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Resistive Wall Mode Stabilization in NSTX

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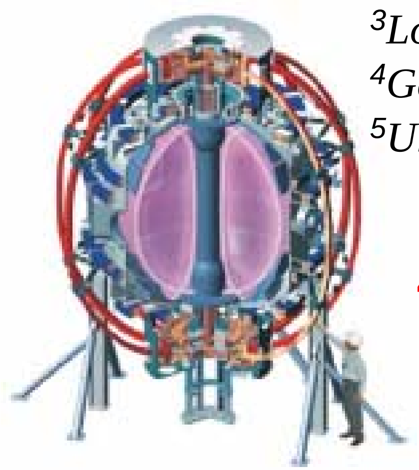

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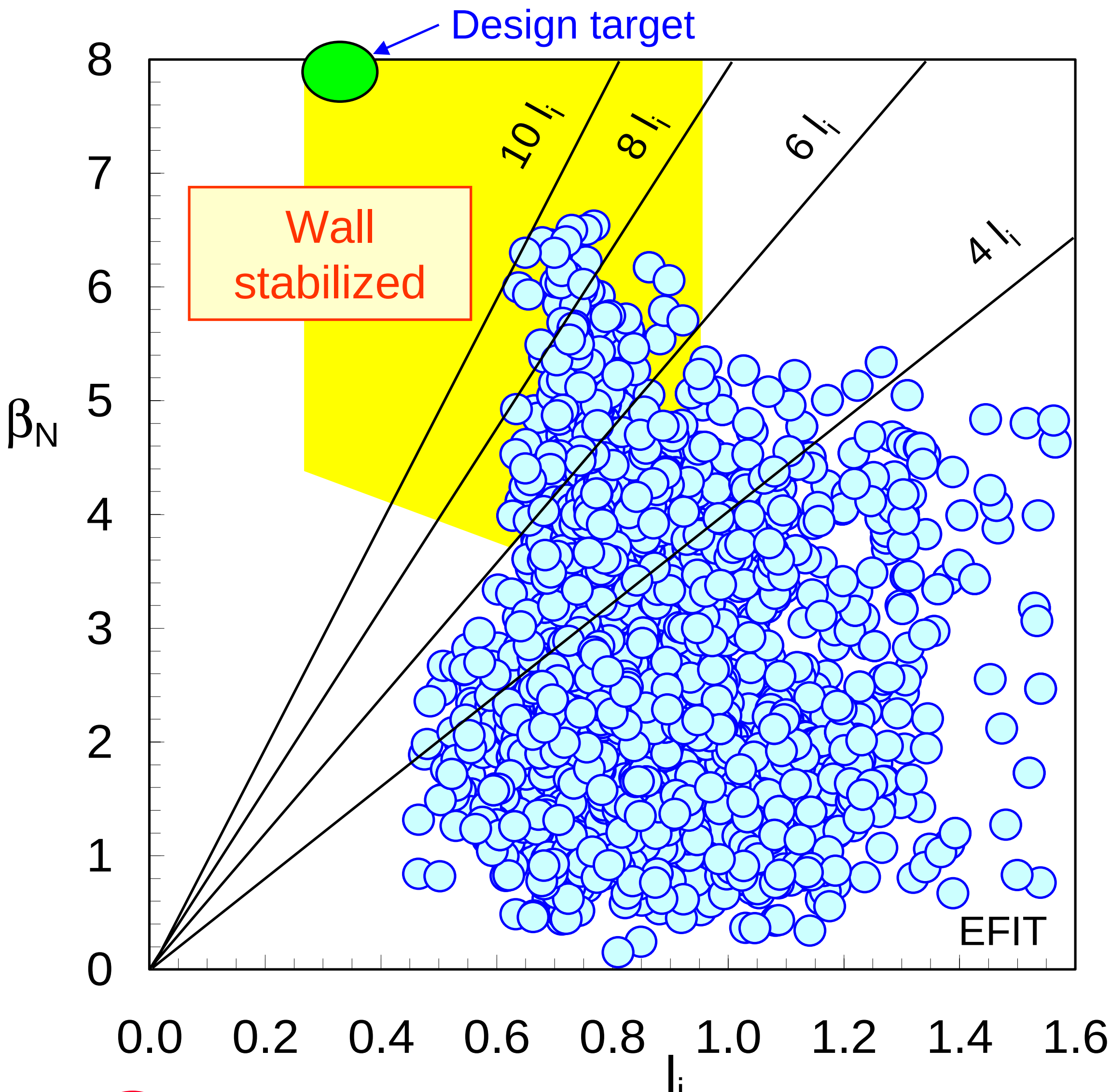
NSTX

NSTX Preparing for Active Stabilization of High β Global MHD Instabilities

- Motivation
  - Resistive wall mode (RWM) identified and associated with global rotation damping
  - Beta collapse can follow rotation damping when $\beta_N > \beta_{N\ \text{no-wall}}$

