Alcator C-Mod Program Plans

Ian Hutchinson: Overview, Science Objectives
Earl Marmar: Budgets, Upgrades, Operations, Schedules

OFES Budget Meeting March 2002

Keying to IPPA

To help key the program to the IPPA we have indicated by small slanted numbers the relevant section which our program element addresses for example:

High-Z metal walls*[3.1.4][3.4.1.3]*

Here 3.1.4 is the Plasma Boundary or Multiphase Interfaces element of the plasma science section, and 3.4.1.3 is the Plasma Facing Components section of the plasma technologies section.

For some objectives the fiscal year they are planned for is shown in parentheses: (02).

Unique Features of C-Mod Tokamak

Alcator C-Mod

Long Pulse Capability (relative to L/R)

- Quasi-Steady AT research and demonstration. *[3.3.1]*,*[3.3.2]*

High Magnetic Field

- Addresses Burning Plasma Experiment issues. *[3.3.3]*

Exclusively RF-Driven*[3.4.1.1]* Reactor-relevant regimes. *[3.1.3]*

- Heating decoupled from particle source. • No momentum source.

Unique Dimensional Parameters

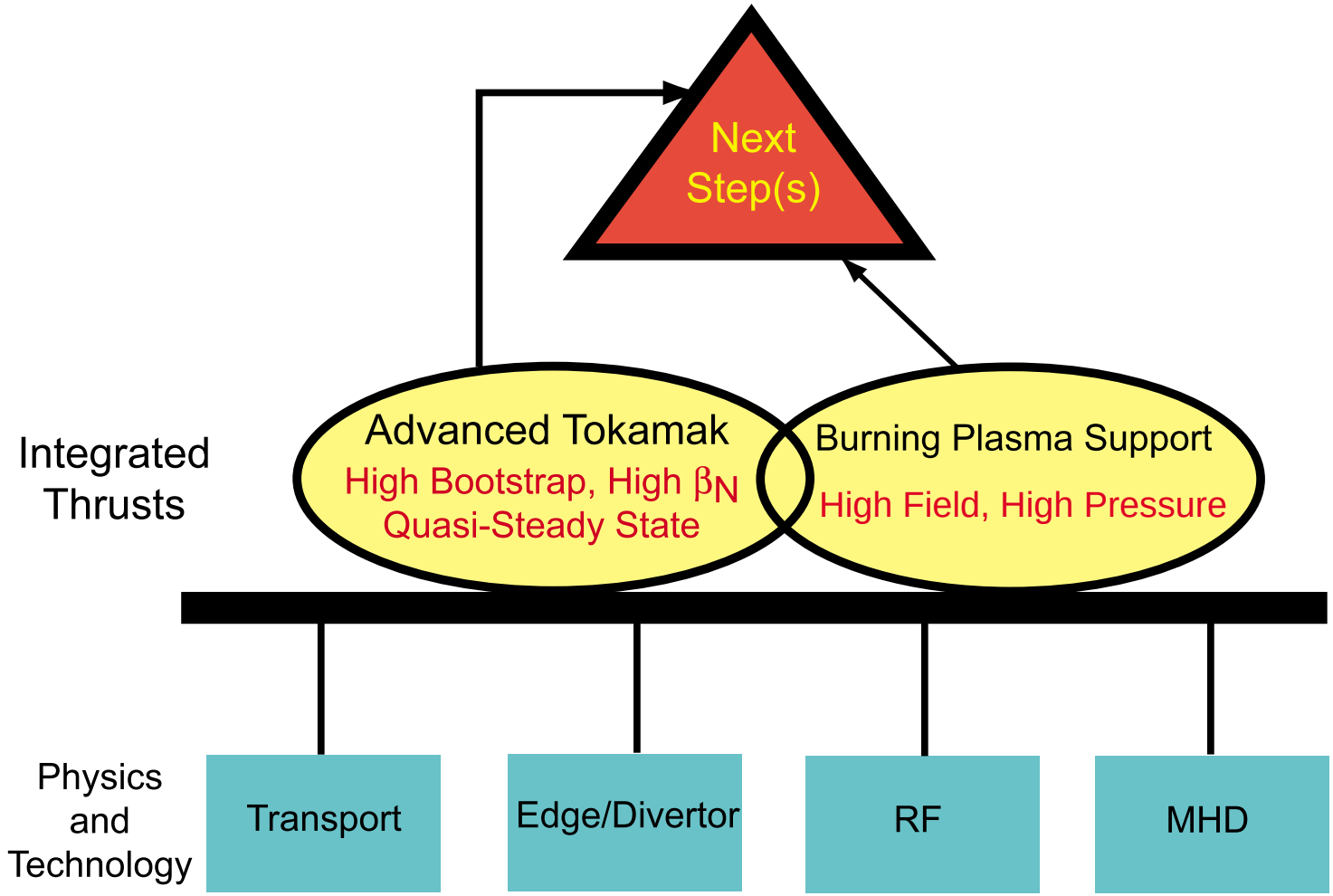
- Key tests of scaling and non-similar processes.*[many]*

High Power Density Scrape-off *[3.1.4][3.4.1.3]*

High-Z metal walls *[3.1.4][3.4.1.3]*

- BPX/Reactor divertor regime, recycling. Generic MFE challenge.

