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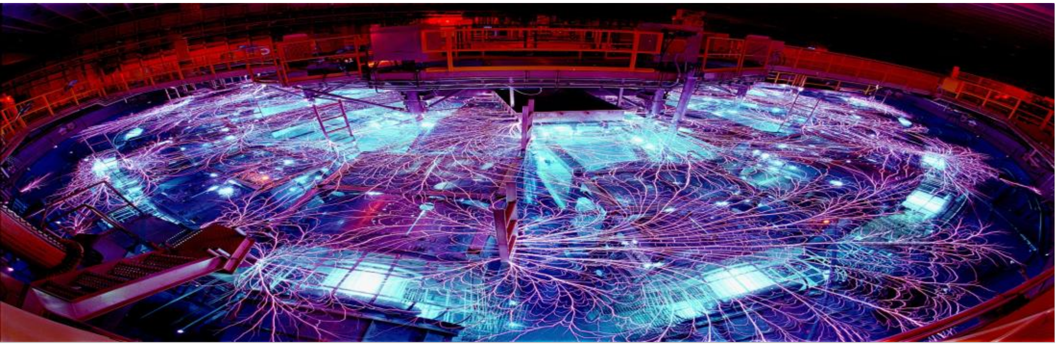
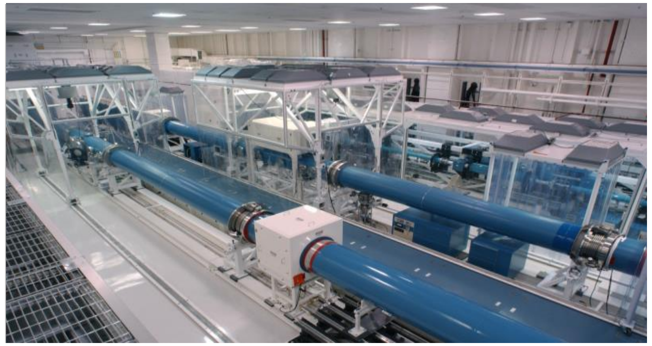
Aaron Lombrozo





