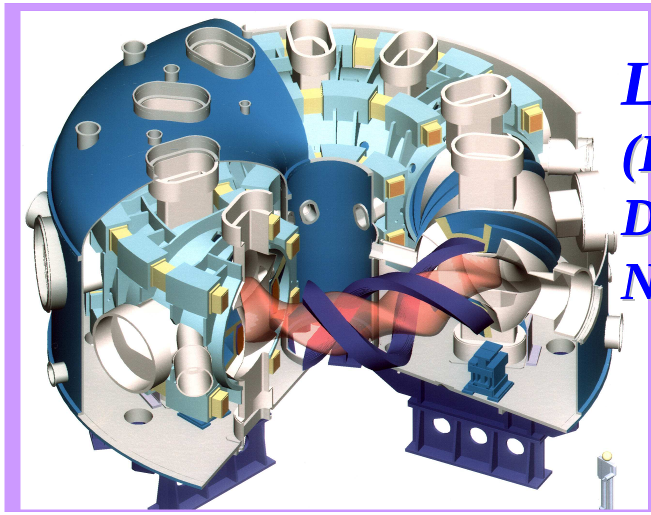
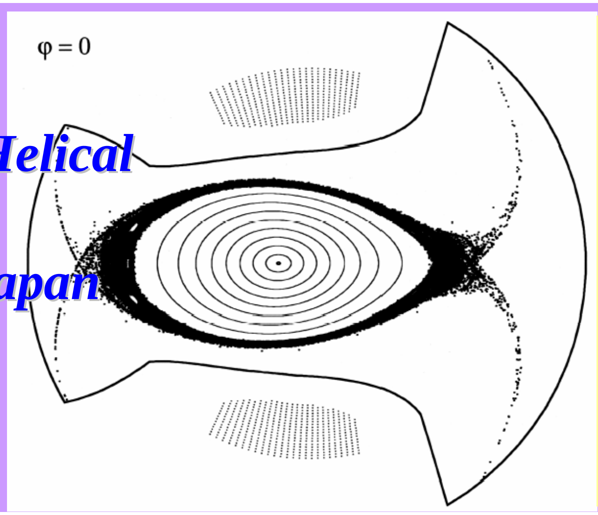
15TH WORKSHOP ON MHD STABILITY CONTROL:
"US-Japan Workshop on 3D Magnetic Field Effects in MHD Control"
U. Wisconsin, Madison, Nov 15-17, 2010

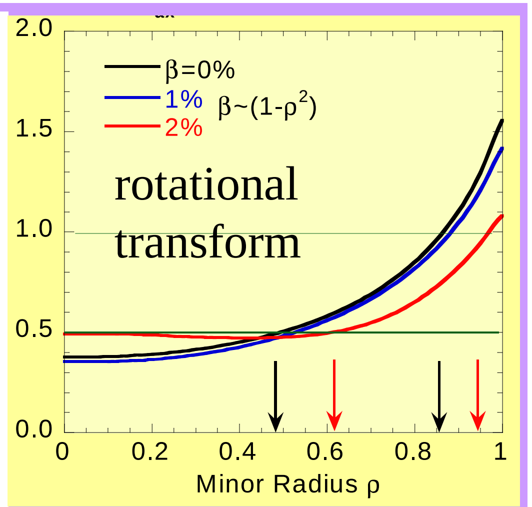
LHD experiments relevant to Tokamak MHD control
- Effect of Stochastic Field and Resonant Magnetic Perturbation on Global MHD Fluctuation -

K.Y.Watanabe, NIFS(Japan)
behalf on high beta-MHD group in LHD experiment

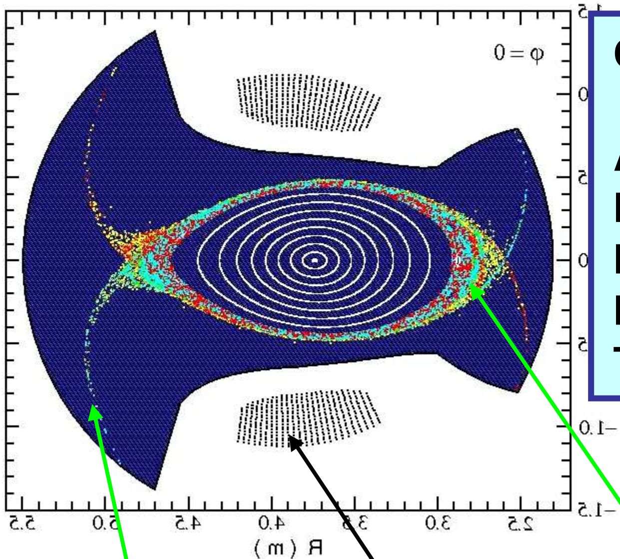


LHD
(Large Helical Device)
NIFS, Japan

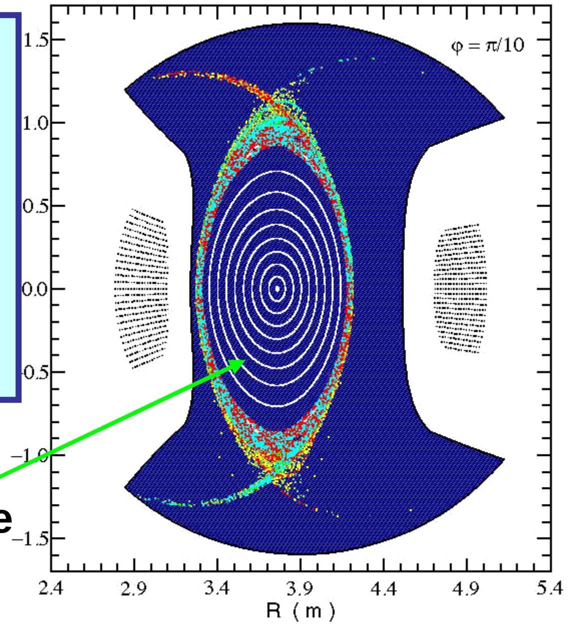


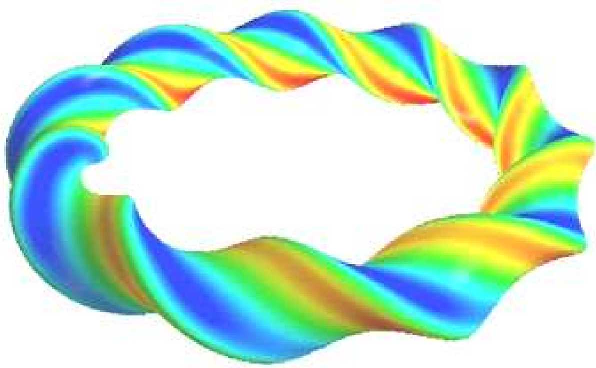


Structure and plasma achievement of LHD



Continuous helical coils of
l=2/m=10 field period
All superconducting coil system
Plasma major radius ~3.7 m
Plasma minor radius ~0.6 m
Plasma volume ~30 m^3
Toroidal field strength 3 T





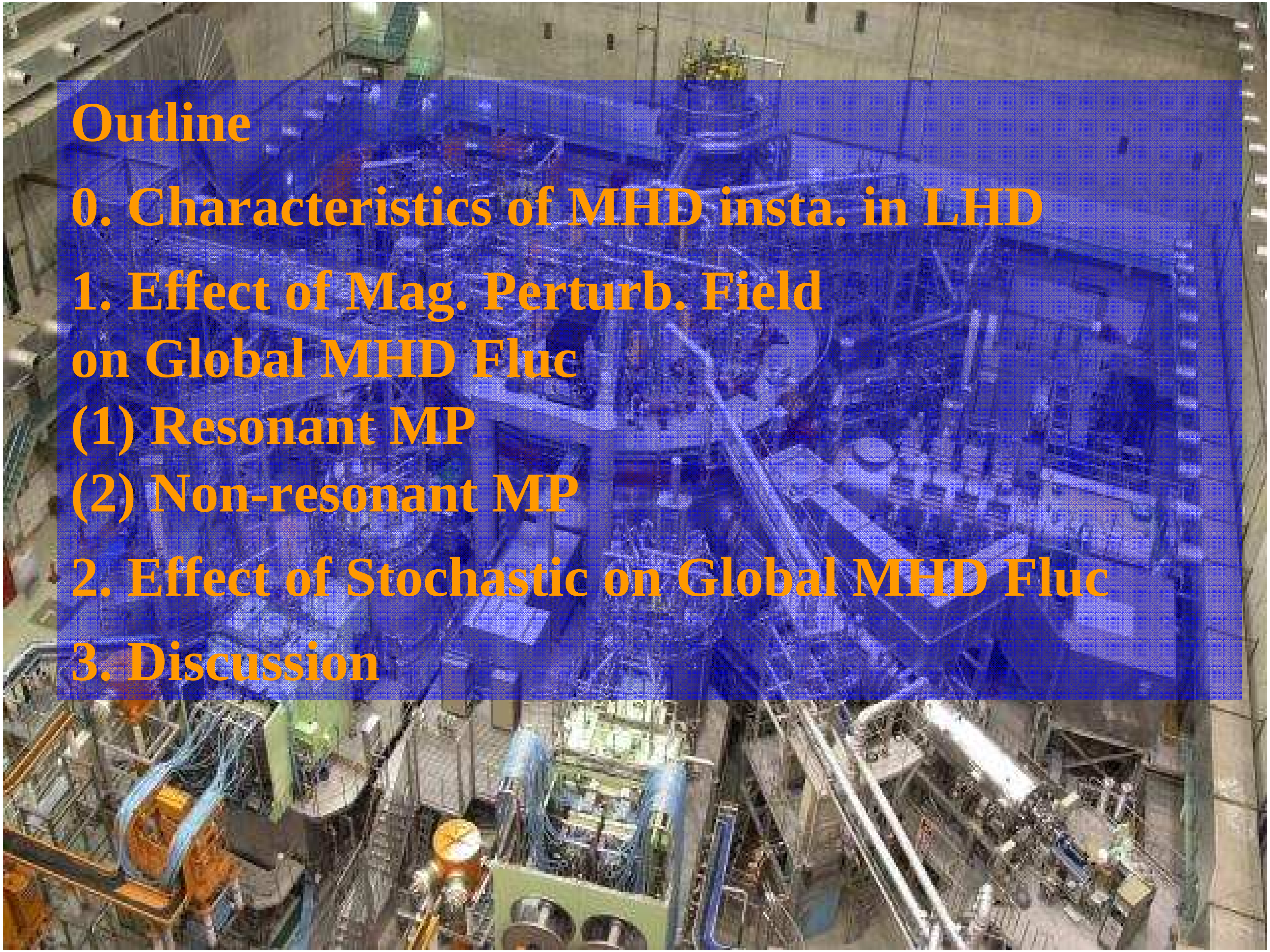
High beta
$\langle\beta\rangle = 5.1\ \%$ at B = 0.425 T
High density
$n_e(0) = 1.2\times10^{21} m^{-3}$ at B = 2.5 T
High ion temperature
$T_i = 5.6$ keV at $n_e = 1.6\times10^{19} m^{-3}$
accompanied by impurity hole
Long pulse : 0.6 MW for 1 hour
$n\,\tau_E\,T = 5\times10^{19}\ m^{-3}$ s keV

