Project X:
Initial Configuration

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Director’s Review CD-0 Cost Range Exercise

March 16, 2009

Initial Configuration Document

- What is its role?
  - Projects have to work within context of DoE order 413.3a
  - Program and Project Management for the acquisition of Capital Assets
  - Critical Decision path
- Input to CD-0 “Approve Mission Need”
  - R&D and Conceptual Planning
  - “A Mission Need Statement is the translation of this gap into functional requirements that cannot be met through other than material means. It should describe the general parameters of the project, how it fits within the mission of the Program, and why it is critical to the overall accomplishment of the Department mission, including the benefits to be realized. **The mission need is independent of a particular solution, and should not be defined by equipment, facility, technological solution, or physical end-item.** This approach allows the Program the flexibility to explore a variety of solutions and not limit potential solutions.”
- requires a cost range!!!!!
  - Define a configuration to cost
  - A Major Systems Project > $750M

Mission Need

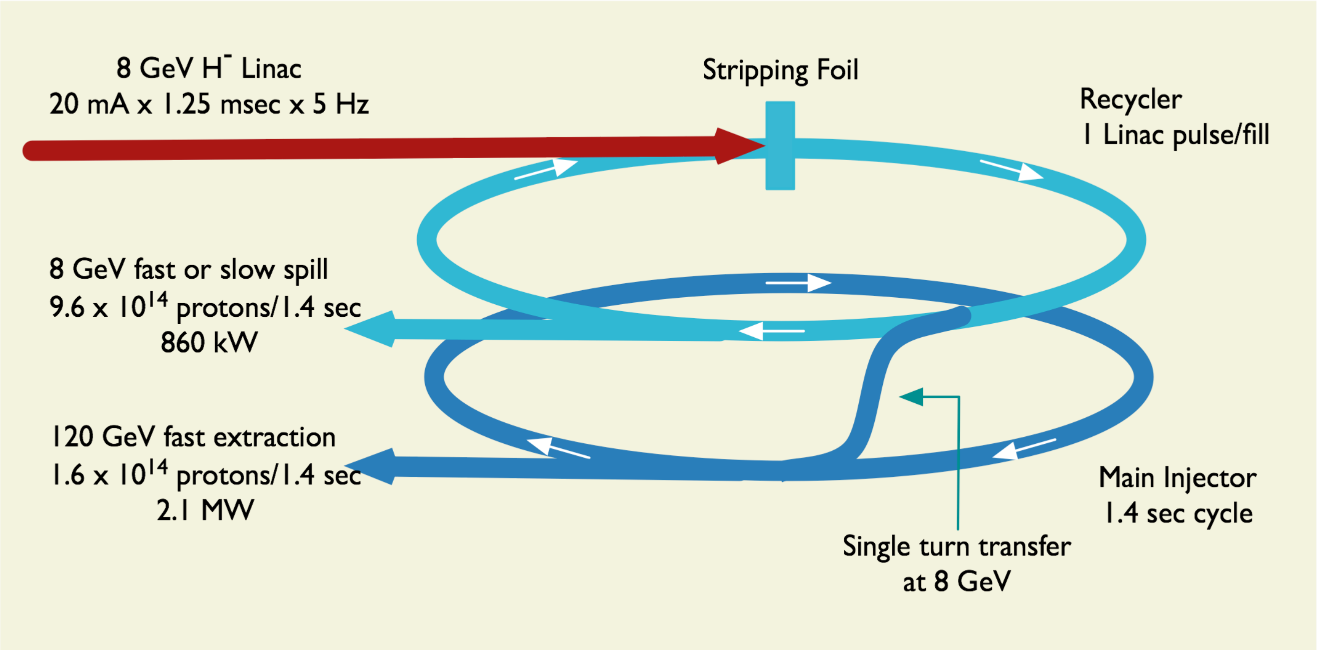
- The P5 report identifies mission need based on:
  - A neutrino beam for long baseline neutrino oscillation experiments. A new 2 megawatt proton source with proton energies between 50 and 120 GeV would produce intense neutrino beams, directed toward a large detector located in a distant underground laboratory.
  - Kaon and muon based precision experiments exploiting 8 GeV protons from Fermilab's Recycler, running simultaneously with the neutrino program. These could include a world leading muon-to-electron conversion experiment and world leading rare kaon decay experiments.
  - A path toward a muon source for a possible future neutrino factory and, potentially, a muon collider at the Energy Frontier. This path requires that the new 8 GeV proton source have significant upgrade potential.

