NLC Update

CLIC Group

CERN
September 2003

D. L. Burke
SLAC

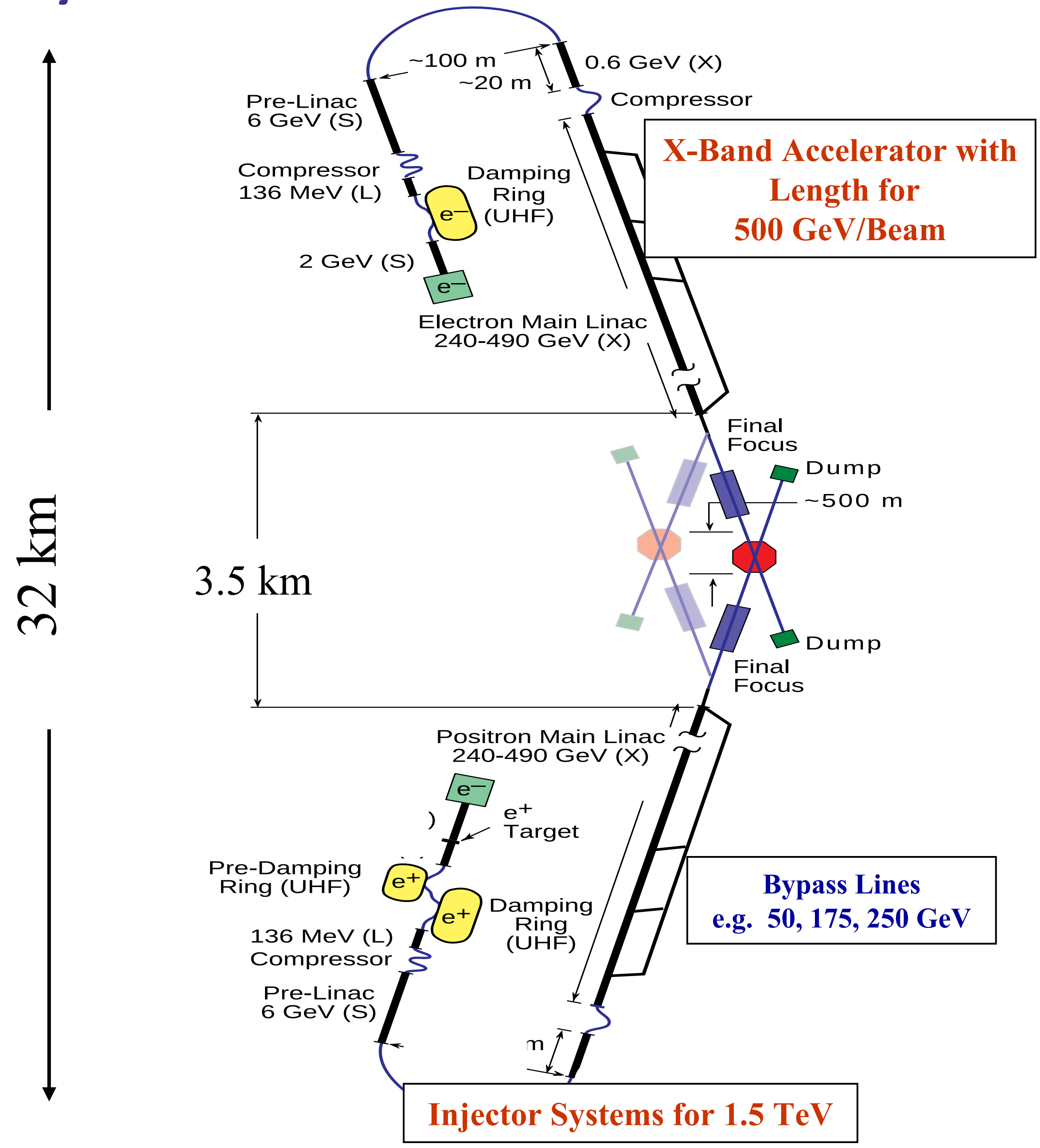
Configuration

Major iterations:

Zero-Order Design
(1996)

DOE "Lehman" Review
(1999)

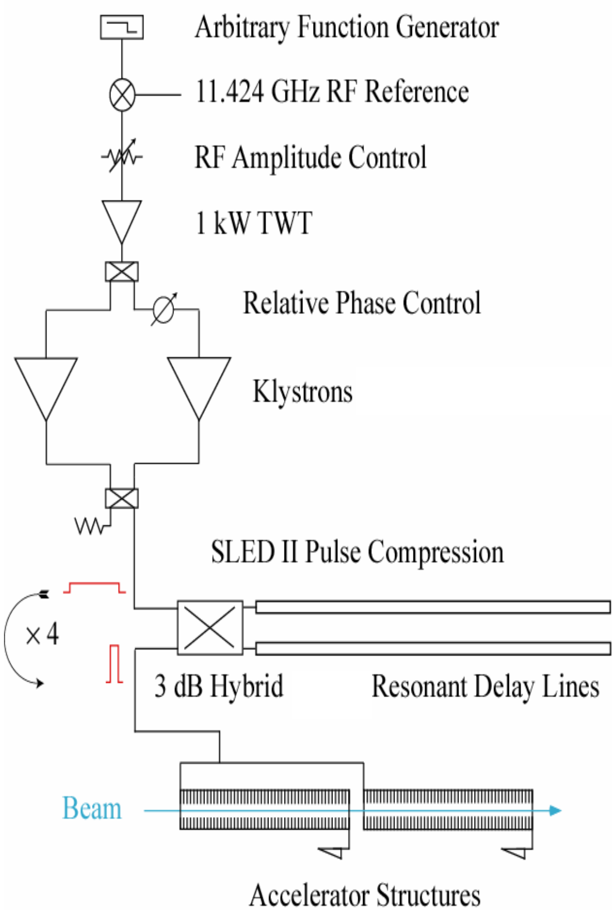
Snowmass 2001
(2001)



X-Band RF Systems

NLCTA
SLED-II System
(ZDR 1996)

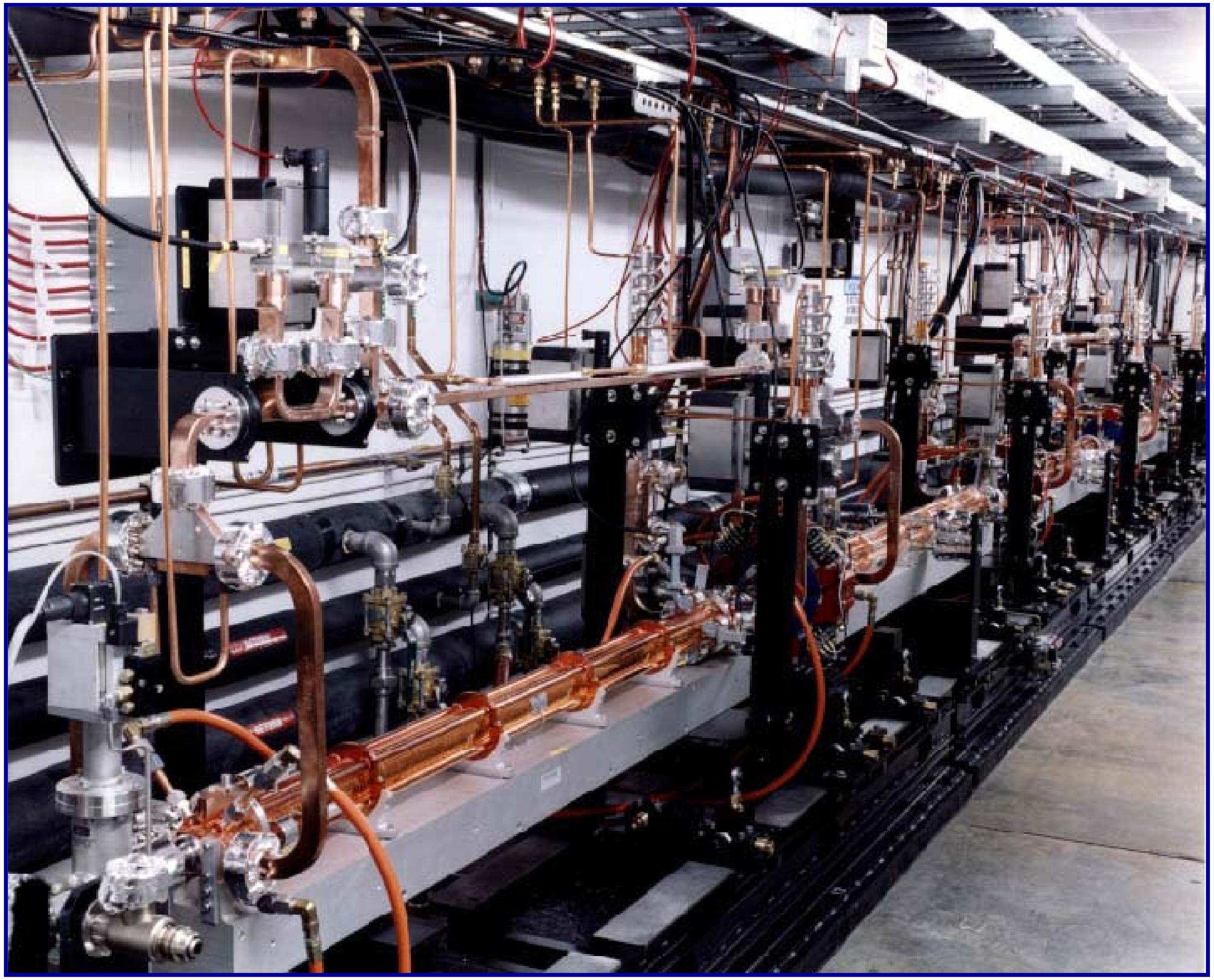
- Conventional PFN modulator
- 50 MW/1.2μs solenoid-focused klystrons
- SLED-II pulse compression
- DDS structures at 40 MV/m



X-Band TeV
SLED-II System
(Baseline 2002)

- Solid-state modulator
- 75 MW/1.6μs PPM-focused klystrons
- Dual mode SLED-II pulse compression
- DDS structures at 65 MV/m

The NLC Test Accelerator at SLAC



The NLCTA with 1.8 m accelerator structures (ca 1997).

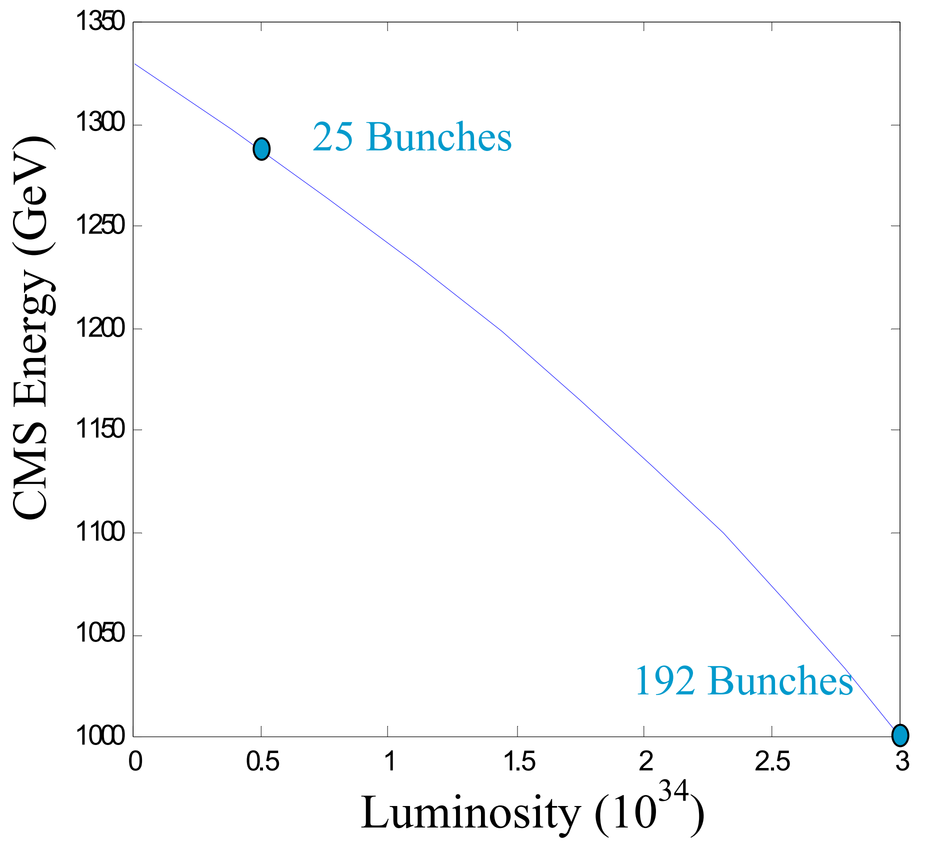
Accelerating gradient of 40 MV/m (25 MV/m loaded) with good wakefield control and energy spread.

Demonstrated ability to reach 500 GeV cms.

