The Resistive Wall Mode and Beta Limits in NSTX

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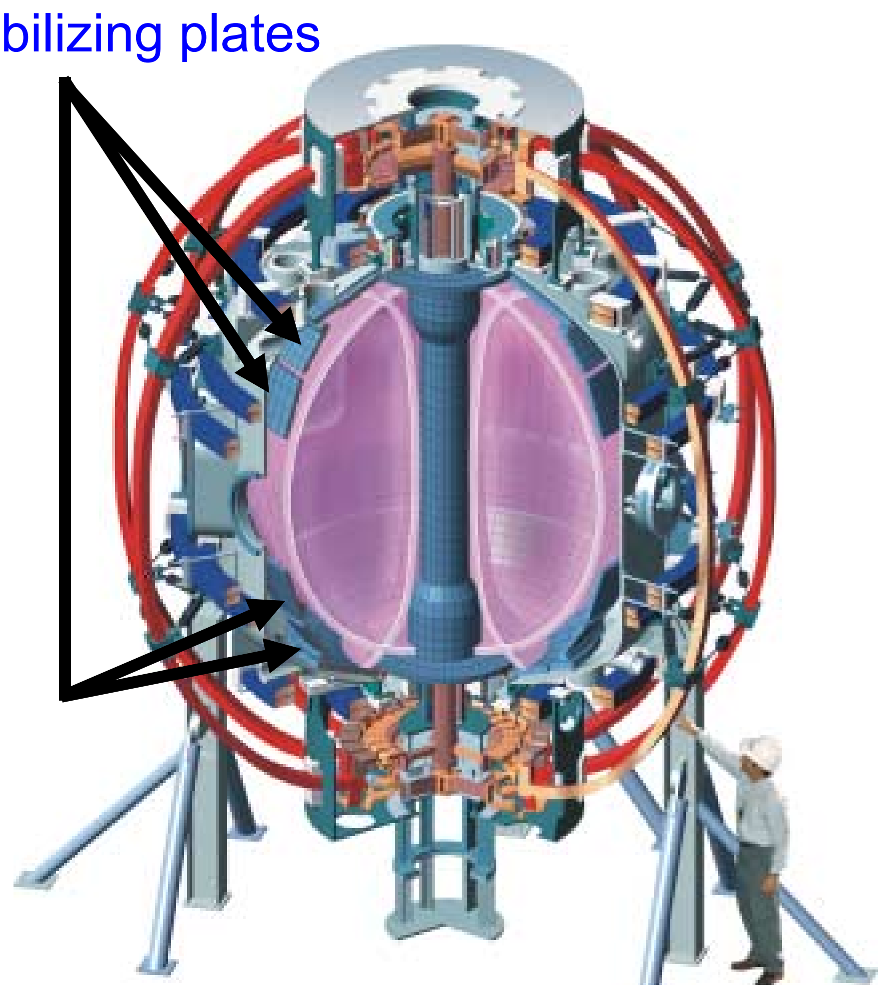
NSTX

NSTX is operating at sufficiently high beta to study passive wall stabilization

- Operation in wall-stabilized, high beta regime
- Resistive wall mode (RWM) and rotation damping
- Physical mechanisms for higher β_N and longer pulse

NSTX is equipped to study passive stabilization



Machine

Aspect ratio	≥ 1.27
Elongation	≤ 2.5
Triangularity	≤ 0.8
Plasma Current	≤ 1.5 MA
Toroidal Field	≤ 0.6 T
NBI	≤ 7 MW

Analysis

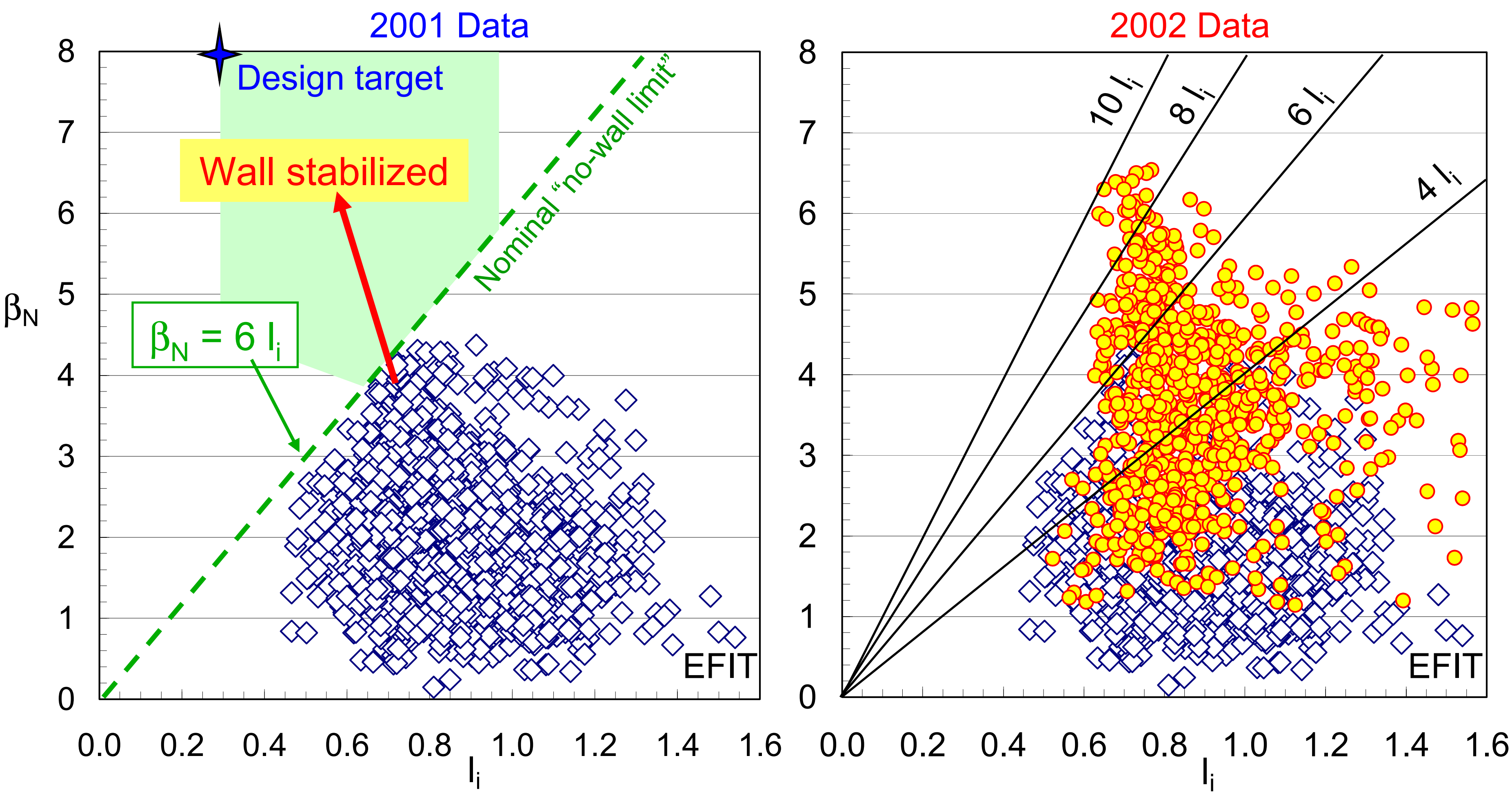
EFIT – equilibrium reconstruction

DCON – ideal MHD stability

(control room analysis)