Orchestrating a Control System

Timing is Everything

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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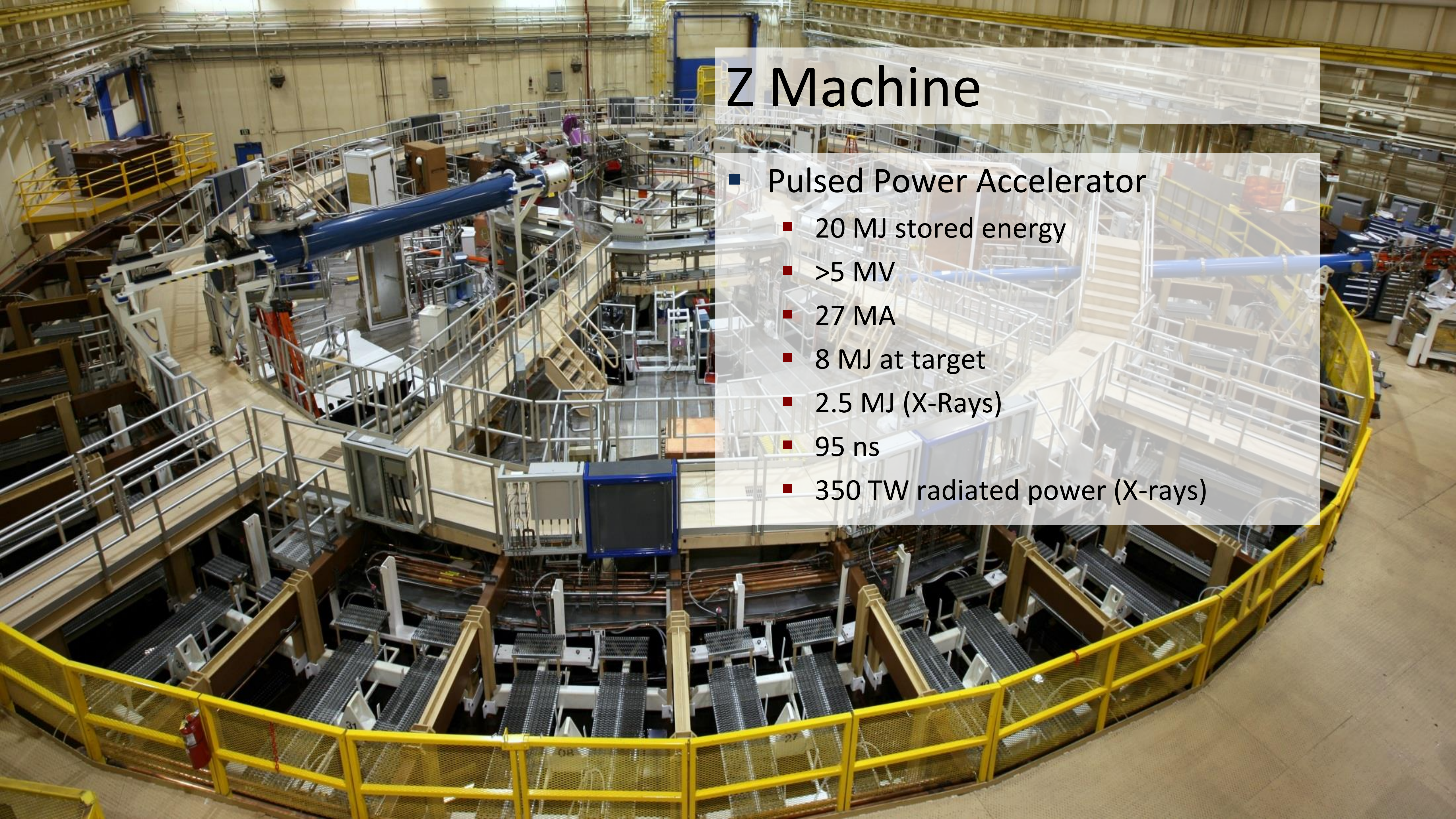
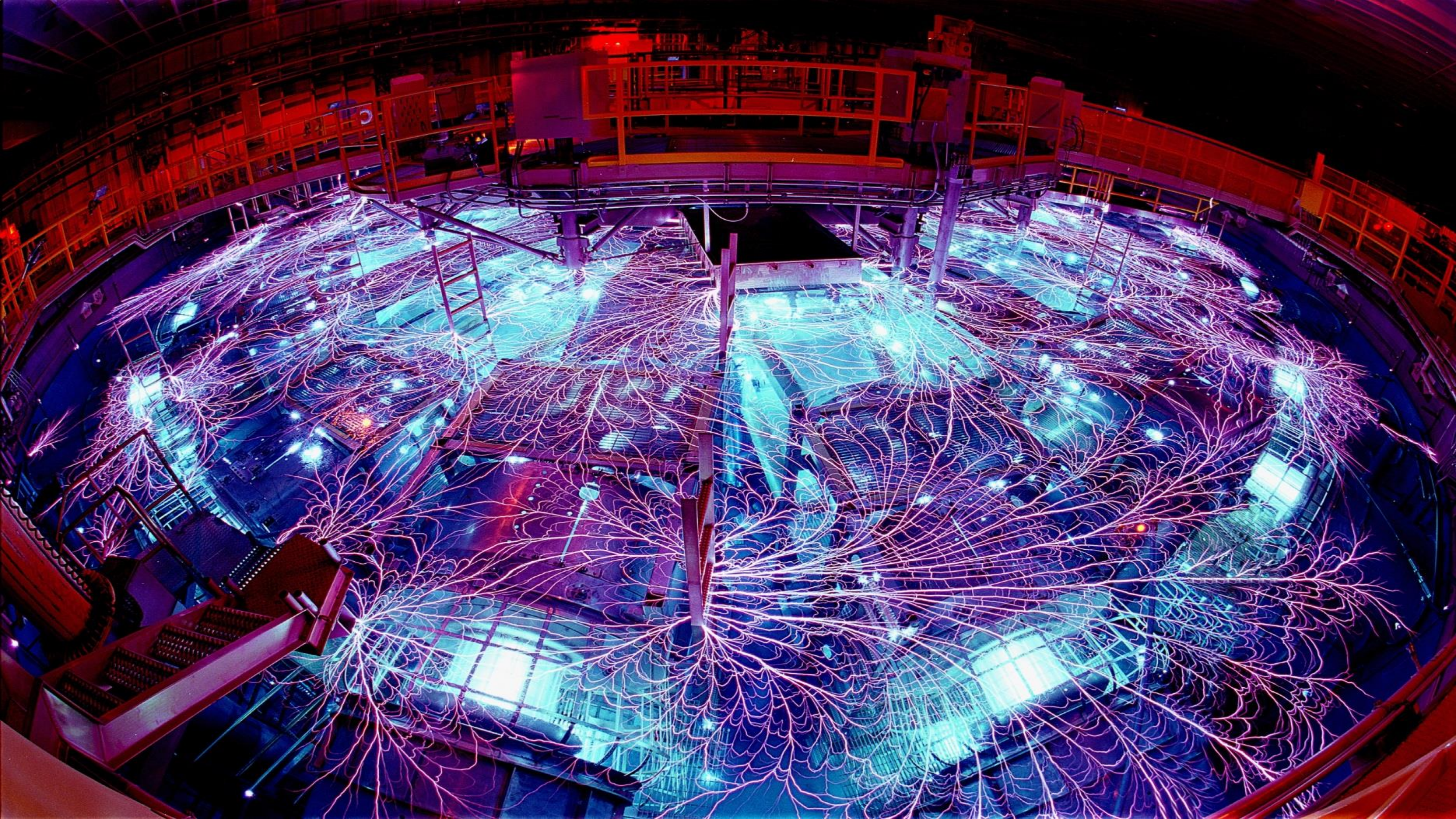
Z Machine

