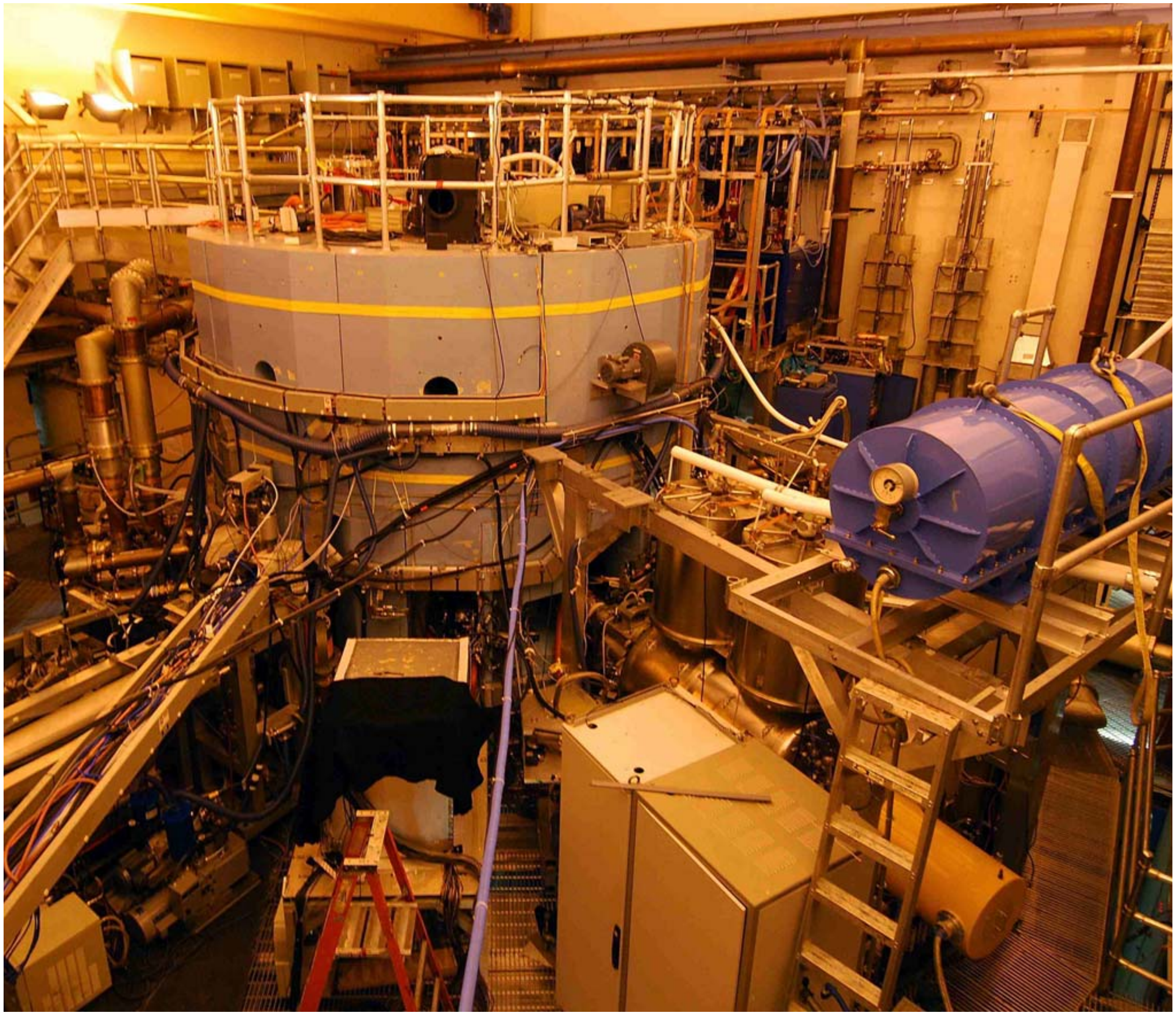
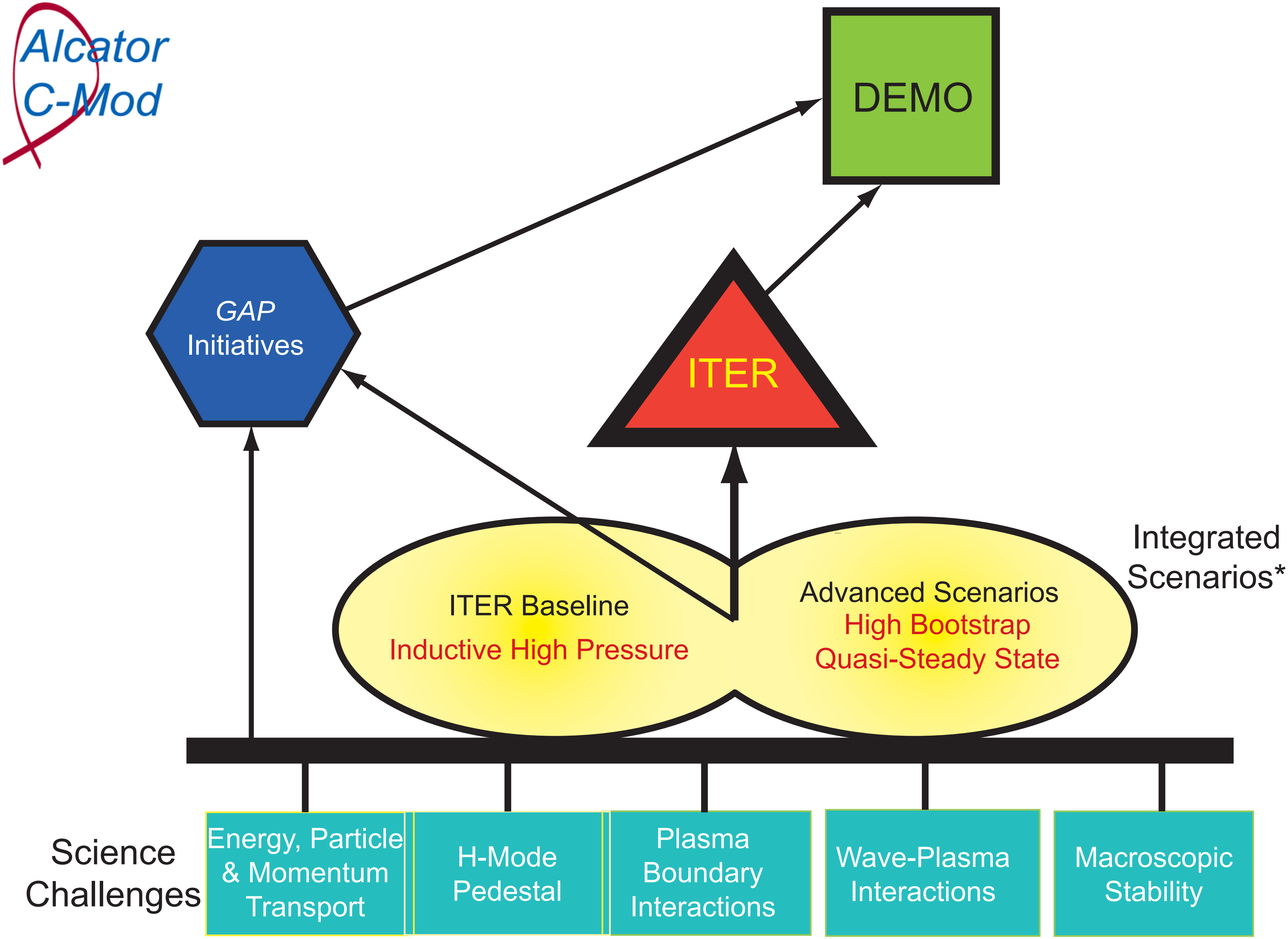
Alcator C-Mod Highlights, Plans, and Budgets



Compact high-performance divertor tokamak research to establish the plasma physics and engineering necessary for a burning plasma tokamak experiment and for attractive fusion reactors.

OFES FY2010
Budget Planning Meeting
March 11, 2008

Research supported by U.S. Department of Energy, Office of Fusion Energy Sciences



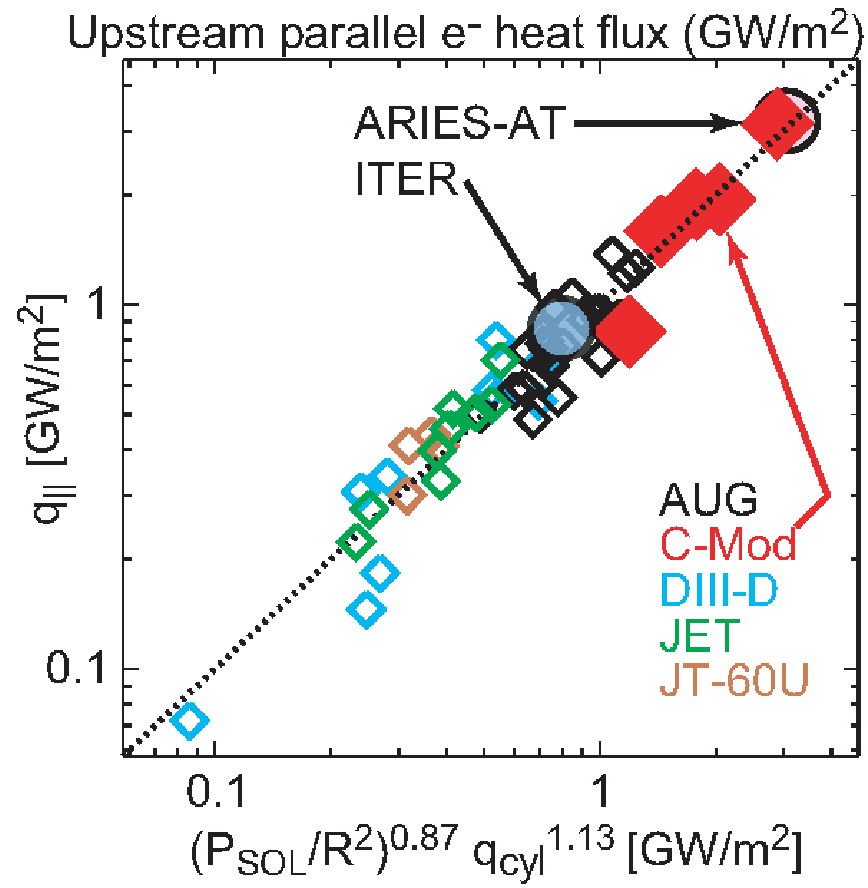
*Equilibrated electrons-ions, no core momentum/particle sources, RF I_p drive

C-Mod Unique in World and US Among High Performance Divertor Tokamaks

Alcator C-Mod

Unique in the World:

- High field, high performance divertor tokamak
- Particle and momentum source-free heating and current drive
- Equilibrated electron-ion coupling
- Bulk all high-Z plasma facing components
- ITER level (and beyond) Scrape-Off-Layer/Divertor Power Density
- Approach ITER neutral opacity, radiation trapping
- Highest pressure and energy density plasmas



Exclusive in the US :

- ICRF minority heating
- Lower Hybrid Current Drive
- A premier major US facility for graduate student training

C-Mod Plays Major Role in Education of Next Generation of Fusion Scientists

Alcator C-Mod

- Typically have ~25-30 graduate students doing their Ph.D. research on C-Mod (more students than scientists)
  - Nuclear Science & Engineering, Physics and EECS (MIT)
  - Collaborators also have students utilizing the facility (U. Texas, U.C. Davis, U. Wisc., ASIPP, China)
  - Current total is 30 **(26 full-time on-site)**
  - Fully involved in all aspects of our research, leading many of the experiments as session leaders
- MIT undergraduates participate through UROP program
- Host National Undergraduate Fusion Fellows during the summer

Collaborators are key participants in all aspects of the program

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Domestic

Princeton Plasma Physics Lab
U. Texas FRC
U. Alaska
UC-Davis
UC-Los Angeles
UC-San Diego
CompX
Dartmouth U.
General Atomics
LLNL
Lodestar
LANL
U. Maryland
MIT-PSFC Theory
ORNL
SNLA
U. Texas IFS
U. Wisconsin

International

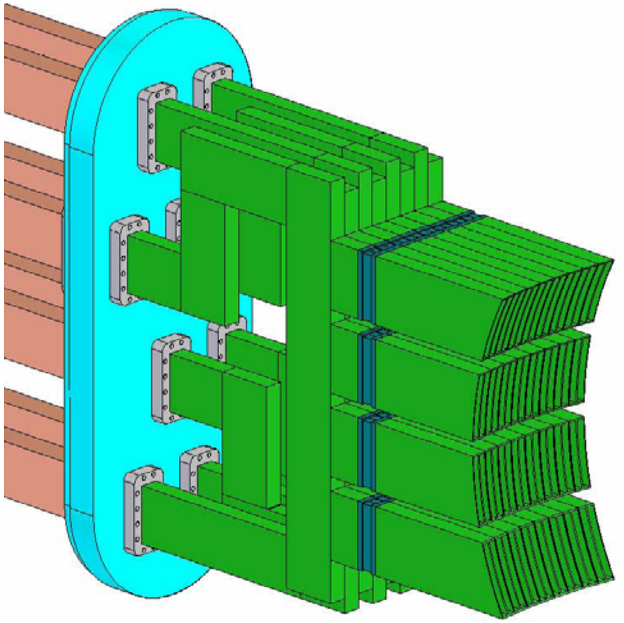
ASIPP/EAST Hefei
Budker Institute Novosibirsk
C.E.A. Cadarache
C.R.P.P. Lausanne
Culham Lab
ENEA/Frascati
FOM Nieuwegein, Netherlands
IGI Padua
IPP Garching
IPP Greifswald
ITER Organization Cadarache
JET/EFDA
JT60-U, JAEA
KFA Jülich
KFKI-RMKI Budapest
LHD/NIFS
Politecnico di Torino
U. Toronto

