Summary of DIII-D/NSTX collaboration activity and opportunities

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PPPL

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Outline

- Summary of proposed and ongoing work by the DIII-D team on NSTX.
- Plans, capabilities and opportunities for work at DIII-D in the coming year.

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Overview of contributions to NSTX research from the DIII-D team

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ISD

- High elongation shape control.
  - Continue learning how to use real time EFIT and the isoflux algorithm for routine NSTX discharge shape control.
  - Develop a higher elongation double-null divertor discharge.
  - John Ferron, Dave Humphreys, Jim Leuer, Mike Walker (Dave Gates).
- Advanced operating regimes.
  - Learn how to best use available tools to produce steady-state optimized discharges.
  - Use techniques developed for DIII-D advanced tokamak discharges (e.g. current ramp rate, neutral beam timing, HHFW, wall conditioning).
  - Initial focus on early heating and H-mode transition in the current ramp, and breakdown reproducibility.
  - Mickey Wade (Jon Menard).

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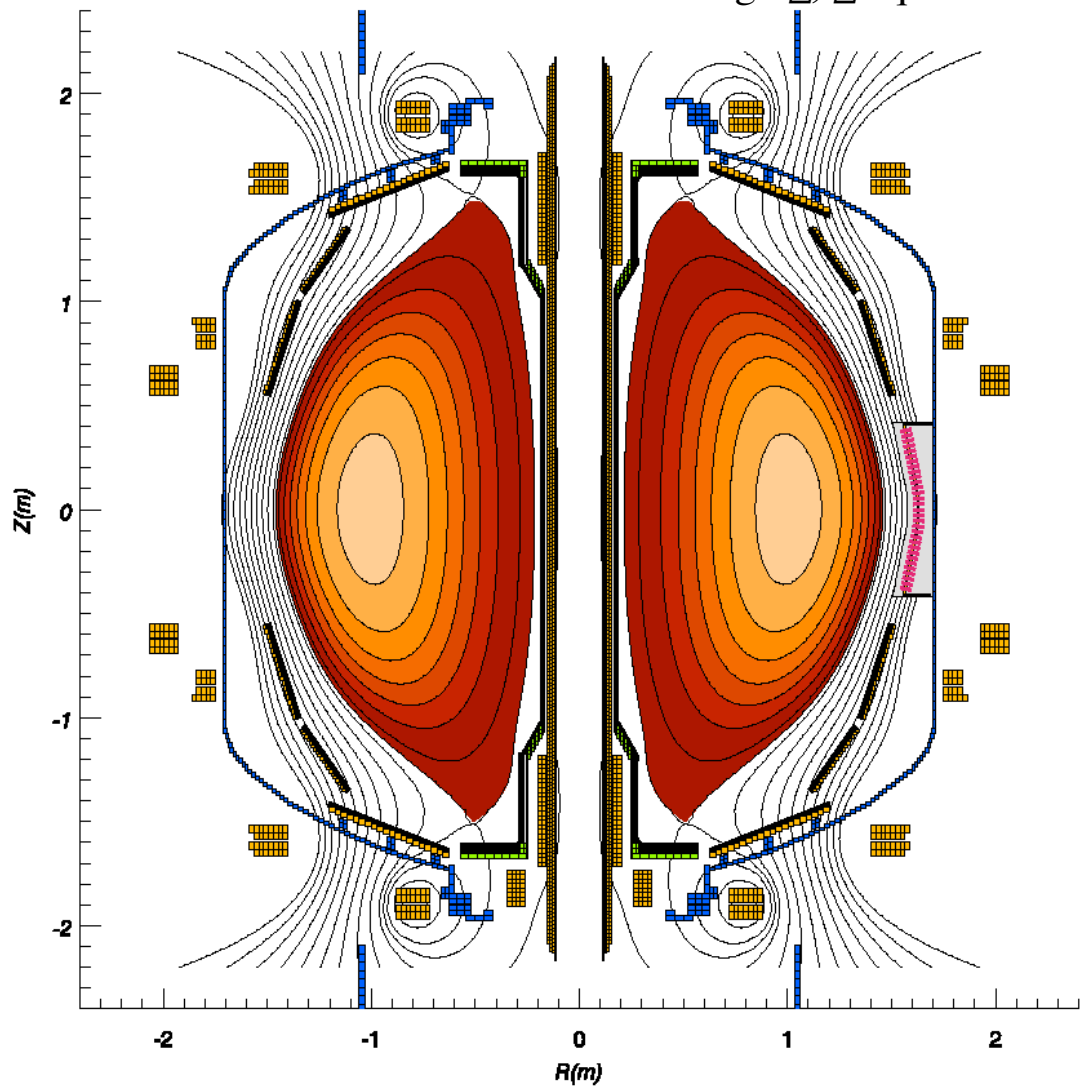
Improved Vertical Control Supports Broader High Performance Goals

- Demonstrate high β operation with moderate β
- Demonstrate high f_{bs} operation
- Maintain plasma boundary shape at high β and high β

Simulated high β, β equilibrium



MHD

- Alfven eigenmode similarity experiments.
  - Experiment on NSTX to understand frequency chirping, an indication of the of the nonlinear saturation mechanism.
  - Experiment on DIII-D to obtain better data on CAE/GAE modes believed observed previously.
  - Bill Heidbrink (Eric Fredrikson).
- Testing of resistive wall mode identification algorithms for real time RWM control.
  - Analysis of NSTX data to assess effectiveness of the matched filter algorithm.
  - Use of NSTX data from $n = 1,2,3$ probe combinations to test compensation for ELM effects. Could motivate new DIII-D diagnostics.
  - Dana Edgell.

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MHD (continued)

- Resistive wall mode physics and control collaboration.
  - Logical extension of existing collaboration between General Atomics, Columbia University and PPPL for DIII-D research.
  - Opportunity for a test of aspect ratio scaling of RWM physics.
  - Initial work, before the error field correction coil is available, would focus on critical rotation, rotation damping and RWM dissipation mechanism.
  - Ted Strait, Andrea Garofalo, Holger Reimerdes and other members of the DIII-D thrust 4 team (Steve Sabbagh, Aaron Sontag).

