The Ion Internal Transport Barrier on HL-2A

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IAEA International Atomic Energy Agency

SWIP Southwestern Institute of Physics

Outline

- **Motivation and the main diagnostics**
- **iITB characteristics and formation criterion**
- **Mechanisms of the iITB formation**
- **Summary**

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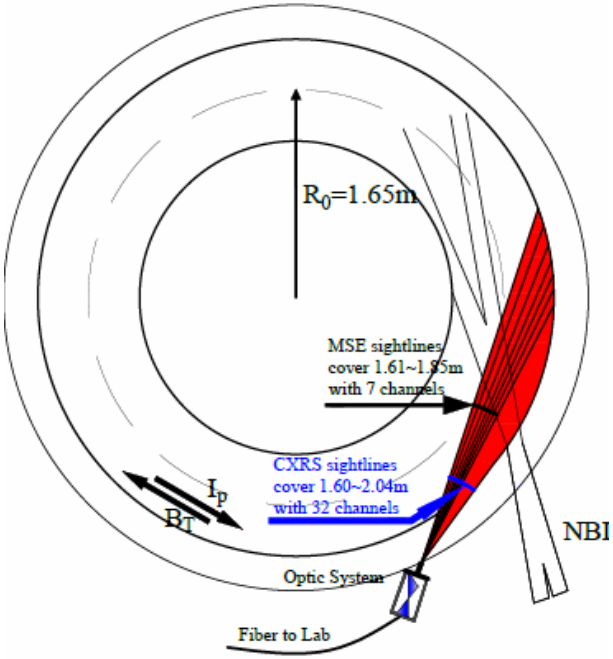
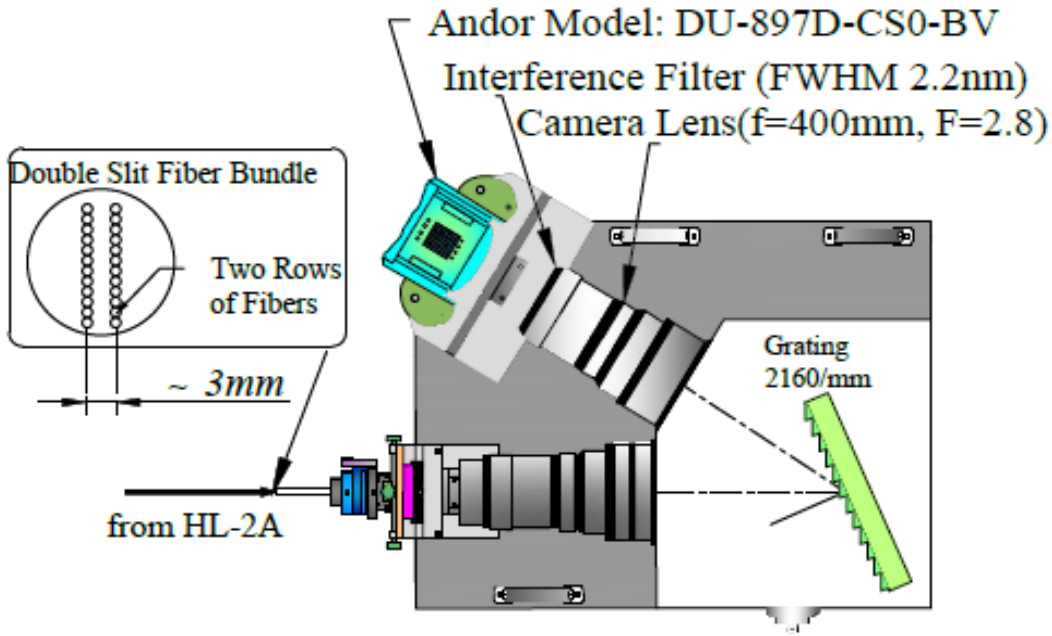
Motivation

- **The plasma with internal transport barriers (ITBs) is favorable for the steady state operation in a tokamak power plant**
- **Discharge with ITB is a promising candidate regime for ITER**
- **The investigation of formation mechanism of transport barrier is still on going**

The CXRS System on HL-2A





- Fast throughput spectrometer (F/2.8)
- Double-slit incidence fiber bundle
- 32/64 channels are available
- T_i & v_t measurements with 250 Hz are available

