Integrated Design and Implementation of Performance Regulation and MHD Stability Control Algorithms for KSTAR

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Overview of Talk

- **Proposed task: advanced, integrated plasma control design for KSTAR**
  - **Advanced shape/stability control**
  - **Operating point, profile control**
- **Proposed task is a natural extension of the KSTAR Day One Plasma Control System (PCS) development effort, now underway (with funding ~0.4 FTE DOE, ~0.25 FTE KSTAR, + KBSI collaboration support)**
  - **Basic R, Z, Ip, coil current control; infrastructure derived from DIII-D PCS**
  - **Uses DIII-D integrated plasma control tools**
- **The Integrated Plasma Control approach**
  - **Used in both Day One PCS task and advanced control task**
- **Task sequence/schedule: FY2006-2010 (extension to 2011-2014)**
- **Summary and Conclusions**

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Proposed Task: Integrated Performance and Stability Control Design for KSTAR

- **Upgraded KSTAR PCS to include advanced equilibrium and MHD stability control in close collaboration with KBSI**
- **Model-based design and simulation tools; simulations to test implementation**
  - **Implementation in KSTAR PCS based on DIII-D PCS**
- **Advanced shape control:**
  - **Full isoflux scheme from DIII-D**
  - **Realtime EFIT**
  - **Model-based multivariable controllers**
  - **Nonlinear (saturation proximity avoidance) algorithms**
- **Operating point control algorithms:**
  - **Density control (fueling/pumping)**
  - **Plasma beta control**
- **MHD stability control:**
  - **High performance digital vertical stability control**
  - **RWM, NTM control algorithms**
- **Off-normal supervisory/response algorithms**

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Proposed Task is Natural Extension of Present Day One KSTAR PCS Design Task

- **Goal of Present task is to design "Day One" KSTAR PCS with basic plasma control**
  - **KSTAR Day One PCS is based on and developed from the DIII-D PCS infrastructure**
  - **Strong collaboration with KBSI personnel**
- **Model-based design and simulation tools; simulations to test implementation**
- **Basic position, vertical stability control:**
  - **R, Z position; velocity-based vertical stability algorithm**
  - **Model-based PID controllers**
- **Operating point control algorithms:**
  - **Coil current control**
  - **Breakdown algorithm**
  - **Plasma current control**
- **KSTAR PCS and algorithms designed to be extendable to full advanced, integrated plasma control**

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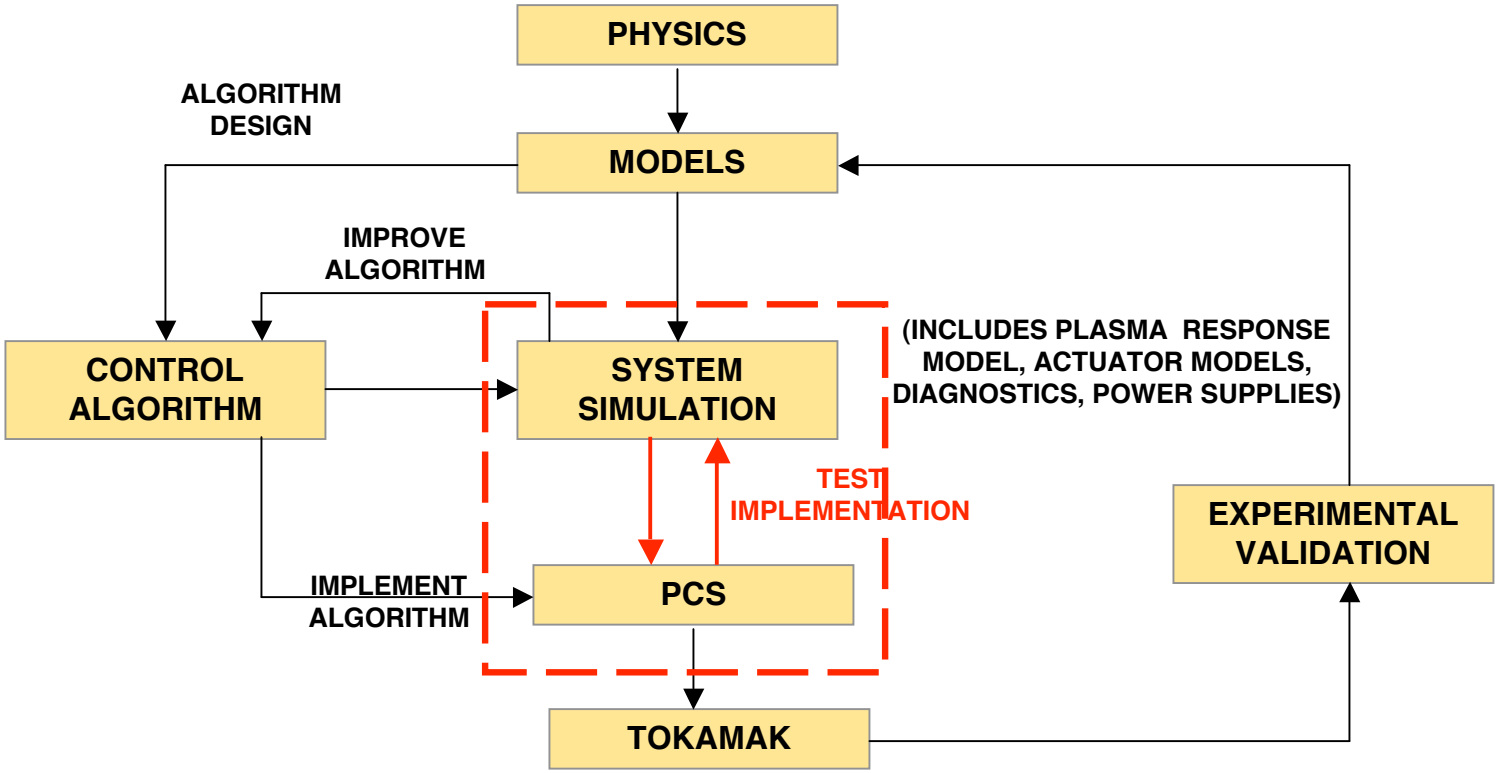
KSTAR Tasks Follow Integrated Plasma Control Approach to Ensure High Reliability, High Performance in Final Implementation



