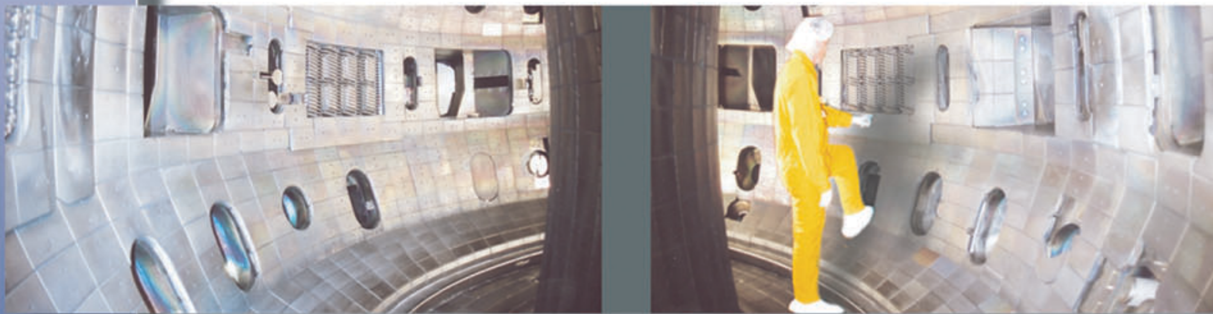

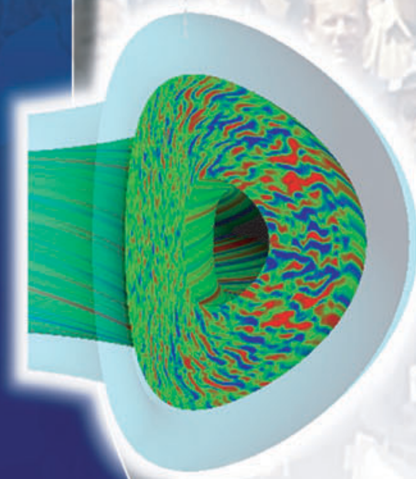

DIII–D Research Plans

DIII–D Mission: to establish the scientific basis for the optimization of the tokamak approach to fusion energy production

by
T.S. Taylor

Presented at
Office of Fusion Energy Science
FY06 Budget Planning Meeting
Washington, DC

March 16–17, 2004

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065-04/TST/rs

- We have obtained outstanding scientific results on DIII–D the last several years — many made possible by new plasma control capabilities and physics measurements

- We have an exciting program planned for the future that will provide excellent progress in

  — ITER research needs

  — High performance steady state advanced tokamak

  — Fundamental science understanding

  ⇒ We are planning additional plasma control capabilities tools and physics measurements that are critical to the success of that program

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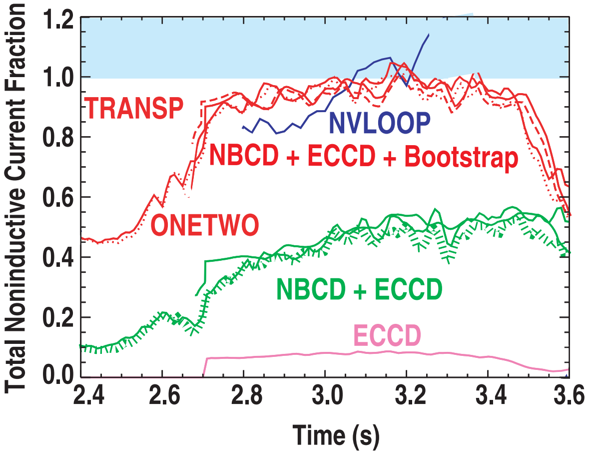
OUTLINE

- Recent (2003) Research highlights
- ITER relevant research
- DIII–D program plans
  - Steady state advanced tokamak
    - ★ MHD stabilization
    - ★ Profile control
  - Transport physics
    - ★ Pedestal
  - Mass transport in the boundary

RESEARCH HIGHLIGHTS 2003

- 100% noninductive, β_N ~ 3.5, AT discharges using higher power ECCD



- Active feedback stabilization of resistive wall modes (RWM) using newly installed internal control coils
- Increased β to β_N ~ 3.5 following ECCD stabilization of m/n = 3/2 NTM using active tracking of Shafranov shift
- Demonstrated long-pulse stationary "hybrid" operation at lower q (higher current), higher β_T, and higher density that scales favorably to ITER
- Measured current density in the edge pedestal region with using Li-Beam polarimetry — first measurement of its kind in edge region
- Demonstrated confinement scaling is independent of β in JET/DIII–D dimensionally similar experiments (ITPA)
- Developed low-frequency "MHD spectroscopy" for probing resistive wall mode physics

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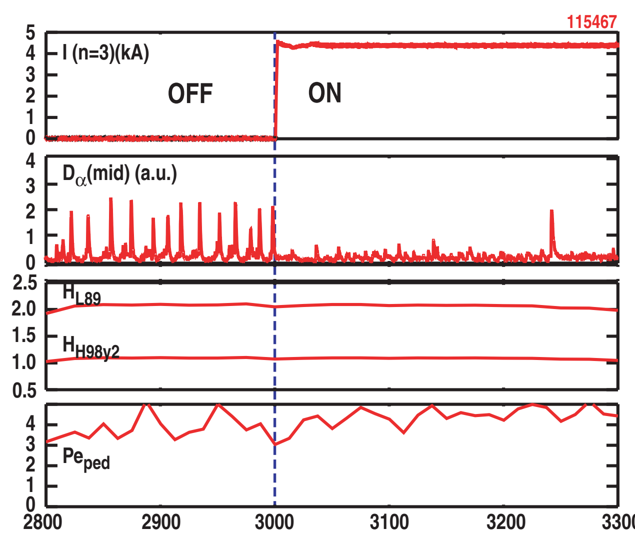
RESEARCH HIGHLIGHTS 2003 (Continued)

- JET and DIII–D experiment indicate that the H–mode pedestal width scales with machine size rather than normalized orbit size (ITPA)
- Evaluation of electron transport with modulated ECH shows no evidence of a critical Te gradient
- Continued development of ELM-free regime, QH–mode, with JET and JT-60U and increased density range at higher triangularity
- High bootstrap fraction $f_{BS} > \sim 70\%$, $\beta_N \sim \beta_P \sim 3$, $I_P \sim 0.6$ MA , $I_{NI} > 100\%$, $t_{DUR} \sim 2$ s, to evaluate interaction of transport, stability, and current profile evolution
- Made preliminary measurements of high k-turbulence with new diagnostics (diagnostic initiative)
- C13 methane injection into 22 identical discharges shows significant poloidal flow and increased co-deposition at the inner divertor leg
- Demonstrated suppression of ELMs with a stochastic edge using recently installed internal coils

— Possible ELM Solution for ITER —



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INTERNATIONAL COLLABORATORS PLAYED A KEY ROLE IN PREPARATION, EXECUTION, AND ANALYSIS OF THE STOCHASTIC EDGE PERTURBATION EXPERIMENT

- **Jeff Harris (ANU, Australia); Paul Thomas (CEA-Cadarache, France); Karl-Heinz Finken (TEXTOR,Germany); Todd Evans (GA, USA); David Pretty (ANU, Australia); Nobuyoshi Ohyabu (NIFS, Japan);and Sugura Masuzaki (NIFS, Japan)**

STRONG INTERNATIONAL INTEREST IS SHOWN IN THE 451 RESEARCH PROPOSALS FOR CY04

FOREIGN PROPOSALS

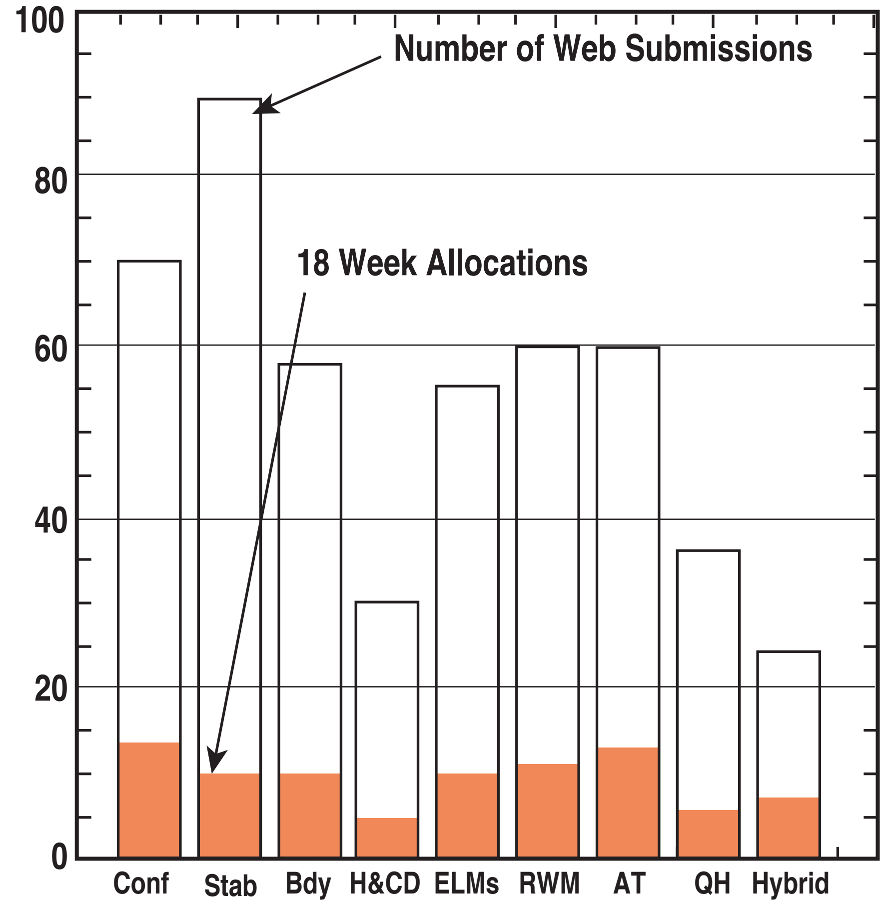
- Belgium 1
- France 4
- Germany 8
- JET 3
- Portugal 3
- Spain 2
- Italy 1
- Switzerland 3
- Russia 3
- Japan 2
- Australia 1
- England 7
- Canada 4

Foreign total: 42

DOMESTIC PROPOSALS BY INSTITUTIONS

- Columbia 29
- FarTech 2
- GA 183
- Lehigh 2
- LLNL 23
- NRL 1
- MIT 3
- ORNL 43
- PPPL 66
- SNL 9
- UCI 2
- UCLA 17
- UCSD 18
- U. Texas 4
- U. Wisconsin 6
- Unaffiliated 1

Domestic total: 409



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SCIENTIFIC PERSONNEL EXCHANGES ENHANCE COLLABORATIONS AND JOINT EXPERIMENTS

2003 -2004

to DIII–D

ELM stability
- T. Oikawa (JAERI)

RWM stabilization
- M. Takechi (JAERI)
- R. Buttery (UKAEA)
- O. Sauter (CRPP)

NTM stabilization
- R. Buttery (UKAEA)

Error fields and locked modes
- T. Hender (UKAEA)

Beta scaling of confinement
- D. McDonald (JET, Culham)

Li beam diagnostic
- H. Mueller (ASDEX)

Electron ITB's
- M. deBaar (FOM, TEXTOR)

Disruption mitigation
- P. Andrew (JET)
- J. Pale (JET)

Edge stochastization
- N. Ohyabu and S. Masuzaki (NIFS, Japan)
- P. Thomas (CEA-Cadarache)
- K.H. Finken (TEXTOR)
- T. Harris and P. Petty (ANA, Australia)

from DIII–D

QH-mode at JET
- P. Gohil
- C. Lusadi

QH-mode at JT–60U
- L. Lao
- P. Gohil
- V. Chan

RWM at JET
- R. La Haye, H. Reimerdes, M. Okabayashi

NTM at JET
- R. La Haye

Error fields and locked modes at JET
- T. Scoville

AT and hybrid scenario JT–60U
- M. Wade
- T. Luce

β scaling of τ_E (JET)
- C. Petty

ITBs (JET)
- E. Doyle

Divertor and 1st wall (ASIPP, China)
- W. West

Divertor Modeling (TRINITI) Russia
- W. West

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SCIENTIFIC PERSONNEL EXCHANGES ENHANCE COLLABORATIONS AND JOINT EXPERIMENTS