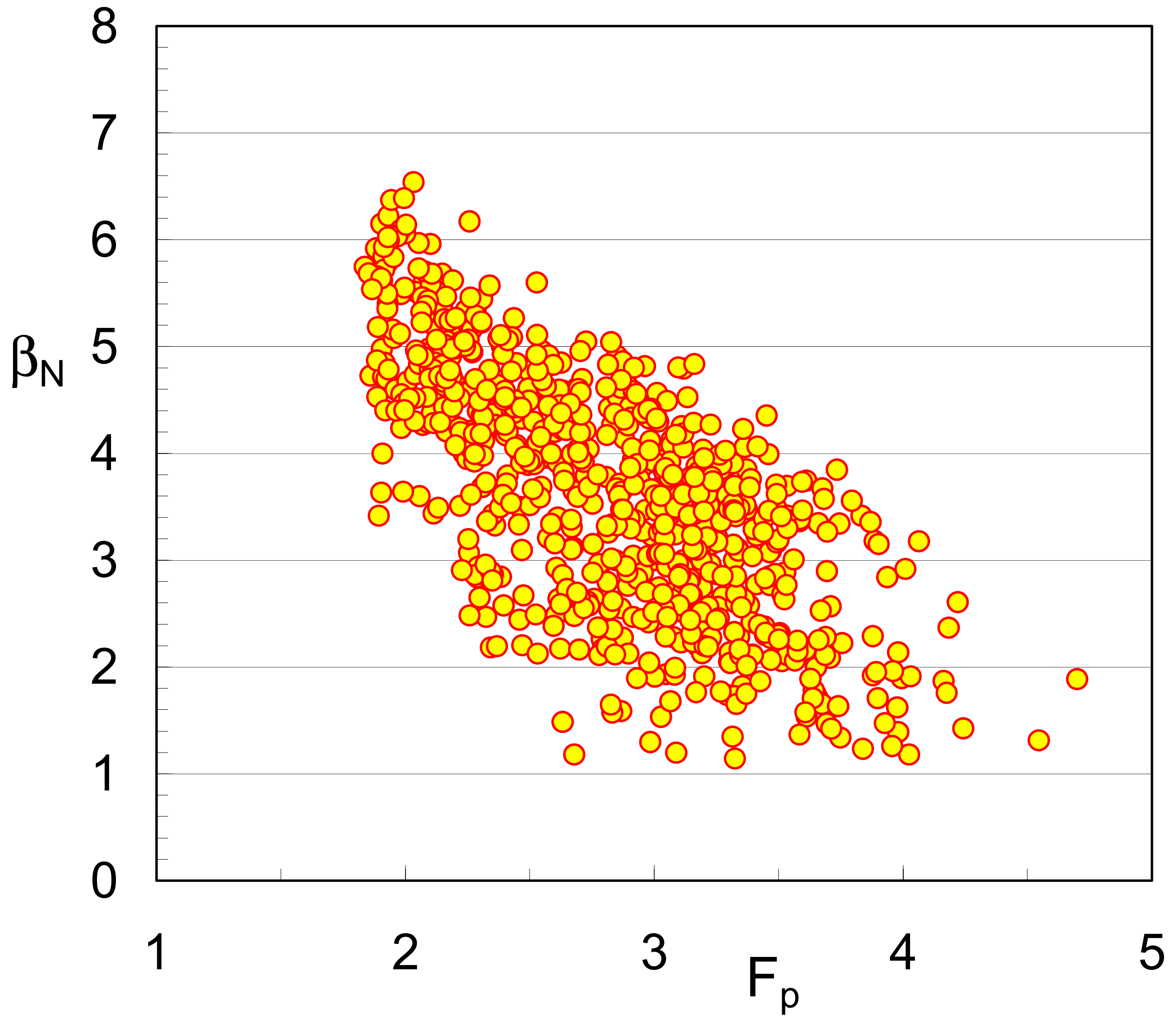
VALEN – RWM growth rate

Plasma operation now in wall-stabilized space



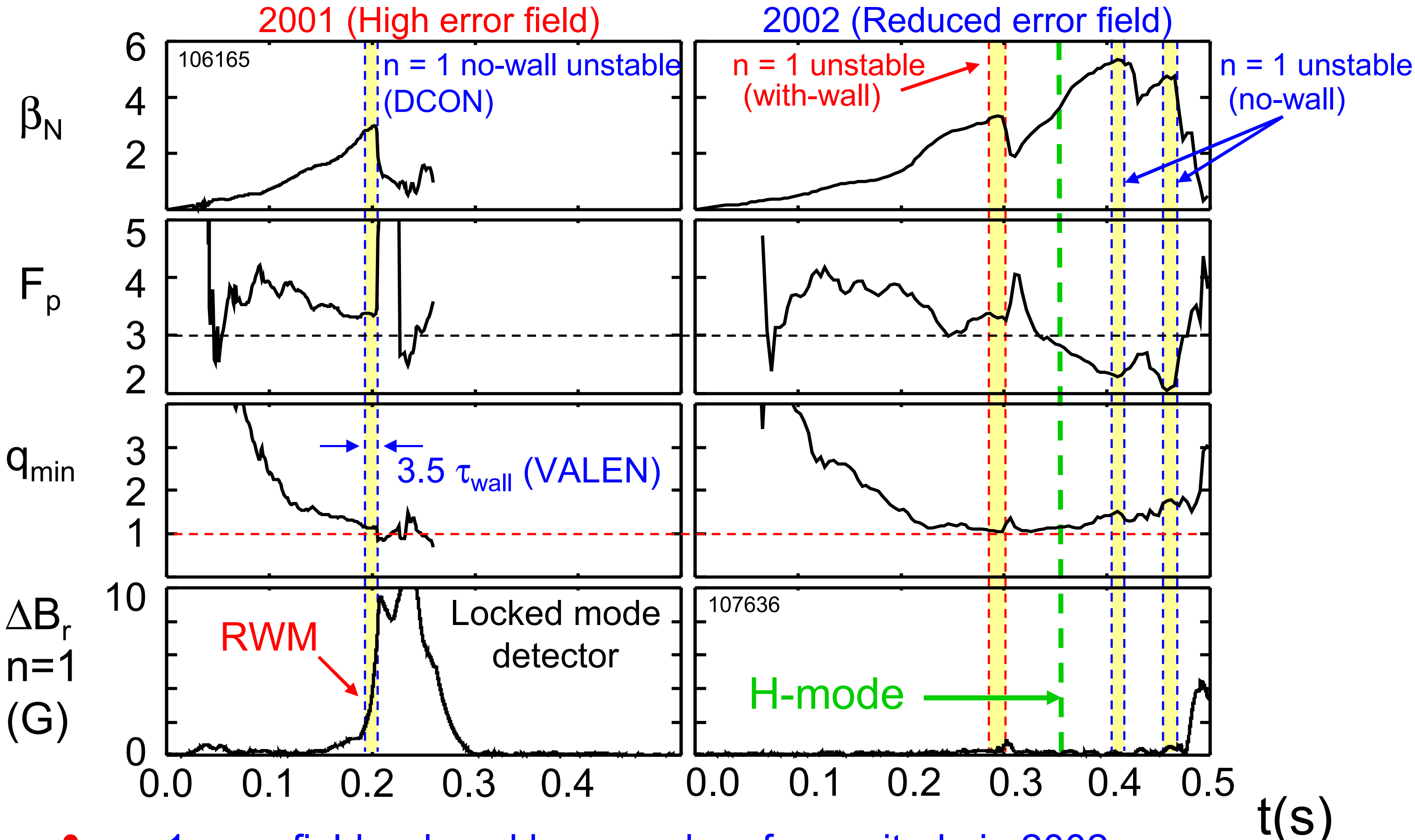
- Normalized beta, β_N = 6.5, with β_N/l_i = 9.5; β_N up to 35% over $\beta_{N\ \text{no-wall}}$
- Toroidal beta has reached 35% ($\beta_t = 2\mu_0\langle p\rangle / B_0^2$)

