Integrated Plasma Control Design for NSTX PCS Algorithm Development

J. Leuer, J. Ferron, D. Humphreys, M. Walker, *General Atomics*; **D. Gates, R. Hatcher, J. Menard, D. Mueller, C. Neumeyer,** *PPPL*; **R. Khayrutdinov,** *TRINITI Lab.*
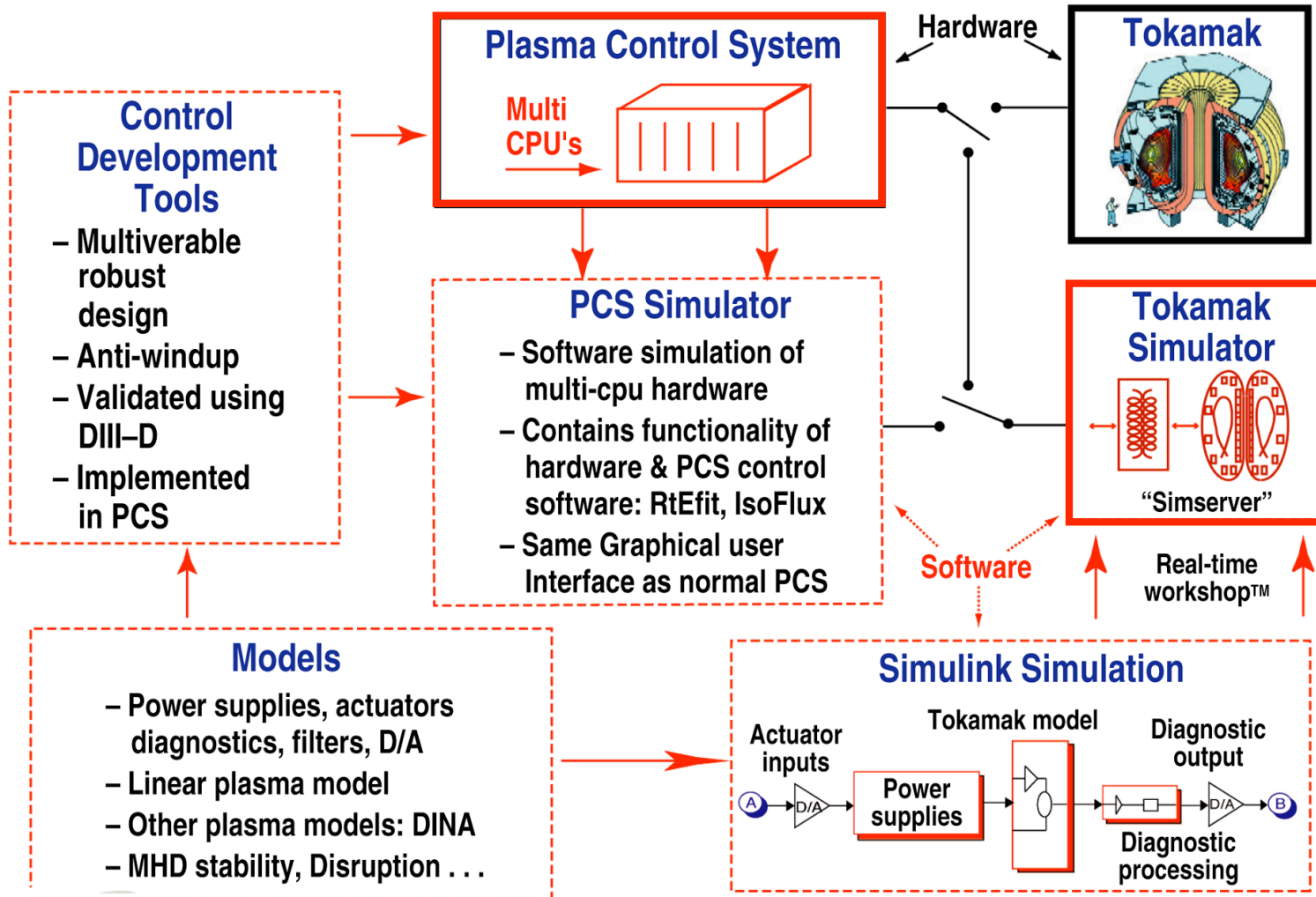
Overview

- Integrated Control Design Concept
- NSTX Model Validation
- Vertical Control Closed Loop Gain Space
- NSTX shape simulator
- Summary

NSTX Results/Research Forum, PPPL, NJ
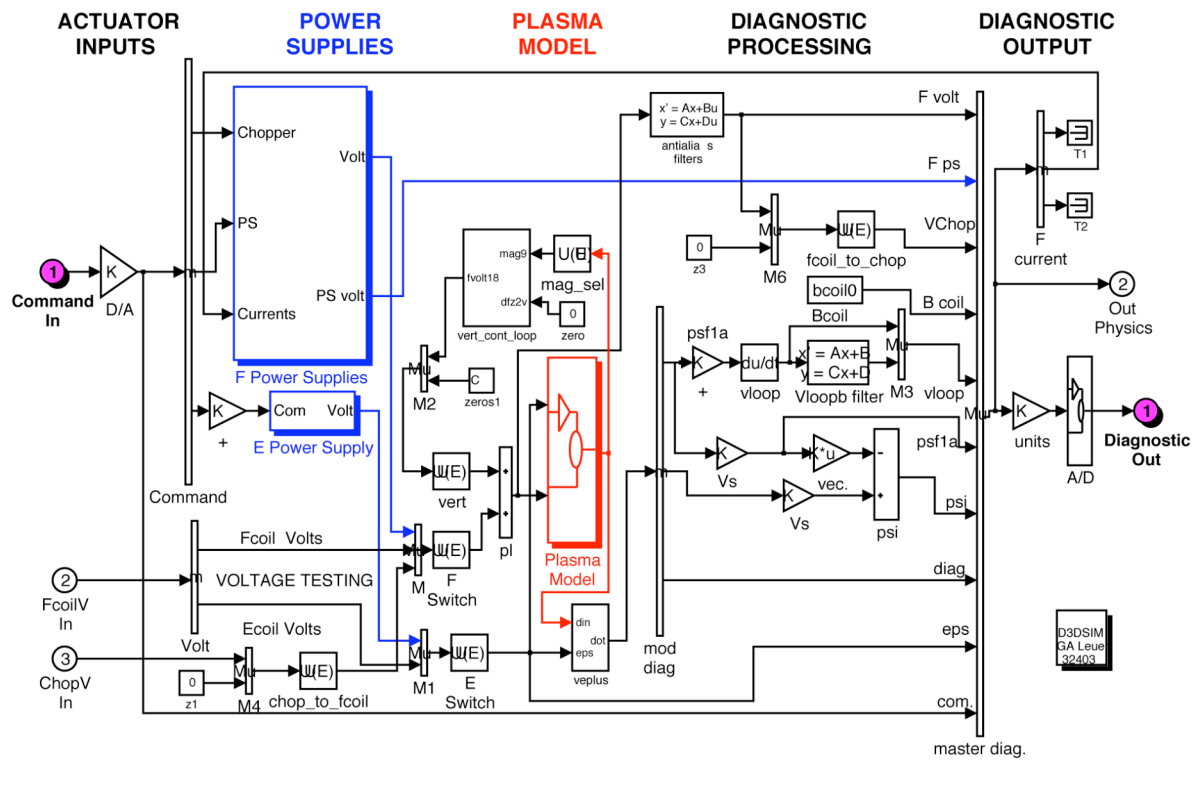**December 12-16, 2005**

