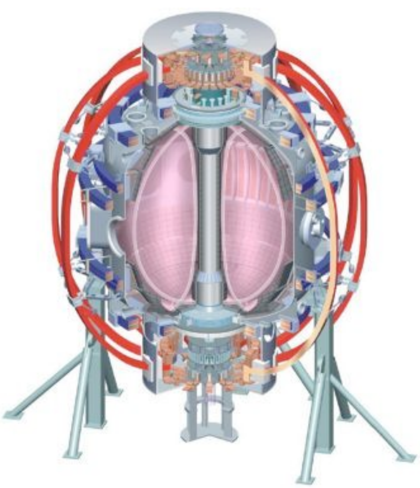
NSTX Supported by U.S. DEPARTMENT OF ENERGY Office of Science

Optimization and Utilization of Beta-Control

College W&M
Colorado Sch Mines
Columbia U
CompX
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Illinois
U Maryland
U Rochester
U Washington
U Wisconsin

S.P. Gerhardt, E. Kolemen, D. A. Gates, S. A. Sabbagh

NSTX 2010 Research Forum
MS TSG Breakout Session
Dec. 1st, 2009



Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

Overview

- Background
  - Rudimentary PCS control of NB injection was shown in 2008.
  - β_N control was demonstrated in 2009.
    - Not “tuned up”.
  - Improved rtEFIT basis vectors were implemented at the very end of the 2009 run.
- Goals of Proposed XP:
  - Achieve reasonable values of the parameters in the β_N control algorithm.
  - Test the ability of β_N control to enable non-disruptive operation near the β_N limit.
- Contributes to:
  - MS Milestone R(10-1): Assess sustainable beta and disruptivity near and above the ideal no-wall limit.

Implementation of β_N Control in NSTX

- Compare filtered β_N value from rtEFIT to a request, and compute an error.

$$e = \beta_{N,reqeust} - LPF\left(\beta_{N,RTEFIT};\tau_{LPF}\right)$$

- Use PID on the error to compute a new requested power.

2009 PID Algorithm

$$\Delta P_{inj} = P_{\beta_N}\overline{C}_{\beta_N} e + I_{\beta_N}\overline{C}_{\beta_N}\int edt + D_{\beta_N}\overline{C}_{\beta_N}\frac{de}{dt}$$

$$P_{inj,i} = P_{inj,i-1} + \Delta P_{inj}$$

$$\overline{C}_{\beta_N} = \tau\frac{I_P V B_T}{200\mu_0 a}\cdot\frac{dt}{0.001}$$

2010 PID Algorithm (?)

$$P_{inj} = P_{\beta_N}\overline{C}_{\beta_N} e + I_{\beta_N}\overline{C}_{\beta_N}\int edt + D_{\beta_N}\overline{C}_{\beta_N}\frac{de}{dt}$$