Maximum β_N strongly depends on pressure peaking



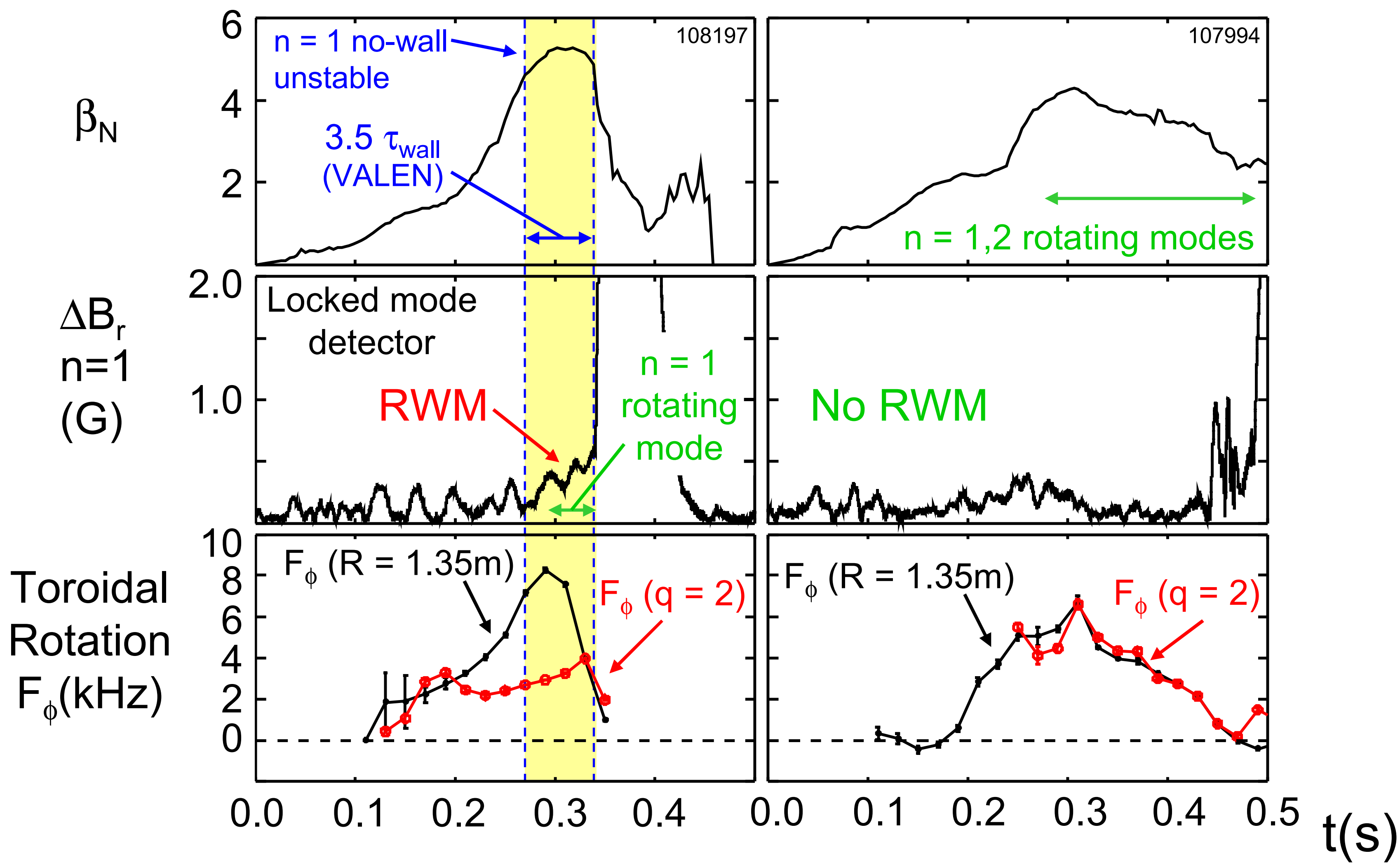
- $F_p = p(0) / \langle p \rangle$
- P profile from EFIT using P_e, diamagnetic loop, magnetics
- Time-dependent calculations required to evaluate stability limits and mode structure

Operational improvements yield higher, sustained β_N



- n=1 error field reduced by an order of magnitude in 2002
- H-mode pressure profile broadening raises β_N limit
- $q_{min} > 1$ maintained (EFIT q_{min} without MSE)

Rotation damping rate larger when $\beta_N > \beta_{N\ no\text{-}wall}$



- Rotation damping rate is ~ 6 times larger when $\beta_N > \beta_{N\ no\text{-}wall}$

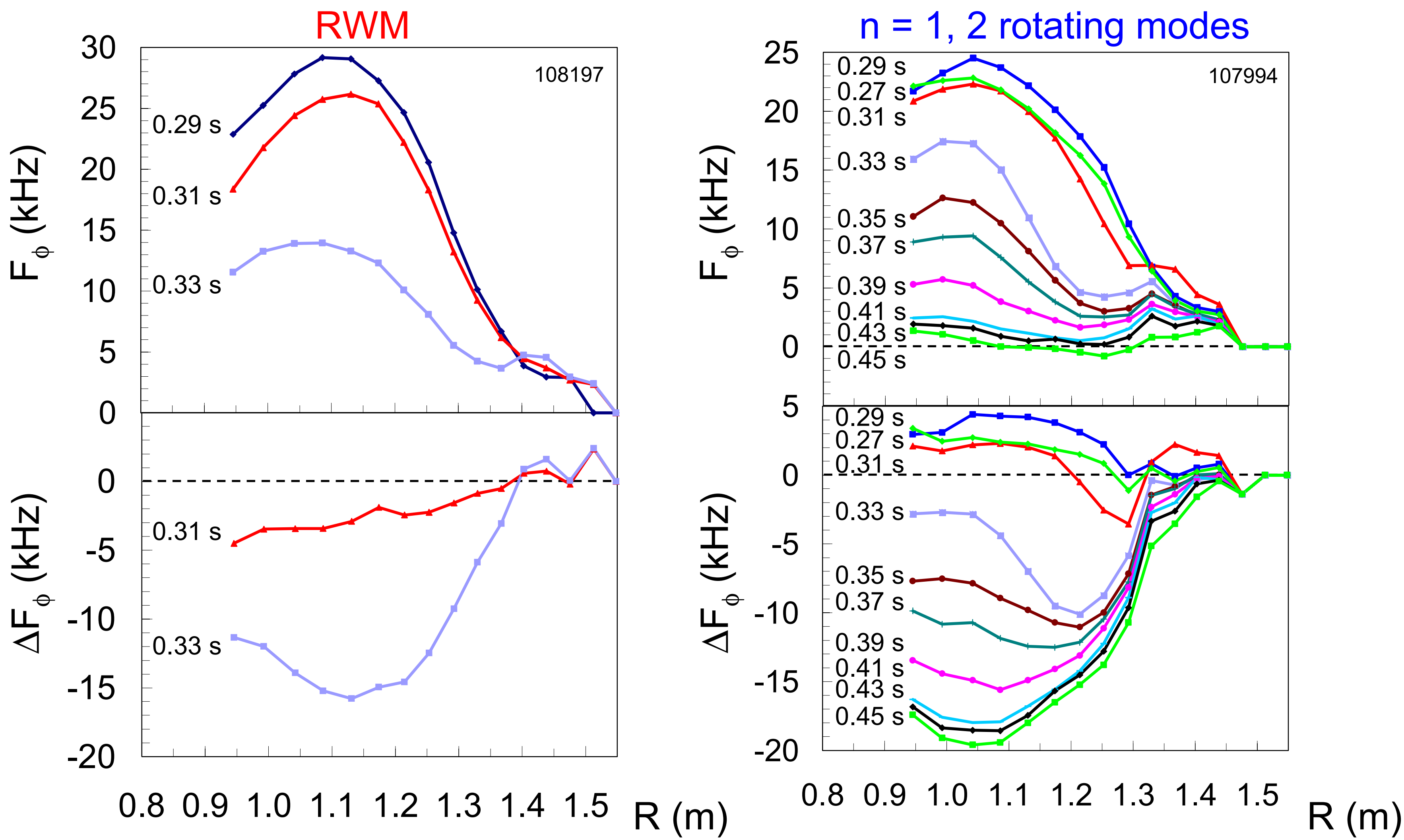
Two stages of rotation damping during RWM

