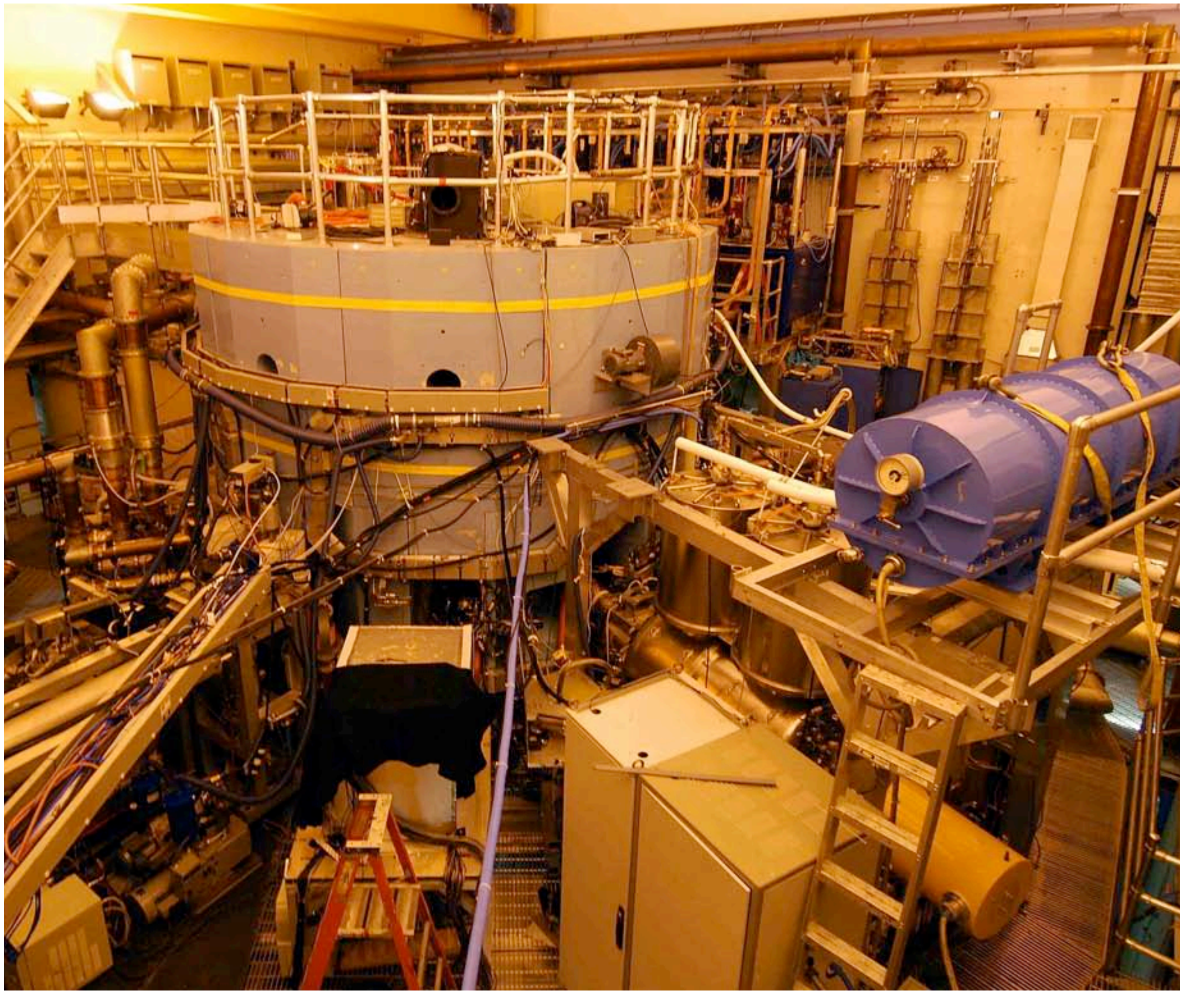
Research Highlights and Plans



Alcator C-Mod

Presented by M. Porkolab

On behalf of the C-Mod Team

Fusion Power Associates

Annual Meeting

Oak Ridge National Laboratory

December 5, 2007

www.psfc.mit.edu/research/alcator

Work Supported by USDoE Office of Fusion Energy Sciences

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 metal high-Z plasma facing components
- ITER level Scrape-Off-Layer/Divertor Power Density
- Approach ITER neutral opacity, radiation trapping
- Highest pressure and energy density plasmas (ITER level)

Exclusive in the US :

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

C-Mod physics regime, machine capabilities and control tools are uniquely ITER-relevant

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- **Edge and Divertor:** All metal walls. High divertor heat fluxes ~0.5 GW/m^2. High SOL neutral opacity *(similar fuelling to ITER).* High Lyman opacity, radiation trapping *(closest to ITER).*