Introduction

Recently MHD stabilities in tokamaks related with RMP, stochastic fields and the islands are strongly concerned.

RWM control;
Interaction between MHD instability and Resonant Magnetic Perturbations
ELM control;
Suppression/Mitigation of ELM activities due stochasitization of edge magnetic fields
NTM;
Island dynamics through interaction among seed island, NC current, flow and so on.

Mag. Perturb., Stochastic region of Mag. Field and Islands are induced even in Vac. Config. in Stell./Heliotrons
=> Responses of MHD instabilities on them are observed.
Today's talk



Outline

0. Characteristics of MHD insta. in LHD

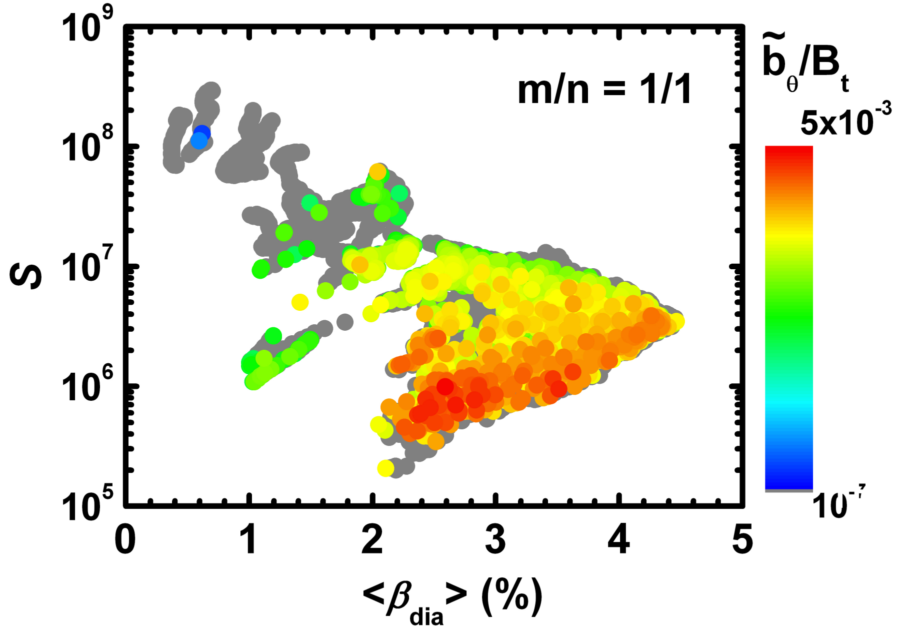
1. Effect of Mag. Perturb. Field on Global MHD Fluc
(1) Resonant MP
(2) Non-resonant MP

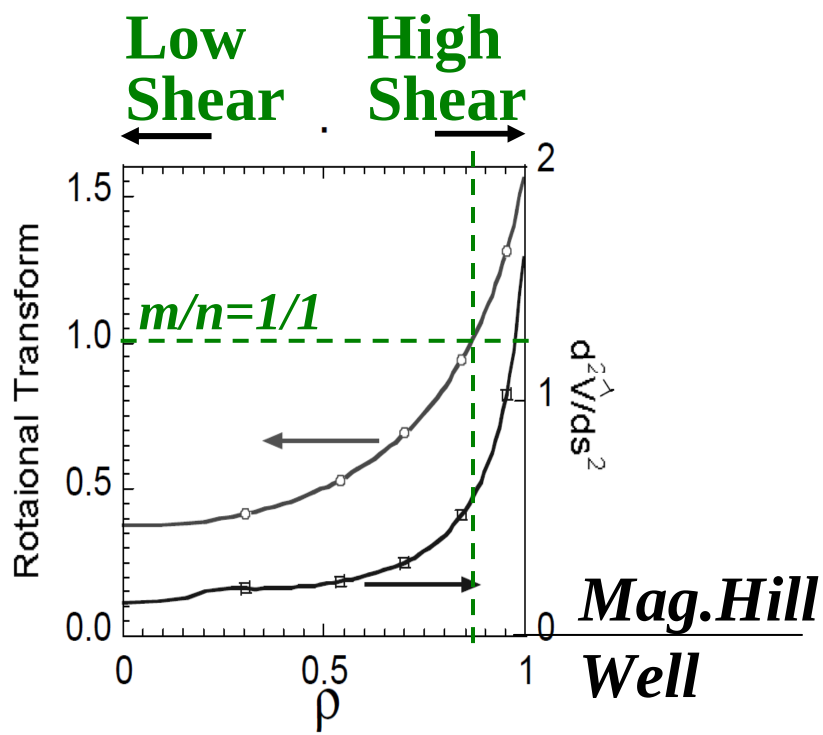
2. Effect of Stochastic on Global MHD Fluc

3. Discussion

Characteristics of MHD instability in LHD

Amp. mag. fluc. low-mn





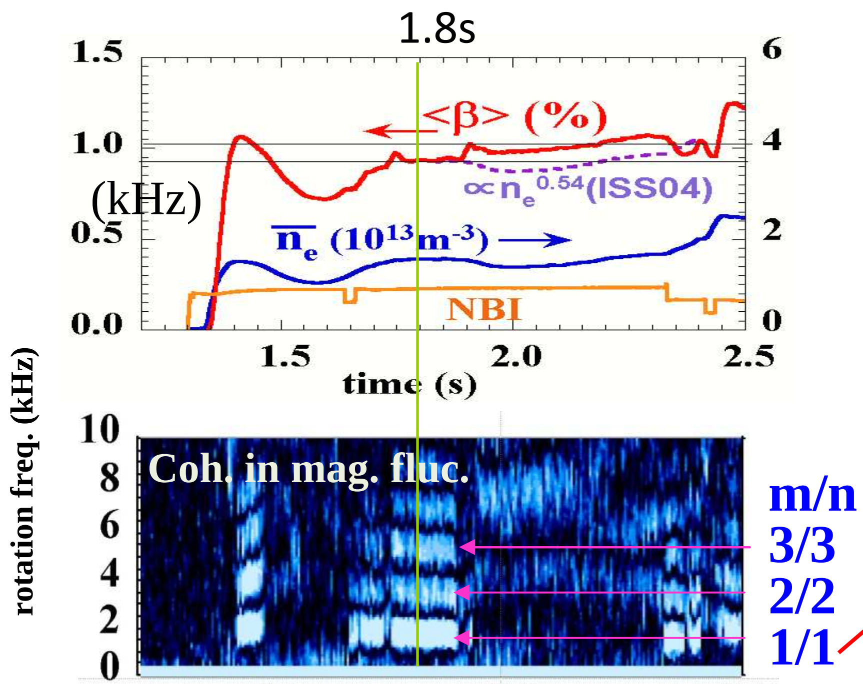
Volume ave. tor. β upto 5%
Mag, Reynolds # 10^6~10^9

