The Resistive Wall Mode and Global Mode Stability Limits in NSTX

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NSTX Results Review

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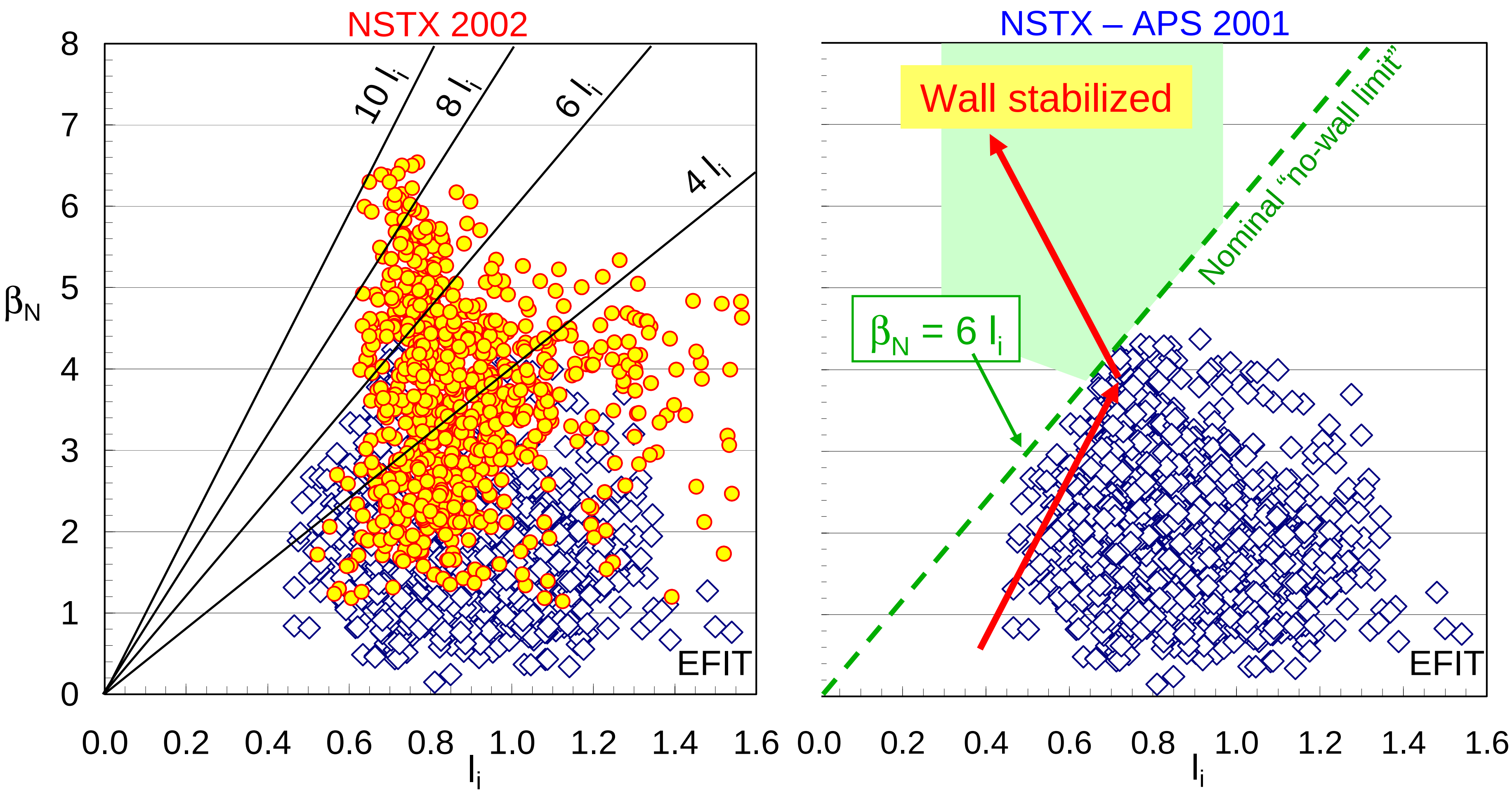
NSTX operating at sufficiently high beta to study beta-induced rotation damping physics

- Research Plan
  - ❑ Establish high beta, wall-stabilized plasma
  - ❑ Evaluate global mode passive stabilization physics
  - ❑ Determine rotation damping mechanisms and physics

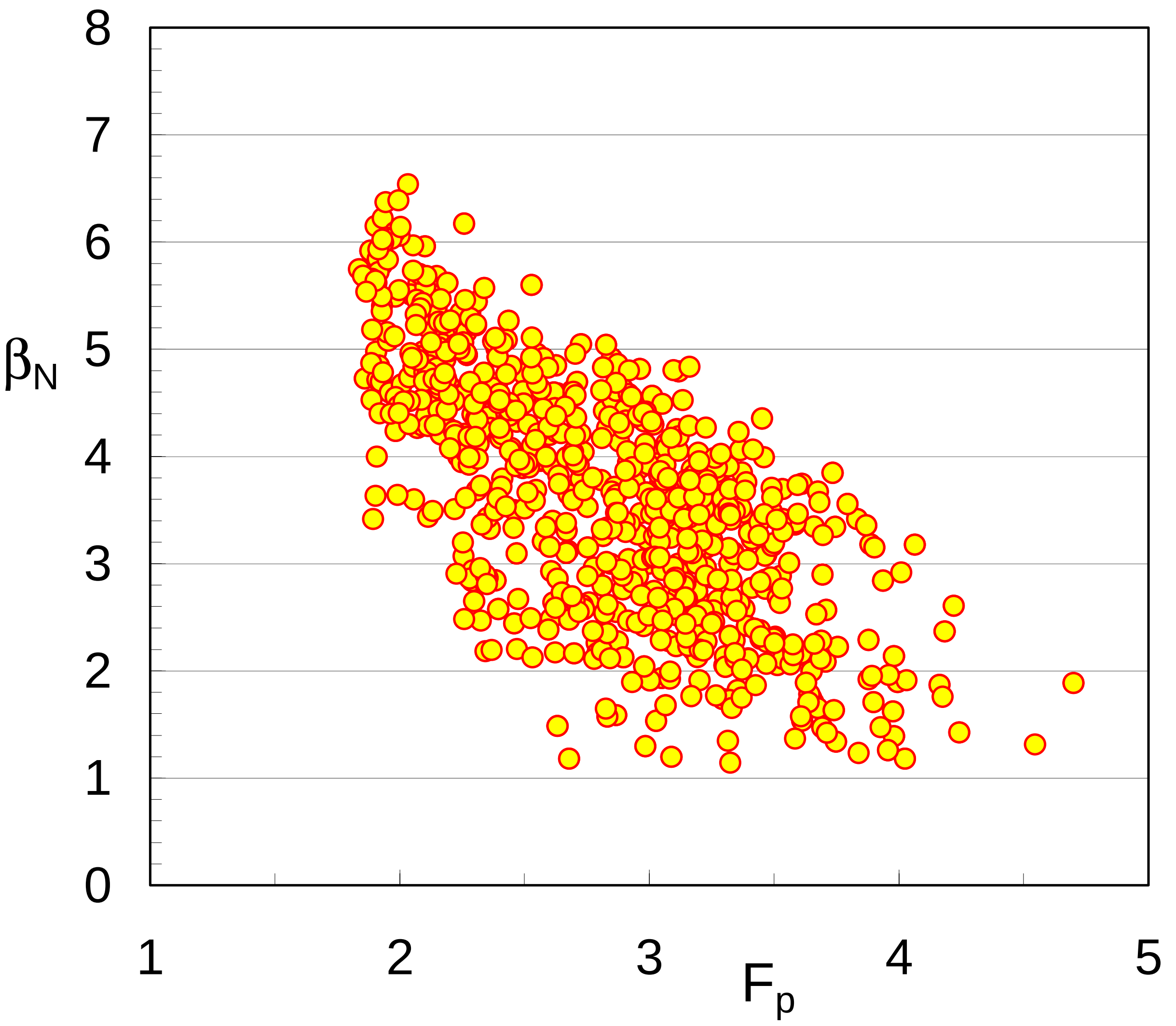
- Outline
  - ❑ Expansion of high beta operating space in CY02
  - ❑ Global mode stabilization by conducting plates
  - ❑ Physics of the resistive wall mode, including rotation damping

