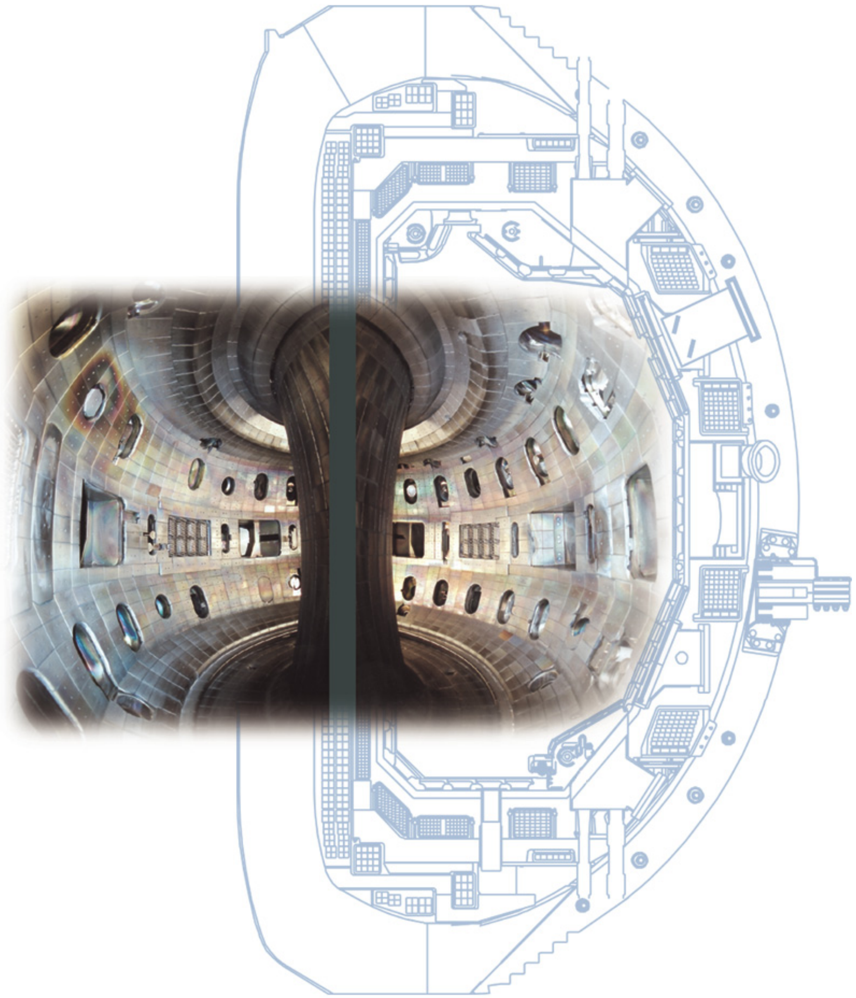
DIII–D National Fusion Program

by
R. Boivin

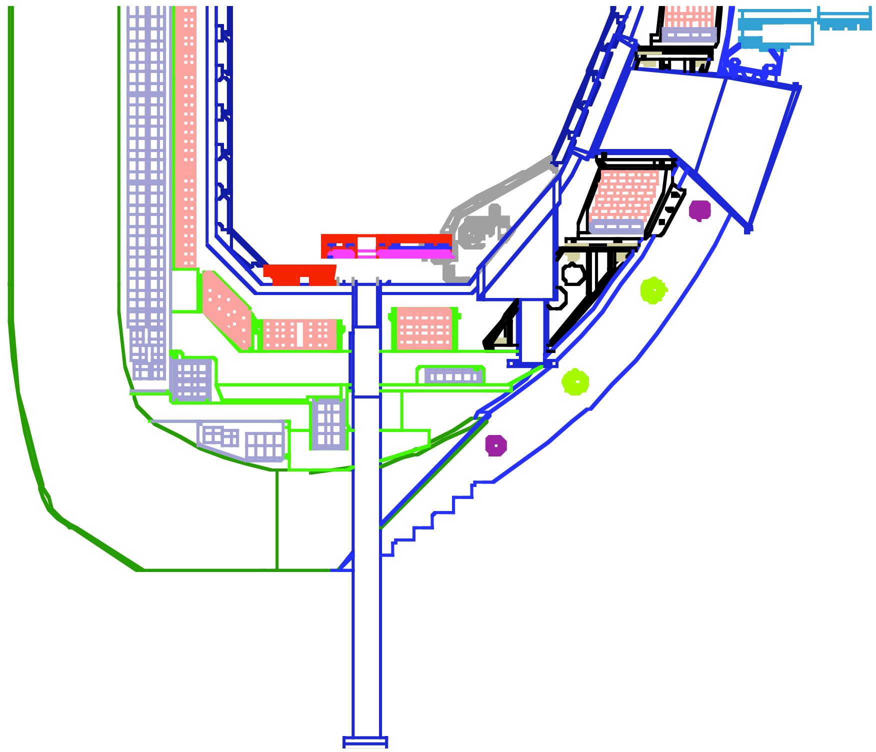


Presented at
Forty-Seventh Annual Meeting
American Physical Society
Division of Plasma Physics
Denver, Colorado

