Project X: A multi-MW Proton Source at Fermilab

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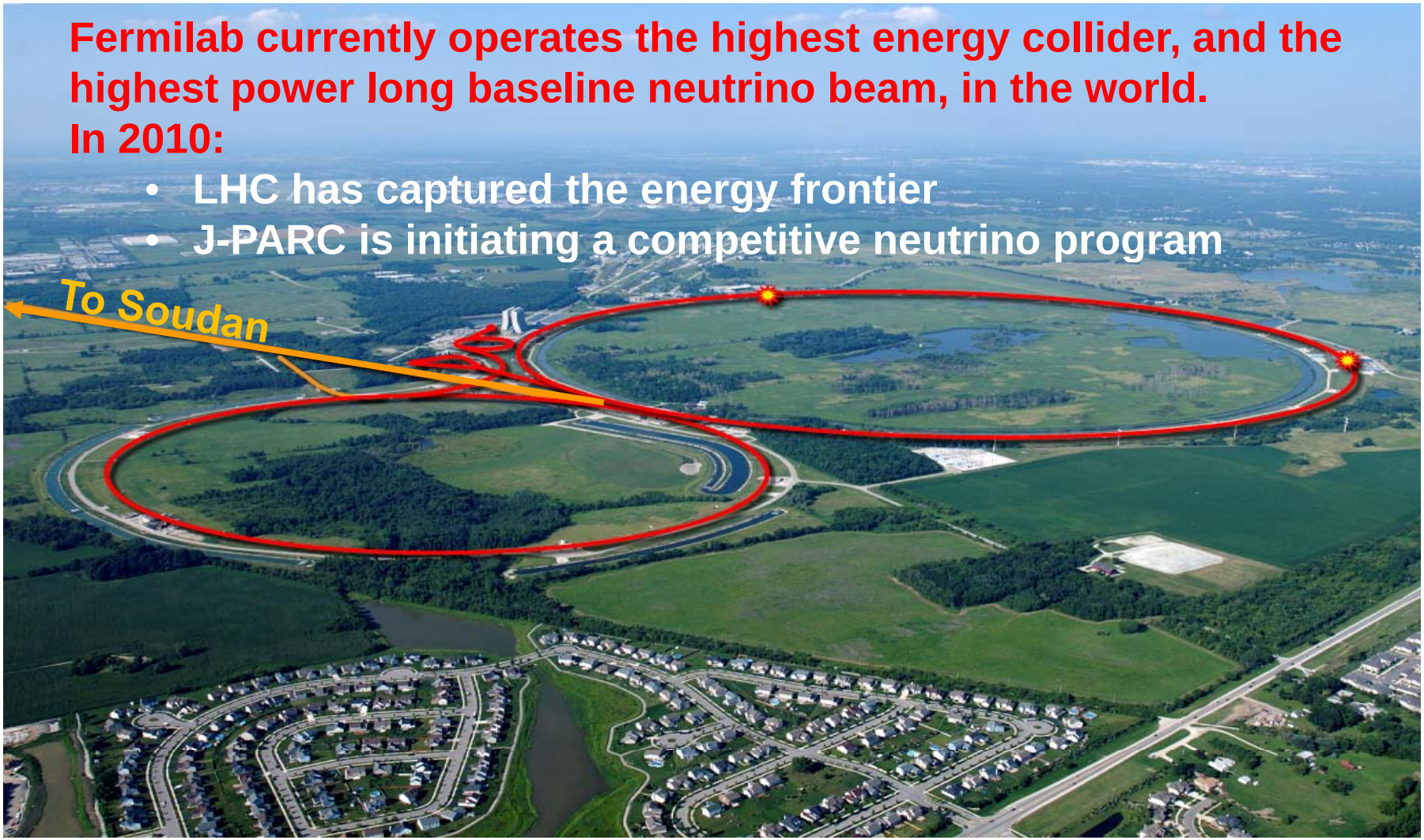
Outline

- Strategic Context/Evolution of the Fermilab Complex
- Project X Goals and Initial Configuration(s)
- Project X Research, Design, and Development Plan
- Relationships to other Programs

Project X website: http://projectx.fnal.gov/

Strategic Context: Fermilab and the World Program



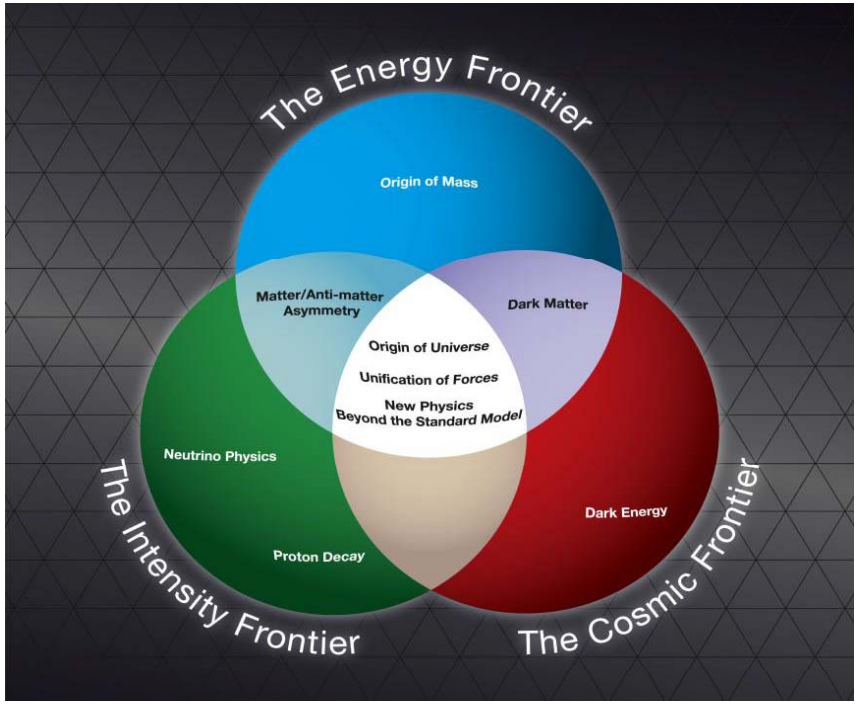
Fermilab currently operates the highest energy collider, and the highest power long baseline neutrino beam, in the world.

