# Edge and Internal Transport Barrier Formations in CHS

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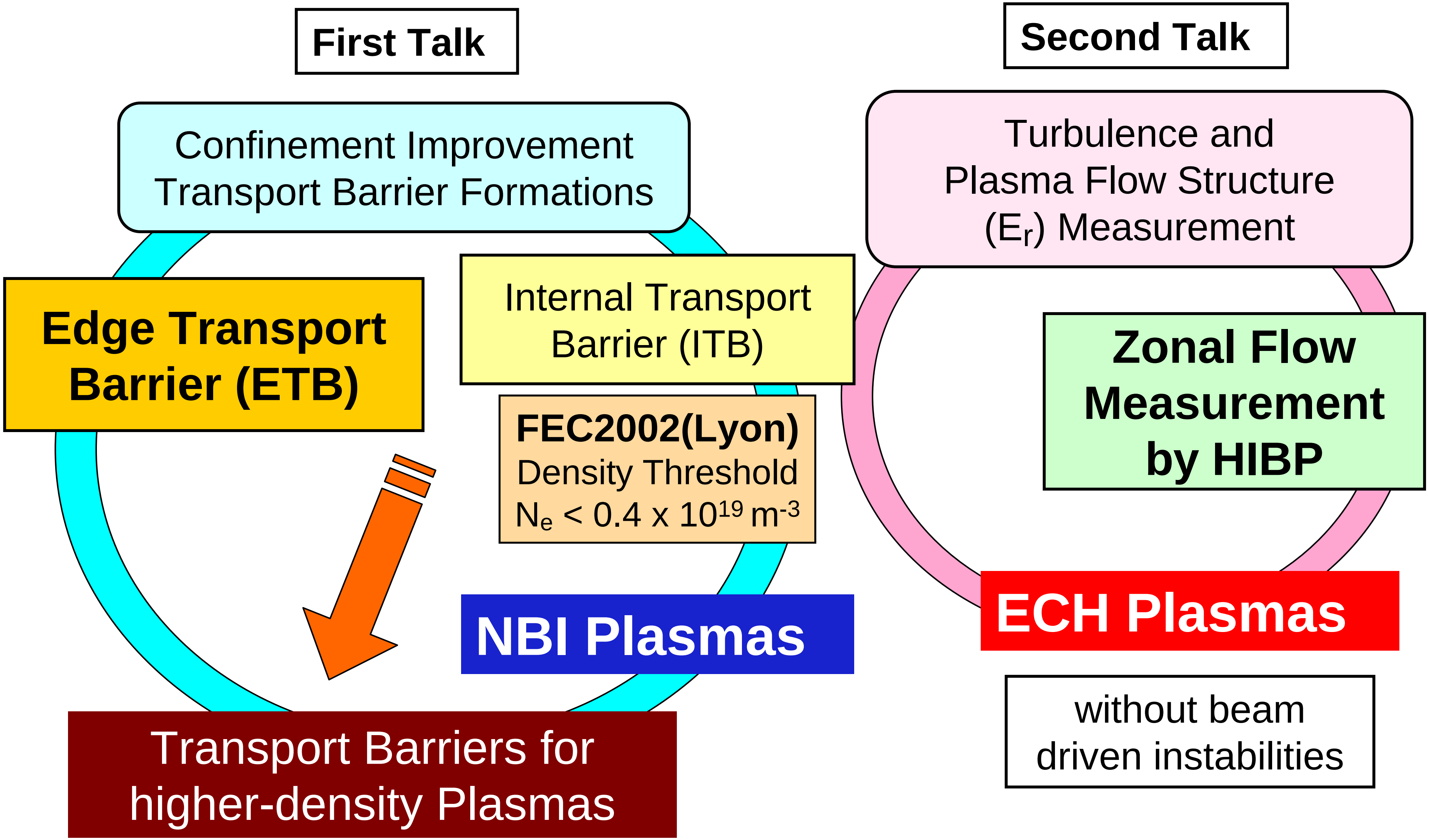
Rapported paper

# Identification of Zonal Flows in CHS and JIPPT-IIU

# Transcport Studies in CHS (Compact Helical System)



# Edge Transport Barriers (ETB) in CHS Experiment

1992 IAEA conference at Würzburg

K. Toi, S. Okamura, H. Iguchi, et al.
" Formation of H-mode like transport barrier in the CHS heliotron/torsatron "

with Ohmic current control

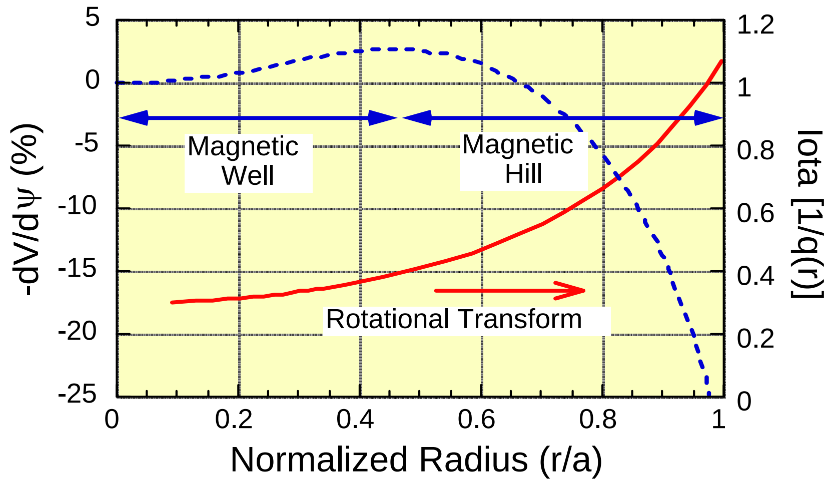
Ip ~ 30 - 40 kA for Bt ~ 1.2 - 1.4 T

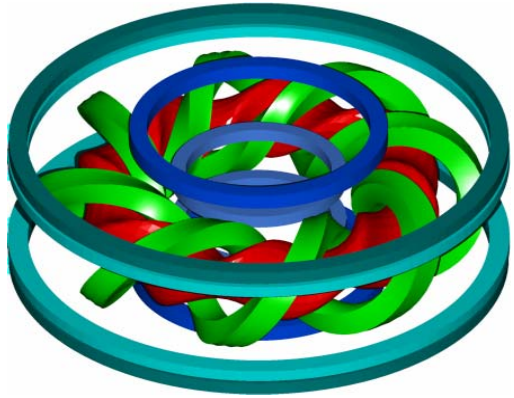
Iota(0) : 0.25 → 0.8
Iota(a) : 0.9 → 1.1

**Present Experiment**

1. Use standard configuration $R_{ax}$ = 92.1 cm
2. No ohmic current drive (< 10 kA bootstrap and beam driven current)
3. Two NBIs both in co-injection

