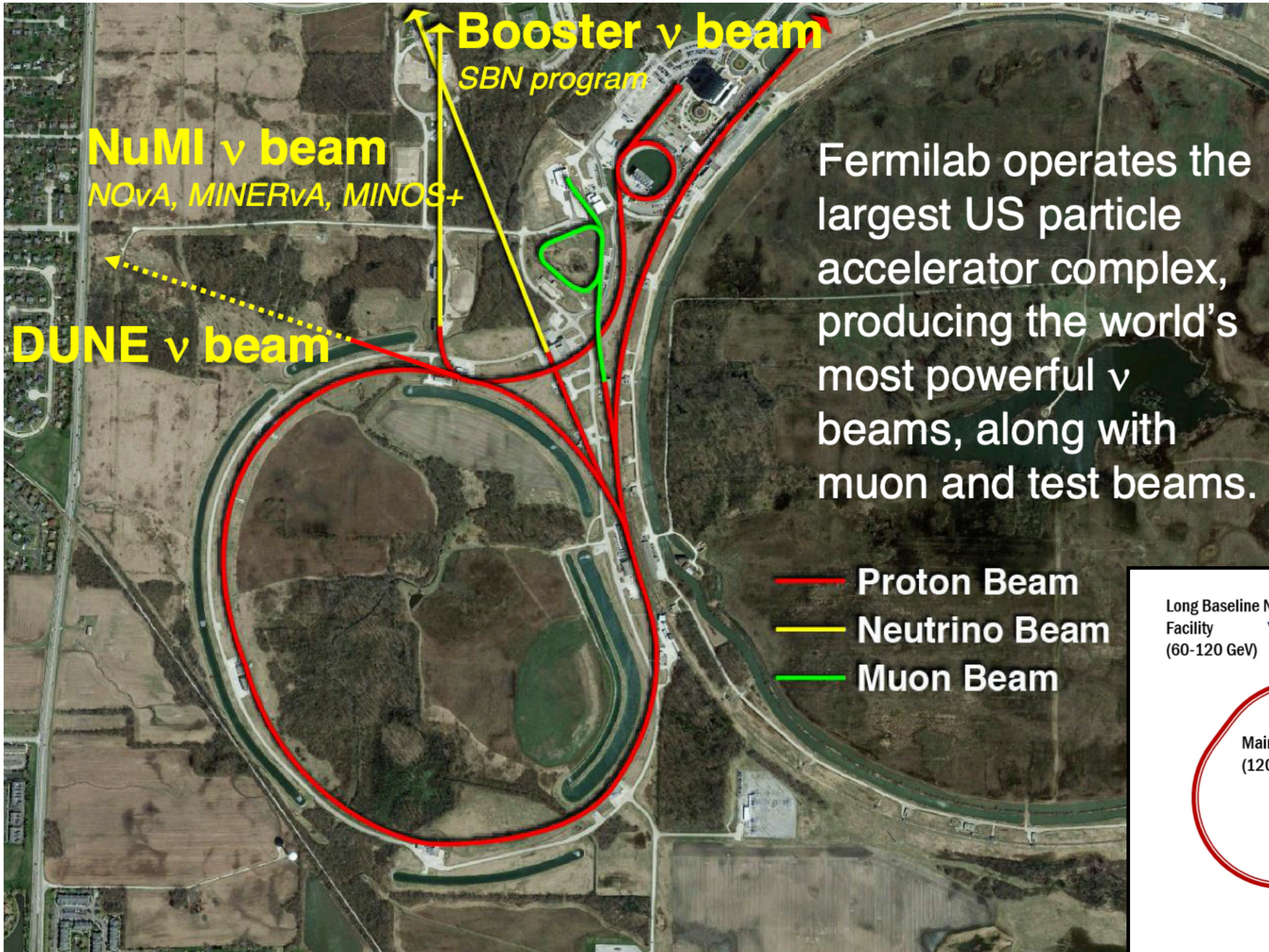
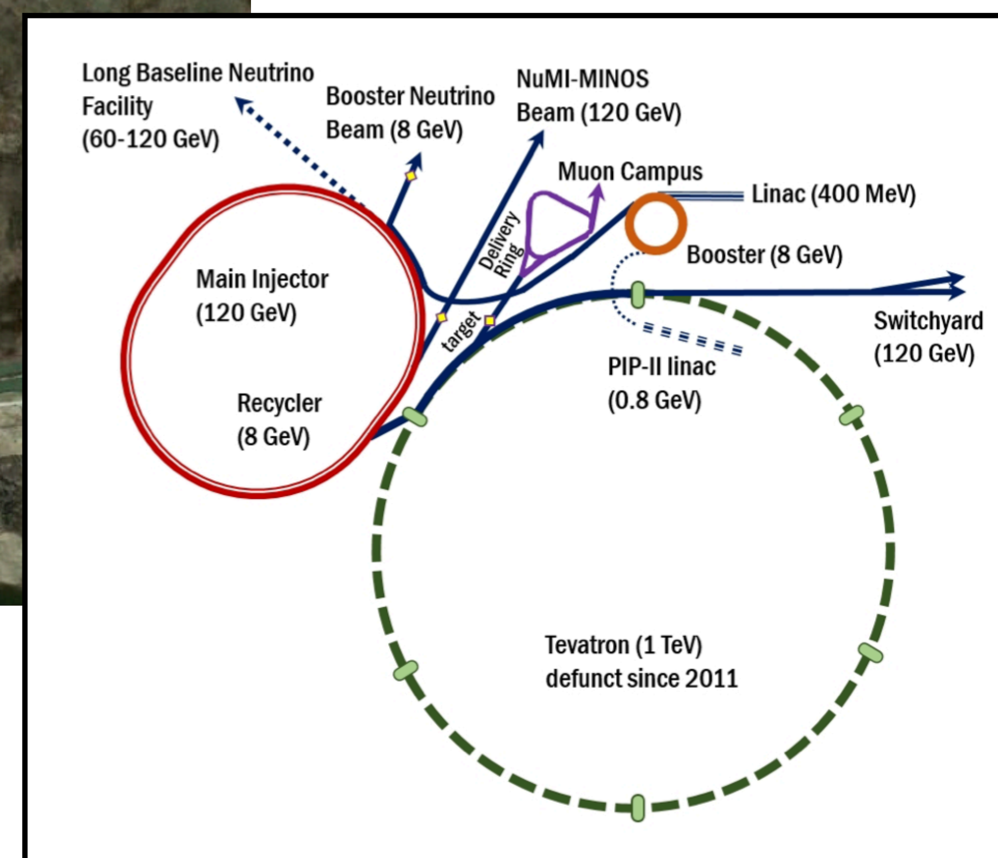
Fermilab Accelerator Division in 10 Minutes