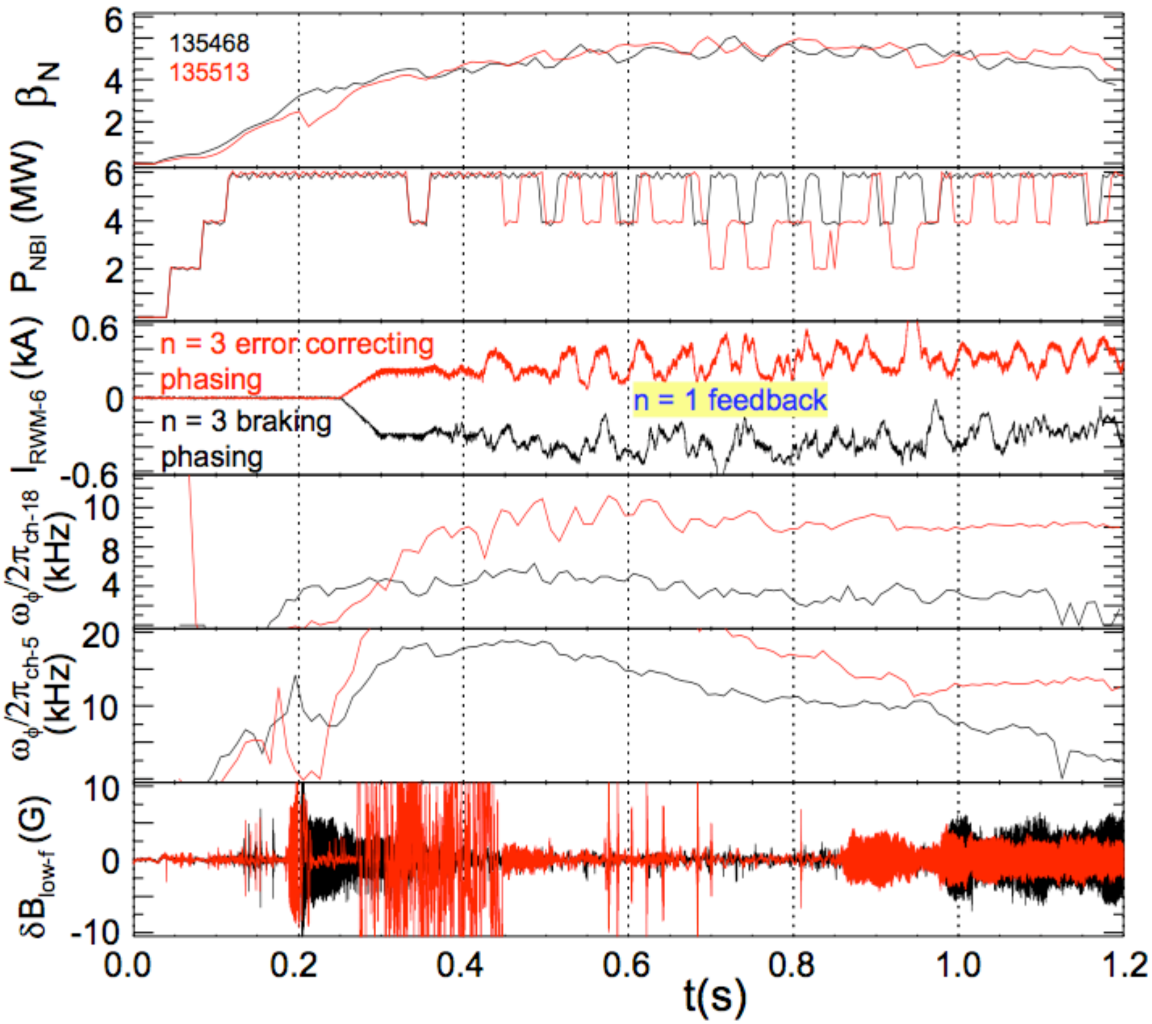
$$\overline{C}_{\beta_N} = \tau\frac{I_P V B_T}{200\mu_0 a}\cdot\frac{dt}{0.001}$$

- Use power from the PID operation, source powers, and "batting order" to determine the duty cycles for each source.
- Use the duty cycles and min. on/off times to determine when to block.

Many Available Adjustments

- Filter time constant on the β_N value sent from rtEFIT.
  - Useful for smoothing transients in the measured β_N.
- Proportional, integral, and derivative gains.
  - Determines the response of the system to transients.
- Batting order array.
  - Determines which sources modulate
  - Switch to a different source if a given source reaches the maximum number of blocks.
  - Also able to prevent A modulations, to keep MSE and CHERS.
- Source powers
  - Can be adjusted in order to prevent modulations.
- Minimum Source On/Off Times.
  - Smaller values will lead to better control, but possibly at the expense of source reliability.
  - 20 msec. has seemed OK so far.