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

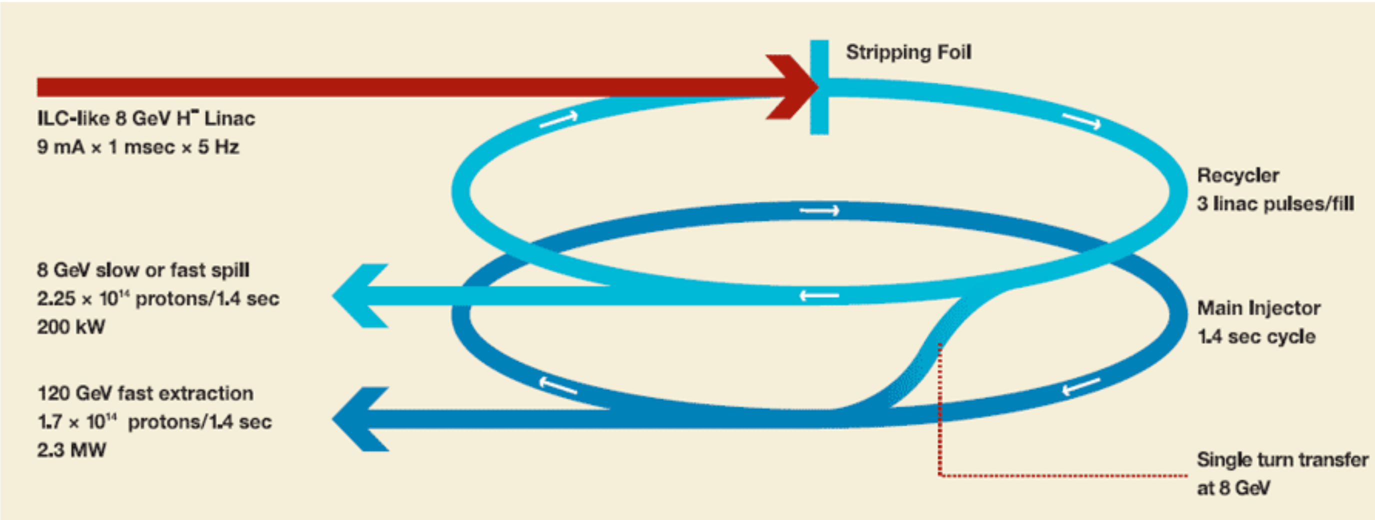
#1: 1.6×10^{14} protons/pulse in MI
2.14 MW @ 120 GeV
1.97 MW @ 60 GeV

#2: 1.6×10^{14} protons/pulse @ 8 GeV
500 kW - 850 kW

#3: Upgrade path:
increase repetition rate 10 Hz
increase pulse length 2.5 msec



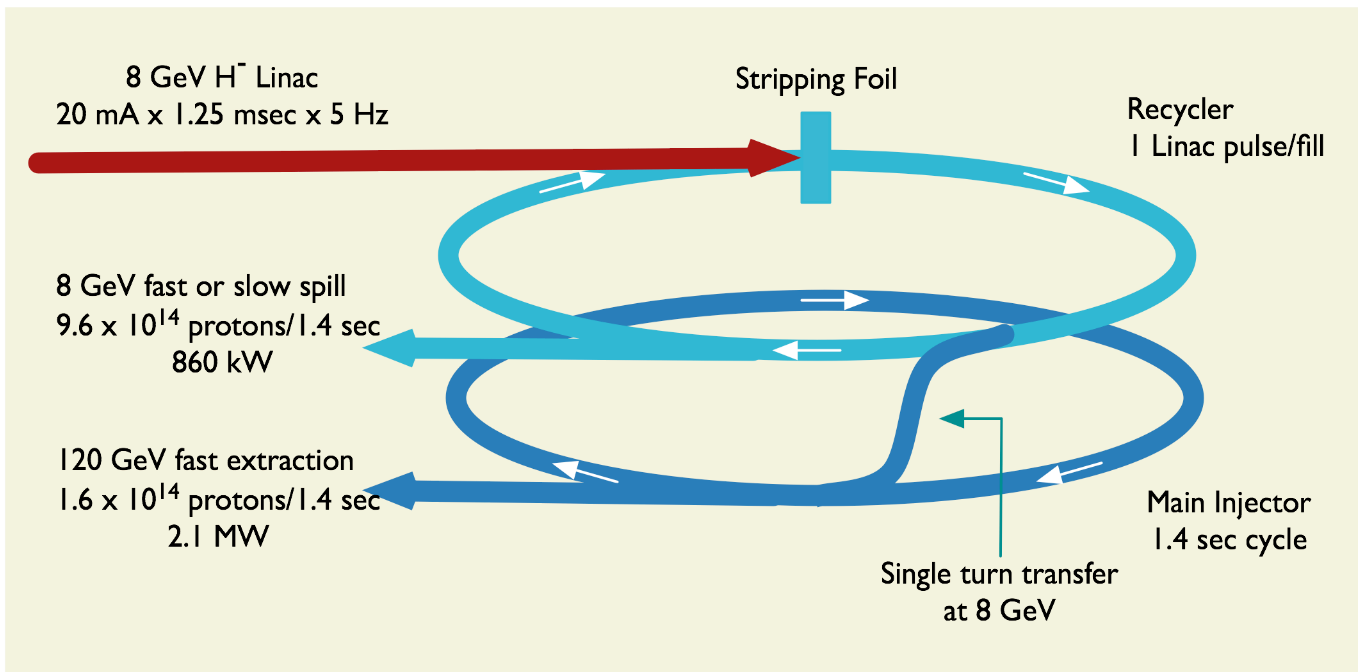
Evolution of Configuration



Steering Group
Project X
2007

Initial Configuration Document

Expect it will continue to evolve



Performance Goals

Linac	Particle Type	H^-
	Beam Kinetic Energy	8 GeV
	Particles per pulse	1.6×10^{14}
	Pulse Rate	5 Hz
	Beam Power	1 MW
Recycler	Particle Type	Proton
	Beam Kinetic Energy	8 GeV
	Particles per cycle to MI	1.6×10^{14}
	Particles per cycle to 8 GeV program	1.6×10^{14}
	Beam Power to 8 GeV program	140 – 860 kW
Main Injector	Beam Kinetic Energy (max)	120 GeV
	Cycle Time (120 GeV)	1.4 sec
	Particles per cycle	1.6×10^{14}
	Beam Power at 120 GeV	2.1 MW

