NLC Issues

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E3 / M3 Joint Session

Introduction

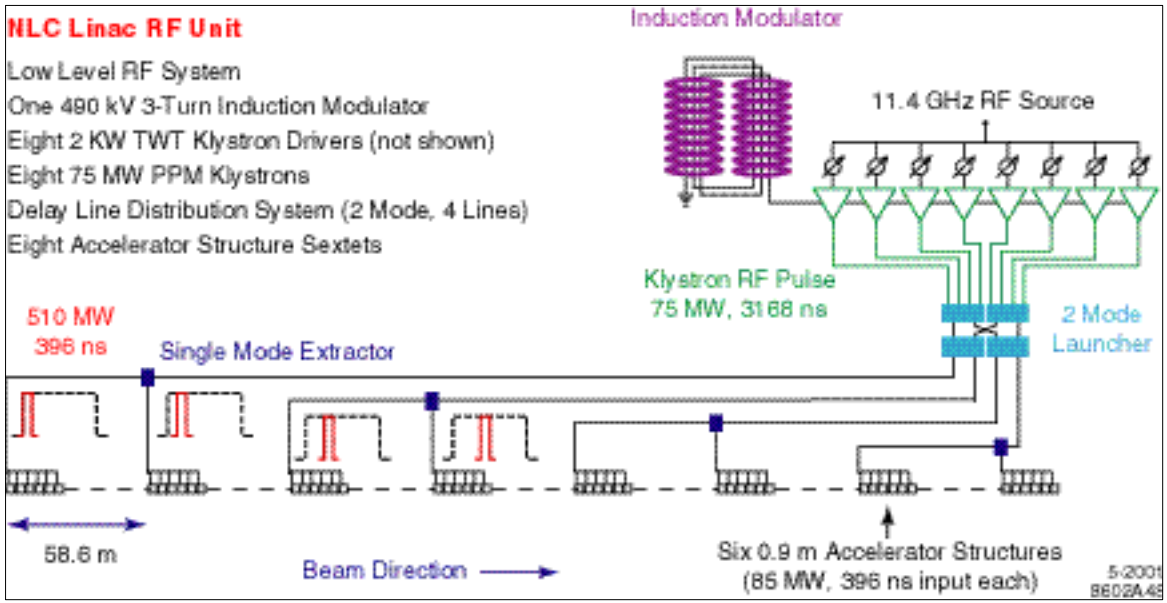
- John Jaros 23 line e-mail of questions to be answered in 20 to 25 minutes!
  - Critical issues and reasons for confidence
  - R&D time line
  - Robustness of luminosity estimates
  - R&D needed for energy expansion
  - Guidance on:
    - Luminosity versus energy
    - Luminosity with 2 Irs
    - Overhead when changing energy
    - Luminosity for first three years
    - Positron polarization

If you want real answers need further discussion or come to M3 group!

Introduction

- Three critical parameters for a linear collider:
  - Energy - David Burke described rf technology status on Monday
  - Cost – 6.4 B$
  - Luminosity – 10^4 times larger than SLC

- Rf system consists of 4 main components:
  - Modulator – convert line ac to pulsed dc for klystrons
  - Klystrons – convert pulsed dc to pulsed X-band rf
  - Distribution – transport power to structures and compress temporally
  - Structures – generate acceleration gradient



NLC RF system

- 3rd iteration on NLC rf system driven by cost reduction and results from R&D program
  - 1st iteration built into NLCTA which started operation in 1996
    - Conventional modulators; XL-4s with 50 MW PPM demonstrated summer of 1996; SLED-II 4x power compression; 1.8-m damped detuned accelerator structures
  - 2nd iteration adopted in 1998
    - Conventional modulators; 75 MW PPM klystron with 1.5 us pulse width; DLDS 4x power compression; 1.8-m damped rounded detuned accelerator structures (gradient and wakefields)
  - 3rd iteration adopted in 2000
    - Solid state modulators; 75 MW PPM klystron with 3 us pulse width; DLDS 8x power compression; 0.9-m rounded damped detuned accelerator structures (gradient and wakefield)

NLC Rf System Status

- Modulator
  - Demonstrated: conventional modulator; short stack for solid state modulator
  - Testing: full prototype of solid state 8-pack modulator
- Klystron
  - Demonstrated: 50 MW solenoidal-focused tubes; 50 MW PPM tubes; 75 MW PPM tubes at low rep rate.
  - Testing: 75 MW PPM tube with cooling for full rep rate operation
- Pulse Compression
  - Demonstrated: SLED-II pulse compression at 400 MW and 240 ns
  - Building: DLDS pulse compression for 600 MW and 400 ns (2003)
- Structures
  - Demonstrated: wakefield control in 1.8-m structures with 40 MV/m gradient; 85 MV/m peak gradient and 65 MV/m operating gradient in 50 cm test structures
  - Building: full NLC prototype structure to be tested in 2002

RF System: Klystron and Modulator

- Solid state modulator delivers 2kA; 500kV; 3kJ
  - IGBT switches developed for electric trains
  - Modular modulator – soft failure modes
  - Full scale prototype has been constructed and tested at low voltage (75 kV and 1 kA)

- Klystrons:

	Focusing	Peak Power	Pulse length	Rep. rate
XL4	**Solenoidal**	**50 MW**	**1.5 us**	**120 Hz**
10 tubes @ 10,000 hrs.		50 MW	1.5 us	120 Hz
		75 MW	1.5 us	120 Hz
		50 MW	2.4 us	120 Hz
PPM-1	**PPM**	**50 MW**	**1.5us**	**60 Hz**
1 tube (1996)		60 MW	1.5 us	60 Hz
		50 MW	2.4 us	60 Hz
XP1	**PPM**	**75 MW**	**1.5 us**	**No cooling**
1 tube (2000)		75 MW	3.1 us	
		90 MW	0.5 us	
XP3	**PPM**	**75 MW**	**3.0 us**	**120 Hz**
Diode test (2001)				

Goal: 75 MW with 3 us pulse width at 120 Hz or greater

RF System: RF Distribution

- Delay Line Distribution System
  - Complicated rf components to exchange modes and direct power
  - Uncertain about power handling (600 MW) and tolerances
  - Massive vacuum system
  - Completely passive
  - Systems tests in 2002 and 2003

- SLED-II – alternate pulse compression system
  - Less efficient than DLDS (65% instead of 85%)
  - Operating on NLCTA since 1996
  - Maximum power tested thus far is 500 MW at 150 ns and 400 MW at 240 ns – want 600 MW at 400 ns