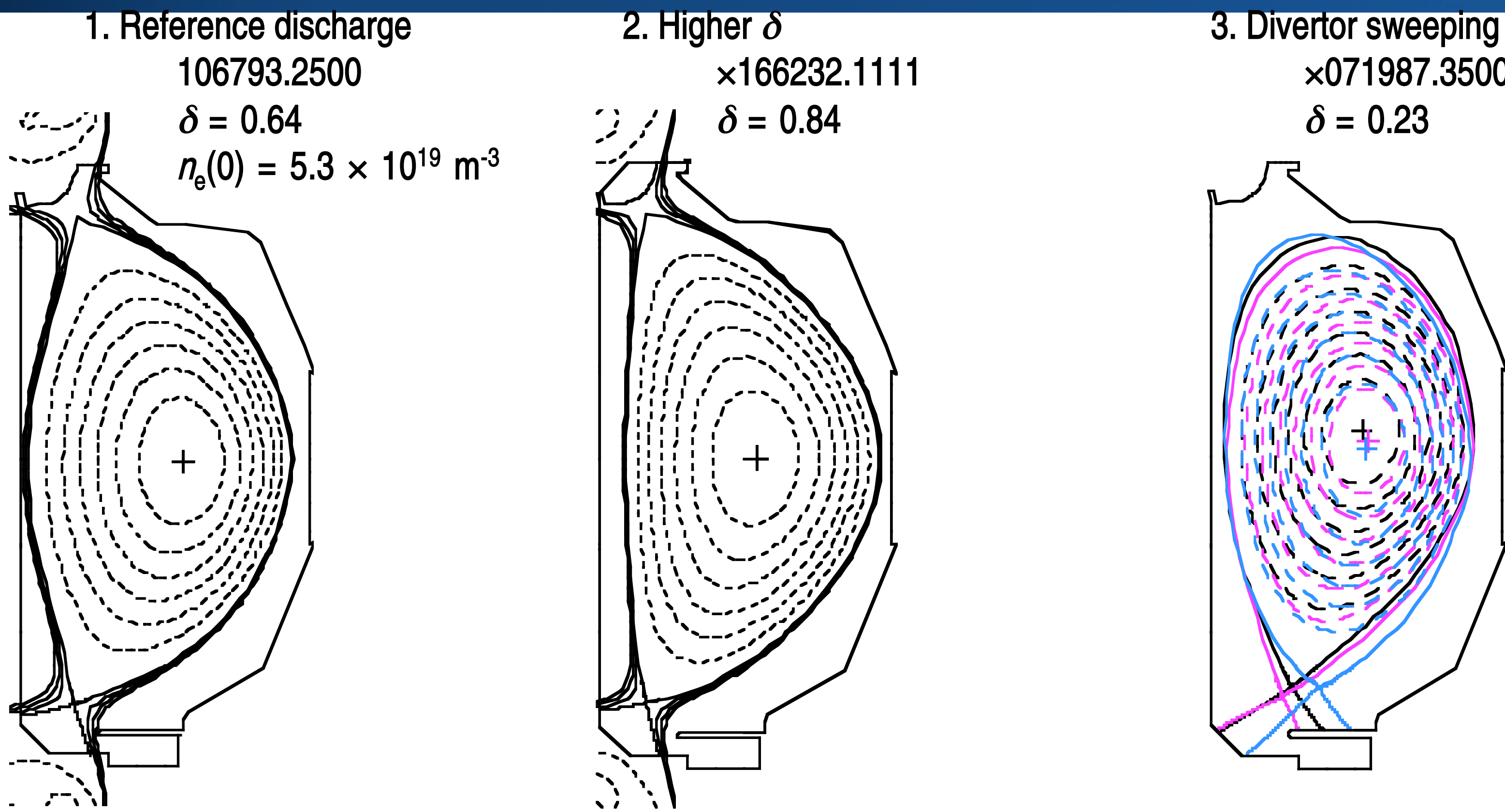
October 24–28, 2005

The Lower Divertor Modifications are Mainly Motivated by The Advanced Tokamak Research Program

- **The lower baffle will be extended by addition of a shelf to allow divertor pumping of a high triangularity plasma**
  - Allows density control in high triangularity symmetric double null plasmas
- **New tile design on and next to shelf**
  - Reduced carbon sources at tile edges
- **New configuration enhances boundary physics capabilities**
- **Enables operation of high performance Advanced Tokamak regimes**
- **QH–mode research will also benefit from the lower pump**



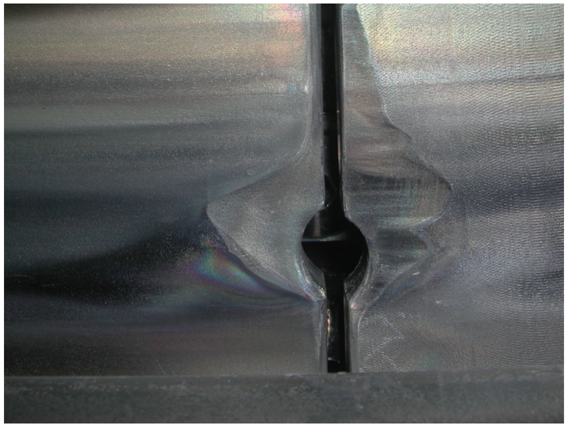
A Variety of Plasma Configurations will be Enabled by the New DIII–D Divertor

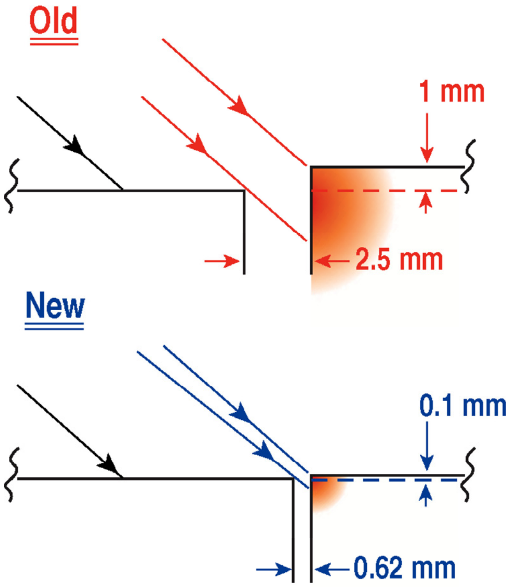


1. **Double-null with density control (good exhaust rate for AT, QH,…)**
2. **Higher triangularity double-null with moderate exhaust rate (stability studies,…)**
3. **Divertor sweeping configuration (divertor physics studies,…)**

Heat Handling Capability of New Tiles Allows 5–10 Second Operation in High Performance Plasmas

