NSTX 5 Year Research Plan 2004 – 2008
Global Mode Stabilization Strategy

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for the

NSTX Global Mode Stabilization Group

NSTX 5 Year Planning Meeting

PPPL – June 30th, 2003

NSTX

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
  - Sustained stabilization at low rotation needed for reactors (active feedback)
- 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

RWM stabilization is part of MHD mission integrating science, performance, and high β control

FY02 | 03 | 04 | 05 | 06 | 07 | 08 | 09

Passive stabilization — Active control — Optimized long-pulse stability

MHD

β limits vs. shape, l_i, F_p

Wall-stabilized β limits

Shape, profile control / optimize

RWM identified

RWM passive stability and rotation damping

RWM suppression

Stability at low V_ϕ

→ **Combine to optimize stability in long-pulse high beta regimes**

NTM β limits

Modes destabilized at $\Delta t \sim \tau_{cr}$

NTM suppression

ELMS & Fast ion modes

β limits & V_ϕ shear stabilization

Impact of ELMS, *AE modes

NSTX mission

Highest performance

- β_T = 30%, $\Delta t > \tau_E$
  β_N = 5: > no wall limit
  HH = 1
- β_T = 40%,
- β_N = 8
  $\Delta t >> \tau_E$, HH = 1.4

Solenoid-free

- J_{NI} > 60%, $\Delta t \sim \tau_{skin}$
- Non-solenoid startup demo
- J_{NI} ~ 100%, $\Delta t > \tau_{skin}$
- Solenoid-free up to hi β_p

40% β_T
$\Delta t >> \tau_{skin}$
β_N = 8
HH = 1.4
70% J_{BS}

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

Tools

- Established Equilibrium (1999-2000)
  - Established boundary shapes, β_t ~ 18%, β_N = 3.1

Between-shots magnetics EFIT

- Established Stability Limits (2000-2001)
  - First H-mode: β_t = 25%, β_N = 4.3, β_N/l_i = 6

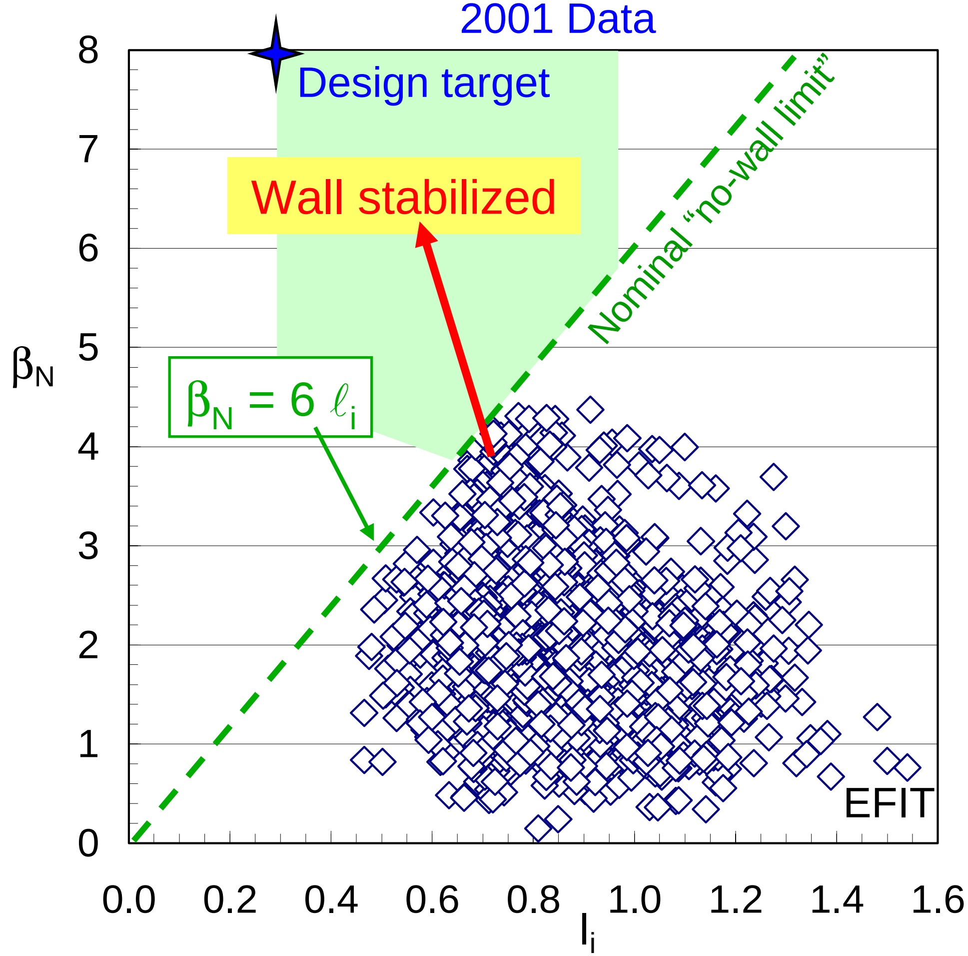
DCON, between shots partial kinetic EFIT