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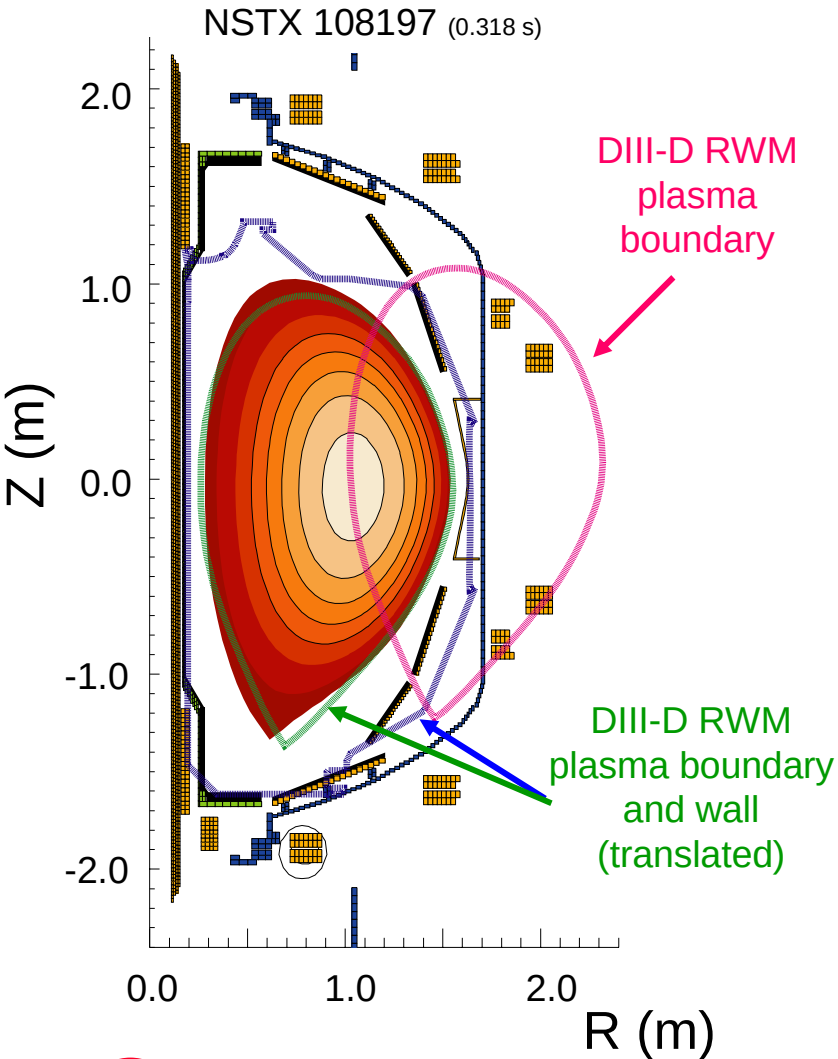
DIII-D / NSTX RWM Similarity Experiment

(Sabbagh, Sontag, Reimerdes, Garofalo, LaHaye, Okabayashi, etc.)



- Address aspect ratio effects on
  - Rotation damping physics
  - Critical rotation for RWM onset
  - RWM dissipation mechanism
- Address stability with / without wall
  - Compare to MAST results when MAST reaches no-wall limit
- Approach
  - DIII-D/NSTX shape already matched
  - More closely match RWM generation
  - 1.5 run days allocated on NSTX
  - 1.0 run days requested for DIII-D

Transport

- Aspect ratio scaling of confinement and transport.
  - Compare discharges in DIII-D and NSTX with dimensionless parameters matched where possible and scaling studies performed to bridge the data where parameter matching isn't possible.
  - Craig Petty (Ed Synakowski).
- Comparison of TRANSP results on DIII-D and NSTX H-mode discharges.
  - Use discharges with comparable engineering parameters from the various aspect ratio scaling experiments.
  - Chuck Greenfield (Stan Kaye).

Transport (continued)

- Assess the effect of aspect ratio on the ELMy H-mode regime.
  - Pedestal height, width and gradients.
  - ELM radial extent, amplitude and frequency.
  - Tom Osborne, Phil Snyder (Rajesh Maingi).
- Calculations to assess potential usage of the NSTX error field correction coil for stocastic boundary experiments.
  - Potential to modify the effect of ELMs.
  - Todd Evans (Rajesh Maingi).

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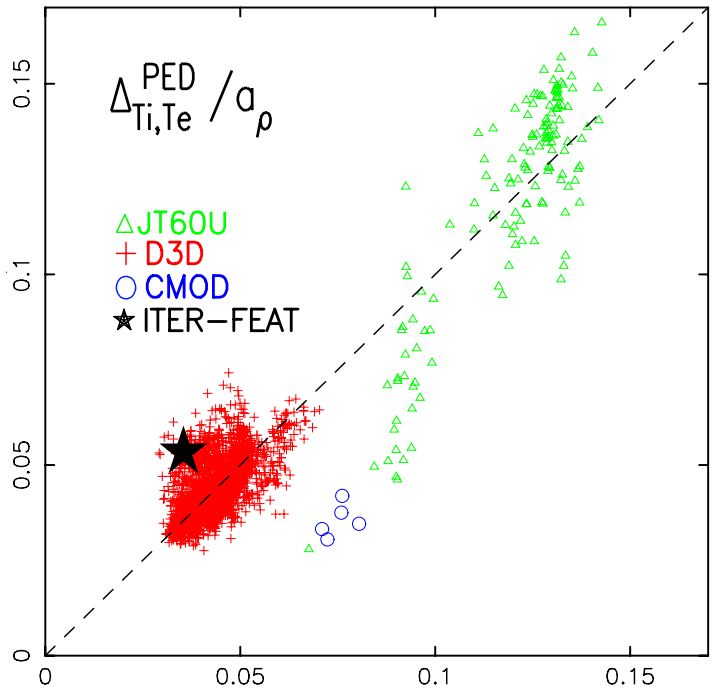
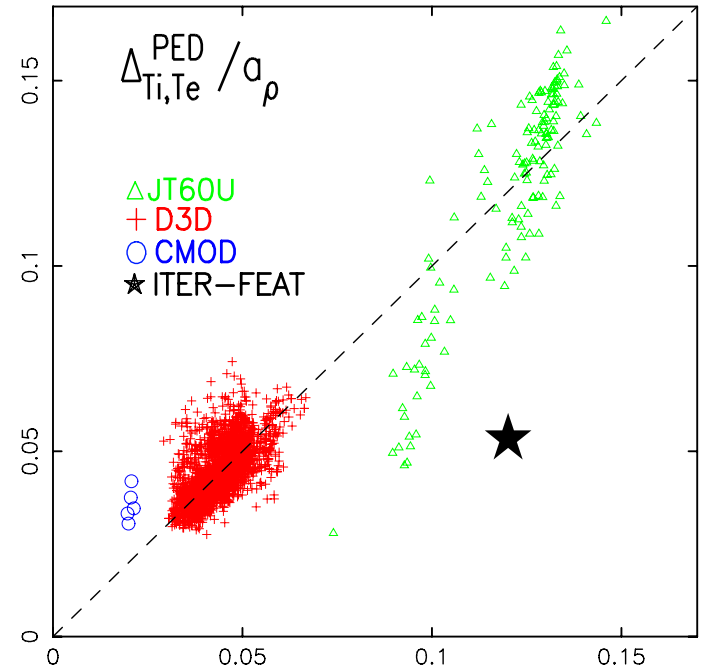
Empirical scaling of Δ

