Project-X at Fermilab

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Project X: What is it?

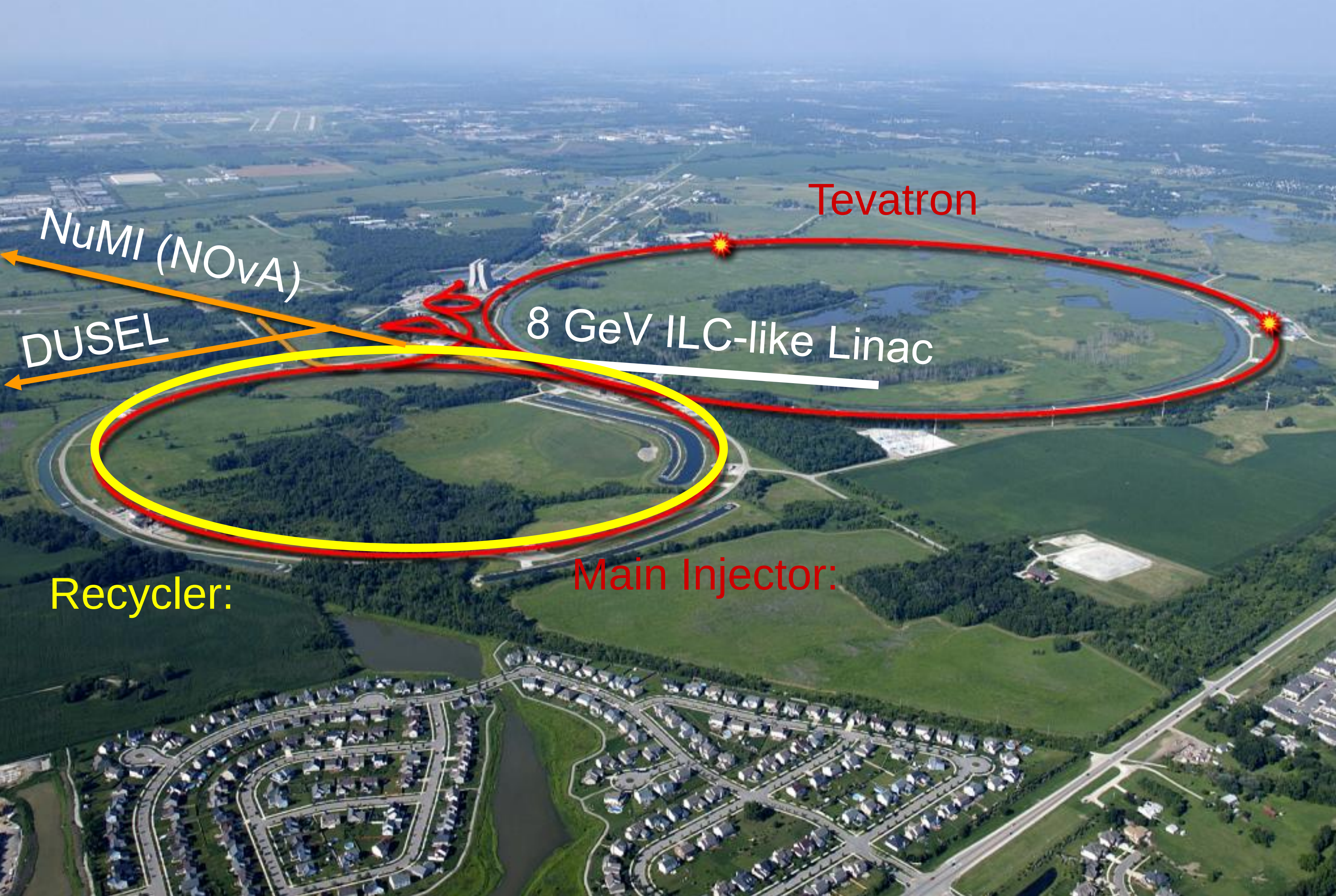
- A new multi-MW Proton Source under development at Fermilab.
- Enables a world-class Long Baseline Neutrino Experiment (LBNE) via a new beam line pointed to DUSEL in Lead, South Dakota.
- Enables a broad suite of rare decay experiments

Currently two versions of this machine are under consideration.

- Both versions provide 2 MW of beam power to LBNE
- ICD-1 is based on a pulsed 8 GeV 20 ma ILC-like H^- linac
- ICD-2 employs a 2 GeV 1 ma CW linac that accelerates H^- or P's
  - Provides an additional 2 MW to the high intensity program
    - Very flexible beam manipulation via RF separators
  - 2-8 GeV = either a pulsed linac or a rapid cycling synchrotron.

