NSTX-U

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NSTX-U Real-time Coil Protection and Power Supply Control

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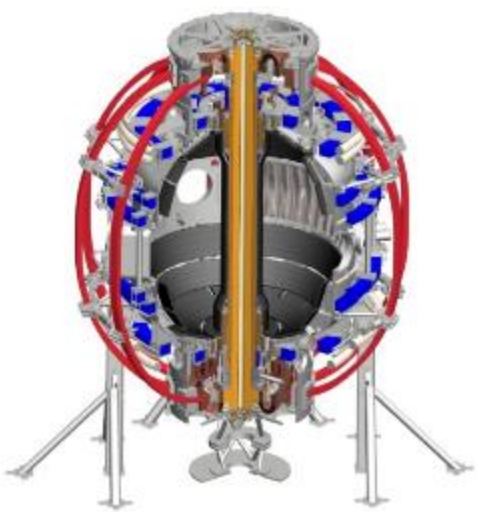

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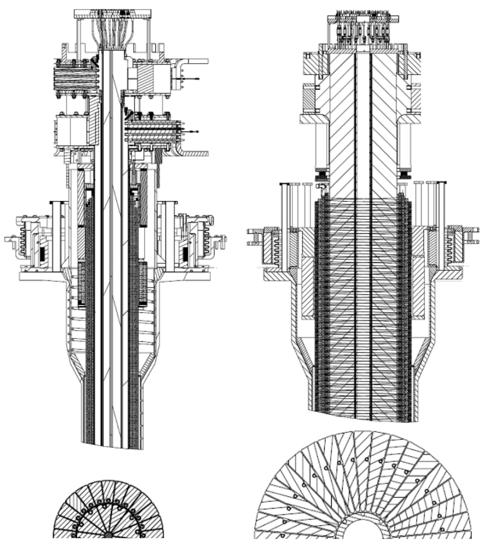
NSTX Multi-Year Upgrade

- NSTX-U extends the purpose and scope of NSTX beyond its initial design parameters and stated goals
  - Elongated pulse length from 1s to 5s
  - Plasma current doubled
  - Magnetic load quadrupled
  - New coils
    - Redesigned Toroidal Field coil for higher B field
    - Higher capacity Ohmic Heating coil
    - Three new Poloidal Field coils

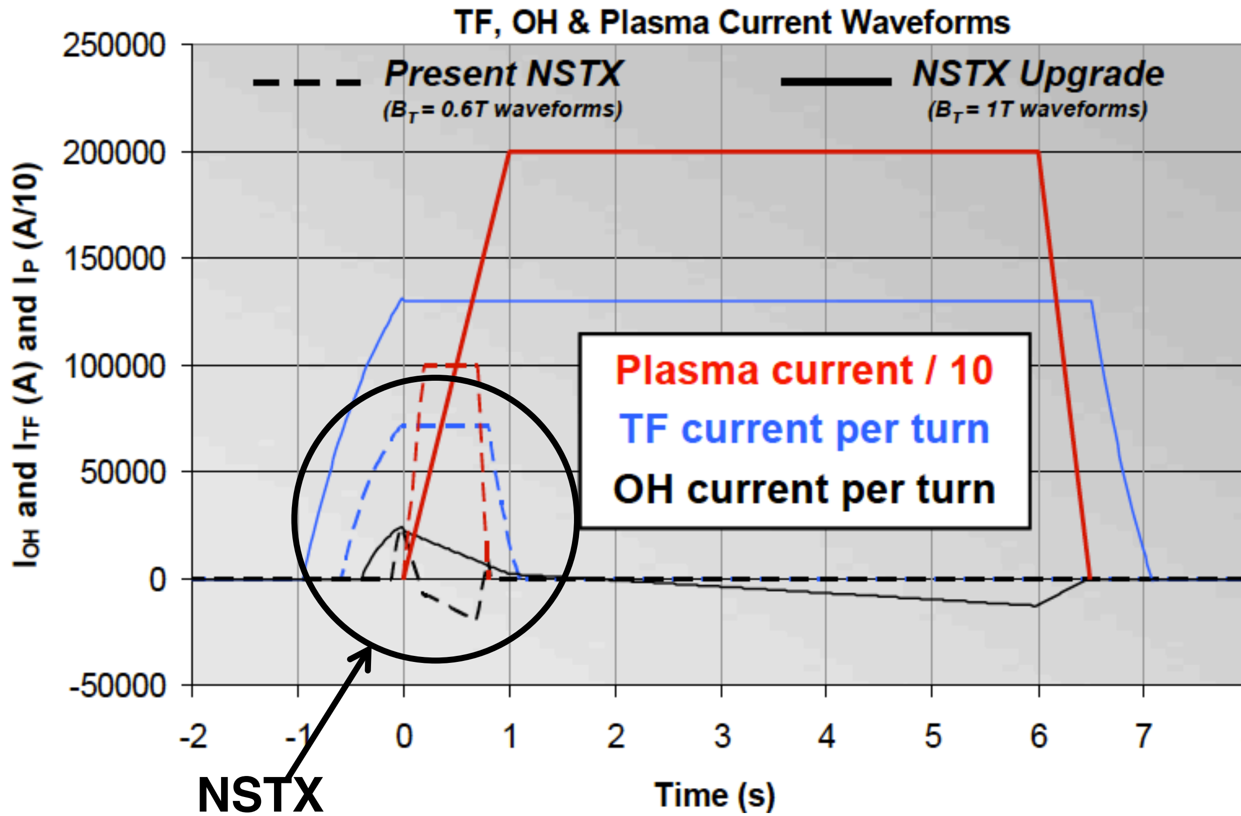
- Major power system changes force new RT software approach

NSTX-U Center Stack Upgrade
Higher performance requires infrastructure enhancements

Previous center-stack | New center-stack



TF OD = 20cm | **TF OD = 40cm**



- **5x longer pulse-length**
- **Expect 2x higher T by doubling B_T, I_P, and NBI heating power**

	R_0 (m)	A_{min}	I_p (MA)	B_T (T)	T_{TF} (s)	R_{CS} (m)	R_{OB} (m)	OH flux (Wb)
NSTX	0.854	1.28	1	0.55	1	0.185	1.574	0.75
NSTX-U	0.934	1.5	2	1	6.5	0.315	1.574	2.1

