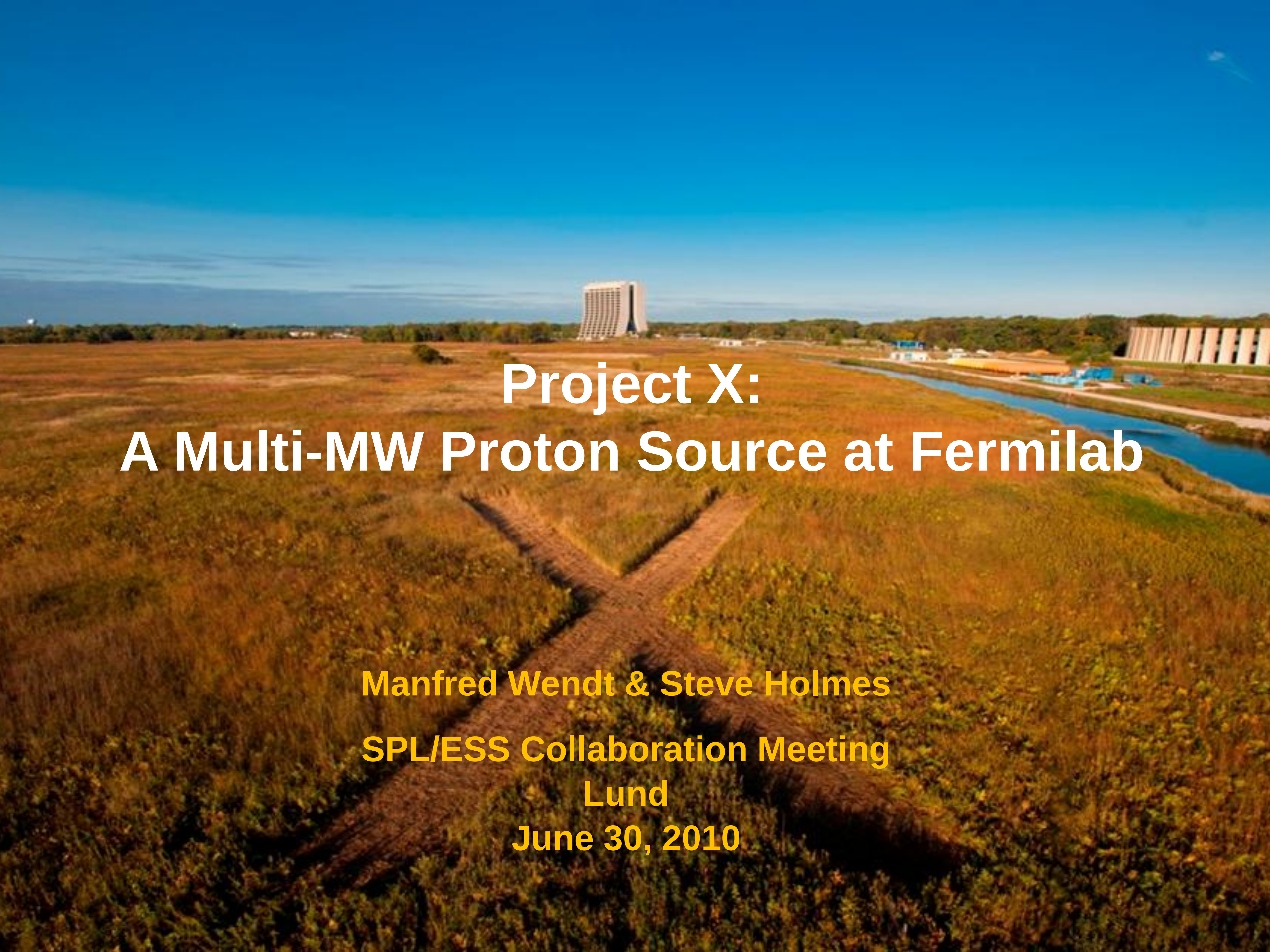


Project X:
A Multi-MW Proton Source at Fermilab

Manfred Wendt & Steve Holmes

SPL/ESS Collaboration Meeting
Lund
June 30, 2010

Outline

- Evolution of the Fermilab Complex
- Project X Goals and Initial Configuration(s)
- Project X R&D Program
- Relationships to other Programs
- Collaborations
- Strategy

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

Strategic Context: Fermilab and the World Program

Project X

The Tevatron has now ceded the energy frontier to LHC

- Operations at 2 TeV will continue through September 2011

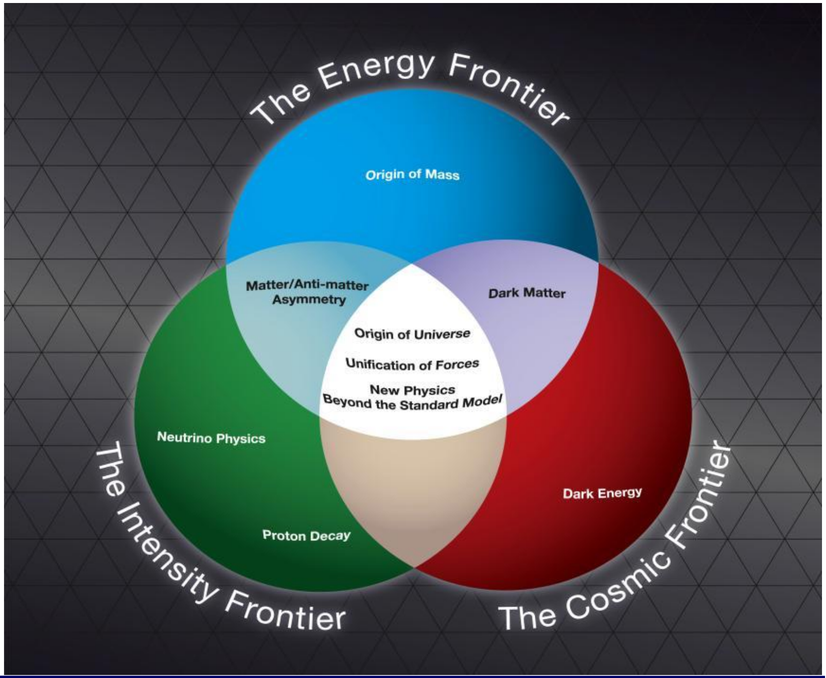
Fermilab operates the highest power long baseline neutrino beam in the world.

