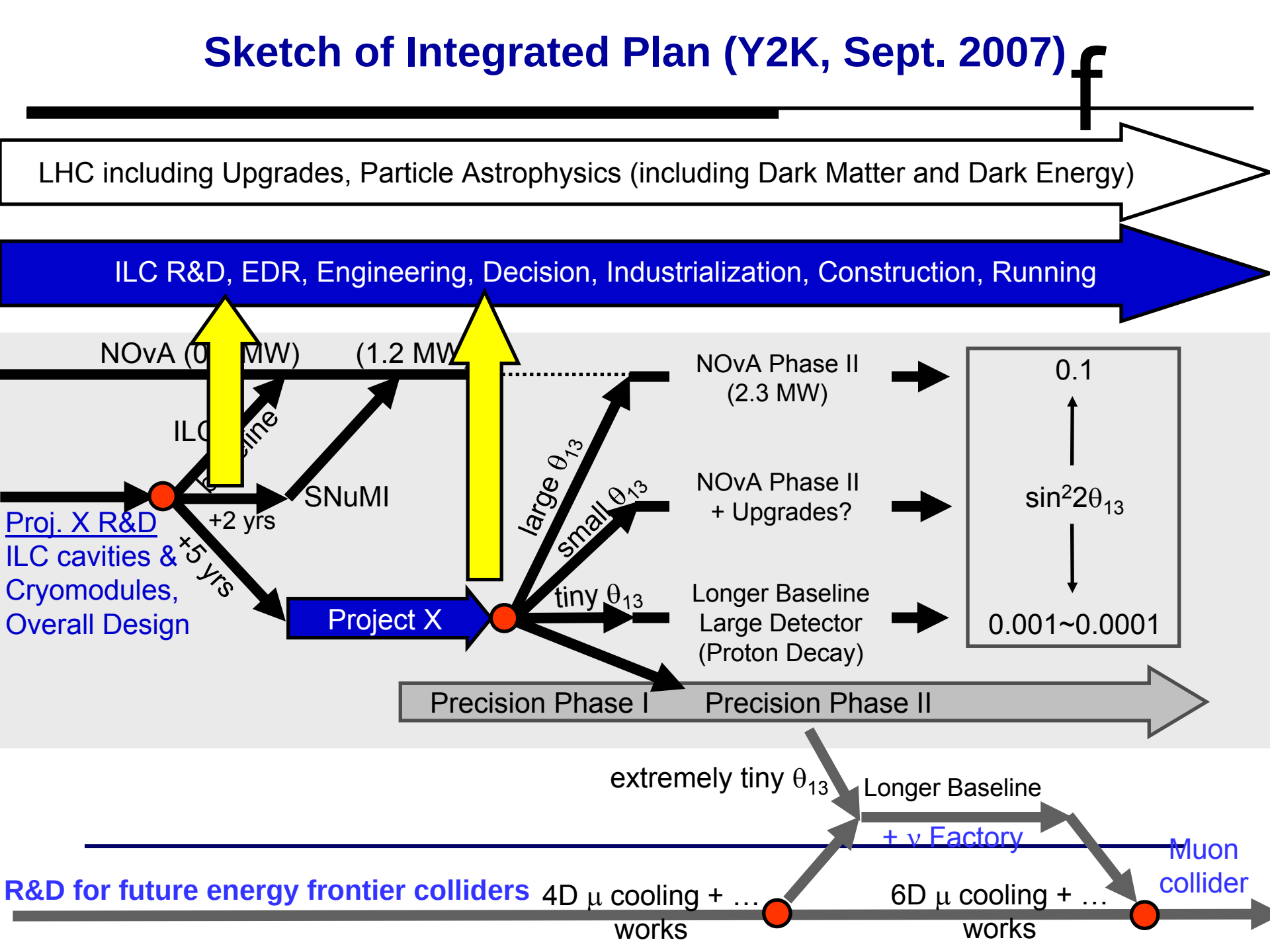
The Fermilab Roadmap, Project X, and Muon Facilities

Steve Holmes

NFMCC Meeting
March 17, 2008

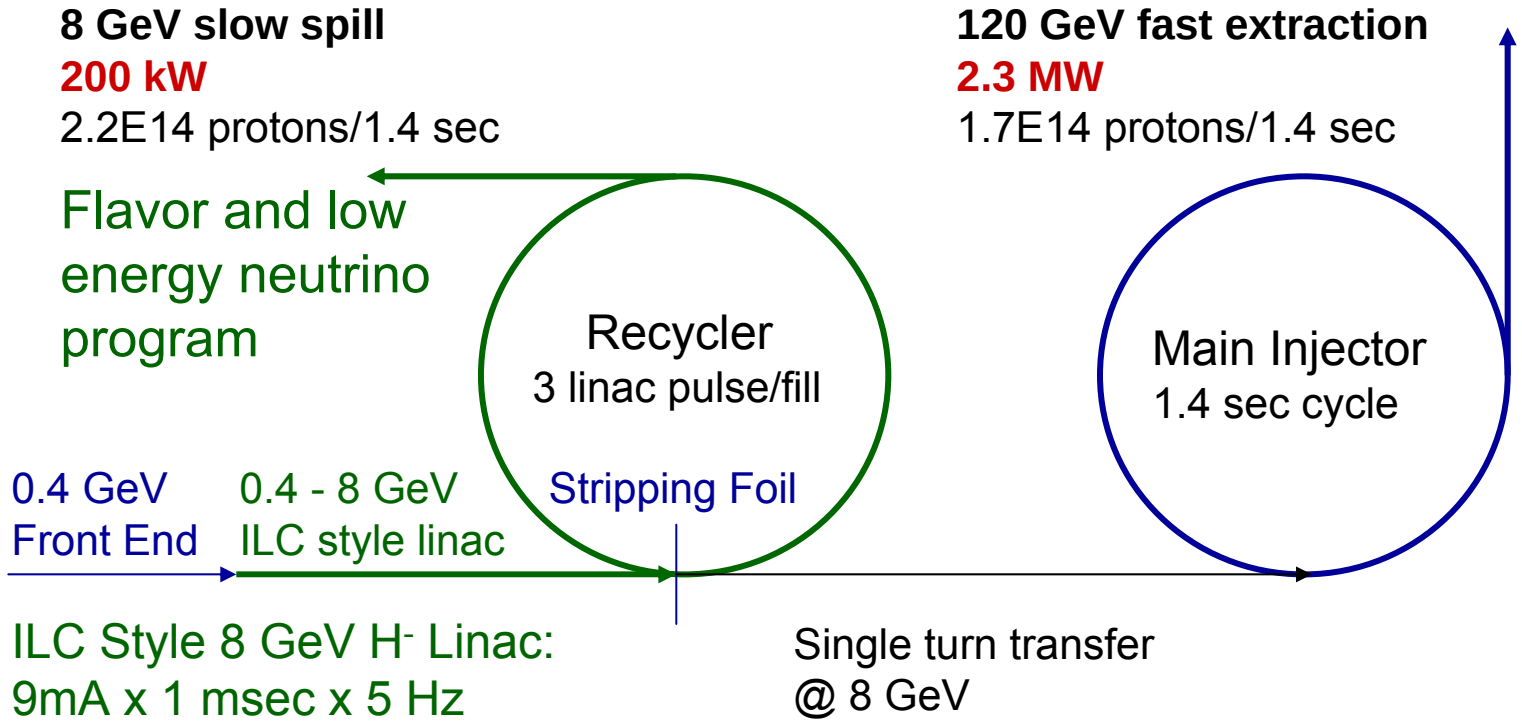
Sketch of Integrated Plan (Y2K, Sept. 2007)



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?



