20th IAEA Fusion Energy Conference, 1-6 November 2004, Vilamoura, Portugal

Confinement Studies of Helical-axis Heliotron Plasmas

FEC2004

Configuration Dependence of H-mode Quality

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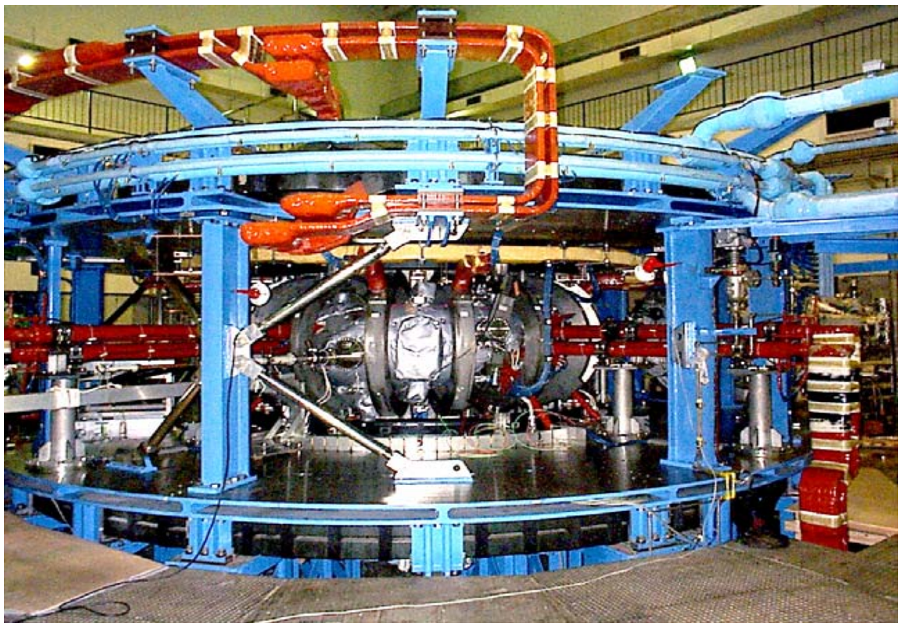
Outline

Heliotron J



R = 1.2 m	ECH < 0.4 MW
a < 0.2 m	NBI < 0.7 MW
B < 1.5 T	ICRF < 0.3 MW
$\iota(a)/2\pi \sim 0.56$	$\delta_{well}(a) \sim 1.5\%$

1. Introduction
2. Objectives
3. Experimental Set-up
4. Results and Discussion

- H-mode transitions for ECH-only, NBI-only and ECH+NBI Plasmas
- Configuration Dependence of H-mode Quality
- Density Threshold of the H-mode Transition
- Edge Plasma Characteristics at the H-mode Transition

5. Summary

Objectives

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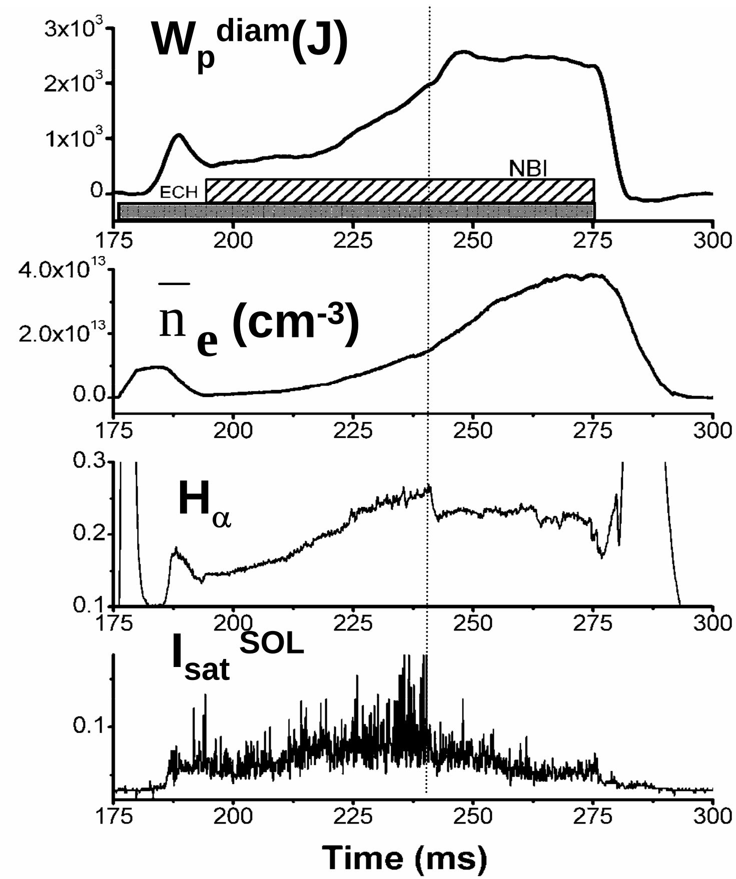
ECH(H^+)+NBI(H^0)



The 2003 campaign

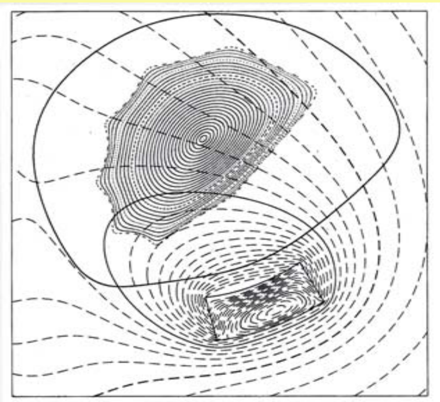
(1) To find out the experimental operational regime of the H-mode at various heating schemes in Heliotron J,

(2) To understand the effects of the operation parameters such as the magnetic configuration, plasma density, heating power flux, etc. on the H-mode performance, and

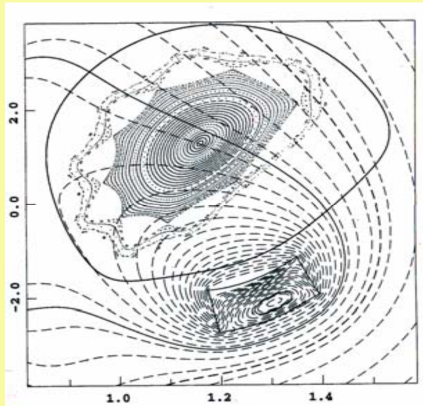
(3) To test the validity of predictive theories of the H-mode

in order to get an experimental and theoretical clue to the optimized design of a helical-axis heliotron.

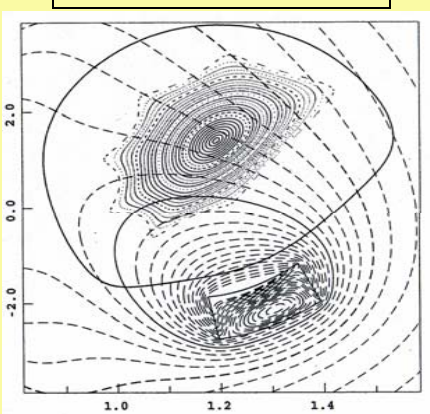
For the configuration studies of the H-mode, the vacuum edge iota, $\iota(a)/2\pi$, was changed by changing the ratio of the H+V current to the TA/TB currents in order that the magnetic axis position should be kept constant for maintaining the central heating of ECH.



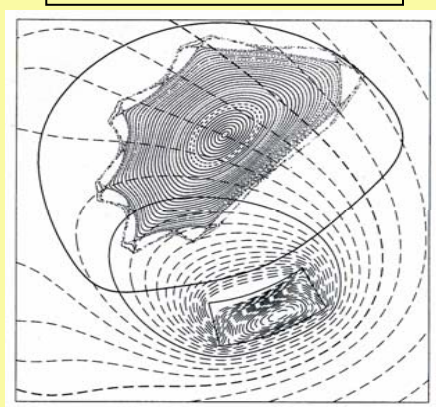
$\iota(a)/2\pi=0.493$



$\iota(a)/2\pi=0.498$



$\iota(a)/2\pi=0.56$



$\iota(a)/2\pi=0.62$

The edge magnetic surfaces at certain iotas of Heliotron J are strongly modified by the resonant Fourier harmonics such as 4/m, etc., and in such a case the plasma is limited from the separatrices of these natural islands of considerable widths due to its low-shear nature.

