Fermilab

Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

Neutrino Beam Plans in the U.S.

Jim Strait, LBNE Project Director

International Meeting for Large Neutrino Infrastructures

22 June 2014

Outline

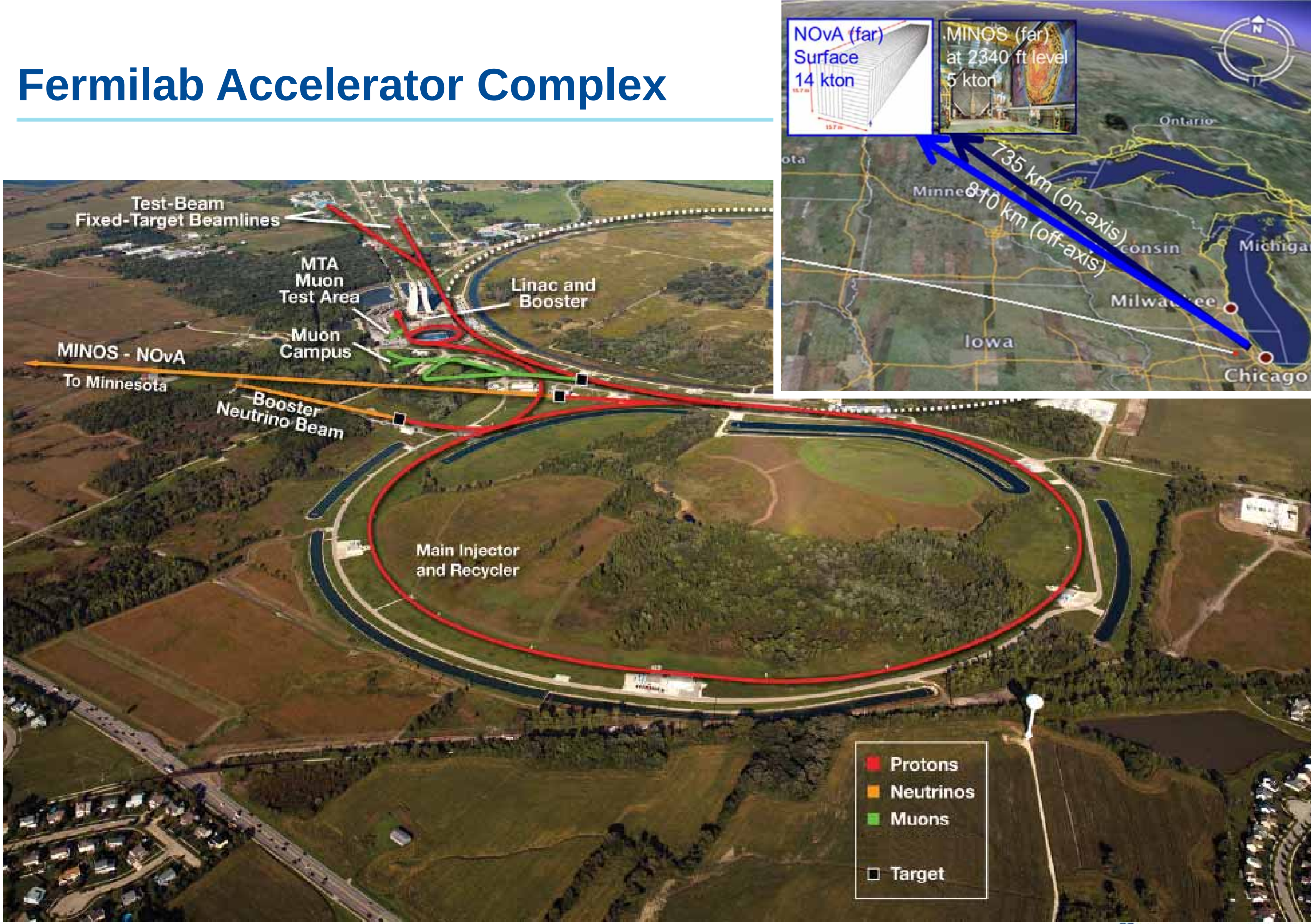
- Survey of existing Fermilab neutrino program
  - Neutrino Beams
  - Running and planned experiments
- Increasing proton beam intensities
  - PIP and PIP-II
- New beam for the new long-baseline neutrino facility

Accelerator-Based Neutrino Program in the U.S.

Fermilab hosts an active and diverse accelerator-based neutrino program.

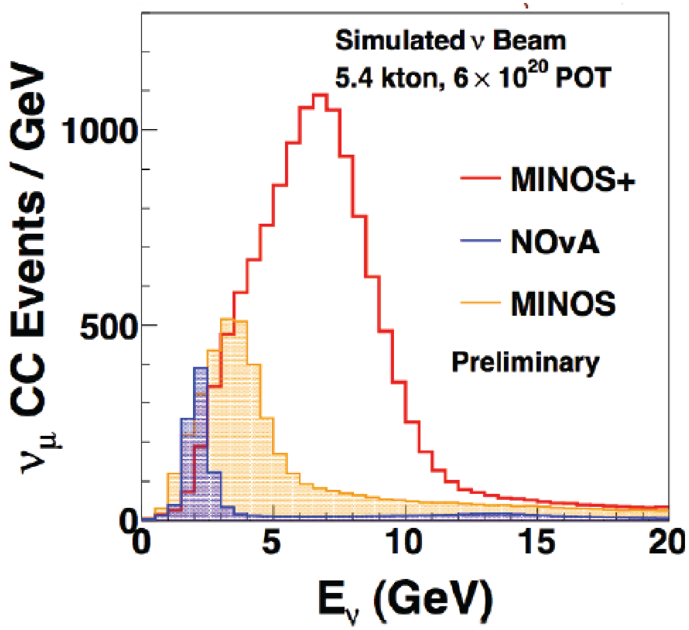
- Two neutrino beams in operation and a third under design
- Four experiments currently taking data
- Three completed experiments analyzing data
- One experiment under construction
- One experiment under design
- Two proposals reviewed by the PAC and under consideration by Fermilab management
- Several experimental proposals submitted or in development.
- Supporting test beam program for detector development and calibration.