CY02 plasma operation now in wall-stabilized space



- Normalized beta, $\beta_N = 6.5$, with $\beta_N/l_i > 9.5$; $\beta_N > 30\%$ over $\beta_{N\ \text{no-wall}}$
- Toroidal beta has reached 34%

Maximum β_N strongly depends on pressure peaking



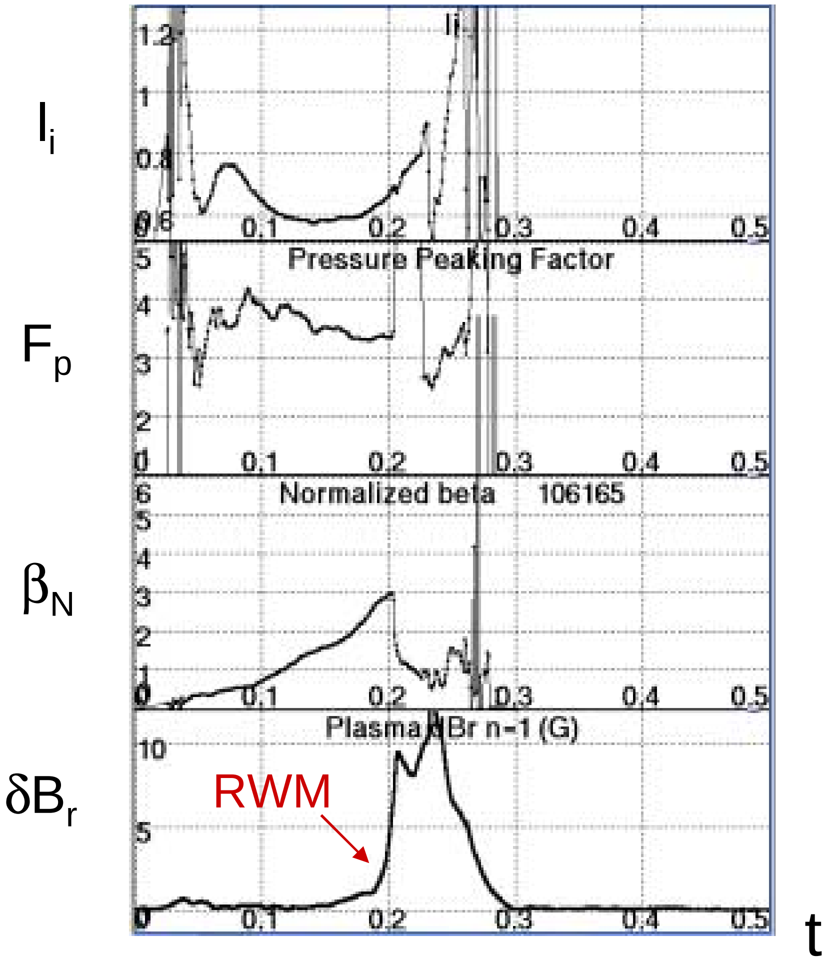
- Time-dependent calculations required to evaluate stability limits and mode structure

Physics improvements yielded higher, sustained β_N

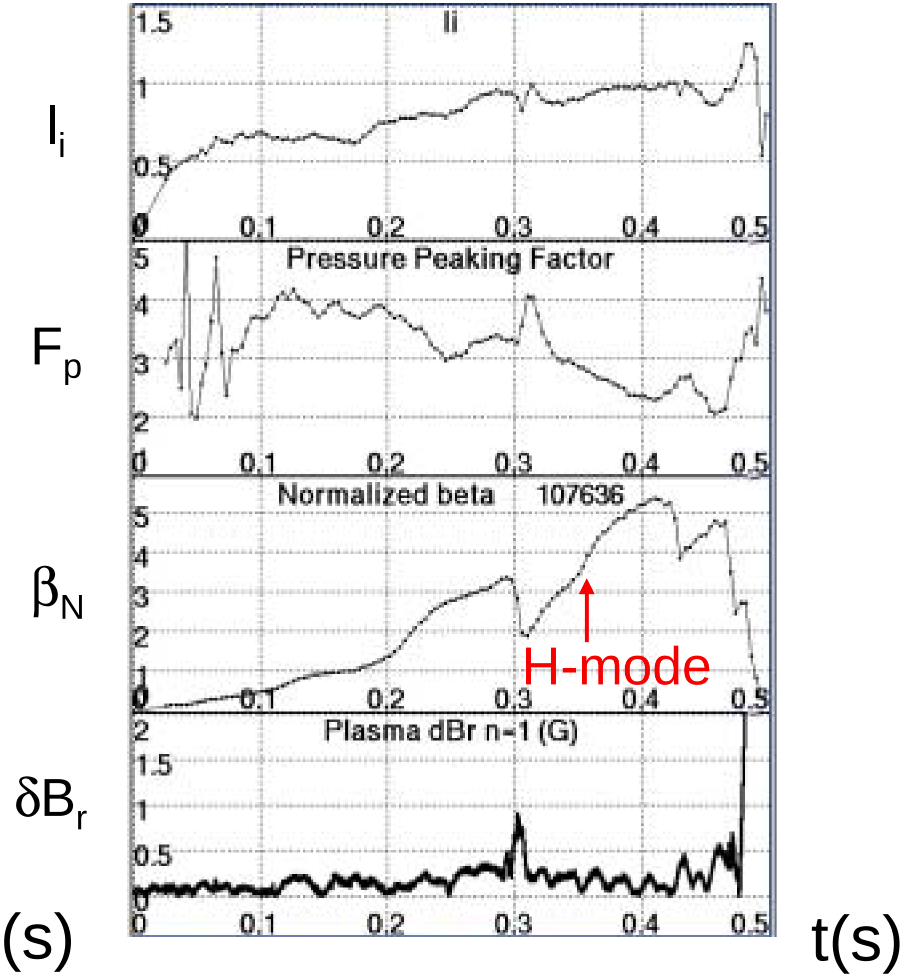
- Reduction of static error field
  - Reduced incidence of low beta locked modes
  - May have reduced rotation damping by mode resonances and beta-driven error field amplified rotation damping
- Maintenance of increased $q_{min} > 1$
  - Previous high β, high static error field plasmas with $q(0) < 1$ typically collapsed without recovery
  - Based on EFIT reconstruction, rather than q measurement
    - Reconstruction constraint “calibrated” to yield correct timing of q(0) appearance and measured inversion radius
- H-mode operation
  - Significant broadening of pressure profile => $F_p = p(0)/\langle p\rangle < 1.9$
  - Profiles are naturally approaching optimal stability profiles (!)

CY02 plasmas operate at high β_N for longer pulse

CY 2001 RWM (High error field)



CY 2002 (reduced error field)



- H-mode broadening of pressure profile raises beta limit
- CY01 RWM induced LMD signal has far greater magnitude than CY02

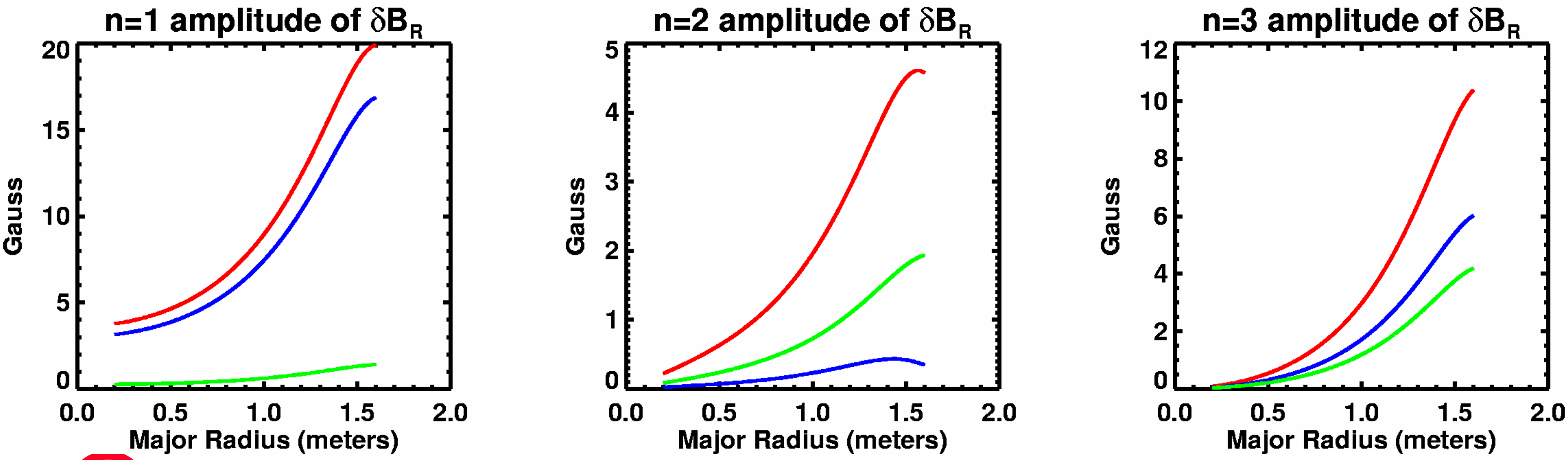
N=1 error field significantly reduced by PF5 correction