Configuration dependence of the H-mode quality in Heliotron J is being studied primarily as the vacuum edge iota scan for :

1. ECH(D^+)-only plasmas
2. NBI($H^0 \rightarrow D^+$)-only plasmas
3. ECH(D^+)+NBI(H^0) plasmas

The 70-GHz, 0.14-MW ECH(D^+)-only plasma develops into H-mode at $\bar{n}_e^{th} \approx 1.2\times10^{19}m^{-3}$ (Phase I), characterized by the appearance of the L-H-L short-lived transition signals of D_α . At 273 ms (Phase II), the H-mode is established with a marked reduction in D_α as well as with a spontaneous, notable increase in density.

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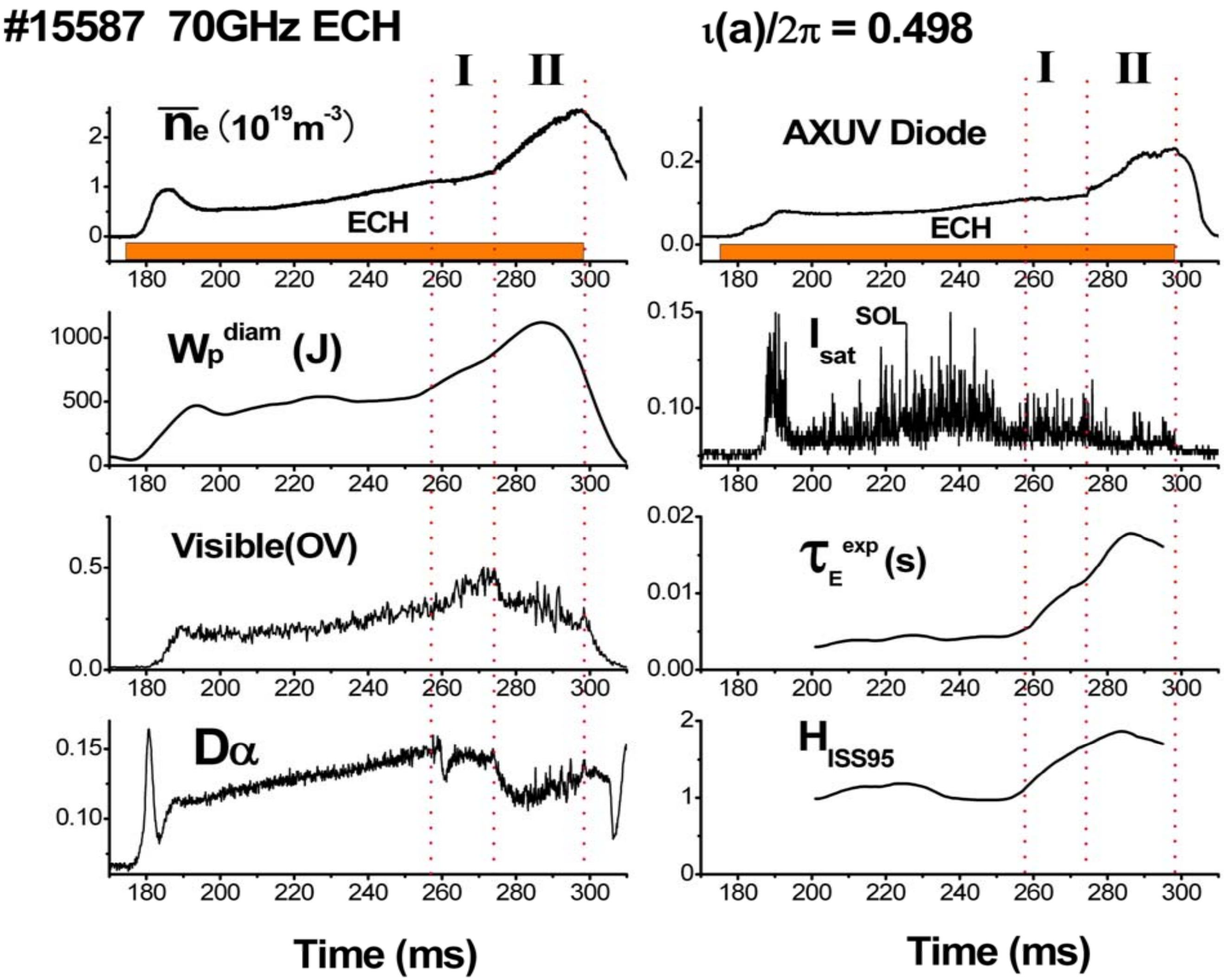

- The maximum increment in $\Delta W_p^{diam}/W_p^{diam}$ reaches about 100% throughout Phases I and II.
- This H-mode is transitory in nature in a time scale of τ_E^{exp}, but the H_{ISS95}-factor reaches ~1.8 during Phase II with that of ~1 before transition.
- This H-mode terminates due to radiation collapse which is caused by the ECH-cutoff at densities $\bar{n}_e > 2\times10^{19}m^{-3}$.
- The edge activities also may become a candidate cause of the saturation and decrease in H_{ISS95}-factor.

For 28-keV, 0.54-MW tangential NBI (H^0) into ECH (D^+), after a short period of the dithering phase (Phase I), a sharp, a factor 2 , reduction of D_α signal (Phase II) takes place at ~228 ms, thus leading to a quiescent H-mode of ~40ms' duration in NBI-only phase until its back-transition.

Heliotron J

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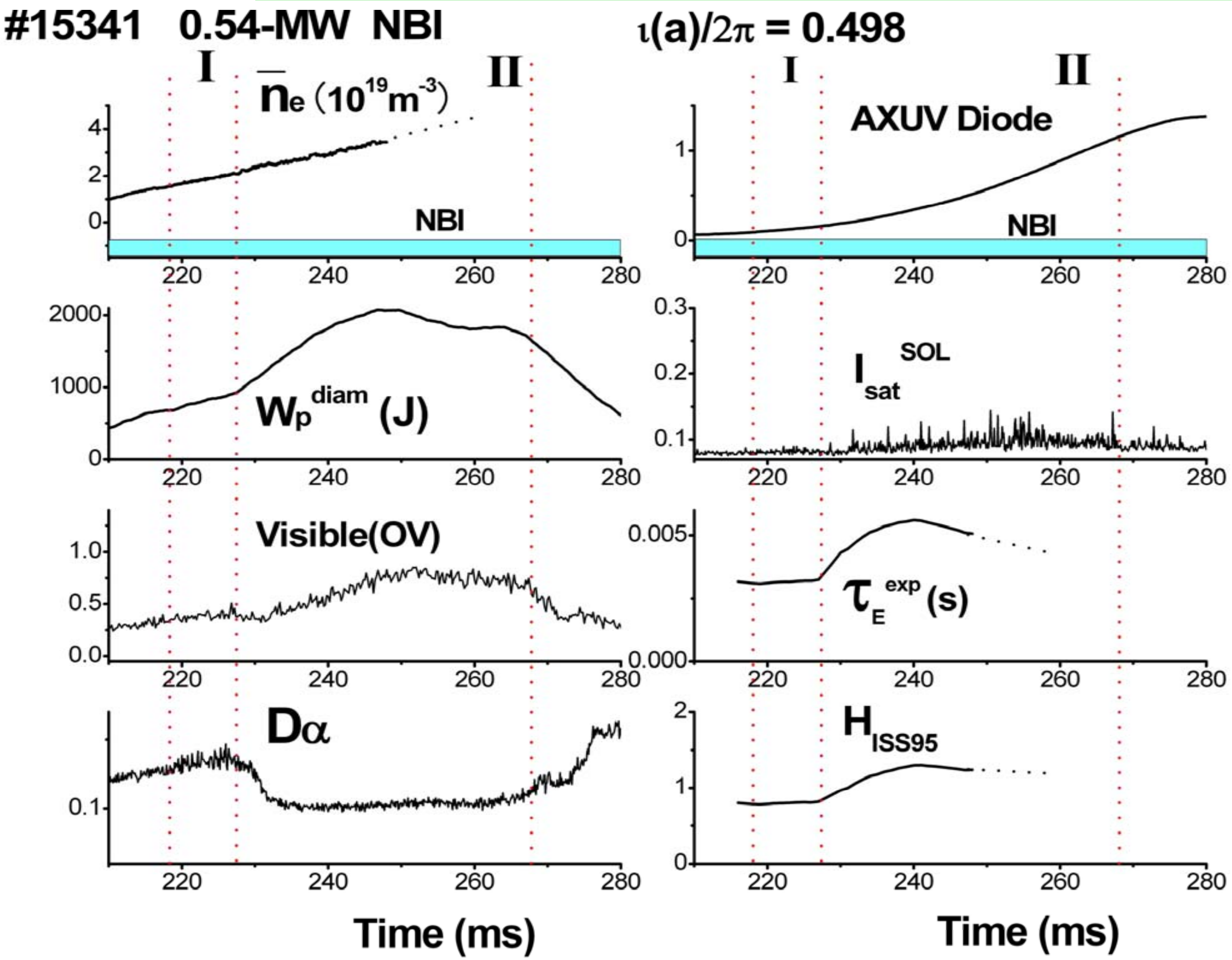

- **After the transition, the $\bar{n}_e$ increase is modest whereas the W_p^{diam} increase is more notable in the initial half period of Phase II.**
- **The peak τ_E^{exp} of 6 ms corresponds to the H_{ISS95} –factor of ~1.3 with that of ~0.8 before transition.**
- **There is a suggestion of impurity accumulation during NBI-only H-mode, based on the growing rate of the AXUV signal as compared with the rising rate of $\bar{n}_e$.**

ECH(D^+)+NBI(H^0) plasma also shows a transition to H-mode. After the dithering period of Phase I, a sharp drop of D_α is attained at ~265 ms, resulting in the final, established H-mode of ~20 ms' duration (Phase II).
The H-mode is terminated by the back-transition to L-mode at ~282 ms.

