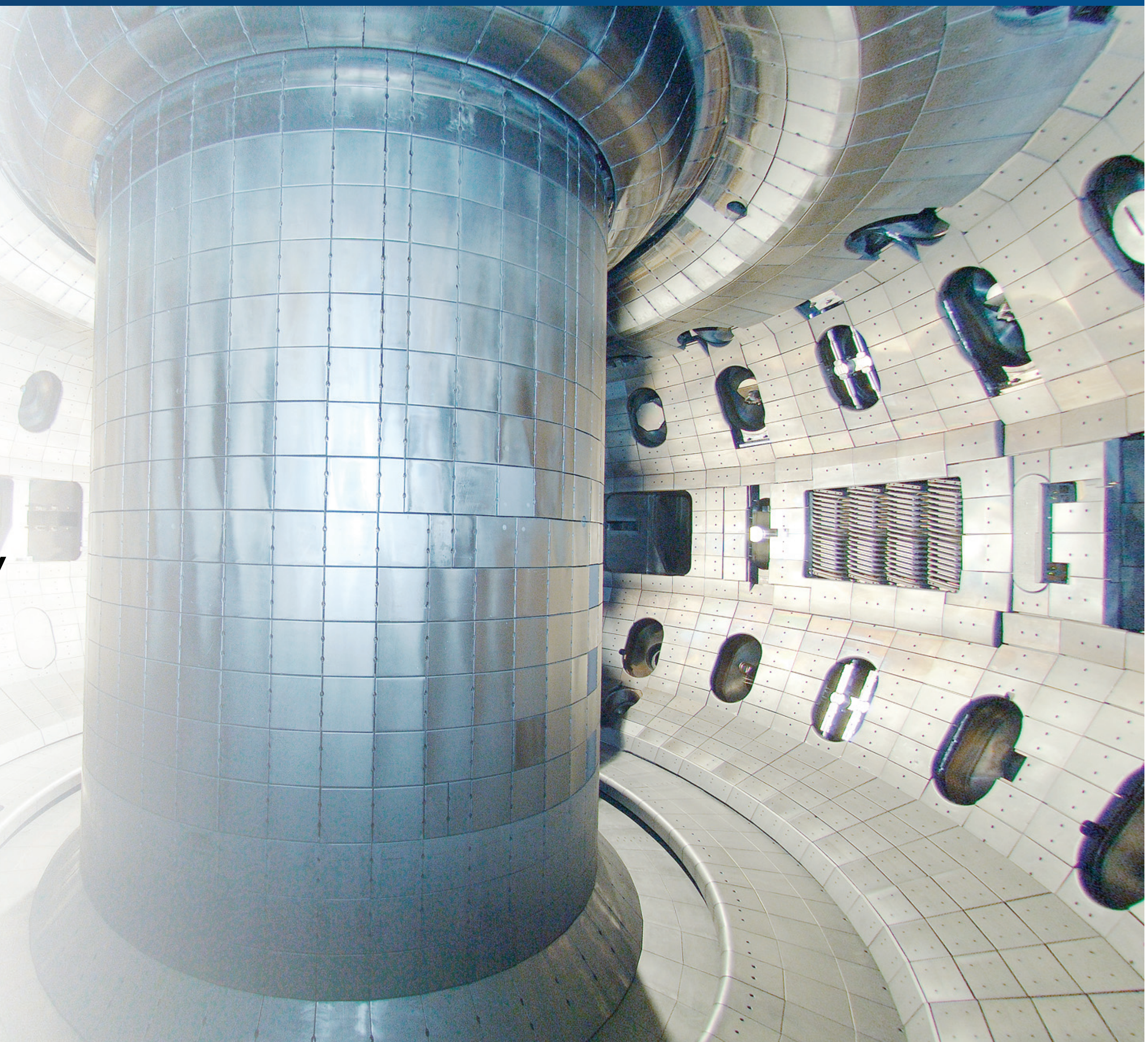
Overview of Recent DIII-D Experimental Results



M.E. Fenstermacher (LLNL)

For the DIII-D Team

Presented at the

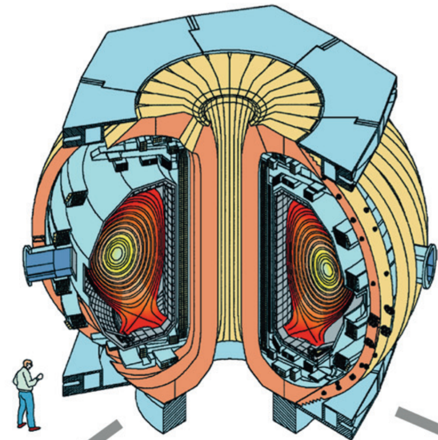
51st American Physical Society Annual Meeting of the Division of Plasma Physics
Atlanta, Georgia

November 2-6, 2009

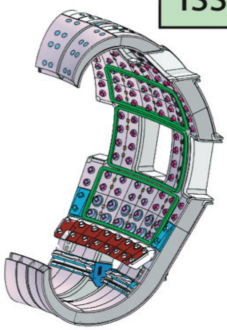
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344, and under Contracts DE-FC02-04ER54698, DE-FG02-07ER54917, DE-FG02-05ER54809.

DIII-D Research Contributes to Solutions of ITER Issues, Advanced Scenario Development and Basic Fusion Science

DIII-D

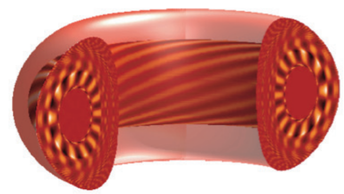


ITER Baseline Issues



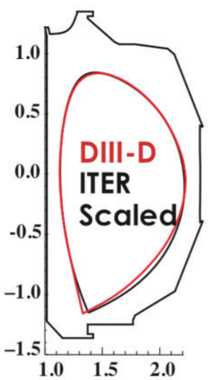
- ELM Control
- Rapid Shutdown
- Tritium Inventory
- Pedestal Width
- He or H Operation

Basic Fusion Science



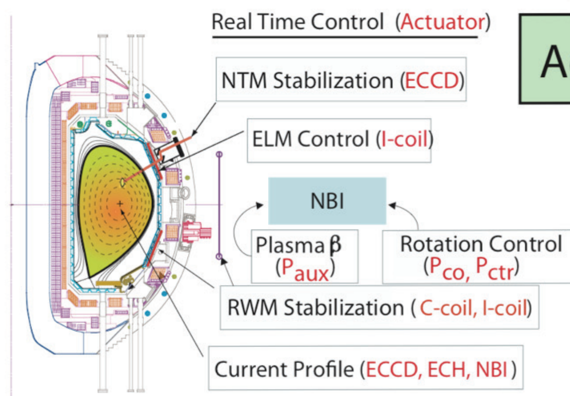
- L-H Transition
- Core Transport
- Plasma Rotation
- Fast Ions
- Stability

ITER Scenario Development



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

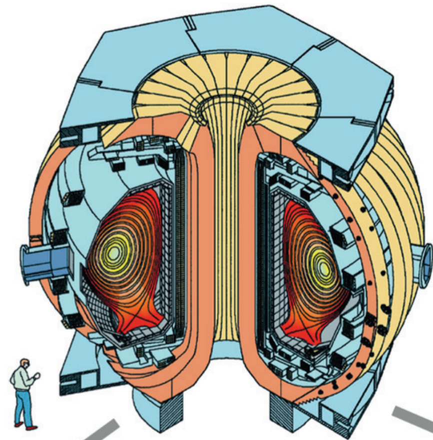
Advanced Scenarios



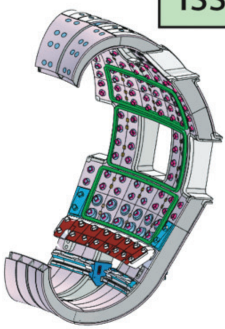
- Integrated Scenario Development
- Core-Edge Coupling
- Instability Control

DIII-D Research Contributes to Solutions of ITER Issues, Advanced Scenario Development and Basic Fusion Science

DIII-D



ITER Baseline Issues



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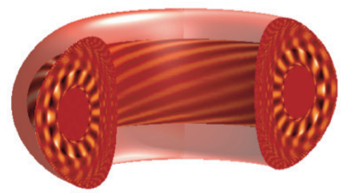
Basic Fusion Science



- L-H Transition
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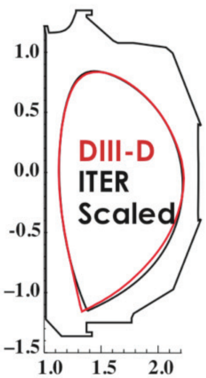
ITER Scenario Development