- J-PARC is initiating a competitive program

Project X Fermilab Long Range Plan

Fermilab is the sole remaining U.S. laboratory providing facilities in support of accelerator-based Elementary Particle Physics

⇒ ***The Fermilab strategy is to mount a world-leading program at the <u>intensity frontier</u>, while using this program as a bridge to an <u>energy frontier</u> facility beyond LHC in the longer term.***



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 for achieving leadership on the intensity and energy frontiers

  – Intensity Frontier:

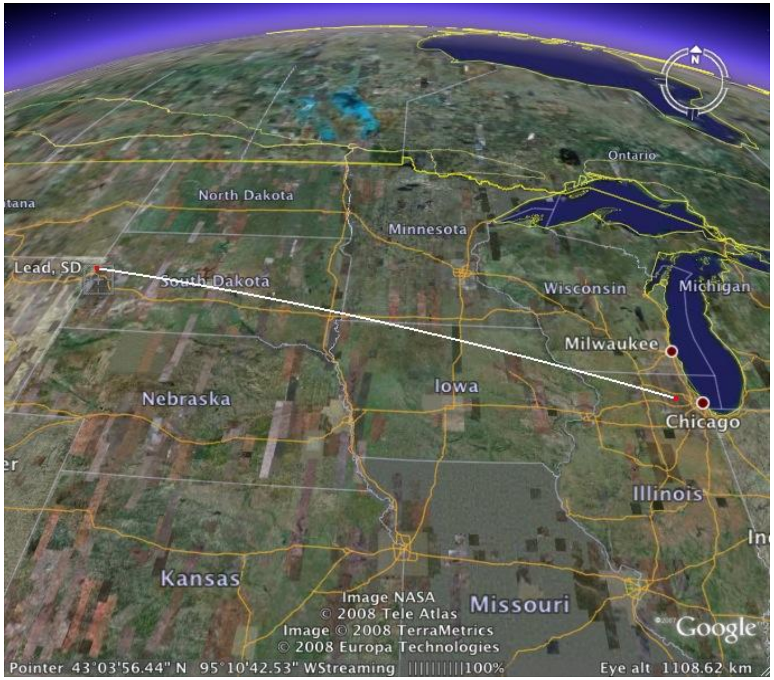
    NuMI→ NOνA→ LBNE/mu2e→ Project X → Rare Processes → NuFact
    - Continuously evolving world leading program in neutrino and rare processes physics; opportunities for applications outside EPP

  – Energy Frontier:

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

Project X Mission Objectives – P5 Report

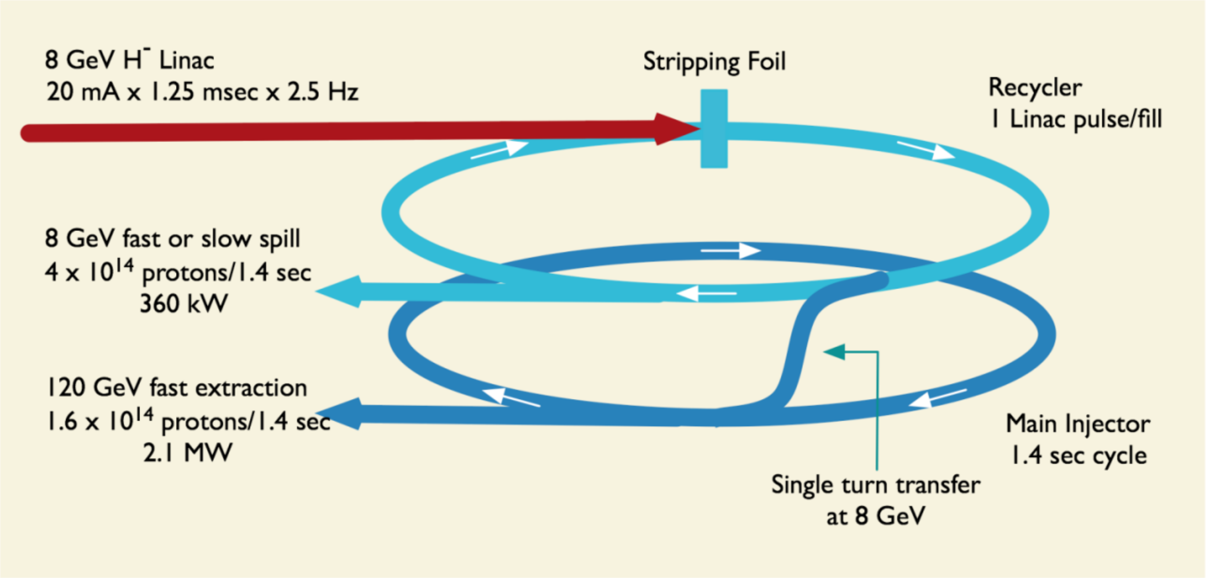
- A neutrino beam for long baseline neutrino oscillation experiments
  - 2 MW proton source at 60-120 GeV



- 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
  - Requires upgrade potential to 2-4 MW at ~5-15 GeV.

Initial Configuration-1

- Initial Configuration-1



- Strong alignment with ILC technologies
- Initial Configuration Document-1 V1.1 released March 2009
  - Accompanying cost estimate ~$1.5B
    (US accounting, i.e. overheads, contingency, labor, etc.)

