Ion internal transport barrier in Large Helical Device

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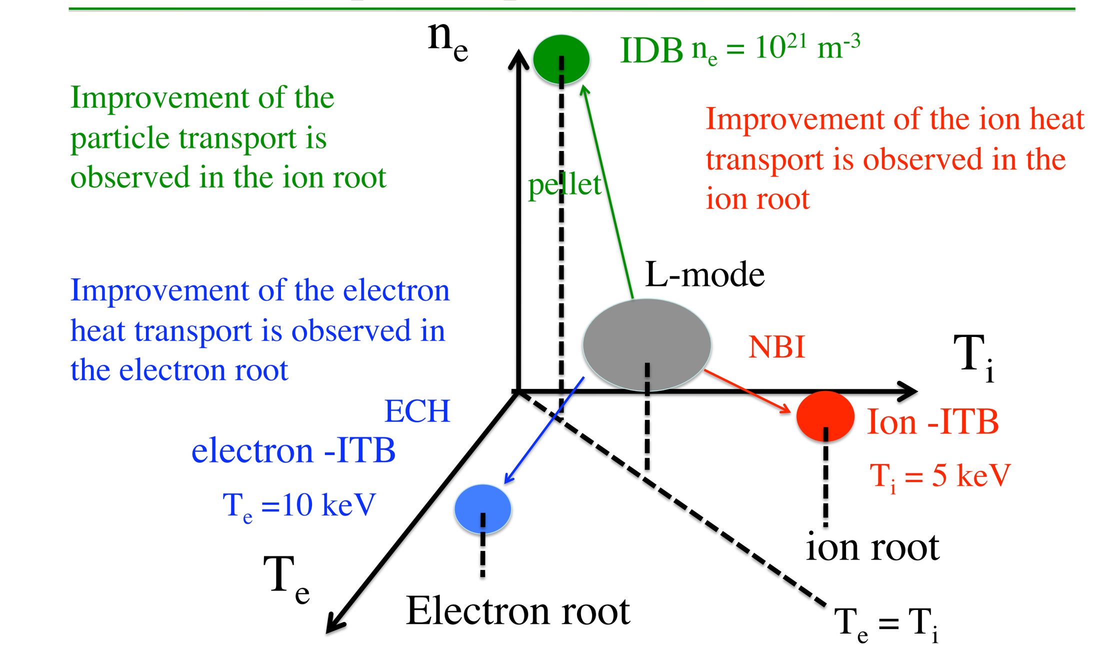
Abstract