β_N Control Has Been Demonstrated in 2009



- ***β_N algorithm compensates for loss of confinement with n=3 braking.***
- ***Control works over a range of rotation levels.***
- ***Goal of XP is to optimize the system.***

S.A. Sabbagh, 2009 NSTX Results Review

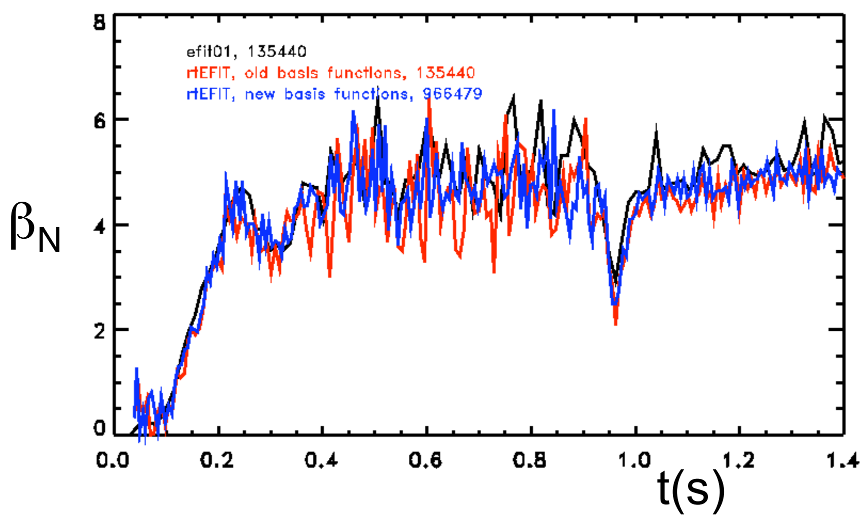
Modifications to the rtEFIT Basis Functions Resulted in Improved Real-time Reconstructions

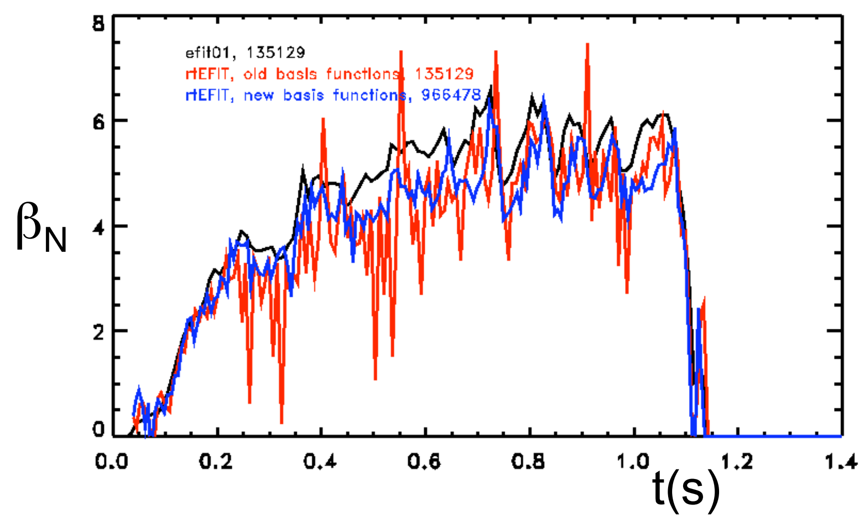
- Occasional poorly converged equilibria lead to incorrect outer gap, β_N
  - Kick off an deleterious transient in the vertical field coil current.
  - Edge current not allowed
- New basis function model based on those developed for off-line magnetics-only reconstruction (Columbia University)
  - Tested on literally > 2 million equilibria
  - Finite edge current through ff’(ψ_n)
- Considerable real-time reconstruction improvement
  - Reduction in β_N “noise” indicative of improved reconstructions

$$p'(\psi_n) = a_1\psi_n(1-\psi_n)$$

$$ff'(\psi_n) = b_0 + b_1\psi_n\left(1-\frac{1}{3}\psi_n^{\,2}\right) + b_2\psi_n^{\,2}\left(1-\frac{2}{3}\psi_n\right)$$

rtEFIT, Old Basis Functions ***rtEFIT, New Basis Functions*** ***Offline Calculation***





Improvement made on 2nd to last day of run….we should take advantage of it this year.