D L Yu 2014, RSI 85 11E402
Y L Wei 2014, RSI85 103503

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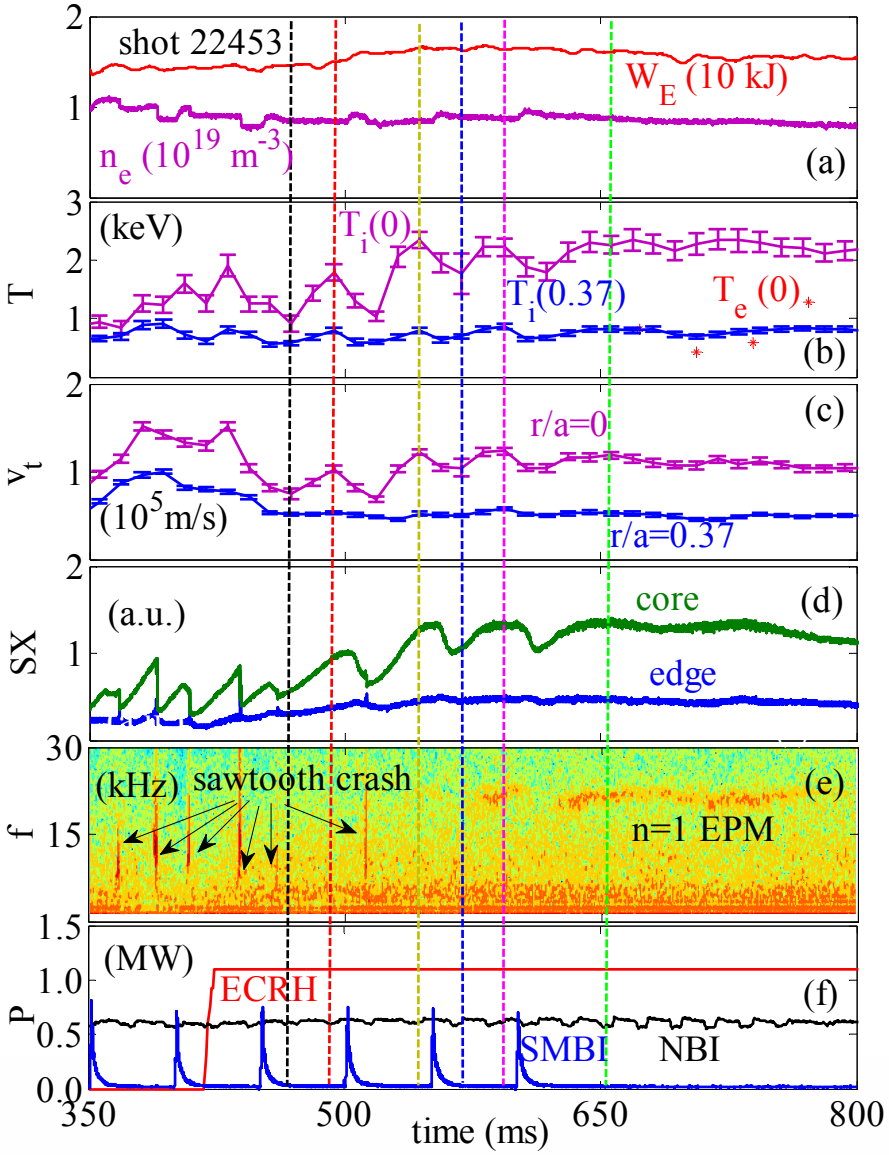
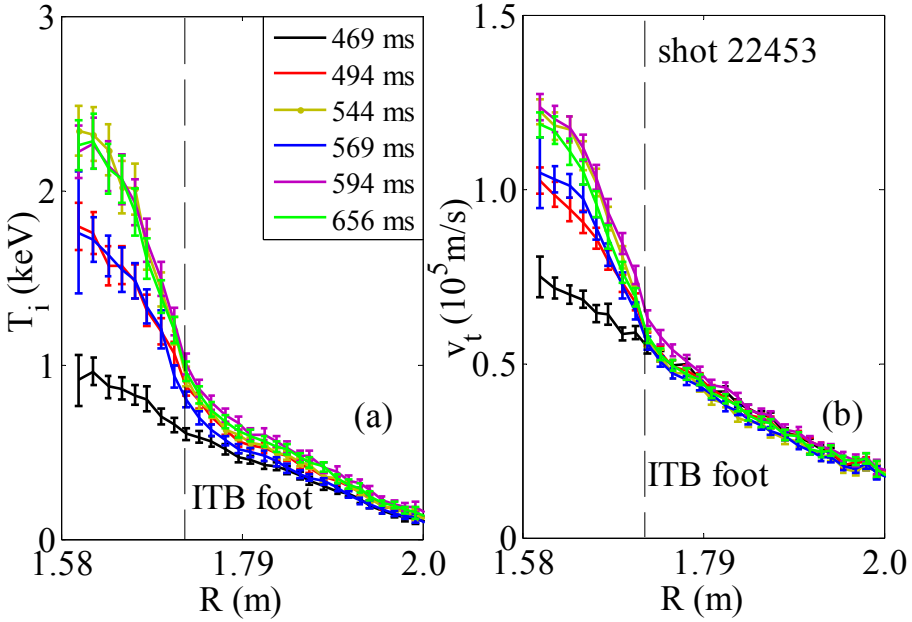
The typical discharge of ITB formation

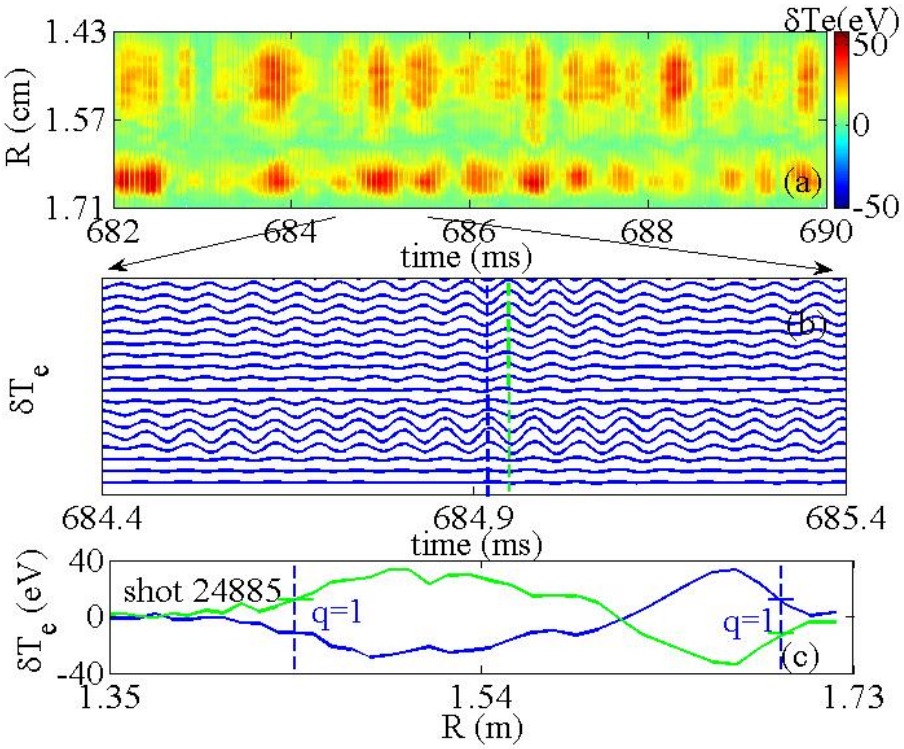


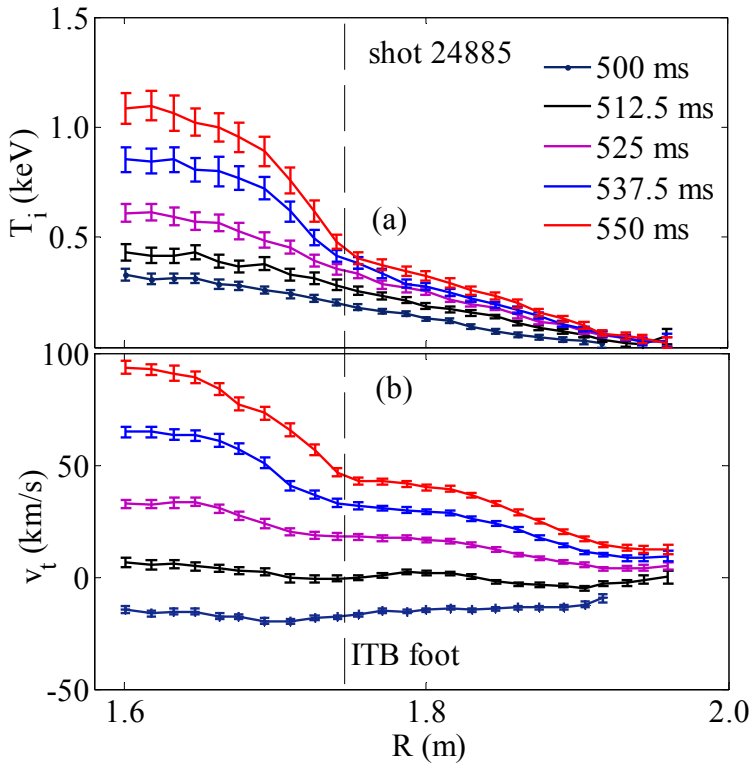
- The ion temperature gradient becomes steeper while stored plasma energy increases ~15%
- The gradient is steeper when the sawtooth disappears