DIII–D
NATIONAL FUSION FACILITY

GENERAL ATOMICS

NSTX

Integrated Plasma Control Tools Allow Systematic Design and Testing of Controllers

Control Development Tools
- Multiverable robust design
- Anti-windup
- Validated using DIII–D
- Implemented in PCS

Plasma Control System

Multi CPU's

Hardware

Tokamak

PCS Simulator
- Software simulation of multi-cpu hardware
- Contains functionality of hardware & PCS control software: RtEfit, IsoFlux
- Same Graphical user Interface as normal PCS

Tokamak Simulator

"Simserver"

Software

Real-time workshop™

Models
- Power supplies, actuators diagnostics, filters, D/A
- Linear plasma model
- Other plasma models: DINA
- MHD stability, Disruption . . .

Simulink Simulation

Actuator inputs

Tokamak model

Power supplies

Diagnostic output

Diagnostic processing

Simulator Complexity Depends on Phenomena Being Modeled

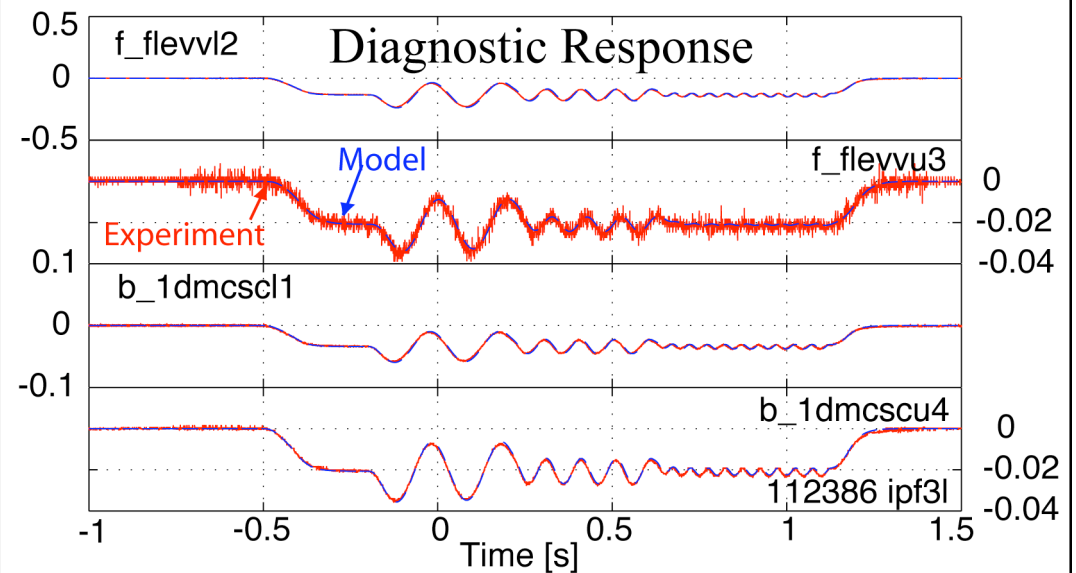# Simulator Complexity Depends on Phenomena Being Modeled
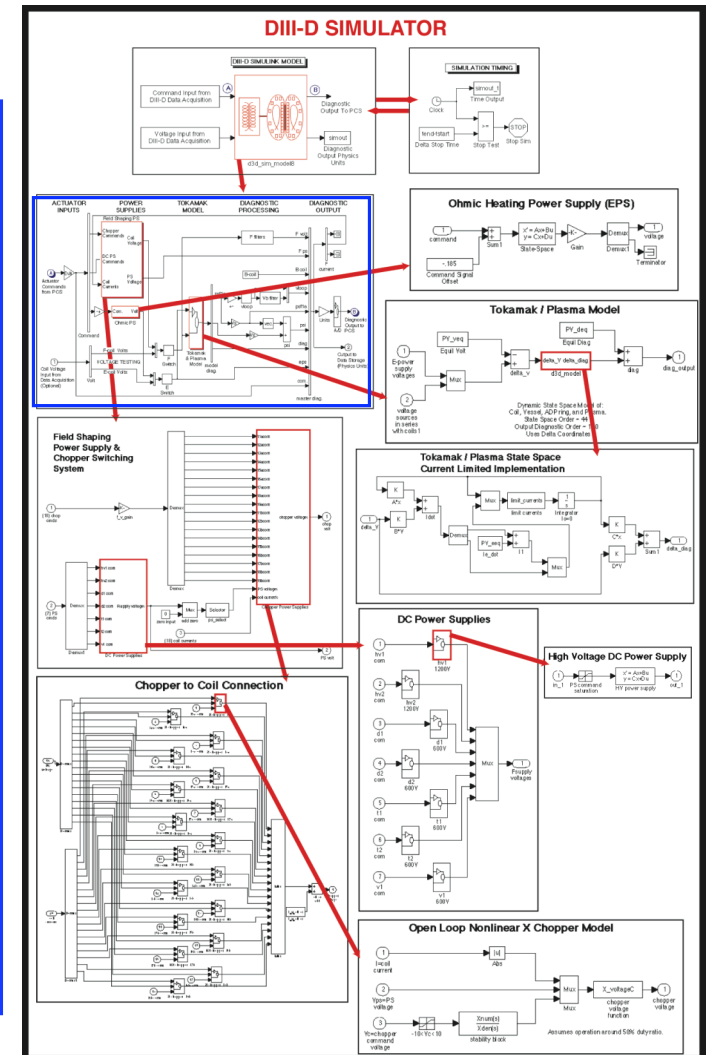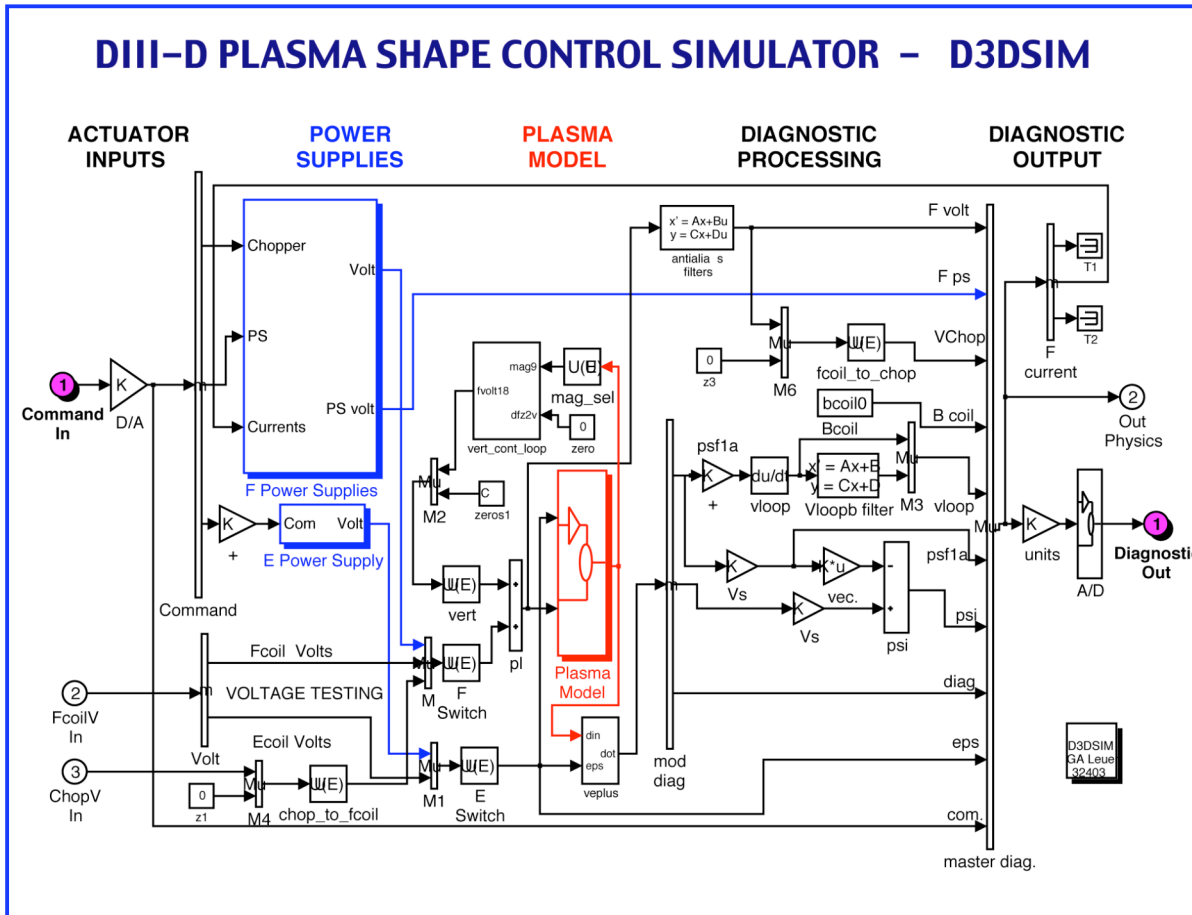
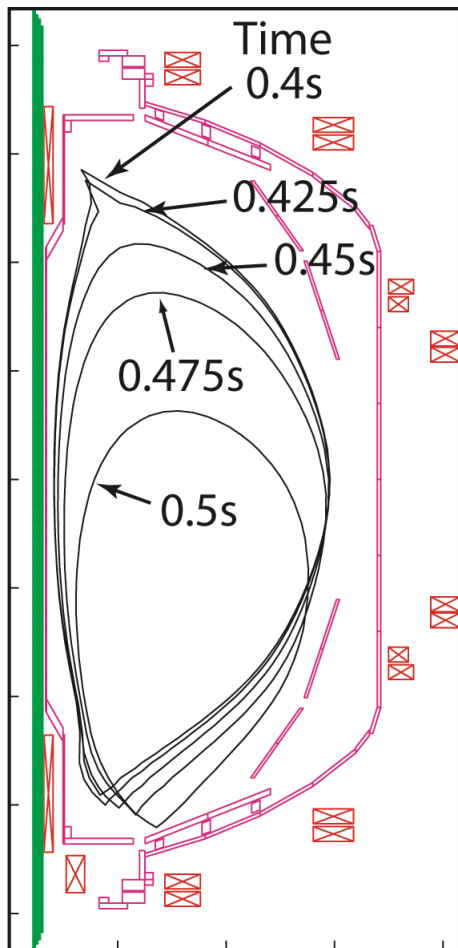# NSTX Single Coil Oscillatory Tests Provide Validation of Coil and Diagnostic Models
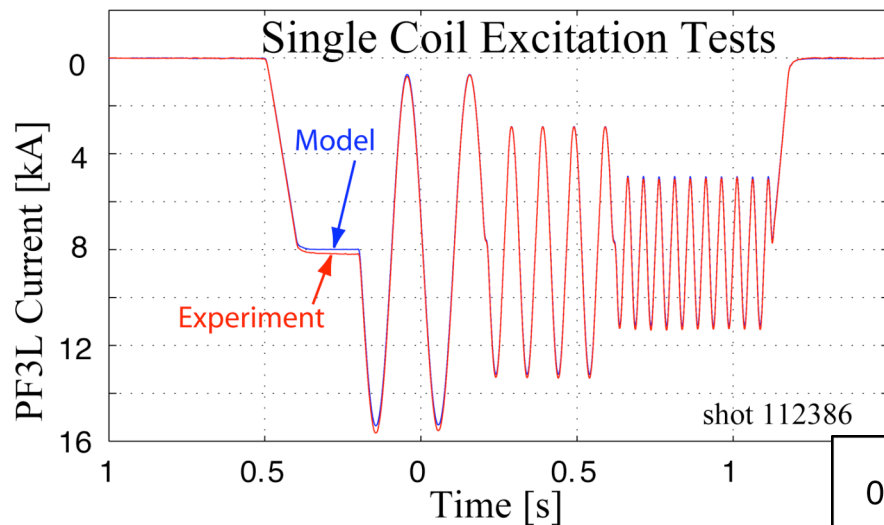
Coil model driven with PS voltages provides good match to experimental data

