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# NSTX 5 Year Research Plan 2004–08
# Global Mode Stabilization Strategy

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**For the NSTX National Team**

**DOE Review of**
**NSTX Five-Year Research Program Proposal**
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# Research Aims to Study Global MHD Instabilities in the ST and Methods of Stabilization at High β

- Motivation
  - Conducting walls can stabilize global modes in a rotating plasma
  - Resistive wall mode (RWM) can heavily damp rotation
  - Active mode control at low rotation may be needed for reactors
- Goals
  - Explore, analyze, and document high β equilibria and β-limiting MHD phenomena in the spherical torus
  - Study passive stabilization and define requirements for active control of β limiting global modes leading to an active feedback stabilization system

# Present research born from successful, long-term plan to operate, study, and stabilize high β ST plasmas

Tools

- Established High β Equilibria (1999-2000)
  - Established boundary shapes, $\beta_t \sim 18\%$, $\beta_N = 3.1$

*Between-shots magnetics EFIT*

- Established No-wall β Limit (2000-2001)
  - First H-mode: $\beta_t = 25\%$, $\beta_N = 4.3$, $\beta_N/l_i = 6$

*DCON, between shots partial kinetic EFIT*

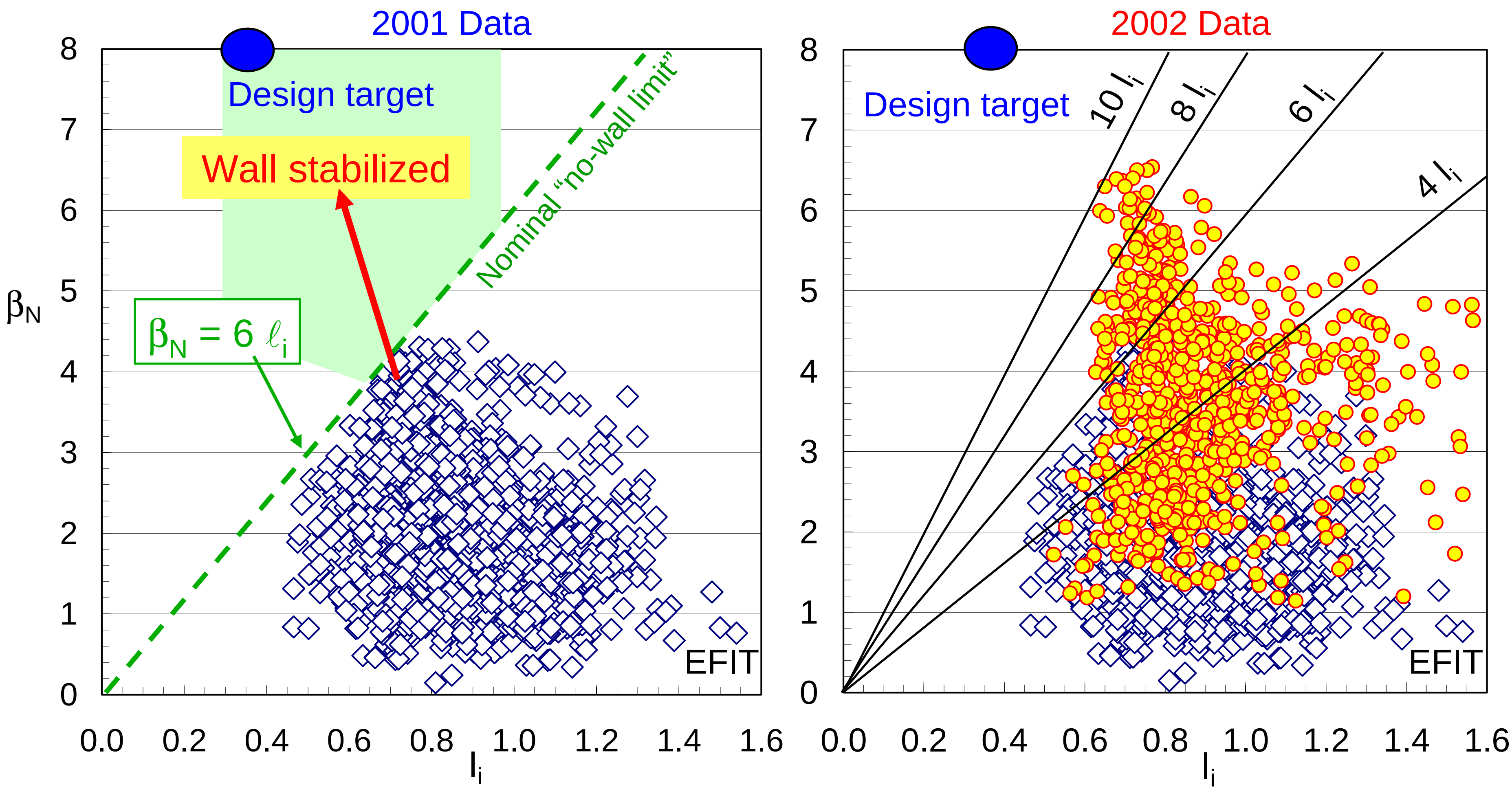
- Established Passive Stabilization (2001-2002)
  - Reduced error field: $\beta_t = 35\%$, $\beta_N = 6.5$, $\beta_N/l_i > 9.5$