D. L. Yu 2016, NF56, 056003

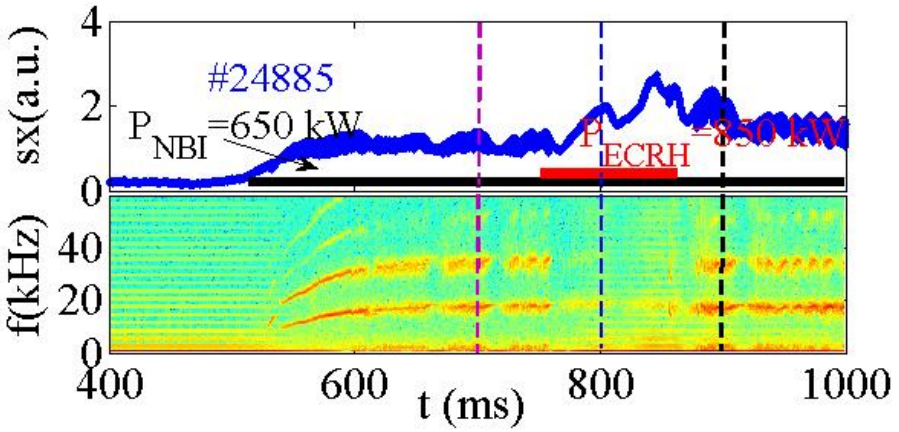
ITB foot locating at q=1 rational surface

