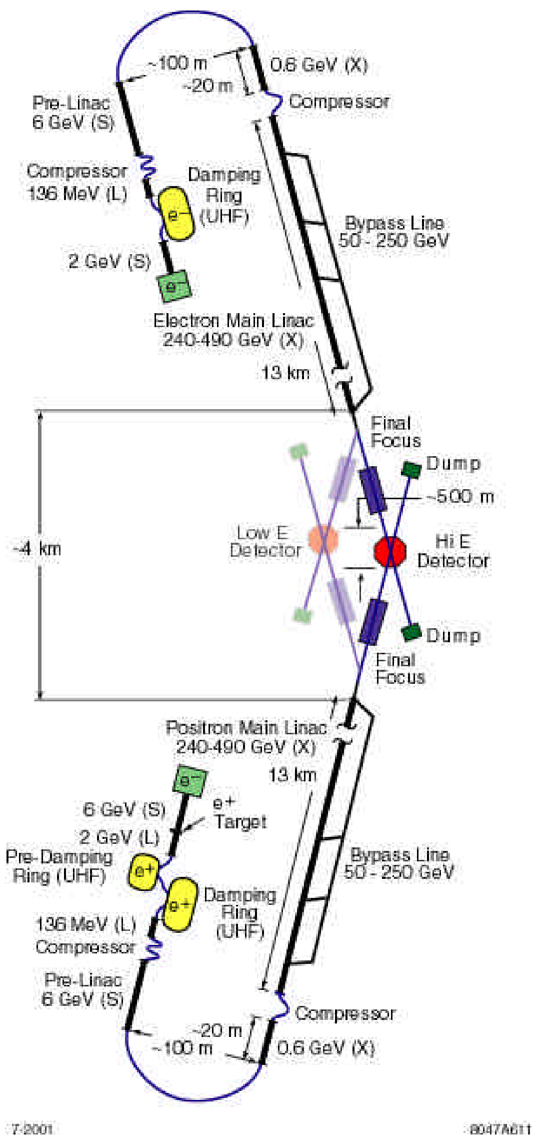
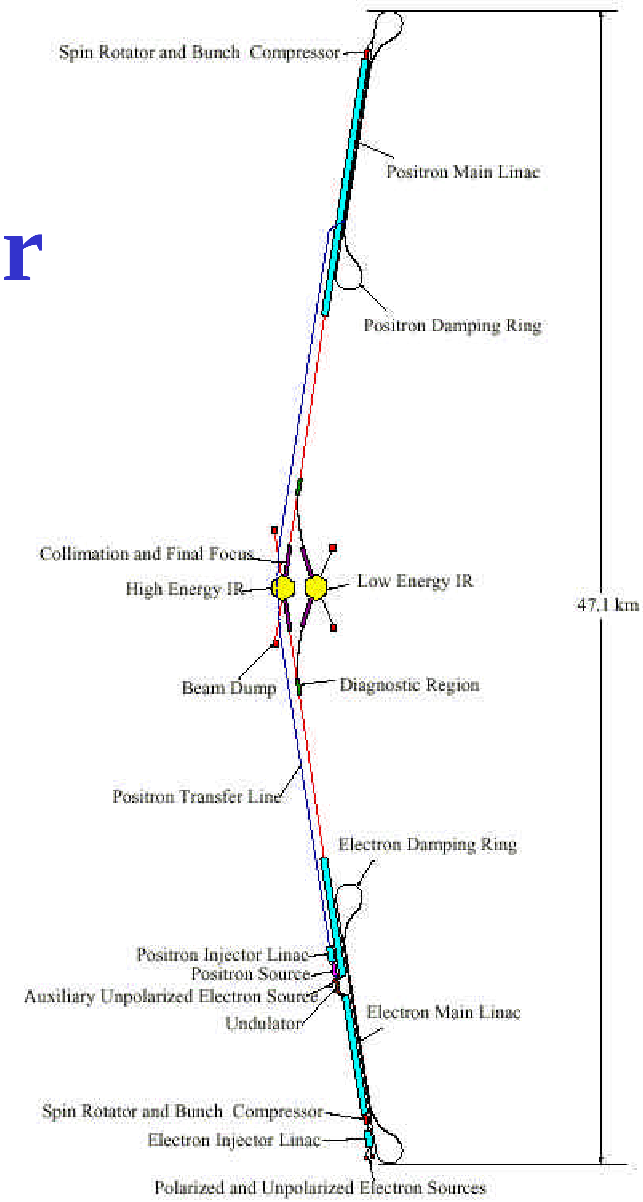


NLC Accelerator Physics

Tor Raubenheimer

SLAC DOE Review

April 10, 2003

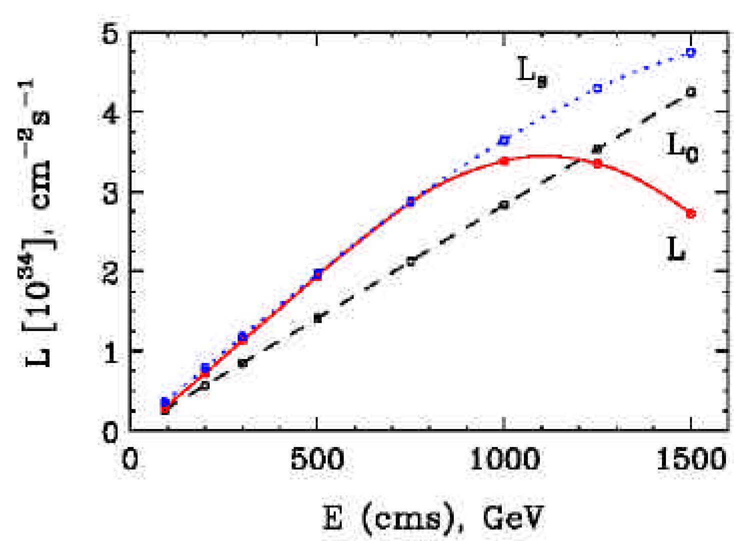


Introduction

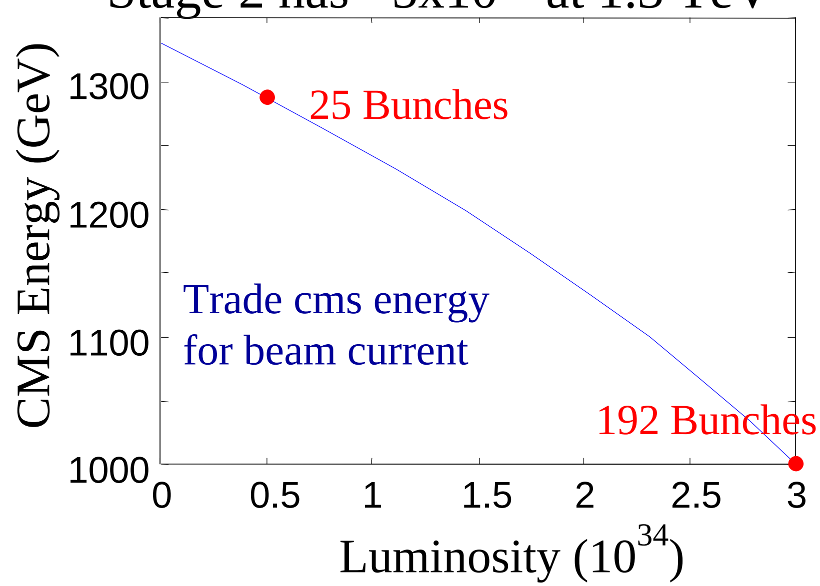
- JLC/NLC Configuration
- US SC LC configuration
- Accelerator physics studies
  - Sources
  - Damping rings
  - Beam delivery
  - Integrated luminosity evaluation
    - Damping ring -> IP -> dump dynamics studies
    - Reliability / availability evaluation
  - Vibration & stabilzation studies

Beam Parameters

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	
ge_y at IP (10^{-8} m-rad)	**4**		**4**	
β_x / β_y at IP (mm)	8 / 0.11		13 / 0.11	
s_x / s_y at IP (nm)	**243 / 3.0**		**219 / 2.1**	
q_x / q_y at IP (nm)	**32 / 28**		**17 / 20**	
σ_z at IP (um)	110		110	
Υave	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)	14.1		28.2	



- Stage 2 has ~$5x10^{33}$ at 1.3 TeV



JLC/NLC RF Configuration

- Baseline RF system has evolved significantly over the last year
  - Moving towards a more conservative design to facilitate a technology comparison

	Modulator	Klystron	RF Pulse Comp.	Structures
May-02	SS 8-Pack	75 MW, 3.2 us	2-mode DLDS	6-90 cm HDS
Aug-02	SS 8-Pack	75 MW, 1.6 us	2-mode SLED-II	6-90 cm HDS
Apr-03	SS 2-Pack	75 MW, 1.6 us	2-mode SLED-II	8-60 cm HDS

  - Will complete demonstration of the TRC R1 (feasibility) items this year and should complete primary R2 item of demonstrating a full rf sub-unit by 2004
  - Details of the RF configuration will be discussed by Chris, Sami, and David

