Project X Status Report

Sergei Nagaitsev (Fermilab)

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Outline

- Previous Project X presentation at HEPAP
  - S. Holmes, Nov 13, 2008
- Developments since Nov 2008
  - Evolution of initial configuration
  - Preliminary IC-1 and IC-2 estimates
  - 4th Project X Physics Workshop
    http://www.fnal.gov/directorate/Longrange/Steering_Public/workshop-physics-4th.html
  - Collaboration
- Technical and cost optimization
- Strategy
  - Cost range strategy

Project X missions

Concurrent

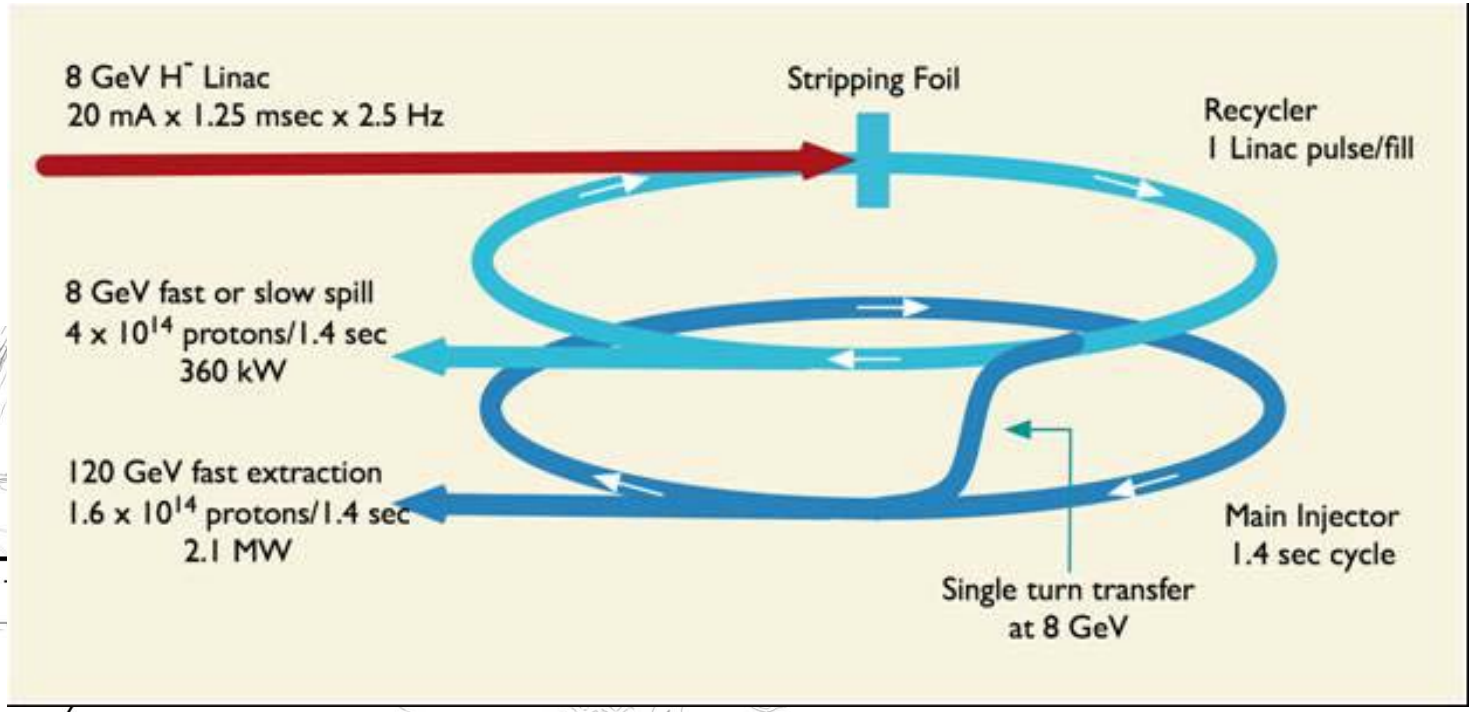
- Long-Baseline
  Neutrino Experiment: 2 MW at 60-120 GeV
  - well understood beam requirements;
  - it will be supported in any configuration we select.
- Rare Processes: ≥ several 100's kW at 2.x – 8 GeV
  - well understood beam requirements for this mission. 4th Project X Physics Workshop (Nov 2009)
- NF/MC Platform: upgradable to 4 MW at 5 – 15 GeV
  - MC beam requirements are (x~10) harder than NF;
  - High on our "radar screen" but is not a driver;
  - Do not need to have it on day 1 of initial program; need to demonstrate a plausible path.