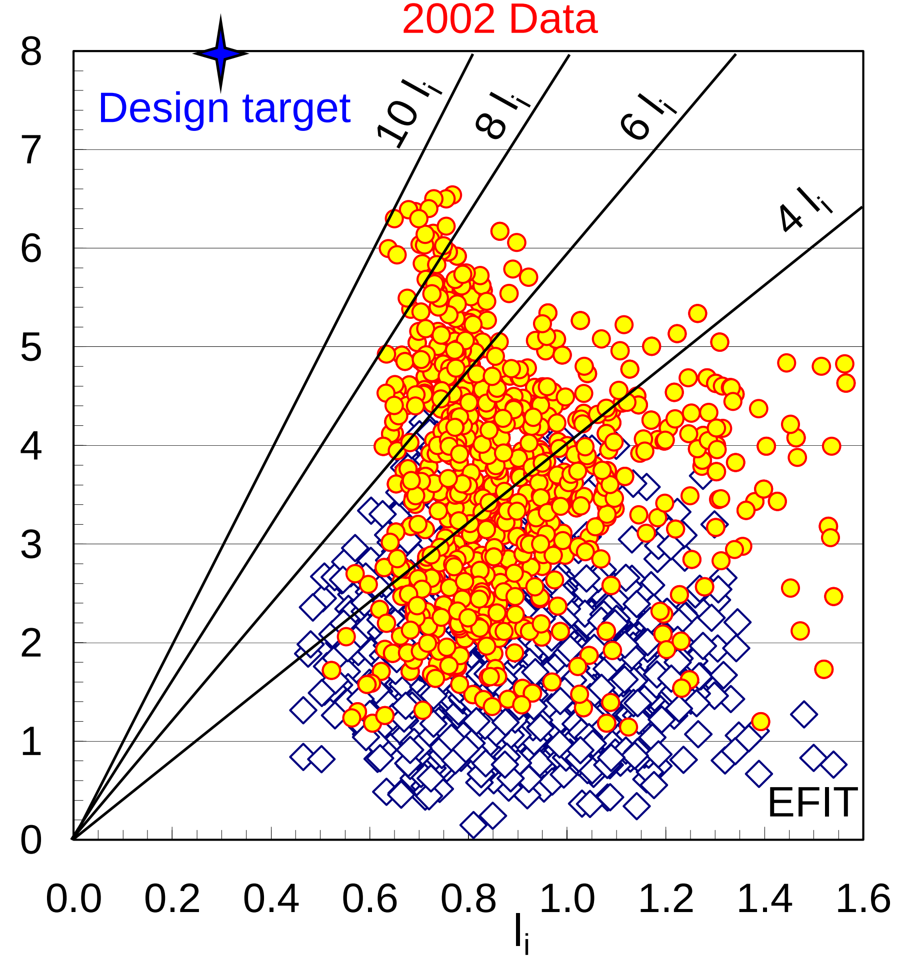
- Established Passive Stabilization (2001-2002)
  - Reduced error field: β_t = 35%, β_N = 6.5, β_N/l_i > 9.5

VALEN, control room DCON, EFIT

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

Plasma operation in low l_i, 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% ($\beta_t = 2\mu_0\langle p\rangle / B_0^2$)

Analysis plan addresses 5-Year IPPA MHD Goal

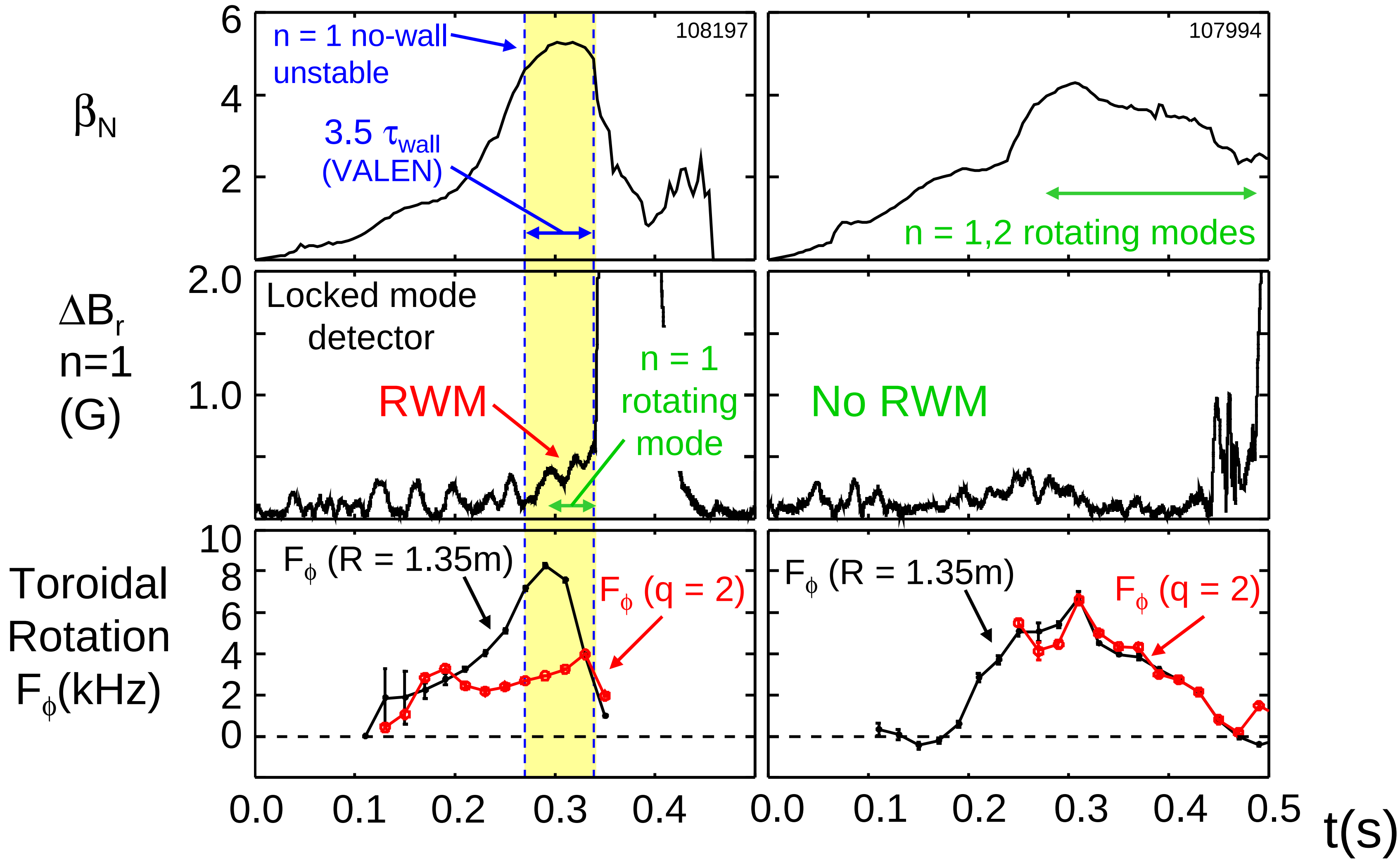
5 Year FESAC (IPPA Report) MHD Science Goal

- 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

- Progress
  - Between-shots, quantitative equilibrium reconstruction with kinetic profile information
    - For physics analysis and operations
  - Quantitative, time-evolved ideal stability analysis as requested
  - Generating adequate statistics
    - > 1e5 equilibria with Thomson
    - > 4e3 stability cases run
  - Standard input to further analysis
    - VALEN, MARS, M3D, RF codes, etc.

