Proton Improvement Plan(s) at Fermilab

Milorad Popovic
Fermilab

NuFact 2015

Outline

- Steve Holmes presentation at DOE Independent Project Review of PIP-II, 16 June 2015
- My suggestions, mostly about siting from ~June 2012

Fermilab

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

Introduction to PIP-II

Steve Holmes

DOE Independent Project Review of PIP-II

16 June 2015

Charge Elements

1. Is the proposed technical concept, including both new construction and modifications to existing infrastructure, likely to satisfy the P5 recommendation? Are there major alternative choices? How well understood are the international in-kind contributions?
2. Is the presented cost range based on sound reasoning, consistent with experience of similar projects? Is it likely to bound the actual cost when PIP-II is built?
3. Does the scheduling strategy fit with other major projects at Fermilab?
4. Is there significant R&D that still needs to be carried out in order to implement the proposed concept? Are all the significant technical and cost risks identified? Does the laboratory have a plan, and sufficient resources, to complete the R&D in a timely manner?
5. Does the management team possess the requisite expertise and experience? Is it appropriately organized and staffed to initiate PIP-II activities?

Outline

- Design Criteria
- Proposed Technical Approach
- Cost Range
- Project Strategy
- International and National Partners
- Organization

Charge Item: #1

Rameika

Design Criteria

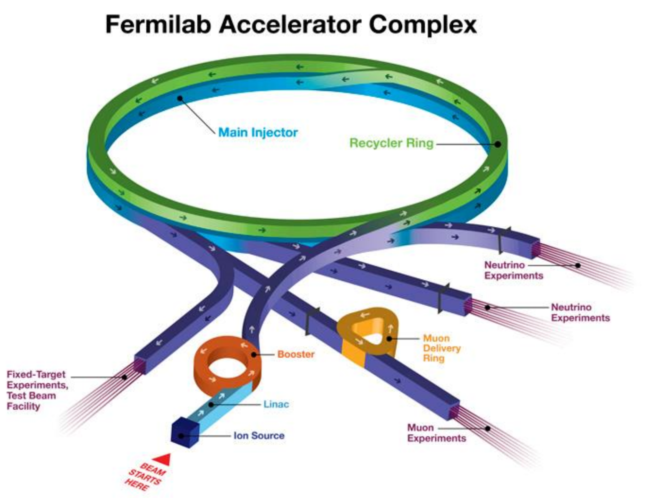
The goal of Proton Improvement Plan-II (PIP-II) is to support long-term physics research goals outlined in the P5 plan, by delivering increased beam power to the U.S. neutrino program and providing a platform for the future

- 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 current 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

Proposed Technical Approach

- The Fermilab complex will be capable (in 2016) of delivering protons at both 8 and 120 GeV, in support of the neutrino and muon programs:
  - Booster: 4.3×10^{12} protons @ 8 GeV @ 15 Hz = 80 kW
  - MI: 4.9×10^{13} protons @ 120 GeV @ 0.75 Hz = 700 kW

- Limitations
  - Booster pulses per second (15 Hz)
    - Total power available to 8 GeV program limited by the repetition rate
  - Booster protons per pulse
    - Limited by space-charge forces at Booster injection, i.e. the linac energy, and total beam loss
  - Reliability
    - Linac/Booster represent a non-negligible operational risk



Fermilab PIP-II

Proposed Technical Approach

- Construct a modern 800-MeV superconducting linac, of CW capable components, operated initially in pulsed mode
  - Ameliorate space-charge forces at Booster injection, allowing an increase Booster/Recycler/Main Injector per pulse intensity of ~50%
- 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 or,
  - Provide factor of 2.5 increase in power to 8 GeV program

Proposed Technical Approach

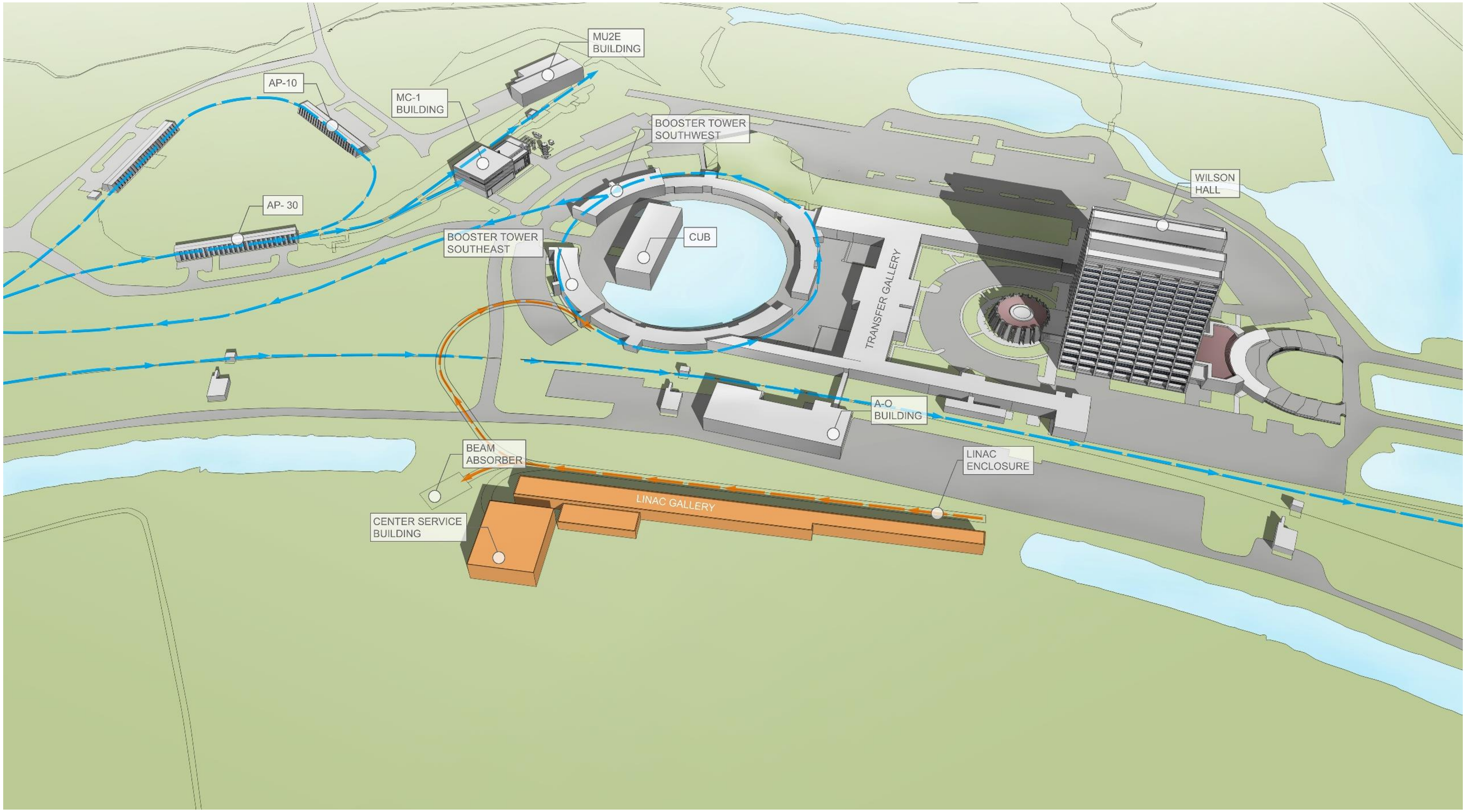
- This approach…
  - Builds on significant existing infrastructure
  - Capitalizes on major investment in superconducting RF technologies
  - Removes the existing 400 MeV linac from service, thereby eliminating significant operational risks
  - Has attracted significant international investment in the Fermilab accelerator complex
  - Provides siting consistent with eventual replacement of the Booster as the source of protons for injection into Main Injector (PIP-III)
  - Provides a platform for maintaining U.S. leadership on the intensity frontier for decades.