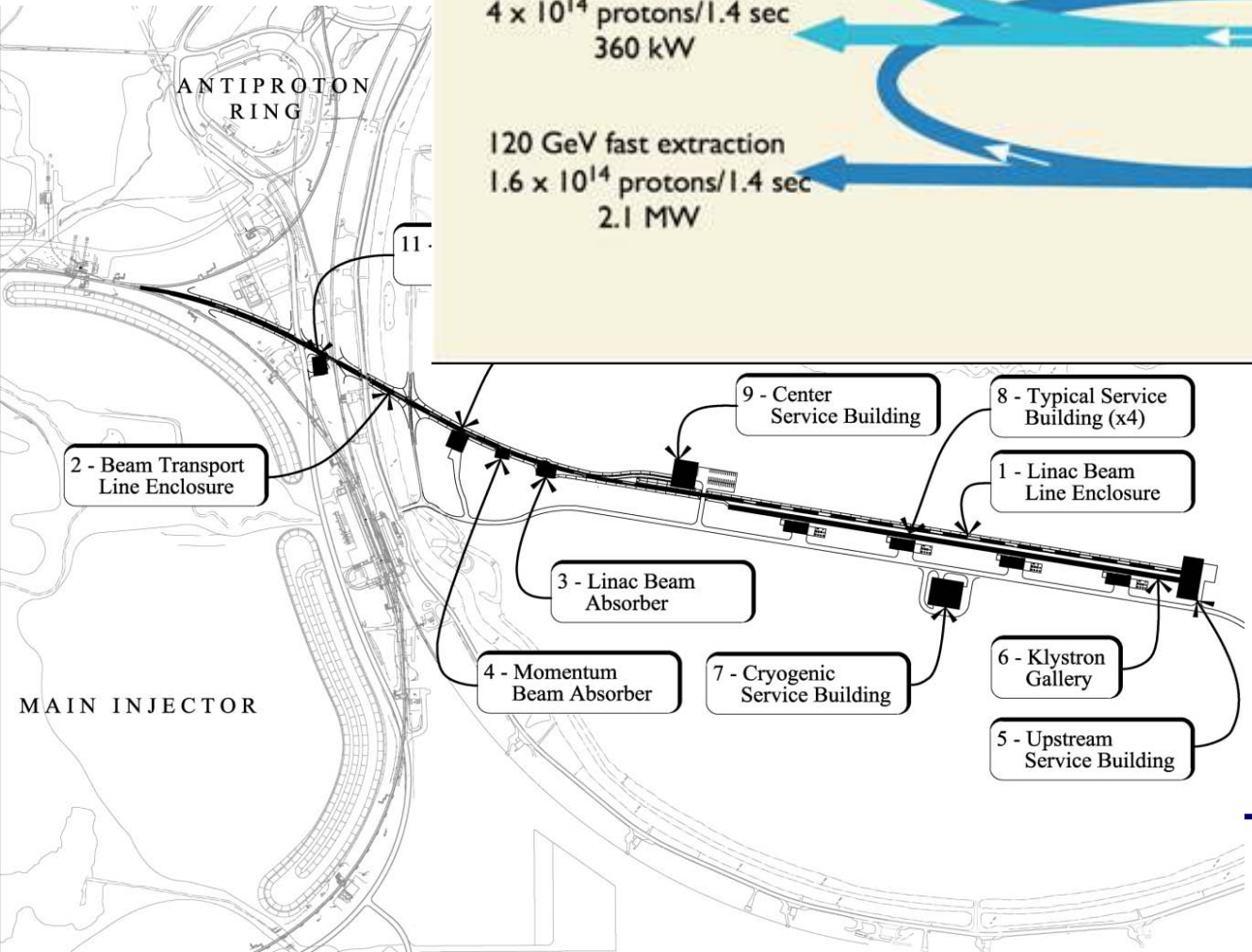
Project X Initial Configuration -1 (IC-1)

- IC-1 has been based on ILC-technology with a pulsed, 325-MHz low-energy and 1.3GHz high-energy SC linac (8 GeV)
- Objectives for the initial proposal (September, 2007)
  - ILC technology test (360 kW proton beam power at 8 GeV)
  - 2 MW at (60 -120 GeV) in the Main Injector for neutrinos
  - 100-200 kW at 8 GeV for rare processes (muons and kaons)
  - Replacement for a ~40 year-old Booster & Linac
- Final IC-1 (as of spring 2009)
  - 2 MW at (60 -120 GeV) in the MI for neutrinos (LBNE)
  - ~300 kW at 8 GeV for rare processes
    - 150 kW to Mu2e (Phase 2) upgraded (with a slow extraction)
  - Reduced coupling to ILC (500 kW proton beam power at 8 GeV)
  - Improved but still comparatively narrow physics program

Project X

IC-1





IC-1 issues

- Rare processes require a stream of bunches with a ~100% duty cycle.

Examples:

	Train Frequency	Pulse Width (nanoseconds)
Kaon experiments	20-30 MHz	<0.2
Muon conversion experiment	0.5-1.0 MHz	<100
$\mu \rightarrow e\gamma$ & $\mu \rightarrow eee$ experiments	80-300 MHz	<0.2

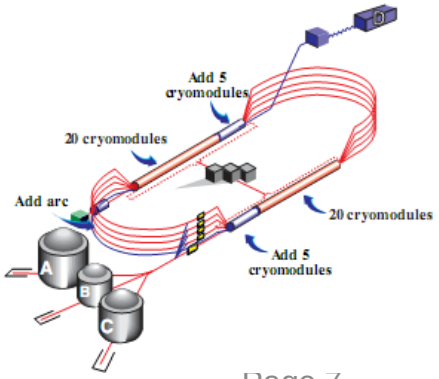
  - A pulsed beam from linac is not optimal; requires beam conditioning in rings and slow extraction.
- There is a fundamental limit to slow extraction: losses at the electrostatic septum
  - Also, space-charge for short bunches, single user for a given bunch format, non-uniform spill rates
  - World's best: AGS, 70 kW (2% loss), unbunched beam (25 GeV); similar beam power from Tevatron in the past
  - JPARC design: several 100 kW at 50 GeV, unbunched (undemonstrated)
- At the end, we understood that slow extraction is the bottleneck.

Initial Configuration - 2

- Mar. 2009: To improve the rare processes program we have focused on a cw proton linac.