NSTX-U Power Supply System

15 Independent power systems for magnetic coils

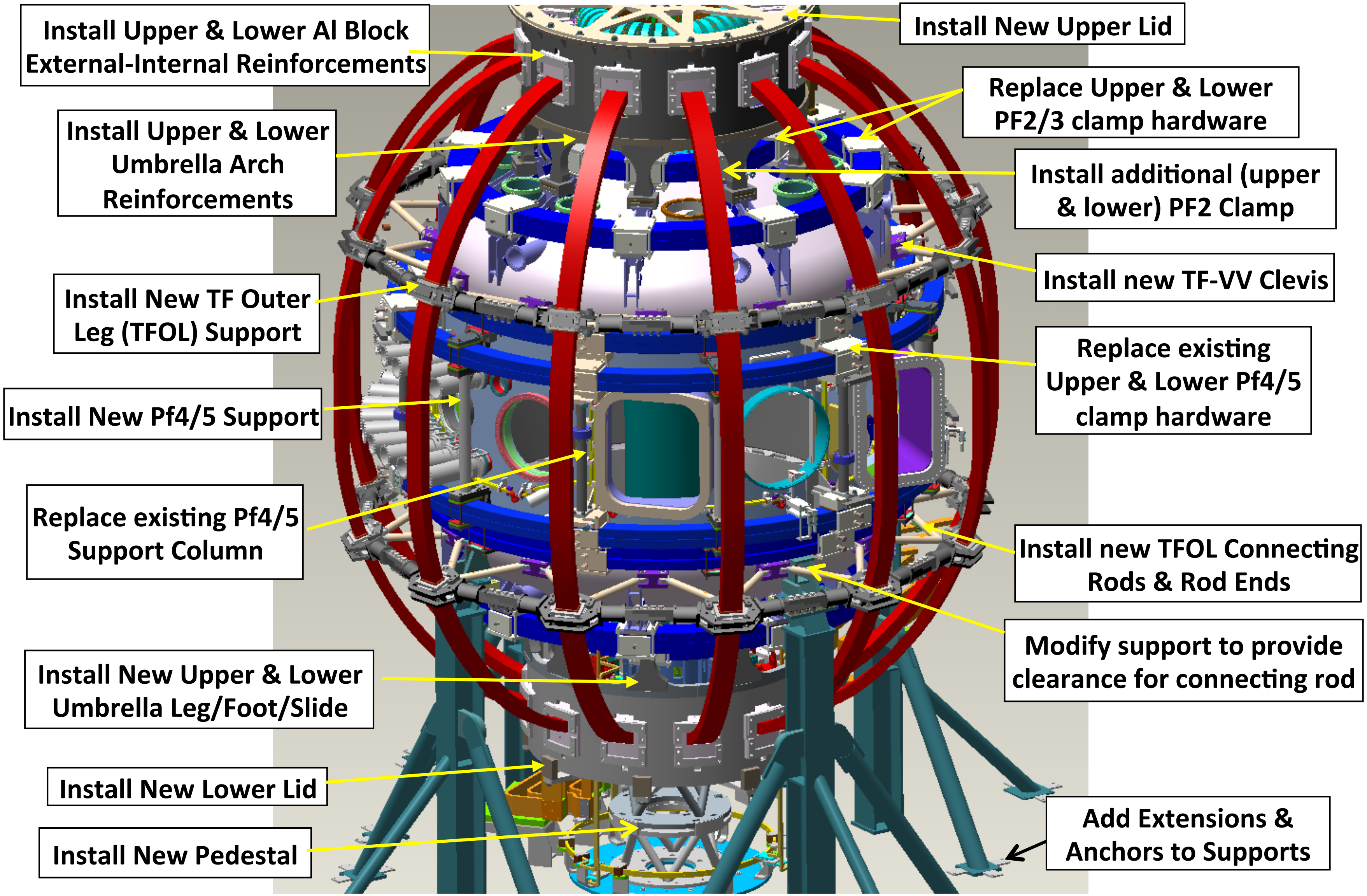
Heterogeneous Systems

- Each individual system is fixed
- Systems differ from each other
  - Unipolar or Bipolar configurations
  - Individual power supply sections
  - Voltage supplied: 1kV – 6kV
  - Current limit: 10kA – 150kA

PF1AU	PF1AL
PF1BU	PF1BL
PF1CU	PF1CL
PF2U	PF2L
PF3U	PF3L

PF4
PF5
OH
TF
HF

NSTX-U Support Structures Enhanced to Handle 4x Electromagnetic Forces



NSTX Upgrade Requires Advanced Control and Protection

- Legacy protection mechanisms ill suited for new scenarios
- Complex interactions require advanced computations
- Computations will change throughout the experiment
- A new approach enables an adaptive, maintainable system that reliably delivers necessary functionality

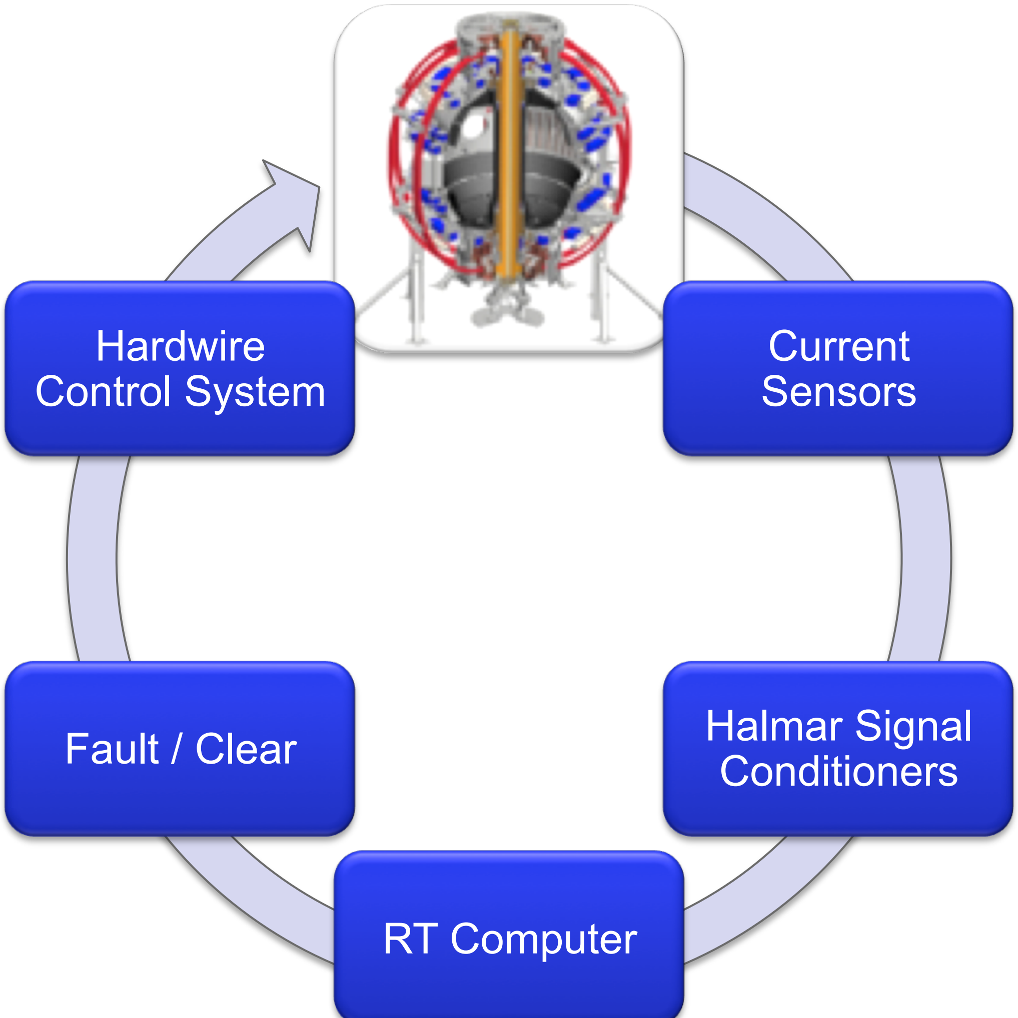
NSTX-U Digital Coil Protection System

- New real-time system connected directly to current measurement devices
  - Immediately terminates pulse when detecting any issue
  - Actively prevents pulse if issues arise between shots
  - Fail safe logic protects against DCPS internal failures

- Large computational capacity
  - Compares ~600 equations against 2 limits each at 5 kHz rate
  - Checks against instantaneous current and multiple predicted currents
  - Over 90% CPU headroom for future growth as needs change
  - Easily extendable and parallelizable