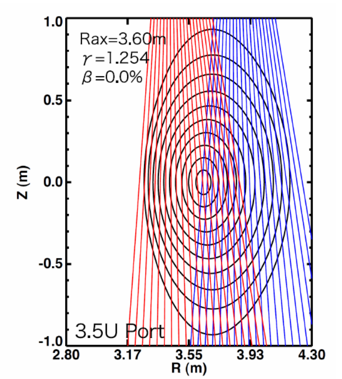
Whole region; Hill

 # Mag. fluc. of global MHD insta. resonated with peripheral low-oder rational surf. are observed in high β regime.

Characteristics of m/n=1/1 mode structure

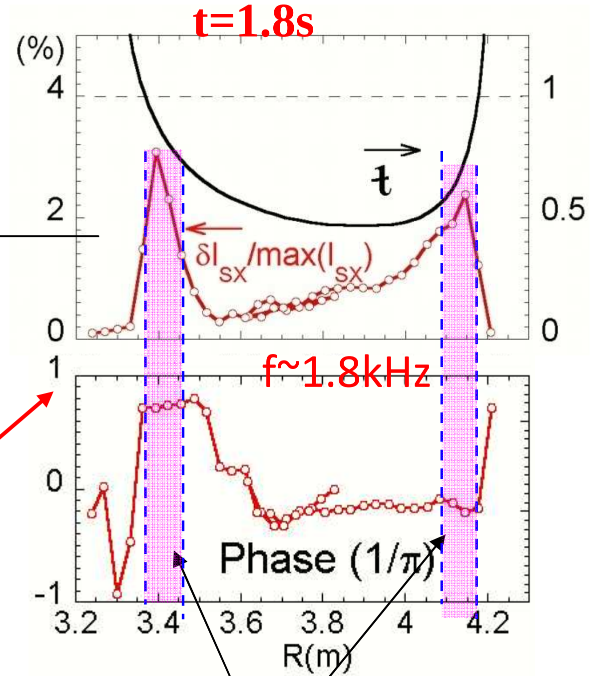
92000, R_{ax}^{V} 3.75m, 0.9T





Sight lines of SX

Radial profile of SXR fluctuation amplitude



Line-integrated

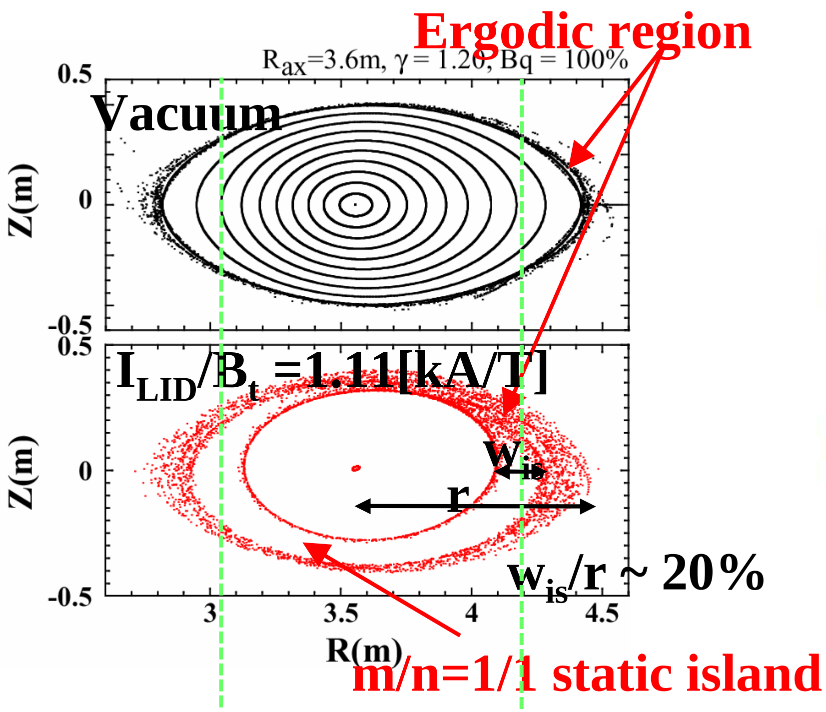
No phase inversion
(No mag. island structure?)
=> Similar structure to linear theory prediction of resistive interchange MHD instability

Effect of Magnetic Perturbation on Global MHD Fluctuation

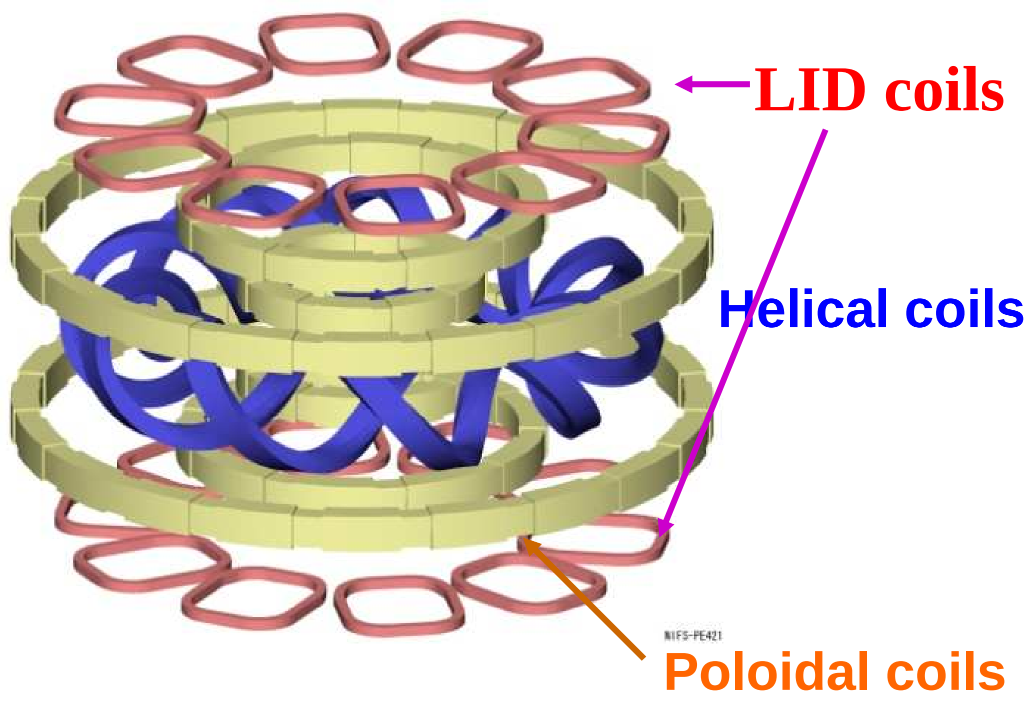
1. Resonant MP
2. Non-resonant MP

ref. S.Sakaibara et al, 33rd EPS, Rome, Italy, (2006),
F.Watanabe et al, Nucl. Fusion (2008)

