Studies of Configuration Control Effects on Dynamic Behavior of Heliotron J Plasmas

Presented by

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IAE, Kyoto University

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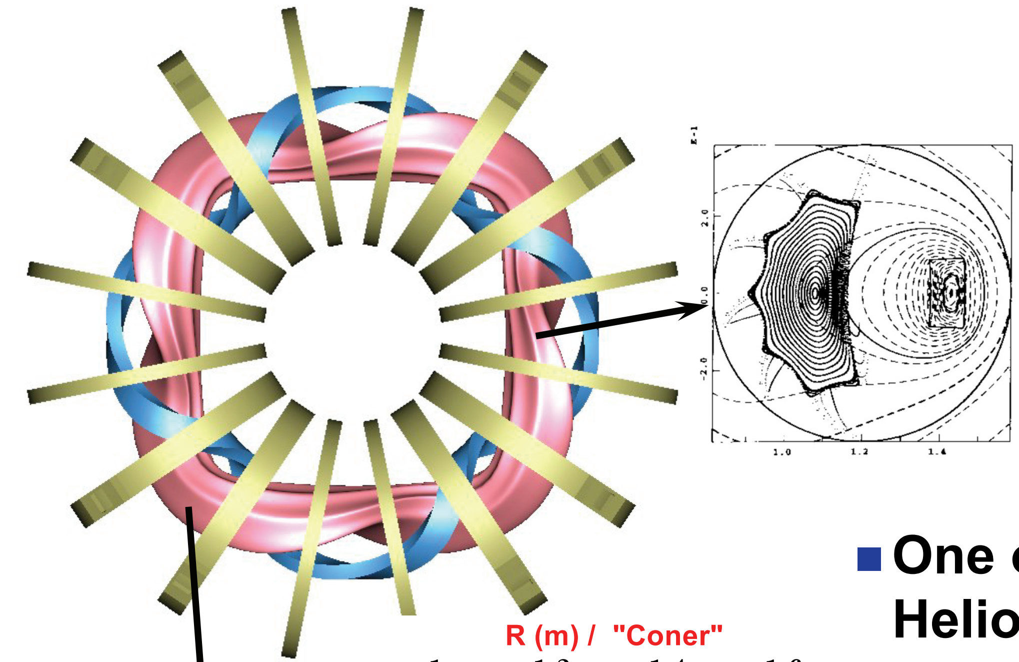
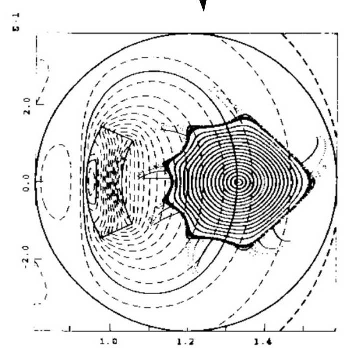
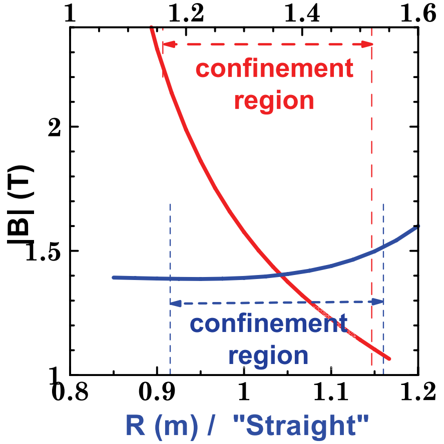
Outline

- Introduction
- Control of Field Configuration
  - Control of vacuum configuration
  - Effects of plasma pressure & current (Numerical calculation)
- Dynamic Behavior during a Discharge
  - Change of Field Topology by Plasma Current
  - Onset condition for Transition Phenomena for NBI-only Plasma
- Summary

The Heliotron J device is a flexible concept-exploration facility for the helical-axis heliotron concept.



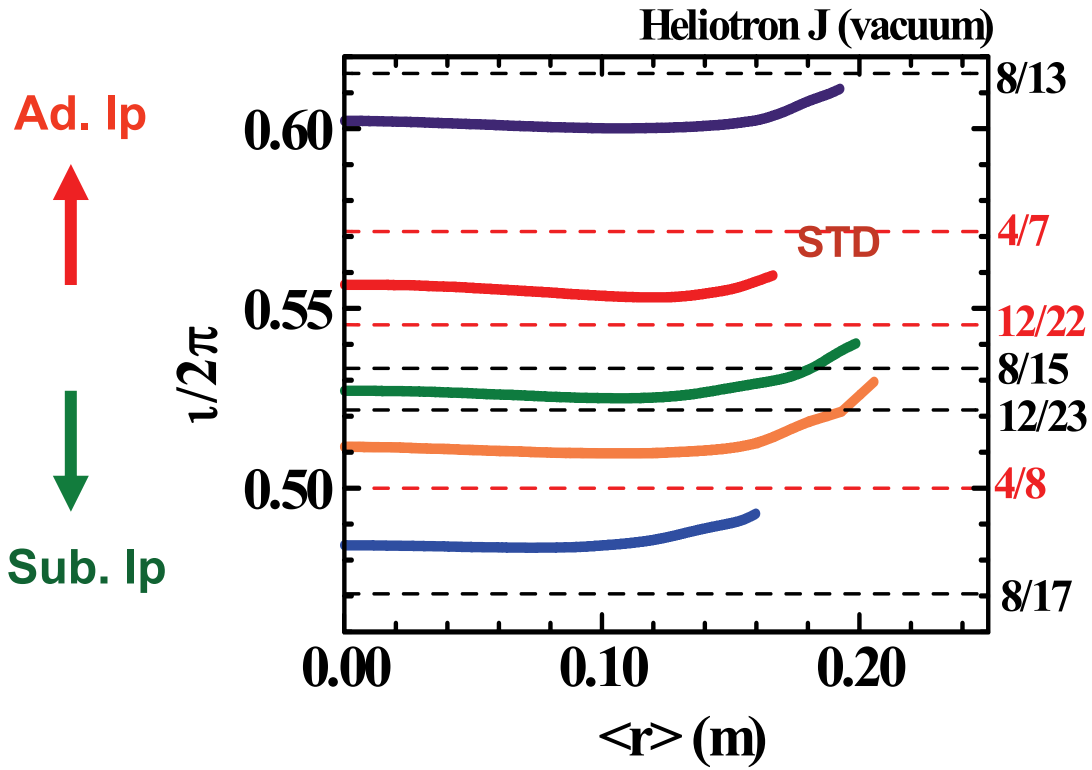




- **Basic idea of the concept:**
  - Bumpiness control in the field harmonics for better confinement
  - Introduction of magnetic well for MHD activity control
- **One of the major objectives of Heliotron J program:**
  - Examination of the configuration effects on the plasma performance.
    - » Rotational transform control, $\iota/2\pi$
    - » Bumpiness control, $\varepsilon_b = B_{04}/B_{00}$
    - » *Effects of non-inductive plasma current (bootstrap, NBCD, ECCD)*

The configuration can be controlled by changing the five sets of the coil current in Heliotron J.

Example of Vacuum Rotational Transform Control



- ☞ The bumpiness is mainly controlled by changing the coil current ratio of two toroidal-coil sets, I_{TA} : I_{TB}.
- ☞ $\iota(r)/2\pi|_{vac}$ can be controlled by mainly changing the current ratio of the helical coil to the toroidal coils.

- ☞ The vacuum ι/2π is usually set not to cross the low-mode rational.
- ☞ However, plasma pressure and toroidal plasma current can modify the ι/2π-profile and make the field topology change in the core and peripheral regions.