⇒ **This concept has been endorsed by P5**

Charge Item: #1

Lebedev

Proposed Technical Approach/Site Layout



Fermilab PIP-II

Proposed Technical Approach/Performance Goals

Charge Item: #1

Lebedev

Performance Parameter	PIP (2016)	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 (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	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

Proposed Technical Approach/ Booster/Recycler/MI Requirements

Charge Item: #1

Lebedev

- Booster
  - New injection region to accept 800 MeV H^- and enable transverse beam painting
  - 20 Hz operations
  - Upgrades to damper and collimator systems
  - LCW system upgrades for reliability
- Recycler
  - RF upgrade for slip-stacking at cycle times as low as 0.7 sec (60 GeV)
- Main Injector
  - RF power upgrade
  - γ_t jump system

Project Strategy

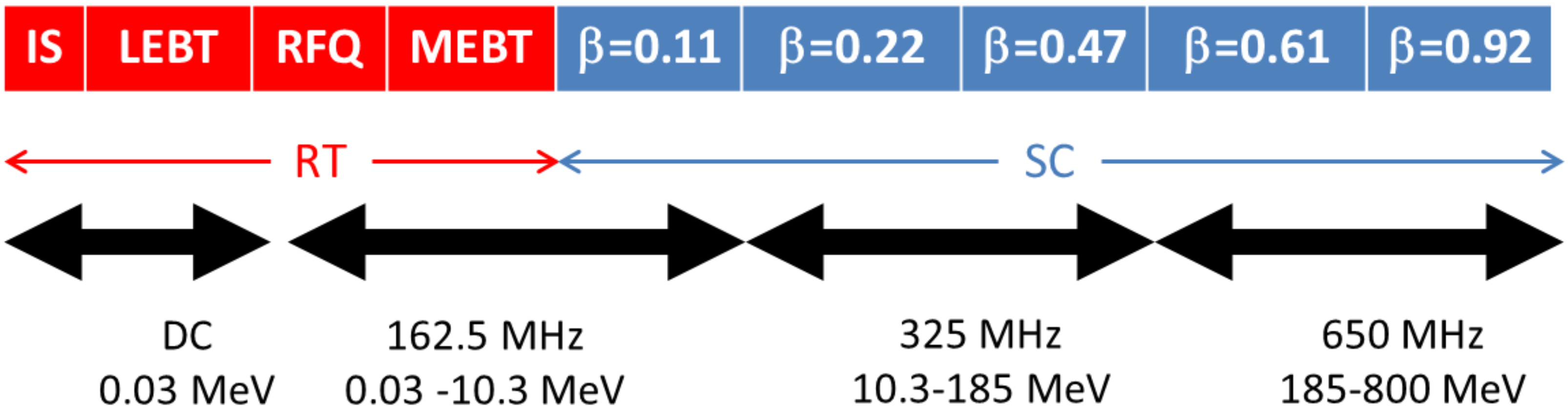
- PIP-II will be executed as a DOE 413.3b project
- Guidance: provide >1MW capability in 2024, with a path to >2MW in 2030
- Strategy
  - Develop/evolve concepts aligned with community needs
  - Undertake R&D on critical technologies
  - Retain documentation in a state of readiness
  - Coordinate with other Fermilab projects
- Status
  - P5 endorsement of PIP-II as a key element in the U.S. neutrino program
  - Reference Design Report defining concept for meeting design criteria, and providing context for R&D
  - R&D program targeting major technical/cost risk elements
  - P2MAC review of RDR and R&D program (March)
  - Strong collaboration with Indian and U.S. laboratories
  - Project Office established within the Accelerator Division
  - Management team in place capable of successfully moving PIP-II through development and construction

Project Strategy/R&D

- Goal is to mitigate risk: Technical/cost/schedule
- Technical Risks
  - Front End
    - Delivery of beam with required characteristics and quality
  - Operations of (high Q_0) 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
    - Beam loss/activation
  - Development of requisite capabilities of international partners
- Cost Risks
  - Superconducting RF
    - Cavities, cryomodules, RF sources represent a major portion of construction costs
- Goal: Be prepared for a construction start in 2019
  - R&D deliverables milestones established

Proposed Technical Approach/Technology Map

Charge Item: #4



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*

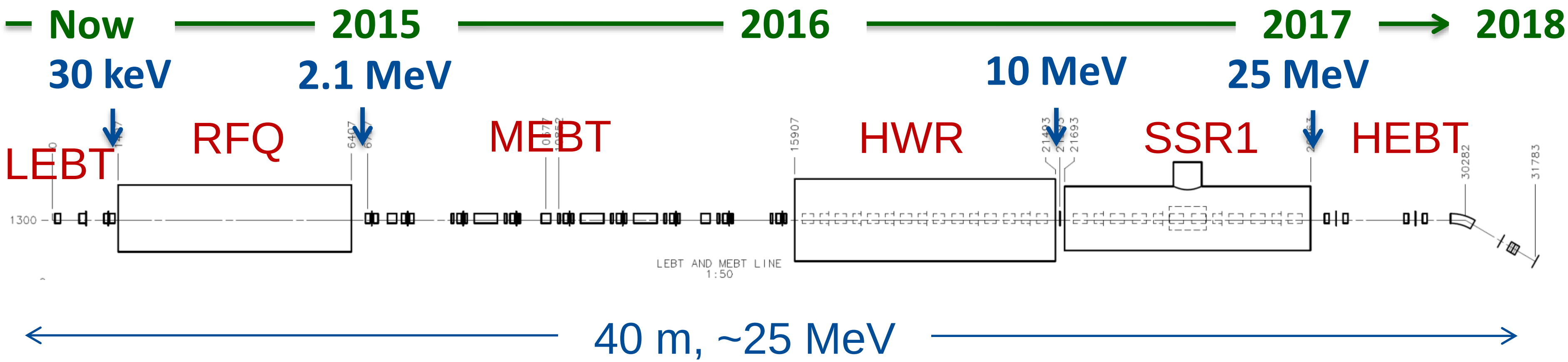
*Warm doublets external to cryomodules

All components CW-capable

Project Strategy/PXIE (PIP-II Injector Experiment)

Charge Item: #4

Shemyakin



PXIE 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
- IUAC: SSR1

Fermilab PIP-II

Charge Item: #4

Yakovlev

Project Strategy/SRF Development Status

Cavity	Frequency	Cavity Type	Beta	Collaboration?	Cavity EM Design Complete	Cavity Mech Design Complete	Single Cell / Prototype Ordered	Full Cavity Prototype Received	Prototype Tested	Cavities for CM Ordered	Cavities for CM Received	Cavities for CM Tested	Cavities for CM Dressed	CM Cold Mass Design	CM Parts Ordered	# of CM Assembled	Est % complete
Half Wave Resonator (HWR)	162.5 MHz	1-HWR CW	0.11	ANL	yes	yes	yes	yes	yes	9	9	2	2	yes	yes	15%	70
Single Spoke Resonator 1 (SSR1)	325 MHz	1-spoke CW	0.22	India	yes	yes	2	2	2	10	10 +2	10	6	80%	70%	not started	75
Single Spoke Resonator 2 (SSR2)	325 MHz	1-spoke CW	0.47	India	yes	yes	not started	not started	not started	not started	not started	not started	not started	not started	not started	not started	10
Low Energy 650 (LE 650)	650 MHz	5-cell CW	0.6	India, JLAB	yes	yes	5	not started	not started	not started	not started	not started	not started	not started	not started	not started	10
High Energy 650 (HE 650)	650 MHz	5-cell CW	0.9	India	yes	yes	5 of 10	4	not started	9	4	not started	not started	5%	not started	not started	20

Legend: green = done, yellow = in process

Project Strategy/PIP-II & LCLS-II

- Fermilab will be designing & constructing 20 cryomodules and the cryogenic distribution systems for the LCLS-II project
  - At the end of this effort PIP-II will inherit a work force and associated infrastructure capable of producing cryomodules efficiently
- The PIP-II R&D and LCLS-II construction phases will overlap in time
  - Lab 2 currently being configured for assembly of SSR1 CM
  - HB650 CM can be assembled either at Lab 2 or in ICB-A
  - Cryo distribution at PXIE scheduled for design in FY16, implementation in FY17
  - Will rely on reassignments from completed projects/programs, Indian engineers/scientists, contract technicians to meet personnel needs
- The PIP-II construction is scheduled to provide a continuity of effort, and an effective transition, from LCLS-II to PIP-II

International Partners/India

Charge Item: #1

Mishra

- Indian Institutions-Fermilab Collaboration (IIFC) created in fall 2007
  - Signatories: Fermilab, BARC (Mumbai), IUAC (Delhi), RRCAT (Indore), VECC (Kolkata)
  - Encompasses R&D on
    - Superconducting accelerating modules
    - HLRF and LLRF
    - Cryogenics
    - Instrumentation
    - Magnets
- U.S. DOE-Indian DAE Implementing Agreement "for Cooperation in the Area of Accelerator and Detector Research & Development for Discovery Science" signed July 2011
- Annex I to the DOE-DAE Implementing Agreement signed in January 2015
  - Enables significant Indian contribution to PIP-II R&D and construction
  - Up to $200M (direct) authorized under the 12th and 13th Indian Plans
    - $60/140M
  - Calls for joint DOE-DAE evaluation of R&D accomplishments in 2018, prior to initiation of 13th plan.
- Pitamber Singh (BARC) participating in this meeting as an official observer

Charge Item: #1
Mishra

Other Partners/Europe & U.S.

