



Fermilab Update

P. Varghese

10 October 2022

Low Level RF Workshop 2022

9-13 Oct 2022, Brugg-Windisch, Switzerland

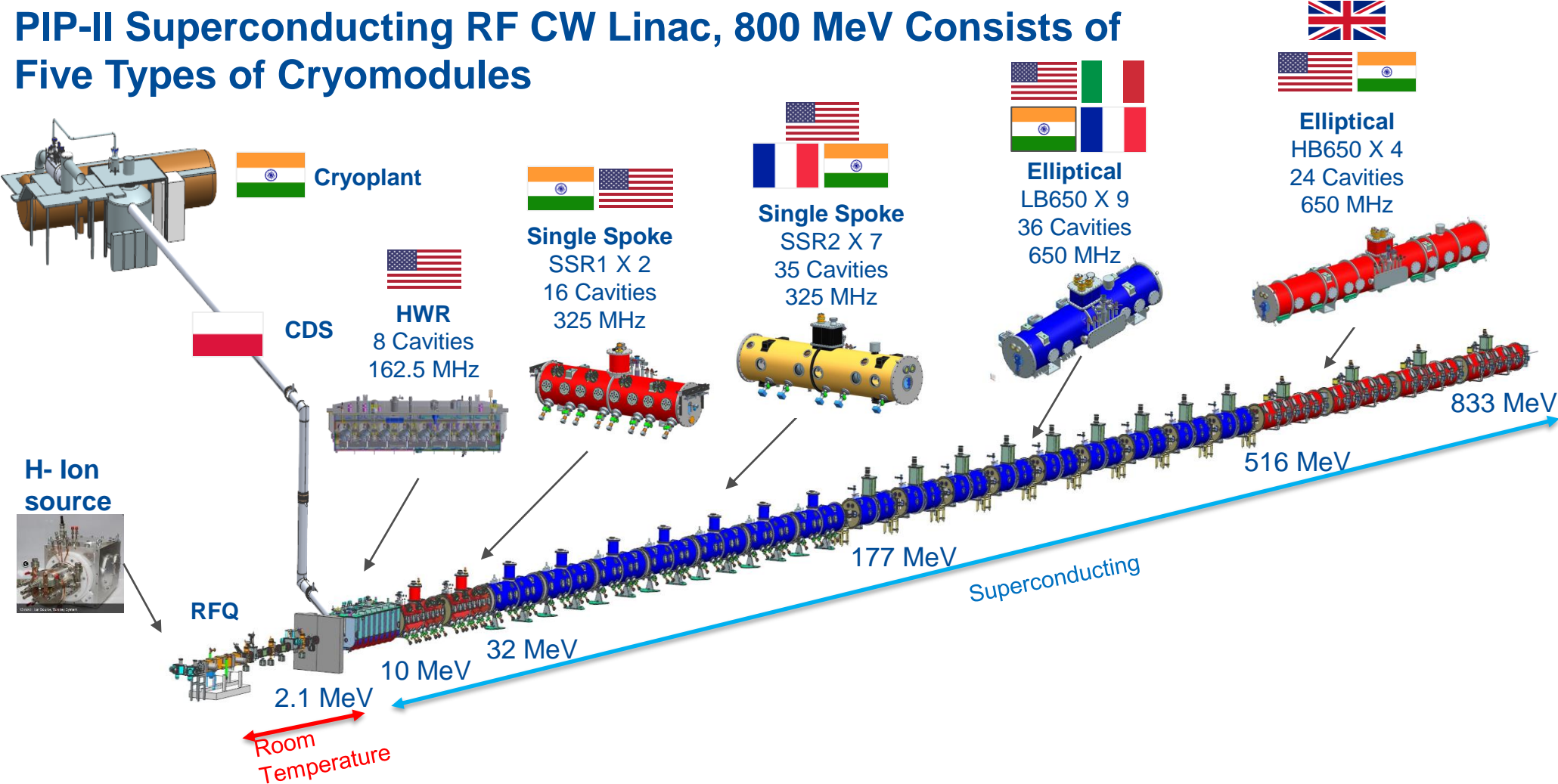


Outline

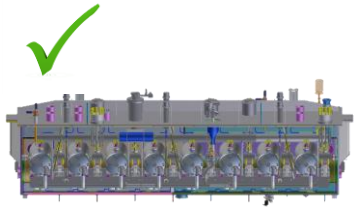
1. PIP-II Linac Progress
2. LLRF Systems for PIP-II
3. Accelerator Upgrades to Main Injector and Booster
4. Muon g-2 and Mu2e Experiments
5. LBNF-DUNE



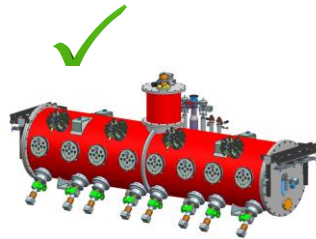
PIP-II Superconducting RF CW Linac, 800 MeV Consists of Five Types of Cryomodules



