Concept and R&D Plans for Project X

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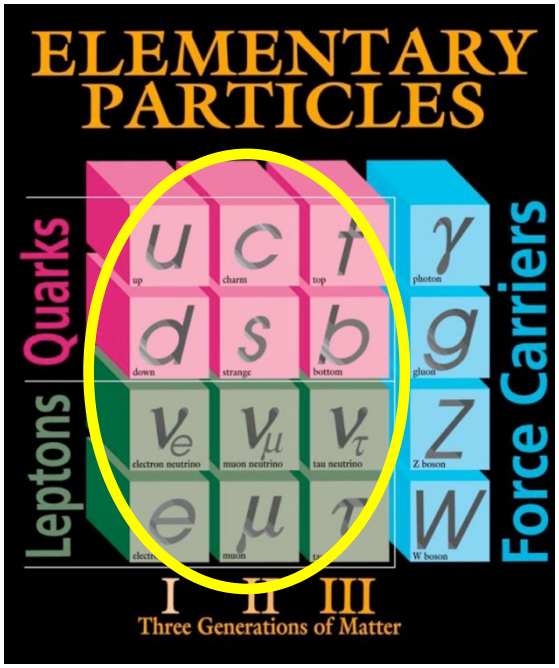
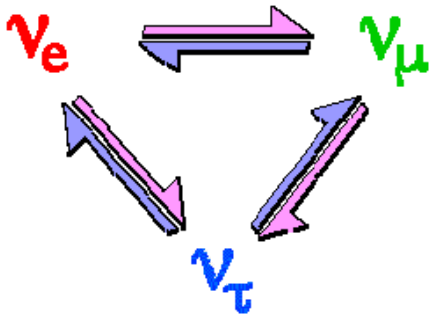
Introduction

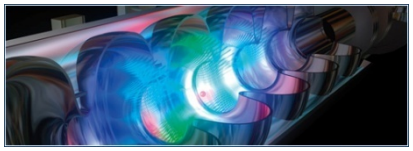
- Intensity Frontier: Needs and Physics Justification
- Project X
  - Description
  - Technical Concepts
  - Timescale
- R&D Plans and Contributing Programs
  - HINS
  - ILC/SRF
- Collaboration Plans
- Conclusions

Physics of Flavor

- Flavor phenomena are essential to understanding physics within and beyond the SM
- SM is incomplete:
  - Neutrino masses (flavor)
    - Only experimental hint of BSM physics.
    - via See-Saw mechanism, point to new physics at a very high mass scale (unification scale). $m_\nu M = (m_{quark})^2$
  - Baryon Asymmetry of the Universe (flavor)
    - Electroweak baryogenesis – LHC and ILC.
    - Leptogenesis - Neutrino CP violation would support it.
  - Dark Matter
  - Dark Energy



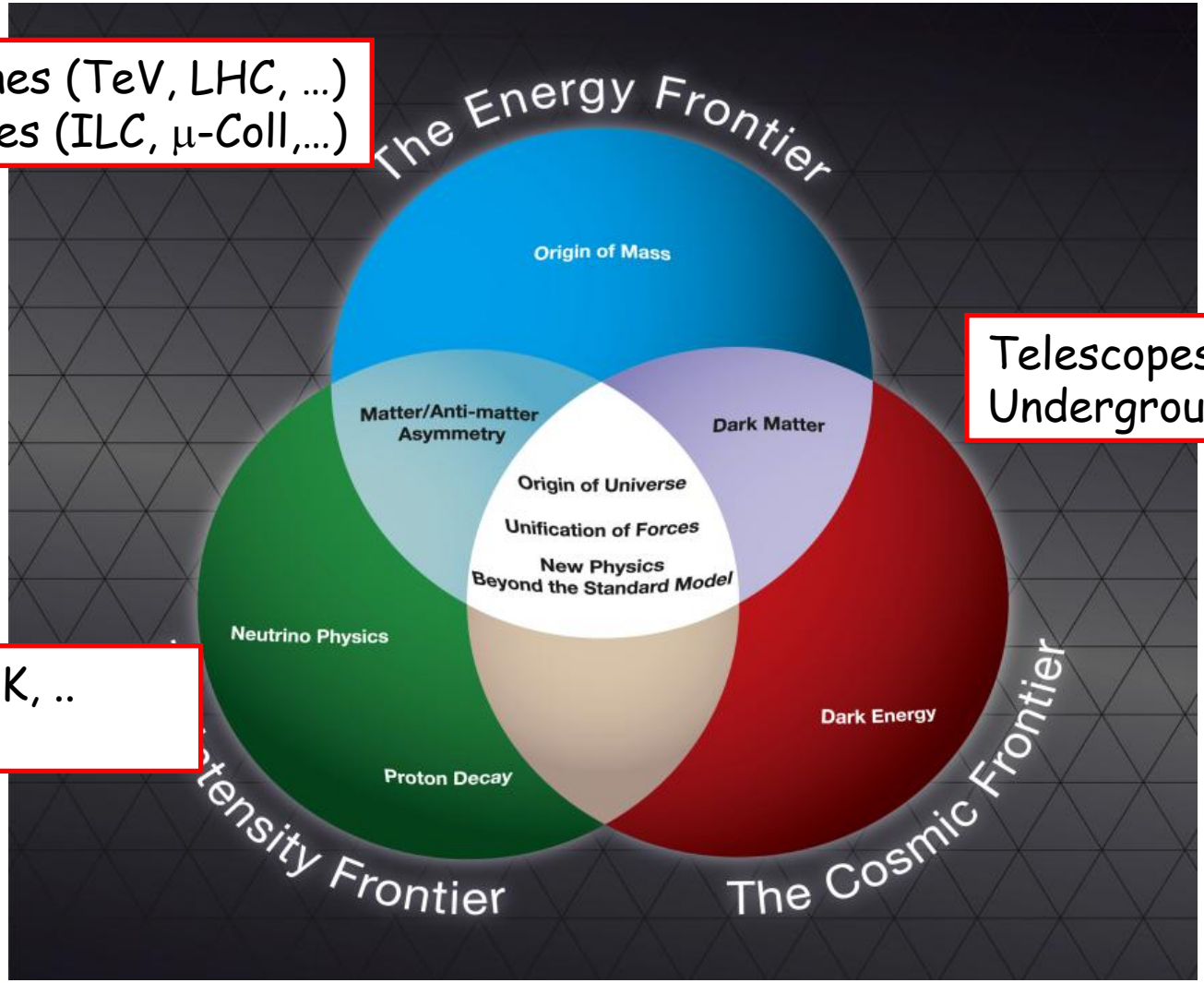




Strategic Context for Long Range Plan

The Fermilab long-term plan incorporates three strategic directions:

Hadron Machines (TeV, LHC, …)
Lepton Machines (ILC, μ-Coll,…)



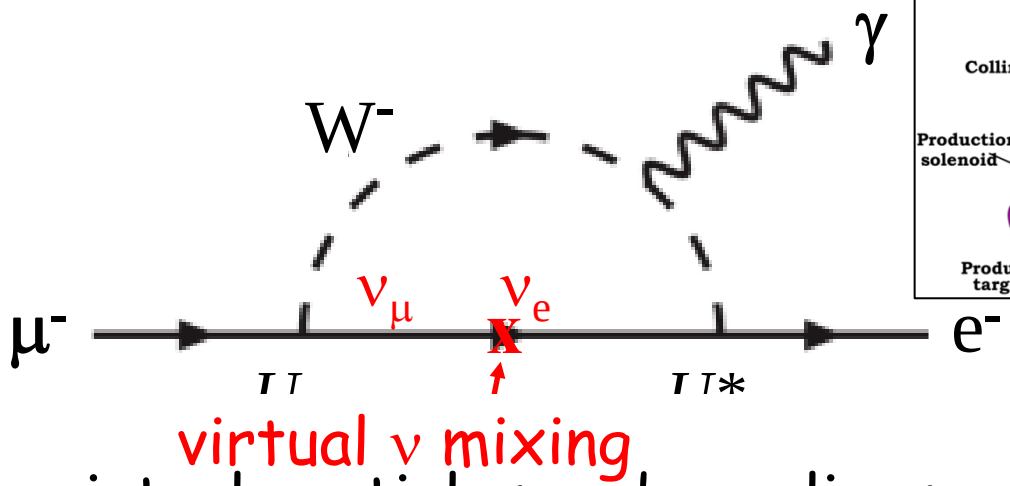
Telescopes and Underground Exp.

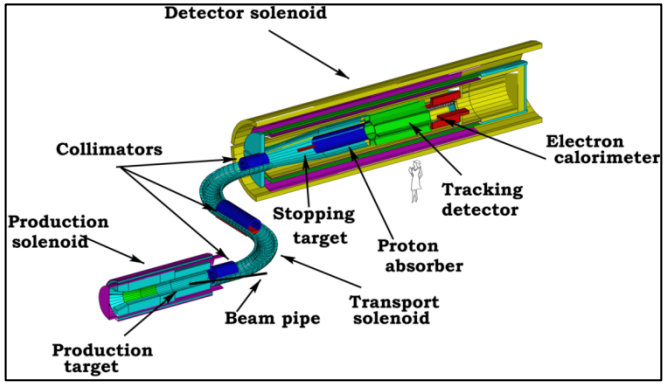
Intense ν, μ, K, .. beams

Rare Decays – Muon and K Physics

- ν change from one kind to another. Do charged leptons do the same ?

