

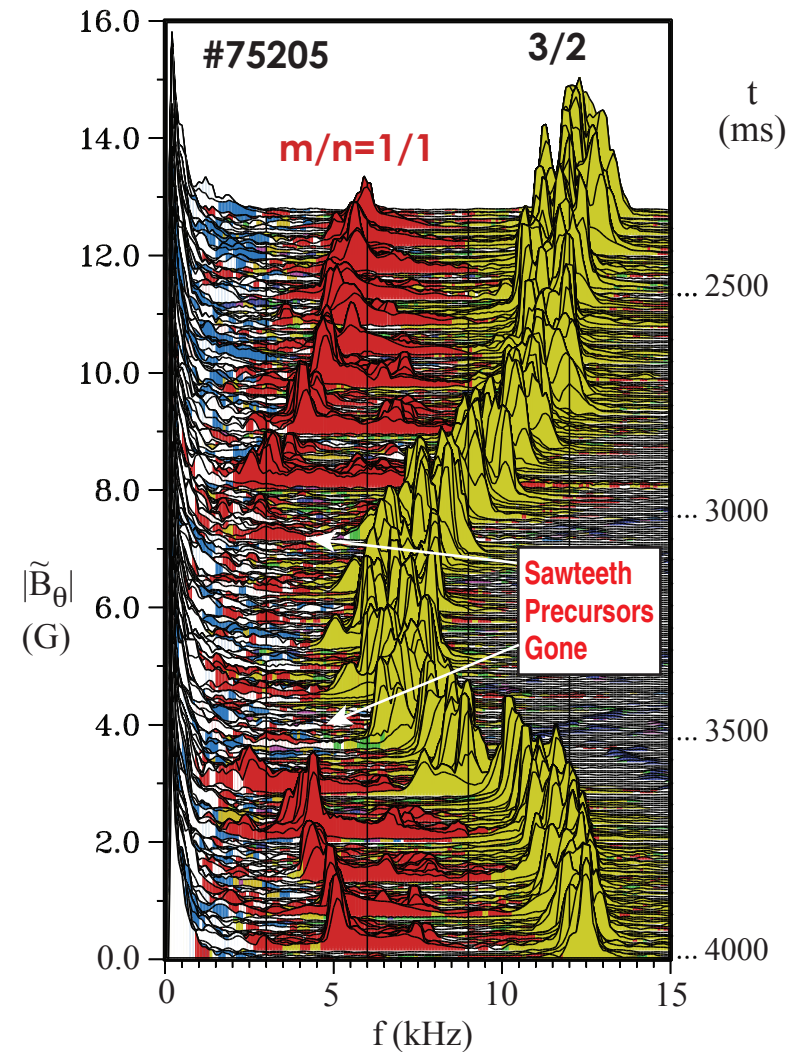
Modification of Sawteeth by Applied $m/n=1/1$ Static Magnetic Field: Revisited

by
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Stability Control

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For “US-Japan Workshop on 3D Magnetic Field Effects in MHD Control”, Passive Control of Sawteeth is here Revisited

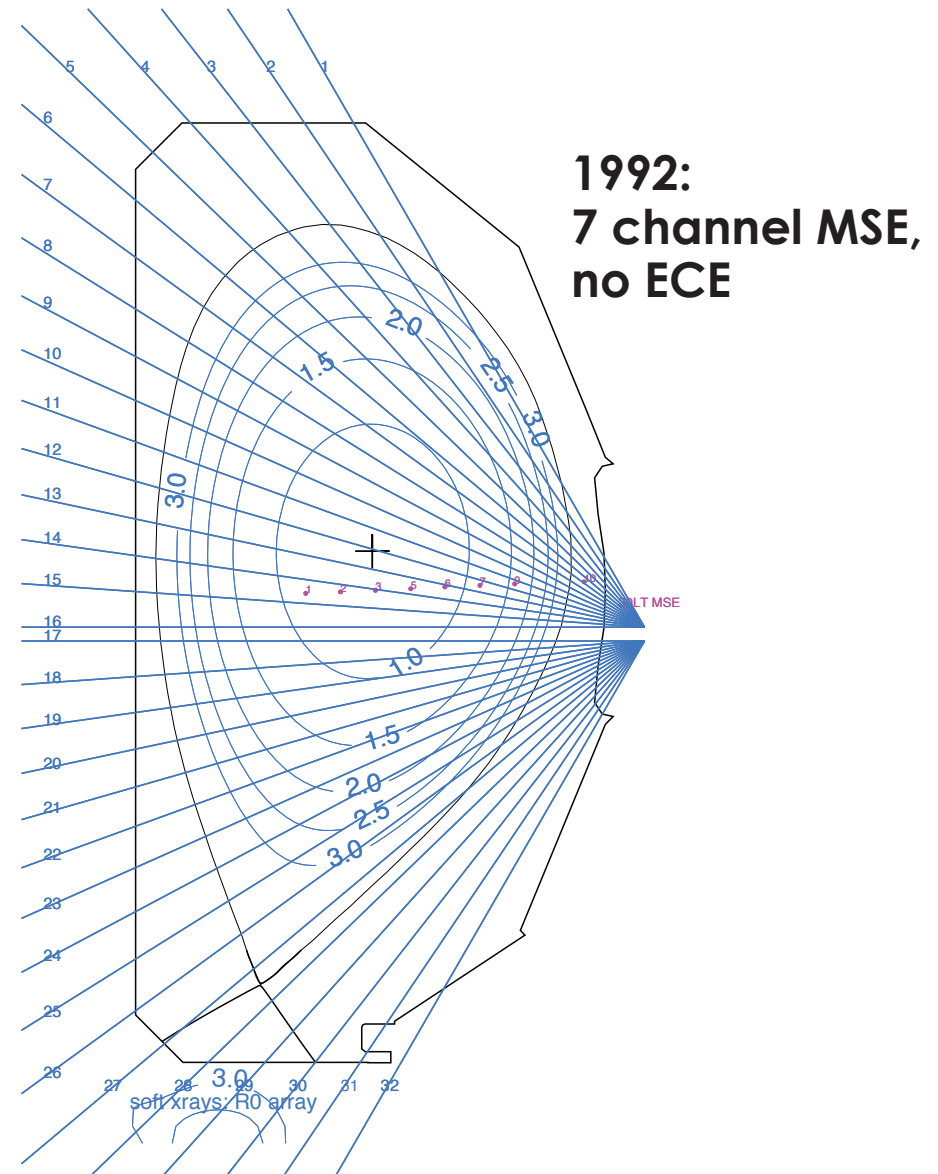
Modification of sawtooth crash behaviour during large error field experiments on DIII-D tokamak

