Modernizing Fermilab's Accelerator Control Hardware

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In partnership with:

Argonne NATIONAL LABORATORY
INL Idaho National Laboratory
OAK RIDGE National Laboratory

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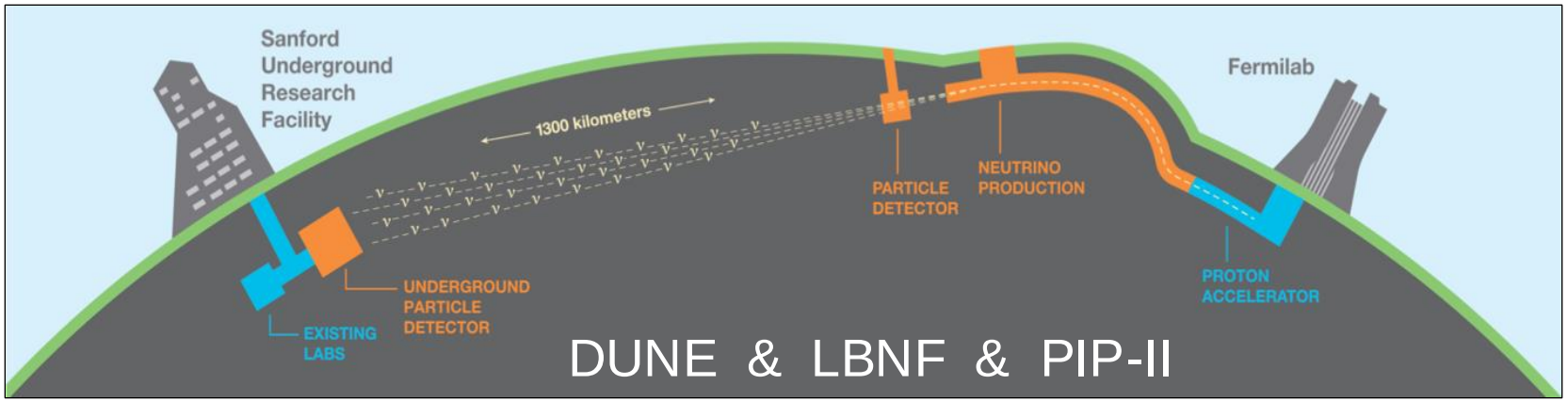
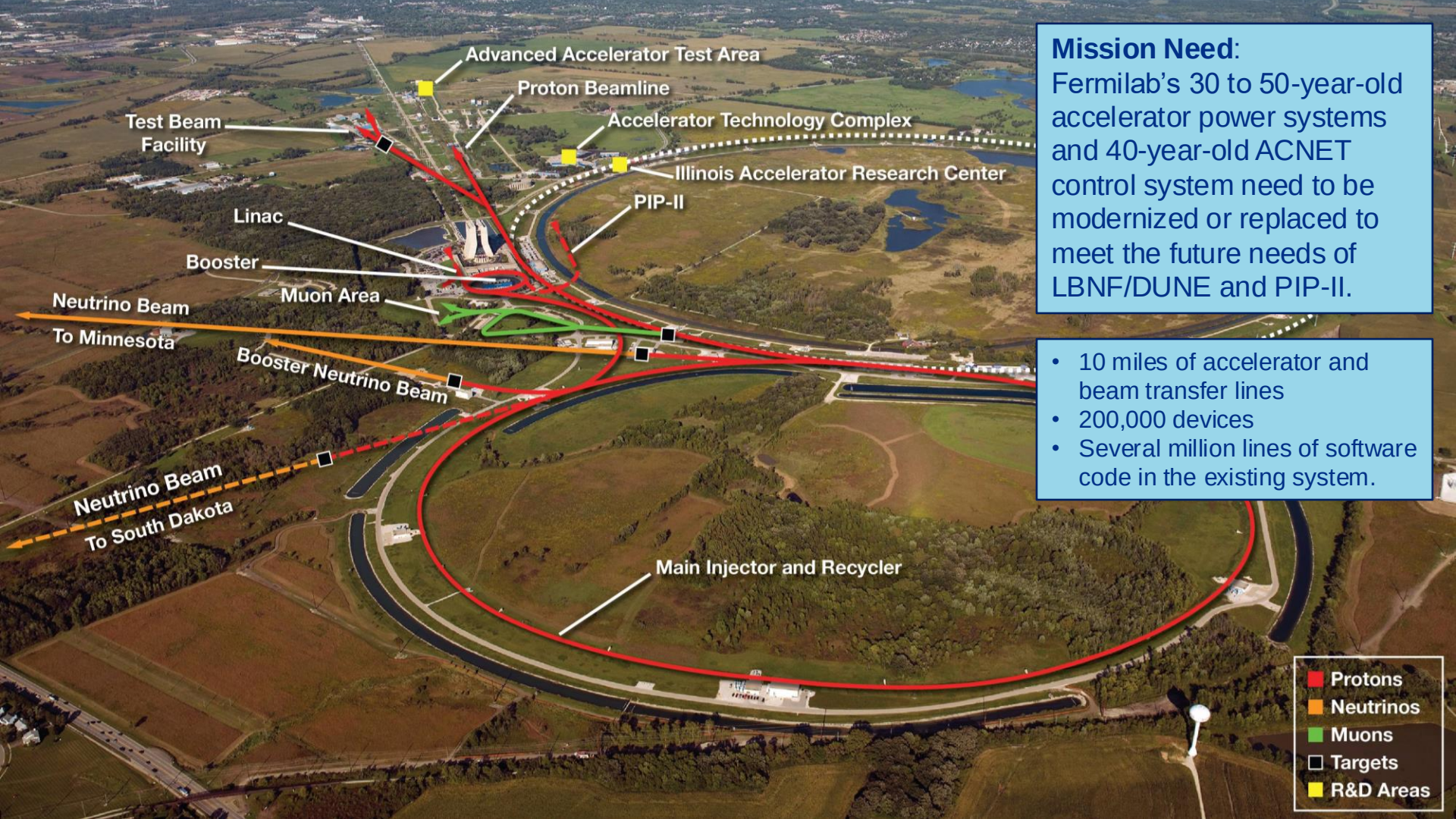
Exploring the Quantum Universe