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

Multi-MW Proton Facility – Project X



Project X

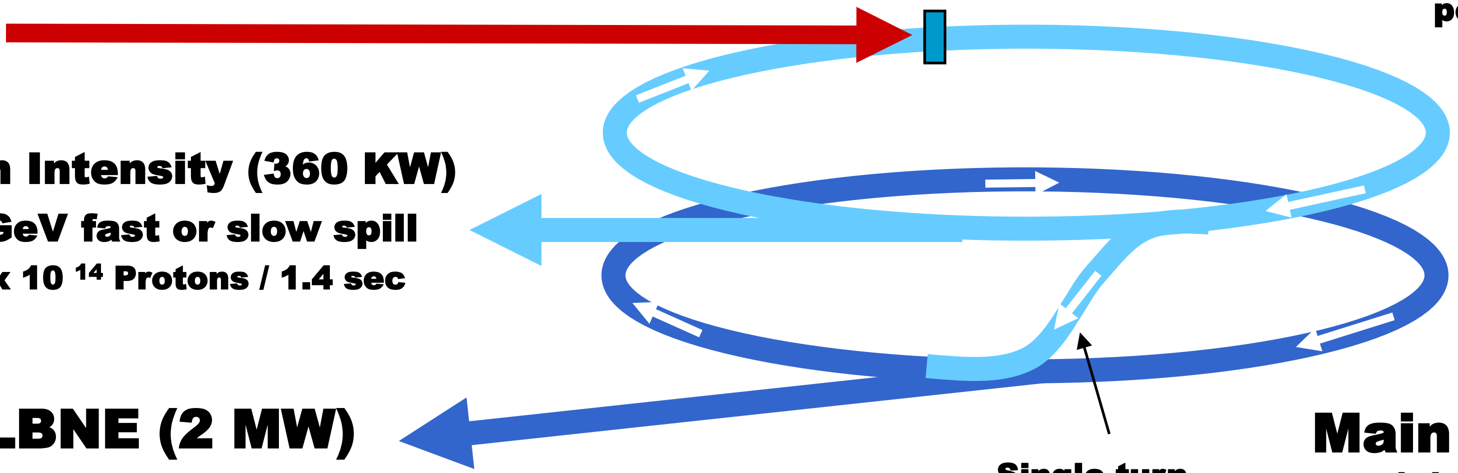
ICD-1 Layout

8 GeV H- pulsed linac
20 ma x 1.25 ms x 2.5 Hz

Stripping foil

Recycler
1 linac pulse per fill

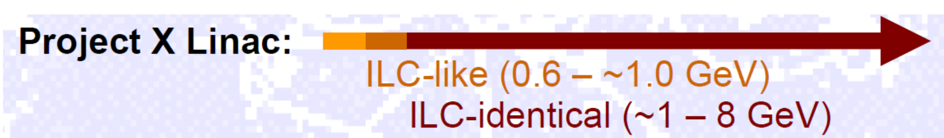
High Intensity (360 KW)
8 GeV fast or slow spill
4 x 10 ^{14} Protons / 1.4 sec



LBNE (2 MW)
120 GeV Fast extraction
1.6 x 10 ^{14} Protons / 1.4 sec

Single turn transfer At 8 GeV

Main Injector
1.4 Sec cycle



46 ILC-like cryomodules→
Synergy with ILC R&D

SRF Linac Technology

Project X
500 kW 8GeV Linac

31 Klystrons (2 types)
445 SC Cavities
58 Cryomodules

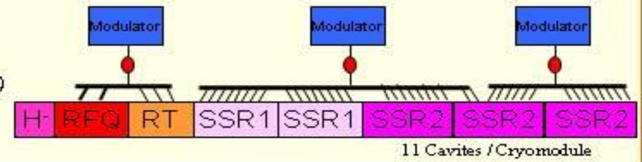
Front End Linac

325 MHz 0-10 MeV

1 Klystron (JPARC 2.5 MW)
RFQ + 18 RT Cavities

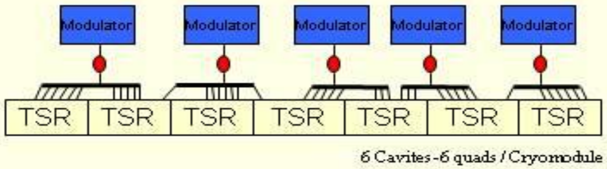
325 MHz 10-120 MeV

2 Klystrons (JPARC 2.5 MW)
51 Single Spoke Resonators
5 Cryomodules



325 MHz 0.12-0.42 GeV

5 Klystrons (JPARC 2.5 MW)
42 Triple Spoke Resonators
7 Cryomodules



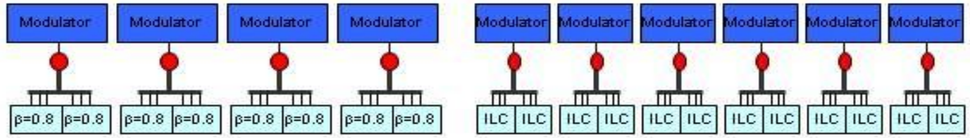
2.5 MW JPARC Klystron

Multi-Cavity Fanout
Phase and Amplitude Control

1300 MHz LINAC

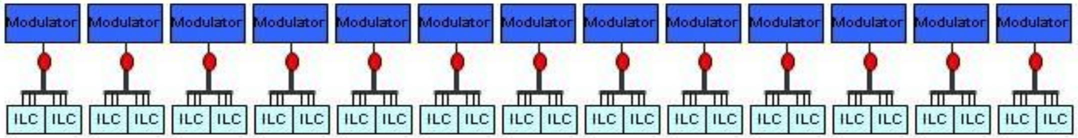
1300 MHz 0.42-1.3 GeV

4 Klystrons (ILC 10 MW MBK)
56 Squeezed Cavities (β=0.81)
8 Cryomodules



1300 MHz 1.3-8.0 GeV

19 Klystrons (ILC 10 MW MBK)
296 ILC-identical Cavities
38 ILC-like Cryomodules



Most ~ 7/8 of LINAC is built of ILC-like CM but ~ 25MV/M gradient

ICD-1
Operational Challenges

- ICD-1 is not ideal for the planned low energy Rare Decay Program
  - **Requirements:**