PIP-II Superconducting Cavities



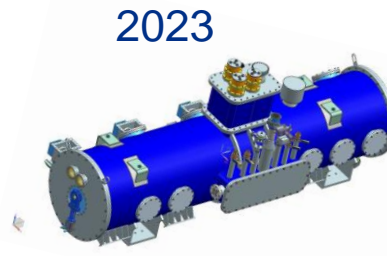
5.9 m



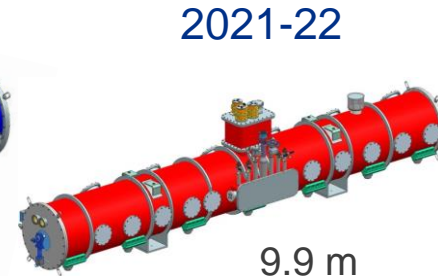
5.3 m



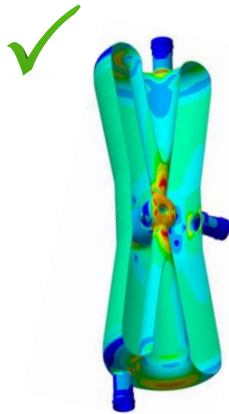
6.5 m



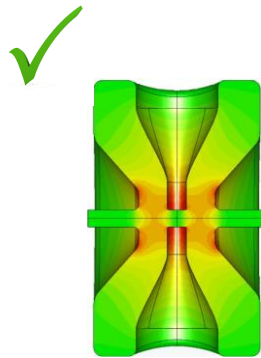
5.5 m



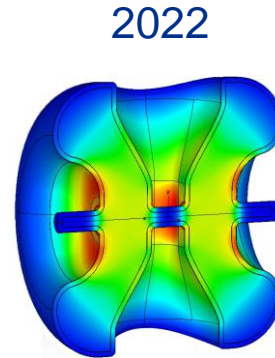
9.9 m



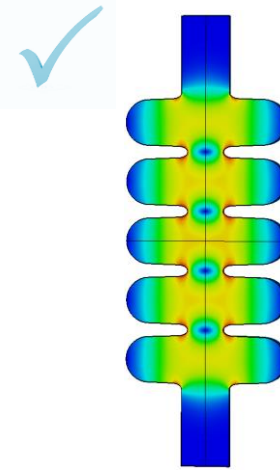
Half Wave Resonator
 $\beta=0.11$ $Q_0=0.85 \times 10^{10}$



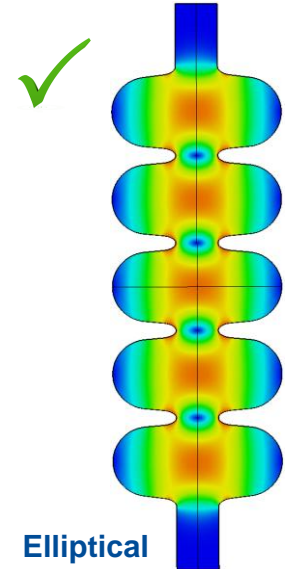
Single Spoke
 SSR1
 $\beta=0.22$ $Q_0=0.82 \times 10^{10}$