In SM



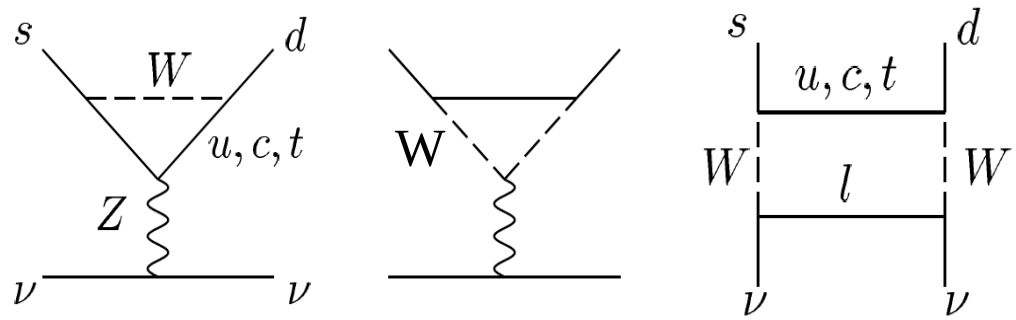


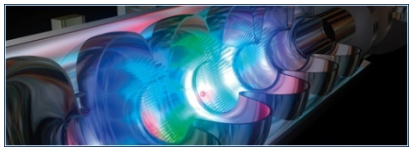
- Explore virtual particles and couplings (μ2e sensitivity: Br ~ 10^{-17})
- K Rare Decays:

  Standard Model

  $Br(K^+ \rightarrow \pi^+\nu\nu) = 8 \times 10^{-11}$

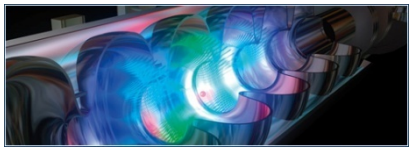
  $Br(K_L \rightarrow \pi^0\nu\nu) = 3 \times 10^{-11}$





Intensity Frontier Vision (P5)

- Intensity Frontier
  - Observe new physics as **VIRTUAL PARTICLES** contributing to RARE PROCESSES and causing departures from the Standard Model expectations in some related physical observables (BRs, CP asymmetries, FB asymmetries, etc.)
- Future (P5) Vision
  - (P5) recommends an R&D program in the immediate future to design a multi-megawatt proton source at Fermilab and a neutrino beamline to DUSEL … R&D on the technologies for a large multi-purpose neutrino and proton decay detector.
  - A neutrino program with a multi-megawatt proton source would be a stepping stone toward a future neutrino source, such as a neutrino factory based on a muon storage ring …to develop a muon collider as a long-term … return to the energy frontier.
    - Ex: $\sin^2 2\theta_{13}$ discovery potential from ~10^{-2} to ~5×10^{-4} with 2 MW source



Fermilab approach to the Intensity Frontier

- Developed a program based on a <u>new injector</u> for the FNAL complex:
  - Can exploit the large infrastructure of accelerators: Main Injector (120 GeV), Recycler (8GeV), Debuncher (8 GeV), Accumulator (8 GeV) – would be very expensive to reproduce.
  - New source uses TESLA/ILC technology and helps development in the US
  - Provides the best program in ν and rare decays in the world
  - Positions the US program for an evolutionary path leading to a neutrino factory and muon collider
- Scope of new injector is based on:
  - 2 MW at 120 GeV
  - Affordable
  - Flexible beam delivery at low energy (8 GeV)
  - Upgradable to multi-MW (~4 MW) at 8 GeV

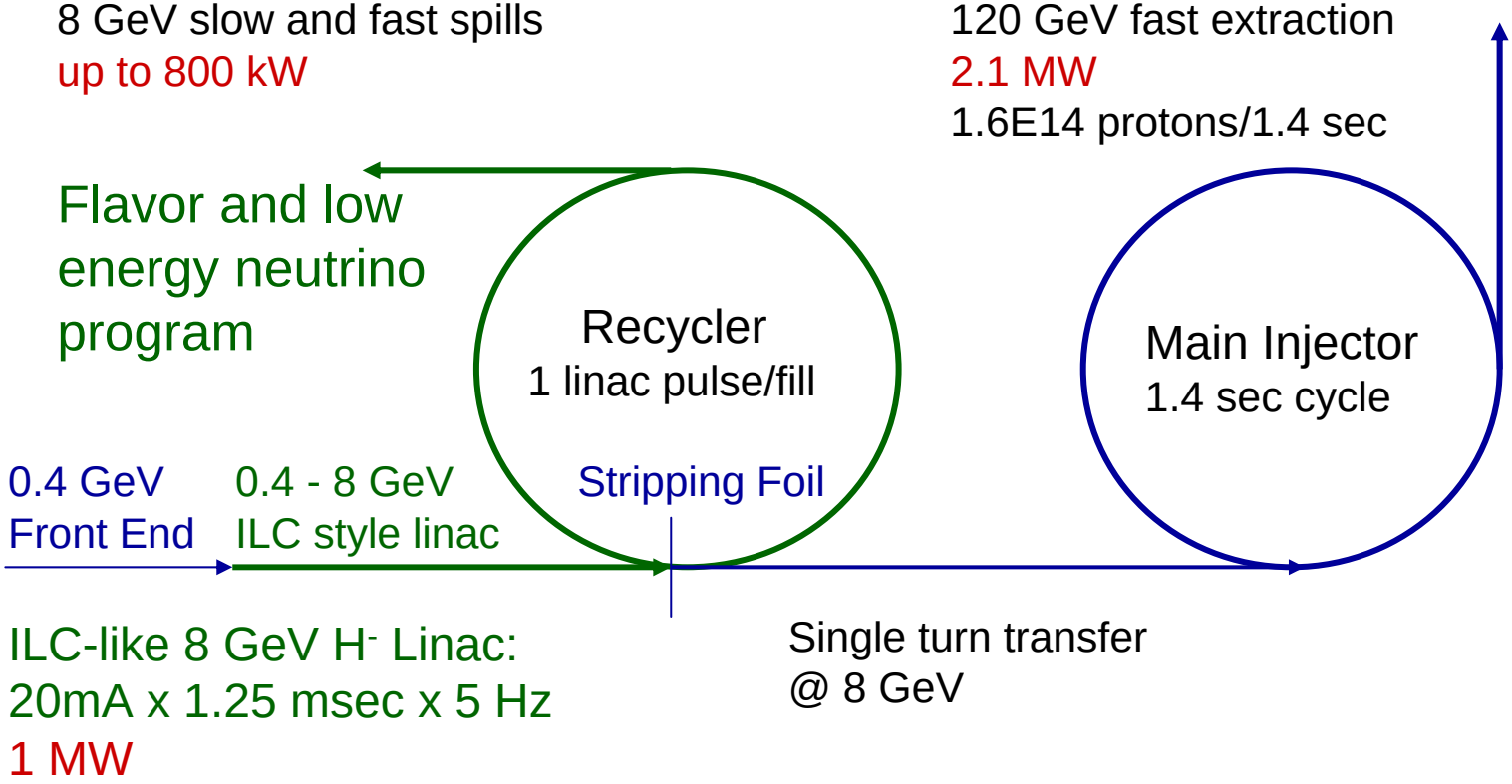
Project X Timescale

- Working backwards:
  - 2013: CD-3 – Start Construction
  - 2012: CD-2 – Establish Baseline*
  - 2011: CD-1 – Establish Baseline Range
    - Requires a complete Conceptual Design Report
  - 2009: CD-0 – Approve mission need
    - Requires new cost (range) estimate which will be reviewed by DOE . Based on Initial Configuration Document* (nearing completion – to be published on Nov 1st, 2008).

(CD = Critical Decision)

*It is anticipated that the final configuration and operating parameters of the linac will be refined through the R&D program in advance of CD-2. The ICD document is to provide a basis for a cost estimate necessary for a CD-0 in 2009.