Effect of Plasma Current on Field Topology

- HINT2 Calculation for STD ($\iota(a)/2\pi \approx 0.56$) configuration -

$$\beta(s) = 0.5\cdot(1-s)^2\ [\%],\ \ j_p = j_{p0}\cdot(1-s)^2$$

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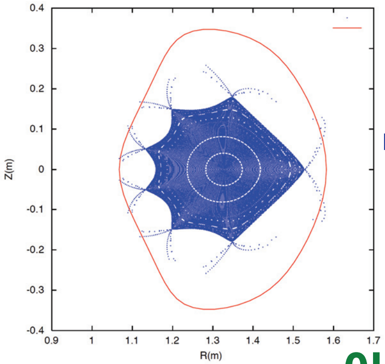
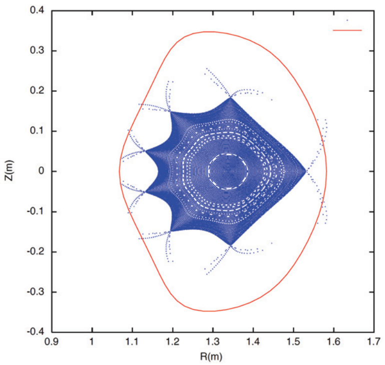
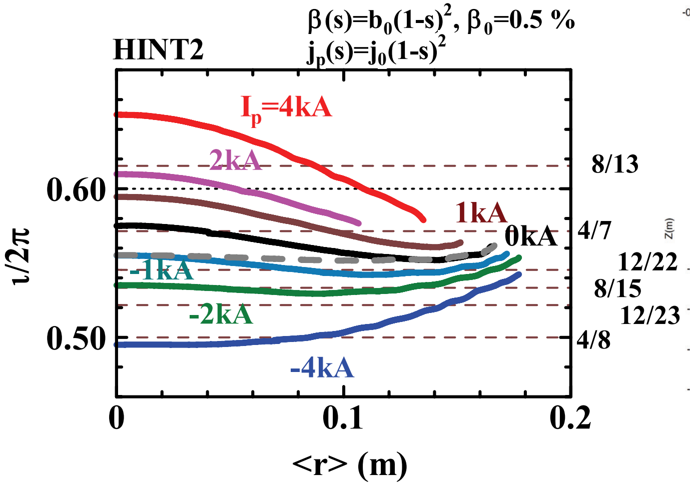
- Plasma current can modify not only the $\iota/2\pi$-profile but also the "shape" of magnetic surfaces.
- Asymmetric effect of plasma current due to the "proximity" to a low-mode rational number.

vacuum

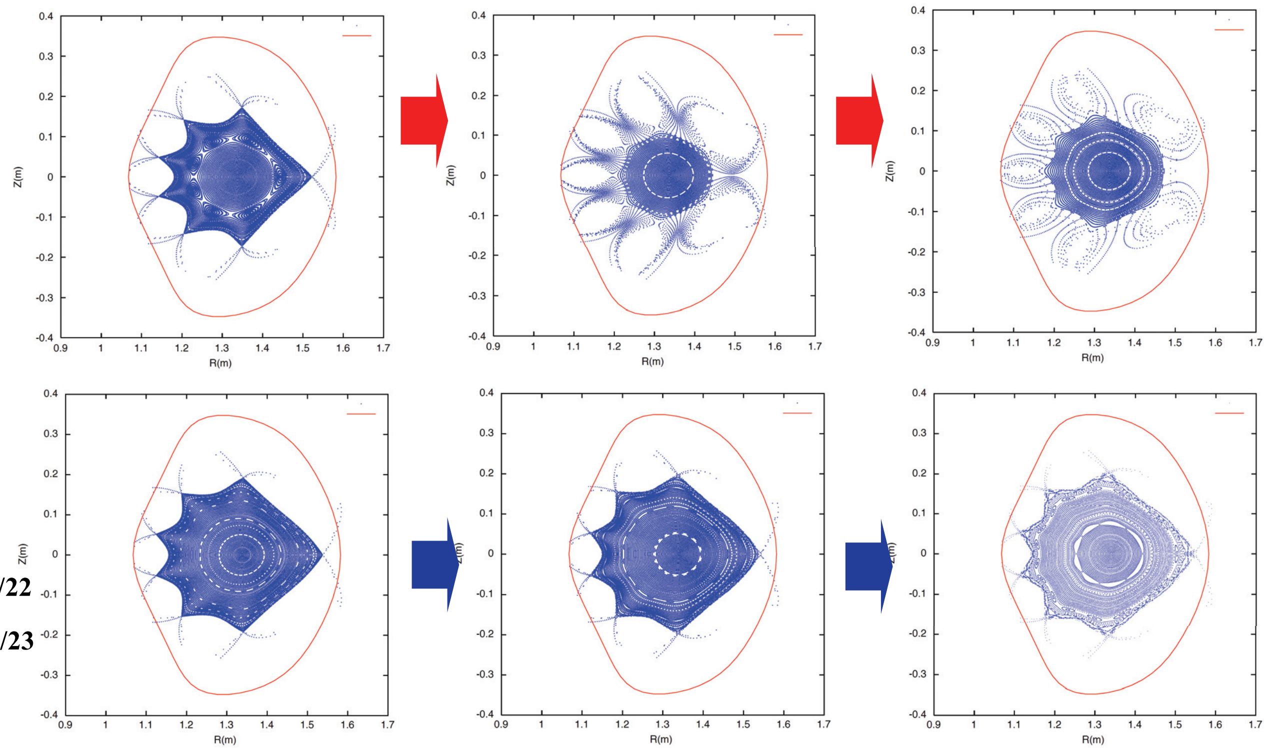


0kA





ad. 1kA | ad. 2kA | ad. 4kA



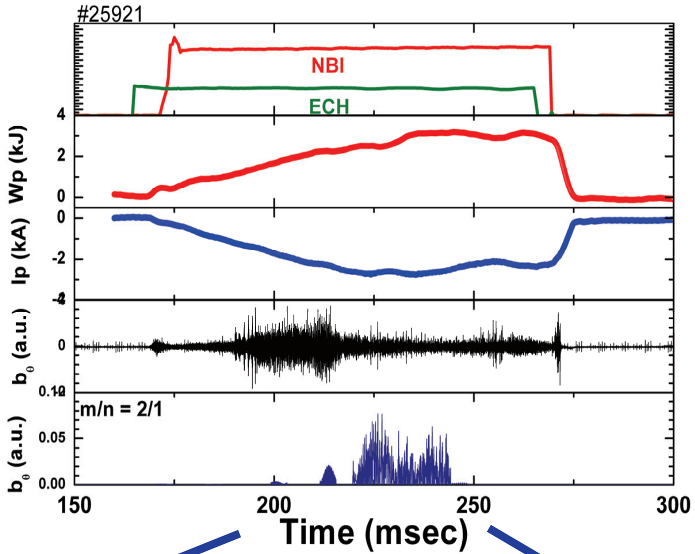
sub. 1kA | sub. 2kA | sub. 4kA

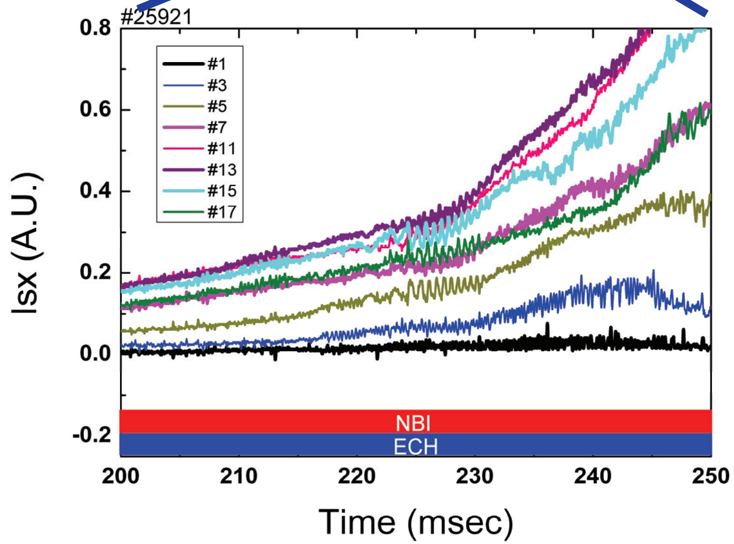
Behavior of MHD-activity indicates the change of ι/2π(r) caused by plasma current.

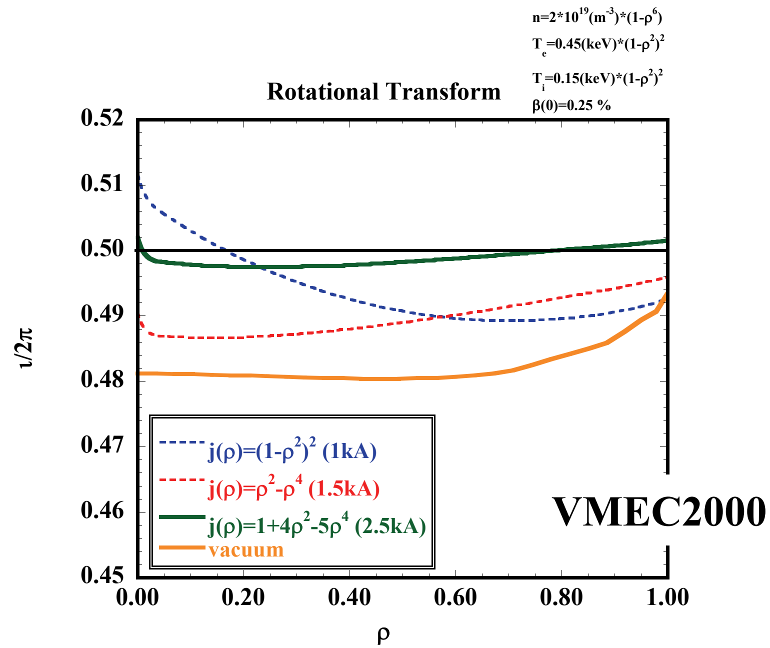
Heli

P2-046 (Wed.) G. Motojima, et al.

