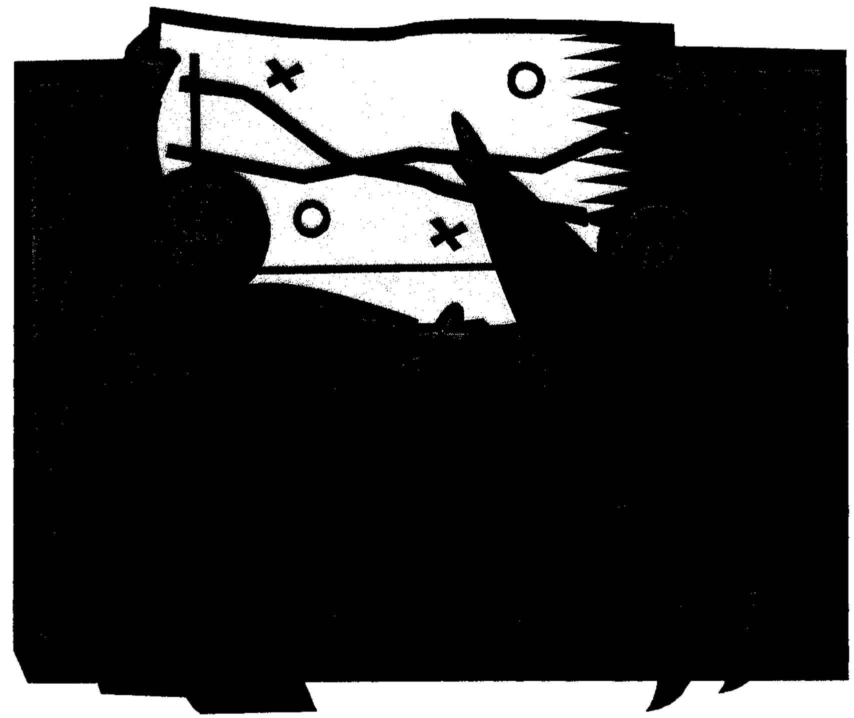
SNOWMASS 2001 7/01

NLC - The Next Linear Collider Project

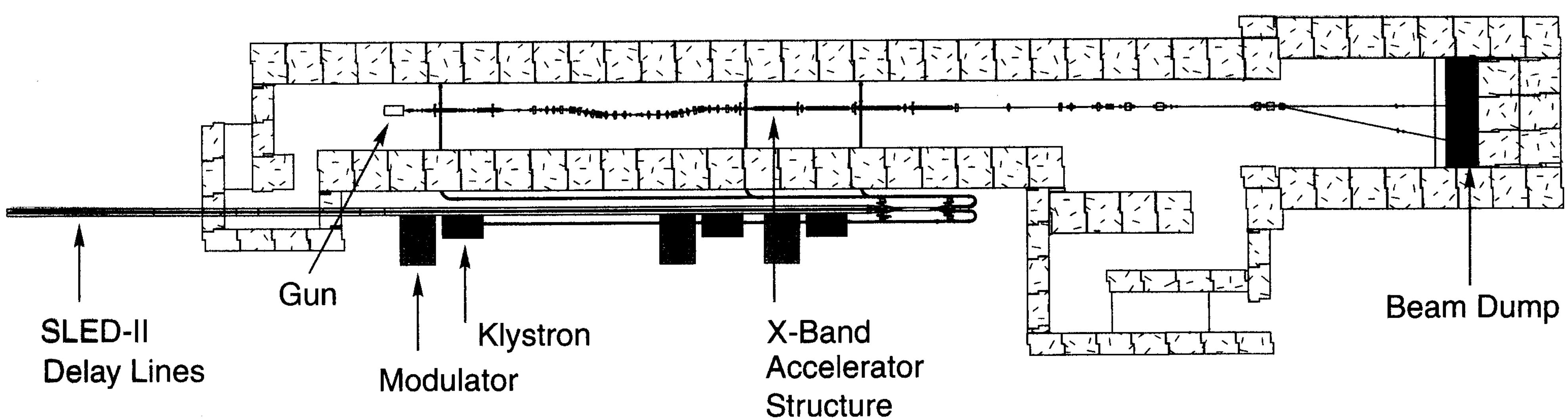
Main Linac RF System Overview



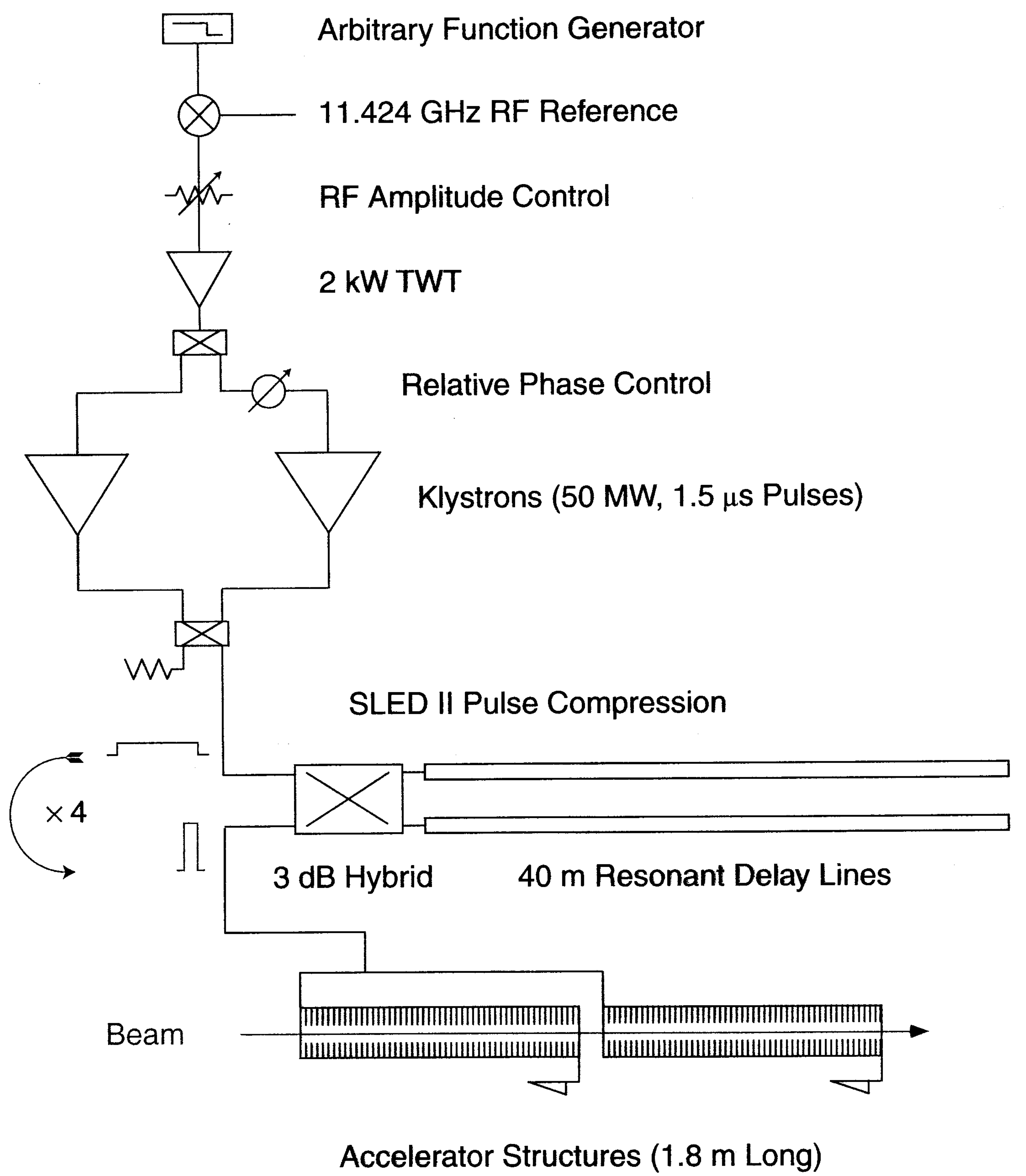
Chris Adolphsen

Next Linear Collider Test Accelerator

- Construction Started in 1993 Using 'First Generation' RF Component Designs
- Goals: RF System Integration Test of a Section of NLC Linac and the Efficient, Stable and Uniform Acceleration of a NLC-like Bunch Train
- In 1997, with All Three RF Units Operational, Successfully Demonstrated 15% Beam Loading Compensation of a 120 ns Bunch Train to < 0.3%



NLCTA RF Unit



NLC Linac RF Unit

Low Level RF System

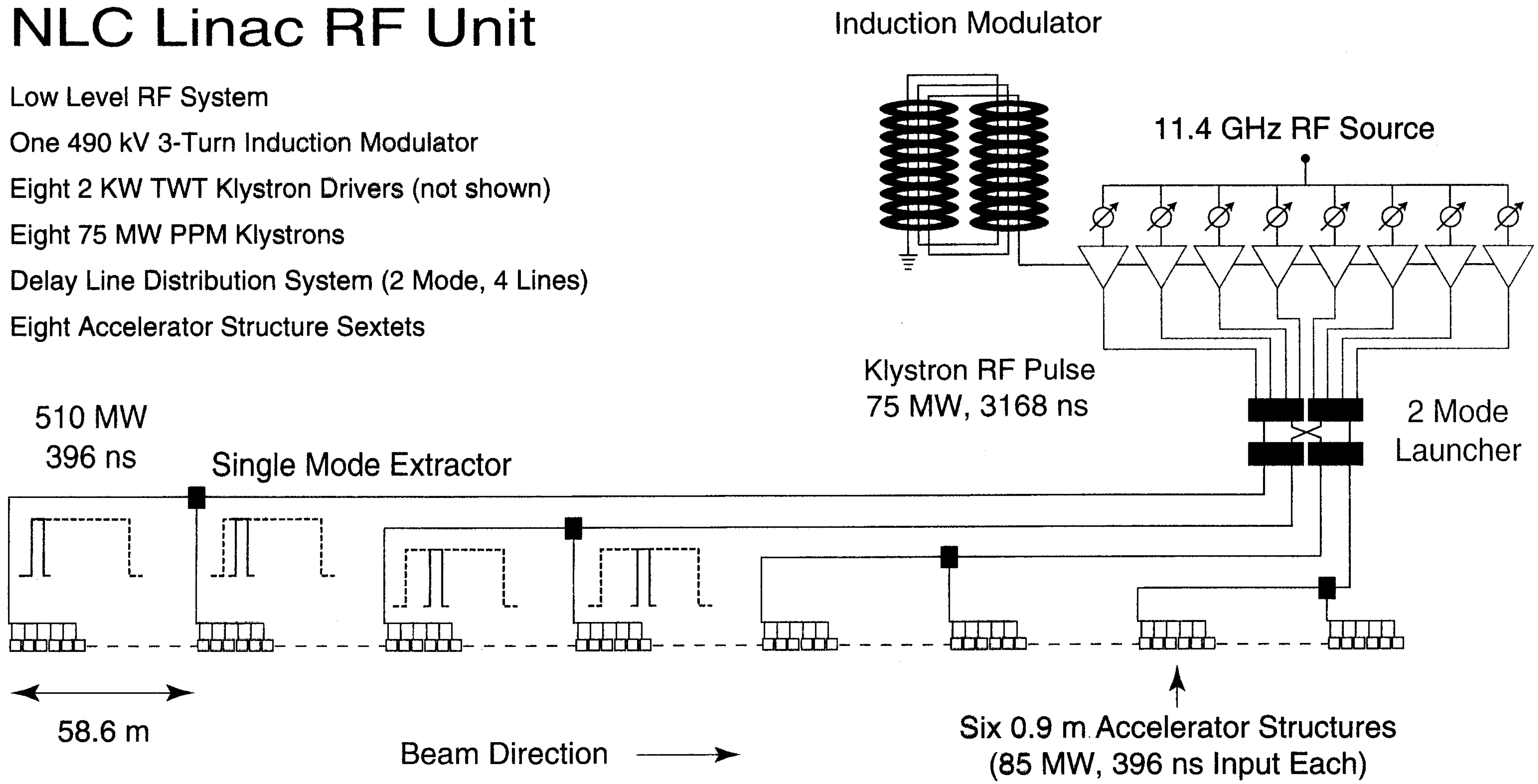
One 490 kV 3-Turn Induction Modulator

Eight 2 KW TWT Klystron Drivers (not shown)

Eight 75 MW PPM Klystrons

Delay Line Distribution System (2 Mode, 4 Lines)