R.T. Snider, R.J. La Haye, A.D. Turnbull and D. Wroblewski, General Atomics, Nucl. Fusion 34 483 (1994)

- From a DIII-D run day on 26 - March - 1992
- Externally applied, static, $m=1$, $n=1$ magnetic field perturbations have a strong effect on sawteeth
- $m=1$, $n=1$ **resistive** MHD internal kink mode is usual in DIII-D
 - appears to be **stabilized by resonance detuning**
 - stabilization of the **resistive** internal kink allowed the plasma to evolve further **until an ideal mode caused the sawtooth crash**
- **THIS TALK REVISITS THIS**

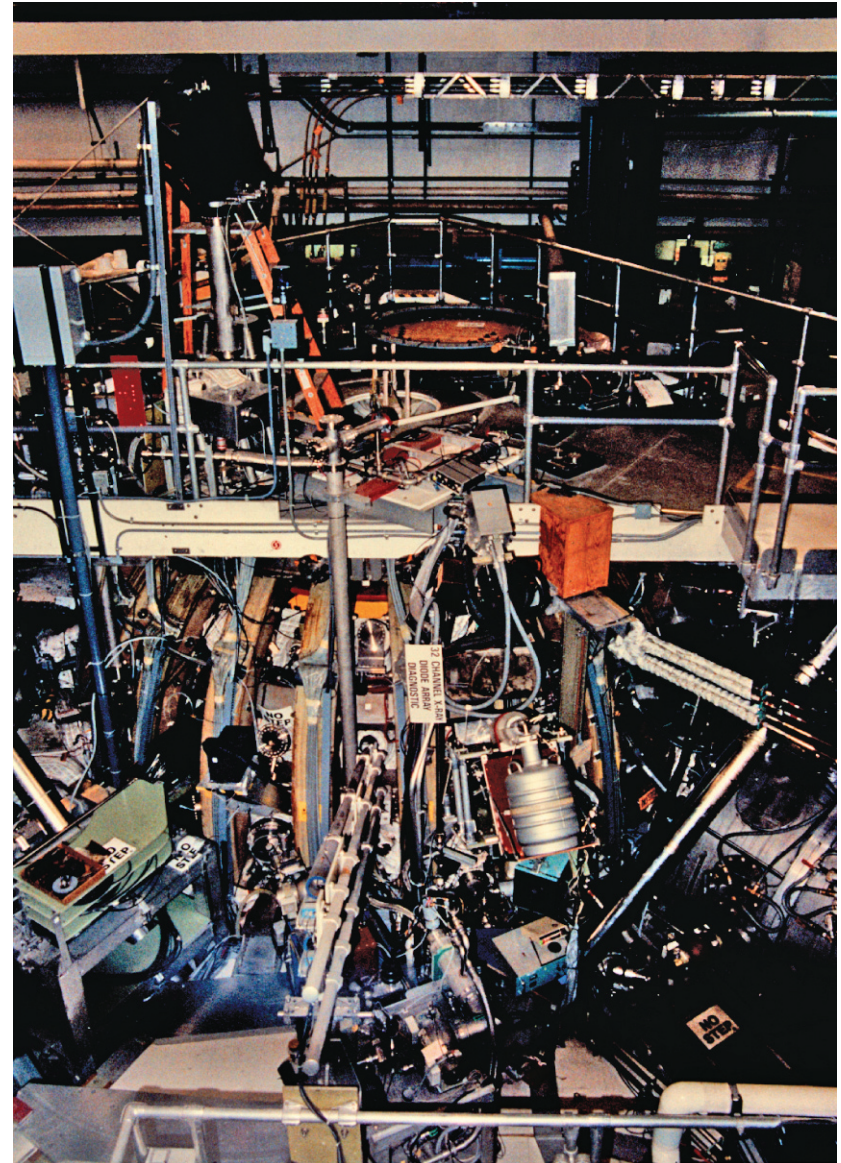
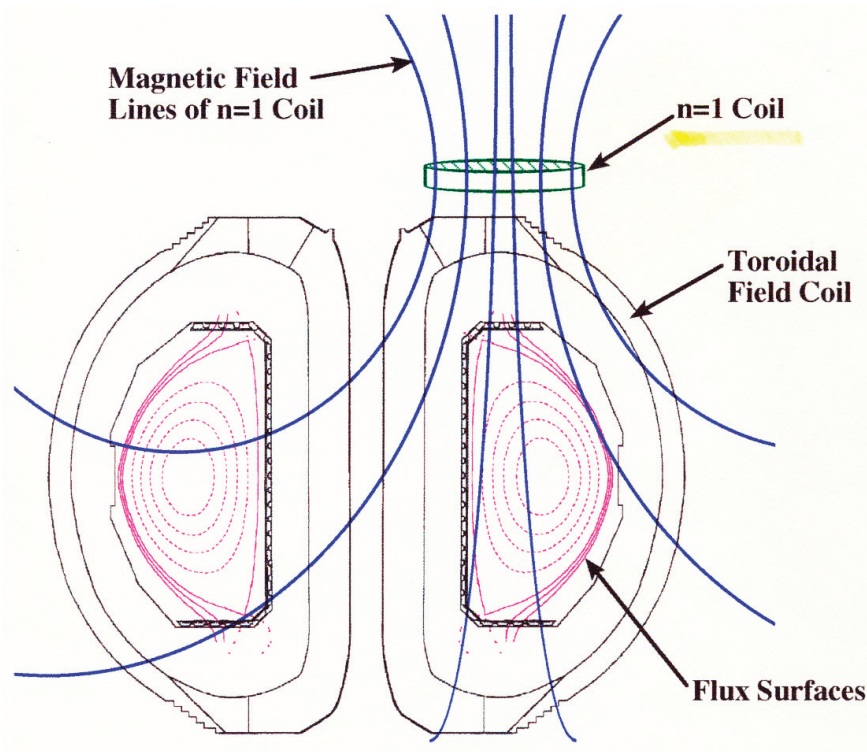
Sawteething Discharges in ELMing H-mode Examined