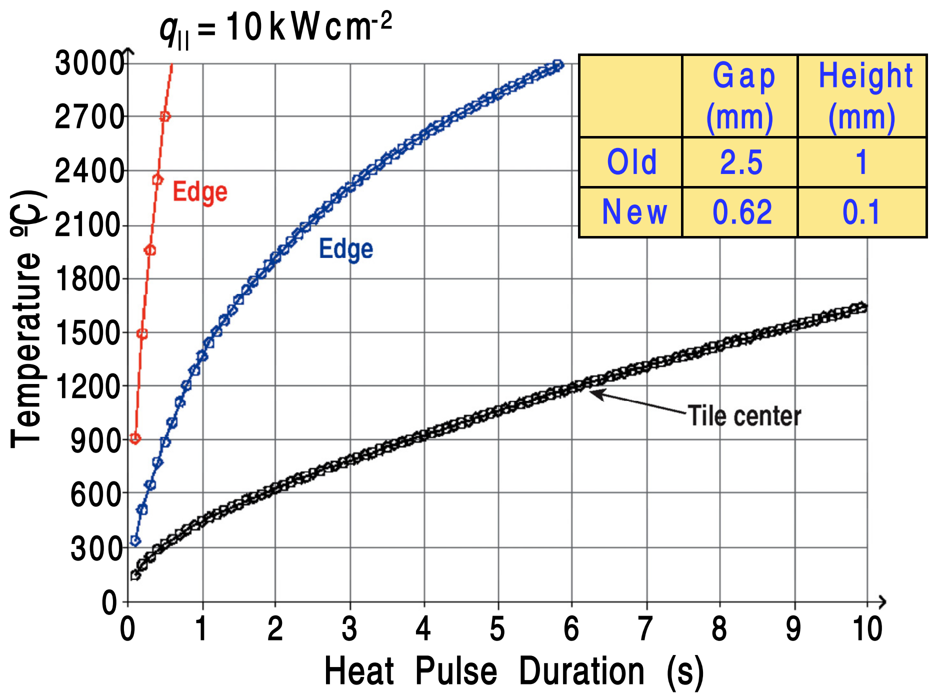
- **Advanced Tokamak program requires density control for 5 – 10 seconds with SOL parallel heat flux of ~100 MW / m^2**
  - Similar heat loads can be encountered in divertor experiments
- **Graphite sublimation at tile edges and bolt holes complicates interpretation of the carbon source and may limit pulse length**
  - Can have detrimental long-term effects
- **The generic design of the new tiles meets AT and Divertor requirements**
  - Bolt holes at high heat load areas are to be plugged
  - Tile gaps and misalignment of the tile edges are reduced to the standard of the upper inner wall
  - Thinned out areas of tiles (shiplaps) are eliminated





New Divertor Tile Design Allows Pulse Length of 5 Seconds without Sublimation (60 MJ into Plasma)

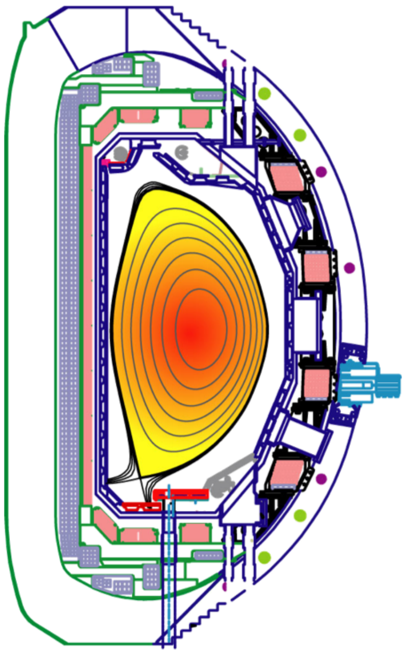
Limit set by time to reach approximately 2700 °C (sublimation point)



	Gap (mm)	Height (mm)
Old	2.5	1
New	0.62	0.1

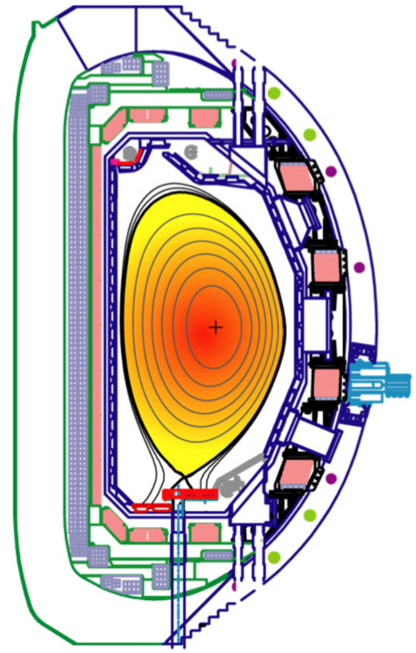
- **Improves boundary physics capabilities**
- **Increases reliability of DIII–D device**
- **120 MJ can be handled later by fish scaled tiles**
  - Would restrict operations to one handedness of field line pitch

New Divertor Enhances Boundary and Pedestal Physics Capabilities while Maintaining Considerable Shape Flexibility