- Initial stage: Global, non-resonant rotation damping

- Final stage: Local rotation damping at resonant surfaces appears as rotation slows

- Analogous to rotation dynamics in induced error field experiments
  - E. Lazzaro, *et al.*, Physics of Plasmas **9** (2002) 3906. (JET)

Rotation damping during RWM is rapid and global



- Field ripple damping by neoclassical toroidal viscosity ~ $\delta B_r^2 T_i^{0.5}$ candidate for observed damping profile during RWM

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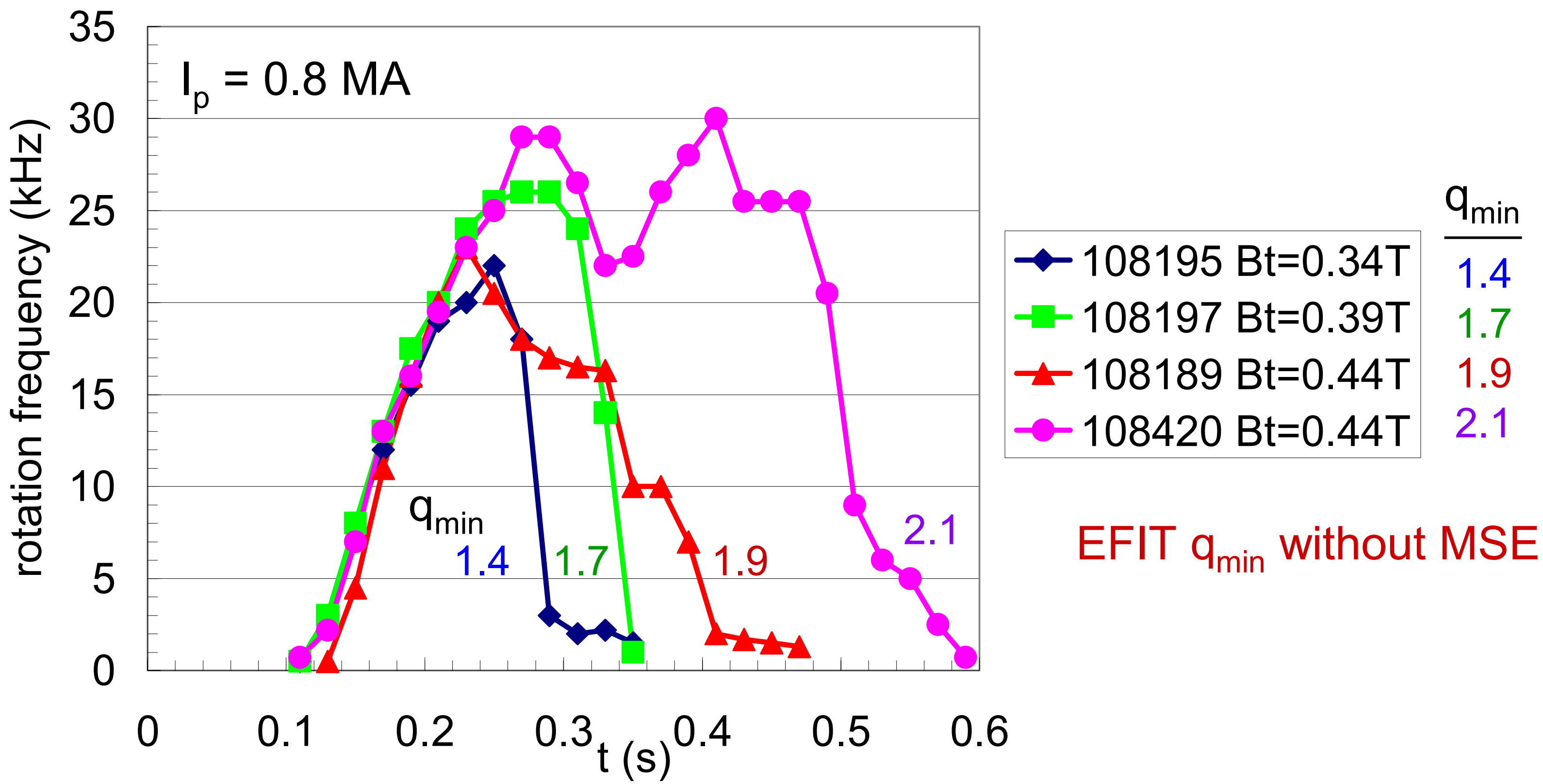
Core rotation damping decreases with increasing q



- Largest rotation damping (dF_ϕ/dt = -600 kHz/s) at B_t < 0.4T, q_{min} < 2
  - Factor of 8 times larger than damping from n=2 island alone
- When q_{min} ~ 2 damping rate is reduced and F_ϕ is maintained longer
- Consistent with theory linking rotation damping to low order rational surfaces