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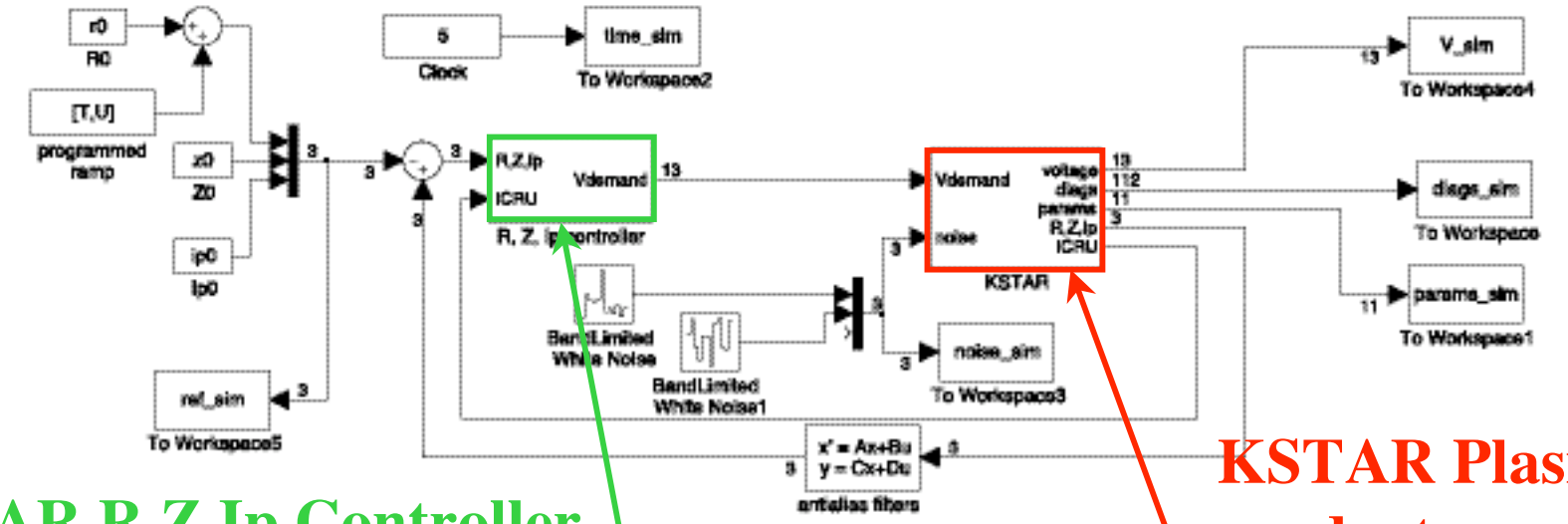
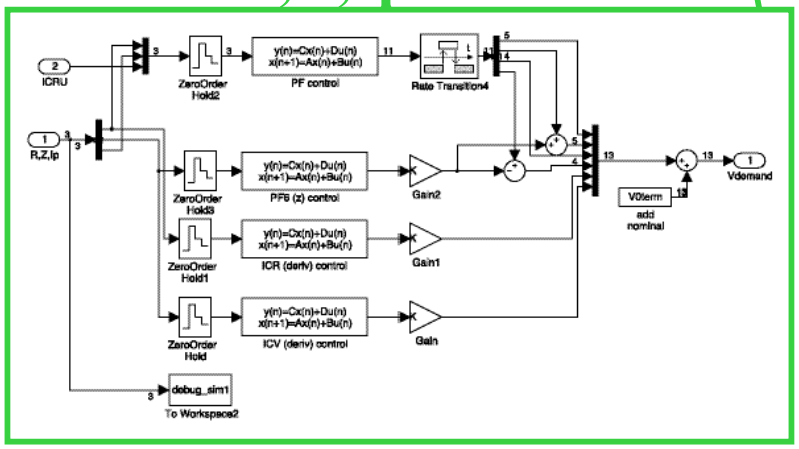
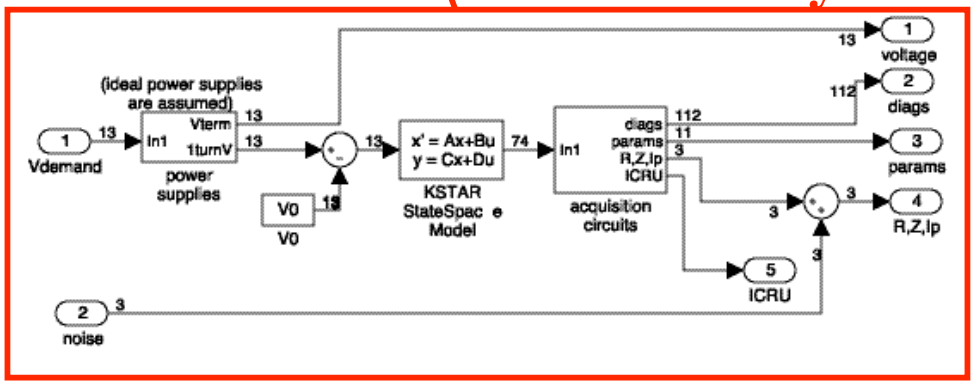
Present KSTAR Simulation Includes Power Supplies, Plasma-Conductor System, Filters, Noise Sources