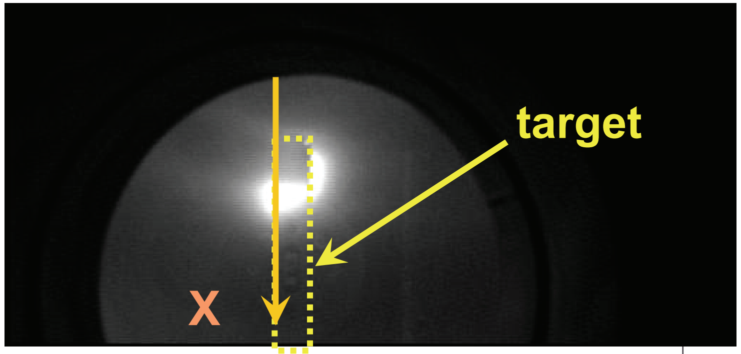
- In this vacuum condition (ι(a)/2π = 0.49), there is no rational of $m/n = 2/1$.
- However, The m/n=2/1 resonant mode has been observed in ECH + Co-NBI plasma.
- This indicates that ι(r)/2π is modified by the plasma pressure and toroidal current, resulting in crossing the rational of $m/n = 2/1$.



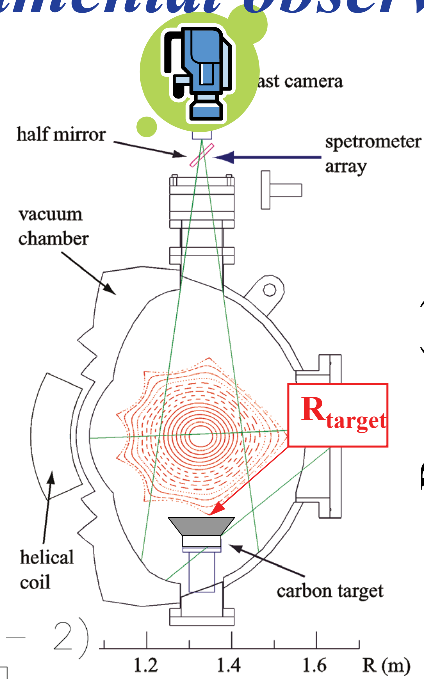


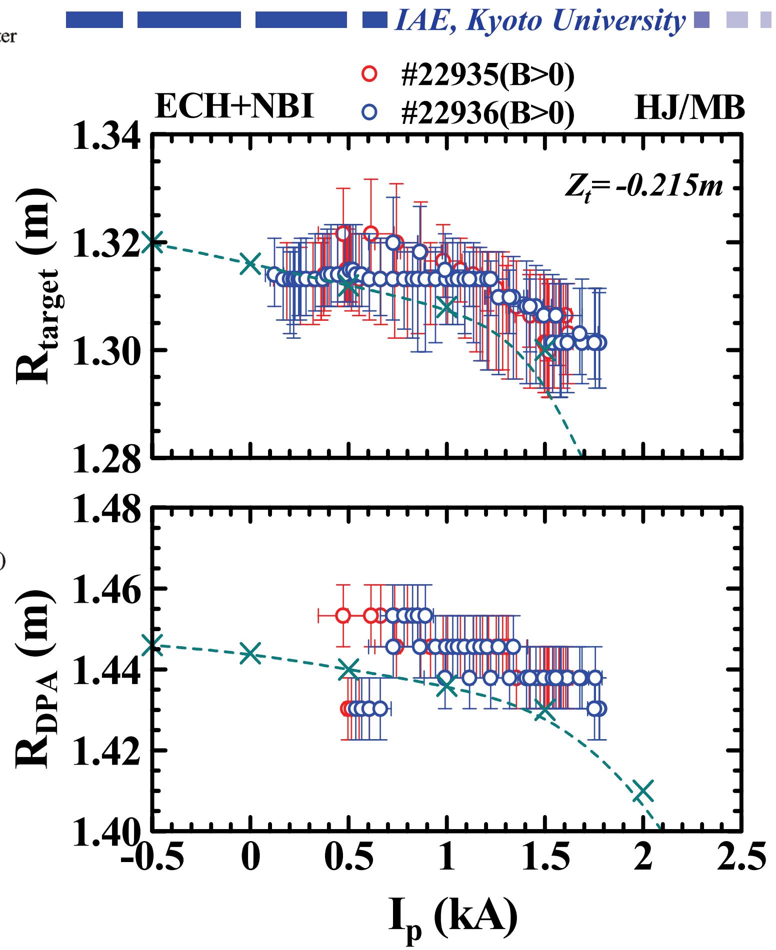


Plasma current can modify the edge field topology.
- Experimental observations -

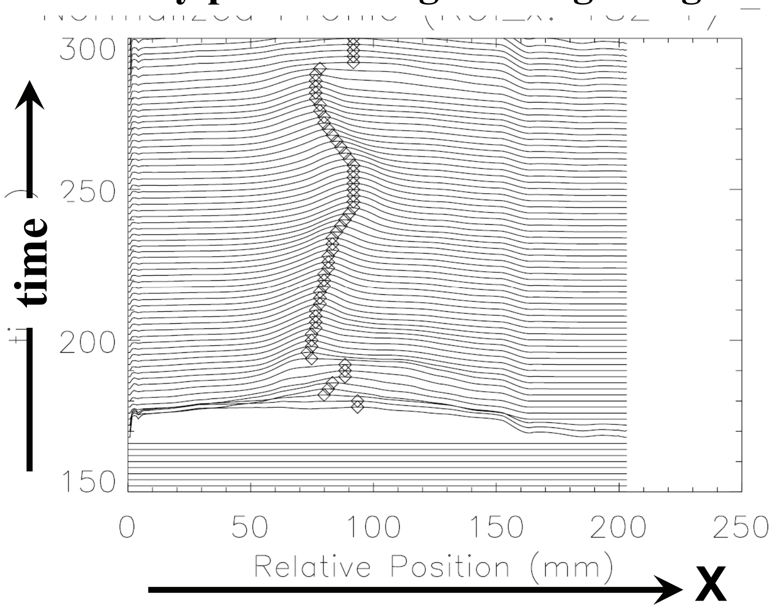


Target Camera Image



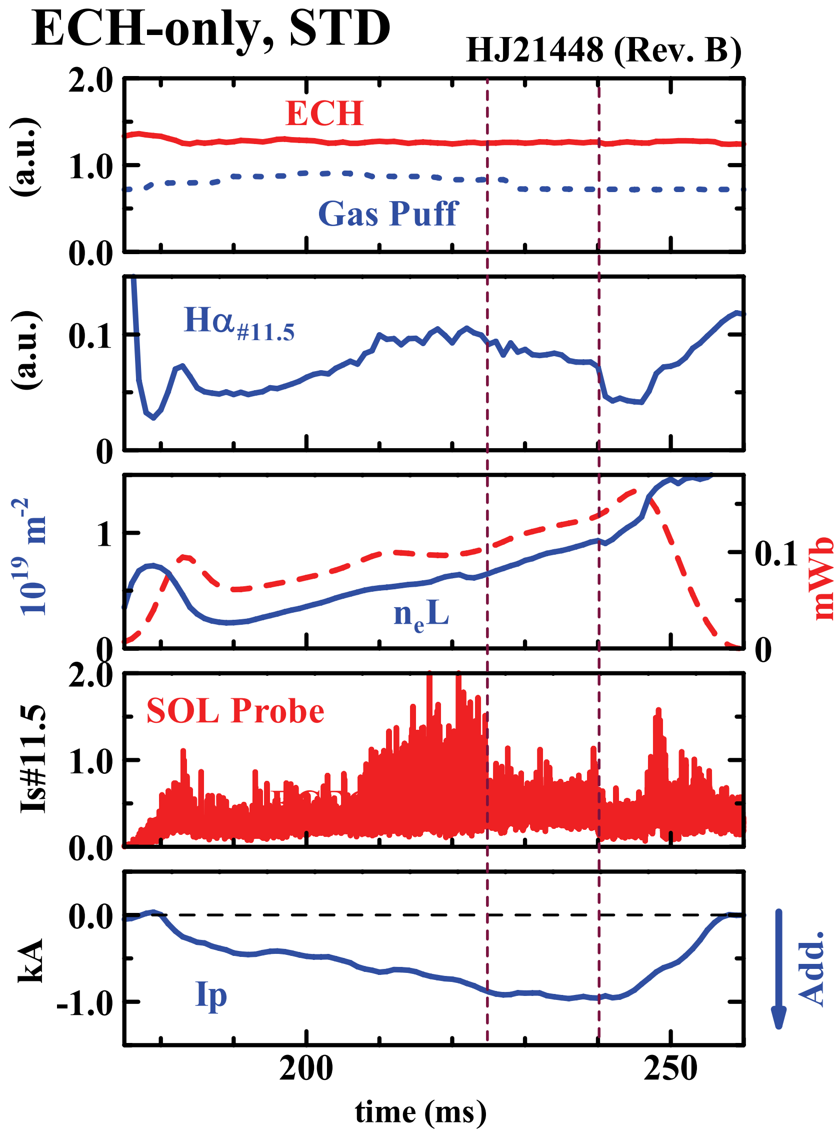


