Fermilab | U.S. DEPARTMENT OF ENERGY | Office of Science

ACORN Overview

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In partnership with:

INL
Idaho National Laboratory

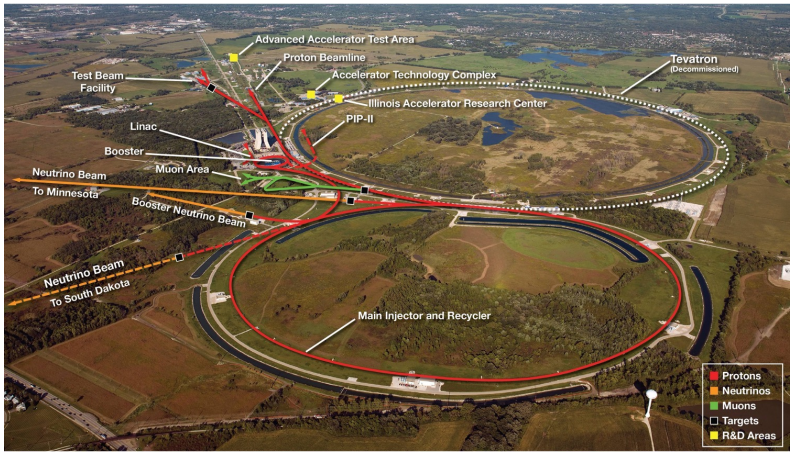
Outline

- Overview
- Risk Analysis
- Requirements
- Research and Development

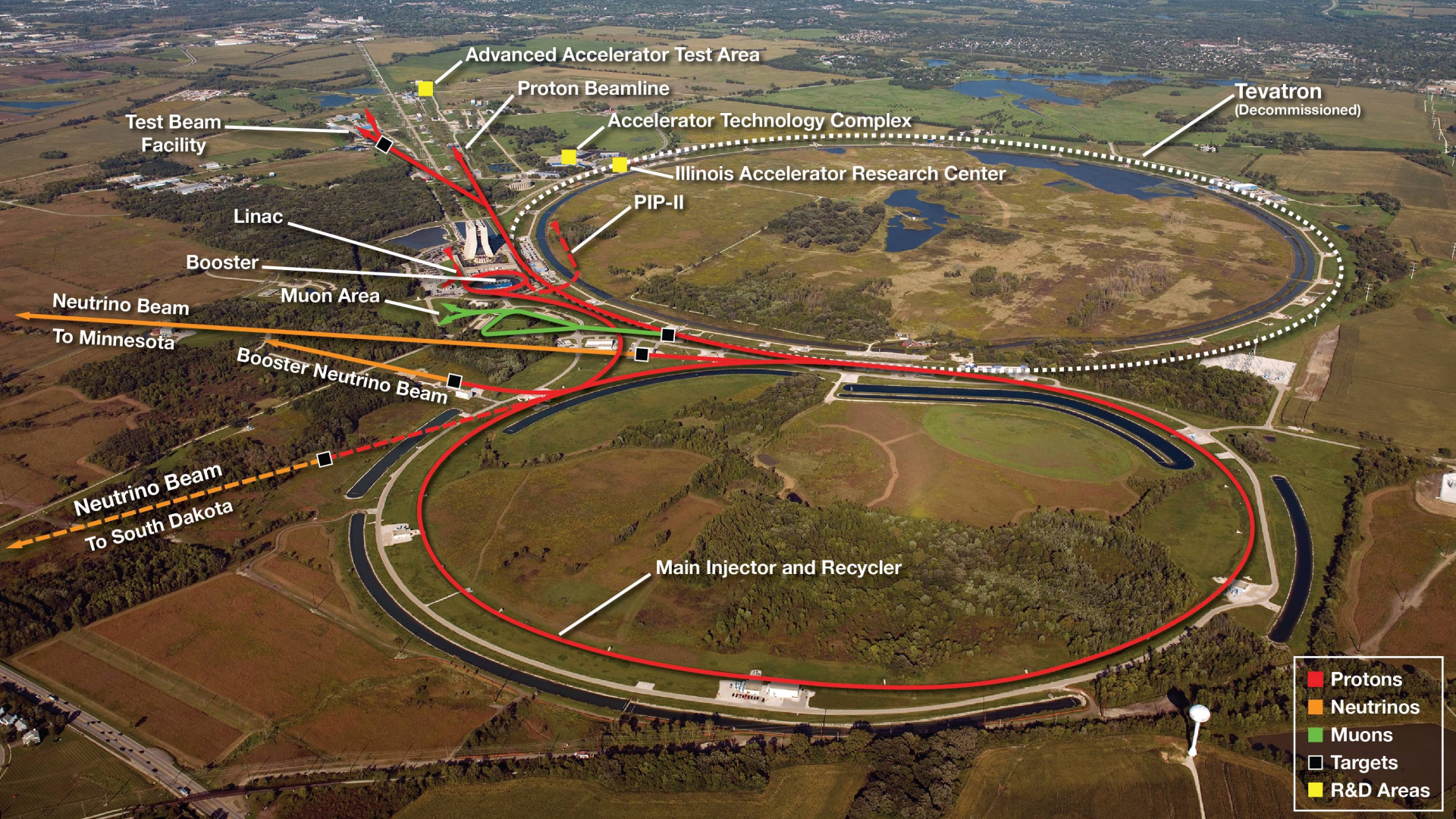
Accelerator Controls Operations Research Network (ACORN)