Sudeshna Ganguly
On behalf of the Accelerator Division at Fermilab
New Perspective
17 August 2021

Fermilab Accelerator Complex





Fermilab Accelerator Division: Mission

Delivering beams for research →

- NOvA neutrino oscillation experiments (NuMI Beamline)
- Short Baseline neutrino experiments (Booster Neutrino Beamline)
- Mu2e, g-2 experiments (Muon Beamline)

Upgrading accelerator complex/beam line/targets to extend scientific reach →

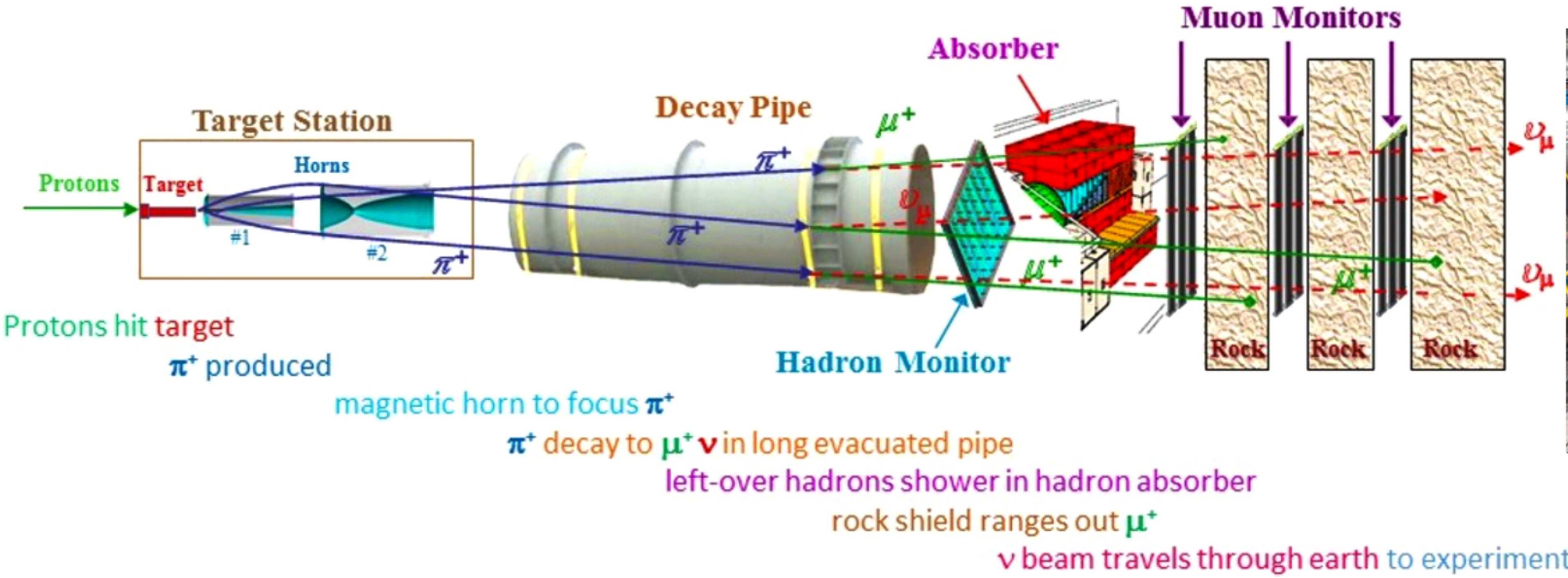
- Proton Improvement Plan-II (PIP-II)

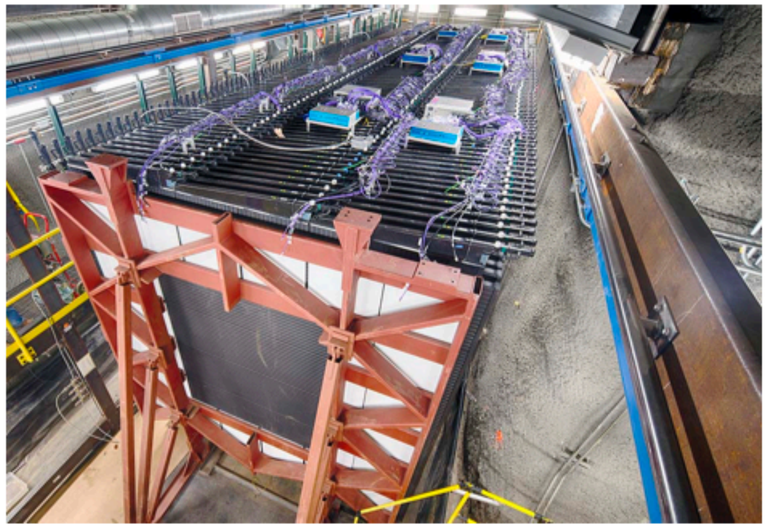
Conducting accelerator physics research →

- Optical stochastic cooling at FAST-IOTA
- Research on High Power Target systems
- Robotics for remote handling
- Application of machine learning