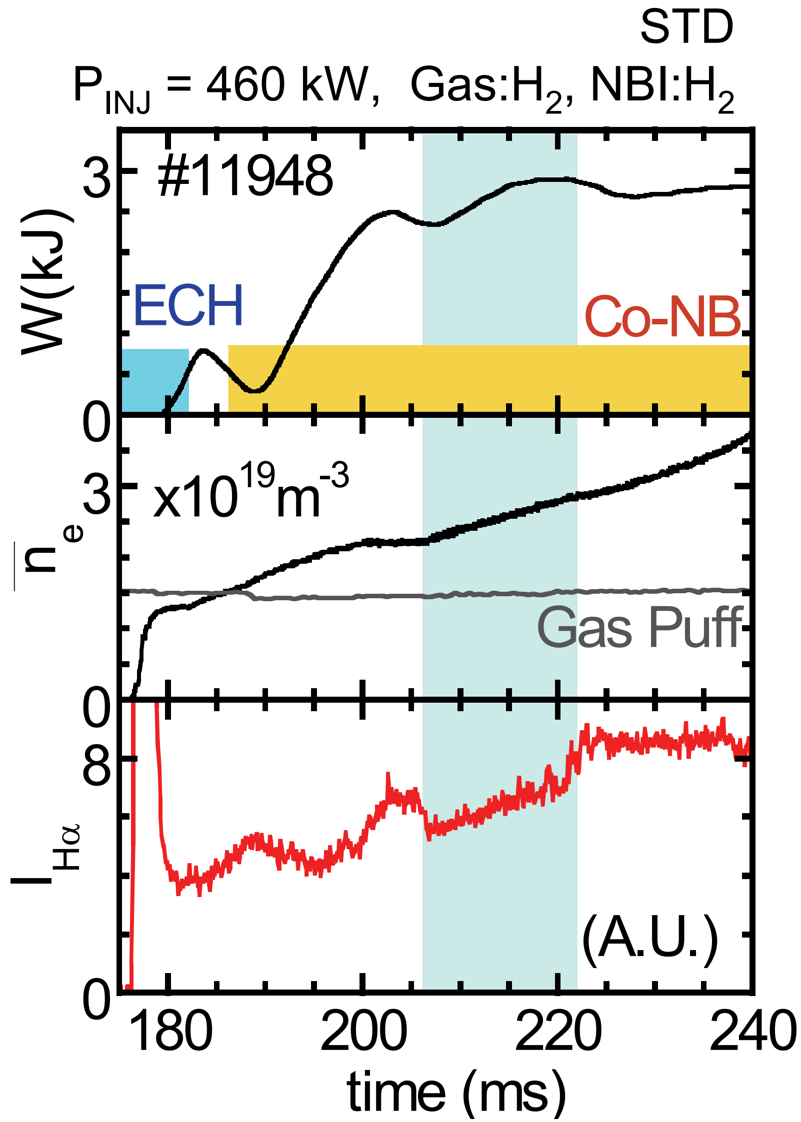
Intensity profile along the target edge



T. Mizuuchi, et al., Nucl. Fusion 47, 395 (2007)

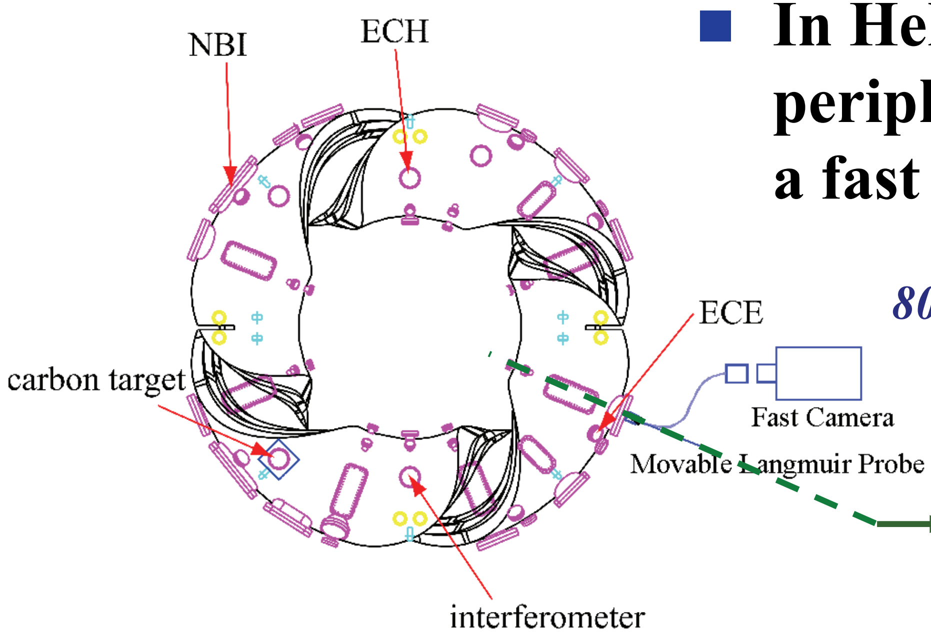
Examples of Transition to improved mode in ECH-only & NBI-only Plasma



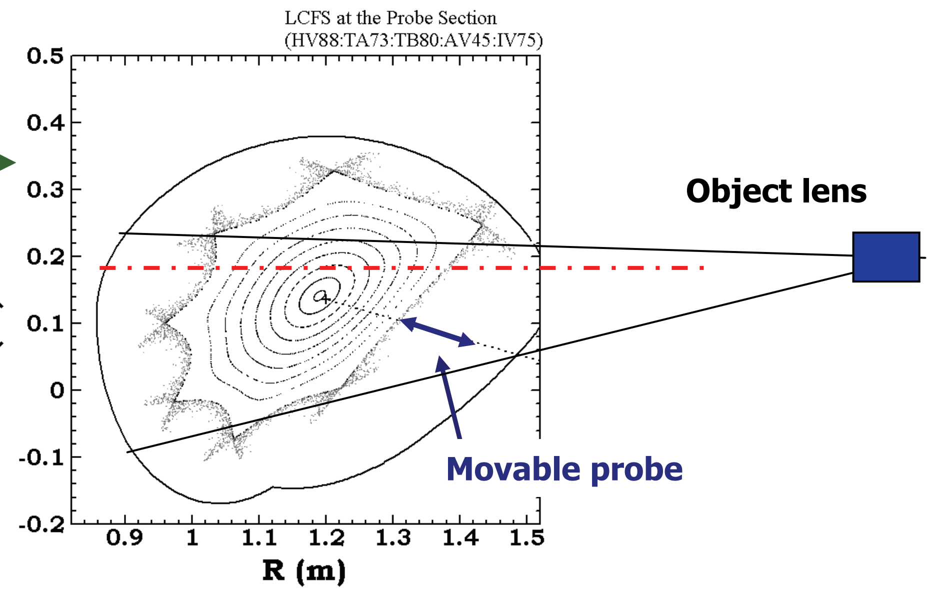


Observation of peripheral plasma turbulence using a fast camera in Heliotron J

- **In Heliotron J, the observation of peripheral plasma turbulence by using a fast camera has been performed.**



80kFPS



- **In this setting, we observed perpendicularly the edge plasma.**
- **In the same toroidal position, a movable Langmuir probe set is installed.**

