PIP-II Goals, Status, and Strategy

Steve Holmes

DOE Independent Project Review of PIP-II

15 November 2016

Charge Item: #4

Steve Holmes

- Role on PIP-II
  - Project Manager
  - IIFC Technical Coordinator (FNAL, delegated)
- Relevant Experience
  - Main Injector Project Manager
  - Accelerator Division Head
  - Associate Laboratory Director for Accelerators

Charge Elements

1. Technical Design: Is the conceptual design for the PIP-II linac sound and likely to meet the specified technical performance requirements? Are R&D efforts being effectively managed to maximize benefits and minimize technical risks to the project?
2. Scope: Is the project's scope sufficiently well-defined to support the preliminary cost and schedule estimates?
3. Cost and Schedule: Are the cost and schedule estimates sufficiently well-defined and of adequate maturity to support the forecasted critical decision milestones and cost range?
4. Management: Is the project being properly managed at this stage? Does the management team possess the skills, expertise and experience necessary to successfully execute the project? Are plans to identify and allocate staffing and resources consistent with current funding guidance?
5. Environment, Safety, and Health: Is environment, safety, and health being properly addressed given the project's current stage of development?
6. India Institutions and Fermilab Collaboration (IIFC): Is the collaboration proceeding satisfactorily towards meeting the goals outlined in the Joint R&D document? Will the deliverables outlined in the Joint R&D document position India for a successful contribution to the PIP-II construction phase?

Since June 2015 IPR

• First hardware deliverables arrive from DAE	July 2015
• Seven DAE engineers/scientists arrive for 2-year residencies	October 2015
• MNS approved and CD-0 issued	November 2015
• Project accounting initiated	January 2016
• Joint IIFC Meetings	January/July 2016
• North American elliptical cavity vendors close shop	March/August 2016
• Associate Project Manager for Planning and Reporting on-board	April 2016
• RFQ commissioned with beam	February-November 2016
• Wetlands delineation report received	July 2016
• Analysis of Alternatives submitted for review	July 2016
– Review committee validation/to OHEP	September 2016
• Draft CDR Released	October 2016
• Responses to all Action Items	October 2016
– See website	

Goals/Mission Need

The goal of PIP-II is to support long-term physics research goals as outlined in the P5 plan, by delivering world-leading beam power to the U.S. neutrino program and providing a platform for the future

- Mission Need Statement/CD-0 approved November 2015
  - Based on Reference Design/cost estimate (June 2015 IPR)
  - India collaboration was critical
- Capability gap/mission need
  - Reduce time required for LBNF/DUNE to achieve world-first results
  - Sustain high-reliability operations of the Fermilab accelerator complex
- Construction period FY2019-FY2025
- Cost range: $465-$650M
  - (Cost to U.S. DOE after international contributions)