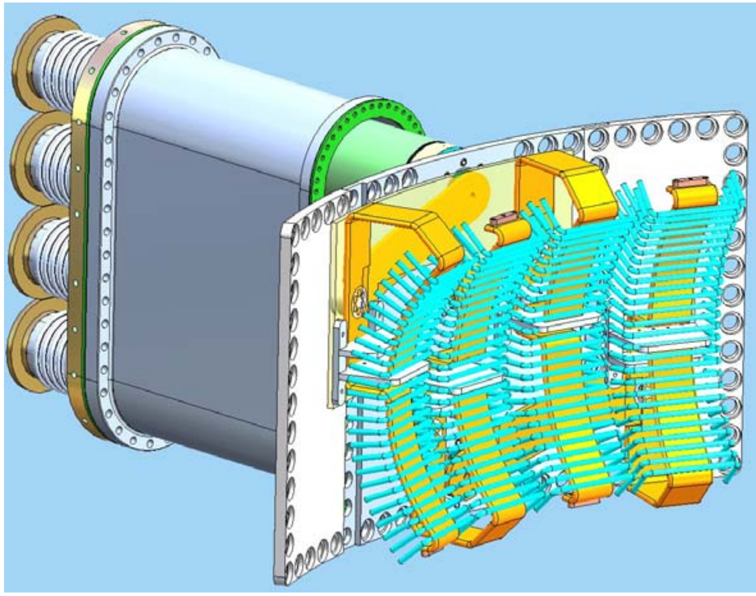
Coordination: USBPO, TTF, ITPA

Facility Plans and Major Enhancements (FY09-FY10)

- Inspections: tokamak core and alternator/flywheel
  - insure facility reliability for at least the next 5 years
- Lower Hybrid upgrades
  - Add 1 MW source (to reach 4 MW)
  - add second launcher/coupler
    - Reduced power density, compound spectra
  - new + spare klystrons
- ICRF upgrades
  - New 4-strap antennas (x2)
    - Maintain full 8 MW ICRF, diagnostic access
  - Fast-Ferrite Tuners for all 4 transmitters (real time adaptive tuning)
  - Power supply/control upgrades* (improved reliability, tube life)
  - Tuneability (40 – 80 MHz) for 3rd and 4th transmitters* (total 4 MW)

*Require incremental funds





Facility Plans and Major Enhancements (cont'd)

- Outer divertor upgrade – DEMO-like divertor
  - Continuous vertical plate (higher power/energy handling)
  - Tungsten lamella plate design
  - Controlled temperature (≤ 600 ^{0}C)
    - Hydrogen isotope retention studies
- Non-axisymmetric coil upgrades* (increased toroidal mode number flexibility, resonant magnetic perturbation, toroidal braking)
- Massively parallel computing cluster upgrade (to 512 quad core processors)
- Magnet power supply upgrades (poloidal field)
  - Improved control at high current*, high elongation, long pulse*

*Require incremental funds

LOKI Parallel Cluster

256 Opteron Processors, 64 Nodes

Jointly funded by PSFC Theory, Director's Initiative and C-Mod

Major Diagnostic Enhancements/Upgrades 2008-2010

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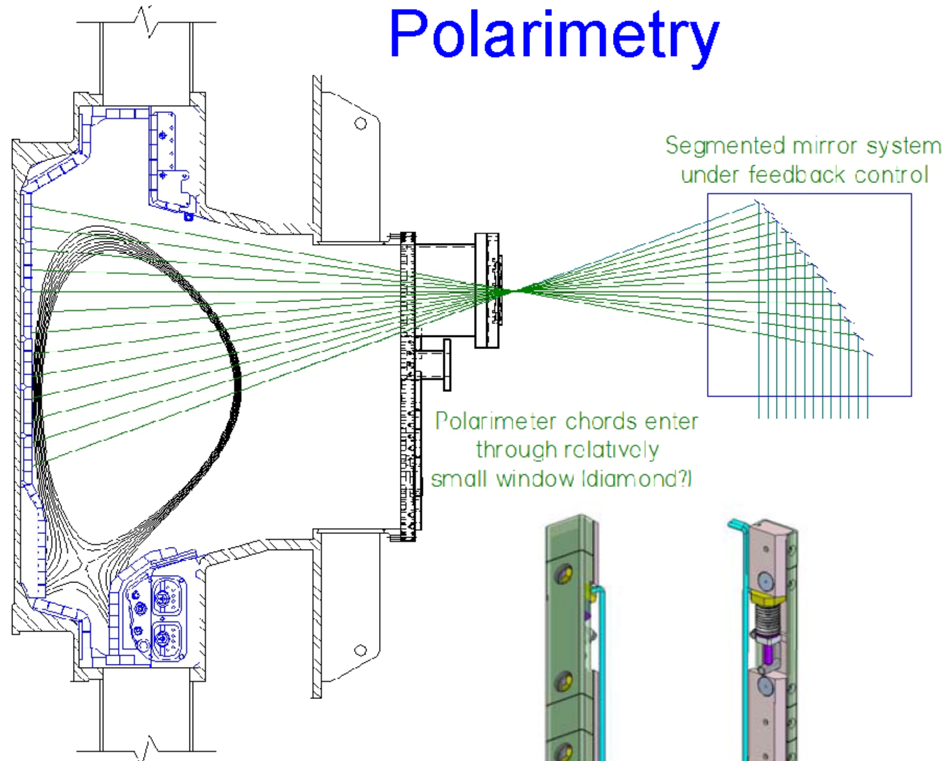
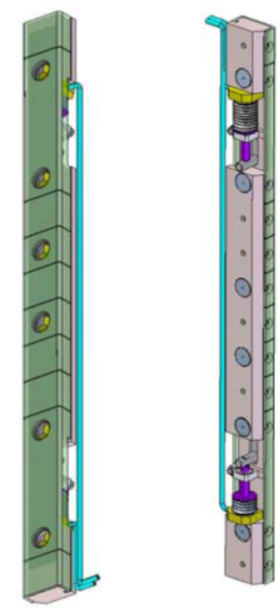
- Polarimetry [j(r), n_e(r), magnetic fluctuations]
- DNB aperture [improved spatial resolution for beam-based diagnostics]
- MSE upgrade [radial channels/spatial resolution]
- Doppler reflectometry [fluctuations, flows]
- Heterodyne ECE upgrade [improved views]
- SOL Thomson scattering
- Compact Neutral Particle Analyzer [multiple chords]
- ICRF antenna reflectometer
- In-situ accelerator [first wall analysis]
- SPRED survey spectrometer*
- Fast-ion loss detector
- IR camera upgrade [divertor heat loading]
- Gas puff imaging upgrades [edge fluctuations]
- Vertical viewing high harmonic ECE [LH-driven fast electrons]
- Synchrotron imaging [runaway electrons]
- CO_2 scattering* [fluctuations, waves]

*Require incremental funds

Polarimetry





Inner wall shutter assembly (FY2007)

C-Mod physics regimes, machine capabilities and control tools uniquely ITER-relevant in many respects:

- **Edge and Divertor:** All high-Z solid plasma facing components (key for D retention, effects on core). Divertor characteristics close to, or same as ITER (power flow, neutral and radiation opacity).

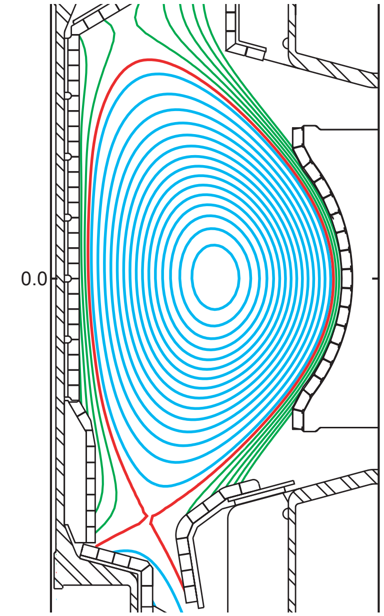
- **Core Transport:** Equilibrated ions and electrons. No core fuelling or momentum sources *(will be very low on ITER).*

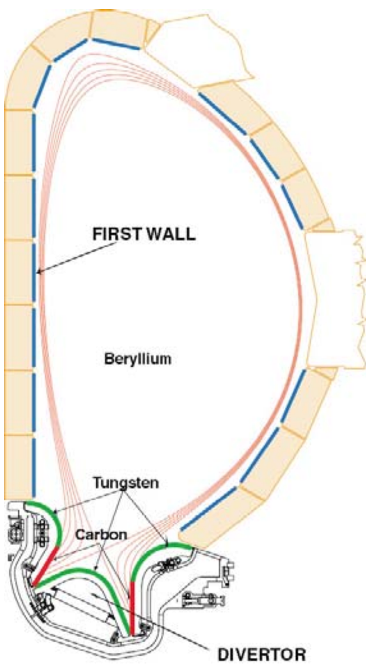
- **Macro-stability:** Can access ITER β range, as well as same B_T and absolute pressures *(important for disruption mitigation).*

- **Wave Physics:** Similar tools (ICRF and LHCD) to ITER. Same B, n => same ω_p, ω_c, similar ω *(key for Waves, LH feasibility).*

- **Pulse length:** $\tau_{pulse} >> \tau_{CR}$ *(exceeds ITER).* Adding non-inductive CD capability *(important for Steady State scenarios).*

Combination of these features is unique and enables integrated studies of many key questions.



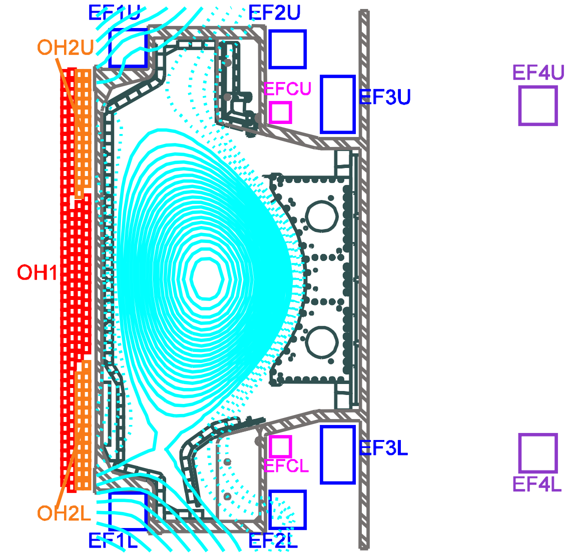


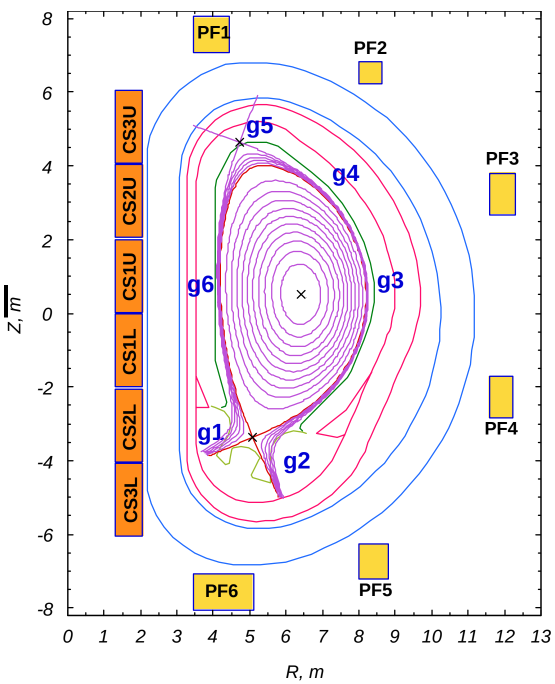
C-Mod Addresses Critical Issues for ITER

Alcator C-Mod

47/60 (80%) completed and planned FY08 experiments are examining ITER issues

- **Integrated Scenarios:**
  - **Breakdown and current rise** (l_i, flux consumption, vertical stability)
  - Reference ITER scenarios for databases and modeling
  - **ITER hybrid scenarios**: experimental development, understand mechanisms for maintaining q_0>1
  - Profile control methods: especially j(r) with LHCD+bootstrap
- **Core Transport:**
  - Regimes with **equilibrated e-i, low momentum input, dominant electron heating**
  - Collisionality dependence of density peaking
  - Develop common technologies for integrated modeling (frameworks, code interfaces, data structures): MDSplus is a model
- **Pedestal Physics:**
  - **L-H power threshold at low density** (at ITER B, high neutral opacity)
  - Improve predictive capability for small ELM and quiescent H-mode regimes; small ELM regimes for β_N>1.3; shaping
  - **ELM control**: stochastic fields with external coils
- **Wave-Plasma Interactions:**
  - **LHCD physics** and coupler technology
  - ICRF heating, current and flow drive

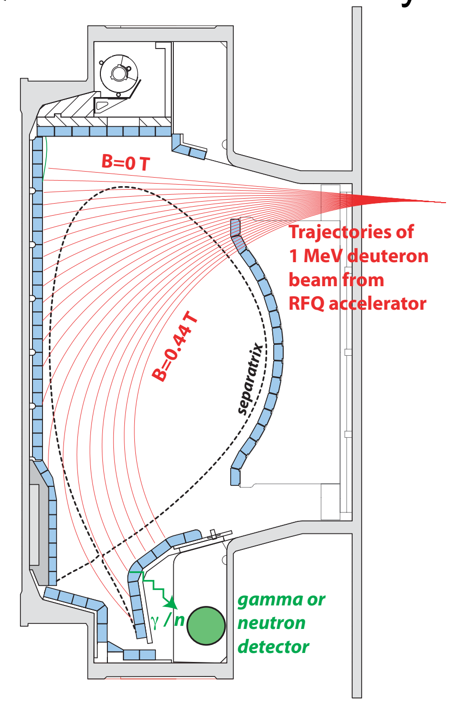




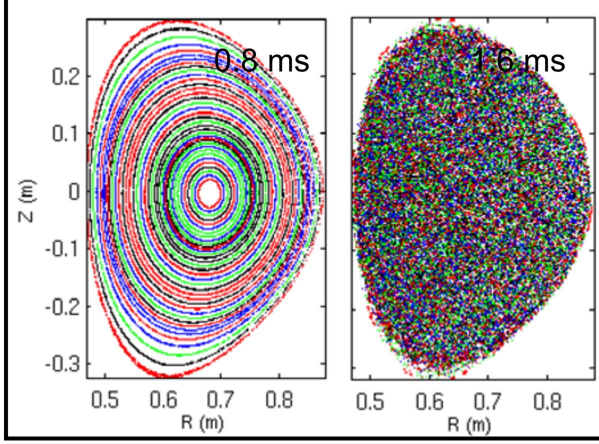
C-Mod Addresses Critical Issues for ITER