- Difficult to reconcile large widths and ρ_p dependence in JT60U with β_P dependence in DIII-D and same relative widths between DIII-D and CMOD.
- Add density dependence to ρ_p scaling plus shape terms.

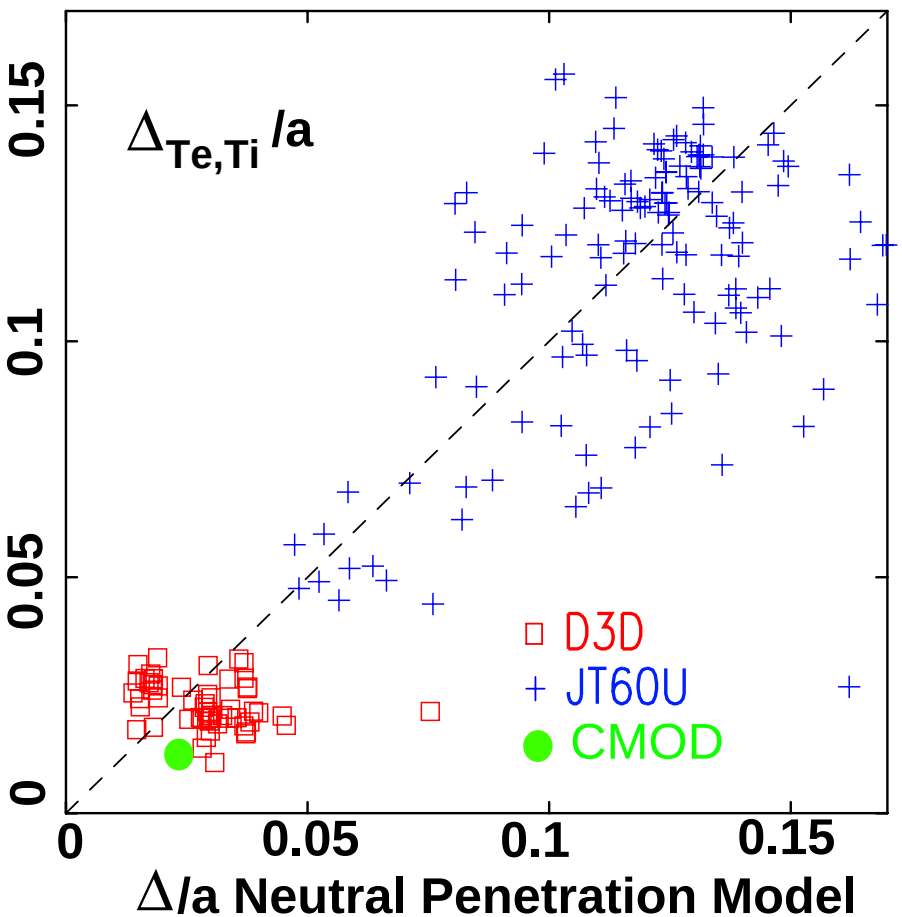




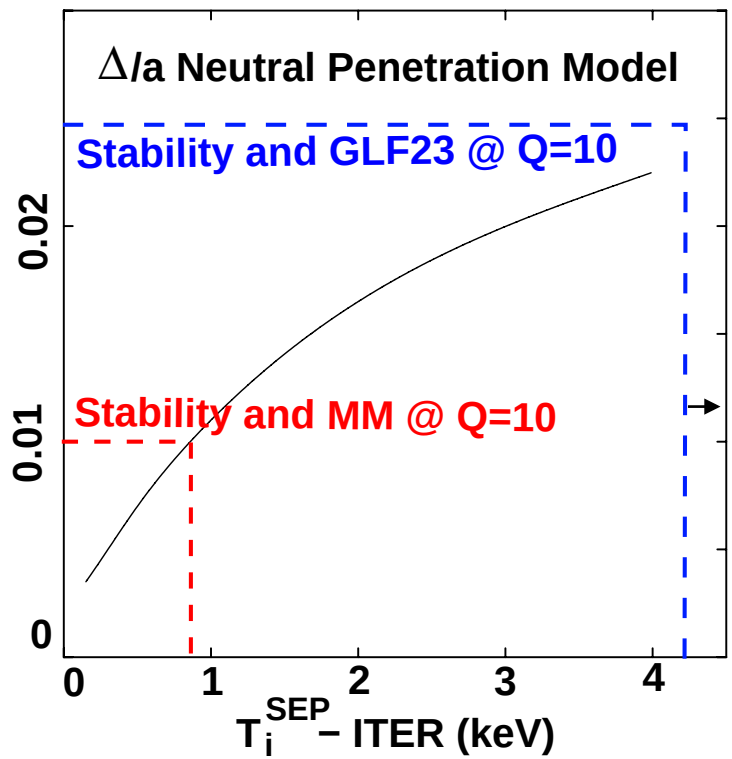
$$\Delta_* = 0.044 \times \rho_{*s}^{0.38} (B_T / B_p^{Ave})^{0.27} n_{*G}^{0.19} \times \kappa^{-0.98} (1+\delta)^{0.52} \varepsilon^{-2.3}$$

$$\Delta_* = 0.12 \times \rho_{*s}^{0.39} (B_T / B_p^{Ave})^{0.31} n_{*G}^{0.19} \times \kappa^{-0.5} (1+\delta)^{0.57} R^{1.6} a^{-0.5}$$