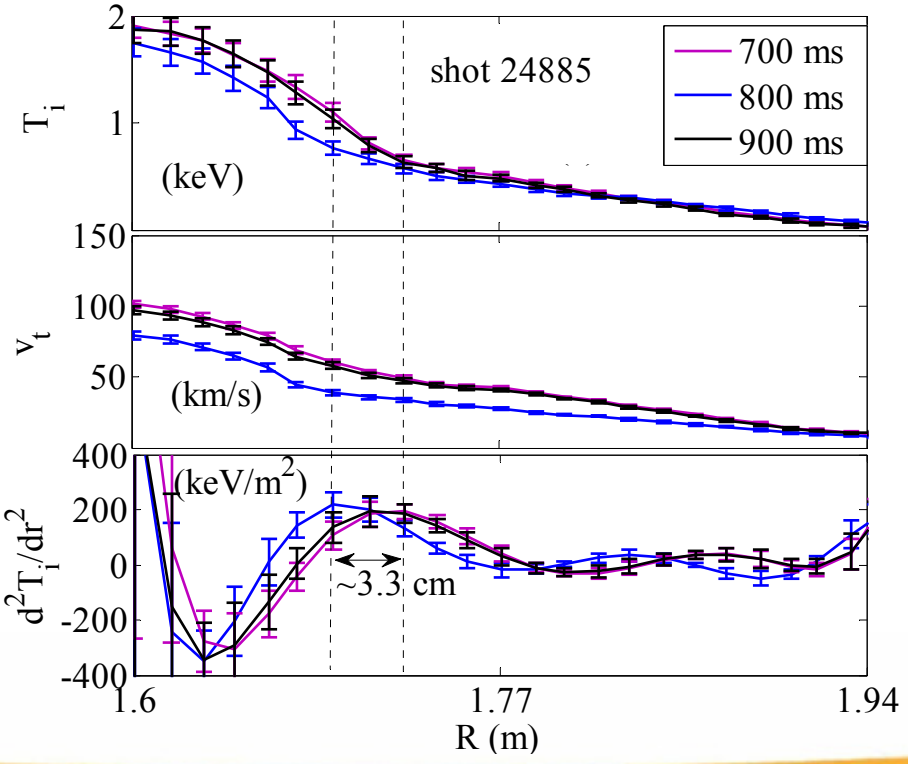


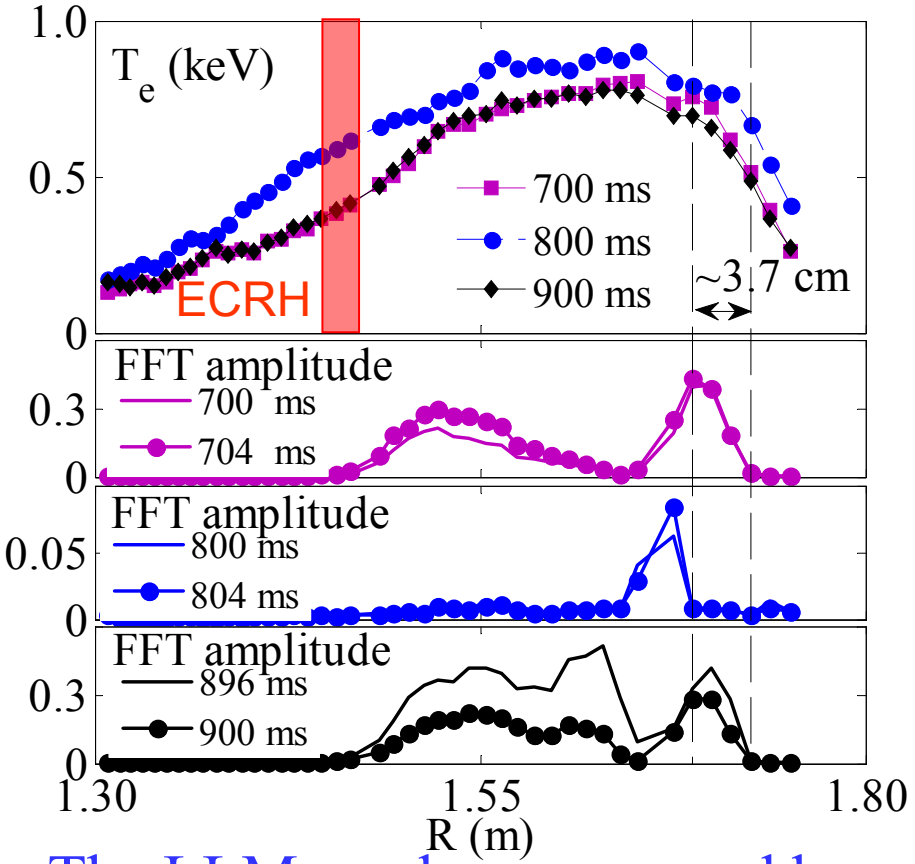


- The ITB formation accompanies with LLM or fishbone
- ITB can be observed both in T_i and v_t channels
- According to ECE and CXRS, the ITB foot locates at q=1 surface

Control the ITB foot with ECRH

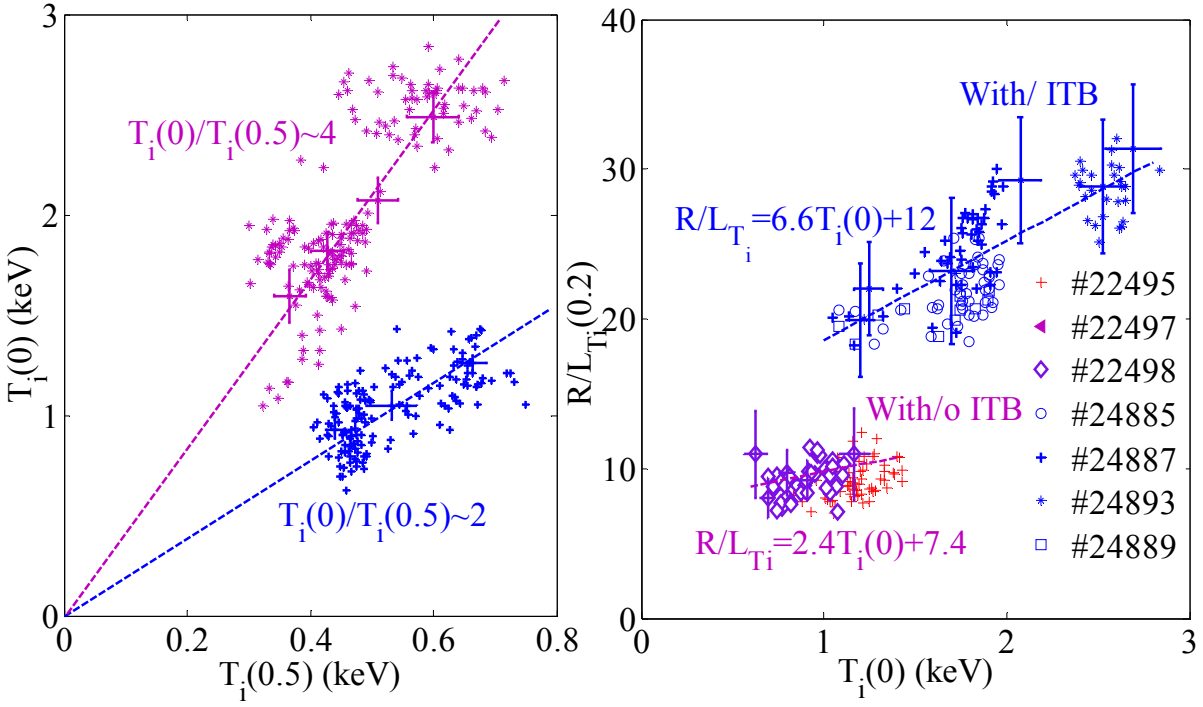






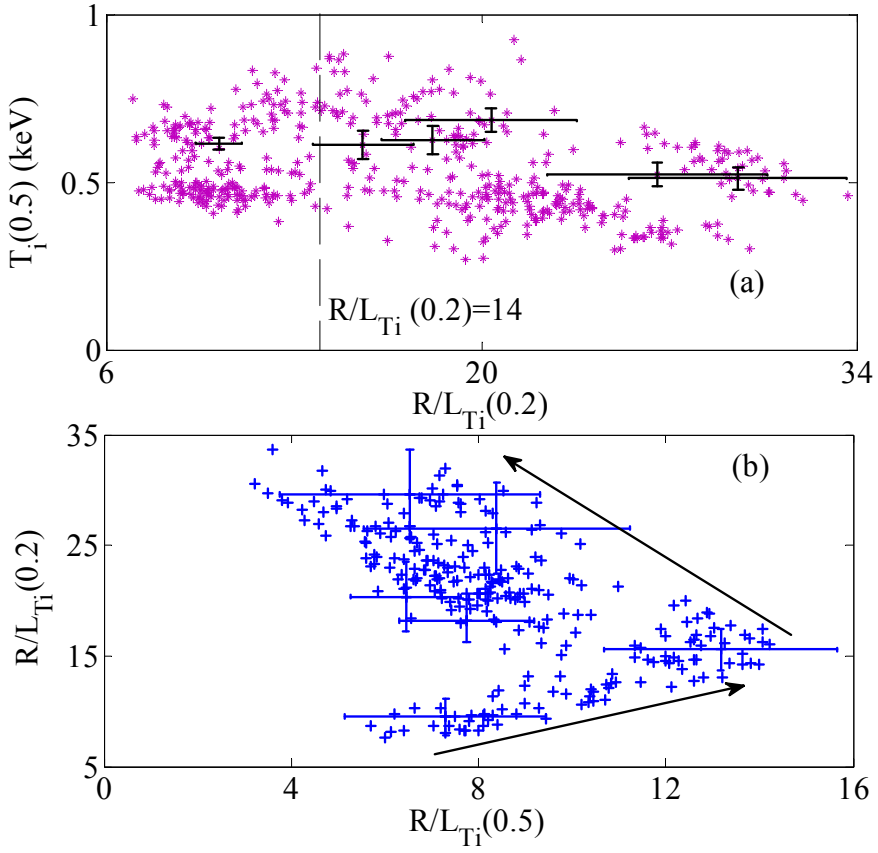
- The LLM can be suppressed by the ECRH
- ECRH controls the ITB foot by changing the q=1 position

