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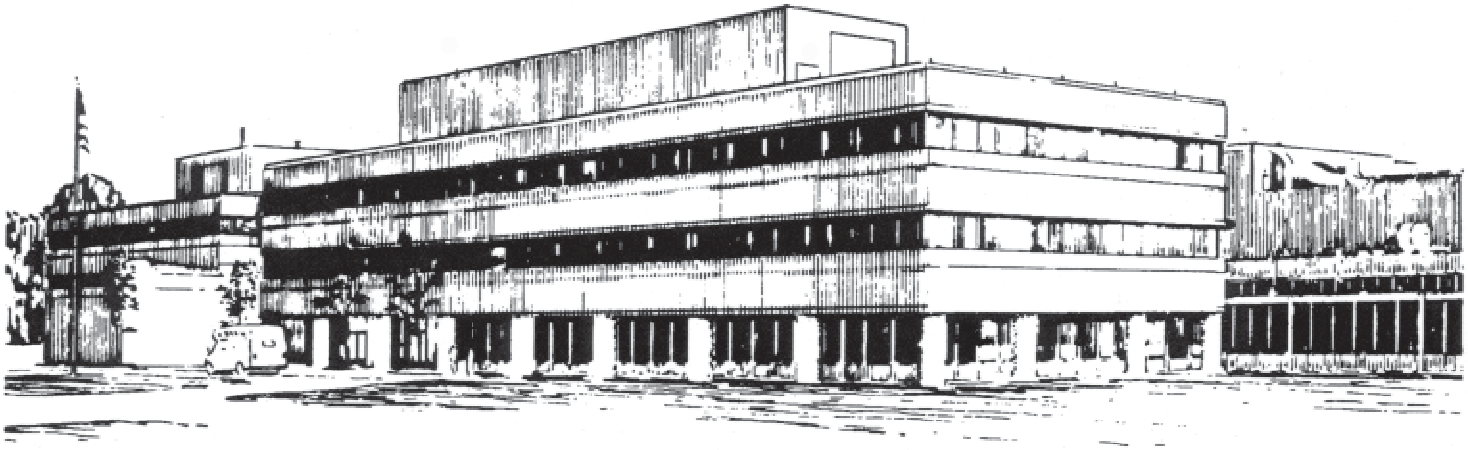

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Effect of Gas Fueling Location on H-mode Access in NSTX

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Abstract – *The dependence of H-mode access on the poloidal location of the gas injection source has been investigated in NSTX. We find that gas fueling from the center stack midplane area produces the most reproducible H-mode access with generally the lowest L-H threshold power in lower single-null configuration. The edge toroidal rotation velocity is largest (in direction of the plasma current) just before the L-H transition with center stack midplane fueling, and then reverses direction after the L-H transition. Simulation of these results with a 2-D guiding center Monte Carlo neoclassical transport code is qualitatively consistent with the trends in the measured velocities. Double-null discharges exhibit H-mode access with gas fueling from either the center stack midplane or center stack top locations, indicating a reduced sensitivity of H-mode access on fueling location in that shape.*

PACs: 52.55Fa

It has been previously reported that in both MAST[1] and NSTX[2], fueling from the center stack region (i.e. high-field side, HFS) allowed more reproducible H-mode access than fueling from the outer midplane or other low-field side (LFS) locations. Quantifying this behavior in NSTX has been challenging, however. Prior to HFS fueling, it was difficult to obtain routine H-modes with LFS fueling in NSTX. In contrast, long reproducible H-modes were obtained during the first attempt with HFS fueling following the first high temperature (~350 ^{0}C) bake-out of the graphite plasma facing surfaces. We note that HFS gas fueling widened[3] the H-mode access space and reduced the power threshold somewhat in COMPASS-D, as compared with LFS fueling. In addition, HFS fueling was about twice as efficient as LFS fueling during DIII-D ELMy H-modes[4], although the gross fueling efficiencies were less than 1% in both cases.