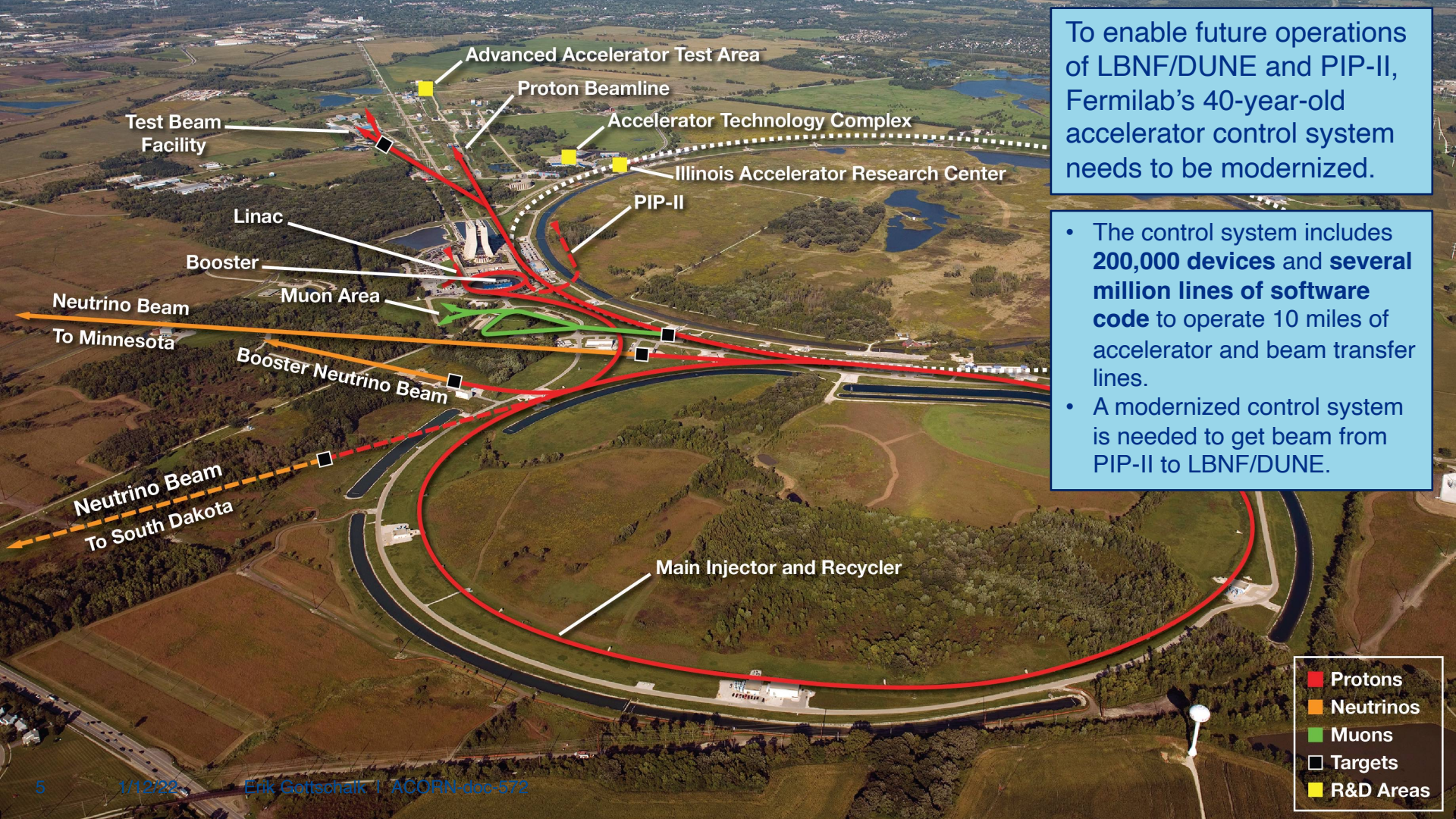
- ACORN will modernize the **accelerator control system** and replace end-of-life **accelerator power supplies** to enable future operations of the Fermilab Accelerator Complex with megawatt particle beams.