In 2010:

- **LHC has captured the energy frontier**
- **J-PARC is initiating a competitive neutrino program**

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 strategy is fully aligned with the HEPAP/P5 plan:
  - Energy and intensity frontiers share strong reliance on accelerators



Evolution of the Fermilab Accelerator Complex

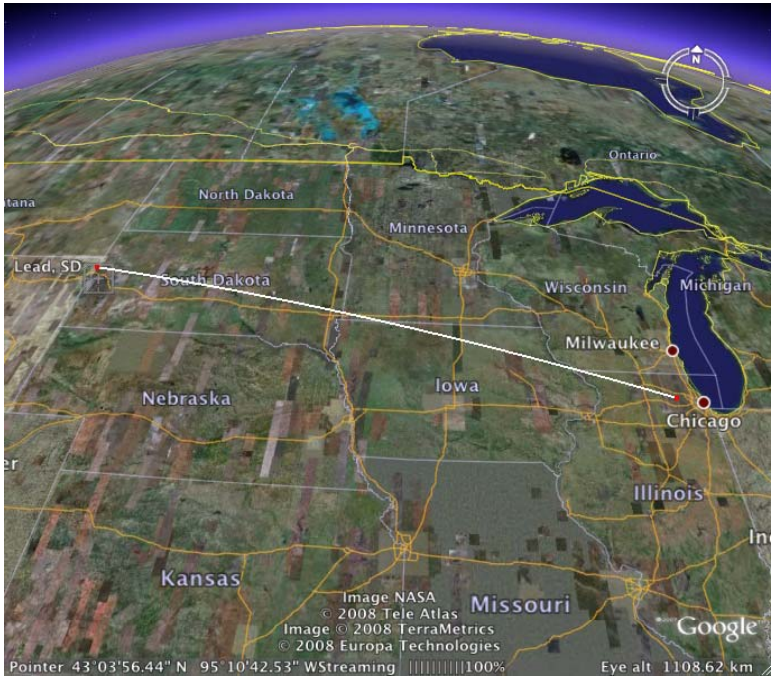
- A multi-MW Proton Source, Project X, is the linchpin of Fermilab's strategy for future development of the accelerator complex.
- Project X provides long term flexibility to pursue a variety of scientific opportunities
  - Energy Frontier:

    Tevatron → ILC or Muon Collider
    - Technology alignment
    - Fermilab as host site for ILC or MC
  - Intensity Frontier:

    NuMI→ NOνA→ LBNE/mu2e→ multi-MW Proton Source → NuFact
    - Continuously evolving world leading program in neutrino physics and other beyond the standard model phenomena

Mission Need

- The P5 report defines mission need for a multi-MW proton source based on :
  - 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
    - Operations simultaneous with the neutrino program.
  - A path toward a muon source for a possible future neutrino factory and/or a muon collider at the Energy Frontier.
    - Requires upgrade potential to 2-4 MW at ~8 GeV.

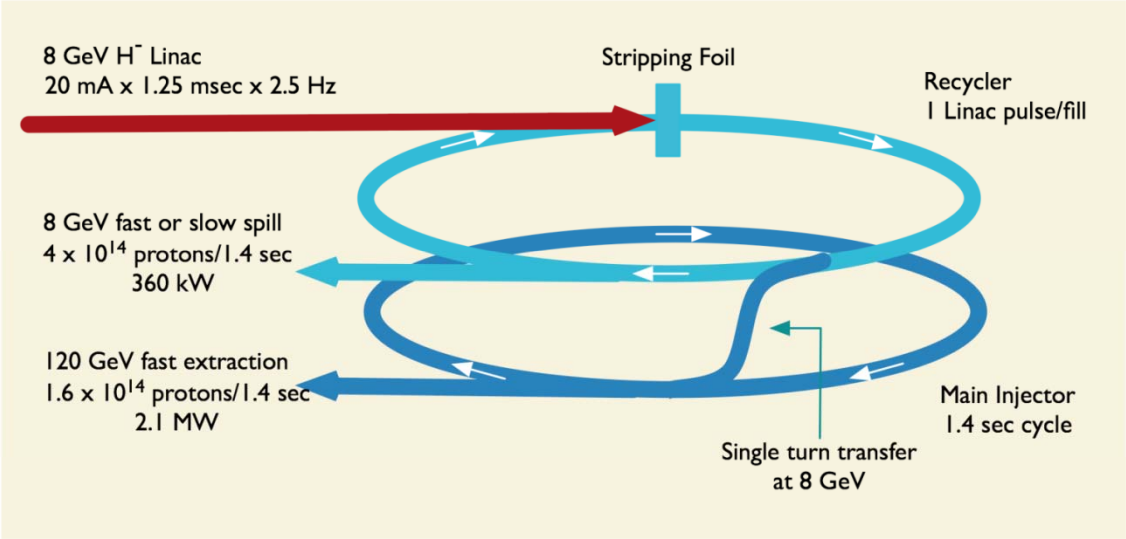


Accelerator Requirements:
Rare Processes

	Proton Energy (kinetic)	Beam Power	Beam Timing
Rare Muon decays	2-3 GeV	>500 kW	1 kHz – 160 MHz
(g-2) measurement	8 GeV	20-50 kW	30- 100 Hz.
Rare Kaon decays	2.6 – 4 GeV	>500 kW	20 – 160 MHz. (<50 psec pings)
Precision K^0 studies	2.6 – 3 GeV	> 100 mA (internal target)	20 – 160 MHz. (<50 psec pings)
Neutron and exotic nuclei EDMs	1.5-2.5 GeV	>500 kW	> 100 Hz