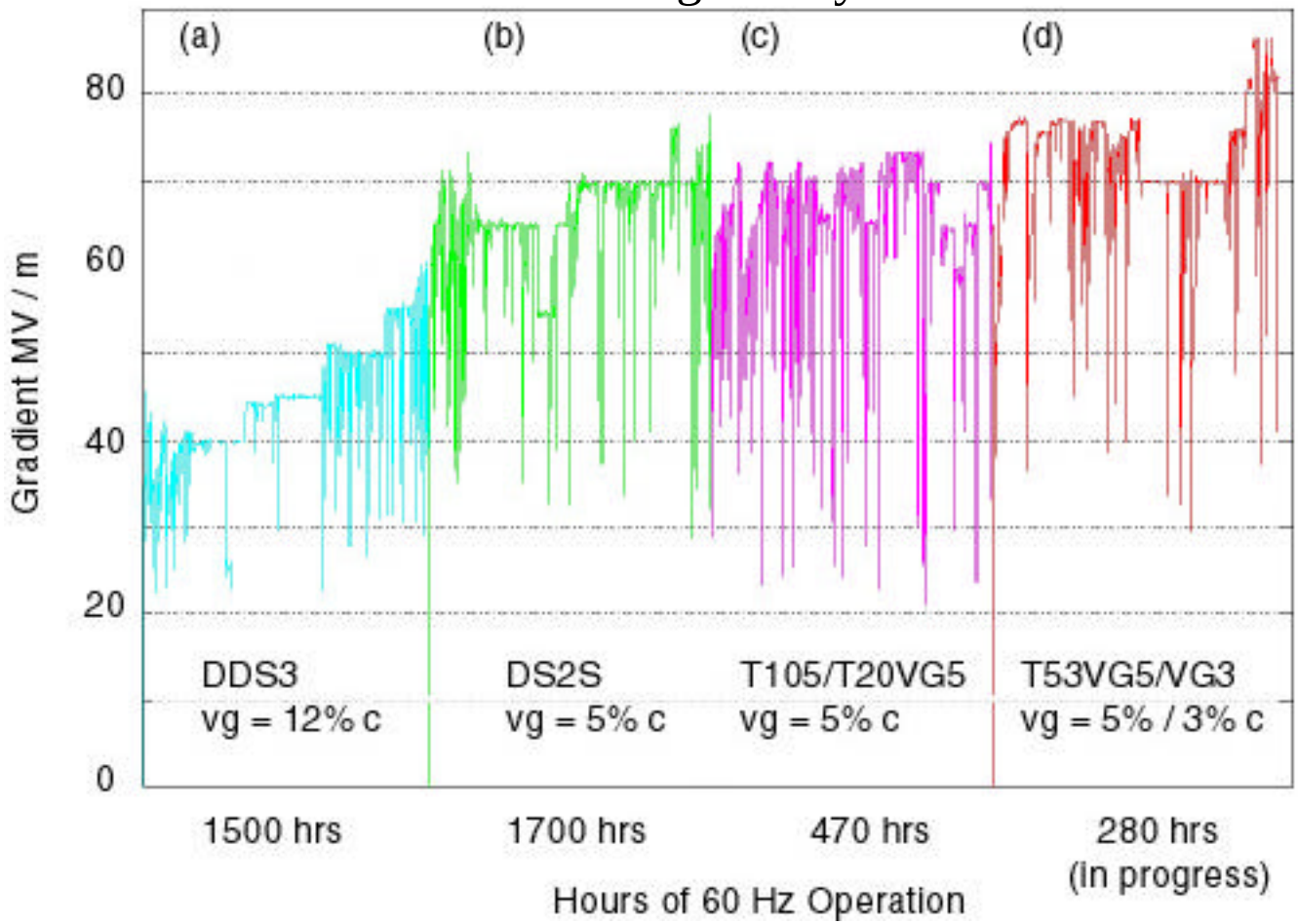
RF System: Accelerator Structures

- Not near gradient limits for copper
  - Single cell cavities hold gradients of 150 ~ 200 MV/m
  - 'Short' structures processed rapidly to >100 MV/m
- Built many 1.8 m structures
  - Meet fabrication tolerances
  - Studied wakefield damping extensively – damping sufficient although not at desired values
  - Don't meet gradient expectations
- Processing model – increase voltage until breakdown
  - Small arcs clean surface / large arcs damage surface
  - Difference between the two is how much energy is available → low vg
  - Some 'damage' is acceptable however need to extrapolate out 10~20 years
  - Other models predict constant damage – inconsistent with single cell data

RF System: Gradient Issues

- Low group velocity structures rapidly process to ~70 MV/m
- Small damage during initial processing
- Minimal damage during subsequent operation
- Breakdown rate is few per hour, i.e. few per 200,000 pulses

Processing history



RF System: Accelerator Structures

- Built many test structures without wakefield control
  - Much better performance with low vg than original NLC design
  - Peak gradients of 70 to 80 MV/m and operate at 65 to 70 MV/m
  - Trip rates look OK
  - Damage looks OK
  - Need more testing to be able to extrapolate results to year timescales

- Test structures do **not** include NLC-style wakefield control
  - Demonstrated single bunch and multi-bunch wakefield control in 1.8-m structures
  - Will build 'NLC' style 90 cm structure with single bunch wakefield control end of this year
  - Will test NLC structures with both single and multi-bunch wakefield control by the end of 2002

Energy Upgrade Routes

- Baseline: Stage 1 with rf system for 1 TeV at gradient for 1 TeV
  - Fill only half of linac tunnel with accelerator structures
  - Upgrade by installing 1 or 2 sectors (50 to 100 GeV) per 3 month down
- Alternate option: Stage 1 at 50% nominal 1 TeV gradient
  - Fill whole tunnel with accelerator structures
  - Upgrade by replacing structures (if necessary) and installing more rf power sources
  - Easier to increase beam energy because all rf power sources are accessible
  - Lower gradient operation has slightly more difficult operational issues: higher beam loading; large emittance dilutions
  - 10~20% luminosity reduction

Rf System Summary

- Multiple iterations of rf system
  - NLCTA operating since 1996 with X-band rf
  - Stupidly Snowmass caught us in the middle of this iteration without an operating rf system
  - 2 years before full system demonstration of these components
- Only one fundamental problem: gradient limitation
  - Gradients >150 MV/m in single cell standing wave structures
  - Testing with gradients 70~80 MV/m in low vg structures
  - 1 year to demonstrate 70 MV/m gradient with lifetime
  - 2 years to demonstrate prototype NLC structure

NLC Costs

NLC cost reduced by ~25% since 1999 Lehman review based on technologies that were still being developed in 1999

Costs estimate reviewed for completeness by Lehman NOT for accuracy!

Concern regarding volume discounts!

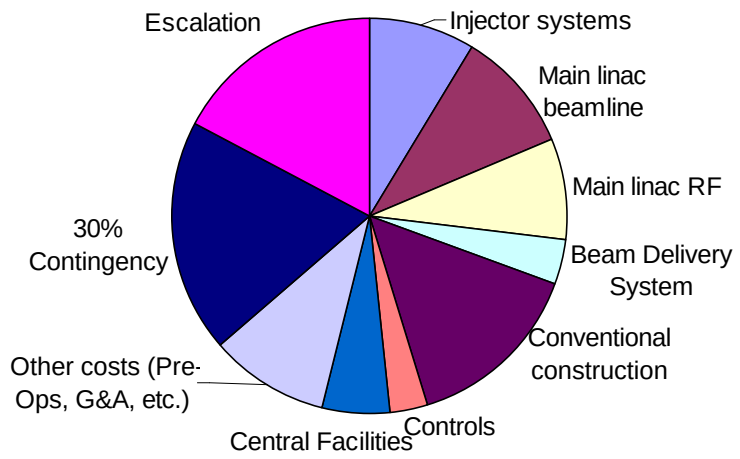
Present cost estimate is roughly 6B$ including contingency, escalation, labor, G&A, and pre-ops

→ Number of modulators and klystrons reduced by factor of 2

→ Overall system power efficiency improved by 60%

→ Beam Delivery system length halved, with multi-TeV energy reach

Cost for 1 TeV is ~25% additional



Design Parameters

High E IP Parameters (3/01)	Stage 1	Stage 2
CMS Energy (GeV)	500	1000
Luminosity (10^{33})	**20**	**34**
Repetition Rate (Hz)	120	120
Bunch Charge (10^{10})	**0.75**	**0.75**
Bunches/RF Pulse	190	190
Bunch Separation (ns)	1.4	1.4
Eff. Gradient (MV/m)	**50.2**	**50.2**
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)	**3.5**	**3.5**
β_x / β_y at IP (mm)	8 / 0.10	10 / 0.12
σ_x / σ_y at IP (nm)	**245 / 2.7**	**190 / 2.1**
σ_z at IP (um)	110	110
Υave	0.11	0.29
Pinch Enhancement	1.43	1.49
Beamstrahlung δB (%)	4.7	10.2
Photons per e+/e-	1.2	1.3
Linac Length (km)	6.3	12.8

Low Energy IP Parameters (8/00)			
CMS Energy (GeV)	**92**	**250**	**350**
Luminosity (10^{33})	**3.5**	**9.4**	**13.2**
Repetition Rate (Hz)	**120**	**120**	**120**
Bunch Charge (10^{10})	**0.75**	**0.75**	**0.75**
σ_x / σ_y at IP (nm)	**630 / 6.2**	**380 / 3.8**	**320 / 3.2**
L0 / Ltotal (%)	62	47	43
Beamstrahlung δB (%)	0.18	1.1	2
Photons per e+/e-	0.49	0.79	0.92
Polarization loss (%)	0.08	0.21	0.34

- Trade luminosity versus beamstrahlung:

$$L \propto \frac{N^2}{\sigma_x \sigma_y} \qquad d_B \propto \frac{N^2}{\sigma_z \sigma_x^2} \qquad d_E \propto \frac{N}{\sqrt{\sigma_z}}$$

increase $\sigma_x \rightarrow \delta_B$ decreases faster than L

Design versus Intrinsic Luminosity

- Intrinsic luminosity:
  - the luminosity the machine could deliver limited by physical effects such as synchrotron radiation or intrabeam scattering
- Design luminosity:
  - includes operational limitations and is the luminosity for which the collider is ***designed***
  - includes use of tuning techniques developed during SLC operation

