Project X Accelerator Overview

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U.S. DEPARTMENT OF ENERGY

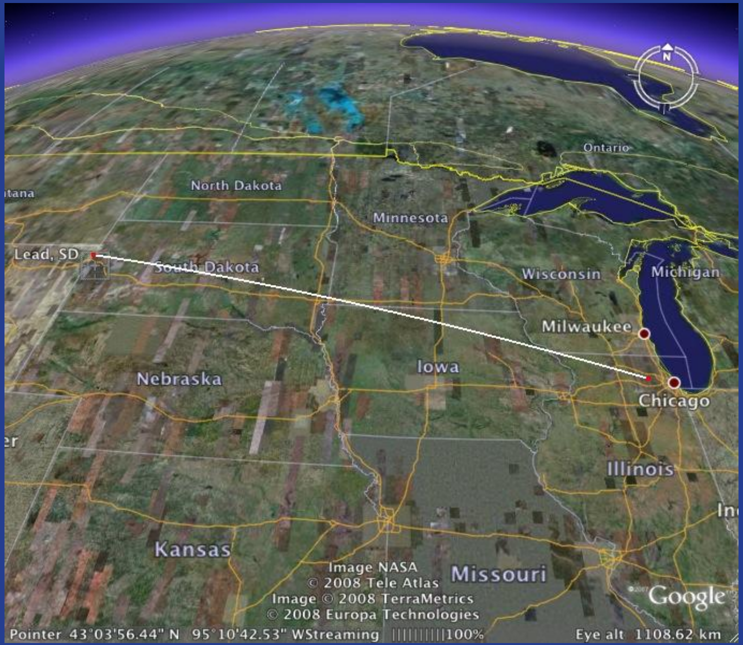
Fermilab

Outline

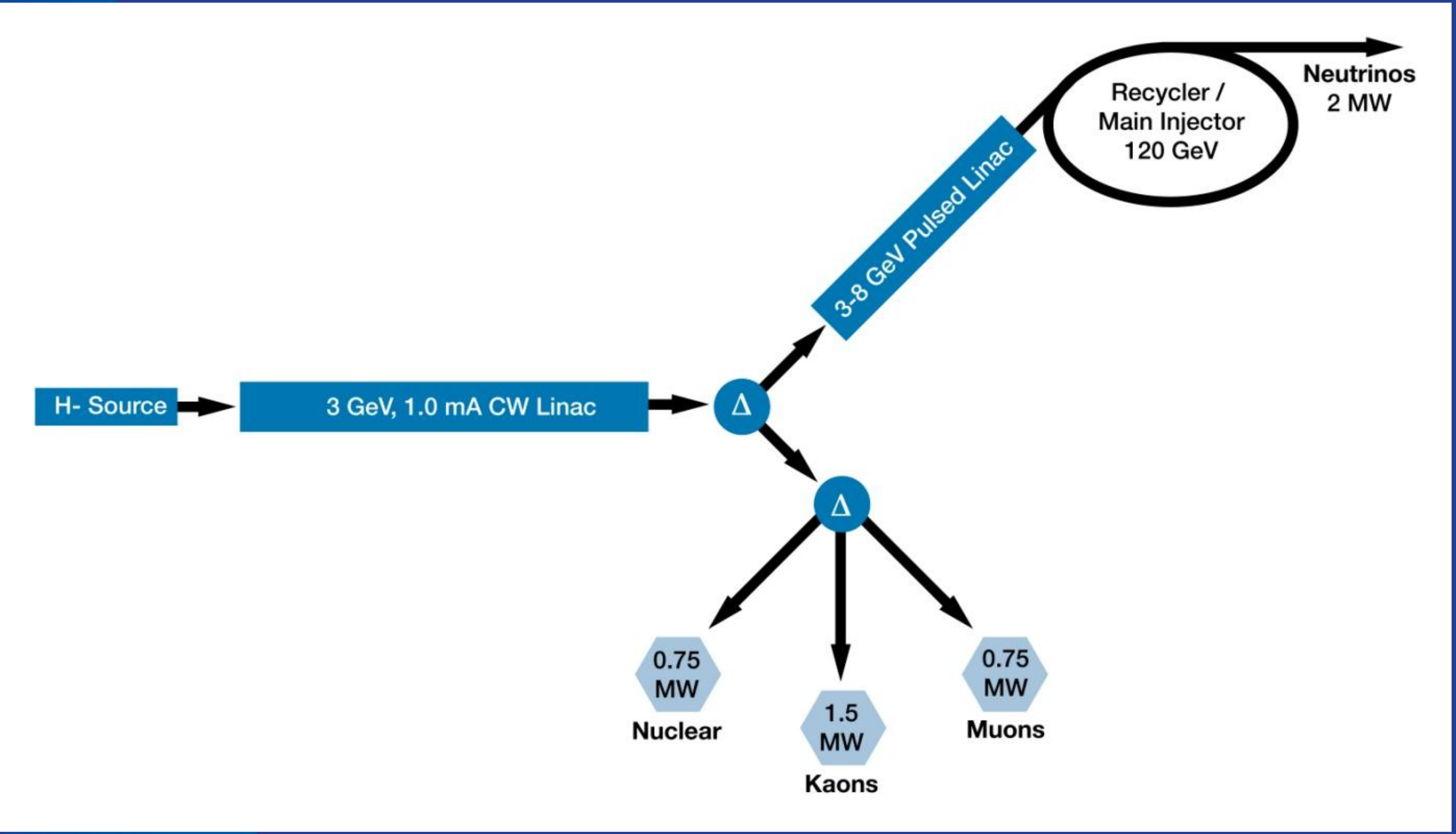
- Project X Reference Design
  - Mission & Goals
  - Reference Design Overview
  - Collaboration
  - Strategy/Timeline
- Project X Cost Range