KSTAR R,Z,Ip Controller



KSTAR Plasma-conductor system



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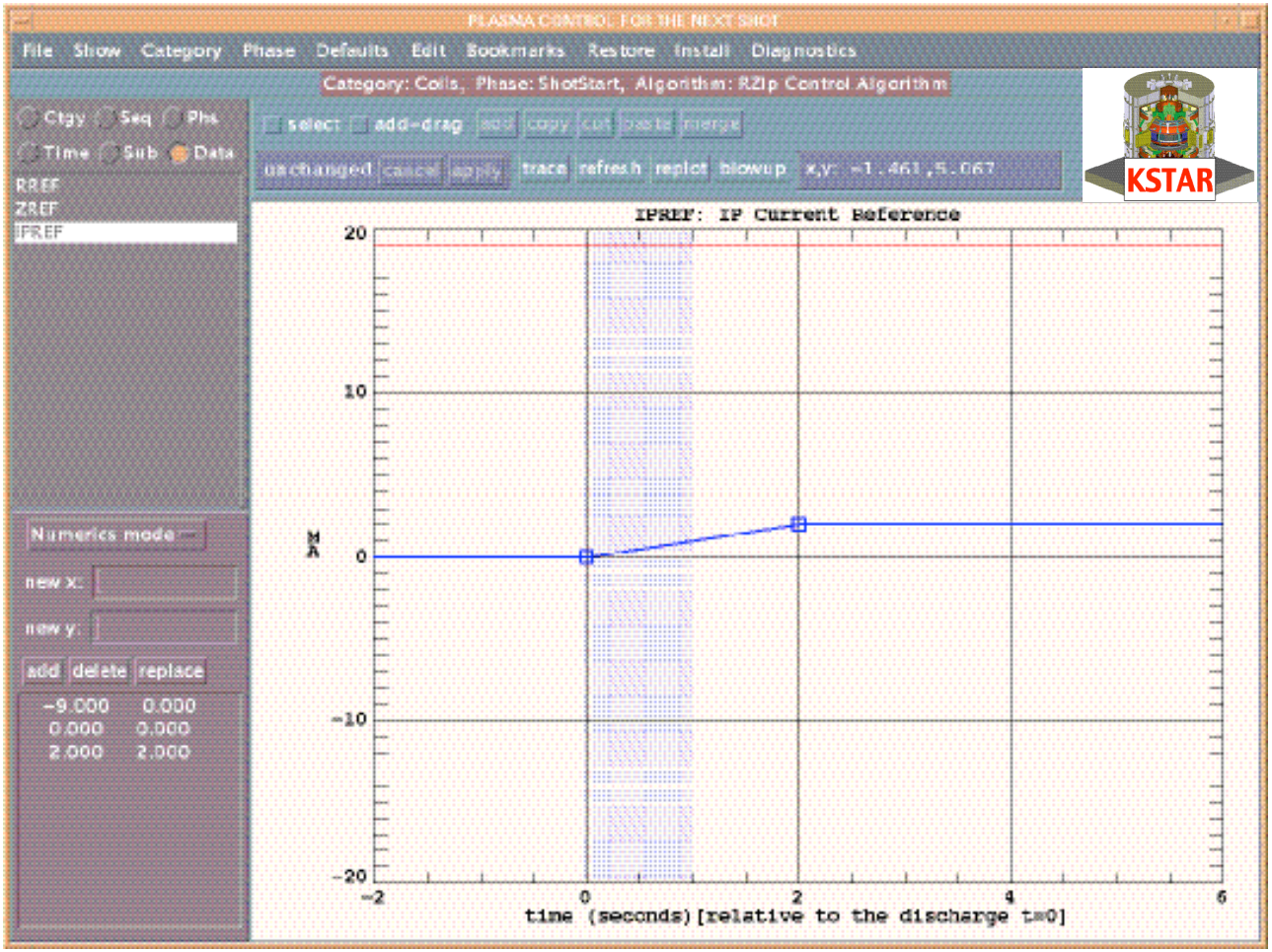
The KSTAR PCS is Based on and Developed from the DIII-D PCS