- CD-0 was approved August 28, 2020.
- ACORN is a DOE O413.3B project.
- Total Project Cost: 100 – 142 M$
- Project Duration: 8 – 10 years



- As an upgrade of the accelerator complex, the ACORN team is analyzing risk associated with current accelerator operations and is developing requirements for modernization.


Advanced Accelerator Test Area
Proton Beamline
Test Beam Facility
Accelerator Technology Complex
Tevatron
(Decommissioned)
Illinois Accelerator Research Center
PIP-II
Linac
Booster
Muon Area
Neutrino Beam
To Minnesota
Booster Neutrino Beam
Neutrino Beam
To South Dakota
Main Injector and Recycler
Protons
Neutrinos
Muons
Targets
R&D Areas



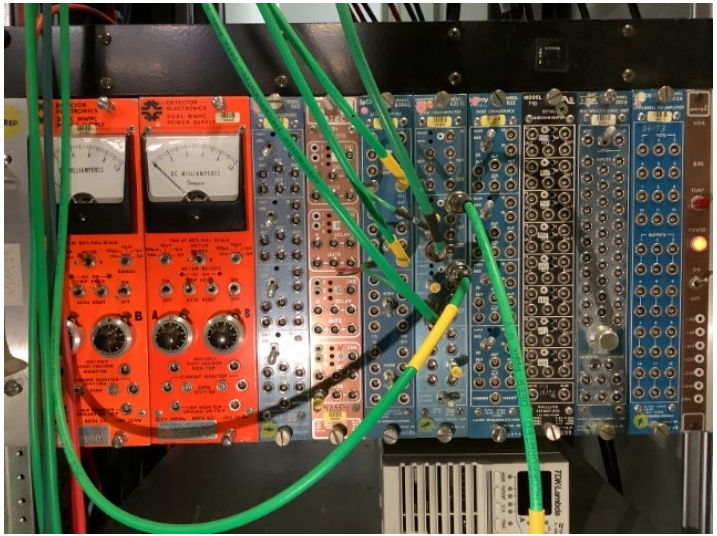
To enable future operations of LBNF/DUNE and PIP-II, Fermilab's 40-year-old accelerator control system needs to be modernized.

- The control system includes **200,000 devices** and **several million lines of software code** to operate 10 miles of accelerator and beam transfer lines.
- A modernized control system is needed to get beam from PIP-II to LBNF/DUNE.

Risk Analysis

1) Perform risk analysis for accelerator operations risks .

2) Use the risk ranking to define the ACORN project scope.