Edge neutral source model predicts high separatrix temperature would be required for ITER

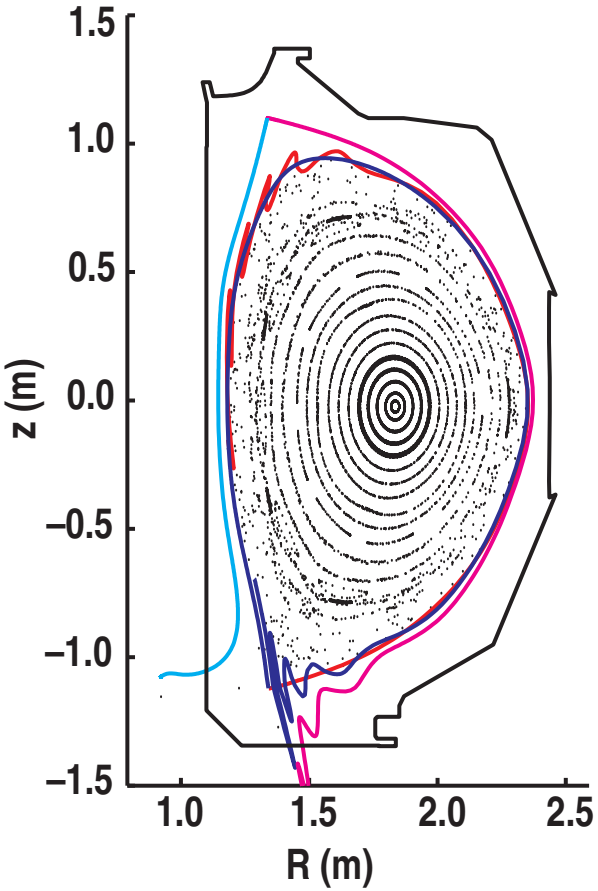


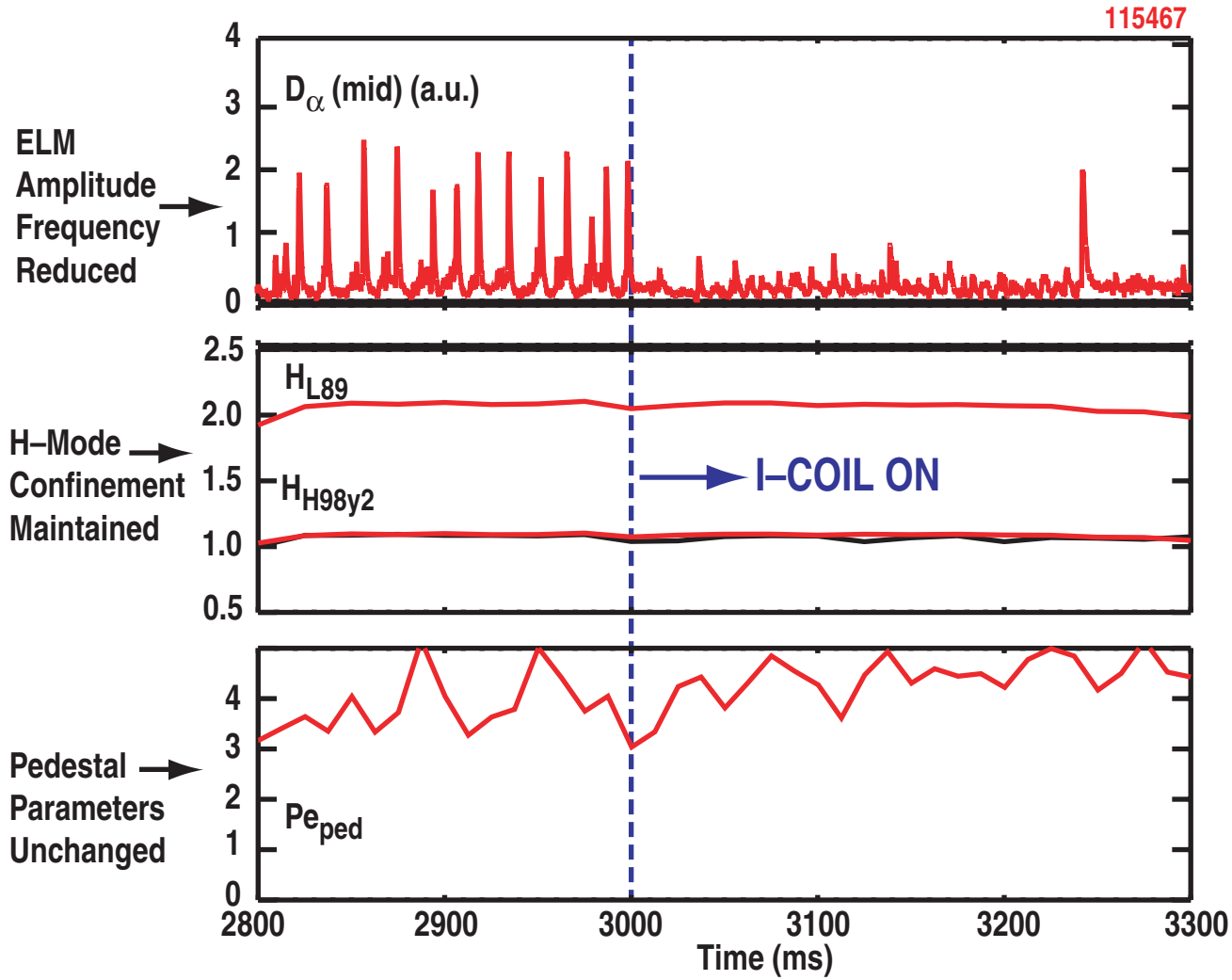
- **Model accounts for large widths in JT60-U relative to DIII-D and CMOD**
- **Pellet fueling could expand barrier**