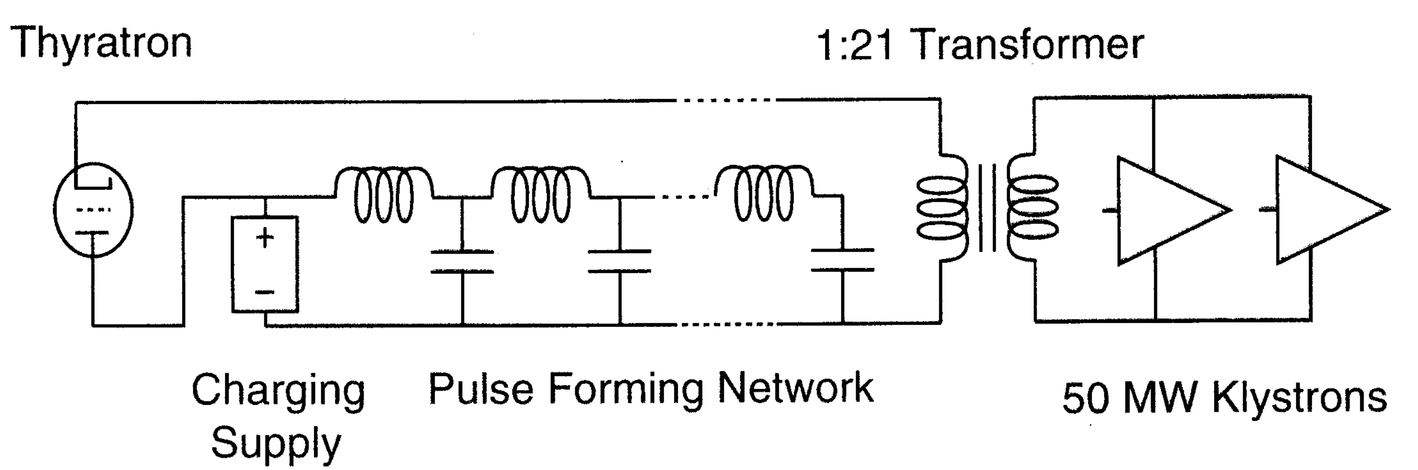
Eight Accelerator Structure Sextets



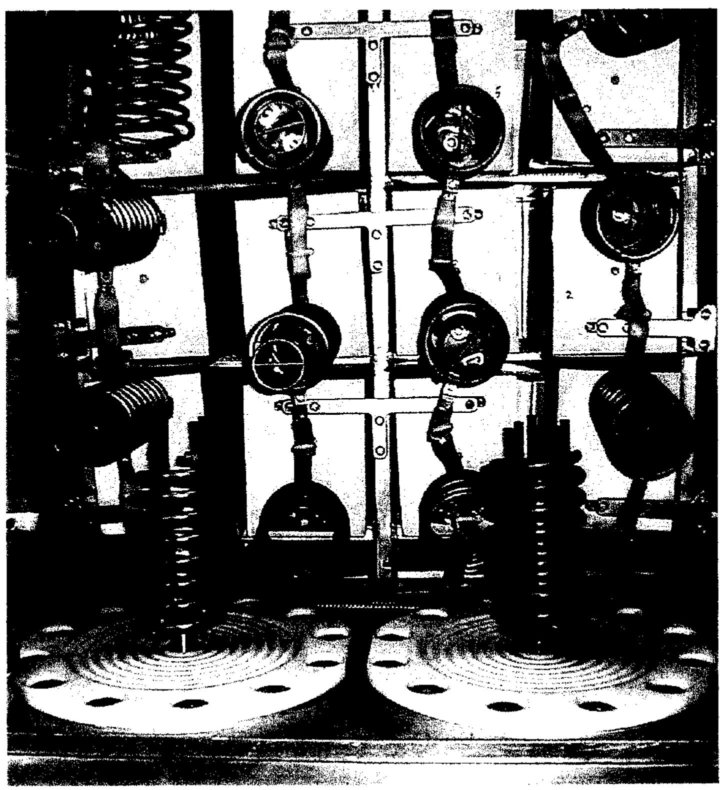
R&D Overview

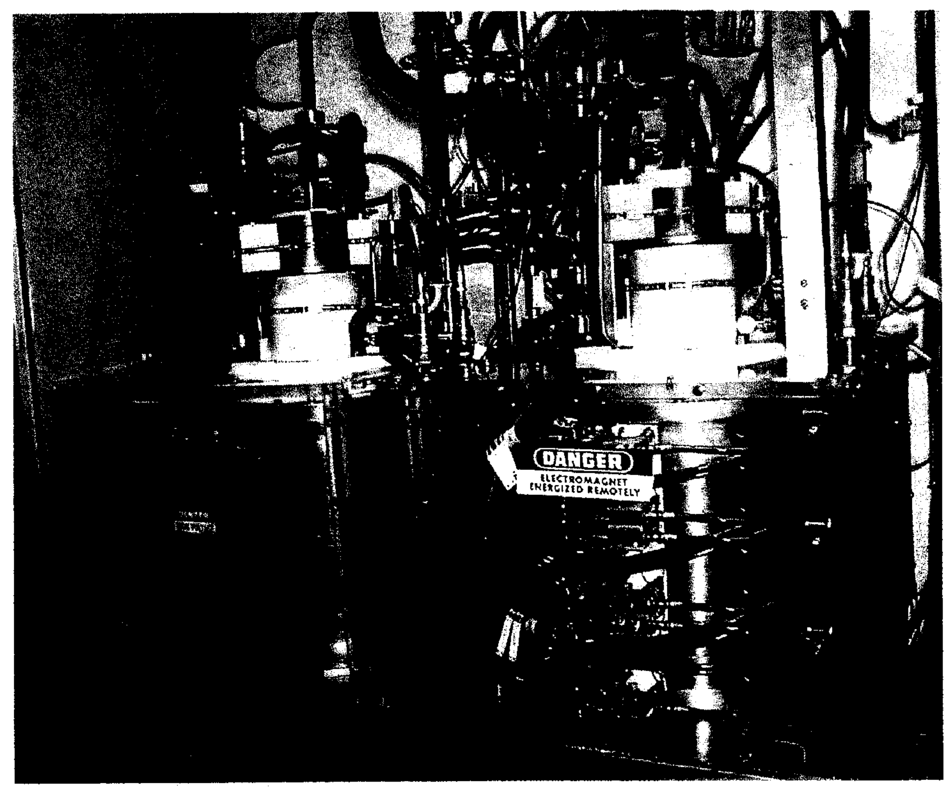
- RF System Critical-Path R&D
  - Develop Induction Modulator (High Efficiency, Low Cost)
  - Produce a Robust 75 MW PPM Klystron
  - Demonstrate High Pulse Energy Operation of DLDS
  - Attack Structure Gradient Problem on Several Fronts
- RF System Validation ('String-Test')
  - System Test (600 MW, 3.2 μs pulses) at NLCTA
    - Full Scale Induction Modulator
    - Eight 75 MW PPM Klystrons
    - Multi-Mode DLDS (2 of 4 Arms Terminated in Loads)
    - Twelve 0.9 m Long, 150° Phase Advance per Cell Structures.

NLCTA Power Source: Conventional Line-Type Modulator Driving Two Klystrons



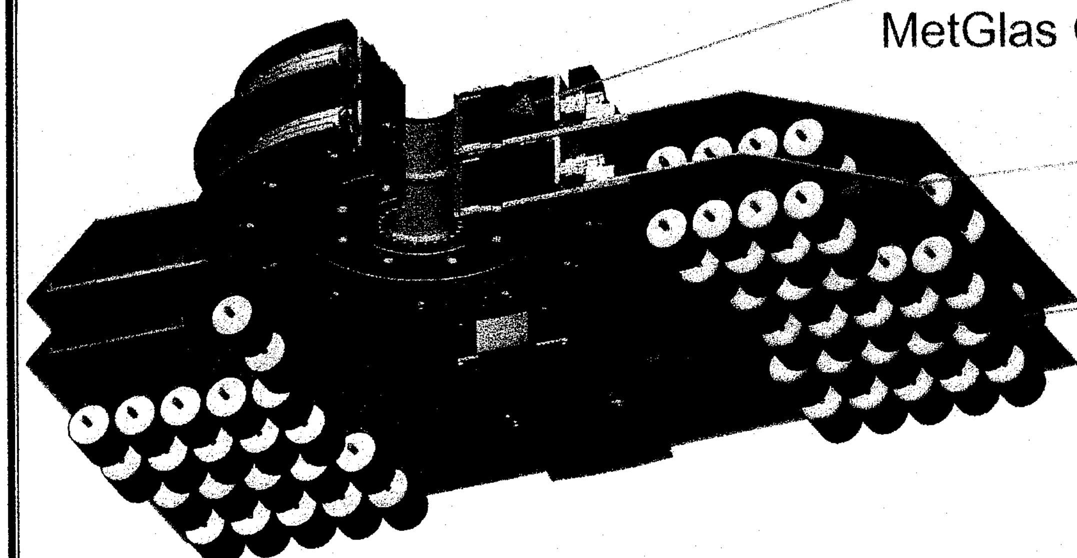
400 KV
300 A per Klystron
1.5 μs Flattop
60 Hz Pulse Rate





