Overview of transport and MHD stability study and impact of magnetic field topology in the Large Helical Device

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National Institute for Fusion Science

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OUTLINE

1 Extension of operation regime in LHD
- 48 minute long pulse discharge
- Simultaneous achievement of high Te and Ti plasmas

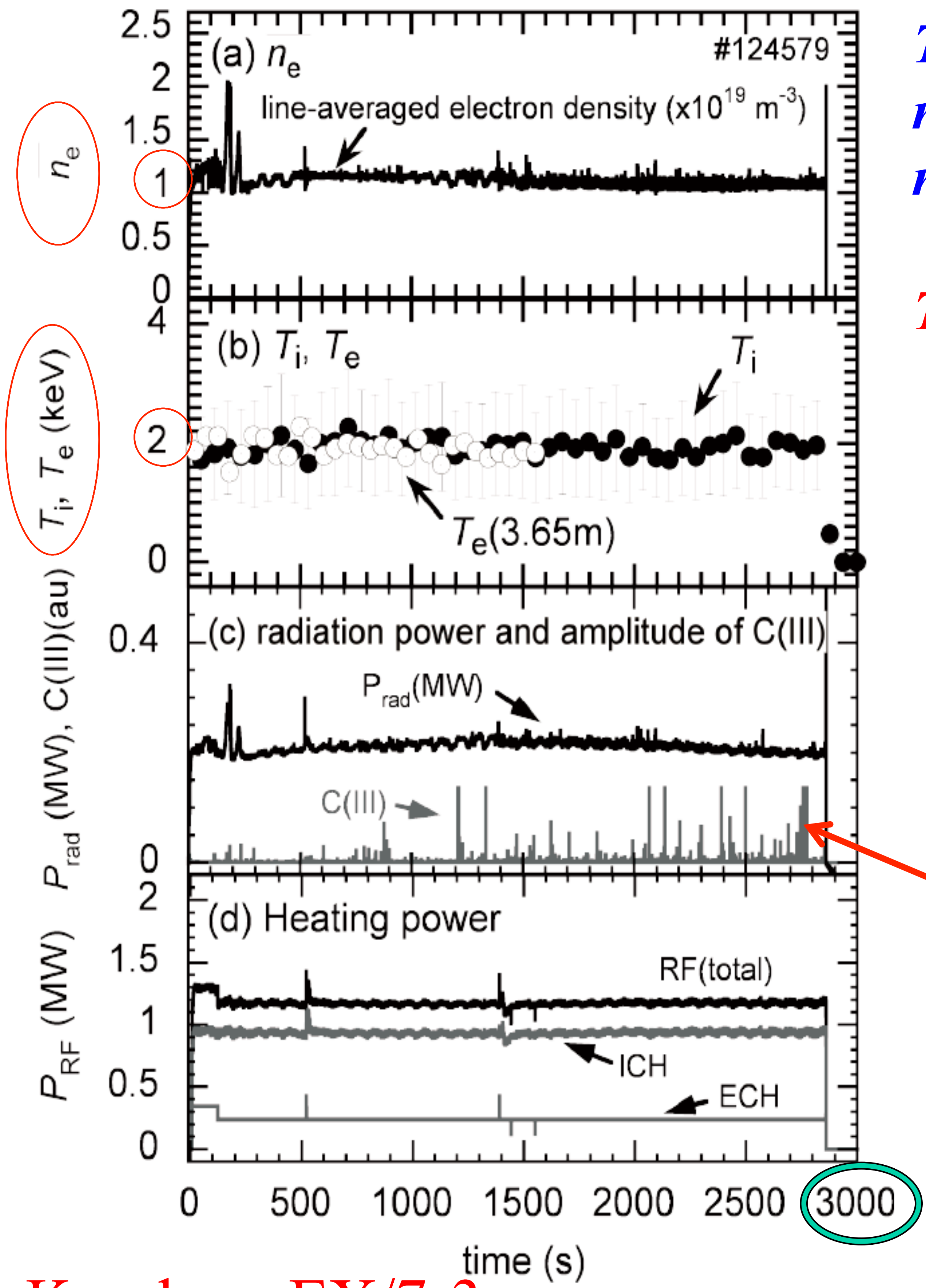
2 Transport analysis beyond power-balance
- Non-diffusive term of momentum and impurity transport
- Heat and momentum transport in modulation ECH experiment

3 MHD–Transport interaction
- Impact of stochastic magnetic field on MHD
- Pellet injection into the magnetic island
- The effect of energetic particle driven MHD to transport

4 Detachment and impurity control
- stabilization of detached plasma by RMP
- impurity behavior in LHD

5 Summary

48 minute long pulse discharge



The ultra-long pulse ($\tau d \sim 48$ min):
$n_e \tau_E T_i \sim 3.5 \times 10^{18}$ keVm^{-3} s,
$n_e \sim 1.2 \times 10^{19}$ m^{-3} meausred with FIR

(T. Akiyama FIP/P8-31)

$T_e \sim T_i \sim 2$ keV,

Simultaneous injection of ICH
(T. Seki FIP/P5-3) ***+ECH***
$P_{RF} \sim 1.2$ MW $P_{inj} \sim 3.4$ GJ.

Mixed-material (C-Fe) deposition layers increase retention of helium and contributes to the wall pumping