Implications of New Baseline

- Changing the baseline rf pulse comp. system to SLED-II:
  - Faster demonstration of both power source and a full rf sub-unit, i.e. 1, 2, or 4 klystron pairs powering structures
    - Depends on final modulator configuration
  - Doubled number of klystrons, modulators, and PC systems and increased the linac length by 8%
    - Obvious cost impact; perhaps some advantage in reliability
    - Decrease in rf efficiency requires 8% additional linac AC power
  - Decreased unloaded gradient by 7%
    - Reduced breakdown rate
    - Tolerances scale with the square root of the gradient
- Changing from 90 cm to 60 cm HDS structures
  - Faster demonstration of gradient and rf sub-unit
  - Increases the number of klystrons, modulators, and PC systems by ~10% (no change to linac length)

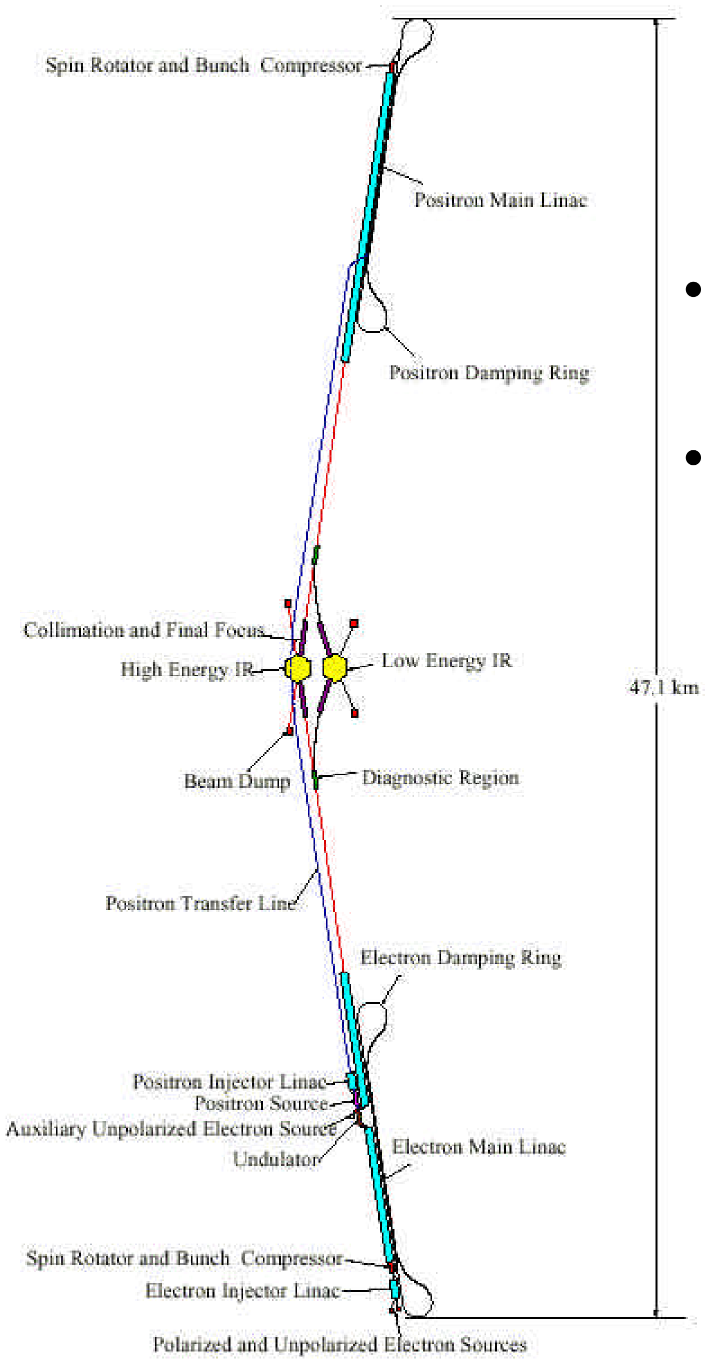
NLC Optical Configuration

- Optics has been relatively stable for last
  - Improved damping ring designs for pre-damping ring and main damping ring
  - Improved e+ yield from conventional source and further investigations of undulator-based polarized source
  - Small changes to linac to follow rf configuration and tunnel schemes
    - Use EM quads from better alignment control and flexibility
  - Many small improvements to beam delivery system design
    - Improvements to collimation system design
    - Request that energy reach of ‘Low Energy IR’ be at least 1.3 TeV
    - Adoption of BNL-style SC final doublet magnets
    - Further dump line studies to improve separation and diagnostics

New baseline design will be documented in report due out in July

US Super-Conducting LC

- Many people from the NLC group are participating in the USLCSG comparison between a warm and cold LC in the US
  - LC specifications from the ALCPG document
- Studies based on existing designs:
  - The warm version will be similar to the JLC/NLC design
  - The cold version will be similar to the TESLA TDR design
- Four working groups (~20 people):
  - Accelerator design: *Gerry Dugan*
  - Site and conventional facilities: *Steve Holmes*
  - Cost and schedule: *David Burke*
  - Reliability/availability: *Tom Himel*
- Complete comparison by September for the USLCSG



US SC LC

- TESLA TDR design was not entirely compatible with US specifications
- Changes to the TDR design:
  - Increase length to support 1 TeV at a *maximum* gradient of 35 MV/m without super-structures
  - Use modified NLC BDS with crossing angle to avoid problems with head-on collisions
  - Modify e+ source to operate at fixed energy and include operational overhead
  - Use TESLA DR concept because we cannot do anything else
  - Consider using two-tunnels for improved reliability / operability
  - Possibly start with 35 MV/m for reduced cost and clearer comparison to X-band

LC Technical Review Committee

Two working groups (plus reliability)

Energy & Technology

Daniel Boussard (Chair)

Chris Adolphsen, SLAC
Hans Braun, CERN
Yong-Ho Chin, KEK
Helen Edwards, FNAL
Kurt Hubner, CERN
Lutz Lilje, DESY
(Pavel Logatchov, BINP)
Ralph Pasquinelli, FNAL
Marc Ross, SLAC
(Tsumoru Shintake, KEK)
Nobu Toge, KEK
Hans Weise, DESY
Perry Wilson, SLAC

Luminosity

Gerald Dugan (Chair)

Ralph Assmann, CERN
Winnie Decking, DESY
Jacques Gareyte, CERN
Witold Kozanecki, Saclay
Kiyoshi Kubo, KEK
Nan Phinney, SLAC
Joe Rogers, Cornell
Daniel Schulte, CERN
Andrei Seryi, SLAC
Ron Settles, MPI
Peter Tenenbaum, SLAC
Nick Walker, DESY
Andy Wolski, LBNL

TRC Energy Conclusions

	JLC/NLC	TESLA	
R1	Test of complete accelerator structure at design gradient with detuning and damping, including study of breakdown and dark current	Building and testing of a cryomodule at 35 MV/m and measurement of dark current	R1
	Demonstration of SLED II pulse compression system at design power level	Test of a complete main linac RF sub-unit (as identified in machine description) with beam	R2
		Testing of several cryomodules at nominal field (23.8 MV/m) over long enough periods to verify breakdown and quench rates, and measure dark current	
R2	Test of a complete main linac RF sub-unit (as identified in machine description) with beam		
	Full test of KEK 75 MW, 1.6 µs PPM klystron at 150 or 120 Hz	Test of RF components at higher powers for 800 GeV operation	
	Full test of SLAC induction mod.		

R1 = required for feasibility; R2 = required for design

TRC Luminosity Conclusions

Common (JLC/NLC and TESLA)

R2 Electron cloud and ion instabilities need study

Additional simulations and experiments on ε correction are needed for damping rings

Demonstrate extraction kicker with better than 0.1% stability

Complete static DR→IP tuning simulations with dynamic effects

Develop most critical beam instrumentation, including intra-train diagnostics

Develop sufficiently detailed prototype of linac girder/cryostat to provide information on vibration

TESLA Only

Further optimization of damping ring dynamic aperture R2

Study tighter alignment and electron cloud and ion instability requirements for 800 GeV upgrade

Development of TESLA DR kicker

Review trade-offs between head-on and crossing-angle collisions

Detailed analysis of the tradeoffs between one and two-tunnel layouts

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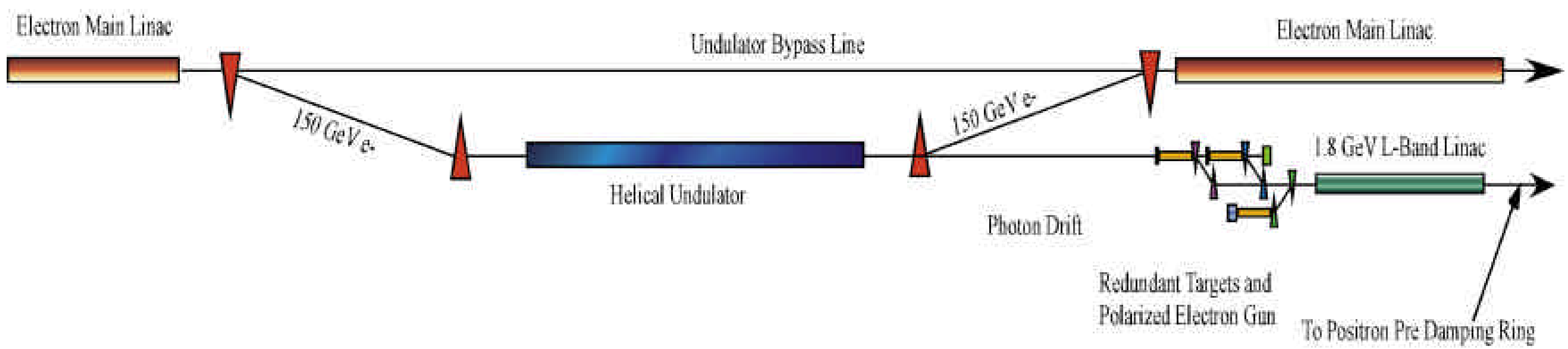
← Detailed evaluation of critical sub-system reliability

