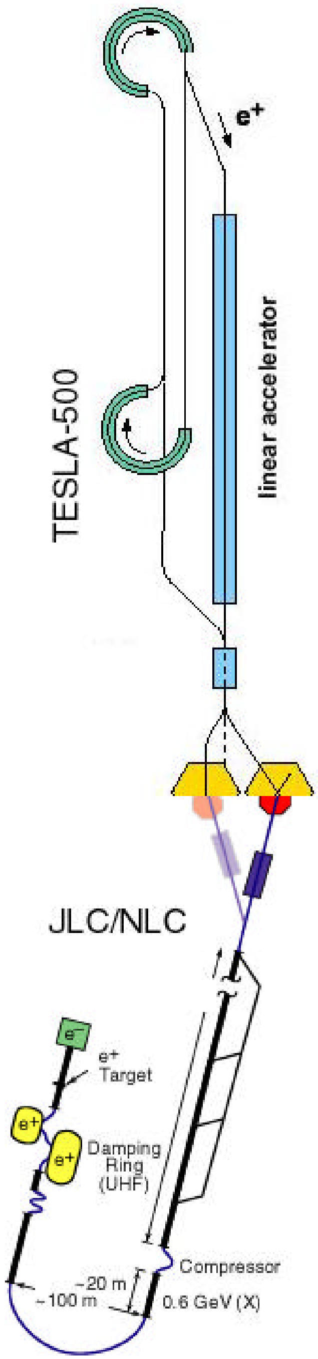


TESLA Status
(A Biased Opinion)

Tor Raubenheimer

Nan Phinney

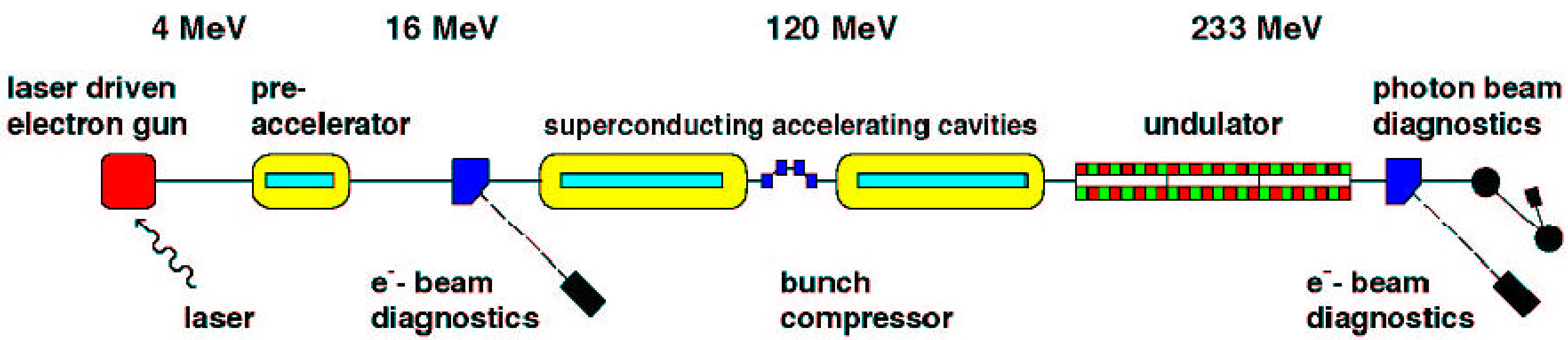
Generated from information exchanged at
Snowmass 2001

