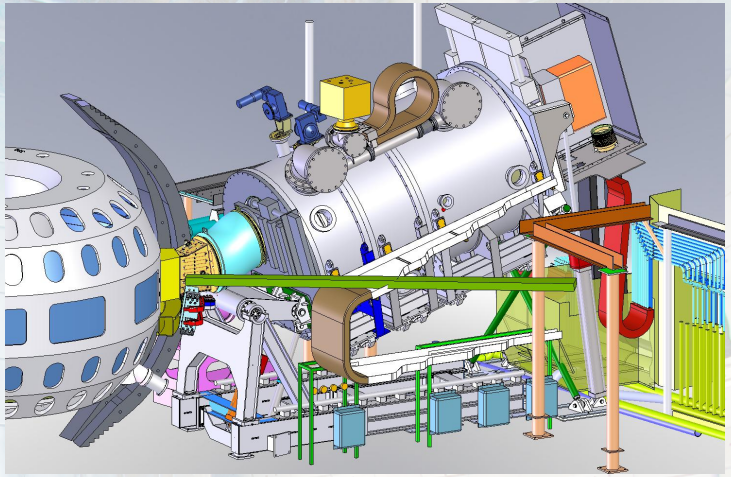
Overview of Recent DIII-D Experimental Results

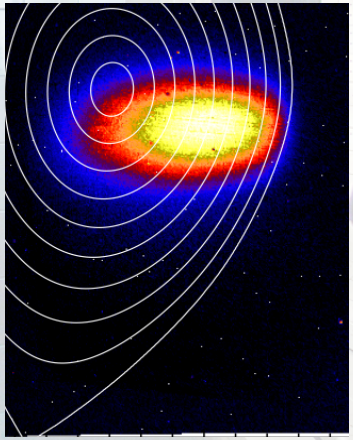
by
P. Gohil

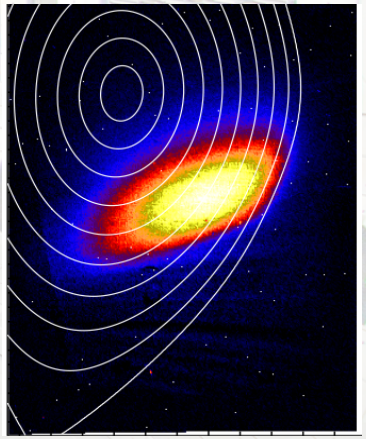
For the DIII-D team



Presented at the
53rd APS Meeting of
the APS Division of Plasma Physics
Salt Lake City, Utah

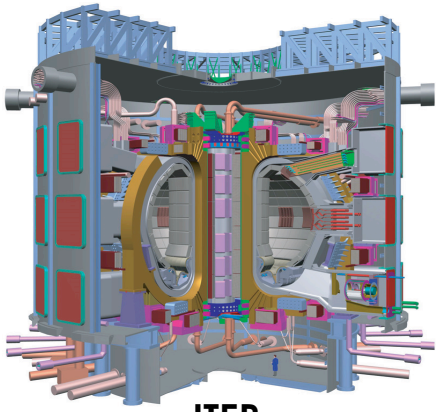
November 14-18, 2011





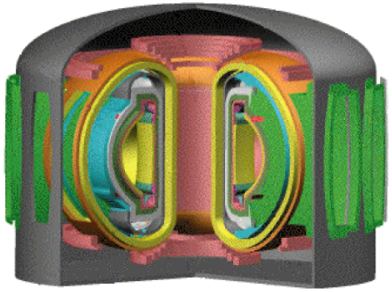
DIII-D Research is Advancing the Physics Basis for Fusion Energy Production

ITER Research



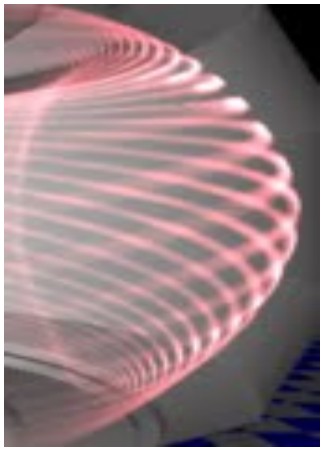
ITER

Advanced Steady-State

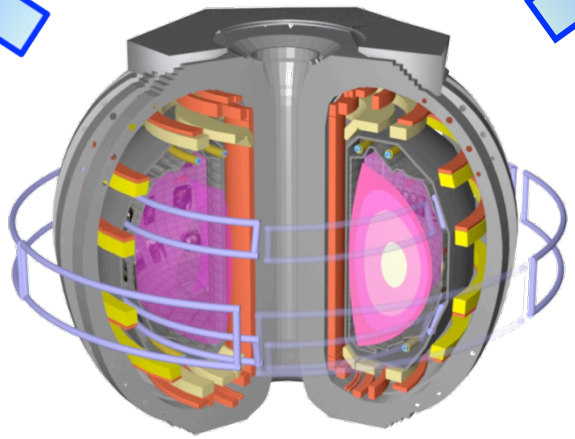


DEMO

Increased Scientific Understanding

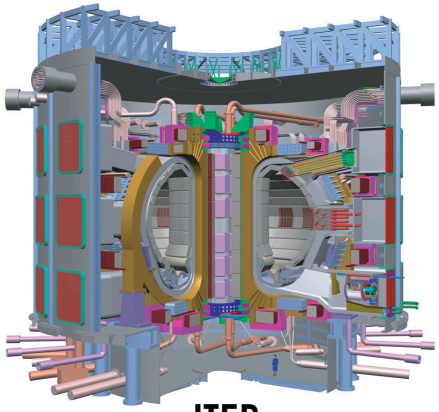


DIII-D



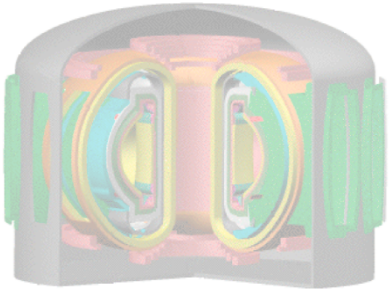
DIII-D Research is Advancing the Physics Basis for Fusion Energy Production