- Reference Scenarios
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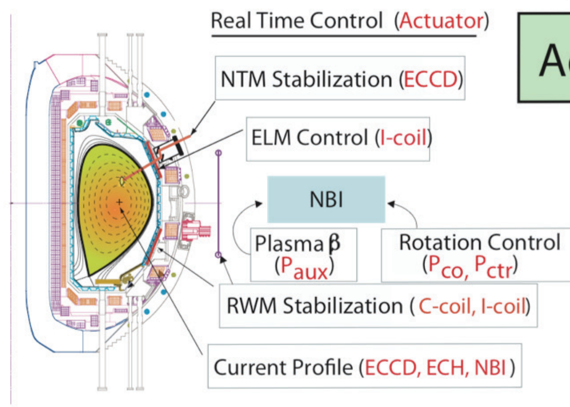
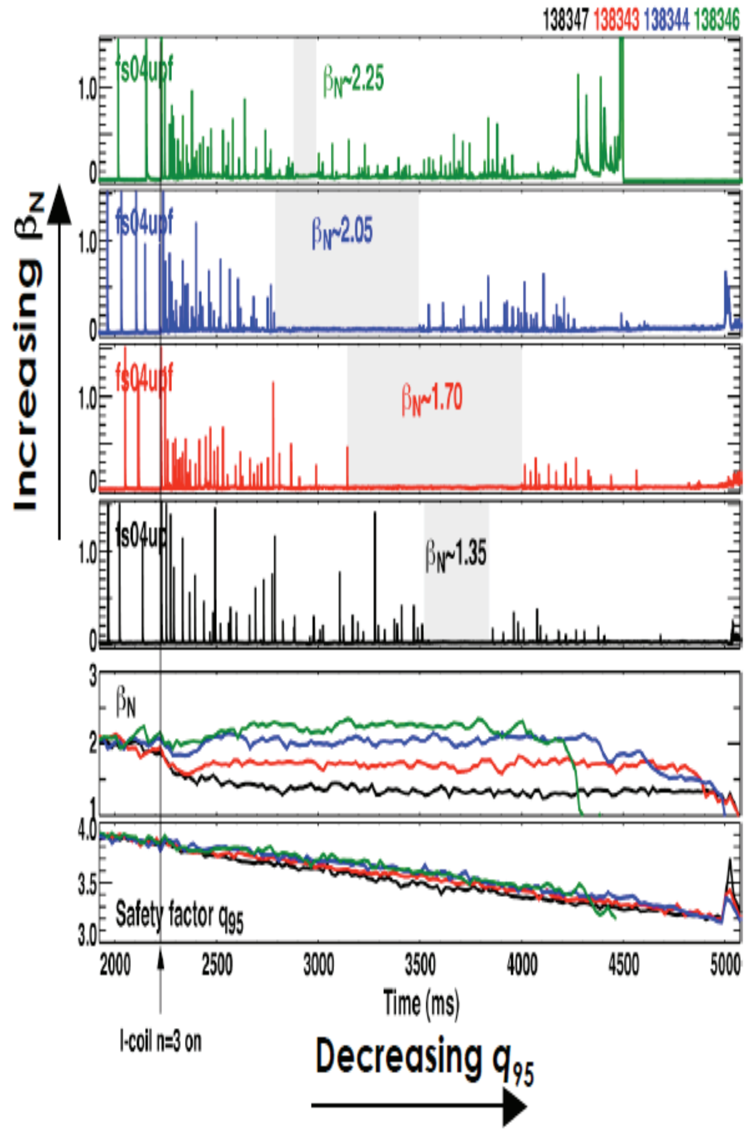
Advanced Scenarios

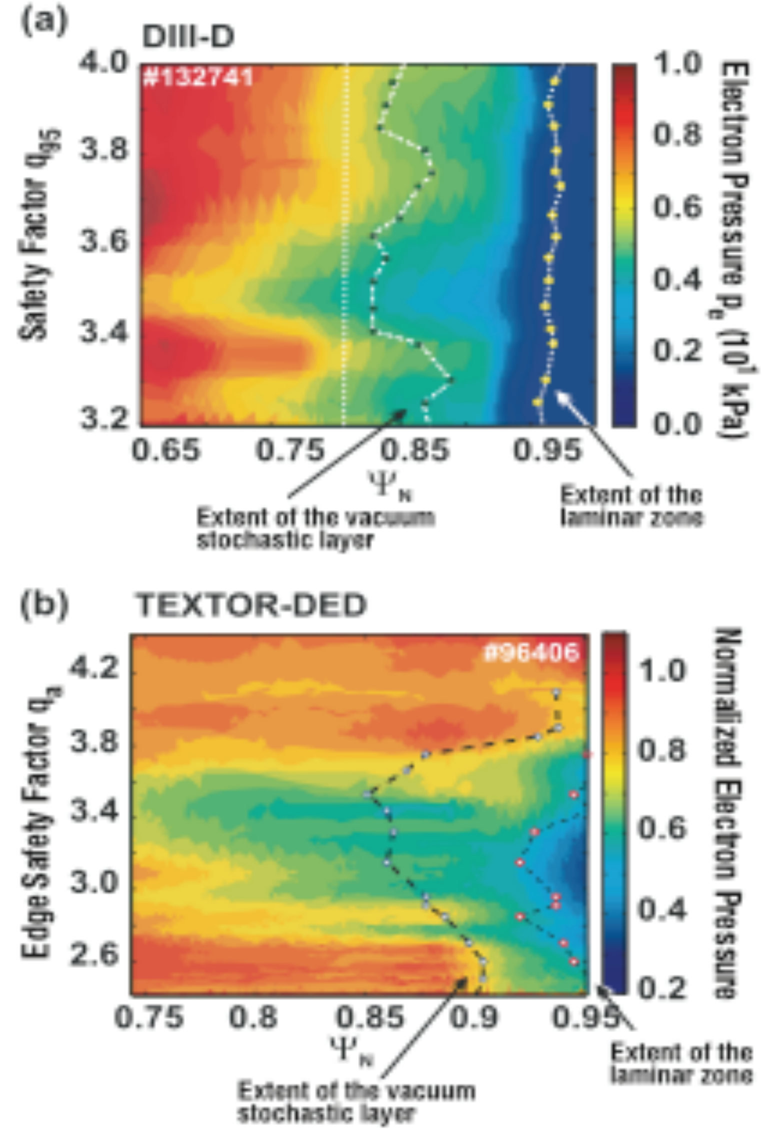


- Integrated Scenario Development
- Core-Edge Coupling
- Instability Control

Plasma Response to Resonant Magnetic Perturbation (RMP) Fields Affects q_{95} Window for ELM Suppression