- Early-stage discussions about a possible European in-kind contribution
  - Discussers: Fermilab, CEA/Saclay, Orsay, INFN, STFC
  - Focus on superconducting elliptical cavities/cryomodules, but other areas open for discussion
- Review observers: Olivier Napoly (CEA/Saclay), Carlo Pagani (INFN/Milano), Juergen Pozimski (ICL/STFC)
- Exploratory discussions about possible U.S. laboratory contributions
  - Discussers: Fermilab, ANL, LBNL, SLAC
  - Focus on SRF support, LLRF, and HLRF, but other areas open for discussion
  - Review observers: Peter Ostroumov (ANL), Wim Leemans (LBNL), Michael Fazio (SLAC)

Charge Item: #5

Holmes_2

Organization

Fermilab

Laboratory Director	N. Lockyer
Chief Accelerator Officer	S. Nagaitsev

Accelerator Advisory Committee
Chair: J. Galambos

PIP-II Machine Advisory Committee
Chair: R. Garoby

Proton Improvement Plan - II

Project Manager	S. Holmes
Deputy PM/Development & Accelerator Integration*	P. Derwent
Deputy PM/Construction Coordination	S. Mishra
Project Scientist	V. Lebedev
Project Engineer	D. Mitchell
SRF Program Manager	H. Padamsee
Associate PM/Planning & Reporting	Offer Extended
Associate PM /Civil Construction	S. Dixon
Associate PM/ESHQ	TBD
Technical Division Coordinator	V. Yakovlev
Procurements Manager	TBD
Financial Officer	C. Jacobsen
Experimental Liaison	R. Tshcirhart

*Joint appointment as AD/PIP-II Department Head

Project Management	Superconducting Linac	Civil Construction	Existing Accelerator Upgrades
S. Holmes	TBD	S. Dixon	TBD

Fermilab PIP-II

Charge Item: #5

Holmes_2

Organization

- The project organization is largely populated
  - Vacant positions will be filled as the role becomes needed
- Critical mass of persons experienced in accelerator development, construction, operations; and in DOE projects
  - Project Manager and Commissioning Czar from the Main Injector Project
  - Associate Project Manager for Accelerator Upgrades and Construction Coordinator from the NOvA Project
  - Commissioning and operations experience from Tevatron, NuMI, NOvA, CEBAF
  - Experienced engineers from the US/LHC Accelerator Project
- Responsibilities, authorities, and accountabilities drafted for all senior management positions

Summary

- PIP-II design concept is responsive to the performance goals established by P5.
  - Design concept described in the Reference Design Report
  - Reviewed by P2MAC
- Potential international in-kind contributions have been identified and are significant, representing ~30% of PIP-II cost.
  - The India collaboration is formalized
  - A potential European collaboration is in the discussion stage.
- A cost range has been established starting with a point estimate for all technical systems, civil construction, R&D, and project management, and incorporating international contributions.
- The cost range is constructed from the point estimate based on DOE costing guidance for a concept of this maturity.
- The proposed cost range is $465-695M

Summary

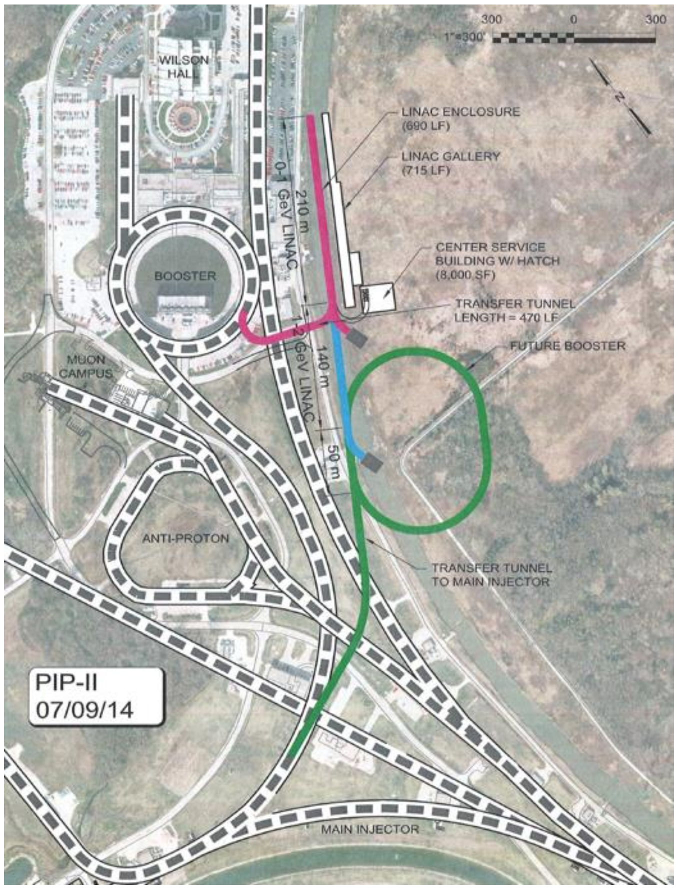
- The PIP-II development and construction schedule is matched to the requirement of providing >1 MW of beam power by 2024, and is consistent with the schedule for the Fermilab contribution to LCLS-II.
- R&D activities are aligned with the technical and cost risks associated with the concept described in the RDR.
  - PXIE is retiring risks associated with the front end
  - The SRF program is retiring risks associated with the superconducting accelerating modules
  - The R&D program is run jointly with our Indian collaborators
  - The R&D program should be completed in 2019
- Staffing requirements are understood for both the R&D and construction phases, and mesh with the LCLS-II plan.
- An experienced management team is in place that can be expected to successfully execute the PIP-II project.

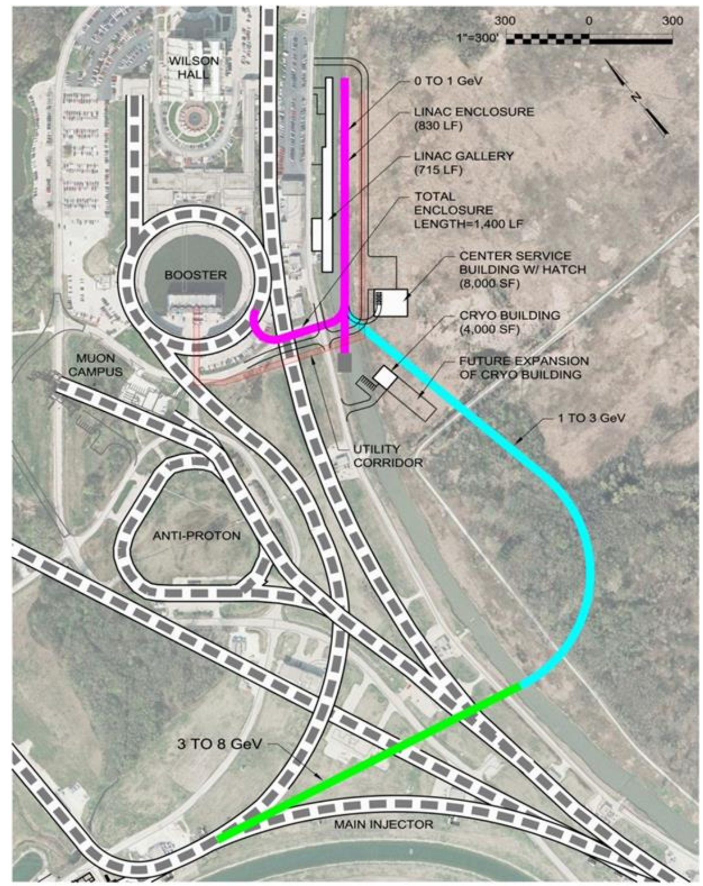
Future Directions

- 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)

Flexible Platform for the Future

- Opportunities for Booster replacement include full energy (8 GeV) linac or RCS





Backups

Charge Item: #4

National Partners

- Collaboration MOU in place since 2009 (Project X era)
  - Development phase (defined as through CD-2)
  - Signatories

ANL	MSU	UTenn
BNL	NCSU	TJNAF
Cornell	ORNL/SNS	SLAC
Fermilab	PNNL	ILC/ART
LBNL		

- A collaboration of this size is not required to construct an 800 MeV linac on the Fermilab site
- Several of these institutions signed on for a neutron-based program that would be enabled by Project X
- Most active at this time are ANL and LBNL
- Exploratory discussions with ANL, LBNL, SLAC for construction phase

Charge Item: #2

Mitchell

Cost Range

- Point estimate:
  - 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

Fermilab

PIP-II

Cost Range

Charge Item: #2
Mitchell

- Point estimate:

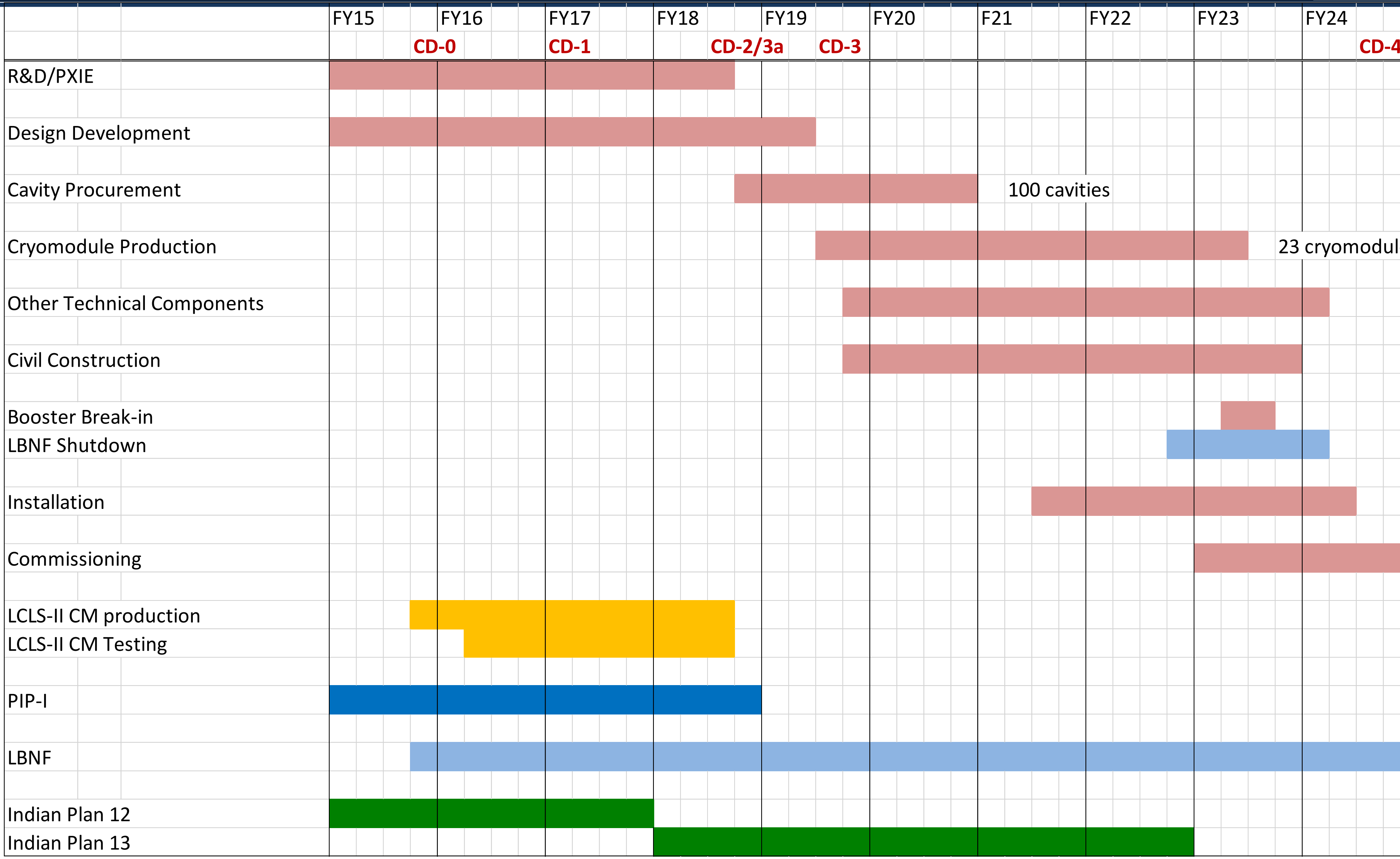
PIP-II	Cost Est	Int'l Contrib	DOE TOTAL
Direct, FY13$ (M)	$347M	$108M	$239M
Overheads			$84M
Escalation			$59M
Contingency			$134M
TOTAL PROJECT COST			$516M

- Propose cost range based on DOE Cost Estimating Guide (DOE G 413.3 – 21) for class 3/4 project maturity
  - Range: -10% to +35%

Proposed Cost Range: $465M – $695M

Project Strategy/Preliminary Schedule

Charge Item: #3



Project Strategy/Staffing Requirement

Charge Item: #3,4

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

	R&D Phase			Construction Phase		
	FTE-years			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**

Project Strategy/Resource Plan

- We understand total resources required and believe it is reasonable to be able to complete development and construction of PIP-II over the period 2016-2024
- Approximate funding plan ($ amounts in millions):

	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	TOTAL
R&D	$16.0	$24.0	$30.2	$18.7	$0.0	$0.0	$0.0	$0.0	$0.0	$88.9
Civil	$1.0	$1.5	$11.0	$20.0	$36.0	$30.0	$14.0	$6.5	$0.0	$120.0
Management	$1.8	$5.0	$8.5	$9.2	$10.0	$10.3	$10.8	$10.8	$8.5	$74.9
Construction	$0.0	$0.0	$0.0	$33.0	$33.0	$40.0	$55.2	$55.8	$15.3	$232.3
Carryover	$0.7	$1.7	$12.0	$11.1	$12.1	$11.8	$11.8	$8.7	$0.0	
TOTAL (new BA)	$19.5	$31.5	$60.0	$80.0	$80.0	$80.0	$80.0	$70.0	$15.1	$516.1

Project Strategy/FY2016-17

Charge Item: #3,4

Anderson/Kuchler

- Fill out Project organization
- Achieve CD-1
  - CDR, cost range estimate, RLS
  - Other supporting documentation
- Initiate work toward CD-2
  - Detailed design work
  - Site characterization
  - Complete NEPA documentation and permitting
- Advance PXIE
  - Commission RFQ with beam
  - Complete installation of MEBT at PXIE
    - Includes all focusing and correction magnets from BARC
  - Deliver and characterize beam through MEBT
  - Deliver HWR and SSR1 prototype cryomodules
  - Complete cryogenic infrastructure
- Complete HB650 cryomodule design (w/ India) and initiate procurements
- Integrate seven Indian engineers arriving for two year residencies

Questions ?

If You Build It, They Will Come

8GeV CW Linac:

A Staged Approach

Milorad Popovic, Fermilab

June 26, 2012

CW Proton Linac on the Fermilab site

•**The linac** is segmented in three parts, based on output energy: 1GeV, 3GeV and 8GeV.

•It is located near the existing Fermilab Proton Source; each section can be used as soon as it is commissioned.

•The suggested sitting and segmentation allow for the construction to start immediately.

•Additional benefits come from the fact that the present linac (the oldest machine in the Fermilab complex) gets replaced. As a result, the Proton Source would preserve its functionally for many years in the future.

• **A storage ring** in the Fermilab Booster tunnel is used to accumulate 1-GeV beam from the ProjectX H-Linac.

• The ring is made out of permanent magnets, and its primary purpose is to accumulate beam for the Booster.

•The ability to chop bunch-by-bunch in the linac creates many opportunities to package beam for different users in the proposed storage ring. For example, the stored beam can be used for:

•Pulsed Spallation Source,

•for a muon-to-electron conversion experiment based on a 100-Hz FFAG ring (Prism/Prime),

•for a pulsed beam for Short Baseline Neutrino Experiments.

These specially packaged beams can be used either directly or after acceleration in the Booster.

Concept creates opportunities for substantial benefits and costs reductions for mu2e/g-2.

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This Talk is Based on two Notes

A Concept: 8GeV CW Linac, Staged Approach

Milorad Popovic (with lot of help from Chuck)

- http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=4108

A 1-GeV Accumulator Ring in the Booster Tunnel

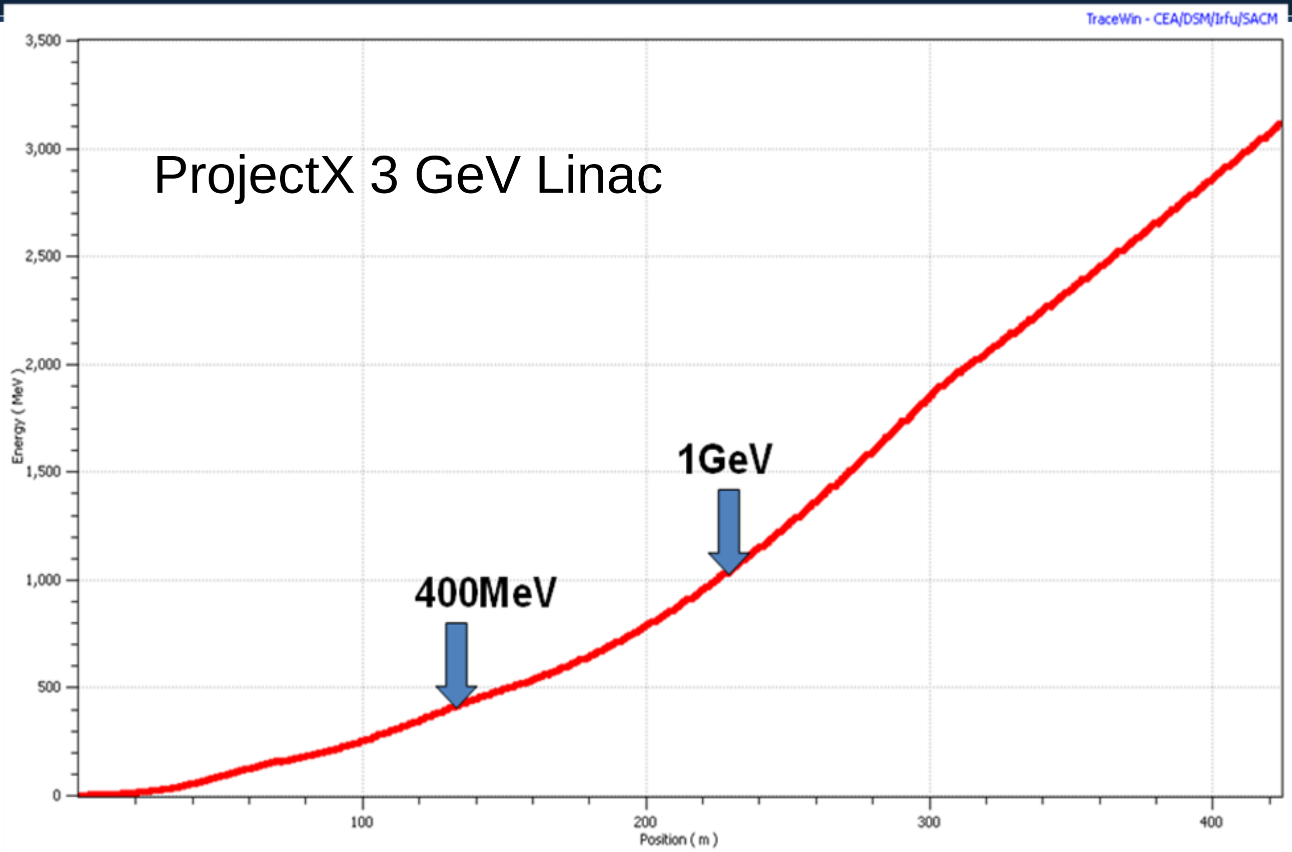
M. Popovic, B. C. Brown, D. Harding, T. Nicol, F. Ostiguy and J. Volk, Fermilab
and C. Ankenbrandt, Muons, Inc.