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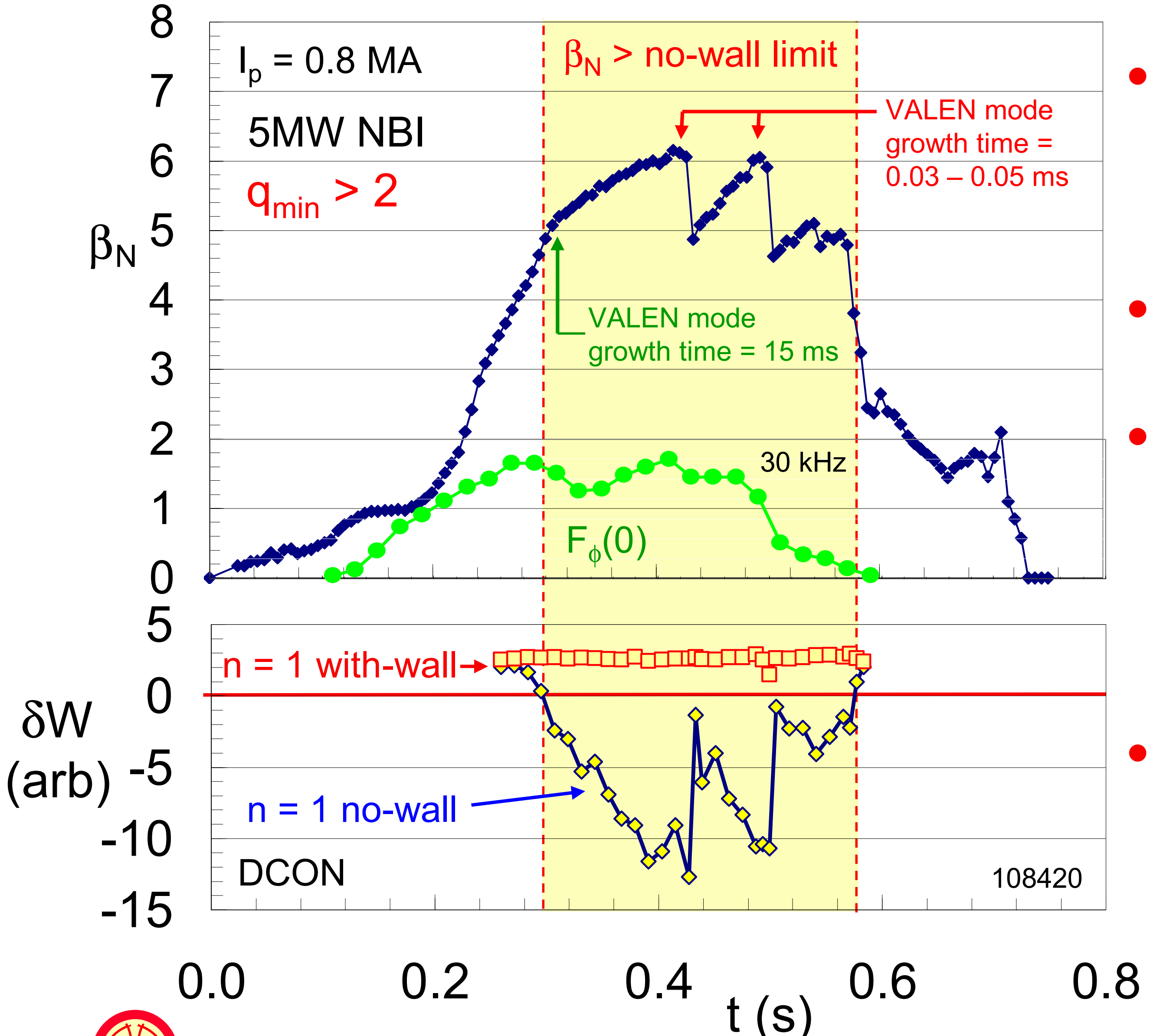
Plasma stabilized above no-wall β_N limit for 18 τ_{wall}



- Plasma approaches with-wall β_N limit
  - VALEN growth rate becoming Alfvénic
- $F_\phi(0)$ increases as β_N >> β_N no-wall
- Passive stabilizer loses effectiveness at maximum β_N
  - Neutrons collapse with β_N - suggests internal mode
- TRANSP indicates higher F_p
  - Computed β_N limits conservative

Research on passive stabilization and high β_N rotation damping physics has begun

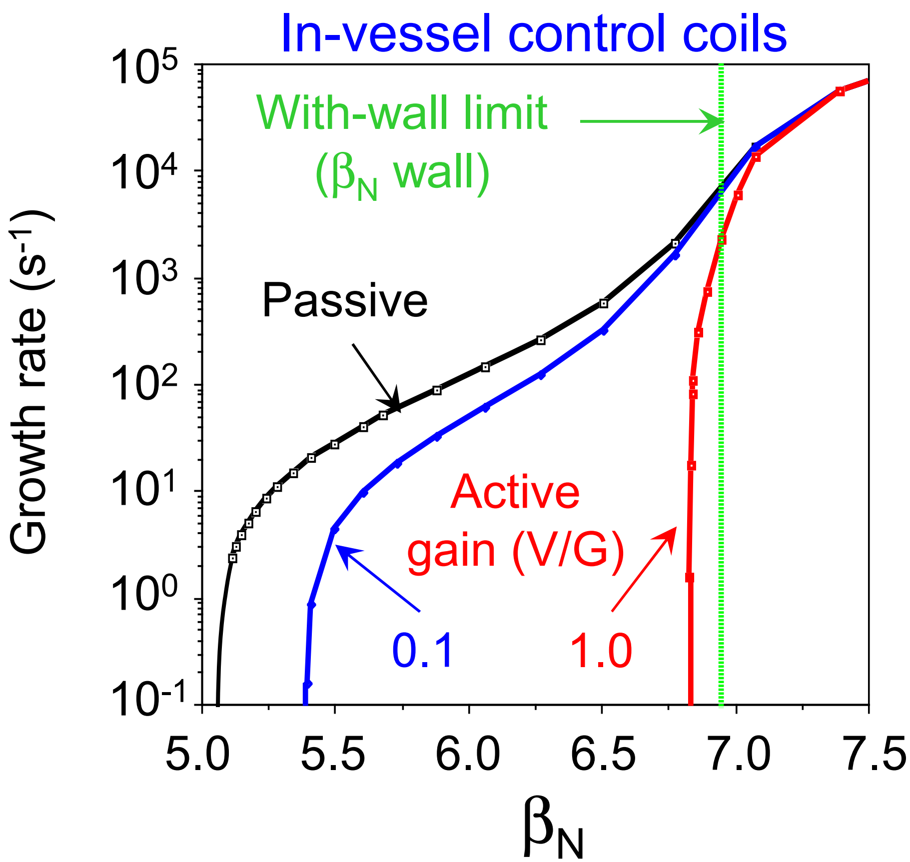
- Passive stabilization above ideal no-wall β_N limit by up to 35%
  - Improvement in plasmas with highest β_N up to 6.5; β_N/l_i = 9.5
- The β_N limit increases with decreasing pressure profile peaking
- Rotation damping at $\beta_N > \beta_{N\ no\text{-}wall}$ has two stages
  - Global, non-resonant damping
  - Local, resonant field damping during final stage
- Rotation damping rate substantially decreases as q increases
- Passive stabilization becomes less effective at highest β_N
- Active feedback design shows sustained $\beta_N/\beta_{N\ wall}$ = 94% possible
  - See Bialek, et al., GP1.107 Tuesday