Delivering Beams for Research

NuMI Megawatt Upgrade project : maximum beam power to target 1 MW



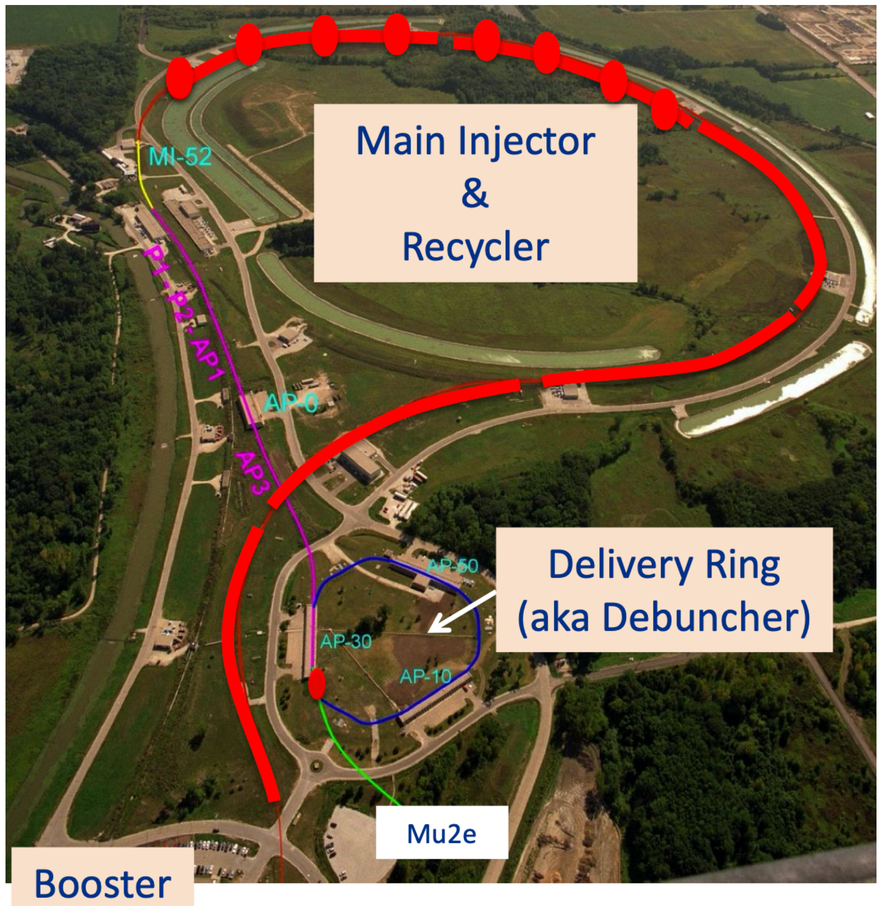

NOvA Experiment

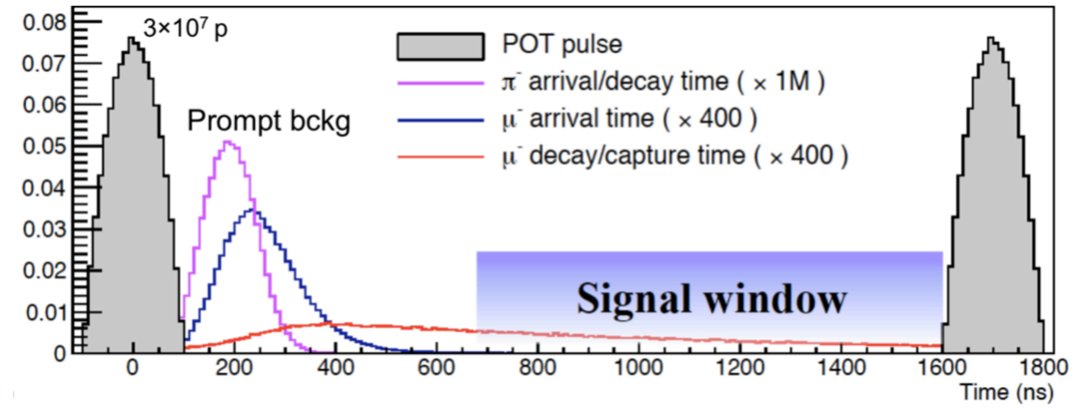
Summer Shutdown Work	
2019	1. Installation of 1 MW target 2. Upgrade of radioactive water system of target & horn 1 3. Upgrade of target, horn cooling system 4. Installation of target chase supplemental shielding
2020	1. Installation of upgraded 1MW horn 1 2. Replacement of the transverse motion driver of horn 3. Upgraded HVAC system for horn cooling 4. Hadron monitor & absorber R & D
2021	1. Installation of radiation hardened hadron monitor 2. Installation of a new gas system for hadron/muon monitors 3. Installation of temperature sensor on downstream target beam window

- **Set a record!** Main Injector delivered **843 kilowatts of proton beam** on NuMI target system on June 15th!
- Beam power will gradually increase to **1 megawatts** as several upgrades and studies are performed
  - » Critical requirement is tuning beam spot size on target
  - » beam optics will be investigated when beam is available

Delivering Beams for Research

Mu2e: search for muons that spontaneously convert to electrons in field of a nucleus ($\mu N \rightarrow eN$)





This beam structure can be realized with delivery ring manipulation for slow (resonant) extraction

- 3rd Order Resonance Extraction
- Quadrupoles drive a 1/3 integer resonance in horizontal tune
- Sextupoles induce a controlled beam instability
- Septum peels off a micro bunch on each turn
- To control spill rate uniformity during resonant extraction, RF knockout technique used