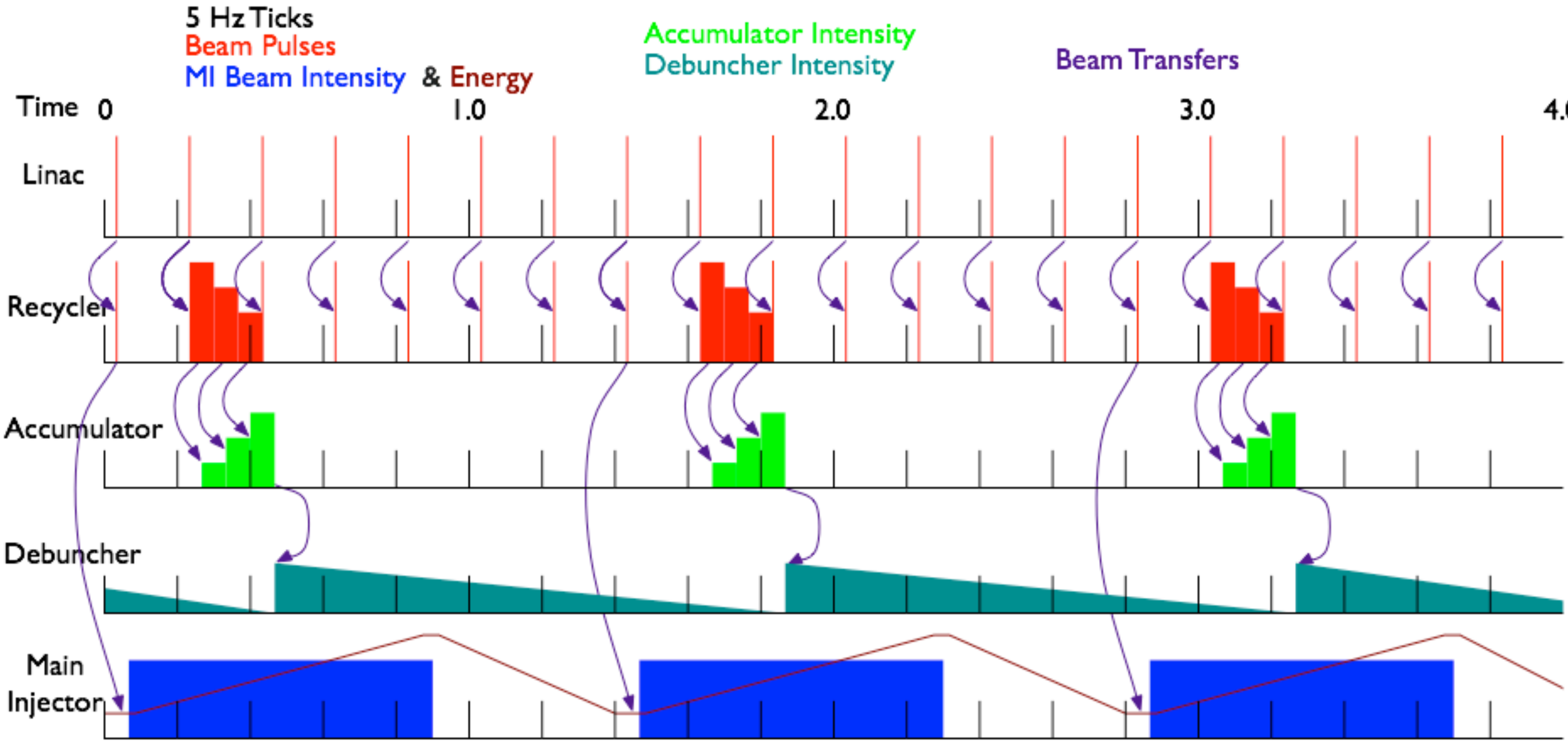
Initially:

2 linac beam pulses/ 1.4 seconds

Remaining (5) pulses available for

- Maintain 2 MW down to 60 GeV
- Future upgrades
- Diagnostics

Operational Scenario



1.6e14 per pulse from Linac (5 Hz)
1.6e14 through Recycler to Main Injector (every 1.4 sec)
8e13 through Recycler to Accumulator (every 1.4 sec)

8e13 through Accumulator to Debuncher (every 1.4 sec)
7 Linac Cycles per MI Cycle: 1 to MI, 1 to mu2e,
5 available for diagnostics/commissioning/future experiments

Initial Parameters

Req. No.	Description		Req.	Unit
1.0	**General**			
1.1		120 GeV Beam Power	2.1	MW
1.2		Total Linac Beam Power	1.0	MW
1.3		Available (outside of MI) Linac Beam Power	0.9	MW
1.4		Available (outside of MI) Duty Factor	86	%
1.5		120 GeV Availability	75	%
1.6		8 GeV Availability	80	%
2.0	**325 MHz Linac**			
2.1		Average Beam Current	20	mA
2.2		Pulse Length	1.25	msec
2.3		Repetition rate	5	Hz
2.4		325 MHz Availability	98	%
2.5		Peak RF Current	31.9	mA
2.6		Final Energy	420	MeV
2.7		Linac Species	H-	
2.8		Transverse Emittance (95% normalized)	2.5	π-mm-mrad
2.9		Macro Bunch Duty Factor	67	%
2.10		Macro Bunch Frequency	53	MHz
2.11		Micro Pulse Length	10.4	microsec
2.12		Micro Pulse Period	11.1	microsec
3.0	**1300 MHz Linac**			
3.1		Average Gradient (ILC portion)	25	MV/meter
3.2		Average Gradient (S-ILC portion)	23	MV/meter
3.3		Average Beam Current	20	mA
3.4		Pulse Length	1.25	msec
3.5		Repetition rate	5	Hz
3.6		1300 MHz Availability	88	%
3.7		Initial Energy	420	MeV
3.8		Peak RF Current	31.9	mA
3.9		Linac Species	H-	
3.10		Maximum Energy Deviation	+/-30	MeV
3.11		Maximum Time of Arrival Deviation	1	nsec
3.12		Final Energy	8	GeV
3.13		Transverse Emittance (95% normalized)	2.5	π-mm-mrad
3.14		Macro Bunch Duty Factor	67	%
3.15		Macro Bunch Frequency	53	MHz
3.16		Micro Pulse Length	10.4	microsec
3.17		Micro Pulse Period	11.1	microsec

