X-Band Linear Collider
Path to the Future

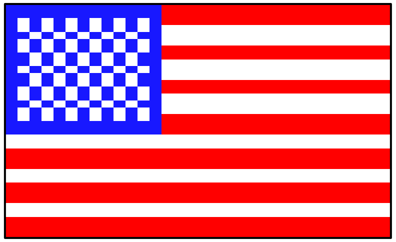
X-Band Linear Collider Report*

D. L. Burke

NLC Program Director

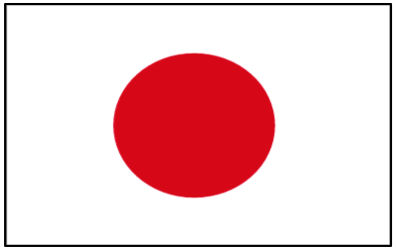
* Abstracted from recent presentations to the International Technical Recommendation Panel.

Extension of conventional warm accelerator technology from 3 GHz (S-Band) to 11.4 GHz (X-Band).



NLC

Led by BNL, FNAL, LBNL, LLNL, SLAC.



JLC

Led by KEK, BINP, HEPL, PAL.

Connected by SLAC-KEK R&D MOU signed in 1998.

Evolution of a common design strategy:

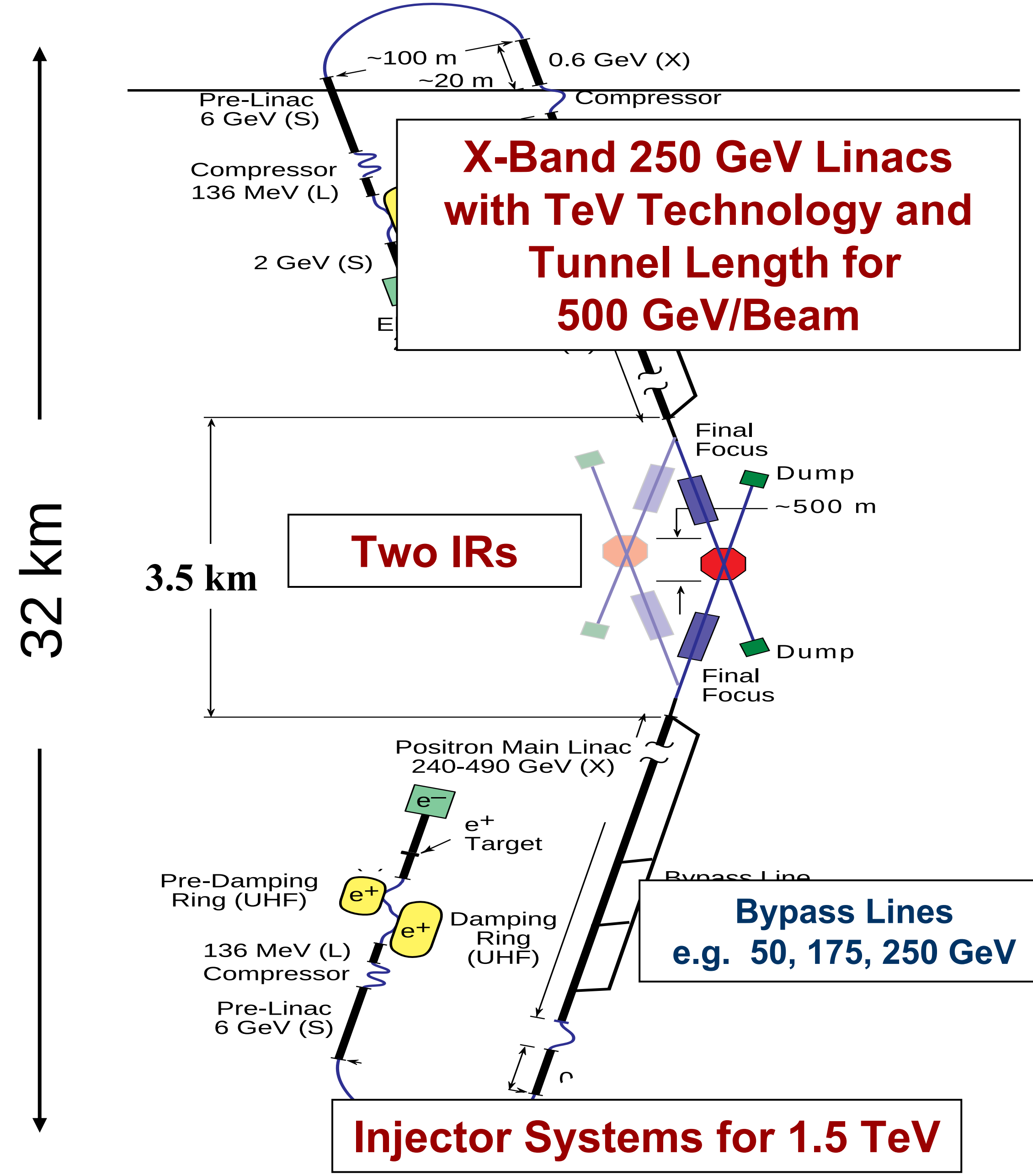
NLC Zero-Order Design
JLC Design Study (1996)

NLC DOE “Lehman” Review (1999)

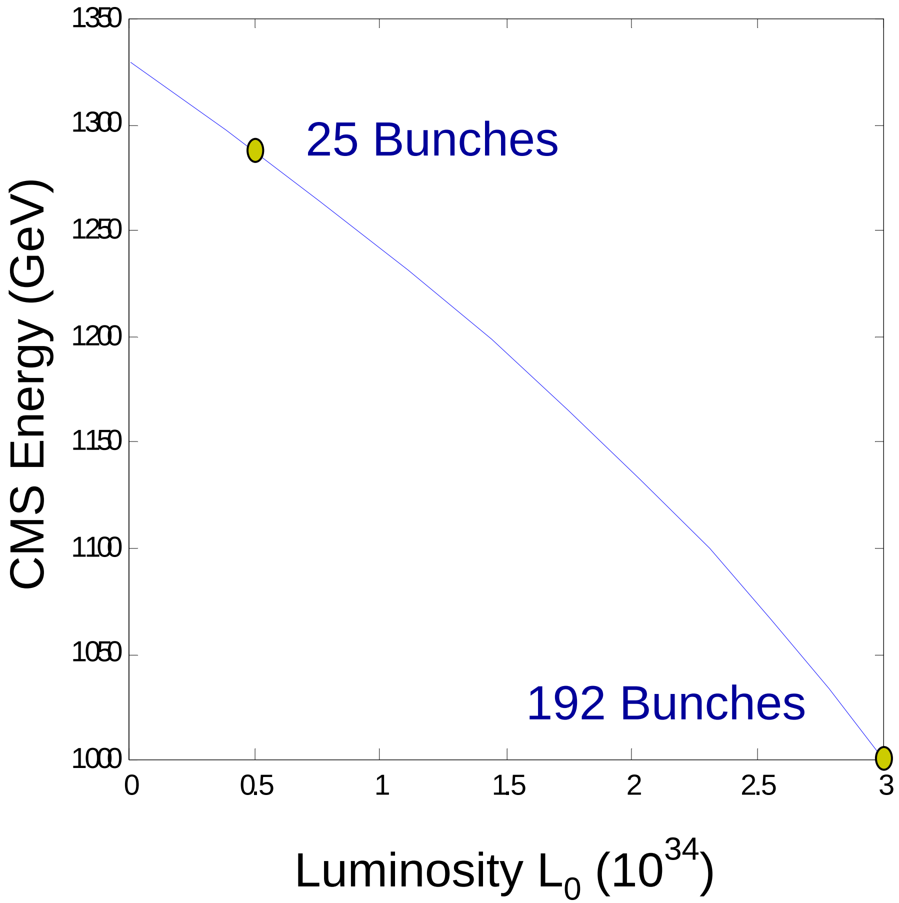
NLC Snowmass 2001 (2001)

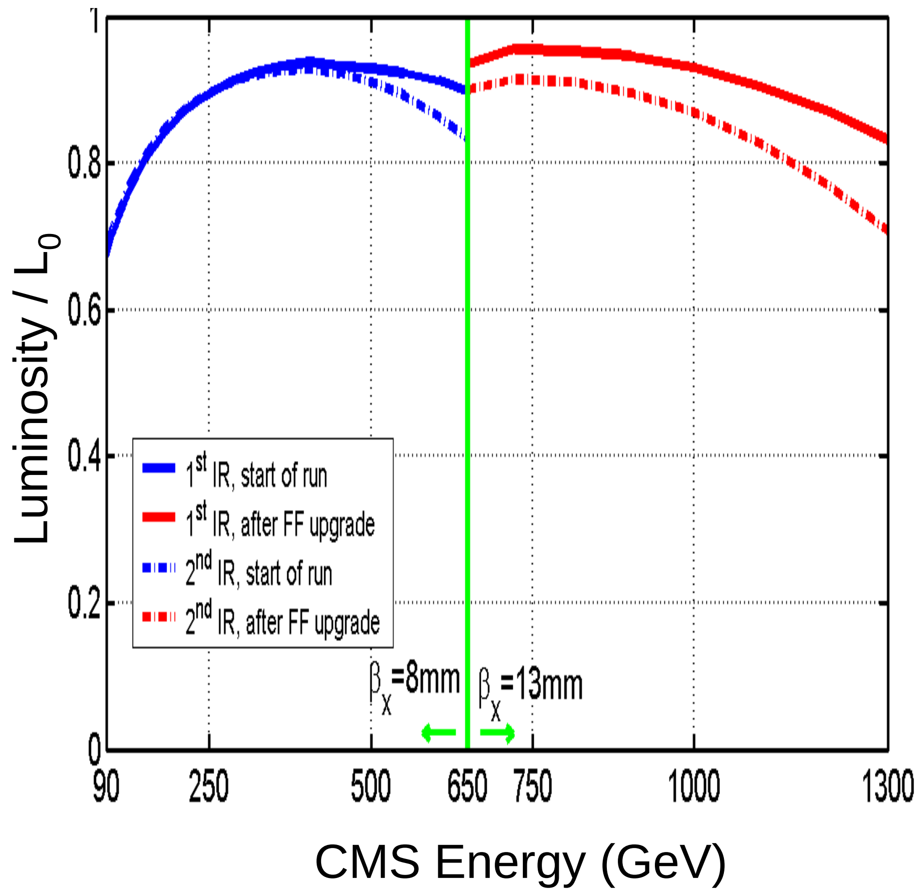
GLC Project Report (2003)

GLC/NLC TRC (2003)



Energy for the Energy Frontier
(GLC/NLC TRC 2003)





A Partner for the LHC

The Challenges
(Presentations to the ITRP)

Luminosity (Raubenheimer)

Beam Control – Emittance and Stability

Beam Power

Energy and Cost (Adolphsen and Cornuelle)

Gradient and Efficiency

Availability (Himel)

Overhead and Margins

Engineering and Design

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Engineering and Design

Next Linear Collider Test Accelerator

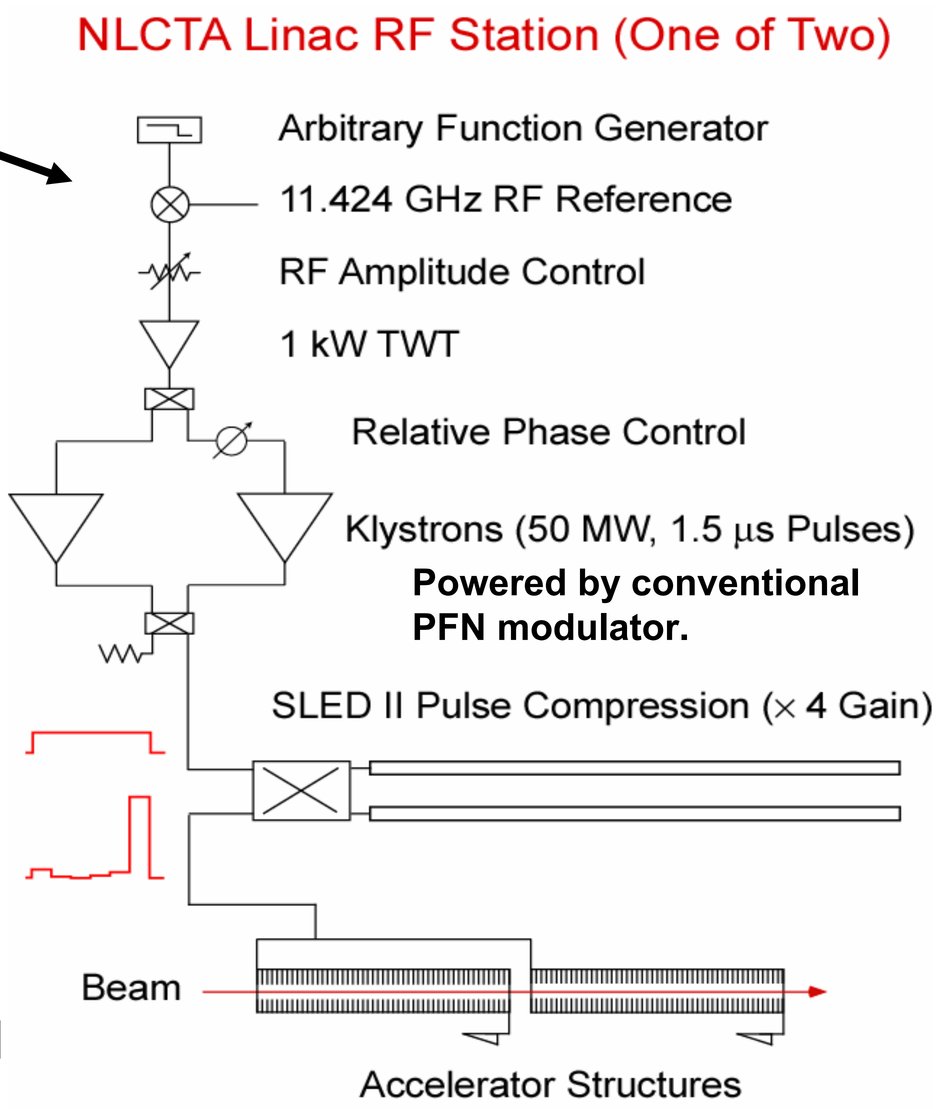
1993 Construction began using first generation X-band components.

