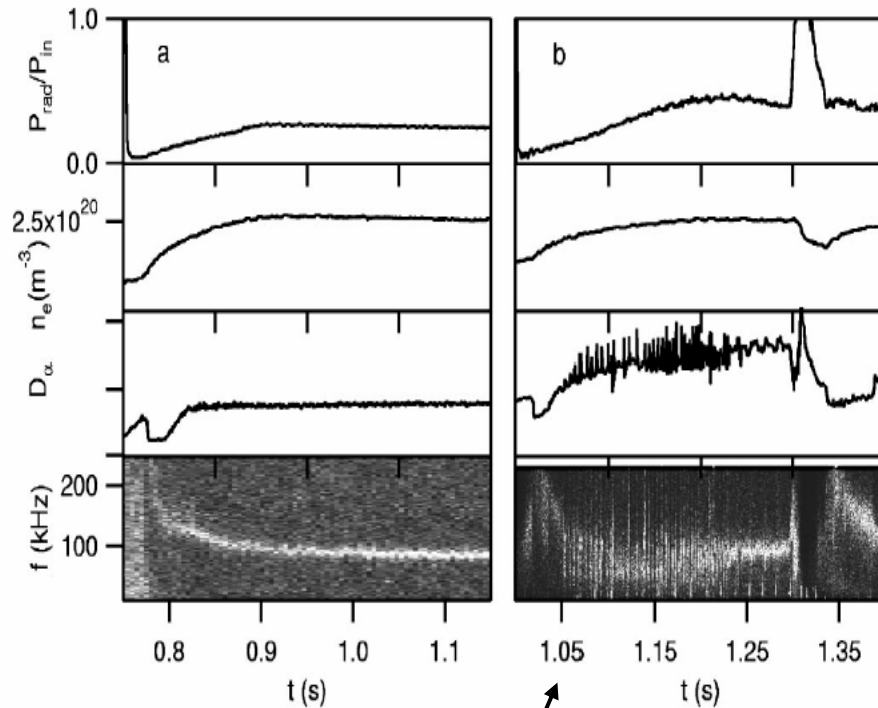

ELMs on C-Mod

**J.W. Hughes for the Alcator C-Mod
team**

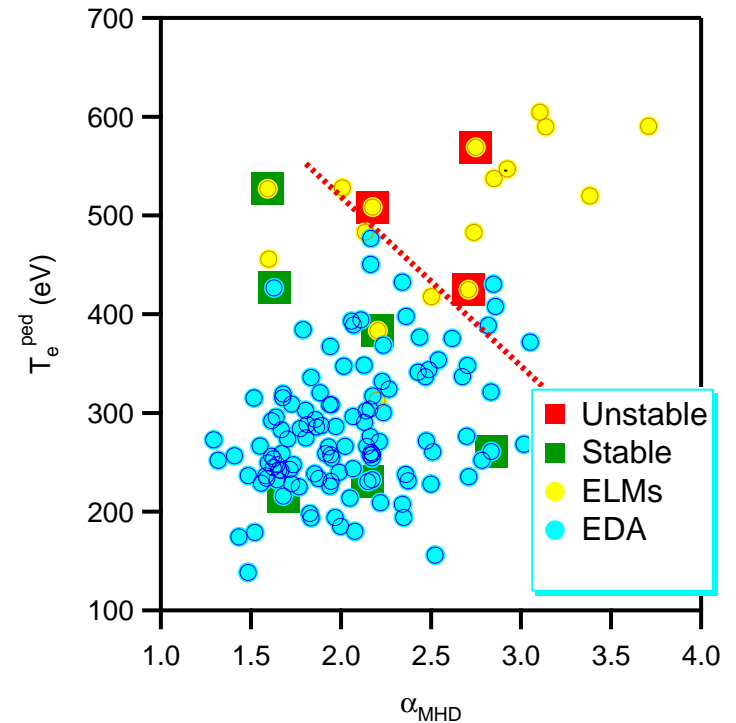
**C-Mod/NSTX Pedestal Workshop
Princeton, NJ
September 7—8, 2010**



EDA H-mode is supplanted by small ELMs at higher beta



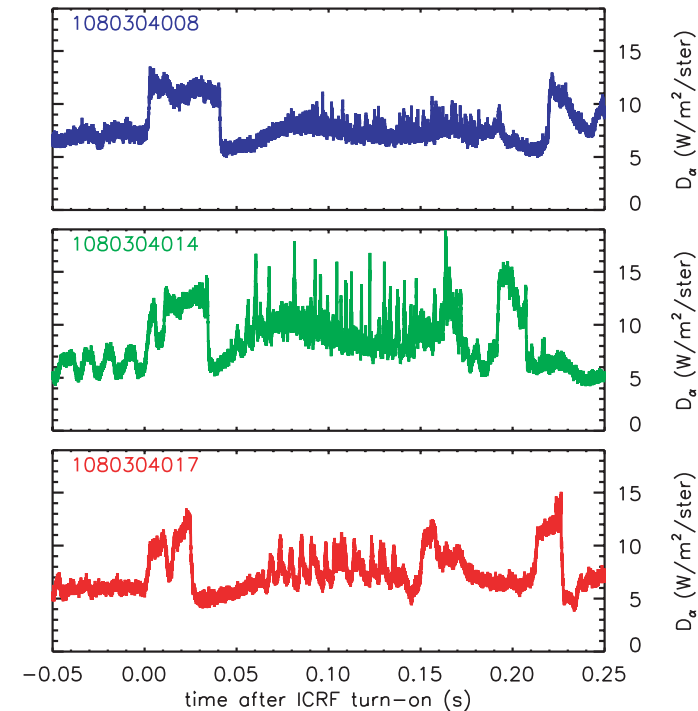
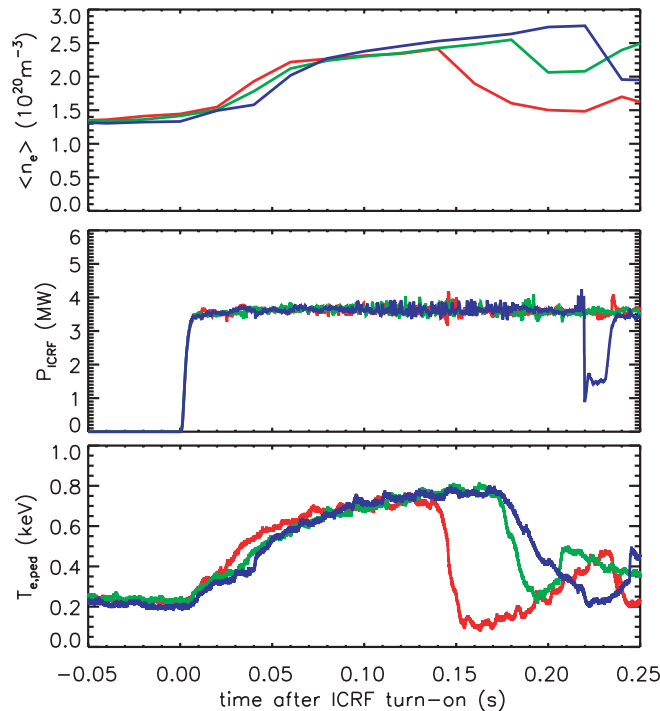
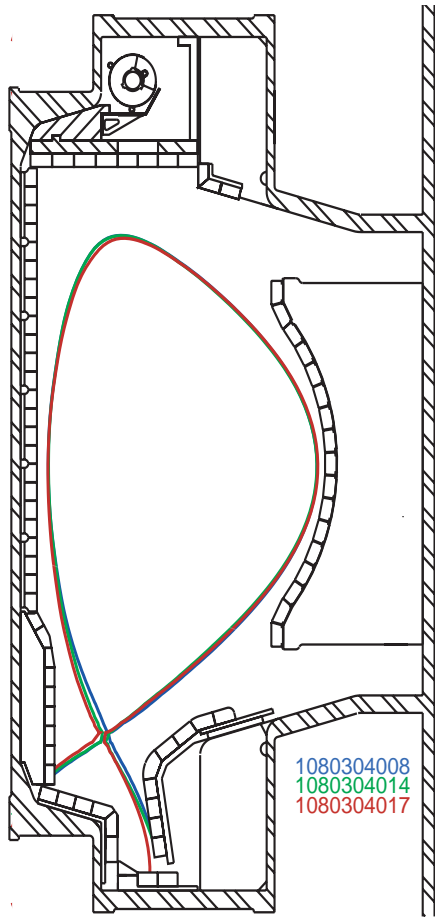
Higher input power