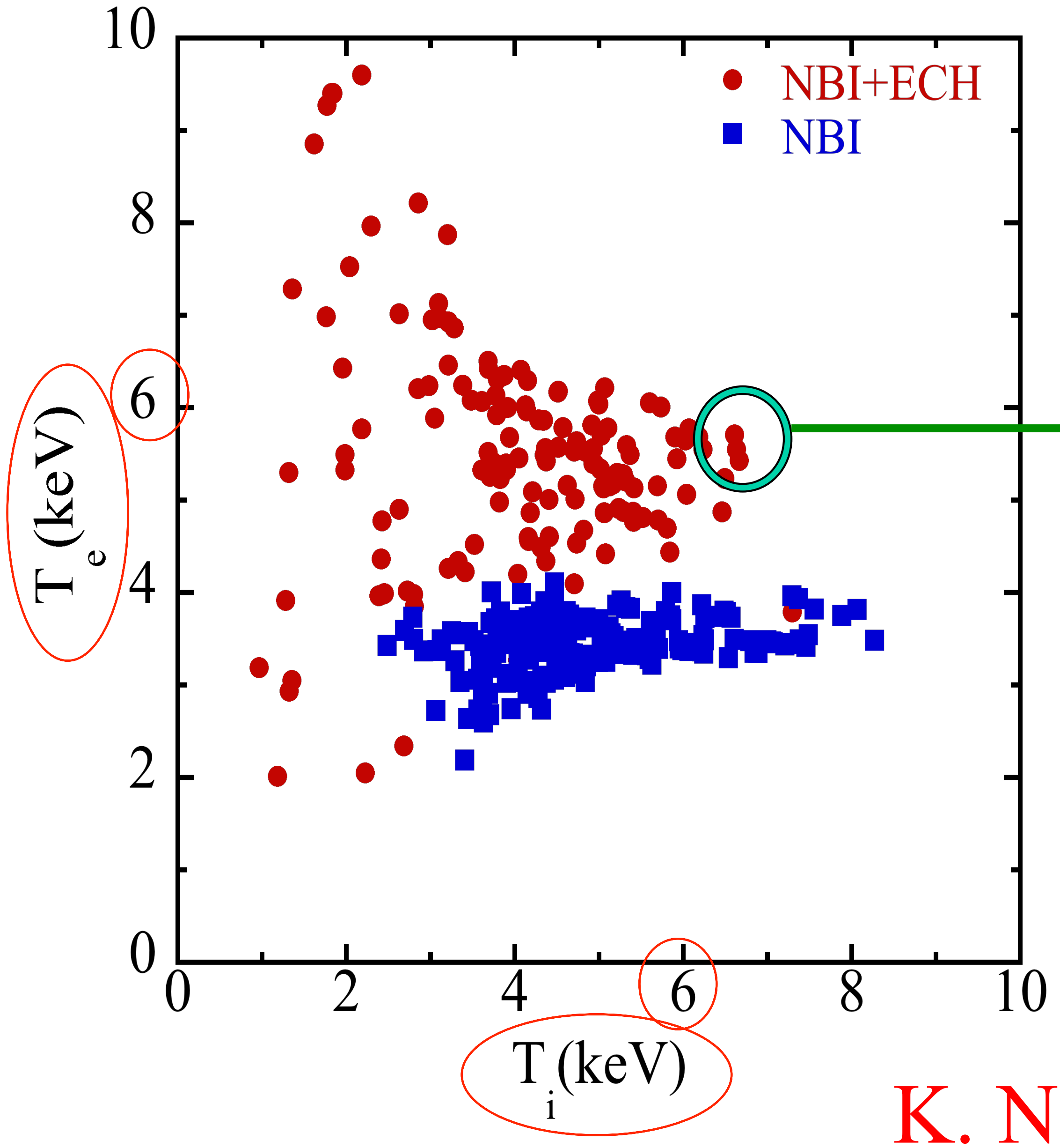
Carbon spikes

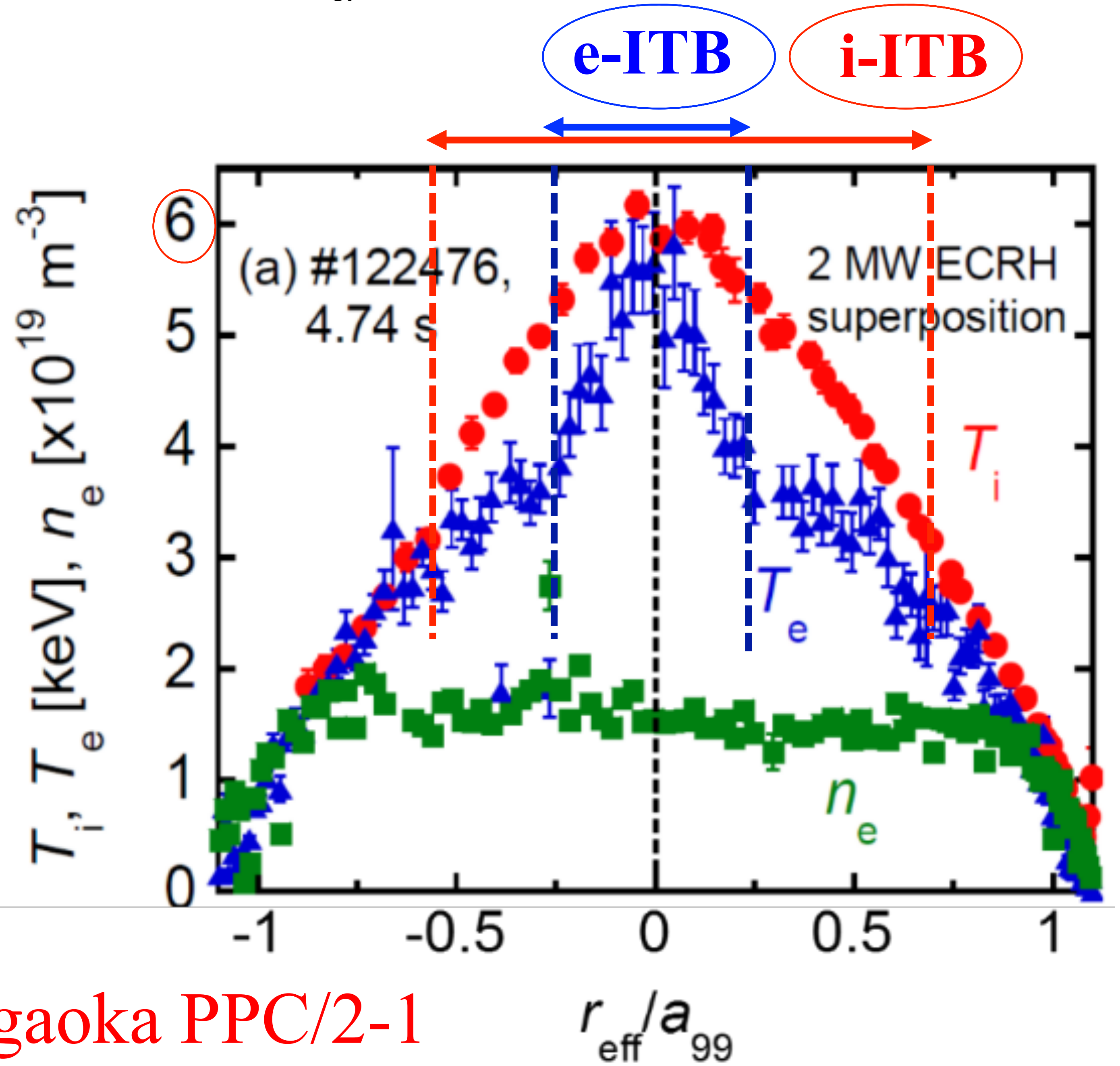
Dusts (M. Shoji EX/P6-33) induce frequent spikes of emission of iron and carbon impurities and trigger the termination of discharge

H. Kasahara EX/7-3

Simultaneous Achievement of High T_e and T_i plasmas

High Te and Ti plasmas are realized with the simultaneous achievement of electron and ion ITB by applying central focused ECH (T. Shimozuma EX/P6-34) and by reducing neutral density, which is confirmed by H_α measurements (K.Fujii EX/P6-31)





K. Nagaoka PPC/2-1

The reduction of turbulence transport is evaluated to be factor more than three by using heat deposition code GNET-TD (S. Murakami TH/P6-38) and transport code TASK-3D (M. Yokoyama EX/P6-27).

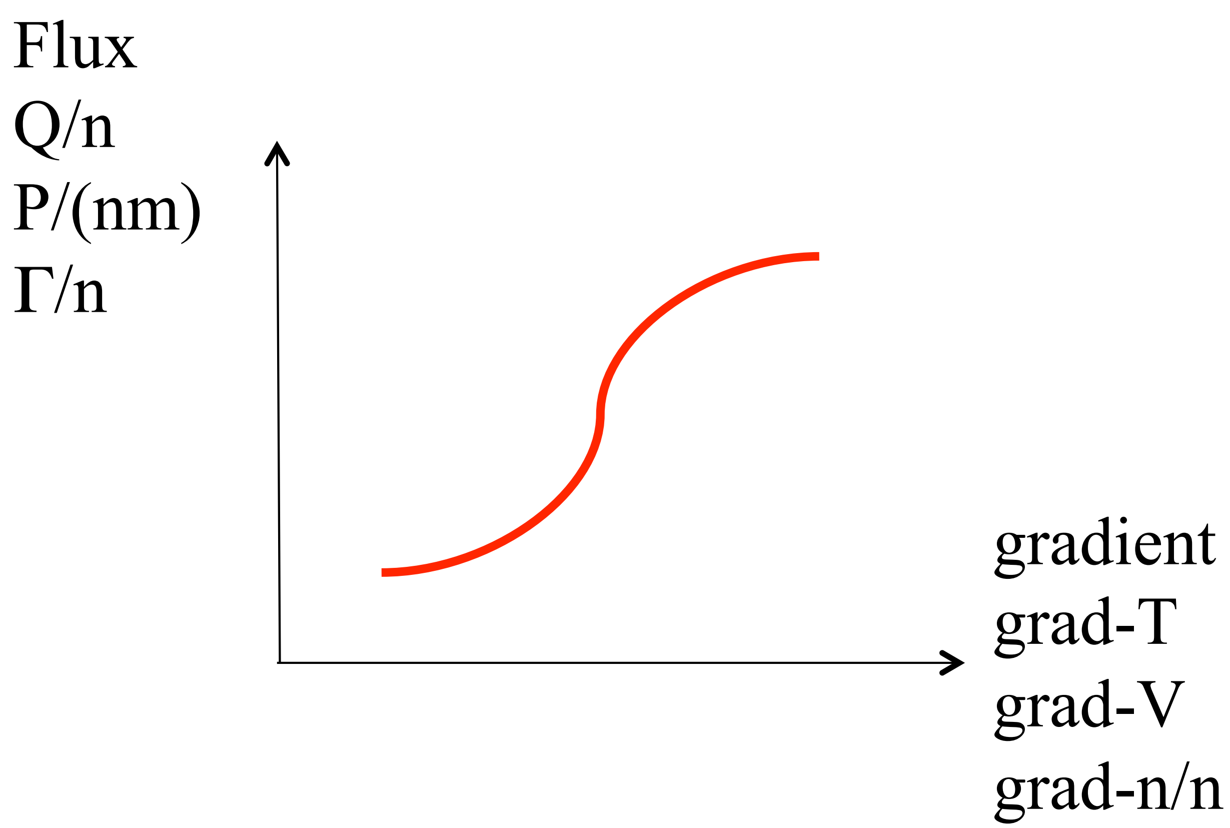
Transport analysis beyond power balance

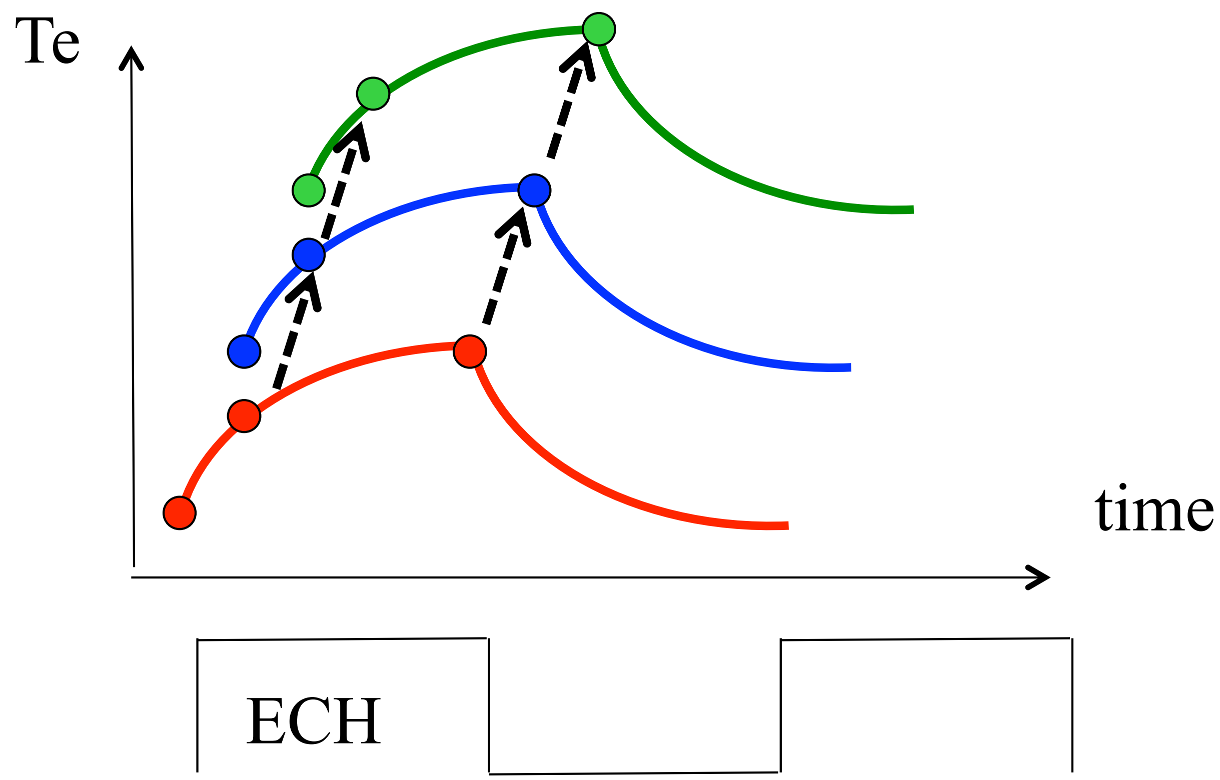
Power balance analysis
(database of χ_i, χ_e, D)