Missions:

- 2 MW at 60-120 GeV in MI for LBNE
  - Same as in IC-1
- Diverse program with muon, kaon, and nuclear physics
  - Different experiments require different time structures
  - “unlimited” beam power on target
- 8 GeV program with a single turn extraction (≥100 kW)
  - g-2, …
- A path to MC/NF
- Experiments in other fields
- CEBAF is an example of such a machine with e-beam

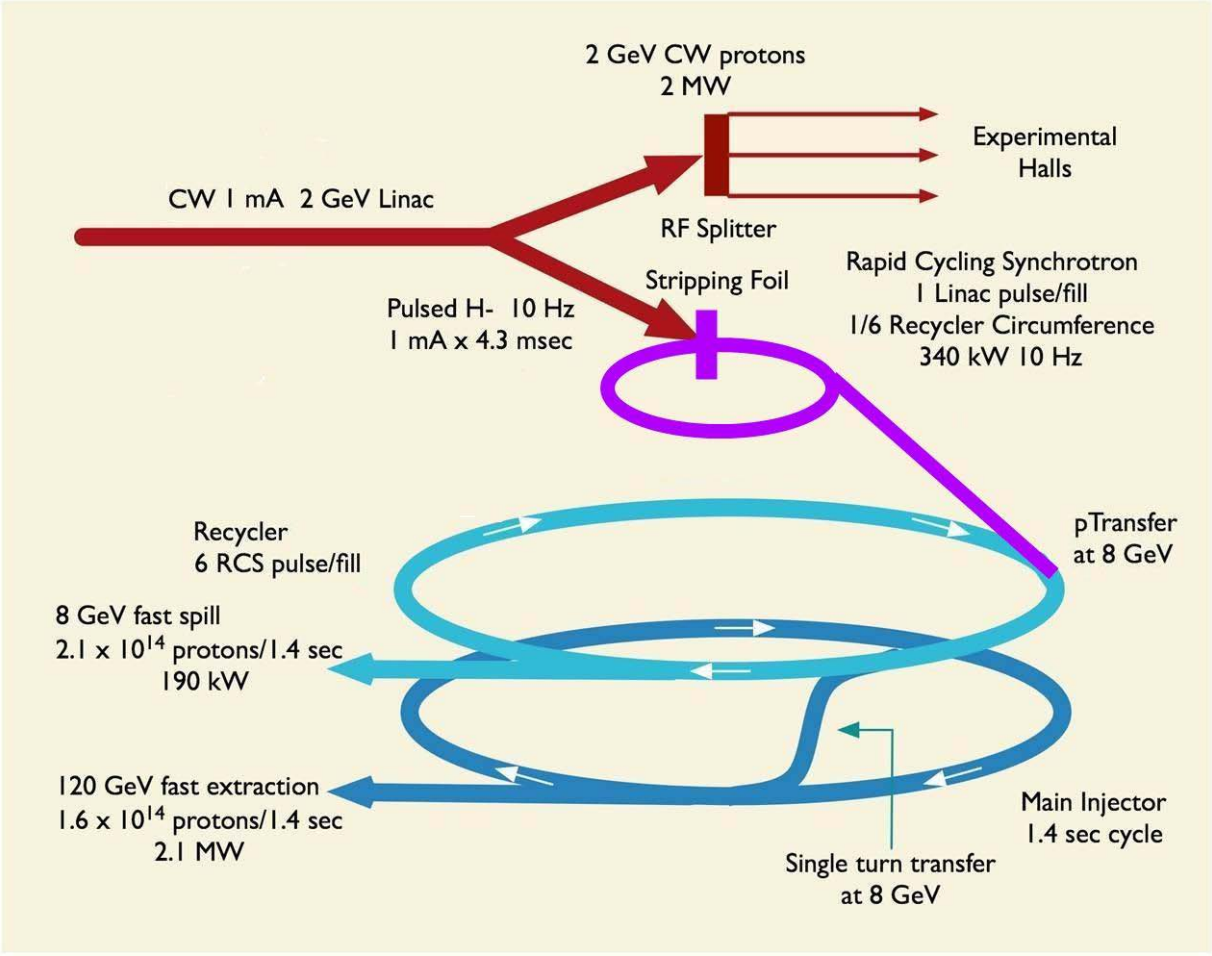


IC-2

- IC-2 concept (as of end of summer 2009)
  - 2.0 GeV CW linac
  - potentially “unlimited power”
  - RF separation + bunch-by-bunch chopping
  - Multiple experiments operating simultaneously
  - Independent bunch structure control

- “Pulsed” 2-to-8 GeV acceleration (10 Hz, 4.3 ms, 5% duty cycle) to support MI program
  - Both synchrotron and pulsed SC linac are a good choice