Positron Source Studies

- Continuing to study target limitations
- Improved yield in capture system for conventional source
  - 30% now but still looking for an additional 30 ~ 40%
- Designing system for undulator-based source
  - Fixed energy at 150 GeV location (keeps γ energy at ~10 MeV)
  - Polarized e+ with yield of 1.4 requires 200 m helical undulator
  - Total insert length is ~ 900 meters with 2.5 meter X separation
  - We calculate yields 2~3 times lower than in TESLA TDR
  - Conventional source is easier for TESLA than JLC/NLC



Damping Ring Studies

- New positron pre-damping ring with better dynamic aperture
- New main damping ring design with larger momentum compaction
  - Eliminates single bunch instabilities from chamber impedance and CSR
  - Reduces IBS to negligible levels
  - Provides overhead on damping (could be run at 150 Hz for JLC)
- Studying electron cloud impact on positron damping rings and positron beam lines
- Studying ion instability impact on electron damping ring and electron beam lines
- Work at ATF prototype ring at KEK studying beam-based alignment techniques

Why a new Damping Ring Design?

- Previous ring version dates from April 2001
  - Driven by concern over nonlinear dynamics and radiation effects in the wiggler
  - Minimized length of wiggler by using strong dipoles in the arcs (1.2 T)
    - Momentum compaction was very small (0.3×10^{-3})
    - Bunch length was very short (3.7 mm)
  - Problems with collective effects
    - CSR, IBS, µwave…
- Further work suggested neither nonlinear dynamics nor collective radiation effects (CSR) in the wiggler limit the ring
- Developed a new lattice with longer wiggler (40m $\rightarrow$ 60m)
  - Increased momentum compaction by a factor of four
  - Increased bunch length a factor of (nearly) two
  - Reduce charge density, and raise thresholds for collective effects

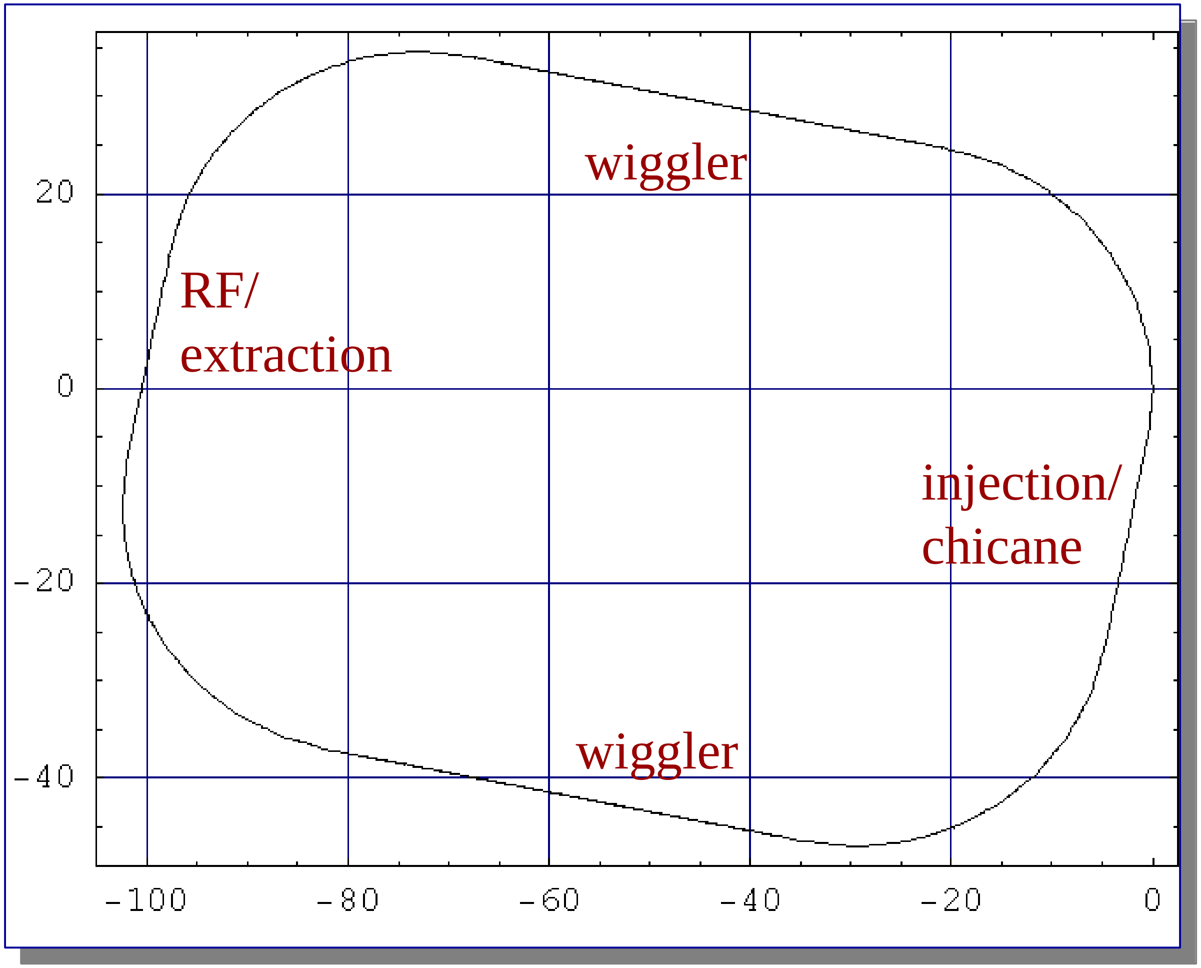
Damping Ring Layout

Same circumference

Longer wiggler

Separated injection and extraction

All the functionality of the old ring with more compact arc cells



Alignment Tolerances

- Compare random alignment and jitter 'tolerances'
  - Uncorrelated misalignments or jitter that would lead to equilibrium emittance, jitter equal to the beam size, or $\Delta\nu = 0.001$
  - These are not specs. on alignment but they are measures of the sensitivity
- Looking for significantly better alignment and stability than has been previously attained

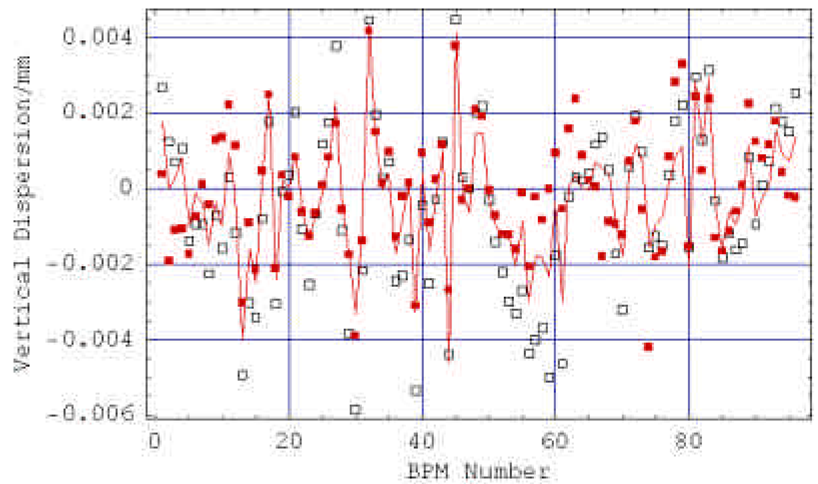
	ALS	APS	SLS	ATF	NLC DR	NLC New DR	TESLA DR
Energy	1.9	7	2.4	1.3	2	2	5
Circ	200	1000	288	140	300	300	17,000
$\gamma\varepsilon_x$ [mm-mrad]	24	34	15	2.8	3	3	8
$\gamma\varepsilon_y$ [nm-rad]	500	140	150	28	13	19	14
Yalign [μm]	135	74	99	87	32	53	11
Roll align [μr]	860	240	530	1475	336	511	42
Yjitter [nm]	850	280	337	320	79	264	80
ΔK/K [0.01%]	1.5	1.4	1.5	2.1	1.8	1.8	1.1

ATF Beam-Based Alignment

- Have been testing beam-based alignment techniques at the ATF prototype damping ring
- Recently tested MIA techniques to correct dispersion
  - First result looked good
  - Second result looked not so good until sign flip was found!
  - Vertical emittance was reduced from 16 pm to 10 pm ($\gamma\varepsilon_y$ = 2.5e-8)
- Working on techniques to correct the coupling