ITER-like configuration

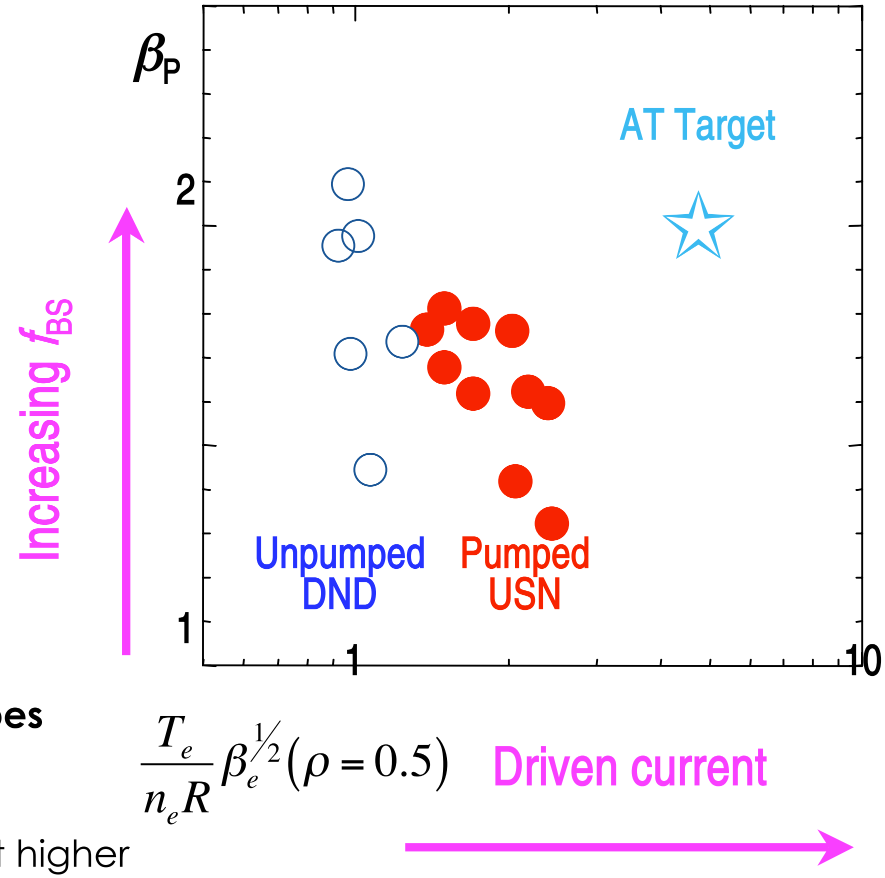
- **Pumped lower single null aligned with edge diagnostic placement**
- **Unique capability in world: can access ν^* range over a factor of 100 in edge**
  - Extend studies to double-null
  - ELM suppression studies
- **Can pump inner divertor leg (detachment control)**
- **Reduced carbon sources at tile edges**
- **Increased heat loads**
- **Diagnostic improvements (Boivin)**
  - Space below shelf for microbalance detectors
  - Direct optical access to inboard strike point
  - Reduced Thomson error in detached plasmas



Inner leg pumping

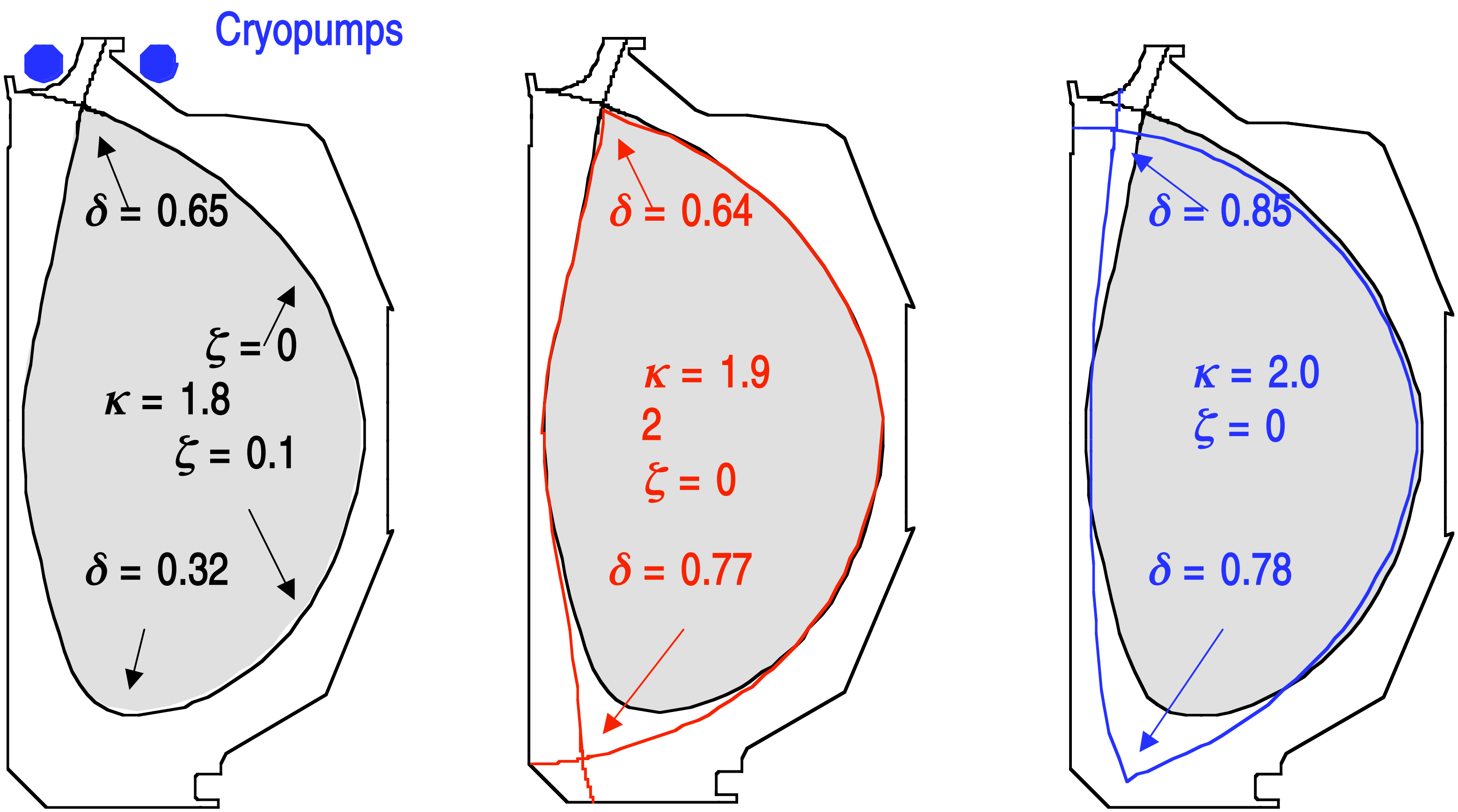
Advanced Tokamak Requirements Motivate Density Control in Double Null Divertor Configurations

- **Sustained advanced tokamak experiments are presently limited to β_N 3.5**
  - We would like to operate with $\beta_N > 4$
  - Steady-state requires large bootstrap current fraction $f_{BS} \propto \beta_P \quad \propto q\beta_N$
  - High fusion gain $\propto \beta\tau_E \quad \propto \beta_N H_{89}/q_{95}^2$
- **We know how to increase the beta limits**
  - May be able to coax β_N up in present configuration, but there is no margin
  - Double null configurations exhibit higher MHD limits (by 10 - 15%)
  - Perceived (but not quantified) improved confinement
    - Observations of (stabilizing) broadened pressure profile in double-null plasmas
- **The present pumping geometry does not provide adequate density control in these optimized shapes**
  - Noninductively driven current increases with decreasing density, e.g. $I_{ECCD} \propto T_e/n_e$
  - Lower pump will allow access to AT regimes at higher levels of performance than currently available