- Pulsed Power Accelerator
  - 20 MJ stored energy
  - >5 MV
  - 27 MA
  - 8 MJ at target
  - 2.5 MJ (X-Rays)
  - 95 ns
  - 350 TW radiated power (X-rays)





Z-Beamlet

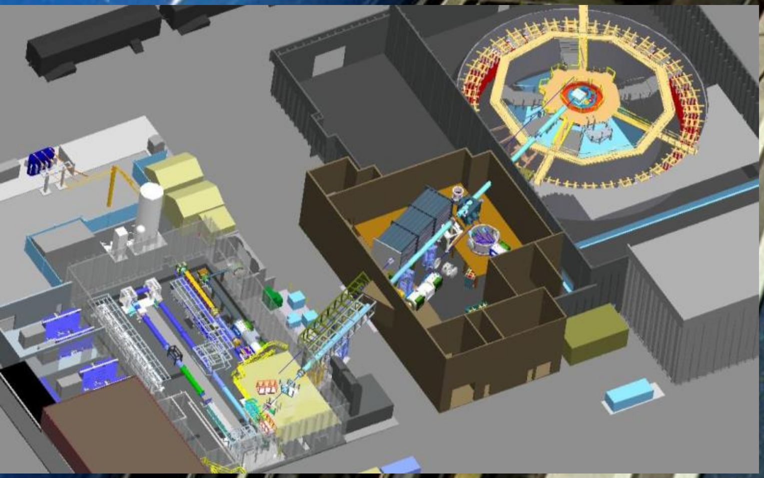
- Pulsed Power Laser
  - 2 – 4.5 kJ of laser energy
  - 0.3 – 8 ns pulse width
  - 75 µm spot size

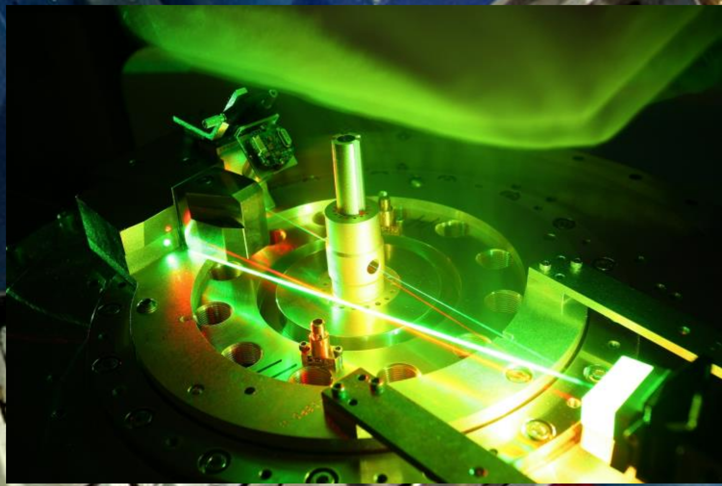
Chaco

- Pulsed Power Laser
  - 100 J of laser energy
  - 100 ps – 10 ns pulse width
  - 20 µm spot size