Fermilab Accelerator Complex



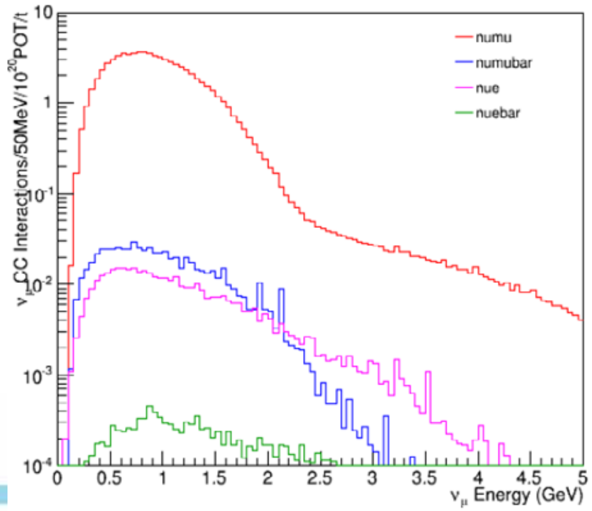
NuMI and Booster Beams

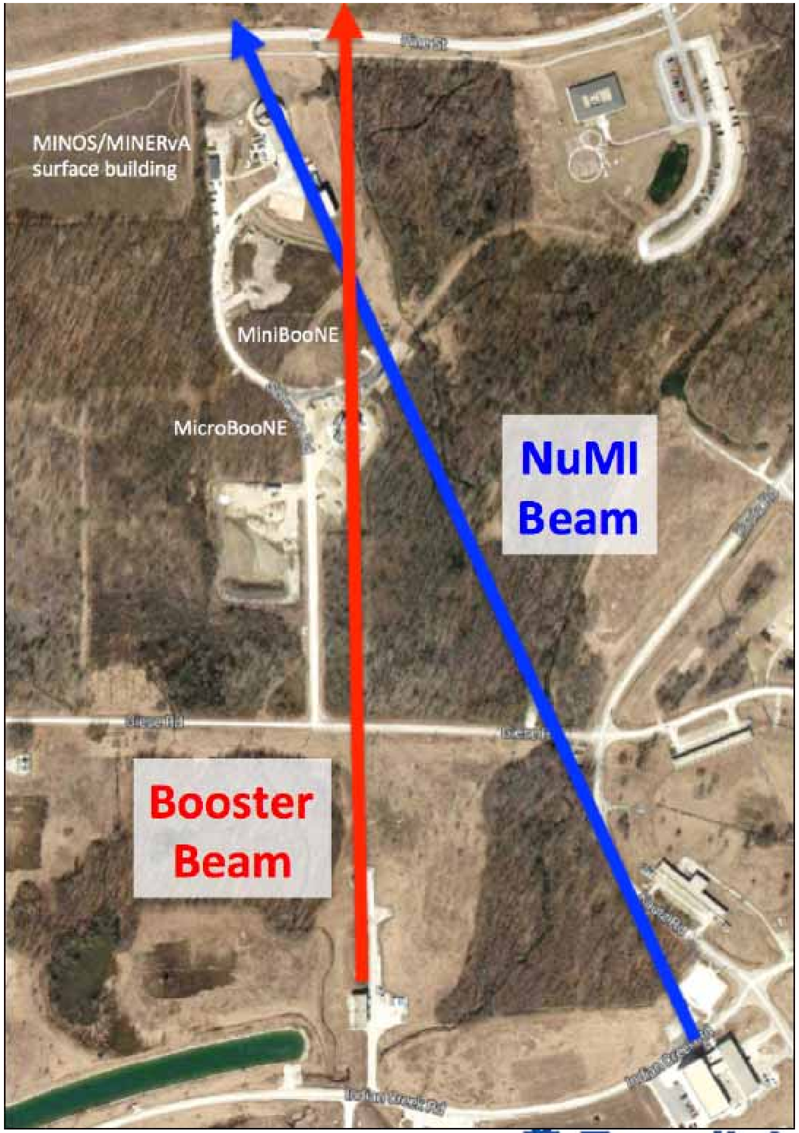
NuMI:
- tunable 1 GeV to >10 GeV
- Near hall at 1 km
- Far detectors 735 – 810 km



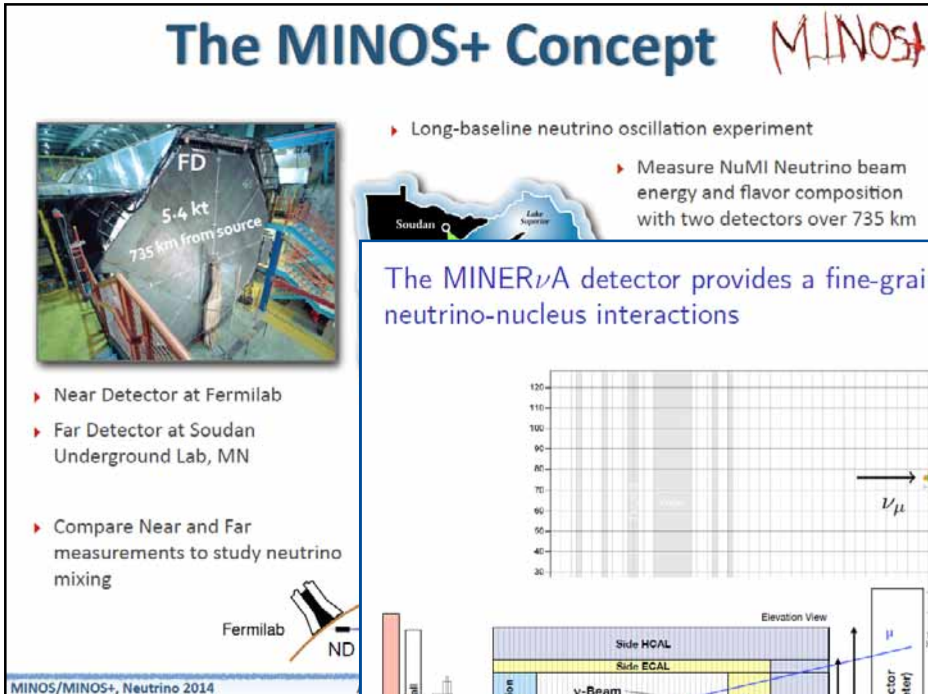
BNB:
- Low energy 0.1 – 1.5 GeV
- Focused on short-baseline oscillations and cross sections