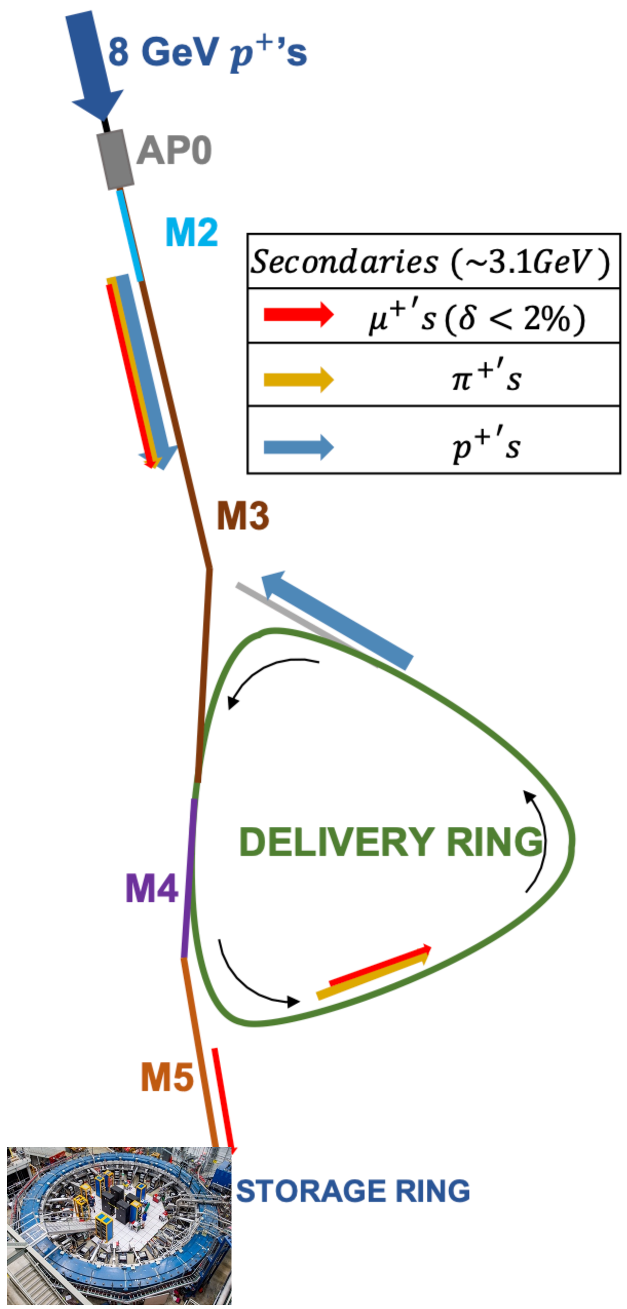
Mu2e production target

Courtesy Dave Pushka

Unique target has been built
- » **Testing of target at AP0, with Mu2e like beam underway**

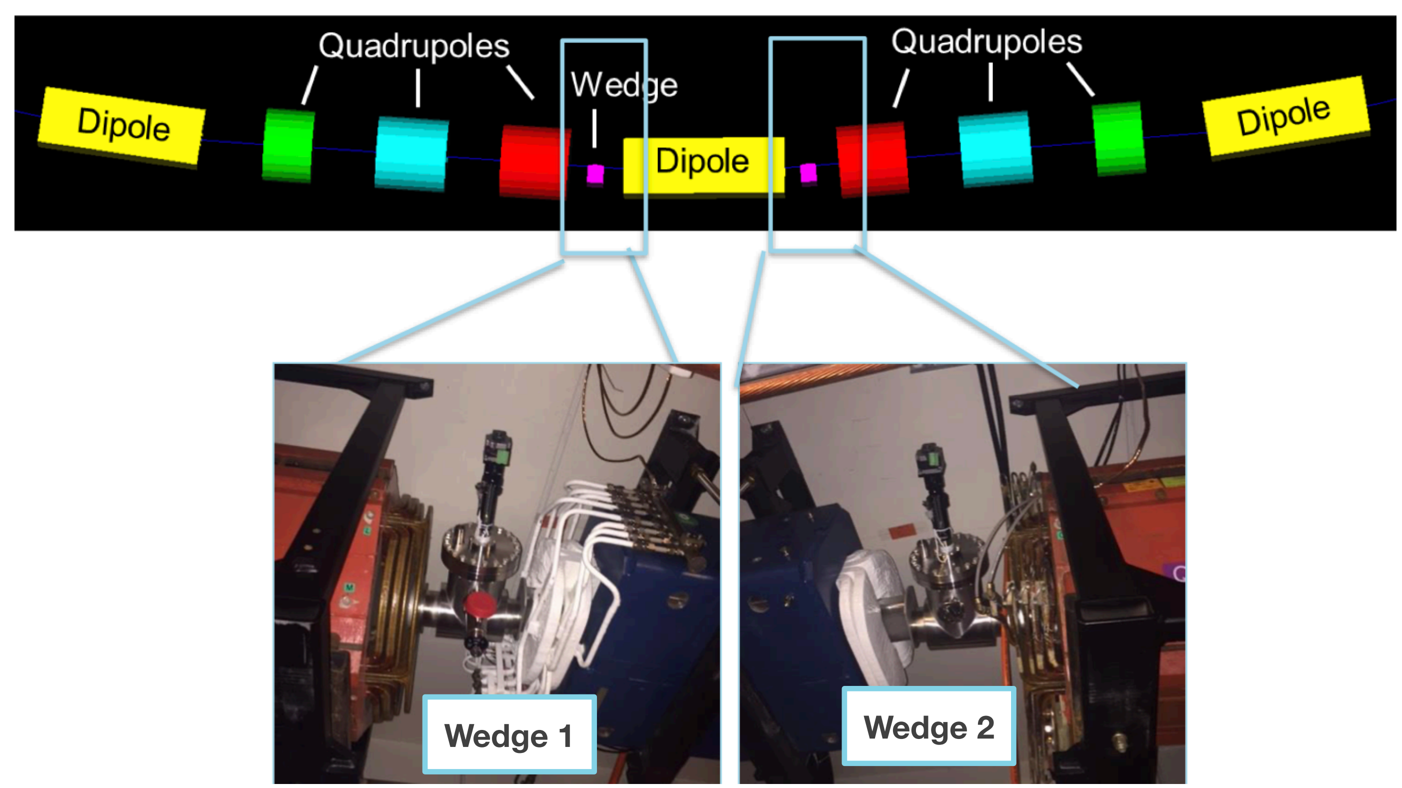
Delivering Beams for Research
Muon g-2

Determined a_μ to an unprecedented 460 ppb precision!