First attempt

RMS reduced from 2.3 mm to 1.6 mm



Second attempt

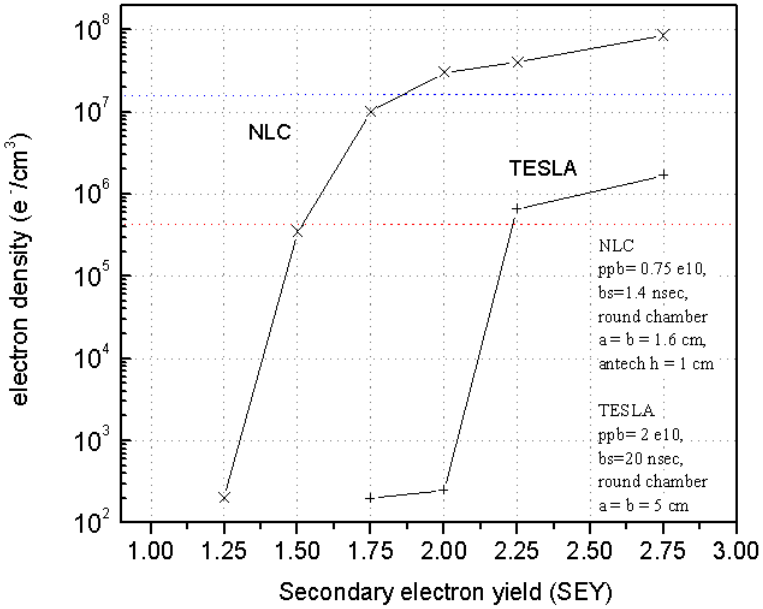
(after using BBA results to steer through sextupoles)

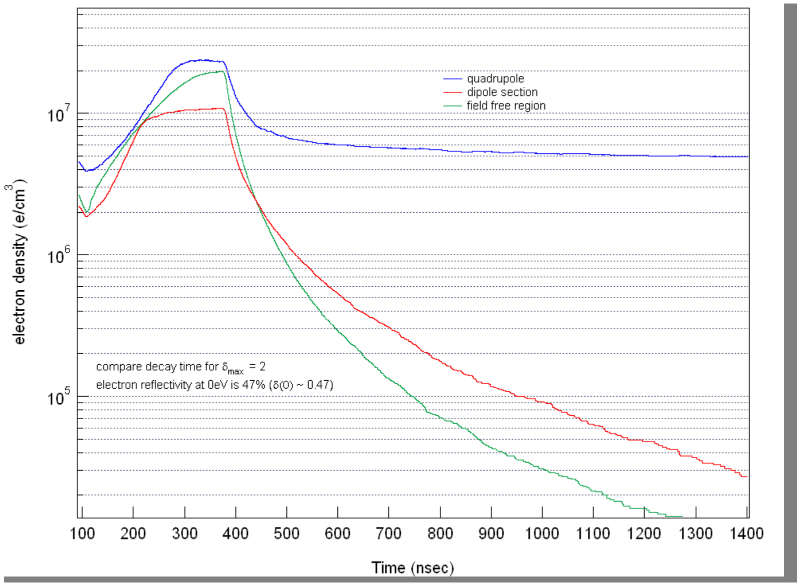
RMS increased from 3.7 mm to 6.5 mm - as predicted!

Electron Cloud Effects

- Neutralization density of electrons too high
  - Single bunch instability ~ 100 μs
  - Multi-bunch instability ~ 20 μs

- Investigating methods of reducing the electron density by three orders of magnitude





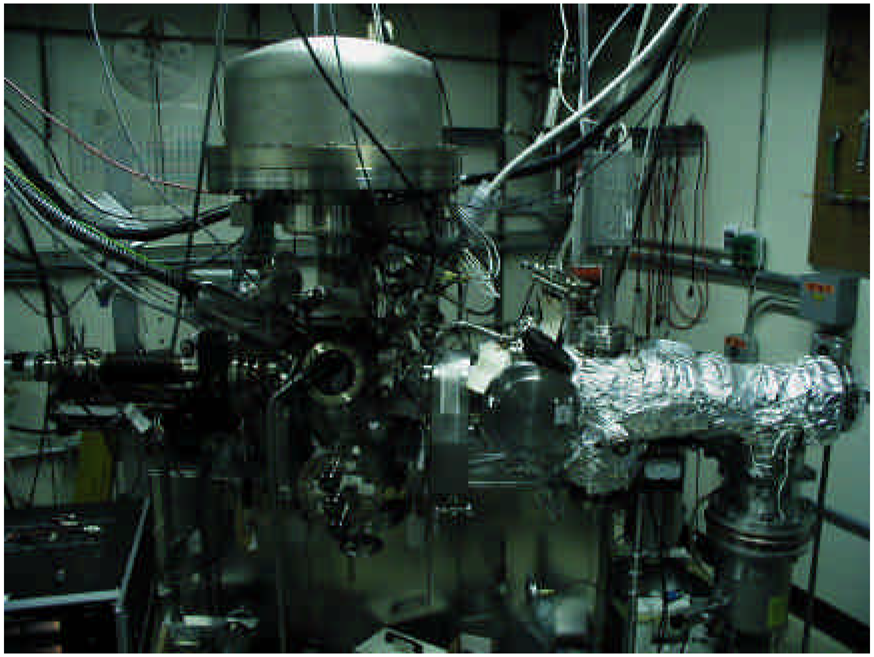
Studying e- cloud in the: straights, bends, quadrupoles, and wigglers

Studying methods of reducing the secondary emission coefficient

Reduction of Secondary Emission

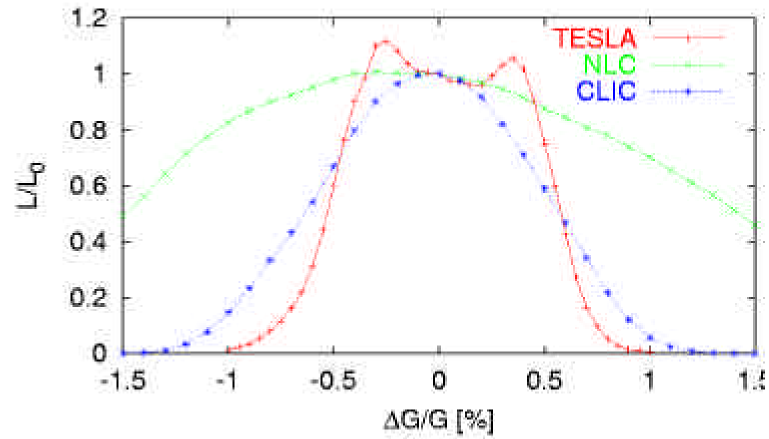
- Would like to reduce SEY to less than 1.4
  - TiN coating but variation in results
  - Surface treatments such as ion bombardment
  - Test other promising materials or techniques (TiZrV, air baking, ...)
  - Need better data on secondary electron spectrum and recombination rates

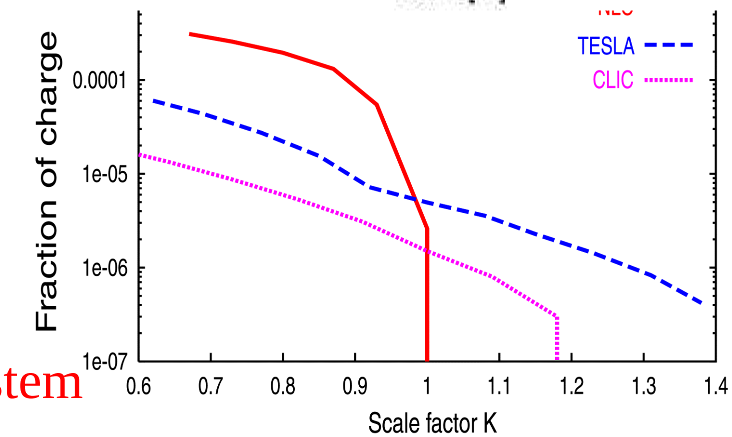
- LBL/SLAC collaboration constructed a new facility for measuring SEY
  - Compare with previous results and improve measurements
  - Verify new techniques
  - Many people interested in testing samples



Beam Delivery System

- NLC beam delivery system is in good shape
  - Starting detailed simulations of backgrounds and and diagnostic performance
  - Simulations performed using MatLIAR, TURTLE, GEANT, and others
- New Raimondi/Seryi FFS design being adopted by all LC's
  - More compact
  - better bandwidth and nonlinear behavior
- Integrated collimation system design is essential for luminosity operation
  - Collimation Task force verified NLC system





