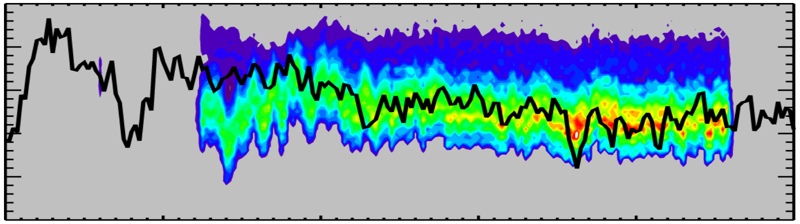
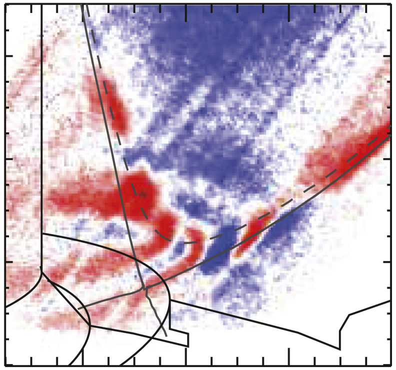
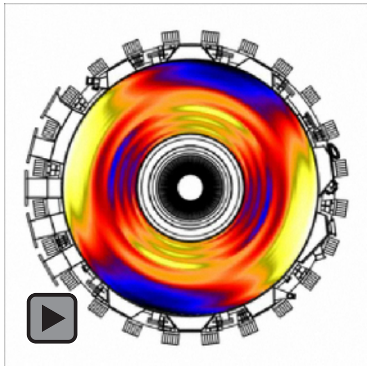
Overview of Recent DIII-D Experimental Results

by
P. Gohil
for the DIII-D Team





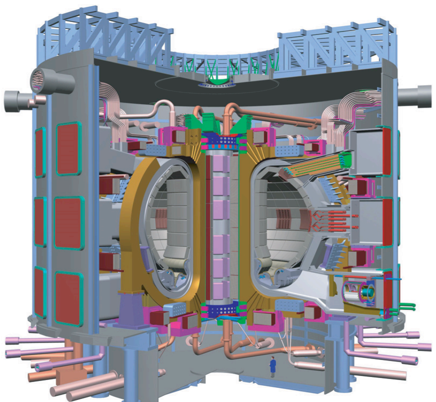


Presented at the
54th Annual APS Meeting
Division of Plasma Physics
Providence, Rhode Island

October 29 — November 2, 2012

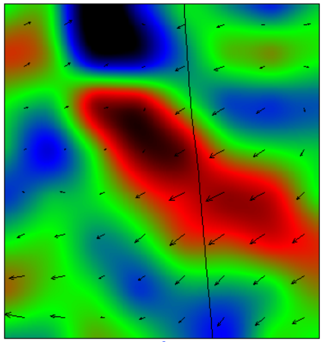
DIII-D Research is Advancing the Physics Basis for Fusion Energy Production

ITER Research

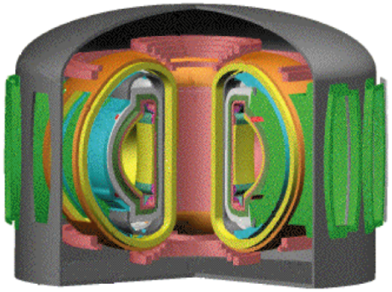


ITER

Increased Scientific Understanding

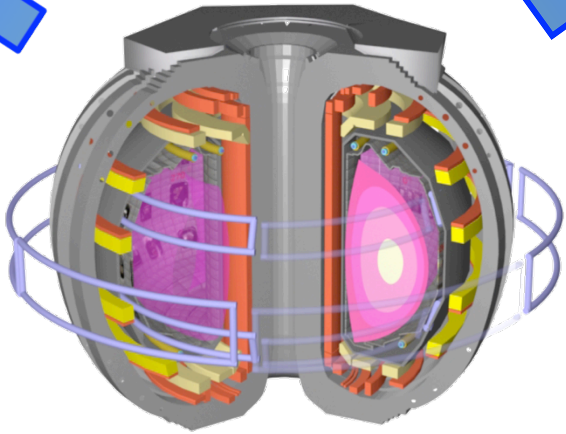


Advanced Steady-State



DEMO

DIII-D



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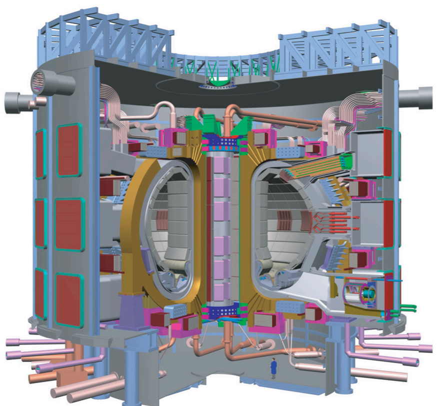

ITER

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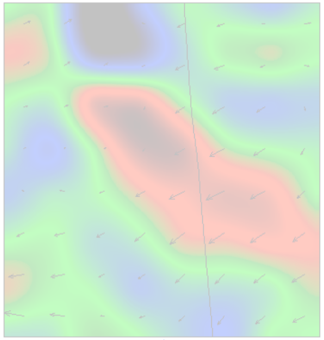

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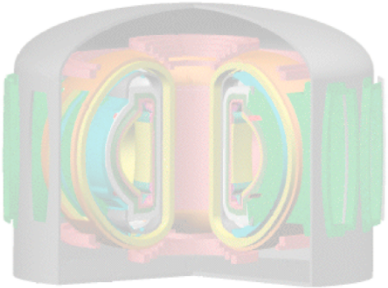
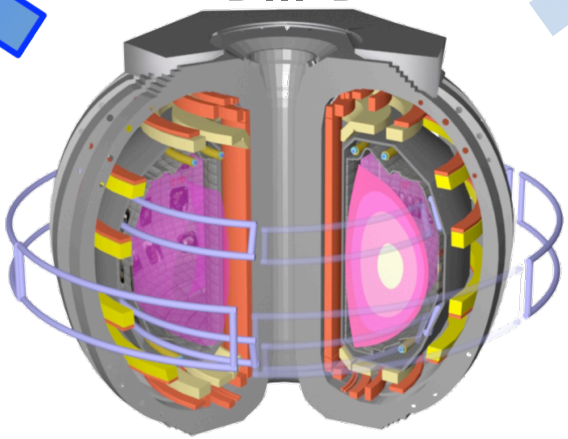
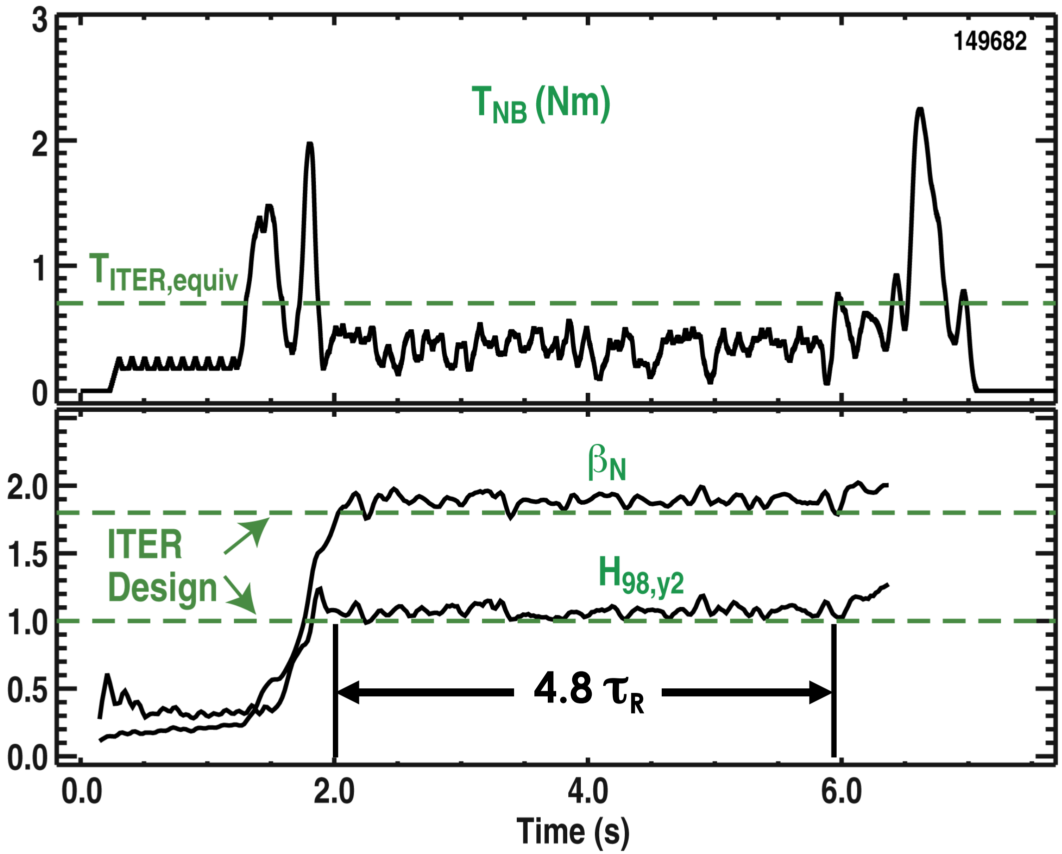


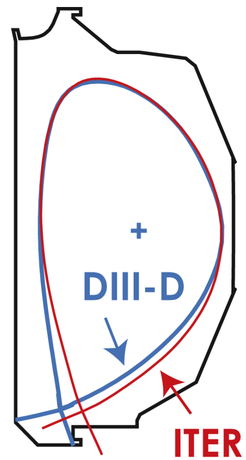
DEMO

DIII-D



Stationary Low-Torque ITER Baseline Discharges Are Maintained for Multiple Current Relaxation Times