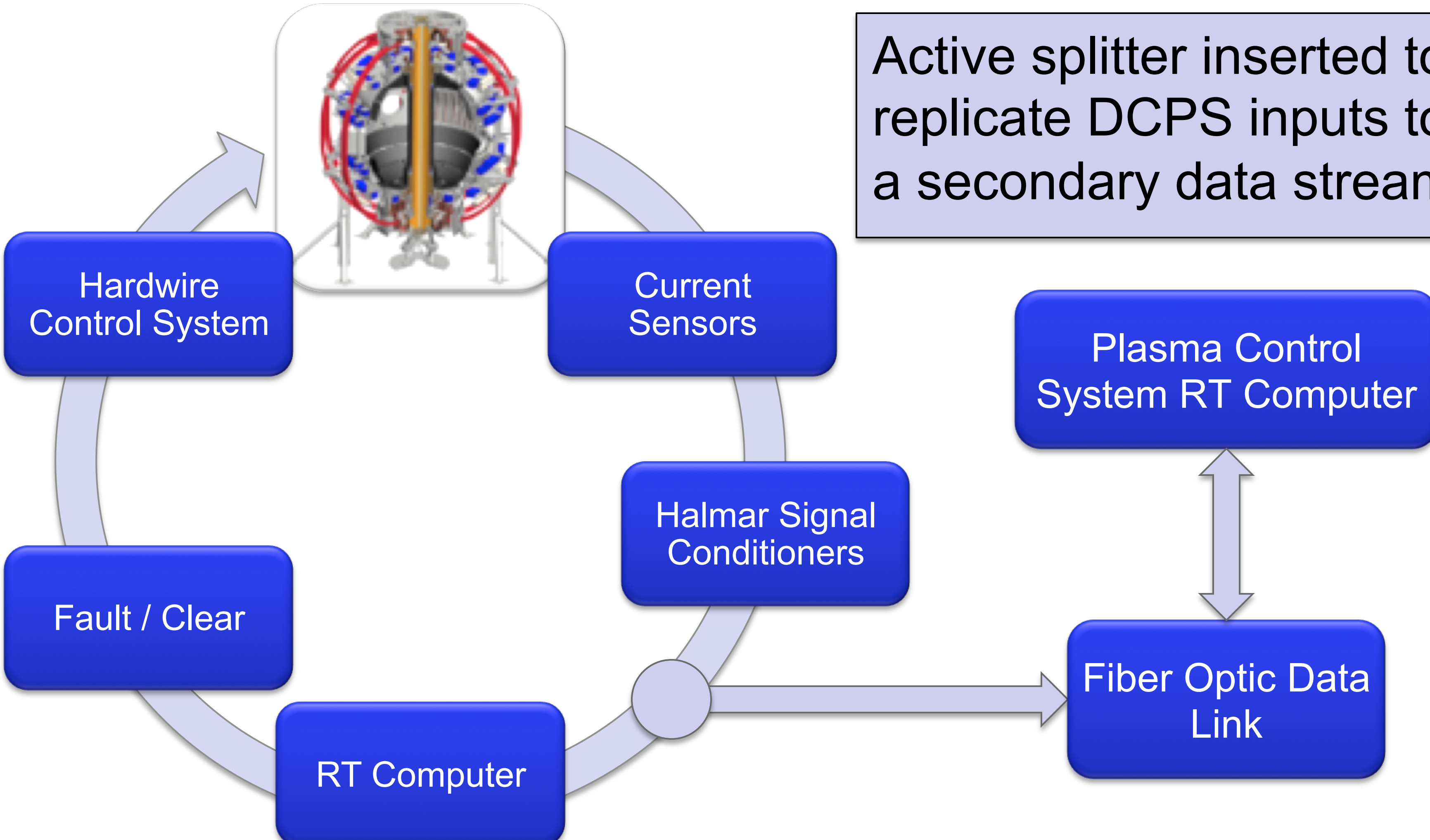
- Already adapted and modified to support NSTX-U Aquapour
  - Production issue with new TF/OH coils restricts current ratios
  - New algorithms instantly added to DCPS to compensate

Digital Coil Protection System Data Flow



Digital Coil Protection System Data Flow

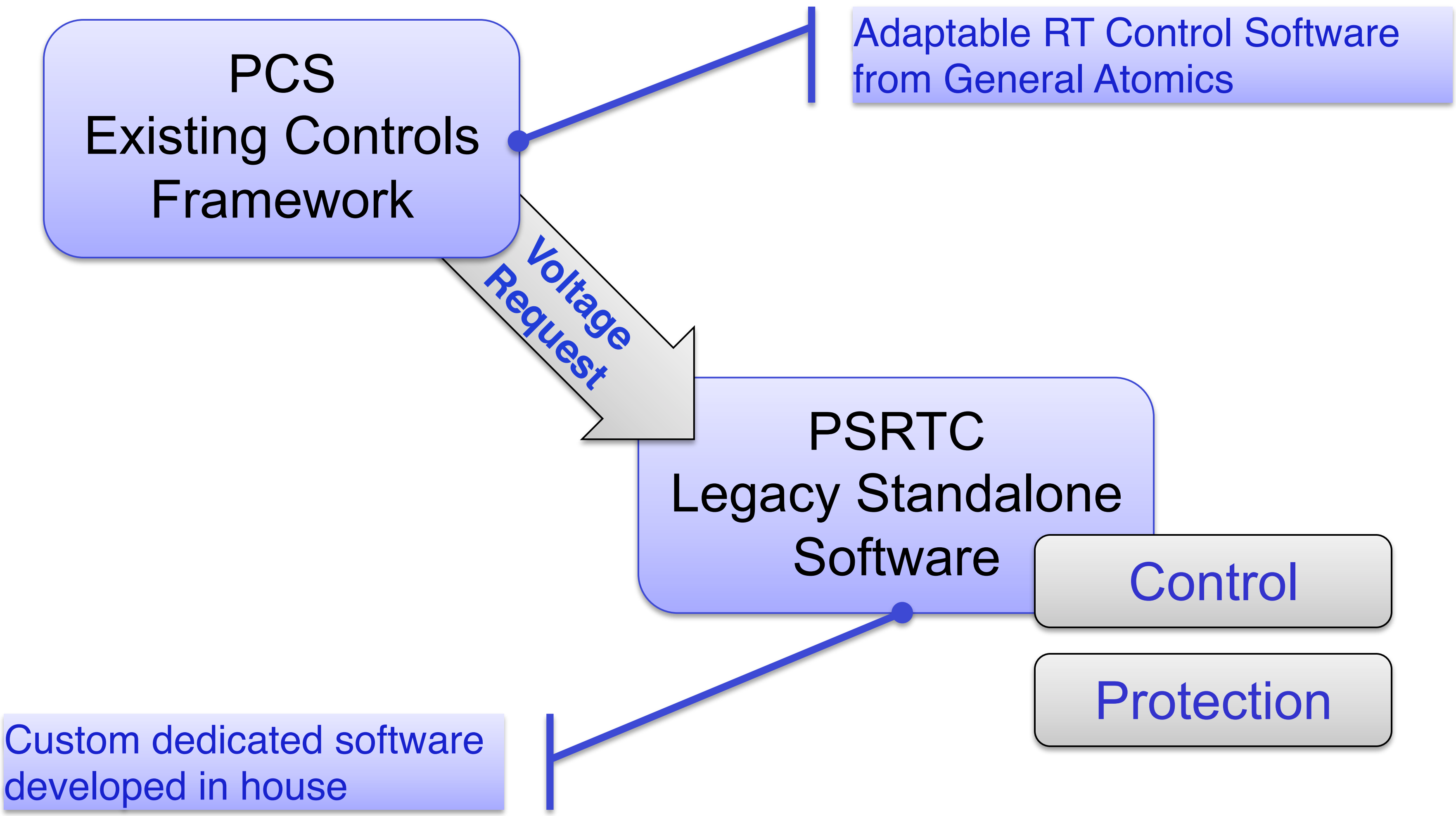
Active splitter inserted to replicate DCPS inputs to a secondary data stream



