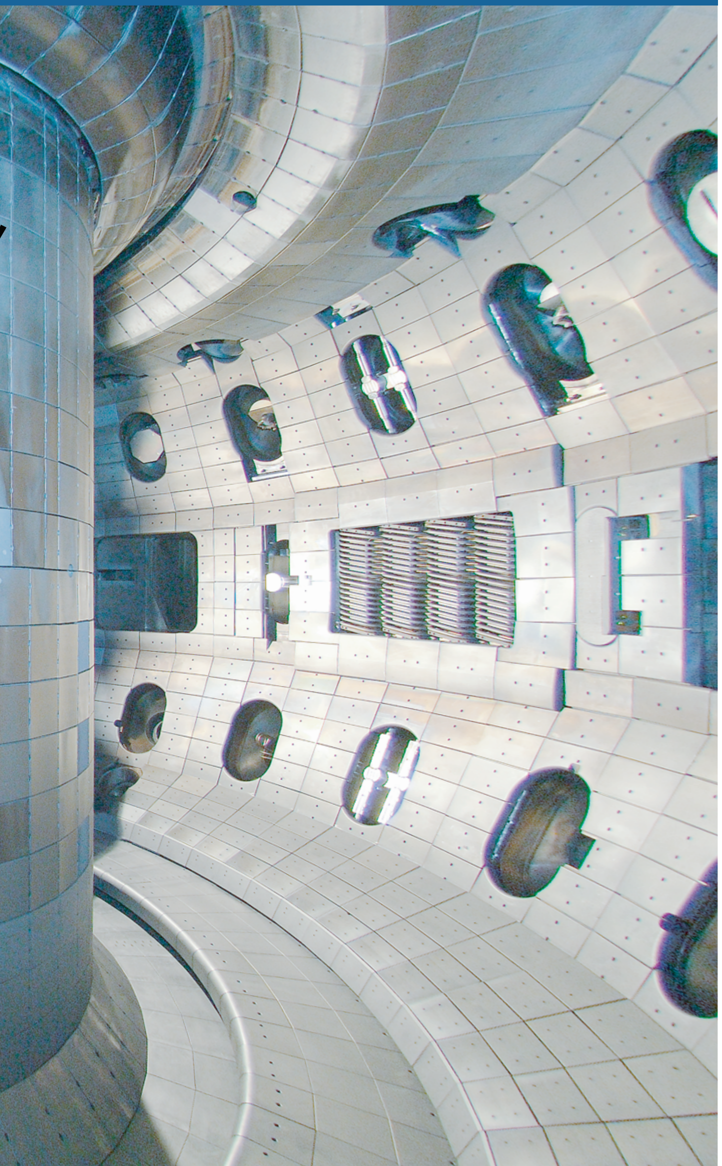
Experimental Simulation of the ITER Rampdown Scenario on DIII-D