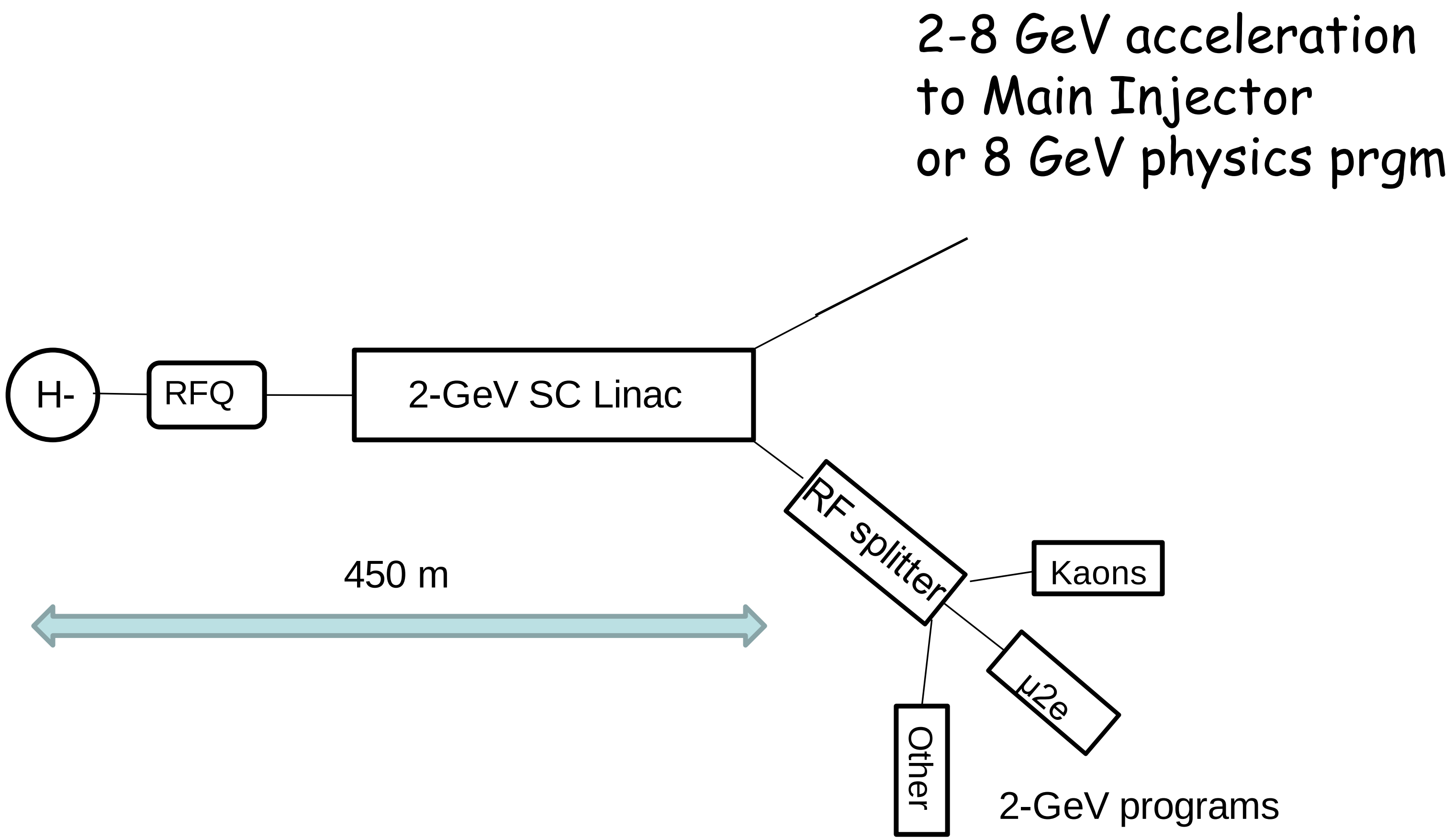
	Train Frequency (MHz)	Pulse Width (nanoseconds)	Inter-Pulse Extinction
Kaon experiments	20-30	0.1-0.2	10^{-3}
Muon conversion experiment	0.5-1.0	50	10^{-9*}
Muon g-2 experiment	30-100	50	---

  - The Recycler was not designed for high intensity slow spilled beam
    - ➢ Recycler delivers 15 Hz packets to the Debuncher for slow spill to mu2e.
    - ➢ The Debuncher appears limited to ~150 kW in this mode
  - ICD-1 does not yet have a solution for the kaon requirements

⇒ ICD-1 generates substantially more 8 GeV beam power than can effectively utilized

⇒ Slow spill is inherently lossly so limits power delivered to rare decay programs