Pathways to Innovation and Discovery in Particle Physics
A Strategic Plan for US Particle Physics

- The lab's primary goal: a **world-leading neutrino science** program.
  - Anchored by the Long-Baseline Neutrino Facility (**LBNF**) and Deep Underground Neutrino Experiment (**DUNE**).
  - Powered by megawatt beams from an upgraded and modernized accelerator complex made possible by the Proton Improvement Plan II (**PIP-II**) .



ACORN



Mission Need:
Fermilab's 30 to 50-year-old accelerator power systems and 40-year-old ACNET control system need to be modernized or replaced to meet the future needs of LBNF/DUNE and PIP-II.

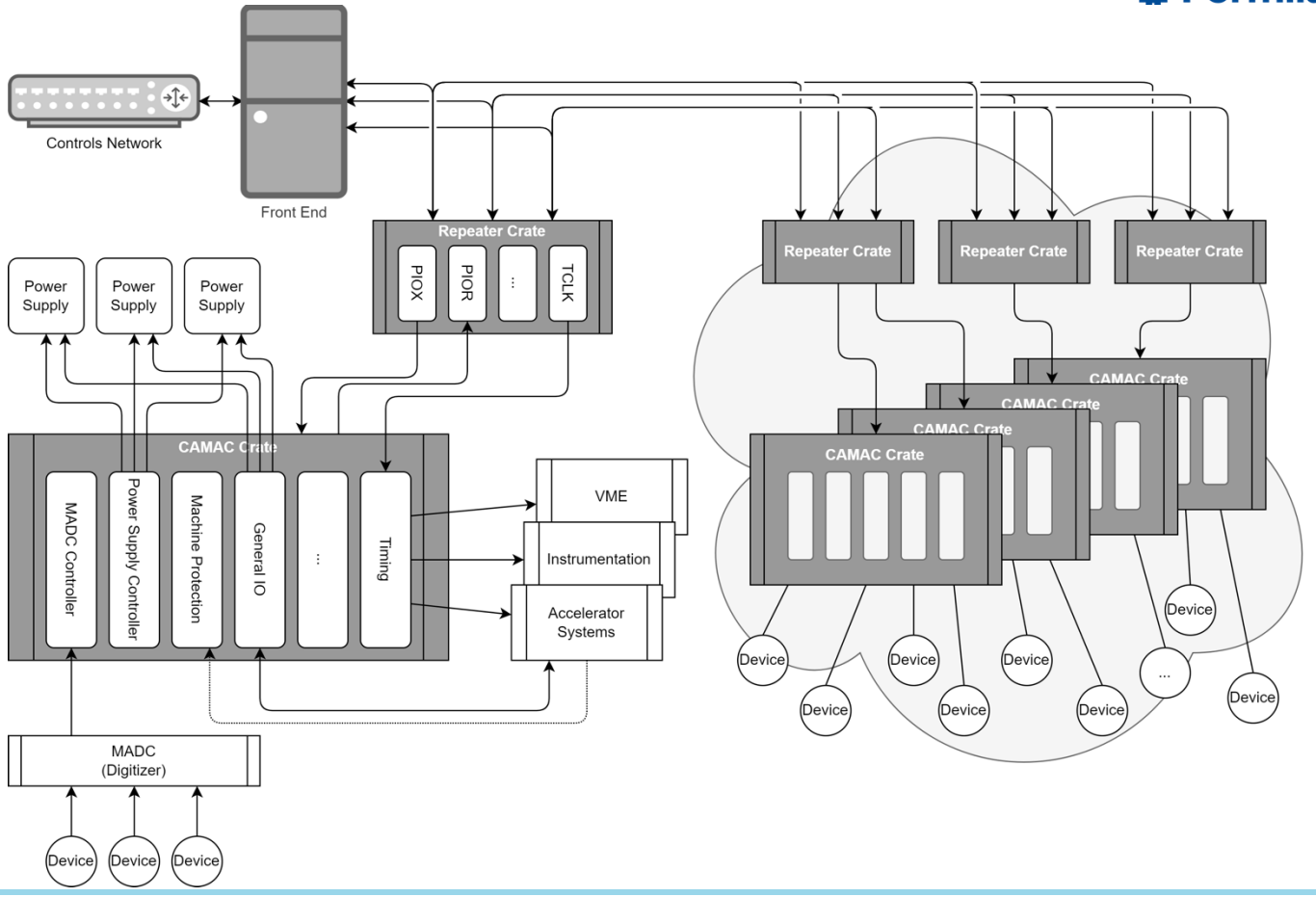
- 10 miles of accelerator and beam transfer lines
- 200,000 devices
- Several million lines of software code in the existing system.