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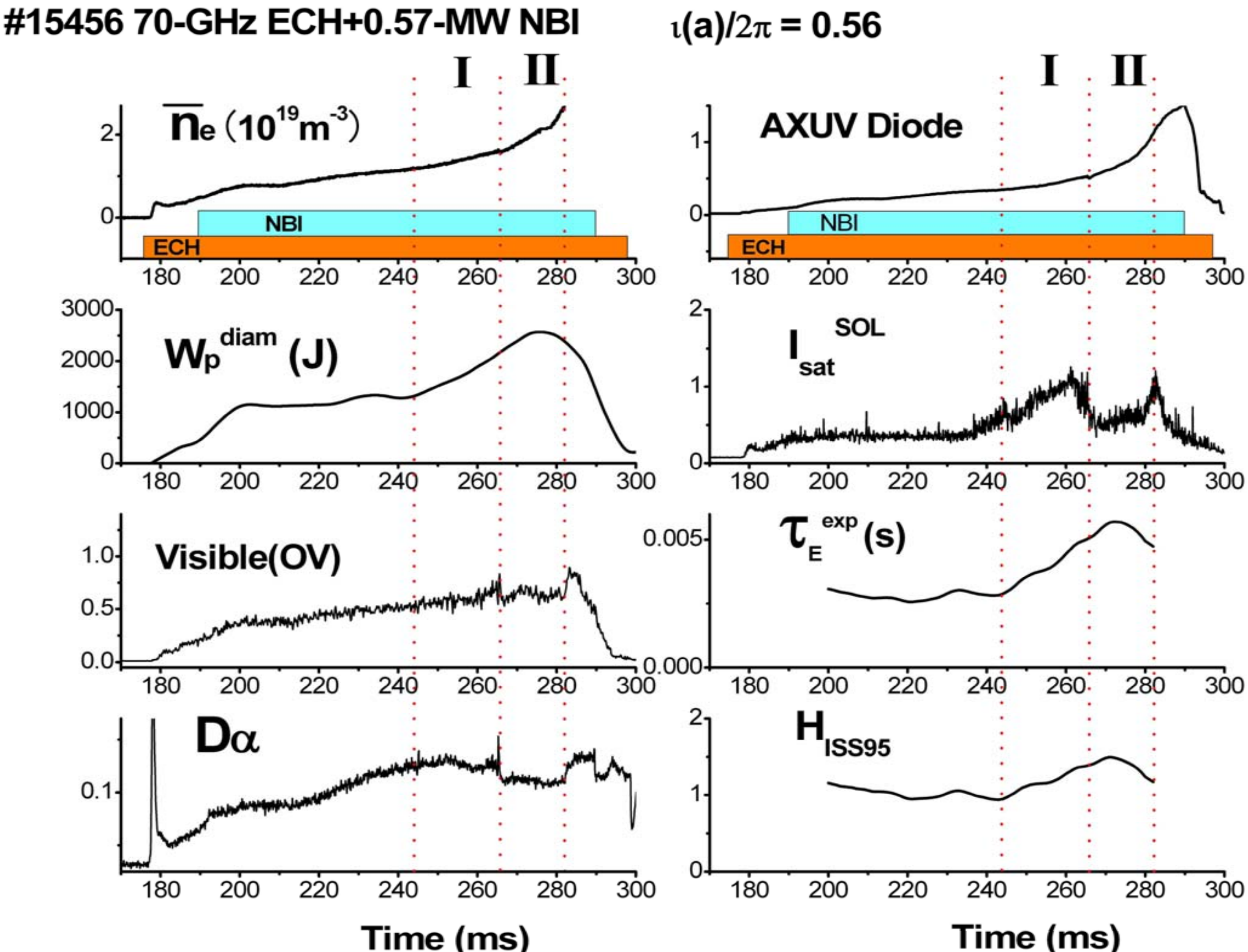

- With the transition to H-mode in Phase II, the particle flux across the separatrix decreases as measured from I_{sat}^{SOL} of the electrostatic probe in the SOL.

- The H_{ISS95} -factor after the transition has achieved ~1.4 with that of ~1 before transition.

Heliotron J

Iota dependence of the peak H_{ISS95}-factor after the transition and of the H_{ISS95}-factor before the transition suggests that the high-quality H-mode ($1.3<H_{ISS95}<1.8$) is achieved in the iota range where the iota is slightly less than, but not on, the major natural resonances of n/m=4/8, 4/7 and 12/22.

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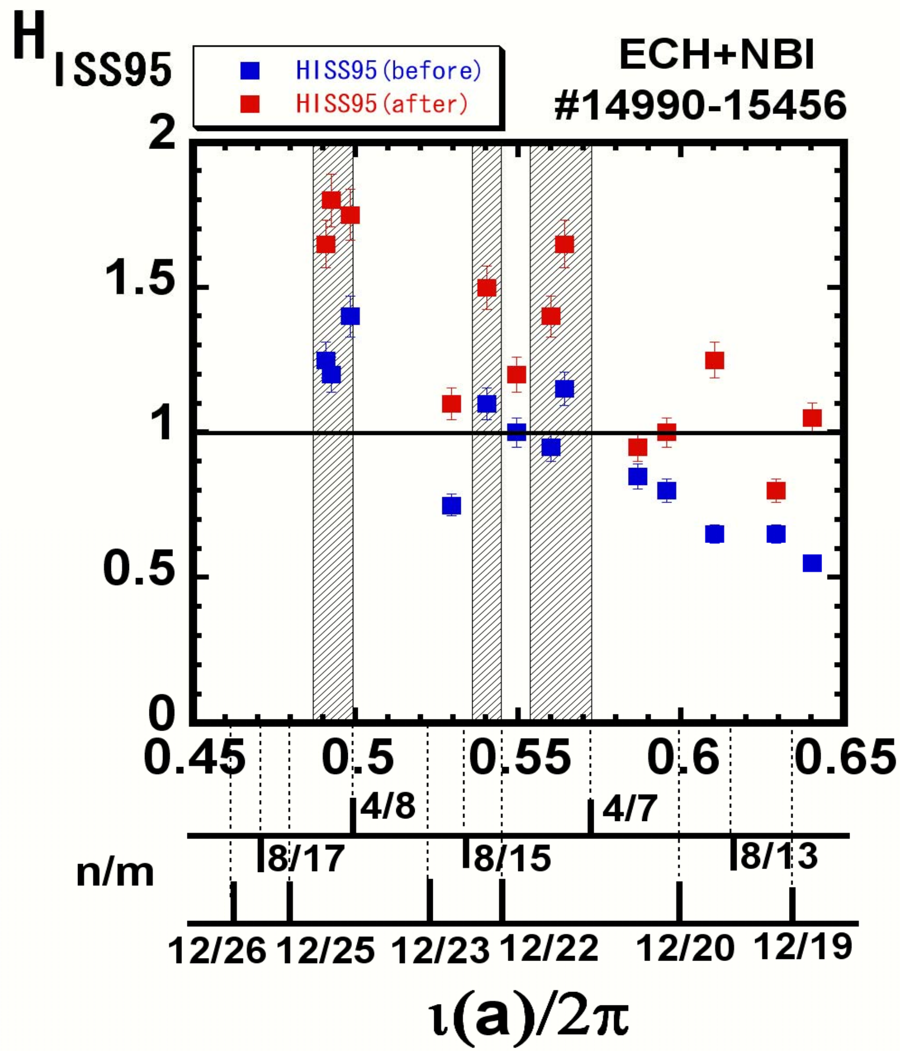