Simple Model For NB Heating

- Coupled equations for the stored energy in thermal particles and fast particles.

$$\frac{dW_{th}}{dt} = \frac{W_f}{\tau_f} - \frac{W_{th}}{\tau_{E,th}}$$

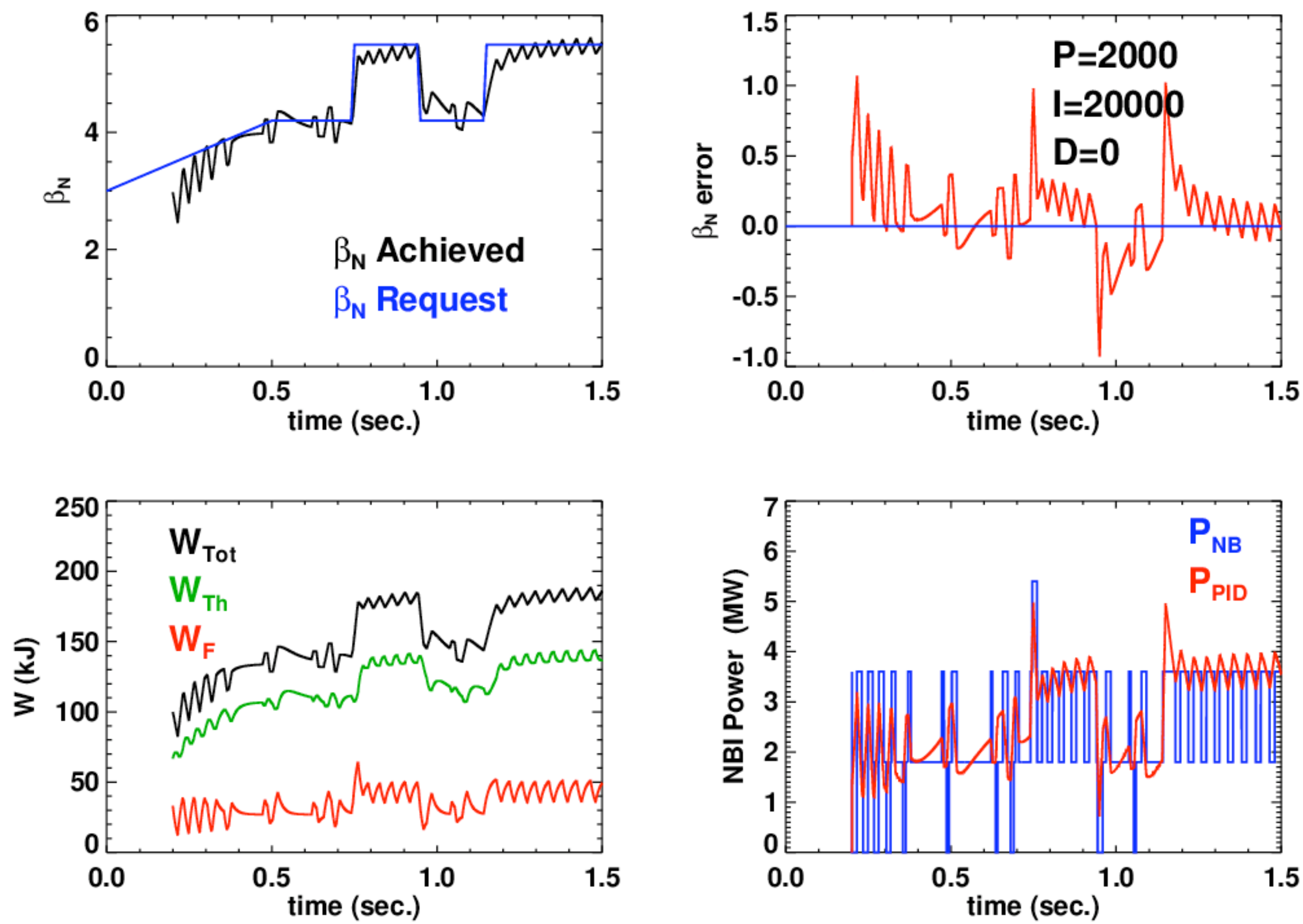
$$\frac{dW_f}{dt} = P_{inj} - \frac{W_f}{\tau_f}$$