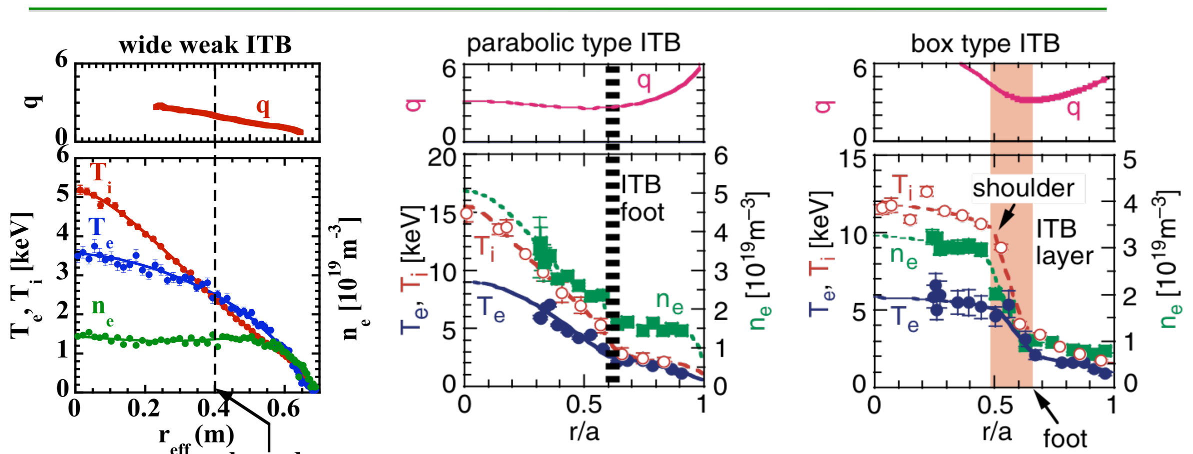
In Large Helical Device (LHD), the ion internal transport barrier (ITB) appears when the P-NB is injected before the N-NB but not when the N-NB is injected before the P-NB, even if the power of the P-NBI and the N-NBI are identical later in the discharge. The Te/Ti ratio at the time both P-NB and N-NB are injected is larger in the discharges with prior N-NBI rather than the discharges with prior P-NBI. These observations suggest that the high Te/Ti ratio contributes to prevent the formation of the ion ITB in LHD. Therefore it is important to keep the Te/Ti ratio close to or below unity at the onset of the high power NBI to achieve a high ion temperature. There are two approaches to achieve high ion temperature plasmas by keeping the T_e/T_i ratio at a low level in LHD. One is to perform the P-NBI injection only before the start of high power heating, which gives the target plasma with a low Te/Ti ratio. Another approach is the injection of hydrogen or carbon pellet before the start of high power heating, which results in a T_e/T_i ratio close to unity. The carbon pellet has an additional benefit in increasing the power deposition of NBI to ions through ion-impurity collisions. At the formation of ion ITB, the ion temperature gradient starts to increase at approximately half of the plasma minor radius (up to ~ 9 keV/m) then the ion temperature gradient farther inside increases later.

Transport improvement in LHD



The electron and ion heat transport and particle transport are independent from each other, which is different from the transport in tokamaks.