- KSTAR/DIII-D PCS provides completely general computational environment for implementing complex algorithms of any type (mathematical operations, logic, waveform programs)
- KSTAR Day One PCS contains basic set of control categories
  - Equilibrium
  - PF coil control
  - Vertical stability
- DIII-D PCS now used as basis for PCS systems at NSTX, MAST, EAST



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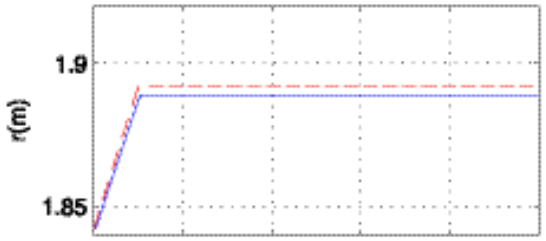
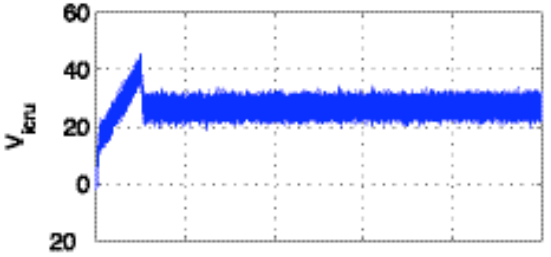
Demonstration of KSTAR PCS Controlling Simulation

- **Simulation of KSTAR major radial position command following**
  - **KSTAR PCS based on DIII-D PCS; presently configured for R, Z, Ip control scheme**
  - **Command following simulation with *fast* internal coil control (no integral error reduction)**
  - **Controller design functions well with saturation, delays, rate limits, anti-alias filters, actual PCS response**

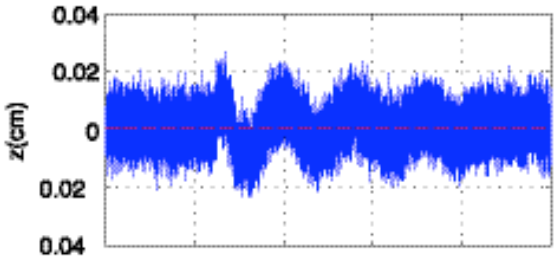
Major Radius R (m)