- Plasmas are LSND
 - ★ ELMing H-mode
 - ... **all co-NBI**
 - ★ $q_{95} \approx 3.5$, $\beta_N \approx 1.9$
 - ... $\beta_N/\beta_{N, \text{nowall}} \approx 0.5$
 - ... $m/n=3/2$ NTM present
 - ★ thus similar to basic ITER scenario (2)

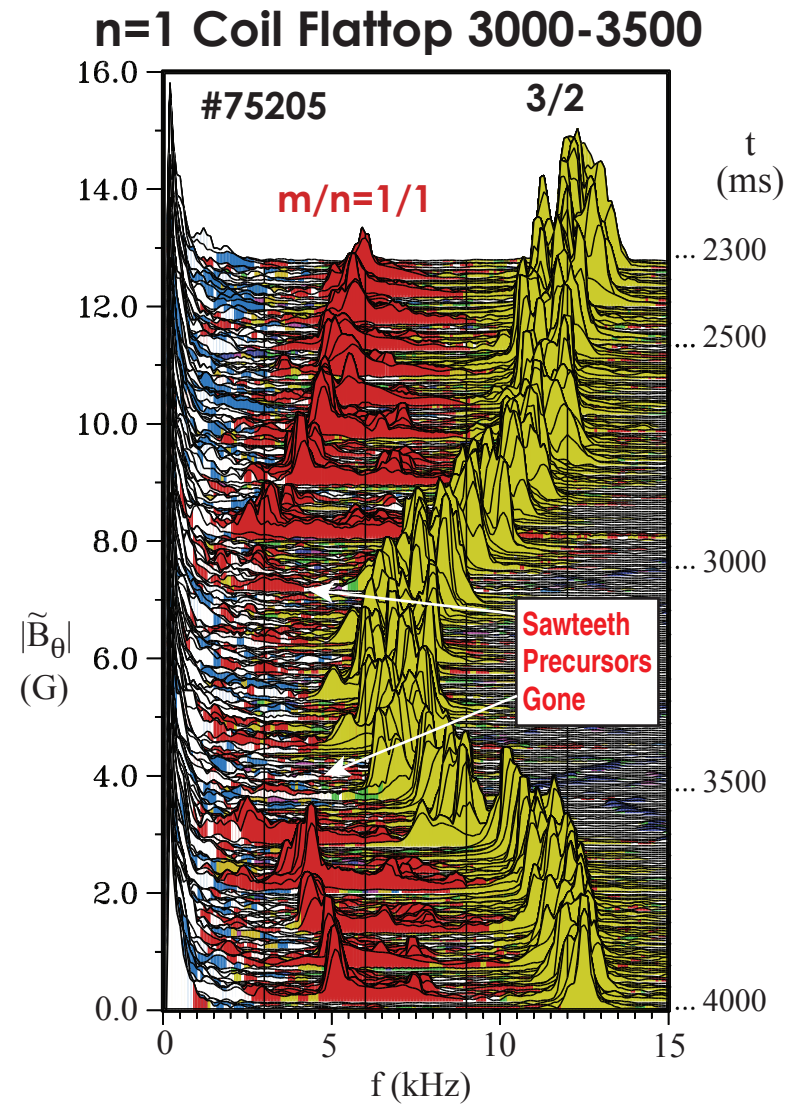
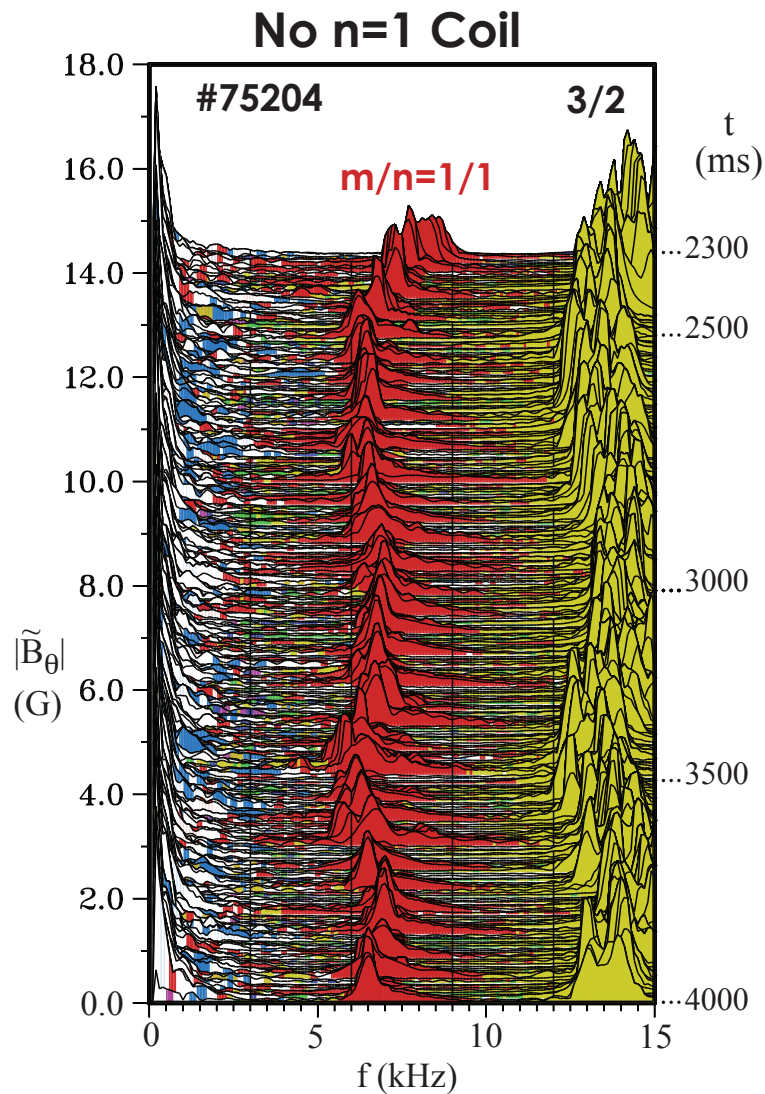


Static Resonant & Non-resonant $n=1$ Magnetic Field Applied by the “ $n=1$ Coil” in DIII-D

- Equal left and right hand helicity
 - ★ $m/n=1/1$ L & R largest modes
 - ... $B_{\perp 11,L} \approx 9G$ on axis
 - $B_{\perp 11,L}/B_{T0} \approx 7 \times 10^{-4}$

