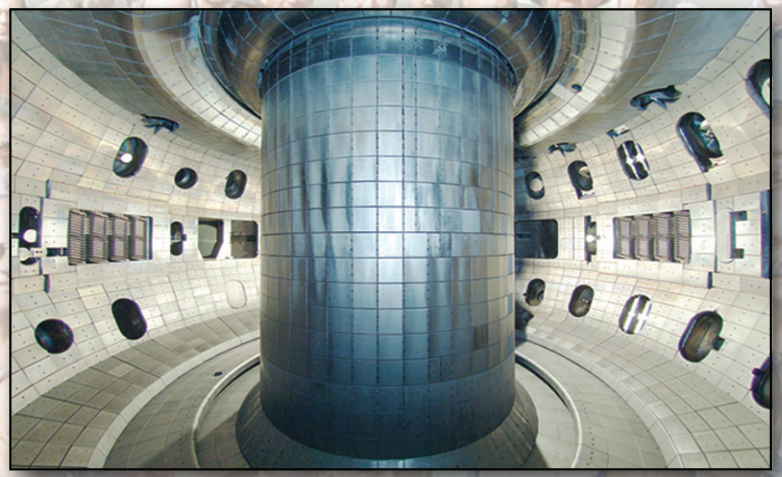
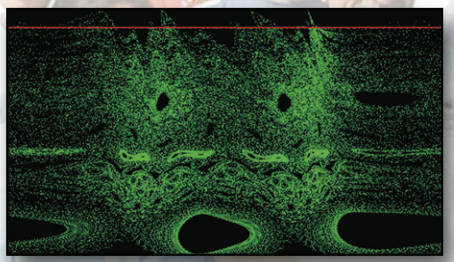
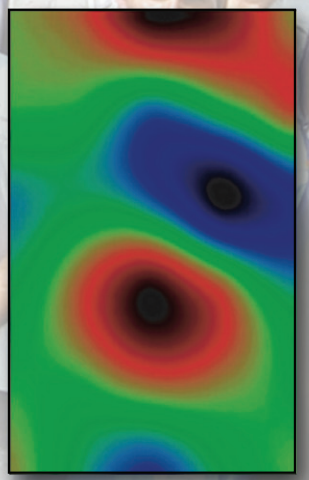
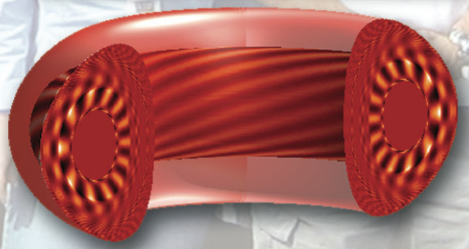
The DIII-D Research Program: Content and Balance

by
D.N. Hill









Presented to the
DIII–D Program Advisory Committee
San Diego, CA

February 15–17, 2011

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

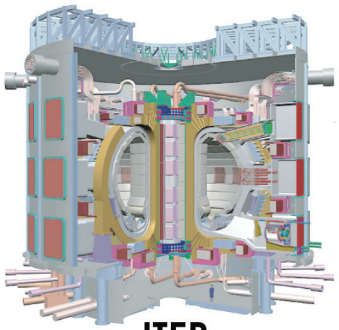
DIII-D Mission is to Establish the Scientific Basis for Optimization of the Tokamak Approach to Fusion Energy Production

Program Objectives

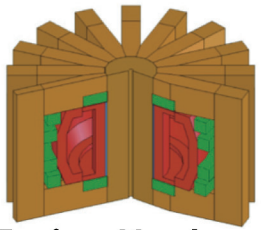
- **ITER Support**
  Enable the success of ITER by providing physics solutions to key issues
  (Reimerdes, Hollmann, Wade)

- **Fusion Science**
  Advance fundamental understanding of fusion plasmas
  (Petty, Groebner, Wade)

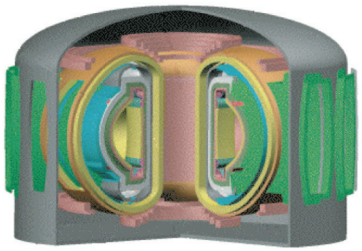
- **Steady-State**
  Establish the physics basis for steady state high performance
  (Buttery, Pinsker, Wade, Leonard)



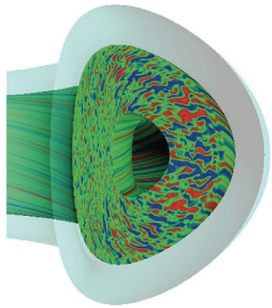
ITER



Fusion Nuclear Science Facility



Power Plant

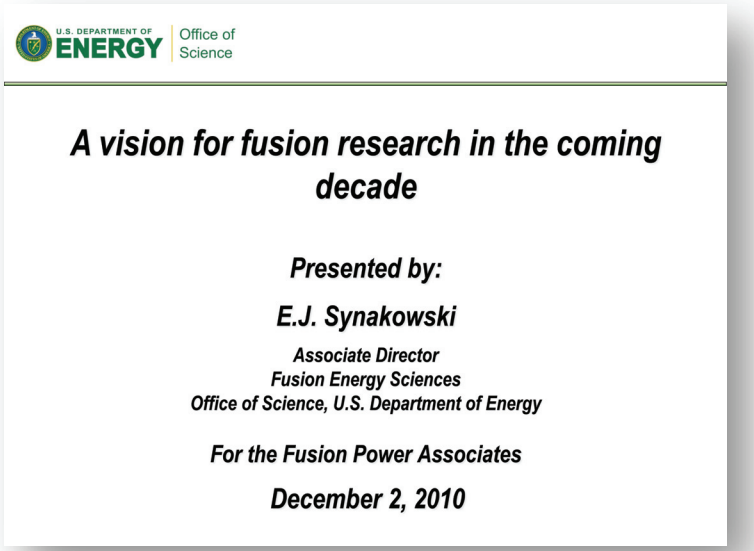


Fusion Simulation

DIII-D will provide key scientific support for planned fusion devices

DIII-D Mission Is Aligned With High Level Priorities and Goals For DOE Fusion Energy Sciences Program