The present H-mode access scenario in NSTX uses LFS fueling for the gas pre-fill before t=0 and during the current ramp up prior to neutral beam initiation, which typically starts at t~0.1 sec. The LFS injection is usually terminated just before NBI turn-on, when HFS fueling is initiated. Due to the long tube used for HFS midplane injection, the e-folding decay time of the flow rate[5] is ~ 0.55 sec, resulting in limited control of the fueling rate.

Motivated by these and other experimental results, a neoclassical transport theory was developed[6,7] to examine the dependence of the momentum balance on the poloidal location of the gas injection source. The theory suggests that the charge-exchange viscous drag is higher for neutral sources on the LFS than the HFS, because the ions lost to charge exchange have the highest toroidal velocity (v_ϕ) at the weakest toroidal field (B_ϕ) point, i.e. the outer midplane. As a result, both the v_ϕ and radial electric field (E_r) have terms with $1/R_*^2$, where R_* is the major radius at which gas fuels the plasma. This effect should be most apparent in a spherical torus because it features the largest variations in R_* from the inner to outer midplane.

Additional gas injectors at various poloidal locations were commissioned in NSTX to test this prediction and improve gas fueling control. Fig. 1 shows the four injector locations: HFS midplane(black), HFS top in upper corner (orange), outer midplane (blue), and lower X-point region (white). These injectors were used to fuel routine lower-single-null, upper-single null, and double-null discharges with plasma current I_P ~ 0.9 MA, toroidal field B_t ~ 0.45 T, and 3.2 MW of neutral beam injected (NBI) power. The unfiltered light patterns from these discharges showed localized emission near the gas injector locations (see Fig. 2). Most of this visible light originates from D_α recycling light, suggesting that the neutral density poloidal variation is affected by the choice of puff location. We do not quantify this variation in this paper, but merely use it as an indicator the neutral density poloidal distribution can be modified to qualitatively test the neoclassical theory prediction above.

The first three injectors were each used to fuel a lower-single null discharge during the neutral beam injection (NBI) phase, e.g. starting at t=0.08 sec in Fig. 3. Prior to NBI (the pre-fill and during plasma current ramp-up), all of the gas fueling was injected with a separate outboard injector. The total gas input during NBI was well matched in the three cases, and the time dependence of the gas injection rate was reasonably well matched. However the HFS midplane injector discharge (black trace) exhibited H-mode access at t=0.26 sec, whereas the other two discharges with LFS and HFS top fueling exhibited prolonged L-modes and early reconnection events. This experiment was conducted near the beginning of the 2003 run period, when the L-H transition power was between one and two NBI sources, i.e. higher than normal threshold levels. We previously reported [2] that the LFS injector only produced H-mode access at an NBI power between 1.6 and 3.2 MW (between 1 and 2 sources) in conditions[8] where the L-H threshold power was measured at ~ 650 kW with HFS midplane fueling, i.e. below 1 full NBI source. In that set of experiments, the required NBI power for H-mode access became similar between the two fueling locations as the gas rate was reduced, but the reproducibility was still better with the HFS midplane injector. The lower limit on fueling rate was set by the occurrence of locked modes with either injector. At very high fueling rates, the H-mode could not be accessed at all with LFS gas puffing, even though access was maintained with the HFS midplane injector. These observations imply that the neutral density magnitude itself likely affects H-mode access criteria. Finally we note that fueling with a combination of the X-point injector and LFS injector failed to produce H-mode transitions, and the temporal characteristics of those discharges were quite different from the other injectors discussed above. Additional experiments are required to fully characterize these differences.

Fig. 4 compares the magnitude of the edge toroidal rotation for two HFS midplane discharges with a LFS fueled discharge and an X-point + LFS fueled discharge. We note that the edge rotation speed for the HFS midplane discharges is marginally but consistently higher (co-I_p, reproducible in other discharges from this experiment) than for the other fueling locations just before the time of the L-H transition of the HFS midplane fueled discharges. Note that the LFS and X-point + LFS fueling cases failed to access H-mode and resulted in shorter discharges (see Fig. 3). The edge rotation velocity is obtained from Abel-inversions of passive edge rotation signals of C-III light [9]. The diagnostic has a ~ 3cm edge spatial resolution and integrates over 10msec. The rotation velocity at the radius of peak emission (R~1.48m, normalized poloidal flux ψ_N ~ 0.97-0.98) is plotted, because it has the lowest statistical and inversion errors. We note that the poloidal rotation array was unavailable during this experiment, precluding a statement on the effect of fueling location on E_r in this paper.