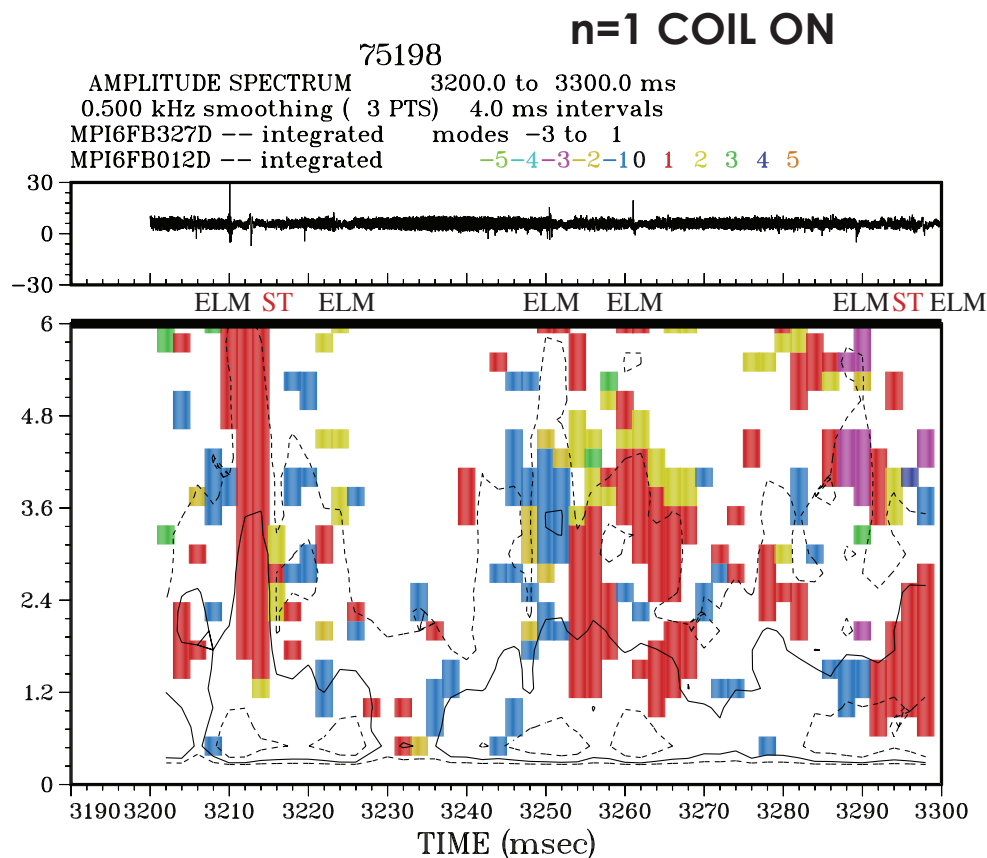
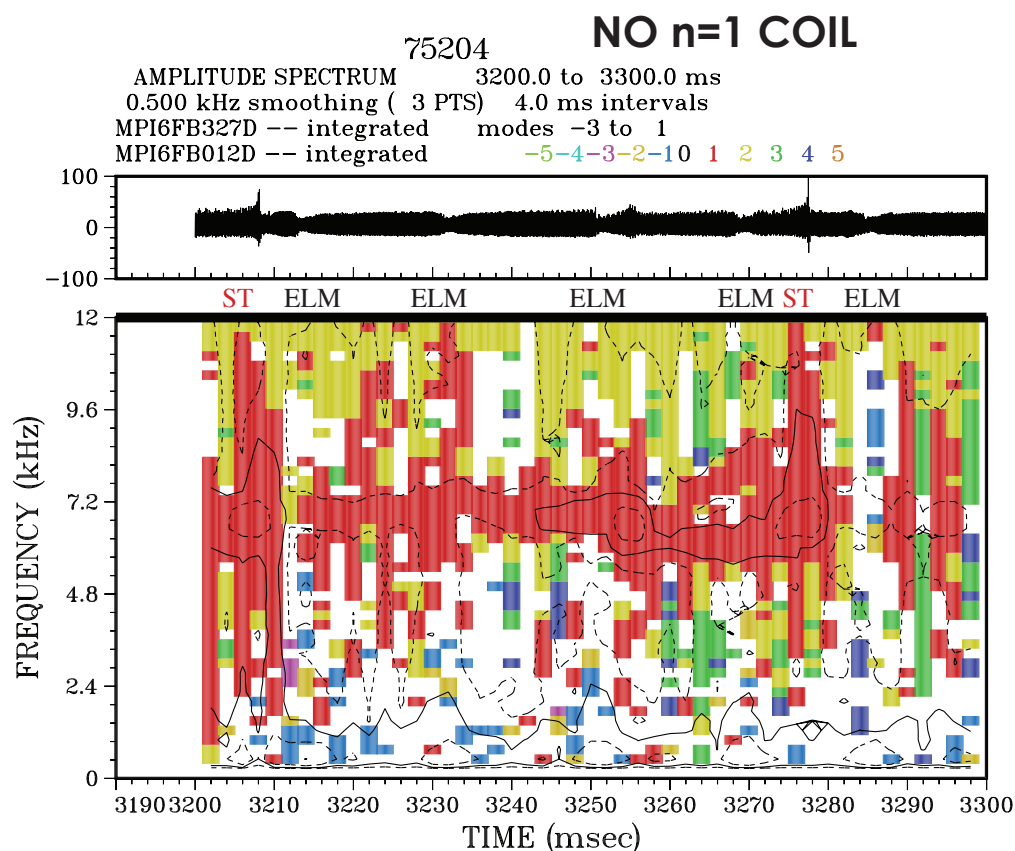


From Toroidal Mirnov Probes, $n=1$ Coil Slows Plasma Rotation AND Changes Nature of Sawteeth



