Unusual Late H-modes from the 2011 KSTAR Tokamak Campaign

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Introduction

Unusual late H-modes have been found in the data of the 2011 KSTAR campaign for B_T 1.96 T and I_P between ~600 kA and ~640 kA.

The elongation, κ, is smaller for these late H-modes than any other H-mode and the values of $\varepsilon\beta_p$ are among the largest.

It also shows that li, the internal inductance, is large for these late H-modes

The late H-modes appear to exhibit ELMS of types I and II (or I and III).

The late H-mode small ELMs have sizes (Δne/ne) that are usually less than 0.5% and have frequencies up to ~250 kHz while the ordinary KSTAR H-modes do not have small ELMs.

The toroidal velocity as measured by the XICS diagnostic shows that the velocity is generally lower than the conventional early H-modes.

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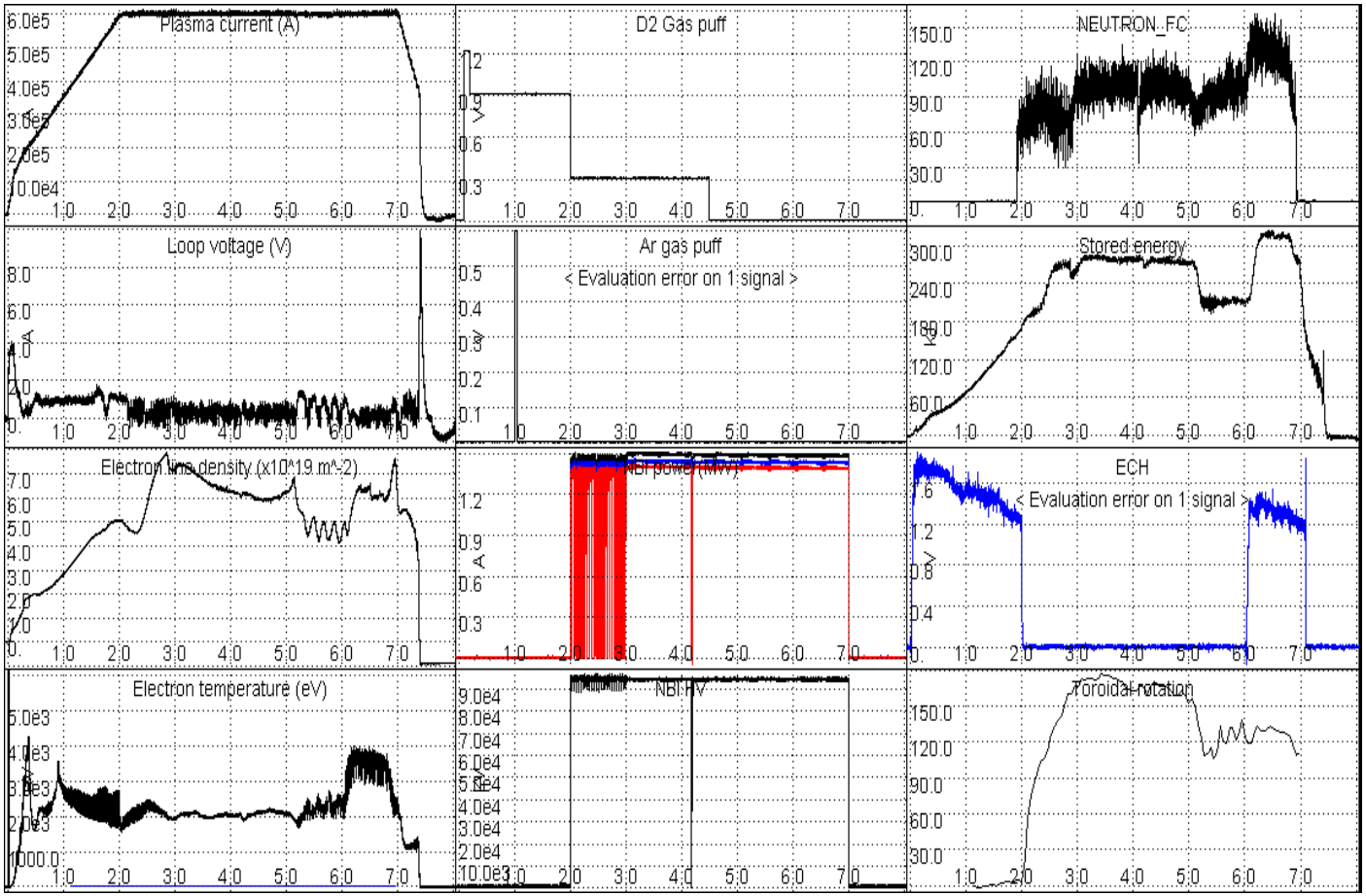
ECRH late H-mode for 95 keV NBI



Plot from jScope for shot 5607, which had a late H-mode triggered by ECRH, showing some of the parameters for this H-mode.

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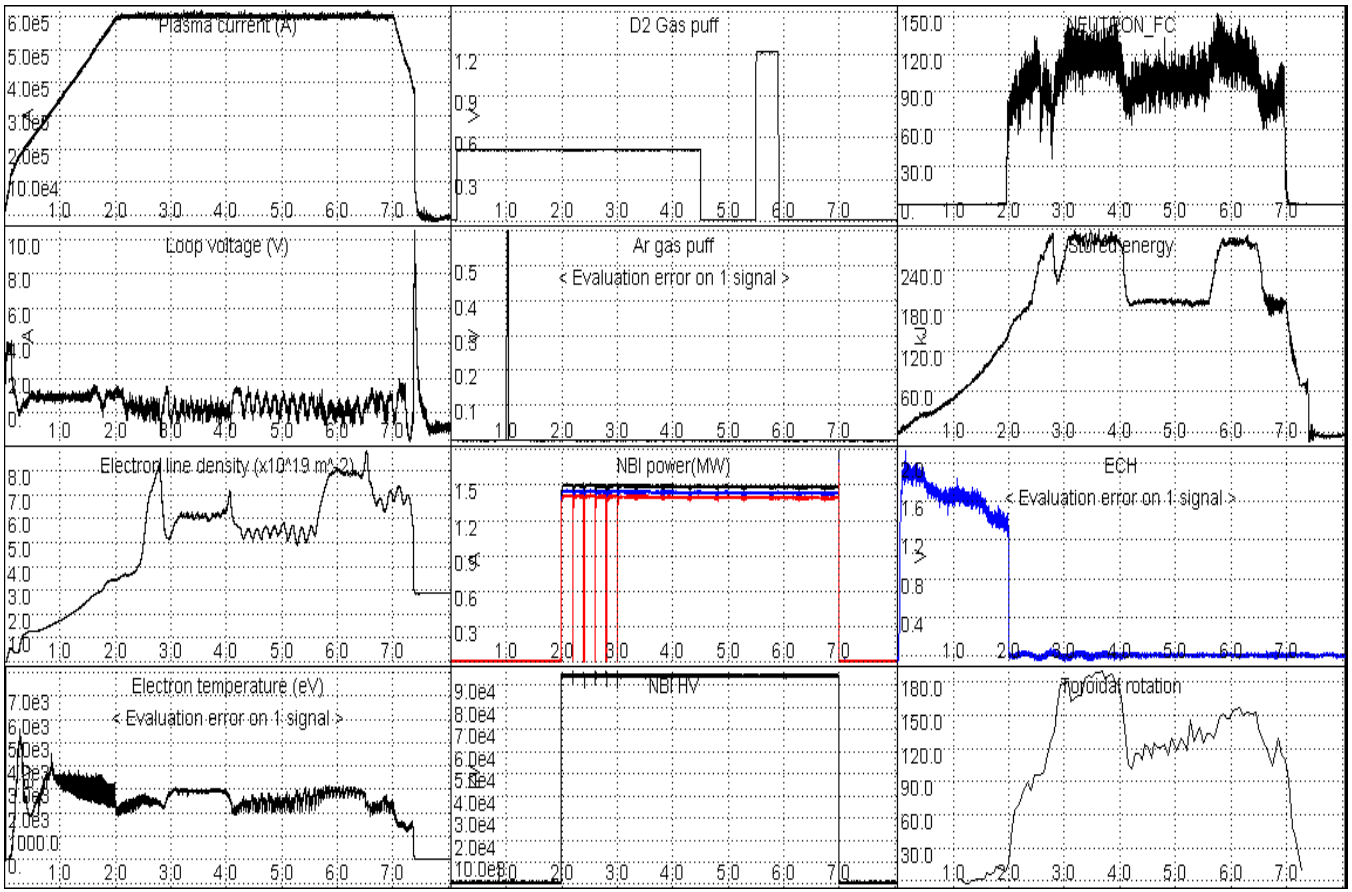
Spontaneous late H-mode for 95 keV NBI



Plot from jScope for shot 5687, which had a spontaneous late H-mode, showing some of the parameters for this H-mode.