JLC/NLC Energy Reach

High Energy IP Parameters

	Stage 1		Stage 2	
CMS Energy (GeV)	500		1000	
Site	US	Japan	US	Japan
Luminosity (10^{33})	**20**	**25**	**30**	**25**
Repetition Rate (Hz)	120	150	120	100
Bunch Charge (10^{10})	**0.75**		**0.75**	
Bunches/RF Pulse	192		192	
Bunch Separation (ns)	1.4		1.4	
Loaded Gradient (MV/m)	**50**		**50**	
Injected $\gamma\varepsilon_x$ / $\gamma\varepsilon_y$ (10^{-8})	300 / 2		300 / 2	
$\gamma\varepsilon_x$ at IP (10^{-8} m-rad)	360		360	
$\gamma\varepsilon_y$ at IP (10^{-8} m-rad)	**4**		**4**	
β_x / β_y at IP (mm)	8 / 0.11		13 / 0.11	
σ_x / σ_y at IP (nm)	**243 / 3.0**		**219 / 2.1**	
θ_x / θ_y at IP (nm)	**32 / 28**		**17 / 20**	
σ_z at IP (um)	110		110	
Υ_{ave}	0.14		0.29	
Pinch Enhancement	1.51		1.47	
Beamstrahlung δB (%)	5.4		8.9	
Photons per e+/e-	1.3		1.3	
Two Linac Length (km)	13.8		27.6	



The NLC/JLC Stage 2 design luminosity is 5×10^{33} cm^{-2} s^{-1} at 1.3 TeV cms.

JLC(X)/NLC Level I R&D Requirements (R1)

- "Test of complete accelerator structure at design gradient with detuning and damping, including study of breakdown and dark current."
- "Demonstration of SLED-II pulse compression system at design power level."

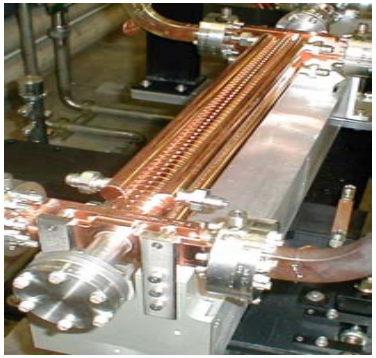
High-Gradient R&D

- After improvements to the rf at NLCTA in 2000, realized the 1.8 m long structures were being damaged during processing and would not meet performance at 65 MV/m.
- Launched aggressive R&D program
  - **Build and test traveling wave structures and standing wave structures.**
  - **Improve structure handling, cleaning and baking methods.**
  - **Study characteristics of rf breakdown in structures, cavities and waveguides.**

➢ **Have tested 25 structures made from a total of approximately 1000 cells.**

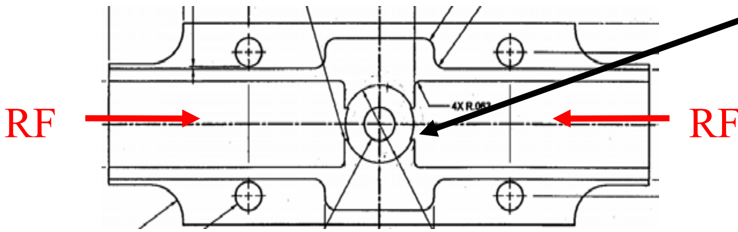
➢ **Over 10,000 hr operation at 60 Hz. $\rightarrow$ 10^9 rf pulses; a total of $\sim 10^5$ rf breakdown events.**

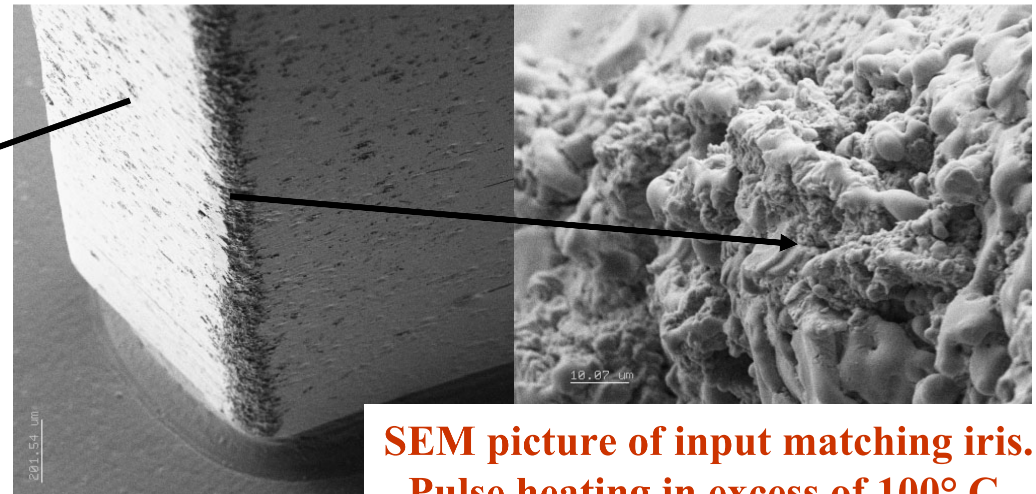
T-Series Structures – 50 cm long low group velocity structures with high shunt impedance.



RF Pulse Heating

T53VG3
(Original Coupler Design)

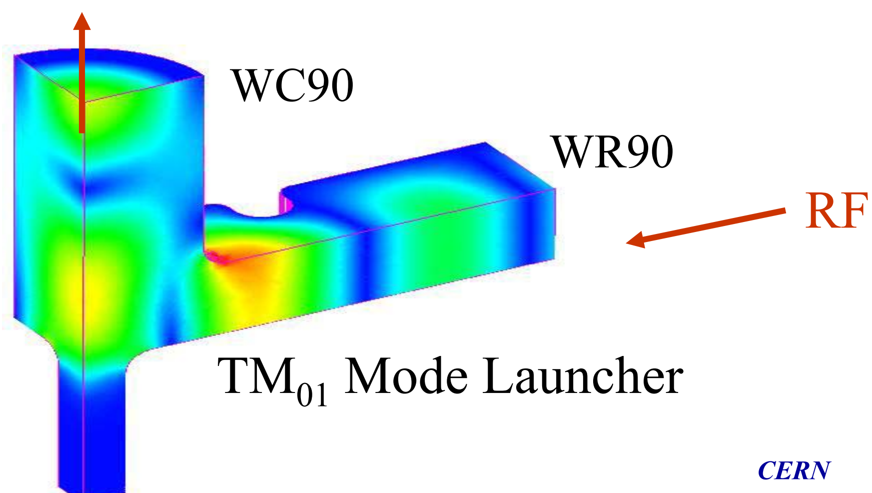




SEM picture of input matching iris.
Pulse heating in excess of 100° C.

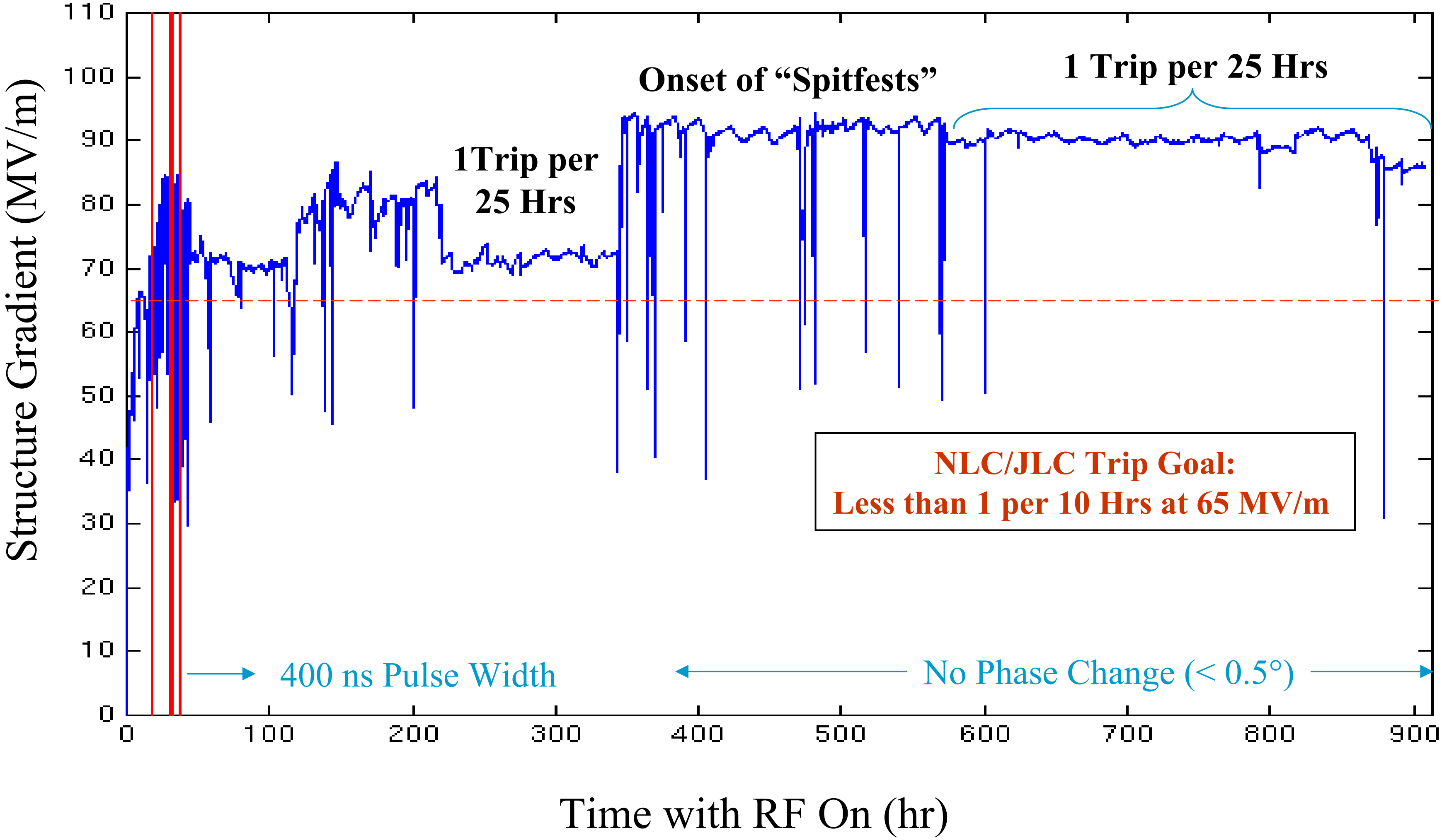
New Mode-Converter (MC)
Coupler Design

Pulse heating less than 3° C.



T53VG3MC Processing History

(Low-Temperature Couplers)

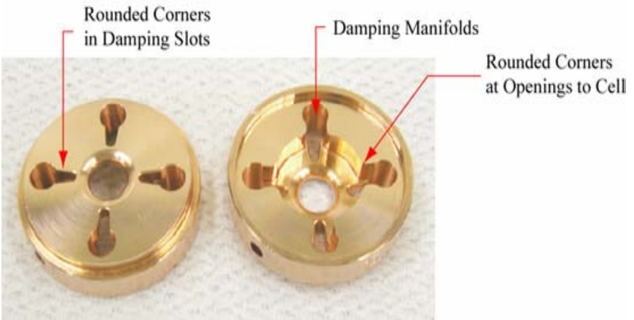


H-Series Structures

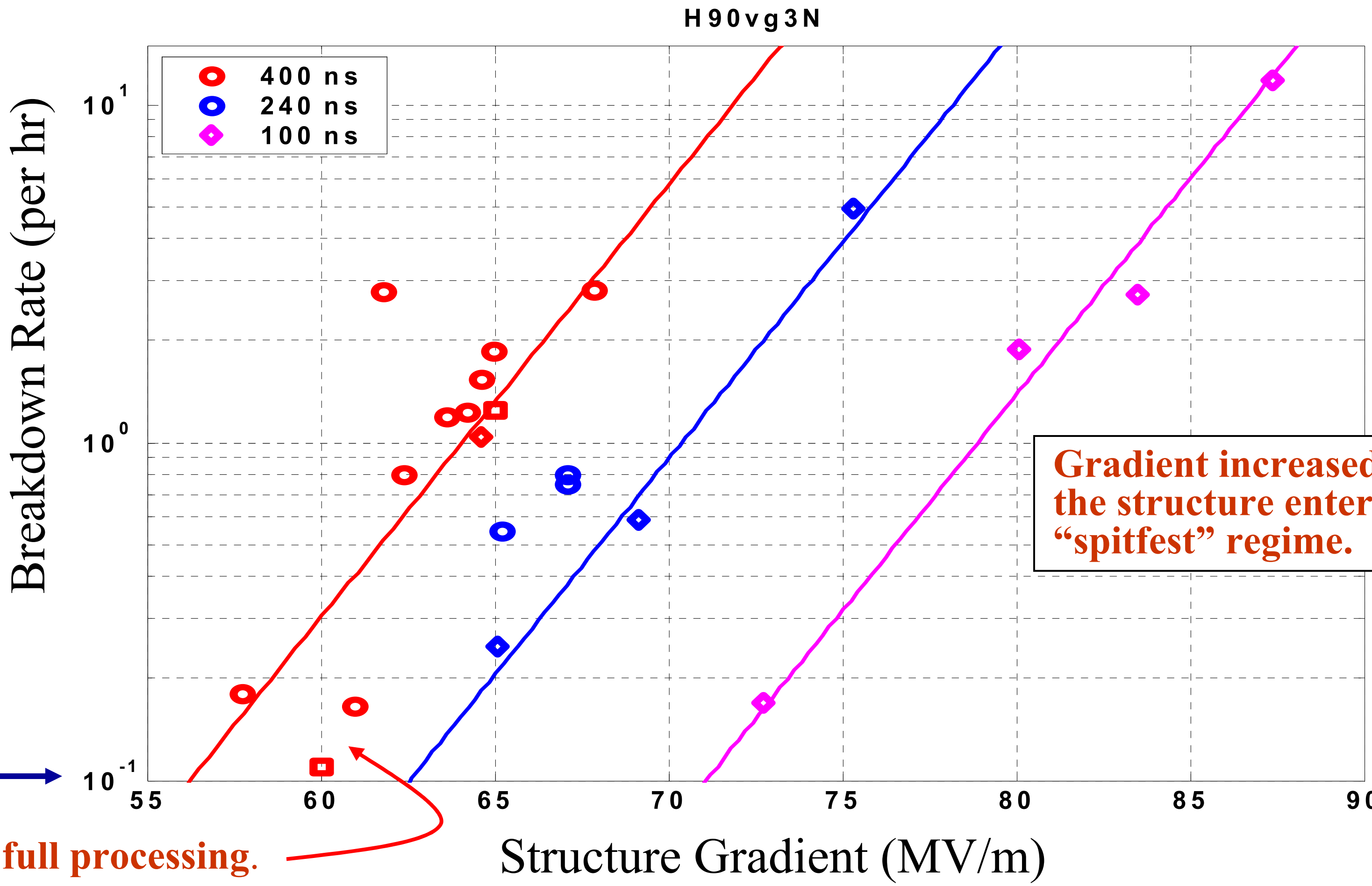
- The T-Series design cannot be used in the NLC/JLC.
  - **The average iris radius, $\langle a/\lambda \rangle$ is smaller (0.13) than desired (0.17-0.18), yielding a transverse wakefield 3 times larger than considered acceptable**.