Joint Experiments through IEA/ITPA

Planned for 2004

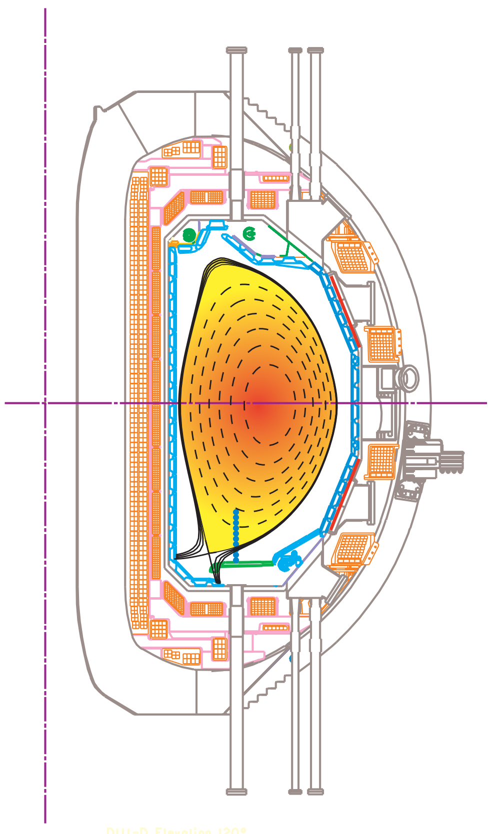
DIII–D $\longrightarrow$ 19 Topics (31/65 days)

CONTINUED RESEARCH ON DIII–D UNTIL ITER OPERATES WILL SIGNIFICANTLY ADVANCE THE RESEARCH PROGRAM ON ITER

- Major DIII–D contributions to the science basis for ITER in confinement, stability, heating and current drive, pedestal, and divertor physics, and long-pulse scenario development

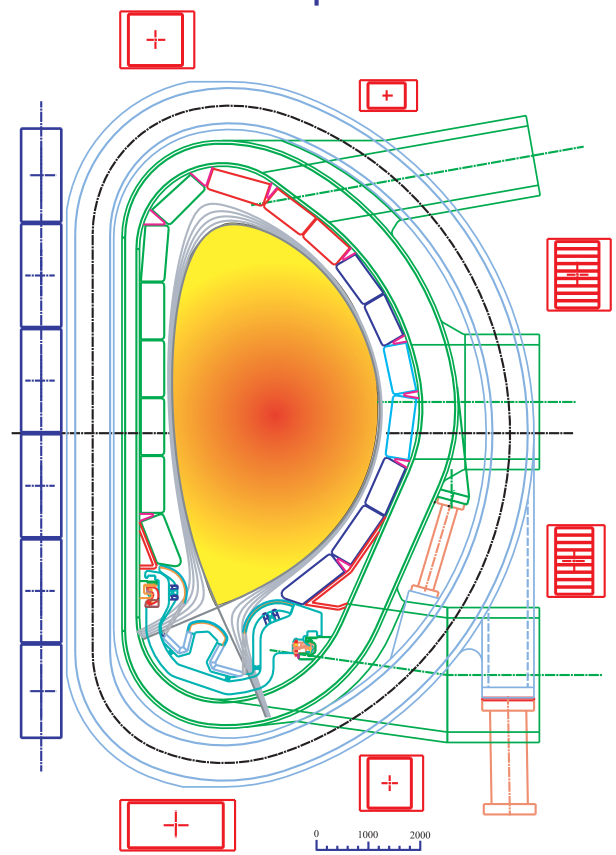
DIII–D

$\delta_{x\text{-}pt} = 0.63$



ITER

$\delta_{x\text{-}pt} = 0.58–0.68$



- DIII–D is ~1/3 scale ITER

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DIII–D CAN BE A TRAINING GROUND FOR U.S. ITER RESEARCHERS

- 20 U.S. universities participate in DIII–D now
- DIII–D has trained
  - 31 graduate students
  - 26 post doctoral fellows

- Post-Doc's work lead to significant contribution (e.g. IAEA 2004)
  - W.M. Solomon (PPPL)
  - M. Groth (LLNL)
  - H. Reimerdes (Columbia)
  - E.M. Hollman (UCSD)

- DIII–D can train more young researchers for ITER and the fusion program

DIII–D PROGRAM ELEMENTS ADDRESS KEY ITER ISSUES

— In cooperation with our ITER partners and the International Tokamak Physics Activity —

Advanced Tokamak

- Develop long pulse, high performance discharges for ITER
  - Hybrid scenarios
  - Full noninductive steady-state Advanced Tokamak scenario
- MHD stabilization
  - Neoclassical tearing mode stabilization
  - Resistive wall mode stabilization
- Disruption mitigation
- Validate models of ECCD and FWCD

Transport

- Develop core transport models
  - To validate performance projections
  - To guide ITER operation
- H–mode pedestal understanding and control
  - Predictive capability of the pedestal height
  - ELM mitigation

Mass Transport

- In-depth understanding of the process contributing to impurity and tritium mass transport
  - Erosion, redeposition, ELMs; measure flows
- Reduction of heat flux to the divertor, radiative divertor

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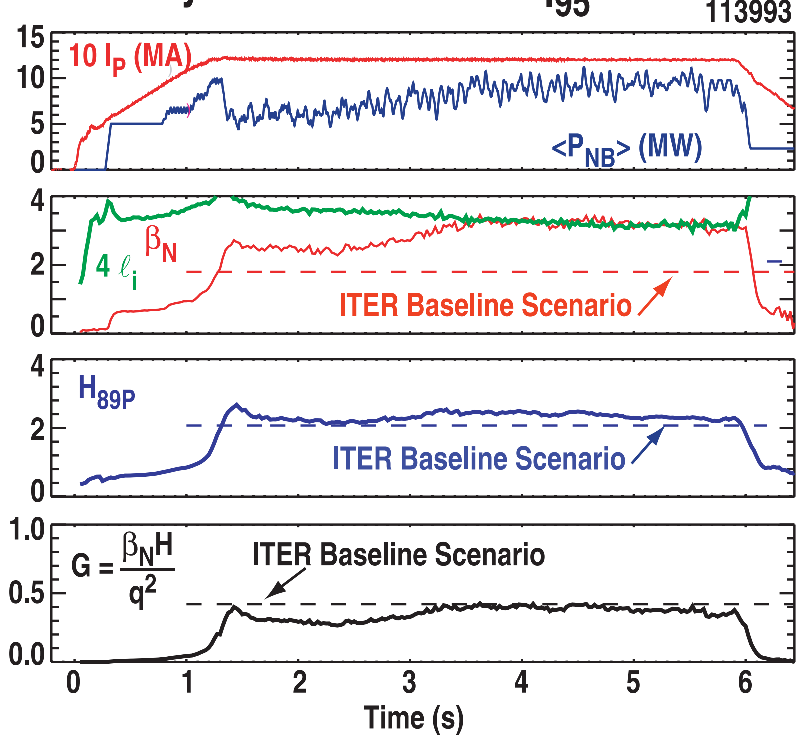
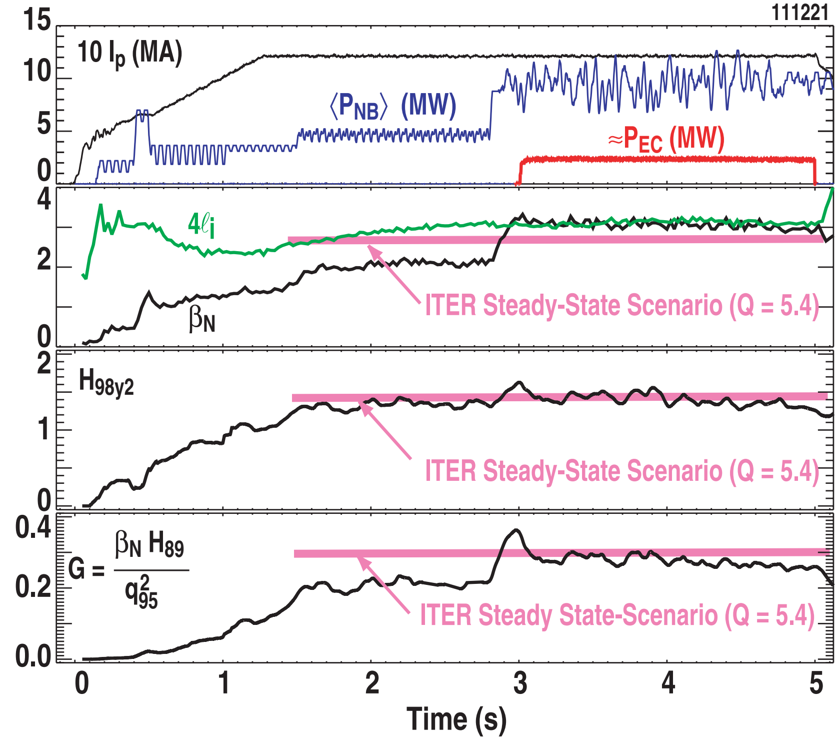
STEADY-STATE *AT* AND STATIONARY "hybrid" SCENARIOS ARE DEVELOPING THE BASIS FOR ITER LONG PULSE DISCHARGES

Hybrid no Sawteeth q_{95} = 4.4



Full non-inductive AT



ITER projection	Hybrid	Full non-inductive AT
	$\beta_N = 3.2$	$\beta_N = 3.2$
	$H_{98y2} = 1.6$	$H_{98y2} = 1.6$
	$Q_{Fus} \approx 5$	$Q_{Fus} \sim 5$
	τ_{DUR} = 5500 s	$\tau_{DUR} = \infty$ (physics)

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OUR VISION: BY THE TIME ITER OPERATES, ADVANCED LONG-PULSE OPERATIONAL SCENARIOS WILL BECOME THE NEW REFERENCE

— Requires Continued Development of Physics by All ITER Partners —

— Examples: hybrid, steady-state AT (weak shear, high ℓ_i) —

- May avoid issues with ITER baseline (inductive) scenario
  - NTM
  - Sawteeth
  - High current disruptions
- Expands operational space to evaluate a range of burning plasma physics
  - Ex: high T, (lower n_e) and range of magnetic shear to evaluate Alfvén eigenmodes
- Will allow testing of fusion energy components including blankets
- Establishes strong case to move forward with DEMO

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
⇒ Validated performance projections
⇒ Guidance for BP operation