- ***"ITER will cost more than anything the Office of Science has ever undertaken"***
  - *"ITER represents an extraordinary commitment of funding and effort"*
  - *"We need to hit the ground running with a vibrant, front-line research team in Cadarache in less than a decade."*


U.S. DEPARTMENT OF ENERGY | Office of Science

A vision for fusion research in the coming decade

Presented by:

E.J. Synakowski

Associate Director
Fusion Energy Sciences
Office of Science, U.S. Department of Energy

For the Fusion Power Associates

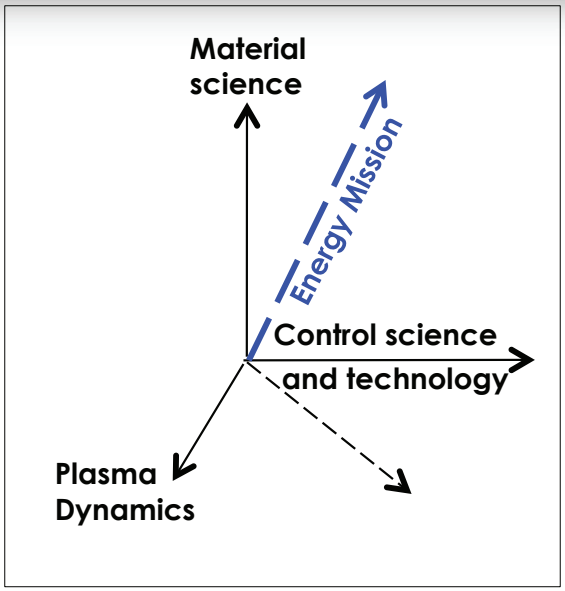
December 2, 2010

1. Plasma dynamics and control science

- Understanding dynamics and stability of the burning plasma state: robust control strategy
- Validated predictive capability
- 3D physics: equilbria, stability, and transport

2. Materials in a fusion environment and harnessing fusion power

- Plasma surface interactions and fuel retention
- Fusion nuclear materials science (FNSF Pathways Assessment)



DIII-D Program Contains Three Main Research Elements: ITER, Advanced Tokamak, and Science

Ensure the Success of ITER

- Provide physics solutions for key ITER issues
- Qualify operating scenarios for ITER
- Develop the physics basis for tokamak operation with dominant electron heating

Develop Predictive Understanding of Fusion Plasmas

- Stability and 3D magnetic fields
- Plasma transport and energetic particles
- Plasma boundary interactions

Develop Physics Basis for Integrated Steady-state Operation

- Develop advanced scenarios for ITER
- Investigate ultimate potential for Advanced Tokamak operation
- Provide physics basis for integrated AT operation (core + edge)
- Explore low-torque non-inductive operation with dominant electron heating

DIII-D Program Contains Three Main Research Elements: ITER, Advanced Tokamak, and Science

Ensure the Success of ITER	Develop Predictive Understanding of Fusion Plasmas	Develop Physics Basis for Integrated Steady-state Operation
• Provide physics solutions for key ITER issues	• Stability and 3D magnetic fields	• Develop advanced scenarios for ITER
• Qualify operating scenarios for ITER	• Plasma transport and energetic particles	• Investigate ultimate potential for Advanced Tokamak operation
• Develop the physics basis for tokamak operation with dominant electron heating	• Plasma boundary interactions	• Provide physics basis for integrated AT operation (core + edge)
		• Explore low-torque non-inductive operation with dominant electron heating

Support for ITER is the Major Focus of DIII-D Research

ITER Timeline

Design & Construction — Initial Operation 2019 — Burning Plasma

World Fusion Community Prepares for ITER Operation

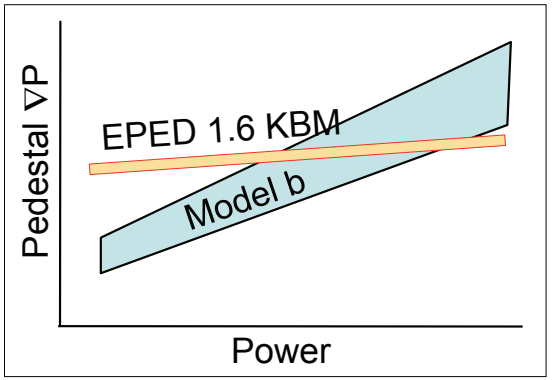
Resolve short-term design issues for ITER	ELM control Disruption mitigation Startup, shape and position control Hydrogenic retention & dust control
Resolve medium-term design issues for ITER	H-mode access in H_2 and He Magnetic field asymmetries & 3D effects Heating & current drive requirements
Address operational issues for commissioning and high-gain operation	Fast-ion instabilities 3D field effects Operational scenarios
Integrated plasma dynamics and control	Strong electron heating $T_e \sim T_i$ Low external torque operation Profile control, Divertor control

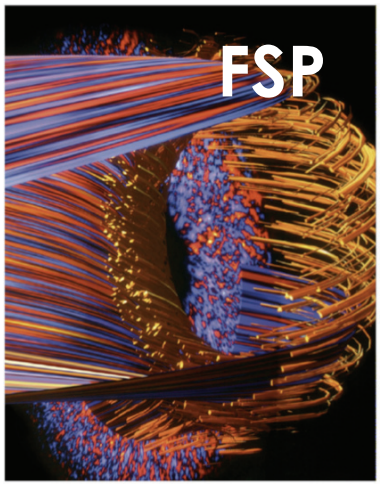
ITER organization, working through ITPA, defines ITER research priorities

The Quest For Scientific Understanding Pervades The Research Program at DIII-D And Elsewhere

- **Potential for gaining qualitative and quantitative understanding is a key factor in selecting experiments**
- **Example: FY2011 Joint Research Target will test predictive models of pedestal structure**
- **DOE FES plans to *"grow emphasis on validation of physics models that are incorporated in fusion simulation."***
- **DIII-D scientists are closely coupled to the theory community and to the new Fusion Simulation Program**

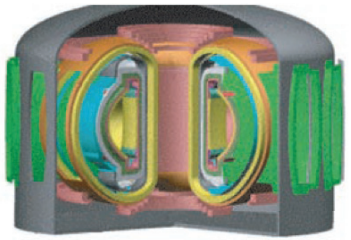
Pedestal experiments in 2011 seek to test several models



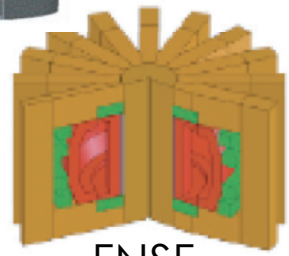


DIII-D Research Informs Discussion of Path Forward For Fusion Nuclear Science in the U.S.