4.0	**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	%
4.5		Momentum Aperture	+/- 0.75	%
4.6		Minimum Transverse Aperture	25	π-mm-mrad
4.7		Maximum Dipole Field	0.05	T
4.8		Transport Efficiency	99.99	%
4.9		Final Energy Variation	+/- 0.11	%
4.10		Energy	8	GeV
5.0	**Recycler**			
5.1		Energy	8	GeV
5.2		Storage Efficiency	99.5	%
5.3		Availability	95	%
5.4		Injection Rate	5	Hz
5.5		Maximum Space Charge Tune Shift	0.05	
5.6		95% normalized transverse emittance	25	π-mm-mrad
5.7		r.m.s. normalized transverse emittance	13	π-mm-mrad
5.8		Bunching factor	2	
5.9		Longitudinal emittance per Bunch	0.5	eV-Sec
5.10		Cycle Time	1.4	sec
5.11		RF Frequency	53	MHz
5.12		Abort Gap Length	700	nsec
5.13		Peak Recycler Beam Current	2.36	A
5.14		Fast Extraction Rate	15	Hz
5.15		Fast Extraction Pulse Length	1.6	microsec
6.0	**Main Injector**			
6.1		120 GeV cycle Time	1.4	sec
6.2		RF Frequency	53	MHz
6.3		Abort Gap Length	700	nsec
6.4		Acceleration Efficiency	99	%
6.5		Main Injector Beam Current	2.36	A
6.6		Final Energy	120	GeV
6.7		120 GeV Beam Power	2.1	MW
6.8		Availability	87	%
6.9		Injection Energy	8	GeV
6.10		Longitudinal emittance per Bunch	0.5	eV-Sec
6.11		Space Charge Tune Shift	0.05	
6.12		95% normalized transverse emittance	25	π-mm-mrad
6.13		r.m.s. normalized transverse emittance	13	π-mm-mrad
6.14		Bunching factor	2	

Facility Scope and Assumptions

Facility Scope

- An 8 GeV superconducting linac
  - 325 MHz section to 420 MeV
  - 1.3 GHz section to 8 GeV
- Beam line for transport to Recycler
- Modifications to Recycler for H^- injection and transfer to MI
- Modifications to Main Injector to support acceleration and extraction of high intensity beams
- Ends at extraction from Recycler or Main Injector

Assumptions

- Existing linac and booster no longer operational
- Existing Tevatron no longer operational (cryo systems available)
- Existing test beam facility in Meson continues at low duty factor
- Existing antiproton source reconfigured and operating in support of μ2e
- Existing neutrino beamline and target for DUSEL

Linac Layout

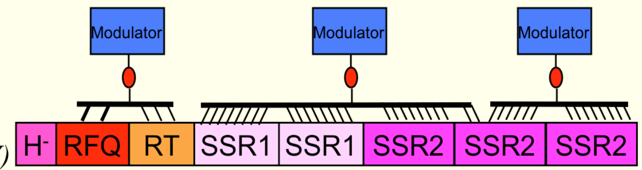
Project X
1000 kW 8GeV Linac

31 Klystrons (2 types)
453 SC Cavities
57 Cryomodules

Front End Linac

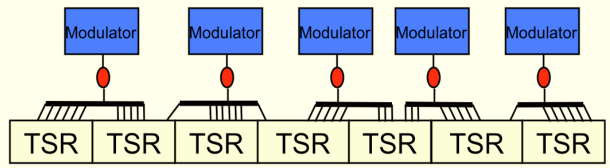
325 MHz 0-10 MeV
1 Klystron (JPARC 2.5 MW)
RFQ + 18 RT Cavities