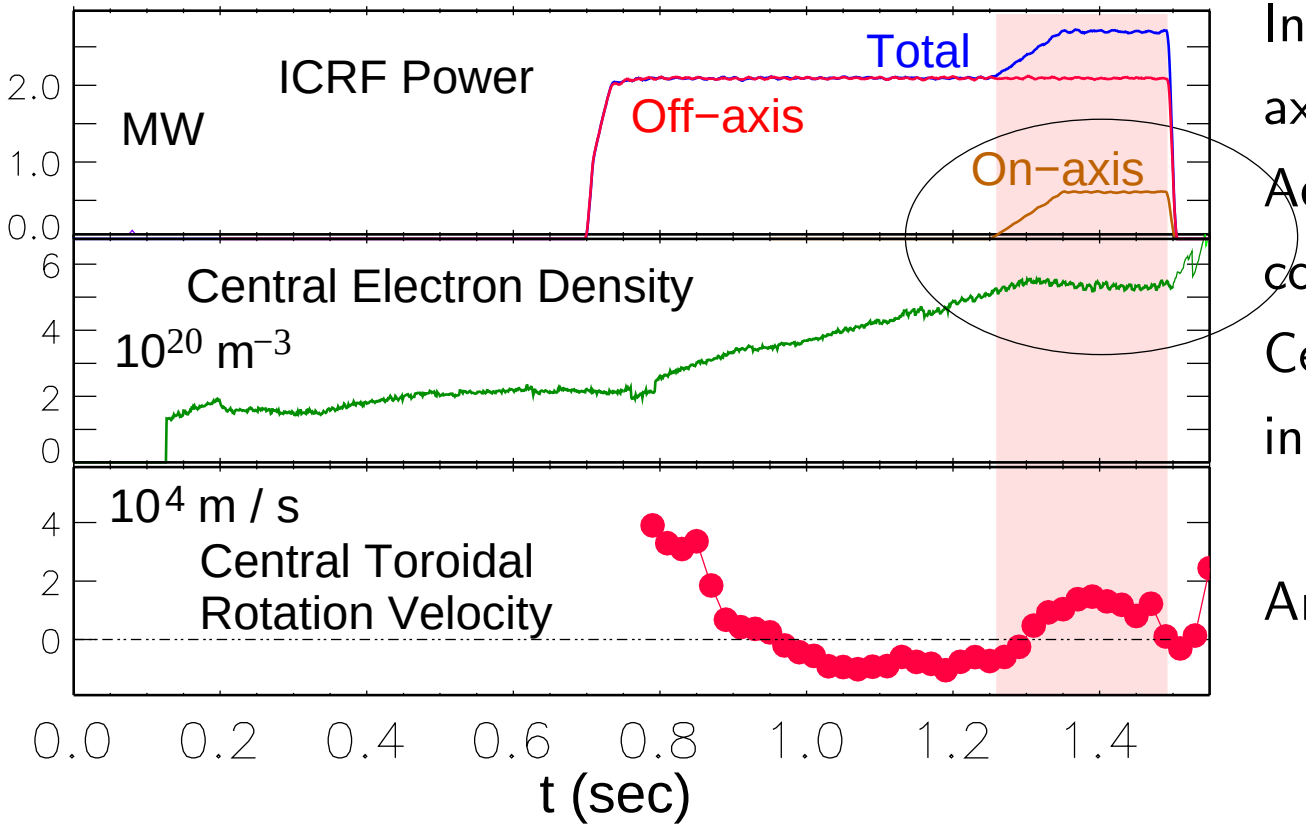
Program Organized for Science Mission



Science topical research undergirds integrated thrusts in support of

- longer-term AT goal , and
- nearer term BP needs.

Transport Barrier Control By ICRF



Initate ITB with off-axis ICRF.

Add on-axis heating for control;

Central density rise during ITB is arrested

And rotation responds.

This mechanism is telling us something about transport as well as offering a tool for profile control.

Advanced Tokamak Thrust Goals

Alcator C-Mod

- Understand mechanism for RF-generated ITBs and develop means to control them. (03) *[3.1.1.2] [3.3.1.3]*

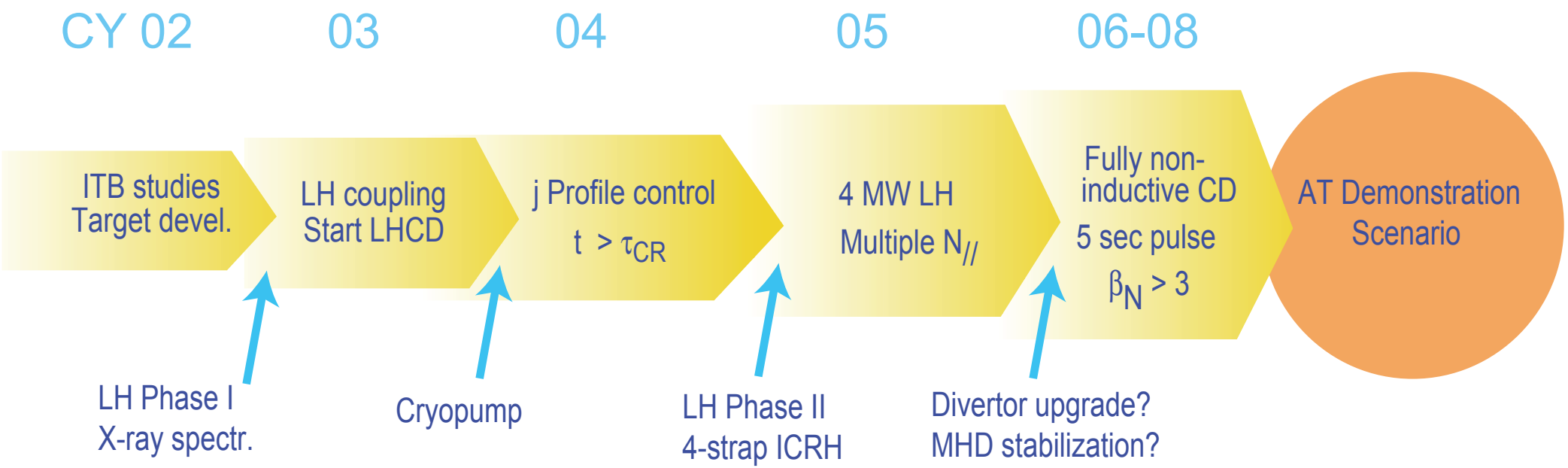
- Explore the influence of current profile on ITBs (04) *[3.1.1.2][3.3.1.1]*

- Evaluate stability and transport of reversed-shear, high (50%) bootstrap-fraction plasmas. (04-05) *[3.1.2.1,2]*

- Understand and control transport so as to maintain stable steady barrier plasmas. (06) *[3.3.1.2,4]*

- Assess physical limits to bootstrap fraction in steady-state. (06-08) *[3.3.1.1]*

Long Term Advanced Tokamak Program



Burning Plasma Support Thrust Goals

Alcator C-Mod

- Evaluate relative merits of Double/Single-null or limiter operation for heat, particle control and confinement performance. (03) *[3.3.3]* *[3.1.4.2]*

- Run ρ^* scaling discharges modelling FIRE, ITER-FEAT, Ignitor to test extrapolation hypothesis. (03-04) *[3.3.3.1]*

- Quantify trade-offs between heat removal, particle and impurity control, and core confinement for dissipative/detached divertor. (04-05) *[3.1.4.1]*

- Indentify optimized pedestal relaxation/control mechanisms through understanding the key stability and transport properties. (06) *[3.1.1.3]*

- Test feedback stabilization of NTM using LHCD and/or MDDC. (07) *[3.3.2.2]*

Transport Science Challenges

Alcator C-Mod

Pedestal Physics *[3.1.1.3]*

- L/H Thresholds and transition dynamics.
- What sets the pedestal width and height, neutrals, stability?
- Profile relaxation mechanisms, ELM phase-space.
- First principles theoretical models of edge transport.

[Marginal] Stability *[3.1.1.1]*

- C-Mod should be near marginal and is . . . but NONlinear boundary.
- What is role of $E \times B$? Transient transport, improved profile diagnostics.

Turbulence measurements comparison with simulations *[3.1.1.1]*

- Role of long-time correlated fluctuations (avalanches etc).
- Upgraded diagnostics, synthetic diagnostics.