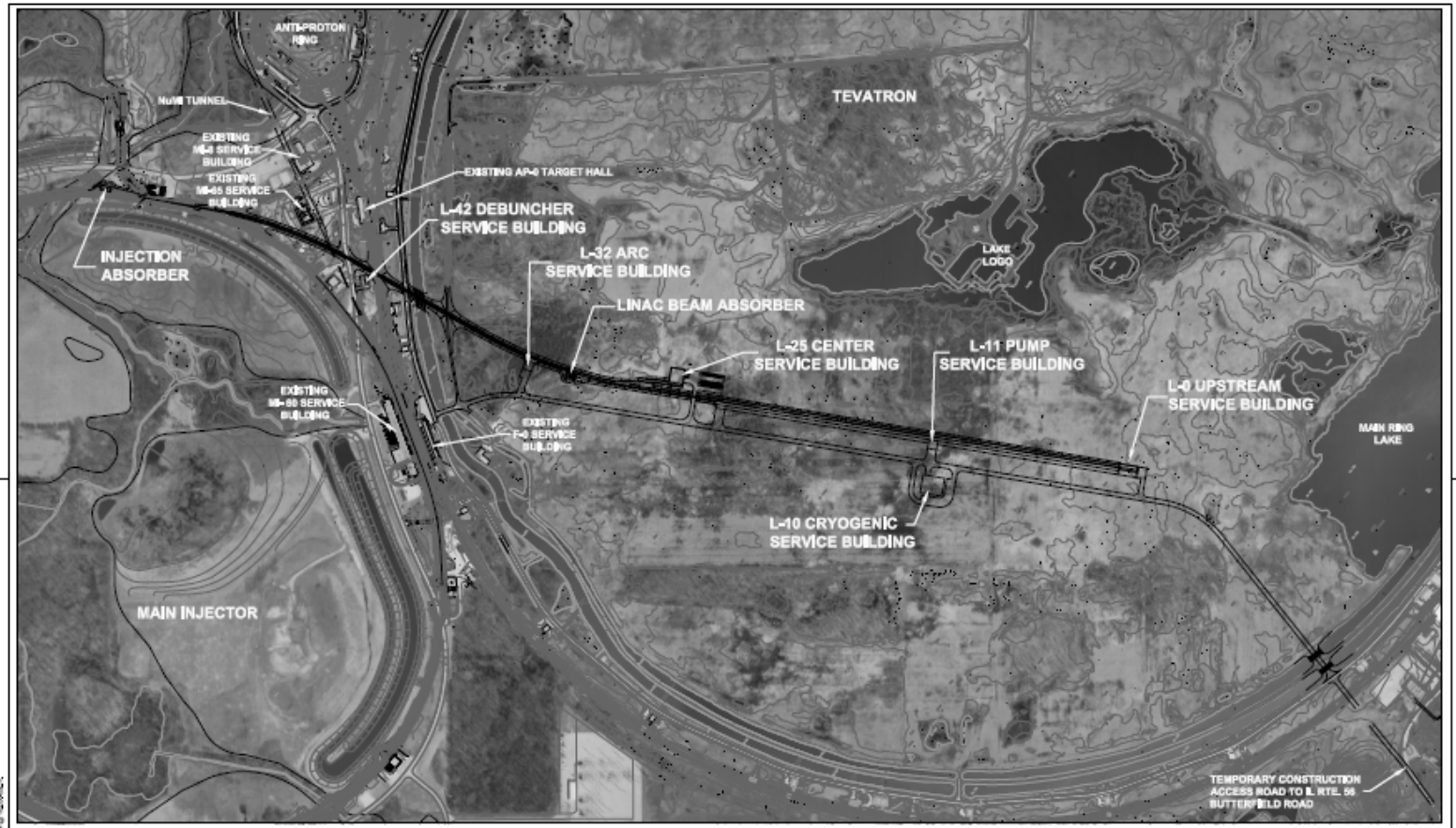
Project X Facility Overview
Scope

- The R&D program supports a facility scope that 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 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 Overview
Provisional Siting



Project X R&D Goals
Program Goals

- The goal of the Project X R&D program is to provide support for a Critical Decision 1 (CD-1) in 2010, leading to a CD-2/3a in 2011.
  - Design and technical component development;
  - Fully developed baseline scope, cost estimate, and schedule for CD-2
  - 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 R&D Goals
Technical Goals

- Complete preliminary design and cost estimate for Project X:
  - technical and conventional construction elements,
  - systems integration, and
  - installation and commissioning plan.
- A supporting technology development program targeting key accelerator physics and engineering challenges
- Alignment with the ILC and SRF programs:
  - Development of shared technologies to the benefit of both efforts
    - ➢ Cavity/cryomodule design, rf sources, e-cloud, civil infrastructure
  - Project X 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.
- Preliminary identification of performance upgrade paths

Project X R&D Goals
Management/Organization Goals

- Formation of a multi-institutional collaboration to carry out the Project X R&D program and to prepare a plan for construction.
- Development all project documentation and organizational structures required by DOE 413.3.
- Timeline:
  - 2008: CD-0
    - Form Project X R&D Collaboration
  - 2009:
    - Start project documentation (including CDR), and accompanying R&D program
  - 2010: CD-1
    - Finish CDR, form collaboration to undertake construction project
  - 2011: CD-2/3a
    - Establish project baseline (scope, cost, schedule)