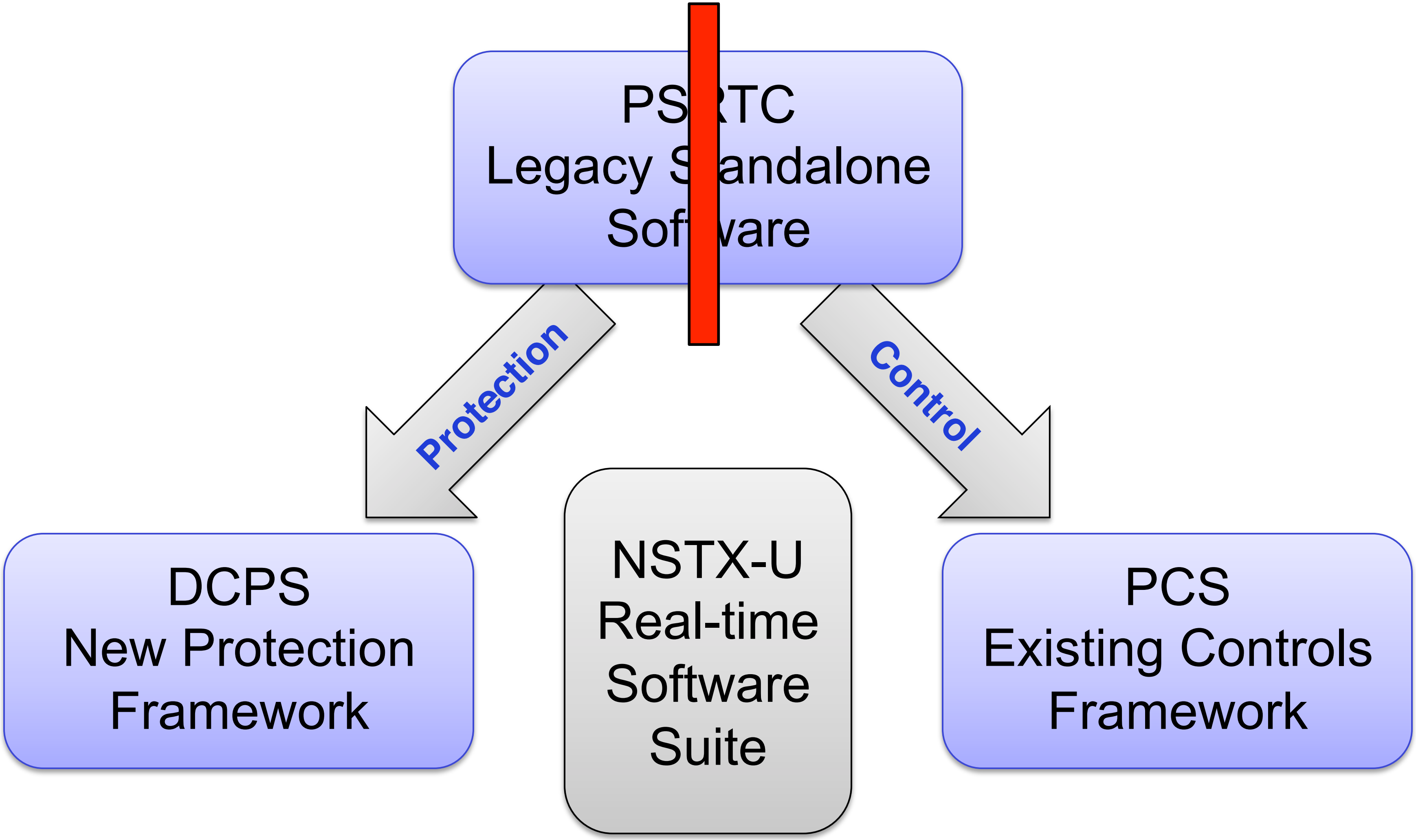
Plasma Control System Features and Motivation

- Cross platform Plasma Control System
  - Built originally for DIII-D by General Atomics
  - Ported to NSTX ~15 years ago
  - Shared with MAST, EAST, KSTAR
- Runs custom algorithms inside a standard framework
- Handles all non-algorithm specific requirements
  - Shot setup via consistent interface
  - Variable cycle timing per CPU core
  - Data archival and retrieval
  - Shot replay for testing purposes

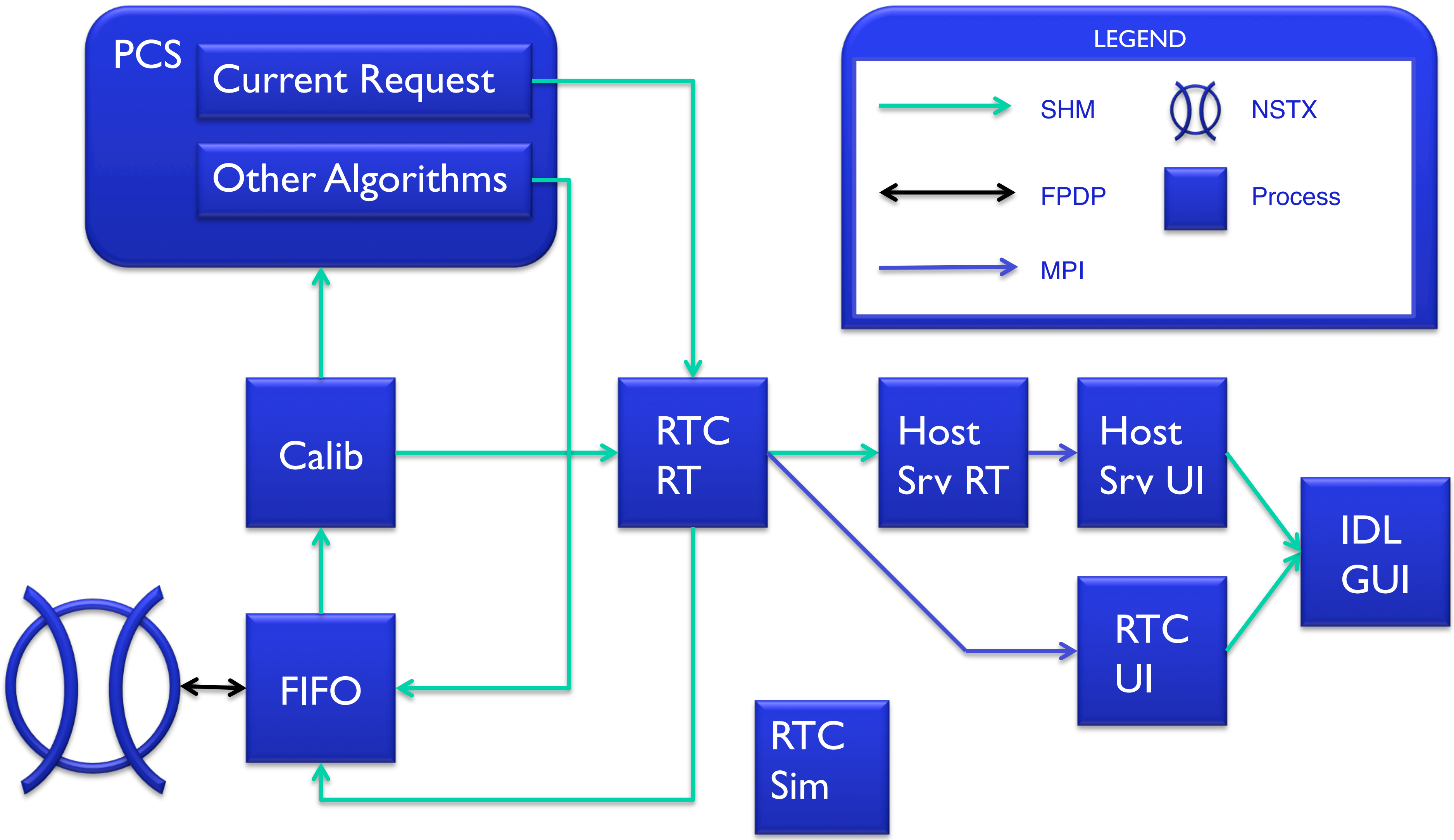
Old System
Multiple Functions Combined Into a Custom Framework