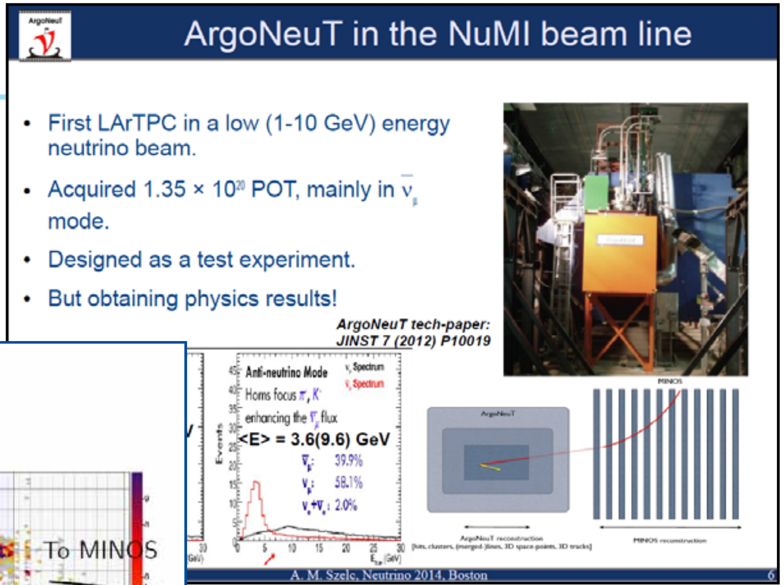
BNB Neutrino mode at 700m

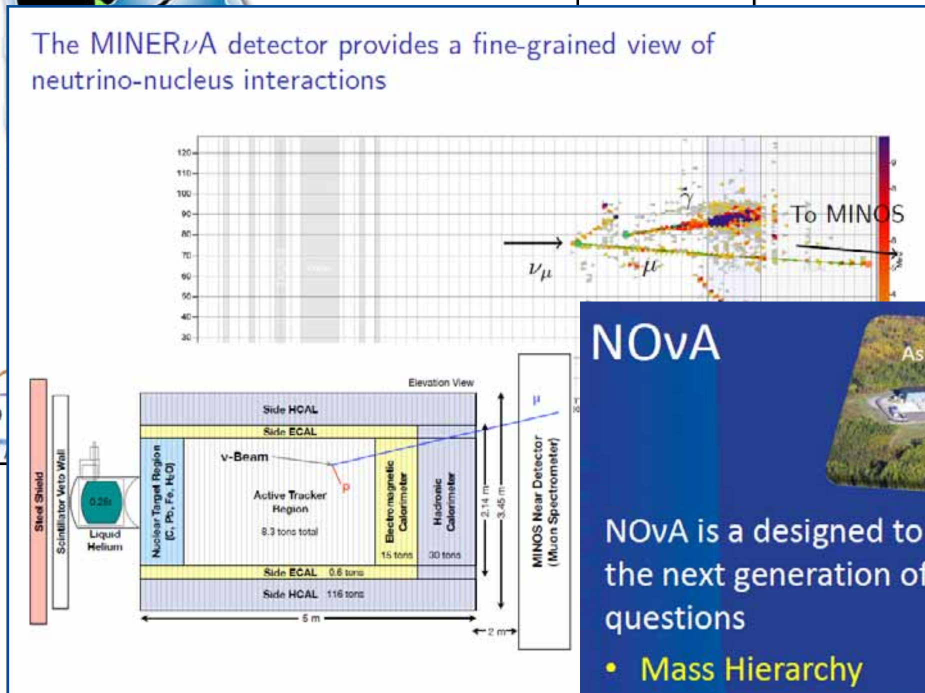


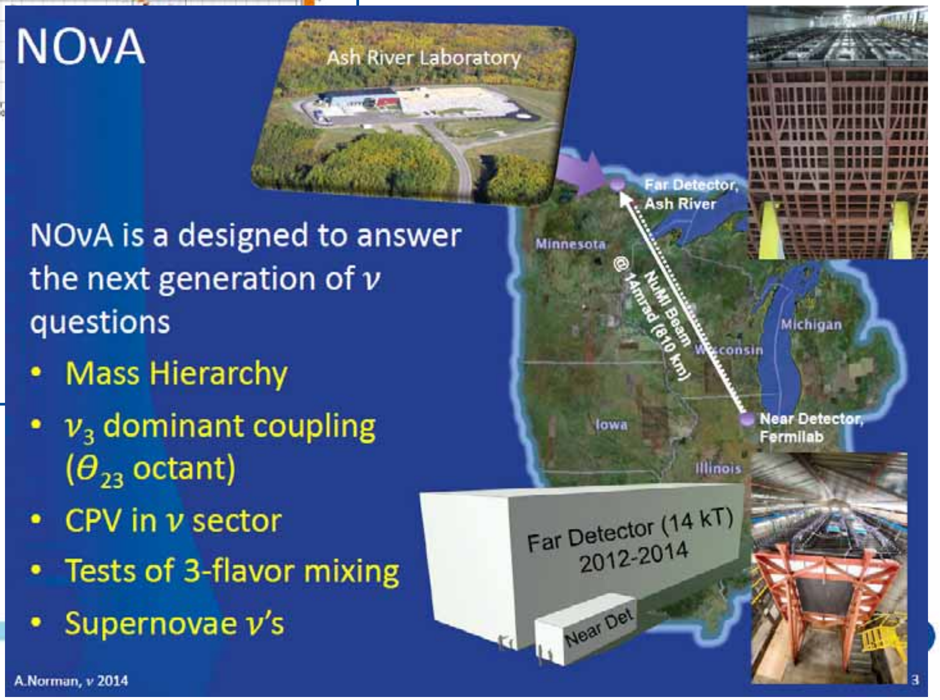


Experiments in the NuMI Beam





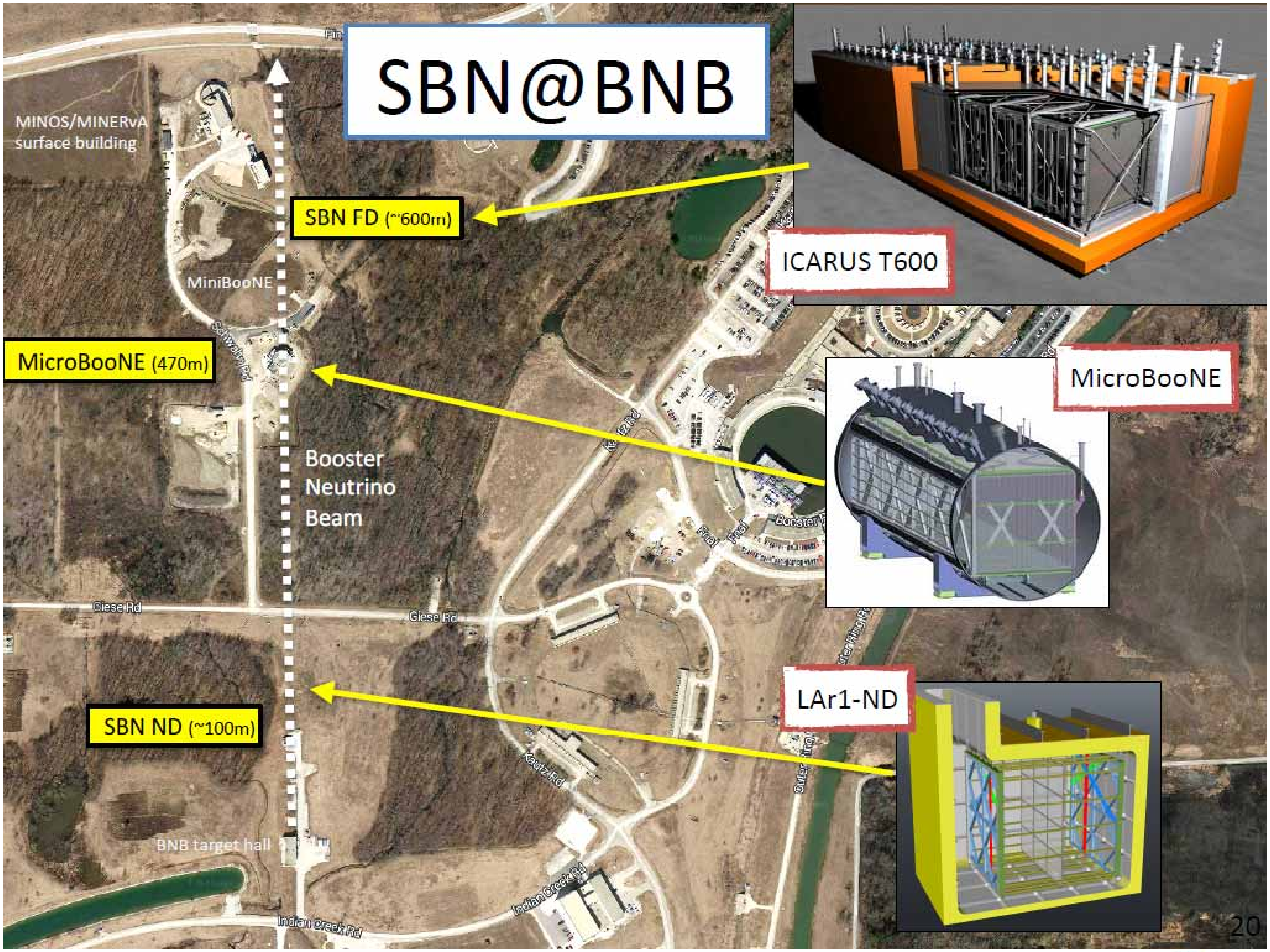




Experiments in the Booster Neutrino Beam

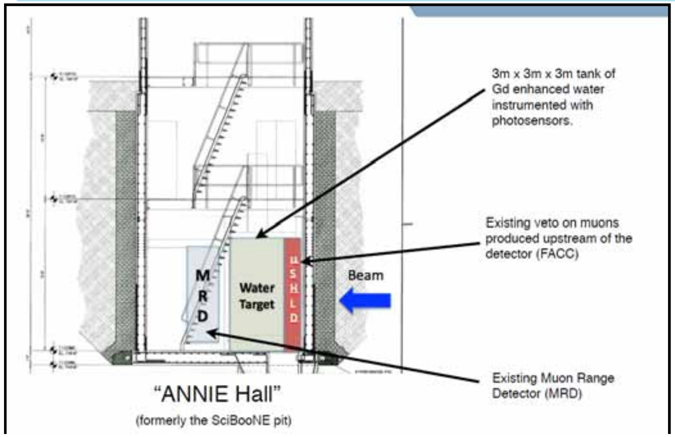
MicroBooNE

Proposed Short-Baseline Neutrino Program

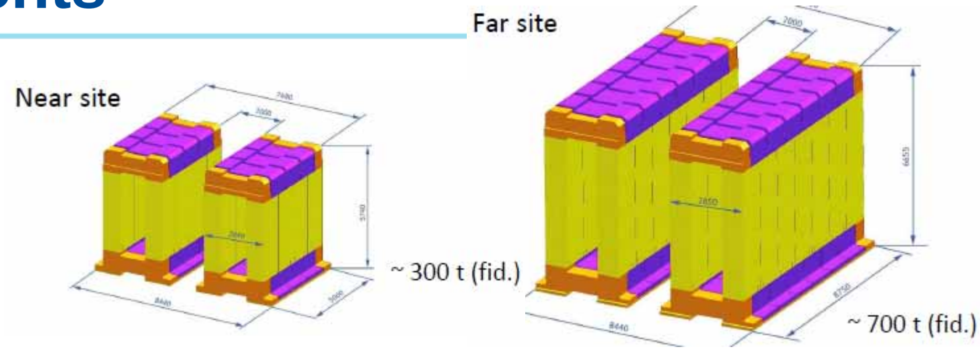


Fermilab

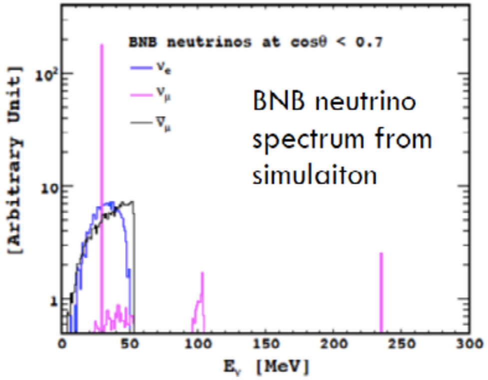
Additional Possible Experiments



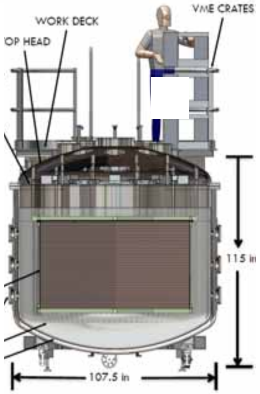
Measure ν-induced backgrounds relevant for large water detectors using an Optical Time Projection Chamber in BNB