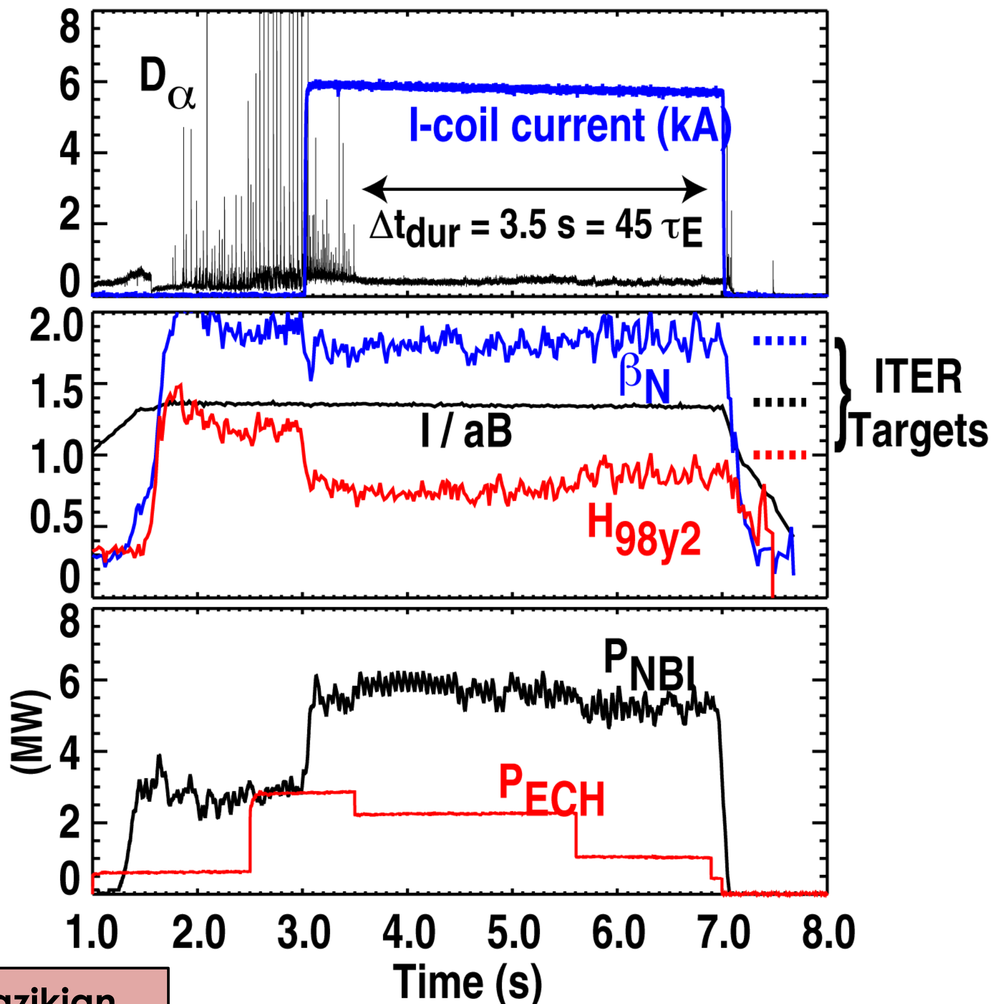


- **ELMing H-mode**
  - Matches I/aB
- **Pulses reach stationary conditions**
- **NBI torque below ITER target value during stationary conditions**

Jackson ITER Oral Thurs. PM

Sustained RMP ELM Suppression Extended to ITER Baseline Scenario

- n=3 perturbation with internal coils
- Suppression at low collisionality using n=2 configuration
- ELM suppression also shown in helium plasmas



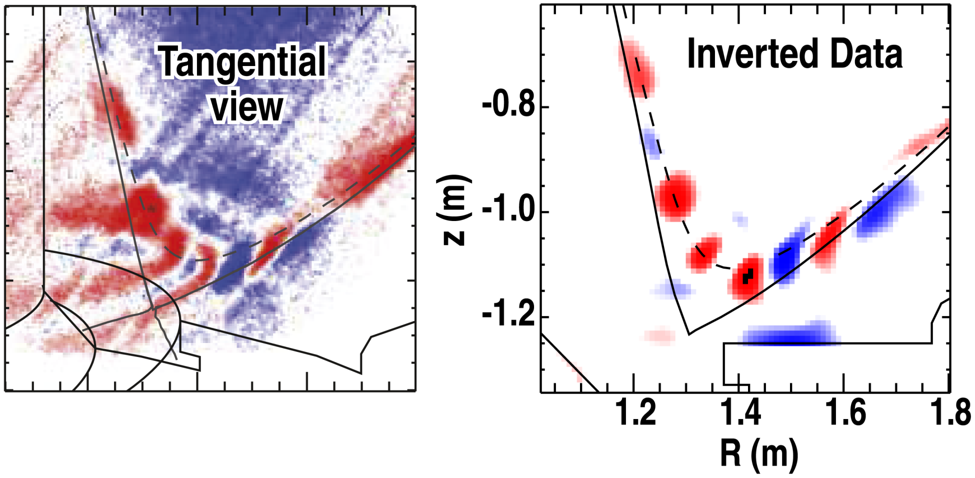
Nazikian this Session

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

Modulated Phase RMP Experiments Point to Island at Top of Pedestal Inhibiting Pedestal Growth and ELMs

- **RMP phase flips reveal MHD structure**
  - Helical displacements seen in X-point SXR (difference imaging)

Experiment: SXR data



Nazikian, Shafer, Ferraro this Session

Modulated Phase RMP Experiments Point to Island at Top of Pedestal Inhibiting Pedestal Growth and ELMs

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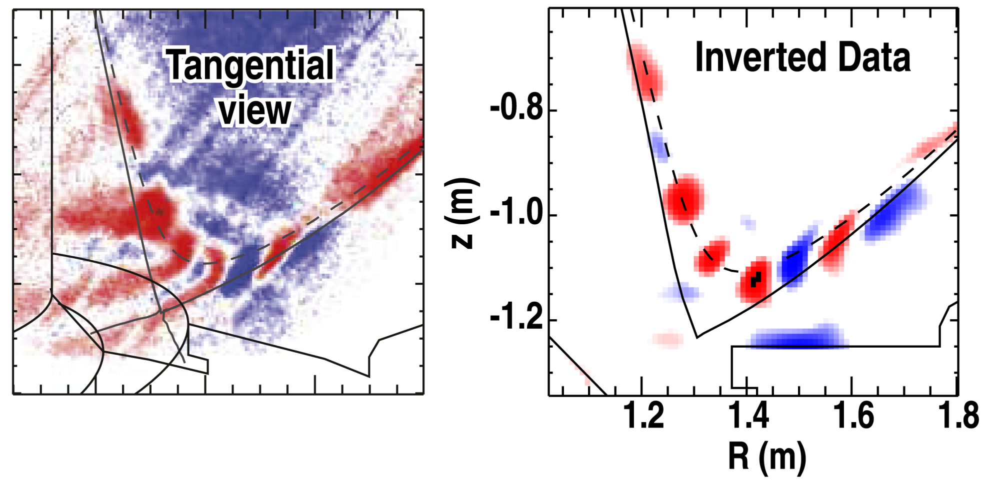
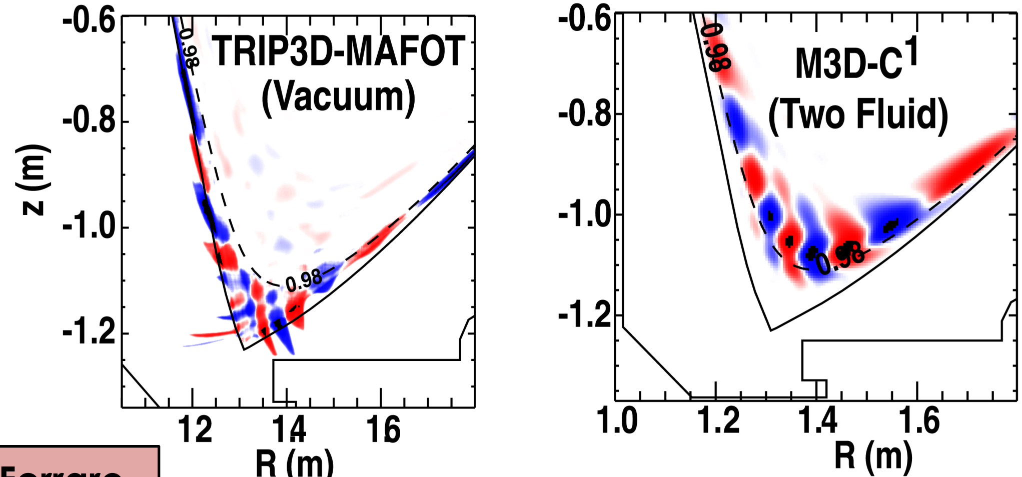


Simulation: SXR Data



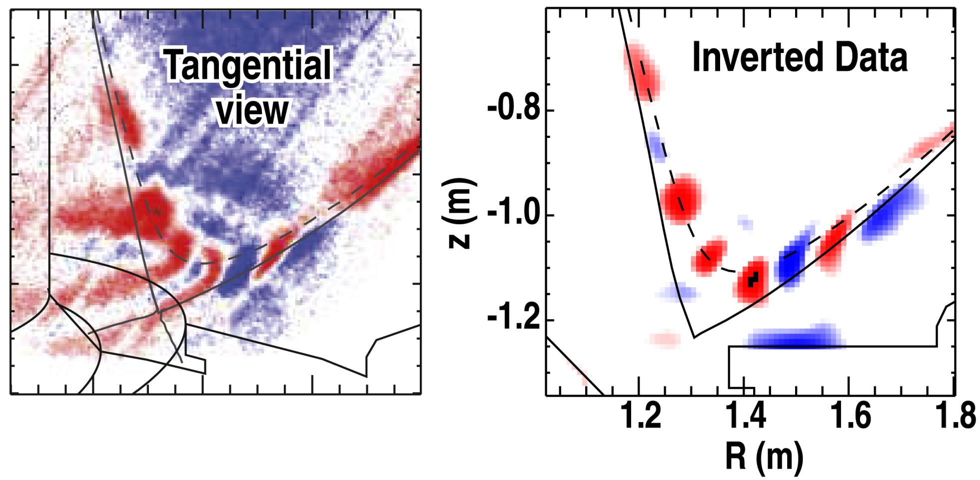
Nazikian, Shafer, Ferraro this Session

Modulated Phase RMP Experiments Point to Island at Top of Pedestal Inhibiting Pedestal Growth and ELMs

- **RMP phase flips reveal MHD structure**
  - Helical displacements seen in X-point SXR (difference imaging)
  - Compared with vacuum field and two-fluid MHD simulation

- **Mechanism: RMP limits width of pedestal**
  - RMP field resonant near top of pedestal
  - Island growth where $\omega_{e,\perp}$~0
  - Island limits inward expansion of high-gradient pedestal