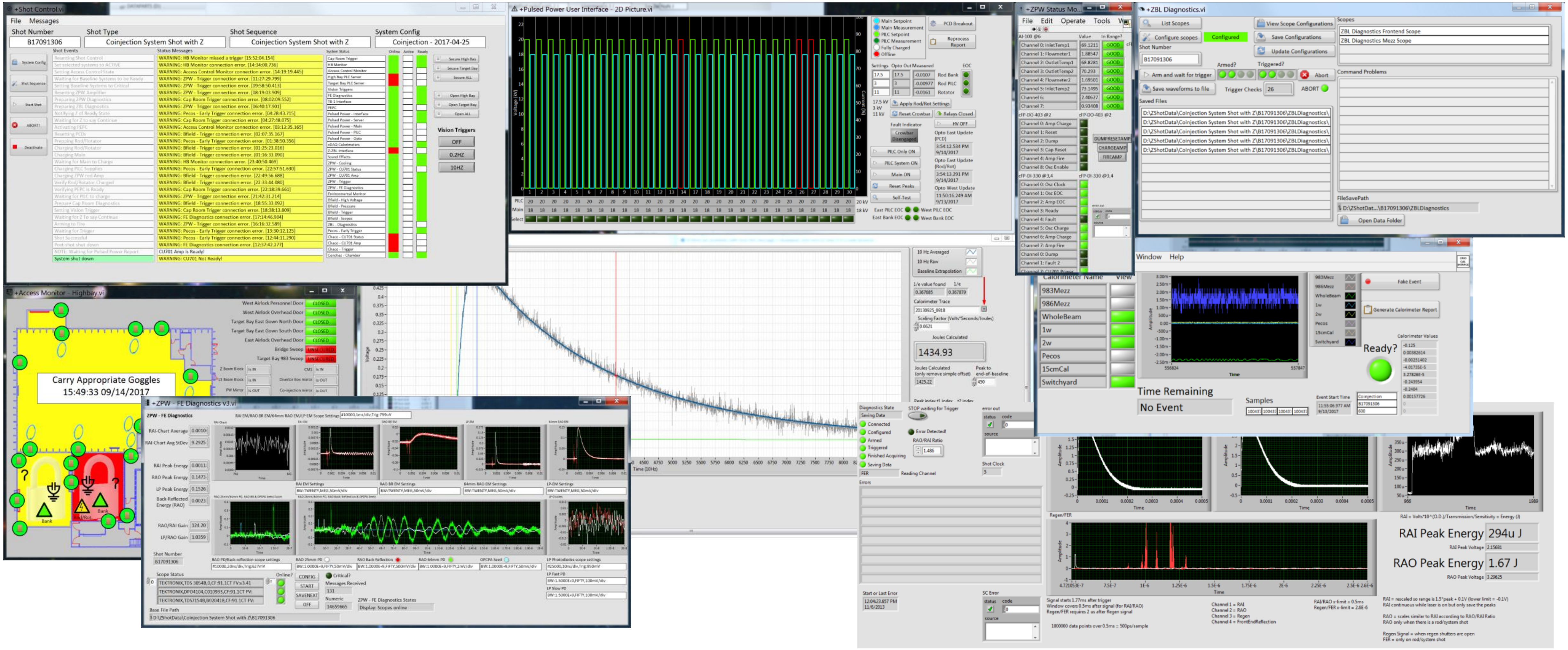
Z-Petawatt

- Pulsed Power Laser
  - 500 J of laser energy
  - 500 fs – 100 ps pulse width
  - 6 µm spot size





Shot Control System (Multi-system Synchronization)



Timing Regimes

Timing Regime	OS	Response/Jitter range	Hardware/ Software	Reliability
Non Real-Time	General Purpose OS	10 ms – 10 s	PC, Windows, Linux, OSX	Low*
Slow Real-Time	Real-time OS (no optimization)	10 ms – 100 ms	PC, Embedded Controller, WinCE, VxWorks, Linux RT	Medium
Fast Real-Time	Real-time OS (with optimization/testing)	10 us – 10 ms		High
FPGA I/O	Hardware Programming	10 ns – 10 us	FPGA	Very High
Delay Generator	Hardware/FPGA	85 ns/100 ps	Delay Generator**	Very High
Digital circuit	Hardware	1 ns – 10 ns	Transistors	Very High

*Catastrophic OS-level interruption could occur. May respond late or never.
**Minimal logic allowed: ready/not-ready, inhibited/not-inhibited

System Requirements

- Timing
  - High-level shot sequence coordination (slow, flexible)
  - Slow charging circuits (reliable, real-time)
  - Trigger sources (very fast response)
- Reliability
  - Interlocked control of lasers, HV supplies, triggers
  - Monitor subsystems for confidence before shot
  - Data logging for troubleshooting
- Flexibility
  - Custom sequences
  - Easily modify timing
- Wide variety of hardware (benchtop, embedded controllers with mixed I/O, subsystems)
  - Don't shoot if unexpected problem occurs with any piece of hardware