Magnetic Perturbation by LID coils in LHD



Coil systems in LHD

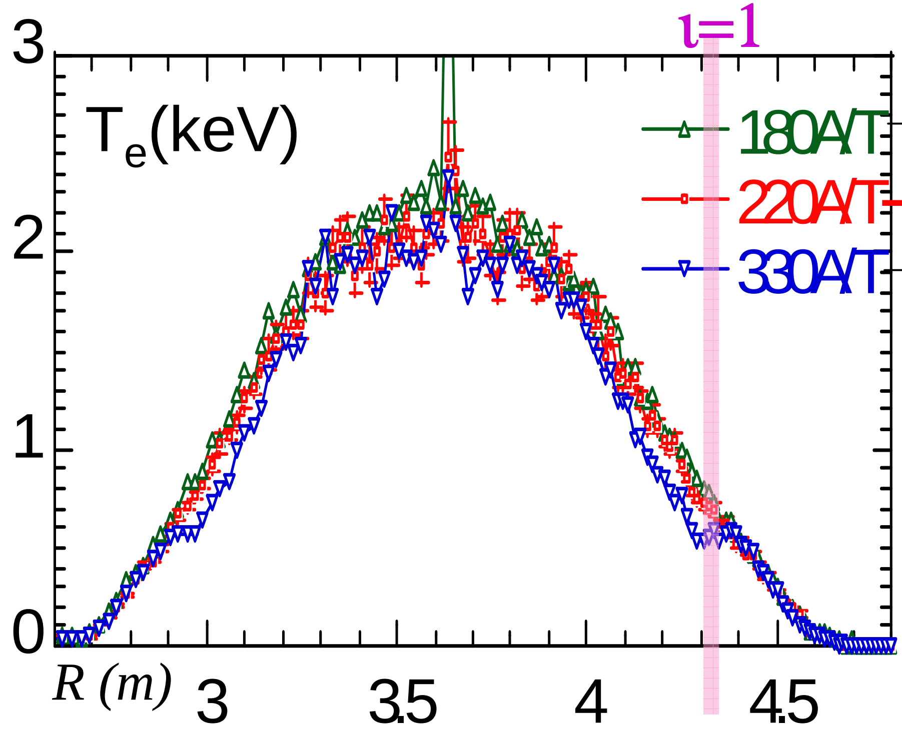


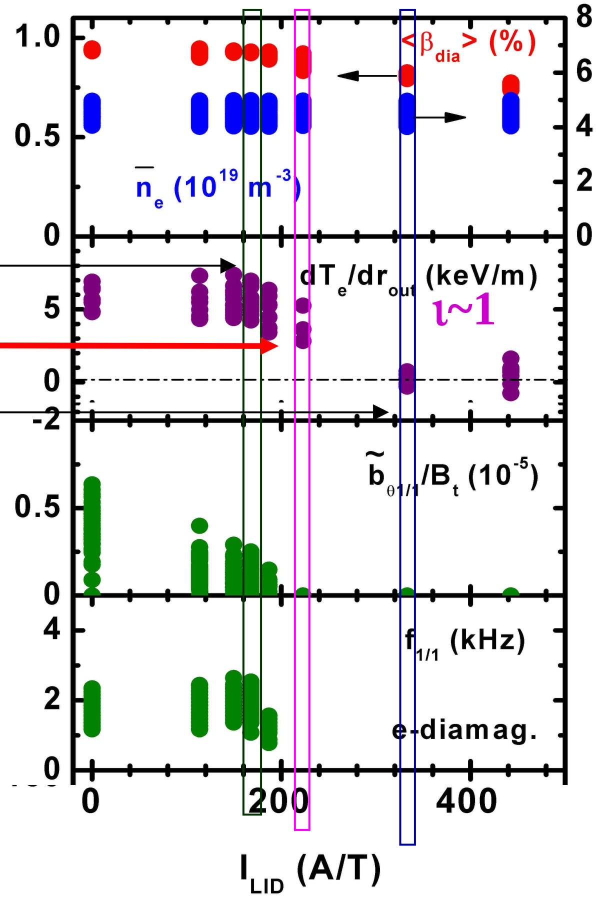
10 pairs LID (for Local Island Divertor config.) coils produce m/n=1/1 RMP.

m/n=1/1 MP of I_{LID}/B_0~1kA/T => w_{is}/r ~ 20% island in vac.

Suppression of *m*/*n* = 1/1 mode by resonant mag. field

R_{ax} = 3.6 m, B_t = 2.75 T, A_p=5.7, NBI,
<β> ~ 1%, D_I < 0.2, D_R >0 , S ~ 10^7



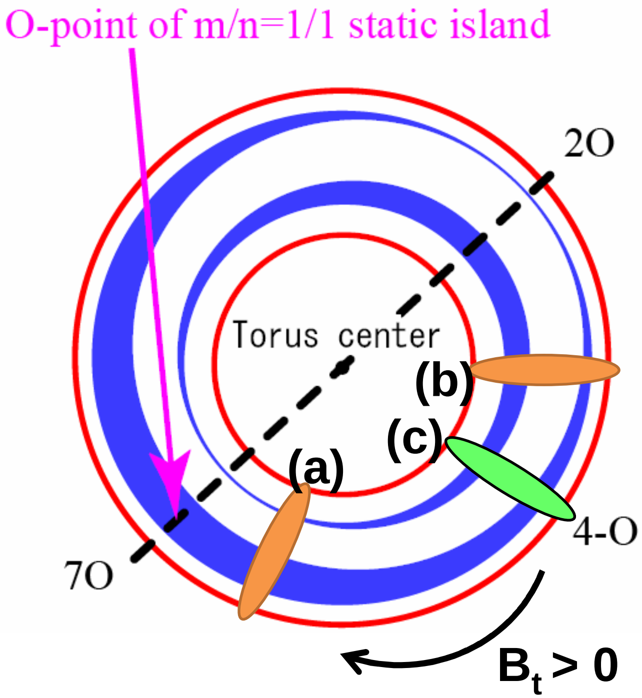


At I_{LID} =220 A/T (W/a_p~0.20),
Fluc. disappears despite finite grad.T_e remains near ι=1 surf.

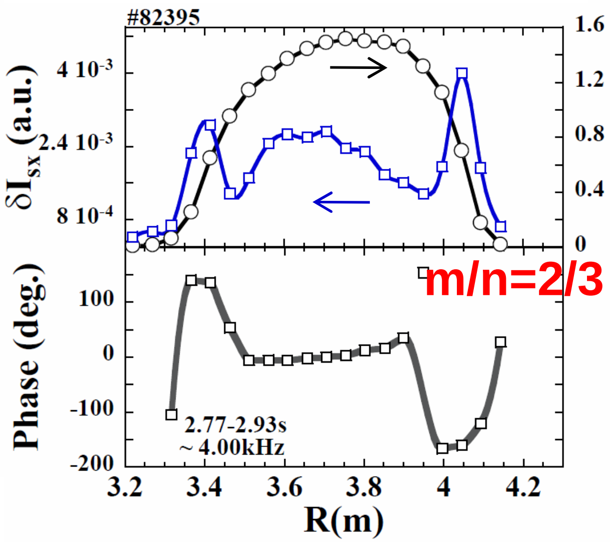
Amp. of Fluc. decreases with reduction of the gradient. Then the mode frequency slowed down.

ref. S.Sakaibara et al, 33rd EPS Conference on Plasma Physics, Rome, Italy, (2006),

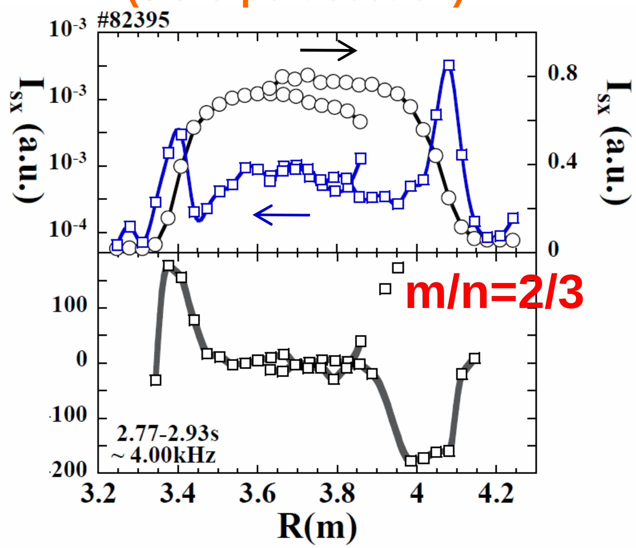
Radial Profiles of MHD Modes with Low Mag. Perturb. (I_{LID}/B_t =0.57kA/T)



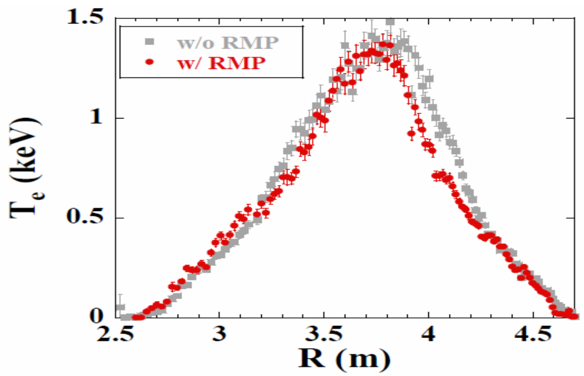
(a) Vertically elongated section (6.5-U port section)



(b) Vertically elongated section (3.5-U port section)



(c) Horizontally elongated section (4-O port section)



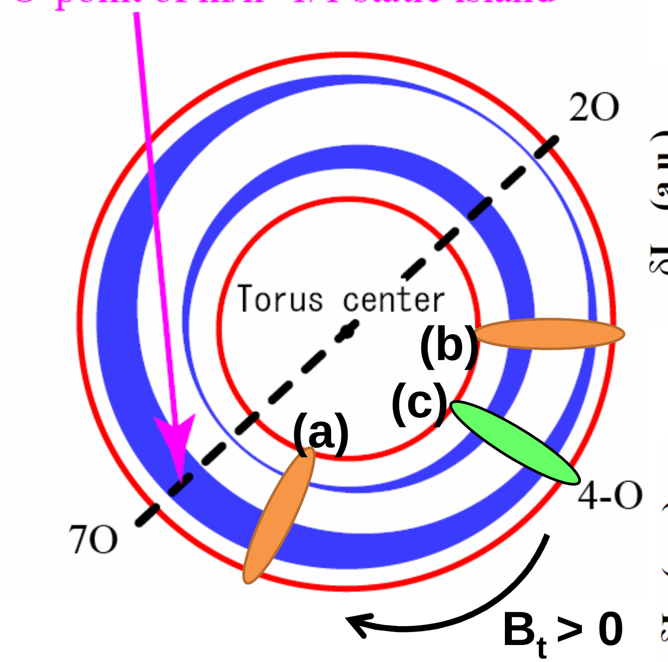
Low MP (0.57kA/T)

Mode has Interchange like structure.

m/n=1/1 static island isn't Clear n Te prof.