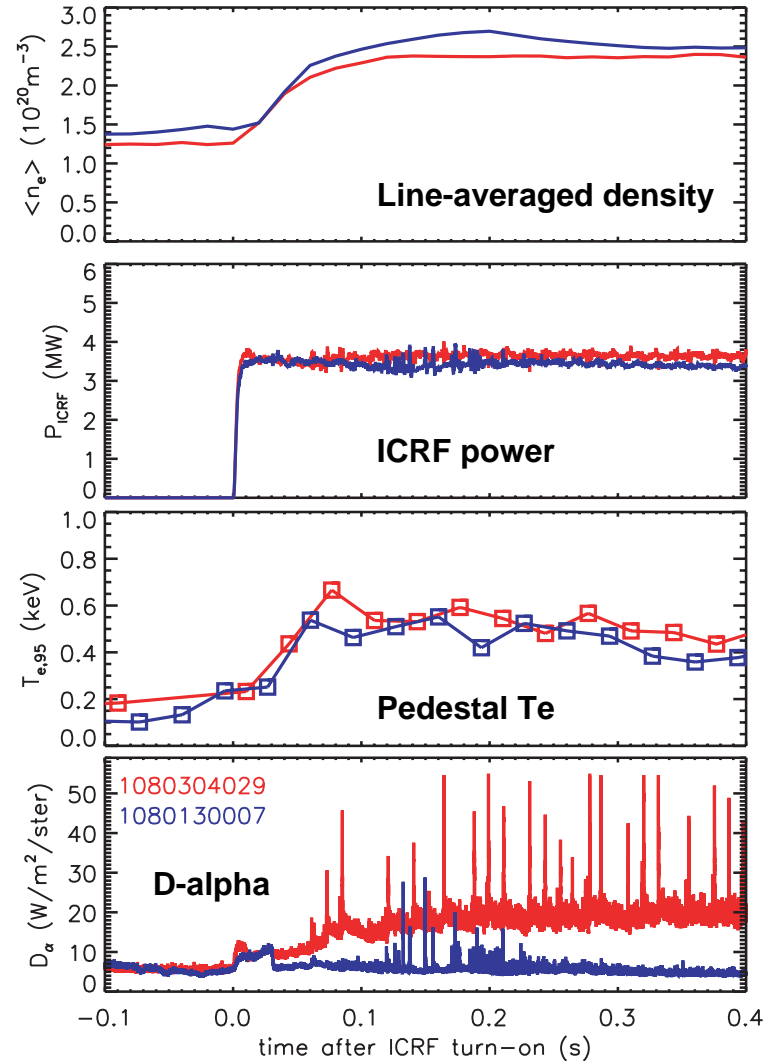
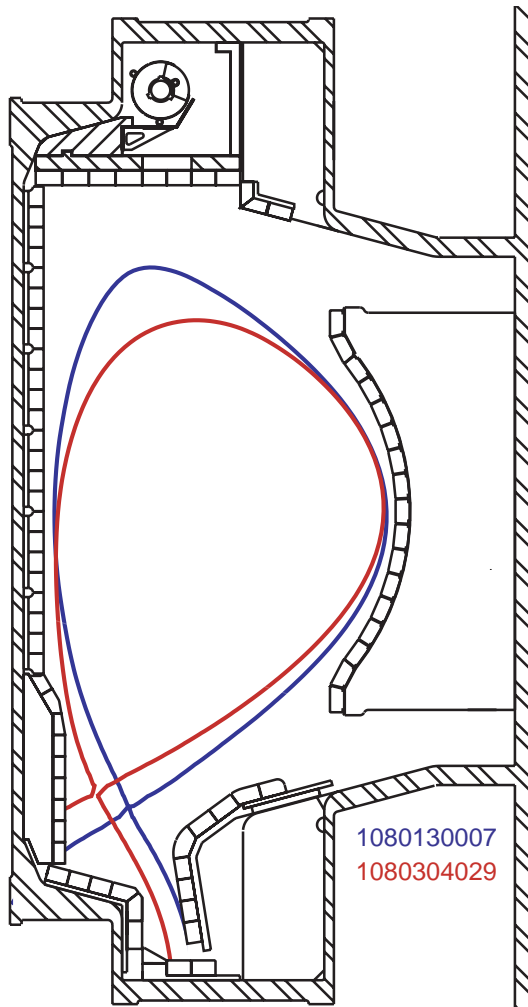
ELITE analysis showed that ELMs were consistent with peeling-ballooning triggers

Mossessian et al., Phys. Plasmas **10** (2003) 1720.