Experiment: SXR data



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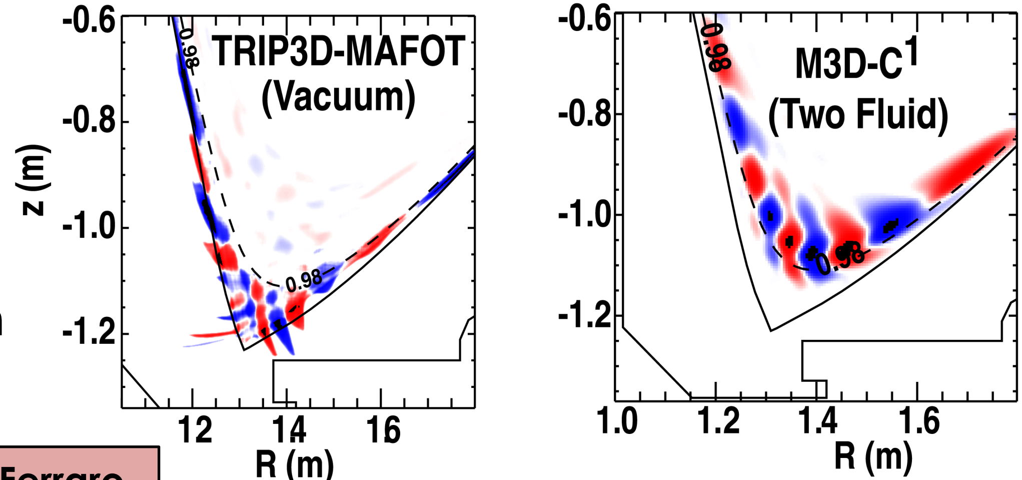
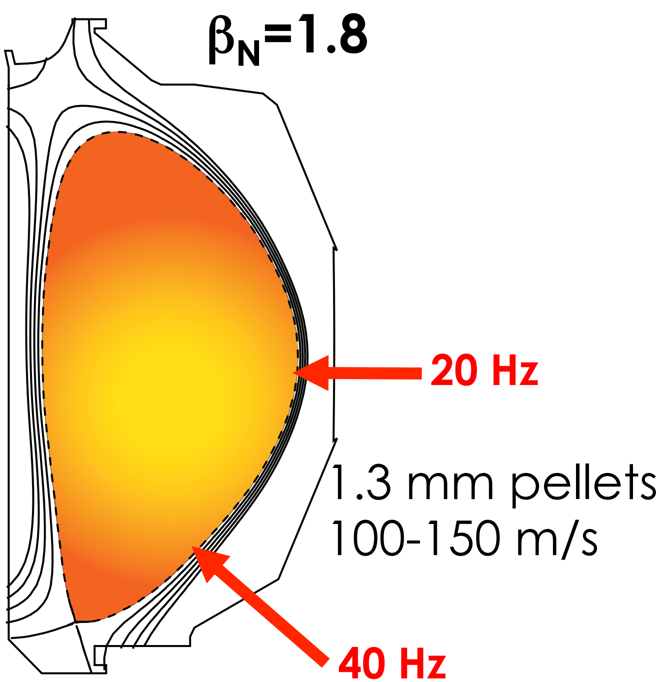
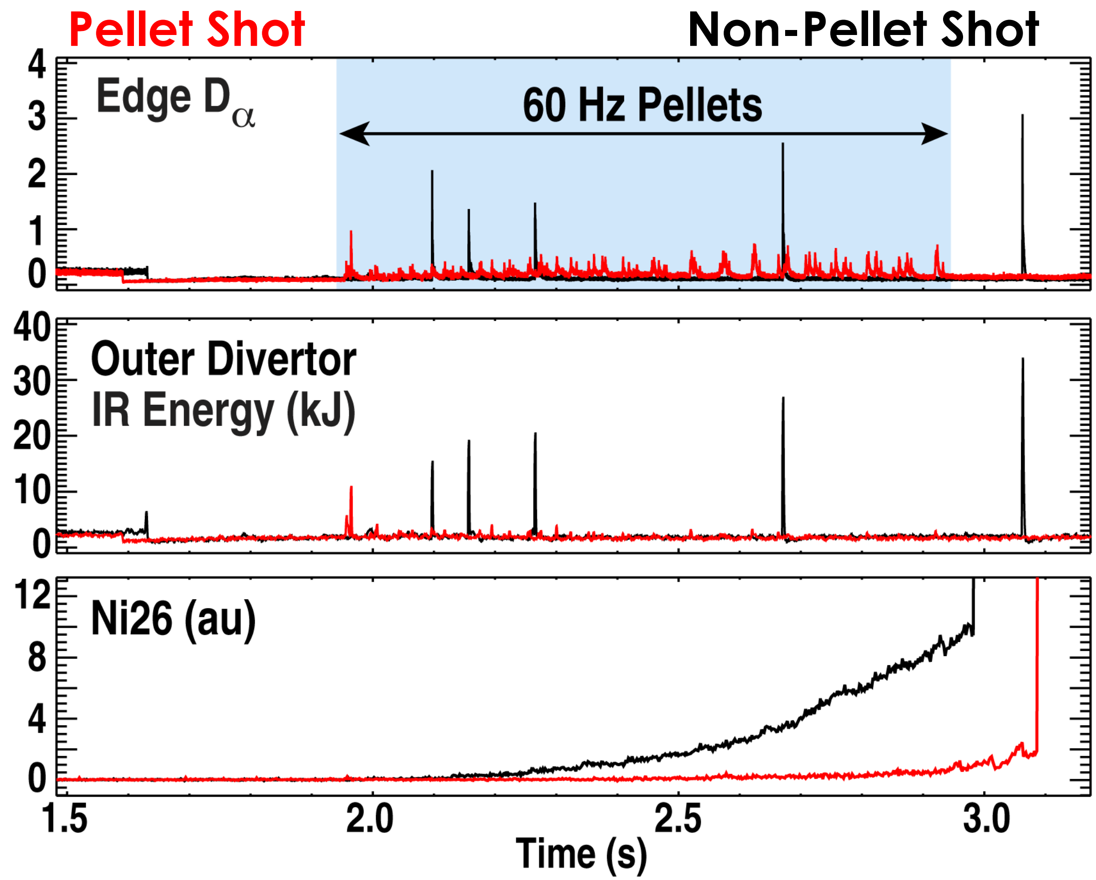


Nazikian, Shafer, Ferraro this Session

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

Pellet Pacing in ITER Baseline Scenario Yields 12x Higher ELM Frequency

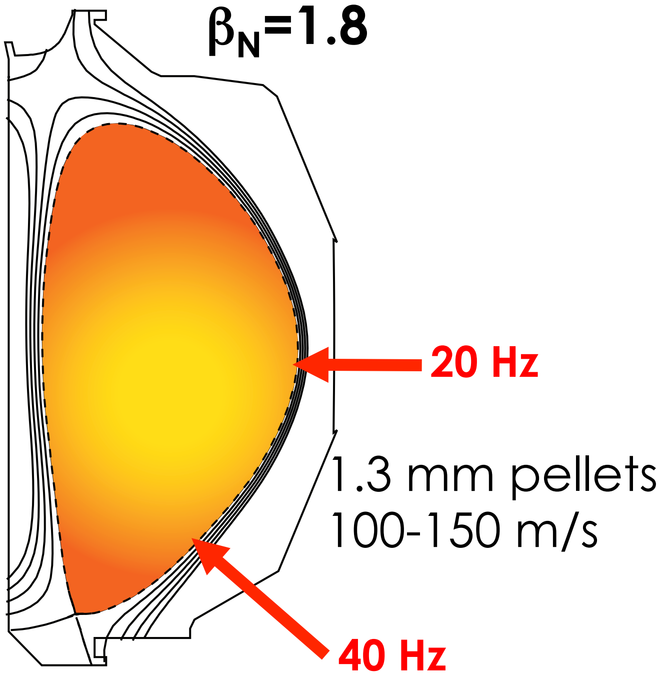


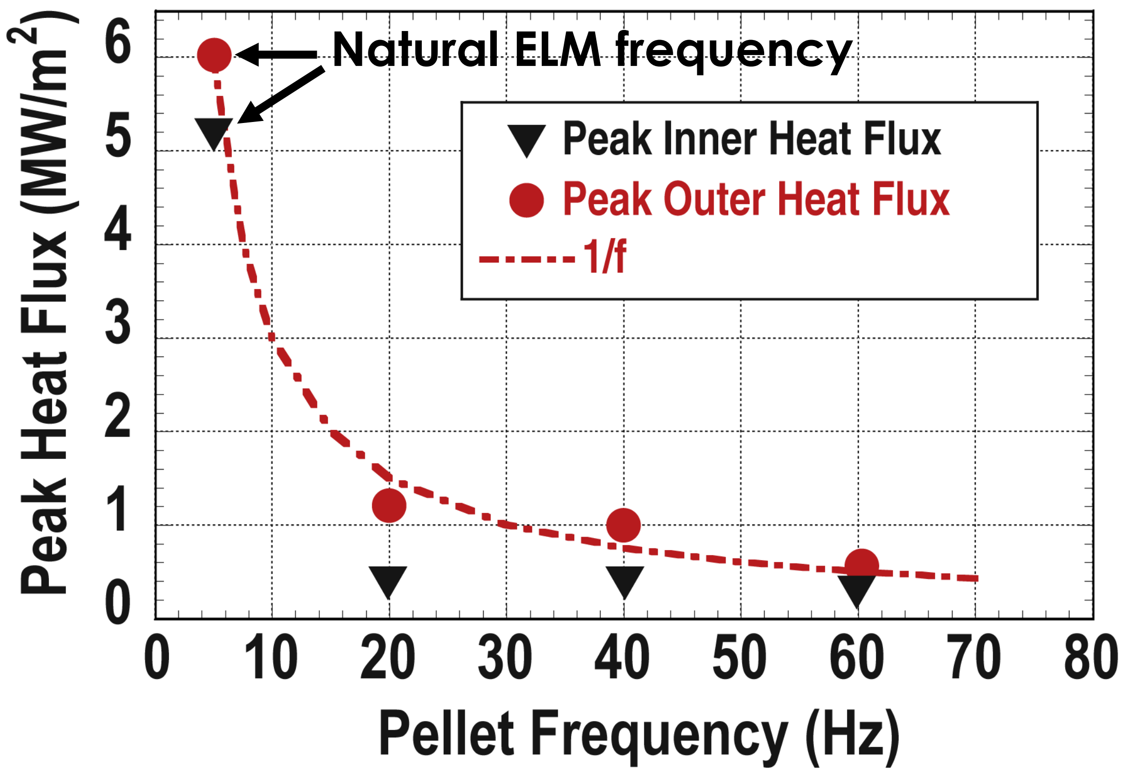


- Reduced ELM energy loss
- Minimal change in confinement
- No fueling increase
- Effective impurity screening