Outline

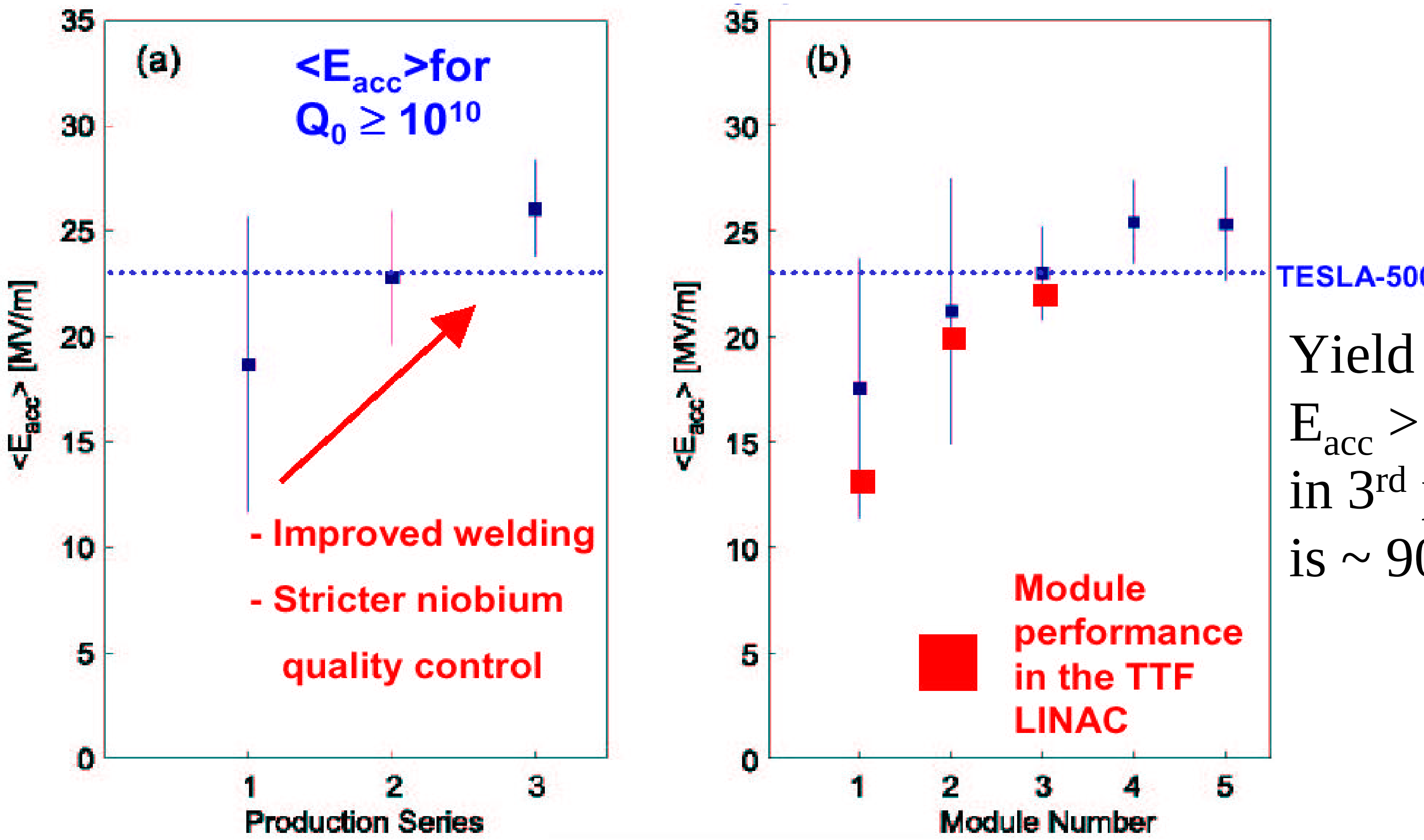
- RF systems
  - Cavities, klystrons, and TTF operation
- Luminosity issues
  - Parameters
  - Damping rings and sources
  - Main linac dynamics and alignment
  - Beam delivery systems
  - IP issues
- TESLA could be built without question
- Point out issues that should be considered for technical comparison and correct some mis-information

TESLA Test Facility

- Operating since 1997
  - 7000 hrs at ~1Hz and ½ length rf pulses with two 8-cavity modules
  - Delivering beam for SASE FEL
    - Good for operational discipline– bad for machine development!
    - 17 MV/m typical gradient
  - Some dedicated TESLA-type operation
    - Measured HOMs
    - Demonstrated beam loading compensation
    - Gradients up to 23 MV/m (TESLA-500 goal) with single module operation (10's of hours at low rate)