325 MHz 10-120 MeV
2 Klystrons (JPARC 2.5 MW)
51 Single Spoke Resonators
5 Cryomodules



11 Cavites / Cryomodule

325 MHz 0.12-0.42 GeV
5 Klystrons (JPARC 2.5 MW)
42 Triple Spoke Resonators
7 Cryomodules



6 Cavites-6 quads / Cryomodule

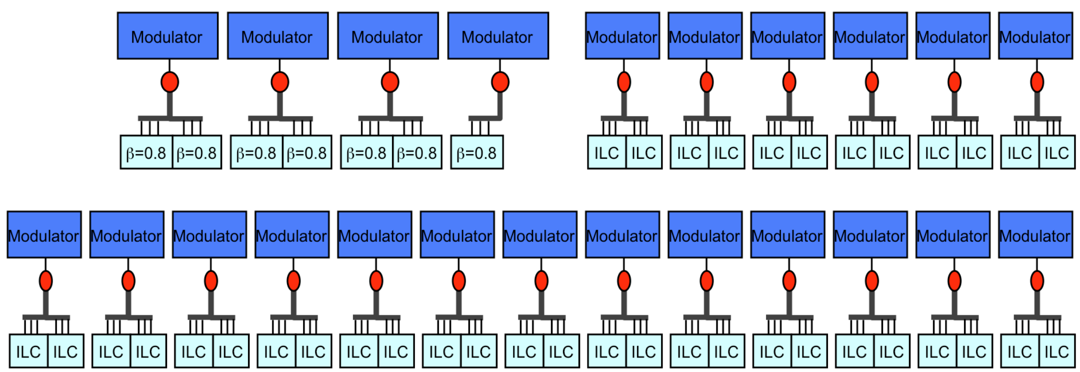
2.5 MW JPARC Klystron

Multi-Cavity Fanout
Phase and Amplitude Control

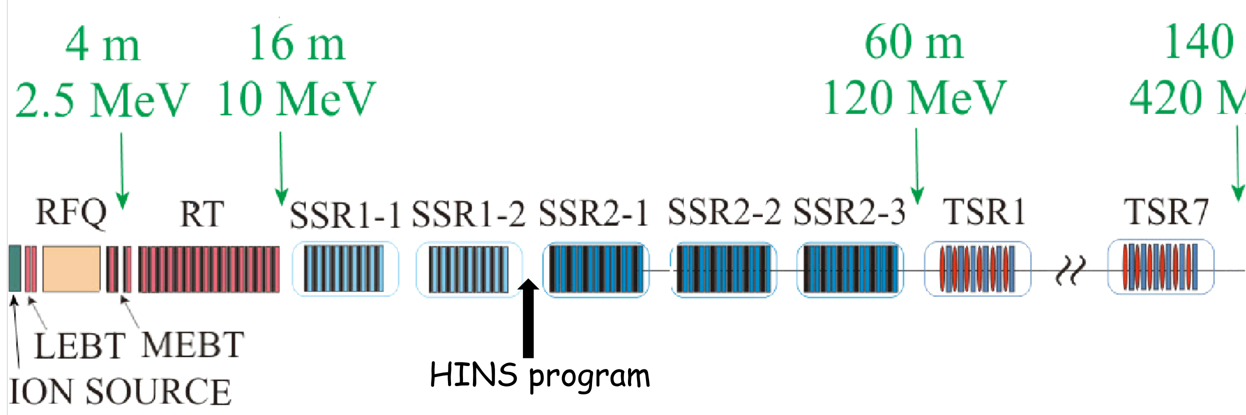
1300 MHz LINAC

1300 MHz 0.42-1.3 GeV
4 Klystrons (ILC 10 MW MBK)
56 Squeezed Cavities (β=0.81)
7 Cryomodules

1300 MHz 1.3-8.0 GeV
19 Klystrons (ILC 10 MW MBK)
304 ILC-identical Cavities
38 ILC-like Cryomodules



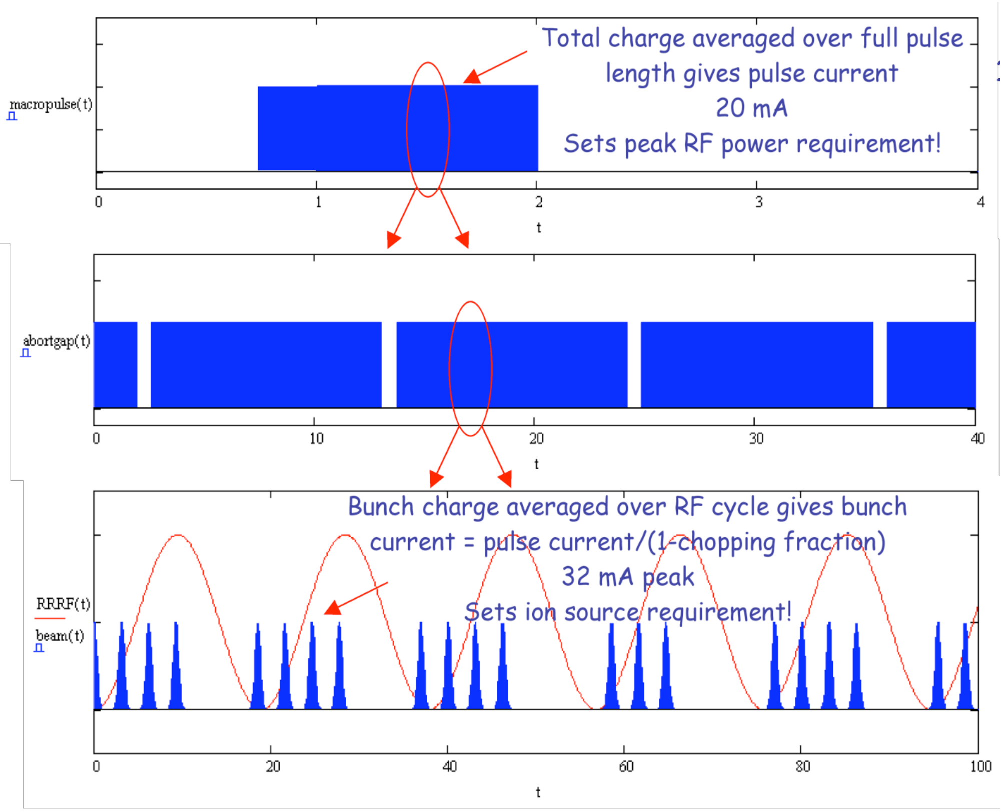
325 MHz Linac



- 50 keV H^- ion source
- 2.5 MeV RFQ
- Medium Energy Beam Transport
  - 2 rebuncher RF cavities
  - 3 solenoids
  - Beam chopper
- Room temperature cavities interspersed with SC solenoids to 10 MeV
- β = 0.22 single-spoke resonator SC cavities to 30 MeV
- β = 0.4 single-spoke resonator SC cavities to 120 MeV
- β = 0.6 triple-spoke resonator SC cavities to 420 MeV
- Vector Modulators throughout -- multiple cavities per klystron

Linac beam structure

- Beam structure:
  - 53 MHz structure for Recycler/Main Injector
  - 700 nsec gap every 11.1 μsec for the Recycler/Main Injector kickers
  - 75 nsec gap every 1.6 μsec for the μ2e pulses (fast kickers)