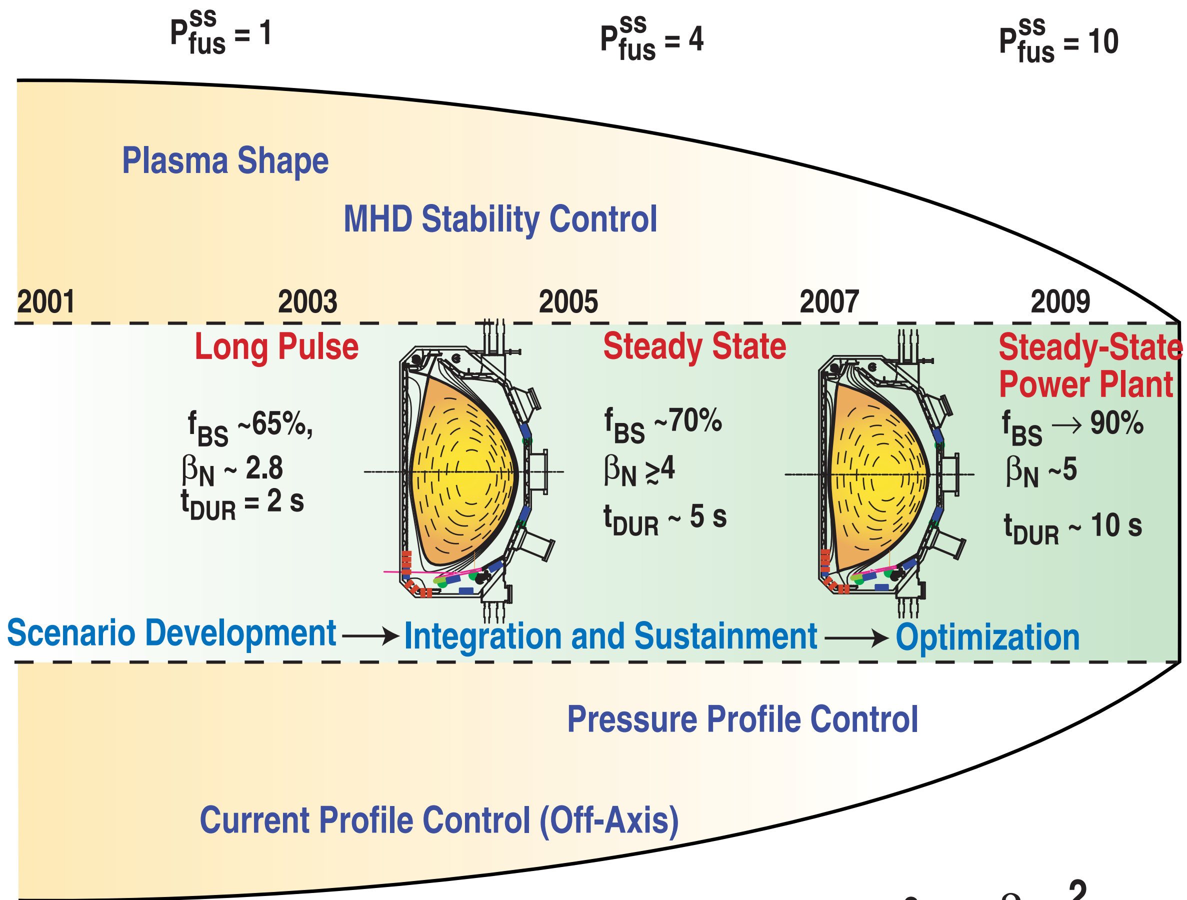
- **Mass transport in the boundary**
  - Measure flows, erosion and redeposition
  - Measure ELM effects
  - Integrated modeling of the boundary

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

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

THE CORE OF THE DIII–D ADVANCED TOKAMAK PROGRAM PLAN IS SCENARIO DEVELOPMENT, INTEGRATION, AND OPTIMIZATION

— Plasma control is a key element of the Advanced Tokamak Program —



Key Progress

- Increase projected fusion power ~ factor of 10
- Increase advanced tokamak duration ~ factor of 5
- Reduce driven current ~ factor of 4
- Approach fully bootstrap driven

J(ρ) control → P(ρ) control

$$\beta_T \beta_p = 25 \left(\frac{1 + \kappa^2}{2}\right) \left(\frac{\beta_N}{100}\right)^2$$

$$P_{fus} \propto \beta_T^2 B^4 \rightarrow \text{ss} \rightarrow \tilde{\propto} \beta_N^4 B^4$$

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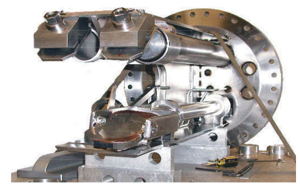
248-03/TST/wj

KEY PLASMA CONTROL TOOLS ARE PLANNED

Key Hardware Element | **Physics/Control**

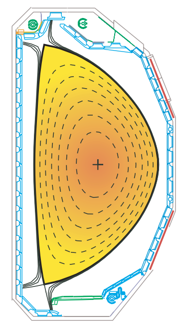
- **Long-pulse EC systems**

	Present		Plan		
LP	3	⇒	6	⇒	8
SP	3	⇒	0		



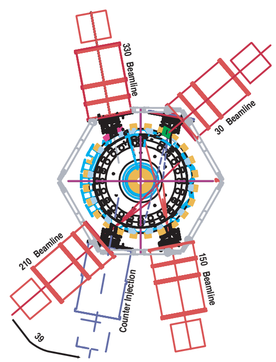
— $J(\rho)$ control
— $P(\rho)$, transport studies
— NTM stabilization

- **High δ divertor**



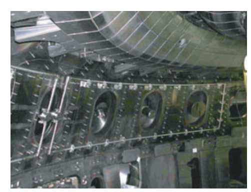
— n_e control in DND

- **Counter NBI**



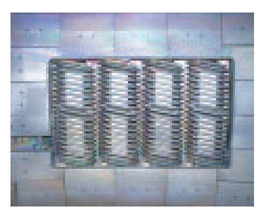
— Transport
— RWM (low rotation)

- **Internal coil**
  — High bandwidth actuators



— RWM feedback
— Stochastic edge

- **FW system operation**
  — ABB ⇒ EIMAC tubes



— J (ρ~0) and $P(\rho)$ control
— β_e↑ for improved current drive efficiency

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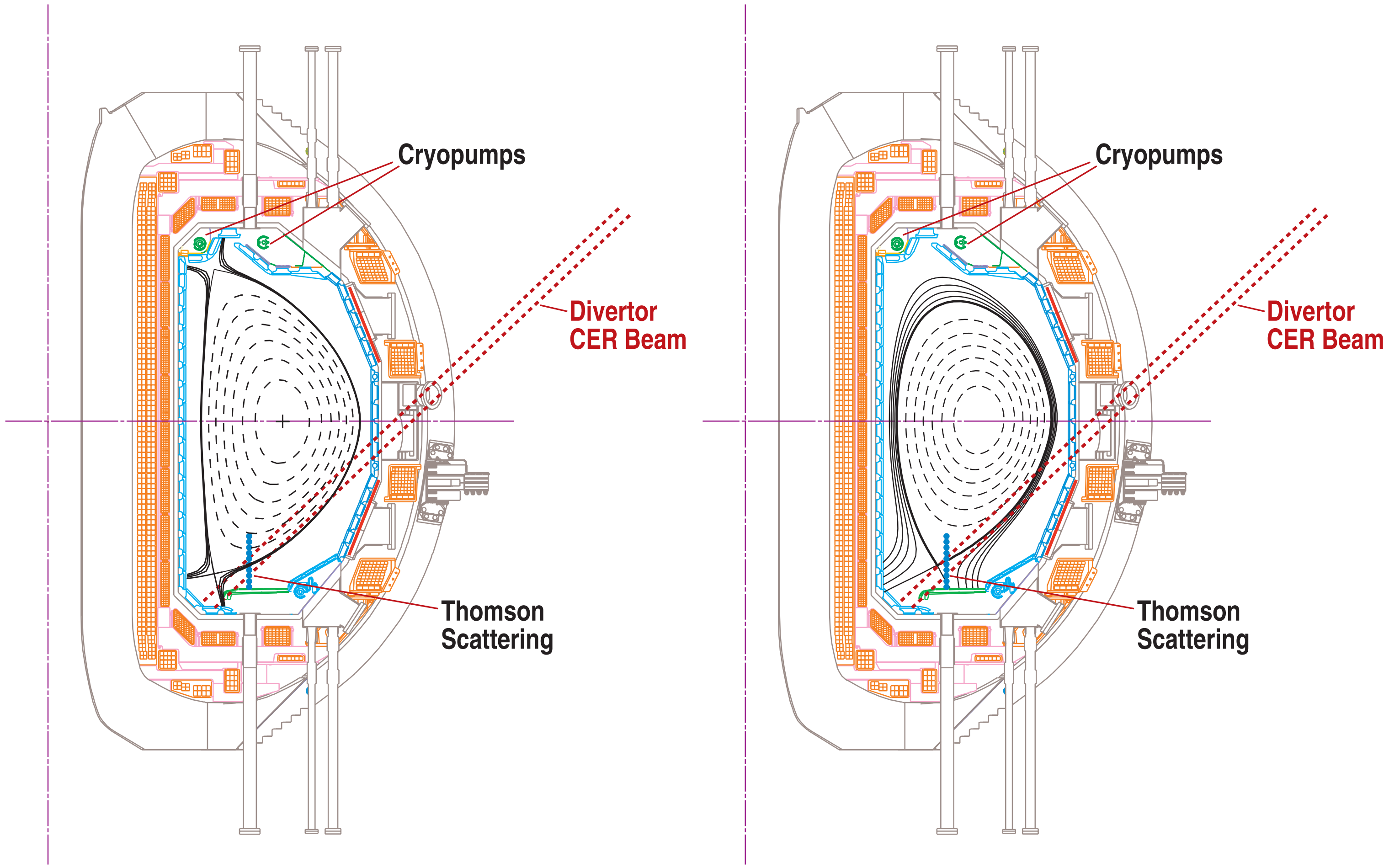
A SIMPLE LOWER DIVERTOR MODIFICATION WILL ENABLE DENSITY CONTROL IN OUR MOST PROMISING HIGH PERFORMANCE PLASMAS AND IMPROVE DIVERTOR RESEARCH



- 15-20% gain in β_N for double null
  (> 30% possible with optimized profiles)

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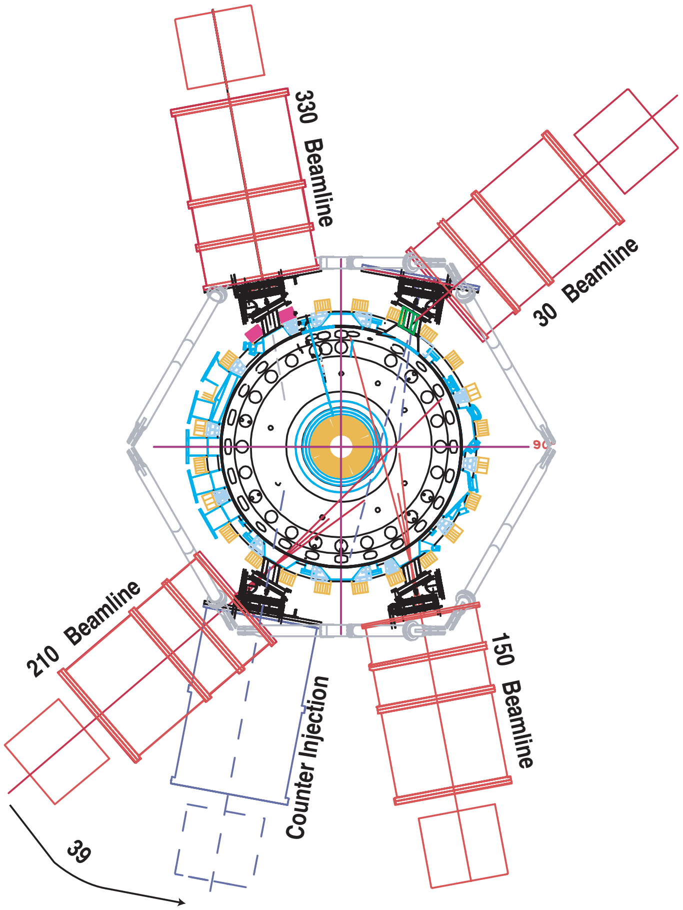
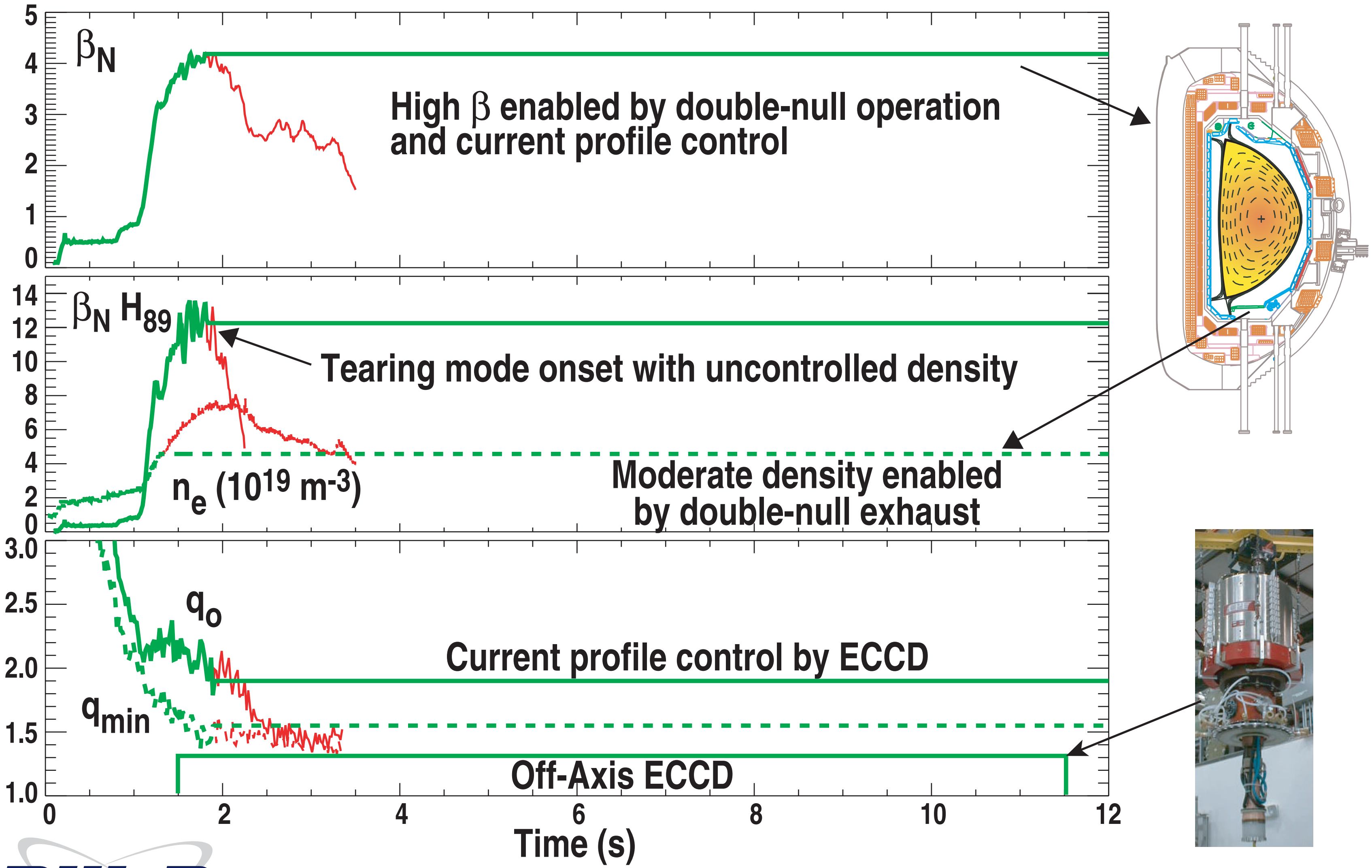
A BEAMLINE REVERSAL IS NECESSARY FOR NEW PHYSICS STUDIES AND IMPROVED PLASMA MEASUREMENTS