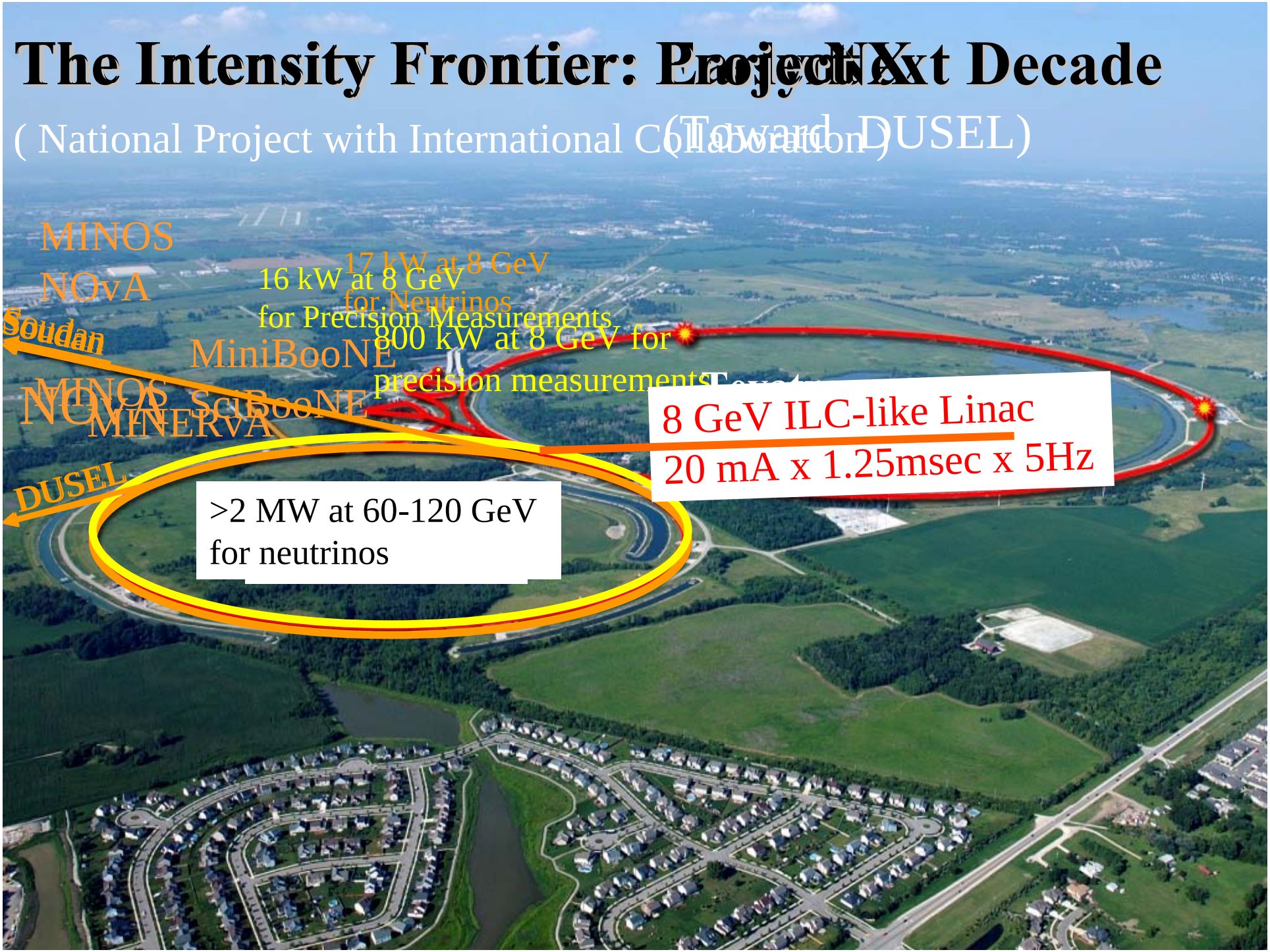
Project X: present concept (Sep 08)



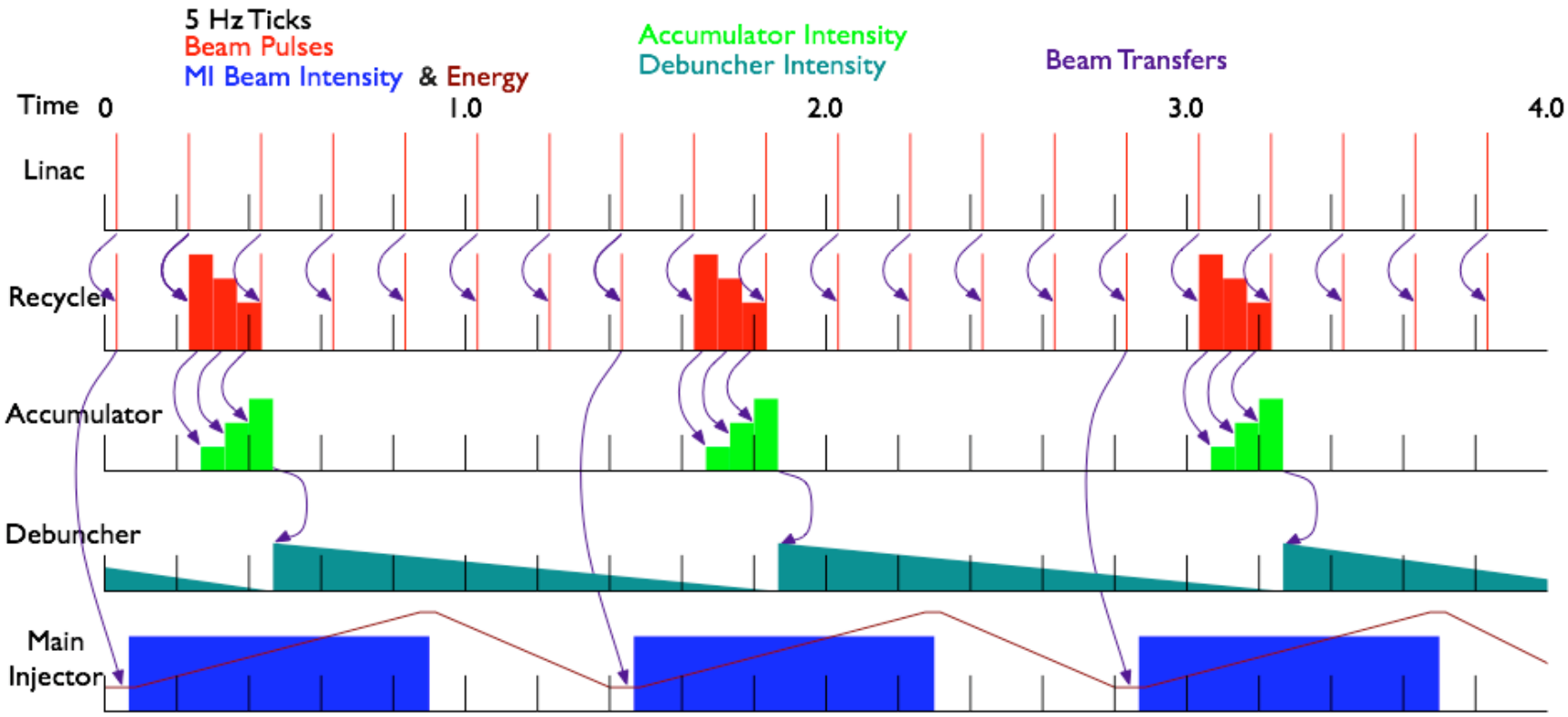
- Initial operational scenario for two users:
  - long baseline neutrino oscillation experiment (DUSEL)
  - muon-to-electron conversion experiment

The Intensity Frontier: Project X Next Decade

(National Project with International Collaboration) (Toward DUSEL)



Project X Initial Operation 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