Initial Configuration - 1
Issues

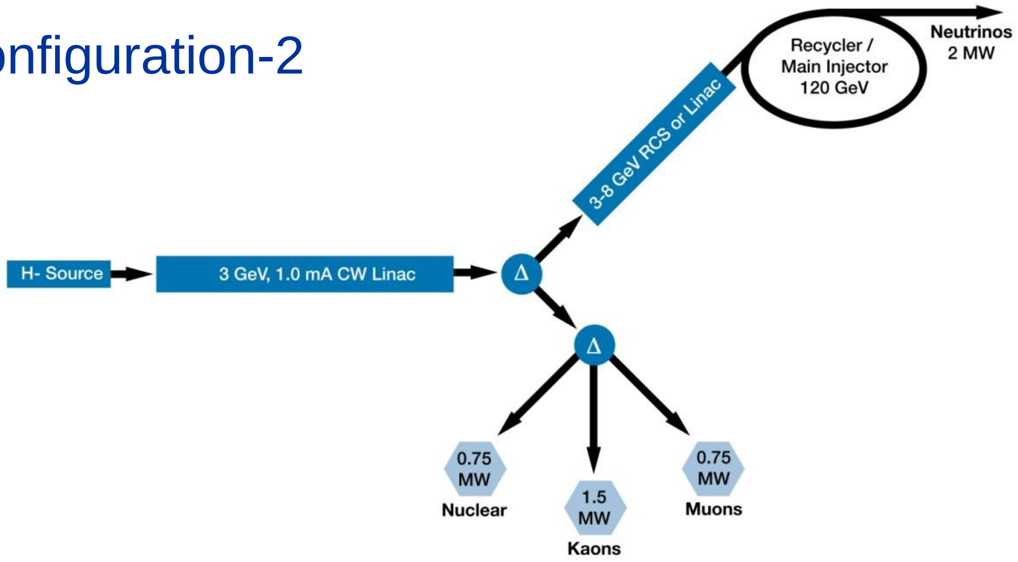
- IC-1 does a great job of meeting the long baseline neutrino mission, but…
- does not provide a strong platform for mounting a low energy rare processes program
  - The Recycler is ill-suited to providing high intensity slow spilled beam
    - Large tune-spread, high chromaticity
  - The Debuncher appears limited to <150 kW in this mode
    - Unacceptable high losses at the septa

  $\Rightarrow$ We believe there is a fundamental limit on the amount of beam power that can be delivered via a resonant extraction system
  - Difficulties supporting multiple users with differing spill structure requirements

$\Rightarrow$ **These considerations led to the development of IC-2**

Initial Configuration-2

- Initial Configuration-2



- 3 GeV CW linac provides greatly enhanced rare process program
  - 3 MW; flexible provision for beam requirements supporting multiple users
- Options for 3-8 GeV acceleration: Pulsed linac (1.3 GHz) or RCS
  - Linac would be 1300 MHz SCRF with 4-30 msec pulse length
- Initial Configuration Document-2 in preparation for summer release

Initial Configuration-2
Performance Goals

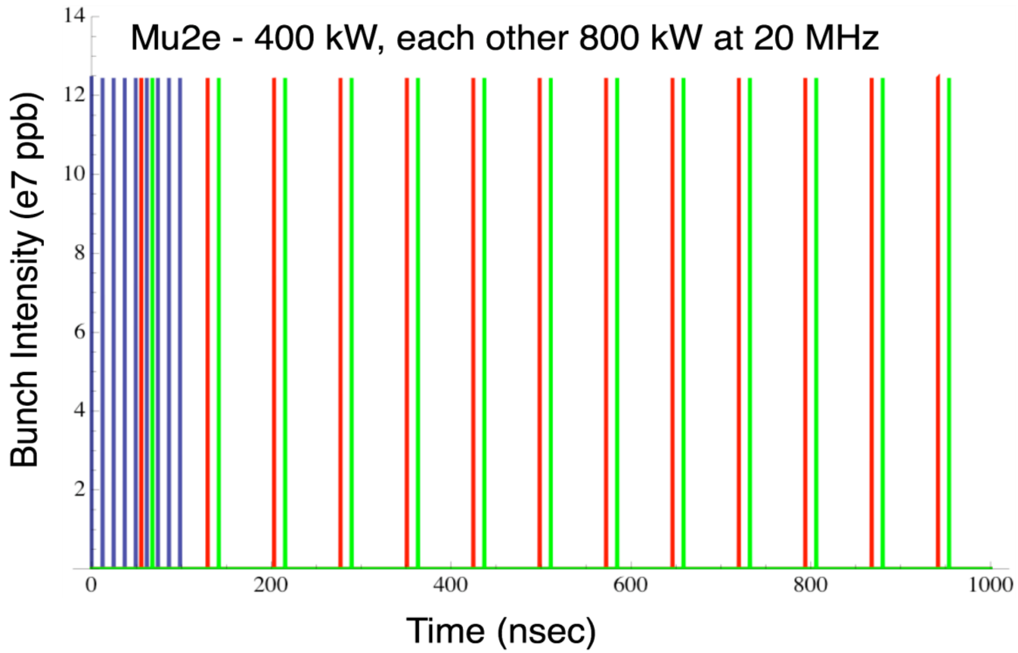
CW-Linac		
Particle Type	H^-	
Beam Kinetic Energy	3.0	GeV
Average Beam Current	1	mA
Linac pulse rate	CW	
Beam Power	3000	kW
Beam Power to 3 GeV program	2870	kW
Short / long pulsed Linac [RCS]		
Particle Type	H^- [protons]	
- Beam Kinetic Energy	8.0 / ~6 [8.0]	GeV
Pulse rate	10 / 2 [10]	Hz
Pulse Width	4.3 / 25 [0.002]	msec
Cycles to MI	6 / 1 [6]	
Particles per cycle to Recycler / Main Injector [MI]	2.6×10^{13}	
Beam Power to 8 GeV program	200	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	2200	kW