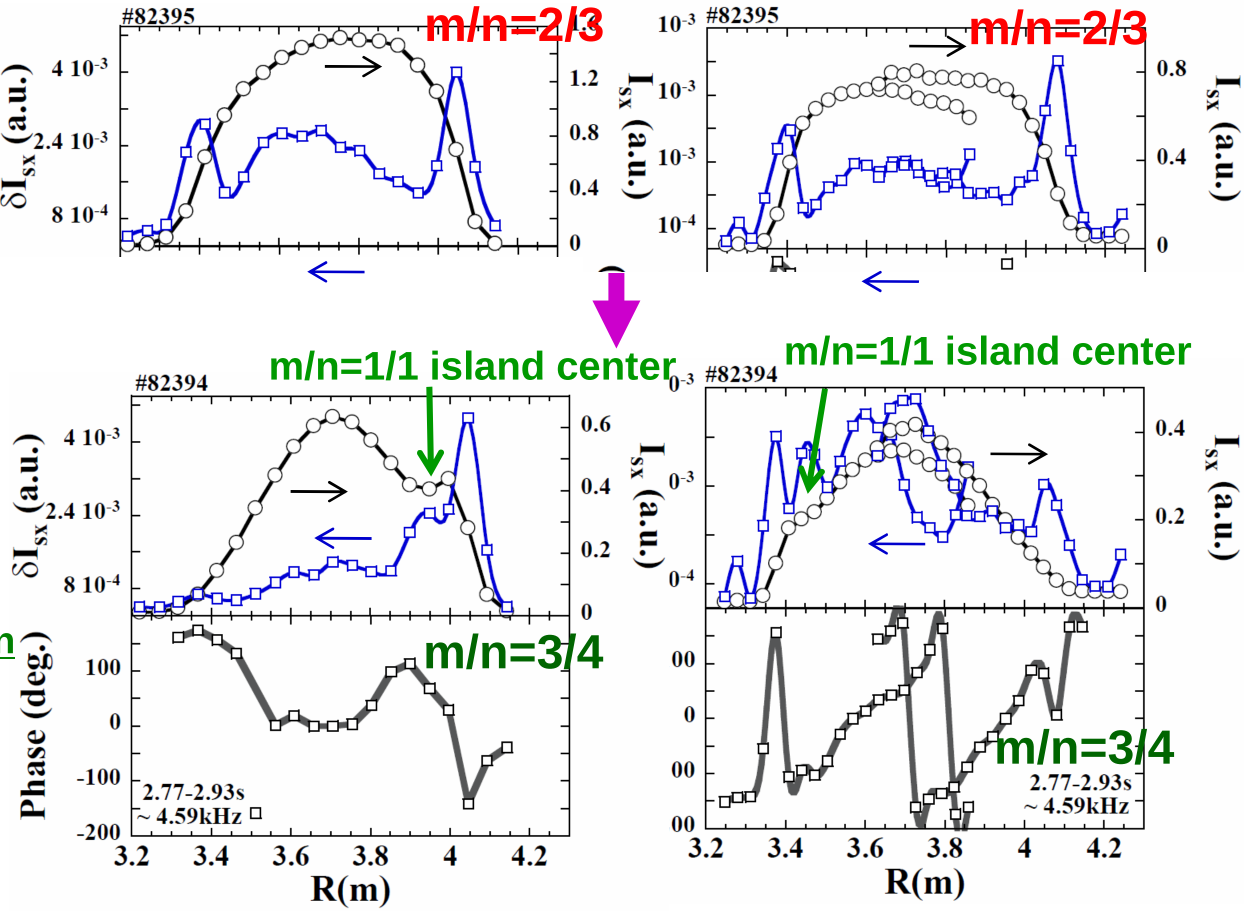
ref F.WATANABE NF (2008)

Radial Profiles of MHD Modes with Large Mag. Perturb. (I_{LID}/B_t =1.13kA/T)

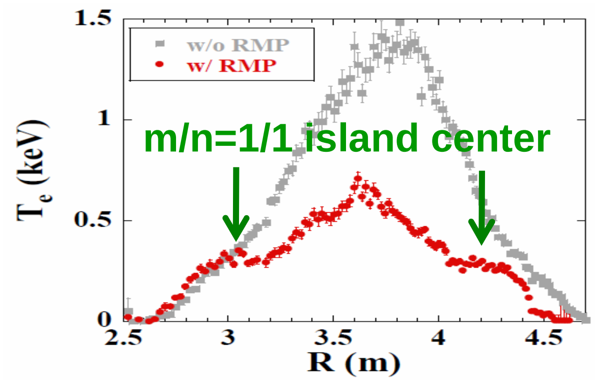


(a) Vertically elongated section (6.5-U port section)

(b) Vertically elongated section (3.5-U port section)



(c) Horizontally elongated section (4-O port section)



- SX fluc in inboard side; decreased. in outboard; strongly enhanced.

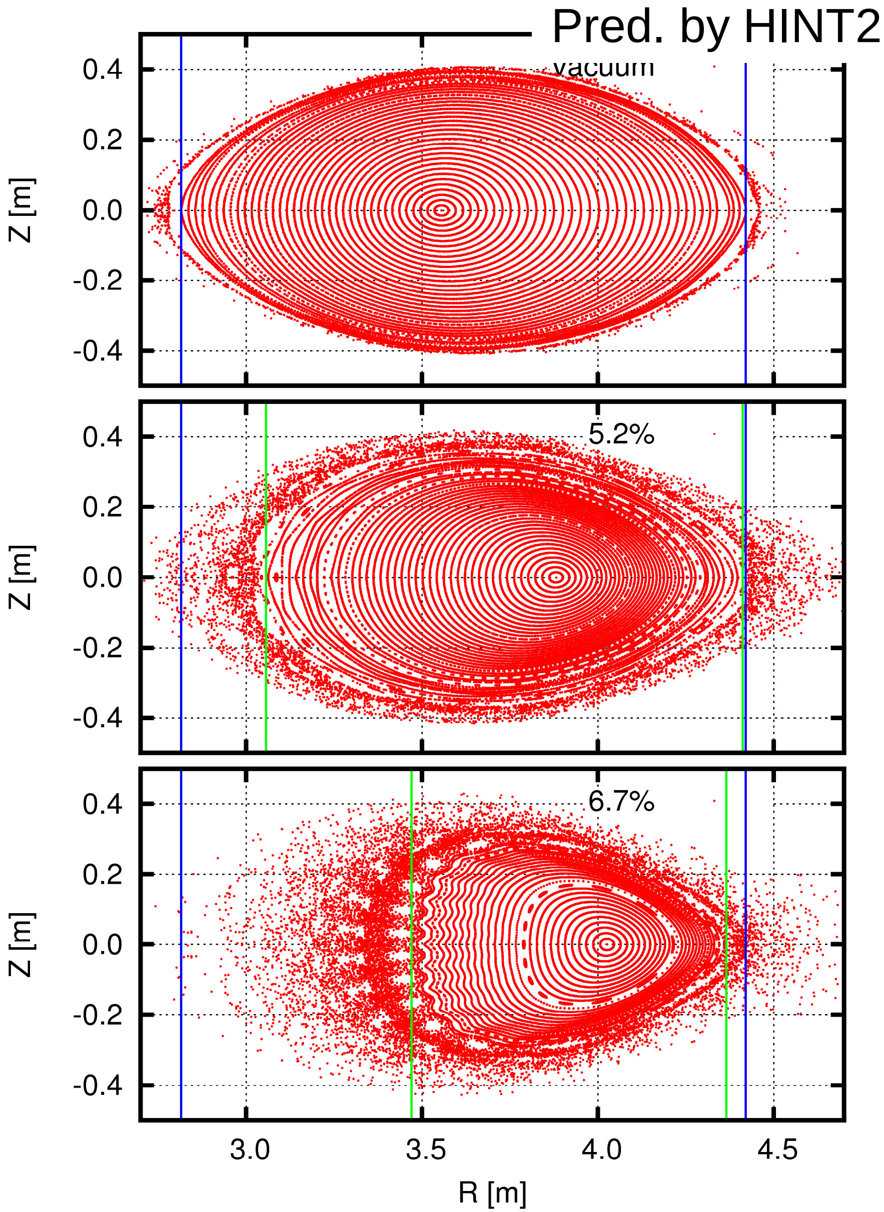
Ballooning-like Character

ref F.WATANABE NF (2008)

Global MHD Fluctuation behavior in Stochastic Region surrounding Nested Flux Surfaces

ref.
K.Y.Watanabe, Annual meeting in Jpn Soc. Plasma & Fusion (2006)
K.Y.Watanabe, Plasma Phys. Contr. Fusion (2007)
Y.Suzuki, Plasma Fusion Res. (2009)