Example:

Emittance at 500 GeV cms

$\gamma\varepsilon_x$ / $\gamma\varepsilon_y$ [10-8 m-rad]

	Intrinsic	**Design**
Damping rings	300 / 1	300 / 2
Main Linac	315 / 1	330 / 3
Beam delivery	330 / 1	360 / 3.5
Luminosity	45×10^{33}	22×10^{33}

Luminosity

- Luminosity is 10^4 larger than in SLC!
  - 6x lower single bunch charge but 190 bunches per pulse and 10x smaller σ_x and 200x smaller σ_y

$$L = \frac{f_{rep}}{4p} \frac{n_b N^2}{s_x s_y} H_D \quad \Rightarrow \quad L = \frac{2P_b}{4p\, E_{cms}} \frac{N}{s_x} \frac{H_D}{s_y}$$

In a linear collider

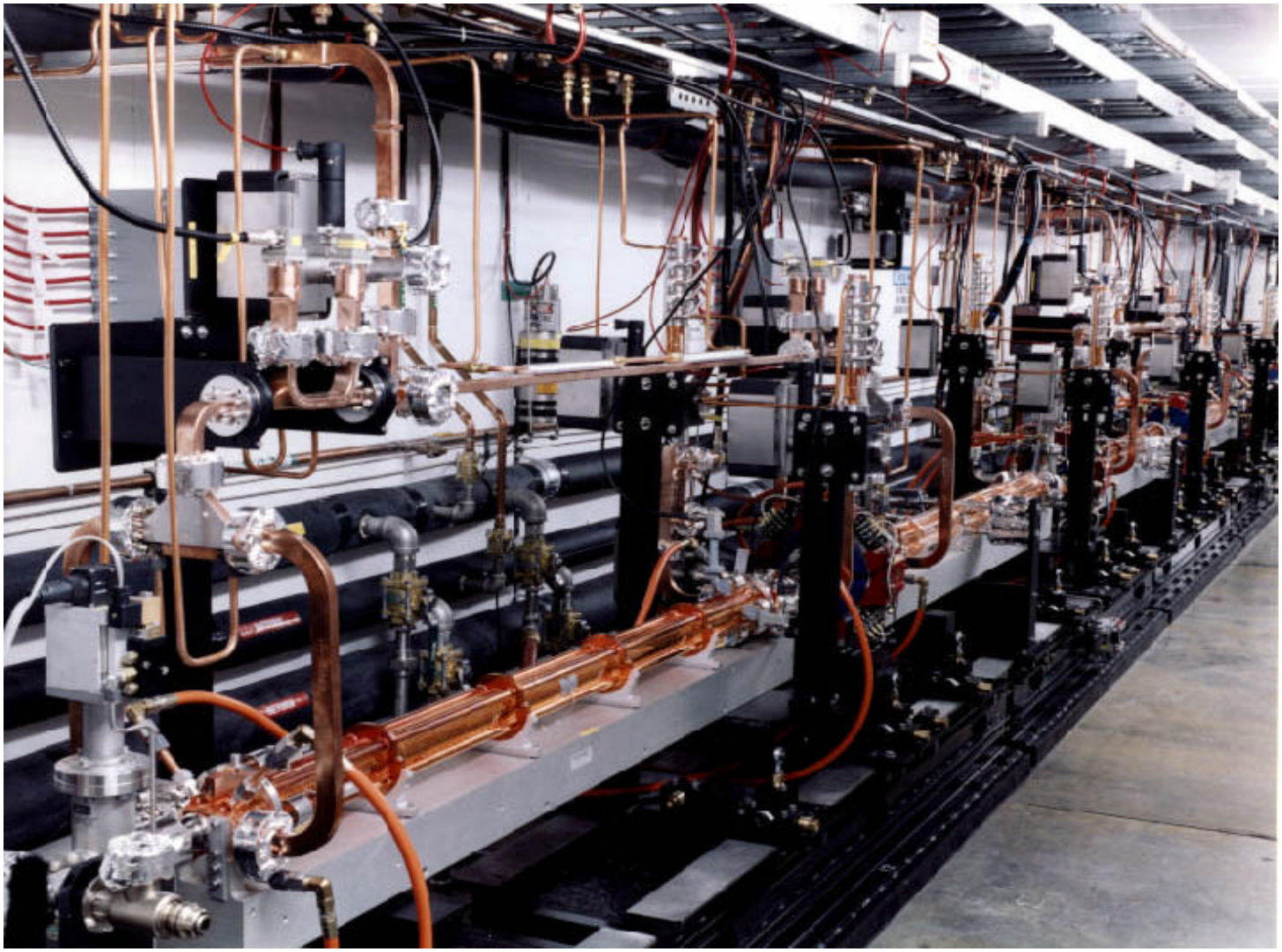
  - P_b is the beam power
  - H_D is the luminosity enhancement
  - (N / s_x) is roughly proportional to the beamstrahlung (backgrounds)

$\Rightarrow$ WAIT! δ_B is not really proportional to just (N / s_x)
Do not use this 'scaling' formula for calculations!

Luminosity: Beam current

- Beam current: 0.9 Amp in 190 bunches and 265 ns versus 0.1 Amp in 3 bunches and 120 ns
  - ‘Conventional’ positron source designed using SLC experience
    - Brute force – will study more elegant (although untested techniques in future)
  - ‘Conventional’ polarized electron source based on SLC
    - Potential limitation due to charge limit at photo-cathode – cathode development is close to demonstrating full polarization at full current
  - Multi-bunch energy effects are not a problem and are straight-forward to calculate and observe in other machines (NLCTA, PEP-II, etc.)
    - Transient beam loading loading compensation in linac (for fundamental) demonstrated at NLCTA in 1997
    - Transient loading in rings will be trickier to compensate directly so design includes complicated dual bunch compressor scheme

NLC Test Accelerator



Operated since 1996

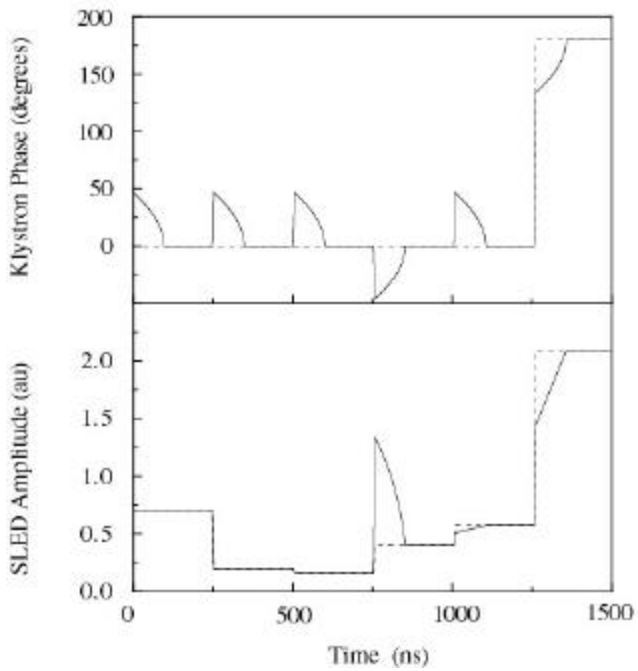
Dual 50MW klystrons

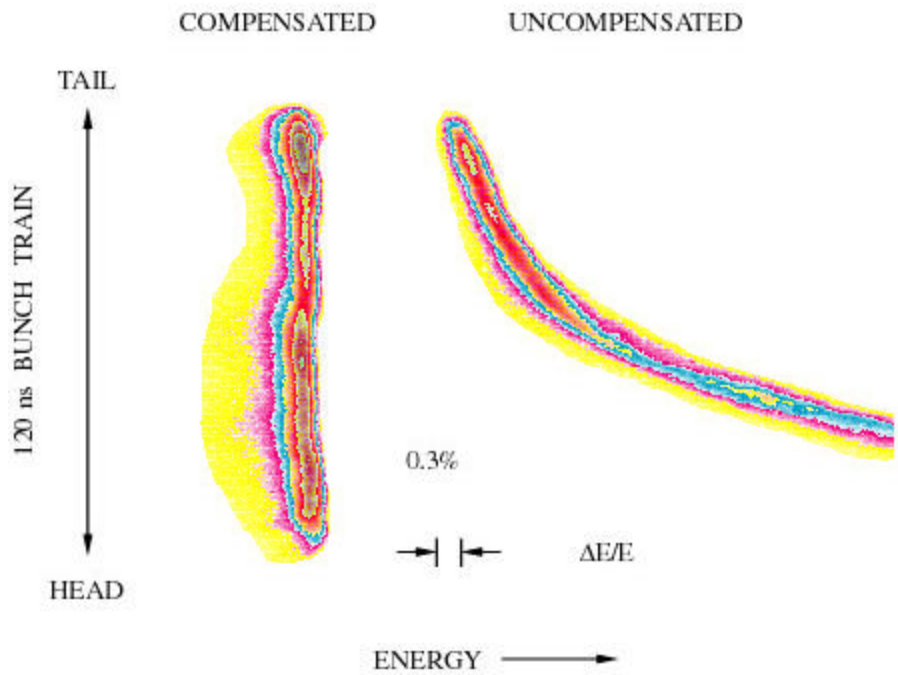
SLED-II

1.8 m long structures

Beam Loading Compensation

- Beam loading in NLC design takes roughly 25% of rf energy
  - Trailing bunches see less rf power in structures
- Compensated by ‘pre-loading’ structures by varying klystrons while structures fill (first 100 ns of rf pulse)
- Technique was verified in 1997 after turn-on of NLCTA