- New designs with $\langle a/\lambda \rangle$ = 0.17-0.18 (H-Series with phase advance per cell of 150°).

  H-Series structures (with $\langle a/\lambda \rangle$ = 0.18):
  - **H90VG5: High-temperature couplers prevented full processing.**
  - **H60VG3: High-temperature couplers – body ran reliably at 65 MV/m.**
  - **H90VG3: Ran reliably at 60 MV/m.**
  - **H60VG3(6C): Six full-featured cells; ran reliably at 60 MV/m, and acceptably at 65 MV/m.**
  - **H60VG3S18: Full-featured structure now under test.**



H90VG3 Processing and Operation



Gradient increased until the structure enters the “spitfest” regime.

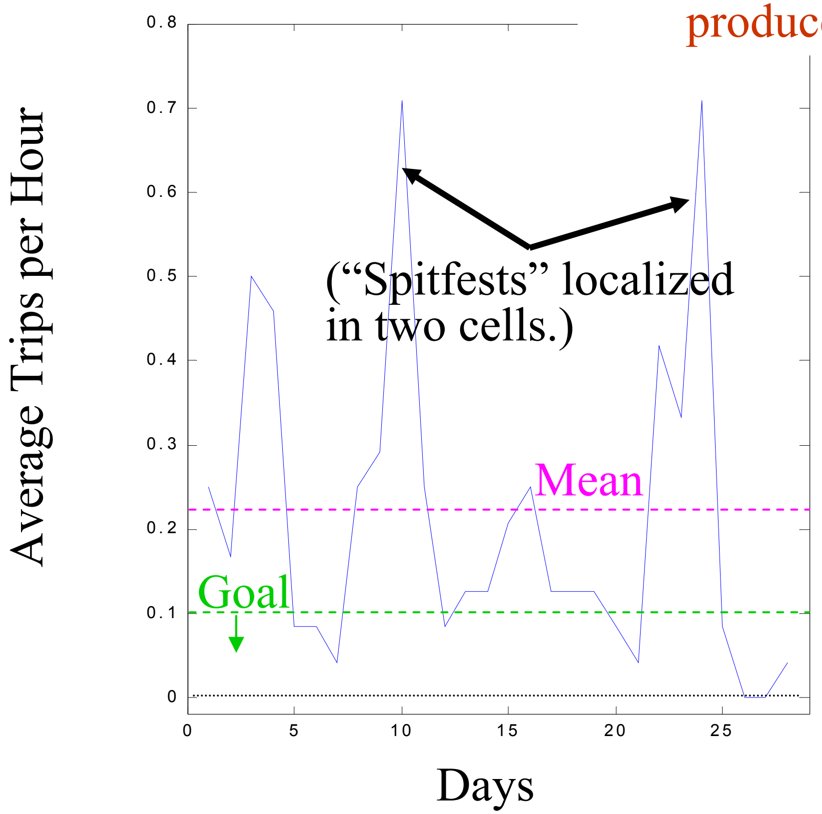
JLC/NLC Goal

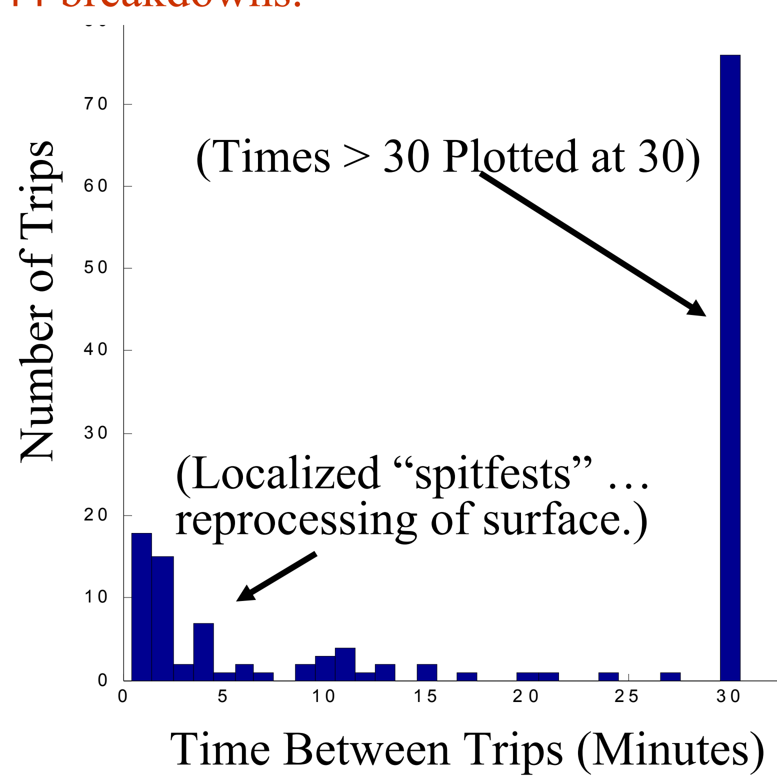
After full processing.

Breakdown Statistics for H60VG3(6C)

(65 MV/m, 400 ns)

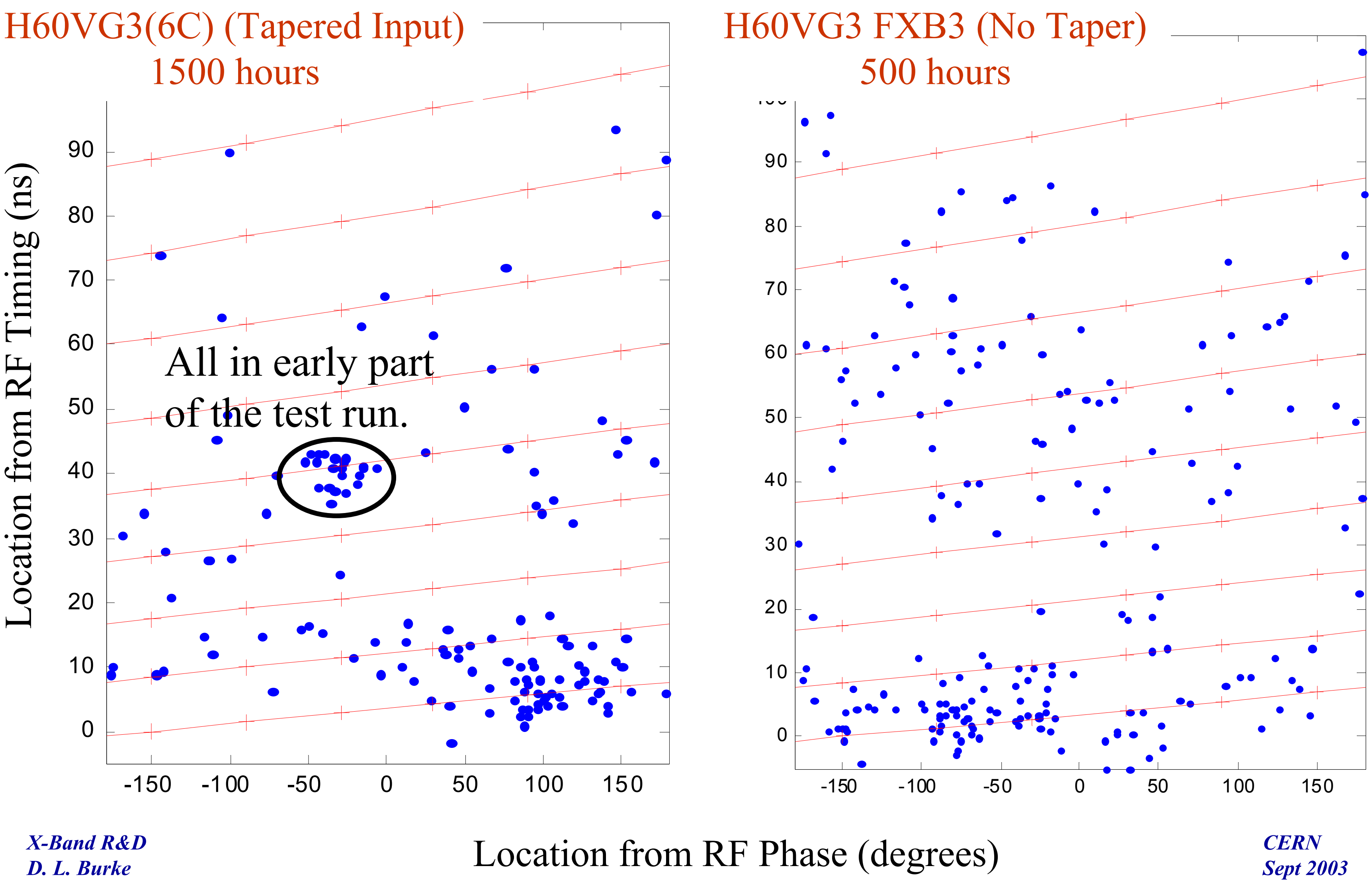
Four-week run (~ 10^8 pulses) produced 144 breakdowns.





Over 1500 hrs with power on this structure and no observed change in its microwave properties.

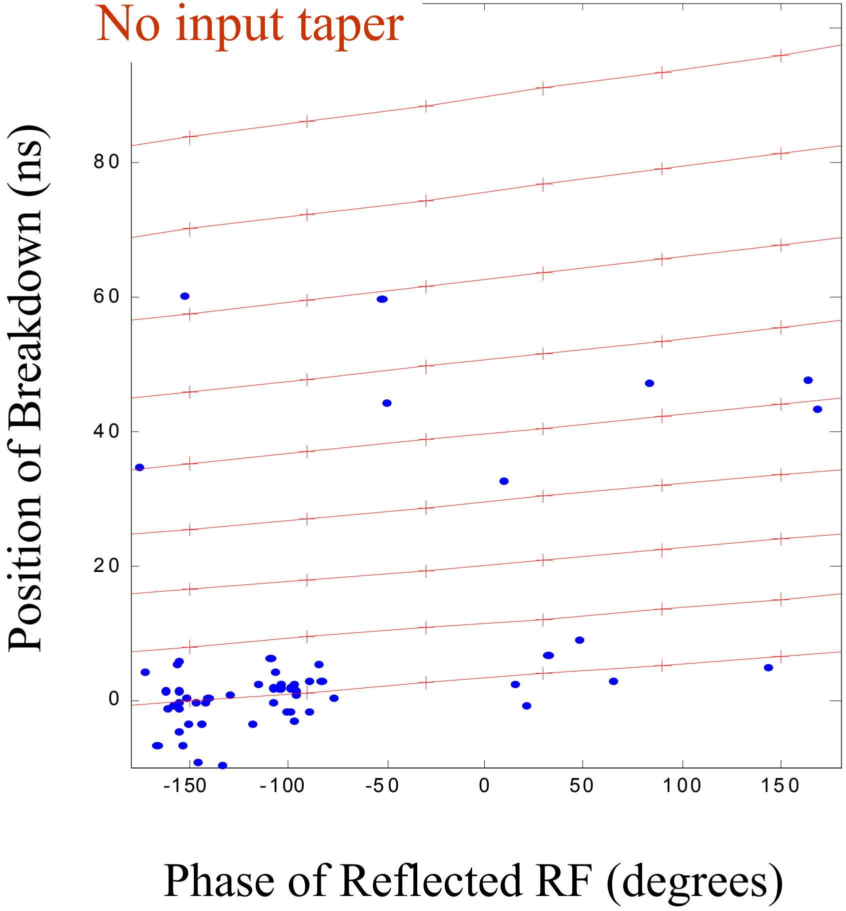
Breakdown Statistics for H60VG3 Structures
(65 MV/m, 400 ns)