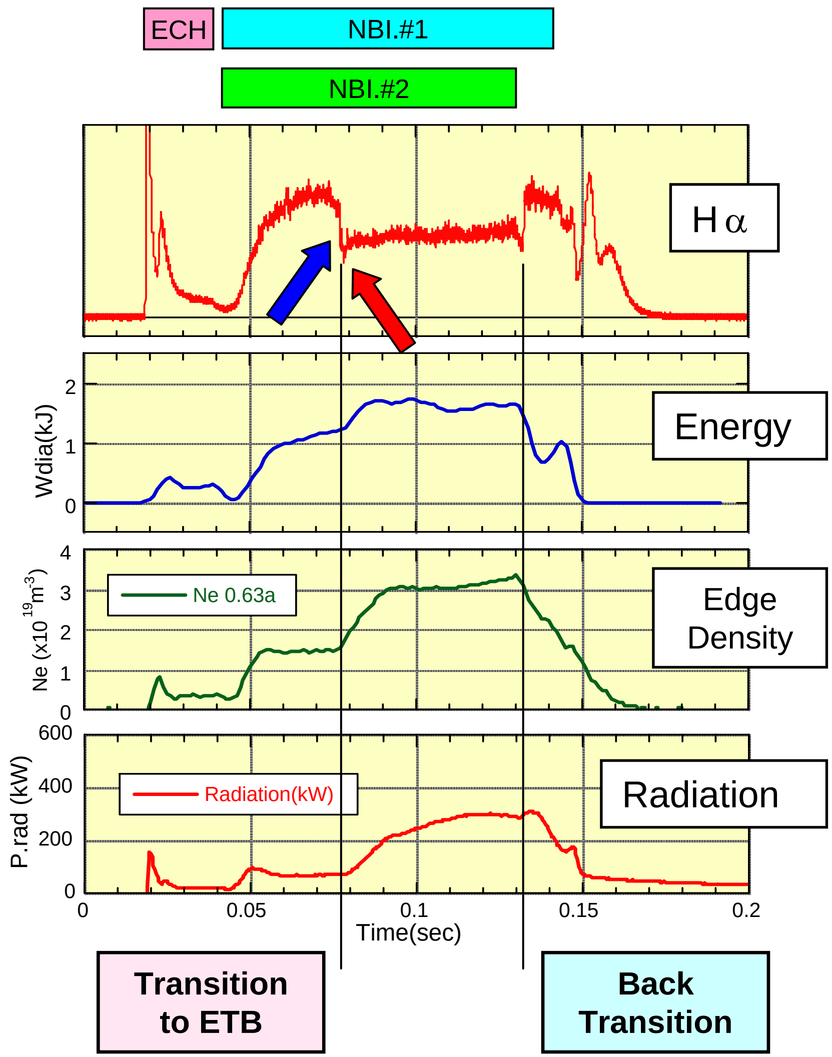
CHS
(Compact Helical System)
R = 1 m, $B_t$ < 2 T, $A_p$ = 5

