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PIP-II Requirements

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Workshop on Booster Performance and Enhancements

23-24 November 2015

Fermilab Program Goals

Fermilab's goal is to construct & operate the foremost facility in the world for particle physics research utilizing intense beams.

- Neutrinos
  - MINOS+, NOvA @700 kW
  - LBNF @ multi-MW
  - SBN @ 10's kW
- Muons
  - Muon g-2 @ 17-25 kW
  - Mu2e @ 8-100 kW
- Longer term opportunities

⇒ ***This requires more protons!***

(and this statement tends to be time invariant)

P5 Report has several specific recommendations on the Fermilab Program

Recommendations from May 2014 P5 Report

- Recommendation 12: In collaboration with international partners, develop **a coherent short- and long-baseline neutrino program** hosted at Fermilab.

- Recommendation 13: Form a new international collaboration to design and execute a **highly capable Long-Baseline Neutrino Facility (LBNF)** hosted by the U.S. To proceed, a project plan and identified resources must exist to meet the minimum requirements in the text. LBNF is the highest-priority large project in its timeframe.

- Recommendation14: 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.

STATISTICS in Neutrino Experiments

Neutrino Events/Unit Time =

Neutrino Flux x ← **BEAM = Protons/year + Target/horns, Beam Energy**

Neutrino Cross-section/Nucleon x ← PHYSICS!

Number of Nucleons ← **Detector = Mass + Efficiency**

Neutrino Experiments Need : Mass * Power * Time

We want to achieve our physics goals in a timely manner!

Time : Neutrino experiments take time

- Consider several options for how one could reach the P5 goals
- We see that the existing 700kW capability, even when paired with the full detector mass leads to an unrealistic time line for achieving the physics goals
- Given the size and complexity – it is difficult to imagine more mass (at least at this time) **40kT with 1.2 MW is a 20 year program**

Detector Fiducial Mass (kton)	Proton Beam Power (MW)	YEARS to reach 120kT.MW.yr	YEARS to reach 600kT.MW.yr	YEARS to reach 900kT.MW.yr
10	0.7	17	86	129
20	0.7	9	43	64
30	0.7	6	29	43
40	0.7	4	21	32
10	1.2	10	50	75
20	1.2	5	25	38
40	1.2	3	13	19
20	2.4	3	13	19
40	2.4	1	6	9

What are the requirements?

- Design Criteria
  - Deliver 1.2 MW of beam power at 120 GeV, approaching 1 MW down to 60 GeV, at the start of LBNF operations
  - Support the current 8 GeV program, including Mu2e, g-2, and the suite of short-baseline neutrino experiments
  - Provide an upgrade path for Mu2e
  - Provide a platform for extension of beam power to LBNF to >2 MW
  - Provide a platform for extension of capability to high duty factor/ higher beam power operations
- Build it over 2015 – 2025