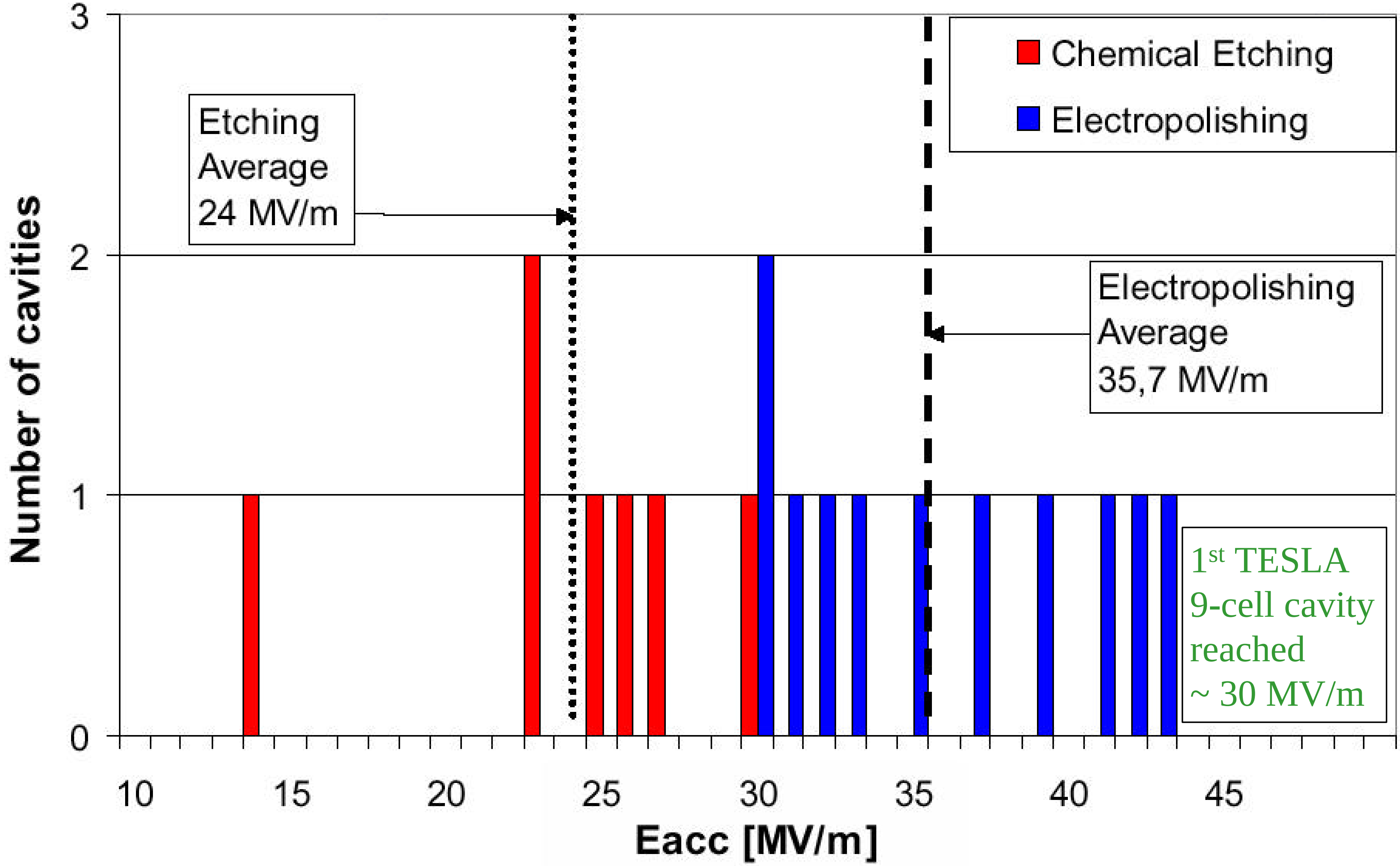


Gradient Achievement!