M. Yokoyama EX/P6-27

Dynamic transport analysis
Flux-gradient relation

Radial propagation of plasma
response to perturbation



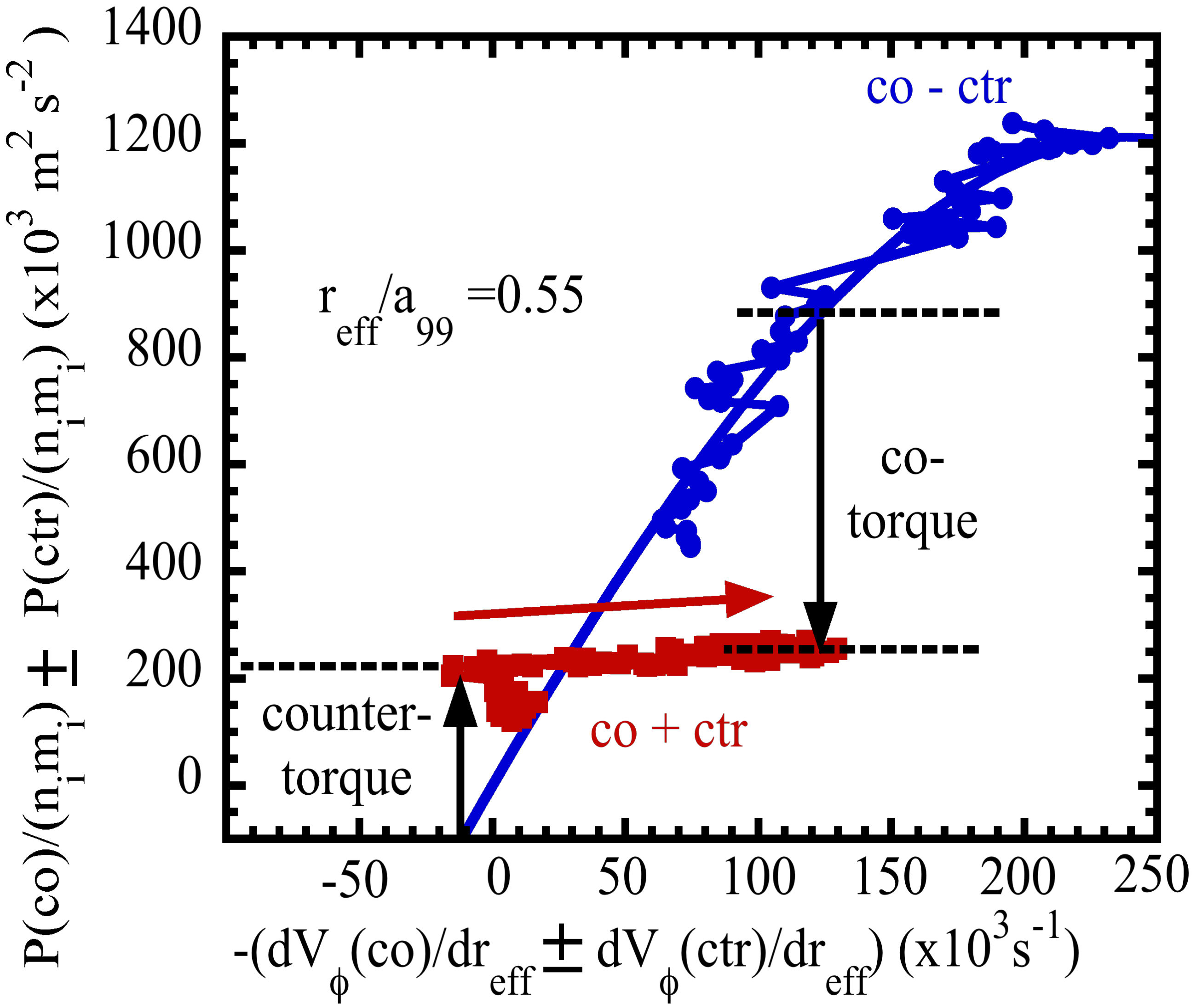


M. Yoshinuma EX/P6-30

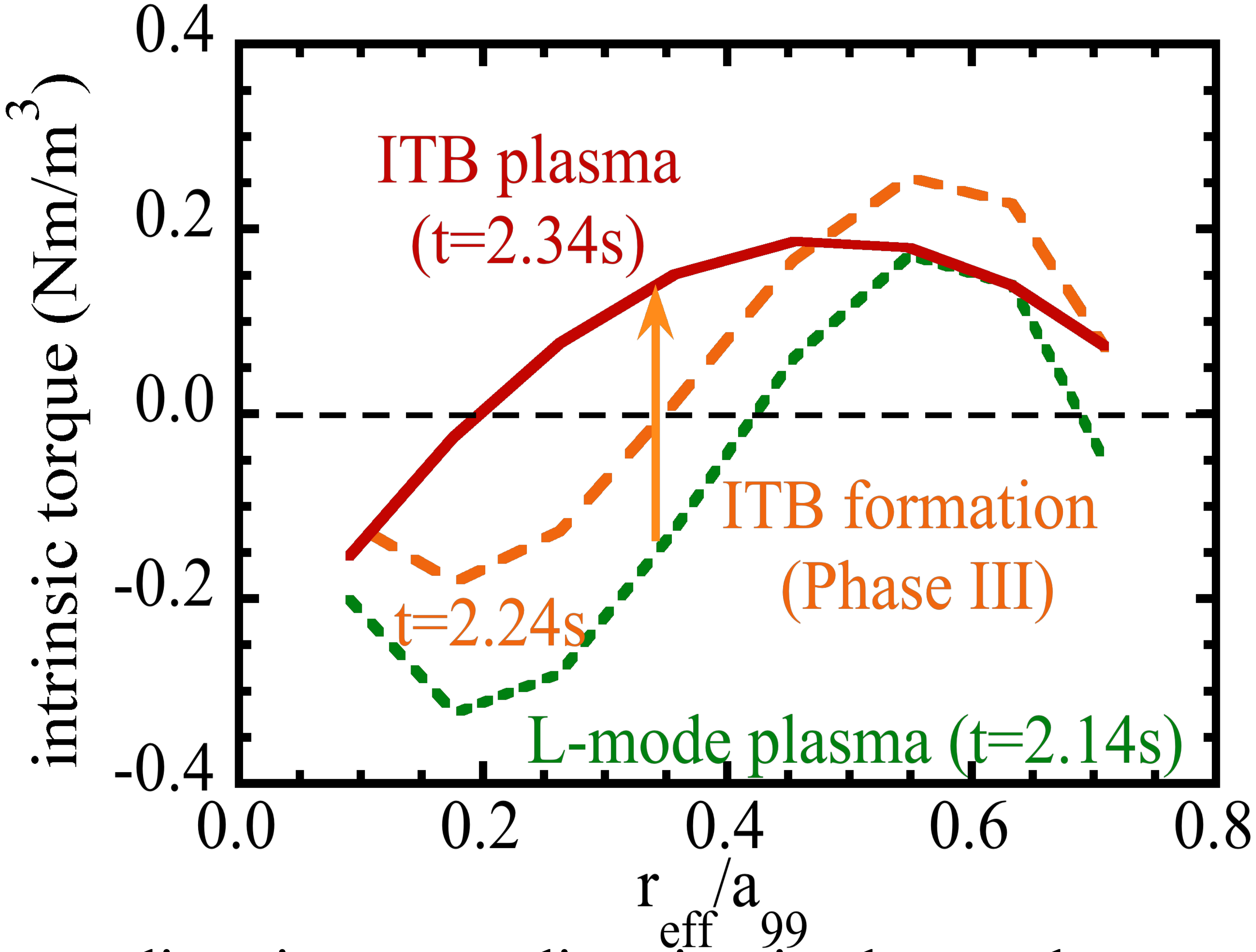
S. Inagaki EX/2-1

Non-diffusive term of momentum transport

Flux-gradient relation



Radial profile of intrinsic torque



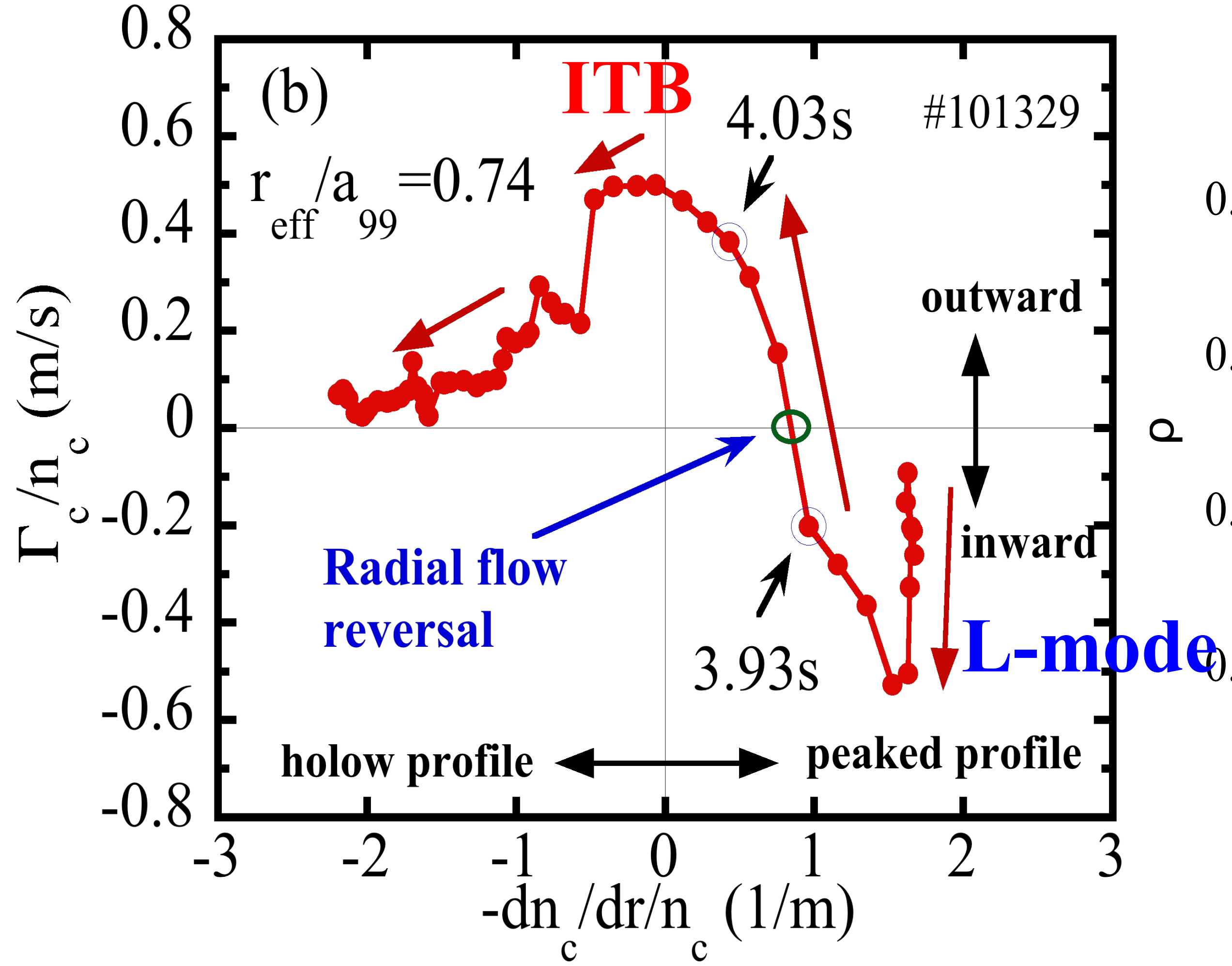
The reversal of intrinsic torque from counter-direction to co-direction is observed to be associated with the formation of ion ITB, where the ITG mode is expected to be unstable due to the increase of ion temperature gradient and flattening of electron density profile.

