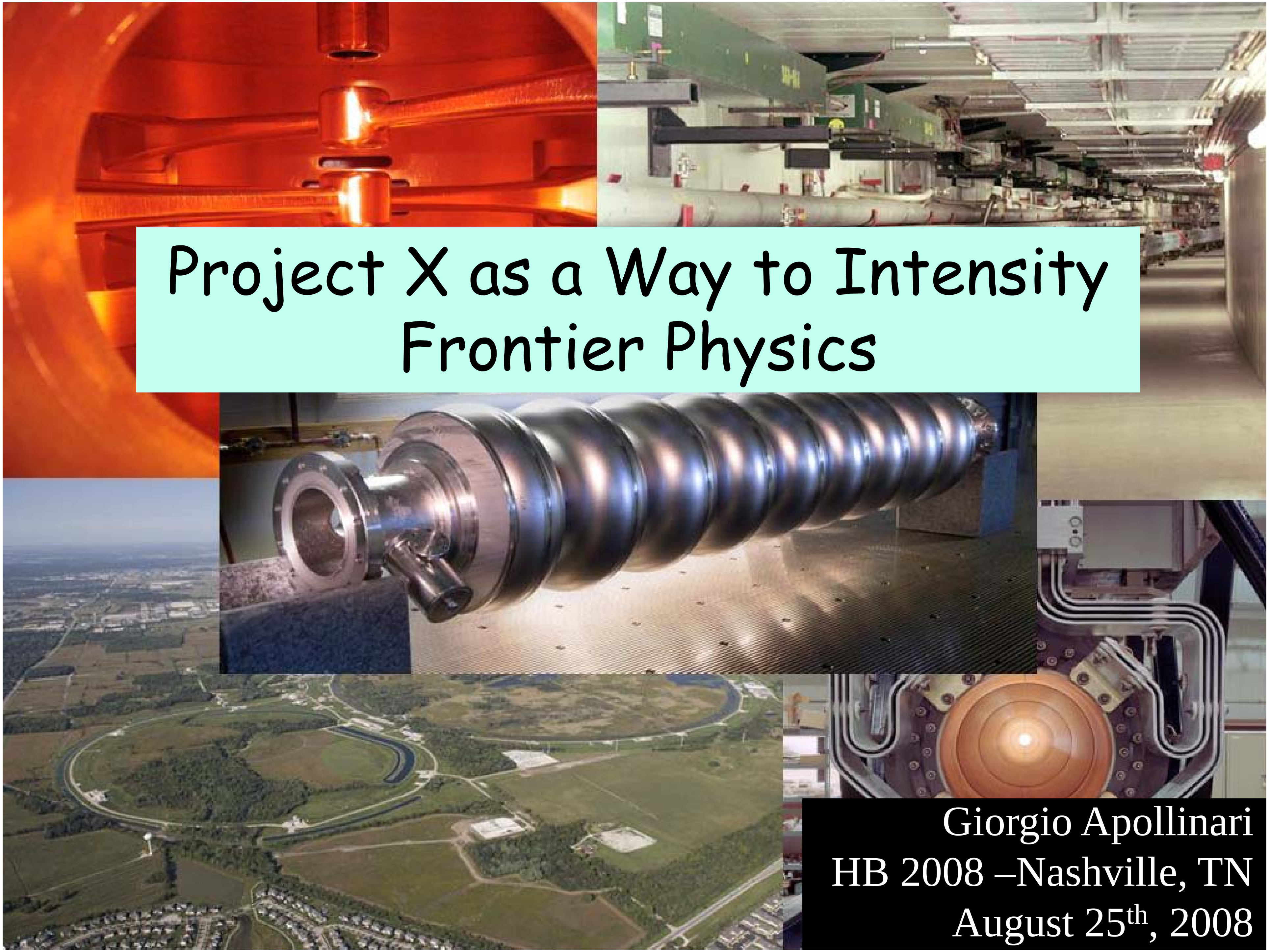
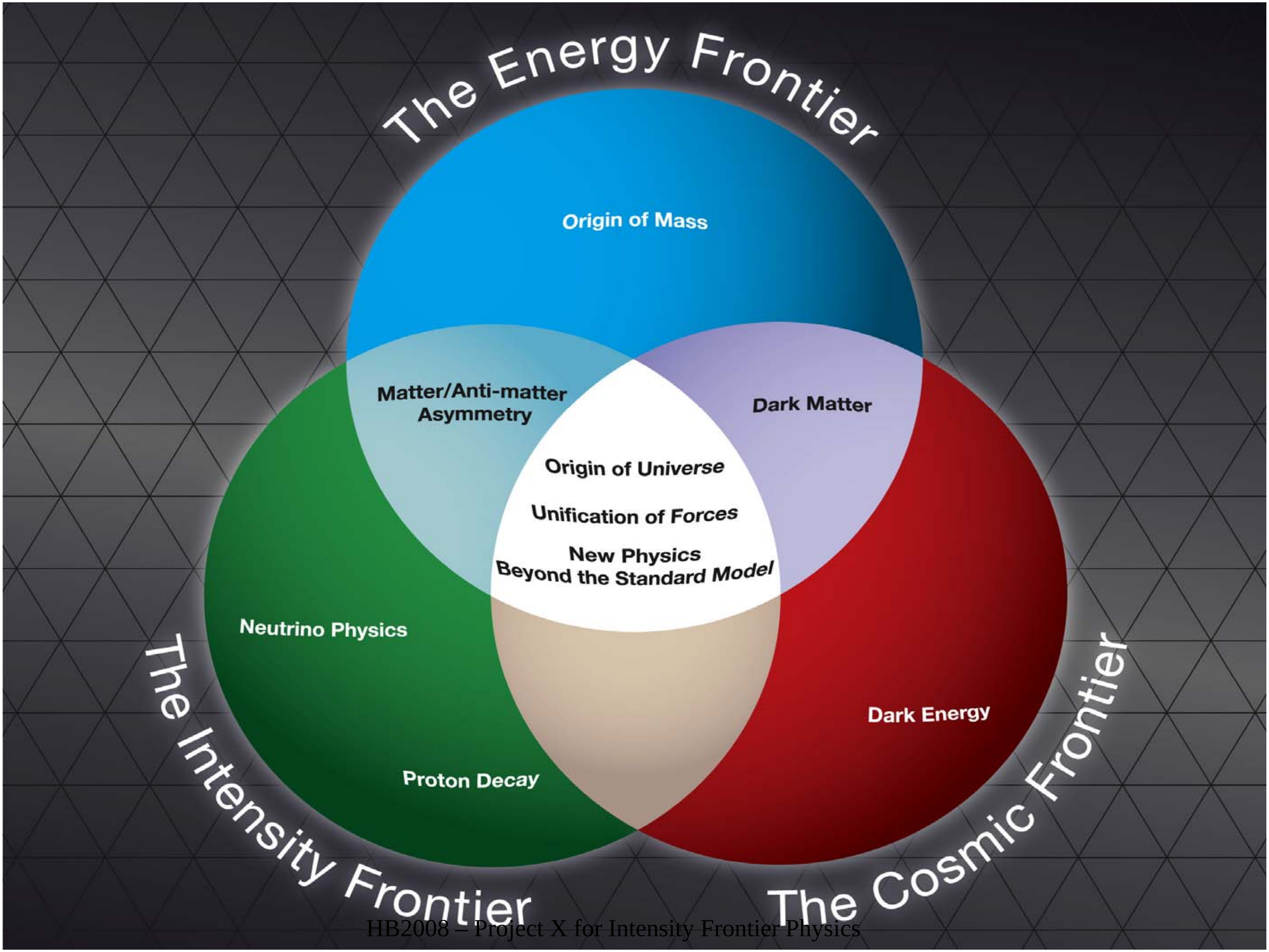
Project X as a Way to Intensity Frontier Physics



Giorgio Apollinari
HB 2008 –Nashville, TN
August 25th, 2008

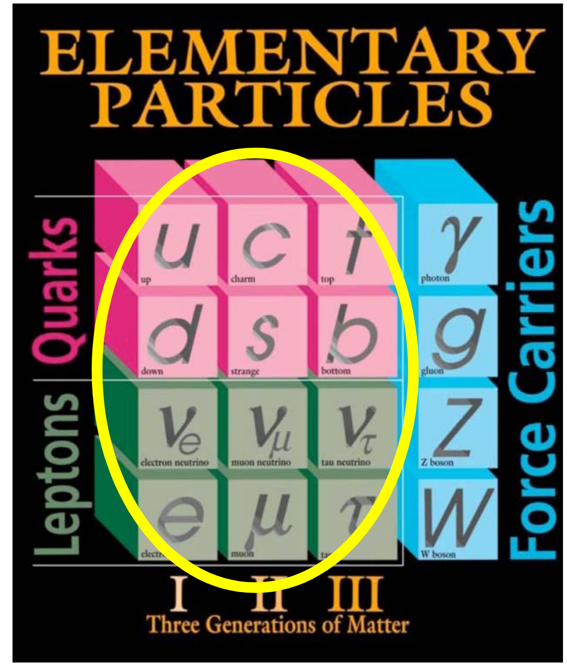
Introduction

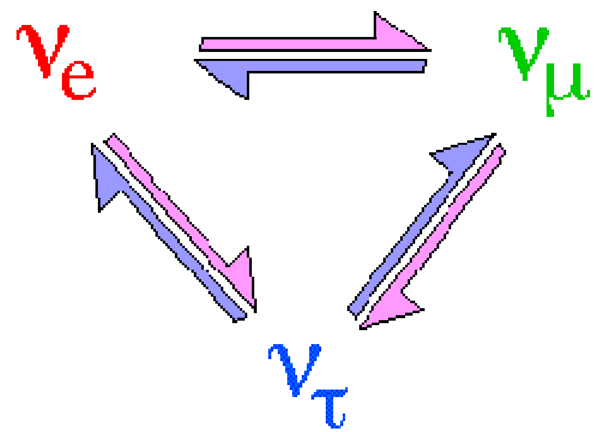
- Intensity Frontier: Needs and Physics Justification
- Project X
  - Description
  - Technical Concepts
  - Timescale
- RD&D Plans
- Contributing Programs
  - HINS
  - ILC/SRF
- Collaboration Plans
- Conclusions