Nature of Sawteeth Changed from Rotating Precursor to No Precursor

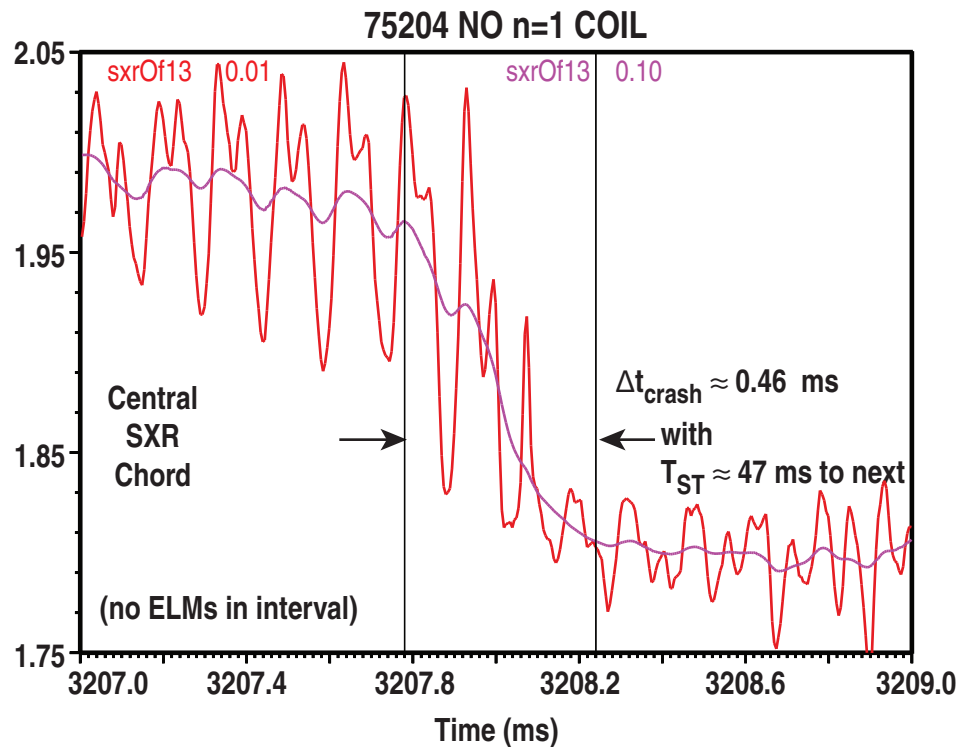
- Both plots are contours of $|\tilde{B}_\theta| = 0.03, 0.0949, 0.3, 0.949, 3.0 \text{ G}$
 - ★ same time windows
 - ... note frequency scale halved for 75198



Sawtooth Crash Changes Character from Slow to Fast

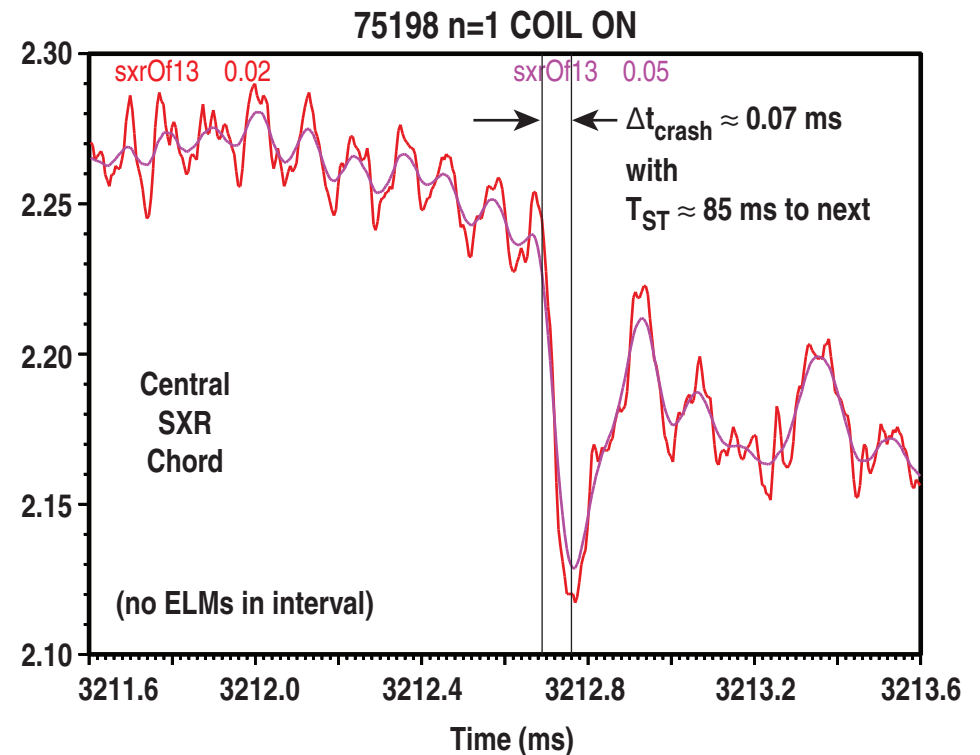
- Resistive

- ★ Large growing precursor
- ★ “Slow” crash
- ★ “Short” period



- Ideal

- ★ Large post-cursor only
- ★ “Fast” crash
- ★ “Long” period



Rapidly Oscillating the $q=1$ Radial Position Could be Producing “Jitter” Stabilization of the Resistive Sawteeth

- A. Thyagaraja, et al., Phys. Fluids B 4, 2733 (1992) proposed a “rapid” $m=0, n=0$ $q=1$ radius oscillation was stabilizing
 - ★ “resonance detuning” when jitter parameter $\lambda > \lambda_{\text{crit}}$
 - ... $\gamma/\gamma_c \approx J_0^2(\lambda) \rightarrow 0$ at $\lambda_{\text{crit}} = 2.4$ with $\lambda = (S_{11} \xi_0/r_{11})/\omega\tau_A$
 - valid when $\gamma_c \ll \omega \ll \tau_A^{-1}$
- In 1994 paper, we proposed a variant in which static driven 1/1 island makes jitter of plasma rotating past it, an “airfoil”
 - ★ let $\xi_0 \approx w_{11}/4$ with shielding of vacuum island by plasma rotation
 - ... $w_{11} = w_{11, \text{vac}}/(\omega\tau_{SP})^{1/2}$ with $w_{11, \text{vac}} \approx (16 R_0 r_{11} B_{\perp 11, L}/S_{11} B_{T0})^{1/2}$
 - ... thus $\lambda \propto S_{11}^{1/2} B_{\perp 11, L}^{1/2}/\omega^{3/2}$
 - larger at lower rotation