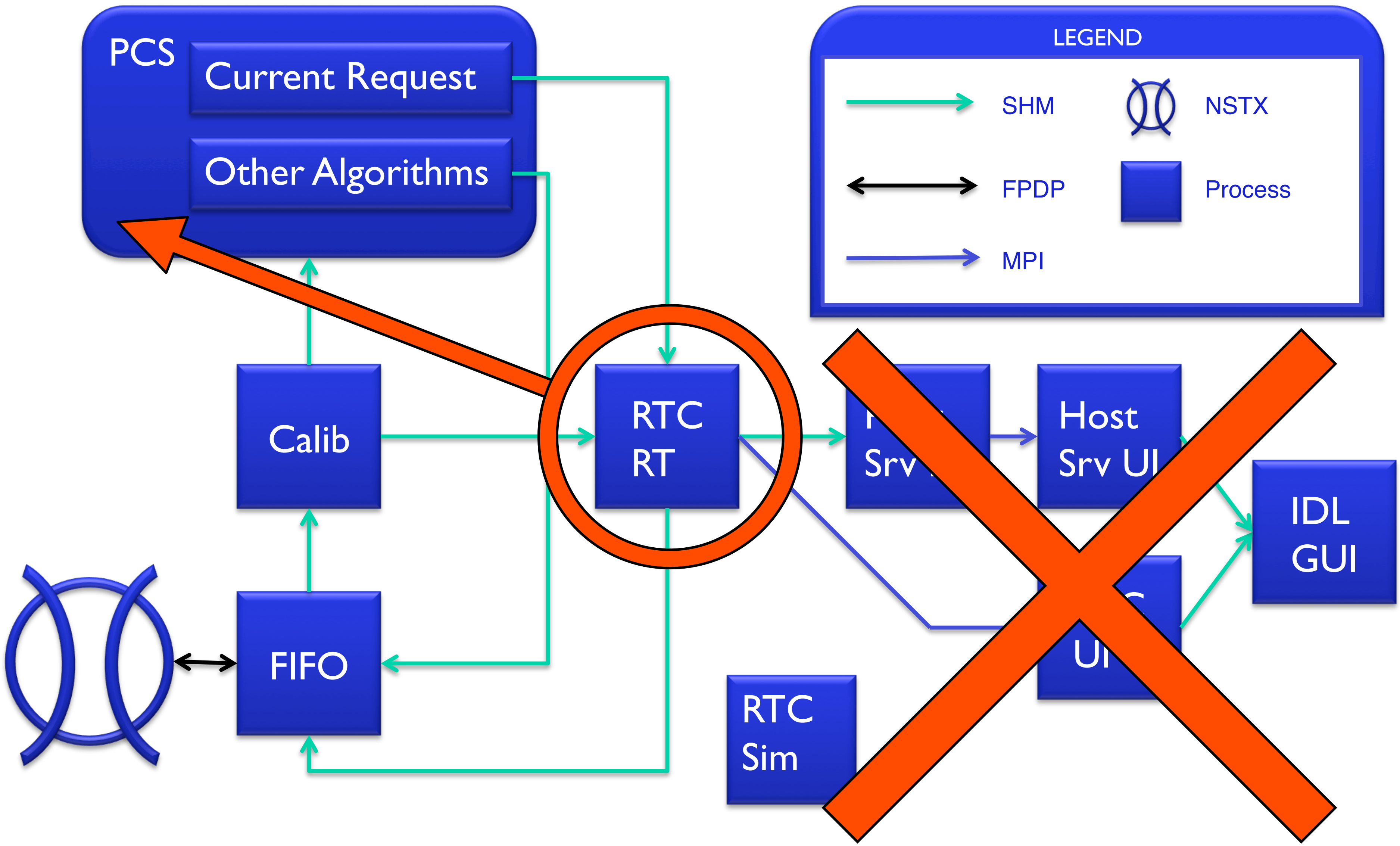
New System
Legacy PSRTC Divided Into Discreet Tasks



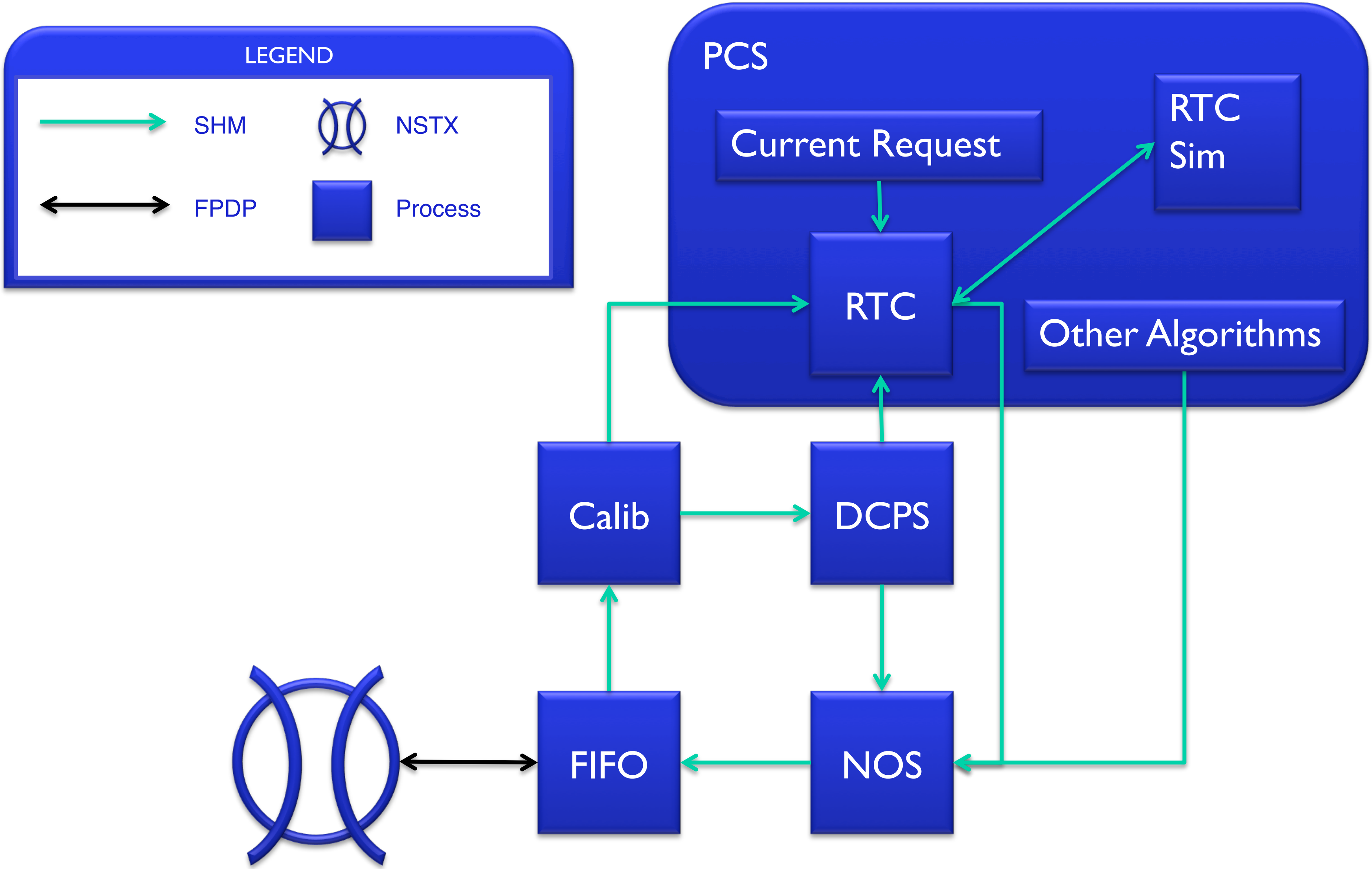
Old RTC Communication Layout
Complex and Brittle