- http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=4139

The Linac is as defined on the official ProjectX Web Page (RFQ162MHz, HWR162MHz ,…)

8 GeV Linac, New Siting

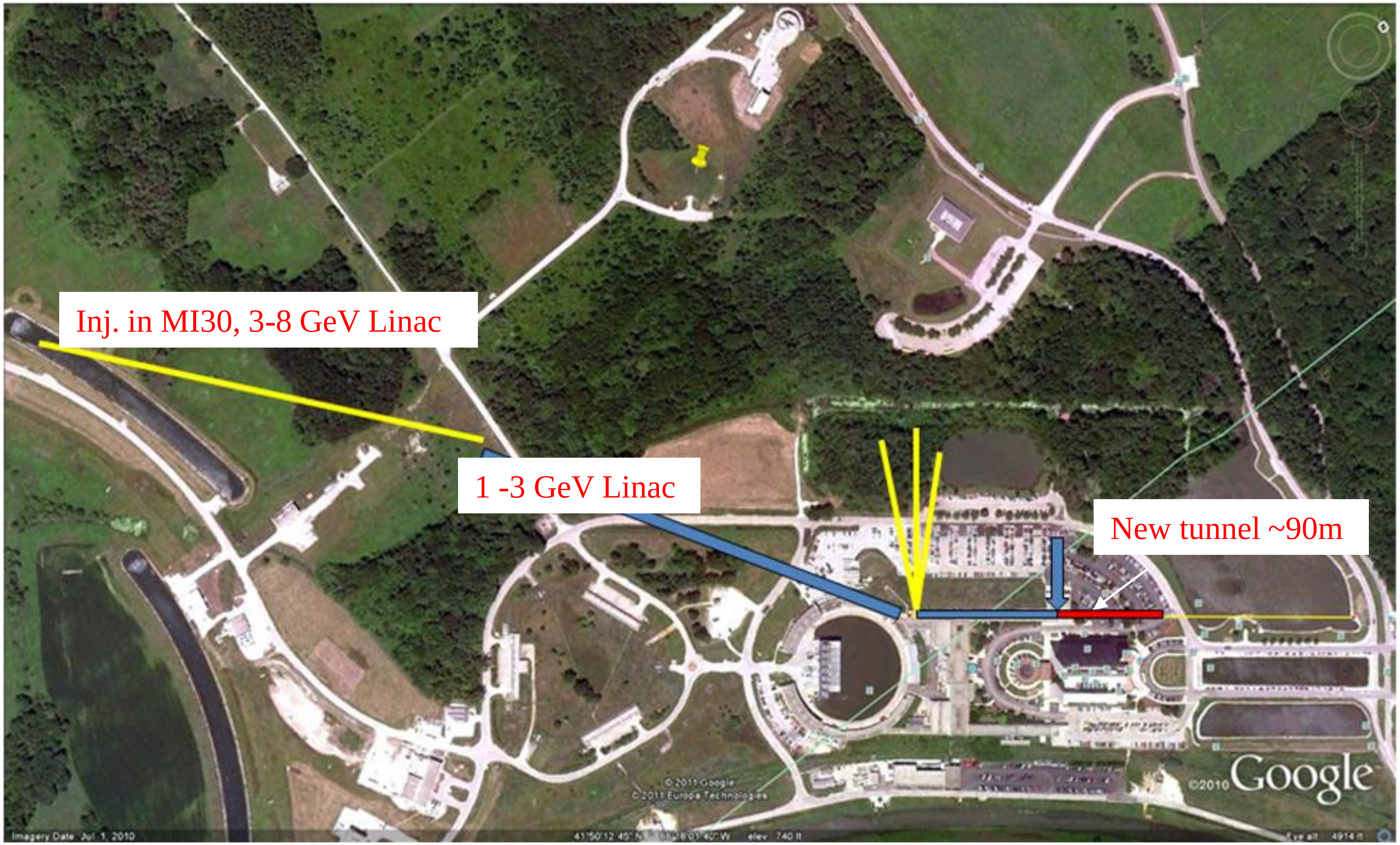
3 GeV ProjectX, Energy & Length



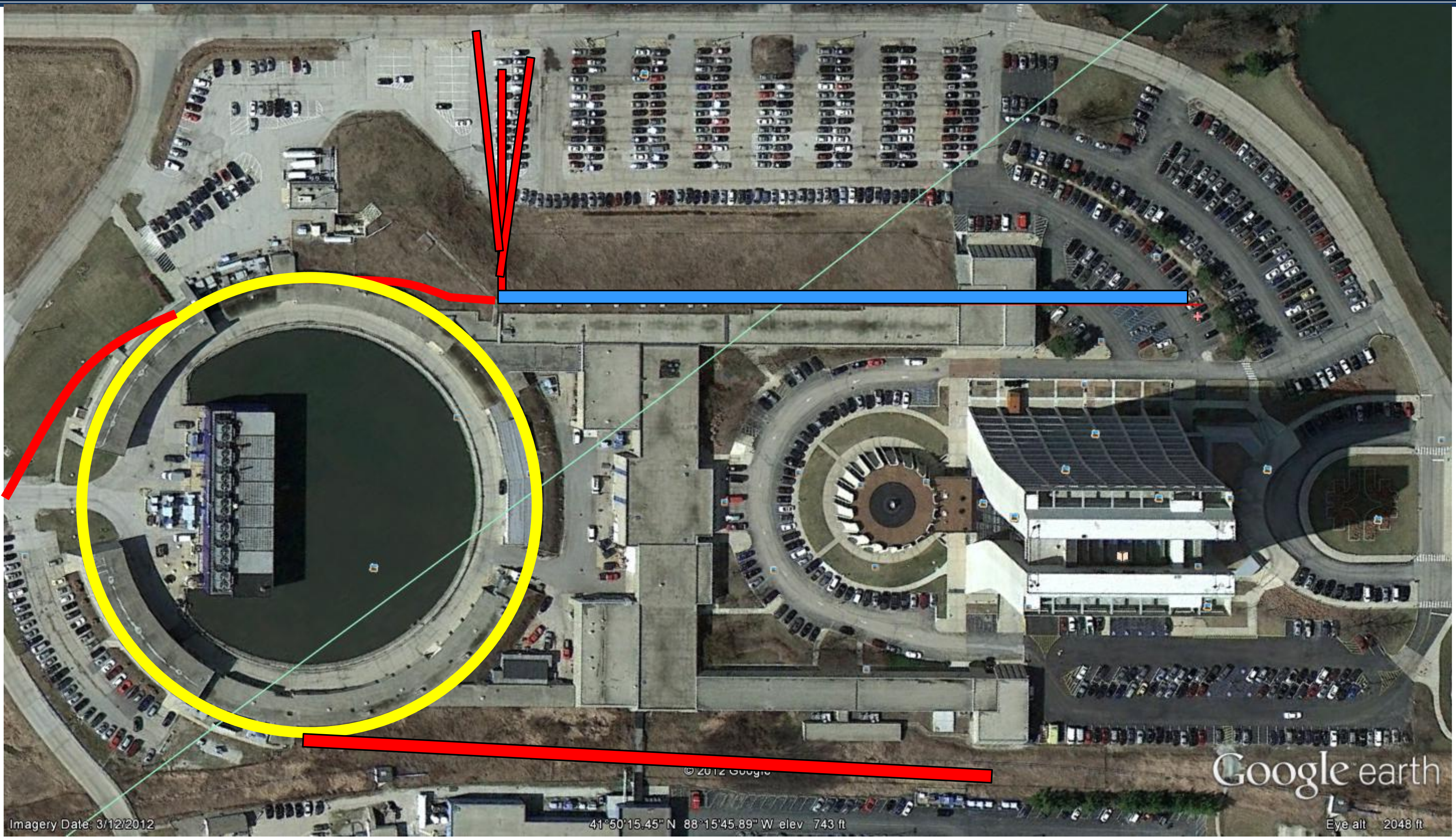
Existing 400MeV linac is ~150 meters long + ~30 m Preacc Building