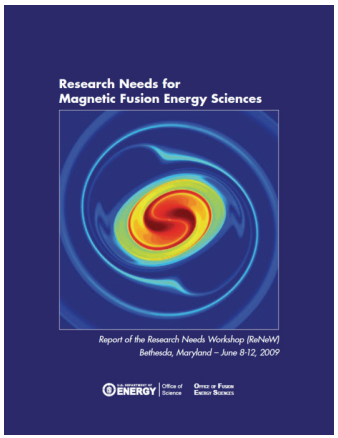
- **ITER and NIF projects motivate increased interest in Fusion Nuclear Science**
- **FESAC "Priorities, Gaps, and Opportunities" and DOE ReNeW reports identified research needs for harnessing fusion power**
- **DOE "Fusion Nuclear Science Pathways Assessment" connects ReNeW to FNSF and DEMO**
  - Defines requirements
  - Develop possible paths forward for U.S.



DEMO

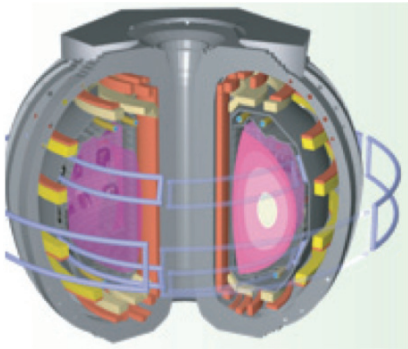


FNSF



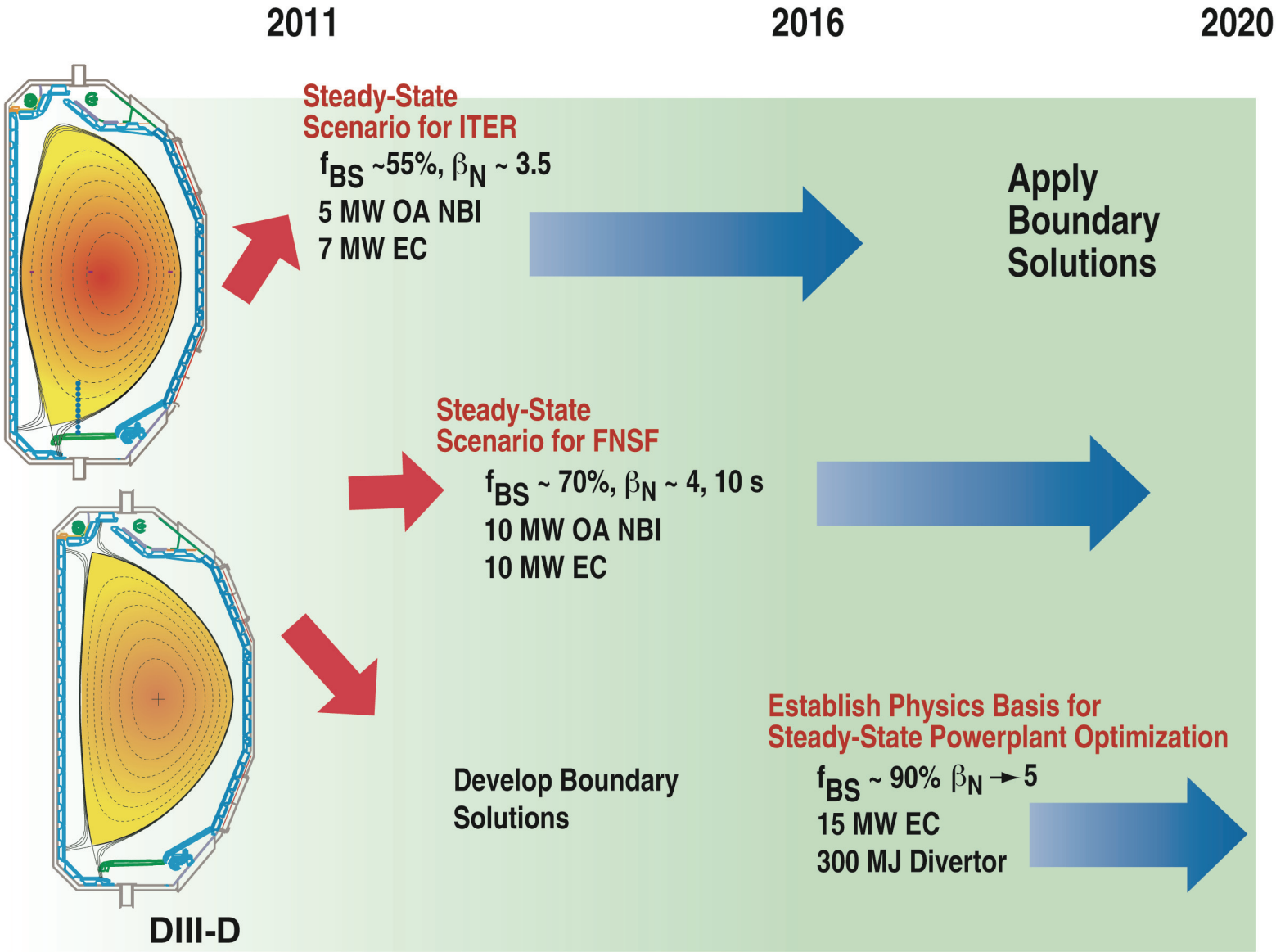
ReNeW Report

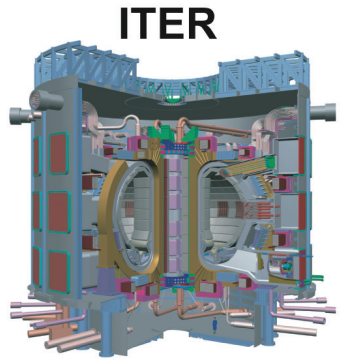
DIII-D

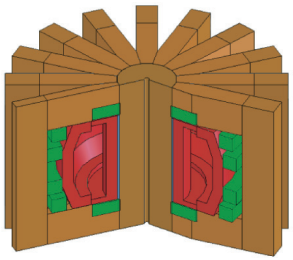


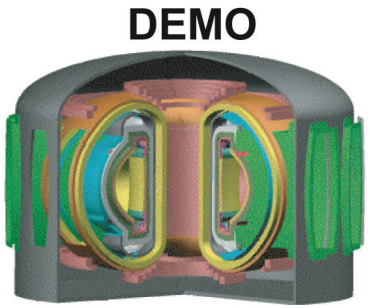
DIII-D research seeks to qualify attractive, reliable operating regimes suitable for a future fusion nuclear science facility