Diagnostic response accurately simulated - problems typically in diagnostic data rather than model predictions
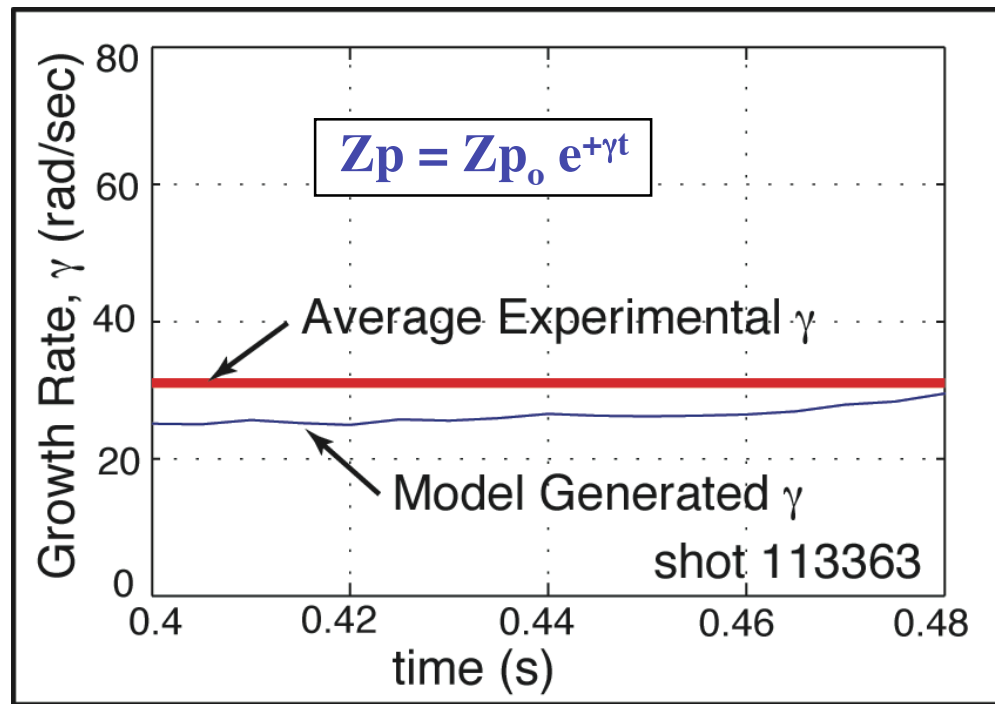
NSTX Physics Model Validation

Triggered VDE experiment

Model-derived and experimental growth rates are similar

$$Zp = Zp_o\, e^{+\gamma t}$$

Vertical Control Gain Space Modeling

- **Full linearized, EFIT derived, model**

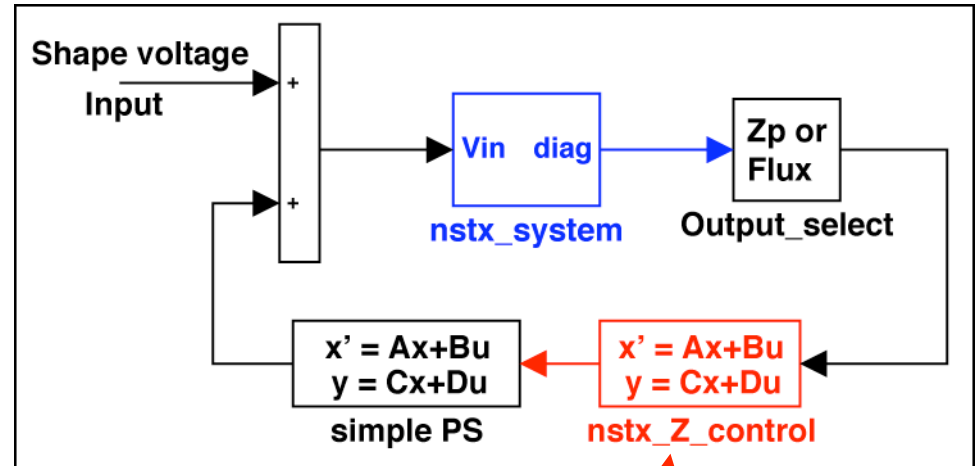- **PID controller**
  - Arbitrary Input, Flux or Zp

