Global Mode Stabilization and Active Feedback System Design in NSTX

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NSTX 5 Year Plan Feedback Forum

PPPL - December 12th, 2002

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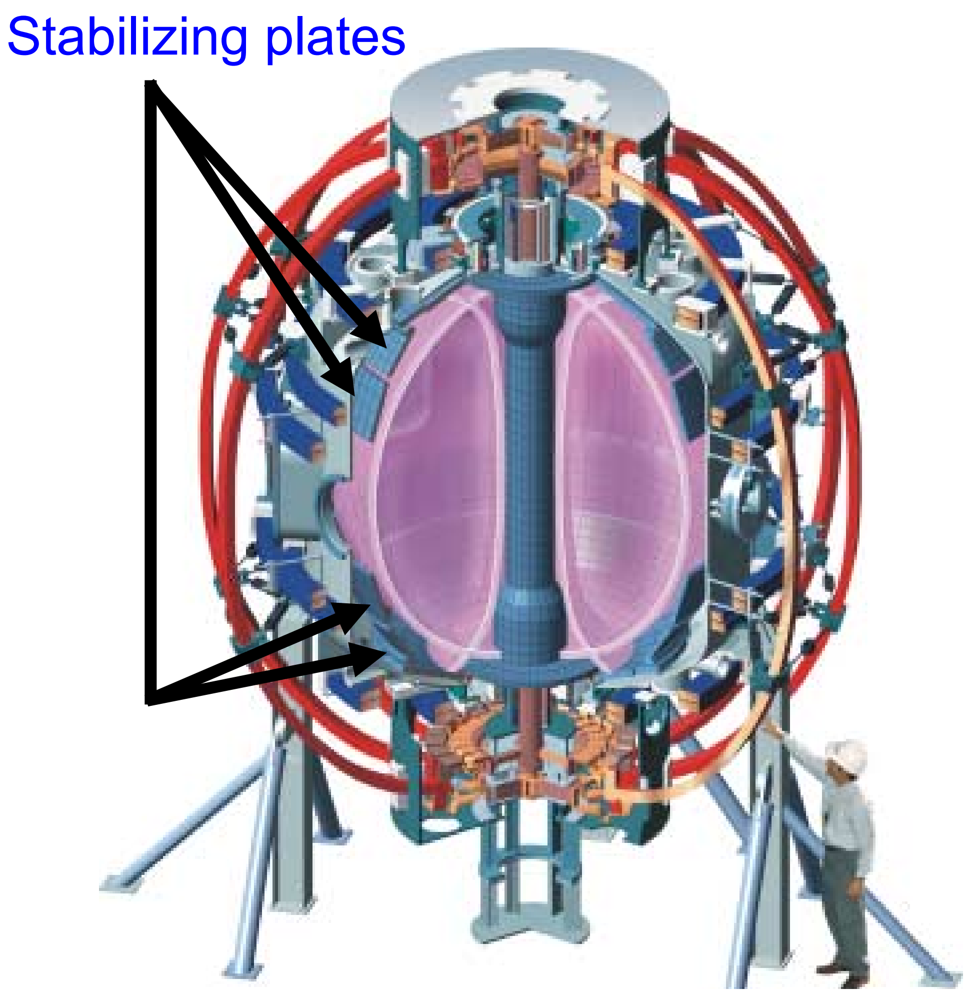
NSTX is operating at sufficiently high beta to study global MHD mode stabilization

- Motivation
  - Carry out proposed ST research on passive / active stabilization of global MHD modes
- Outline
  - FY02 – FY03:
    - Operation in wall-stabilized, high beta regime
    - Resistive wall mode (RWM) and rotation damping
    - Physical mechanisms for higher β_N and longer pulse
  - FY03 – FY05:
    - Active feedback stabilization system design / installation
  - FY05 – FY08:
    - Timeline for active mode control physics research

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

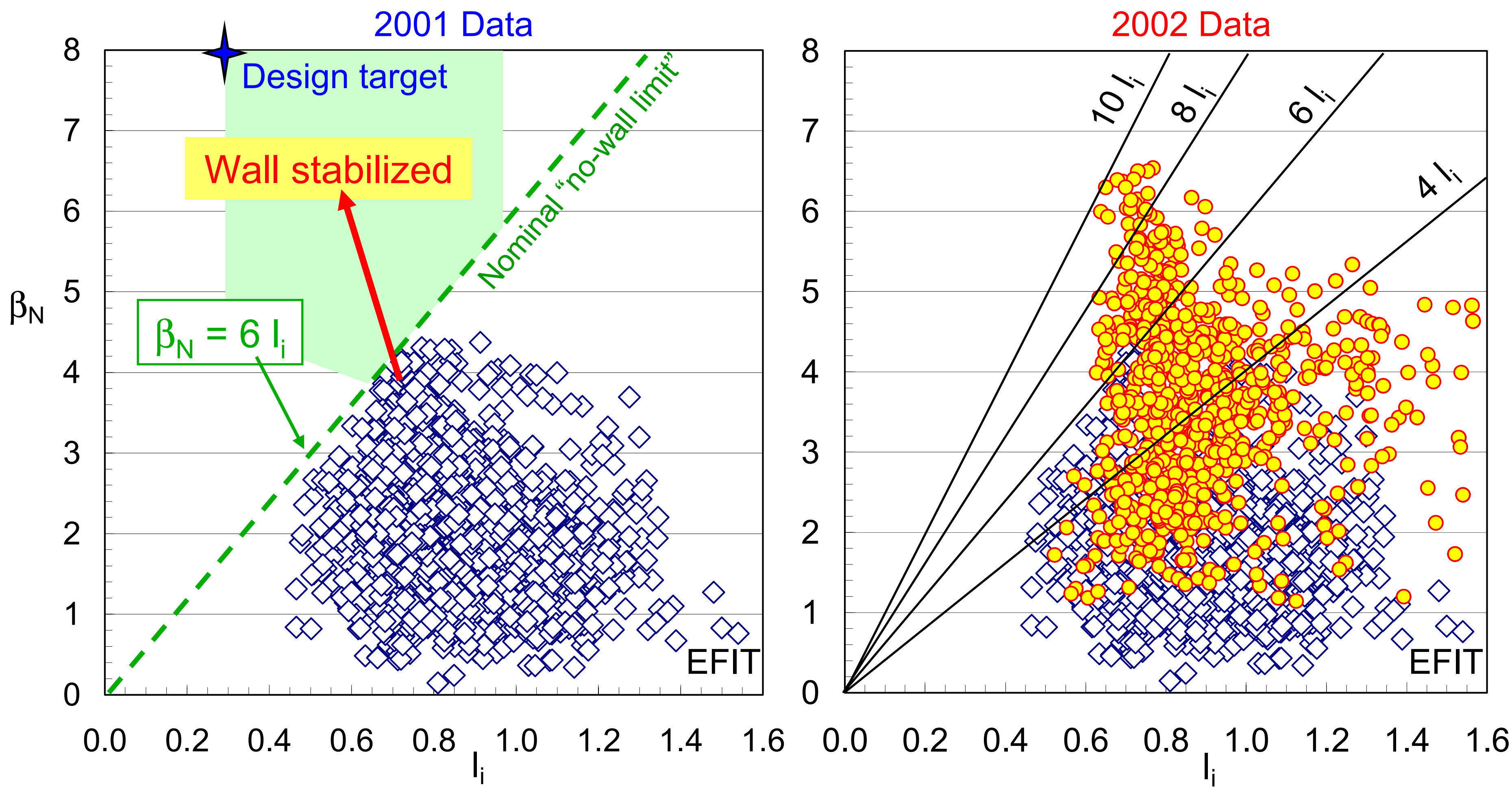
EFIT – equilibrium reconstruction

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% ($\beta_t = 2\mu_0\langle p\rangle / B_0^2$)