Modernizing the control system

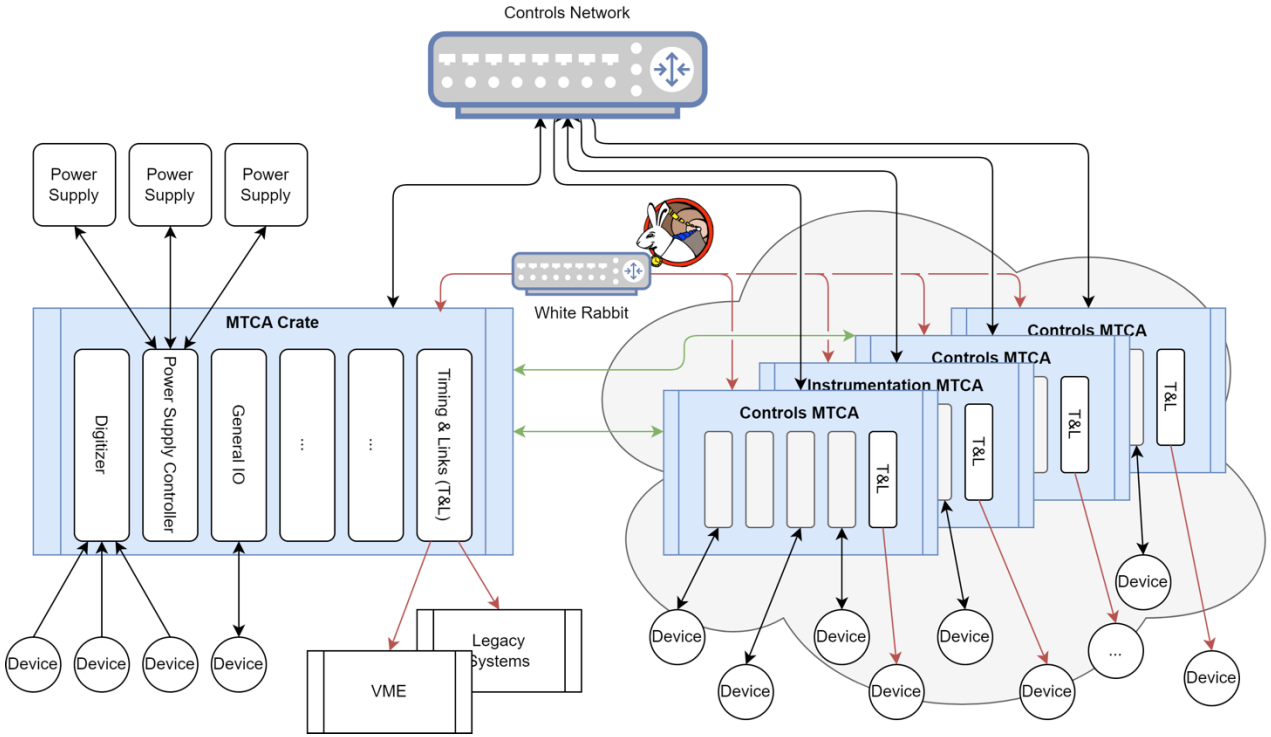
- The Accelerator Controls Operations Research Network (ACORN) project will
  - Replace end-of-life, obsolete, or antiquated hardware (power supplies, computer infrastructure, data acquisition and control hardware)
  - Implement an architecture that promotes a highly reliable and resilient control functions.
  - Support the development and deployment of AI/ML capabilities for accelerator operations.