In double-null discharges, the differences between fueling from the HFS midplane and HFS top were more subtle. Discharges fueled by either injector allowed H-mode access at comparable power levels; the major difference was the location of the D_α fueling light, which was centered about the midplane for midplane fueling and near the upper corner for top fueling (fig. 2).

We have simulated the effect of neutral source poloidal location variation in the lower-single null configuration with a new 2-D Monte Carlo, guiding center code (XGC)[10] with neoclassical and/or anomalous cross-field transport in an X-point geometry. The poloidal distribution of the neutral fueling source is a Gaussian plus a baseline as a function of the poloidal angle, θ. The location of the peak of the Gaussian is selected to match the fueling location. The ratio of the maximum fueling source of the Gaussian to the baseline value is set (somewhat arbitrarily at a high value for exploration) to 50. The integral of the fueling source term (in effect, the maximum of the Gaussian) is constrained by the input edge density value. The model edge temperature is constrained by the input experiment value, and the anomalous cross-field coefficients are selected to approximately match the n_e and T_e profiles. Three simulations were conducted: one of the LFS midplane fueled L-mode phase, one of the HFS midplane fueled L-mode phase, and one of the HFS midplane fueled H-mode phase after the L-H transition. An anomalous cross-field diffusion coefficient of 2 m^2/s was used to model the L-mode phases, which was then reduced to 0.1 m^2/s for modeling of the H-mode phase.

Fig. 5 shows that the flux surface averaged toroidal rotation is predicted to be higher for the HFS midplane fueling than the LFS fueling cases, consistent with the analytic theory [6]. The toroidal rotation is in the co-NBI direction, except close to the separatrix where rotation is negative due to the negative E_r. Fig. 6 shows that the edge toroidal rotation is predicted to be reduced in the H-mode phase, and the width of the counter rotation region is increased. This occurs because of the larger negative E_r in the H-mode phase and the larger edge pressure gradient, both of which drive counter rotation. We note that the predictions show in Figs. 5 and 6 are qualitatively consistent with the data in

Fig. 3-4, albeit with the acknowledgement that the diagnostic does not presently have the spatial resolution to measure the fine structure of the predicted velocity for ψ_N between 0.99 and 1.0. Note that the simulation does not attempt to explore the dynamics of the transition itself, but rather the pre- and post-transition states.

In summary, we have conducted experiments to test the effect of gas injector location on H-mode access and quality. We find that HFS midplane fueling leads to the most reproducible access in lower-single null discharges with an obviously lower L-H threshold power. These results are qualitatively consistent with an analytic theory and Monte Carlo transport calculations. In double-null configuration, H-mode access is equally well achieved by HFS midplane or HFS top corner injection, which may be due to improved trapping of gas along the inboard boundary in double-nulls.

The degree to which the poloidal dependence of the fueling source can be affected by the gas puff location, however, requires extensive neutral density measurements. At a minimum the neutral density distributions need to be measured at the inner and outer midplanes, as well as the X-point regions. Such measurements would allow an assessment of the importance of local and main chamber recycling/fueling, as compared with divertor fueling in the vicinity of the X-point regions.

Acknowledgements

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Figure captions

1 – gas injector locations in NSTX.

2 – visible light emission (unfiltered) during fueling from different poloidal locations. Circles highlight the regions of enhanced emission.

3 – comparison of discharges fueled from the HFS midplane (black-solid), the outboard side (blue-dashed), and HFS top (orange-dash-dot). All discharges had the same NBI timing. The gas flow rate time dependence (b) is slightly different for the HFS top injector, but the total gas input (c) is well matched. The toroidal rotation (d) at the edge near the separatrix is marginally higher (more co-I_p*) just prior to the L-H transition in the HFS midplane fueling discharge, but then turns sharply negative after the L-H transition at t~ 0.255 sec. The HFS top and LFS fueling discharges did not undergo an L-H transition, as shown in the* D_α *(e).*

4 – *comparison of edge toroidal rotation for discharges fueled from the HFS midplane (black-solid and green-dash-dot-dot), the outboard side (blue-dashed), and HFS top (orange-dash-dot). The edge rotation was marginally higher for the two HFS midplane discharges which exhibited H-mode transitions (times indicated by the vertical bars).*

5 – comparison of predicted toroidal rotation with HFS midplane (inside) and LFS (outside) fueling with the XGC code.