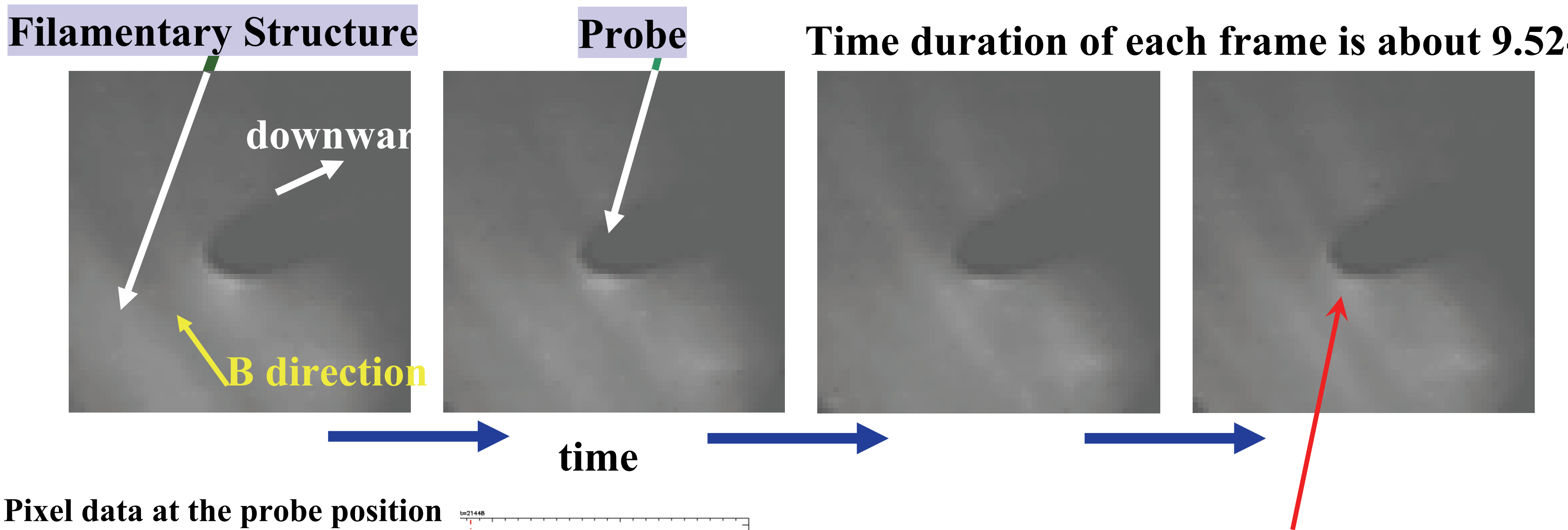
Fast camera images reveal the filamentary structure of the edge plasma perturbation.

Filamentary structure seems to move crossing the magnetic field.

Example for ECH-only plasma

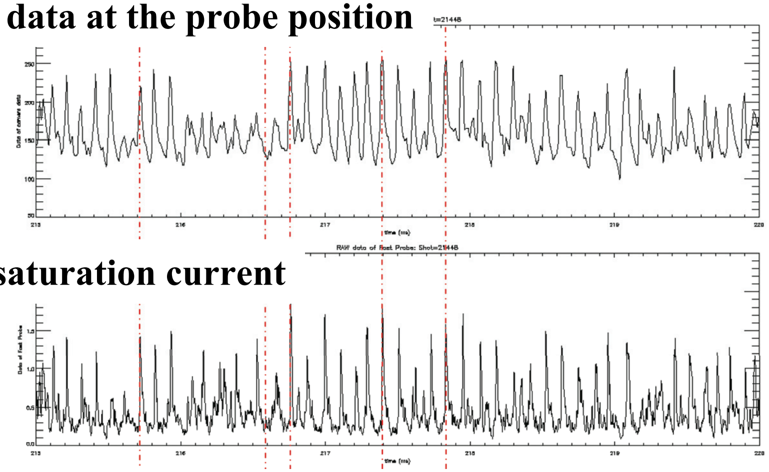
80kFPS

Time duration of each frame is about 9.524 μs



Pixel data at the probe position

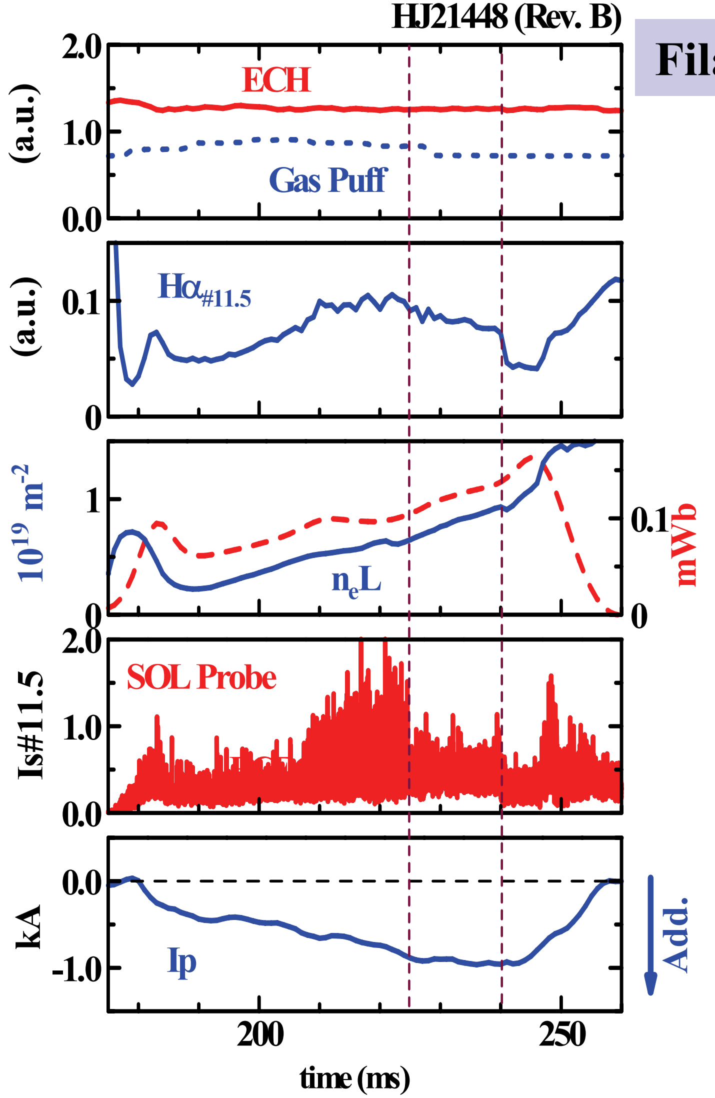
Ion-saturation current

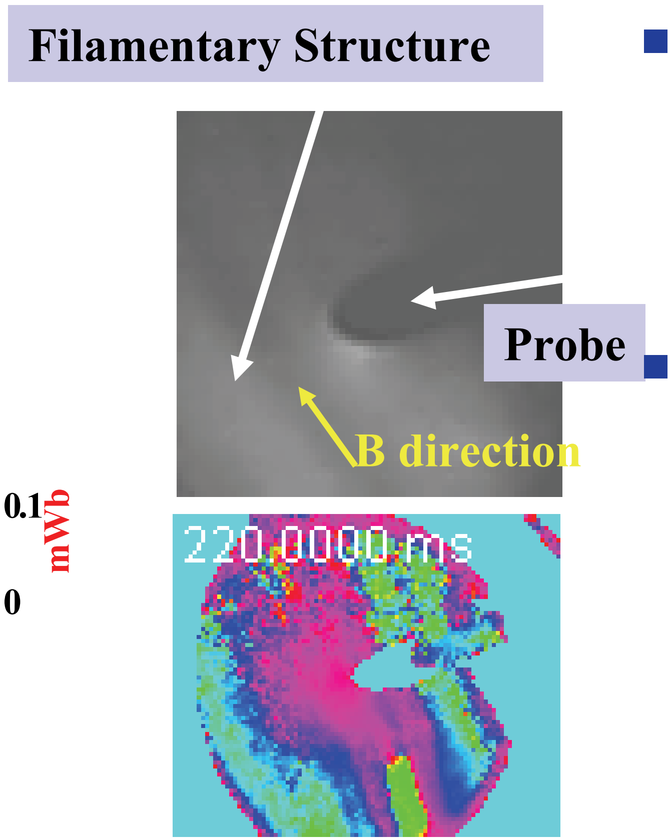


When the "filament" hits the probe, the ion-saturation current shows a burst.

Motion of the 2D phase pattern for #21448 shot (ECH-only plasma)