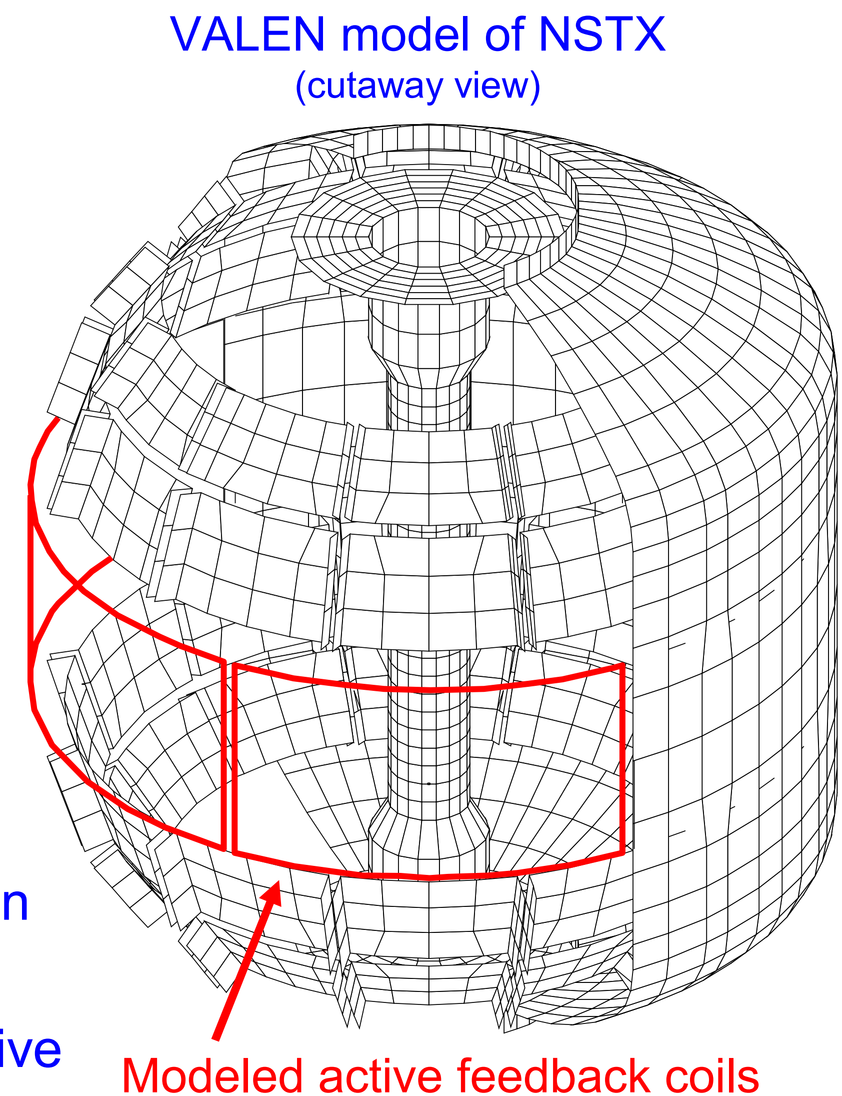
For more RWM detail, see NSTX poster session (Tuesday)

Other presentations on NSTX beta limits, RWM, and mode stabilization

Subject	Presentation
• High toroidal beta plasmas	Gates, et al., BI1.001 Monday
• High poloidal beta plasmas	Menard, et al., CO1.002 Monday
• Resistive wall modes	Zhu, et al., GP1.106 Tuesday
	(Sabbagh for) Paoletti, et al., GP1.105 Tuesday
• RWM active feedback design	Bialek, et al., GP1.107 Tuesday

Active stabilization might sustain 94% of with-wall β limit

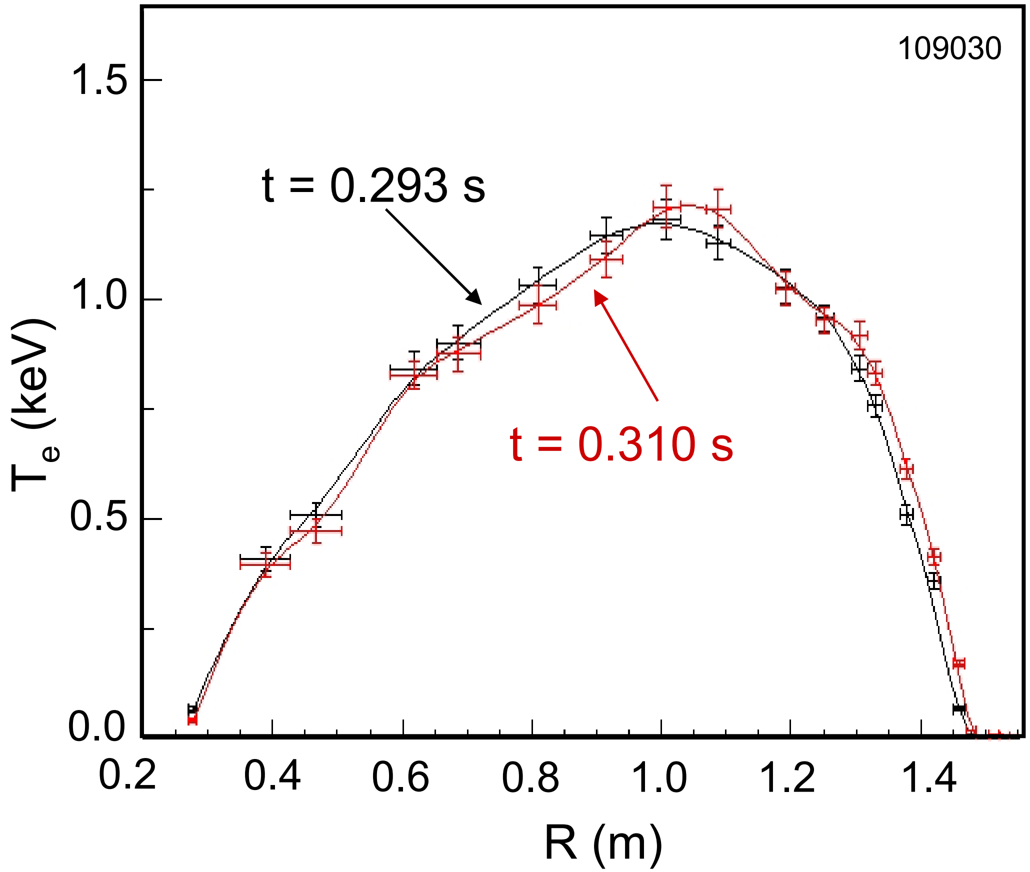


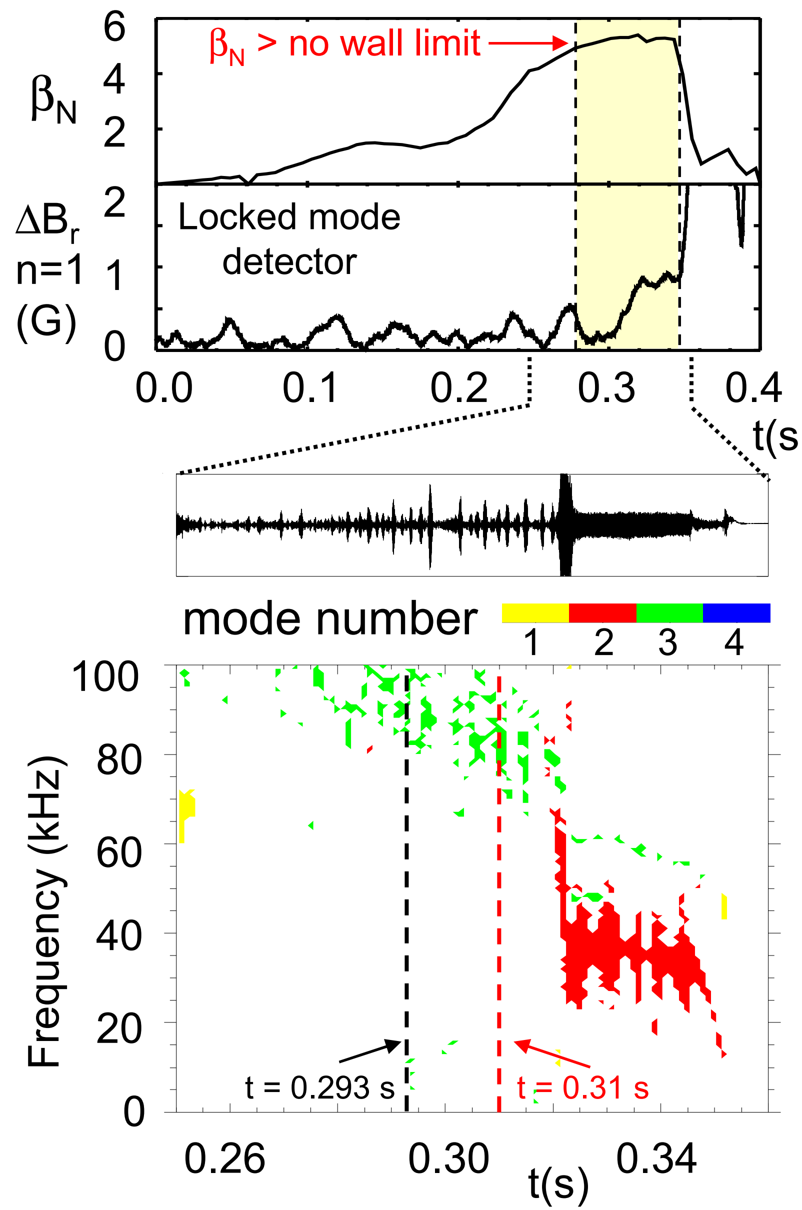


- System with ex-vessel control coils can reach 72% of $\beta_{N\ wall}$
- System with control coils among passive plates can only reach 50% of $\beta_{N\ wall}$