- QDB regime with central co-rotation
- Understanding physics of rotation
- RWM stability with low rotation
- NTM stabilization with modulated rf
- Transport barrier control (separate E×B and Shafranov shift effects)
- Separate E_r and J(r) in MSE measurement
- Co and counter CER
- Evaluate very high bootstrap fraction *AT* plasmas

CURRENT PROFILE AND DENSITY CONTROL WILL ENABLE LONG PULSE HIGH PERFORMANCE

- Long pulse gyrotrons for off-axis current drive
- Lower divertor modification to provide density control in strongly shaped plasmas



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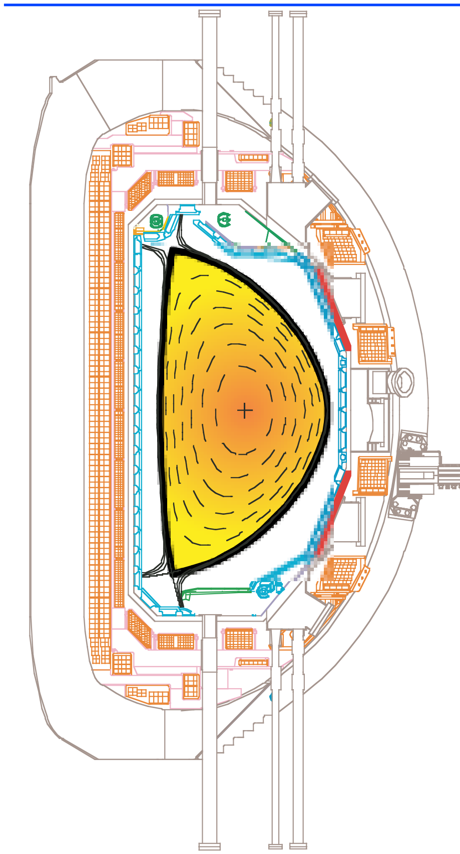
THE LOWER DIVERTOR MODIFICATION IS ESSENTIAL FOR ADEQUATE DENSITY CONTROL IN DOUBLE-NULL

MEASUREMENTS IN PRESENT CONFIGURATION

Fraction of neutral beam particles removed	Upper Single Null	Double Null
Upper Inner Pump	54%	26%
Upper Outer Pump	40%	36%
Total	94%	62%
Missing pumping capacity	6%	38%

NEW CONFIGURATION



- Lower outer pump can supply the missing pumping capacity if the shelf is installed so that the pump can engage the plasma

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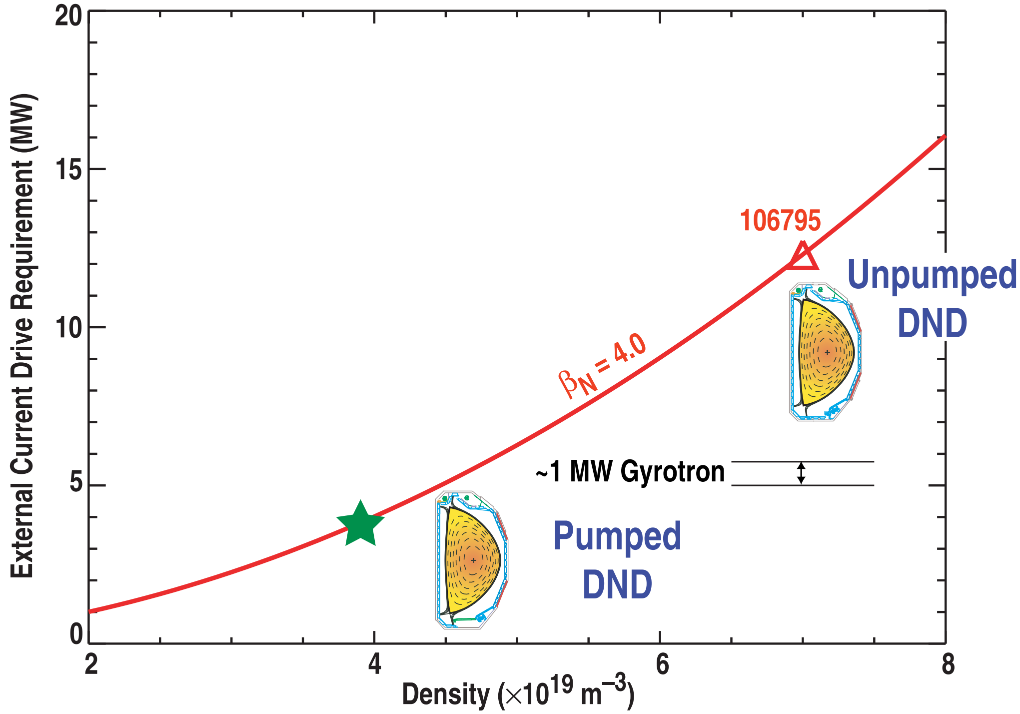
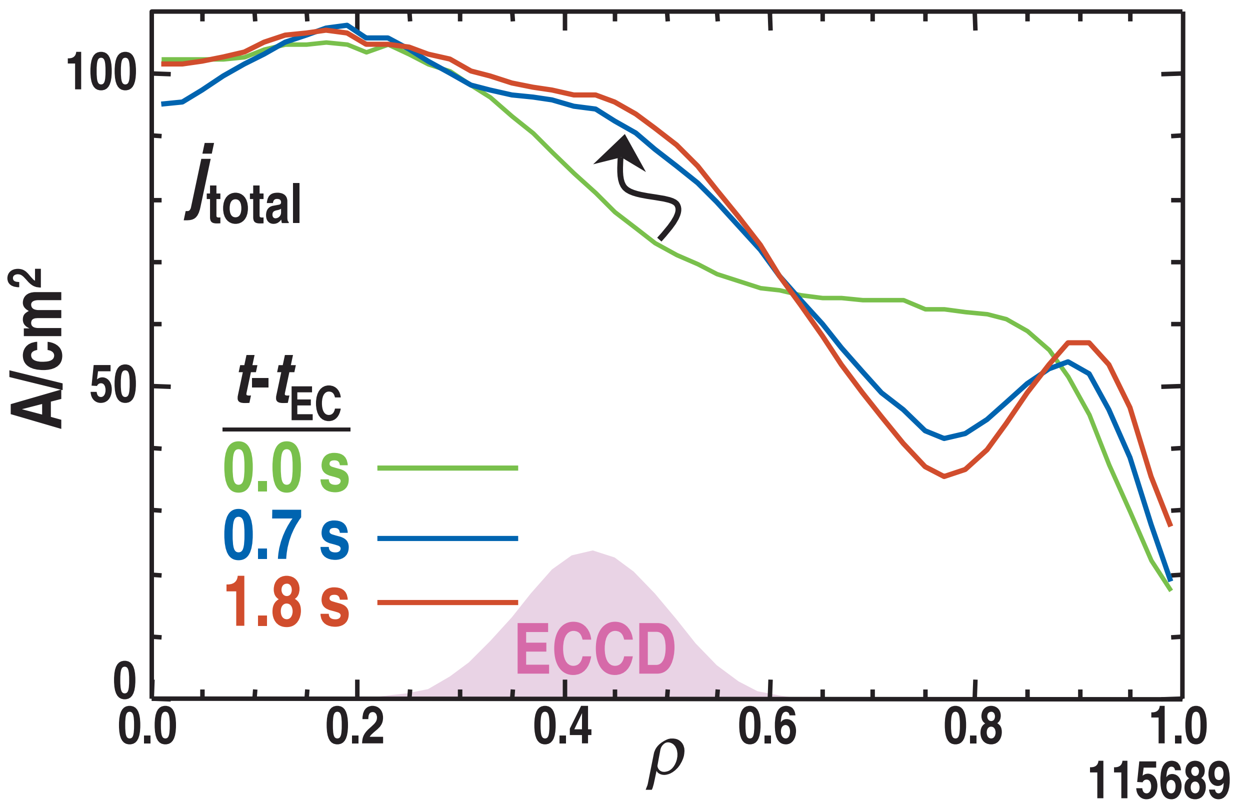
PUMPING THE DOUBLE NULL IS WORTH ~8 MW OF CURRENT DRIVE POWER

$$P_{CD} \propto \frac{n_e^2\, a\, R\, (1 - C_{BS}\sqrt{\varepsilon}\,\beta_P)}{\beta_N\, B}$$ for full non-inductive



- New tools provide flexibility to examine an expanded operating range
  - Improve β_N through shaping
  - Long pulse gyrotrons for CD
  - Density control to modify η_{CD}

PRESENT EC POWER LEVELS (2.5 MW) HAVE SHOWN OFF-AXIS ECCD CAN PREVENT INWARD CURRENT PENETRATION



- More long pulse EC power is needed farther off-axis for our planned steady-state scenarios

