# First observation of the ion internal transport barrier on HL-2A

Presented by D.L. Yu[1)]

On behalf of

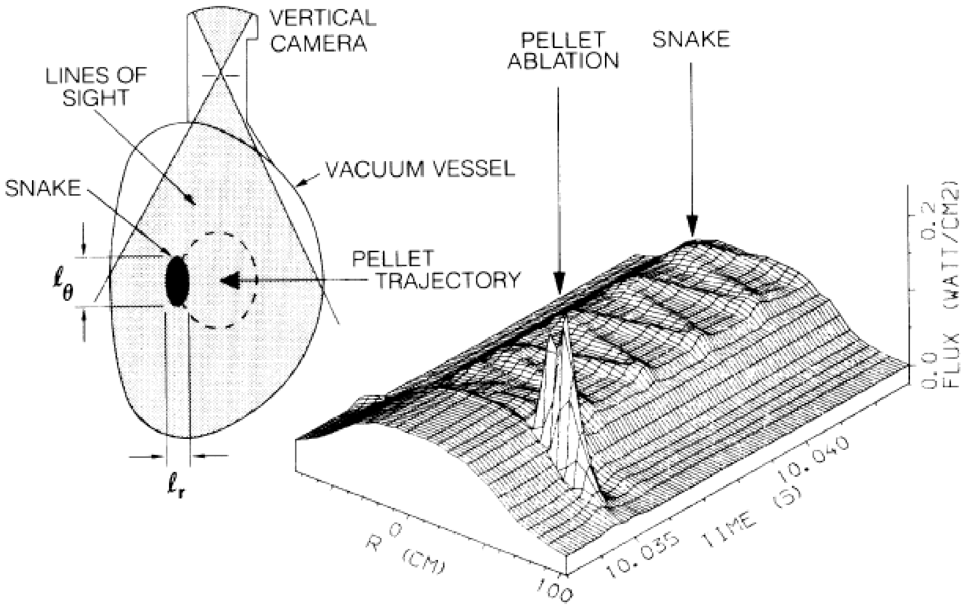
Y. L. Wei[1)], L. Liu[1)], K. Ida[2)], M. von Hellermann[3,4)], J. Y. Cao[1)], A. P. Sun[1)], Z. B. Shi[1)], W. J. Chen[1)], Q. Ma[1)], X. X. He[1)], K.J. Zhao[1)], X.Q. Ji[1)], Y. Zhou[1)], M. Jiang[1)], W. L. Zhong[1)], W. Deng[1)], Y.G. Li[1)], J.M. Gao[1)], Yi Liu[1)], Y. Xu[1)], L. W. Yan[1)], Q. W. Yang[1)], X. T. Ding[1)], J.Q. Dong[1)], X. R. Duan[1)], Yong Liu[1)] and HL-2A team

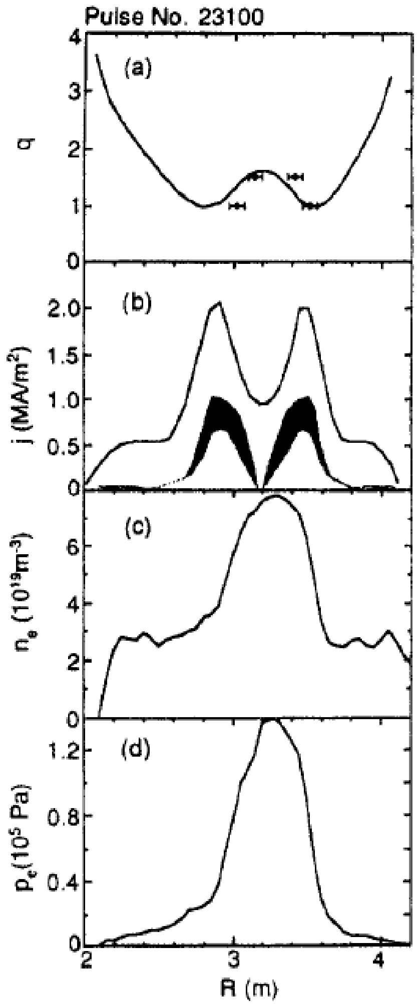
1) Southwestern Institute of Physics, Chengdu 610041, China
2) National Institute for Fusion Science, Toki 509-5292, Japan
3) ITER Diagnostic Team, IO , Route de Vinon sur Verdon, 13115 St Paul lez Durance, France
4) FOM-Institute for Plasma physics "Rijnhuizen", Association EURATOM, Trilateral Euregio Cluster, 3430 BE Nieuwegein, Netherlands

# Outline

- Background and motivations
- The CXRS on the HL-2A
- Observation of the ITB
- Summary

# Background and Motivations



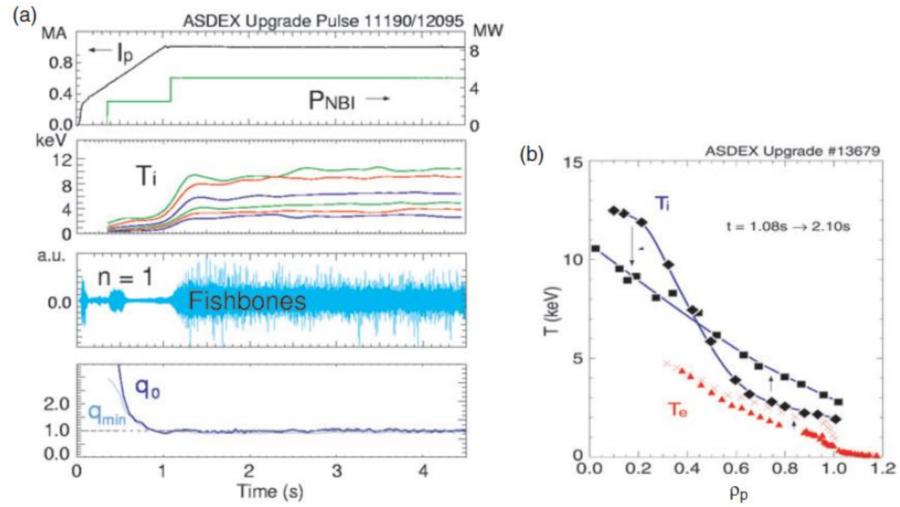



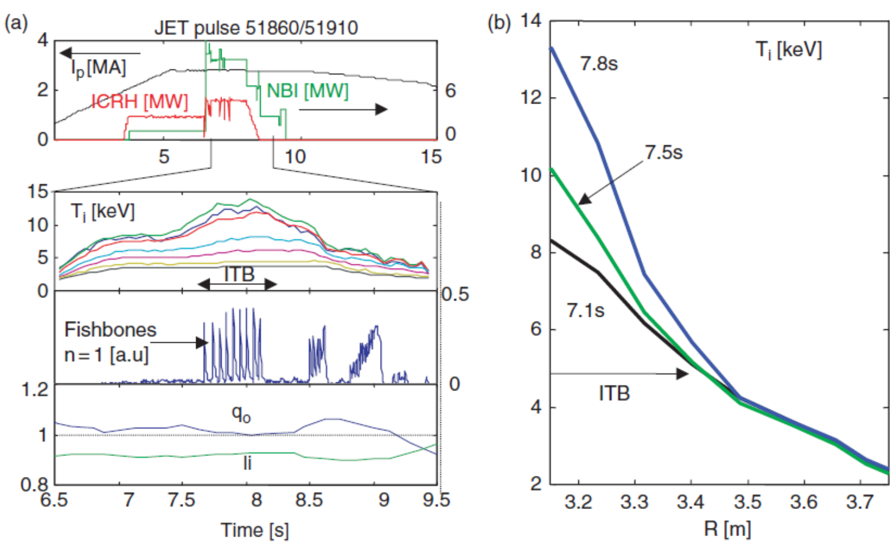

Snakes + reverse shear

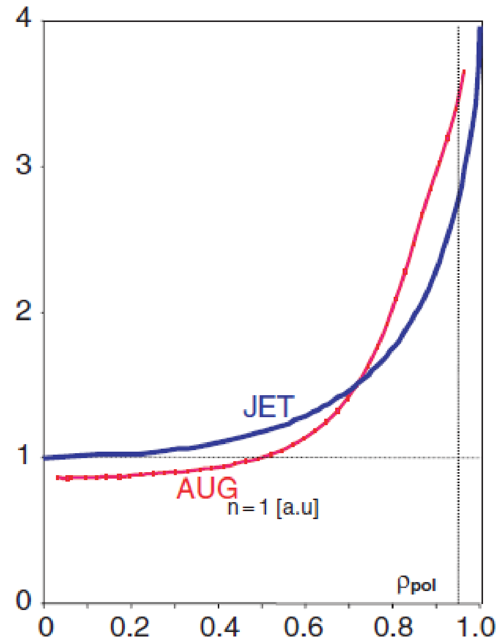
A. Weller, PRL **59** 2303(1987)