Baylor
Thurs. 9:30 AM

Pellet Pacing in ITER Baseline Scenario Yields 12x Lower ELM Divertor Heat Pulse



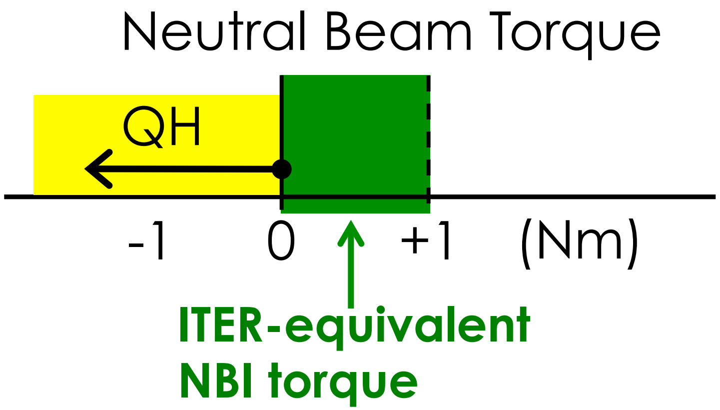


- **Reduced ELM energy loss**
- **Minimal change in confinement**
- **No fueling increase**
- **Effective impurity screening**

$$f_{pellet} \times q_{div} = const$$

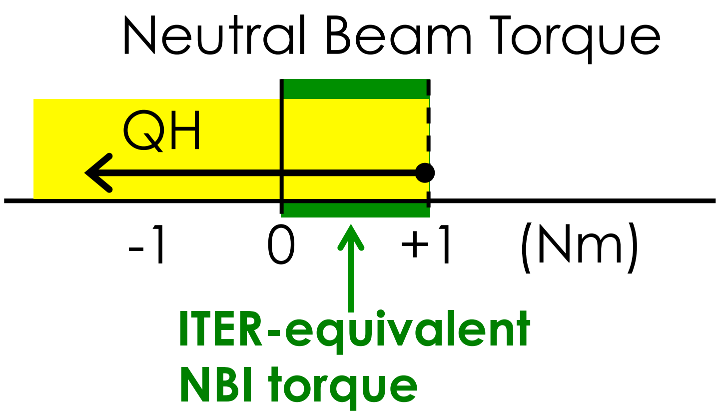
Baylor
Thurs. 9:30 AM

Operating Range for ELM-free QH-mode Extended to ITER Relevant Torque Using External 3D Coils



Burrell, This Session

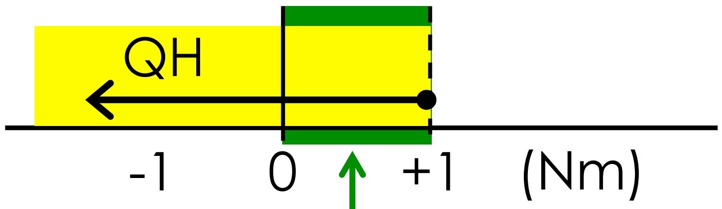
Operating Range for ELM-free QH-mode Extended to ITER Relevant Torque Using External 3D Coils



- **Achieved using external n=3 coils to drive edge rotation shear**

Burrell, This Session

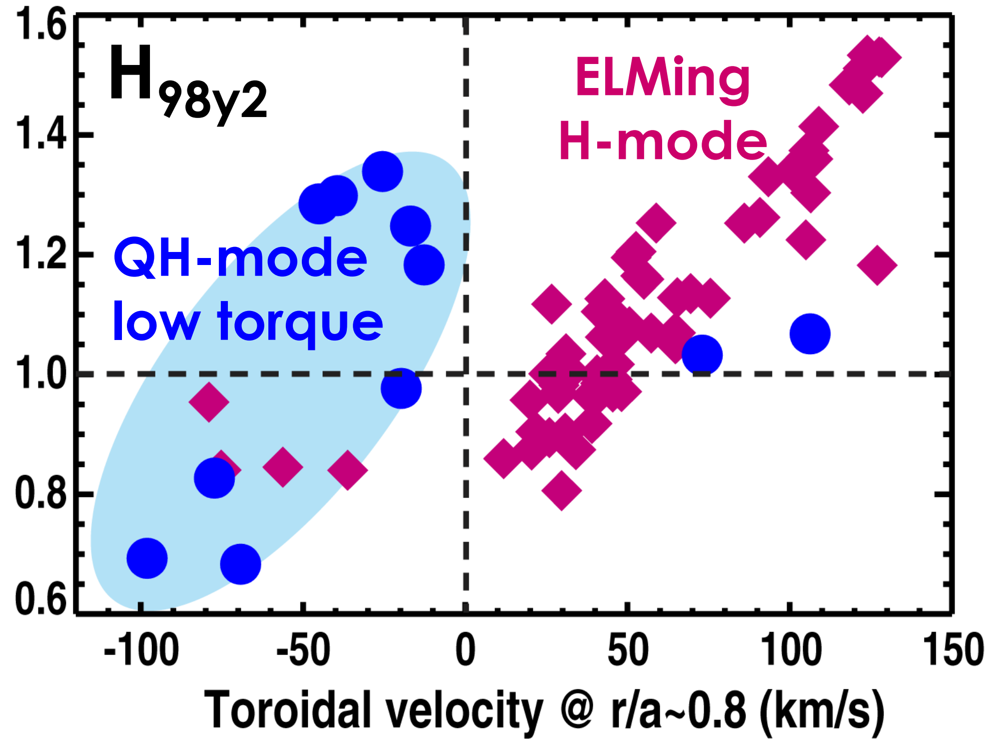
Operating Range for ELM-free QH-mode Extended to ITER Relevant Torque Using External 3D Coils



- **Achieved using external n=3 coils to drive edge rotation shear**

QH-mode is an attractive candidate ELM-free scenario for ITER

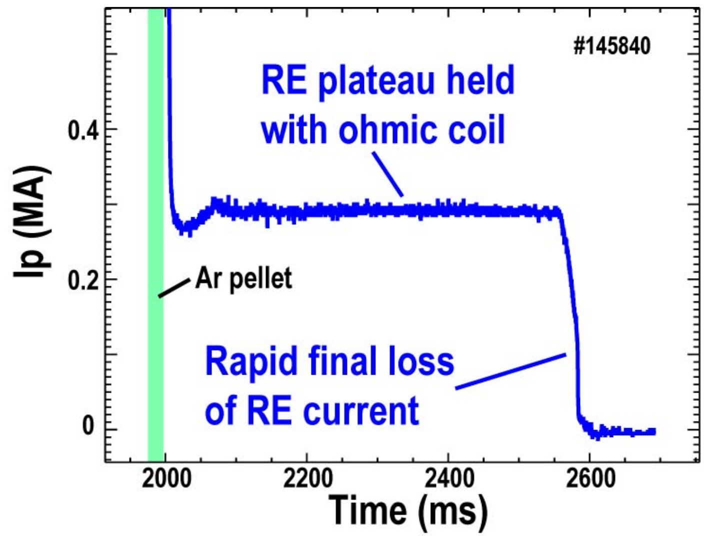
Excellent energy confinement quality at low rotation: H_{98y2}=1.3

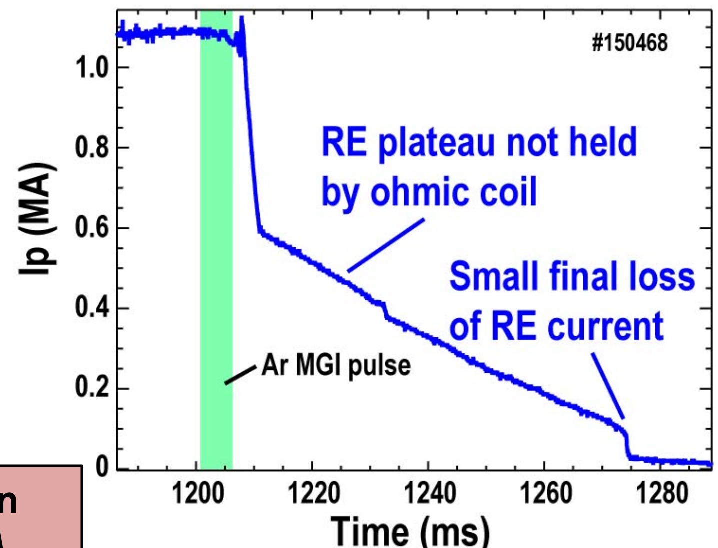


Burrell, This Session

Disruption Runaway Electrons Current can be Dissipated with Sufficient High-Z Impurities

- Large runaway electron beams can be formed with sudden Ar injection
- Low Ar content gives weakly dissipating beam which can be held with ohmic coil
- High Ar content gives rapidly dissipating beam which cannot be held by ohmic coil
- Possible path for ITER to dissipate disruption RE current - with massive Ar injection into RE plateau?