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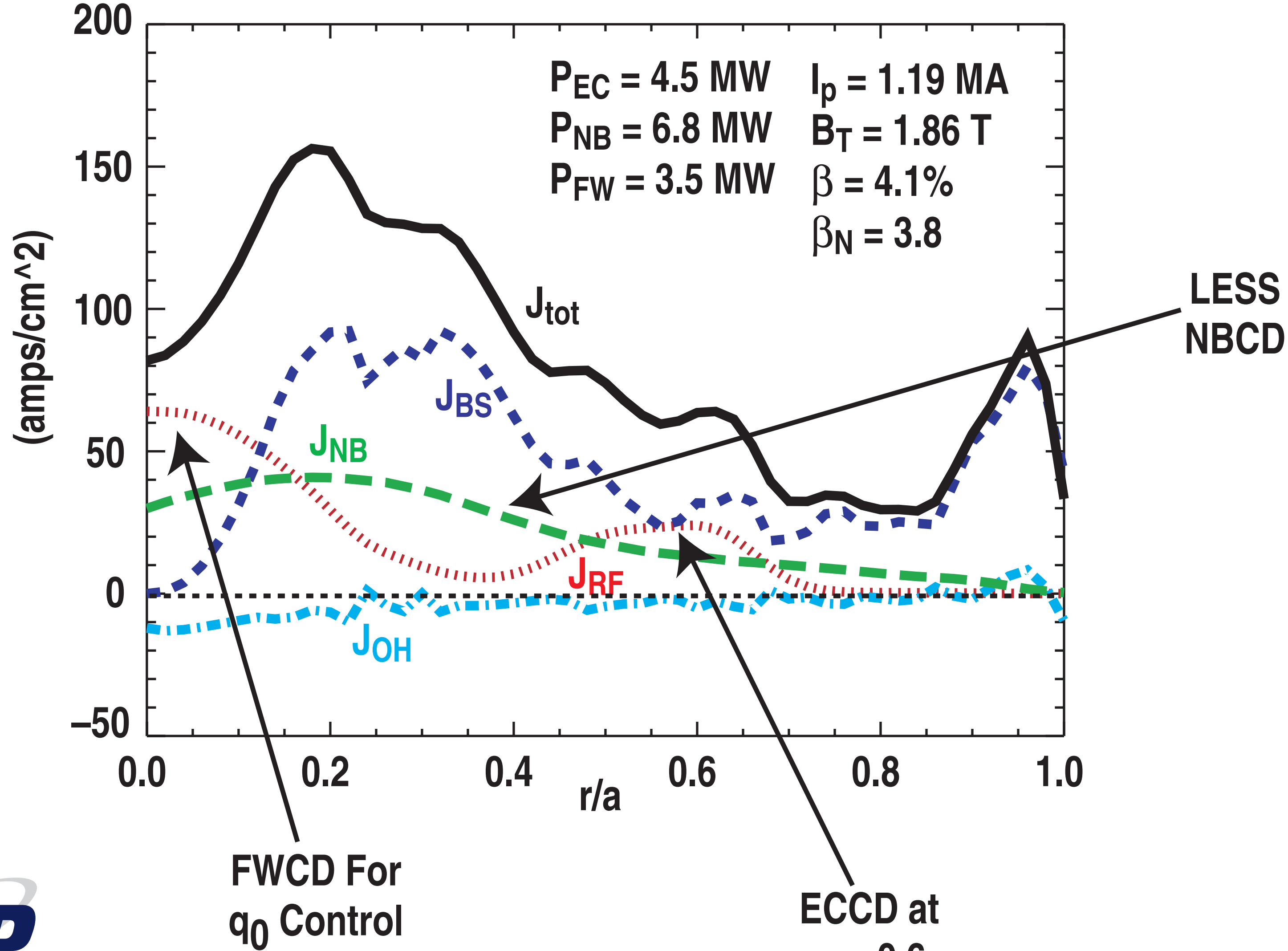
SIMULATIONS SHOW STEADY-STATE OPERATION SHOULD BE POSSIBLE WITH 6-7 LONG PULSE GYROTRONS AND DENSITY CONTROL



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DIII–D ADVANCED TOKAMAK PLANS FOR 2004-2006

- Plans for 2004-5
  - Complete optimization of 100% noninductive NCS at high beta with single-null divertor configuration
  - Study transport and stability in alternate q profile scenarios
    - ★ Flat q
    - ★ Extremely hollow current profiles (“current hole”)
    - ★ High ℓ_i ($q_0 \leq 1$)
  - Evaluate fast wave coupling and current profile modification in AT plasmas
  - Develop real-time current profile control

- Plans for 2006
  - Evaluate physics of fully noninductive discharges with relaxed current density profiles, $t_{DUR} > 5$ s (long-pulse gyrotrons)
  - Compare transport and stability in long-pulse steady-state discharges with single- and double-null divertor geometries (lower divertor)
  - Improved current profile control (long-pulse gyrotrons, fast-wave and advanced control algorithms)
  - Evaluate physics of plasmas with self consistent profiles and reduced I_{NBCD} (counter-NBI)

MHD STABILITY AT HIGH BETA IS ESSENTIAL FOR ADVANCED SCENARIOS IN DIII–D AND ITER

Plans for FY 04–05

- Compare RWM feedback control with internal vs. external coils
  — Plasma rotation reduced by resonant, non-resonant magnetic perturbations
- Initial assessment of RWM control with extended bandwidth feedback system
- Raise beta with NTM suppression by ECCD
- Validate models of gas jet penetration for disruption mitigation
- Validate the role of bootstrap current in edge stability

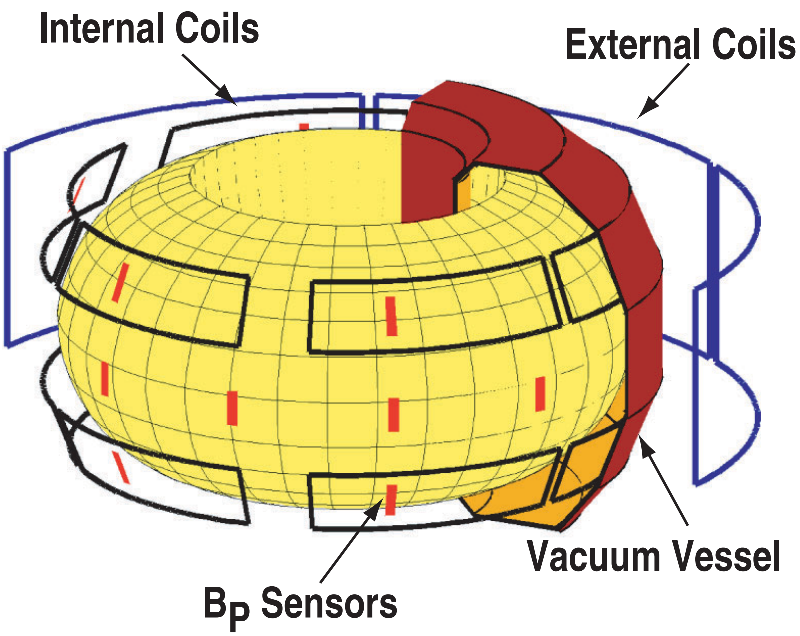
Plans for FY 06

- Explore RWM feedback stabilization with controlled plasma rotation (counter NBI)
- Begin experiments on NTM stabilization with modulated current drive

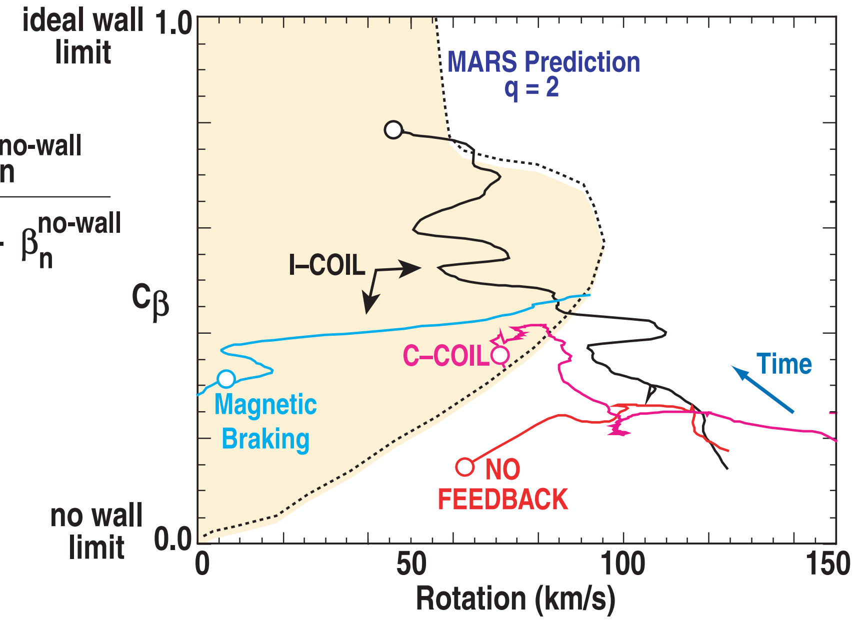
  ⇒ Power requirements for ITER

NEWLY INSTALLED INTERNAL CONTROL COILS: AN EFFECTIVE TOOL FOR ACTIVE AND PASSIVE STABILIZATION OF THE RWM

- Key relevance to ITER, FIRE, CTF, and other magnetic configuration (ST, RFP...)
- Active feedback: $\beta_N > \beta_N^{\text{no wall}}$ without rotation (high bandwidth actuators)



$$C_\beta = \frac{\beta_n - \beta_n^{\text{no-wall}}}{\beta_n^{\text{ideal-wall}} - \beta_n^{\text{no-wall}}}$$



- RWM control expands operating space for ITER steady-state AT scenarios
  – Optimal use of external coils or simple design for internal coils

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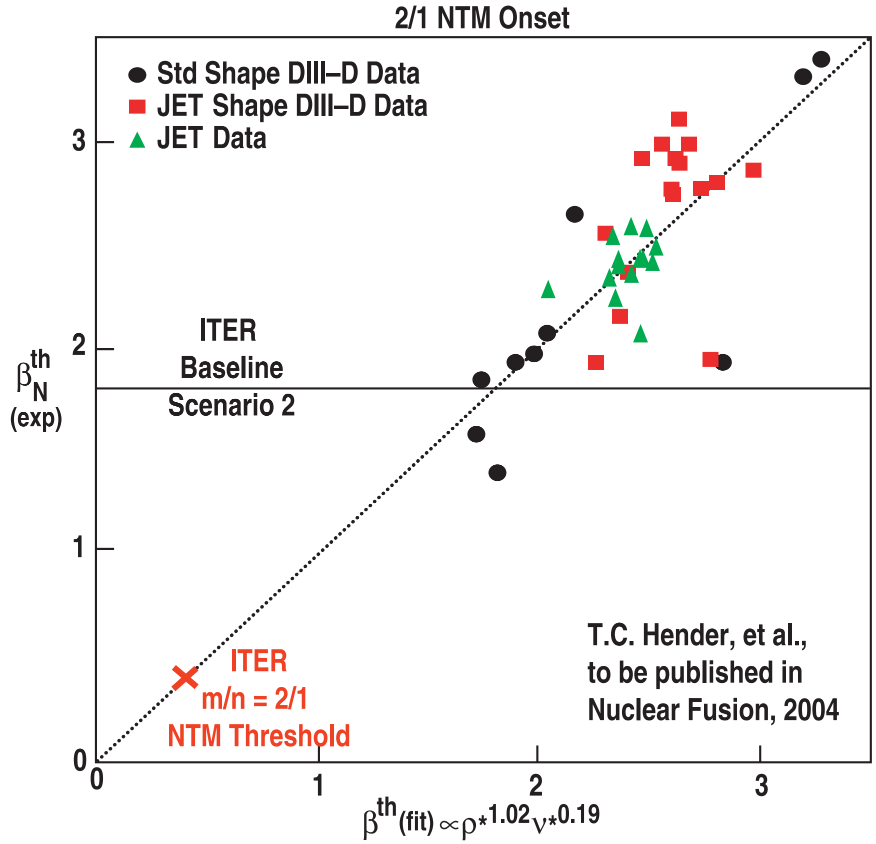
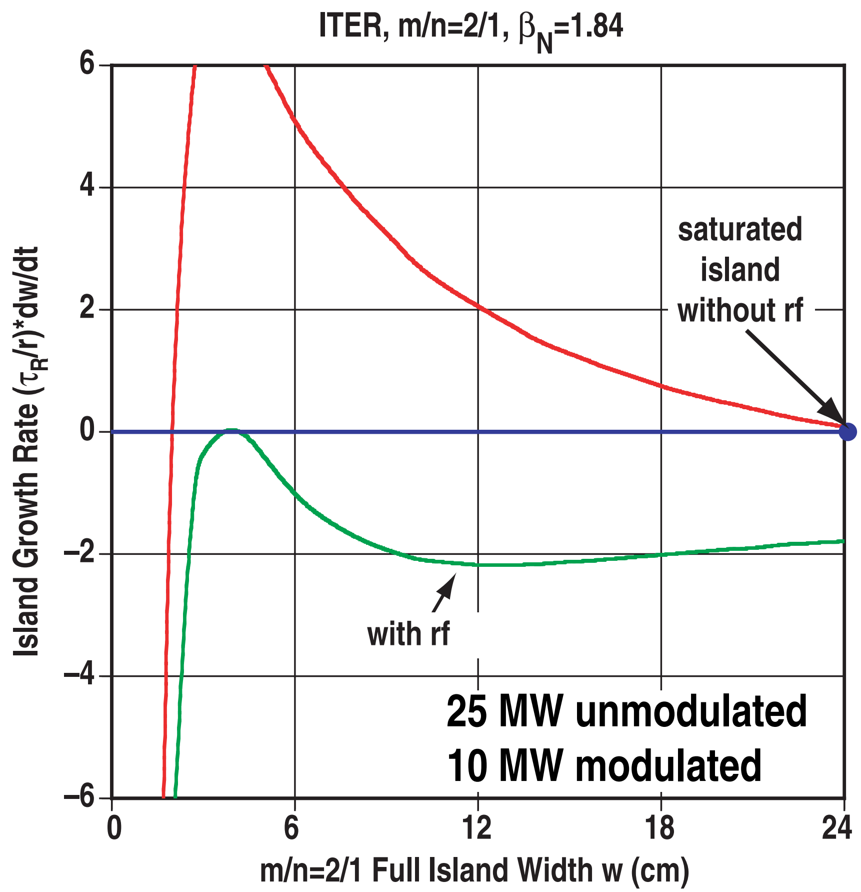
DIII–D NTM RESEARCH AIMED AT SUPPORTING ITER STABILIZATION OF 2/1 NTMs