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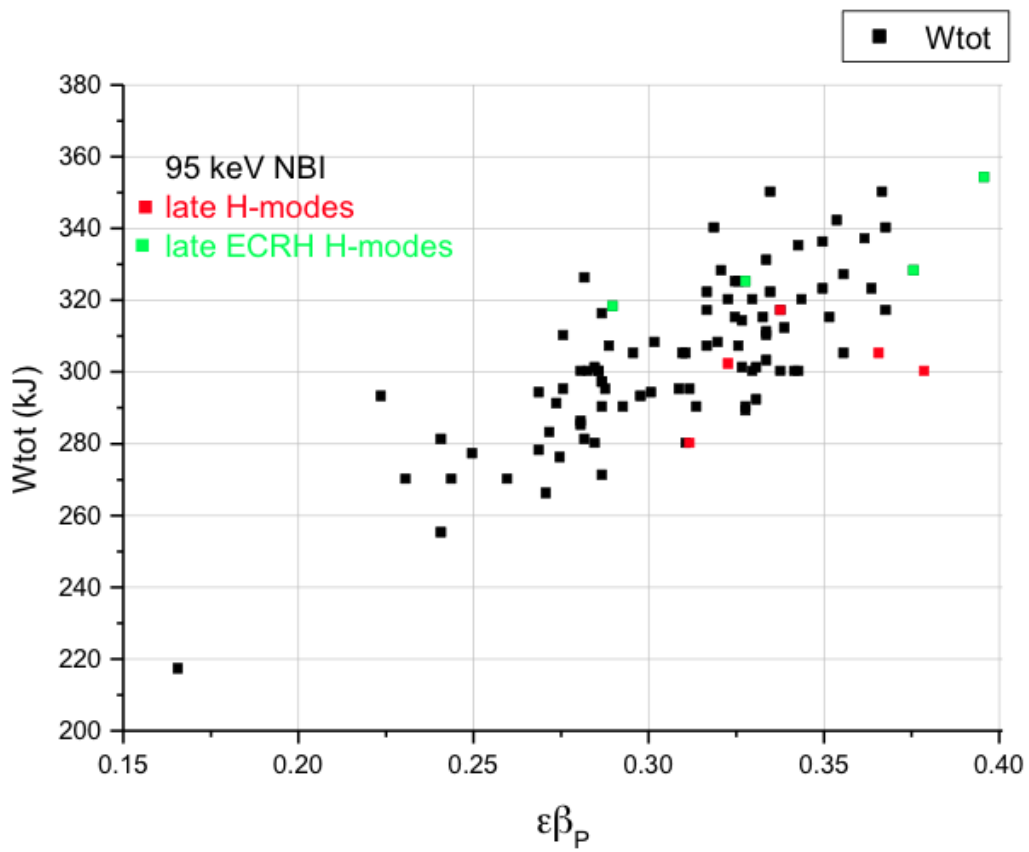
Total Energy, W_{tot} *vs.* $\varepsilon\beta_P$ for 95 keV NBI



The late H-modes are among the shots with the highest values of W_{tot} and $\varepsilon\beta_P$.

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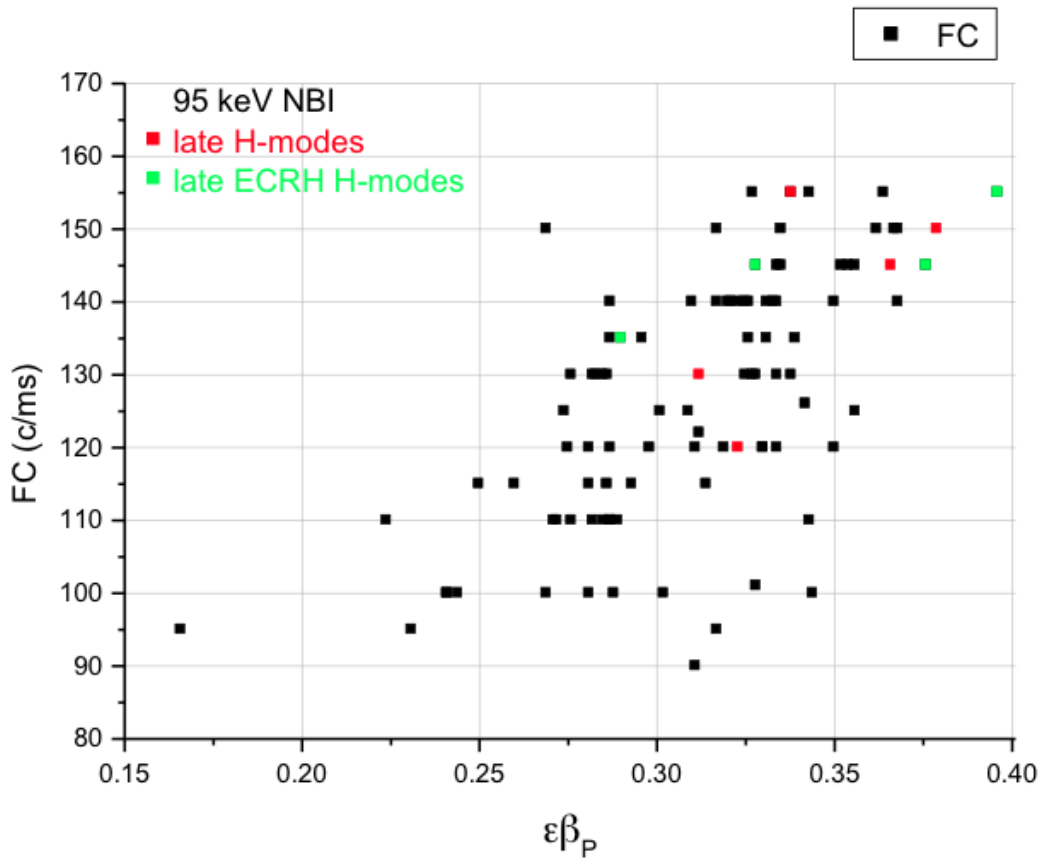
Neutron rate *vs*. $\varepsilon\beta_P$ for 95 keV NBI



The late H-modes have the highest values of neutron count rate, FC, and $\varepsilon\beta_P$.

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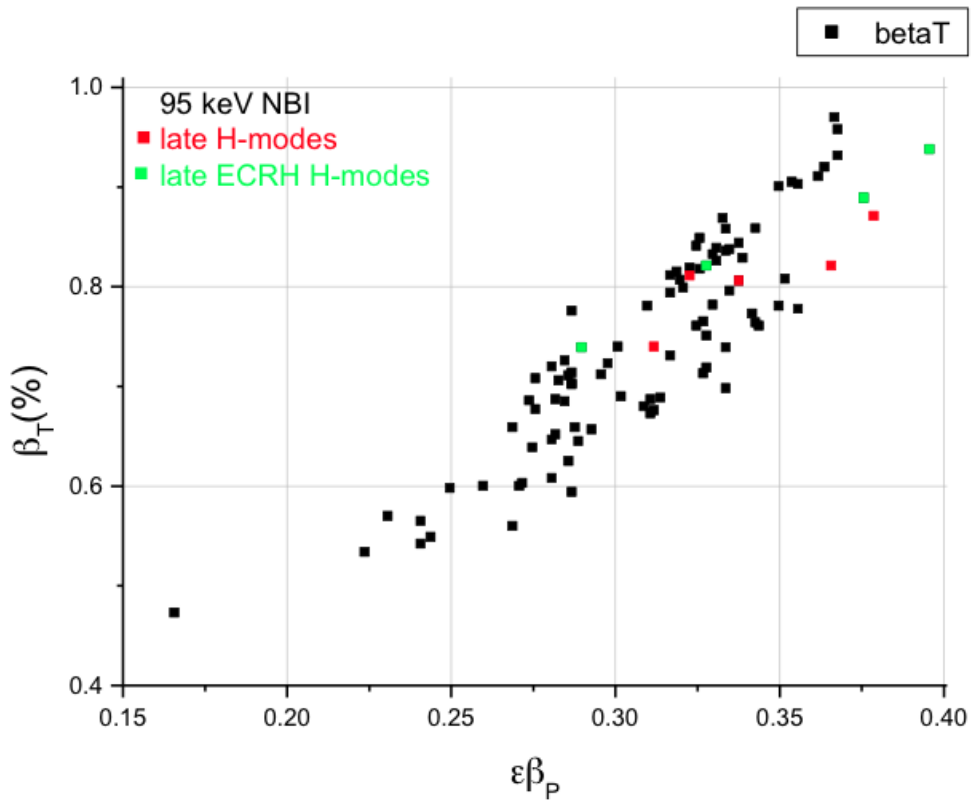
Toroidal beta, β_T *vs.* $\varepsilon\beta_P$ for 95 keV NBI



