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Detachment and scrape-off layer radial transport characterization in Negative Triangularity discharges in DIII-D

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Experiments performed during the 2023 armored negative triangularity (NT) campaign in DIII-D simultaneously achieved divertor detachment, an ELM-free edge, and tolerance to extrinsic impurities for divertor dissipation, demonstrating the potential for a core-edge integrated scenario. Detachment without impurity seeding was achieved via an increase in plasma density for the first time in NT discharges (triangularity $\delta_{top}=\delta_{bot}=-0.5$). Detachment onset conditions in the outer divertor were sustained with H-mode level confinement $H_{98-y2}\sim1$ and normalized pressure levels $\beta_N\sim2$. Energy confinement degradation (~20-30%) was observed with deeper detachment, which correlated with the loss of the edge electron temperature pedestal and the movement of the radiation front in contact with closed flux surfaces.

Parametric dependence of access to detachment on plasma current I_p and power flowing into the scrape-off layer P_{SOL} was consistent with expectations from detachment scalings (linear dependence on I_p and sublinear dependence on P_{SOL}). However, densities higher than in positive triangularity (PT) (Greenwald fraction $f_{GW}>0.9$), were needed to achieve detachment, due to the shorter parallel connection length and narrowing of the scrape-off layer heat flux width at the strongest NT, approaching values typical of PT H-mode discharges. Impurity seeding with nitrogen and neon reduced the detachment density up to 30% at the expense of core dilution. Detachment onset density was 40% higher with ion B×∇B drift into the divertor compared to out of the divertor in NT ($f_{GW}\sim1.3$ vs. 0.9), while this difference is typically less than 15% in PT. The effect of cross-field drifts on divertor profiles was larger than observed in PT discharges due to the lower toroidal field at the X-point in NT shapes. Discharges with lower average NT ($\delta_{top}=-0.4$, $\delta_{bot}=0.2$) and longer midplane to target parallel connection length detached at ~30% lower line-averaged densities compared to discharges at the largest NT, showing that the very high density needed is not intrinsic to NT but due to the divertor geometry used in these experiments. Edge fluid simulations (UEDGE, SOLPS) quantitatively reproduce the observed drift dependences and high densities needed for detachment, increasing confidence in extrapolation to future NT divertor design.

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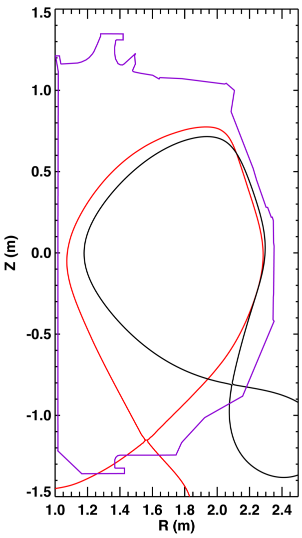

Figure 1. Experimental magnetic equilibria for NT discharge with $\delta_{top}=\delta_{bot}=-0.5$ (black) and discharge with reduced negative triangularity $\delta_{top}=\delta_{bot}=-0.5$

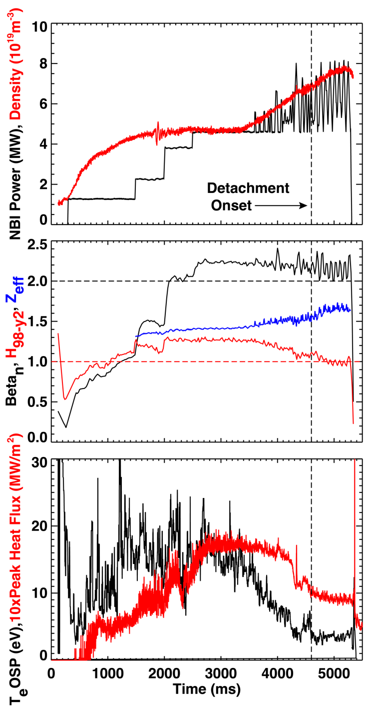

Figure 2. (top) line averaged n_e (red), input power (black); (middle) normalized plasma pressure β_n (black), H-mode confinement factor H98-y2 (red) and effective charge Z_{eff}; (bottom) T_e at the outer strike point and peak heat flux (red). Detachment onset conditions are indicated with a dashed line.