Project X and the Neutrino Factory

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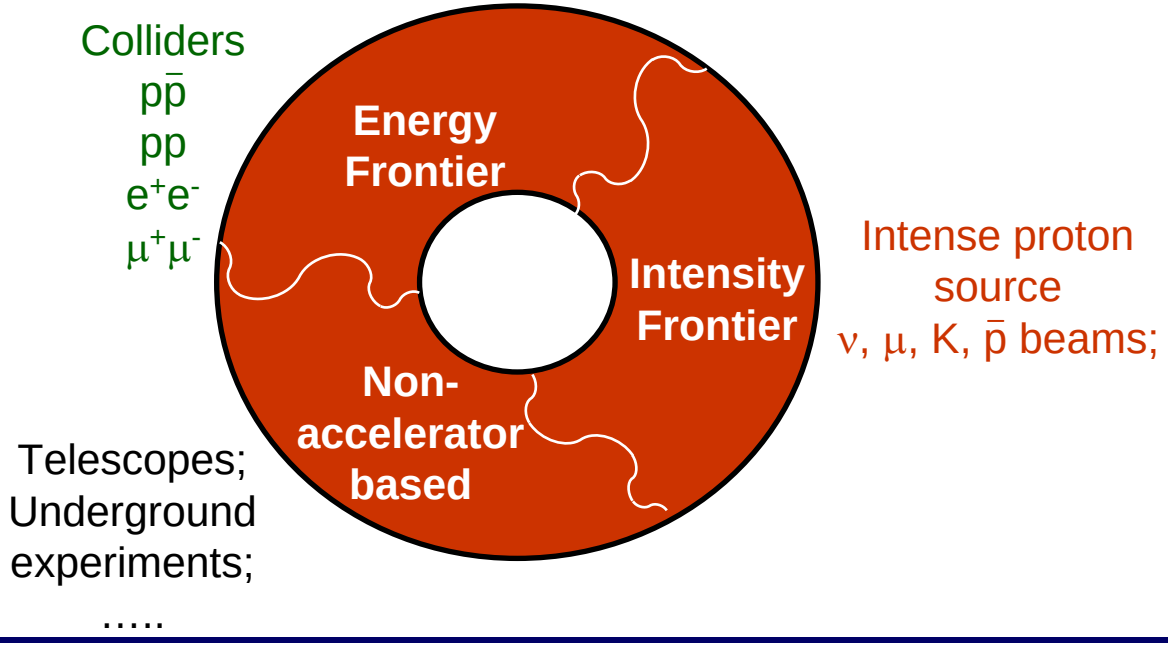
Strategic Context
Fermilab Long Range Plan

- Fermilab is the sole remaining U.S. laboratory providing facilities in support of accelerator-based Elementary Particle Physics.
- The Fermilab long-term plan incorporates three strategic directions:



Neutrino Program Evolution
World View

- Long term physics goals:
  - Measure neutrino mass hierarchy
  - Measure complete neutrino mixing matrix, including CP-violating phase, δ
- How?
  - $\sin^2 2\theta_{13}$ to 0.1 $\rightarrow$ 0.01: Double Chooz $\rightarrow$ Daya Bay/T2K/NOvA
  - Mass hierarchy for $\sin^2 2\theta_{13}$ to 0.02: NOvA + T2K
  - $\sin^2 2\theta_{13}$ to 0.001: Project X/DUSEL
  - CP-violation for $\sin^2 2\theta_{13}$ to few x 0.001: Project X/DUSEL
  - $\sin^2 2\theta_{13}$ less than 0.001: NuFACT

Neutrino Program Evolution
P5 Recommendations

- Intensity Frontier
  - The panel recommends a world-class neutrino program as a core component of the US program, with the long-term vision of a large detector in the proposed DUSEL and a high-intensity neutrino source at Fermilab.
  - The panel recommends an R&D program in the immediate future to design a multi-megawatt proton source at Fermilab and a neutrino beamline to DUSEL…
  - A neutrino program with a multi-megawatt proton source would be a stepping stone toward a future neutrino source, such as a neutrino factory based on a muon storage ring… This in turn could position the US program to develop a muon collider as a long-term means toreturn to the energy frontier in the US.

