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Ion Heating Experiments Using Perpendicular Neutral Beam Injection in the Large Helical Device

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Introduction

Before 9th campaign of LHD;

N-NBI with high beam energy of 180keV
⇨ Low ion heating power

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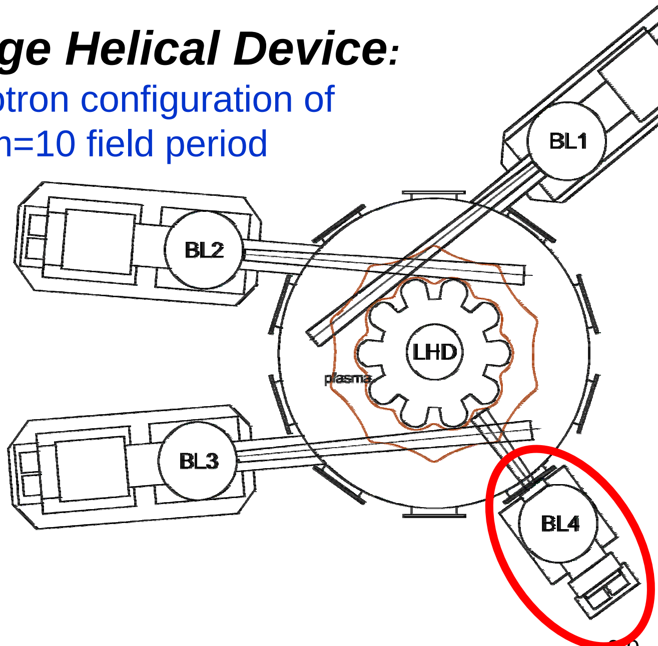
The ion heating experiments

High Z discharge ➡ Ti(0)=13keV

Large Helical Device:
Heliotron configuration of
l=2/m=10 field period



For ion heating experiments in low Z discharge, the low energy and high power NBI was required

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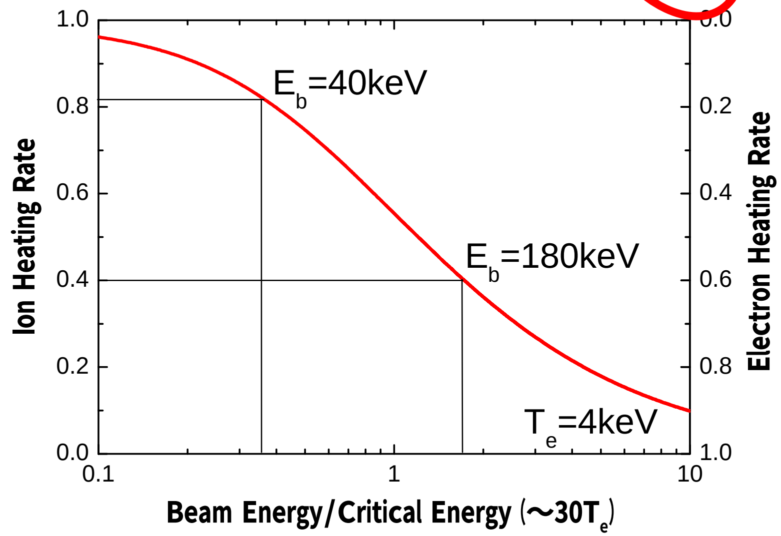
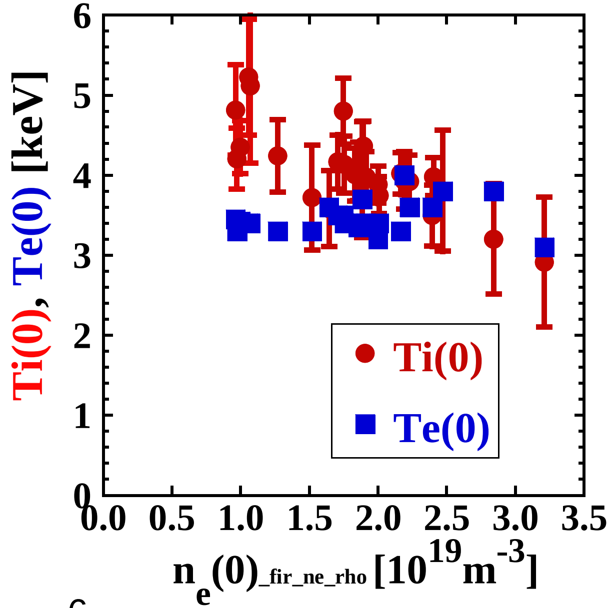
Installation of Perpendicular NBI (40keV) in 9th and 10th campaigns of LHD



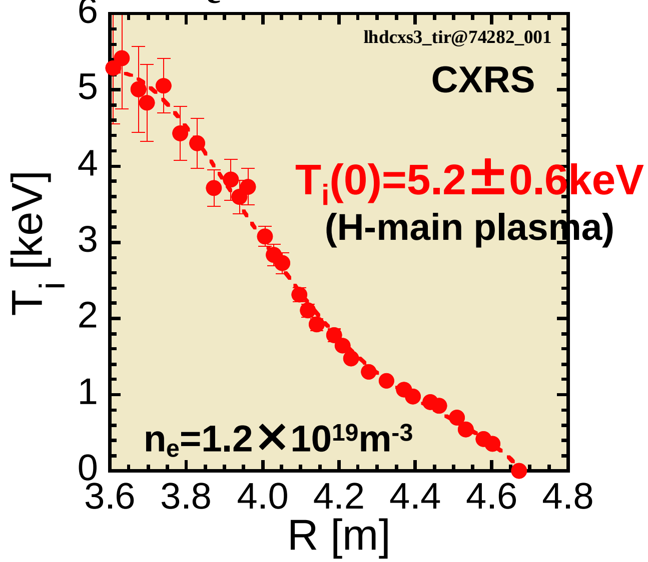
Introduction

P-NBI can be utilized for

- High Power Ion Heating
- Measurement of Ion Temperature Profile
  - -Charge exchange spectroscopy
- Particle Fueling
  - -1.56x$10^{20}$$s^{-1}$$MW^{-1}$ for 40keV
  - (0.35x$10^{20}$$s^{-1}$$MW^{-1}$ for 180keV)