Comparison of radial profiles with tokamak ITB

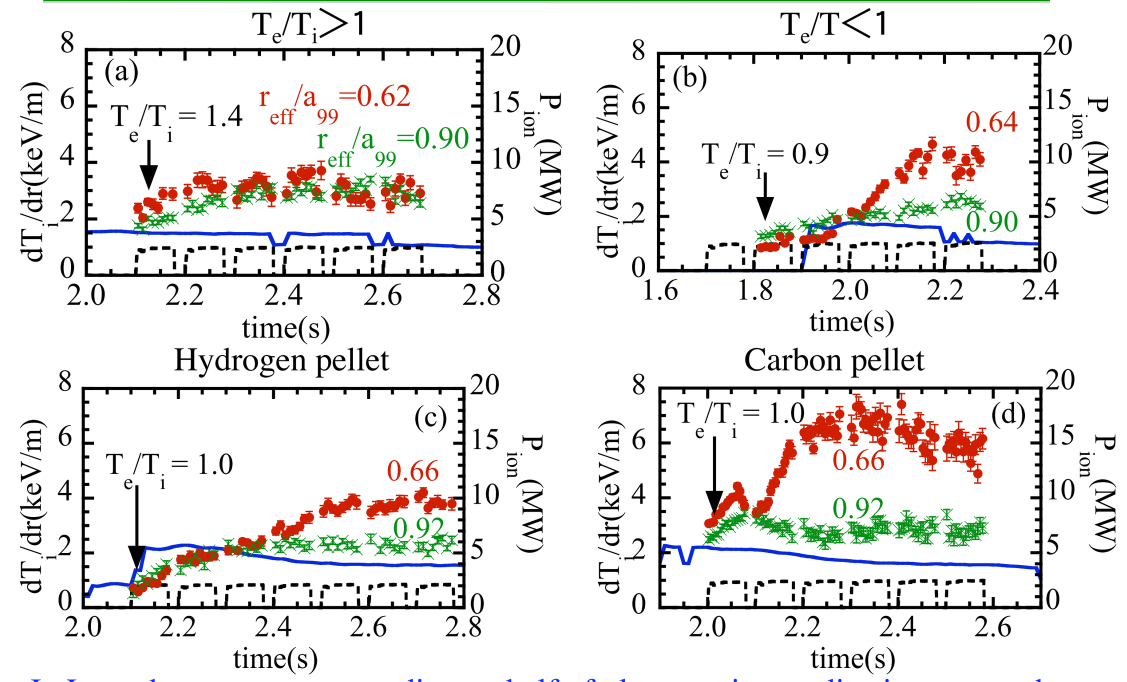


T.Fujita et al., Plasma Phys. Control. Fusion **44 (2002) A19**

The ITB structure appears only in the ion temperature profile in LHD
→ $T_i(0) \sim T_e(0)$ in L-mode, $T_i(0) > T_e(0)$ in the ion ITB mode
→ The density and electron temperature gradient near the plasma center is small

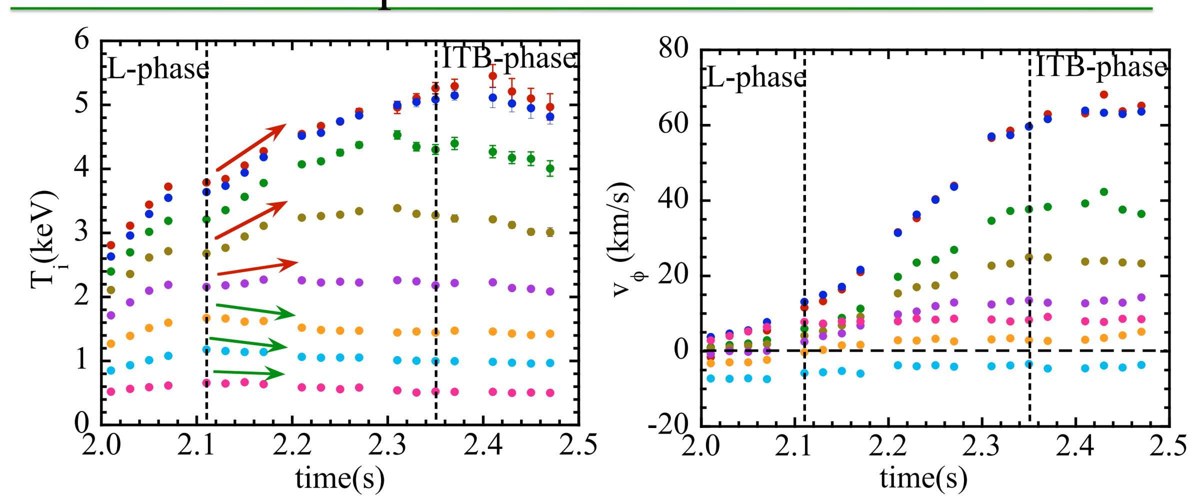
The ITB structure appears both ion temperature, electron temperature, electron density in most ITB plasma in tokamaks

Formation of ion-ITB



In L-mode, temperature gradient at half of plasma minor radius is same as the gradient at the edge as $\nabla Ti(0.6) \sim \nabla Ti(0.9)$.
When the T_e/T_i ratio is close to unity, the ITB appears at the higher heating power and the temperature gradient at the mid-radius increases and $\nabla T_i(0.6) > \nabla Ti(0.9)$