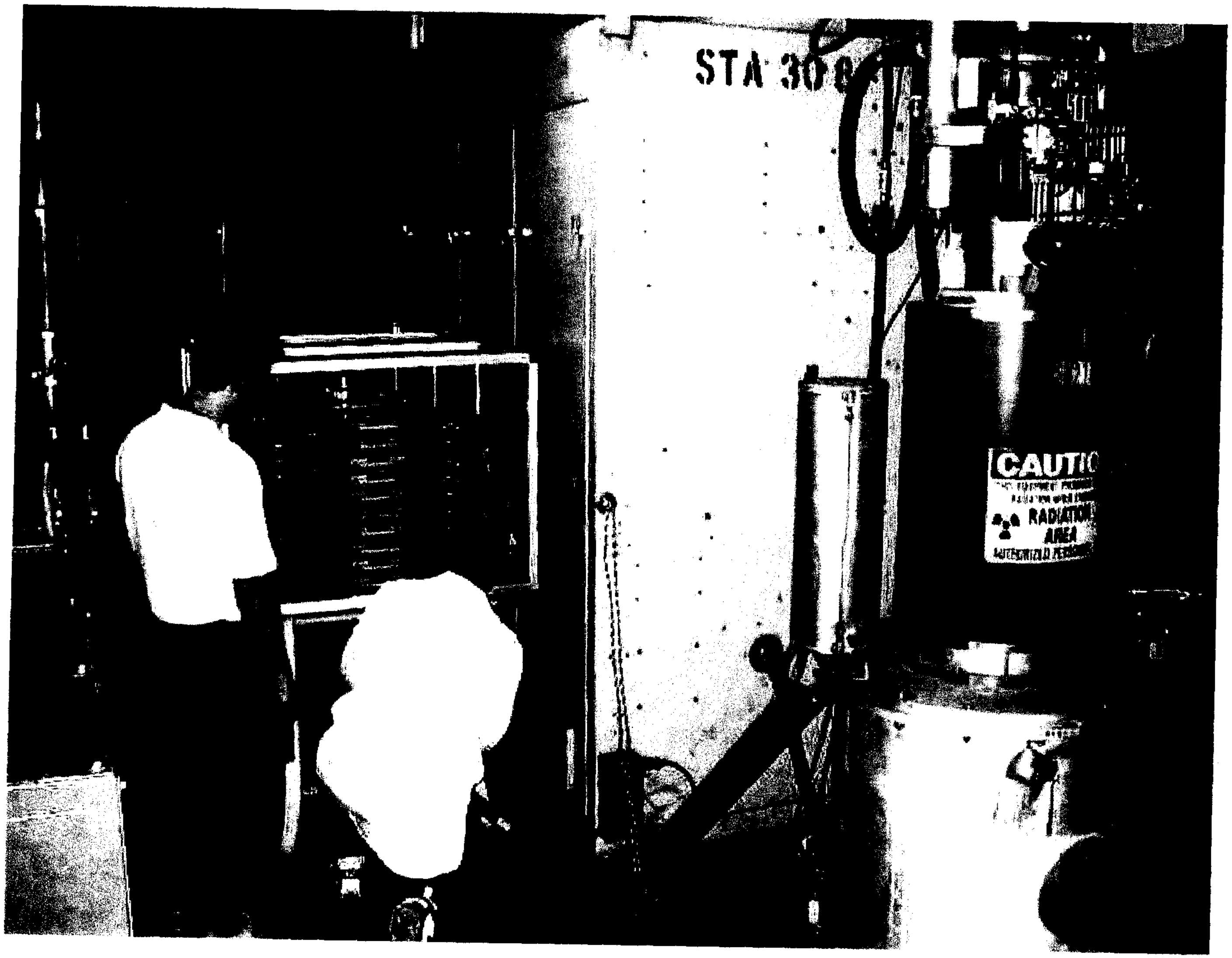
Induction Modulator
10 Core Test Setup

Generated 22 kV, 6 kA,
3 μs Pulses



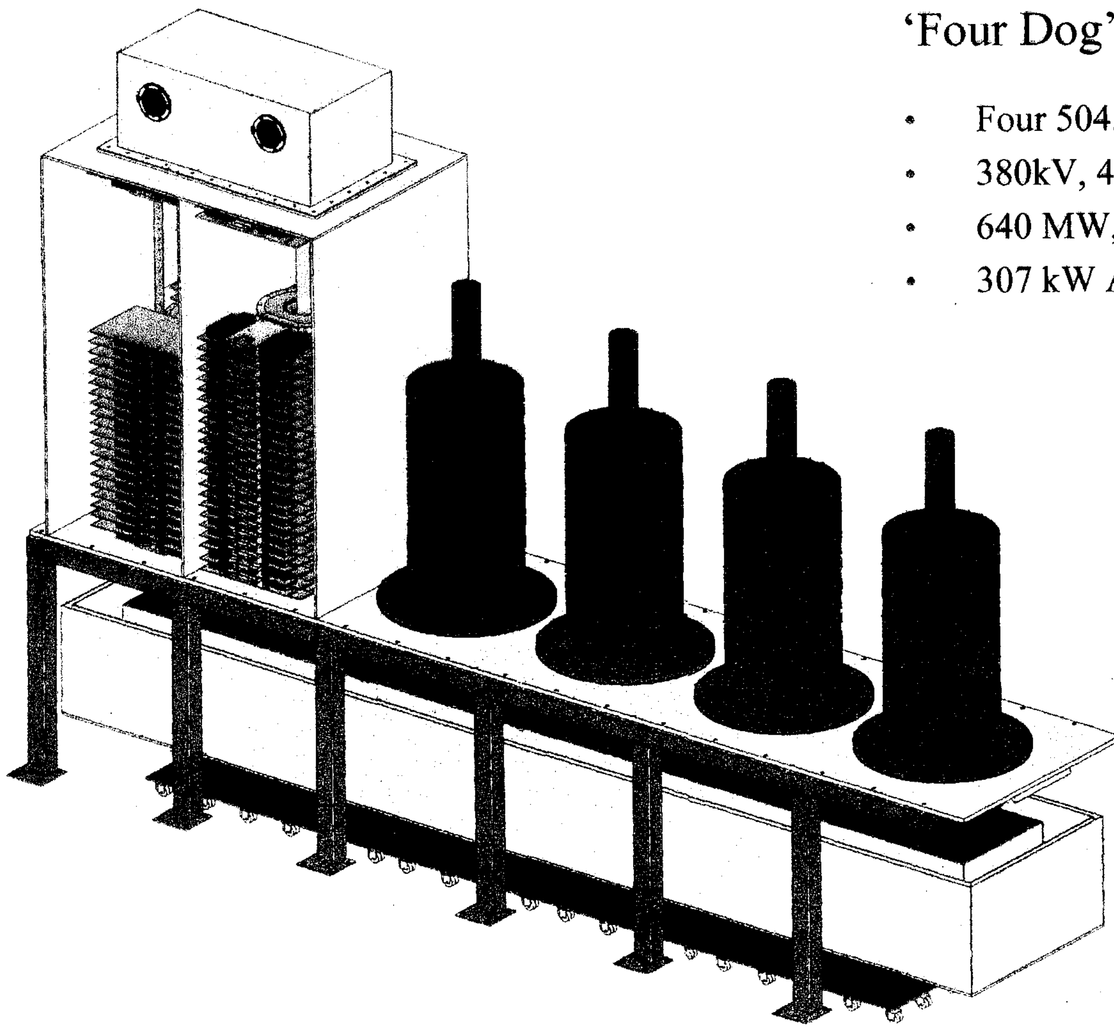
SLAC / LLNL / Bechtel NV

Gallery Prototype



- Desktop Modulator
- Solid State 10-Stack installed by Gallery line-type PFN unit.
- 22 kV => 330 kV via 15:1 Xfmr.
- Prototype currently at 255 kV @ 2.2 μsec @ 120 PPS.

Induction Modulator Prototype

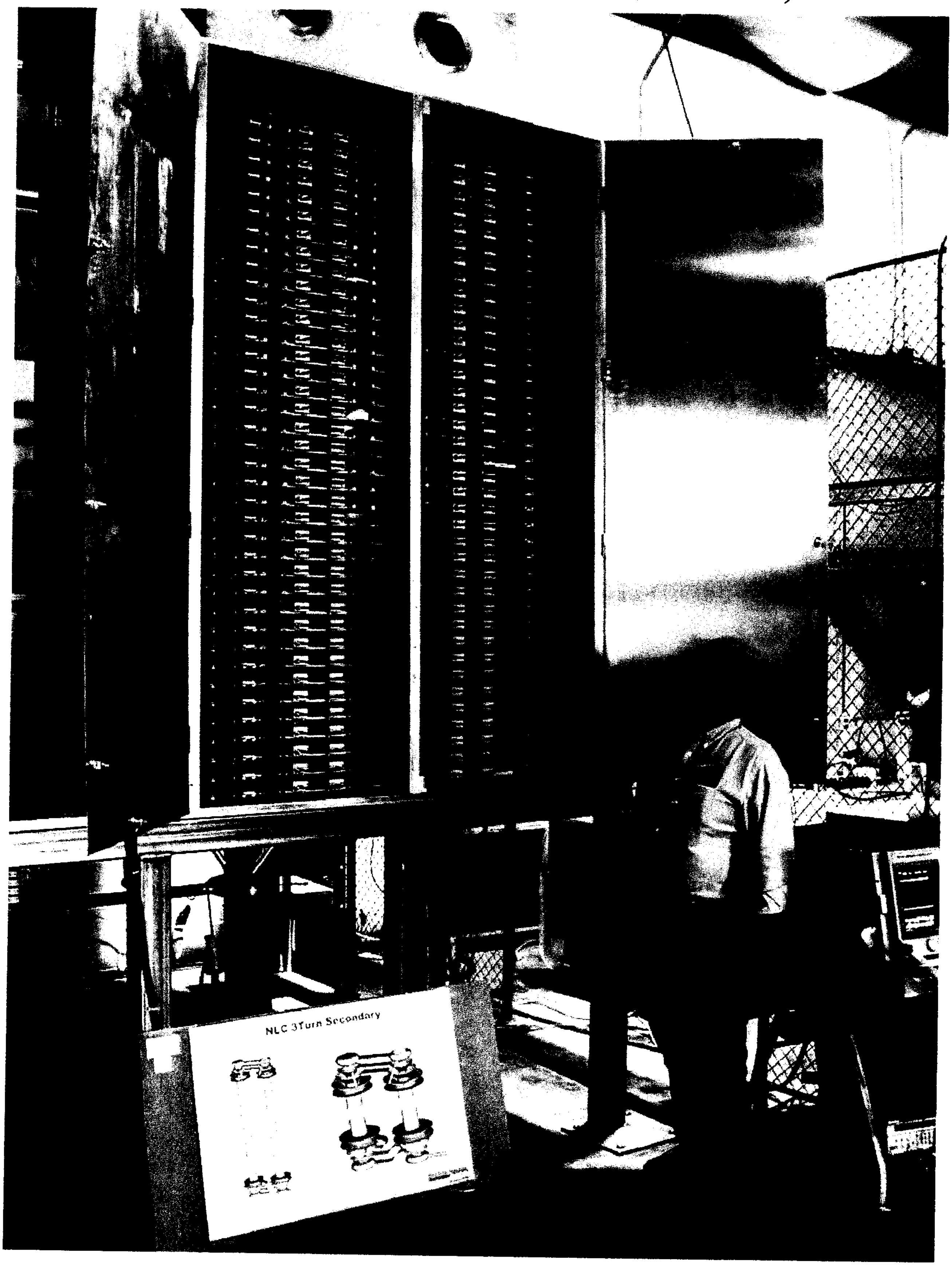


'Four Dog' Test (NLC Operation)

- Four 5045 Klystrons (Eight 75 MW PPMs)
- 380kV, 420 A Each (500 kV, 250 A)
- 640 MW, 4μs pulse (1000 MW, 3μs Pulse)
- 307 kW Ave. @ 120 PPS (360 kW)

Full Scale Induction Stack

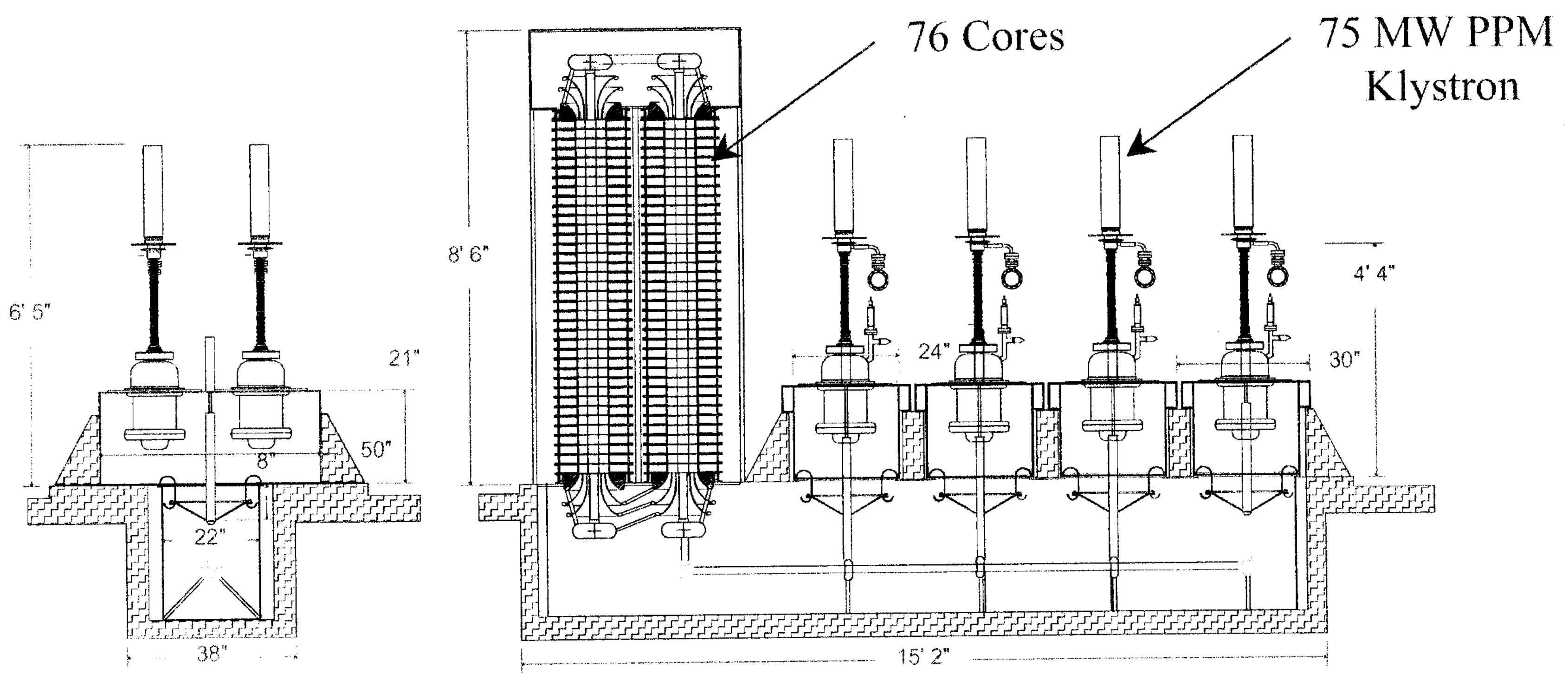
(Tested w/o oil at 75 kV, 1.1 kA)



Eight Klystron Induction Modulator

Estimated Efficiency = 75–80 % (≈ 60% for Line-Type)

Cost/Joule < 1/2 of Line-Type



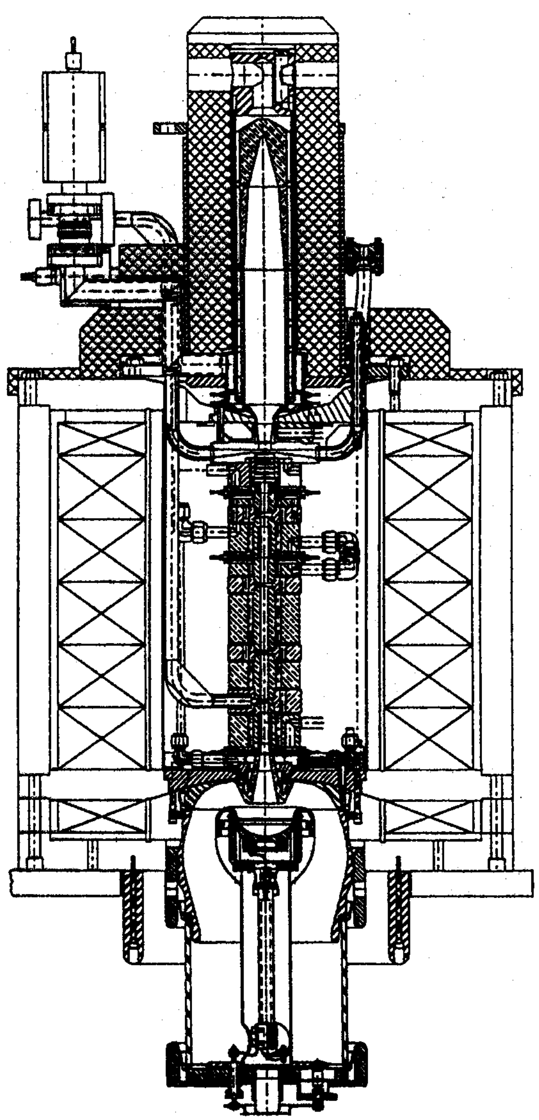
SLAC / LLNL / Bechtel NV

Modulator Summary

- Modulator development proceeding toward qualification of a full power 8-Pack prototype.
- Gallery test setup will give first measure of performance under realistic conditions.
- 4-Dog tests in Summer 2001 will give first opportunity to study arcing in a 4-tube setup. After testing at SLAC, modulator will be shipped to FNAL.
- DFM design will build on 4-Dog experience: LLNL-BN will lead this effort in 2001. Goal is to complete System Test Version by end of 2002.