K. Ida K., et al 2013 Phys. Rev. Lett. 111 055001

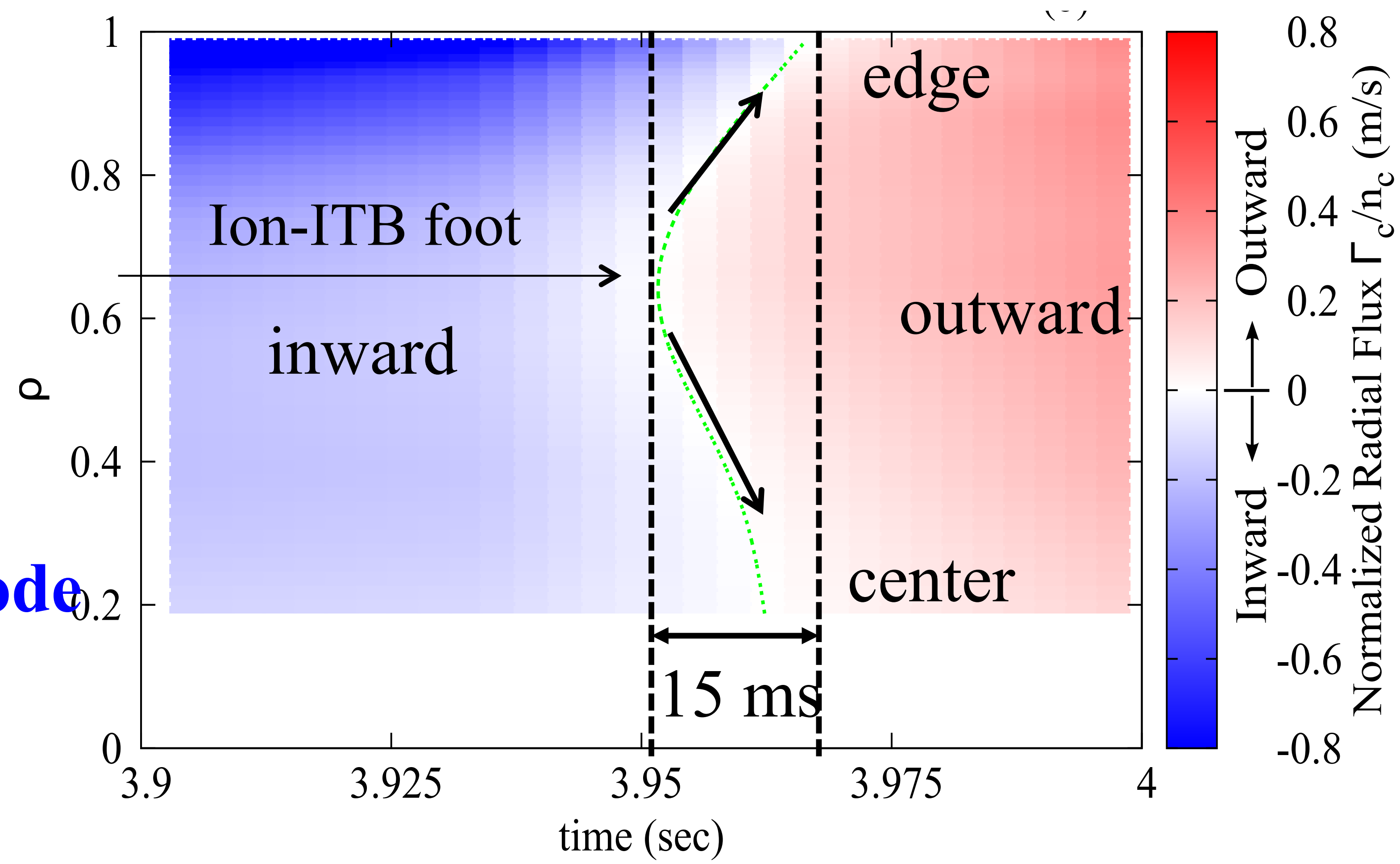
ITG mode M. Nunami TH/P7-9.   Analysis tool M. Emoto FIP/P8-28

Non-diffusive term of impurity transport

Flux-gradient relation



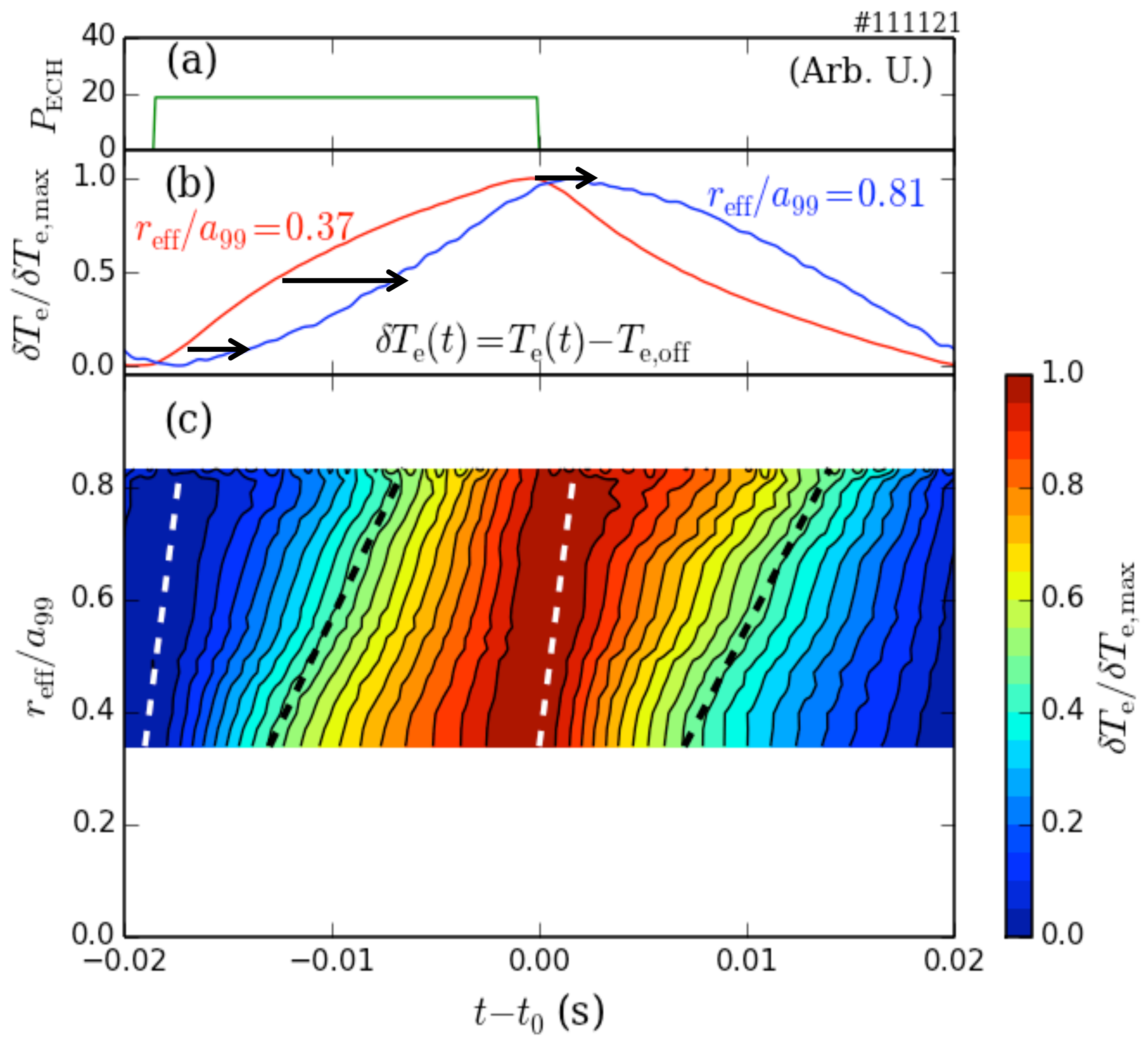
Normalized radial particle flux of carbon impurity



