**NLC - The Next Linear Collider Project**

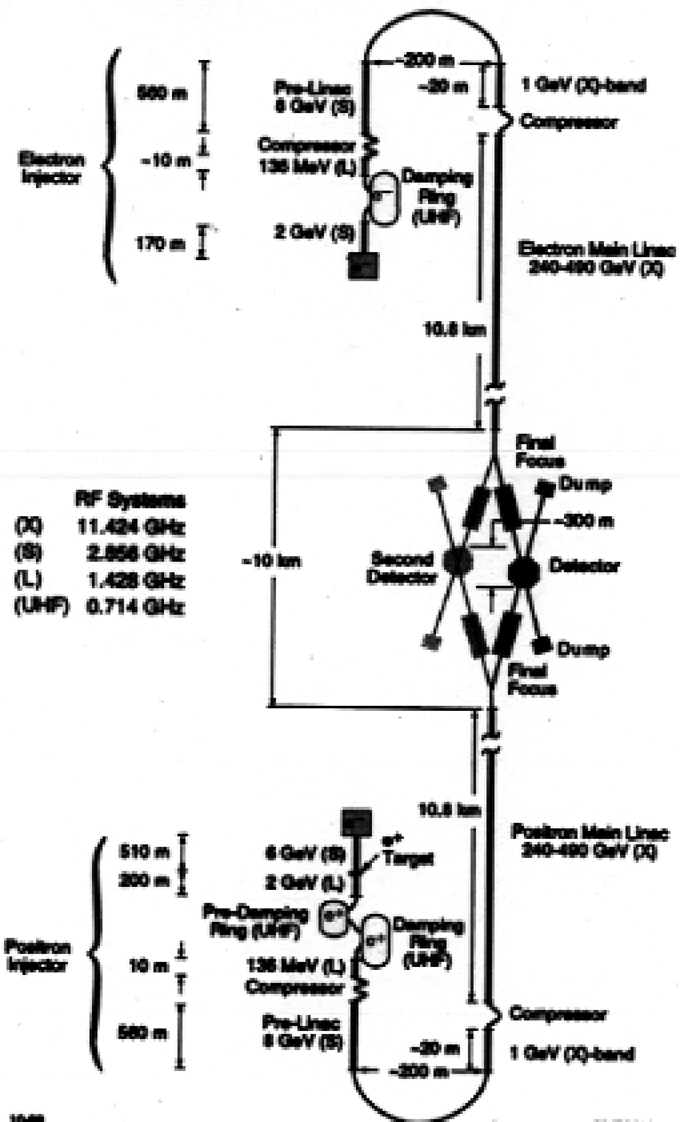
# SLAC Activities towards NLC

**ICFA Meeting**

**October 6th 1999**

***Tor Raubenheimer***

# Next Linear Collider




- $e^+/e^-$ linear collider based on X-band rf technology
- Initial cms energy of 500 GeV with $\mathcal{L} \geq 5\times10^{33}$
- Straight-forward upgrade to 1 TeV with $\mathcal{L} \geq 1\times10^{34}$
- Upgrade routes to 1.5 TeV
- Technology based on results from test facilities: FFTB, NLCTA, ASSET, KEK ATF
- Incorporates knowledge gained from SLC operation

# NLC Project Scope

- Injector Systems — 1.5 TeV
- Main Linac — 0.5 - 1.0 TeV
  - Housing with all internal services
  - Half filled for initial 500 GeV cms
  - Upgrade by adding rf, water, power to the 2nd half of the tunnels

  (1.5 TeV with increased length or gradient)
- Beam Delivery — 1.5 TeV
  - Two BDS tunnels and IR halls with services but only one beam line

# NLC Progress

- Established collaborations with KEK, LBNL, and LLNL
- Optimized parameters and established common rf design with KEK
- Converted from R&D mode to a 'project'
- Performed bottoms-up cost estimate for Lehman review
- Successful Lehman review—questionable budget!
- Establishing collaboration with Fermilab
- Have demonstrated almost all *necessary* rf hardware
- Improving rf designs for reduced cost and improved efficiency
- Working on cost reduction throughout design!

# 500 GeV and 1 TeV Parameters

| IP Parameters for the JLC / NLC (8/8/98) | 500 GeV | | | 1 TeV | | |
|---|---|---|---|---|---|---|
| | A | B | C | A | B | C |
| CMS Energy (GeV) | 535 | 515 | 500 | 1046 | 1008 | 978 |
| Luminosity ($10^{33}$) | 7.7 | 7 | 6 | 15 | 13 | 11.6 |
| Repetition Rate (Hz) | 120 | 120 | 120 | 120 | 120 | 120 |
| Bunch Charge ($10^{10}$) | 0.75 | 0.95 | 1.1 | 0.75 | 0.95 | 1.1 |
| Bunches/RF Pulse | 95 | 95 | 95 | 95 | 95 | 95 |
| Bunch Separation (ns) | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 |
| Eff. Gradient (MV/m) | 57.2 | 55 | 53.3 | 57.2 | 55 | 53.3 |
| Injected $\gamma\epsilon_x$ / $\gamma\epsilon_y$ ($10^{-8}$) | 300 / 3 | 300 / 3 | 300 / 3 | 300 / 3 | 300 / 3 | 300 / 3 |
| $\gamma\epsilon_x$ at IP ($10^{-8}$ m-rad) | 400 | 450 | 500 | 400 | 450 | 500 |
| $\gamma\epsilon_y$ at IP ($10^{-8}$ m-rad) | 6 | 10 | 14 | 6 | 10 | 14 |
| $\beta_x$ / $\beta_y$ at IP (mm) | 10 / 0.1 | 12 / 0.12 | 13 / 0.2 | 10 / 0.125 | 12 / 0.15 | 13 / 0.2 |
| $\sigma_x$ / $\sigma_y$ at IP (nm) | 277 / 3.4 | 330 / 4.9 | 365 / 7.6 | 197 / 2.4 | 235 / 3.9 | 280 / 5.4 |
| $\sigma_z$ at IP (um) | 90 | 120 | 145 | 90 | 120 | 145 |
| Yave | 0.14 | 0.11 | 0.09 | 0.38 | 0.3 | 0.25 |
| Pinch Enhancement | 1.41 | 1.36 | 1.5 | 1.41 | 1.46 | 1.5 |
| Beamstrahlung $\delta B$ (%) | 4.5 | 4 | 3.6 | 10.9 | 10.3 | 9.7 |
| Photons per e+/e- | 1 | 1.1 | 1.17 | 1.3 | 1.43 | 1.51 |