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

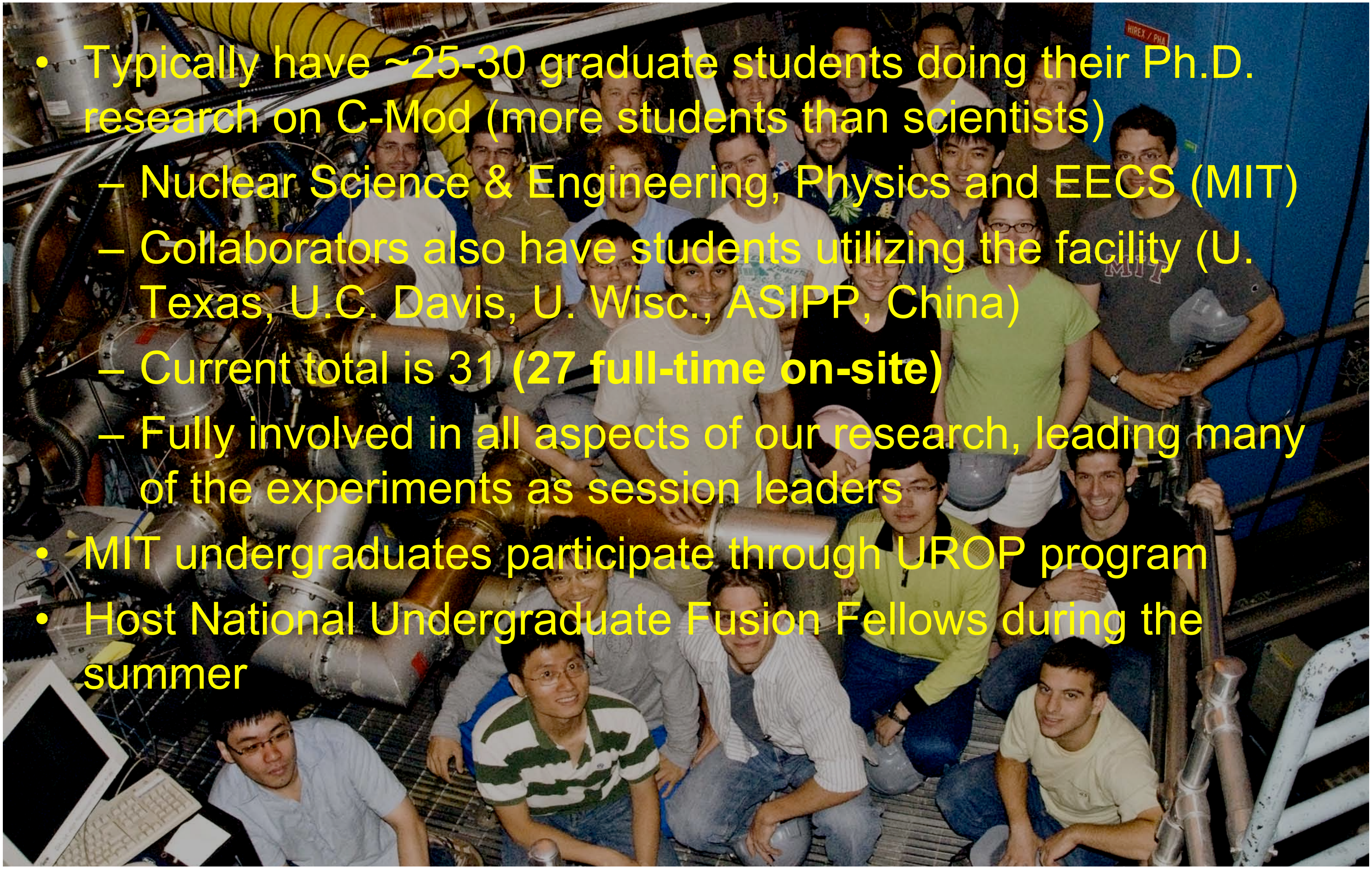
- **Macro-stability:** Can access ITER β range, as well as same B_T and absolute pressures *(important for disruption mitigation).*

- **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 Plays Major Role in Education of Next Generation of Fusion Scientists



- 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 31 **(27 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

Lower Hybrid Current Drive: ~0.8 MA Driven with Phased Array Grill : Key Tool for AT Physics

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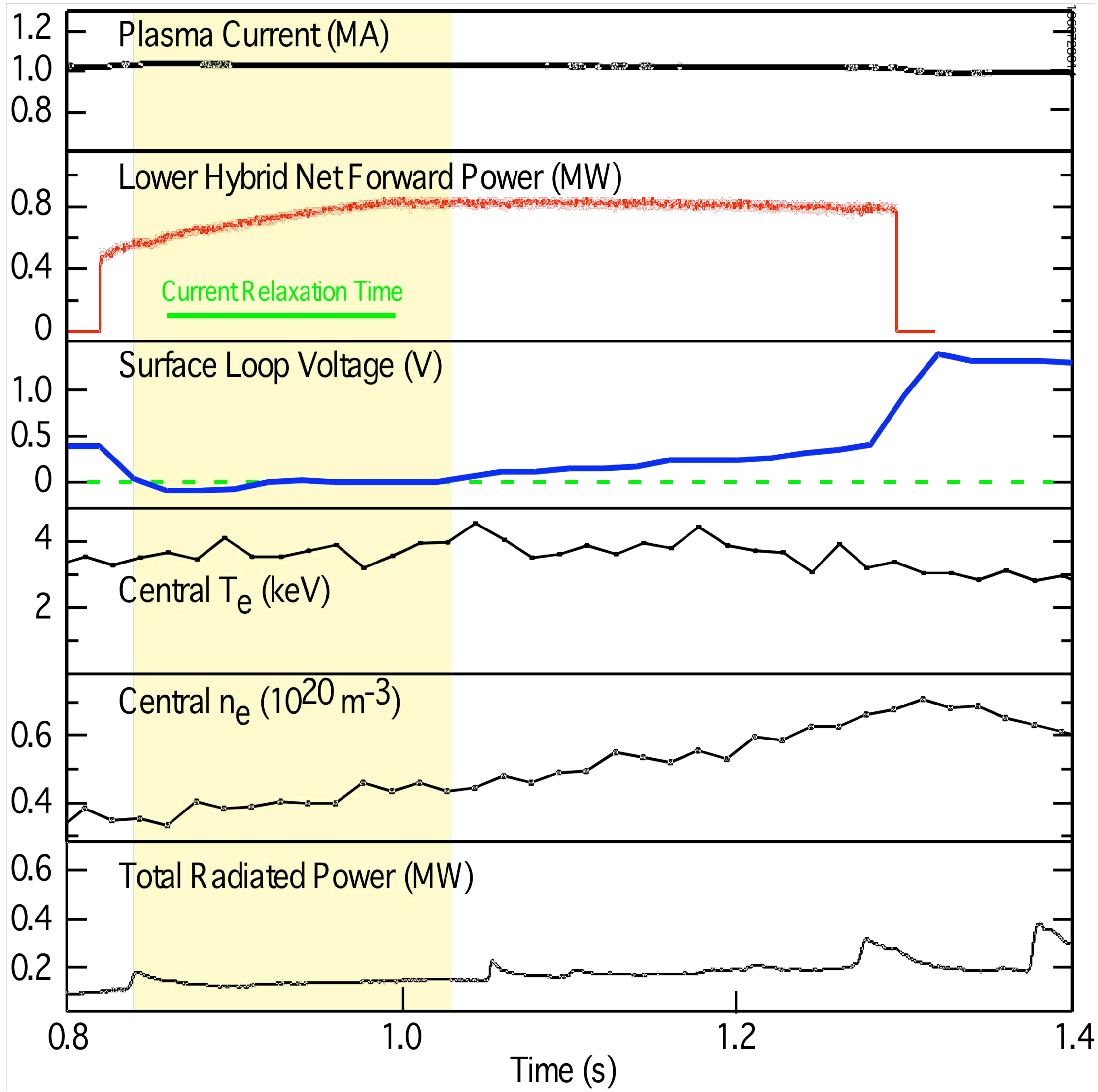
- System commissioning went very well
  - Up to 2 MW source applied so far from 12 klystrons
    - No signs of power limits or significant arcing on couplers
- Close to 100% of current driven non-inductively in 1 MA plasma
  - Loop voltage 0 or reversed for more than 1 current relaxation time
  - Modeling indicates about .8 MA off-axis current drive from LH