Charge Item: #1

Lebedev

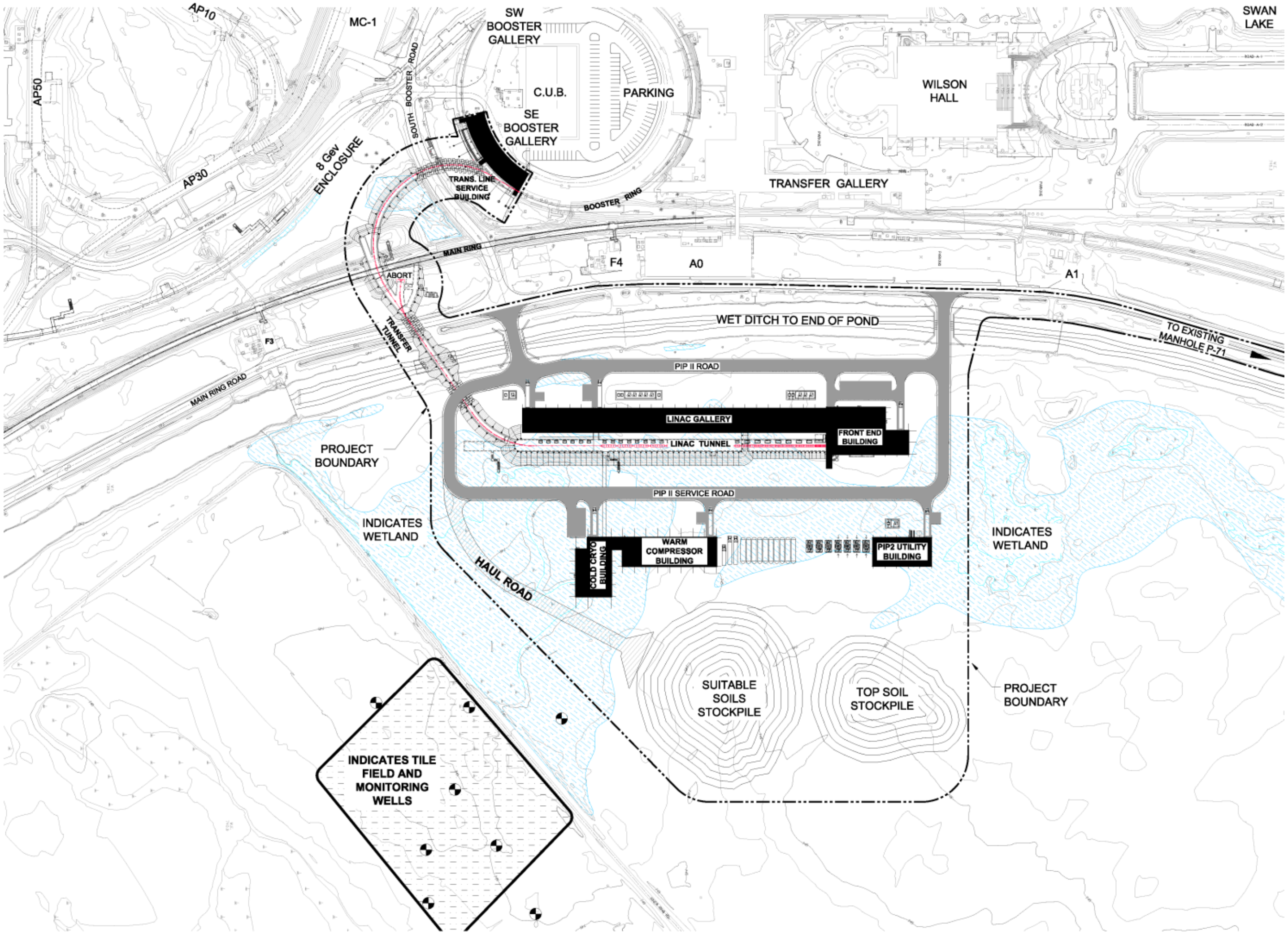
Proposed Technical Approach

- Construct a modern 800-MeV superconducting linac, of CW capable components, operating initially in pulsed mode
  - Ameliorate space-charge forces at Booster injection, allowing an increase Booster/Recycler/Main Injector per pulse intensity of ~50%, while preserving transverse & longitudinal emittance at current levels
- Accompanied by modifications to Booster/Recycler/Main Injector to accommodate higher intensities and higher Booster injection energy
- Increase Booster repetition rate to 20 Hz
  - Maintain 1 MW down to 60 GeV <u>or</u>,
  - Provide factor of 2.5 increase in power to 8 GeV program
- Described in the draft Conceptual Design Report

Proposed Technical Approach/Site Layout

Charge Item: #1

Dixon



Fermilab 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	0.54	msec
Linac Pulse Repetition Rate	15	20	Hz
Linac Beam Power to Booster	4	17	kW
Linac Beam Power Capability (@>10% Duty Factor)	4	~200	kW
Mu2e Upgrade Potential (800 MeV)	NA	>100*	kW
Booster Protons per Pulse	4.3×10^{12}	6.5×10^{12}	
Booster Pulse Repetition Rate	15	20	Hz
Booster Beam Power @ 8 GeV	80	166	kW
Beam Power to 8 GeV Program (max)	32	83	kW
Main Injector Protons per Pulse	4.9×10^{13}	7.5×10^{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

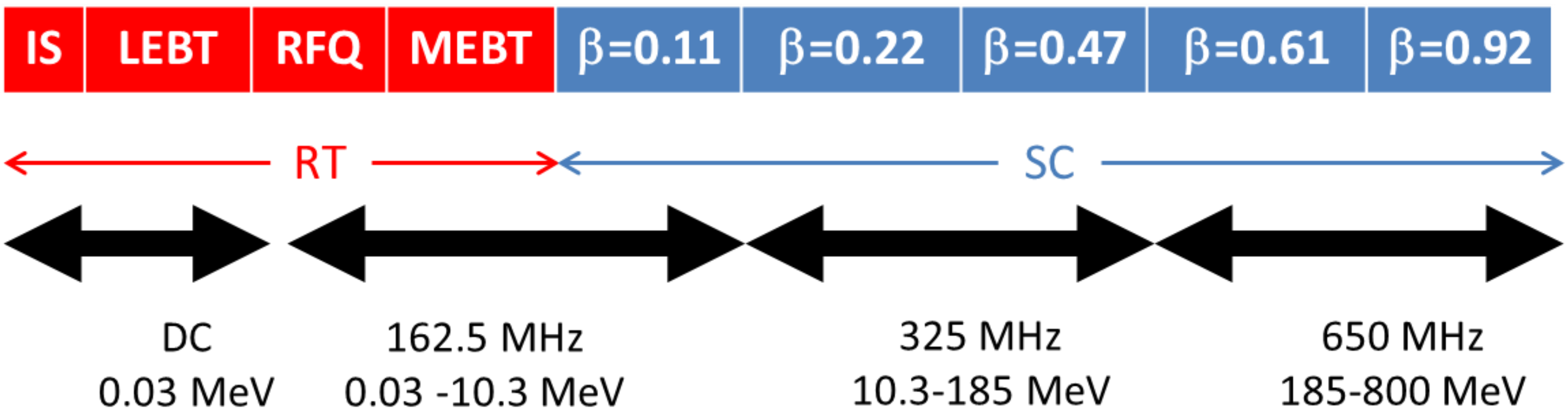
* India in-kind cryoplant would support CW operations on day-1

Scope

The scope of PIP-II includes all management, permitting, design, development, fabrication, construction, and procurement activities associated with the construction and commissioning of:

- An 800-MeV superconducting linac, constructed of CW-capable accelerating structures and cryomodules, operating with a peak current of 2 mA and a beam duty factor of 1.1%;
- Beam transport from the end of the SC Linac to the new Booster injection point, and to a new 800-MeV beam dump;
- Upgrades to the Booster to accommodate 800-MeV injection, and acceleration of 6.5×10^{12} protons per pulse;
- Upgrades to the Recycler to accommodate slip-stacking of 7.7×10^{13} protons delivered in twelve Booster batches;
- Upgrades to the Main Injector to accommodate acceleration of 7.5×10^{13} protons per pulse to 120 GeV with a 1.2 second cycle time, and to 60 GeV with a 0.7 second cycle time.
- All associated conventional facilities and infrastructure

Scope/Technology Map



Section	Freq	Energy (MeV)	Cav/mag/CM	Type
RFQ	162.5	0.03-2.1		
HWR (β_{opt}=0.11)	162.5	2.1-10.3	8/8/1	HWR, solenoid
SSR1 (β_{opt}=0.22)	325	10.3-35	16/8/ 2	SSR, solenoid
SSR2 (β_{opt}=0.47)	325	35-185	35/21/7	SSR, solenoid
LB 650 (β_g=0.61)	650	185-500	33/22/11	5-cell elliptical, doublet*
HB 650 (β_g=0.92)	650	500-800	24/8/4	5-cell elliptical, doublet*