*VALEN, control room DCON,*

- Establish Active Stabilization (2004-2008)
  - Suppress error field amplification (EFA)
  - Stabilize resistive wall mode, rotating plasma
  - Stabilize resistive wall mode, "static" plasma

*- EFIT with toroidal rotation (being tested)*
*- MSE*
*- resistive DCON*
*- kinetic effects*

# Plasma operation in low $l_i$, wall-stabilized space




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

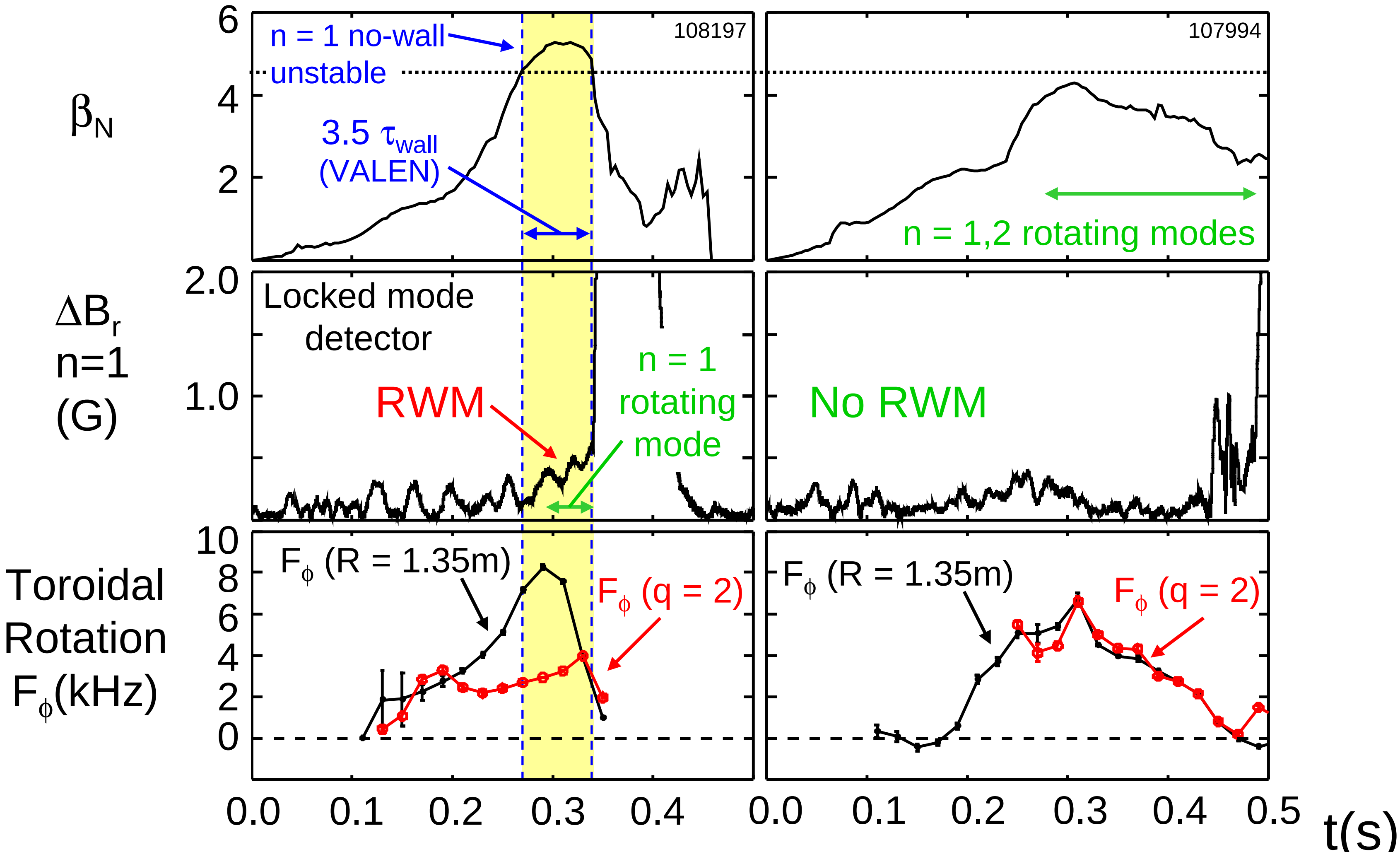
# Analysis plan addresses 5-Year IPPA MHD Goal

## 5 Year FESAC (IPPA Report) MHD Science Goal

- Develop detailed predictive capability for macroscopic stability, including resistive and kinetic effects
  - Progress measured by the level of agreement between predicted and observed stability regimes and by improvements in the stability of operating confinement devices