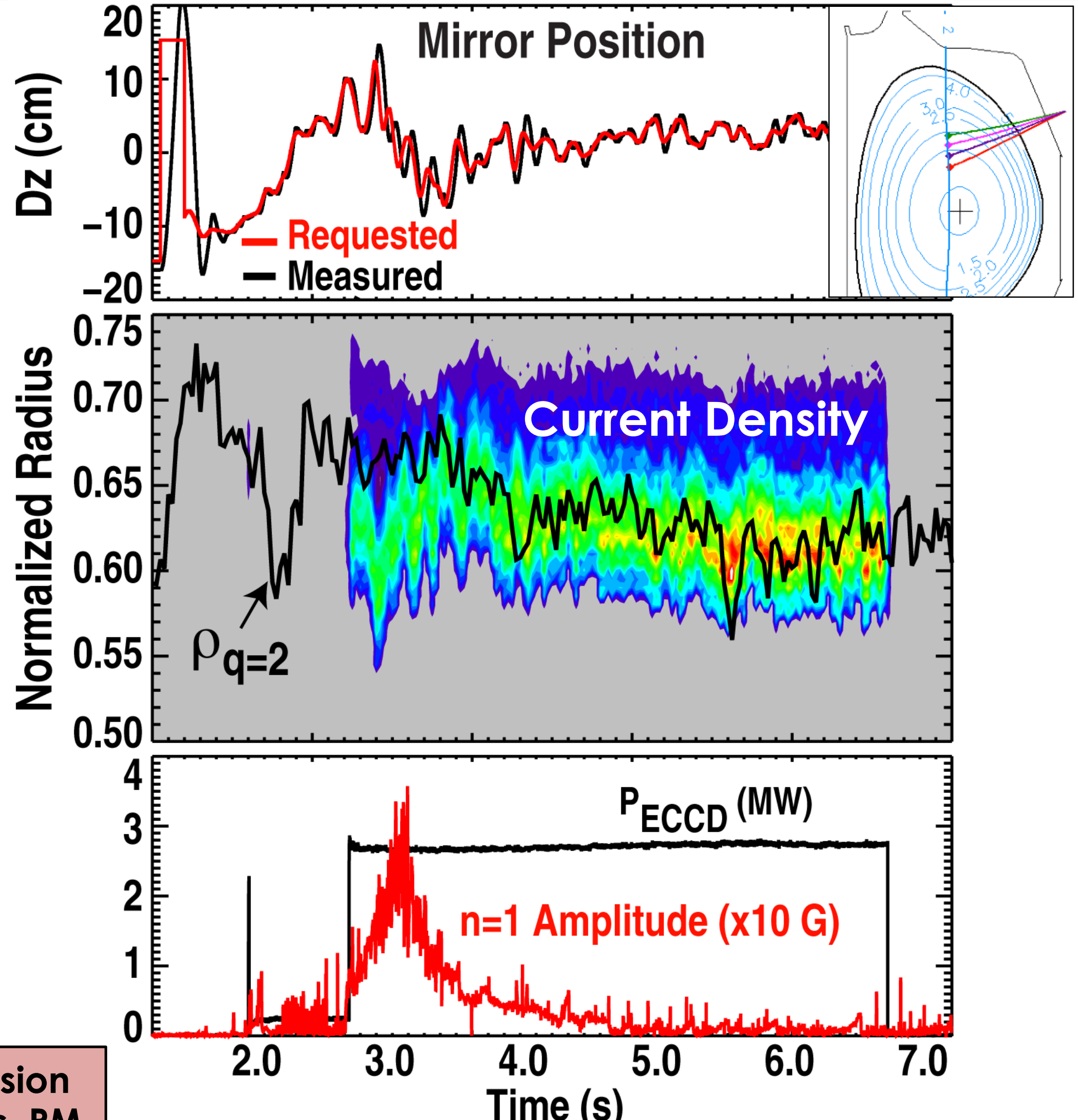




Commaux, This Session
Wesley, ITER Thurs. PM

Successful Integration of Key Elements of Tearing Mode Control for ITER

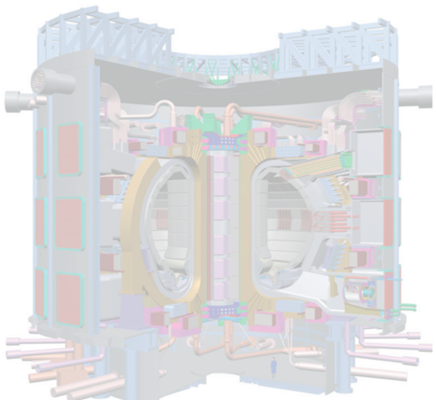
- ***Real-time*** **control of EC power and mirror steering to q=2 surface**
- **PCS detects growing 2/1 tearing mode and turns on ECCD**
- ***Real-time*** **control provides complete stabilization of m/n=2/1 tearing mode**



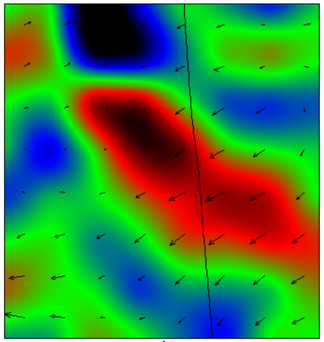
Welander, This Session
Kolemen, ITER Thurs. PM