*Warm doublets external to cryomodules

All components CW-capable

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Derwent et al

R&D

- The goal is to mitigate risk: Technical/cost/schedule
- Technical Risks
  - Front End
    - Delivery of beam with required characteristics and reliability
  - Operate (high Q_L) SC Linac in pulsed mode at low current
    - Primary issue is resonance control in cavities
  - Booster/Recycler/Main Injector beam intensity
    - 50% per pulse increase over current operations
    - Longitudinal emittance from Booster for slip-stacking
    - Transition crossing
    - Beam loss/activation
  - Develop requisite capabilities of partners and vendors

PIP2IT

- Cost Risks
  - Superconducting RF: Cavities, cryomodules, RF sources represent major portion of construction costs
  - Cavity Q_0: plays a critical role in the capital and operating costs of the cryoplant

Current funding profile will support R&D completion in early FY2020

R&D Strategy

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We would like to have the following protoypes and/or demonstrations completed at the time of CD-3

- PIP2IT
  - Beam accelerated and characterized through the SSR1 prototype cryomodule
  - Demonstration of effective microphonics/LFD mitigation
- SRF
  - HWR and SSR1 cryomodules tested with beam
  - SSR2 and LB650 dressed cavities tested at full rf power
  - HB650 prototype cryomodule tested at full rf power
  - All utilizing associated RF power and RF controls systems
- Main Injector/Recycler
  - Selection and demonstration of MIRF power amplifier
  - Gamma-t jump prototype magnet

R&D: PIP-II Injector Test

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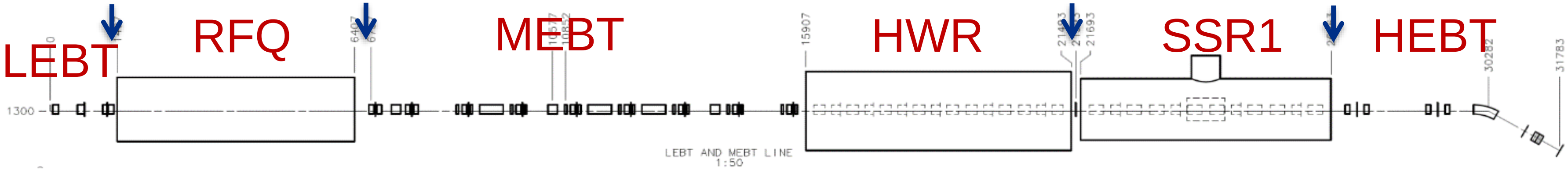
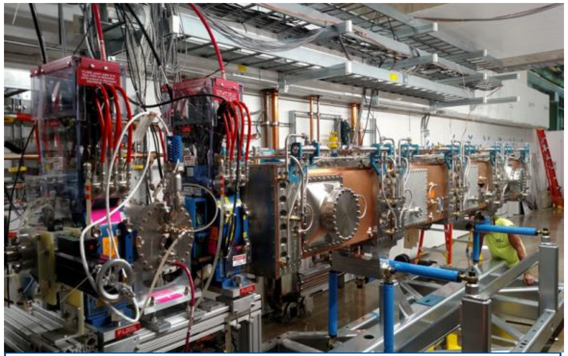
2015 — Now — 2017 — 2018 → 2019

30 keV — 2.1 MeV — 10 MeV — 25 MeV



40 m, ~25 MeV



PIP2IT will address the address/measure the following:

- LEBT pre-chopping: **Demonstrated**
- Vacuum management in the LEBT/RFQ region: **Demonstrated**
- Validation of chopper performance
  - Bunch extinction, effective emittance growth
- MEBT beam absorber
  - Reliability and lifetime
- MEBT vacuum management
- CW operation of HWR
  - Degradation of cavity performance
  - Optimal distance to 10 kW absorber
- Operation of SSR with beam
  - CW and pulsed operation
  - Resonance control and LFD compensation in pulsed operations
- Emittance preservation and beam halo formation through the front end

Collaborators
- ANL: HWR
- LBNL:LEBT, RFQ
- SNS: LEBT
- BARC: MEBT, SSR1, RF
- IUAC: SSR1

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Jacobsen

Cost Range

- Point estimate developed for the June 2015 IPR:

PIP-II	Cost Est	Int'l Contrib	DOE TOTAL
Direct, FY13$	$347M	$108M	$239M
Overheads			$84M
Escalation (to FY20$)			$59M
Contingency			$134M
TOTAL PROJECT COST			$516M

- Propose cost range based on DOE Cost Estimating Guide (DOE G 413.3 – 21) for class 3/4 project maturity
  - Range: -10% to +26%

Mission Need Statement Cost Range: $465M – $650M

- Cost estimate will be updated as part of the development of the Resource Loaded Schedule in advance of CD-1

Schedule

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Lari

Resource Loaded Schedule (RLS) under development in P6

- WBS established
  - Segregates OPC and TEC funds
  - Will support EVMS reporting
- T0, 1, 2, 3, 4 milestones established for project duration
  - I3, I4 milestones: International contributions lie outside DOE scope, but essential to track
- Resource loading for R&D phase in process; major activities have been loaded
  - PIP2IT
  - SSR2, HB650
  - RF Sources
  - Cryogenic distribution syste (PIP2IT)
  - Conventional Facilities