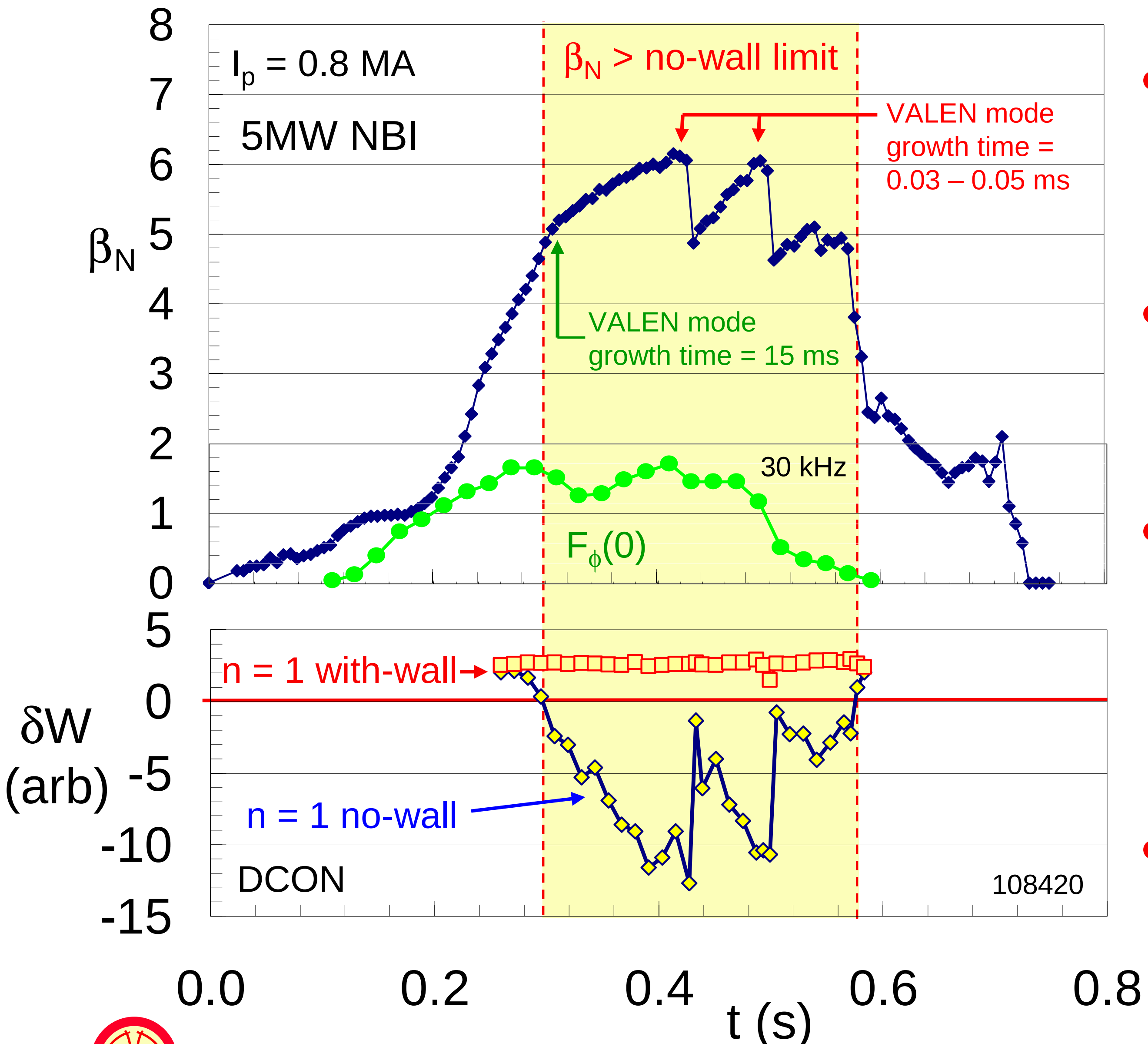
- Some Planned Upgrades
  - Additional between-shots diagnostic input when available
    - Rotation, MSE, etc.
  - Assess / include rotation effects
    - Presently being tested
  - Assess / include kinetic effects
  - Resistive stability evaluation
    - Resistive DCON, when available

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 CY02 experiments: improve sensors