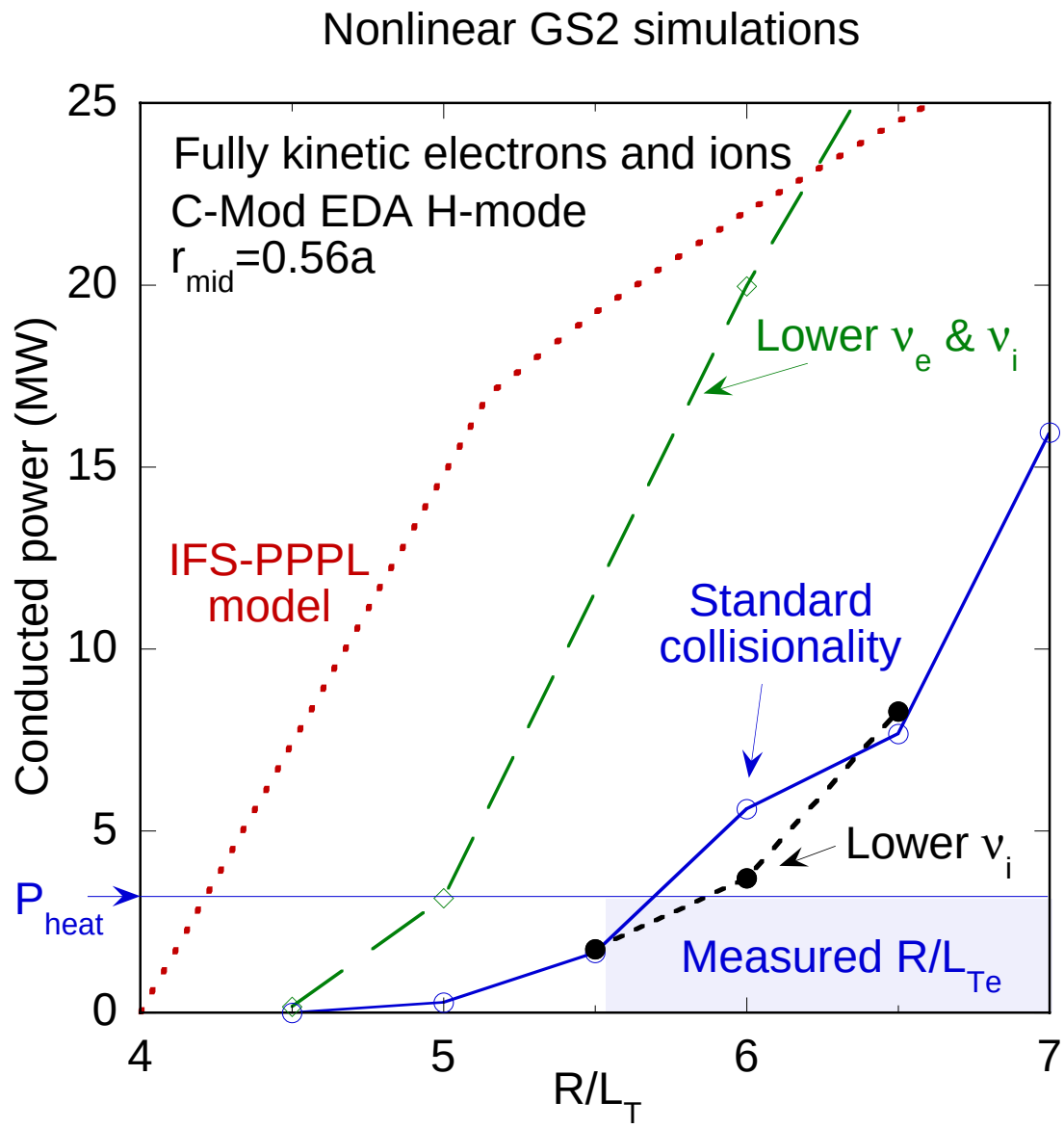
Core Rotation and Momentum Transport *[3.1.1.2]*

- Improved diagnostics. Understanding!

Importance of Non-linear Stability

The Dimits upshift is needed, to explain C-Mod results

But the effective upshift depends on electron collisionality.



Transport Science Goals

- Physics of Pedestal Width/Height. *[3.1.1.3]*

  Neutrals (02-03)

  Plasma Physics processes (04-07)

- Marginal Stability *[3.1.1.1]*

  Quantitative understanding of non-linear ∇T_i (03-05)

- Detailed comparison with turbulence simulations. (03-06) *[3.1.1.1]*

- Electron transport — Characterize small-scale transport (05-08) *[3.1.1.1]*

- Rotation — Understand mechanism. *[3.1.1.2]*

RF Heating and Current Drive

Supports the whole C-Mod program. Almost every element of the program depends on RF.

RF is not as reliable as NBI. Despite great progress, there remain many challenges in the launchers, at the interface of engineering and plasma physics.

Burning Plasma Experiments depend on RF too.

C-Mod's mission is not to do technology. But in ICRF (and LH to come) we are obliged to address critical technology-integration challenges.

We have made substantial progress in systematizing the ICRF antenna issues as well as ensuring that the ICRF heats! We shall continue to contribute in this area. Perhaps technology programs should be more closely coupled to the major facilities.

RF (Wave-Particle) Science Goals

- MCIBW flow control. Investigate the physics and feasibility. (03) *[3.1.3.1]*
- Investigate and model D(He^3) absorption physics. (03) *[3.1.3.1]*
- Evaluate coupling efficiency and power handling of 1st LH launcher. (03-04) *[3.4.1.1]*
- Investigate MCCD feasibility. (03-04) *[3.1.3.1]*
- Begin current profile modification with LHCD. (04) *[3.3.1.1]*

Edge/Divertor Goals

Alcator C-Mod

- Edge Turbulence and Transport *[3.1.4.1]*

  "Bursty" SOL transport (03) Scaling and n_e limit (04-08)

  Plasma flows and SOL turbulence (04-08)

  SOL interactions with LH, and optimization for LHCD.

- Neutral Dynamics and Fueling *[3.1.4.1,2]*

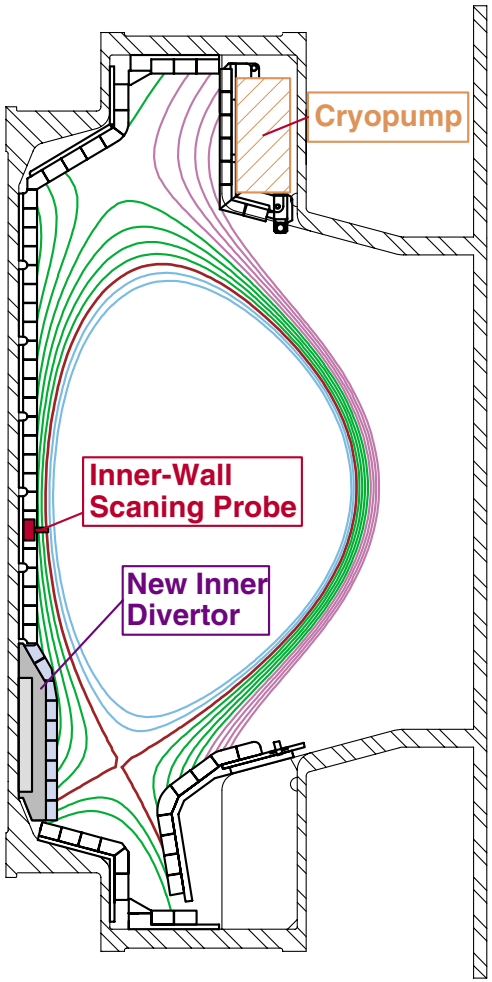
  Main chamber recycling (02-04) Active pumping (04-08)