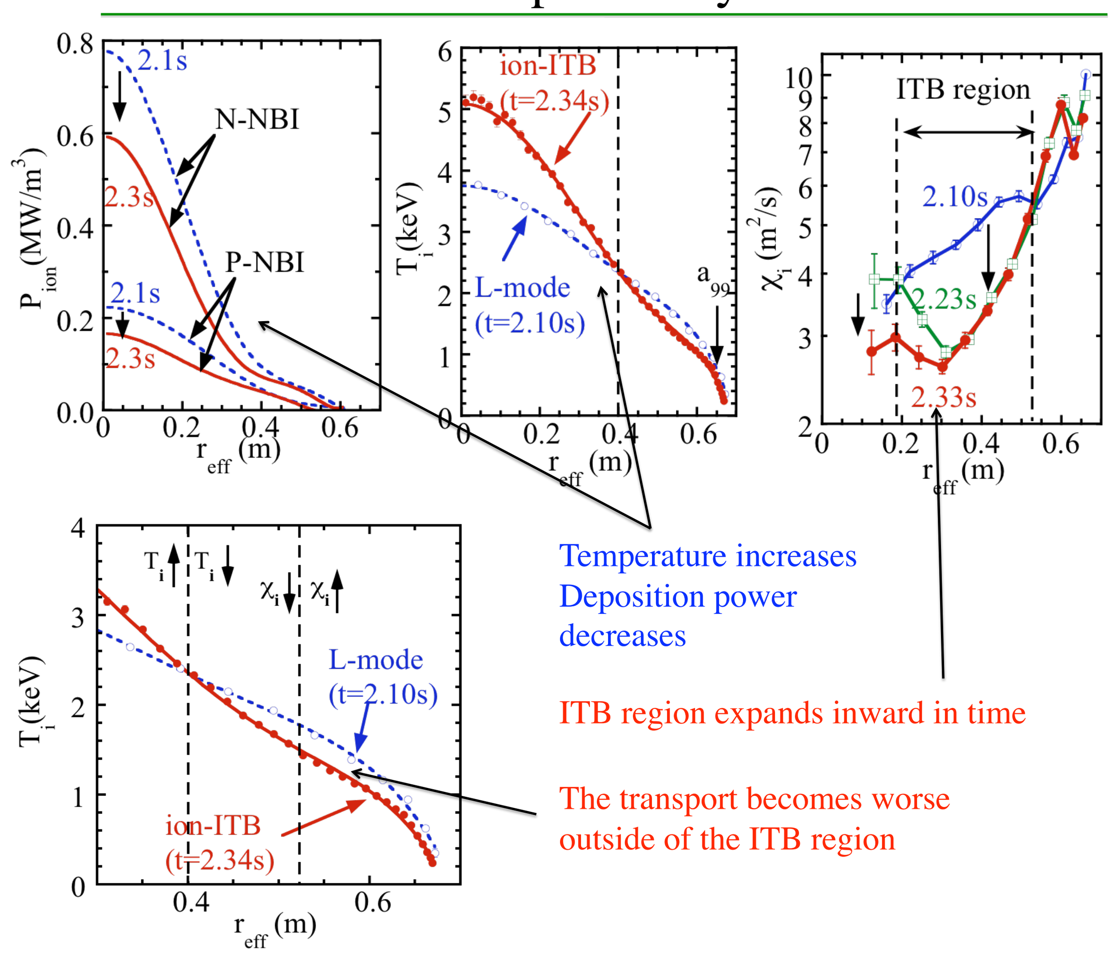
Ion temperature and toroidal rotation



Aster the transition ion temperature in the core increases while the ion temperature near the edge decreases.