- Key objectives for accelerator control system modernization:
  - Replace CAMAC systems, deliver hybrid ACNET/EPICS control system, replace network switches, replace power supplies, and deliver critical user applications.

Current System



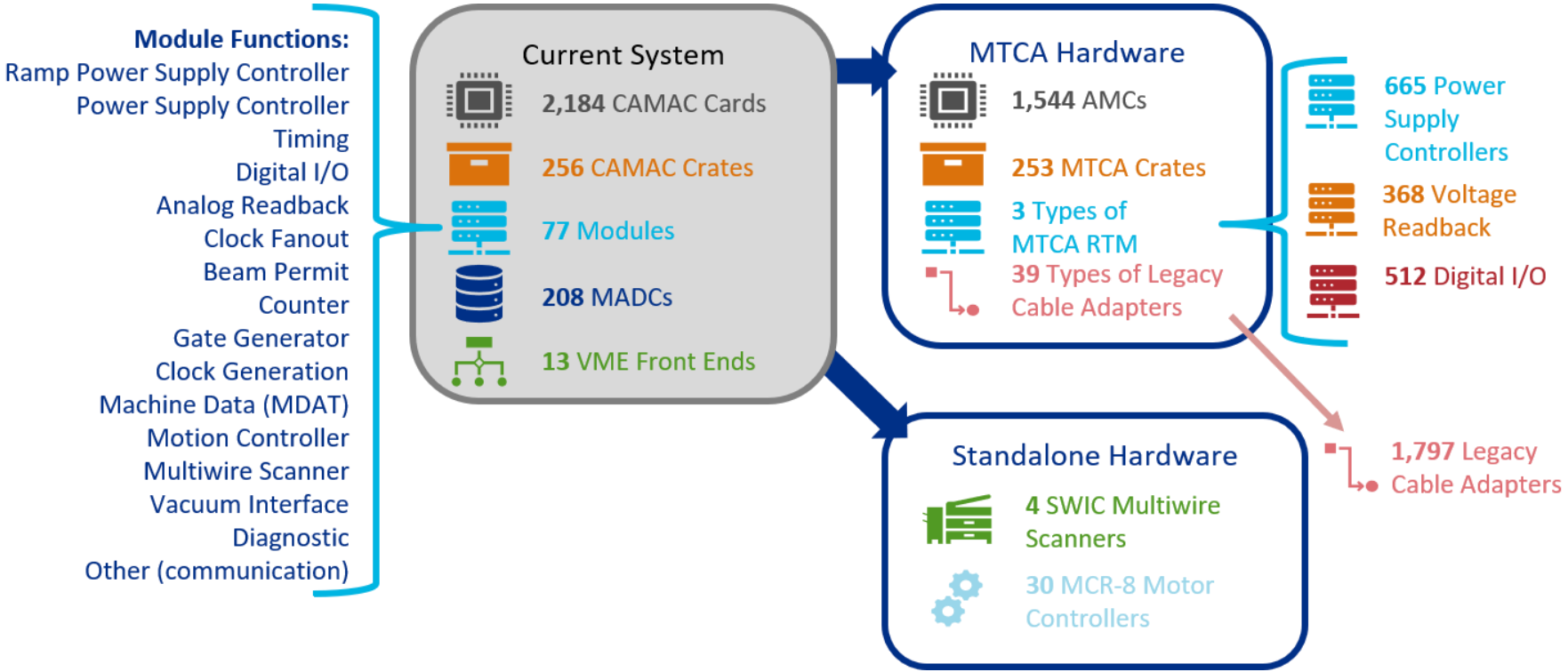
ACORN Data Acquisition & Control Hardware