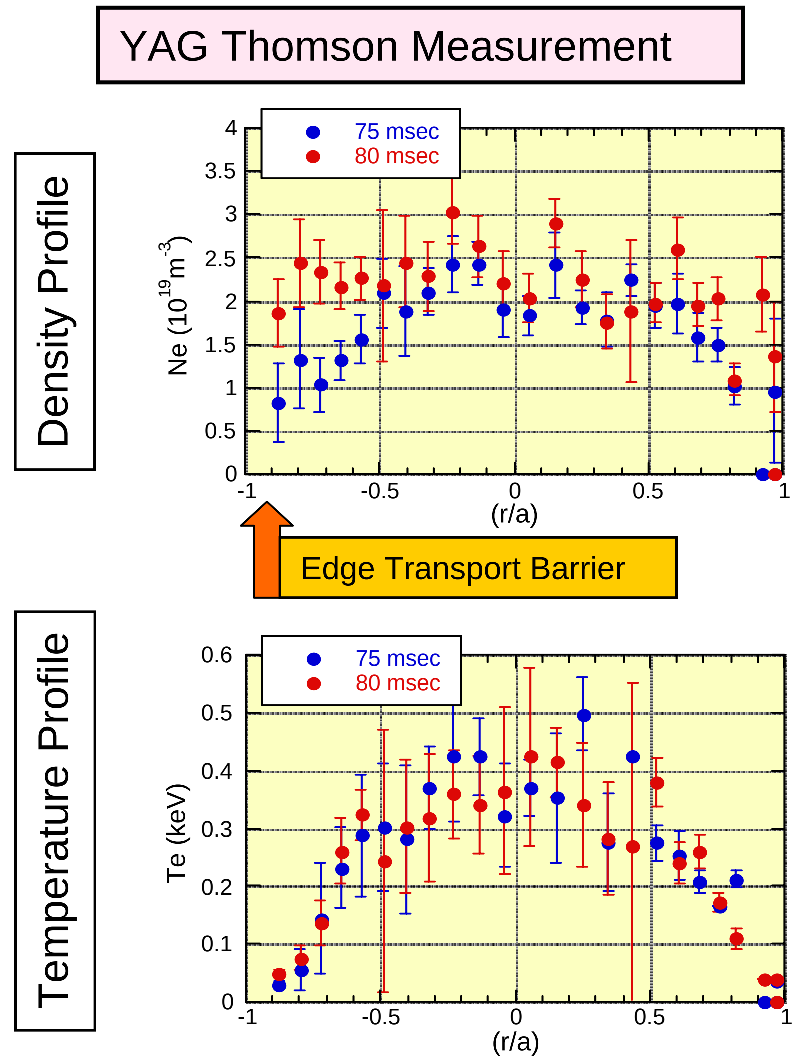


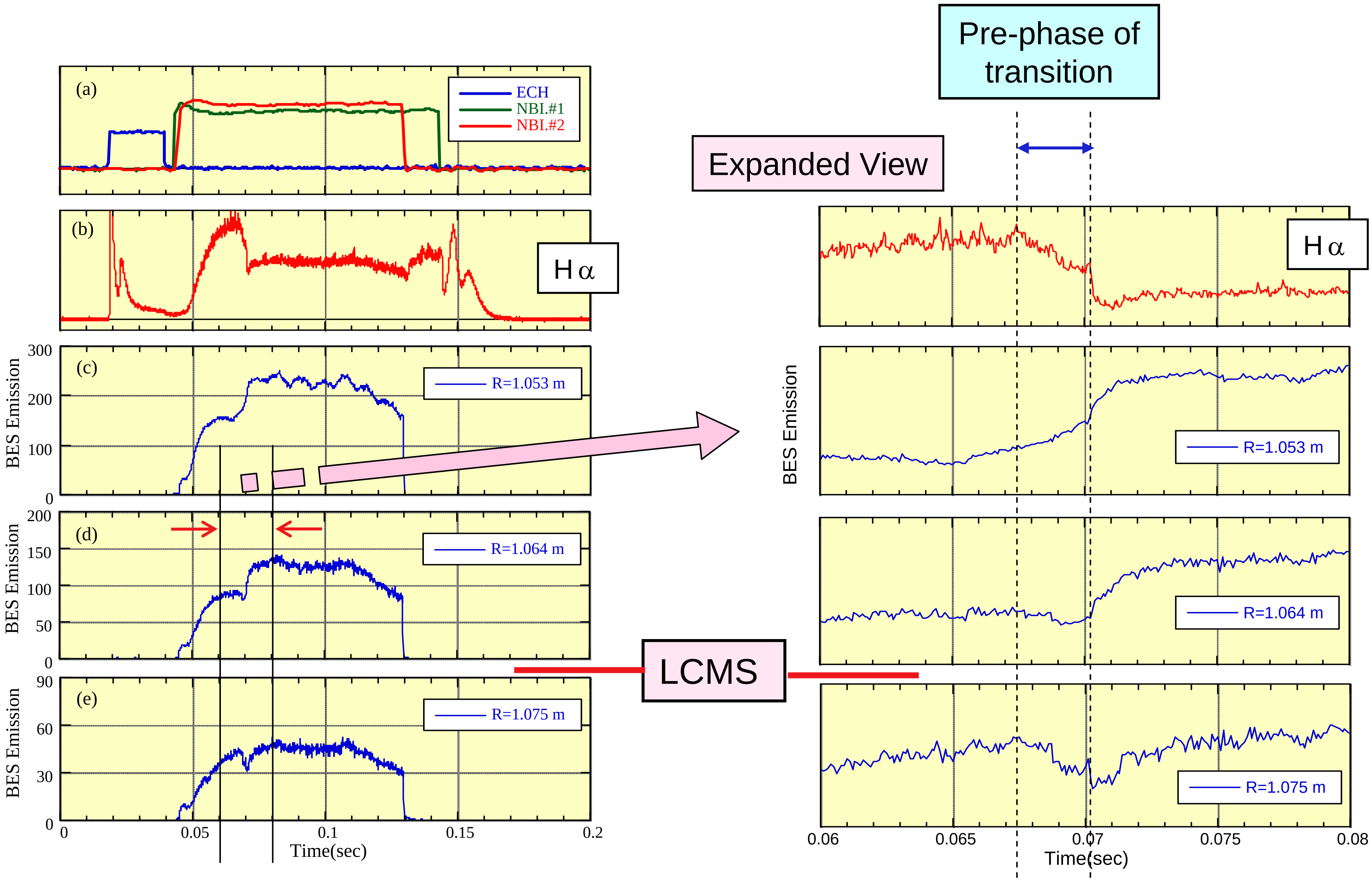
# H-mode Transition in NBI Heated Hydrogen Discharge

Magnetic Configuration : $R_{ax}$= 92.1 cm, κ= 1.22   $B_t$= 0.95 T, $P_{NBI}$= 0.6 MW



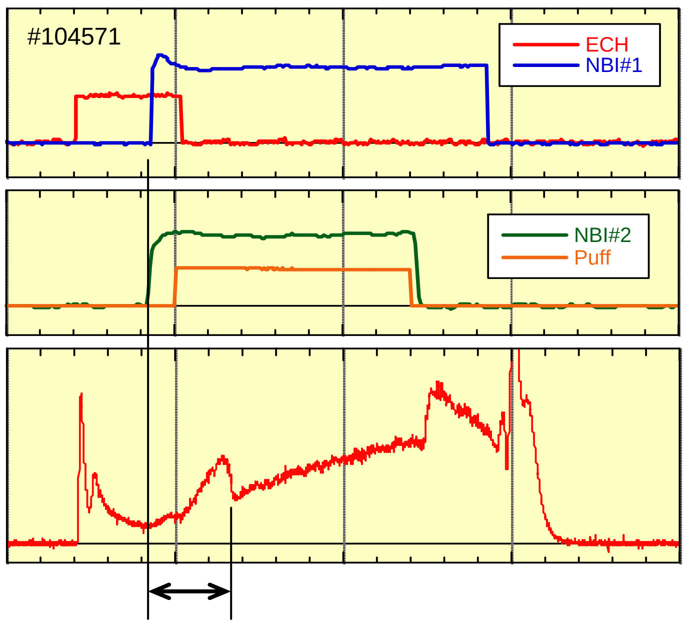
# Beam Emission Spectroscopy (BES) for Local Density Measurement



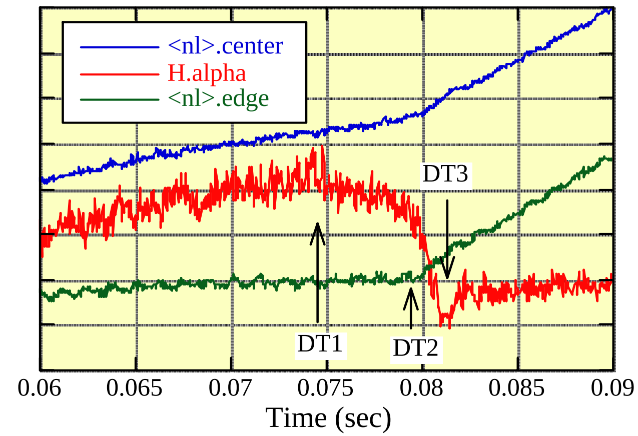
# Heating Power Dependence of Transition

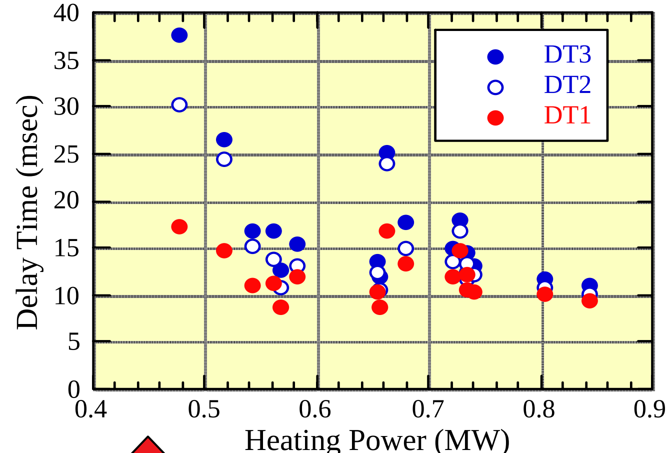
Magnetic Configuration : $R_{ax}$= 92.1 cm,