- **Plasma-Boundary Interactions**
  - **Tritium retention and removal**: **solid high Z PFCs**; plasma and nuclear effects; surface modification
  - **Surface effects**: ICRF-related impurity generation; boronization
  - **Power handling and impurity control**: SOL transport; radiative/detached divertor.
- **Macrostability:**
  - **Disruption database** (energy loss, halo current): excellent diagnostics (radiated power, surface heating, erosion, runaways)
  - **ITER applicable disruption mitigation**, validate 2 and 3-D MHD codes with radiation: pioneering studies of C-Mod experiments with NIMROD/KPRAD; LH tool to seed non-thermal electron population
  - Develop **reliable disruption prediction** methods: developing robust algorithms; real-time automatic mitigation implemented in Digital Plasma Control System
  - NTM physics: effects of rotation; LHCD control/stabilization; sawtooth control
  - Understand intermediate n AEs; damping and stability of AEs; active MHD antennas couple to intermediate n modes.
  - Redistribution of fast particles by AEs: ICRF ion tails drive AEs unstable; excellent diagnostics (PCI, CNPA, lost ion detector)

RFQ In-Situ Surface Analysis*



NIMROD/KPRAD Simulation:
Mitigated C-Mod Disruption



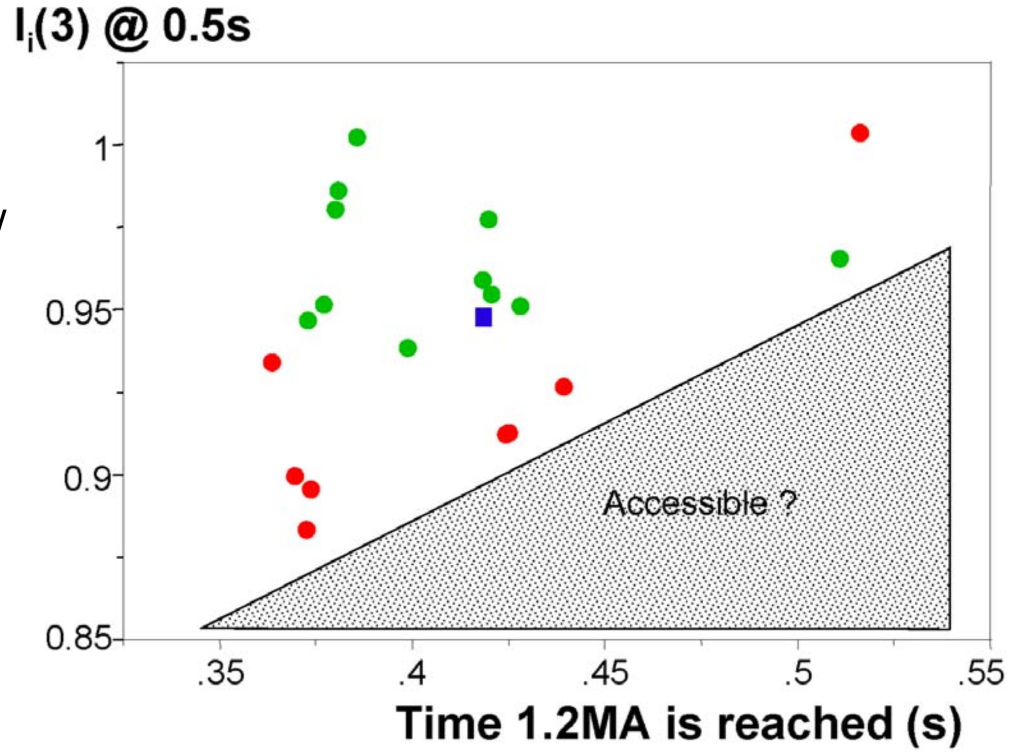
*RFQ Surface Analysis funded by OFES Diagnostic Initiative

Joint Experiments Coordinated through ITPA

Alcator C-Mod

- **Many issues (especially for ITER) studied in close coordination with other tokamak facilities**
- Current areas of emphasis on C-Mod
  - Confinement scalings (CDB-4, CDB-8)
  - Density peaking (CDB-9)
  - Impurity transport (under discussion)
  - Transport in high performance operation with low momentum input (TP-4)
  - Scaling of spontaneous rotation (TP-6.1)
  - SOL transport, blobs (DSOL-5, DSOL-15)
  - Disruption mitigation (MDC-1, runaways under discussion)
  - NTMs (MDC-3, MDC-5, MDC-8, MDC-14)
  - Error fields (MDC-6)
  - TAE studies (MDC-10, MDC-11)
  - Non-resonant magnetic braking (MDC-12)
  - Resonant magnetic perturbations, ELMs and pedestal (PEP-19)
  - Pedestal structure, width (PEP-6, PEP-7)
  - Small ELMs (PEP-13, PEP-16)
  - Low density H-mode threshold (CDB-11)
  - Steady-state scenarios (SSO-1, SSO-3, TP-2)
  - Hybrid scenarios (SSO 2.1/TP-2, SSO-2.2/CDB-8, SSO-2.3, SSO-3, TP-2)
  - ITER startup scenarios (SSO-5)
  - Pedestal in advanced scenarios (SSO-PEP-1/PEP-20)

Internal Inductance during Current Rampup
Present ITER Spec is $\leq$0.85

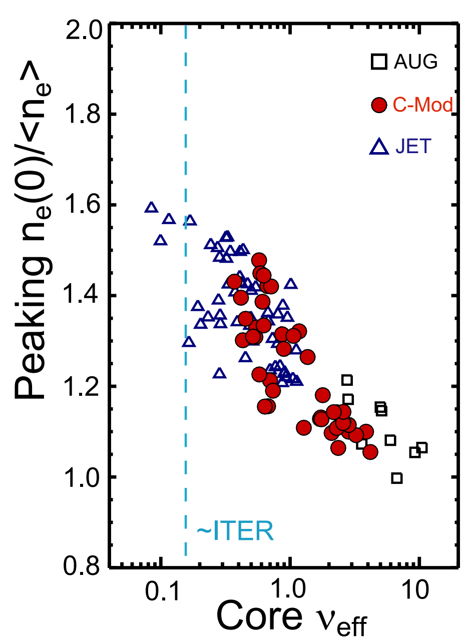


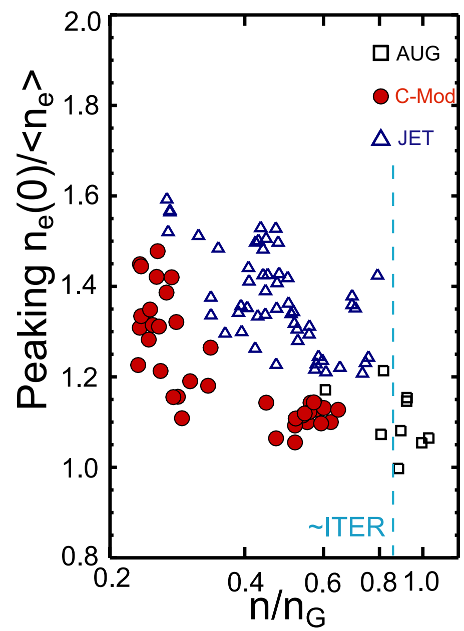
ITPA SSO-5, Joint C-Mod, ASDEX-U, JET, DIII-D

Core Transport – Major Themes

- **Overarching: Model Testing and Code Validation**
  - Systematic and quantitative comparisons with nonlinear turbulence codes
  - Quantitative where codes and models are more mature
    - Role of magnetic shear
    - Electron transport
- **Particle and Impurity Transport**
  - How to predict fueling, density profile and impurity content?
  - Now within capabilities of gyrokinetic codes
- **Self-Generated Flows and Momentum Transport**
  - How to extrapolate to source-free, reactor-like conditions?
- **Internal Transport Barriers**
  - Access conditions and control, especially in absence of dominant ExB
  - Important element in advanced scenarios research

Addition of C-Mod data to ASDEX/JET studies of density peaking with decreased collisionality – breaks the correlation between ν and n/n_G

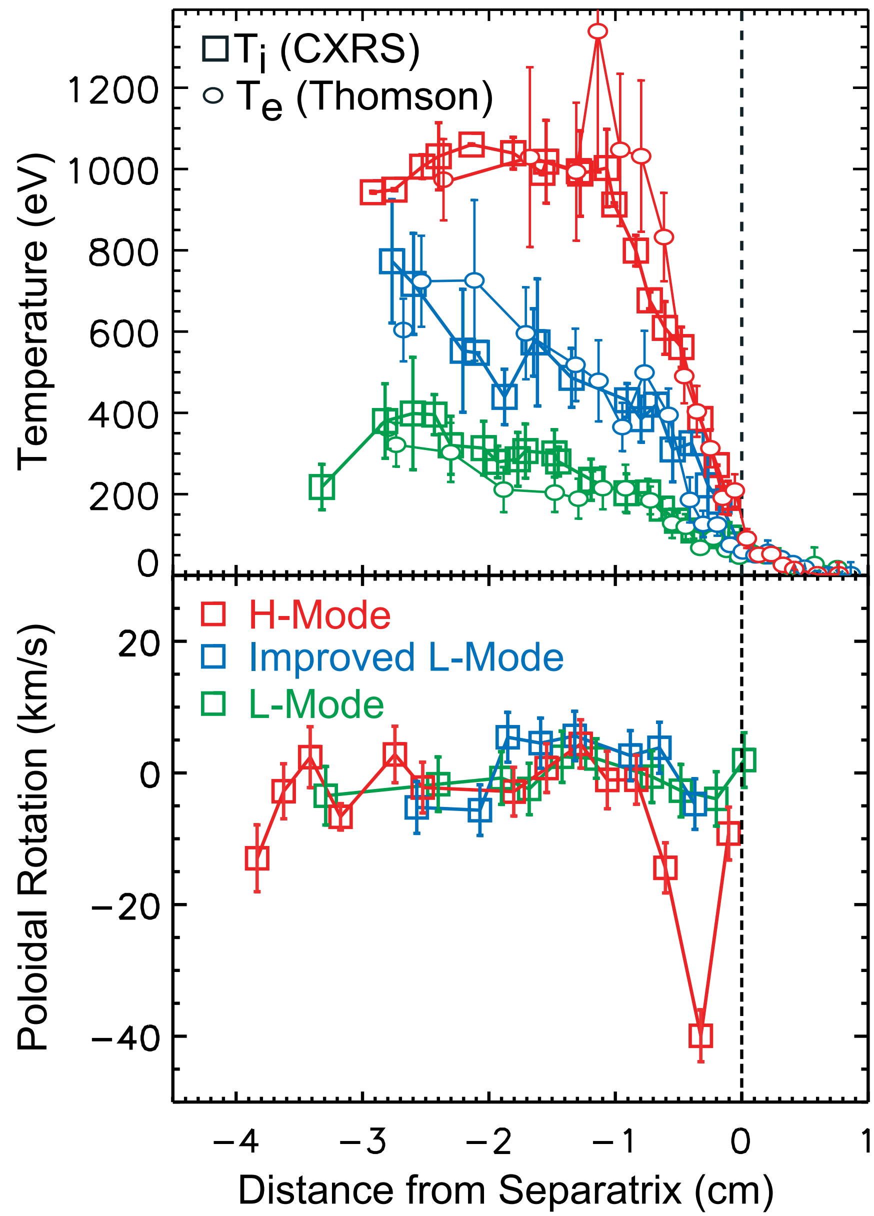




Pedestal Physics – Major Themes

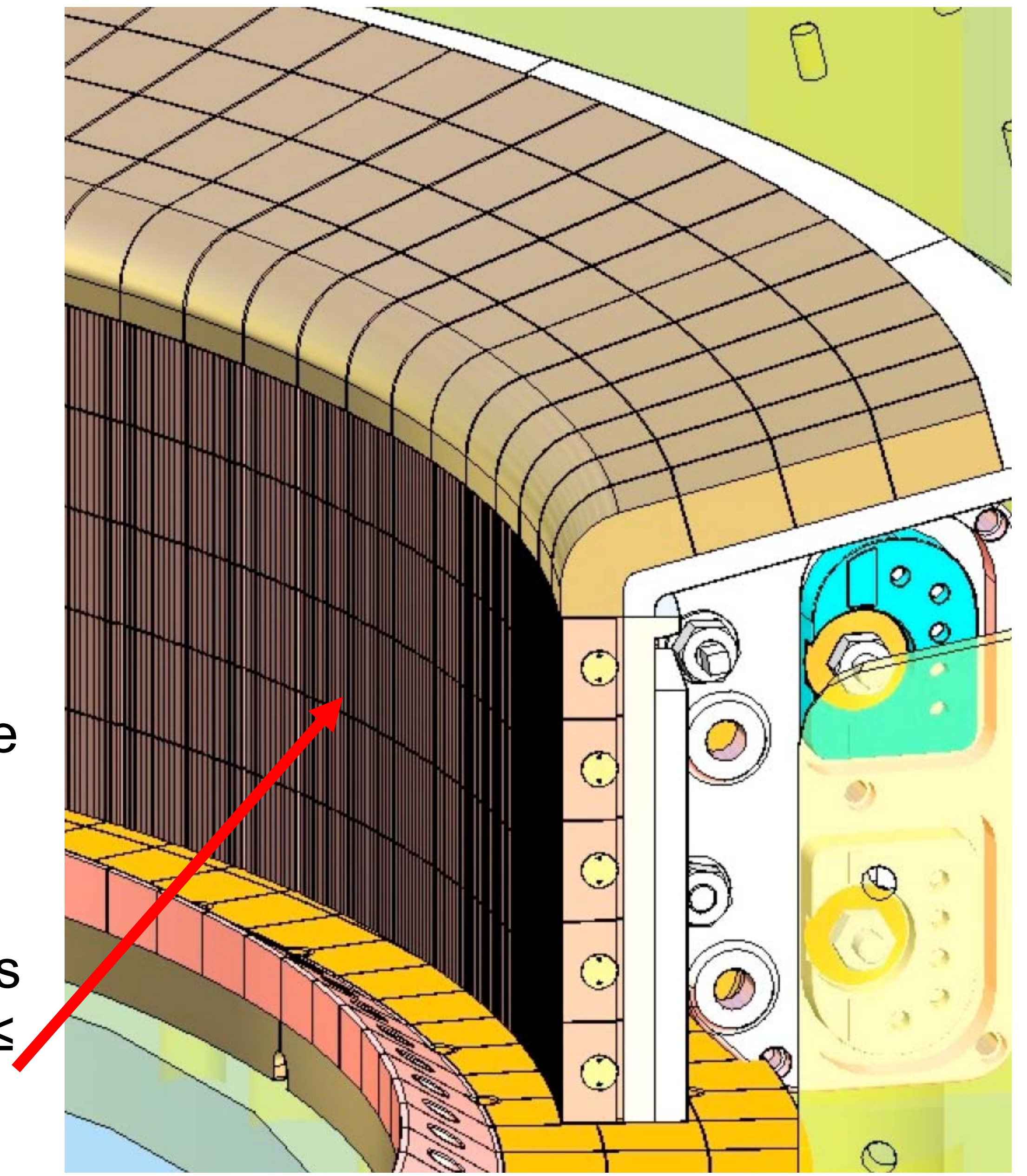
- **Pedestal structure and transport**
  - Effects of shaping, shear
  - Neutral penetration
  - Momentum transport
- **Edge relaxation mechanisms**
  - Small/no ELM regimes
- **Pedestal control**
  - Shaping, topology
  - External fields (RMP)
  - Applications of LHCD, ICRF
    - Initial LHCD H-mode results show intriguing pedestal regulation effects
- **L-H transition**
  - Slow transitions
  - Low density threshold scaling