2022
Single Spoke
 SSR2
 $\beta=0.47$ $Q_0=0.82 \times 10^{10}$



Elliptical
 LB650
 $\beta=0.61$ $Q_0=2.4 \times 10^{10}$



Elliptical
 HB650
 $\beta=0.92$ $Q_0=3.3 \times 10^{10}$

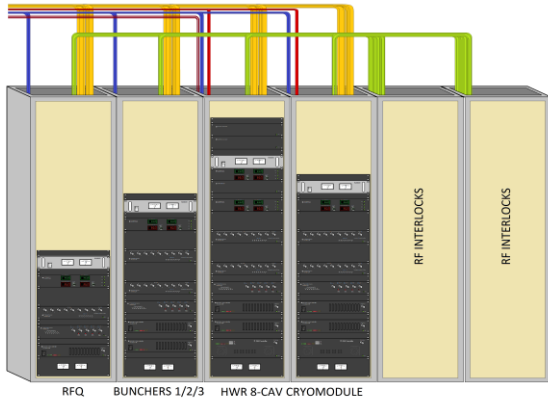
Performance validated
 Testing in progress
 Dates: component built



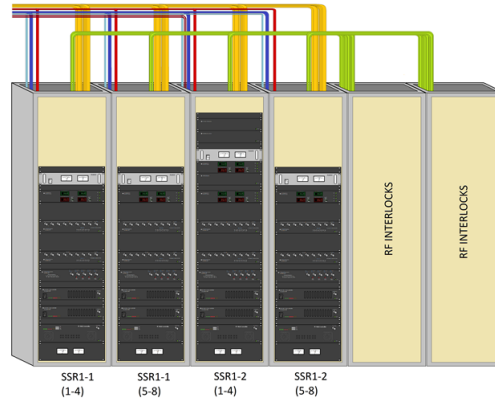
LLRF Station Configurations For PIP-II

PIP-II LLRF 162.5 Rack Station 1
Ed Callahan
4/22/2018

PIP-II LLRF 325 Rack Station 1
Ed Callahan
4/22/2018



S1 – RFQ, B1-4, HWR



S2 – SSR1-1, SSR1-2



S3-S10 – SSR2 (7), LB650 (9), HB650 (4)

- 3/8" Hellax RF Drive
- 3/8" Hellax CAV, FWD, REV, REF
- 3/8" Hellax 1320 MHz CLK/L0
- 1/4" Hellax Interlocks
- Peizo Control
- Stepper Control

	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9	Station 10	Total
	RFQ B1-4 HWR	SSR1-1,2	SSR2-1,2,3	SSR2-3,4,5	SSR2-5,6,7	LB650-1,2,3	LB650-4,5,6	LB650-7,8,9	HB650-1,2	HB650-3,4	
Number of cavities	14	16	12	12	11	12	12	12	12	12	125 119 sc 6 nc
RF Freq (MHz)	162.5	325	325	325	325	650	650	650	650	650	