Project X Mission

- A neutrino beam for long baseline neutrino oscillation experiments
  - 2 MW proton source at 60-120 GeV
- High intensity, low energy protons for kaon and muon based precision experiments
  - <u>Operations simultaneous</u> with the neutrino program
- A path toward a muon source for possible future Neutrino Factory and/or a Muon Collider
  - Requires ~4 MW at ~5-15 GeV .
- Possible missions beyond P5
  - Standard Model Tests with nuclei and energy applications



Project X Reference Design



Project X Scope

- 3 GeV CW superconducting H- linac, capable of delivering 1 mA average beam current.
  - Flexible provision for variable beam structures to multiple users
  - Starts at ion source; ends at 3-way split (with stubs)
  - Supports rare processes programs
- 3-8 GeV pulsed linac capable of delivering 300 kW at 8 GeV
  - Supports the neutrino program
  - Establishes a path toward a muon based facility
  - Provision for 1 GeV extraction for nuclear energy program
- Upgrades to the Recycler and Main Injector to provide ≥ 2 MW to the neutrino production target at 60-120 GeV.
  - Ends at MI extraction kicker
  - Supports the long baseline neutrino program
- All interconnecting beamlines

Project X Capabilities

- > 2 MW delivered to a neutrino target at any energy between 60 – 120 GeV
- Simultaneous delivery of ~3 MW of high duty factor beam power to the 3 GeV program
  - Variable beam formats to multiple users
  - CW beam at time scales >1 μsec
  - 10% duty factor on time scales < 1 μsec
- Potential for development of additional programs at:
  - 1 GeV for nuclear energy experimentation
  - 8 GeV for neutrino or muon experimentation
- The utilization of a CW linac creates a facility that is unique in the world, with performance that is unlikely to be duplicated in any synchrotron-based facility