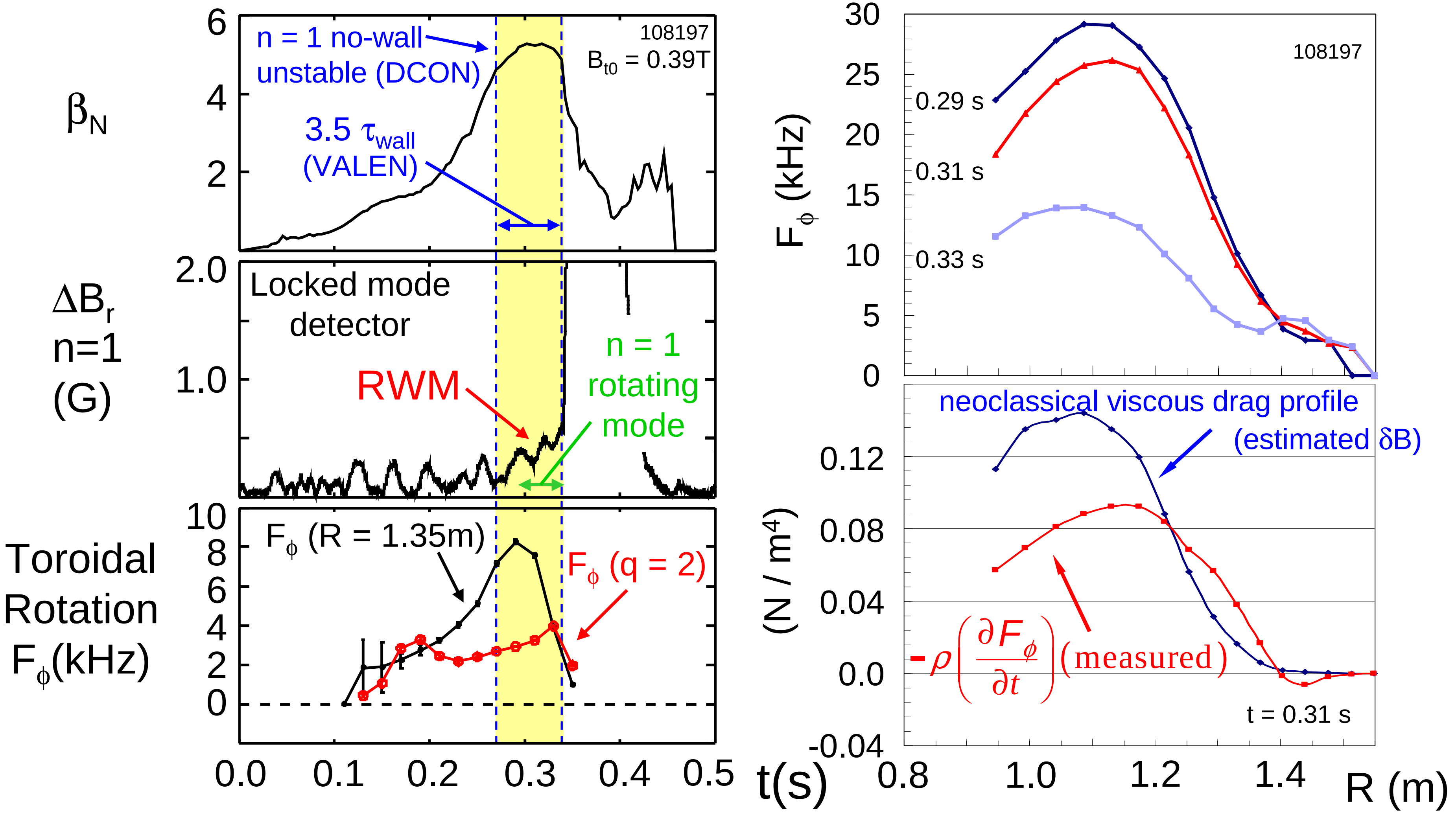
- Approach
  - Examine physics of passive stabilization
  - Enhance mode detection system (A. Sontag, talk KO1.005)
  - Study rotation damping mechanisms (W. Zhu, poster LP1.013)
  - Determine impact of rapid rotation on equilibrium
  - Design and implement active feedback stabilization system

NSTX plasmas operate in wall-stabilized space



- Normalized beta, $\beta_N = 6.5$, with $\beta_N / l_i > 9.5$
- β_N up to 35% over $\beta_{N\ \text{no-wall}}$ (computed using DCON)
  - Stability limit dependent on both l_i and pressure peaking