- **n=1 amplitude reduced by factor of 12**
- n=2 amplitude increased slightly
  - Still only 2 Gauss at plasma edge
- n=3 is largest predicted amplitude
  - 4 Gauss at plasma boundary
  - Localized effect from coil feeds

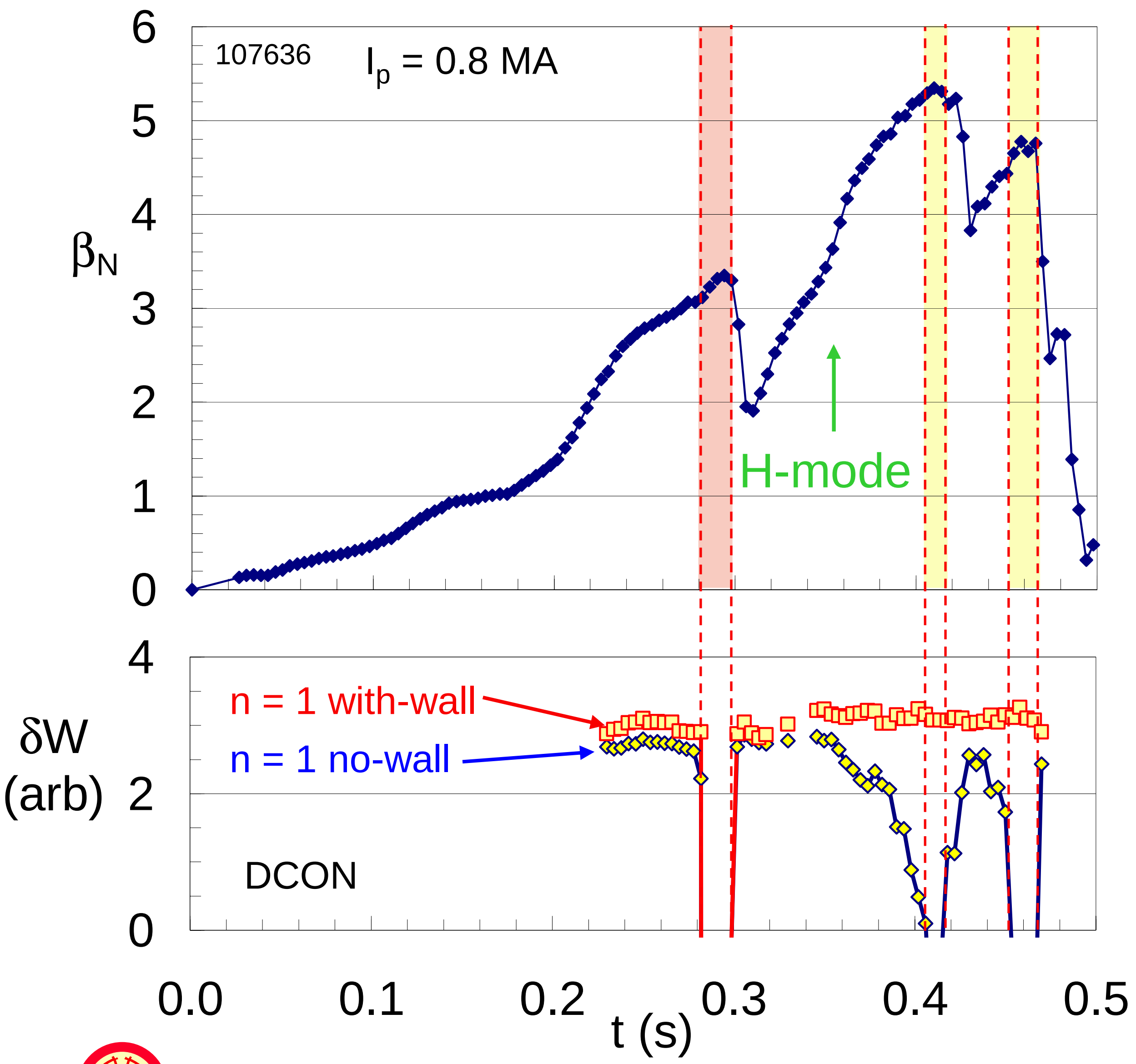
Calculations assume I_{PF5}=10kA

- **RED** = magnetic measurements **before correction**
- **BLUE** = measured coil radius, **before correction**
- **GREEN** = measured coil radius, **after correction**

J. Menard



Ideal MHD stability compared to plasma evolution

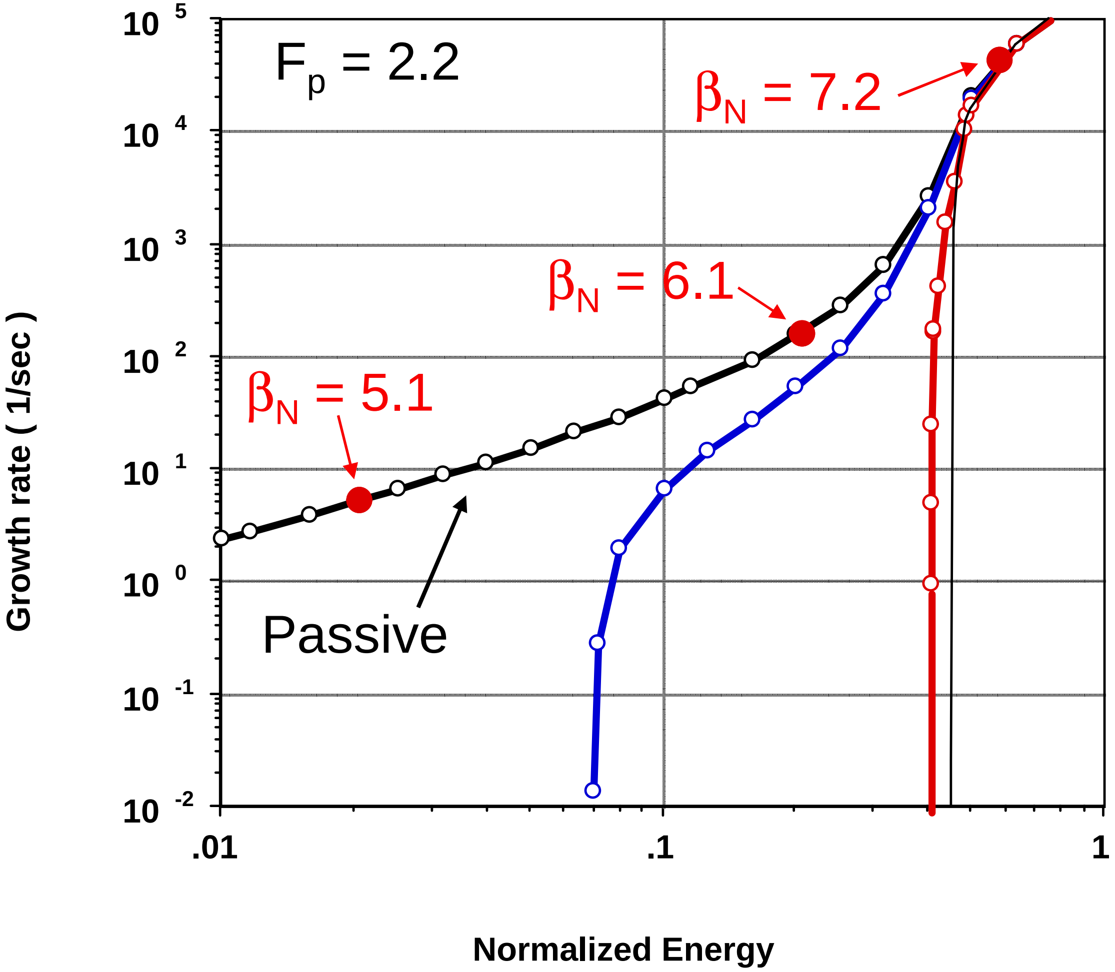


- "Between-shots" stability analysis using DCON
- First beta collapse occurs when with-wall β limit is violated
  - Pre-H-mode
  - Plasma recovery a new feature since PF5 error field reduced
- High β_N plasma computed stable with NSTX wall
  - No-wall limit mildly violated
  - Rotation insufficient for passive stabilization?