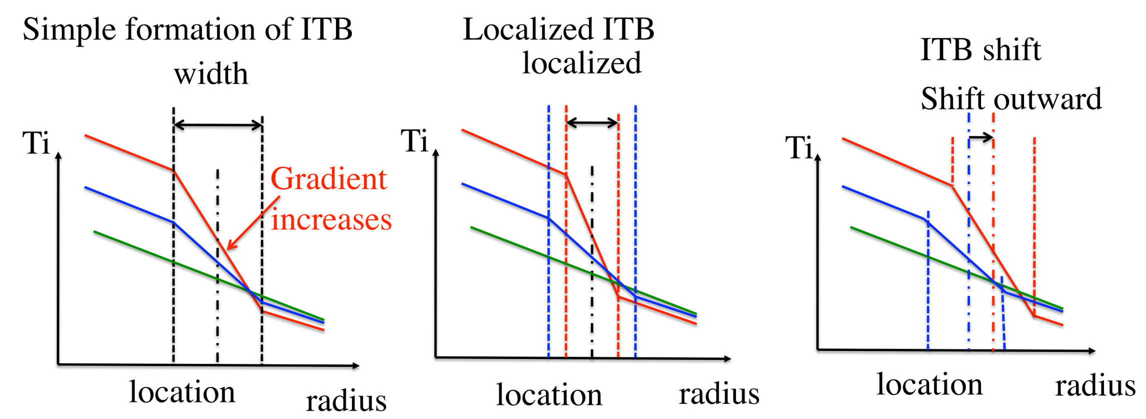
The delay of the increase of toroidal rotation velocity is due to the appearance of spontaneous rotation driven by ion temperature gradient.

Transport analysis

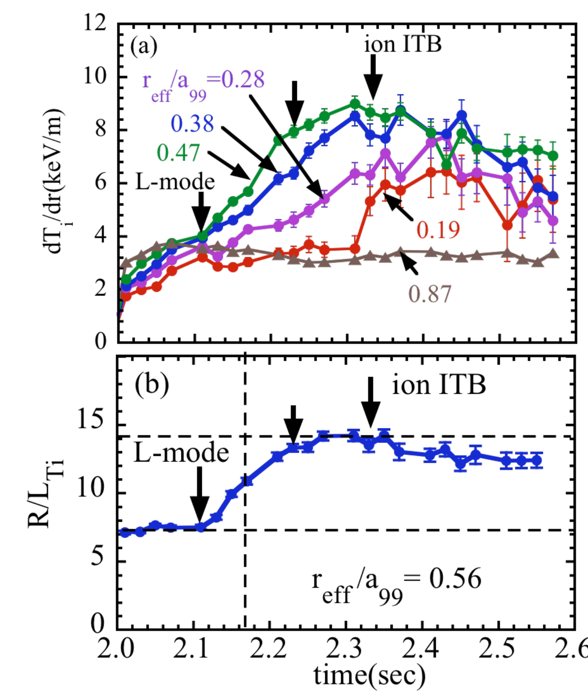


Three parameters of ITB

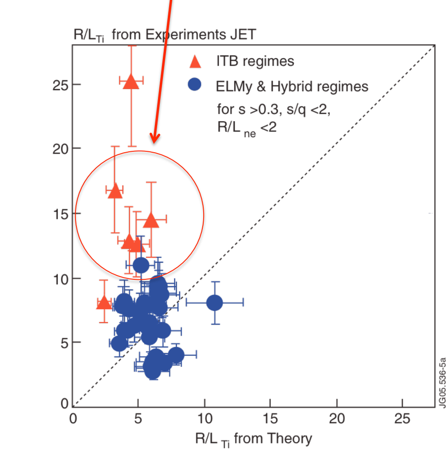
1 Strength of ITB (∇T_i) strong ITB←weak ITB
2 Width of ITB wide ITB←narrow ITB
3 Location of ITB (ITB radius)



ITB strength



The normalized ion temperature gradient increases up to 14, which is equivalent to that in the weak ITB in tokamak



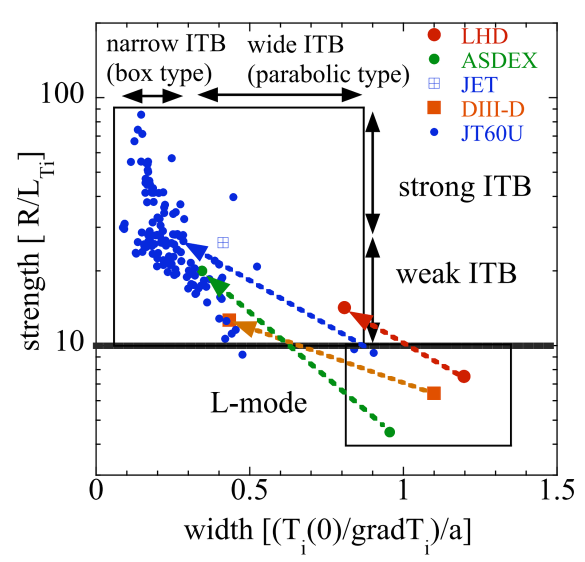
W.C. Wolf, Plasma Phys. Control. Fusion **45 (2003) R1.**