Short-baseline ν_μ-disappearance measurement in BNB (NESSiE)



space is available in and out of building at points A, B and C



Calibrate LAr TPC response to low-energy neutrinos with stopped pion beam

Fermilab

Neutrino beam delivery over the last 15 years:

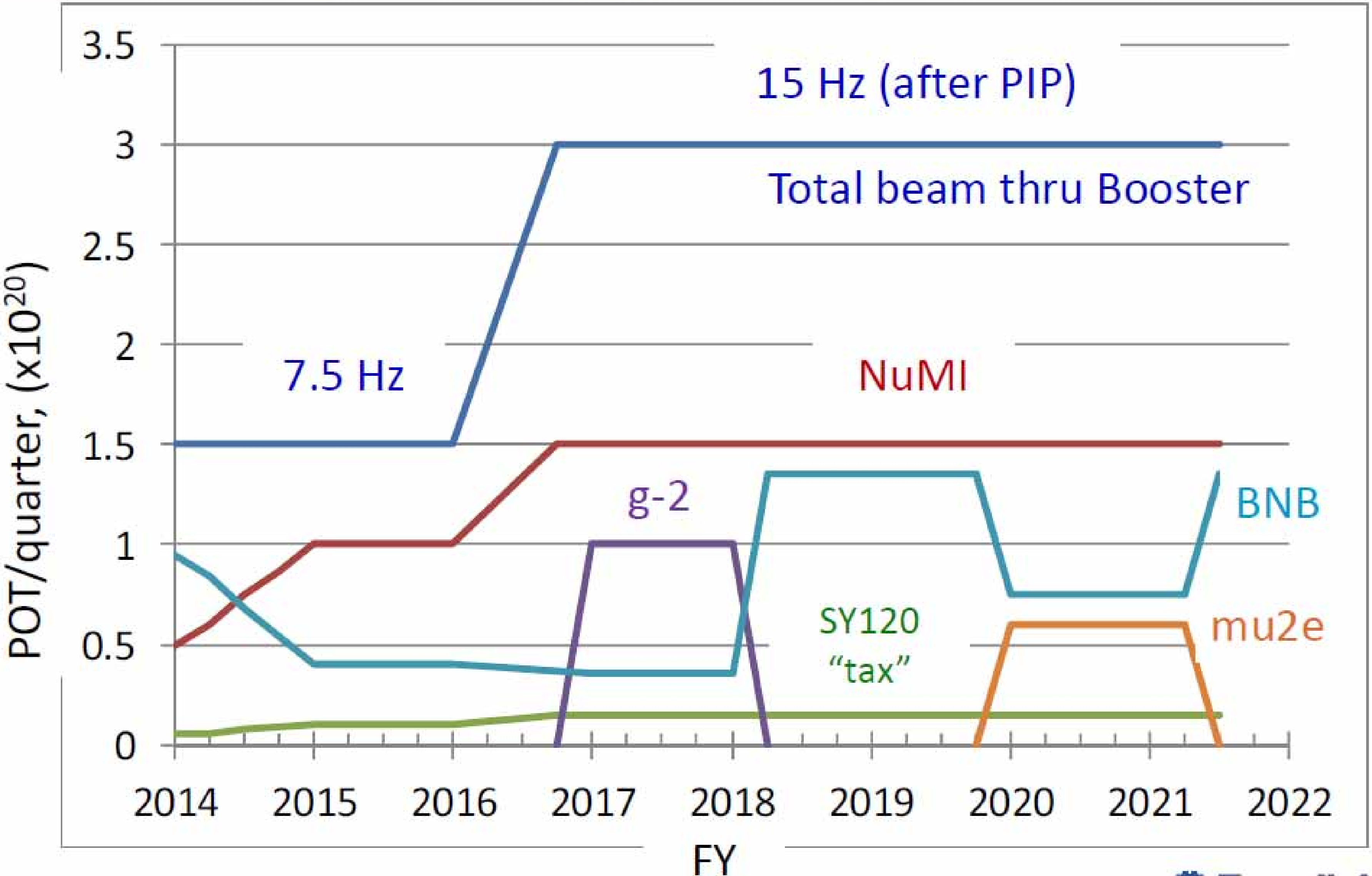
	protons on target ($\times 10^{20}$)
K2K	0.92
T2K	6.70
OPERA/ICARUS	1.81
	9.43 = total Asia + Europe
NuMI	18.00
BNB	17.50
	35.50 = total Fermilab

- *Delivering protons to neutrino experiments is a top priority for the Fermilab accelerator complex.*