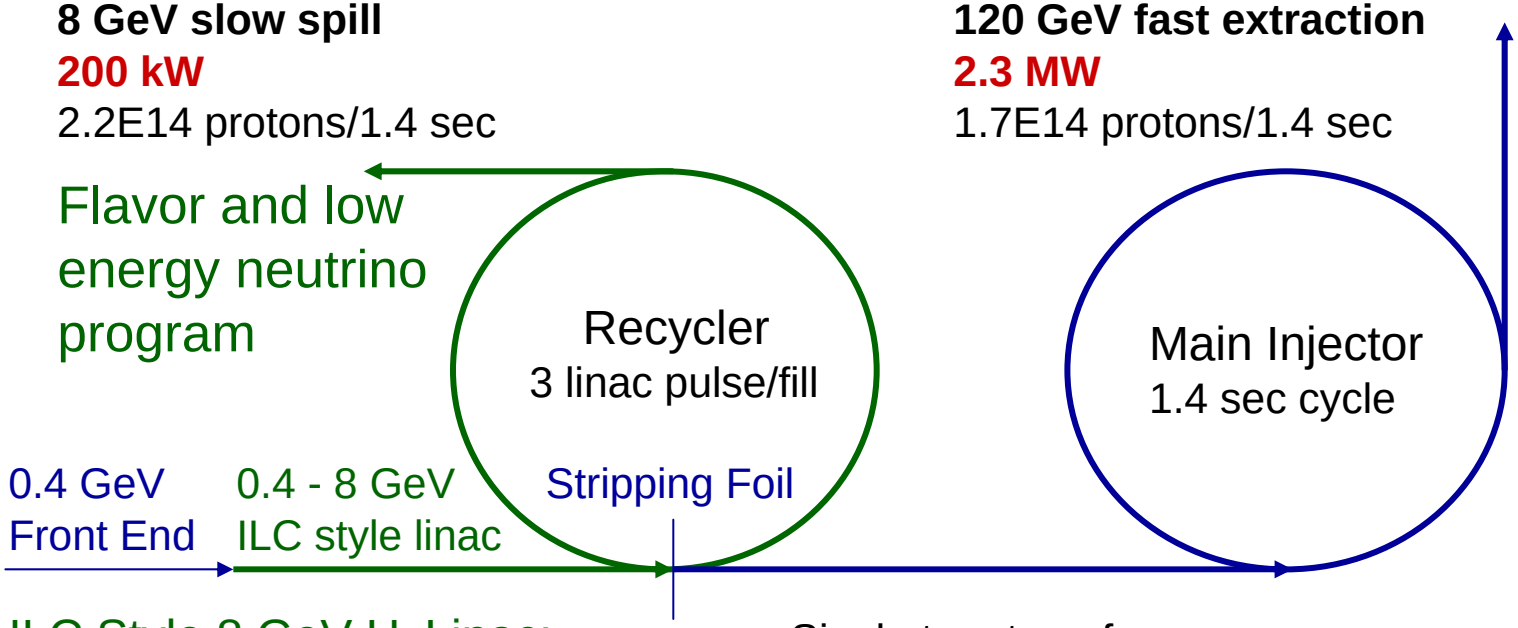
Project X Facility Overview

Project X is a high intensity proton facility aimed at supporting a world leading program in neutrinos and rare decays.

