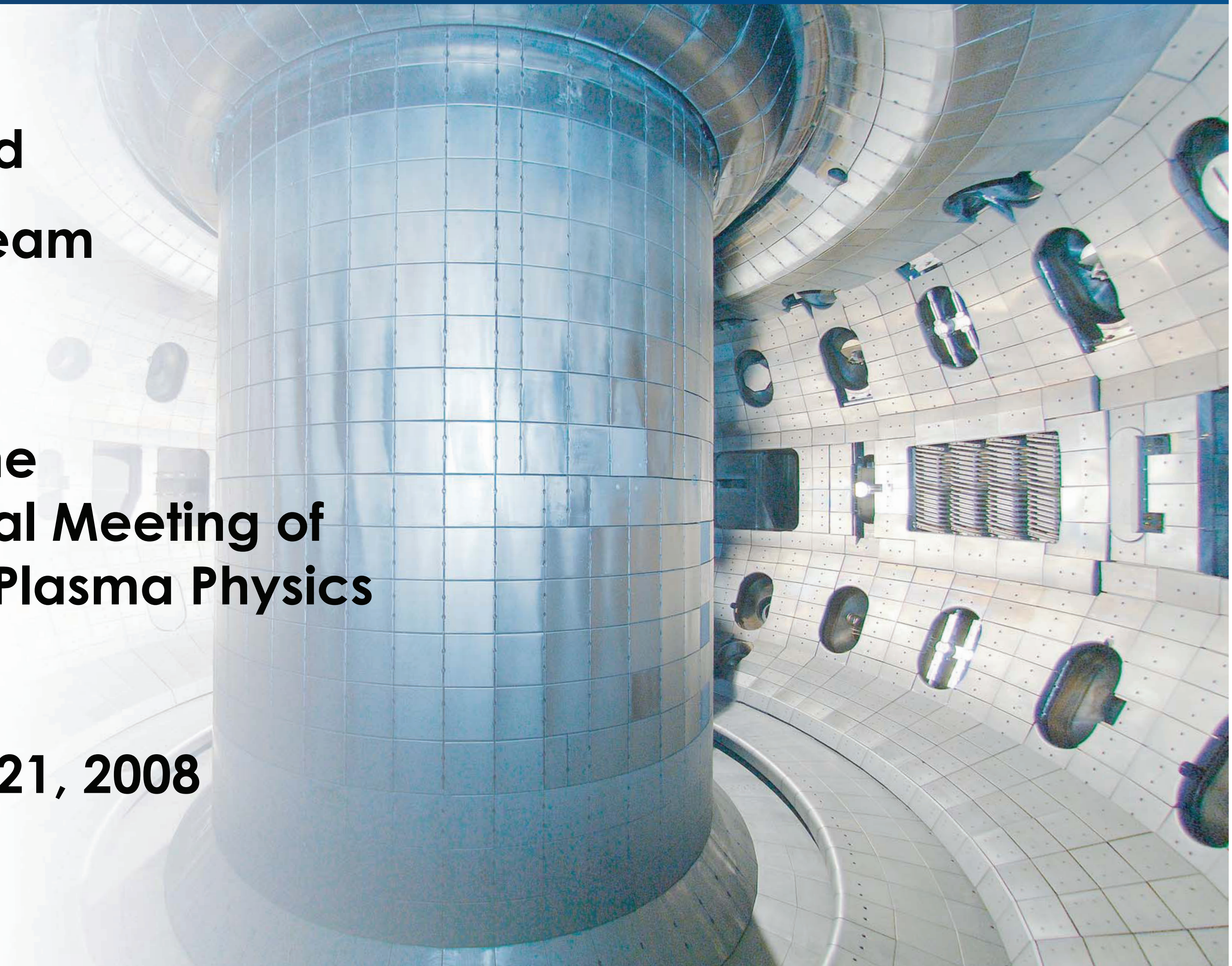
Overview of Recent DIII-D Results in Support of ITER



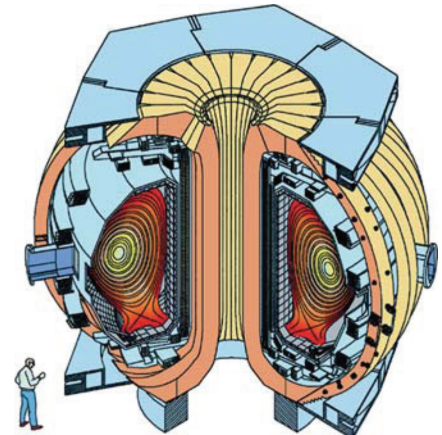
by
C.M. Greenfield

for the DIII-D Team

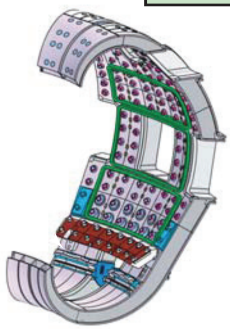
Presented at the
50th APS Annual Meeting of
the Division of Plasma Physics
Dallas, Texas

November 17–21, 2008

DIII-D research has made significant contributions in the design and physics basis for ITER

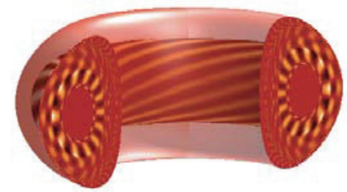


Baseline Design



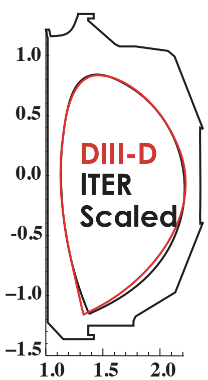
- ELM Control
- Vertical Stability
- PF coil Capabilities

Physics Basis



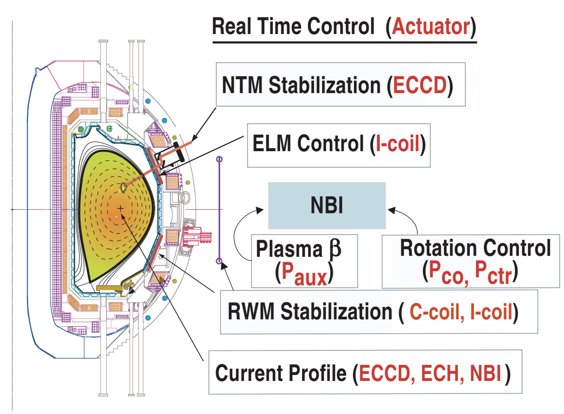
- L-H Transition
- Pedestal Height
- Core Transport
- Plasma Rotation
- Fast Ions

Scenario Development



- Reference Scenarios
- ITER-relevant Startup
- High β Scenarios

Control Solutions



- MHD Stability
- Disruption Mitigation
- Particle Control

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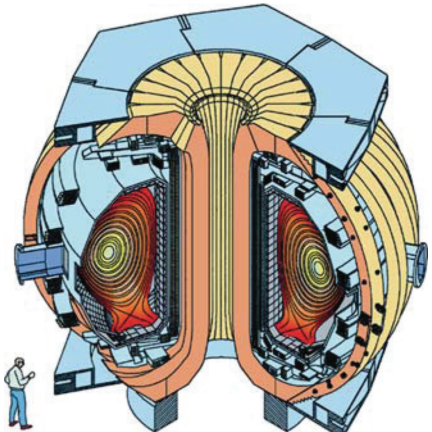