Ion heating experiments in low Z discharge using P-NBI started at 9th campaign

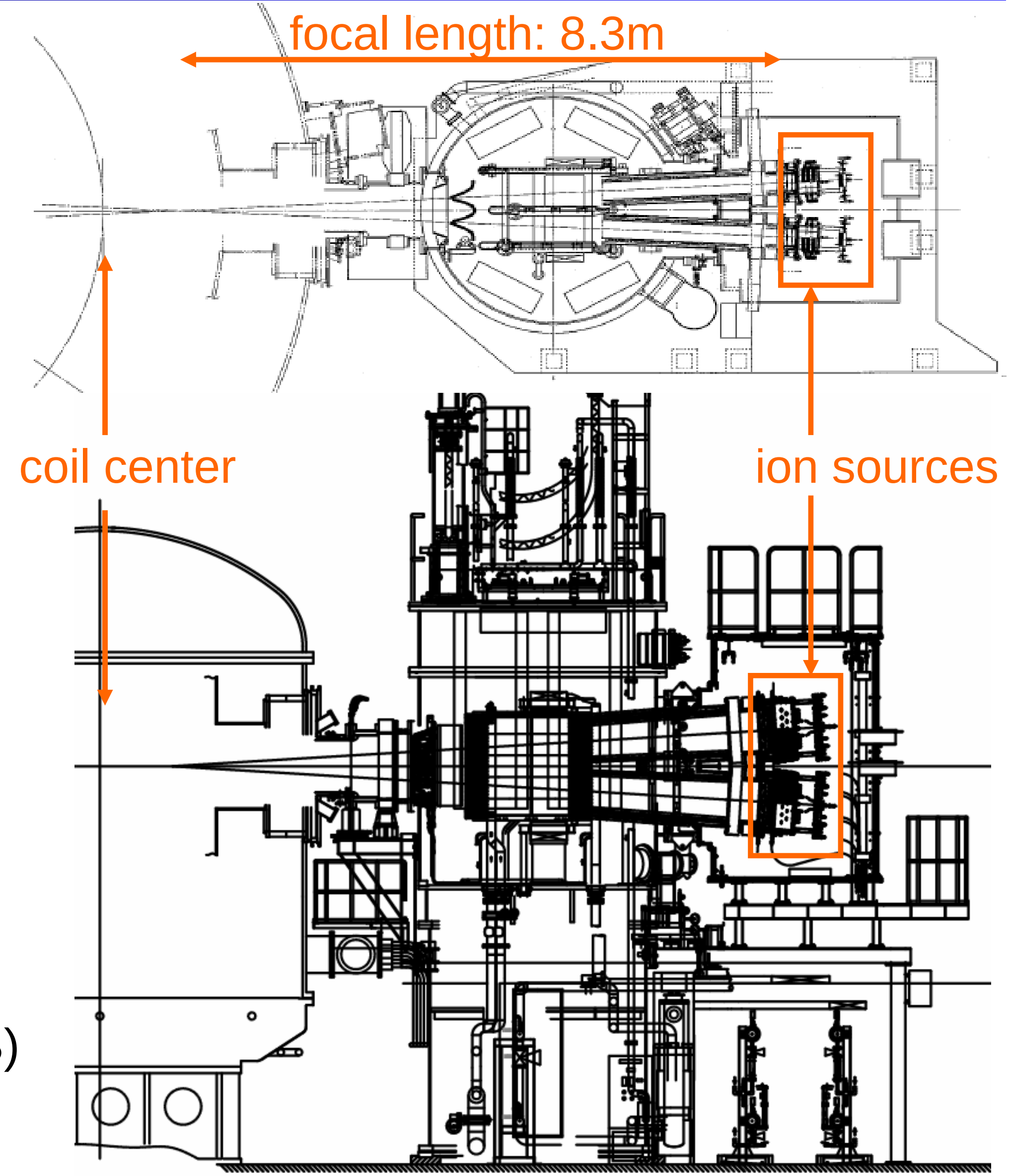


In this talk,
recent experimental results on high-ion-temperature discharge using P-NBI (Ti(0)=5.2keV) and ***related phenomena*** were presented.

Perpendicular NBI (BL4) in LHD

- ○Beam Energy：**40keV**
- ○Port-through Power：
  6MW
- ○Positive Ion Source：
  4 I/Ss (UA, LA, UB, LB)
- ○Power Supply System：
  Two independent systems
  Acc PS x 2
  Dec PS x 2
  Arc PS x 4
  Filament PS x 4
- ○Pulse duration：**10 sec**
- ○Injection Port: 5-O
- ○Beam Species: Hydrogen

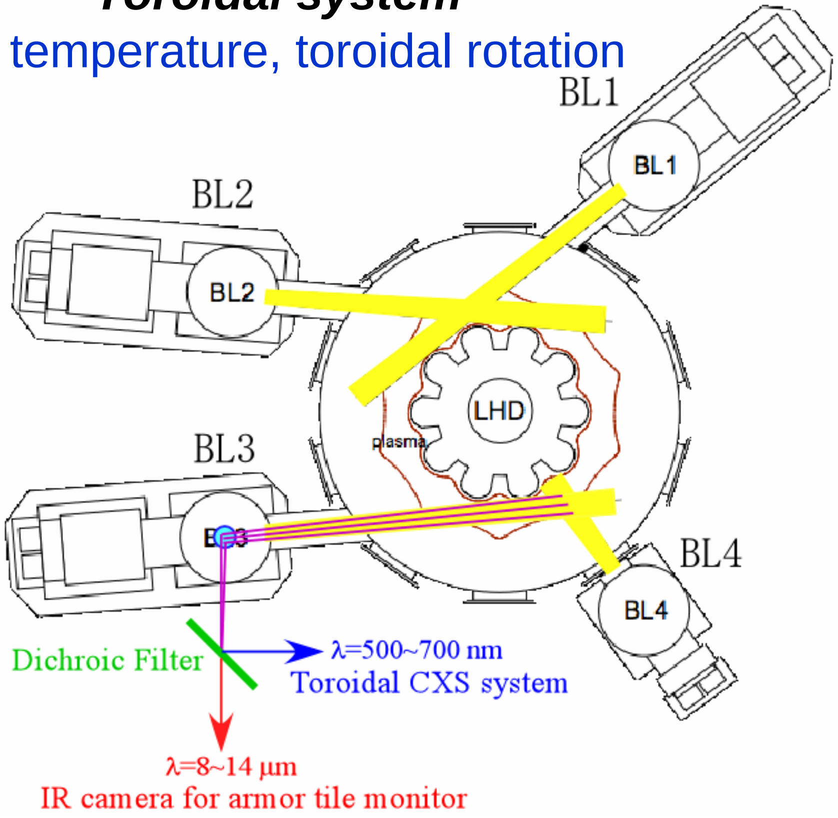
The two power supply systems (4A,4B) can be operated independently.