1997 Demonstrated 17% beam loading compensation in 1.8m structures at 40 MV/m.

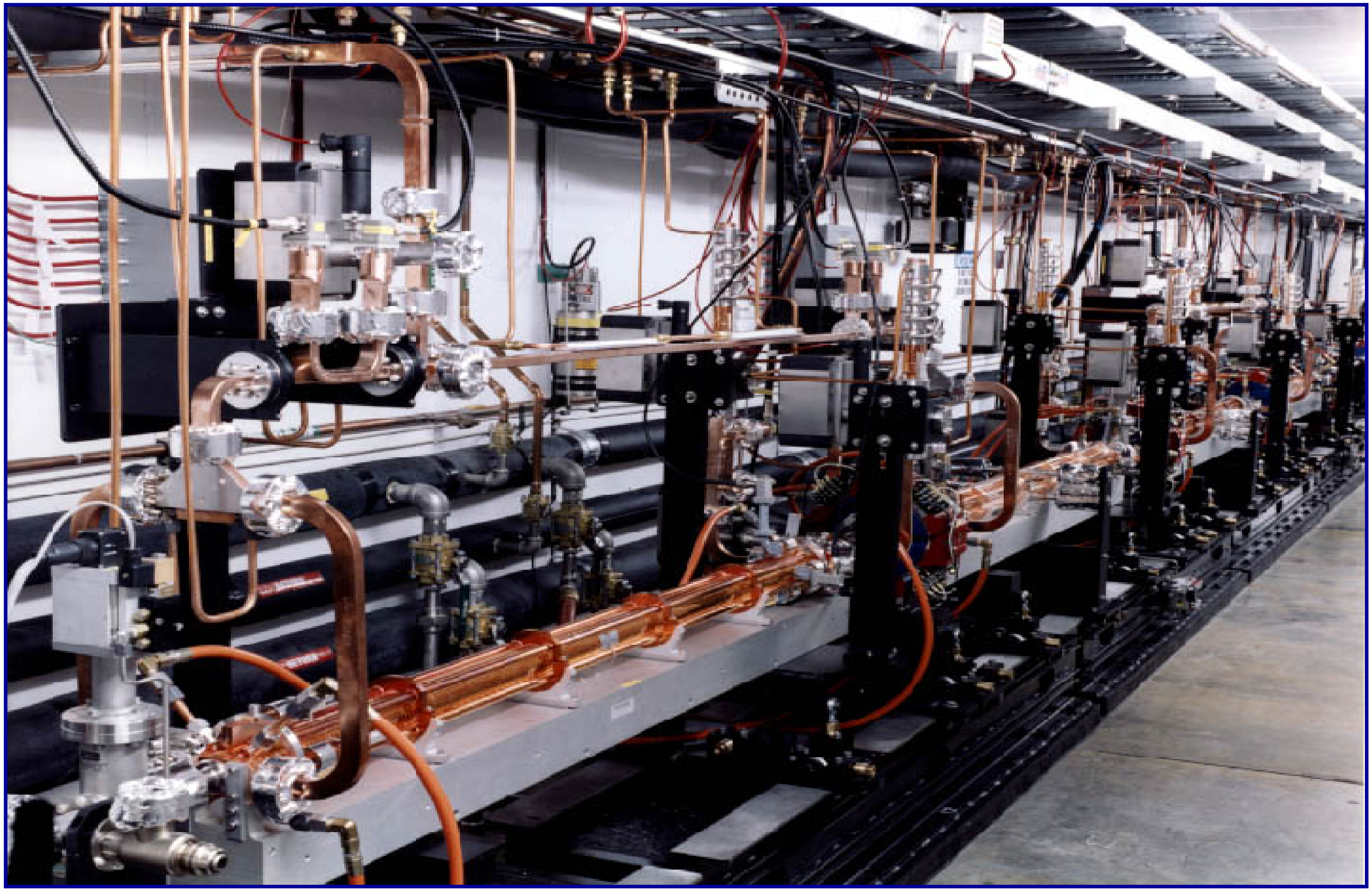
→ Demonstrated ability to reach 500 GeV cms.

1999 Added second klystron to each linac rf station.

2000- High gradient studies, and extension using second generation components aimed at 1 TeV cms.

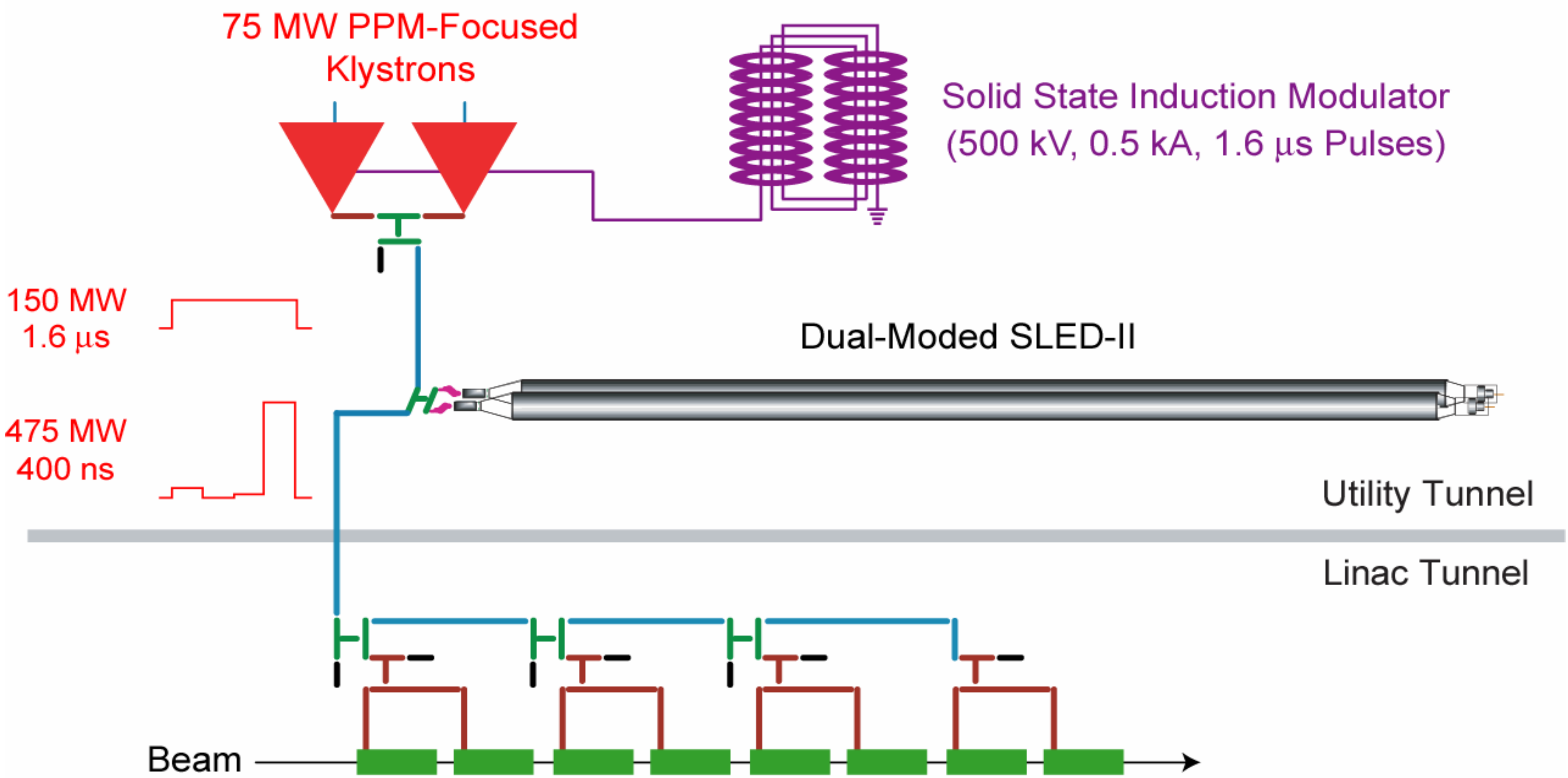


The NLCTA (ca. 1997)



X-Band 1 TeV Baseline RF Unit

(One of ~ 2000 at 500 GeV cms, One of ~ 4000 at 1 TeV cms)



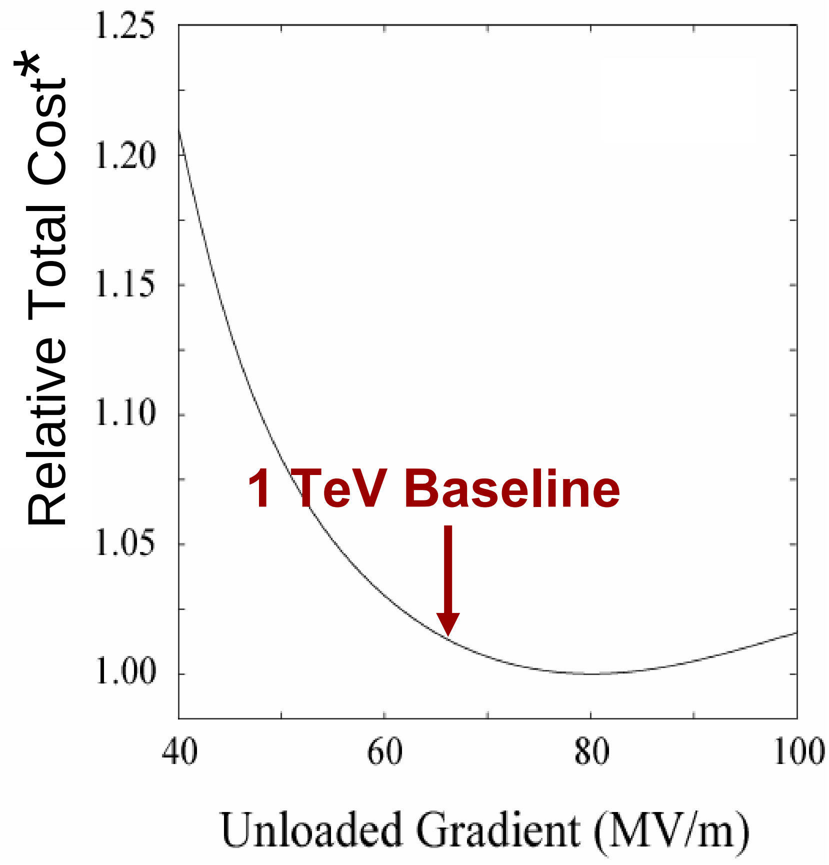
Eight 0.6 m Accelerator Structures (65 MV/m Unloaded, 52 MV/m Loaded)

Cost Versus Gradient

Linac cost is a balance between cost of the power sources (increases with gradient), and cost of accelerator length (decreases with gradient).

Minimum occurs at about 80 MV/m where these are equal, but total collider cost is only 5% higher at 55 MV/m.

→ **Baseline at 65 MV/m.**



(*The linac is about half the total cost of the collider.)

Interlaboratory Collaboration for R&D Towards TeV-scale Electron-Positron Linear Colliders

International Linear Collider Technical Review Committee
ILC-TRC

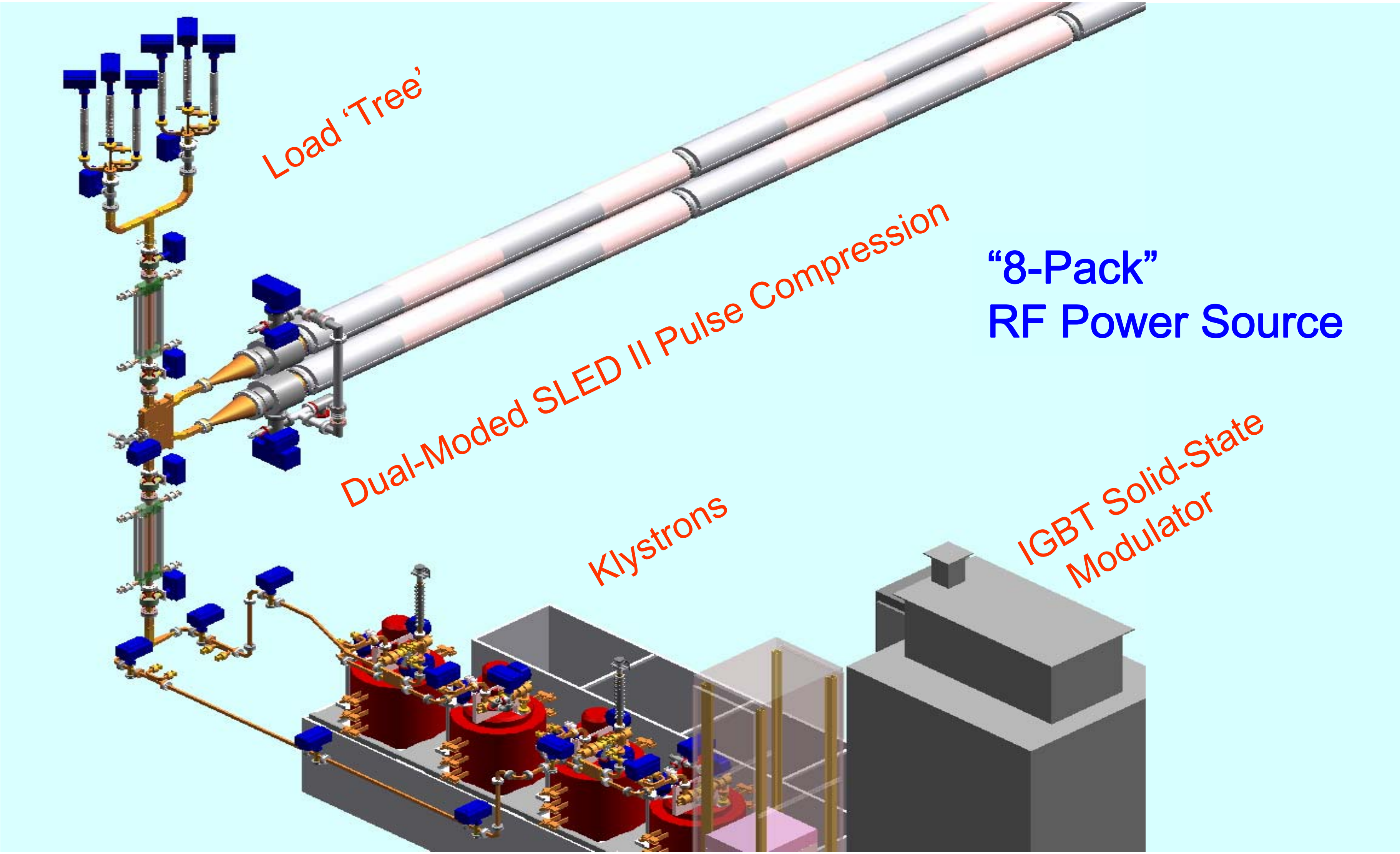
GLC/NLC Level I R&D Requirements (R1) 2003

"Demonstration of SLED-II pulse compression system at design power level."

"Test of complete accelerator structure at design gradient with detuning and damping, including study of breakdown and dark current."