ITER Research



ITER

Advanced Steady-State



DEMO

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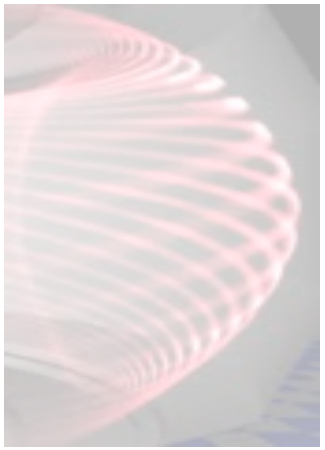
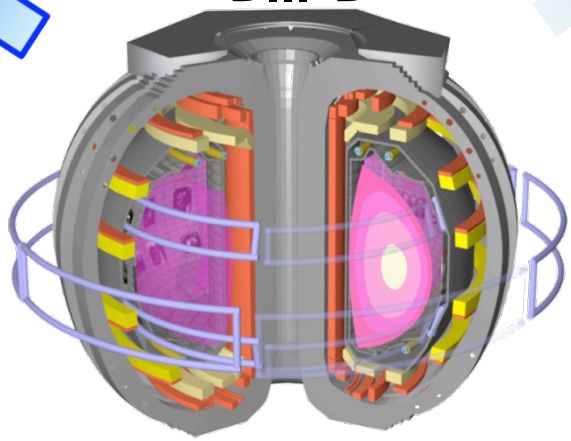
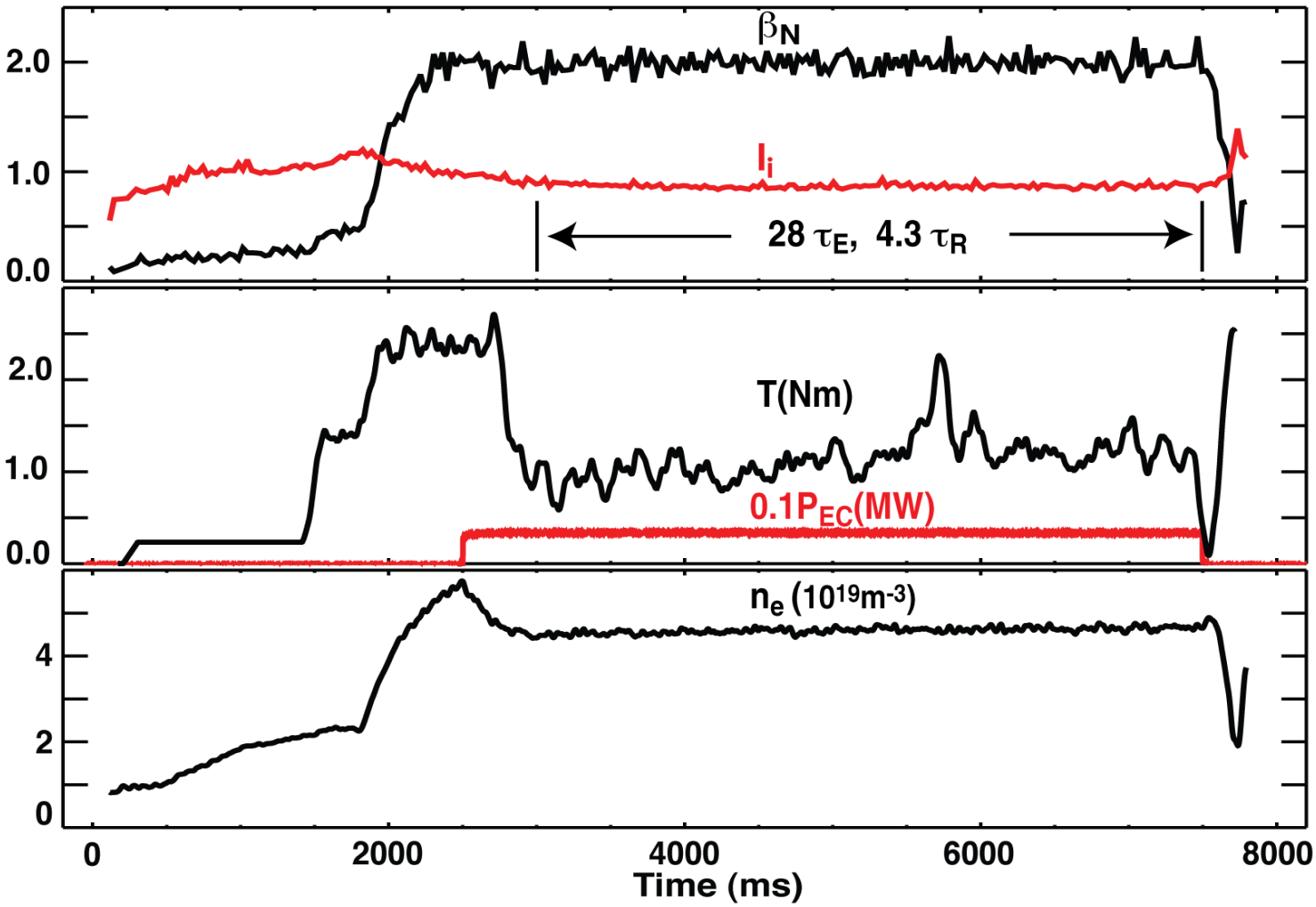
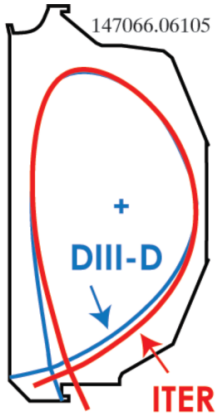


DIII-D



ITER Operational Scenarios: Achieved Stationary Conditions in Long Pulse ITER Baseline Discharges at Low Torque

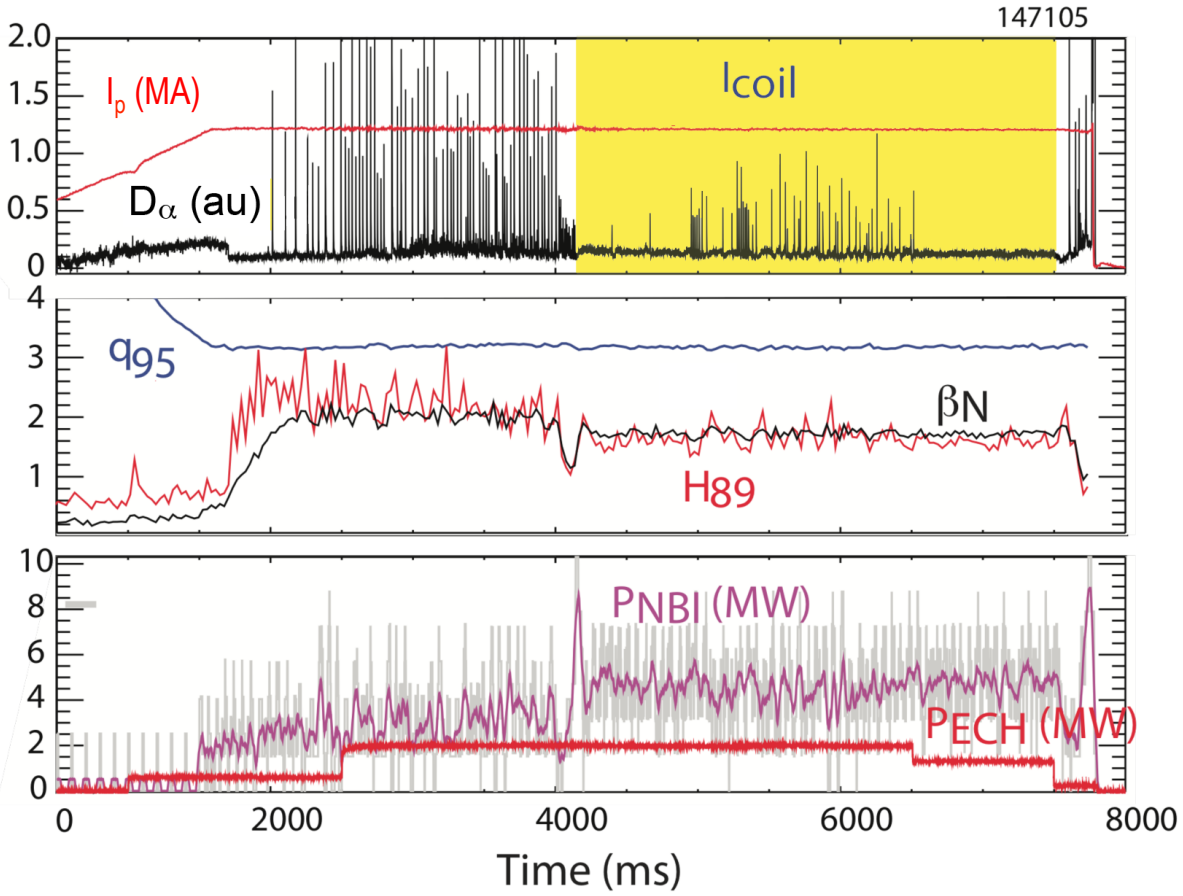




- ITER shape
- ITER-like torque in steady state
- Broad EC Deposition near q=3/2

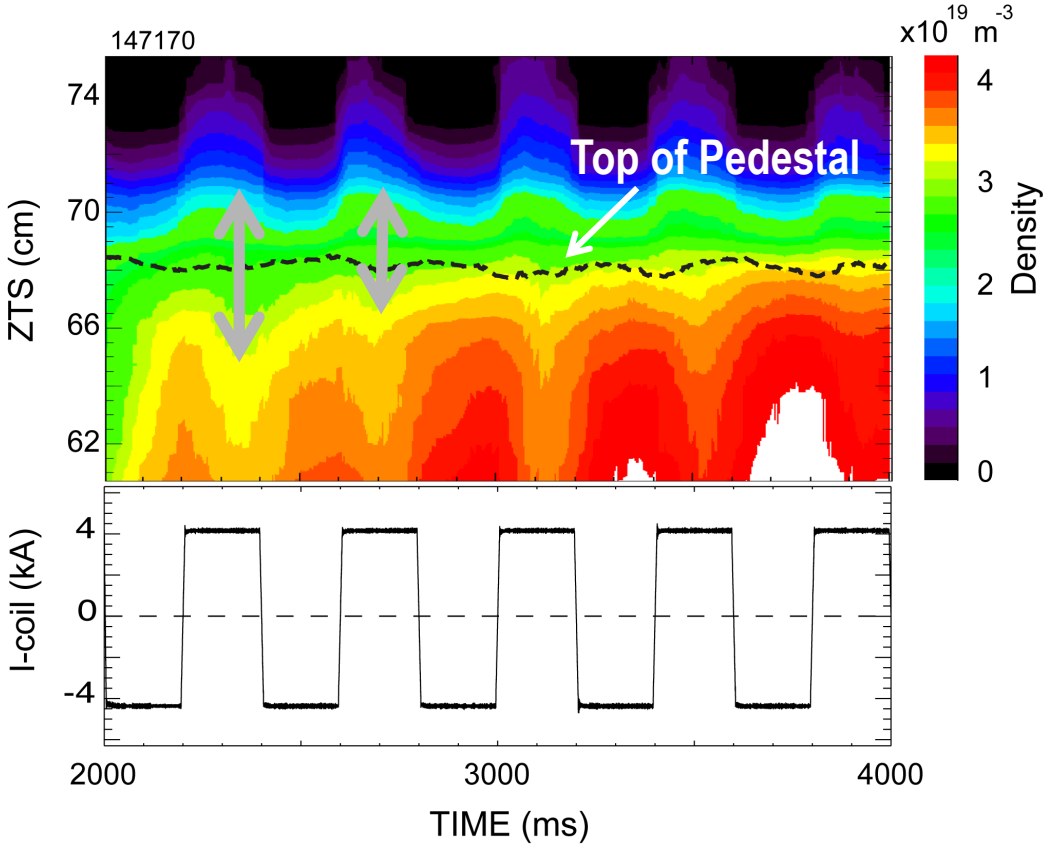
ELM Suppression Demonstrated in ITER Baseline Scenario