Identification of iITB through R/L_{Ti}



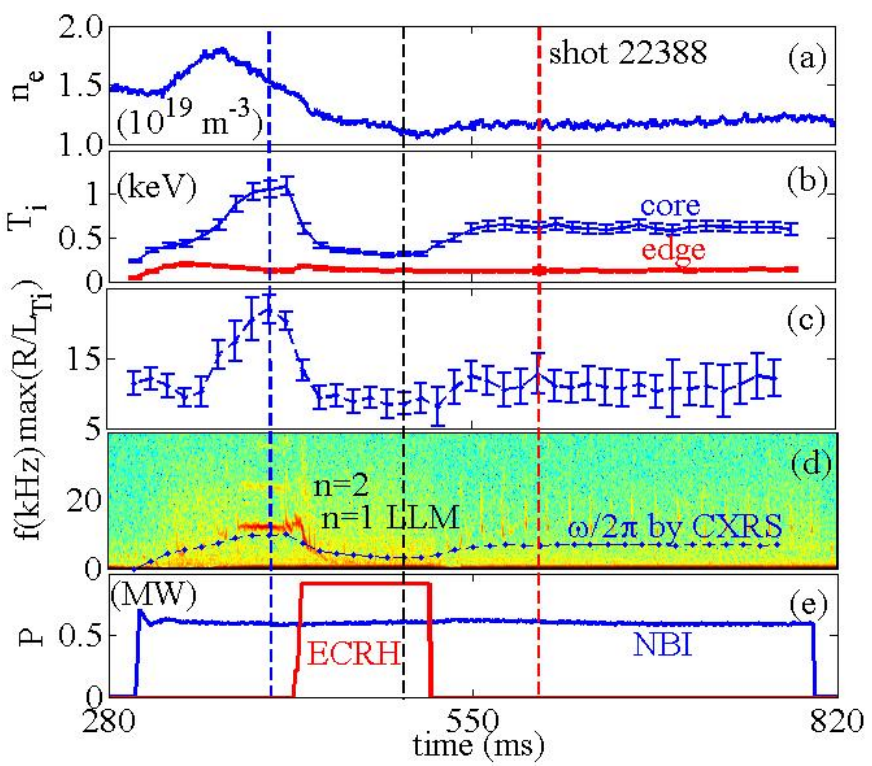
- R/L_{Ti} from 7 shots have been compared
- The R/L_{Ti} values with EPM (long lasting modes and fishbone oscillations) are higher than the others

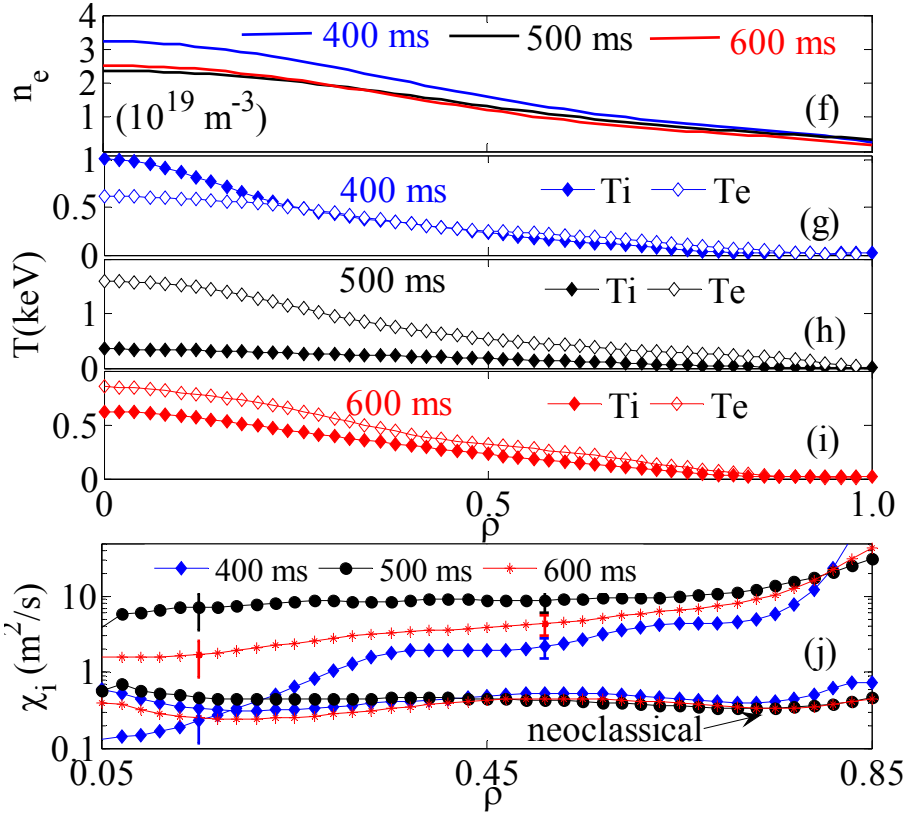
Criterion of iITB formation is $R/L_{Ti}>14$



- The T_i (0.5) increases with the R/L_{Ti} , whereas it decreases when R/L_{Ti} is higher than 14
- The criterion for characterizing iITB is whether R/L_{Ti} is larger than 14 or not