Risks Analysis – Process

- Interviewed Accelerator Division (AD) department heads and subject matter experts
  - Asked for greatest operations risks: Technical, External, People, Key Assets
  - ”What keeps you up at night?”
- Combined these operations risks with risks in the Fermilab operations risk register.
  - ACORN project team and AD leadership reviewed the operations risks to identify the risks that ACORN could potentially mitigate
- Asked risk owners to assess ACORN-related operations risks.
  - Assess probability and impact of each risk to determine risk ranking
  - Identify mitigations and urgency
- ACORN team is using the risk rankings to define the project scope.

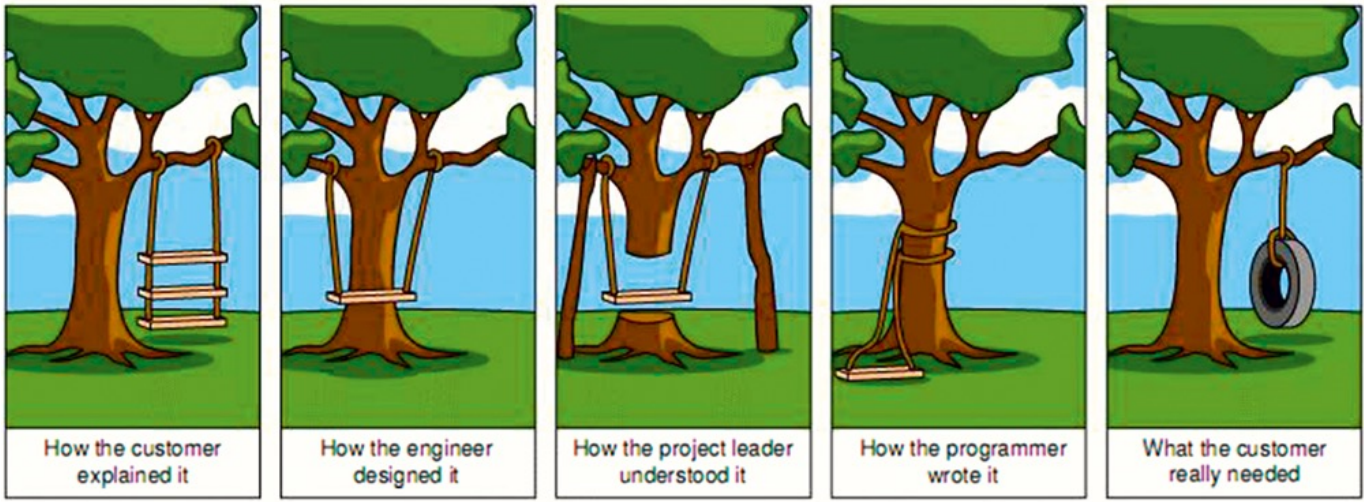
Accelerator Operations Risks – Examples

Risk Title	Impact – Technical	Impact – Cost	Impact – Schedule	Probability % (annual)	Mitigations	Impact
Failure of obsolete CAMAC hardware in MI, Booster, Recycler	High	Low	Low	Medium 21-39%	Phased replacement of various CAMAC systems	Interruption of experimental area until failed hardware is replaced; minutes to a week
Failure of accelerator communication link due to radiation exposure	Low	Low	Low	Low 9-21%	Regular testing of fiber integrity. If degradation is present, new fiber can be purchased before failure occurs and replacement can be planned for a shutdown period without interrupting beam operation.	Beam operation compromised or curtailed which jeopardizes beam to users

Requirements

1) Develop functional requirements for the existing accelerator control system.

2) Identify new requirements needed to implement new capabilities.



Requirements Gathering – Use Cases

- Use Cases are used to identify **functional requirements.**
- Methodology:
  - Develop questionnaires to identify use cases
  - Conduct interviews of subject matter experts, users of the control system, and other stakeholders
  - Communicate results to the project team and make results available to stakeholders
- Two rounds of Use Case interviews:

Level	Objectives	Interviewer / Interviewee
Discovery Interview	• Identify general use cases (goals). • Validate actor characterization (description).	The use case team interviews a group of individuals that fill an actor role.
Detail Interview	• Obtain details for a list of use cases. • Write drafts of the main success scenario for each use case. • List possible extension points.	Interview between one (or two) use case team member(s) and one individual actor person.