- **ITER Shape, q_{95} = 3.15**
- **β_N = 1.8, H_{89} = 1.8**
- **Sustained for >1 s**
  - Duration limited by available EC duration
- **Achieved with single row n=3 I-coil RMP**
- **"ELMs" during n=3 associated with internal n=1/m=1 activity**



Island-Like Displacements Observed During n=3 RMP Toroidal Phase Shifts

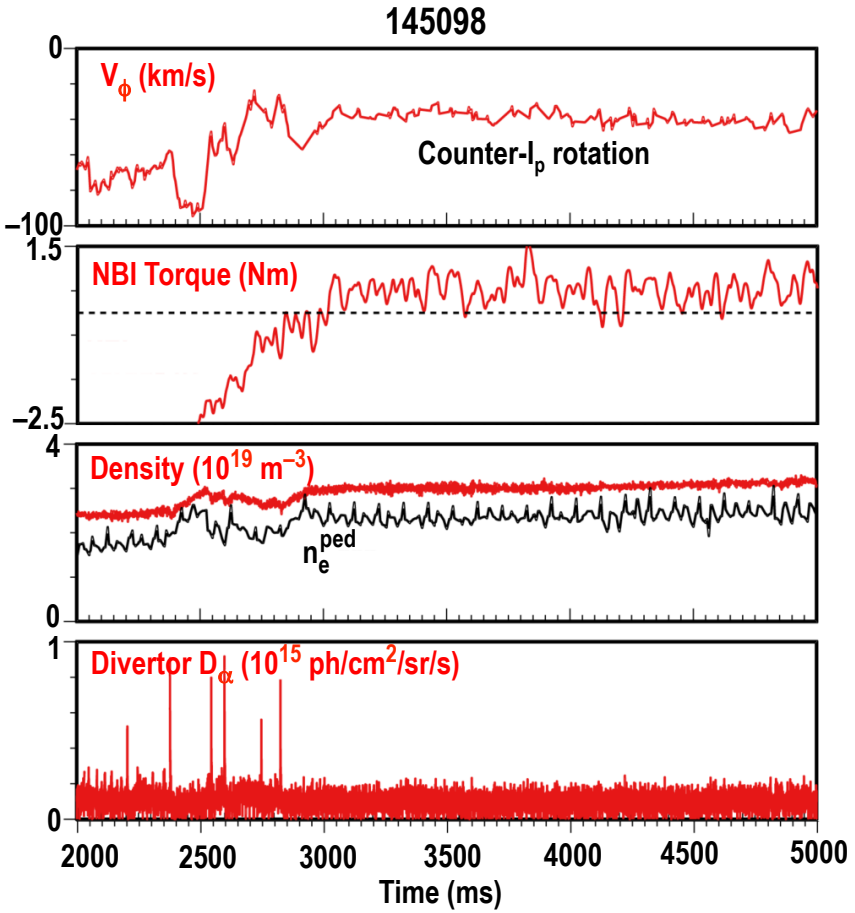
- **Toroidal phase of n=3 RMP switched by 60° every 200 ms**
- **Thomson scattering density contours separate only in 0° phase**
  - Suggestive of island formation
  - Localized near top of pedestal
- **Similar structures seen for electron temperature**



[positive coil current = 0° phasing
negative current = 60° phasing]

Nonresonant n=3 Magnetic Field Provides Additional Torque Maintaining Edge Rotational Shear for QH-mode

- QH-mode produced with reactor relevant level of co-I_p NBI torque
- Counter-rotation with co-I_p NBI torque

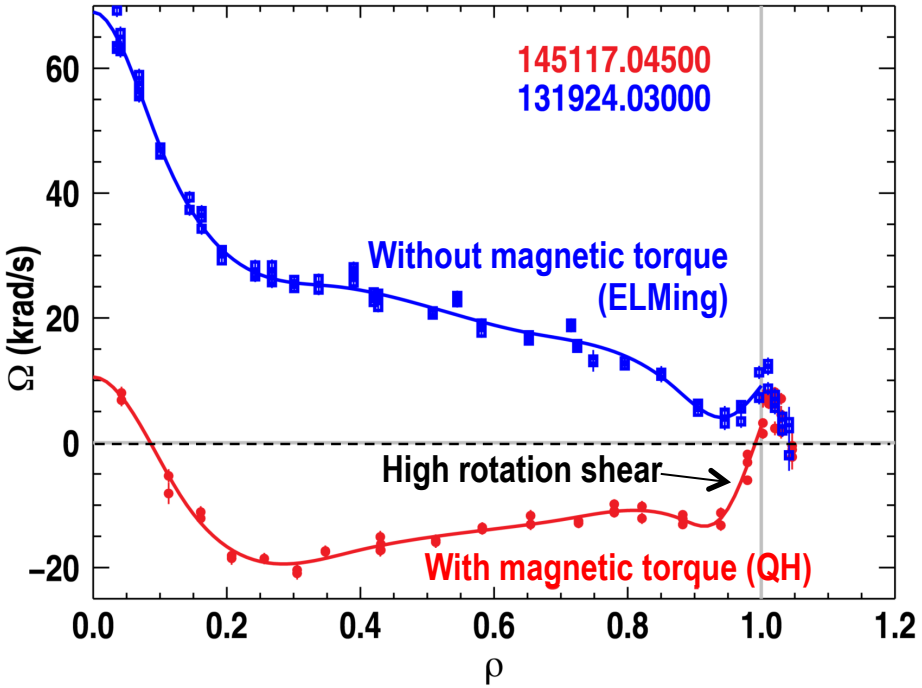


DIII-D NATIONAL FUSION FACILITY

Burrell, Friday 9:30
Garofalo, Thursday AM Posters

Nonresonant n=3 Magnetic Field Provides Additional Torque Maintaining Edge Rotational Shear for QH-mode

- With co-I_p NBI torque, toroidal rotation is co-I_p and edge rotational shear is small
- For similar co-I_p NBI torque, adding n=3 field maintains counter-I_p rotation and larger edge rotational shear
- Comparison made at similar density and NBI torque