Increasing beam intensity

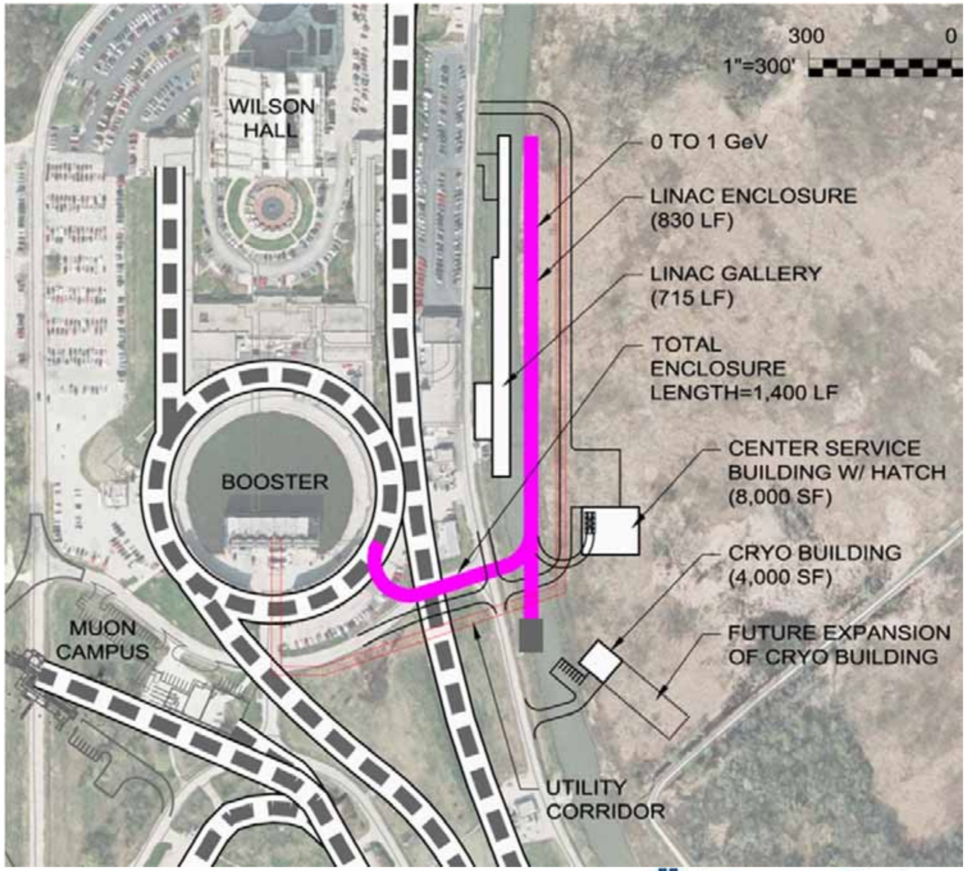
- Upgrades to the Main Injector and Recycler done as part of the NOvA construction will enable doubling the NuMI beam power to 700 kW
  - Convert Recycler to proton-stacking ring
  - Increase Main Injector ramp rate
  - ~10% increase in intensity per pulse
- Proton Improvement Plan (PIP) to increase proton flux from Booster to the Main Injector
  - Refurbish Booster RF system: 7.5 → 15 Hz beam operation
  - Upgrades to Linac and Booster for higher reliability
- Combined upgrades will deliver 700 kW to NOvA and increase the intensity of the Booster Neutrino Beam.

Proton delivery scenario (approximate)



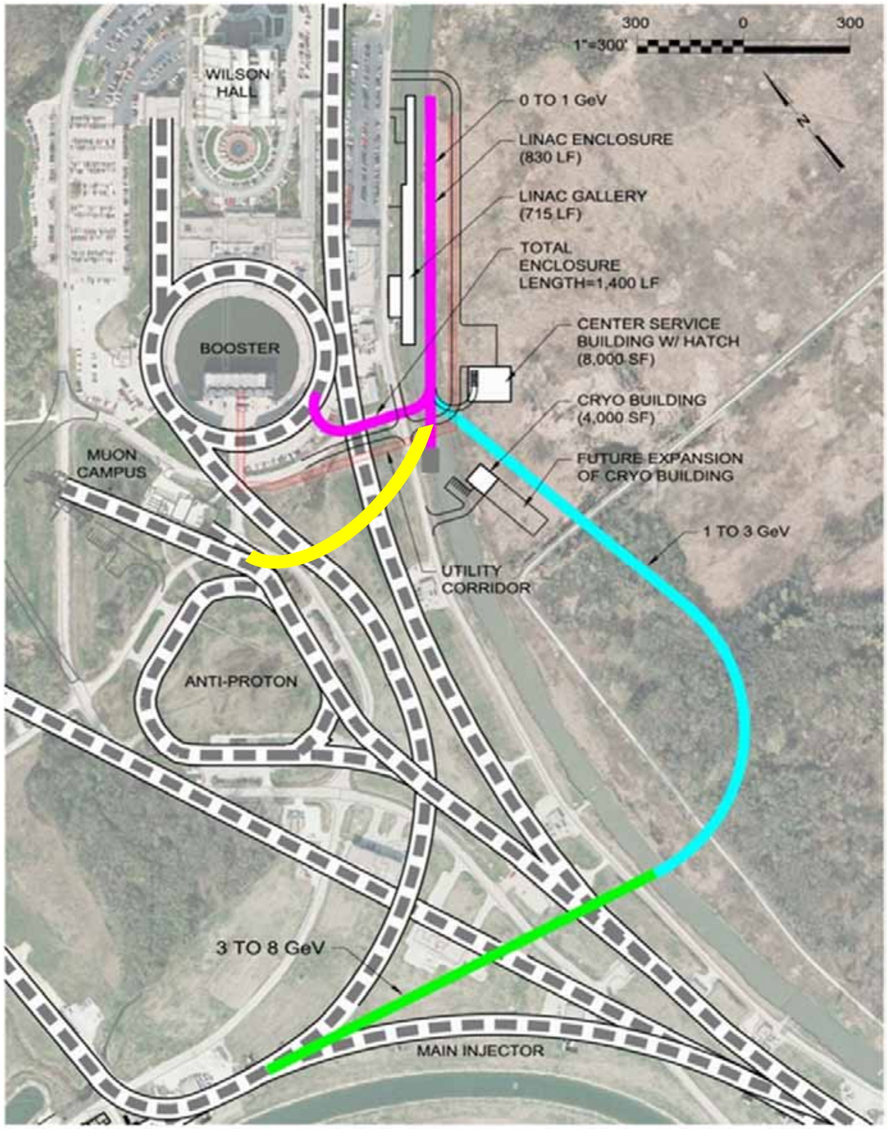
Proton Improvement Plan II (PIP-II)

- Goal is to increase Main Injector beam power to 1.2 MW.
  - Replace the existing 400 MeV linac with a new 800 MeV superconducting linac => 50% increase in Booster intensity.
  - Shorten Main Injector cycle time 1.33 → 1.2 sec.
- Build this concurrently with new long-baseline facility => deliver 1.2 MW to LBNE from t = 0.
- This plan is based on well-developed SRF technology.
- Developing an international partnership for its construction
- Strong support from DOE and P5



Flexible Platform for the Future

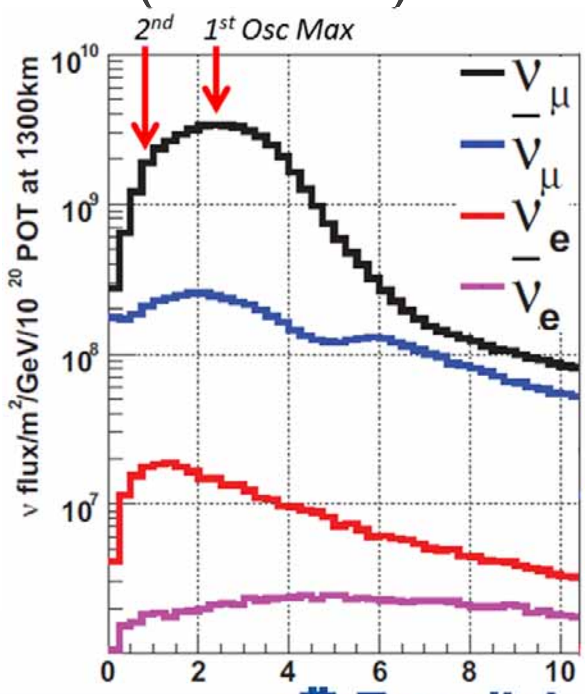
- PIP-II Inherent Capability
  - ~200 kW @ 800 MeV
  - x10 Mu2e sensitivity
- Future upgrade would provide > 2 MW to LBNE
- Flexibility for future experiments
  - Muons, Kaons at 100's kW