Project X
1000 kW 8GeV Linac

28 Klystrons (2 types)
461 SC Cavities
58 Cryomodules

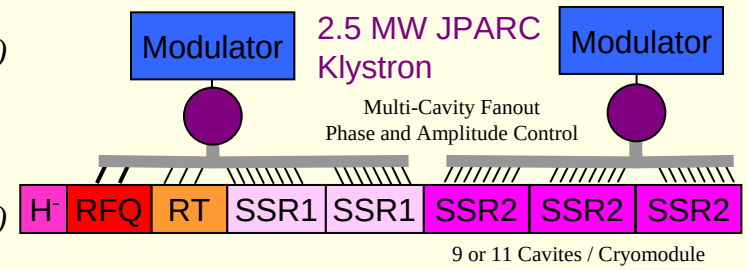
Front End Linac

325 MHz 0-10 MeV

1 Klystron (JPARC 2.5 MW)
16 RT Cavities

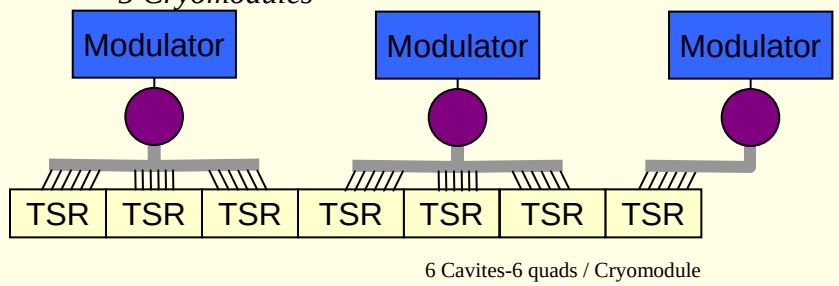
325 MHz 10-120 MeV

1 Klystron (JPARC 2.5 MW)
51 Single Spoke Resonators
5 Cryomodules



325 MHz 0.12-0.42 GeV

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



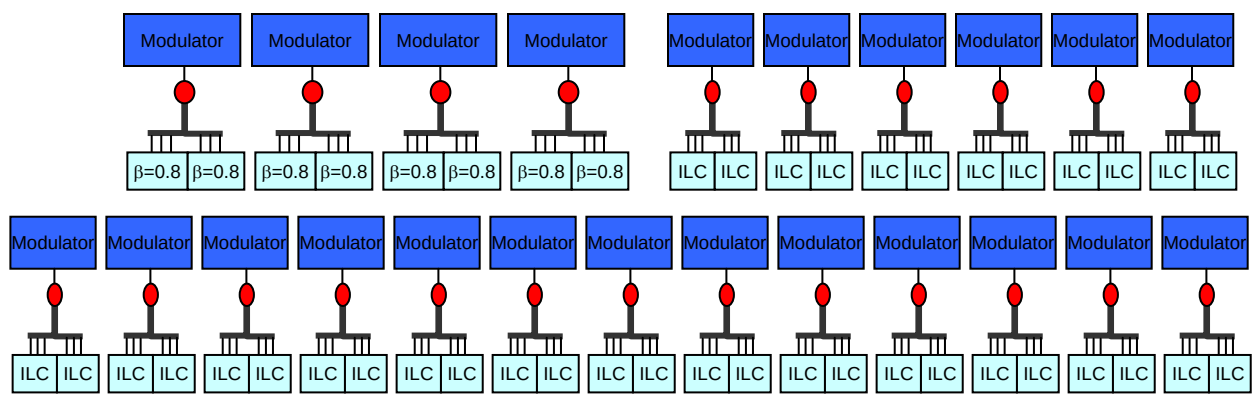
1300 MHz LINAC

1300 MHz 0.42-1.3 GeV

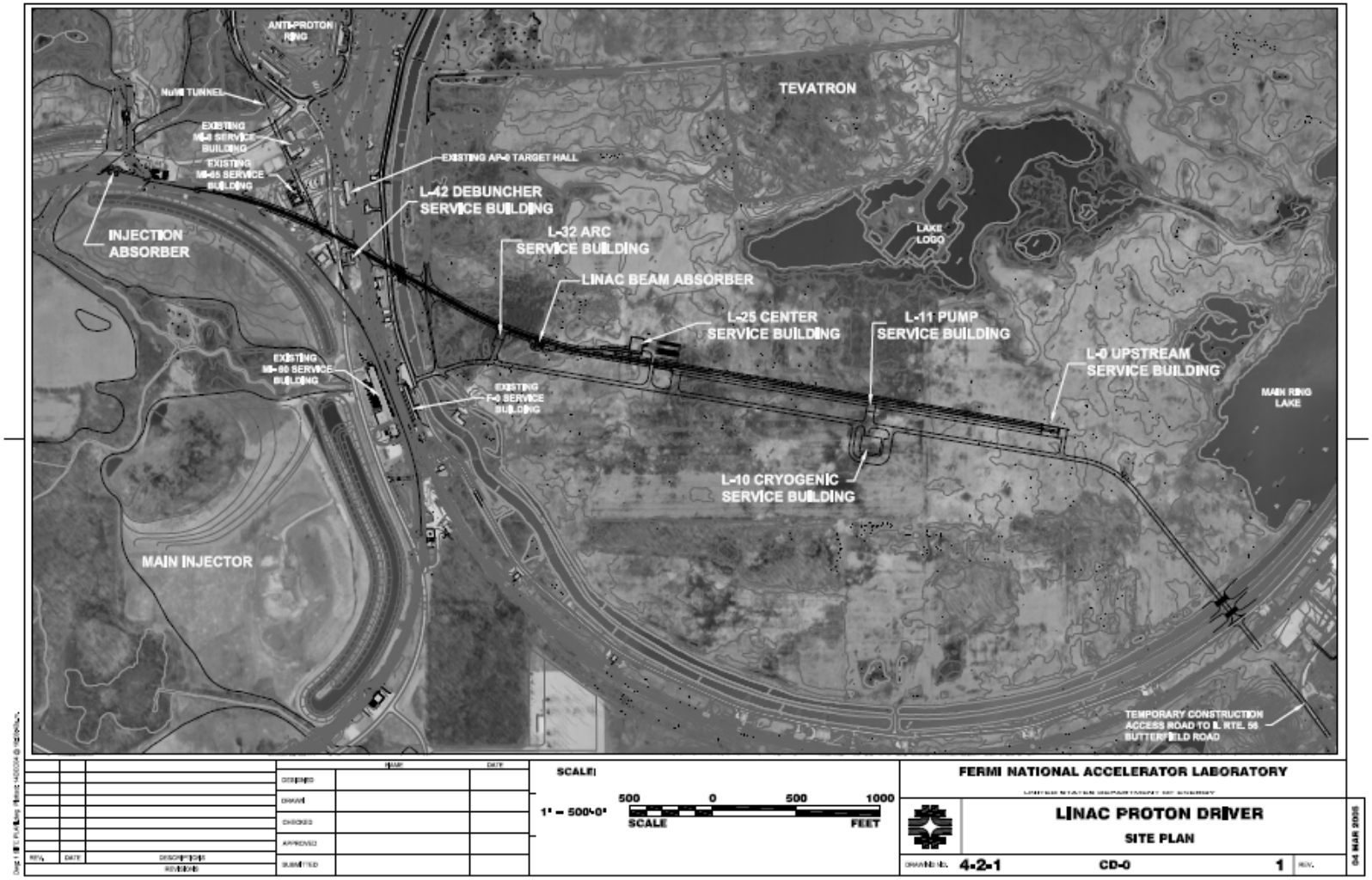
4 Klystrons (ILC 10 MW MBK)
64 Squeezed Cavities (β=0.81)
8 Cryomodules

1300 MHz 1.3-8.0 GeV

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



Project X Provisional Siting



Project X Linac Alignments

- ILC-like technology parameters bas
  - 1.3 GHz, pulsed beam at 20 mA x 1.25 msec x 5 Hz rate (1.5×10^{14})

HINS program

- 325 MHz RFQ to 2.5 MeV
- 325 MHz RT accelerating structures to 10 MeV
- 325 MHz SC spoke-type structures to 0.4 GeV
- SC solenoid focusing in 2.5-120 MeV range

ILC/SRF

- ILC squeezed structures to 1.2 GeV
- Standard ILC structures to 8 GeV
- SC focusing quadrupole magnets for tansverse focusing from 120 MeV to 8 GeV
  - Standard ILC focusing lattice in final four RF units
- Development of High Intensity Proton source supporting a ν-factory and μ-collider:
  - Typically requires 2-4 MW @ 10$\pm$ 5 GeV proton energy, 50 Hz rep.
  - Natural Evolution: Project X $\rightarrow$ Neutrino Factory $\rightarrow$ Muon Collider

R&D Plan: Major Technical Issues

- 325 MHz Linac (0-420 MeV)
  - No special accelerator issues are posed by a 420 MeV Linac with initial PrX intensity
  - Technology Choice
    - Room Temperature vs. Superconducting (HINS), upgrade Path
  - Present PrX requirements pushing envelope of existing H- sources
- 1300 MHz Linac (0.42 – 8 GeV)
  - PrX gradient less stringent than for ILC (25 vs. 31.5 MeV/m)
  - 20 mA x 1.25 msec x 5 Hz (1 MW @ 8 GeV) vs. ILC 9 mAx1 msec x 5 Hz
  - Higher power to individual cavities (500 kW over 300 kW).
    - Power Coupler Development and HOM
  - Production rate of cryomodules (needed 1 cryo/month)
  - Use of IQM vs Vector Sum.
  - Loss cavity/cryomodule during operation

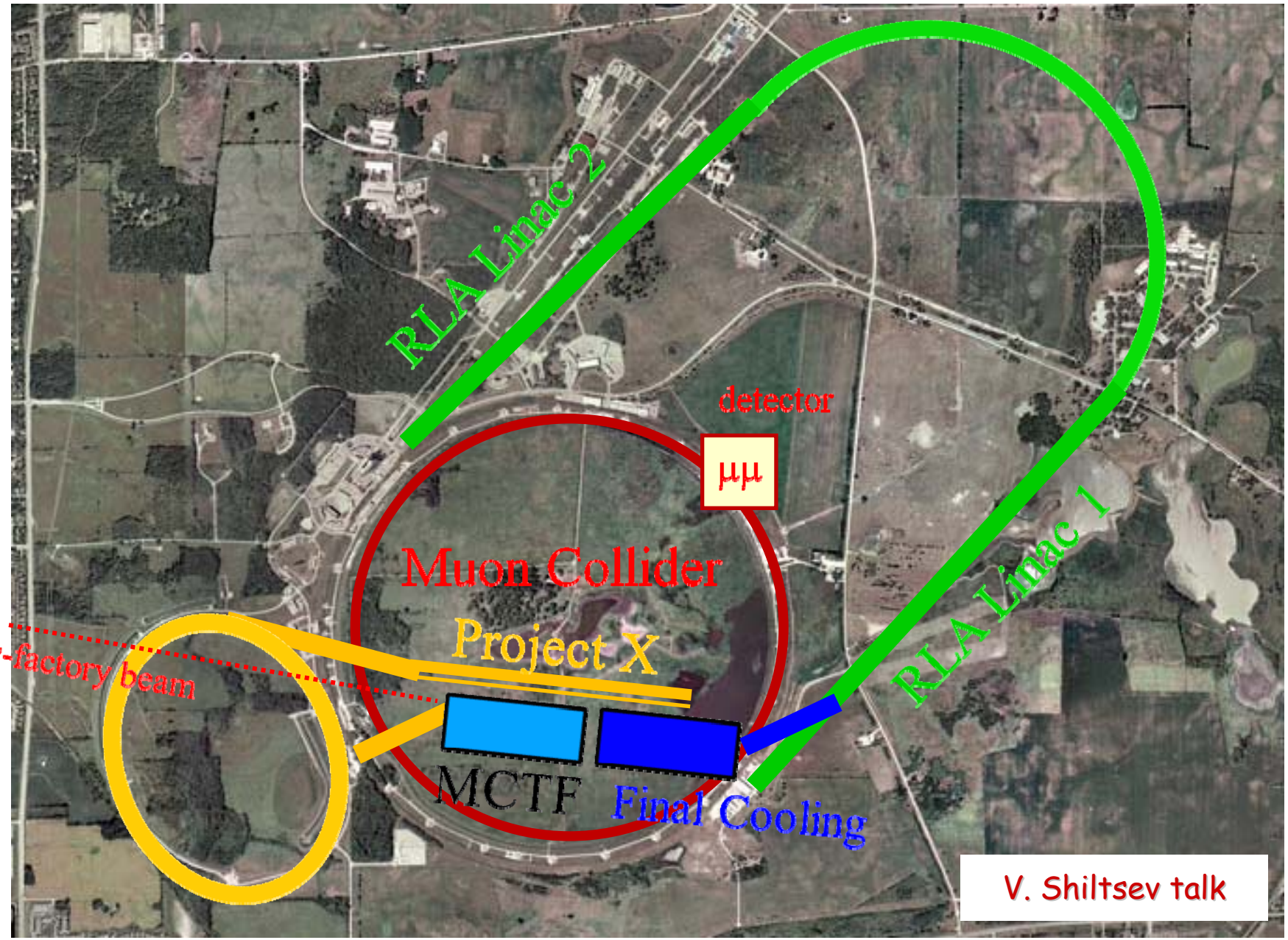
R&D Plan: Major Technical Issues

- 8 GeV Transfer Line
  - Control and mitigation of losses
  - Stripping Efficiency and lifetime
- Main Injector (and Recycler)
  - Electron Cloud Instabilities (x3 more proton/bunch than current operations)
    - Simulations, Beam pipe coating
  - Transition Crossing in the Main Injector
  - Second Harmonic RF system