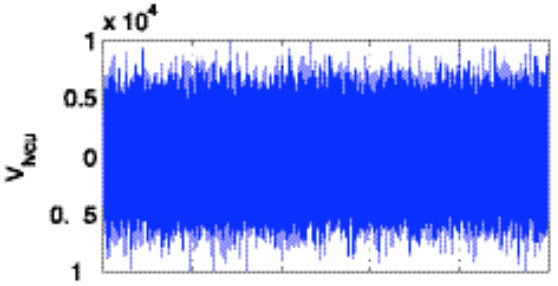




ICR Voltage

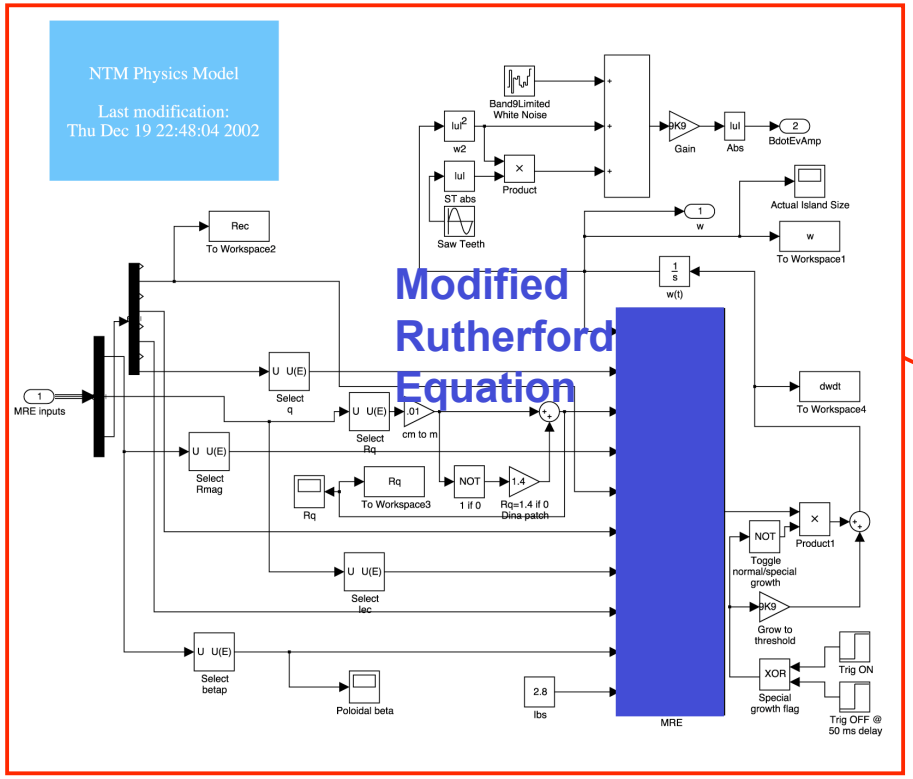
Vertical Position Z (cm)





ICV Voltage

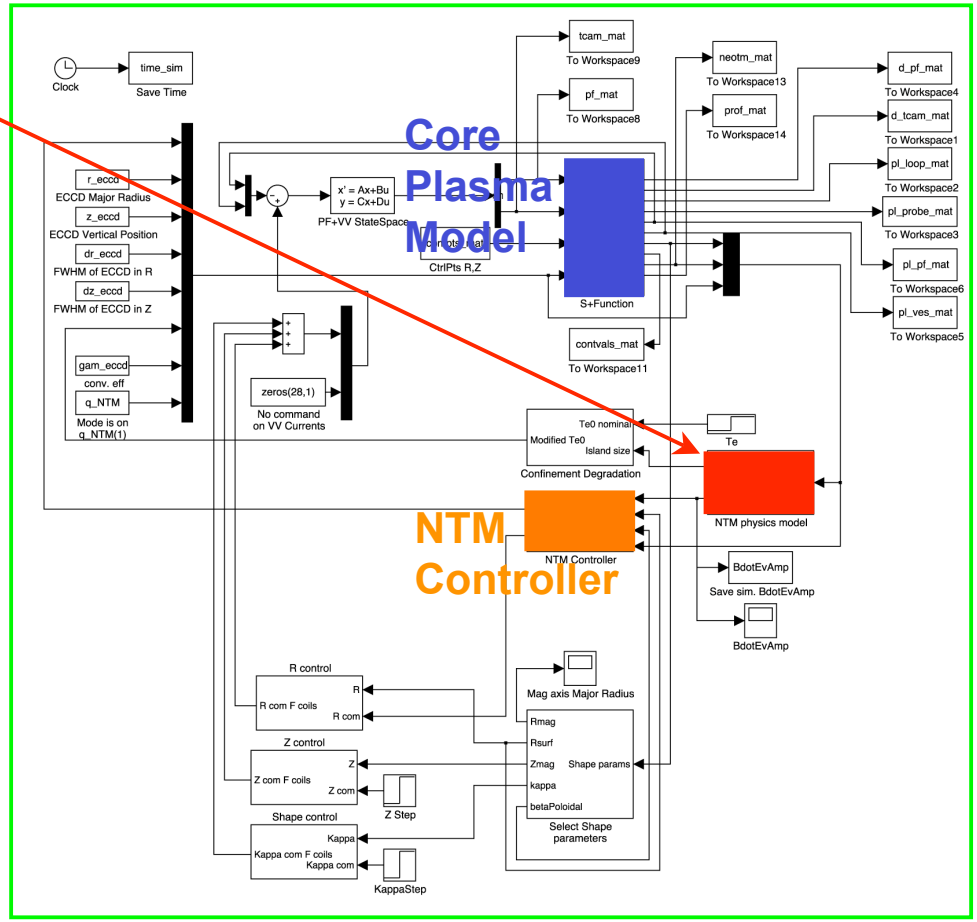
KSTAR Simulation Modules for MHD Physics and Control Design Will be Based on DIII-D Modules