From Accelerator Physics pages in NLC www area

# Design Parameter Space and Margins

- Operating plane over which $\mathcal{L}$ ~ constant but current, final focus optics, and spot sizes vary by ~50% *(similar to SLC experience)*
  - component requirements set by tightest tolerances in range
- Allow for 1.4 ns or 2.8 ns bunch spacing to trade multi-bunch vs. single-bunch $\varepsilon$ dilutions and backgrounds
- Systems are all specified with **additional** overheads to produce better beams than required—for example:
  - E- injector designed to produce **40%** additional charge
  - Linac tolerances do **not** assume emittance correction

# Design Parameter Space and Margins

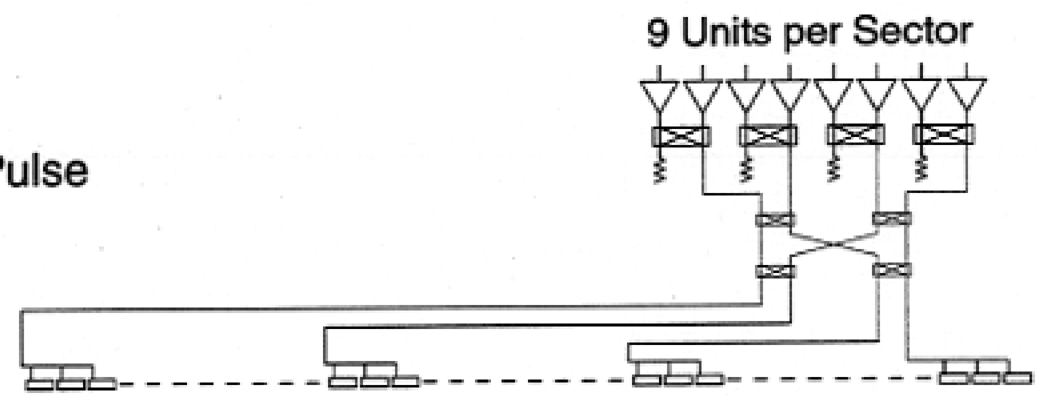
- Studied high luminosity options:
  - Assume all design specifications are attained
    - 3 times nominal luminosity at 500 GeV cms
    - 2 times nominal luminosity at 1 TeV cms
  - Operate with rounder beams
    - Higher pinch enhancement of luminosity
    - Much higher beamstrahlung (30 to 40%) at 1 TeV cms
    - 3 to 4 times nominal luminosity
    - Difficult interaction region and backgrounds (not studied)
- NOT part of design assumptions however flexibility is essential!

# NLC 'Models'

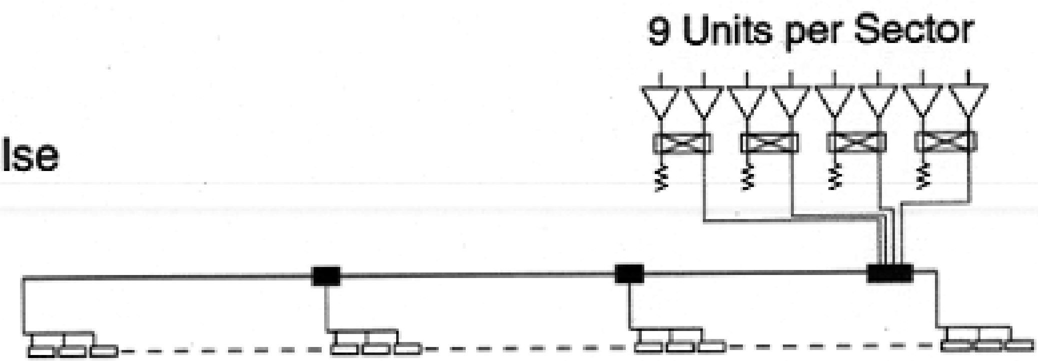
- 'CD-1' model developed for Lehman review in May '99
  - Complete collider but not cost-optimized!
  - Designed conservatively where uncertainty existed
  - Developed full WBS and first pass at loaded schedule
  - Bottoms-up cost estimation
- Reviewing design with eye towards cost reduction while maintaining project scope ⇒ CD0.4 model
  - Incorporating improvements in rf technology (solid-state modulators, multi-moded DLDS, …)
  - Looking at all areas from civil construction to collider parameters for cost reduction with analysis based on CD-1 cost numbers
  - Re-evaluate costs in roughly one year
- Re-iterate for CD0.8 model