$\kappa$= 1.11 $B_t$= 0.95 T




Time delay from NBI start to transition



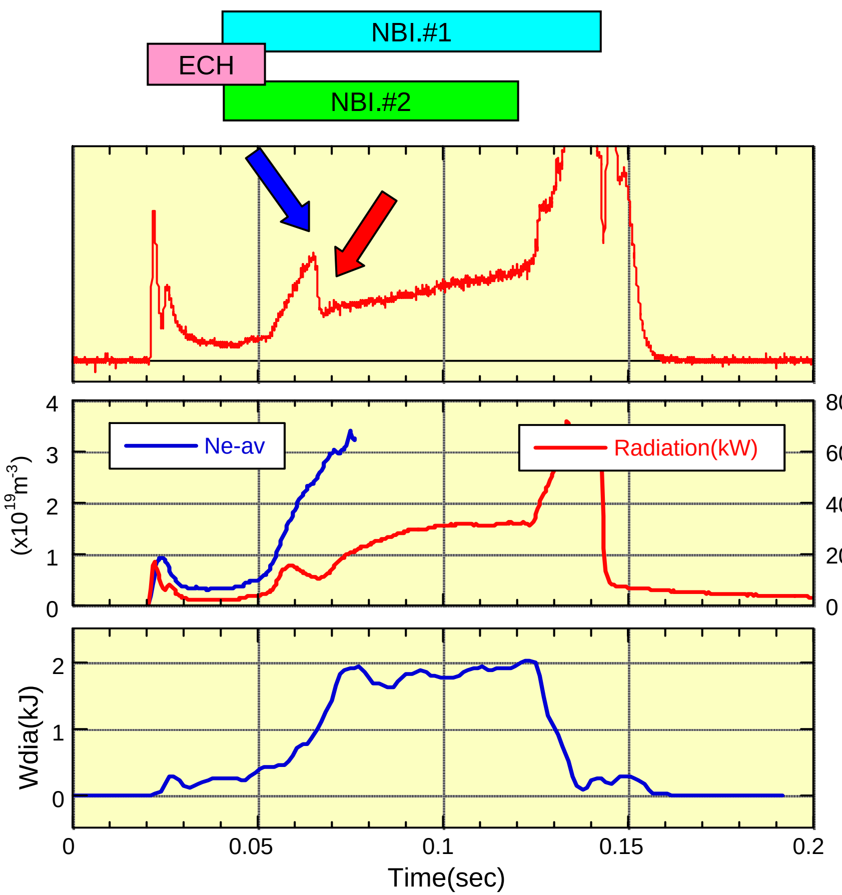




Power threshold for Ne = 2 x $10^{19}$ $m^{-3}$

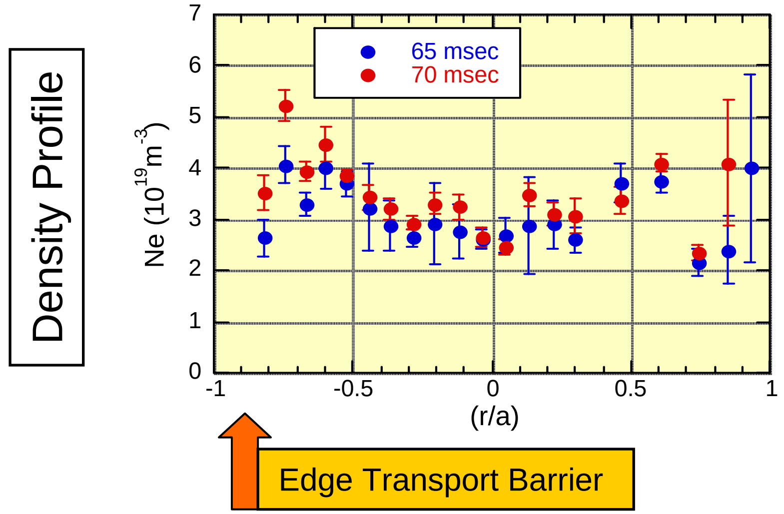
Twice larger than tokamak scaling

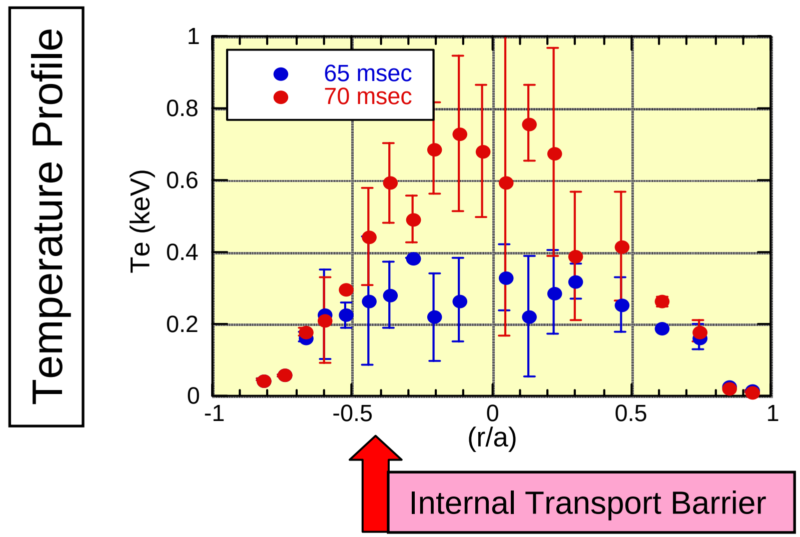
# ETB Formation with Improved Electron Confinement

When the density profile shape is hollow during the transition phase, improved electron confinement is simultaneously obtained with ETB for NBI plasma without ECH




YAG Thomson Measurement



# SUMMARY

1. Formation of transport barrier at plasma edge for particle flow was observed in CHS and dynamics of edge density profile was studied.
2. Heating power threshold exists for the transition. It is roughly two times larger than tokamak scaling.
3. When the density profile is hollow shape during the transition, the improvement of electron heat transport was simultaneously observed (without ECH) for middle density plasma ($N_e \sim 3 \times 10^{19}$ m$^{-3}$) which is above density threshold of previous ITB experiments in CHS.

# Identification of Zonal Flows in CHS and JIPPT-IIU

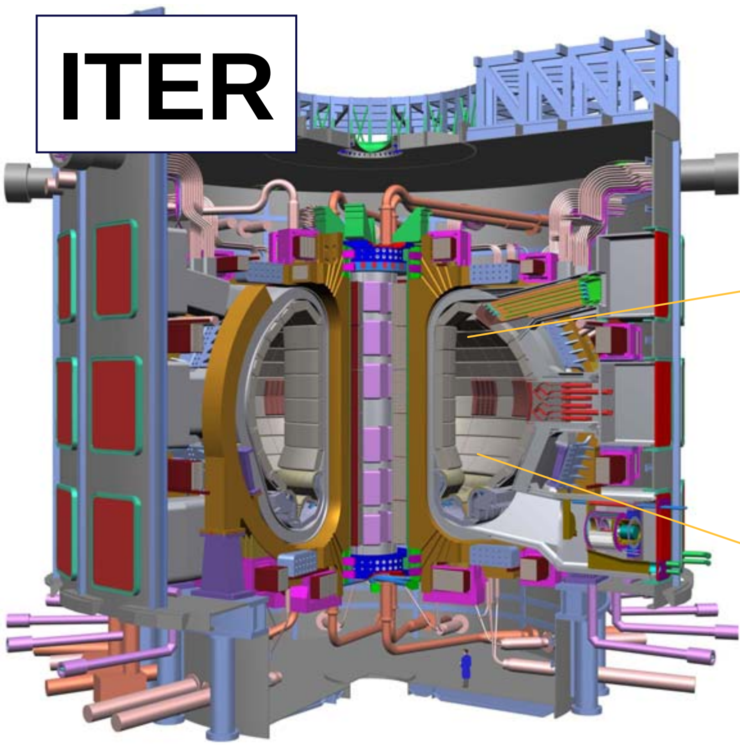
A. Fujisawa, K. Itoh, H. Iguchi, K. Matsuoka, S. Okamura, A. Shimizu, T. Minami, Y. Yoshimura, K. Nagaoka, C. Takahashi, M. Kojima, H. Nakano, S. Ohshima, S. Nishimura, M. Isobe, C. Suzuki, T Akiyama, K. Ida, S.-I. Itoh[1] and P. H. Diamond[2]