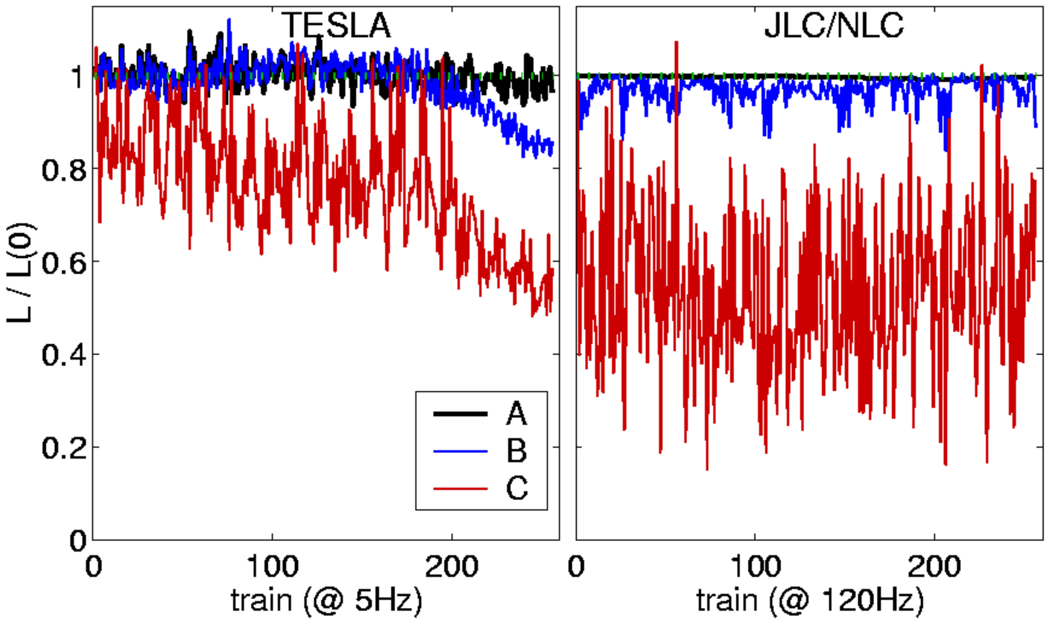
Integrated Luminosity

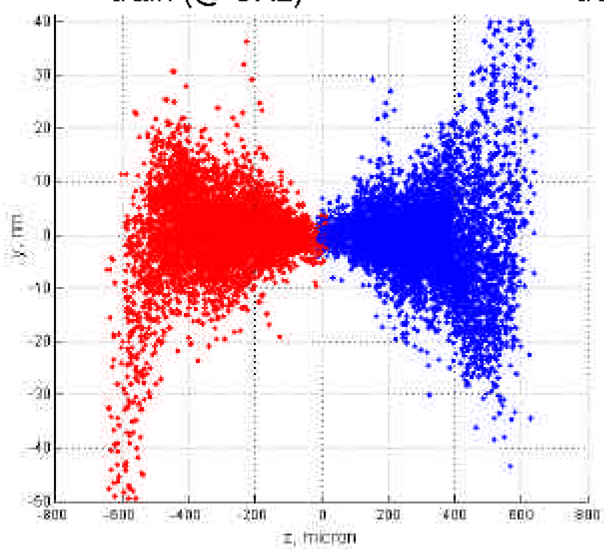
- Primary goal of beam dynamics studies!
  - Huge problem to tackle
- The integrated luminosity consists of three parts:
  - Nominal (peak) luminosity
    - Includes loss due to normal tuning: fast feedbacks, beam jitter, static ε dilutions
  - Beam efficiency
    - Includes trip recovery, invasive tuning time, and machine development
  - Hardware availability
    - Time lost due to inoperable hardware
- Approach from two sides:
  - Detailed studies of beam dynamics to get at the ‘nominal’ luminosity
  - Monte Carlo approach to study requirements on hardware with *best estimates* on recovery and tuning times

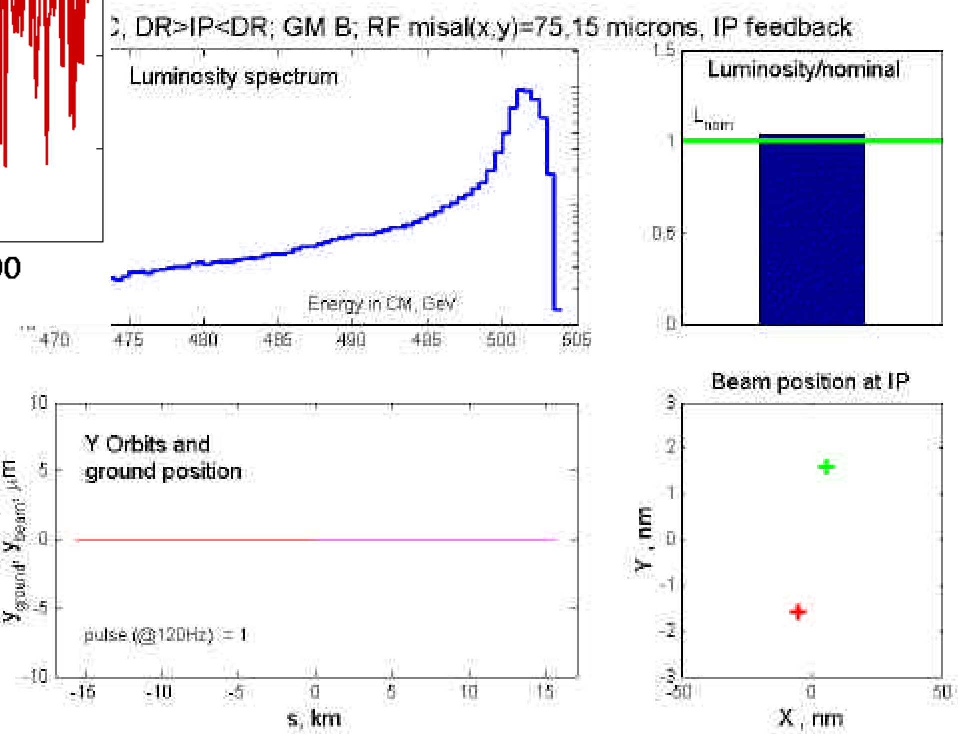
Low Emittance Transport

- LET simulations are performed using the MatLIAR code
  - LIAR to simulate regions with accelerator structures & wakefields
    - Linear optics; longitudinal position is fixed
  - DIMAD to simulate bunch compressors and beam delivery system
    - Many macro particles make this too slow for linac calculations
  - GuineaPig to simulation beam-beam interaction
  - MatLab drives the whole package allowing fast development of correction and feedback algorithms
  - Package was compared against DESY and CERN codes
- Package has been used to:
  - Verify multibunch performance (not very interesting if done right)
  - Study feedback system performance and effect of ‘dynamic’ errors
  - Study ‘static’ alignment procedures
  - Studies combining fast and slow effects are starting

Examples: Dynamic studies







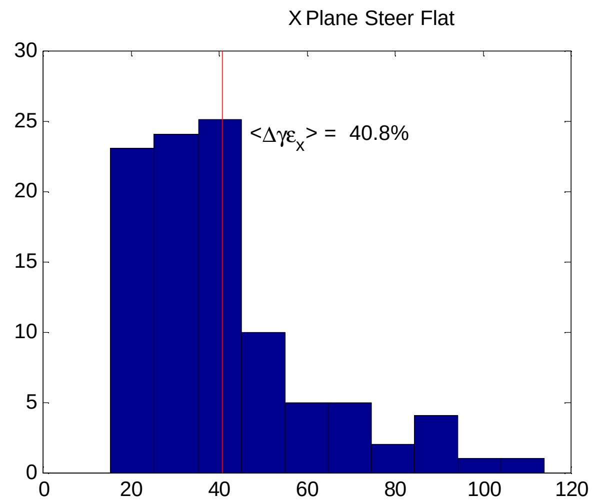
Examples: Static Tuning

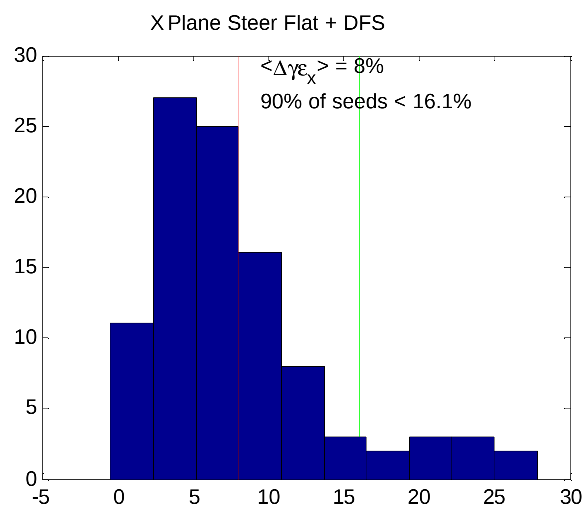
250 GeV linac
plus bypass line

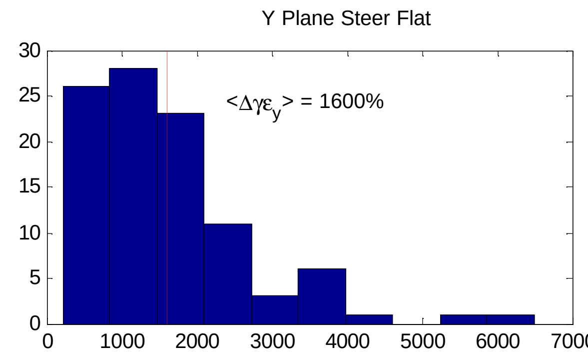
Insensitive to
initial alignment

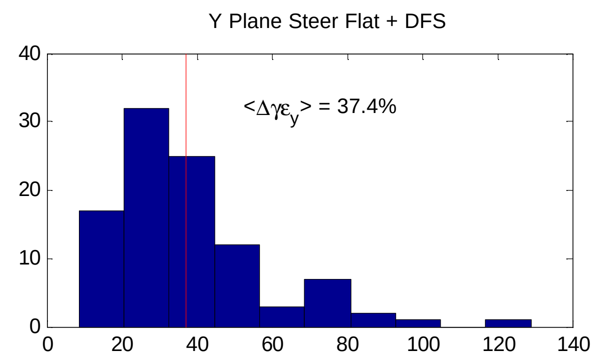
PM quads with
25 μm errors
between quad
and BPM centers
(error arises from