Beamline for a new Long-Baseline Neutrino Facility

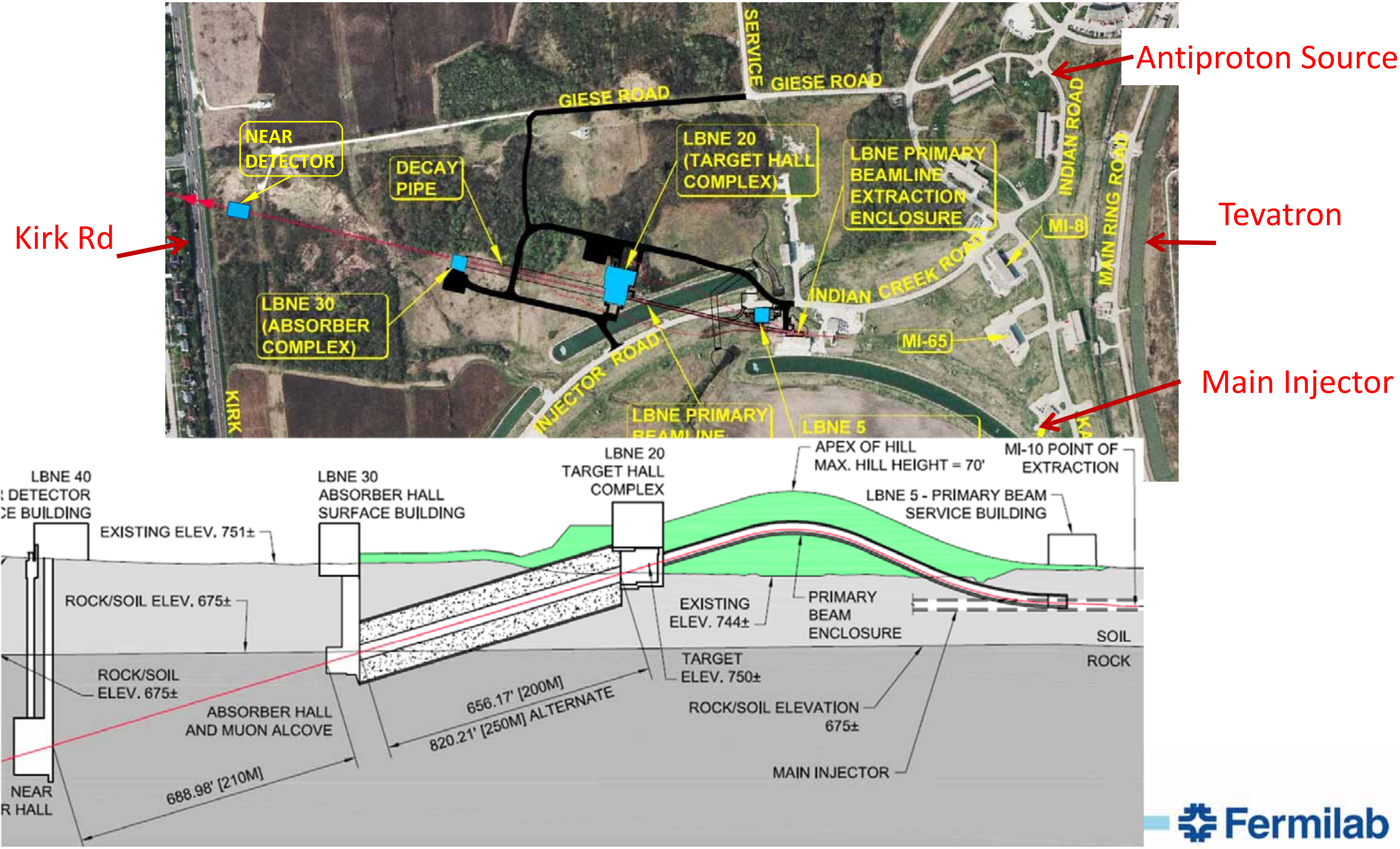
LBNE is developing a design for a new neutrino beam at Fermilab, to support a new long-baseline neutrino facility.

- Directed towards the Sanford Underground Research Facility (SURF) in Lead, South Dakota, 1300 km from Fermilab.
- Beam spectrum to cover 1st (2.4 GeV) and 2nd (0.8 GeV) oscillation maxima => Cover 0.5 ~ 5 GeV
- All systems designed for 1.2 MW initial proton beam power.
- Facility is upgradeable to ≥2.3 MW proton beam power.