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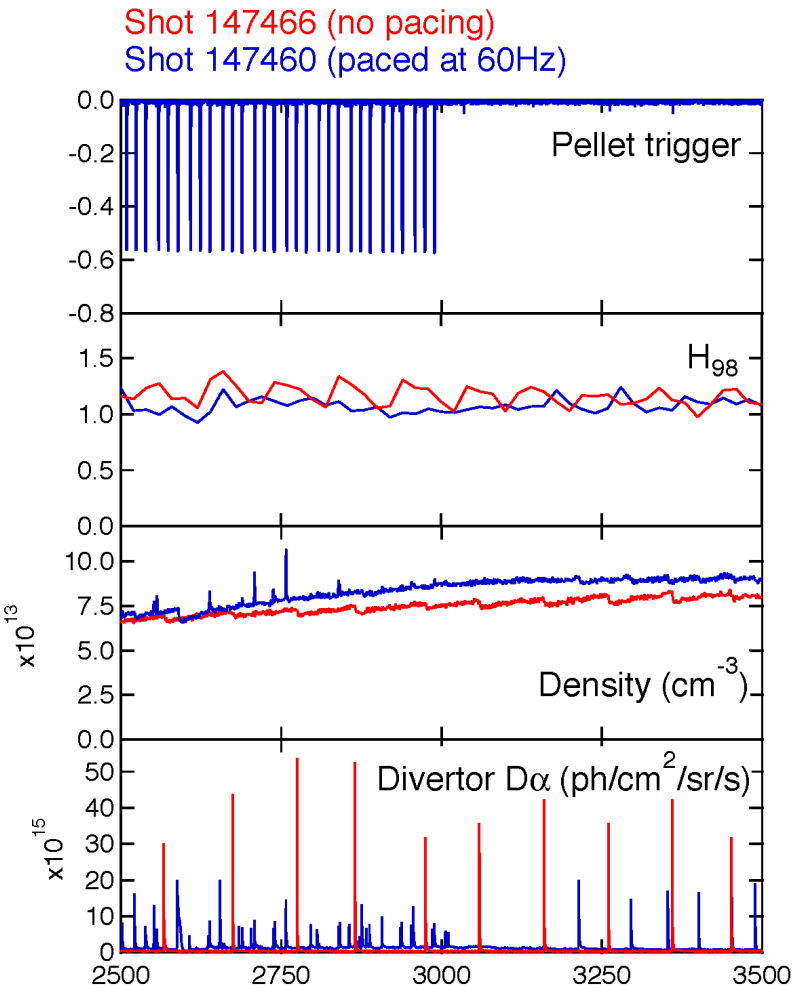
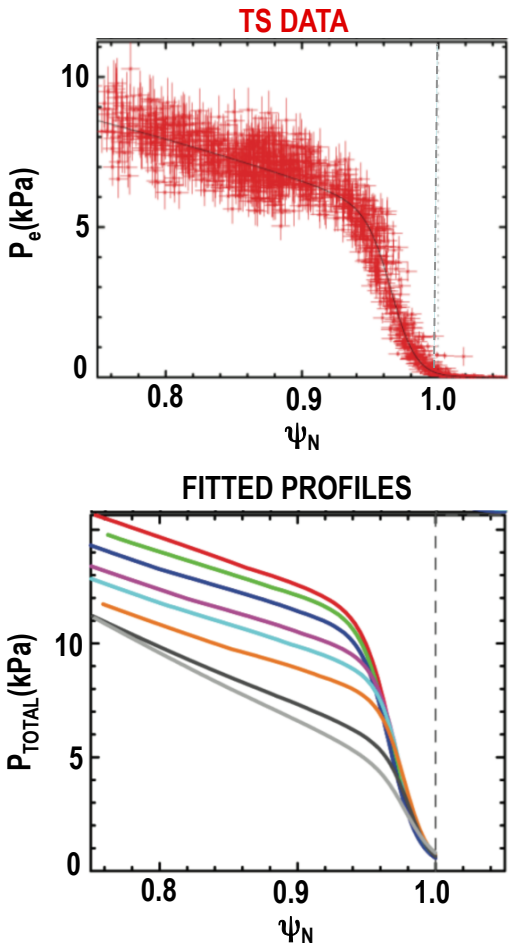
First Demonstration of ELM Pacing with 60 Hz Pellets: Substantial Reduction in ELM Size

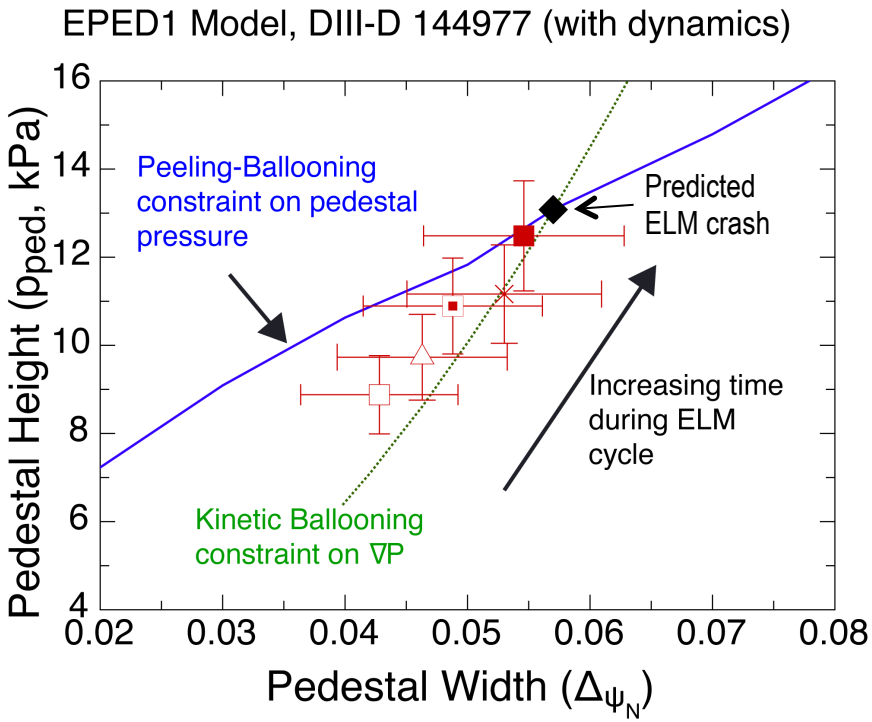
- **ELM pellet pacing at 5x the natural ELM frequency**
- **ITER shape, $\beta_N = 1.8$**
- **No significant change in energy confinement**



High Resolution Data from Upgraded Thomson System Enables Detailed Studies of Pedestal Evolution



- **Detailed profile evolution between ELMs**
- **Allows good comparisons with models**



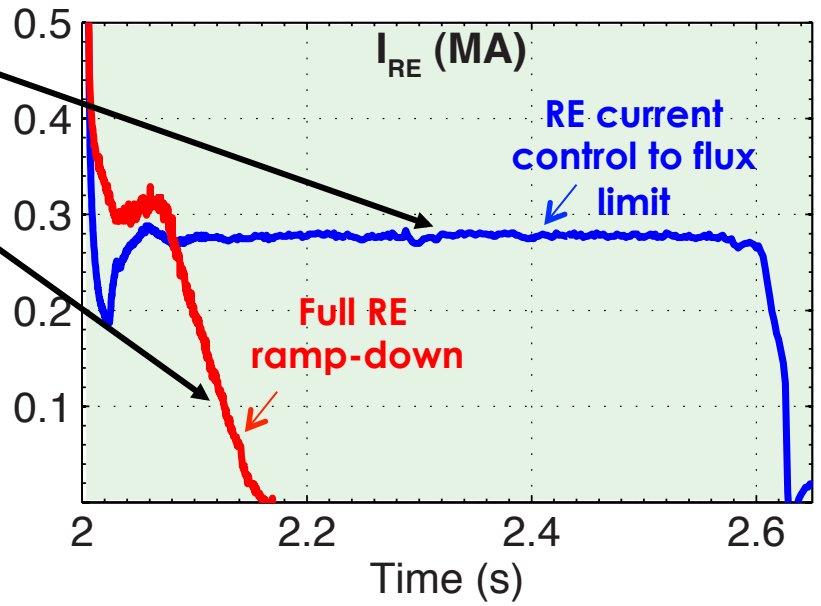
- **The EPED model predicts the observed evolution in the pressure gradient and the limit at the ELM crash**

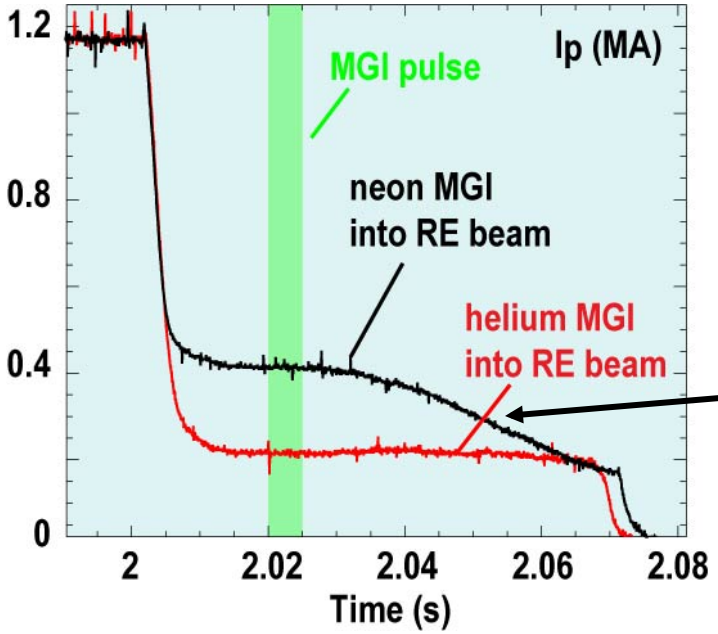
DIII-D NATIONAL FUSION FACILITY

Snyder, Monday 4:00
Groebner, This Session

Disruptions: Runaway Electron Beam Control Allows for Safe Dissipation of Beam Energy

- RE beam position held stable with control system
- RE beam current can be ramped down with ohmic coil