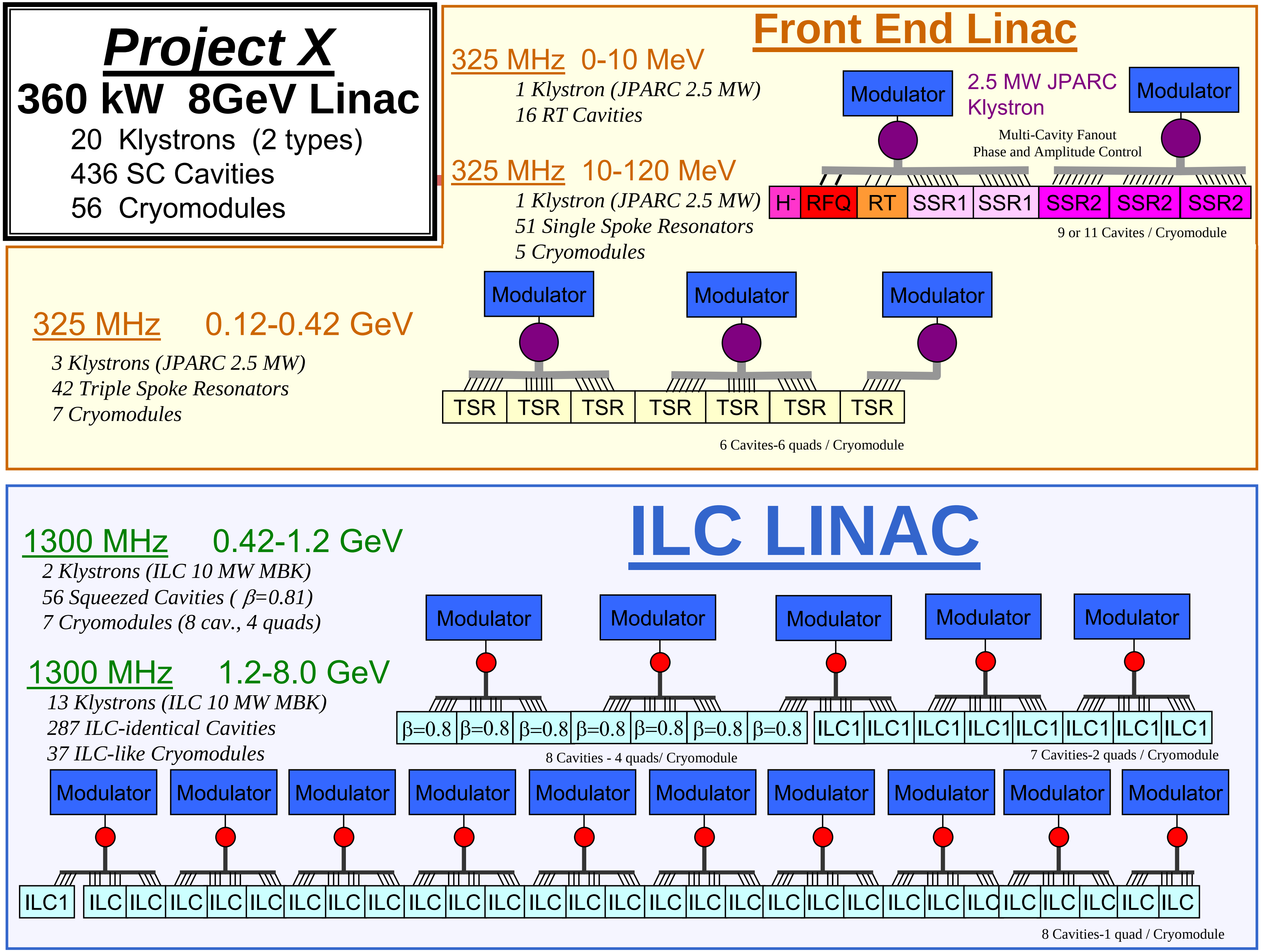
Project X R&D Strategy

Preliminaries

- Proton Driver Design Studies over 2002-2004
  - Director's Review in March 2005
- Project X Preliminary Report - August 1, 2007
  - Delivered to Fermilab Directorate Long Range Steering committee
  - Reviewed by Fermilab Accelerator Advisory Committee
    - "We congratulate the Project X team on an innovative design…Project-X is especially suitable for Fermilab in the current scenario of a not well-defined schedule of ILC construction, because of synergies with ILC…The committee therefore very strongly supports the work that is planned for Project-X."

      http://projectx.fnal.gov/AACReview/ProjectXAacReport.pdf
- Project X Accelerator Physics and Technology Workshop - Nov. 12-13, 2007
  - 175 attendees from 28 different institutions.

    http://projectx.fnal.gov/Workshop/ProjectXWorkshopReport.pdf



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
8 Cavities-1 quad / Cryomodule

Project X R&D Strategy

Major System Requirements

Req. No.	Description	Req.	Unit	Reference Requirements			
1.0	**General**						
1.1	120 GeV Beam Power	2.3	MW				
1.2	8 GeV Beam Power	360	kW				
1.3	8 GeV Slow Spill Beam Power	200	kW				
1.4	8 GeV Slow Spill Duty Factor	55	%				
1.5	120 GeV Availability	75	%				
1.6	8 GeV Availability	80	%				

Req. No.	Description	Req.	Unit	Reference Requirements			
2.0	**325 MHz Linac**						
2.1	Average Beam Current	9	mA	1.2			
2.2	Pulse Length	1	mS	1.2			
2.3	Repetition rate	5	Hz	1.2			
2.4	325 MHz Availability	98	%	1.6			
2.5	Peak RF Current	14.4	mA	2.1	2.11	2.13	2.14
2.6	Final Energy	420	MeV	3.6			
2.7	Energy Variation (rms)	1	%	3.10			
2.8	Bunch Phase jitter (rms)	1	degree	3.11			
2.9	Linac Species	H-		4.1			
2.10	Transverse Emittance (95% normalized)	2.5	π-mm-mrad	5.7	5.8		
2.11	Macro Bunch Duty Factor	67	%	5.10	5.12		
2.12	Macro Bunch Frequency	53	MHz	5.12			
2.13	Micro Pulse Length	10.4	uS	5.13			
2.14	Micro Pulse Period	11.1	uS	5.13			

Project X R&D Strategy

Major System Requirements

Req. No.	Description	Req.	Unit	Reference Requirements			
3.0	**1300 MHz Linac**						
3.1	Average Gradient (ILC portion)	26	MV/meter				
3.2	Average Gradient (S-ILC portion)	23	MV/meter				
3.3	Average Beam Current	9	mA	1.2			
3.4	Pulse Length	1	mS	1.2			
3.5	Repetition rate	5	Hz	1.2			
3.6	1300 MHz Availability	88	%	1.6			
3.7	Initial Energy	420	MeV	2.6			
3.8	Length (approx.)	700	meters	3.1	3.13		
3.9	Peak RF Current	14.4	mA	3.3	3.15	3.17	3.18
3.10	Linac Species	H-		4.1			
3.11	Energy Variation (rms)	1	%	4.9			
3.12	Bunch Phase jitter (rms)	1	degree	4.9			
3.13	Final Energy	8	GeV	4.10			
3.14	Transverse Emittance (95% normalized)	2.5	π-mm-mrad	5.7	5.8		
3.15	Macro Bunch Duty Factor	67	%	5.10	5.12		
3.16	Macro Bunch Frequency	53	MHz	5.12			
3.17	Micro Pulse Length	10.4	uS	5.13			
3.18	Micro Pulse Period	11.1	uS	5.13			

Project X R&D Strategy

Major System Requirements

Req. No.	Description	Req.	Unit	Reference Requirements			
4.0	**8 GeV Transfer Line**						
4.1	Injection Stripping efficiency	98	%				
4.2	Length (approx.)	1000	meters				
4.3	Maximum average activation level	20	mrem/hr				
4.4	Availability	98	%	1.6			
4.5	Momentum Aperture	+/- 0.8	%	3.10			
4.6	Minimum Transverse Aperture	25	π-mm-mrad	3.13	4.3		
4.7	Maximum Dipole Field	0.05	T	4.1	4.3		
4.8	Transfer Efficiency	99.99	%	4.3			
4.9	Final Energy Variation	+/- 0.11	%	5.10			
4.10	Energy	8	GeV	5.1			