Current Density Profile Control with Lower Hybrid Waves (LHCD)

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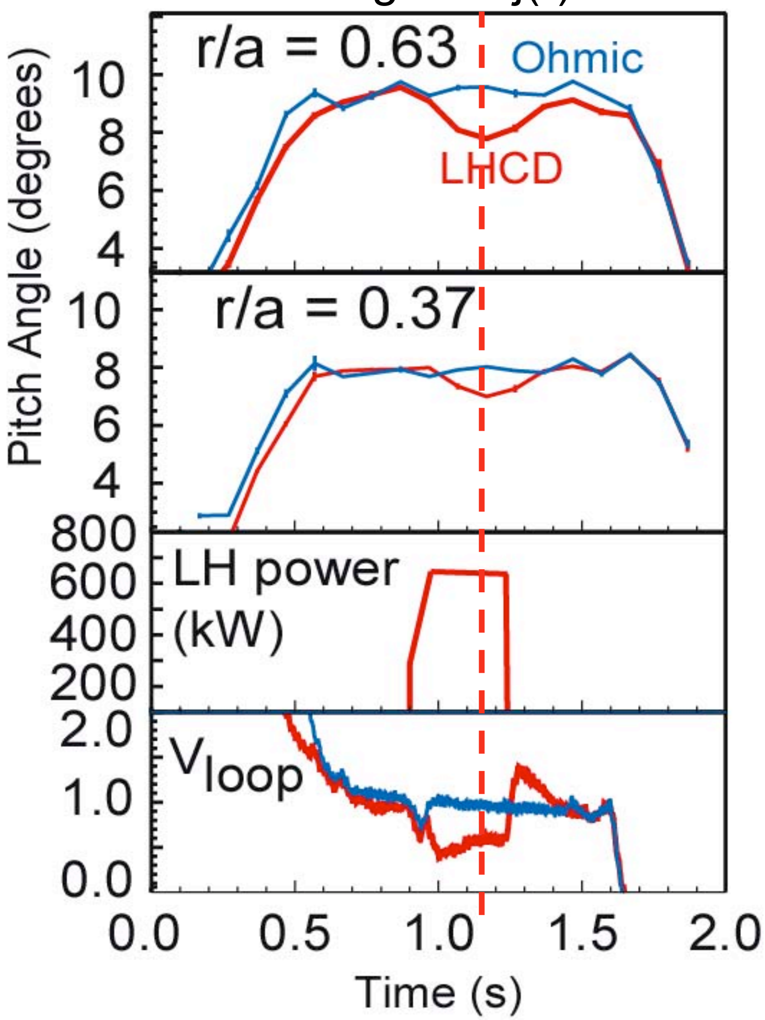
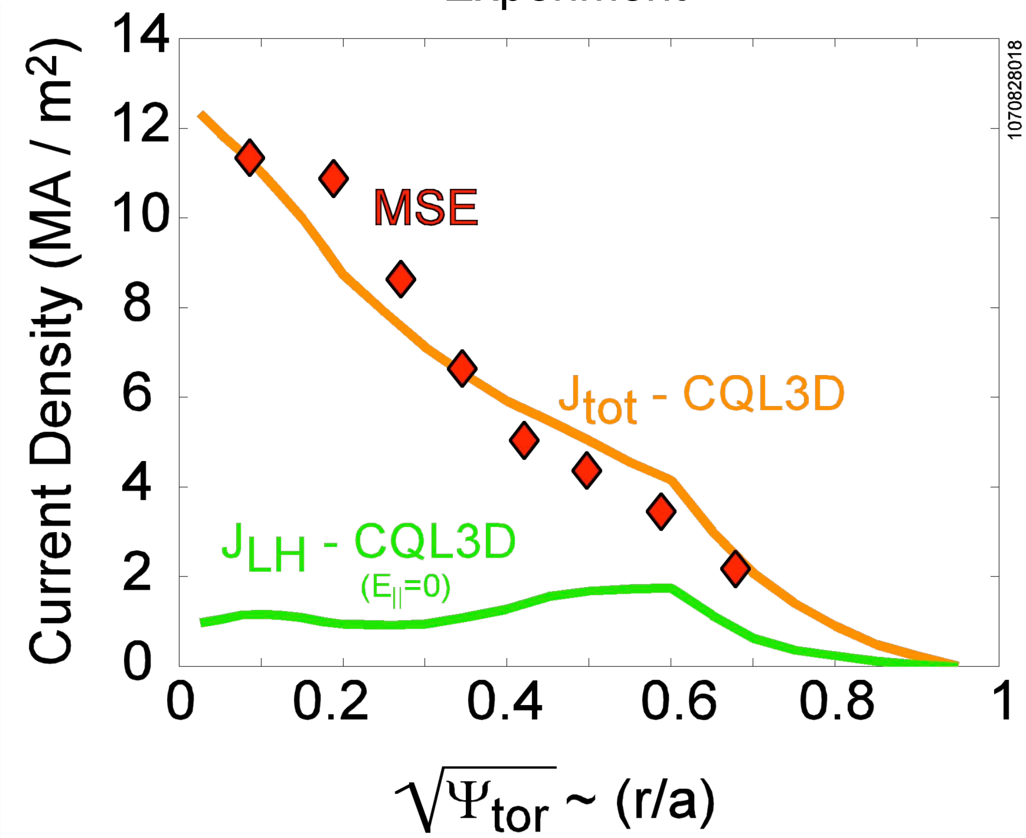
MSE Diagnostic Measures Changes in j(r)