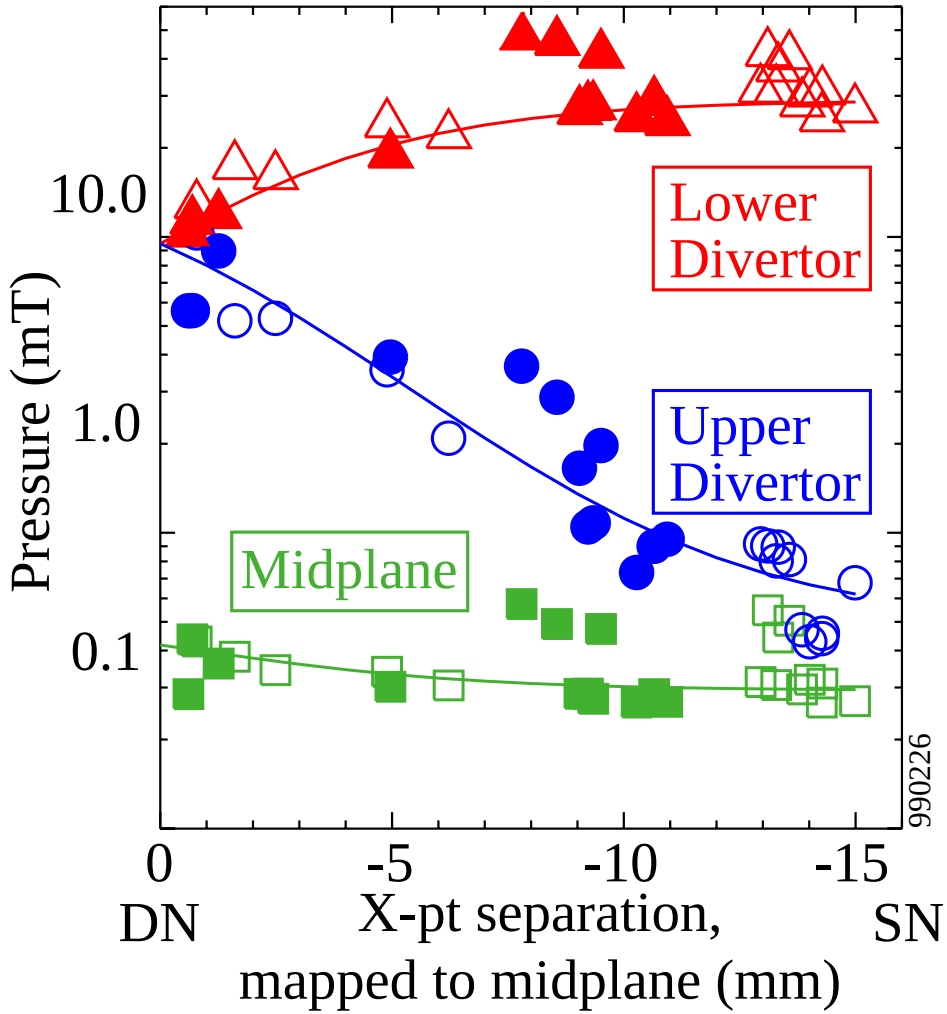
- Impurity sources and transport (ICRF 02-04, LH 03-06) *[3.1.4.3]*

- Advanced divertor materials technology integrated testing *[3.1.4.3]*

  Tungsten Brush (Tile 03, Module 05)

Neutral Dynamics, Divertor Balance





When separatrix is balanced (DN) so are neutrals — despite open top divertor. Consequences for pumping, BPXs?

MHD Science Goals

- Pedestal Stability and ELM characterization. *[3.1.2.3]*

- Stability of AT profiles *[3.3.2.3]*

  Active MHD spectroscopy to sense stability. (04) *[3.3.2.3]*

  Stability during current profile relaxation. (05-06) *[3.3.2.3,4]*

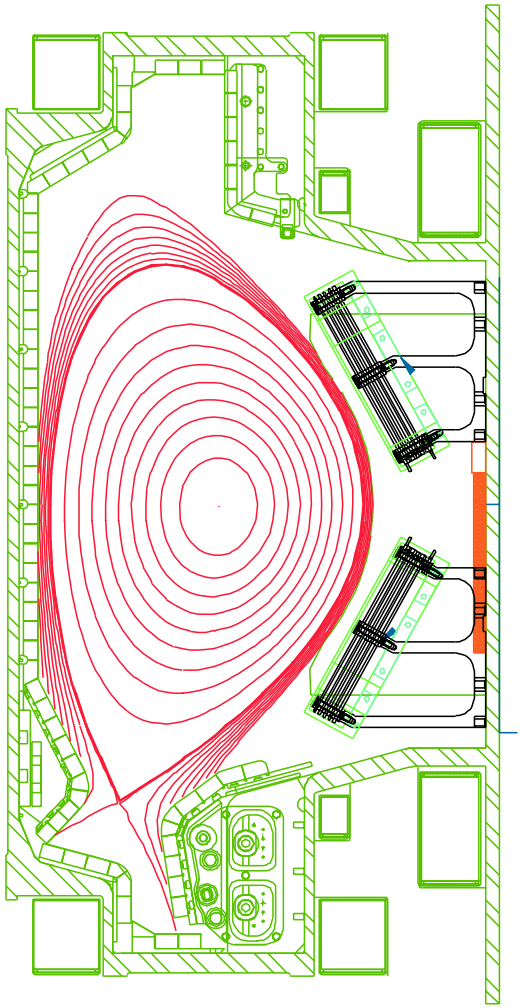
- NTM physics at high density (04-05) *[3.1.2.3]*

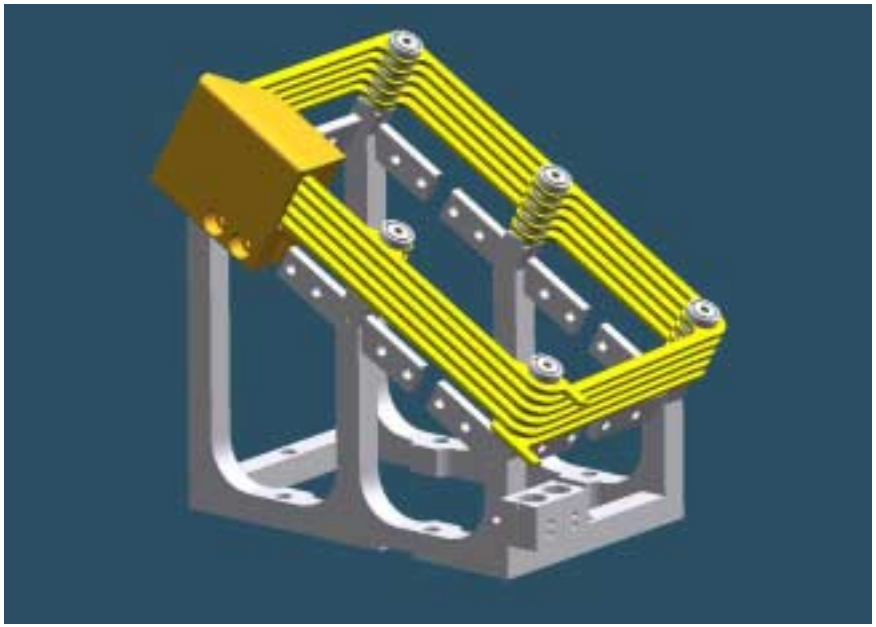
  Stabilization with LH (or MCCD). (05-06) *[3.1.2.2]* *[3.3.2.2]*