6 – comparison of predicted toroidal rotation in H-mode and L-mode phases of HFS midplane fueling with the XGC code.

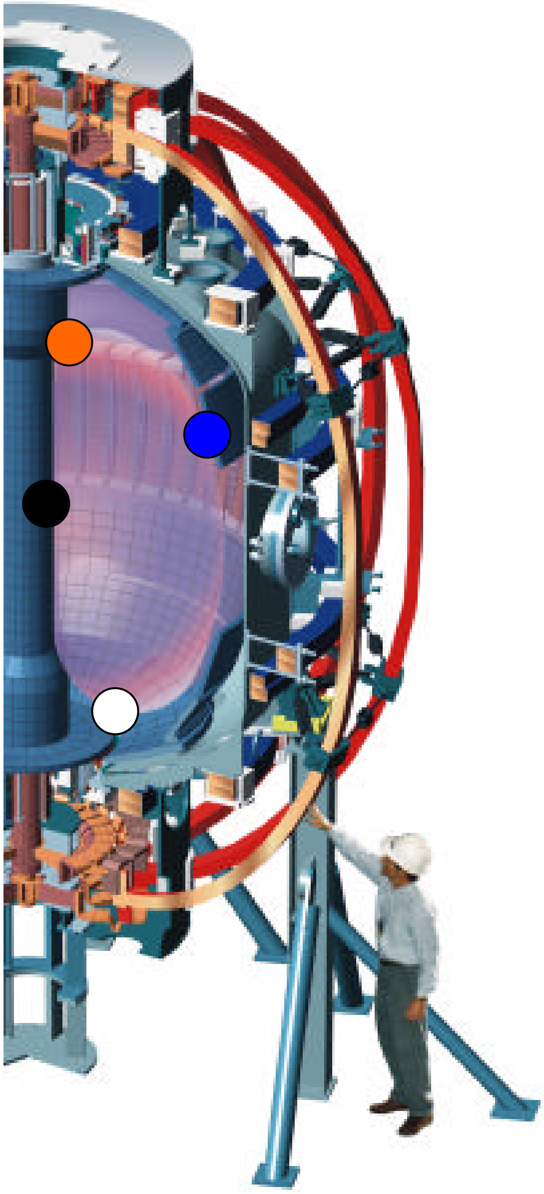
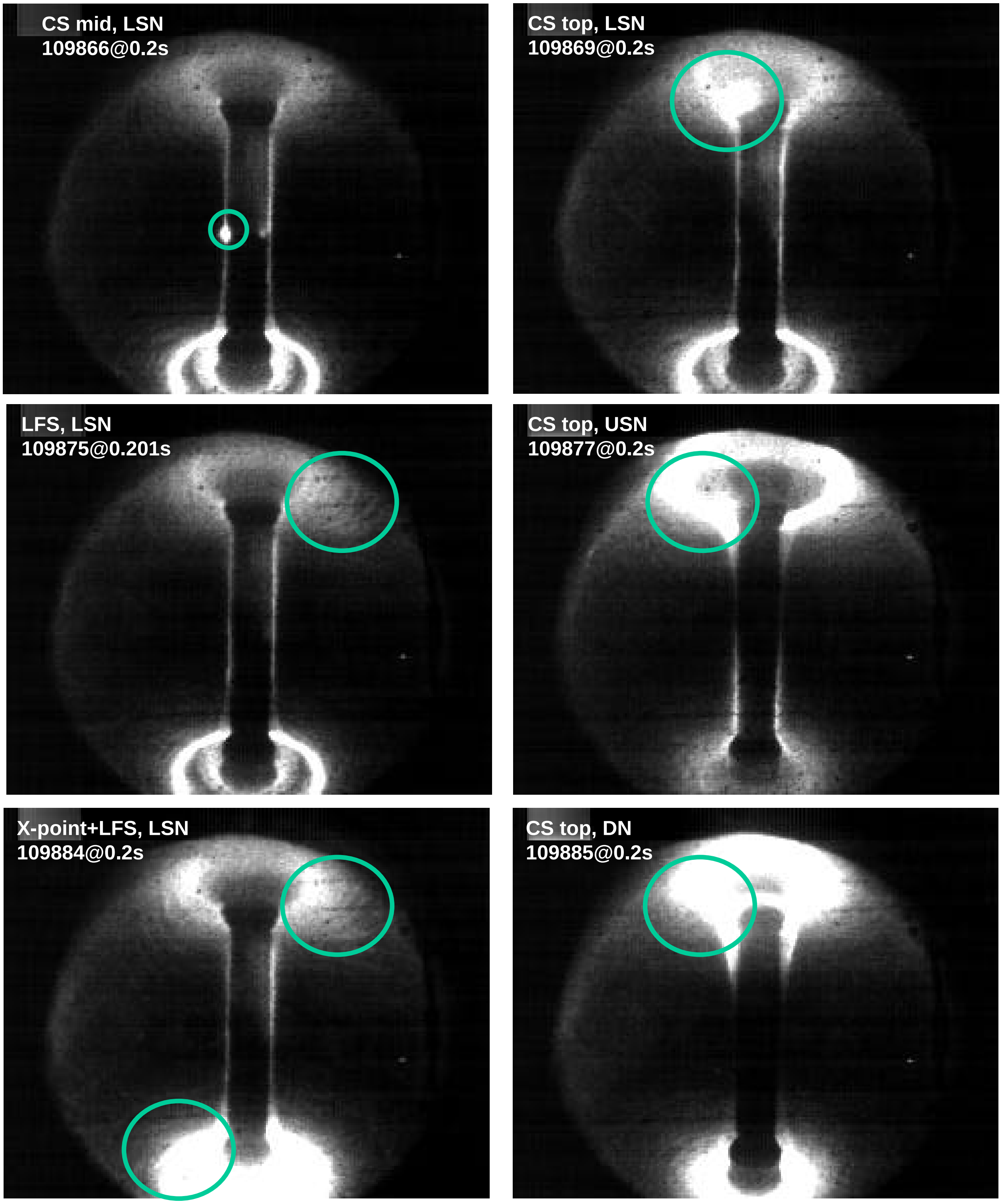