I-COIL-GENERATED STOCHASTIC MAGNETIC BOUNDARY OBSERVED TO SUPPRESS ELMs WITHOUT DEGRADING CONFINEMENT

I–coil with n = 3 Even Parity
Current = 4300 Amperes





- Resonant q effect
- See T.E. Evans QP1.037

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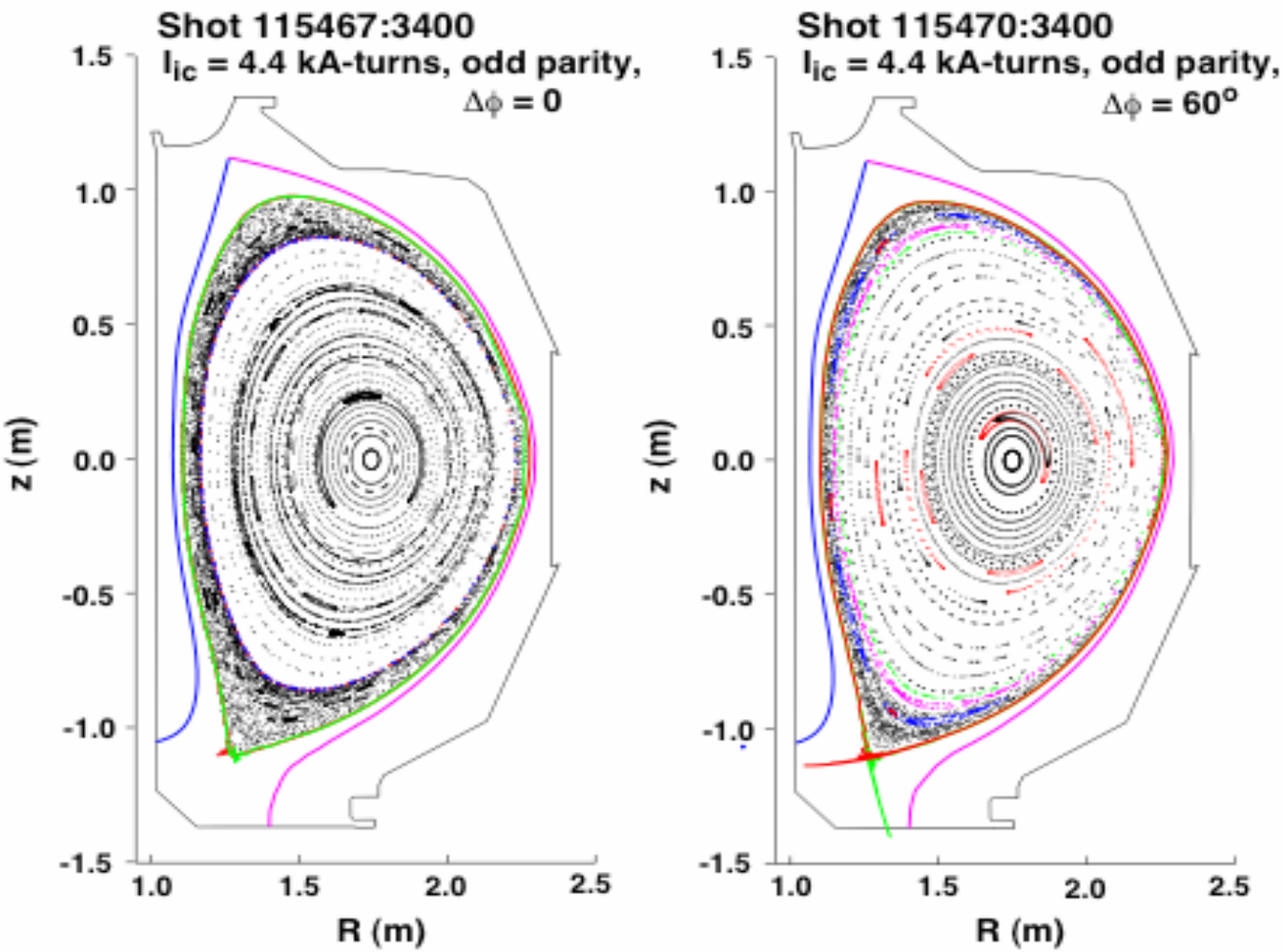
In the n=3 configuration, with full I-coil current, the edge stochastic layer is significantly smaller than with the C-coil and the core islands are smaller



- The toroidal phase of the I-coil perturbation has a small effect on the stochastic layer due to a difference in the mixing with intrinsic error fields, with $\Delta\phi=0$, $\Delta\psi_{slw}=12.6\%$ and $\Delta\psi_{fl}=1.7\%$ while with $\Delta\phi=60^o$, $\Delta\psi_{slw}=10.2\%$ and $\Delta\psi_{fl}=0.7\%$.
- Although the stochastic layer is smaller with the I-coil the effect on ELMs is larger.

TRIP3D modeling (no plasma response included)

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RF

- HHFW:
  - Continued participation in ongoing NSTX experiments.
  - Proposal: NSTX/DIII-D cross-machine comparison of Parametric Decay Instability and edge ion heating during HHFW (dependence on absolute B-field at fixed f/fci at antenna, etc.).
  - Bob Pinsker.
- EBW:
  - Theoretical study of poloidally-phased waveguide launcher for direct X-B scheme.
  - Bob Pinsker.

Boundary

- The UCSD group has fast stroke probe diagnostics on both NSTX and DIII-D.
  - Comparison of intermittency in NSTX and DIII-D.
  - Comparison of turbulent transport (broadband) in NSTX and DIII-D.
  - Jose Boedo

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CHI and Startup

- Enhancement of the EFIT equilibrium reconstruction code for improved handling of CHI discharges.
  - Reconstructions include the current on open field in the fitting to diagnostics.
  - Use to support and analyze new CHI experiments.
  - Mike Schaffer, Lang Lao, Dylan Brennan.
- Finish a general theory of helicity transport and publish.
  - Mike Schaffer.
- Proposal: measure helicity flux with the reciprocating probe.
  - Work with Jose Boedo and Hantao Ji on probe head design.
  - Mike Schaffer.