- Sawtooth Stabilization with RF (05) *[3.1.2.2]*

- Disruption halo current studies. *[3.1.2.4]*

Active MHD Spectroscopy



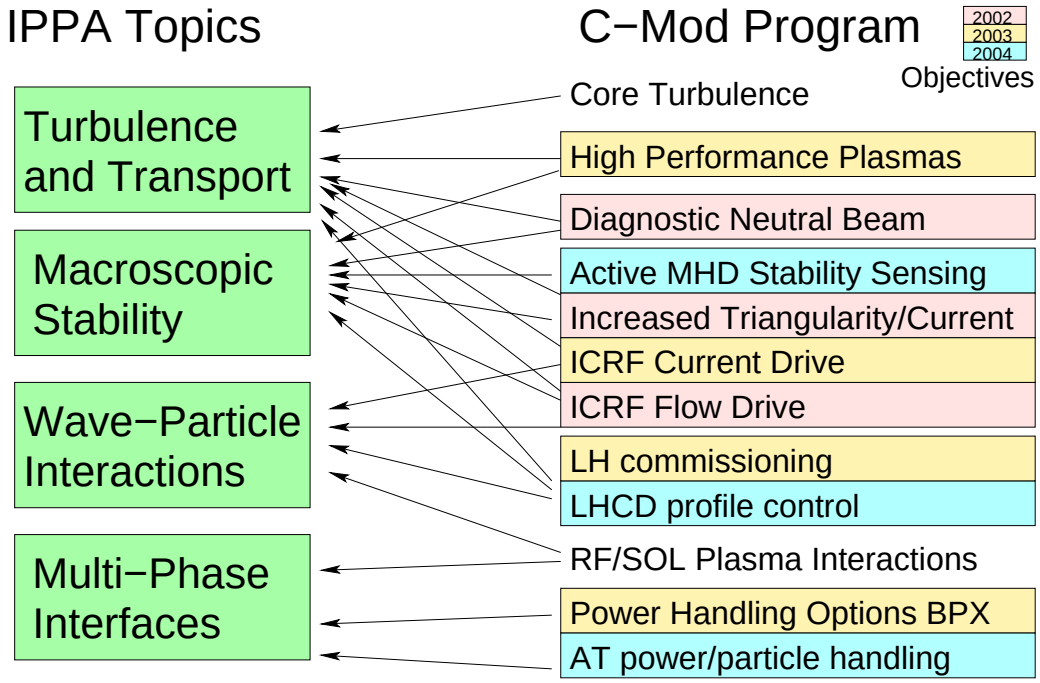


Active MHD Antenna

May enable us to implement avoidance **before** unstable mode appears.

Plain English Goals Related to IPPA

Goals achieved in 2001: • Control of ITB. • Turbulence Imaging.



FY2004 goals:

Sensing approach to instability using active coils

Current Profile Control with Microwaves

Power and Particle Handling for Advanced Tokamak Plasmas

Full text for 2002-4 goals in the FWP document.

Some Key C-Mod 2001 Achievements

Alcator C-Mod

Internal Transport Barrier

- Off-axis ICRF-induced high or low B side. • Established χ-reduction.
- Controlled with 2nd ICRF frequency. • Analysed with heat-pulse.

Edge Transport Intermittency and New Understandings

- Dominance of perp transport (vs $\|$). • Imaging of bursty fluctuations.
- Relevance to density-limit physics. • Probe perturbation importance.

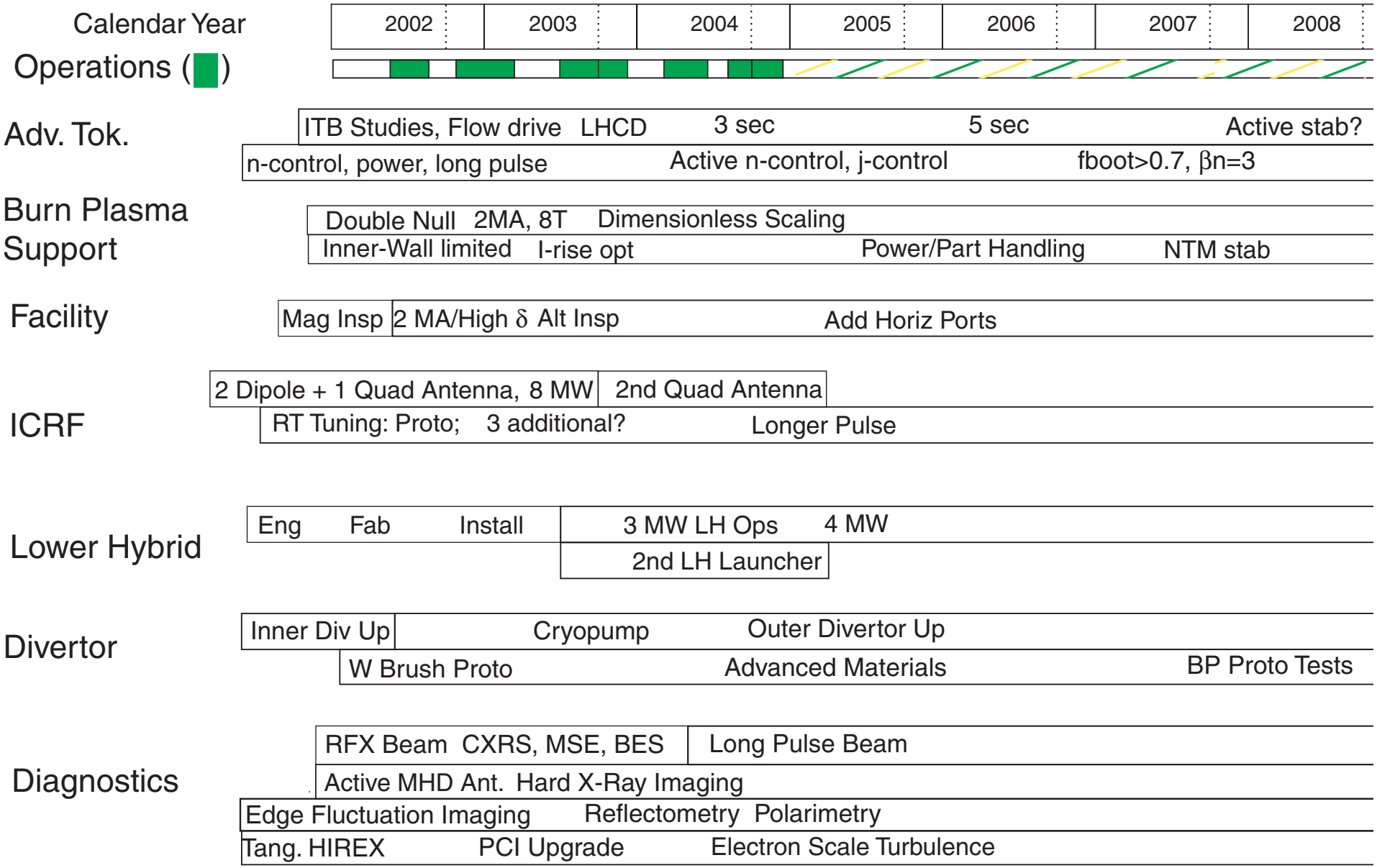
ICRF Antenna: Redesign eliminates stripline arcs

3-second duration plasma operation ($t \gg \tau_{cr}$).

Pedestal dimensionless similarity (w DIII-D).