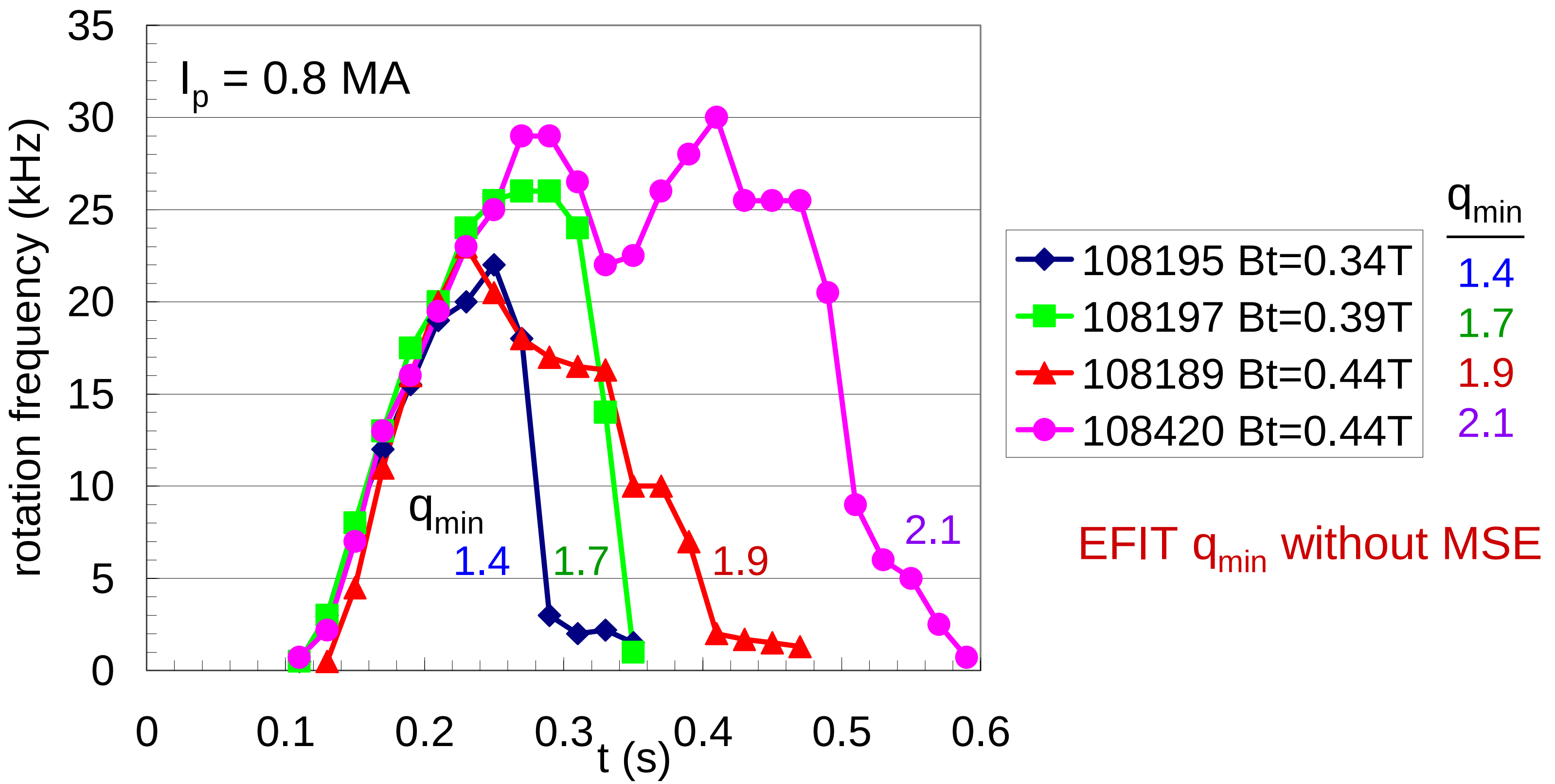
Plasma stabilized above no-wall β_N limit for 18 τ_{wall}



- Plasma approaches with-wall β_N limit
  - VALEN growth rate becoming Alfvénic
- Core rotation frequency $F_\phi(0)$ increases as β_N >> $\beta_{Nno\text{-}wall}$
- Passive stabilizer loses effectiveness at maximum β_N
  - Neutrons collapse with β_N - suggests internal mode
- Plasma has elevated q_{min} > 2
  - EFIT without MSE