mm Scale Resolution Diagnostics Reveal Pedestal Details



Plasma Boundary – Major Themes

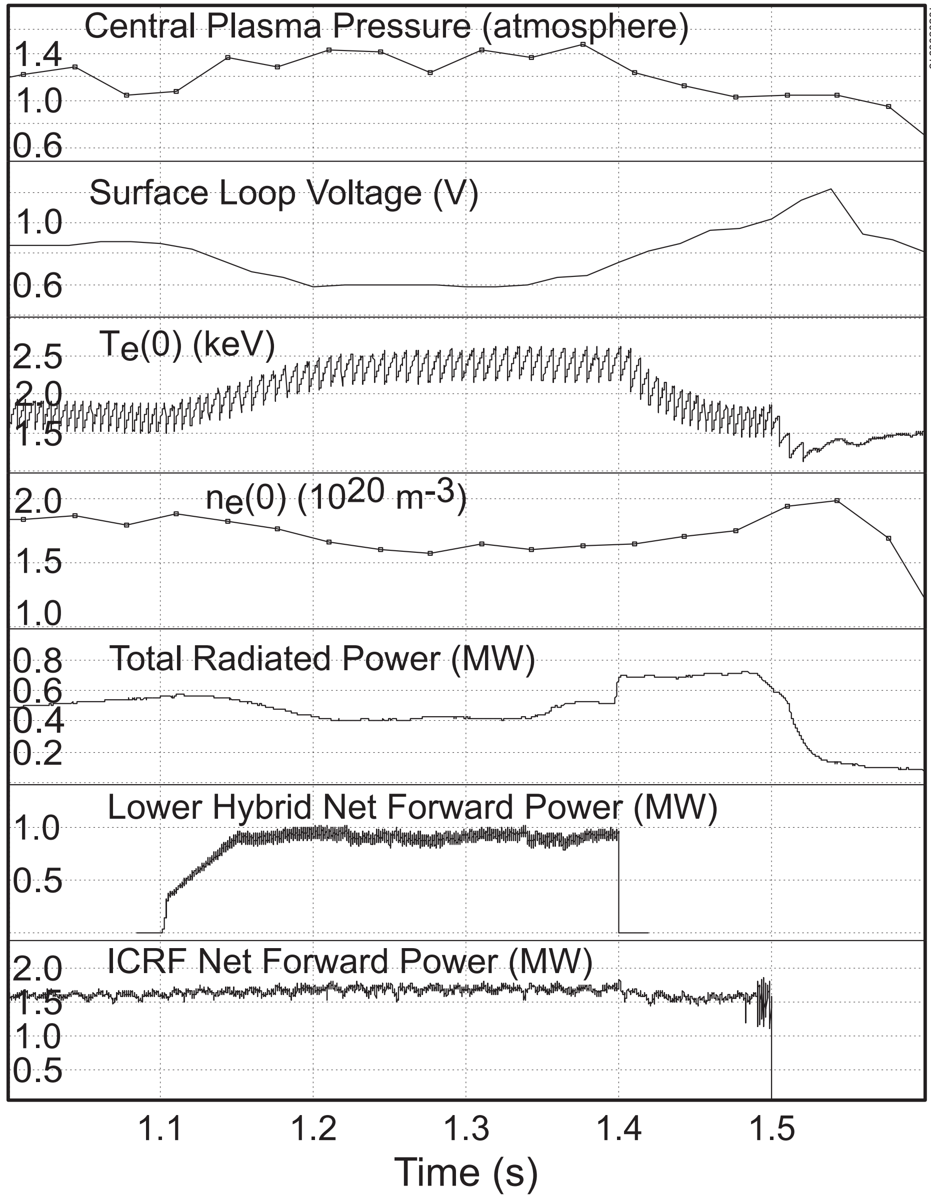
- **Transport** - controls heat loads, impurities
  - Perpendicular transport
    - Time-averaged, turbulent
  - Parallel heat transport
  - Divertor physics
- **Plasma-surface interaction** - Crucial information for a reactor (high-Z tiles)
  - Fuel retention
  - Effects of RF waves on the edge
  - Material properties and surface conditioning
- **First-wall development towards fusion DEMO**
  - Molybdenum and tungsten tiles
  - DEMO-like tungsten divertor (≤ 600 ^{0}C)
  - Operation in FY2011



Waves-Plasma Interactions– Major Themes

- **Current Drive**
  - LHRF: far off-axis current drive
    - LHCD is operational, and results are extremely promising
      - Nearly full current drive (I_p ~ 1MA) at n_e~0.5×10^{20} m^{-3}, with ~900 kW coupled
      - Excellent coupling, accessibility, current drive in H-mode plasmas (with ICRF)
      - Evidence of pedestal regulation
  - ICRF: core current drive (seed current), and applications to sawtooth control
- **Lower Hybrid physics at ITER-relevant parameters**
  - Same wave, plasma, and cyclotron frequencies
- **Coupler and Antenna Technology**
- **Model development and validation**
  - State of the art predictive models, scalable to ITER and reactors.

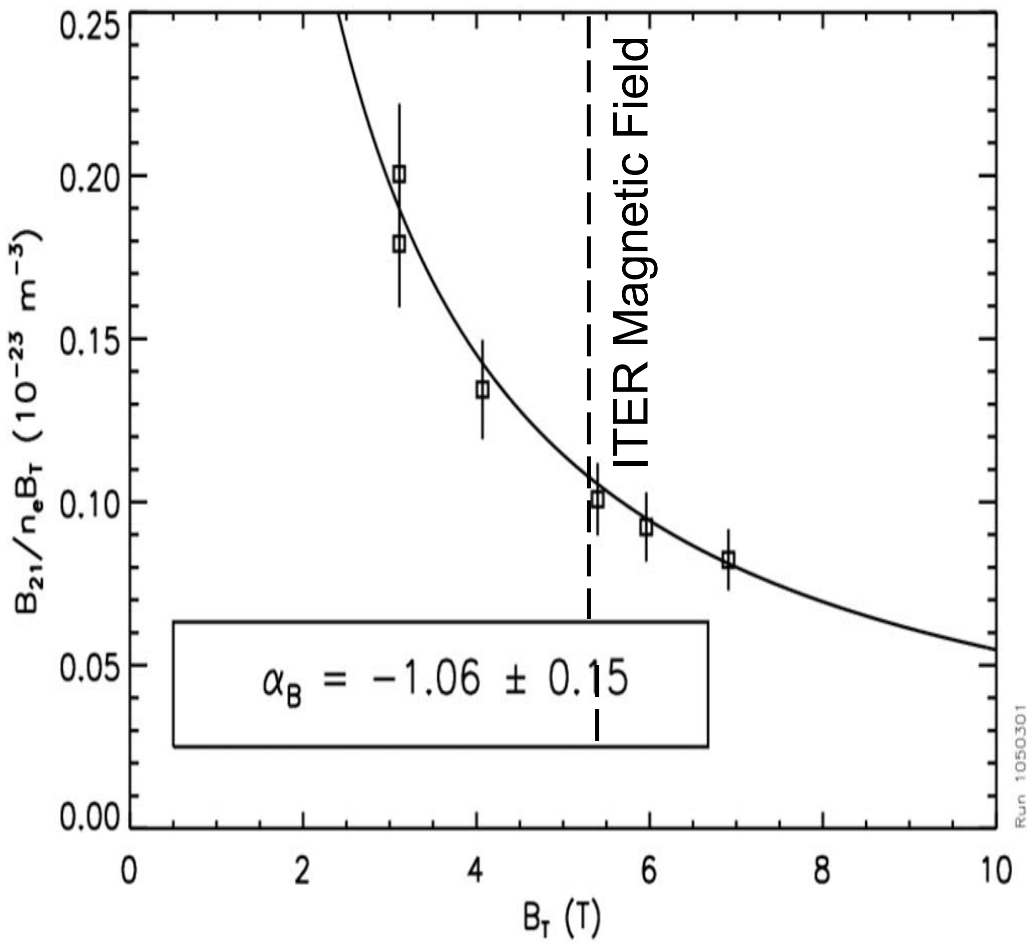
Combined ICRF+LHCD in H-Mode



Macroscopic Stability – Major Themes

- **Non-Axisymmetric Fields**
  - Error fields, Locked modes, Rotation
  - RMP edge regulation
- **Disruption avoidance/mitigation**
  - Real-time anticipation/action
  - Runaway electron amplification/suppression
  - Advanced MHD simulation
- **Neoclassical Tearing Mode studies**
  - thresholds, LHCD stabilization
- **Energetic particle driven modes**, interactions with RF
- **Alfven Eigenmodes**
  - Active probing of stable intermediate toroidal mode number modes

C-Mod locked mode threshold in error field spans ITER B



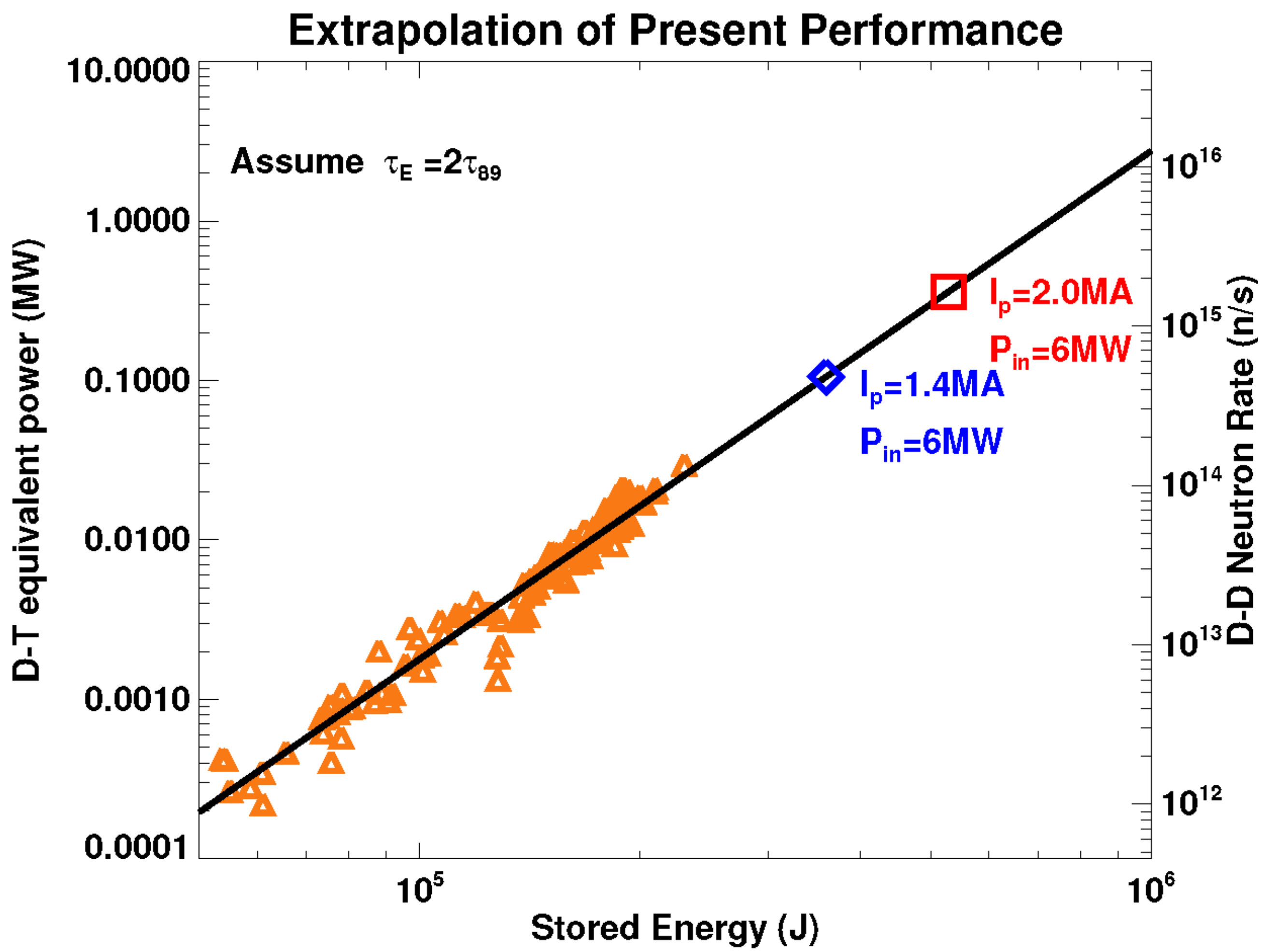
Joint experiments with JET & DIII-D (ITPA)