- Toroidal beta has reached 35% ($\beta_t = 2\mu_0 \langle p \rangle / B_0^2$)

Rapid rotation damping before β collapse at B_t < 0.4T



- Rotation damping rate more than 5 times greater vs. $\beta_N < \beta_{N\ no\text{-}wall}$
- Global F_ϕ damping mechanism rather than localized, resonant effect

(quantitative experimental comparison - W. Zhu, poster LP1.013)

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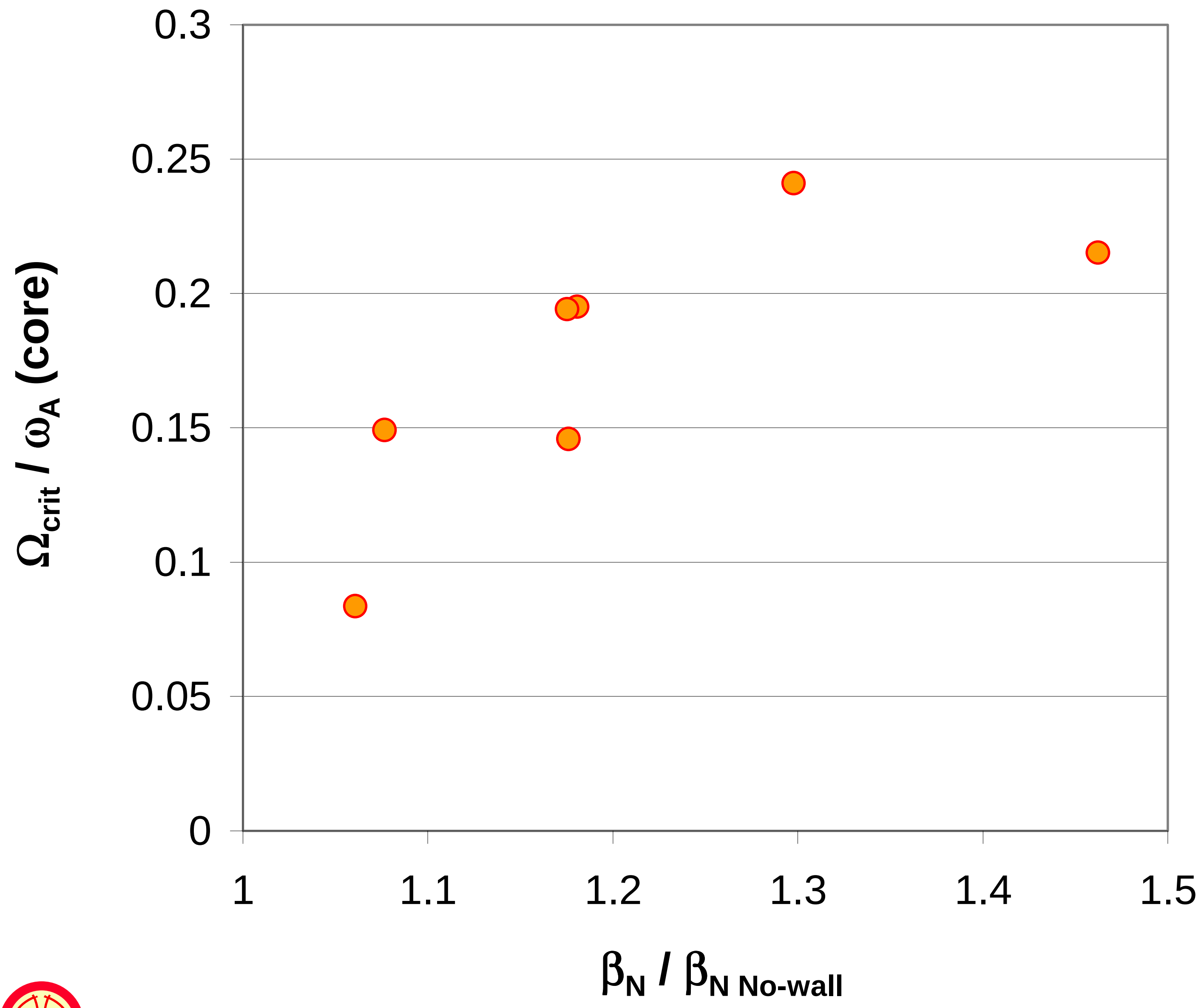
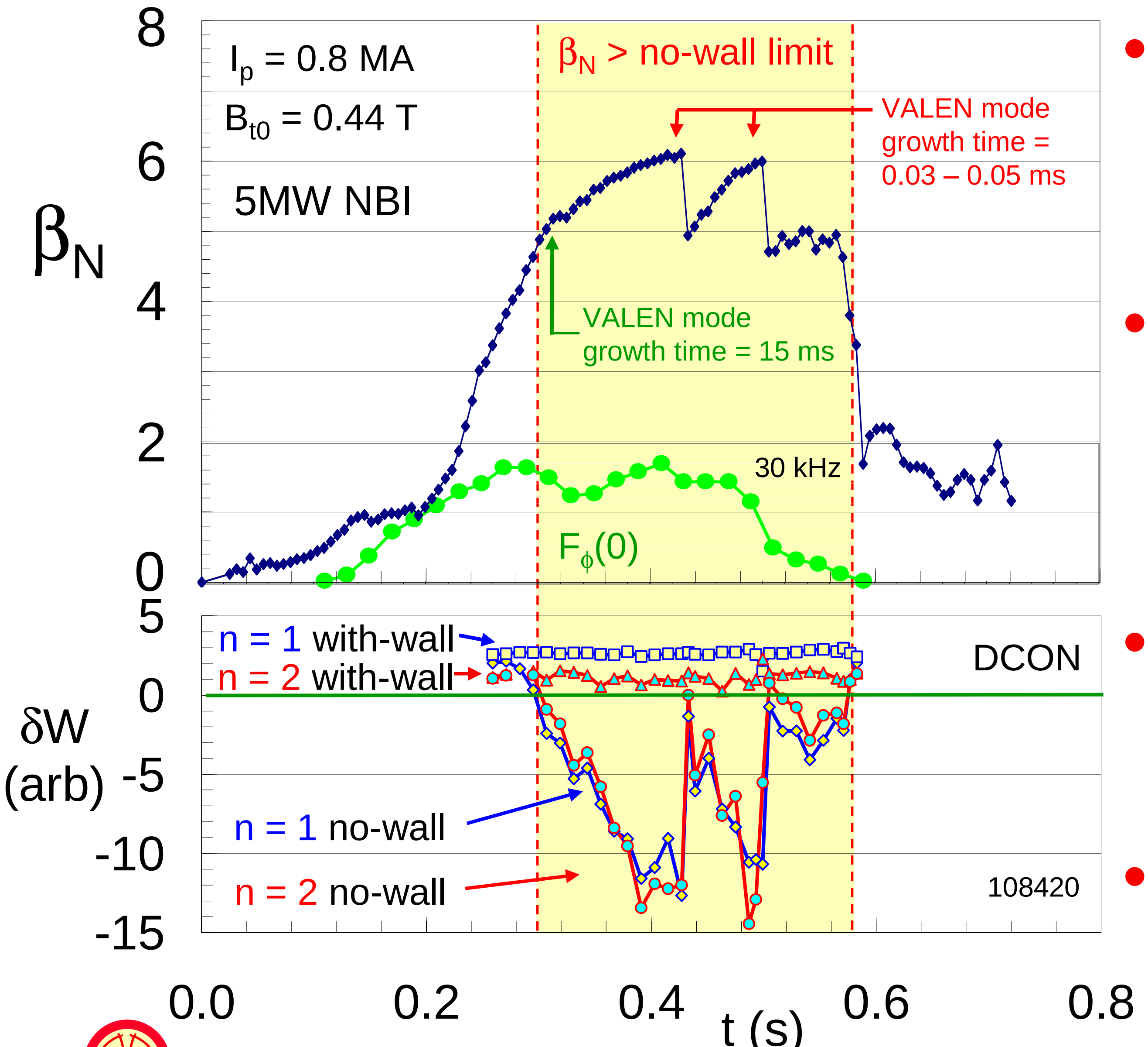
Critical rotation frequency depends on $\beta_N/\beta_{N\text{-Nowall}}$