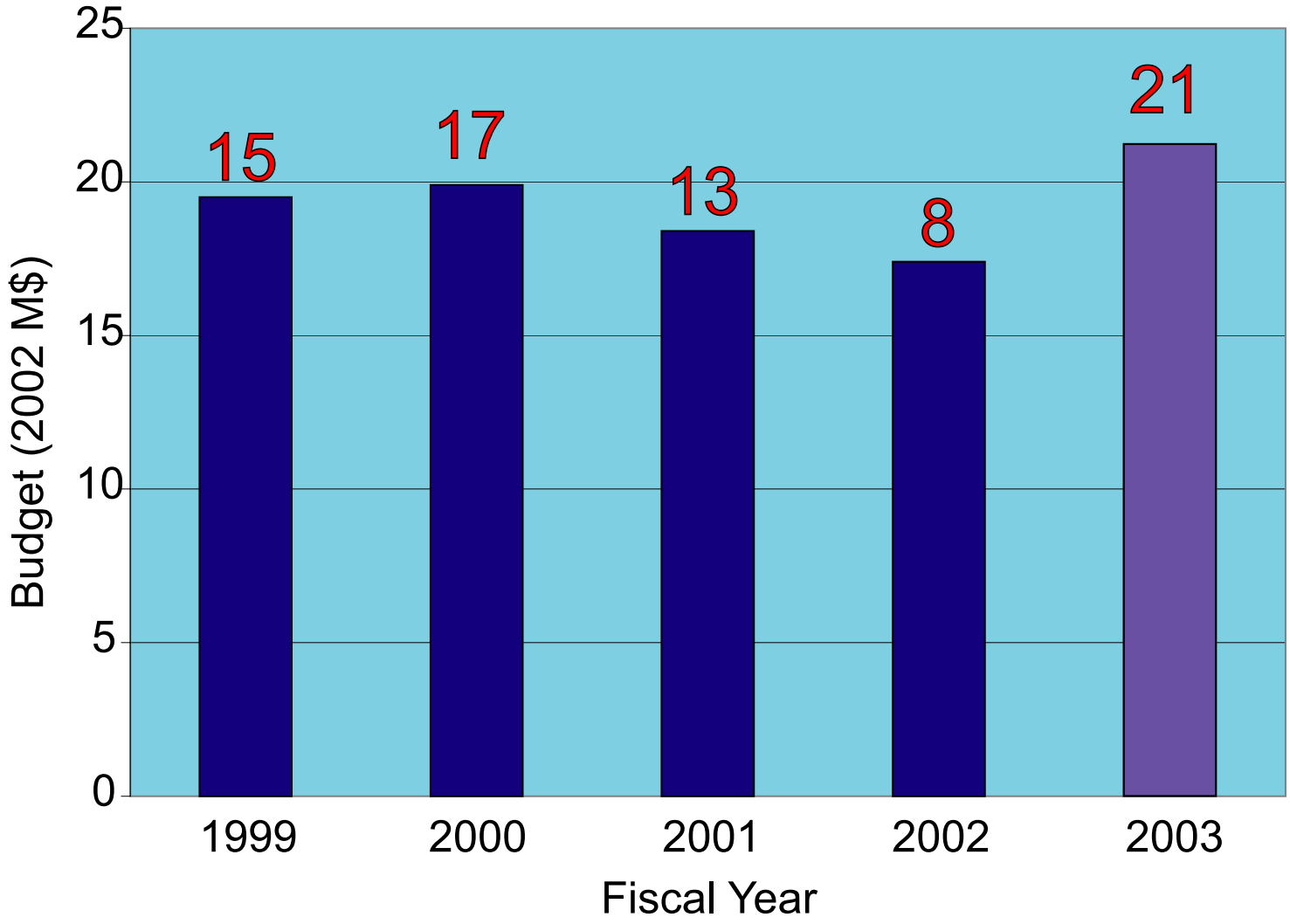
Internal observation of MCIBW (and modeling).

Alcator C-Mod National Facility
Overview Schedule (March 2002)

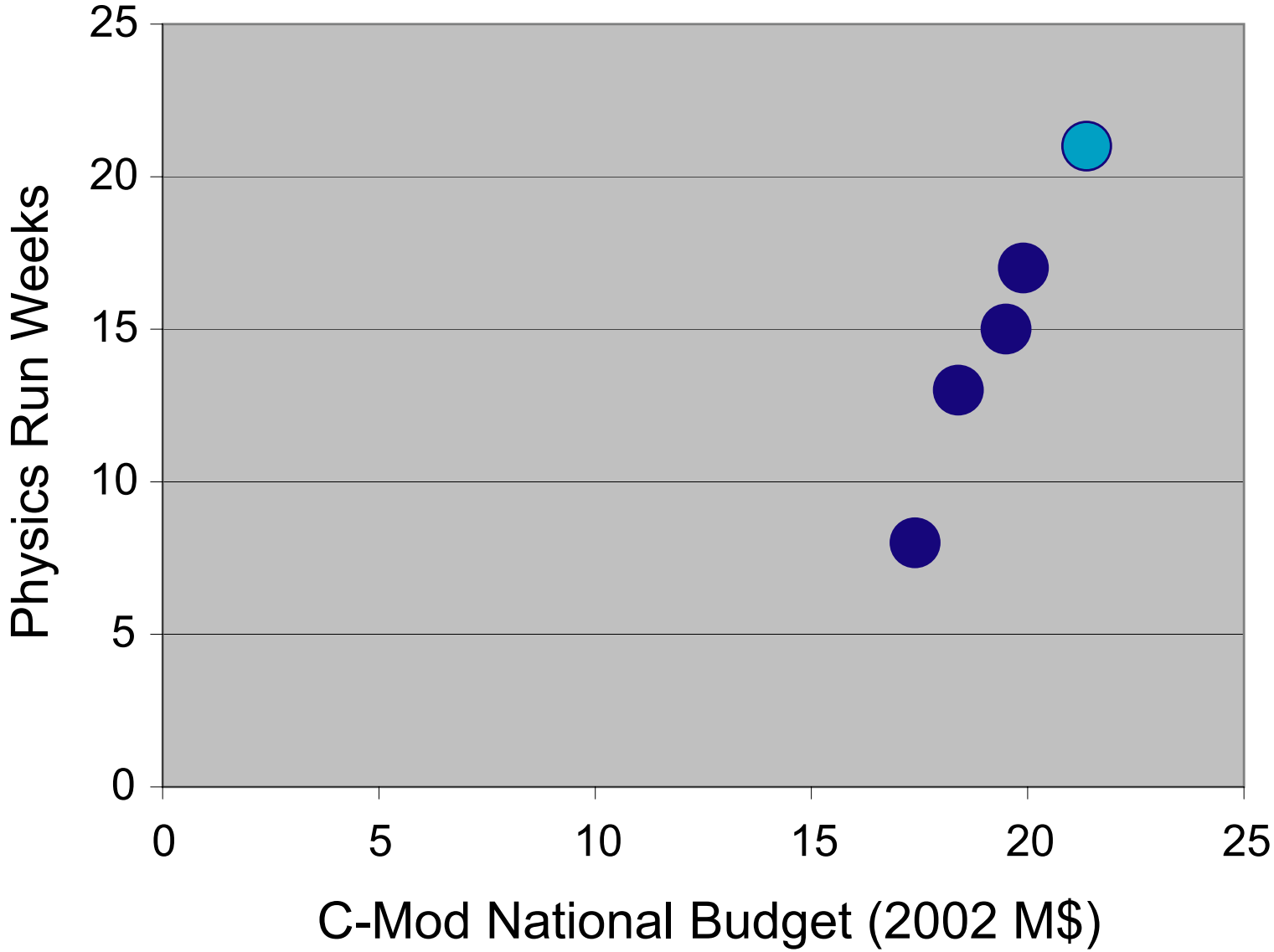


Budget Constraints have Led to Significant Underutilization

C-Mod National Budgets and Physics Run Weeks



Physics Output Greatly Enhanced with Relatively Modest Budget Increase



FY03 Guidance Allows Significant Increase in Run Time

Alcator C-Mod

Guidance Budgets

Fiscal Year	2001	2002	2003	2004
Run Weeks	13	8	**21**	**21**
Run Hours	430	270	**700**	**700**