M. Popovic

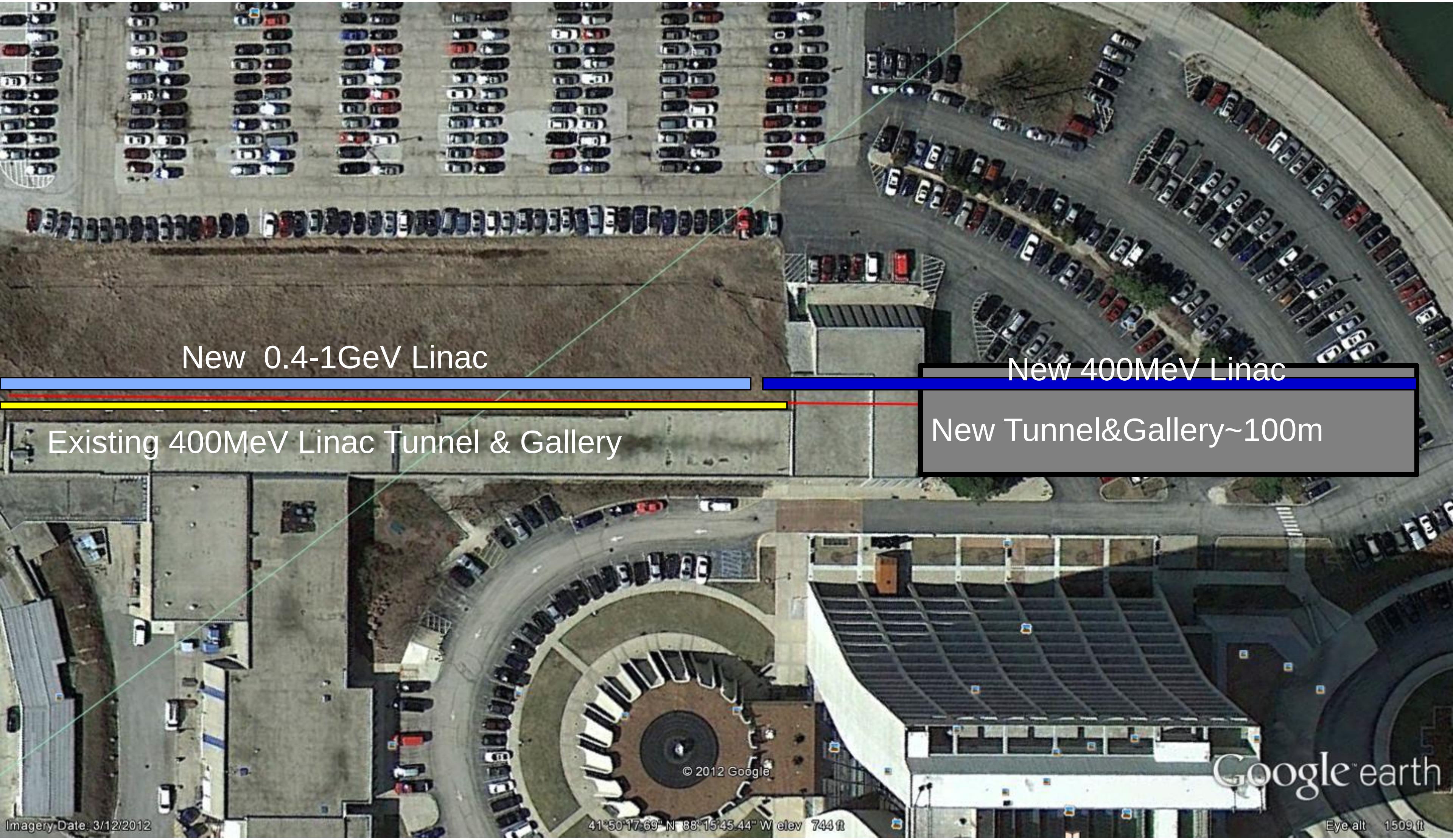
Add 90 m to the existing Linac tunnel at the Low Energy End



Stage 1, 1 GeV Linac & Storage Ring



1 GeV Linac



New 0.4-1GeV Linac
New 400MeV Linac
New Tunnel&Gallery~100m
Existing 400MeV Linac Tunnel & Gallery
© 2012 Google
Google earth
Imagery Date: 3/12/2012
41°50'17.69" N 88°15'45.44" W elev 744 ft
Eye alt 1509 ft

Booster Operation: from 0.4 to 1 GeV

• At present, 400MeV H- beam from the linac is transported along a ~40 m transfer line to the Booster tunnel and ~5E12 protons are injected.

•Peak current is ~30mA and injection lasts for 12 Booster turns or 26 us (total injection time 12*2.2us).

•Present transfer line has two 12-degrees vertical bending magnets and two 10-degrees horizontal bending magnets.

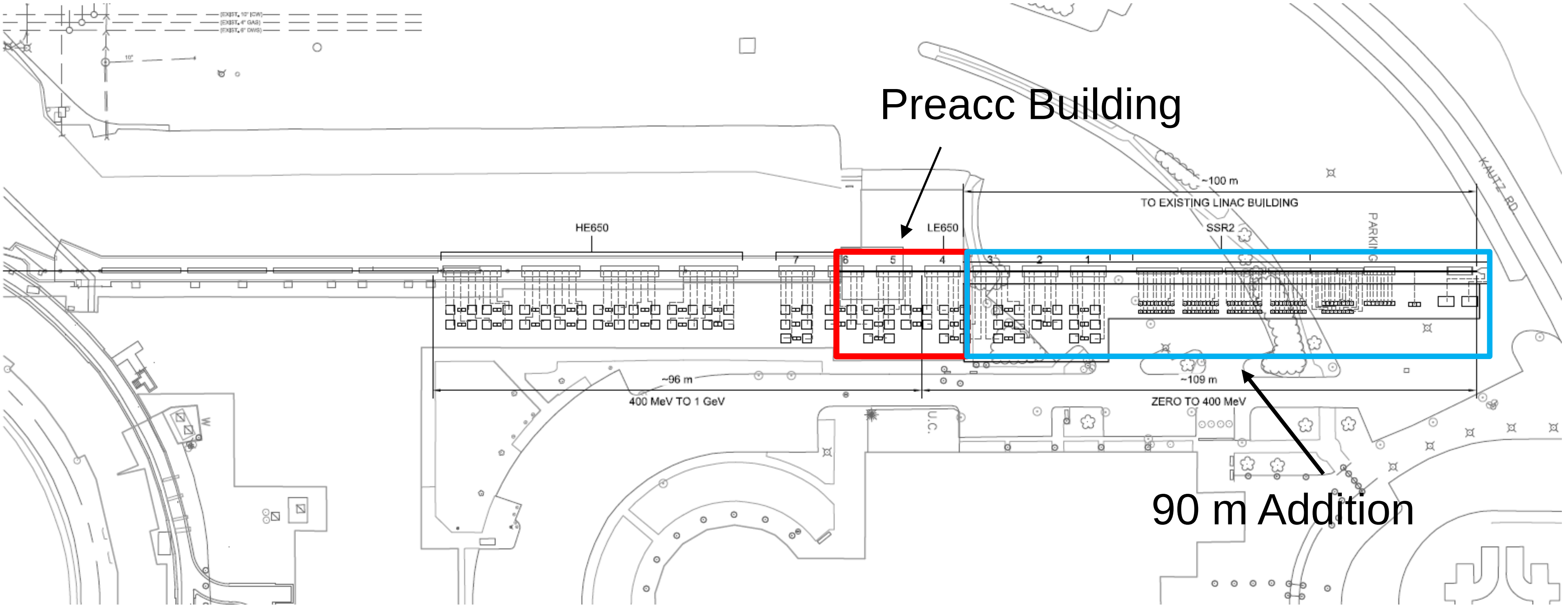
- The bends should be replaced with weaker magnets to keep H- stripping at minimum (~5E-5) for beam at 1GeV.
- The bends have to have field ~0.35T and length of 2.8 meter.

The rest of the transfer line can be used as is, with the exception of the injection system.

•The middle magnet of the injection system has to be run at 88% higher current or should be replaced with a 50% longer magnet.

•An other possibility is to use correctors for additional displacement and painting during injection.

~ 1GeV Staging



- Build new ~400 MeV linac in new+Preacc enclosure
- Build a transfer line along present linac and inject in Booster
- Decommission the existing linac and extend new linac up to ~1 GeV in existing tunnels and galleries
- Add a Storage Ring in the Booster tunnel

Direct 1GeV Injection in the Booster

•The beam from new linac has a peak current of 5mA.
An injection time longer then 180us will be required to inject more beam than we do today.
To avoid a relative momentum swing exceeding 1E-4, the injection time should not exceed 240us. For a linac current of 5mA, this corresponds to 7.5E+12 protons injected in the Booster. This also insures that space charge tune shift will be half of the value that we have right now at Booster injection. This gives 150kW of beam power from Booster at 8GeV and from Main Injector, 0.5MW at 120GeV without slip staking.