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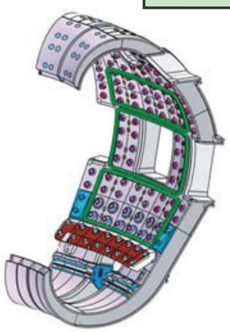

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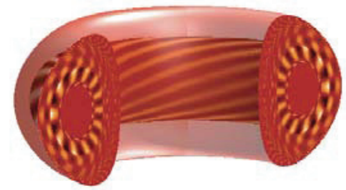

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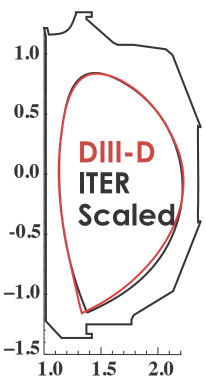

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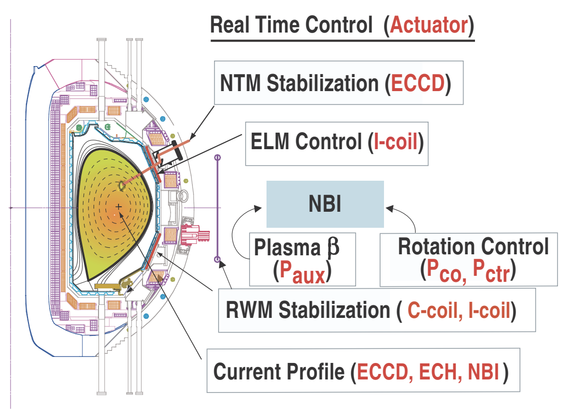

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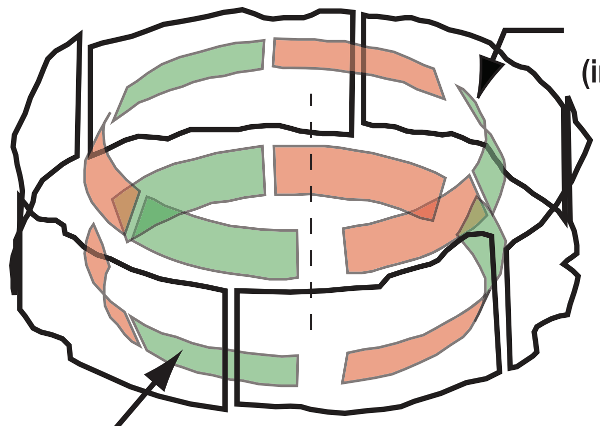
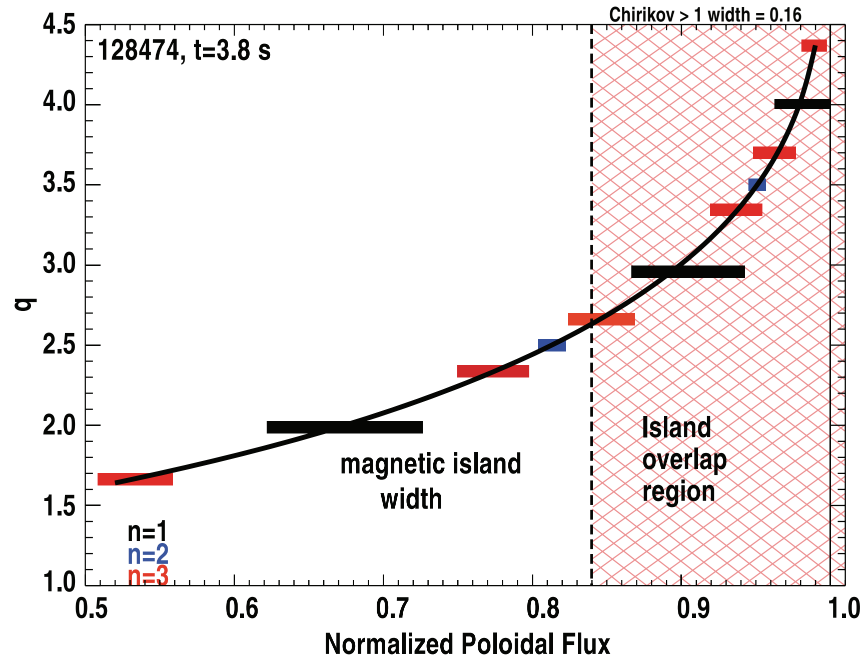
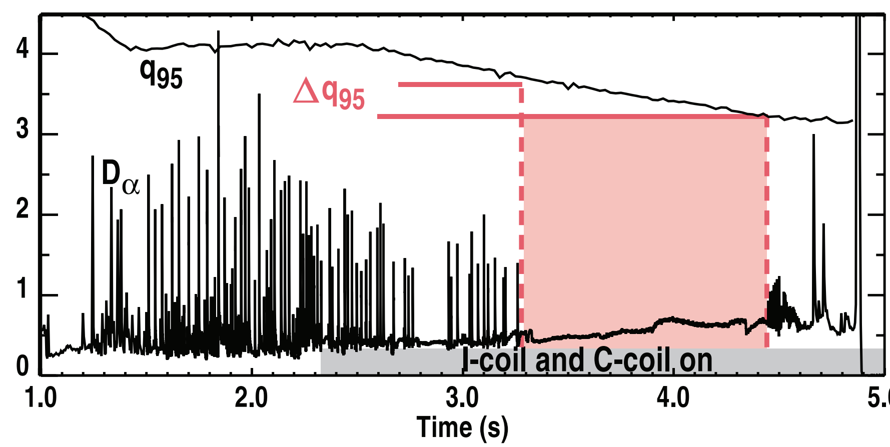
DIII-D ELM suppression experiments show important role of resonant magnetic spectrum