PIP-II Linac and Beam Line



Project received
DOE CD-3
approval in 2022

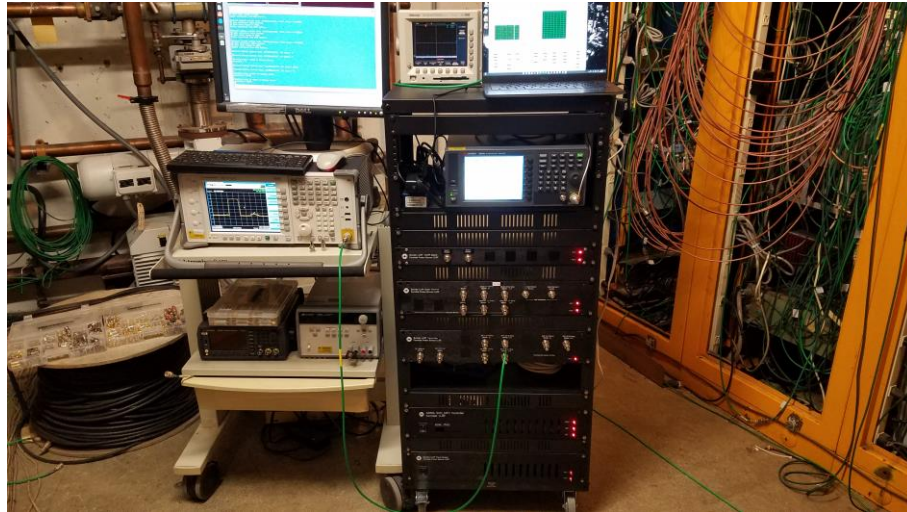
LLRF System
final design
review in 2023

Upgrades for
Booster and Main
Injector for higher
beam power



Booster Upgrades

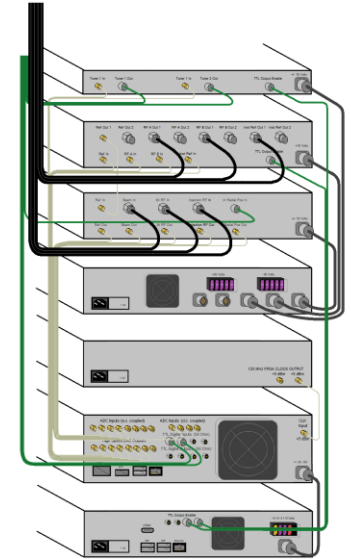
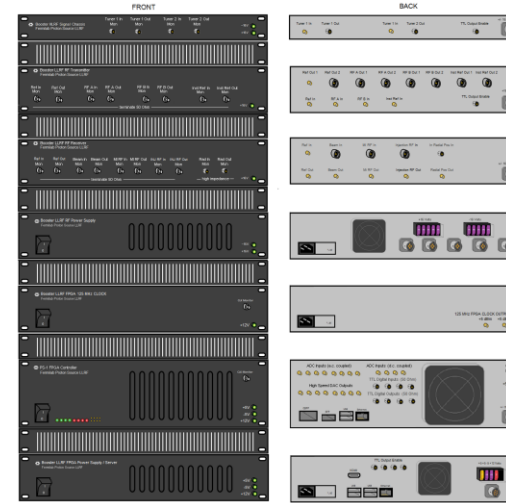
Prototype LLRF System