MTCA.4:

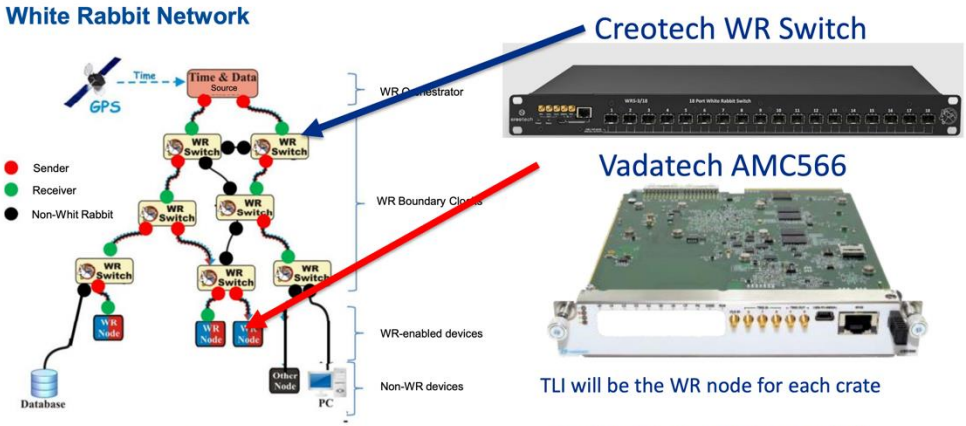
- Supports modern standards
- Designed for high-reliability systems
- Designed to be easy to maintain
- Good community/commercial support
- Similar formfactor

Reducing complexity

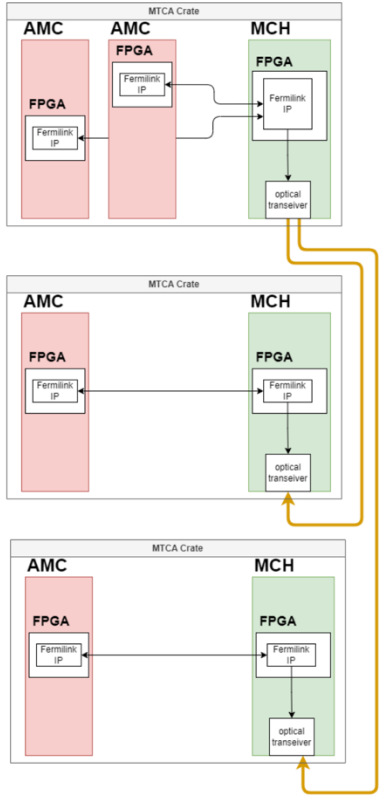


Timing and Links

- The control system needs to support event-based timing, machine protection, beam synchronous clock distribution, and data links
- White Rabbit + high-speed serial protocol (Fermilink)
  - Support: higher bandwidth inter-crate communication, better device synchronization, unified timestamping, and consolidated timing & data link infrastructure