P.A. Politzer, G.L. Jackson, D.A. Humphreys,
T.C. Luce, and A.W. Hyatt

General Atomics
San Diego, California

51st Annual Meeting of the
APS Division of Plasma Physics
Atlanta, Georgia

November 2–6, 2009

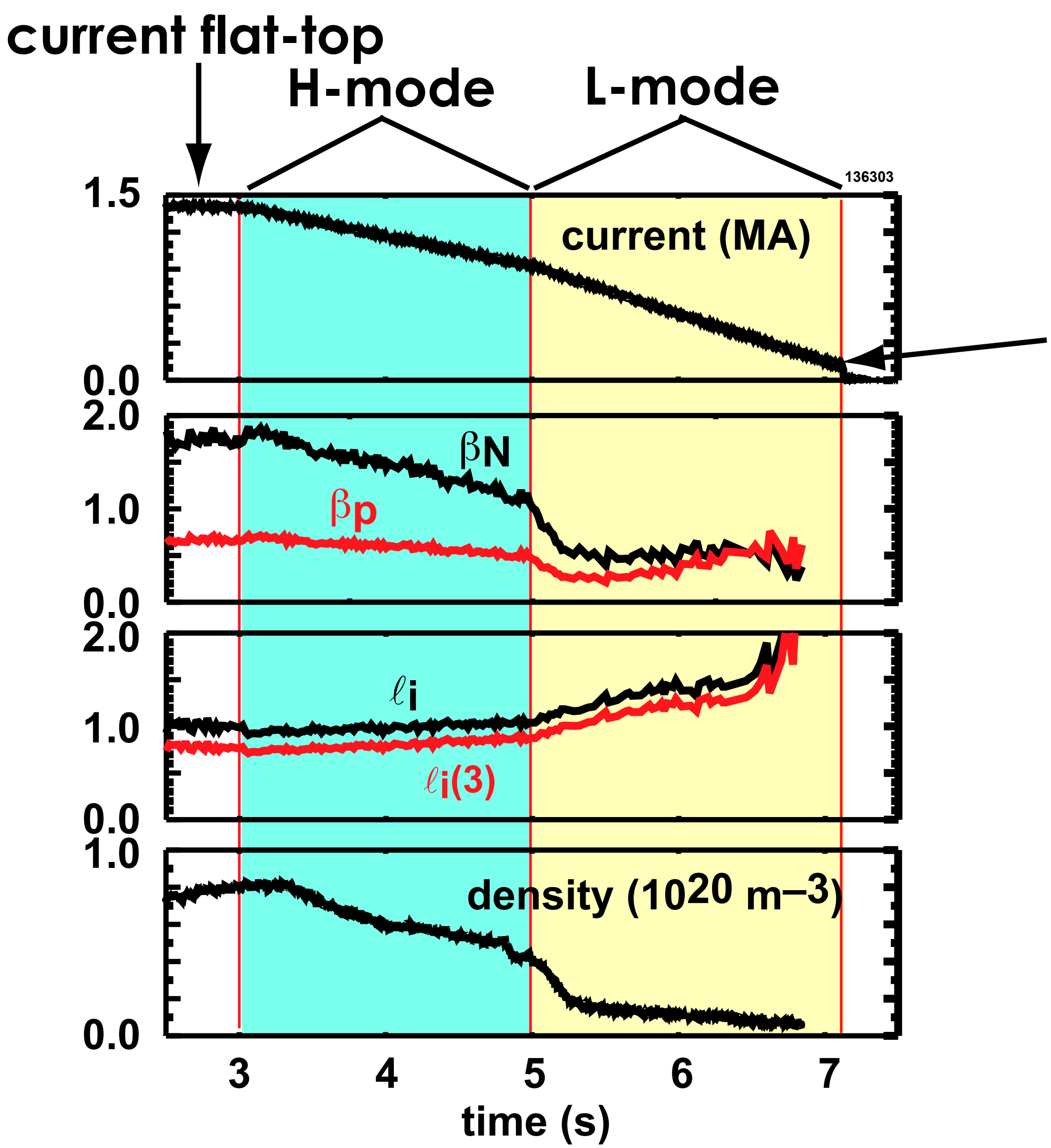
Controlled termination (rampdown) of an ITER discharge is necessary

- **As tokamak size increases, controlled discharge termination becomes more important.**
- **If released rapidly, the thermal and magnetic energy is large enough to cause serious damage.**
  – 750-1000 MJ in the 15 MA ITER baseline scenario.
- **To shut down slowly and safely, it is necessary to remain within the operating limits of the ITER power and control systems.**
- **The DIII-D tokamak program has undertaken a study of the rampdown phase of an ITER discharge. The objectives are**
  – to simulate the details of the proposed ITER scenario,
  – to identify potential issues and problems, and
  – to improve upon these scenarios with an eye to both mitigating difficulties and improving performance.

DIII-D has successfully tested the reference rampdown scenario for the ITER baseline (15 MA)

- **Same dimensionless parameters: shape, β_p, ℓ_i, I/aB**
- **Dimensions scaled by 3.6:1, current 10:1, time 50:1**
- **Important ITER requirements:**
  - maintain the separatrix strike-point locations (on the armored portion of the ITER divertor),
  - keep β_p and ℓ_i within control limits particularly while significant energy remains available,
  - reduce the current and energy to a low level at the end of the ramp,
  - reduce density as the current is reduced,
  - keep linked flux and Central Solenoid current below limits (use during burn, not rampdown)

Experimental simulation reproduces the scaled ITER prescription



> *ITER prescription:*
  – maintain constant q95 and ℓ_i
  – 1st 100 s → H-mode to 10 MA
  – 2nd 100 s → L-mode to ≤ 1.4 MA