High Level Schedule

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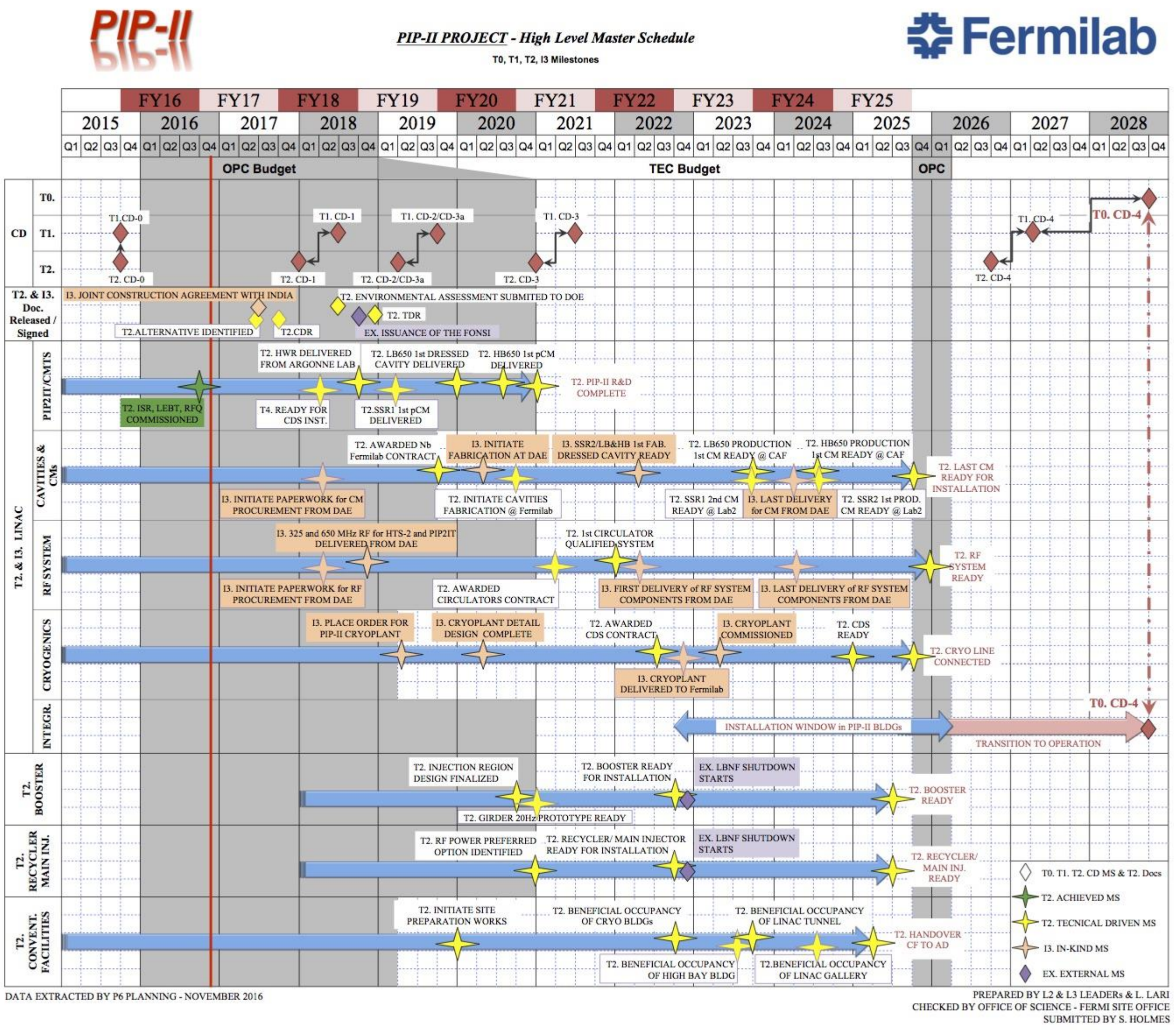
Lari



Schedule/Funding Profile

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Lari

- Currently working with the following profile:

FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25
$15.7	$18.2	$25.0	$40.0	$60.0	$100.0	$100.0	$100.0	$100.0	$91.1