The late H-modes are among the shots with the highest values of β_T and $\varepsilon\beta_P$

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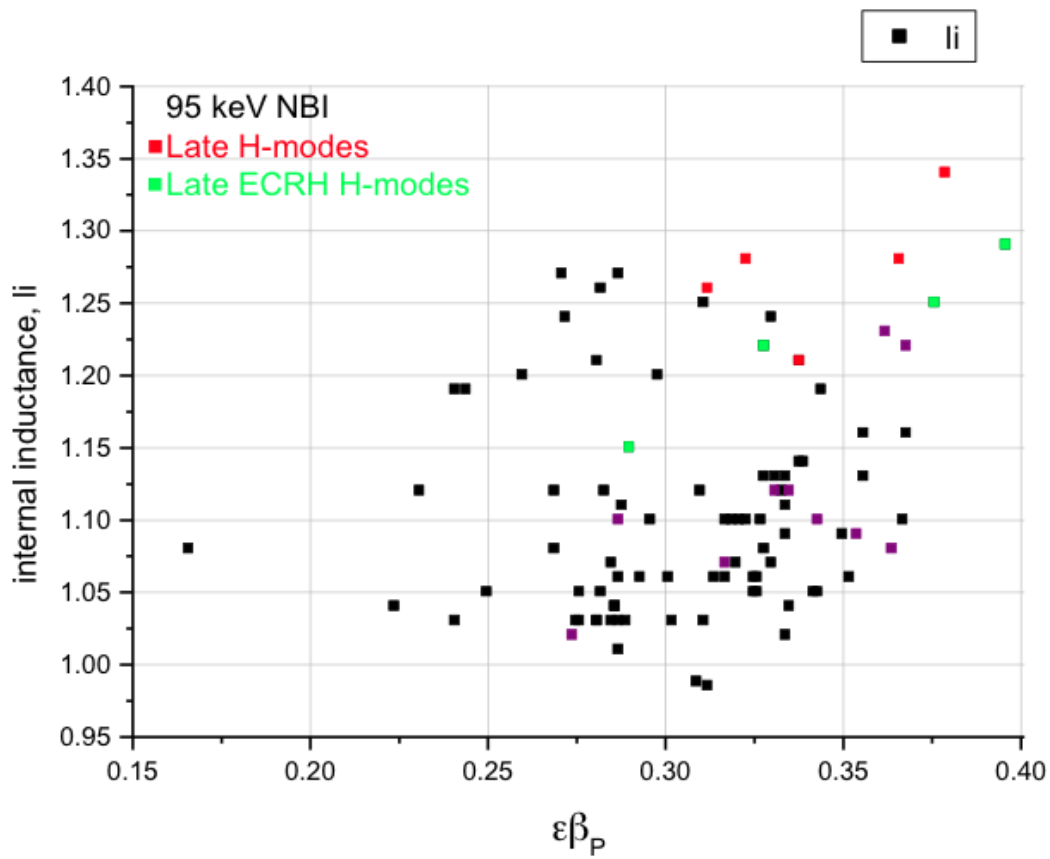
Internal inductance, li *vs.* $\varepsilon\beta_P$ for 95 keV NBI



Some of the late H-modes have the highest values of li and $\varepsilon\beta_P$.

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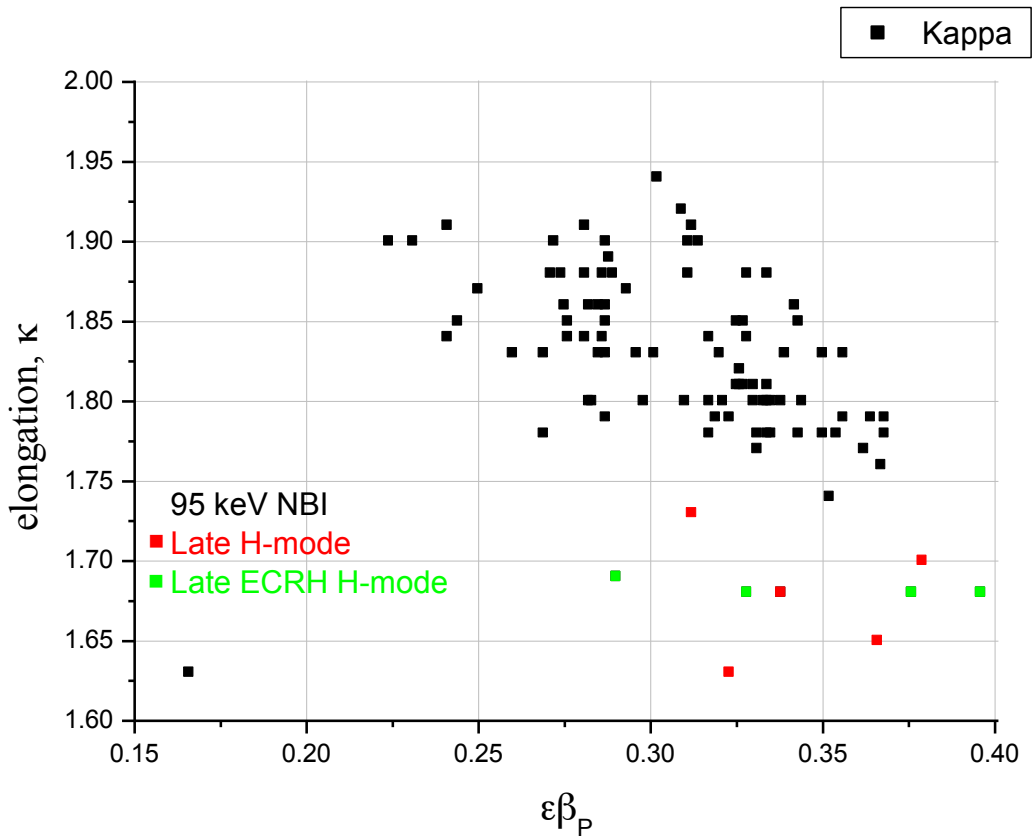
Elongation, κ *vs*. $\varepsilon\beta_P$ for 95 keV NBI



Values of κ are lower that the values for the normal earlier H-modes.

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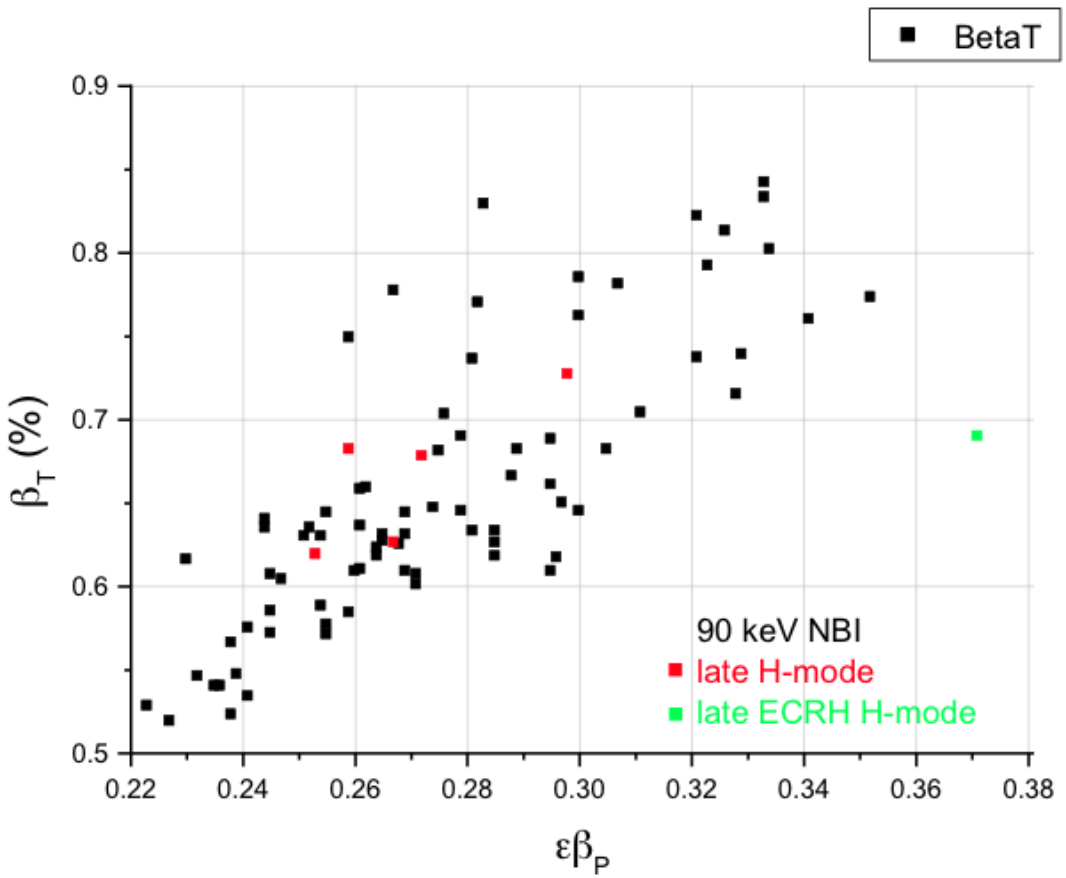
Total Energy, W_{tot} *vs.* $\varepsilon\beta_P$ for 90 keV NBI