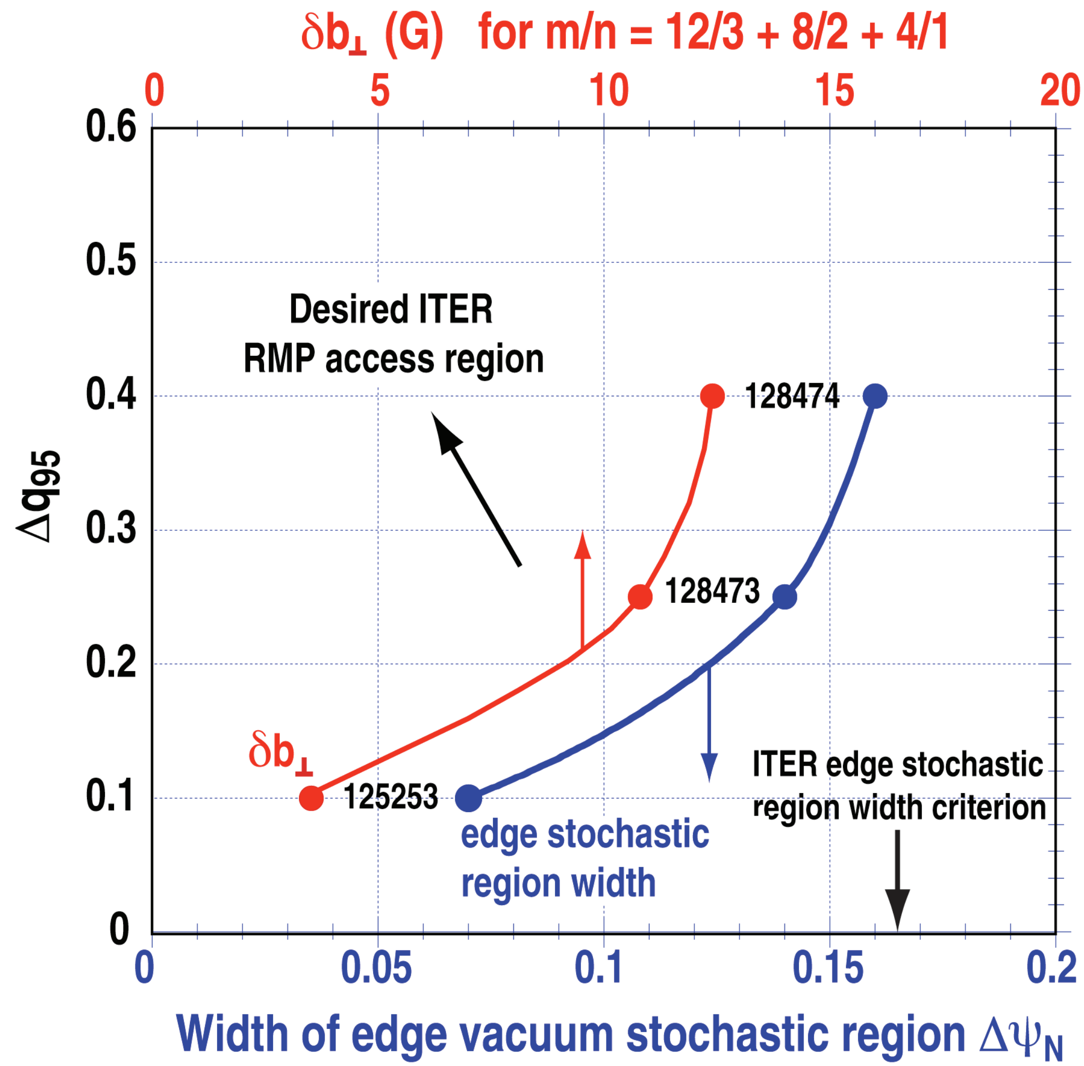


- **Width of island overlap region determines stochastic character of edge**



Progress Made on Critical Design Issues for Use of RMP Coils for ELM Control in ITER

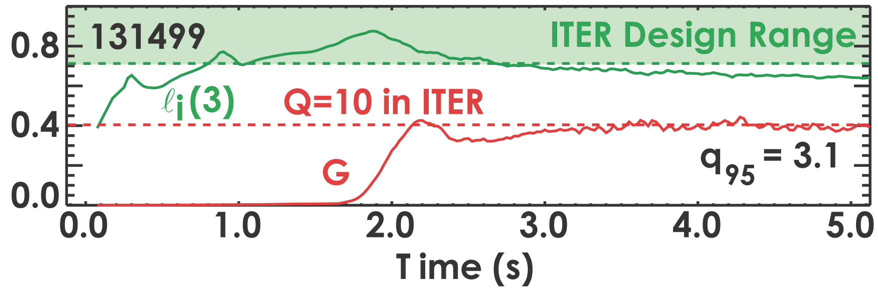
- **ELM size and suppression threshold correlated with vacuum stochastic layer width**
  - Design criterion for the ITER RMP coil
- **Width of the q_{95} ELM suppression resonant window increases with increasing $\delta b_\perp$ and width of vacuum stochastic layer**
  - n=4 ITER coil design expected to provide larger q_{95} operating window

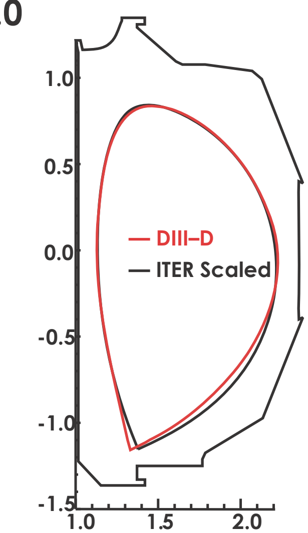


DIII-D experiments have achieved fusion performance at the level required for ITER goals

Flattop performance in ITER Operating Scenarios with ITER shape, aspect ratio, *I/aB*

- **Baseline**
  - Reference operating case
  - Q=10 at 15 MA, $\beta_N \approx 1.8$, $q_{95} \approx 3$





$G = \beta_N H_{89} / q_{95}^2$

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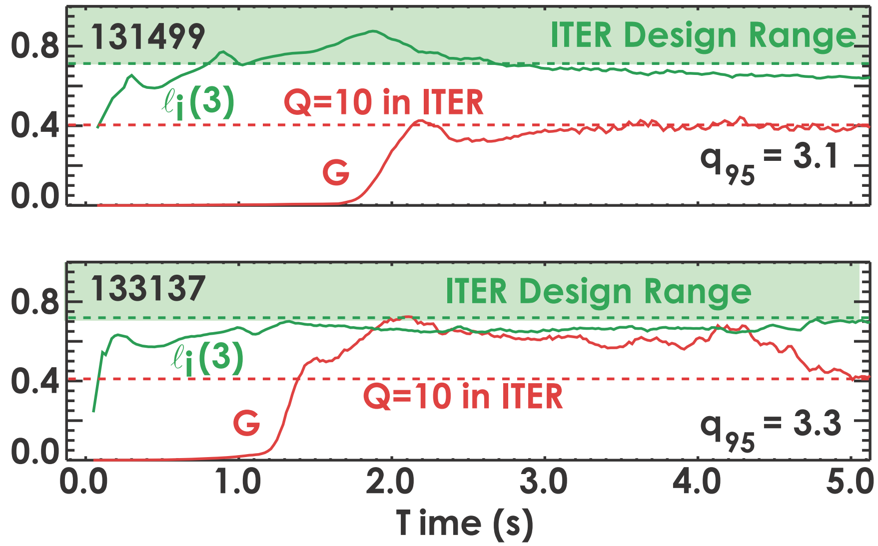
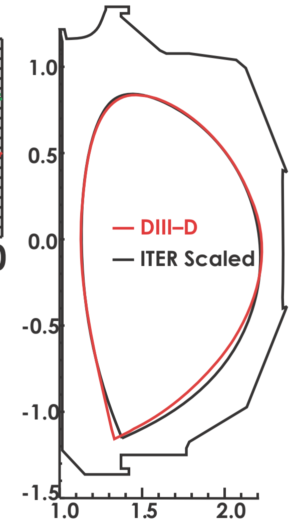
  - High fusion gain
  - Q=30 at 15 MA, $\beta_N \approx 2.8$, $q_{95} \approx 3$