- Discovery interviews have been completed (may schedule more if gaps are identified).
- Detail interviews started by interviewing MCR operators about User Interface requirements.

Requirements Gathering – Results So Far

- 229 high level **functional requirements** identified

Category	Number of Requirements
AI/ML	7
Alarms	8
Core Functionality	38
Controls Development	32
Interfaces	12
Logging	8
Operations	90
Research	1
Security	16
User Interface	17

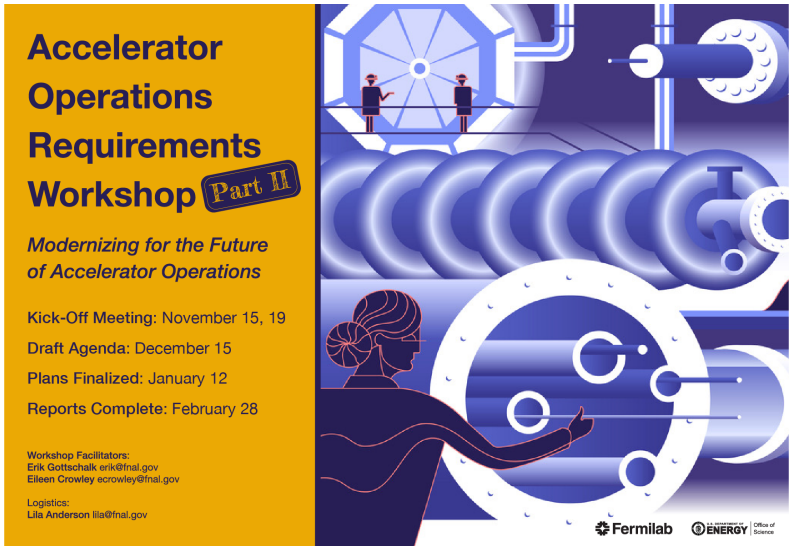
- Top 3 categories: **Operations**, Core **Functionality**, and Controls **Development**
- **Usability** and **extensibility** of the control system is highlighted as major concern of the stakeholders
- Non-functional requirements are collected as part of the interview process

- The functional requirements represent the core set of requirements that define the existing accelerator control system.
- New requirements will be added based on results from the two-part Accelerator Operations Requirements Workshop.

Accelerator Operations Requirements Workshop – Part II

- A strategic planning workshop hosted by AD to envision the future of accelerator operations.
- Working groups and group leaders:
  - AI/ML for Accelerator Operations (**Nhan Tran, Tia Miceli**)
  - Common Infrastructure/Software (**Dennis Nicklaus**)
  - Cybersecurity and Access Control (**Anthony Tiradani**)
  - ES&H (**Madelyn Schoell**)
  - Experiment Operations (**Mandy Kiburg**)
  - Machine Protection (**Paul Czarapata**)
  - Robotics (**Mayling Wong-Squires**)
  - Software Development (**Julian Badillo Rojas**)
  - User Interface Design (**Kyle Hazelwood**)

- ACORN expects to receive new requirements from all (or most) of these working groups.

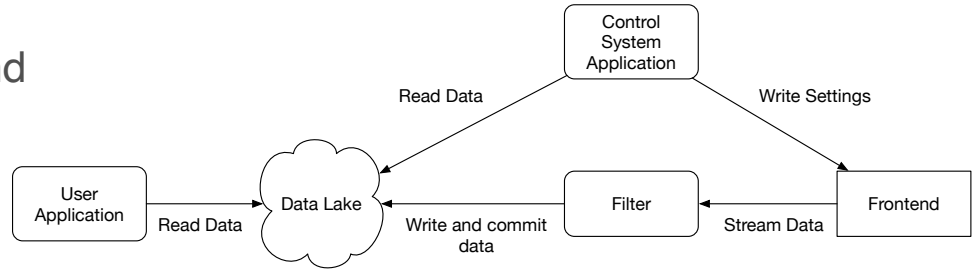


Research and Development

- ACORN will explore unique engineering challenges to enable new capabilities for future accelerator operations.
- ACORN will perform or support R&D efforts as part of the project's R&D program.
  - ACORN R&D activities include research into new data acquisition capabilities, support for AI/ML for accelerator operations, evaluation of 5G technology, support for robotics, and evaluation of Experimental Physics and Industrial Control System (EPICS) for different control system design concepts.
  - AI/ML for accelerator operations (see Nhan's talk **Feb. 23, 9am**)
  - Robotics for accelerator operations (see Mayling's talk **Feb. 23, 1pm**)