- **Simplified Linear Power Supply**

- **Ability to:**
  - Determine stable gain space
  - Vary stability parameter
  - Vary model parameters to study influence
  - Determine influence of Z-predictor
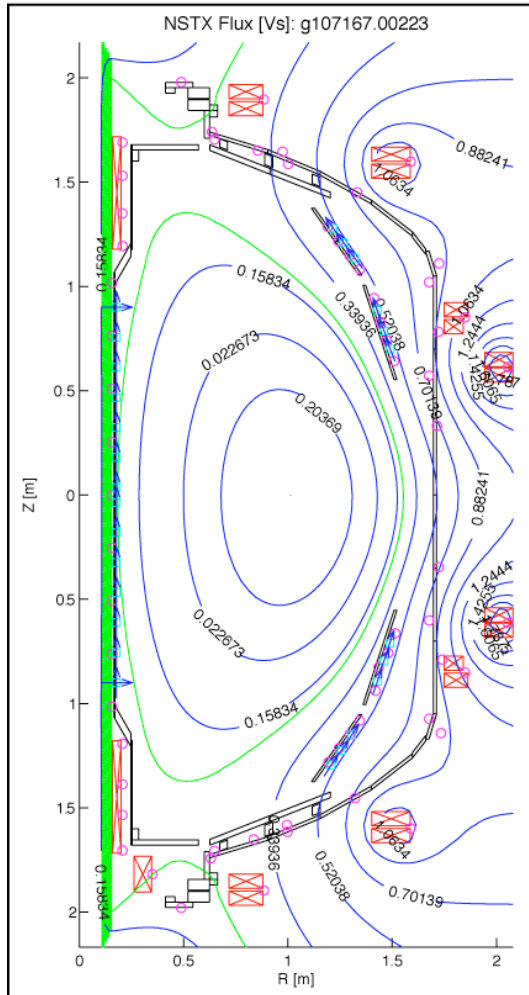
- **Limitations**
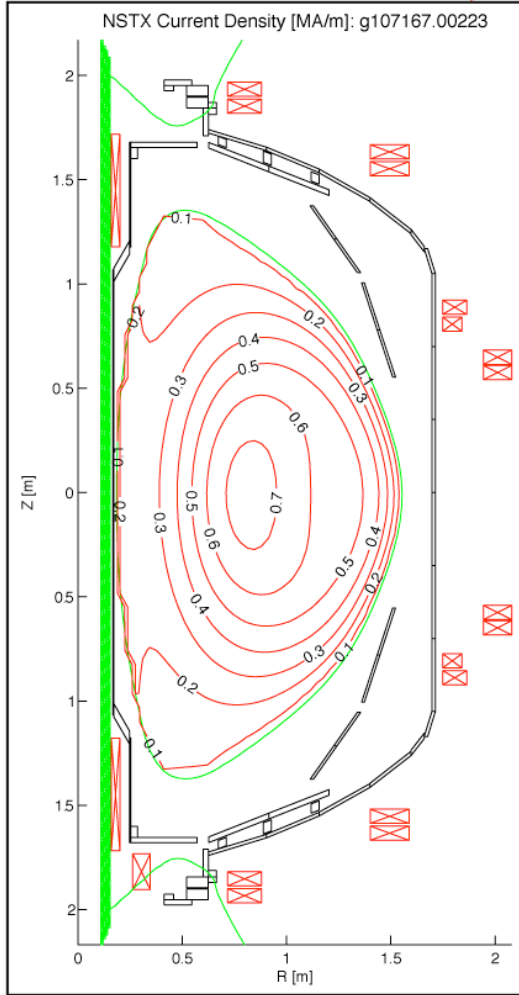 - Linear analysis, no inclusion of PS and PCS non-linearities

Controller Parameters
G_p Proportional Gain
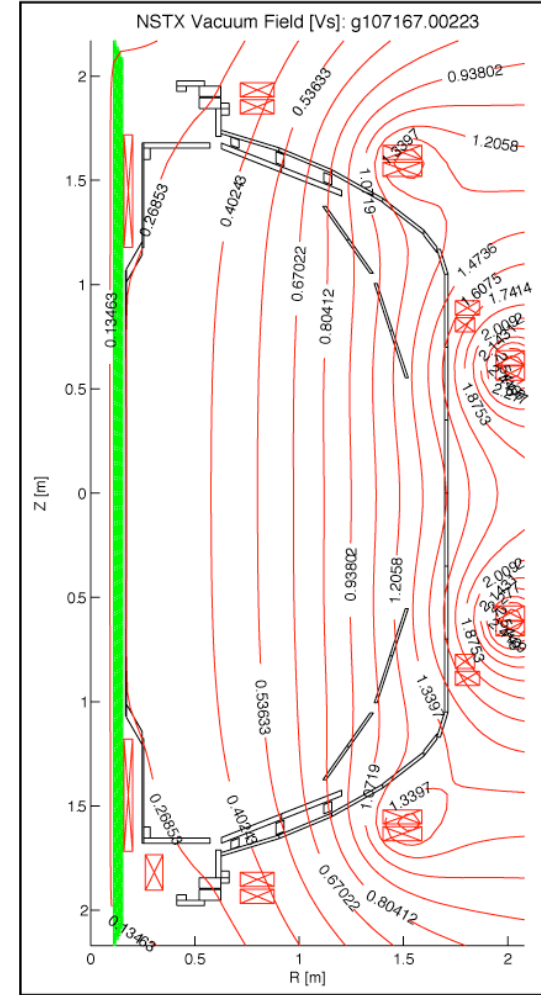G_d Derivative Gain
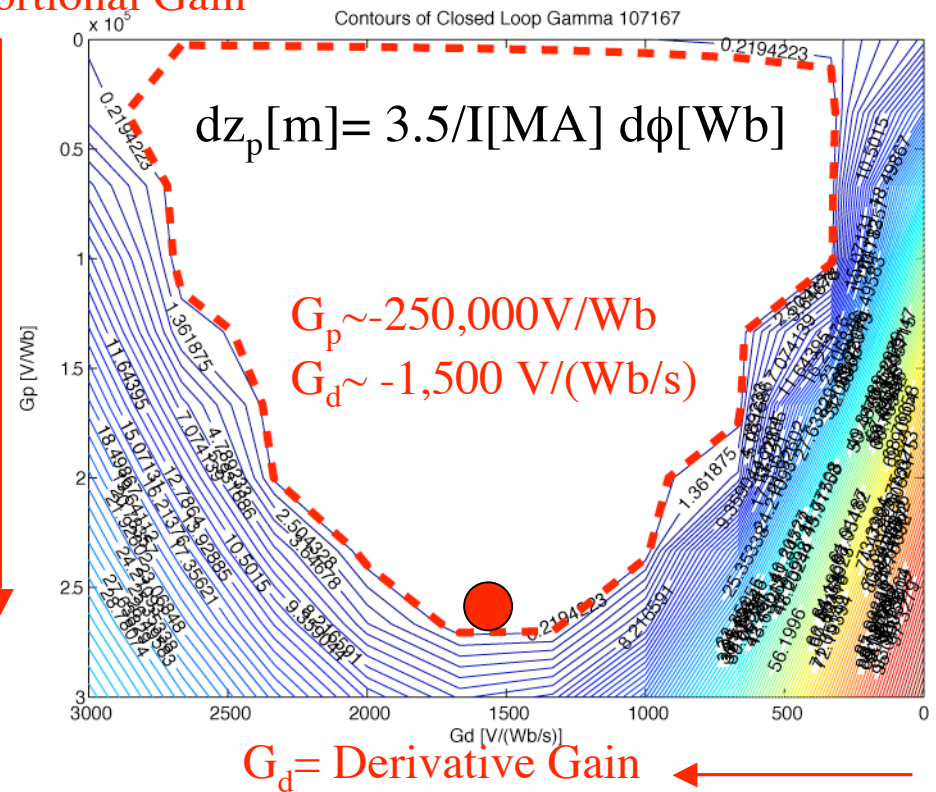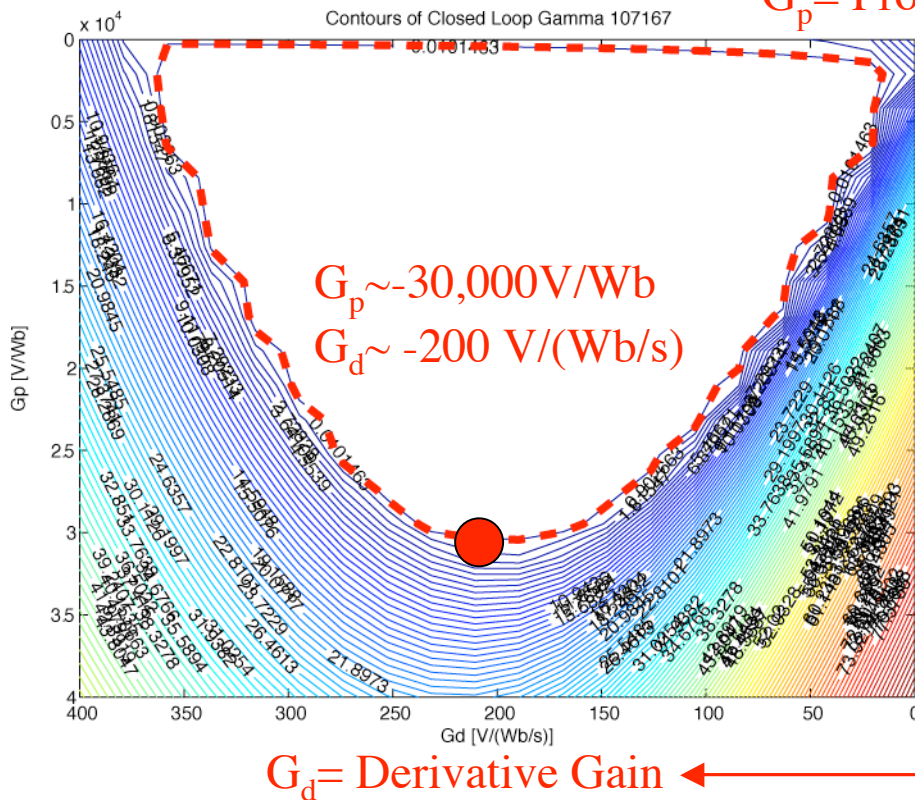G_i Integral Gain