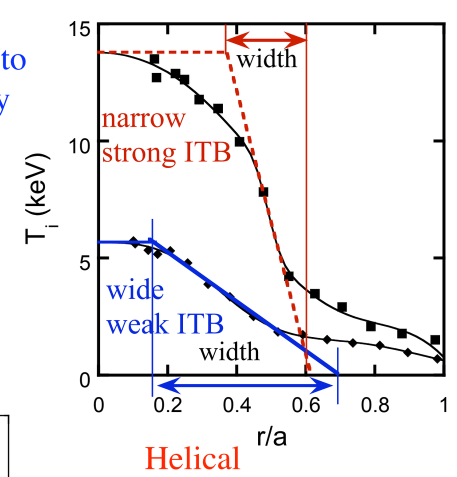
ITB width

ITB width→ The ratio of central T_i to maximum T_i gradient normalized by minor radius : $T_i(0)/\max\nabla T_i/a$

The width can be defined in the L-mode plasma .

L-mode plasma → the width > 1
ITB plasma → the width < 1



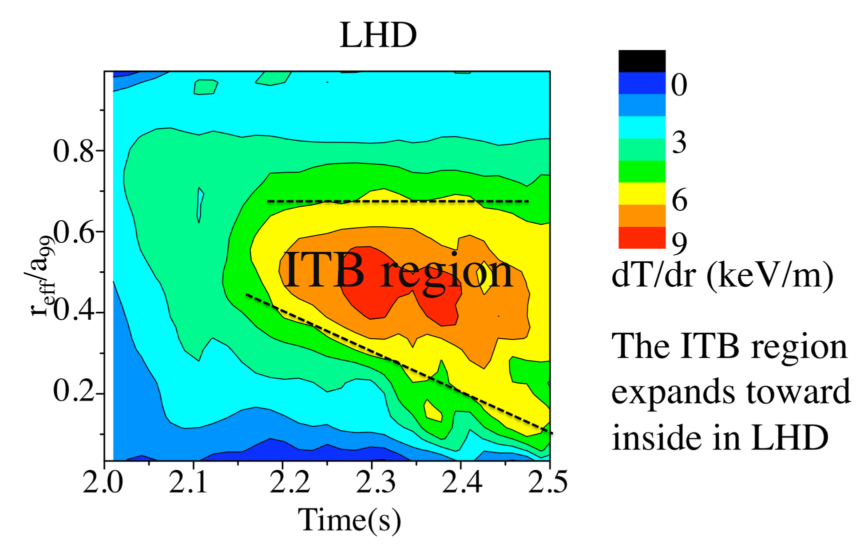


Helical
wide weak ITB
→MHD stable

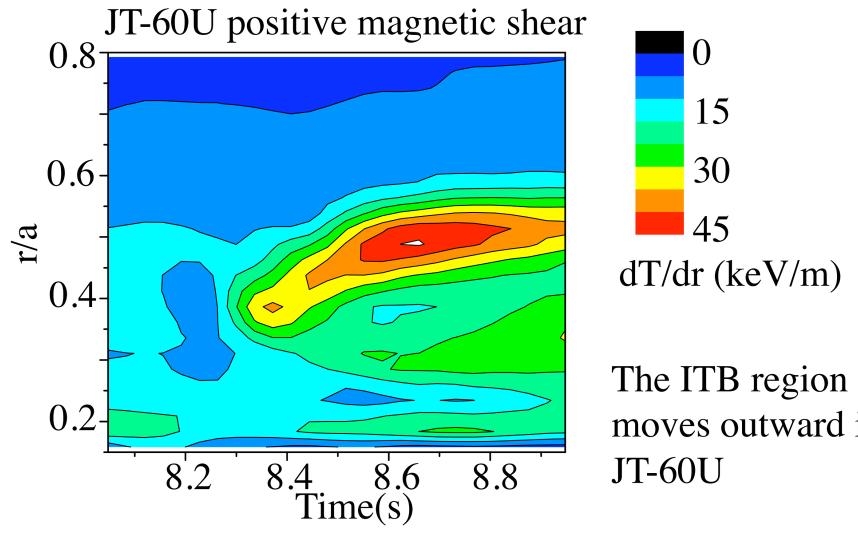
Tokamak
wide variation from wide weak to narrow strong

Narrow strong ITB
→ MHD unstable

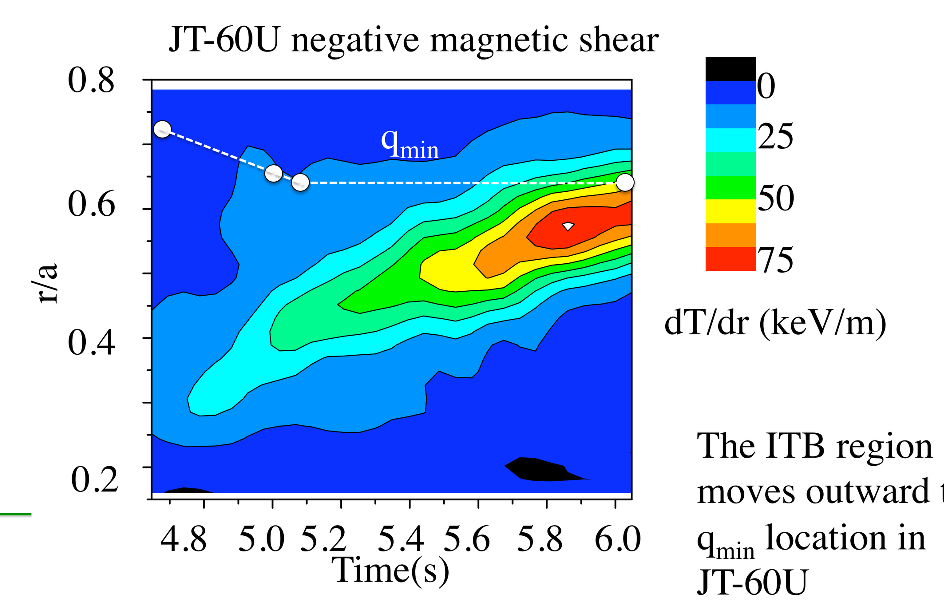
ITB location



The ITB region expands toward inside in LHD



The ITB region moves outward in JT-60U



The ITB region moves outward to q_{min} location in JT-60U

Summary

ITB structure which is characterized by increase of temperature gradient at mid-radius [$\nabla T_i(0.6) > \nabla T_i(0.9)$] appears when the T_e/T_i ratio of the target plasma for high power heating is small enough (~1).

The ITB structure appears only in the ion temperature profile, which is in contrast to the ITB in tokamak, where the ITB structure appears both in ion, electron temperature and density.

ITB strength and width
The ITB strength is weak (the normalized T_i gradient R/L_{TI} ~ 14) but the width is large ($T_i(0)/\max(\nabla T_i)$ /a ~ 0.8) compared with the ITB in tokamak

ITB location (ITB radius)
The ITB location move inward and the region is expanding during the formation, which is in contrast to the fact that the ITB region is localized and move outward in tokamak ITB.

The mechanism of ITB location shift is not clarified but would be related to the strong space coupling in transport (local model can not explain it)