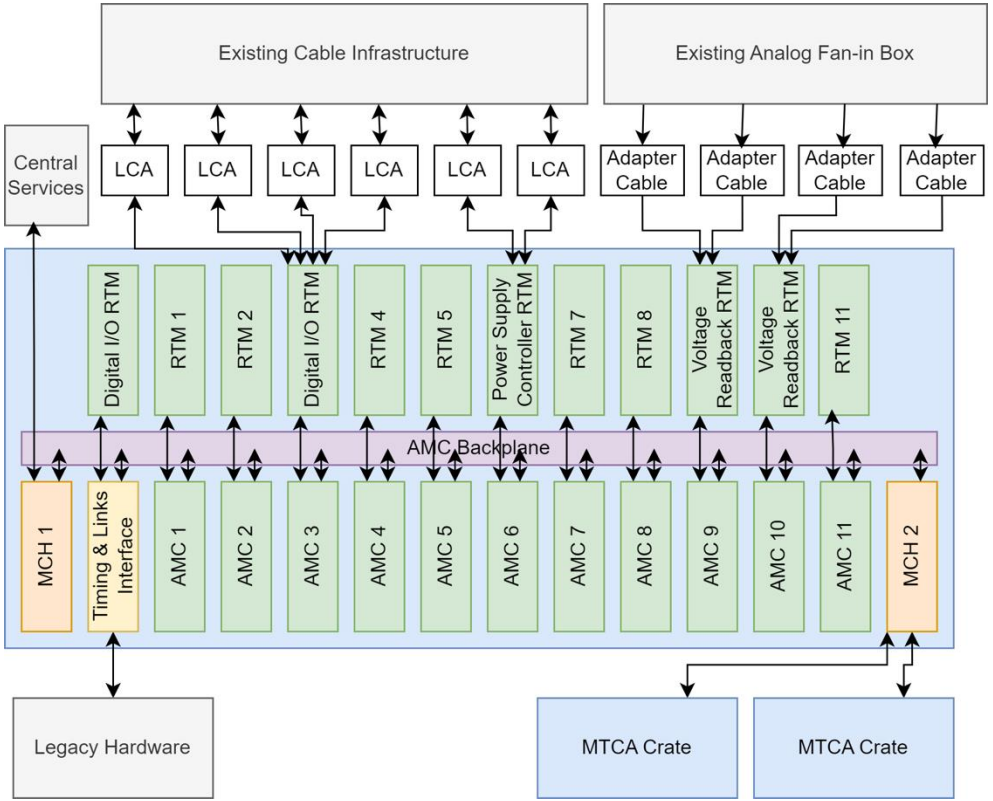


Credit: White Rabbit Cookbook



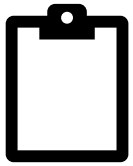
Crate Architecture

- Each slot is a common AMC + one of three types of RTMs
- MCH will provide ethernet on base and fat pipe ports
- In addition, all common IO (timing links, MPS, and data links) will interface with AMCs either through a dedicated *Timing & Link Interface AMC* or a second MCH
- Supports both legacy crate interfaces and WR + Fermilink

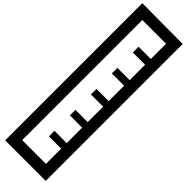


Progress so far on ACORN CAMAC replacement…

Conducted 20+ stakeholder interviews to gather requirements

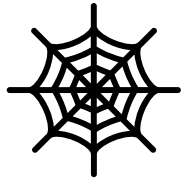


Inventories of:
- CAMAC hardware
- Unused fiber cables
- Unused rack space



Prototype Development:
- Advanced Mezzanine Card
- Digital I/O Rear Transition Module

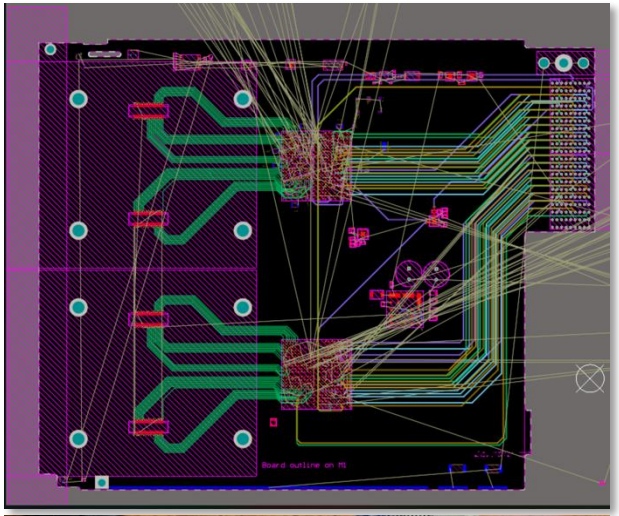
Creating a development environment for firmware/software