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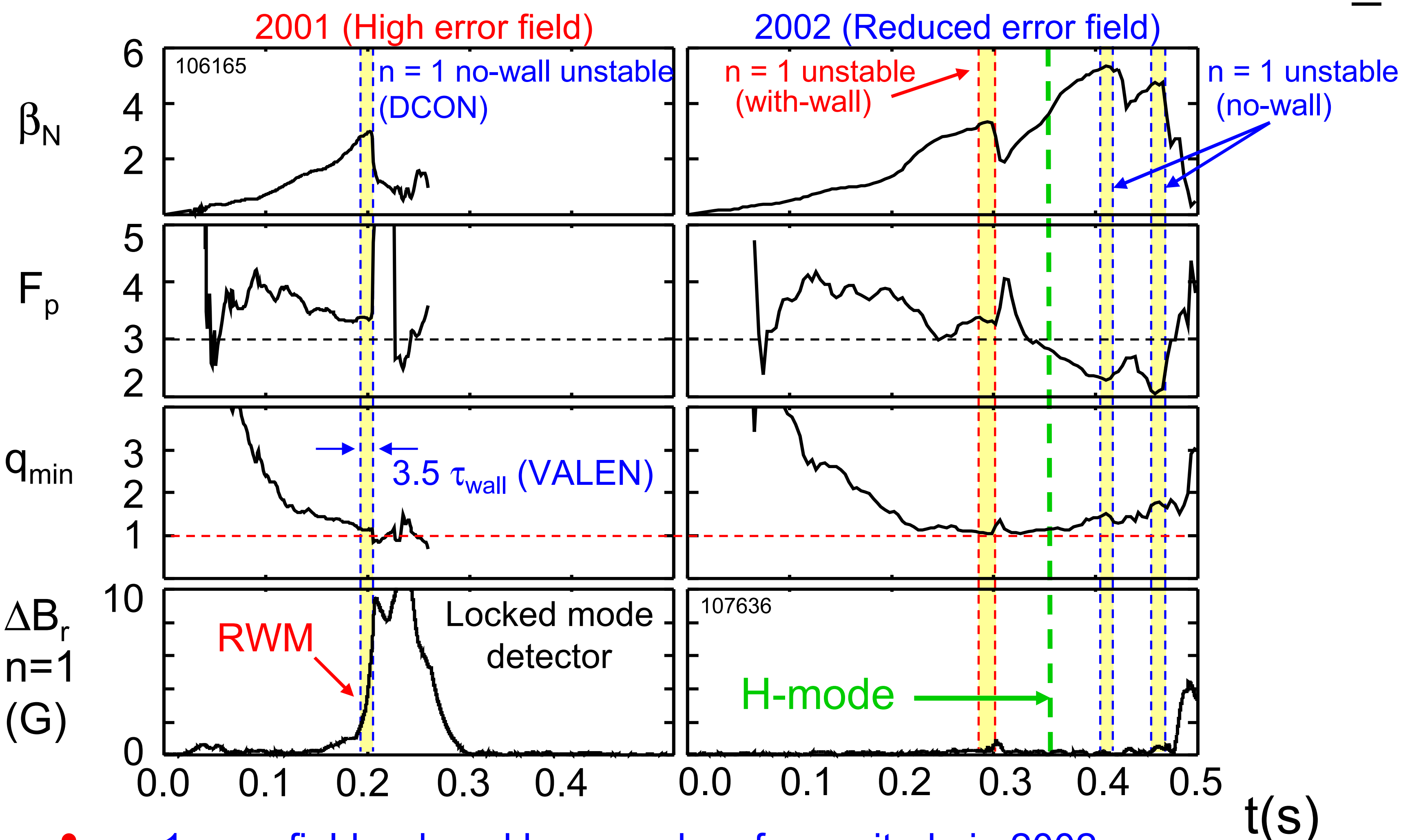
Operational improvements yield higher, sustained β_N



- 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)

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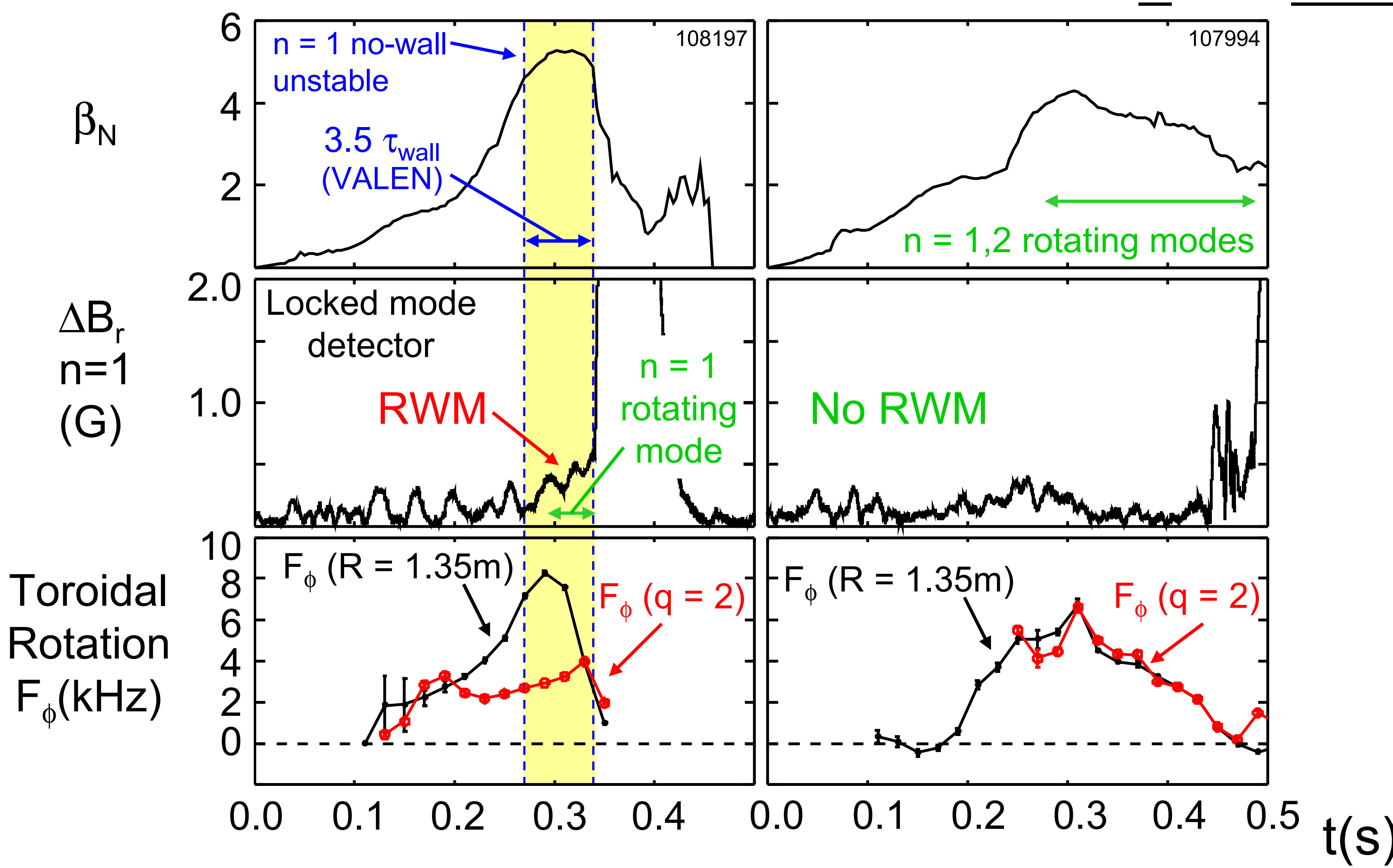
Rotation damping rate larger when $\beta_N > \beta_{N\ no\text{-}wall}$



- Rotation damping rate is ~ 6 times larger when $\beta_N > \beta_{N\ no\text{-}wall}$
- RWM signal weak in CY02 experiments: improve sensors

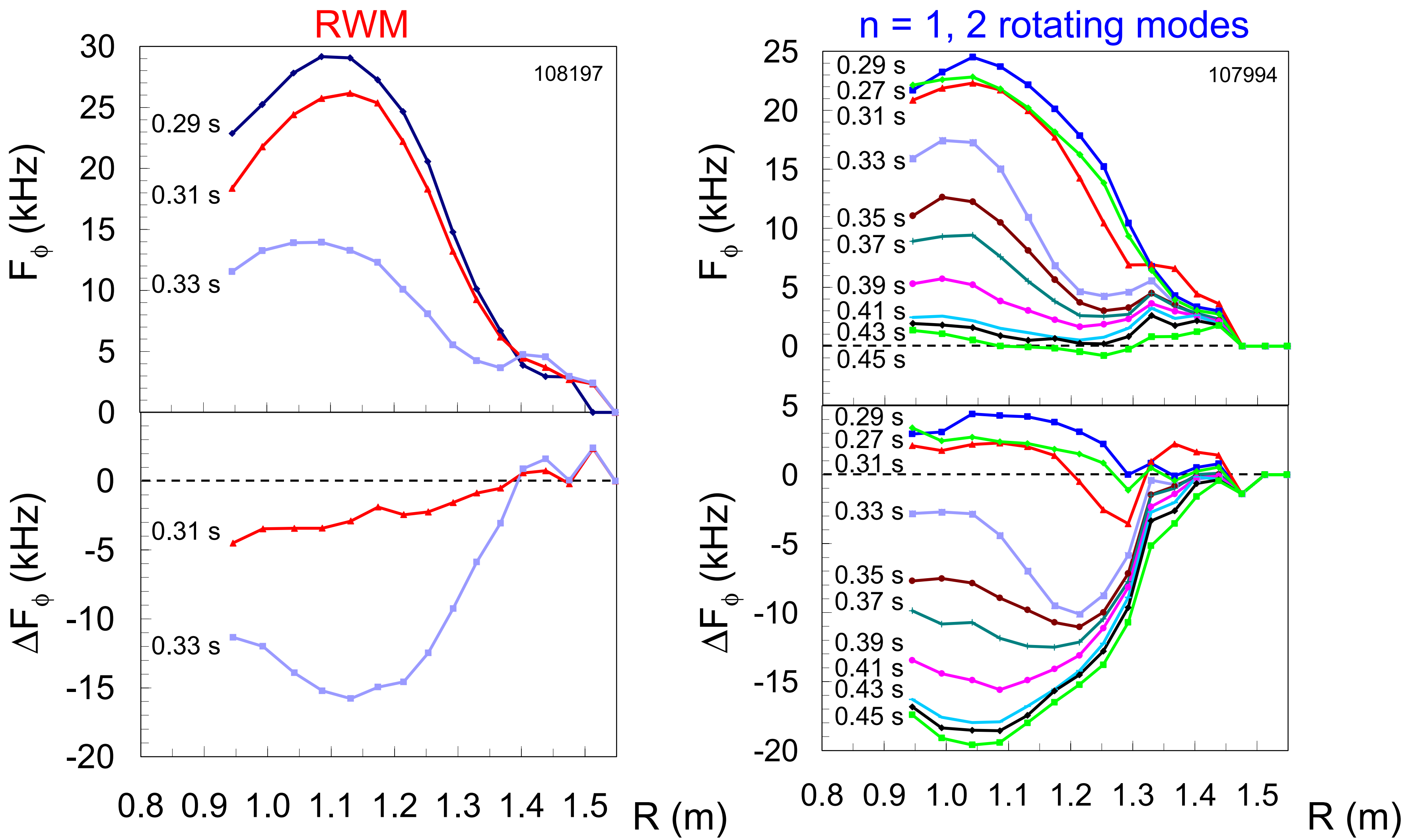
Two stages of rotation damping during RWM