NSTX

Core rotation damping decreases with increasing q

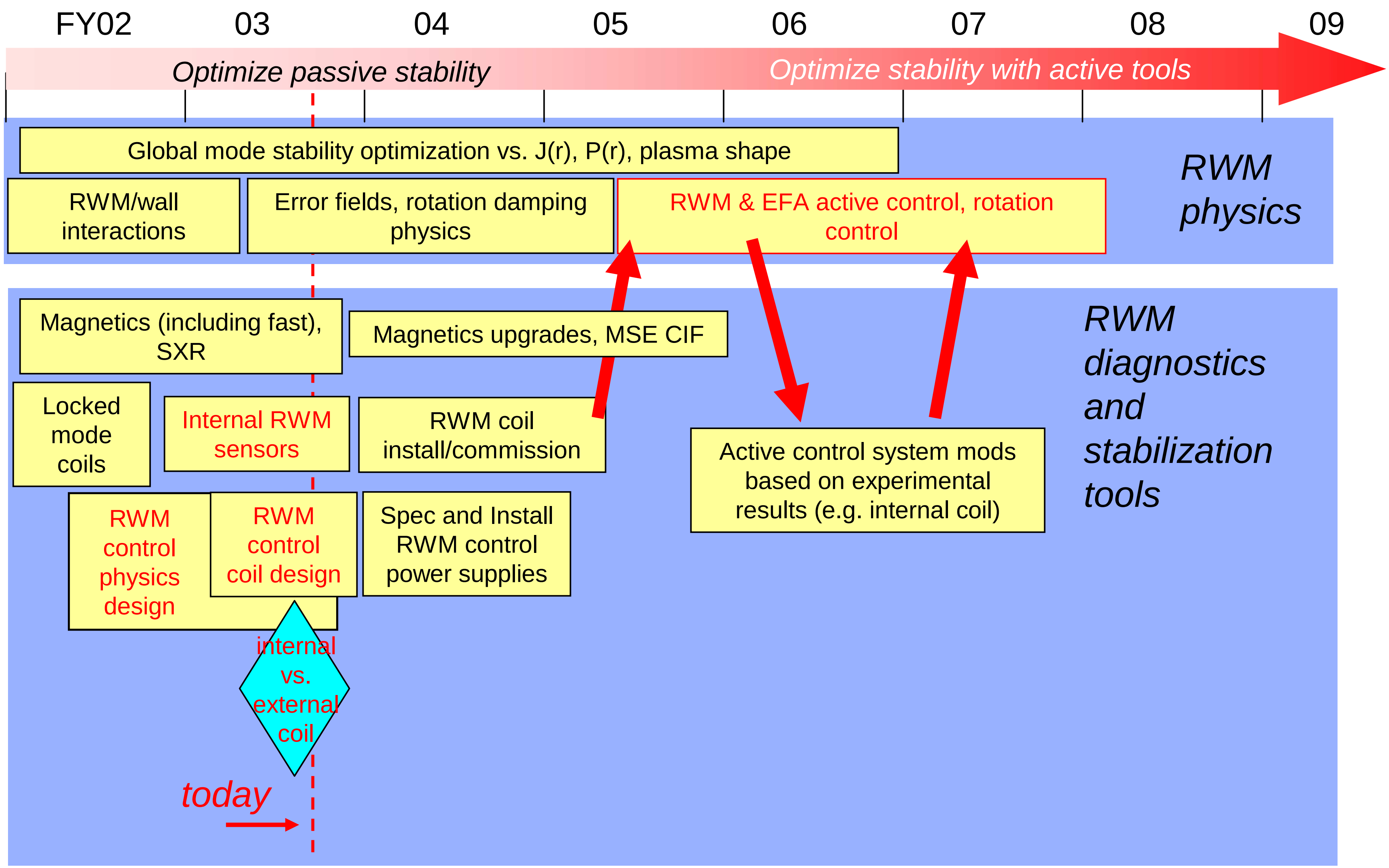


- Database shows plasmas with q_{min} > 2, have longer pulse length exceeding no-wall β_N limit
- Consistent with theory linking rotation damping to low order rational surfaces
  - Inconsistent with continuum damping dissipation mechanism?

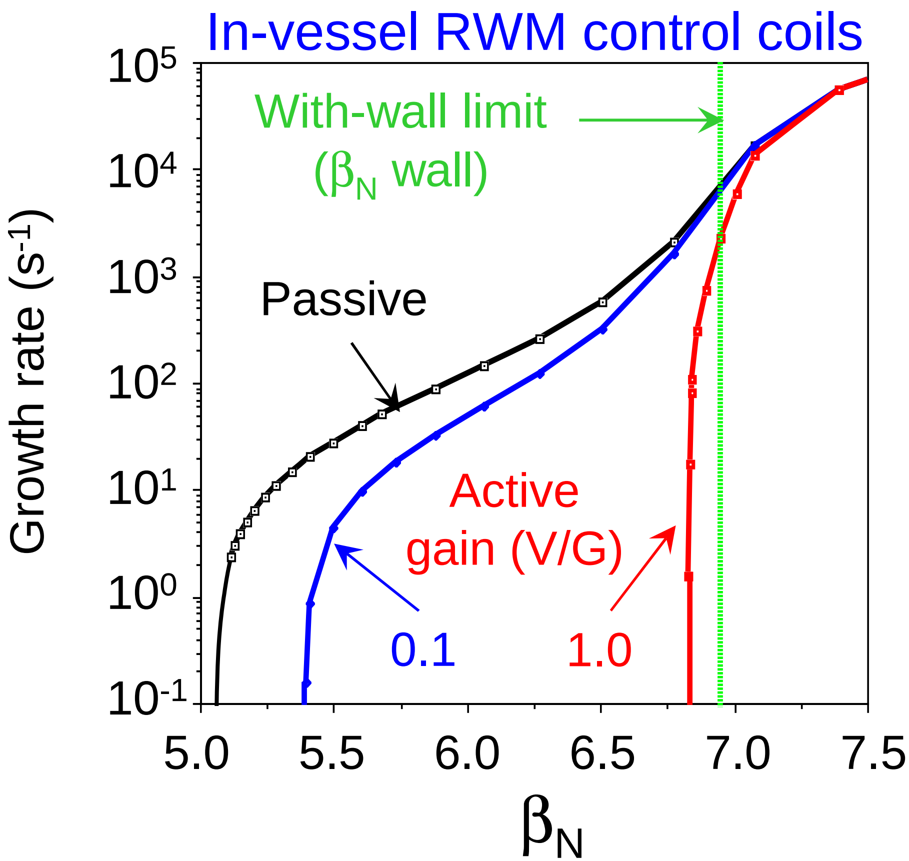
Studying passive stabilization and RWM physics in ST

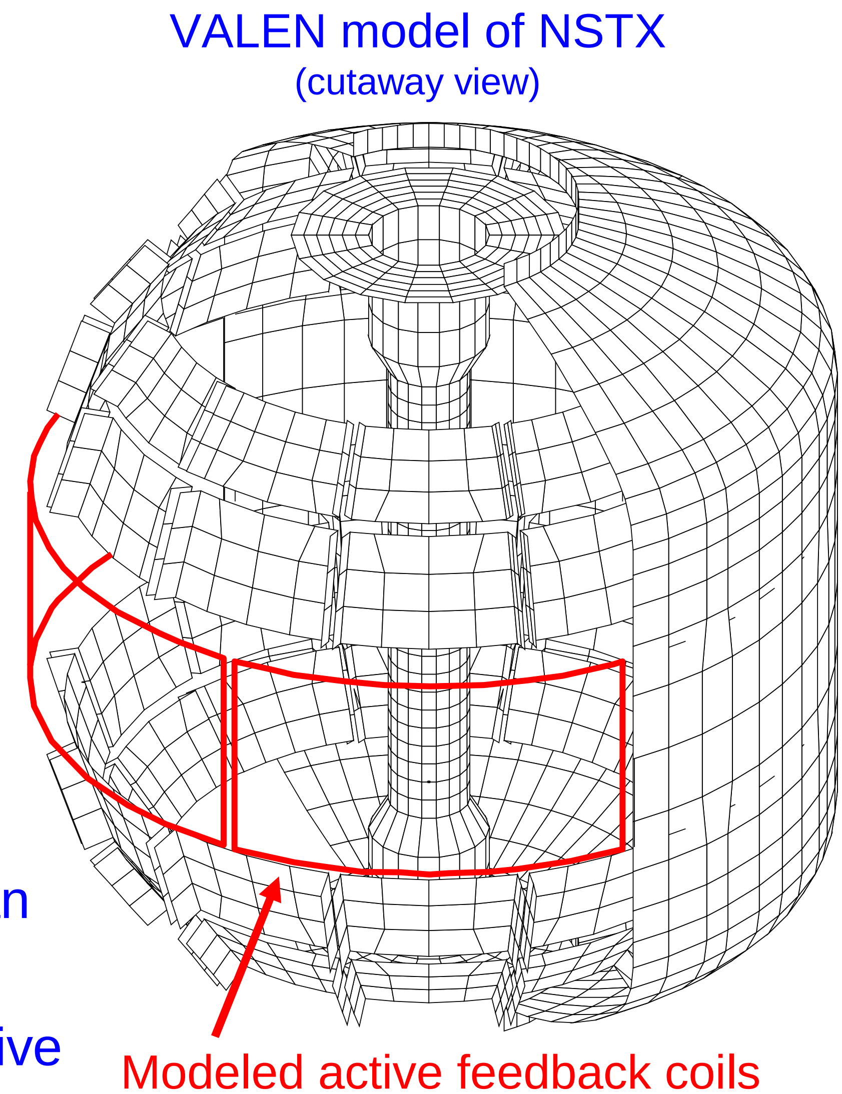
- FY2003-04
  - Continue investigation of unstable RWMs in modifying rotation
    - Compare non-resonant vs. resonant rotation damping theories, aspect ratio dependence
  - Perform initial theoretical assessment of expected critical rotation frequency for RWM stabilization in NSTX and associated scalings with beta, q profile, shaping
  - 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 (β_N, V_ϕ 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 might sustain 94% of with-wall β limit