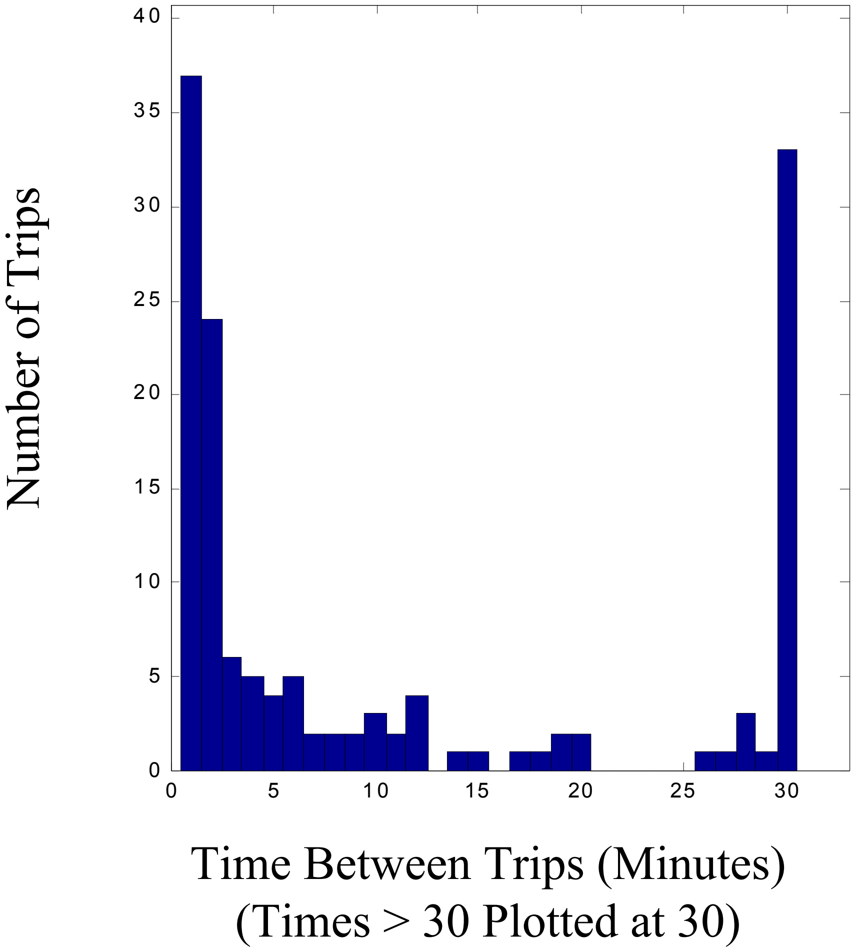


Breakdown Statistics for H60VG3S18

(80 hours at 65 MV/m, 400 ns)

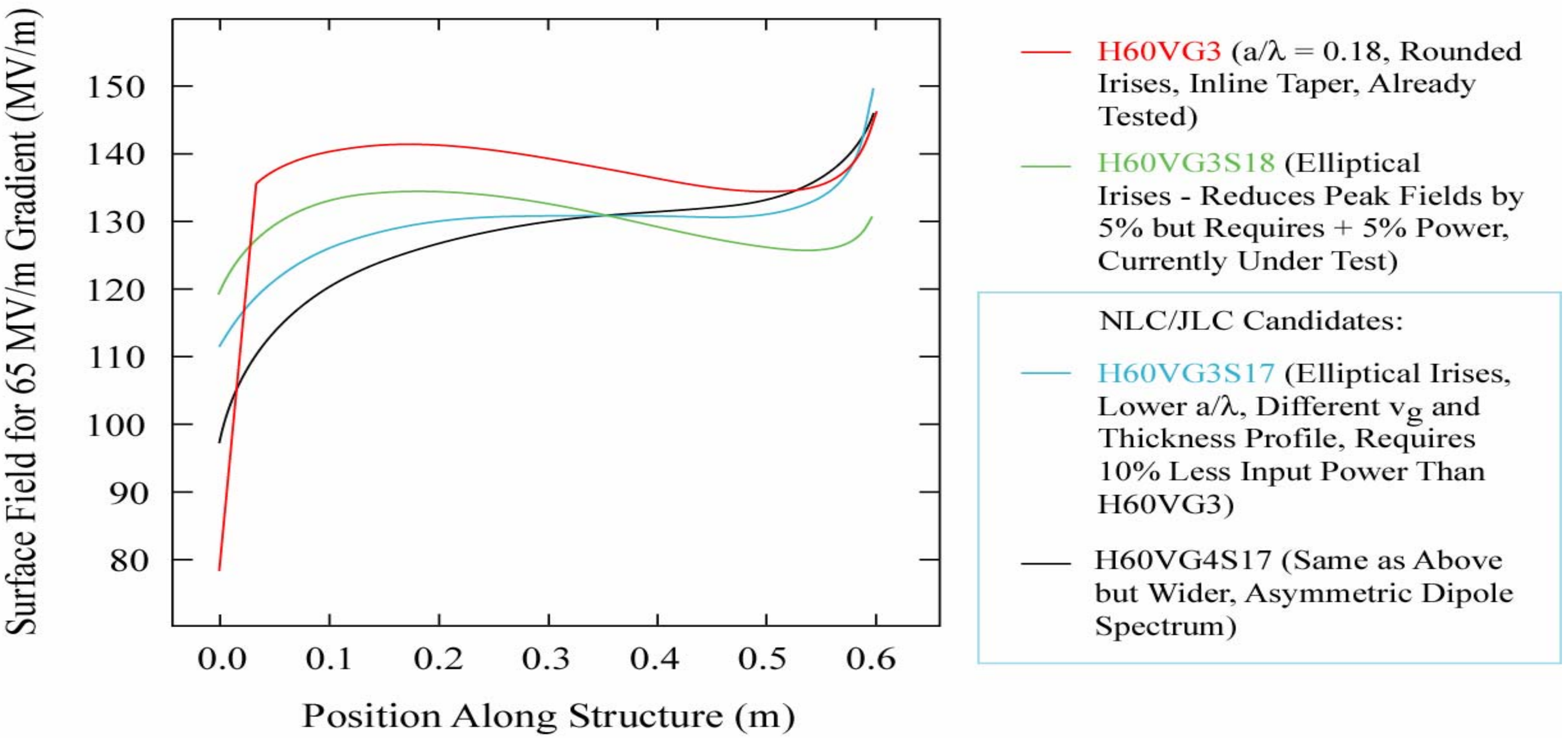
No input taper



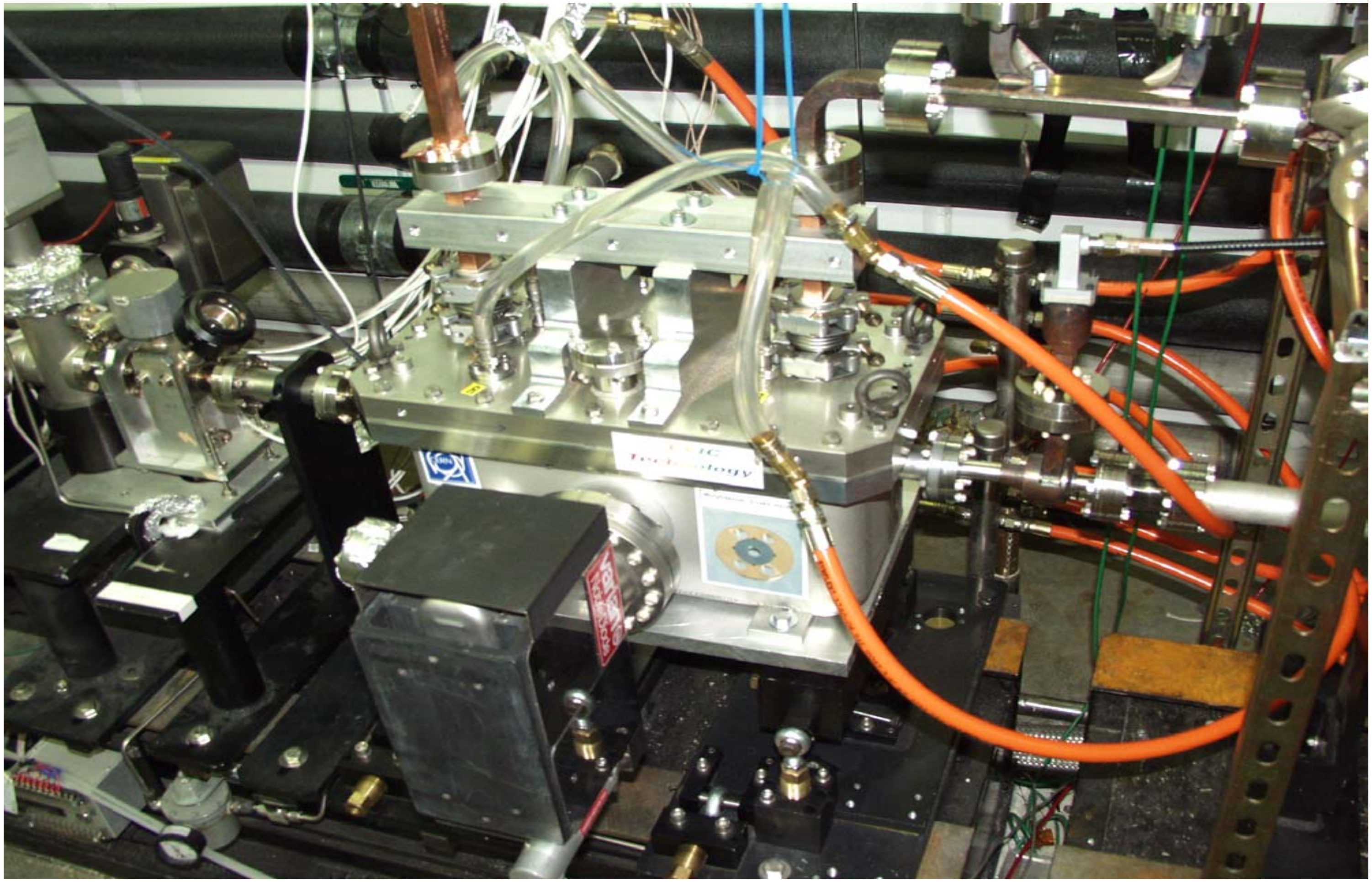


a/λ = 0.17 Designs

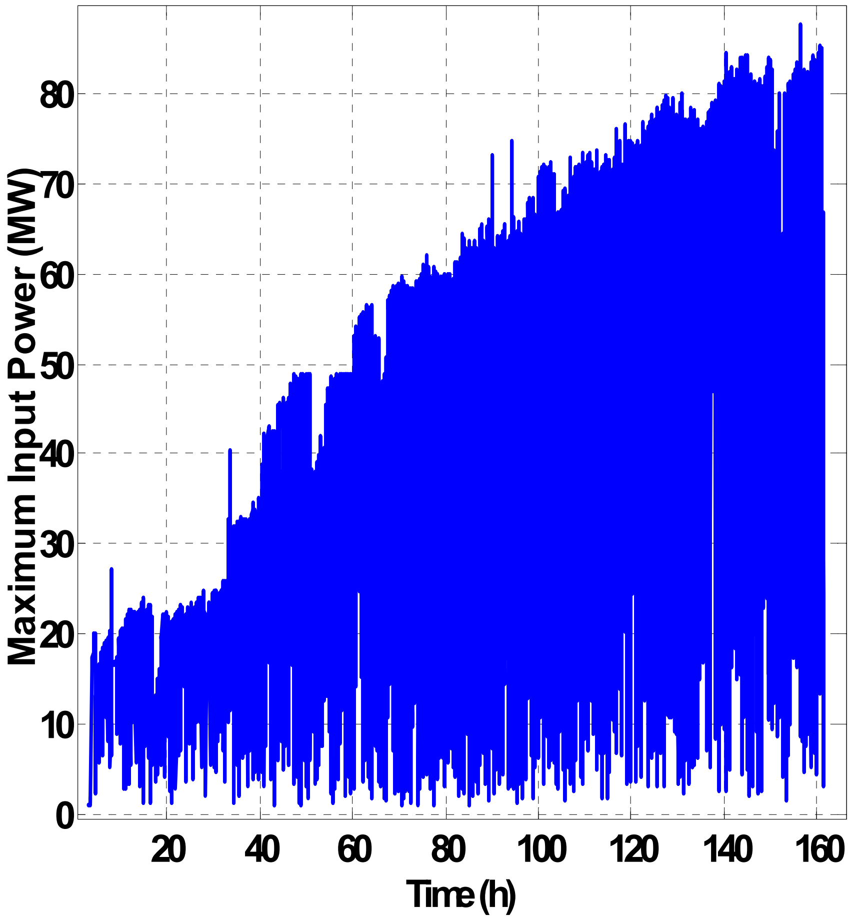
Peak Surface Field Profile -vs- Structure Type