Req. No.	Description	Req.	Unit	Reference Requirements			
5.0	**Recycler**						
5.1	Energy	8	GeV				
5.2	Storage Efficiency	99.5	%				
5.3	Average Recycler Beam Current	0.6	A	1.2			
5.4	Availability	95	%	1.6			
5.5	Injection Rate	5	Hz	2.3			
5.6	Maximum Space Charge Tune Shift	0.05		5.2			
5.7	95% normalized transverse emittance	25	π-mm-mrad	5.6			
5.8	r.m.s. normalized transverse emittance	13	π-mm-mrad	5.6			
5.9	Bunching factor	2		5.6			
5.10	Longitudinal emittance per Bunch	0.5	eV-Sec	5.6	5.12		
5.11	Cycle Time	1.4	S	6.1			
5.12	RF Frequency	53	MHz	6.2			
5.13	Abort Gap Length	700	nS	6.3			
5.14	Peak Recycler Beam Current	2.4	A	6.5			

Project X R&D Strategy

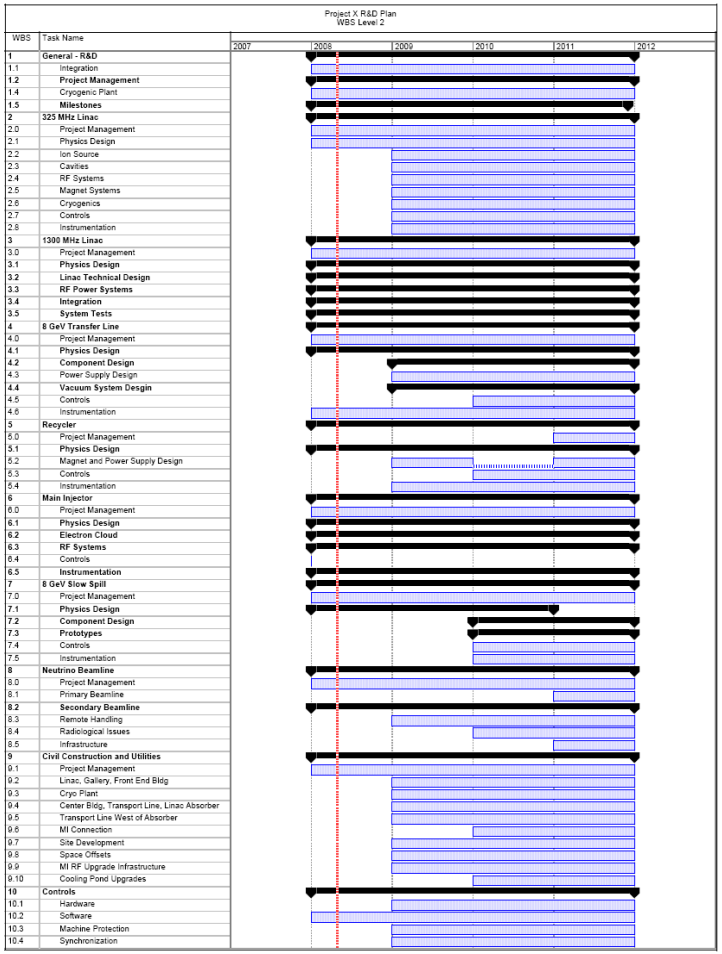
Major System Requirements

Req. No.	Description	Req.	Unit	Reference Requirements		
6.0	**Main Injector**					
6.1	120 GeV cycle Time	1.4	S			
6.2	RF Frequency	53	MHz			
6.3	Abort Gap Length	700	nS			
6.4	Acceleration Efficiency	99	%			
6.5	Main Injector Beam Current	2.4	A	1.1		
6.6	Final Energy	120	GeV	1.1		
6.7	120 GeV Beam Power	2.3	MW	1.1		
6.8	Availability	87	%	1.5		
6.9	Injection Energy	8	GeV	5.1		
6.10	Longitudinal emittance per Bunch	0.5	eV-Sec	6.2	6.11	
6.11	Space Charge Tune Shift	0.05		6.4		
6.12	95% normalized transverse emittance	25	π-mm-mrad	6.11		
6.13	r.m.s. normalized transverse emittance	13	π-mm-mrad	6.11		
6.14	Bunching factor	2		6.11		
7.0	**8 GeV Slow Spill**					
7.1	8 GeV Slow Spill Beam Power	200	kW	1.3		
7.2	Peak Spill Rate	280	$x10^{12}$ pps	1.3	1.4	7.5
7.3	8 GeV Slow Spill Duty Factor	55	%	1.4		
7.4	8 GeV Availability	80	%	1.6		
7.5	Cycle Time	1.4	S	6.1		
7.6	Peak Recycler Beam Current for slow spill	0.8	A	7.2		
8.0	**120 GeV Targeting**					
8.1	120 GeV Beam Power	2.3	MW	1.1		
8.2	120 GeV Availability	95	%	1.5		
8.3	Cycle Time	1.4	S	6.1		

Project X R&D Plan
Master Schedule

- Based on resource loaded schedule (RLS – see report for readable version)
- Covers FY2008-2011
- Incremental to ILC, SRF, HINS
- Major Milestones

CD-0 Approved	8/1/08
Start CD-1 Documentation	9/1/08
Complete CD-1 Document.	4/1/10
Start CD-2 Documentation	5/3/10
CD-1 DOE Review	6/1/10
CD-1 Approved	8/2/10
Complete CD-2 Document.	4/1/11
Start CD-3 Documentation	5/2/11
CD-2 DOE Review	6/1/11
CD-2/3a Approved	9/1/11



Project X R&D Plan
Budget Profile

	Project X R&D Plan Budget Profile (Dollar amounts in millions, fully burdened)					
	FY08	FY09	FY10	FY11	FY12	TOTAL
SWF	$6.7	$10.5	$19.1	$26.3		$62.6
M&S	$1.5	$4.9	$6.2	$13.7		$26.3
TOTAL	$8.1	$15.5	$25.4	$40.0		$88.9
				PED		
	CD-0		CD-1		CD-2/3a	