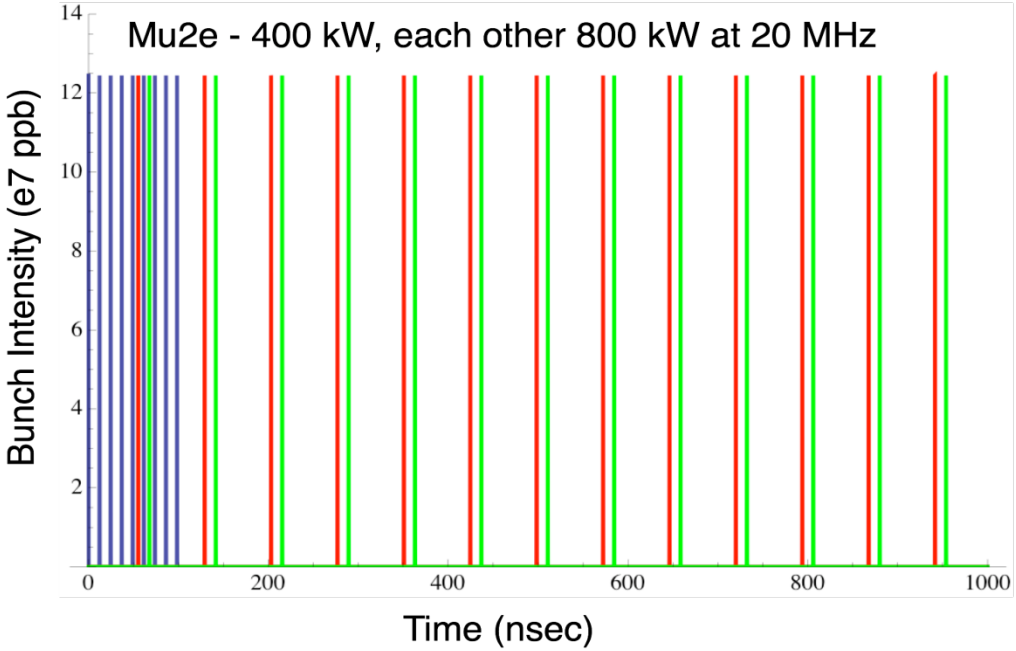
IC-2 Overview

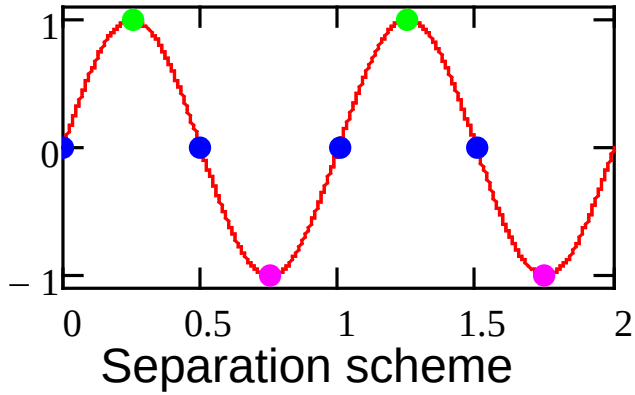


IC-2 Operating Scenario

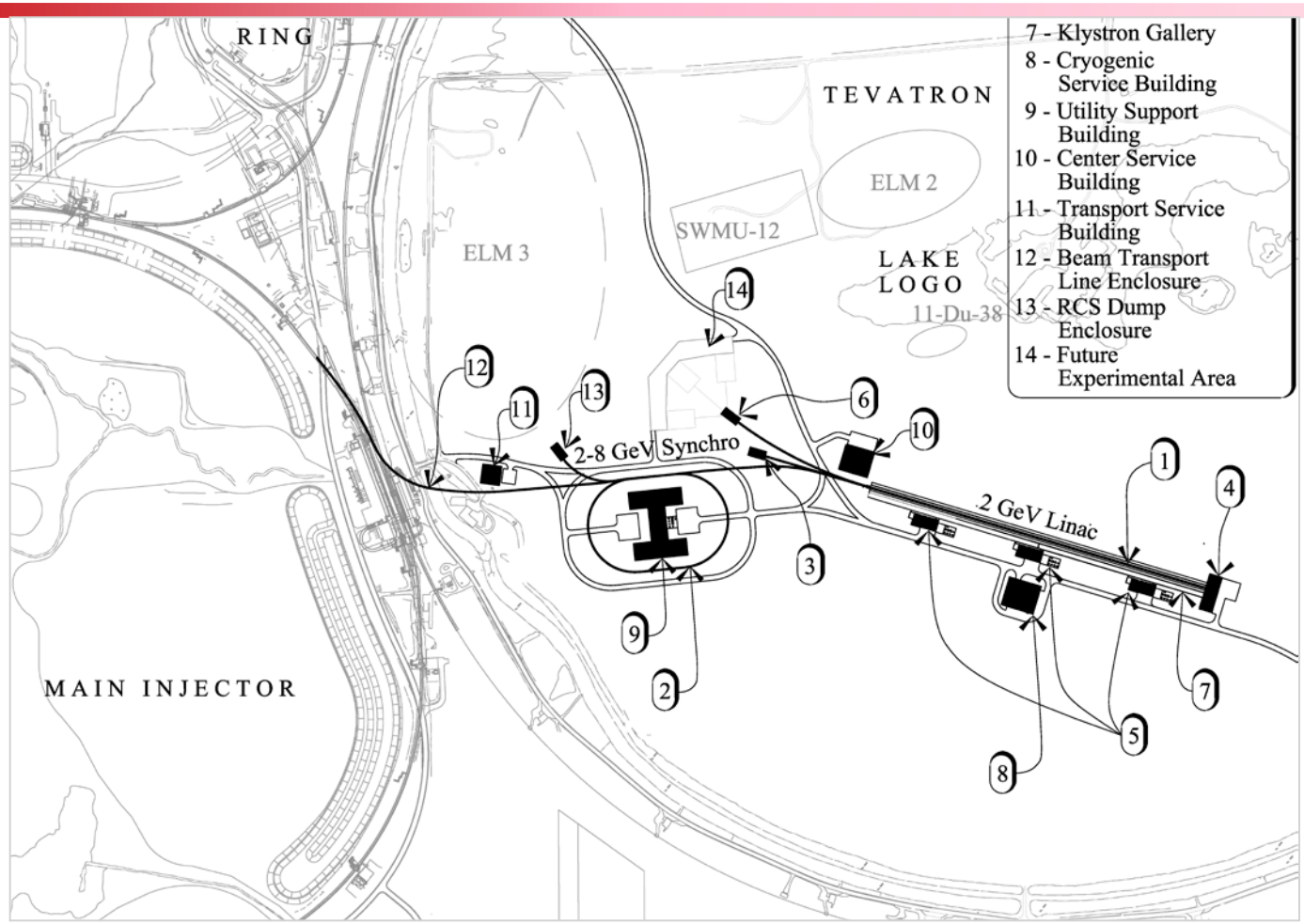
1 μsec period at 2 GeV

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

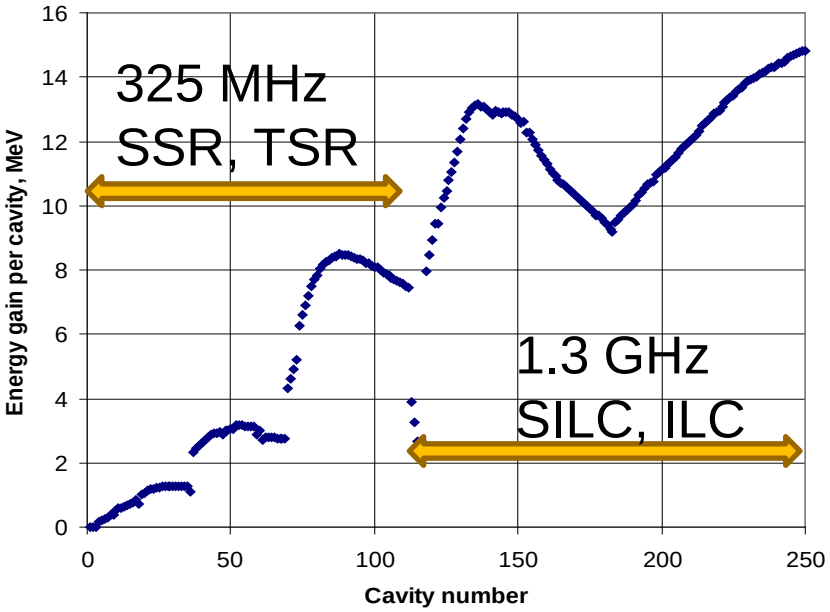


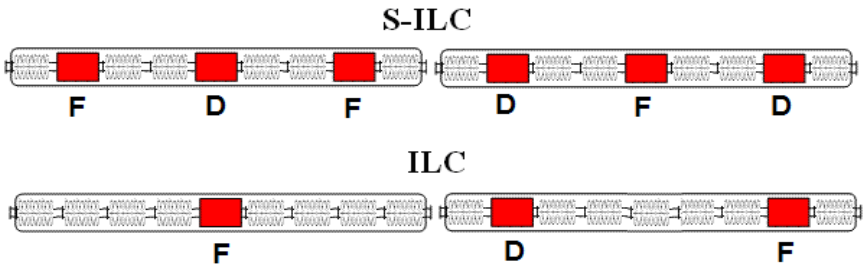


IC-2 Provisional Siting



Initial Configuration-2
Technology Map
2-GeV Super Conductive cw linac





Preliminary IC-2 Estimate

- IC-1 point estimate completed March 2009, subject to Director's Review
  - Assessed to be conservative w/ caveats: escalation, scope, schedule
- IC-2 point estimate completed in October 2009
  - Same estimators and methodology as IC-1
  - Not yet reviewed
  - ~6% higher than IC-1 – within range of error.

	IC-1 ($M)	IC-2 ($M)
Base Cost	$743.5	$798.4
Overhead	$185.9	$187.5