ICD-2 (alternative front end)
2 GeV CW linac

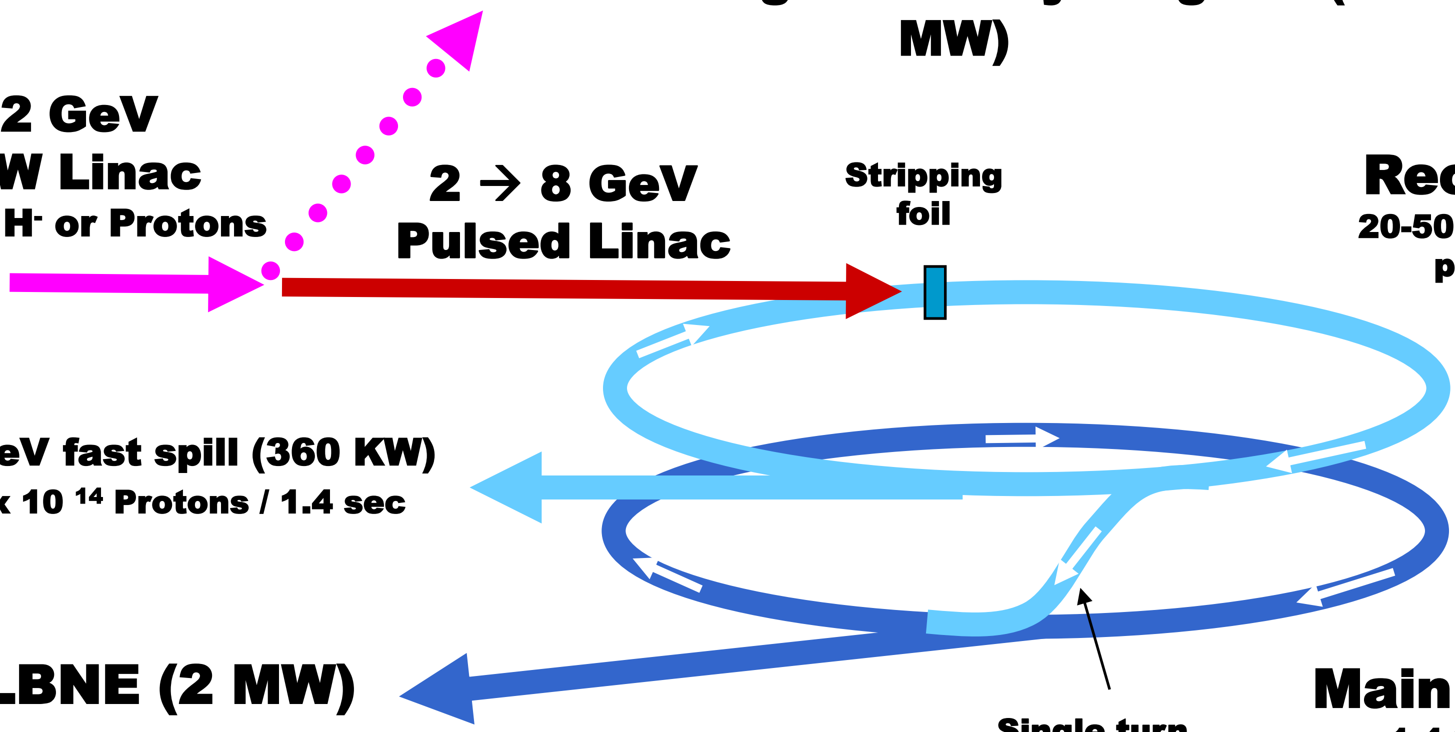


⇒ Still feeds H- at 8 Gev to MI for the DUSEL neutrino program

⇒RF splitter delivers desired bunch structures to rare decay programs (with low losses)

Project X

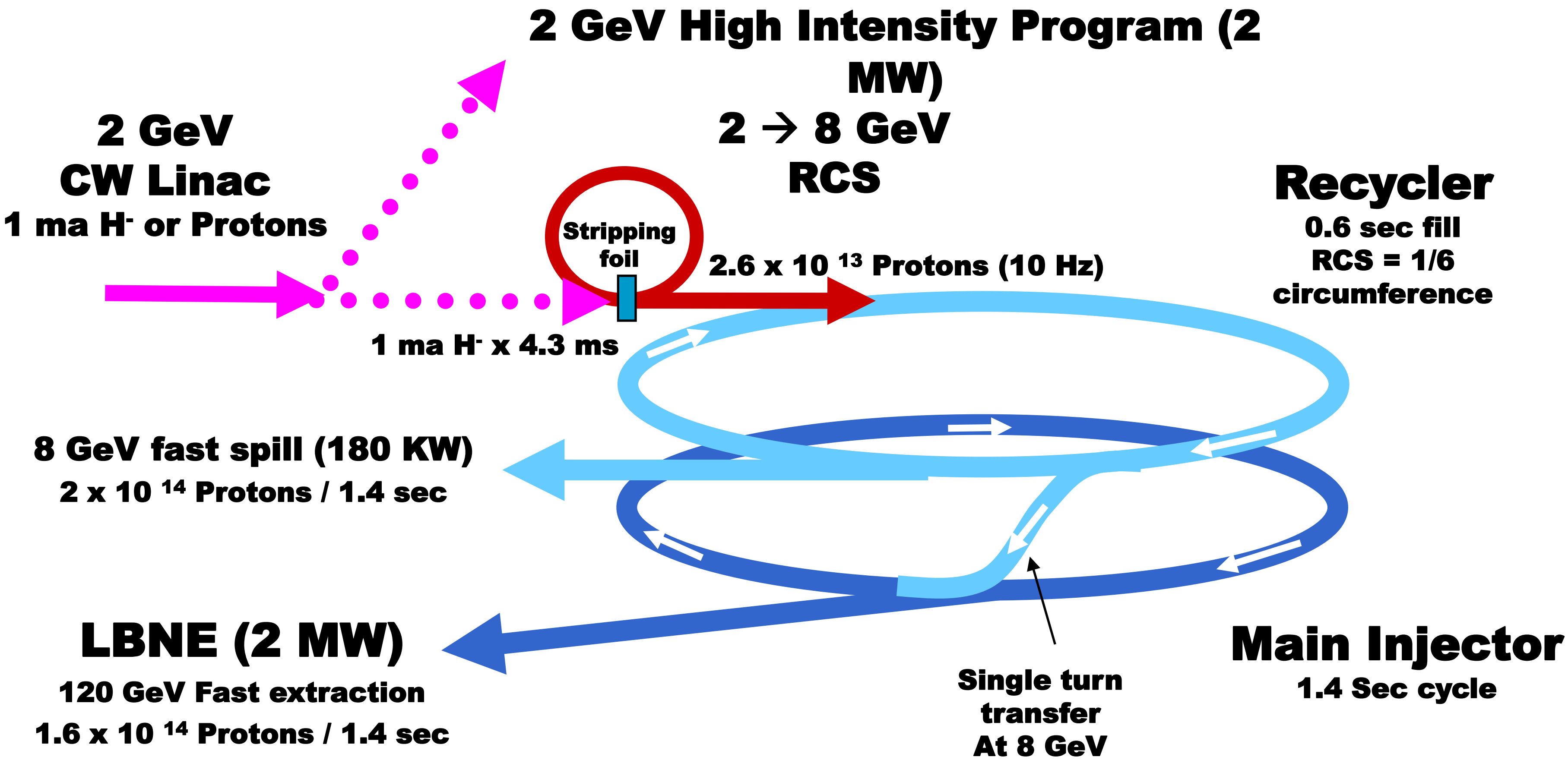
ICD-2 Layout (1)