Bialek, et al., GP1.107 Tuesday

T_e perturbation measured during RWM





- No low frequency (< 80 kHz) rotating modes observed during measured δT_e
- δT_e displacement precedes n=2 rotating mode

Thomson scattering (LeBlanc)

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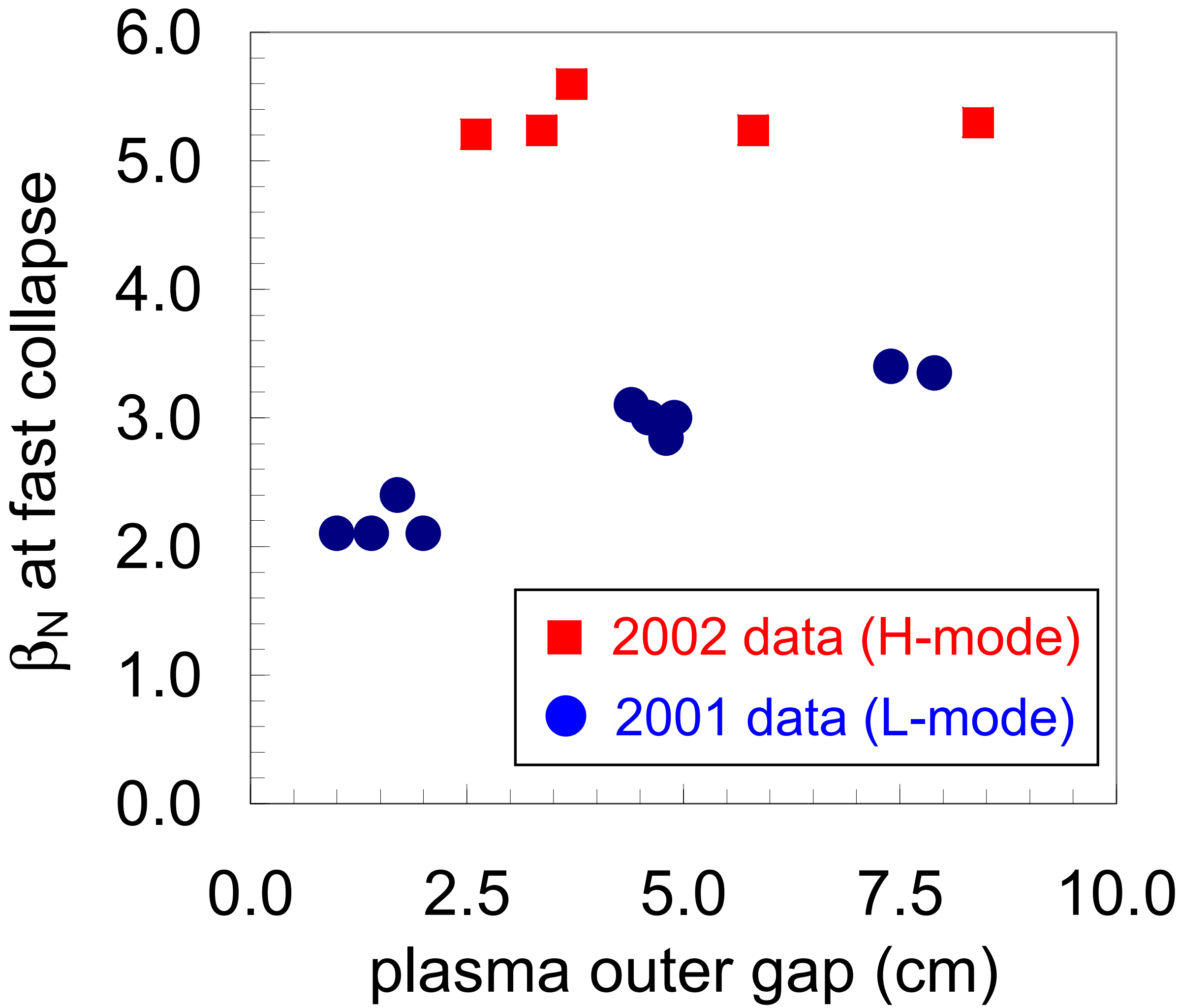
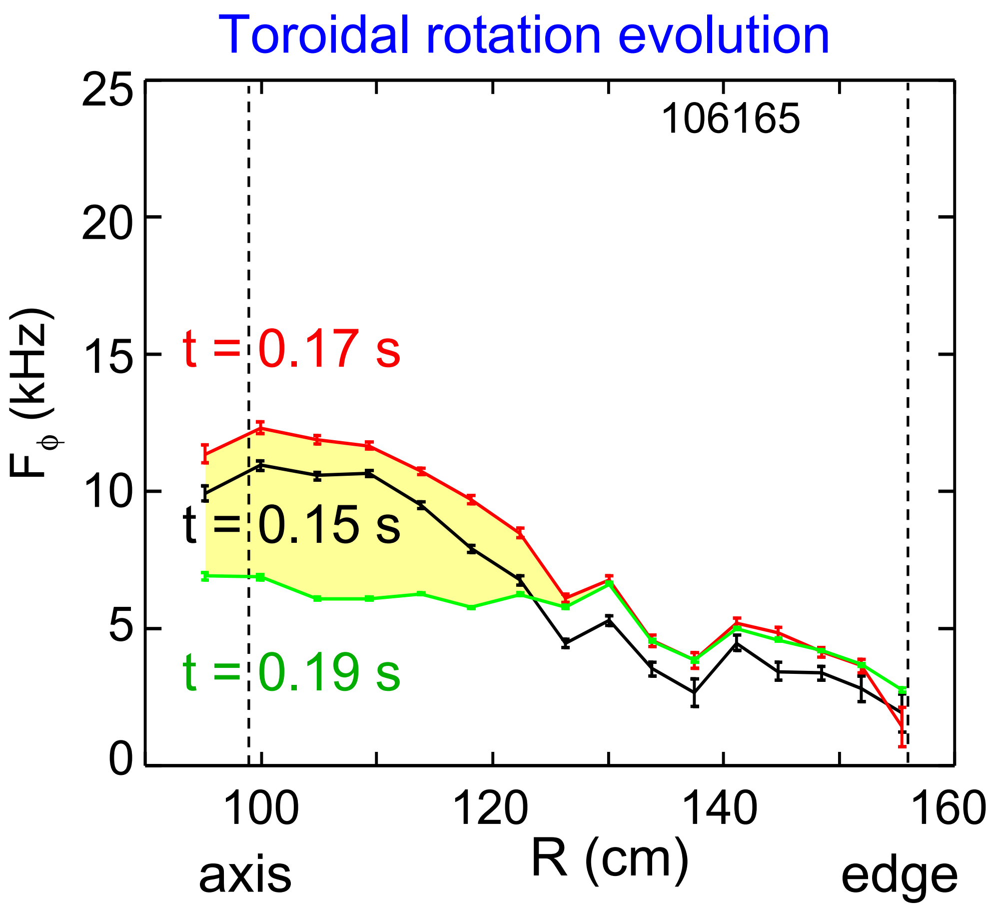
β_N limit now insensitive to plasma proximity to wall