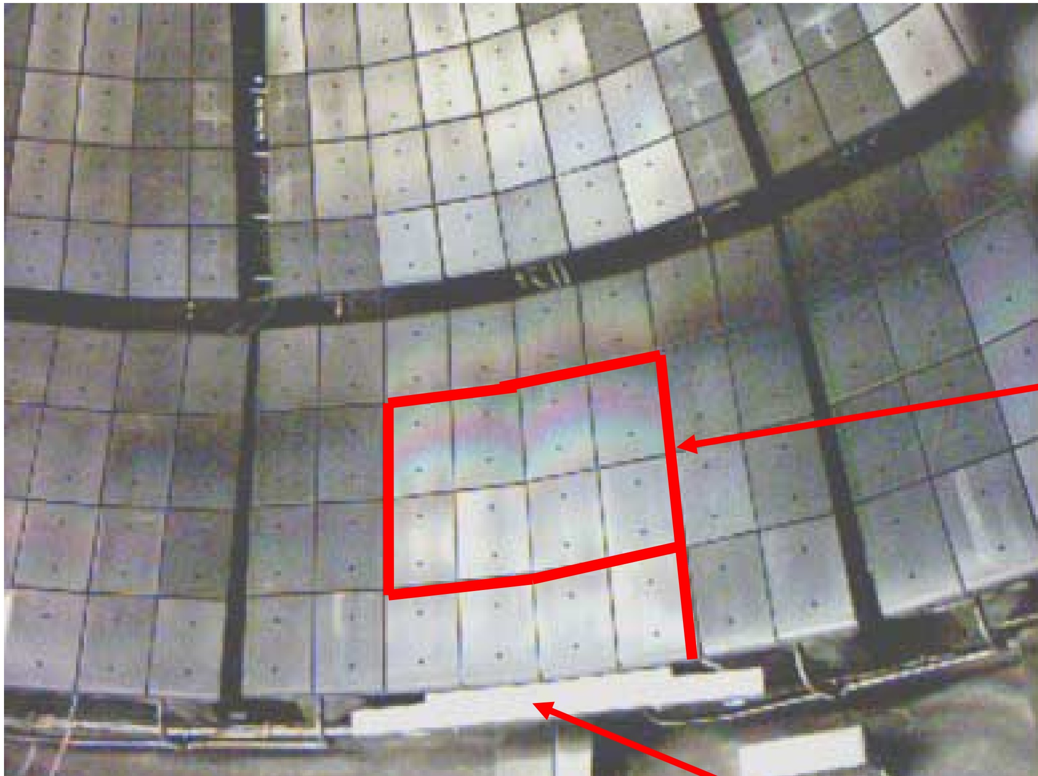


- System with ex-vessel control coils can reach 72% of $\beta_{N\ wall}$
- System with control coils among passive plates can only reach 50% of $\beta_{N\ wall}$

VALEN (J. Bialek)