Modified Rutherford Equation

Model of plasma/island response to ECCD

NTM Control Algorithm



Core Plasma Model

NTM Controller

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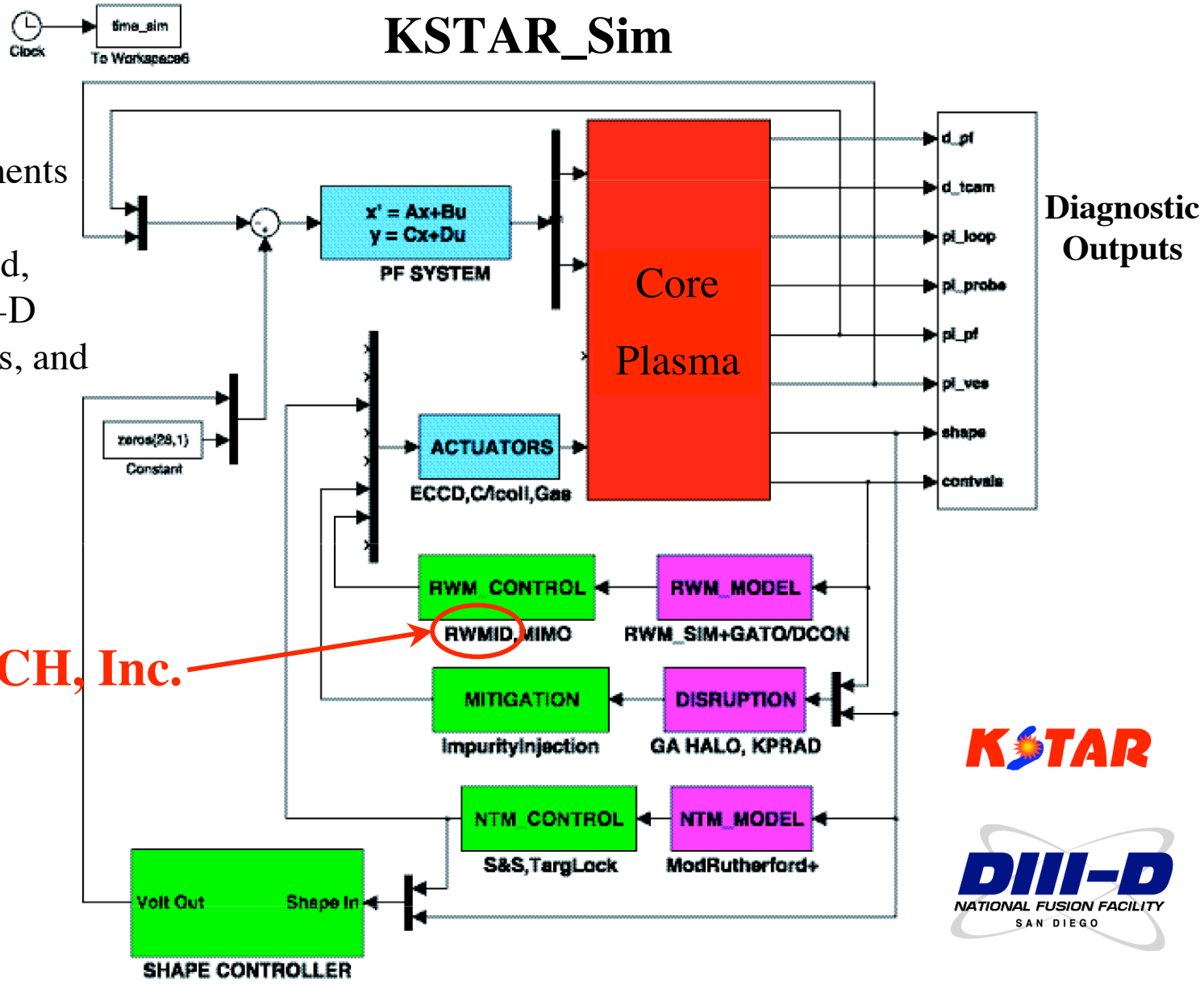
The Vision of Integrated Plasma Control Includes Modeling and Simulation of all Key AT Elements