Y. Hamada, A. Nishizawa, T. Ido, T. Watari, K. Toi, Y. Kawasumi and JIPPT-IIU group

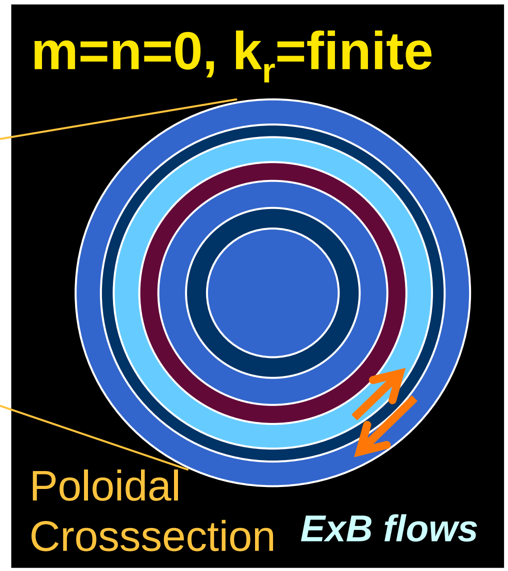
*National Institute for Fusion Science*
[1]*Kyushu University, RIAM*
[2]*University of California, San Diego*

# Zonal Flows

***Is that really present in toroidal plasma?***




**zonal flows: regulating turbulence and transport**




**Two branches**

1) **Zonal flow**
nearly zero frequency
*This finding!*

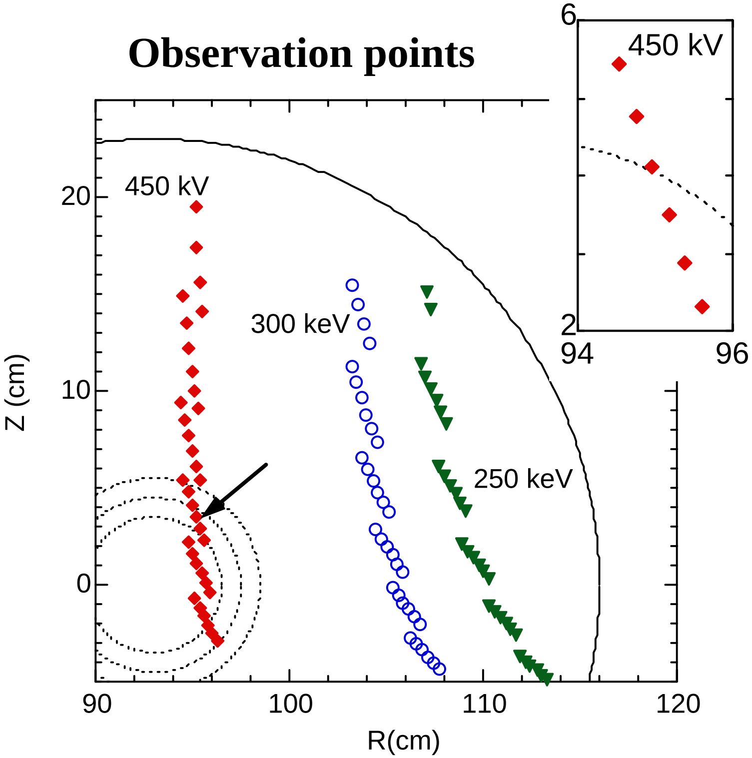
2) **Geodesic acoustic mode**
Oscillatory (f~ $C_s$/R)
-DIII-D(BES)
-ASDEX-U(Reflectometor)
-H1-heliac (probes)
-JFT-2M (HIBP)