- Needed for ITER baseline (inductive) scenario





DIII–D Plans

- Evaluate NTM stabilization with EC applied before NTM onset
  - Track rational surface with real-time q-profile reconstruction
- Validate gain in effectiveness of EC for modulated EC (10 MW vs 25 MW)
  - Counter NBI is effective tool to reduce rotation

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PROFILE CONTROL IS A KEY FOCUS OF HEATING AND CURRENT DRIVE RESEARCH

PLANS 04-05

- Electron cyclotron current drive ECCD
  - Far off-axis current drive ($\rho > 0.5$) to extend validation of models (2/1 NTM stabilization for ITER)
  - ECCD efficiency at high T_e and high power density
  - Control of $J(\rho)$ in AT scenarios
- Fast wave current drive FWCD
  - Antenna coupling to high performance ELMing H–mode
  - FWCD efficiency in the strong absorption regime (high T_e, β_e with EC)

PLANS 2006

- Active profile control with ECCD (off-axis) and FWCD (on-axis)
- Measure absorption of FW power on fast ions $\rightarrow$ relevant to ST
- Extend bootstrap production ($f_{BS} \gtrsim 90\%$) with balanced beam and high power EC and FW to evaluate profile evolution

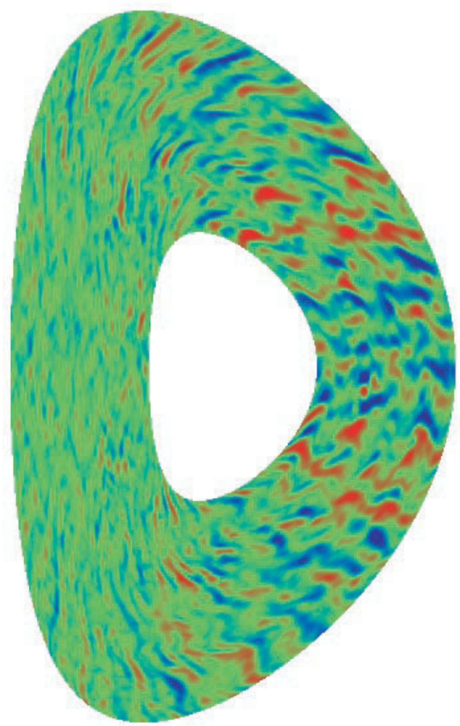
THE DIII–D PROGRAM PLANS A FOCUSED EFFORT ON UNDERSTANDING TURBULENT TRANSPORT

— As part of a community-wide effort, in concert with TTF —

- **Primary goal is predictive understanding of transport**

  DIII-D goal: to play a lead role in a national effort to understand the basic physics processes by which plasma turbulence produces cross field transport and to use that knowledge to control transport

- **For the first time, codes contain essential physics needed for meaningful comparison with experiment**
  - Kinetic ions and electrons at finite beta
  - Complete two dimensional geometry
  - Finite gyroradius
  - Profile variation (q, T_e, T_i, E×B flow...)
  - Self consistent E×B shear flow



Fusion SciDAC Computing Initiative

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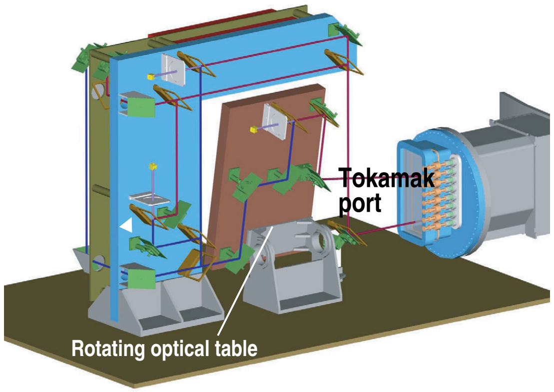
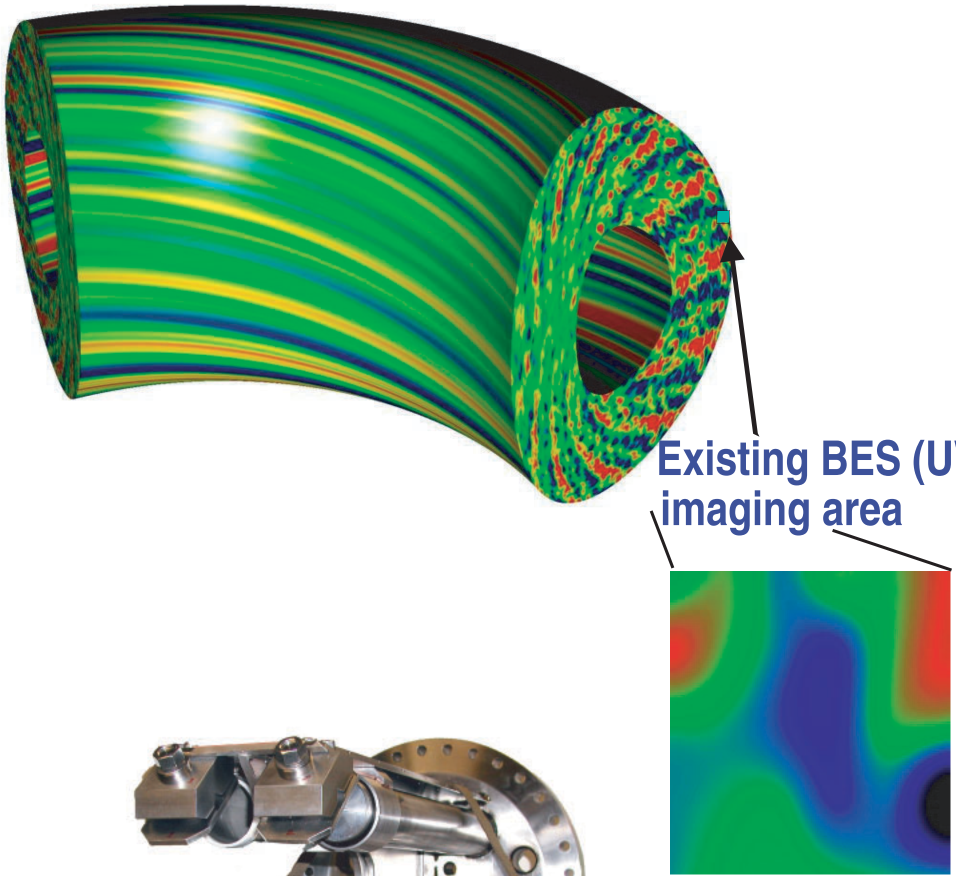
⇒ **New diagnostic measurements and more computer power are essential for this comparison**

277–03/RDS/wj

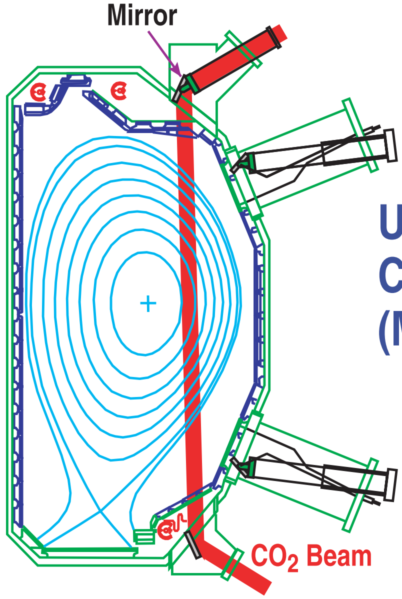
NEW TURBULENCE MEASUREMENTS NEEDED FOR SMALL SPATIAL SCALES AND 2-D IMAGING



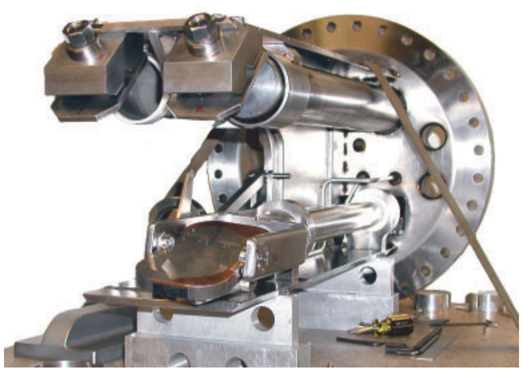
Enhanced spatial resolution high-k scattering (UCLA)



Existing BES (UW) imaging area



Upgraded Phase Contrast Imaging (MIT)



Microwave backscattering (UNM, UCLA, PPPL)

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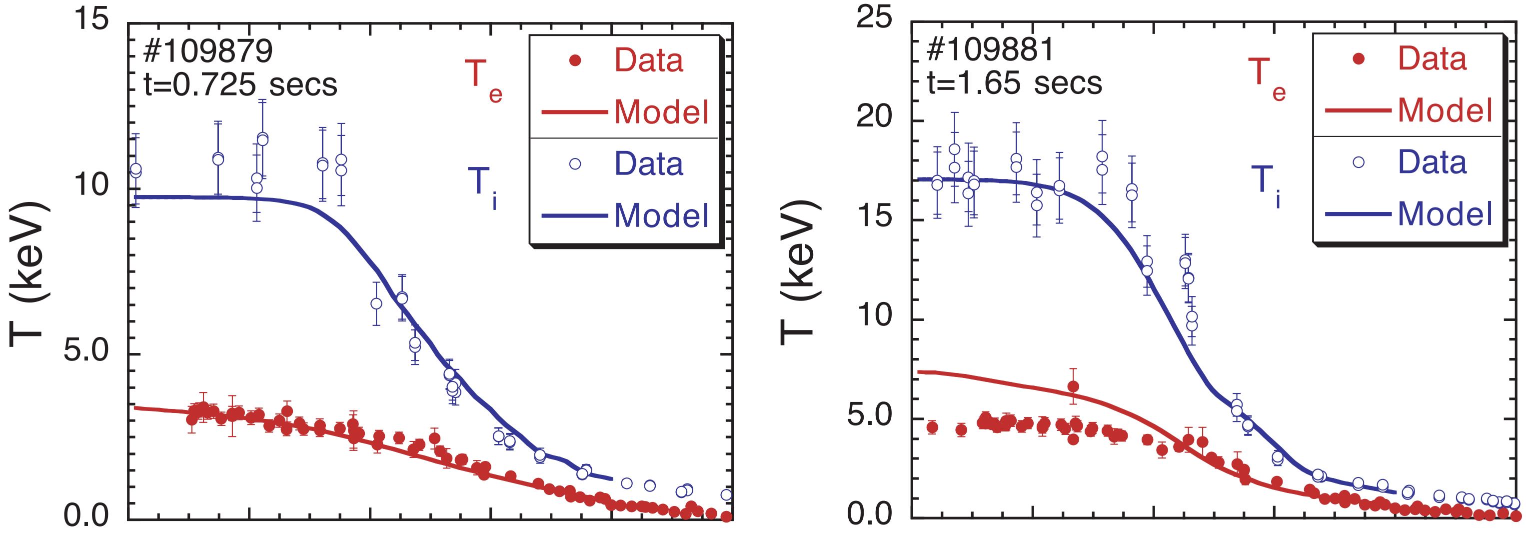
EXPERIMENTS IN 2004–2006 ADDRESS OUR TRANSPORT GOALS