At 90 keV the late H-modes do not have unusually high values of β_T or $\varepsilon\beta_P$

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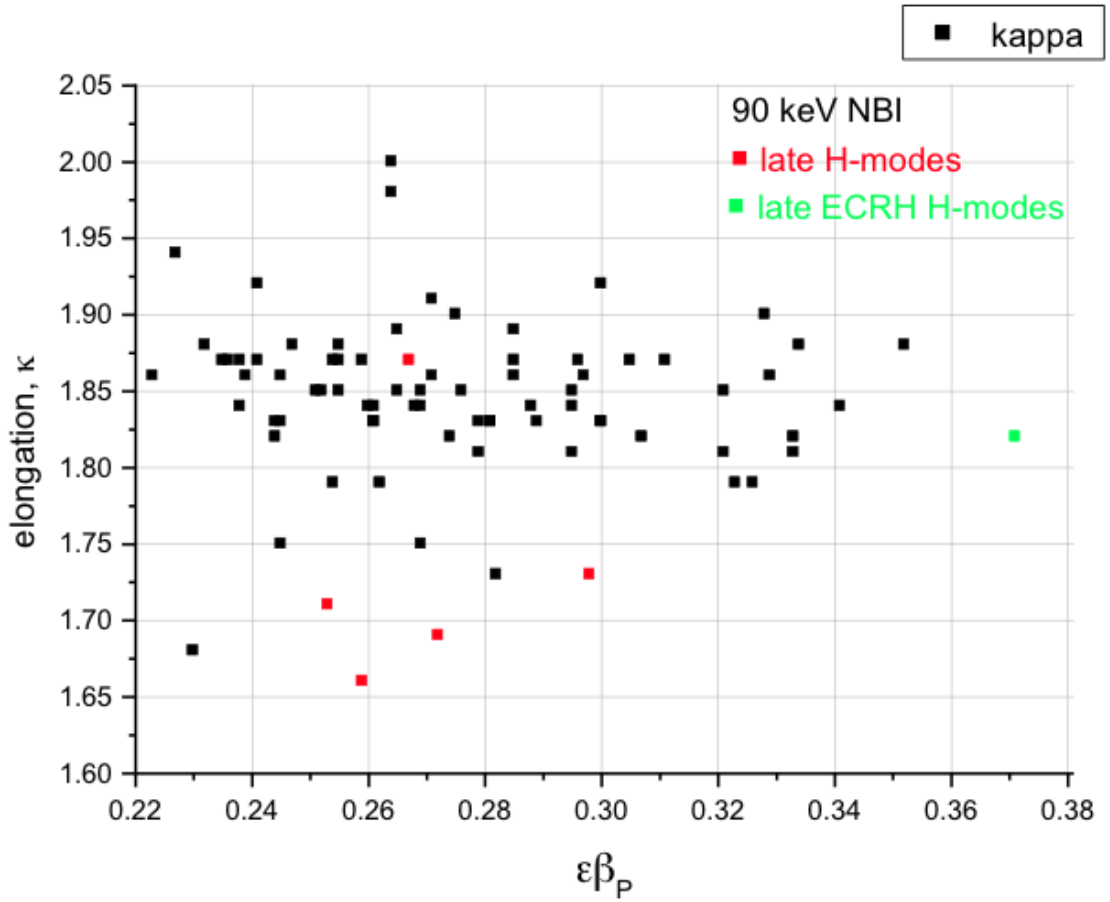
Elongation, κ *vs.* $\varepsilon\beta_P$ for 90 keV NBI



The values of elongation are not unusually low for the 90 keV NBI late H-modes

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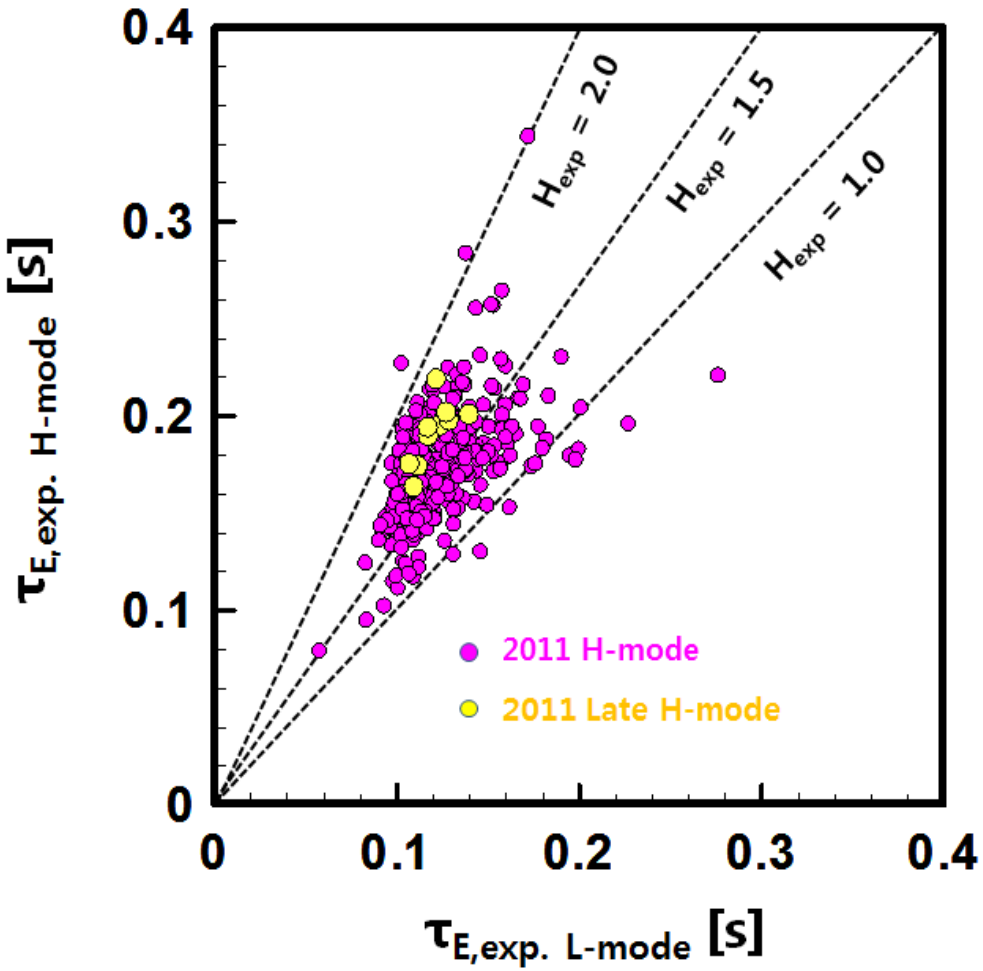
H-mode confinement time H factors for 95 keV NBI



The experimental late H-mode confinement time H factors are all between H_{exp}= 1.5 and H_{exp}=2.0.