Power and Beam Characteristics

$P = 1.6\ {}^{EN}/_{t}$ kW

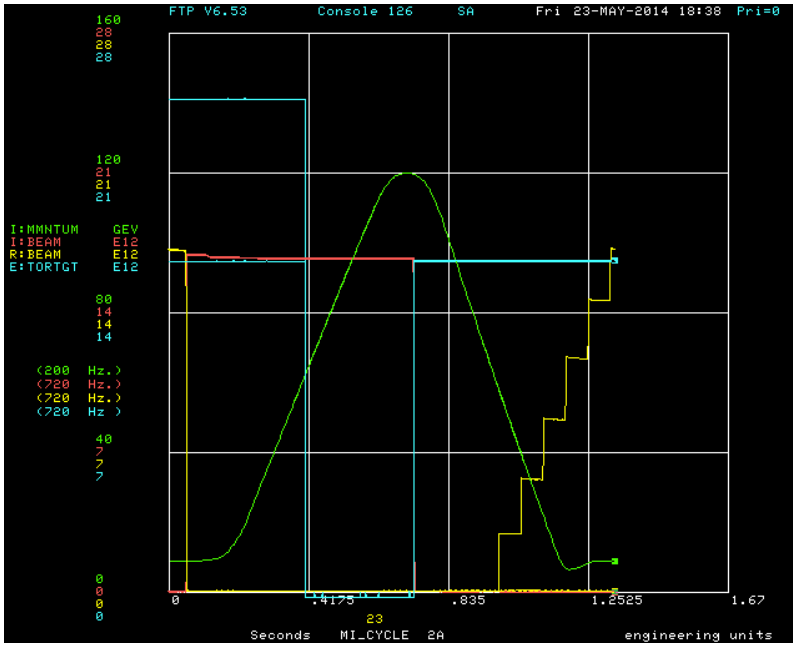
E in GeV

N in 1e13

t in seconds

- Getting to 1.2 MW
  - 7.5e13 @ 120 GeV every 1.2 seconds
  - MI Ramp: 240 GeV/second + parabolas + reset
  - Booster operating at 20 Hz: cycles multiples of 50 msec
  - Slip Stacking: 12 cycles = 0.6 sec

Energy (GeV)	Intensity(e13)	Cycle Time (sec)	Power (kW)
120	7.5	1.2	1200
110	7.5	1.1	1200
100	7.5	1.05	1143
90	7.5	0.95	1137
80	7.5	0.9	1067
70	7.5	0.8	1050
60	7.5	0.7	1029
50	7.5	0.65	923
40	7.5	0.6	800
30	7.5	0.6	600



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Proton Improvement Plan-II (PIP-II)

