EXPLORATION OF HIGH-PERFORMANCE PEDESTALS AND EPED MODEL VALIDATION IN SHAPE AND VOLUME RISE (SVR) STUDIES ON DIII-D

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Capitalizing on the commissioning of a newly implemented divertor configuration designed to support improved plasma shaping and higher plasma volumes (SVR), some of the largest pedestal pressures ever documented on the DIII-D tokamak have been attained. Guided by recent promising calculations based on the peeling-ballooning framework [1], DIII-D enhanced its attainable plasma triangularity and volume to improve pedestal stability, aiming to access deep Super H-mode as predicted by the EPED model [2] to raise overall plasma performance. Precisely, Super H-mode enables reactor relevant core-edge integration by simultaneously achieving high density and elevated pressure in combination with a radiative divertor [3]. Experiments were conducted on DIII-D in the SVR shape to study a wide range of pedestal parameters and modify Super H-mode channel properties, among others through shape scans in squareness and triangularity, as well as current ramps to scan the safety factor. Experimentally, pedestal pressures ranging from 15 to 40 kPa were achieved, scanning triangularity from 0.7 to 0.85 and lower squareness from 0.35 to 0.45. The plasma current range was 1.8-2.2 MA (q_{95}=3.5-4.5). A typical discharge is outlined in figure 1. Best pedestal performance marked by the high pedestal temperatures (electron here above 2 keV, ion temperature 3 keV) and pressures, was achieved following a strategic discharge design that begins with delayed LH-transition, enabled by a low-power L-mode phase unfavorable drift direction with $\nabla B \times B$ drifts away from SVR divertor, followed by a rapid transition to high power after flipping the plasma with into the new upper divertor in the favorable drift direction. Modifications to the plasma control system and a novel configuration of power supplies for the shaping coils provide access to the large plasma shapes and facilitated a singular current ramp up to 2.2 MA. Note that the early high performance and high β_N was associated with global MHD events coupling to ELMs that terminated the actual Super H-mode phase, as

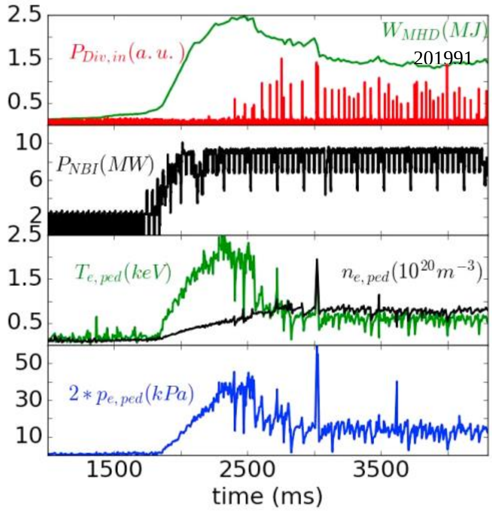

Figure 1 Super H-mode SVR discharge a) stored energy and ELM activity indicated by divertor power measurement b) injected NB heating power c) pedestal temperature and density d) pedestal pressure

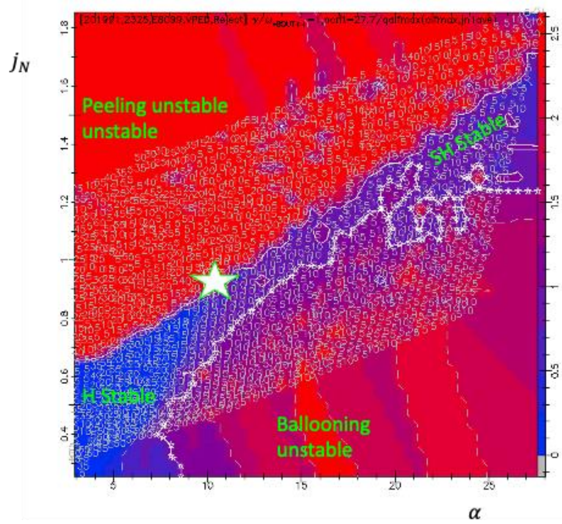

Figure 2 Peeling ballooning diagram of 201991, normalized edge current density vs normalized pressure. Stable blue regions of standard H-modes and expected SH-mode stability are indicated.

indicated by the steep drop in stored energy (Figure 1), leading to a transition into standard H-mode with ballooning type pedestal, as observed previously on DIII-D [4]. While careful shaping of the startup sequence is essential for achieving conditions of high density and low collisionality on DIII-D, they are expected to emerge naturally in future fusion power plant devices.