But
- 5mA for 250us may be problem for CW linac RF
- May be we would like to have more than 7E+12 protons from Booster
- ???

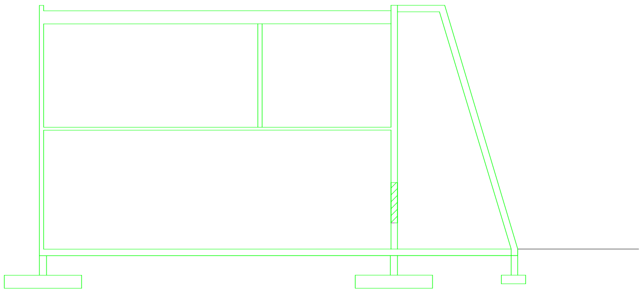
1-GeV Accumulator Ring in the Booster Tunnel

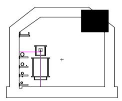
•The ring is made out of permanent magnets, and its primary purpose is to accumulate beam for the Booster.
•The beam intended for the Booster is accumulated into stationary buckets at ~47 MHz (for 1GeV beam) during ~1 msec. (This is much simpler than trying to inject “on the fly” into the ramping Booster.) The beam is then transferred bucket to bucket in a one-turn extraction into the Booster.
•For the rest of the Booster cycle time of 66.7 msec, the permanent magnet ring can be used to accumulate and store beam for other purposes.
The ability to chop bunch-by-bunch in the linac creates many opportunities to package beam for different users in the proposed storage ring.
Examples:

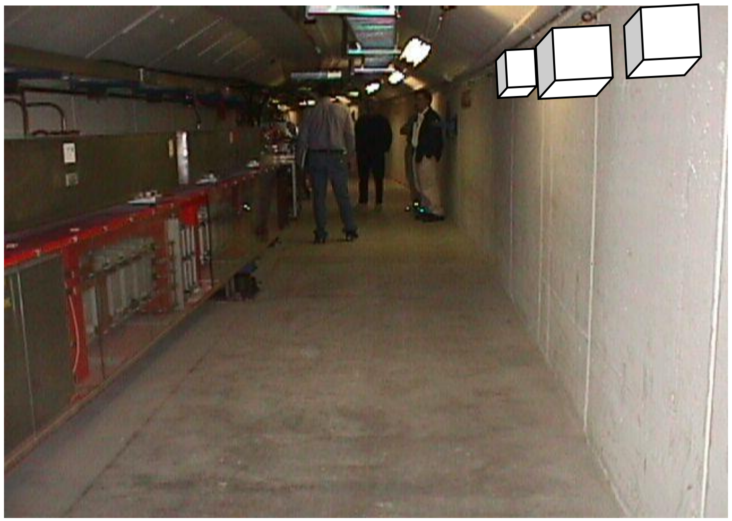
- the stored beam can be used for a Pulsed Spallation Source,
- for a mu2e conversion experiment based on a 100-Hz FFAG ring (Prism/Prime),
- for a pulsed beam for Short Baseline Neutrino Experiments.

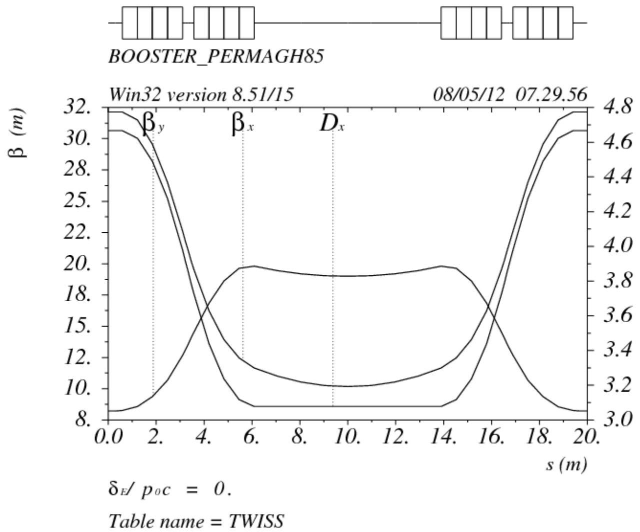
These specially packaged beams can be used either directly or after acceleration in the Booster.

Storage Ring in Booster





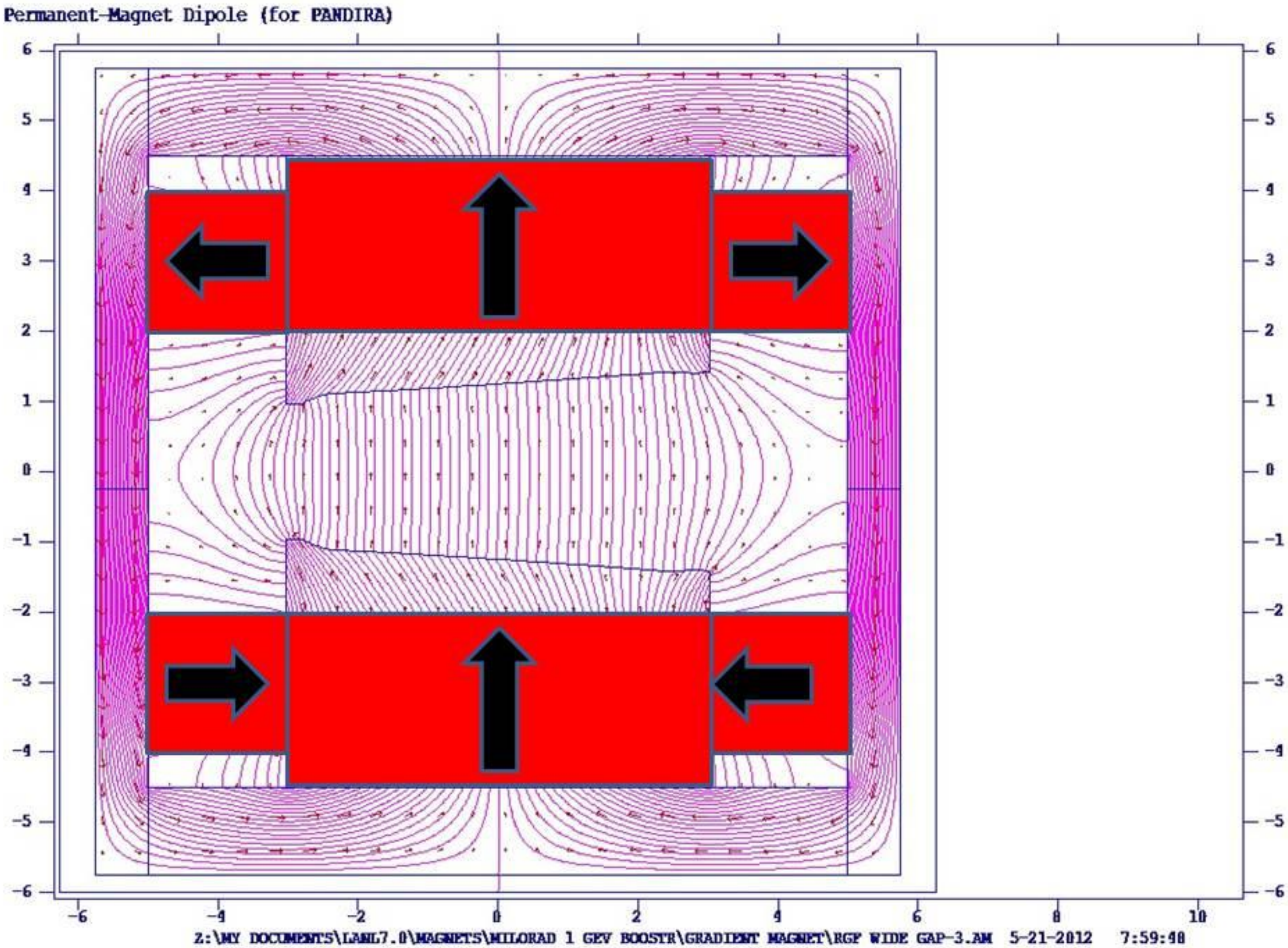




Magnet	length	Dipole(T)	Grad(T/m)	Sagitta (m)	Width /Gap(m)
D	2.516	0.159	-0.326	0.013	0.155/0.065
F	2.517	0.159	0.301	0.015	0.155/0.065

Parameter	X	Y	
Total length(m)			24*19.9862=479.6
Tune	24*0.214=5.136	24*0.226=5.437	
BetaMax(m)	32.14	19.8	
DispersionMax(m)	4.66	0	
GamaT			4.419

J. Volk Preliminary Design of Magnet



Project X RF Segmentation

v. 5.3

Section	Freq, MHz	Energy, MeV	Cav/mag/CM	~Length of CM
HWR	**162.5**	**2.1 – 10.8**	**8/8/1**	**5.26 m**
SSR1	**325**	**10.8 – 35.1**	**16/8/2**	**4.76 m**
SSR2	**325**	**35.1 – 165.4**	**36/20/4**	**7.77 m**
LB 650	**650**	**165.4 – 556.2**	**42/14/7**	**7.1 m**
HB 650	**650**	**556.2 – 3064.5**	**152/19/19**	**11.21 m**

Section	Freq, MHz	Energy, MeV	Cav/mag/CM	Length of CM
ILC / Pulsed	**1300**	**3000 - 8000**	**224/28/28**	**11.7 m**

Energy	
3 GeV	**Transport to RF Splitter** **Transport to Dump** **Transport to 8 GeV** **Transport to an Experimental Target**
8 GeV	**Transport to Dump** **Transport to MI/RR**

Two Stages to ~1 GeV

Stage 1.
Build 400 MeV linac and 400 MeV Storage Ring
Stage 2.
Develop and Build HB650 modules up to 1.18 GeV
Double number of permanent magnets to store 1.18GeV Beam

Or even better, use all LB650 modules

Stage 1.
Build 520 MeV linac and 520 MeV Storage Ring
Stage 2.
Develop and Build HB650 modules up to 1.5 GeV
Double number of permanent magnets to store 1.5GeV Beam

Why do Staging & why near Wilson Hall ?