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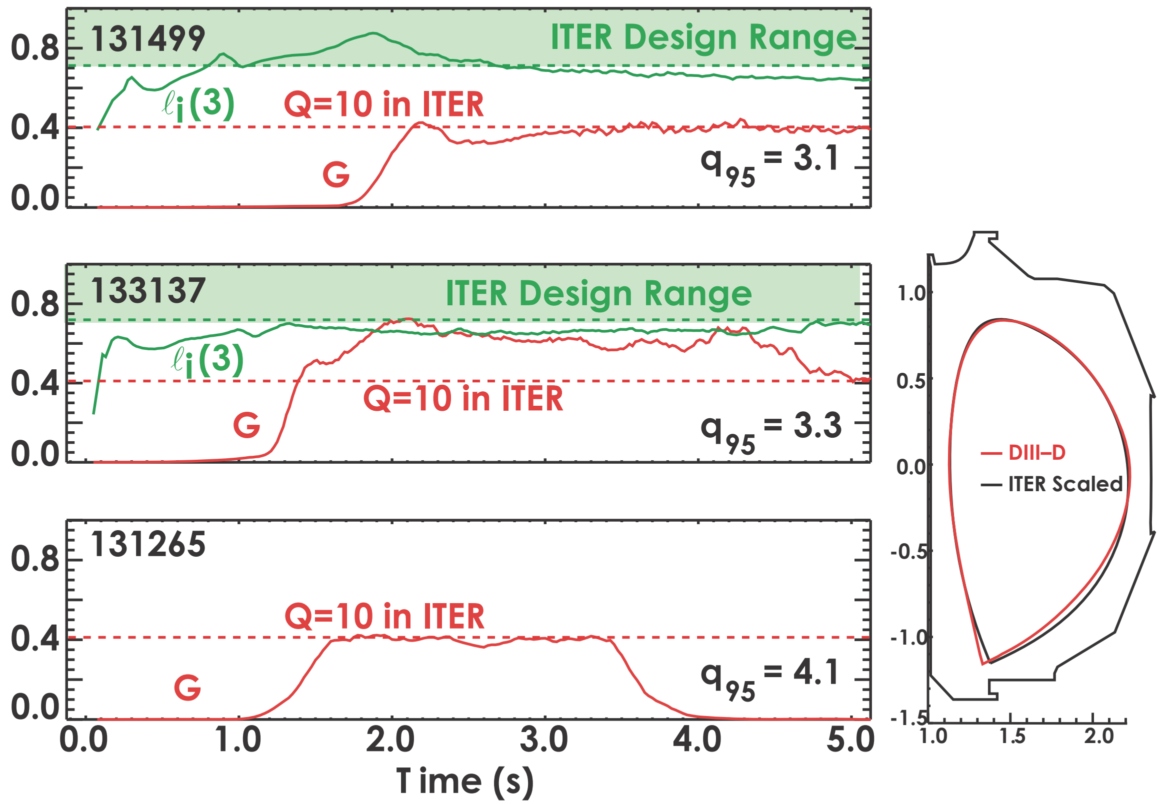
- **Hybrid**
  - Long pulse, high fluence
  - Q=5 at 12 MA, $\beta_N \approx 2.5$, $q_{95} \approx 4$



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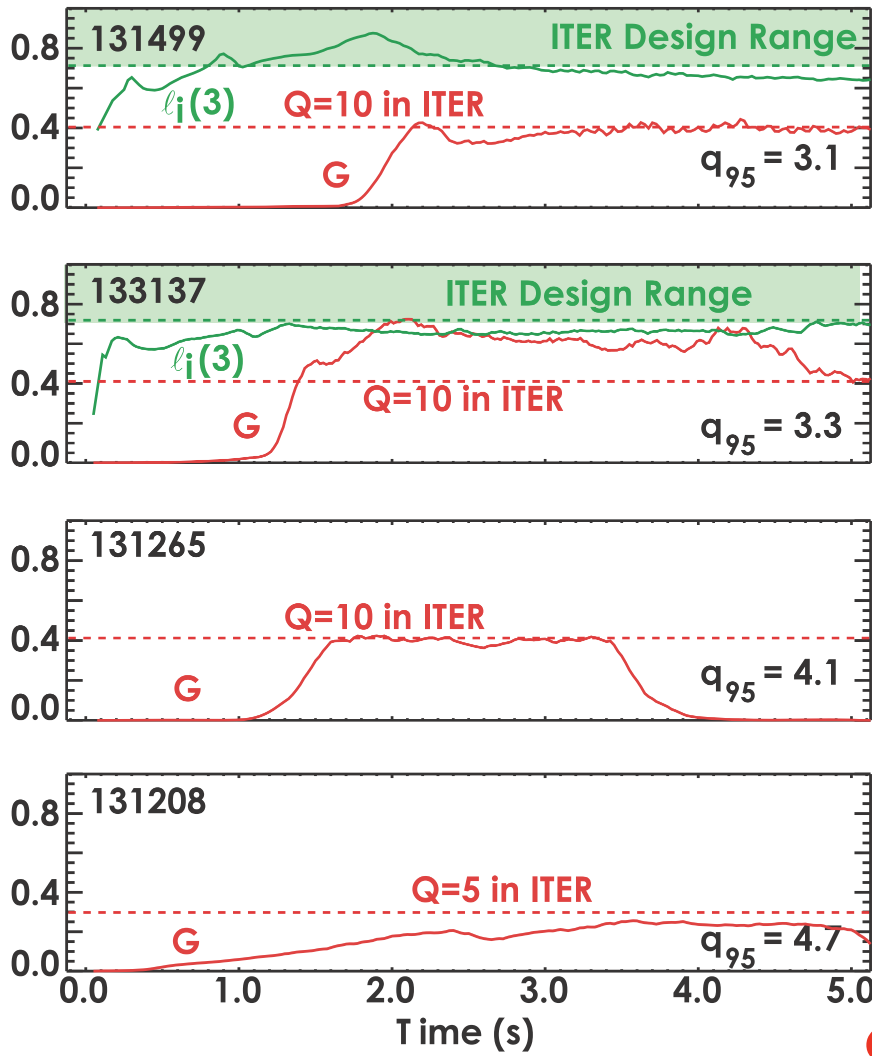
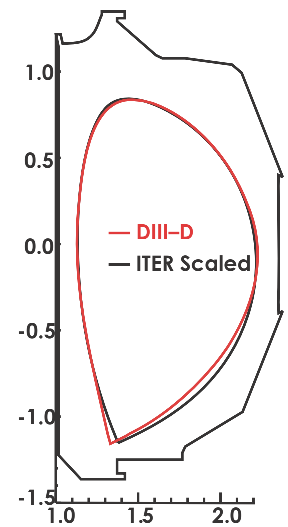
- **Hybrid**
  - Long pulse, high fluence
  - Q=5 at 12 MA, $\beta_N \approx 2.5$, $q_{95} \approx 4$
- **Steady-state**
  - Fully non-inductive
  - Q=5 at 9 MA, $\beta_N \approx 3$, $q_{95} \approx 5$