Charge exchange spectroscopy systems on LHD

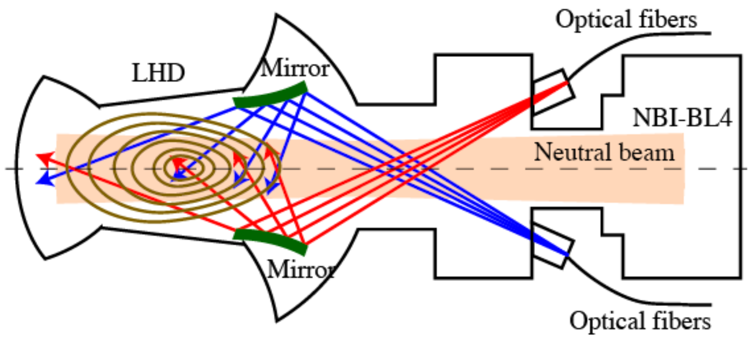
Toroidal system

Ion temperature, toroidal rotation

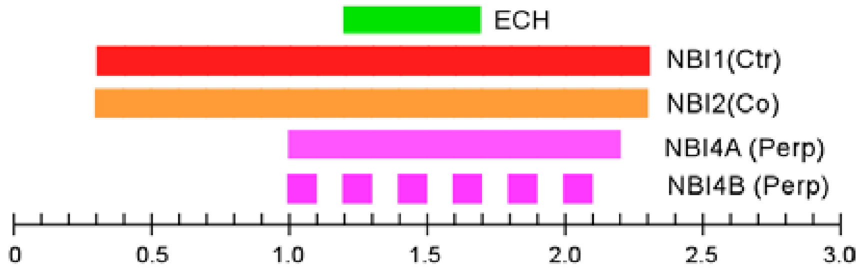


Poloidal system

Ion temperature, poloidal rotation



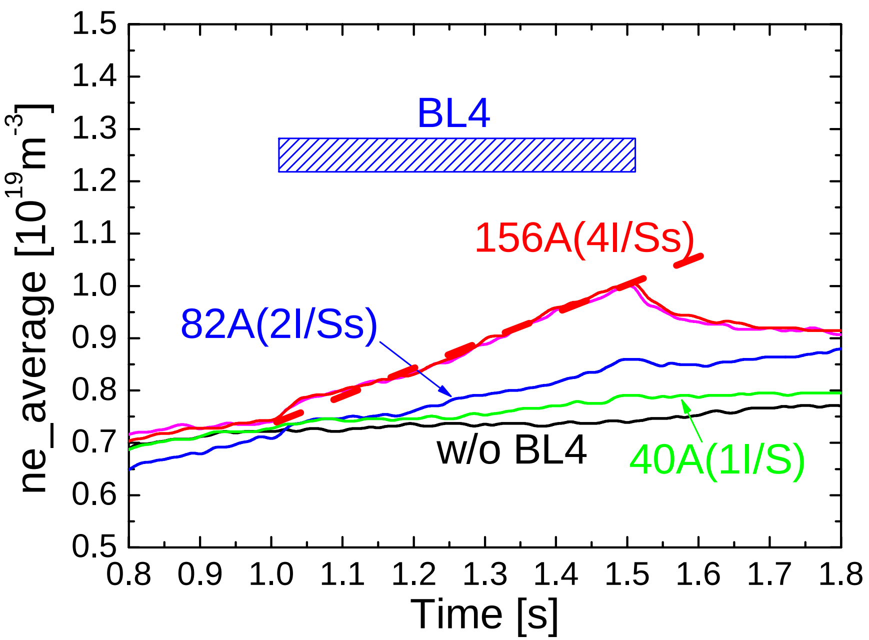
Typical NBI pattern for CXS measurements

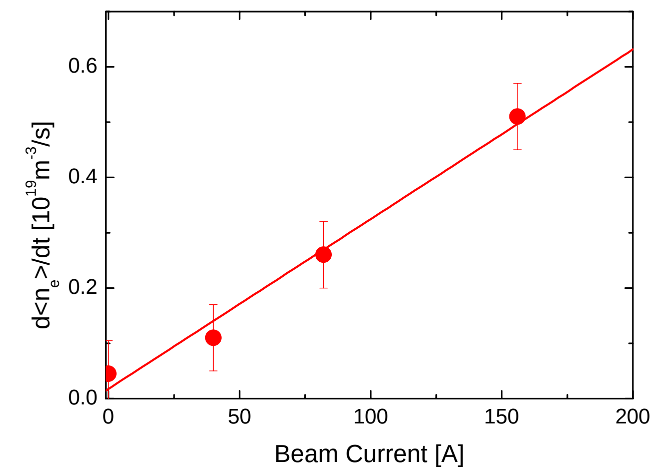


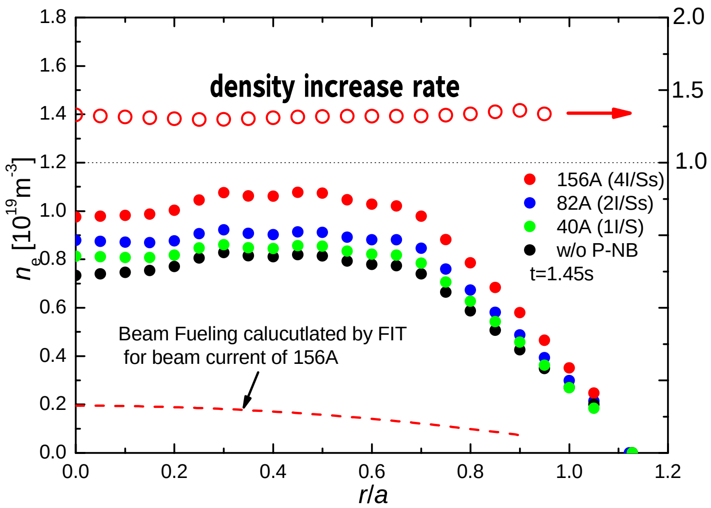
When the carbon impurity profile is extremely hollow (impurity hole), only toroidal system is available in core region.

To acquire the background signals, the half of P-NBI (4B) is modulated with 100msec ON and 100msec OFF.

Beam Fueling

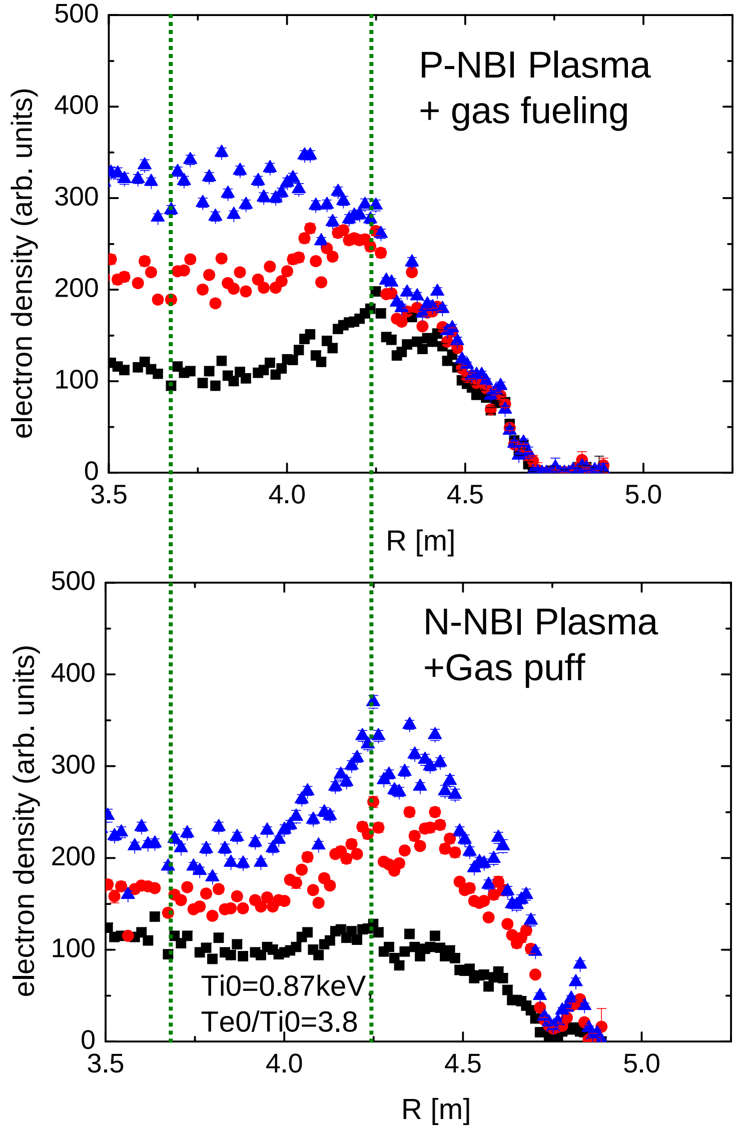


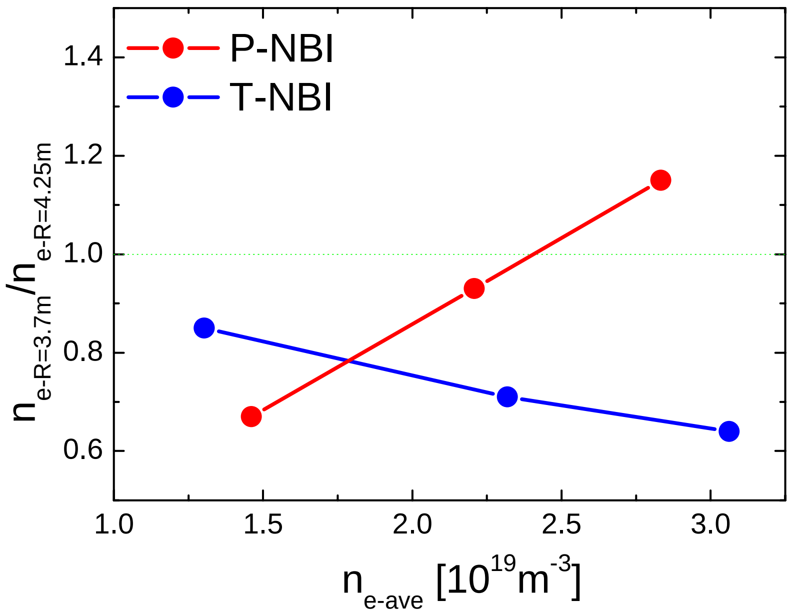




- Beam current scan of P-NBI was performed, and the density increase rate of $3x10^{16}m^{-3}s^{-1}A^{-1}$ ($2.3x10^{20}s^{-1}MW^{-1}$) was obtained.
- The beam fueling calculated by FIT code is consistent with the experimental observation.