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CHI and Startup (continued)

- Stability analysis with current on open field lines.
  - SCOTS stability code.
    - Gives the linear eigenfunction and growth rate for equilibria with current on open field.
    - Simple linear eigenfunction result
  - NIMROD stability code.
    - Gives linear eigenfunction and growth rate with current on open field
    - Fewer assumptions and more physics included in the model
      - No nested flux surfaces
      - Resistivity and viscosity (necessary).
    - Nonlinear evolution can be studied
  - Dylan Brennan
- Planning and modeling of ohmic startup using only poloidal field coils.
  - Phil West (Masa Ono).

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Plans, capabilities and opportunities for work at DIII-D in the coming year

- DIII-D research opportunities forum scheduled for December 9-11, 2003.
- Machine checkout December 15-January 30.
- Physics operations starts February 2.

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THE DIII–D RESEARCH PROGRAM FOCUSES ON KEY AREAS FOR THE FUTURE

- **Advanced Tokamak: in-principle steady-state, high performance discharges**
  - Scientific understanding of key elements
    MHD stabilization; profile optimization
  - Plasma control
  - Integrated self-consistent scenarios

High average power
⇒ ITER
⇒ CTF
⇒ Power plant

- **Transport: major advance in turbulent transport understanding and control**
  - State-of-the-art predictive simulations
  - Measure turbulence generated flows and short wavelength turbulence

A grand challenge in plasma science

- **Mass transport in the boundary**
  - Measure flows, erosion and redeposition
  - Measure ELM effects
  - Integrated modeling of the boundary

Key R&D for high power divertors
⇒ Radiative divertor
⇒ Tritium retention

DIII–D remains committed to progress in a broader range of scientific issues

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DIII–D PROGRAM ELEMENTS SUPPORT ITER

— In cooperaation with Internatinal Tokamak Physics Activity —

AT

- Develop long pulse, high performance discharges for ITER
  - Hybrid scenarios
  - Full steady-state advanced tokamak
- Resistive wall modes
  - Detailed physics understanding
  - Feedback control
- Neoclassical tearing modes
  - Threshold, stabilization, avoidance
- Disruptions: gas jet penetration

Transport

- Develop core transport models to develop ITER operational scenarios
- Pedestal physics: understand and control the width and height of the pedestal
  - Develop control techniques: small ELMs, QH–mode, stochastization . . .

Mass Transport

- In-depth understanding of the process contributing to tritium retention, “mass transport”
  - Erosion, redeposition, ELMs
  - Transport channels; measure flows

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The DIII-D program includes each year work in four Topical Science Areas

- The experiments in the topical science areas have both broad scientific interest and support for the advanced tokamak focus of DIII-D research.
  - Stability: measuring and understanding stability boundaries and instability control.
  - Confinement/transport: fundamental turbulence, testing of theory-based models, non-dimensional transport, core transport and H-mode physics.
  - Boundary: core-boundary interface, SOL and divertor plasma, plasma-material interaction, tests of new divertor concepts and materials.
  - Heating and current drive: theory validation, tool development.

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THE DIII–D RESEACH PROGRAM IS ALSO ORGANIZED INTO CROSS-TOPICAL THRUST AREAS

- The Thrust areas come and go, as the needs of the AT focus require.
- Thrust areas for 2003:

T1: Edge pedestal:	Determine the pedestal height and ELM size dependence on plasma parameters and atomic physics
T3: NTM stabilization:	Optimize ECCD feedback stabilization schemes to increase β
T4: RWM stabilization:	Advance the physics understanding of resistive wall mode and validate the effectiveness of the new Internal Coils
T8: AT scenario:	Continue high β, full noninductive scenario development using the new tools
T9: QH–mode:	Develop an understanding of the Quiescent H–mode for ELM-free scenario projection to burning plasmas (BP)
T10: Hybrid scenarios:	Integrated, long-pulse scenario development for BP