Facility Upgrades Are Staged to Provide Critical Input to ITER, FNSF, and DEMO

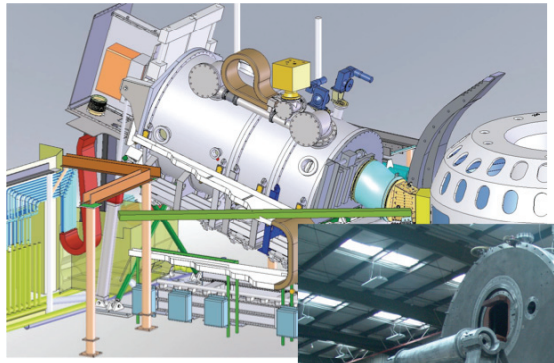




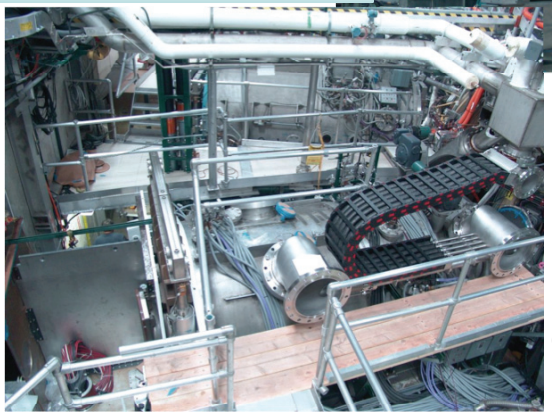




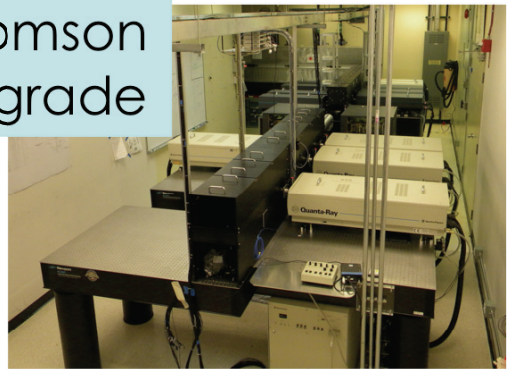
2011 Experimental Plan Utilizes Significant New Capabilities Provided by the Long Torus Opening