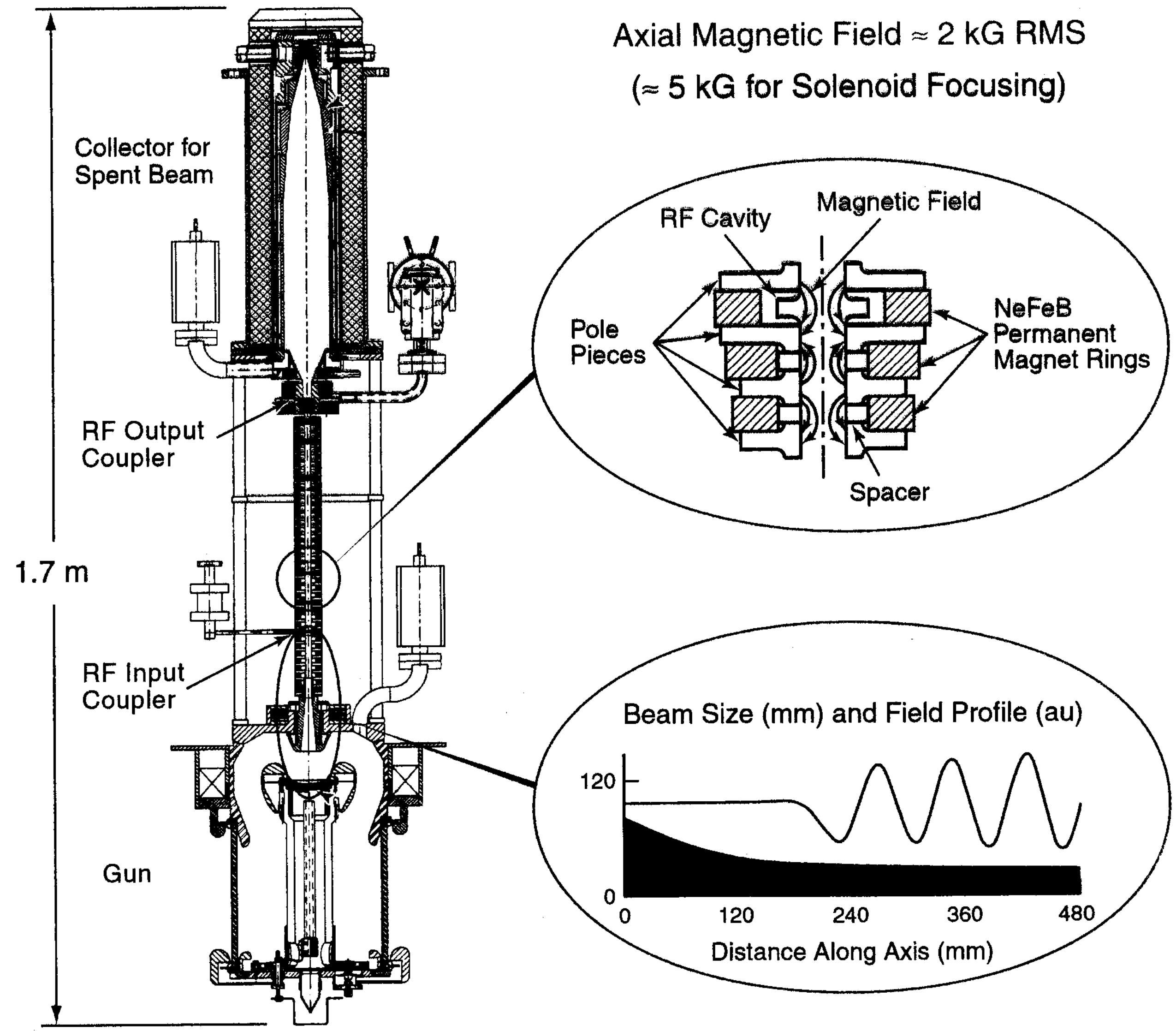
X-Band (11.4 GHz) KLYSTRONS

Solenoid Focused
Solenoid Power = 25 kW



Periodic Permanent Magnet (PPM) Focused

Axial Magnetic Field ≈ 2 kG RMS
(≈ 5 kG for Solenoid Focusing)



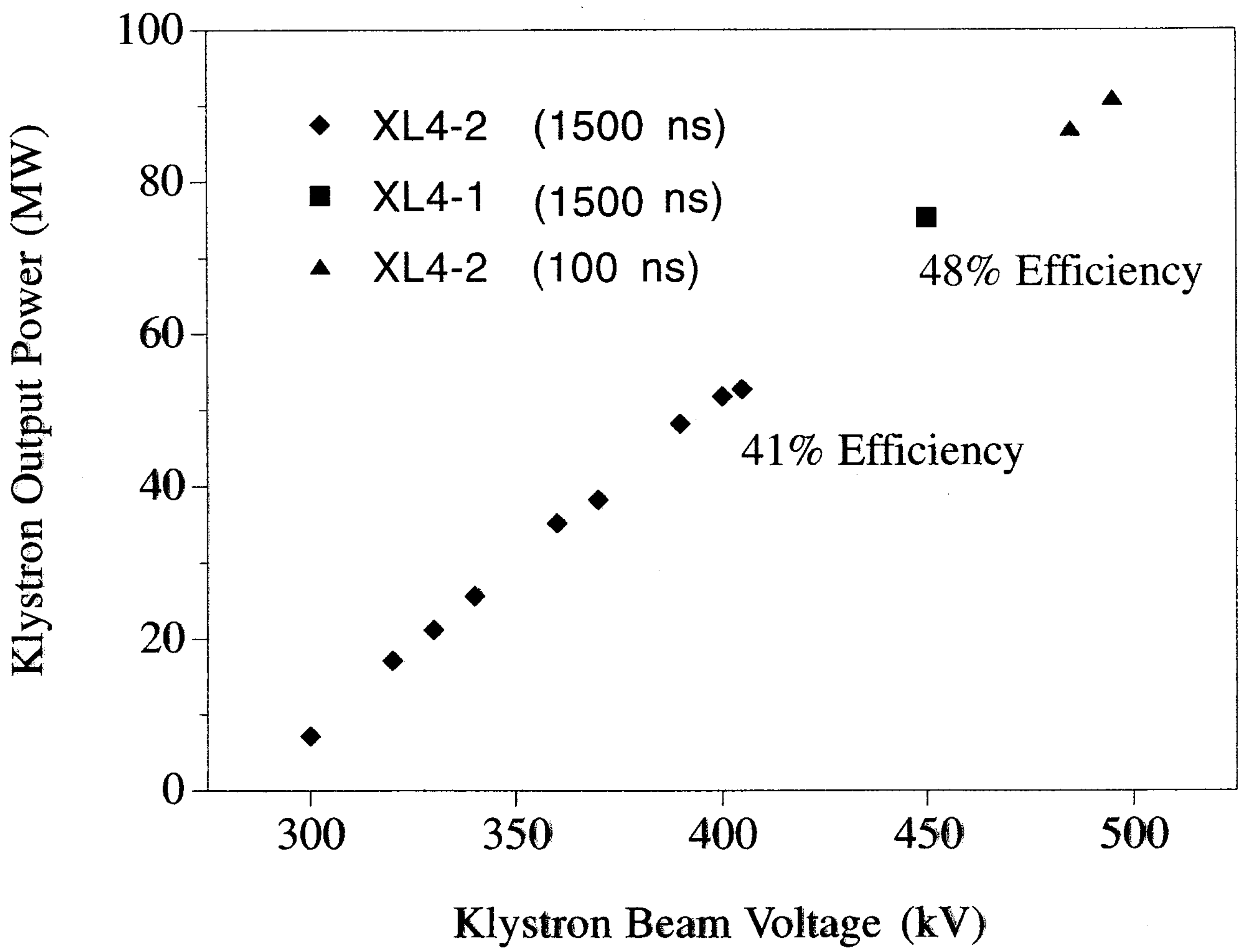
NLCTA Klystrons: 50 MW XL4's

Solenoid Focused ($\mu P = 1.2$, 4-Cell TW Output Cavities)

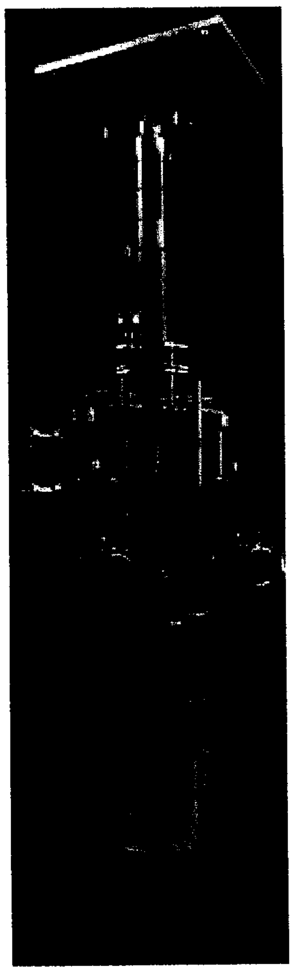
10 Built - Operated about 10 khrs Total @ 60 Hz

Few Failures - Leaks / Broken Windows: Now Using
 Higher Power Window Design

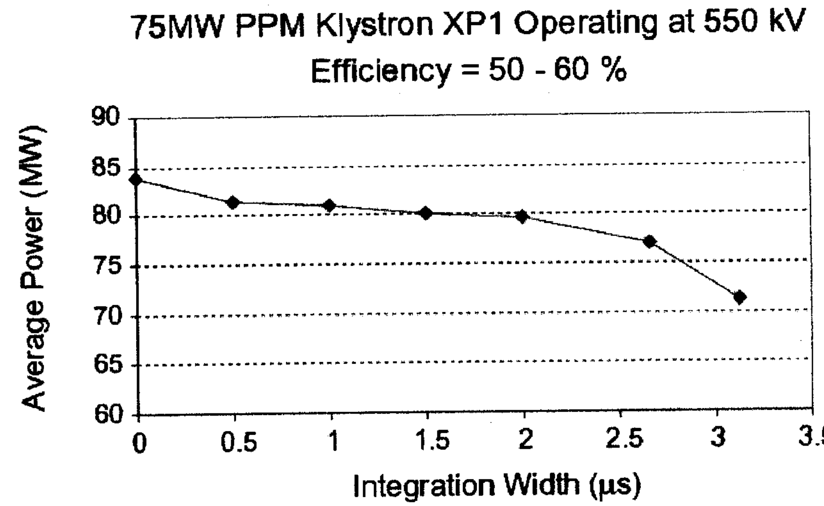
Planning Test at 75 MW, 3 μs @ 120 Hz



SLAC 75 MW PPM Klystron Program



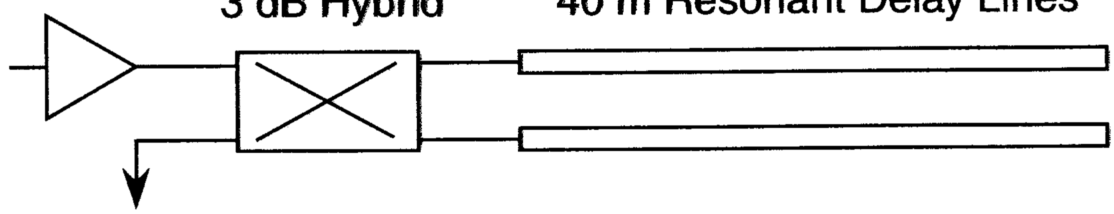
XP1: After a Number of Fixes, Achieved Stable Performance Over 70 MW at Twice the Design Pulse Length (3 μs, Which Was Modulator Limited)



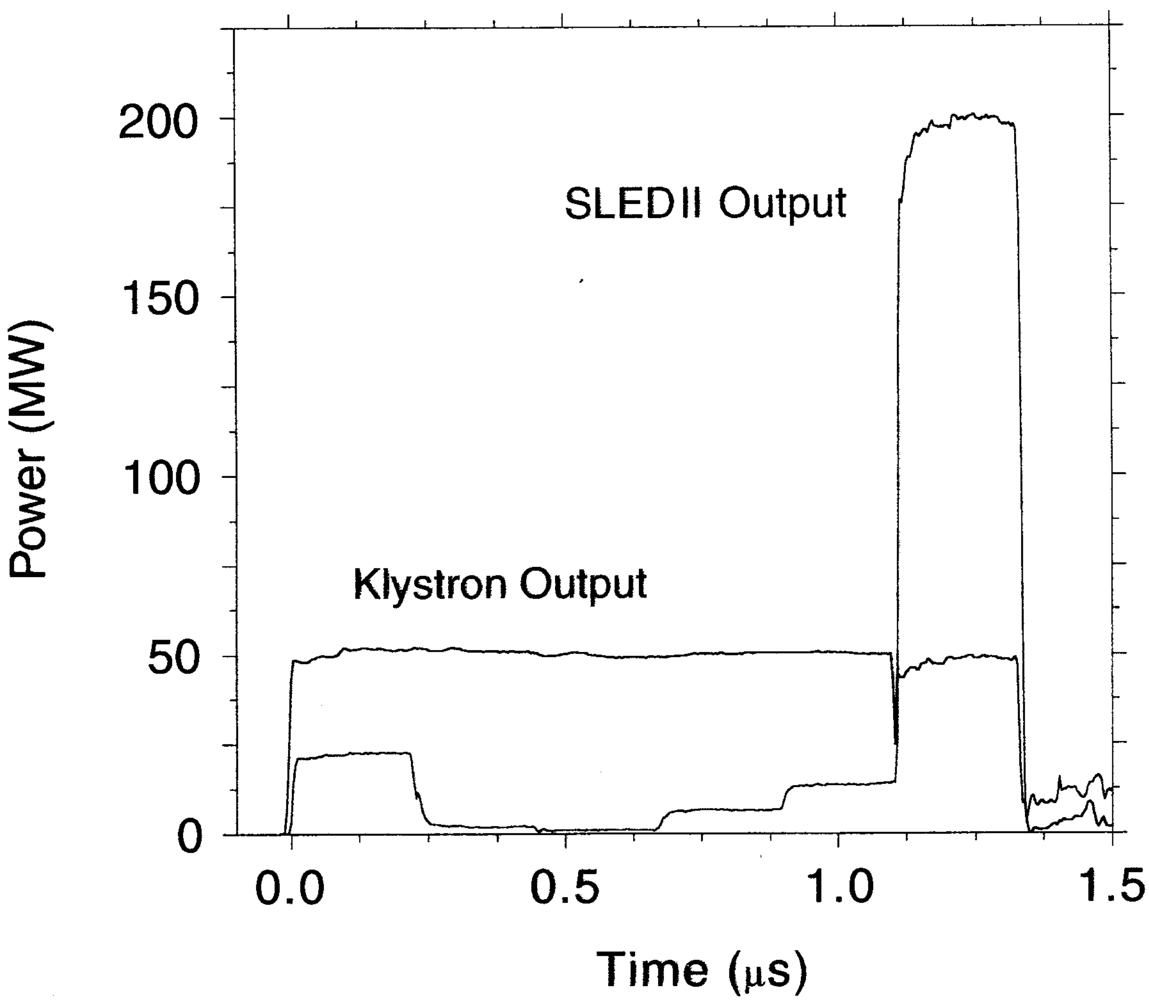
XP3: Next Generation Tube Designed for Manufacturability

- Incorporate Lessons Learned from XP1.
- Diode Version Has Been Successfully Tested.
- Klystron to be Tested in September.