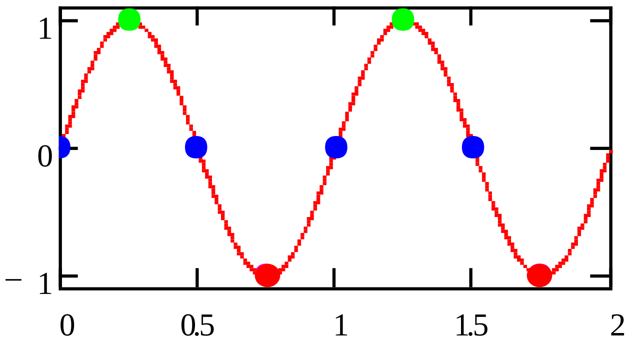
simultaneous

Initial Configuration-2
Operating Scenario

1 μsec period at 3 GeV

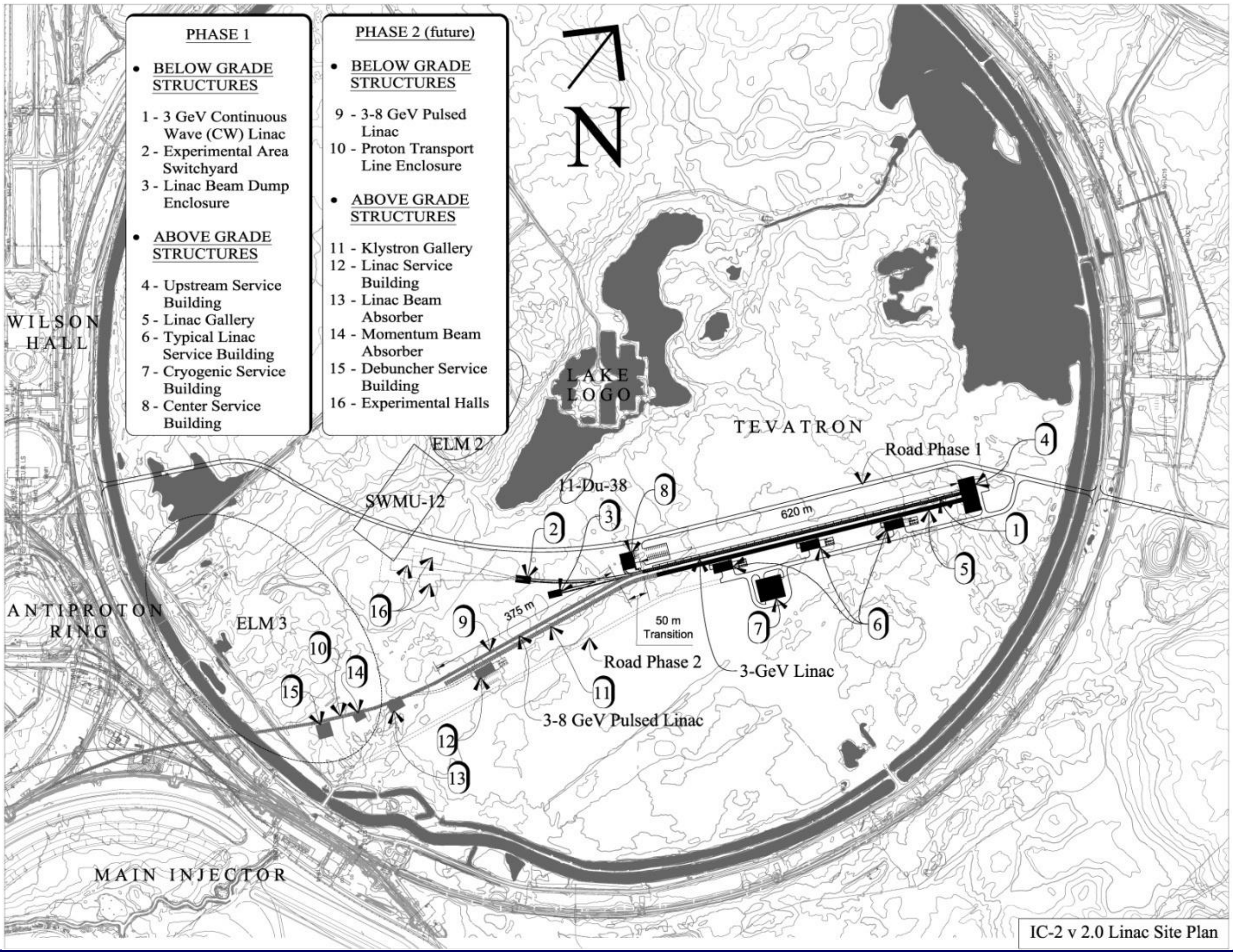
mu2e pulse (9e7) 162.5 MHz, 100 nsec	400 kW
Kaon pulse (9e7) 27 MHz	800 kW
Nuclear pulse (9e7) 27 MHz	800 kW



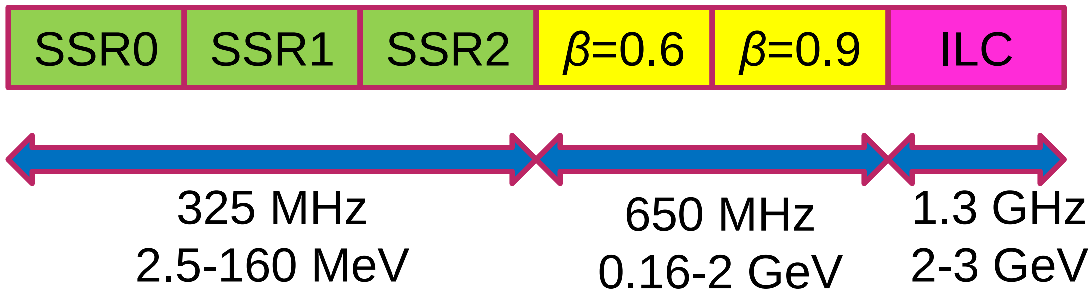


Separation scheme

Initial Configuration-2
Provisional Siting



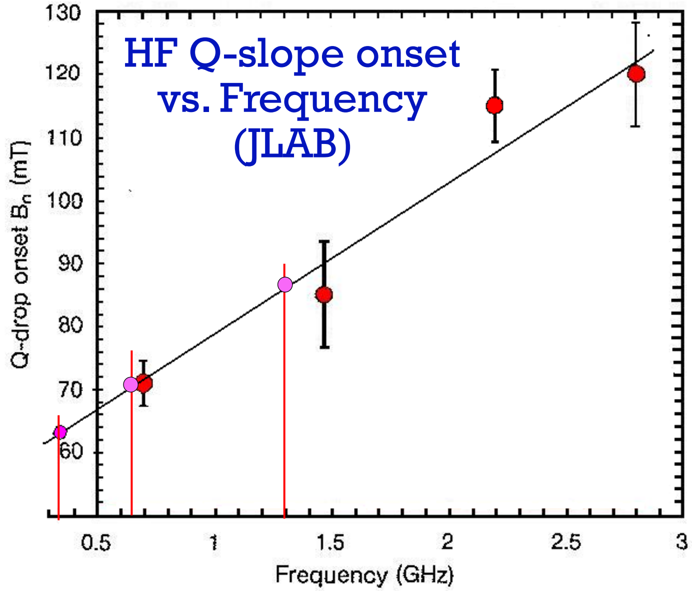
Initial Configuration-2
SCRF Technology Map