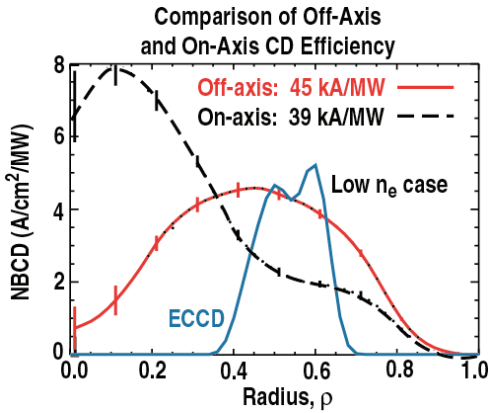
Off-axis neutral beam



Thomson upgrade



MSE upgrade



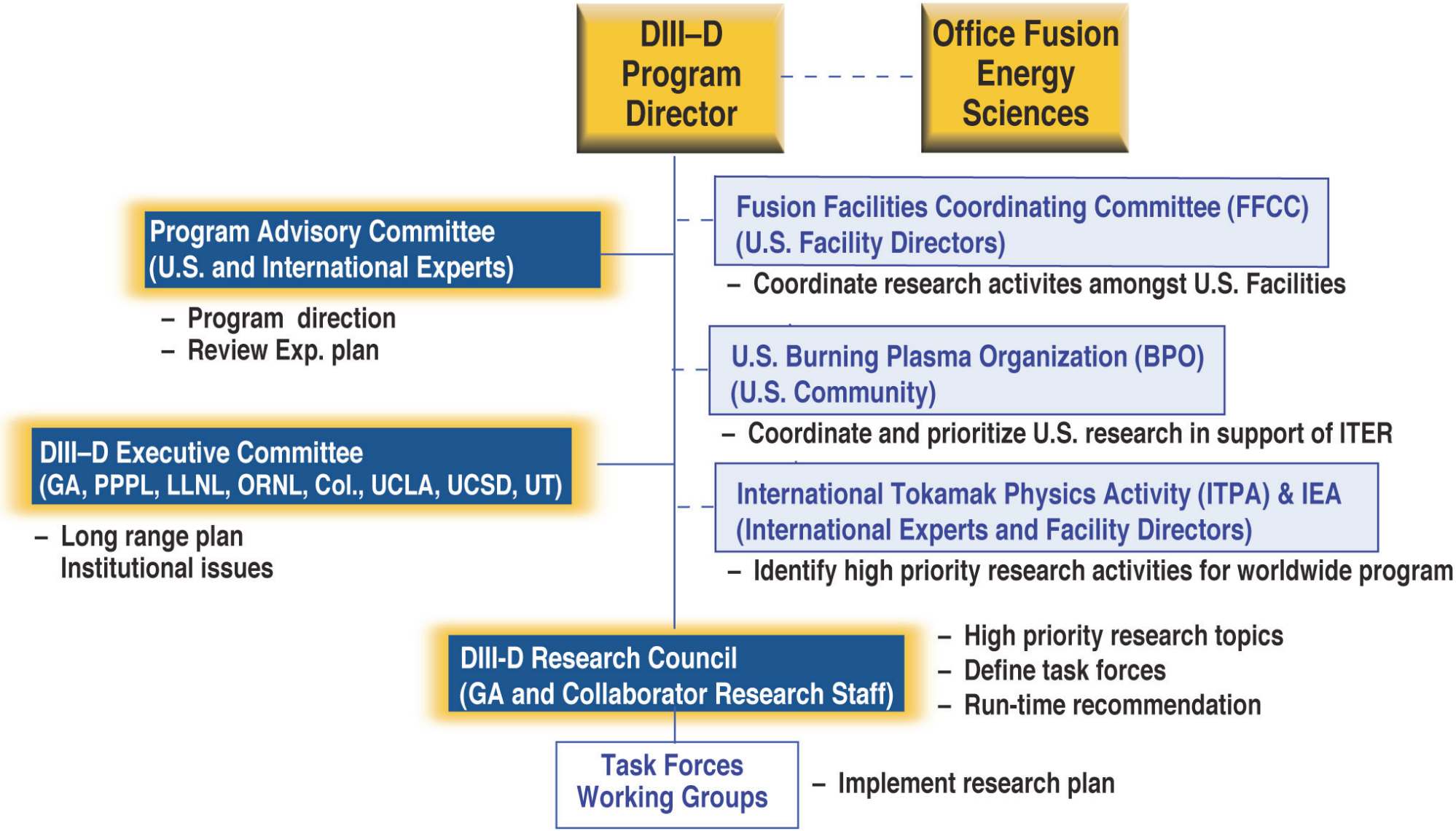
New ELM Pellet Pacing

Tangential X-point SXR

Eight High Priority Research Topics for 2011 Were Identified At The Start Of The Planning Process

	ITER	FSP	FNSF
• ELM Control (for ITER): 3-D Field Induced Transport	✓		
• Alternative Techniques for ELM Control	✓		
• Runaway Electron Dissipation and Control for ITER	✓		
• Pedestal Structure	✓	✓	
• Scenario Development at Low Torque/Rotation for FNSF and ITER	✓		✓
• Evaluation of Off-Axis NBI Physics		✓	✓
• Profile Stiffness and Critical Gradients		✓	
• Fully Noninductive Scenarios with Off-Axis Neutral Beam Injection			✓

Experimental Planning Effectively Engages the U.S. and International Research Community



Research Opportunities Forum Generates Many New Ideas for Experiments Addressing High Priority Topics

- Over 500 proposals submitted on line and during meeting
- Ideas for experiments from 38 institutions
- Videoconference allowed broad participation from US and abroad, including ITER Cadarache.

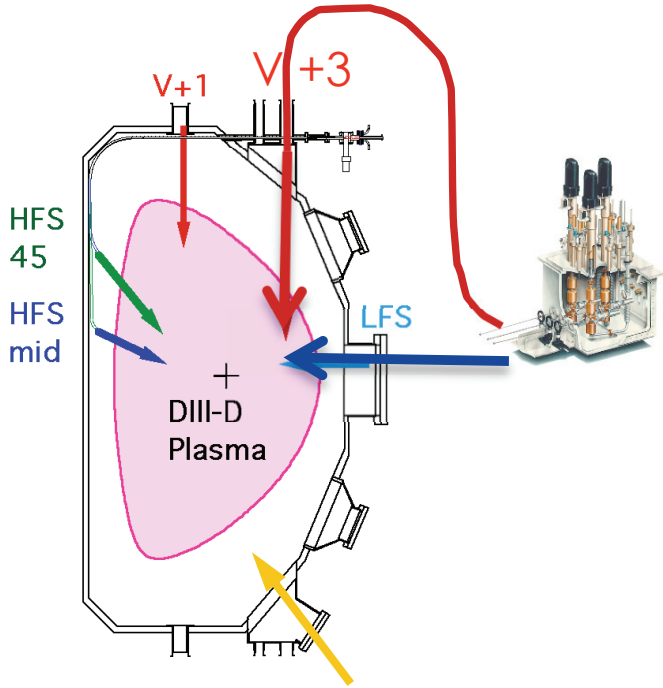
Torkil Jensen Award for Innovative Experiments

- 2 days Director's Reserve
- 11 ROF Proposals
- Selection committee: Jim DeBoo, Jerry Navratil, Miklos Porkolab

DIII-D Research Plan Addresses ITER High Priority Needs

- **Qualify H/He low activation scenarios for ITER**
- **ELM control research to inform ITER design issues**
  - 3D field-induced edge transport physics
  - Alternate methods (pellet pacing, QH-mode…)
- **Disruption-induced runaway electron control**
  - Examine RE control and dissipation
  - Improve impurity delivery techniques
- **Error field control research**
  - Test ideal and non-ideal plasma response
  - Extend empirical scaling of mode-locking thresholds to H-mode

multiple launch locations (ORNL)



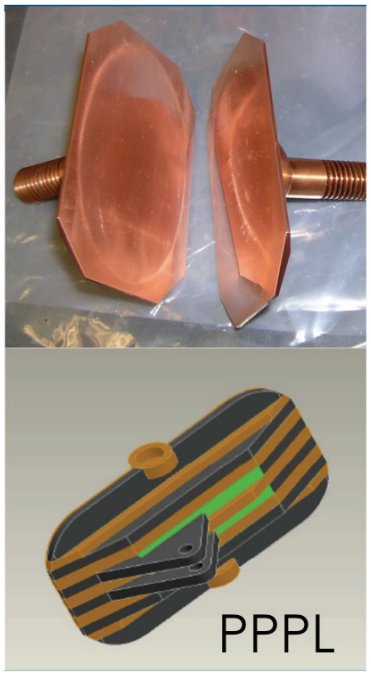
ITER team submitted ROF proposals and priorities were discussed with ITER management as plan was developed

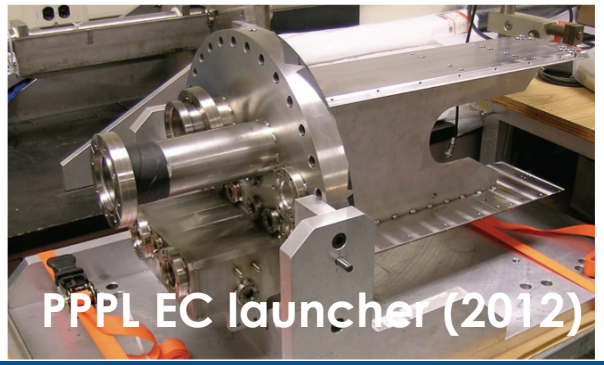
EC System Improvements Enhance Fidelity of ITER Scenario Development Studies