$\tau_E^{exp} = W_p^{diam}/P_{LOSS}$

$P_{LOSS} = P_{abs} - \partial W_p^{diam}/\partial t$

$P_{abs}=\eta_{abs}(ECH) \cdot P_{ECH} + \eta_{abs}(NBI) \cdot P_{NBI}$

$\tau_E^{ISS95}=0.08\, a^{2.2}\, R^{0.65}\, n_e^{0.51}\, P_{LOSS}^{-0.59}\, B^{0.83}\, \iota^{0.4}$

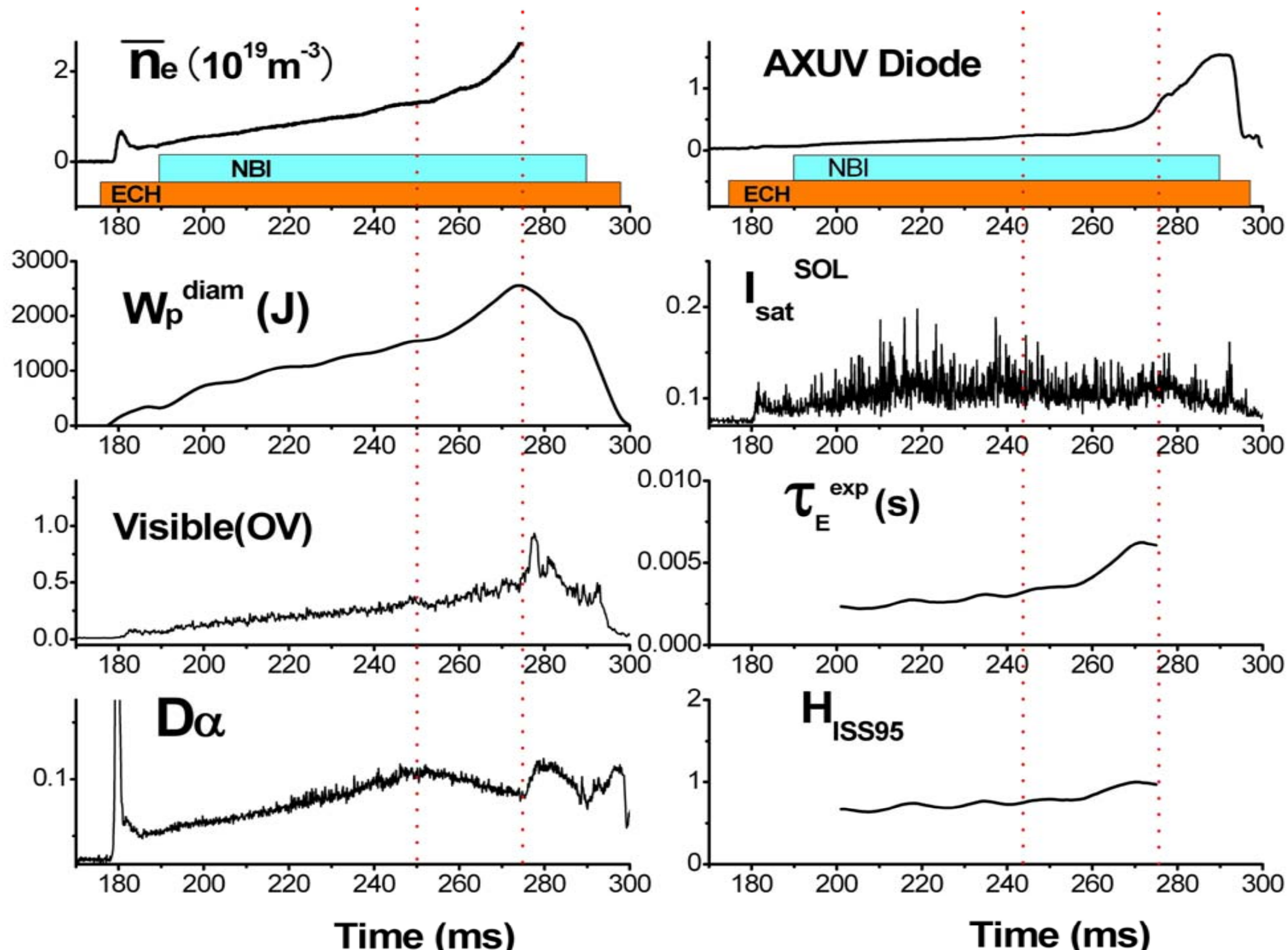
$H_{ISS95} = \tau_E^{exp}/\tau_E^{ISS95}$

The vacuum edge iota is taken as the label of the magnetic configuration since the change of the edge iota with increasing beta compensates, to some extent, the change of the edge iota with increasing plasma current.

The experiments have revealed the presence of weaker versions of the H-mode, the quality of which degrades (H_{ISS95} ~1) as compared with the high-quality H-mode.

A weaker, modified version of H-mode for ECH+NBI plasma can be seen for the configuration of $\iota(a)/2\pi=0.596$. After the transition to H-mode, the drop of D_α is very slow and falls linearly with time during ~25 ms until its back-transition at ~275 ms. Although τ_E^{exp} increases by a factor of 2 in this H-mode phase, the enhancement of H_{ISS95}-factor is limited to be minor

#15103 70-GHz ECH+0.57-MW NBI $\iota(a)/2\pi = 0.596$



One of the key ingredients for the enhancement of the H-mode quality is considered to be the reduction of the poloidal viscous damping rate coefficient $C_p = \langle e_p \cdot \nabla B / B \rangle$ in the outer plasma region [1]. From the iota scan experiments changing the $|B|$ spectrum, there seems to be some coincidence between the enhancement of H_{ISS95}-factor and the numerical reduction of C_p. However, this result still remains inconclusive.

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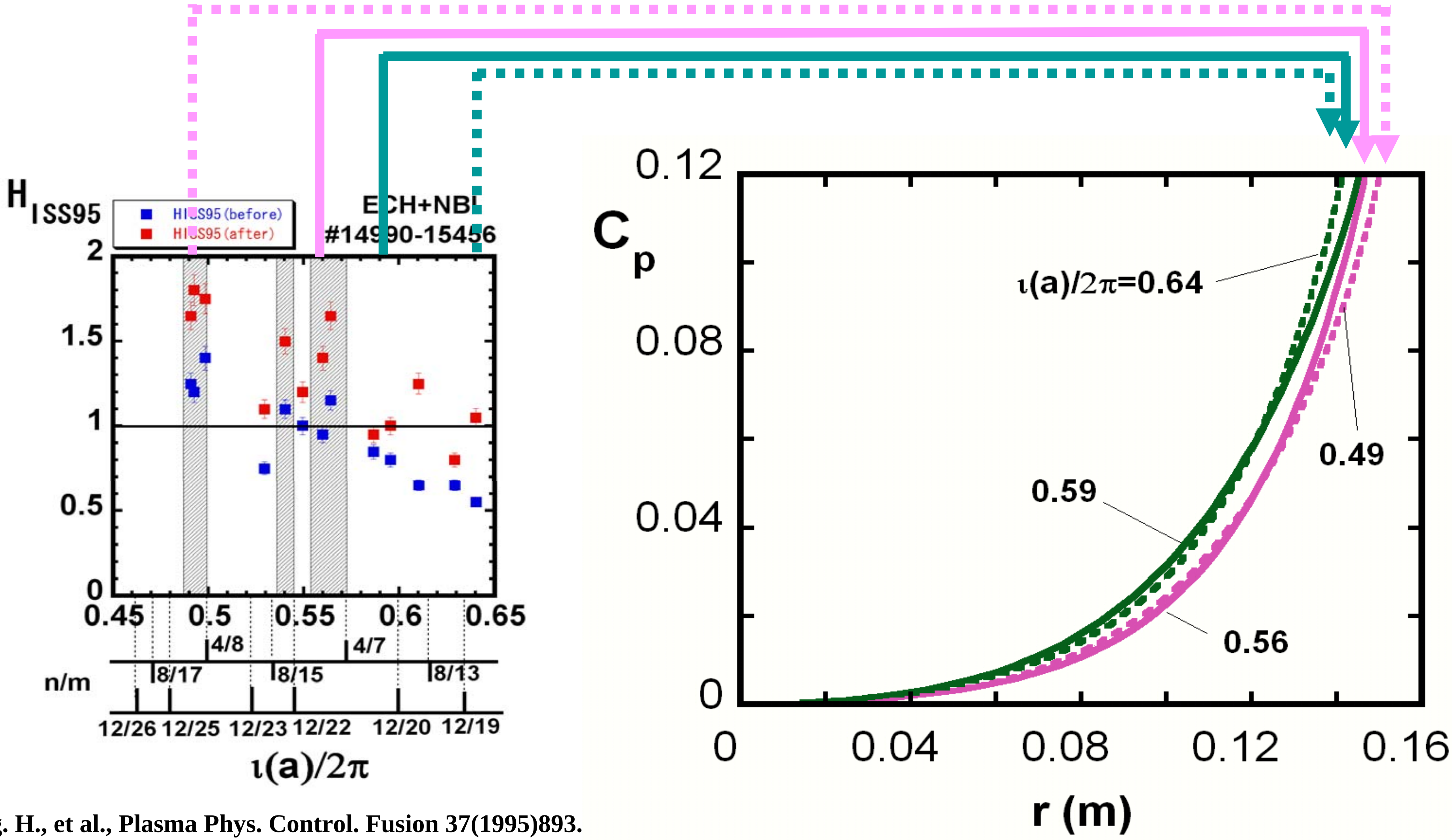

[1] Wobig. H., et al., Plasma Phys. Control. Fusion 37(1995)893.