Schematic layout of the beam delivery system to Muon g-2

- **Goal of the Accelerator Division is to provide as many muons within magic momentum (~3.1 GeV/c) band**
- Proposal is to reduce the momentum spread in M4/M5
  - » Supported by Fermilab's LDRD program: to design, install and test a wedge in Fermilab's muon campus, system installed and commissioned
    - » **Primary test showed up to a 7% improvement on stored muons**
- Continued work on improving M2/M3 and delivery ring optics to optimize improvement rate of stored muons



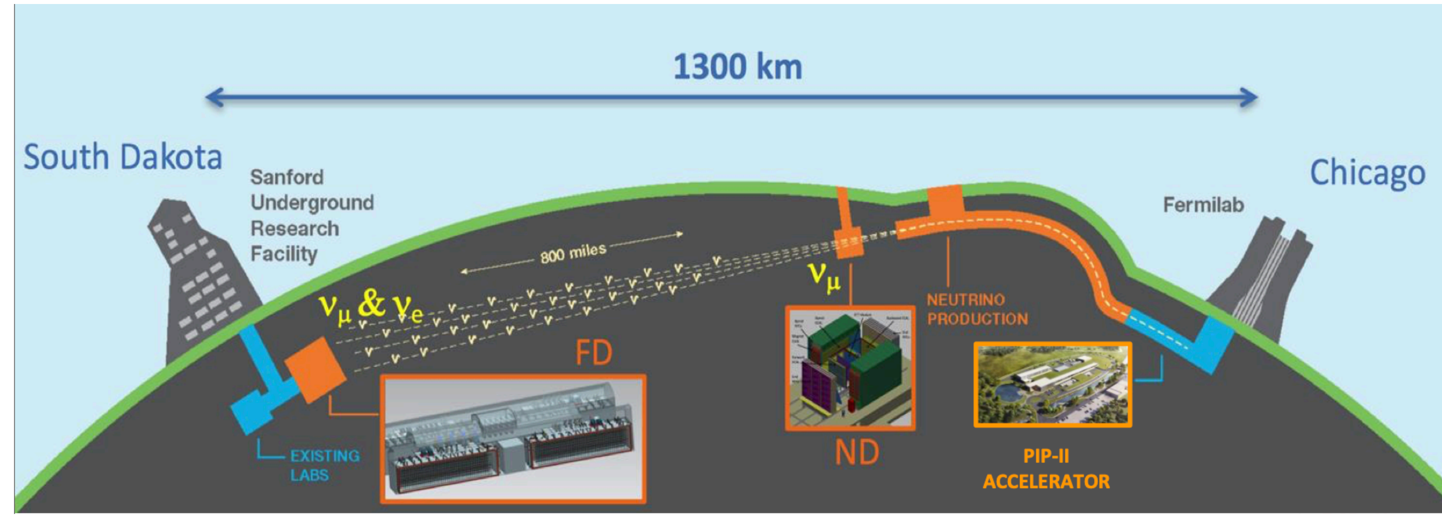
Courtesy Diktys Stratakis

Upgrading Accelerator Complex
PIP-II/LBNF

- **Powerful proton beams (PIP-II) will enable world's most intense neutrino beam to LBNF/ DUNE, and a broad physics research program**

PIP-II high level performance requirements:

- **Beam Power**
  - Meeting the needs for the start of DUNE (1.2 MW proton beam)
  - Upgradeable to multi-MW capability (2.4 MW in phase 2)
- **Flexibility**
  - Compatible with CW-operations which greatly increases the linac output
  - Customized beams for specific science needs
  - High-power beam to multiple users simultaneously
- **Reliability**
  - Fully modernizing the front-end of the Fermilab accelerator complex



Path to 1.2 MW on LBNF Target

- Increase no. of protons per extracted Booster pulse from $4.3\text{x}10^{12}$ to $6.3\text{x}10^{12}$
- Reduce Main Injector cycle from 1.33 s to 1.2 s
- Increase Booster rep. rate from 15 Hz to 20 Hz

  ➡Enable LBNF operations down in energy range 60-120 GeV

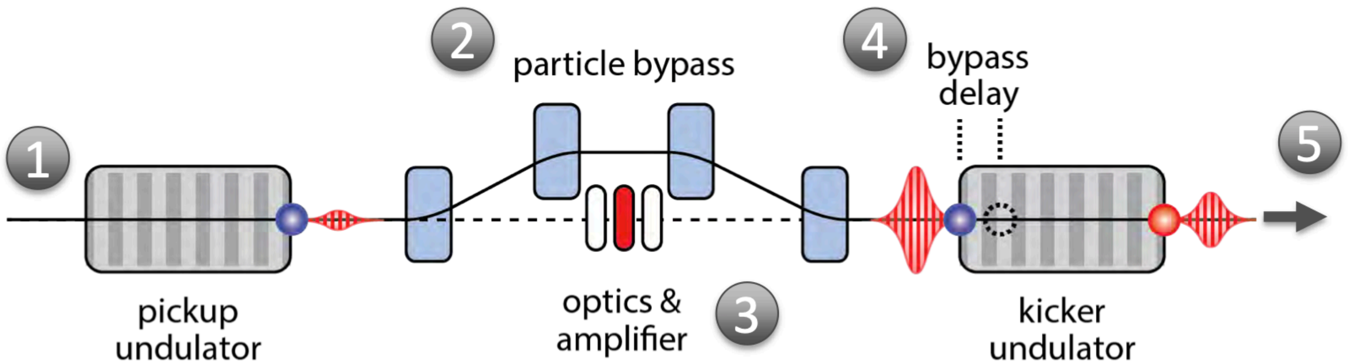
  ➡Support multiuser operations
- New 800 MeV superconducting linac as Booster injector
- Upgrades to Booster, Recycler Ring (RR), and Main Injector (MI)