Buck ground; Extension of Stochastic region



According to HINT calc.,
Stochastic region extends
with β
in LHD configurations

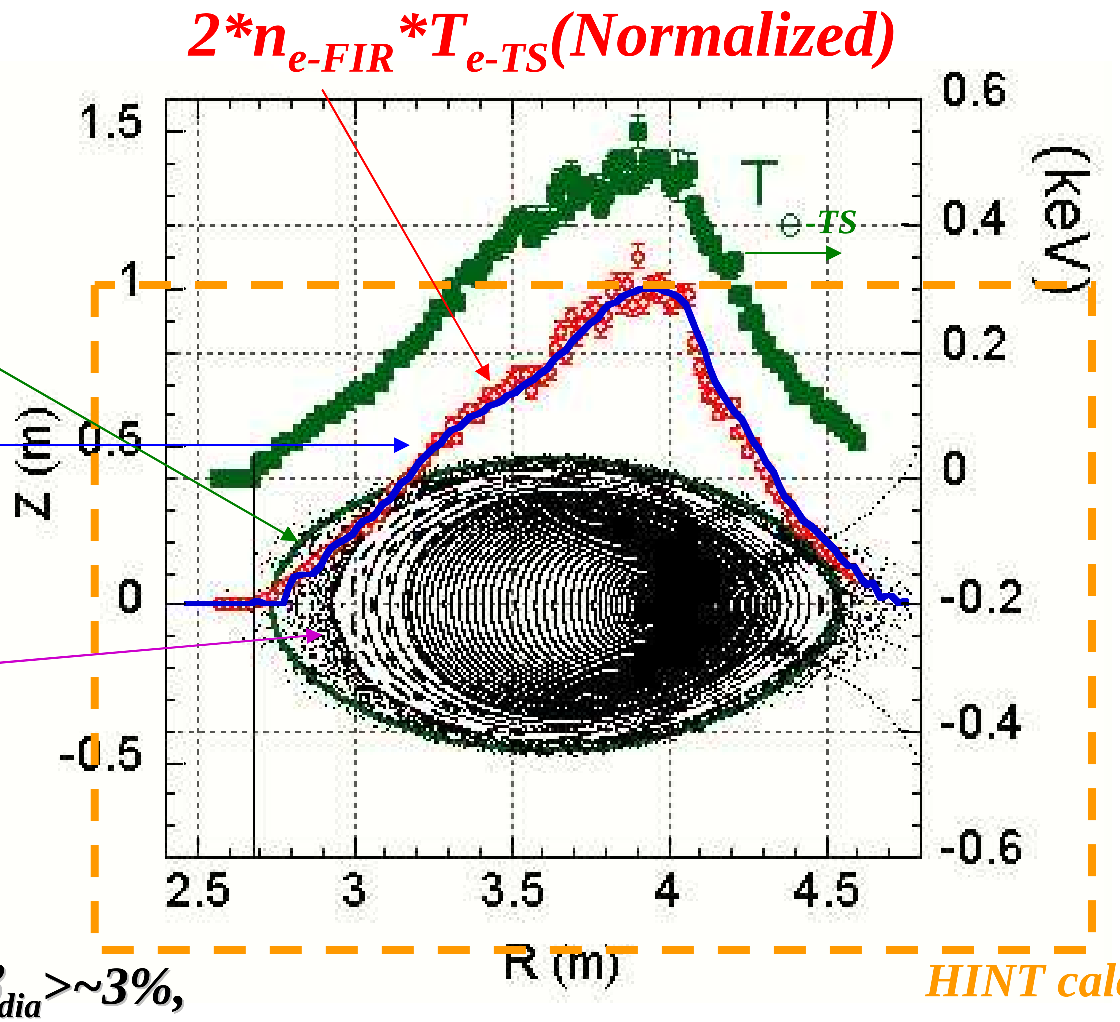
HINT code;
Full 3D MHD equilibrium
analysis code in real coordinates
=>
can treat Islands/Stochastic fields

Reconstructed MHD equil. and Mag. surf. in high β using HINT

Well defined last closed mag. surf. in vac.

p_{HINT}

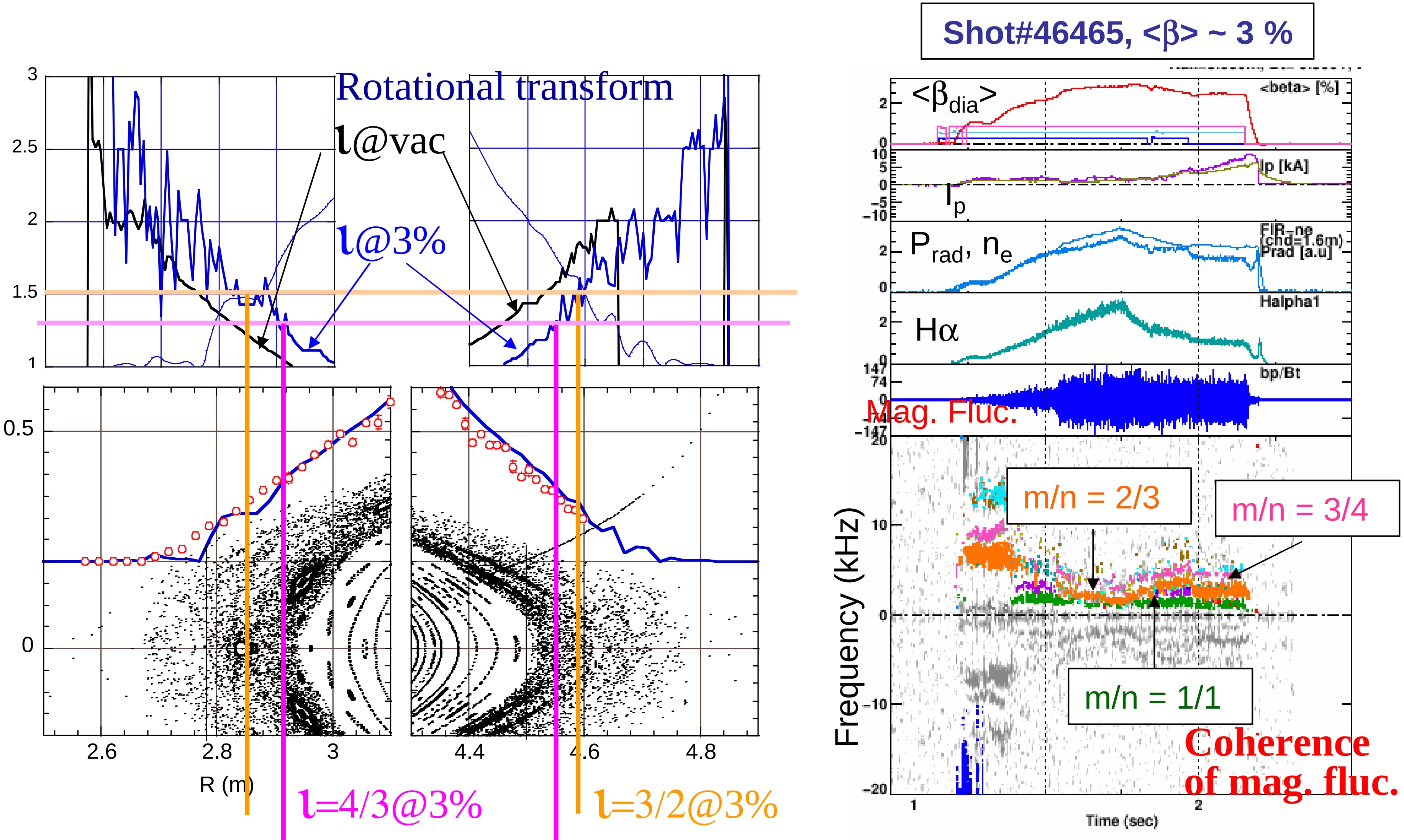
Mag. surf. predicted by HINT



#46465(1.625s),
R_{ax}^{V}=3.6m/0.5T, $<\beta_{dia}>$~3%,

In Region; Stochastic mag. surf is expected by HINT, Finite p_e and T_e are observed

Observ. of Coherent MHD fluc. in Stochastic Region



In Region; Stochastic mag. surf is expected by HINT, Resonated Coherent fluc. are observed

Brief Summary

Effect of Mag. Perturb. (MP) on global MHD instabilities

1. Global MHD instability are suppressed by resonant MP before T_e is flattened.
2. Interchange like instability is observed in small non-resonant MP and w/o MP. On the contrary, ballooning like global MHD instability appears in large non-resonant MP.

Observation of coherent global MHD fluctuation in stochastic region in finite β plasmas predicted by HINT.

Discussion

Simulation of Interaction between MHD instabilities and Island/Stochastic field should be accelerated.

Accompany with the following experimental study;

(1) Accurate estimation of perturbed mag. Field in plasmas
Sometimes RMP looks shielded by plasmas.

(2) Confirmation of stochasticity
In actual plasmas, is mag. field stochastic?

Discussion (Cont.)

(1) Sometimes RMP looks shielded by plasmas.
Island does NOT appear as RMP simply superposed in vac. fields (Heals/Enhased)