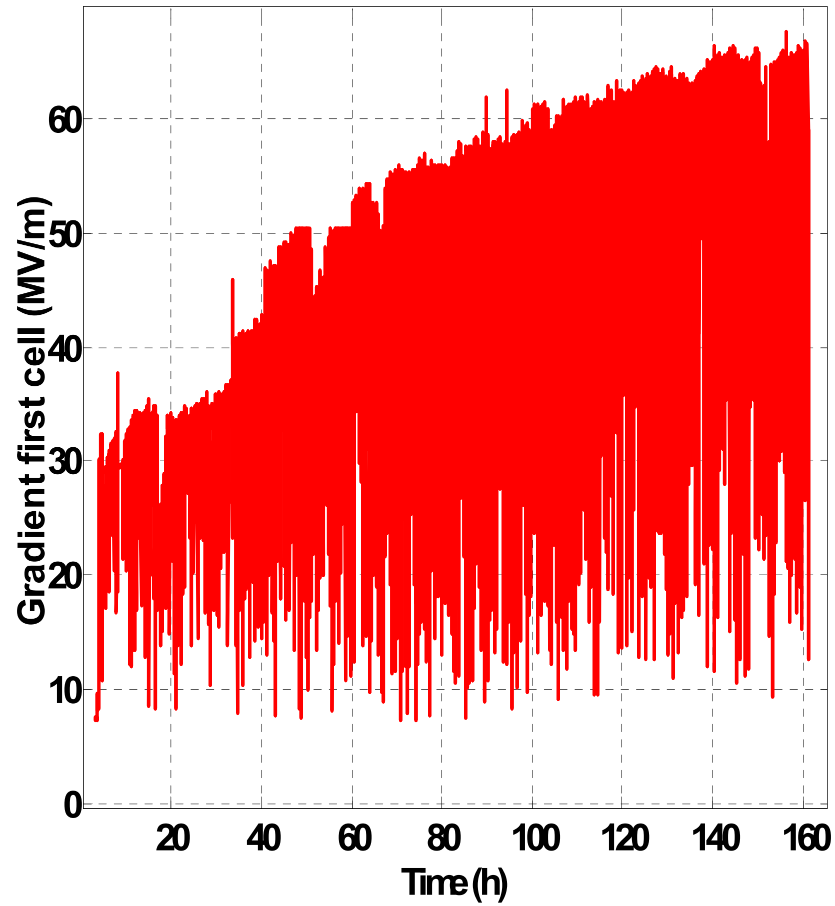


C30vg4-Mo - Installed

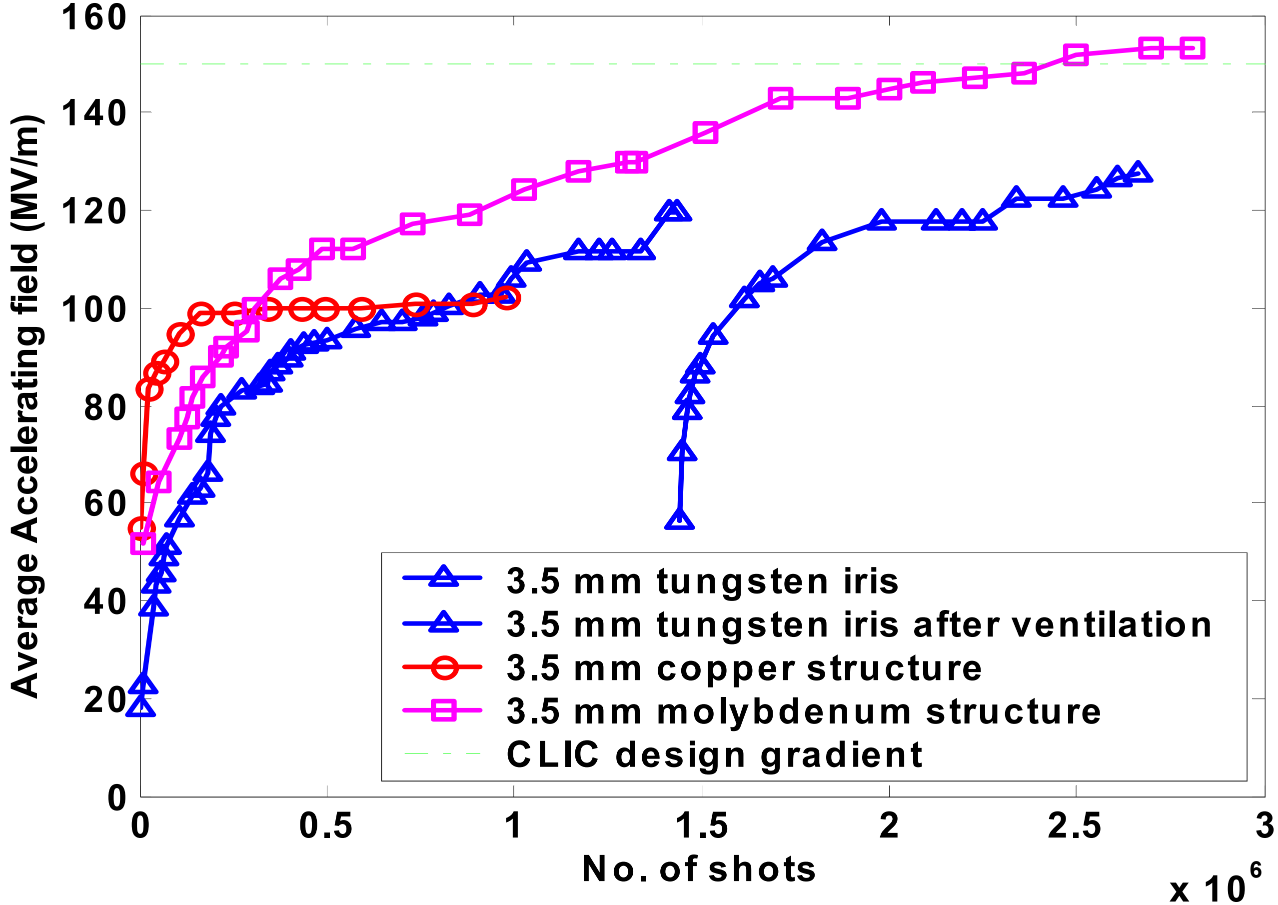


C30vg4-Mo – Processing To Date





CERN-Mo vs Cu – Processing History



NLC/JLC SLED-II Baseline Test

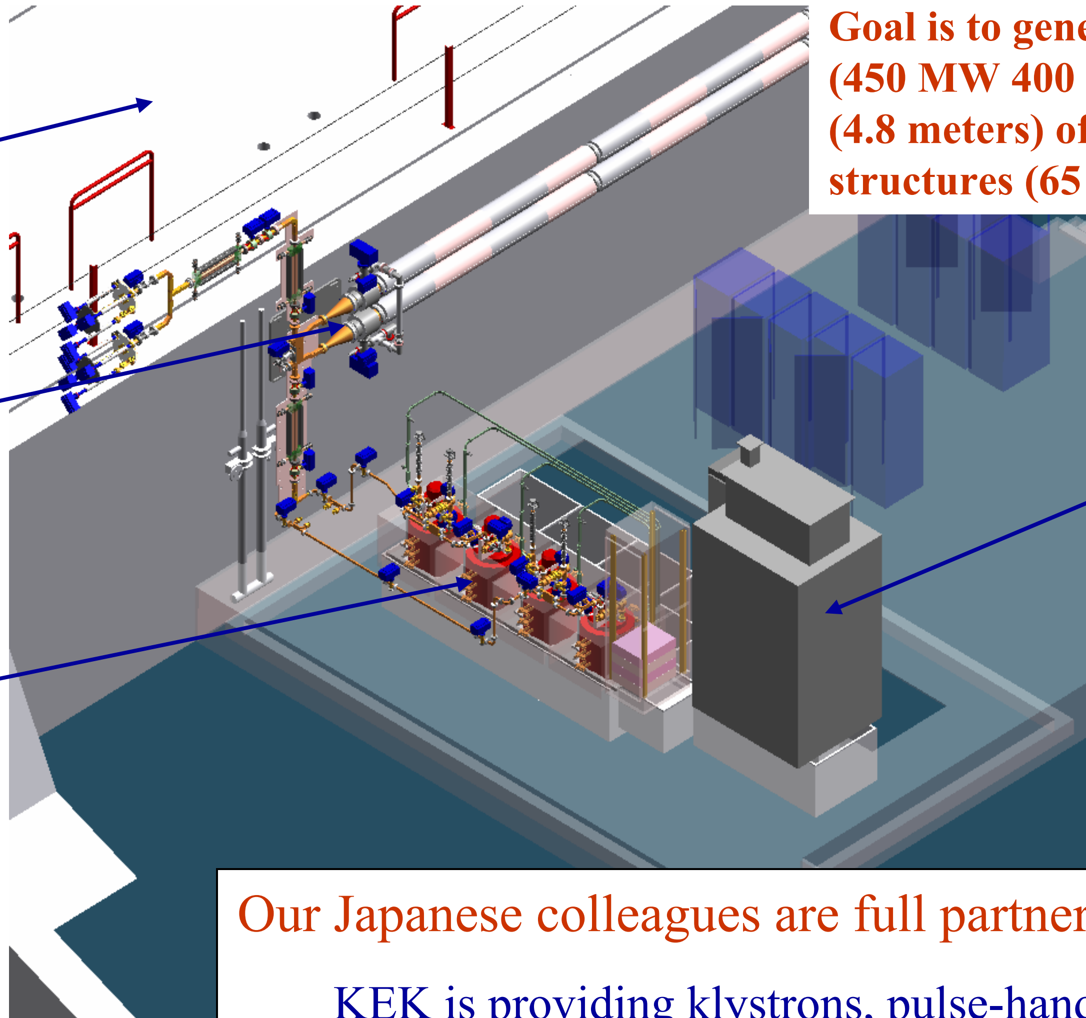
Goal is to generate an RF pulse (450 MW 400 nsec) for a girder (4.8 meters) of high-gradient structures (65 MV/m).

NLCTA Housing

Dual-Mode SLED-II

Solenoid-Focused Klystrons (to be replaced with PPM tubes).

Solid-State Modulator



Our Japanese colleagues are full partners in this plan.

KEK is providing klystrons, pulse-handling, and accelerator structures, and participating in testing.

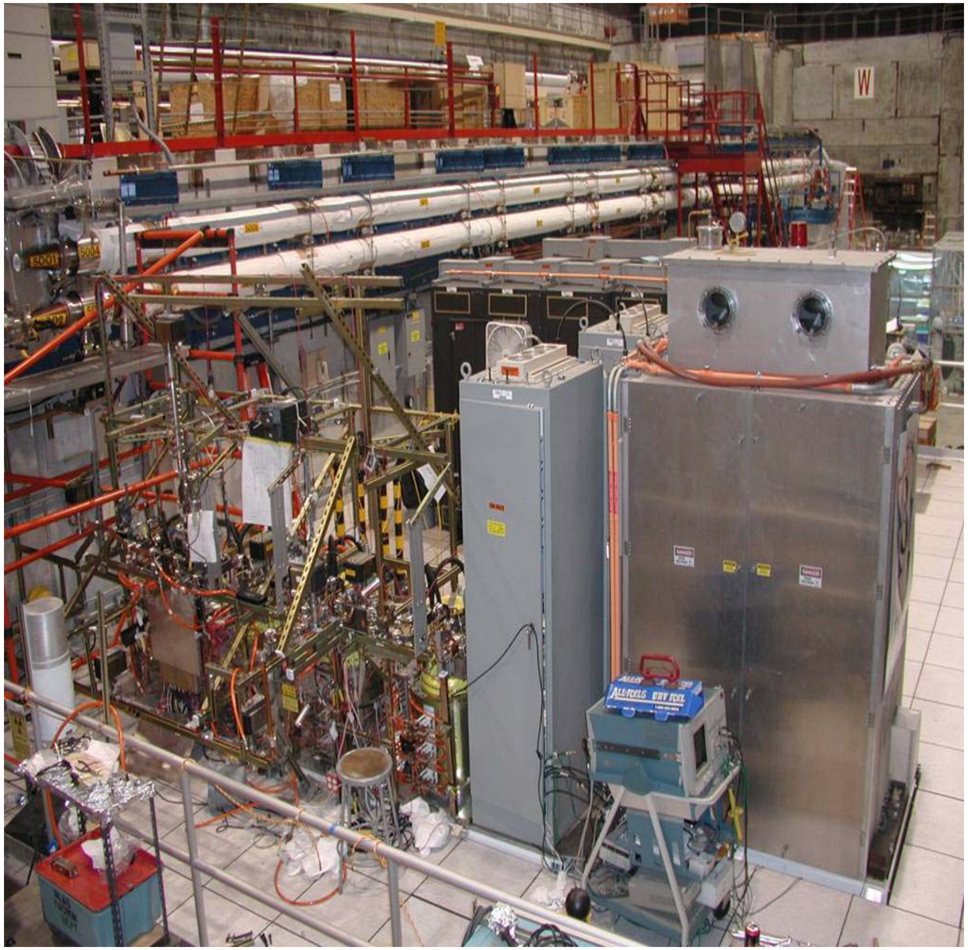
SLED-II Baseline Test

- Modulator is on-line and driving four XL-4 klystrons.