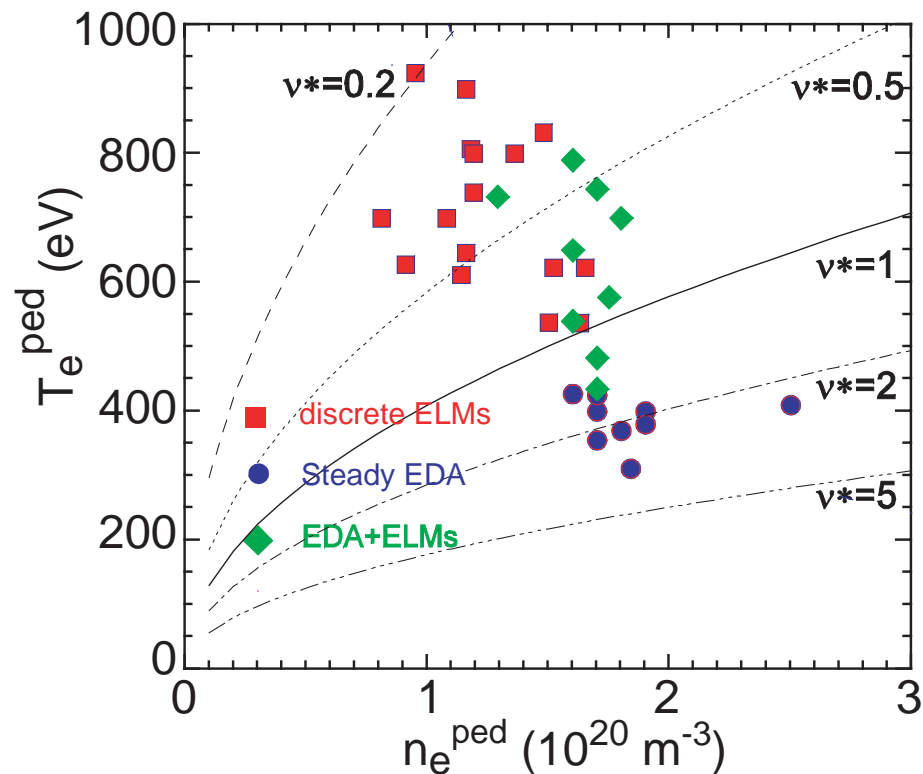
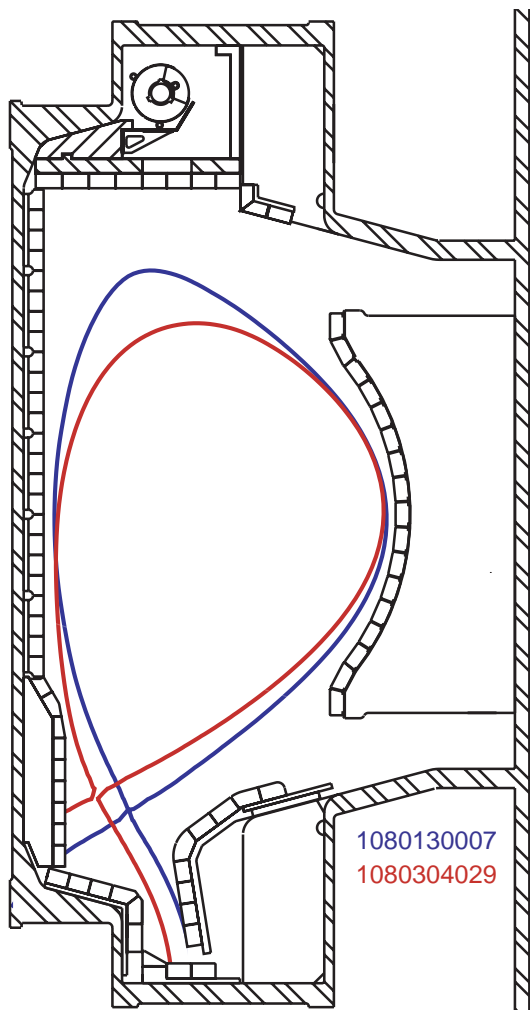
ELM signatures extremely sensitive to *shaping*



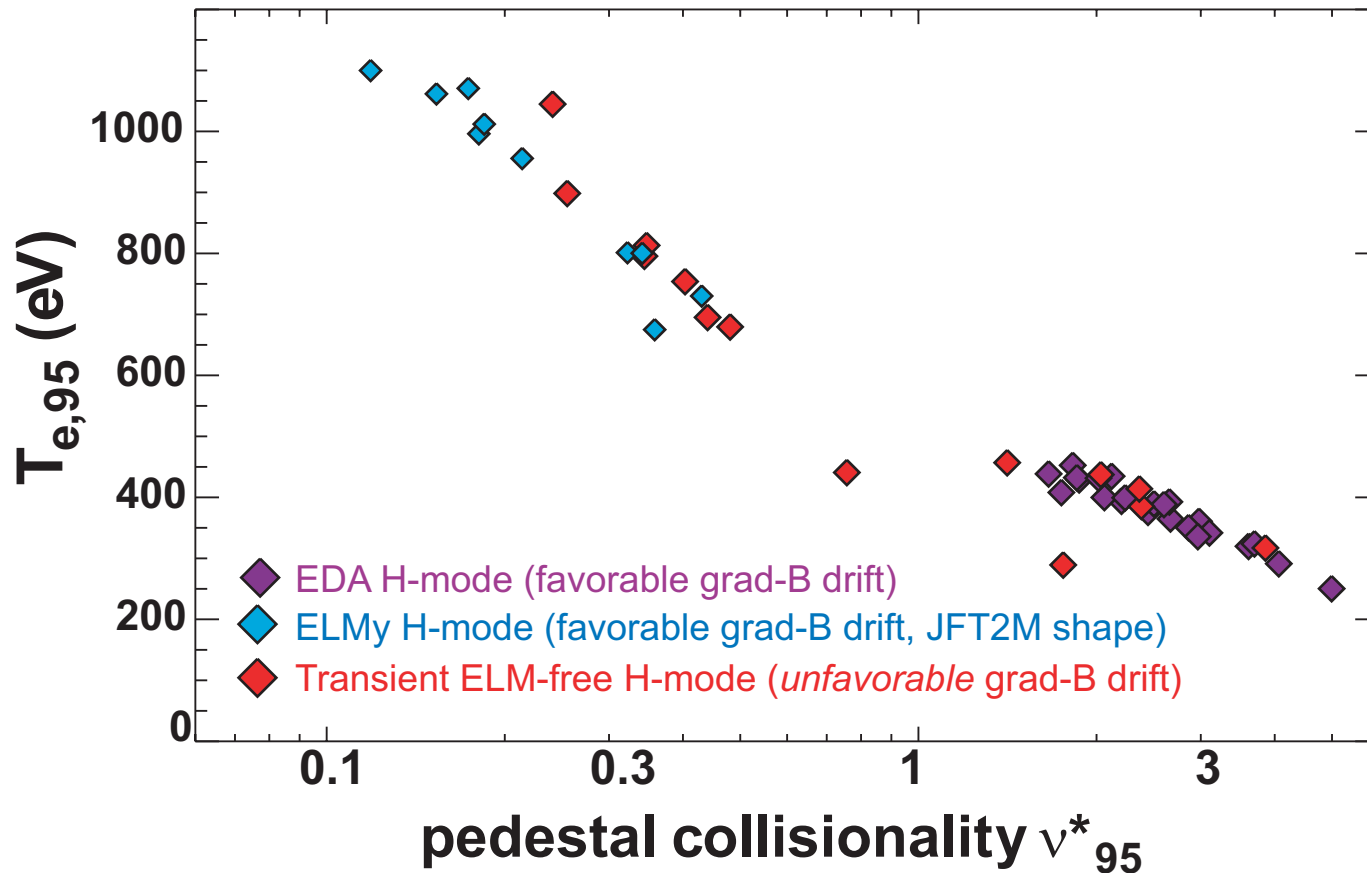
More extreme shaping, density reduction crucial to larger ELM access