=>

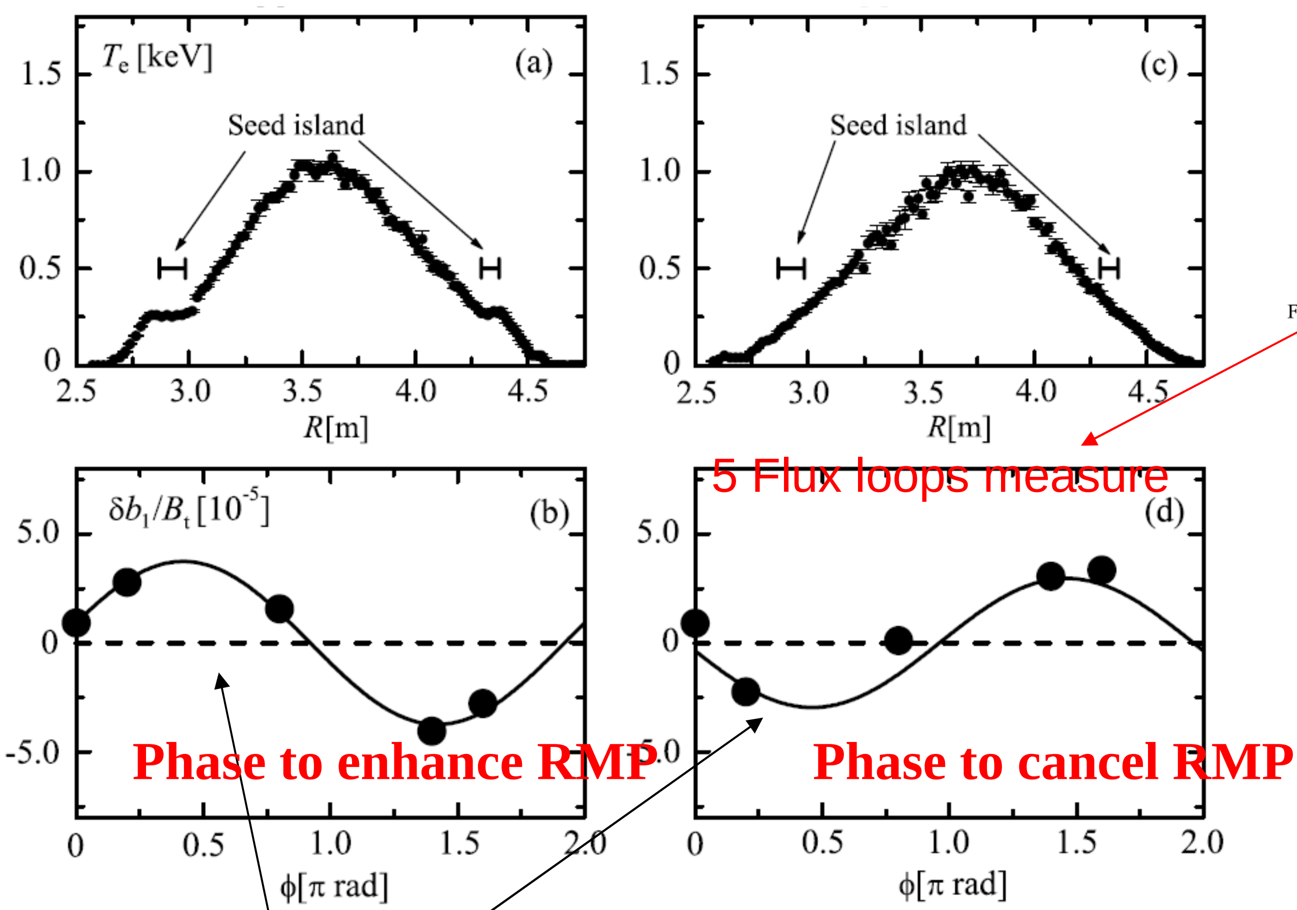
How does plasma shield RMP?

=>

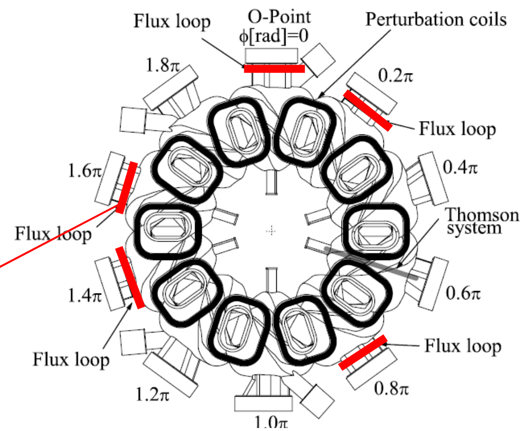
Accurate estimation of perturbed Mag. Field in plasmas is important

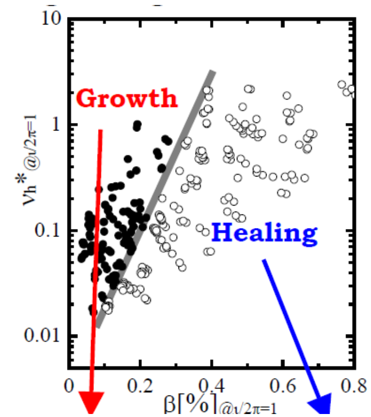
ref.
Y.Narushima, Nuclear Fusion (2008)
S.Sakakibara, 15th ICPP (Santiago de Chili, 2010)
Y.Narushima, 23rd IAEA Conf. (Daejon, 2010) EX/5-2

Island does NOT appear as RMP simply superposed in vac. (Heals/Enhansed)



Top view of LHD





Response of Perturb. Field from Plasmas

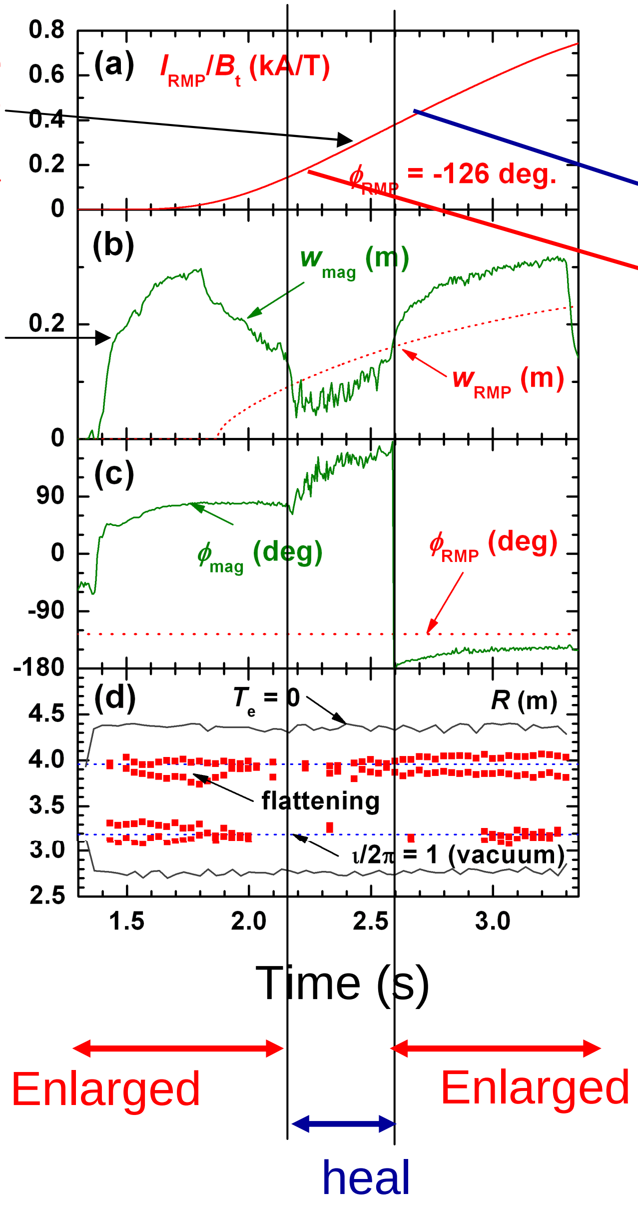
Response depending on β and ν*

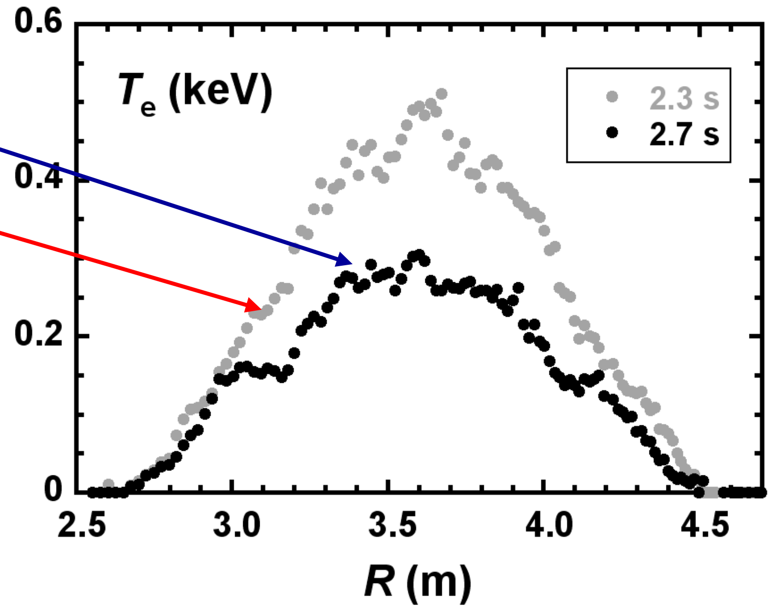
Where perturb. current flows inside/outside/on resonant surf?

Example of Dynamical response of Static island by MP of ex. coils

Time trace of RMP from Coil

Response of RMP from Plasma





Detail time response is under investigation

Discussion (Cont.)