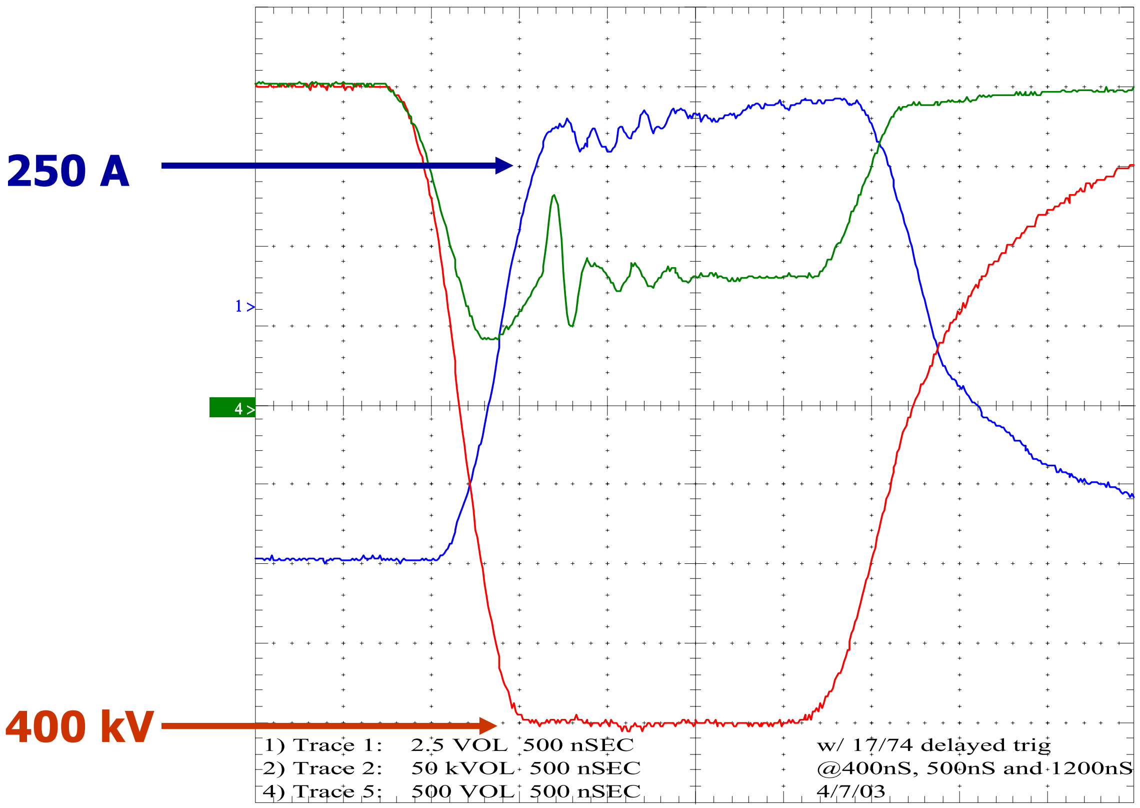
- Software and control logic being tested and debugged.

- All SLED-II designs passed microwave "cold tests" and components are being installed and baked out.

→ Power tests to loads in October.



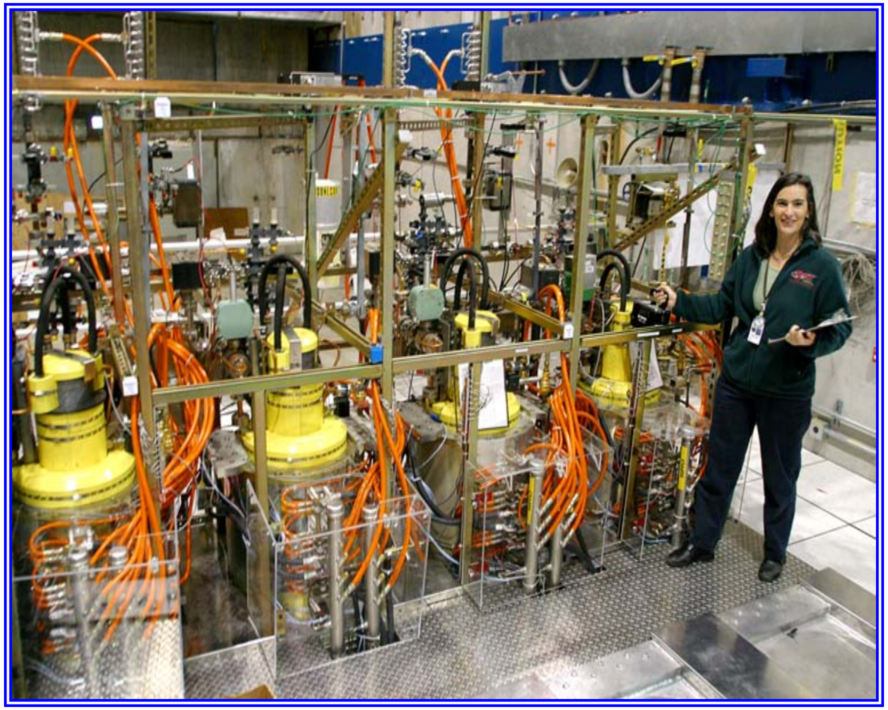
Solid State Modulator



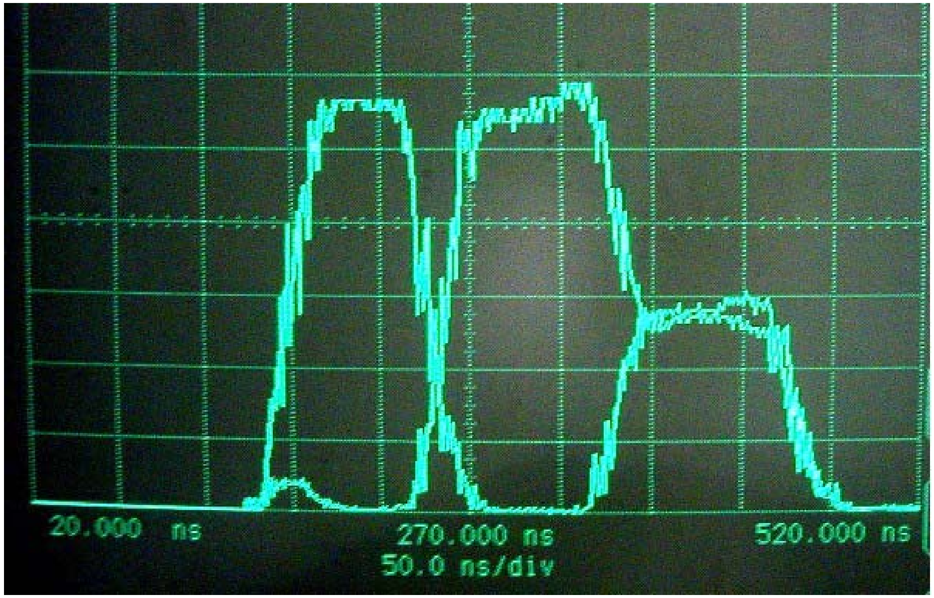
Voltage pulse flattened by delayed firing sequence of boards in the IGBT stack.

Now running steadily (~ 8 hrs/day).

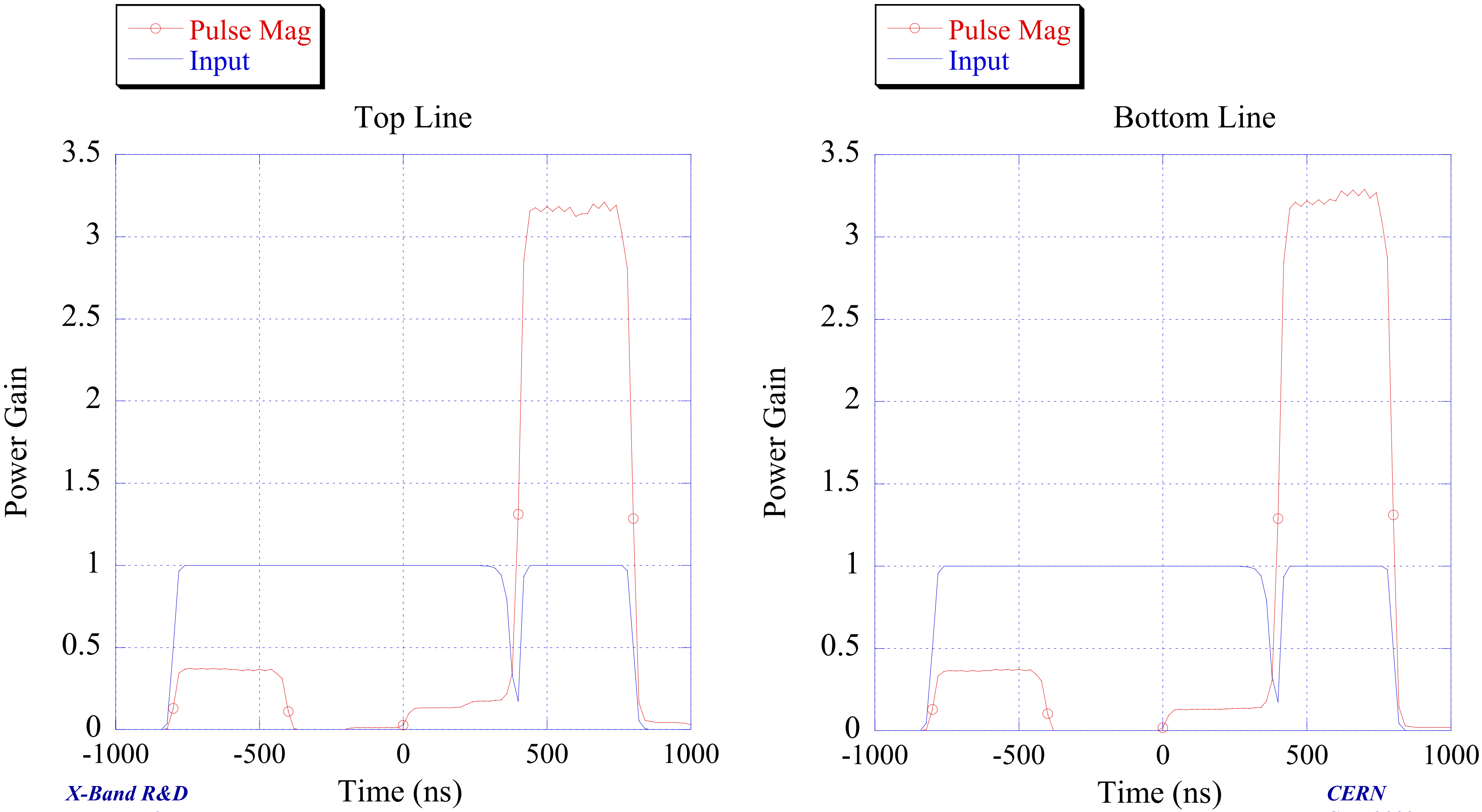
XL-4 Klystrons, LLRF, and Controls



Scope trace below shows phase manipulation of pairs of klystrons alternately sending all power to one load, then the other, then splitting it between the two.