# DLDS Options with Eight 75 MW Klystrons

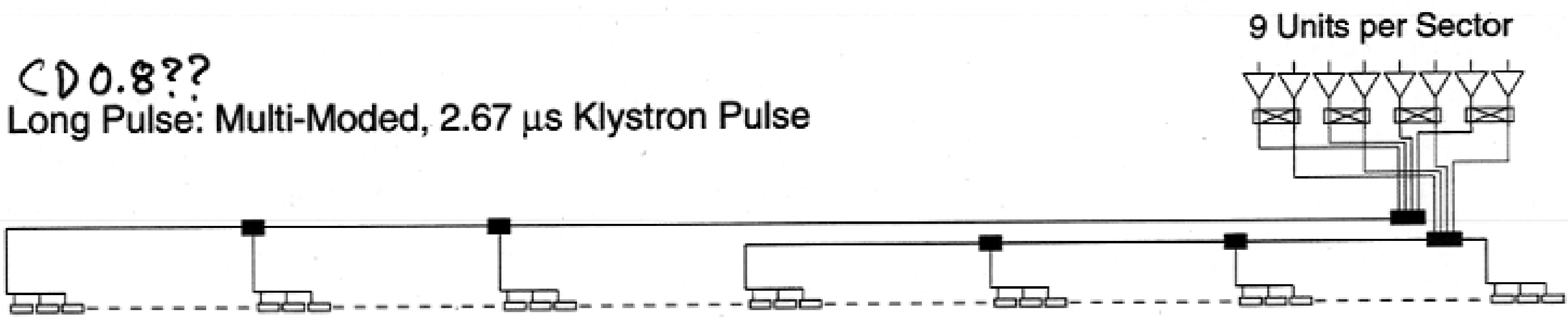
CD-1:
Baseline: Single-Moded, 1.53 μs Klystron Pulse




CDR 0.4: Multi-Moded, 1.53 μs Klystron Pulse




CD0.8??
Long Pulse: Multi-Moded, 2.67 μs Klystron Pulse



# SLAC / KEK Collaboration

- MOU signed in '98 to pursue common R&D towards LC
- Optimized JLC and NLC designs towards common parameters and rf designs
- 'ISG' meetings every 6 months alternating between SLAC and KEK sites:
  - Six working groups from Parameters to Interaction Region
  - Focus is on RF development (accelerator structures, rf pulse compression, klystrons, and modulators)
    - Accelerator structures built at KEK and tested at SLAC
    - Multi-mode DLDS components built at SLAC verified at KEK
  - http://www-project.slac.stanford.edu/lc/ilc/ISG_Meetings/isg_index.html
- Working on document to summarize progress

**Next Linear Collider**

# International Study Group
## Meetings

NLC Technical Page • Meeting Schedule • SLAC Home Page

- **First Linear Collider International Study Group Workshop, SLAC, January 26 - 29, 1998**
- **Second Linear Collider International Study Group Workshop, KEK, July 13 - 16, 1998**
- **Third Linear Collider International Study Group Workshop, SLAC, January 25-28, 1999**
- **Fourth Linear Collider International Study Group Workshop, KEK, July 19-23, 1999**

*Created: 07/27/98 by Tor Raubenheimer*

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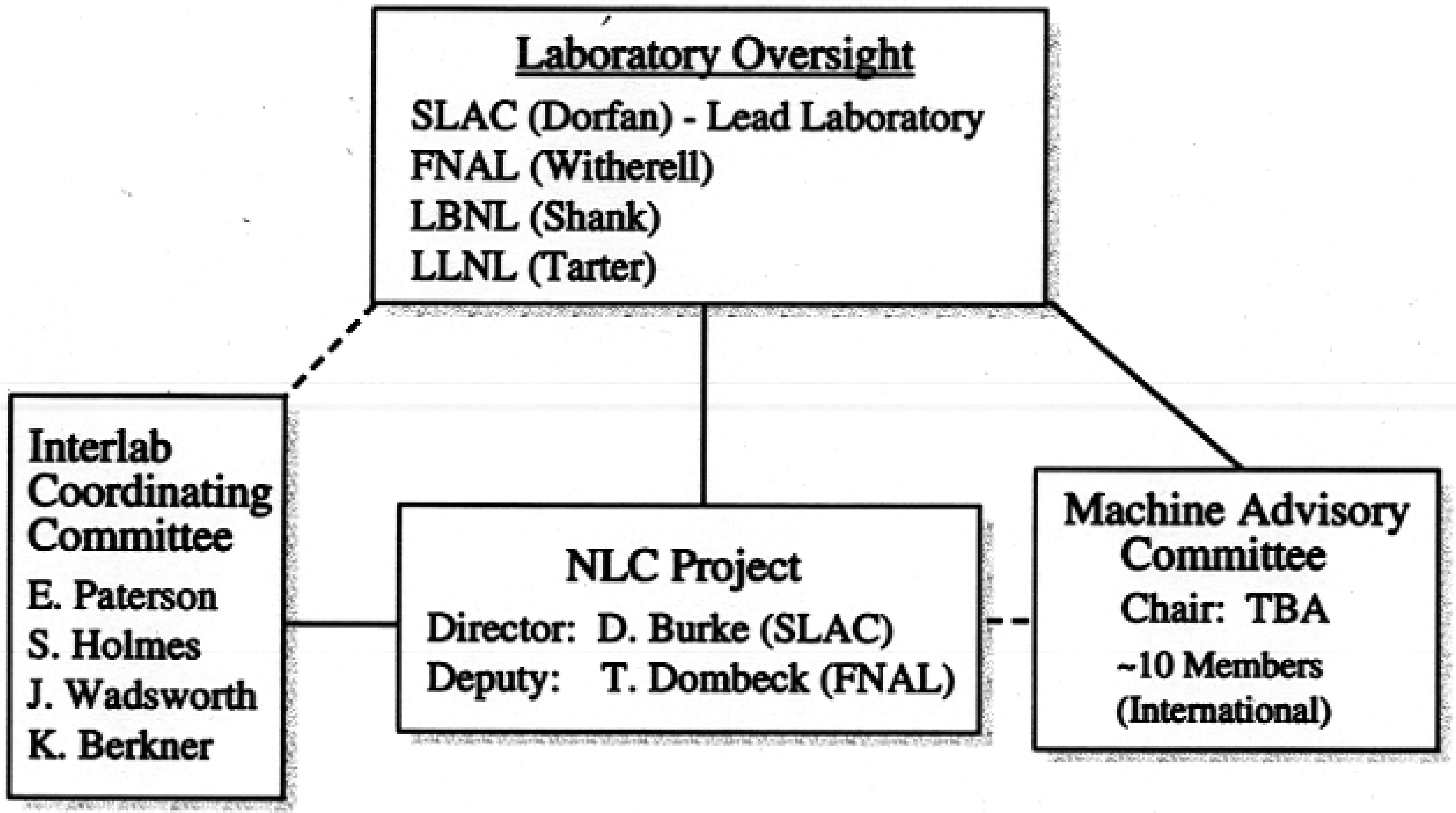
***August 02, 1999***