Integrated Scenarios for ITER and Beyond

- By demonstrating high performance plasmas similar to the planned ITER baseline scenario (H-Mode) and advanced scenarios (also relevant to DEMO), with relevant parameters and control tools, C-Mod will address many of the same challenges as ITER.
  - Integrates elements of all of the science topical areas
- For the inductive **H-mode regime** (q~3, β_N=1.8), these include pedestal issues, high heat fluxes and RF-wall interactions.
- For the **hybrid scenario** (q~4, 50% non-inductive), we will assess whether improved confinement is still achieved in torque-free plasmas and with RF current profile control.
- **Steady-state** regime aims at full non-inductive CD, with progressively increasing bootstrap and β_N, staying below no-wall limit (~3). As on ITER, achieving this requires both full power and high confinement.
  - Will demonstrate **far off-axis LHCD** at same B, n_e , similar frequency proposed for ITER
  - Pulse length capability of 5 to 10 current relaxation times for **fully relaxed current profiles**

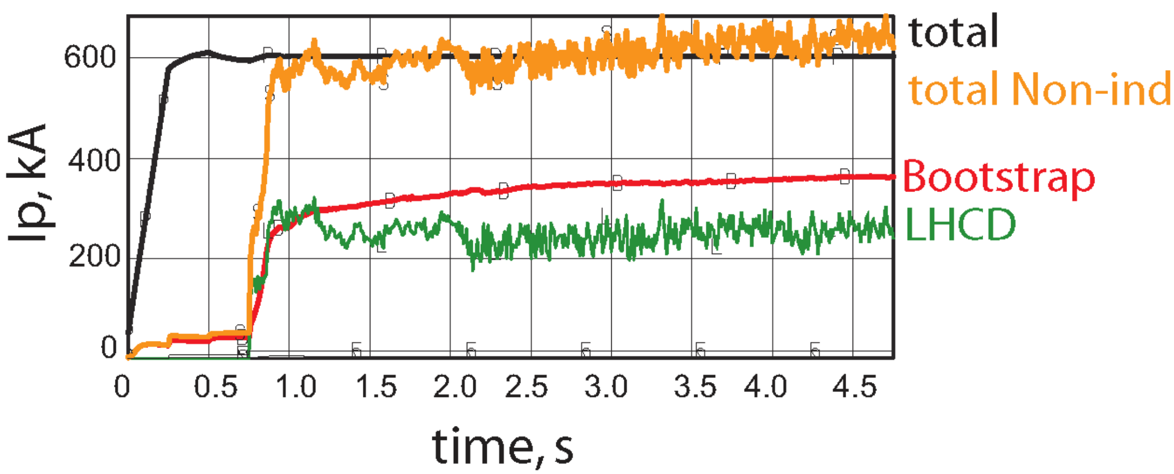
ITER H-Mode Baseline Scenario – Major Themes

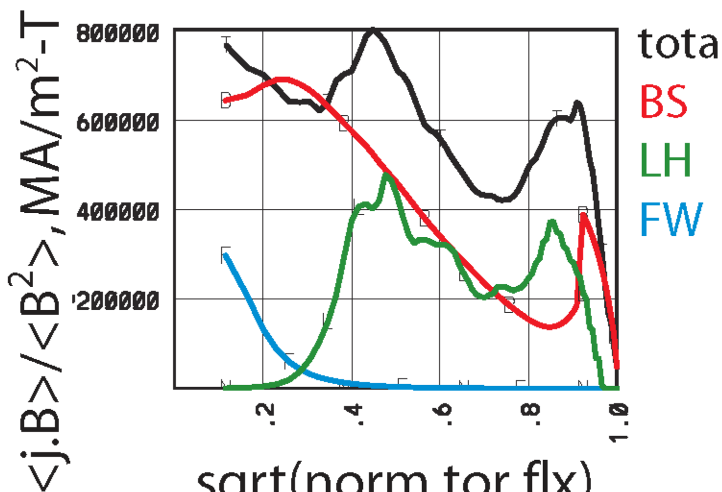
- **ITER-like H-mode regimes**
  - Same pressure, β, field, Z_{eff}, shape
- **Pedestal relaxation mechanisms**
  - Small/no-ELM regimes
- **ITER-relevant plasma control**
  - Similar configuration/coil-set, advanced control system



Advanced Scenarios – Major Themes

- **Develop operational scenarios for ITER and beyond**
  - Hybrid
  - Non-inductive steady-state
  - ITB and double-barrier regimes
- **Compatibility of all scenarios with SOL and divertor**
  - High power density, low plasma density
- **Integrated modeling essential to guide the research**





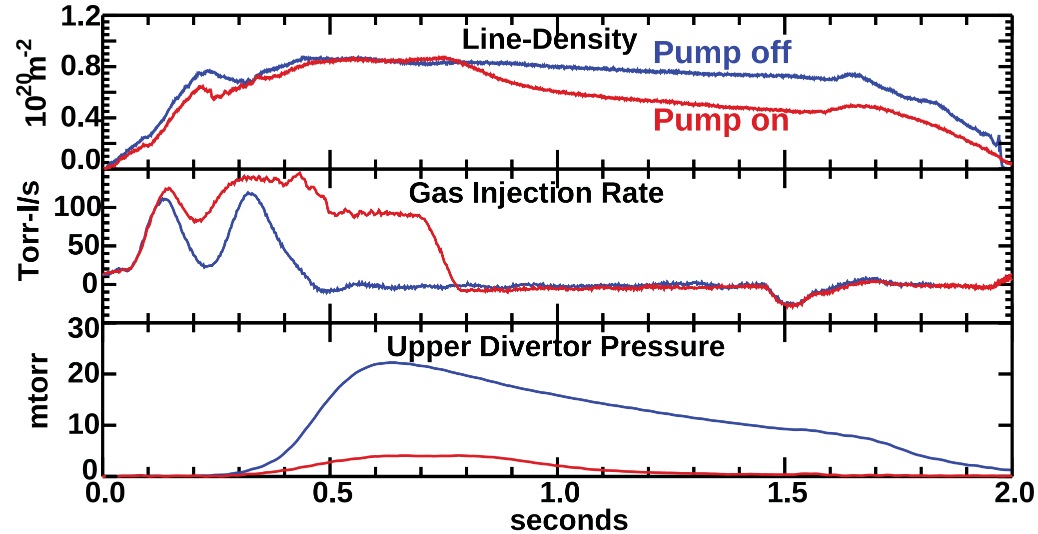
TSC simulation of fully non-inductive scenario with H-mode density profiles ($1.5x10^{20}$ m^{-3})

LH: 2.5 MW; ICRF: 4 MW; I_p=0.6 MA, 5.4 T, H_{98-y2}=1.44. bootstrap fraction is 60%

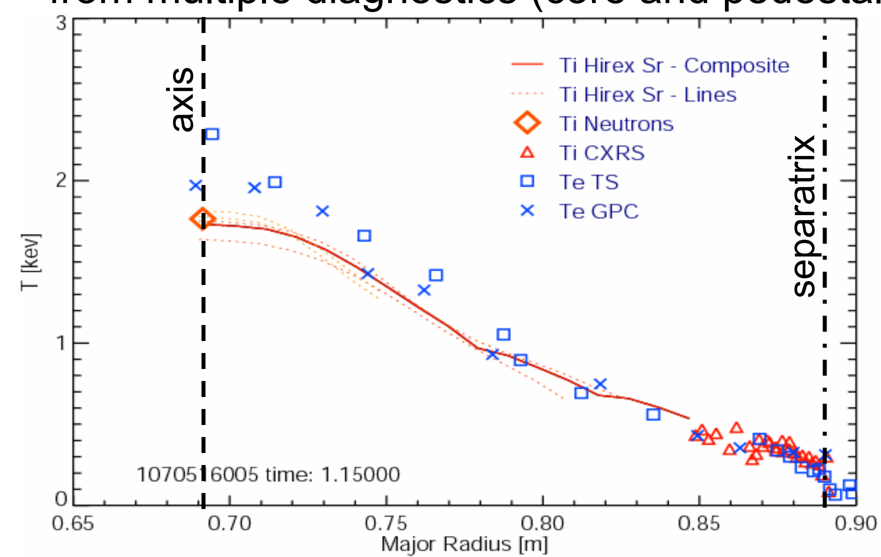
Recent upgrades/enhancements bearing fruit

- **Lower Hybrid Current Drive**
- **ICRF Fast-Ferrite Tuning**
- **Divertor Cryopump**
- Tungsten lamella divertor tiles
- **Surface Science Station**
- **Diagnostics**
  - Profiles
    - MSE [j(r)]
    - Hard x-ray imaging [fast e^- profiles]
    - CXRS [T_i, v_ϕ, v_θ, E_r]
    - High throughput, high spectral and spatial resolution soft x-ray imaging [T_i, v_ϕ]
  - Fluctuations
    - PCI [Spatially resolved, high k δn]
    - Inner-wall scanning probes [flows also]
    - Reflectometry [edge δn]
- **Loki parallel computing cluster**
  - Advanced non-linear simulations

Good density control with divertor cryopump (~200 T-l/s pumping)



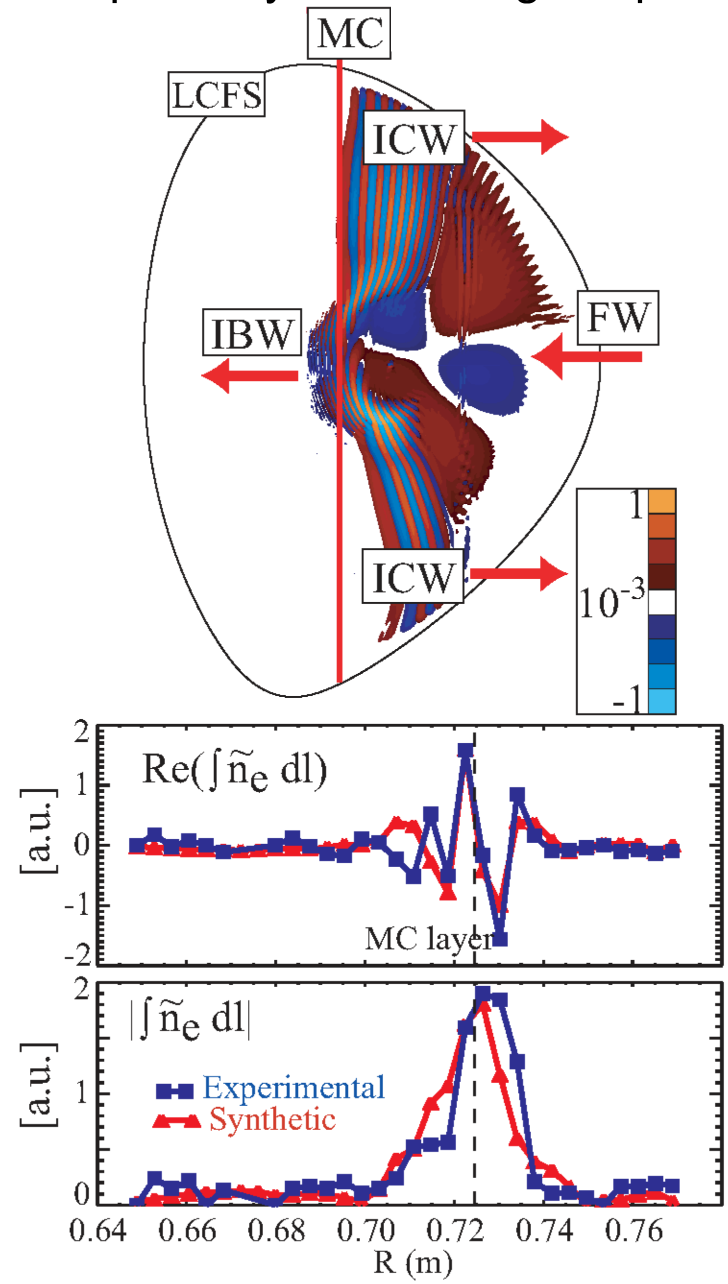
Detailed ion and electron temperature profiles from multiple diagnostics (core and pedestal)



C-Mod Helping to Resolve Key Issues on the Path to DEMO

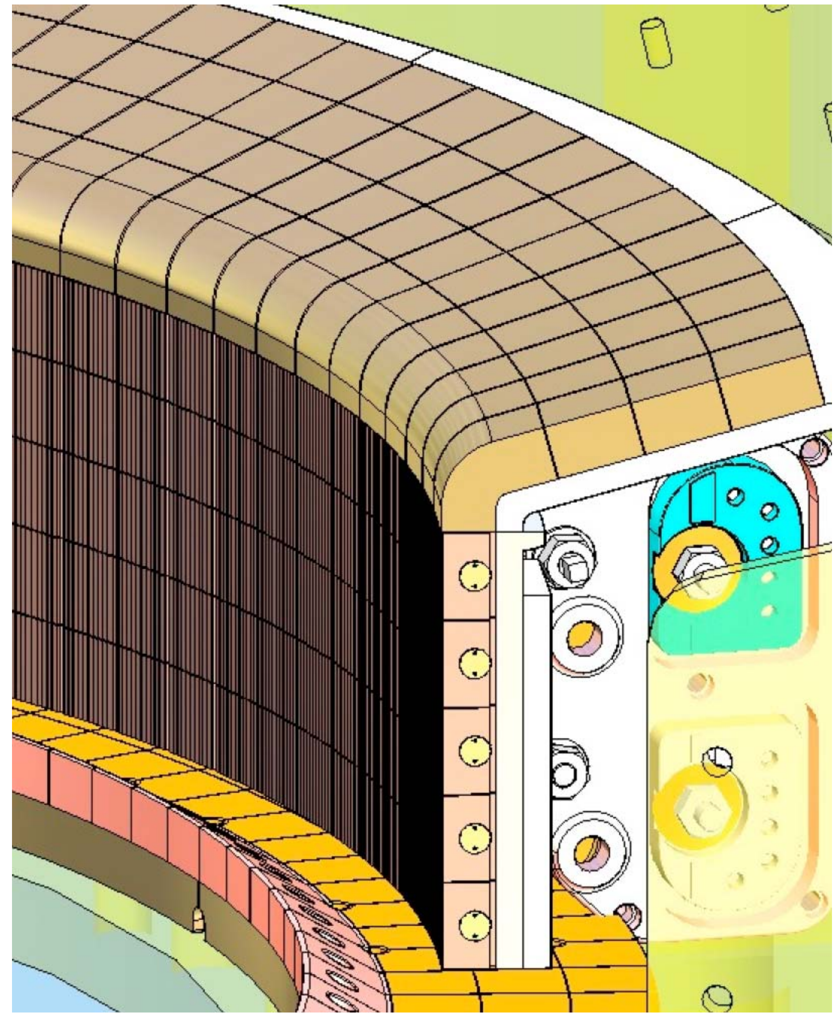
- Recent FESAC panel identified critical "gaps" on the path from ITER to DEMO that will require new initiatives
  - *Assumes successful resolution of many issues first on existing facilities and ITER*
- **C-Mod helping to resolve many of these key issues**
  - **Plasma facing components**: high Z metals, ultra-high SOL power densities.
  - **Off-normal events**: disruption avoidance, prediction and mitigation.
  - **Plasma-wall interactions**: SOL and divertor transport, erosion/redeposition, hydrogen isotope retention.
  - **Integrated, high performance plasmas**: focus of integrated thrusts.
  - **Theory and predictive modeling**: code benchmarking, discovery of new phenomena, iteration of theory and comparison with experiment.
  - **Measurements**: new and improved diagnostic techniques.
  - **RF antennas, launchers and other internal components**: advancing the understanding of coupler-edge plasma interactions, improvement of theory and modeling.
  - **Plasma modification by auxiliary systems**: RF (ICRF and LHRF) for current drive, flow drive, instability control; ELM control
  - **Control**: maintaining high performance advanced scenarios with fully relaxed current profile.