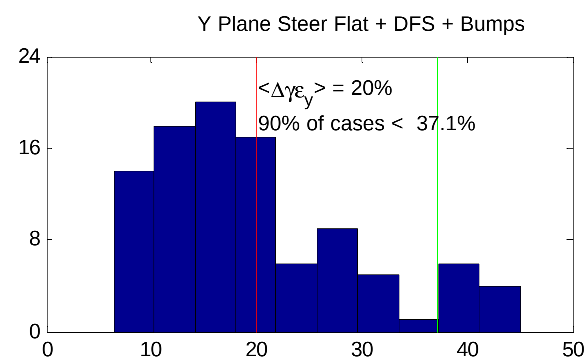
BPMs with 0.4 μm
resolution











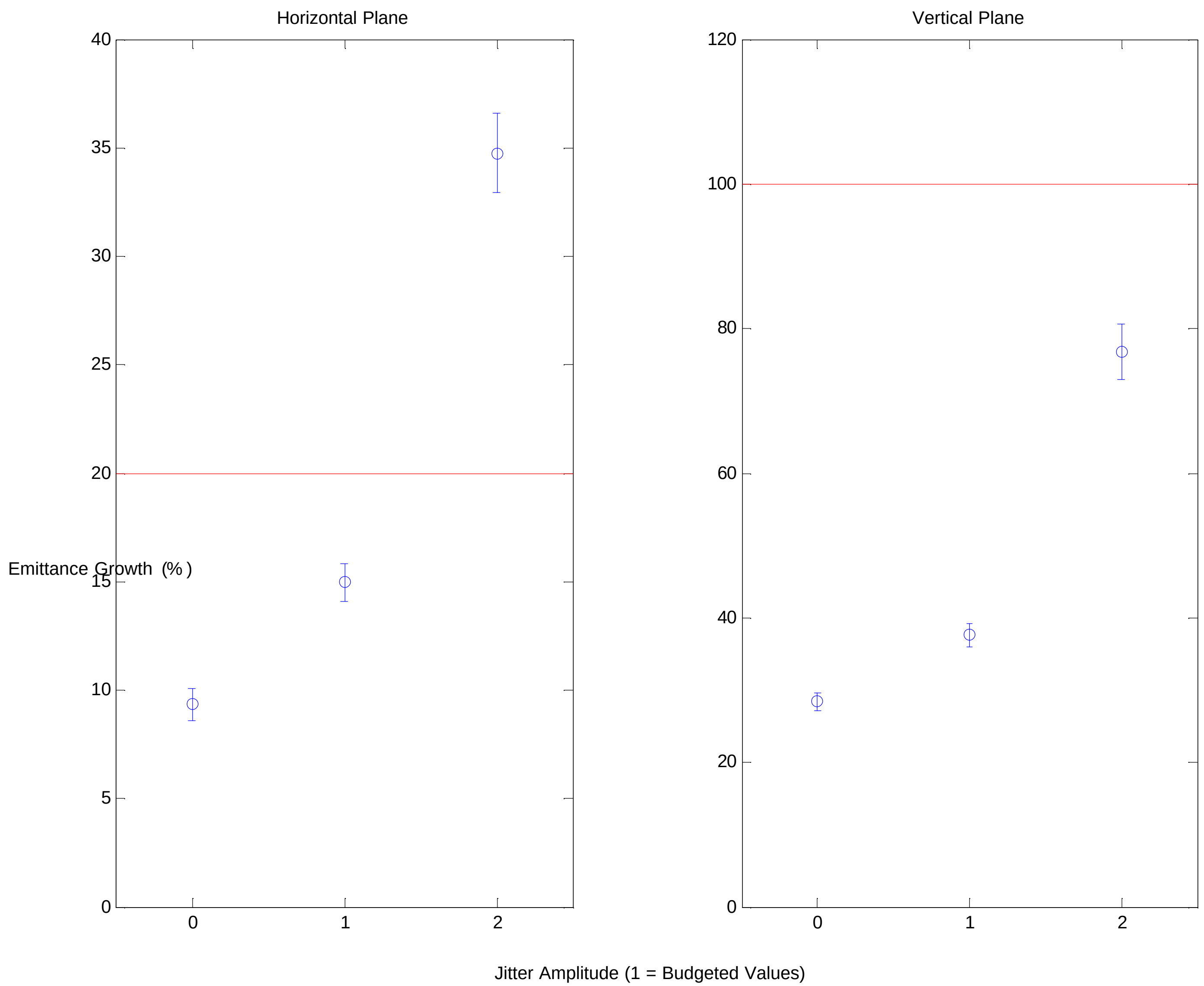
Examples: Static Tuning with Beam Jitter

Beam jitter rapidly degrades alignment algorithm effectiveness

Main limitation is (probably) DFS

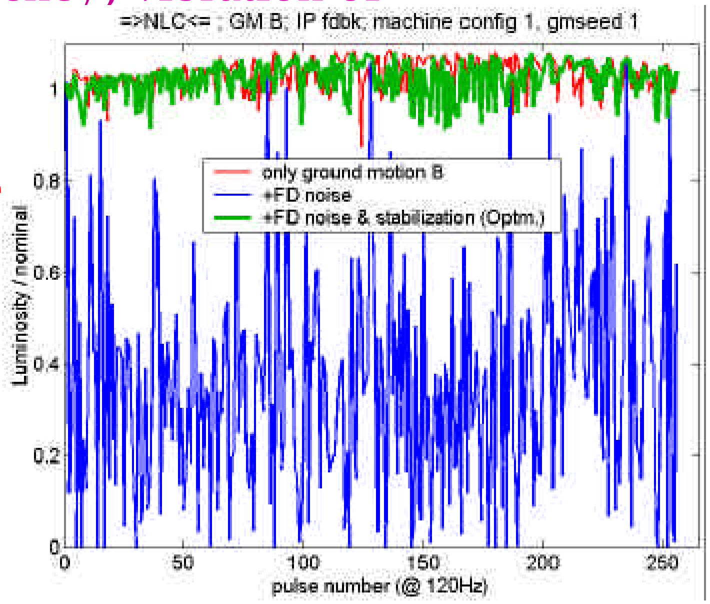
One motivation for reconsidering EM quadrupoles

