Prevention of the 2/1 Neoclassical Tearing Mode in DIII–D

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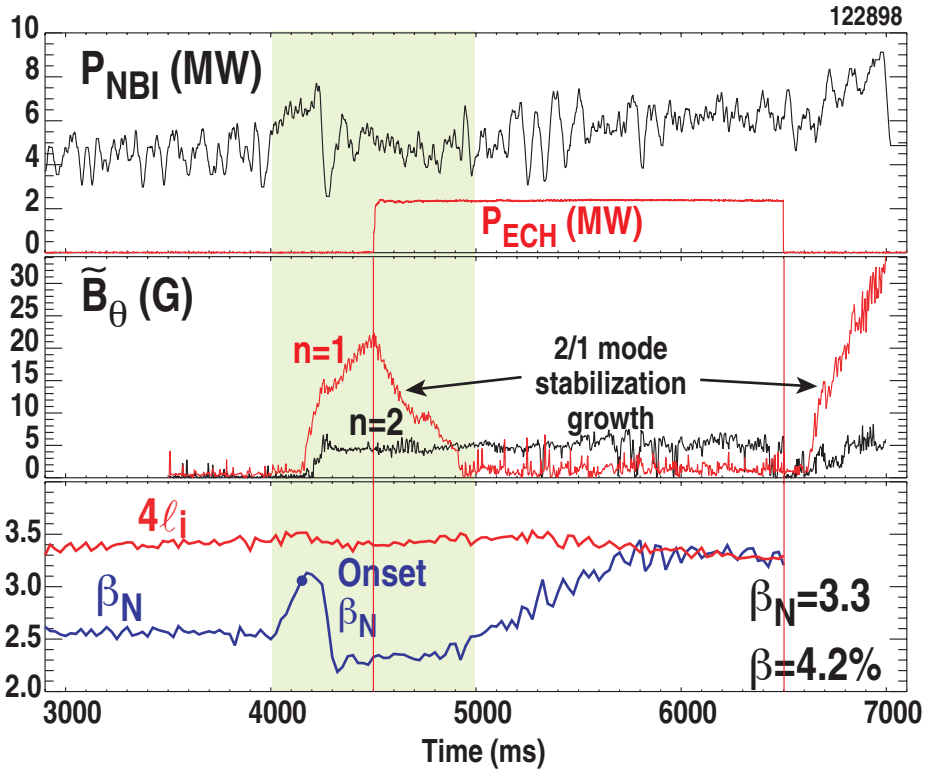
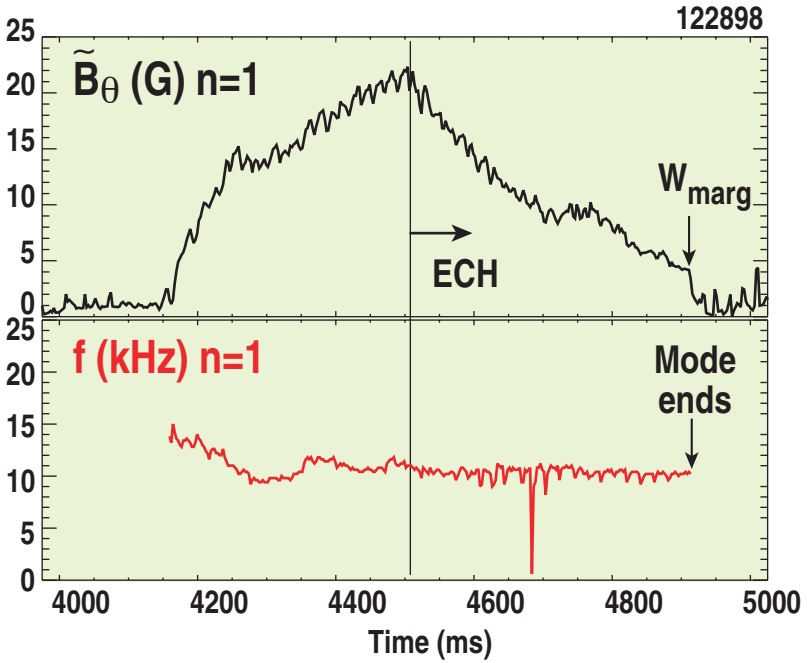
Prevention of the 2/1 NTM by Pre-emptive Application of ECCD has Provided Stable Operation at the No-wall n=1 Kink Mode β Limit (β_N = 3.2)