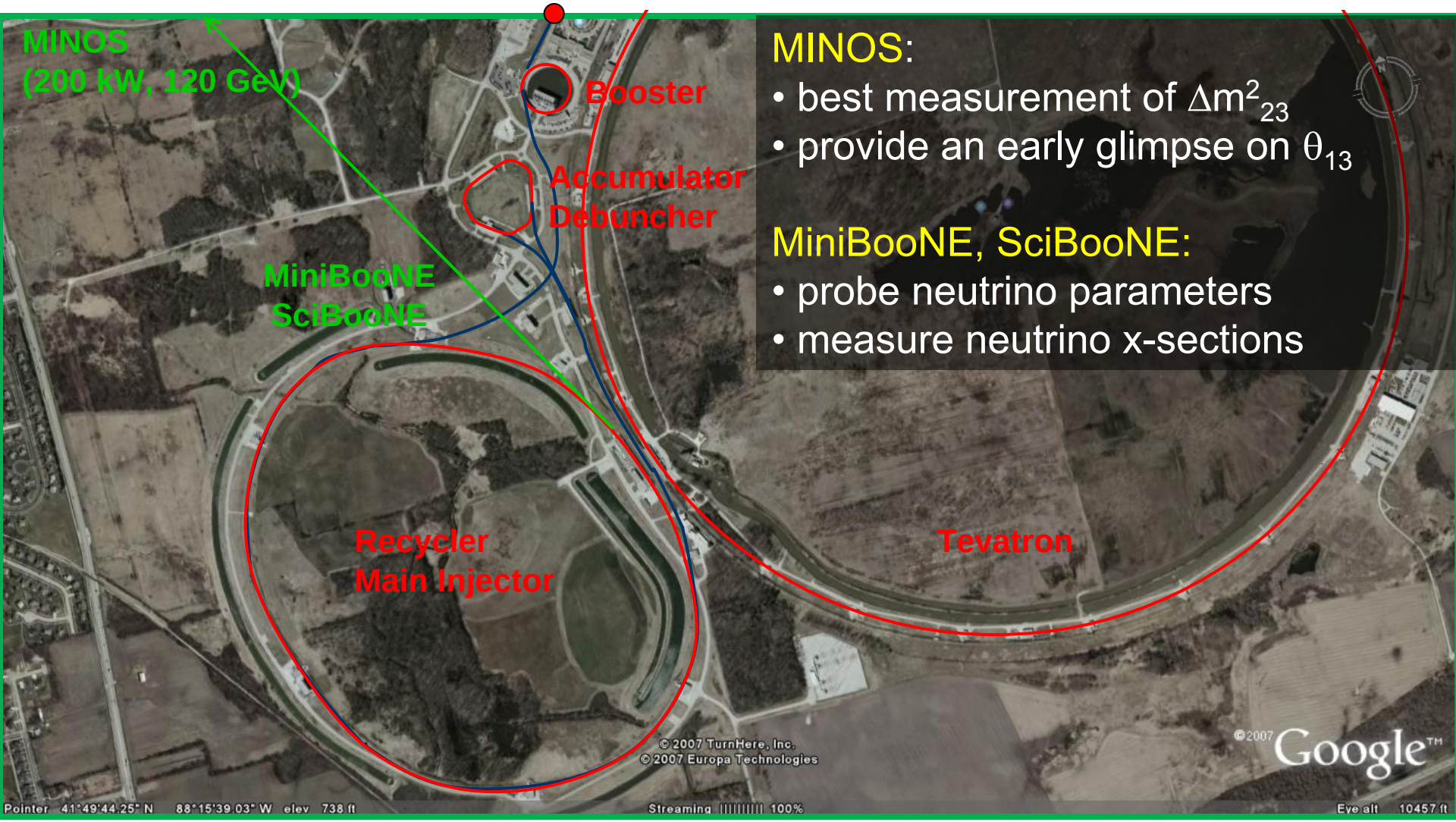
Project X R&D budget profile

- Scientists not included
- Can produce this table with any combination of scientists in or out, FY08 or AY$, burdened or unburdened
- Incremental to ILC, SRF, and HINS programs

Project X R&D Plan
An Integrated SRF Plan

	FY08	FY09	FY10	FY11	FY12	FY13
ILC C+CM	CM1	CM2	CM3 (Type IV)		CM4 rf unit syst.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-2/3a**		

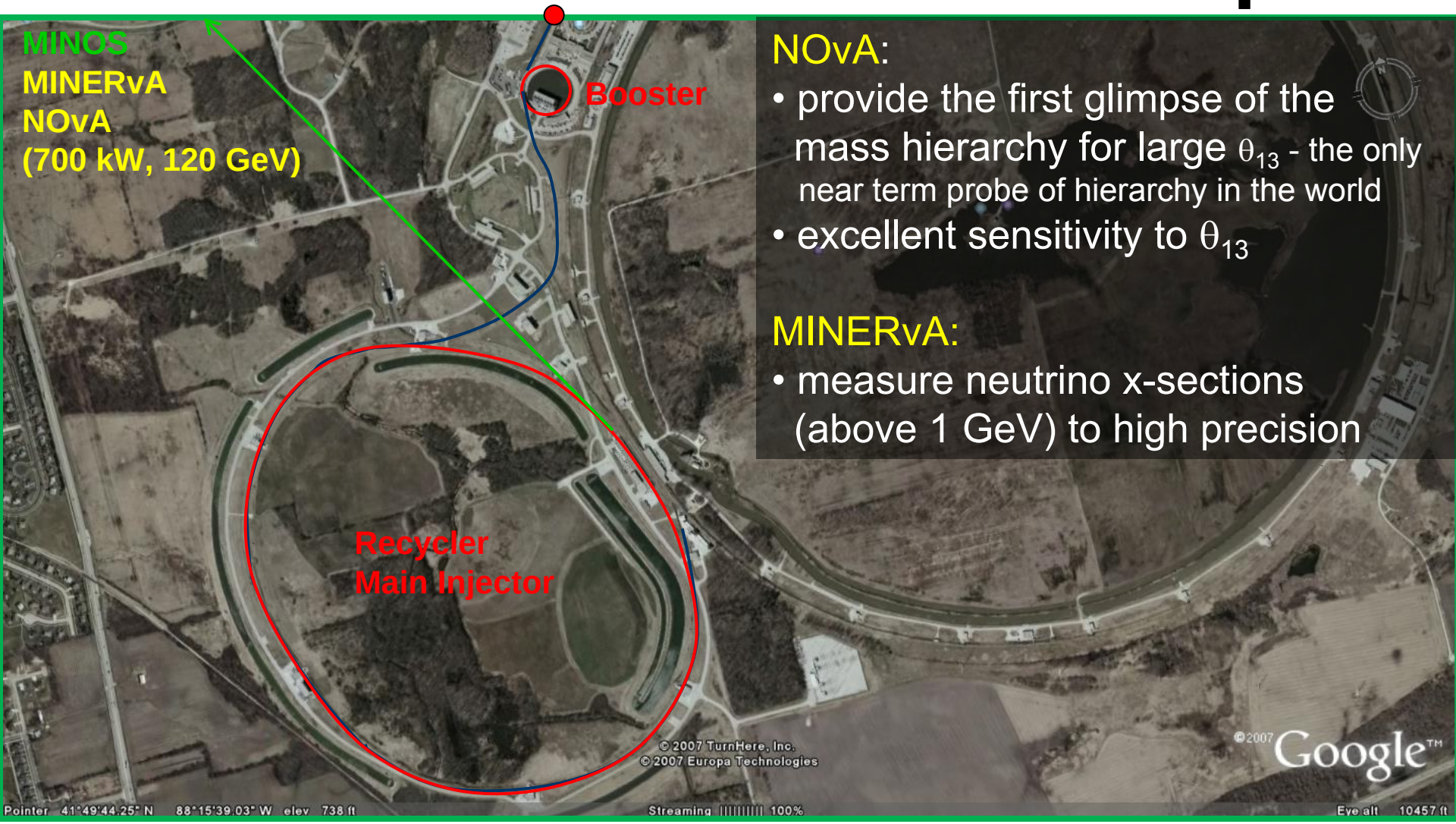
Evolution of a world-leading neutrino program: Present