1.25 msec linac beam pulse
4 msec full scale

Linac beam chopped for
700 nsec abort gap
40 μsec full scale

Linac 325 MHz beam
chopped for RR RF
Multiple linac bunches per
53 MHz RR RF cycle
100 nsec full scale

1300 MHz Linac

- 0.42-1.3 GeV β=0.81 Section:
  - S-ILC: same frequency, shorter cavity
  - Needs to be developed!
- ILC Type 4 Cryomodules β=1 Section
  - 8 cavities, 1 quad
  - 25 MV/m
  - 2 CM/klystron
- Linac Parameters:
  - 25 MV/m, 1.5 msec pulse, 5 Hz
  - 20 mA, 1.25 msec flattop

- 10 MW multi beam klystron
  - Developed for ILC
- Coupler power 550 kW max
  - Average power < 5 kW
- Handle voltage transients
  - 53 MHz spacing
  - Kicker gaps every 11 μsec

Cavity and Klystron Counts

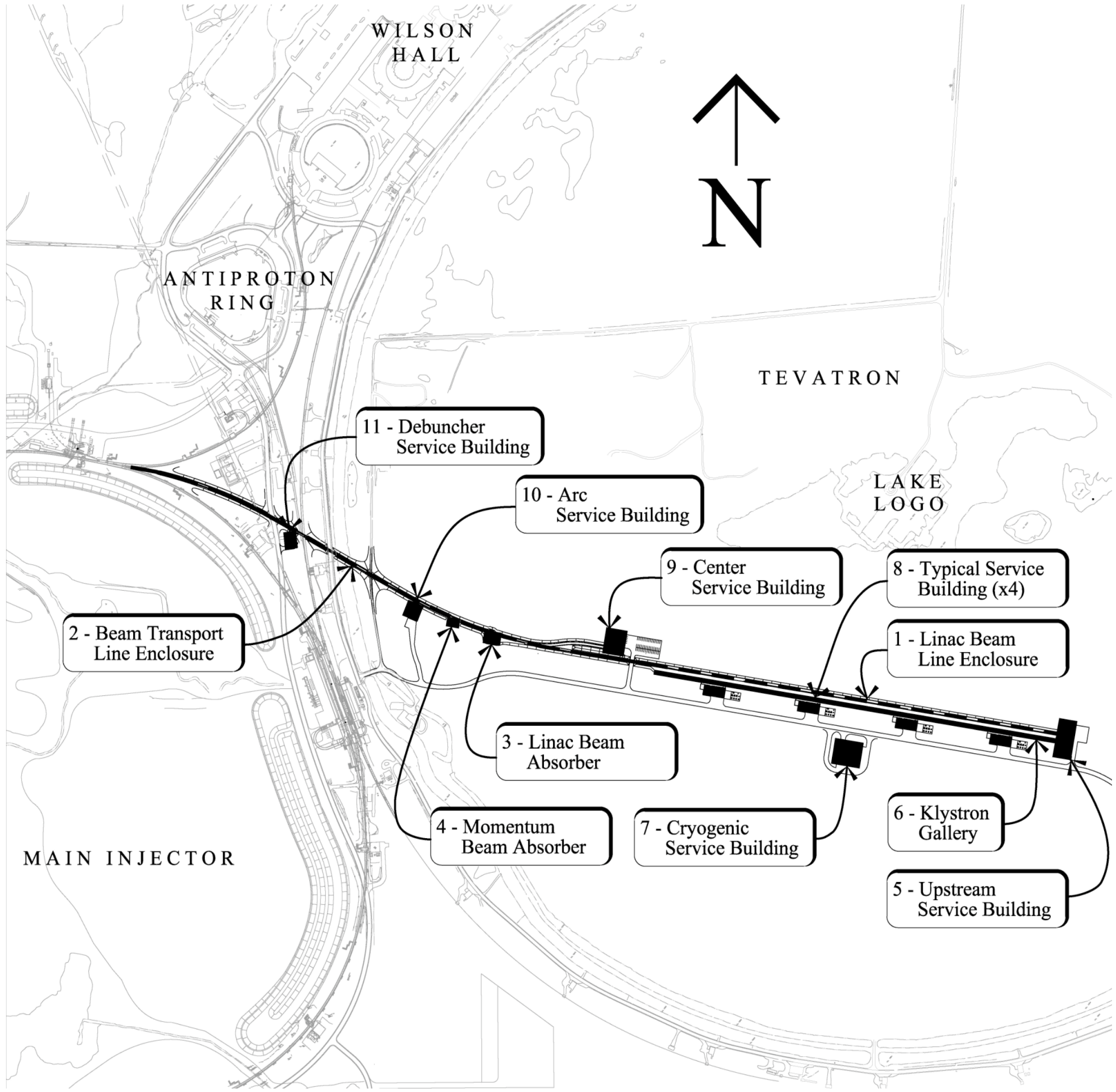
	Cavities	Cryomodules	Klystrons
SSR (2 types)	51	5	2 2.5 MW
TSR	42	7	5 2.5 MW
S-ILC	56	7	4 10 MW MultiBeam
ILC	304	38	19 10 MW MultiBeam
Total	453	57	30 (+1 for warm section)

Transfer Line

- Linac output to MI Tunnel
  - ~1 km
  - Cryo shield -- mitigate blackbody stripping
  - <500 G fields -- mitigate magnetic stripping
- Collimation
  - Transverse: large amplitude
  - Momentum: off momentum
- Losses < 1W/m => >99.9% transmission efficiency