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 /24/ 4	SSR, solenoid
LB 650 (β_G=0.61)	650	160-520	42 /21/ 7	5-cell elliptical, doublet
HB 650 (β_G=0.9)	650	520-2000	96 /12/12	5-cell elliptical, doublet
ILC 1.3 (β_G=1.0)	1300	2000-3000	64 / 8/ 8	9-cell elliptical, quad

R&D Program
Choice of Cavity Parameters

- Identify maximum achievable surface (magnetic) field on basis of observed Q-slope "knee"
- Select cavity shape to maximize gradient (subject to physical constraints)
- Establish Q goal based on realistic extrapolation from current performance
  - Goal: <20 W/cavity
- Optimize within (G, Q, T) space

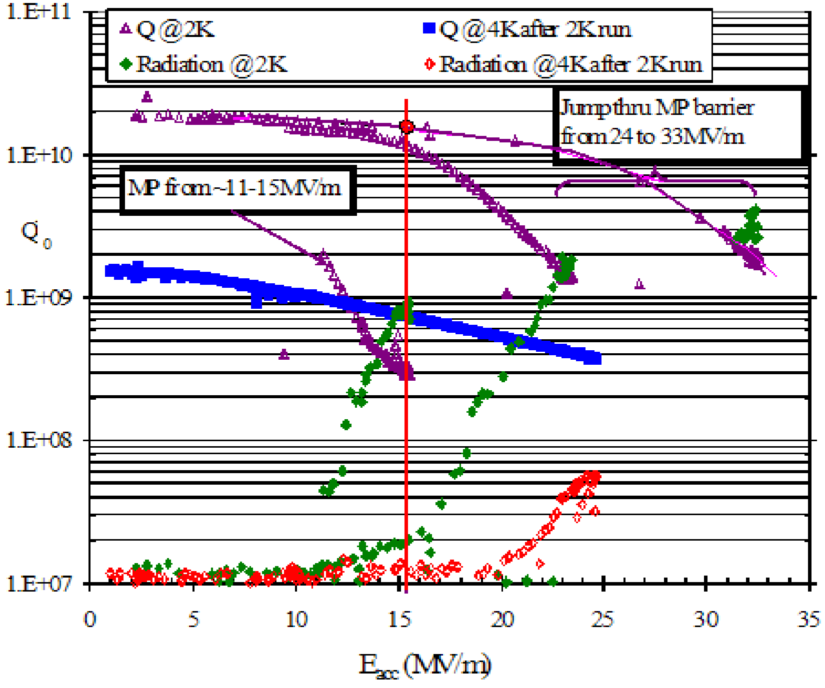


(Initial) Performance Goals

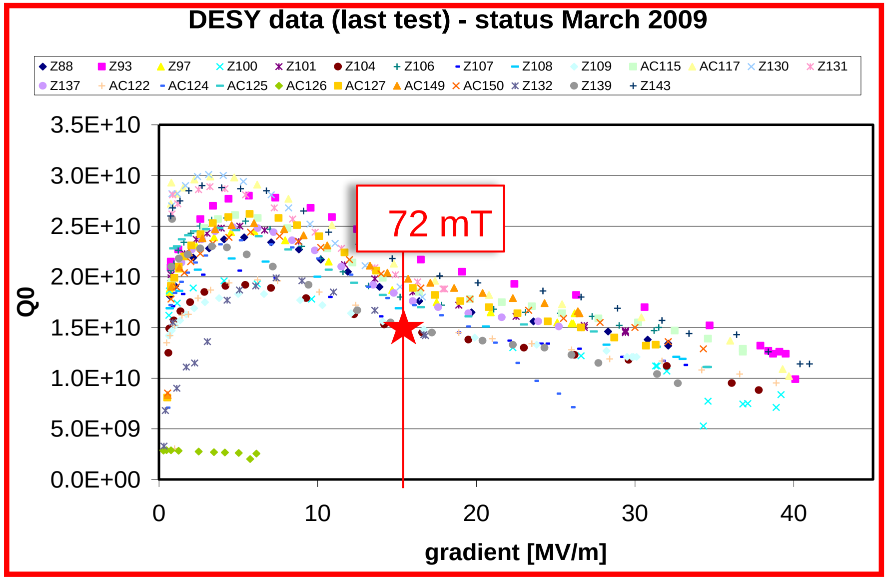
Freq (MHz)	B_{pk}(mT)	G (MV/m)	Q	@T (K)
325	60	15	1.4E10	2
650	72	16	1.7E10	2
1300	72	15	1.5E10	2