RF Pulse Compression at NLCTA (SLED II)



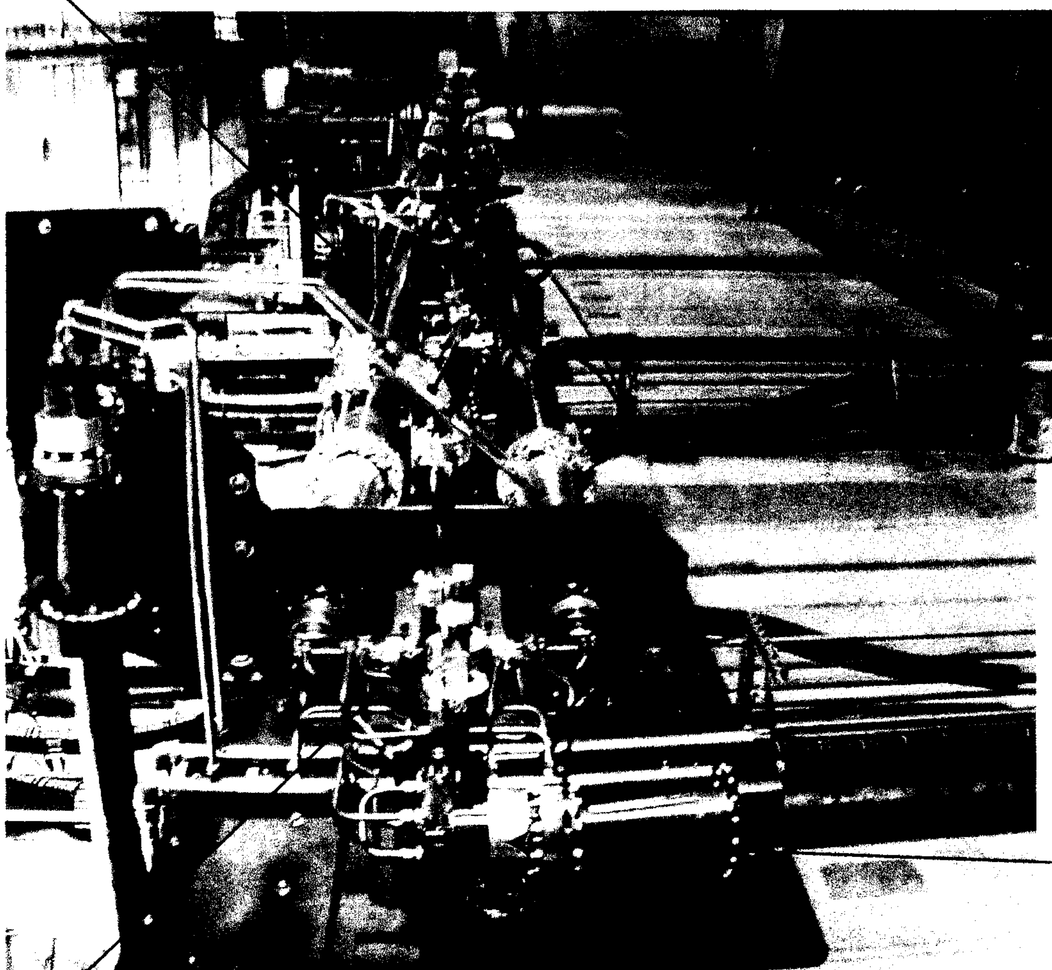
SLED II Operation



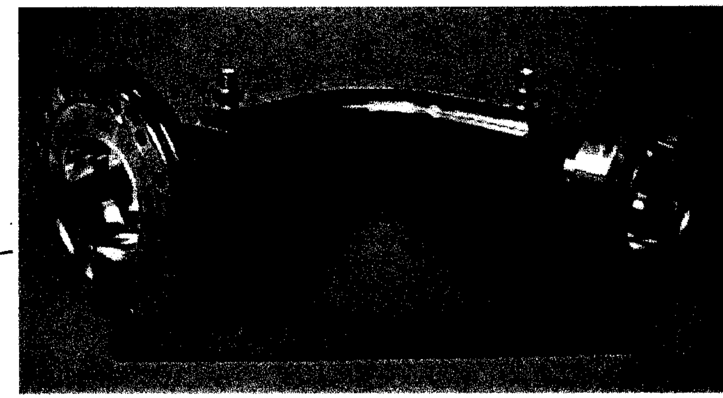
SLED II Layout Above the Beam Line Enclosure at NLCTA

To Transport > 200 MW, Replaced Original 'Flower-Petal' Bends and Mode Converters with the Components Shown

40 m Long, 12 cm Diameter Circular Waveguide

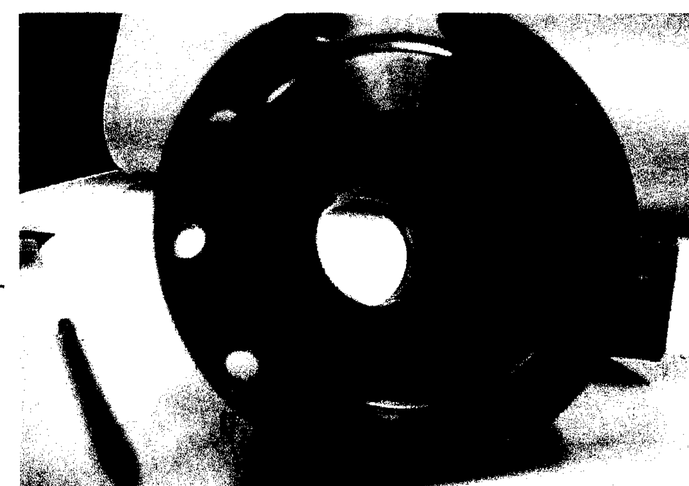


3 dB Hybrid Using a 'Magic Tee'



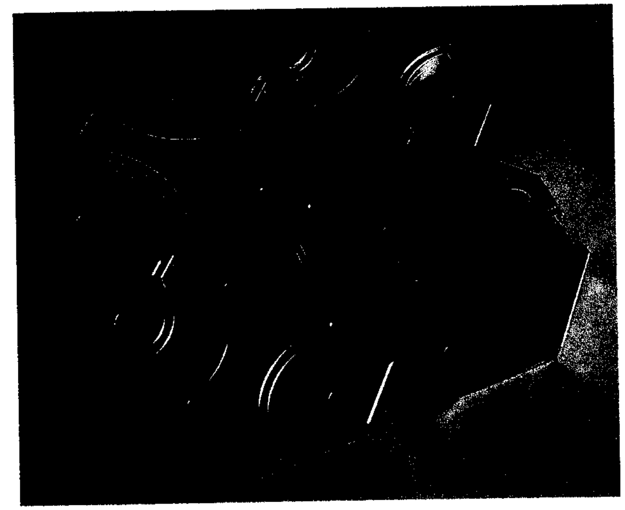
90 Degree Bend Using TE02/TE20 Modes

Wrap Around Mode Converter

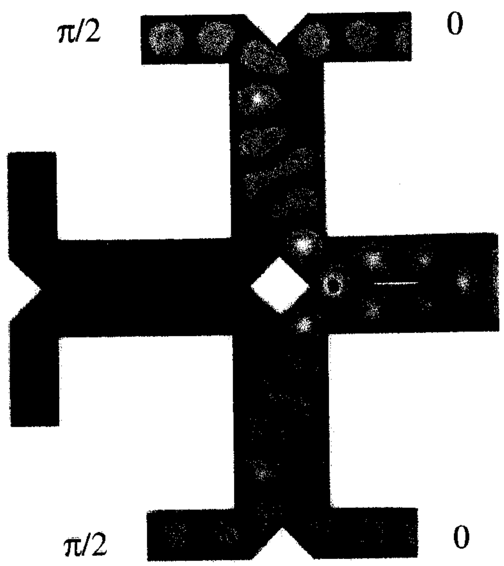


NLC RF Distribution

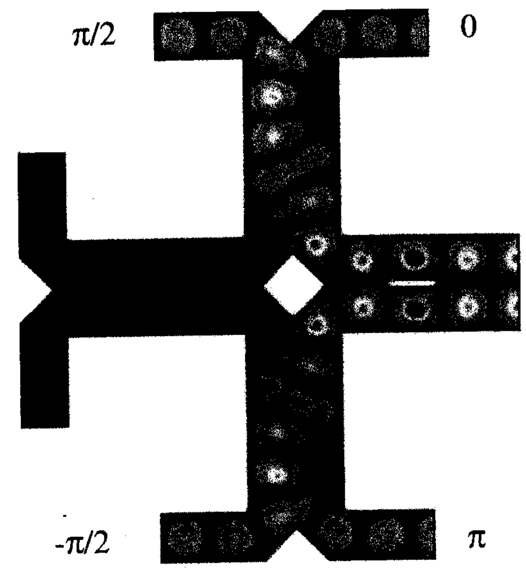
Switch Power Using a 'Cross Potent' Two-Mode Hybrid



Cold-Test Model with Cover Removed



a)



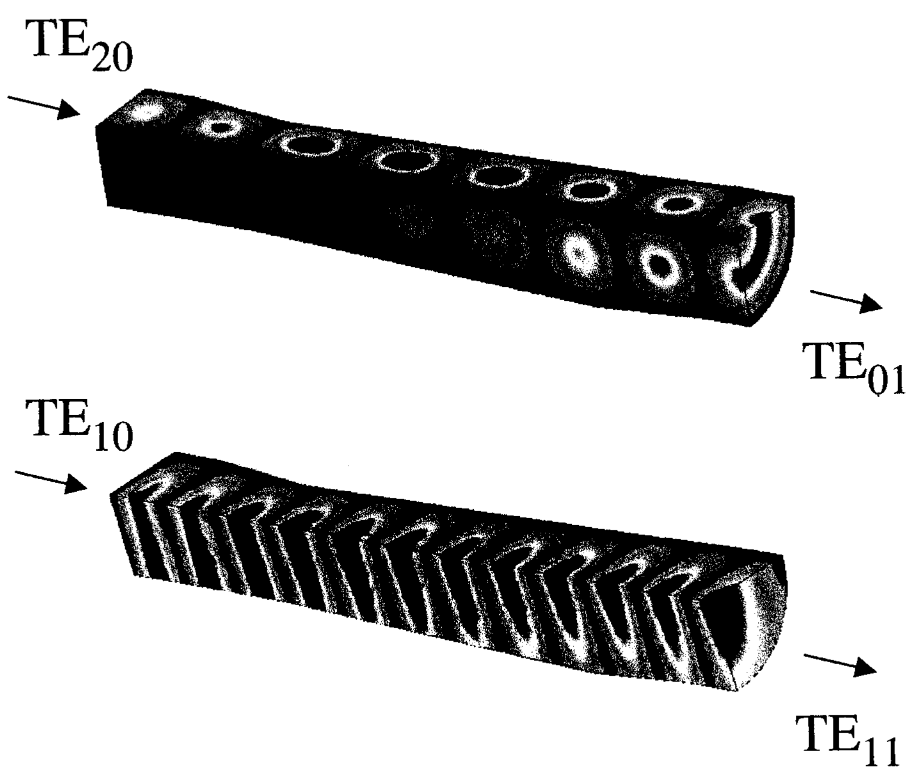
b)

Cross Potent operation with simulated electric field illustrating launching a) TE_{10} and b) TE_{20} in the right over-moded rectangular port with the indicated relative phases for four equal amplitude inputs. Alternate phases of the inputs sends the power to either of the left ports.