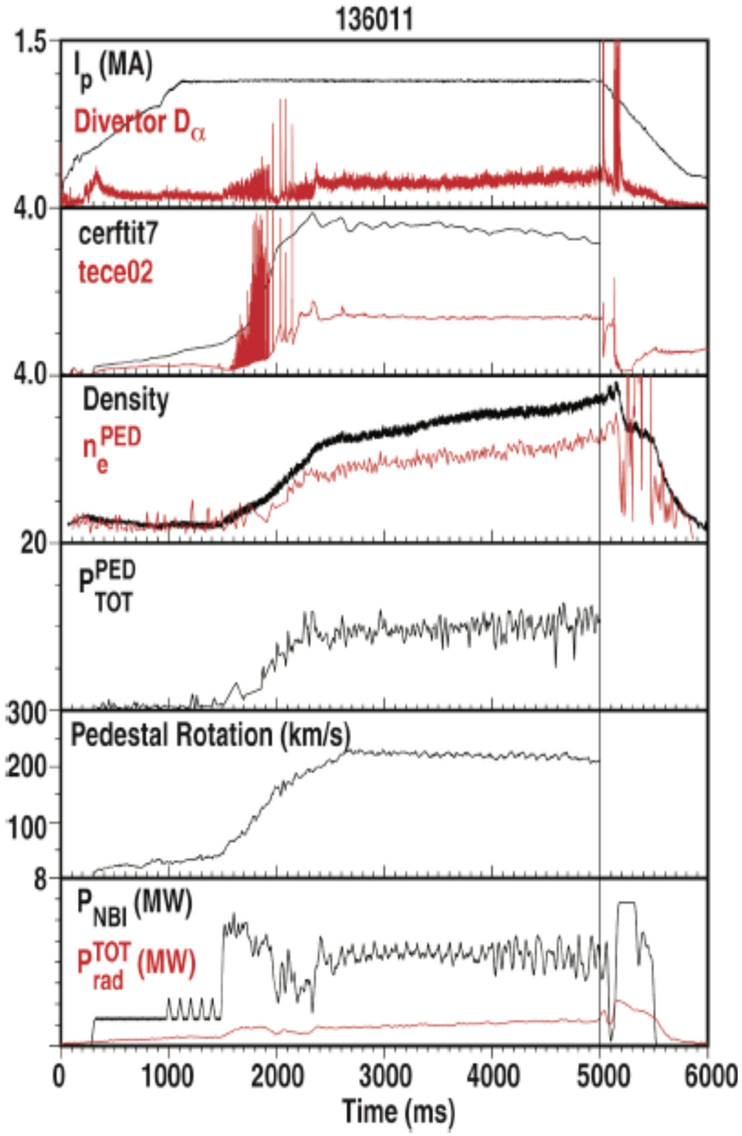


- ELM suppression window shifts to higher q_{95} with higher β_N
- Largest q_{95} window for ELM suppression at intermediate β_N
- Resonant response of pedestal T_e also seen during q_{95} scans with RMP ELM suppression

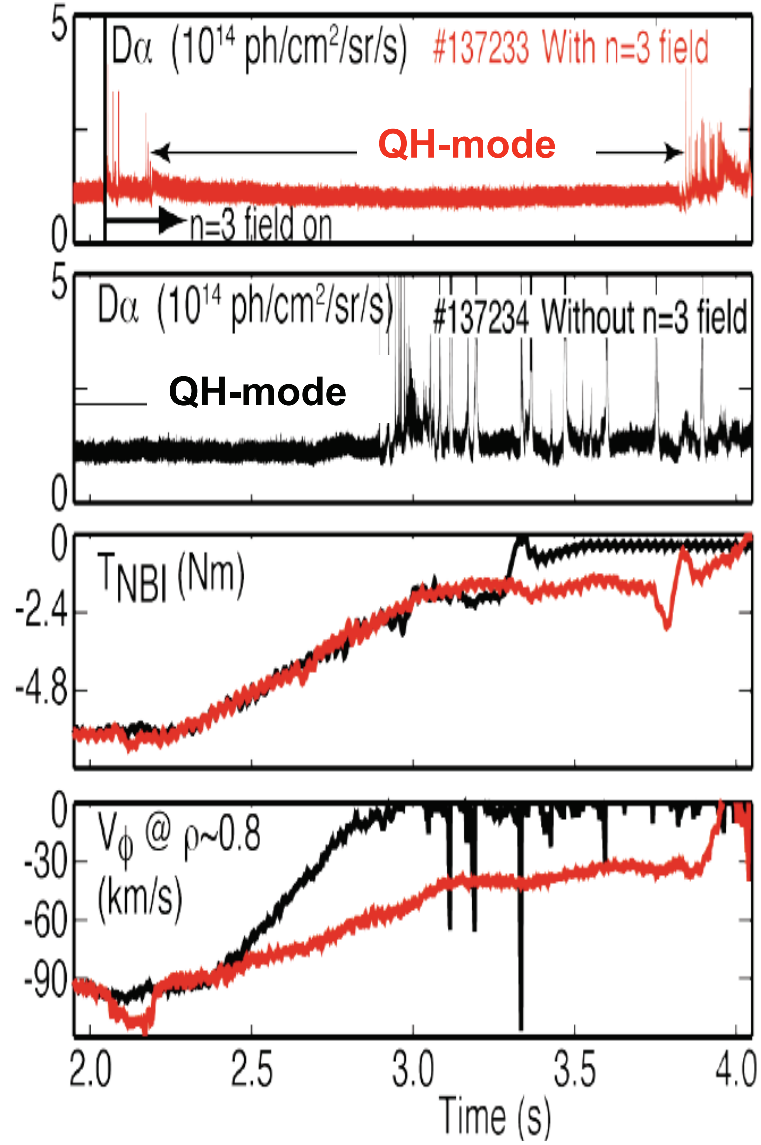


O. Schmitz, S. Mordijck this session, Posters Tues pm

QH-mode Operating Space Extended With Co-NBI and to Low NBI Torque Regimes With Non-Resonant Fields



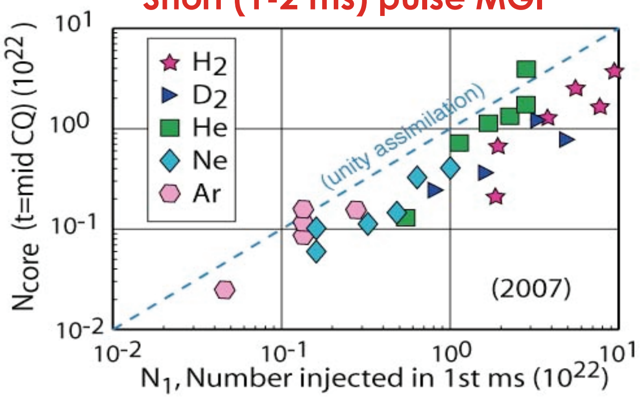
- **QH-mode with co-NBI extended to available beam pulse**
  - Co-directed V_{rot} high
  - P_{rad} low
- **Torque from predominantly non-resonant magnetic fields extends QH-mode to low NBI input torque regimes**
  - NTV theory



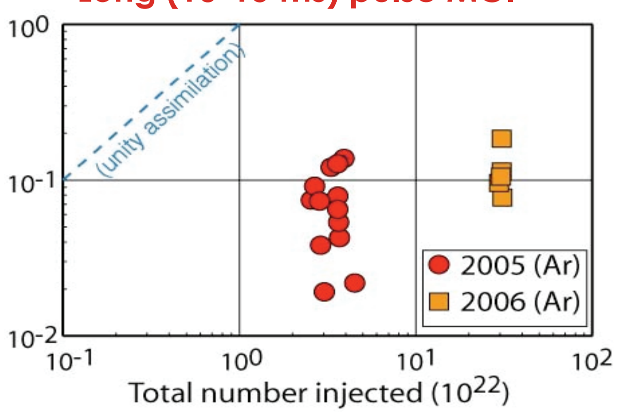
A. Garofalo, Z. Yan, this session Posters Thurs am

Multiple Schemes for Rapid Plasma Shutdown and Runaway Electron Mitigation Were Demonstrated and Compared

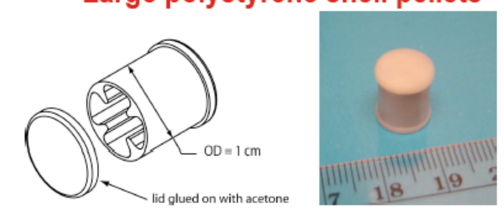
Short (1-2 ms) pulse MGI



Long (10-15 ms) pulse MGI

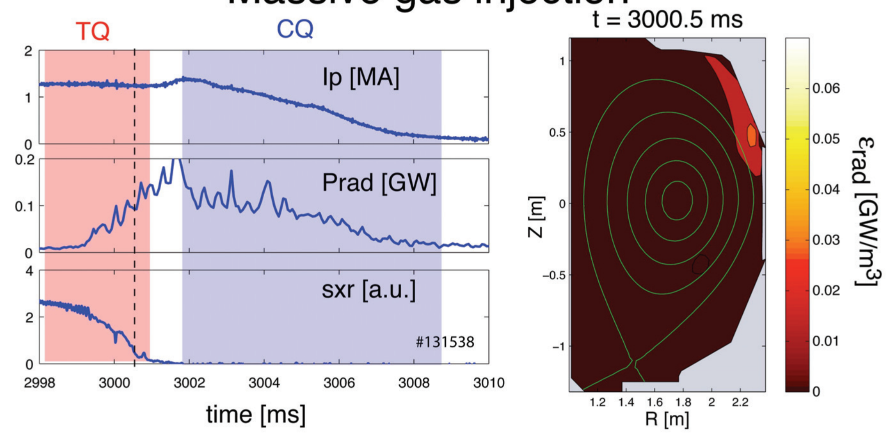


Large polystyrene shell pellets

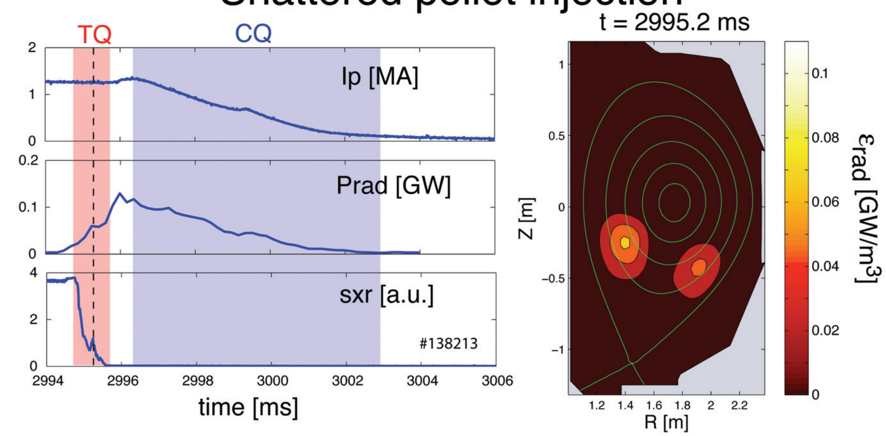


- He MGI particle assimilation optimized at ~2 ms in DIII-D
- Shattered D_2 pellet provided very rapid TQ and high n_e
- Large shell pellets penetrated through DIII-D plasma
- RMP fields (n=3) de-confine runaway electron beams