Initial Configuration-1

- Project X Design Criteria
  - >2 MW of beam power over the range 60 – 120 GeV;
  - Simultaneous with >150 kW of beam power at 8 GeV;
  - Compatible with future upgrade to 2-4 MW at 8 GeV



- Initial Configuration Document-1 V1.1 released March 2009
  - Accompanying cost estimate subject of Director's Review March 2009

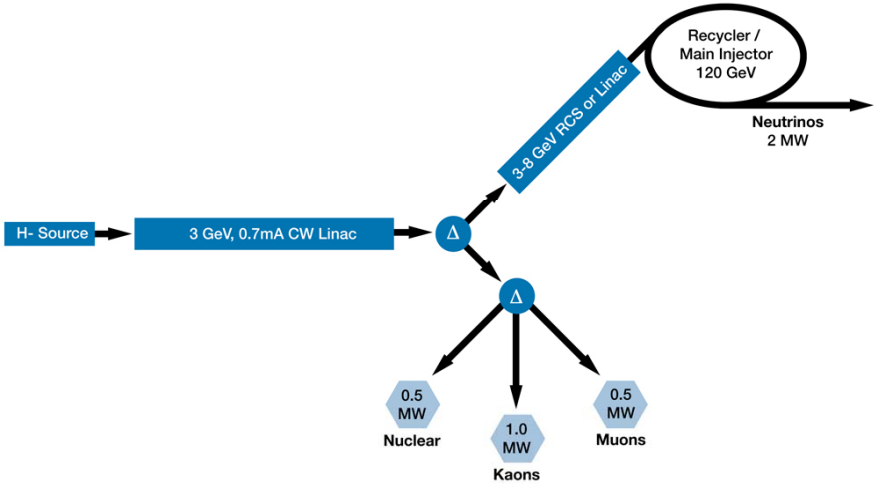
Initial Configuration-1
Operational Challenges

- We know that IC-1 does not provide an ideal platform for mounting a low energy flavor program.
  - Rare processes programs require high duty factor beams with varying bunch structures
  - The Recycler is ill-suited to providing high intensity slow spilled beam
    - In IC-1 the Recycler delivers 15 Hz packets to the Debuncher for slow spill to mu2e.
      - The Debuncher appears limited to <150 kW in this mode
      - We believe <u>there is a fundamental limit on the amount of beam power that can be delivered via a resonant extraction system</u>.
  - IC-1 does not (yet?) have a solution for the kaon requirements

⇒ **We are able to generate substantially more beam power in the IC-1 than we can effectively utilize.**

Initial Configuration-2

- Project X Design Criteria
  - 2 MW of beam power over the range 60 – 120 GeV;
  - Simultaneous with 2 MW beam power at 3 GeV;
  - Compatibility with future upgrades to 2-4 MW at 8 GeV



- ICD-2 V1.0 being prepared for Feb 2010 release

Initial Configuration-2
Performance Goals

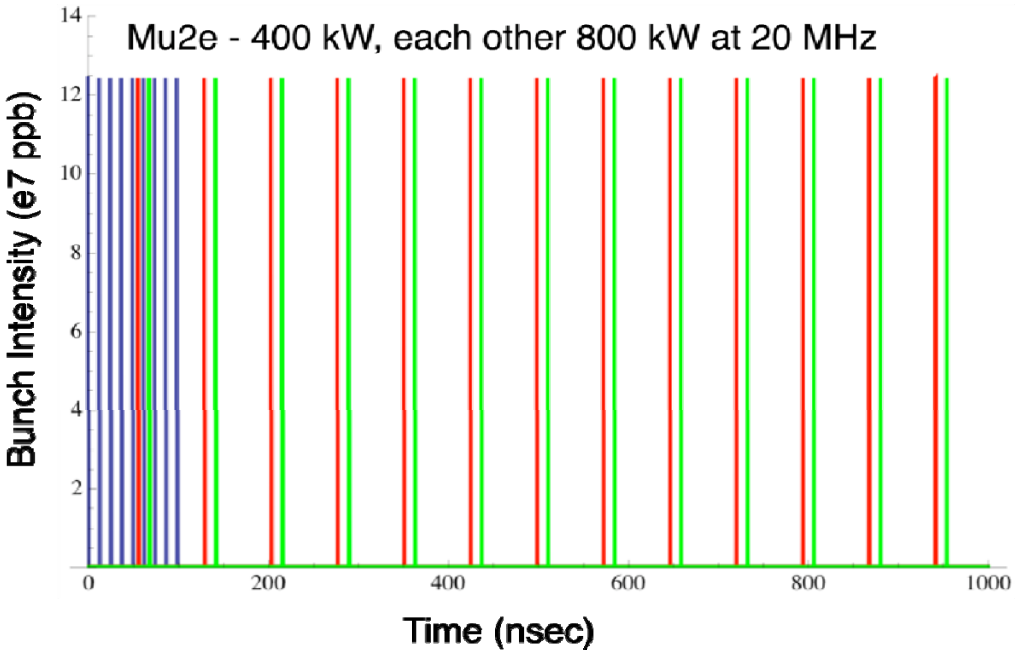
Linac		
Particle Type	H^-	
Beam Kinetic Energy	3.0	GeV
Average Beam Current	0.67	mA
Linac pulse rate	CW	
Beam Power	3000	kW
Beam Power to 3 GeV program	1920	kW
RCS		
Particle Type	protons	
Beam Kinetic Energy	8.0	GeV
Cycle time	0.1	sec
Particles per cycle to MI	2.6×10^{13}	
Beam Power to 8 GeV program	190	kW
Main Injector/Recycler		
Beam Kinetic Energy (maximum)	120	GeV
Cycle time	1.4	sec
Particles per cycle	1.6×10^{14}	
Beam Power at 120 GeV	2100	kW