NOνA initially,
DUSEL later

8 GeV slow spill
200 kW
2.2E14 protons/1.4 sec

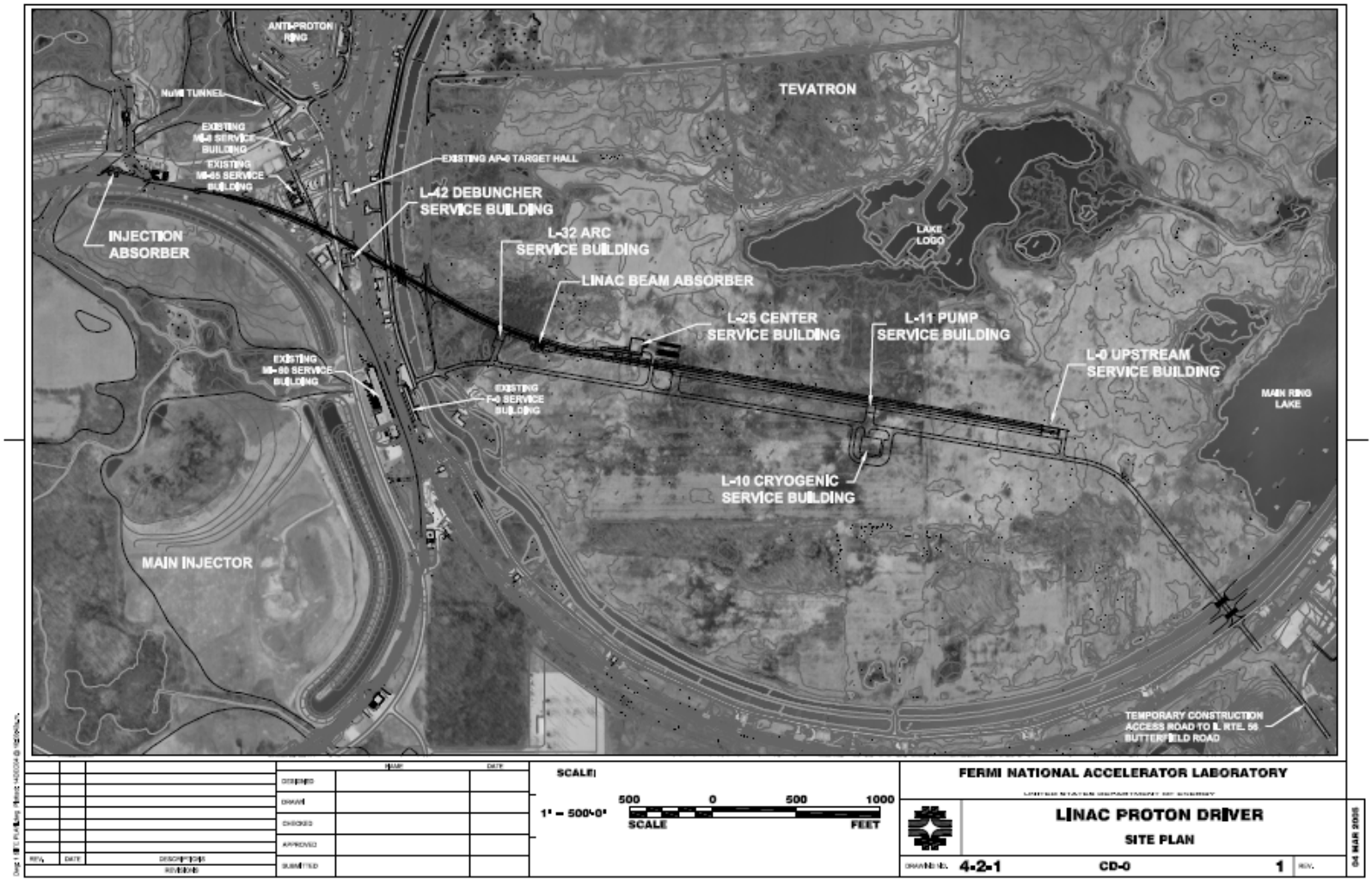
120 GeV fast extraction
2.3 MW
1.7E14 protons/1.4 sec