DIII-D Research is Advancing the Physics Basis for Fusion Energy Production

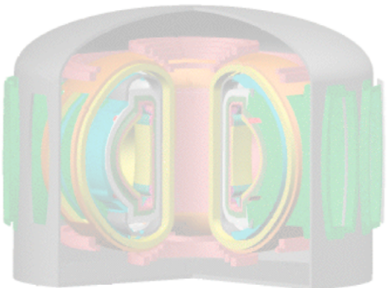
ITER Research



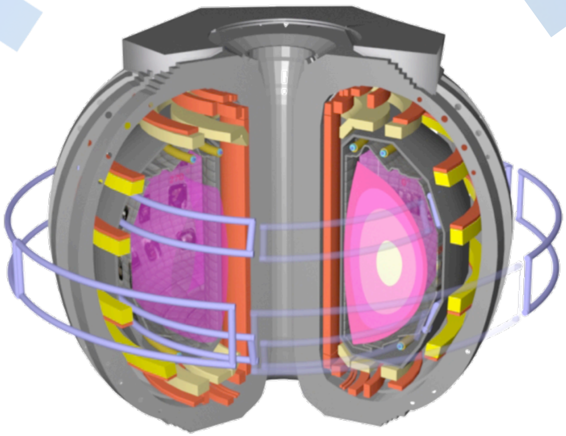
Increased Scientific Understanding



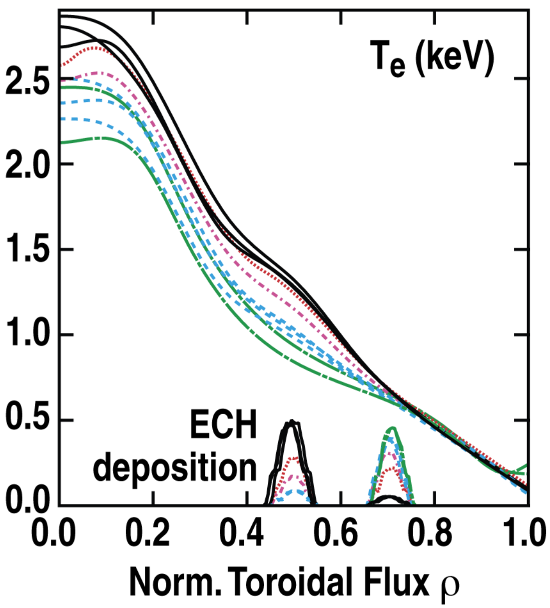
Advanced Steady-State

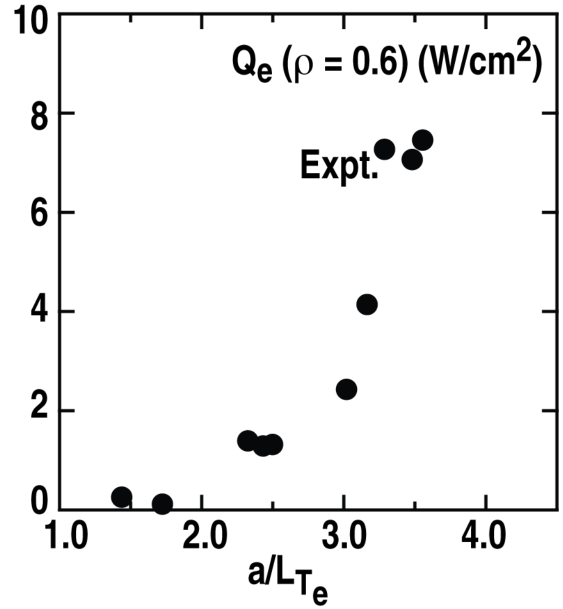


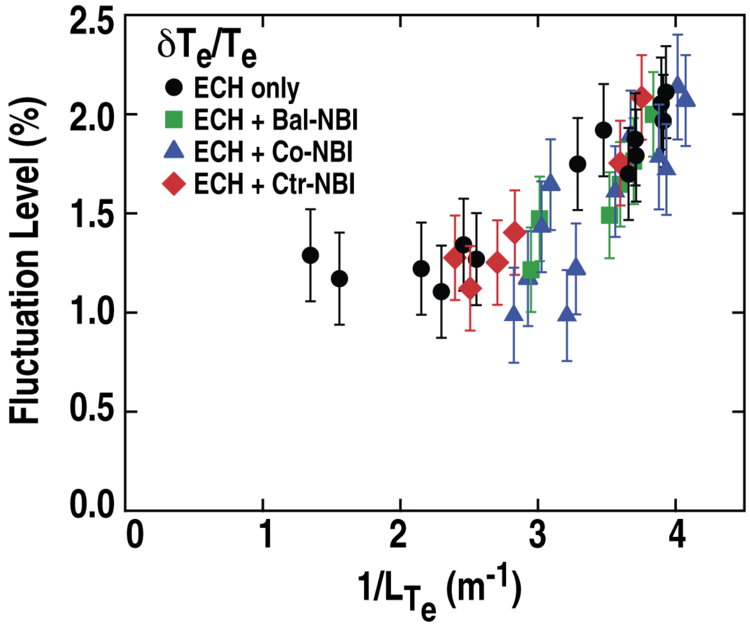
DIII-D



Critical-Gradient Transport Experiments Test Profile Stiffness Predictions



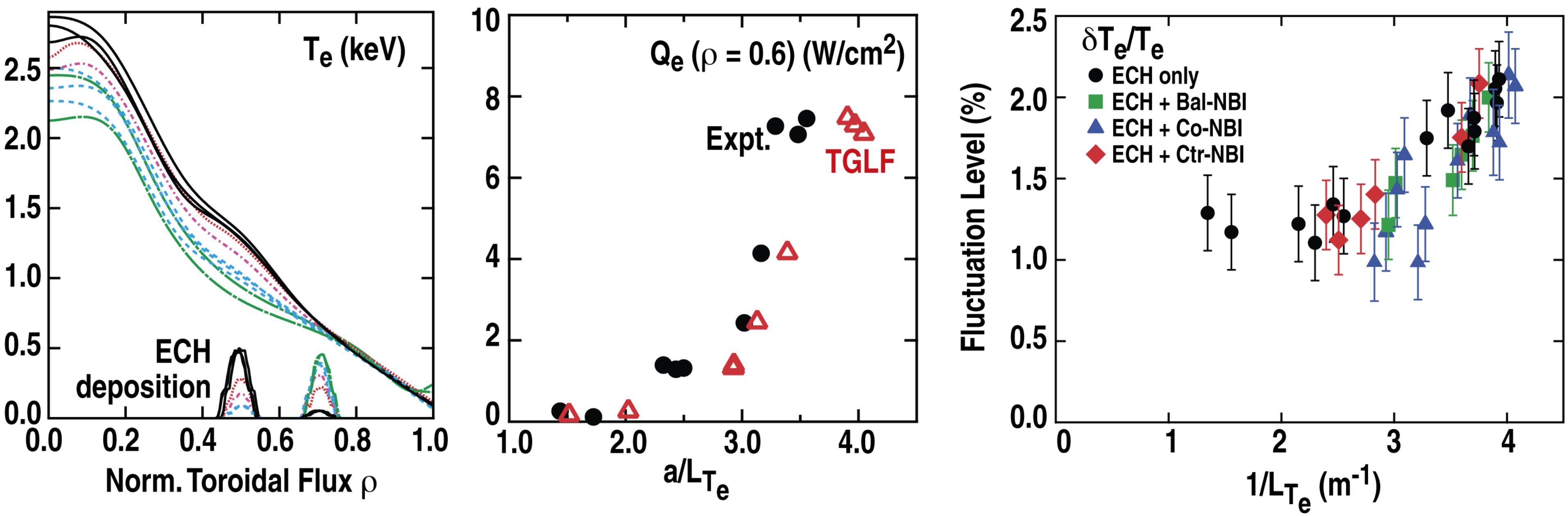




- **Vary ECH location to change L-mode ∇T_e with T_e ~ constant**
- **Transport exhibits critical gradient threshold**
- **Sharp rise in measured T_e fluctuations is consistent with TEM dominant turbulence**

Hillesheim, Mon. 4:00 PM
Petty, This Session
S.P. Smith, Thurs. AM Poster

Critical-Gradient Transport Experiments Test Profile Stiffness Predictions



- Vary ECH location to change L-mode ∇T_e with T_e ~ constant
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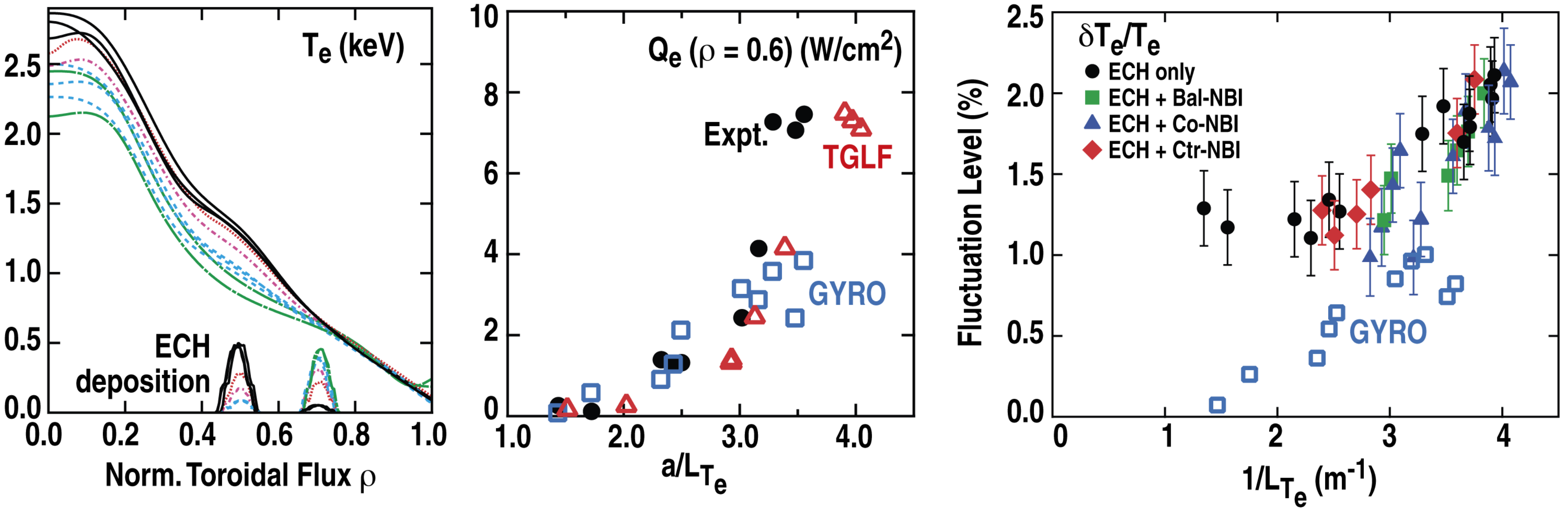
Hillesheim, Mon. 4:00 PM
Petty, This Session
S.P. Smith, Thurs. AM Poster

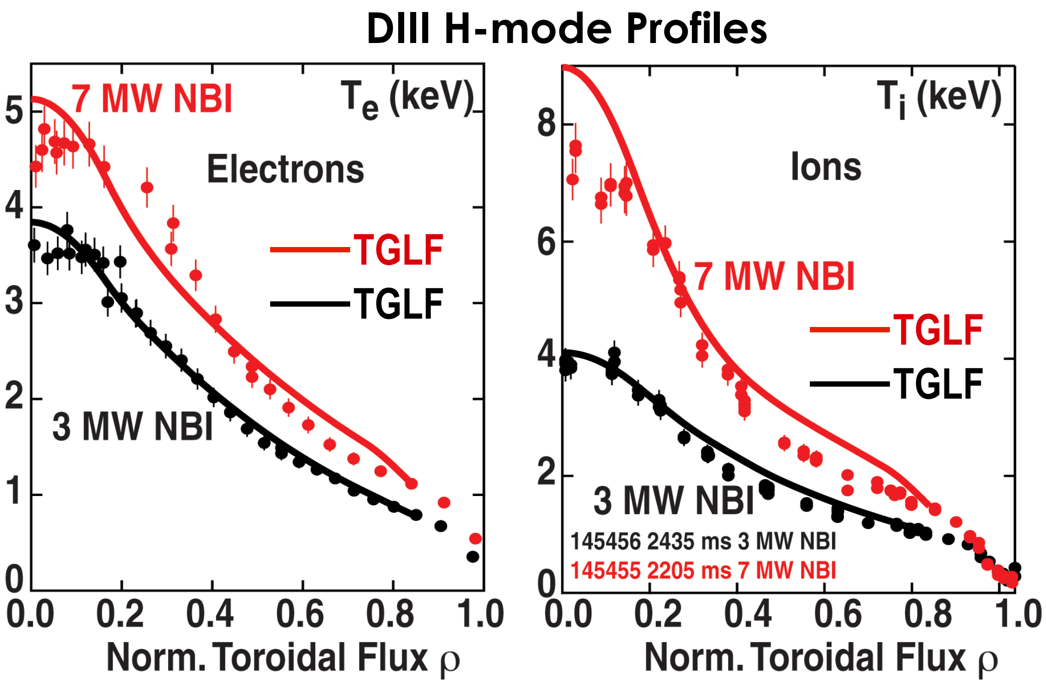
Critical-Gradient Transport Experiments Test Profile Stiffness Predictions

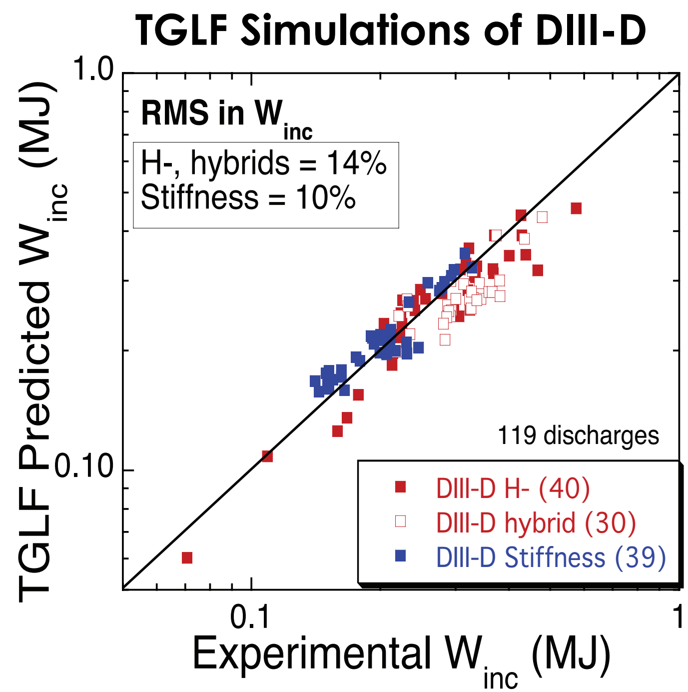


- Vary ECH location to change L-mode ∇T_e with T_e ~ constant
- Transport exhibits critical gradient threshold; agrees with simulation
- Sharp rise in measured T_e fluctuations is consistent with TEM dominant turbulence; effort underway to understand mismatch with gyrokinetic simulations

Hillesheim, Mon. 4:00 PM
Petty, This Session
S.P. Smith, Thurs. AM Poster

Core Transport H-mode Stiffness Experiments Support TGLF Predictions for ITER



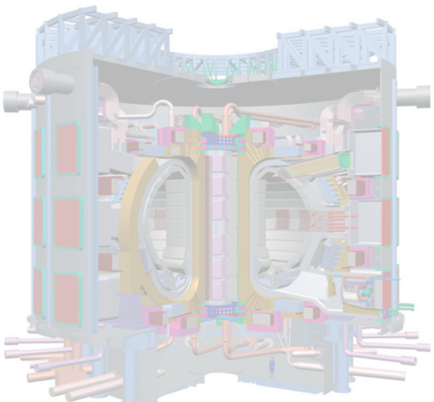


- **Stiffness refers to sharp increase in transport above a critical ∇T**
- **H-mode heat flux scan shows electrons are more stiff than ions**
- **TGLF agrees with results of dedicated H-mode stiffness experiment as it does with the broader H-mode database**

Marinoni, This Session

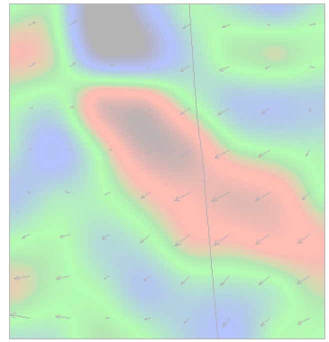
DIII-D Research is Advancing the Physics Basis for Fusion Energy Production