CY02 data show details of passive stabilization

- For stabilization to occur (simplest case)
  - β_N > ideal no-wall limit
  - Toroidal rotation > Ω_{crit} (typically defined at rational surface)
  - Mode must couple to wall => $\gamma^{*}\tau_{wall}$ ~ 1
- Data shows
  - Plasmas have exceeded ideal no-wall β limit by > 30%
  - Ω_{ϕ} must remain sufficiently large (preliminary result: need CHERS)
  - Plasmas have reached with-wall limit and suffered β collapse
  - Mode growth rate dependent on beta
    - wall less effective at higher beta due to higher instability drive and change of mode structure
  - Plasma drops to lower beta (near no-wall ideal limit) during high beta “cycles”, where the wall regains stabilization effect.
  - NOTE: CHERS DATA is core only and is *preliminary*

Theoretical mode passive stabilization growth rate depends on β_N

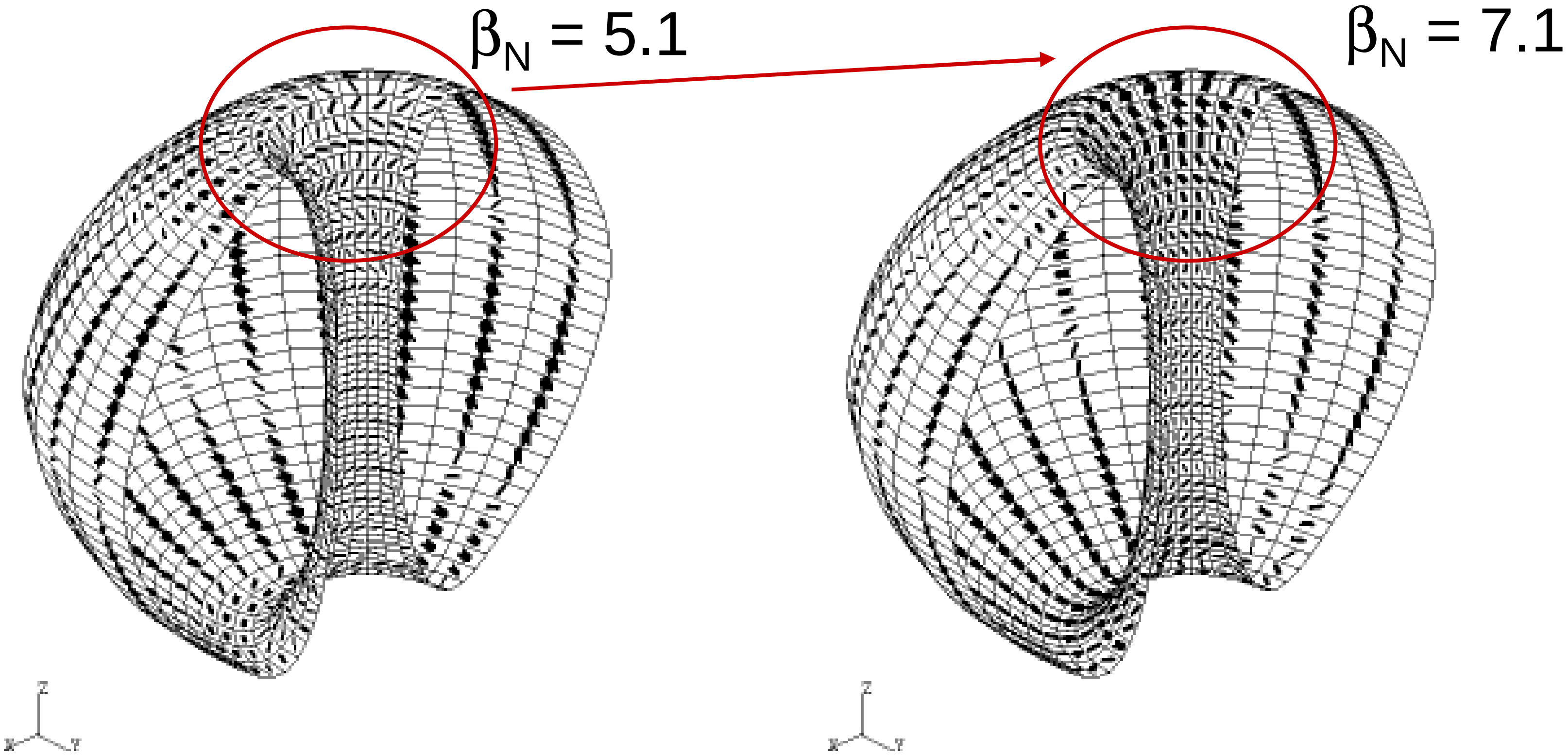


- VALEN calculations based on extrapolation of shot 106165
- Growth rate also depends on mode structure

VALEN: J. Bialek

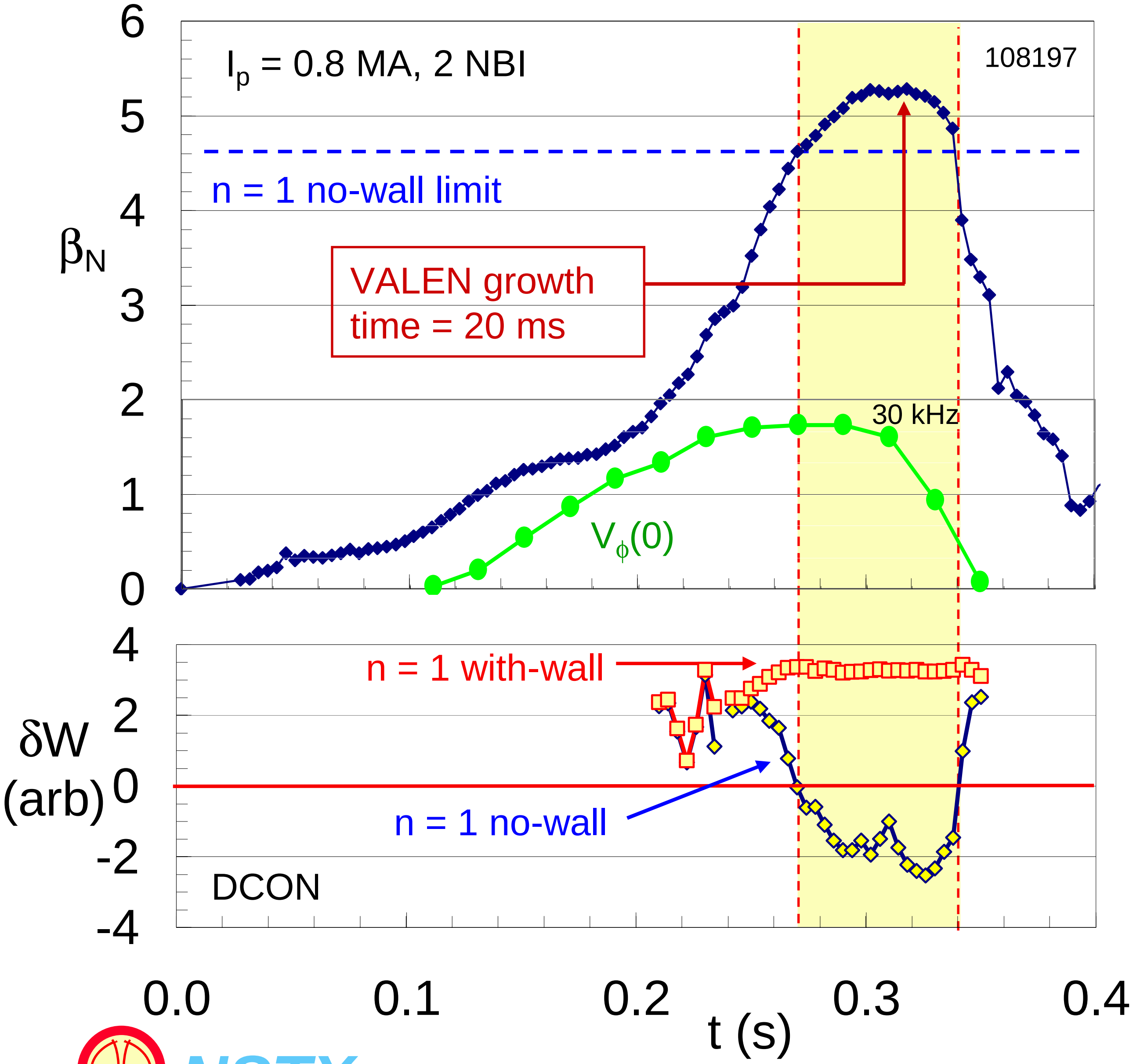
Mode intensifies in divertor region at highest β_N