The Energy Frontier
Origin of Mass
Matter/Anti-matter Asymmetry
Dark Matter
Origin of Universe
Unification of Forces
New Physics Beyond the Standard Model
Neutrino Physics
Proton Decay
Dark Energy
The Intensity Frontier
The Cosmic Frontier

Physics of Flavor

- Flavor phenomena are essential to understanding physics within and beyond the SM
- SM is incomplete:
  - Neutrino masses (flavor)
    - Only BSM physics seen so far in the Laboratory
  - Baryon Asymmetry of the Universe (flavor)
  - Dark Matter
  - Dark Energy





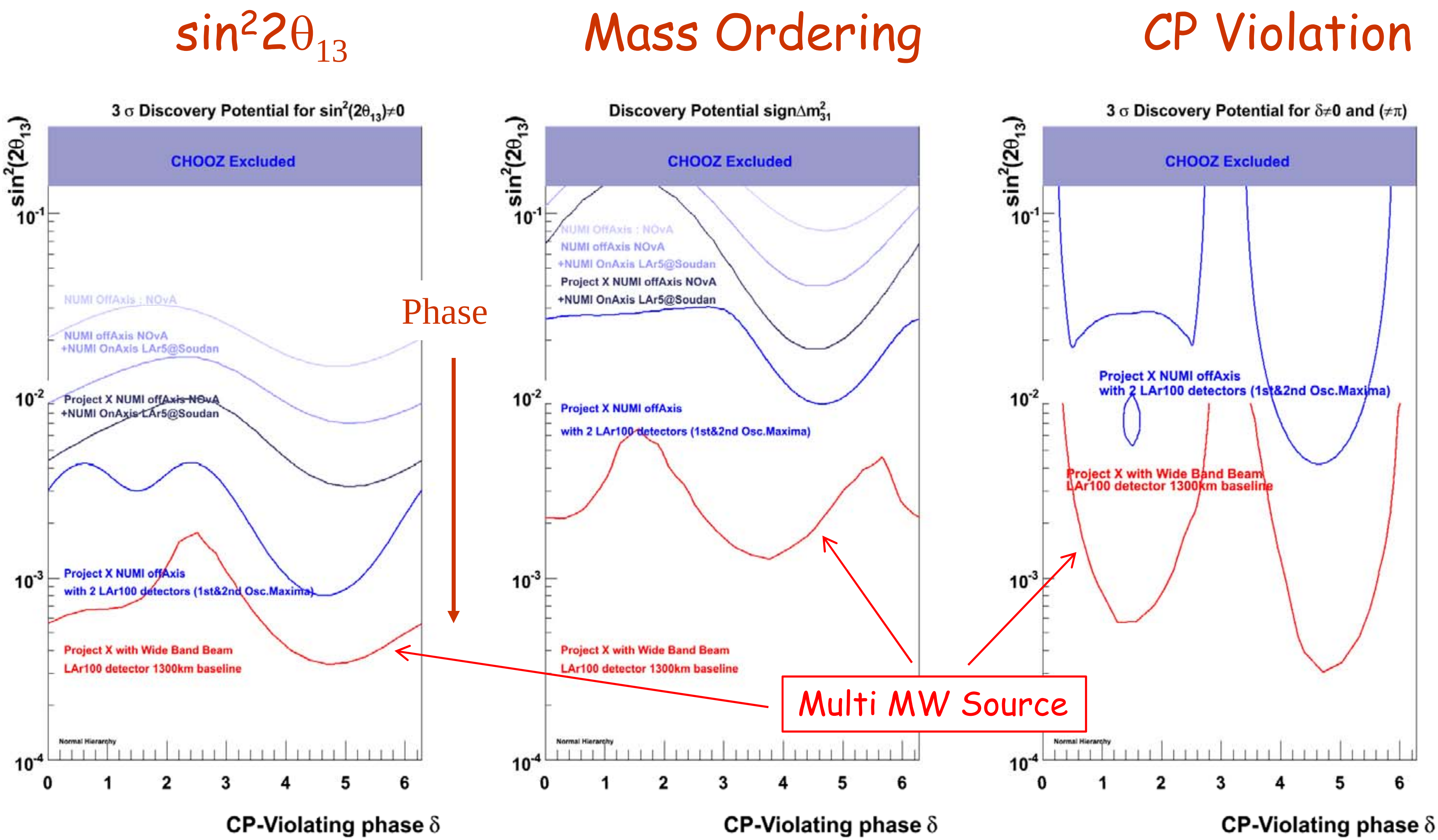
Neutrino Physics

- Neutrino masses
  - 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
  - Possible scenarios as the source
    - Electroweak baryogenesis – LHC and ILC.
    - Leptogenesis – Neutrino CP violation would support it.
- The Four Measurements
  - value of $\sin^2 2\theta_{13}$
  - Are neutrino masses Dirac or Majorana?
  - Is the mass ordering normal or inverted?
  - CP violation

3σ Reach of the Successive Phases

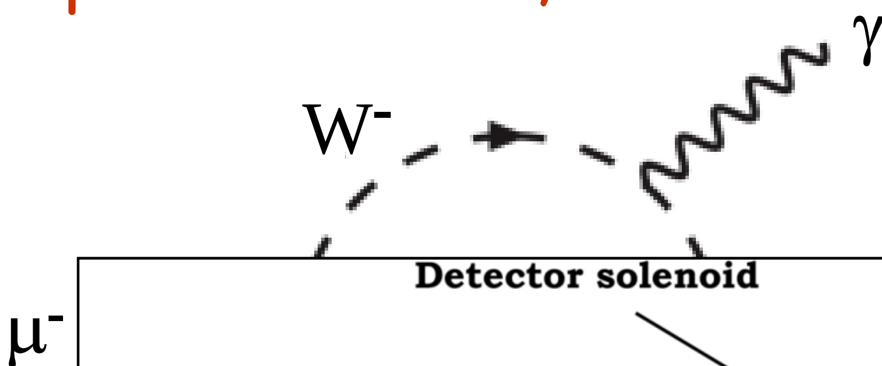


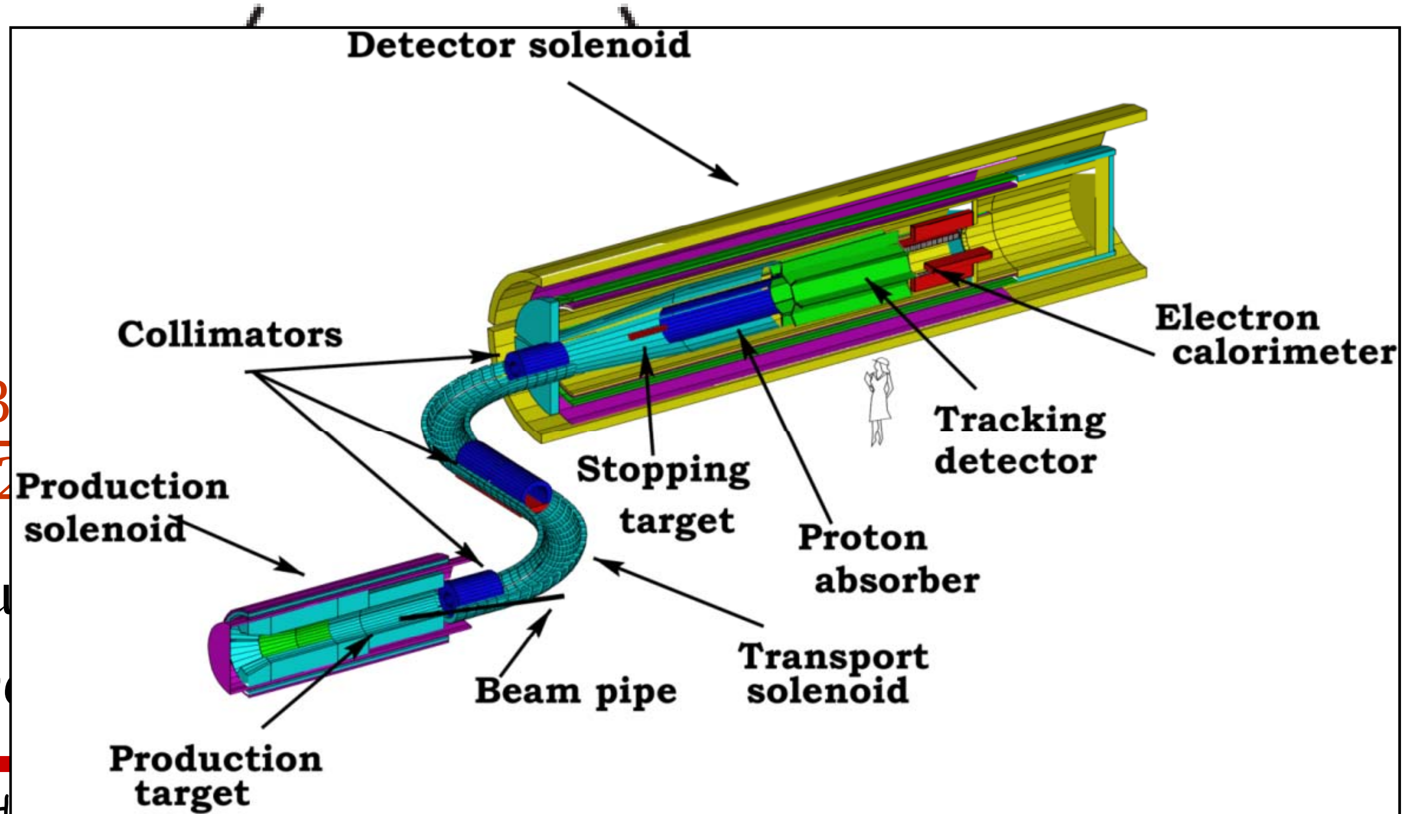
Muon Physics

Neutrinos change from one kind to another.

Do charged leptons do that, too?