- Prevention is obtained by application of highly localized Electron Cyclotron Current Drive (ECCD) at the q=2 surface
- In the absence of an island, feedback of the ECCD location is used to track the q=2 surface determined from real-time reconstructions of the equilibrium
- The power needed to avoid the 2/1 NTM is well predicted by theory
- This work builds on previous work on stabilizing pre-existing islands

Stabilization of Pre-existing 2/1 NTM by ECCD Allows Operation at Higher β_N in High Performance Discharges



- Stable operation at the no-wall β limit
- Stringent requirements on location and magnitude of ECCD



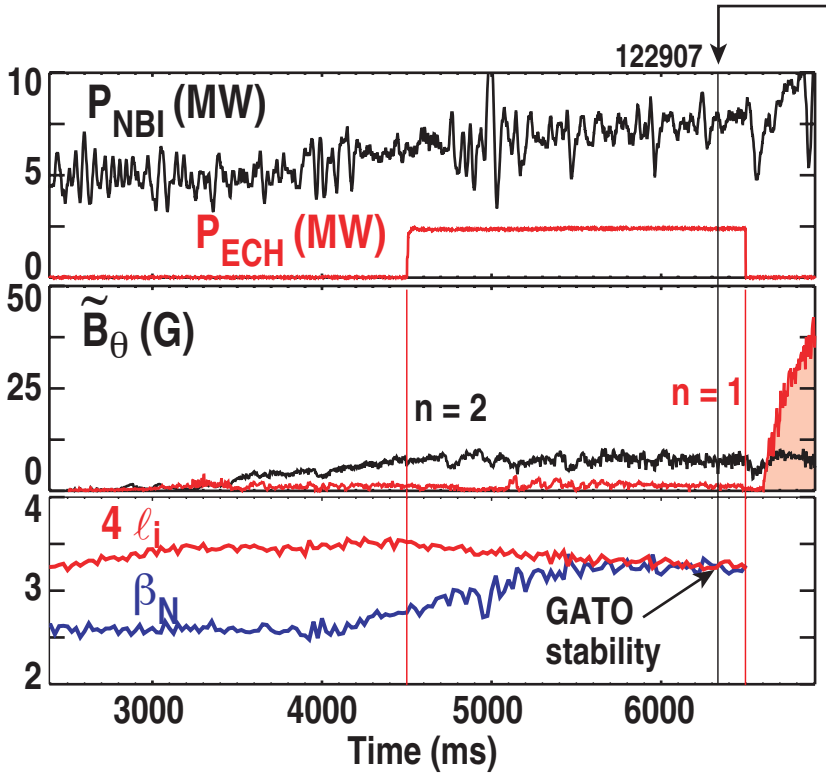
- Mode rotation is maintained during stabilization process

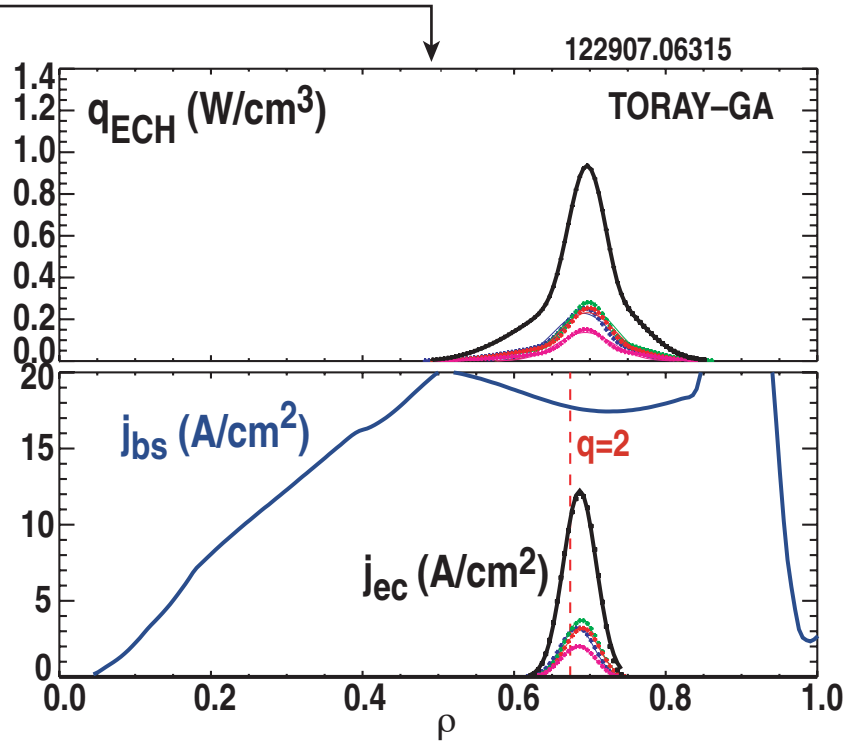
This process of reducing β after mode onset to avoid locking while the ECCD acts is not so suitable for ITER...