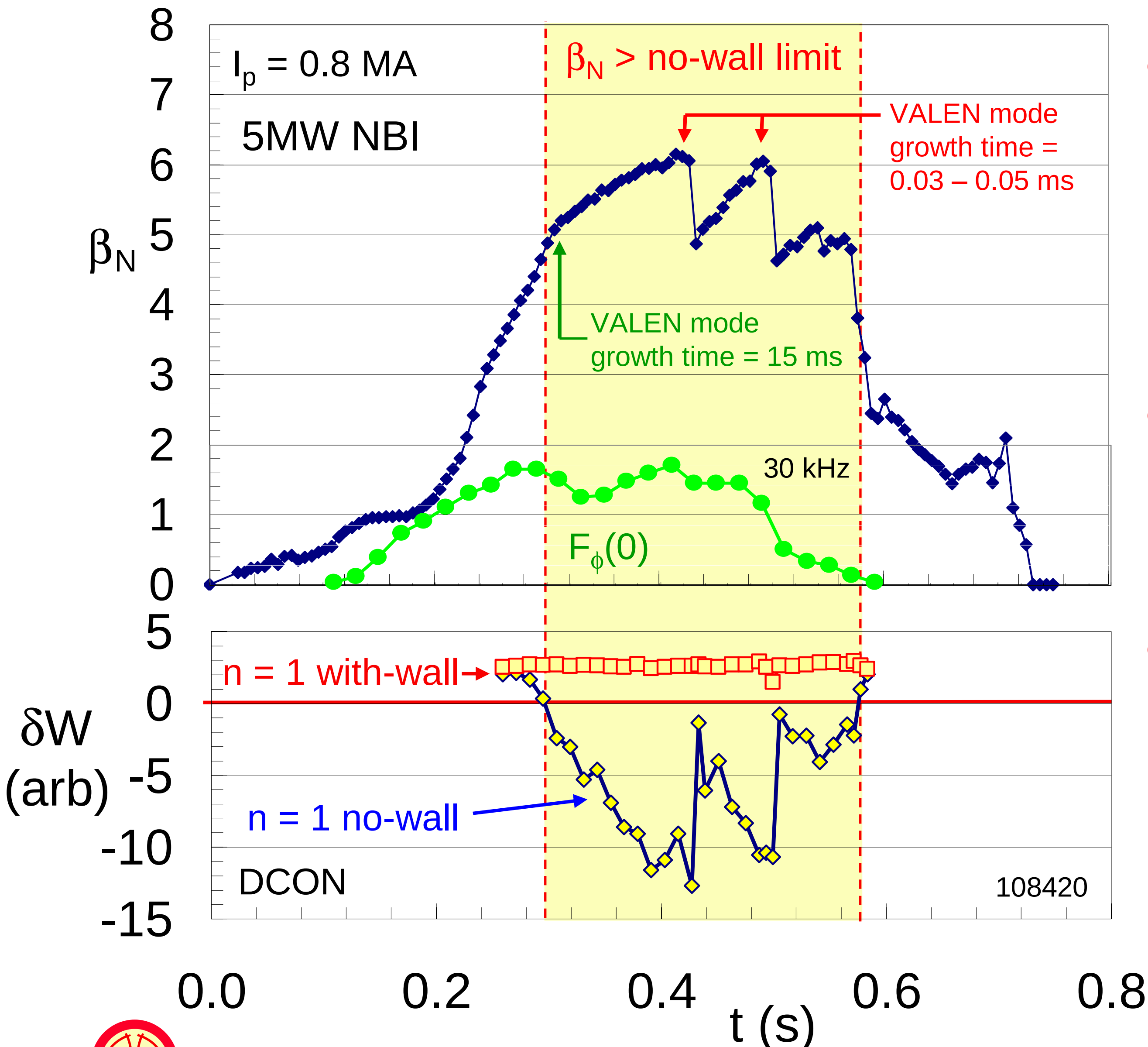
- Physics analysis closely couples theory and experiment
  - Between-shots, quantitative equilibrium reconstruction with kinetic profile information
    - Serves NSTX operations as well as physics
  - Quantitative, time-evolved ideal stability analysis in control room
    - Correlate with rotation damping, $\beta$ collapses
  - Generating adequate statistics
    - > 1e5 equilibria with Thomson; > 4e3 stability cases run
  - Standard input to further analysis
    - VALEN, MARS, M3D, RF codes, etc.
- Planned upgrades quantitatively address analysis needs

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




- Rotation damping is global; rate is ~ 6 times larger when $\beta_N > \beta_{N\ no\text{-}wall}$
- RWM signal weak in present experiments: improved sensors for next run