Control Hardware Choices

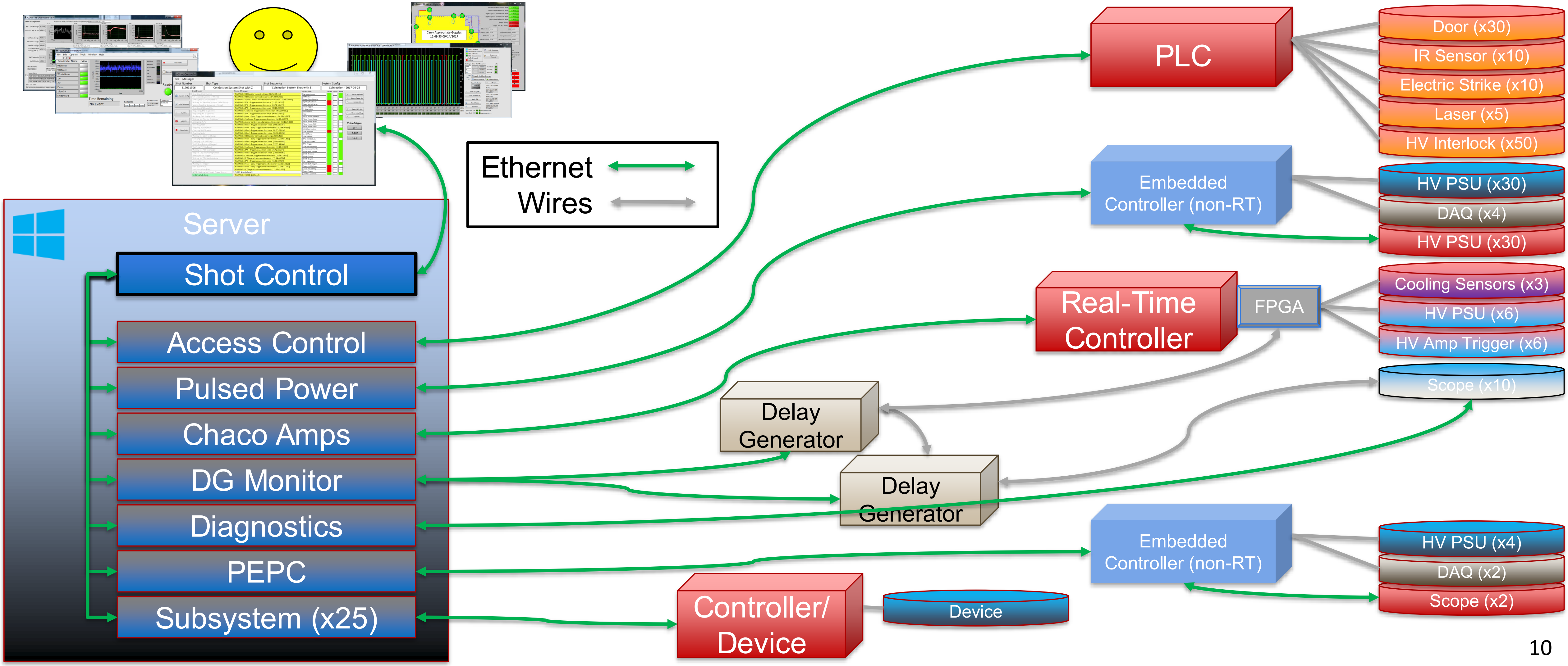



- Low-speed, Non-RT (100+ ms)
  - User Interface
  - High-level shot sequence
  - Device monitor (DGs, Scopes, HV PSs, DAQs, embedded controllers)
- High/Low-speed RT (10-100 ms)
  - Pressure sensors, switches, relays, triggers, slow signals (100 ms), voltage monitors
- FPGA (55 ns - 10 us)
  - Verify interlocks, verify amp state, and trigger proper flash lamps
- Delay Generators (100 ps)
  - Primary trigger chain for initial trigger, amplifiers, laser heads, scopes, cameras, etc.

Software Architecture

- High level coordinator with custom sequences
  - Ensures central control of sequenced events and condition checks
  - Easy to troubleshoot, easy to modify
- Low-level subsystems written for specific purposes
  - Easier to program for individual tasks without modifying high level coordinator
  - Easy to write, easy to test
- Push commands (TCP/IP)
  - Fast response, low jitter
- Poll status (NI-PSP)
  - Known response/jitter, easy to plan for

Shot Control Subsystem Diagram



Summary

1. Understand timing requirements for hardware
2. Select your ecosystem based on secondary requirements
3. Architect your software appropriately to make it easier to satisfy timing, reliability, and troubleshooting requirements
4. Keep it simple

Questions/Discussion/Comments

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Come see our posters on Tuesday to learn more about the Z Facility.