Luminosity: e generation

- Very small beam spots require small emittance generation, good emittance preservation, small beta functions, and stability: $\sigma = \mathrm{sqrt}(\beta * \gamma\varepsilon / \gamma)$

- Emittances are generated in damping rings similar to 3rd generation light sources like ALS at Berkeley and KEK ATF

	NLC MDR	PEP-II LER	LBNL ALS	KEK ATF
Energy (GeV)	1.98	3.1	1.5	1.28
Circumference (m)	300	2200	197	139
Current (A)	0.8	2.16	0.4	0.004
$\gamma\varepsilon_{x,\ equilib.}$ **(10^{-6} m-rad)**	2.17	400	12	3.5
$\gamma\varepsilon_{y,\ equilib.}$ **(10^{-6} m-rad)**	0.014	12	0.12	0.038

  - ATF test facility at KEK is verifying many aspects
  - New effects like intrabeam scattering and ions instabilities are expected at some level although ATF results are not well understood yet
  - Some confidence from proximity to other operating rings, however, every new ring has found something unexpected!

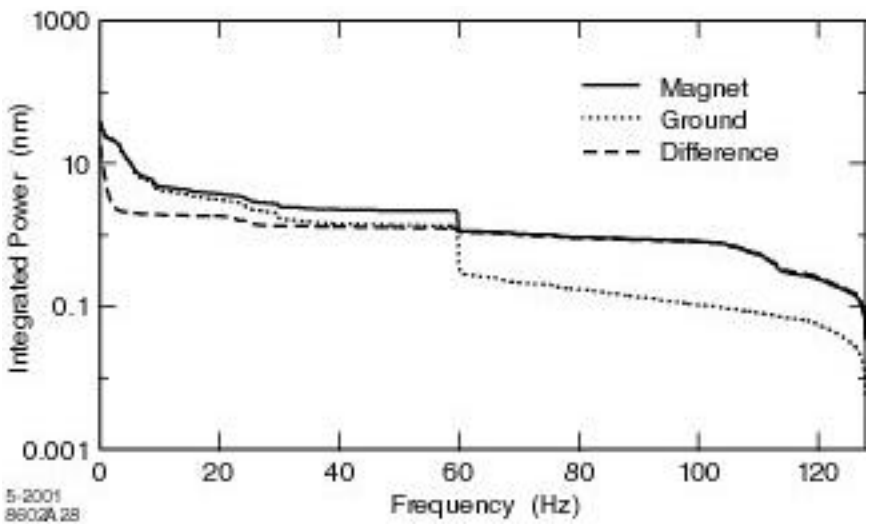
Luminosity: b-function and Stability

- Other issues for luminosity are small beta functions at the IP and stability
  - FFTB demonstrated beta functions needed (as well as instrumentation and beam based alignment)
  - Spot sizes were roughly 10x larger than in NLC because of larger incoming emittances: $\sigma = \mathrm{sqrt}(\beta * \gamma\varepsilon / \gamma)$
- Stability has been measured many places!
  - Natural motion is sufficiently small
  - Need to be very careful with cultural sources
  - Demonstrated 10x damping with active stabilization system on rigid block
  - Will extend these tests to quadrupole-like object in 2002
  - Plans for FFS test using modified SLC FFS to study engineering issues and systems integration

Stability: Jitter and Supports

- Jitter tolerances are at nanometer level
- Natural motion is also nm level – cannot tolerate significant additional motion from cultural sources

FFTB quad moves at 2nm relative to ground with water and power

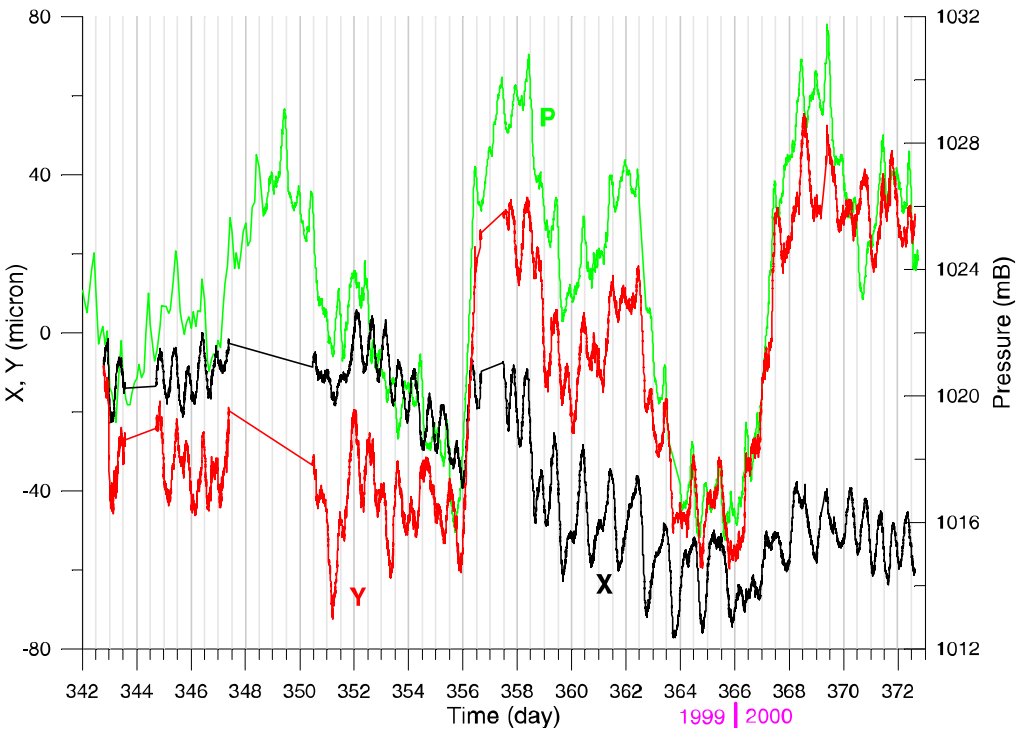


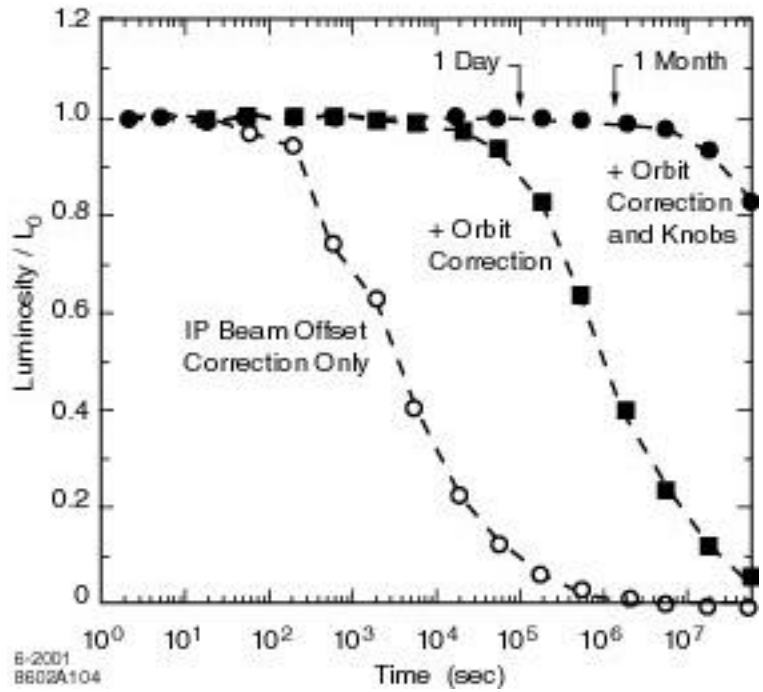
- In contrast, SLC quadrupoles moved at micron level!
- Poor (30 year-old) girder design and direct coupling to accelerator cooling