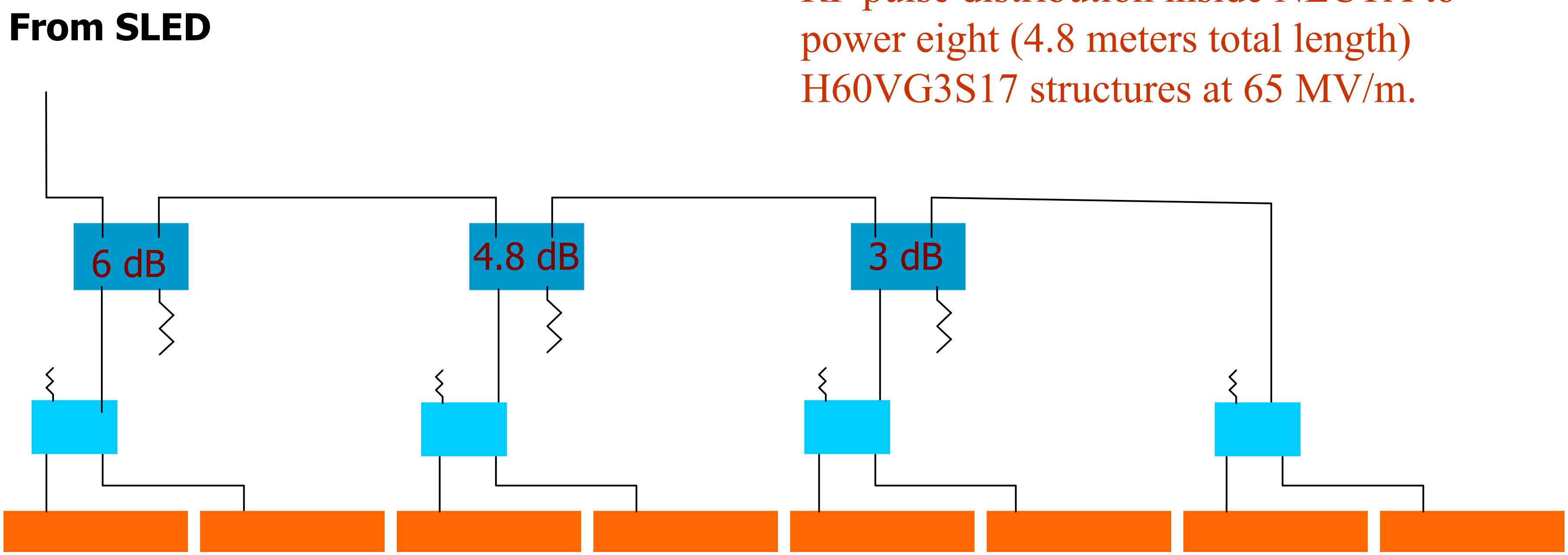


Cold Test Performance of the Dual-Mode SLED II Delay Lines



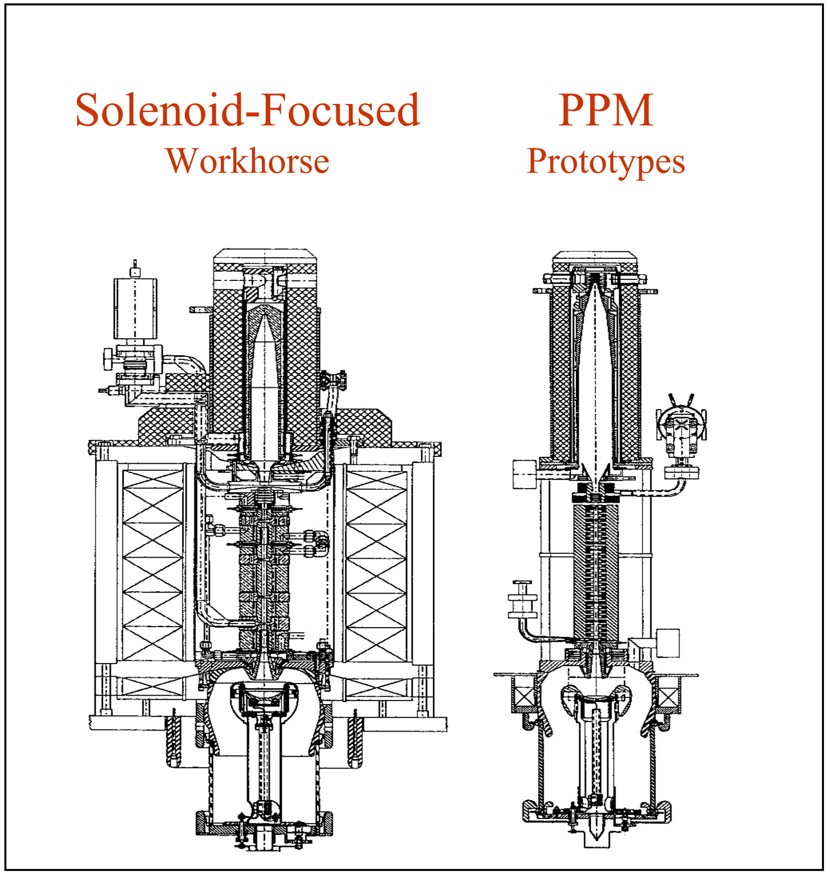
SLED-II Phase 2 Plans

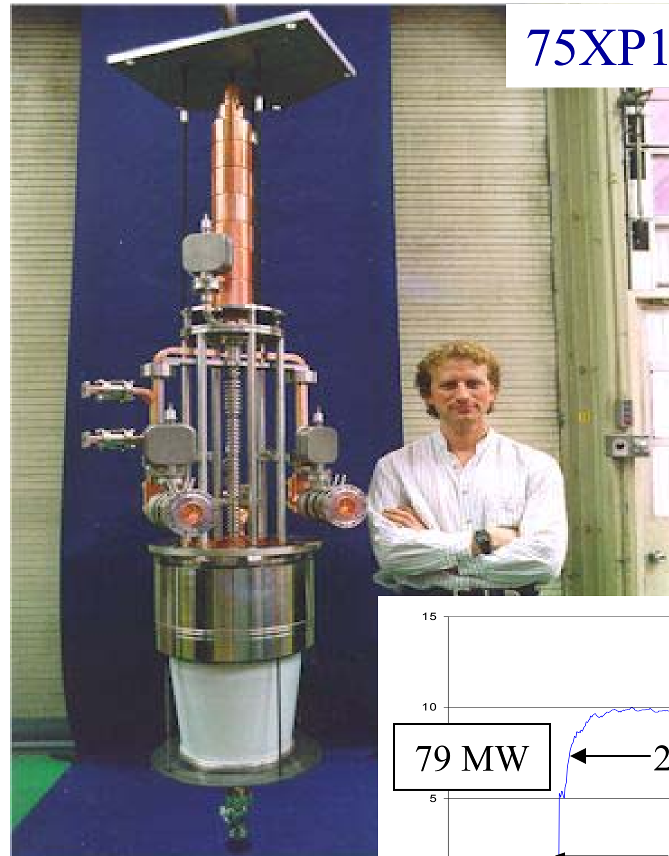
RF pulse distribution inside NLCTA to power eight (4.8 meters total length) H60VG3S17 structures at 65 MV/m.

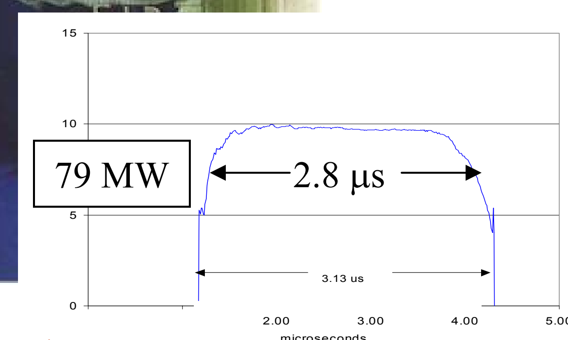


- Fabrication of pulse distribution hardware has started.
- Goal is to complete next spring, and run ~ 2000 hours of high-gradient operation next year.

Permanent Magnet Focused (PPM) Klystrons







Repetition rate limited to 1 Hz due to lack of cooling.

High Rep-Rate
Permanent Magnet Klystrons

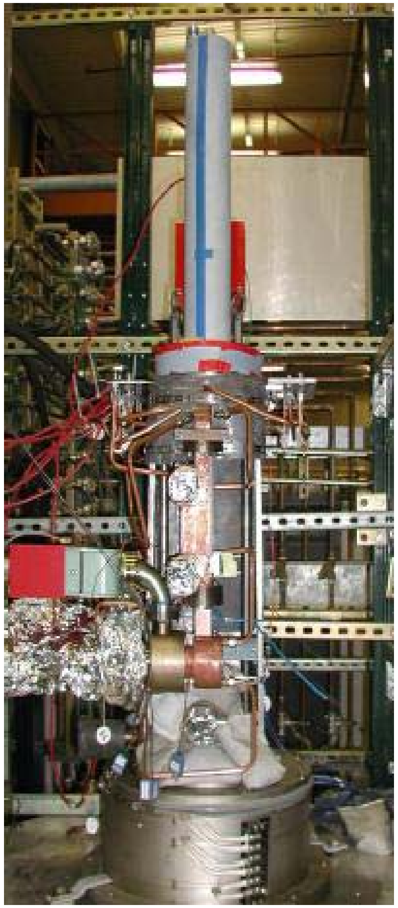
KEK/Toshiba

PPM2: Previously achieved 70 MW at 1.5 μs at KEK (limited by modulator performance), and now under test at SLAC.

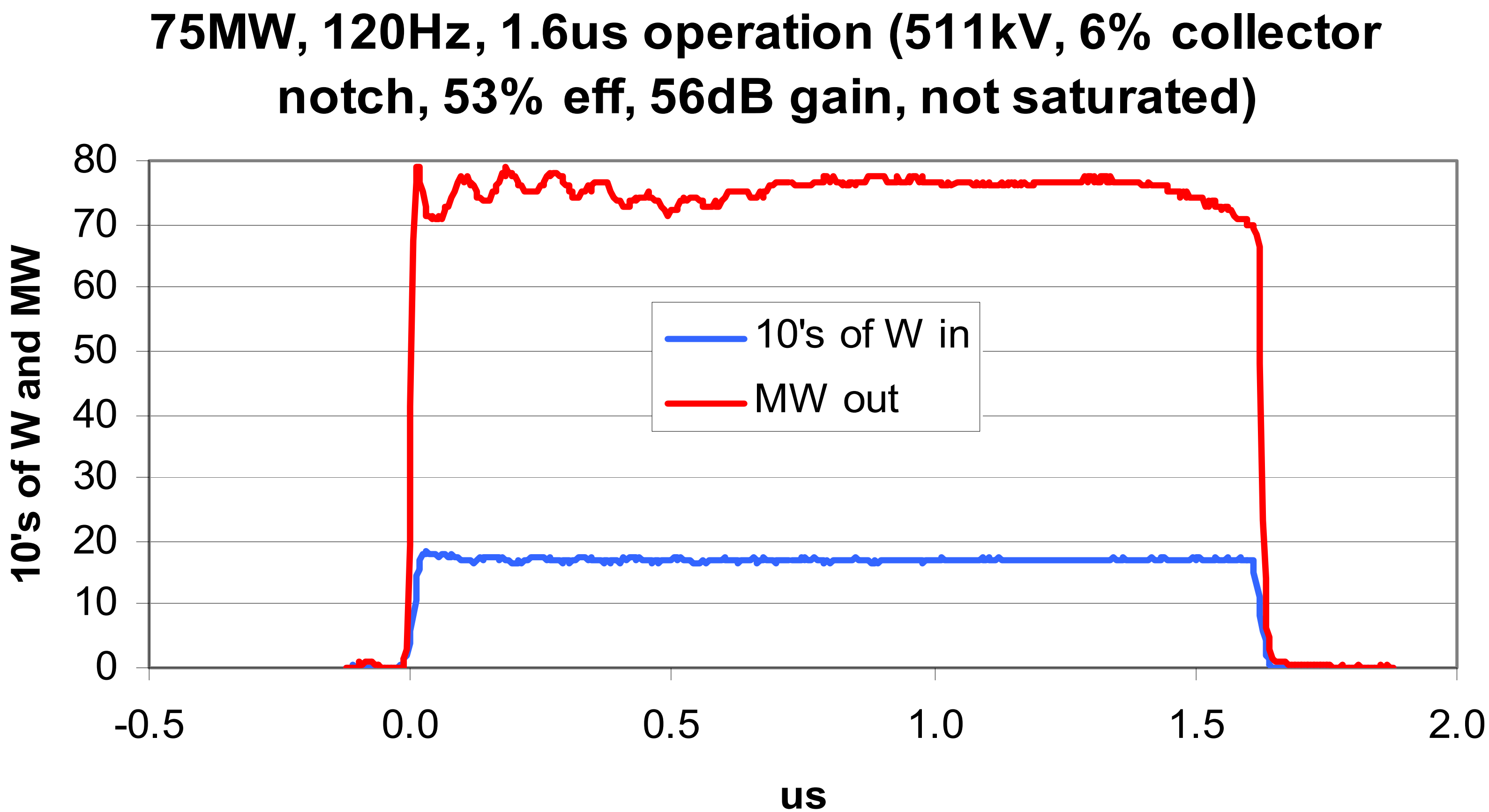
PPM4: Being processed at KEK: currently running 76-78 MW pulses 1.6 μsec at 50 Hz.

SLAC XP3-3

Met full power specifications of 75 MW pulses 1.6 μsec duration at 120 Hz.



SLAC XP3-3 Waveforms



Second Generation IGBT Modulator

"DFM" Stack

6.5 kV IGBTs
Cast casings.
Improved cooling.
Improved connections.

Bechtel-LLNL-SLAC "DFM" 20 kV test stack.

US LC Evaluation

- The Accelerator Subcommittee of the US Linear Collider Steering Group (USLCSG) has been charged by the USLCSG Executive Committee with the preparation of options for the siting of an international linear collider in the US.

Membership of the USLCSG Accelerator Subcommittee:

David Burke* (SLAC)
Gerry Dugan* (Cornell) (Chairman)
Dave Finley (Fermilab)
Mike Harrison (BNL)
Steve Holmes* (Fermilab)
Jay Marx (LBNL)
Hasan Padamsee (Cornell)
Tor Raubenheimer (SLAC)

* Also member of USLCSG Executive Committee

US LC Physics Requirements from the USLCSG Physics and Detector Subcommittee

- Initial energy 500 GeV cms.
- Upgrade energy: at least 1000 GeV cms.
- Electron beam polarization > 80%.
- An upgrade option for positron polarization.
- Integrated luminosity 500 fb^{-1} within the first 4 yrs of physics running, corresponding to a peak luminosity of $2\text{x}10^{34}$cm^{-2}s^{-1}.
- Beamstralung energy spread comparable to initial state radiation.
- Site consistent with two experimental halls and a crossing angle.
- Ability to run at 90-500 GeV c.m. with luminosity scaling with E_{cm}.

Specific Charge

- Two technology options are to be developed: a warm option, based on the design of the NLC Collaboration, and a cold option, similar to the TESLA design at DESY.

- Both options will meet the physics design requirements specified by the USLCSG Scope document.

- Both options will be developed in concert, using, as much as possible, similar approaches in technical design for similar accelerator systems, and a common approach to cost and schedule estimation methodology, and to risk/reliability assessments.

Task Forces

- To carry out the charge, the Accelerator Subcommittee has formed four task forces:
  - Accelerator physics and technology design.
  - Cost and schedule.
  - Civil construction and siting.
  - Availability design.

- Risk assessment will be carried out by a team formed from members of the other 4 task forces.