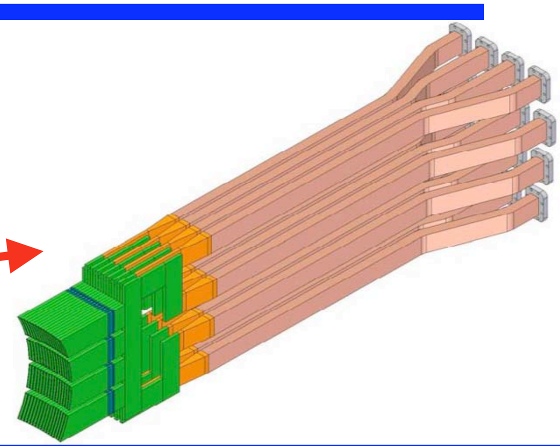


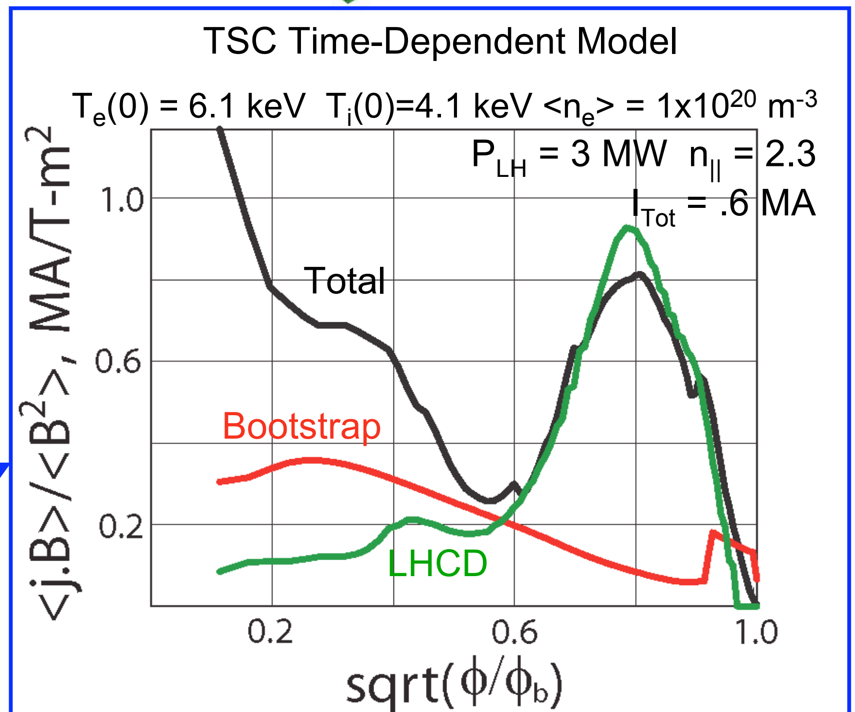
Modeling in Very Good Agreement with Experiment



Planned LHCD Upgrades (2009)

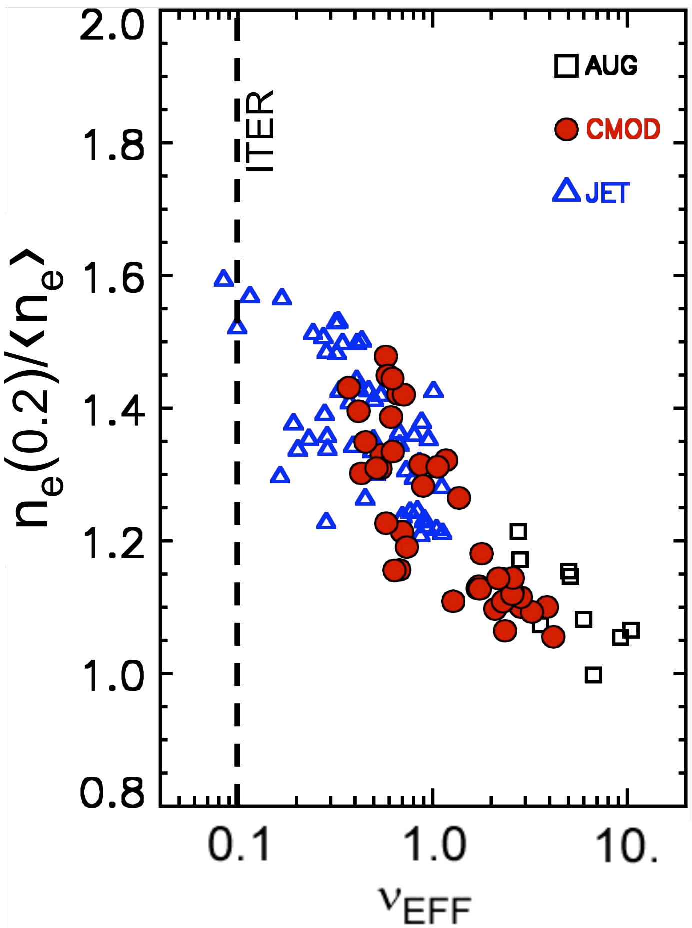
- Increased source power (from 3MW currently installed to 4 MW total)
- Advanced low-loss couplers/launchers
- More than doubling of net power to plasma (>2.5 MW)
- Improved j(r) diagnostics
  - Upgraded MSE (spatial channels)
  - Polarimeter array (ITER geometry)
- Goal: fully non-inductive, long pulse AT scenarios

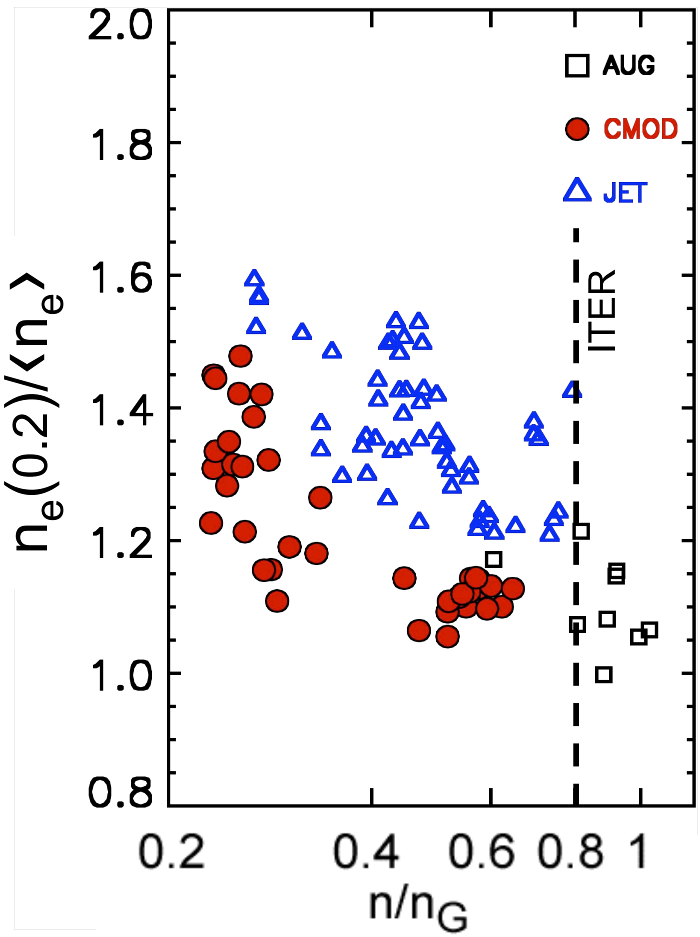




Density Peaking at Low Collisionality: Good News for ITER

C-Mod Data Help Break Covariance Between ν and n/n_G Makes Extrapolation to ITER More Certain