Escalation	$135.7	$144.0
Contingency (40%)	$426.1	$452.0
Total	$1,491.2	$1,581.9

4th Project X Physics Workshop
November 9-10, 2009

- Identified optimum energies for various programs

	Proton Energy (kinetic)	Beam Power	Beam Timing
Rare Muon decays	2 – 3 GeV	> 500 kW	1 kHz – 160 MHz
Precision K^0 studies	2.6 – 3 GeV	> 200 kW	20 – 160 MHz (< 50 psec pings)
Rare Kaon decays	2.6 – 4 GeV	> 500 kW	20 – 160 MHz (< 50 psec pings)
(g-2) measurement	8 GeV	20 – 50 kW	30 - 100 Hz
Neutron and exotic nuclei EDMs	1.5 – 2.5 GeV	> 500 kW	> 100 Hz

IC-2 remaining issues

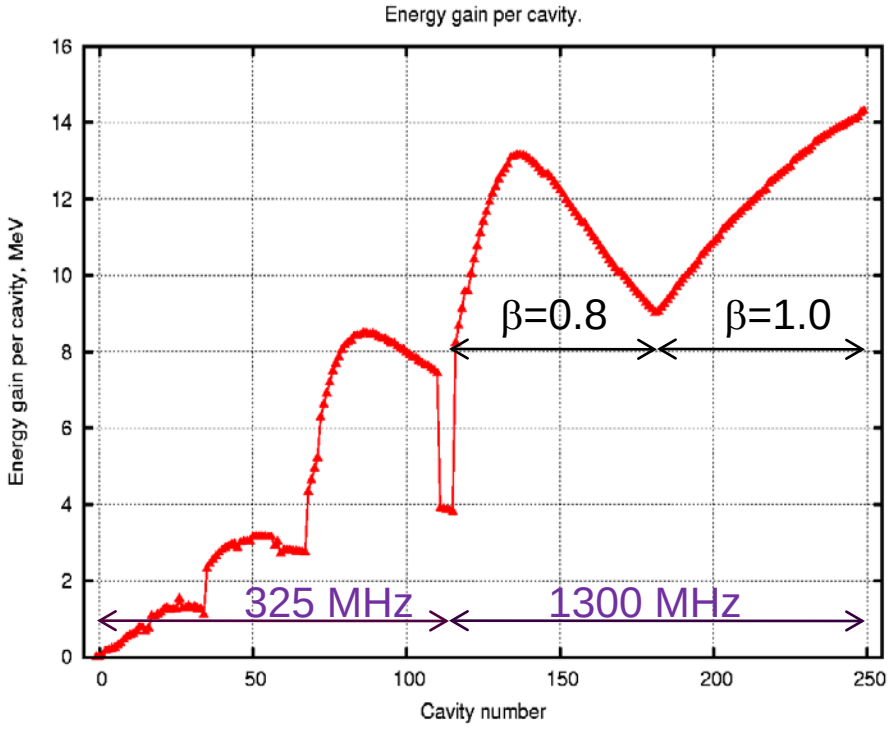
- Solved the IC-1 problems (slow extraction)
- But…
- two issues remained…

1. Low proton beam energy (2 GeV intead of 3)
2. Inefficient acceleration in the linac

IC-2 optimization
(since Nov 2009)

- What problem are we trying to solve?