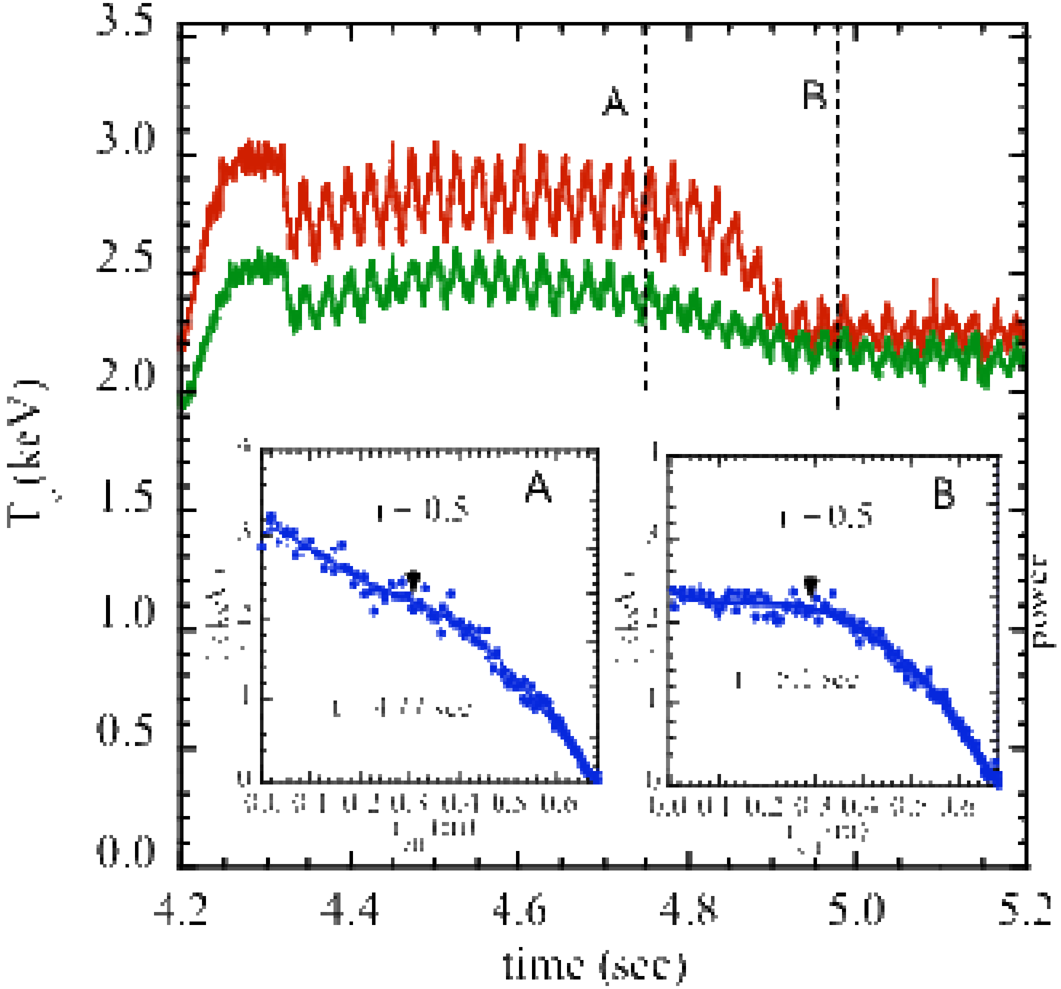
(2) In actual plasmas, mag. field is NOT stochastic.
=> Confirmation of stochasticity is important

In LHD, Response of transient electron thermal transport response by Power modulation of ECH
=>
Identify mag. island and stochastic structure of mag. field

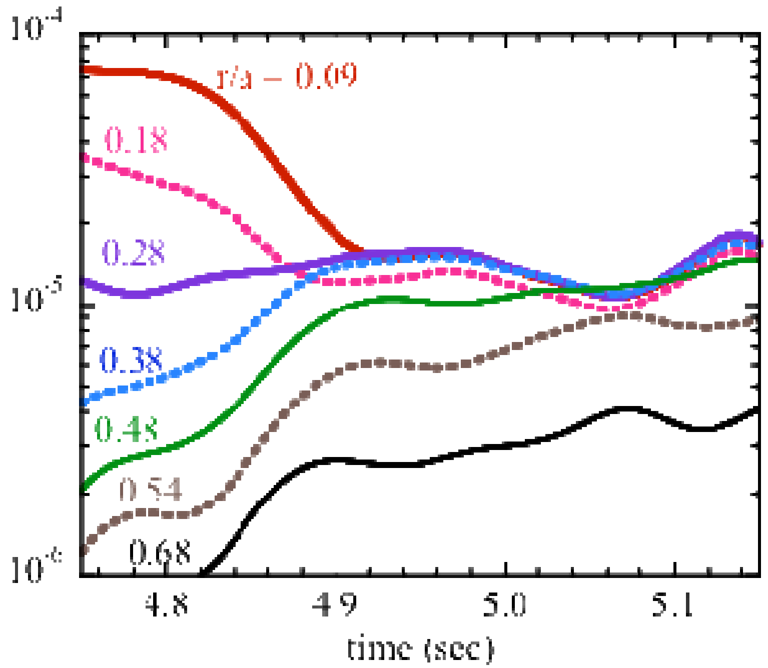
ref. K.Ida, 23rd IAEA Conf. (Daejon, 2010) EX/5-2

Modulation ECH

modulation ECH is applied to study the heat pulse propagation in the Te flat region



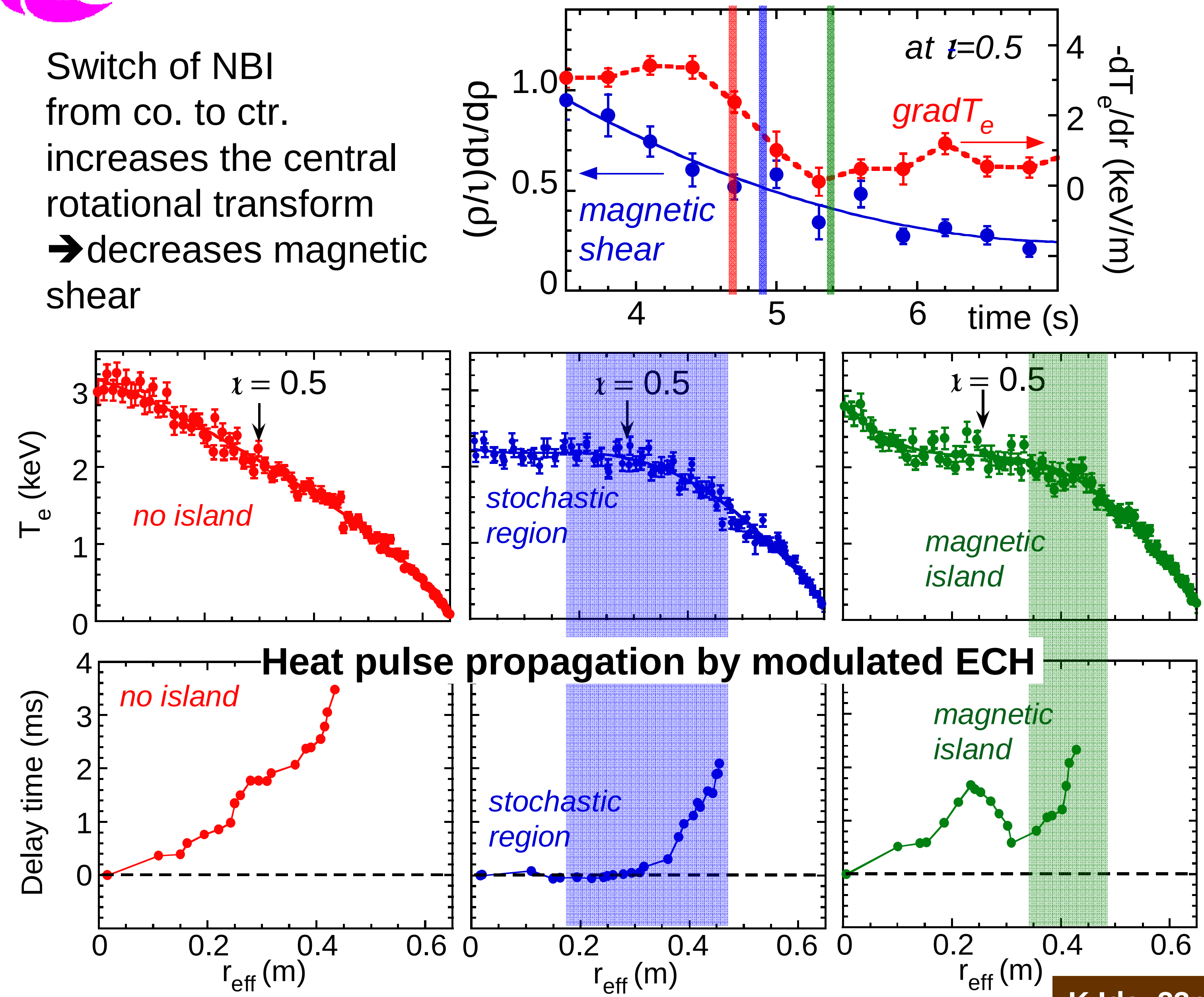
The modulation power (A^2) drops at r/a ~ 0
Increases at r/a ~ 0.5



Flattening of modulation power suggests that heat pulse propagates radially faster than the transport time scale determined by thermal diffusivity χe.

Identification of stochastization of magnetic fields

Switch of NBI from co. to ctr. increases the central rotational transform ➔decreases magnetic shear



K.Ida, 23rd IAEA (2010) EX/2-5

Discussion (Final page)

Future subjects in LHD exp.

 # Accurate estimation of perturbed mag. Field in plasmas

=>

Dynamical response of Static island

Response of Heavy Ion Beam trajectory

on Perturbed Field induced by external MP coils

 # Confirmation of Pred. Stochastic region

By Modulation of ECH

(analysis trough transport response)

Welcome to your proposal!!