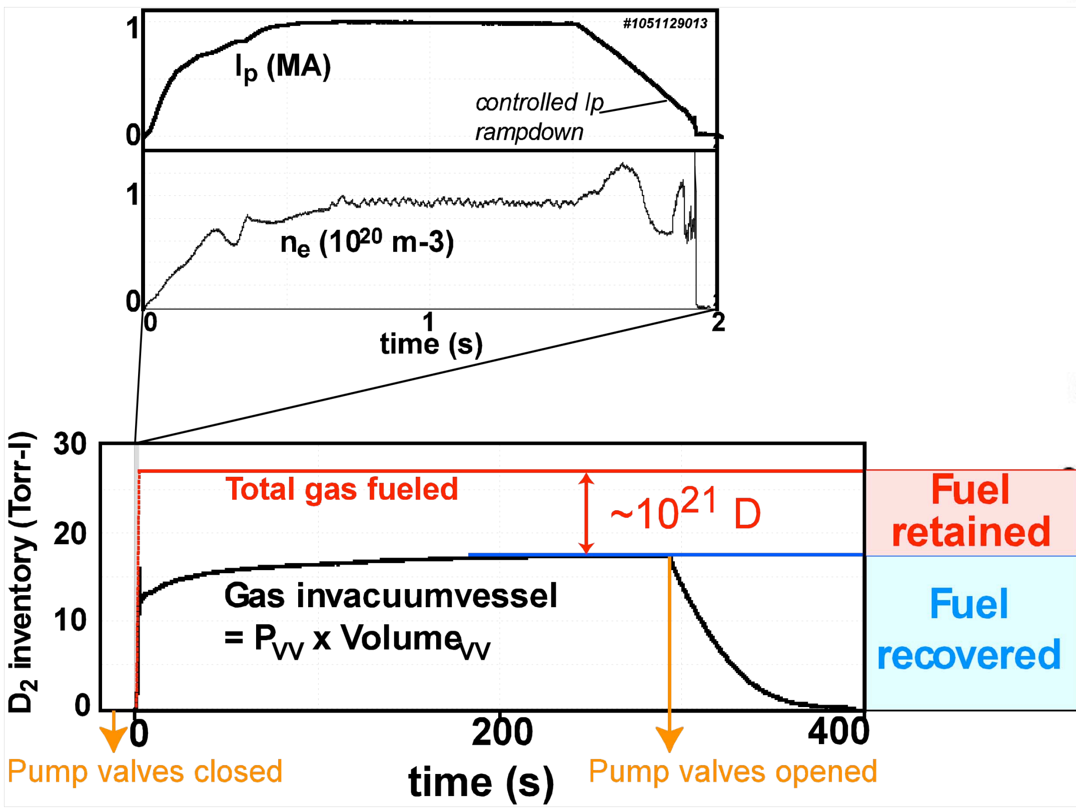


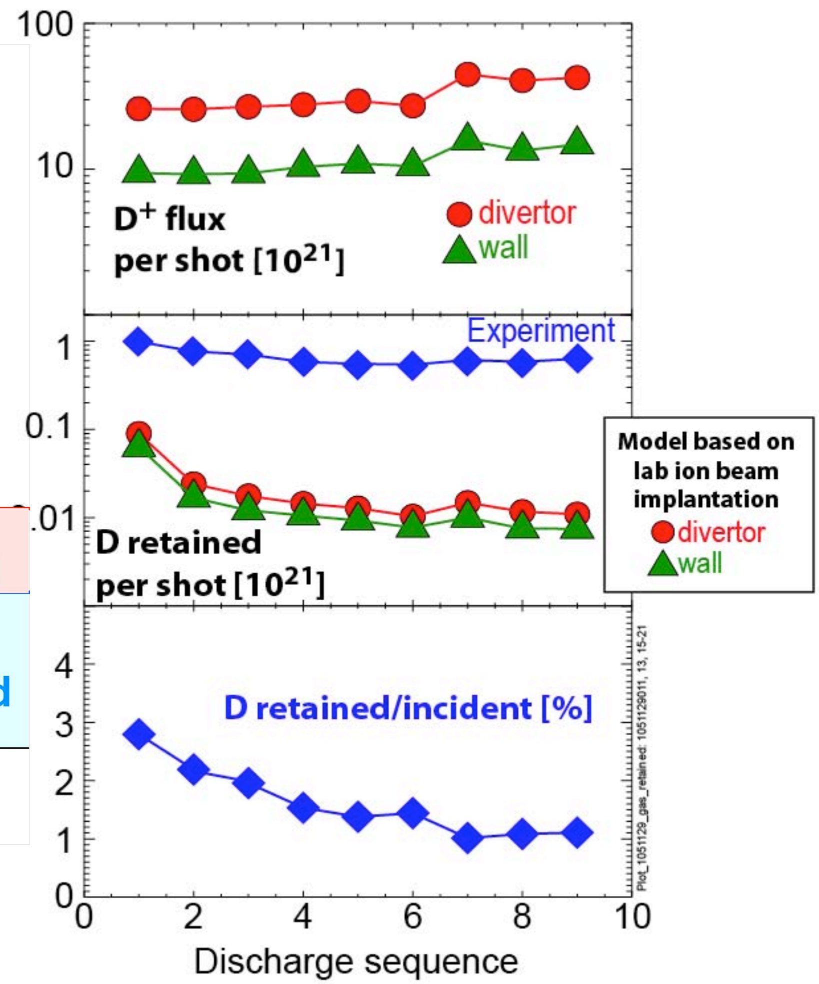
Tritium Retention is Major Challenge for ITER