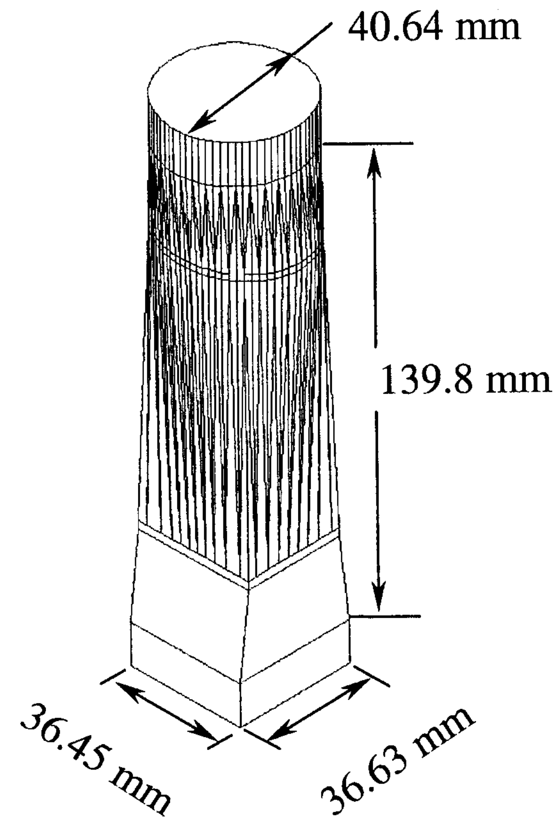
Rectangular-to-Circular Mode Converter

Convert to Low-Loss Circular WG Modes to Transport Power Hundreds of Meters

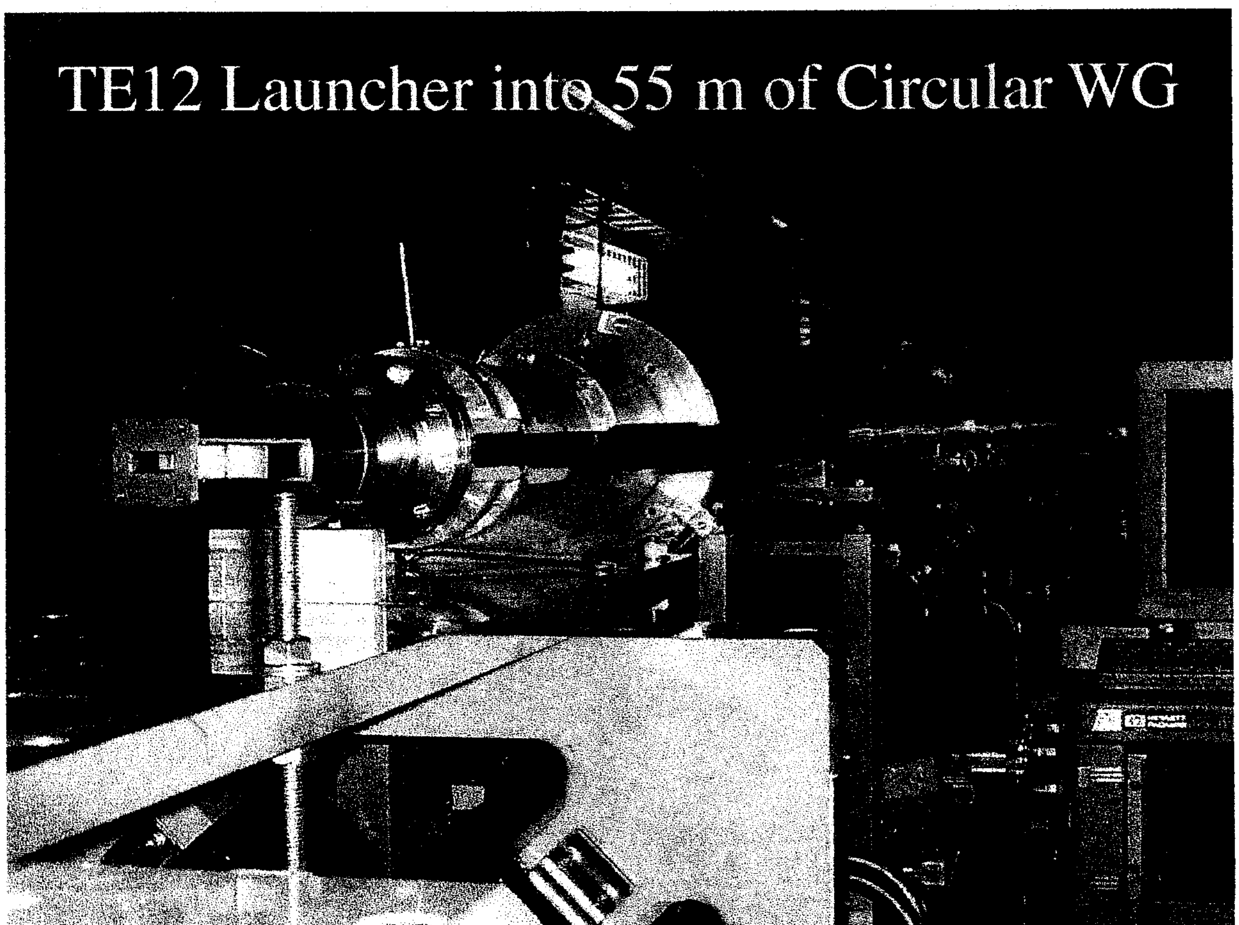
Electric Field Patterns

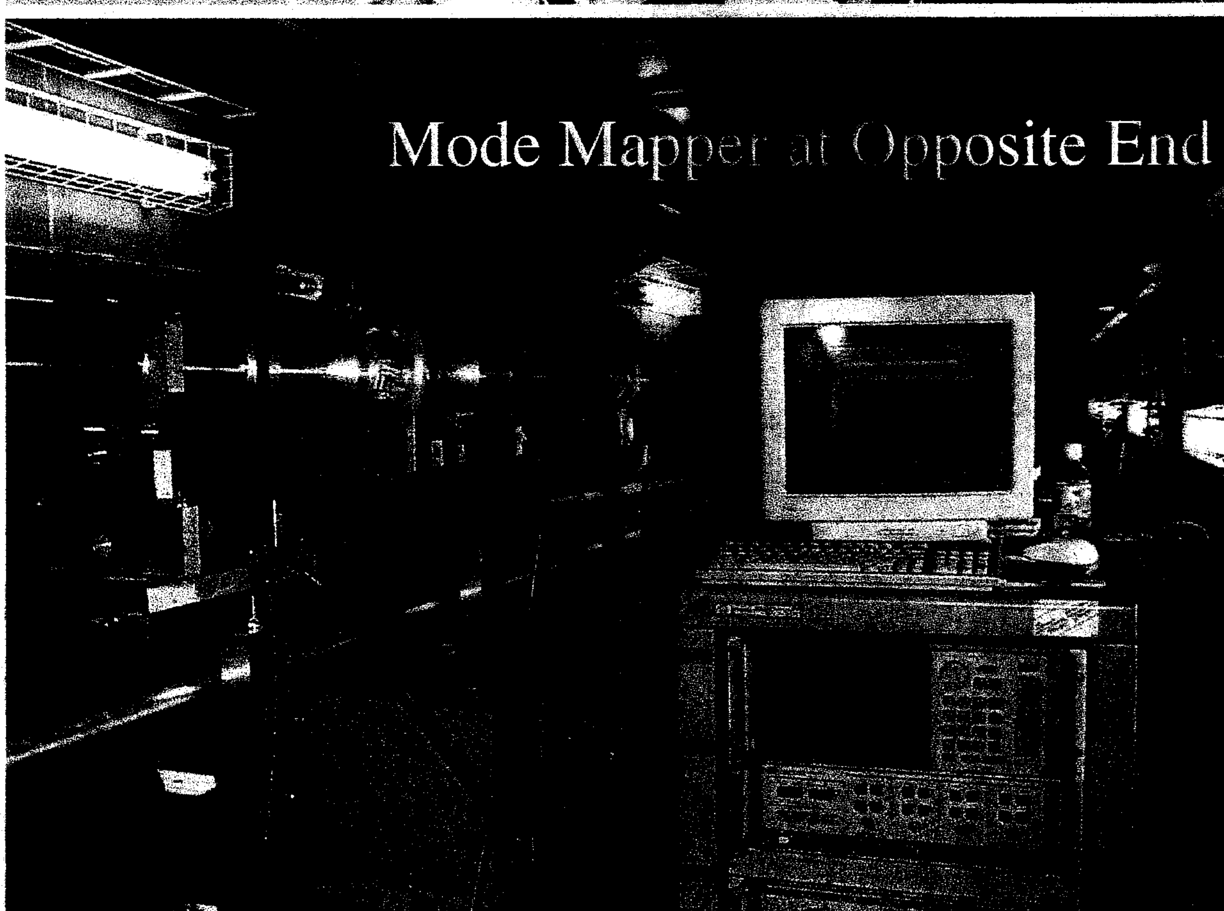


Converter Geometry

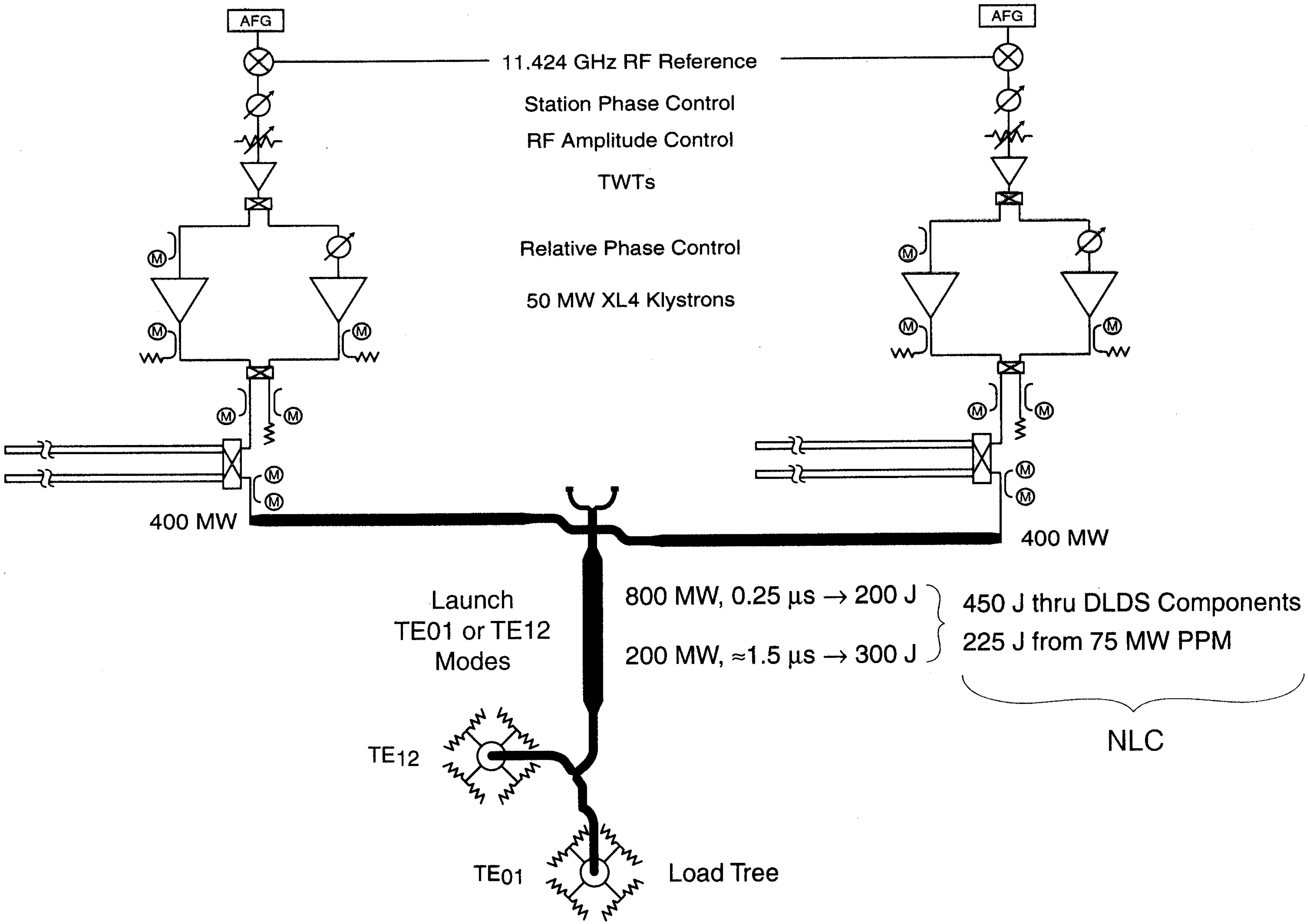


Mode Transmission Experiment at KEK





High Power Test of DLDS Components in NLCTA Planned for 2002

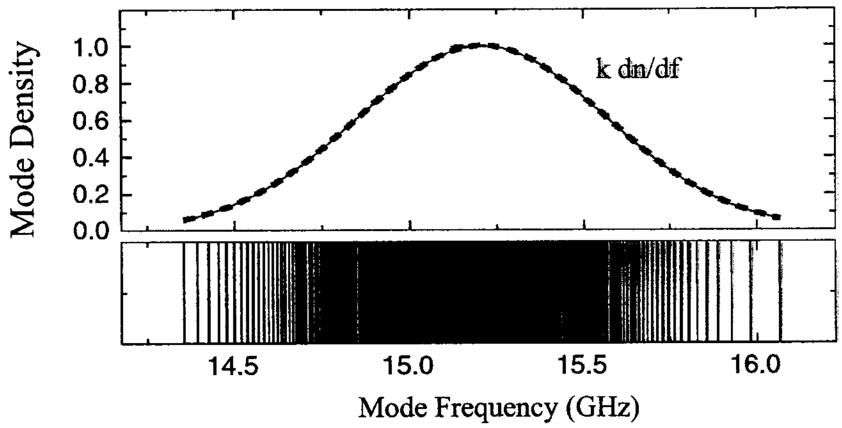


RF Distribution Summary

- Have Built High Power Hybrids and Circular-to-Rectangular Mode Converters and Tested Them to ≈ 500 MW (150 ns).
- Have Tested Polarized Mode Transmission in a 55 m Long Delay Line.
- Have Conceptual Designs for all Components in a Two-Moded DLDS Scheme.
- Have Yet to Test any Components at Full Power and Full RF Energy – To this End,
  - Will Build Two-Moded Components and Test at
    - > 600 MW (240 ns) in the NLCTA in 2002
    - 600 MW (3000 ns) in a System Test in 2003-4
- Also, Will
  - Continue Low Power Tests of Polarized Mode Generation and Transmission at KEK and FNAL.
  - Explore Feasibility of a Four Mode DLDS Scheme.