Plasma stabilized above β_N-no-wall for 18 τ_{wall} (B_t > 0.4T)



- Plasma approaches with-wall β_N limit
  - VALEN growth rate becoming Alfvénic
- Passive stabilizer loses effectiveness at maximum β_N
  - Neutrons collapse with β_N - suggests internal mode
- n = 1 RWM not observed
  - n = 2 computed to be unstable
- EFIT reconstructed β_N includes rotation

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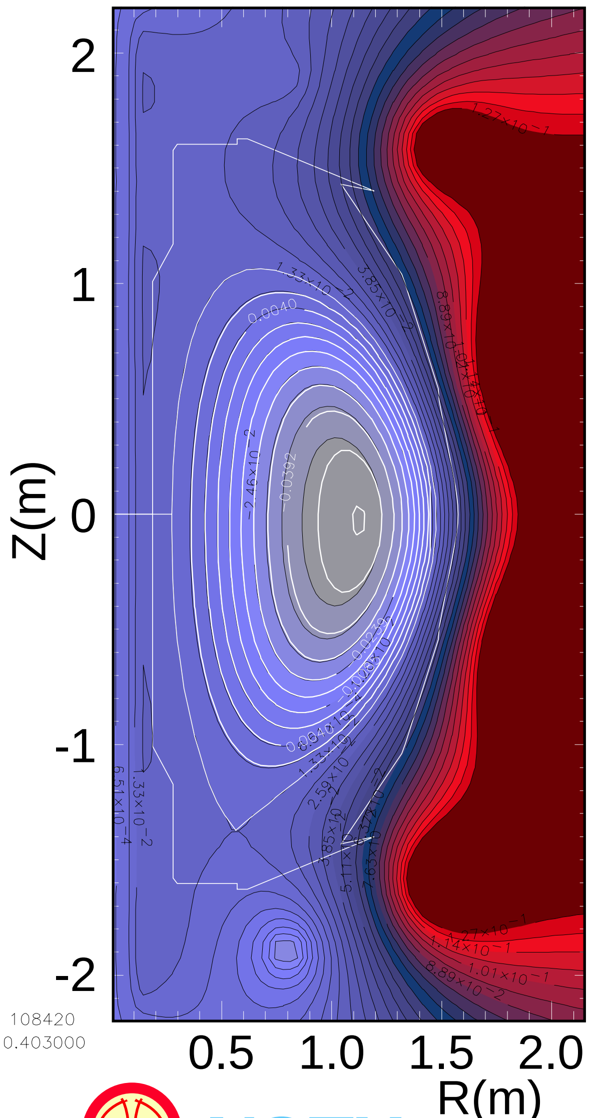
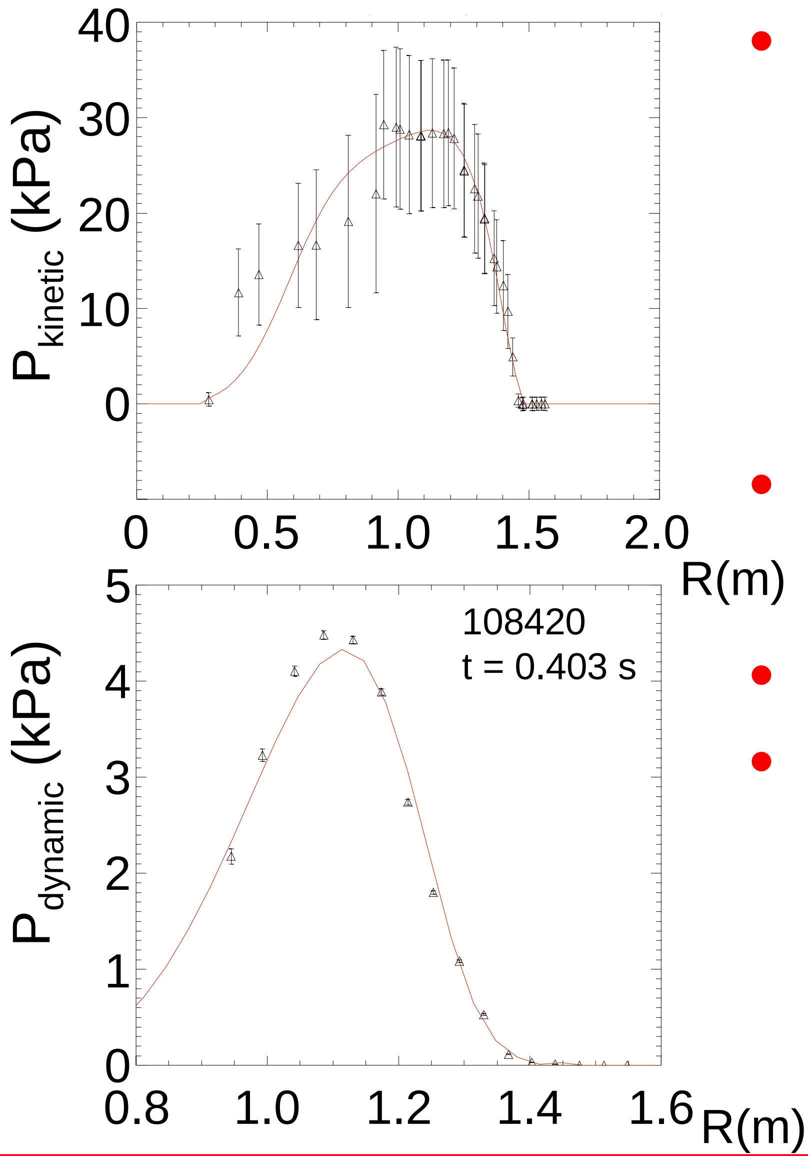
NSTX EFIT reconstructions now using T_i, Z_{eff} profiles, and fit to plasma toroidal rotation