Captured beam and accelerated through transition to 8 GeV

New LLRF System

Booster LLRF Hardware
Arria 10 v2.0.0
8/8/22



Single SOC FPGA controller for vector control of 19 NC RF cavities



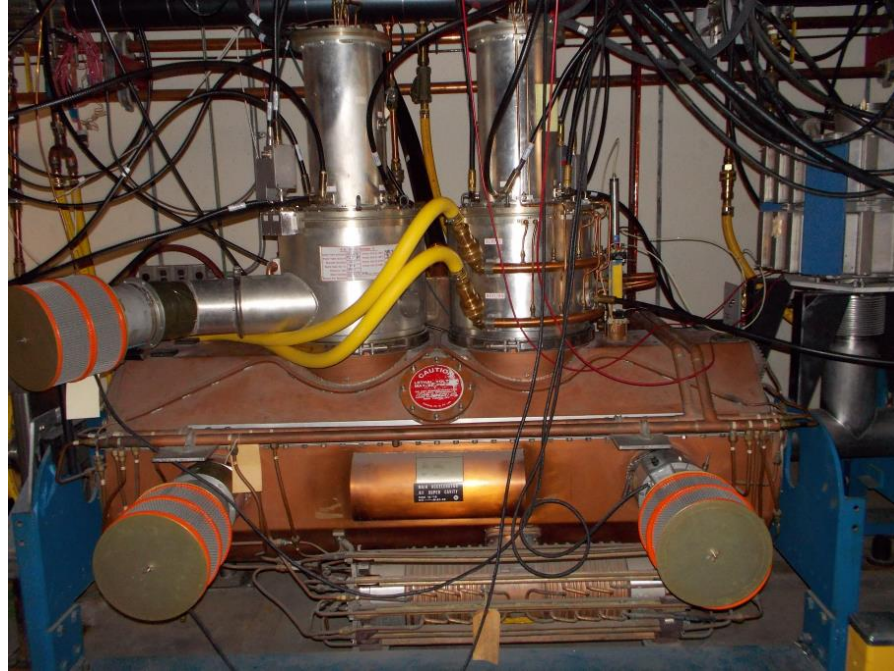
Main Injector Upgrades

Table 9.12: Power calculations of current RF cavities.

	PIP-II	Main Injector - Present Capability
Beam Intensity	7.5×10^{13} protons	6.24×10^{13} protons
Harmonic Number	588	588
Number of Filled Buckets	504	504
Frequency	52.808-53.104 MHz	52.808-53.104 MHz
Acceleration Ramp Slope	240 GeV/s	240 GeV/s
Beam Intensity	7.5×10^{13} protons	6.24×10^{13} protons
Main Injector Ramp Rate	1.2 s	1.2 s
Beam Power at 120 GeV	1.2 MW	998.8 kW
Beam Accelerating Power	2.88 MW	2.40 MW
Number of Accelerating Cavities	20	20
Cavity R/Q	104	104
Maximum Cavity Accelerating Voltage	235 kV/cavity	235 kV/cavity
Operating Peak Voltage	210 kV/cavity	210 kV/cavity
Accelerating Voltage Required: $V \sin \phi_2$	2.66 MV	2.66 MV
Total Accelerating Voltage Available	4.7 MV	4.7 MV
Total Operating Voltage	4.2 MV	4.2 MV
Cavity Power Loss	45.11 kW/cavity	45.11 kW/cavity
Total Apparent Power	240.5 kW/cavity	204.2 kW/cavity
Robinson Stability Factor	4	4

Individual Main Injector cavity needs to be able to supply 240 kW of power.