Prevention of 2/1 NTM is Safer Than Stabilization of a Grown Island

- **In the low rotation ITER, a 2/1 island will lock when w = a/40, leading to severe loss of confinement and possibly to disruption**
  [La Haye, EX/P8-12]
  - Raises issues about detectability and time response if locking is to be avoided
- **Reduces physics uncertainties**
  - Broadening of ECCD profile by islands
  - Coupling to other modes (e.g., harmonic component of 2/1 is 4/2, which can couple to 3/2)
  - Nonlinear effects on classical tearing stability
- **First results on NTM avoidance were obained for 3/2 mode on JT-60U** [Nagasaki, NF, 2003] **and DIII–D** [Prater, NF, 2003]

Preventing 2/1 NTM by Pre-emptive ECCD Allows Stable Operation at the No-wall Stability Limit

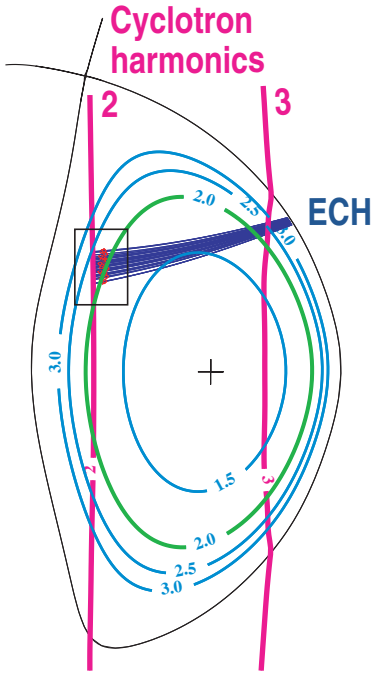


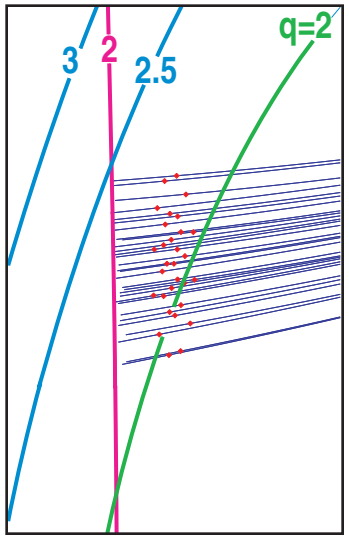


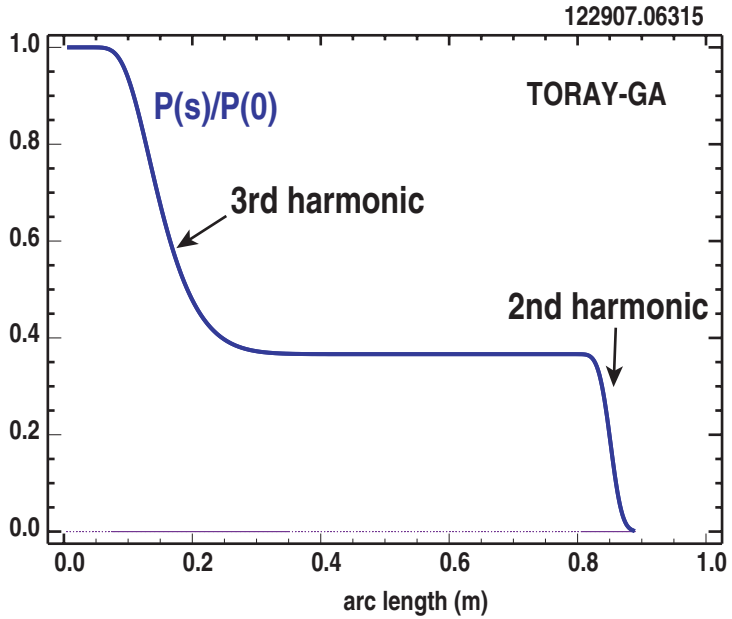
- β_N is raised smoothly to the no-wall stability limit