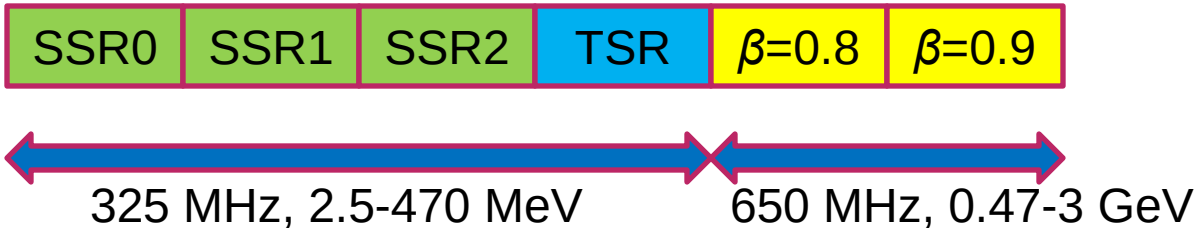
Energy gain/cavity in IC-2



- 1300 MHz section is not an efficient accelerator (for protons)
- Primary culprit is transit factor
  - also, number of cells per cavity
- Maximal gain at zero synchronous phase is 17 MeV (for β=1) but for a 2-GeV proton beam it is close to 15 MeV

Several 3-GeV linac schemes analyzed

#1



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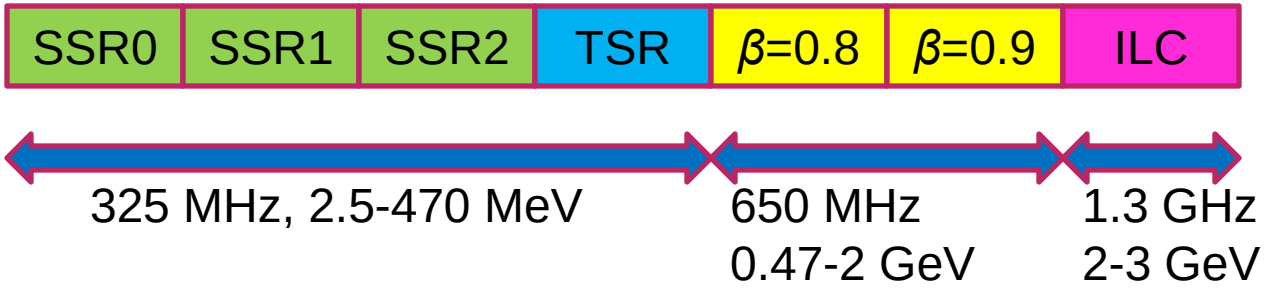

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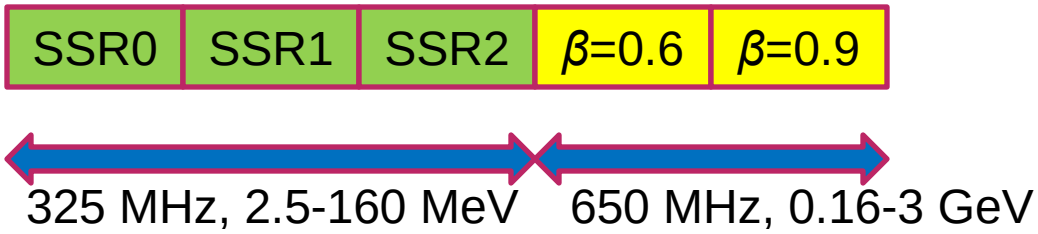

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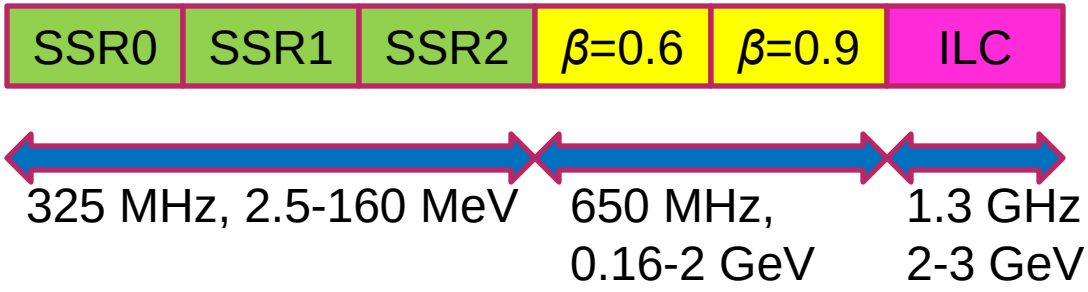
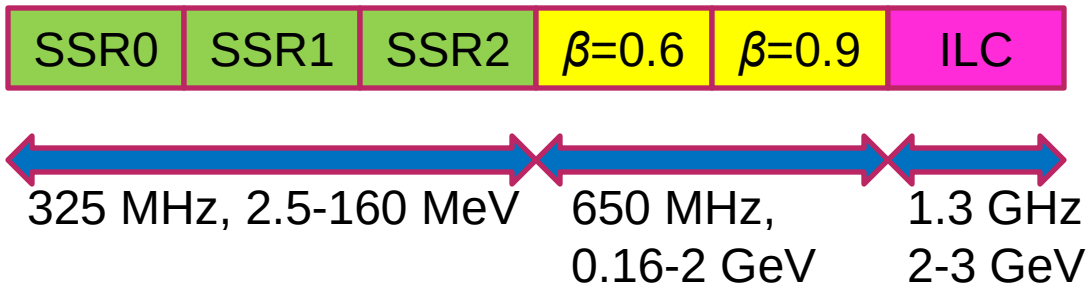