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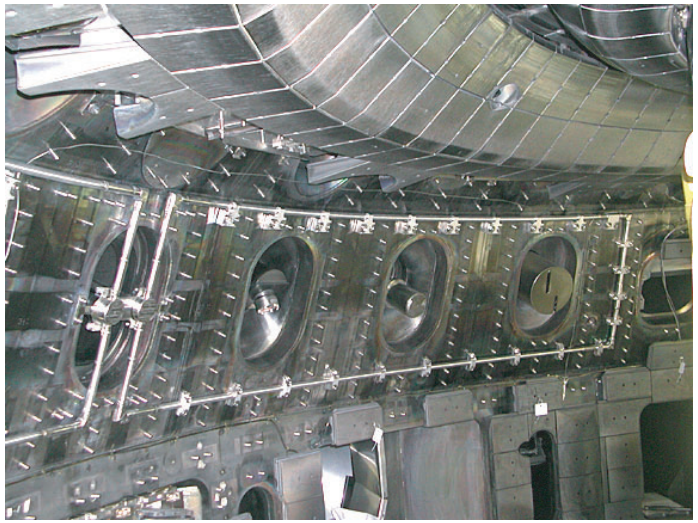
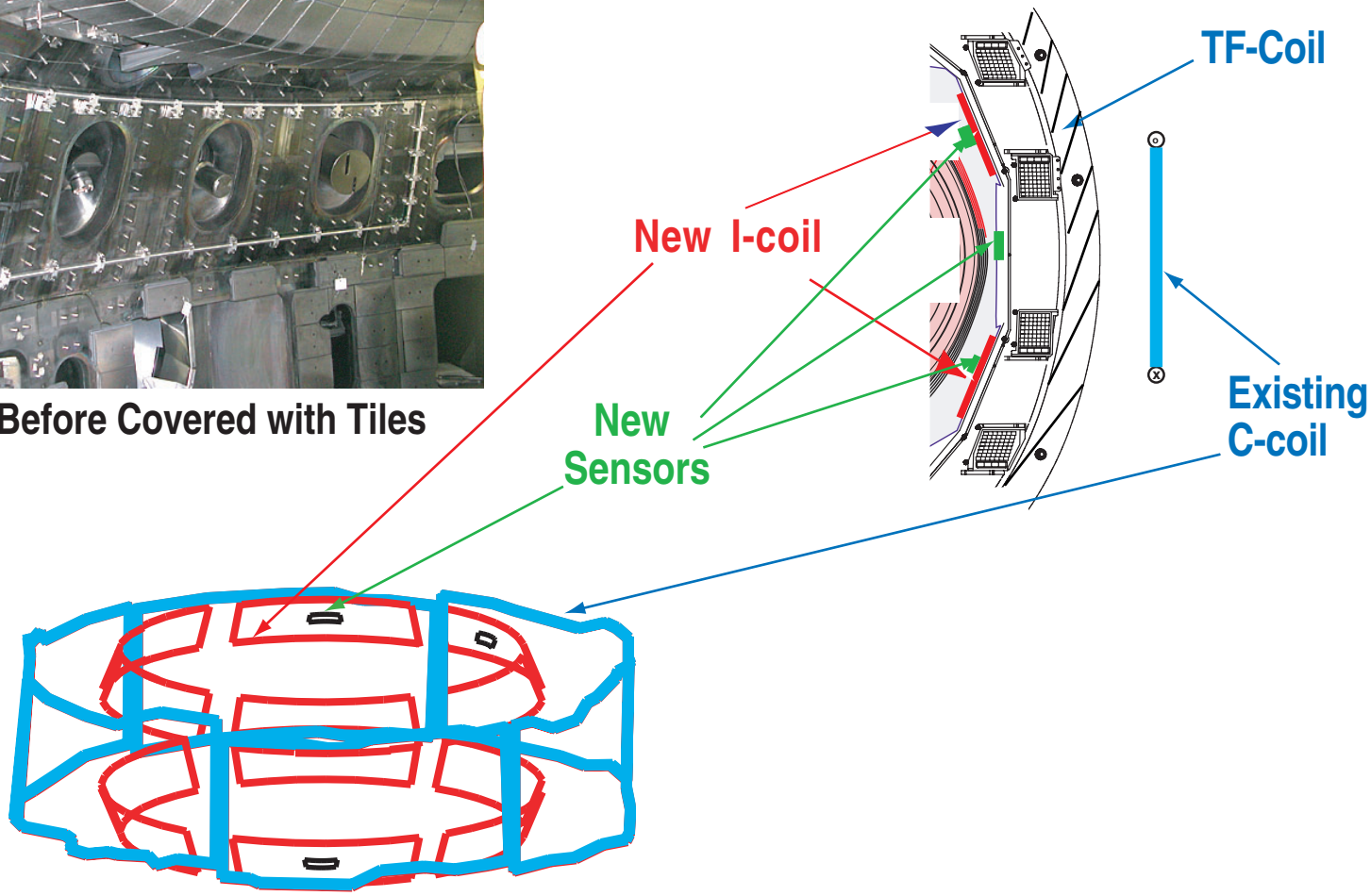
NEW CAPABILITY IN 2003: 12 INTERNAL COILS (I-COIL) FOR RESISTIVE WALL MODE STABILIZATION



Coils Before Covered with Tiles



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G.L. Jackson, G01.002
E.J. Strait BI1.006

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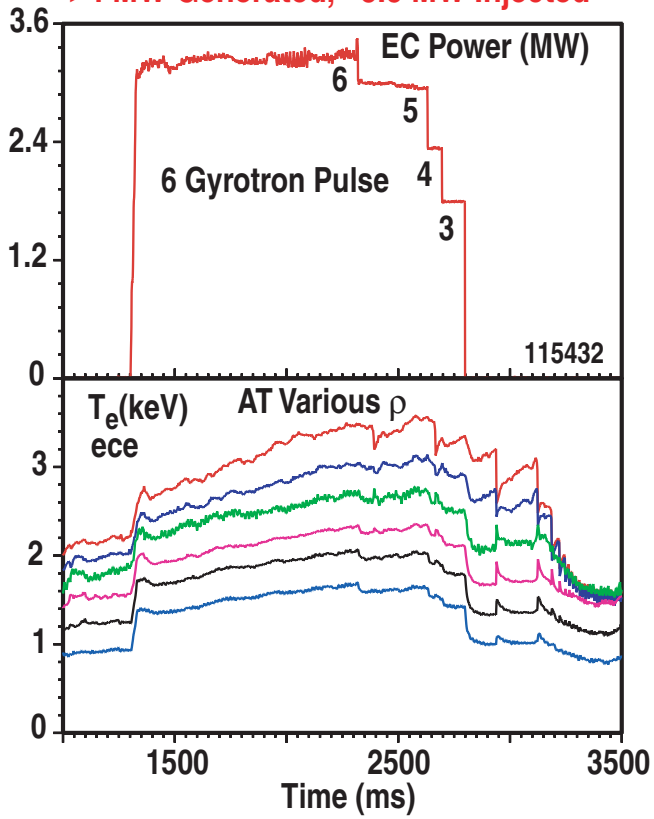
NEW CAPABILITY IN 2003: EXPERIMENTS WITH 6 GYROTRONS ADDITIONAL PPPL LAUNCHER