# U.S. NLC Collaboration

- MOUs signed with LBNL and LLNL
  - Berkeley concentrating on damping ring design
  - Livermore focusing on solid-state modulators
- Fermilab joining collaboration
  - Initial meetings in August to frame program
  - Site visits to review issues and discuss program
  - Meetings last few days to further develop near-term goals
  - First collaboration meeting at Fermilab in November to review CD0.4 model with follow-up meeting in January at SLAC
- Work at universities primarily related to physics and interaction region
- Numerous SBIRs to further technology development

# U.S. NLC Organization



# Next Linear Collider (rf issues)

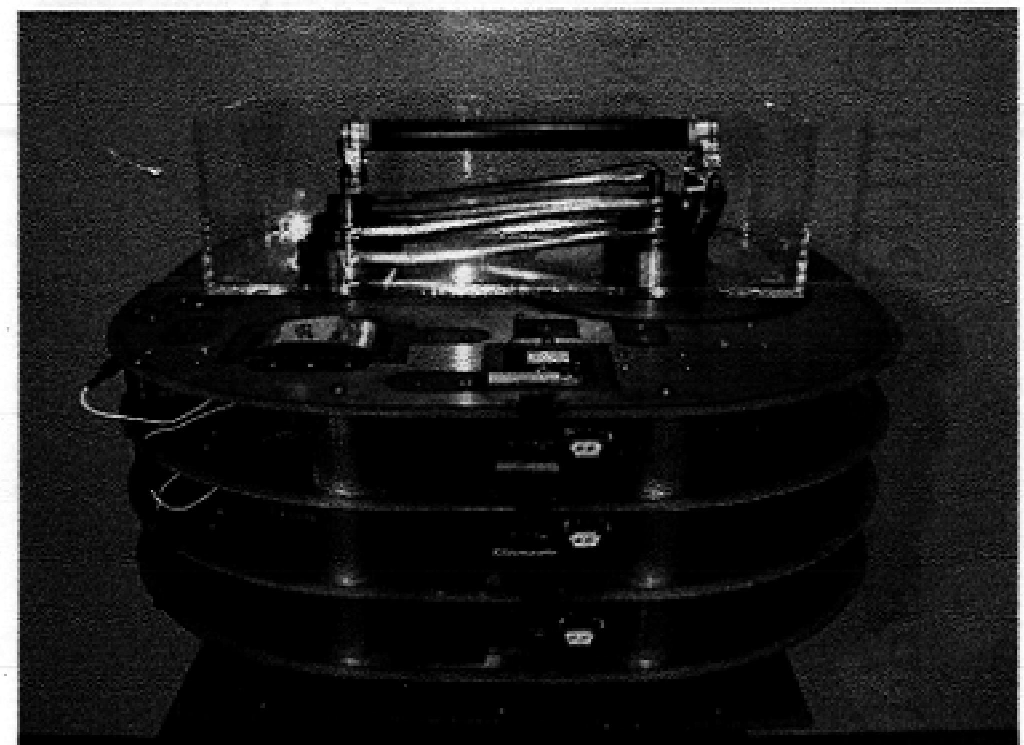
- To attain high acceleration gradients, NLC uses higher rf frequency for acceleration: 11.424 GHz (4 times SLAC)
  - need high efficiency to minimize ac power and heat loads
  - power sources (klystrons) are more difficult — considering two options: 75 MW, 1.5 μs or 50 MW, 2.4 μs
  - conventional modulators pushed to edge — looking at solid state
  - short rf pulse length requires rf pulse compression — many techniques
  - ability to handle high peak power (600 MW in places)
  - concerns about rf breakdown and gradients

# RF Highlights

- Developing solid-state modulator with LLNL
  - Less expensive, more reliable, smaller package
- Demonstrated 50 MW klystron operation for NLC
  - 2.4us rf pulse delivers energy needed
- Working on 75 MW klystron for reduced cost
  - Requires less pulse compression
- Tested mode propagation needed for multi-moded DLDS
  - Less expensive rf pulse compression system
- Built DDS3 structure and working on RDDS1 structure
  - DDS3 exceeded alignment requirements
  - RDDS will shorten linac length by 6%