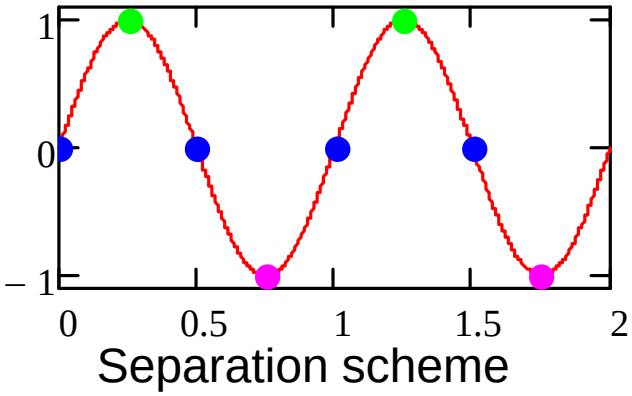
simultaneous

Initial Configuration-2
Operating Scenario

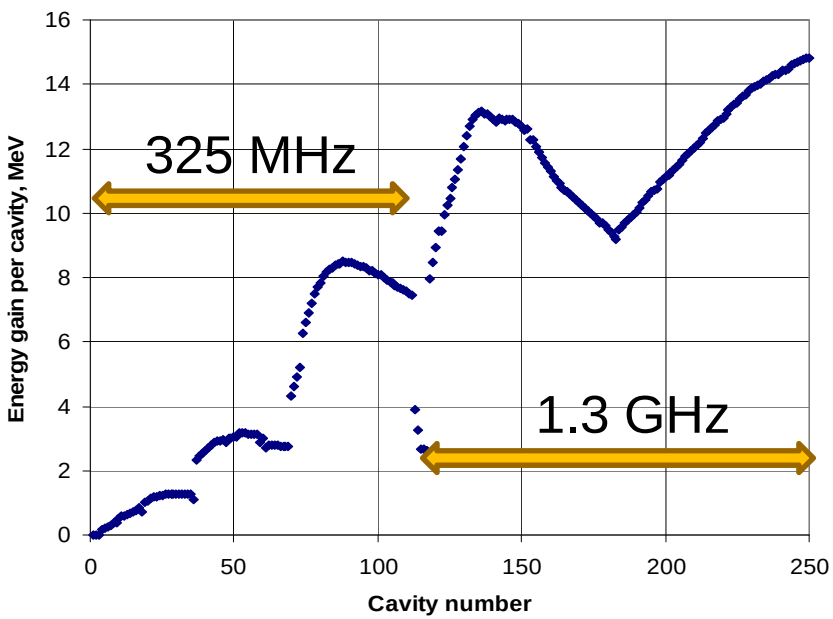
1 μsec period at 3 GeV

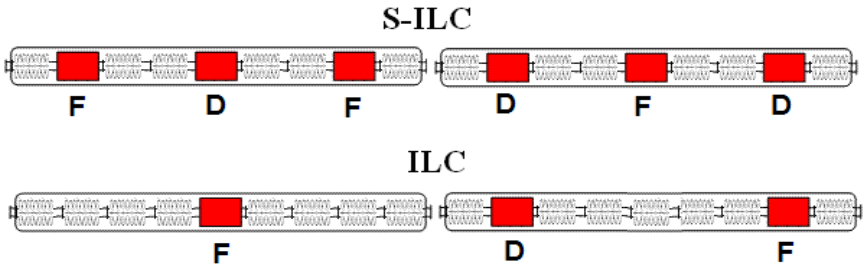
mu2e pulse (9e7) 162.5 MHz, 100 nsec	400 kW
Kaon pulse (9e7) 27 MHz	800 kW
Other pulse (9e7) 27 MHz	800 kW