~ Synergy with ILC R&D but long pulse R&D needed

Could also go directly to MI

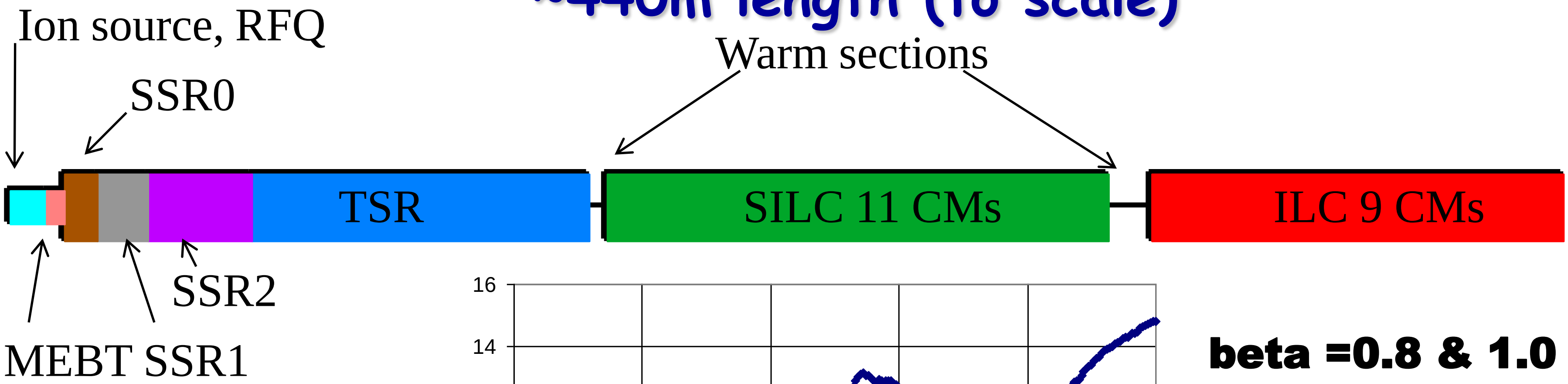
ICD-2 Layout (2)



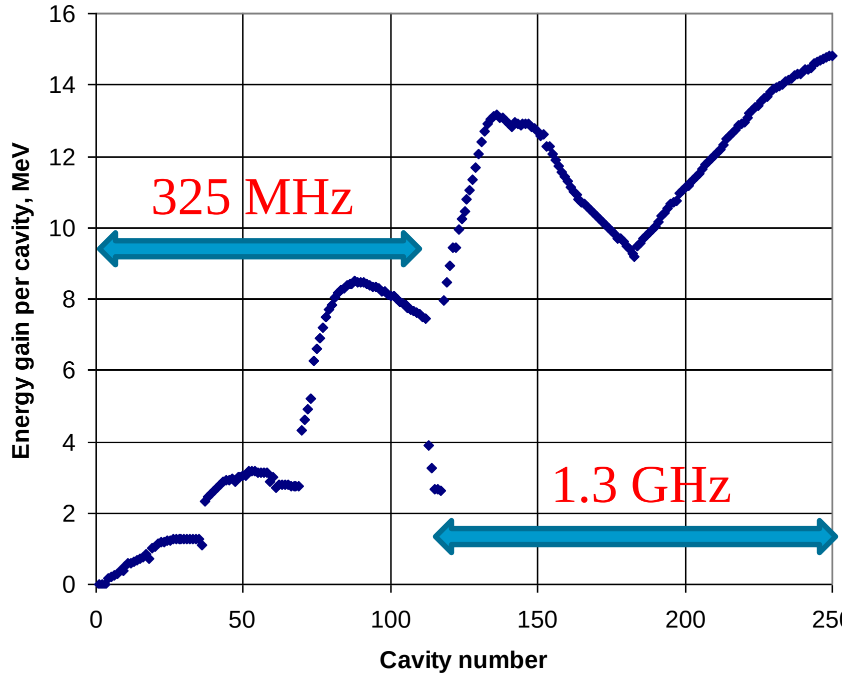
Evaluating Rapid Cycling Synchrotron for possible cost savings

ICD-2
2-GeV CW linac schematic

~440m length (to scale)



4 families of spoke resonators (similar to ICD-1)
325 MHz to 440 GeV



beta =0.8 & 1.0 elliptical cavities 1.3 GHz to 2 GeV

but

operate at 18 MV/m in CW mode Q_0 > 1.5 x 10^{10}

Project X

Cavity and CM Summary

Frequency Shape	Type beta	# cells gaps	ICD-1	ICD-2 (1) Required	ICD-2(2) Required
325 MHz Spoke resonator	SSR0 0.11	2	Warm	4 CM 18 cavities	4 CM 18 cavities
325 MHz Spoke resonator	SSR1 0.22	2	2 CM 18 cavities	2 CM 18 cavities	2 CM 18 cavities
325 MHz Spoke resonator	SSR2 0.40	2	3 CM 33 cavities	3 CM 33 cavities	3 CM 33 cavities
325 MHz Triple Spoke resonator	TSR 0.60	3	7 CM 42 cavities	8 CM 48 cavities	8 CM 48 cavities
1.3 GHz Squeezed Elliptical	S-ILC 0.81	7,9, 11 ?	8 CM 56 cavities	11 CM 66 cavities	11 CM 66 cavities
1.3 GHz Tesla shape Elliptical	ILC 1.0	9	38 CM 296 cavities	41 CM 316 cavities	9 CM 68 cavities