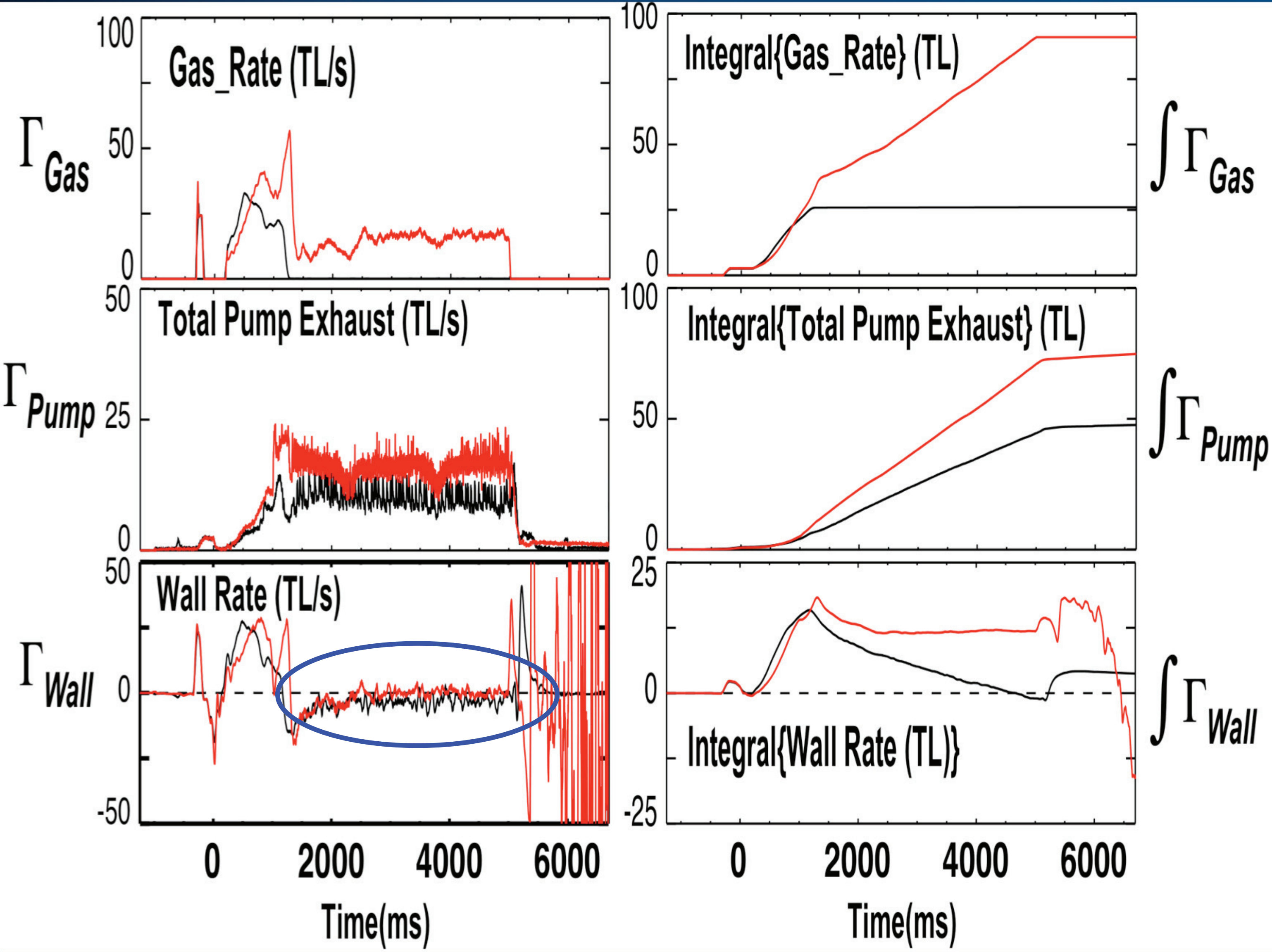
Massive gas injection



Shattered pellet injection



Detailed Particle Balance Showed Large Wall Uptake in L-mode and Very Low Uptake in H-mode

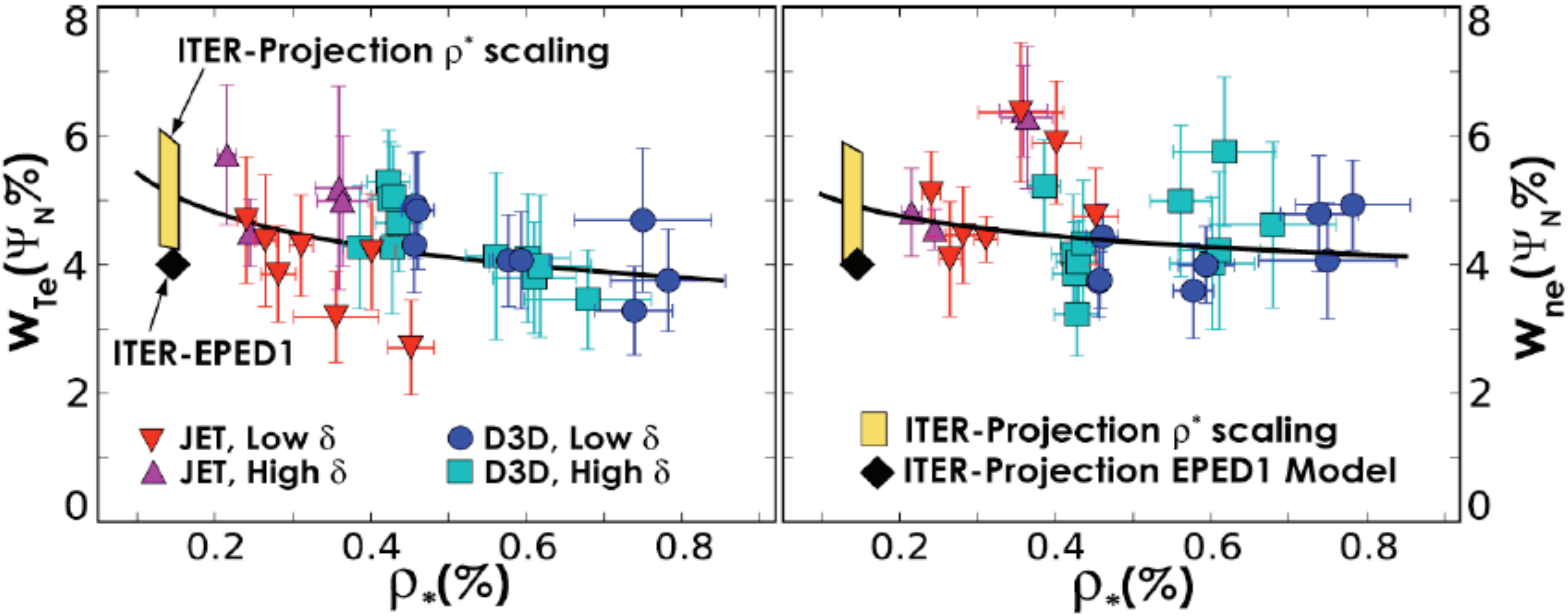


- **Low wall uptake in H-modes with ECH or NBI**
- **ITER tritium retention estimates may be reduced**
- **Static and dynamic particle balance methods agree**
  - ECH H-mode: within ±5%
  - NBI H-mode: within ±12%