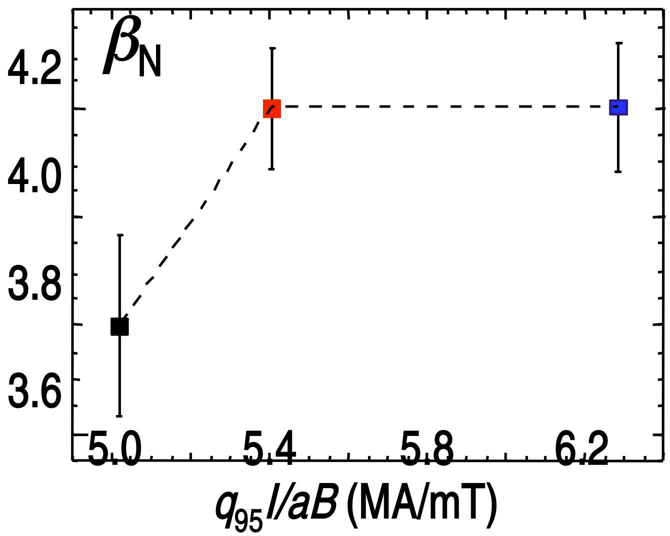
Experimental Comparison of Achievable β_N: Present Pumping Shape Versus Two "Stronger" Shapes

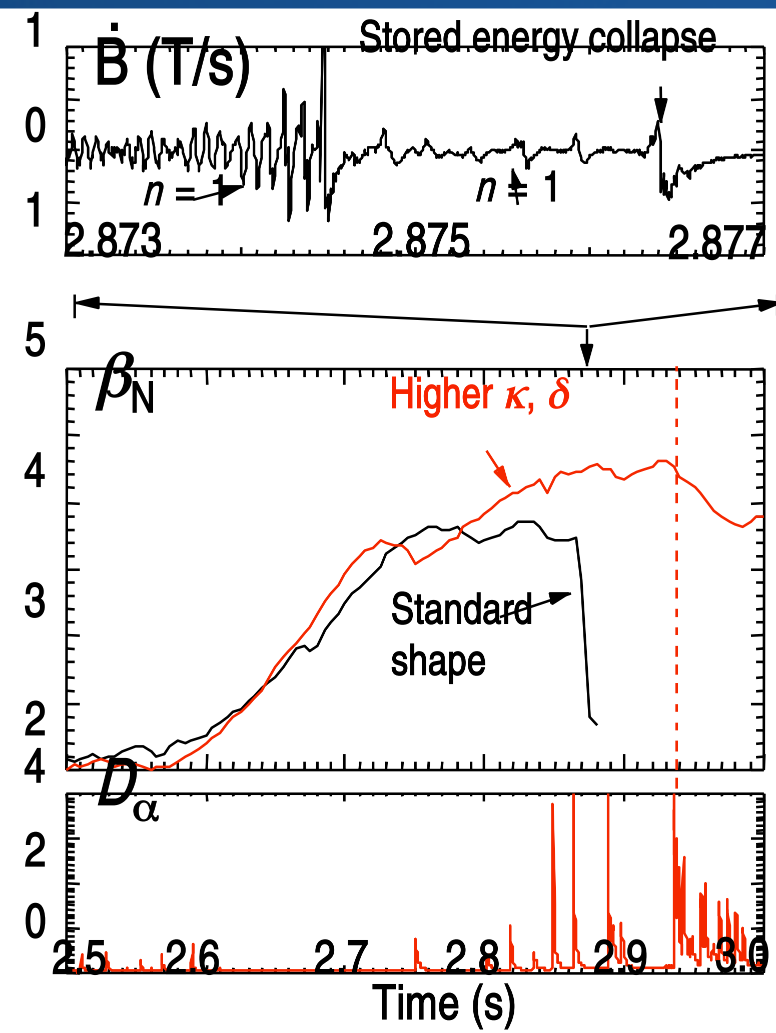
Standard pumping shape | Up/down balanced double null | Increased elongation and triangularity