$$\tau_{E,th} = \tau_{E,0}\left(\frac{4\times 10^6}{P_{inj}}\right)^{p_{\exp}}$$

$$W = W_{th} + W_f$$

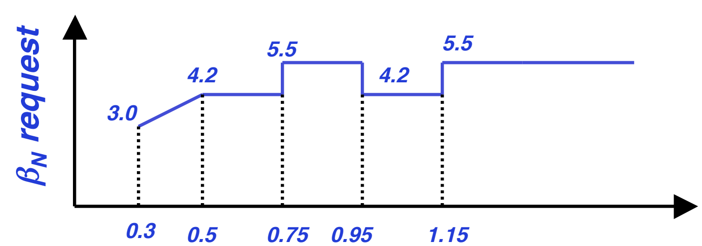
- Two free parameters in model:
  - Time-scale for thermal energy loss: $\tau_{E,th}$
  - Time-scale of energy transfer from fast to thermal particles: τ_f
- Compute these parameters using beam modulations and TRANSP
- Simple model designed for control.
  - No direct fast-ion loss.
  - Collapse thermal electron and ion energy loss rates into a single parameter.
- Tune the model parameters (τ_f, $\tau_{E,th}$, p_{exp}) with TRANSP.
- Use model in a feedback simulation to get gains correct.

Example: Proportional And Integral FB, Modulating All Sources

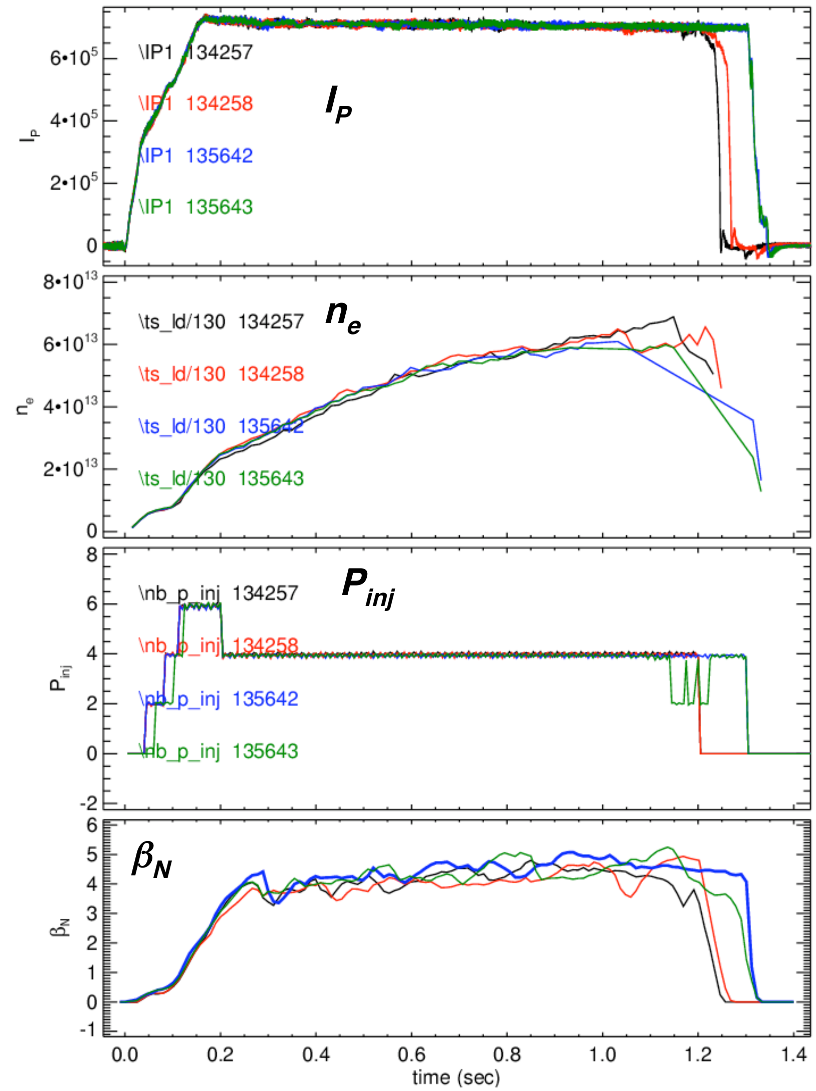


XP Plan: Algorithm Optimization (1/2 day)

- Establish a high-performance reference.
  - Should be long pulse at 4 MW, to allow room for modulations.
  - Consider 700-800 kA fiducial.
- Add in β_N control with reasonable parameters, step in β_N request.
- Adjust gains to achieve best match to desired waveform.
- What min on/off times to use?
  - 20/20 was used last year.
- Use full RWM control.