Poloidal flux and pressure

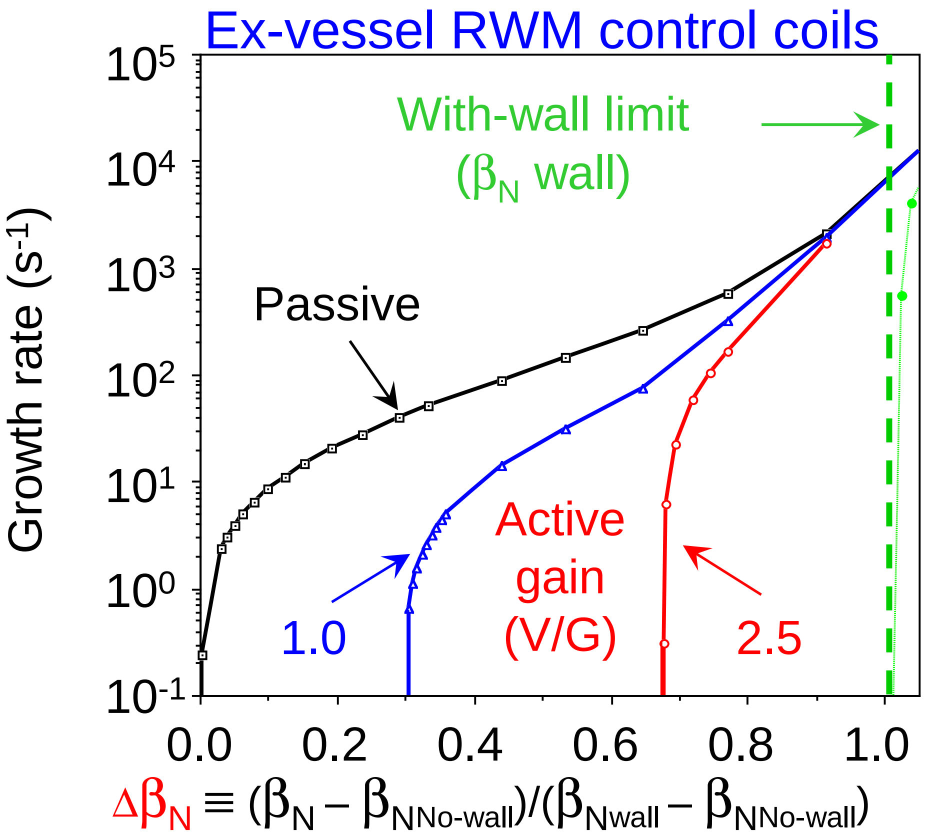


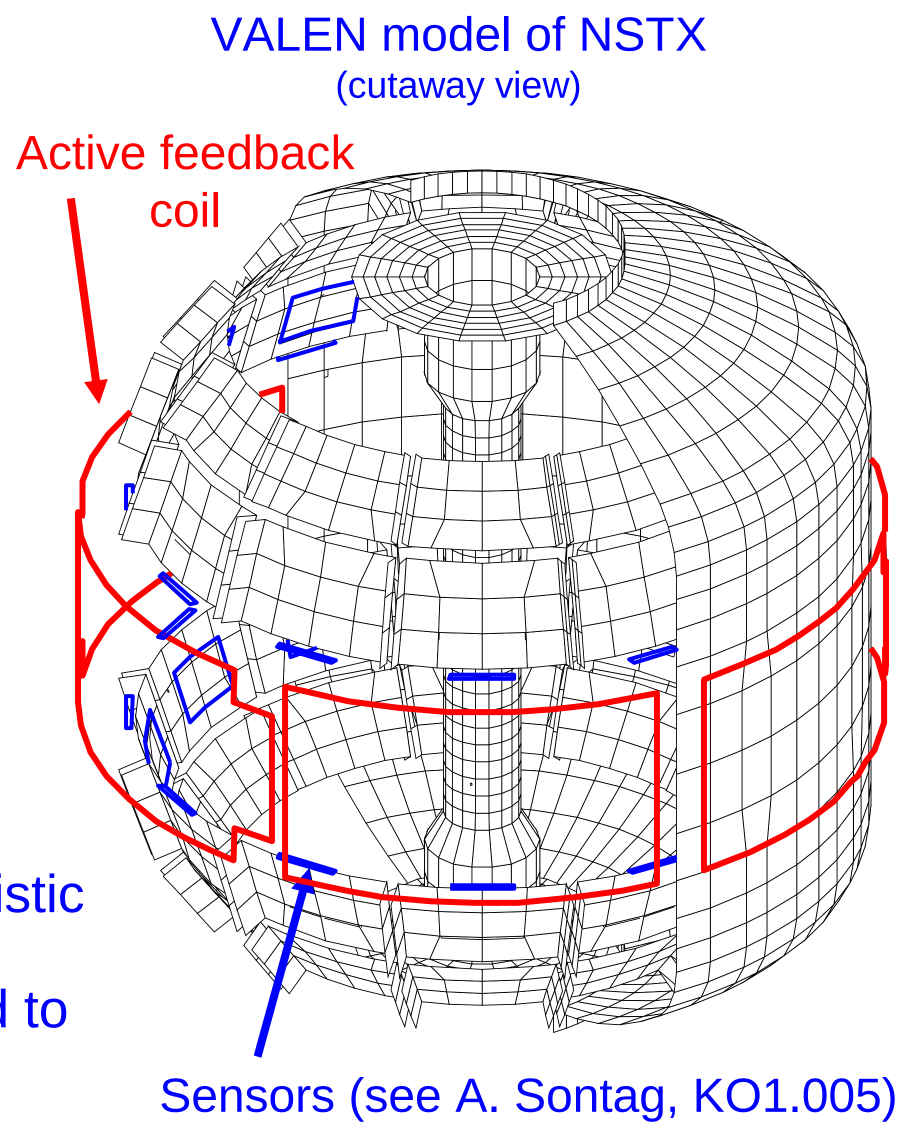


- Exact rotation solution fitting total and dynamic plasma pressure at (R, Z=0)
  - A few thousand shot*times run
  - Estimate for P_{fast}
- Stored energy with/without $V\phi$ = +/- 3%
- $(R_{pmax} - R_{axis})/a$ = 8%
- Significant drop in χ_{mag}^2 and χ_p^2 even though 50% more P channels and smaller error bars

(special thanks to L. Lao)

Active control may sustain 68% margin above $\beta_{Nno\text{-}wall}$



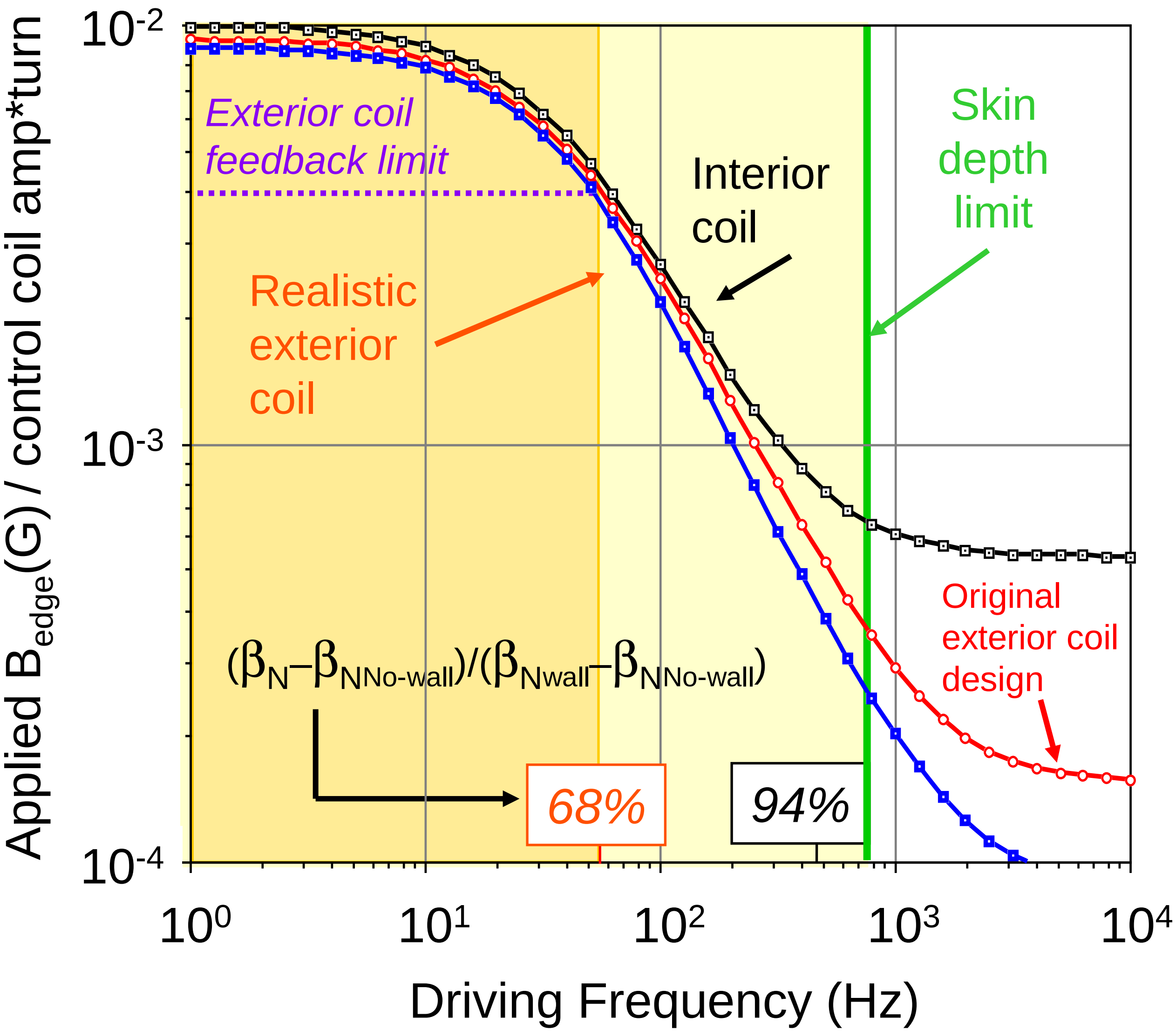


- External control coil design with realistic geometry
- Internal control coil design computed to reach $\Delta\beta_N$ = 94%

(Equilibria used have $\beta_{Nno\text{-}wall}$ = 5.1; β_{Nwall} = 6.9)

VALEN (J. Bialek)