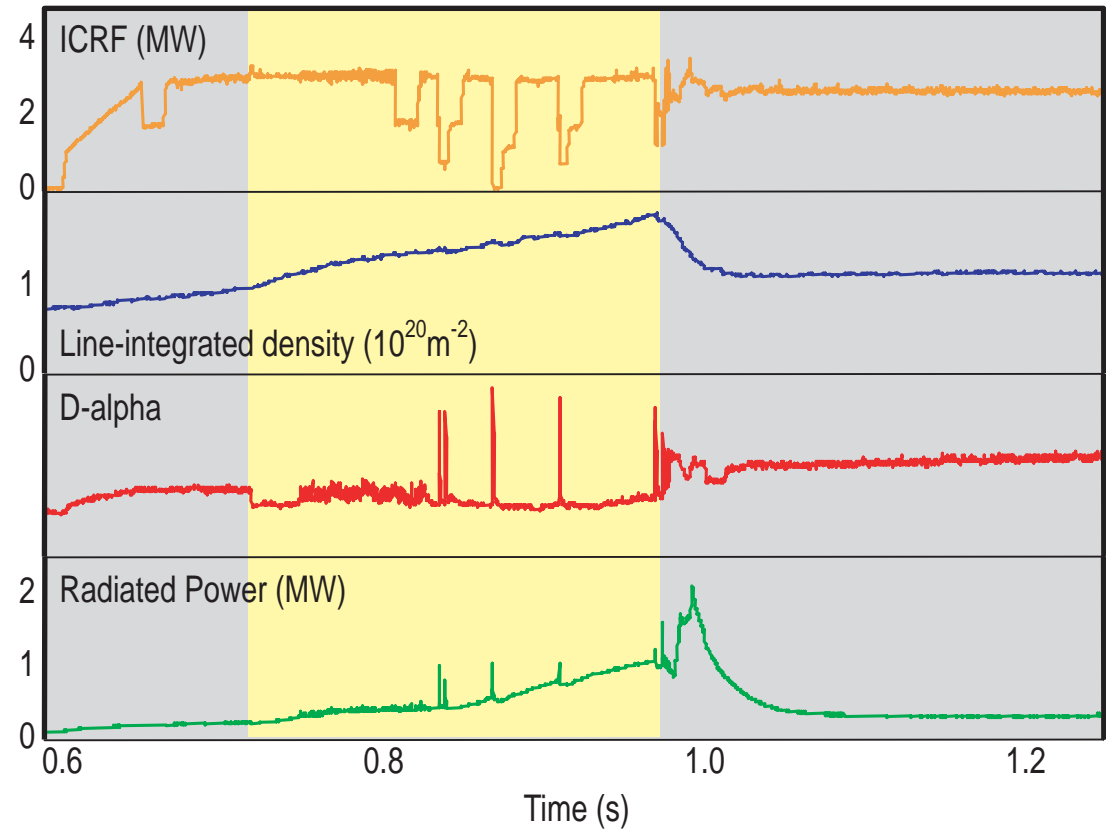
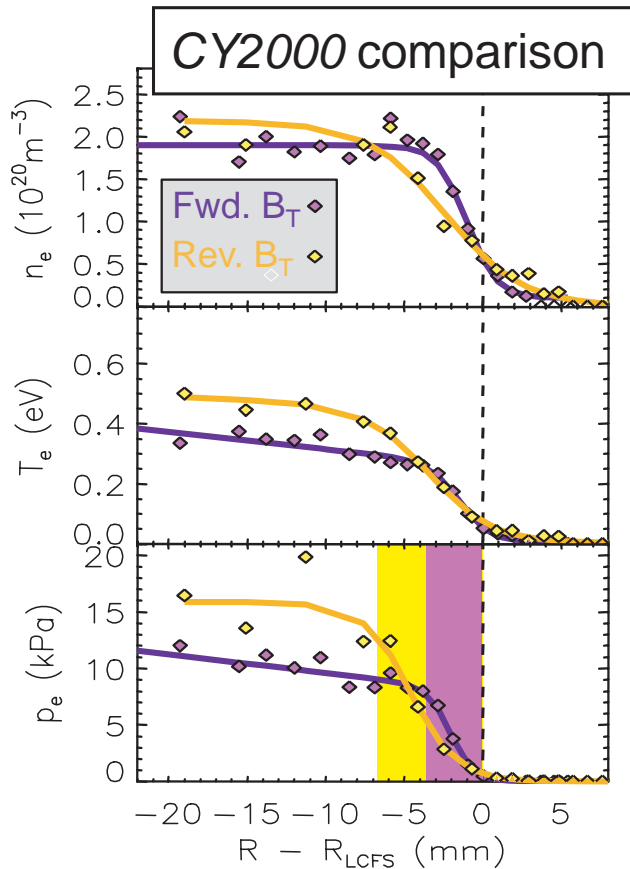
More extreme shaping, density reduction crucial to larger ELMy access



Differently shaped equilibria, magnetic topologies play a big role in edge stability

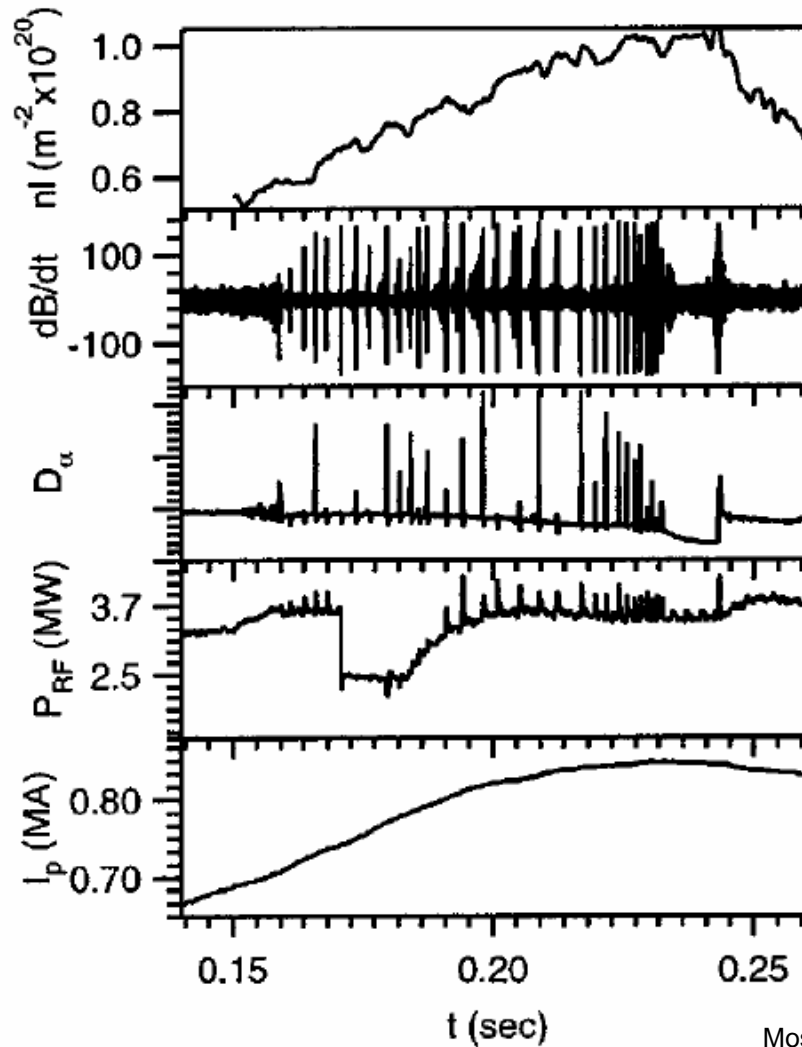


ELMs have been observed in reversed-field (non-EDA) H-modes



Unfortunately when conditions were matched in 2006, ELMs were not reproduced. Hidden variables? (c.f. L-H thresholds)

ELMs have also been observed during current ramp-up



Also not consistently reproduced

Mossessian et al., Phys. Plasmas **10** (2003) 1720.