# Plasma stabilized above no-wall $\beta_N$ limit for 18 $\tau_{wall}$

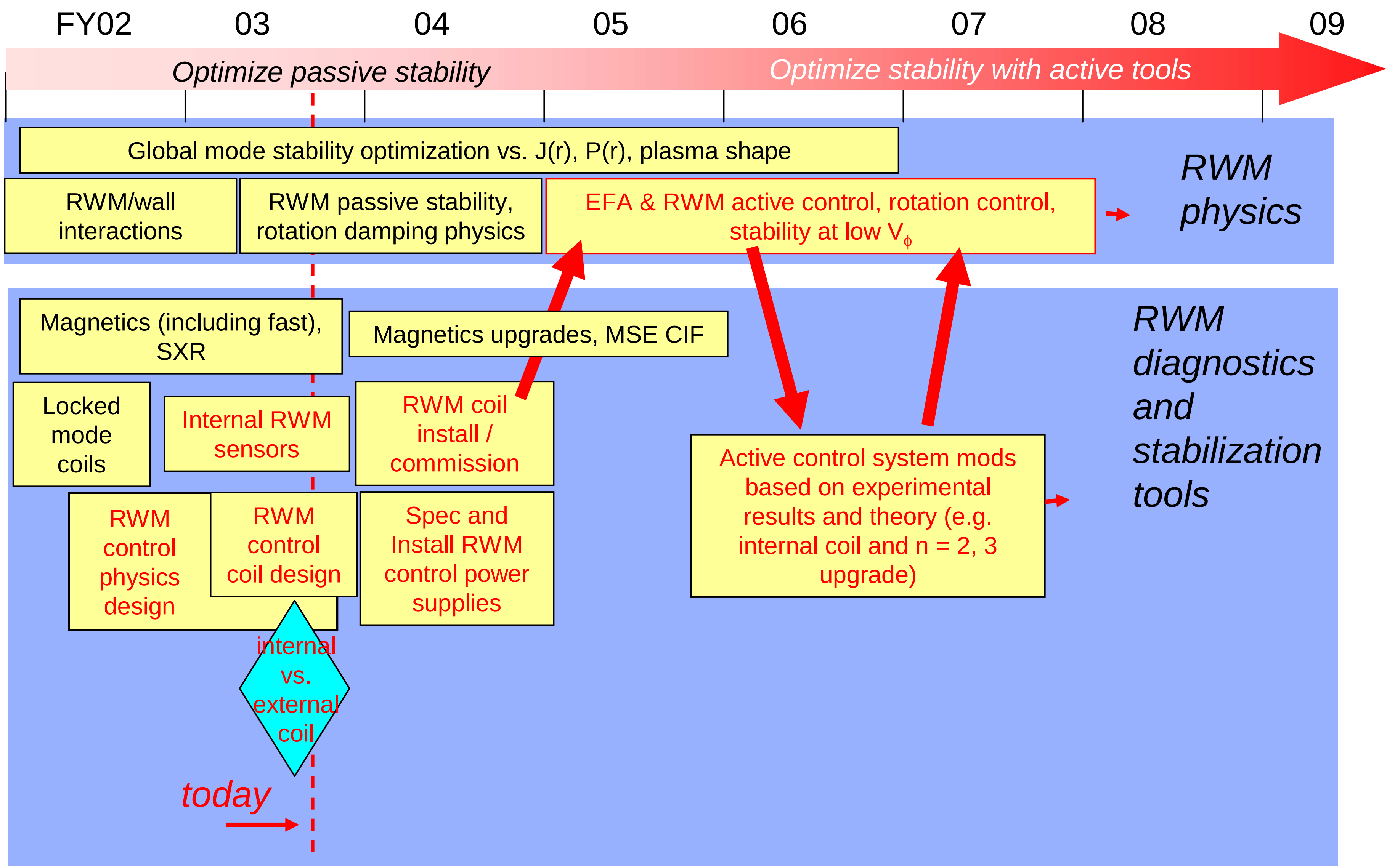



- Core rotation frequency $F_\phi(0)$ recovers as $\beta_N$ >> $\beta_{N\text{no-wall}}$
  - $B_t \geq 0.43$T
  - EFIT $q_{min} > 2$
- Plasma approaches with-wall $\beta_N$ limit
  - VALEN growth rate becoming Alfvénic
- Passive stabilizer loses effectiveness at maximum $\beta_N$
  - Neutrons collapse with $\beta_N$ - suggests internal mode