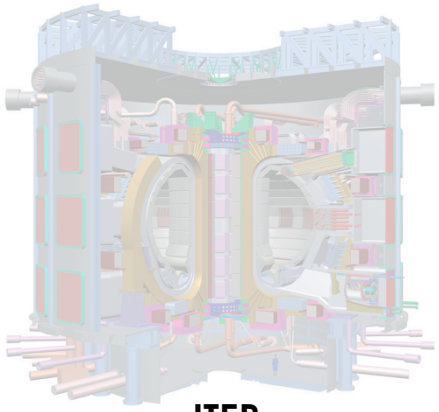




- RE beam current can be dissipated by injection of high-Z gas

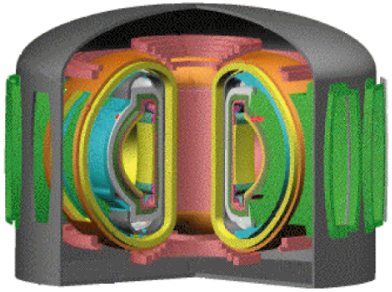
DIII-D Research is Advancing the Physics Basis for Fusion Energy Production

ITER Research



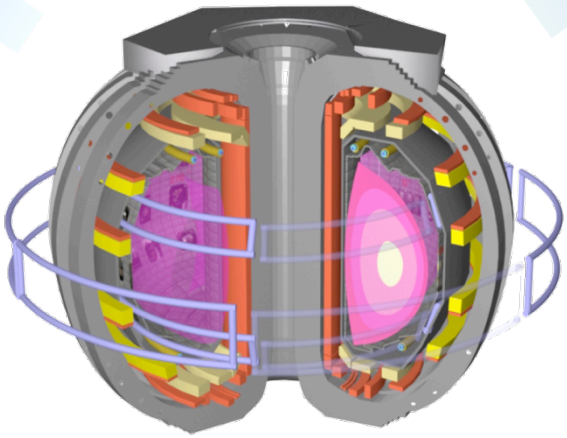
ITER

Advanced Steady-State

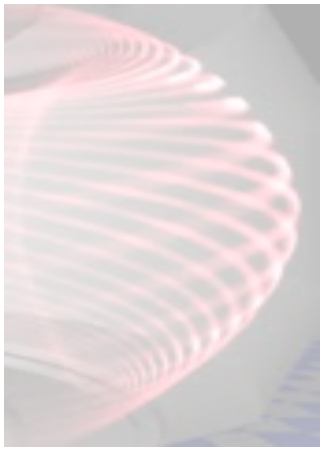


DEMO

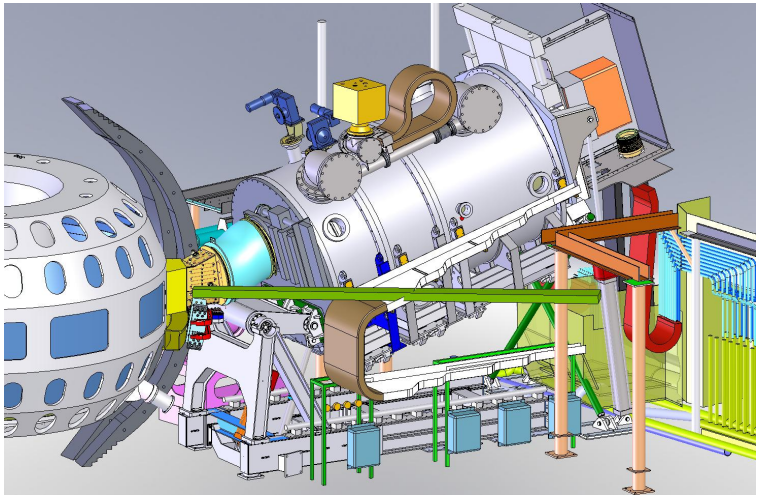
DIII-D

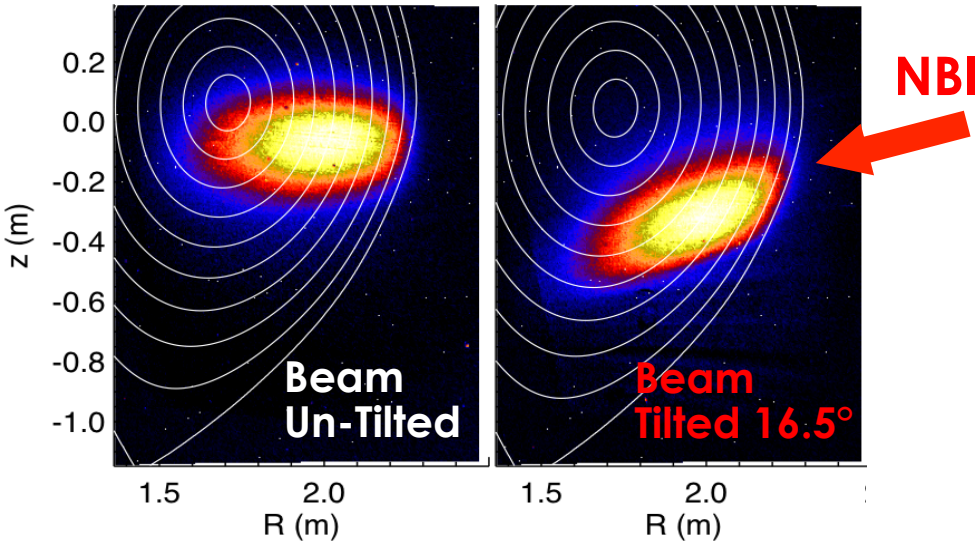


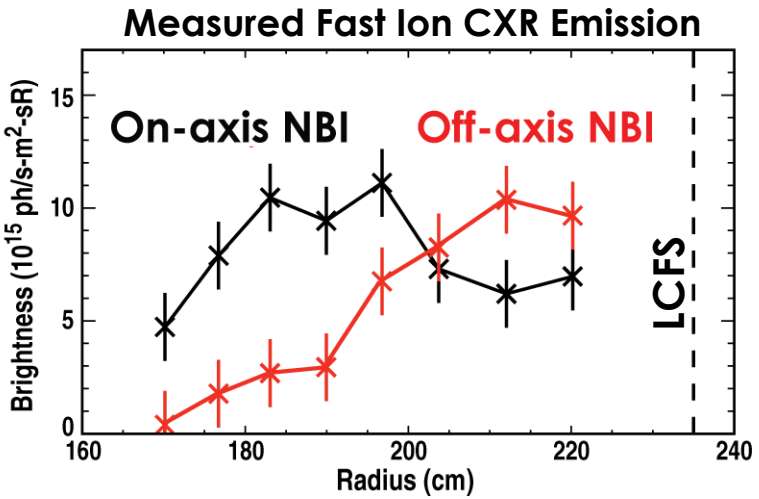
Increased Scientific Understanding

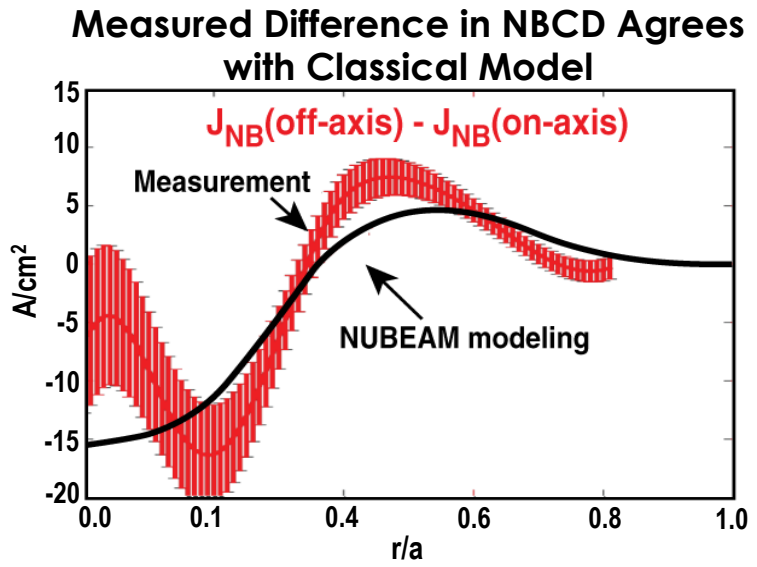


DIII-D Neutral Beam Modified for Off-Axis Injection Provides up to 5 MW Heating for Support of Physics and AT Goals