Stability: Tuning

Simple tuning techniques ease effect of ground motion

Ground motion meas. at SLAC → Effect on NLC BDS



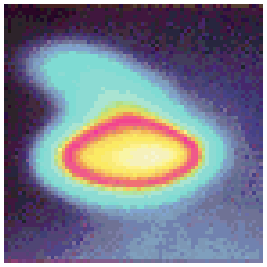


Luminosity: e preservation

- Emittance preservation in linac requires control of wakefields and component alignment
  - Must operate collider far from Beam BreakUp (BBU) regime
    - BBU in linacs very well understood phenomena
    - Long-range wakefields from structures are directly verified at ASSET facility
    - Beam parameters have been chosen to make effect of short-range wakefield on beam 4x **less** than in SLC!
  - Alignment tolerances still roughly 10~20x tighter than in SLC because of smaller emittances and more components (sqrt(n) for random errors)
    - Multiple layers of beam-based alignment / feedback
    - Accurate diagnostics that have been demonstrated or are reasonable extrapolations from present experience

Beam Break-Up Instability

- BBU arises from resonant interaction between bunches and structures



- BBU **amplifies** trajectory jitter
- BBU is *different* from the static alignment problem

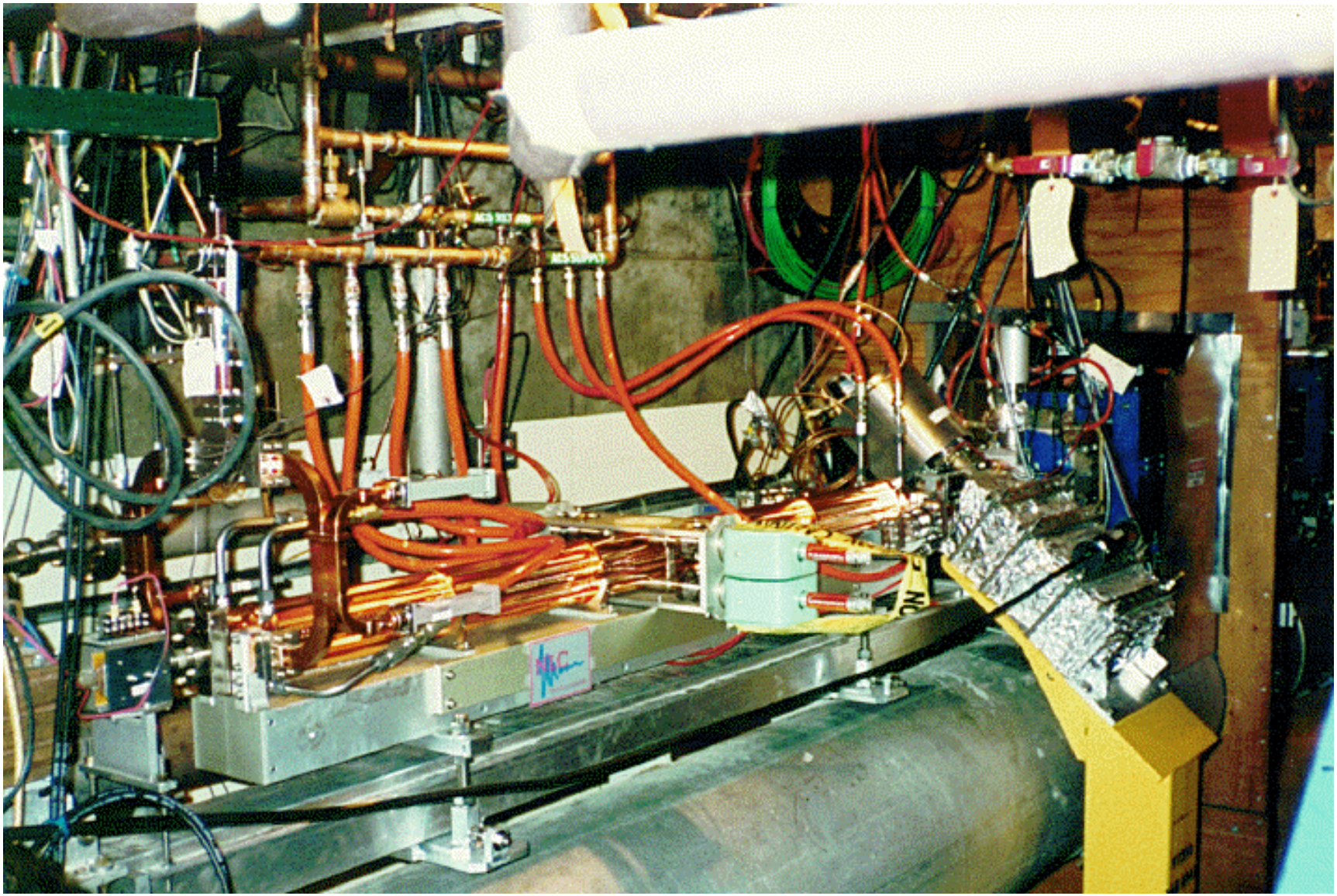
- The static dilution from BBU can be removed by steering however BBU makes steering more difficult (impossible)
- Cannot operate the collider with any significant level of BBU amplification

- First need to correct the BBU and then are left with $\Delta\varepsilon$ from misalignments

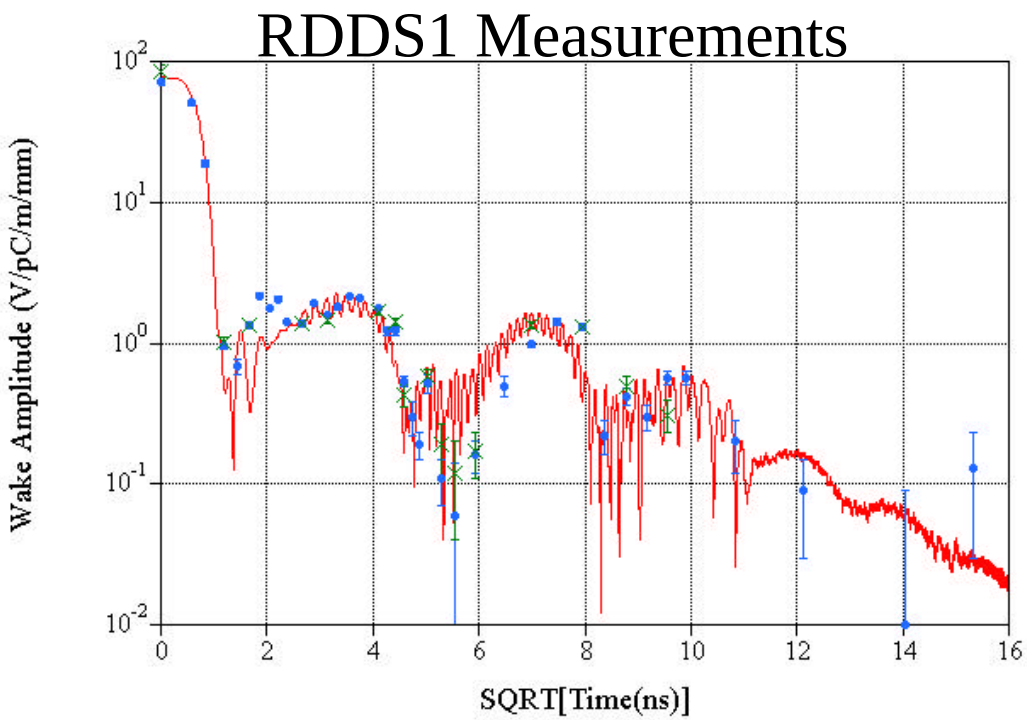
Beam Break-Up Instability

- BBU is the most obvious concern in long linac
  - effect of long-range wakefields observed at SLAC in 60's
  - effect of short-range wakefields observed in SLC in mid 80's
- BNS damping has been used since 1986 in SLC linac to eliminate single bunch BBU (SB-BBU)
  - NLC parameters were chosen to make SB-BBU smaller than SLC!
  - Require less than 1% $\Delta E/\sigma_z$ for 'autophasing' BNS
- Long-range wakefield is directly reduced to prevent multi-bunch BBU (similar approach taken in SLAC linac)
  - Need reduction of roughly 100 between 1st and subsequent bunches
  - Wakefield can be directly verified at ASSET
  - Can add bunch-to-bunch energy deviation to further suppress MB-BBU