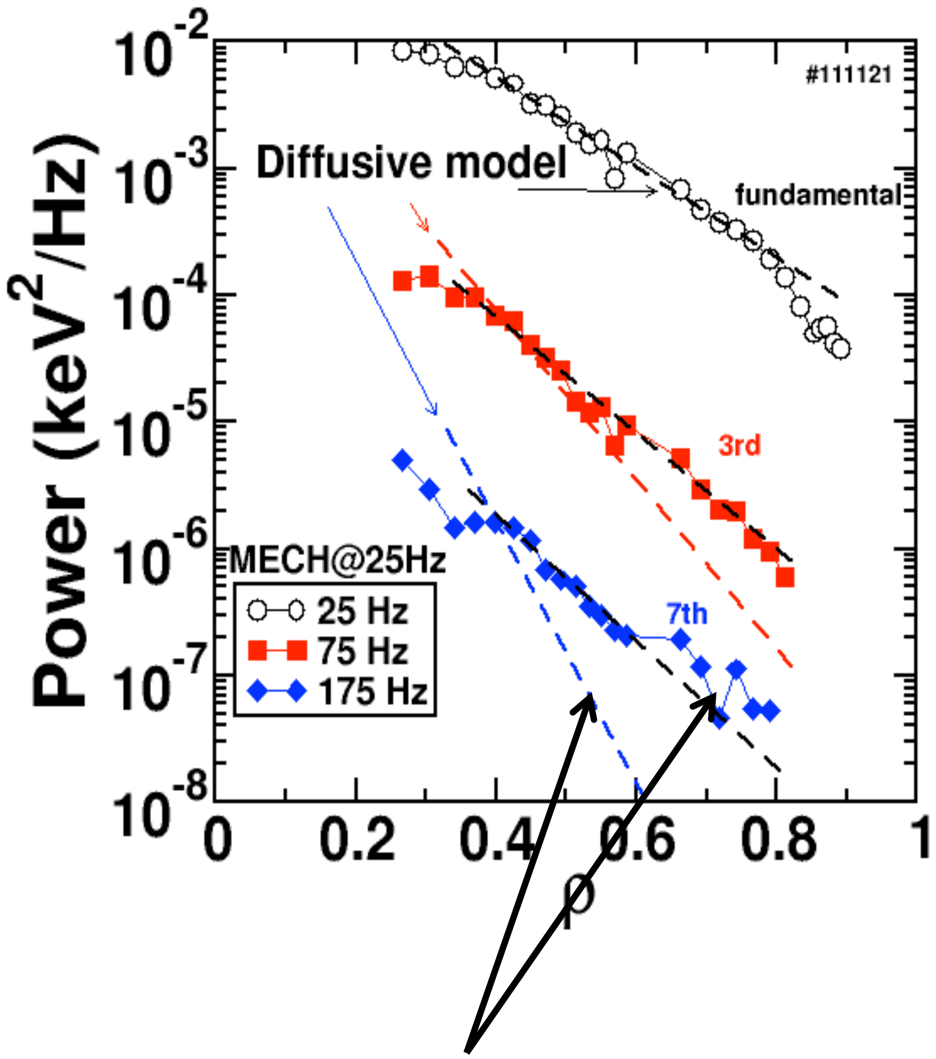
The reversal of radial flux starts at $r_{eff}/a_{99} = 0.65$, where the ITB also starts, and propagates toward the edge and center in the time scale of 15 ms which is much shorter than the time scale of change in the mean plasma parameter.

M. Yoshinuma EX/P6-30

Heat pulse propagation



Fourier transform analysis



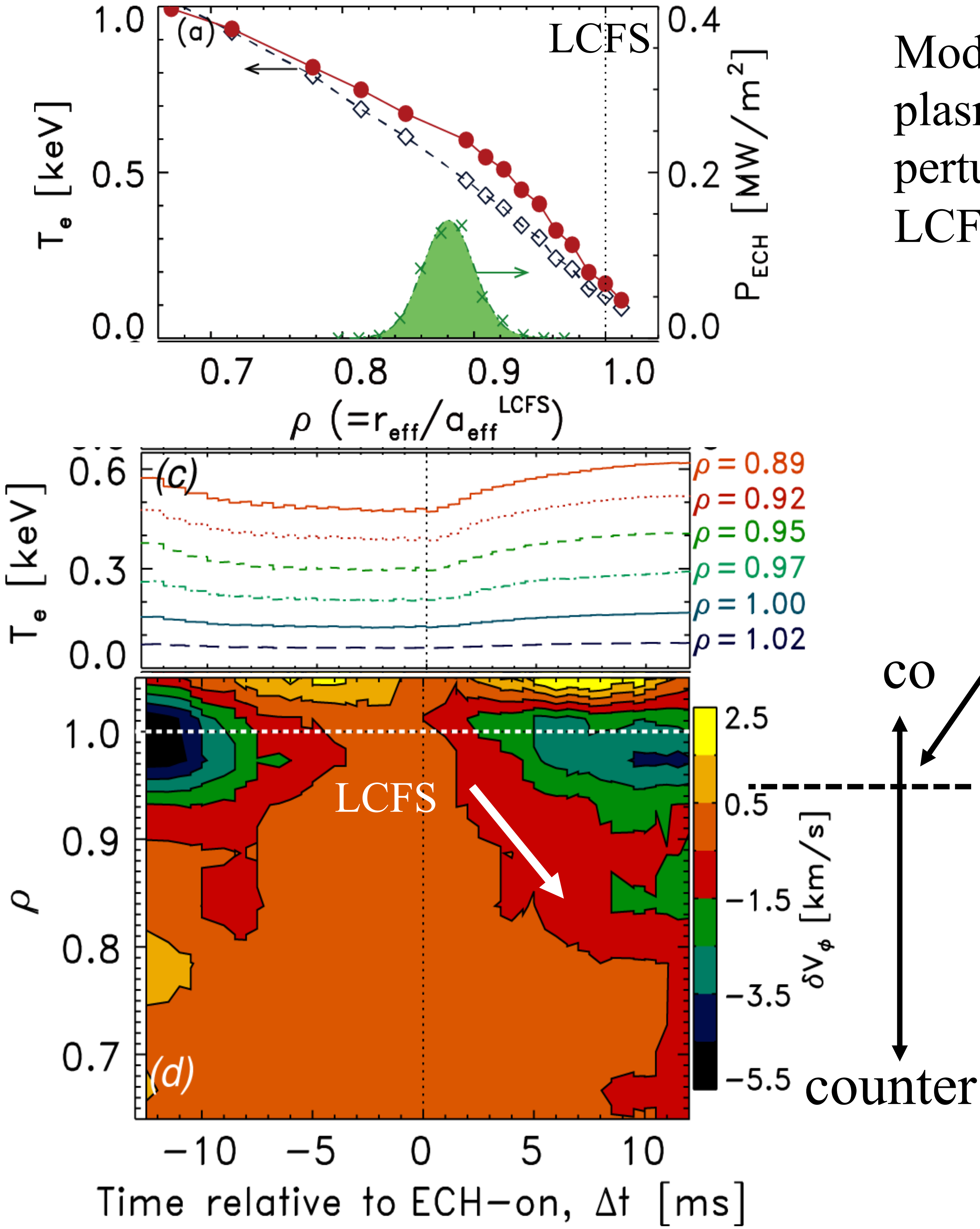
Bulk propagation (fundamental frequency) → slow
Front propagation (higher harmonic frequency)→fast

The propagation length of higher harmonic frequency was found to be larger than that predicted by the diffusive model because of the fast propagation.

S. Inagaki (Kyushu Univ.) EX/2-1

Turbulent Transport is far from diffusive model

Intrinsic rotation at LCFS



Modulation ECH is applied near the plasma boundary of $r_{eff} \sim 0.88$ to make a perturbation of temperature gradient at LCFS in LHD

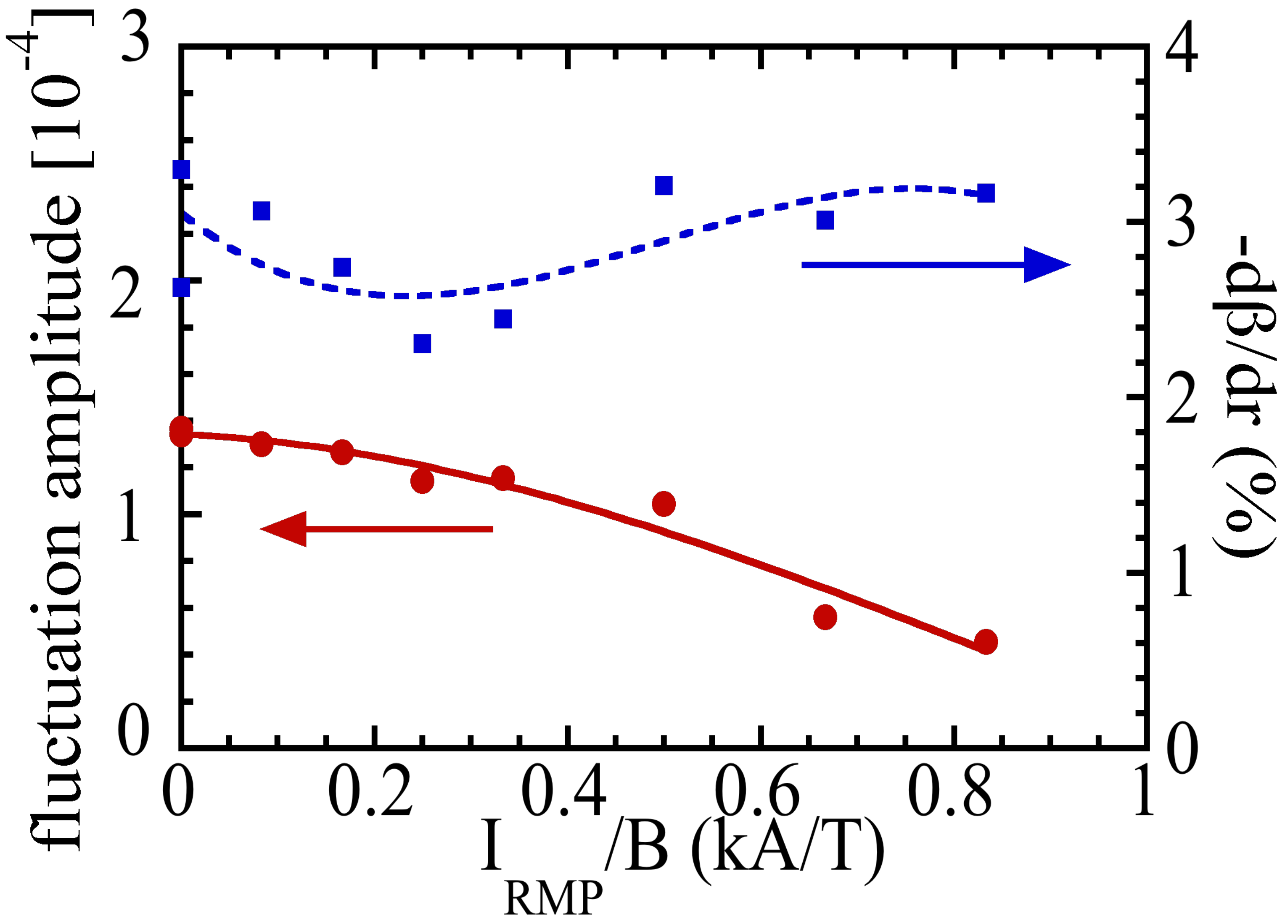
The modulation of toroidal rotation $V\phi$ at the LCFS is clearly observed.

The driven rotation is in the counter-direction for positive Er and it propagates inward from LCFS.

This experiment suggests the existence of strong intrinsic toque at the boundary of plasma.

K. Kamiya (JAEA)

Effect of stochastic field on MHD and transport



When the stochastization of the magnetic field is enhanced by the RMP, the pressure driven mode is suppressed even without a change in the pressure gradient itself.