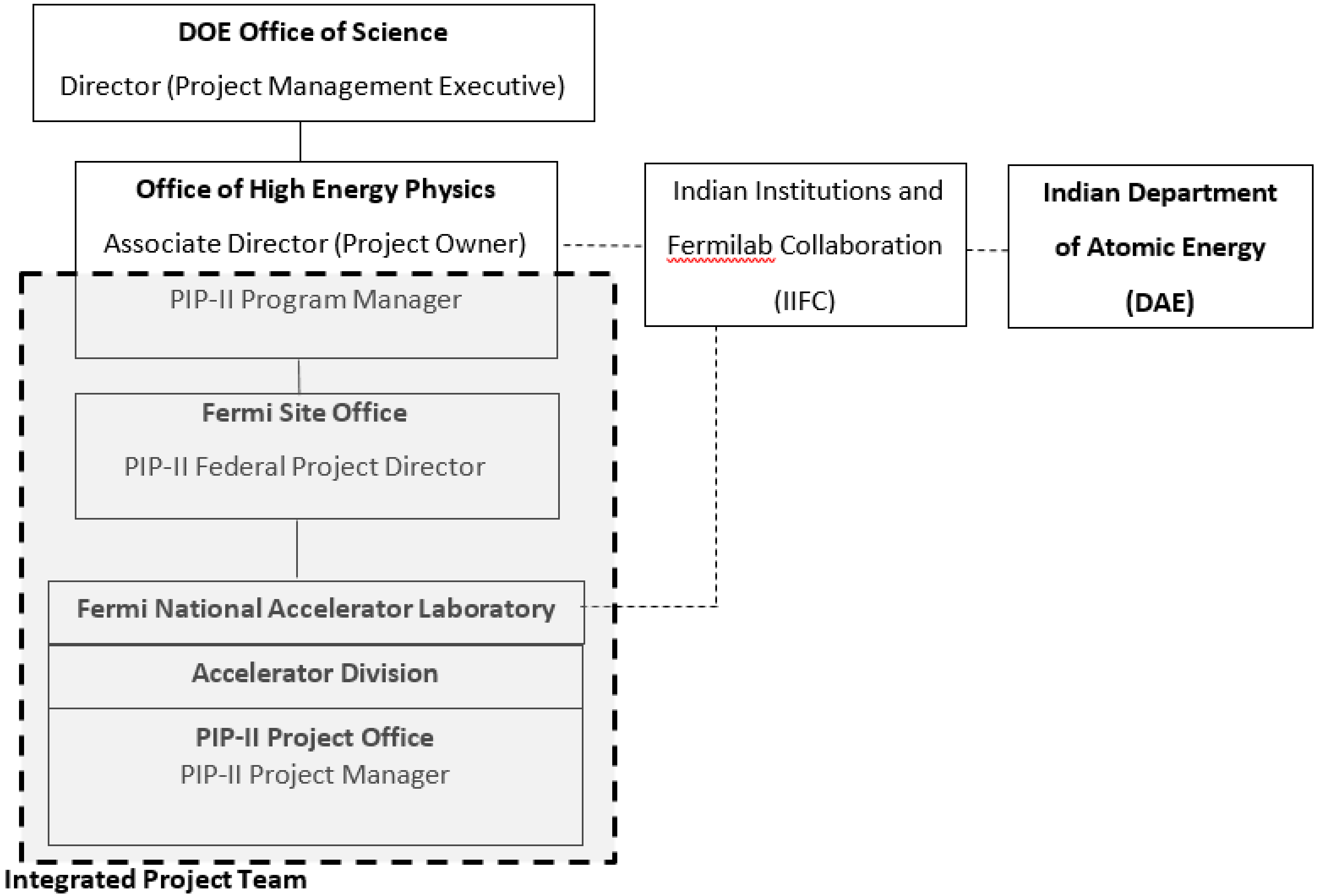
  – Sums to upper cost range

- Associated CD dates:

	MNS	Early	T0/T1
CD-0	Q1FY16	Q1FY16	Q1FY16
CD-1	FY17	Q4FY17	Q4FY18
CD-2/3a	FY18	Q1FY19	Q1FY20
CD-3	FY20	Q4FY20	Q4FY21
CD-4	FY26	Q3FY26	Q1FY29

RLS required to reconcile funding profile and CD dates

Organization



Organization

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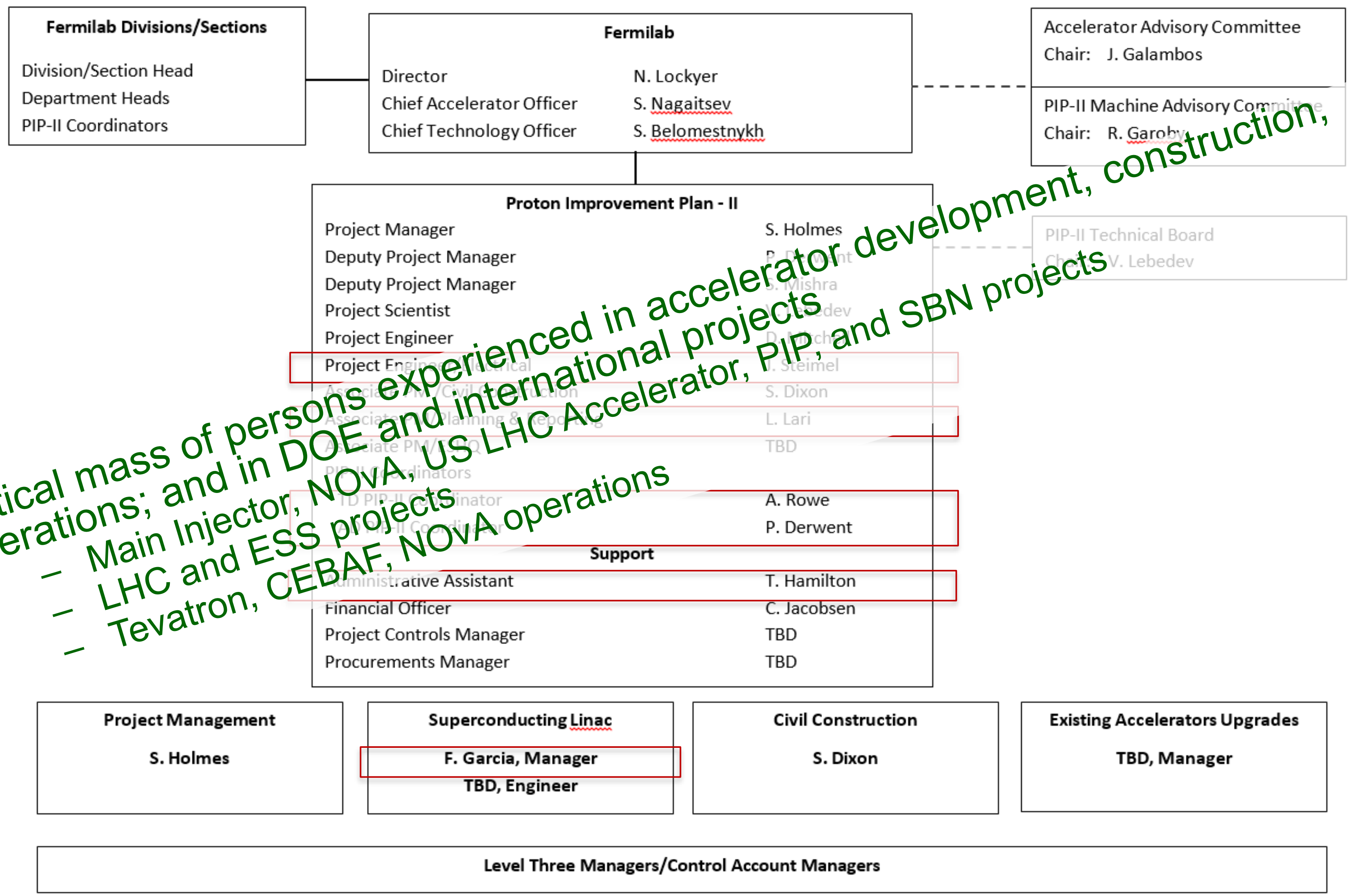
Holmes_pm