Cavity Totals — 445 — 499 — 251

R&D Plan

- Goals:
  - Complete baseline design, cost and schedule estimates in 2012
  - Technical component and infrastructure development
- Linac (325 MHz)
  - Spoke resonator development
  - High speed variable chopping patterns (325 MHz)
  - RF control of multiple accelerating structures from single klystron
- Linac (1.3 GHz)
  - Cavity & CM development coordinated with ILC
  - 25 MV/m gradient with good yield
  - ICD-1: (20 mA average) x 1.25 msec x 2.5 Hz
    - 3 times the charge/pulse of ILC
  - ICD-2: ILC cryomodules operated with CW
    - 2-8 GeV linac requires 20-50 ms 1 ma pulses

  (differences)
- H^- transport, multi-turn injection, space charge, e-cloud, civil, etc

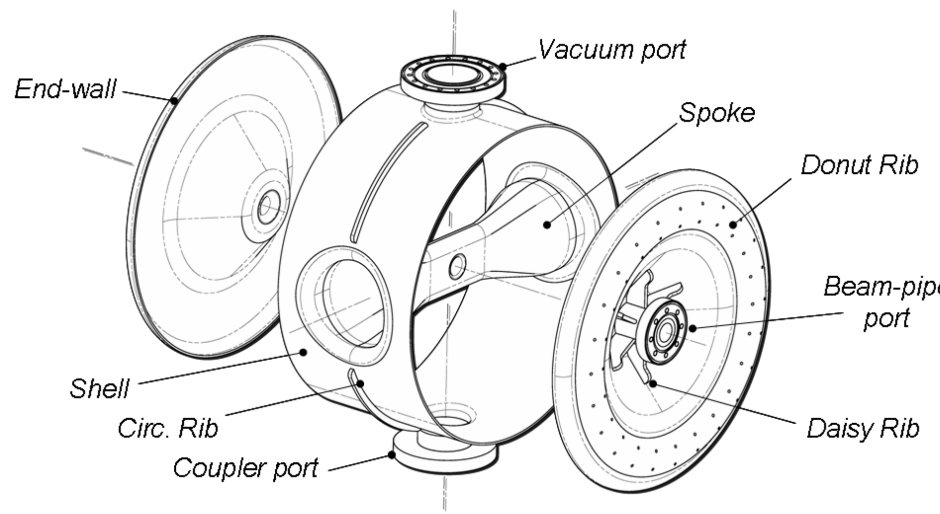
Project X

HINS 325 MHz Single Spoke Design Parameters

Quantity	Value
Operating temperature	**4.4 K**
HINS accelerating gradient, E_{acc} *	**10 MV/m**
Q_0 at accelerating gradient	**> 0.5×10^{9}**
Beam pipe, Shell ID	**30 mm, 492 mm**
Lorenz force detuning coefficient	**3.8 Hz/(MV/m)^2 (with He vessel)**
E_{peak}/E_{acc} *	**2.56**
B_{peak}/E_{acc} *	**3.87 mT/(MV/m)**
G	**84 Ω**
R/Q_0	**242 Ω**
Geometrical Beta, β_g	**0.21**

Original Plan (operating temperature and accelerating gradient)

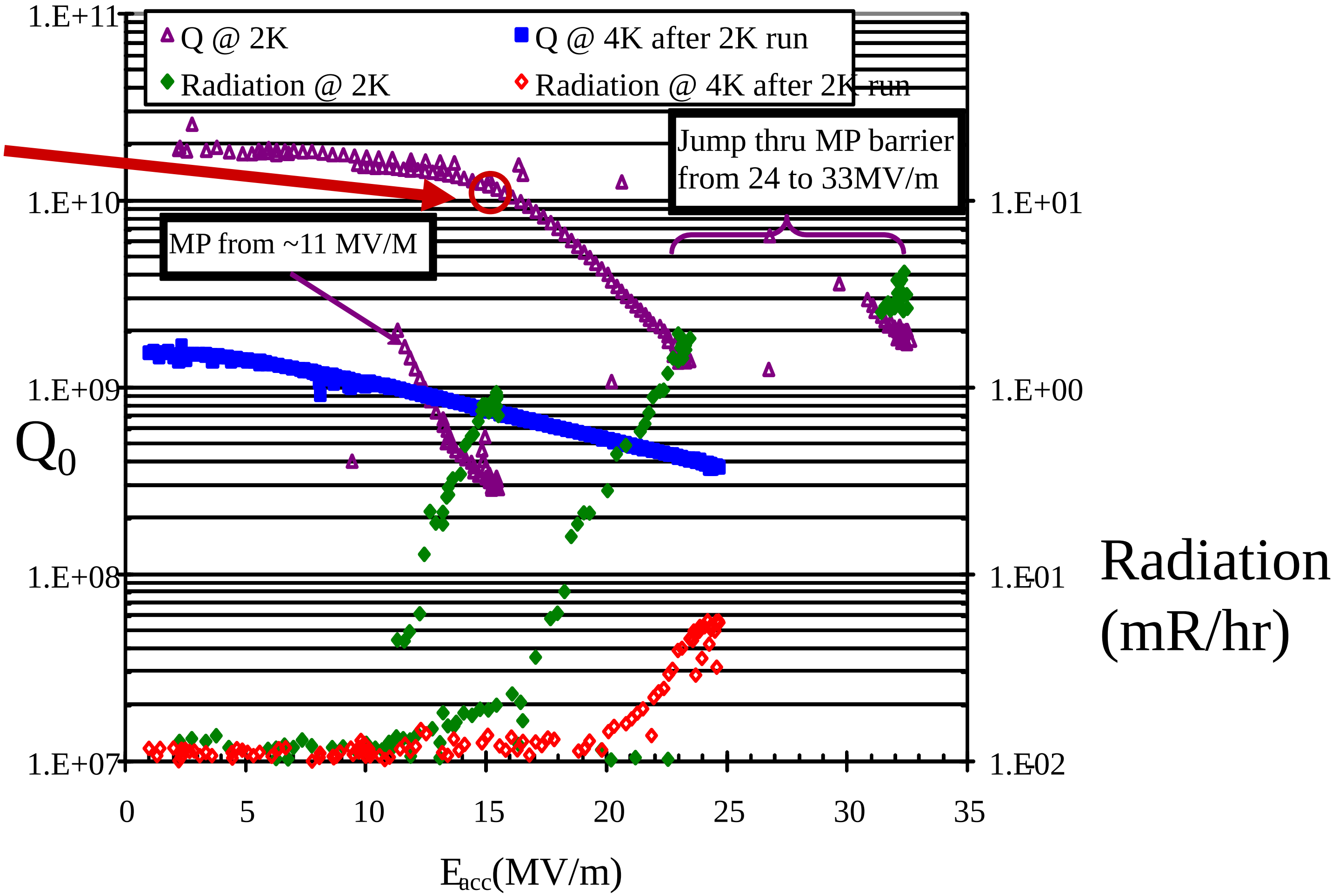
SSR1-02, the 2nd SSR1 prototype. Fabricated by Roark.