ILC Style 8 GeV H^- Linac:
9mA x 1 msec x 5 Hz

Single turn transfer
@ 8 GeV

Project X Facility Overview
Provisional Siting



Project X Facility Overview
High Level Performance Goals

Linac		
Particle Type	H^-	
Beam Kinetic Energy	8.0	GeV
Particles per pulse	5.6×10^{13}	
Pulse rate	5	Hz
Beam Power	360	kW
Recycler		
Particle Type	protons	
Beam Kinetic Energy	8.0	GeV
Cycle time	1.4	sec
Particles per cycle to MI	1.7×10^{14}	
Particles per cycle to 8 GeV program	2.2×10^{14}	
Beam Power to 8 GeV program	206	kW
Main Injector		
Beam Kinetic Energy (maximum)	120	GeV
Cycle time	1.4	sec
Particles per cycle	1.7×10^{14}	
Beam Power at 120 GeV	2300	kW

Project X Facility Overview
Scope

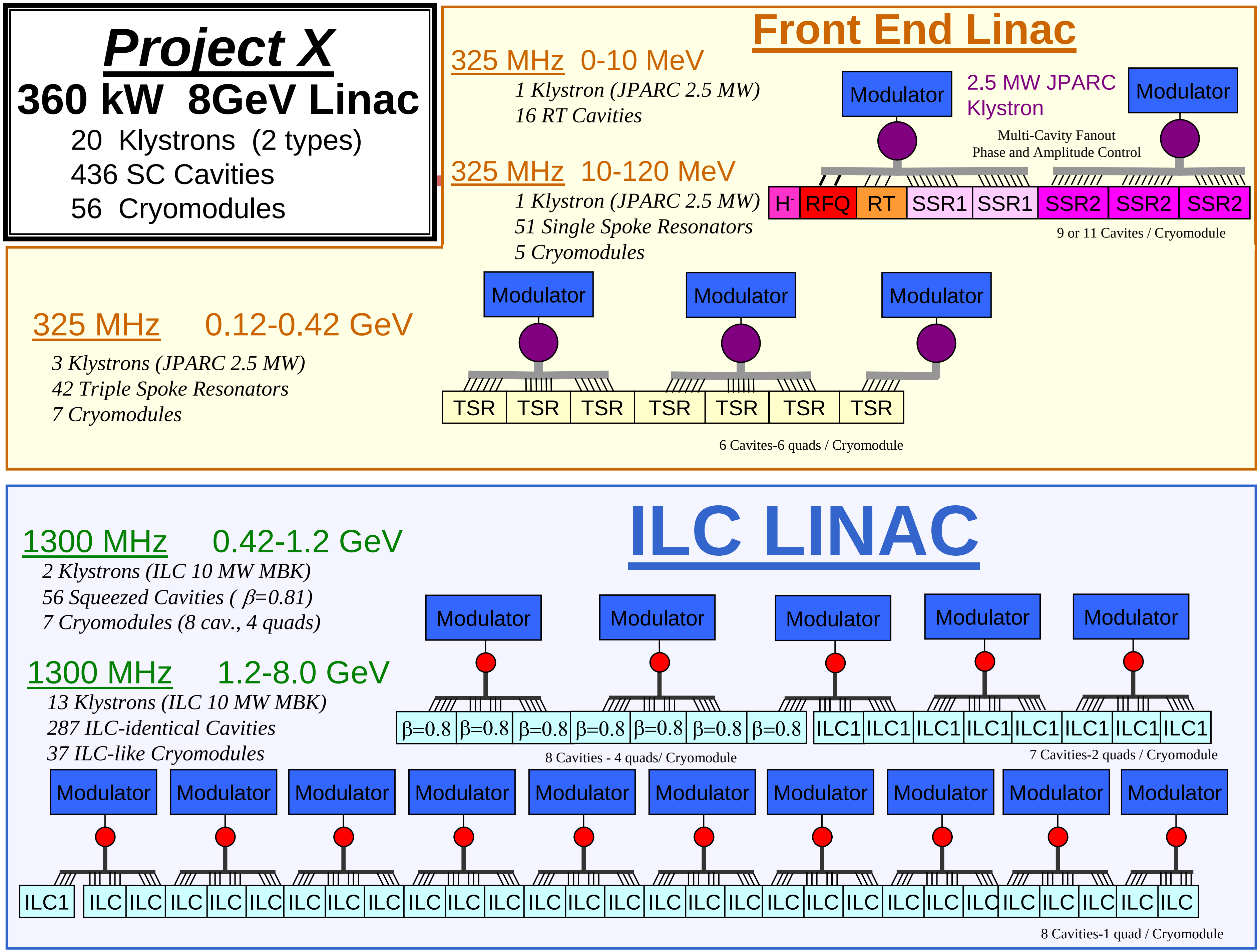
- The Project X Facility scope includes:
  - A new 8 GeV, superconducting, H^- linac;
  - A new beamline for transport of 8 GeV H^- from the linac to the Recycler Ring;
  - Modifications to the Recycler required for 8 GeV H^- injection, accumulation, and delivery of protons to the Main Injector;
  - Modifications to existing beamlines to support transfer of 8 GeV protons from the Reycler to the Main Injector;
  - Modifications to the Main Injector to support acceleration and extraction of high intensity proton beams over the range 60-120 GeV;
  - Modifications to the NuMI facility to support operations at 2 MW beam power;
  - Modifications to the Recycler to support a new extraction system that will allow delivery of 8 GeV protons in support of a dedicated flavor program.