10% Increment in 2004: Increase to 25 Weeks

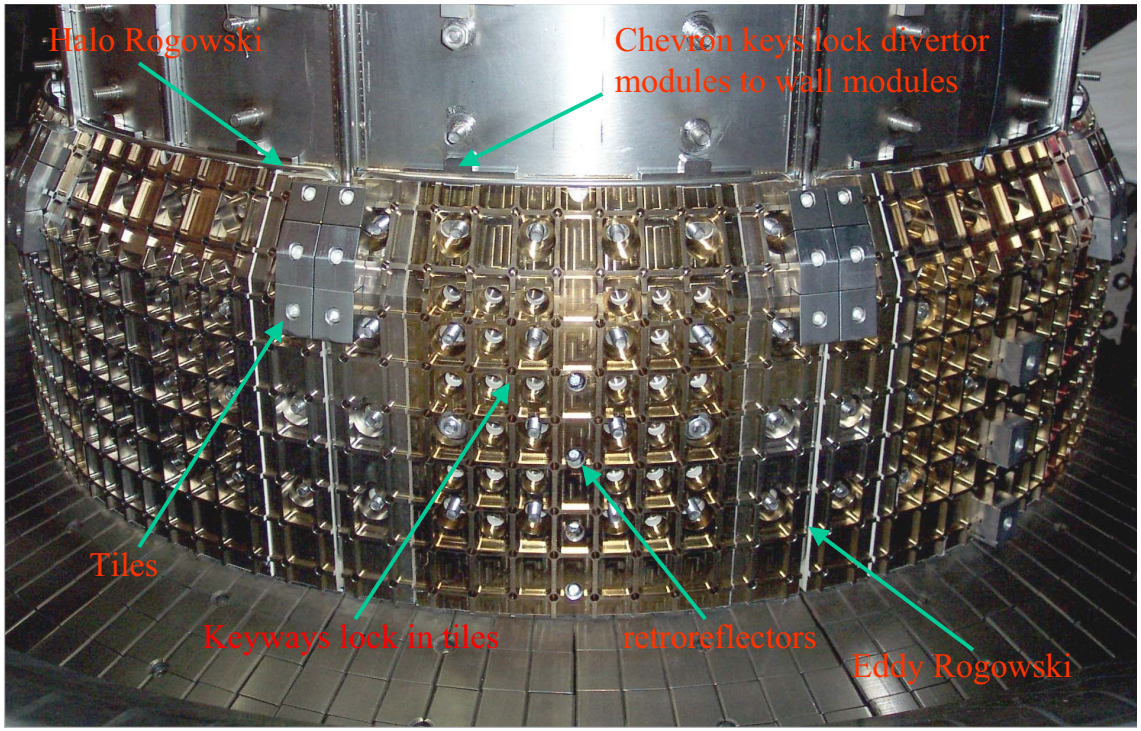
Fiscal Year	2001	2002	2003	2004
Run Weeks	13	8	21	**25**
Run Hours	430	270	700	**830**

10% Decrement in 2004: Reduce to 18 Weeks

Fiscal Year	2001	2002	2003	2004
Run Weeks	13	8	21	**18**
Run Hours	430	270	700	**600**

Milestones Completed Since March 2001

Evaluate operation of modified J-port 4 strap antenna	SEP 2001
Investigation of ITB control with multiple frequency ICRF	SEP 2001
Evaluate density control	FEB 2002
Complete inner wall modifications	MAR 2002

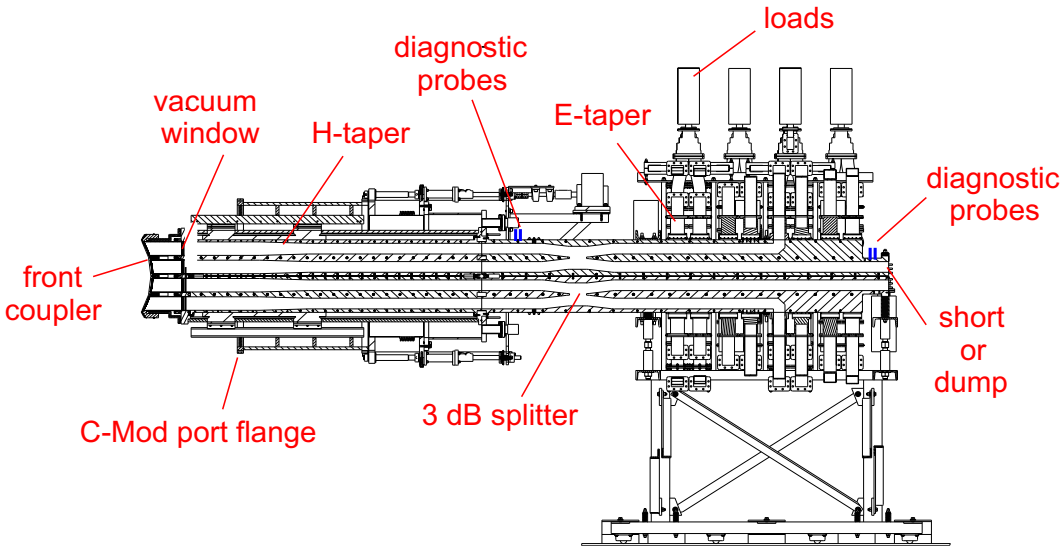


Outstanding and New Milestones

Evaluate performance at high triangularity	SEP 2002
Compare single-null, double-null and inner-wall-limited discharges	SEP 2002
Completion of Lower Hybrid Fabrication Project	MAR 2003
Measure edge rotation profile with CXRS	MAY 2003
Measure current density profile with MSE	MAY 2003
Evaluate mode conversion flow drive	MAY 2003
Evaluate mode conversion current drive	SEP 2003
Operate with plasma current of 2 MA	SEP 2003
Evaluate integrated H-mode performance, 6 MW ICRF, $I_p \geq 1.2$ MA	SEP 2003
Establish limits of divertor power handling for AT regimes	SEP 2004
Initial assessment of Lower Hybrid current drive	SEP 2004
Assess active MHD technique for sensing instability damping rates	SEP 2004

Lower Hybrid Current Drive Phase I (MIE)

- 3 MW source power from 12 klystrons (MIT)
- 96 waveguide launcher in single port (PPPL)
- Total budget $5.2M (FY00-FY03)
- Project completion with delivery of launcher to MIT (March, 2003)



Lower Hybrid Upgrade (Phase II)