For the high-quality H-mode plasmas in $\iota(a)/2\pi=0.498$ and 0.56, the density threshold at the start of Phase I is located in the range of $\bar{n}_e=0.7\sim1.4\times10^{19}m^{-3}$, suggesting an insensitive power dependence of this threshold density. With regard to the threshold density at the start of Phase II, there seems to be some power dependence although the dataset is still insufficient.

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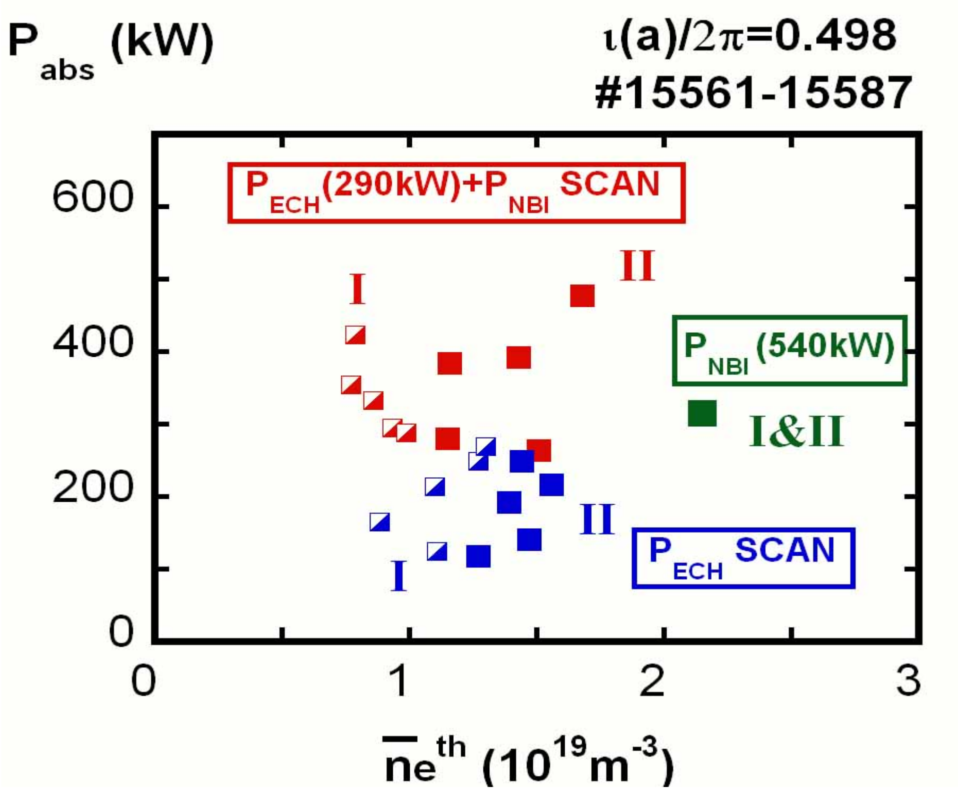
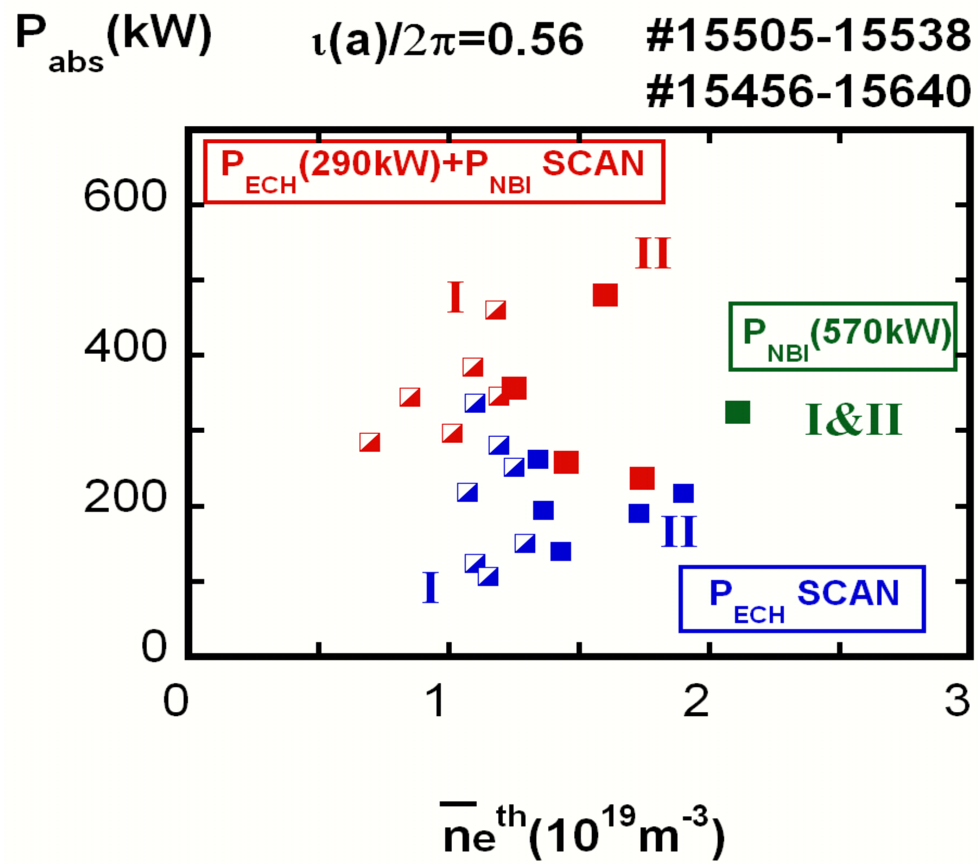
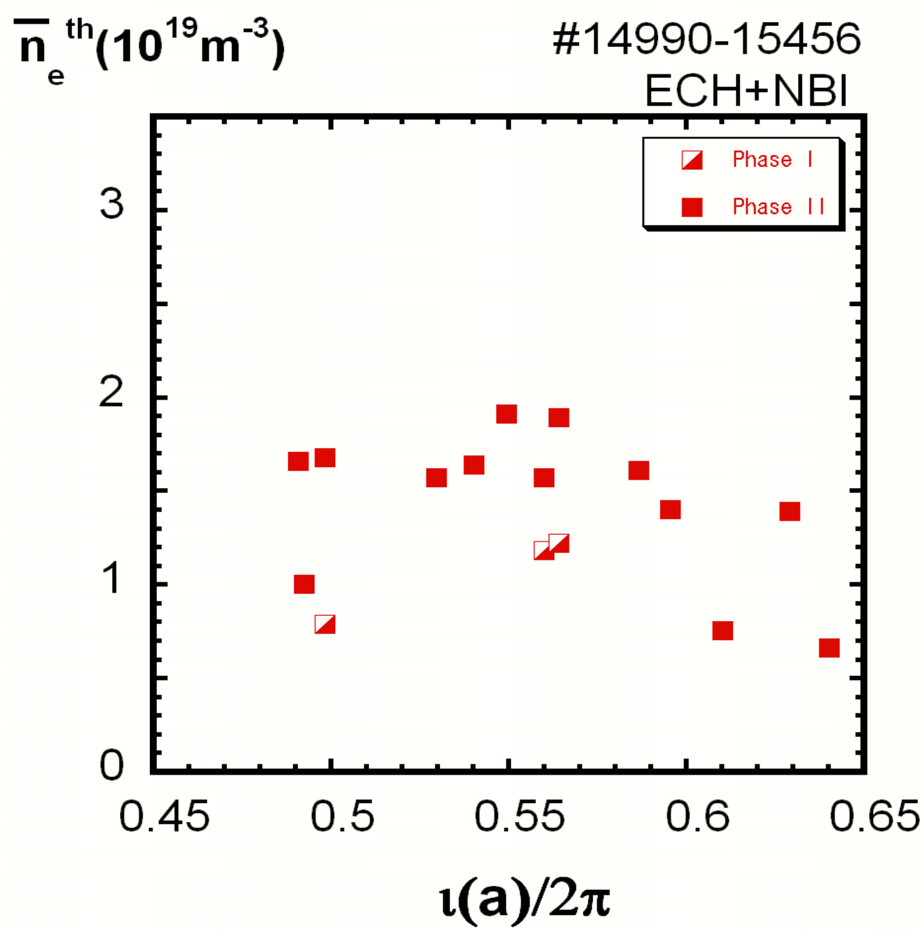
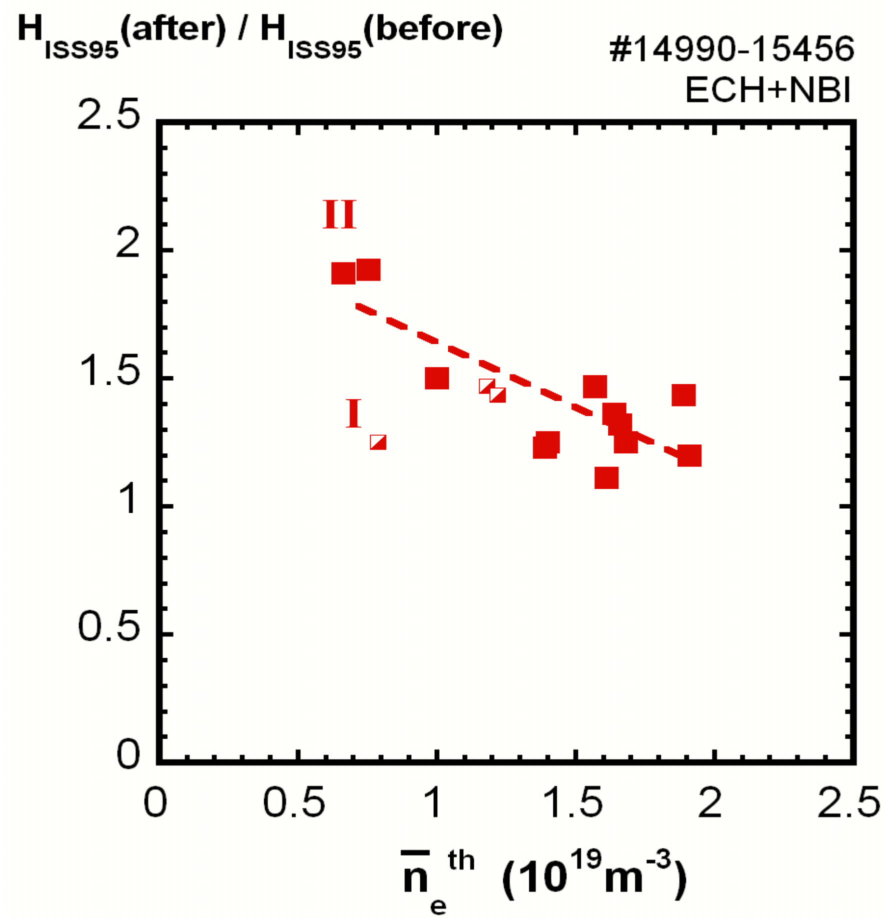