- Initial stage: Global, non-resonant rotation damping

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

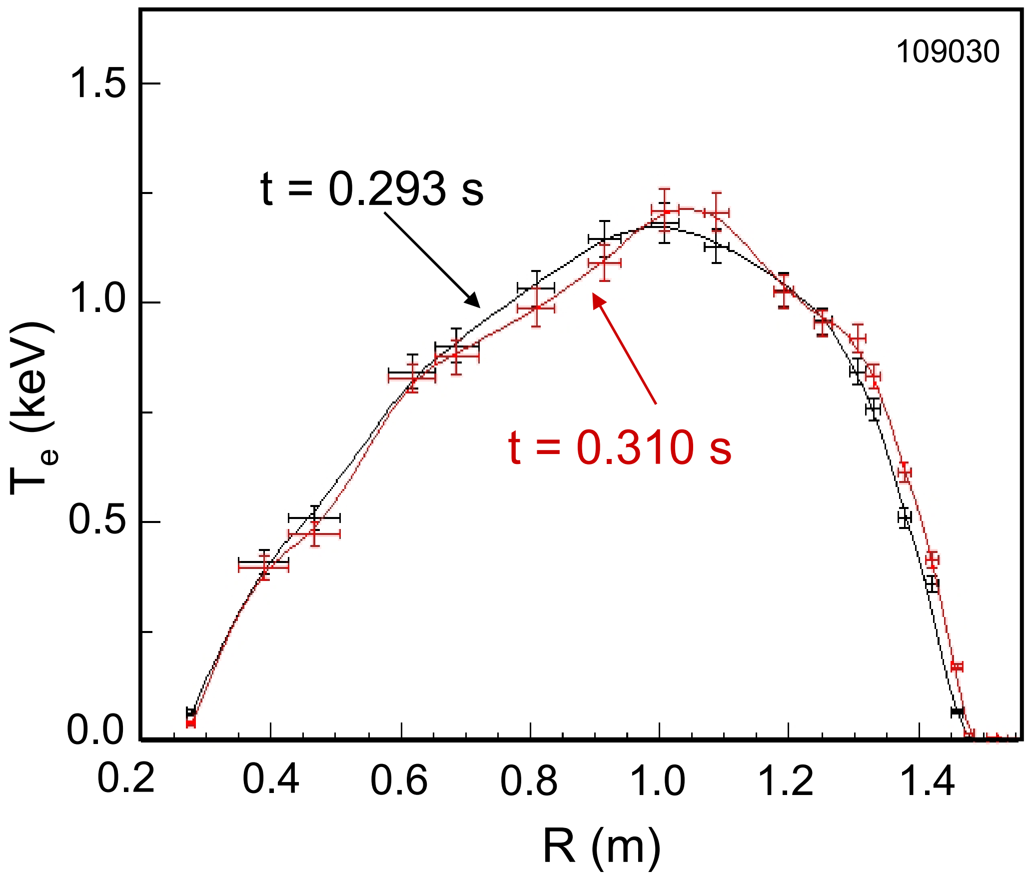
- Analogous to rotation dynamics in induced error field experiments
    - E. Lazzaro, *et al.*, Physics of Plasmas **9** (2002) 3906. (JET)

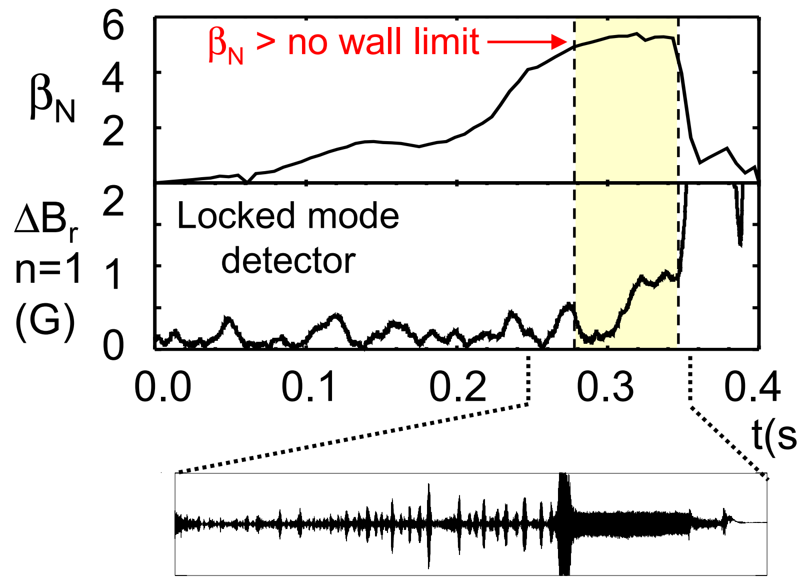
Rotation damping during RWM is rapid and global