Summary of observations

- **Robust ELMy regimes are only accessed in an atypical shape on C-Mod**
- **We seem to be on the cusp of ELM instability in many of our more typical configurations. What makes things so stable?**
- **Can modeling explain extreme sensitivity of ELM character to X-point position?**
- **Are there hidden variables in the ELM problem?**

- **Meanwhile, we have sought ways to trigger ELMs, which might prevent radiative collapse of naturally ELM-free H-modes**

Can rapid vertical jogs stimulate ELMs?

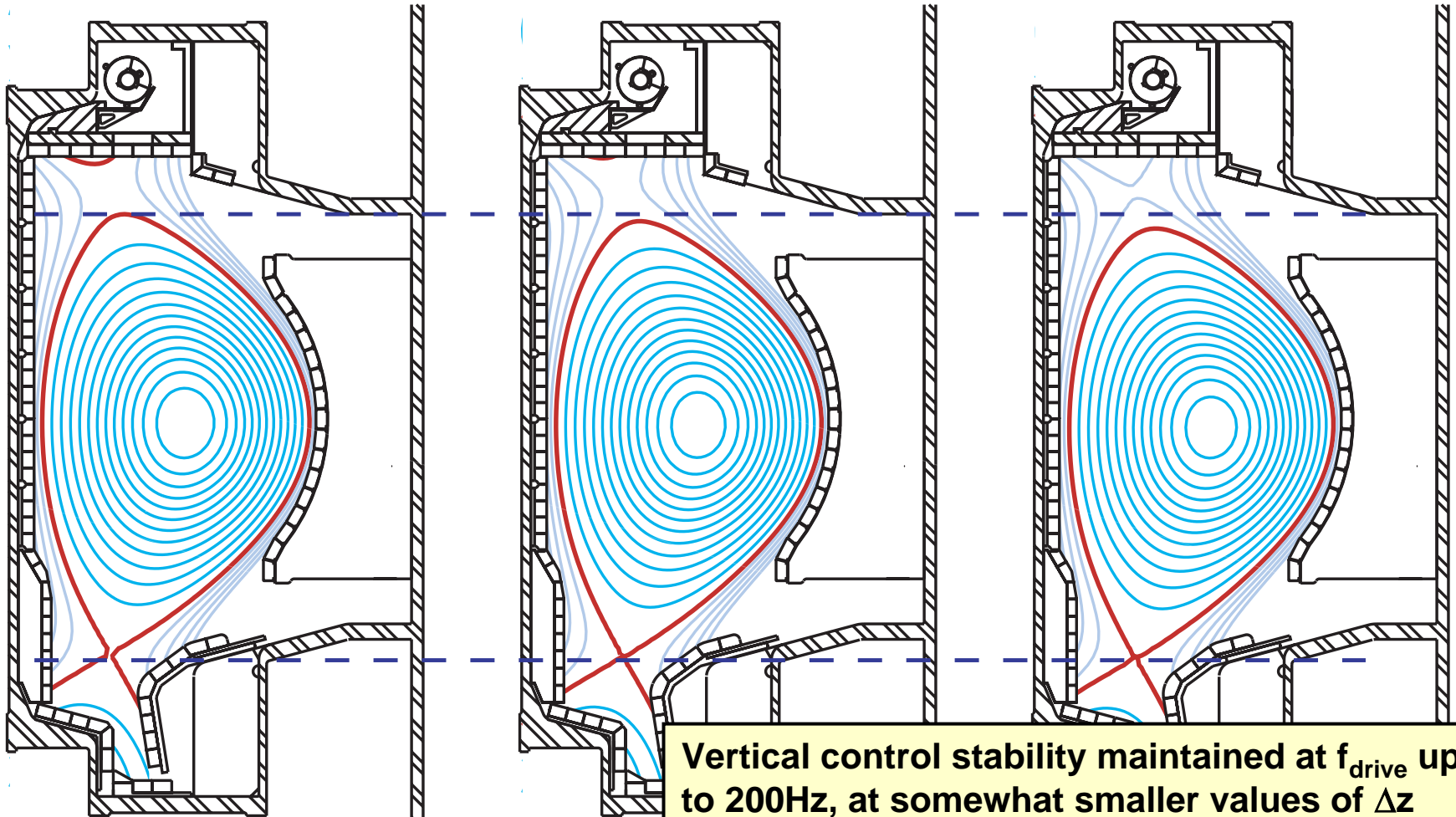
- **Would like the ability to *stimulate ELMs in normally shaped low collisionality H-modes for density and impurity control***
- **Rapid vertical displacement of plasma equilibrium has been observed to trigger and/or pace ELMs on multiple devices**
 - TCV [*Degeling 2003*], AUG [*Lang 2004*], JET [*Sartori 2008, de la Luna 2009*], NSTX [*Gerhardt 2009*]
- **Experimental approach**
 - Get close to ELM stability boundary: High power H-modes with high edge T, grad-p
 - Jog plasma centroid (ZCUR, z_{magx}) rapidly ($dz/dt=1\text{---}4\text{m/s}$), many times during H-mode
 - In recent (Feb/Mar 2010) experiments we successfully implemented Z-modulation scheme
 - At frequencies up to 100Hz in L-modes with $q_{95}\geq 3.1$
 - At frequencies up to 200Hz in H-modes (EDA and ELM-free) with $q_{95}\geq 3.5$