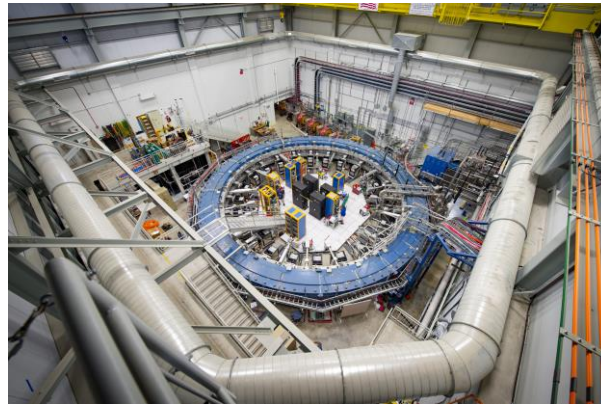
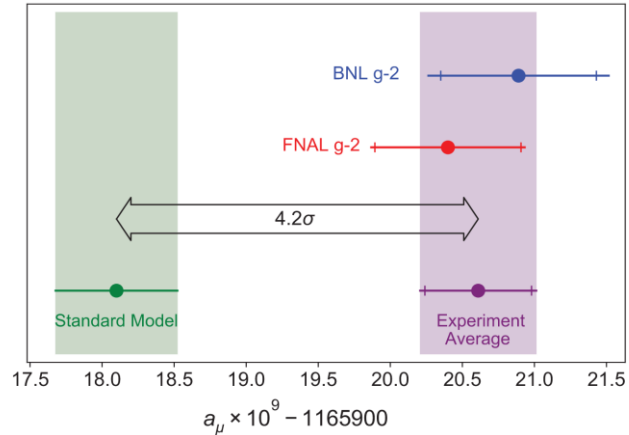
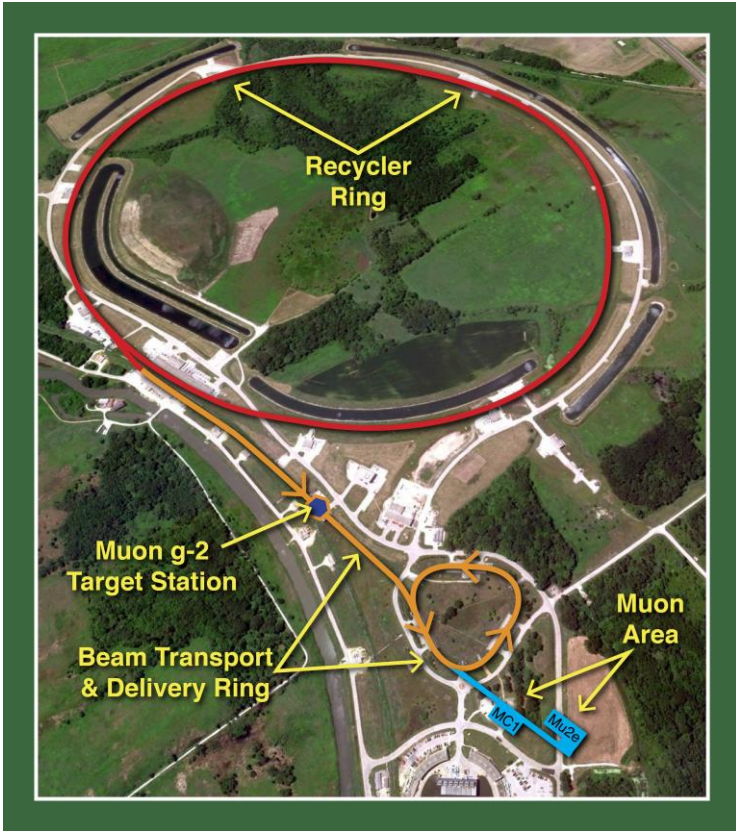
Main Injector Dual PA Upgrade



Station 5 of the Main Injector was upgraded to a Dual PA cavity and has operated in this mode for the last two years with beam intensities up to $5.4E13$. It can supply 400 kW of power. The two PAs operate in a push-pull mode and easily surpasses the 240 kW needed for PIP-II operations.