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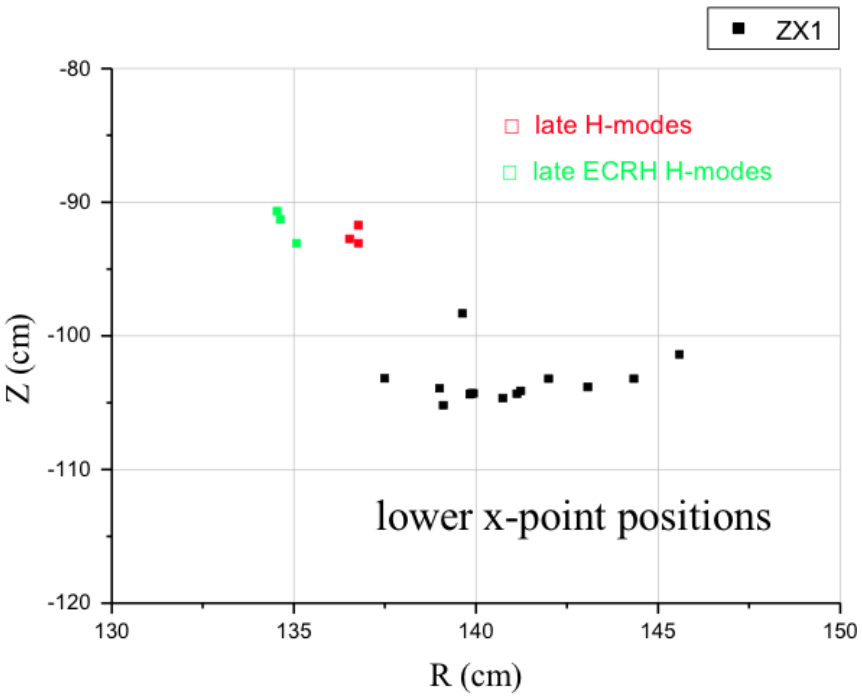
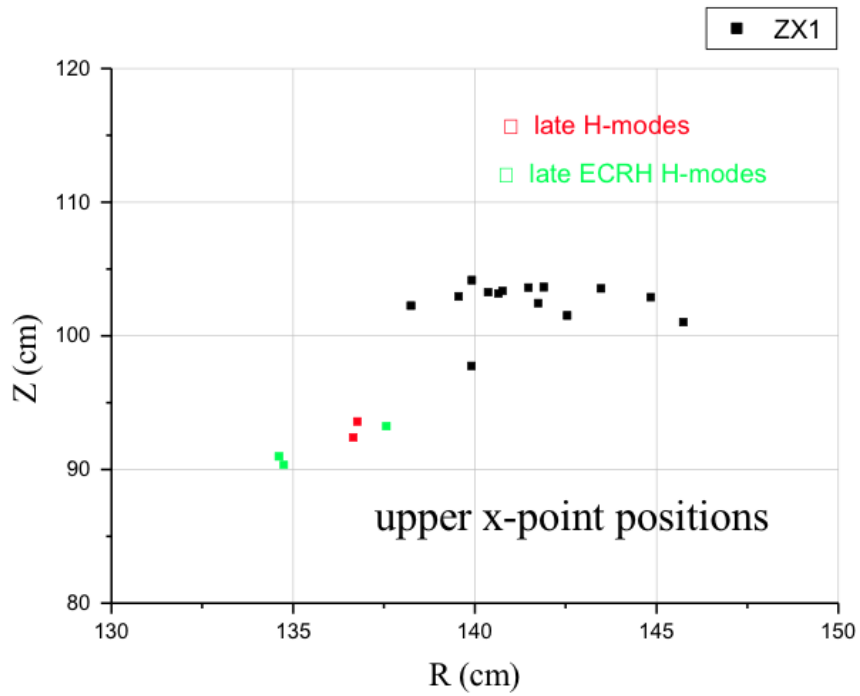
Late H-mode lower and upper x-point positions





Late H-mode x-points are at smaller radii and closer to the midplane than the normal early H-modes as determined by EFIT.

NSTX smaller radius x-points require higher auxiliary heating to achieve the H-mode.

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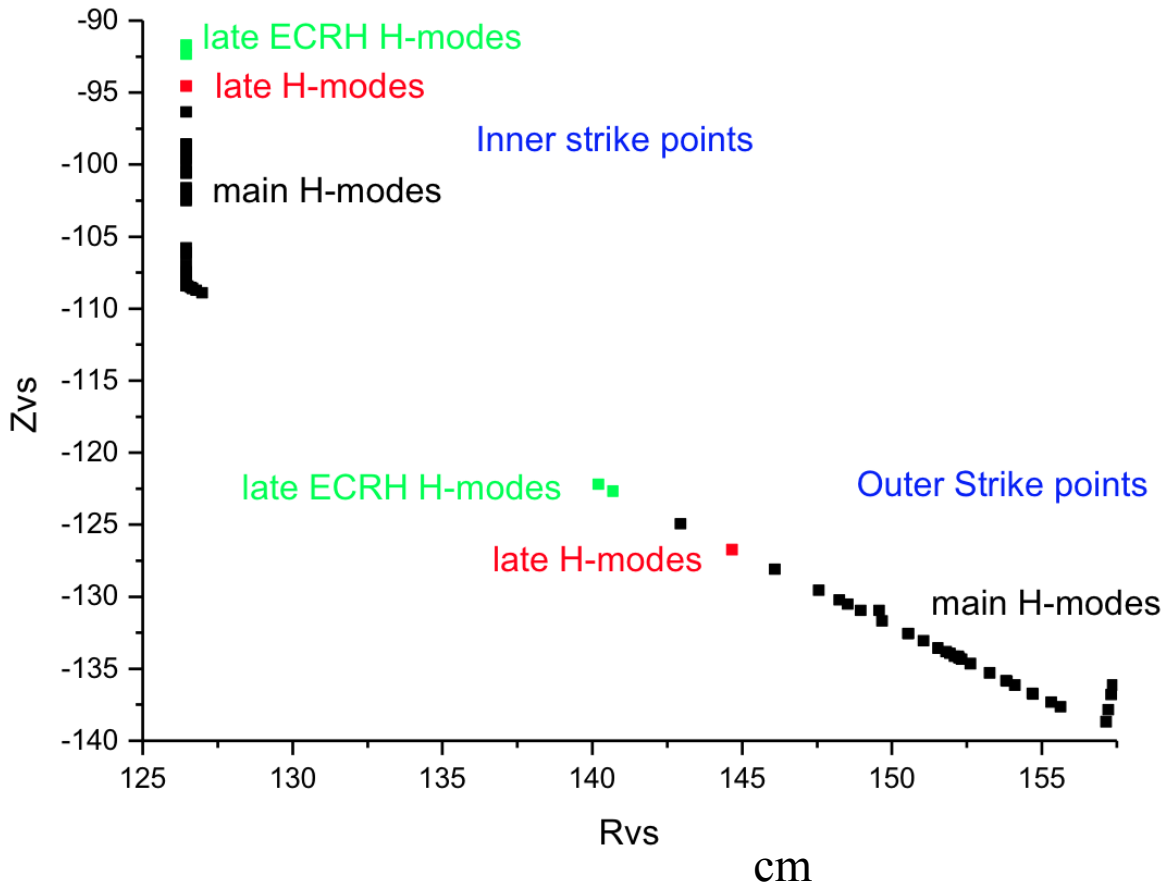
Strike Points from EFIT



EFIT calculations show the late H-mode strike points are closer to the mid-plane than the normal H-modes, as expected. Typical error is a few cm.