Project X

R&D Program
Choice of Cavity Parameters



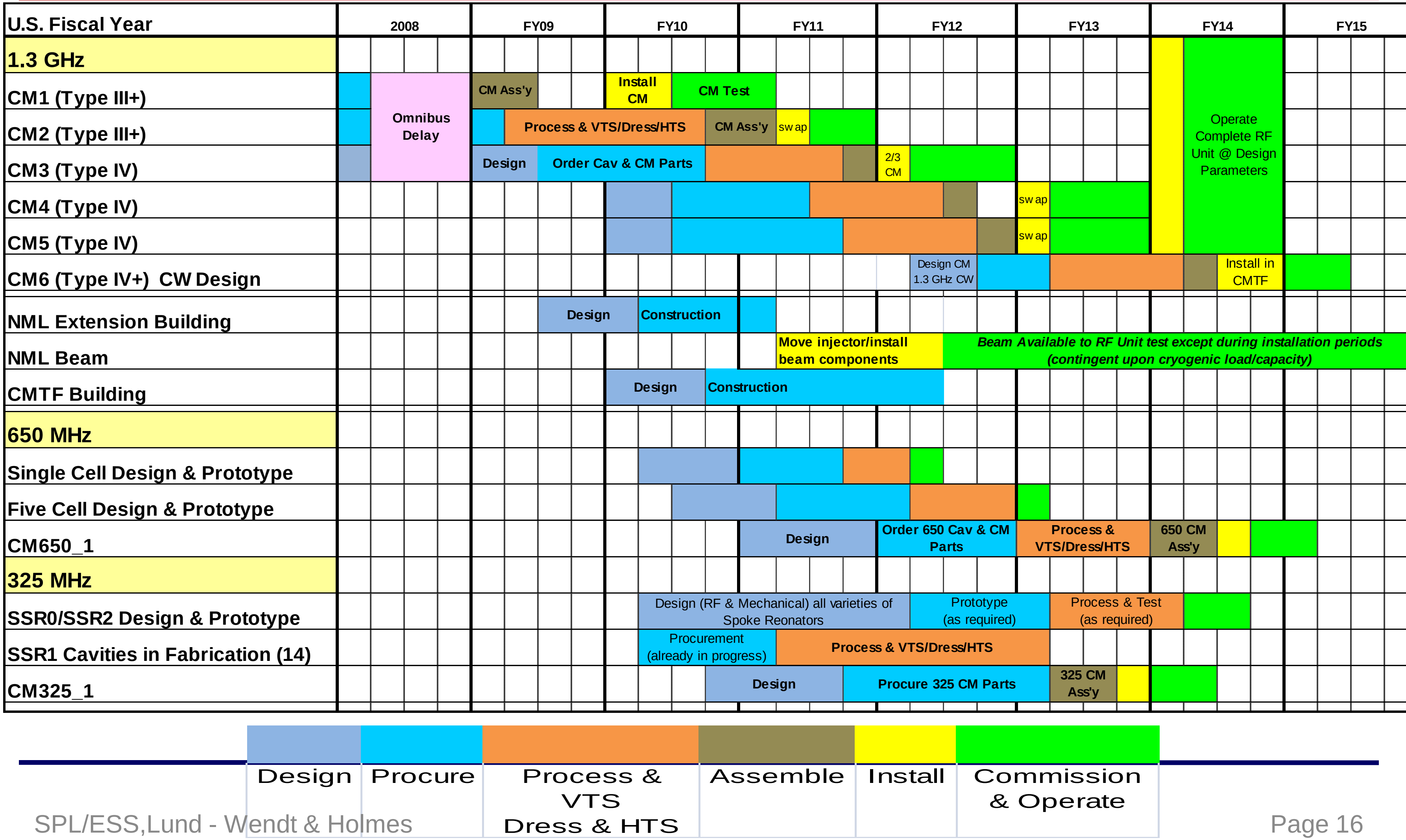
SSR1:
325 MHz
$Q_0=1.4\cdot10^{10}$ @ 2K



ILC:
1.3 GHz
$Q_0=1.5\cdot10^{10}$ @2K

Project X

Integrated SRF Plan
ILC + Project X

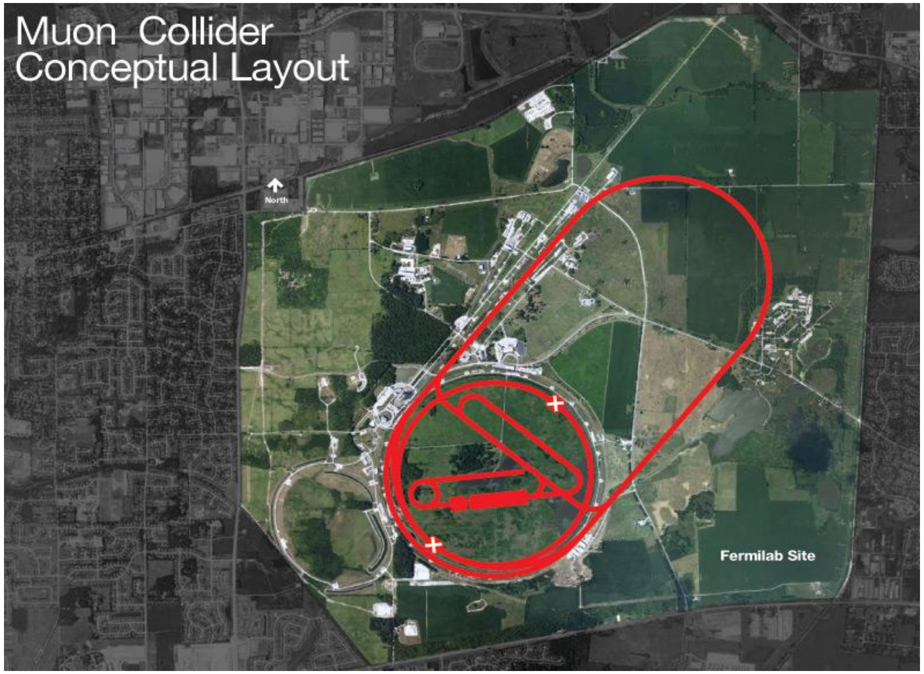


Integrated SRF Plan
ILC + Project X

NML test facility: ILC and Project X R&D

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
  - Primary issues are related to beam “format”
    - NF wants proton beam on target consolidated in a few bunches
    - Muon Collider requires a single bunch
  - Project X linac is not capable of delivering this format



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

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	BARC/Mumbai
BNL	MSU	IUAC/Delhi
Cornell	TJNAF	RRCAT/Indore
Fermilab	SLAC	VECC/Kolkota
LBNL	ILC/ART	

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

Project X Collaborations with ESS / SPL

- Fermilab invites ESS & SPL colleagues to collaborate on Project X!
  - Many R&D activities beyond the “frequency problem”
    - SCRF technologies
    - Beam dynamics
    - Beam instrumentation and diagnostics
    - Machine protection
    - …
  - Beam studies at test accelerators
    - Fermilab operates two test facilities:
      HINS (325 MHz protons / H^- front-end) and
      ILCTA-NML (SCRF test accelerator using electrons)
  - Exchange of visiting scientists
  - …

Strategy

- Next six months: Complete all preliminary design, configuration, and cost range information for IC-2
  - ICD-2v2.0
  - Cost estimate
- Continue conceptual development on outstanding technical questions
  - Baseline concept for the chopper (broadband / resonant)
  - Concepts for marrying a 3-8 GeV pulsed linac to CW front end
  - Injection into a RCS or Main Injector / Recycler, laser or foil stripping
- Pursue R&D aimed at the CW linac
  - Emphasis of SCRF development at all relevant frequencies
  - Engage external collaborators and identify roles
- U.S. Department of Energy has advised that the earliest possible construction start is FY2015
- We believe that we could construct Project X over a five year time period, assuming a commensurate funding profile