Muon g-2 Experiment



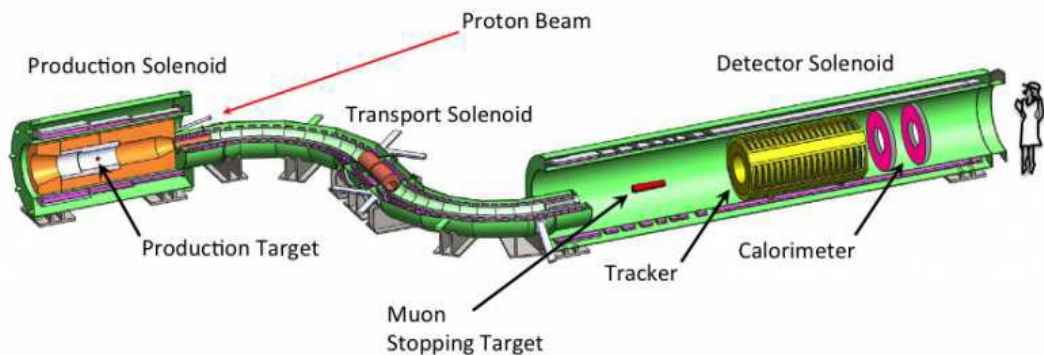
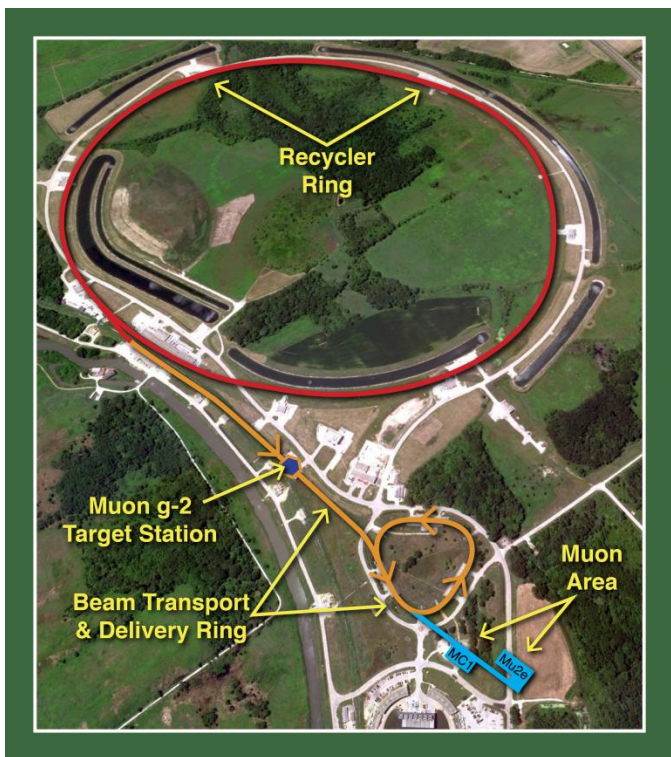
Run-1 FNAL measurement compared with the previous BNL experiment

Run-1-5 focused on measurement of a_μ for the positive muon

Run-6 Data taking starting this month
 New measurement of a_μ for the negative muon in Run-6