→ **Both R1 requirements have now been met.**

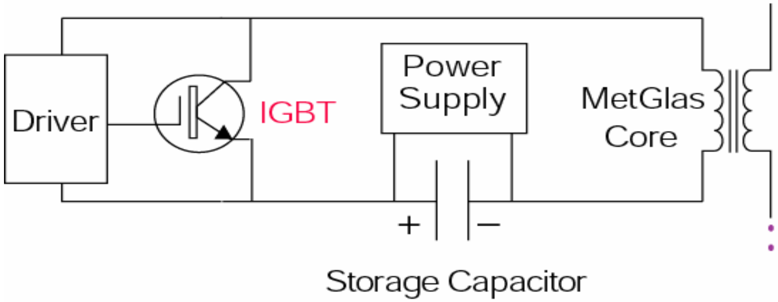
Second Generation NLCTA
(X-Band 1 TeV Baseline Demonstration)

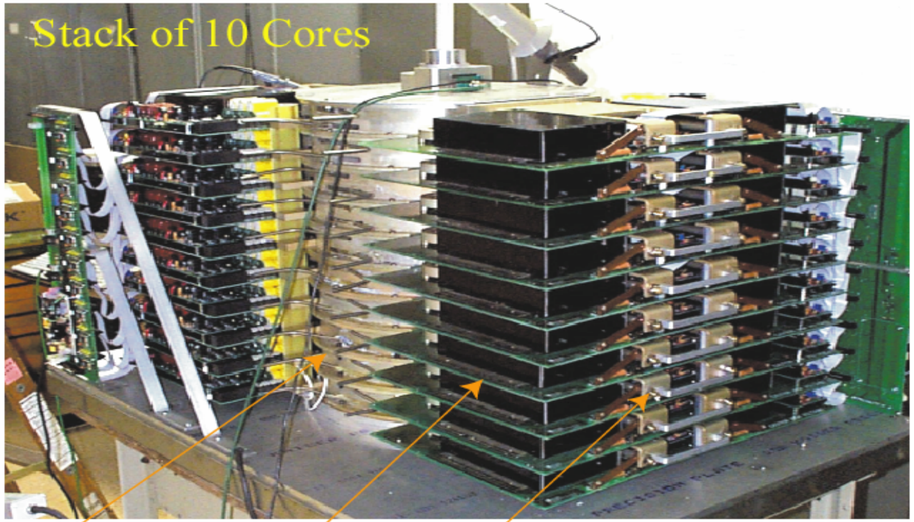


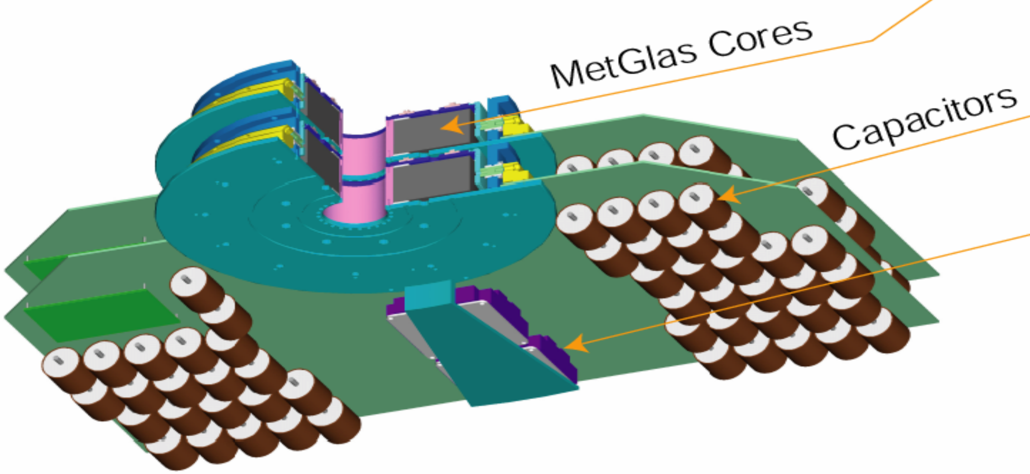
Solid State IGBT Modulator Test Stack

SUM MANY LOW VOLTAGE (~ 2 kV) SOURCES INDUCTIVELY

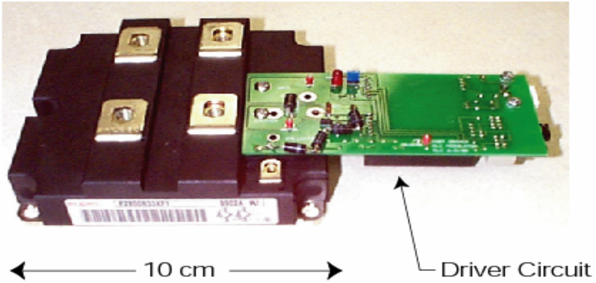
INDUCTION CIRCUIT (1 OF N)







Insulated Gate Bipolar Transistors



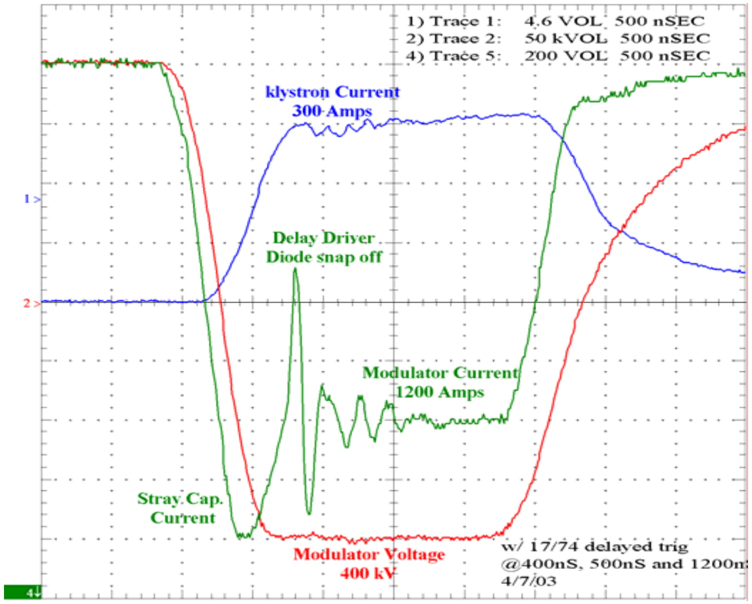
8-Pack IGBT Modulator

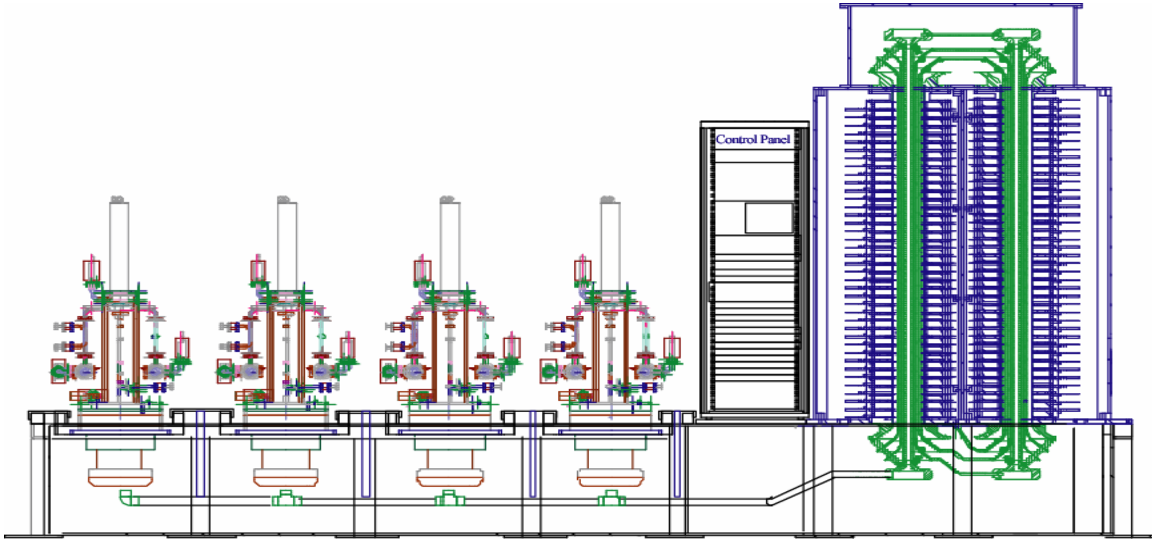
76 Cores

Three-Turn Secondary

> 1000 Hours of Operation

Waveforms When Driving Four 50 MW Klystrons at 400 kV, 300 A Each

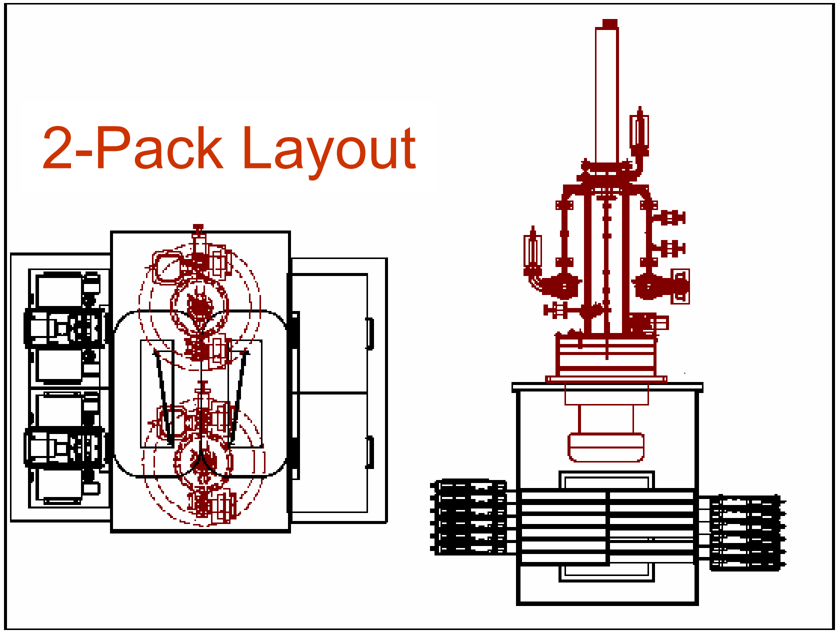




Next Generation: The 'Two-Pack'

Features

- 6.5 kV IGBTs with in-line multi-turn 1:10 transformer.
- Industrialized cast casings.
- Improved oil cooling.
- Improved HV feed through.



Bechtel-LLNL-SLAC Team

A hybrid 2-Pack modulator is currently running in the SLAC Power Conversion Department lab.

Modulator Performance

(1.6 μs Pulse Width)

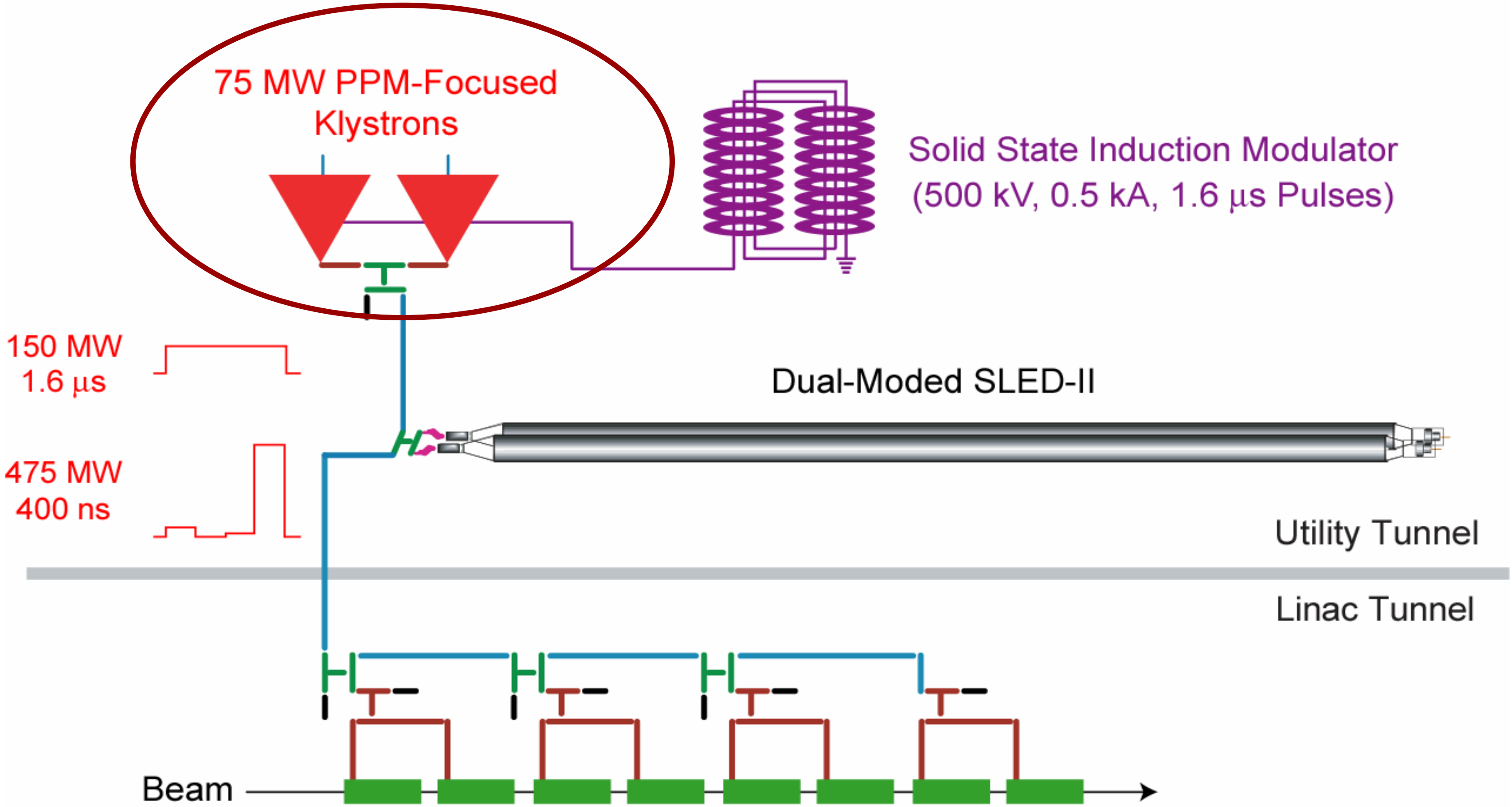
	Config	Load	Voltage (kV)	Current (A)	Rate (Hz)	Efficiency (%)
Achieved	8-pack	Water	500	1000	10	
	8-Pack	Four XL4 Klystrons	400	1200	60	58
	2-Pack Hybrid	Water	500	500	120	60
NLC/GLC Baseline	2-Pack	Two PPM Klystrons	500	500	120	70

Prototype modulators operate at voltages and currents exceeding NLC/GLC requirements.

2-Pack efficiency is lower than goal due to hybrid transformer – expect > 70% in next version with integrated transformer.