Critical mass of persons experienced in accelerator development, construction, operations; and in DOE and international projects

- Main Injector, NOvA, US LHC Accelerator, PIP, and SBN projects
- LHC and ESS projects
- Tevatron, CEBAF, NOvA operations

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Project Strategy/Staffing Requirements

- We are able to generate total resource requirements based on FTE estimates gathered as part of the point estimate*.

	R&D Phase FTE-years				Construction Phase FTE-years		
Resource	**Total Effort**	**Int'l Visitors**	**U.S. Net**		**Total Effort**	**Int'l Visitors**	**U.S. Net**
Accelerator Physicists	25	0	25		41	0	41
Computer Professionals	1	0	1		16	0	16
Conventional Facility Engineers	0	0	0		69	0	69
Cryogenic Engineers	13	8	5		29	10	19
Electrical/Electronics Engineers	9	0	9		13	0	13
Mechanical Engineer	27	8	19		62	10	52
Project Management	35	0	35		126	0	126
RF Engineers	28	8	20		41	10	31
Technicians	41	0	41		83	0	83
TOTAL	**178**	**24**	**154**		**479**	**30**	**449**

*Does not include contingency

- Note: PIP-II current utilization is 53-59 FTE

ESH

Charge Item: #5

Kuchler

- Accelerator Safety Requirements
  - PIP2IT operations conform with laboratory policies and procedures
    - Shielding assessments
    - Interlocked enclosure as required
    - ODH (eventually)
    - Operations permits specify beam intensity authorization
  - Exemption from DOE O 420.2C as a “room-sized accelerator”
- National Environmental Policy Act (NEPA)
  - Monthly strategy meeting established with FSO, ESH Section, and PIP-II Project
  - Environmental Evaluation Notification Form (EENF) drafted and shared with FSO
  - Wetlands delineation study complete (summer 2016)
  - Environmental Assessment (EA) to be launched late FY17/early FY18 (funding dependent)
  - Require FONSI prior to CD-2
- Expect to appoint APM/ESHQ at end of FY2017

Charge Item: #6

Mishra

International Partners/India

- Indian Institutions and Fermilab Collaboration (IIFC) established in 2009
  - Collaborative development of technologies associated with high intensity superconducting proton accelerators
  - Critical to achieving CD-0
- High-level management via two (DOE & DAE) Principal Coordinators, supported by (Fermilab & DAE)Technical Coordinators
- Technical integration of work via Fermilab SPMs and Indian SPCs
  - Weekly teleconferences providing coordination
- Joint R&D document: defines scope of work and deliverables dates
  - Fermilab has proposed revision to the deliverables dates to provide consistency with the current RLS for the R&D phase. Not yet formally accepted by PCs
- Semi-annual reviews of progress
- Seven Indian engineers/scientists at Fermilab for 2-year residencies
  - Plus multiple short term visits
- DAE observers/presenters at this review:
  - Ranajit Kumar/Head, DAE Nuclear Control and Planning Wing
  - Satish Joshi/Head, Proton Linac and Superconducting Cavities Division, RRCAT
  - Srinivas Krishnagopal/High Intensity Proton Linac Section, BARC
  - Vikas Jain/RRCAT, Fermilab Guest Engineer

Other Partners/Europe

- Partnership forming with INFN
  - LB650 prototype cavity design and fabrication
  - Led by INFN/Milano
- UK institutions proposal to STFC for support of LBNF/PIP-II
  - PIP-II: HB650 cryomodules
  - To be led by CI/ASTeC (Daresbury)
- The prospects for European deliverables should be clear later this fall
- Review observer
  - Carlo Pagani (INFN/Milano)

Summary

- PIP-II conceptual design meets the requirements outlined in the Mission Need Statement
  - Concept is mature; will provide ≥1.2 MW of beam power at LBNF/DUNE startup
  - Flexible platform for the future
- R&D activities are aligned with the technical and cost risks associated with the conceptual design
  - PIP2IT retires risks associated with the front end and resonance control
  - SRF program retires risks associated with the superconducting accelerating modules
  - R&D program is run jointly with our Indian collaborators
  - Major accomplishments over the last year
- PIP-II project scope is well defined
  - 800-MeV superconducting linac
  - Modifications to the Booster/Recycler/Main Injector
  - Site layout established
- Resource Loaded Schedule under development
  - WBS and high level milestones established
  - Major R&D elements are incorporated
  - Will provide consistency with funding profile
- Targeting completion of R&D program/initiation of construction (CD-3) in 2020

Summary

- An experienced management team is in place that can be expected to successfully execute the PIP-II project.
  - Recent addition of Associate Project Manager for Planning and Reporting
- Staffing requirements are understood for both R&D and construction phases
  - Competition for resources with other projects will require careful coordination at the laboratory level
- Laboratory safety policies and procedures are governing beam operations at PIP2IT
- NEPA strategy developed and being implemented
  - Wetlands delineation complete
  - EENF in draft
- The collaboration with India/DAE is in the R&D phase
  - Deliverables defined in Joint R&D document
  - Scope aligned with potential DAE contributions to the construction phase
  - Actively managed by DOE/Fermilab/DAE
- Potential for Italy/INFN and/or UK/STFC contribution to the construction phase
- Next Step: CD-1!*