M. Hugon, NF**32** 33 (1992)

# Background and Motivations




q=1, weak shear, fishbone, Ti>Te

E. Joffrin PPCF **44** 1203(2002)

# Background and Motivations

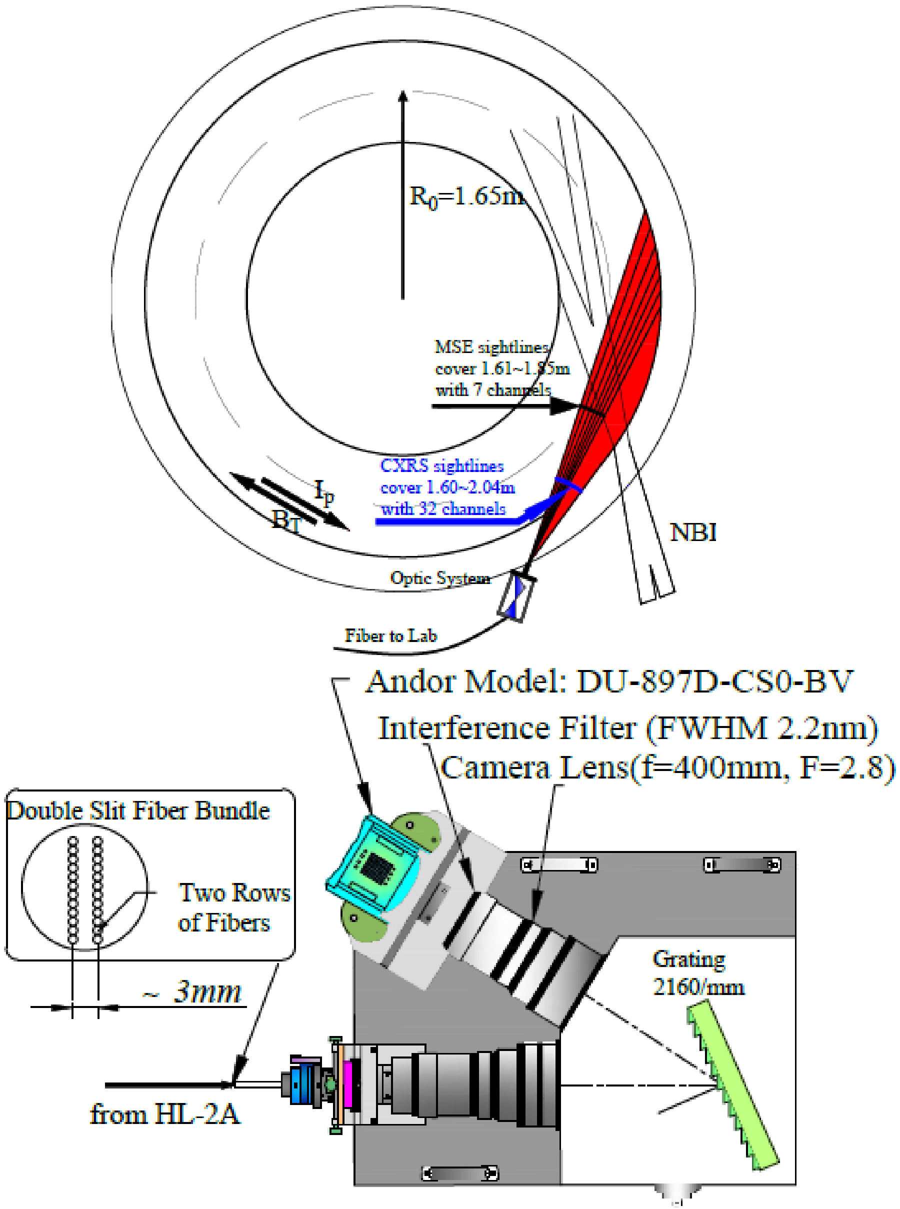
- The fusion power plant requires an operating point characterized by high beta, high energy containment time, and a large fraction of bootstrap current;

- The plasma possessing internal transport barriers (ITBs) is a basis for the steady state operation of a tokamak power plant;

- Discharge with ITB is a promising candidate regime for ITER.