1 TeV X-Band Baseline RF Unit

(One of ~ 2000 at 500 GeV cms, One of ~ 4000 at 1 TeV cms)

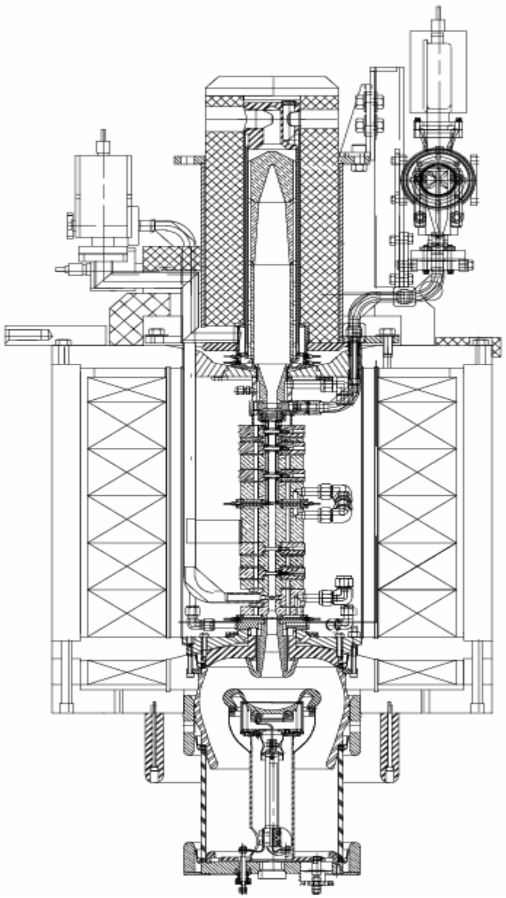


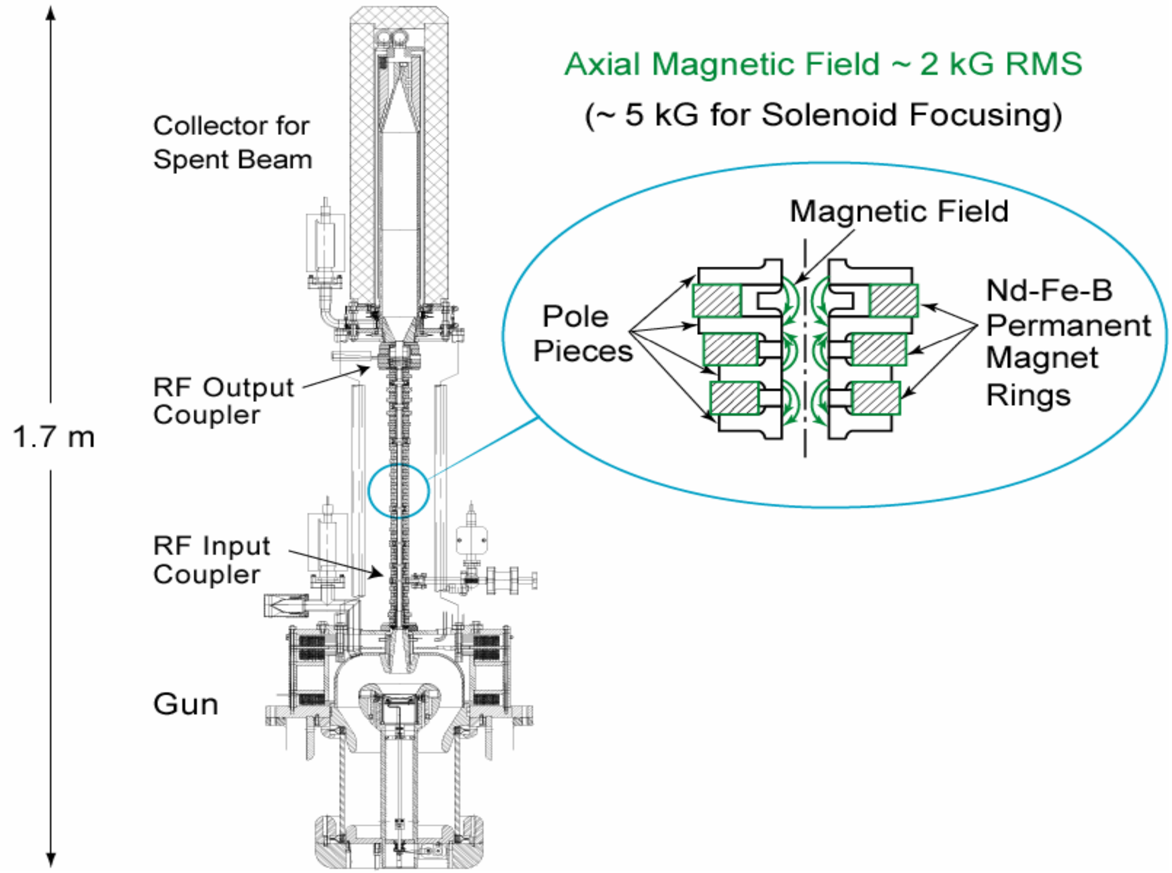
Eight 0.6 m Accelerator Structures (65 MV/m Unloaded, 52 MV/m Loaded)

X-Band Klystrons

Solenoid-Focused Tubes: Have Twelve, 50 MW Tubes for Testing, However Solenoid Power = 25 kW.

Developing Periodic Permanent Magnet (PPM) Focused Tubes to Eliminate the Power Consuming Solenoid.





PPM Klystron Overview

PPM Klystrons being developed at SLAC, and at KEK in collaboration with Toshiba.

50 MW and 75 MW Tubes tested during past six years:

- Five at KEK/Toshiba.
- Six at SLAC.
- Two industrial (EEV and Toshiba).
- Two tubes to date have met NLC/GLC requirements (all key parameters concurrently).

TRC R2 requirement of 120 Hz operation has been met.

PPM Klystron Performance

(75 MW, 1.6 μs, 120/150 Hz, 55% Efficiency Required)

KEK/Toshiba

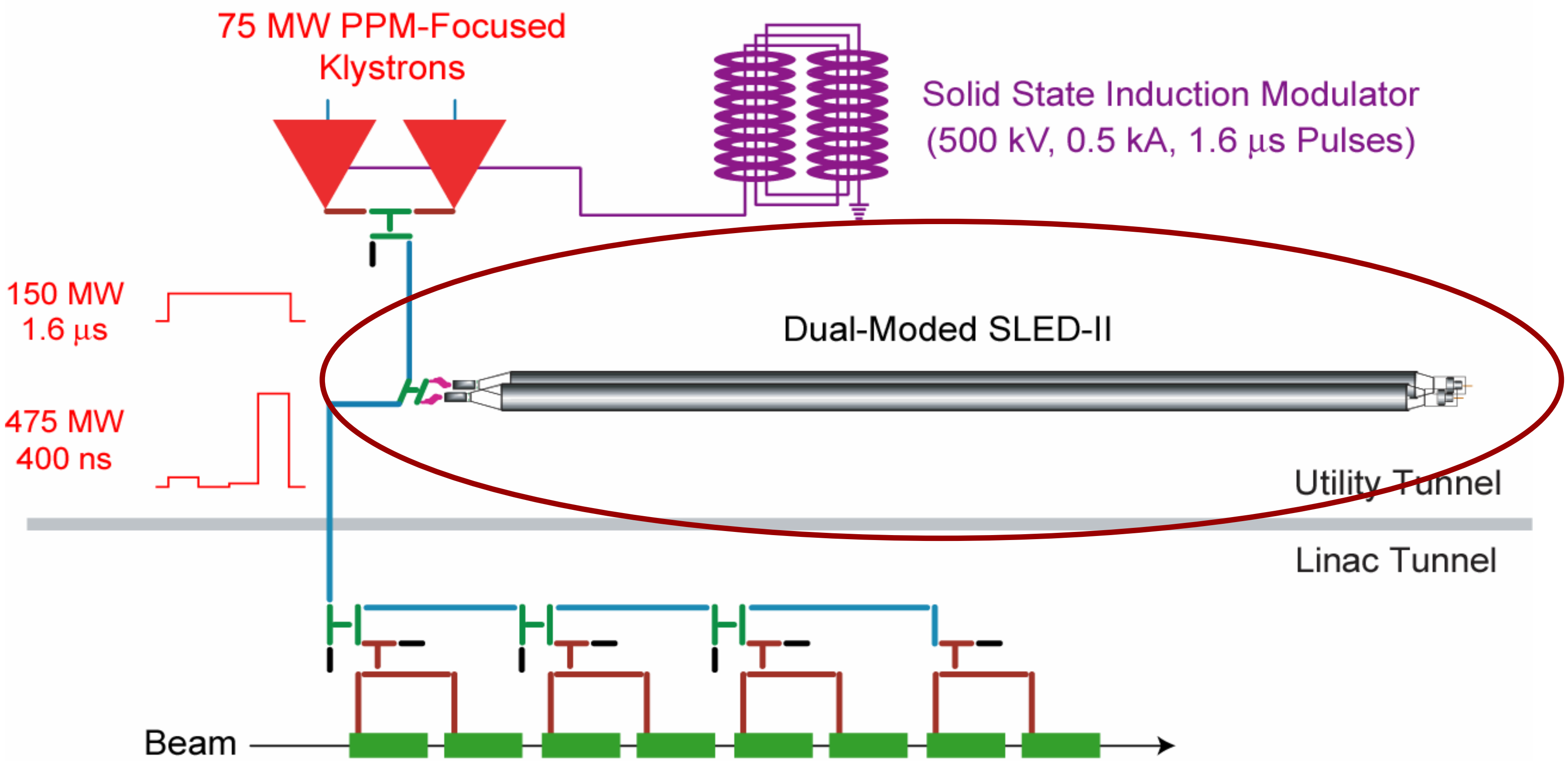
Two tubes tested at
75 MW with
1.6 ms pulses at
50 Hz (modulator limited).
Efficiency = 53-56%.

SLAC

Two tubes tested at
75 MW with
1.6 ms pulses at
120 Hz.
Efficiency = 53-54%.

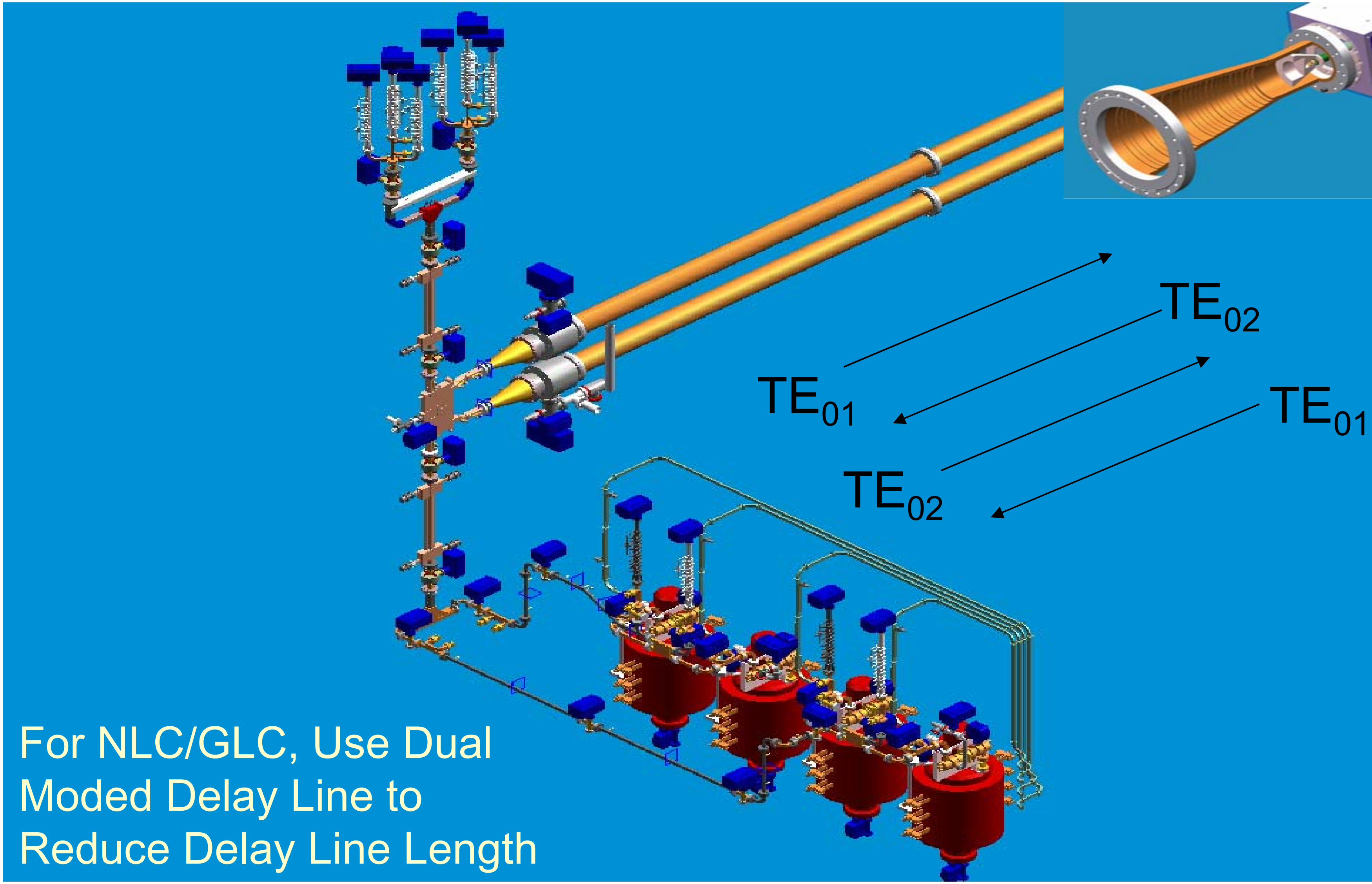
1 TeV X-Band Baseline RF Unit

(One of ~ 2000 at 500 GeV cms, One of ~ 4000 at 1 TeV cms)



Eight 0.6 m Accelerator Structures (65 MV/m Unloaded, 52 MV/m Loaded)

Second Generation SLED II at NLCTA

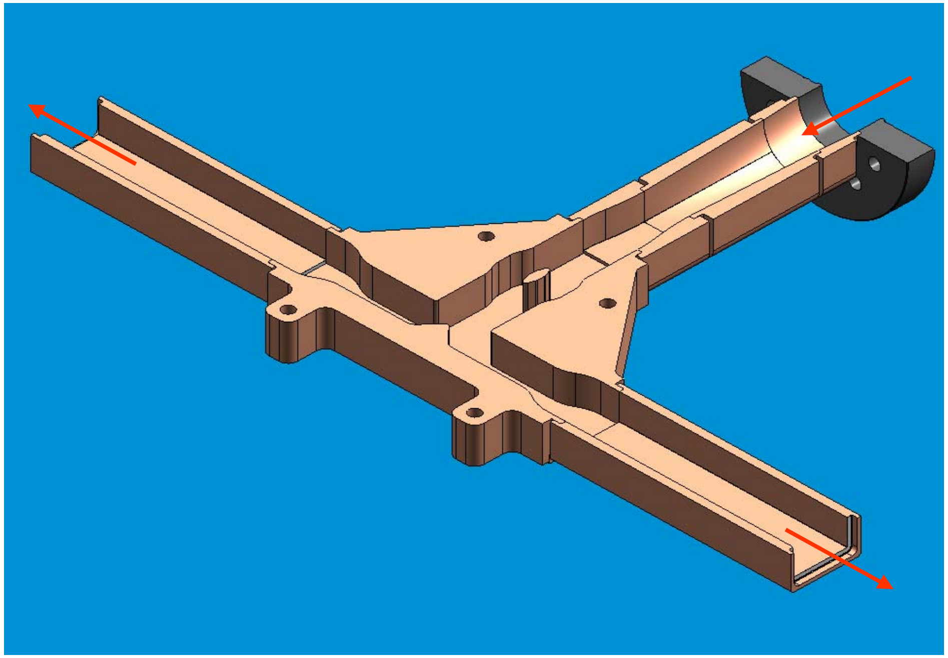


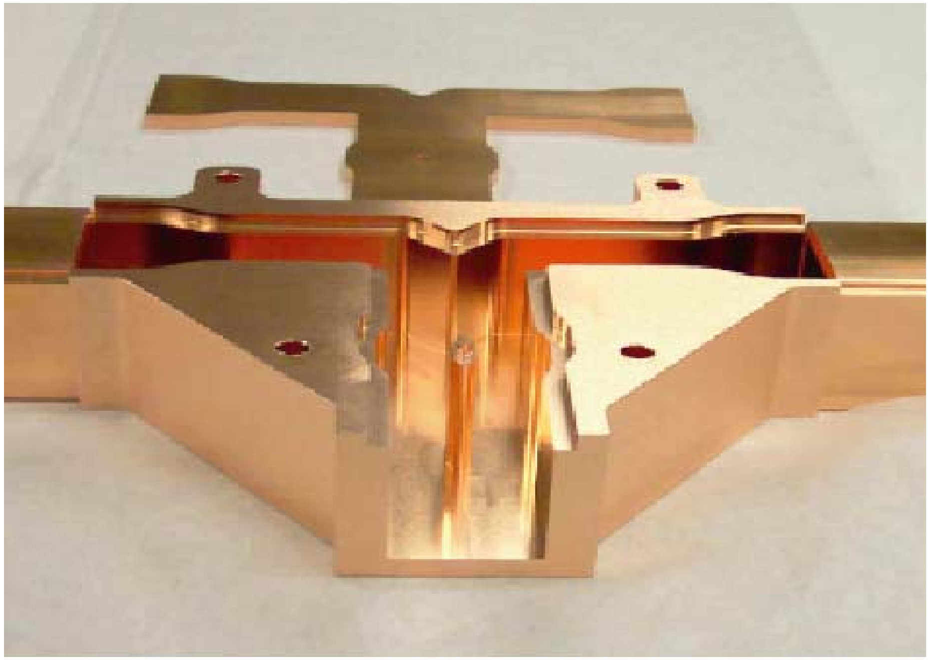
For NLC/GLC, Use Dual Moded Delay Line to Reduce Delay Line Length in Half