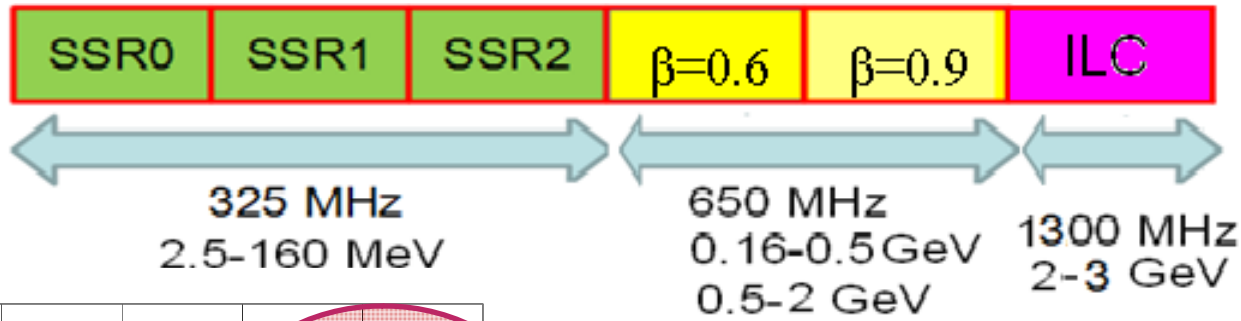
IC-2v1.0
Technology Map

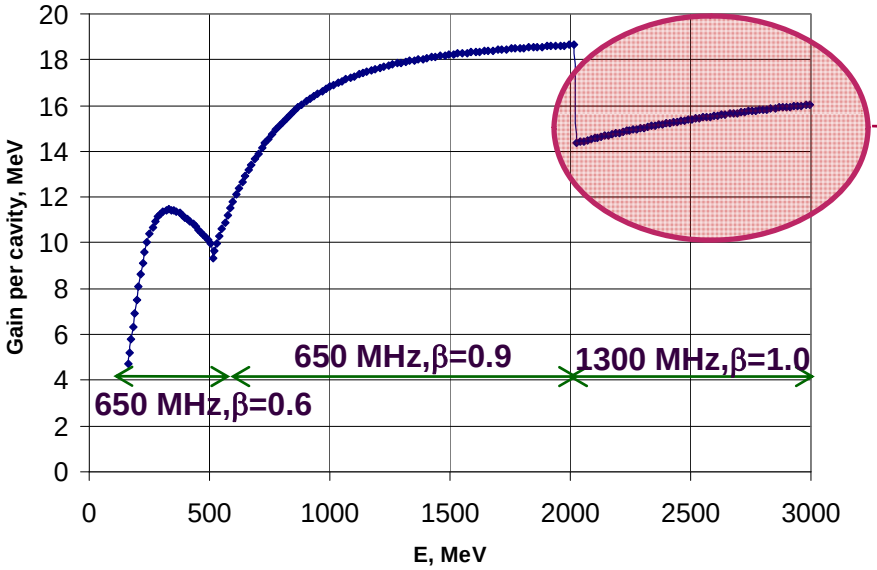




IC-2v2.0
Technology Map

- Current configuration under consideration:



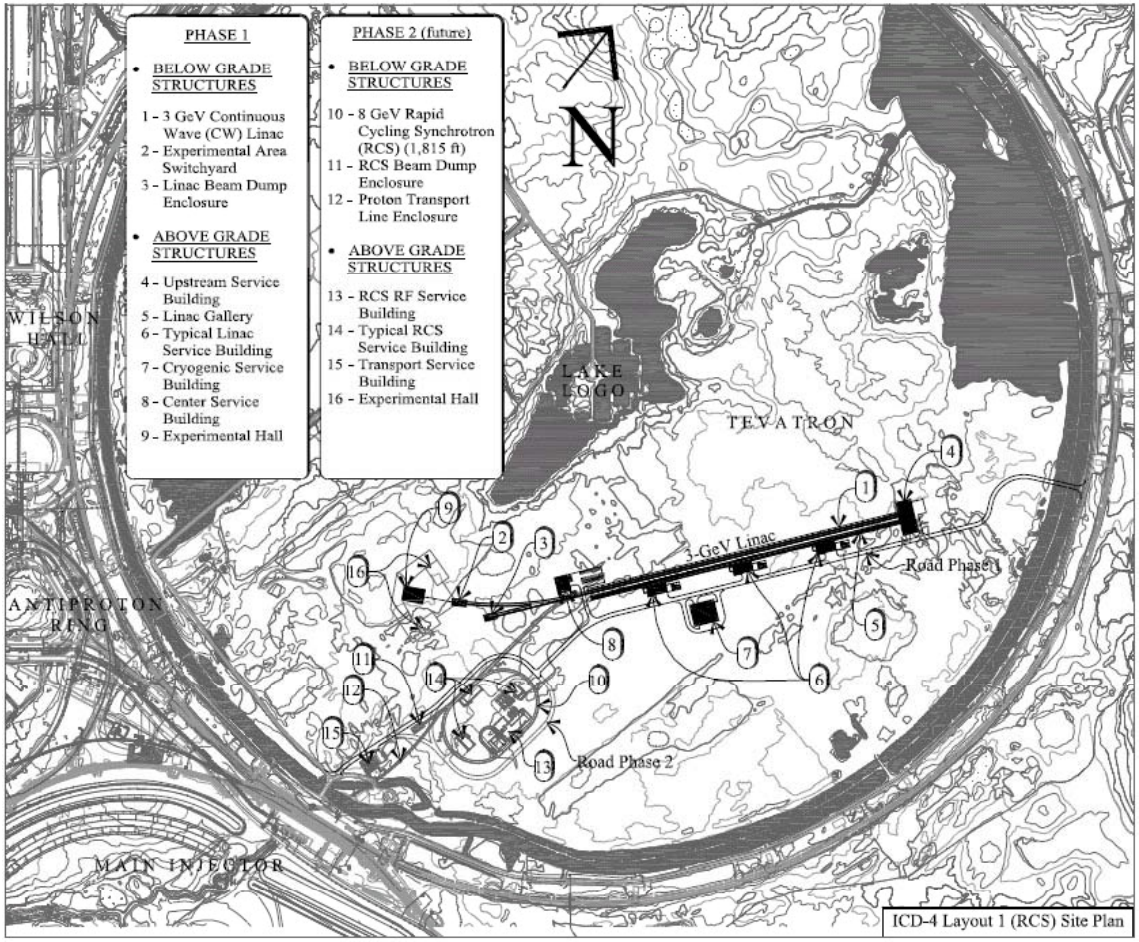


Notes:

Discontinuity effectively eliminated with β=0.95, low loss cavity design

650 MHz, β=0.9, 5-cell cavities are same physical length as 1300 MHz, β=1.0, 9-cell cavities

Initial Configuration-2
Provisional Siting

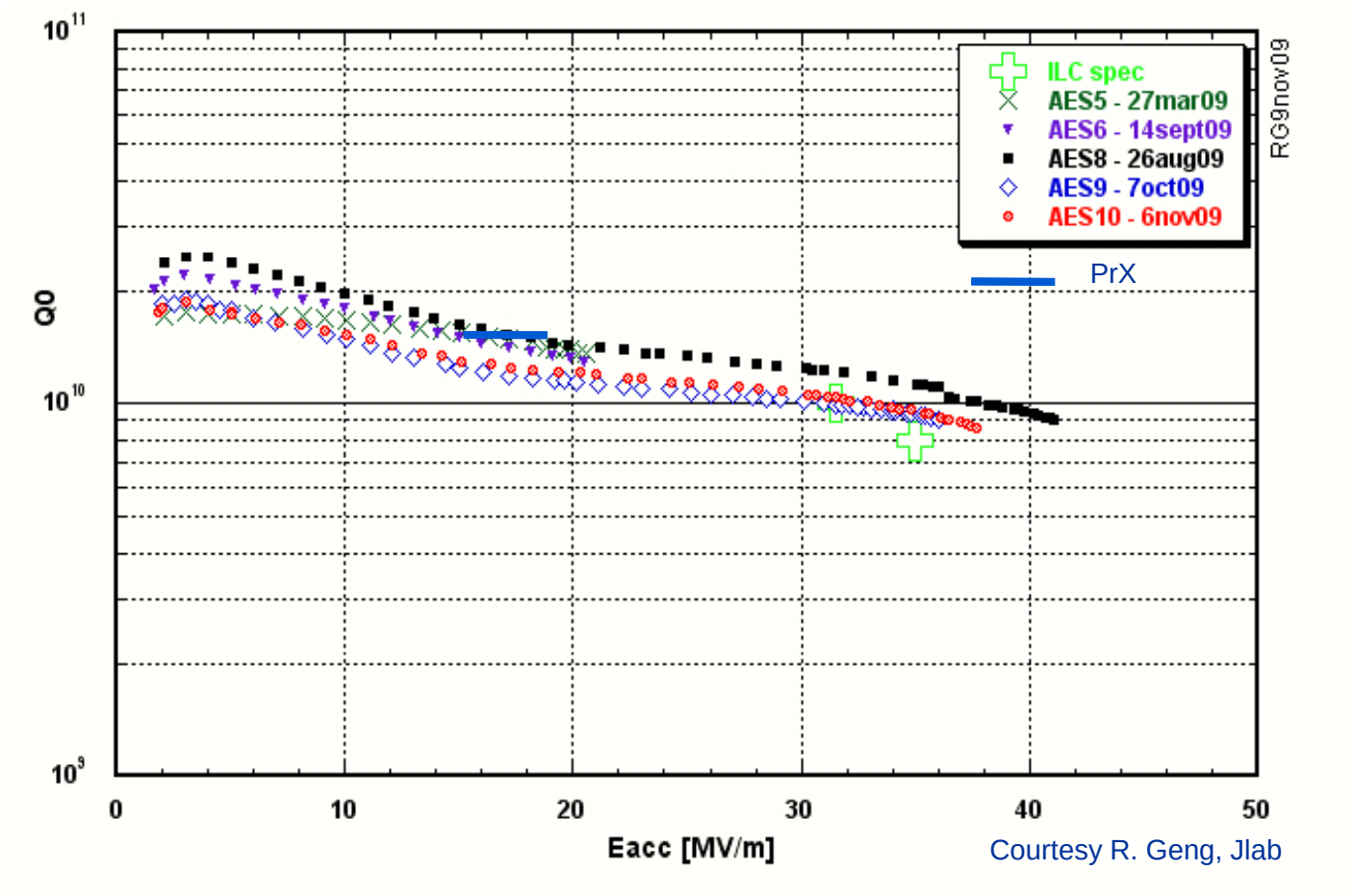


Joint PX/ILC/SRF Strategy

- Project X shares 1.3 GHz technology with the ILC
  - Project X requires 9-20 ILC-like cryomodules, depending upon the final frequency configuration
    - Design is migrating at the detail level from the ILC
      - CW vs pulsed
      - 18 MV/m vs 31.5 MV/m
      - Perhaps lower beta and lower loss cavity shape
- However, there is very significant infrastructure and expertise on the ILC program that can be applied
  - Close coordination between Project X and GDE
    - Common development effort
    - Shared facilities for assembly and testing
    - Yield vs gradient is key metric

SRF Development

Summary of recent 9-cell results: U.S.



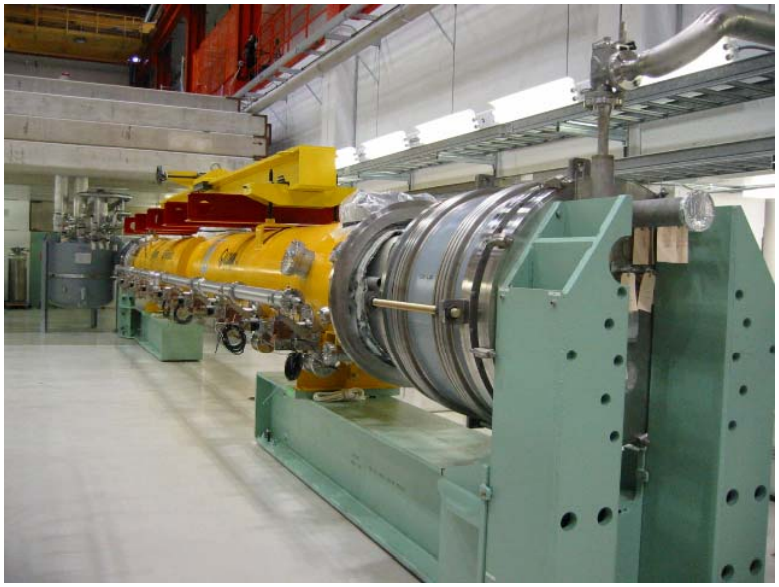
Courtesy R. Geng, Jlab

Joint PX/ILC/SRF Strategy

- Industrialization
  - Production of 1.3 GHz CMs for Project X over a~4 year period represents a significant step beyond current capabilities; however, the production rate remains well below that required by ILC.