VALEN / DCON



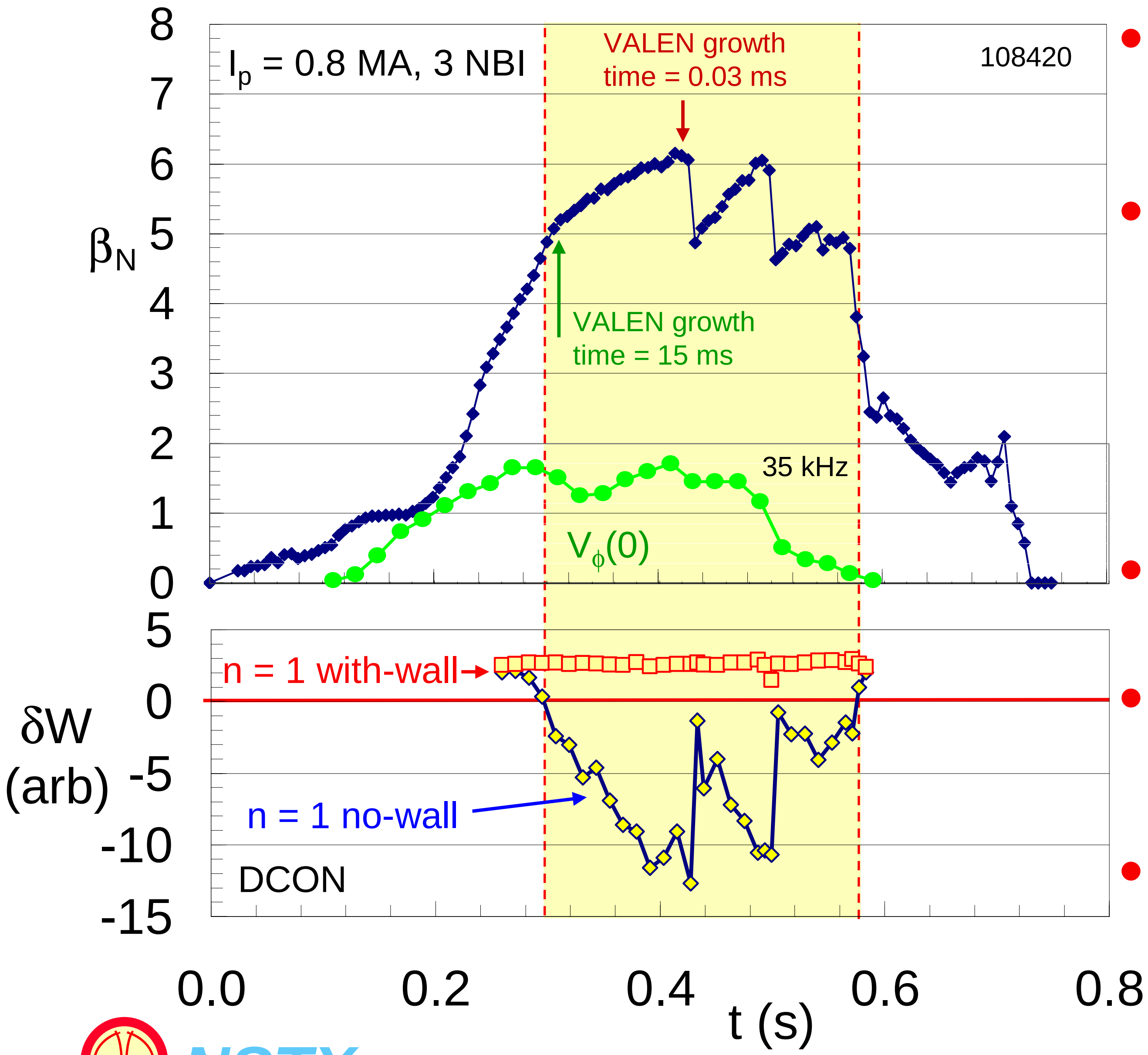
- Increased pressure drive and mode structure change yield lower growth time

Passive stabilization effective with sufficient V_ϕ



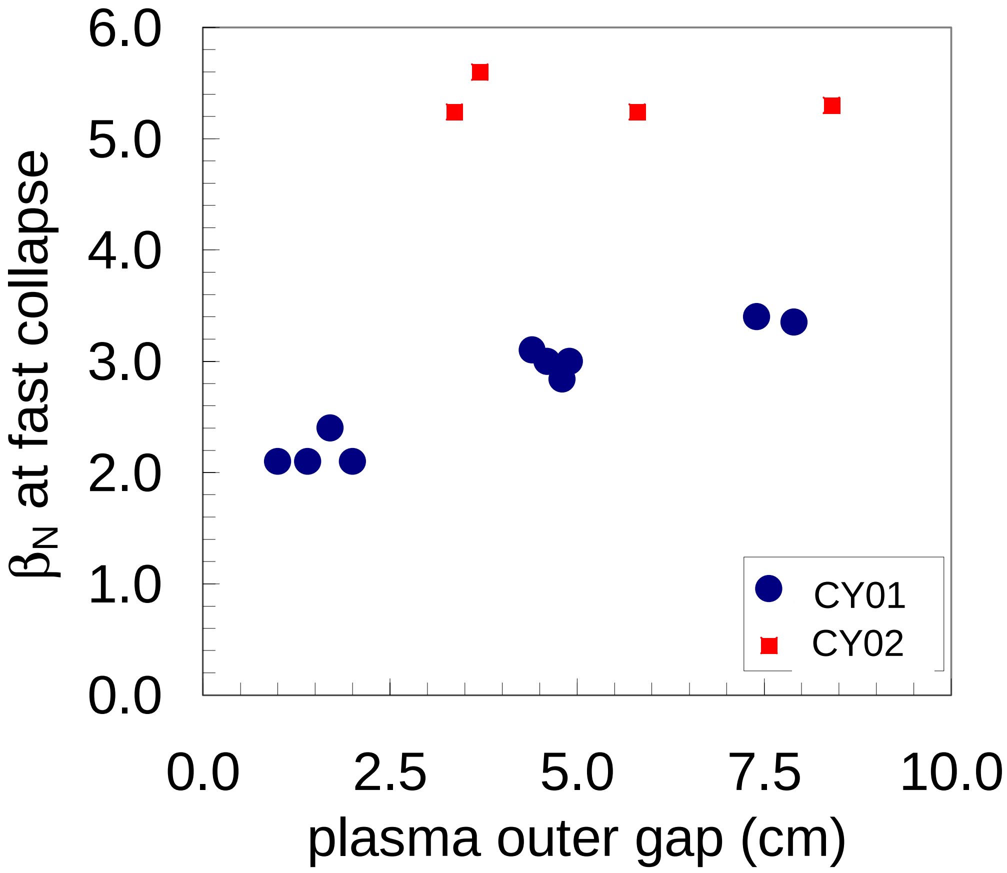
- Beta collapse on timescale τ_{wall}
  - VALEN growth time = 20ms
  - Duration ~ 3.5 τ_{wall}
- Passive stabilizer effectively slows growth in this condition
- Rapid rotation damping slows plasma in ~ τ_{wall}, leading to β collapse

Passive stabilization less effective at highest β_N



- Plasma sustained at 30% over no wall limit for 18 τ_{wall}
- Passive stabilizer loses effectiveness at maximum β_N
  - ❑ VALEN growth time now much shorter (0.03 ms) at collapse time
- $V_\phi(0)$ increases as $\beta_N >> \beta_N$ no-wall
- Stabilizer regains effectiveness after β_N collapse
- Operation above no-wall limit ceases when $V_\phi(0)$ small