# Solid-State Modulator

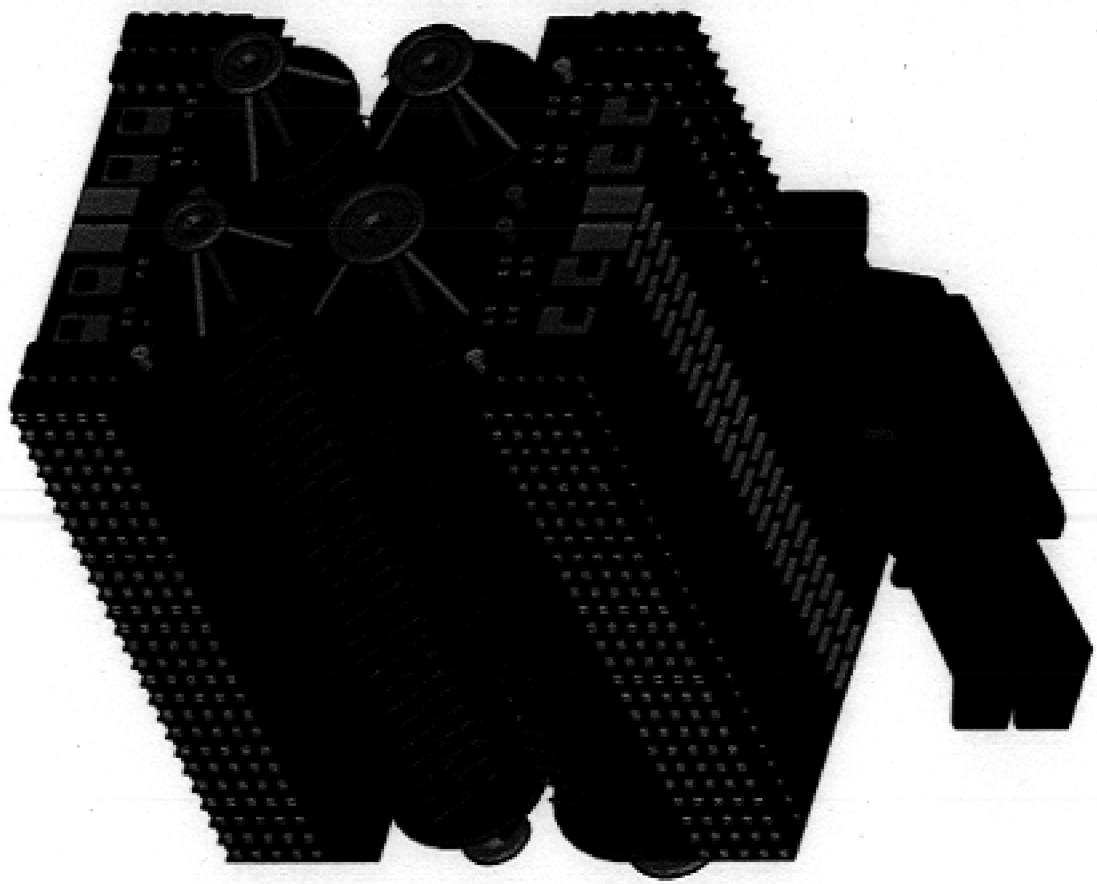
- Conventional modulators are expensive and inefficient
- Looking at solid-state IGBTs: 3 to 5 kV and 2kA and Metglass cores
- Program at LLNL to develop 'Induction Modulator'
- Drive 8 klystrons using a stack of 100+ IGBTs and no transformer



Testing of full unit 2000

# Induction Modulator Assembly

NLC
Solid
State
Modulator
-
4 Stack



2 IGBTs /Bd
5kw/core
26 cores/stack
125kV/stack
500kV total
Powers 8 Klystrons

- LLNL & Bechtel Nevada

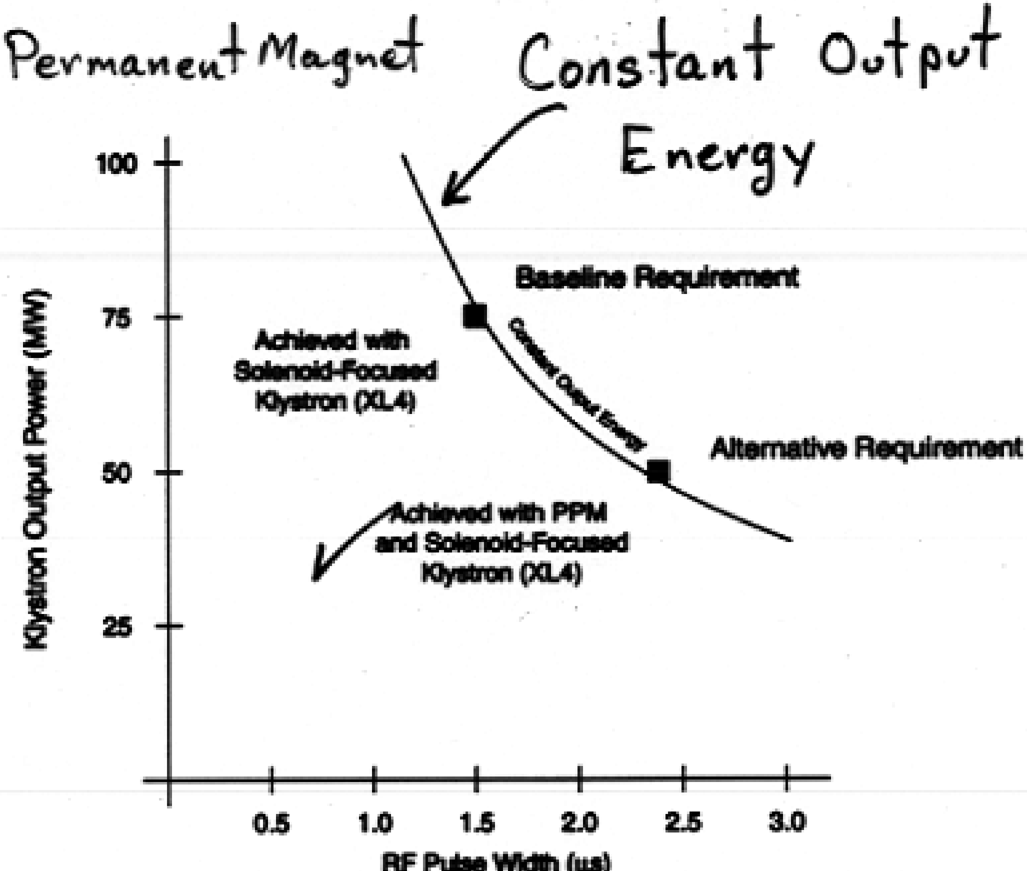
# Klystrons

- XL-4 solenoid focused klystron produces *either* 75 MW or 50 MW pulses that are required but efficiency is low due to solenoid