Project X RD&D Plan

- The goal of the RD&D program is to provide support for Critical Decision 2 (CD-2) in 2011, leading to 2012 construction start.
  - Design and technical component development;
  - Fully developed baseline scope, cost estimate, and schedule;
  - Formation of a multi-institutional collaboration capable of executing both the R&D plan and the follow-on construction project.
- The primary technical goal is a complete facility design that meets the needs of the US research program, as established via CD-0.
  - 2 MW of beam power over the range 60 – 120 GeV,
  - Simultaneous with at least 100 kW of beam power at 8 GeV
  - Compatibility with future upgrades to >2 MW at 8 GeV

Project X RD&D Plan
Strategy

- Working backwards (potential delay if/when FY2009 CR):
  - FY12: CD-3 – Start Construction
  - FY11: CD-2 – Establish Baseline
  - FY10: CD-1 – Establish Baseline Range
    - ➢ Requires a complete Conceptual Design Report
  - FY09 (spring): CD-0
    - ➢ Requires new cost (range) estimate which will be reviewed by DOE
- FY2008 Goals
  - Establish basic performance parameters
  - Develop design concept sufficient to from basis of a cost estimate
  - Understand how/if the linac could support a 2+ MW upgrade
  - Form Project X RD&D Collaboration and establish work assignments for FY09


Project X
360 kW 8GeV Linac
20 Klystrons (2 types)
436 SC Cavities
56 Cryomodules
Front End Linac
325 MHz 0-10 MeV
1 Klystron (JPARC 2.5 MW)
16 RT Cavities
325 MHz 10-120 MeV
1 Klystron (JPARC 2.5 MW)
51 Single Spoke Resonators
5 Cryomodules
Modulator
2.5 MW JPARC Klystron
Modulator
Multi-Cavity Fanout
Phase and Amplitude Control
H- RFQ RT SSR1 SSR1 SSR2 SSR2 SSR2
9 or 11 Cavites / Cryomodule
325 MHz 0.12-0.42 GeV
3 Klystrons (JPARC 2.5 MW)
42 Triple Spoke Resonators
7 Cryomodules
Modulator Modulator Modulator
TSR TSR TSR TSR TSR TSR TSR
6 Cavites-6 quads / Cryomodule
ILC LINAC
1300 MHz 0.42-1.2 GeV
2 Klystrons (ILC 10 MW MBK)
56 Squeezed Cavities (β=0.81)
7 Cryomodules (8 cav., 4 quads)
1300 MHz 1.2-8.0 GeV
13 Klystrons (ILC 10 MW MBK)
287 ILC-identical Cavities
37 ILC-like Cryomodules
Modulator Modulator Modulator Modulator Modulator
β=0.8 β=0.8 β=0.8 β=0.8 β=0.8 β=0.8 β=0.8
ILC1 ILC1 ILC1 ILC1 ILC1 ILC1 ILC1 ILC1
8 Cavities - 4 quads/ Cryomodule
7 Cavities-2 quads / Cryomodule
Modulator Modulator Modulator Modulator Modulator Modulator Modulator Modulator Modulator Modulator
ILC1 ILC ILC ILC ILC ILC ILC ILC ILC ILC ILC ILC ILC ILC ILC ILC ILC ILC ILC ILC ILC ILC ILC ILC ILC ILC ILC ILC ILC ILC
8 Cavities-1 quad / Cryomodule