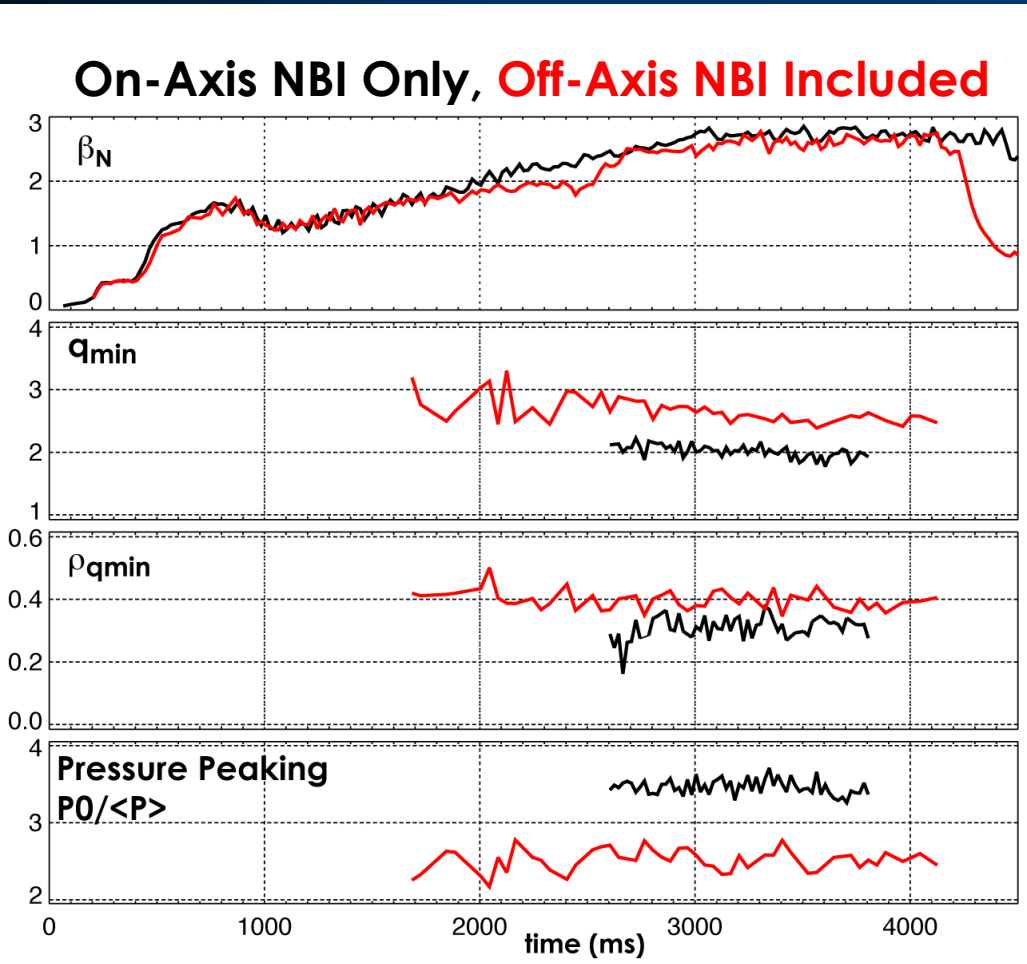


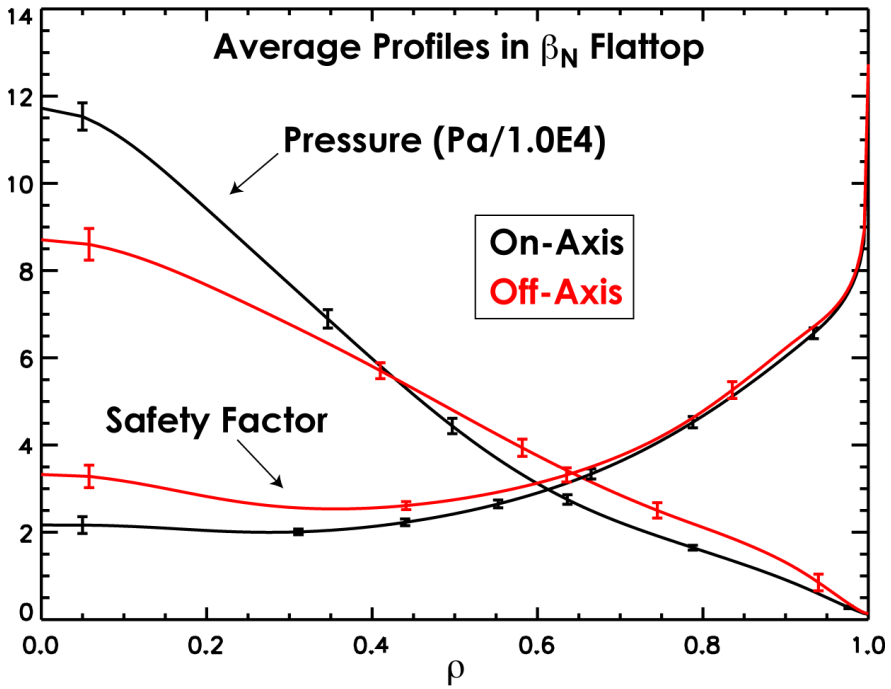


DIII-D NATIONAL FUSION FACILITY

M. VanZeeland,
J.M. Park, This Session

Off-Axis NBI Produces Broad Current & Pressure Profiles with Sustained q_{min}>2 for Higher β_N Stability Limits





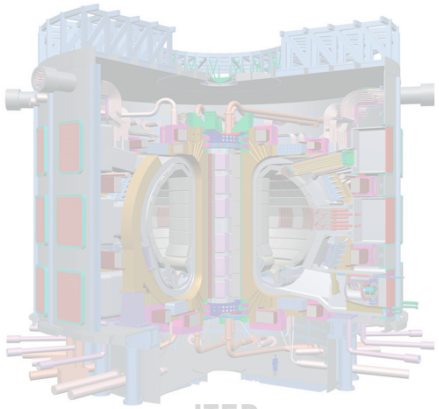
- q_{min}>2 avoids 2/1 tearing modes
- Achieved β_N=3.2 limited by transport – needs further study
- Plasmas produced using off-axis NBI have higher predicted ideal-wall stability limits (β_N ~4)

DIII-D NATIONAL FUSION FACILITY

Holcomb, This Session
Ferron, Thursday AM Poster
Turco, Friday 11:00

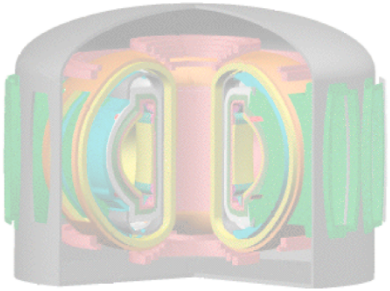
DIII-D Research is Advancing the Physics Basis for Fusion Energy Production