Hydrogenic Retention in Refractory Metals (Mo, W) Surprisingly High

Closing pump valves during and after shot: accurate accounting for total particle inventory

Sequence of disruption-free shots shows continual, constant uptake of D by the walls





ICRF Sheaths Cause Impurity Sputtering: Depend on Wall Conditions and Plasma Transport

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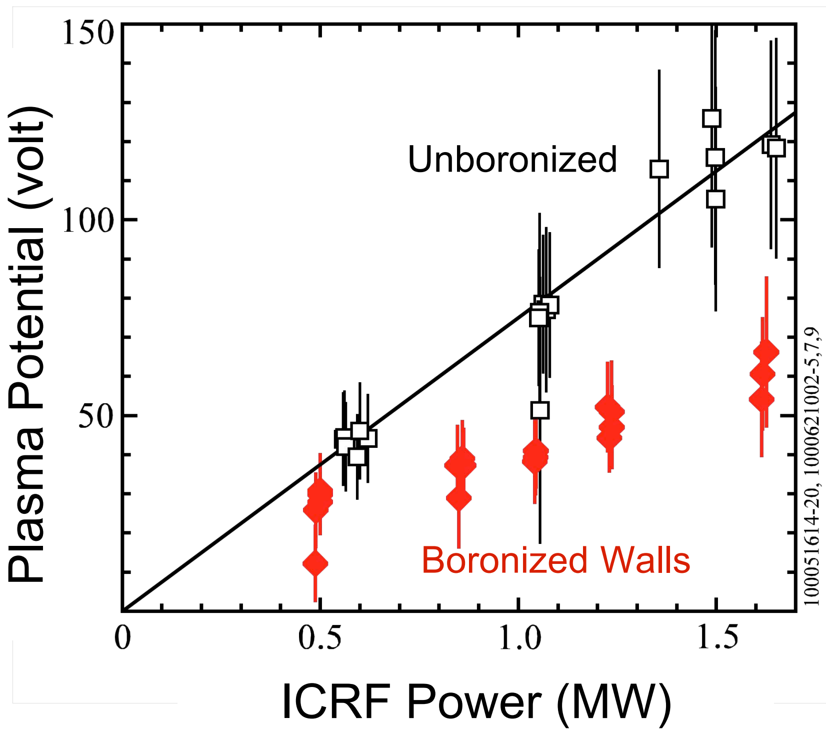
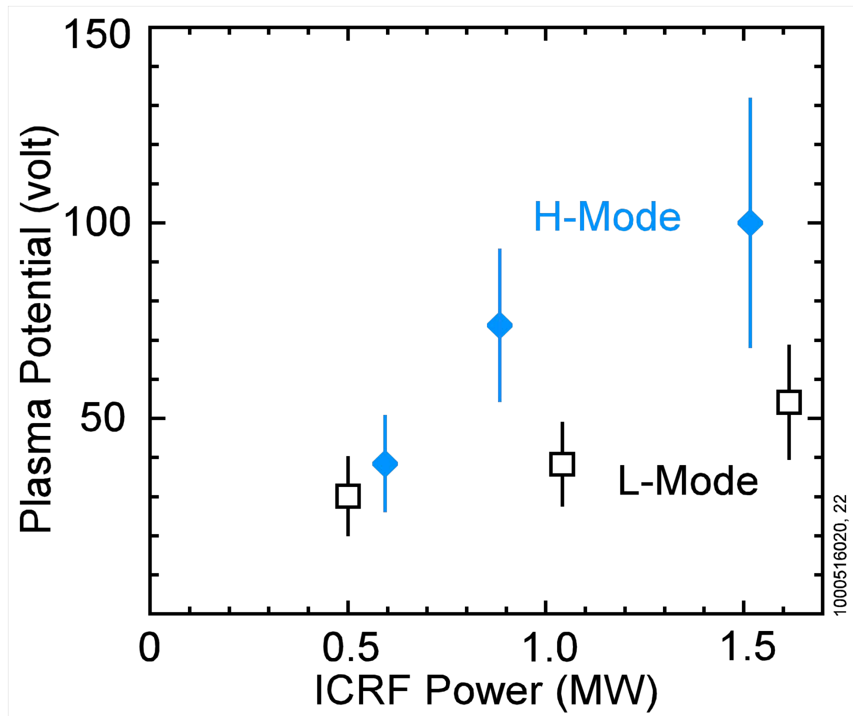
V_{sheath} Smaller after Boronization