Fig. 1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X-point+LFS, LSN
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CS top, DN
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Fig. 2.

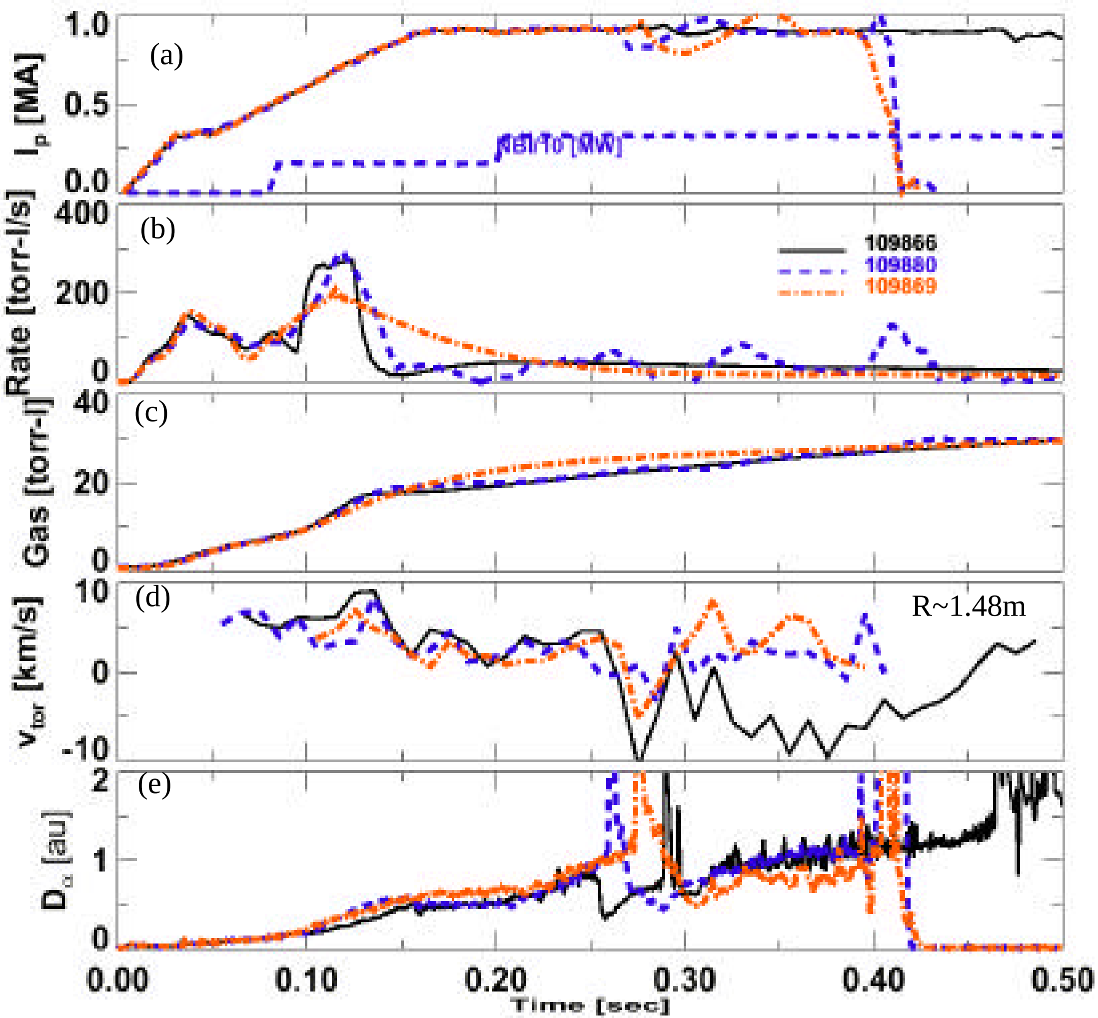

(a)
I_p [MA]
1.0
0.5
0.0
NBI/10 [MW]
(b)
Rate [torr-l/s]
400
200
0
109866
109880
109869
(c)
Gas [torr-l]
40
20
0
(d)
v_tor [km/s]
R~1.48m
10
0
-10
(e)
D_α [au]
2
1
0
0.00
0.10
0.20
0.30
0.40
0.50
Time [sec]