In SM





$\mathrm{Br}(\mu \rightarrow e\gamma) = \left| \frac{3}{32 \ldots} \right.$

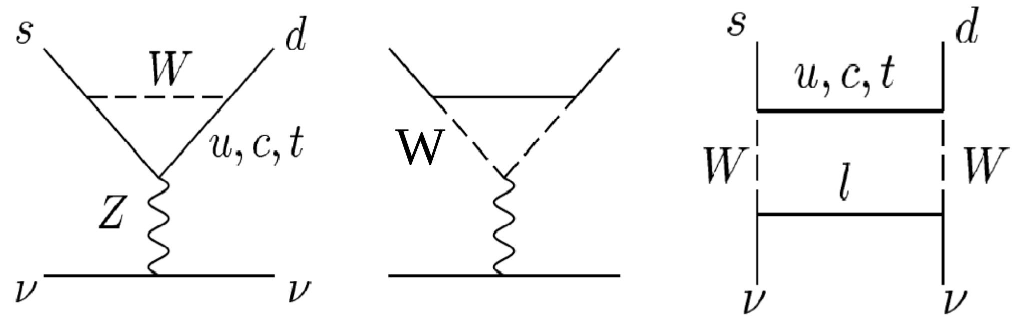
γ can be real (μ

Experimental r

H

Kaons Physics

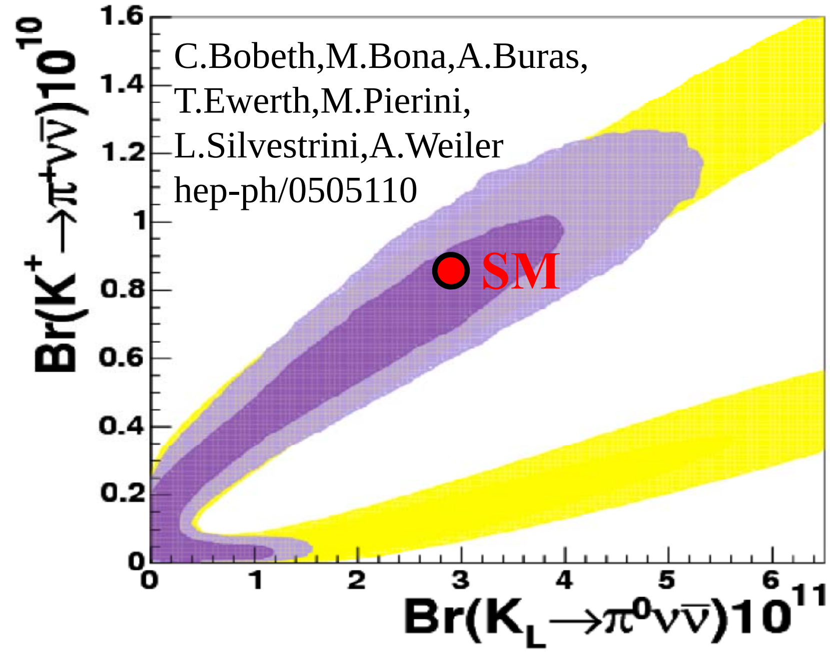
Standard Model
Br($K^+ \rightarrow \pi^+\nu\nu$) = 8 x 10^{-11}
Br($K_L \rightarrow \pi^0\nu\nu$) = 3 x 10^{-11}



An almost-Minimal Flavor Violation World:

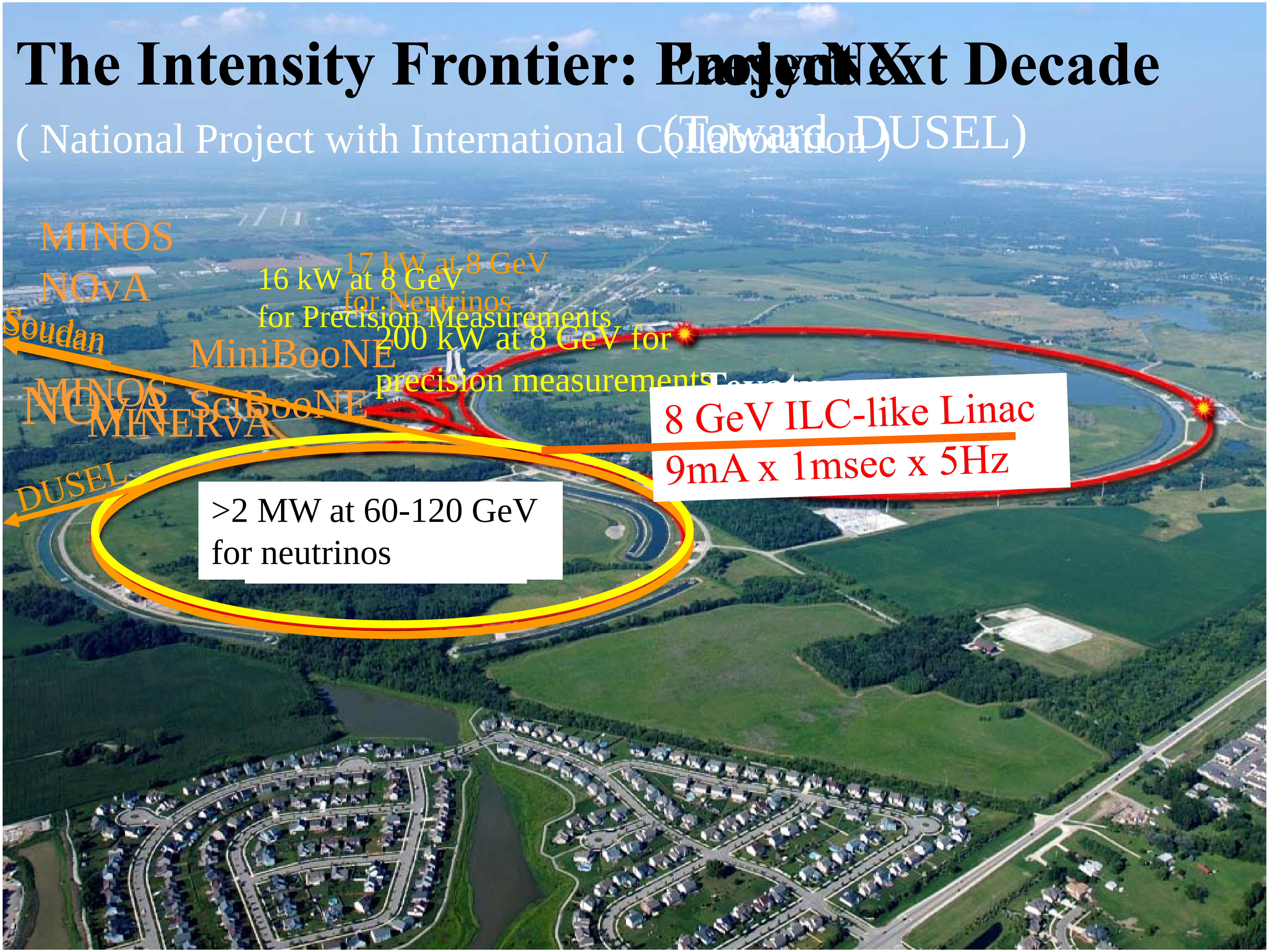
Measuring small deviations from SM is important.

MFV SUSY Effects on K → πνν



Intensity Frontier: FNAL Present and Future Vision (P5)

- Intensity Frontier - now
  - FNAL actively pursuing a program of neutrino physics with MINOS, MiniBooNE and NOvA
- Intensity Frontier – Future (P5) Vision
  - The panel 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 …. This in turn could position the US program to develop a muon collider as a long-term means to return to the energy frontier in the US.
- Phased approach with ever-increasing beam intensities and detector capabilities.