Over-Height Planar Waveguide

Lower Surface Electric Fields (< 50 MV/m) and Limited Pulse Heating (< 40° C)

Example: Power Splitter





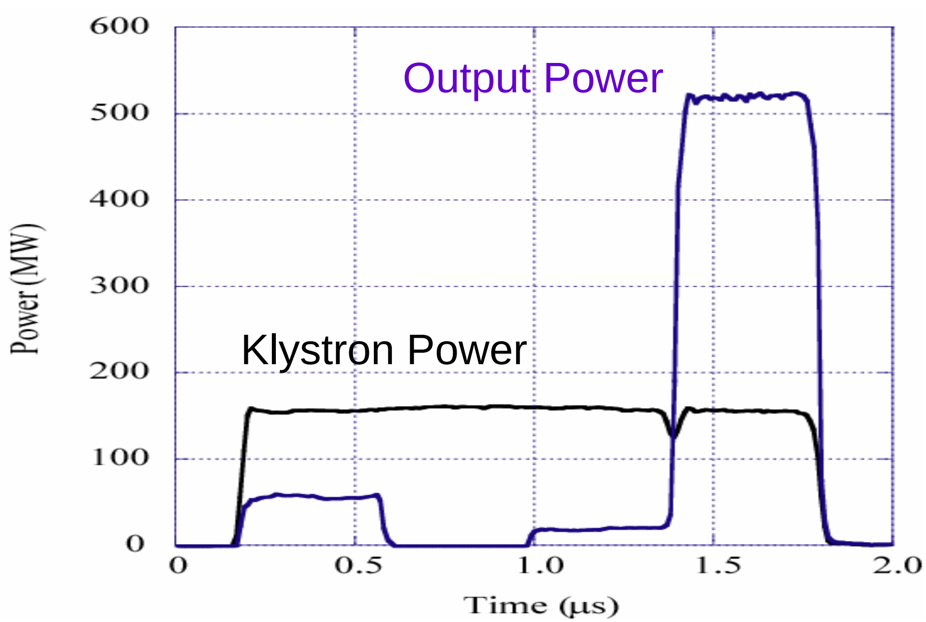
Solid-State Modulator and Dual-Mode SLED-II

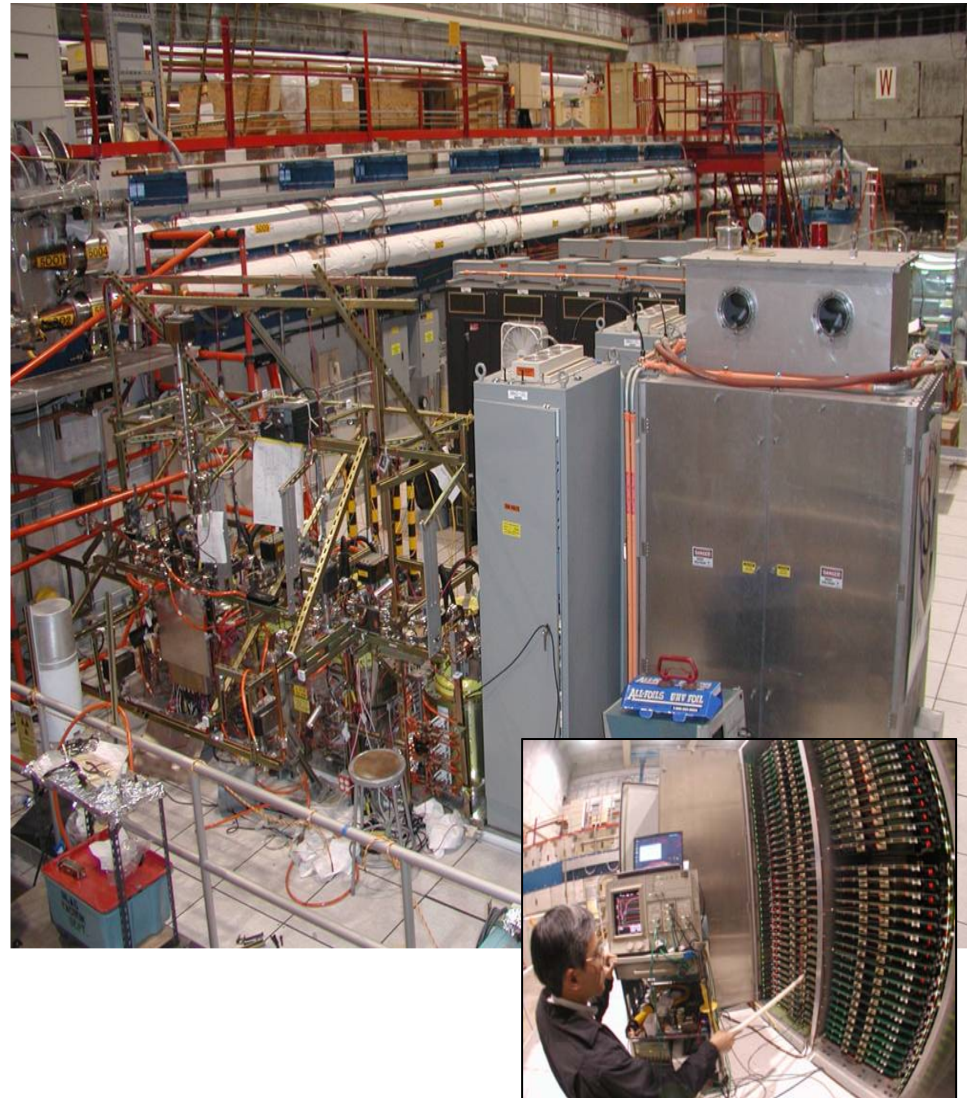
TRC R1 Done.

Power 580 MW to loads (design is 475 MW) at 400 ns.

Operated 300 hours at 510 MW, and over a 1000 at 320 MW.

Turn-key with feedbacks.





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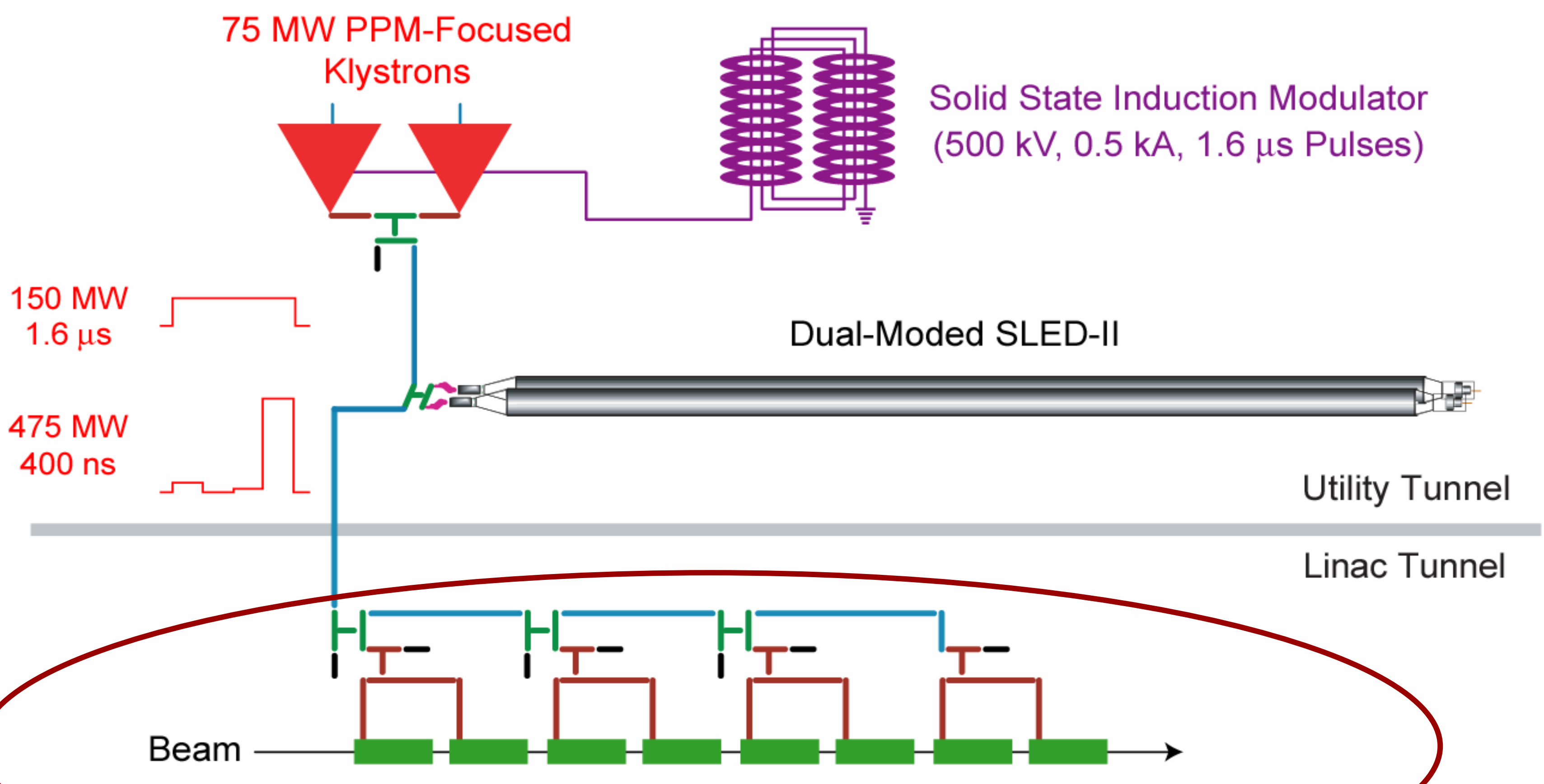


Eight 0.6 m Accelerator Structures (65 MV/m Unloaded, 52 MV/m Loaded)

High Gradient Structure Development

In 1999, discovered gradient limitations in original 1.8 m structures – have since:

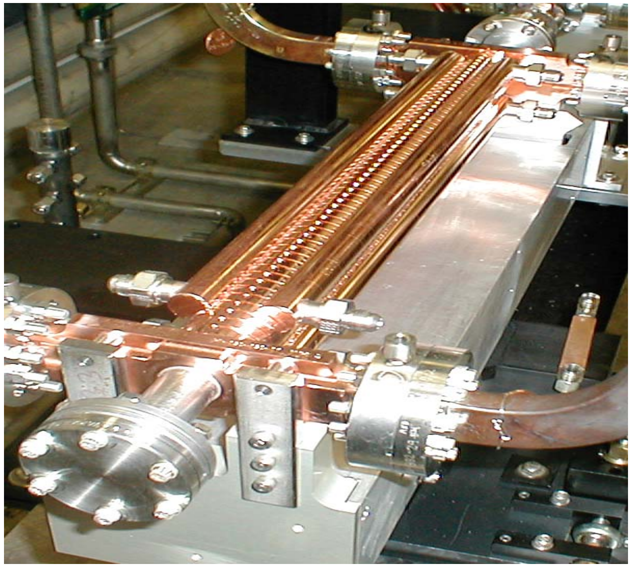
Tested 34 structures with over 20,000 hrs of high power operation at NLCTA.

Improved structure preparation procedures – chemical etching, high temperature firing, and high-power processing protocol.

Found structures with lower input power (lower group velocity) more robust against damage from rf breakdown.

Developed designs with low surface currents, optimized gradient profiles, and needed wakefield detuning and damping.

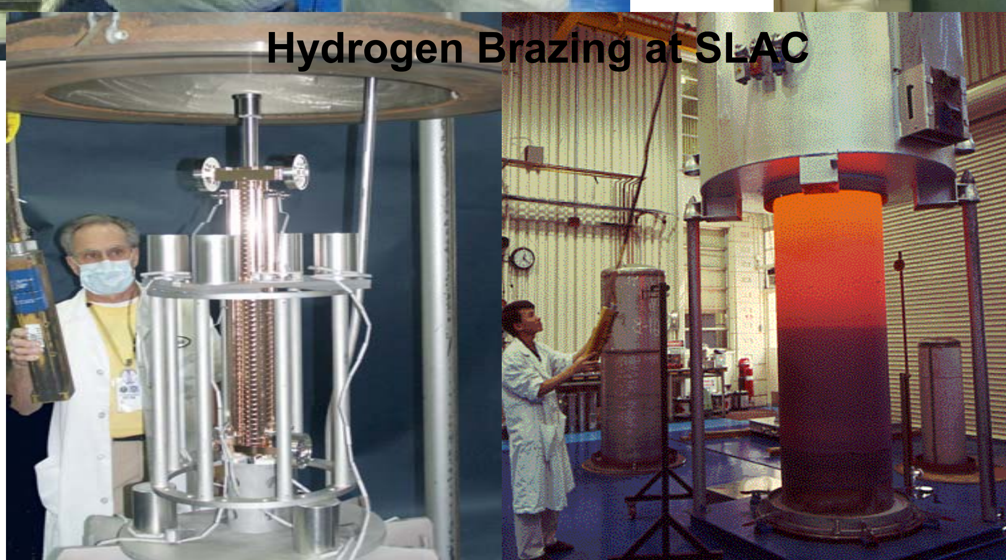
Traveling-Wave Structure
(60 cm)



Structure Fabrication


Inspection and Assembly at FNAL
(Class 1000 Clean Room)