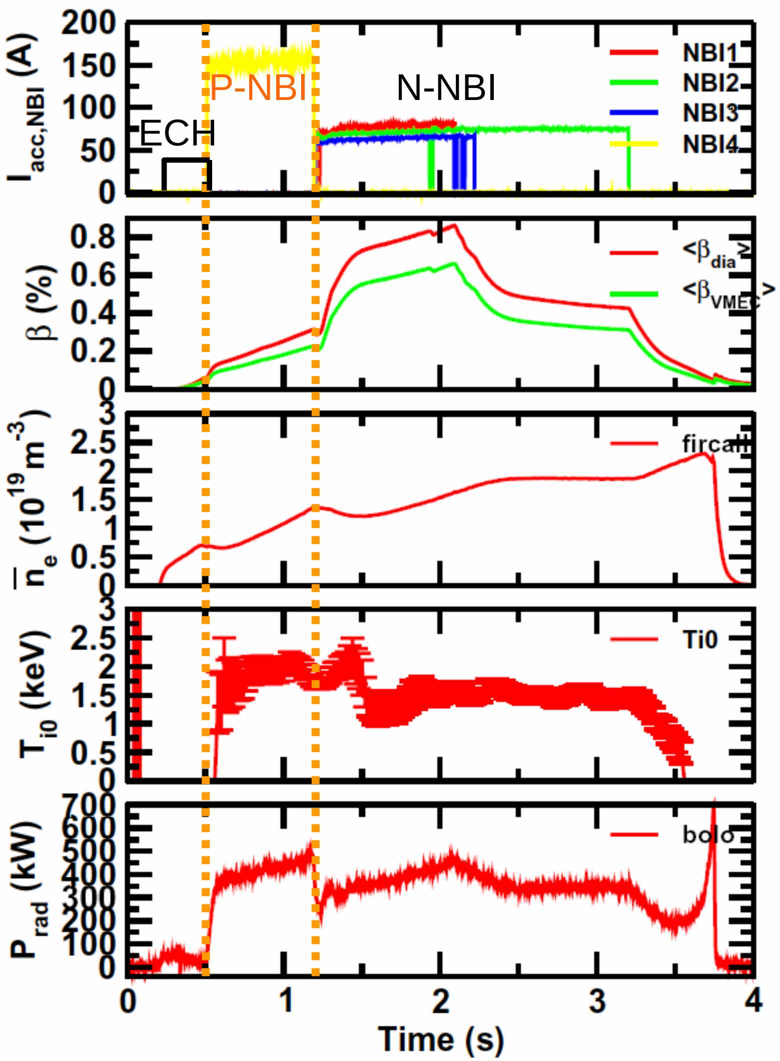
Control of Density Profile

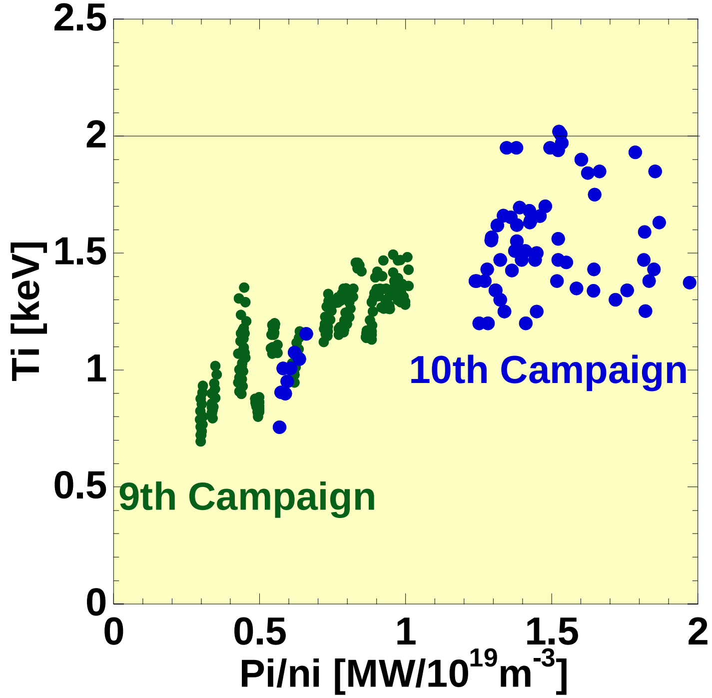




The density profile tends to be peaked by P-NB, and flat or hollow by N-NB. The beam fueling of P-NB is estimated about 40% of density increase in this case, indicating other effects (such as inward pinch) exist.