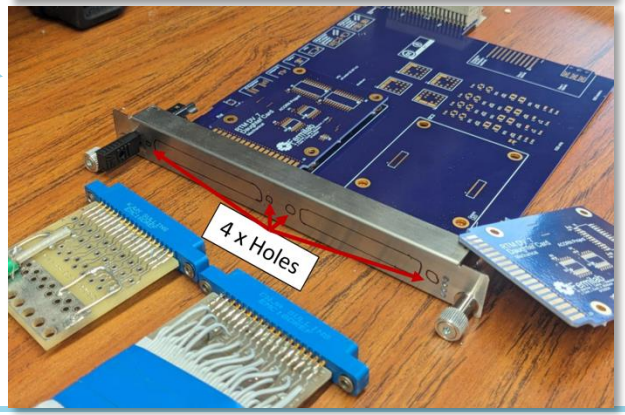


Studied crate-to-crate communication networks

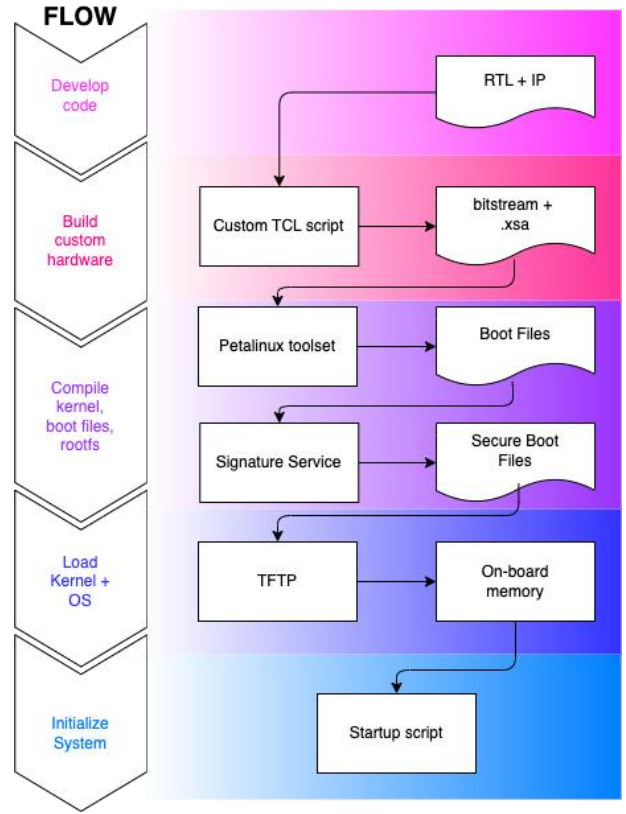
Prototype RTM

- Prototyping one solution in which legacy cables connect directly with RTMs
  - Starting with a digital IO cards
  - Building off the DESY RTM template
  - Built a mechanical prototype before finishing layout