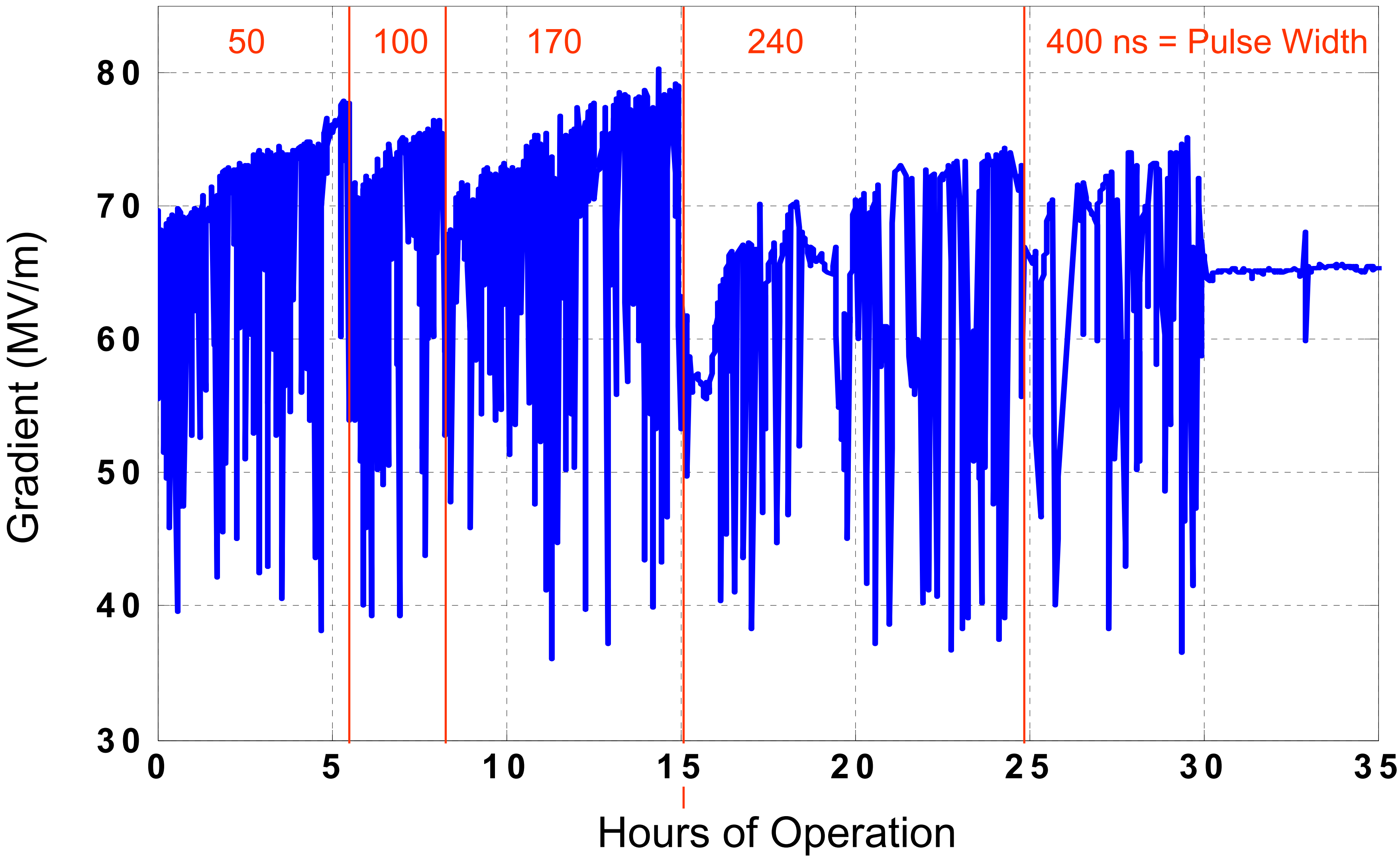

Chemical Etching of Cells at KEK


Hydrogen Brazing at SLAC

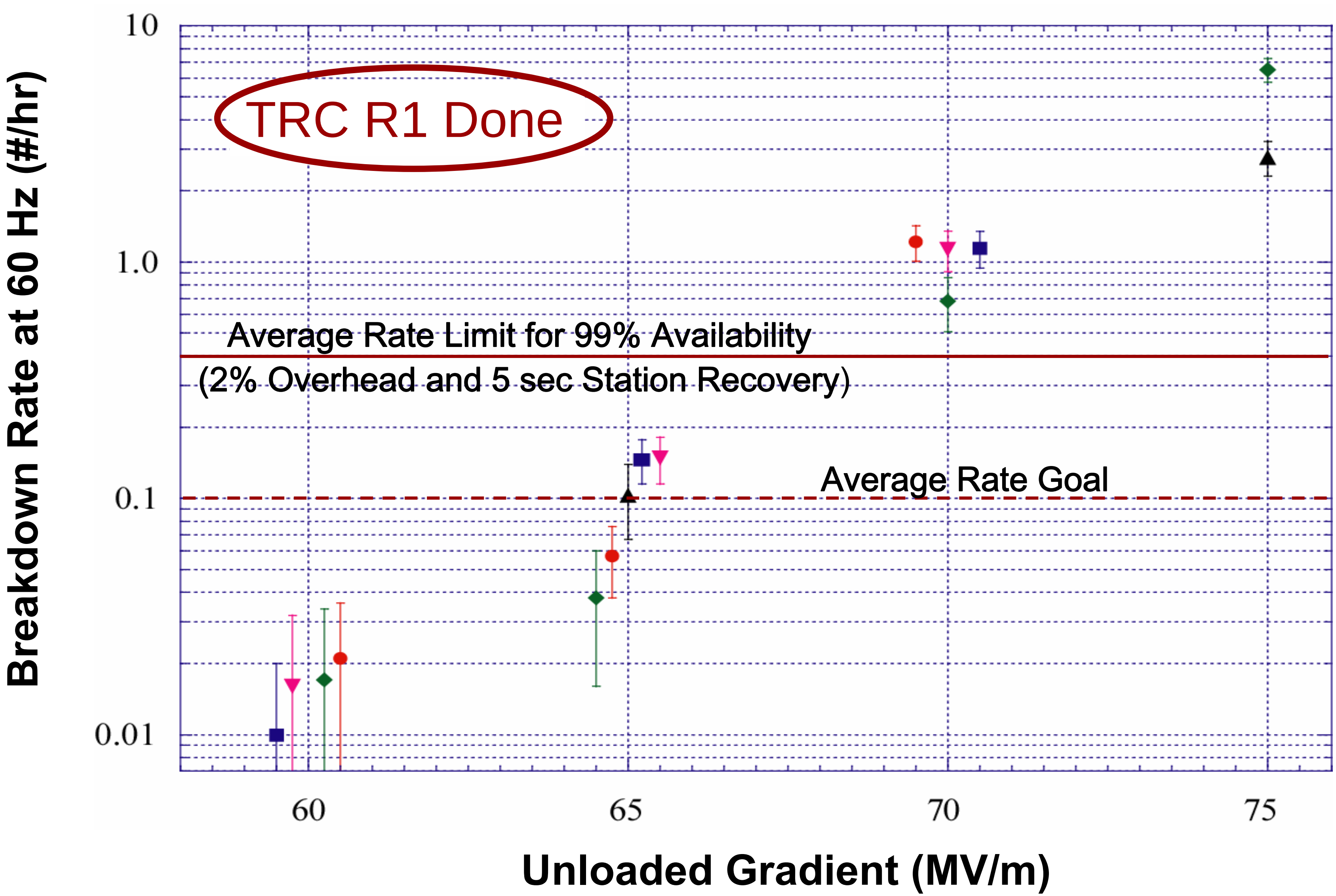
Complete structures are assembled at FNAL, SLAC, and KEK with parts made in industry.

Tests of first structures completely built in industry now beginning.

Processing Structures in NLCTA

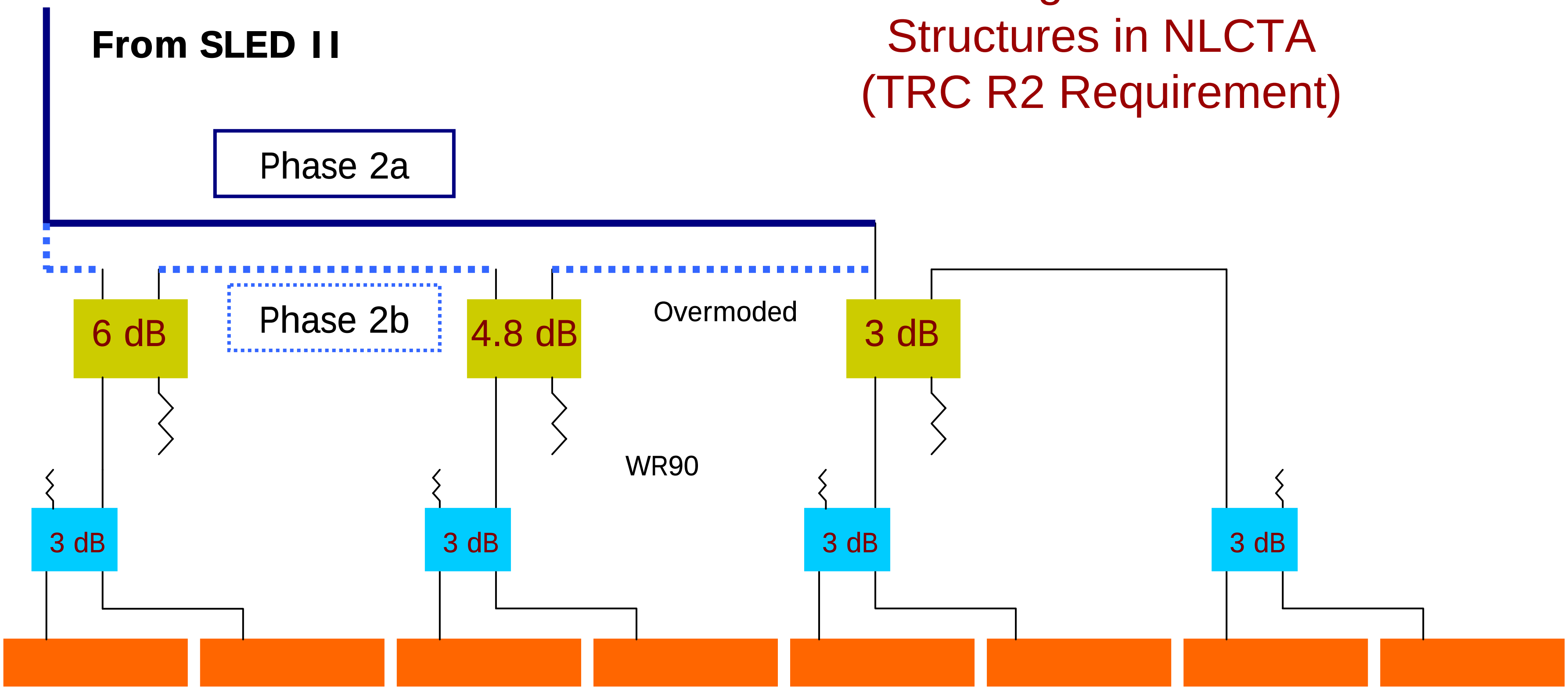


High Gradient Performance of Recent Structures



System Demonstration and Operation

Power Eight Accelerator Structures in NLCTA (TRC R2 Requirement)



First four structures continue to be powered by original NLCTA stations.

Running 24/7 since first of April; 700 hours of operation with > 90% uptime … →

April Operation of NLCTA

Structure	Manufacturer	Gradient (MV/m)	Trip Rate (#/hr)
H60vg4R17-1	SLAC	63.0	0.09
H60vg4R17-2	SLAC	62.0	0.14
H60vg3S17-FXC4	FNAL	60.8	0.13
H60vg3S17-FXC3	FNAL	59.9	0.09
H60vg3-FXB6	FNAL	60.6	0.03
H60vg3-FXB7	FNAL	62.4	0.07
H60vg4S17-1	KEK/SLAC	59.1	0.19
H60vg3R17	SLAC	60.6	0.07
Average		61.1	0.10

May Operation of NLCTA

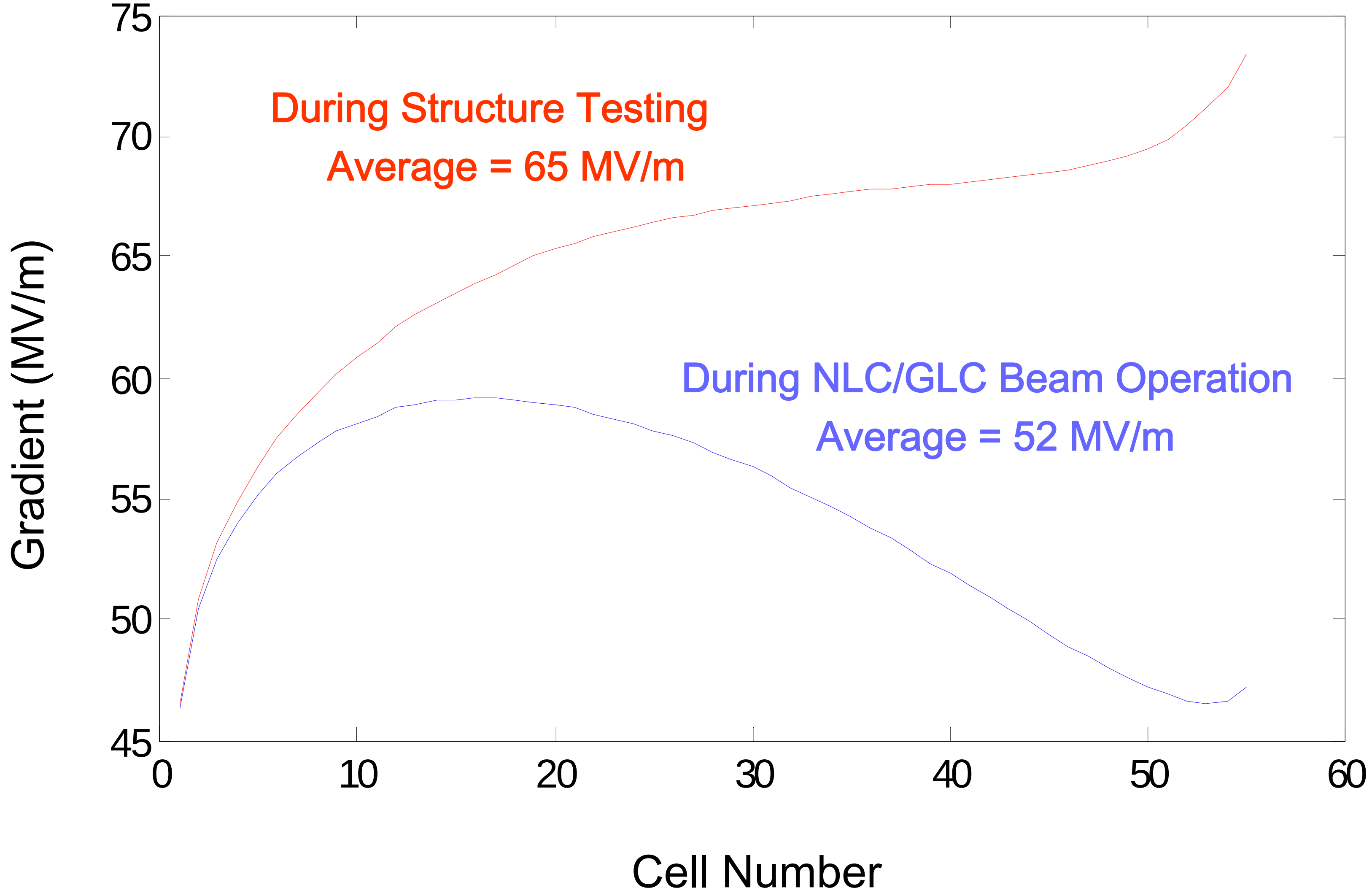
(* = Installed first of May)

TRC R2 Done

Structure	Manufacturer	Gradient (MV/m)	Trip Rate (#/hr)
H60vg4S17-FXD1A *	FNAL	65.5	0.31
H60vg3S17-FXC5 *	FNAL	64.5	0.17
H60vg4S17-3 *	KEK/SLAC	65.5	0.23
H60vg3S17-FXC3	FNAL	64.5	0.13
H60vg3-FXB6	FNAL	64.7	0.01
H60vg3-FXB7	FNAL	66.6	0.05
H60vg4S17-1	KEK/SLAC	63.1	0.21
H60vg3R17	SLAC	64.7	0.19
Average of All 8		64.9	0.16
Average of Original 5 (was 0.09 @ 60.5)		64.7	0.12

→ **Performance improved with running time.**

Expect Lower Rates During Beam Operation



Support for Industrialization

(Ultimately to be planned by Global Design Organization.)