~1cm peak-to-peak displacement, Δz , possible with 100Hz z_{magx} -oscillation

Shot= 1100209025 Time= 0.995 Ip = 1.01

Shot= 1100209025 Time= 0.997 Ip = 1.01

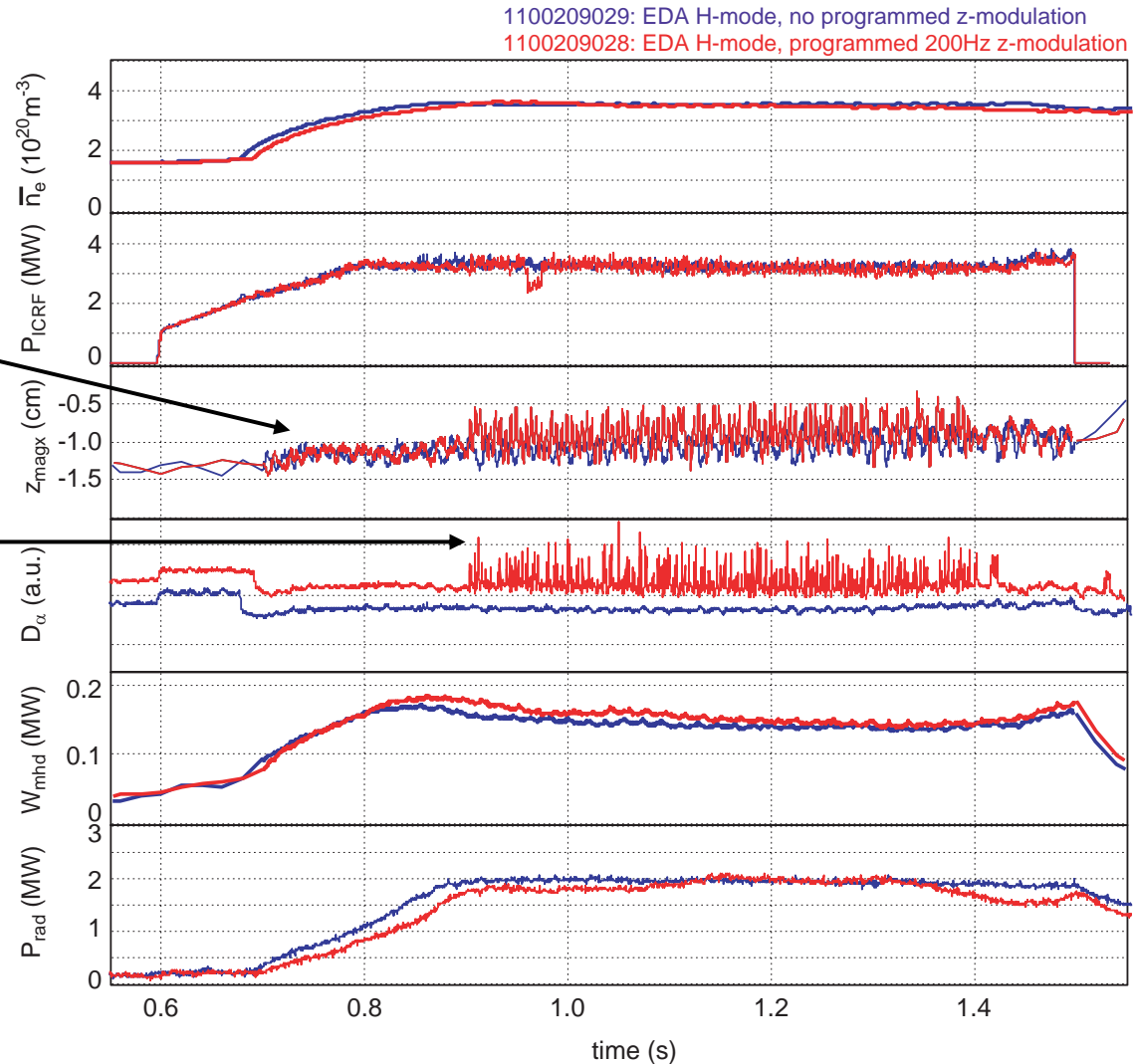
Shot= 1100209025 Time= 1.000 Ip = 1.01



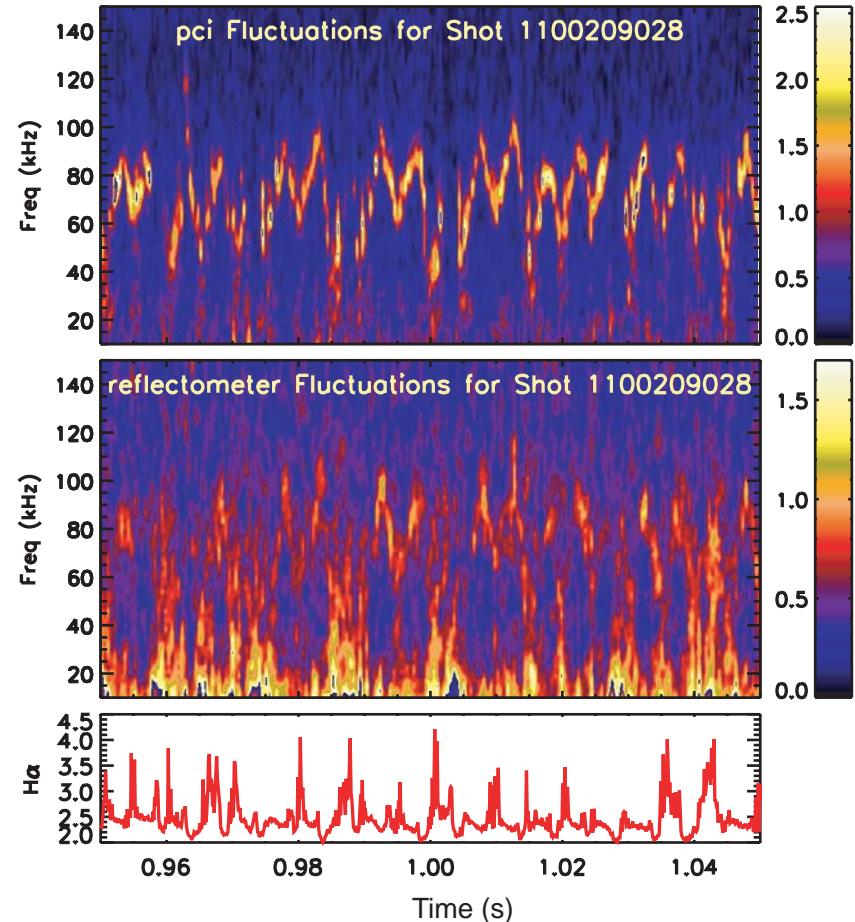
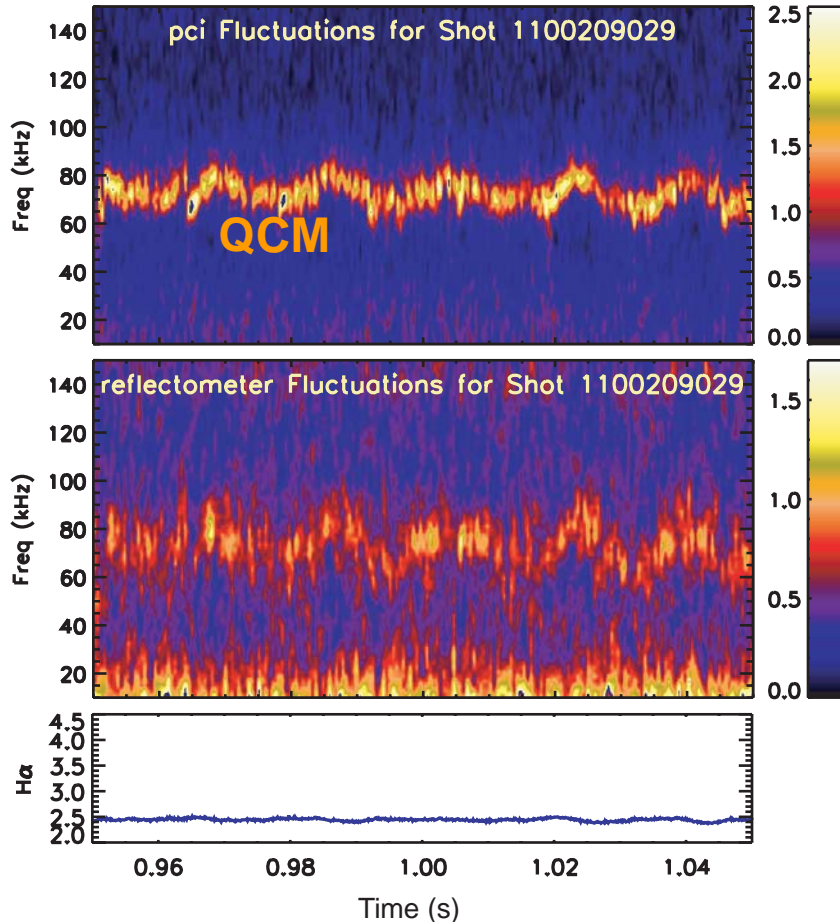
Vertical control stability maintained at f_{drive} up to 200Hz, at somewhat smaller values of Δz