* E_{acc} is the total accelerating voltage divided by L_{eff}, where $L_{eff} = (2/3)\beta\lambda = 135$ mm, the distance between the edges of the accelerating gaps at the two endwalls.

SSR1 Spoke Resonator
VTS of bare cavity

Pick
Project X
Operating
Point
15 MV/M
@2 K

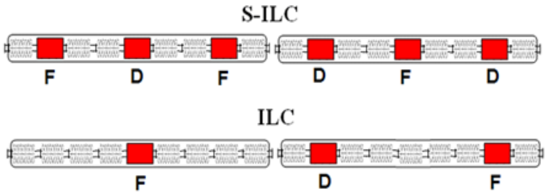


Q_0 .vs. E_{acc} and x-ray intensity as measured at the top of the VTS

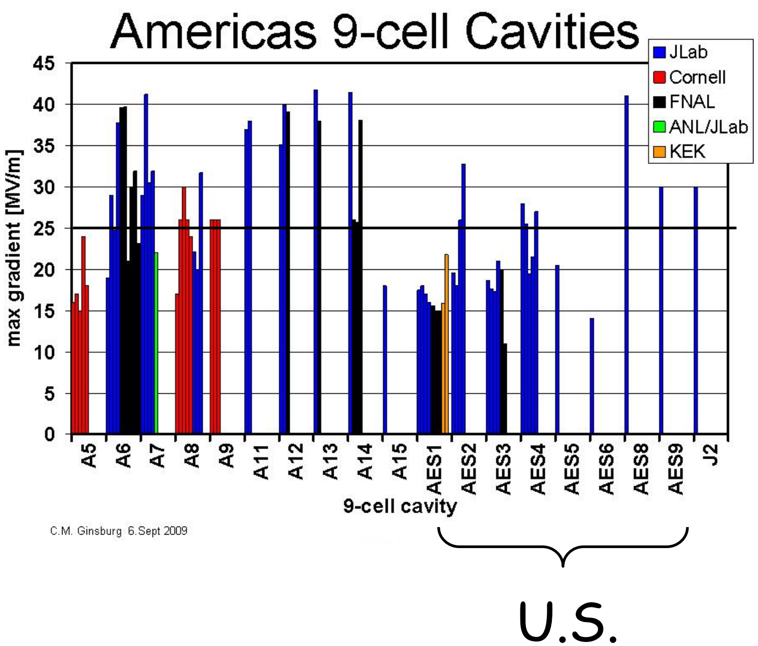
1.3 GHz Joint Development Strategy

- Project X shares 1.3 GHz technology with the ILC
  - Project X requires 20-52 ILC-like cryomodules.
    - In detail they will not be identical to ILC:
    - Focusing required in all CMs
    - Gradient: 25 MV/m spec (but try for higher)