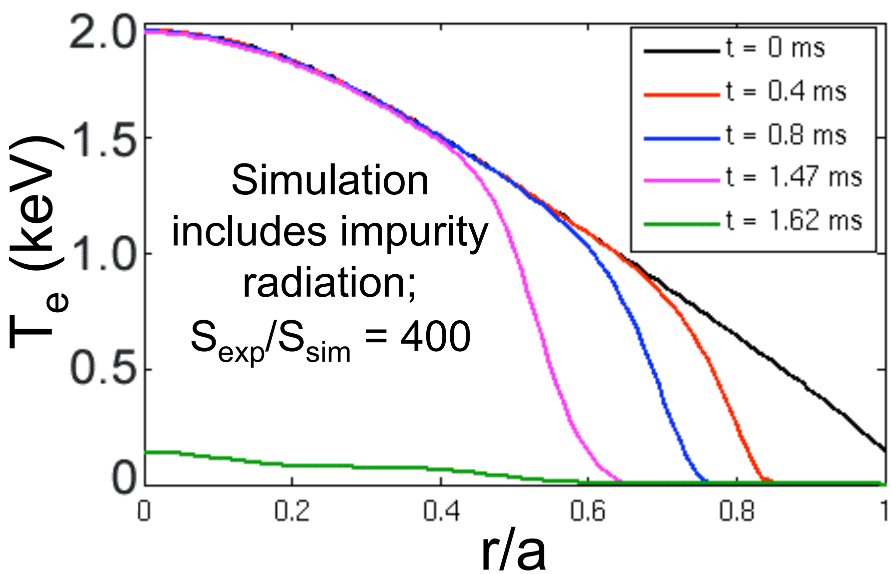


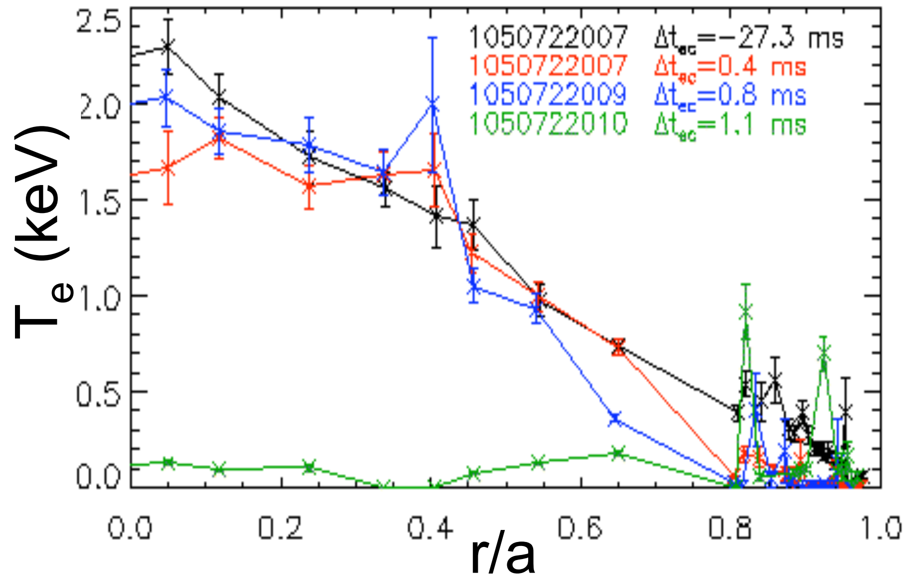
V_{sheath} Larger for H-Mode than for L-Mode



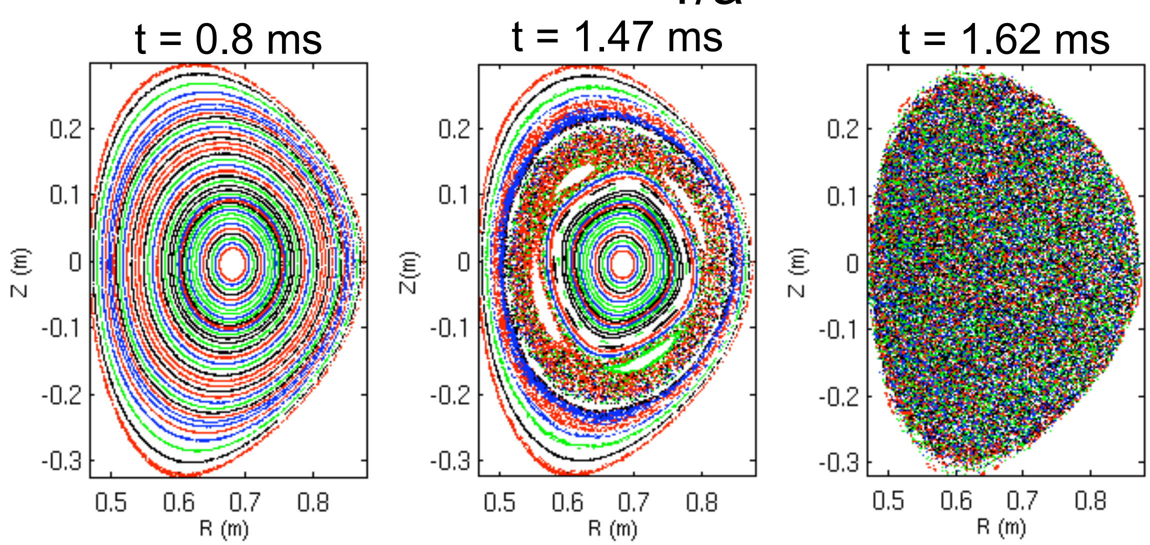
For 2009: Designing new antenna to minimize radial RF fields, minimize sheath potential

NIMROD Modeling of Massive Gas Disruption Mitigation: Excellent Agreement with Experiment





- Flux surfaces promptly destroyed by MHD
  - Rapid core cooling without the need for deep impurity particle penetration
- Good news for ITER
  - Next challenge:
  - runaway electrons (use LHCD to investigate)



Facility Plans and Major Enhancements

(Blue colored items require additional funds not in base program)

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- Inspections (2008-09) – insure facility reliability for at least the next 5 years
- Lower Hybrid upgrades
  - Add 1 MW source (to 4 MW); refurbish first launcher (reduced losses, simplified splitting/phase control, increased voltage/power handling); add second launcher/coupler (2009); spare klystrons (2008-2010)
  - Gas puff system at each coupler (improved plasma matching)
  - Add 5'th MW (if required, 2013)
- ICRF upgrades
  - New 4-strap antenna (consolidate 2 antennas into 1 port, 2009)
  - Fast-Ferrite Tuners for all 4 transmitters (real time adaptive tuning, 2009-10)
  - Power supply/control upgrades (improved realiability, 2011)
  - Convert transmitters 1 and 2 from fixed frequency to tunable (2012)
- Outer divertor upgrade (2012)
  - Continuous vertical plate (higher power/energy handling)
  - Tungsten in highest-heat-flux regions