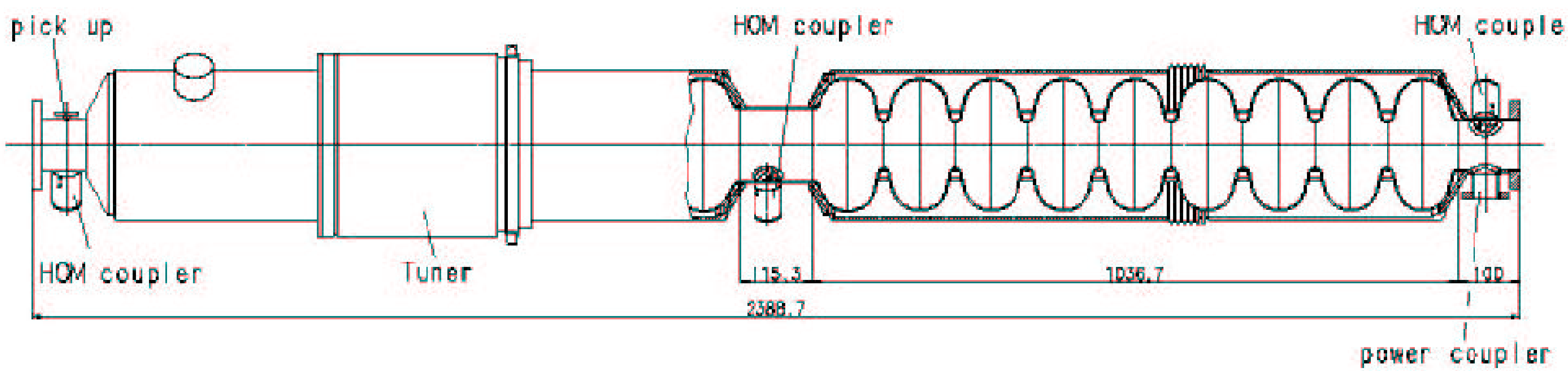
Yield with E_{acc} > 23 MV/m in 3rd production is ~ 90%