Backups

Design Criteria

- Deliver >1 MW of proton beam power from the Main Injector over the energy range 60 – 120 GeV, at the start of LBNF operations
- Support the ongoing 8 GeV program including Mu2e, g-2, and short-baseline neutrinos
- 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

Goal: Initiate operations in newly-configured complex in ~2025

Cost Estimate

Charge Item: #3

Jacobsen

- Point estimate constructed for June 2015 IPR
  - Estimate starts in FY16
  - Estimate as if everything constructed by Fermilab
  - M&S estimates for all major systems, conventional facilities, project management, and R&D
    - Scope: Superconducting linac + beam transfer line +required modifications to Booster, Recycler, Main Injector
    - Includes component fabrication and installation
    - Estimates in direct FY13$
  - Effort estimated for above in person-years by skills type
    - Includes EDIA
    - Translated to SWF at Fermilab FY13 labor rates
  - Remove costs for international contributions
  - Apply published Fermilab overhead rates
  - Apply escalation of 18.2% (FY13 to FY20 @ 2.4%/year)
  - Apply across-the-board 35% contingency

Future Directions

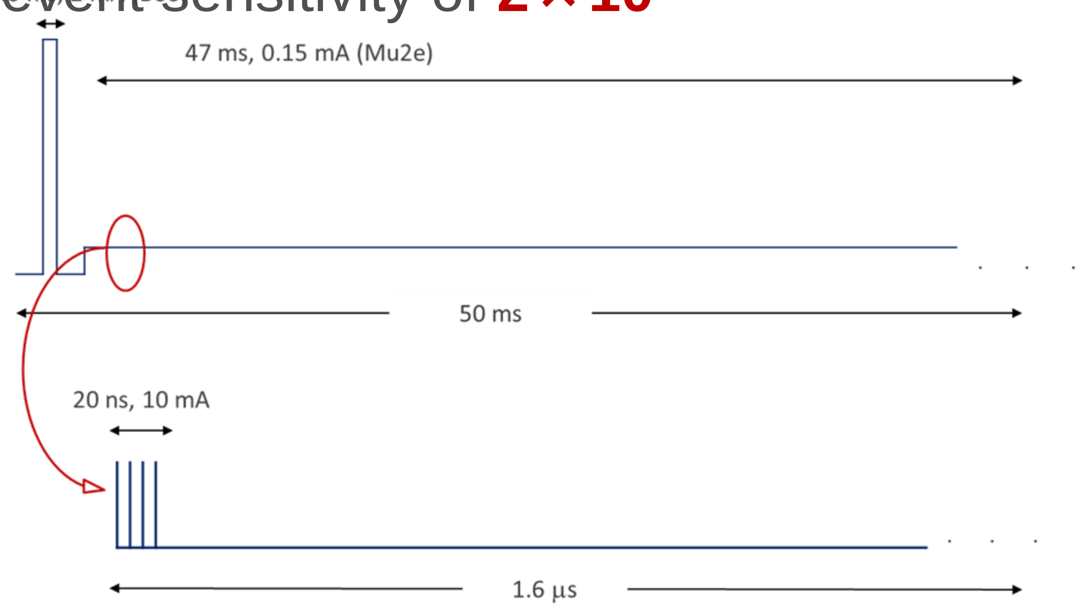
- The configuration and siting of the PIP-II linac are chosen to provide opportunities for future performance enhancements to the Fermilab proton complex
  - >2 MW to LBNF
  - 100's kW for a rare processes program
    - CW capability at 0.8 – 3 GeV
  - Front end for a muon-based facility
- The natural next steps would be upgrading the PIP-II linac to CW operations and replacement of the Booster with higher performance accelerator (PIP-III)

PIP-II and Next Generation Mu2e

- India is planning on providing, as an in-kind contribution, a cryoplant of sufficient capacity to support CW operations
- PIP-II front end can produce arbitrary bunch patterns subject to the following contraints:
  - Peak current ≤10 mA
  - Average current ≤2 mA
- This provides an opportunity for delivering 800-MeV protons directly from the SCL to a second generation Mu2e

PIP-II and Next Generation Mu2e

- Possible beam structure:
  - Beam pulse length: ~20 nsec
  - Pulse repetition period: 1.6 μsec
  - Beam power: **100 kW**
  - Three-year run achieves single event sensitivity of **2×10^{-18}**



PIP-III (~2030)