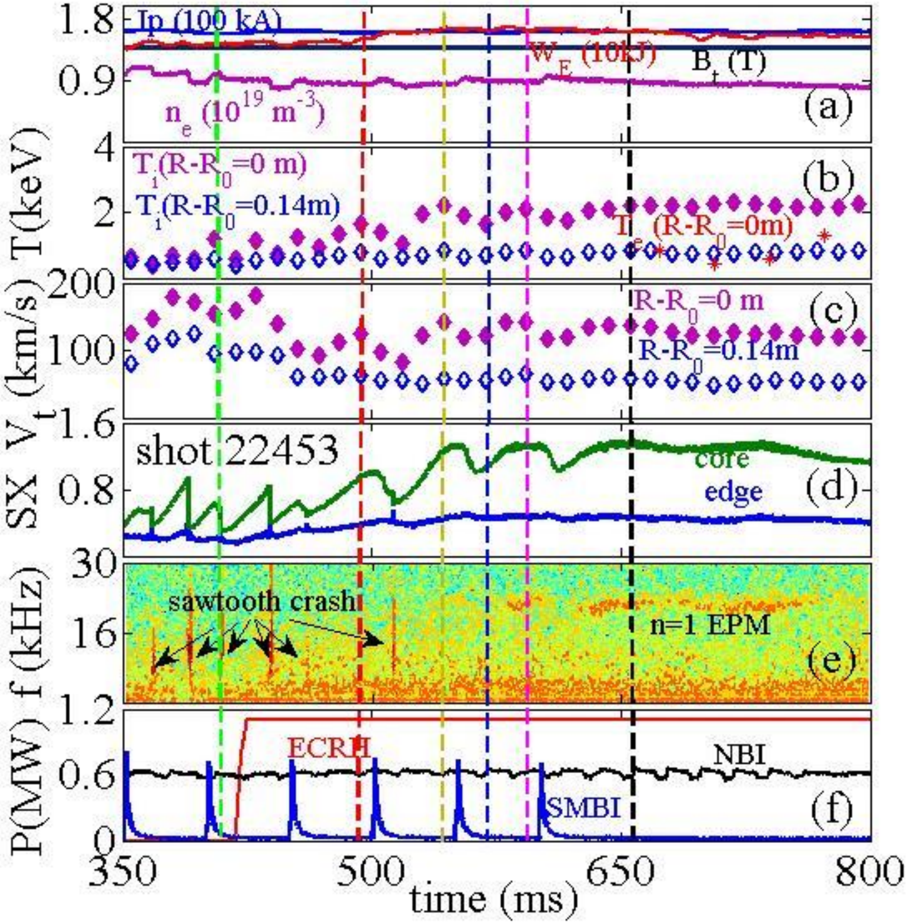
# The CXRS System

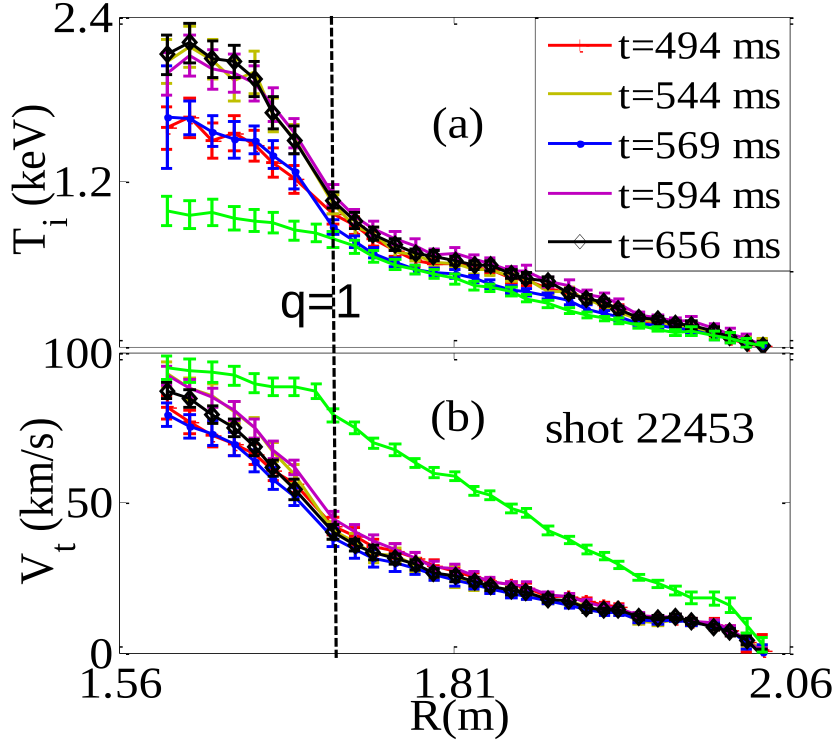



- The system consists of the collection optics, fibers, spectrometer (F/2.8) and data acquisition system;
- Double-slit incidence fiber bundle;
- The grating with 2160g/mm (about 0.011nm/pixel@530nm);
- 32/64 channels are available;
- Frequency higher than 400 Hz;
- 200 Hz of $T_i$ & $V_t$ measurement are realized.


[1] Yu D L, RSI., 85 11E402(2014)
[2] Wei Y L,RSI., 85 103503(2014)

# The features of the ITB

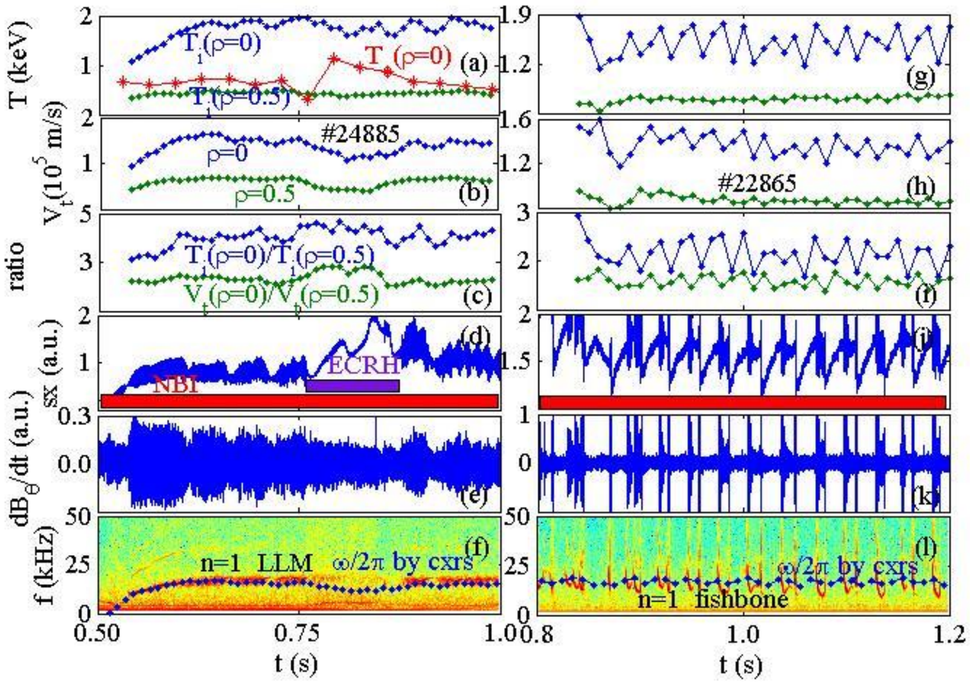



◆The ion temperature gradient becomes steeper when the stored plasma energy is higher;

◆The gradient becomes steeper and the stored energy increases when the sawtooth disappeared.

# Comparison between sawtooth and LLM



$P_{NBI}$=650 kW

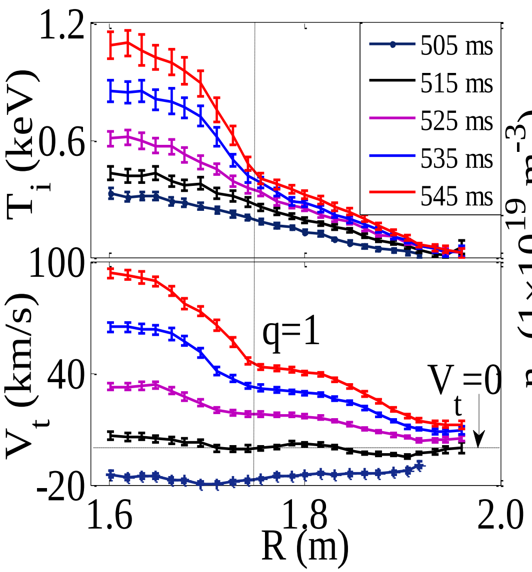
$n_e=1.5\times10^{19}\ m^{-3}$

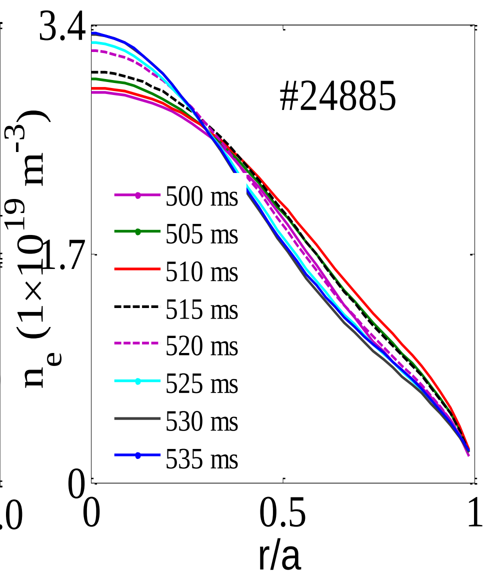
$P_{NBI}$=750 kW

$n_e=1.1\times10^{19}\ m^{-3}$

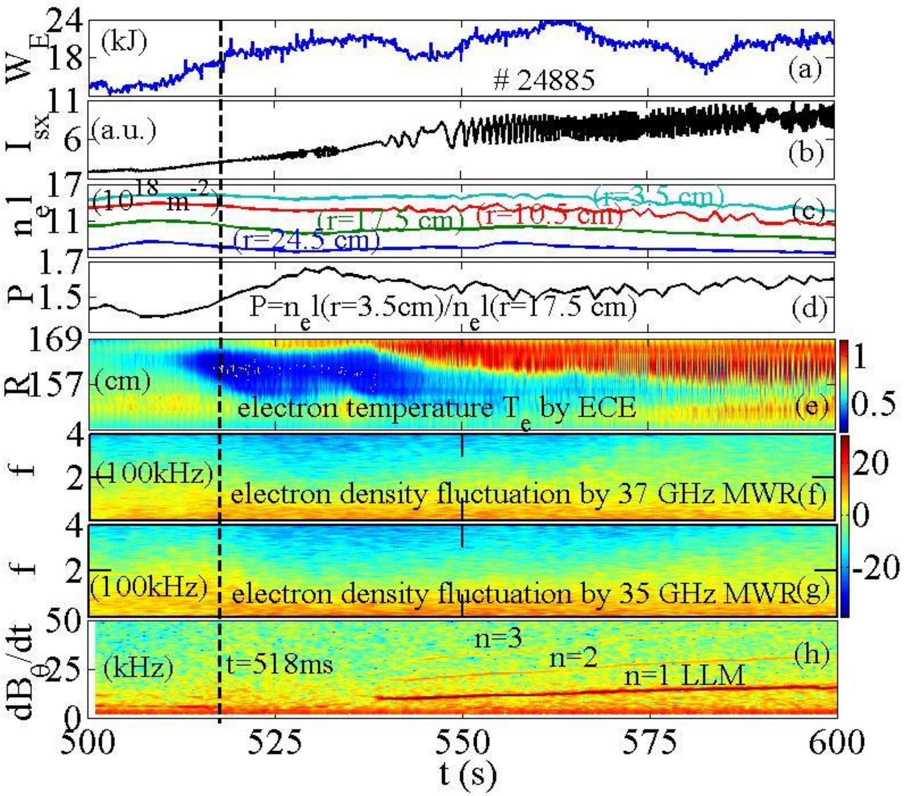
- ◆The steady state of the ITB can be obtained for the plasmas without sawtooth;
- ◆The ion temperature and toroidal rotation oscillate in the plasma core;
- ◆The ion temperature is higher than that of electron in the plasma core;
- ◆The ion temperature of sawtooth plasma can be as high as that of the long-lasting mode, but the peakness is not.