- Multi-turn injection system
  - 1.25 msec = 110 turns in Recycler
  - Thin foil stripping
- Transverse & Longitudinal Painting
  - Minimize space charge tune shift in Recycler and Main Injector (< 0.05)
- Elevation matched to MI elevation
  - Shielding
  - Interferences with existing enclosures
  - Line longer -- Vertical bend to reach Recycler

Site Layout



WILSON HALL
ANTIPROTON RING
TEVATRON
LAKE LOGO
MAIN INJECTOR
N
11 - Debuncher Service Building
10 - Arc Service Building
9 - Center Service Building
8 - Typical Service Building (x4)
1 - Linac Beam Line Enclosure
2 - Beam Transport Line Enclosure
3 - Linac Beam Absorber
4 - Momentum Beam Absorber
7 - Cryogenic Service Building
6 - Klystron Gallery
5 - Upstream Service Building

Rings

Recycler

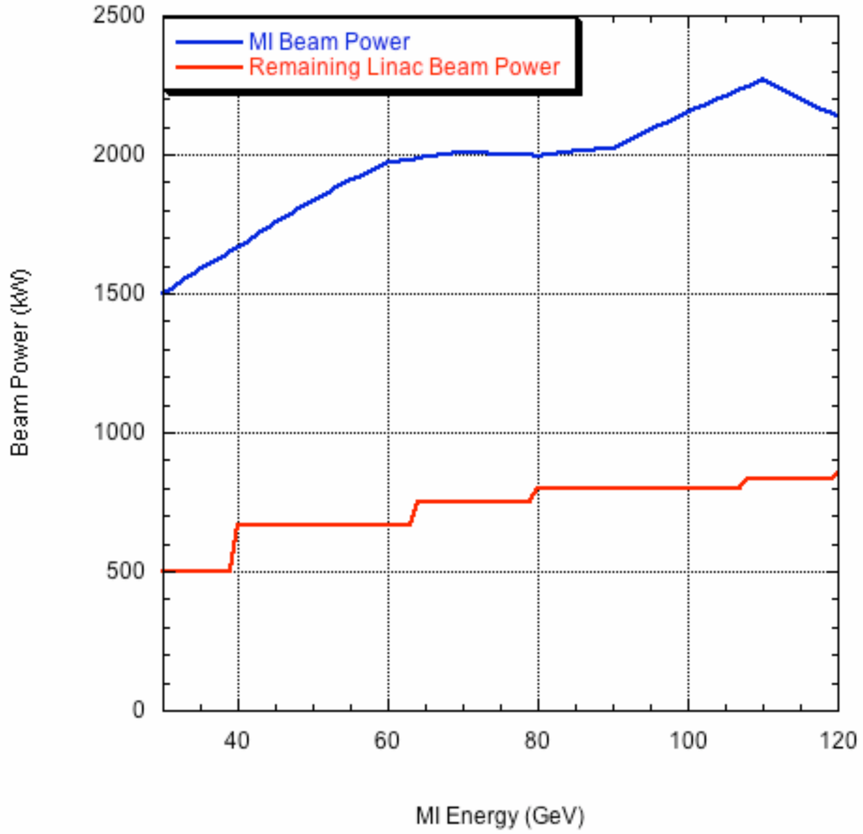
- Proton ring with single turn transfer to MI : already done for Nova
- Lattice Modifications for injection
- 53 MHz and 106 MHz RF for capture
- Fast extraction for μ2e
  – Move Nova injection kicker
- Electron cloud mitigation
  – Coat beam pipe?

Main Injector

- Single turn injection from Recycler
- ~3x Intensity of Nova era
- 53 MHz and 106 MHz RF
  – Increase bucket area for acceleration
  – 53 MHz design exists, 106 MHz does not
- Electron cloud mitigation
  – Coat beam pipe?
- Matched γ_t jump (W. Chou et al., PAC 1997)
  – 8 pulsed quad triplets
  – 2 units in 0.5 msec (16x faster)

Main Injector Beam Power

- Optimum energy for long baseline neutrino program?
  - Deliver > 2 MW for extracted beam energies > 60 GeV (1.8 MW at 50 GeV)
    - ➢ Varying the MI cycle time
    - ➢ Holding beam in the Recycler to match 5 Hz from linac
  - Deliver > 500 kW for 8 GeV beam