- ECCD focussed at q=2 surface
- j_{ec}/j_{bs} ~70%

Geometry Chosen to Optimize Control of ECCD Location by Changes in B_T







f_{EC} = 110 GHz

B_T = –1.5 T

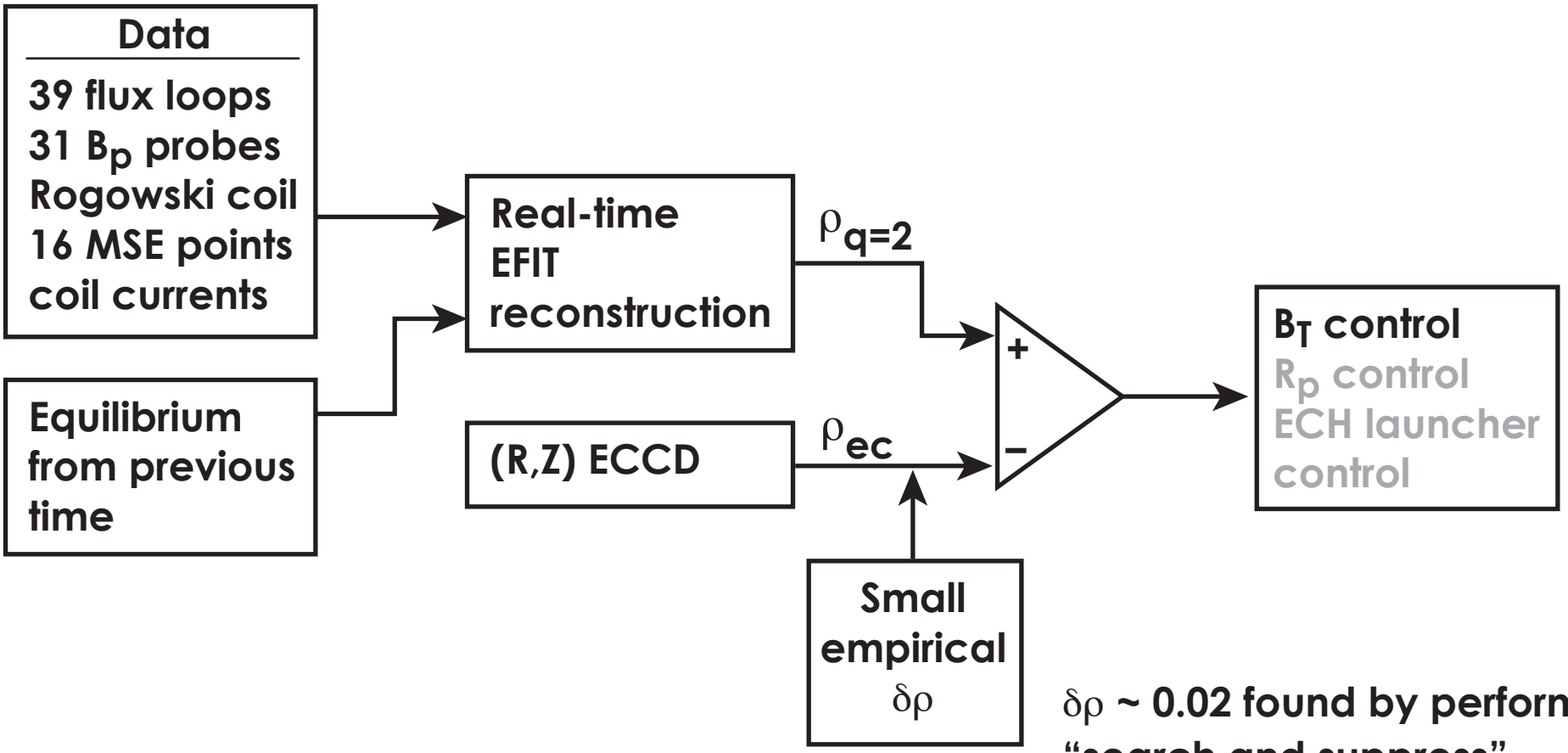
H-mode

Hybrid discharge

Non-sawtoothing

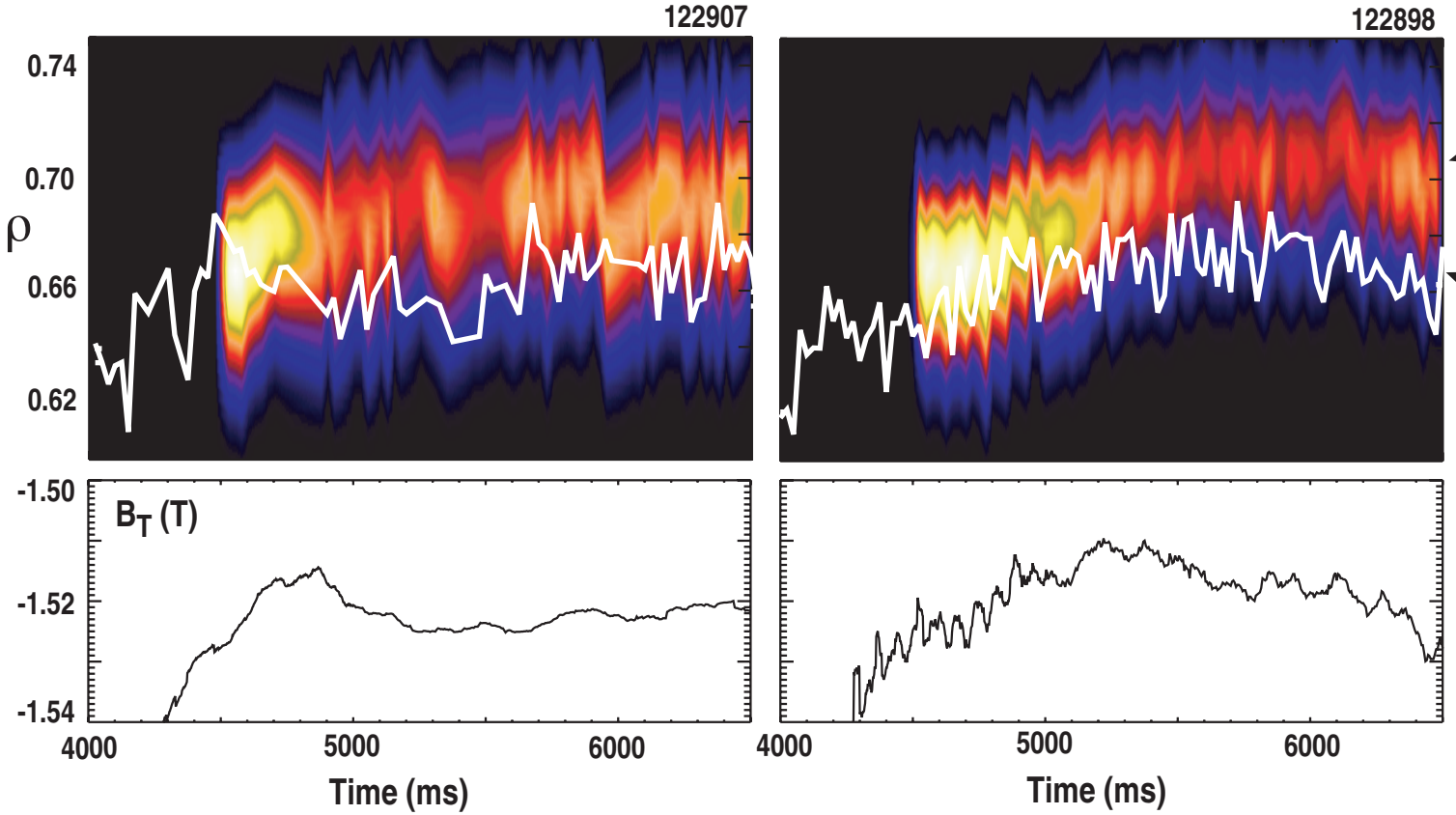
- Rays deposit power near intersection of q=2 and 2nd harmonic resonance
- Changing B_T shifts radial location of ECCD
- Ray absorption at the third harmonic limits how far B_T can be reduced

Real-time EFIT Reconstructions Are Used to Keep ECCD on the q=2 Surface in Absence of Islands



$\delta\rho$ ~ 0.02 found by performing "search and suppress" with ECCD on a similar discharge which has islands

Plasma Control System with Real-time EFITs Adequately Follows Movement of q=2 Surface



J_{ec} Needed to Avoid the 2/1 NTM can be Understood from a Physical Model

Modified Rutherford equation governs the physics:

$$\frac{\tau_R}{r}\frac{dw}{dt} = r\Delta'_0 + r\delta\Delta' + a_2 \frac{j_{bs}}{j_{||}} \frac{L_q}{w}\left[1 - \frac{w_{marg}^2}{3\,w^2} - K_1\left(\frac{w}{\delta_{EC}}, \frac{\Delta R}{\delta_{EC}}\right)\frac{j_{ec}}{j_{bs}}\right]$$