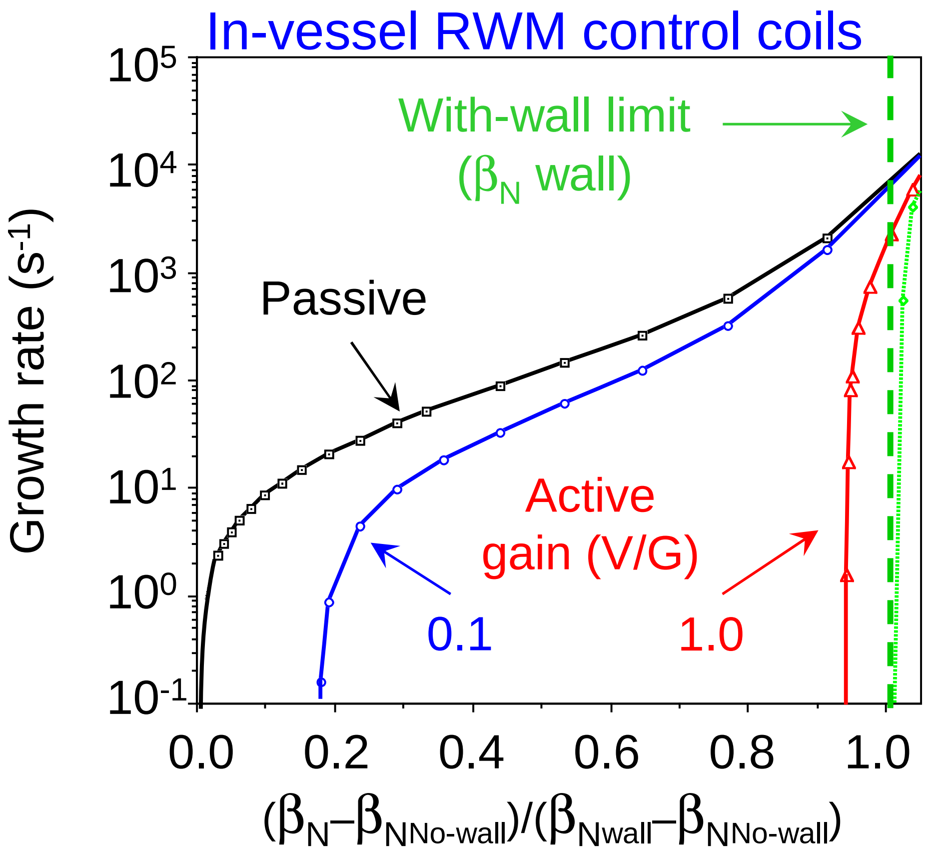
# Studying passive stabilization and RWM physics in ST

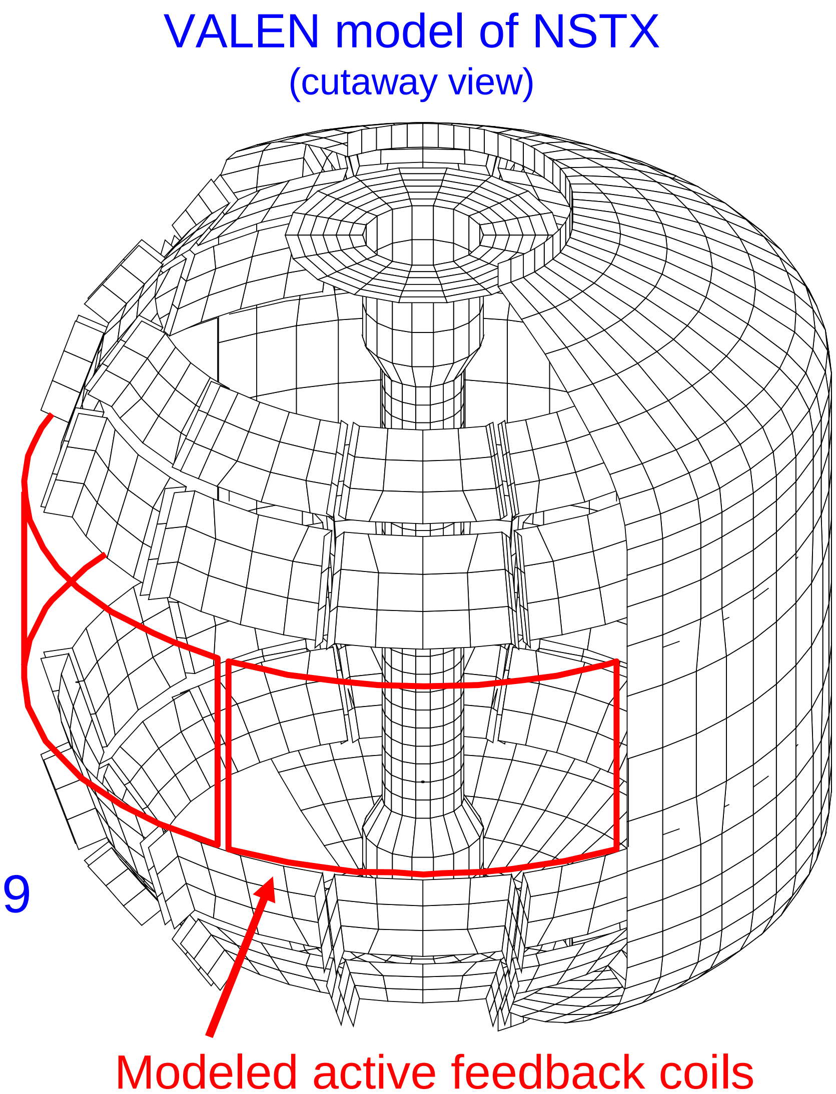
- FY2003-04
  - Continue investigation of unstable RWMs in modifying rotation
    - Compare non-resonant vs. resonant rotation damping theories, aspect ratio dependence
  - Perform initial theoretical assessment of expected critical rotation frequency for RWM stabilization in NSTX and dependence on beta, q profile, shaping, $V_A$
    - Coordinate research with complementary DIII-D results
  - Perform investigation of RWM dissipation theory comparison to experiment
  - Conduct NSTX / DIII-D similarity XP to investigate aspect ratio dependence of RWM induced rotation damping, critical rotation frequency
- FY2004
  - Use equilibria with MSE to assess role of q in RWM stability and rotation damping
  - Compare theoretical and experimental mode structure using internal sensors
    - n=2 RWM presently computed unstable - attempt to measure it
  - Begin benchmarking stability codes against measurements in ($\beta_N$, $V_\phi$ space)
- FY2005-future
  - Using experimental results and comparison to theory, assess rotation required for stabilization of RWM in long-pulse high-β operating regimes.
  - Use knowledge gained to test active feedback stabilization physics in plasmas with low rotation speed and to project to future ST devices.