Major Diagnostic Enhancements/Upgrades Planned 2009-2013

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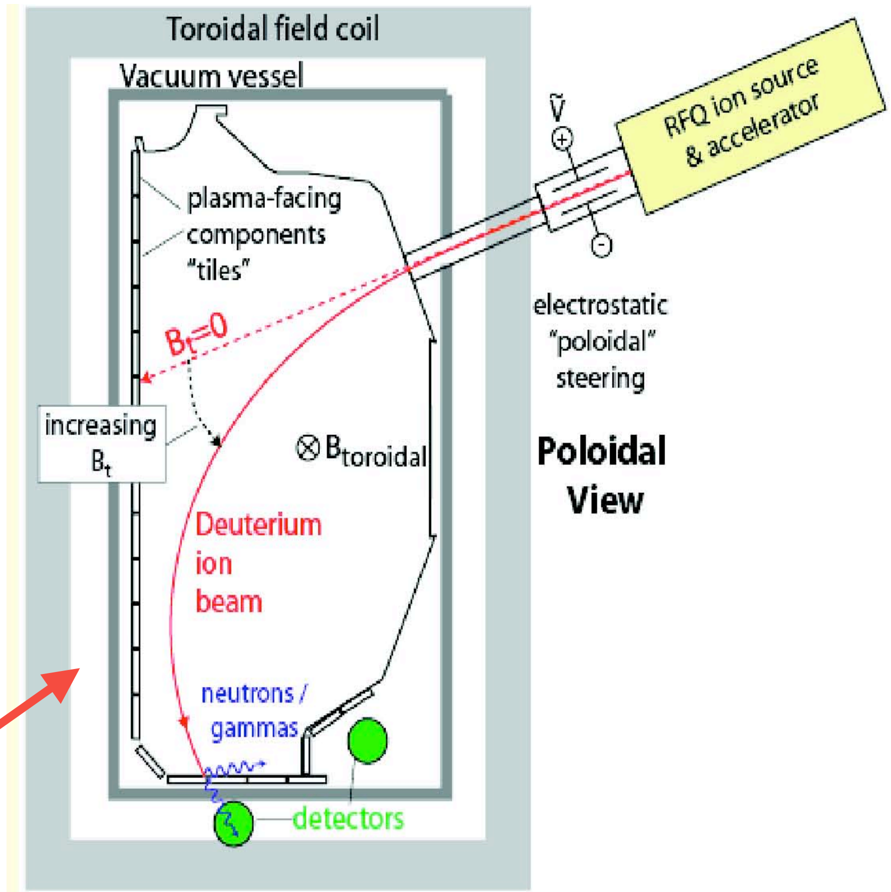
(Blue colored items require additional funds not in base program)

- Polarimetry [j(r), n_e(r), magnetic fluctuations] (2009)
- DNB aperture [improved spatial resolution for beam-based diagnostics] (2010)
- MSE upgrade (PPPL) [more radial channels] (2010)
- Doppler reflectometry (U. N.M.) [fluctuations, flows] (2010)
- Heterodyne ECE upgrade (U. Texas) [improved views] (2012)
- SOL Thomson scattering (2010)
- Compact Neutral Particle Analyzer [multiple chords] (2009)
- CO_2 scattering [fluctuations, waves] (2010)
- ICRF antenna reflectometer (2009)
- In-situ accelerator [first wall analysis] (2010)
- SPRED survey spectrometer (2009)
- Fast-ion loss detector (ASDEX) (2010)
- IR camera upgrade [divertor heat loading] (2009)
- Gas puff imaging upgrades (PPPL) [edge fluctuations] (2010)



C-Mod is Well Positioned to Continue Major Progress for Fusion Science and Fusion Energy

- Flexible, Capable, Cost Effective 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

Collaborators are key participants in all aspects of the program

Alcator C-Mod

Domestic Institutions

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 Institutions

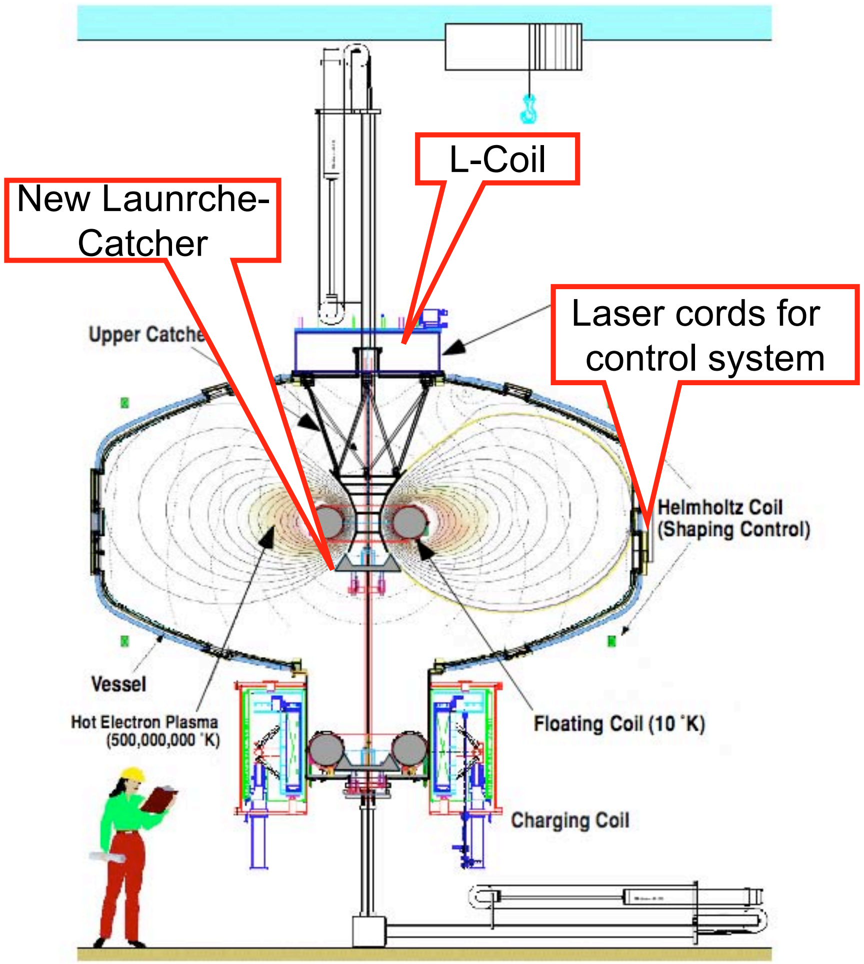
Budker Institute, Novosibirsk
C.E.A. Cadarache
C.R.P.P. Lausanne
Culham Lab
ENEA/Frascati
IGI Padua
IPP Garching
IPP Greifswald
JET/EFDA
JT60-U, JFT2-M/JAEA
KFA Jülich
KFKI-RMKI Budapest
LHD/NIFS
Politecnico di Torino
Risø National Laboratory.
U. Toronto

Coordination: USBPO, TTF, ITPA

Levitated Dipole Experiment

Research Staff: 1 scientists (Dr. Garnier), 1 engineer, 2 graduate students, PI's (Kesner & Mauel), + 2-3 undergrad students

Massachusetts Institute of Technology



FY07/08 Campaign

- Perform initial experiments in levitated plasma heated with ECRH ; Floating coil: 0.7(1.2) MA, 1200 lbs
- Damaged upper support HT_c L-Coil: Replaced with Cu levitation coil
- Investigate stability of ECRH plasma confined by levitated dipole

FY09 Campaign

- Expanded diagnostics for detailed physics studies and increased run time
- Investigate the unique capability for high beta, high energy confinement, and adiabatic convective flows.
- Answer critical questions to evaluate the potential for advanced (non D-T) fuels.