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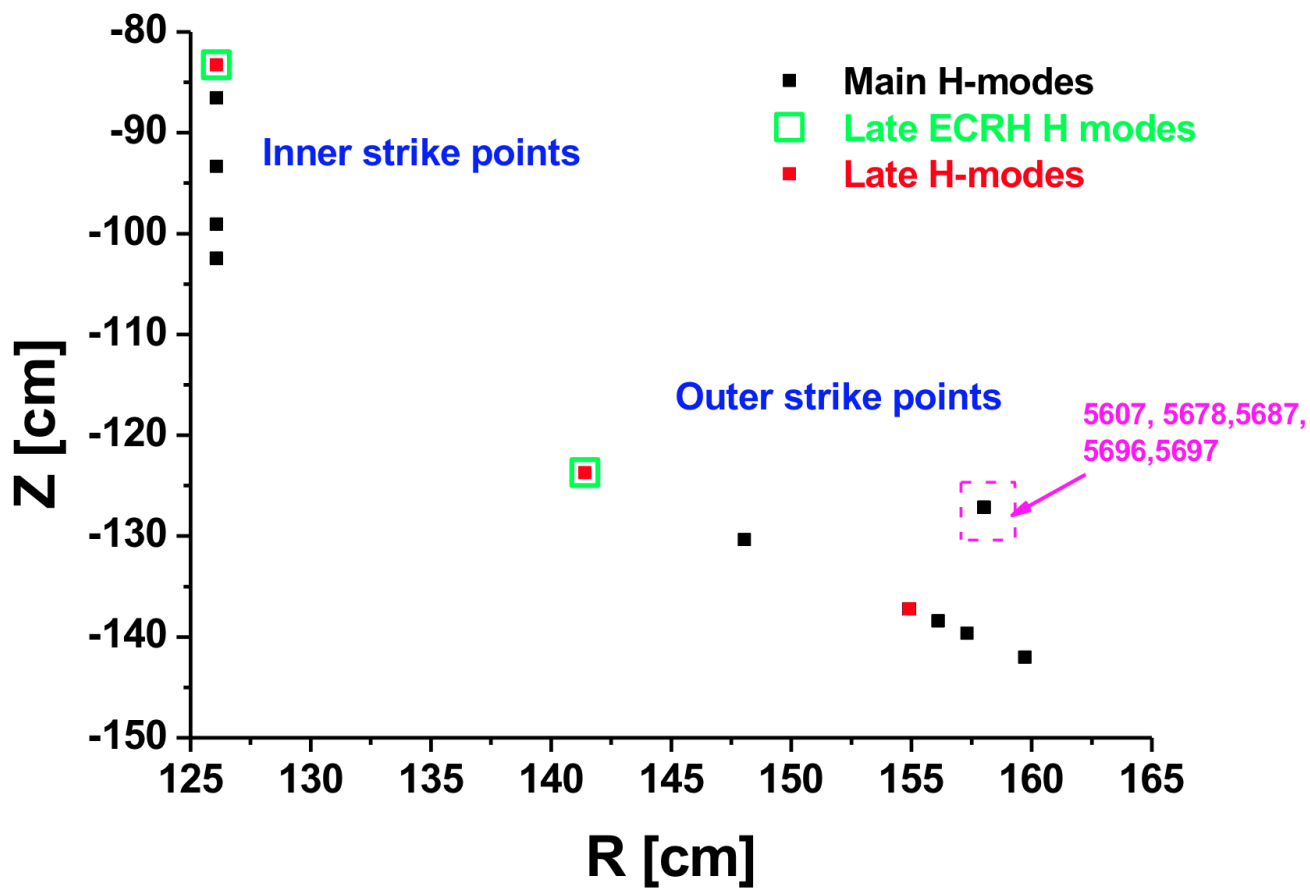
Measured Strike Points



The measured strike points are closer to the midplane as expected but not at the location as specified by EFIT. Cross field transport may play a role.

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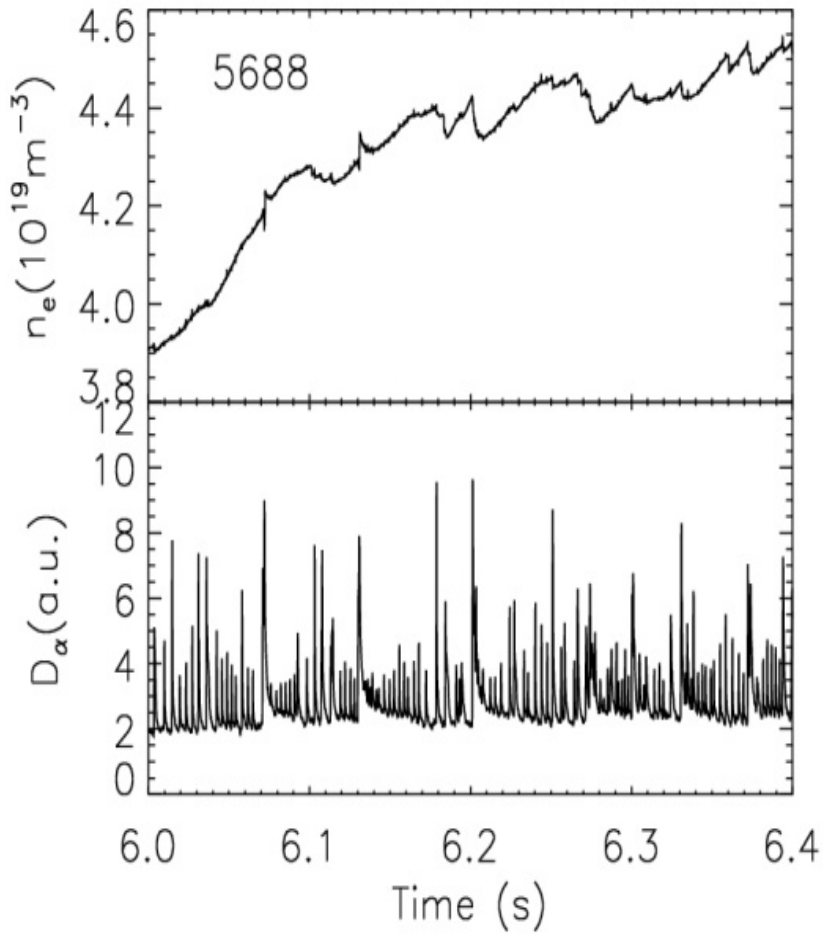
The late H-mode δRsep values

The late H-modes all have EFIT values of δRsep near -0.5 cm. They are more tightly clustered than the regular H-modes but there are many fewer of them. The EFIT plots indicate that the configuration is near usually SLND and close to DND.

ELM types



Signals of n_e and Dα from the divertor region for the late H-mode of shot 5688. The ELMs appear to be type I and II or type I and III.

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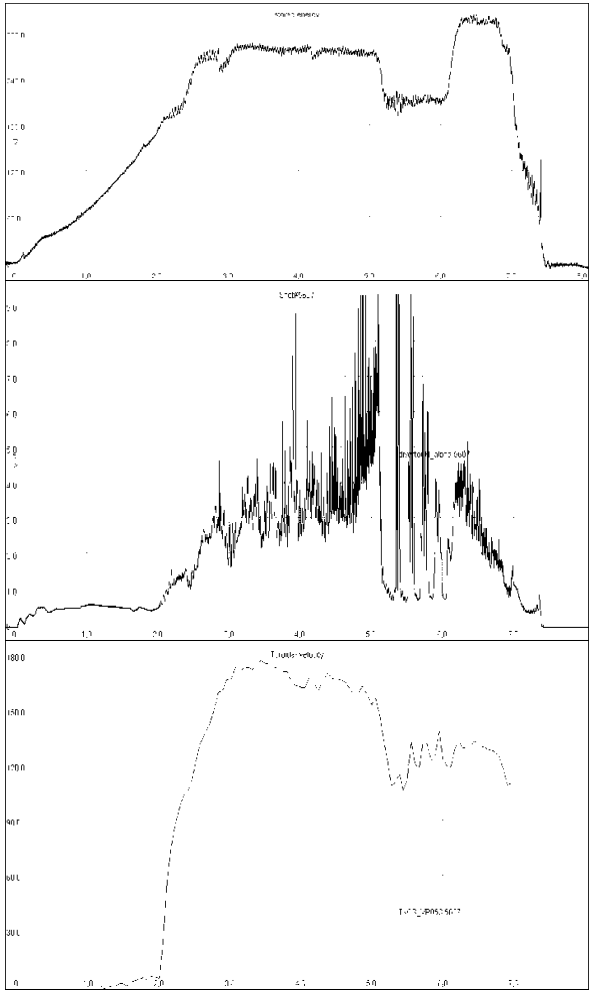
Late H-mode toroidal velocity



The late H-mode toroidal velocity measured by XICS is lower than the normal early H-mode toroidal velocity for shot 5607.