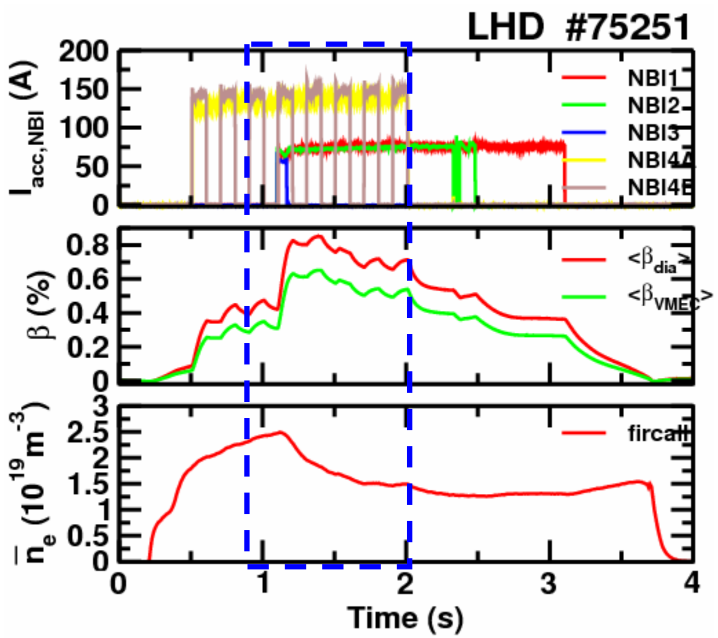
Ion Heating Using P-NBI

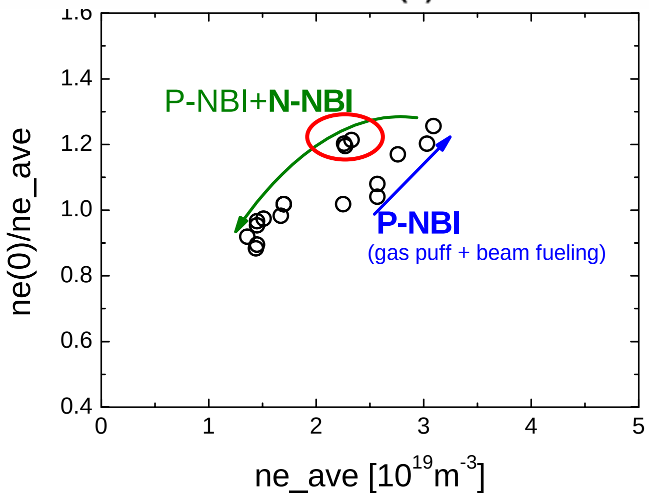


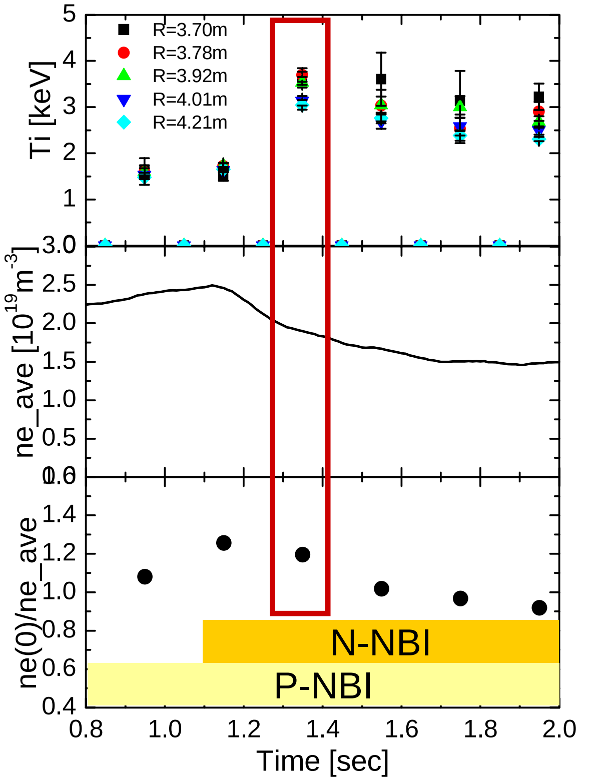


The higher ion temperature was obtained in P-NB heating plasmas. The ion temperature increases with the power of P-NB.

High Ion Temperature Discharges

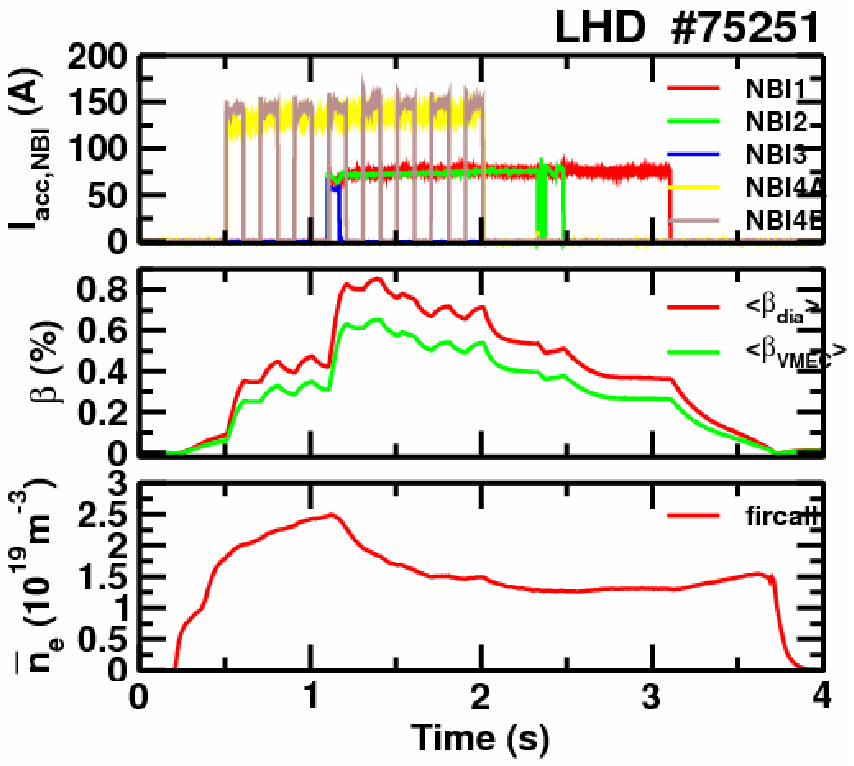


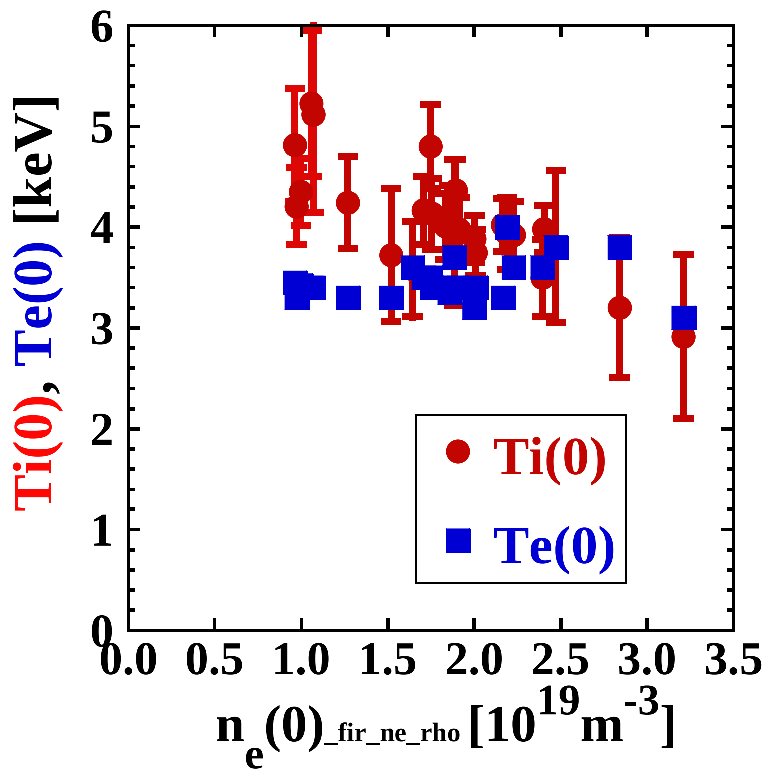




The highest ion temperature is obtained in the density-decay phase with peaked profile, implying the importance of density profile, and peaked profile seems to be preferable to realize high ion temperature.