Fig. 3

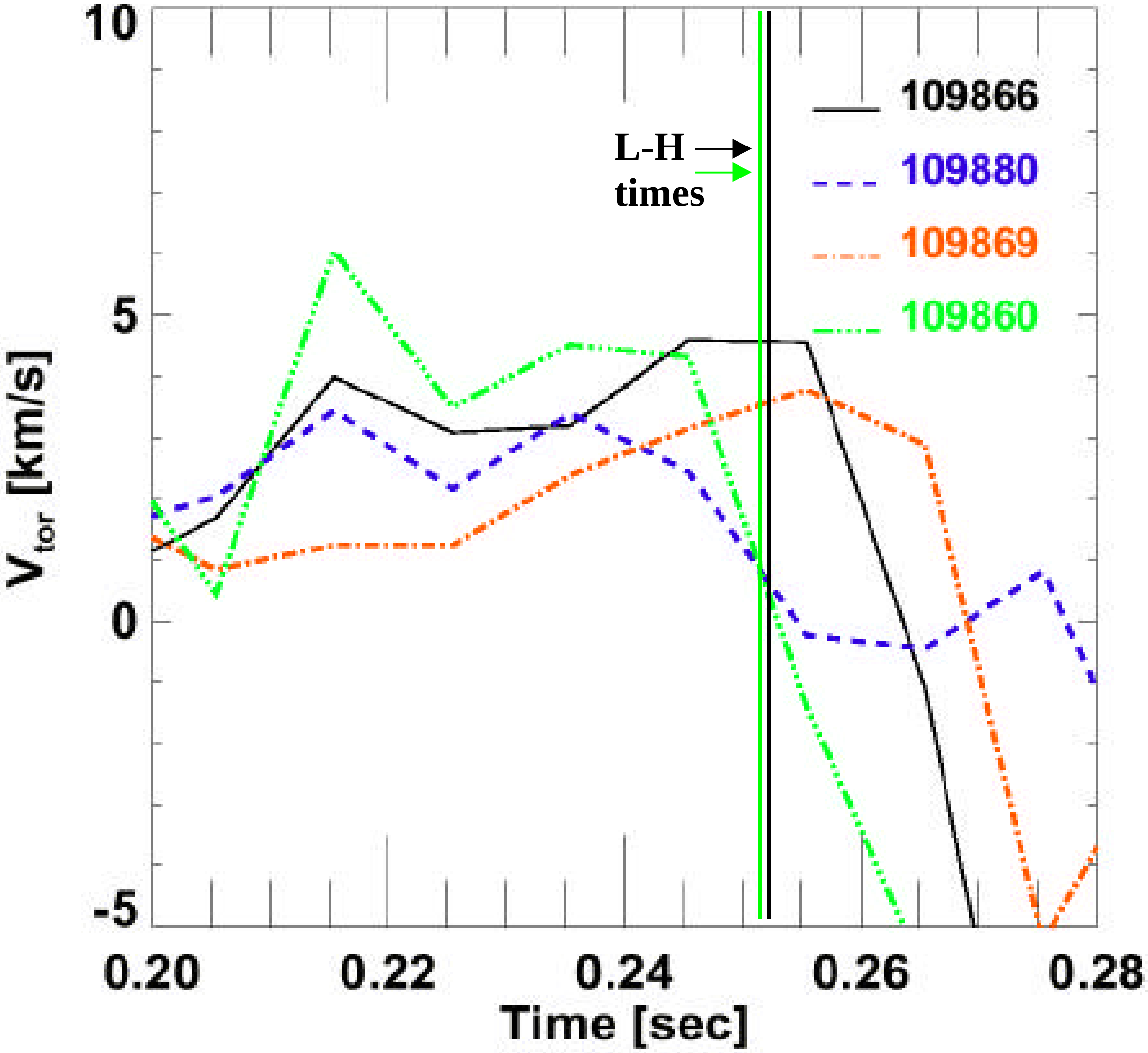
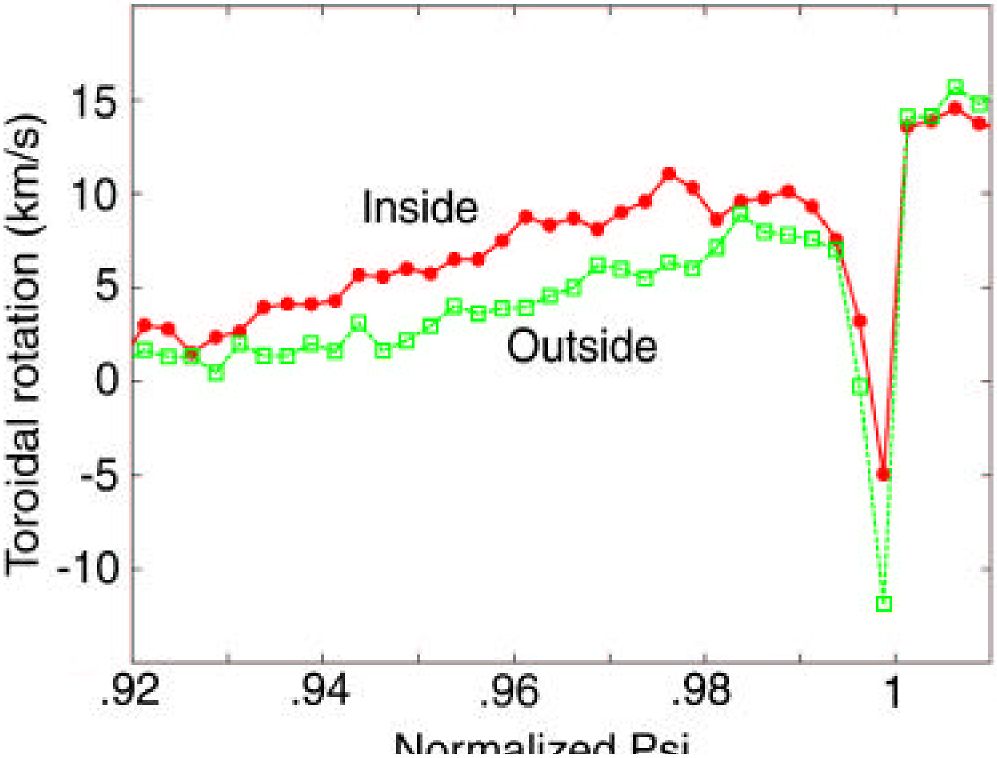
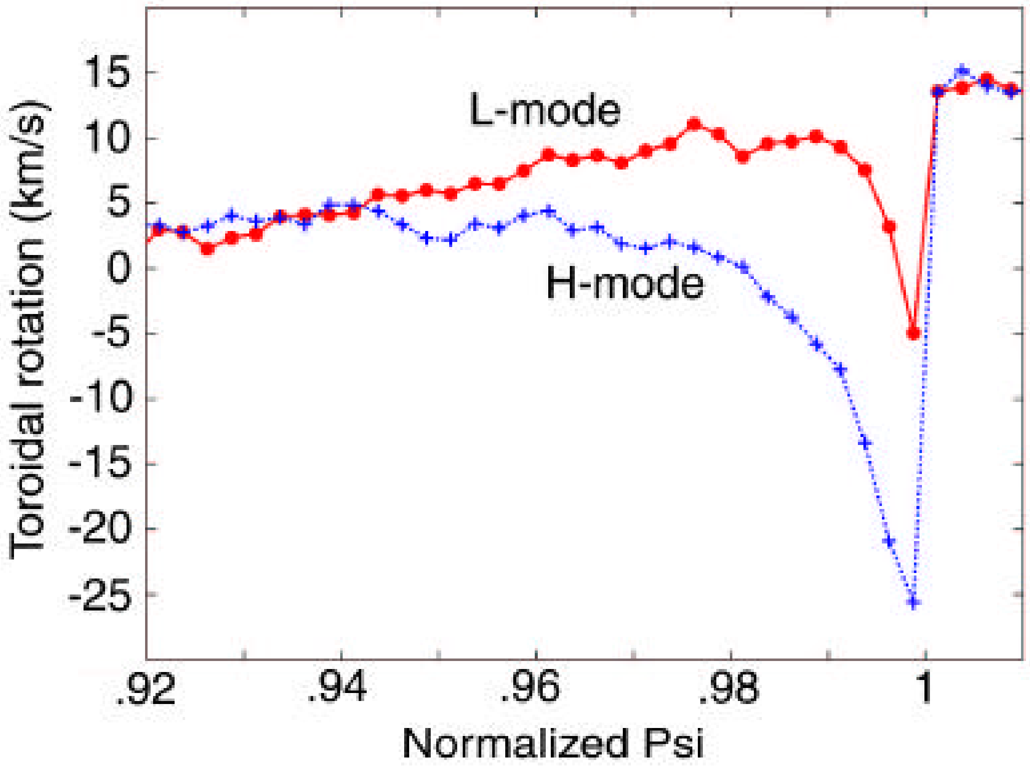

10
5
0
-5
0.20
0.22
0.24
0.26
0.28
Time [sec]
V_{tor} [km/s]
L-H
times
109866
109880
109869
109860

Fig. 4



Toroidal rotation (km/s)
15
10
5
0
-5
-10
Inside
Outside
.92
.94
.96
.98
1
Normalized Psi

Fig. 5



L-mode
H-mode
Toroidal rotation (km/s)
15
10
5
0
-5
-10
-15
-20
-25
.92
.94
.96
.98
1
Normalized Psi

Fig. 6

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