DIII-D NATIONAL FUSION FACILITY

S.L. Allen this session

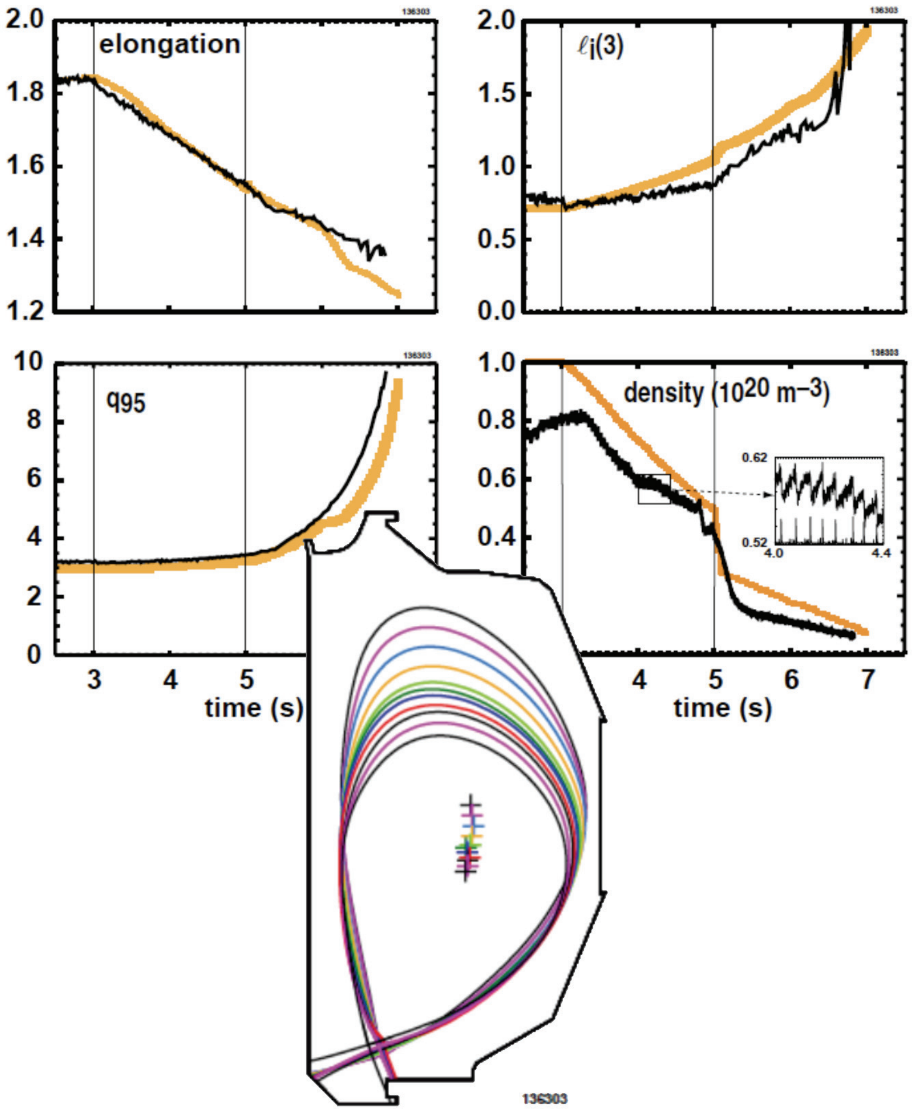
Factor of 4 Variation of ρ* in DIII-D and JET Shows Essentially No Dependence of Pedestal Widths on ρ_*



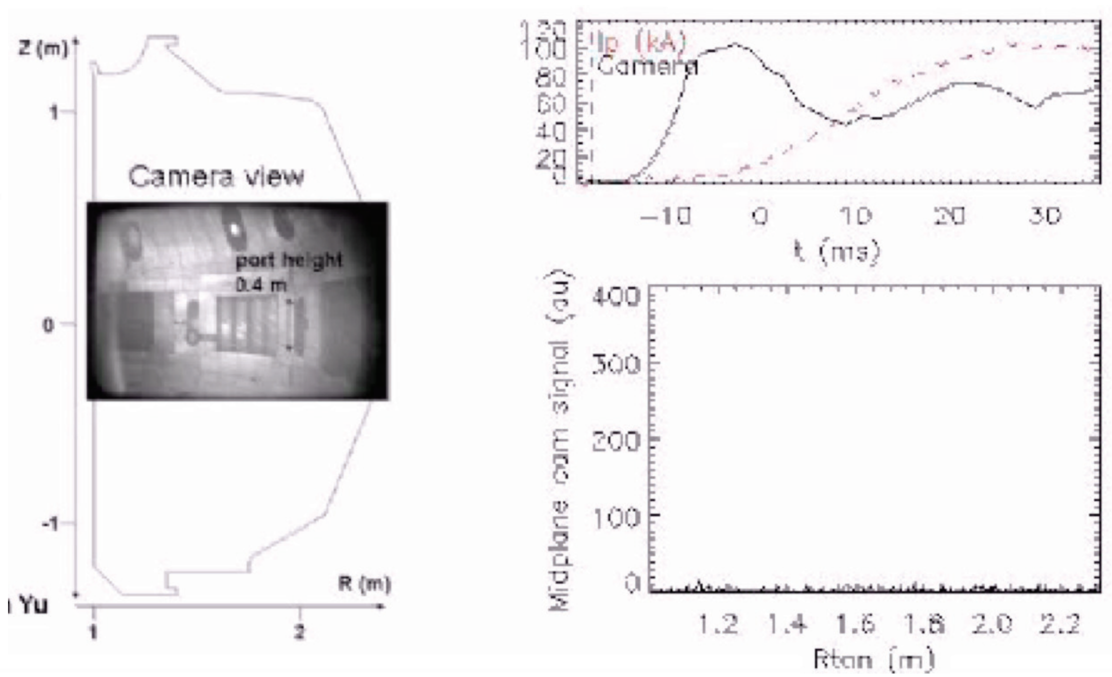
- **Fits of widths in Ψ_N give weak inverse dependence on ρ_***
  - Much weaker and in opposite direction than $(\rho_*)^{1/2}$ or $(\rho_*)^1$ as predicted by several theories
- **Potentially good news for ITER scenarios with small ρ_***

M.A. Beurskens, T.H. Osborne et al., PPCF (2009)

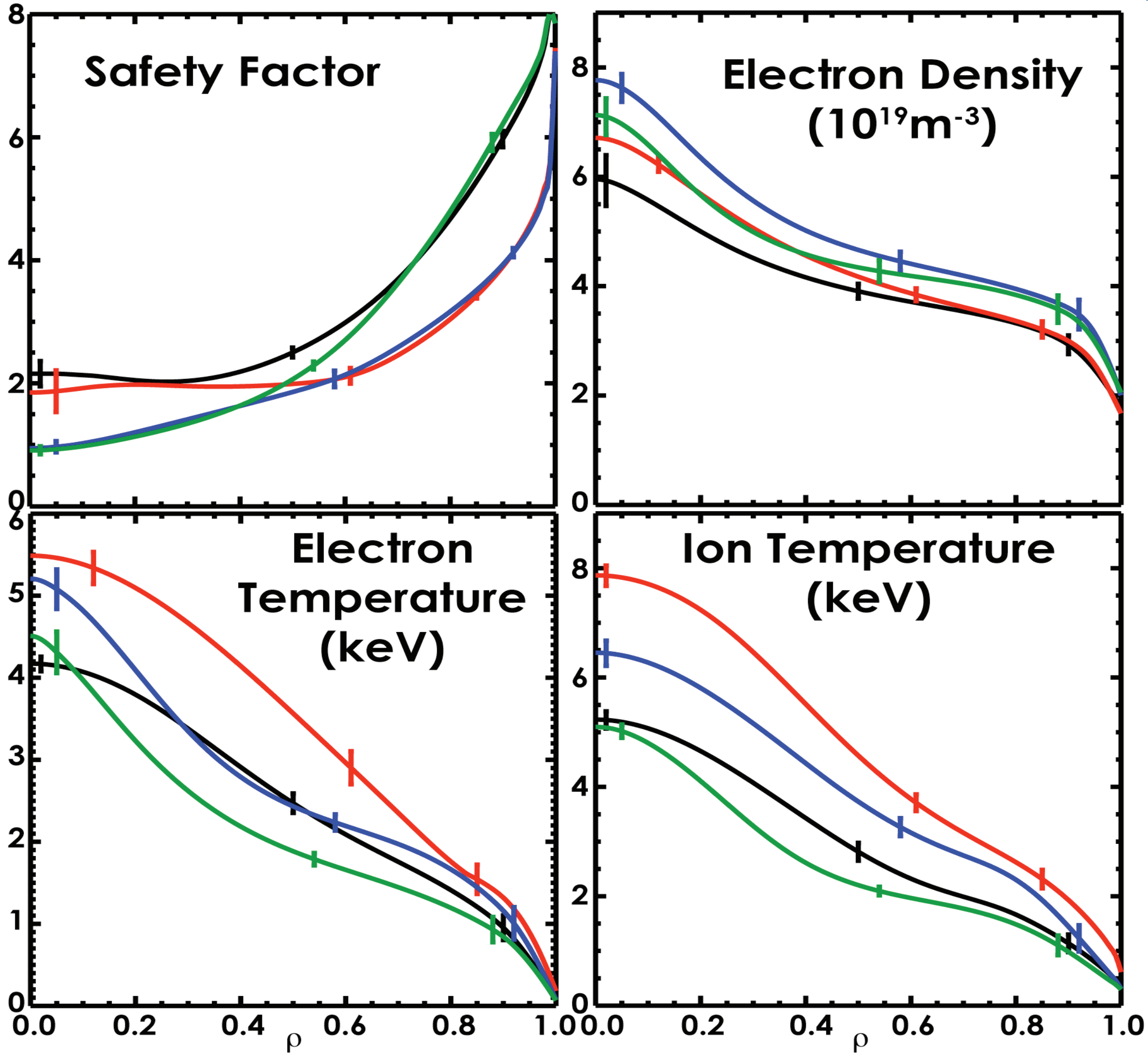
Plasma Startup at Low ITER-like Voltage and ITER Rampdown Scenarios Demonstrated