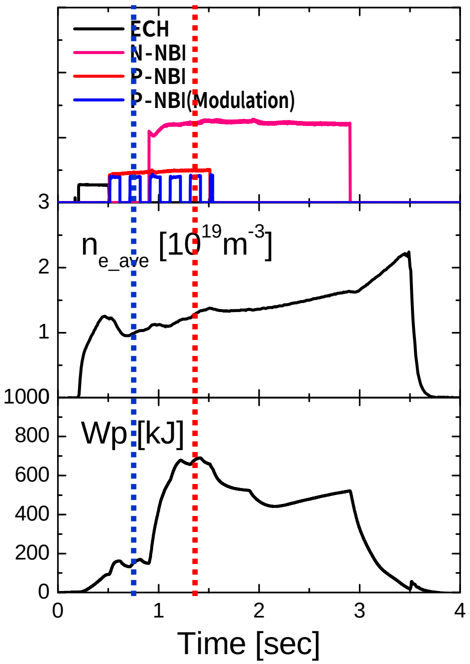
High Ion Temperature over 5keV

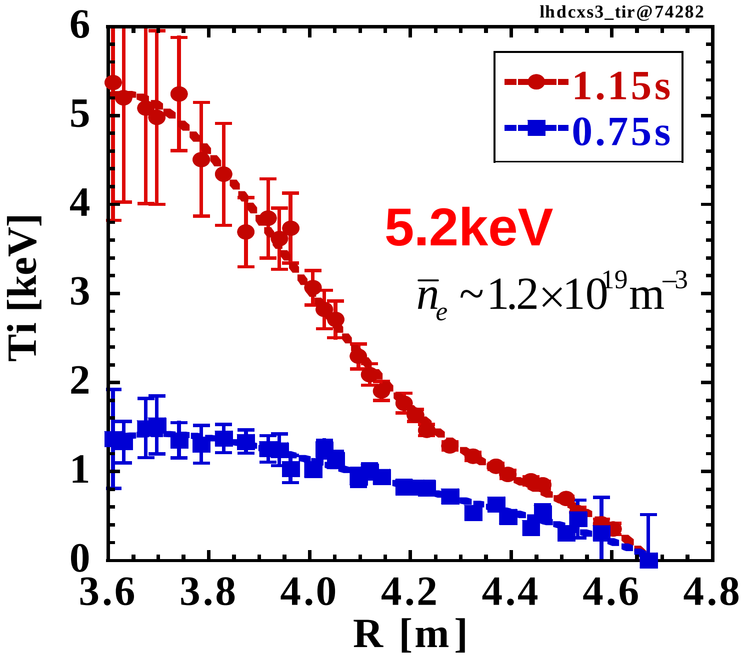


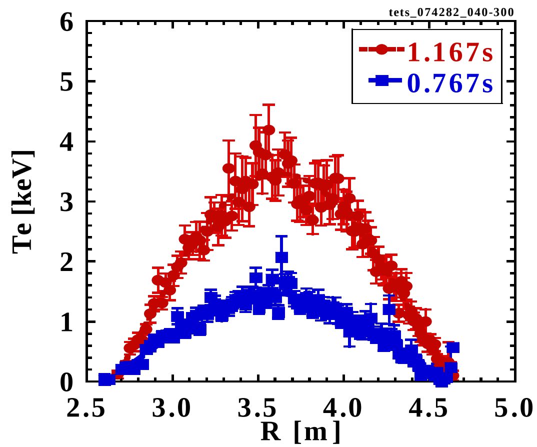


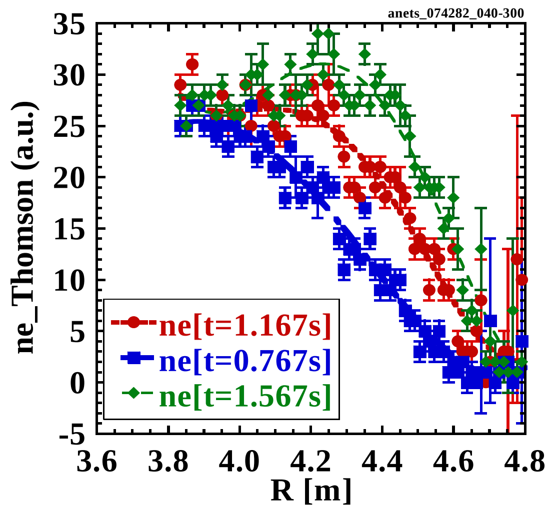
High-ion-temperature of 5.2keV was realized in hydrogen plasmas with n_e=1.2x10^{19}m^{-3}. The high-Ti regime has been extended toward higher density plasmas, and the central ion temperature of 3keV was obtained with density of n_e=3.2x10^{19}m^{-3}.

Ion Temperature Profile



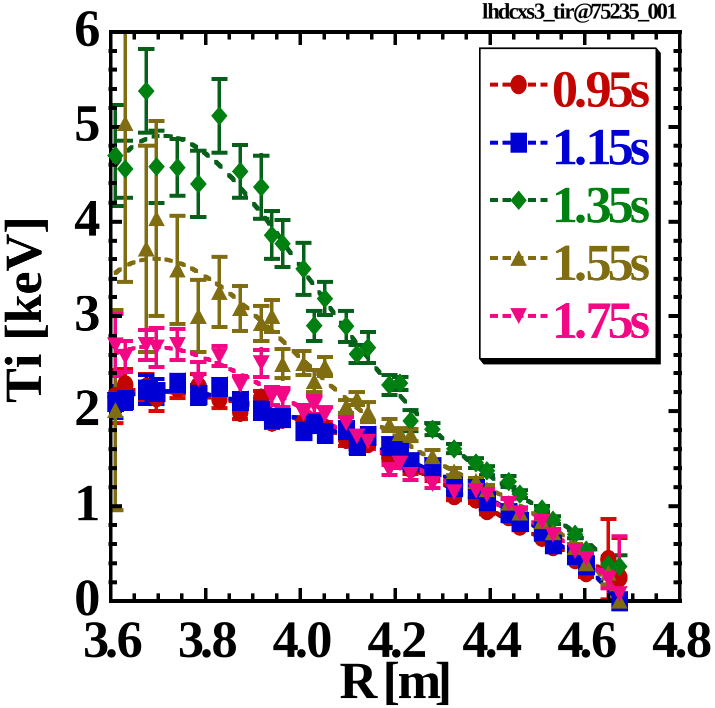


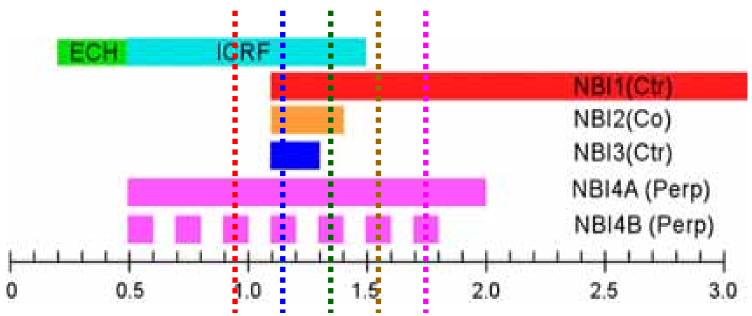




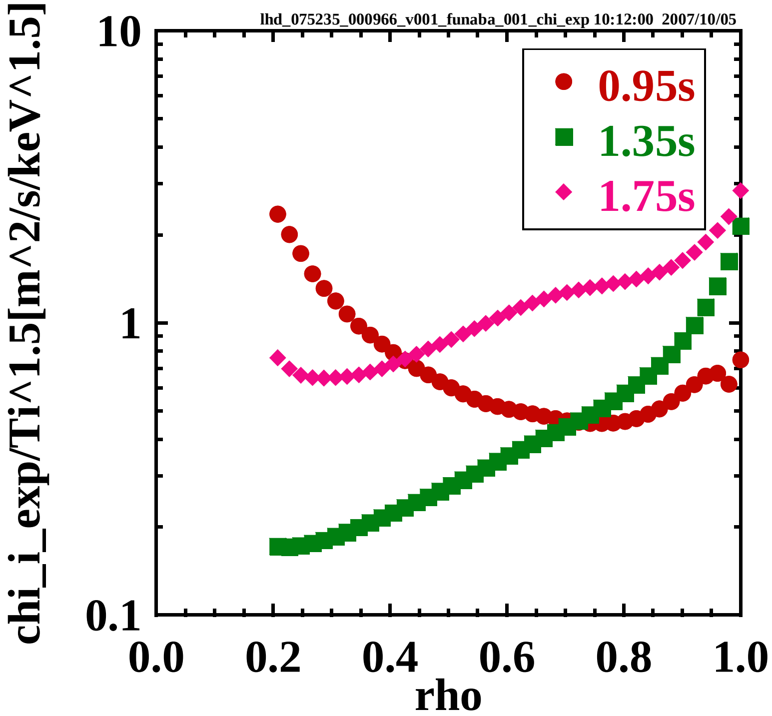
The peaked profile of ion temperature was observed by CXS. The electron density is peaked/flat profile, and electron temperature is lower than ion temperature, when high ion temperature is realized.