ITER Research

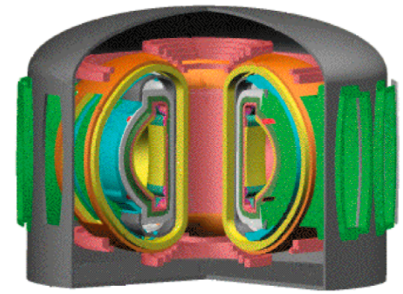


ITER

Increased Scientific Understanding

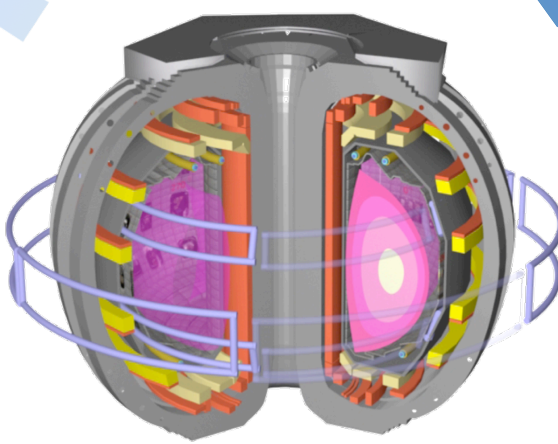


Advanced Steady-State

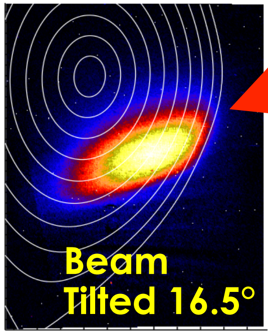


DEMO

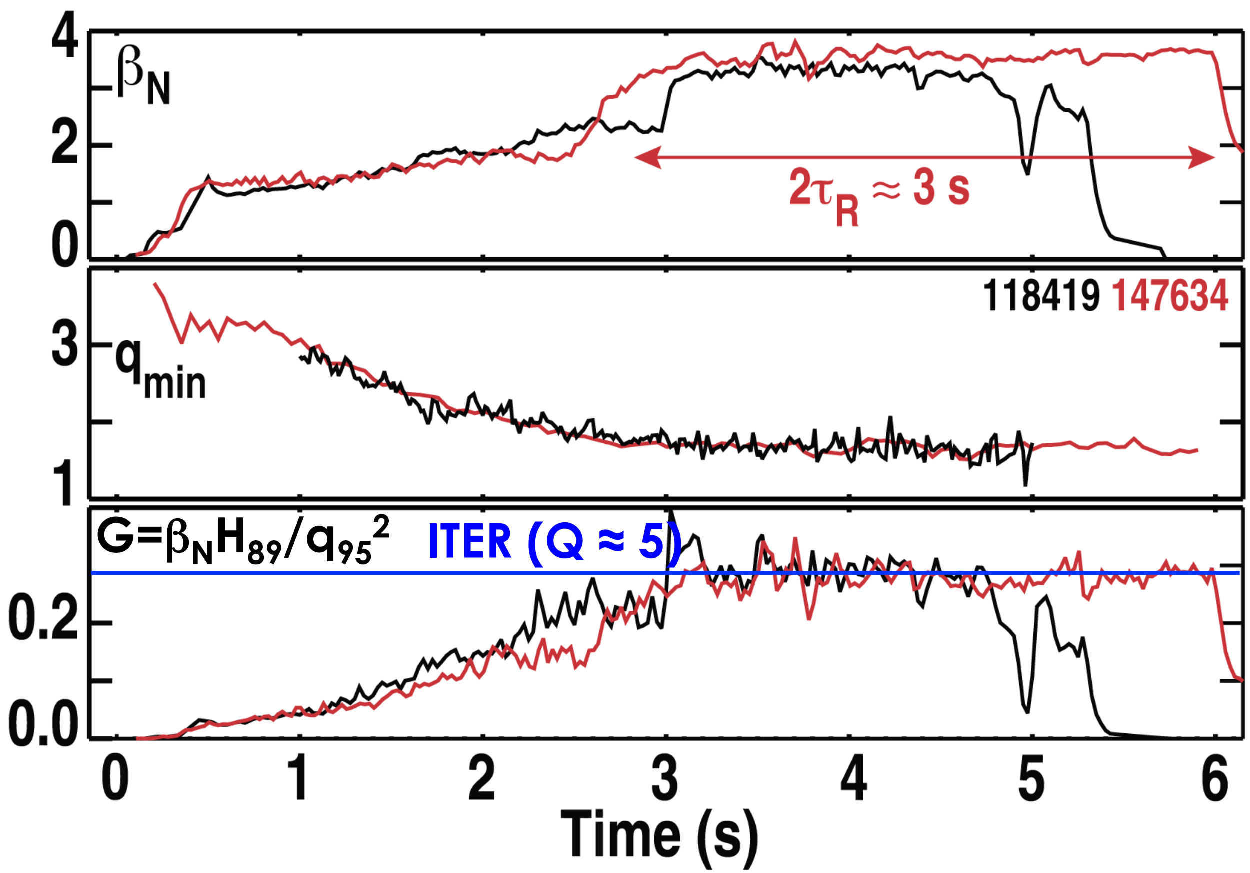
DIII-D



Off-Axis NBI Enables Advanced Performance with Relaxed q_{min}~1.5 Needed for ITER/FNSF



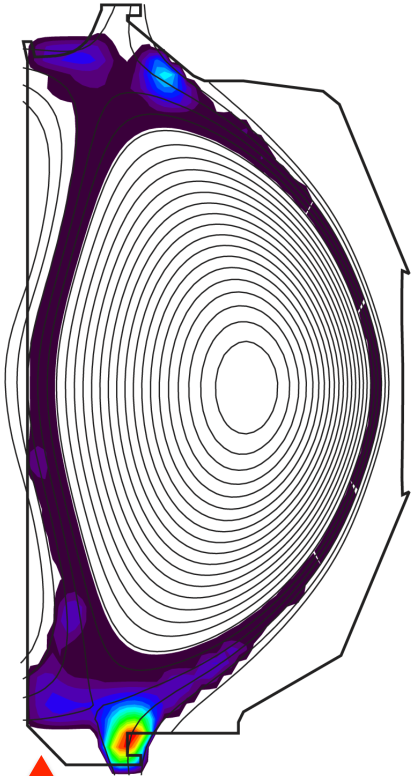
- Off-axis beam sustains stable stationary operation
- f_{NI} = 70%
- Modeling shows potential to raise β_N and f_{NI} further



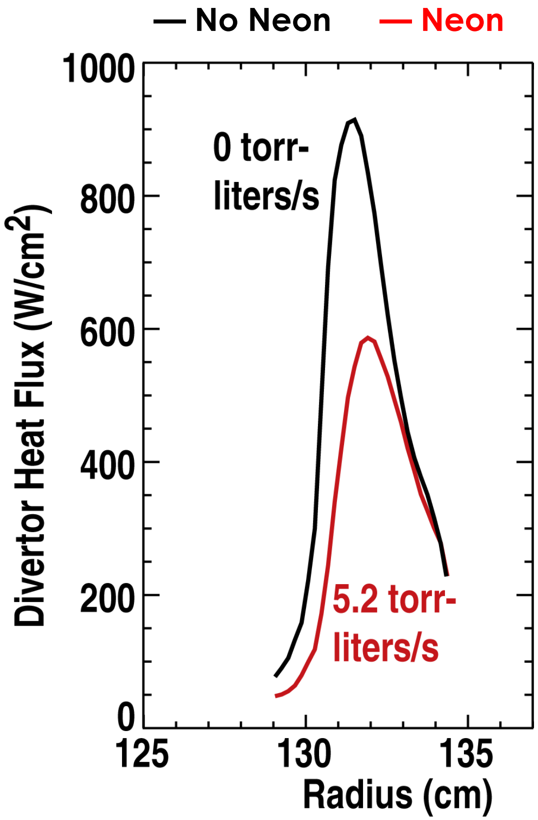
J.M. Park, This Session
Holcomb, Thurs. AM Poster
Ferron, Thurs. 3:30 PM

q_{min}≈1.5 Scenario Appears Compatible with Radiating Mantle for Divertor Heat Flux Reduction