NSTX Equilibrium

Vertical Control Gain Space for Nominal System

Input: $d\phi = \phi_{pppu2} - \phi_{pppl2}$

Input: dz_p (model)

Nominal Case

G_p = Proportional Gain

$dz_p[m] = 3.5/I[MA]\, d\phi[Wb]$

$G_p \sim -30,000\,V/Wb$
$G_d \sim -200\,V/(Wb/s)$

$G_p \sim -250,000\,V/Wb$
$G_d \sim -1,500\,V/(Wb/s)$

G_d = Derivative Gain
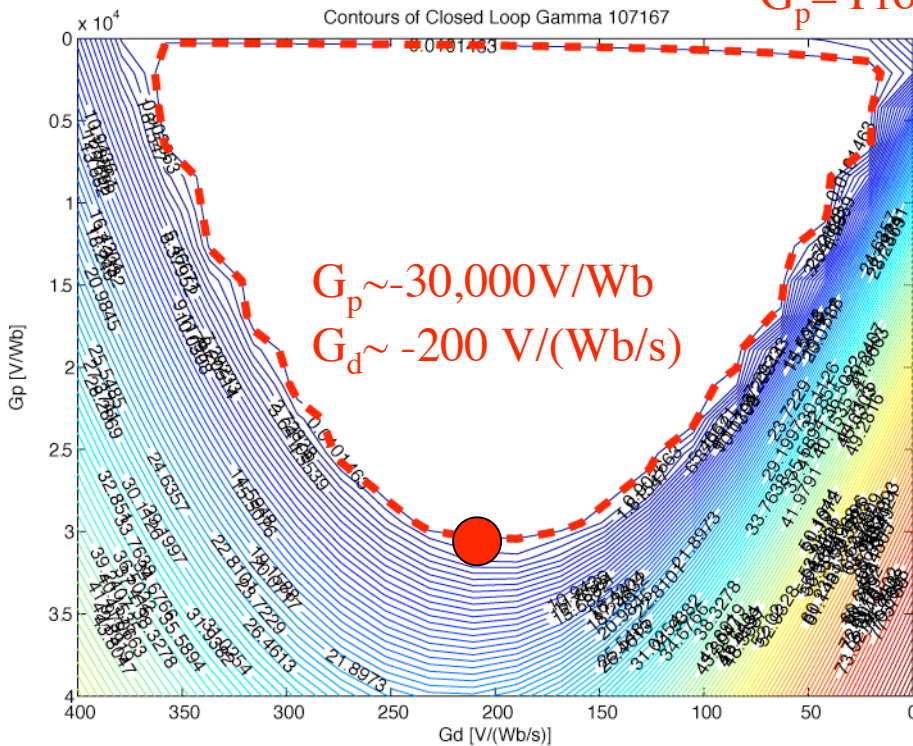
G_d = Derivative Gain