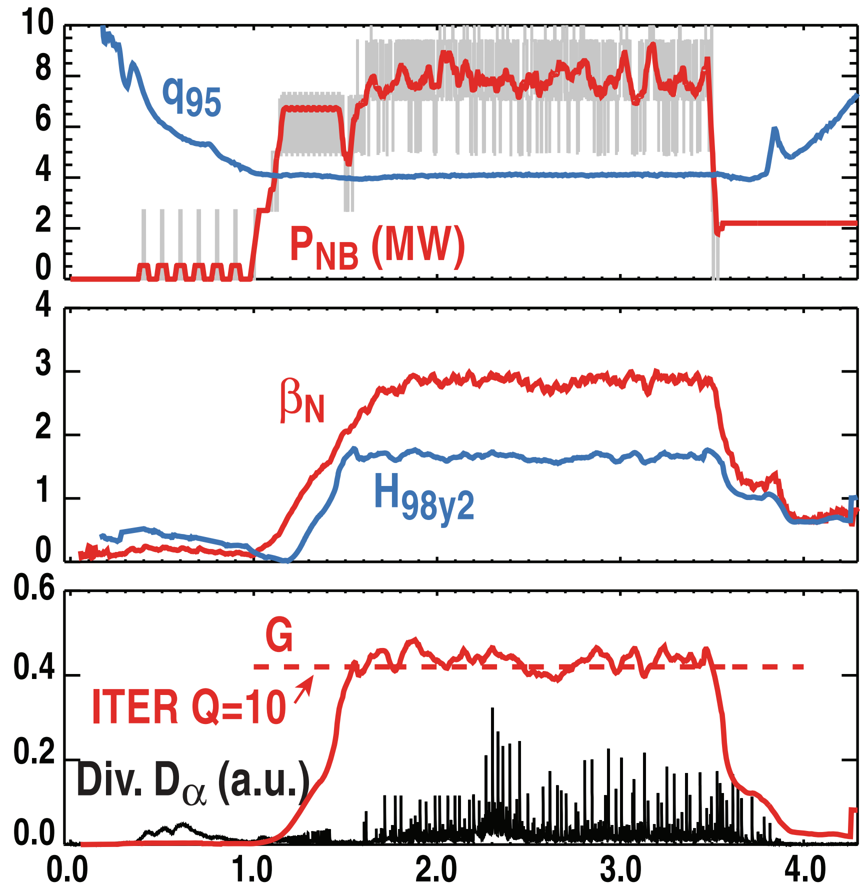


$G = \beta_N H_{89} / q_{95}^2$

Hybrid scenario with excellent performance accessed with large bore ITER startup

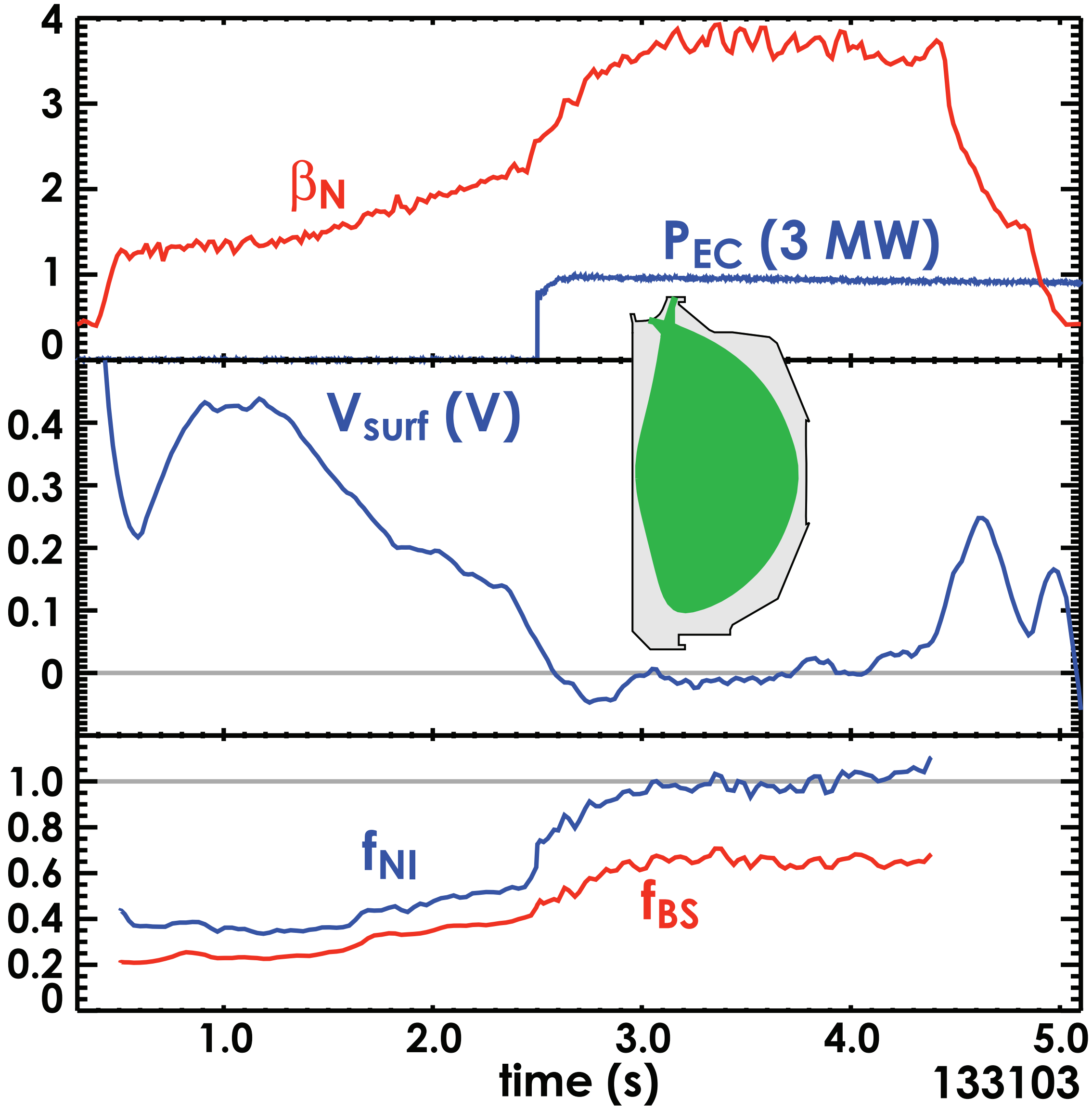
- **Large Bore startup includes**
  - Initiation on outer limiter
  - Large cross-section early in limiter phase
  - Early x-point formation
  - No auxiliary heating until close to full current

- **Excellent plasma performance**
  - $\beta_N = 2.9$
  - $H_{98y2} = 1.6$
  - $G = 0.42 \rightarrow$ sufficient for Q = 10 in ITER at 11.6 MA



- **At higher q_{95}, hybrid scenario achieved with ~50% bootstrap current and ~100% non-inductive current**

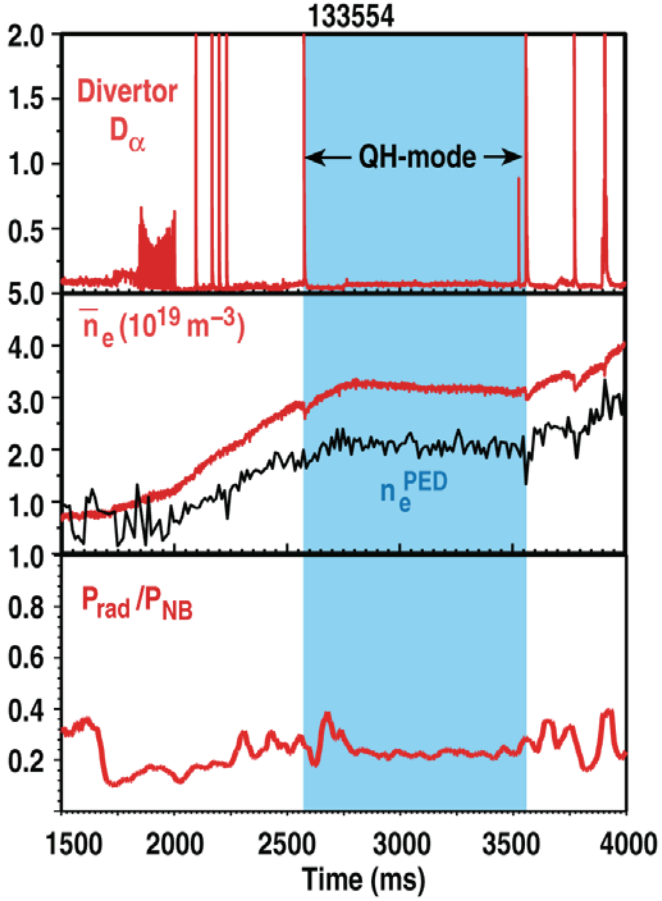
Duration of f_{ni}~1 at high β_n and f_{bs} extended with optimized shape and increased ECCD power