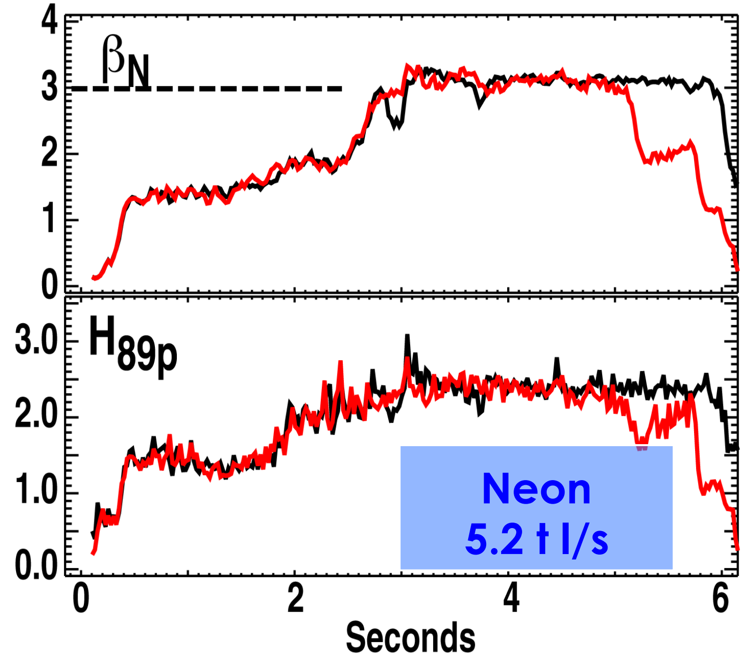
2D Radiation Plot



Neon injection



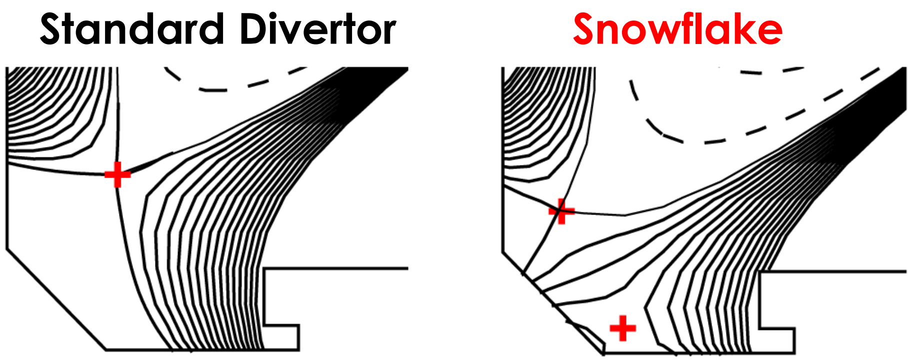
Peak divertor heat flux reduced ~35%



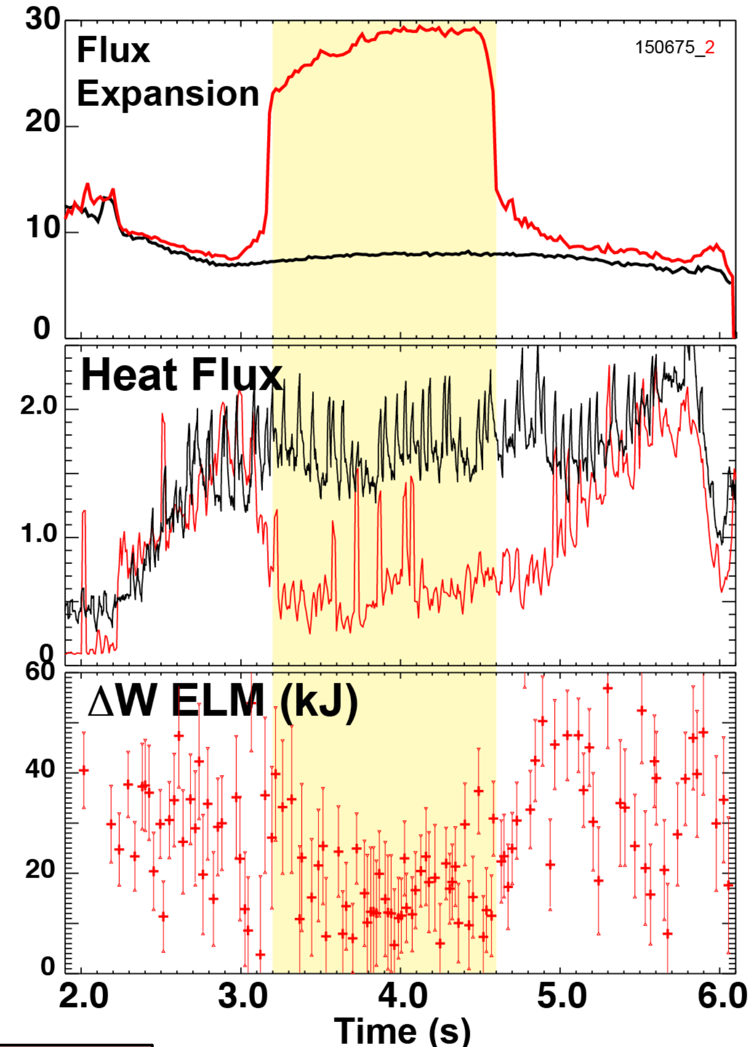
P_{RAD} doubles without significant performance degradation

Petrie, Thurs. AM Poster

Snowflake Divertor Configuration Reduces ELM and Steady-State Heat Flux

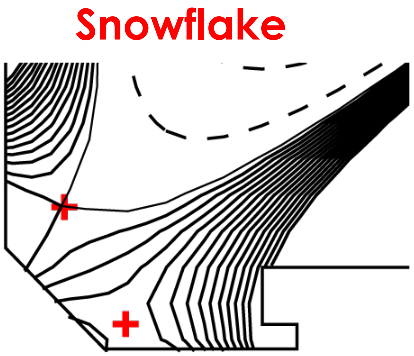


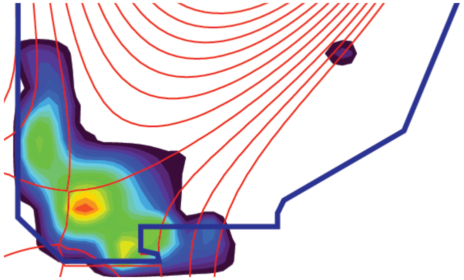
- SF configuration reduces heat flux 2-3X by flux expansion
- ΔW(ELM) reduced
- Core confinement ($H_{98y2} > 1$) and pedestal constant



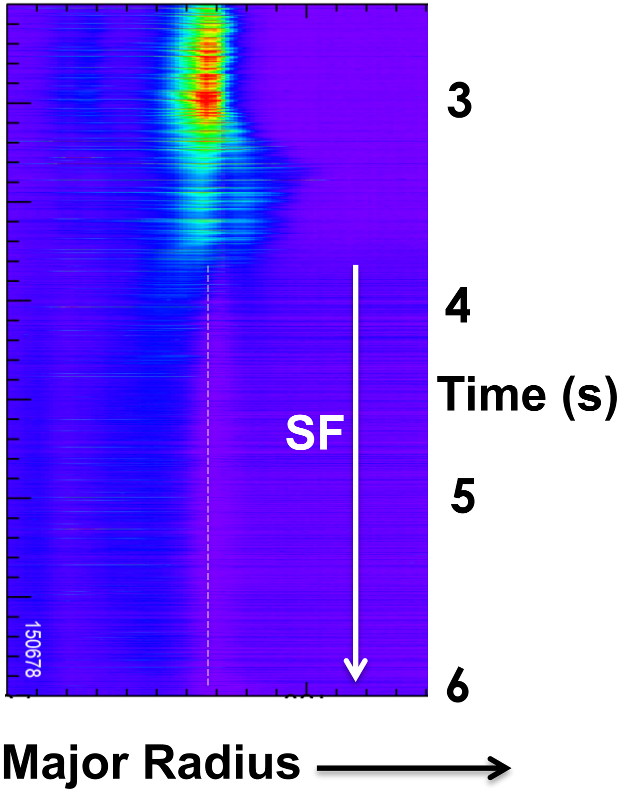
Soukhanovskii, NSTX Poster Wed. PM

Snowflake Divertor Configuration Reduces ELM and Steady-State Heat Flux





- SF configuration reduces heat flux 2-3X by flux expansion
- ΔW(ELM) reduced
- Core confinement ($H_{98y2} > 1$) and pedestal constant
- ELM heat flux reduced dramatically with gas puffing



Soukhanovskii, NSTX Poster
Wed. PM

Talks in this Session Present DIII-D Research Supporting ITER, Steady-State High Performance and Fusion Plasmas

- **Providing solutions to key ITER issues**
  - R. Nazikian NO4.02: Latest Results On Resonant Magnetic (RMP) Induced ELM Suppression On DIII-D
  - M. Shafer NO4.03: Edge Soft X-Ray Imaging Measurements
  - N. Ferraro NO4.04: Modeling Edge Plasma Response to 3D Fields in DIII-D
  - T. Osborne NO4.05: Time Evolution of the H-Mode Pedestal Characteristics in Type I ELM Discharges in DIII-D
  - M. Makowski NO4.06: Measurements and Modeling of the Divertor Heat Flux Width in DIII-D
  - A. Welander NO4.10 Control of Neoclassical Tearing Modes in DIII-D
  - X. Chan NO4.11 Neutral Beam-ion Prompt Loss Induced by Alfvén Eigenmodes in DIII-D
  - N. Commaux NO4.12 Particle Dissemination Study During Shattered Pellet Injection in DIII-D
  - K. Burrell NO4.15 ELM-free, Quiescent H-mode Operation in DIII-D Under Reactor-relevant Condition Using Non-Axisymmetric Magnetic Fields from Coils Outside the Toroidal Field Coil
- **Developing physics basis for steady-state operation**
  - J.M. Park NO4.13 Transport and Stability Characteristics of High q_{min} Steady-state Scenarios with Off-axis NBI
  - W. Solomon NO4.14 Impact of Torque and Rotation in High Fusion Performance Plasmas
- **Advancing fundamental understanding of fusion plasmas**
  - Z. Yan NO4.07 The Dynamics of Turbulence and Flow Diving
  - A. Marinoni NO4.08 Plasma Fluctuations Measurements in Ion Stiffness Experiments Using Phase Constant Imaging
  - C. Petty NO4.09 Electron Transport Stiffness and Heat Pulse Propagation on DIII-D

DIII-D Program Much More Extensive Than Can Be Described Here — See Invited and ITER Talks Plus Poster Sessions

DIII-D talks on several topics in ITER oral session on Thursday PM

Review, Invited and Tutorial				
Mon.	2:00	Candy	Theory, Verification and Validation of Finite-Beta Gyrokinetics	Tutorial
Mon.	3:30	Waltz	Search for the Missing L-mode Edge Transport and Possible Breakdown of Gyrokinetics	Invited
Mon.	4:00	Hillesheim	Observation of a Critical Gradient Threshold for Electron Temperature Fluctuations in the DIII-D Tokamak	Invited
Tue.	9:30	Stangeby	Reduction of Net Erosion of High-Z Divertor Surface by Local Redeposition in DIII-D	Invited
Tue.	4:00	Pace	Energetic Ion Transport and Neutral Beam Current Drive Reduction Due to Microturbulence in Tokamaks	Invited
Wed.	3:00	Izzo	Impurity Mixing, Radiation Asymmetry, and Runaway Electron Confinement in MGI Simulations of DIII-D and ITER	Invited
Thurs.	9:30	Baylor	Reduction of ELM Intensity on DIII-D by On-demand Triggering With High Frequency Pellet Injection and Implications for ITER	Invited
Thurs.	11:30	Turnbull	Comparisons of Linear and Nonlinear Plasma Response Models for Non-Axisymmetric Perturbations	Invited
Thurs.	12:00	Moyer	Plasma Rotation and Radial Electric Field Response to Resonant Magnetic Perturbations in DIII-D	Invited
Thurs.	3:30	Ferron	Progress Toward Fully Non-inductive Discharge Operation in DIII-D Using Off-axis Neutral Beam Injection	Invited
Fri.	8:00	McKee	Turbulence in Magnetically Confined Plasmas	Review

DIII-D Poster Sessions: Tuesday Morning and Thursday Morning