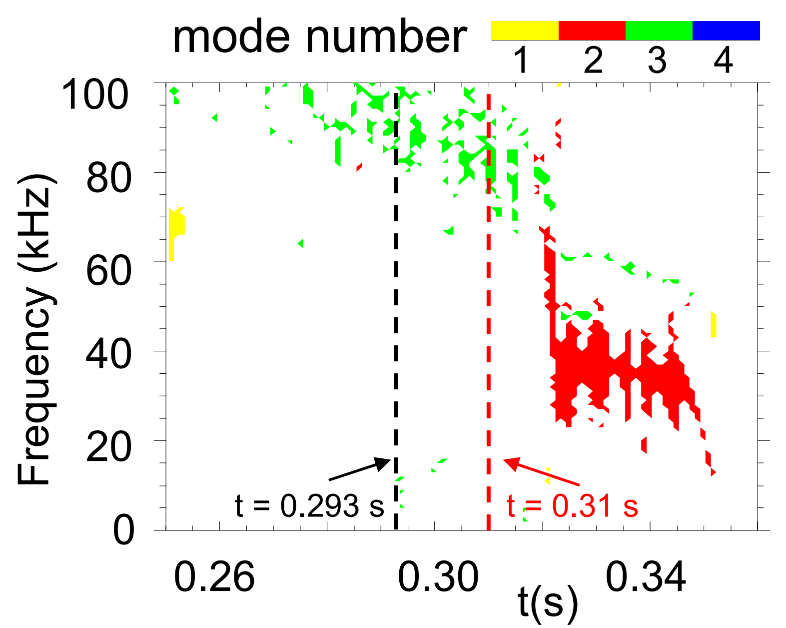


- Damping from rotating modes alone is localized and diffusive

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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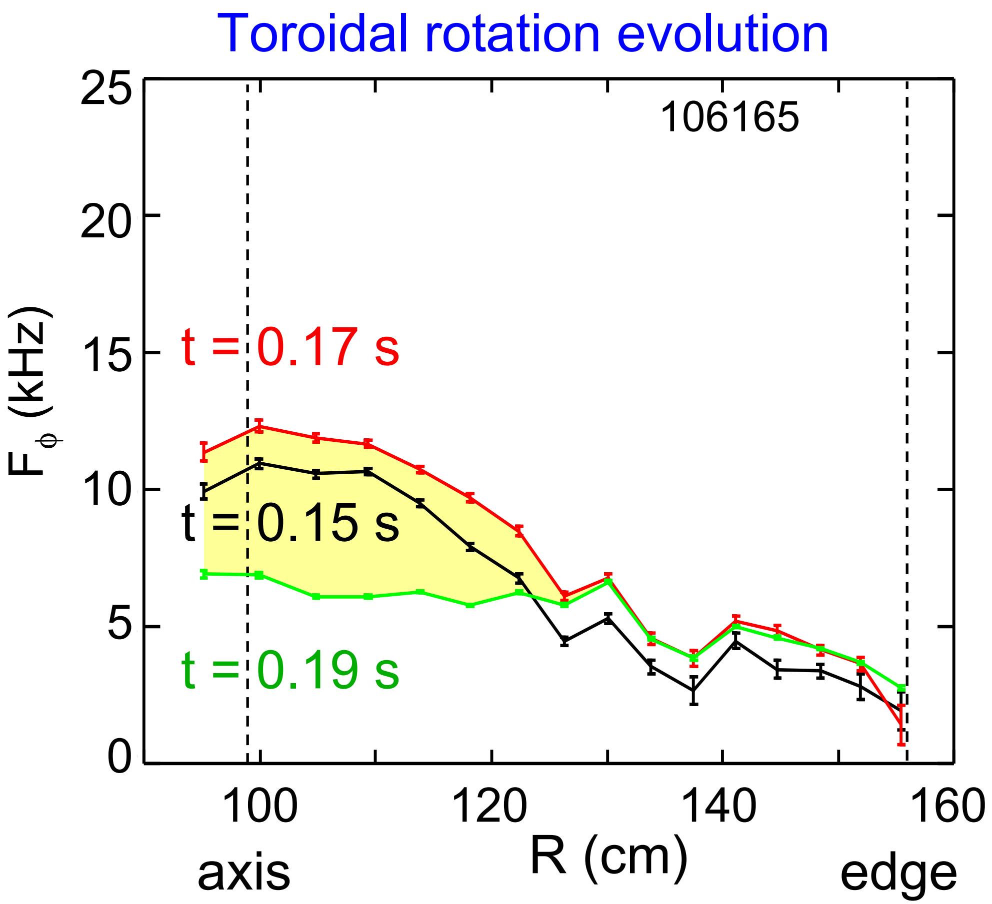
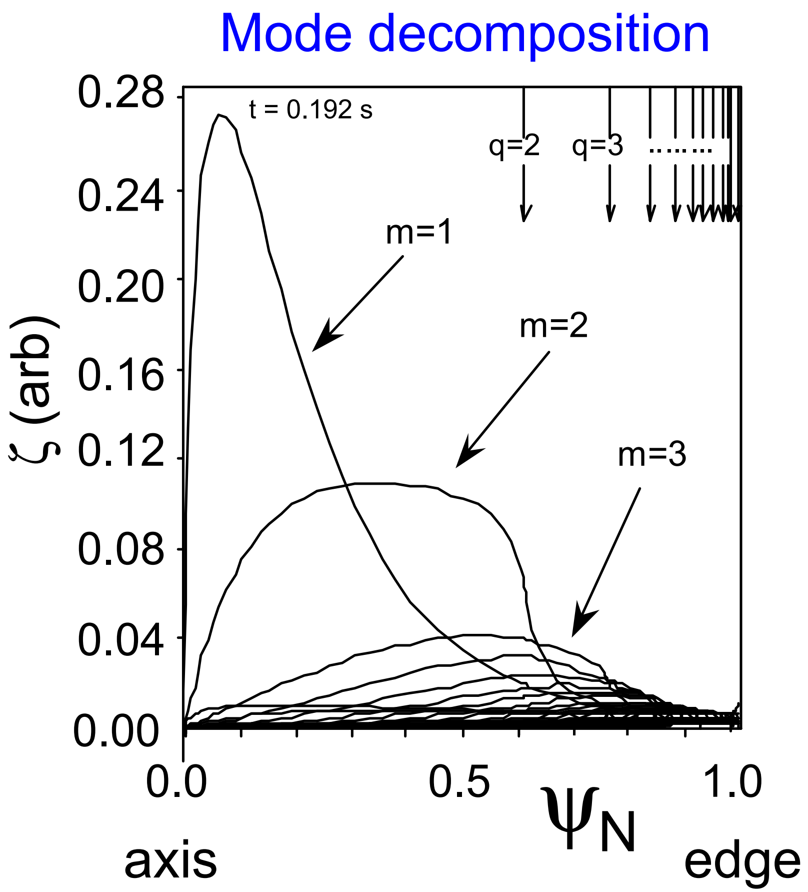
Rotation damping strongest where mode amplitude largest





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

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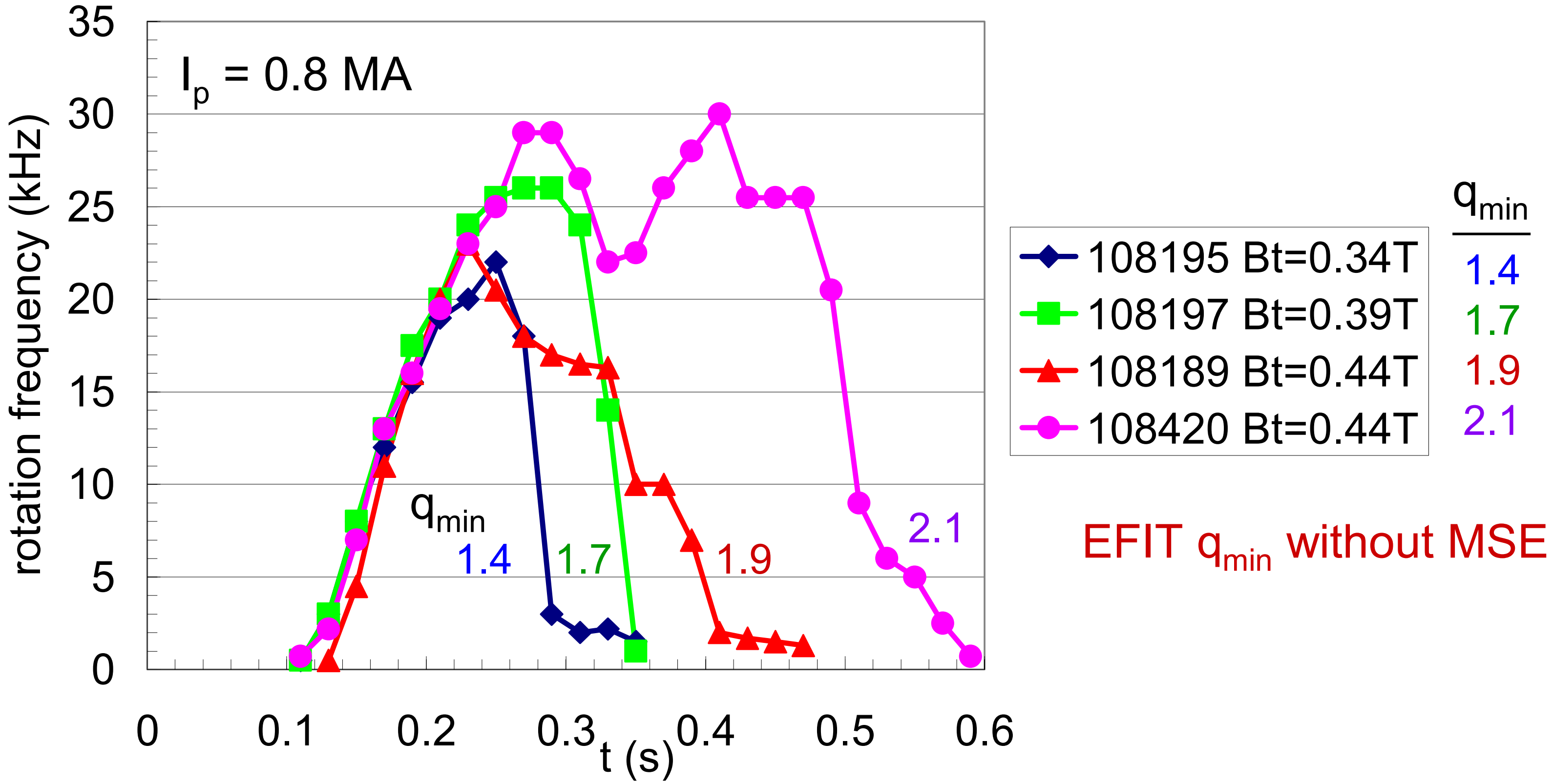
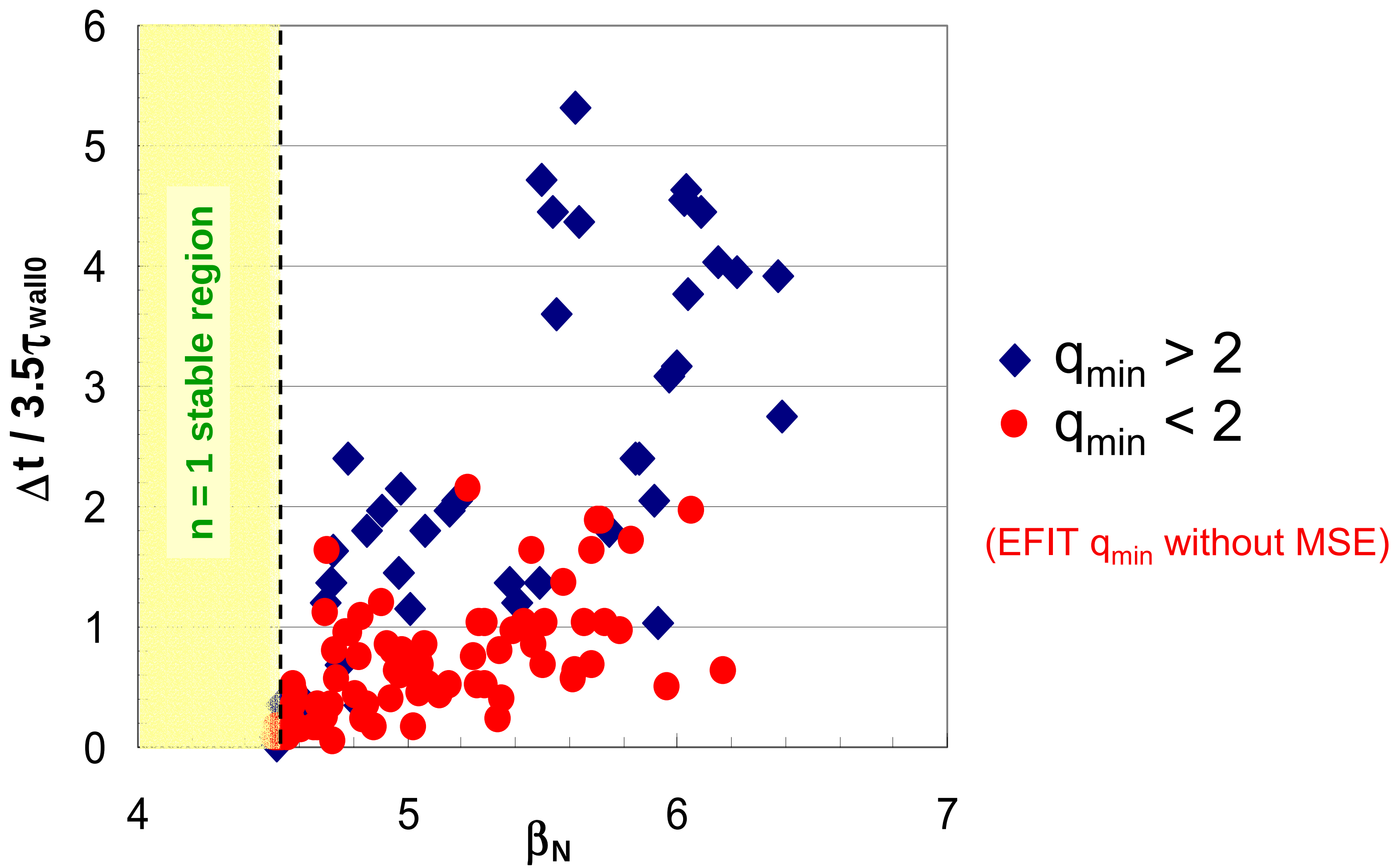
Core rotation damping decreases with increasing q