# RWM stabilization research follows a logical timeline



# Active control computed to sustain 94% ideal wall β limit

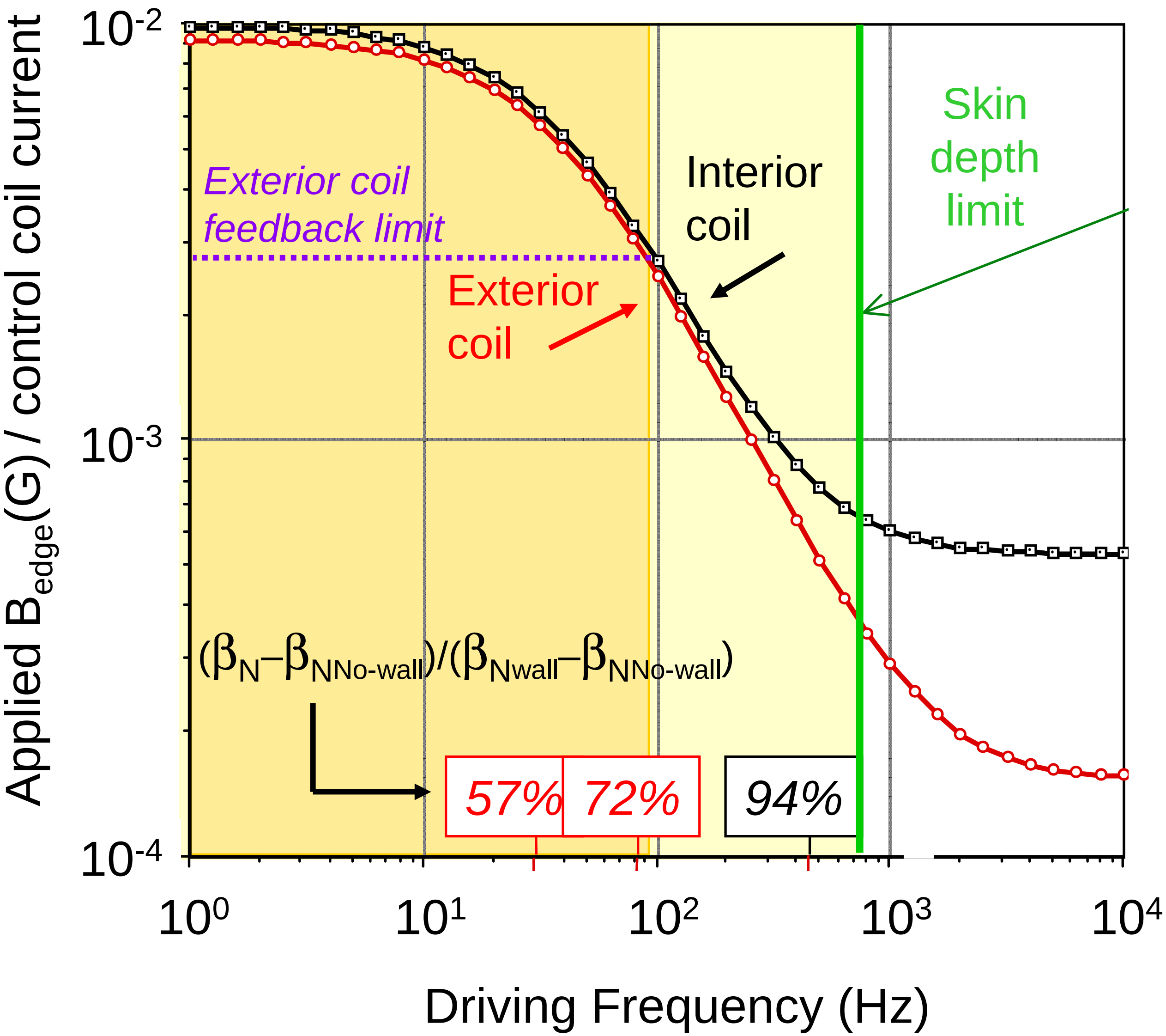



- Equilibria have $\beta_{N\,no\text{-}wall} = 5.1$; $\beta_{N\,wall} = 6.9$
- Ex-vessel control coils computed to reach 72% of $\beta_{N\ wall}$
- Control coils among passive plates computed to reach 50% of $\beta_{N\ wall}$

VALEN (J. Bialek)