Model Passive Plate Greatly Shields Flux Signal

Input: $d\phi = \phi_{pppu2} - \phi_{pppl2}$

Nominal Case

Increase PP Resistance x 2

G_p = Proportional Gain

$G_p \sim -30,000 \text{V/Wb}$
$G_d \sim -200 \text{ V/(Wb/s)}$

$G_p \sim -55,000 \text{V/Wb}$
$G_d \sim -300 \text{ V/(Wb/s)}$

G_d = Derivative Gain
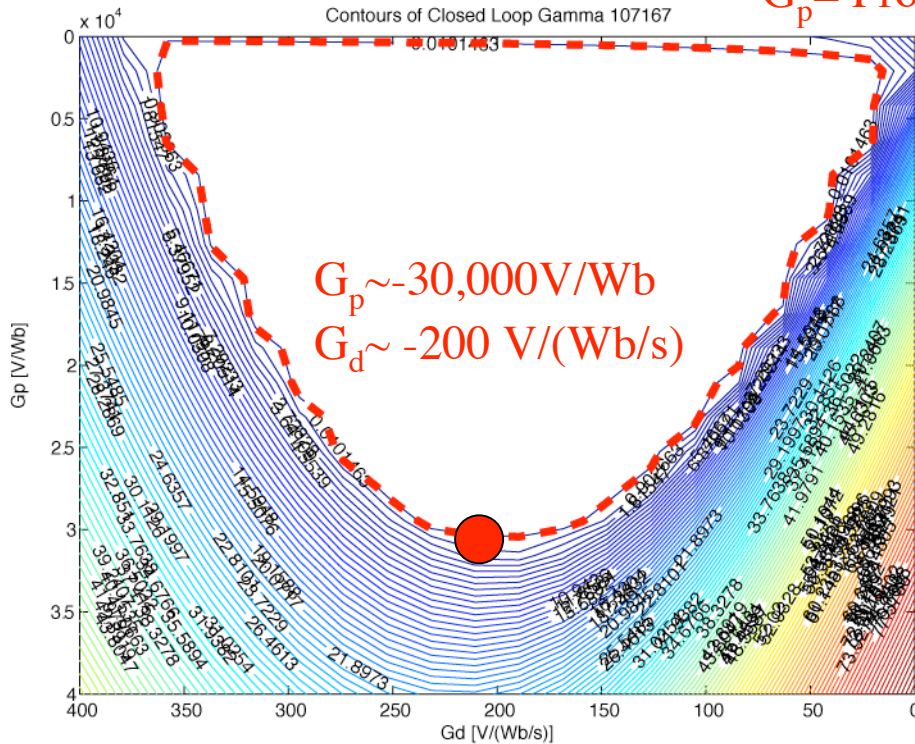
G_d = Derivative Gain

Increase Growth Rate Reduces Operational Space
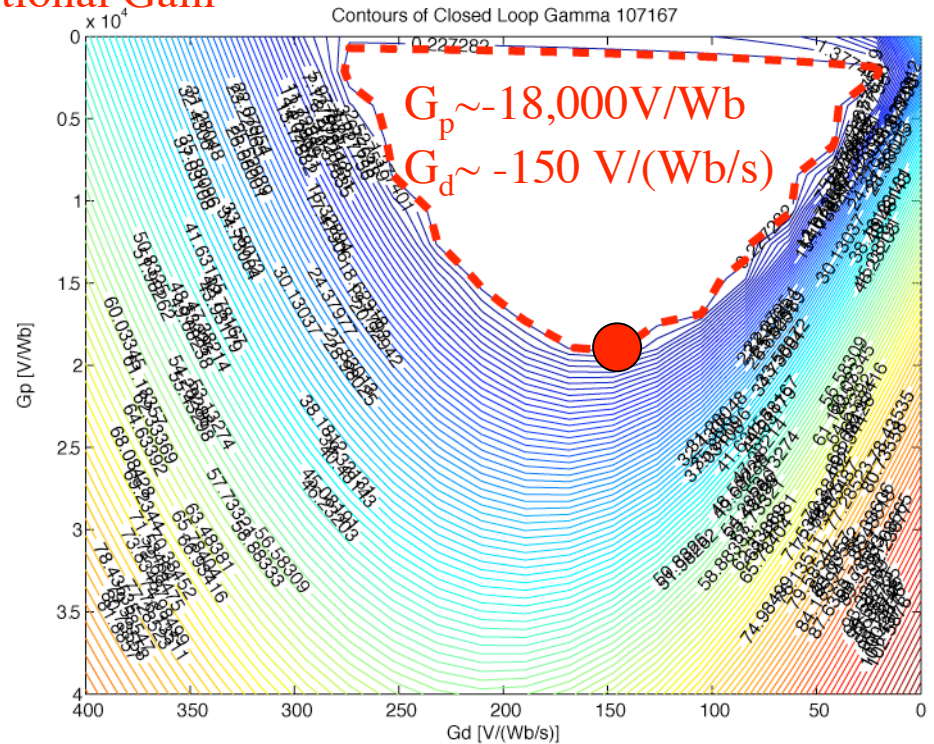
Input: $d\phi = \phi_{pppu2} - \phi_{pppl2}$

Nominal Case

Increase Growth Rate x 5 ($40s^{-1}$)
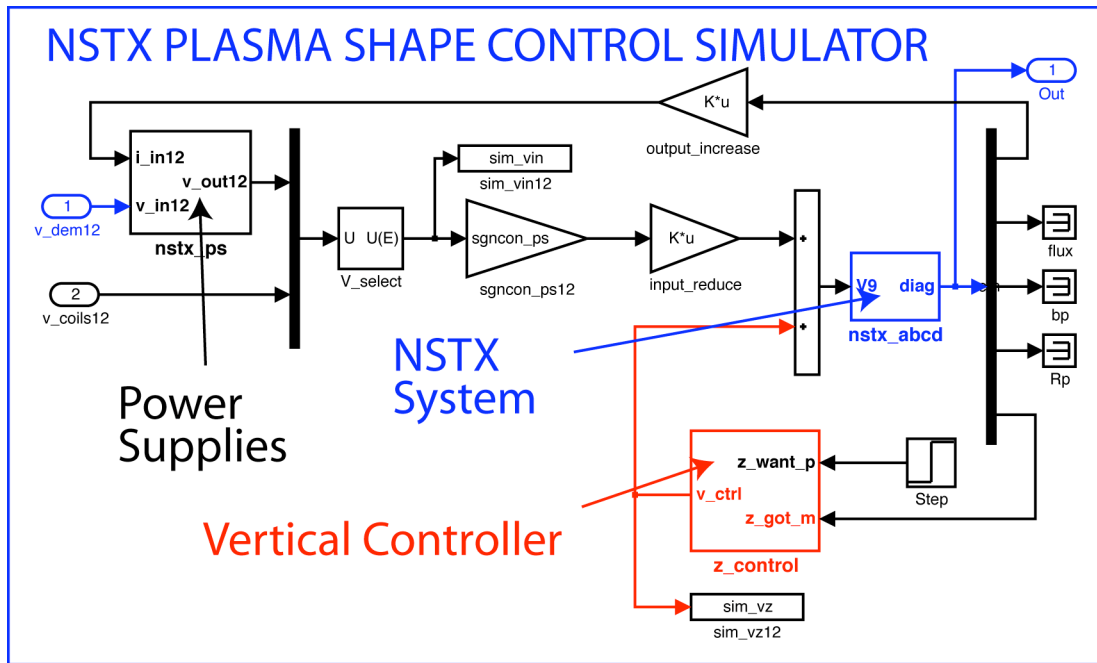
G_p = Proportional Gain