- 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
- When q_{min} ~ 2, rotation damping rate is reduced and F_ϕ is maintained longer
- Consistent with theory linking rotation damping to low order rational surfaces

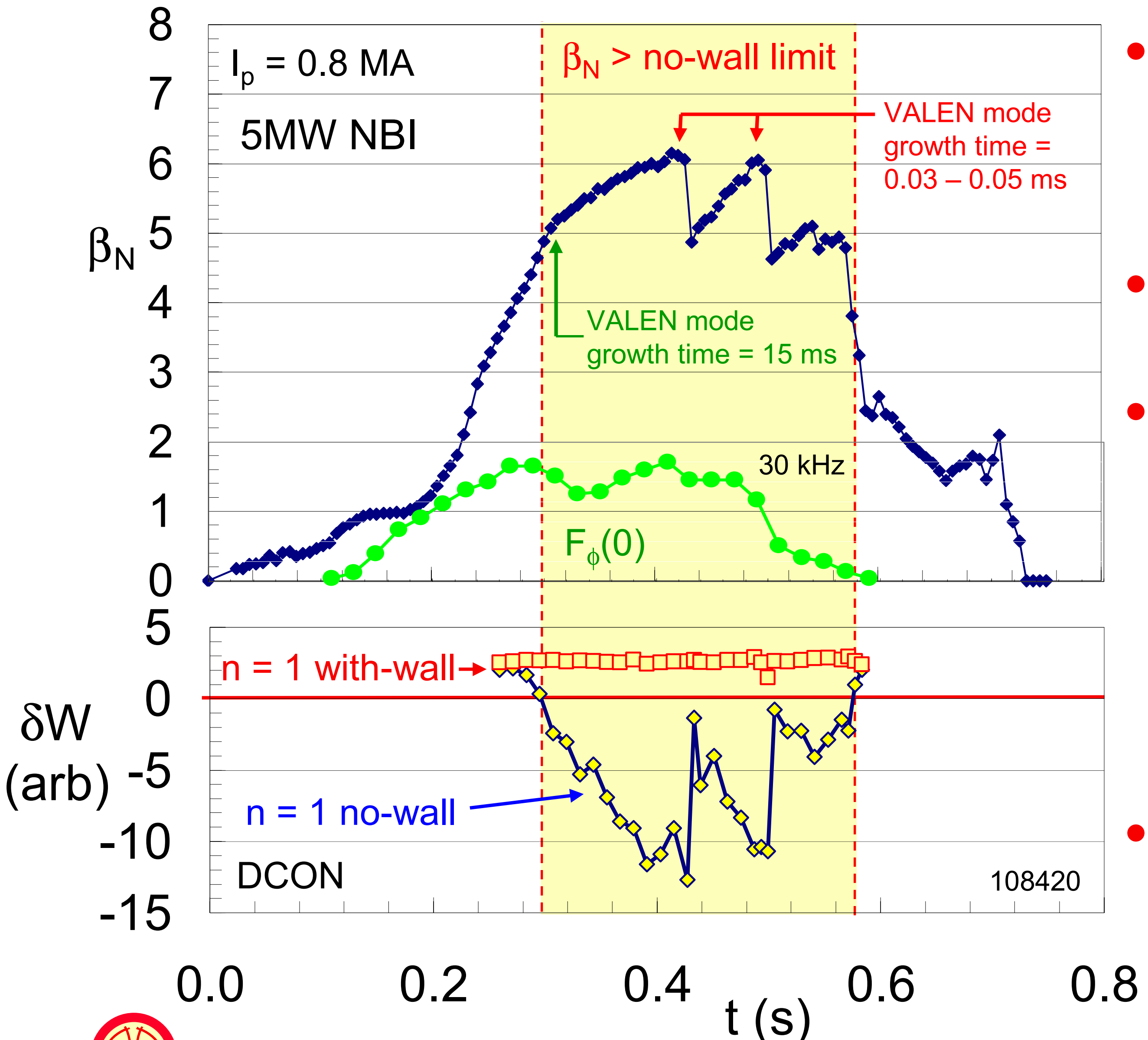
High β_N plasmas with q_{min} > 2 have longer pulse length



- Typically (15 ms < τ_{wall} < 25 ms), τ_{wall0} ≡ 20 ms
- (1.8 < F_p < 2.3); n=1 mode typically computed stable for β_N< 4.5