ITER Research



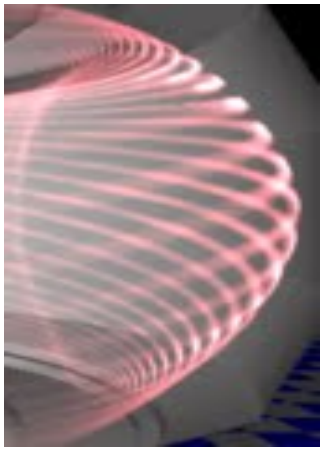
ITER

Advanced Steady-State

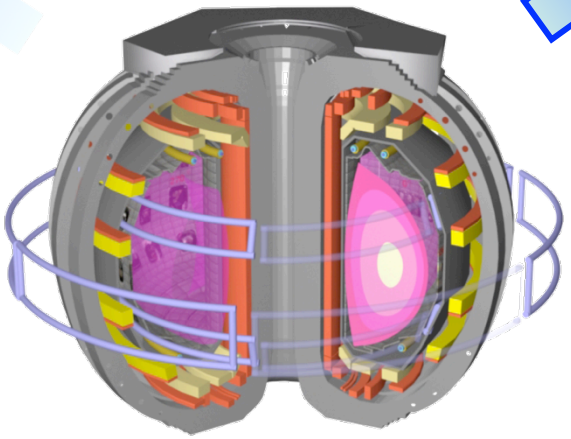


DEMO

Increased Scientific Understanding

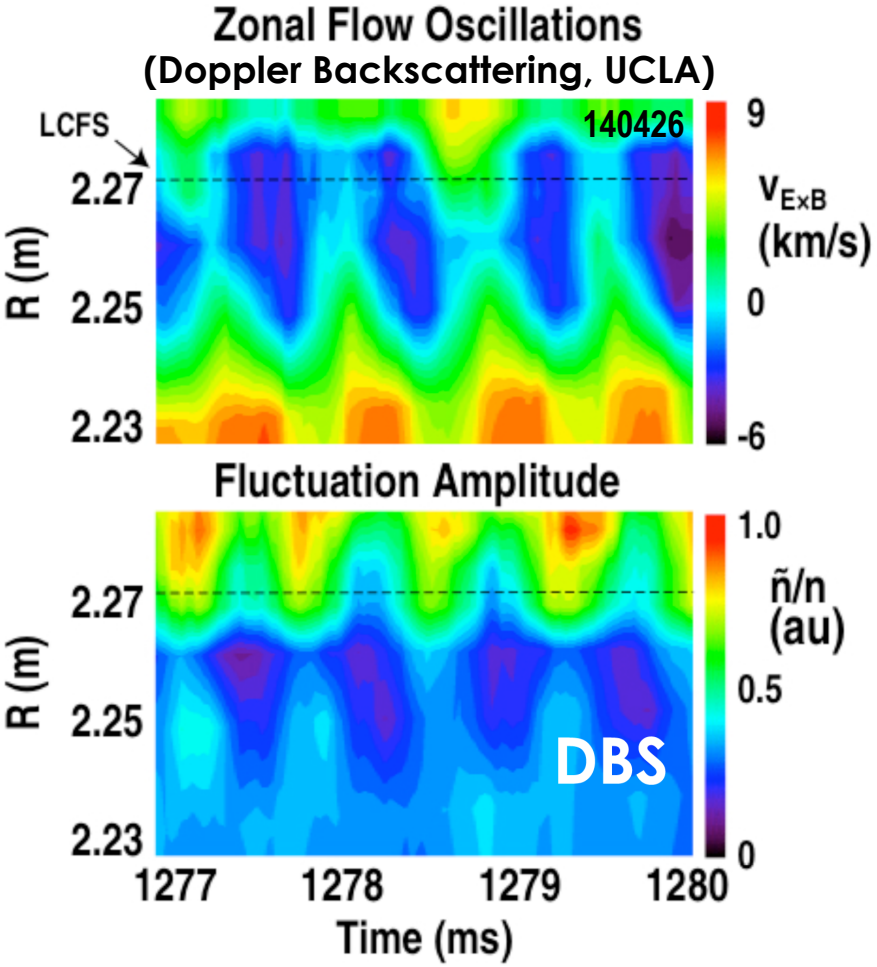


DIII-D



L-H Transition: High-resolution Measurements Demonstrate Turbulence-zonal Flow Dynamics Approaching Transition

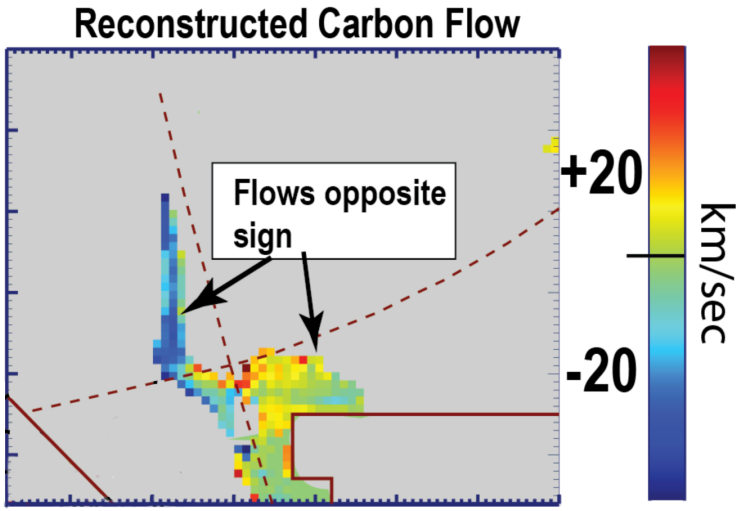
- Limit-cycle oscillations between L & H-mode show interplay between zonal flow (predator) and turbulence (prey)
- Poloidal velocity spectra (from BES) evolves from geodesic ascoustic mode (GAM) dominated to zonal flow dominated close to transition
- Zonal flow measured by fast reynolds stress probe increases just prior to transition



Yan, This Session
Schmitz, Wed 2:30

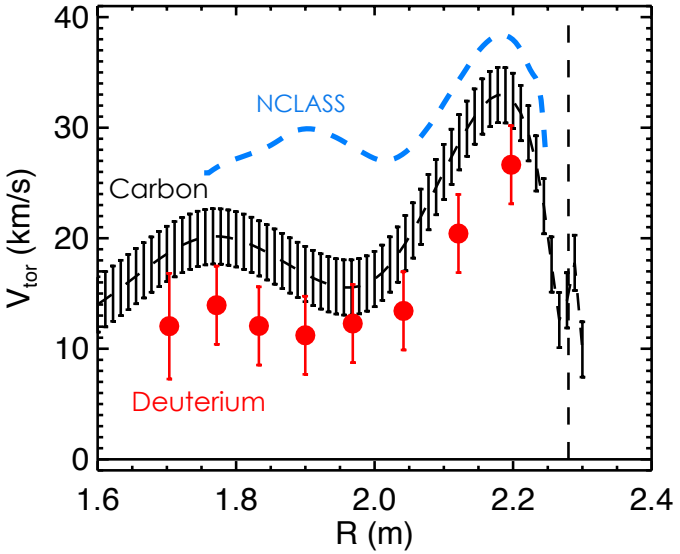
Enhanced Diagnostics Reveal New Physics Insights

Coherence imaging spectrometer (ANU, LLNL)



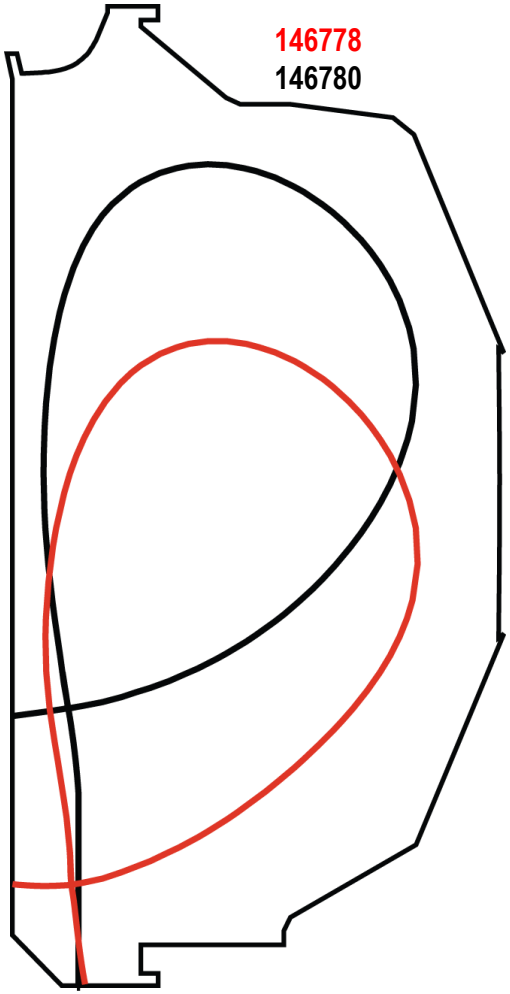
- New measurement of C^{2+} flows
- Strong flows towards inner and outer strikes points due to drag by main ion flows (Weber this session)

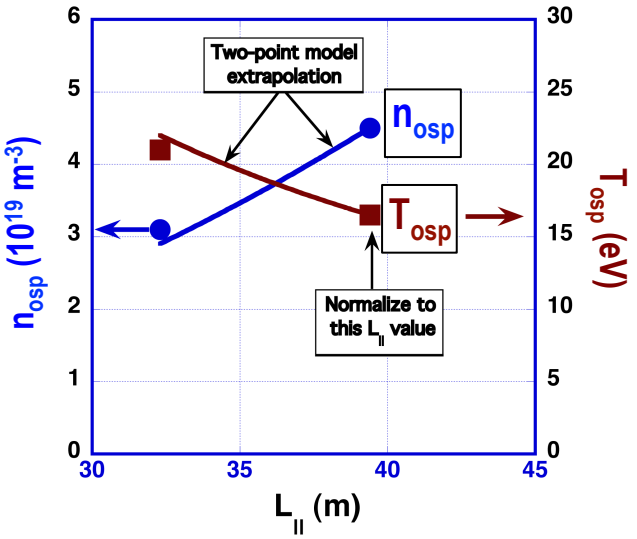
Main ion CXRS (PPPL)



- Fitting thermal D_α emission spectra
- Differences in v_ϕ between main ions, carbon and neoclassical predictions (Grierson Wed. 11:30)