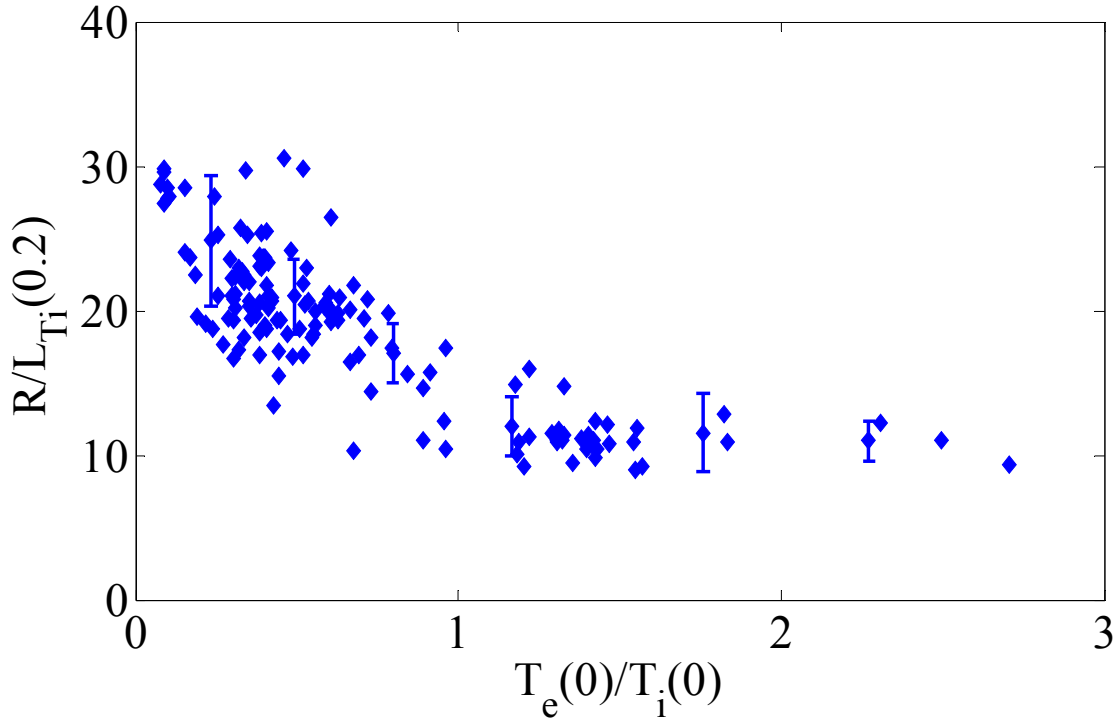
χ_i as low as neoclassical level in iITB





- The ion thermal diffusivity (by ONETWO code) can be as low as neoclassical level
- The ITBs is more easily formed at the early phase of the NBI heating

R/L_{Ti} dependent on temperature ratio



- The R/L_{Ti} decreases with the temperature ratio $T_e(0)/T_i(0)$
- Typical value of R/L_{Ti} is higher than 14 when the ratio is less than 1

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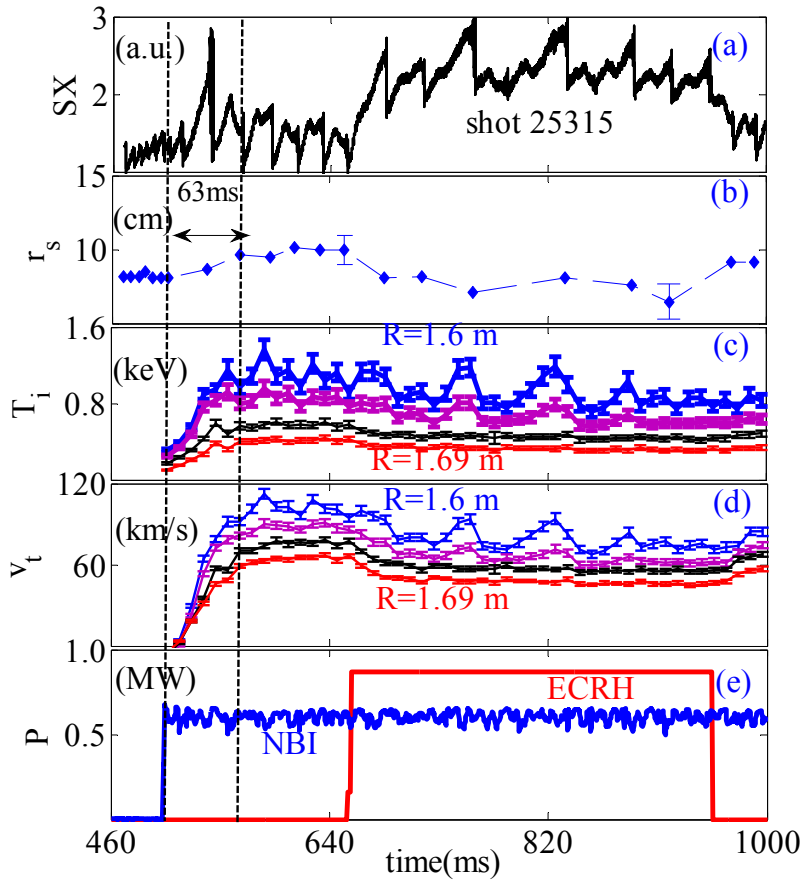
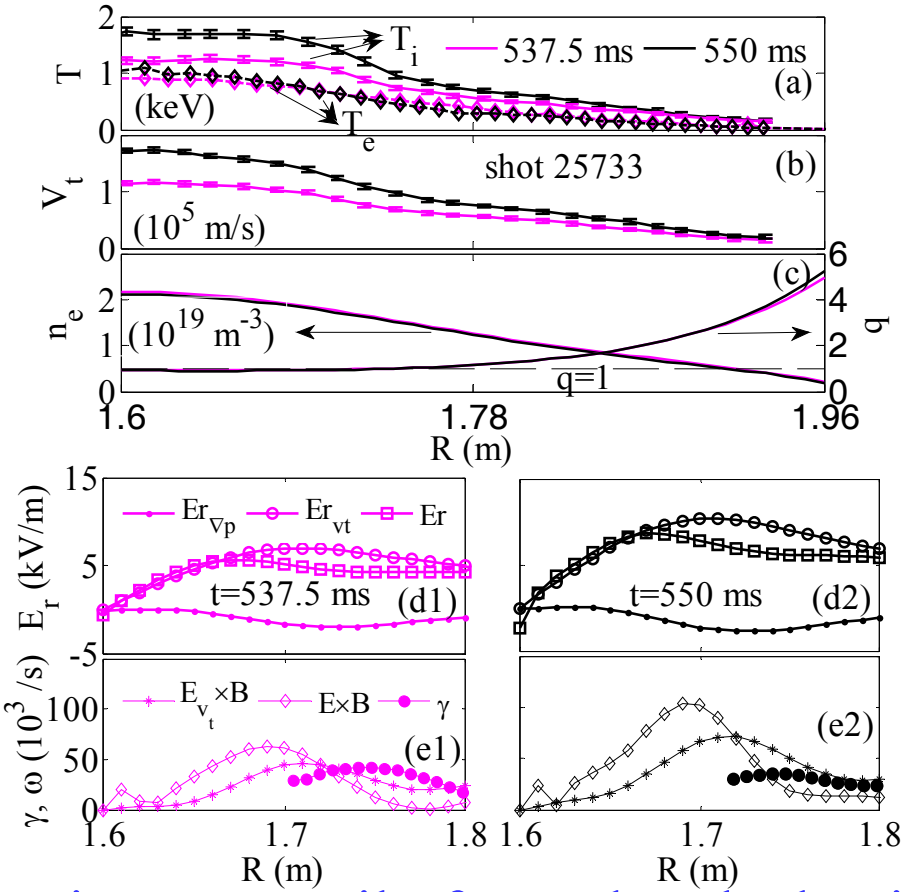
Reason of iITB tending to form at beginning of NBI