Project X Upgradability

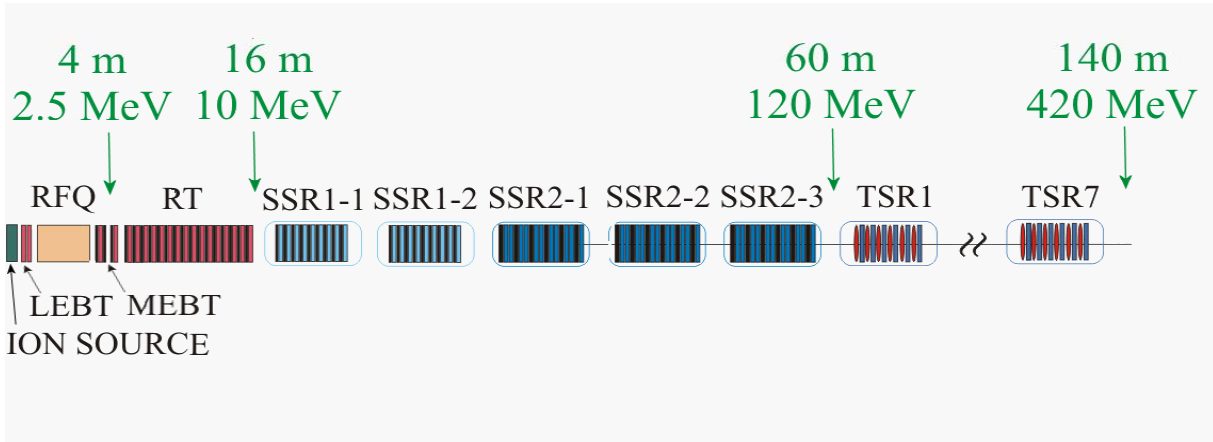
- Initial configuration exploits alignment with ILC
- But it is expandable:
  - increase the rep rate
  - increase the pulse length
- We are studying the possibility to develop existing 8 GeV rings (Recycler, Debuncher, Accumulator) to deliver and tailor beams, allowing full duty cycle for experiments with the correct time structure: *K* decays, $\mu \rightarrow e$ conversion, *g-2.*
- Would position the program for a multi-megawatt (2-4 MW) source for intense muon beams at low <8 GeV energies – very difficult with a synchrotron.

1.5-4 TeV Muon Collider at Fermilab



V. Shiltsev talk

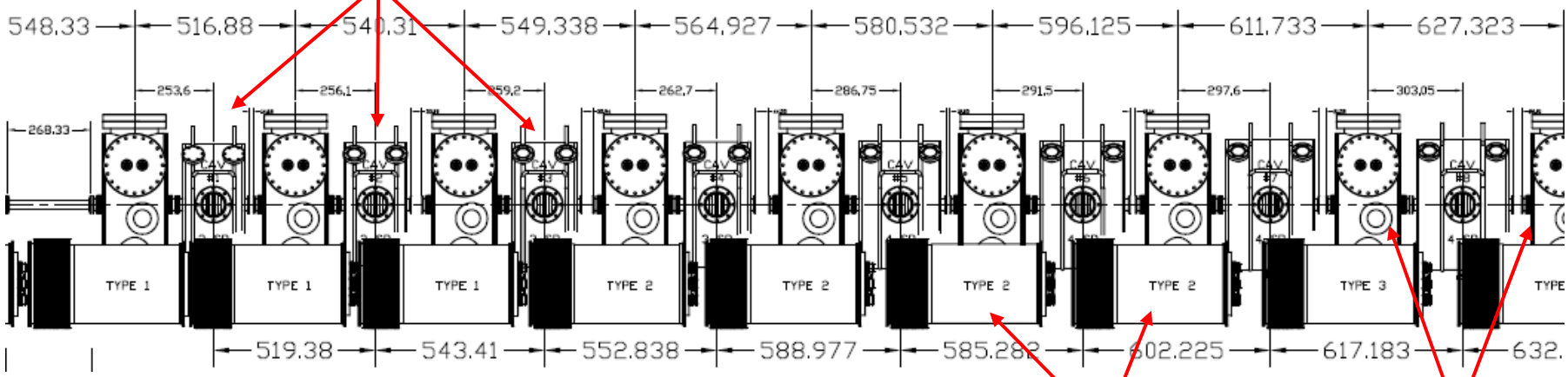
PrX R&D Plan and HINS Program



	Ion Source	RFQ	MEBT	Room Temp	SSR1	SSR2	TSR
Eout	50 keV	2.5 MeV	2.5 MeV	10 MeV	30 MeV	120 MeV	~600 MeV
Zout	0.7 m	3.7 m	5.7 m	15.8 m	31 m	61 m	188m
Cavities			2 buncher cavities and fast beam chopper	16 copper CH-spoke cavities	18 single-spoke SC β=0.2 cavities	33 single-spoke SC β=0.4 cavities	66 triple-spoke SC β=0.6 cavities
Gradient					10 MV/m	10 MV/m	10 MV/m
Focusing			3 SC solenoids	16 SC solenoids	18 SC solenoids	18 SC solenoids	66 SC quads
Cryomodules					2	3	11