For ECH(0.29MW)+NBI(0.57MW) plasmas, the observed iota dependence of the threshold density indicates that there is a general tendency of the lower threshold density to result in a larger relative enhancement of H_{ISS95}-factor, i.e., the ratio of the peak H_{ISS95}-factor after the transition to that before the transition.





In the low P_{abs} limit of H-mode in ECH+NBI operation at $\iota(a)/2\pi=0.493$, low frequency fluctuations (~2 kHz) are observed to appear on the D_α signal, which are well correlated with strong magnetic pulses of Mirnov coils, I_{sat}^{SOL} fluctuations, soft X-ray fluctuations etc., whereas these D_α fluctuations disappear (or are stabilized) at higher P_{abs} plasmas.

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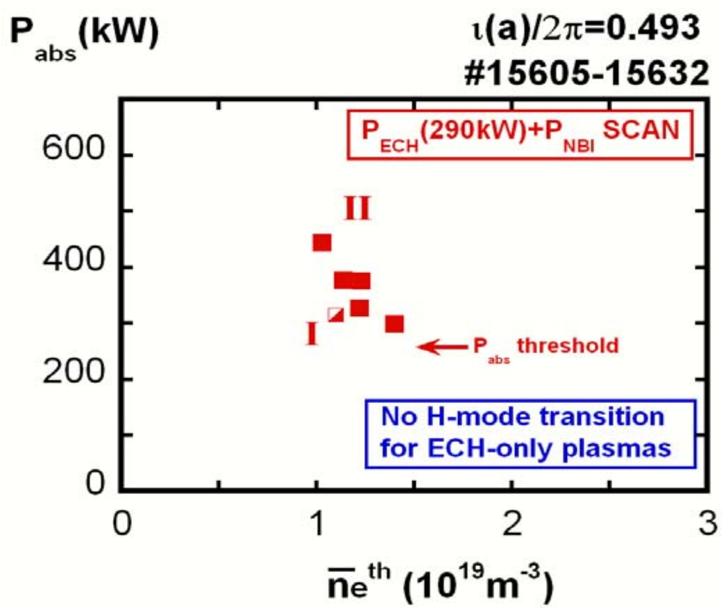
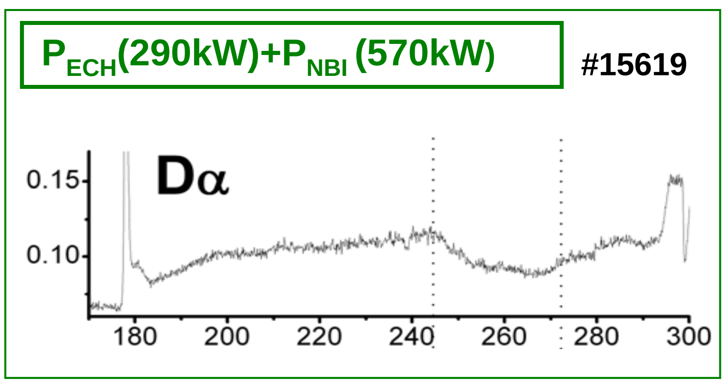
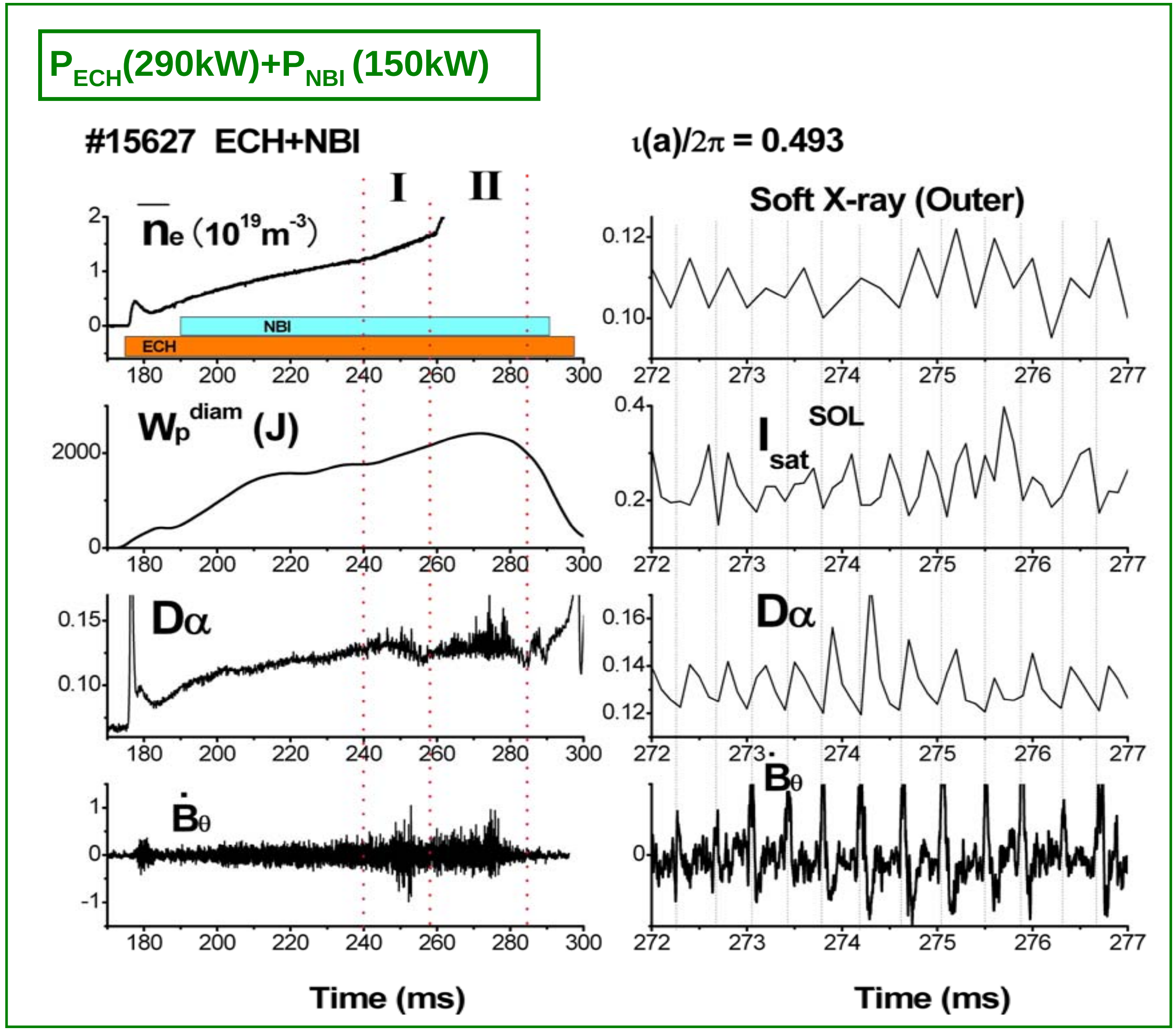
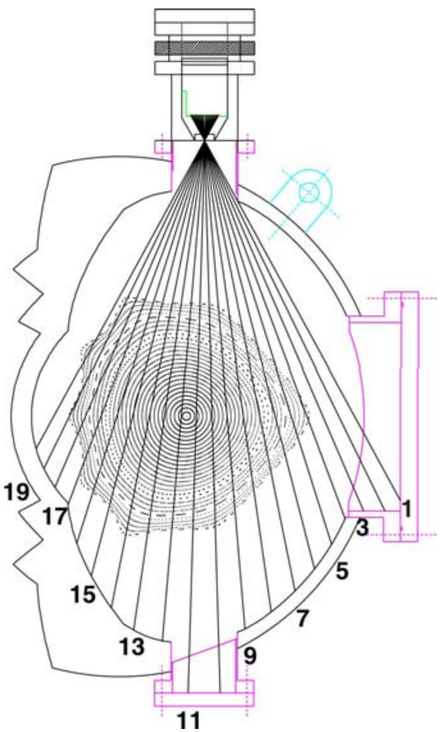