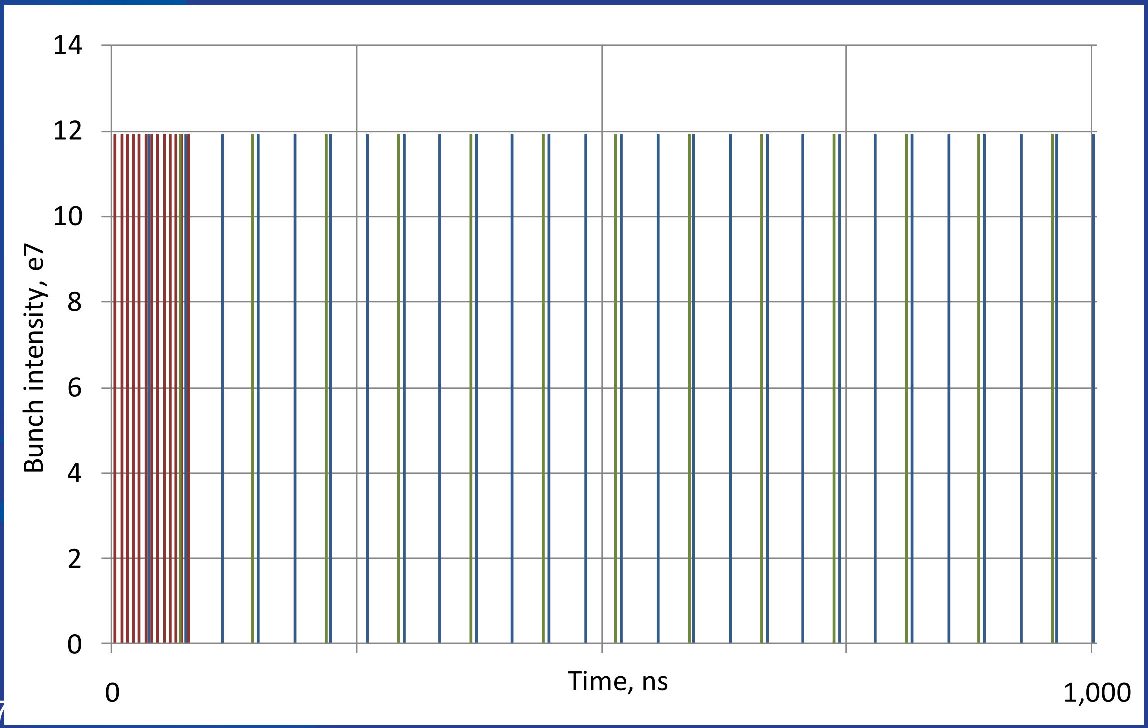
Project X Reference Design
Operating scenario

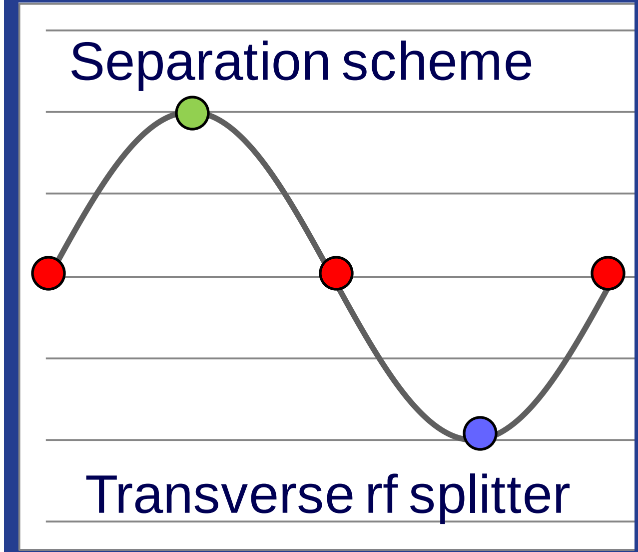
1 μsec period at 3 GeV

Muon pulses (12e7) 162.5 MHz, 80 nsec	750 kW
Kaon pulses (12e7) 27 MHz	1500 kW
Nuclear pulses (12e7) 13.5 MHz	750 kW

Ion source and RFQ operate at 6.2 mA

83% of bunches are chopped @ 2.5 MeV ⇒ maintain 1 mA over 1 μsec





Project X Supporting Documentation

http://projectx-docdb.fnal.gov/

- Functional Requirements Specification
- Reference Design Report
- Research, Design, & Development Plan
- Cost Estimate
- Resource Loaded Schedule