# Formation of the ITB



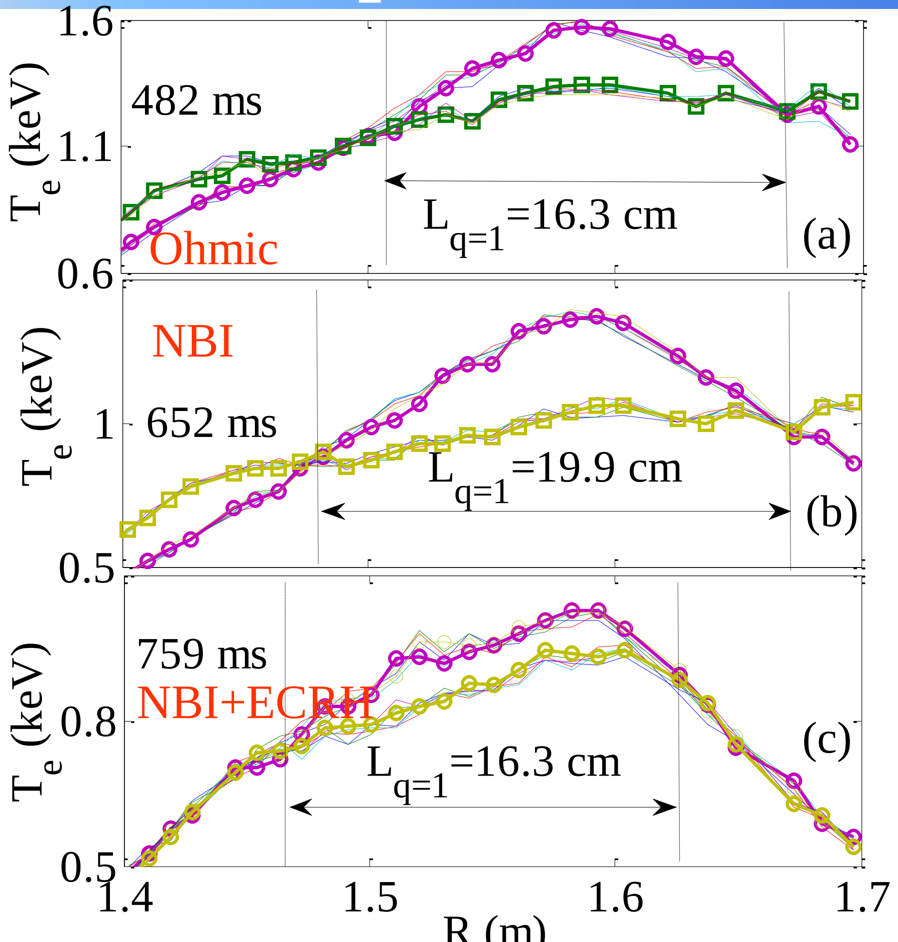

◆The ITB forms right after the small size long lived mode;

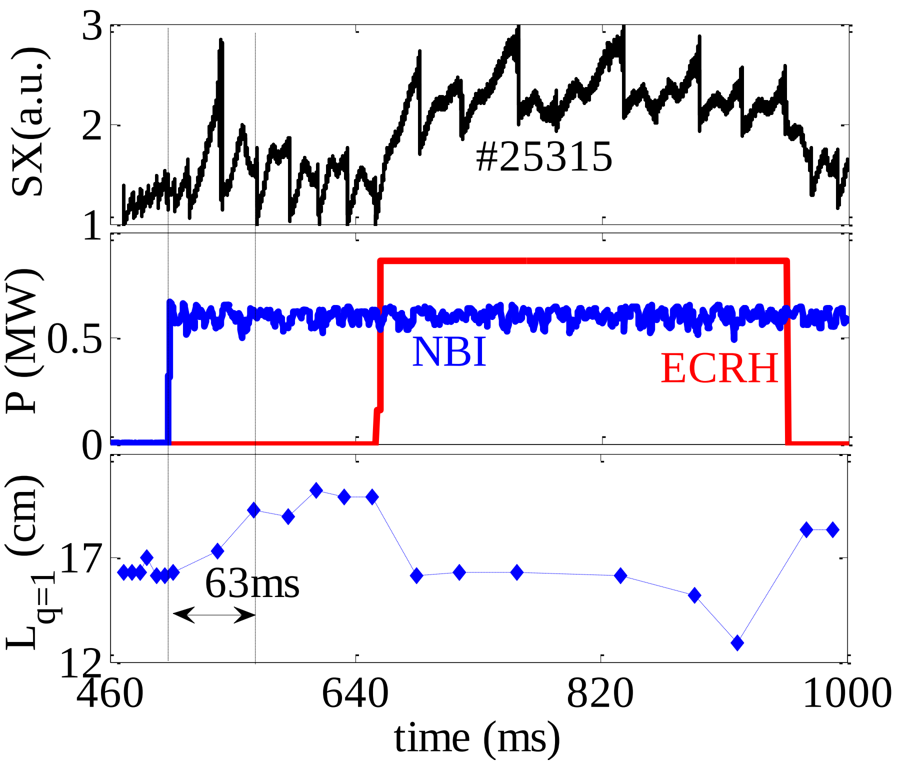



◆From the ion temperature and toroidal rotation, the ITB forms at ~535 ms;

◆The plasma density peaked in the core during the ITB formation.

# The q=1 surfaces of sawtooth discharge



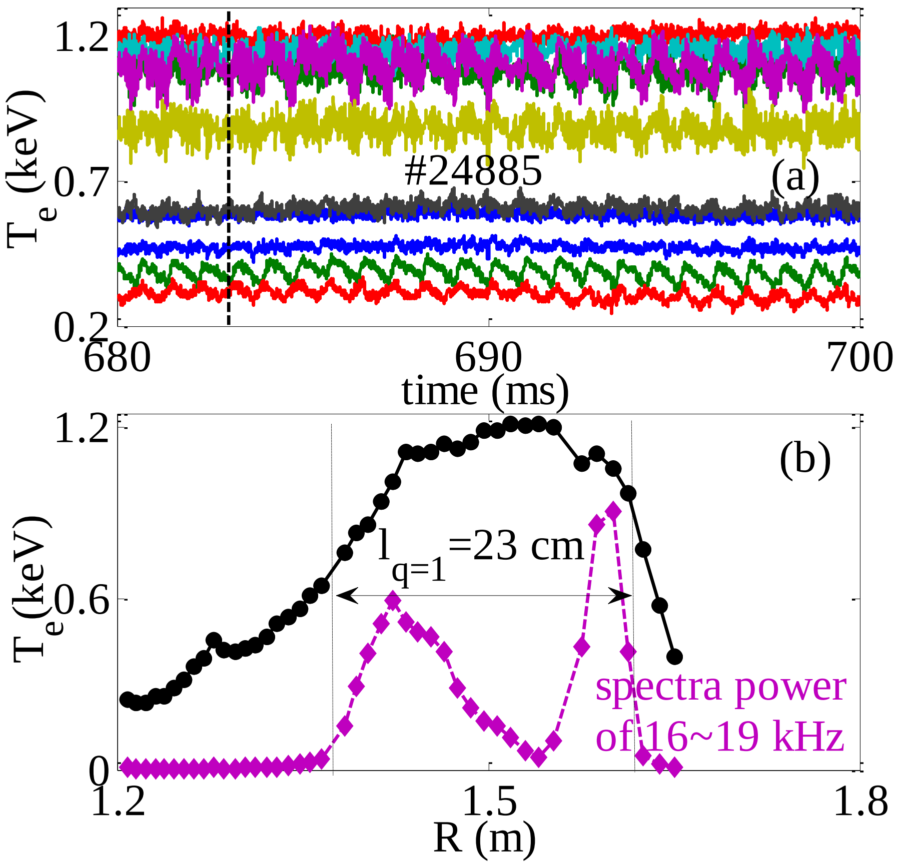




◆Estimated by the sawtooth crash, the width between the q=1 surfaces increases at the beginning of the NBI;

◆The width will decrease if the ECRH is launched;

◆Duration for the width increase of q=1 surfaces is about 63 ms.