- Classical linear stability
- Effect of ECCD on Δ'
- Stability at small island size
- Effect of ECCD on island

$r\Delta'_0 \approx -m = -2.0$

$w_{marg} \approx 2\,\varepsilon^{1/2}\,\rho_{\theta i}$ **from experiments on** β **ramp-down and ECCD suppression** [La Haye et al., NF 2006]

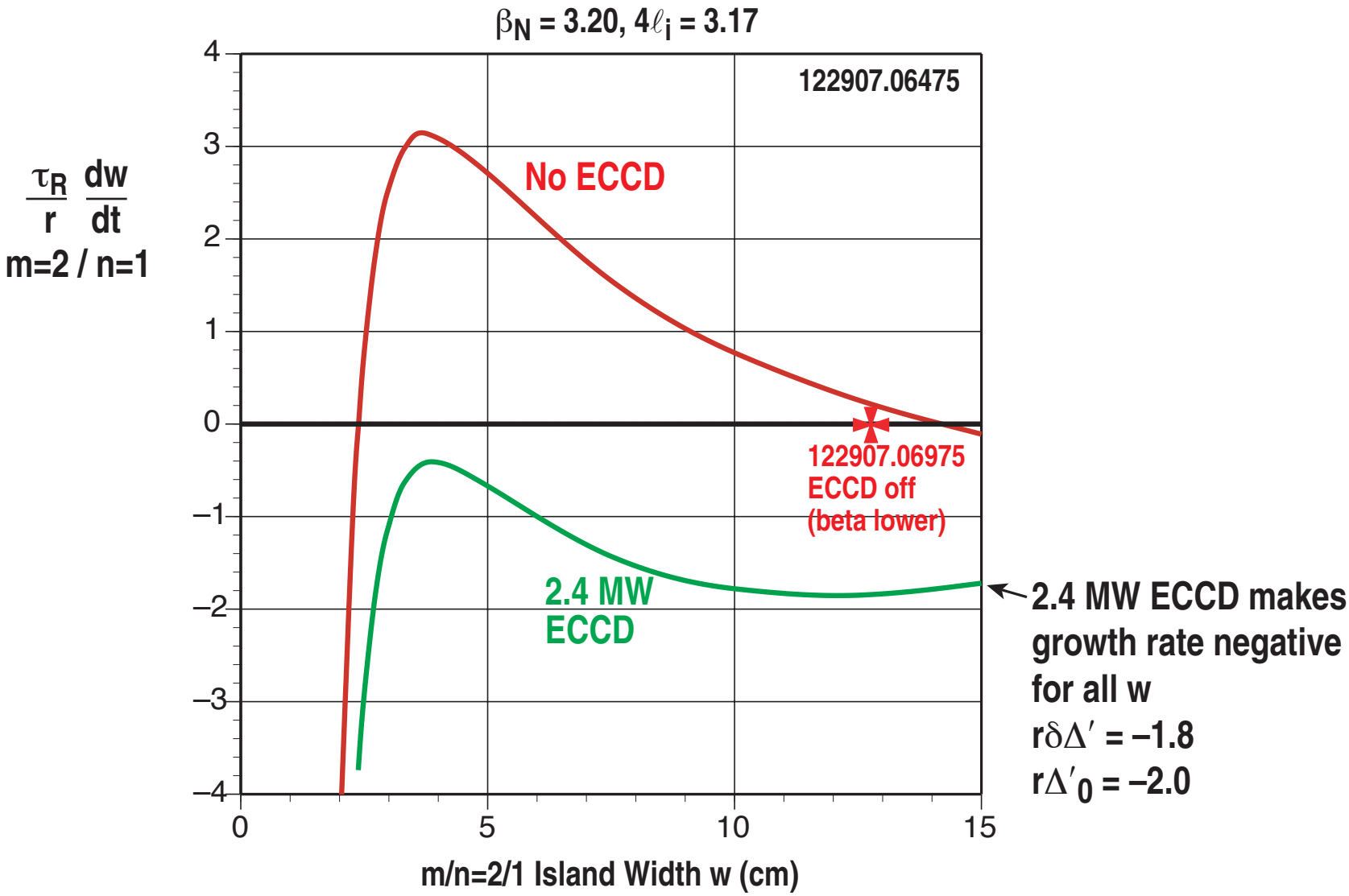
a_2 **~ 4 fitted from size of saturated island**