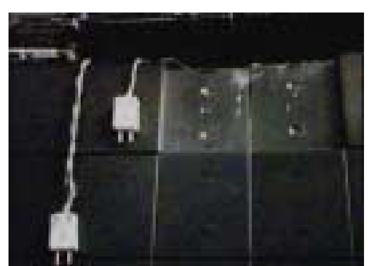
NSTX

New internal magnetic field sensors installed to study locked modes and RWMs



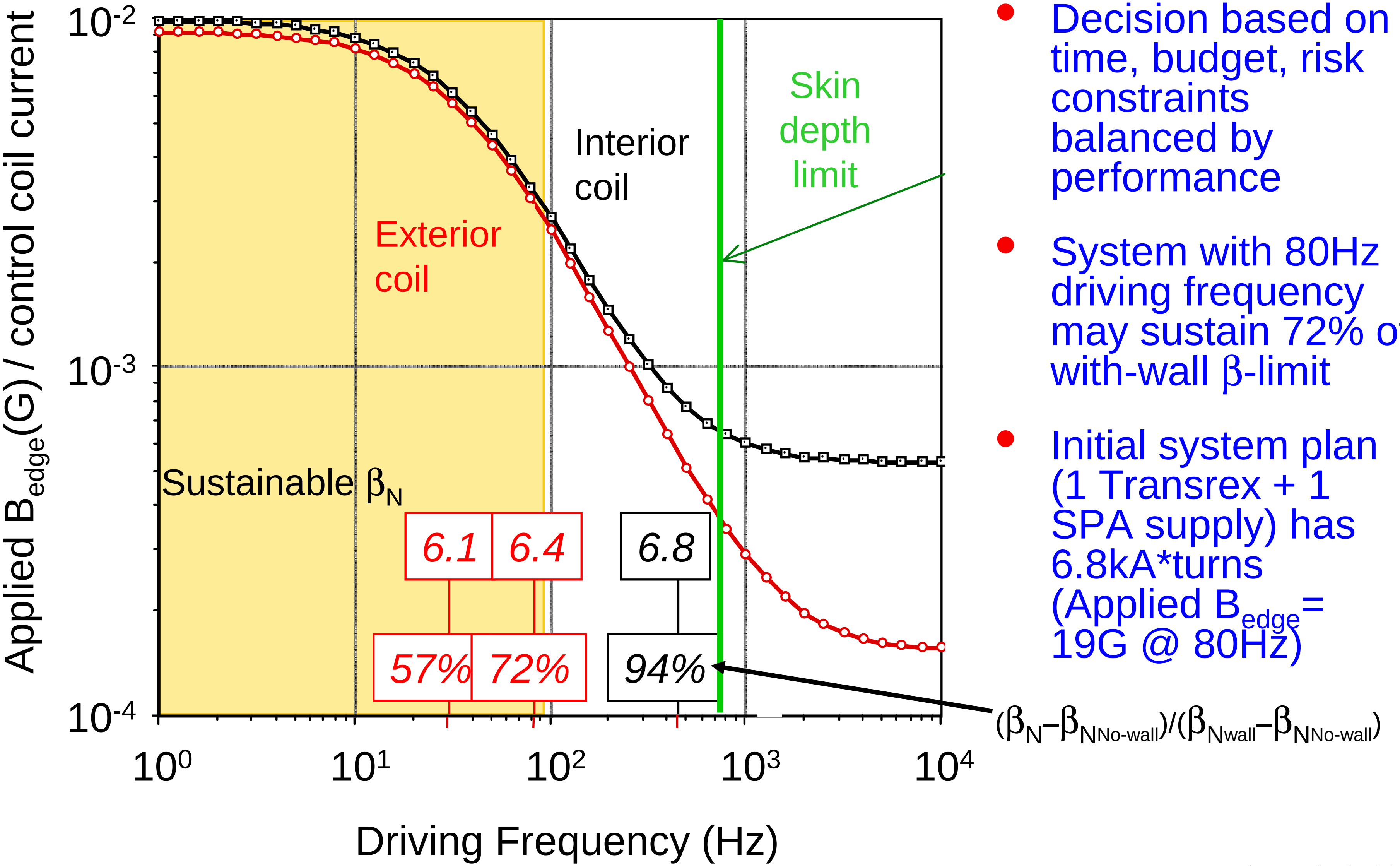
- Full toroidal coverage
  - 24 $B_\perp$ and 24 B_P
    - Each 12 above, 12 below
- $B_\perp$ measured by single turn loop
  - Embedded in tiles
- B_P measured at ends of primary plates
  - Glass insulated Cu wire wound on macor forms
  - SS304 shields

Thermocouple connectors allow easy installation and upgrade potential



- Internal ➔ more sensitive
- Use as sensors for future active feedback system

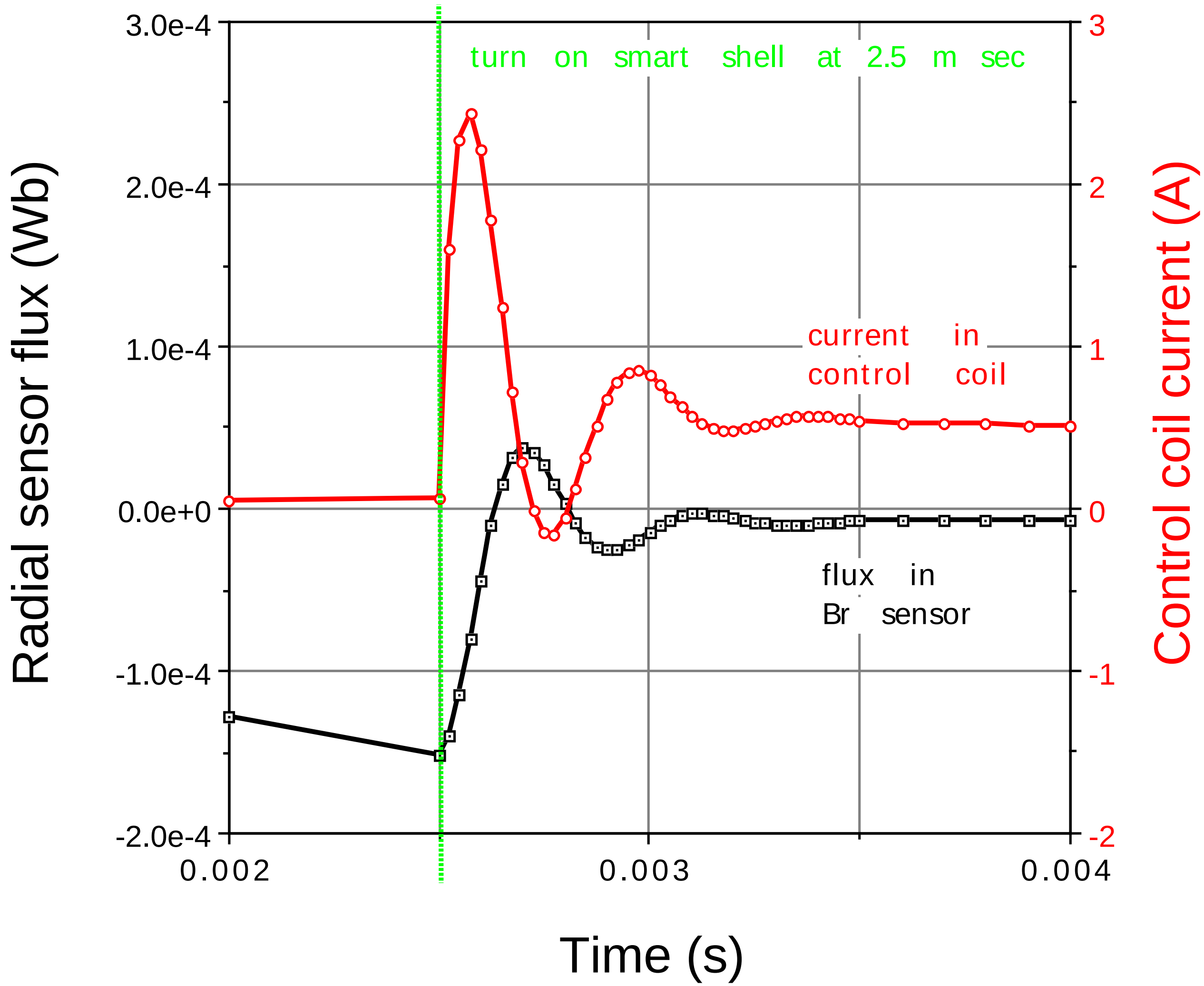
Exterior control coil chosen for initial feedback system