- **Cryopumps were not used, so no change in particle pumping with shape**

The Maximum β_n was Obtained in the Up/Down Symmetric Double-Null Shapes

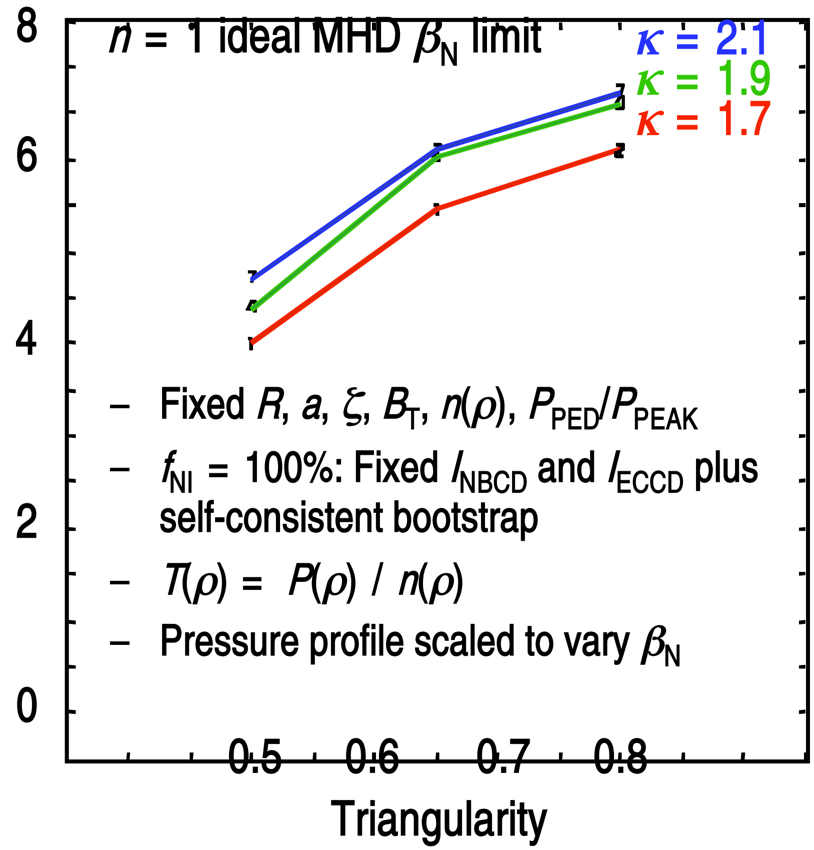




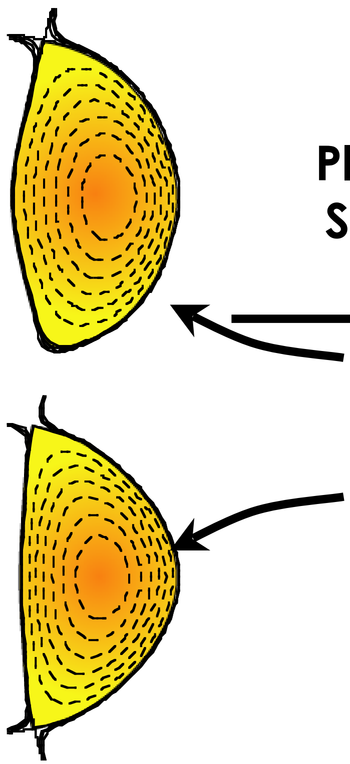
- **β_N not limited by an ideal kink**
  - Standard shape: fast growing core n = 1 leads to a disruption
  - Higher κ, δ shapes: large ELMs lead to soft collapse
- **Changes in profiles could also be important:**
  - ℓ_i, $p(0)/\langle p \rangle$, H–mode pedestal…

Modeling Studies Predict That Increases in κ and δ Increase the Ideal, Low-n β_N Limits

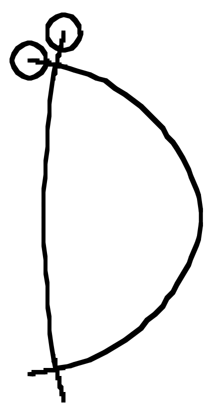
- Indicates increase in experimental β_N likely results from increase in κ, δ and transition from single- to double-null shape

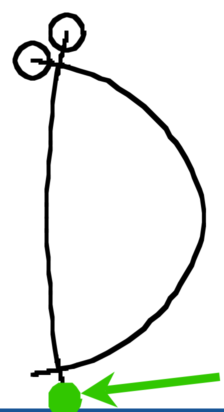


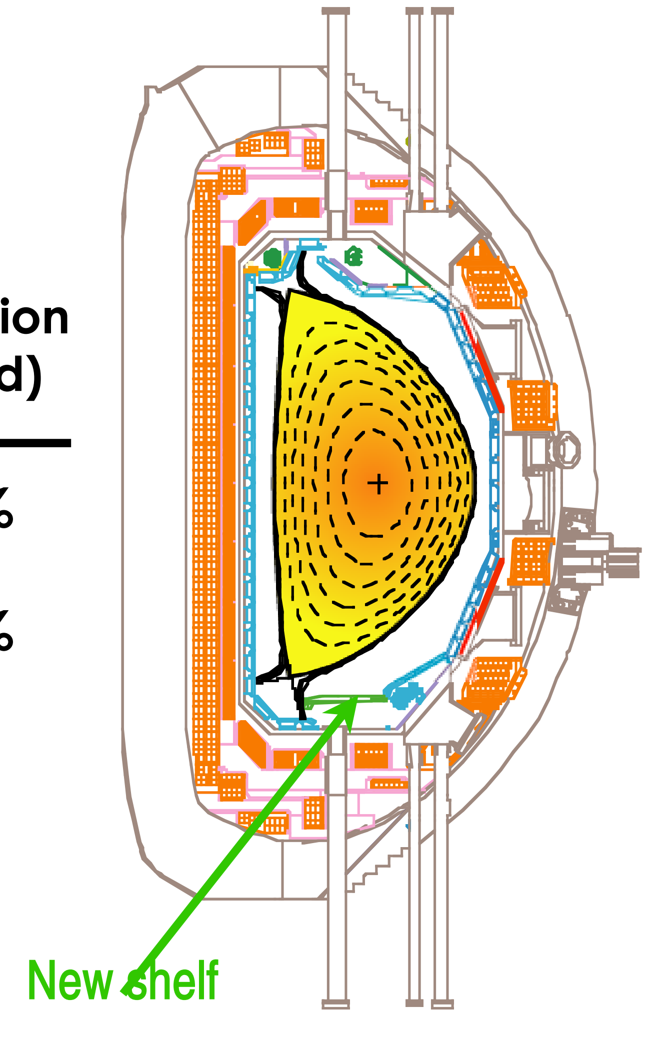
The Lower Divertor Modification is Essential for Adequate Density Control in Double-Null



Plasma Shape	Particles Exhausted / Beam Particle Input: Present Configuratio n (Measured)	New Configuration (Predicted)
SN	75–90%	90–100%
DN	50–60%	85–100%