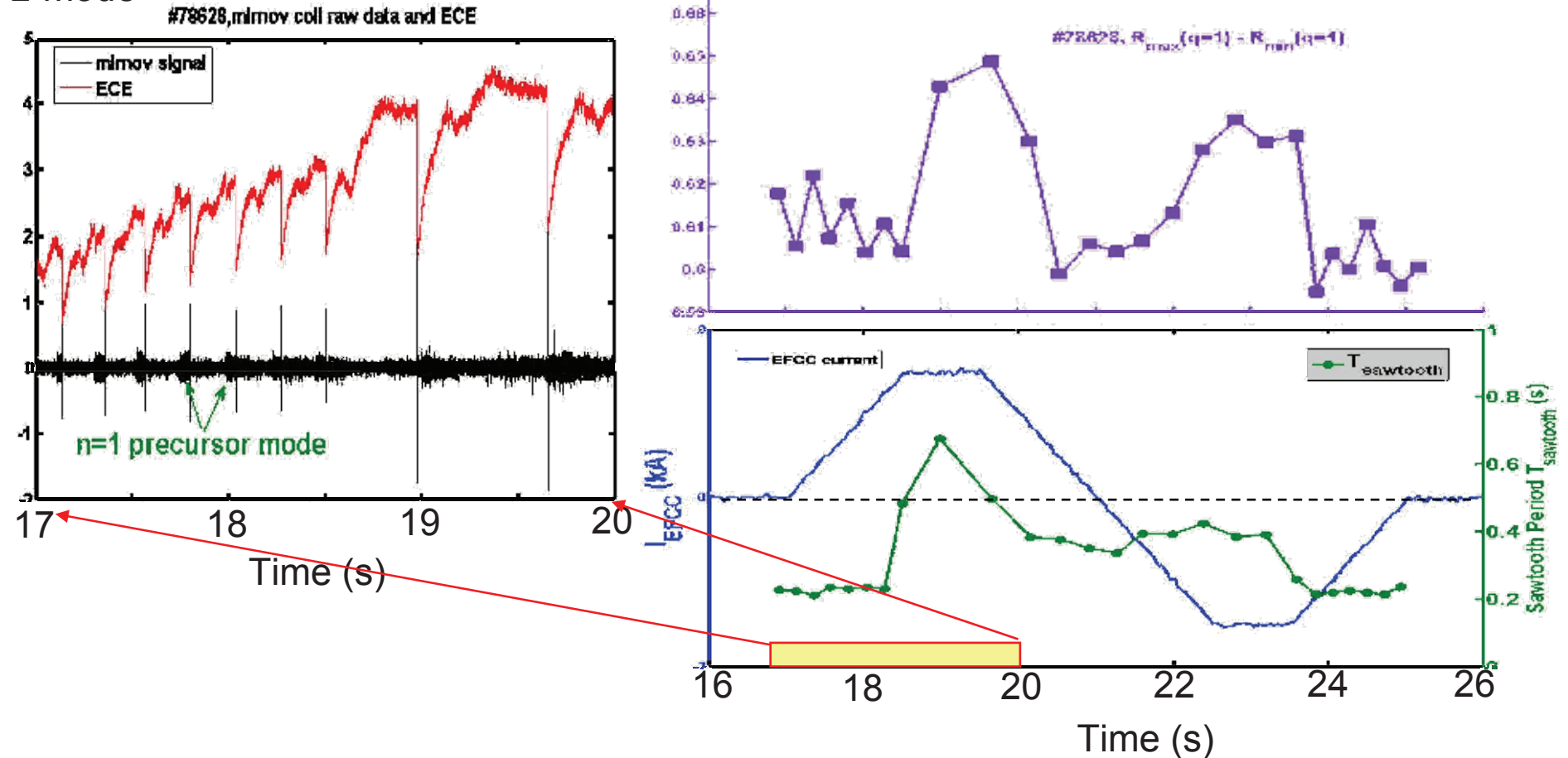
Which is Key or Even Necessary, Resonant 1/1 Field and/or Slow Core Rotation?

- In COMPASS-C (T.C. Hender 1992) applying a large 1/1 static resonant error field ($B_{\perp 11,L}/BT \sim 3 \times 10^{-3}$, 4x in DIII-D) to a rapidly rotating ohmic plasma “had no obvious effect on sawteeth”
- Kink distortion of the magnetic axis could lead to “super bananas” to “super bananas” and stability changes (S.V. Putvinskij 1993)
- JET n=2 EF exps observed similar to DIII-D change in sawteeth (Y. Liang, EFDA PSCTG General Mtg., Culham, 17-19 Mar 2010)
 - ★ no n=1 EFC: n=2 applied to control/mitigate ELMs
 - ... magnetic braking lowers rotation
 - ... sawtooth precursor weakens, crash time “not clear yet”
 - ★ n=1 applied field had similar effect on sawteeth
 - ... n=1 or 2 effects only in NBI, not in ohmic
- DIII-D experiments in 2009 examined slowly turning off n=1 EFC from I-Coil AND continuing past zero to “anti-correction”
 - ★ m=2, 3 n=1 and little m=1, n=1 in I-Coil but intrinsic 1/1 EF present
 - ★ core rotation slows by a factor of 3
 - ... resistive sawteeth stabilized