MINOS:
- best measurement of Δm^2_{23}
- provide an early glimpse on θ_{13}

MiniBooNE, SciBooNE:
- probe neutrino parameters
- measure neutrino x-sections

Evolution of a world-leading neutrino program



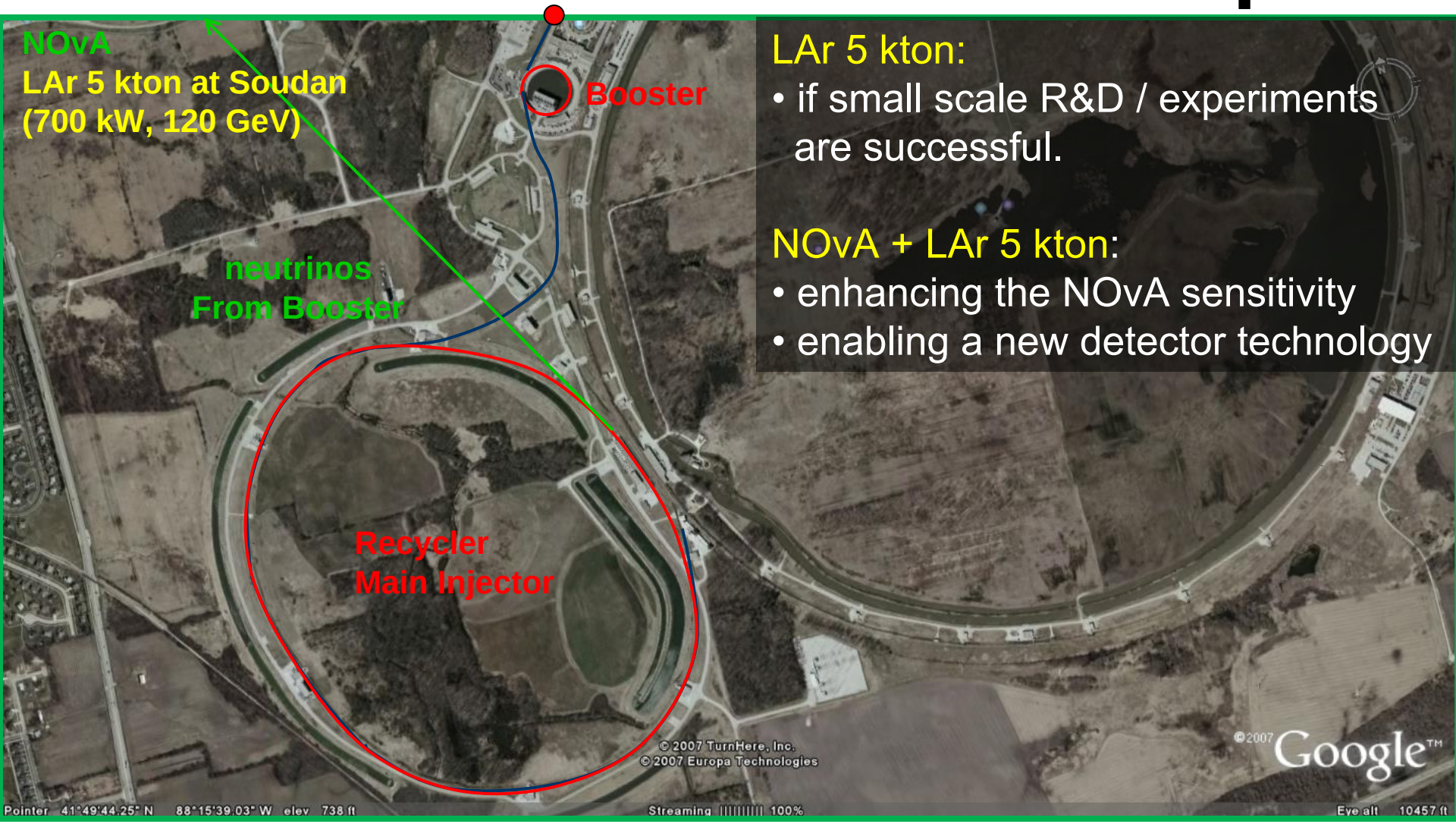
NOvA:

- provide the first glimpse of the mass hierarchy for large θ_{13} - the only near term probe of hierarchy in the world
- excellent sensitivity to θ_{13}

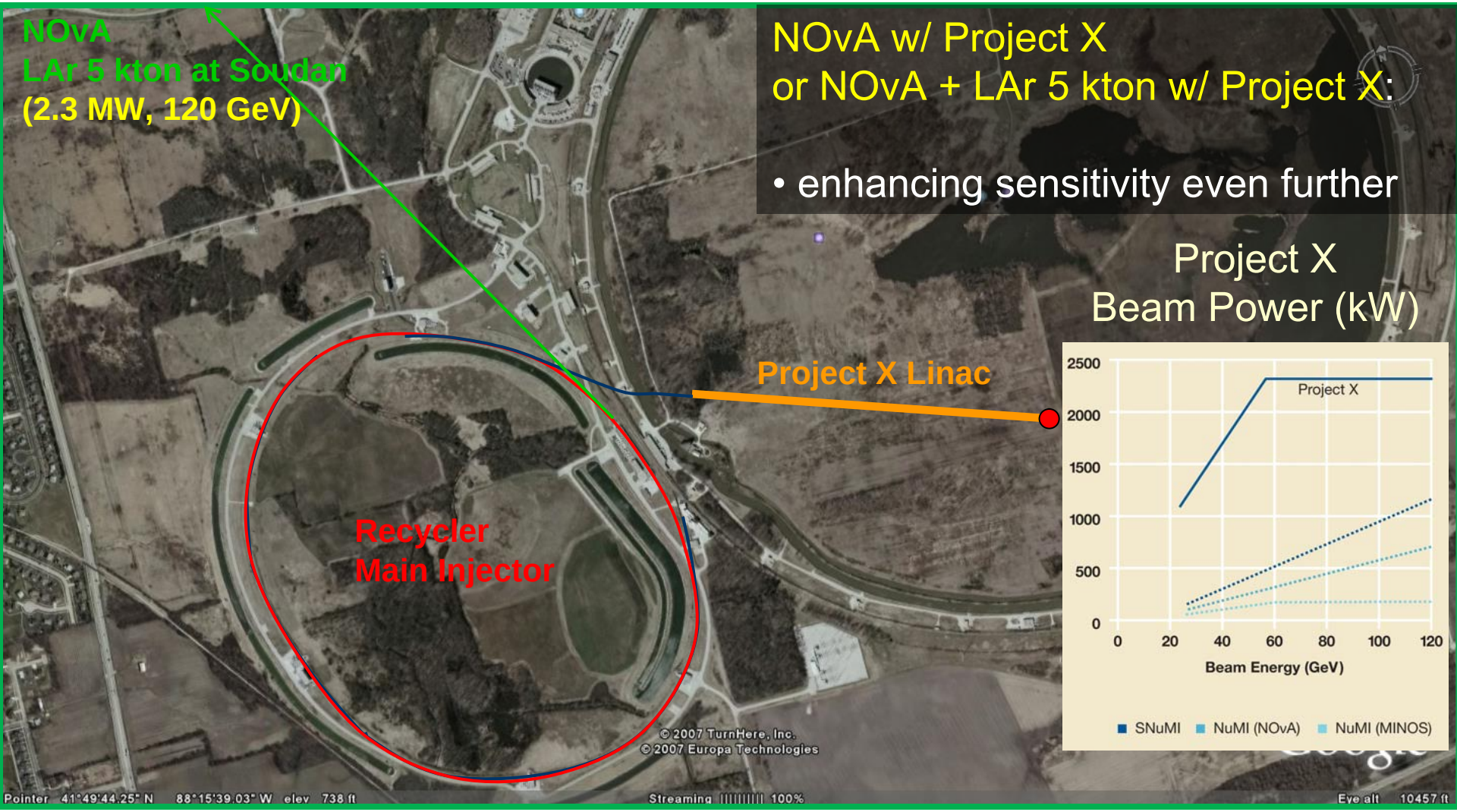
MINERvA:

- measure neutrino x-sections (above 1 GeV) to high precision

Evolution of a world-leading neutrino program



Evolution of a world-leading neutrino program



Evolution of a world-leading neutrino program

Project X beam to DUSEL:

- enhancing the sensitivity markedly

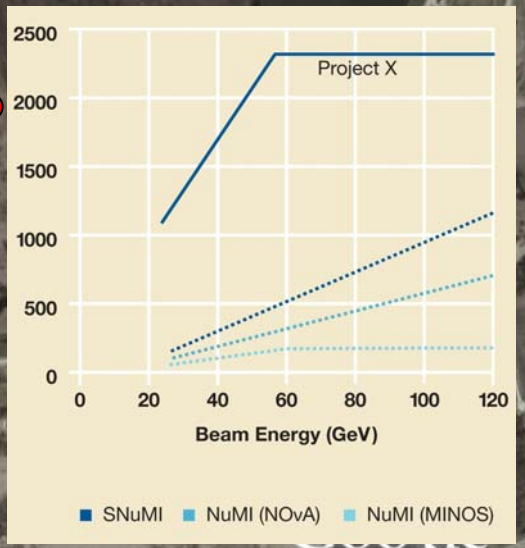
DUSEL (WC or/and LAr)
(>2 MW, 50 – 120 GeV)

(ν Detector = Proton Decay Detector)