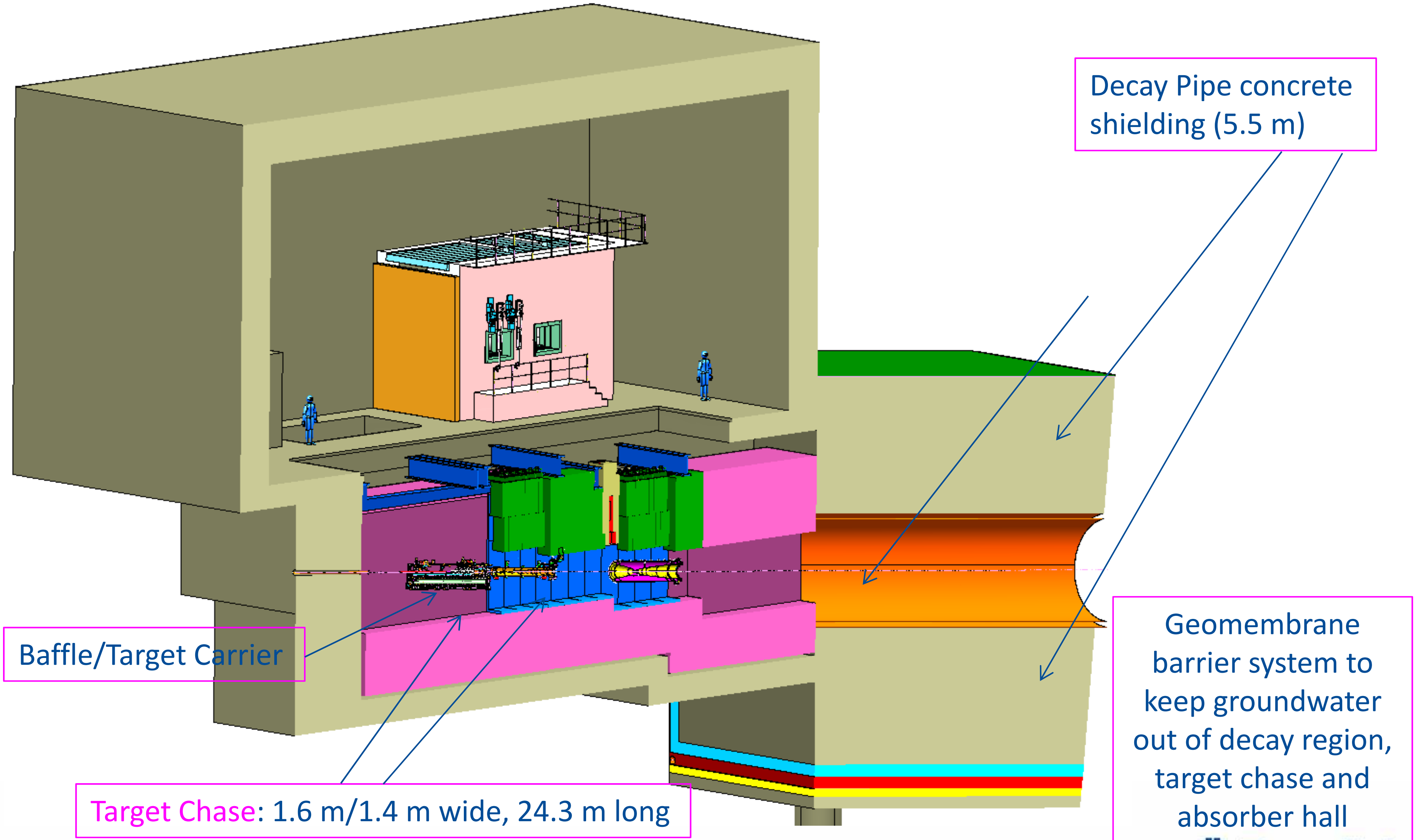
Fermilab Accelerator Complex

Beamline for a new Long-Baseline Neutrino Facility

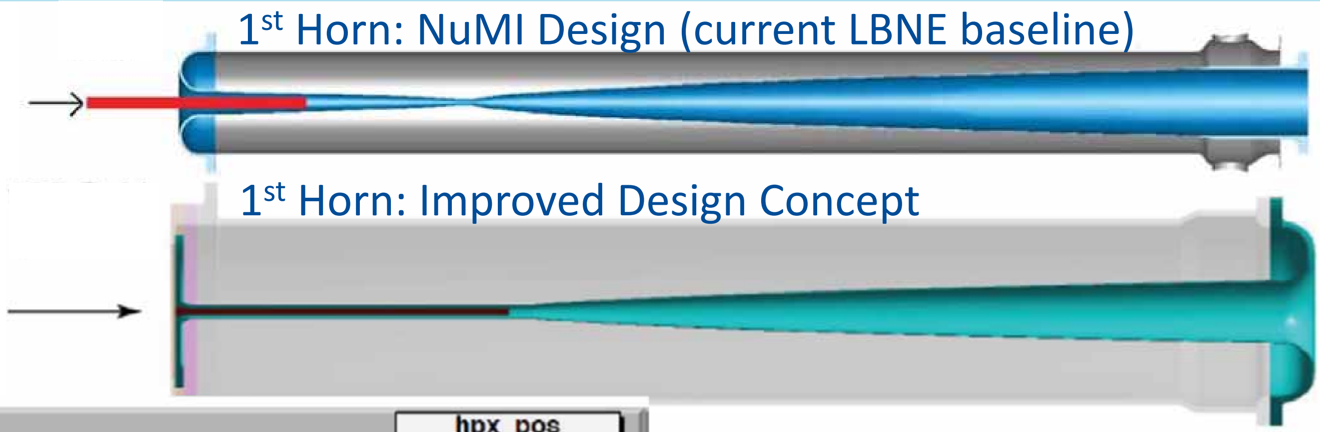


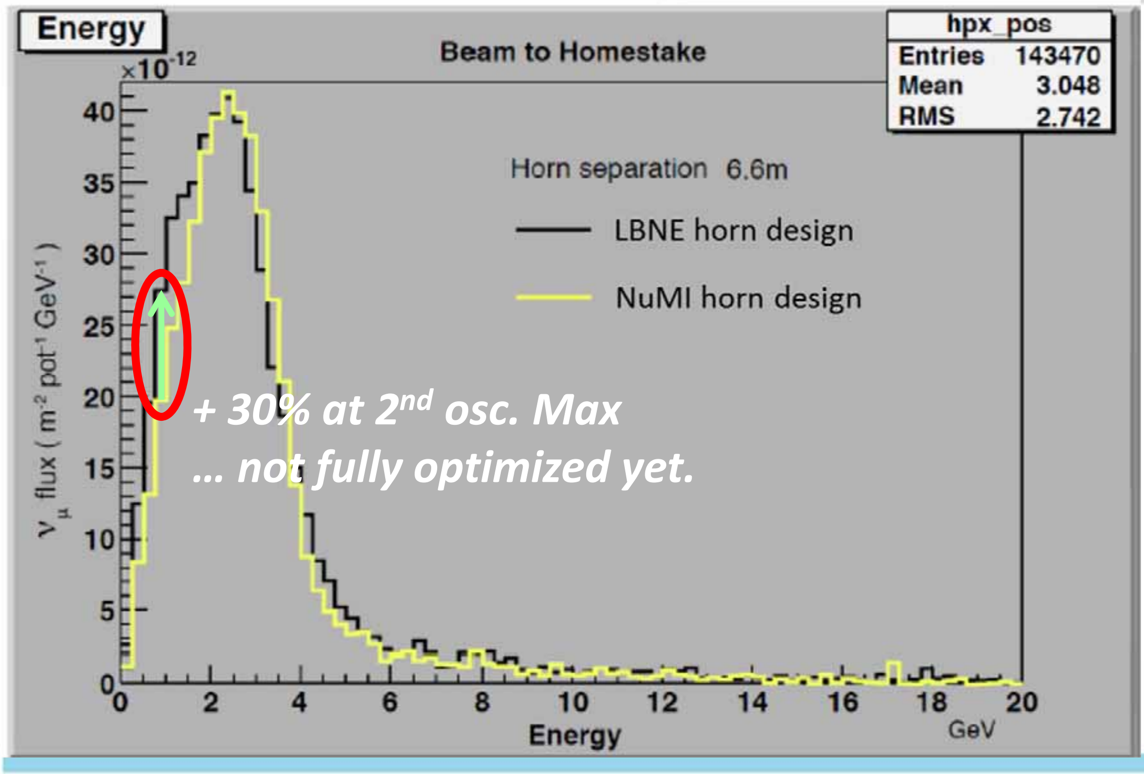
Fermilab

Target Hall and Decay Pipe Layout



Improved Focusing for Second Oscillation Maximum





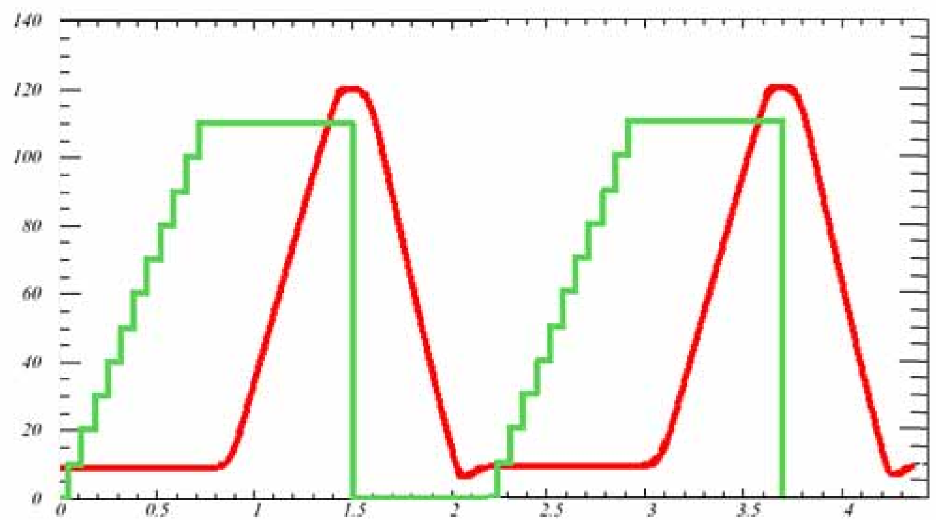
This is one example of significant improvements that are possible and needed, which new collaborators could bring into the design of the long-baseline neutrino facility beam design.

Summary

- Fermilab hosts an active and diverse accelerator-based neutrino program.
- Fermilab has a record of delivering high-intensity proton beams with high reliability and long running time for neutrino physics.
- On-going upgrades will increase the Main Injector beam power to 700 kW over the next ~2 years.
- PIP-II will further increase the beam power to 1.2 MW and provide a platform for future beam power >2 MW.
- A neutrino beam design is being developed to support a new long-baseline neutrino facility directed from Fermilab to SURF. There is substantial room for new collaborators to bring new ideas to improve the design and performance.