PPM = Periodic Permanent Magnet

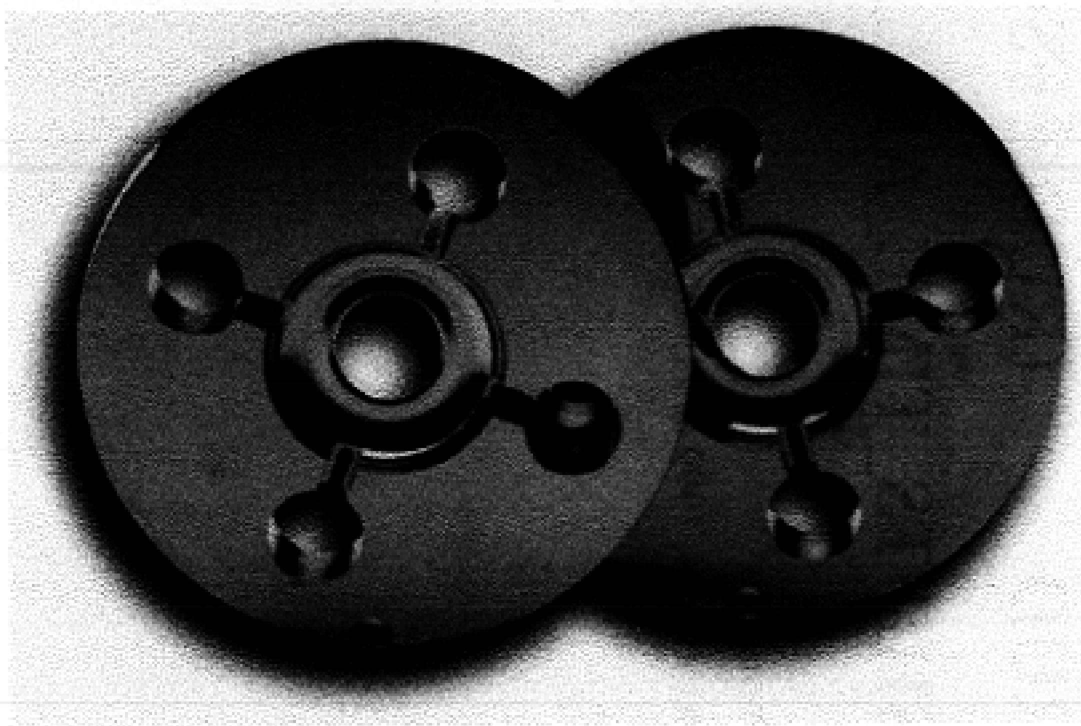
- 50 MW PPM klystron achieved the needed efficiency and pulse length but does not operate at 75 MW

- 75 MW PPM tube is under development

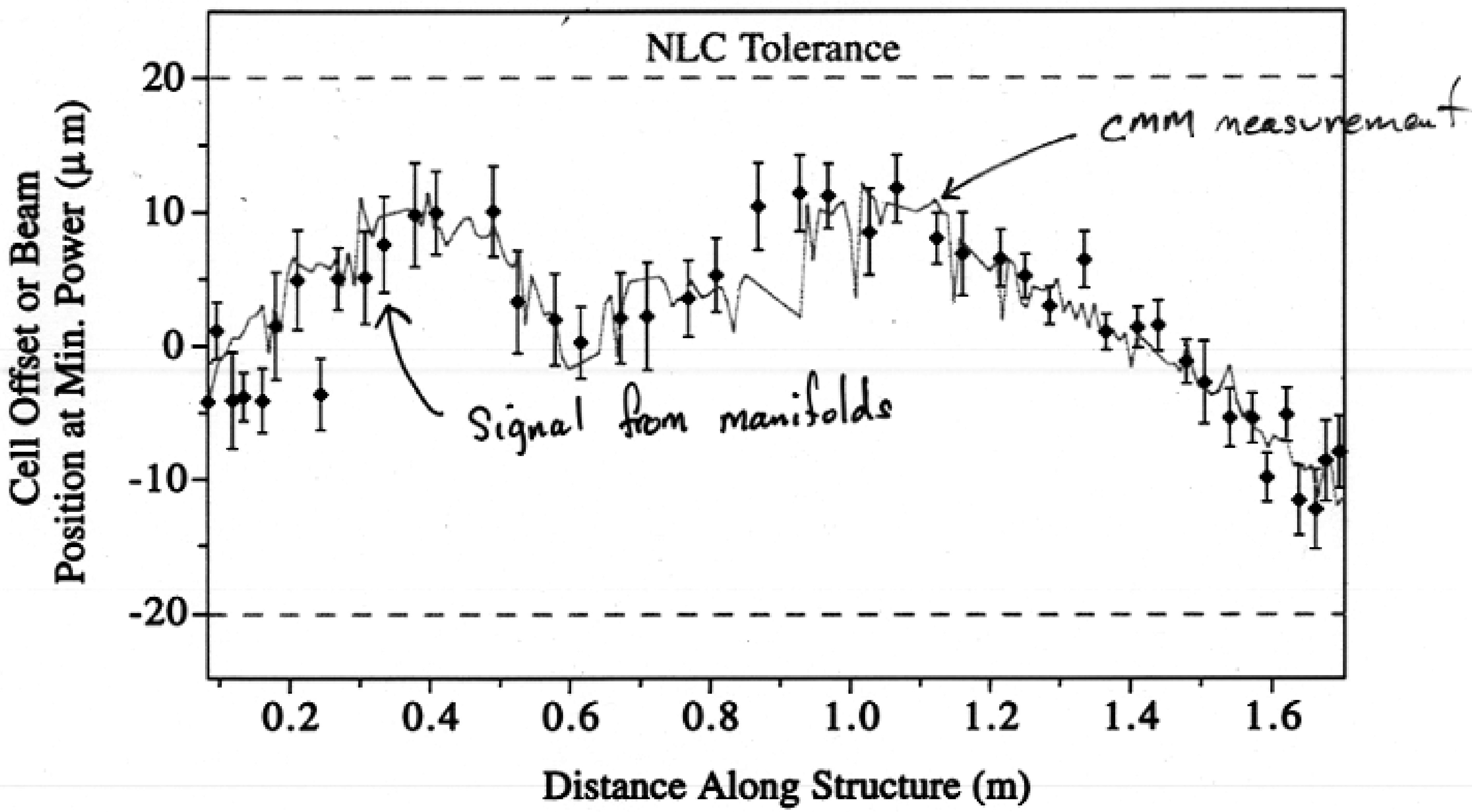


# Rounded Damped-Detuned Structure

- Need to damp or decohere long-range dipole modes to prevent the Beam Break-Up instability
- Each X-band structure has 206 cells, each with a different dipole mode frequency
- Manifolds provide signal for beam-based alignment
- Latest structure design: RDDS has cells with +12% shunt impedance