- **Improved ECCD tearing mode stabilization**
  - Steerable mirrors
  - ECE and Mirnov analysis for phase modulation
  - Confirm physics basis and requirements for ITER

- **Improve projections to ITER for reference scenarios**
  - Increased ECH power to explore dominant electron heating
  - Develop and optimize scenarios with low rotation and low external torque

High power, steerable EC mirrors 2011

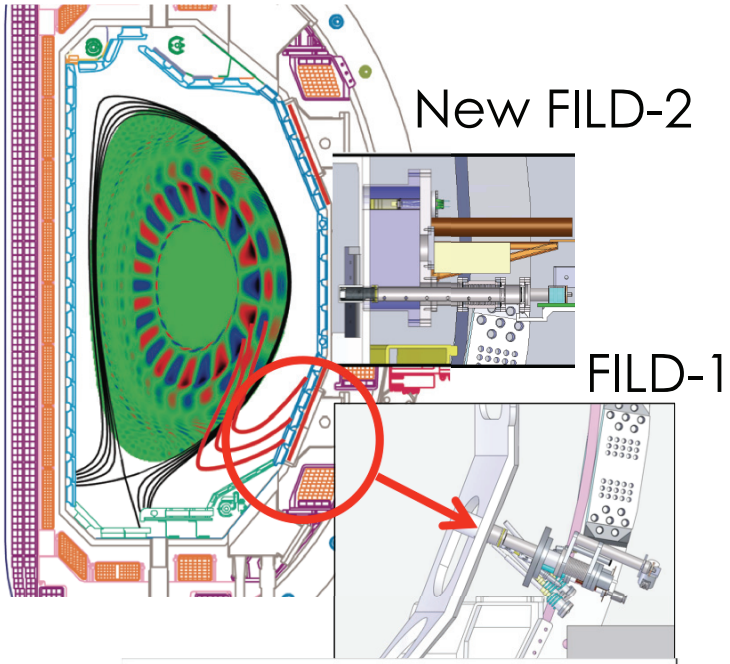


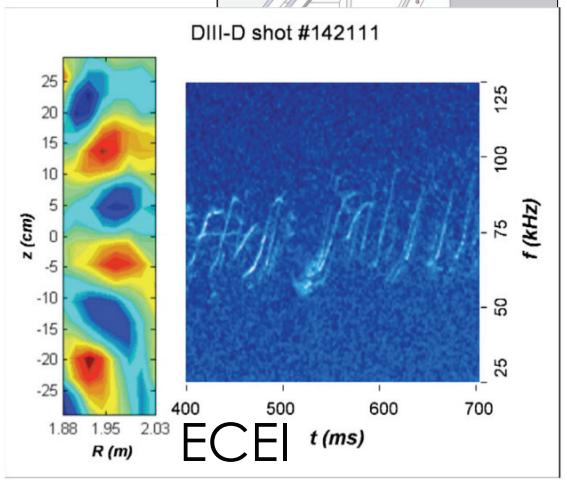


New Off-axis Neutral Beam Enables a Number of Fundamental Fusion Science Experiments

- **Qualifying Physics Basis for use of off-axis Injection will test fundamental assumptions**
  - Does the OANB drive current where expected?
  - Can we validate models describing fast-ion behavior?

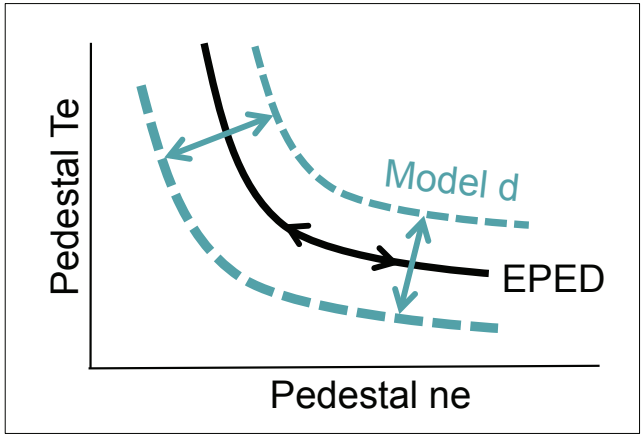
- **Continued diagnostic improvements and new AE measurements enable sophisticated comparison with simulation**
  - Use off-axis NBI to vary gradient of n_{beam} to affect AE stability, mode structure, and effect on fast ion losses



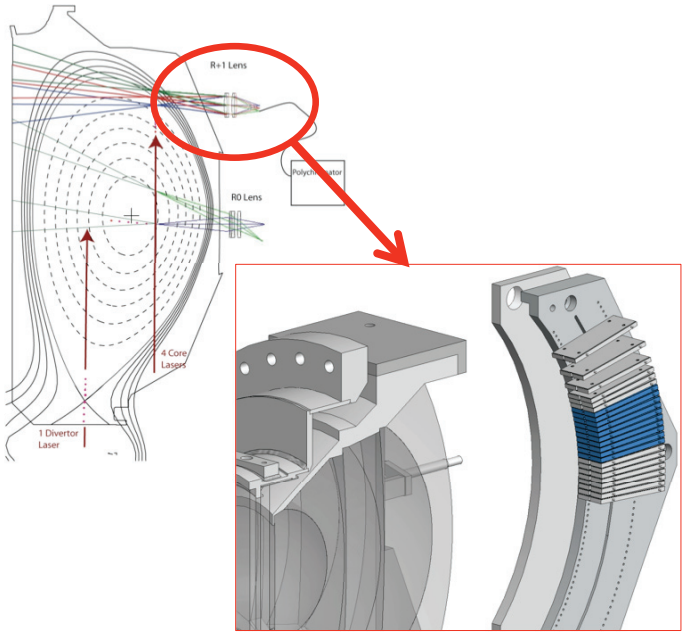


Transport Research Continues Model Validation Efforts in Both Core Plasma and Pedestal