- 80kFPS, ~ 8.8kHz BP filter -



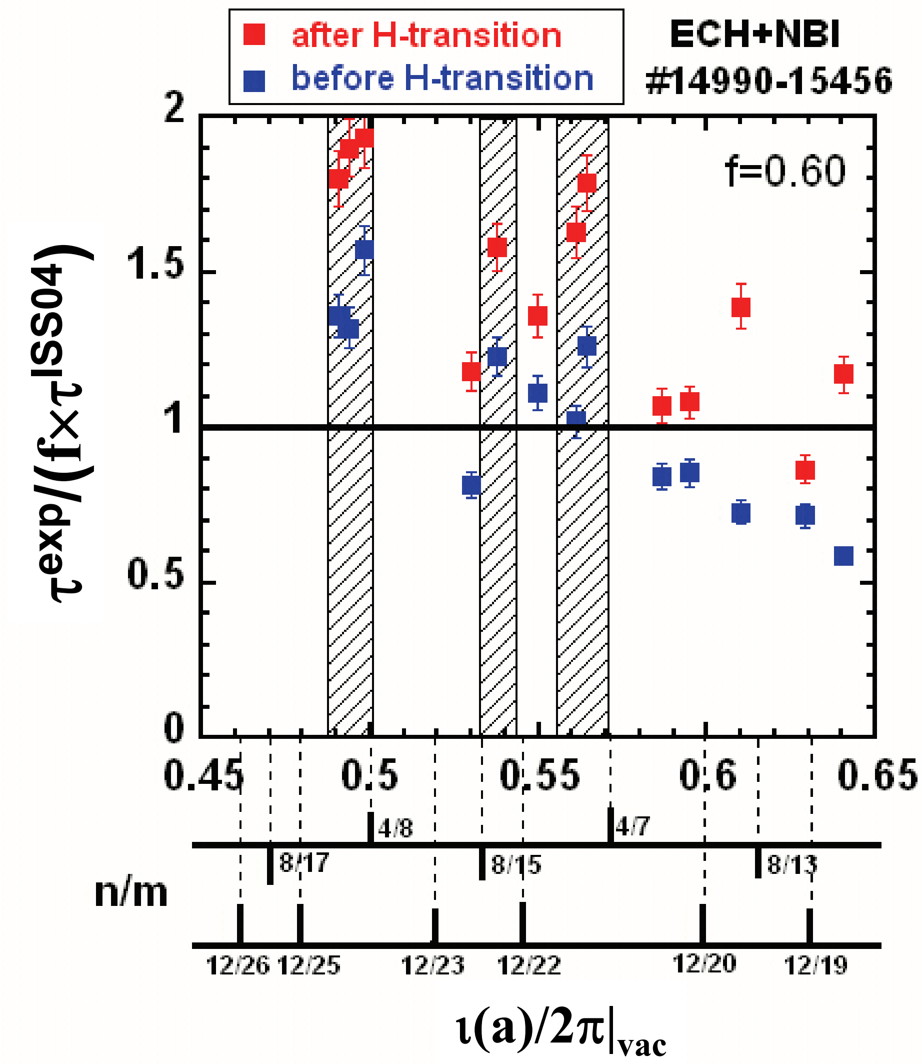


220 - 250ms
~8.8kHz

- 2D-phase images of ~8.8kHz are shown.
  - All phase images above 5kHz were similar in this shot.
- *The motion of the filamentary structure seems to be reversed when the transition takes place.*

P1-020
N. Nishino, et al.

Configuration effects on the global energy confinement have been examined by controlling the vacuum $\iota/2\pi(a)$.



F. Sano, et al., Nucl. Fusion 45 (2005) 1557.

- Transition to better confinement mode is observed in higher n_e region.
- The rotational transform windows for the high quality H-mode ($\tau_{exp}/(f\times\tau^{ISS04}) > 1.5$) are close to the low-mode rationals of the vacuum $\iota/2\pi(a)$.
  - ✓ The influence of the topology ("shape") of the magnetic surfaces with regard to the poloidal viscous damping rate has been discussed.

How about non-inductive current effects?

⇓

NBI-only plasma instead of ECH+NBI

→ simple situation

→ current control in higher n_e ($>n_{e,th}$)

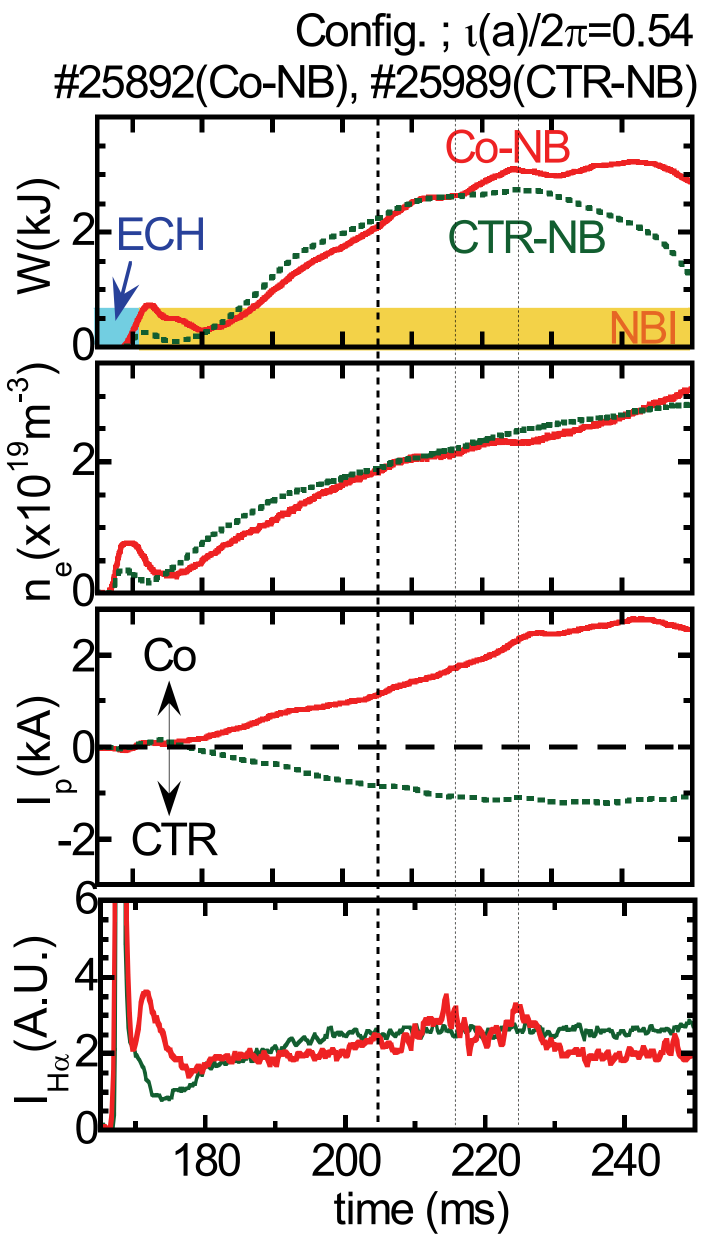
Comparison between Co/CTR plasmas for ι(a)/2π = 0.54

- No transition in CTR NBI -

- **Comparison between Co- & CTR-NBI plasmas at ι(a)/2π ~ 0.54**
  - **natural rational surface of m/n=15/8 exists (ρ=0.87)**
- **Almost the same injection power**
  - P_{INJ} *= 0.58MW(Co), 0.56MW(CTR)*
- **Achieved toroidal current**
  - *Co :* I_p *~ +3kA ↔ CTR :* I_p *~ -1kA*
  - *The current direction is consistent with NBCD*
- **Bootstrap (Co direction) + NBCD (Co or CTR)**
- **n_e = 2.0 ~ 3.0 x 10^{19} m^{-3}**

◆ **In Co-NBI, the transition were observed, but no transition in CTR-NBI.**

☞ **Difference in P_{th} for transition due to**
- ☐ **Position of rational surface,**
- ☐ **Shear,**
- ☐ **Shape of LCFS,**
- ☐ **Direction of momentum input ?**



Time delay Δt from the start of NBI to the onset of the transition is observed.

For NBI-only discharges

in $\varepsilon_b \approx 0.15$ (high-ε_b) and 0.06 (medium-ε_b) cases. ($\iota(a)/2\pi|_{vac}$~0.56)

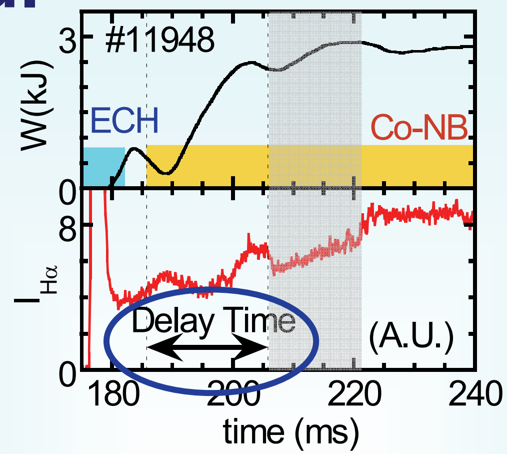
- The delay times for two configurations are almost the same and decrease as increase of $P_{inj.}$

  $n_e \sim$ 1.5-2×10^{19} m^{-3}

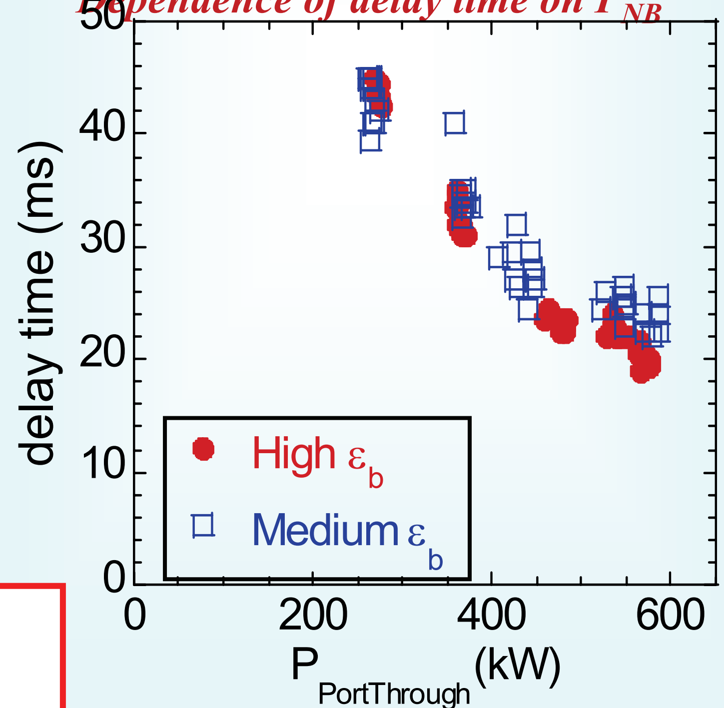
  → almost the const. abs. efficiency

- No transition in low ε_b (≈ 0.01) case.
  - *Cf. Transition can be rather easily observed for ECH+NBI discharges.*
  - *P_{th} or ECH effects?*

