# HIGH PEDESTAL PRESSURE PATH TO HIGH FUSION PERFORMANCE LEVERAGING THE NEW "SHAPE AND VOLUME RISE" DIVERTOR ON DIII-D EX-P

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A new divertor geometry enabling high shaping on DIII-D has been leveraged to achieve among the highest pressure pedestals observed to date on the device, yielding 1) plasmas with Edge Localized Modes (ELMs) at high absolute parameters ($\beta_N^{ped} > 1.3$, $T_e^{ped}$>2keV, $T_i^{ped}$>3keV), 2) highly decoupled peeling and ballooning instabilities through high shaping at $\delta = 0.96$ and $\kappa = 2.04$, 3) Quiescent H-mode (QH) plasmas with $n_{e,0} = 1.2 \times 10^{20} m^{-3}$ and $n_e^{sep}$ six times greater than typical QH-mode values, separately attaining $T_i^{ped} = 5.5keV$, and 4) Resonant Magnetic Perturbation (RMP) studies indicating enhanced resonance with elevated $\beta_N^{ped}$values, particularly for high triangularity plasmas close to magnetic balance. Peeling-ballooning model calculations [1] suggested increased plasma triangularity and volume would allow the pedestal stability boundary to develop a broad channel of operation at high density and pressure simultaneously, leading to a state of a low collisionality pedestal top at high density. This state is rarely achieved in present devices and represents a path for significant gains in future devices, highlighting it as a key challenge for core-edge integration physics.

A phased approach was taken to leverage physics from the new divertor to quantitatively characterize the pumping efficiency, develop three scenarios to target access to the Super H-mode channel (ELMy, QH-mode, and RMP ELM suppressed regimes), perform shape scans to validate the motivational EPED modeling, and leverage the state of high pressure at high density to study physics like detachment, impurity transport, and pellet fueling. The plasma control system was modified and a novel arrangement of the field shaping coil power supplies allowed both access and control for large plasma shapes up to 2.2MA, as seen in Figure 1.

The ELMy H-mode scenario achieves the highest absolute parameters, with pedestal profiles shown in Figure 2. The peeling limited pedestal pressure is about double the value of the ballooning limited pedestal, which is consistent with model predictions. The electron and ion pedestal temperatures remain elevated above 2keV and 3keV, respectively. This was achieved through a tailored front end of the discharge with a low power L-mode phase biased in the unfavorable $\nabla B \times B$ drift direction transitioning rapidly to a high power phase after flipping to the new upper divertor in the favorable drift direction. The tailored front end is necessary to achieve the high density, low collisionality conditions that are expected to occur naturally in future devices.

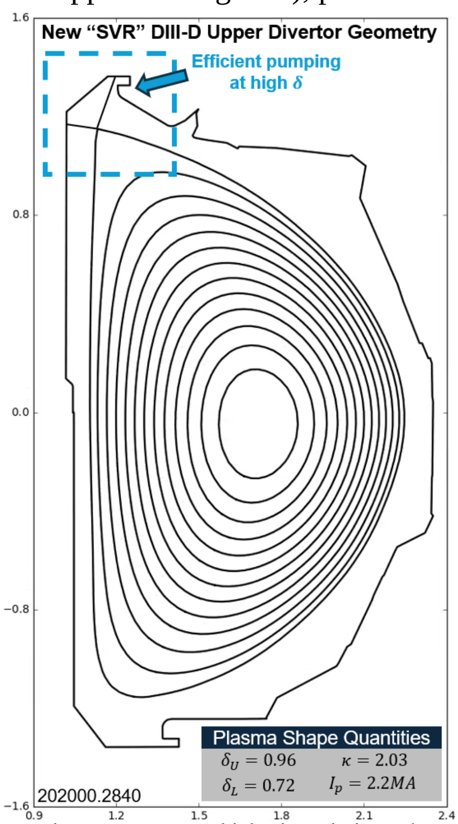

Fig. 1: New DIII-D high triangularity and elongation shape.