Project X RD&D Plan
Relationship to Other Programs: ILC/SRF

- Project X design concept aligns beam parameters with ILC:
  - 9 mA × 1 msec × 5 Hz
    - ➢ Alternatives under consideration may provide enhanced performance and/or flexibility
  - Linac designed to accommodate accelerating gradients in the range 23.6 – 31.5 MV/m (XFEL – ILC)
    - ➢ Final design gradient determined prior to CD-2
- Industrialization role
  - Project X requires 37 β=1, ILC-like cryomodules
  - Production over a two-to-three-year period represents a significant advance over capabilities anticipated in ~2010; however, the production rate is below that required by ILC

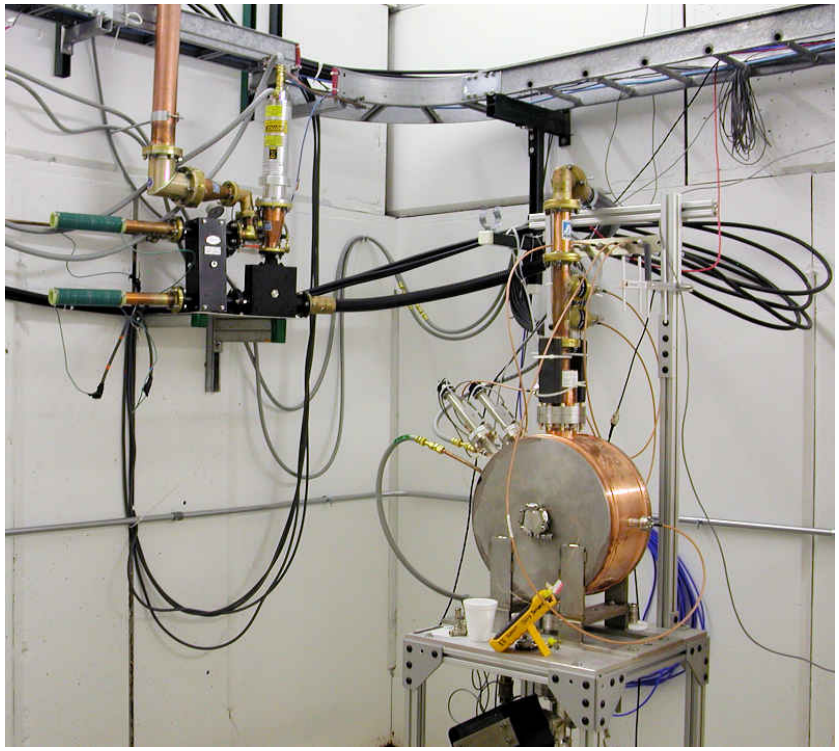
  $\Rightarrow$ This activity could represent the initial phase of an industrialization buildup for ILC (in the U.S.).

Project X RD&D Plan
ILC/SRF Joint Development Strategy

- There is a single 1.3 GHz development program at Fermilab, supporting the ILC/GDE program and simultaneously understanding Project X requirements.
- At an appropriate time (before CD-2) the Project X cryomodule design will be developed.
  - The expectation is that it will be similar, but not identical, to the ILC design (including choice of gradient).
  - The design will be compatible with an identified upgrade path.
- Creation of facilities capable of fabricating one cryomodule/month remains the responsibility of the SRF infrastructure program.
- ILCTA-NML is being constructed under the SRF Infrastructure program to support beam testing of a complete rf unit.
  - This configuration supports substantial progress toward ILC (S1 and S2) goals: demonstration of stable high-power operations.