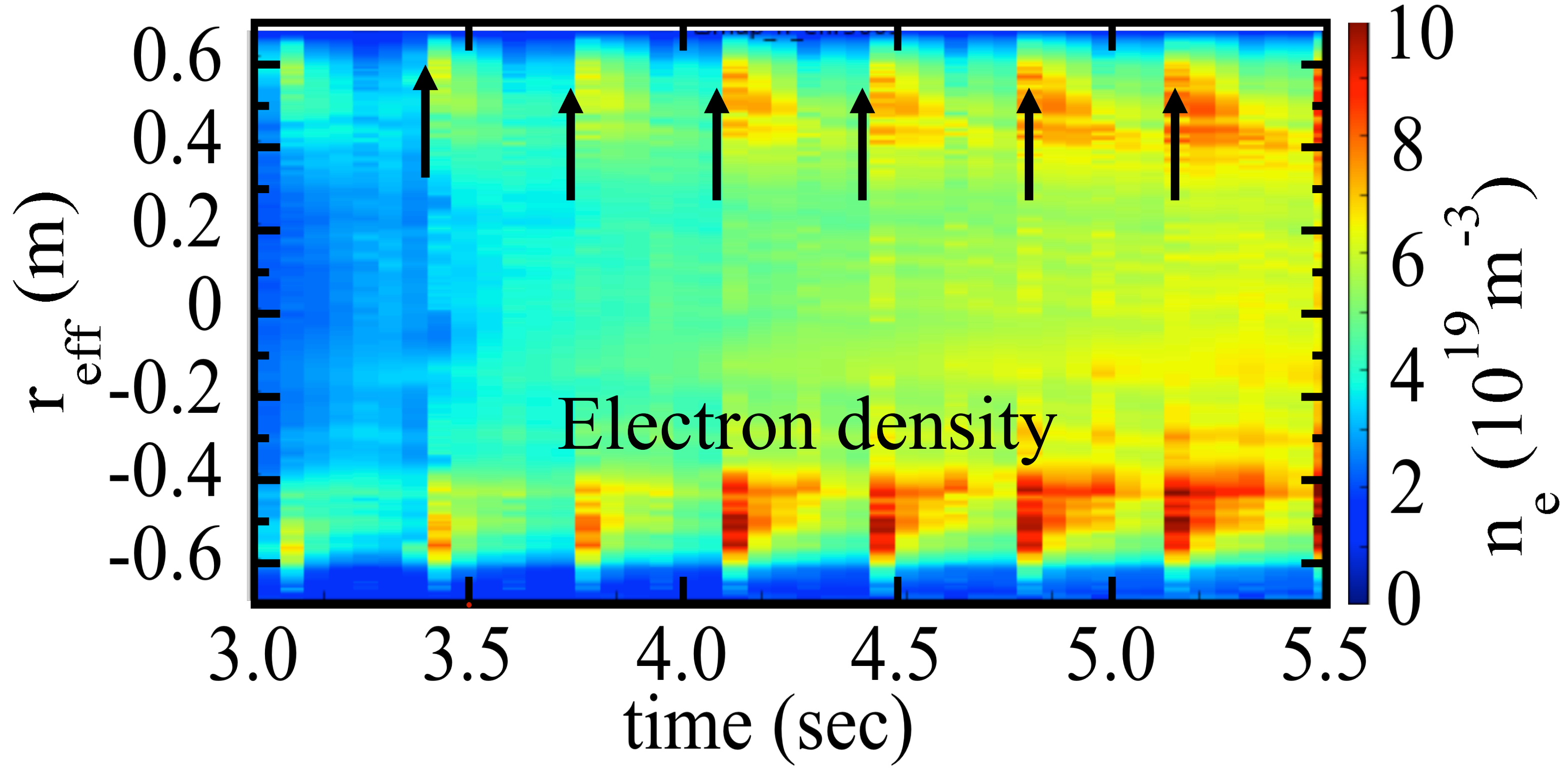
Amplitude of m/n = 2/3 mode are reduced by the RMP field when the normalized RMP coil current I_{RMP}/B exceeds 0.7.

S. Ohdachi EX/P6-29

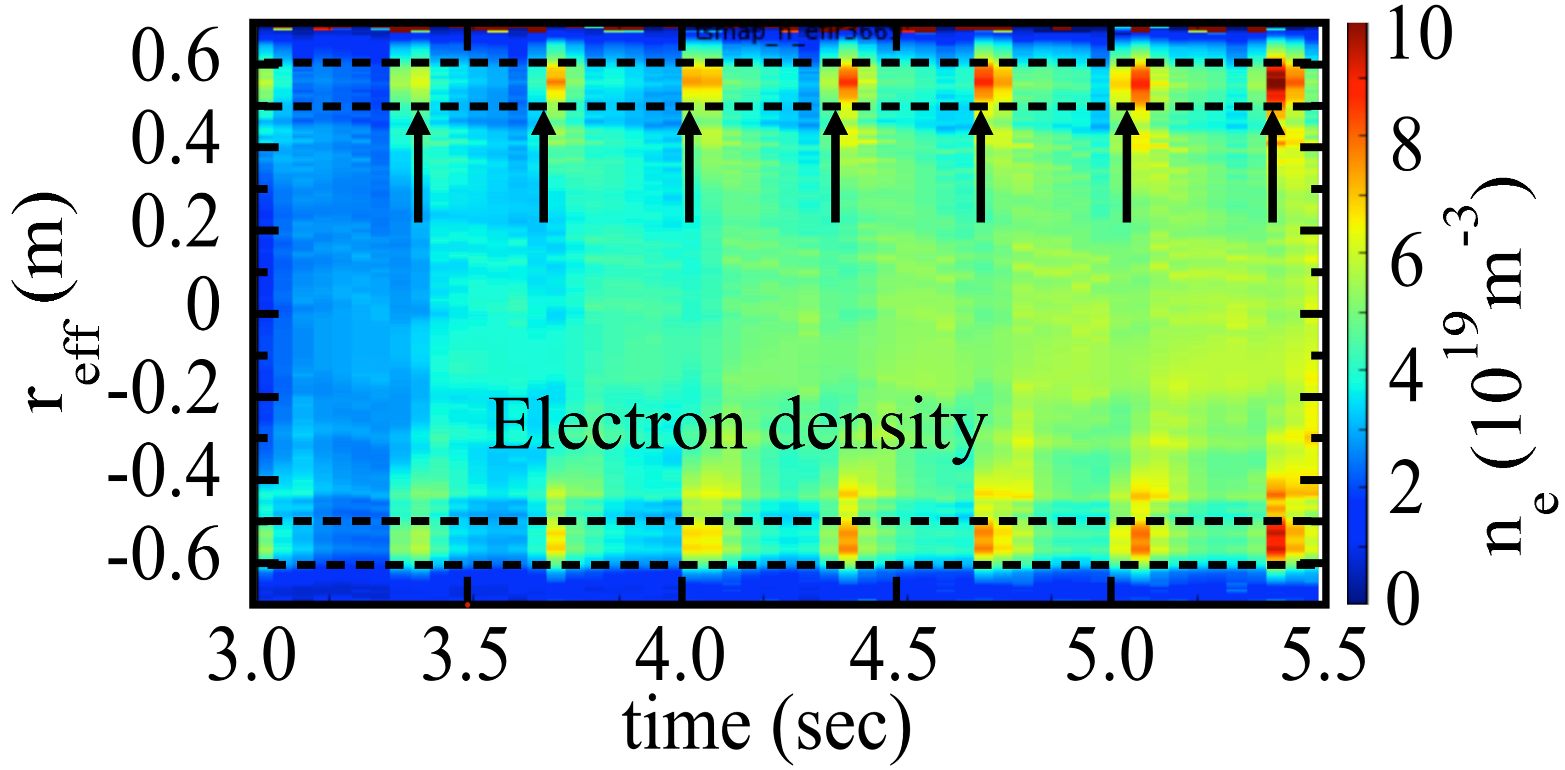
Related Simulations K. Ichiguchi TH/6-2 and A. Ishizawa TH/P6-40

Pellet injections into magnetic island

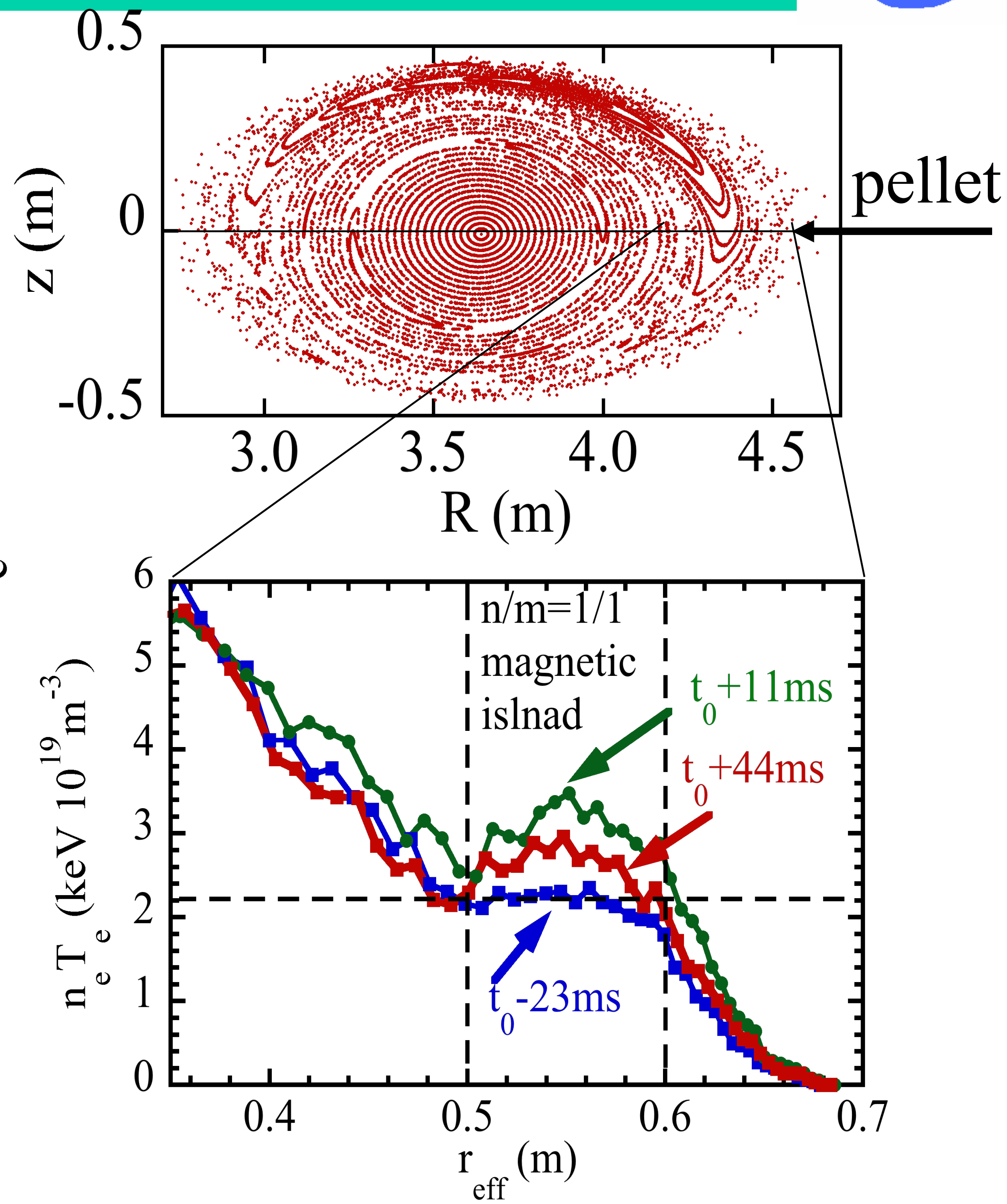
No magnetic island (without RMP)



