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[OV POSTER TWIN] DIII-D Research Advancing the Physics Basis for Optimizing the Tokamak Approach to Fusion Energy

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DIII-D physics research addresses critical challenges for operation of ITER and the next generation of fusion energy devices through a focus on innovations to provide solutions for high performance long pulse operation, development of scenarios integrating high performance core and boundary plasmas, and fundamental plasma science and model validation. Substantial increases in off-axis current drive efficiency from an innovative top launch system for EC power (Fig. 1), and in pressure broadening for Alfven eigenmode control from a co-/counter-Ip steerable off-axis neutral beam, both improve the prospects for optimization of future long pulse/steady state high performance tokamak operation. A high beta-p optimized-core scenario with an internal transport barrier that projects nearly to Q=10 in ITER at 9 MA was coupled to a detached divertor, and a Super H-mode optimized-pedestal scenario with co-Ip beam injection (Fig. 2), was coupled to a radiative divertor. Fundamental studies into the evolution of the pedestal pressure profile, and electron vs. ion heat flux, measuring both density and magnetic field fluctuations, validate predictive models of pedestal recovery after ELMs (Fig. 3).
Link to High Resolution Figures 1, 2, 3

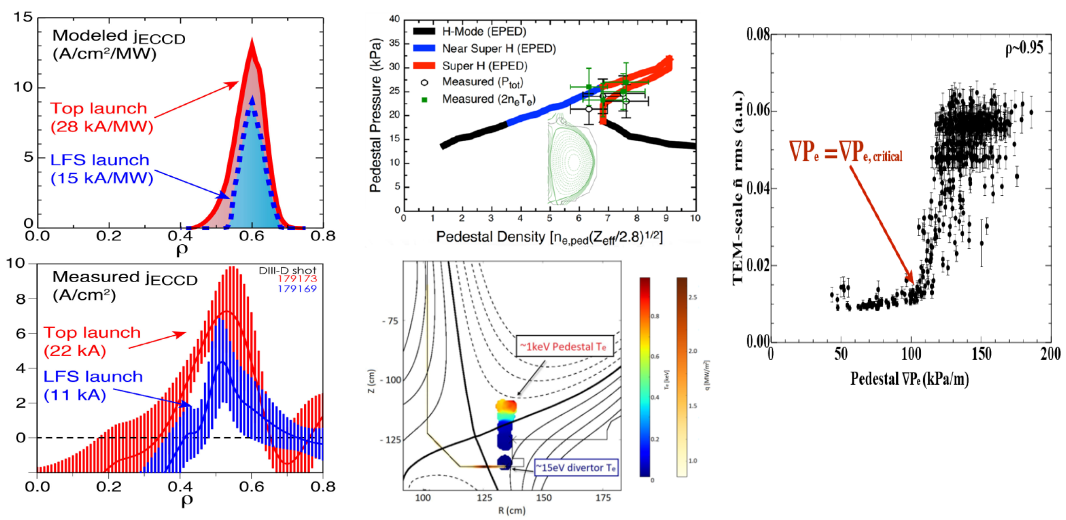

Fig. 1 Fokker-Planck predictions agree with measured 2x larger driven current from new Top Launch EC injection

Fig. 2 SH-mode shape and (ne, pe) operating points with high (~1 keV) pedestal Te coupled to low (~15 eV) target radiative divertor

Fig. 3 TEM scale ($k_\theta \rho_s$~1) turbulence threshold vs. critical pressure gradient during ELM cycle

Figure 1: Figures 1, 2, 3

The achievement of more than double the off-axis ECCD efficiency using top launch geometry compared with conventional low field side (LFS) launch, as predicted by quasi-linear Fokker-Planck simulations, is due to the longer absorption path for the EC waves which also interact with higher v|| electrons that suffer fewer trapping effects than outside launch. In addition, the new unique co-/counter-Ip steerable off-axis neutral beam broadens the energetic particle (EP) pressure profile and reduces Alfven eigenmode (AE) drive in scenarios with both high toroidal rotation and those with net zero average input torque. New EP measurements show a beam current threshold for Compressional AEs, insensitivity of Beta-induced Acoustic AEs to fast beam ions, and resolution of phase-space flows caused by AEs, from first-of-a-kind Ion Cyclotron Emission (ICE) and Imaging Neutral Particle Analyzer (INPA) data.