Influence of low n fields on the core MHD

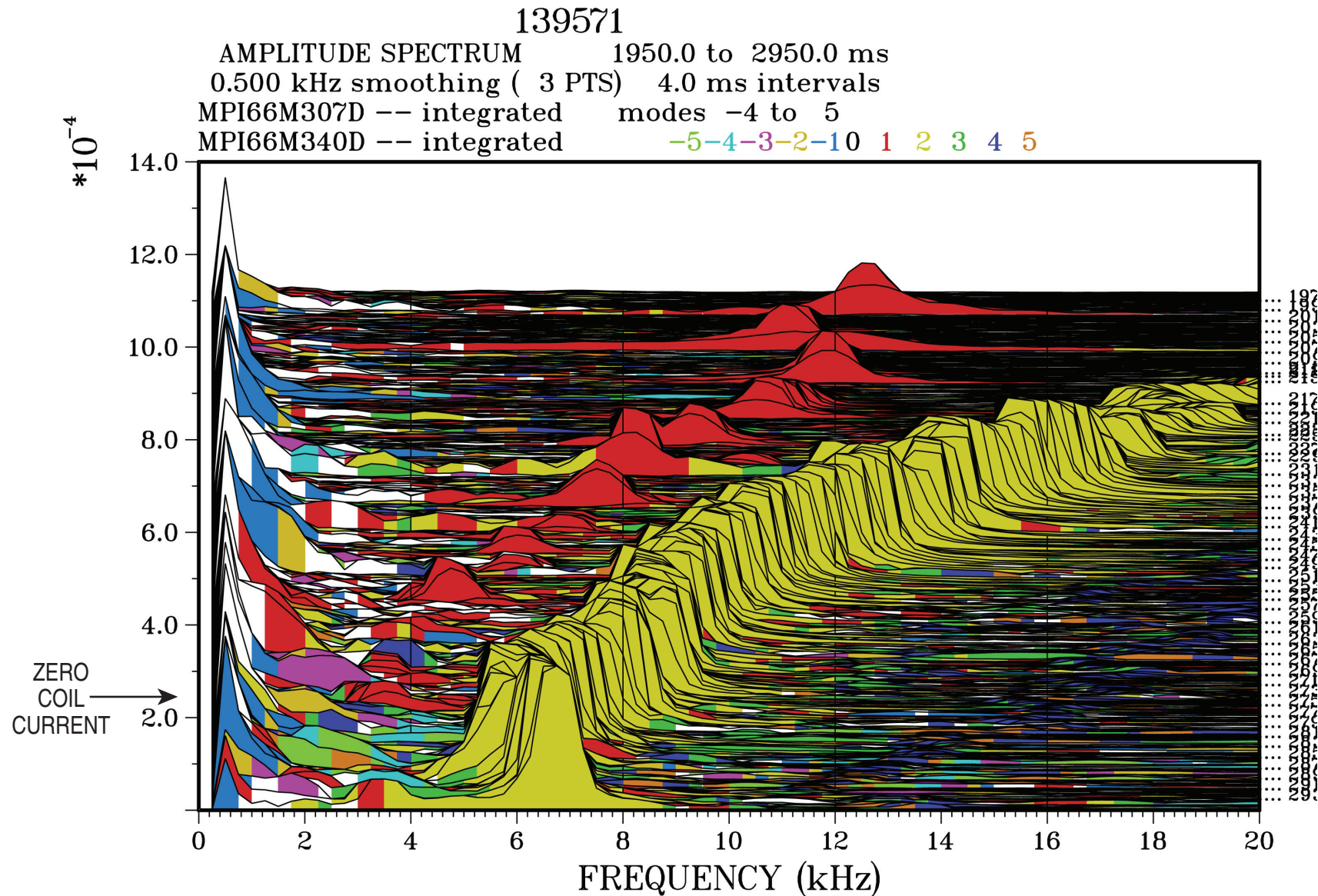
L-mode



- Increasing of the sawtooth period has been observed during application of $n = 2$ field.
- broaden of the $q = 1$ surface

➤ Similarly, the amplitude of the $n = 1$ precursor mode decreases.

I-Coil n=1 EFC Slowly Removed and Swept to Anti-Correction



Conclusions on Passive Control of Sawteeth by 3D Field in DIII-D

- DIII-D observed that static applied $m=1$, $n=1$ field:
(1) Slowed plasma rotation and (2) changed (stabilized) resistive sawteeth into ideal sawteeth (destabilized)
 - ★ consistent with jitter stabilization at low plasma rotation
 - ★ issue is how could one also stabilize ideal sawteeth?
 - ... induce “permanent” kink distortion of magnetic axis?
 - ... counter ECCD on axis to keep $q(0)$ up?
 - $q(0)=0.95$ resistive, ≈ 0.91 ideal, before crash
- In 1992, DIII-D had only co-NBI and no ECCD
 - ★ with counter-NBI now available, the rotation can be independently controlled for study
 - ★ C-Coil also has largest field 1/1
 - ★ real-time steerable ECCD for 2011