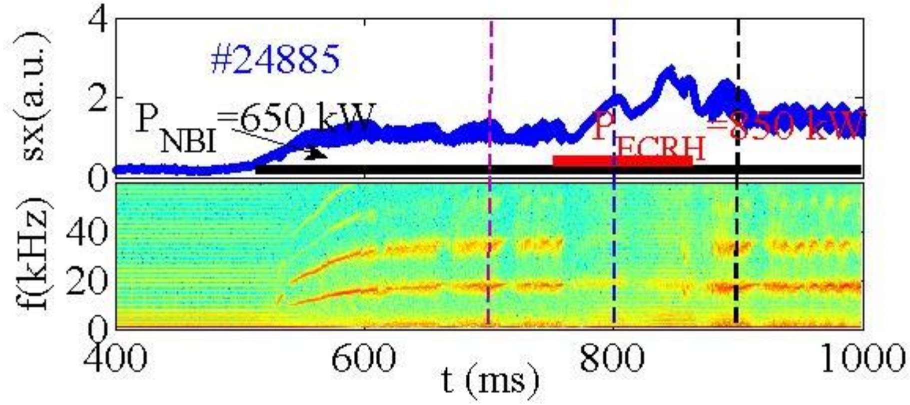
# The ITB foot (1)

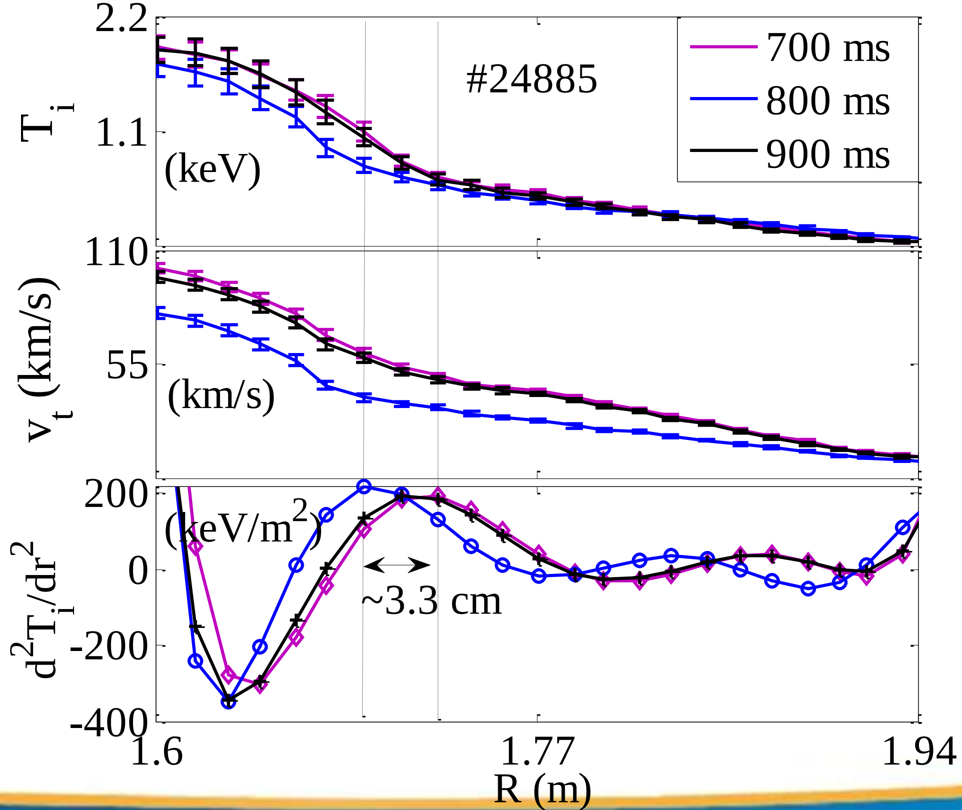


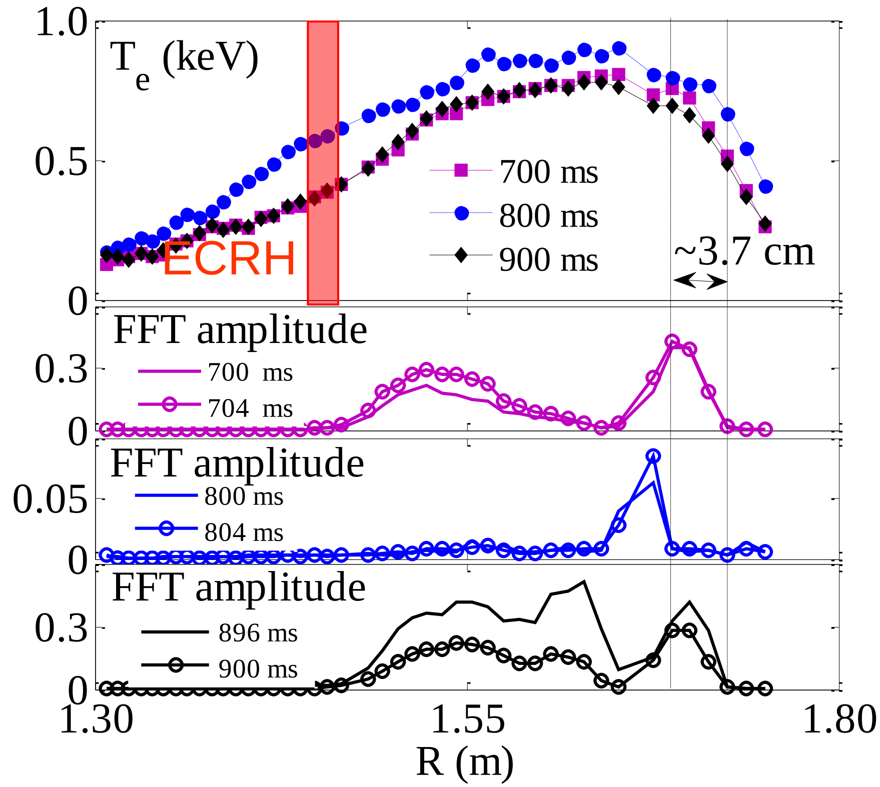

◆The ITB formation is LLM (fishbone oscillations) accompanying;

◆From the ECE and CXRS, the ITB foot locates at the q=1 surface.