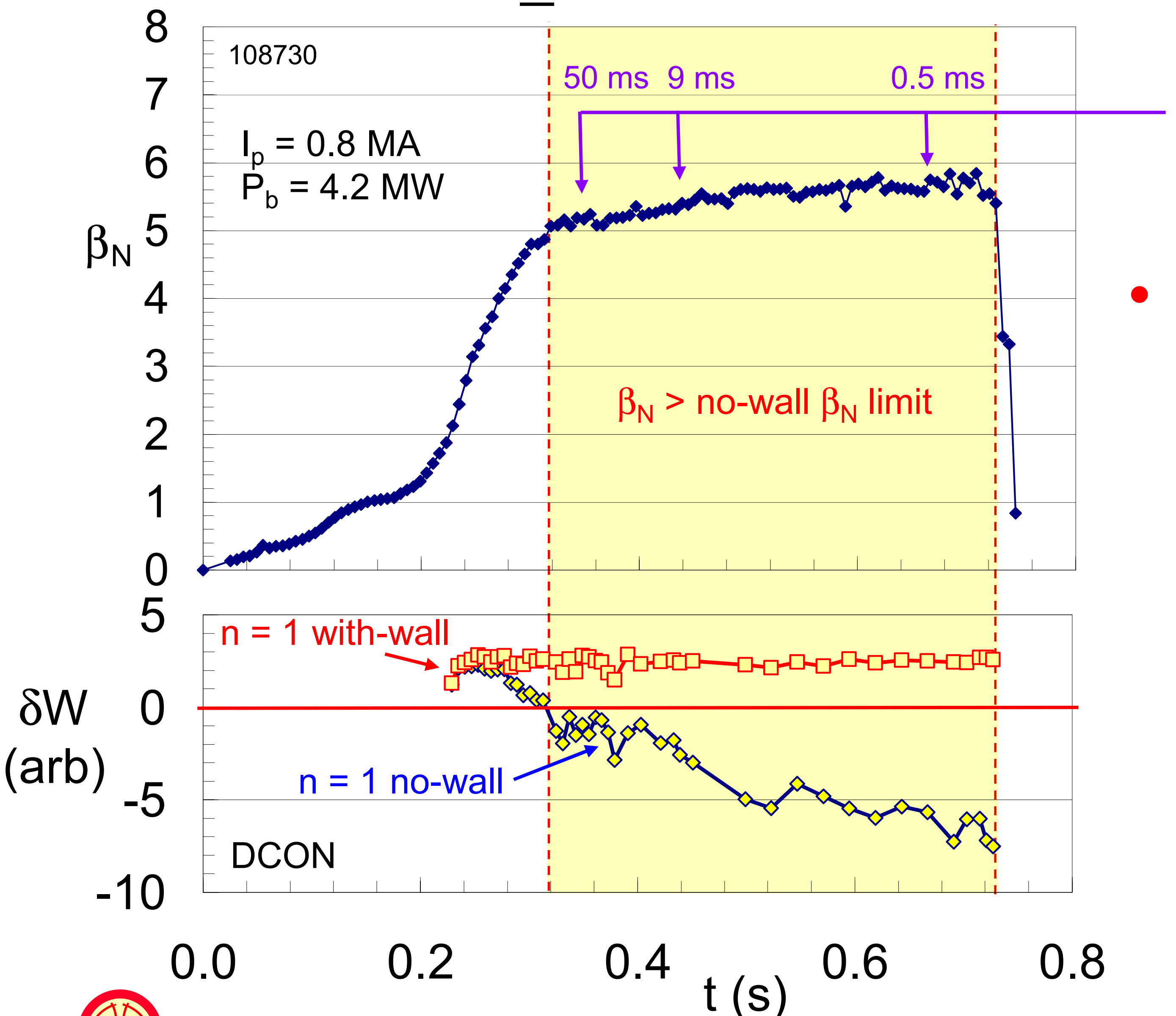
W. Zhu

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
  - Larger ∇p drive, mode shape change
- TRANSP indicates higher F_p
  - Computed β_N limits conservative

Ideal no-wall β_N limit exceeded and maintained



- Ideal no-wall limit violated for 400 ms
  - $t_{pulse} \sim 8\ \tau_E$
  - Computed τ_{wall} for n = 1 mode decreases by factor of 100
  - Average of computed τ_{wall} gives pulse length > 20 τ_{wall}

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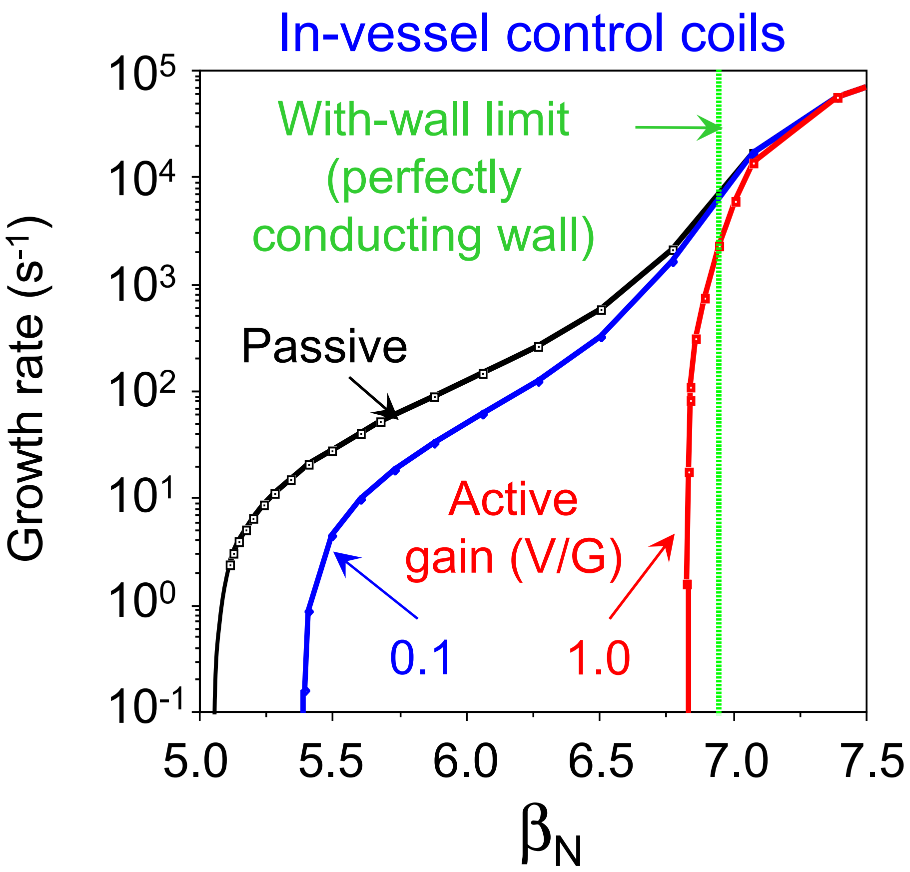
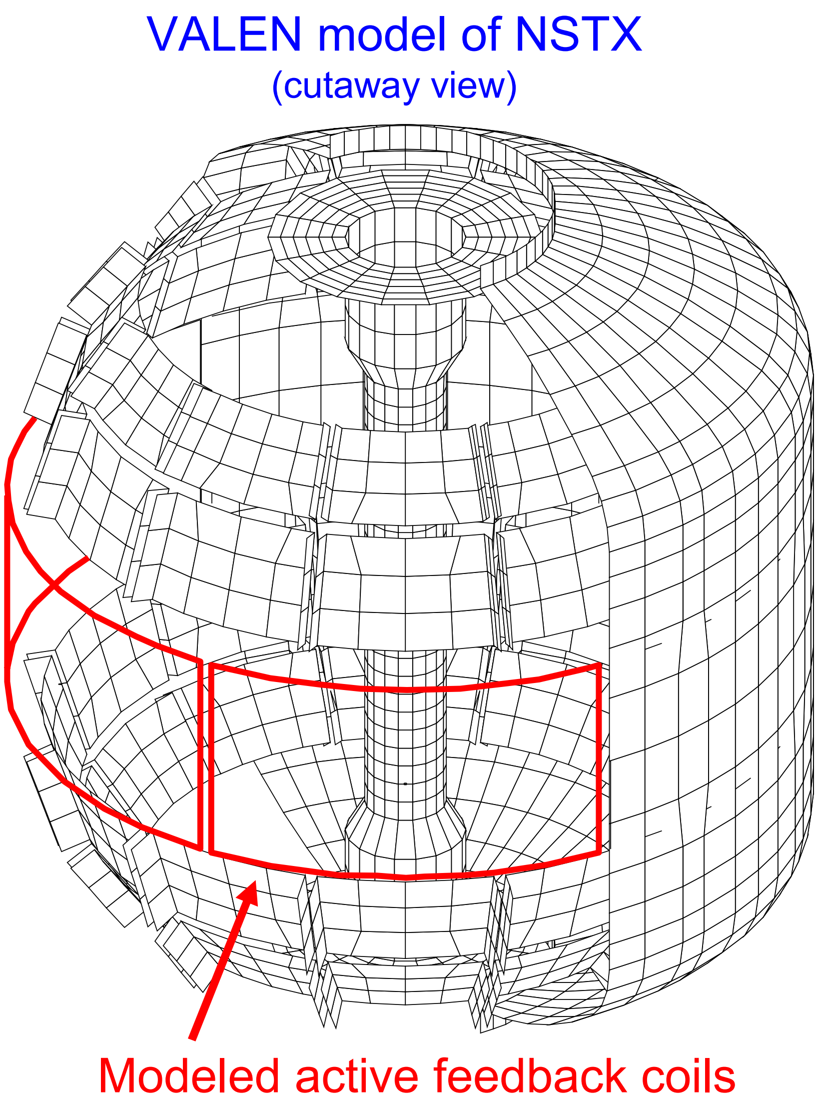
Active stabilization might sustain 94% of with-wall β limit