- Staging gives you:
  - Beam to Booster as soon as 400 MeV is build
  - More beam from Booster even at 400 MeV
  - Reduce vulnerability from old linac

- Location gives you :
  - No Need to move PXIE
  - immediate use of new structure with only ~90 m of new tunnel
  - Saving of about 150 m of tunnel and galleries
  - Saving of new accumulation ring tunnel
  - Saving in PIP cost
  - Saving in combining Cryo costs for ProjectX, Mu2e and g-2
  - Visibility of project (name can be changed)????

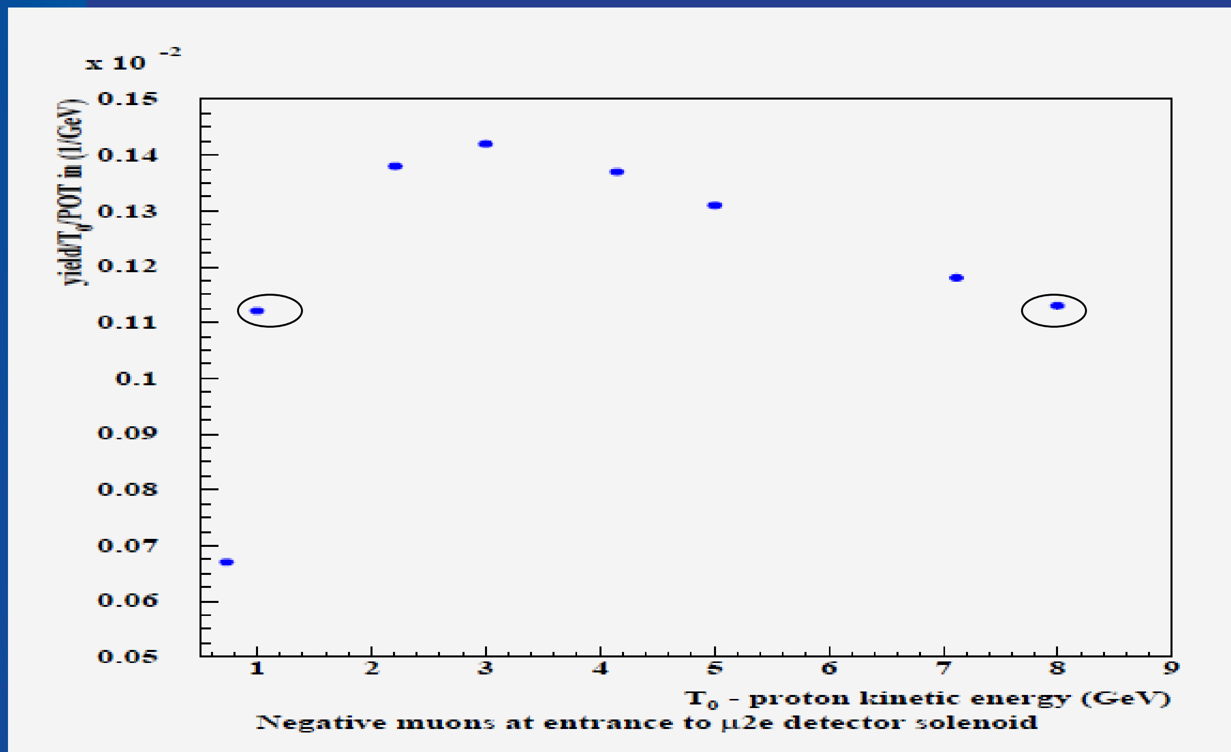
What about experiments, mu2e, g-2, …

Implications for mu2e and g-2

Beam for mu2e!

What is the optimum proton beam energy to drive a MELC/MECO/Mu2E experiment?

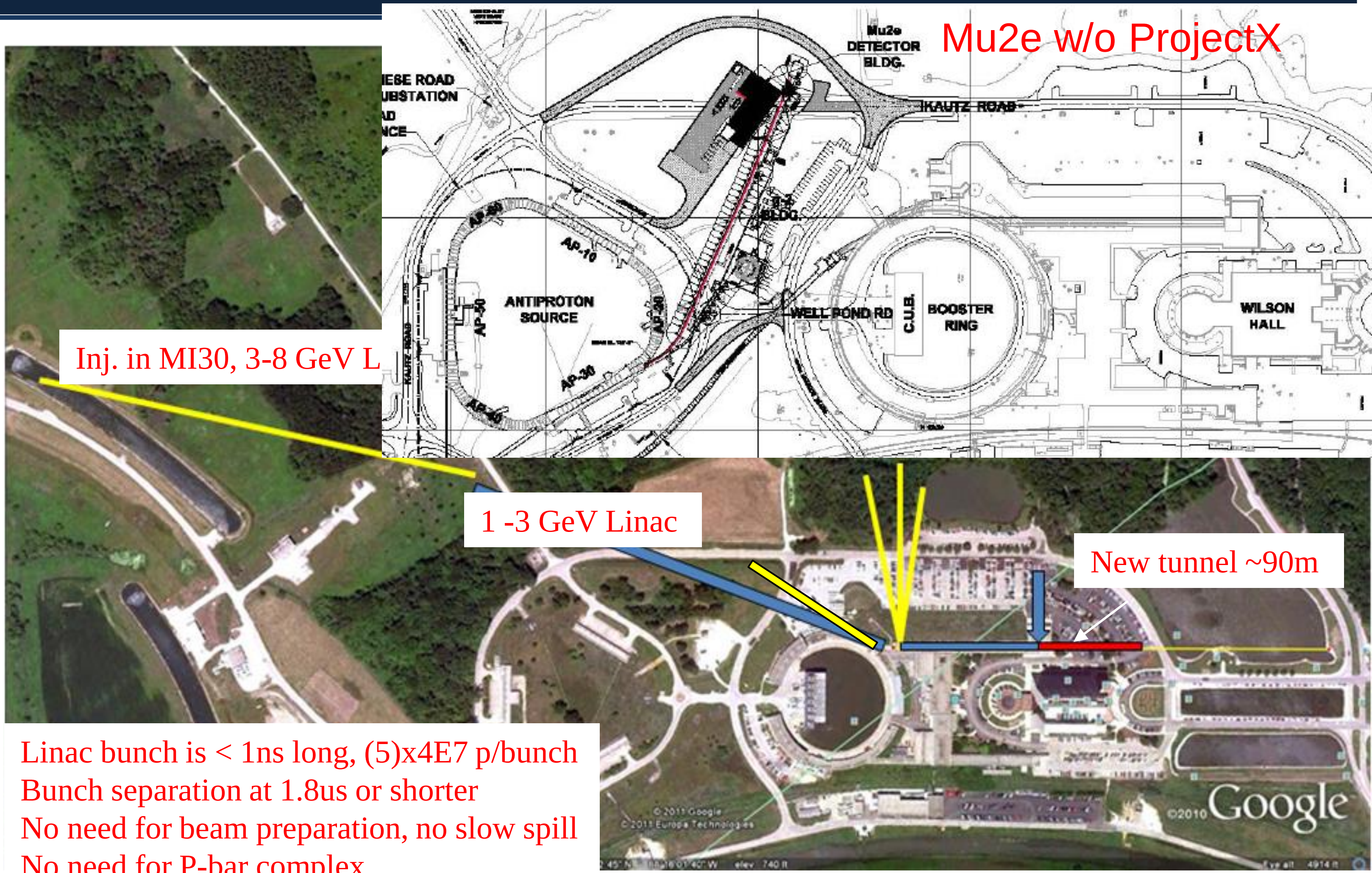
Yield / Watt



S. Striganov et al, work in progress

45 R. Tschirhart, Fermilab Wine & Cheese June 2012 Fermilab

mu2e with Project X, Stage 1



Linac bunch is < 1ns long, (5)x4E7 p/bunch
Bunch separation at 1.8us or shorter
No need for beam preparation, no slow spill
No need for P-bar complex
No need for RR

Old & New Linac in Tunnel