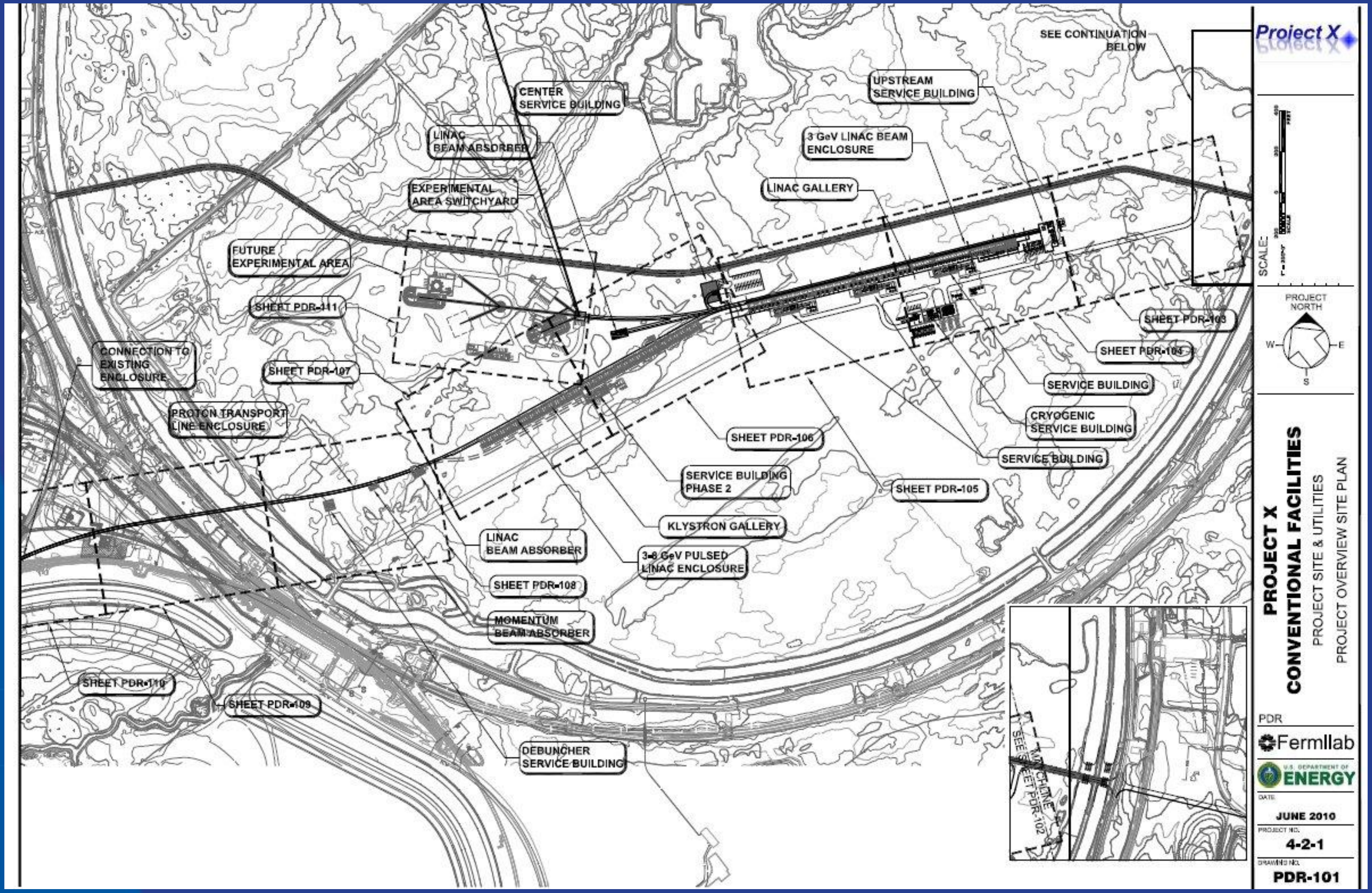
Project X Functional Requirements

Requirement	Description	Value
L1	Delivered Beam Energy, maximum	3 GeV (kinetic)
L2	Delivered Beam Power at 3 GeV	3 MW
L3	Average Beam Current (averaged over >1 μsec)	1 mA
L4	Maximum Beam Current (sustained for <1 μsec)	10 mA
L5	The 3 GeV linac must be capable of delivering correctly formatted beam to a pulsed linac, for acceleration to 8 GeV	
L6	Charge delivered to pulsed linac	26 mA-msec in < 0.75 sec
L7	Maximum Bunch Intensity	1.9×10^{8}
L8	Minimum Bunch Spacing	3.1 nsec (1/325 MHz)
L9	Bunch Length	<50 psec (full-width half max)
L10	Bunch Pattern	Programmable
L11	RF Duty Factor	100% (CW)
L12	RF Frequency	325 MHz and harmonics thereof
L13	3 GeV Beam Split	Three-way
P1	Maximum Beam Energy	8 GeV
P2	The 3-8 GeV pulsed linac must be capable of delivering correctly formatted beam for injection into the Recycler Ring (or Main Injector).	
P3	Charge to fill Main Injector/cycle	26 mA-msec in <0.75 sec
P4	Maximum beam power delivered to 8 GeV	300 kW
P5	Duty Factor (initial)	< 4%