CY02 beta limit with reduced error field independent of plasma proximity to wall



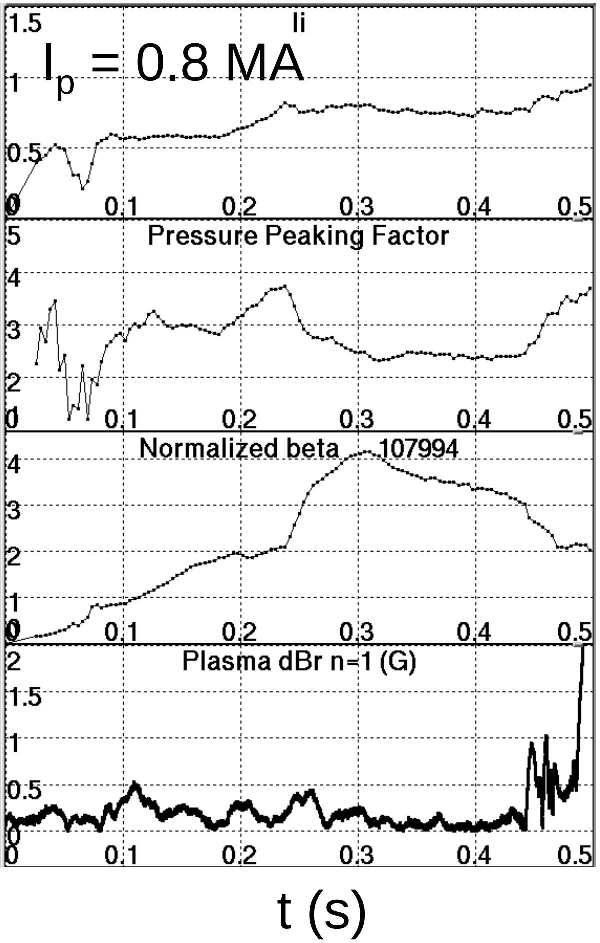
- At β_N ~ 5, mode is well-coupled to the wall, independent of gap
- Higher error field in CY01 may also have caused lower limit with smaller outer gap
  - Increased rotation damping

RWM Identified and Linked to Rapid Rotation Damping

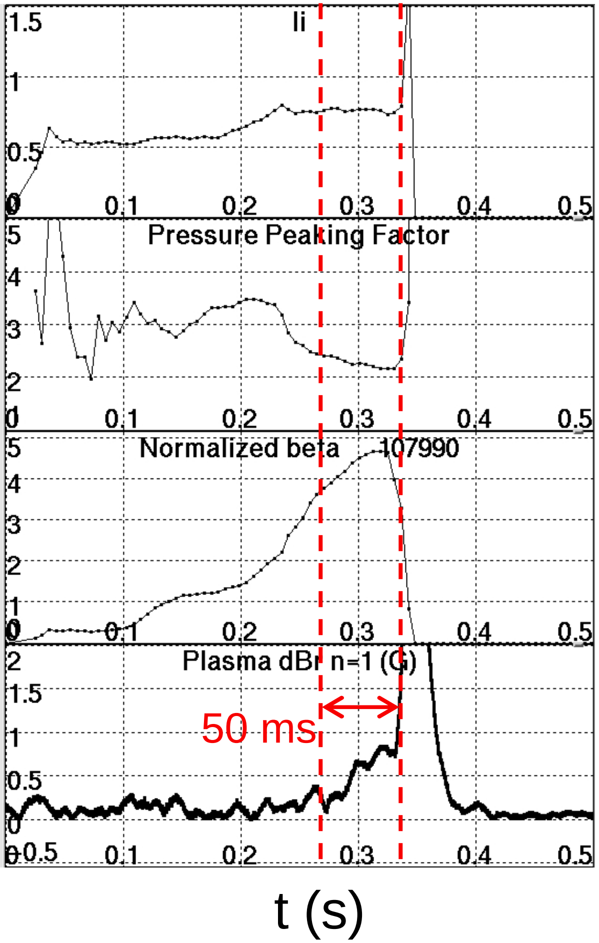
- Three phases of rotation damping in RWM evolution
  - ❑ (1) Slow rotation damping, mode not detected in LMD
  - ❑ (2) Beta saturation and reduction; increased V_ϕ damping
  - ❑ (3) Very rapid V_ϕ decrease over $\Delta t \sim \tau_{wall}$, followed by rapid beta collapse; mode detected in LMD, but not always at high $B_t > 0.4$ T.
- RWM is pressure driven
  - ❑ Non-beta effects may reduce toroidal rotation before RWM onset
    - Error field resonances, islands, density increase
- Global mode observed as precursor to enhanced rotation damping