Many of these elements have already been developed, validated, and applied to DIII-D designs, simulations, and experiments



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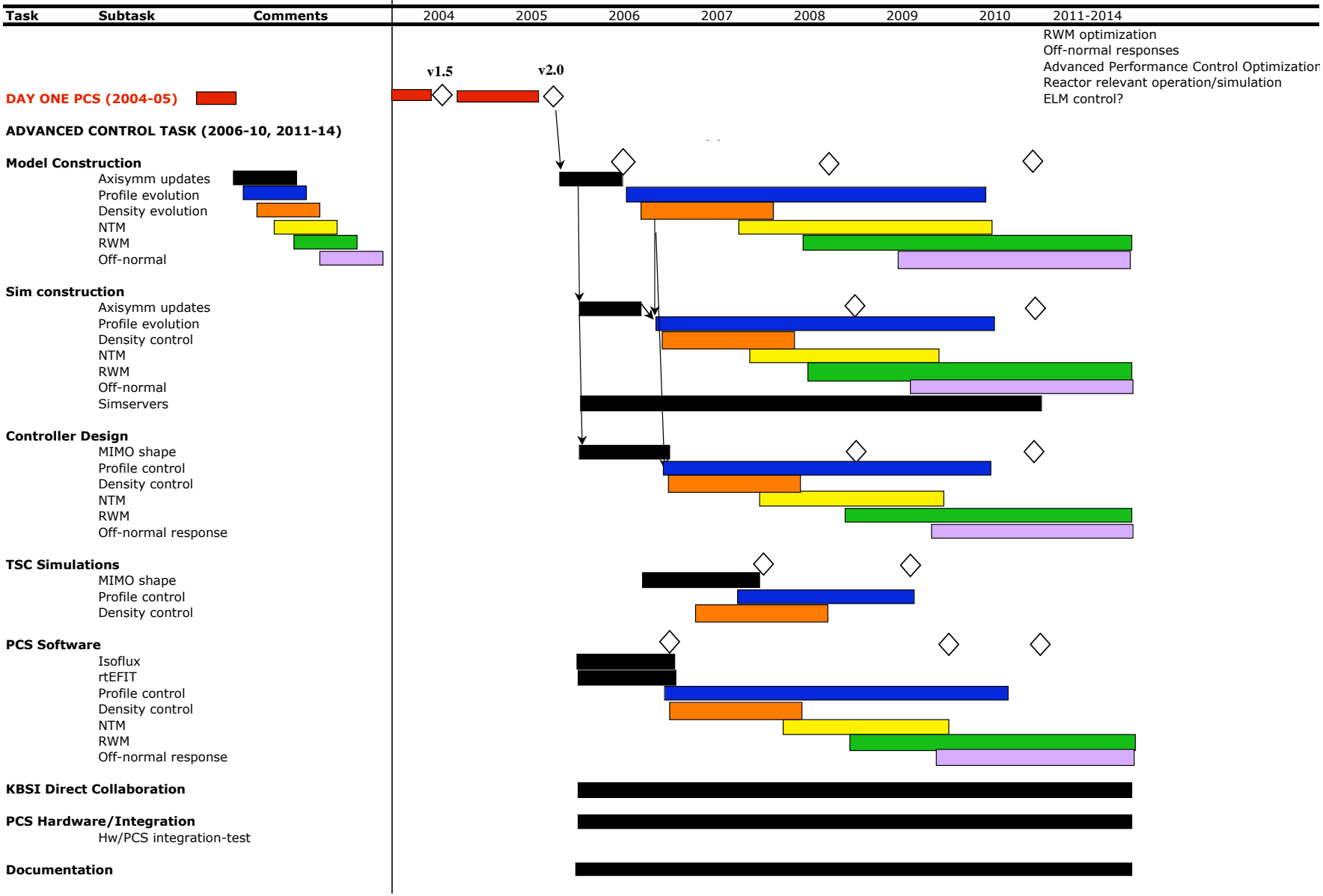
Strawman Task Sequence/Schedule