Project X Functional Requirements

Requirement	Description	Value
M1	Delivered Beam Energy, maximum	120 GeV
M2	Delivered Beam Energy, minimum	60 GeV
M3	Minimum Injection Energy	6 GeV
M4	Beam Power (60-120 GeV)	> 2 MW
M5	Beam Particles	Protons
M6	Beam Intensity	1.6×10^{14} protons per pulse
M7	Beam Pulse Length	~10 μsec
M8	Bunches per Pulse	~550
M9	Bunch Spacing	18.8 nsec (1/53.1 MHz)
M10	Bunch Length	<2 nsec (fullwidth half max)
M11	Pulse Repetition Rate (120 GeV)	1.2 sec
M12	Pulse Repetition Rate (60 GeV)	0.75 sec
M13	Max Momentum Spread at extraction	2×10^{-3}
I1	The 3 GeV and neutrino programs must operate simultaneously	
I2	Residual Activation from Uncontrolled Beam Loss in areas requiring hands on maintenance.	<20 mrem/hour (average) <100 mrem/hour (peak) @ 1 ft
I3	Scheduled Maintenance Weeks/Year	
I4	3 GeV Linac Operational Reliability	
I5	60-120 GeV Operational Reliability	
I6	Facility Lifetime	
U1	**Provisions should be made to support an upgrade of the CW linac to support an average current of 4 mA.**	
U2	Provisions should be made to support an upgrade of the Main Injector to support a delivered beam power of ~4 MW at 120 GeV.	
U3	Provisions should be made to deliver CW proton beams as low as 1 GeV.	
U4	Provision should be made to support an upgrade to the CW linac such that it can accelerate Protons.	

Project X Reference Design
Siting



Reference Design: CW Linac Technologies

Section	Freq	Energy (MeV)	Cav/mag/CM	Type
SSR0 (β_G=0.11)	325	2.5-10	26 /26/1	SSR, solenoid
SSR1 (β_G=0.22)	325	10-32	18 /18/ 2	SSR, solenoid
SSR2 (β_G=0.4)	325	32-160	44 /22/4	SSR, solenoid
LB 650 (β_G=0.61)	650	160-520	42 /42/7	5-cell elliptical, doublet
HB 650 (β_G=0.9)	650	520-2000	96 /24/12	5-cell elliptical, doublet
ILC 1.3 (β_G=1.0)	1300	2000-3000	72 /9 /9	9-cell elliptical, quad

Expect to continue with 650

Pulsed Linac

- Superconducting pulsed linac for acceleration from 3 to 8 GeV
- ILC style cavities and cryomodules
  - 1.3 GHZ, β=1.0
- ILC style rf system
  - 5 MW klystron
  - Four cryomodules per rf source
- Must deliver 26 mA-msec to the Recycler every 0.75 sec. Options:
  - 1 mA x 4.4 msec pulses at 10 Hz
    - Six pulses required to load Recycler/Main Injector
  - 1 mA x 26 msec pulses at 10 Hz
    - One pulse required to load Main Injector

Collaboration

- A multi-institutional collaboration has been established to execute the Project X RD&D Program.
  - Organized as a "national project with international participation"
    - Fermilab as lead laboratory
    - International participation via in-kind contributions, established through bi-lateral MOUs.
  - Collaboration MOUs for the RD&D phase outlines basic goals, and the means of organizing and executing the work. Signatories:

ANL	ORNL/SNS	BARC/Mumbai
BNL	MSU	IUAC/Delhi
Cornell	TJNAF	RRCAT/Indore
Fermilab	SLAC	VECC/Kolkata
LBNL	ILC/ART	

- It would be natural for collaborators to continue their areas of responsibility into the construction phase.