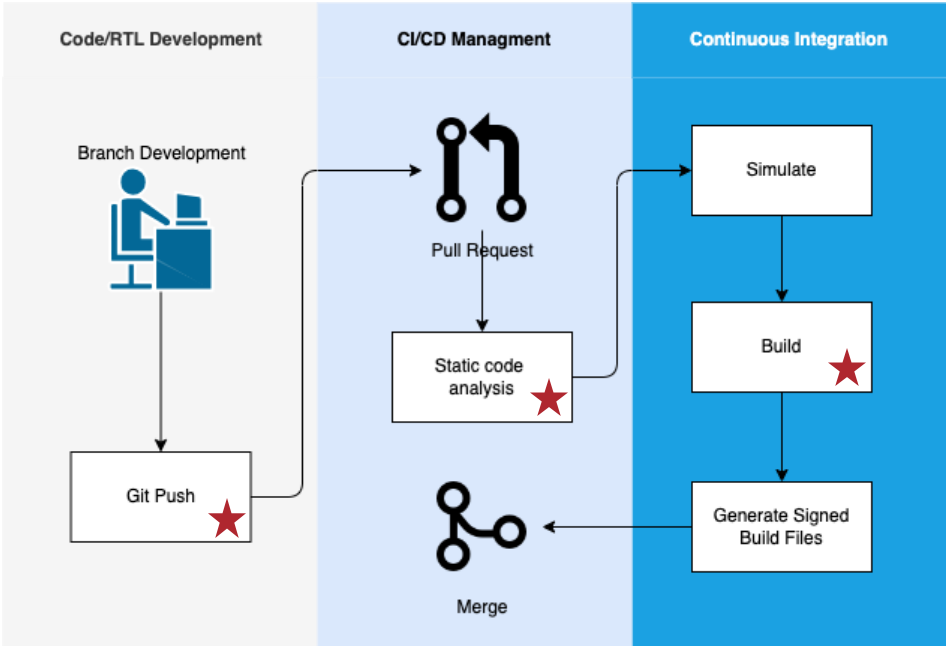




Firmware/software development workflow



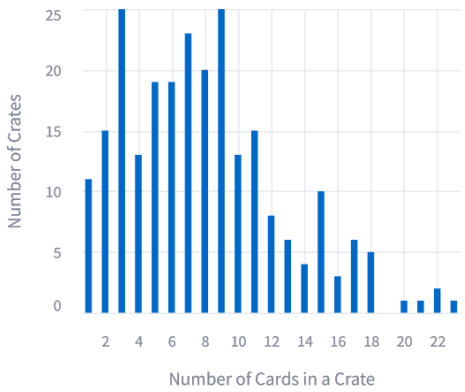
★ Prototyped and tested



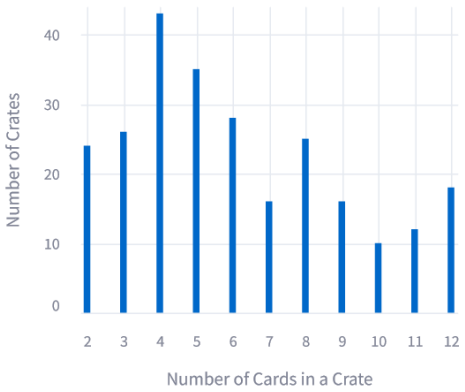
ACORN Hardware Visualization Tool

Hardware Overview

Quantity of Cards in All of the CAMAC Crates



Quantity of Cards in All of the MTCA Crates

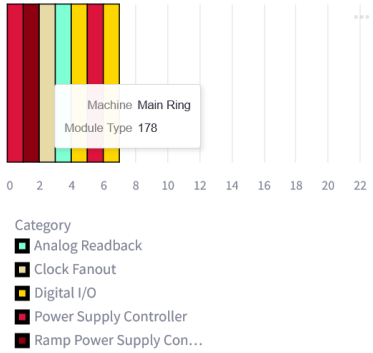


Select building:

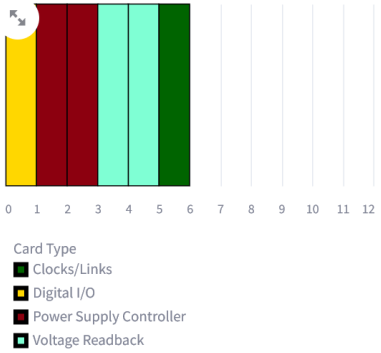
A1

Crate: TEVA-A1

CAMAC Hardware

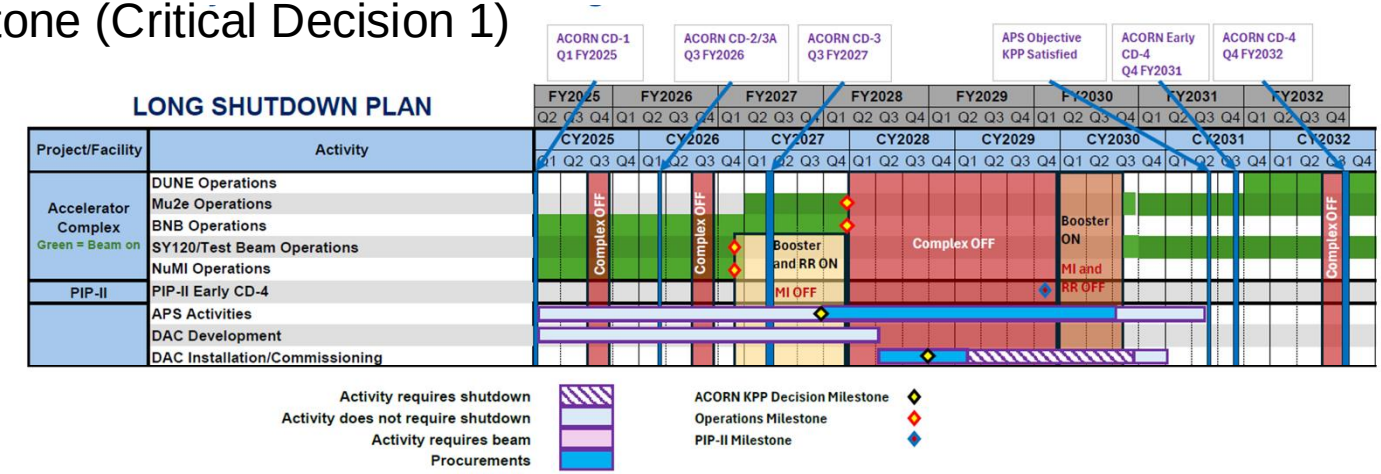


New Hardware



Work to follow

- In 2025, ACORN DAC team will be building a variety of prototypes to develop preliminary designs of key elements of the system
  - Small-scale White Rabbit & Fermilink networks
  - Fully functional MTCA test stand
- Project will go through a DOE review in the spring to achieve our next major project milestone (Critical Decision 1)



Extras

CAMAC Card Counts by Function

- Most cards control power supplies
- Most of the remaining cards fall into one of three other categories:
  - Timing and links functions
  - Digital I/O
  - MADC control