Assessed the Effect of Divertor Geometry on Divertor Conditions



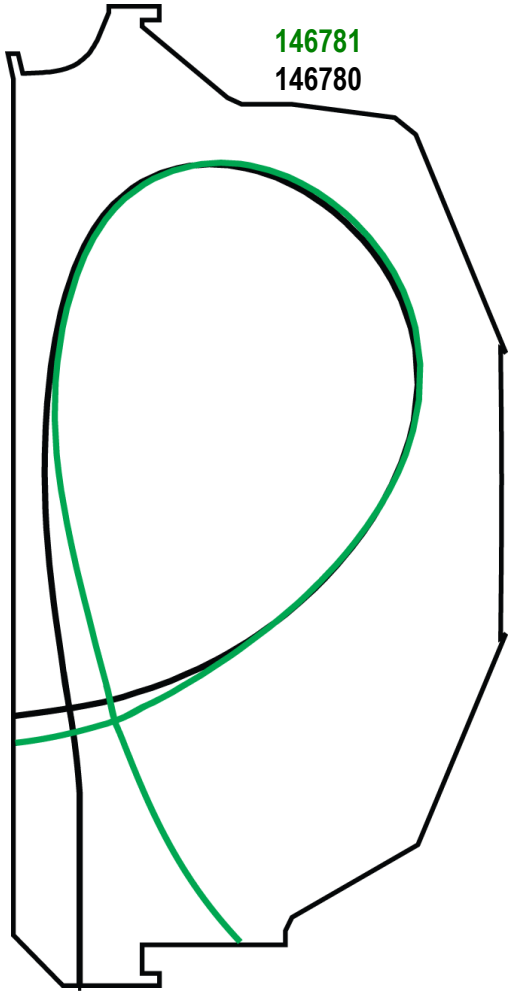


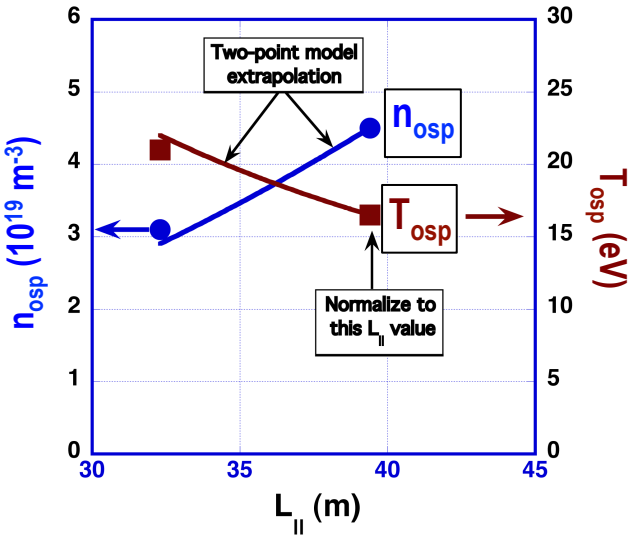
<u>Preliminary</u> results for H-mode plasmas:

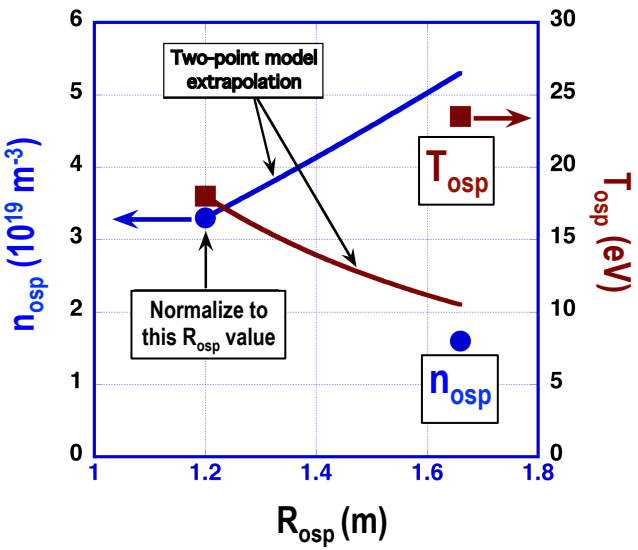
- $\uparrow L_{||} \longrightarrow \uparrow n_{osp}$ & $\downarrow T_{osp}$ — as expected

  ($L_{||}$ = parallel connection length)

Assessed the Effect of Divertor Geometry on Divertor Conditions







<u>Preliminary</u> results for H-mode plasmas:

- $\uparrow L_{||} \longrightarrow \uparrow n_{osp}$ & $\downarrow T_{osp}$ — as expected

  ($L_{||}$ = parallel connection length)

- $\uparrow R_{osp} \longrightarrow \downarrow n_{osp}$ & $\uparrow T_{osp}$ — against expectation
  - neutral trapping plays a critical role (preliminary SOLPS analysis)

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

- **Providing solutions to key ITER issues**
  - R. Groebner GO4.05: Testing Pedestal Models for Joint Research Target on DIII-D
  - L. Zeng GO4.07: Effects of Resonant Magnetic Field Perturbations on Density Profiles, Particle Transport, and Turbulence in DIII-D
  - J. Callen GO4.08: RMP Effects on Pedestal Structure and ELMs
  - P. Stangeby GO4.09: The relation between upstream radial widths of n_e and T_e and outer target power width for H-mode discharges in DIII-D
  - T. Weber GO4.10: C^{2+} Flow Measurement in DIII-D Using Coherence Imaging Spectro-Polarimetry
  - J. Wesley GO4.14: Attributes of argon pellet fast shutdowns in DIII-D
- **Developing physics basis for steady-state operation**
  - M. Van Zeeland GO4.02: Initial Off-Axis Neutral Beam Checkout and Physics Experiments on DIII-D
  - J.M. Park GO4.03: Off-Axis NBCD Experiments in DIII-D
  - C. Holcomb GO4.04: High q_{min} Steady State Scenario Development Using Off-axis Neutral Beam Injection on DIII-D
  - W. Solomon GO4.15: Advanced Inductive Plasmas with Low Torque Startup
- **Advancing fundamental understanding of fusion plasmas**
  - Z. Yan GO4.06: The Dynamics of Turbulence and Shear Flow Approaching the L-H Transition
  - R. Pinsker GO4.11: Comparison of 3-D Modeling with Experimental Results on Fast Wave Antenna Loading in DIII-D
  - G. Kramer GO4.12: Simulation of Observed EGAM Induced Beam-ion Losses in DIII-D
  - J. Hanson GO4.13: Measuring Kinetic Contributions to Resistive Wall Mode Stability Using Active MHD Spectroscopy

DIII-D NATIONAL FUSION FACILITY

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

N04 Oral Session on Research in Support of ITER			
Wed.	9:42	Wade	Plasma Response and Transport Associated with RMP ELM Suppression on DIII-D
Wed.	11:18	Murakami	Impact of different heating and current drive mixes on steady-state scenarios for ITER
Wed.	11:42	Izzo	Shape and Current Profile Effects on Runaway Electron Confinement
Wed.	11:54	Humphreys	Operating ITER Robustly Without Disruptions
Wed.	12:18	Austin	Plans for ECE diagnostic components for ITER
Invited & Tutorial			
Mon.	2:00	Thomas	Beams, Brightness and Background — Using Active Spectroscopy Techniques for Precision Measurements in Fusion Plasma Research
Mon.	2:30	Mordijck	Particle Transport Modification Due to Resonant Magnetic Perturbations on the DIII-D Tokamak
Mon.	4:00	Snyder	The EPED Pedestal Model: Gyrokinetic Extensions, Experimental Tests, and Application to ELM-suppressed Regimes
Tue.	2:30	Ferraro	Calculation of Linear Two-Fluid Plasma Response to Applied Non-Axisymmetric Fields
Tue.	4:00	Buttery	Tearing Under Stress–The Collusion of 3D Fields and Resistivity in Low Torque H-modes Room
Wed.	11:30	Grierson	Measurements of the Deuterium Ion Toroidal Rotation in the DIII-D Tokamak and Comparison to Neoclassical Theory
Wed.	2:30	L. Schmitz	Predator-Prey Oscillations and Zonal Flow-Induced Turbulence Suppression Preceding the L-H Transition
Wed.	4:00	Makowski	Analysis of a Multi-Machine Database on Divertor Heat Fluxes
Thurs.	3:00	Eidietis	Control of Post-disruption Runaway Electron Beams in the DIII-D Tokamak
Fri.	9:30	Burrell	Neoclassical Toroidal Viscosity from Non-Axisymmetric Magnetic Fields Allows ELM-free, Quiescent H-mode Operation in DIII-D under Reactor-relevant Conditions Room
Fri.	11:00	Turco	Sensitivity of Transport and Stability to the Current Profile in Steady-state Scenario Plasmas in DIII-D
DIII-D Poster Sessions: Thursday Morning and Thursday Afternoon			