***The zonal flow appears in E-field fluctuation in toroidal plasma***

***HIBP is a strong candidate for identification of zonal flows***

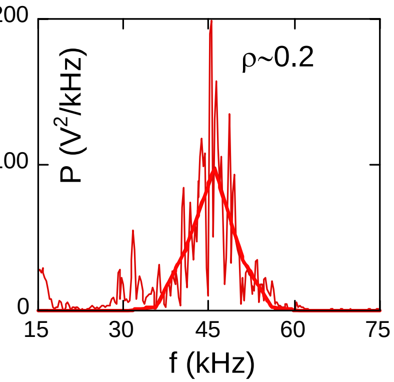
# HIBP in JIPPT-IIU Tokamak

### Observation points

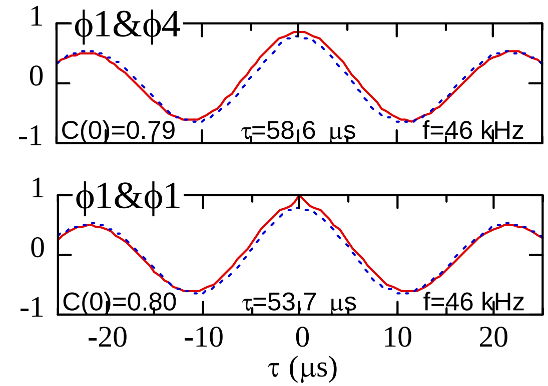



*Multi-channel measurements up to 6*

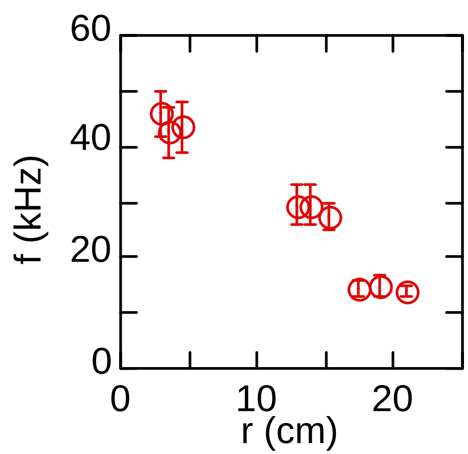
### Potential fluctuation



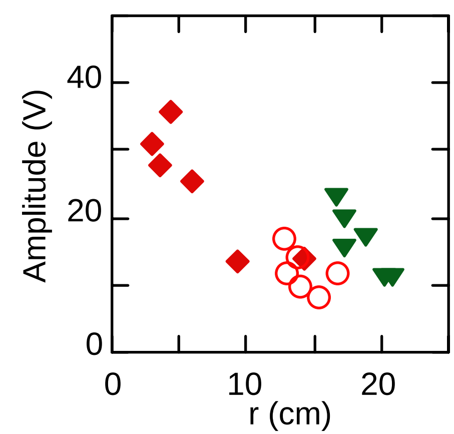

### M=0 symmetry




### Frequency vs. radius




### Amplitude vs. radius

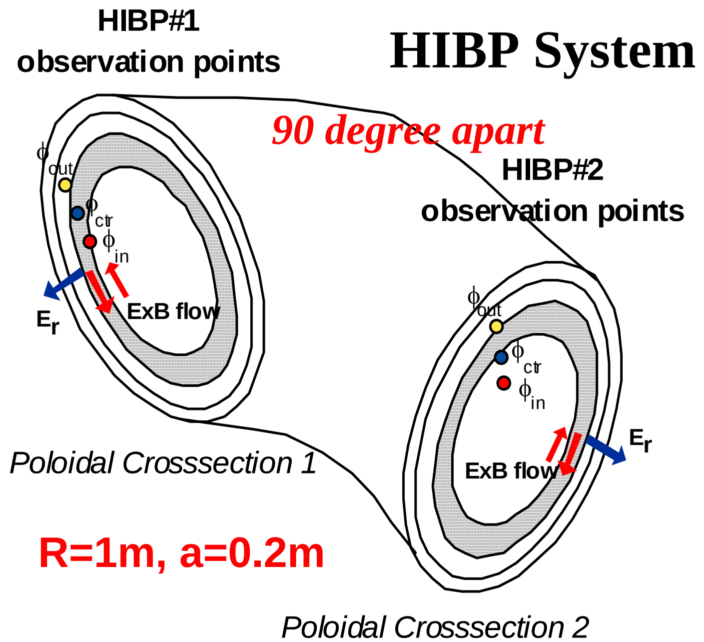



## Coherent oscillation was found to show GAM characteristics

# Dual HIBPs in CHS

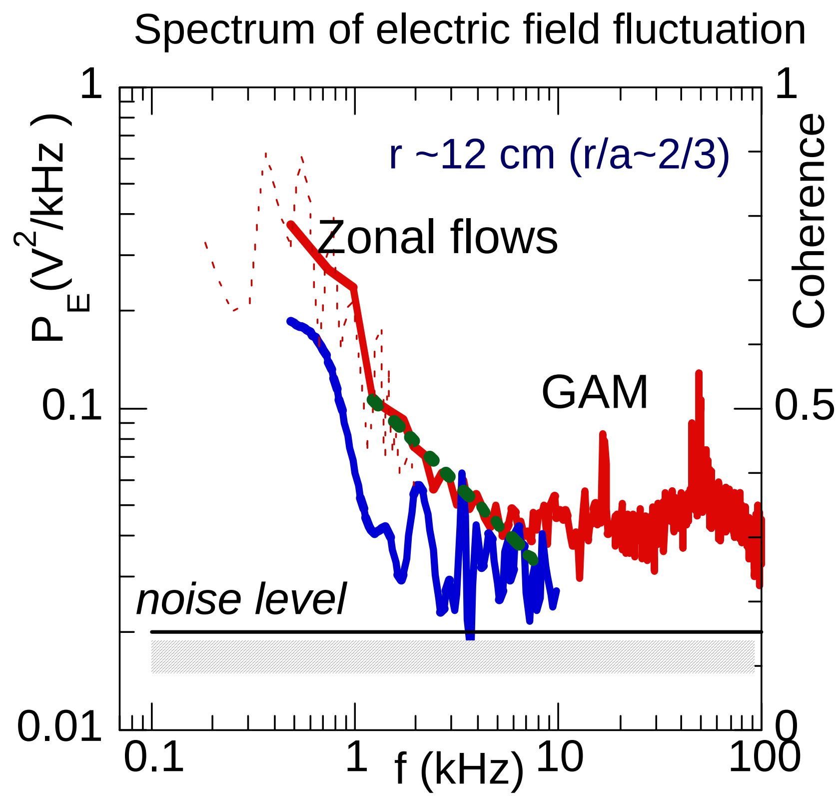
### *Electric field measurement*

$$\Delta\phi = E_r \Delta r = \phi_{out} - \phi_{cen}$$




### *ECR-heated plasma*

$n_e$=5x10$^{12}$cm$^{-3}$ $T_e$=1.5 keV $T_i$=0.1 keV



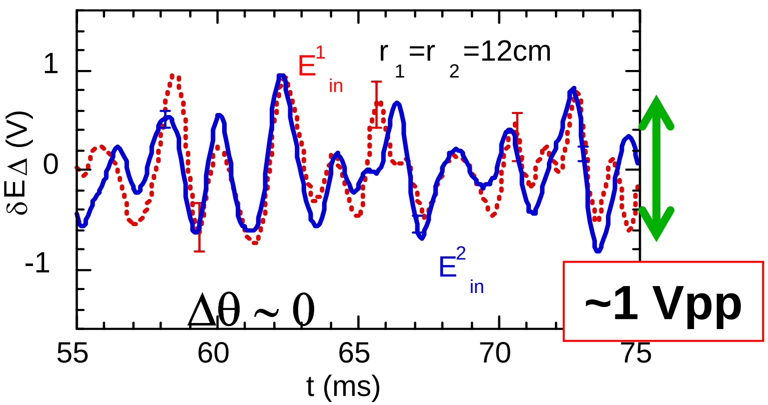

**Low frequency fluctuation (f<1kHz) shows a long-range correlation**

**Zonal flow is identified**

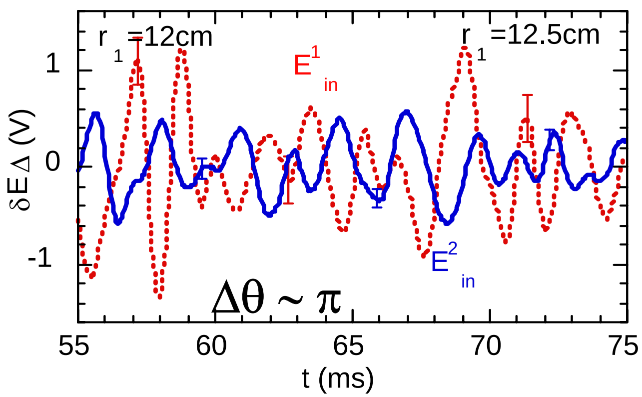
# Dynamics and Structure of Zonal Flows

**A numerical filter is used to remove high frequency (f>1 kHz)**

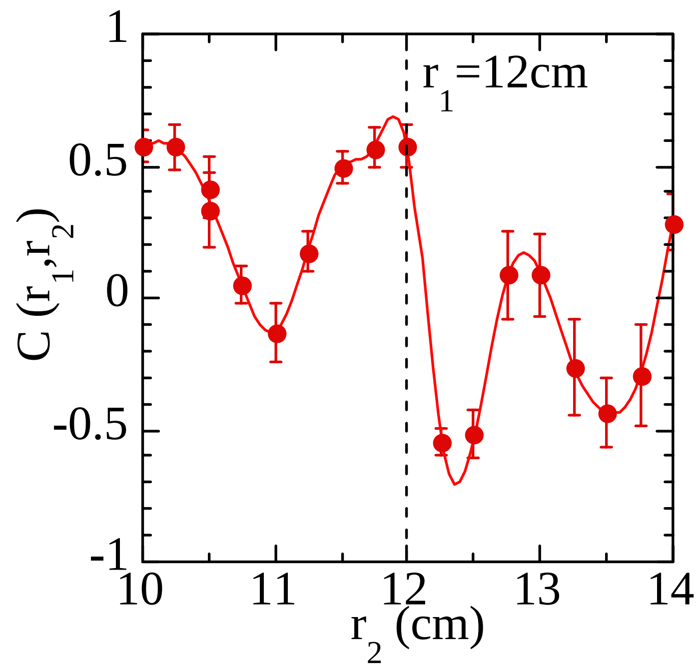
on a magnetic flux surface




on slightly different magnetic flux surfaces




$$C_{crs}(r_1, r_2) = \langle E_1(r_1) E_2(r_2) \rangle / \sqrt{\langle E_1^2(r_1) \rangle \langle E_2^2(r_2) \rangle}$$