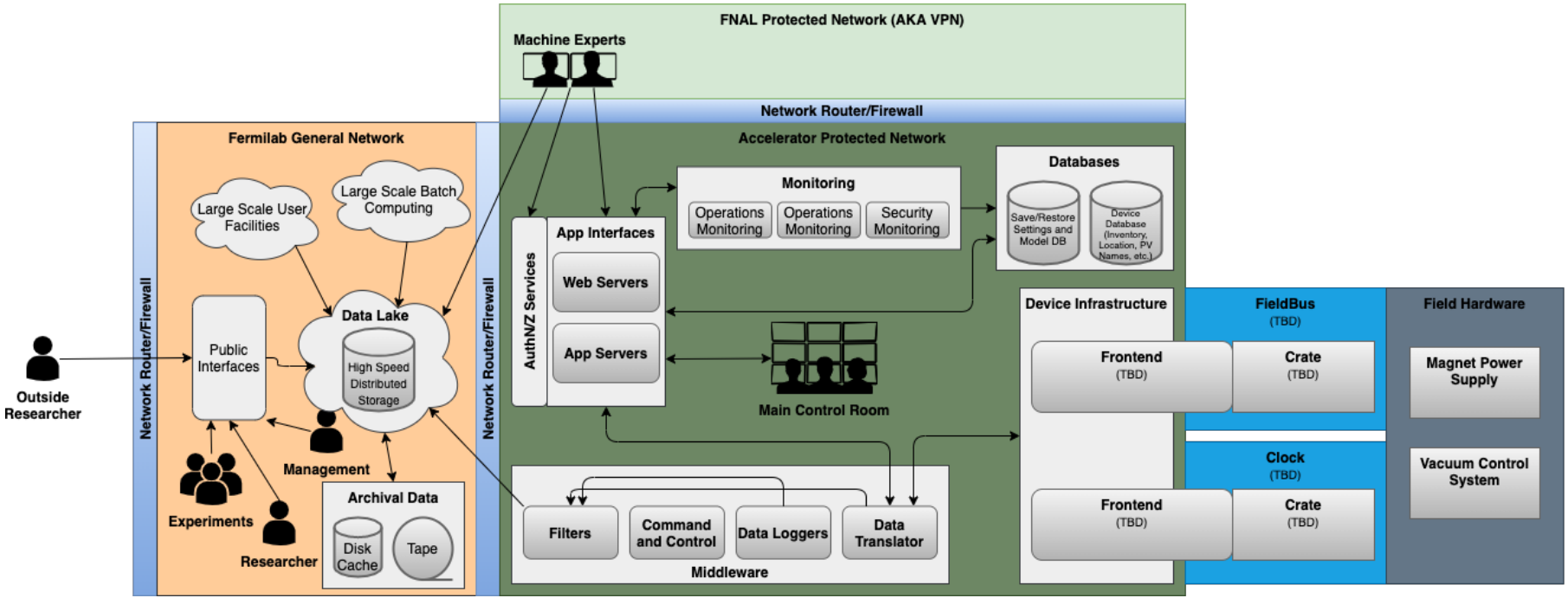
Data Acquisition R&D

- Measure expected data flows from different types of frontends
- Create a testbed “Data Lake”
  - Measure total data volumes
  - Test filters to select and store relevant and interesting data
  - Measure “commit” latencies for writing data
  - Measure latencies for reading data