As predicted by the EPED model, there is a clear decoupling of peeling and ballooning modes when operating near or in the Super H-mode channel (Figure 2). While the experimental data agrees with computational predictions on the decoupling of peeling and ballooning modes, and the pedestal pressure constrained by peeling modes reaches approximately twice that set by ballooning limits, there are still open questions around the depth of the channel: the computationally predicted pressures of Super H-mode channel could not be verified yet experimentally in the SVR experiment (Figure 3). This is most likely caused by the performance limitation of the global MHD events, as the Super H-mode phase was too short to apply additional gas fueling to increase density.

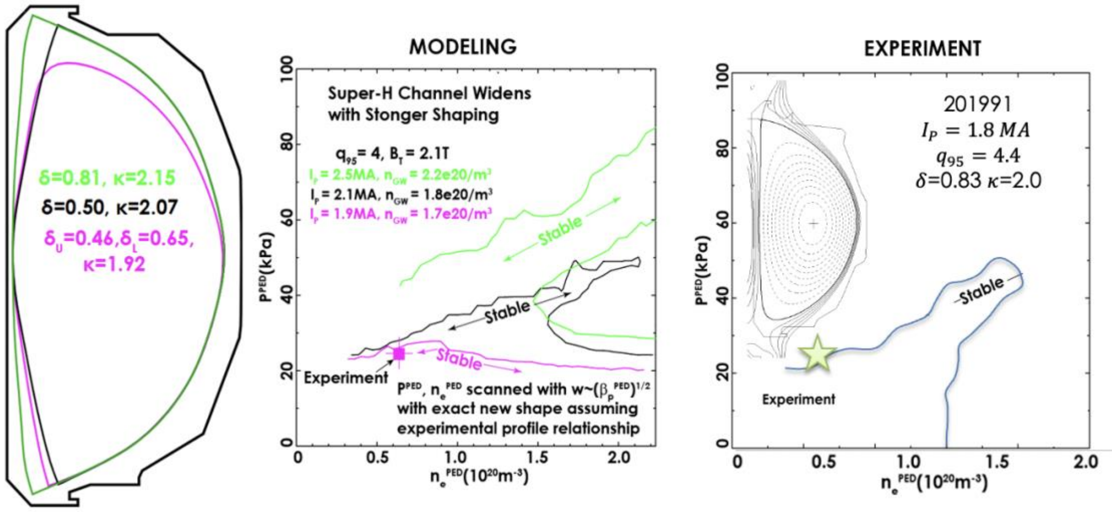

Figure 3 Comparison of Super H mode channel depth predictions (adapted from [1]) and experimental results in SVR discharge 201991.

The shape scan revealed an additional width dependence of the pedestal on the pedestal beta poloidal resulting in a range of $w_{ped} = (0.7\sim1.0) \cdot \sqrt{\beta_{pol}}$within this experiment that could include further quantities influencing the channel depth. Note also that as expected, a decrease in squareness leads to higher pedestal temperatures, reducing collisionality and increasing the peeling character, while a decrease in triangularity leads to a stronger ballooning mode dominated pedestal.

Hence, this experiment has verified EPED predictions for enhanced pedestal performance due to shaping related peeling mode stability by better plasma shaping, raising confidence of extrapolation towards future fusion devices and further advance our knowledge of the integrated tokamak exhaust and performance (ITEP) challenge. However, deep Super H-mode channel access remains to be confirmed in future SVR experiments. Those could employ tailored beam power ramps for optimized Super H-mode access, as well as tailoring the q profile and pellet injection for avoiding the global MHD events.

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