Jogs implemented easily in EDA H-modes

- **Example: 200Hz oscillation applied to “ZCUR” controller from 0.9—1.4s**
 - Note ~55Hz oscillation in non-modulated plasma
- Minimum jog duration ~2ms in this discharge
- Small “blips” in D_α observed, roughly synchronized to jogs, both up and down. (Probably a diagnostic feature)
- Pedestal and global confinement properties essentially unchanged



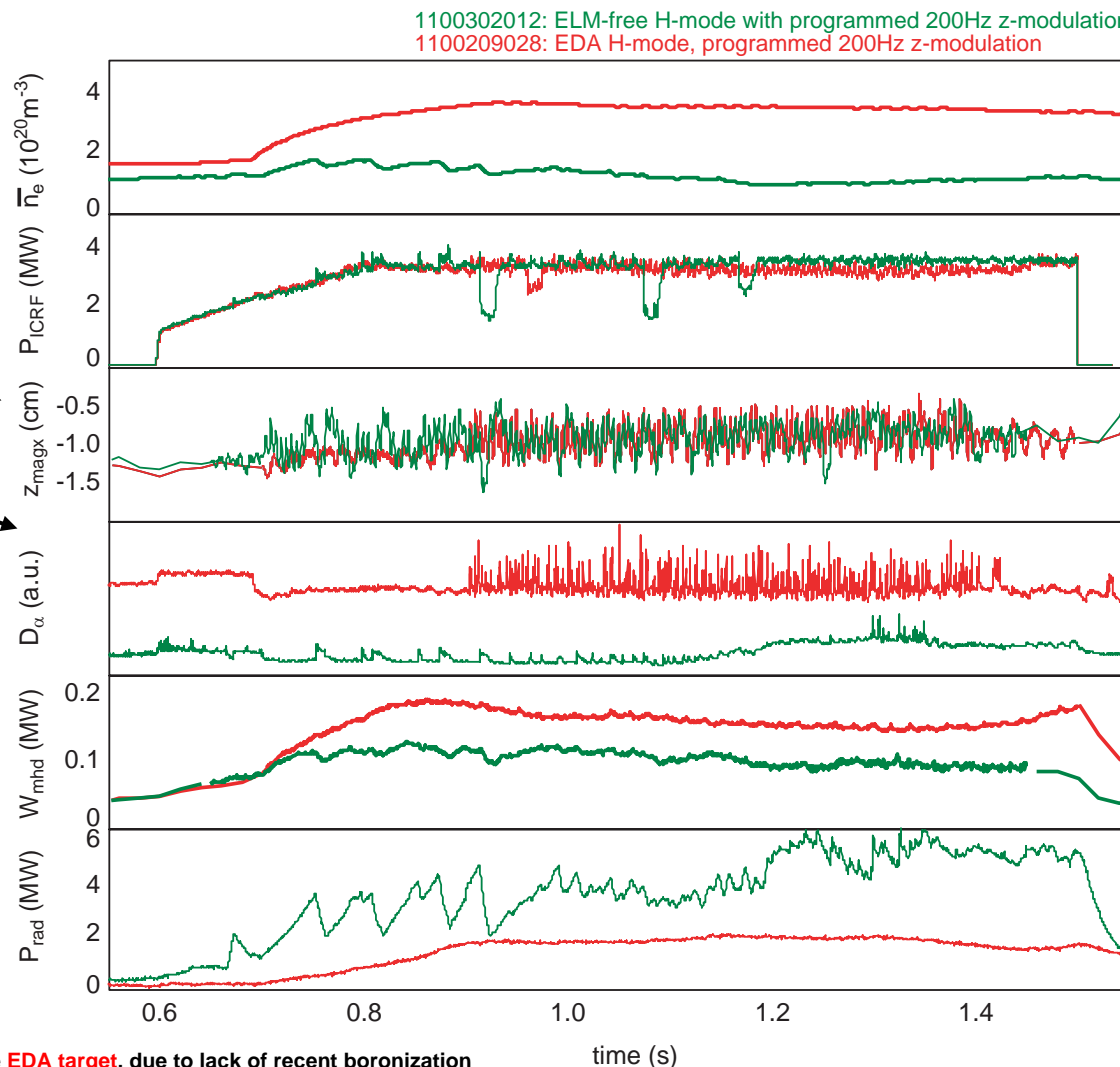
Underlying edge transport in jogged EDA H-mode not substantially changed



- Quasi-coherent mode ($f_c \sim 70\text{kHz}$) persists in **jogged EDA**, though with modulated lab-frame frequency and interrupted by largest edge “events”
- QCM seems to continue to govern edge transport at the same level as without jogs