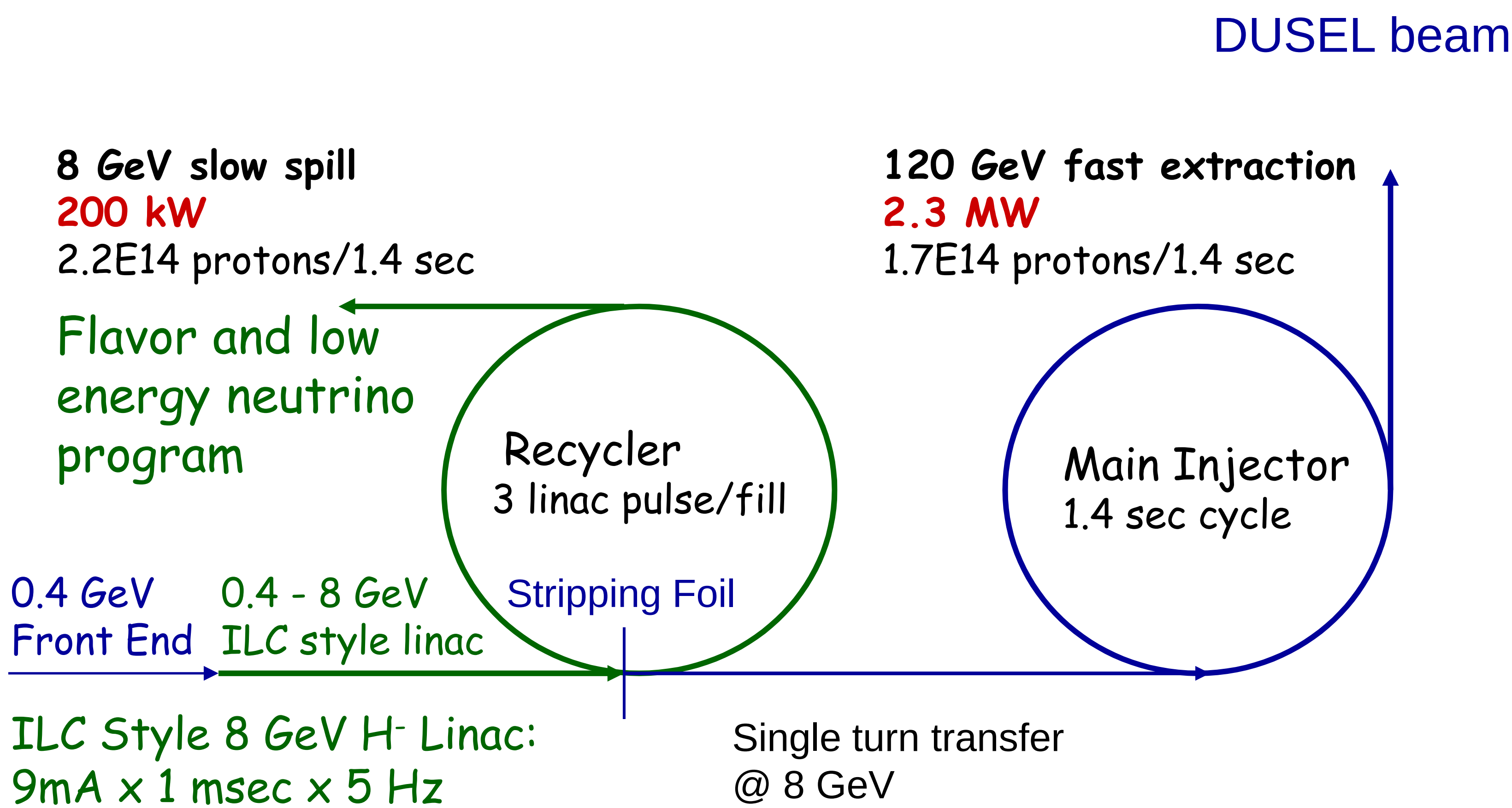

The Intensity Frontier: Early Next Decade
The Intensity Frontier: Project X
(National Project with International Collaboration)
(Toward DUSEL)
MINOS
NOvA
Soudan
MiniBooNE
16 kW at 8 GeV
for Precision Measurements
17 kW at 8 GeV
for Neutrinos
200 kW at 8 GeV for
precision measurements
MINOS
NOvA
SciBooNE
MINERvA
DUSEL
8 GeV ILC-like Linac
9mA x 1msec x 5Hz
>2 MW at 60-120 GeV
for neutrinos

Project X: Design Motivations

- The 8 GeV Linac should be made to look as ILC -like as possible to benefit from extensive ILC engineering
  - Same beam parameters and configuration
    - 9mA with 1 ms long pulse at a rate of 5 HZ
    - Cryomodules, RF & Cryogenic distribution and for $\beta = 1$
- But 2 MW requires 150×10^{12} protons every 1.4 seconds at 120 GeV
  - 24 mA x 1.0 (2.6) mS = 150×10^{12} protons (more klystrons/ pulse)
  - 9 mA x 1.0 mS = 56×10^{12} electrons (ILC)
- Accumulation ring inserted between the 8 GeV Linac and the Main Injector reduces the charge/pulse of the 8 GeV Linac.
- Feed consecutive pulses of beam from the 8 Gev Linac into the Recycler every 0.2 seconds (5Hz)
  - The H- linac beam is stripped in the Recycler
  - Each pulse is over-laid on top of the previous Linac pulse.

Project X Facility Overview

Project X is a high intensity proton facility aimed at supporting a world leading program in neutrinos and rare decays.



Project X Performance Goals

- Linac
  - Particle Type and Kin. Energy — H^- at 8.0 GeV
  - Particles per pulse — 5.6×10^{13}
  - Pulse rate — 5 Hz
  - Beam Power — 360 kW
- Recycler
  - Particle Type and Kin. Energy — p @ 8.0 GeV
  - Cycle time — 1.4 sec
  - Particles per cycle to MI — 1.7×10^{14}
  - Particles per cycle to 8 GeV program — 2.2×10^{14}
  - Beam Power to 8 GeV program — 206 kW
- Main Injector
  - Beam Kinetic Energy (maximum) — 120 GeV
  - Cycle time — 1.4 sec
  - Particles per cycle — 1.7×10^{14}
  - Beam Power at 120 GeV — 2300 kW

Project X Linac Concept

- ILC technology parameter base
  - 1.3 GHz, pulsed beam at 9 mA x 1 msec x 5 Hz rate (5x10^{13} part)
  - Upgradable to ~2 MW at 8 GeV
- Injection into Recycler ring
  - 8 GeV energy

HINS program

- 325 MHz RFQ to 2.5 MeV
- 325 MHz RT accelerating structures to 10 MeV
- 325 MHz SC spoke-type structurs to 0.4 GeV

- ILC squeezed structures to 1.2 GeV
- Standard ILC structures to 8 GeV
- SC solenoid focusing magnets from 2.5 – 120 MeV
- SC focusing quadrupole magnets for tansverse focusing from 120 MeV to 8 GeV
  - Standard ILC focusing lattice in final four RF units