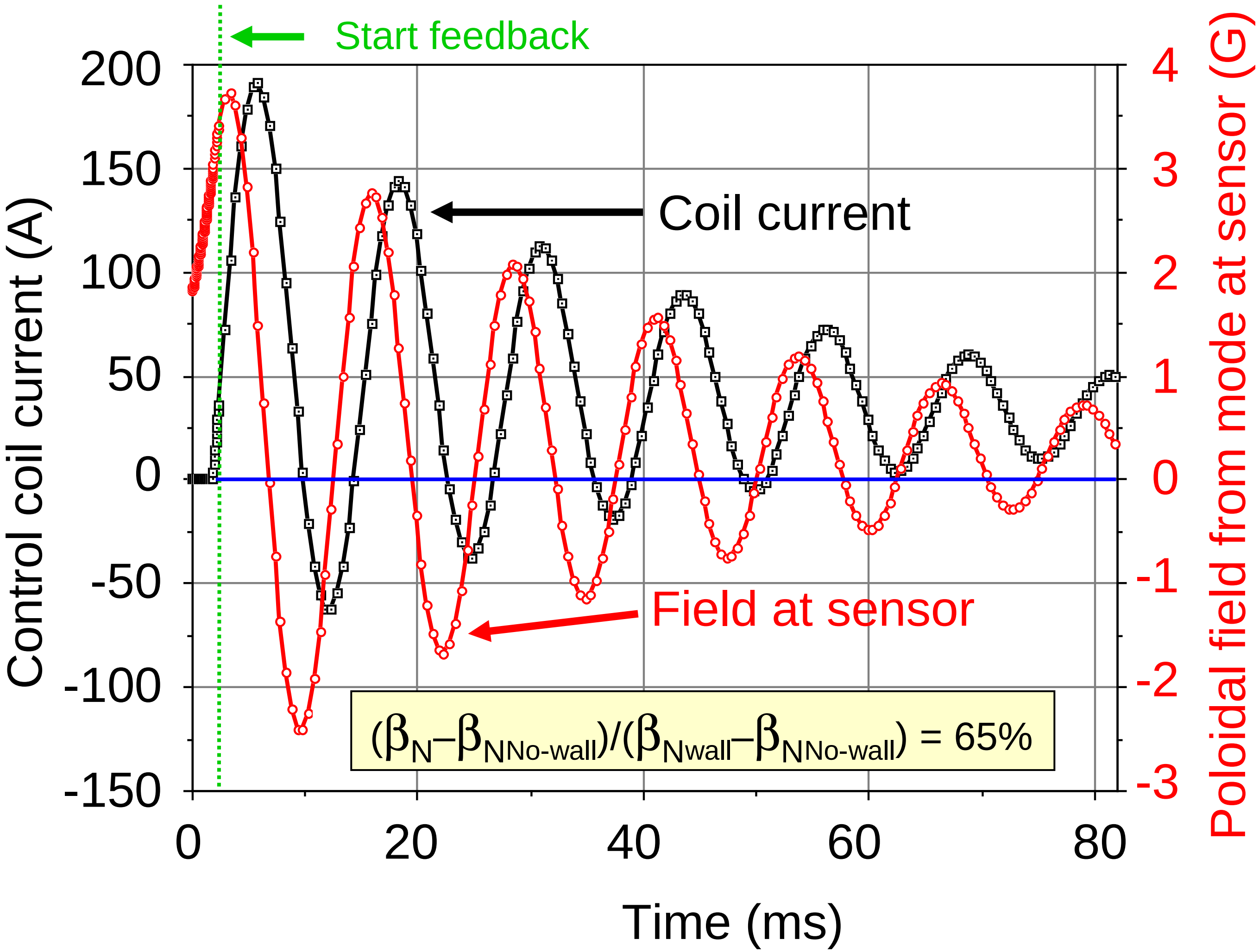
Exterior control coil can provide adequate stabilizing field



- Initial system plan has 6.8kA*turns (Applied B_{edge}= 27G @ 54Hz)
- Exterior coil design decision based on time, budget, risk constraints balanced by performance

VALEN (J. Bialek – poster FP1.040)

Active mode control modeling shows mode stabilization



- "Mode control" feedback algorithm simulation
- Ideal system response (no latency)
- Simulations including latency show 200 μs is maximum time delay allowing stabilization at highest β_N

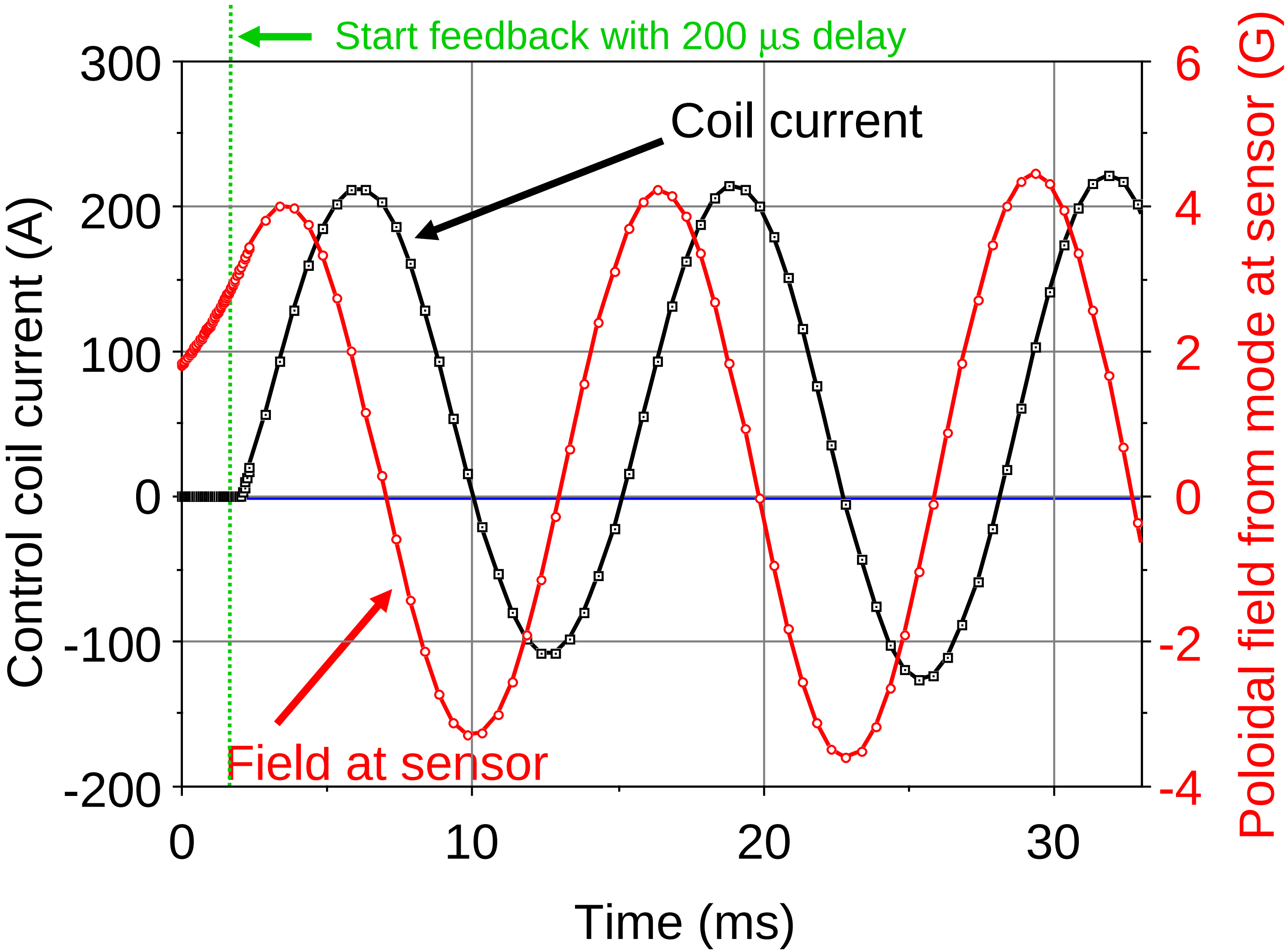
VALEN (J. Bialek)