S. Kobayashi, et al.,
EPS2007, H-mode Workshop (Sept., 2007)

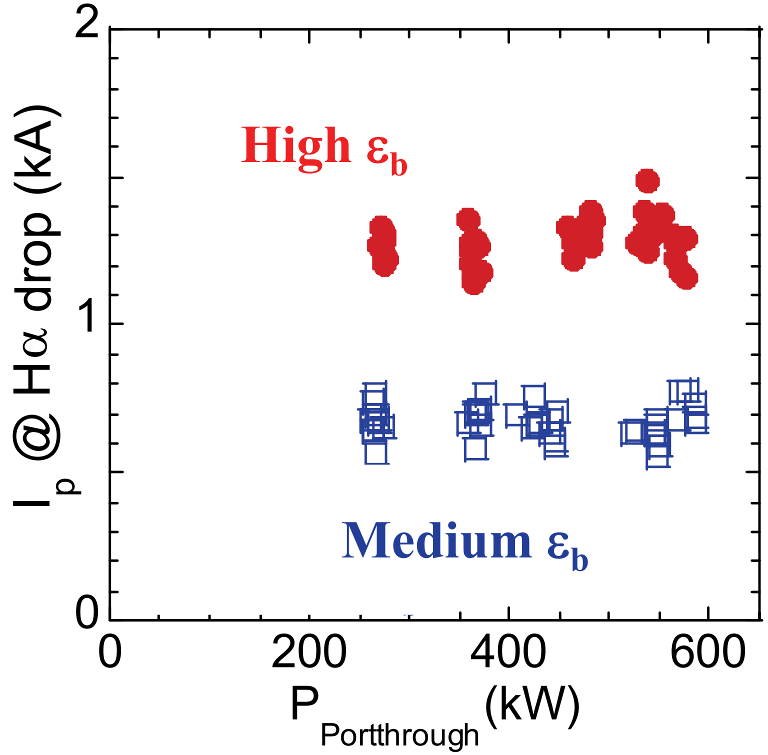


Dependence of delay time on P_{NB}



The transition is observed when the plasma current reaches a critical value.

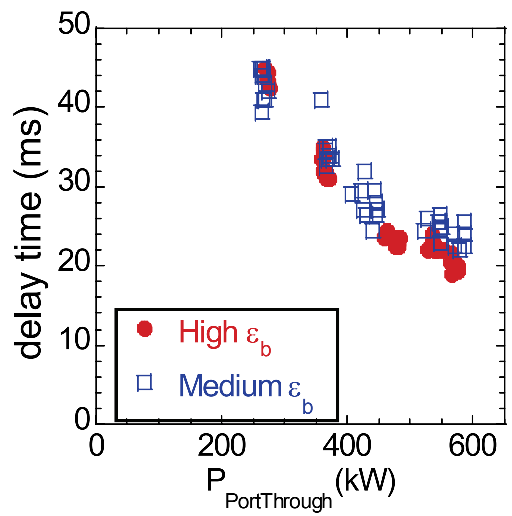
Dependence of I_P at transition on P_{NB}



−*In high ε_b case, higher I_p was required.*

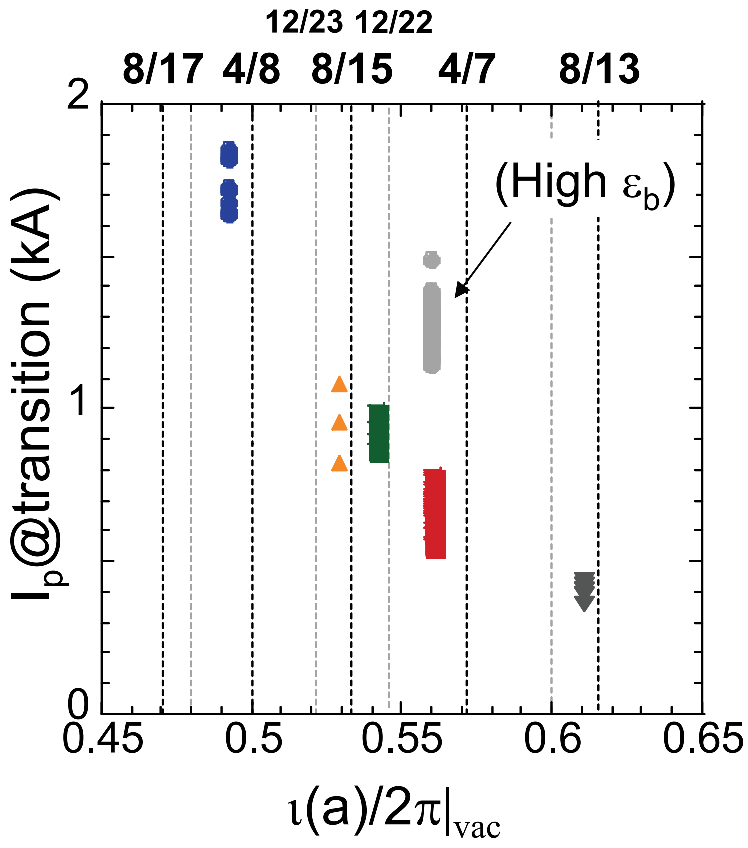
- **The critical value of the plasma current depends on the configuration;**
  0.7±0.1kA in middle ε_b
  1.3±0.2kA in high ε_b cases.
- **The observed time delay would be related to the growing-up time of the current.**

Dependence of delay time on P_{NB}

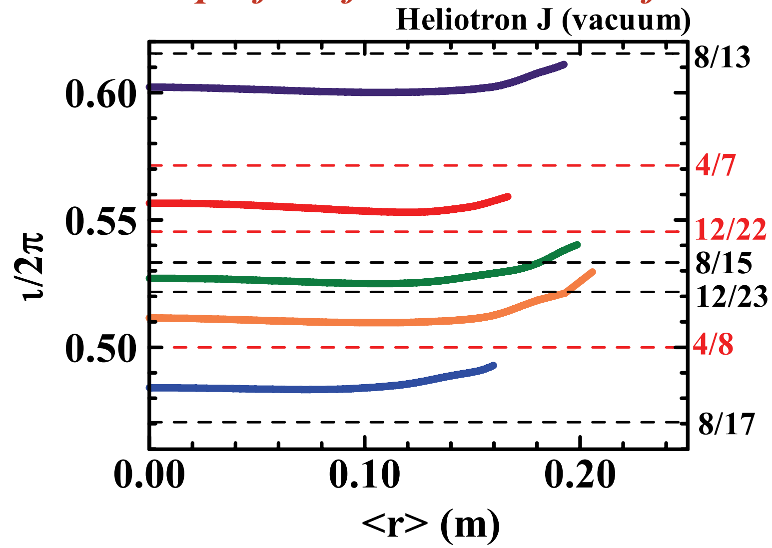


The effects of the plasma current on the field configuration should depend on the vacuum rotational transform. → $\iota(a)/2\pi|_{vac}$-*scan experiment.*

The critical current for *NBI-only plasma* strongly depends on ι/2π.