# Exterior control coil chosen for initial feedback system




- Decision based on time, budget, risk constraints balanced by performance
- System with 80Hz driving frequency may sustain 72% of with-wall β-limit
- Initial system plan (1 Transrex + 1 SPA supply) has 6.8kA*turns (Applied $B_{edge}$= 19G @ 80Hz)

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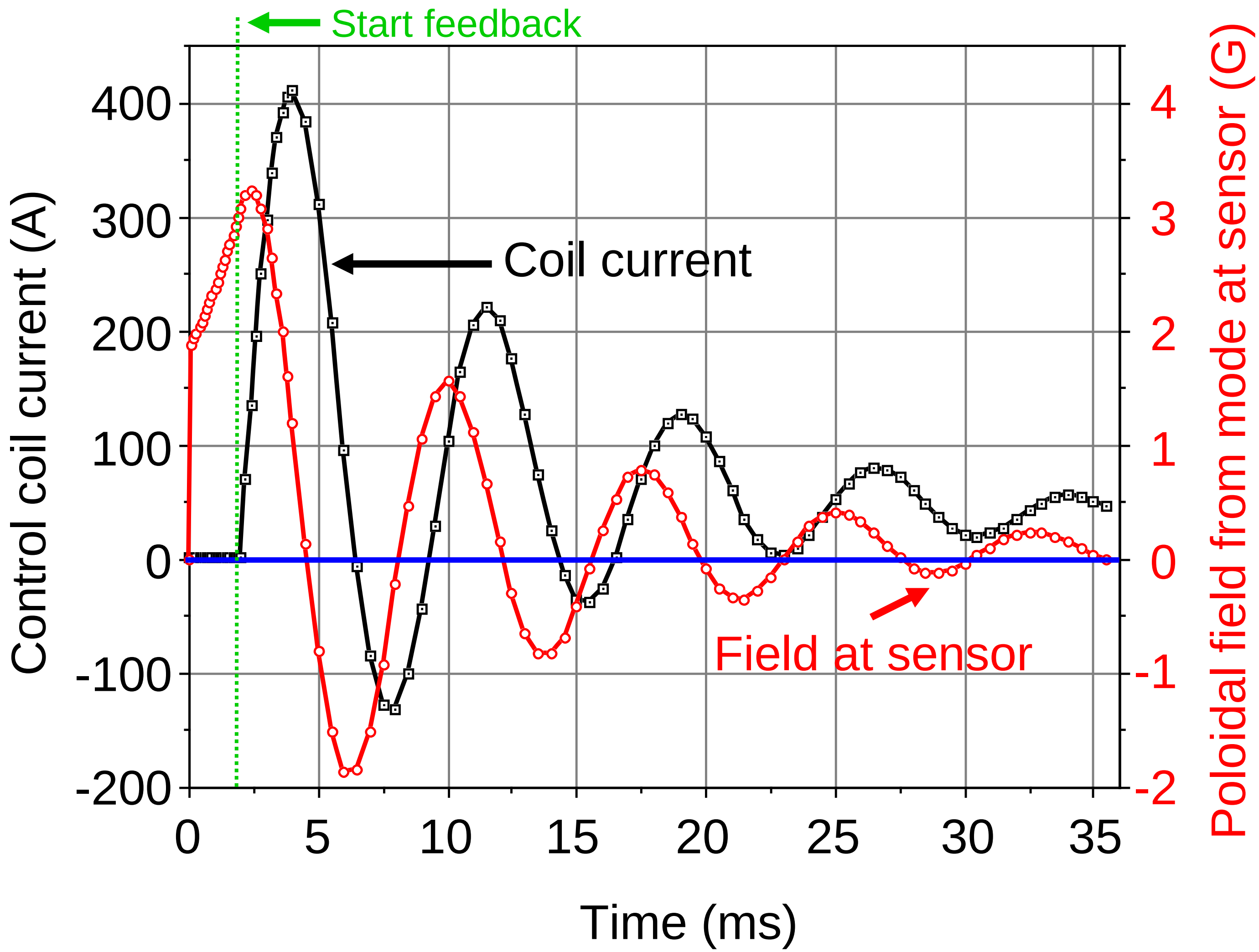
# Active mode control physics design effort moving on to feedback modeling