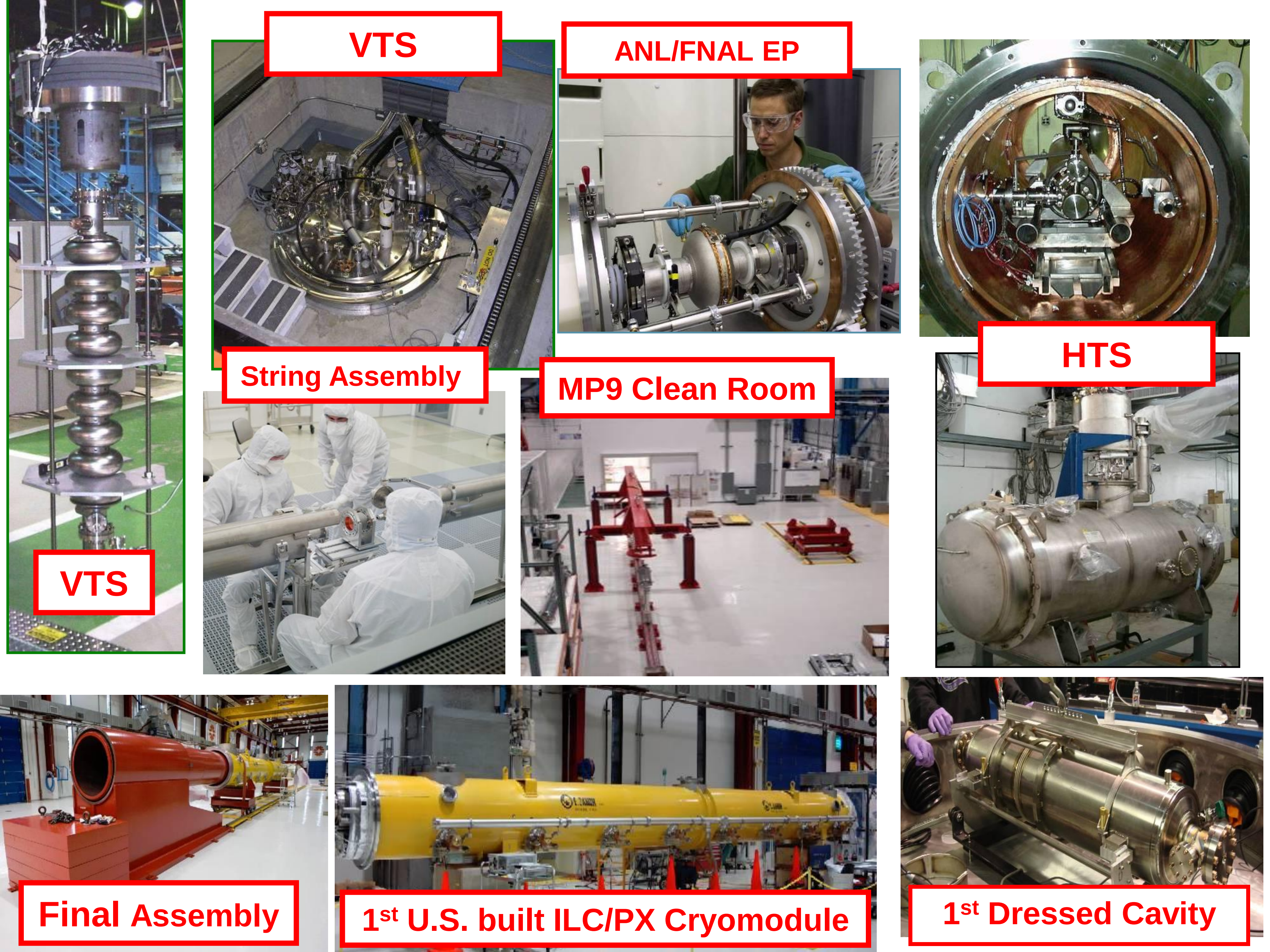
2/5/8 style CM



- Close coordination of Project X and ILC R&D program
  - Developing U.S. cavity vendors
  - Cavity gradient and yield!
  - Shared facilities for assembly & test
  - RF unit beam facility



- 4 year construction ➔1 CM/month
  - Building extensive infrastructure at FNAL for both Project X and ILC R&D


VTS
VTS
ANL/FNAL EP
HTS
String Assembly
MP9 Clean Room
Final Assembly
1st U.S. built ILC/PX Cryomodule
1st Dressed Cavity

1st Cryomodule moving to NML

NML is our RF unit test facility
An important facility for both Project X & ILC R&D

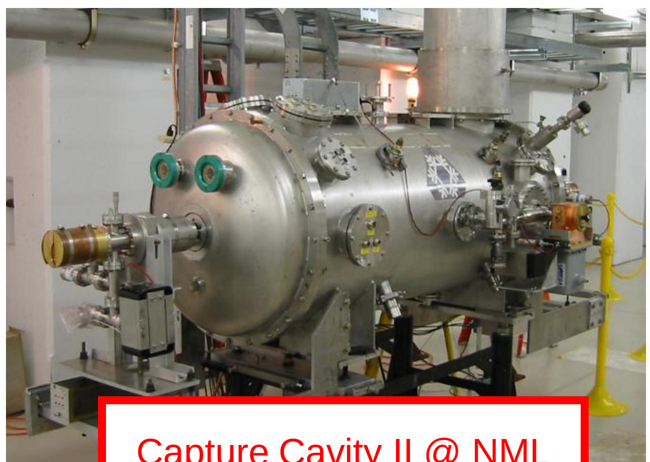
Progress at NML


1st Cryomodule Test fit


CM Feed Can


Large Vacuum Pump


Control Room


Capture Cavity II @ NML


He Refrigerator

Summary

- Project X is central to Fermilab's strategy:
  - Energy Frontier: Aligned with ILC technology development; preserves Fermilab as potential site for ILC or a Muon Collider
  - Intensity Frontier: Supports a world leading program in neutrinos and rare processes; preserves Fermilab as potential Neutrino Factory site
- An initial configuration (ICD-1) has been established meeting requirements as specified in the P5 report
  - >2 MW at 60-120 GeV, simultaneous with >150 kW at 8 GeV
- An alternative (ICD-2) is being explored that could also deliver
  - ~ 2 MW at 2 GeV with beam structure optimized for rare decays
- The facility could be constructed over the period ~2014 - 2018
- The initial configuration can be upgraded to 2-4 MW
- Active and growing Project X R&D program ($ 52.7 M of stimulus!)
- R&D integrates effort on Project X, ILC, SRF, and Muon Facilities