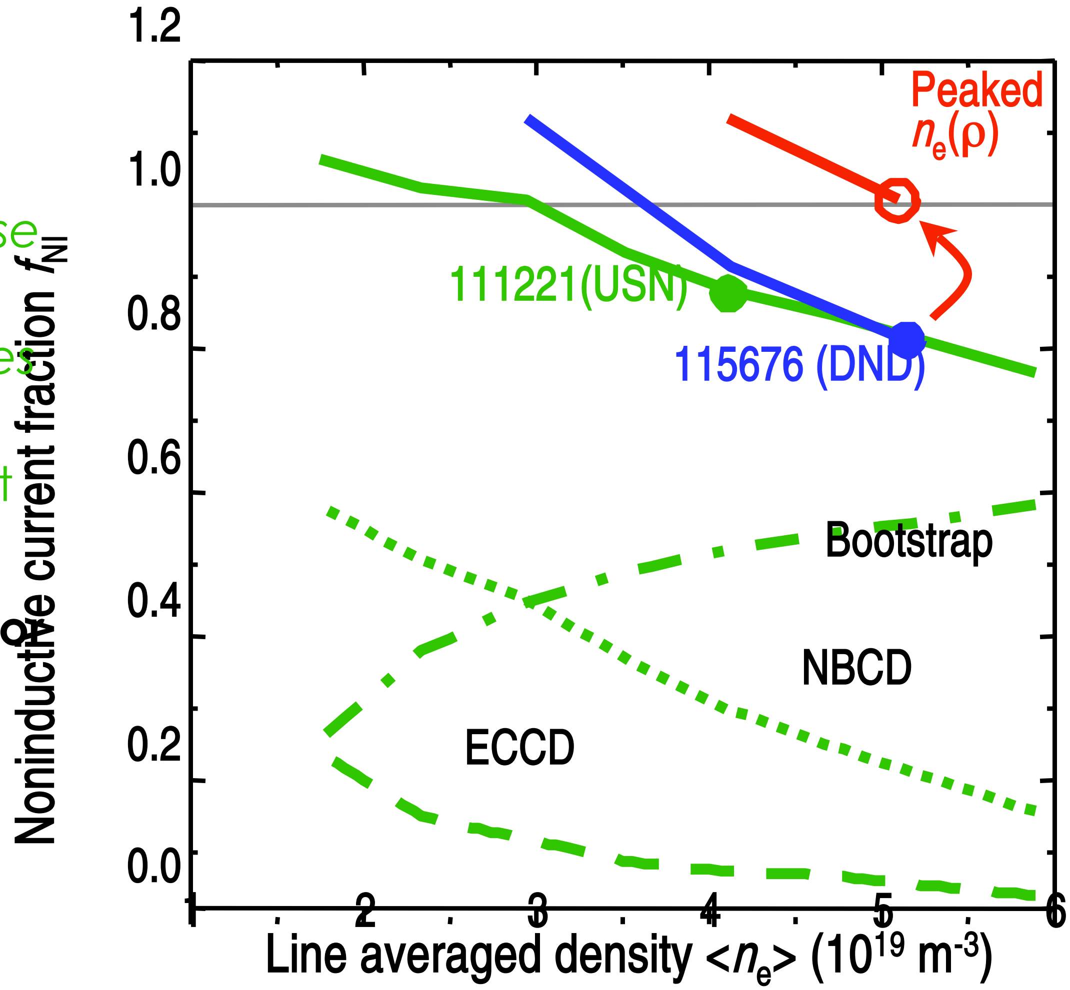






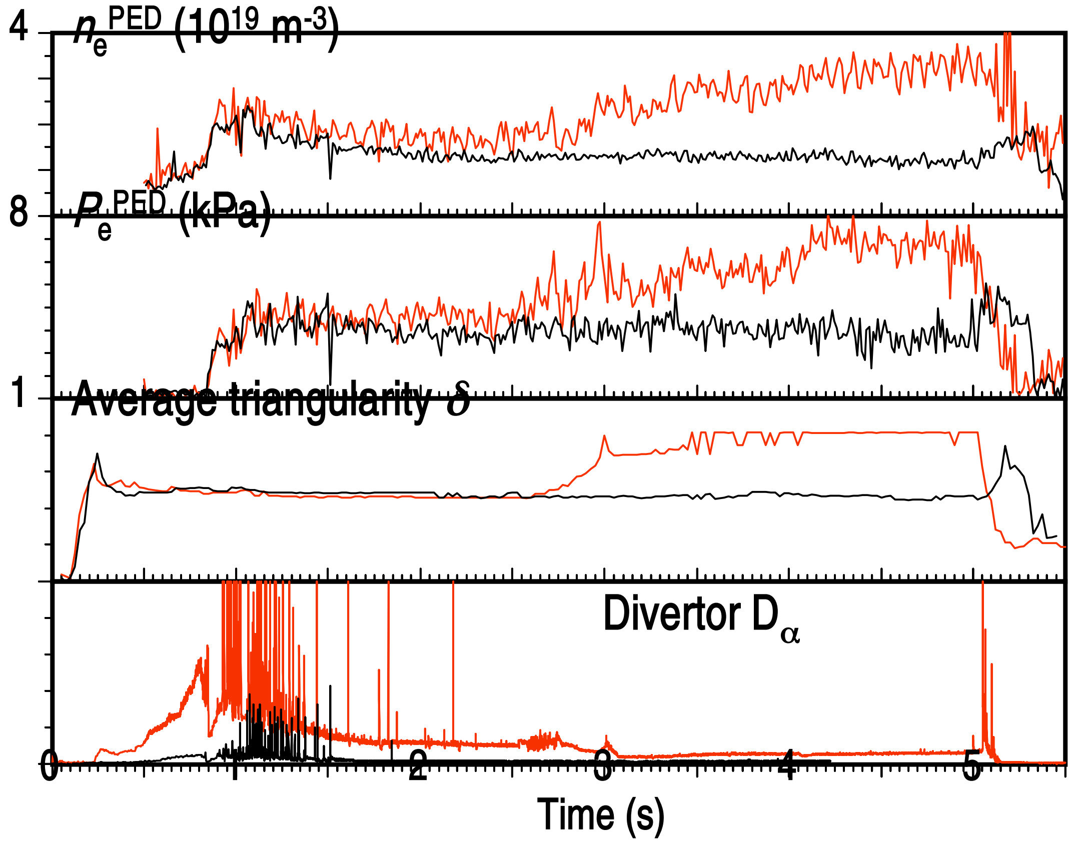
Simulations Indicate the Total Noninductive Current Fraction Increases with Decreasing Density