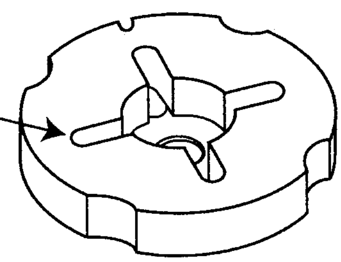
Long-Range Transverse Wakefield Suppression

Detuning: Systematically Vary Cell Dimensions to Yield a Gaussian Dipole Mode Distribution



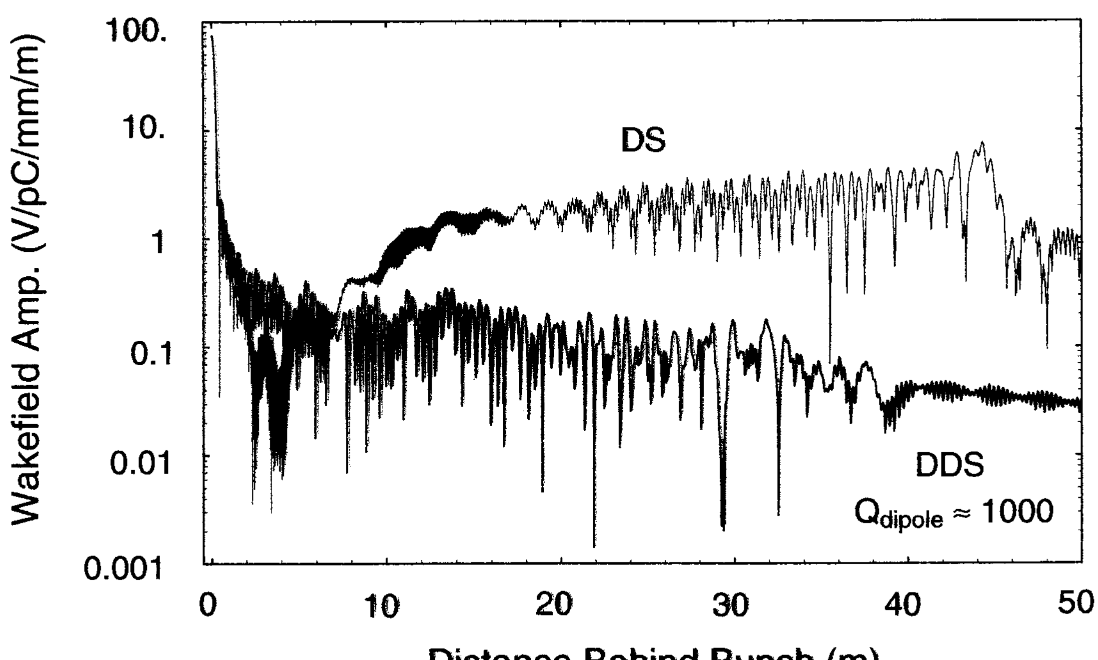
Dipole Mode Spectrum

Damping: Add Manifolds to Couple Out Dipole Power



Structure Cell (1 of 206)

Expected Wakefield for a Damped (DS) and a Damped Detuned Structure (DDS)



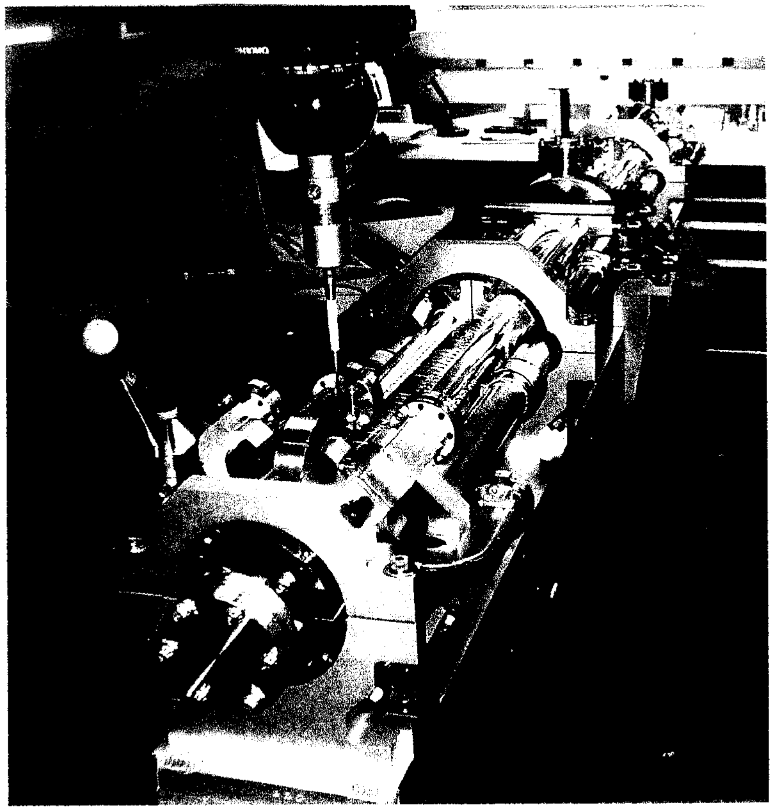
Rounded Damped Detuned Structure (RDDS1)

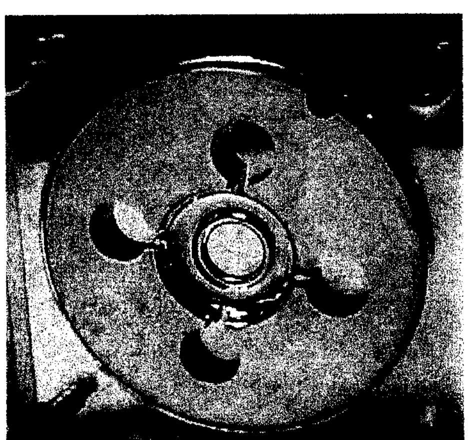
SLAC/KEK Collaboration to Improve on DDS Design:

- Rounded Cell Design for Increased (19%) Shunt Impedance
- Four Output Ports to Damp Both Polarizations of the Dipole Modes Near the End of the Structure
- Better Optimized Dipole Mode Distribution for Detuning
- High Precision Cell Fabrication ($< 1 \times 10^{-4}$ Freq Errors)

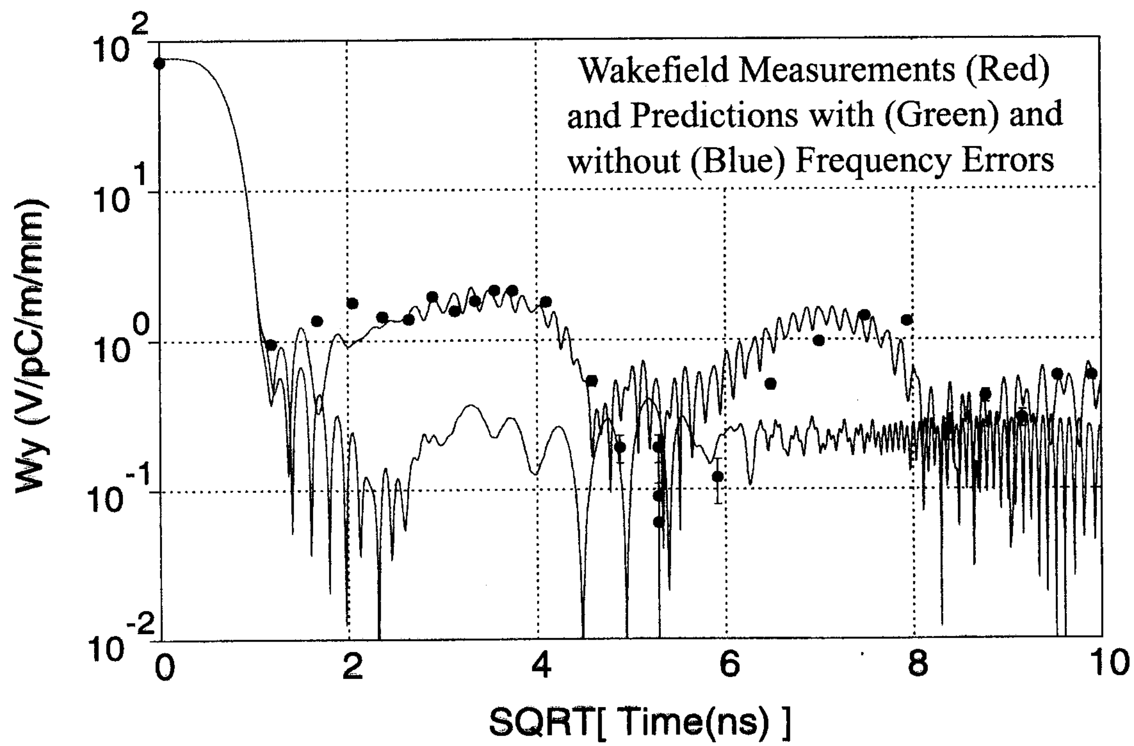
But,

- Differential Expansion during Bonding & Brazing Distorted Cells: Some Corrected, Fix Remainder after ASSET Test



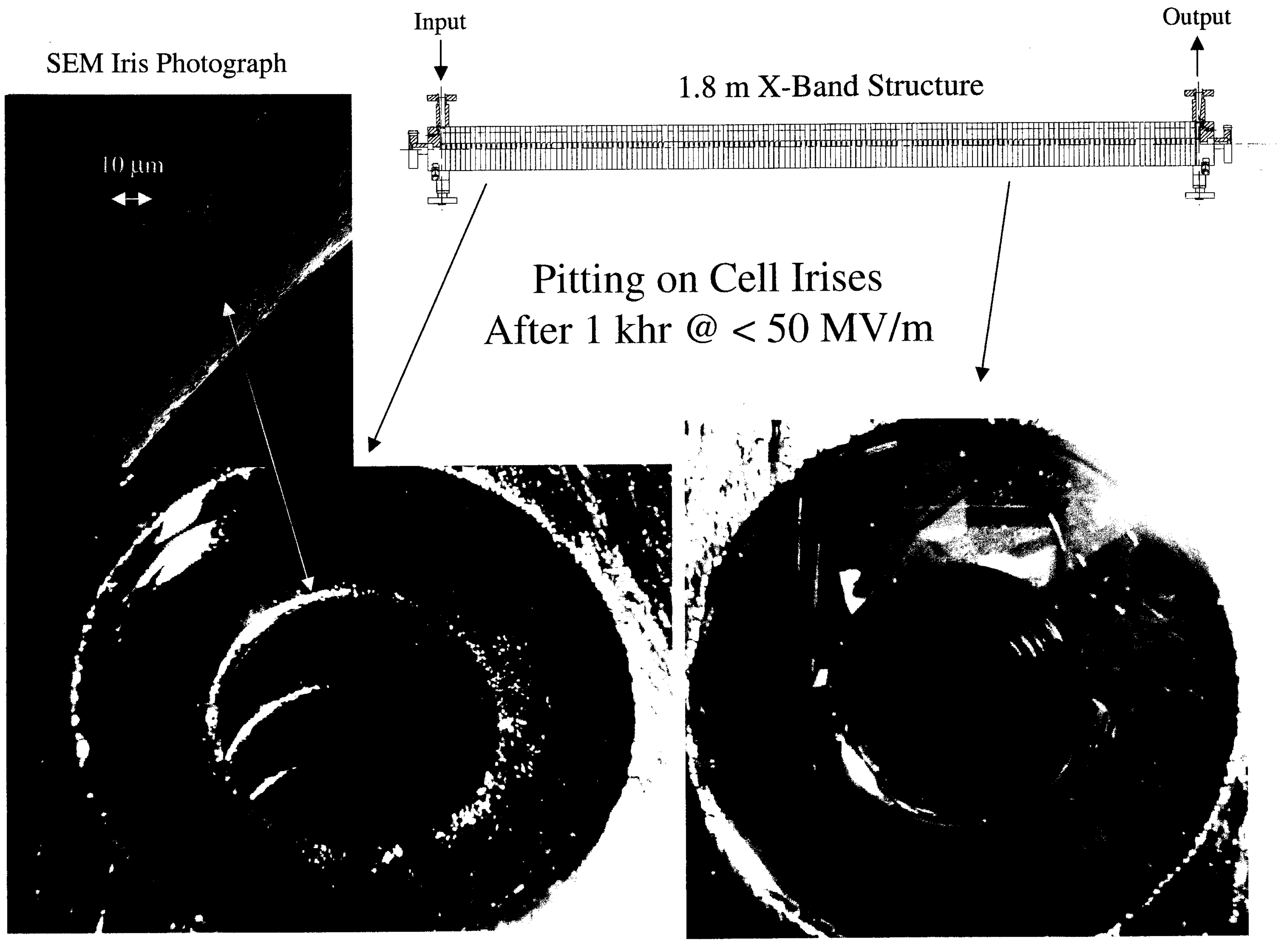


RDDS1 on Coordinate Measuring Stand (above) and 1 of 206 Cells (below)