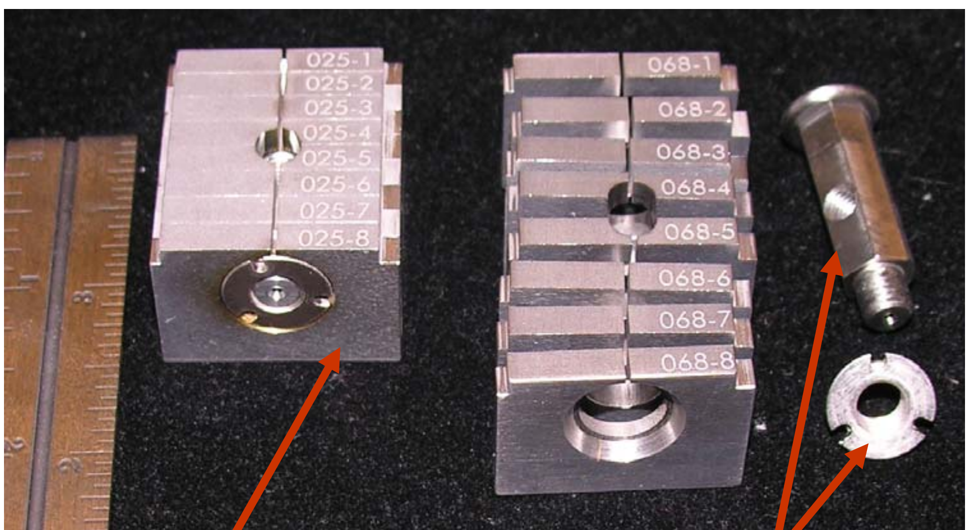
Code Benchmarking
Compare: Synthetic Diags/Exp.



DEMO-like divertor can directly address significant aspects of Gap G-9

- DEMO-Like Tungsten Divertor (600 ^{0}C) can actually address a significant part of Gap G-9: *Sufficient understanding of all plasma-wall interactions necessary to predict the environment for, and behavior of, plasma facing and other internal components for DEMO conditions*.
  - First investigations in a tokamak with actively heated high temperature metal plasma facing
  - Critical tests of plasma-wall interactions, hydrogenic retention
- Design, construction, installation (FY08-FY10)
- First operation, FY11



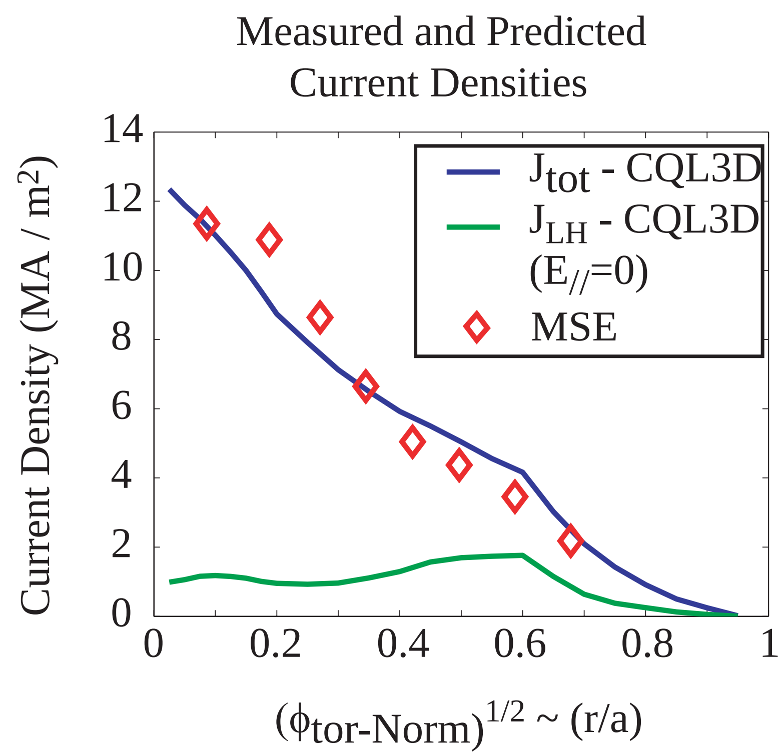


Assembled tungsten lamella tile as installed in C-Mod

Bolt and nut secure tiles and anchor to support plate

Validation: Comparing State of the Art Code Results with C-Mod Data

- Pedestal, Edge and Boundary
  - XGC code being developed through SciDAC FSP Prototype Center
    - prediction of pedestal height and width
  - GEM, BOUT, ESEL
  - ELITE for MHD stability of intermediate to high n ballooning modes
- Waves
  - (TORIC, AORSA) + (CQL3D, ORBIT RF, LSC) for minority tail evolution, ICH, LHCD, MCEH, MCCD, FWEH, FWCD, ICCD
    - Synthetic diagnostic comparisons with PCI, hard X-ray and CNPA measurements.
  - TOPICA + (TORIC) for comparisons with antenna loading and antenna electrical characteristics
- Macroscopic Stability
  - NIMROD + KPRAD - simulate gas puffing
  - M3D - sawtooth reconnection and NTM stabilization
  - NOVA-K to simulate Alfven cascades
    - Synthetic PCI diagnostic implemented
- Transport and Scenario Modeling
  - GS2, GYRO – Transport, barrier simulations (internal and edge)
  - TSC-TRANSP simulations for AT scenario development



Research Goals (FY08-FY10)

Alcator C-Mod

C-Mod is currently operating.
We have completed 7.5 of planned 15 weeks research in FY08.

Generation of plasma rotation and momentum transport (OFES JOULE target, joint with DIII-D and NSTX)	FY 2008
Confinement at high plasma current	FY 2008
Active control of ICRF antenna	FY 2008
Hybrid Advanced Scenario investigations	FY 2009
Self-generated plasma rotation	FY 2009
Testing a model of the fuel retention process in first-wall tiles	FY 2010
Study of runaway electron dynamics during disruptions	FY 2010
Characterize accessibility conditions for small edge-localized modes	FY 2010

Budget Profiles (k$)

Alcator C-Mod

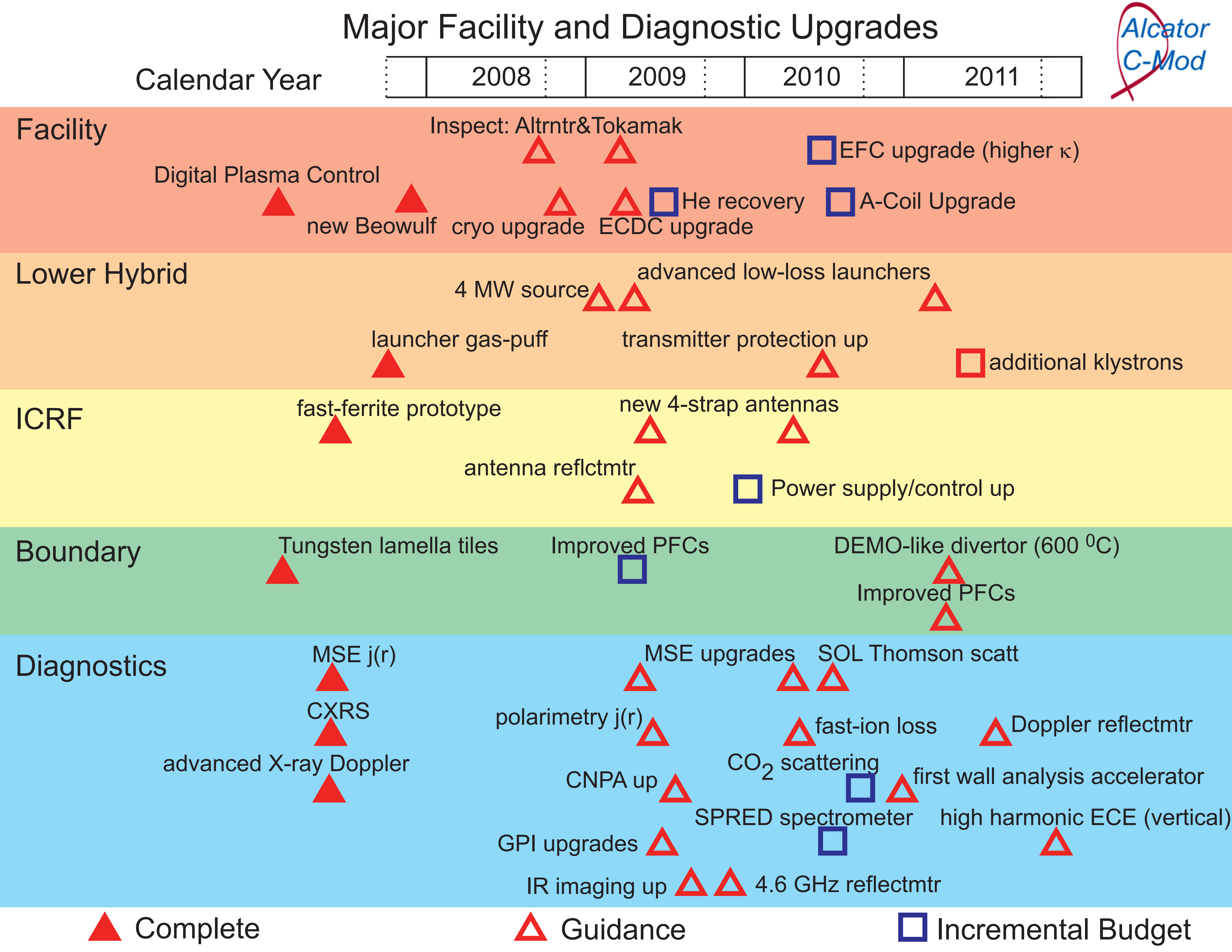
Institution	FY08 (Appropriation)	FY09A* (Guidance)	FY10A* (Base)	FY10B (Full)	FY10D* (-10%)
MIT	22,567	20,712	21,120	27,430	19,000
PPPL	2,090	2,070	2,110	3,240	1,900
U Texas	415	400	408	440	367
LANL	103	103	106	127	95
National Project Total (research run weeks)	25,175 (15)	23,285 (10)	23,744 (13)	31,237 (24)	21,362 (8)

*Reductions in Force

FY09A: 1 Scientist, 1 Student, 1.5 Engineers

FY10A: 1.5 Scientists, 1 Student, 1.5 Engineers

FY10D: 4 Scientists, 2 Students, 2 Post-Docs, 3.5 Engineers, 1 Technician



Major Facility and Diagnostic Upgrades
Calendar Year
2008
2009
2010
2011
Alcator C-Mod
Facility
Inspect: Altrntr&Tokamak
EFC upgrade (higher κ)
Digital Plasma Control
He recovery
A-Coil Upgrade
new Beowulf
cryo upgrade
ECDC upgrade
Lower Hybrid
advanced low-loss launchers
4 MW source
launcher gas-puff
transmitter protection up
additional klystrons
ICRF
fast-ferrite prototype
new 4-strap antennas
antenna reflctmtr
Power supply/control up
Boundary
Tungsten lamella tiles
Improved PFCs
DEMO-like divertor (600 ^{0}C)
Improved PFCs
Diagnostics
MSE j(r)
MSE upgrades
SOL Thomson scatt
CXRS
polarimetry j(r)
fast-ion loss
Doppler reflectmtr
advanced X-ray Doppler
CO_2 scattering
CNPA up
first wall analysis accelerator
SPRED spectrometer
high harmonic ECE (vertical)
GPI upgrades
IR imaging up
4.6 GHz reflectmtr
Complete
Guidance
Incremental Budget

Incremental Funds for C-Mod in FY09-10 would Enable Significantly Extended Scientific Progress*

Alcator C-Mod

Transport Science	Role of e^- heating and LHCD on self-generated flows	Impurity and momentum transport	Nature of momentum coupling at edge	Gyrokinetic modeling of fluctuations and fluxes in ITB regimes	Investigate portion of k-space responsible for electron energy transport
Pedestal Physics	Shaping and pedestal regulation	Low density H-mode threshold	Influence of neutral fueling/ionization	Slow L-H transitions, improved L-modes	Simulations of pedestal structure
Plasma Boundary	SOL turbulence and transport; Blob dynamics; Validation of E-M turbulence models	Ly-α opacity, modeling	Deuterium retention	Sheath rectification, sputtering; Erosion	DEMO-like tungsten divertor
Wave-Plasma	LHCD with compound phasing (2 launchers)	ICRF sheath physics	ICRF/LHCD synergies	ICRF mode conversion regimes; Flow drive	Measure 4.6 GHz LH waves in core plasma
Macro-Stability	Adaptive disruption mitigation; NIMROD/KPRAD modeling	Magnetic rotation braking, comparisons with NTV theory	Fast-particle-driven collective modes in low/reversed shear	Safe scenario control development for axisymmetric stability (ITER like equilibria)	Disruption induced runaway electron dynamics
Conventional H-Modes	Approach to nominal ITER H-mode operating point	ELM pacing, Influence of pedestal on core	Simulated burn control	Control algorithms mimicking ITER	High power handling of tungsten divertor
Advanced Scenarios	Hybrid scenario feasibility with LHCD	Internal Transport Barriers with LHCD	Advanced Scenario modeling	Combined high power ICRF/LHCD	Shear modification of core barriers with LHCD