Goals

Fully utilize existing infrastructures and facilities.

Provide intellectual ownership and experience with X-Band to those leading Main Linac work packages.

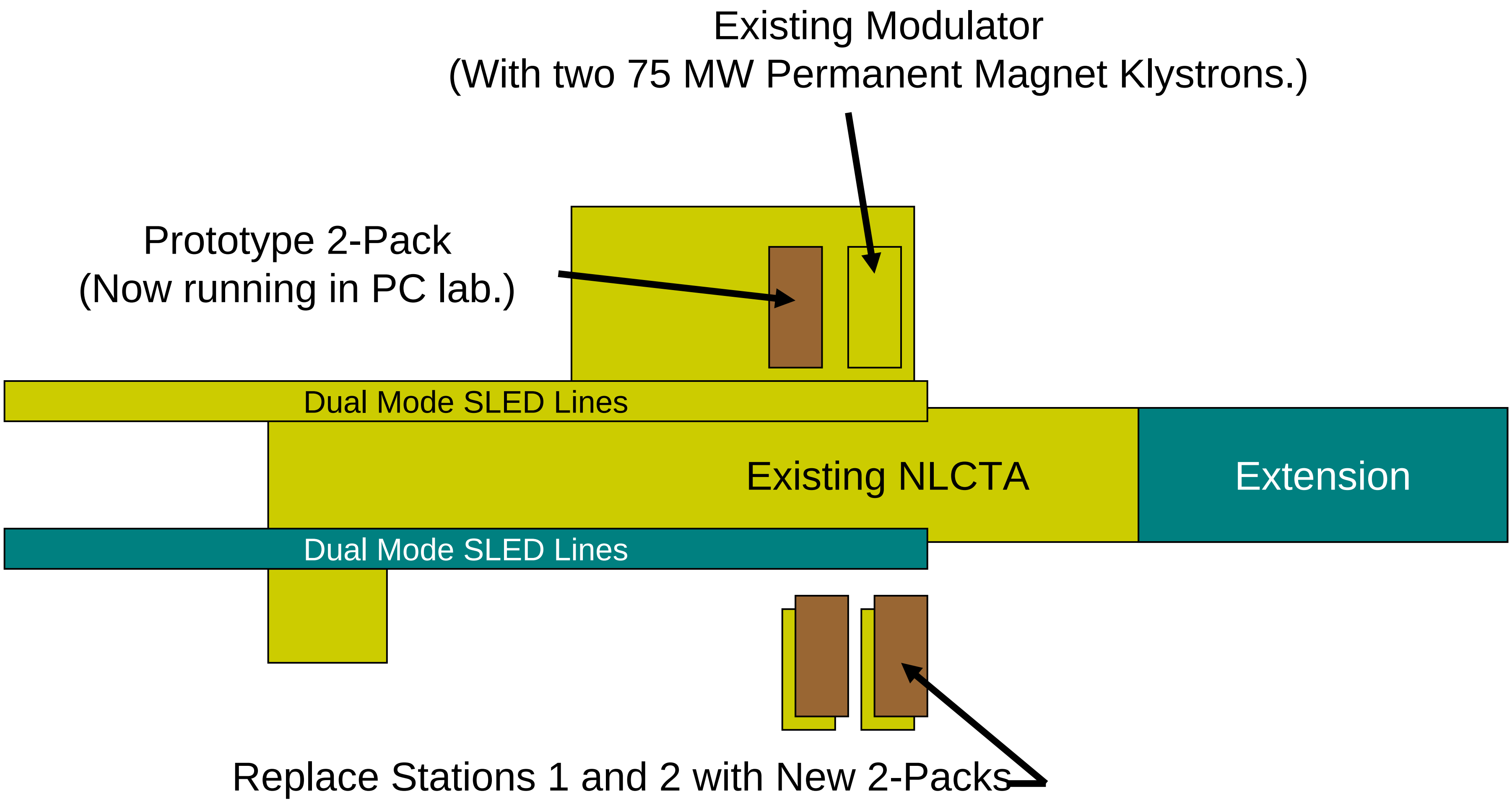
Provide liaison and testing facilities for participating industries.

Plan

Extensions of GLCTA and NLCTA test facilities.

Beams available for component and system testing.

Extension of NLCTA to 1 GeV
(See also GLCTA.)



The Challenges
(Presentations to the ITRP)

Luminosity (Raubenheimer)

Beam Control – Emittance and Stability

Beam Power

Extended discussions in the afternoon break-out tour.

Energy and Cost (Adolphsen and Cornuelle)

Gradient and Efficiency

Availability (Himel)

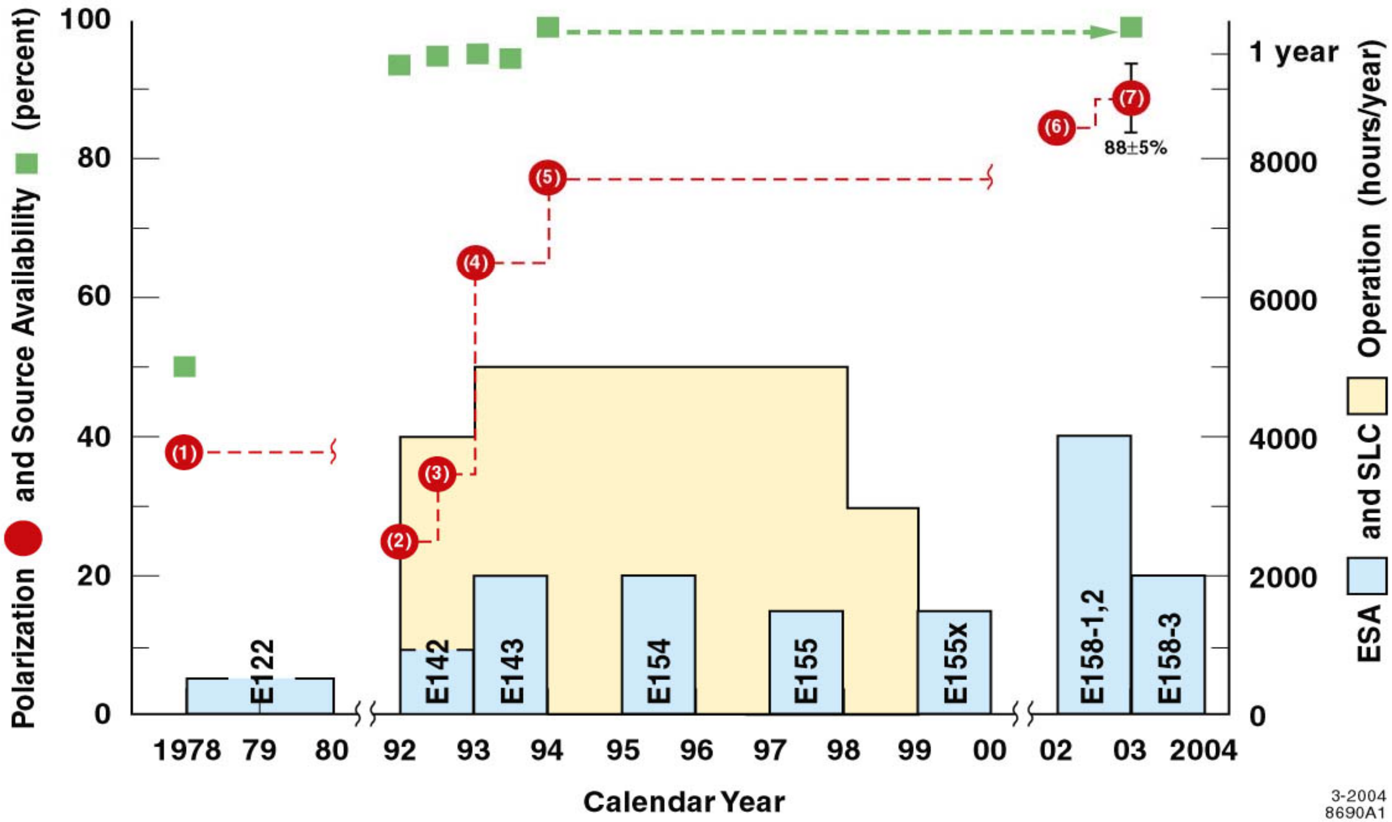
Overhead and Margins

Engineering and Design

Polarized Electron Source

SLC and SLAC ESA

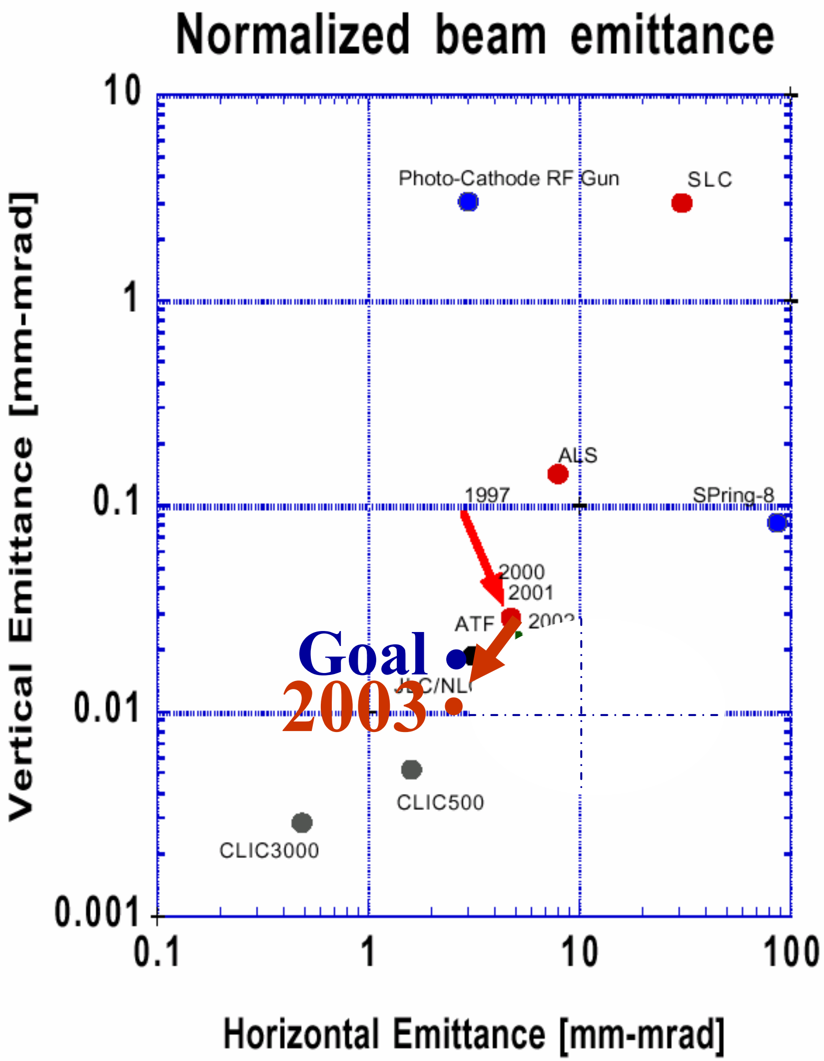
(1) Thick GaAs, LN2 Temp., Dye Laser
(2) Thick GaAs, RT, Dye Laser
(3) Thick AlGaAs, RT, Dye Laser
(4) 300-nm Strained GaAs, YAG-Ti Laser
(5) 100-nm Strained GaAs, YAG-Ti or Flash-Ti Laser
(6) 100-nm Gradient-doped Strained GaAs
(7) 100-nm Gradient-doped, Strained-superlattice GaAs/GaAsP



ATF Damping Ring at KEK

SLAC and KEK physicists survey the ring.

"Laser Wire"



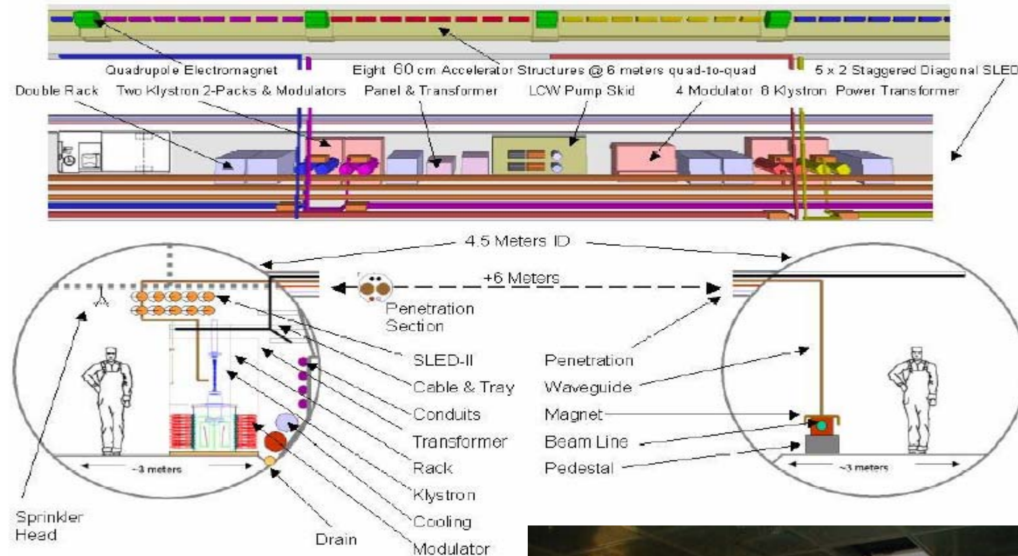
IP Stabilization

Three Layers

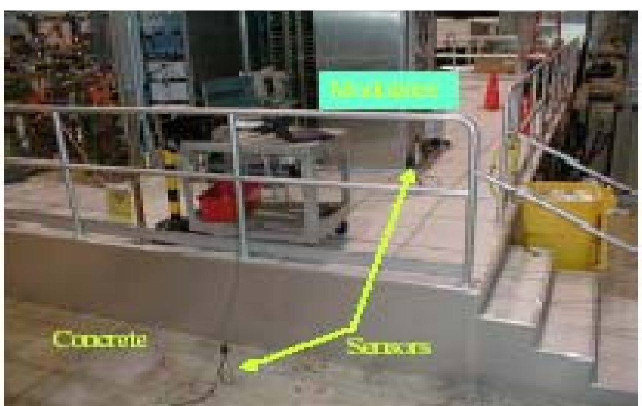
1. Site (many suitable sites identified) and facilities.
2. IR/Detector engineering and active (inertial) stabilization.
3. Fast intra-train beam feedback (FONT at NLCTA and FEATHER at ATF).