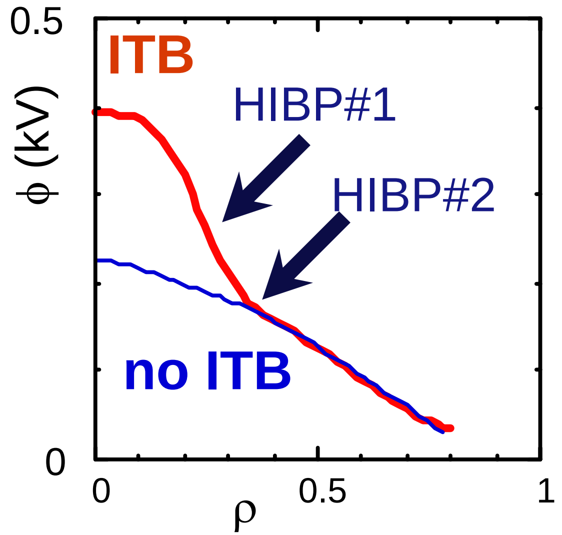



***Radial wavelength ~1.5 cm***

**Dynamics and radial structure of zonal flows are measured.**

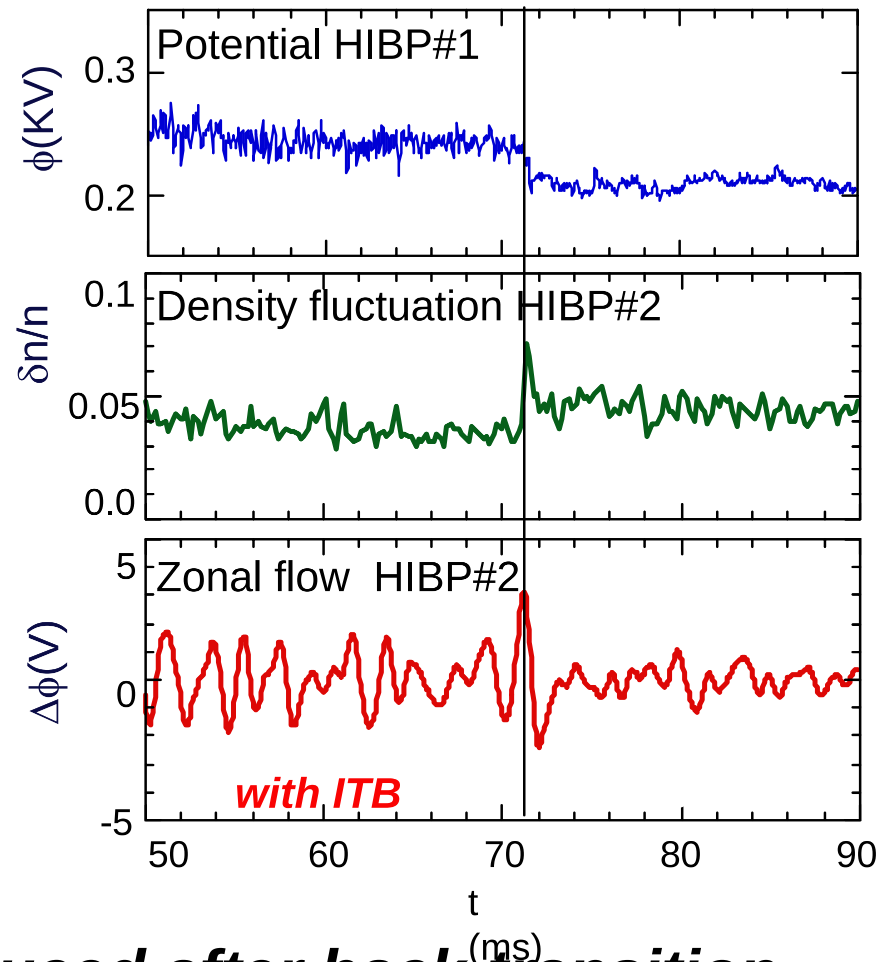
# Confinement & Zonal Flow

Bifurcated states in CHS




*Dual HIBPs caught the exact moment of spontaneous transition in a discharge.*

Time evolution of turbulence &zonal flow




***Zonal flow amplitude is reduced after back-transition***

# Summary

***JIPPT-IIU***

1. Coherent oscillation with GAM characteristics was found in the HIBP measurements on JIPPT-IIU tokamak.

***CHS***

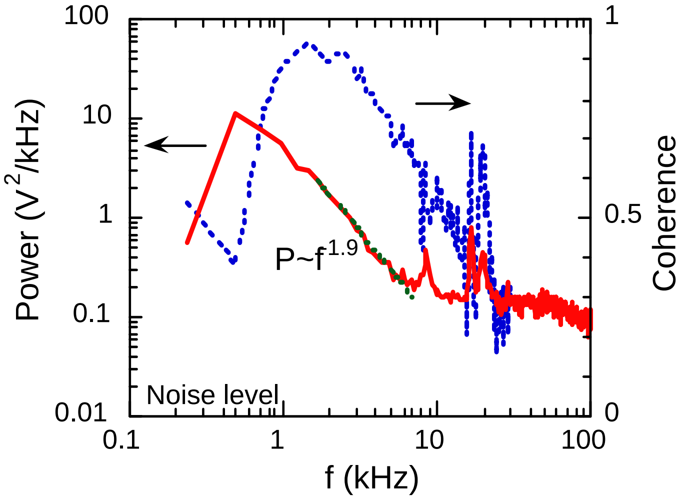
1. Heavy ion beam probe successfully measured the local electric field fluctuation spectrum.

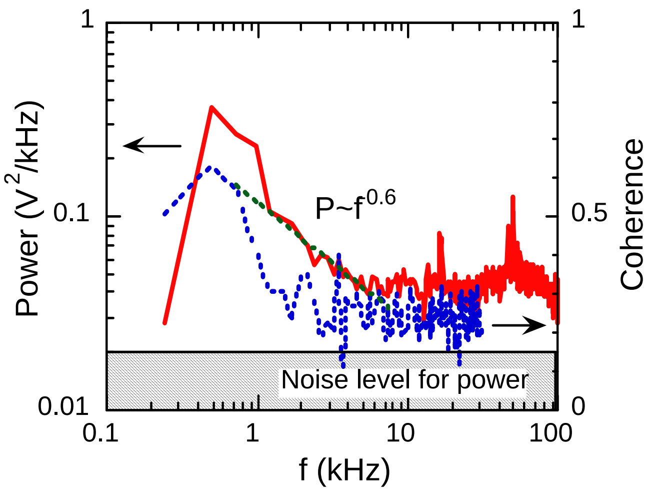
2. Dual HIBPs confirm the presence of zonal flows (f<~1kHz) by showing a long-distance correlation with toroidal symmetry in electric field fluctuation