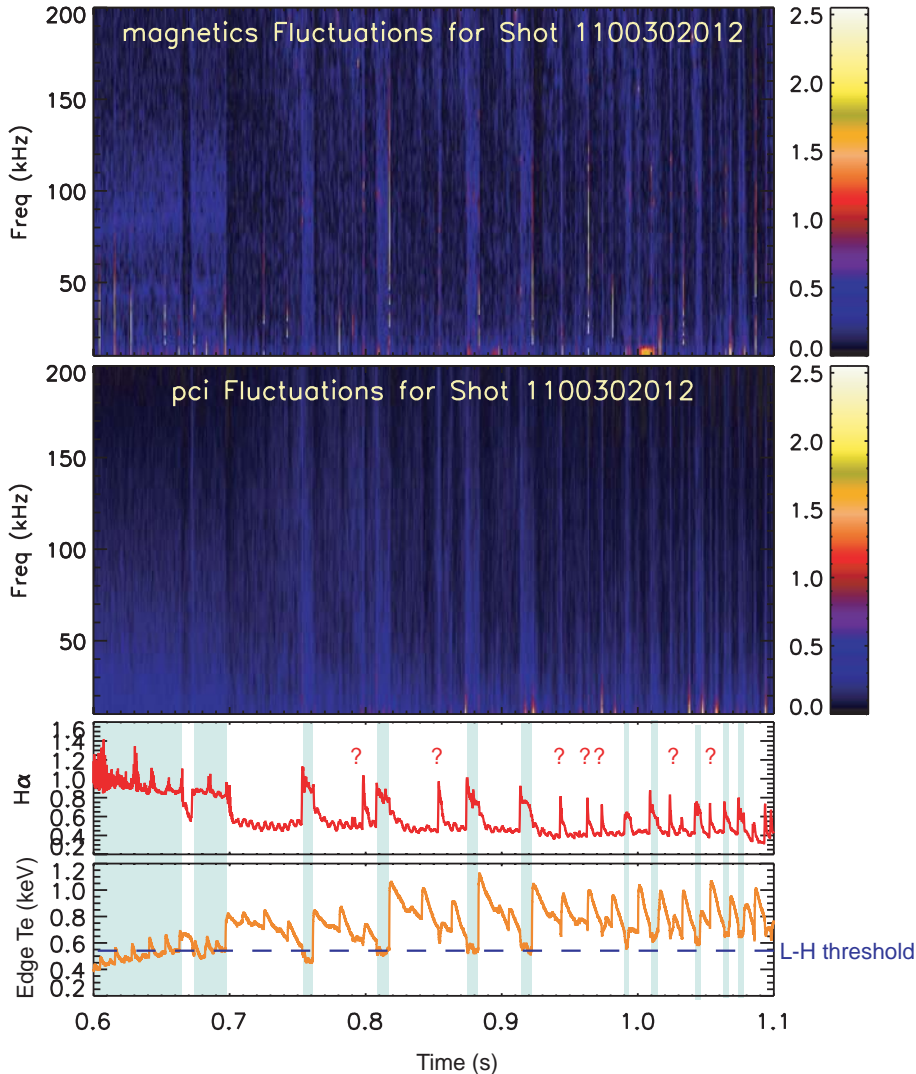
Can jogs induce ELMs in otherwise ELM-free H-modes?

- L-mode density lowered to obtain **ELM-free target**
- Z-modulation now applied starting at H-mode transition, from 0.7—1.4s
- Multiple back-transitions with gradual density reduction until ~1.0s
 - cryopump was utilized in the ELM-free case
- At lowest densities, back-transitions gradually become replaced with shorter ELM-like events



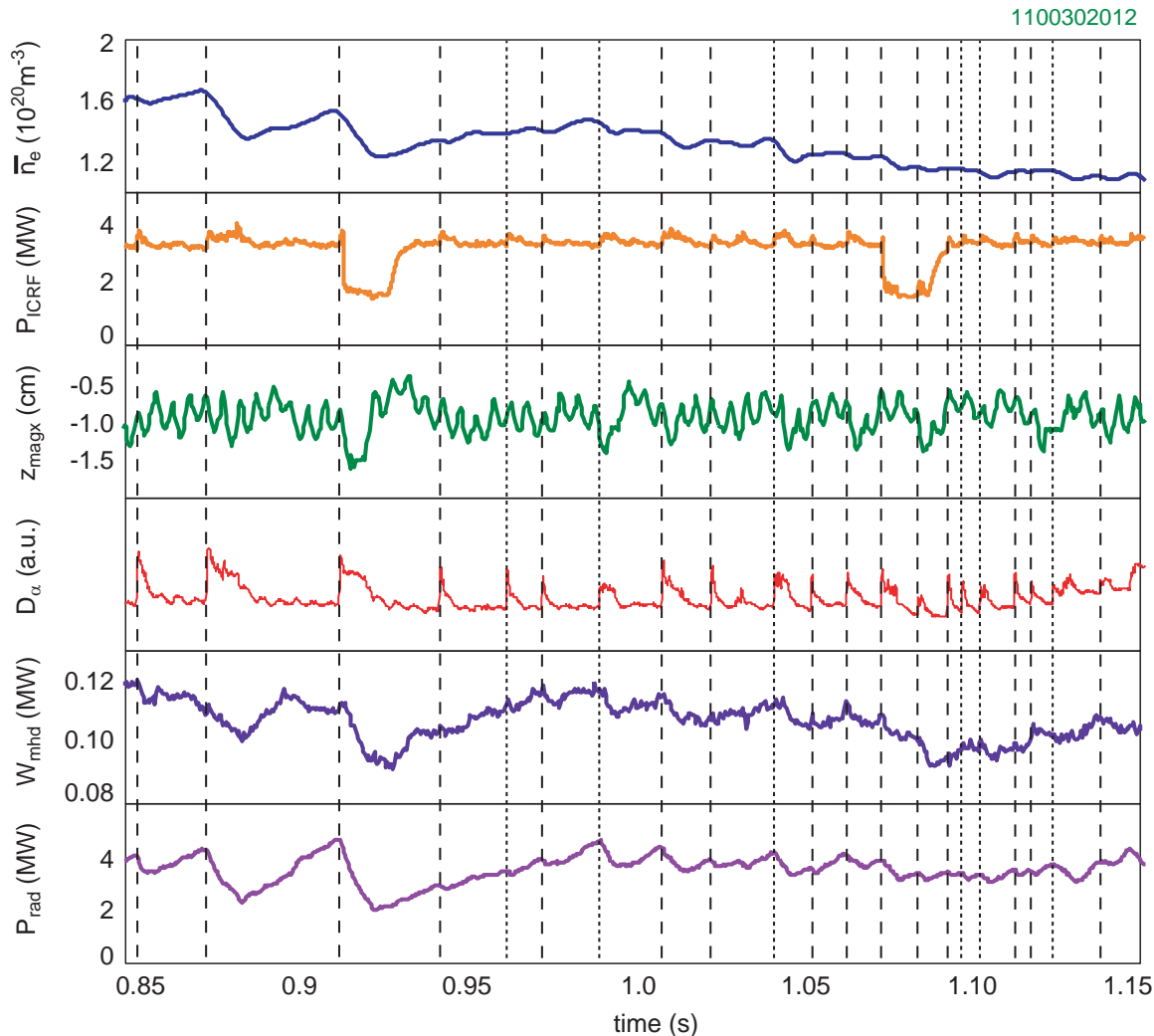
Note: L-mode P_{rad} in the ELM-free target is higher than the EDA target, due to lack of recent boronization

Edge fluctuation levels are low between events in ELM-free discharges



- **Numerous H-L back-transitions** observed early in discharge (unsurprising)
- These yield several ms periods of L-mode transport
- Also shorter events (<1ms) which are either very short L-phases or ELMs

Most relaxation events occur when **plasma z** is at or approaching local maximum



Dashed lines: events corresponding to max. z_{magx}

Dotted lines: other events

Summary of vertical jogging

- **These preliminary results represent efforts to scope out H-mode regimes where vertical jogs might produce beneficial effects**
- **EDA H-modes generally resilient to controlled vertical oscillations**
- **ELM-free discharges with cryopumping show some promise of triggering edge relaxation events, controlling impurity accumulation**
- **Future work**
 - Induce ELMs in ELM-free discharges in a well-boronized machine
 - Systematically test edge event triggering dependence on jog rate, amplitude, phase
 - Characterize pedestal profiles, equilibrium characteristics leading to ELM triggering; perform stability analysis
 - Attempt jogs to trigger/pace ELMs in I-modes