- Current drive by NBI helps the ITB formation

Toroidal rotation shear vs. ITB formation

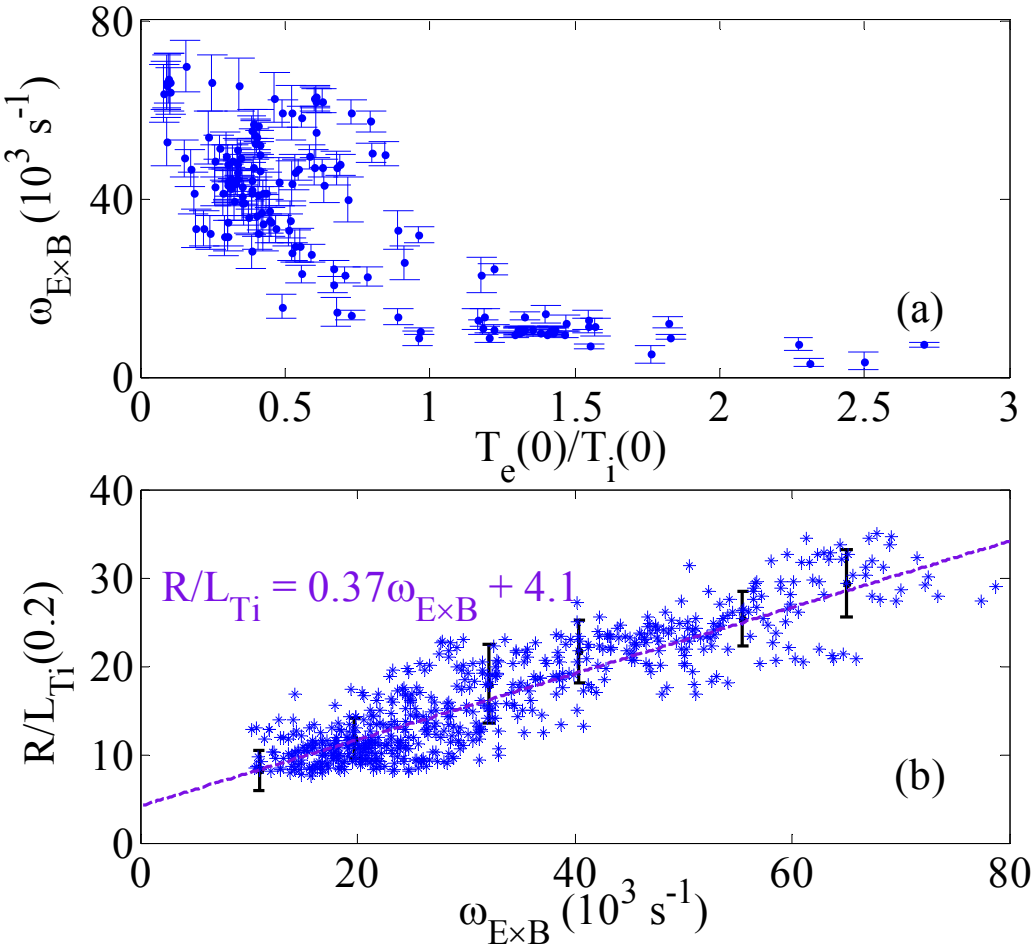


$$E_r = \frac{1}{Z_i e n_i}\frac{dP_i}{dr} + v_{\phi_i} B_{\theta_i} - v_{\theta_i} B_{\phi}$$

Dominant term

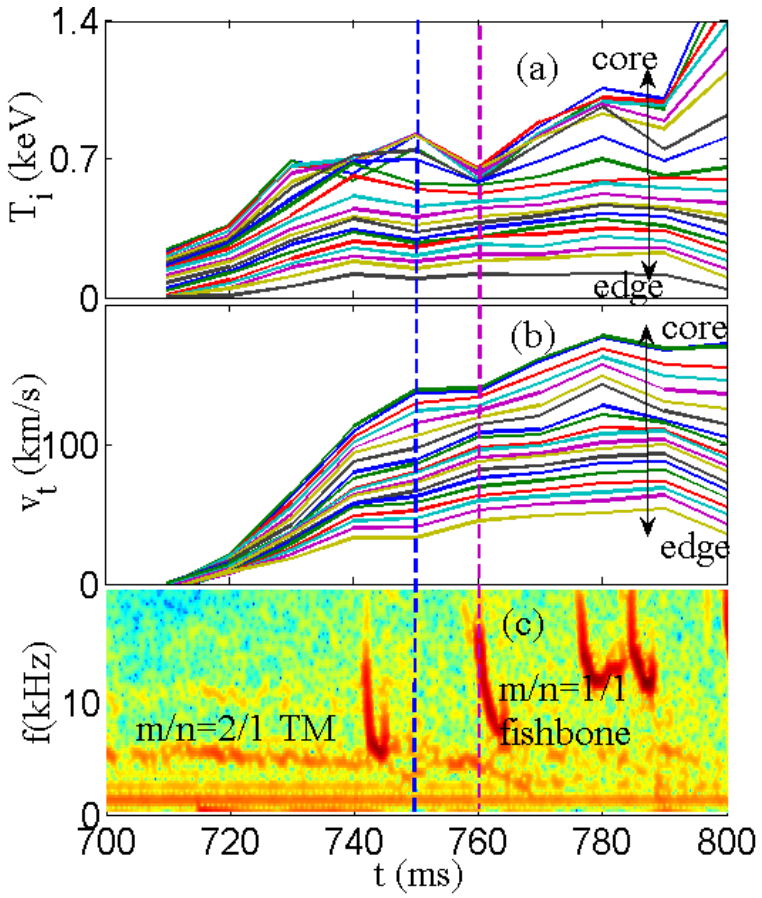
- The ITB is more easily formed at the beginning of NBI heating
- The toroidal rotation term is dominant in E_r
- The flow shear rate $\omega_{E\times B}$ is higher than the ITG growth γ (by HD7 code) inside the maximum T_i (v_t) gradient regions