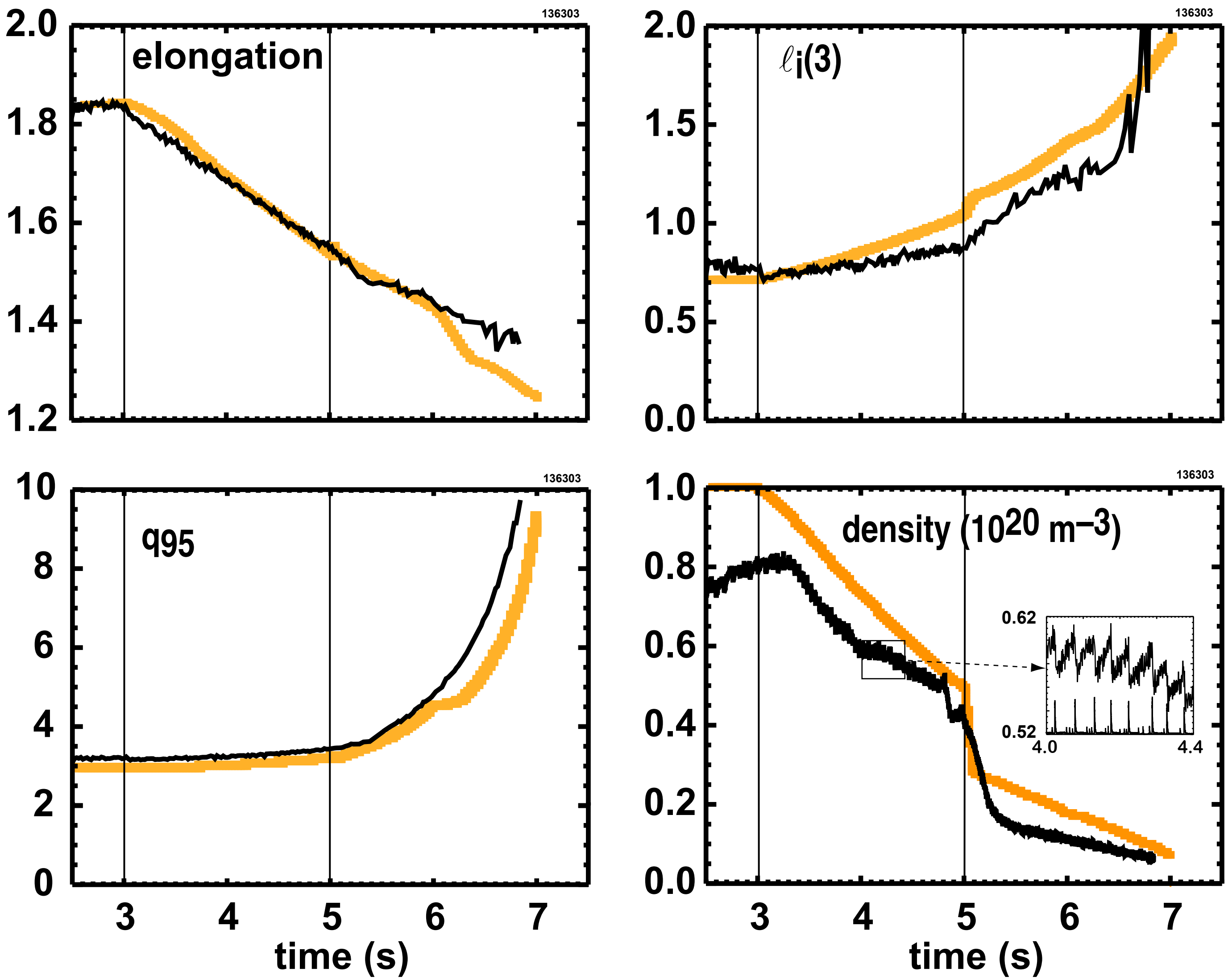
- **I_p reduced to <100 kA (1 MA ITER equiv).**
- **At H-L transition, energy is ~42% of flat-top value; at termination, ~0.5% remains.**
- **Small variation in β_p and ℓ_i; remain within control range.**
- **Density drops as current decreases.**

Excellent shape and strike-point control

Figure shows separatrix every 400 ms during the full 4 s rampdown.

- **x-point and strike point locations are held within mm, except at lowest current,**
  - in ITER, must keep strike points on armored part of divertor.