- **2011 DOE Joint Research Target on pedestal structure seeks to test predictive models against experiment**
  - Thomson scattering upgrades will improve temporal and spatial resolution in pedestal region

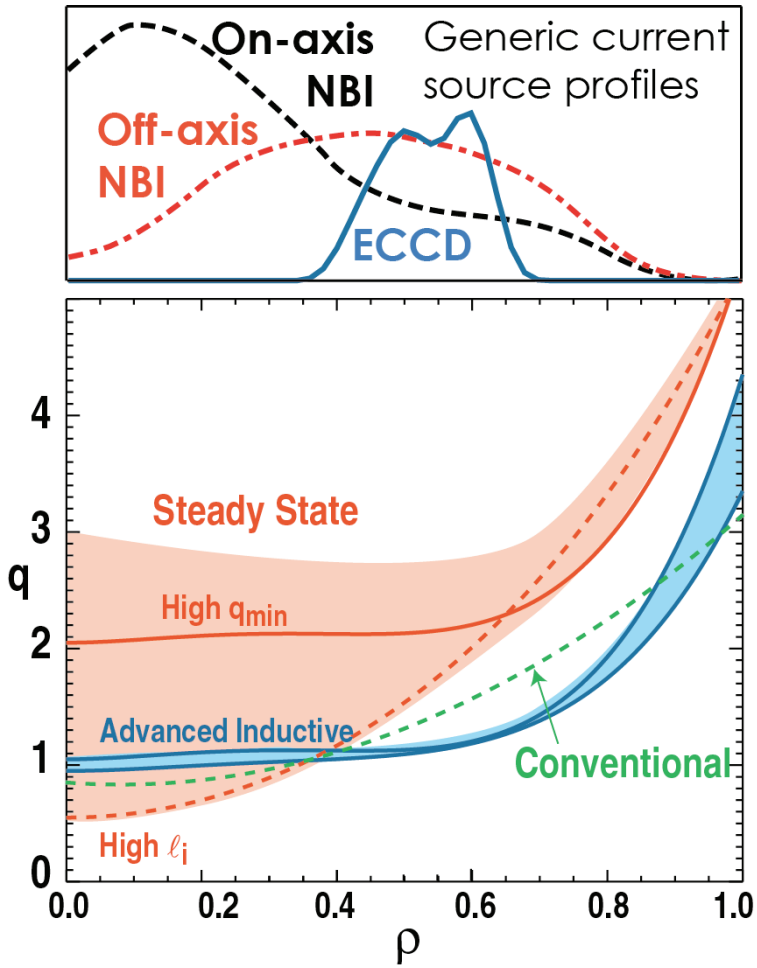


- **Transport research will focus on profile stiffness as part of ongoing effort on model validation**
  - Test critical gradient predictions (TGLF) against experimental data
  - Investigate both ion and electron profile stiffness



Integrated Steady State Scenario Development Will Use Off-Axis Neutral Beam For Current Profile Control

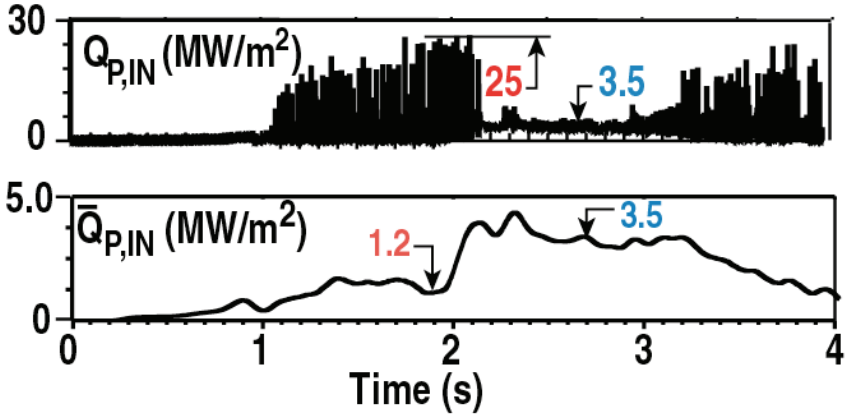
- **Develop steady-state scenarios with $q_{min} > 2$**
  - Off-axis NB current drive well matched to target steady-state profile
- **Develop low-NBI torque advanced inductive scenarios using maximum electron heating**
  - Off-axis current drive to clarify physics of current profile
- **Will examine fast wave heating in advanced inductive discharges in support of FW assessment at end of 2011**

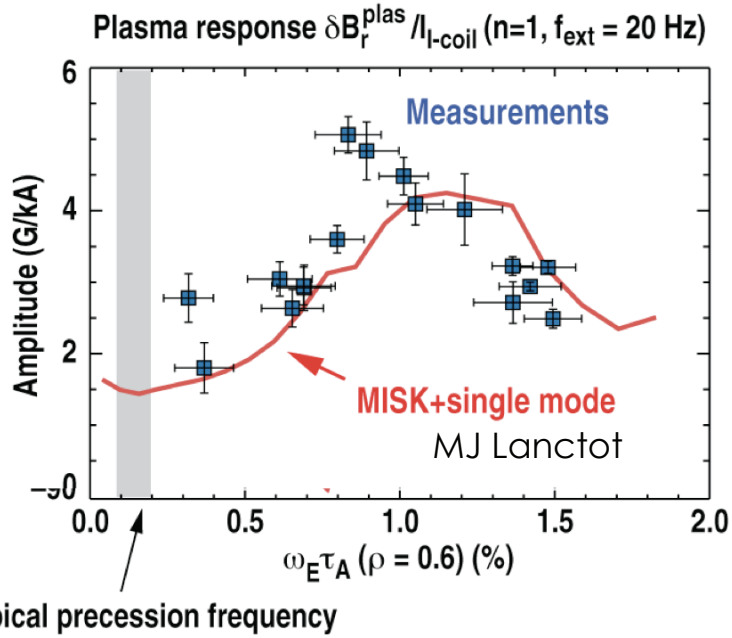


Integrated Steady State Scenario Development Also Addresses ITER and FNSF Longer-Term Research Needs