ILC/SRF program

Project X

360 kW 8GeV Linac

20 Klystrons (2 types)
436 SC Cavities
56 Cryomodules

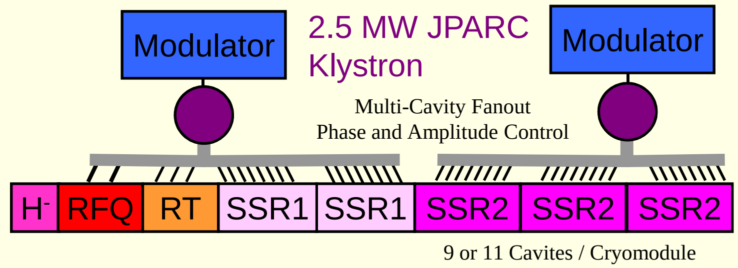
Front End Linac

325 MHz 0-10 MeV

1 Klystron (JPARC 2.5 MW)
16 RT Cavities

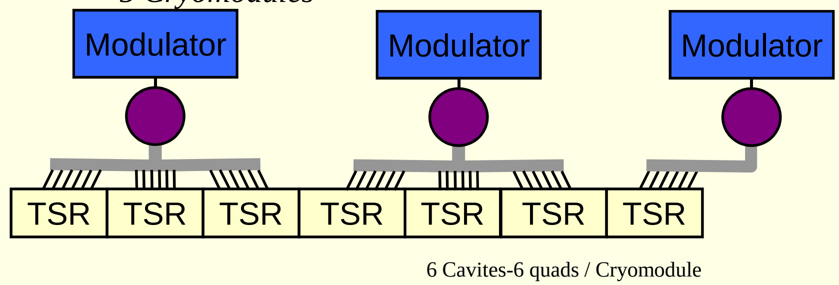
325 MHz 10-120 MeV

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



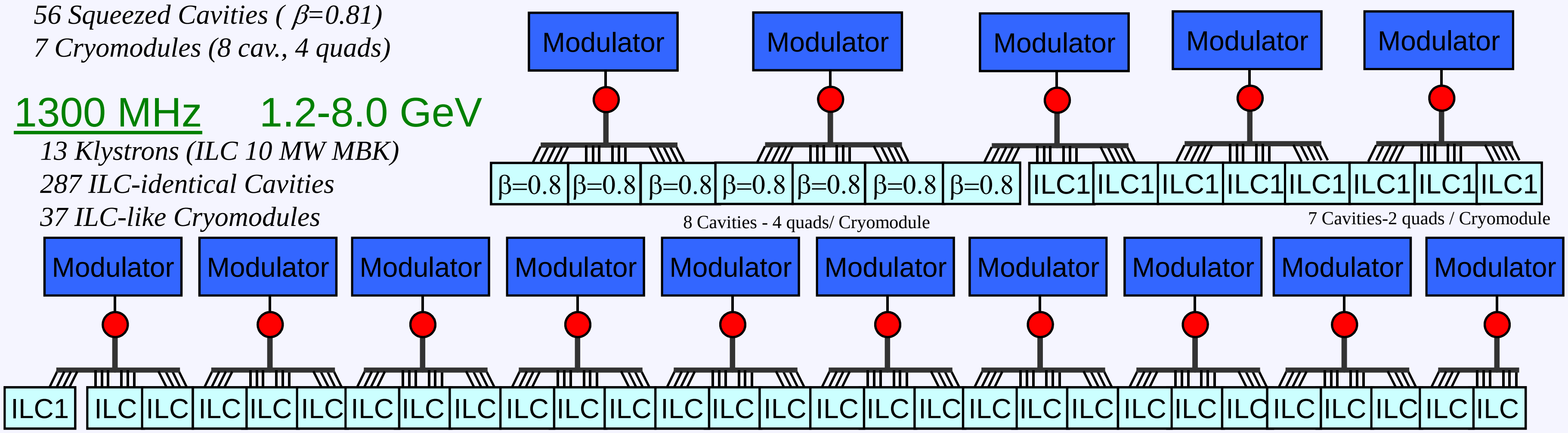
ILC LINAC

1300 MHz 0.42-1.2 GeV

2 Klystrons (ILC 10 MW MBK)
56 Squeezed Cavities (β=0.81)
7 Cryomodules (8 cav., 4 quads)

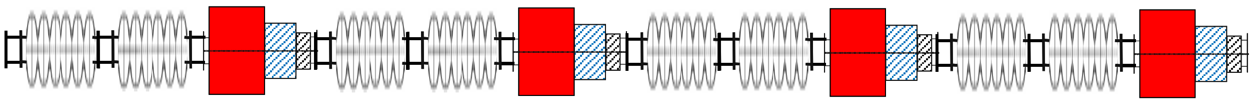
1300 MHz 1.2-8.0 GeV

13 Klystrons (ILC 10 MW MBK)
287 ILC-identical Cavities
37 ILC-like Cryomodules

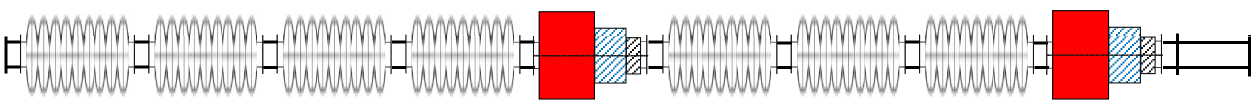


8 Cavities-1 quad / Cryomodule

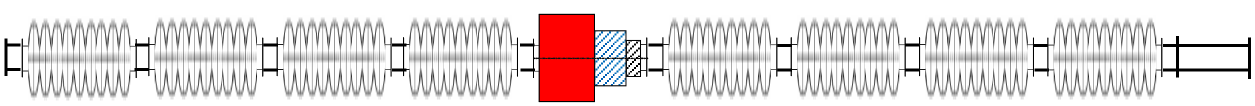
Project X 1.3 GHz Cryomodules Concept



- β=**0.81**: *7 cryomodules, 56 cavities, 16 quads* *0.42 – 1.2 GeV*

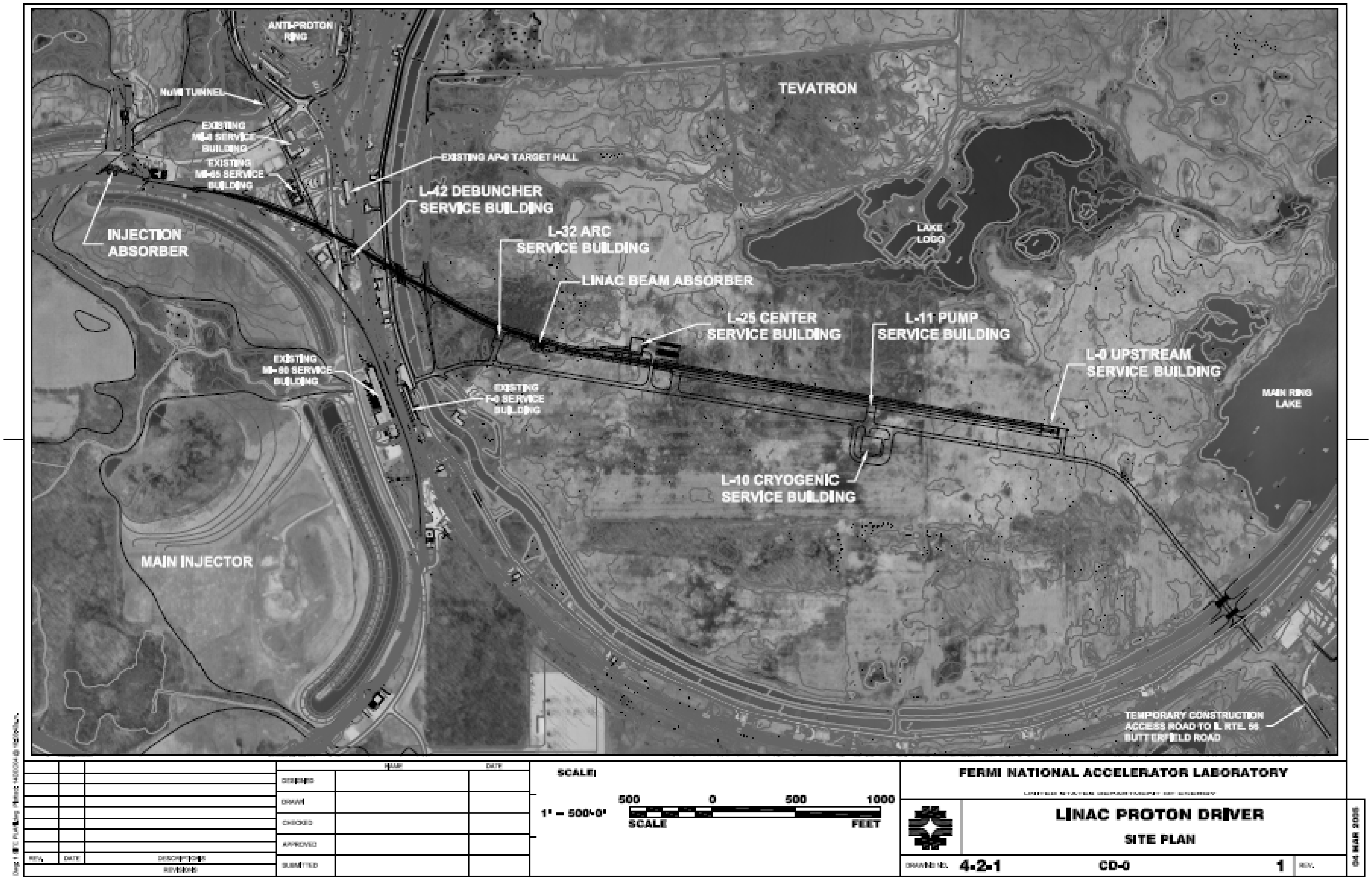


- ILC-1: *9 cryomodules, 63 cavities, 18 quads* *1.2 – 2.4 GeV*



- ILC : *28 cryomodules, 224 cavities, 28 quads* *5.2 – 8.0 GeV*

Project X Provisional Siting



Project X Timescale

- Working backwards (probable delay if/when FY09 CR):
  - FY12: CD-3 – Start Construction
  - FY11: CD-2 – Establish Baseline
  - FY10: CD-1 – Establish Baseline Range
    - Requires a complete Conceptual Design Report
  - FY09 (spring-summer): CD-0
    - Requires new cost (range) estimate which will be reviewed by DOE
- Present Tasks/Achievements
  - Establish basic performance parameters
  - Develop design concept sufficient to form basis of a cost estimate
  - Understand how/if the linac could support a 2+ MW upgrade
  - Form Project X RD&D Collaboration and establish work assignments for FY09

Project X RD&D Plan Alignments

- Alignment with future accelerator facilities
  - ILC and SRF programs:
    - Development of shared technologies to the benefit of both efforts
    - Project X linac designed to accommodate accelerating gradients in the range 23.6 – 31.5 MV/m (XFEL – ILC)
  - Muon facilities
    - Develop upgrade concept for the Project X linac aimed at >2 MW
    - Develop a performance specification for a Proton Driver supporting a Neutrino Factory and Muon collider, consistent with Project X concepts.
      - Typically require 2-4 MW @ 10± 5 GeV proton energy, 50 Hz rep.
      - Natural Evolution: Project X → Neutrino Factory → Muon Collider
- Alignment with present R&D efforts
  - High Intensity Neutrino Source (HINS) program
    - Development of 325 MHz based technology for acceleration of low-energy high intensity beams

RD&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)
  - Requirements for PrX gradient less stringent than for ILC (24 MeV/m vs. 31.5 MeV/m)
  - Production rate of cryomodules (needed 1 cryo/month)
  - Use of VM/single cavity power in part of 1.3 GHz Linac
  - Power Upgrade Plans

RD&D Plan: Major Technical Issues

- 8 GeV Transfer Line
  - Control and mitigation of uncontrolled losses
  - Stripping Efficiency and lifetime
- Main Injector (and Recycler)
  - Electron Cloud Instabilities (x3 more proton/bunch than current operations)
    - Simulations, Beam piper coating
  - Second Harmonic RF system
- Neutrino Beamline
  - Development of proton target and magnetic horn capable of handling 2.3 MW at 120 GeV.

Upgrade Paths to 8 GeV Physic Program

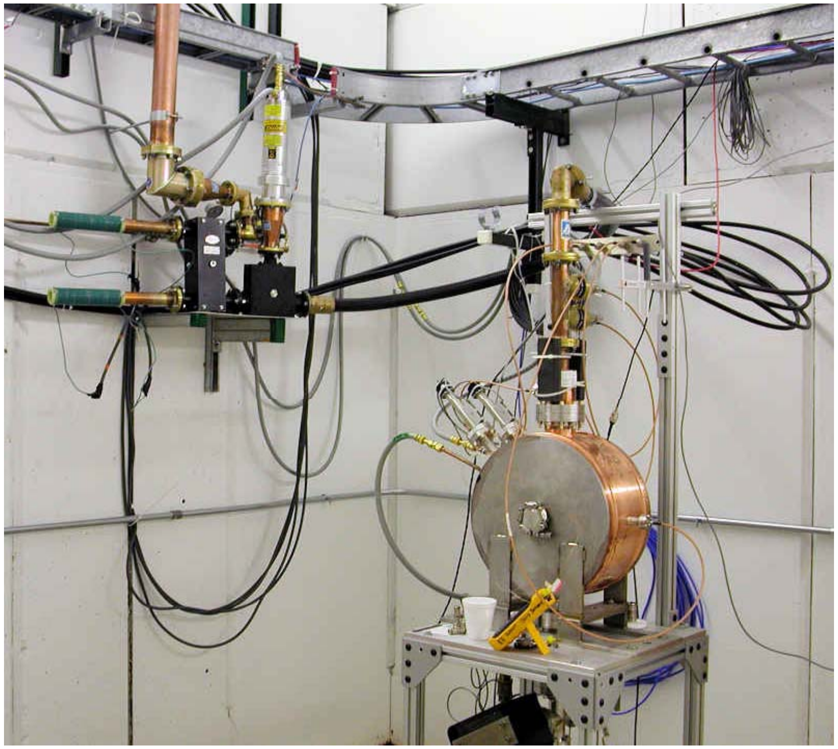
- The other advantage to stripping in the Recycler is that the stripping system is available to the Linac while the Main Injector is ramping.
  - There is 0.8 seconds left before the Recycler needs to be reloaded for the Main injector
  - Load and spill 4 pulses for an 8 GeV physics program
- Upgrade Paths
  - 9 mA x 1 ms x 5 Hz = 360 kW at 8 GeV
  - 9 mA x 3 ms x 10 Hz = 2100 kW at 8 GeV
  - 27 mA x 1 ms x 10 Hz = 2100 kW at 8 GeV

PrX RD&D Plan and the ILC/SRF Program

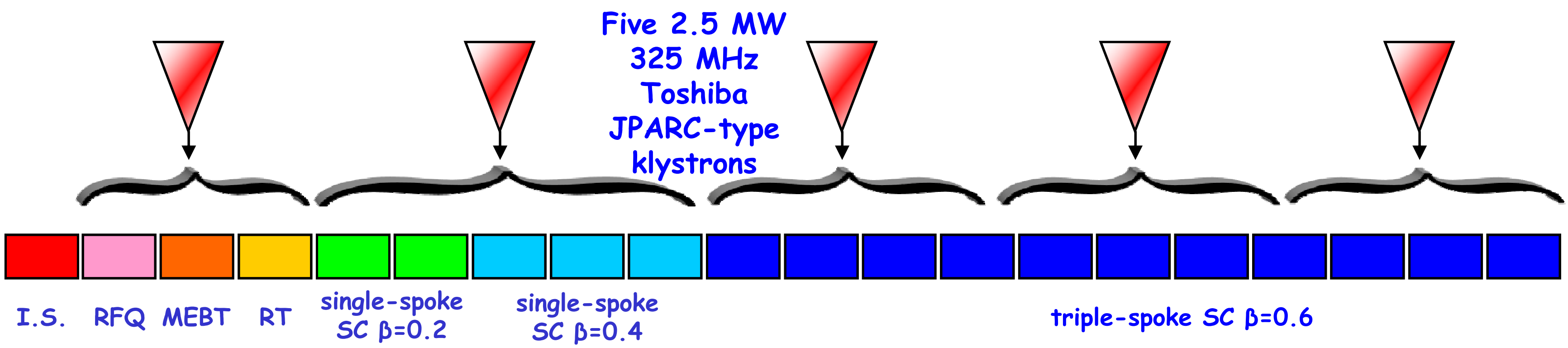
- Project X design concept aligns beam parameters with ILC:
  - 9 mA × 1 msec × 5 Hz
- Industrialization role
  - Project X requires 37 β=1, ILC-like cryomodules
  - Production over a two-to-three-year period represents a significant advance over capabilities anticipated in ~2010; however, the production rate is below that required by ILC
- There is a single 1.3 GHz development program at Fermilab, supporting the ILC/GDE program and simultaneously understanding Project X requirements.