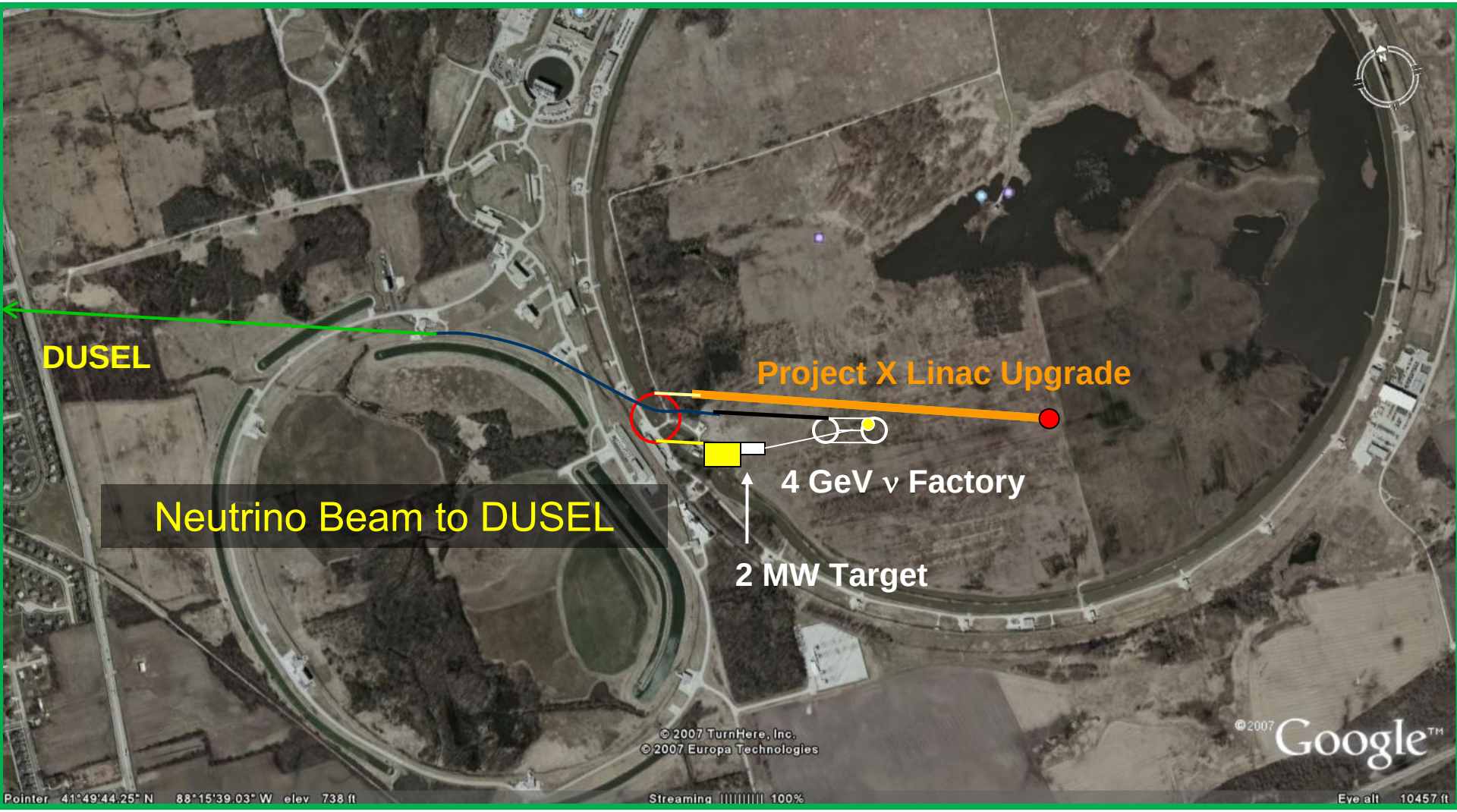
Project X Linac

Recycler
Main Injector

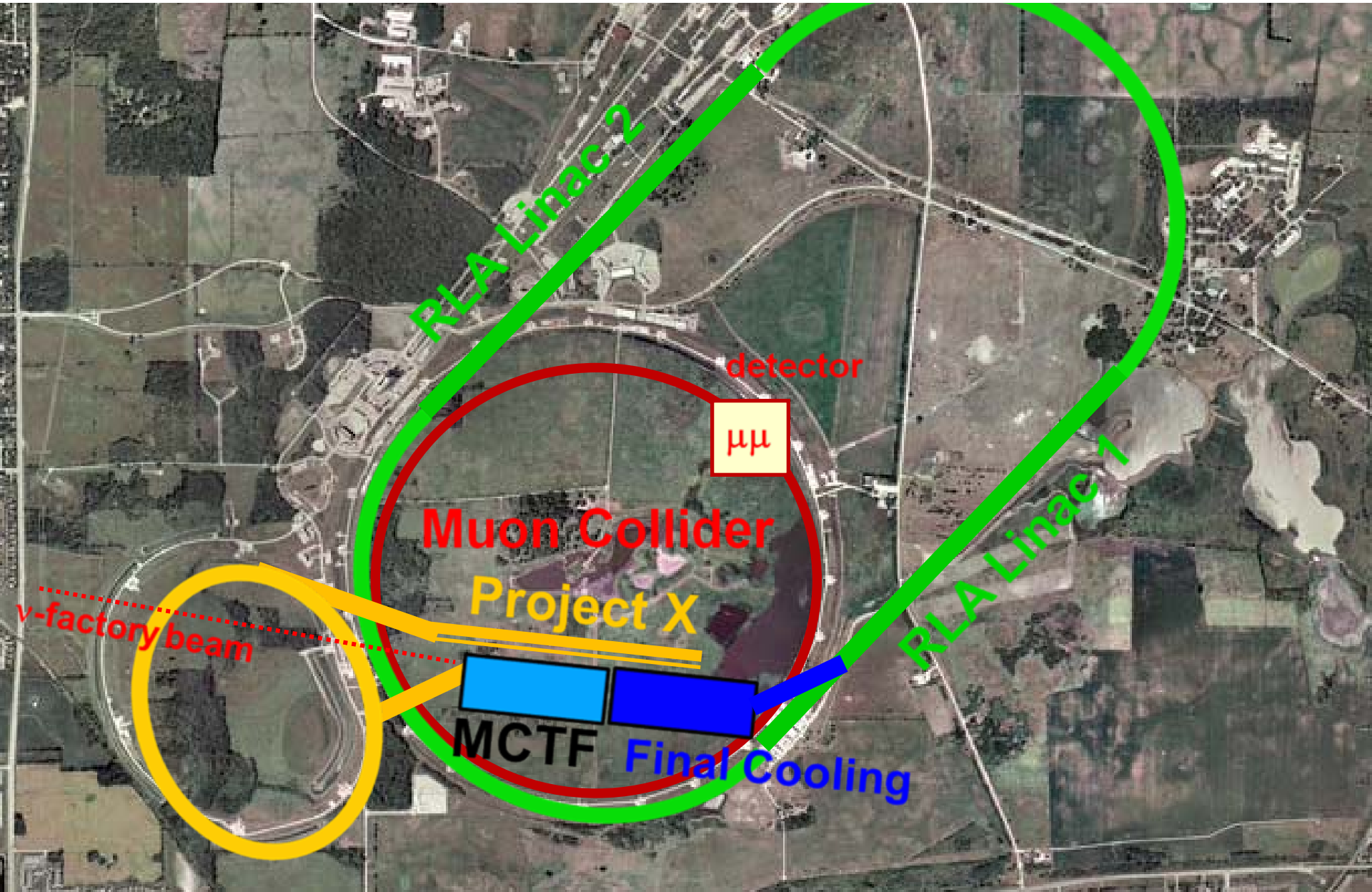
Project X
Beam Power (kW)



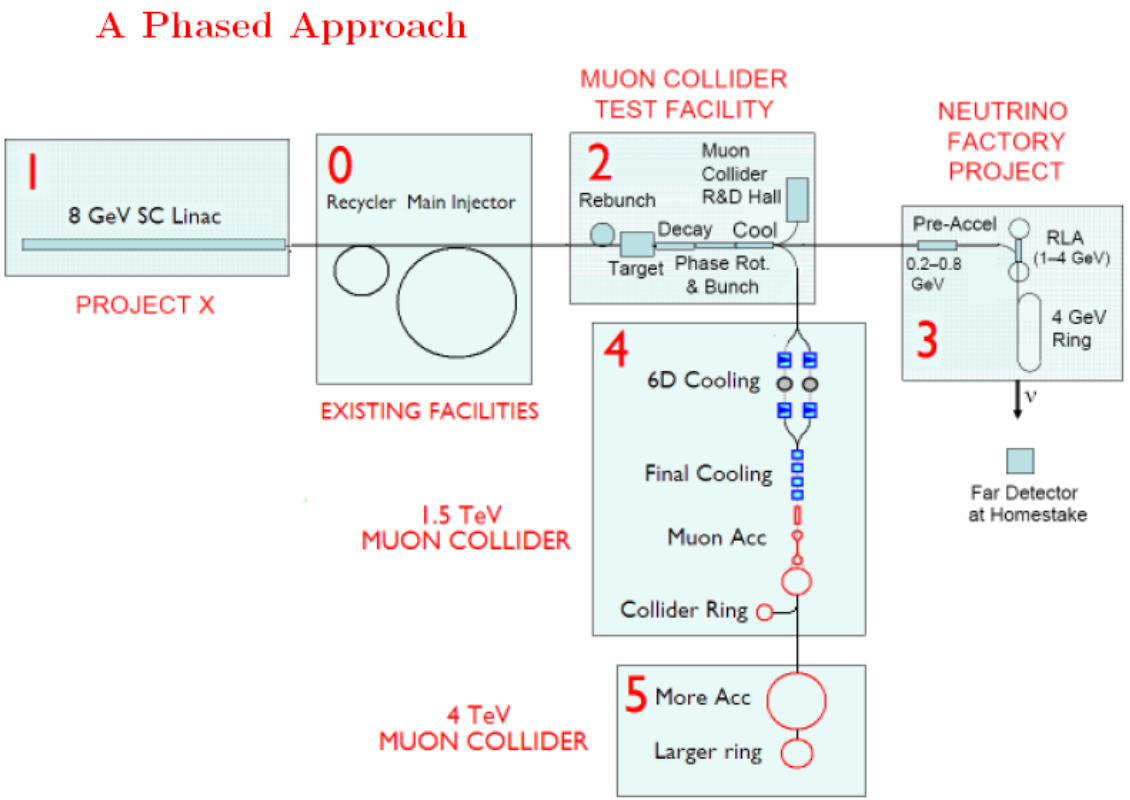
Evolution of a world-leading neutrino program



Evolutionary Path to $\mu^+\mu^-$ Collider



Consistent Vision as Presented to P5 by R. Palmer



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
  - Potential upgrade paths to mulit-MW at 8 GeV exist
  - Design aligned with needs of ILC development
- R&D plan developed covering the period through CD2/3a (2011)
  - Integrates effort on Project X, ILC, and HINS
  - Resource plan exists
- 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.