- Turbulence characterization
  - Zonal flow studies using upgraded BES
  - Detailed studies of edge turbulence across L–H transition
- Electron thermal transport
  - Use short wavelength turbulence measurements to experimentally determine effect of a short scale turbulence
  - Investigate critical gradient effects (with ASDEX-U)
  - Use co plus counter NBI to separate effects of Shafranov shift and $E \times B$ shear stabilization
- Angular momentum transport
  - Investigate rotation without torque (RF heated plasmas)
  - Separate effects of heating and torque using co plus counter NBI
- Experiments are designed to investigate key aspects of theories
  - Zonal flows, ETG (short wavelength turbulence)

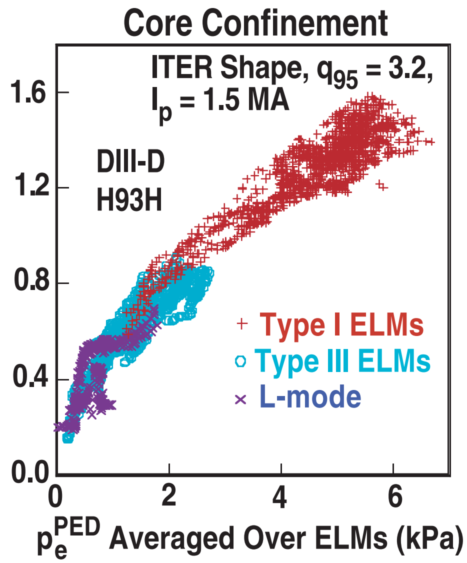
DEVELOPING VALIDATED TRANSPORT MODELS IS ESSENTIAL FOR ITER OPTIMIZATION

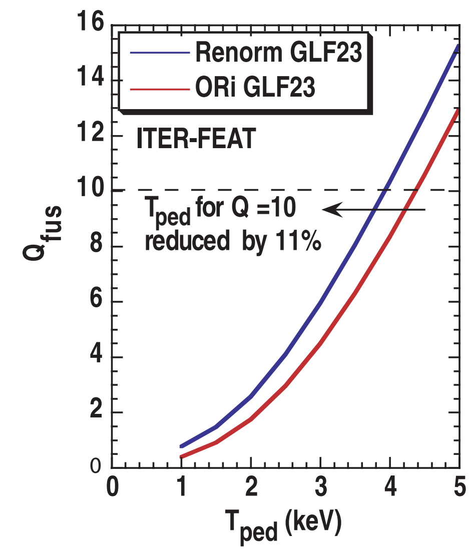
- Developing all ITER operating scenarios will require extensive modelling before the discharges are run
  - Validated predictive transport models will be essential for this
- GLF23 model is being validated through experimental tests
  - Example shown is from experiment investigating effects of Shafranov shift and ExB shear



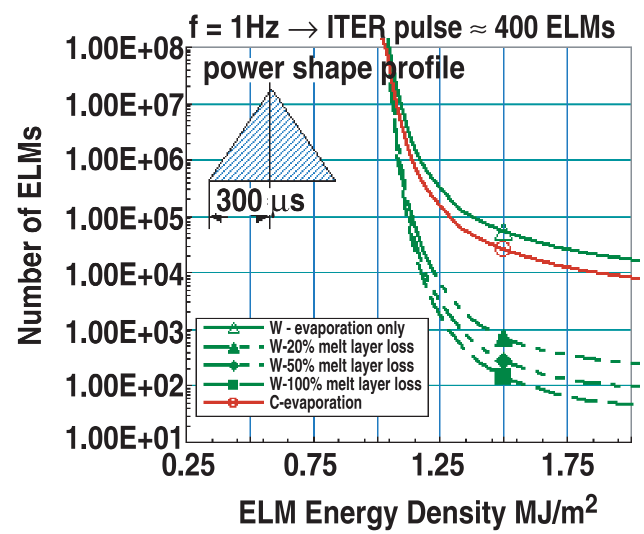
H–MODE PEDESTAL PHYSICS IS ESSENTIAL FOR ITER

- Pedestal height determines core performance





- ELM damage determines component lifetime



037-04/TST/jy

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PEDESTAL PHYSICS PLANS IN FY04-05 AND FY06

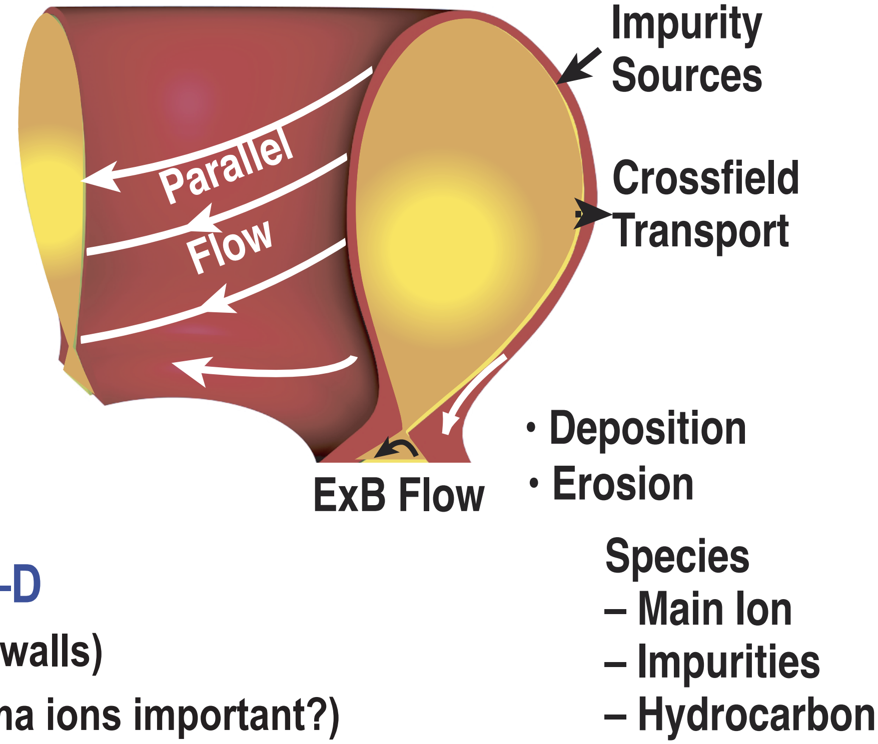
- **FY04-05 Plan**
  - Validate peeling - ballooning physics model of ELM onset including measured j_{edge}
  - Test scaling models of pedestal width and height **(ITPA)**
  - Test models of stochastic magnetic perturbation on edge transport and ELMs **(ITER)**
  - Evaluate the pedestal physics processes that produce the extremely high pedestals in VH-mode and extend VH-mode duration
  - Develop physics understanding of QH-mode and expand operating regime **(ITPA)**

- **FY06 Plan**
  - Develop a physics based understanding of H-mode pedestal structure, ELM instability and ELM energy loss for extrapolation to ITER
  - Apply pedestal physics models to develop ITER relevant techniques for Type-I ELM mitigation and control (edge stochasticity) or avoidance (Type-II regime)
  - Evaluate ELM-free H-mode scenarios (QH/QDB) with co-counter beam mix **(ITER)**

BOUNDARY SCIENCE ADDRESSES KEY ITER ISSUES

What is "Mass Transport" and why is it ITER relevant?

- **Plasma fueling (deuterium and tritium)**
  - Important for understanding core fueling
  - Density control with active pumping
  - On DIII-D, core recycling control



- **Impurity transport – primarily carbon in DIII–D**
  - What is the source of carbon? (divertor or main walls)
  - Is carbon sputtering physical or chemical (plasma ions important?)
  - How is carbon transported in the SOL and divertor regions?
    - ★ SOL flow, "blobby transport"
  - Where is the carbon re-deposited, and what is its form?
    - ★ C13 tracer experiments, quartz microbalances

Key research for ITER because the largest tritium inventory is expected to be co- deposited with carbon

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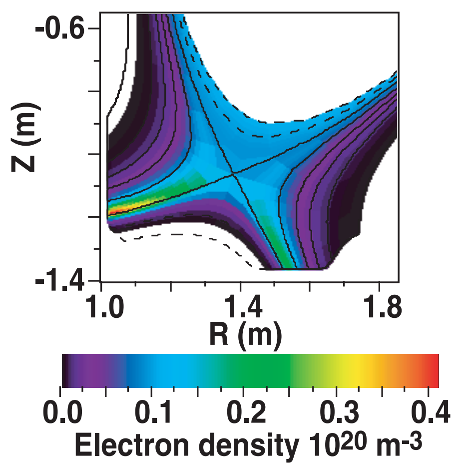
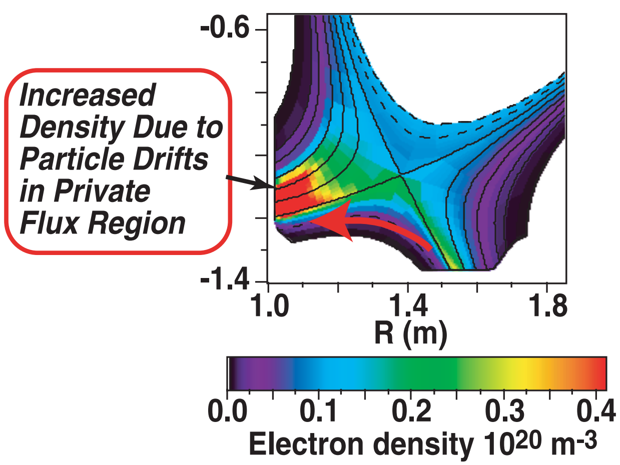
NEW MEASUREMENTS ARE ESSENTIAL TO UNDERSTANDING MASS TRANSPORT IN THE PLASMA BOUNDARY