- **Low voltage (V_L=3V, E_T=0.3 V/m) startup with ITER geometry and ECH assist demonstrated**
- **ITER scenario rampdown demonstrated**
  - H-L transition without disruption
  - DINA simulation validated



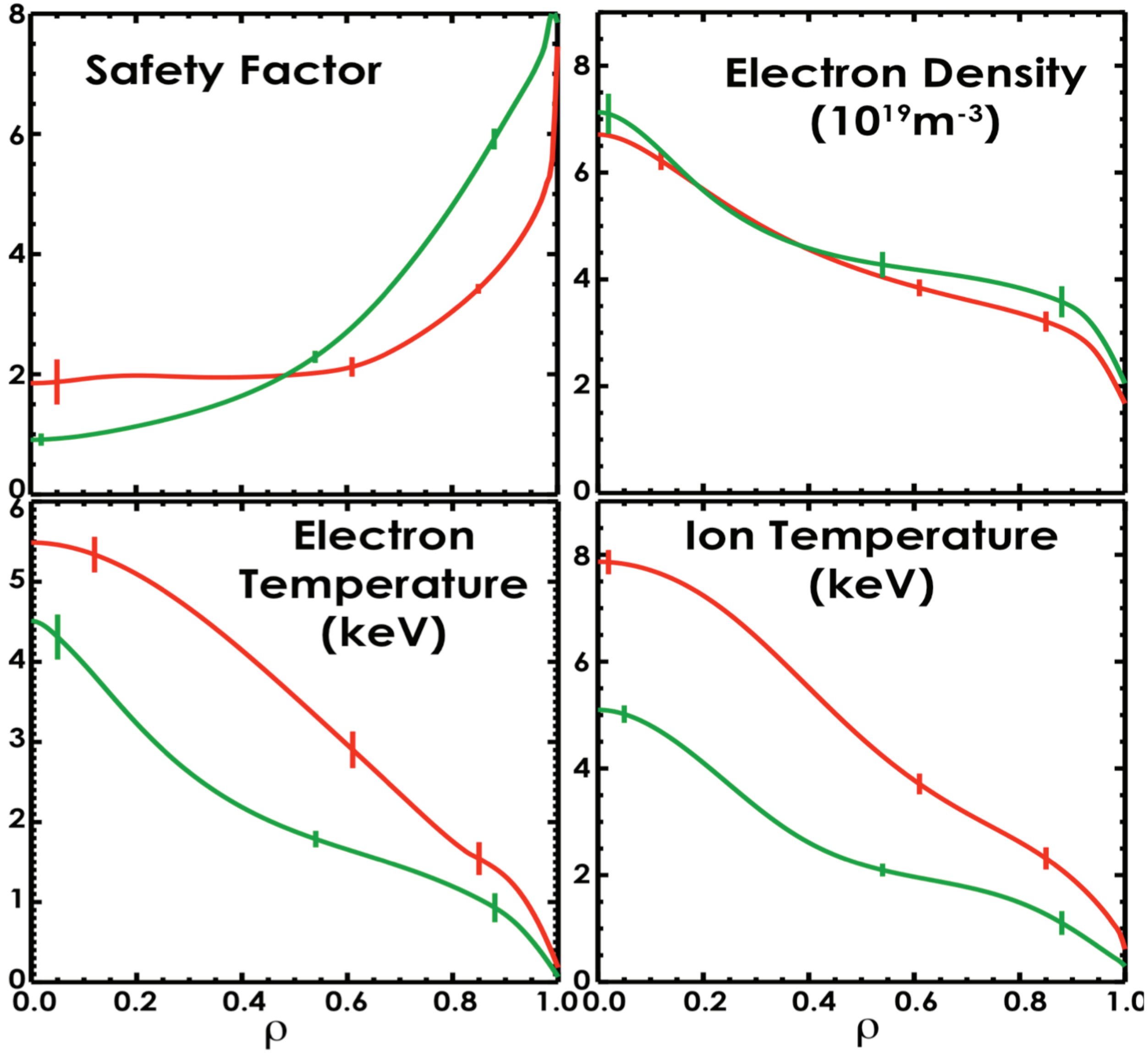
Systematic Variation of n_e, T_e, and T_i Profiles Seen at Fixed β_N with q_{min} and q_{95} Variation in Advanced Tokamak Scenarios



- **Fully relaxed averaged profiles**

		q_{95}	q_{95}
		4.5	6.8
q_{min}	2	136837	136835
q_{min}	1.1	136854	136853

Systematic Variation of n_e, T_e, and T_i Profiles Seen at Fixed β_N with q_{min} and q_{95} Variation in Advanced Tokamak Scenarios



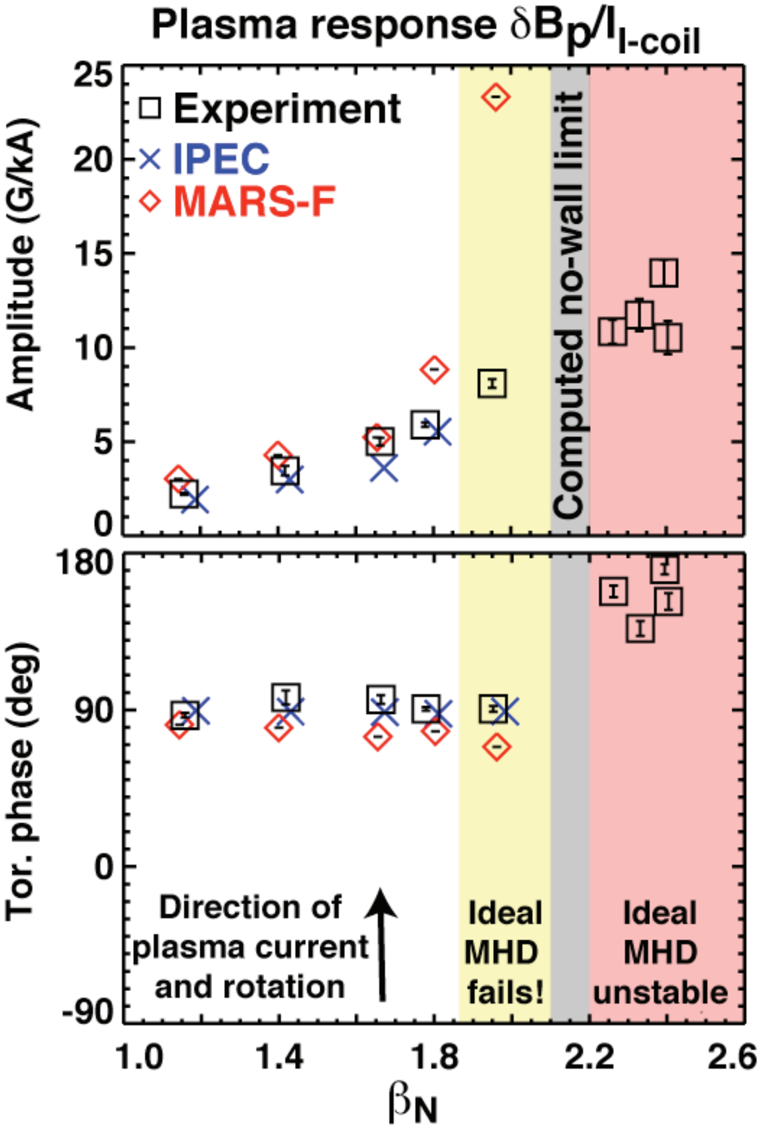
- **Fully relaxed averaged profiles**

		q_{95}	q_{95}
		4.5	**6.8**
q_{min}	**2**	**136837**	**136835**
q_{min}	**1.1**	**136854**	**136853**