Project X RD&D Plan
Relationship to Other Programs: HINS

- The HINS program is developing front end technology beyond the requirements of Project X initial goals:
  - 60 MeV front end @ 27 mA × 1 msec × 10 Hz
  - Demonstrate novel technologies for a high intensity non-relativistic linac
    - Multiple room temperature and sc cavities driven by a single rf source (high power vector modulators)
    - High speed (nsec) beam chopping at 2.5 MeV
  - Establish technical feasibility and cost basis by ~2011



Project X RD&D Plan
HINS Joint Development Strategy

- HINS provides a natural starting point for a Project X upgrade
  - 27 ma × 1 msec × 10 Hz = 2 MW (if accelerated to 8 GeV)
  - Other options: 9 ma × 3 msec × 10 Hz
- Two decisions (prior to CD-2):
  - Do we use HINS as the initial front end or do we utilize a conventional (room temperature) front end?
    - Cost-benefit analysis
  - Can we establish an 8 GeV upgrade path via HINS and if so, how does this impact the 1.3 GHz linac facility design?
- In either case it will be essential to carry the 60 MeV facility through to completion

Project X RD&D Plan
Integrated SRF Plan

	FY08	FY09	FY10	FY11	FY12	FY13
ILC C+CM	CM1	CM2	CM3 (Type IV)		CM4 rf unit sys.tst	
ILC RF Power		MBK	PFN modulator			
SRF Infra.				NML complete		CAF complete (1 CM/month)
HINS				60 MeV beam tests		
Project X		CDR		FE decision Gradient decision baseline docs	rf unit sys.tst	
	CD-0		**CD-1**	**CD-2**	**CD-3**	

Project X RD&D Plan

Relationship to Other Programs: Neutrino Factory

- NF Proton Driver requirements as described by ISS:
- Project X in general will not meet requirements in initial configuration

Proton energy	10±5	GeV	8	GeV
Average beam power	4	MW	360	kW
Pulse rep rate	50	Hz	5	Hz
Proton bunch length (rms)	2±1	nsec	2	nsec*
Number of proton bunches	3 or 5		500	*
Sequential extraction delay	>17	μsec	>17	μsec*
Pulse duration (LHg target)	<40	μsec	>11	μsec*
Pulse duration (solid target)	>20	μsec	>11	μsec*