1600% vertical Δε/ε after steering flat will decrease to about 50%



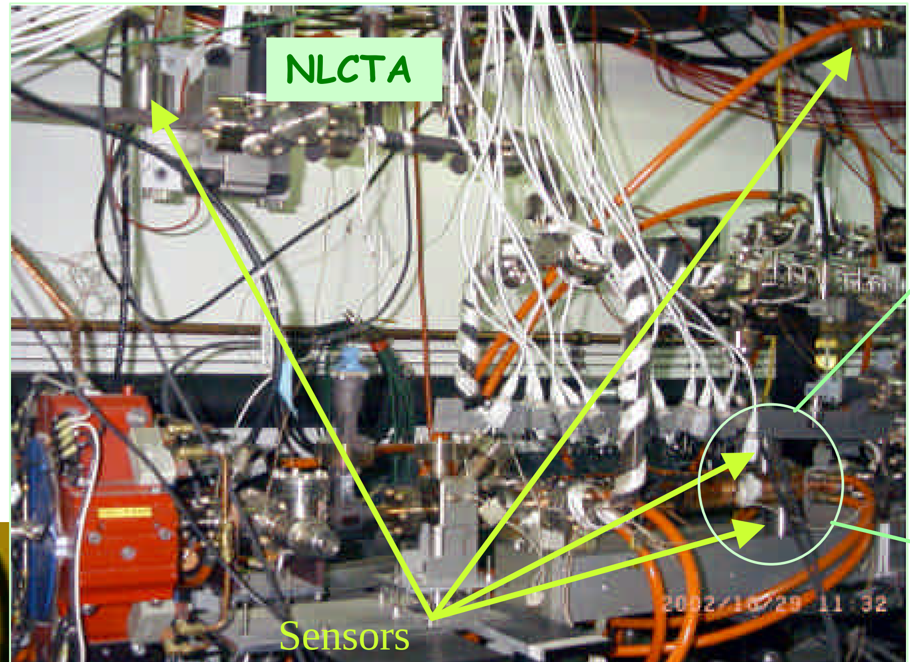
Vibration and Stabilization

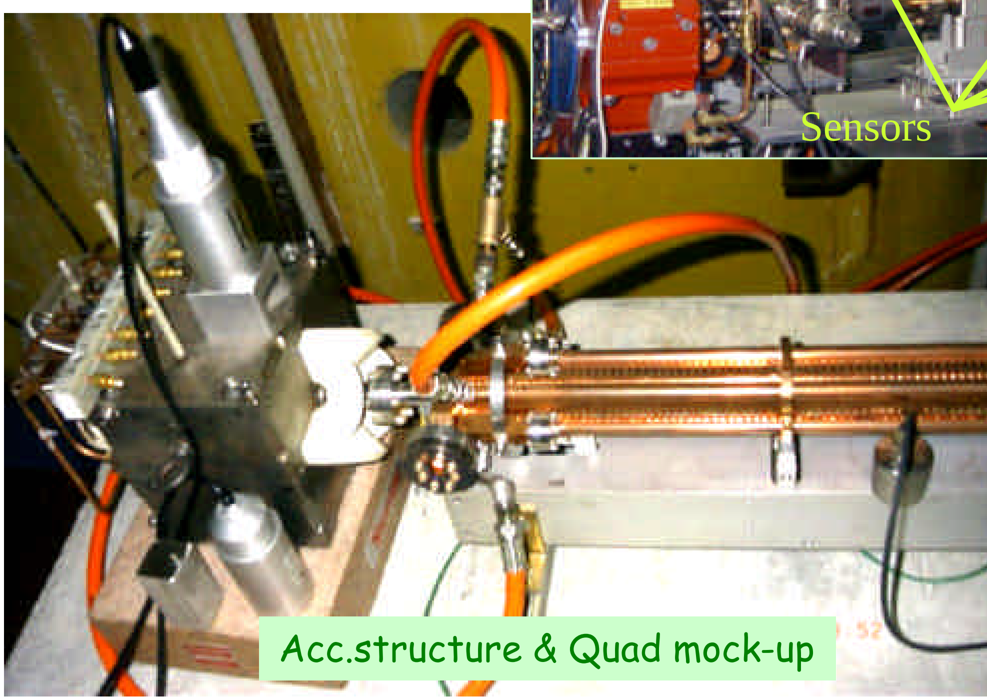
- Development ground motion models based on measurements from around the world
  - Natural motion is not a limitation for operation (even case C, i.e. DESY site) but may limit the ability to tune
- Need to measure/model cultural sources
  - Will likely be much more important than ground motion
  - Presently assume 10 nm random (high frequency) vibration of most quadrupoles with 20 nm vibration of final doublet
  - Working to quantify source of cultural noise
- Need to stabilize the final doublet in almost any scenario
  - Demonstrated stabilization of rigid block
  - Moving to stabilize and extended object



Cultural Noise Sources

Study of vibration of accelerating structures due to
- RF pulse
- Cooling water





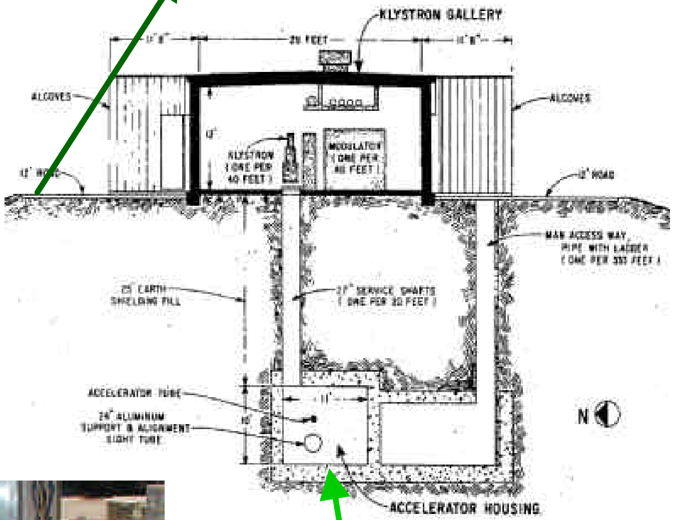
- Experiment shows that additional vibration of structures is acceptable
- Vibration coupling to linac quads is small. Design optimization is ongoing to make it negligible
- Vibration due to RF pulse is negligible

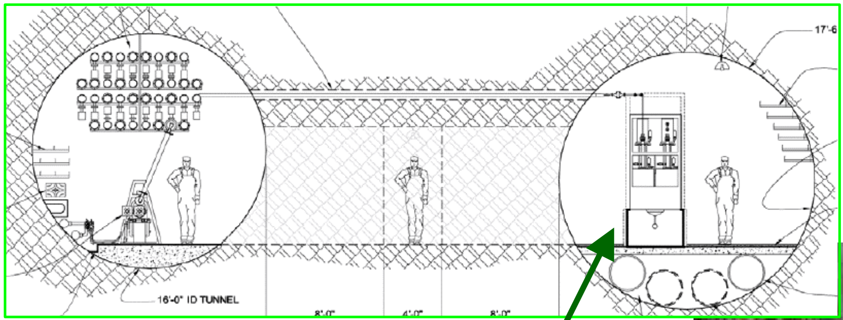
Cultural Noise Propagation

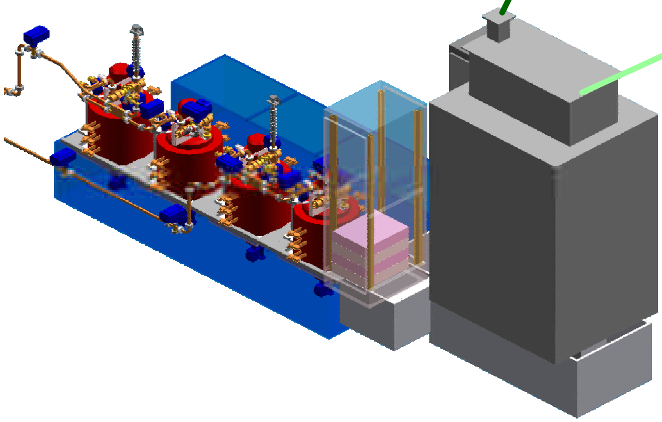
Studied vibration transfer from surface to SLAC tunnel

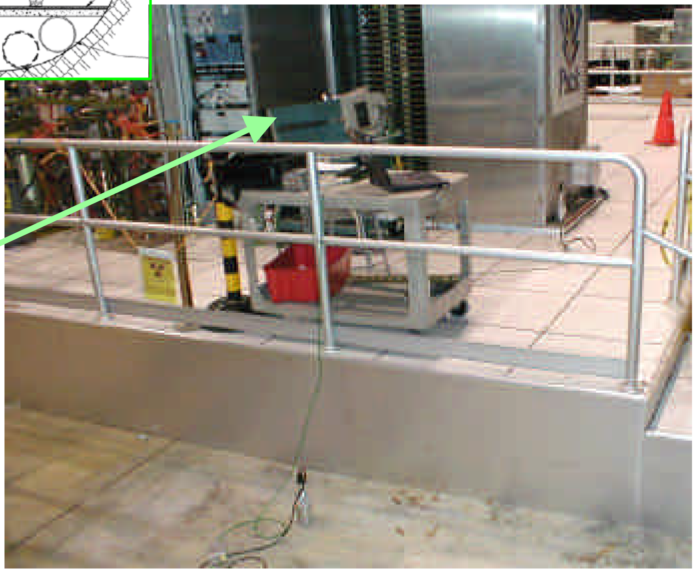
Preparing to study vibration transfer between parallel tunnels (using LA metro lines)