PrX RD&D Plan and the HINS Program

- The HINS program is developing front end technology beyond the requirements of Project X initial goals:
- 60 MeV front end @ 27 mA × 1 msec × 10 Hz (2 MW @8 GeV)
- HINS as Project X upgrade
- Demonstrate novel technologies for a high intensity non-relativistic linac
  - Multiple RT and SC cavities driven by a single rf source (hi-power VM)
- Questions
  - Do we use HINS as the initial front end or do we utilize a conventional (RT) front end?
  - Can we establish an 8 GeV upgrade path via HINS and if so, how does this impact the 1.3 GHz linac facility design?



Contributing Program: HINS



	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 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

HINS Challenges

- A “first-of-its-kind” design for high-intensity, pulsed beams
  - No existing example of large-scale, high-intensity linac with solenoidal focusing and ‘round’ beams
  - No existing example of high-intensity machine with transition to superconducting cavities at this low energy
- Chopper requirements are challenging
- Superconducting spoke cavities
  - Little is known about performance under conditions of pulsed high-power RF (e.g. Lorentz detuning)
  - Beam acceleration with this type cavity has never been demonstrated up to now
- RF distribution and control
  - No existing example of a large system with high power vector modulators and controls necessary to operate many independent cavities driven from one klystron

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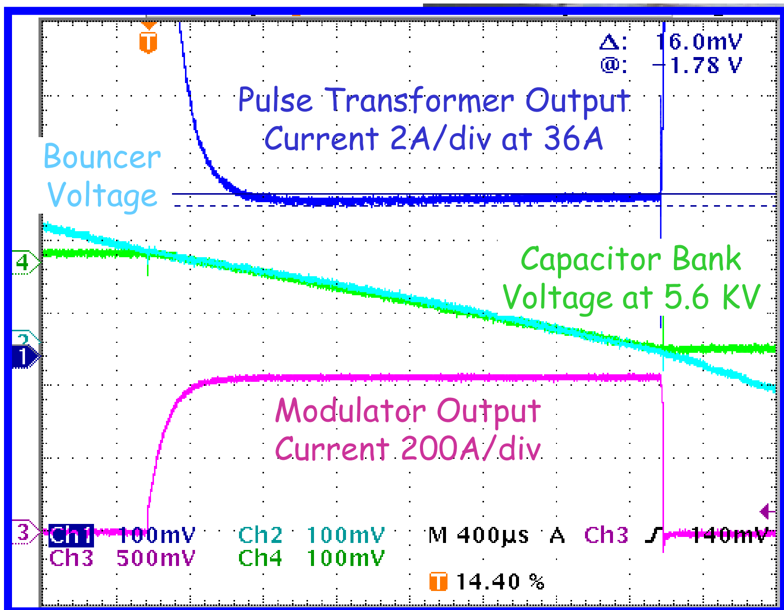
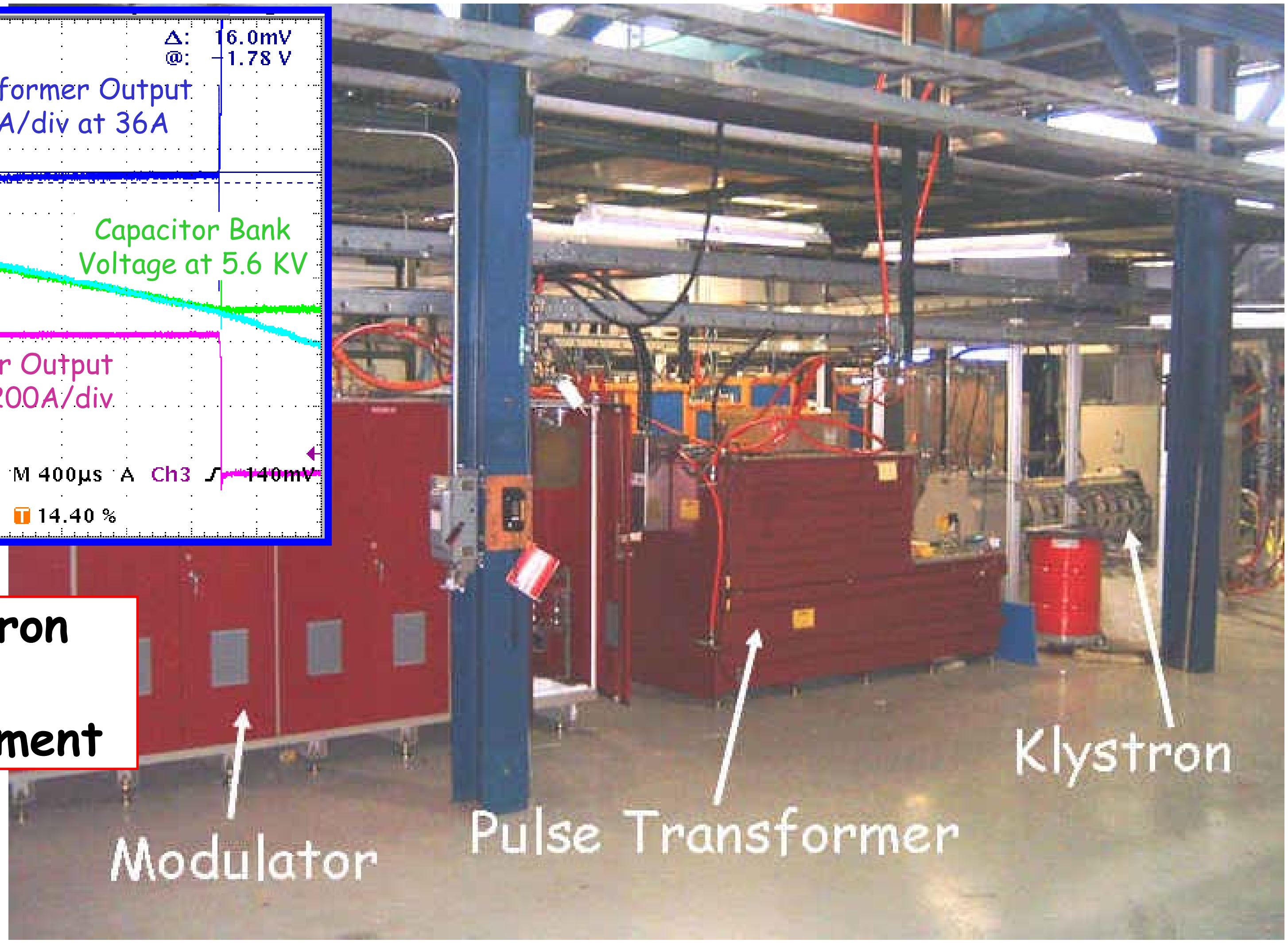
Klystron Modulator and Pulse Transformer