Task Force Membership

1. Accelerator physics and technology design task force
   - Chris Adolphsen (SLAC)
   - Gerry Dugan[1,2] (Cornell)
   - Helen Edwards (Fermilab)
   - Mike Harrison[2] (BNL)
   - Hasan Padamsee[2] (Cornell)
   - Tor Raubenheimer[2] (SLAC)
2. Site-specific civil design (CA and Fermilab sites) task force
   - Dave Burke[2] (SLAC)
   - Clay Corvin (SLAC)
   - Dave Finley[2] (Fermilab)
   - Steve Holmes[1,2] (Fermilab)
   - Vic Kuchler (Fermilab)
   - Marc Ross (SLAC)
3. Cost and schedule task force
   - Dave Burke[1,2] (SLAC)
   - John Cornuelle (SLAC)
   - Dave Finley[2] (Fermilab)
   - Warren Funk (Jefferson Lab)
   - Peter Garbincius (Fermilab)
   - Mike Harrison[2] (BNL)
   - Steve Holmes[2] (Fermilab)
   - Ted Lavine (SLAC)
   - Cindy Lowe (SLAC)
   - Tom Markiewicz (SLAC)
   - Hasan Padamsee[2] (Cornell)
   - Brett Parker (BNL)
   - Kem Robinson (LBNL)
   - John Sheppard (SLAC)
4. Availability Design and Specification
   - Paul Czarapata (Fermilab)
   - Helen Edwards (Fermilab)
   - Tom Himel[1] (SLAC)
   - Marcus Huening (Fermilab)
   - Nan Phinney (SLAC)
   - Marc Ross (SLAC)

[1] Primary liasion to USLCSG Accelerator Subcommittee
[2] USLCSG Accelerator Subcommittee member

US Cold LC Reference Design

The major changes made to the TESLA design are:

- An increase in the upgrade energy to 1 TeV (c.m.), with a tunnel of sufficient length to accommodate this in the initial baseline.
- The use of a two-tunnel architecture for the linac facilities.
- The choice of 28 MV/m as the initial main linac design gradient for the 500 GeV, but cavities must meet 35 MV/m needed for 1 TeV.
- Use of the same injector beam parameters for the 1 TeV upgrade as for 500 GeV.
- An expansion of the spares allocation in the main linac.
- A re-positioning of the positron source undulator to make use of the 150 GeV electron beam, facilitating operation over a collision energies from 91 to 500 GeV.
- An NLC-style beam delivery system with superconducting final doublet quads.
- At the subsystem and component level, specification changes to facilitate comparison with the warm LC option.

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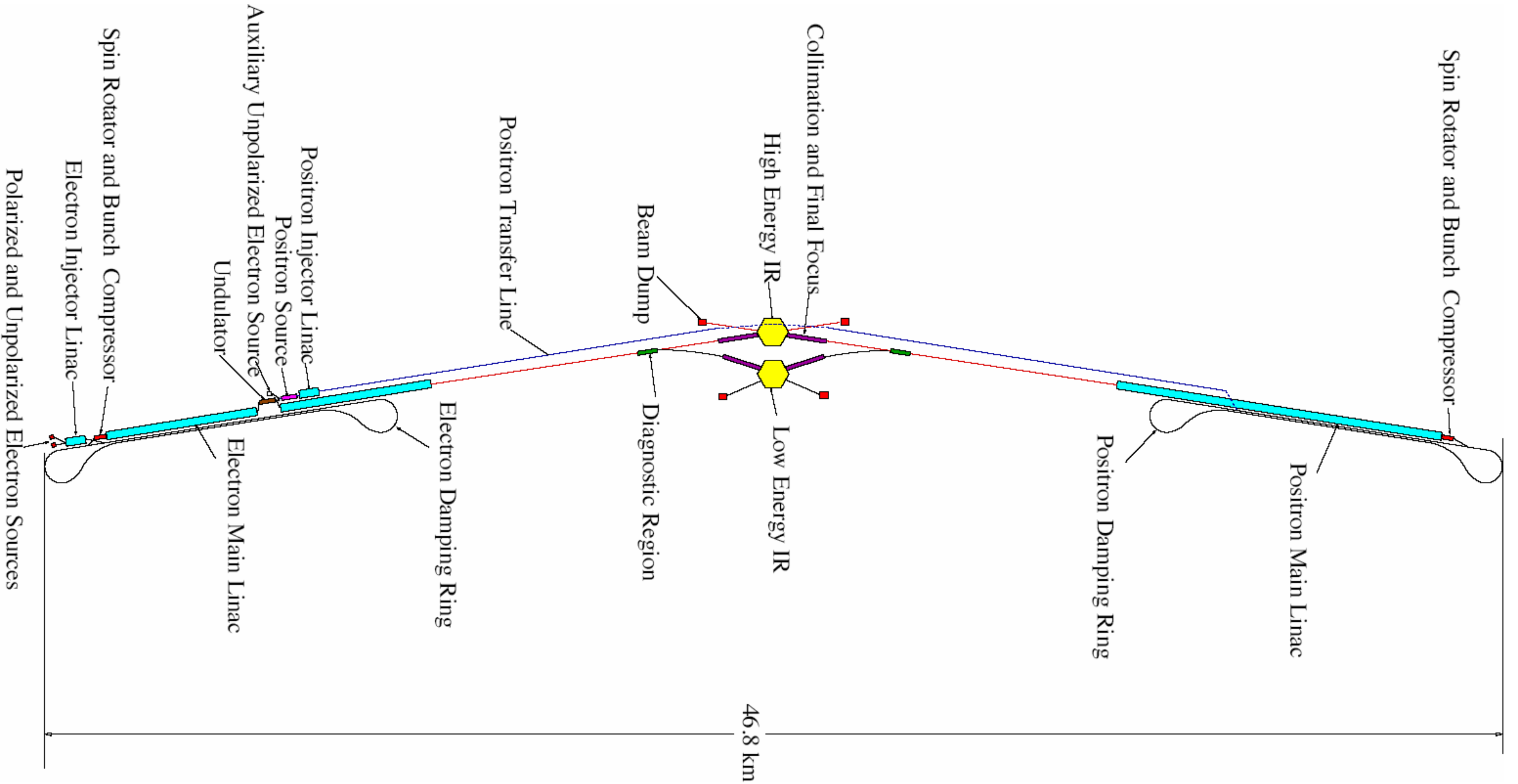
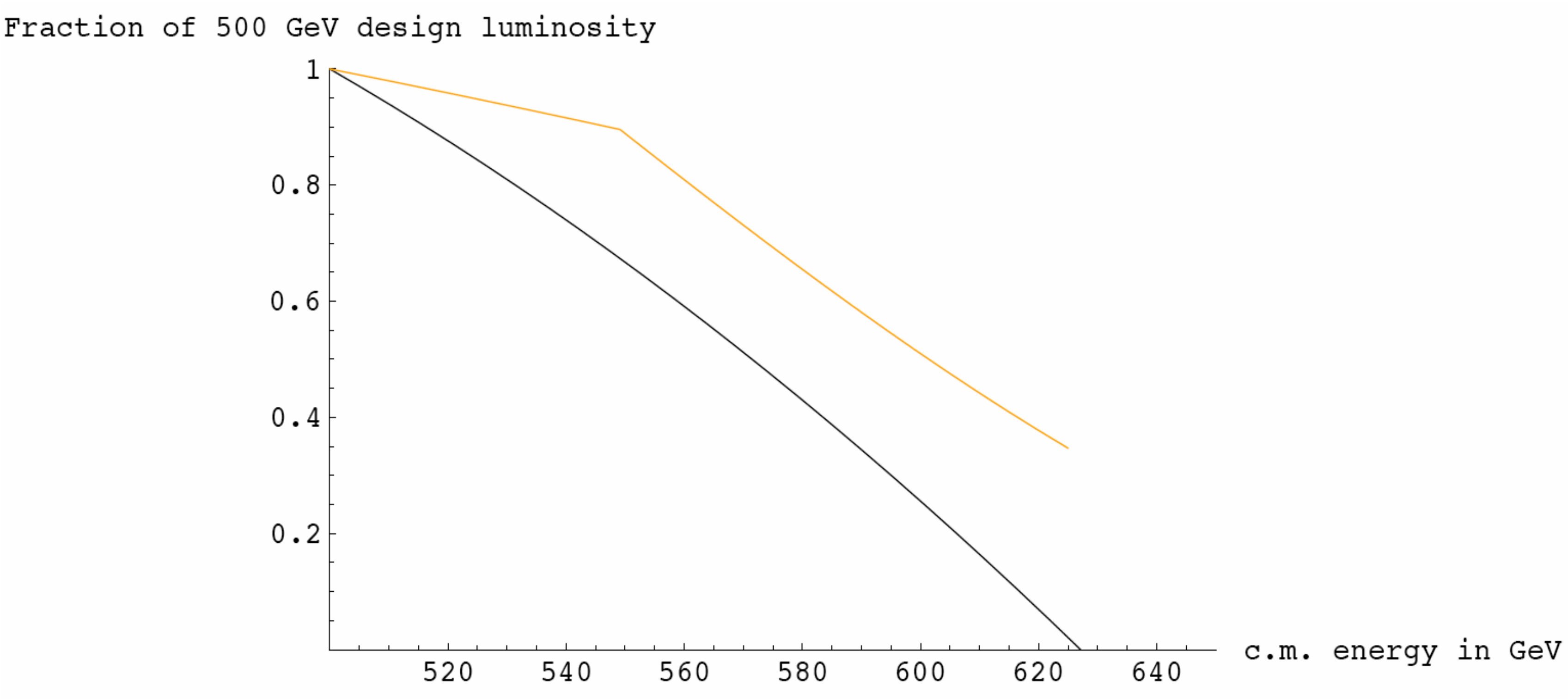
US Cold LC Layout



Initial Stage Energy Reach

Black: warm option, structures qualified at unloaded gradient 65 MV/m, loaded gradient 52 MV/m.
Red: cold option, cavities qualified at max gradient 35 MV/m,
operating gradient at 500 GeV= (52/65)*35 MV/m= 28 MV/m.



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Cost and Schedule Task Force Charge and Interpretation

"The Cost and Schedule (C&S) Task Force is charged to provide estimates of the TPC and schedule for completion of each of the machine configurations if entirely funded by the U.S. and built in the United States by U.S. labs and universities and global industries on a competitive basis."

Interpretation

- "Provide" not "Make"
  - Fully utilize existing work done by NLC/JLC and TESLA Collaborations.
  - Fully utilize previous analysis of this work. (E.g. Fermilab-led restatement of costs from TESLA, and Lehman Review of the NLC.)
- Configurations provided by the Accelerator Design Task Force for the warm and cold technology options are not exactly the official NLC/JLC or TESLA Collaboration configurations.

Costing Assumptions

- LC Will be Built in the U.S.
- U.S. DOE Financial Practices Apply
- As Much Scope as is Reasonable Will be Contracted Out
- Currency conversion for TDR costs: 1 Euro = 1 US Dollar
- Civil Construction Rules and Regulations Will Be U.S. Content
- The Cost Impact (If Any) of "In-Kind" or Politically-Directed Contributions/Purchases Will be Ignored
- Common WBS structure used for both options.

→ Final report will not (likely) contain absolute cost numbers, but will be a cost comparison between the warm and cold options.

Overview of Goals and Key Issues

- *Develop a Design Solution for Each of Four Options:*

  Cold and Warm in CA and Cold and Warm in IL
  Using a Twin Tunnel Configuration in all Cases.

- *Develop a Fifth Option for a Cold Machine Using a Single Tunnel Configuration.*

- *Deliverables for Each Design Solution to Consist of a Written Configuration Summary, Schematic Design Drawing Set and Cost Estimate.*

- *Analysis of Construction Issues Related to a One-Tunnel vs Two Tunnel Solution for a Cold Machine.*

Availability Design Task Force

- Establish top level availability requirements such as
  - Annual scheduled operating time
  - Hardware availability
  - Beam efficiency
- Consider 3 machines:
  - Warm
  - Cold in 1 tunnel
  - Cold in 2 tunnels
- Allocate top-level availability requirements down to major collider systems.
- As time allows attempt to balance availability specs. to minimize risk and cost.
- Compare to data from existing accelerators.

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Availability Task Force

- Write a simulation that, given the MTBFs, MTBRs, numbers and redundancies of components, and access requirements for repair can calculate the integrated luminosity per year. Luminosity will be either design or zero in this simulation.

- Collect data on MTBFs and MTBRs from existing machines to guide our budgeting process.

- Make up a reasonable set of MTBFs that give a reasonable overall availability.

- Iterate as many times as we have time for (probably once during this task force) to minimize the overall cost of the LC while maintaining the goal availability.

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Risk Assessment

- The USLCSG charge to the Accelerator Sub-Committee included a requirement to make a risk assessment of the LC options.
- A fifth task force will be formed, from members of the other 4 task forces.
- The collective Task Force team has carried extensive discussion to identify potential risks to the performance metrics of the collider.
- “Risk” is not the probability that something will go wrong – things will go wrong. We anticipate the Project Plan will include contingency in schedule and budget to deal with unknowns and errors.

→ The Assessment will be of Risk to the **Mission Goal** to deliver 500 fb^{-1} at 500 GeV on schedule and budget, and to be up-gradable to 1 TeV.

USLCSG

Schedule for US LC Evaluation

- Jan. 10: Charge from USLCSG Executive Committee.
- April 14: Joint task force meeting #1
- May 22-23 Cost review meeting at DESY
- June 5-6 Design review meeting at DESY
- June 15-16: Joint task force meeting #2
- Aug 27-28: Joint task force meeting #3
- Sept 1-3: Second cost review at DESY
- Oct 13-14: Joint task force meeting #4
- November: Completion of task force work, writing of final report, and submission of report to the USLCSG Executive Committee.