Transport Analysis



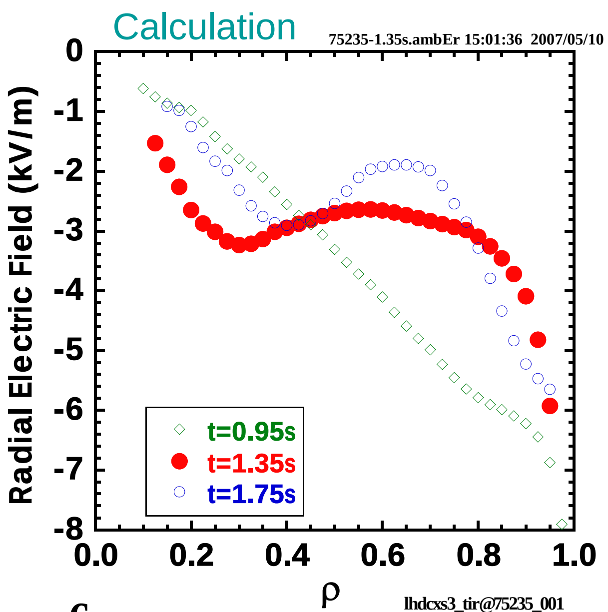


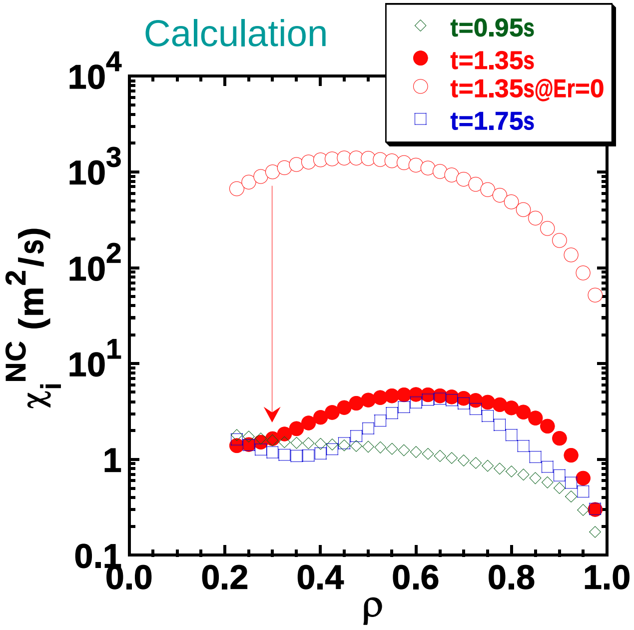
Power balance

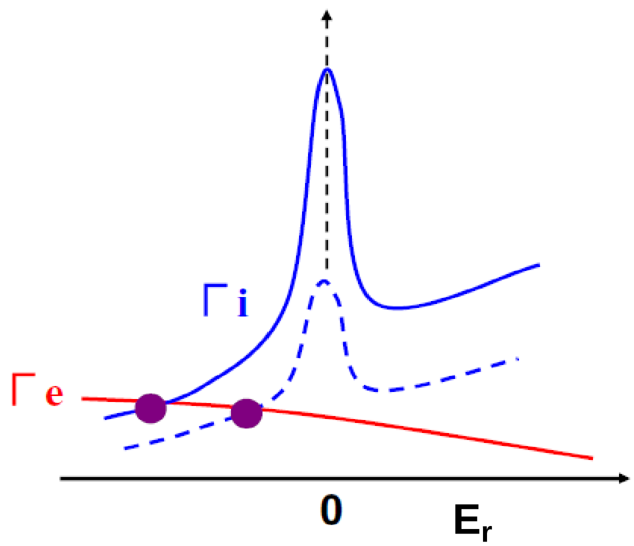


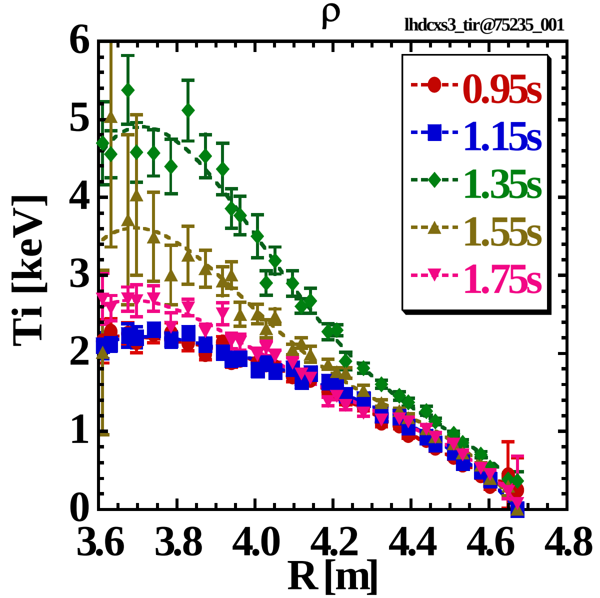
When ion temperature reaches the maximum, the ion thermal diffusivity decreases at the center, and in this phase, electron transport remains unchanged.