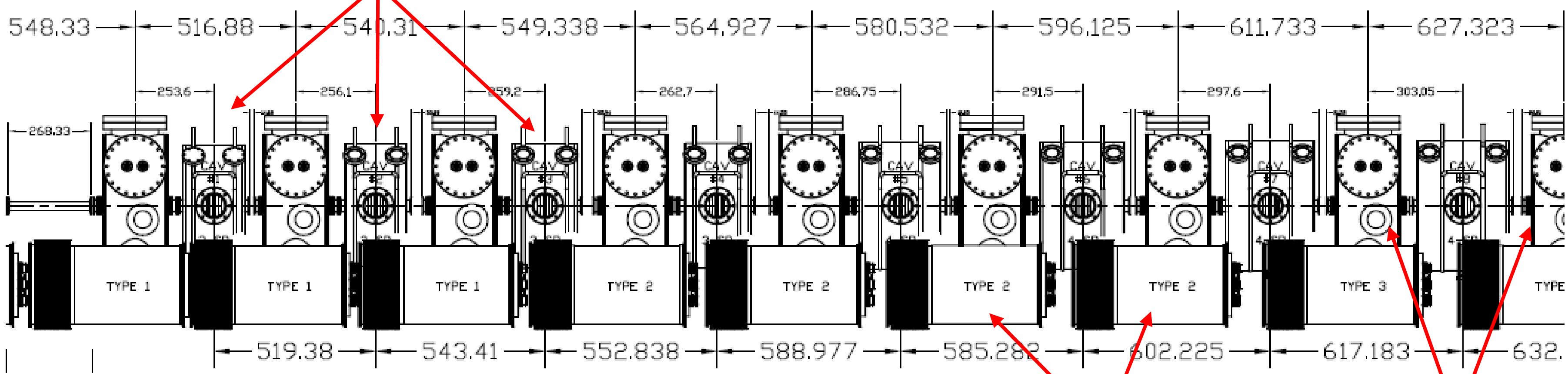




325 MHz klystron inherited from JPARC development

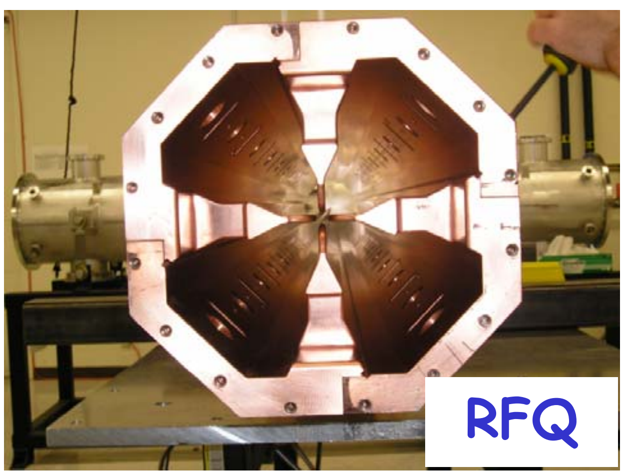
HINS - RT (10 MeV) Section

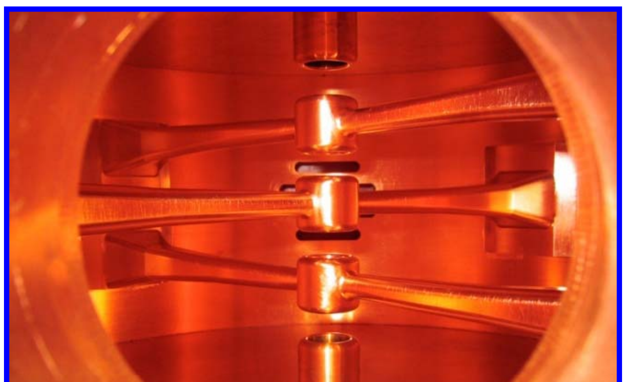
copper cavities

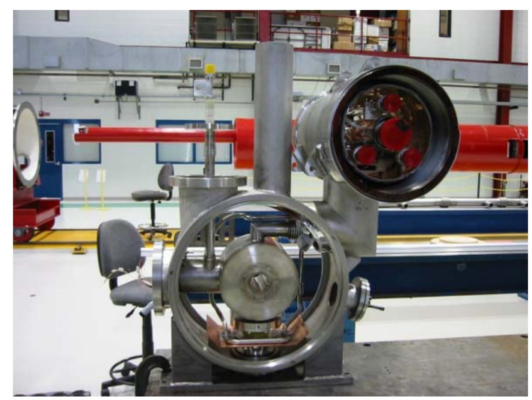


helium transfer line

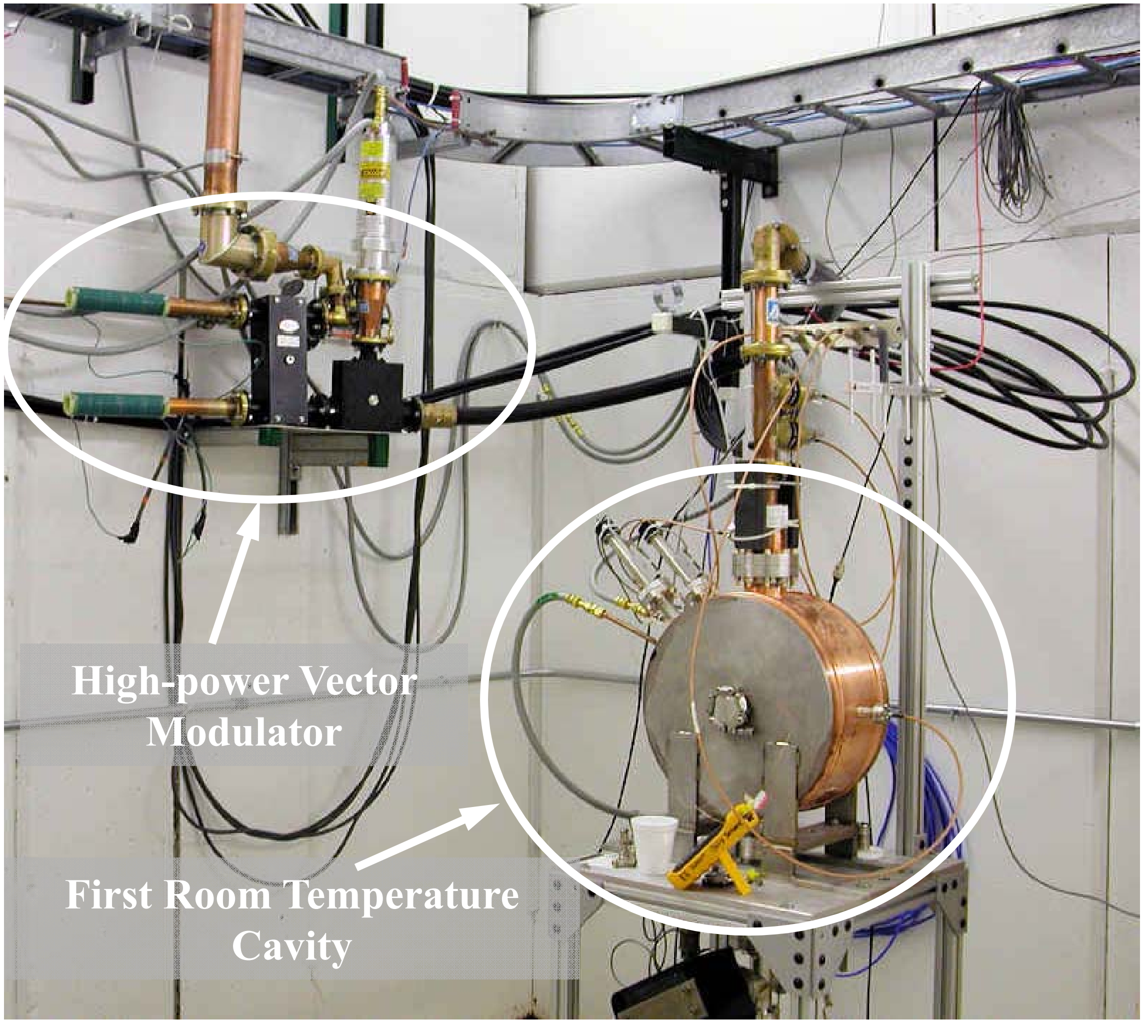
solenoids

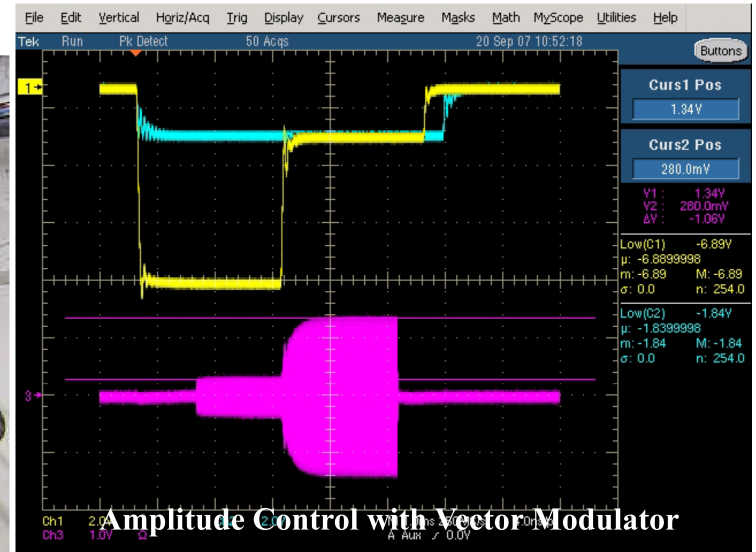

RFQ

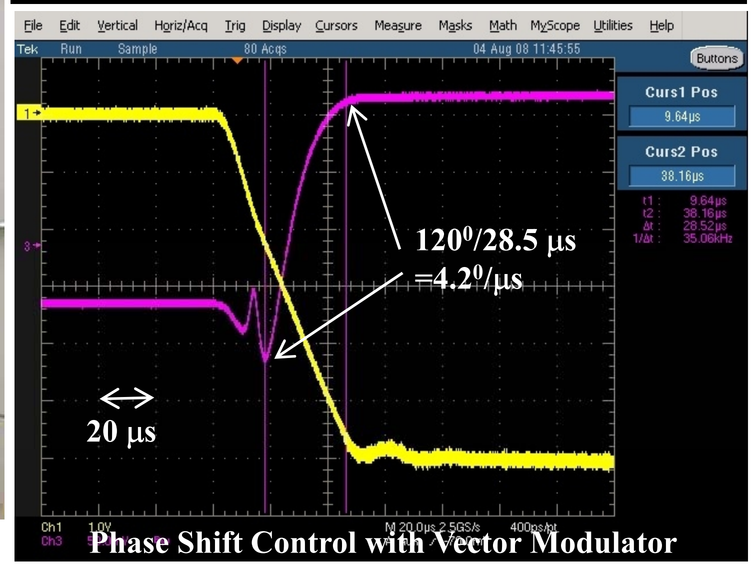

3-spoke Copper Cavity



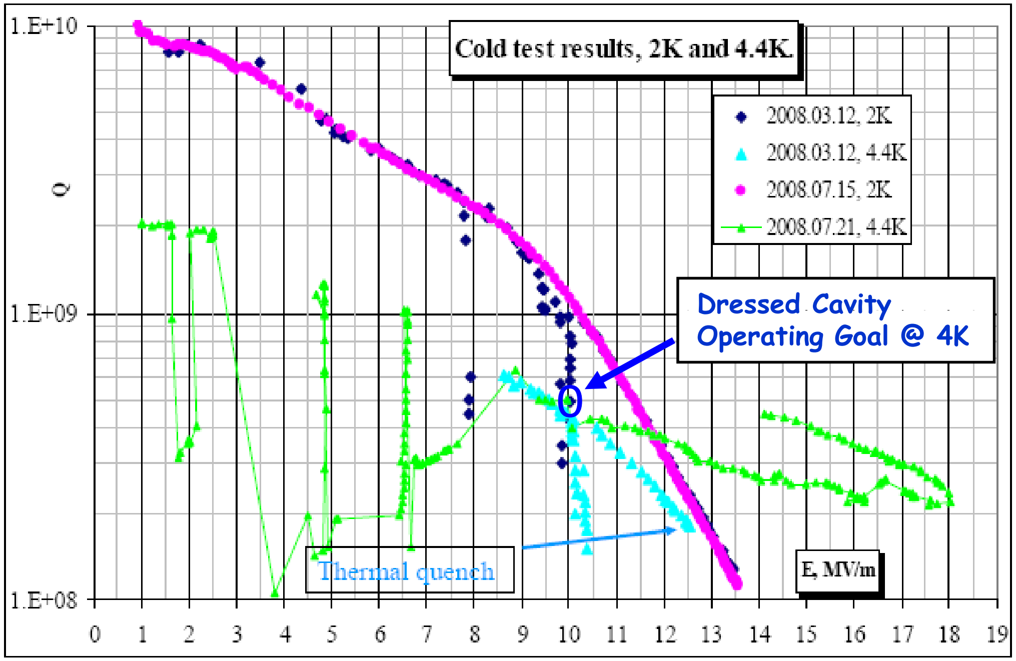
HINS- 325 MHz Cavity and Modulator Tests