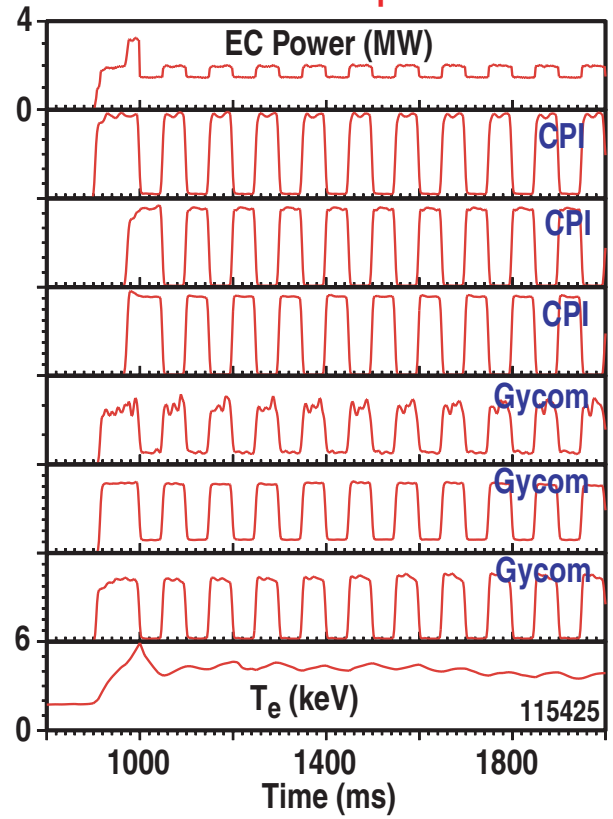
CPI Gyrotron Installation

PPPL Remotely Steerable Launcher

Steady Power Pulse:
>4 MW Generated, ~3.5 MW Injected



Slow Modulation of 6 Gyrotrons for
Current Drive Experiment



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R. Prater JR1

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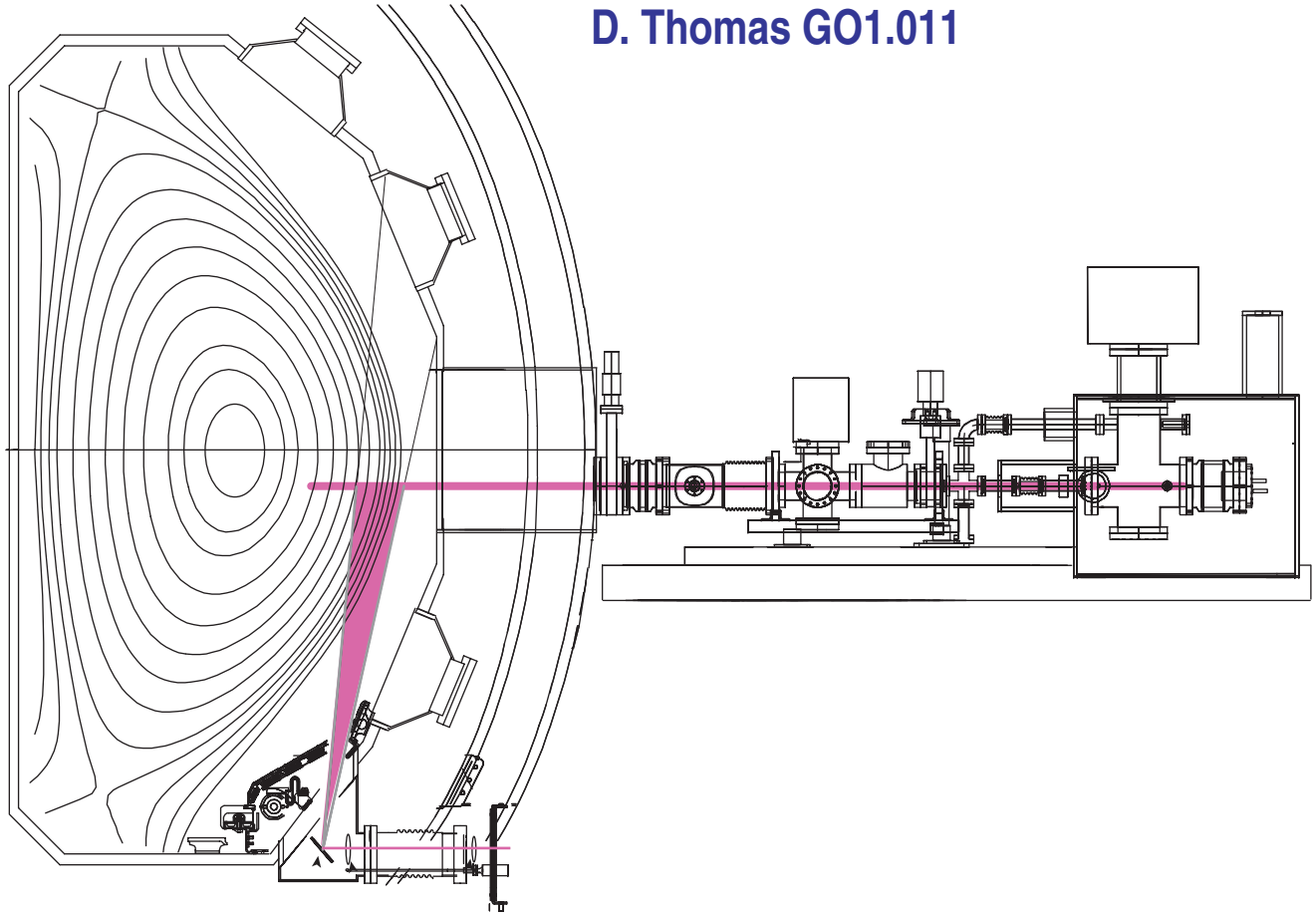
LITHIUM BEAM DIAGNOSTIC CAME ONLINE FOR MEASUREMENT OF EDGE J(r)

- Edge J(r) measured in L–and H–mode discharges
  D. Thomas GO1.011



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The DIII-D program benefits from collaborations with the NSTX and PPPL teams

Some examples:

- Modeling and experiments on dependence of beta limits on discharge shape (J. Menard, C. Kessel working with the DIII-D thrust 8 group).
- Construction of ECH antennas.
- Refurbishment, maintenance and operation of RF transmitters.
- Participation in the thrust 4 work on resistive wall mode instabilities. (M. Okabayashi)
- Analysis of poloidal rotation from CER data for comparison with neoclassical theory. (W. Solomon)
- Participation in tokamak operations. (A. Nagy)
- Many institutions that are part of the NSTX team are also collaborators on DIII-D.

KEY STRENGTH OF THE DIII–D PROGRAM IS THE INTERNATIONAL RESEARCH TEAM

>60 Participating Institutions

Come join us

Research Opportunities Forum, December 9–11, 2003
http://web.gat.com/exp/2004/forum.html

Contact: T.S. Taylor (taylor@fusion.gat.com)
D.R. Baker (baker@fusion.gat.com)

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