# The ITB foot (2)

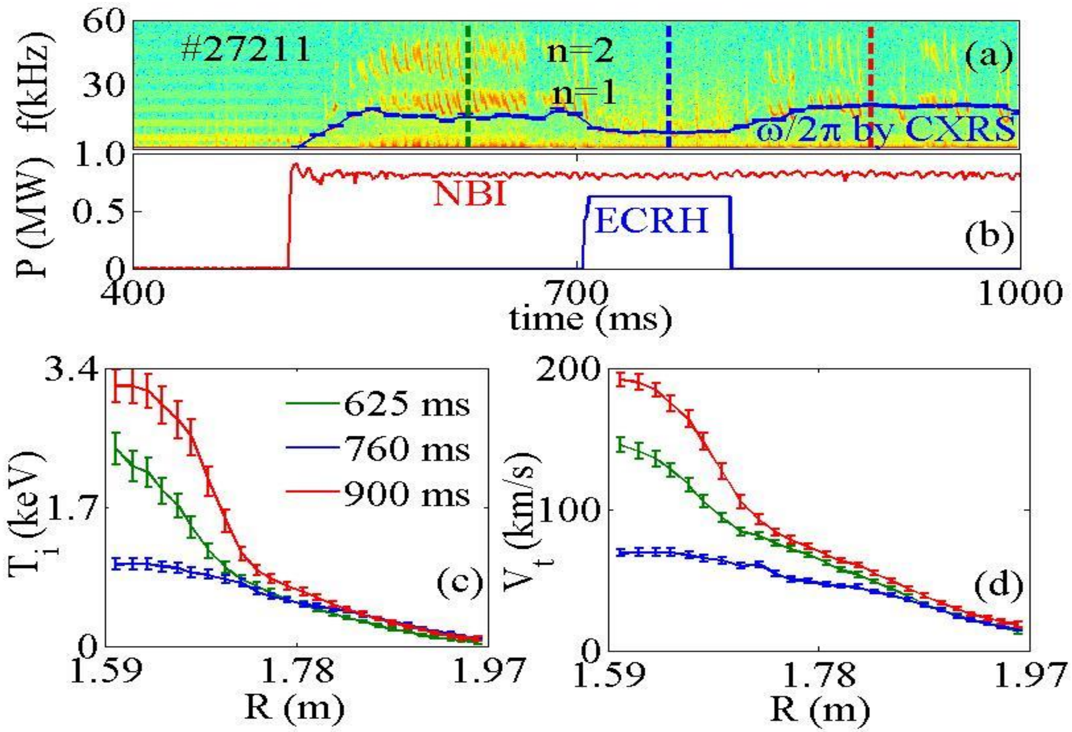


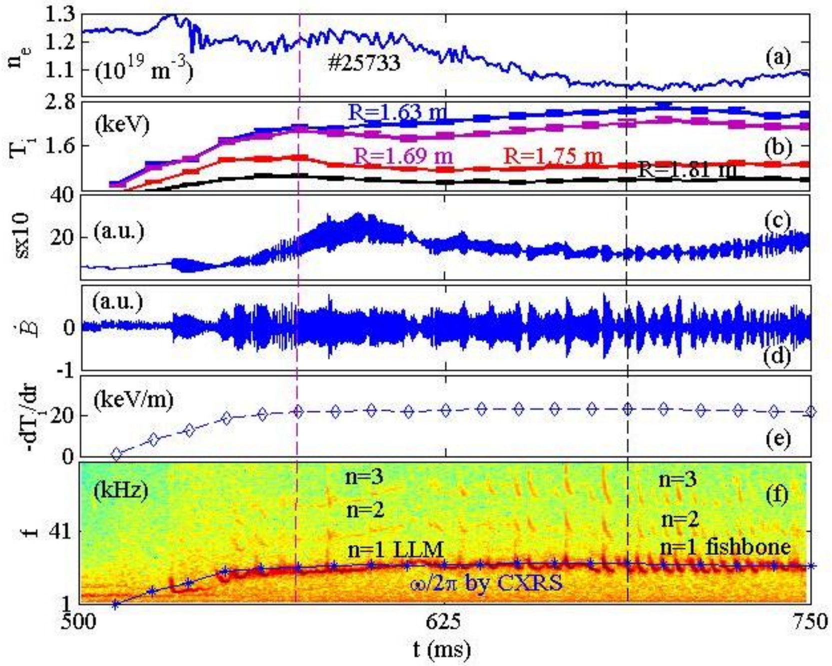

- The LLM seems partly to be suppressed by the ECRH;
- ECRH controls the ITB foot by changing the q=1surface position.

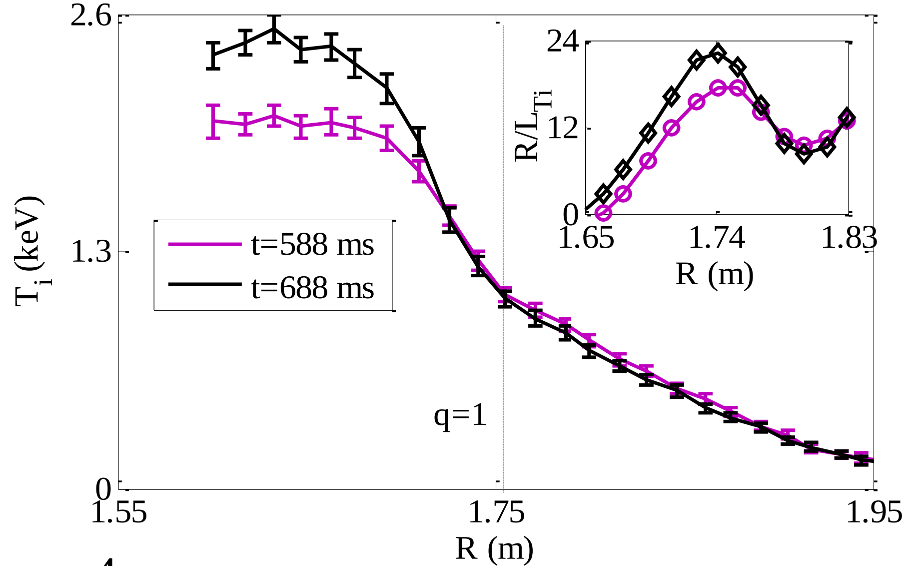
# ECRH controlling the ITB

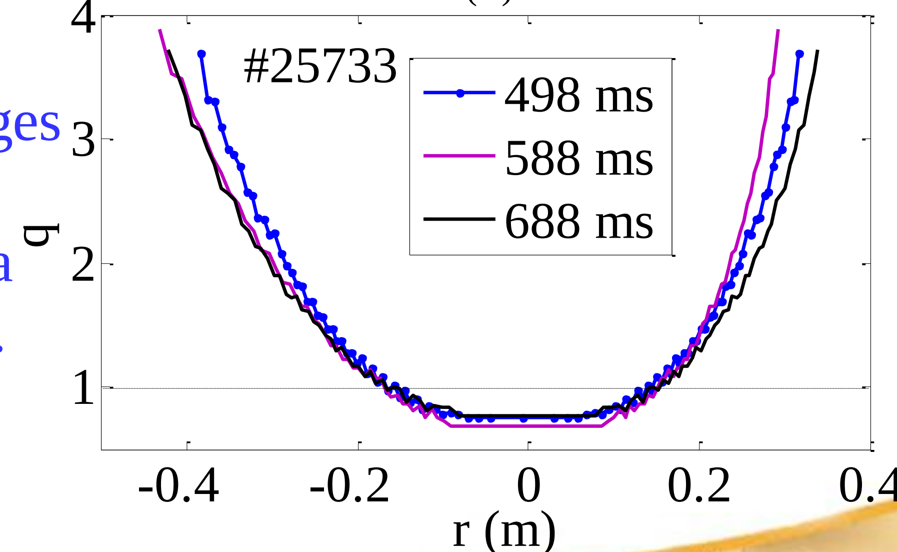



◆The LLM/fishbone can survive whereas the ITB is suppressed by the ECRH.