HINS - 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

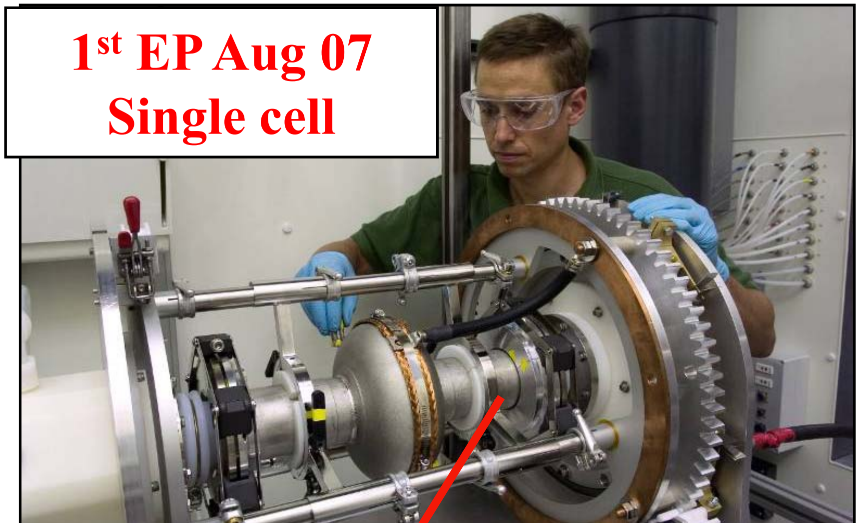
- There is a single 1.3 GHz development program at Fermilab, supporting the ILC/GDE program and simultaneously understanding Project X requirements.
  - 9 mA × 1 msec × 5 Hz Linac
  - Alternatives under consideration may provide enhanced performance and/or flexibility
- At an appropriate time (before 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).
- 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.

New ANL-FNAL Processing Facility

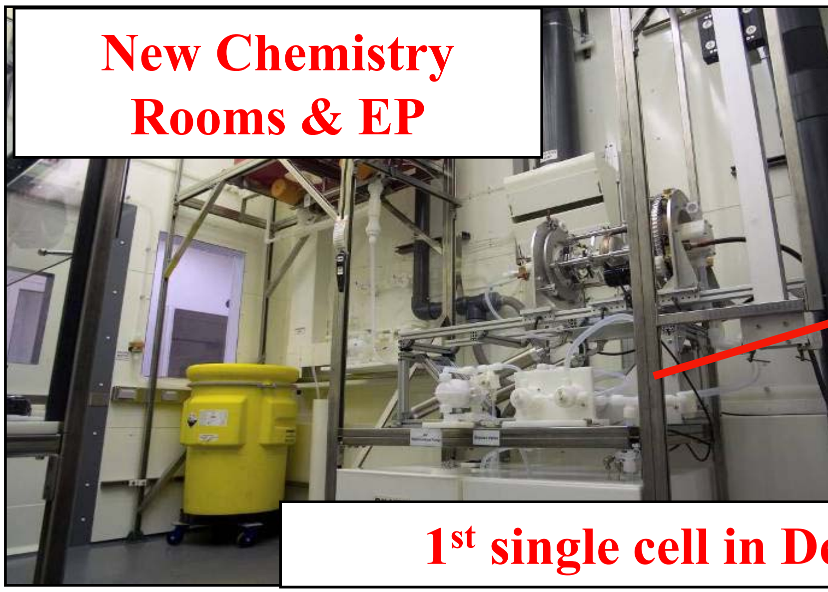
Chemistry, Clean rooms, BCP,HPR & state-of-the-art EP @ANL

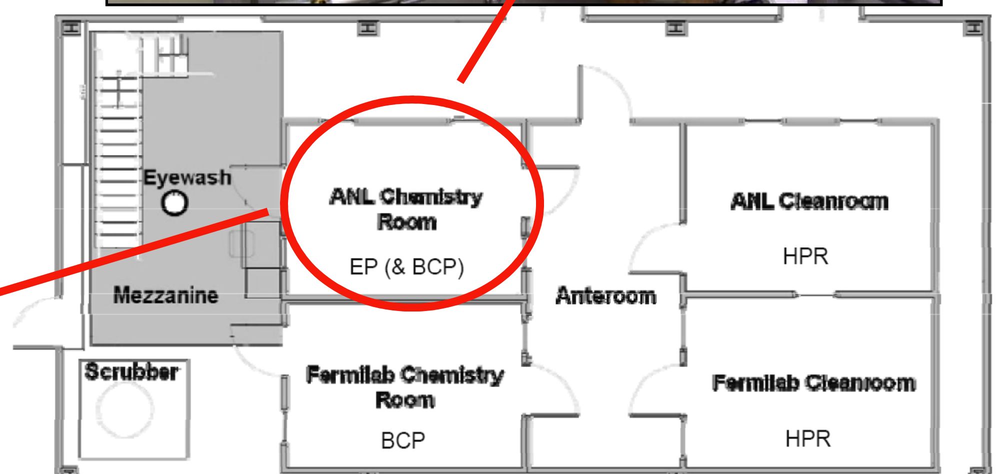
New Clean Rooms

1st EP Aug 07
Single cell



New Chemistry Rooms & EP

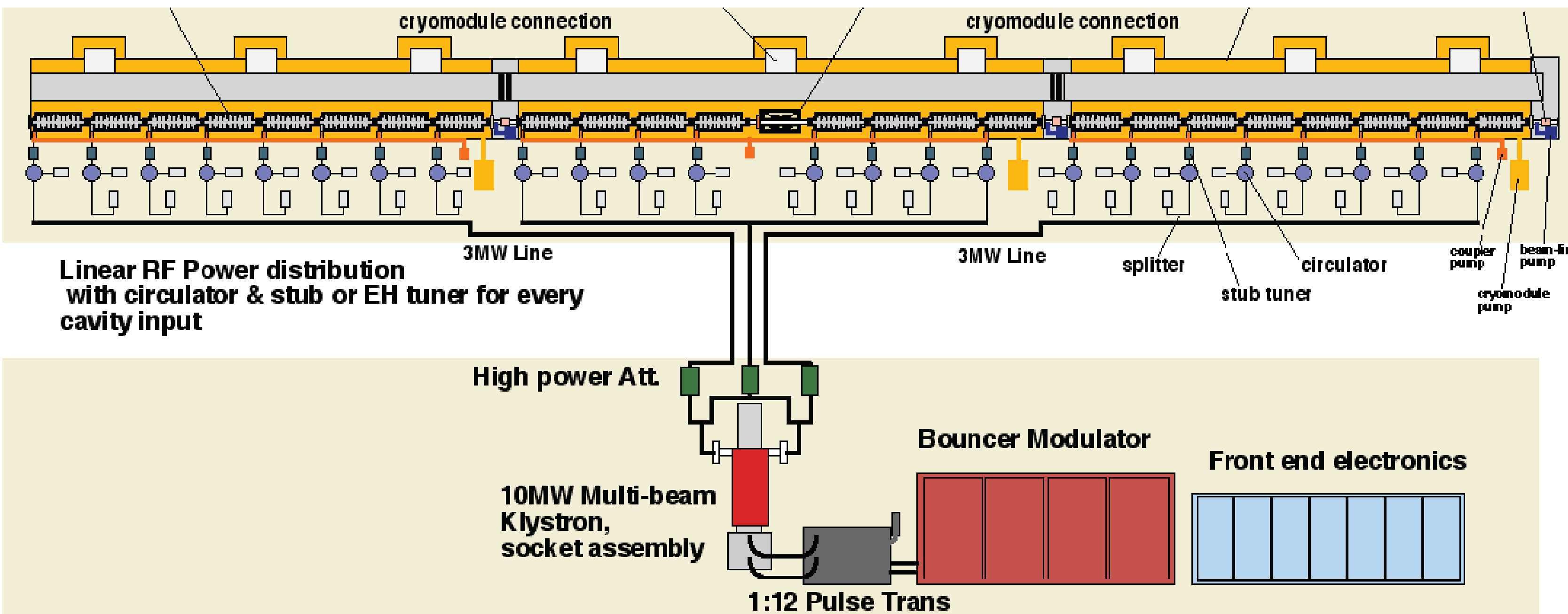




1st single cell in Dec, 9 cell in May 08 ~ 40 EP cycles/yr

ILC RF Unit

- ILCTA-NML is being constructed under the SRF program
  - Demonstration of stable high-power operations.
  - Planning on using ILC Modulator and 10 MW ILC klystron
    - Longitudinal dynamics of low-β H^- beam and possible cavities field variations over time (SNS experience) may require use of IQM modulators throughout the Linac



ILC RF Unit: 24-26 Cavities, 3 CM, klystron, Modulator, LLRF

ILC/SRF: NML Test Facility

First US-build 1.3 GHz Cryomodule installed in NML Facility
August 6th, 2008

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 RD&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 RD&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 Collaborators:
    - ANL, BNL, Cornell, LBNL, ORNL/SNS, MSU, TJNAF, SLAC

Additional Information

- 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
- Project X Accelerator Workshop
  - projectx.fnal.gov/Workshop/
- Additional Technical Information
  - protondriver.fnal.gov/

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.
- Several R&D Efforts (HINS, ILC/SRF, etc) are actively addressing technical issues.

- Project X Collaboration Meeting
  - FNAL, Nov. 21st-22nd 2008