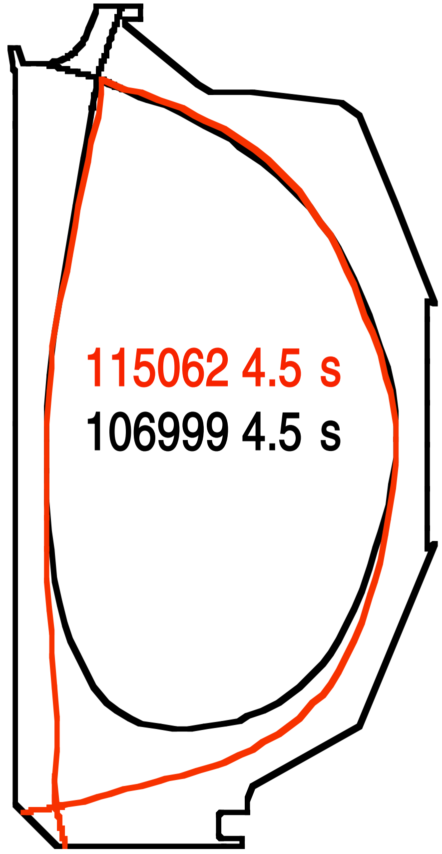
- **GLF23 simulations based on single-null discharge with f_{NI} ≈ 90%:**
  - ECCD and NBCD *decrease* with $\langle n_e \rangle$
  - Bootstrap current *increases* with $\langle n_e \rangle$
  - Total noninductive current decreases with $\langle n_e \rangle$
- **Similar dependencies found for higher den asity double-null discharge**
- **f_{NI} increases with peaked density profile consistent with pumping**



Higher Triangularity Greatly Expands QH–Mode Parameter Space

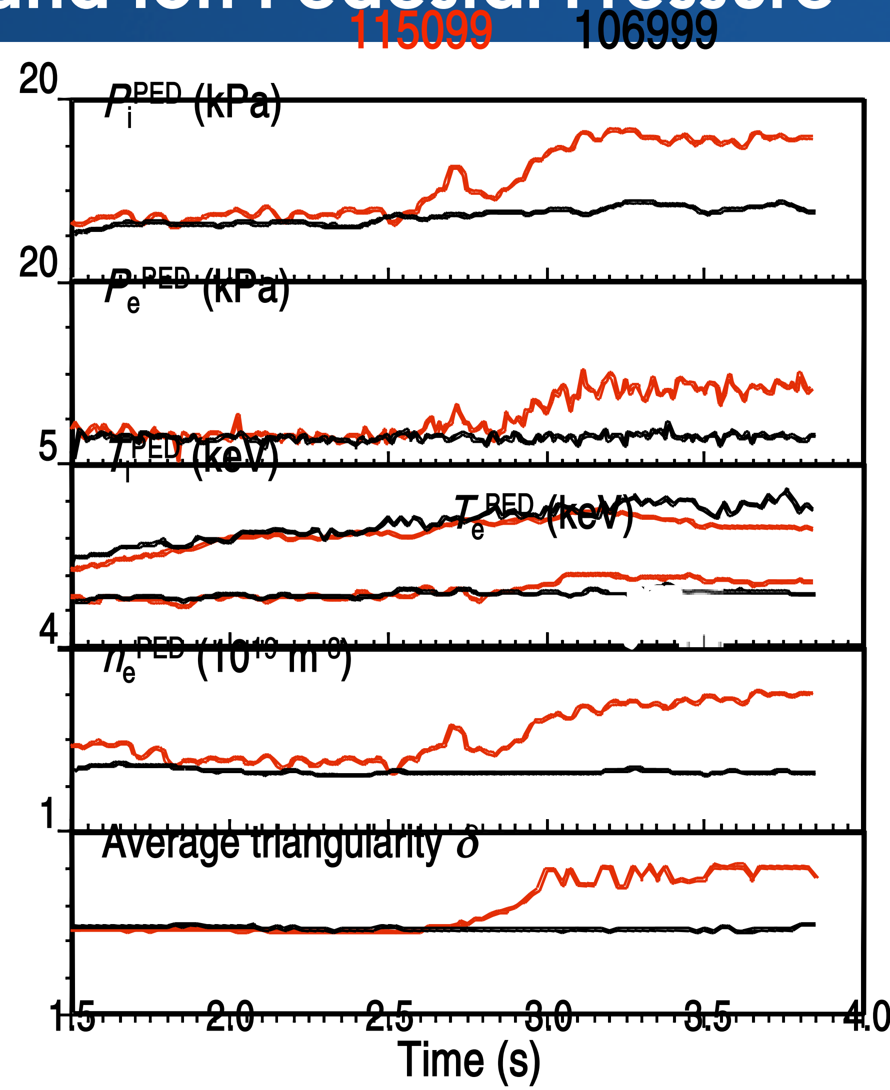
- **More than doubled the pedestal density and pressure with higher triangularity**
- **n_e^{PED}/n_G rises from 0.1 to 0.25**





Increasing Triangularity in Double Null Plasma Produces Rise in Electron and Ion Pedestal Pressure

- **Ion pedestal pressure doubles and electron pedestal pressure more than doubles**
- **Ion pressure is dominant contribution to pedestal pressure**
- **Increased triangularity is the key to quiescent operation at higher pedestal pressure and density**
  - ELMS return at this density in lower triangularity shots



The New Lower Divertor Pumping Geometry will Enable Progress in the Advanced Tokamak

- **Expected to enable operation at β_N > 4 in configurations similar to present AT experiments**
  - Maintained for >5 seconds
- **Opens up margin in a critical parameter for AT studies**
- **Enables other studies**
  - QH–modes with reactor relevant densities
  - Enhances our ability to study boundary physics
  - Comparative studies to experimentally determine whether benefits of double-null geometry might merit use in DEMO
  - Long-pulse fully noninductive AT discharges (enabled in part by this modification) would provide a good target to develop divertor heat control strategies for AT regimes in ITER

The Lower Divertor Modifications are Mainly Motivated by The Advanced Tokamak Research Program

- **The lower baffle will be extended by addition of a shelf to allow divertor pumping of a high triangularity plasma**
  - Allows density control in high triangularity symmetric double null plasmas
- **New tile design on and next to shelf**
  - Reduced carbon sources at tile edges
- **New configuration enhances boundary physics capabilities**
- **Enables operation of high performance Advanced Tokamak regimes**
- **QH–mode research will also benefit from the lower pump**