Neoclassical Transport Analysis





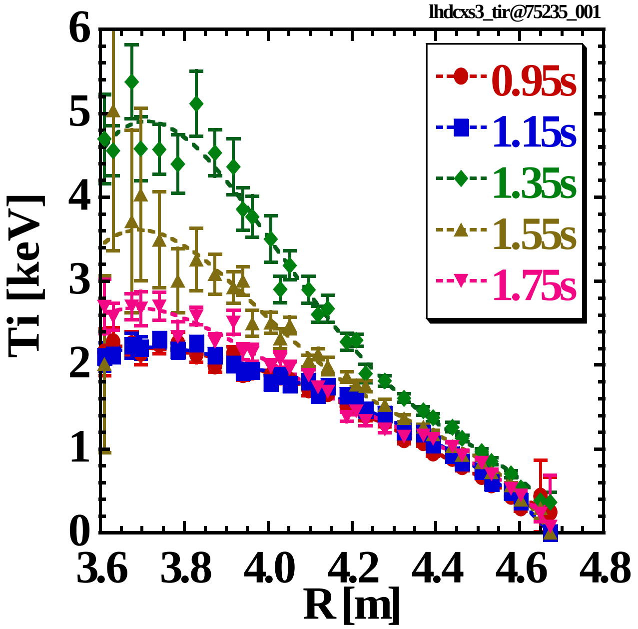


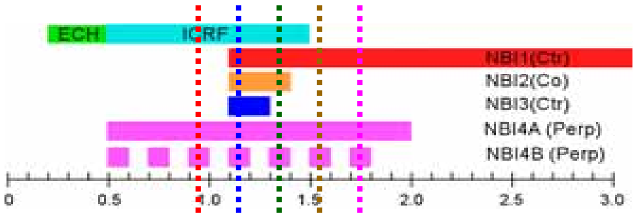


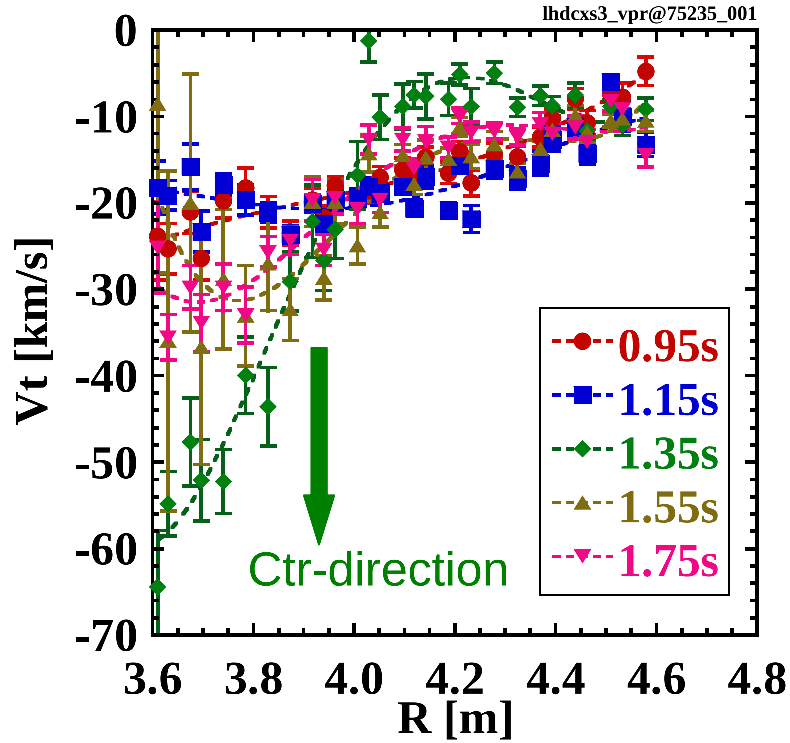
Neoclassical ambipolar calculation indicates negative E_r (ion root). The change of ion thermal diffusivity between high and low Ti cases is not so large. Thus, the degradation of neoclassical transport due to Ti rise is significantly suppressed by negative E_r (P2-013 Matsuoka).

It is concluded that anomalous transport is improved when ion temperature become high.

Toroidal Flow Formation

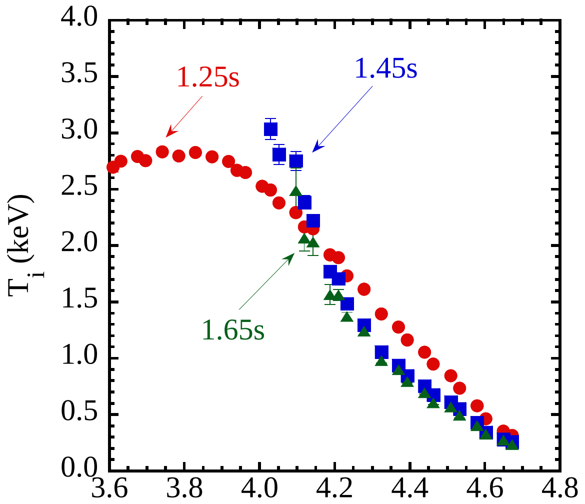


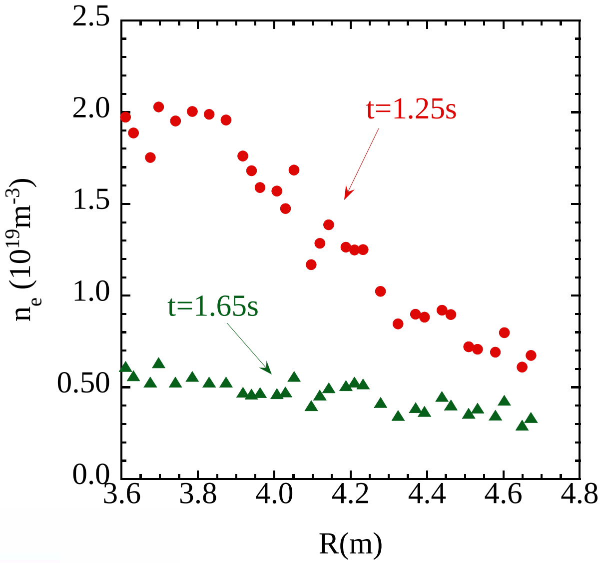


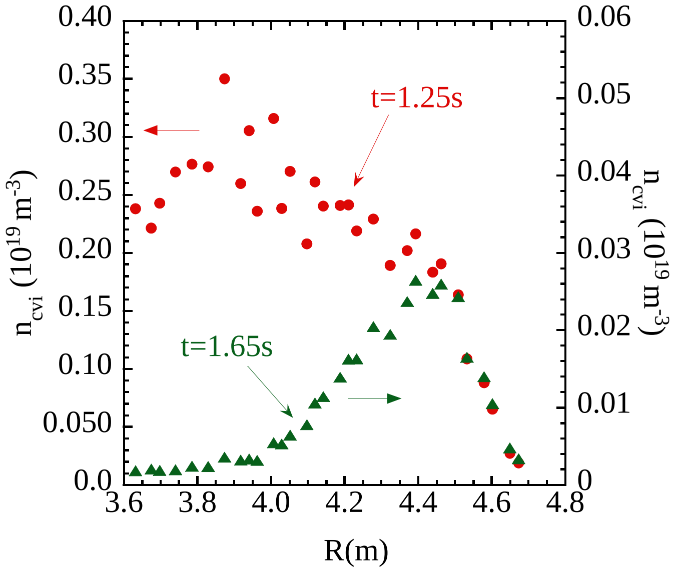


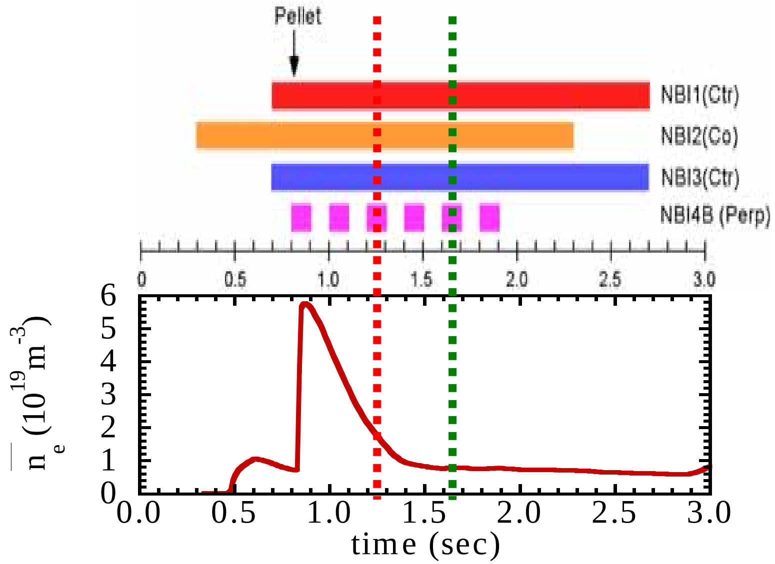
The large toroidal flow associated with high-ion-temperature was observed in the core region. The flow direction is consistent with the direction of NBI (O-12 Yoshinuma). The analysis of toroidal viscosity and the effective ripple are in progress (P1-036 Yokoyama).

Impurity Hole









The decrease of carbon impurity emission was observed in core region, and carbon impurity hole was formed associated with the increase of core ion temperature. The outward flow of carbon impurity was also observed, but the dynamics of carbon impurity are not understood yet.

Summary

- P-NBI was installed in LHD and the measurement of ion temperature profile started in 9th campaign.
- The peaked density profile can be produced in P-NBI heating plasmas, and seems to be preferable to high ion temperature.
- The high-ion-temperature of 5.2keV with $n_e=1.2 \times 10^{19} m^{-3}$ and 3keV with $n_e=3.3 \times 10^{19} m^{-3}$ were realized in hydrogen plasma.
- The NC calculation shows that the degradation of NC transport due to ion temperature rise is significanly suppressed by negative *E*r (ion-root).
- The decrease of thermal diffusivity indicates the reduction of anomalous transport when high ion temperature was realized.
- The strong toroidal flow and the impurity hole were observed with ion-temperature rise.