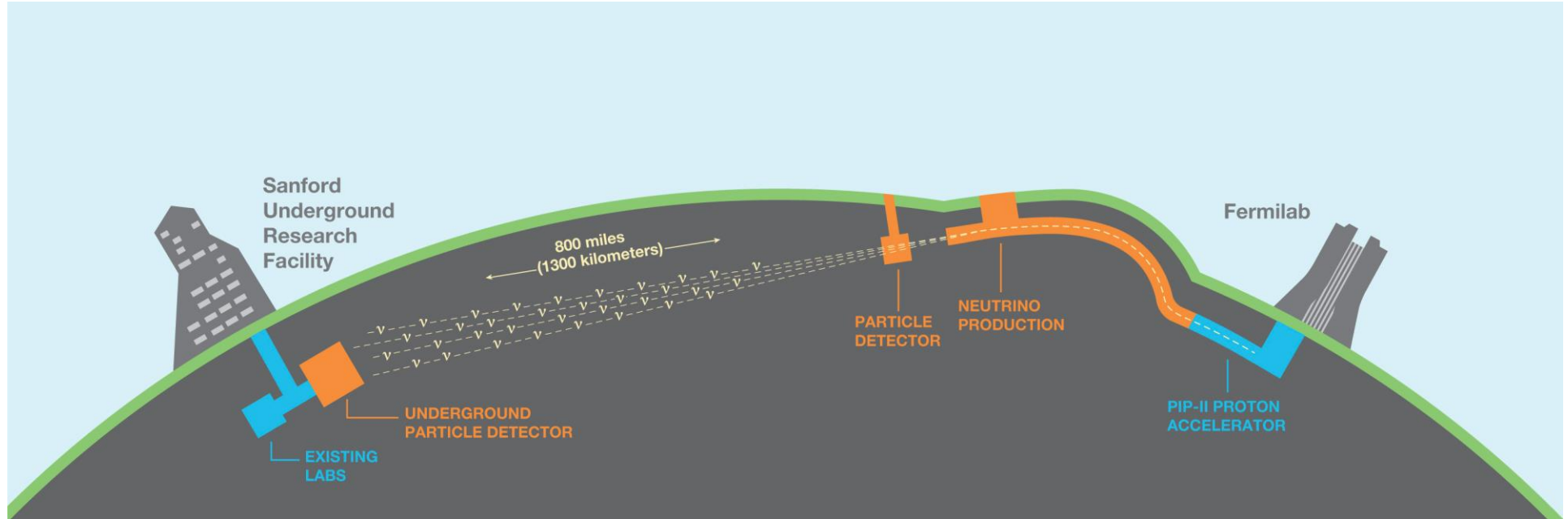


Mu2e Experiment



Mu2e construction is under way. A first run in 2025-2026 is expected. A second run will follow PIP-II installation, starting in 2029.

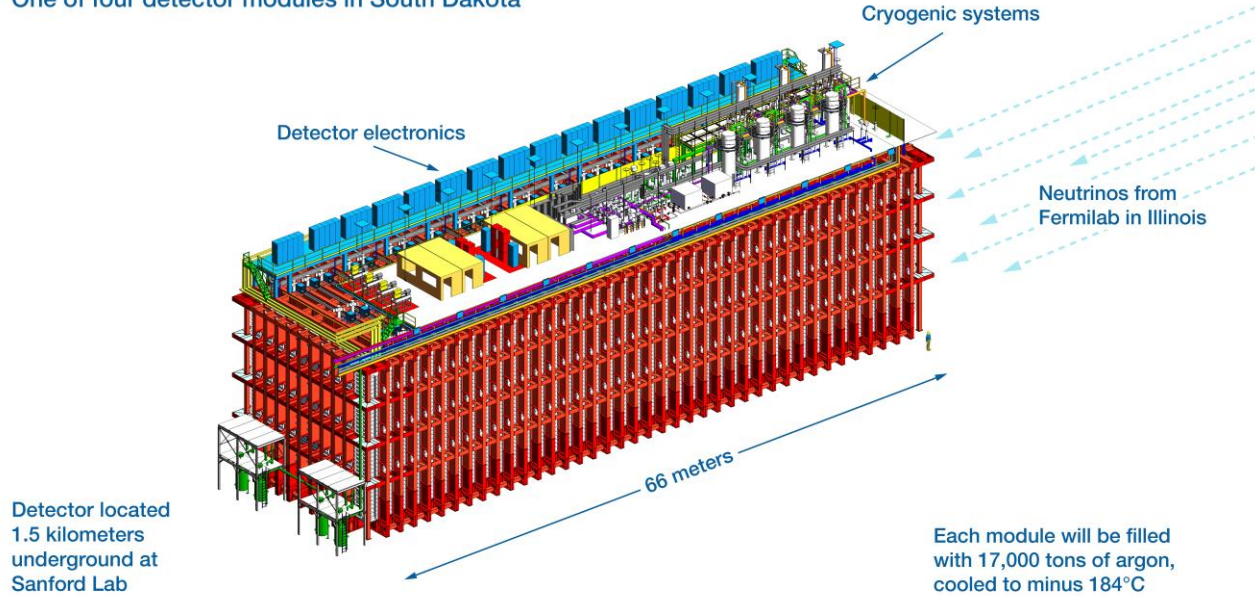
LBNF - DUNE



- The 1.2 MW proton beam on a graphite target produce other particles with electric charge that are focused into a tight beam by a series of magnets called horns
- The DUNE near detector is 60 meters (200 feet) underground at the Fermilab site

LBNF - DUNE

Deep Underground Neutrino Experiment One of four detector modules in South Dakota



- DUNE will compare the rates of neutrino and antineutrino oscillations
- ProtoDUNE detectors were constructed and used to test potential DUNE technologies at CERN

Conclusion

- Three major projects in full construction mode over the next decade
- Several upgrade projects to replace aging subsystems including LLRF
- Current projects total 5.6 B \$ in approved funding

Thank You !