- Determine if a Data Lake satisfies accelerator control system requirements

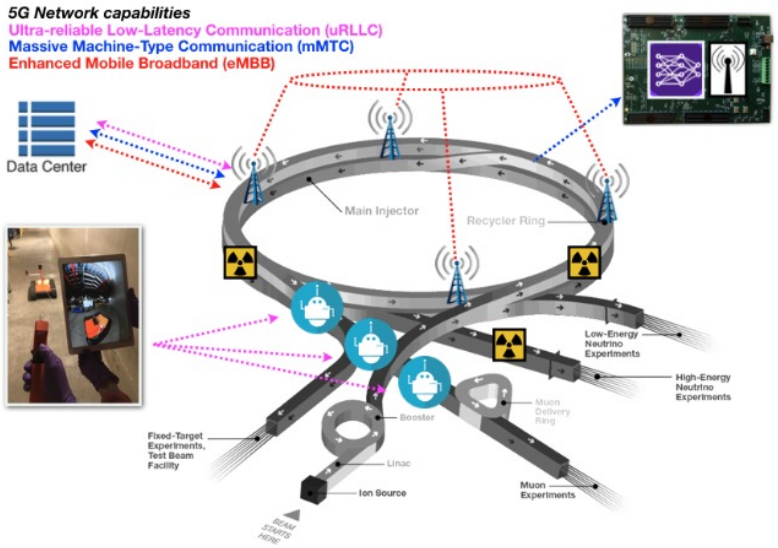
Data Acquisition R&D – Centralized Architecture



5G Feasibility Study and ACORN R&D

DOE requested an evaluation of 5G technology as part of the CD-0 approval process for ACORN:

- “R&D for the project will evaluate the feasibility of operating 5G mmWave wireless technology in accelerator tunnels.”
- 5G has the potential to significantly improve accelerator operations.
- Benefits include increased personnel safety by minimizing radiation exposure.
- Autonomous or remotely controlled robots would be able to provide live-streaming data, video/audio upload, and two-way communication to diagnose and repair urgent operational issues.



Possible applications of 5G technology in the Fermilab Accelerator Complex.

5G Use Cases and R&D

- Use Cases
  - Accelerator control system integration in challenging environments, such as locations that are difficult or expensive to service with wired network connections.
  - Provide ubiquitous, non-static data access underground (for example: mobile phones, tablets, robots)
  - High data rate, low-latency communication without cable cost
    - Underground instrumentation
  - New use-cases with custom solutions:
    - Ultra-Reliable Low Latency Communications (URLLC)
    - Massive Machine Type Communications (mMTC)
    - Industrial Internet-of-Things (IIOT)
- Future R&D
  - Multiband on single radiating coax antenna
  - Equipment lifetime in a radiation environment
  - Interference with accelerator equipment
  - Signal propagation in accelerator tunnels

Robotics R&D

Development and proliferation of robotics at Fermilab will bring novel technical challenges to the future accelerator control system. Technical challenges include the following:

- Low-latency feedback and control between robot and operator to minimize errors
- High-resolution and frame-rate video streaming for navigation feedback and reconnaissance
- Transmitting and logging data from a diverse array of sensors such as temperature, humidity, photography, thermal imaging, and radiation mapping.
- Data storage and computation for training robots to autonomously navigate and manipulate tooling for maintenance and installation tasks.

Robotics for accelerator operations (see Mayling's talk **Feb. 23, 1pm).**

Summary

As an upgrade of the accelerator complex, the ACORN team is analyzing risk associated with current accelerator operations and developing requirements for modernization.

- The project team will use risk rankings to define the ACORN project scope based on probability and impact of accelerator operations risks.
- The team has developed functional requirements for the existing accelerator control system based on stakeholder interviews.
- Results from the Accelerator Operations Requirements Workshop (April 2021– May 2022) will identify new requirements for future capabilities such as AI/ML and robotics for accelerator operations.
- ACORN R&D includes research into new data acquisition capabilities, support for AI/ML and robotics, evaluation of 5G technology, and evaluation of EPICS for ACORN design concepts.

Additional Slides

Work Breakdown Structure

L2 WBS Elements

L3 WBS Elements