# The q profiles during the ITB



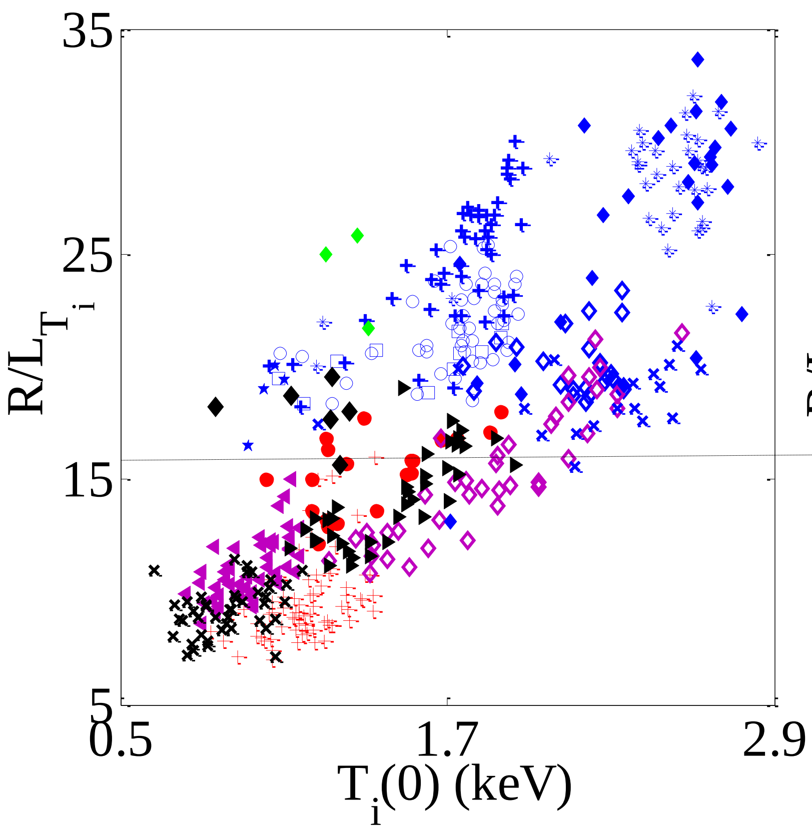



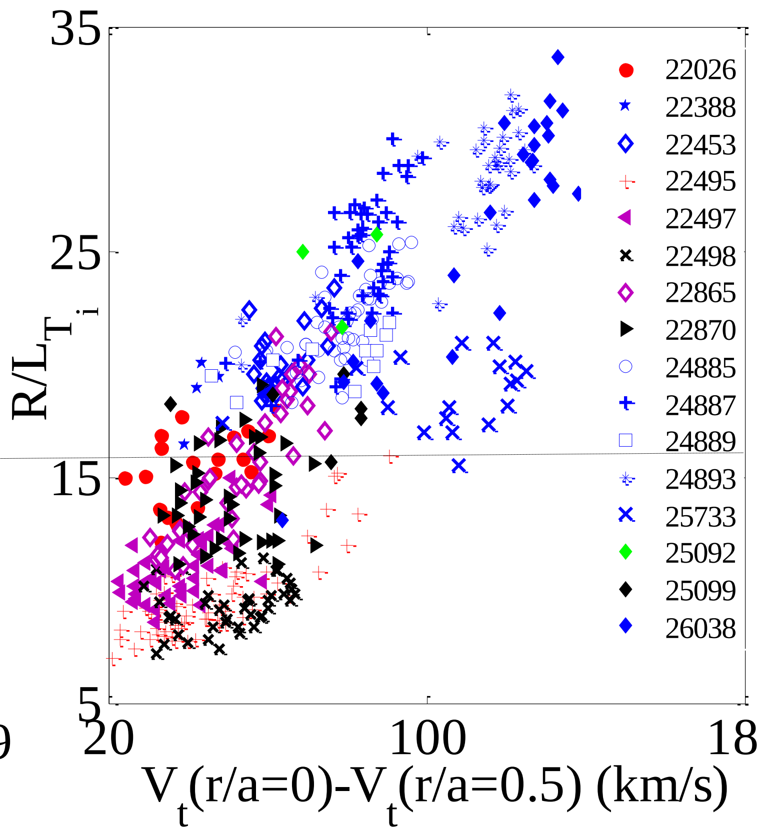




◆The ITBs can be developed in discharges with LLM ( fishbone oscillations) indicating the safety factor profile plays a very important role in the ITB formation.

◆The q profiles during LLM (fishbone oscillations) is slightly wider during the NBI.

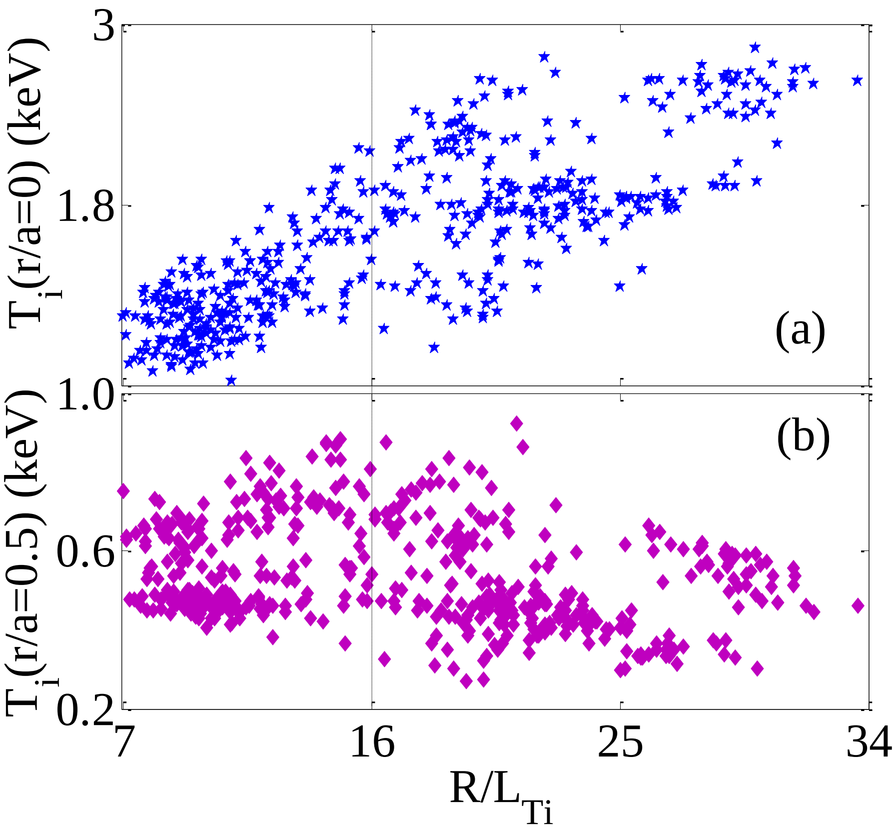
# The critical value of $R/L_{Ti}$

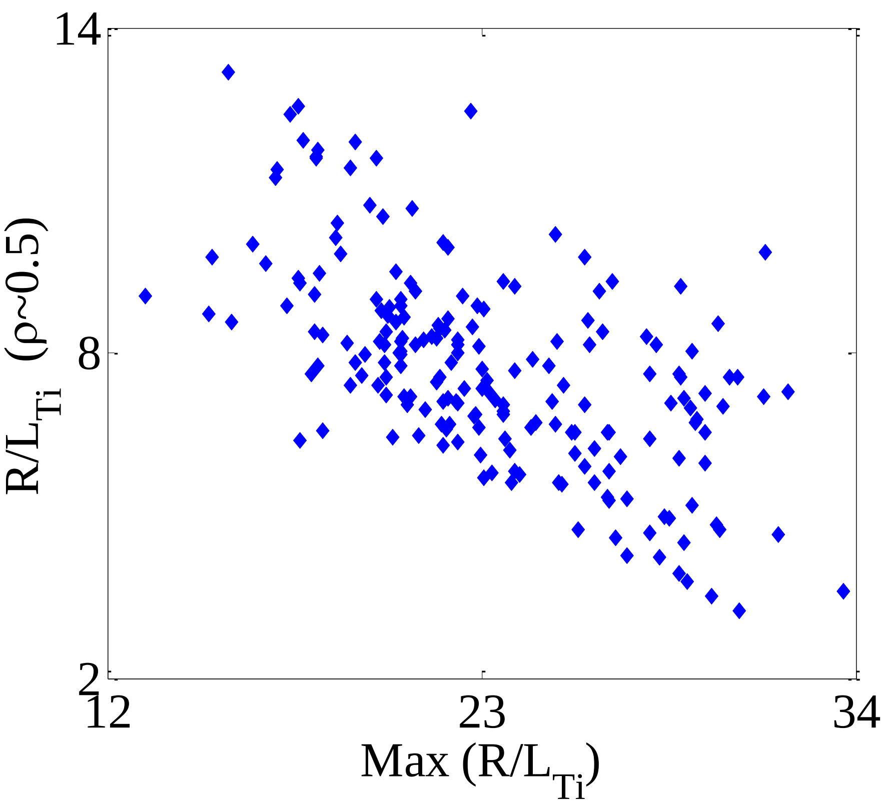



- The critical value of $R/L_{Ti}$ from 16 shots (~490 data) have been compared;
- The $R/L_{Ti}$ with EPM ( long lasting modes and fishbone oscillations) are higher than the others.