Magnetic island (with RMP) at r_{eff} = 0.5 – 0.6 m



T. Evans(GA) EX/1-3

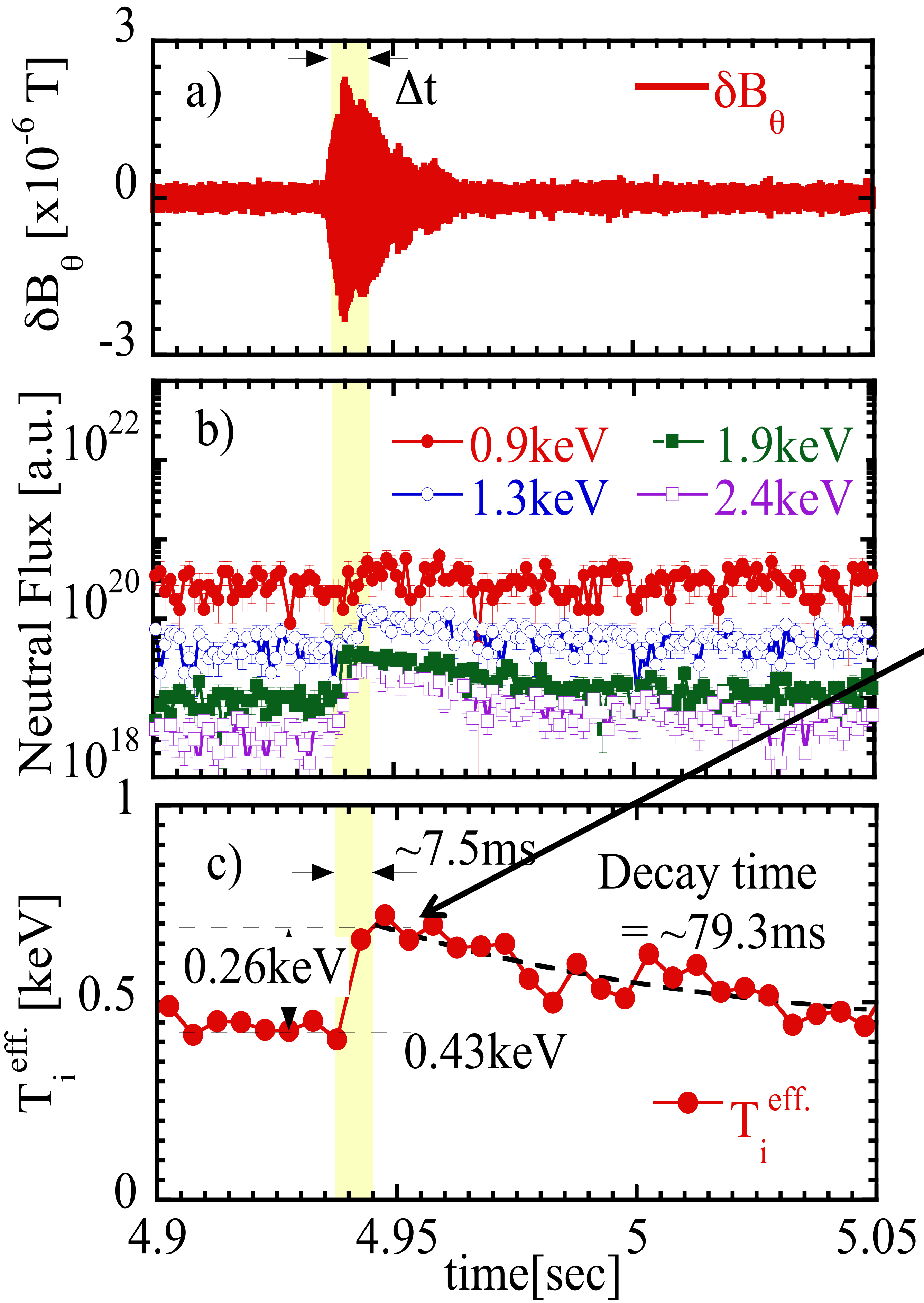


Hydrogen pellets are injected into the O-point of the magnetic island.

The magnetic island prevent the inward shift of density.

The significant peaked pressure profile inside the magnetic island is observed.

Effective Ion heating by energetic particle driven MHD



MHD burst excited by energetic particle driven GAM is observed in the very low density plasma of $5x10^{17}$ m^{-3}.

The increases of effective ion temperature evaluated from the neutral particle spectra is observed associated with EGAM excitation.

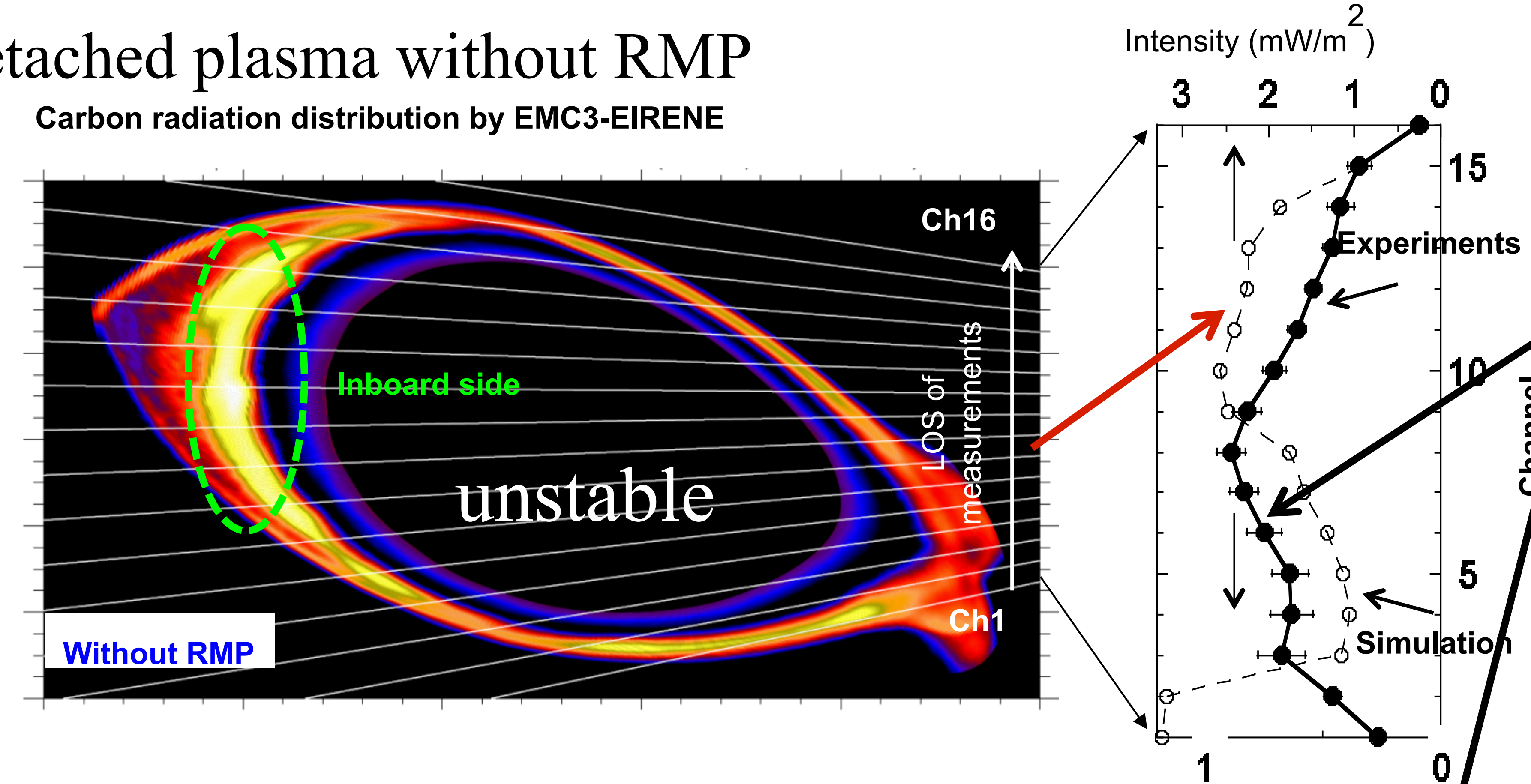
This is a clear evidence for the interaction between MHD instability and heating/transport in the plasma.