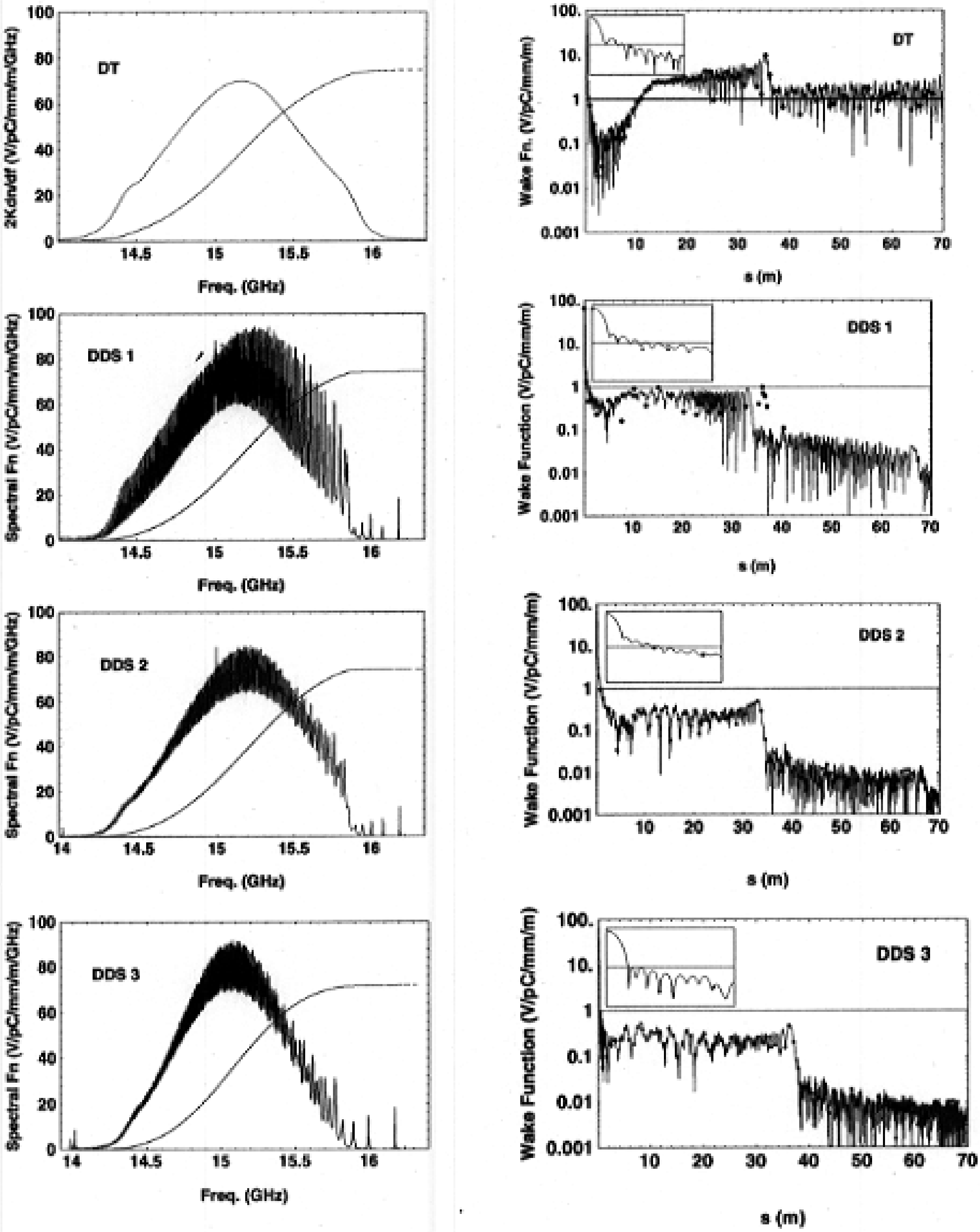


# DDS3 Structure BPM Test



# Long-Range Wakefields and Accelerator Structure Designs

- Choose parameters to optimize energy transfer to beam at high gradient but beams induce 'wakefields' in structures
- Longitudinal wakefield causes energy variation along bunch train—compensated by adjusting rf pulse amplitude (and phase)—verified in NLCTA!
- Transverse wakefields cause Beam Break-Up instability and can make linac inoperable!
- Careful design of the structures to ensure small transverse wakefields and eliminate problem ***by design***


DT
2Kdn/df (V/pC/mm/m/GHz)
Freq. (GHz)
Wake Fn. (V/pC/mm/m)
s (m)
DDS 1
Spectral Fn (V/pC/mm/m/GHz)
Freq. (GHz)
Wake Function (V/pC/mm/m)
s (m)
DDS 2
Spectral Fn (V/pC/mm/m/GHz)
Freq. (GHz)
Wake Function (V/pC/mm/m)
s (m)
DDS 3
Spectral Fn (V/pC/mm/m/GHz)
Freq. (GHz)
Wake Function (V/pC/mm/m)
s (m)