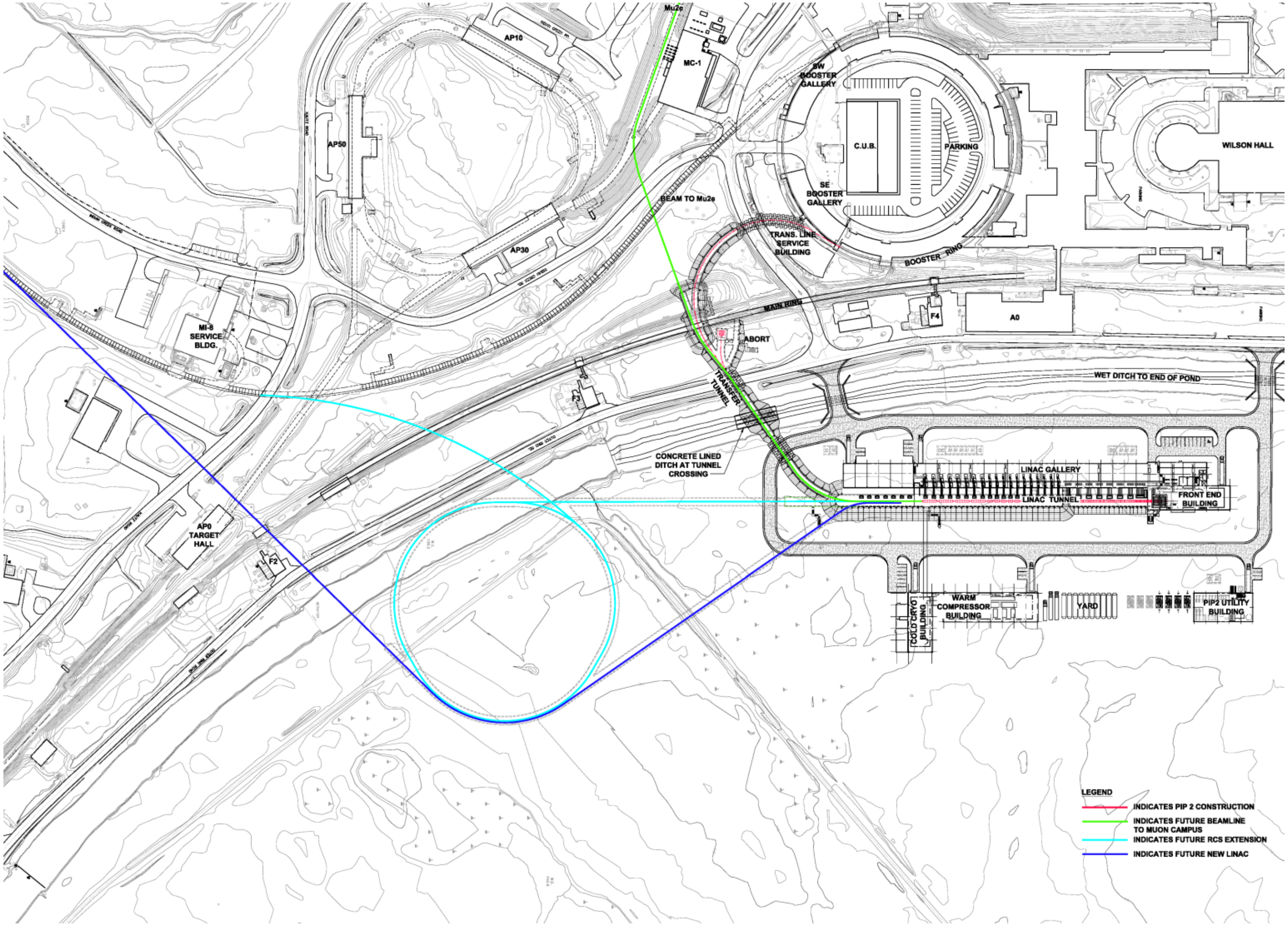
- 2.4 MW requires 1.5×10^{14} particles from MI every 1.2 s @ 120 GeV
  - Every 0.6 sec @ 60 GeV
- Slip-stacking in Recycler is not an option at these intensities
  - Need to box-car stack 6 × 2.5×10^{13} protons in less than 0.6 sec
  - >10 Hz rep-rate
  - Or inject a long (linac) pulse directly into Main Injector
- Booster is not capable of accelerating 2.5×10^{13} no matter what the injection energy, or how it is upgraded: many issues…
- Achieving 2+ MW will require replacement of the Booster with either a 6-8 GeV pulsed linac or a rapid cycling synchroton (RCS) fed by a ≥1.5 GeV linac
- PIP-III: 20 Hz operations of a new RCS at ~2.5×10^{13} ppp
  - Deliver 2.4 MW @ 60-120 GeV from the Main Injector to the LBNF beamline in support of the DUNE experiment
  - Deliver up to 80 kW @ 8 GeV to support g-2, Mu2e, and short-baseline neutrinos
  - Deliver ~100 kW @ 800 MeV to support a second generation Mu2e

Possible Parameters for post-PIP-II Complex

	RCS	Linac	
Proton Source			
Particle Type	p	H-	
Beam Kinetic Energy	8.0	8.0	GeV
Protons per Pulse	2.5×10^{13}	1.5×10^{14}	
Beam Pulse Length	0.0016	10	msec
Pulse Repetition Rate	20	3.33	Hz
Pulses to Recycler	6	NA	
Pulses to Main Injector	NA	1	
Beam Power at 8 GeV (Total)	640	640	kW
Beam Power to Main Injector*	160/320	160/320	kW
Beam Power Available to 8 GeV Program*	480/320	480/320	kW
Main Injector			
Beam Kinetic Energy*	120/60	120/60	GeV
Main Injector Protons per Pulse	1.5×10^{14}	1.5×10^{14}	
Main Injector Cycler Time*	1.2/0.6	1.2/0.6	sec
LBNF Beam Power*	2.4/2.4	2.4/2.4	MW

* First number refers to 120 GeV MI operations; second to 60 GeV

PIP-III (~2030)



Mu2e
MC-1
AP10
AP50
AP30
SW BOOSTER GALLERY
C.U.B.
PARKING
SE BOOSTER GALLERY
WILSON HALL
BEAM TO Mu2e
TRANS. LINE SERVICE BUILDING
BOOSTER RING
MAIN RING
F4
A0
MI-8 SERVICE BLDG.
ABORT
TRANSFER TUNNEL
F3
WET DITCH TO END OF POND
CONCRETE LINED DITCH AT TUNNEL CROSSING
LINAC GALLERY
LINAC TUNNEL
FRONT END BUILDING
AP0 TARGET HALL
F2
WARM COMPRESSOR BUILDING
COLD CRYO BUILDING
YARD
PIP2 UTILITY BUILDING
LEGEND
INDICATES PIP 2 CONSTRUCTION
INDICATES FUTURE BEAMLINE TO MUON CAMPUS
INDICATES FUTURE RCS EXTENSION
INDICATES FUTURE NEW LINAC