Current Institutional Responsibilities

	Front End	Cav & CMs	RF	Cryo	Instru	Cntrls	MI/Recycler	Beam Trnspt	Accel Phys	Systm Integ	Test Facil
ANL		X	X						X		
BNL		X						X			
Cornell		X					X				
Fermilab	X	X	X	X	X	X	X	X	X	X	X
LBNL	X				X				X		
SNS					X						
MSU		X									
TJNAF		X									
SLAC	X		X				X		X		X
ILC/ART		X									
BARC	X	X	X	X	X				X		X
IUAC		X		X							
RRCAT		X	X	X							X
VECC		X		X							

RDR Cost Methodology

- Same methodology as previous IC-1 and IC-2 estimates
  - Base estimate of direct costs based on 2010 dollars
    - Bottoms up estimates from technical leads
    - Use or scale IC-1/2 estimates where appropriate
    - Includes spare components
    - Includes R&D
    - FNAL labor rates (13 categories)
  - Full estimate derived from base
    - FNAL standard overhead rates
    - Construction over FY15-19
    - DOE Escalation rates
    - Contingency (40% top down)
    - Time phased RD&D + construction model in two ~500 line MS Projects

Project X Base/Total Estimates
Full Estimate, $Then-year$

- Three estimates, with differing scopes
  - IC-1 $1,500M
    - 8 GeV pulsed linac + Recycler/MI
    - Limited capabilities for rare processes
  - IC-2 $1,600M
    - 2 GeV CW linac + 2-8 GeV RCS + Recycler/MI
    - 2 GeV too low for rare processes (Kaons)
    - Ineffective platform for Neutrino Factory or Muon Collider
  - RDR: $1,800M
    - 3 GeV CW linac + 3-8 pulsed linac + Recycler/MI
    - Ameliorates above deficiencies

Cost Comparisons

- RDR is 20% higher than IC-1, 13% higher than IC-2
  - 3.4% is an additional year's escalation
  - 7.3% is in the cryo systems
  - 3.0% is the rf systems
  - 4.7% is the R&D program
- RDR full estimate in $FY10$ is ~$1.5B

Cost Range

- Cost of 3-8 GeV acceleration
  - $302 M with RCS
  - $420 M with pulsed linac
- Direct injection into MI at 6 GeV
  - 3-6 GeV Pulsed linac
  - Requires solution for injection of 26 msec H- pulse
  - $305 M for pulsed linac (net Recycler)
- Bottom Line: Could save ~$115M by either:
  - Substitute RCS for 3-8 GeV pulsed linac; <u>or</u>
  - Direct inject into Main Injector at 6 GeV with pulsed linac

⇒ Preference is to retain the pulsed linac as it provides much better platform for muon based facilities, and leverages world-wide technology development

Strategy/Timeline

- November: Finalize all preliminary design, configuration, and cost range documentation for CD-0.
  - Functional Requirements Specification
  - Reference Design Report
  - RD&D Plan
  - Cost estimate/range
  - Resource Loaded Schedulee
- Deliverables: Next four years
  - All documentation required by the Department of Energy prior to authorizing construction
  - Supporting technical R&D required to validate the design and establish fabrication methods
- Assumed Critical Decision dates
  - CD-0: January 2011
  - CD-1: July 2012
  - CD-2: August 2013
  - CD-3: September 2014
  - CD-4: September 2019