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Late H-mode toroidal velocities

Shot	Early H-mode velocity (km/s)	Late H-mode velocity (km/s)
5607	~170	~130
5608	~190	~130
5609	-	-
5611	-	-

Table 1
ECRH late H-mode toroidal velocities

velocities

Shot	Early H-mode velocity (km/s)	Late H-mode velocity (km/s)
5612	-	-
5687	~180	~150
5688	~200	~165
5689	-	~180
5690	-	~195

Table 2
Spontaneous late H-mode toroidal velocities

Where there was a late H-mode preceded by an early H-mode, the late H-mode velocity was clearly smaller both for the ECRH late H-modes as well as the spontaneous late H-modes

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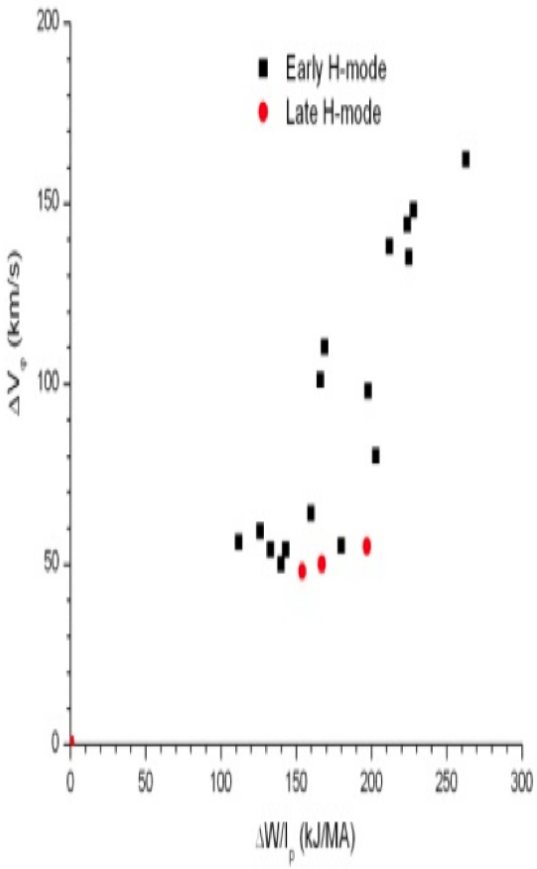
Rice Scaling



The H-modes of the 2011 KSTAR campaign have been observed to obey Rice scaling. That is, the change in toroidal rotation velocity from L to H mode is proportional to the change in stored energy normalized by the plasma current.

There were only nine late H-modes with four of them having ECRH triggers and five being spontaneous H-modes.

Of the five spontaneous late H-modes only three of them have XICS toroidal rotation measurements.

The three late H-modes are consistent with Rice scaling but do appear at the lower limit of the distribution of the normal H-modes. The two ECRH late H-modes are not plotted because the ECRH removes them from Rice Scaling.

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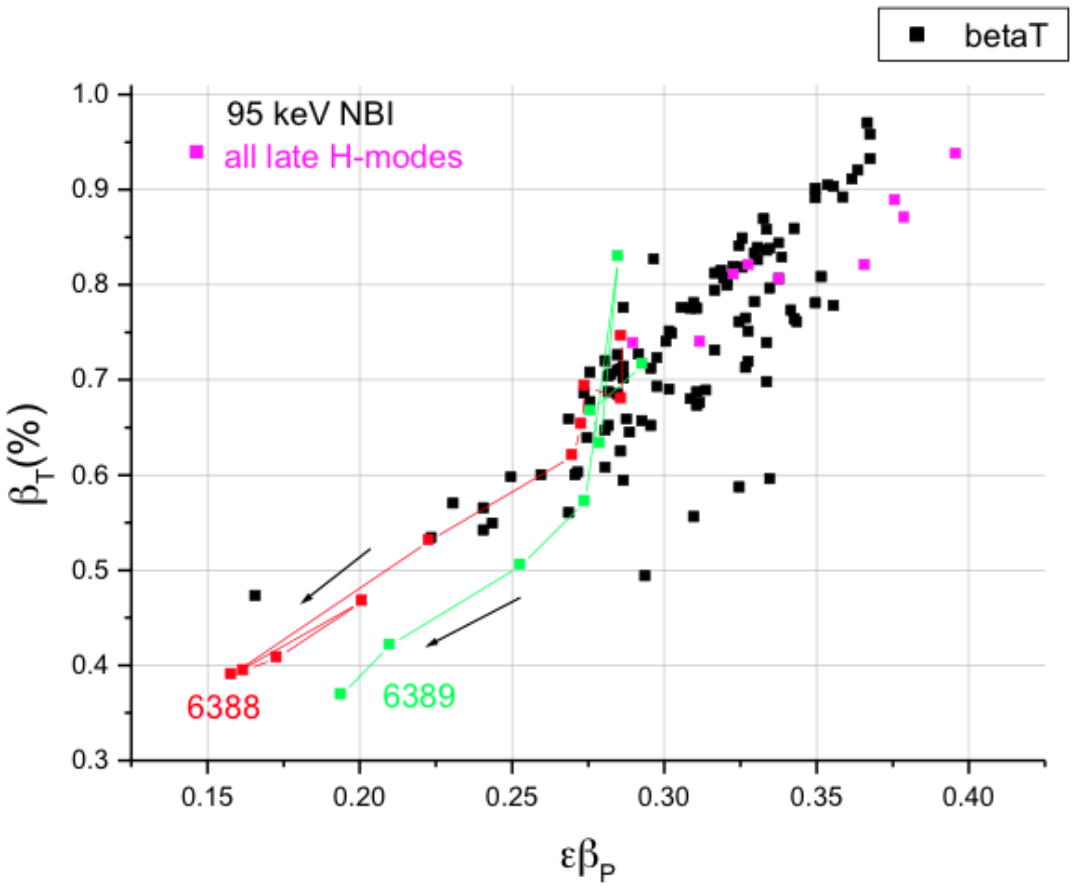
Evolution of long-lived H-modes

Time evolution of long lived H-mode shots 6388 and 6389 superimposed on a plot of initial values of β_T vs. $\varepsilon\beta_P$ for the H-modes.



The long lived H-modes evolve towards the lower left of the plot and do not end at a region near the late H-modes.

Similar plots for elongation, κ, and internal inductance, li, also show the evolution away from the high $\varepsilon\beta_P$ region.

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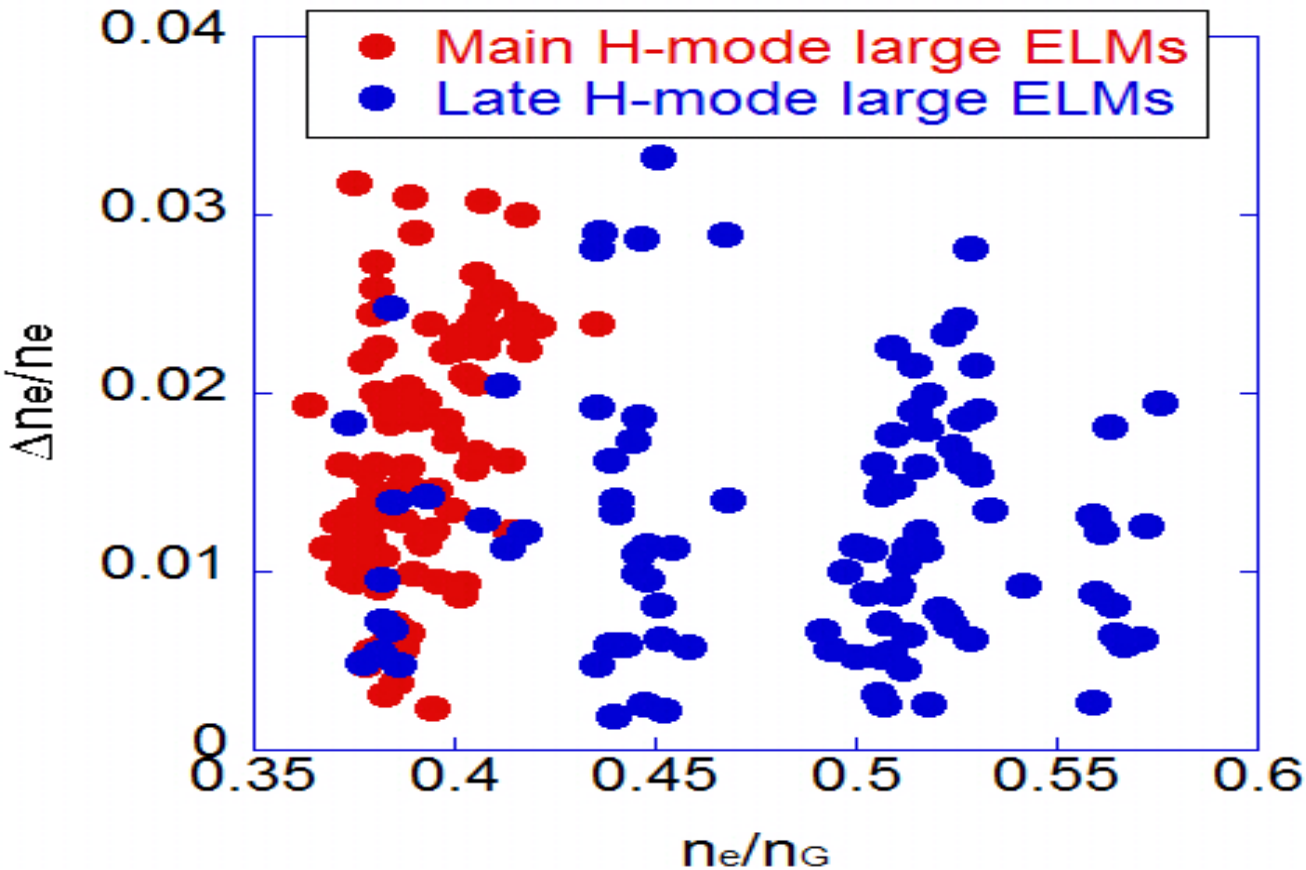
Size and Greenwald factor comparison



For both the main H-modes and the late H-modes there is no correlation between size ($\Delta n_e/n_e$) and Greenwald factor (n_e/n_G) but the late H-modes have larger Greenwald factors.