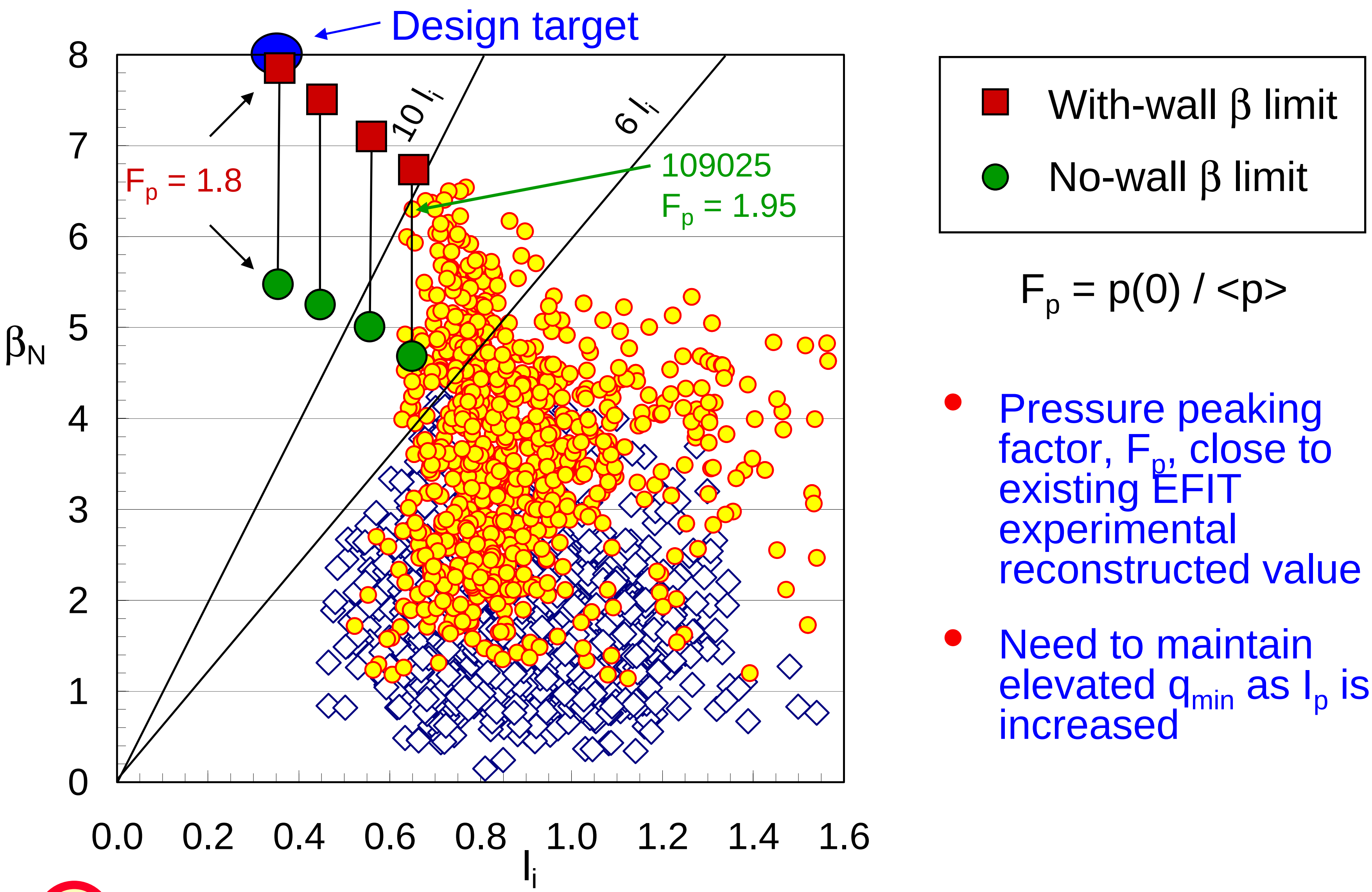

- "Mode control" feedback algorithm simulation
- Planned upgrades include:
  - Error field amplification
  - Realistic sensor noise (e.g. ELMs)

VALEN (J. Bialek)

# Evaluating and implementing active feedback for global MHD

- FY2003
  - Finalized physics design of active coil sets using DCON+VALEN analysis
  - Decided on external coil set and began engineering design
  - Initiate procurement of power supplies
  - Commission internal RWM/EFA sensor array electronics
- FY2004
  - Procure, install, and commission initial active coil set and active coil supplies
  - Purchase and install DAQ for PCS; reduced bandwidth capability to suppress EFA
- FY2005
  - Complete interface of supply controls to PCS
  - Active feedback on RWM at full capability of coil, algorithm optimization
- FY2006
  - Maintain high $\beta$ plasmas with plasma rotation below the critical rotation frequency
  - Determine options required for high frequency mode stabilization (e.g. internal coil)
    - Possibly modify NTM island formation
- FY2007-future
  - Utilize RWM feedback to operate close to ideal-wall limit in long-pulse discharges
  - Assess impact of stochastic divertor boundary on edge profiles / divertor heat flux

# Access to $\beta_N$ = 8 conceptual design target exists




$F_p = p(0) / \langle p \rangle$

- Pressure peaking factor, $F_p$, close to existing EFIT experimental reconstructed value
- Need to maintain elevated $q_{min}$ as $I_p$ is increased

# Research aims to fulfill the long-term plan of high β plasma stabilization in the ST

- Progress
  - A four year effort has yielded the tools, experimental data, and initial physics understanding of passively stabilized, high β ST plasmas
- Future
  - Implement hardware to stabilize global modes and sustain high β
    - With plasma rotation above RWM critical rotation frequency:
      - Use initial feedback system to suppress EFA with external control coil
      - Attempt RWM stabilization with external coil
      - Assess need for optimized control coil options
    - Repeat study with plasma rotation below RWM critical rotation frequency
  - Expand physics analysis as needed to couple theory to experiment