IC-2v2.0
"Option 4"

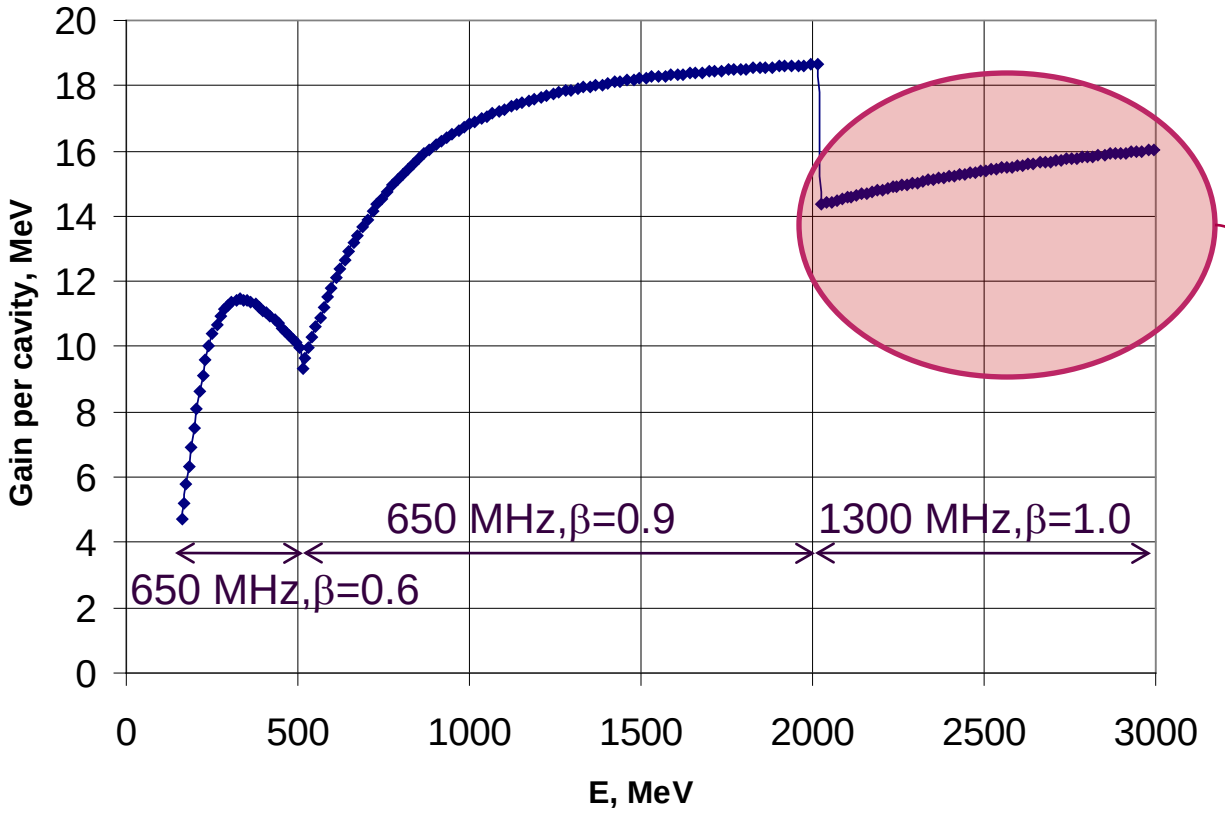
- Option 4: a 3-GeV CW linac with a 650 MHz intermediate system, based on 5-cell cavities.



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

IC-2v2.0
"Option 4"

Energy gain/cavity in IC-2v2.0



Discontinuity can be effectively eliminated with a β=0.95 cavity

IC-2v2.0 "Option 4"

- Total number of cavities in each configuration:
  IC-2v1.0: 316 cavities (to 3 GeV)
  IC-2v2.0: 250 cavities (less if β=0.95)
- Total linac length is reduced by ~20% (for 3 GeV)
  - Or, 3 GeV linac (option 4) is ~20% longer than the 2 GeV linac in IC-2v1.0
- Early analysis of cost trade-offs indicate that 1300 MHz cavity becomes more cost effective than 650 MHz somewhere in the range of 2 GeV
- Development of IC-2v2.0 (option 4) will allow us to explore issues related to introduction of a third frequency, and variations on the 1300 MHz cavity shape

Short Term Strategy
(Next 6 months)

- Develop an estimate for a 3 GeV CW linac operating at 1.5-2 MW
  - Identify (cost) break points (with respect to beam power) on the rf system and cryogenics distribution system
  - Establish a better optimized (i.e. reduced cost) linac configuration: cavity types, cavity frequencies, and transition points
- Retain RCS within the estimate but limit work to critical issue(s)
  - Injection
- Investigate options for pairing a 3-8 GeV pulsed linac to CW front end
- Update RD&D Plan to cover CW linac
- Archive ICD-1 and associated cost estimate
- Proposed strategy for CD-0
  - Attempt to get cost of 3 GeV linac at or below $1.0 B
  - Conduct a Director's Review to validate a cost range that extends below $1.0 B

Short Term Plan
(Next 6 months)

- Goals of the Director's Review:
  - Validate the cost estimate for IC-2
  - Validate a cost range proposed by the project
- Upper end of range = **IC-2v1.0**, with linac at 3.0 GeV/1.0 mA. RCS, Recycler, MI
  - Release ICD-2V1.0 as is (2.0 GeV) after final edit
  - Update the estimate with the incremental cost of adding 1 GeV of CW linac
- Lower end of range = **IC-2v2.0,** with linac at 3.0 GeV/0.5 mA, no RCS, Recycler, MI
  - Update to ICD-2V2.0 based on "Option 4" configuration
  - Update the cost estimate based on "Option 4" configuration

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 .