Electropolishing versus Etching



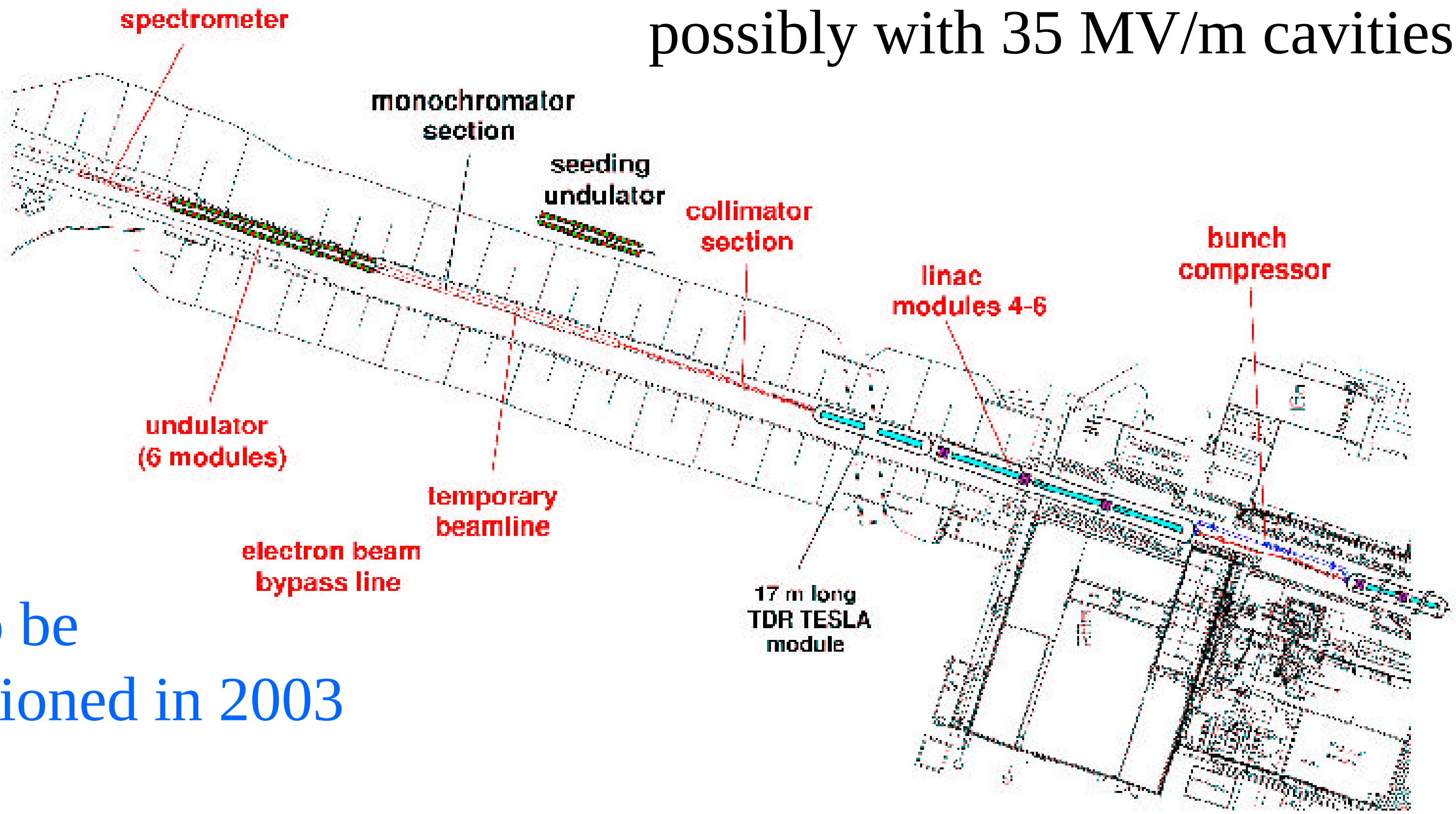
Super-Structures

- Super-structure will increase filling factor from 74% to 79%
  - TESLA-500 gradient would be 22 MV/m
  - TESLA-800 gradient would be 35 MV/m
- Super-structures reduce number of couplers by 50% and HOM couplers by 25%
- 2x7 super-structure to be tested next year and 2x9 later?
- Designing new couplers for super-structures



RF System Tests

- Test superstructure concept with 2x7 cavities in 2002
- Build 2 more 8-cavity cryo-modules for TTF-2 (6 total)
- Build one 17m 12-cavity TDR-style module in ~ 2004 possibly with 35 MV/m cavities



TTF-2 to be commissioned in 2003

Upgrade Routes and Costs

- NLC and TESLA costs are similar in value for 500 GeV
- Baseline upgrade route: install 35 MV/m cavities at onset, double rf system, upgrade cryo plant
- Assuming initial installation of 35 MV/m cavities, cost to upgrade to 800 GeV cms is 20% of initial project cost
- Upgrade from 800 GeV to 1 TeV is another 25% for a total of 45% of the initial project cost
- If cavities also have to be replaced, then the upgrad cost would be roughly 85% of the initial cost