# Spot Size Issues

- Beams must be focused to extremely small sizes (250 nm by 5 nm)
  - very small beam phase space ⇒ novel damping ring designs
  - accurate diagnostics to use beam-based alignment in linacs and transport lines to attain micron level alignment
  - very accurate cancellation of non-linearities and chromatic effects in final focusing system (FFTB)
- Beam must be highly stable to allow tuning
  - understand instabilities in damping rings and linacs
  - minimize vibrations from ground motion and cultural activities
  - rely on beam-based feedback systems with non-linear interactions
- Because of high energy density, the beam is very destructive

# Damping Rings

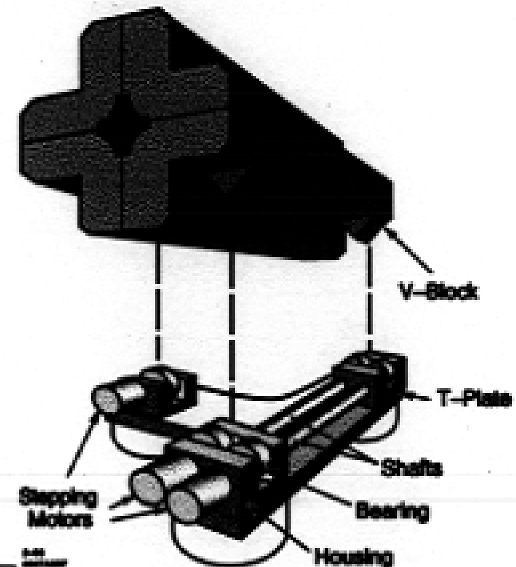
- Damping rings like 3rd generation SR sources with similar problems except require faster damping

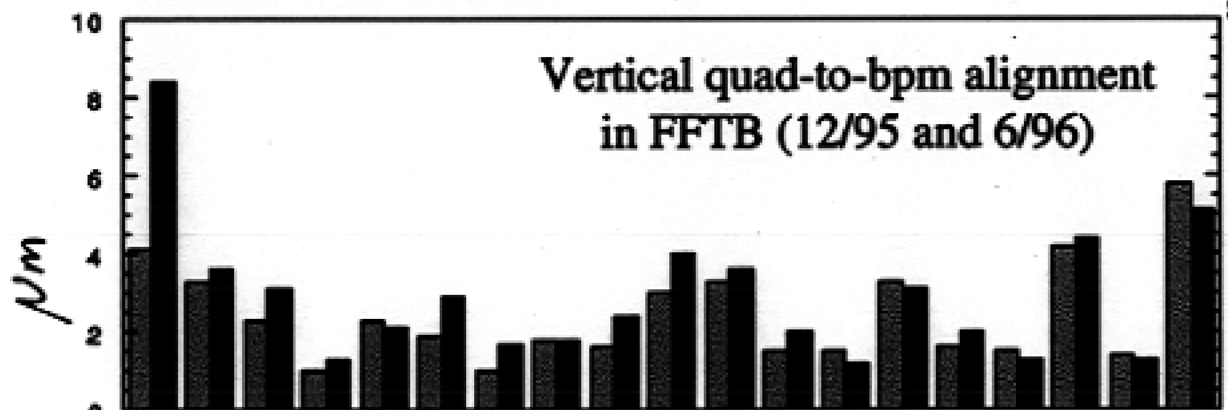
- ZDR damping rings needed re-design because of parameter change—longer bunch trains
  - Lattice **without** *combined-function dipole magnets*
  - Increased **momentum compaction and increase RF voltage** by including more wiggler (25m → 45m)
  - Increased **vacuum and ante-chamber apertures** for reduced impedance and easier beam handling

- R&D started at LBNL on kickers, wiggler, and RF cavities

# Beam-Based Alignment

- Movers developed for Final Focus Test Beam (FFTB) have steps ~ 0.5μm
- Stripline Beam Position Monitors (BPMs) for FFTB have <1μm resolution and rf cavity BPMs have 40nm resolution




- In CD-1 all elements from damping rings downstream have independent power supplies and are on magnet movers

# Collimation System and MPS

- Collimation system and machine protection (MPS) intimately related—difficult for ***all*** linear collider designs
- Collimation system consists of two parts:
  - Pre-linac collimation at the end of the pre-linac (10 GeV)
  - Main collimation at end of main linac
- Pre-linac system is 'easy'
- Main collimation system is hard because high density beams will destroy materials (linac beam: $\Delta T \sim 8 \times 10^5\,°C$!)

  ⇒ increase beam size but makes optics difficult!
- ZDR system was designed to have passive protection but had very tight tolerances—working on new design

# Final Focus and Interaction Region

- Focus beams to the very small spot sizes
- Final focus is a scaled up model of the Final Focus Test Beam (FFTB) beamline—FFTB demonstrated greater **demagnification** than needed for NLC

- Need to design a stable support for the final magnets with ~1nm vibration at frequencies greater than a few Hz
- Length of system: IP switch, big bend, final focus, is roughly 2.5 km—driven by synchrotron radiation effects at high energy — big cost implication!

# Interaction Region Vibration

- IP spot size is roughly 5 nm ⇒ tight vibration tolerances on final quadrupoles
- Four approaches:
  - Passive isolation—measuring expected motions in SLD collider hall
  - 'Optical anchor'—use laser interferometer to detect motion relative to bedrock
  - 'Inertial Sensors'—use inertial sensors to eliminate high-frequency motion
  - Fast IP feedback—use very fast intra-train feedback system to correct within a single pulse
- All seem possible—plan to test IR mock-up in roughly one year

# Summary

- Lots of progress on NLC in last year!
- Lehman review of project verified status
- Collaborations making progress
  - Collaboration with KEK producing enhanced accelerator structures
  - Collaboration with Livermore designing advanced modulators
  - Collaboration with Berkeley designing damping rings
  - Collaboration with Fermilab starting
- No ‘show-stoppers’ except possibly cost!
- Continual improvement in rf components $\Rightarrow$ cost reductions
- Using CD-1 cost estimates to review design for further reductions!