$G_p \sim -18,000 V/Wb$
$G_d \sim -150 V/(Wb/s)$

$G_p \sim -30,000 V/Wb$
$G_d \sim -200 V/(Wb/s)$

G_d = Derivative Gain
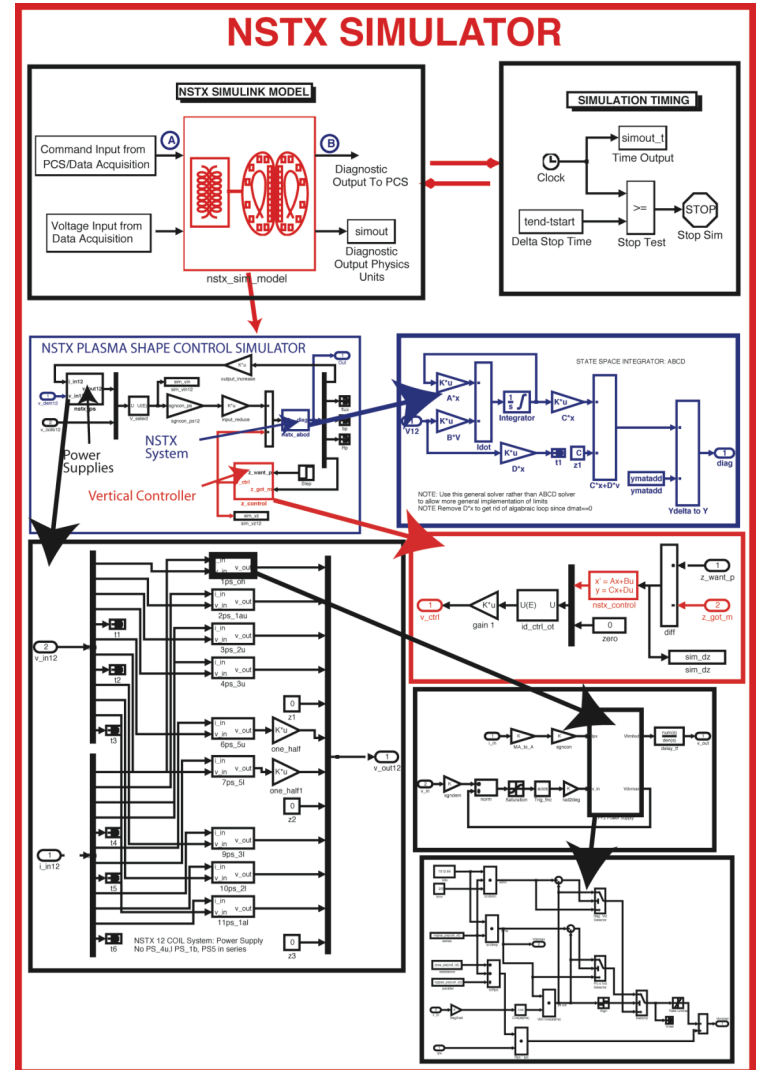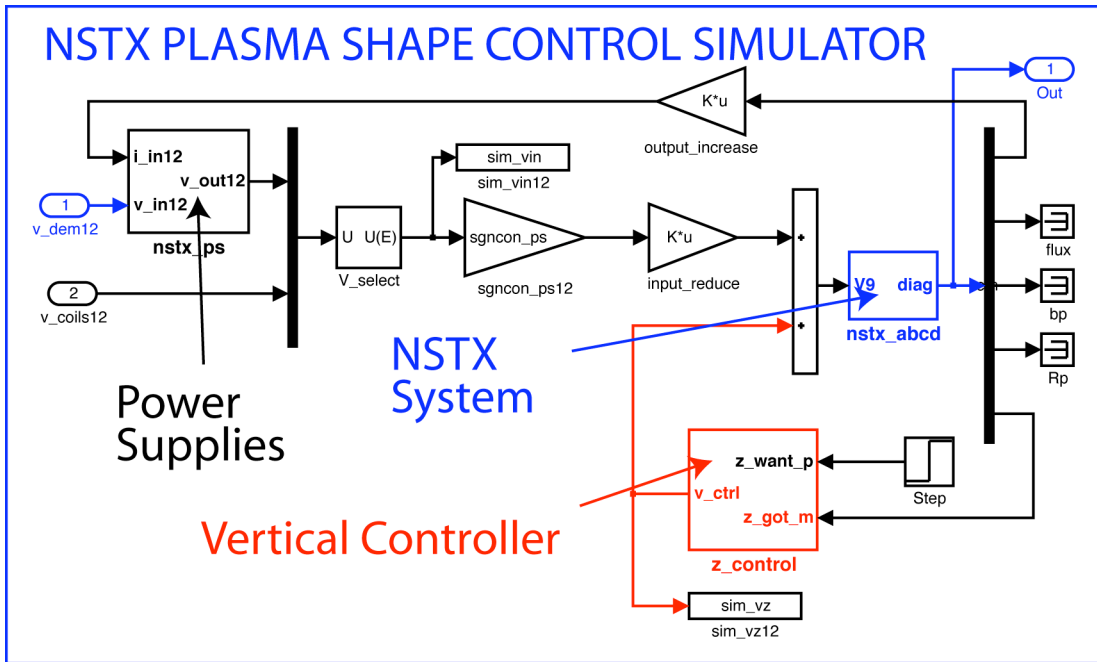
G_d = Derivative Gain

NSTX Plasma Shape Simulator

NSTX Plasma Shape Simulator

Summary

- **The DIII-D suite of Integrated control design tools is being validated and developed for use in NSTX controller development**

- **These tools allow development of sophisticated control systems with little or no experimental time**

- **Status:**
  - Validation of most sub-models complete
  - Complete simulation model being validated
  - Has been used to simulate: VDE's, vertical stability gains, solenoid less operation (DINA)

- **Future development:**
  - Final validation of PP model & vertical control PCS transfer functions
  - PCS simserver development for control algorithm development
  - Application to control problems in NSTX PCS