Radial profile of rotational transform



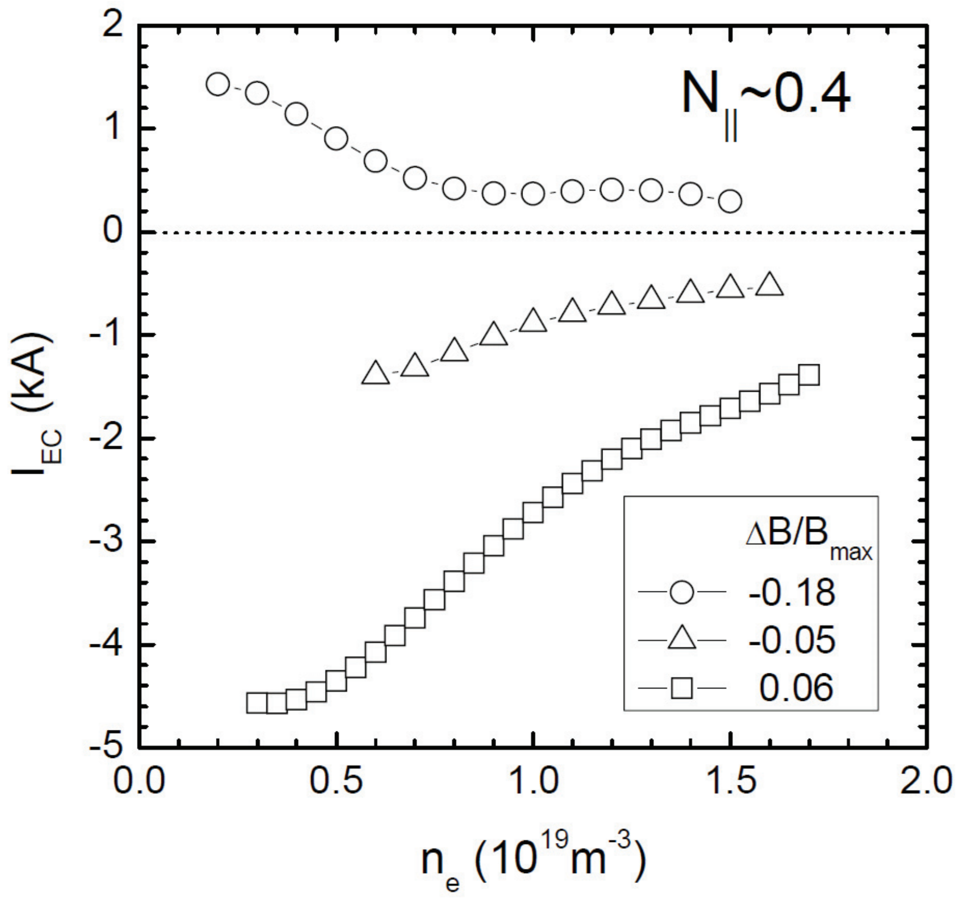
- **$\iota(a)/2\pi|_{vac}$ –scan for NBI-only plasma (mainly the medium-ε_b condition)**
- **the critical current exists for all config.**
- **The value systematically decreases as increase of $\iota(a)/2\pi|_{vac}$**
- ***So far, the spontaneous transition was observed only in Co-NBI (ad. NBCD) plasmas (P_{inj} < 0.6 MW)***

0.25 MW < P_{inj} < 0.6 MW,
$n_e \sim$ 1.5-2×10^{19} m^{-3}

Plasma current control by ECCD scenario is effective in rather low-density plasma.

Heliotron J

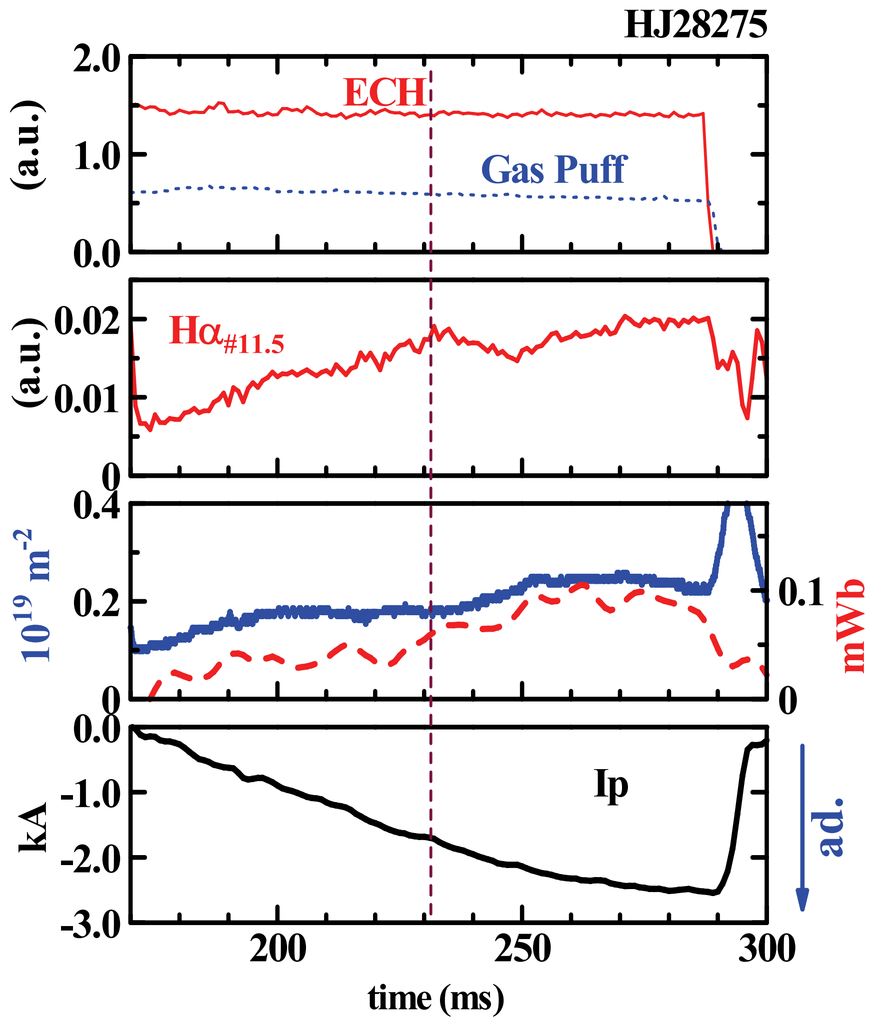
I-17 (Fri.) K. Nagasaki, et al.



- **The density dependence of EC current for three field configurations.**
  - ✓ **the BS current is eliminated.**
- **The maxi. EC current of 4.6 kA is attained *at the ripple top heating*.**
- **The EC current flows *in the opposite direction at the ripple bottom heating*, and its amplitude is one-third as low as the ripple top heating.**

- ***The transition study in ECH-only plasma with ECCD control would give us useful data to understand the phenomena.***

Does a high ECCD current opens a new window for the transition in lower density region?.



- **A spontaneous change to a better confinement mode was observed in a high ECCD current discharges. (Low-ε_b, $\iota/2\pi(a) \sim 0.56$, ECH-only with $P_{ECH} > 0.3$ MW)**
- **The line-averaged density is much lower than the critical low-density limit observed in the previous experiments for STD configuration.**

- ***No enough experiments, from this point of view, in sub. high ECCD condition.***

Summary

- **In recent Heliotron J experiments, we are interested in the configuration effects on the plasma performance especially relating to the field *modification by non-inductive current*.**
  - ⇐ ***prediction of free-boundary equilibrium calculations,***
  - ⇐ ***MHD-activities relating to resonance condition which does not exist for vacuum condition,***
  - ⇐ ***the shift of the diverter footprints during a discharge.***
- **Transition to an improved confinement mode in *NBI-only plasma* has been investigated, focusing on the onset condition of the transition.**
  - **Under the experimental condition (P_{inj} and mag. configuration), no transition has been observed in the CTR-NBI-only plasmas.**
  - **Transition was observed for medium- or high-ε_b, but not for low-ε_b.**
  - **The existence of the critical current for the onset of the transition is found out in NBI-only plasma.**
  - **This critical current depends on $\iota(a)/2\pi|_{vac}$ and the bumpiness, but is independent of P_{inj}.**

Thanks for joining our experiments and fruitful discussions!

KYOTO UNIVERSITY

F. Sano, T. Mizuuchi, K. Hanatani, K. Nagasaki, H. Okada, S. Kobayashi, Y. Ijiri, T. Senju, K. Yaguchi, M. Shibano, K. Tohshi, K. Sakamoto K. Kondo, Y. Nakamura, H. Arimoto, G. Motojima, S. Watanabe, F. Hamagami, D. Katayama, H. Matsuoka, A. Matsuyama, K. Mukai, K. Murai, A. Nakajima, H. Takahashi, H. Yasuda, K. Hosaka, Y. Kowada, S. Mihara S. Murakami S. Yamamoto

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Z. Feng, Q. Yang

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- **P1-020** **N. Nishino, et al.,**
  Measurement of peripheral plasma turbulence using a fast camera in Heliotron J
- **P2-034** **S. Yamamoto, et al.,**
  Energetic ion driven MHD instabilities and their impact on ion transport in Heliotron J plasmas
- **P2-046** **G. Motojima, et al.,**
  Study of toroidal current effect on rotational transform profile by MHD activity measurement in Heliotron J
- **P2-054** **Y. Nakashima, et al.,**
  Analysis of neutrals in helical-axis Heliotron-J plasmas using the DEGAS Monte-Carlo code
- **P2-071** **S. Kobayashi, et al.,**
  Observation of Ion tails in ECH/ECCD plasmas in helical devices
- **P2-091** **S. Watanabe, et al.,**
  Measurement of radiation profile at density ramp-up phase by using AXUV photodiode arrays in Heliotron J
- **I-17** **K. Nagasaki, et al.,**
  ECCD Experiments in Heliotron J, TJ-II, CHS and LHD