*Progress expected in most topics (red indicates incremental funds required to speed up hardware upgrades and/or increased run time)

Summary National Budgets, Run-time and Staffing

Funding ($ Thousands)		FY08	FY09A	FY10D	FY10A	FY10B
Research		7,222	6,700	6,320	6,870	8,600
Facility Operations		14,694	13,377	12,500	14,015	18,500
Capital Equipment		416	400	0	0	0
PPPL Collaborations		2,090	2,070	1,900	2,110	3,240
UTx Collaborations		415	400	367	408	440
LANL Collaborations		103	103	95	106	127
MDSplus		155	155	140	155	170
International Activities		80	80	40	80	100
Total (inc. International)		25,175	23,285	21,362	23,744	31,177
Staff Levels (FTEs)						
Scientists & Engineers		55.01	51.96	42.22	51.34	61.84
Technicians		26.64	26.63	24.99	26.73	30.73
Admin/Support/Clerical/OH		15.53	15.07	14.35	15.27	17.07
Professors		0.34	0.35	0.35	0.41	0.41
Postdocs		1.83	3.00	2.00	3.00	4.00
Graduate Students		28.15	27.03	25.03	28.03	29.28
Industrial Subcontractors		1.90	1.70	1.00	1.50	2.10
Total		129.40	125.74	109.94	126.28	145.43
	FY07 Actual	FY08	FY09A Request	FY10D Reduced	FY10A Guidance	FY10B Full
Facility Run Schedule						
Research Run Weeks	14.7	15	10	8	13	24
Users (Annual)						
Host	40	41	39	35	39	45
Non-host (US)	67	67	65	58	66	80
Non-host (foreign)	48	50	45	40	48	60
Graduate students	30	30	29	27	29	33
Undergraduate students	5	5	4	3	5	10
Total Users	190	193	182	163	187	228
Operations Staff (Annual)						
Host	68	70	67	61	66	76
Non-host	4	4	4	3	4	5
Total	72	74	71	64	70	81

C-Mod will Continue to Make Major Progress for Fusion Science and Fusion Energy

Alcator C-Mod

- Flexible, Capable Facility
- Excellent Tools and Diagnostics
- Key Upgrades to Facility and Diagnostics

Unique and Complementary Contributions to Joint (National and International) Experiments

Model Validation across Broad Range of Dimensional and Dimensionless parameters

Key Contributions to Solution of Challenges for ITER and Beyond

Research supported by U.S. Department of Energy, Office of Fusion Energy Sciences

MIT INSTITUTIONAL ISSUES

Miklos Porkolab

Organized successful Symposium on Magnetic Fusion at the AAAS Meeting in Boston, Feb 16, with 6 speakers, (including E. Velikhov, Sir C. L. Smith, P. Kaw, R. Fonck, R. Stambaugh and K. McCarthy) to celebrate the 50-th year anniversary of the 1958 Geneva Conference (Talks on FIRE WEBSITE)

FY2009 OFES Budget Planning Meeting
March 11 -12, 2008, Gaithersburg, Md

Fusion Technology & Engineering Division

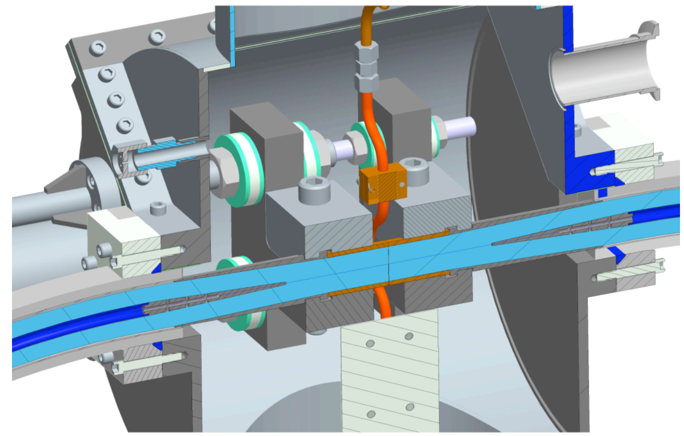
Joe Minervini, Head

- VLT magnets base program focused on basic technology R&D
- ITER Magnets work focused on and limited to preparatory R&D
- Budget Guidance
  - VLT Base
    - FY07 Request: $904K ⇒ FY07 Funding: $160K
    - FY08 Guidance $410K: Leads to drastic reduction of base program
    - Eliminate grad students (now only 3 remaining and future uncertain) and 1 staff and results in jeopardy of long term program
  - ITER Magnets
    - FY07 Request: $3200K ⇒ Guidance: $1450K
    - FY08 Guidance $900K (Verbal guidance was $2.7M before Omnibus Bill)
    - FY09 Guidance $0 ?
    - Combined reductions in Base and ITER programs leads to loss of core interdisciplinary magnet capabilities (Loss of ~ 8 FTE's and grad students)

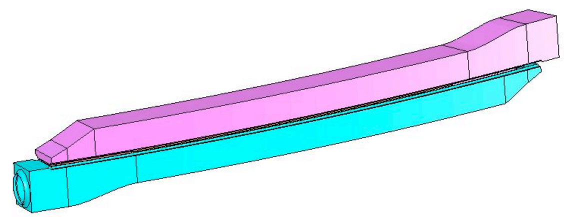
➢ **MIT stuck with severance pay package of order $1 M due to late notice (late January) and lack of severance pay from DOE**

Pulsed Test Facility (PTF) at PSFC can provide critical data on ITER magnet joints

Massachusetts Institute of Technology



CS Butt Joint



CS Lap Joint

PTF is the only facility in world that can test ITER-size (50 kA) superconductors and joints in pulsed field background; could test 2 CS joint options –Butt Joint & Lap Joint Under reduced staff and budget and without ITER funding PTF may not be operable

Magnets Enabling Technology

Massachusetts Institute of Technology

Critically important to maintain future core capability, including training of graduate students, for a balanced MFE program

Consider 3 Funding Cases for FY09/FY10

\$1 M Case (Survival program, 2 FTE senior staff, 1 postdoc, 2 students, keep lab)

1. Base program director – ½ FTE
2. Superconducting magnet code development – ½ FTE, 1 student
3. Fiber optic QD and 'superthermometer' development – 1 Postdoc
4. Optical laboratory \$100 k
5. HTS 2G (YBCO) tape-in-plate + joint development – 1 FTE , 1 student

\$1.5 M = \$1M case +add: (Keeps another 1.5 FTE senior staff + 1 more student)

1. Nb_3Sn bending strain standard test development – 1 FTE, ½ student
2. 3D strain studies – code development, experiment analysis – ½ student, ½ FTE
3. Fiber optic – cabled strain gauge development – 1 student (with above Postdoc)

\$2 M = \$1.5M case + add: (Desired minimum effective program by keeping key staff)

1. Full-time sc magnet code development, cabling effects – ½ FTE, 1 student
2. Insulation system development – high shear strength, high rad resist – 3/4 FTE, 1 student + \$50K industrial subcontract and \$20K MIT reactor
3. High Current, High Effective Current Density (J_{eff}) HTS 2G conductor development - \$50K industrial subcontract

PSFC Theory Program Requests

Peter Catto, Head, PSFC Theory Program

Massachusetts Institute of Technology

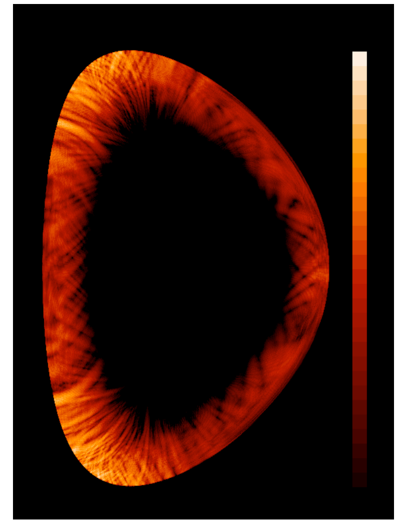
- New 256 processor cluster up and running, thank you DOE theory program !
  - Full wave code simulation of LH and ICRF waves done in-house
  - Nonlinear gyrokinetic simulations of turbulence done in-house
  - Planned upgrade to 512 processors - Need $75K from DOE
- Recent fusion theory contributions
  - Developed MHD + kinetic description for NIMROD and M3D
  - Hybrid gyrokinetic + fluid description developed for turbulence modeling on transport time scales
  - Need additional student RA at $65 K in FY 2009, $130 K in 2010
- NSTX support for theory cut (ECH modeling, A. Ram)
  - Propose collaborations with MAST ?

  -Abhay Ram, needs $105 K in FY 09, FY 2010

Fully converged LH Full Wave Code operational

P.T. Bonoli, D. Ernst, J. Wright, T. Baker
Massachusetts Institute of Technology

- Using the new PSFC computing cluster, full-wave LH field simulations in Alcator C-Mod have been performed
- Diffraction and focusing effects fully resolved (N_m=2047, N_r=980)
  - Satisfies 2008 Joule Theory Milestone
  - Some differences of power deposition profile as compared to ray tracing code
- Enables self-consistent LHCD and ICRF modeling for C-Mod
- Coupling of TORIC ICRF Full Wave Code to Fokker Planck Code in progress



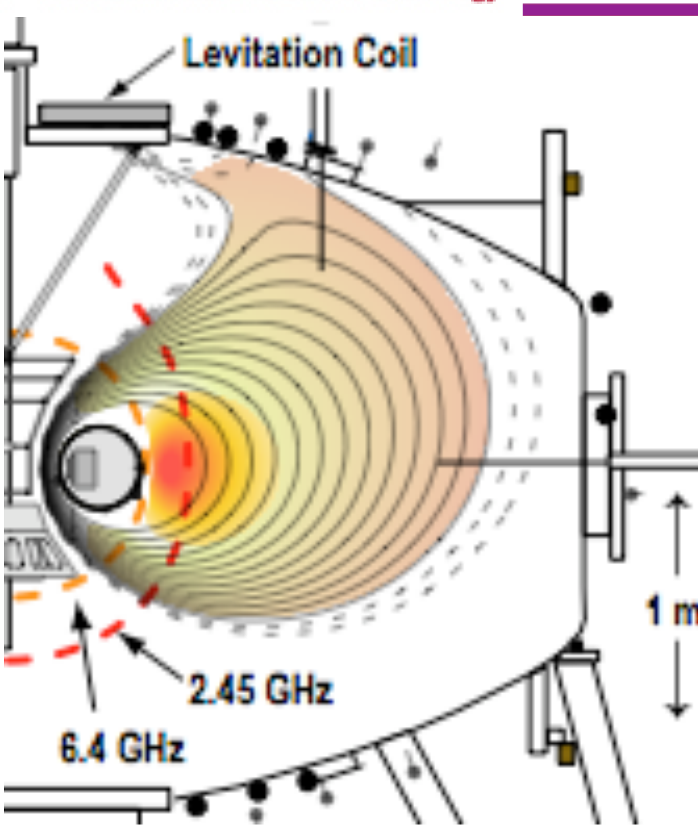
Contours of Re{$E_{||}$} for marginal $N_{//}$ spectrum and linear Landau damping

❖ **However, coupling and iteration of LH FW code with a Fokker-Planck code (CQL-3D) will require leadership class computer**

Levitated Dipole Experiment (LDX)

J. Kesner, M. Mauel Co-PIs, D. Garnier, + students

Massachusetts Institute of Technology



- **First experiments with levitation of LDX floating coil (1.3 MA, 1200 lb) took place on 2/9/07**
- **Low frequency ECRH (5 kW total, 2.45 GHz, 6.4 GHz) creates central torus of energetic electrons (~ 100 keV, high beta > 20%) stabilized by a cooler background plasma**
- **Near term will add 10 kW of 10 GHz ECRH to increase density, beta**
- **In FY 2009, 2010 propose to add the 28 GHz gyrotron sources at MIT to get higher density and higher beta thermal plasma**

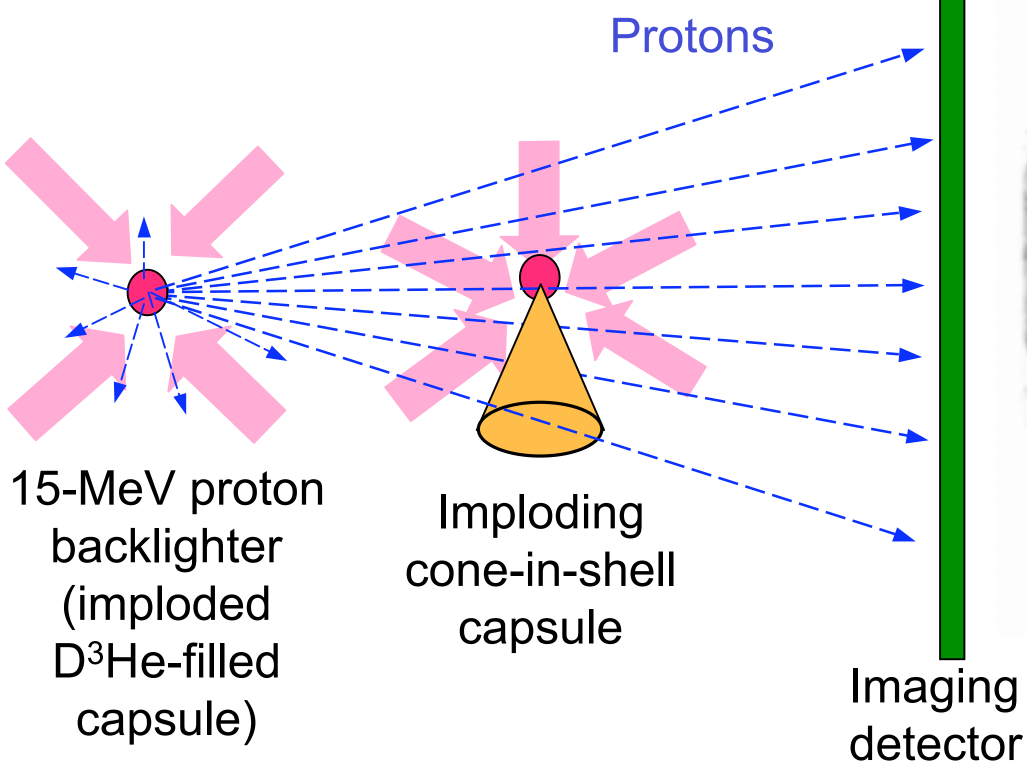
➢ **Need $174/$184 K/year in FY 2009/2010 to fund Paul Woskov to lead installation of 28GHz ECH system on LDX and operate it with students**

