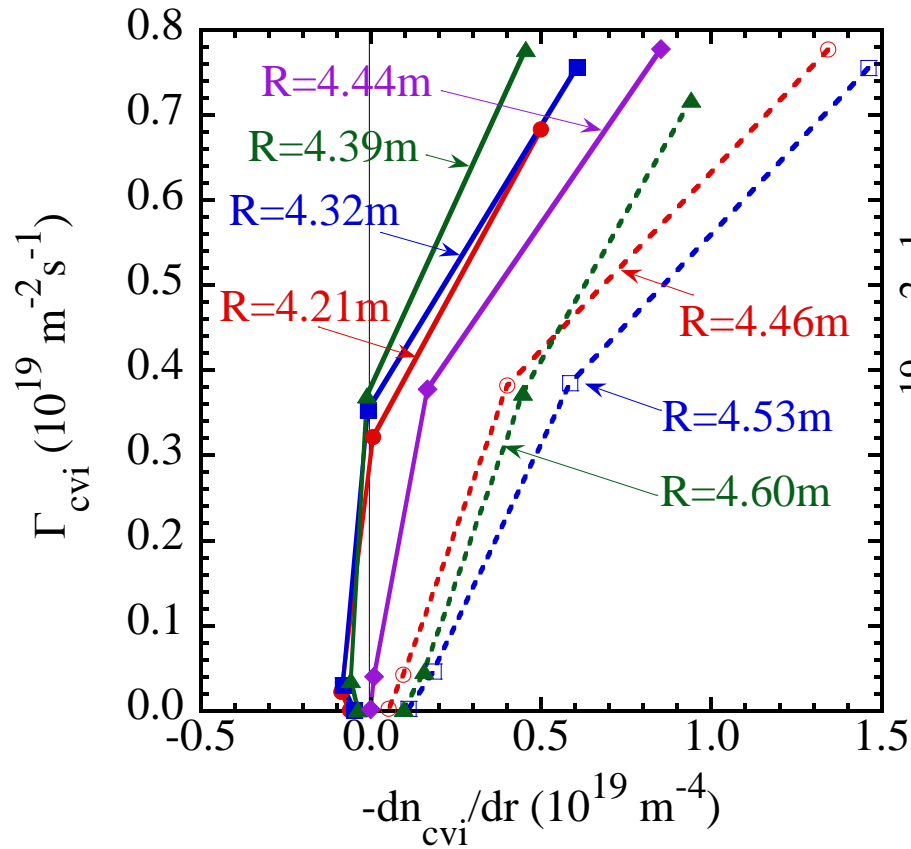


An extreme hollow profile of carbon impurity is observed.

The ratio of  $n_{\text{cvi}}/(n_{\text{cvi}}+n_{\text{H}})$  is achieved to 0.3% at the plasma center, while it is 10% near the edge.