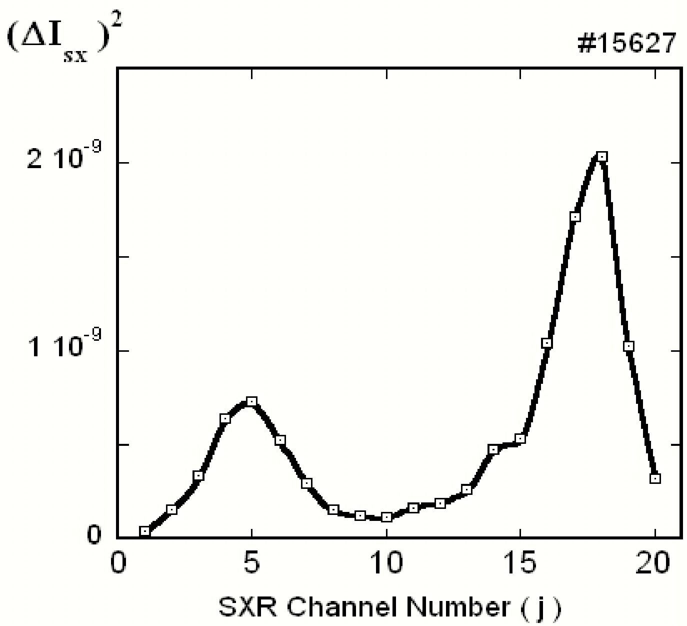


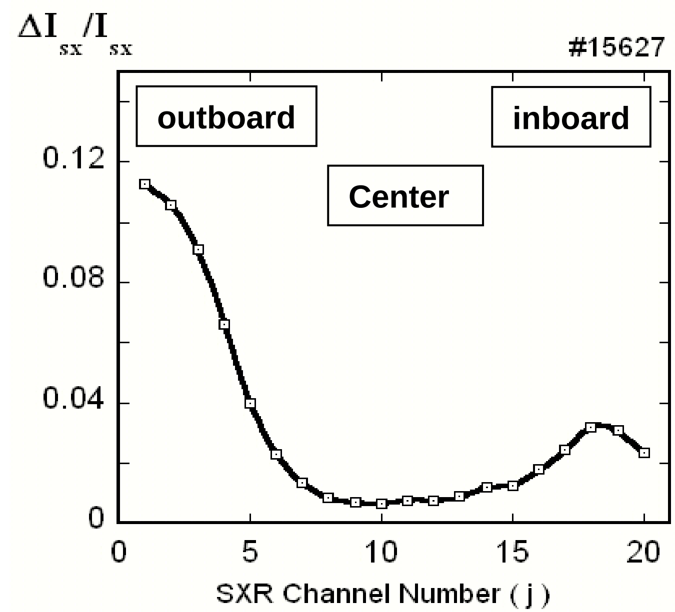


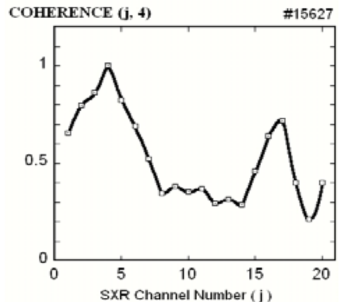
To study these fluctuations, the radial distribution of the soft X-ray (SXR) fluctuation amplitude was measured by the vertical SXR array. The result suggests that these fluctuations are located in the outer plasma region and that the structure of the fluctuations resembles an m="odd " mode.

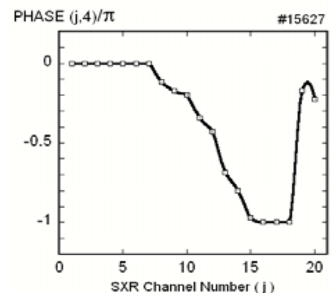
260 ms < t < 280 ms 1.5 kHz < f < 2.5 kHz