RWM observed at B_t = 4kG and is pressure dependent

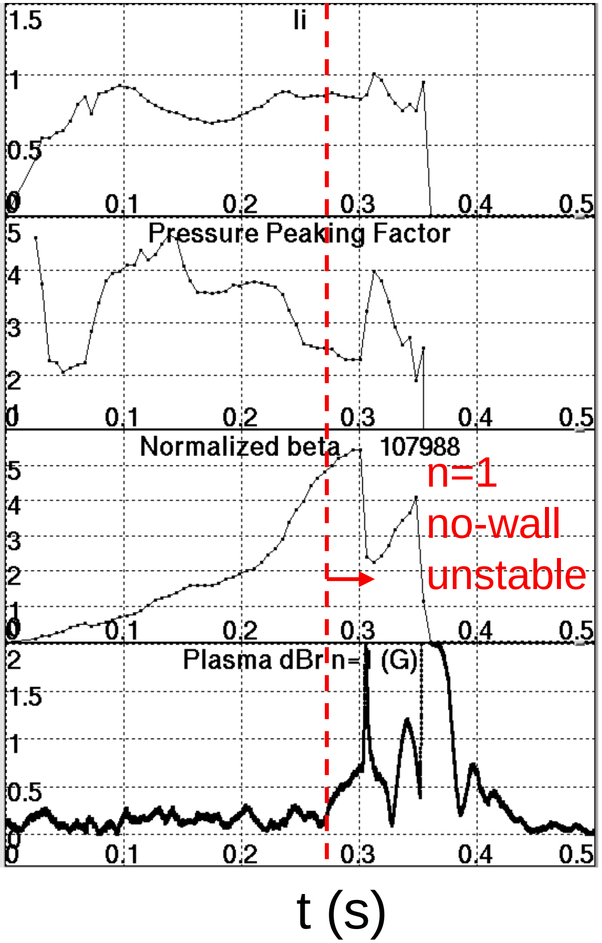
1 NBI source



2 NBI sources

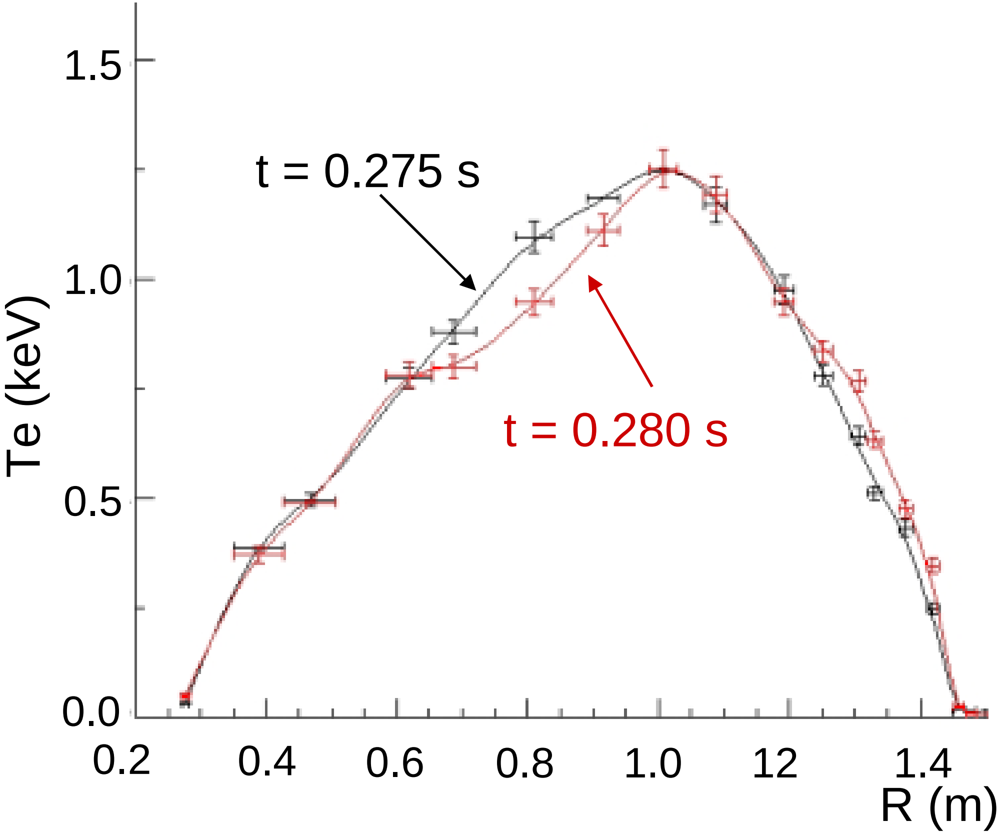


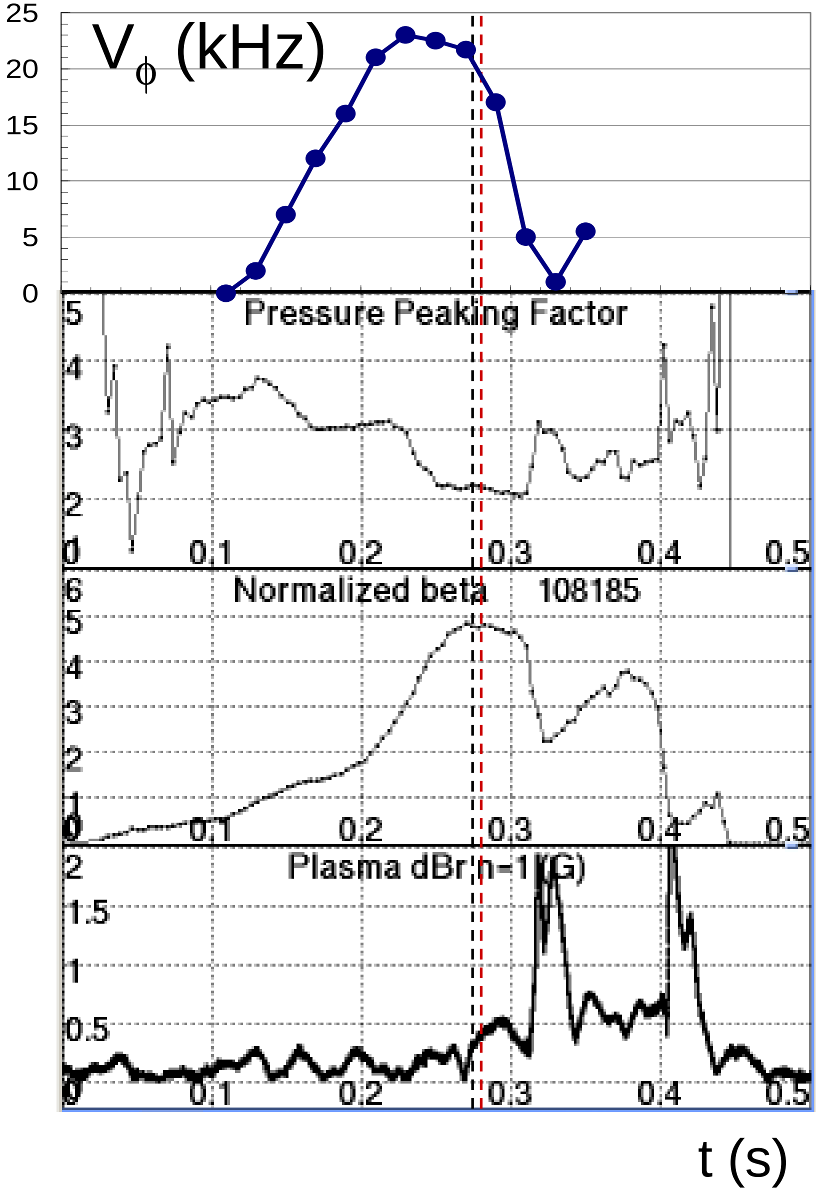
3 NBI sources



- VALEN growth time => 2 NBI: 58 ms 3 NBI: 34 ms

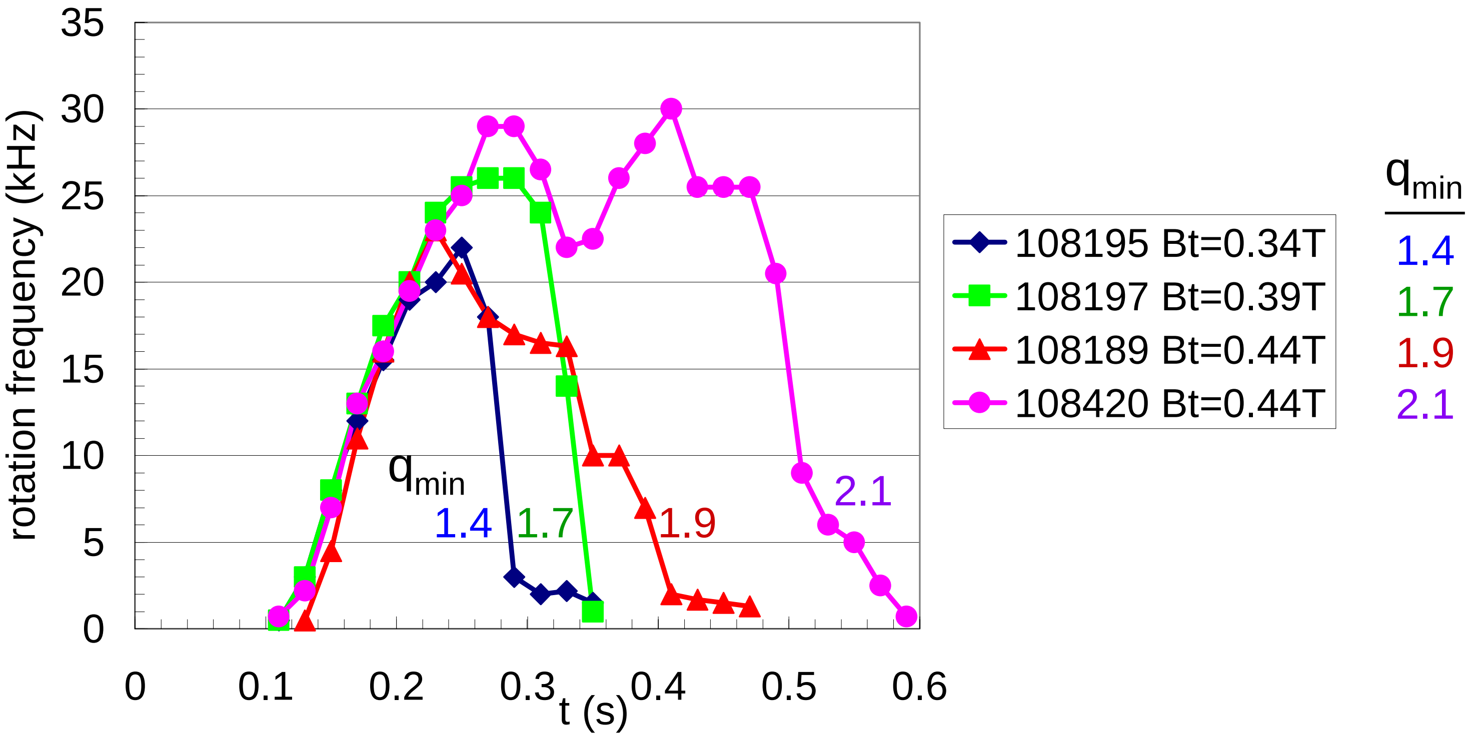
T_e perturbation measured during RWM





- δT_e is an asymmetric kink-type displacement
- Core rotation damping greatly increases as kink develops