- **Gradually increasing emphasis on the physics of core-edge integration**
  - RMP in high performance discharges
  - Radiative divertor in steady-state scenarios
  - Plasma flow and detachment studies

- **Develop sustained high-beta operation with low NBI torque**
  - Validate kinetic models for RWM stability
  - Develop advanced RWM feedback control





DIII-D Run Time Guidance for 2011 Planning Seeks Balance Between High Priority Focus and Program Breadth

Research Area or Topical Group

Task Force on ELM Control: 3D Field Induced Transport

Task Force on Runaway Electron Dissipation and Control for ITER

Steady State Integration Topics

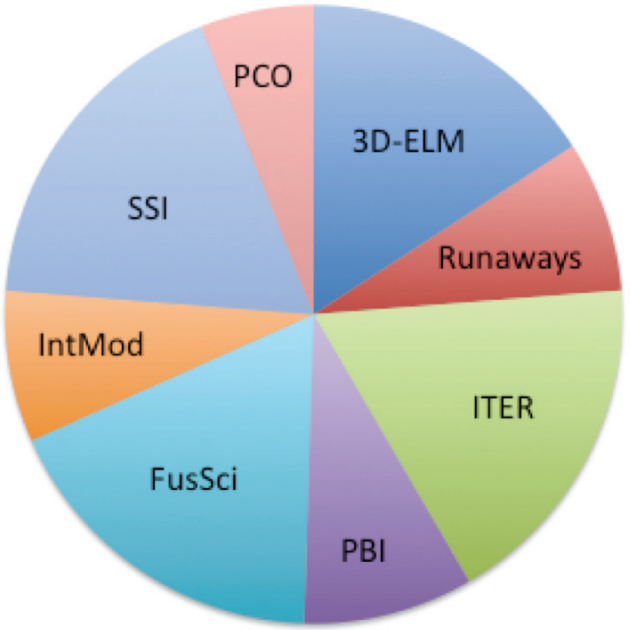
Integrated Modeling

ITER Physics

Plasma Control and Operations

Fusion Science

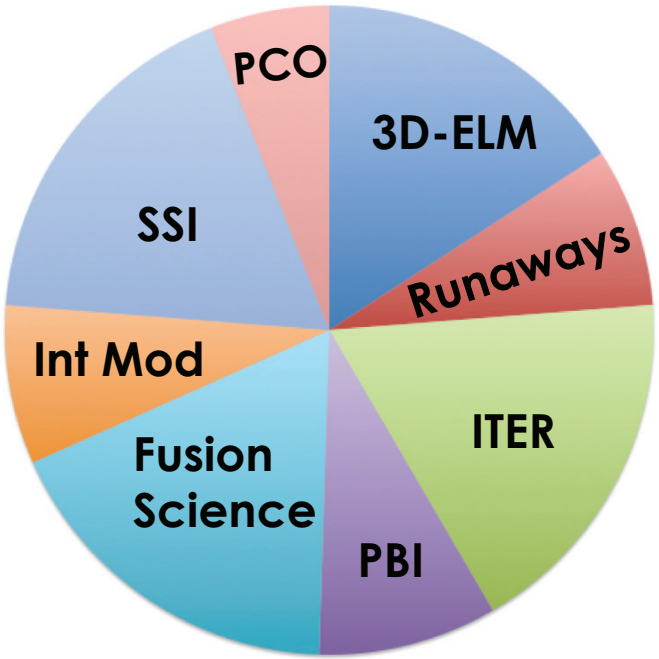
Plasma Boundary Interface



DIII-D Run Time Guidance for 2011 Planning Seeks Balance Between High Priority Focus and Program Breadth

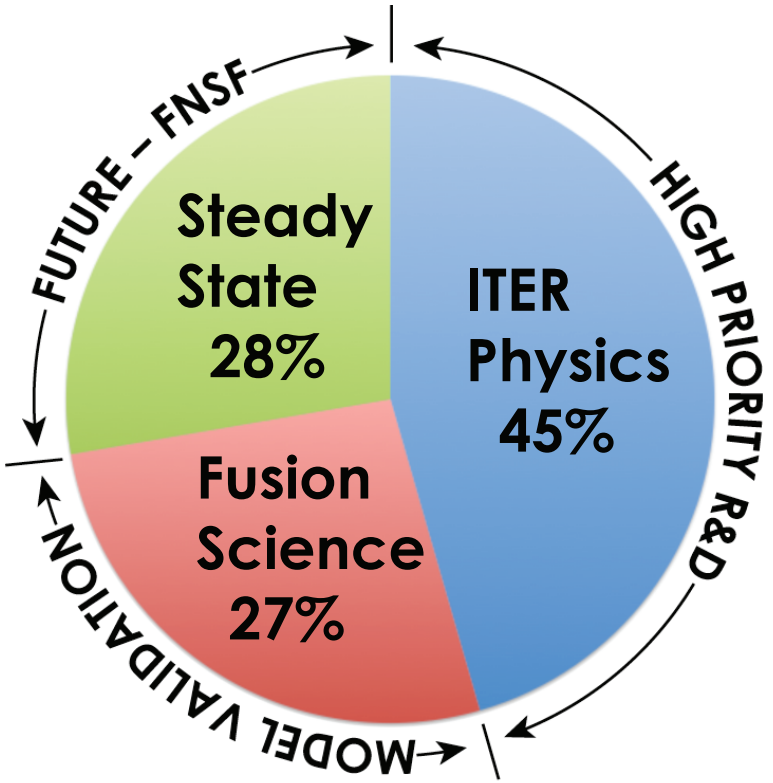
High Priority Research Areas

- ELM Control: 3D field induced transport (Task Force)
- Runaway Electron Dissipation and Control for ITER (Task Force)
- Steady State Integration Topics
- Integrated Modeling
- ITER Physics
- Plasma Control & Operations
- Fusion Science
- Plasma Boundary Interface



DIII-D Run Time Guidance Balances High Priority ITER Research vs. Recognized Needs For Fusion Development

- Strong focus on ITER to resolve urgent issues and prepare for participation in the burning plasma research program.
- Conduct systematic experiments to validate key physics needed for predictive simulation codes.
- Maintain steady effort on key research needs for development of fusion energy (e.g., for FSNF and DEMO)



Mapping to mission elements by priority driver