Summary

- The configuration for Project X has evolved to maximize physics outcome since the initial proposal in 2007
  - At every step we have improved the performance
  - A new approach to high-duty factor beams and rare processes
  - Not another rendition of JPARC
  - x10 beam power of the IC-1 rare-process program, x7 goal of JPARC
  - Capture leadership in intensity frontier

- We now know what we want to build!
- We propose to build Project X based on a 3-GeV CW linac.
  - Could be constructed in a 5-year time period
  - Multi-user facility concurrent with LBNE
  - An rf splitter sends beam to 3 users (muon, kaon and nuclear physics), but technology is not limited to 3 users.

Backup: Potential cost reductions

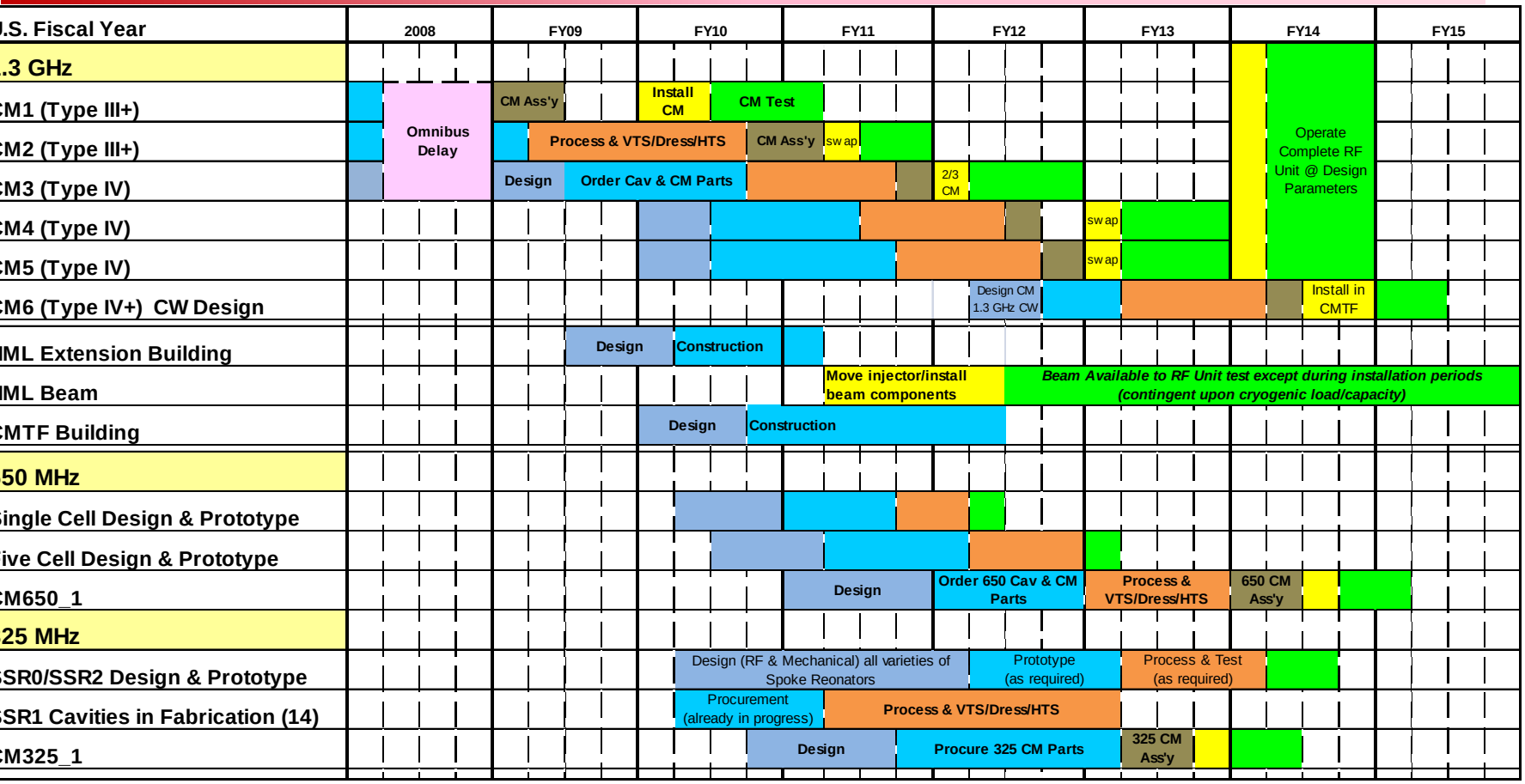
- Extend cost range further downward by establishing a set of potential cost reductions that can be applied to either configuration
  - Reoptimization of linac configuration
  - Review of CM estimate to identify cost reduction opportunities
  - Identify rf infrastructure that is frequency independent vs dependent
  - Review of rf power and distribution system to identify breakpoints (with respect to beam current)
  - Review the cryo estimate to identify breakpoints with respect to segmentation, and complete G vs Q vs T
  - Identify potential in-kind contributions from international partners
  - Remove space offset budgets
  - Develop a reduced overhead model
  - Update R&D plan to configuration IC-2

  $\Rightarrow$ Consolidate all of the above into a cost opportunities spreadsheet

Backup: Project management

- We have assembled a senior management team (3 people part-time)
  - assempled a team of level-2 managers (all part-time)
- We are preparing an integrated SCRF plan
  - includes our commitments to the ILC program (1.3 GHz, pulsed)
- The FY2010 budget for Project X is $10.3M. Of this $1.6M is set aside for work at the collaborating institutions.

Integrated SRF Plan
Cryomodules



Integrated SRF Plan
Infrastructure