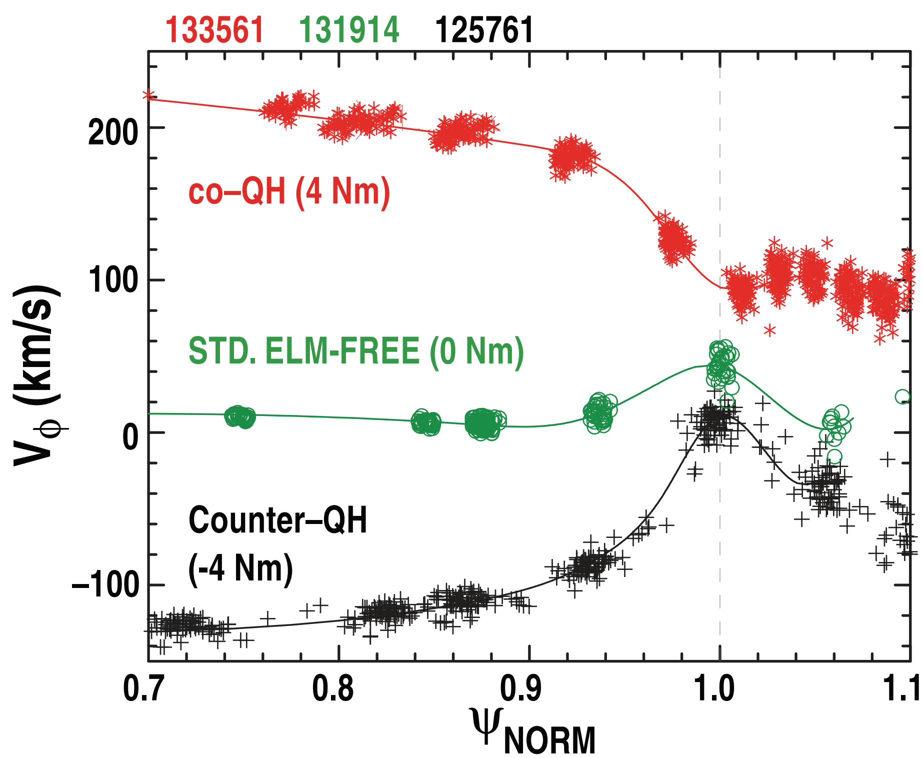
- **High triangularity, moderate squareness, slightly upward biased double-null**
  - $\beta_N \approx$ 3.5-3.9 (≤30% above no-wall limit)
  - $V_{surf} \approx 0$ for ~$0.7\tau_R$
  - $q_{min} \approx 1.5$, $H_{98} \approx 1.5$ at start of high-β_N phase
- **Transport code simulations calculate $f_{NI} \approx 1$ and $f_{BS} \approx 0.65$**
- **Best previous:** **$\beta_N \approx$ 3.2-3.6, with $V_{surf} \approx 0$ for $0.4\tau_R$**

Quiescent H-mode (ELM-free) achieved with co-NBI

- **ELM-free operation for ~1s**
  - Radiated power, core density, and pedestal density are constant

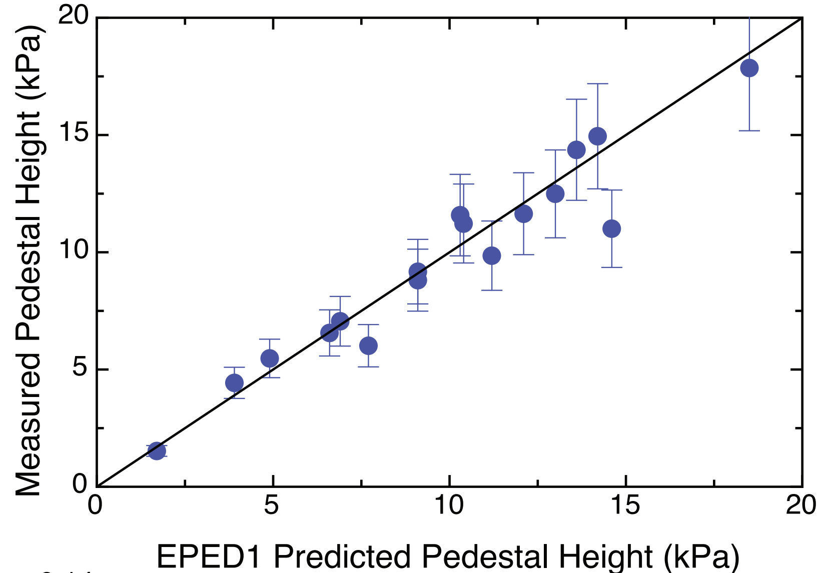


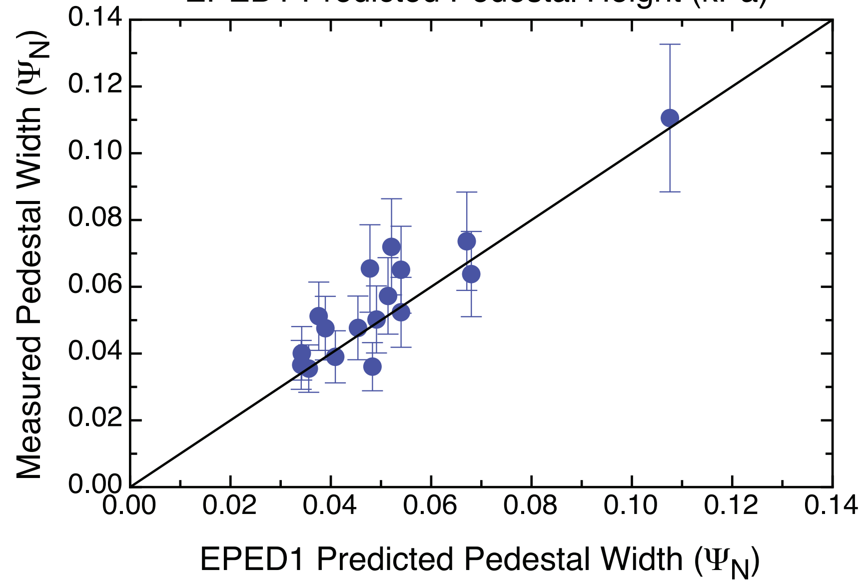
- **QH-mode plasmas have strong rotational shear at the edge**
  - Consistent with predicted stability of peeling-ballooning mode



H-mode pedestal characteristics predicted by EPED1 pedestal model in agreement with experiment