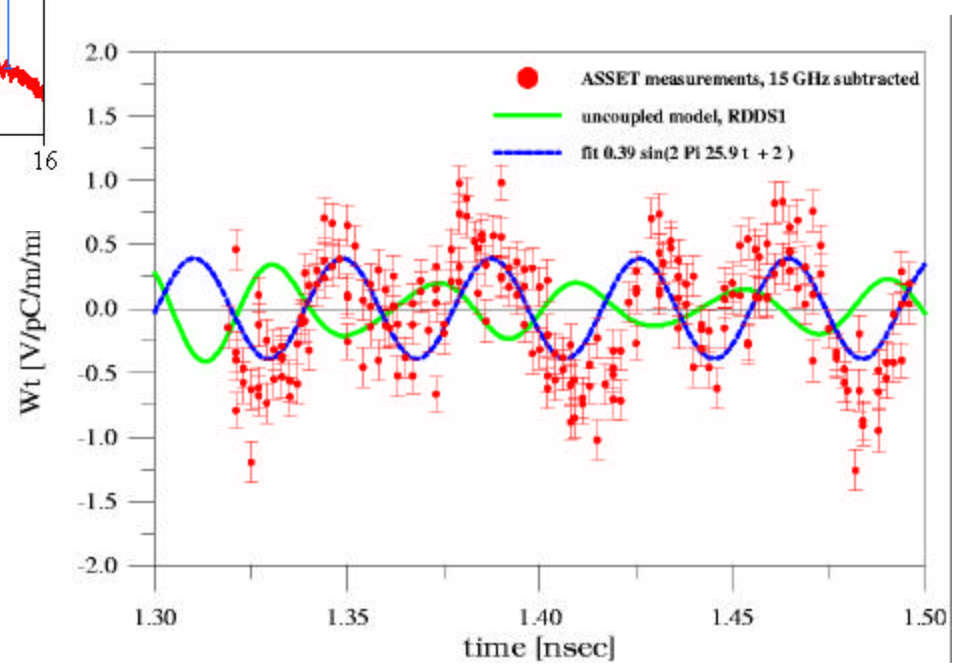
ASSET Wakefield Test Facility



Long-Range Wakefield Measurements



- Three DDS-style structures have been built and tested
- Wakefield model agrees well with measurements

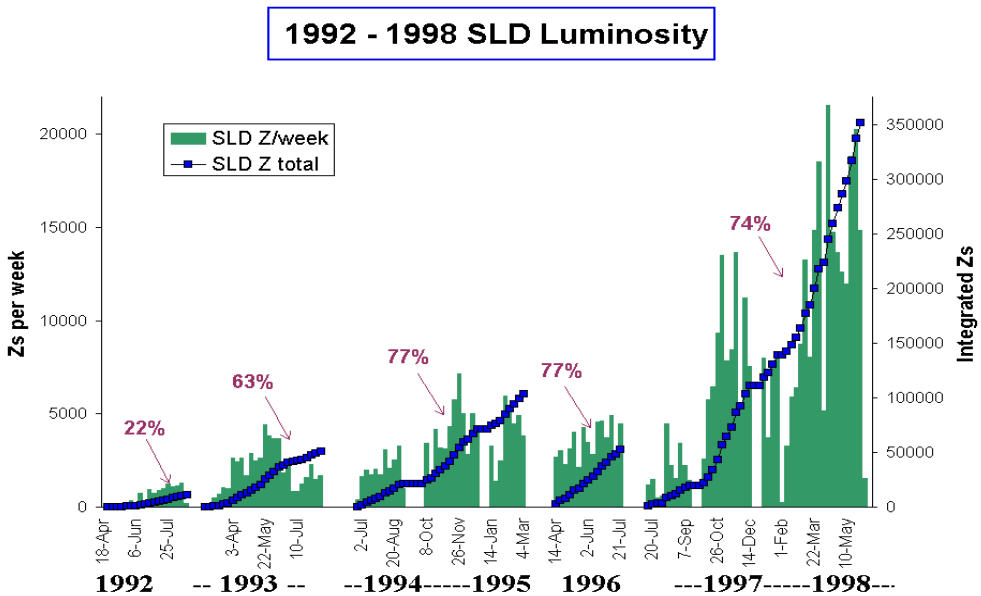


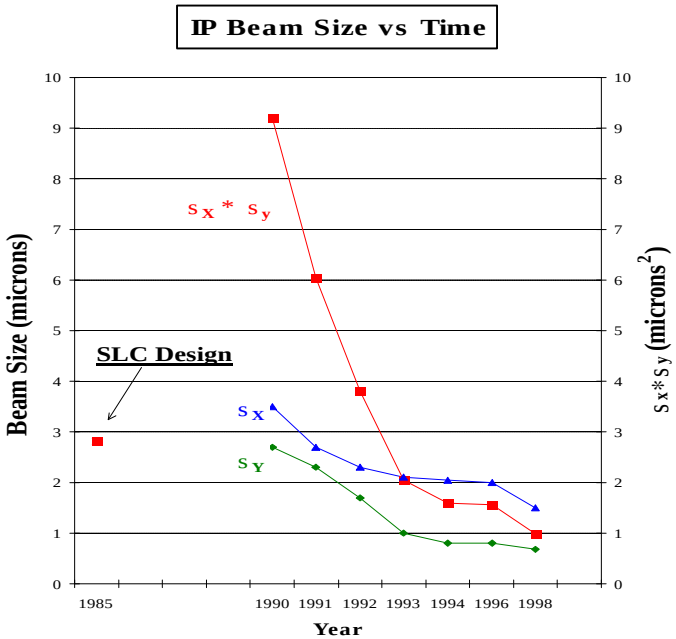
- Lowest band is around 15 GHz
- Next band (25 GHz) is visible after 1.4 ns

Structure Design and Wakefields

- Structure design is in good shape
  - codes are making 3-D calculations with sub-MHz accuracy
- Short-range wakefield calculation is in good shape
  - decades of experience with these calculations
  - compared SLAC S-band longitudinal with measurements
  - comparing SLAC S-band transverse with measurements
  - compared NLC mid-range transverse with ASSET results
- Long-range wakefield calculation is in good shape
  - calculation based on two-band circuit model
  - some issues still unresolved like higher dipole bands
  - compared accurately against ASSET data which measures exactly what the bunch train would see!
  - Need faster technique than ASSET to QC the structures
- Don’t have final structure or wakefield design yet but know how!!

Building on the SLC





New Territory in Accelerator Design and Operation

- Extensive feedback & online modeling
- Correction techniques expanded from first-order (trajectory) to include second-order (emittance), and from hands-on by operators to fully automated control

"It's the diagnostics, stupid"

Required Diagnostic Performance

Item	Specification	Achieved	Improvement Needed
Quadrupole BPMs	0.3 μm resolution	1 μm resolution (FFTB striplines) [1] 0.025 μm resolution (FFTB cavities) [2]	**Factor of 3** **None**
RF structure BPMs	5.0 μm resolution	2 μm resolution (NLC structure prototypes DDS3 and RDDS1) [3]	**None**
Magnet Movers	0.05 μm step size	0.3 μm step size (FFTB magnet movers) [4]	**Factor of 6**
RF Girder Movers	1 μm step size	0.3 μm step size (FFTB magnet movers) [4]	**None**
Laser Profile Monitor	Measure 1 μm RMS beam size	Measure 1 μm RMS beam size (SLC laser wire) [5] Measure 0.06 μm RMS beam size (FFTB laser interferometer profile monitor) [6]	**None** **None**
Magnet/Girder Supports	Add < ~3 nm vibration w.r.t. tunnel floor	Add ~2 nm vibration w.r.t. tunnel floor (FFTB quadrupole supports) [7]	**None**