- *"The central element is a new 800 MeV superconducting linac operated at low duty factor but constructed to be capable of continuous operation" P5 report, p. 47*

- PIP-II plans to build an 800 MeV superconducting pulsed linac, extendible to support multi-MW operations to LBNF and constructed of continuous wave (CW) capable components
  - Builds on significant existing infrastructure
  - Capitalizes on major investment in superconducting rf technologies
  - Eliminates significant operational risks inherent in existing linac
  - Siting consistent with eventual replacement of the Booster as the source of protons for injection into Main Injector
- Reference Design Report available at:

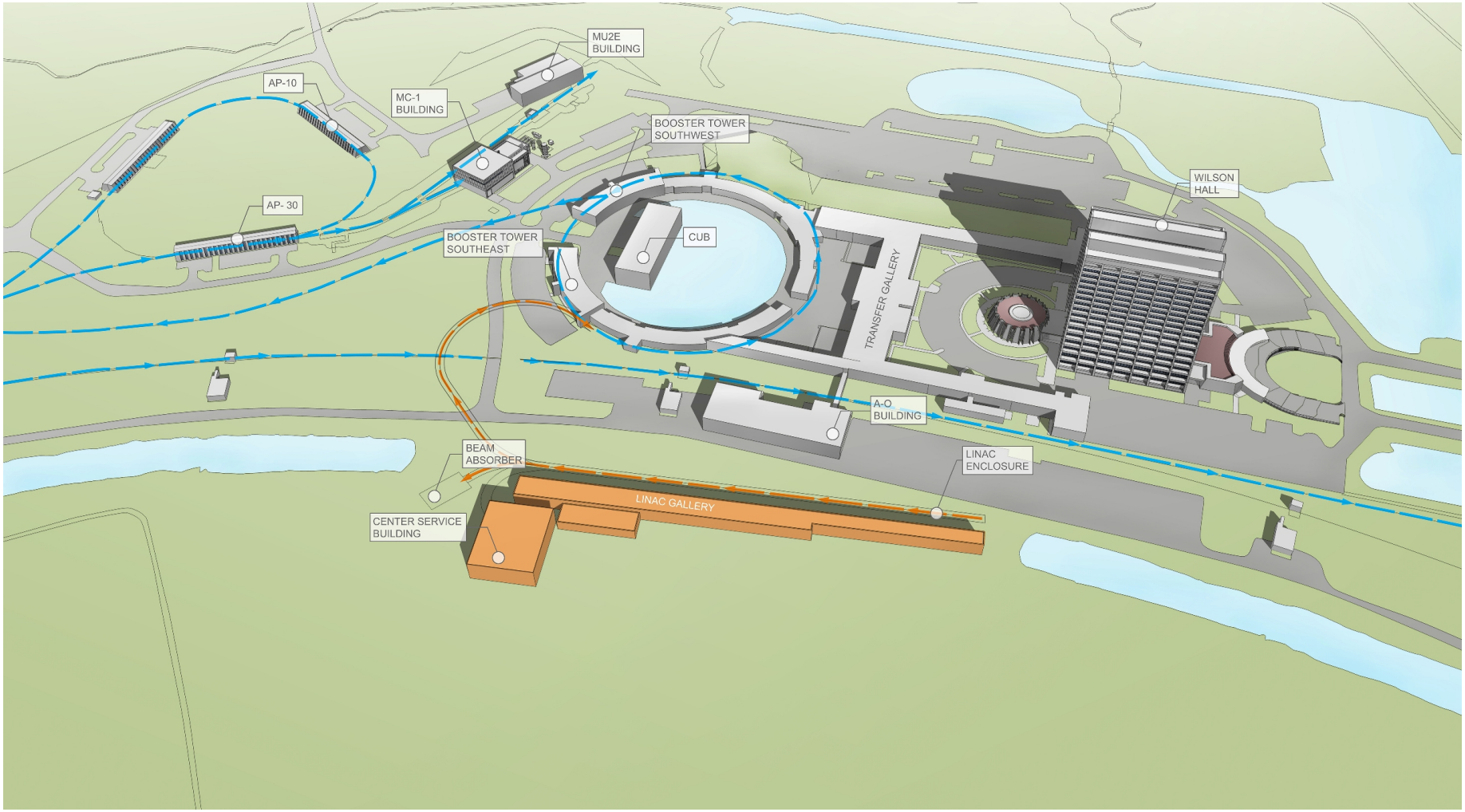
  pip2-docdb.fnal.gov/cgi-bin/ShowDocument?docid=1