Courtesy Eduard Pozdeyev

Accelerator Physics Research

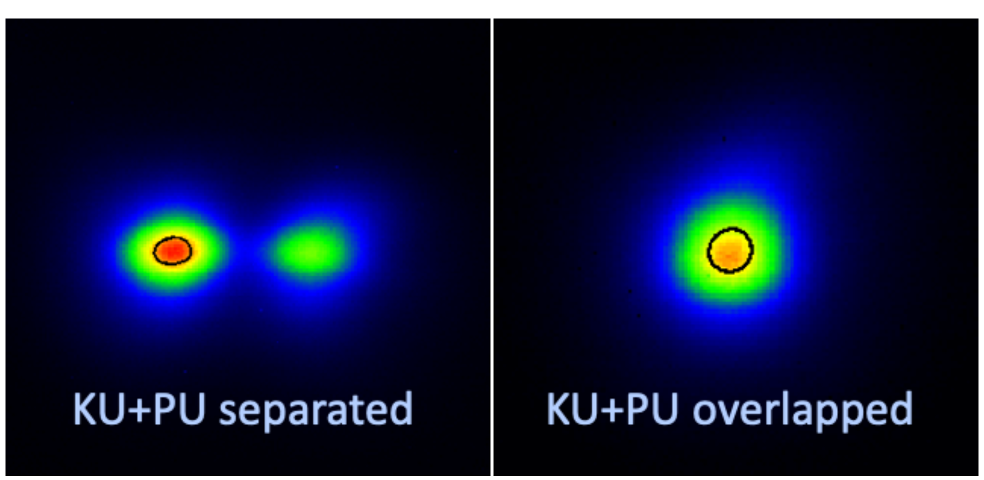
Stochastic Beam Cooling

- **Stochastic Cooling**: measurement and correction of incoherent particle motions via random-sampling process, a powerful technique but limited to GHz BW (highest frequency utilized to date is **8 GHz**)
  - » Stochastic cooling used for antiprotons in accumulator and recycler rings during Tevatron era
- **Optical Stochastic cooling** extends **SC** principle to optical bandwidth

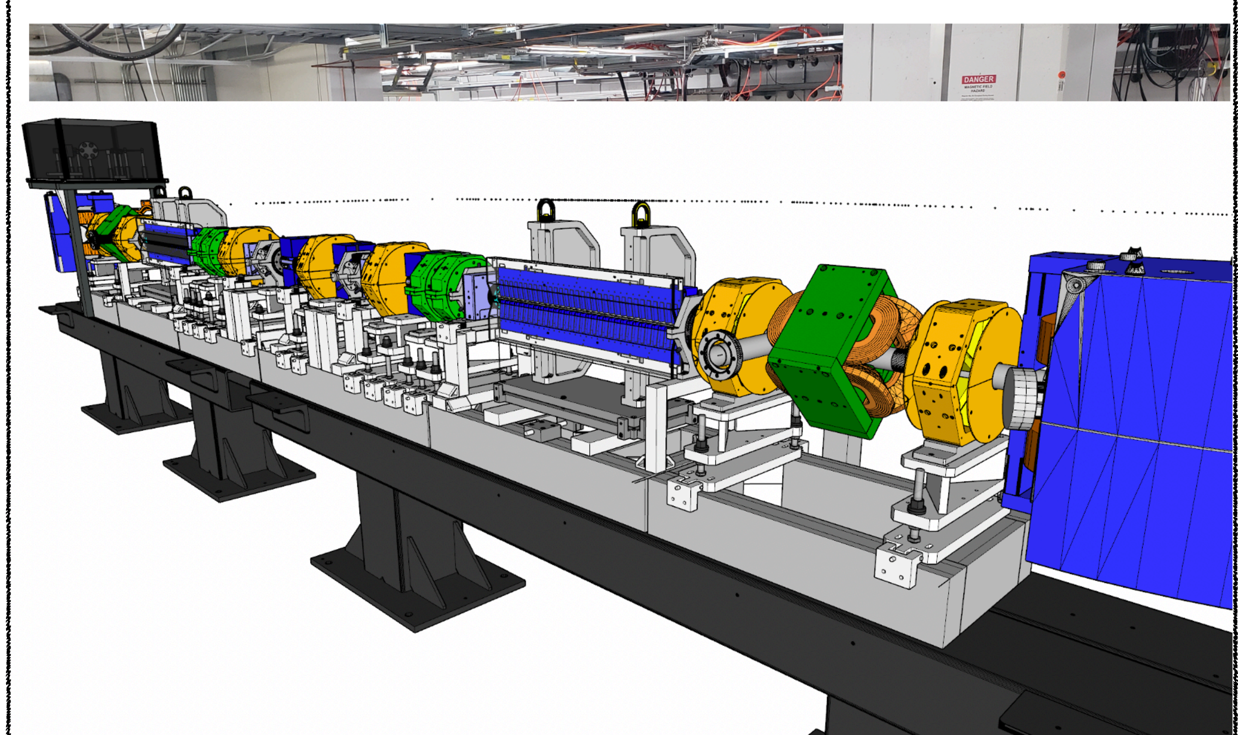


10^3 – 10^4 increase in cooling rate with OSC over SC (~10s of THz BW vs few GHz)

- **Stability required for OSC was demonstrated in April, 2021**
- **OSC energy exchange has character of interference, observed on 04/20/21**



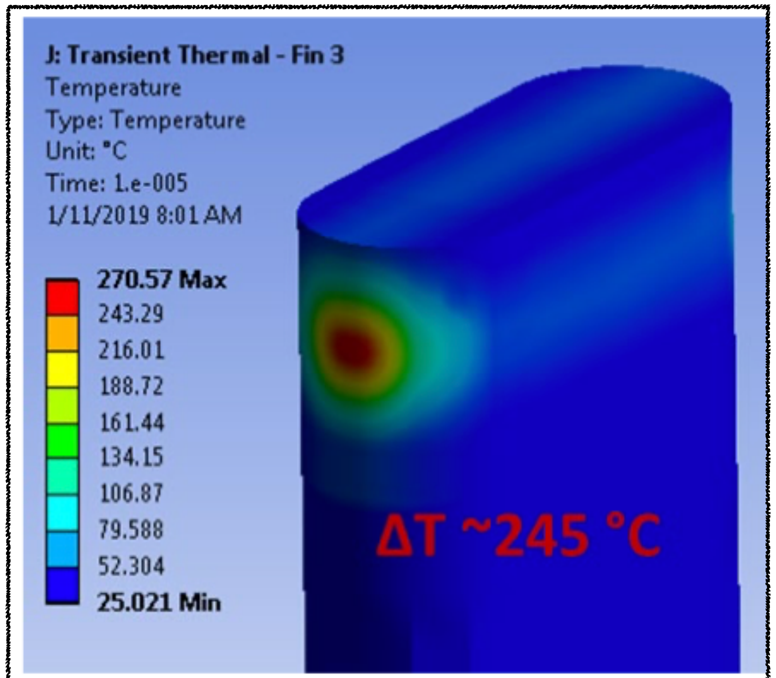
OSC apparatus successfully integrated in IOTA