Emittance and Jitter Budgets for 500 GeV cms Parameters

Emittance budget for NLC Stage 1 Parameters

	$\gamma\varepsilon_x$ [mm-mrad]	$\gamma\varepsilon_y$ [mm-mrad]
Emittance from DR	3	0.02
After BC	3.2	0.022
After Linac	3.3	0.030
At IP	3.6	0.035

Jitter budget for NLC Stage 1 Parameters

	$\Delta x / \sigma_x$	$\Delta y / \sigma_y$	$\Delta E/E$
From DR	0.1	0.1	0.1%
From BC	0.1	0.1	0.1%
From Linac	0.1	0.3	0.2%
From BDS	0.1	0.3	-
From FD	0.1	0.25	-
At IP	0.22	0.51	0.25%
Luminosity loss	1%	3%	2%

‘Bare’ Machine Tolerances

- ‘Bare’ machine tolerances are the component alignment tolerances without any non-local tuning or correction
  - NLC is designed with emittance correction like storage rings are designed with orbit correction (many rings use η-correction)

Bare Tolerances for 500 GeV cms

	Injector	**Main Linac**	**BDS**
Quad jitter	10 nm	10 nm	1-10 nm
Quad alignment	10 μm	2 μm	2-5 μm
Structure alignment	40 μm	10 μm	-
Quad roll	100 μr	300 μr	300 μr
$\Delta\varepsilon/\varepsilon$	10%	40%	25%

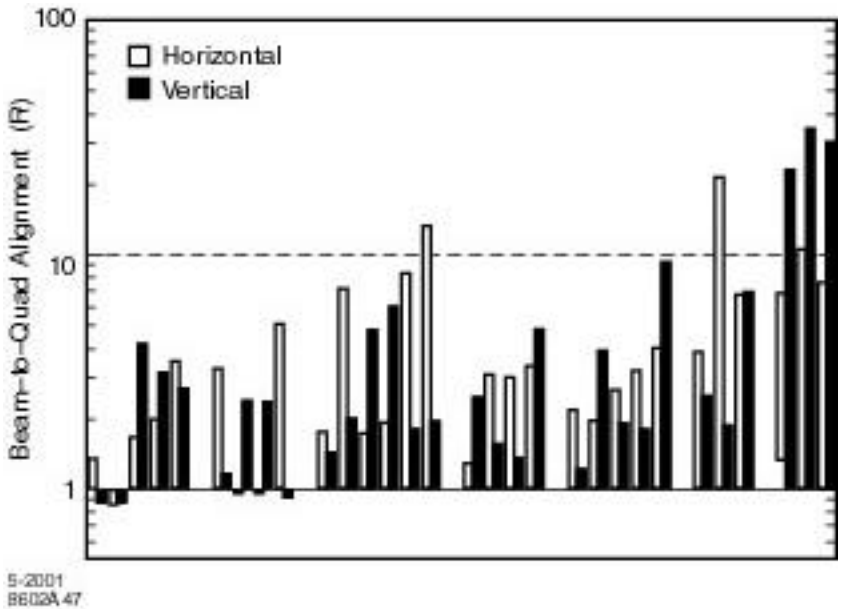
Local and Non-Local Alignment

- To preserve emittance must correct net effect of individual dilution sources
- 'Local' correction - directly correct dilution sources
  - Beam-based alignment
  - Most robust solution / least sensitive to energy or strength errors
- 'Quasi-Local' correction - correct dilution effects over short distance, i.e. betatron wavelength
  - Dispersion-Free steering
  - Based on 'measurements' of dilution / sensitive to systematics
- 'Global' correction - tune emittance using direct ε diagnostics
  - Directly corrects desired quantity / sensitive to phase advance
- All techniques have been demonstrated in SLC & FFTB!

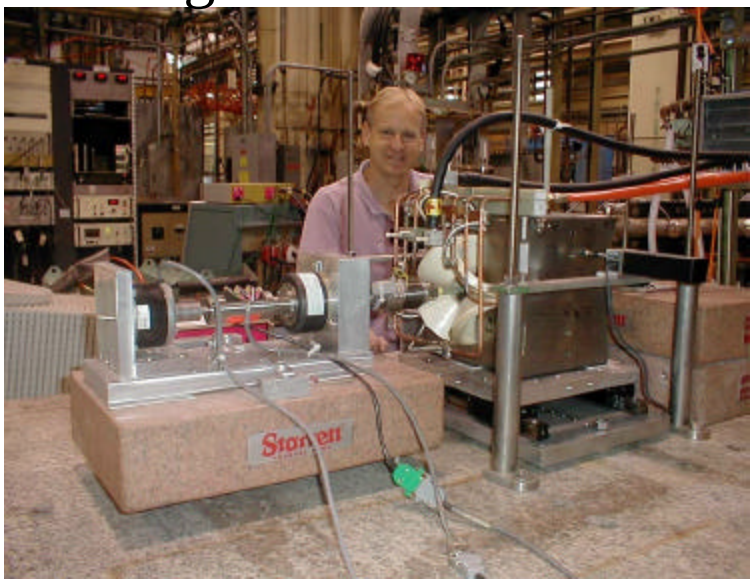
FFTB Beam-Based Alignment

- FFTB project developed excellent diagnostic equipment
- Demonstrated beam-based alignment at 10 micron level

FFTB BBA results



Magnetic center meas.



- Need to be careful with quadrupole design because magnetic forces, heating, variations in μ all cause center shifts

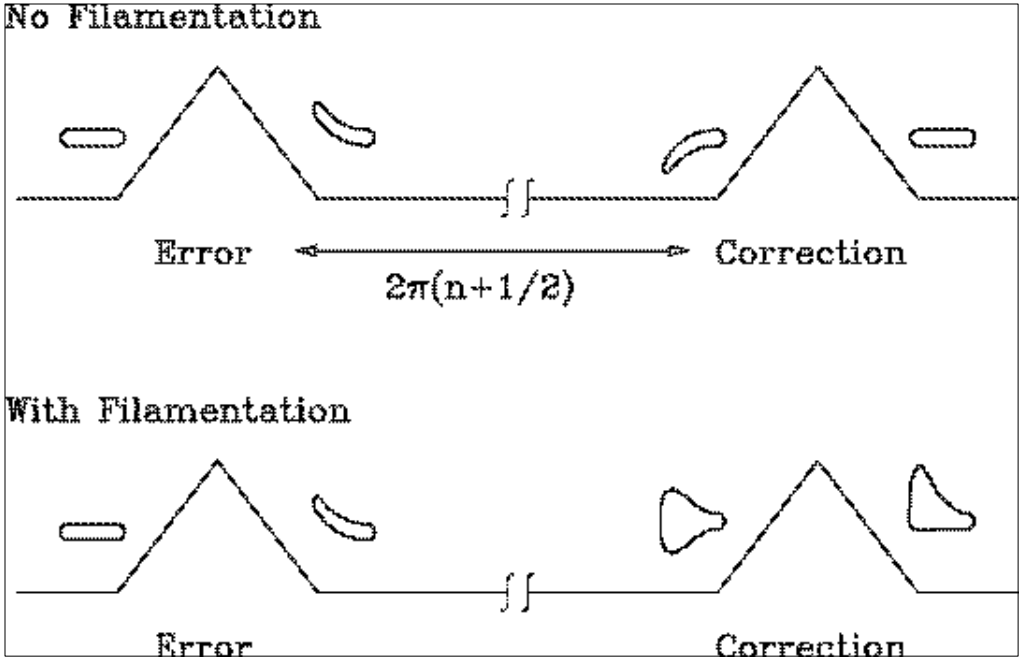
Emittance Correction (Global Correction)

- Most sources of emittance dilution come from conservative processes: transverse wakefields, dispersive errors, etc.