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

Summary

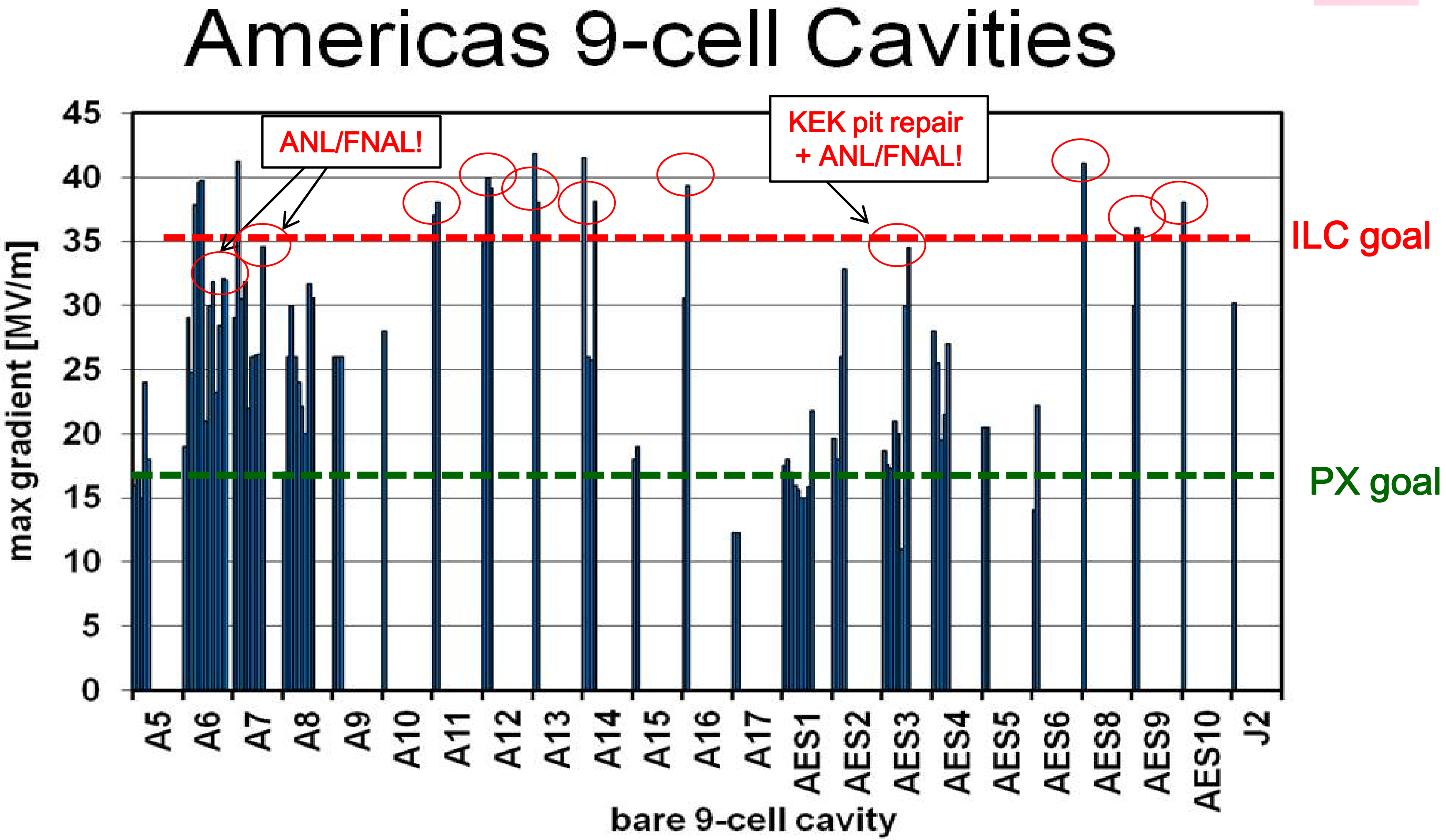
- Project X is central to Fermilab's strategy for development of the accelerator complex over the coming decade
  - World leading programs in neutrinos and rare processes
  - Aligned with ILC and Muon Accelerators technology development;
  - Potential applications beyond elementary particle physics.
- The design concept has evolved over the last year, providing significantly enhanced physics capabilities
- Current configuration (snapshot 2010):
  - >2 MW at 60-120 GeV, simultaneous with 3 MW at 3 GeV
  - Flexibility for supporting multiple experiments
  - CW linac is unique for this application, and offers capabilities that would be hard/impossible to duplicate in a synchrotron
- Project X could be constructed over the period ~2015 - 2020

Backup Slides

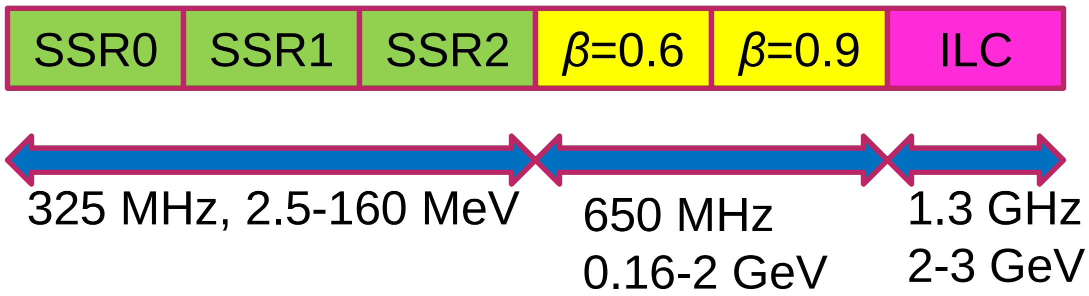
Accelerator Requirements:
Rare Processes