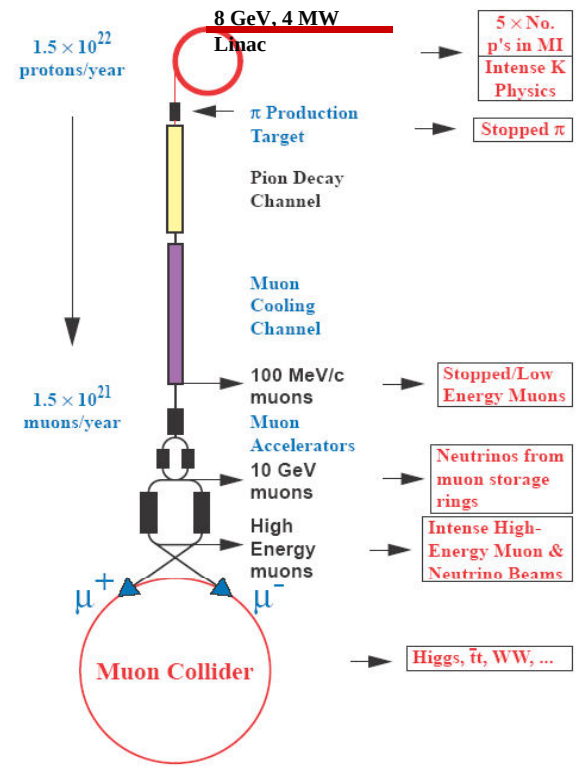
  ⇒This activity could represent the initial phase of an industrialization buildup for ILC (in the U.S.).

- Cryomodule Assembly Plan
  - CM1: TESLA Type III (2009)
    - Based on DESY supplied cavities
  - CM2: TESLA Type III (2010)
    - Based on U.S. supplied cavities
  - CM3: Type IV.1 (2011)
    - U.S. supplied cavities
  - CM4: Type IV.2 (2012)
    - Project X prototype



Joint 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
    - Requires upgrade of the Project X linac to 2-4 MW
    - The ICD-1 includes such a concept: rep rate x8 (20 Hz)
  - 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



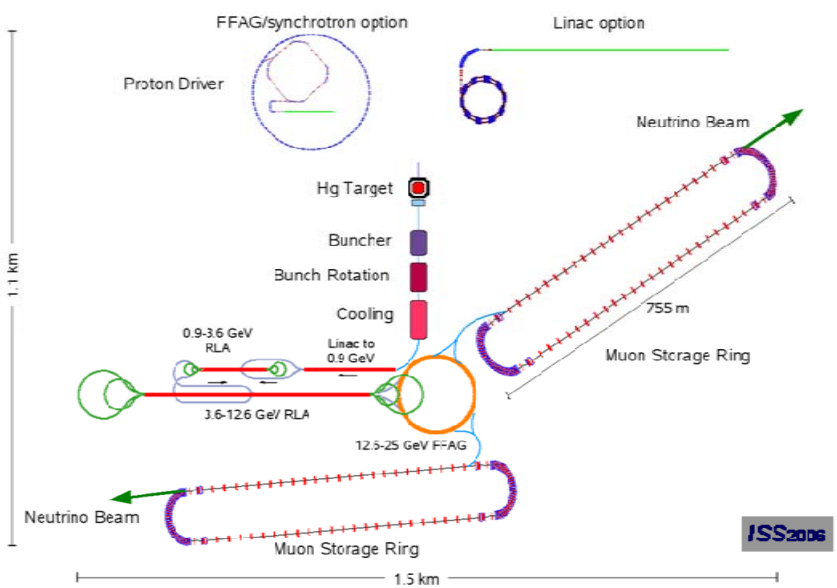
⇒ It is inevitable that a new ring(s) will be required to produce the correct beam format for targeting.

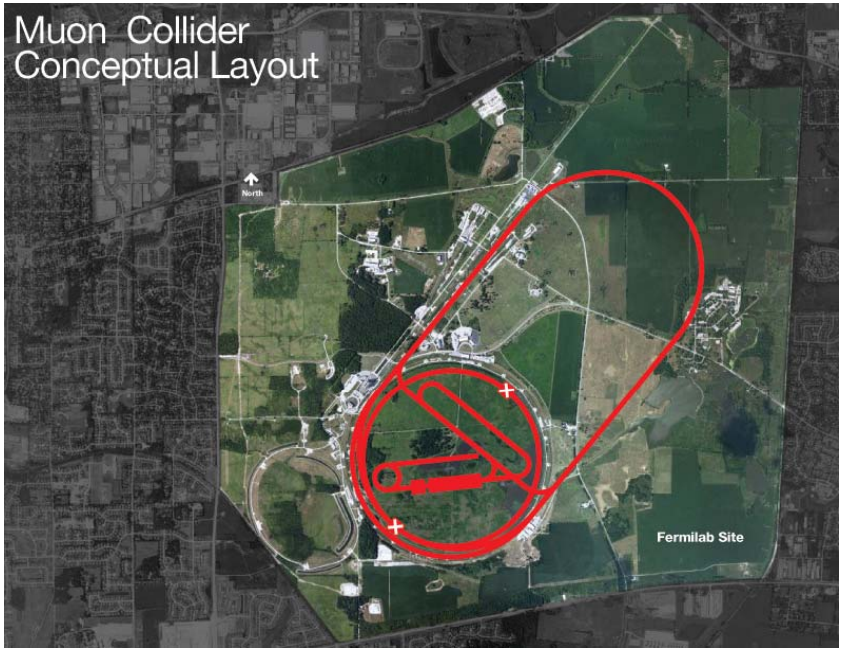
Joint PX/NF/MC Strategy

- Natural evolutionary schemes through neutrino superbeams:

  NOνA$\rightarrow$ LBNE$\rightarrow$ Neutrino Factory $\rightarrow$ Muon Collider

- Close coordination between MAP and IDS_NF





Collaboration Plan

- 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. (First MOU with India in place)
  - Collaboration MOU for the RD&D phase outlines basic goals, and the means of organizing and executing the work. Signatories:

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

  - Collaborators to assume responsibility for components and sub-system design, development, cost estimating, and potentially construction .