- **As q_{95} reduced:**
  - Higher n_e, T_e, and T_i
  - Lower f_{bs}
- **As q_{min} reduced:**
  - n_e higher and more peaked
  - T_e more peaked
  - Improved stability
  - T_i lower

T. Luce Review Mon am
C. Holcomb this session

Linear Ideal MHD Theory Describes Measured *n*=1 Plasma Response for Values of β up to 70% of No-wall Stability Limit

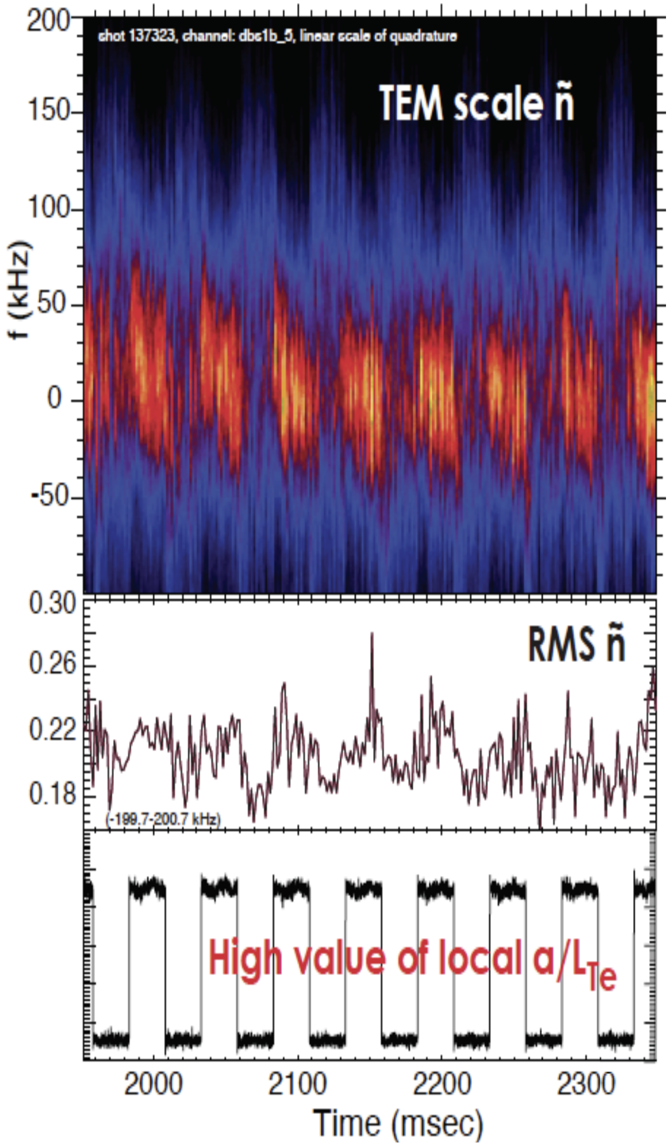


… but ideal theory fails at higher β_N

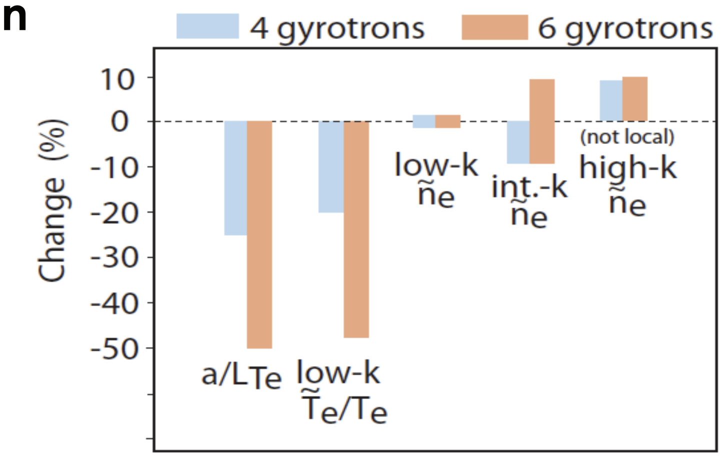
- **Probe rotating H-mode plasmas with externally applied *n*=1 fields**
- **For β_N < 1.7 ideal MHD models (MARS-F, IPEC) predict the perturbed field to within 20%**
  - Good agreement found at multiple poloidal and toroidal locations
- **For higher β_N, non-ideal effects modify response**
  - Plasmas remain stable above the ideal MHD no-wall stability limit
  - Calculated response amplitude diverges near marginal stability
- **A validated model of the plasma response to external fields is essential for understanding the error field threshold, testing magnetic braking theory, etc.**

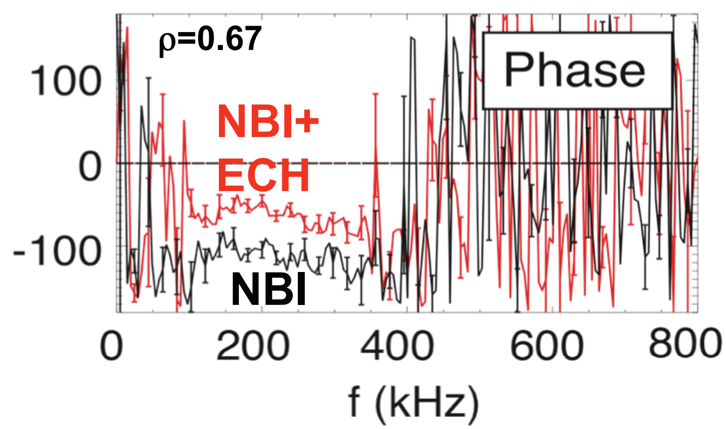
M. Lanctot this session

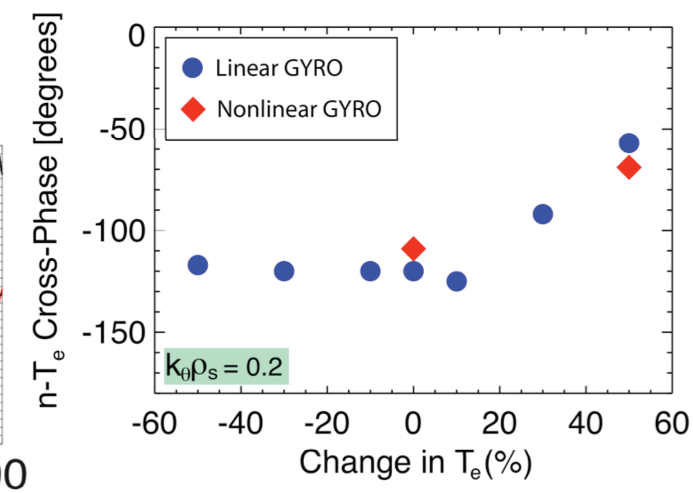
ECH Used to Modulate Local Value of ∇T_e and a/L_{Te} to Isolate and Test Electron Mode Physics in Turbulence Simulations



- **Isolates and tests electron mode physics**
  - Electron modes (TEM and ETG) dominate ITG modes
- **Multiple broad k-range fluctuation fields show complex response that will constrain simulations**
- **Predicted variation of n_e-T_e cross phase validated by measurements**