At completion of PIP-II the existing 400 MeV linac will be removed from service

PIP-II Status and Strategy

- Reference Design Report describes:
  - An 800-MeV superconducting linac, constructed of CW-capable components, operated initially in pulsed mode
  - Modifications to Booster/Recycler/Main Injector to accommodate higher intensities
    - New Booster injection region to accept 800-MeV beam
    - Upgrades to Booster damper and collimator systems
    - Recycler RF upgrade for slip-stacking at 0.7 sec cycle time
    - MI RF power upgrade
    - MI γ_t-jump system
  - Increase of Booster repetition rate to 20 Hz
    - Maintain 1 MW down to 60 GeV or,
    - Provide factor of 2.5 increase in power to 8 GeV program

PIP-II Status and Strategy/Site Layout



Performance Goals

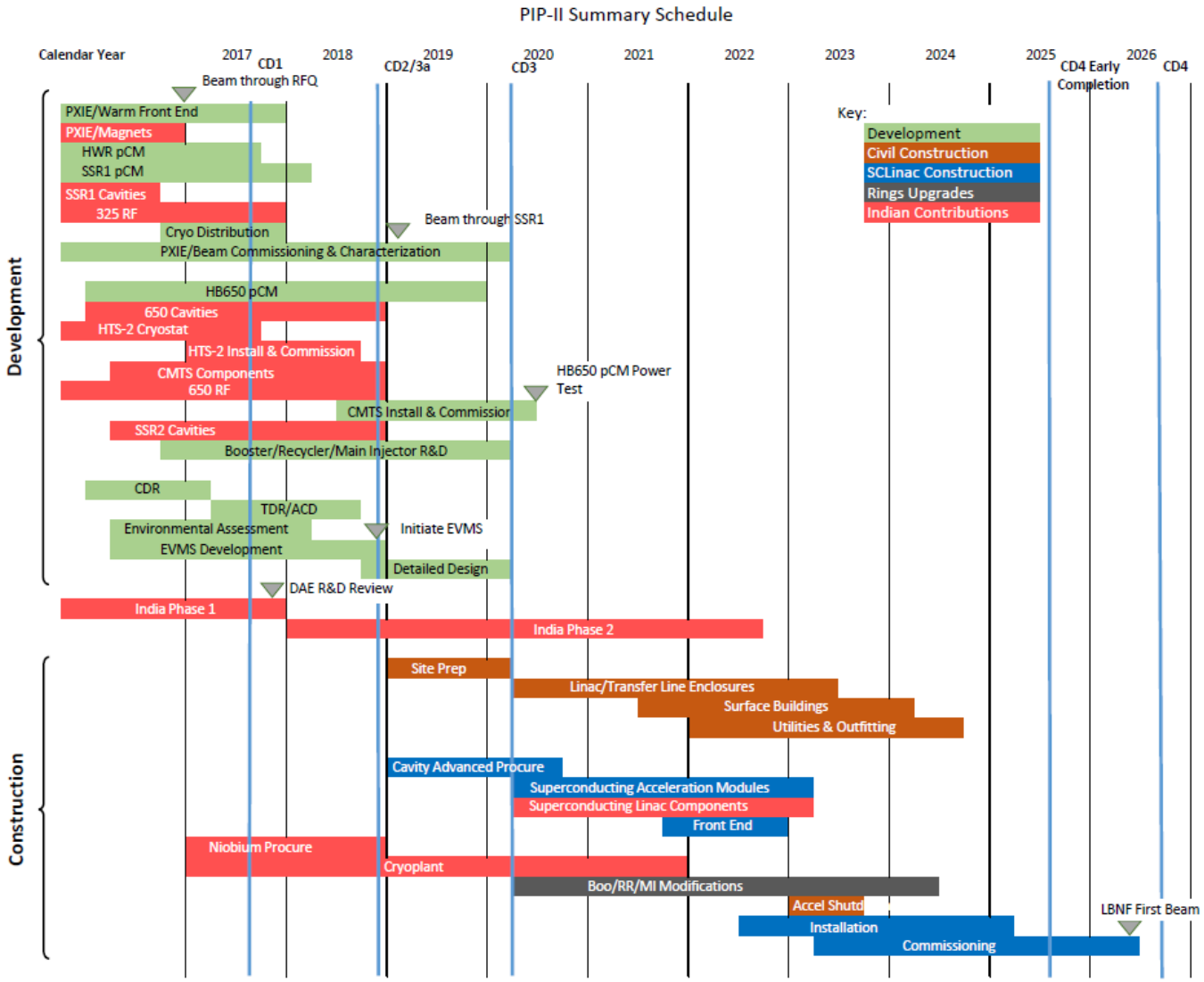
Performance Parameter	PIP	PIP-II	
Linac Beam Energy	400	800	MeV
Linac Beam Current	25	2	mA
Linac Beam Pulse Length	0.03	0.5	msec
Linac Pulse Repetition Rate	15	20	Hz
Linac Beam Power to Booster	4	18	kW
Linac Beam Power Capability (@>10% Duty Factor)	4	~200	kW
Mu2e upgrade potential	NA	>100	kW
Booster Protons per Pulse	4.2×10^{12}	6.5×10^{12}	
Booster Pulse Repetition Rate	15	20	Hz
Booster Beam Power @ 8 GeV	80	160	kW
Beam Power to 8 GeV Program (max)	32	80	kW
Main Injector Protons per Pulse	4.9×10^{13}	7.6×10^{13}	
Main Injector Cycle Time @ 60-120 GeV	1.33*	0.7-1.2	sec
LBNF Beam Power @ 60-120 GeV	0.7*	1.0-1.2	MW
LBNF Upgrade Potential @ 60-120 GeV	NA	>2	MW

*NOvA operations at 120 GeV

PIP-II Strategy

- PIP-II will be executed as a DOE 413.3b project
  - CD-0 November 12 2015
- Strategy
  - Develop/evolve concepts aligned with community needs
  - Undertake R&D targeting major technical/cost risk elements
  - RDR defines concept for meeting community requirements, and provides context for R&D
  - Coordinate with other Fermilab projects and programs
- Construction complete in 2025
  - LBNF tie in to MI tunnel in 2023?
  - Booster construction tie in at same time
  - Commission operations with beam before turning off current Linac and finishing the Booster tie in
- Status
  - PIP-II endorsed by P5 as a key element in the U.S. neutrino program
  - R&D program underway:
    - PXIE and SRF R&D geared toward a 2020 construction (CD-3) start
  - P2MAC review of RDR and R&D program (March)
  - Strong collaboration with Indian and U.S. laboratories
    - Possible collaboration with Europe
  - Project Office established

Project Strategy/Preliminary Schedule



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Why on the other side of the Booster?