M. Osakabe EX/10-3

Stabilization of Detachment Plasma by RMP

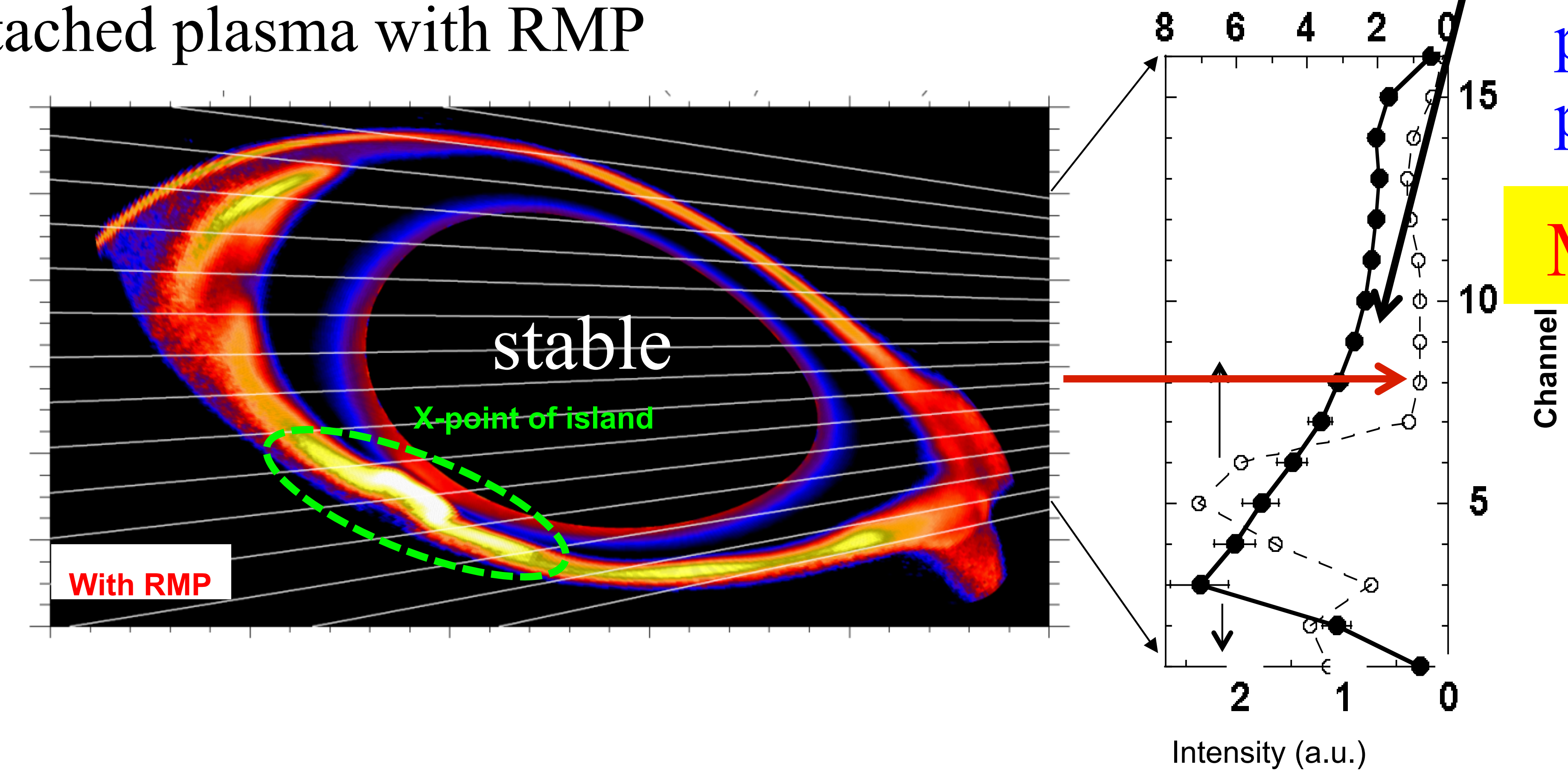
Detached plasma without RMP

Carbon radiation distribution by EMC3-EIRENE



The chord-integrated intensity has a reasonable agreement with the experimental results.

Detached plasma with RMP



The detached plasma can be stabilized by localizing the radiation spot at the X-point of magnetic island produced by the RMP.

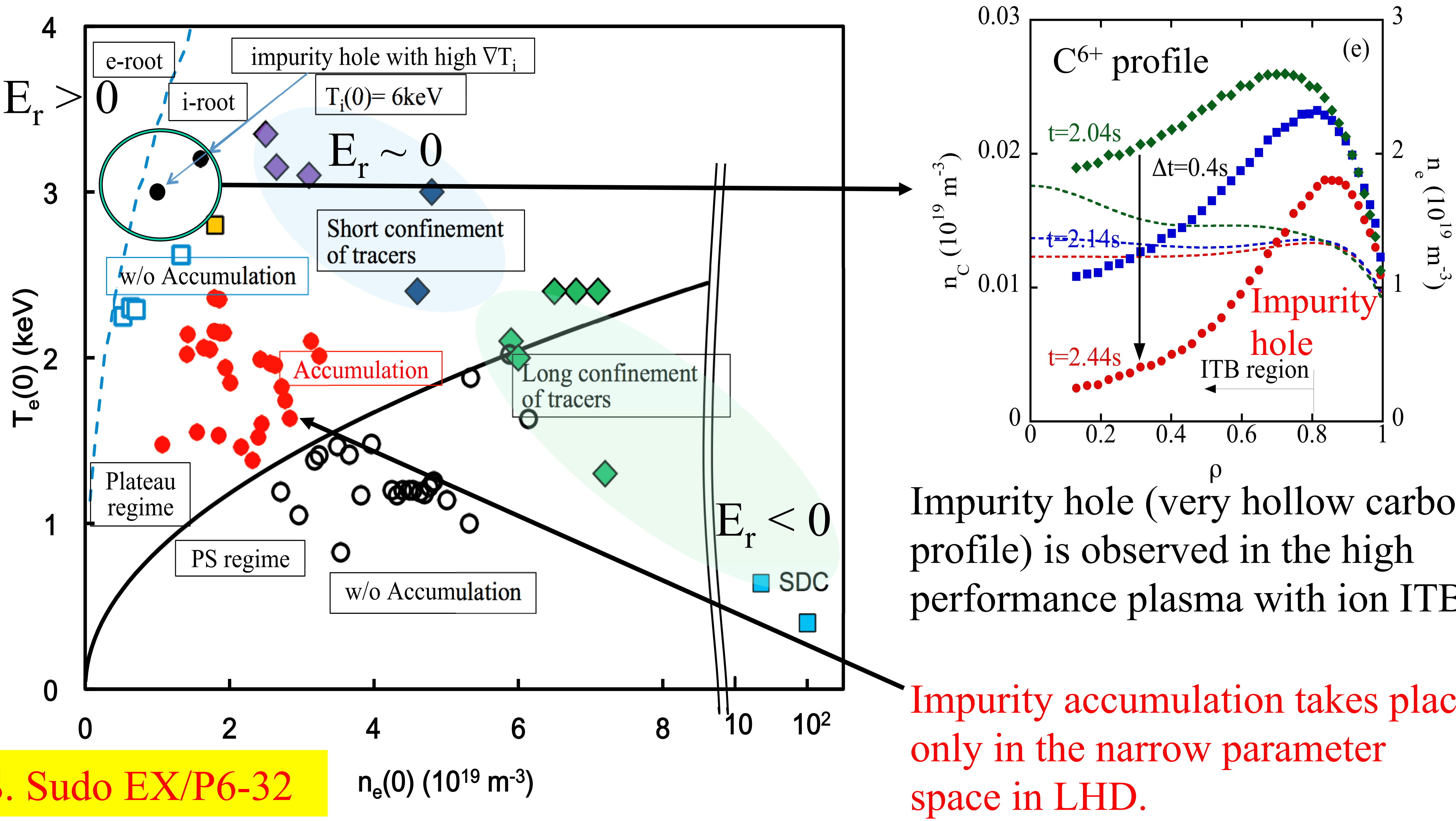
M. Kobayashi OV/4-4

K. Mukai EX/P6-25

N. Ohno EX/P6-26

G. Kawamura TH/P6-39

Impurity behavior in LHD



Impurity hole (very hollow carbon profile) is observed in the high performance plasma with ion ITB

Impurity accumulation takes place only in the narrow parameter space in LHD.

S. Sudo EX/P6-32

Simultaneous achievement of high temperature and low impurity concentration is expected in the future heliotron/stellarator devices.

Tungsten impurity transport : D. Kato MPT/P7-36 I. Murakami EX/P6-28.

Summary

1 Transport analysis beyond power-balance provides new understanding of transport

●The time scale of sign flip of momentum/particle non-diffusive term is shorter than the time scale of profile change.

→ non-diffusive term is directly connected to turbulence states rather than gradients.

●Heat pulse driven by MECH shows "fast" and "long" front propagation

→ Diffusive transport model is too simple to explain the front propagations.

2 MHD–Transport interaction

●Stochastic magnetic field ---- stabilizes the MHD instability

●Magnetic island ---- change the transport

(not just flattening but playing a role of transport barrier)

3 Detachment and impurity control

●RMP --- stabilizing the detached plasma by controlling radiation spot

●Stochastic magnetic field at the plasma edge --- reducing impurity influx

List of LHD presentation

0rals

10/14 (Tue.)

T. Evans (GA)		EX/1-3
	DIII - LHD joint experiment	
M. Kobayashi		OV/4-4
	Topical Overview	

10/15 (Wed.)

S. Inagaki (Kyushu Univ.)		EX/2-1
	MECH experiment	

10/16 (Thur.)

A. Dinklage (IPP)		FIP/3-1
	W7X – LHD – TJ-II joint paper	

10/17 (Fri.)

H. Kasahara		EX/7-3
	Long pulse operation	
K. Nagaoka		PPC/2-1
	High Te and Ti	
K. Ichiguchi		TH/6-2
	MHD with RMP	
M. Osakabe		EX/10-3
	EGAM	

Posters

10/14 (Tue.)

H. Wang	TH/P1-12

10/15 (Wed.)

M. Jakubowski (IPP)	EX/P3-4

10/16 (Thur.)

T. Seki	FIP/P5-3
K. Mukai	EX/P6-2
N. Ohno	EX/P6-2
M. Yokoyama	EX/P6-27
I. Murakami	EX/P6-28
S. Ohdachi	EX/P6-2
M. Yoshinuma	EX/P6-30
K. Fujii	EX/P6-31
S. Sudo	EX/P6-32
M. Shoji	EX/P6-33
T. Shimozuma	EX/P6-34
Y. Narushima	EX/P6-35
X. Du	EX/P6-36
S. Sakakibara	EX/P6-37
S. Murakami	TH/P6-38
G. Kawamura	TH/P6-39
A. Ishizawa	TH/P6-40

10/17 (Fri.)

M. Nunami	TH/P7-9
D. Kato	MPT/P7-36
T. Goto	FIP/P7-16
M. Emoto	FIP/P8-28
T. Akiyama	FIP/P8-31