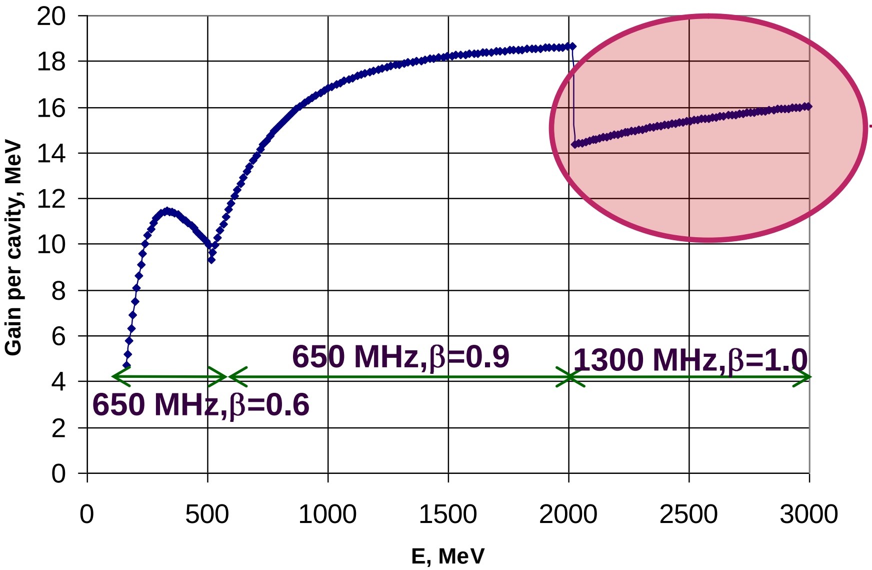
	Proton Energy (kinetic)	Beam Power	Beam Timing
Rare Muon decays	2-3 GeV	>500 kW	1 kHz – 160 MHz
(g-2) measurement	8 GeV	20-50 kW	30- 100 Hz.
Rare Kaon decays	2.6 – 4 GeV	>500 kW	20 – 160 MHz. (<50 psec pings)
Precision K^0 studies	2.6 – 3 GeV	> 100 mA (internal target)	20 – 160 MHz. (<50 psec pings)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

SRF Development
Cavity Gradient



Initial Configuration-2
Technology Map





Notes:

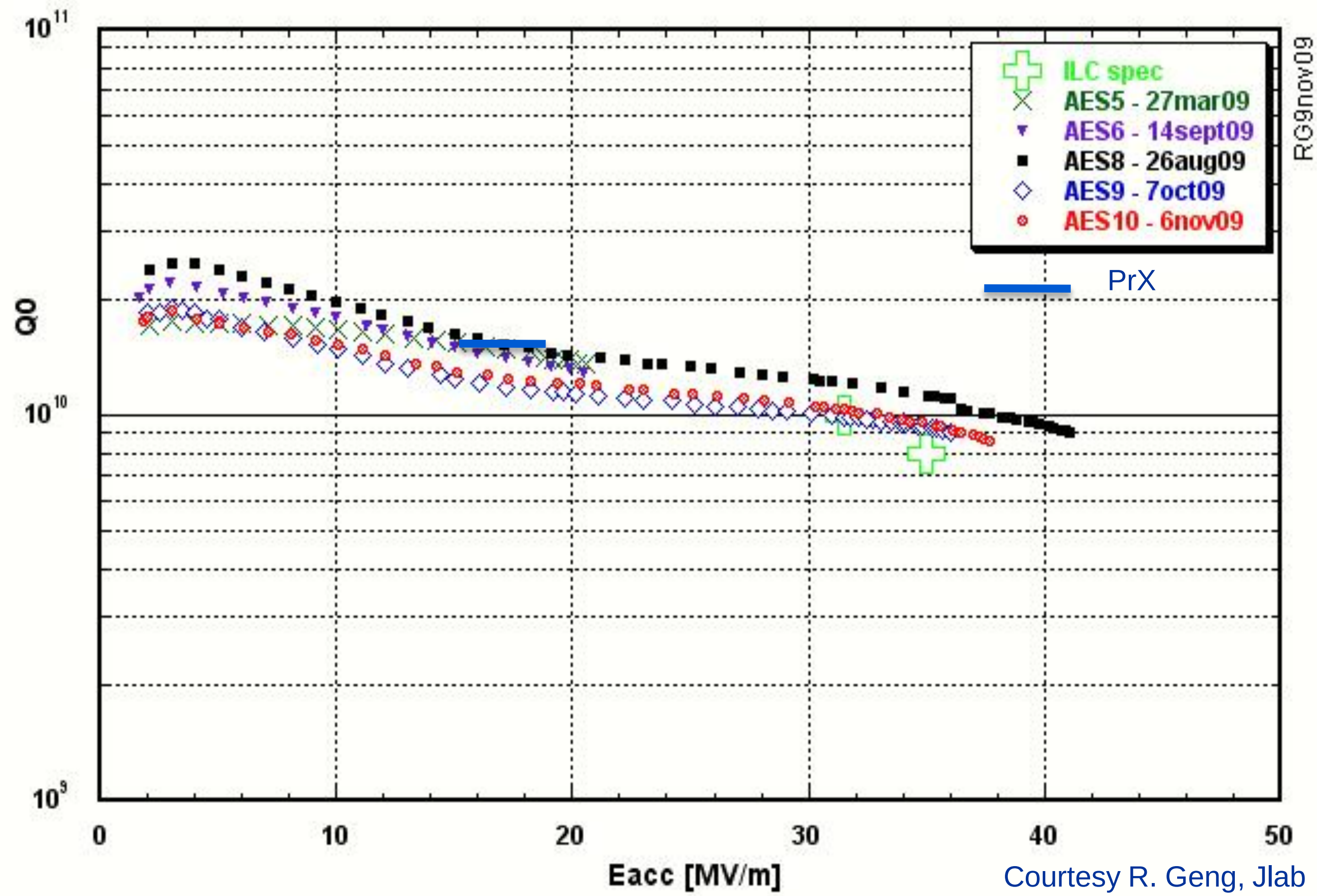
Discontinuity may be reduced significantly with β=0.95, low loss cavity design

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

R&D Program
1300 MHz 3-8 GeV Pulsed Linac

- Current concept:
  - Use standard ILC cavities and cryomodules
  - Operate with ILC-like RF system
  - 4-5 ms 1 mA beam pulses at 10 Hz (5-6 pulses to fill Recycler)
  - Operate at ~ 25 MV/M gradient
  - Adjust couplers for ~ 10 mA to decrease cavity fill time at the expense of reflected power during acceleration
- A 3-8 GeV linac requires
  - 200 ILC β=1, 9 cell cavities in 25 Type IV cryomodules
- A Rapid Cycling Synchrotron is still an option
  - A 3-8 GeV RCS costs the ~ same as a 3-8 GeV linac
  - But… the linac has more up side potential in terms of power, technology alignment with ILC, and flexibility for the future

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



Courtesy R. Geng, Jlab