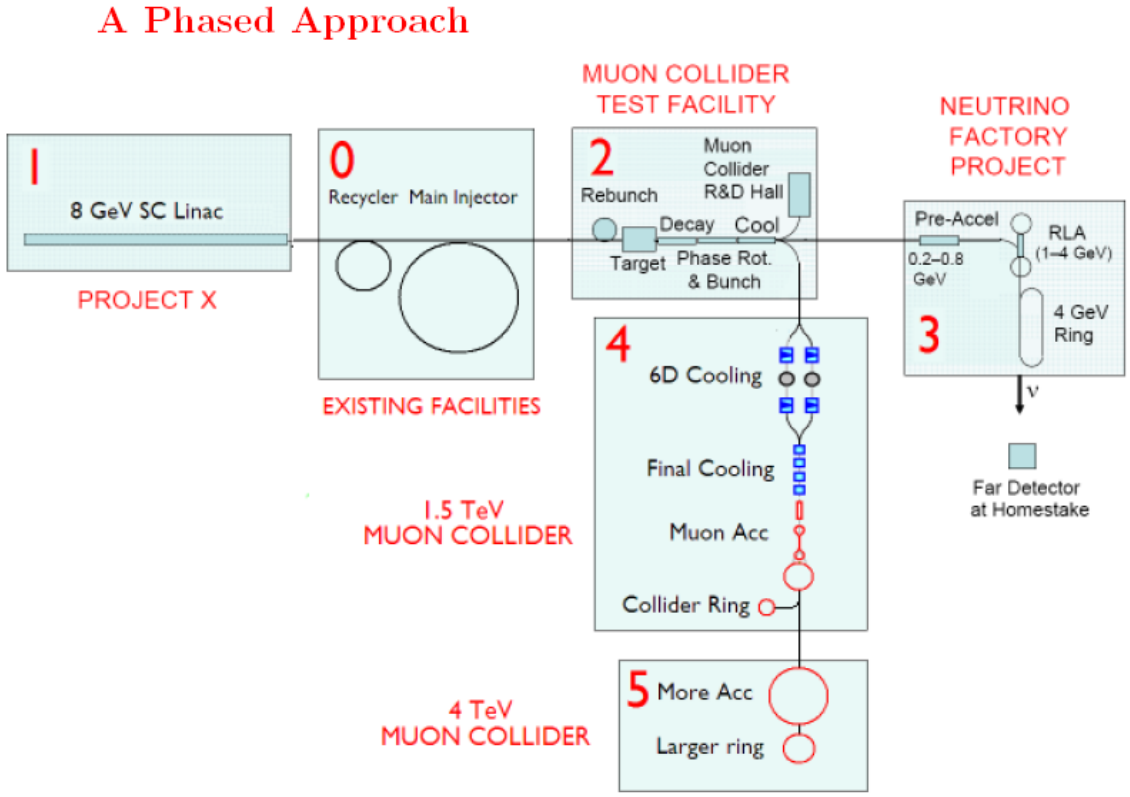
* Based on accumulation within the Recycler Ring.

Project X RD&D Plan

Neutrino Factory Joint Development Strategy

- Develop upgrade concept for the Project X linac aimed at >2 MW (currently underway)
  - Integrate necessary requirements into the initial (360 kW) design
- Develop a performance specification for a Proton Driver supporting a Neutrino Factory (APC), consistent with Project X concepts.
  - Issues: Average beam power, repetition rate, particles/bunch, bunch intensity
- Develop a conceptual design for the NF Proton Driver based on Project X linac and downstream accumulation/packaging ring(s).
- Coordinate with IDS_NF, NFMCC (, and MCTF)

Project X RD&D Plan
Long Term Vision (R. Palmer)



18

Project X RD&D Plan
Collaboration Plan

- Intention is to organize and execute the RD&D Program via a multi-institutional collaboration.
  - Goal is to assign collaborators complete and contained sub-projects, meaning they hold responsibility for design, engineering, cost estimating, and potentially construction if/when Project X proceeds.
  - Project X R&D Collaboration to be established via a Collaboration Memorandum of Understanding (MOU) outlining basic goals of the collaboration, and the means of organizing and executing the work.
    - Goal: Establish RD&D Collaboration by end of FY08
  - It is anticipated that the Project X RD&D Program will be undertaken as a “national project with international participation”. Expectation is that the same structure of MOUs described above would establish the participation of international laboratories.

Project X RD&D Plan
Collaboration Plan

- A draft MOU covering the period through CD-2 is currently circulating for comment among the management of the following potential U.S. collaborators:
  - ANL
  - BNL
  - Cornell
  - LBNL
  - ORNL/SNS
  - MSU
  - TJNAF
  - SLAC
- Expect to hold initial Project X Collaboration Meeting in late summer/early fall

Summary

- Design concept exists for a facility capable of delivering in excess of 2 MW beam power over the energy range 60 – 120 GeV, simultaneous with 8 GeV beam power in the range 100 – 200 kW.
  - Major sub-system performance goals established
  - Design aligned with needs of ILC development
- RD&D plan developed covering the period through CD2 (2011)
  - Integrates effort on Project X, ILC, and HINS
  - Anticipates upgrade to >2 MW at 8 GeV
- Working towards organizing as a national project with international participation.
- Retain good communication with the NFMCC/MCTF to assure Project X is designed to preserve utility in a future muon facility.