Near Term Strategy
(~Next 6 months)

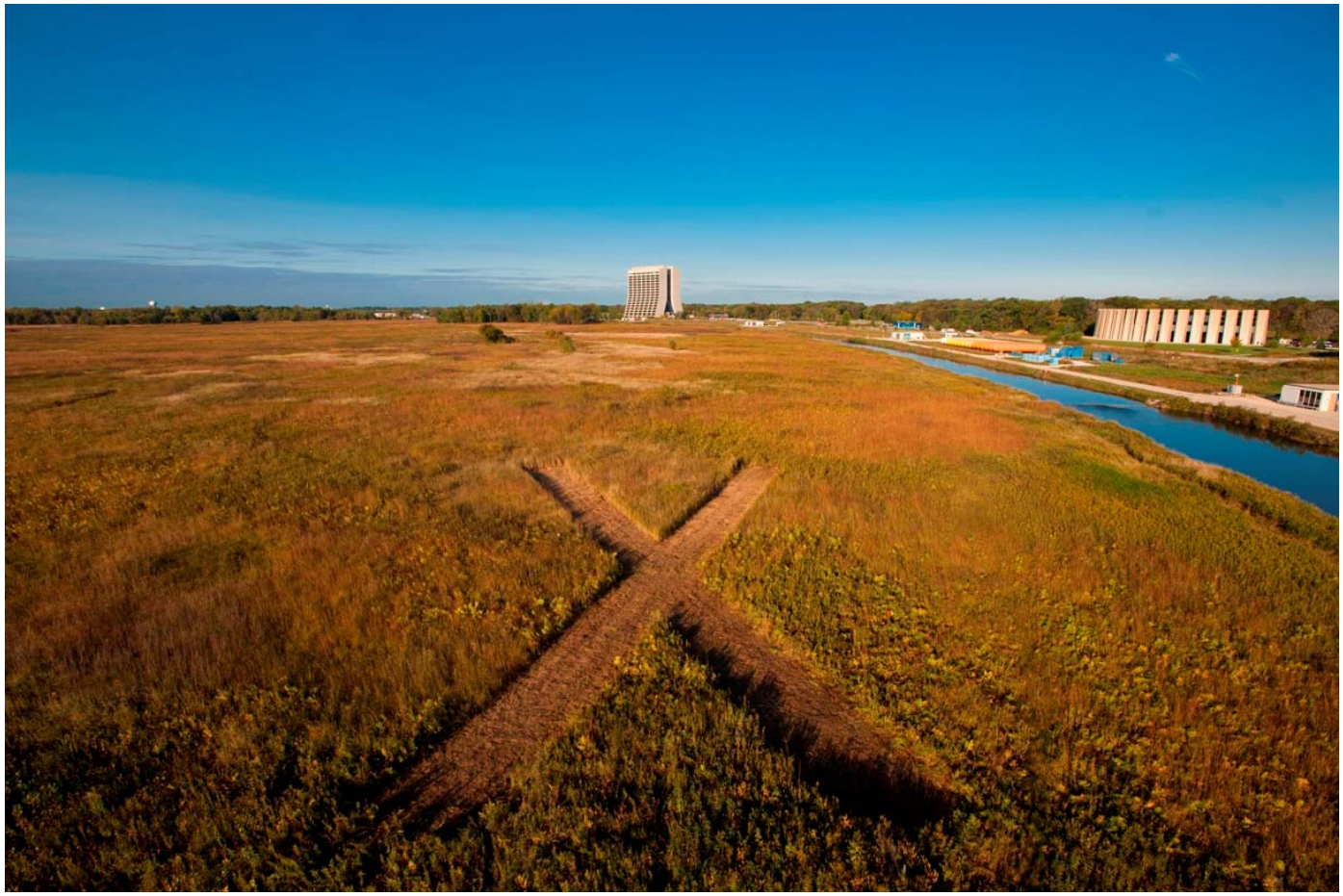
- Establish a cost-range for Project X based on:
  - Upper end of range = **IC-2v1.0**: 3.0 GeV/1.0 mA linac RCS, Recycler, MI
  - Lower end = **IC-2v2.0:** 3.0 GeV/0.5 mA linac, no RCS, Recycler, MI
  - Extend cost range further downward by establishing a set of potential cost reductions that can be applied to either configuration
- Update R&D plan to configuration IC-2
- Retain RCS within the estimate but limit work to critical issue(s)
- Continue work on outstanding technical questions
  - Identify a baseline concept for the chopper
  - RCS injection, including does this even work at 0.5 mA?
  - Identification of the cost breakpoint between RCS and pulsed linac
- Investigate options for pairing a 3-8 GeV pulsed linac to CW front end

$\Rightarrow$ All cost range/configuration info. available for CD-0 by late spring

Long-Term Strategy

- DOE has advised us that the earliest possible dates are:
  - PED funding: FY2012
  - Construction start: FY2015
- We believe that we could construct Project X over a five year time period, assuming a commensurate funding profile

⇒Project X could be up and running ~2020

Summary

- Project X is central to Fermilab's strategy for future development of the accelerator complex:
  - Intensity Frontier: World leading program in neutrinos and rare processes; Fermilab as potential Neutrino Factory site
  - Energy Frontier: Aligned with ILC technology development; Fermilab as potential site for ILC or a Muon Collider
- Initial configurations, and preliminary cost estimates, established
  - >2 MW at 60-120 GeV, simultaneous with up to 2 MW for rare processes program
  - Upgradable to 2-4 MW at 8 GeV
- Integrated effort on Project X, ILC, and Muon Facilities
- Project X could be constructed over the period ~2015 - 2019
- Collaboration formed to undertake the R&D program