Experimental parameters follow scaled ITER modeling

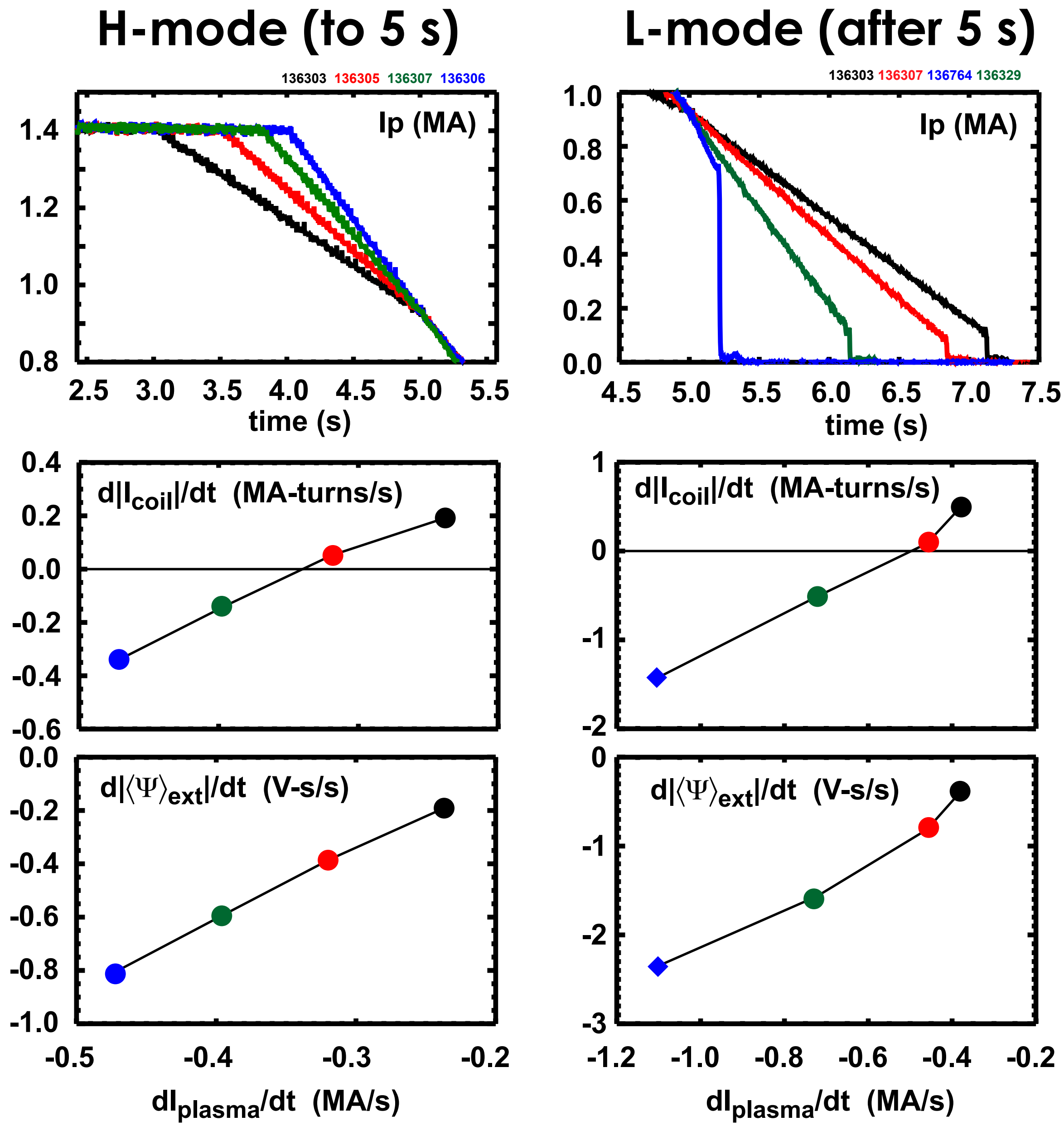


black: DIII-D
gold: modeling by ITER using DINA code
(ITER density trajectory is assumed)

Note strong density modulation by ELMs

Rampdown rate scan indicates need to ramp faster

- **Current ramp rate in both H-mode and L-mode phases must be faster than the scaled ITER reference case (black)**
  – to avoid further increase of the inner coil currents (limit to burn duration in ITER).
- **Too fast leads to disruption.**
- **Flux consumption is not a problem.**
  $-d|\langle\Psi\rangle|/dt$ always < 0.