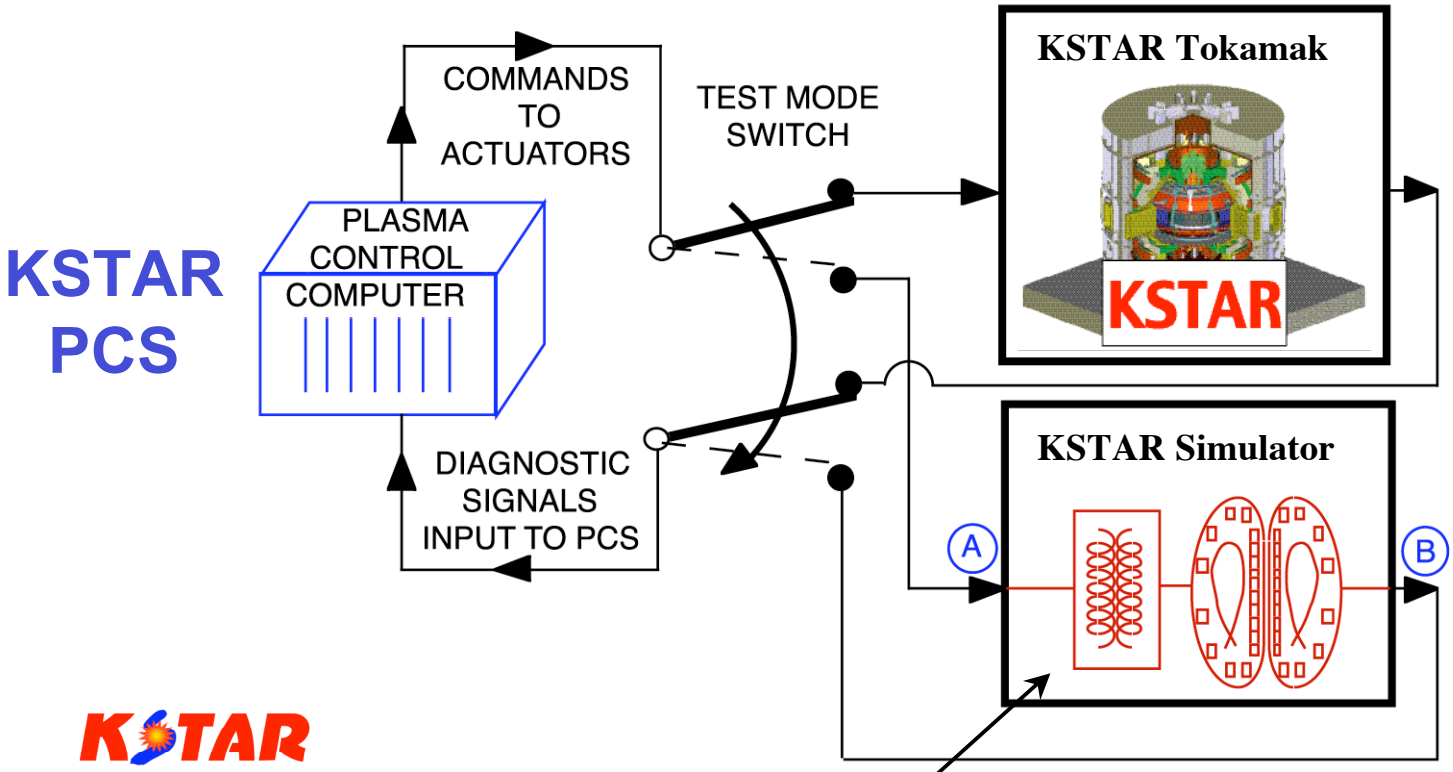
Strawman KSTAR Advanced Control Task Sequence/Schedule 2006-2014



Summary and Conclusions

- **The proposed KSTAR Integrated Plasma Control design task will extend present Day One PCS design efforts to provide coordinated, high performance, high reliability control for KSTAR**
- **Key elements of Integrated Plasma Control include:**
  - **Model-based control design, using models validated by experiment**
  - **Multivariable design techniques which include performance optimization**
  - **Realistic, accurate simulations for systematically confirming control performance, both offline and with actual control computer hardware/software**
- **KSTAR advanced control elements to be designed and implemented in the proposed task in close collaboration with KBSI**
  - **KSTAR PCS developed to support new advanced control elements**
  - **Advanced shape control (isoflux, rtEFIT)**
  - **Advanced operating point control (beta, density, profiles)**
  - **MHD control: high performance vertical, NTM, RWM**
- **Proposed Task execution over FY2006-2010 (optional extension to 2011-2014)**
- **Level of effort ~0.8 FTE over duration of task (~0.8 Man-Year per year of task)**

Simulations Allow Testing of KSTAR Control Algorithms Before and After Implementation



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"Hardware-in-the-Loop" simulation uses the KSTAR Simulator to verify actual implementation in KSTAR PCS