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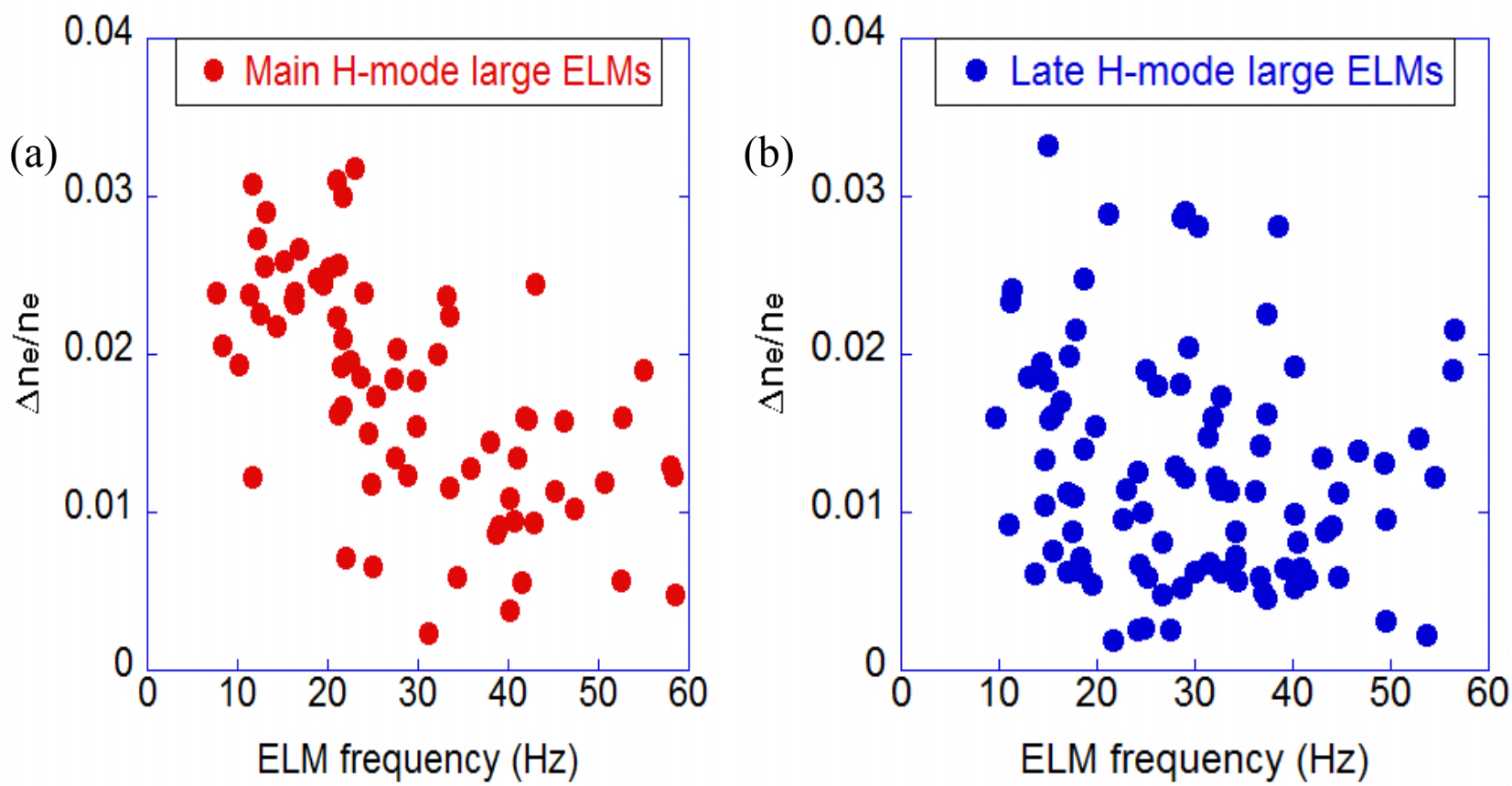
H-mode ELM frequency



For both the (a) main H-modes and the (b) late H-modes the large ELM size decreases slightly with frequency. The main H-mode large ELMs have a clearer inverse dependence on the ELM frequency than the late H-mode large ELMs.

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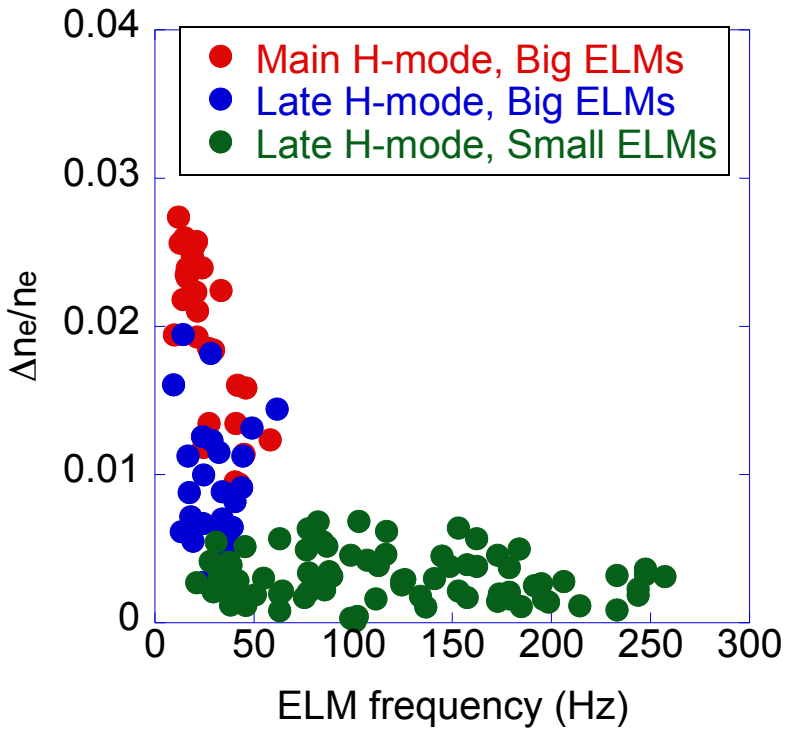
Main and Late H-mode ELM frequency



The late H-mode ELMS tend to be smaller than the main H-modes

The late H-mode small ELMs had frequencies up to ~260 kHz

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Summary and Conclusions - 1

Late H-modes from the 2011 KSTAR campaign have unusual properties.

Large increases in Wtot and neutron yield are produced by ECRH and by some spontaneous effect.

These late H-mode peaks have W_{tot} values that are equal to or larger than the earlier H-mode peaks in the same shot, if there were any.

Of these nine late H-modes, all but one was preceded by a gas puff.

The elongation, κ, is smaller for these late peaks than any other H-mode. It also shows that li, the internal inductance, is large for these peaks.

The late H-modes appear to exhibit ELMS of types I and II or types I and III.

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Summary and Conclusions - 2

The x-point locations of the late H-modes are at lower radius and closer to the midplane than the normal H-modes.

The strike points have a similar location closer to the midplane

The δRsep values for the late H-modes are all near -0.5 cm indicating LSND which is very close to DND

The small ELM frequency ranges up to 250 Hz and the ELM size is less than 0.5%.

The Greenwald fraction for the large ELM late H-modes is from 0.35 to 0.6 and is larger than the normal H-modes. The frequencies are as high as 60 Hz.

The toroidal velocity as measured by the XICS diagnostic shows that the velocity is generally lower than the conventional early H-modes.

Summary and Conclusions - 3

The late H-modes obey Rice scaling: the change in the toroidal velocity as compared to the L mode is proportional to the change in stored energy divided by the plasma current.

The study of 90 keV NBI does not show such unusual behavior. None of the 90 keV NBI late H-modes was preceded by a gas puff.

There were only 11 H-modes found for 80 keV NBI and there were no late 80 keV H-modes observed.

Future Work

This appears to be a promising method for making high quality H-modes and will be explored in the 2012 KSTAR campaign.

During this next campaign the NBI acceleration voltage is expected to reach 100 kV and late H-modes with higher acceleration voltage will be explored.