- 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)

VALEN (J. Bialek)

Active mode control physics design effort moving on to feedback modeling



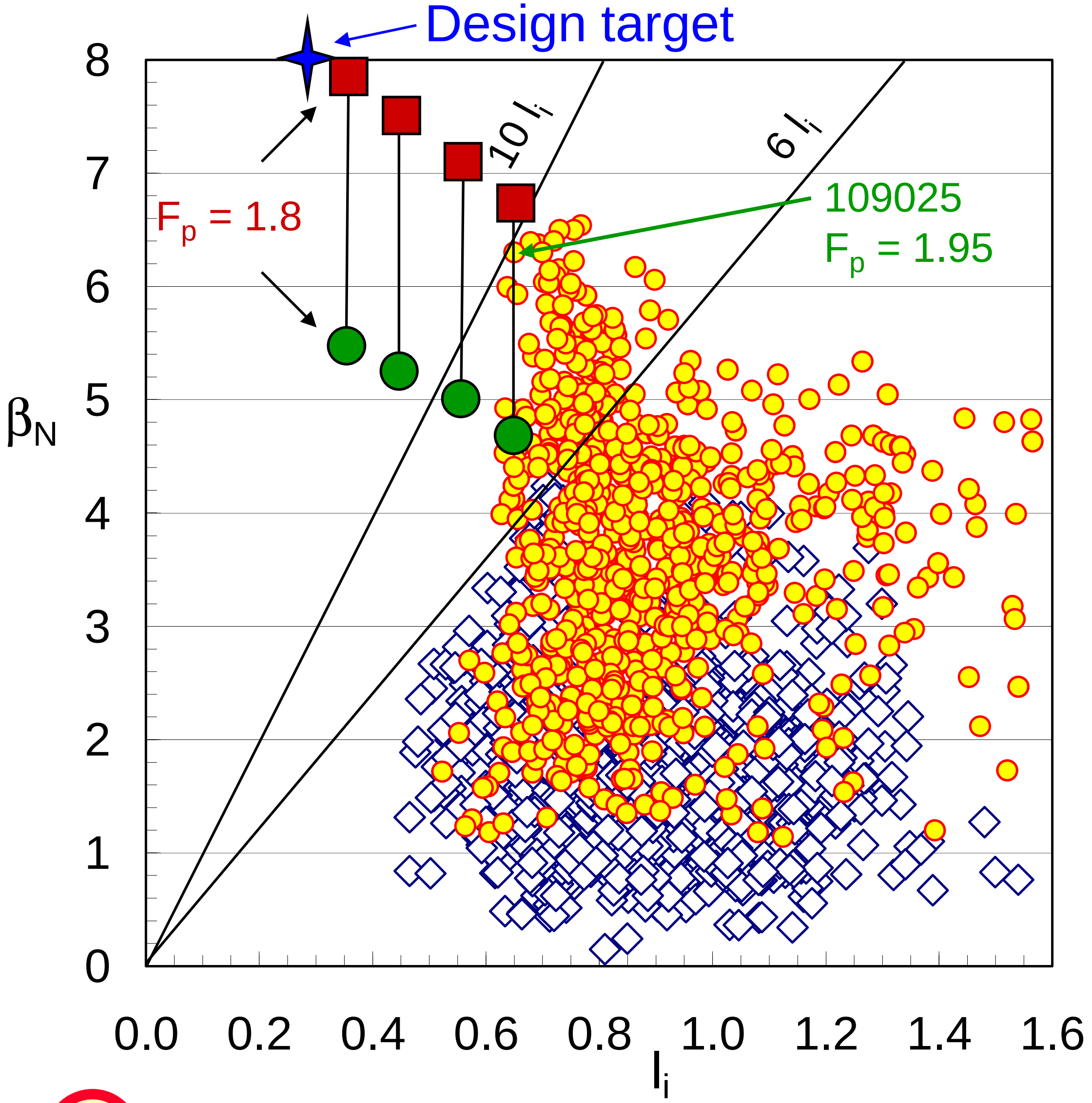
- "Smart-shell" feedback algorithm simulation – HBT-EP
- Error field amplificatio also being modeled with VALEN

VALEN (J. Bialek)

Implementing and evaluating active feedback for global MHD

- FY2003
  - Finalize physics design of active coil sets using DCON+VALEN analysis
  - Decide on either internal or external coil set, and begin engineering design
  - Initiate procurement of power supplies
    - Purchase supplies capable of fast feedback for high β RWM control
  - Commission internal RWM/EF 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 β plasmas with plasma rotation below the critical rotation frequency
    - Flow damping from non-resonant error field excitation using active coils and/or controlled error field amplification of the RWM are possible means
  - Determine options required for high frequency mode stabilization (e.g. internal coil)
    - Projected to stabilize the RWM up to the ideal-wall limit; modify NTM island formation
- FY2007-future
  - Utilize RWM/EF feedback to operate close to ideal-wall limit in optimized long-pulse discharges
  - Assess long-pulse impact of stochastic divertor boundary on edge profiles and divertor heat flux

Access to β_N = 8 conceptual design target exists



- Pressure peaking factor 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
      - Reconsider internal control coil option if system improvement desired
    - Repeat study with plasma rotation below RWM critical rotation frequency
  - Expand physics analysis as needed to couple theory to experiment