Made first studies of modulator vibration signatures







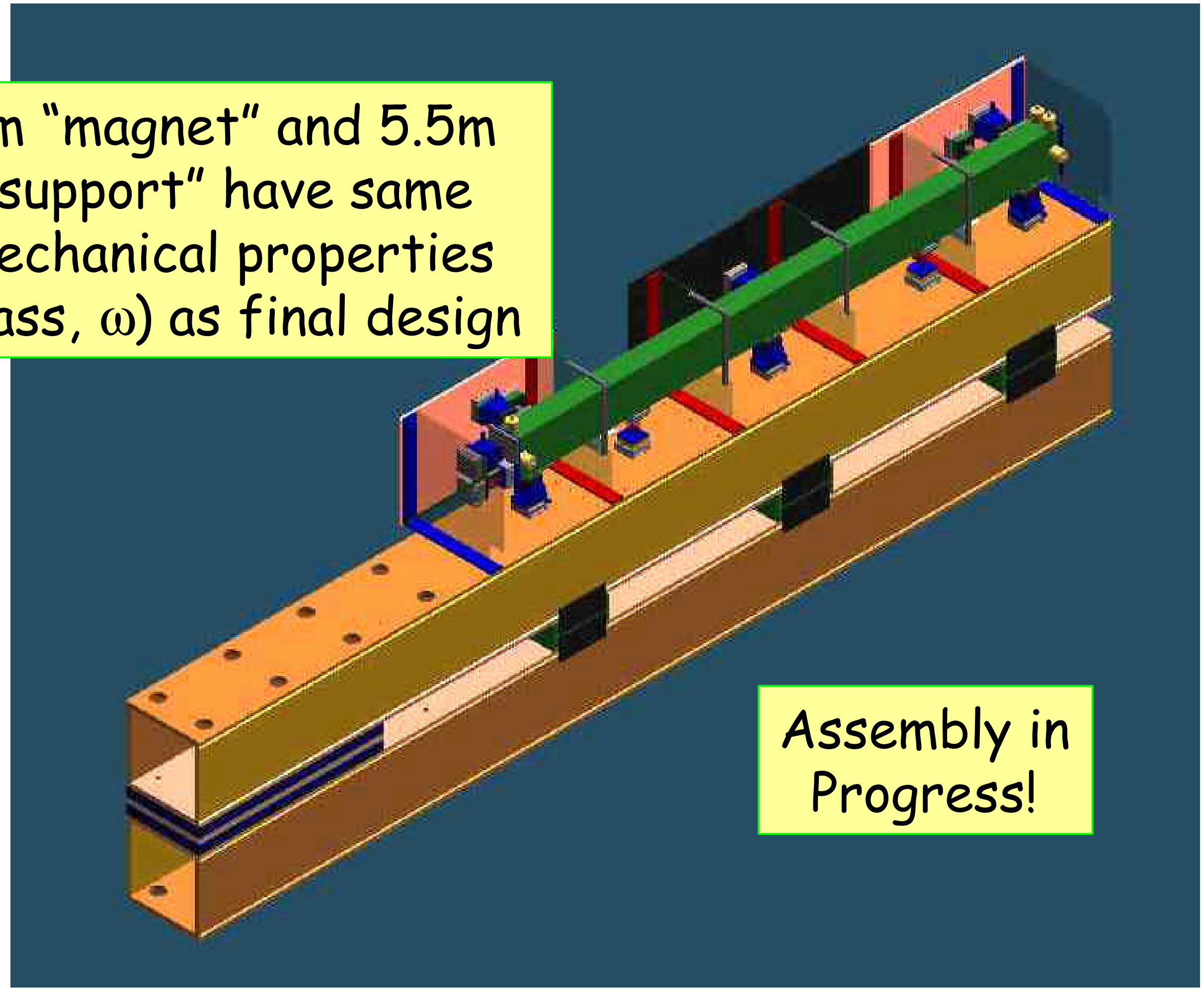


Final Doublet Stabilization

Study internal modes and stiffness in a semi-realistic system

Springs & Stages

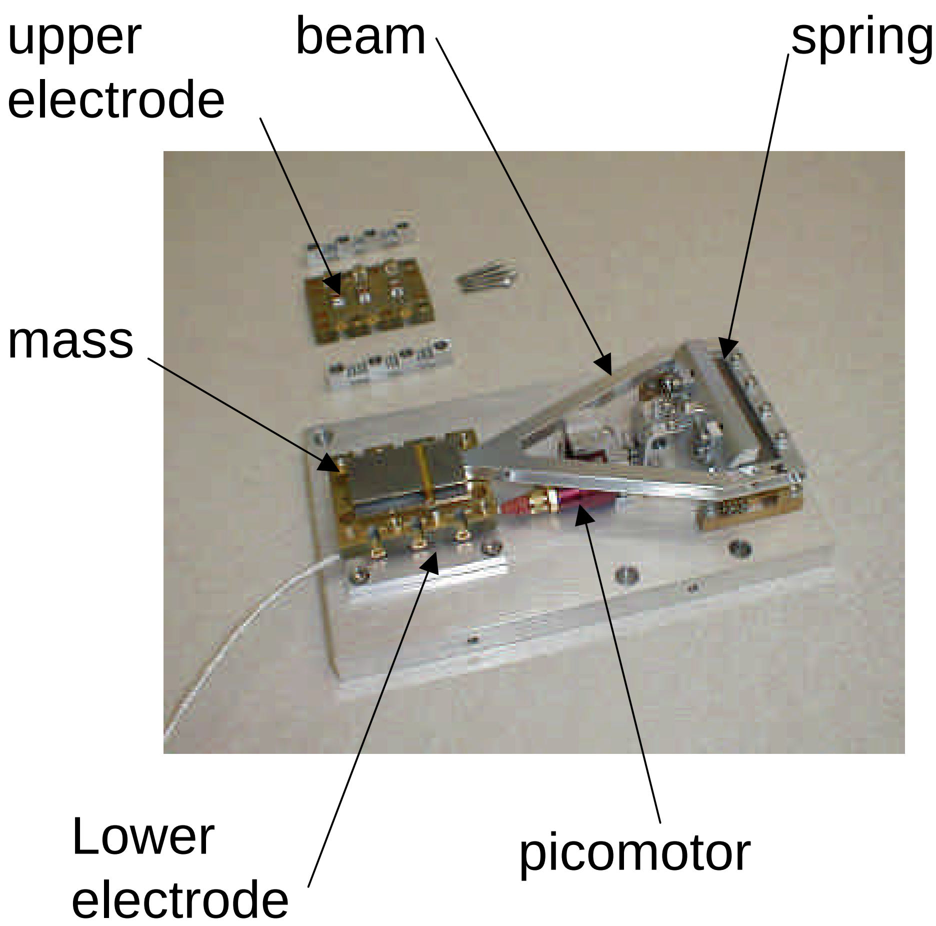
3m "magnet" and 5.5m "support" have same mechanical properties (mass, ω) as final design

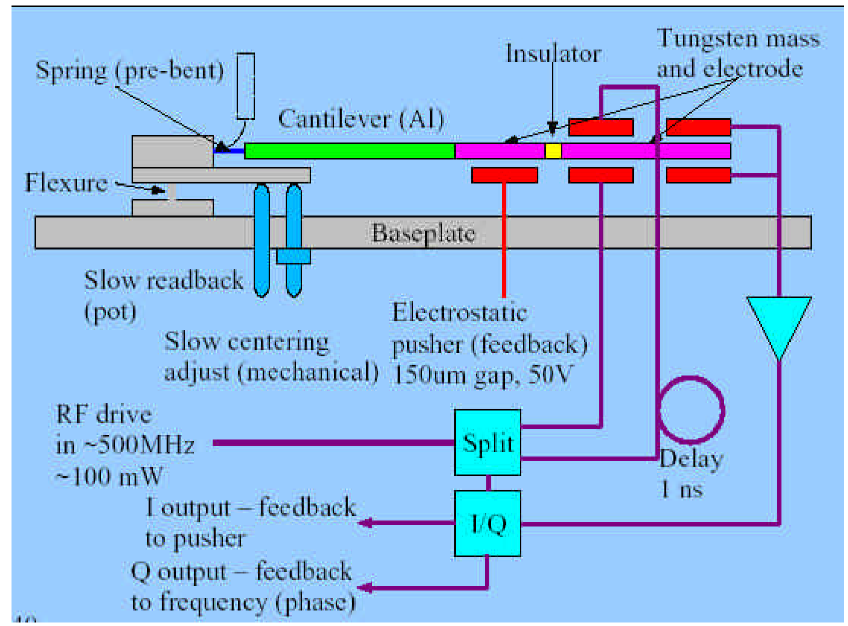


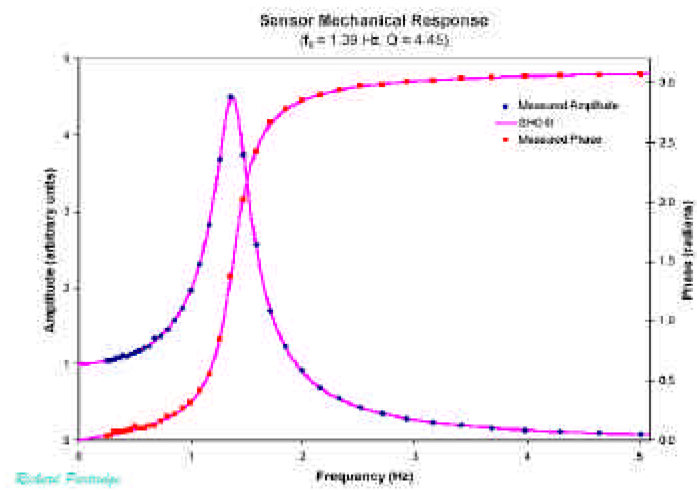
Assembly in Progress!

Support & Cantilevered Beams

Compact Low Noise Sensors







Two prototypes under test; 10 planned

Summary

- JLC/NLC rf system is making great progress
  - JLC/NLC is designed with an energy reach from 90 GeV to 1.3 TeV
- NLC optical design is in good shape
- Luminosity issues are still a large concern
  - Damping rings are essential for stable operation
    - Lots of potential problems
  - Both linear collider designs require complicated BBA procedures
    - FFTB and SLC developed instrumentation and techniques necessary for beam-based alignment – nobody can do a full demonstration
  - Evaluation of integrated luminosity is very difficult
    - Tools being developed to approach problem from two sides
- Either a SuperConducting or JLC/NLC collider could be built
  - Different risks and different connections to the future
  - Tools developed for JLC/NLC will be essential in either case