$\Rightarrow$ Project X could be up and running in ~2020

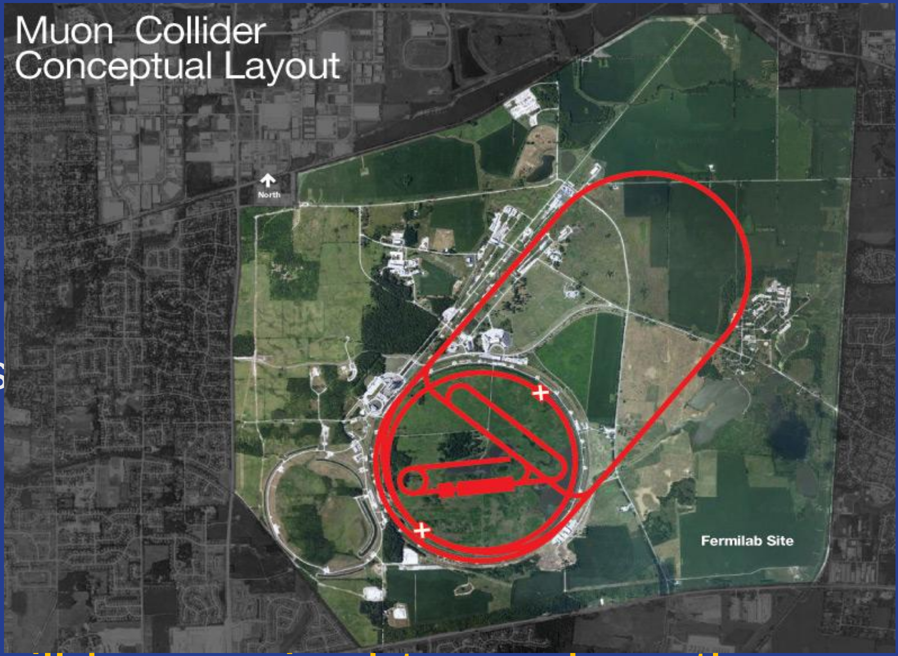
Summary

- Project X will enable a world-leading accelerator based HEP program at Fermilab for decades
- The Project X Reference Design as established over the last year provides capabilities that will be unique in the world
  - 2 MW to the neutrino program over 60-120 GeV
  - 3 MW to the rare processes program
  - Flexible provision for variable beam formats to multiple users
  - Technology aligned with ILC and NF/MC
- The Reference Design cost range is $1.7-1.8B
  - 20% increase over IC-1
    - Some of this is inflation
    - Most is related to increased costs associated with a high power, CW linac
  - Assumes construction over FY2015-2019
  - Does not account for in-kind international contributions
- We are ready for CD-0

Backup Slides

PX/NF/MC Strategy

- Project X shares many features with the proton driver required for a Neutrino Factory or Muon Collider
  - NF and MC require ~4 MW @ 10± 5 GeV
  - Primary issues are related to beam "format"
    - ➢ NF wants proton beam on target consolidated in a few bunches; Muon Collider requires single bunch
  - Project X linac is not capable of delivering this format



⇒ It is inevitable that a new ring(s) will be required to produce the correct beam format for targeting.

Benchmarks

- Cavity/Cryomodule costs
  - JLab
  - ILC R&D
- Cryogenic costs
  - SNS
  - JLab
- RF costs
  - $/watt
- Conventional
  - Means + recent Fermilab experience

International Governance
Organizing Principles

- DOE and Fermilab hold sole responsibility for delivery of the facility and subsequent operations.
  - Supported by high level institutional board providing advice on establishing the international context, distribution of work, publicizing efforts, establishing operational modes, etc.
- All international contributions should be in-kind.
- All arrangements between Fermilab and international partners should be bi-lateral.
  - Fermilab does not want to mediate interactions between foreign countries.
  - Each deliverable should be the responsibility of a single country.
- Each deliverable should have a Fermilab manager and a manager/point of contact from the corresponding country.
  - Indian Institutes Fermilab Collaboration model
  - No Fermilab sub-project manager should be coordinating with more than one country.

Loaded, Escalated, Contingency

- FNAL Std OH on SWF and M&S, incl. large procurements (~24%)
- DOE Escalation Rate for Lab(14.6%)
- Budget profile
- Top Down Contingency (40%)

	IC-1	IC-2
Base Cost	$743,545,773	$798,398,035
Labor OH	$141,706,717	$137,168,282
M&S OH	$44,210,773	$50,389,042
Base + OH	$929,463,263	$985,955,359
FY09$-->TY$	$135,701,636	$143,949,482
Escalated Base + OH	$1,065,164,900	$1,129,904,842
Contingency	$426,065,960	$451,961,937
Total	$1,491,230,859	$1,581,866,778

Opportunities (Loaded Estimate)

- Review FNAL Overheads, negotiate for direct project costs vs. lab services / support
  - Current OH ~24%; comparison 12GeV / 6%+support; NSLS-II (10%); FRIB 10%+MSU$+zero on some items
- Review Contingency
  - Currently top down at 40%; some technical leads note this is very conservative for components available off the shelf
  - Compare base numbers w/ data from JLab, XFEL…..
  - Integration, Civil construction require large uncertainties
- Utilize International Collaborations

Opportunities (base estimate)

- Value engineering on all aspects of Conventional Facilities design requirements
- Value engineering and consolidation of RF designs
- Continued studies on HE Linac cavities and cryomodules
  - IC-1 Review pointed out HE Linac cryomodules could be ~300/400k$ less in qty (-18M$ (IC1), -7M$ (IC2))
  - Review pressure ratings, 5K shield, HOM couplers, piezo tuners, …
- Review of LE Linac cryomodules and consolidation of HE / LE cryomodule technical design criteria
  - LE Linac cryomodules should have a similar target as HE Linac (-9M$)
- Review of uncertainties in component heat loads and effect on cryogenic system
- Overall development of consolidated beamline and instrumentation scheme