3. The amplitude of zonal flow is about 1 V. The radial wavelength is ~1.5 cm.

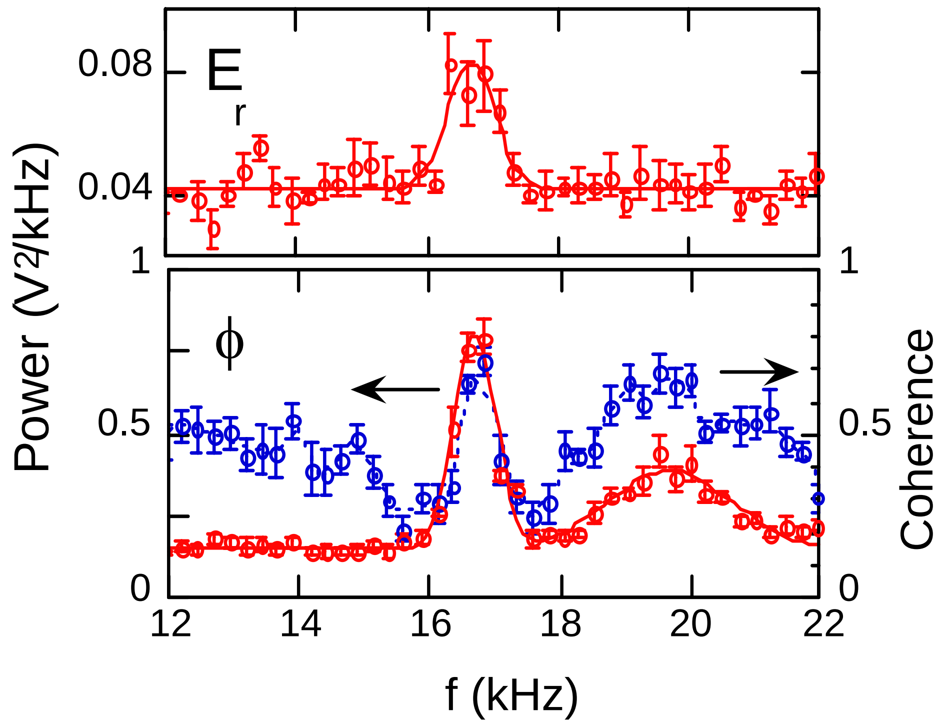
4. The amplitude of the zonal flows is found to be reduced in the barrier location after the transport barrier decayed.

# GAM in CHS

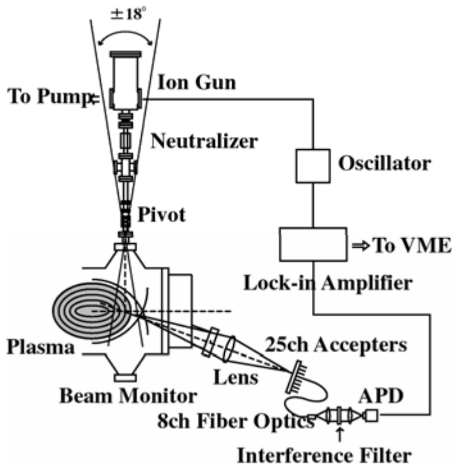


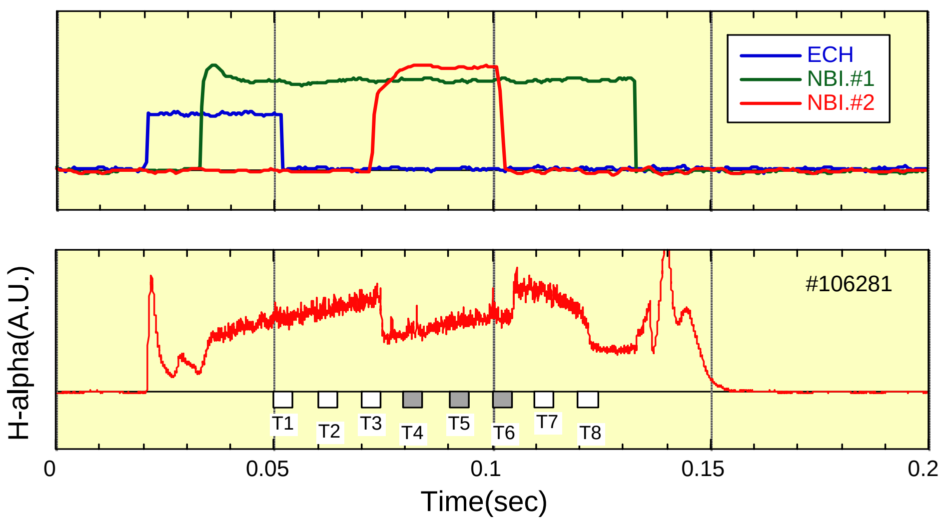



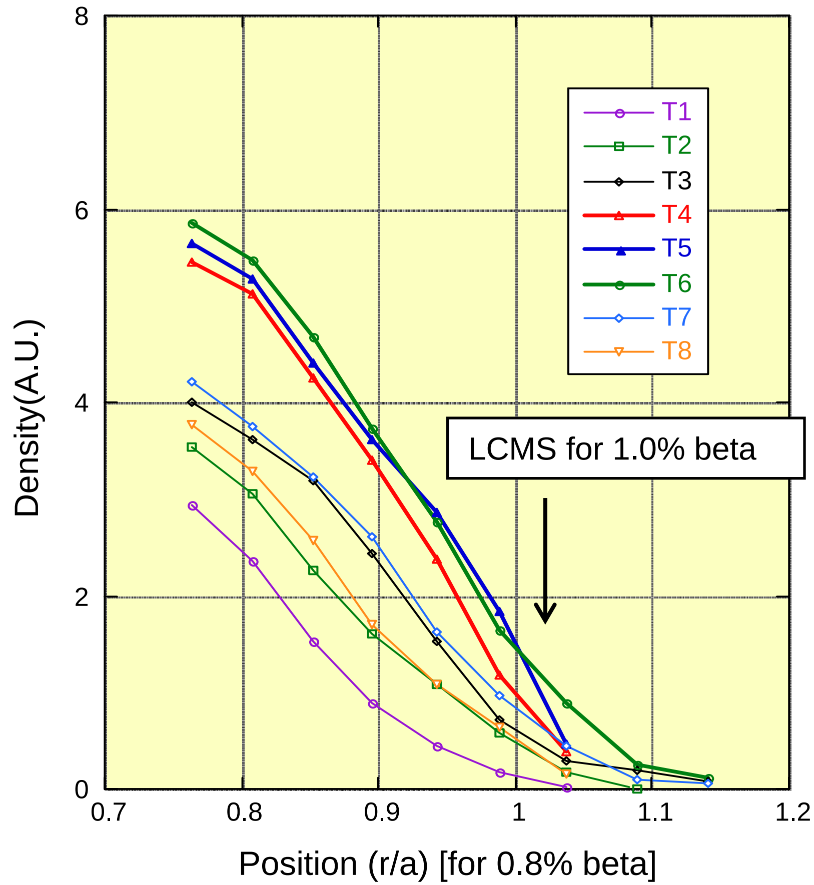

## GAM in potential & electric field



# Lithium Beam Probe Measurement of Edge Density Profile



# Confinement Improvement in Comparison with Scaling

New International Stellarator Scaling

H. Yamada, et al. :
This conference EX/1-5

$$\tau_E^{ISS04v3} = 0.148 a^{2.33} R^{0.64} P_{abs}^{-0.61} \overline{n}_e^{0.55} B^{0.85} ɫ_{2/3}^{0.41}$$

for CHS/ATF/Heliotron-E renormalization factor = 0.42

Maximum energy of each discharge is plotted as a function of average density

Confinement improvement of about 40% is given by ETB formation