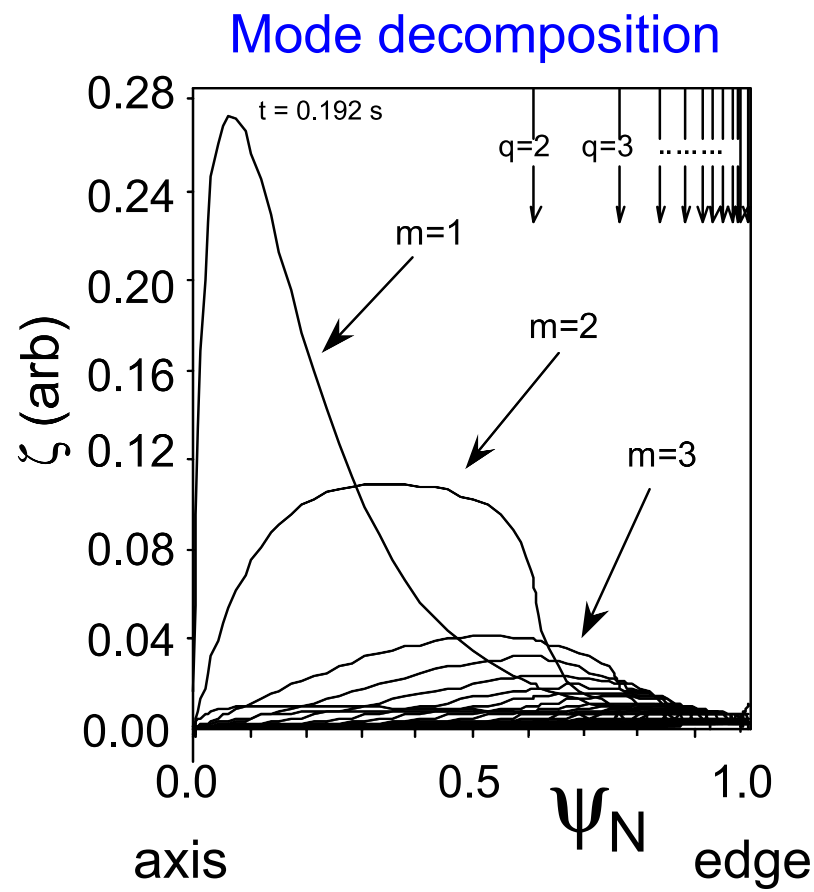


- At high $\beta_N \sim 5$, external modes are well-coupled to passive stabilizing plates, independent of gap
  - Confirmed by ideal MHD stability calculations
- Higher error field (2001 data) may have also lowered β limit for smaller outer gap

See W. Zhu, et al., GP1.106 Tuesday

Rotation damping strongest where mode amplitude largest





- Field ripple damping by neoclassical parallel viscosity ~ $\delta Br^2 T_i^{0.5}$ possible candidate for observed damping profile

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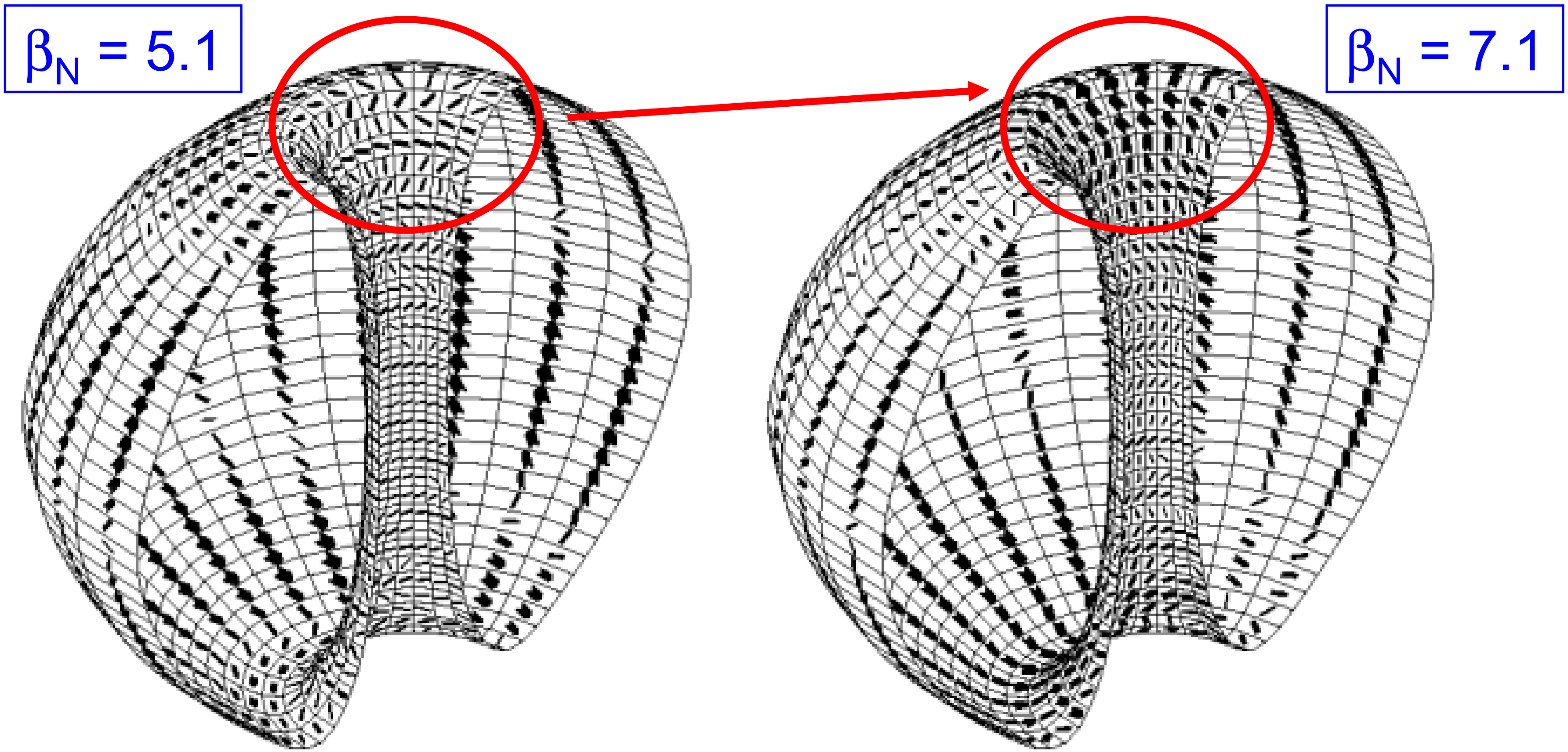
Mode intensifies in divertor region at highest β_N

VALEN / DCON computed *n* = 1 external mode currents



- Increased ∇p drive more significant in producing higher growth rate