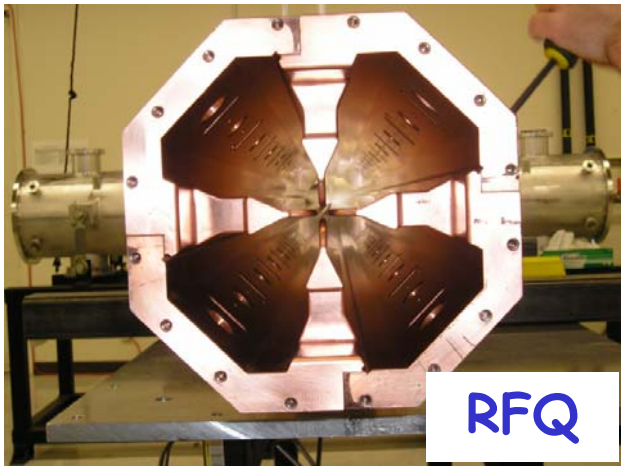
HINS - RT (10 MeV) Section

copper cavities

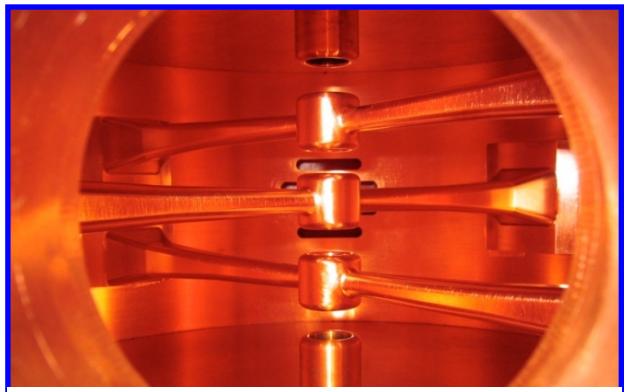


helium transfer line

solenoids

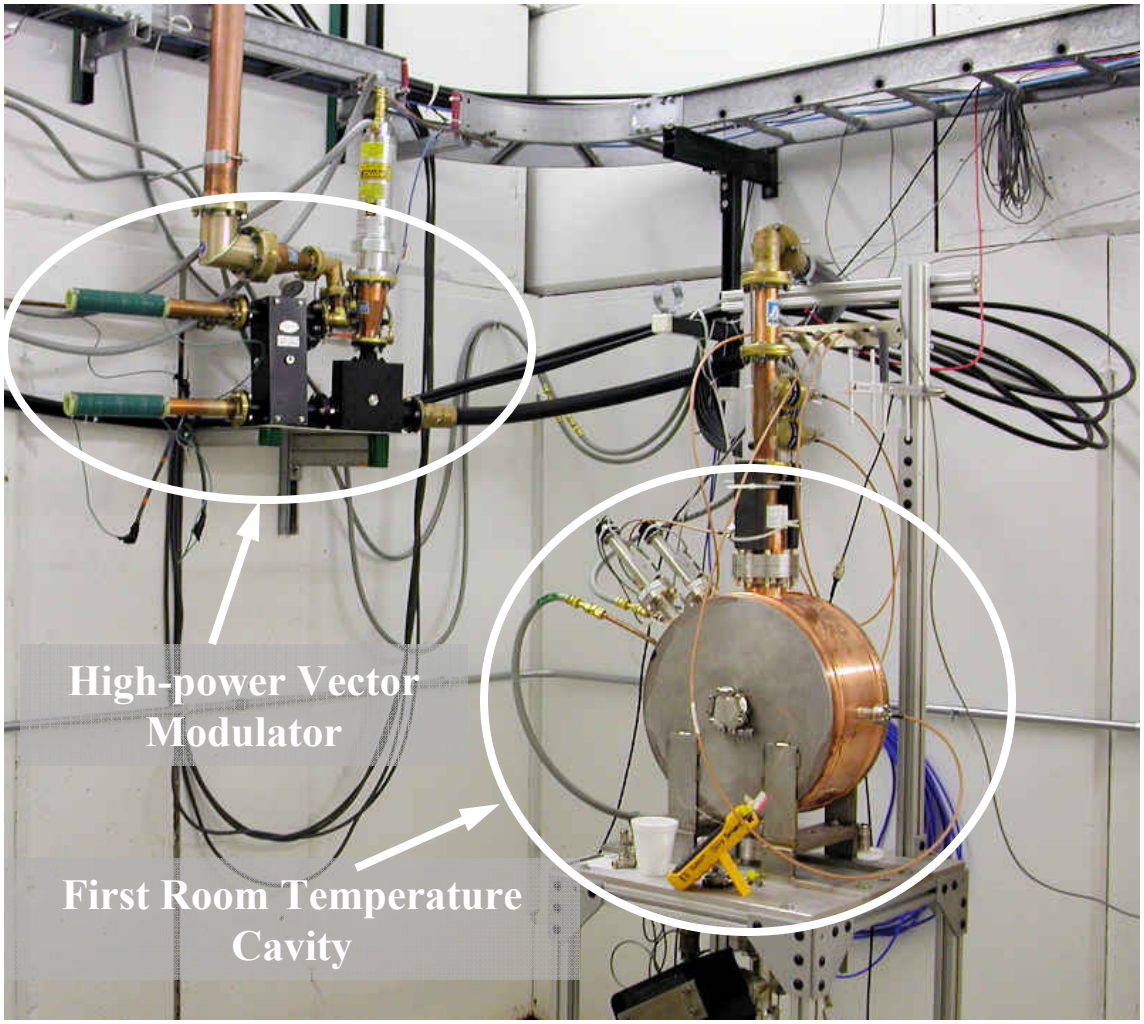


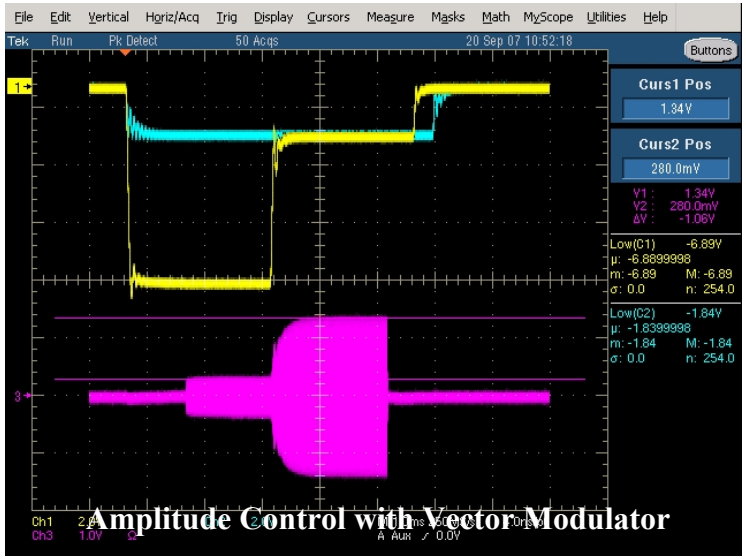
RFQ

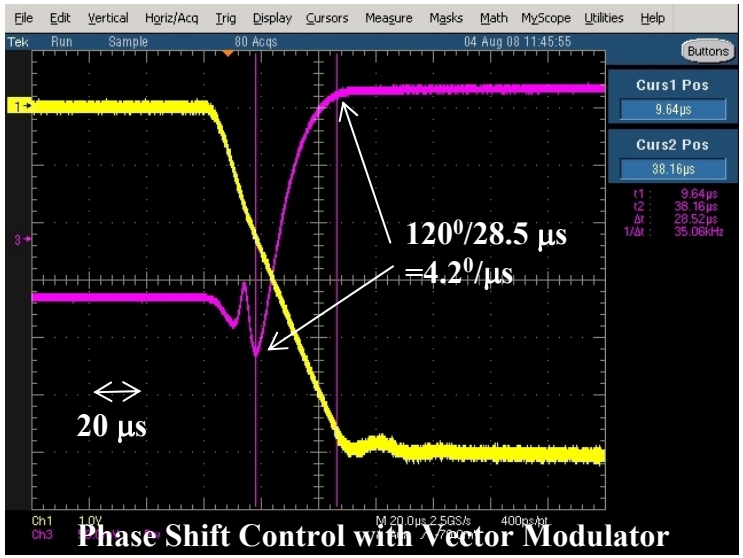


3-spoke Copper Cavity

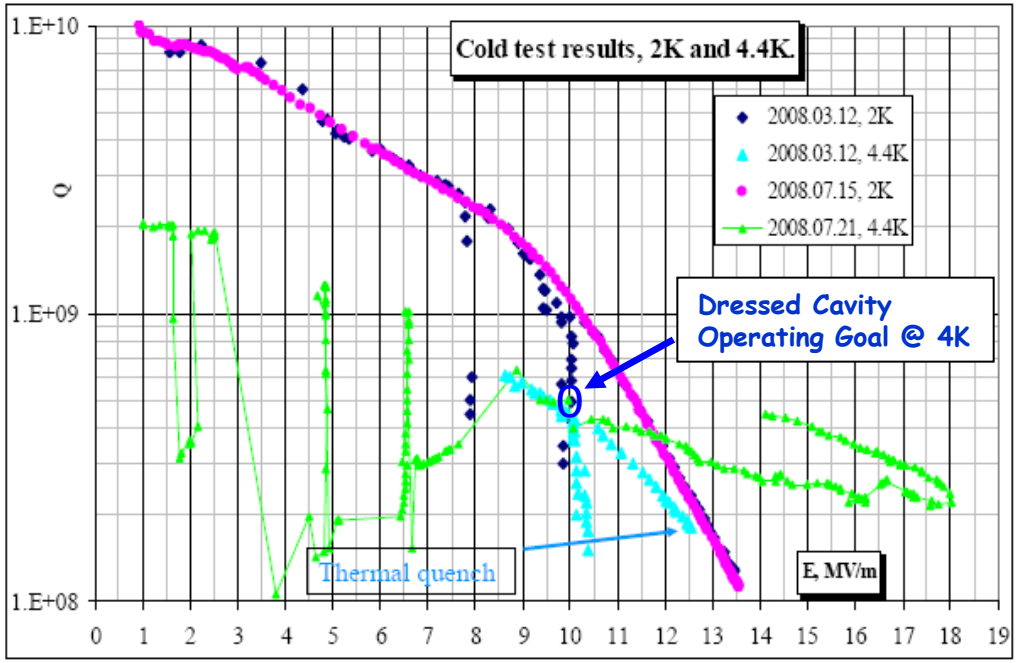
HINS- Cavity and Modulator Tests







Superconducting Spoke Cavities

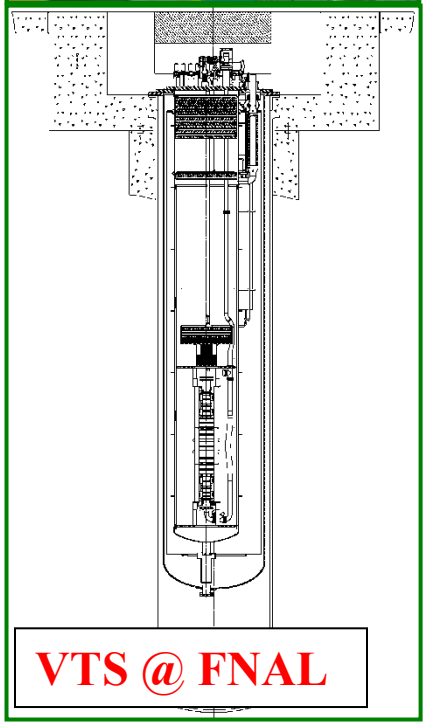


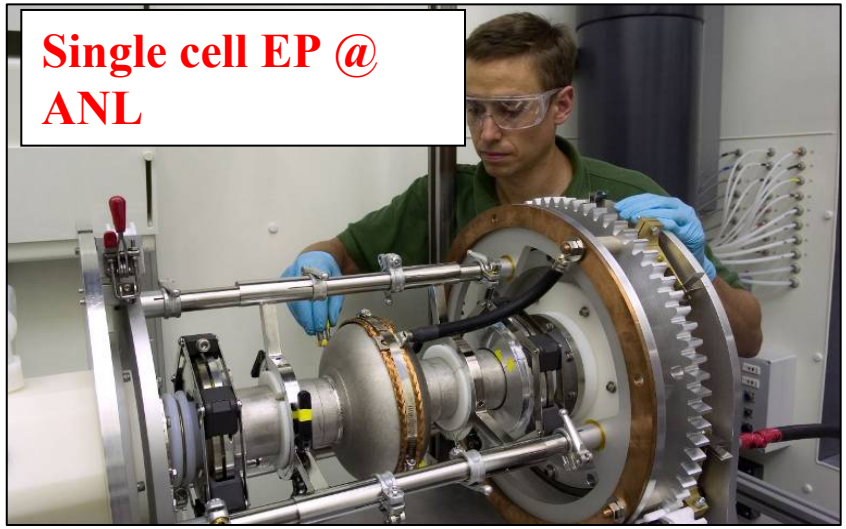
- First SC spoke cavity fabrication has been received from Zanon
- Second cavity has been completed at Roark, IN, ready for processing
- Fabrication of two additional cavities is beginning in India