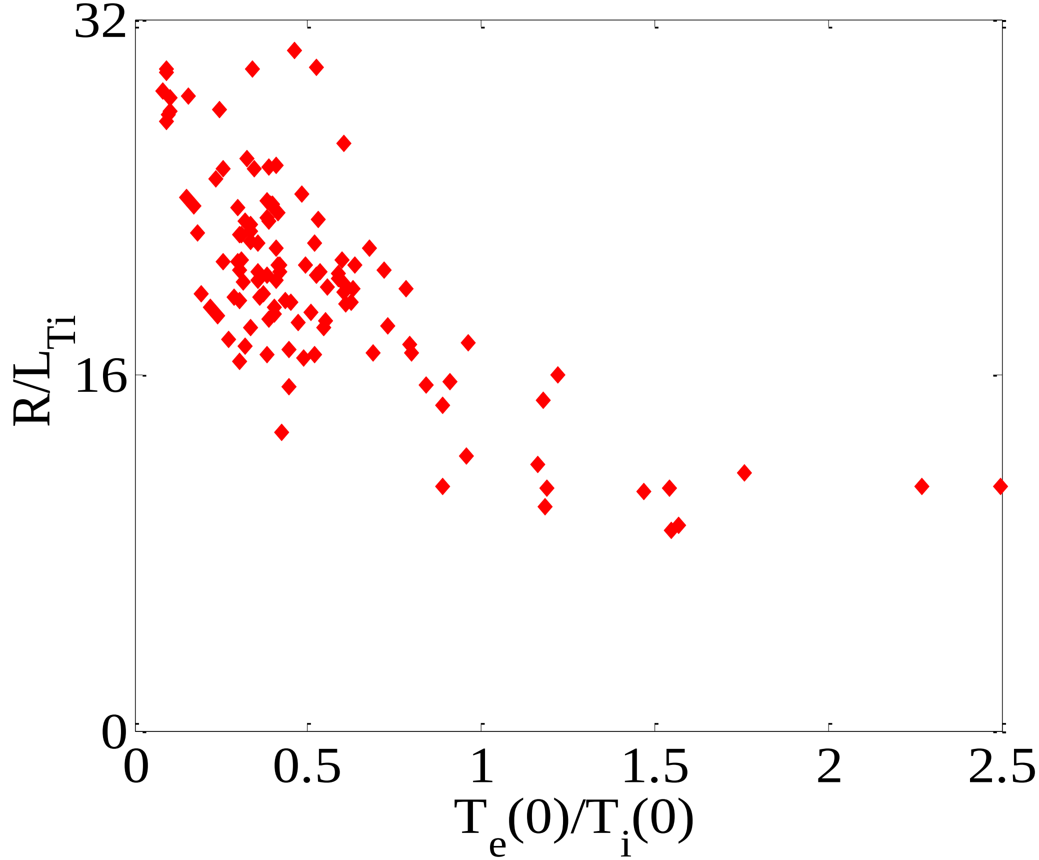
# Confinement outside the q=1 surfaces



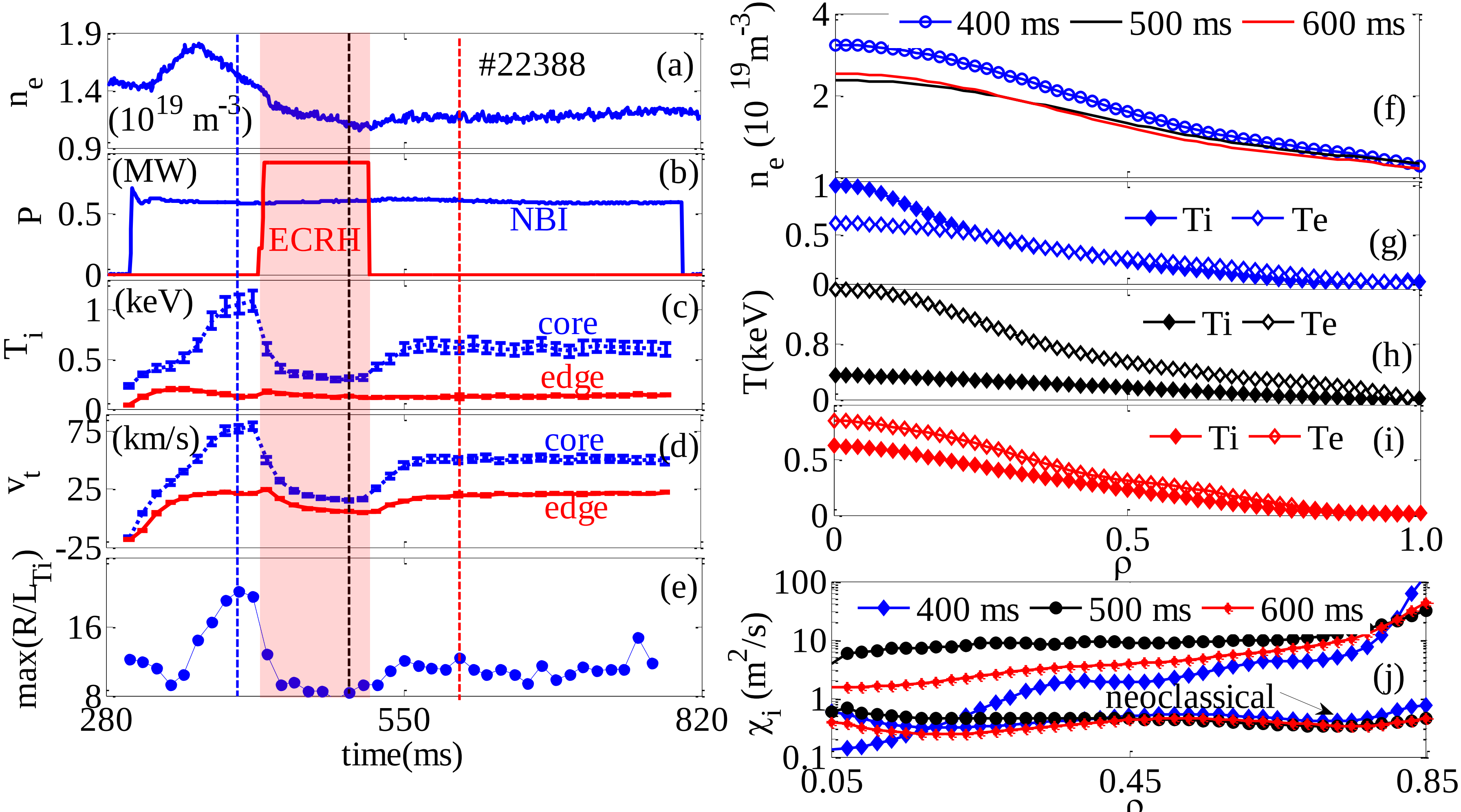

- The Ti (0) increases with the $R/L_{Ti}$, whereas the $T_i$ (r/a=0.5) decrease when the $R/L_{Ti}$ is higher than 16;
- The $R/L_{Ti}$(~0.5) features the same trend, the mechanism is not known.

# Influence of temperature ratio on ITB formation




- ◆The $R/L_{Ti}$ decreases with the temperature ratio ($T_e(0)/T_i(0)$);
- ◆The critical value of $R/L_{Ti}$ is higher than16 when the ratio is less than 1.

# $\chi_i$ of the ITB




◆The ion thermal diffusivity can be as low as neoclassical level.

◆The ITBs can be more easily formed at the beginning of the NBI heating phase.

# Summary

- The ITB can be developed with very low NBI power;
- The ITB foot locates at q=1 surface;
- The ITB features EPM (LLM and fishbone oscillations) indicating the weakly positive or negative magnetic shear can be helpful to the ITB formation;
- The ITB formation is closely related to current drive of the NBI;
- The ITB can be more frequently observed at the beginning of the NBI heating;
- The temperature ratio plays an important role in the ITB formation.



Thank you for your attention!