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Future Directions

- The configuration and siting of the PIP-II linac are chosen to provide opportunities for future performance enhancements to the Fermilab proton complex
  - multi-MW to LBNF
    - PIP-III : Possible Booster Replacement?
      - 8 GeV Linac
      - New RCS

E. Prebys later this morning

  - PIP-II may very well be a CW facility from day 1
    - 100's kW for a rare processes program
      - Muons
      - Kaons (at 3 GeV?)
      - Neutrons
  - Front end for a muon-based facility

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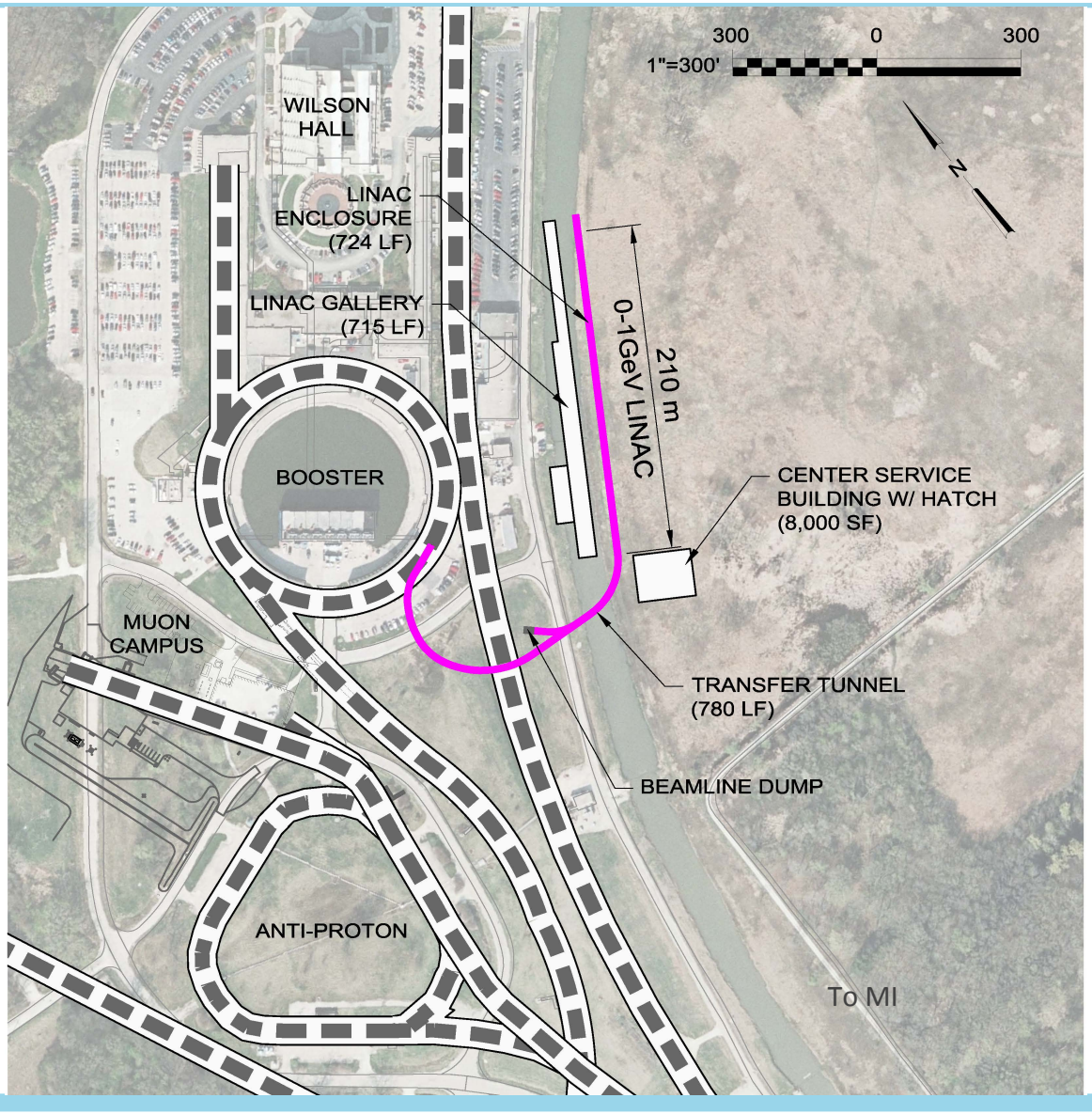