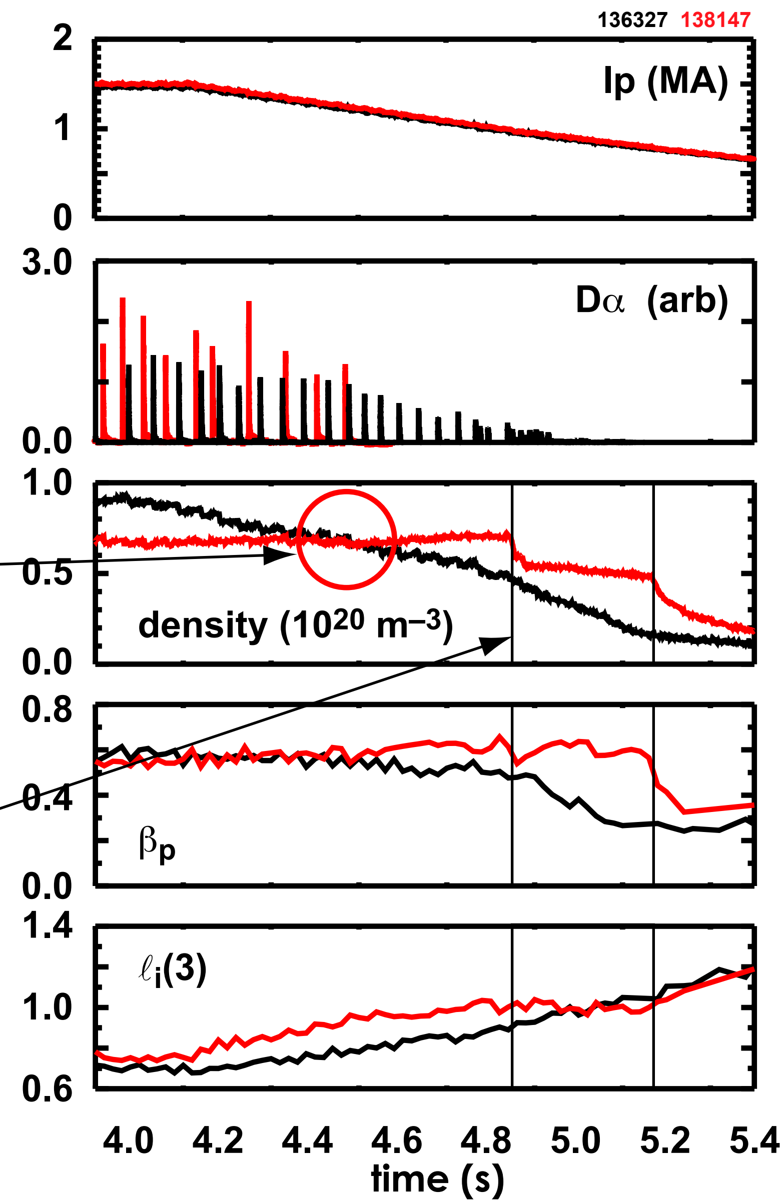


Tested full-bore rampdown; encountered stability and density control problems

– *Full-bore: maintain constant, full-size shape as current is ramped down.*

- Compare full-bore (red) with ramped κ (black) rampdown.
- Less frequent ELMs.
- ELM-free H-mode at 4.5 s.
  - higher ℓ_i, lower P_{NB}
  - density increases
  - β_p increases
  - n=1 mode appears and locks

> *Risks density limit and vertical instability during rampdown.*



Summary and conclusions

- **DIII-D has reproduced the ITER baseline (15 MA) rampdown scenario (including scaled time dependence) with respect to shape, scaled current, β_p, κ, and ℓ_i.**
  - Vertical stability can be maintained down to < 1 MA (equiv); ~0.5% of flat-top energy remains.
  - Separatrix strike points are held fixed.
  - The ITER-specified elongation ramp is needed to avoid density limit and vertical instability during rampdown.
  - Current rampdown rates in both the H- and L-mode phases must be faster than the ITER prescription to avoid exceeding Central Solenoid current limits.
  - Density control will be needed during rampdown so that the density decreases with the current.