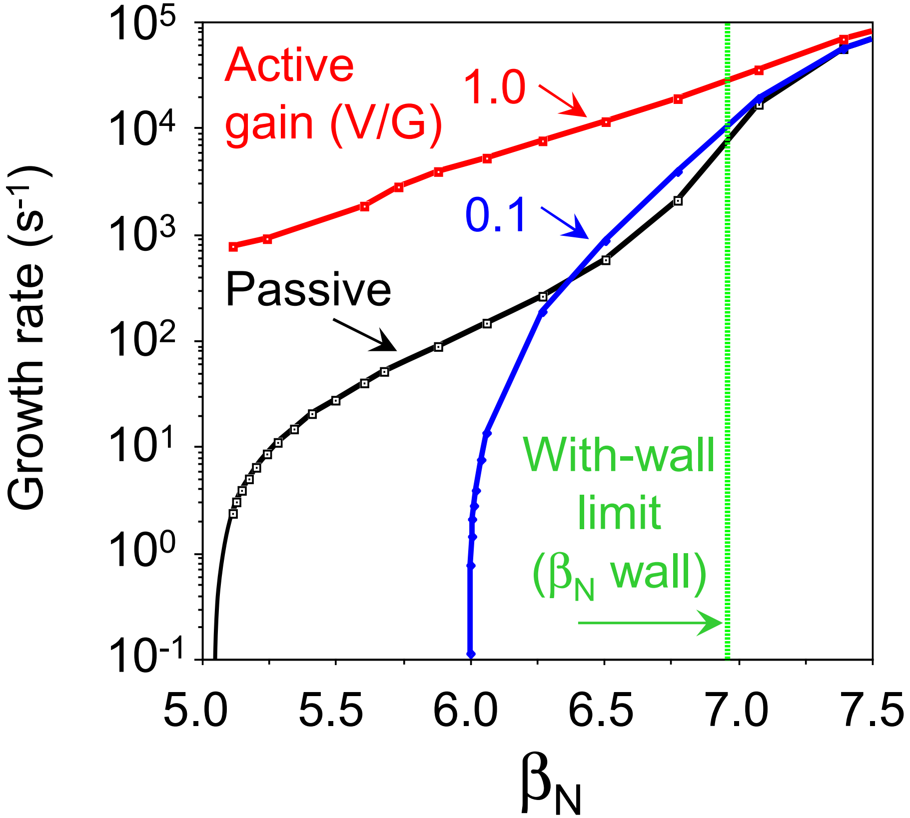


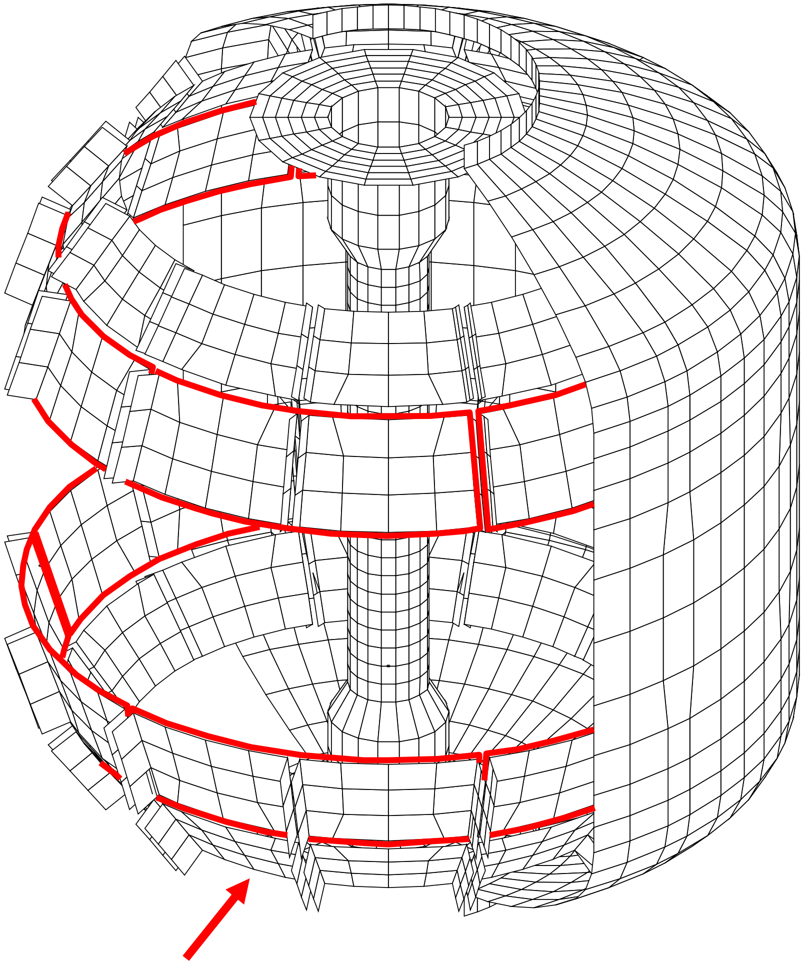


- System with ex-vessel control coils reaches 72% of with-wall limit, $\beta_{N\ wall}$