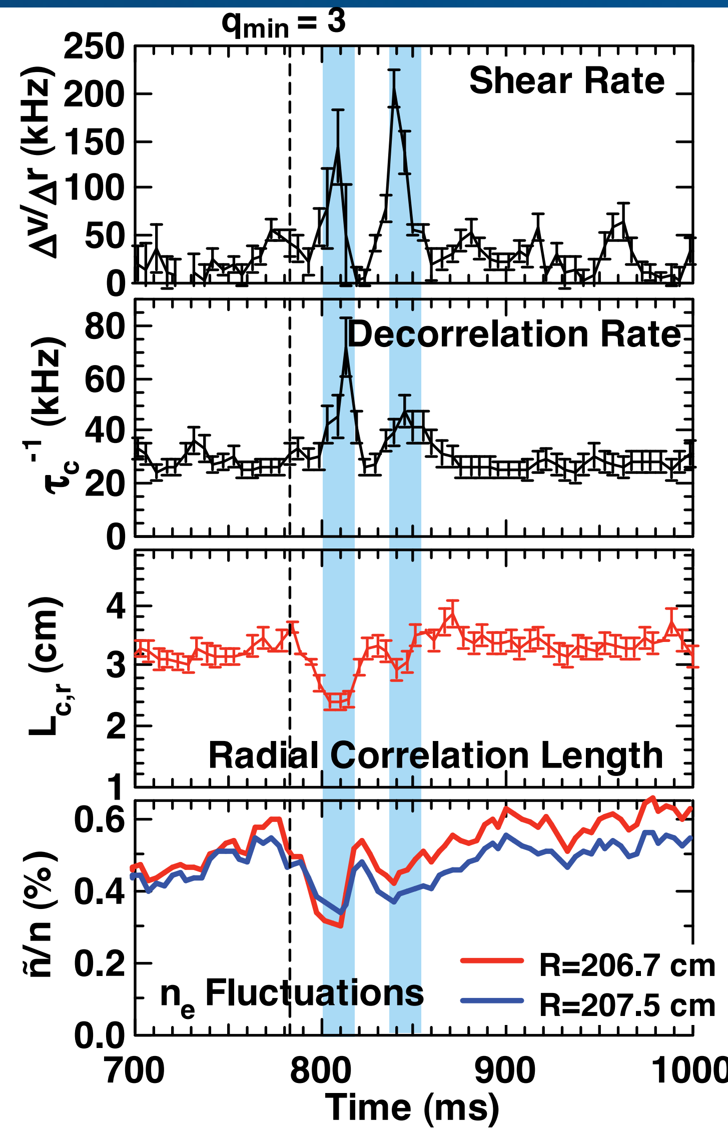
- **Input: B_T, I_P, R, a, κ, δ, n_{eped}, β_{global}**
- **Output: Pedestal height and width**
  - Peeling-ballooning stability from ELITE
  - Width: $\Delta_{\psi_N} = 0.076\beta_{p,ped}^{1/2}$
- **Validated with DIII-D data with large parameter variations**
  - Comparisons with JET and JT-60U yield reasonable agreement
- **Preliminary prediction for ITER pedestal parameters supports favorable performance predictions**





Increased local shear suppression suppresses and decorrelates turbulence during rational q_{min} events

- **Local poloidal velocity shear rate calculated via $\Delta v_\theta/\Delta r$**
  - Shear rate increases following q_{min}=3
- **Correlation time shortens during increased velocity shear**
  - Increased decorrelation rate
- **Reduction in radial correlation length and density fluctuation simultaneously observed**
- **Firs shear suppression model [P.W. Terry, Rev. Mod. Phys. 72, 109 (2000)]**
  - Eddy lifetime and size decreases as shear rate rises

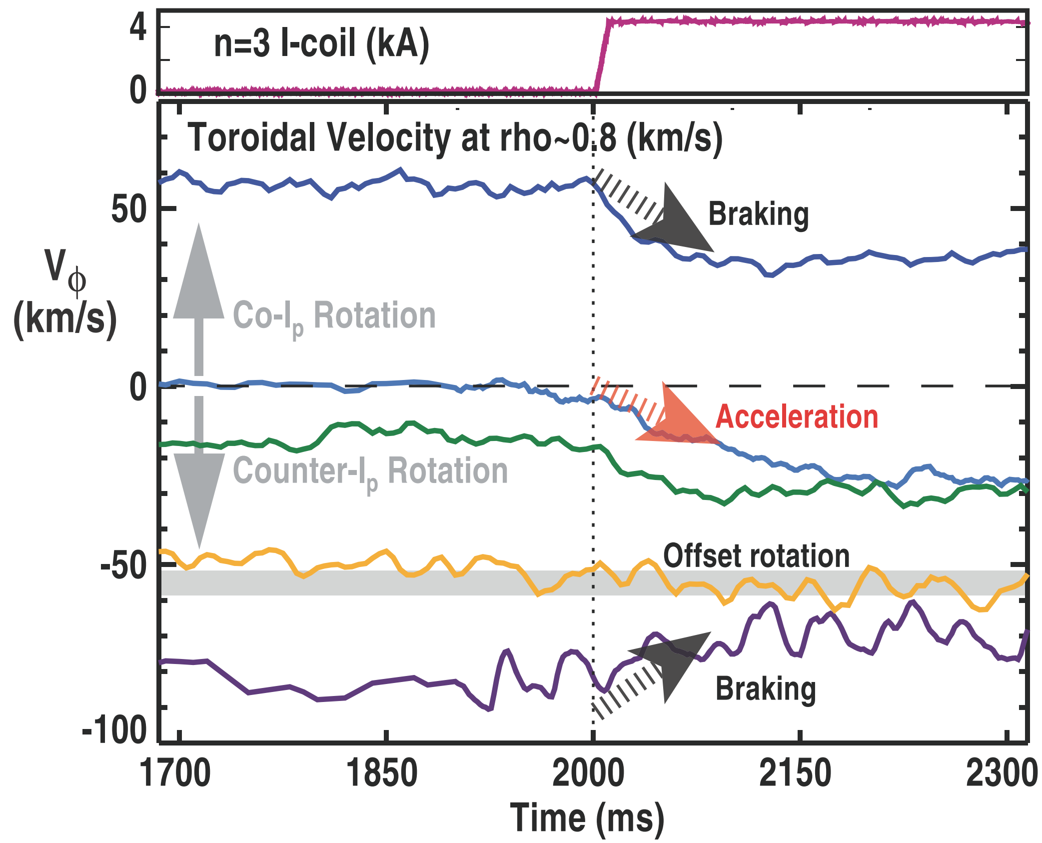


BES measurements at r/a≈0.57 (outside q_{min})