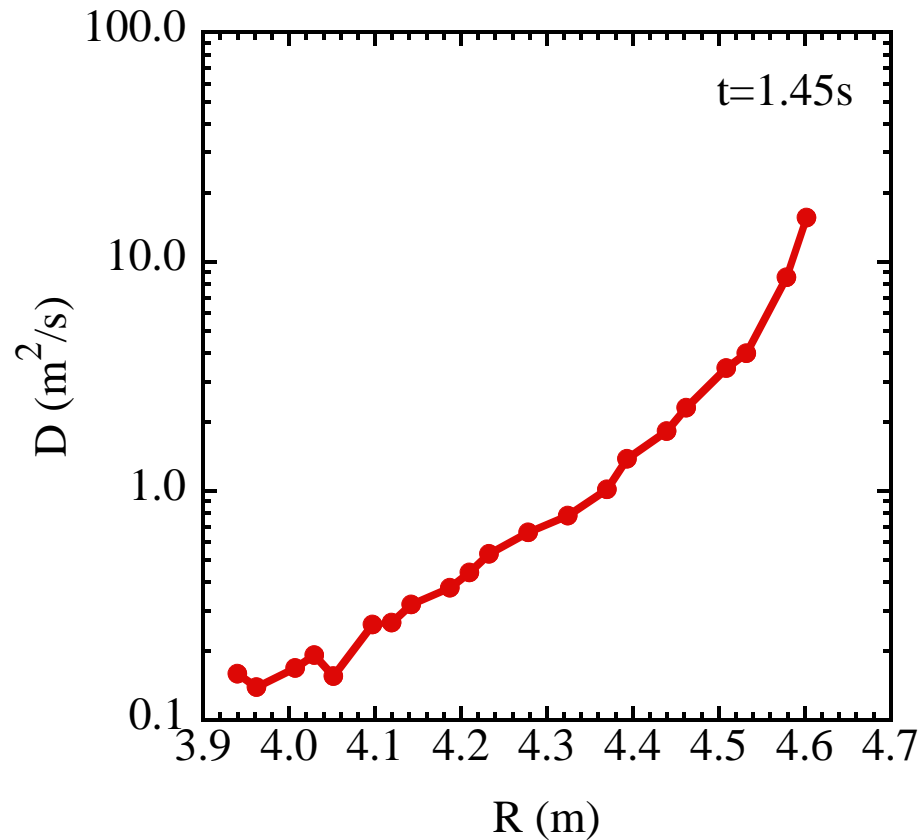
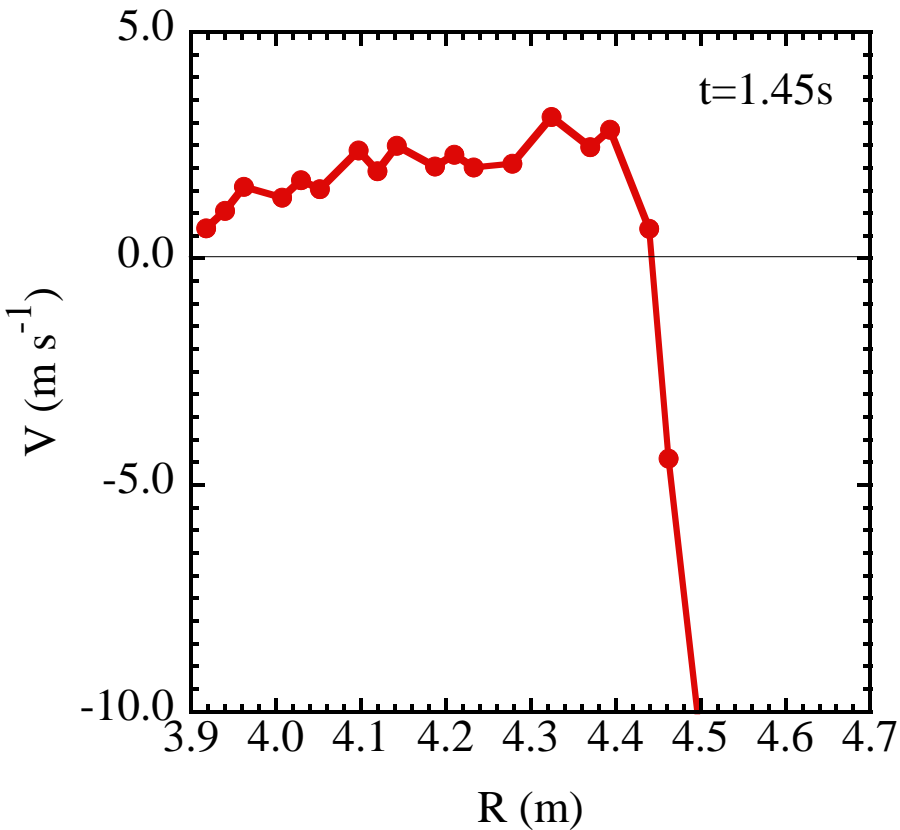


# Flux of carbon impurity



Outward flux (positive  $\Gamma$ ) is observed even while the density gradient  $-\text{dn}_{\text{cvi}}/\text{dr}$  become negative.

# Profile of Convection and Diffusion



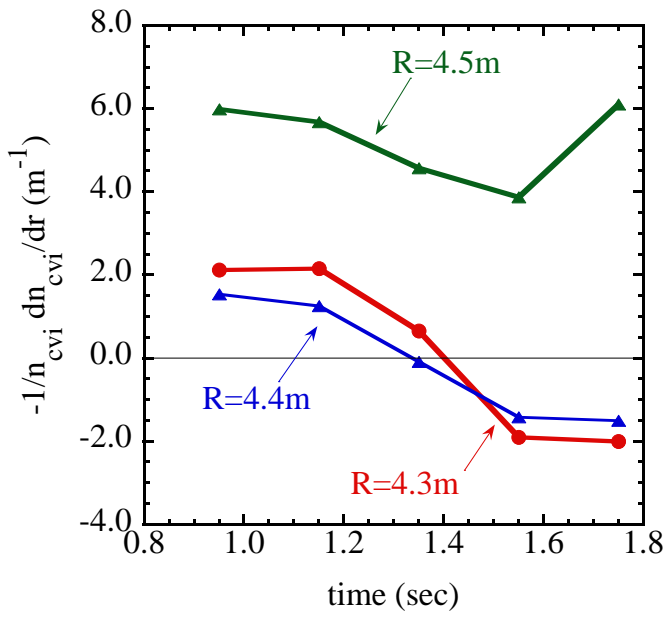
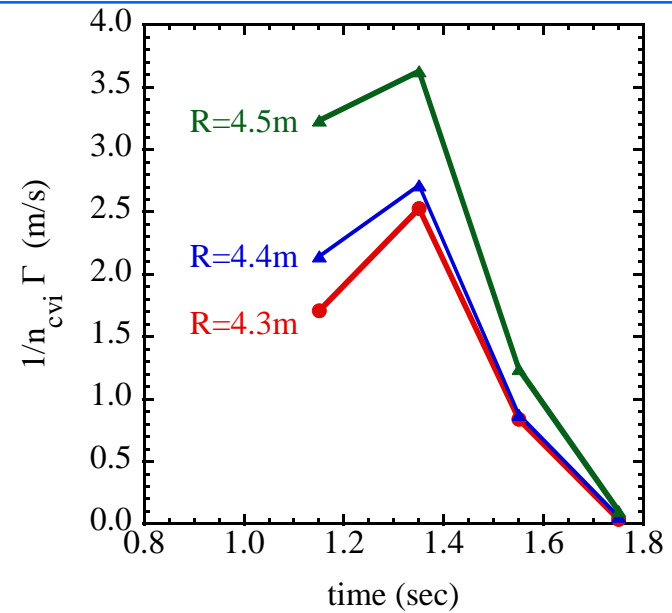
Outward flow is observed inside the hole where the diffusion is small, while inward flow is observed at the edge.