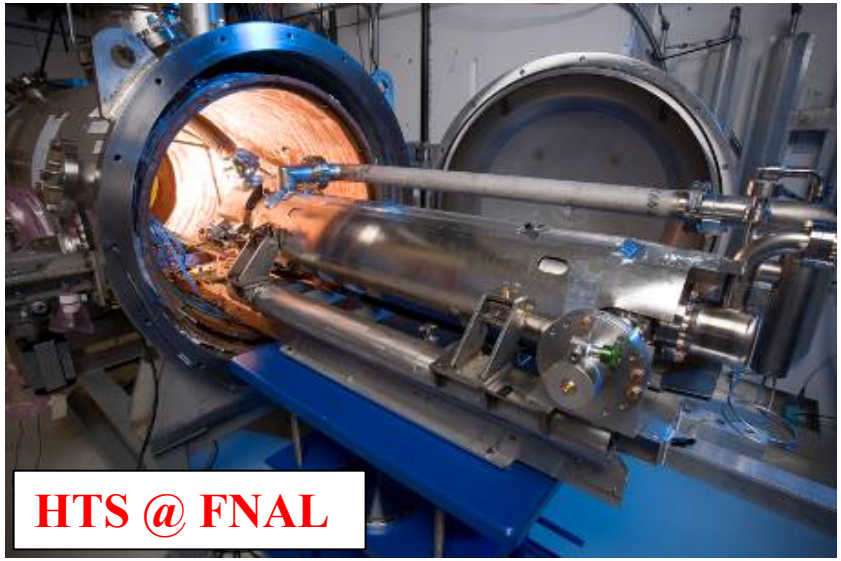
Contributing Program: ILC/SRF

- There is a single 1.3 GHz development program at Fermilab, supporting the ILC/GDE program and simultaneously understanding Project X requirements.
- At an appropriate time (before CD-2) the Project X cryomodule design will be developed.
  - The expectation is that it will be similar, but not identical, to the ILC design (including choice of gradient and focusing needs).
  - CM development plans lead to CM4 being a PrX prototype
  - Development strategy coordinated with ILC on basis of "plug compatibility"
- ILCTA-NML is being constructed under the SRF Infrastructure program to support beam testing of a complete rf unit.
  - This configuration supports substantial progress toward ILC (S1 and S2) goals: demonstration of stable high-power operations.

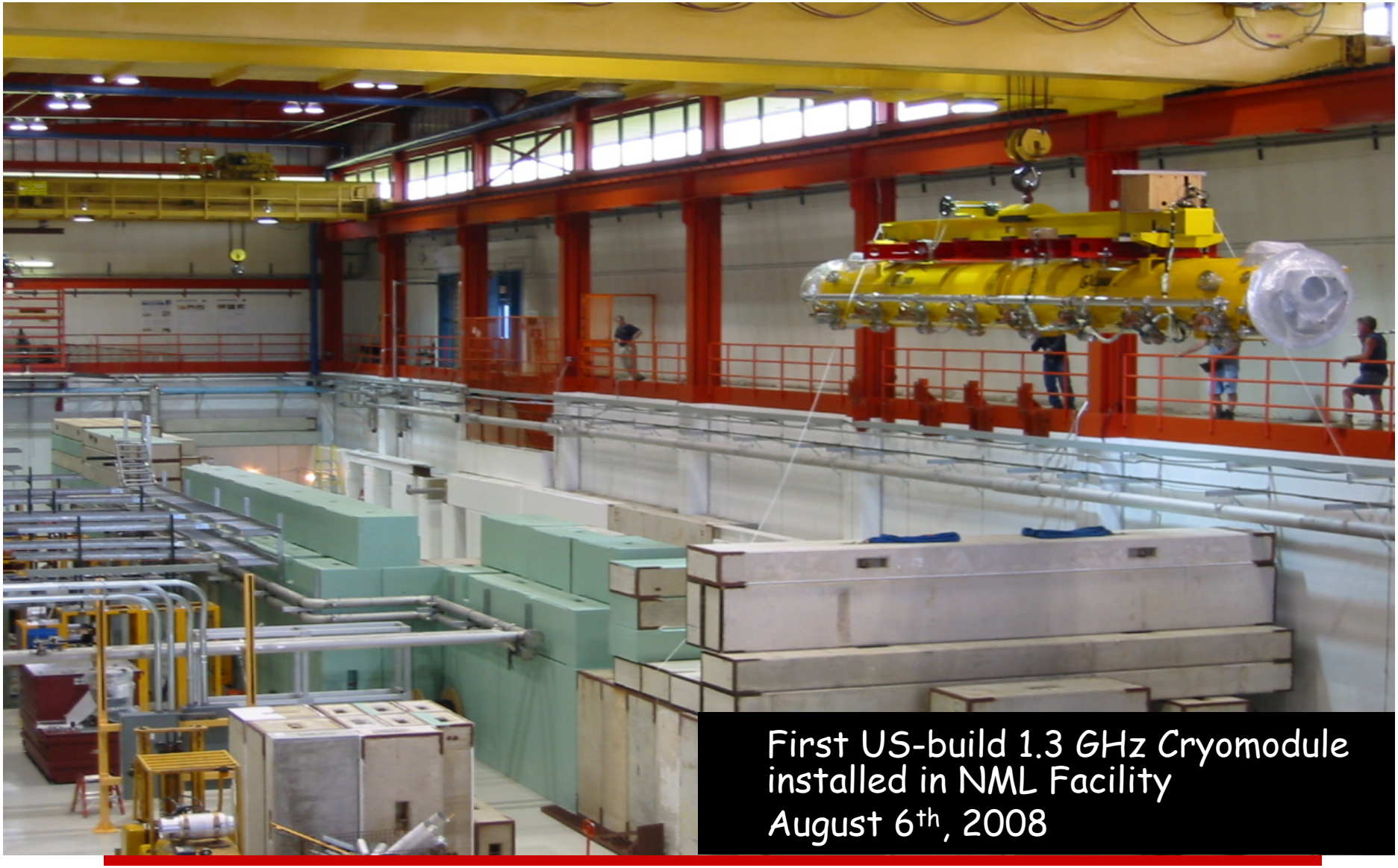
ILC/SRF Infrastructure Development %







ILC/SRF: NML Test Facility



Project X Collaboration Plan

Disclaimer: This is not formally agreed to, although institutions have been invited to comment as this has been developed.

- Intention is to organize and execute the R&D Program via a multi-institutional collaboration.
  - Goal is to give collaborators complete and contained sub-projects, meaning they hold responsibility for design, engineering, estimating, and potentially construction if/when Project X proceeds via an MOU Program.
  - It is anticipated that the Project X R&D Program will be undertaken as a "national project with international participation". Expectation is that the same structure of MOUs described above would establish the participation of international laboratories.
  - Potential US Laboratory Collaborators:
    - ANL, BNL, Cornell, LBNL, ORNL/SNS, MSU, TJNAF, SLAC
  - First Collaboration Meeting: Nov 21-22, 2008

Additional Information

- Project X
  - http://projectx.fnal.gov/
- P5 Report
  - www.er.doe.gov/hep/files/pdfs/**P5_Report**%2006022008.pdf
- FNAL Steering Group Report
  - http://www.fnal.gov/directorate/Longrange/Steering_Public/
- Intensity Frontier Physics Workshops
  - www.fnal.gov/directorate/Longrange/Steering_Public/workshop-physics.html
  - www.fnal.gov/directorate/Longrange/Steering_Public/workshop-physics-2nd.html
  - www.fnal.gov/directorate/Longrange/Steering_Public/workshop-physics-3rd.html

Conclusions

- The goal of physics research in the next decade is to push the knowledge envelope on three frontiers: Energy, Intensity and Astrophysics
- The proposal of Project X, an 8 GeV Proton Source that provides beam for a 2 MW physics program, meets the requirements to support the Intensity Frontier research program.
- An upgradable Project X can provide a stepping stone to the Energy Frontier
- Several R&D Efforts (HINS, ILC/SRF, etc) are actively addressing Project X technical issues.
- Project X Collaboration Meeting
  - FNAL, Nov. 21st-22nd 2008
  - http://projectx.fnal.gov/meeting_11_08/nov_08_collab_mtg.html

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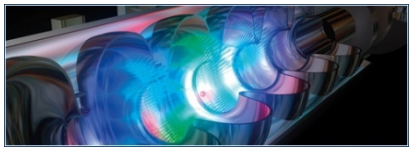