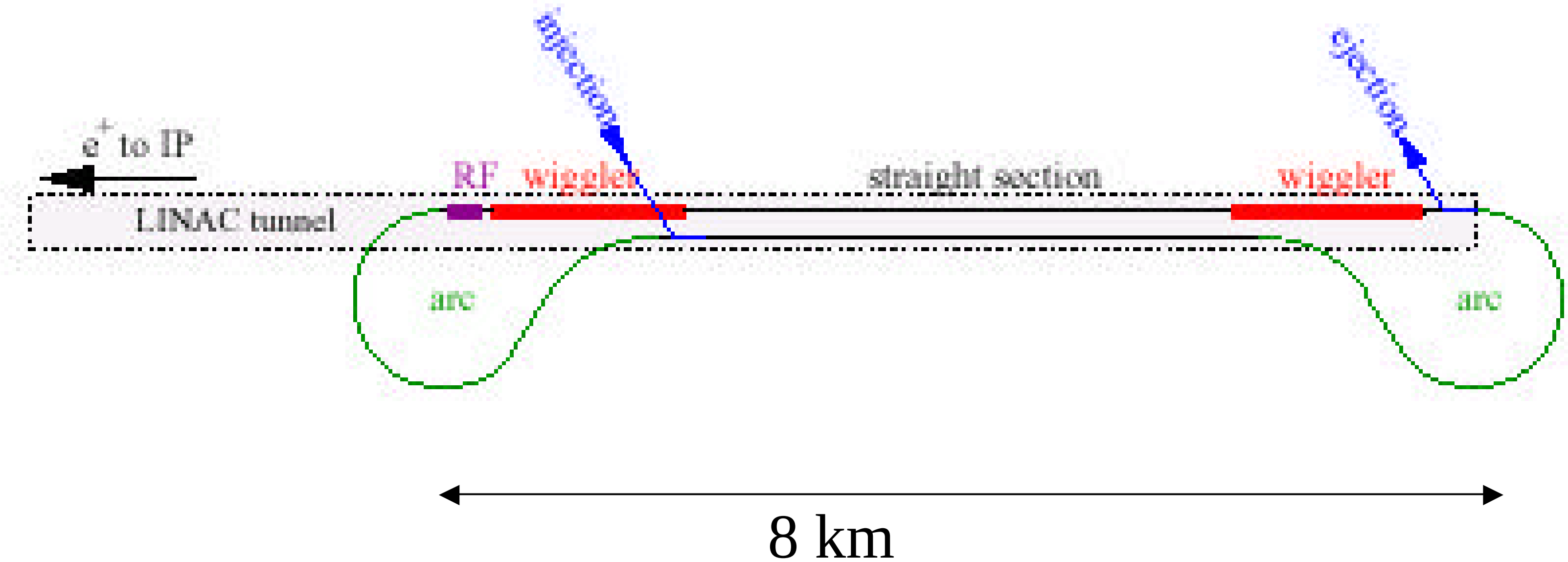
Nominal Parameters

NLC and TESLA Parameters				
	Stage 1		Stage 2	
	NLC	TESLA	NLC	TESLA
CMS Energy (GeV)	500	500	1000	800
Luminosity (10^{33})	**20**	**34**	**34**	**58**
Repetition Rate (Hz)	120	5	120	4
Bunch Charge (10^{10})	**0.75**	**2**	**0.75**	**1.4**
Bunches/RF Pulse	190	2820	190	4886
Bunch Separation (ns)	1.4	337	1.4	176
Eff. Gradient (MV/m)	**50.2**	**23.4**	**50.2**	**35**
Injected $\gamma\varepsilon_x$ / $\gamma\varepsilon_y$ (10^{-8})	300 / 2	1000 / 2	300 / 2	800 / 1
$\gamma\varepsilon_x$ at IP (10^{-8} m-rad)	360	1000	360	800
ge_y at IP (10^{-8} m-rad)	**3.5**	**3**	**3.5**	**1.5**
β_x / β_y at IP (mm)	8 / 0.10	15 / 0.4	10 / 0.12	10 / 0.12
s_x / s_y at IP (nm)	**245 / 2.7**	**553 / 5**	**190 / 2.1**	**391 / 2.8**
σ_z at IP (um)	110	300	110	300
Υ_{ave}	0.11		0.29	
Pinch Enhancement	1.43	2.1	1.49	2.1
Beamstrahlung δB (%)	4.7	3.2	10.2	4.3
Photons per e+/e-	1.2	2	1.3	2??
Linac Length (km)	6.3	30	12.8	30

- Most TESLA studies performed with 500 GeV parameters
- 800 GeV parameters require improved damping ring performance and smaller IP emittances

Damping Rings

- Generate beams needed for collision
  - Stability and emittance performance is essential!
  - TESLA ring is enormous because of long bunch train
  - Every bunch is extracted individually
  - Bunch separation of 25 ns requires fast stable kicker system



Damping Rings

	NLC/JLC	ATF	ALS	**TESLA**	LEP
circumference / m	**300**	140	200	**17,000**	26,000
energy / GeV	**2**	1.3	1.9	**5**	46
emittance ε_x / nm	**0.56**	1.4	5.6	**0.9**	-
ratio $\varepsilon_y / \varepsilon_x$ / %	**0.5**	1 – 3 (0.5?)	0.5 – 3	**0.2**	0.5
damping time / ms	**5**	12 (no wigg.)	15	**28**	26
wiggler length / m	**45**	8	6?	**400**	
space charge ΔQ	**0.05**	~0.02		**0.23 → 0.04 (x-y bump)**	0.2 (4 IP)