Preparation for active feedback stabilization research in high β_N ST plasmas 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; $\beta_N/l_i = 9.5$
- Rapid rotation damping/β collapses at $\beta_N > \beta_{N\ no\text{-}wall}$ and lower B_t
  - Global, non-resonant damping mechanism associated with RWM
  - Unlike slower, localized, diffusive damping observed with island locking
- Plasmas passively stabilized for > 18 τ_{wall} at increased B_t
  - n = 1 RWM not observed; n = 2 computed unstable
- Toroidal rotation now included in equilibrium reconstructions
  - Large shift of core pressure contours from magnetic surfaces
  - Reconstructed stored energy essentially unchanged
- Ex-vessel active control coil design chosen for initial feedback system
  - Targeting sustained operation at $\Delta\beta_N = 68\%$

Supporting slides follow

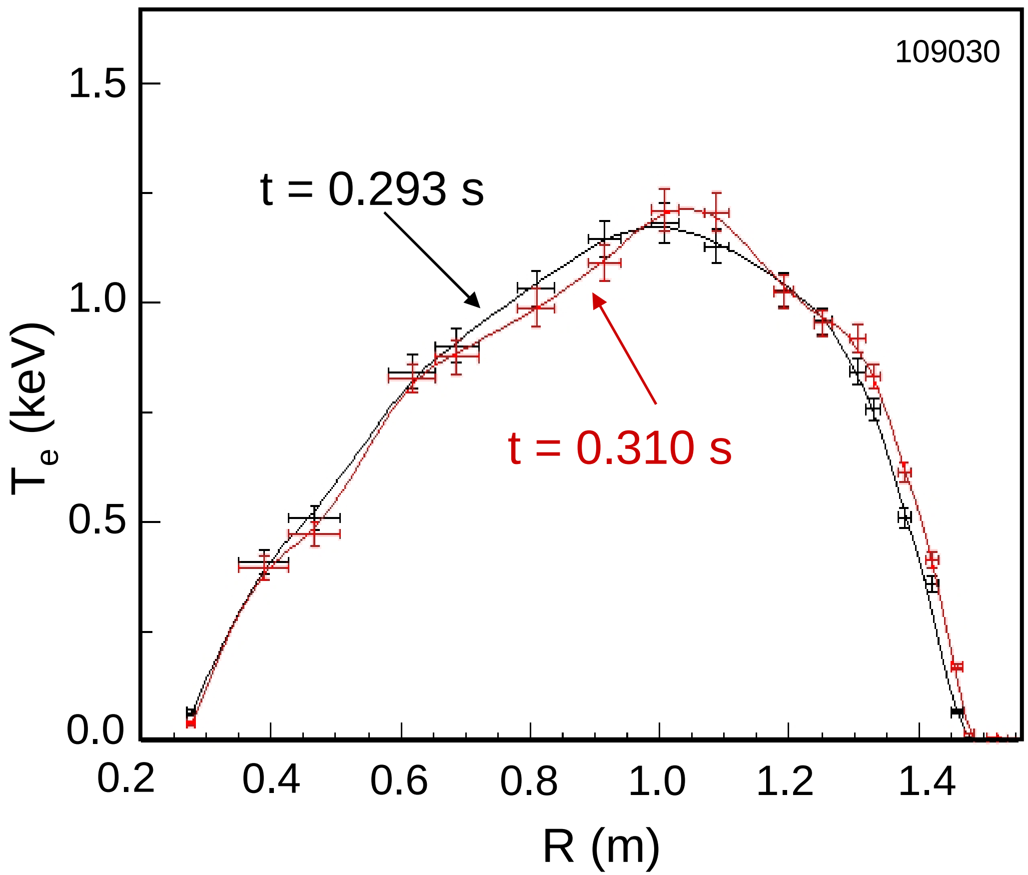
Maximum circuit time delay to allow feedback stabilization evaluated at maximum β_N