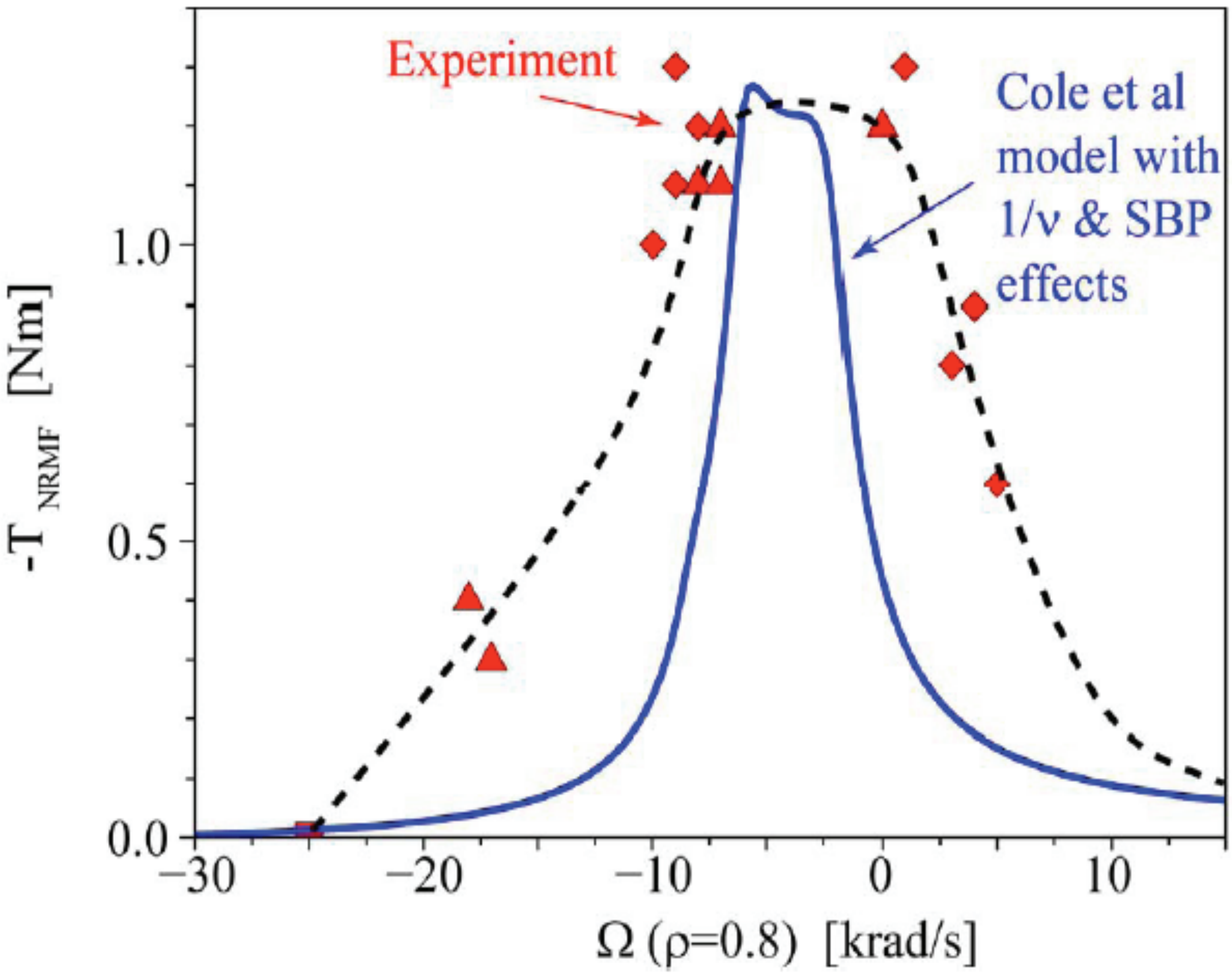




DIII-D NATIONAL FUSION FACILITY

J . DeBoo, Invited Tues pm
J. Candy, Invited Mon pm

Evidence Found for Increased Torque in 1/ν Regime in Agreement with Neoclassical Toroidal Velocity Theory



- **Torque from non-resonant fields deduced from input NB torque required to hold rotation constant**
- **Magnitude of torque peak in 1/ν regime similar to theory**
- **Width of torque peak larger than predicted**
  - Theory development in progress

Talks In This Session Present DIII-D Research Supporting ITER, Steady-State High Performance and Fusion Science

- **Enable the success of ITER by providing physics solutions to key physics issues**
  - S. Allen — CO4.02 : Particle Control and Carbon Transport Experiments on DIII-D
  - O. Schmitz — CO4.03 : Observations of Thermal Transport Enhancement in Stochastic Boundary Experiments at DIII-D and TEXTOR
  - S. Mordijck — CO4.04 : Correlation Between Density Pump-out and Free Streaming Particle Transport in Low Collisionality Resonant Magnetic Perturbation H-modes
  - T. Osborne — CO4.13 : Scaling of H-mode Pedestal and ELM Characteristics With Gyroradius
  - A. Garofalo — CO4.15 : QH-Mode Plasmas with Rotation Driven by Static Non-axisymmetric Fields
- **Develop the physics basis for steady-state operation in ITER and beyond**
  - C. Holcomb — CO4.05 : Dependence of Bootstrap Current, Stability, and Transport on the Safety Factor Profile in DIII-D Steady-state Scenario Discharges
  - M. Lanctot — CO4.06 : Global Structure of a Stable, Driven Kink Mode: DIII-D Measurements and Model Validation
  - V. Izzo — CO4.10 : Studies of Runaway Electron Confinement in MHD Disruption Simulations
  - J. Leuer — CO4.11 : Solenoid-free Startup of DIII-D
  - C. Challis — CO4.12 : Identity Experiments in the Hybrid Regime on DIII-D and JET
- **Advance the fundamental understanding of fusion plasmas along a broad front**
  - R. Pinsker — CO4.07 : Synergy in Two-Frequency FW Cyclotron Harmonic Absorption in DIII-D
  - J. Hillesheim — CO4.08 : Measurements of Spatial Structure of Geodesic Acoustic Modes in DIII-D
  - M. Austin — CO4.09 : Heat Transport in Off-axis EC-Heated Discharges in DIII-D
  - Z. Yan — CO4.14 : Pedestal Density Fluctuations During Quiescent and ELMing H-mode Plasmas

DIII-D Review and Invited Talks (Posters in Sessions Following Talks) and Contributed Orals At This Meeting

NO4 Oral Session on International Tokamak Research and ITER			
Weds	11:18	Rudakov	SOL Width Studies for ITER Ramp-up
Weds	11:30	Prater	Confinement and Pedestal Characteristics in H-mode With ECH Heating
Weds	11:54	Schaffer	ITER Test Blanket Module (TBM) Error Field Experiments in DIII-D
UO4 Oral Session on Research in Support of ITER			
Thurs	2:36	Commaux	Disruption Mitigation Experiments Carried Out on DIII-D
Thurs	3:36	Politzer	Simulation of the ITER Rampdown Scenario on DIII-D
Thurs	4:48	Doyle	Progress in Developing ITER Operational Scenarios on DIII-D
Review and Invited Talks			
Mon	8:00	Luce	Review: Realizing Steady State Tokamak Operation for Fusion Energy
Mon	3:30	Candy	Predictive Gyrokinetic Transport Simulations and Application of Synthetic Diagnostics
Tues	9:30	Turnbull	A New View of Internal Kink Modes and Their Relation to the Sawtooth Instability
Tues	10:30	LaHaye	Islands in the Stream: The Effect of Plasma Flow on Tearing Stability
Tues	3:00	White	Marshall N. Rosenbluth Outstanding Doctoral Thesis Award: Simultaneous Measurement of Electron Temperature and Density Fluctuations in the Core of DIII-D Plasma
Tues	4:00	Deboo	Probing Plasma Turbulence by Modulating the Electron Temperature Gradient
Weds	10:00	Solomon	Generation and Sustainment of Rotation in Tokamaks
Weds	4:00	McLean	Quantification of Chemical Erosion in the DIII-D Divertor
Thurs	9:30	Choi	Iterated Finite Orbit MC Simulation with Full Wave Fields for Tokamak ICRF Wave Heating Experiments
Thurs	11:00	Jackson	Understanding and Predicting the Dynamics of Tokamak Discharges during Startup and Rampdown
Fri	10:00	Bass	Gyrokinetic Simulations of Enhanced Alpha Transport by De-stabilized Alfven Turbulence
Fri	10:30	Zhang	Energetic Particle Transport by Microturbulence
Fri	11:00	Hollmann	Experiments in DIII-D Toward Achieving Rapid Shutdown with Runaway Electron Suppression
DIII-D Posters Tuesday Afternoon and Thursday Morning			