Courtesy Jonathan Jarvis

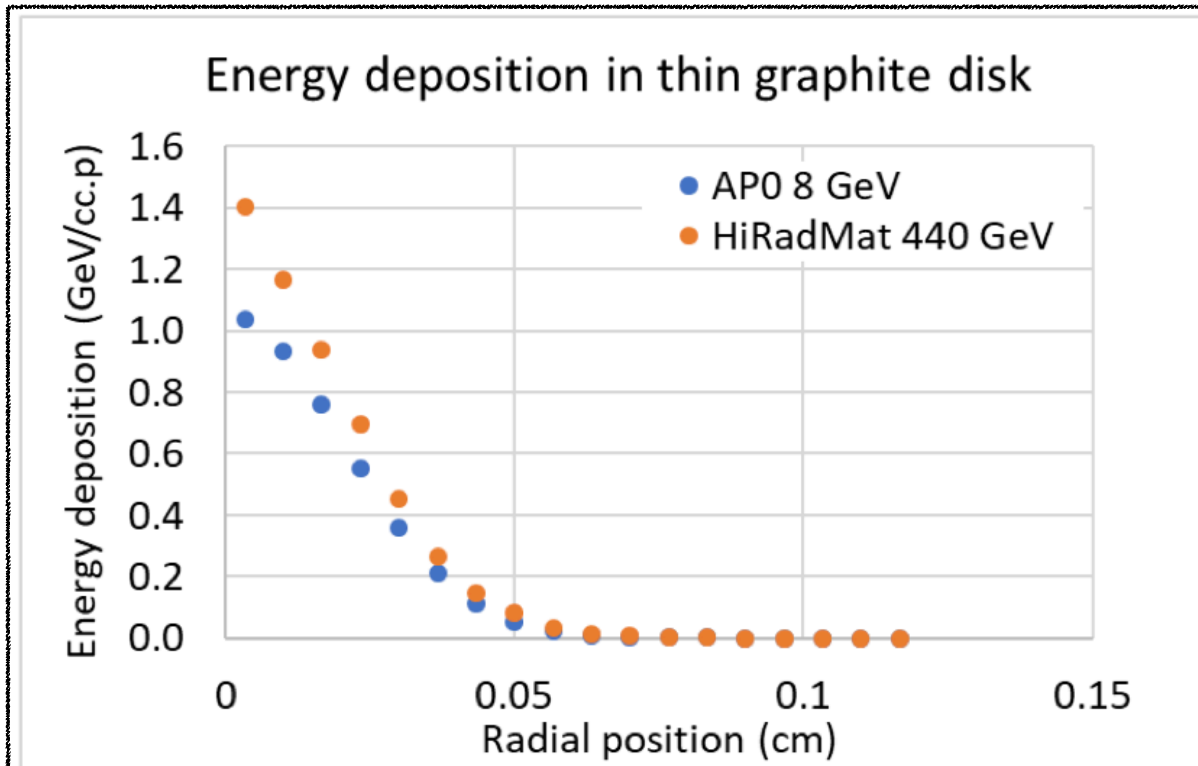
Accelerator Physics Research
High Power Targetry

- High-Power Target System is a key element to complete future High Energy Physics (HEP) experiments
- Current target technology tolerates ~ 1MW but future projects aim to deliver up to 2-5 MW
- Thermal Shock and Radiation Damage most cross-cutting challenges facing high power target facilities and can lead to premature failure of the components



K. Ammigan, ΔT from 10 µs beam pulse, 1 MW graphite target fin

Rapid thermal expansion of material surrounded by cooler material creates a sudden localized area of high compressive stress



K. Ammigan, MARS simulation

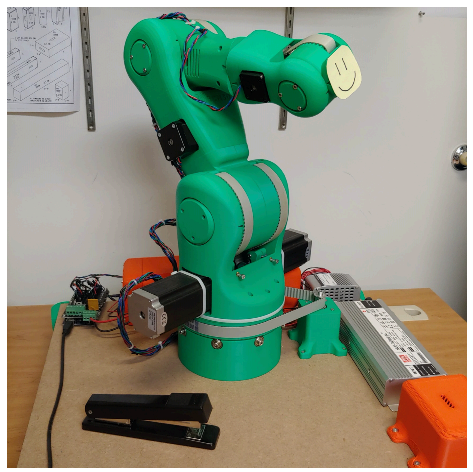
- **Thermal Shock Study at HiRadMat Facility at CERN in 2015 & 2018**
- **Currently exploring ideas to perform test at FNAL**

Courtesy Frederique Pellemoine

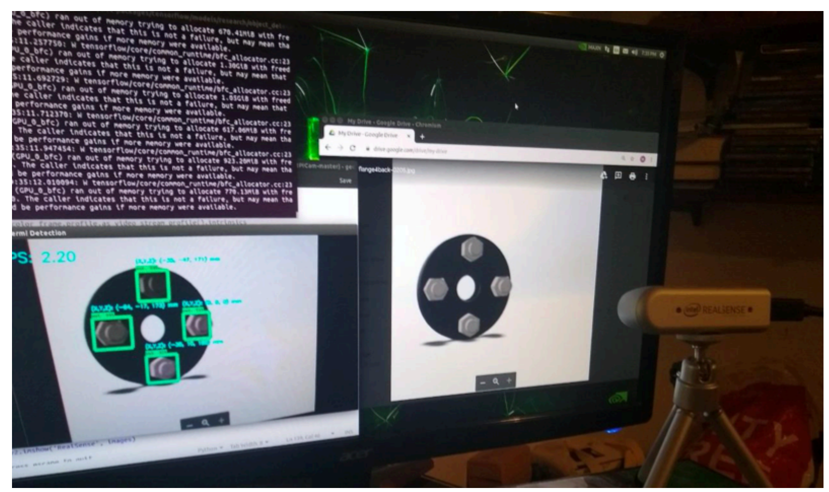
Accelerator Physics Research
Robotics in Remote Handling

AD scientists and engineers are working hard to introduce robotics in remote handling to minimize radiation exposure

AD has committed to placing a req for a Boston Dynamics SPOT robot!
Initial uses: Camera rover with ability to climb stairs (search + secure)