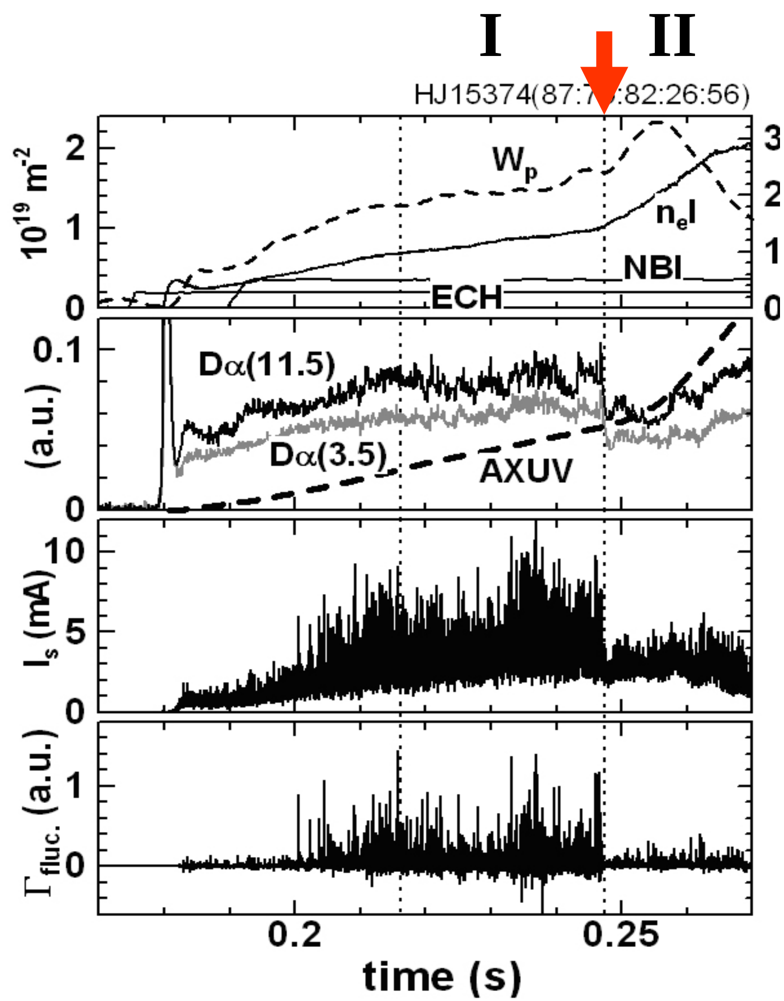


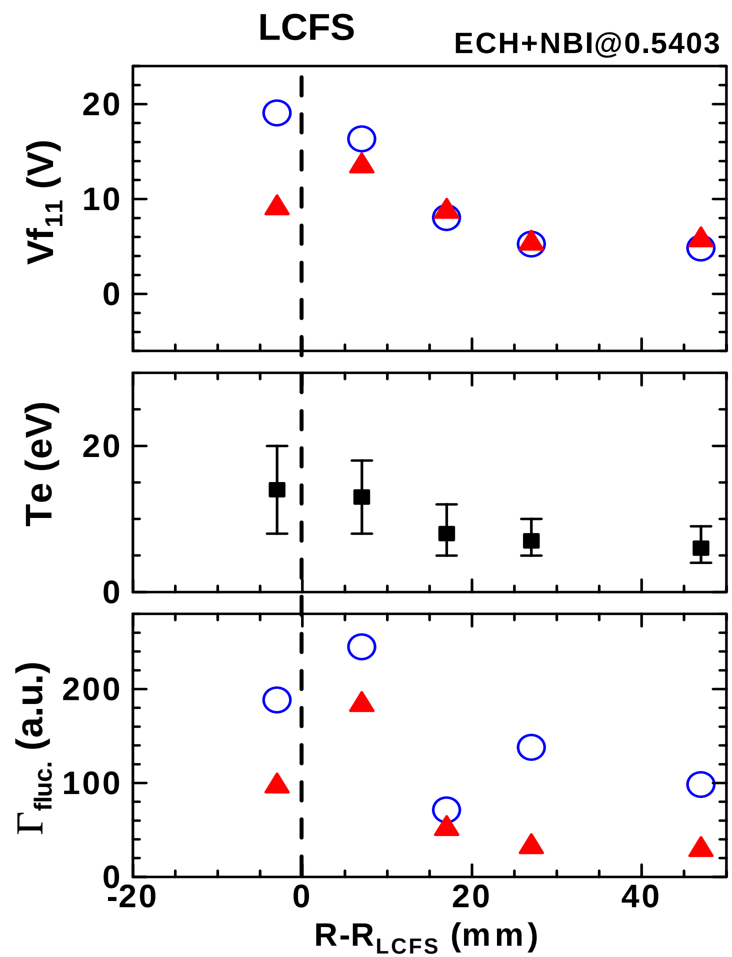




The key question of what physics mechanism triggers the m=odd mode and how can this phenomenon propagate into the core confinement region remains to be resolved as a future work.

Langmuir probe measurements in the SOL for the high-quality H-mode at $\iota(a)/2\pi=0.54$ have shown that the rapid drop of V_f (negative E_r or E_r-shear) occurs near LCFS at the H-mode transition of Phase II, accompanied by the rapid reductions of the D_α, the SOL density I_s, the SOL density fluctuation $_s$ and the estimated fluctuation-induced particle flux $\Gamma_{fluc.}$





Summary

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- L-H transition studies of ECH(D^+)-only, NBI(H^0)-only and ECH+NBI combination heating plasmas have revealed the existence of the notable magnetic configuration dependence of the H-mode quality. The high-quality H-mode ($1.3<H_{ISS95}<1.8$) is located in the specific iota range of slightly less than the values of the major natural resonances of n/m=4/8, 4/7, and 12/22.

- The threshold line-averaged density, depending on the configuration, is in the region of $0.7\sim2.0\times10^{19}$ m^{-3} in ECH (0.29MW)+NBI (0.57MW) operation. It is found that there is a general tendency of the lower threshold density to result in a larger relative enhancement of the ratio of the peak H_{ISS95}-factor after the transition to that before transition.

- Edge plasma measurements suggest the reduction of the fluctuation-induced transport in the SOL and the formation of the negative E_r (or E_r-shear) near the last closed flux surface at the transition. However, the detailed study has just started.

- We need to continue to improve theory-experiment comparison to further improve understanding of the L-H transition and to attain the quasi-steady state, high-quality H-mode in Heliotron J as an interesting challenge to the next experimental campaign.

For plasma heating, (i) 70-GHz, 0.4-MW 2nd harmonic X-mode ECH of the top launching type and (ii) 30-keV, 0.7-MW NBI (H^0) of the tangential co-injection type were used. In the 2004 experimental campaign, the working gas of target ECH plasmas was deuterium.

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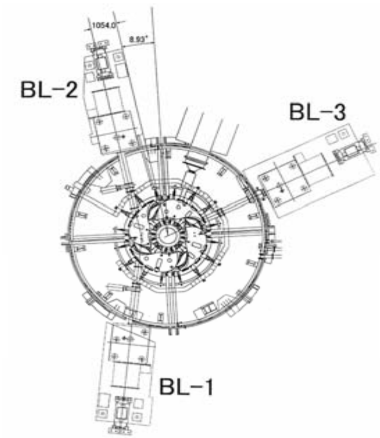
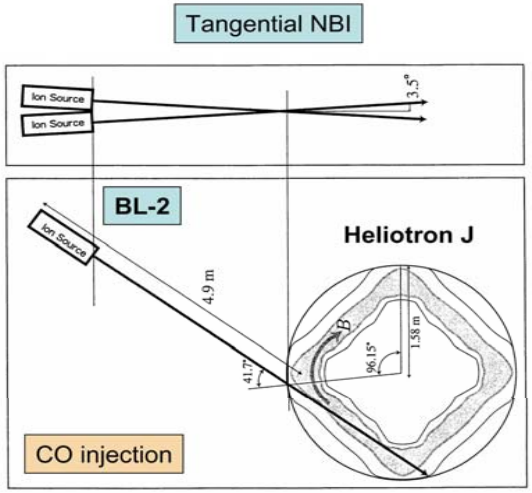
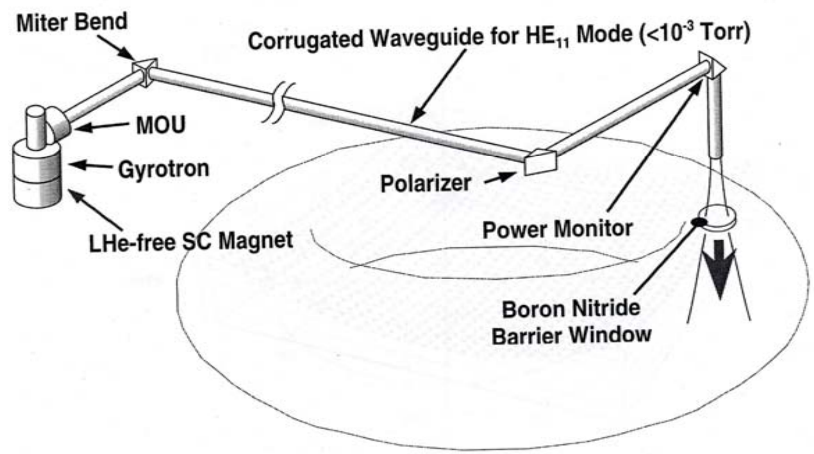
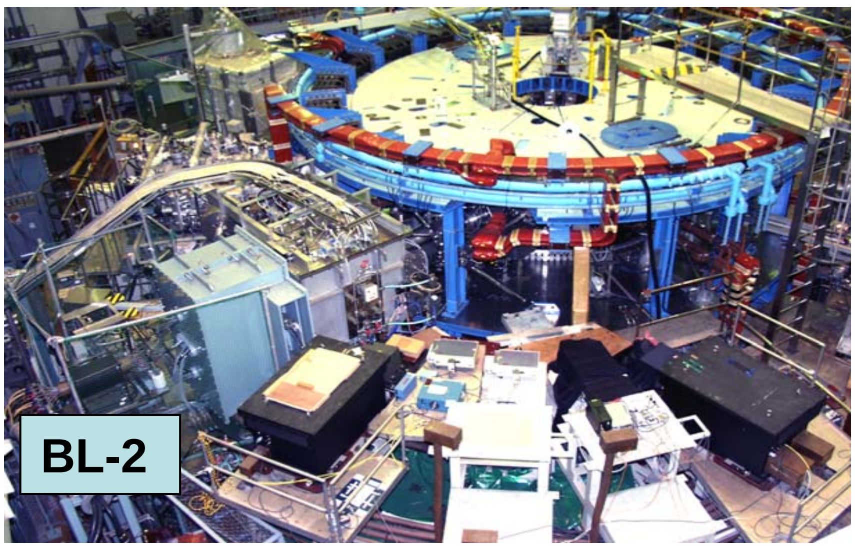






70-GHz, 0.4-MW

ECH system



30-keV,0.7-MW

NBI system (BL-2)