Studies of high current runaway electron (RE) beams reveals excitation of current-driven (low safety factor) kink instabilities that promptly terminate the RE beam on an Alfvenic time-scale, offering an unexpected alternate pathway to RE beam mitigation without collisional dissipation. Newly developed real-time stability boundary proximity control and neural-net-based Vertical Displacement Event (VDE) growth-rate calculations are shown to prevent VDEs. The effectiveness of emergency shutdown and disruption prevention tools projects to at least 50% of ITER disruptions being delayed until normalized-Ip is at safe levels, and demonstration of a novel technique for healing flux surface with 3D fields shows promise for providing current quench (CQ) control. Single and multiple Shattered Pellet Injection particle assimilation rates and current quench (CQ) densities are shown to be predictable from 0-D simulations and empirical scaling laws.

Several core-edge integration scenarios demonstrate coupling of a high performance core and radiative divertor operation for target heat flux control. High density and stored energy plasmas with Super H-mode edge pedestals were made both in a lower single null shape accessible by JET and in a higher triangularity near double null shape coupled to a radiative divertor for target heat flux control using nitrogen injection in a core-edge integrated scenario. High-performance plasma with high poloidal beta, large Shafranov shift, and Te and Ti internal transport barriers coupled to a detached divertor with active feedback-controlled Nitrogen puffing also demonstrated integration of core-edge solutions. A high performance hybrid core demonstrated compatibility with radiative divertor operation using Neon or Argon gas injection. Core impurity peaking in the hybrid was substantially reduced using near-axis electron cyclotron heating.

The ability to predict the impurity seeding needed for divertor dissipation has advanced through new capability for measuring charge-state resolved densities of impurity species in the divertor. Also electric drifts in detached divertors with convection dominated heat transport lead to expanded radiative volume. Using these advances, SOLPS-ITER simulations show the synergy between SOL drifts and the SAS divertor geometry for achieving lower density detachment. Modeling of intra-ELM tungsten gross erosion with an analytic Free-Streaming plus Recycling Model is now validated in ITER-relevant mitigated-ELM regimes using pellet pacing and RMPs. SOL tungsten transport in plasmas with both BT directions is consistent with strong entrainment in SOL flows and ExB drift effects.

Advances in pedestal physics through new measurements of density and internal magnetic fluctuations suggest a possible role for micro-tearing and trapped electron modes in DIII-D pedestal transport. Main ion CER measurements indicate ion heat flux is anomalous at low collisionality and transitions to near neoclassical levels at high collisionality. Plasma rotation scans, and both new non-linear analytic theory and 2-fluid code simulations, confirm that ELM suppression by RMPs requires near zero ExB velocity at the top of the pedestal, and achieving suppression appears to be closely linked to a high field side plasma response. The wide pedestal QH-mode regime was obtained with zero input beam torque, electron heating, and LSN shape, consistent with requirements for ITER.

Recent fundamental research on L-H mode power threshold physics shows that turbulence driven shear flow through Reynolds stress and the coexistence of modes associated with various instabilities can lower the L-H power threshold across multiple parameters: eg. q95 and ion grad-B drift direction. Application of RMPs raises turbulence decorrelation rates and reduces Reynolds stress driven flow and flow shear, hence increasing the L-H power threshold. Finally, plasmas with negative triangularity show weak power degradation of H-mode level core confinement while maintaining an L-mode-like edge without ELMs.

In 2020 and beyond DIII-D will install additional tools for optimizing tokamak operation through current and heating profile control using a low field side 1 MW helicon high harmonic fast wave CD system, a unique high field side Lower Hybrid CD system, increased ECH power, and coupling to boundary advances using a new high power closed divertor and a wall insertion test station. Experiments will continue the optimized coupling of high performance core and high power density divertor solutions.

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