- RVR (Remote Viewing Robot)
- 360 and regular cameras, both with real-time image and video streaming to an iPad or phone
- Future Upgrades: Adding radiation detectors
- Sensors to automate the robot Robotic arms
- 5-Axis Robotic Arm
- Designed to mount onto RVR for remote-control camera positioning



Work underway on unique and cheap robot for accelerator facility: combine computer vision and ML to identify and locate objects by UIC senior students robotics project

Work underway on Mu2e target remote handling

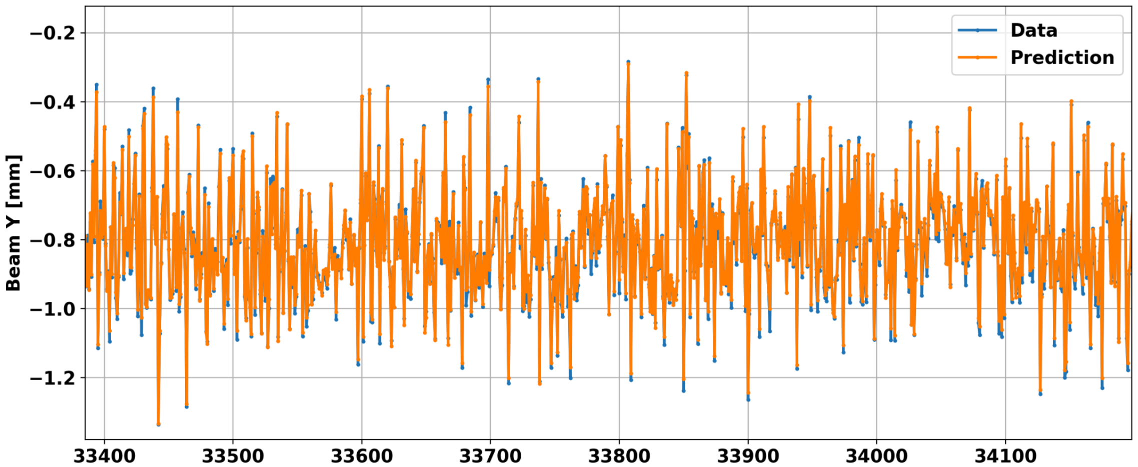
Courtesy Mike Campbell, Yun He, George Lolov, Katsuya Yonehara, Kris Anderson,Noah Curfman

Accelerator Physics Research
Application of Machine Learning

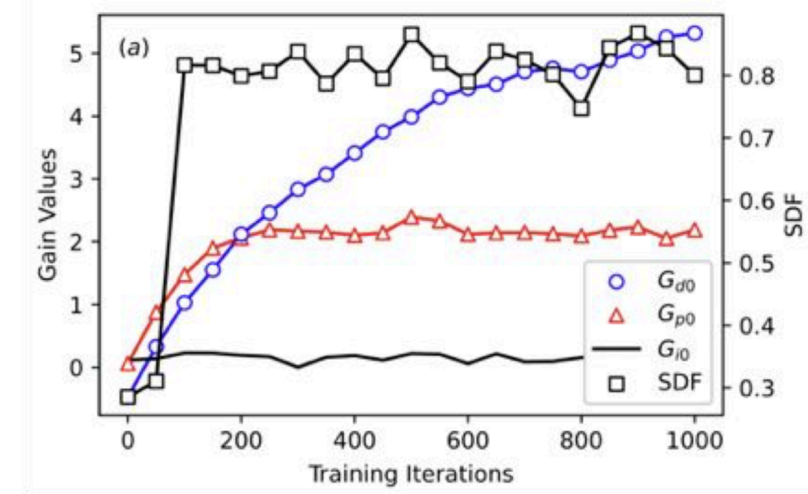
Implementation of AI to improve the accelerator system performance:

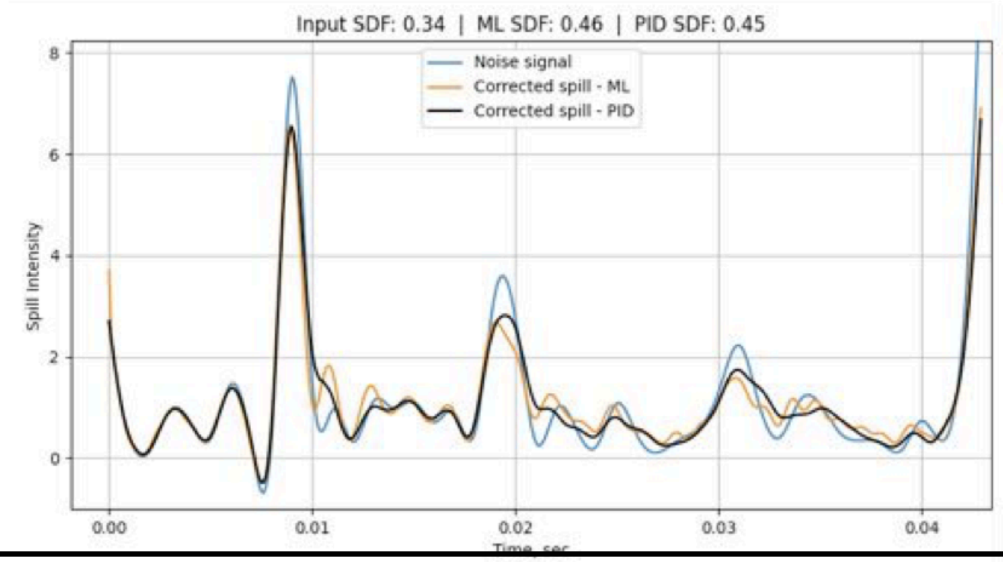
- Identifying / predicting incidents
- Detecting anomalies
- Tuning beam parameters
- Optimizing beam quality
- Predicting beam parameters for QA

Example of predicting beam position: NuMI proton beam on target



Courtesy Athula Wickremasinghe





Comparing different ML regulation schemes: Optimized PID regulator vs ML regulator

READS (Real-Time Edge AI for Distributed Systems):

- Improve real-time spill regulation with reinforcement learning algorithms for guided operations optimization
  - » Increases Spill Duty Factor of slow spill extraction

Courtesy A. Narayanan & M. Thieme, Published work progress at IPAC’21, paper THPAB243

Thank you from Accelerator Division!