Core rotation damping rate dependent on B_t

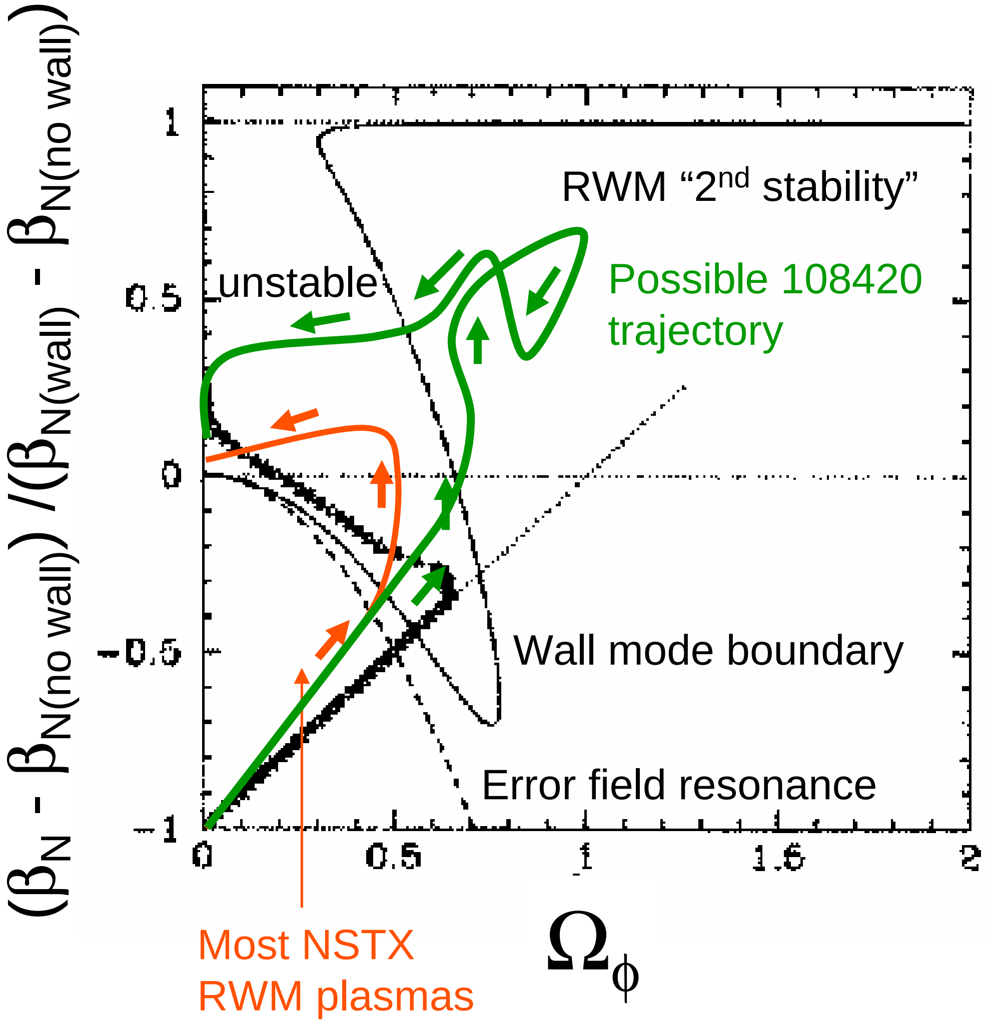


- Largest rotation damping at $B_t < 0.4T$, $q_{min} < 2$ ($dV_\phi/dt \sim -600$ kHz/s)
  - Factor of 8 times larger than damping from n=2 island (2001 result)
- When $q_{min} \sim 2$, initial rotation damping rate is reduced and V_ϕ is maintained longer
- Theory expects rotation damping rate to depend on rational surfaces in plasma. Is $q_{min} > 2$ cause of lower rotation damping?

Many key RWM physics results await CHERS data

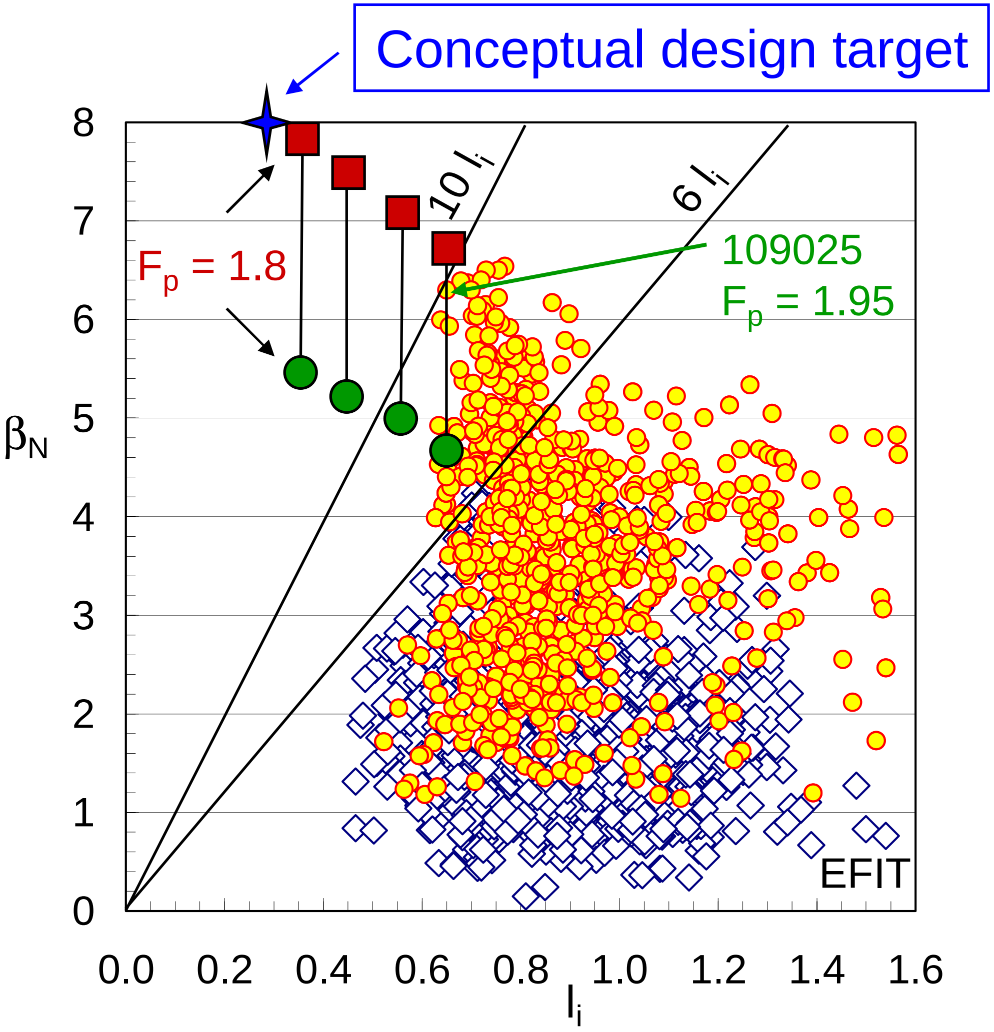
- Identification of the RWM
  - V_ϕ rotation damping (profile) most sensitive indication of RWM
- Rotation damping profile
  - Effect of error field resonance; rational surfaces in RWM plasma
- Rotation damping rate scaling with δB_r
- Critical rotation frequency
  - Need V_ϕ profile evolution to determine Ω_{crit}
  - Does Ω_{crit} scale with Alfven speed, or sound speed?
  - Compare Ω_{crit} to theory: Gimblett-Hastie; Fitzpatrick-Aydemir
- Resistive wall mode operational space
  - Trajectories in (β_N, V_ϕ space) and comparison to RWM stability theories

Fitzpatrick-Aydemir RWM Stability Space



- Simplified model of RWM stability
  - Cylindrical, single “m” number
- Dispersion relation includes
  - error field resonance drag
  - RWM drag
- RWM “second stability” is a possible hypothesis for shot 108420
  - Need CHERs rotation profile evolution to map out NSTX trajectory in this space

Access to high beta conceptual design target exists



F. Paoletti

- Need to determine passive stabilizer effectiveness along access path

Research on passive stabilization, RWM and rotation damping physics has begun

- Plasmas have exceeded ideal no-wall β_N limit by 30%
- The β_N limit strongly decreases with increasing pressure profile peaking
- Passive stabilizers can become ineffective at highest β_N due to increased pressure drive and altered ST mode structure
- Mode measured by Thomson that correlates with onset of enhanced rotation damping when $\beta > \beta_N$.
- Core rotation damping rate dependent on B_t
  - ❑ May be related to eliminating drag-inducing q = 2 surface
- More key RWM / rotation damping physics questions may be addressed, *but only when $V_\phi(R,t)$ becomes available!*