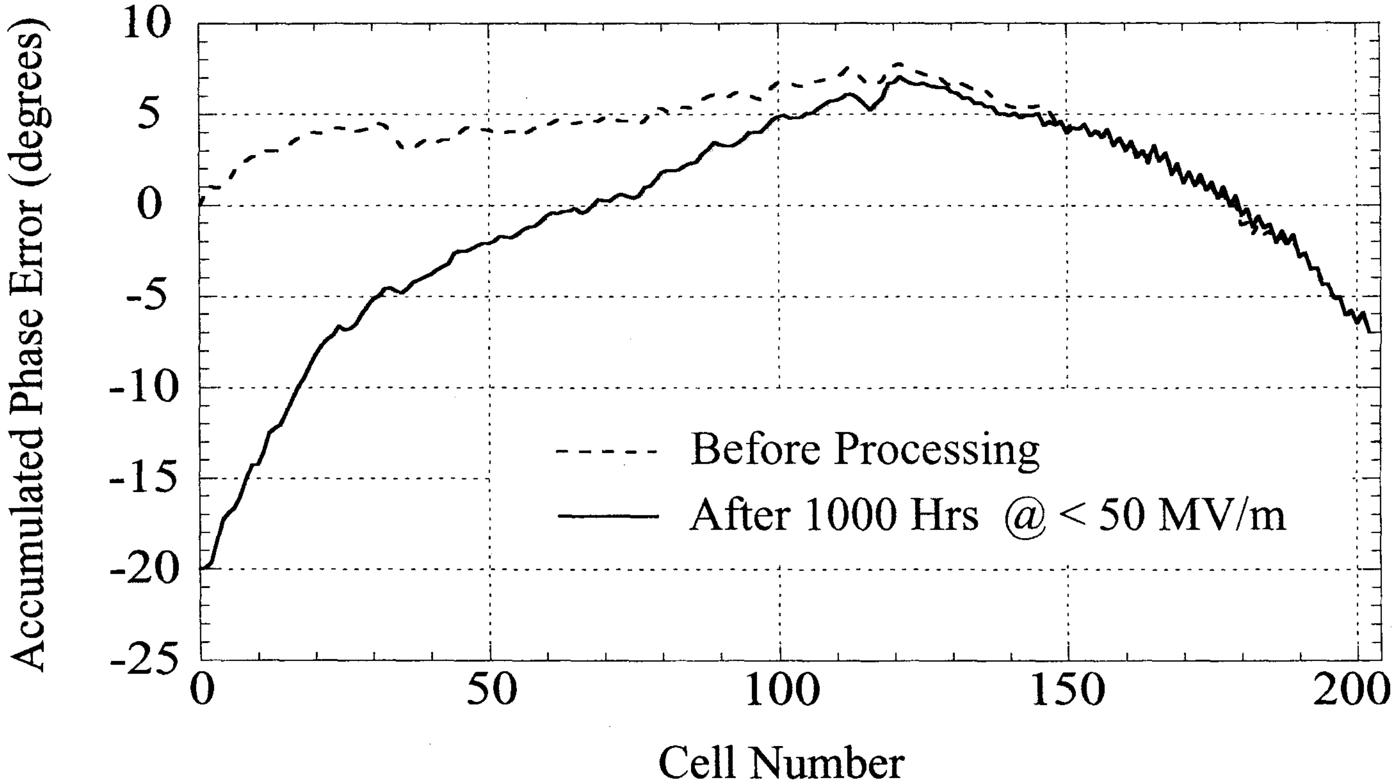
NLC Linac Gradient Considerations

- To minimize cost, want unloaded gradient (G_U) in the X-band linacs to be 70 +/– 10 MV/m.
- For expandability, assuming lower cost X-band power sources are available in the future, want $G_U > 100$ MV/m.
- Gradient potential: have achieved > 100 MV/m at X-band in standing wave and short (0.3 m), low group velocity (< 3%) traveling wave structures.



SEM Iris Photograph
10 μm
Input
Output
1.8 m X-Band Structure
Pitting on Cell Irises
After 1 khr @ < 50 MV/m

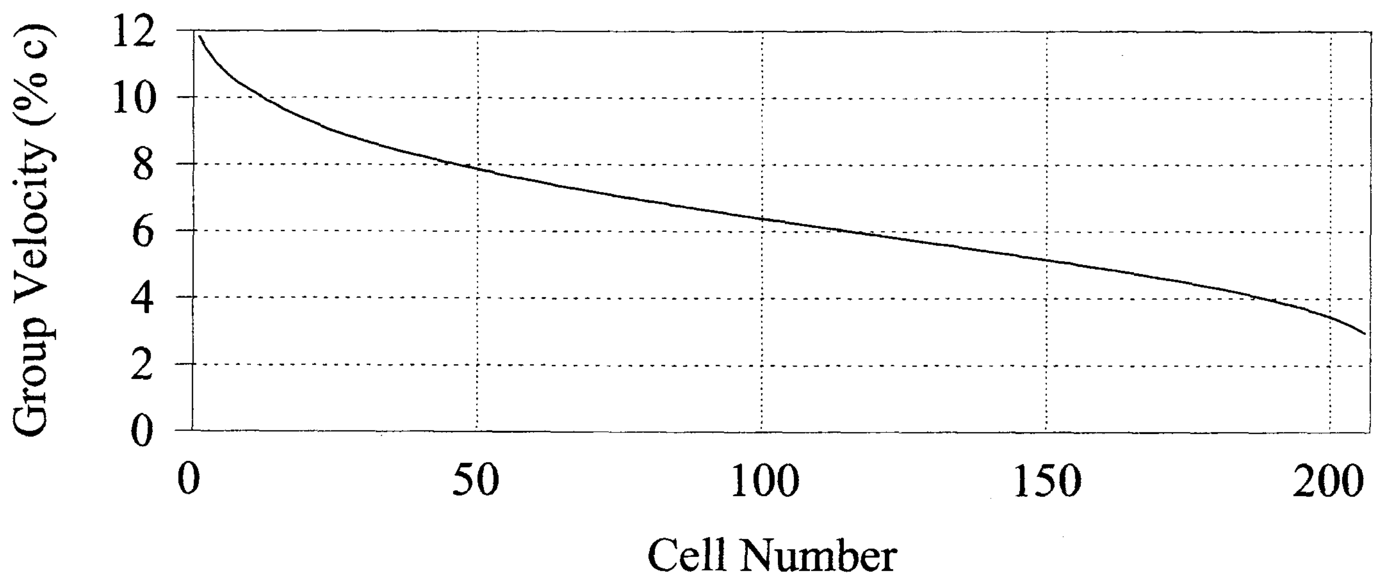
Breakdown Effect on Phase Advance per Cell



Why is Most Damage at the Upstream End ?

If Breakdown is Modeled as a Load Impedance,
Power Absorbed in the Load Scales as

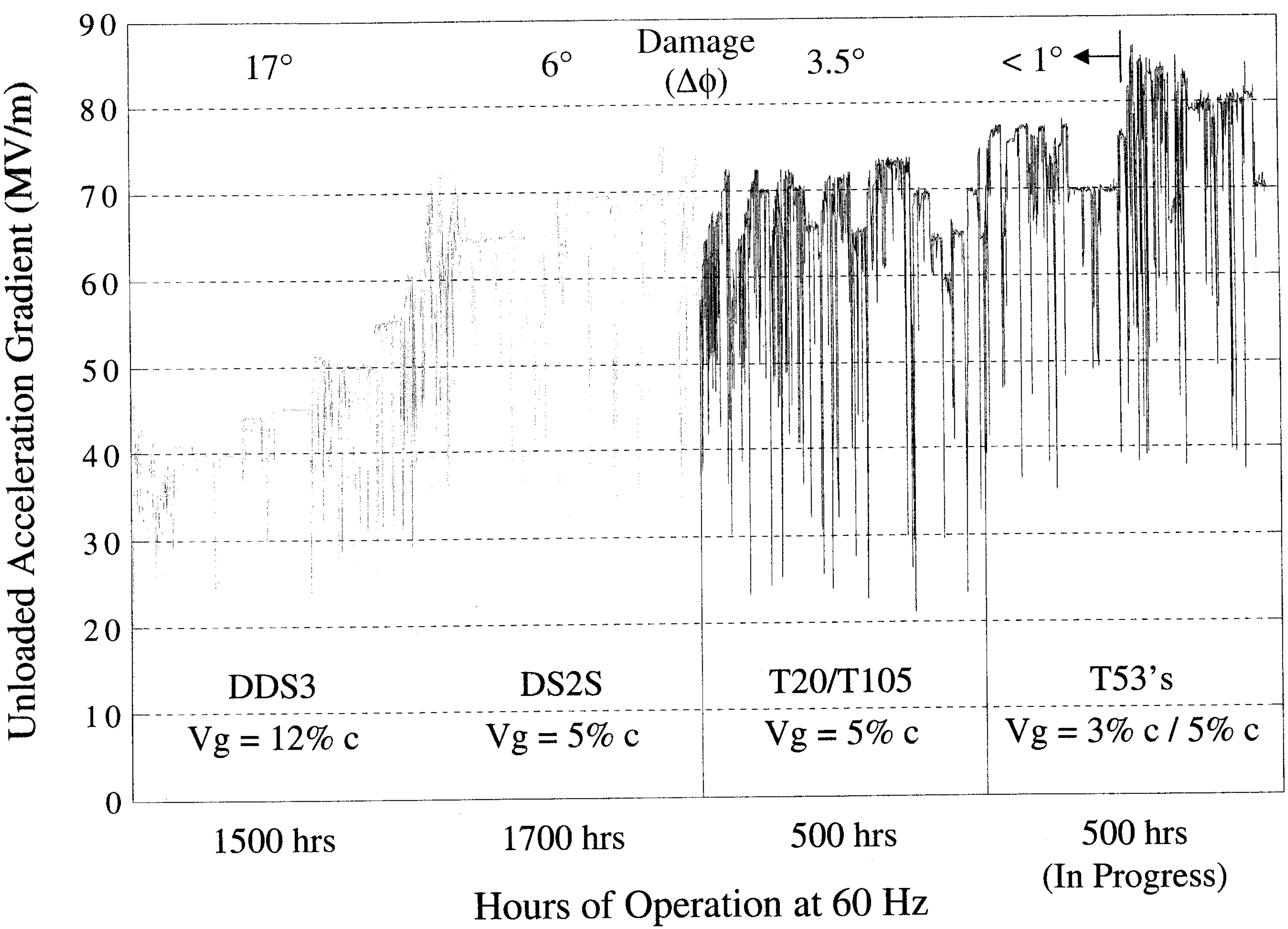
$$\text{Group Velocity}^2 \times \text{Gradient}^2$$



Program to Improve High Gradient Performance

- Structure parameters
  - Compare performance of traveling wave structures with different
    - ✓ Initial group velocity (5 % and 3% c)
    - ✓ Lengths (20, 50 and 100 cm).
  - Test 15 cell standing wave cavity.
- RF processing
  - Process a 1.8 m long, 12% c initial group velocity structure 'more gently.'
  - Systematically study breakdown events (measure RF, light, sound, X-rays, currents and gas) in structures, waveguide and single cavities.
- Materials and handling
  - Improve degassing: wet H_2 fire + vacuum bake + in-situ bake test structures.
  - Measure surface cleanliness/damage with SEM and auger.
  - Test different cleaning techniques: ultra pure water rinsing, glow discharge cleaning and high pressure water rinsing.
- Theory and modeling
  - Use 'MAGIC' particle-in-cell code to simulate the breakdown effect on RF.

Operation History of Several Test Structures



High Gradient Summary

- Discovered RF Circuit Affects Achievable Gradient
  - Breakdown damage not just a function of surface field.
- Encouraged by Recent Low Group Velocity Structure Tests
  - Achieved gradients > 70 MV/m with no discernable damage.
  - Breakdown rate at 70 MV/m is about 1 per hour (1 in 200,000 pulses), which is marginally acceptable for the NLC.
    - Nearly all breakdown occurs near the input coupler at this gradient.
    - Will soon test high impedance coupler aimed at eliminating these events.
- If This Proves to be the Right Approach
  - Have efficient designs for 5% and 3% c group velocity structures meeting NLC short-range transverse wakefield requirements.
  - Modifications to suppress the long-range wakefield are in development.

Next Generation X-Band Structure

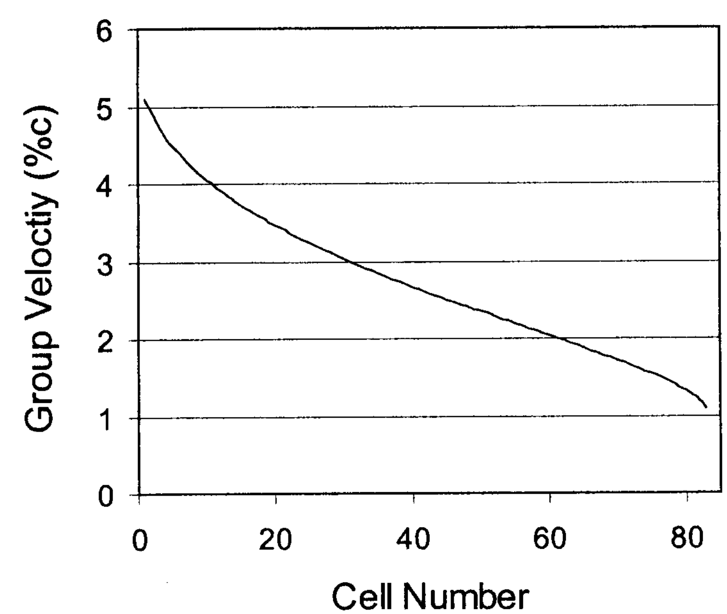
Increase Phase Advance to 150^0/cell (from 120^0/cell)

To Achieve Lower Group Velocity: 5.1 → 1.1 % (11.8 → 3.0 %)

with

Same Average Iris Radius / $\lambda = 0.18$

- Structure Length: 0.9 m (1.8 m)
- Cell Length: 10.9 mm (8.7 mm)
- Number of Cells: 83 (206)
- Input Power: 85 MW (170 MW)
- Unloaded Grad: 70.0 (72.4 MV/m)
- Es/Ea: 2.5 → 2.1 (3.0 → 2.2)



NLCTA RF System Test Setup

Low Level RF System

One 490 kV 3-Turn Induction Modulator

Eight 2 KW TWT Klystron Drivers (not shown)

Eight 75 MW PPM Klystrons

Reduced Delay Line Distribution System (2 Mode)

Two Accelerator Structure Sextets