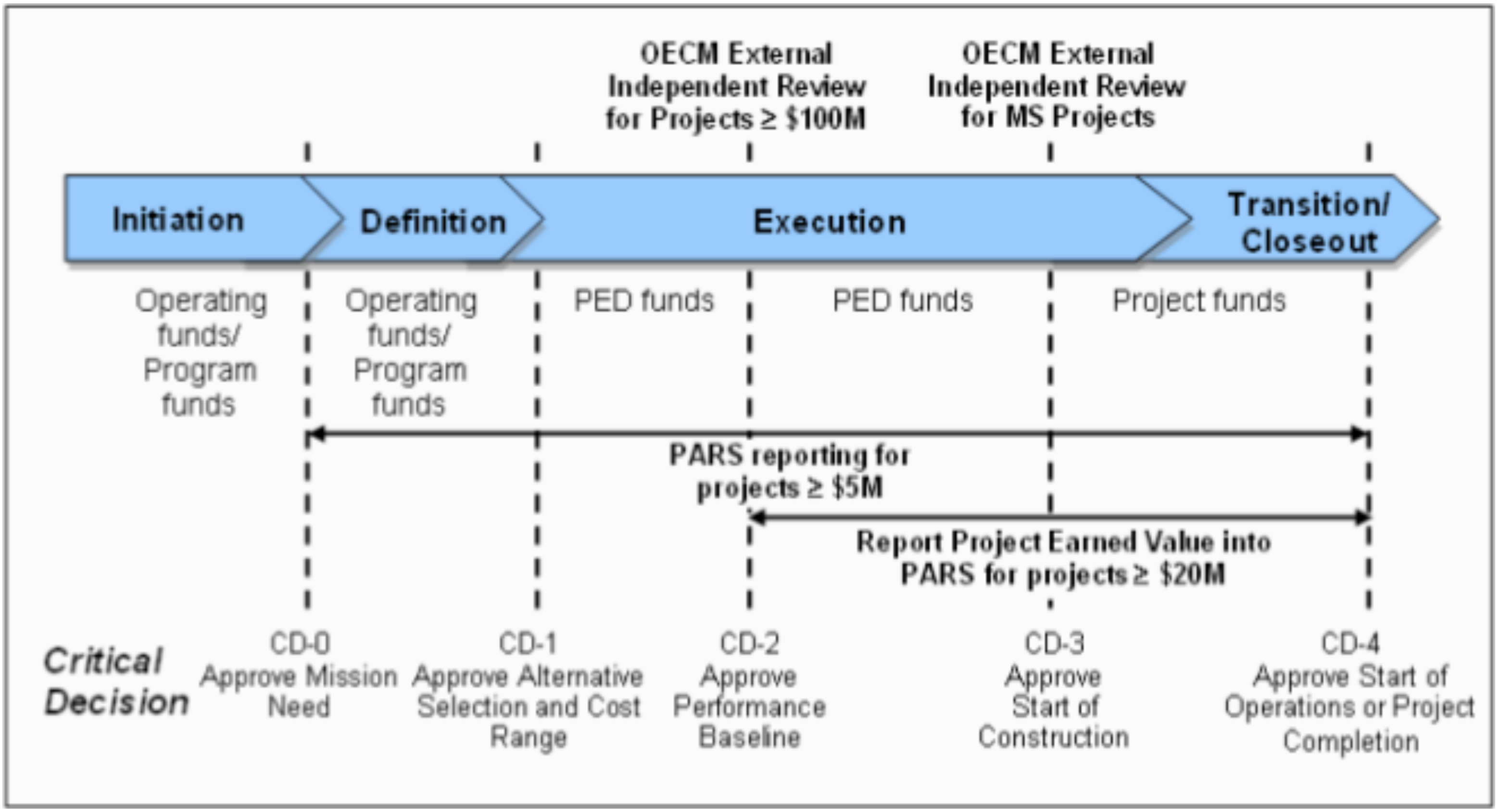


Additional Pieces

- Conventional Facilities
  - Tunnels
  - Service buildings
  - Site prep
  - Utilities
- Cryogenic Plant
  - 325 MHz: two phase liquid helium at 4.5 K
  - 1.3 GHz: saturated He II at 2 K
  - Segmentation and Distribution
- Controls
  - Time Stamping
  - Machine Protection
  - ~1 M devices and properties
  - Evolving system
    - ➢ Support existing complex
- Instrumentation
  - Beam loss monitoring
  - Beam position monitoring
  - Machine protection
  - Development of new instruments
    - ➢ In SRF section

Where are we?

- Initiation Phase of project
- Director's Review March 2009
  - Expect "Detailed estimate that represents the upper range of cost"
  - Input to CD-0



Where are we going?

- CD-0: July 2009
  - DoE writes the Mission Need Justification document, based on
    - P5 Report
    - Cost Range exercise (from ICD)
  - not a technology choice or a baseline
    - " The mission need is independent of a particular solution, and should not be defined by equipment, facility, technological solution, or physical end-item"
  - a "Major System Project" >750 M$
    - changes review process and who has critical decision authority (e.g., the Secretarial Acquisition Executive or the Under Secretary of Science)

- With CD-0, enter Definition Phase
  - Alternative Concepts considered to arrive at a recommended alternative
    - To establish the optimal configuration for baseline
  - Applications of Value Management & Engineering
    - Performance, scope, schedule, cost, security, ES&H
  - Provide Details necessary to develop a range of estimates for the project cost and schedule
  - Request for Project Engineering Design Funds, which fund the project from CD-1 to CD-3

Where are we going?

- CD-1 ("Approve Alternative Selection and Cost Range")
  - "CD-1 approval marks the completion of the project Definition Phase, during which time the conceptual design is developed. This is an iterative process to define, analyze, and refine project concepts and alternatives. This process uses a systems methodology that integrates requirements analysis, risk identification and analysis, acquisition strategies, and concept exploration to evolve a cost-effective, preferred solution to meet a mission need."
  - Conceptual Design Report
  - Design Review of the Conceptual Design
  - Additional documents for Project (16 separate documents and plans)
- CD-2 ("Approve Performance Baseline")
- CD-3 ("Approve Start of Construction")

Project X

Summary

- Developed an Initial Configuration that meets the Mission Need
  - > 2 MW at 60-120 GeV from MI
  - Additional 8 GeV beam for other experiments (mu2e)
  - Upgrade path to higher beam power at 8 GeV
    - Double the repetition rate (5 Hz => 10 Hz)
    - Double the pulse length (1.25 msec => 2.5 msec)
    - Conventional facilities, cryo plant, utilities designed with upgrades in mind
  - 325 MHz and 1.3 GHz superconducting RF linac
  - Multi-turn injection to Recycler
  - Single turn transfer to Main Injector
- Developed an RD&D plan:
  - Plan to go from initial configuration to baseline configuration
  - Input to the total cost
  - Basis for PED fund request
- Developed a cost range based on this configuration
  - Cost through hardware commissioning (CD-4)