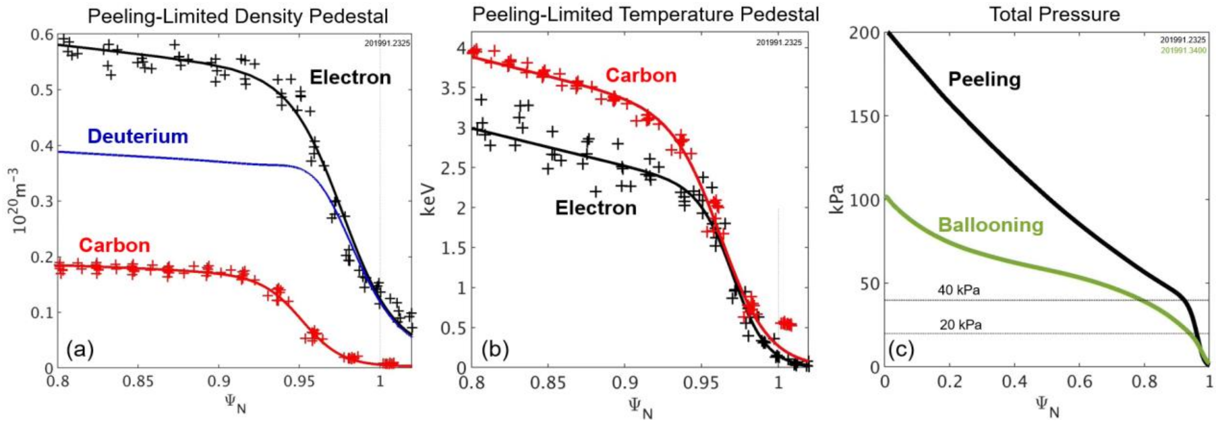


Fig. 2: a) Ion and electron density pedestals, b) ion and electron temperature pedestals, c) full profile of total pressure for DIII-D discharge 201991 with a peeling-limited and subsequent ballooning-limited pedestal. The peeling-limited pedestal exhibits about double the pedestal and core pressures

The QH-mode scenario was developed at Ip=1.4MA and reached record conditions for the regime for densities in the core, pedestal, and separatrix/scrape off layer. The QH-mode profile structures were similar to those expected in future devices with shallow density gradients exhibiting $n_e^{sep}/n_e^{ped} > 0.5$. Absolute values of $n_e^{sep} \sim 3 \times 10^{19} m^{-3}$ exceed typical values for QH-modes by about 6 times. Density ramps increased the pedestal height to the entrance of the Super H-mode channel, as shown by the peeling-ballooning stability diagrams in Figure 3 for both the ELMy and QH-mode scenarios.

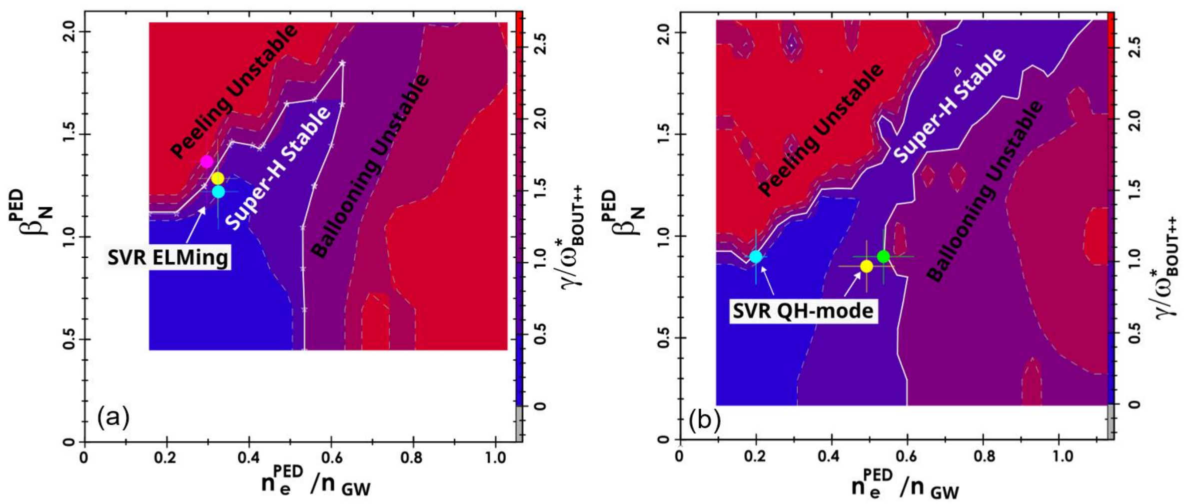


Figure 3: ELITE-EPED analysis showing pedestal performance $\beta_N^{ped}$ vs pedestal Greenwald fraction for the a) ELMy scenario, and b) QH-mode scenario without ELMs with stability diagram calculated for the peeling-limited case (cyan). The channel becomes broader at increased density.

Enhanced plasma response to RMPs was observed in biased double null shapes with an elevated $\beta_N^{ped}$ required for Super H-mode channel access. Full ELM suppression has been achieved in double null geometry at lower plasma current with enhanced $\beta_N^{ped}$, but only ELM mitigation has been achieved at higher plasma current with reduced $\beta_N^{ped}$even with 3cm bias towards upper single null magnetic geometry.

The new DIII-D divertor has been leveraged to develop three new plasma regimes investigating access to reactor relevant conditions of simultaneous high pressure and density with a pedestal limited by peeling instabilities and high absolute parameters to extend understanding of the integrated tokamak exhaust and performance (ITEP) challenge.


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