Damping Rings and Sources

- TESLA positron production using novel system
  - Production efficiency depends on beam energy (only factor of 2 at 500 GeV cms and factor of 1 at 320 GeV cms)
  - Much lower yield between 200 and 300 GeV cms
  - Very interesting system but no plans to test

- TESLA has very novel damping rings with new dynamical issues:
  - 400~500 meters of wiggler
  - large incoherent space charge requiring coupling bumps
  - Ion trapping in straight sections and possible electron-cloud effects
  - DESY site has vertical bending to follow earth's curvature -- spin precession may drive imperfection and intrinsic spin resonances

Linac Dynamics

- Two separate issues: Beam BreakUp (BBU) and ‘static’ alignment or emittance dilutions
  - BBU quasi-exponential amplification of incoming trajectory errors
    - Well understood and well simulated!
    - Multi-bunch BBU seen in 60’s in SLAC linac
    - Single bunch BBU solved in SLC in mid-80’s
    - Need to measure/model wakefields
  - Quasi-static emittance dilutions
    - Cavity alignment
    - Magnet alignment
    - Rf deflections
    - Stray fields
    - Use beam-based alignment!
    - Techniques developed and tested at SLC, FFTB, ASSET, and elsewhere!

Wakefield Summary

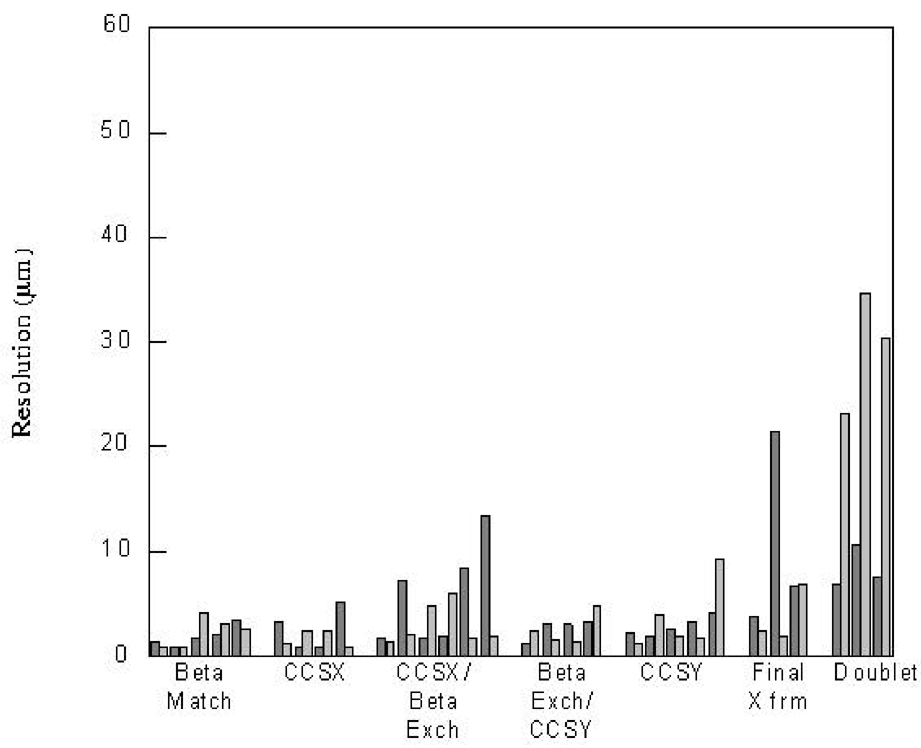
- Wakefields have been measured in the TTF and the ASSET facility at SLAC using beam
  - Both wakefields are larger than design although sufficient
    - NLC errors were due to known construction errors
    - TESLA cavity errors were due to calculation errors
  - Both cases are not ‘final’ prototype cavities
    - Final prototypes available in 2003 for NLC and 2004? For TESLA
  - Devil is in the details!
- NLC aims to measure ‘final’ cavity prototype in 1.5 yrs
  - Must develop high gradient structure with low group velocity and wakefield control
- TESLA will choose between 2x9 superstructure and present single cavity design
  - 2x7 superstructure to be tested next year and 2x9 to follow