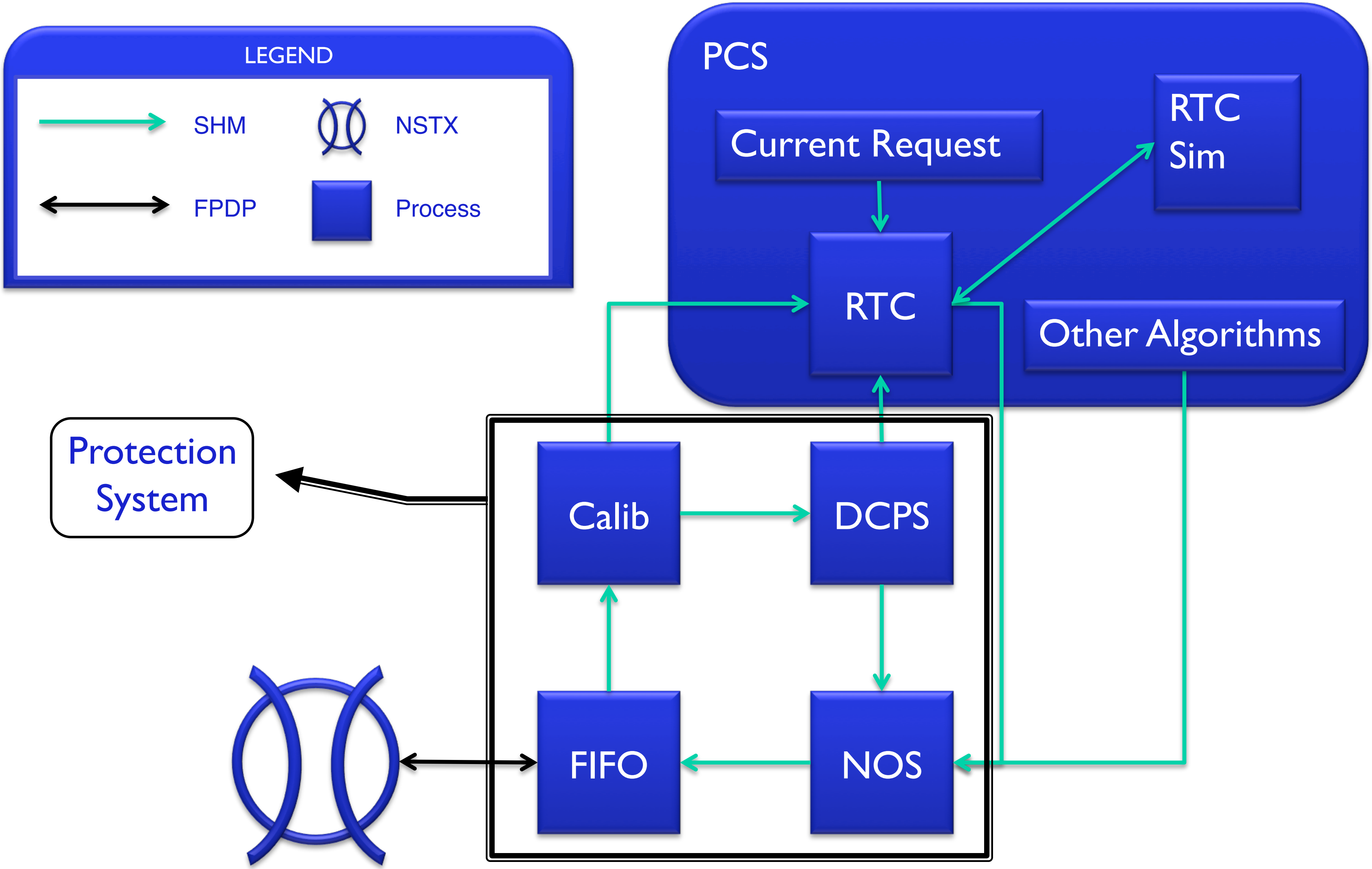
Old RTC Communication Layout
Complex and Brittle



New RTC Communication Layout
Streamlined and Reliable



New RTC Communication Layout
Separation by Function



New System Layout Organizes Responsibility

- Control and Protection functionality decoupled
  - RTC handles all Control functions
  - DCPS handles all protection functions
- RTC Sim integrated into actual runtime framework
  - RTC code is identical in Real or Sim modes
  - RTC Sim injects input and samples output
- RTC utilizes PCS infrastructure
- RTC and PCS can communicate easily for more advanced control or safer shutdowns

NOS – NCS Output Subsystem

- Purpose:
  - Formulate all command words
  - Adjudicate input from RTC and DCPS
- Command words are conceptually and logically separate from the core functions of RTC, DCPS, and PCS
- Both RTC and DCPS will provide information on coils
- During a pulse, upon DCPS fault signal:
  - RTC can attempt to invert off the power supply if desired
  - Wait a preset time (0-100ms), and then suppress and bypass
- Between pulses, upon DCPS fault signal:
  - RTC will not be running
  - Immediately suppress and bypass

Real-time Computer Upgrade From Original Prototype Required to Support Added Functionality

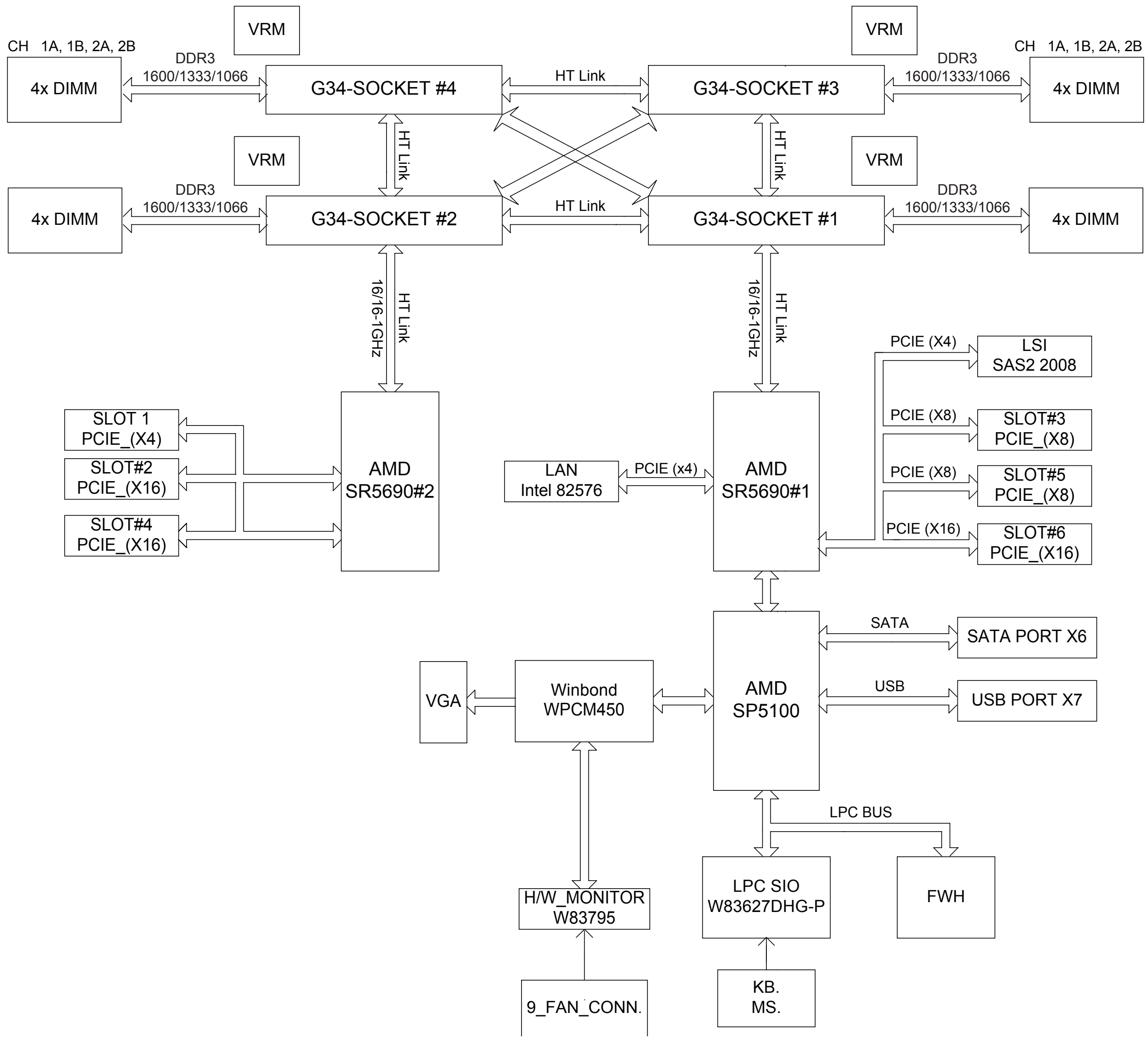
- Concurrent RedHawk 6.5, not MRG
- Supermicro H8QGL
  - Opteron 6386 SE 2.8GHz
  - 4 sockets x 16 cores = 64 core total
  - 64 GB Registered ECC memory