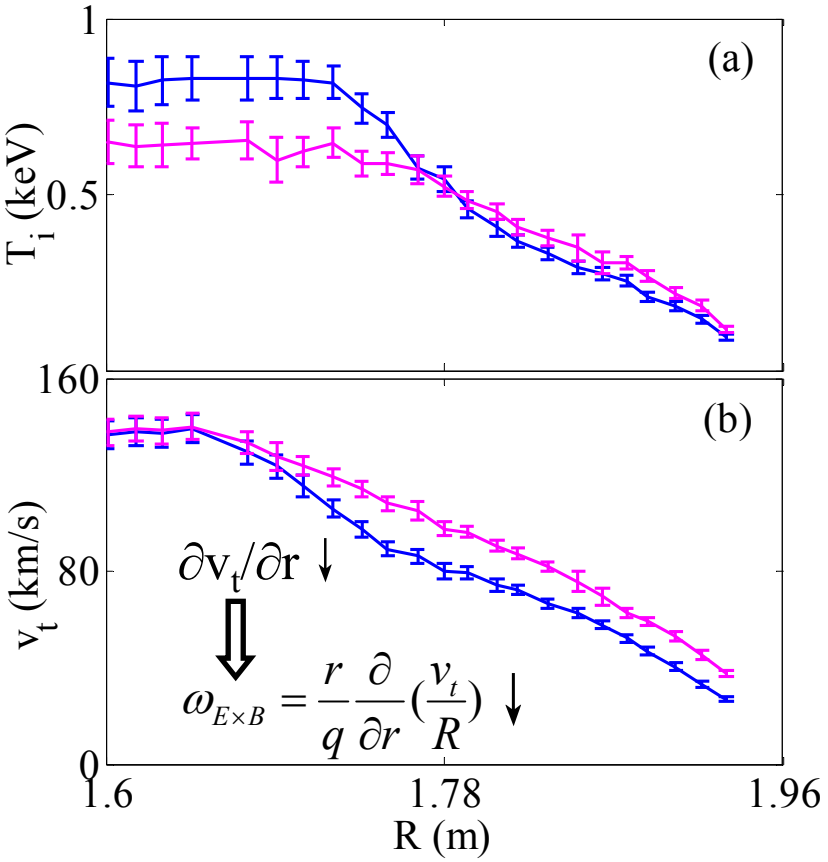
Shearing rate VS the T_e/T_i and R/L_{Ti}



- Shearing rate decreases with the temperature ratio
- The maximum R/L_{Ti} increases with $\omega_{E\times B}$

TM degrades confinement, FB suppresses TM





- m/n=2/1 TM can be influenced by FB
- The FB enhances the confinement by suppressing the TM

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- The ITB can be developed with very low co-I_p NBI power, and frequently observed at the beginning of the NBI heating
- The ITB foot locates at q=1 surface
- The criterion of ITB is R/L_{Ti} higher than 14
- E×B shearing rate is higher than the ITG growth rate inside the maximum gradient of T_i/v_t region during the iITB phase

Next step work

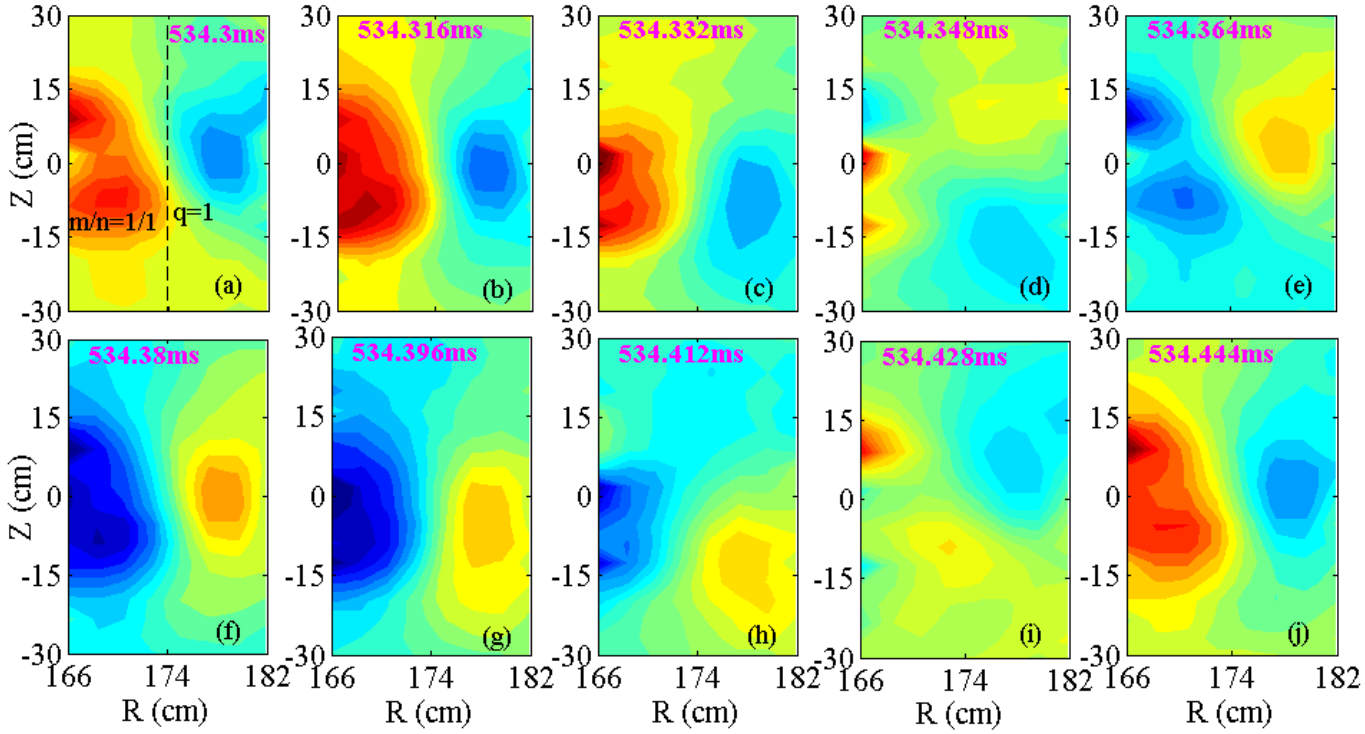
- To actively control the ITB
- To compare with the simulations

  Some results coincide with the simulations, for example

  Th/P3-3 K. Imadera

Thank you for your attention!

How LLM/FB influences the TM?



- The LLM/FB induces the T_e turbulence suppressing the TM