⇒ 6-D phase space *does not* increase
(only the projected phase space increases)

- Any conservative dilution can be removed but this is difficult after phase space mixing from betatron frequency variations

- Filamentation is significant in NLC



Luminosity Evolution since 1996 ZDR

	1996	1999	2000
Lum. [10^{33}]	5.5	7	20
n_b x N	90 x 0.75e10	95 x 0.95e10	190 x 0.75e10
ge_y **[mm-mrad]**	0.09	0.10	0.035
sx / sy [nm]	294 / 5.2	330 / 4.9	245 / 2.7
d_B[%] / P_b [MW]	3.7% / 4.8	4% / 4.3	4.7% / 6.8

- Factor of 3 increase from increase in P_b and decrease in $\gamma\varepsilon_y$
  - Factor of 2 in Y spot
  - Factor of 50% in beam power
  - Ratio of N / σ_x is roughly constant $\Rightarrow$ constant δ_B (20% level)

Smaller Emittances

- Primary emittance dilutions:
  - Single bunch wakefields: $\Delta\varepsilon \propto (N\, dW_\perp/dz\, \sigma_z\, y_{tol})^2\, f(\text{optics})$
    - $dW_\perp/dz$ set by structure aperture (don't want to decrease this)
    - σ_z set by longitudinal wakefield compensation $\propto N$
    - For constant tolerances, $\Delta\varepsilon$ scales as N^4
  - Dispersion: $\Delta\varepsilon \propto (\sigma_{E/\Delta E}\, y_{tol})^2$
    - BNS energy spread proportional to $N\, dW_\perp/dz\, \sigma_z$
    - Tolerances scale in the same manner as above
  - Y emittance budget in linac decreased from 4e-8 to 0.8e-8

  $\Rightarrow$ **Y tolerances decreased by 30% (from 15 mm to 10 mm on struct.)**

- Performance of S-BPM much better than originally expected with 1~2 μm precision versus 10 μm assumed
- Q-BPMs spec. resolution of 300 nm instead of 1 μm

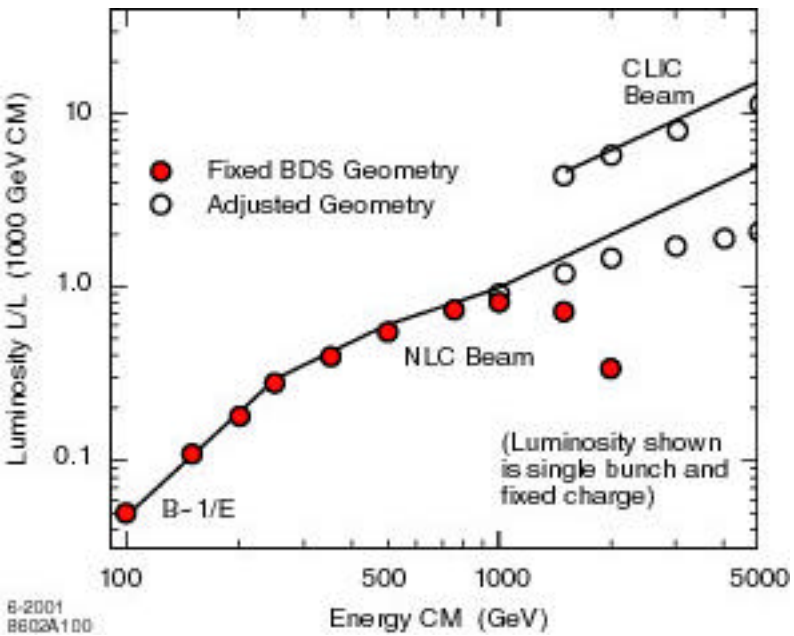
Smaller Emittances

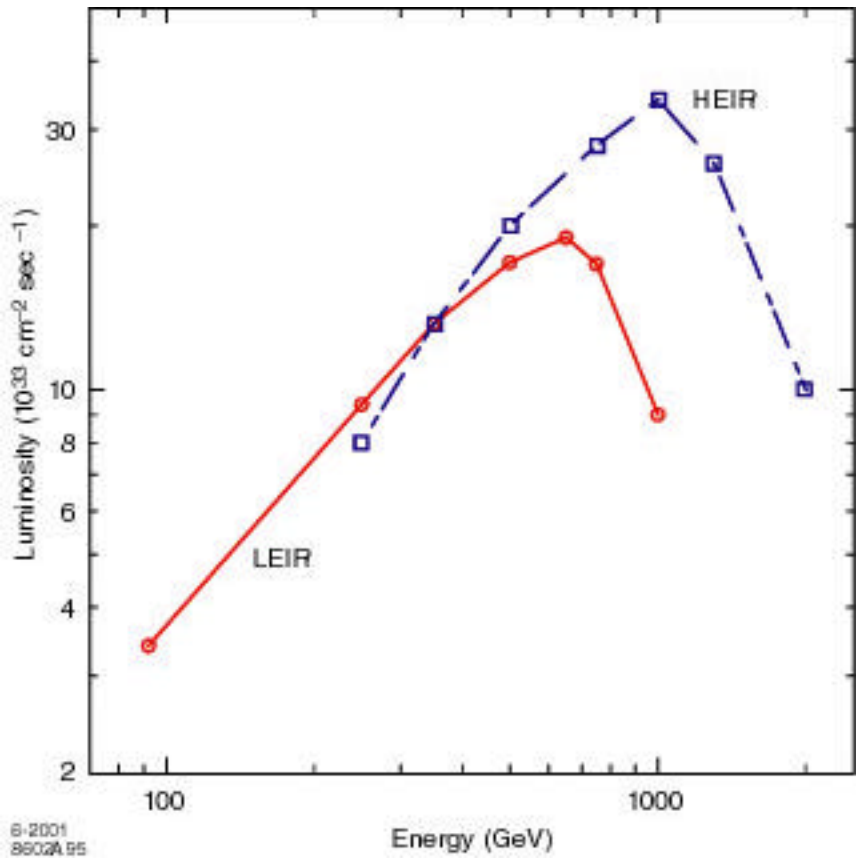
- Horizontal emittance:
  - X emittance linac budget decreased from 60e-8 to 10e-8
  - X emittance tolerances are 3 ~ 4 times larger than Y tolerances
  - X jitter tolerances are 10 times Y jitter tolerances
- Roughly 25% luminosity dilution included in budgets:
  - 10% in luminosity number to include beam jitter and tuning
  - 15% in emittance / spot size increase in BDS
  - May not be enough - need studies
- Problem with smaller emittance budgets is decreased margin for other effects: betatron coupling, rf deflections, etc.

Luminosity Versus Energy

Luminosity scales linearly with beam energy until limited by synchrotron radiation at high energy or aberrations at low energy

Single FFS has limited energy range





Luminosity Startup Model

- New terrain for collider operation
  - Almost certain to find unexpected behavior
  - Extensive diagnostics to trace problems but ….
- Staged turn-on will uncover many issues early however it will still take time to optimize operation

Year	Energy	Luminosity	Integrated Lum.
1	500 GeV	25 fb^{-1}	25 fb^{-1}
2	500 GeV	75 fb^{-1}	100 fb^{-1}
3	500 GeV	150 fb^{-1}	250 fb^{-1}
4	500 GeV	200 fb^{-1}	450 fb^{-1}

0	350 GeV	15 fb^{-1}	15 fb^{-1}

  - Assumes 9 month run with 2 month commissioning period; 1 month additional downtime; 85% availability during operation; average luminosity equal to 75% of peak; no brown-outs!

Model for Energy Changes

- $\Delta E/E < 5\%$ (threshold scans)
  - Linac optics unchanged (minor matching tweaks at end)
  - BDS retuned on standardization curve (knob optimization)
  - Re-calibrate few feedback loops
  - < 1 hour
- $5\% > \Delta E/E > 25\%$
  - Linac optics re-tuned and alignment checked (use by-pass line?)
  - BDS standardized, retuned, and alignment verified
  - Re-calibrate many feedback loops
  - < Few shifts?
- $25\% > \Delta E/E$
  - Linac optics re-tuned with by-pass line and alignment checked
  - BDS standardized, retuned, and alignment verified
  - New final doublet at ~700 GeV in HEIR and ~200 GeV at LEIR

Summary (1)

- RF system components are reasonable extrapolations from present technology
  - Components will be verified in 2002
  - System will be demonstrated in 2003
- Luminosity based on:
  - Low emittance rings similar to operating rings
  - Emittance preservation techniques developed at SLC and FFTB using diagnostics that are reasonable (2~3x better) extrapolations
    - ASSET facility directly verifies long-range wakefield effects
    - Looking at further demonstrations of BBA in SLC linac
  - Beam focusing has been demonstrated at FFTB
    - Very difficult to demonstrate final spot sizes at low energy
  - Stability requirements can be attained however need constant vigilance!

Summary (2)

- Increasing the energy beyond 500 GeV should be straight-forward
  - No parameter changes although small sqrt(2) decrease in the spot sizes implying slightly tighter jitter tolerances
  - RF system designed for 1 TeV from onset
  - Much much smaller extrapolation than that from SLC → 500 GeV!

- Additional options such as higher repetition rate, polarized e+, simultaneous operation at two Irs are not sufficiently explored to quantify