Potential Target: Long Pulse 700 kA with Fiducial Shape.



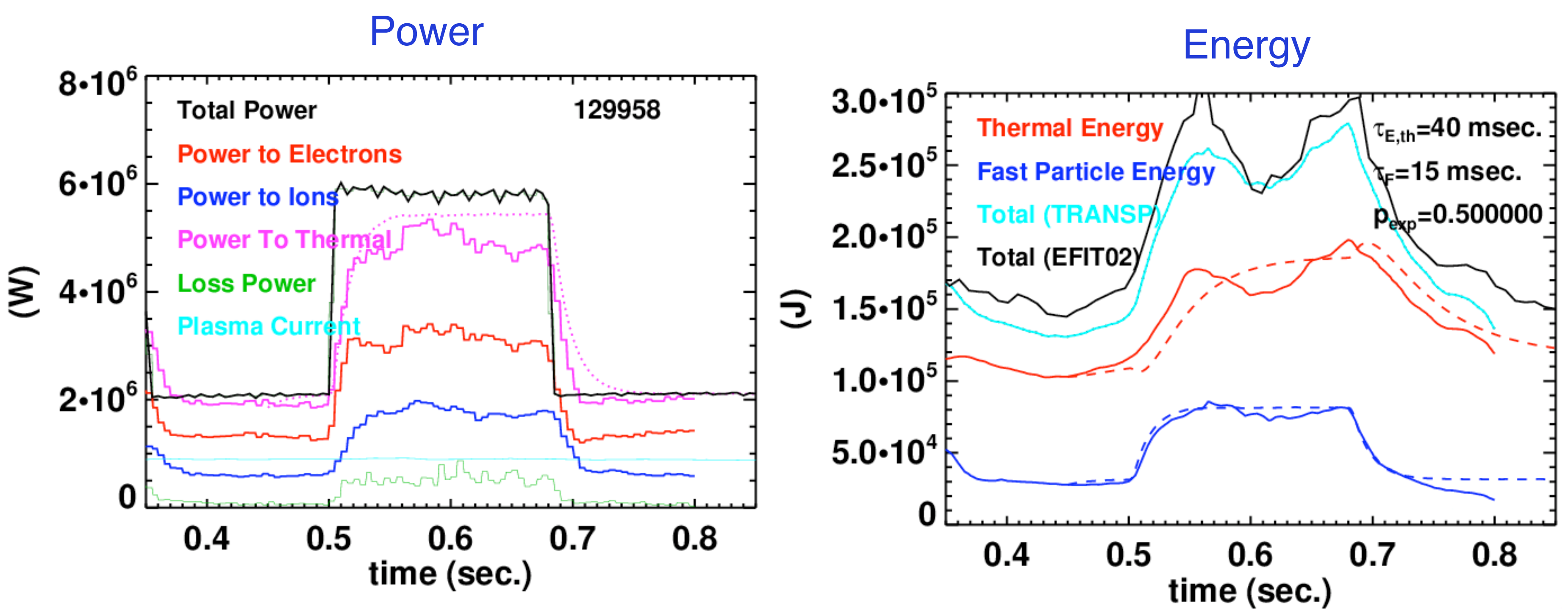
XP Plan: Test For Disruptivity Reduction (1/2 day)

- Establish a discharge regime that disrupts with a 6 MW of input power.
  - Maybe just use the previous 700 kA target?
- Re-run with β_N request reasonably below the disruptive value.
  - Should not disrupt any more
- Increase the β_N request in small increments to where it disrupts.
  - Bracket the unstable heating power.
- Adjust the source voltage to achieve approximately the same waveforms.
  - These are pre-programmed
  - Re-run and see if the level of β_N fluctuations is increased, disruptions re-appear.
- Status of RWM Control?
  - Inclined to use slow control (DEFC), but not fast feedback.
  - Provides test of disruption control in the wall-stabilized regime.