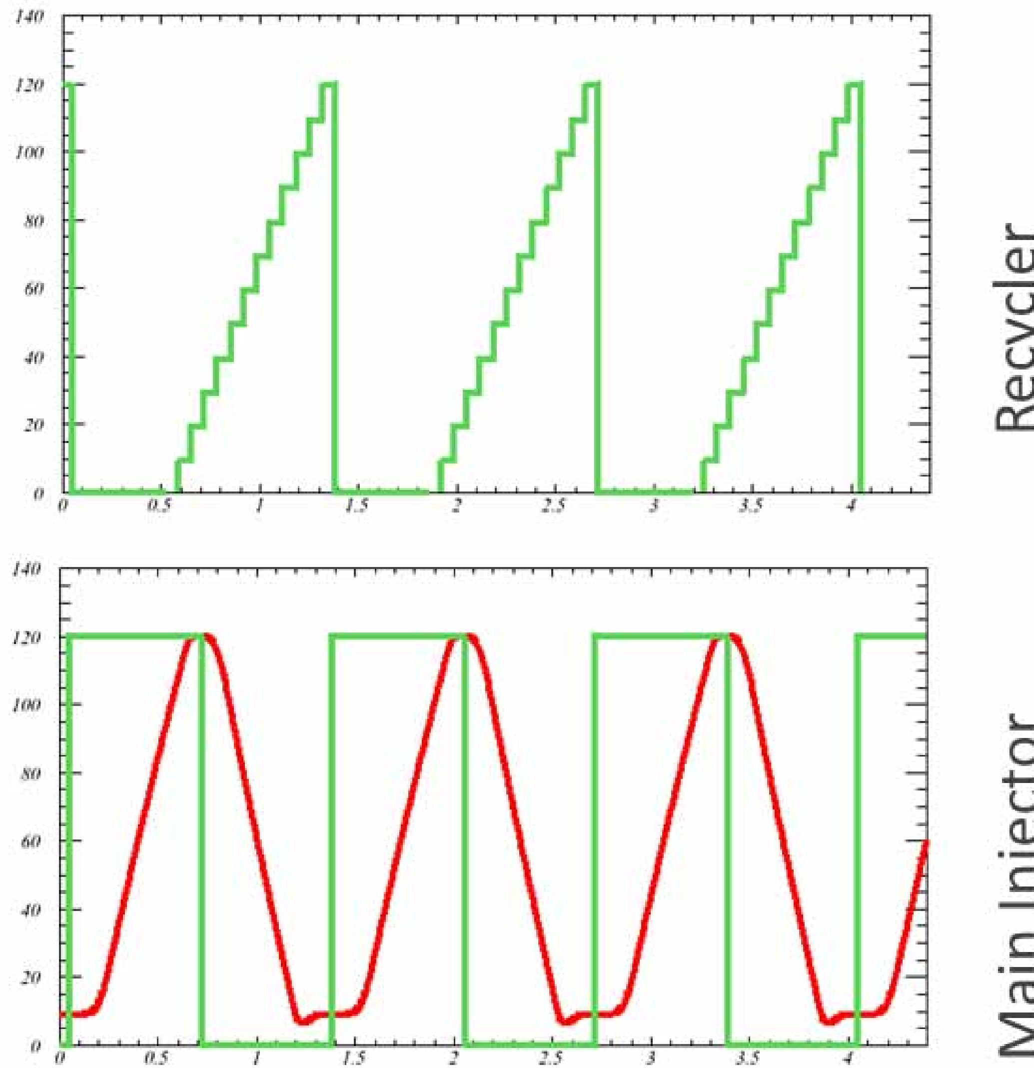
320 kW on target

- Previous operation:
  - H- linac at ~35 mA
  - Charge exchange injection into Booster 10-11 turns: 4.3e12
  - 9 pulses (at 15 Hz) into Main Injector with RF slip stacking
  - Ramp to 120 GeV at 204 GeV/s and extract to NuMI target
  - 3.7e13 / 2.2 sec cycle 323 kW



Increasing Beam Power to 700 kW

- Move slip-stacking to recycler
- 11 batch -> 12 batch
- Increase Main Injector ramp rate (204 GeV/s -> 240 GeV/s)
- 330 (380) -> 700kW with only ~10% increase in per-pulse intensity
- Peak intensity 10% just more frequent
- Achieving 700 kW will require the 15-Hz Booster operations



The Status and the Plan

- Booster at 4.3e12 ppp, 7.5 Hz ✔
- Started NuMI operation with MI only ✔
  - 2.5e13 0.6 Hz (1.67 s cycle)
  - ~290 kW peak
- We can currently run the Recycler with~2.2E13 p every 1.33 sec ✔ (300KW or 270KW with one slow-spill event).
  - 6 Booster batches (no slip-stacking)
  - We run in this mode a few hours every day. Need to finish damper commissioning and reduce the losses before we can run 100% like this (expected before the end of June)
- Increase the Recycler beam intensity to 2.5E13 p delivering 345 kW (beginning of July).
- Plan to reach 450 kW by the end of the summer by using 8 Booster batches (4 slip stacked plus 4 single).

PIP-II Performance Goals

Performance Parameter	PIP	PIP-II	
Linac Beam Energy	400	800	MeV
Linac Beam Current	25	2	mA
Linac Beam Pulse Length	0.03	0.5	msec
Linac Pulse Repetition Rate	15	15	Hz
Linac Beam Power to Booster	4	13	kW
Linac Beam Power Capability (@>10% Duty Factor)	4	~200	kW
Mu2e Upgrade Potential (800 MeV)	NA	>100	kW
Booster Protons per Pulse	4.2×10^{12}	6.4×10^{12}	
Booster Pulse Repetition Rate	15	15	Hz
Booster Beam Power @ 8 GeV	80	120	kW
Beam Power to 8 GeV Program (max)	32	40	kW
Main Injector Protons per Pulse	4.9×10^{13}	7.5×10^{13}	
Main Injector Cycle Time @ 120 GeV	1.33	1.2	sec
LBNF Beam Power @ 120 GeV*	0.7	1.2	MW
LBNF Upgrade Potential @ 60-120 GeV	NA	>2	MW

*LBNF beam power can be maintained to ~80 GeV, then scales with energy

PIP-II Status and Strategy

- PIP-II is currently pre-CD-0
  - Complete concept exists
    - Documented in whitepaper; technical backup in PX RDR
  - R&D program underway
    - Front end (PXIE) and superconducting rf development
- Strong endorsement from P5
  - Recommendation 14: Upgrade the Fermilab proton accelerator complex to produce higher intensity beams. R&D for the Proton Improvement Plan II (PIP-II) should proceed immediately, followed by construction, to provide proton beams of >1 MW by the time of first operation of the new long-baseline neutrino facility.
    - Applies in all budget scenarios considered.
- Discussions with P5, Fermilab, and DOE/OHEP management have been in context of FY19 construction start
  - Consistent R&D deliverables list established
  - Preliminary discussions on potential international in-kind contributions
  - Aligned with LCLS-II and LBNF activities
- Goals for the next year
  - Release PIP-II specific RDR
  - Maintain PXIE and SRF development on established schedules
  - Support DOE in the development of Mission Need Statement
  - Establish PIP-II Office, within Accelerator Division

Beam Improvements Under Consideration

Changes	0.5-2 GeV	2-5 GeV	Extra Cost
Horn current 200 kA → 230 kA	1.00	1.12	$0
Proton beam 120 → 80 GeV,700 kW	1.14	1.05	$0
Target graphite → Be	1.10	1.00	< 1 M$
DP Air → He	1.07	1.11	~ 8 M$
DP diameter 4 m → 6 m	1.06	1.02	~ 17 M$
DP length 200 m → 250 m	1.04	1.12	~ 30 M$
Total	1.48	1.50	

34% 31%

- Target/horn system can be replaced with more advanced designs as they become available.
- Decay pipe design must be fixed at the beginning.
- First four improvements appear technically and financially feasible.
- The last two proposals regarding the decay pipe diameter and length are still under study.