$r\delta\Delta'$ **from Westerhof model** [Westerhof, 1990]

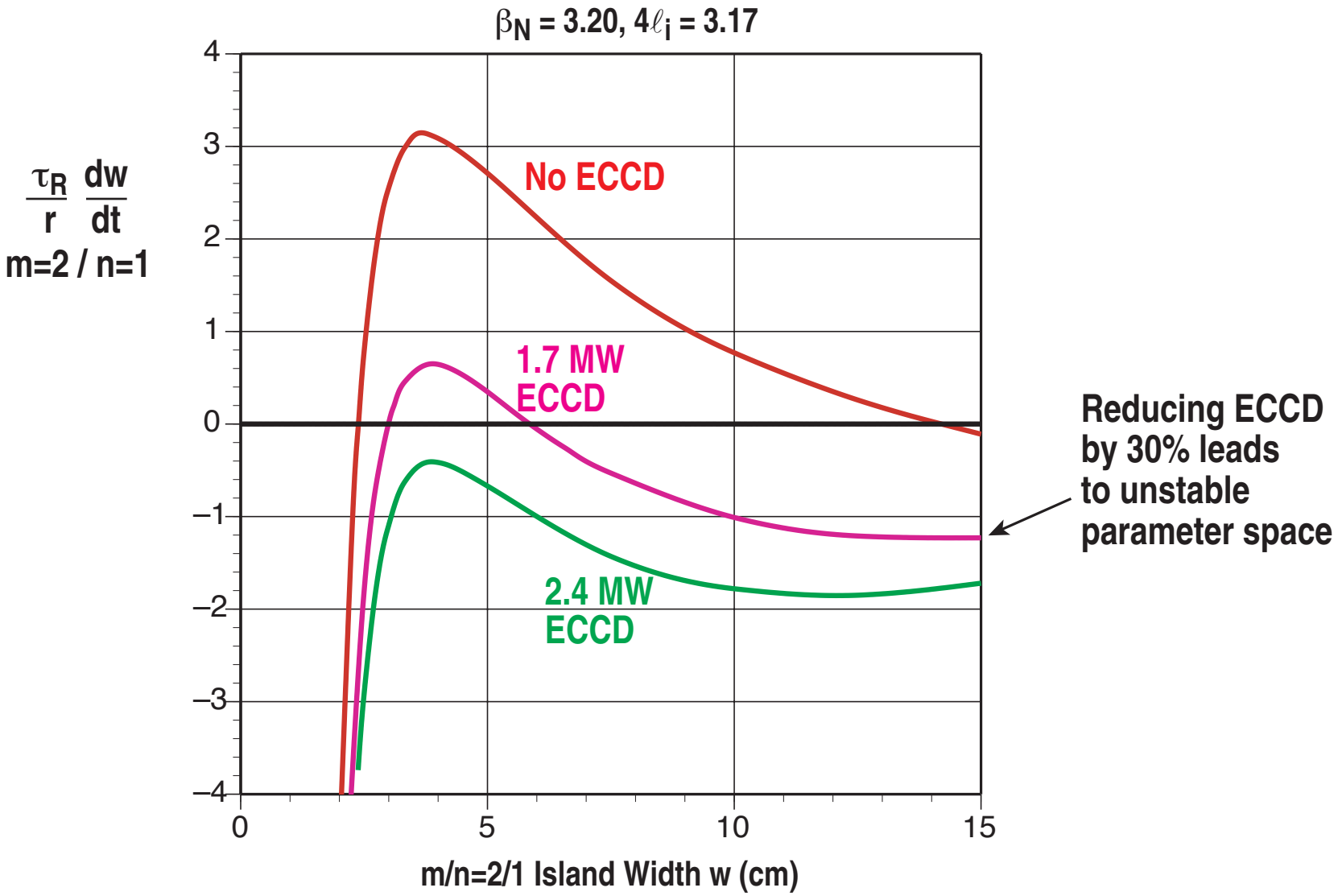
K_1 **from Perkins model**

ΔR **estimated at 1 cm**

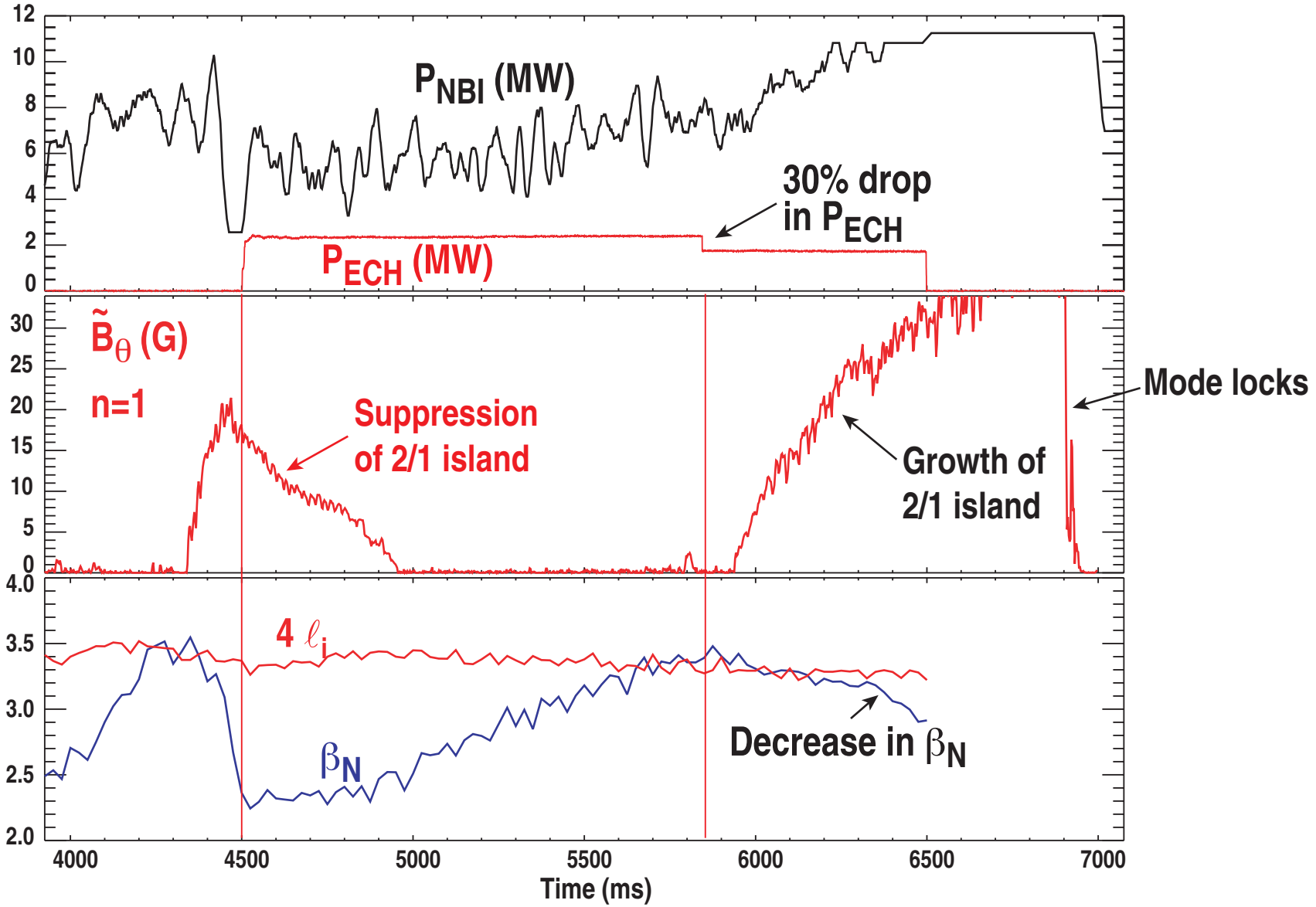
Modeling Shows That 2.4 MW of ECCD Power Eliminates Instability



Modeling Shows That Reduction of ECCD Power to 1.7 MW Introduces a Range of Instability



Reduction of EC Power by 30% Allows Island to Grow, in Agreement with Model



Conclusions

- **ECCD at q=2 surface allows β_N as large as 4 ℓ_i, the n=1 ideal kink-mode limit, without the 2/1 NTM**
- **Real-time EFIT reconstructions are adequate for keeping the ECCD on the $\rho_{q=2}$ target**
- **The 2/1 island grows when the power is reduced below the threshold found from the modeling using the modified Rutherford equation**
- **Future plans:**
  - Raise β_N above n=1 no-wall stability limit
  - Use launch angle control for position feedback of ECCD
  - Test improved performance in stabilizing pre-existing islands using modulated ECCD