- Bus separation required to maintain RT determinism
- 6 PCI Express Slots in two separate banks
  - CUDA capable video
  - Serial FPDP I/O
  - Realtime Clock and Interrupt Module (RCIM)

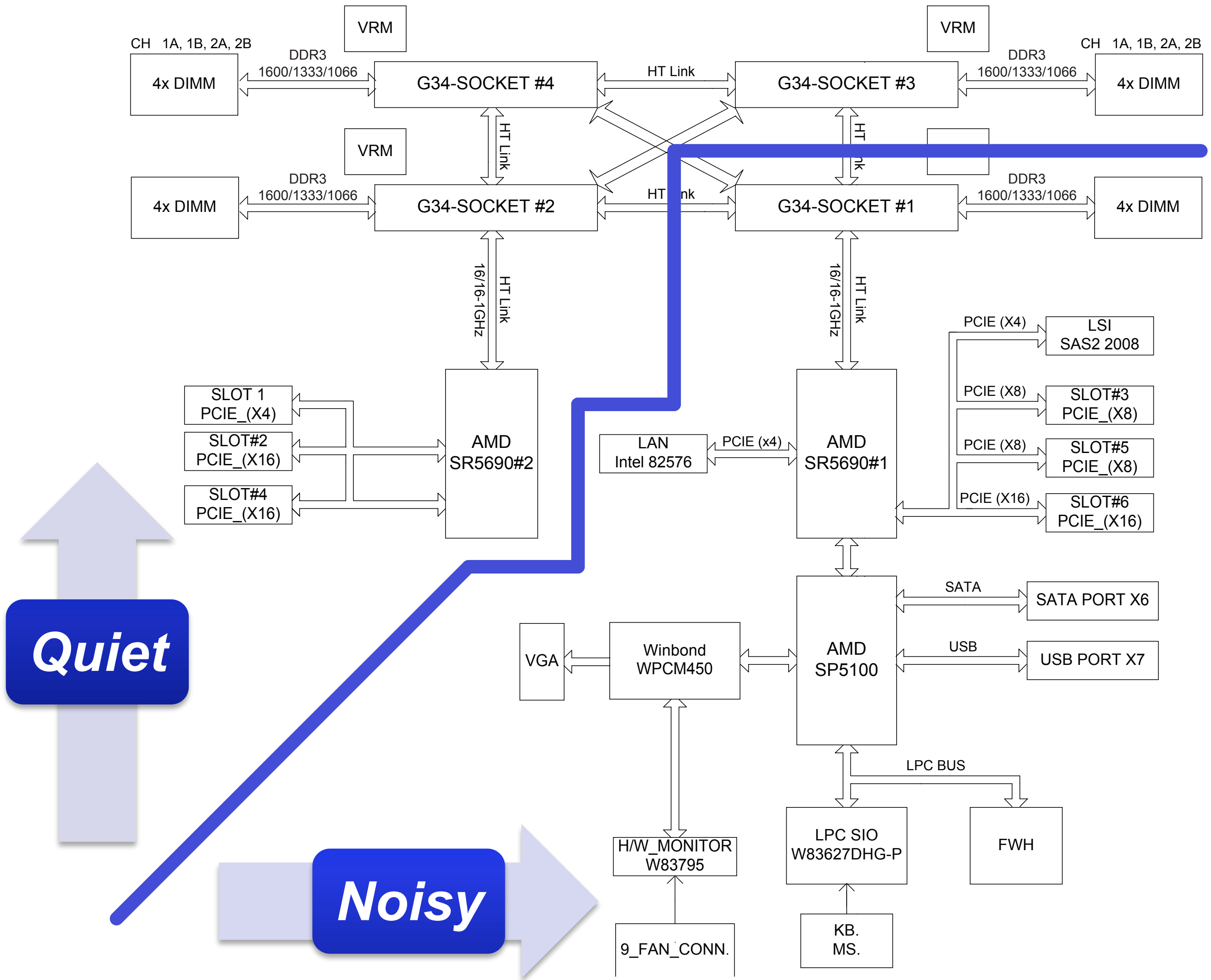
Outsourcing OS Expertise Removes Distractions from DCPS Development

- Concurrent Corp. offers Red*Hawk*
  - Based on Red*Hat*
  - Custom kernel to support deterministic run time behavior
  - NightStar analysis package permits performance optimization
  - Guaranteed process dispatch latency of less than 15 us
- Provides certified I/O drivers
  - Full support
  - Source code available
- Provides RT development support services
- Troubleshoots all operating environment issues
- Superior approach to RT Linux compared to MRG
  - Kernel separation, not preemption
  - More reliable, easier to manage, more efficient