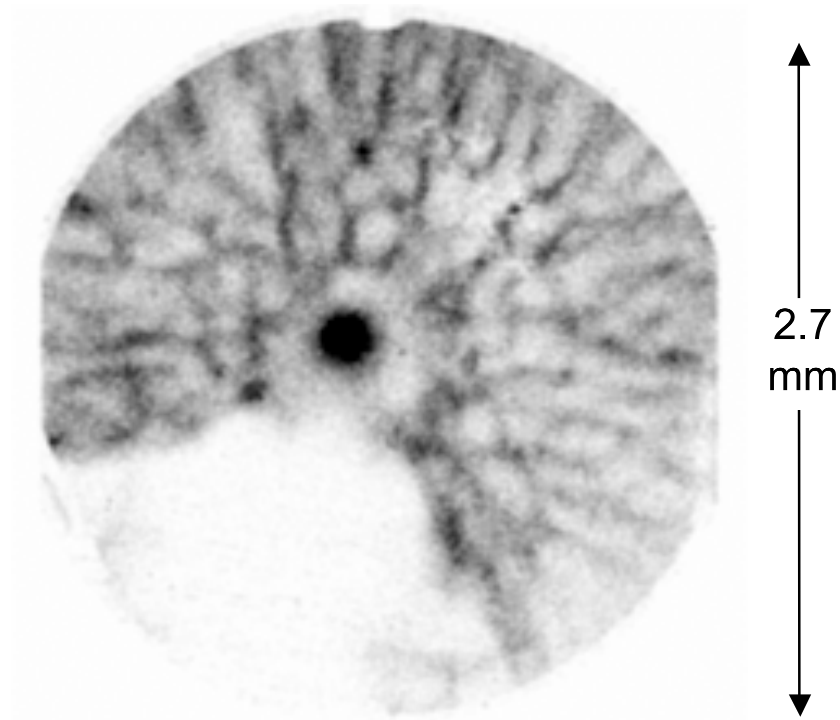
➢ **In addition, will submit new renewal proposal next year**

Proton Radiographs of Imploding ICF Capsules Show Filamentary External MegaGauss B-Fields and Internal E-Fields

(R. Rygg…R. Petrasso et al, *Science*, 29 Feb 2008)

Massachusetts Institute of Technology





PSFC HEDLP Program for FY2009 and 2010

R. Petrasso , Division Head

Massachusetts Institute of Technology

- Utilizing the MIT developed mono-energetic charged particle and radiography methods, perform experiments with Megagauss fields in dense HED plasmas
  - Laser-plasma interactions (ie, growth and decay of B fields)
  - Magnetic reconnection with β between ~ 1 and ~ 100
  - Growth and evolution of instabilities
  - Measurements of B- fields associated with the Rayleigh-Taylor instability and their impact on the evolution of HED plasmas
- Experimental study of the slowing of charged particles in classical and non-classical plasmas (i.e. warm dense matter) utilizing the MIT developed mono-energetic charged particles (protons, alphas, …)
- Funding from OFES at $155K (via U. Rochester) and from NNSA

➢ To exploit HEDLP science opportunities, need additional funding from OFES for post-docs, students, theory support and travel at $450K/$650K in FY09/FY10

Waves and Beams Division ECH Program Plans

Rick Temkin, Division Head

Massachusetts Institute of Technology

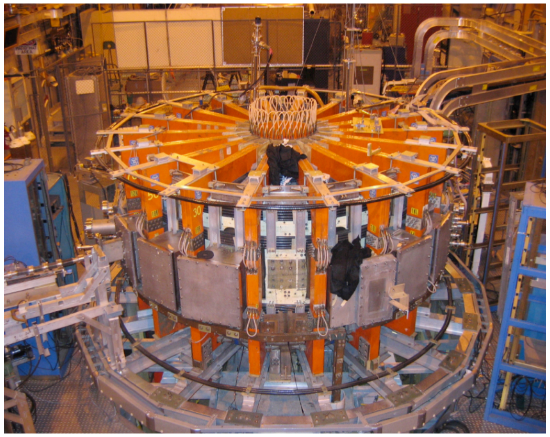
- **FY09 Plans for MIT:**
  - **High efficiency 1.5 MW, 110 GHz gyrotron research with depressed collector and improved internal mode converter ; goal is to exceed 60% overall efficiency; (VLT support).**
  - **Low power testing at 170 GHz of components for the ITER transmission line (US ITER Project support) and graduate student research on mode conversion at miter bends (VLT support)**
  - **Continue collaboration with JAEA and EU on gyrotrons and transmission lines.**
  - ❖ **Funding guidance: $520K from VLT, $200K from ITER**
- **FY09 Plans for CPI Industrial Gyrotron Development:**
  - **Gyrotron reliability and efficiency studies funded through no cost extension of prior year funds.**
  - **Impending loss of US industrial capability (CPI phased out ?)**
  - ❖ **Should find means to restore funding at CPI**
- **FY10 Plans for MIT:**
  - **Continuing research on gyrotrons and transmission lines, supporting domestic, ITER and international programs.**
  - ❖ **Funding request : $531K from VLT, $200K from ITER**

Massachusetts Institute of Technology

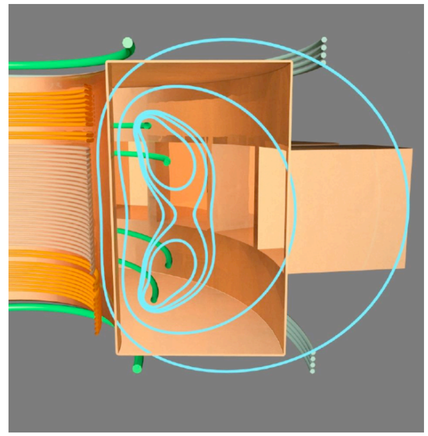
Reconnection Experiment in VTF: Connection to Fusion and Space Physics

J. Egedal + students

(A)



(B)



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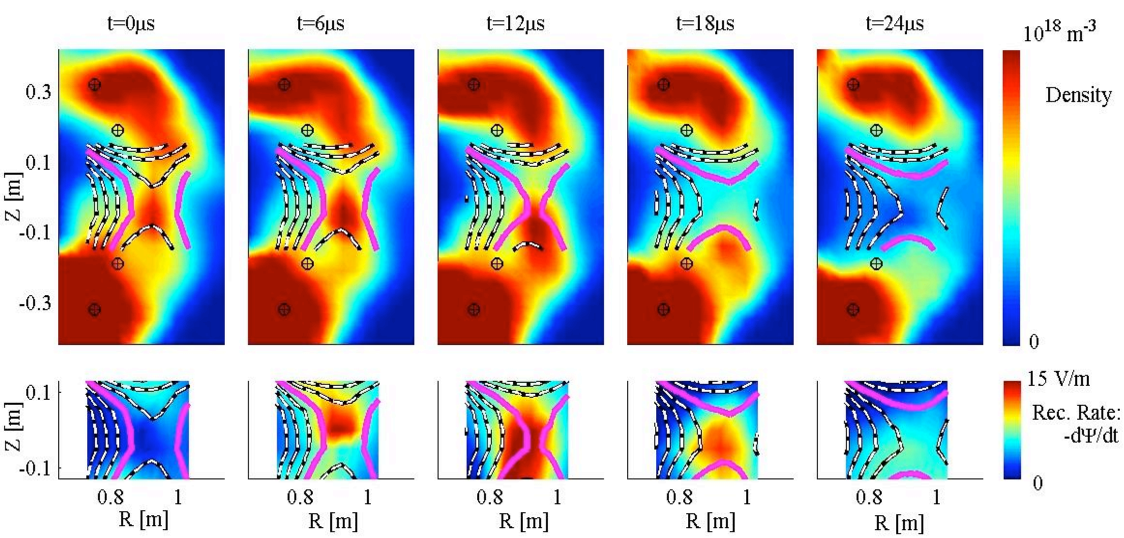


From J. Egedal et al., (2007) Phys. Rev. Lett. **98**, 015003

VTF funding include Prof. Egedal's DOE's Junior Faculty Award program and a continuation of the DOE/NSF award DE-FG02-03ER54712. Other minor source of funding is from the OFES Center for Multi-Scale Plasma Dynamics Studies (1 student RA only).

- Most recent results include observation and measurement of turbulence during spontaneous reconnection events (Will Fox et all, AGU Meeting, San Francisco, 12, 2007)

- J. Egedal will submit new proposals in FY 09/10

Diagnostic Initiatives

Result of Recompetition (Darlene Markevitch)

Massachusetts Institute of Technology

Good News

- Phase Contrast Imaging (PCI) and DIII-D and C-Mod (M. P. as PI, with 1 research staff, 4 graduate students) was highly rated and was renewed for another 3 years
- New Proposal by Dennis Whyte of MIT of the "in -situ accelerator " proposal to study surface interactions was selected for funding in FY09 for 3 years

Bad News

- Alpha diagnostic development, based on Collective Thomson Scattering by 140 GHz ECH signal on Asdex-U and Textor, a collaboration with EU, was terminated in spite of excellent technical progress. EU will continue to develop this for ITER.
- Paul Woskov, key MIT scientist, on layoff notice after 25 years of contribution to fusion and low temperature plasma applications, with 6 R&D 100 Awards

Alcator C-Mod Program

Division Head: Earl Marmar

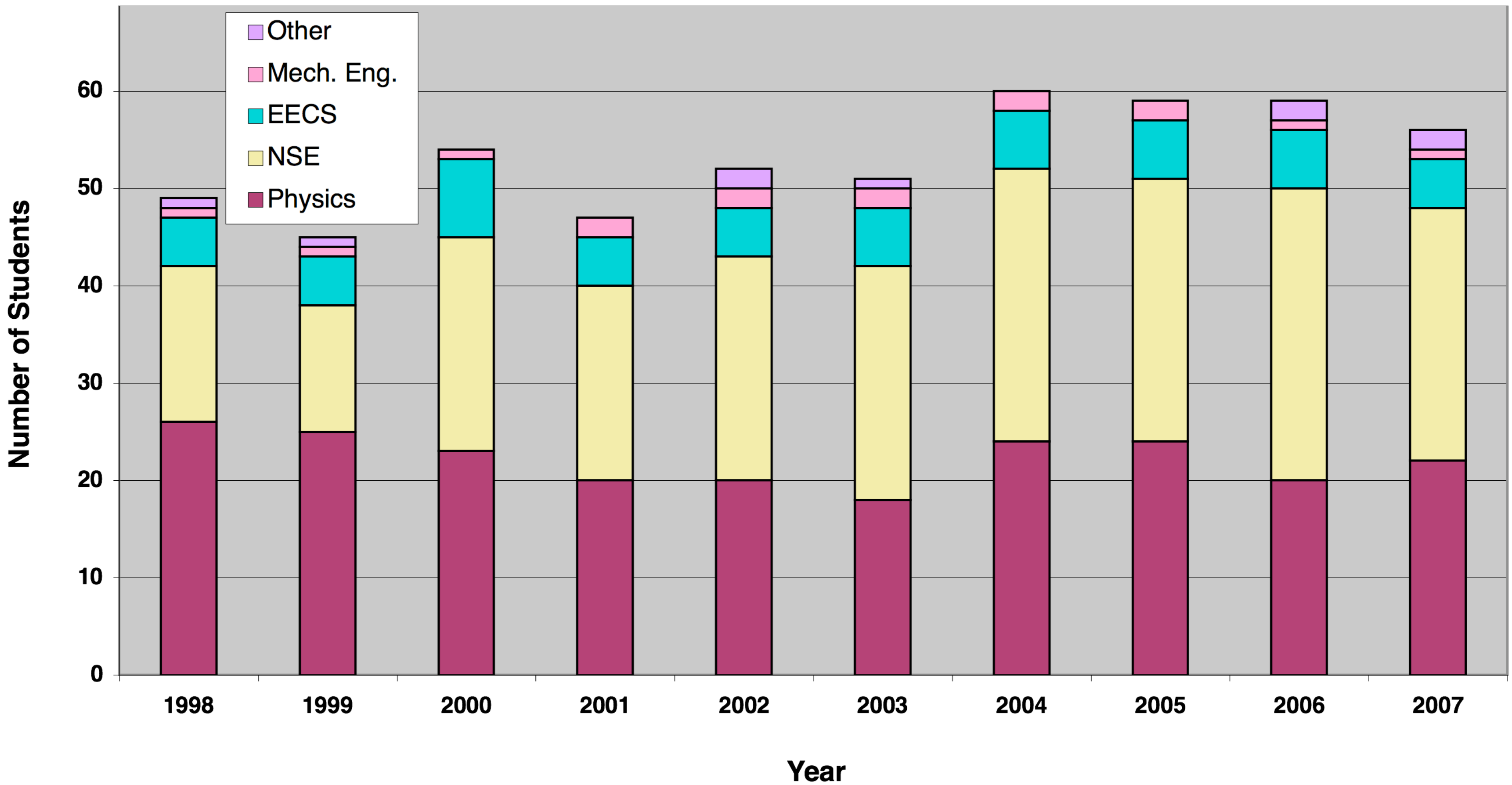
Massachusetts Institute of Technology

Reducing C-Mod funding by $1.85 M for FY 09 relative to FY 08 is highly detrimental to maintain staff, and to implement needed equipment to more fully utilize the facility in FY10, to train graduate students and to provide needed ITER relevant physics data

Total Number of Graduate Students at the PSFC, by Year

(Fall, 2007)

Massachusetts Institute of Technology



Note: Headcounts are for Fall Semester