Site and Conventional Facilities

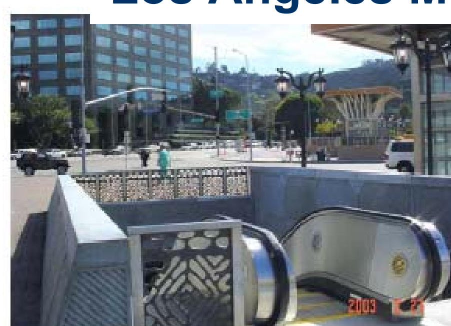
Site Studies in CA and IL



Measurements at the 8-Pack



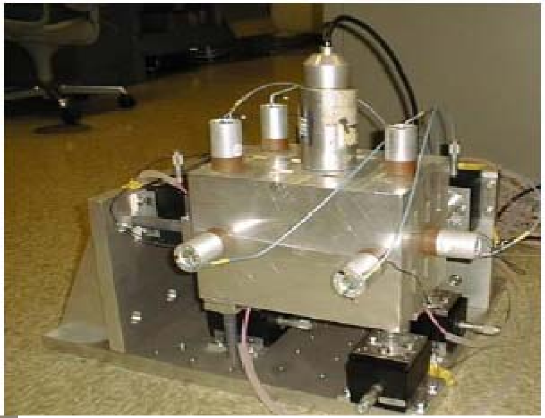
Los Angeles MTA

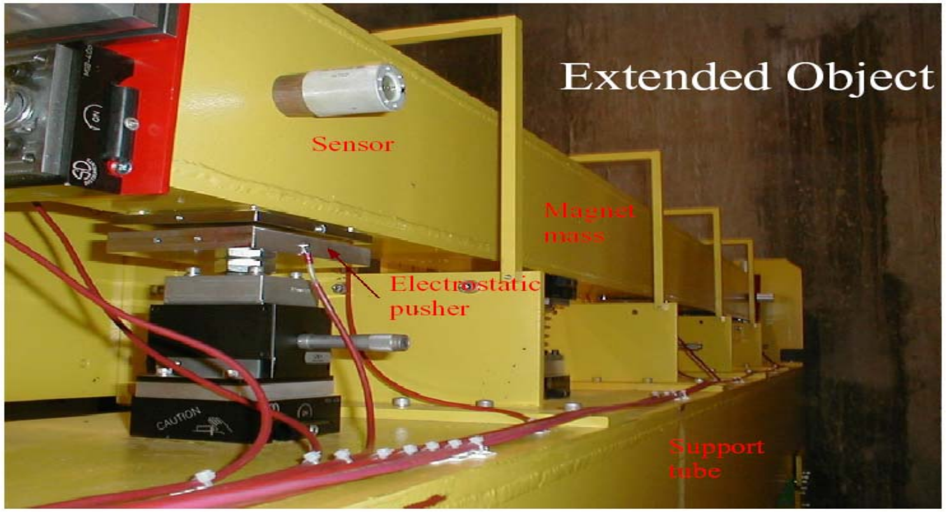


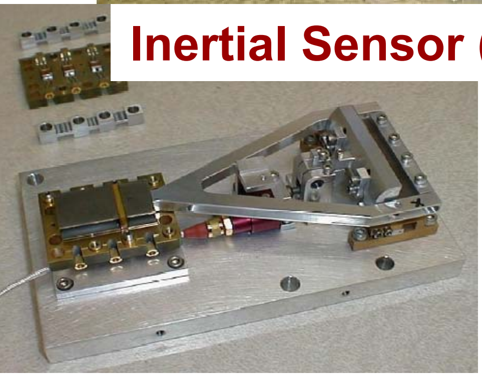
Universal City

Beam Collision Stabilization

Inertial Systems

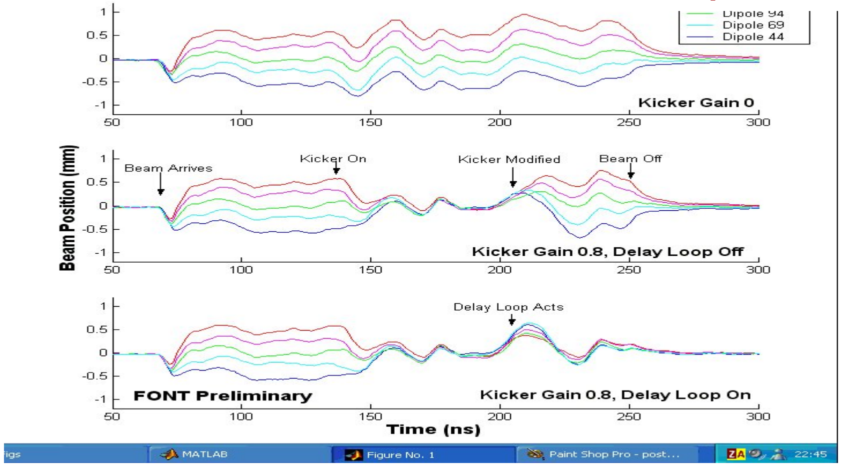






Inertial Sensor (SLAC)

FONT at NLCTA (Oxford, Queen Mary)



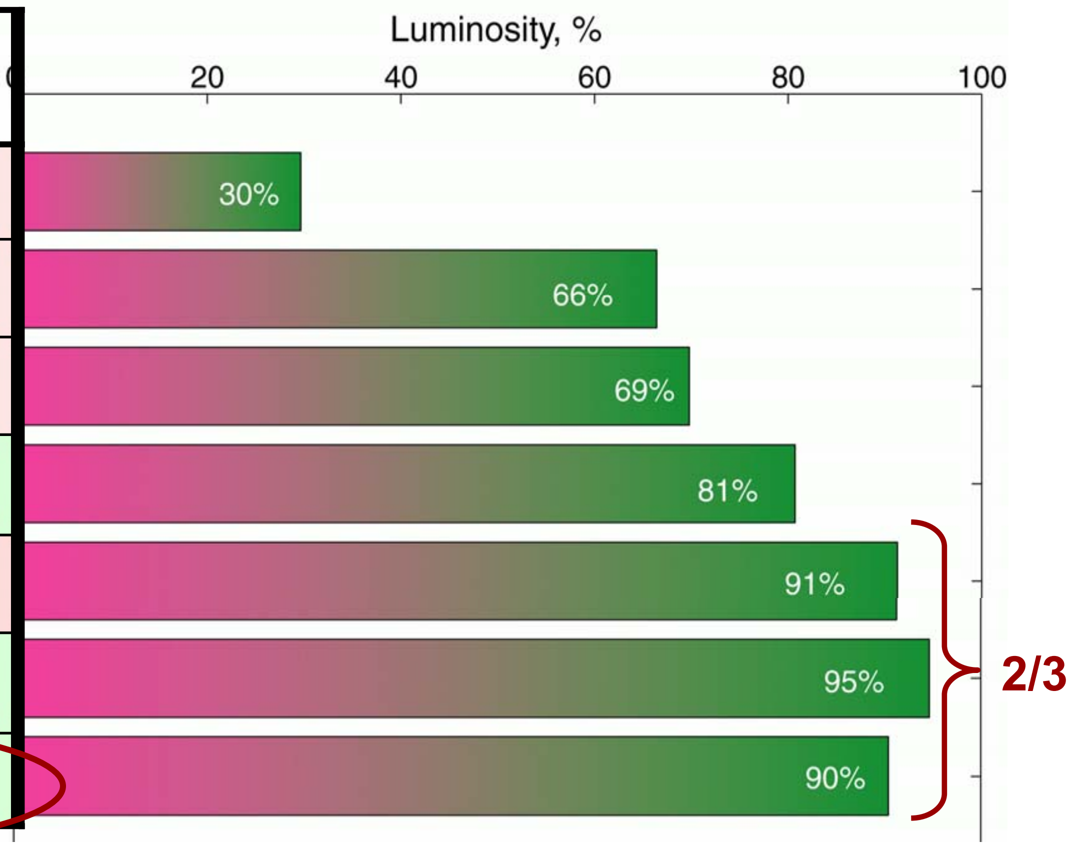
- Demonstrated ~15x suppression of offsets.
- Latency was about 60 ns (c.f. 390 ns bunch train).

IP Stabilization Summary

IP collisions can be stabilized with >90% of peak luminosity using any two out of the three approaches.

Quiet Detector	Active Stabilization	FONT
20 nm	No	No
4 nm	No	No
~20 nm*	Yes*	No
20 nm	No	Yes
4 nm	Yes	No
4 nm	No	Yes
~20 nm*	Yes*	Yes*

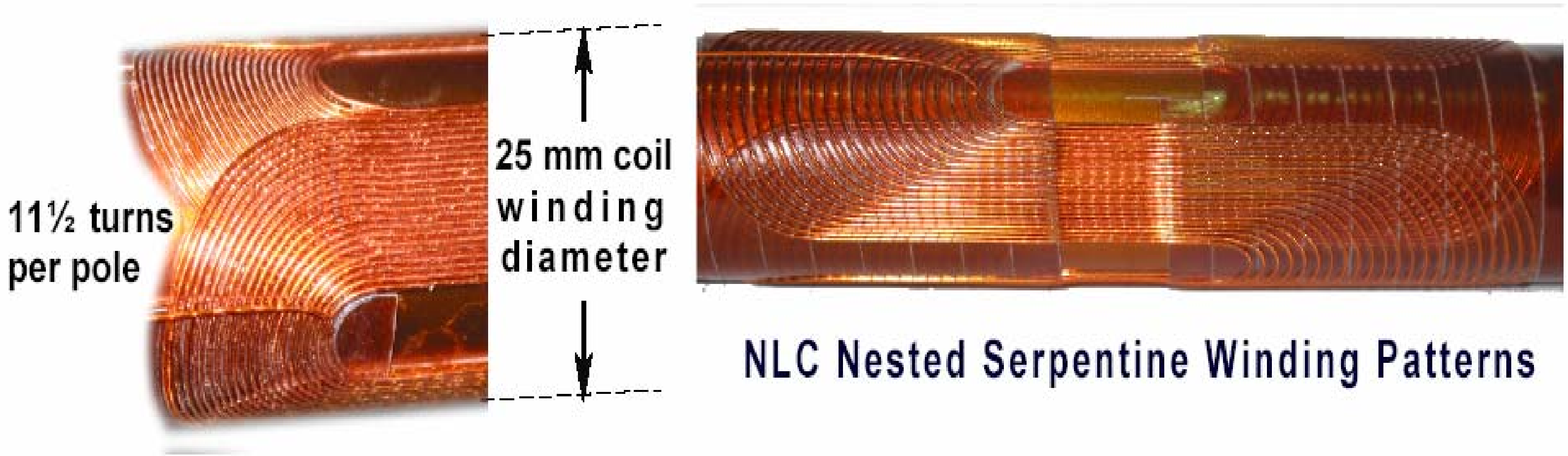
Simulations of Beam Collisions



*** Measured 20 nm vibration on SLD. Demonstrated R&D solution.**

IP SC Magnet Development at BNL

- New "Nested Serpentine" winding (based on HERA magnets).
- Allows continuous variation of the beam energy.
- Study vibrations introduced by cryogenic fluids.



Prototype of the Final IP Quadrupole

Ready to Initiate International Linear Collider Project

Baseline technologies and design are proven.

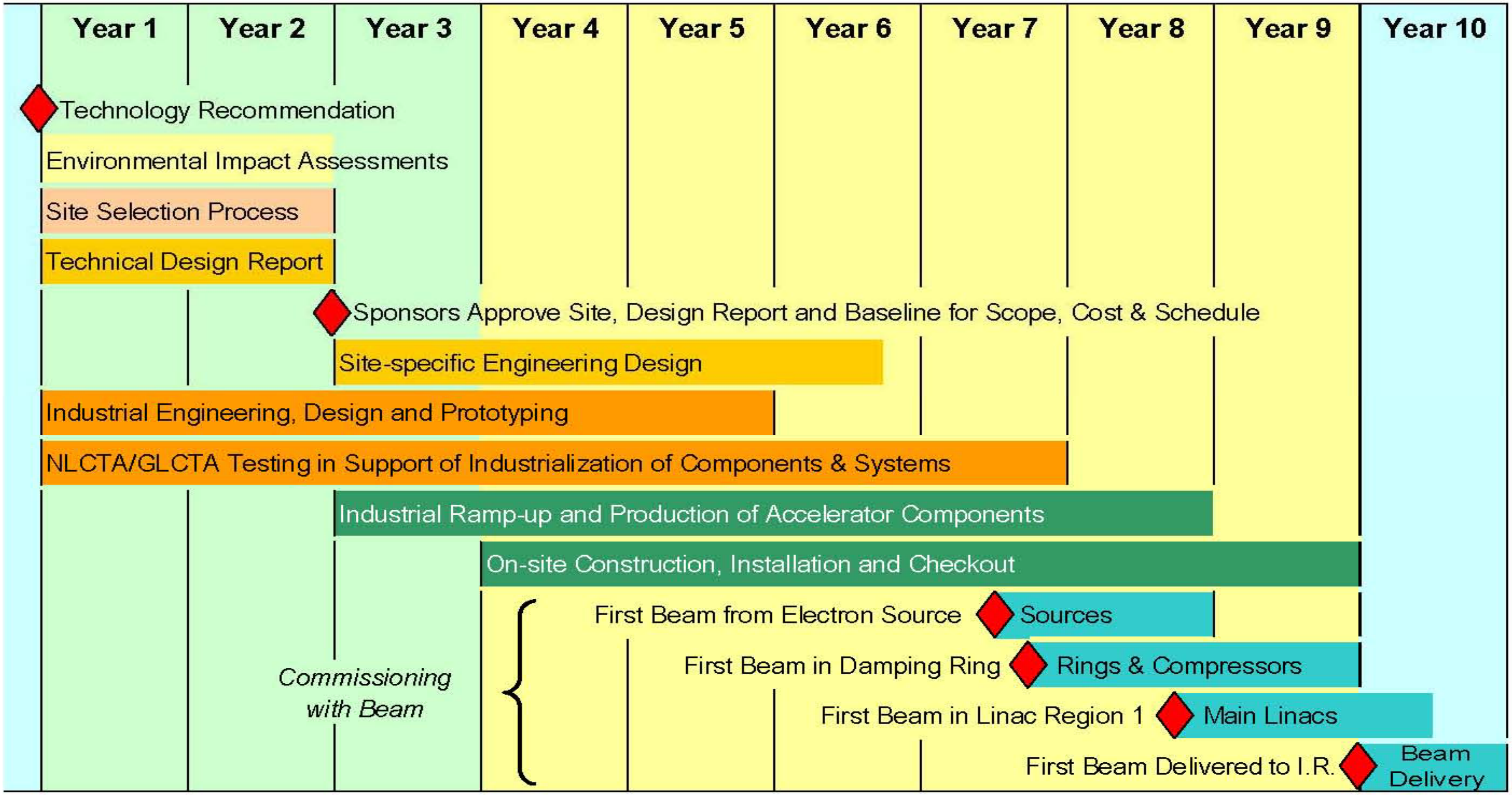
Major improvements will come from value engineering and industrial design for manufacture, reliability, and serviceability.

Industrial technologies readily and widely available.

R&D will continue to look for ways to improve on the baseline – e.g., better power efficiency with DLDS – and support CDR/TDR engineering and design .

NLC Project Milestones

Technically-Limited Schedule



Independence of Sources, Damping Rings, Linacs, and Beam Delivery allow significant commissioning with beam during construction.