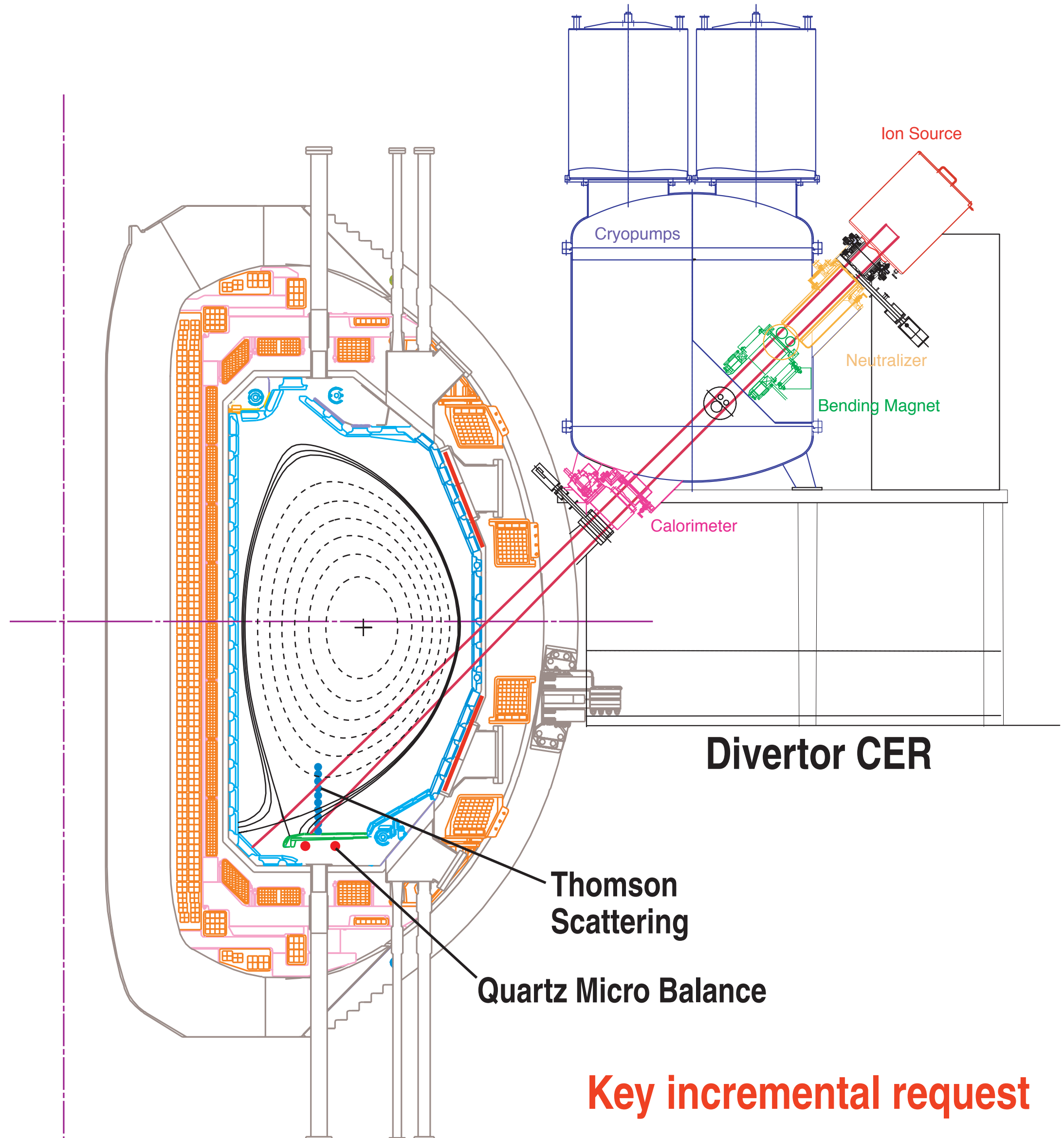
New measurements of divertor T_i and V open new frontiers in edge physics

n_e *Without* Drifts UEDGE Fluid Code



n_e *With* Drifts UEDGE Fluid Code





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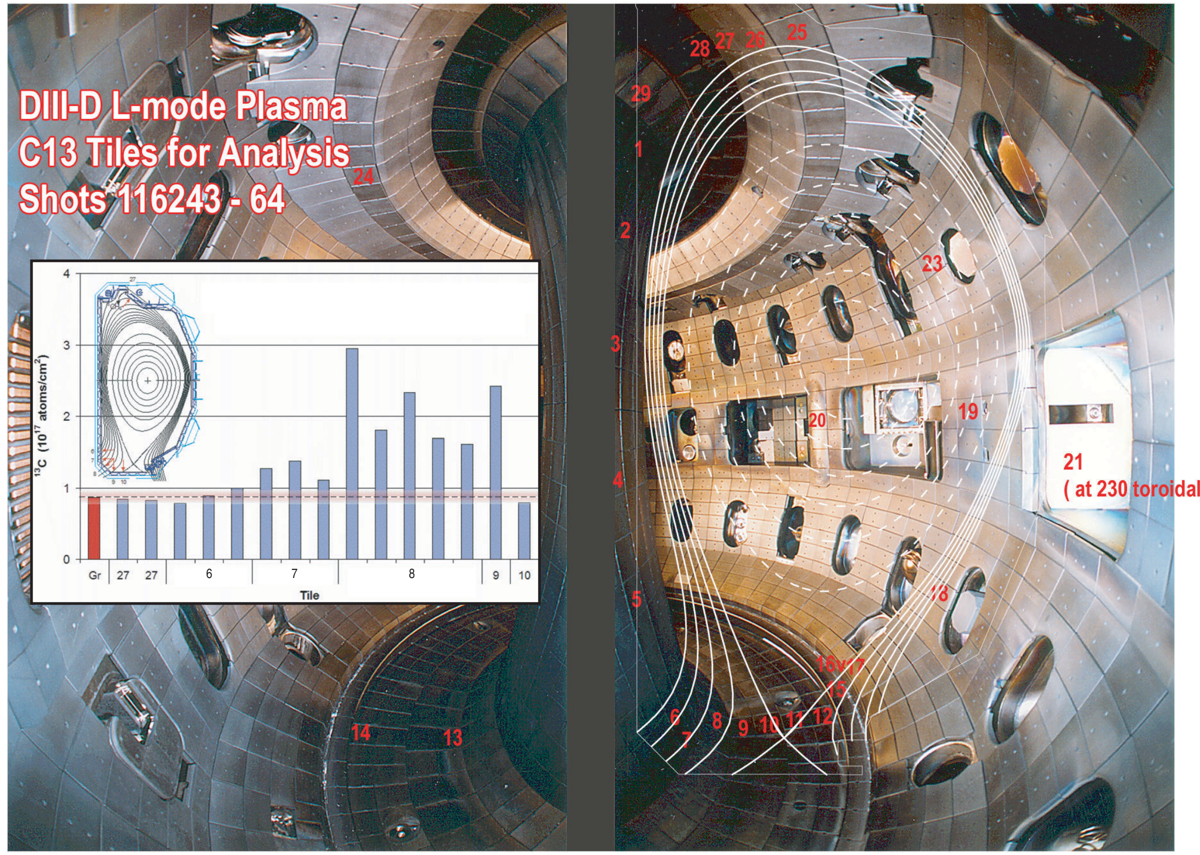
Key incremental request

065–04/TST/wj

MULTI-NATIONAL COLLABORATIONS ARE FORGED TO ADDRESS TRITIUM MIGRATION AND RETENTION

- **C13 injection**
  UT, JET, UW, LLNL, PPPL, FZJ-IPP, GA
- **Surface analysis**
  SNL-NM, SNL-L
  UT, UW, GA
- **Quartz Micro Balance**
  UW, UT, JET, FZJ-IPP, GA
- **O_2 bake**
  UT, PPPL, UW, GA, SNL-NM, LLNL, FZJ, JET
- **Heated tile**
  UT, IPP Garching, UW, GA, SNL-L



Preliminary Result: C13 found in tiles near inner strike point

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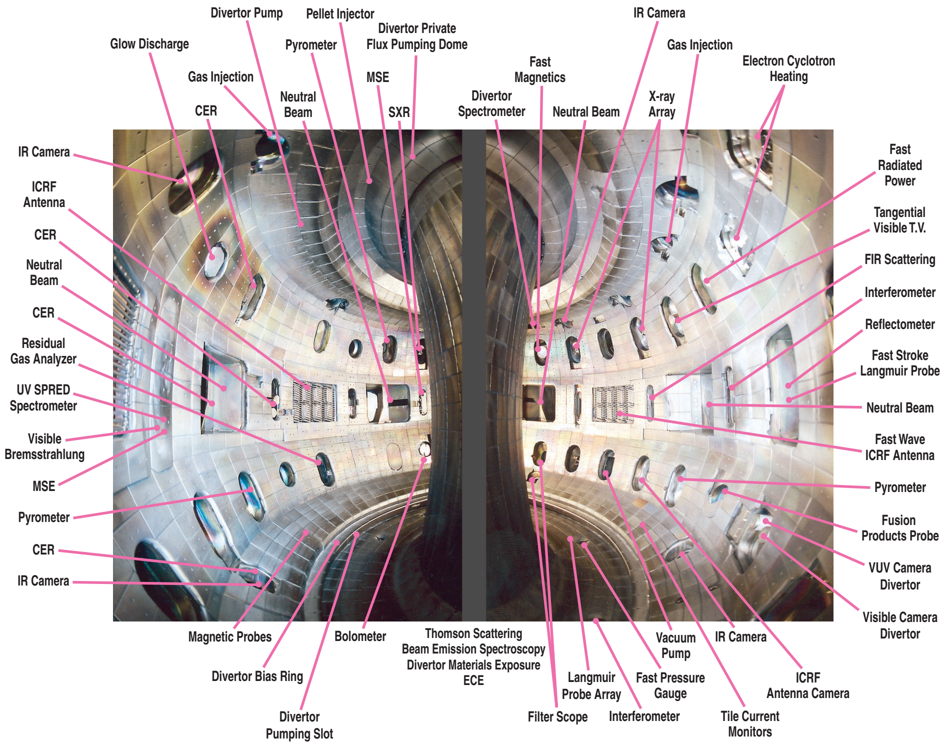
THE BOUNDARY SCIENCE PLAN WILL FOCUS ON KEY CONCERNS WITH THE PRESENT ITER DESIGN

FY04-06

- Develop models, compared with data, and calculate ITER cases
  - UEDGE, DEGAS — radiative divertor solutions (with drifts) for DIII–D and ITER (handle higher heat flux)
  - BOUT – fundamental turbulence (kinetic in development) (FY05)
- Tritium inventory in ITER
  - Related to carbon co-deposition
  - Study carbon transport in DIII–D
  - New diagnostic to measure plasma flow - input to models (FY06 incremental)
- ELM power and particle flow in SOL and divertor
  - New, higher time resolution diagnostics (FY04-05)
  - Improved modeling

EXTENSIVE AND ACCURATE DIAGNOSTICS ARE ESSENTIAL TO GOOD SCIENCE

World Class Diagnostic Set



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New Measurements

- Edge J(ρ), lithium beam polarimetry
- Advanced multi-fluid 2-D optical turbulence measurements (Wisc)
  - $\tilde{n}$, $\tilde{v}_r$, $\tilde{v}_\theta$ (BES)
  - $\tilde{T}_i$ (CHERS)
- Enhanced spatial high k-scattering (UCLA)
  - $\tilde{n}$, $10 < k < 40\ cm^{-1}$, spatially localized
- Phase contrast imaging (MIT)
  - $\tilde{n}$, $k < 100\ cm^{-1}$
- Fast ion (profile measurement)
- Boundary flows (divertor CER, DNB)
- Micro balance surface detectors
- Turbulence imaging

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DIII–D WILL CONTINUE TO BE A WORLD CLASS PROGRAM AND FACILITY TO CARRY THE U.S. PROGRAM FORWARD TO BURNING PLASMAS

- DIII–D program will complete key research for ITER
  - Strong international partnerships
  - IEA/ITPA joint experiments

- DIII–D program will develop solid scientific base for steady state high performance discharges in support of ITER and beyond

- DIII–D program will play a lead role in advancing plasma science

  ⇒ Added plasma control capabilities and new physics measurements are high leverage items to increase the productivity and scientific excellence of the program

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DIII–D RESEARCH SUPPORTS PROGRESS IN FOUR FUSION PROGRAM THRUSTS

- ITER (support?)

Burning plasmas
Fundamental understanding
Enabling technology

- Advanced Tokamak: in principle steady state high performance discharges
  - MHD stabilization
  - Profile control and optimization

Configuration optimization
Burning plasmas
Fundamental understanding
Enabling (control) technology

- Transport: major advance in turbulent transport understanding and control
  - Pedestal

Fundamental understanding
Burning plasmas (ITER)

- Mass transport in the boundary

Burning plasmas
Fundamental understanding materials
Techchology (materials)

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DIII–D FOCUSED EFFORTS SUPPORT THE FESAC/IPPA GOALS

• Advanced Tokamak: in-principle steady-state, high performance discharges	Integration and optimization High performance 3.3 Science 3.1 Configuration 3.2 Profile control 3.3.1, 3.1.3 High beta & disruptions 3.3.2, 3.1.2 Density control 3.3.1, 3.1.4 Enabling (control) technologies 3.4.1
• Transport: major advance in turbulent transport understanding and control	Turbulence and transport 3.1.1
• Mass transport in the boundary	Burning plasmas 3.3.3 Boundary science 3.1.4

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