Successive Phases of ν Flavor Physics Reach

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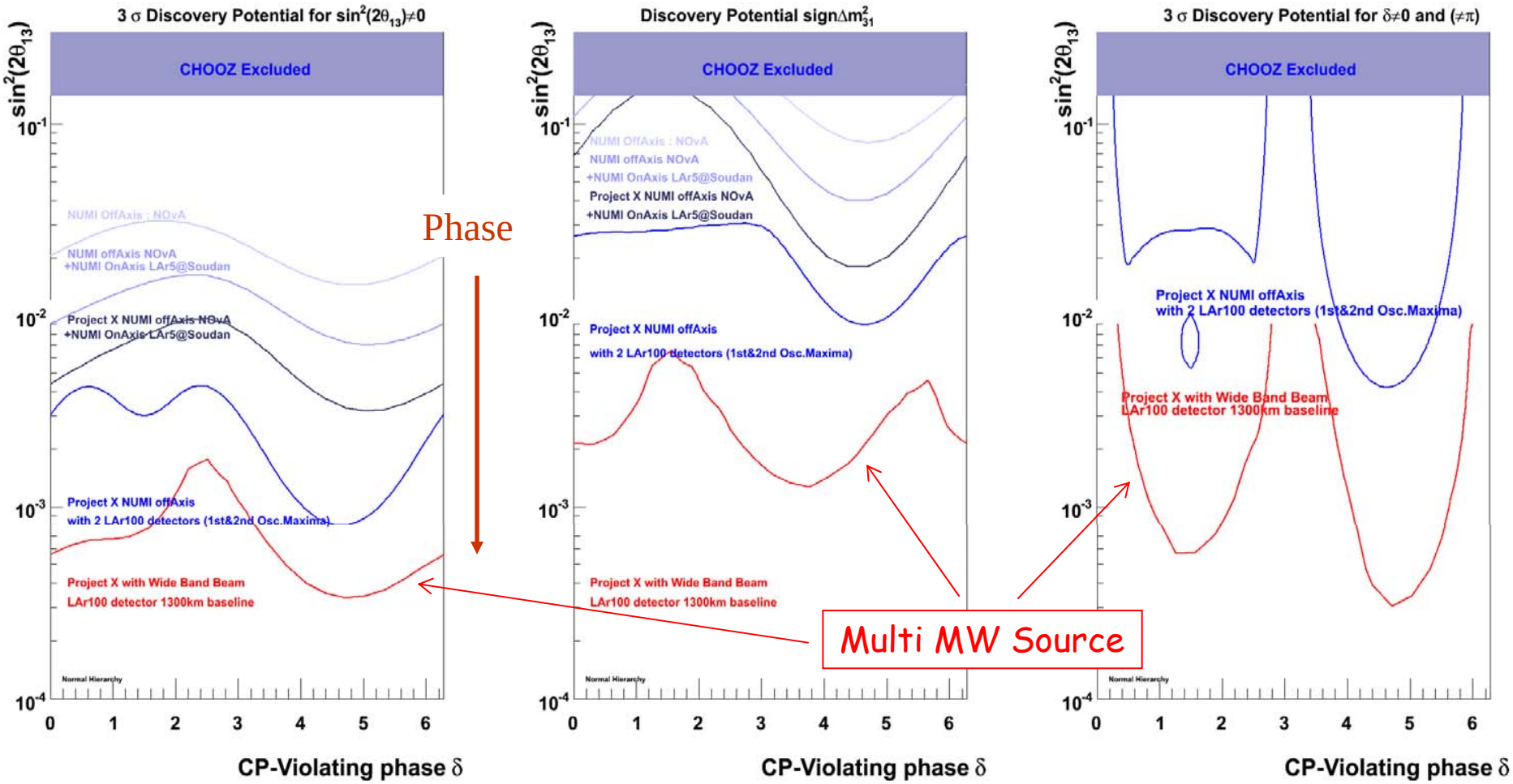
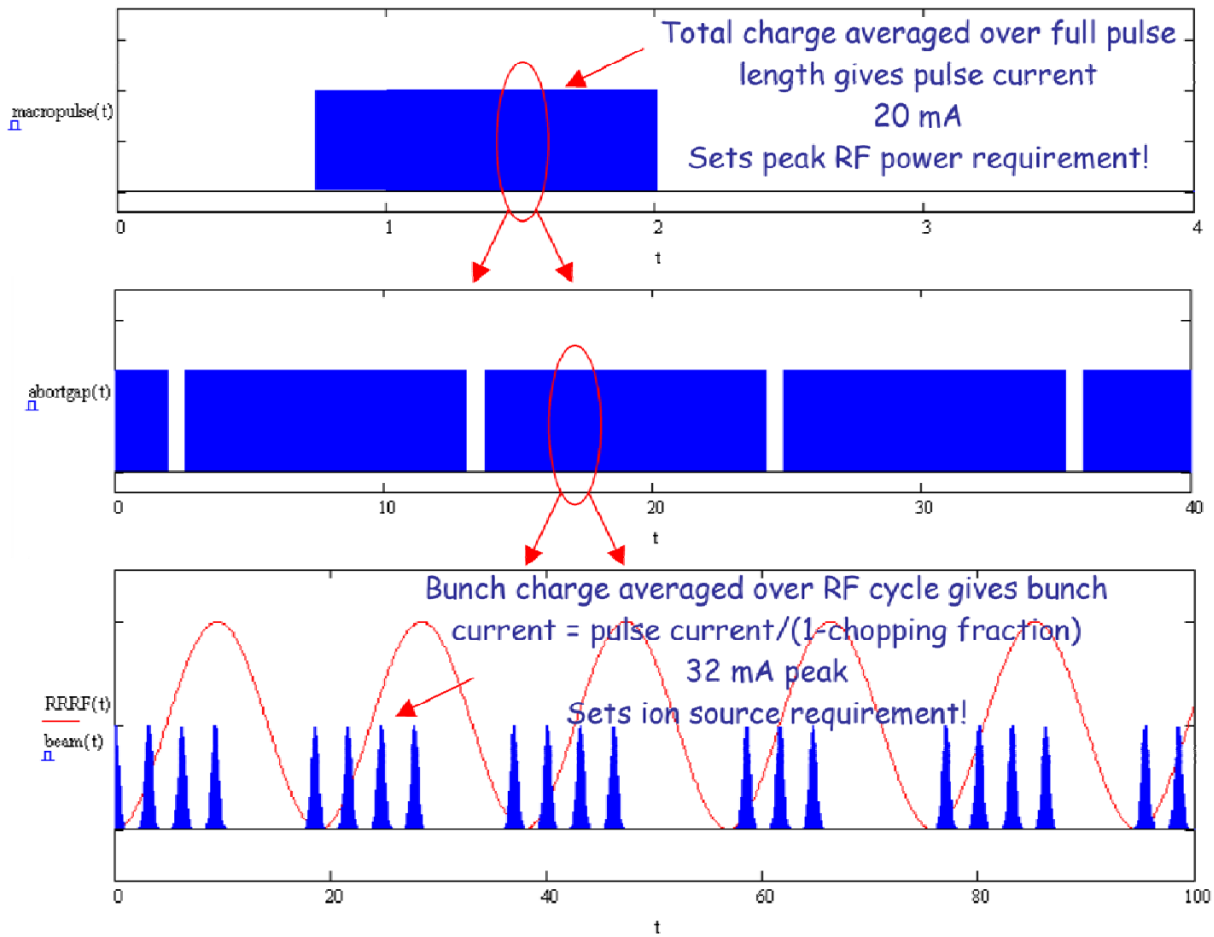
$\sin^2 2\theta_{13}$ | Mass Ordering | CP Violation



Beam Structure



1.25 msec Linac beam pulse
4 msec full scale

Linac beam chopped for
700 nsec RR 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

Evolution of Linac Parameters in Project X Design

%

	Proton Driver Phase 1 Design	Proton Driver Phase 2 Design	HINS capability	Project X Base Design (Nov-07)	Project X ICD (Sep-08)	
Particle	H-	H-	H+ then H-	H-	H-	
Nominal Bunch Frequency/Spacing	325 3.1	325 3.1	325 3.1	325 3.1	325 3.1	MHz nsec
Particles per Pulse	15.6	15.6	37.5 *	5.6	15.6	E13
Pulse Length (beam)	3	1	3/1	1	1.25	msec
Average Pulse Current	8.3	25	~20	9	20	mA
Pulse Rep. Rate	2.5	10	2.5/10	5	5	Hz
Chopping -6% @ 89KHz and 33% @ 53MHz	37.5%	37.5%	0 - 37.5%	37.5%	37.5%	
Bunch Current	13.3	39.8	32	14.3	32	mA
Bunch Intensity	2.5 41	7.6 122	6.1 98	2.7 ** 44	6.1 98	E8 pCoul

* full un-chopped 3 msec pulse at klystron-limited 20 mA

** ILC bunch intensity is 2E10 (electrons)

HINS Goals

- Use of a single high power klystron to drive multiple accelerating cavities with individual high power vector modulators for amplitude and phase control
  - OBJECTIVE → RF cost savings
- Performance of a focusing lattice comprised of superconducting solenoids to form axially-symmetric beam
  - OBJECTIVE → control of emittance growth and beam loss
- Use of superconducting spoke resonator RF structures for beam acceleration starting at 10 MeV
  - OBJECTIVE → RF cost savings
- High-speed (nanosecond) beam chopping at 2.5 MeV
  - OBJECTIVE → beam loss control in Linac and subsequent synchrotrons
- Overall performance evaluation of a Linac based on these design concepts and the resulting beam quality up to 60 MeV
- A "first-of-its-kind" design for high-intensity, pulsed beams