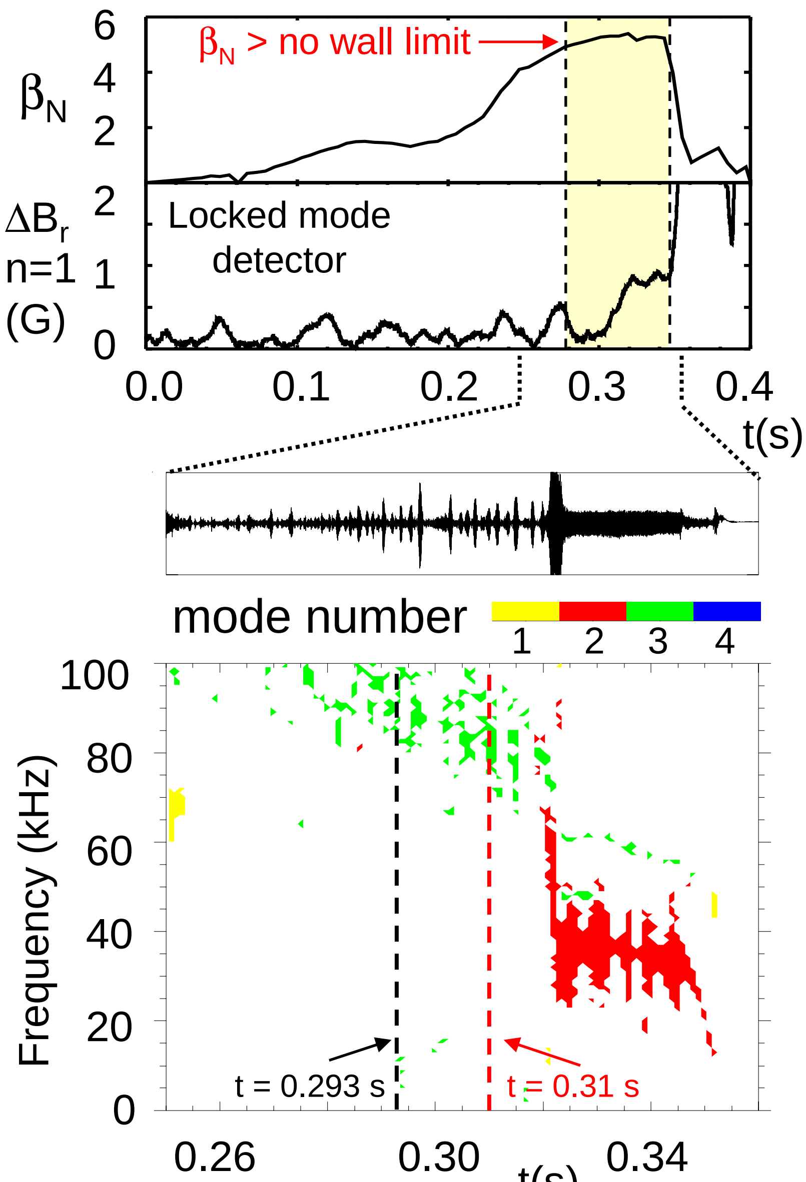


- Instability at $\Delta\beta_N$ = 65%
- Two-turn coil with realistic geometry yields 200 μs maximum time delay with "mode control" feedback algorithm

VALEN (J. Bialek)

T_e perturbation measured during RWM



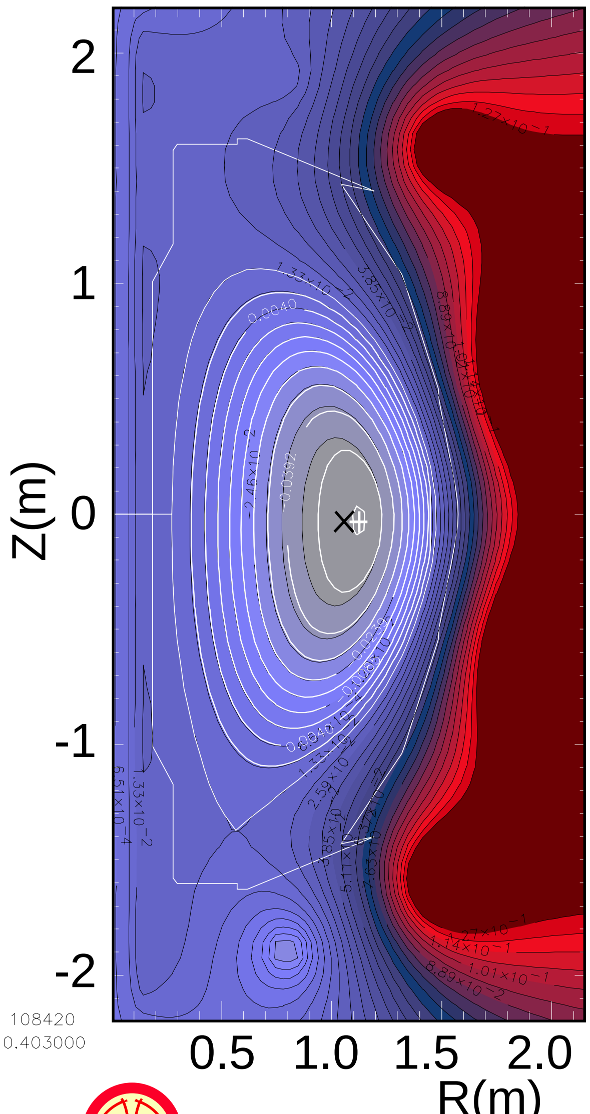


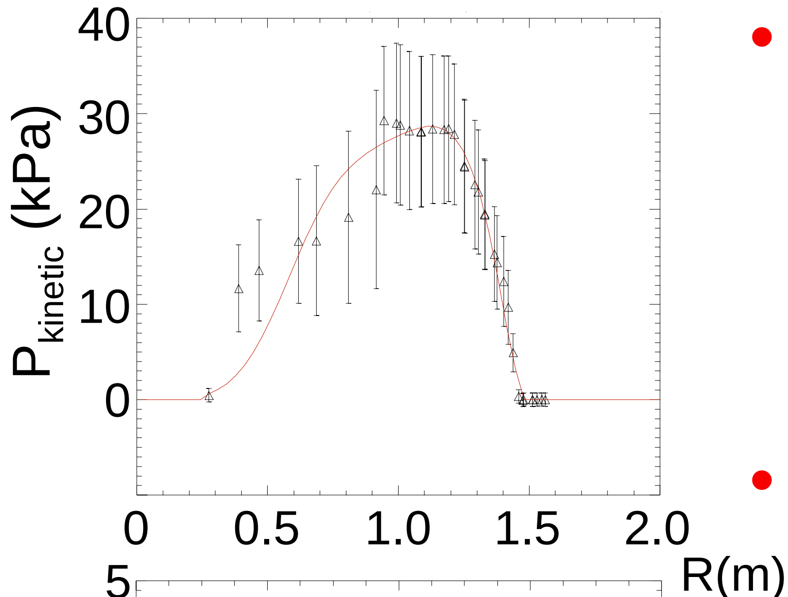
- No low frequency (< 80 kHz) rotating modes observed during measured δT_e
- δT_e displacement precedes n=2 rotating mode

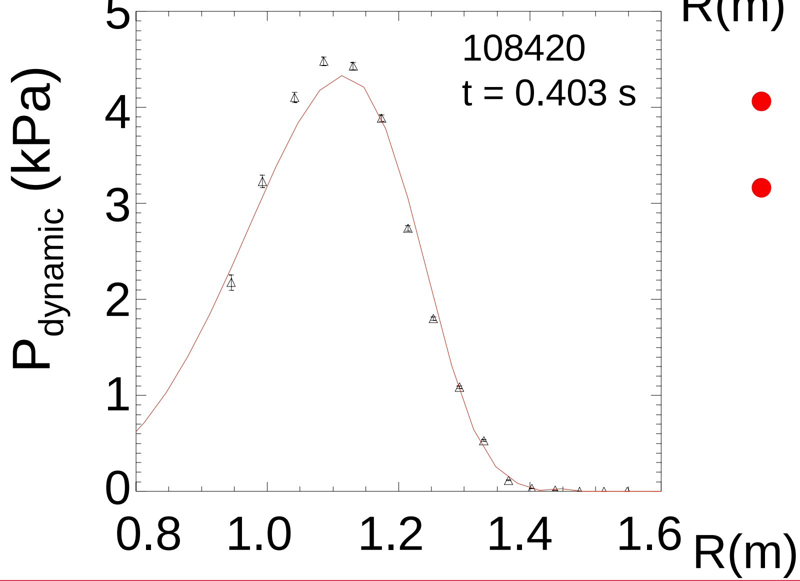
Thomson scattering (LeBlanc)

NSTX EFIT reconstructions now using T_i, Z_{eff} profiles, and fit to plasma toroidal rotation

Poloidal flux and pressure







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