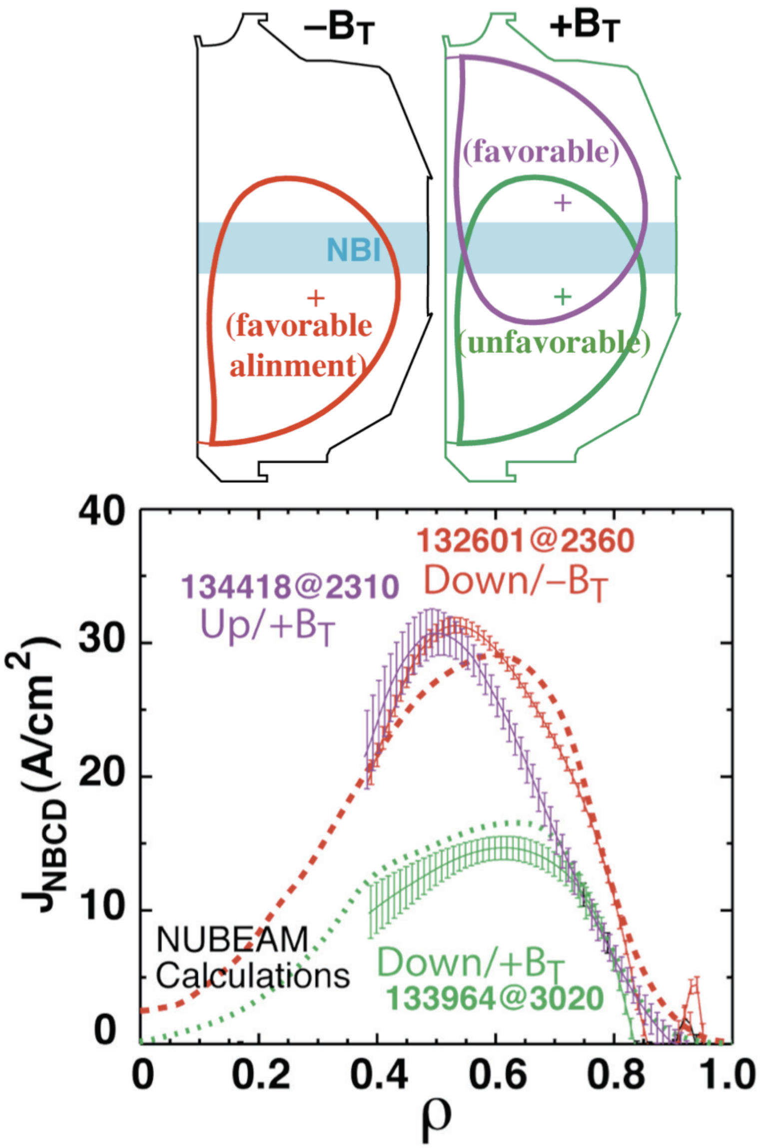
M.W. Shafer, this session

Multiple sources of torque will affect ITER's rotation

- **Static non-resonant n=3 fields apply a torque to the plasma**
  - Rotation accelerates for cases with small, negative, rotation
- **Torque is consistent with prediction of Neoclassical Toroidal Viscosity theory**
  - Drags rotation toward a non-zero offset rotation ~ $-\omega_i^*$
- **Torque from non-resonant part of ELM control field predicted to be >>T_{NBI} in ITER**
- **Other experiments show "intrinsic" torque consistent with thermal ion orbit loss**



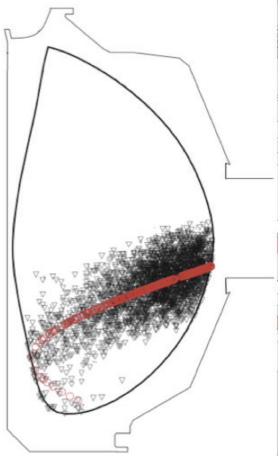
Validated off-axis neutral beam current drive model contributes to physics basis for planned modification

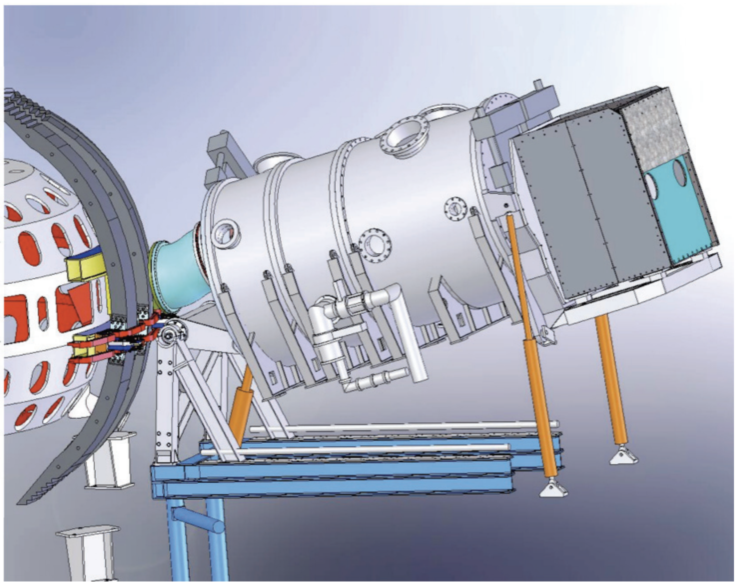


- **Prototype off-axis NBCD experiment in DIII-D**
  - Vertically shifted small plasmas and existing (midplane) NBI
  - Validates prediction that misalignment with local pitch of magnetic field lines can reduce NBCD by 60-65%
- **Implications:**
  - Guides design of off-axis NBI for DIII-D
  - In ITER, ~20% increase if B_T is reversed
- **Modification of the DIII-D NBI system will**
  - Support steady state scenario development for ITER and beyond
  - Provide a flexible scientific tool

J.M. Park, Thursday afternoon (invited)

Validated neutral beam current drive model contributes to physics basis for planned modification





Planned modification to a DIII-D beamline will allow on- or off-axis aiming of NBCD

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In this session, we present results of DIII-D research supporting ITER, developing a physics basis for steady-state high performance, and advancing fusion science

- **Enable the success of ITER by providing physics solutions to key physics issues**
  - R.A. Moyer: Particle Transport in RMP H-modes
  - A.G. McLean: Hydrogenic retention
  - W. Wu: 1-D Modeling of Massive Particle Injection (MPI) in Tokamaks
  - T.A. Casper: Experimental and Model Validation of ITER Operational Scenarios
  - *More in session GO3: Research in Support of ITER*
- **Develop the physics basis for steady-state operation in ITER and beyond**
  - J.R. Ferron: High beta steady-state operating scenarios
  - T.W. Petrie: Core-edge coupling
  - H. Reimerdes: Wall-stabilization
  - Y. In: Feedback stabilization of current-driven resistive-wall-modes
- **Advance the fundamental understanding of fusion plasmas along a broad front**
  - R.J. Buttery: Response of tearing stability to variations in rotation
  - J.S. deGrassie: Intrinsic rotation
  - A.E. White: Simultaneous measurements of T_e and n_e fluctuations
  - M.W. Shafer: Turbulence suppression and shear flow dynamics
  - J.C. DeBoo: Modulation of TEM Turbulence in DIII-D L-mode Discharges
  - R. Nazikian: Alfvén eigenmode research

Other DIII–D and related talks and posters at this meeting

Session GO3: Research in Support of ITER (Tuesday morning)		
2	M.E.Fenstermacher	Comparison of ELM Control Using One vs. Two Rows of RMP Coils in DIII-D
4	P.Gohil	H-mode Power Threshold, Pedestal and ELM Characteristics and Transport in Hydrogen Plasmas in DIII-D
6	D.A.Humphreys	ITER Vertical Stability Guidance from Multi-machine Experiments
8	P.A.Politzer	Demonstration of ITER Operational Scenarios on DIII-D
12	E.M.Hollmann	Impurity Assimilation During Massive Gas Injection for Disruption Mitigation in DIII-D
Invited talks		
Mon 10:15AM	A.M.Garofalo	Plasma rotation driven by static nonresonant magnetic fields
Mon 3:00PM	C.T.Holcomb	Optimizing stability, transport, and divertor operation through plasma shaping for steady-state scenario development in DIII-D
Tue 10:15AM	N.N.Gorelenkov	Beta-induced Alfvén-Acoustic Eigenmodes in NSTX and DIII-D Driven by Beam Ions
Wed 9:45AM	P.B.Snyder	Development and Validation of a Predictive Model for the Pedestal Height
Wed 10:45AM	K.H.Burrell	Edge Pedestal Control in Quiescent H-Mode Discharges in DIII-D Using Co plus Counter Neutral Beam Injection
Thu 11:00AM	J.H.Yu	Fast imaging of transients and coherent MHD modes in DIII-D
Thu 12:00PM	E.Belli	Drift-Kinetic Simulations of Neoclassical Transport
Thu 3:00PM	J.M.Park	Validation of On- and Off-axis Neutral Beam Current Drive Against Experiment in DIII-D
Thu 4:30PM	F.Volpe	Advanced Techniques for Neoclassical Tearing Mode Control by Electron Cyclotron Current Drive in DIII-D
Fri 11:15AM	L.Schmitz	Reduction of TEM-scale density fluctuations in the core and edge of H-mode DIII-D plasmas
DIII-D Poster Sessions: JP6 (Tuesday afternoon) and TP6 (Thursday, 9:30AM)		