VALEN: J. Bialek

Control coils among plates reach only 50% of $\beta_{N\ wall}$

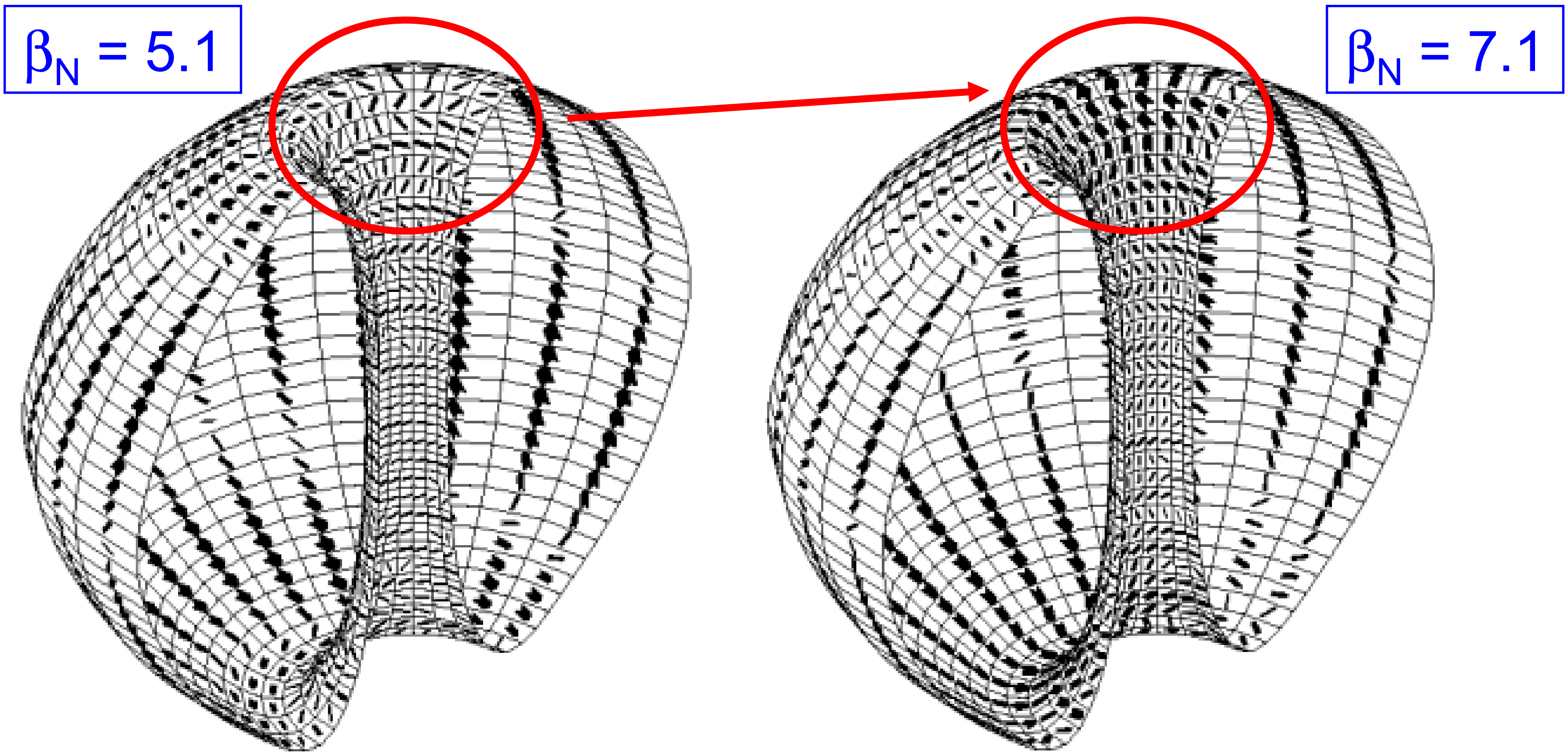




VALEN: J. Bialek

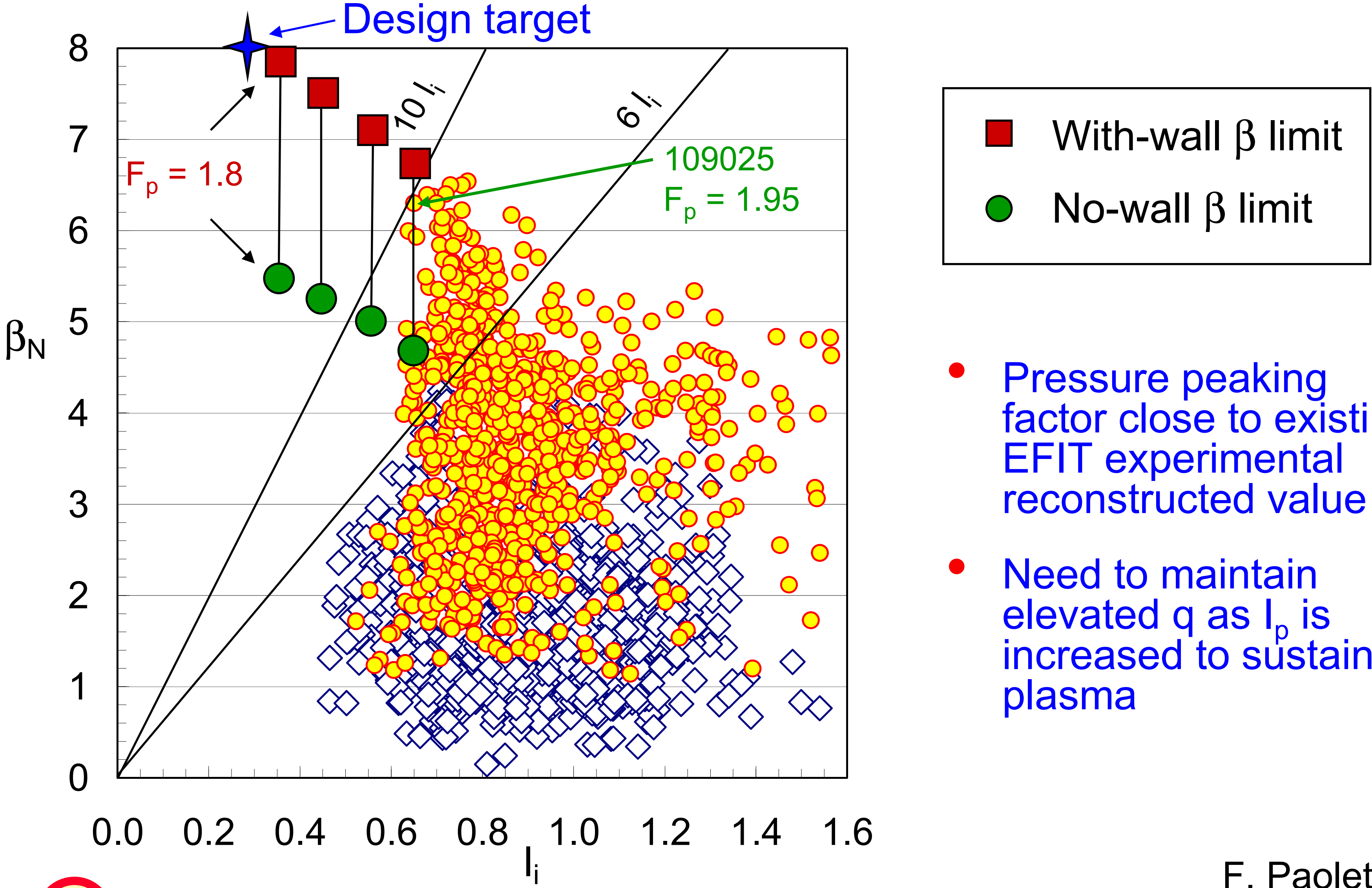
Mode intensifies in divertor region at highest β_N

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



- Determine passive plate modification to optimize RWM stabilization in close coordination with cryopump design (FY03 effort)

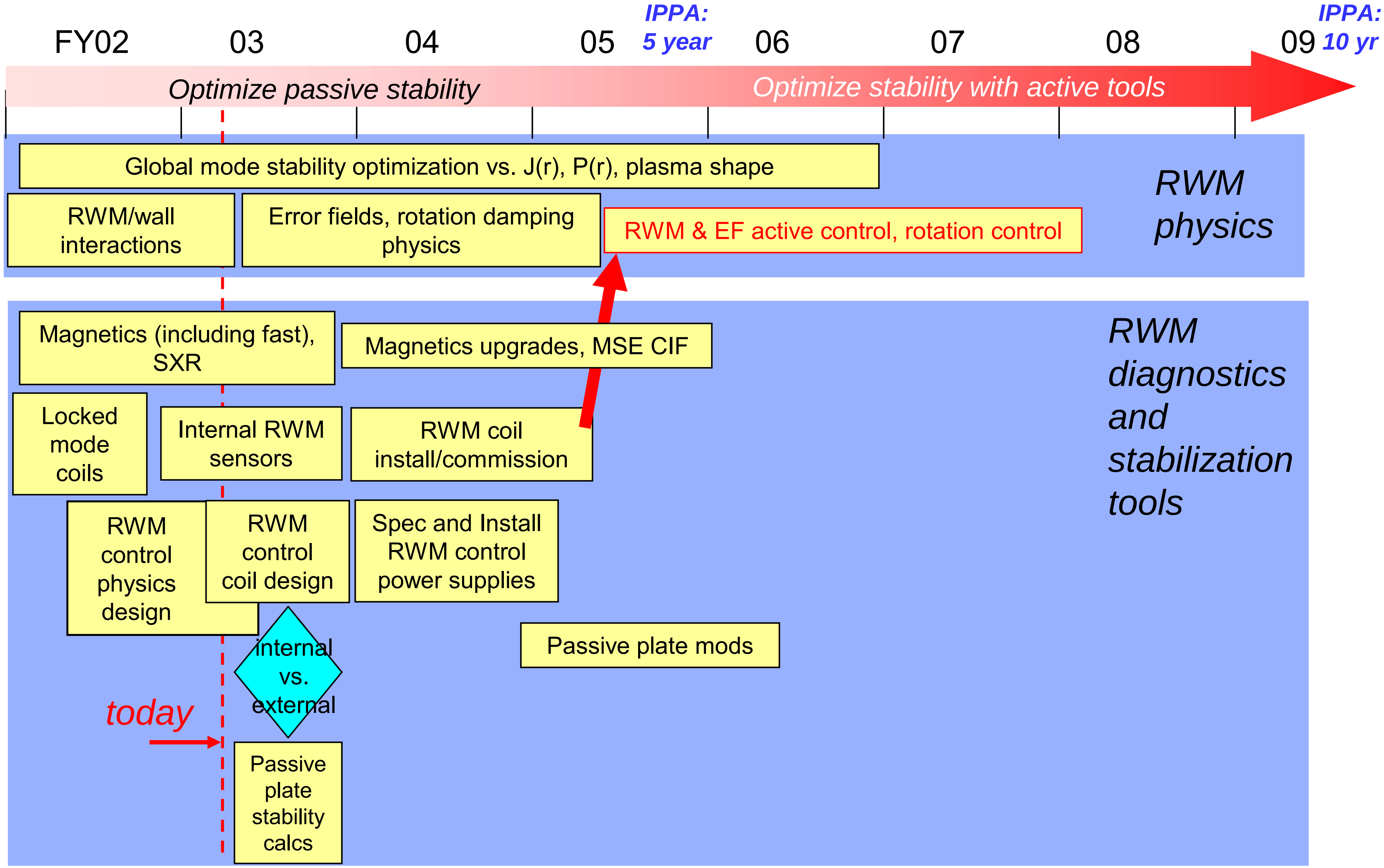
Access to β_N = 8 conceptual design target exists



- Pressure peaking factor close to existing EFIT experimental reconstructed value
- Need to maintain elevated q as I_p is increased to sustain plasma

F. Paoletti

RWM stabilization research follows a logical timeline



High beta global mode stabilization research is being conducted according to plan

- Passive stabilization above ideal no-wall β_N limit by up to 35%
  - Improvement in plasmas with highest β_N up to 6.5; $\beta_N/l_i = 9.5$
- The β_N limit increases with decreasing pressure profile peaking
- Global T_e perturbation measured during RWM
- Rotation damping at $\beta_N > \beta_{N\ \text{no-wall}}$ has two stages
  - Global, non-resonant damping
  - Local, resonant field damping during final stage
- Rotation damping rate substantially decreases as q increases
- Passive stabilizers may become ineffective at highest β_N
  - Passive stabilizer modification coordinated with cryopump design
- Active feedback design shows sustained $\beta_N/\beta_{N\ \text{wall}}$ = 94% possible
- Active feedback system engineering design is the next step