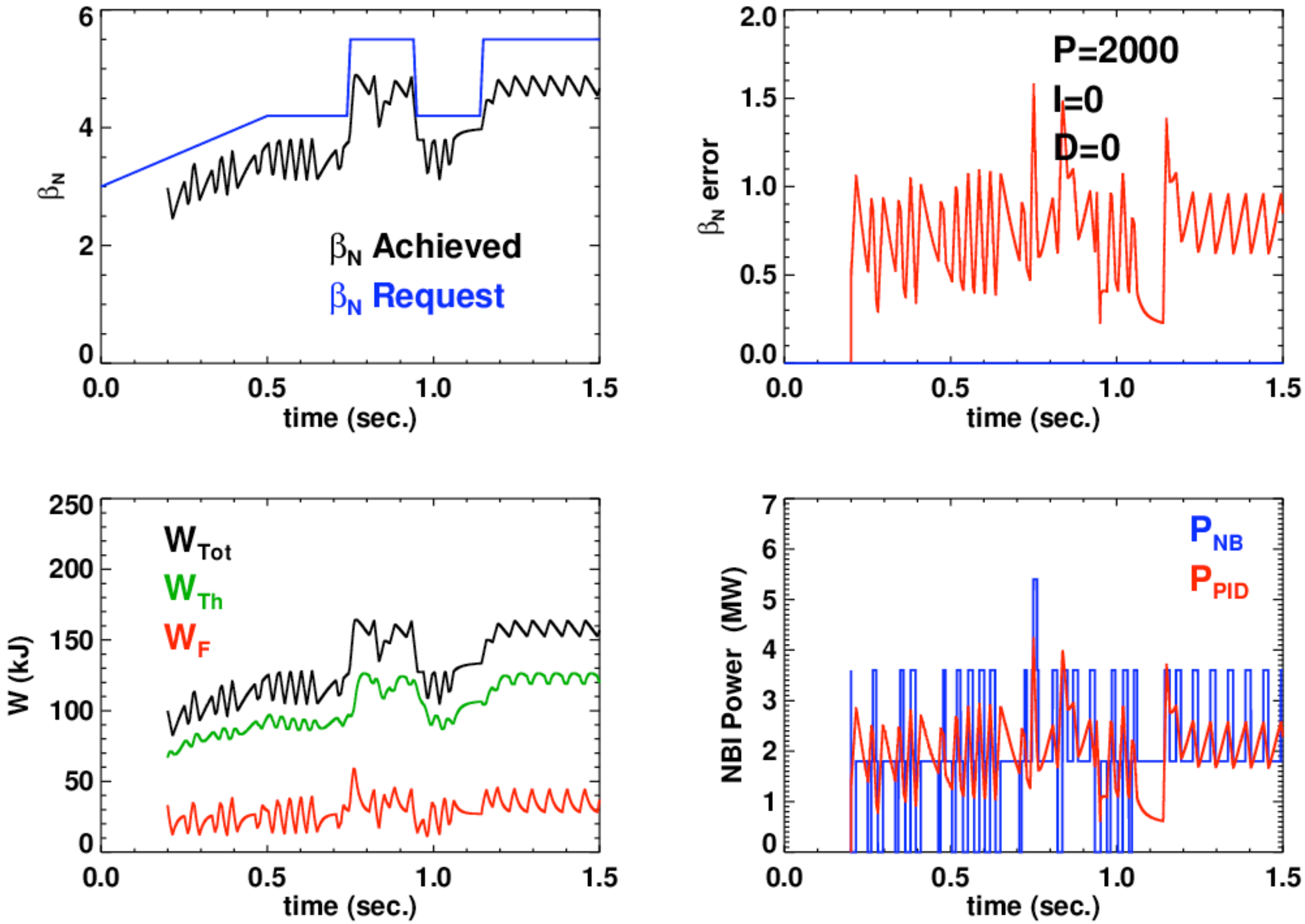
Backup

Example of Model

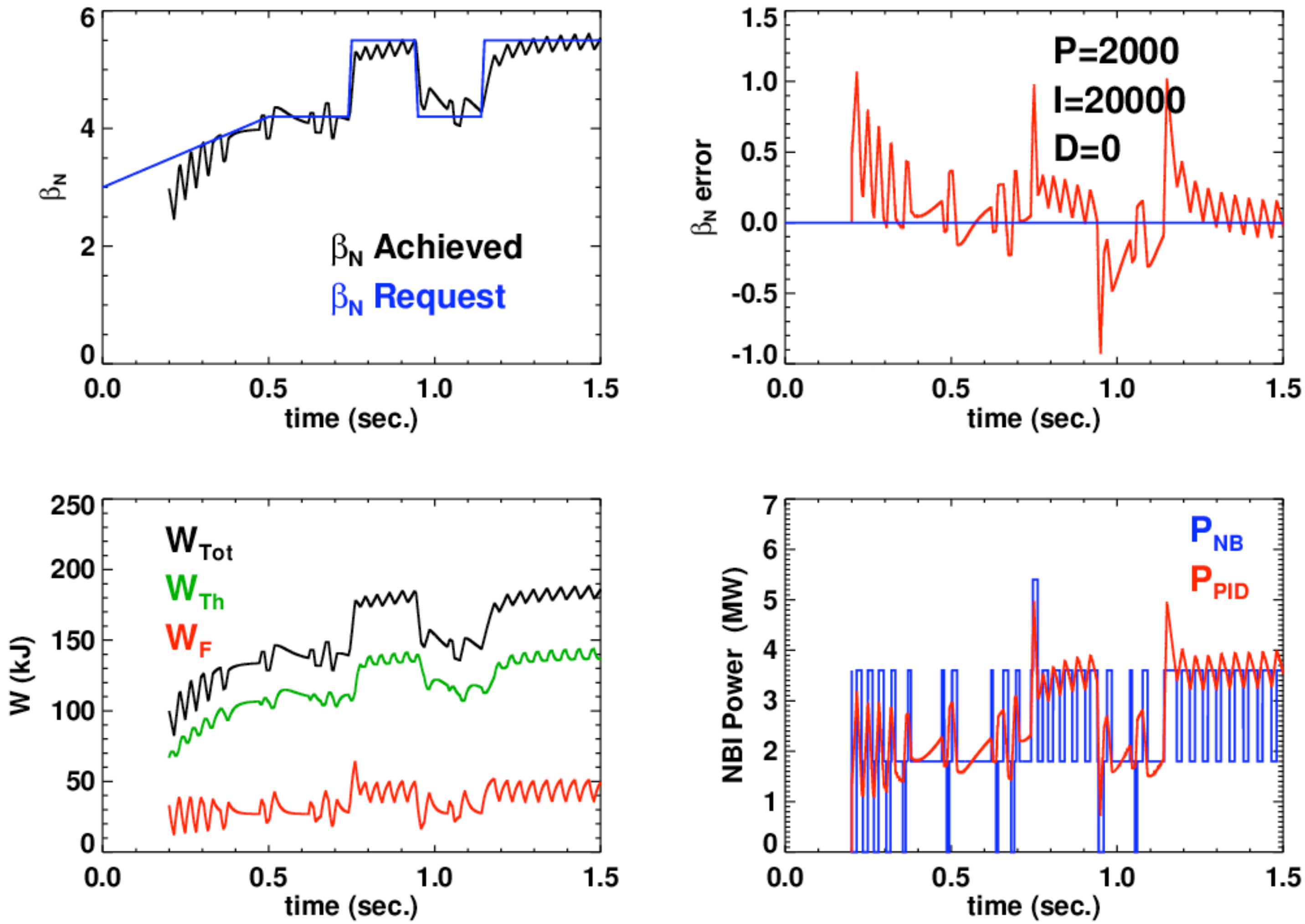
- Solid: TRANSP Quantities
- Dashed: Model
- 900 kA fiducial like discharge



Simulation #1: Proportional FB Only, Modulating All Sources



Simulation #2: Proportional And Integral FB, Modulating All Sources



Simulation #3: Proportional And Integral FB, Modulating B & C Only