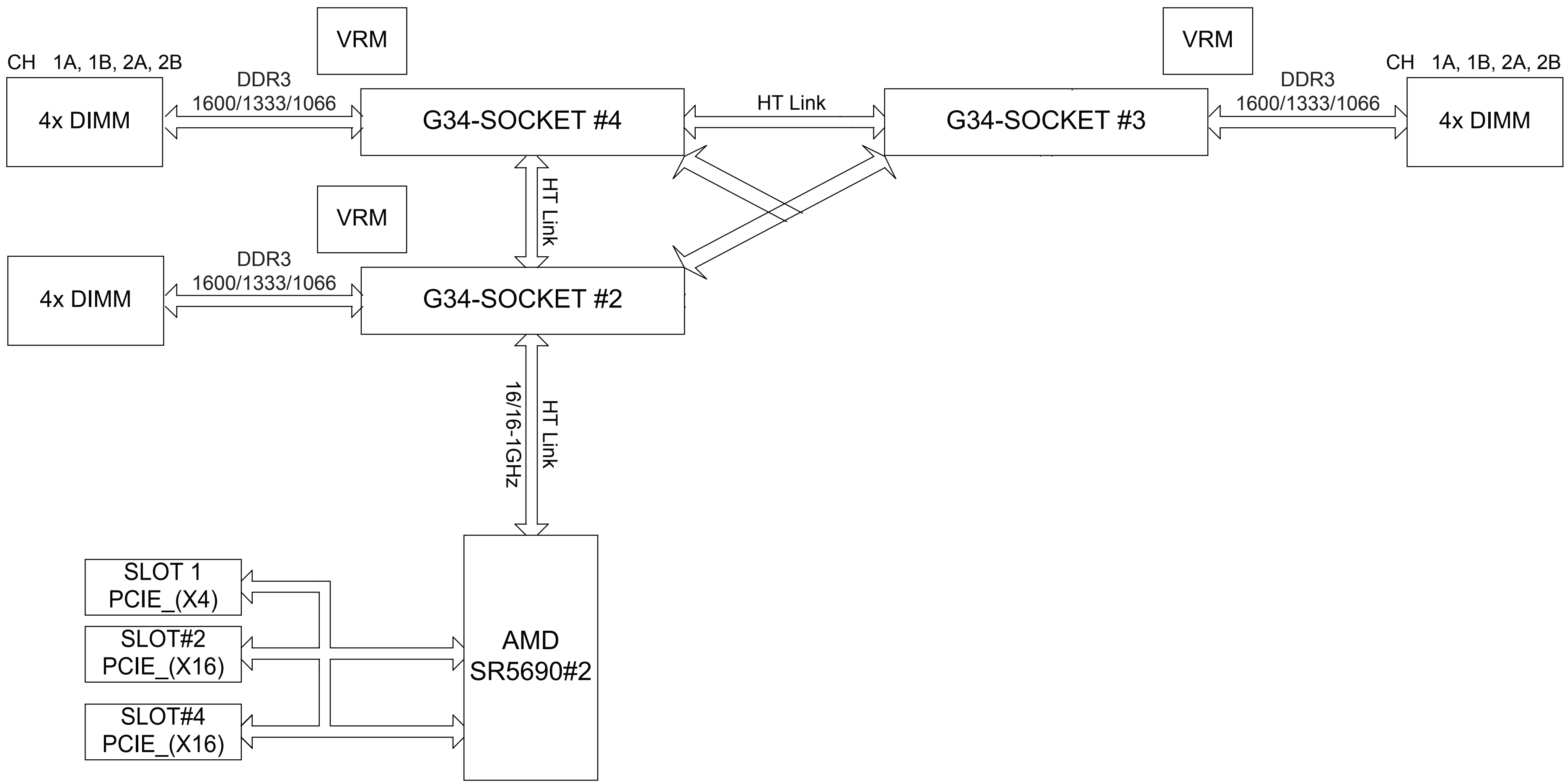
Super Micro H8QGL Internal Schematic



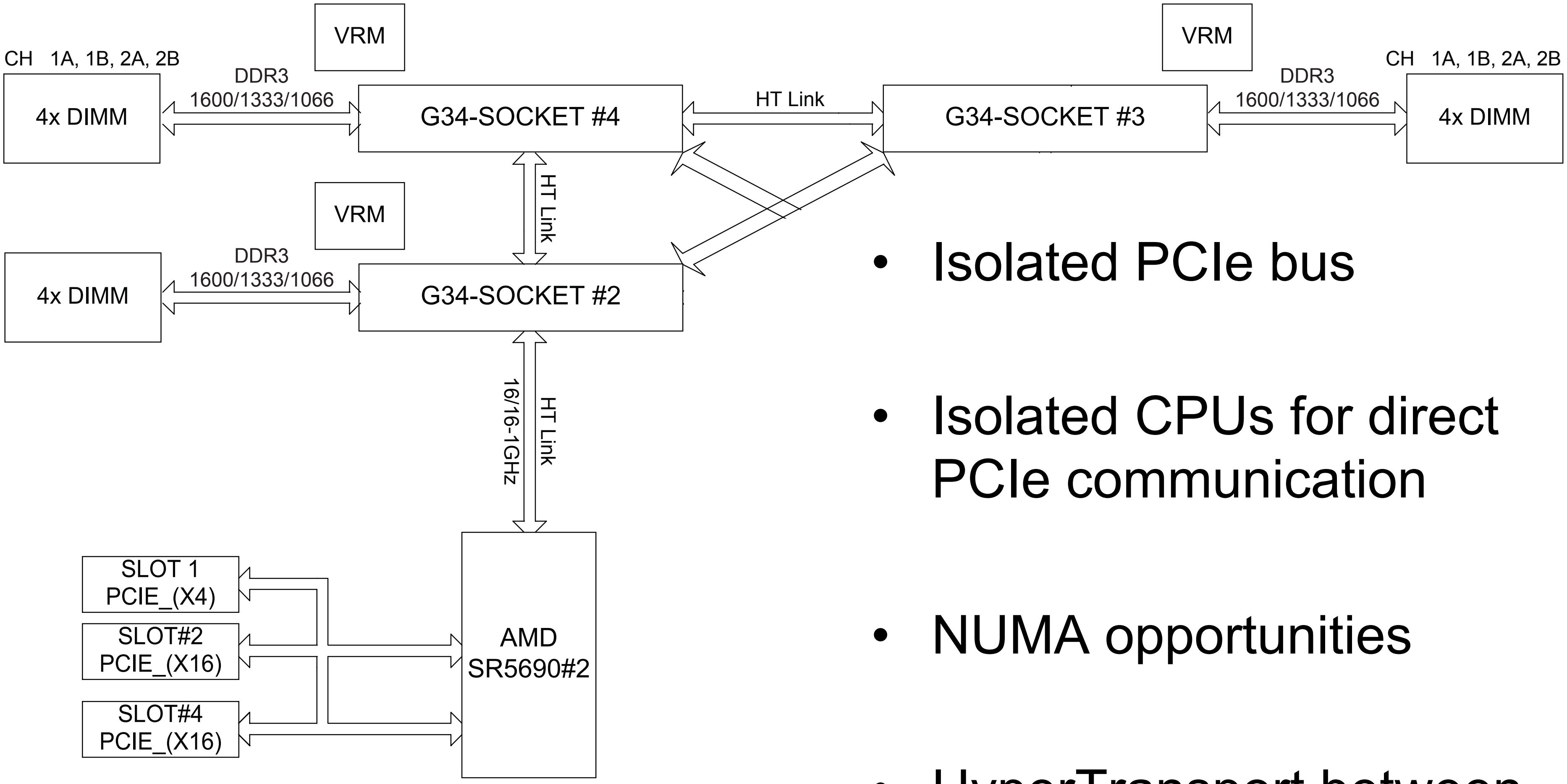
Super Micro H8QGL Internal Schematic



Super Micro H8QGL Quiet Bus Schematic



Super Micro H8QGL Quiet Bus Schematic



- Isolated PCIe bus
- Isolated CPUs for direct PCIe communication
- NUMA opportunities
- HyperTransport between CPU sockets

Computing Requirements

RT

DCPS

- 18 Algorithm cores
- 3 I/O cores
- 4 Monitoring cores

25 cores

PCS

- 4 General Use cores
- 3 I/O cores

7 cores

Non-RT

OPERATING ENVIRONMENT

- 16 User cores (shared)
- 16 OS cores (shared)

16 cores

48 cores total

Summary

- NSTX-U changes necessitate rethinking real-time software
- Control and Protection mechanisms decoupled
- Protections runs twice
  - Dedicated direct connection on separate computer
  - Identical software on the controls computer
- Control incorporated into existing physics control framework
  - Improves Physics and Engineering communication
  - Enables future advanced controlled shutdown methods
- Computer upgrade enables enhanced capabilities
  - Satisfies immediate near term needs
  - Allows eventual long term growth