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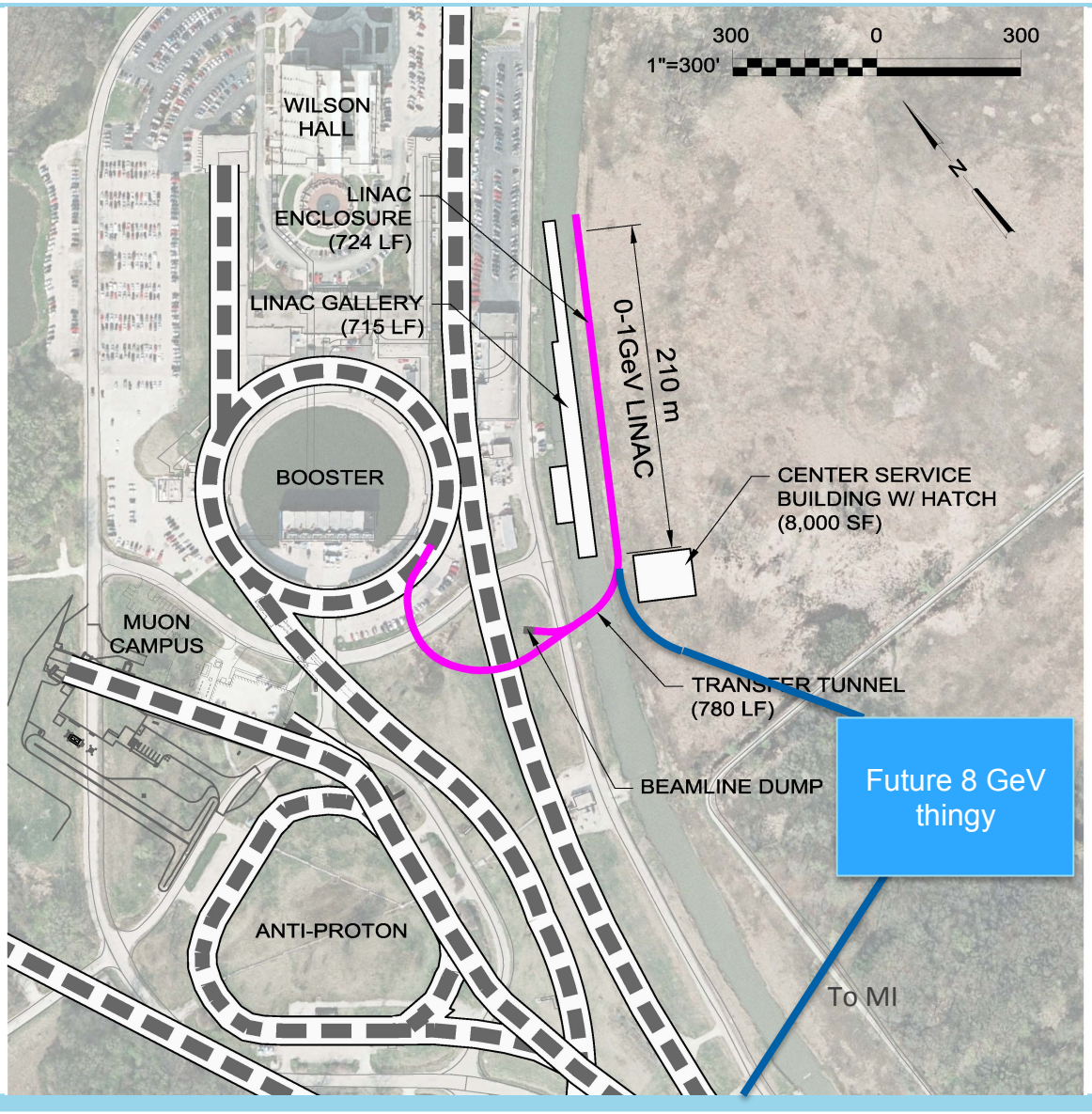

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Summary

- PIP and PIP-II have been developed as steps in establishing a world-leading facility for particle physics research based on intense beams, at Fermilab
  - LBNF >1 MW at startup
  - 8 GeV program >40 kW coincident with LBNF
  - Requirements for the Booster:
    - 6.5e12 per pulse
    - 20 Hz
    - Longitudinal and Transverse Emittance for Slip Stacking
- PIP-II retains flexibility to eventually realize the full potential of the Fermilab complex
  - multi-MW to LBNF
  - multi-MW to SBN program
  - CW capability at 800 MeV

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