- Second launcher (PPPL)
- +1 MW source power from 4 additional klystrons (MIT)
- Under guidance budgets, start in FY04, complete in FY05
- New 4-strap ICRF antenna required to maintain diagnostic port access

Personnel

- Over 160 scientists and students involved with the C-Mod Project
  - Includes 22 PhD candidate graduate students, 5 undergraduates and 3 post-doctoral fellows
  - Over 35 institutions (both domestic and international) represented
- Host users: 20 scientists + 17 graduate students
- Majority of directly supported personnel are at least fractionally involved in operations and upgrades
  - In FY02, about 60 FTE's total for operations and upgrades

Increased Operation Utilizes Majority of Budget Increase

- Personnel (1019k)
  - 2.5 Engineers, 2 Scientists, 1 Technician, Technician overtime
- Consumables (777k)
  - LN2, electricity, fuses, switchgear, spares, M&S
- Data Acquisition and Instrumentation (168)

- Alternator and Flywheel (1030k)
  - Must be inspected between the two FY03 operation periods

Highest Priority Upgrades Included in Guidance Budgets (FY03-04)

- Completion of Lower Hybrid Current Drive (Phase I)
- ICRF instrumentation upgrades (more reliable ops)
- Data acquisition, control and analysis facilities (partially replace obsolete hardware)
- Cryopump (density control for AT program)
- Replace borrowed DNB
- Begin Phase II of LHCD (+1 MW, additional launcher)
- Begin construction of new 4-strap ICRF antenna

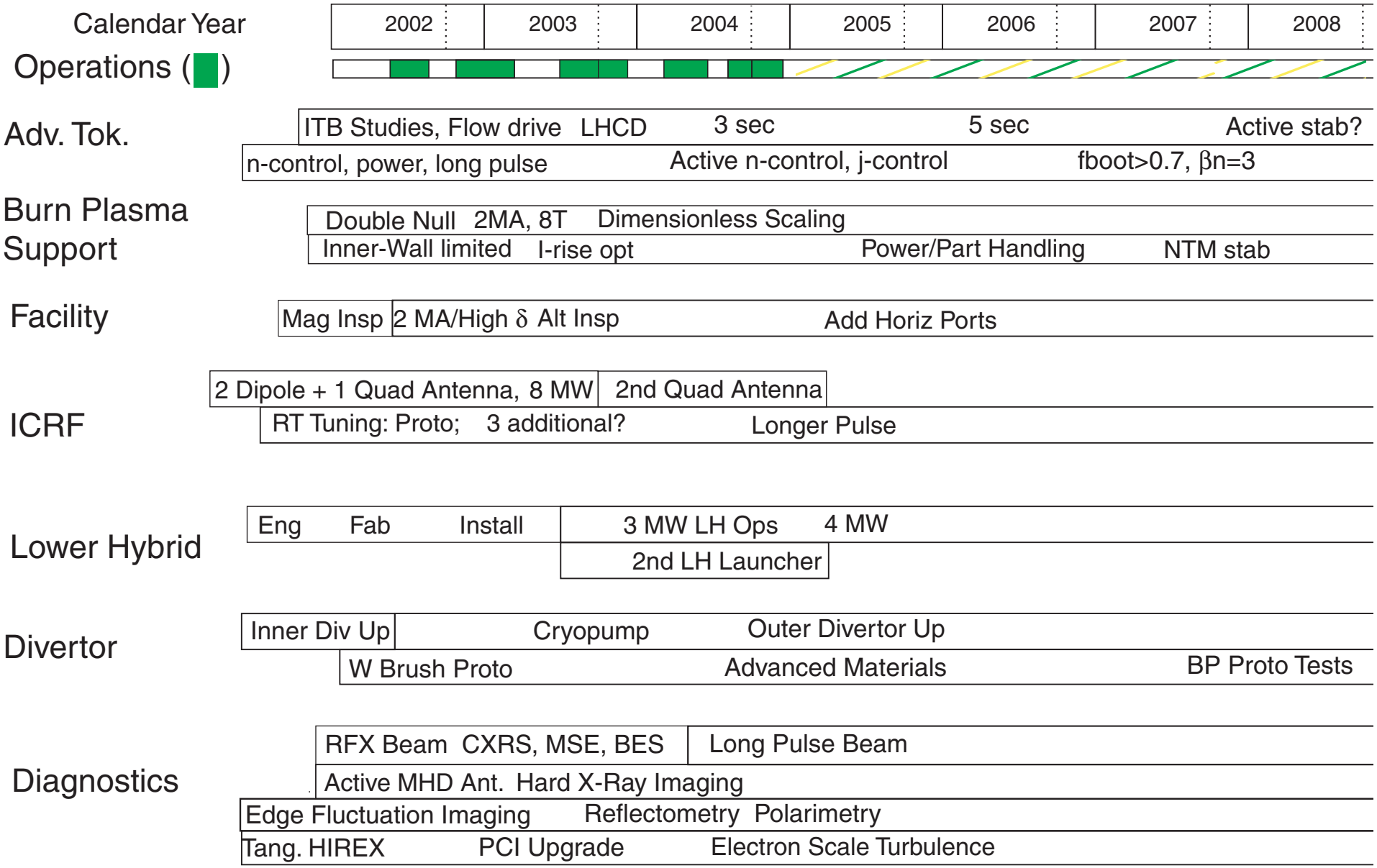
Consequences of 10% Cut (FY2004)

- Personnel cuts:
  - 1 scientist, 1 engineer, 2 technicians
- 3 week reduction in physics operation (to 18)
- Important upgrades, new diagnostics deferred/delayed
  - Phase II Lower Hybrid
  - 4-strap ICRF antenna
  - Turbulence and flow measurements
  - Replacement of DNB
  - Replacement of obsolete data acquisition and computer resources

High Priority Elements Requiring Incremental Funding

- Fast Ferrite Tuners (Real-time ICRF matching): 750k
- 4 additional run-weeks (to 25): 850k
- Diagnostic upgrades
  - MSE E_r profiles, improved spatial resolution: 540k
  - Various: 465k
- Earlier completion of Phase II LHCD: 650k
- Power supply upgrades (high current, long pulse): 820k
- Outer divertor upgrade (earlier implementation): 940k
- Data acquisition, control, computers (more timely replacement): 900k
- Additional international collaborations (JET, FTU): 80k

C-Mod National Budgets (k$, Feb 2002 Guidance)

		FY02	FY03A	FY03 (Incr.)	FY04A	FY04 (Incr.)
MIT	Research	5,139	5,790	162	5,790	205
	Operations	8,201	11,972	2,790	12,391	2,982
	Lower Hybrid MIE	710	419	0	0	0
	International Collaborations	55	0	77	0	80
	MDSplus	149	147	0	147	5
	MIT Total	**14,254**	**18,328**	**3,029**	**18,328**	**3,272**
PPPL	Research	1,270	2,231	0	1,931	0
	Operations	230	221	0	221	0
	Lower Hybrid MIE	800	300	0	0	0
	Equipment/Upgrades	0	0	630	600	550
	PPPL Total	**2,300**	**2,752**	**630**	**2,752**	**550**
UTx	Research	555	640		640	
	Operations	257	296		296	
	U. Tx. FRC Total	**812**	**936**		**936**	
	LANL Research	**95**	**99**		**99**	
	Alcator Project Total	**17,461**	**22,115**		**22,115**	

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