# Summary

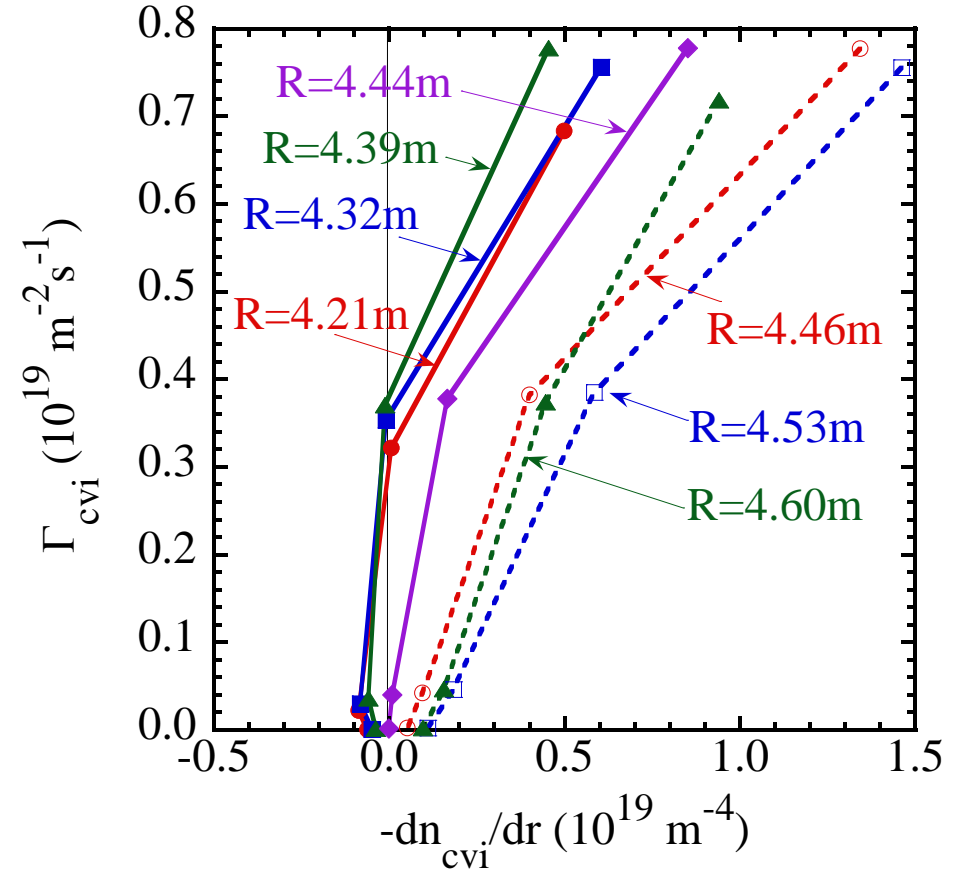
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- (1) The profiles of ion temperature, toroidal rotation velocity and carbon impurity are measured with charge exchange spectroscopy using the charge exchange line of fully ionized carbon with toroidal line of sights.
- (2) Strong toroidal rotation is observed in the core region of the plasma and its direction is consistent with the direction of NBI injection .
- (3) In the experiment with the carbon pellet injection, the impurity profile suddenly changes to extreme hollow profile while the ion temperature grows higher in the decay phase of the electron density.
- (4) The ration of  $n_{\text{Cvi}}/(n_{\text{Cvi}}+n_{\text{H}})$  is achieved to 0.3% at the plasma center, while it is 10% near the edge.

# Flux of carbon impurity



Flux of carbon impurity vs gradient of  $n_{cvi}$



Outward flux (positive  $\Gamma$ ) is observed even while the density gradient  $-dn_{cvi}/dr$  become negative.