Beam-Based Alignment (ε Tuning)

- To preserve emittance must correct **net** effect of individual dilution sources
- 'Local' correction - directly correct dilution sources
  - Beam-based alignment – tested SLC; FFTB; other beam lines
  - 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 – tested in SLC; LEP; other rings
  - Based on 'measurements' of dilution / sensitive to systematics
- 'Global' correction - tune emittance using direct ε diagnostics
  - Directly corrects desired quantity / sensitive to phase advance – tested SLC

FFTB Quadrupole Alignment

- Used quadrupole shunting technique
  - Fit residuals ranged from 2 µm to 30 µm at the end of the beam line
    - FFTB optics poorly designed for beam-based alignment
    - Ran out of BPMs to measure deflected trajectory!
  - Dispersion measurements show errors in 1st two regions < 7 µm after alignment
    - Confirms technique
  - NLC designed for BBA with better diagnostics and smoother optics
    - Would expect a factor of 2 ~ 3 improvement
    - Other techniques as backup



Rf Cavity Alignment

- NLC structures (cavities) must be aligned to beam within 10 µm rms for 20% Δε
  - Every structure has two rf-BPMs with better than 2 µm accuracy
  - Short-range wakefields depend on average of structure offset
  - Average position of the 6 structures on an rf girder and move girder end-points with remotely controlled movers
- TESLA cavities must be aligned with 500 µm rms for 15% Δε
  - Achieved +/- 250 µm alignment within cryostat
  - But effects add → tolerance for 12 cavities in cryostat ~ 140 µm
  - Effect is worst at ¼λ_β = 150 m → tolerance for cryostats ~ 45 µm
  - Either add read-backs on HOM dampers and steer beam to center of cavities or use global emittance bumps like those used in SLC to cancel dilutions
  - RF deflections imposes 100 urad tolerance on cavities for 5% Δε

Other Issues

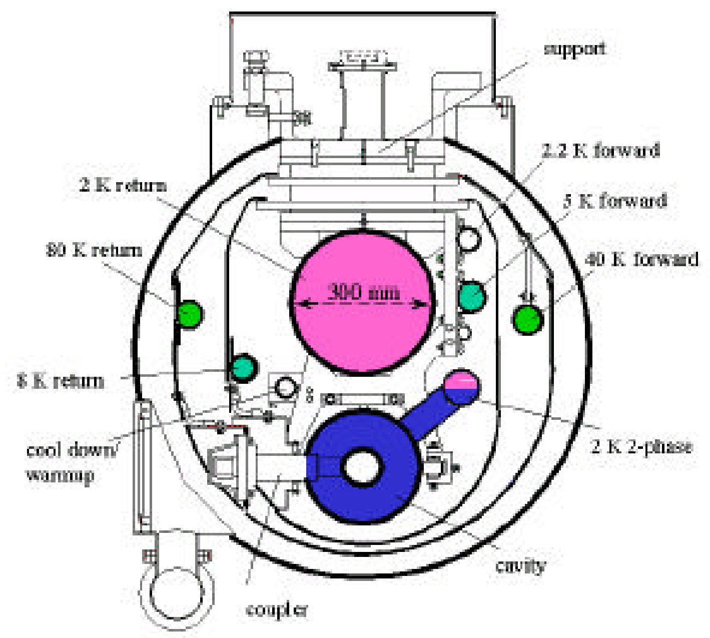
- TTF cannot measure effects like rf deflections or coupler asymmetries at the relevant level

- Main couplers are not a symmetric design - some question about observations at TTF with regard to ‘rf kicks’
- Rf kicks also arise from misaligned cavities as noted

- Skew fields from couplers was a significant effect in CEBAF linac (added many skew quads along linac) but this was not discussed

Alignment Summary?

- TESLA cavities and quadrupoles are ‘hung’ off the Gas Return Pipe (pink)
- GRP is attached to the cryostat at 3 points
  - Each end moves by 26 mm during cool-down
  - Invar pole is used to maintain longitudinal position of cavities
- Cavities and quads are aligned with respect to GRP
- Module is aligned using 3 points referenced to GRP
- Linac is aligned using move-able tachymeter to +/- 200um

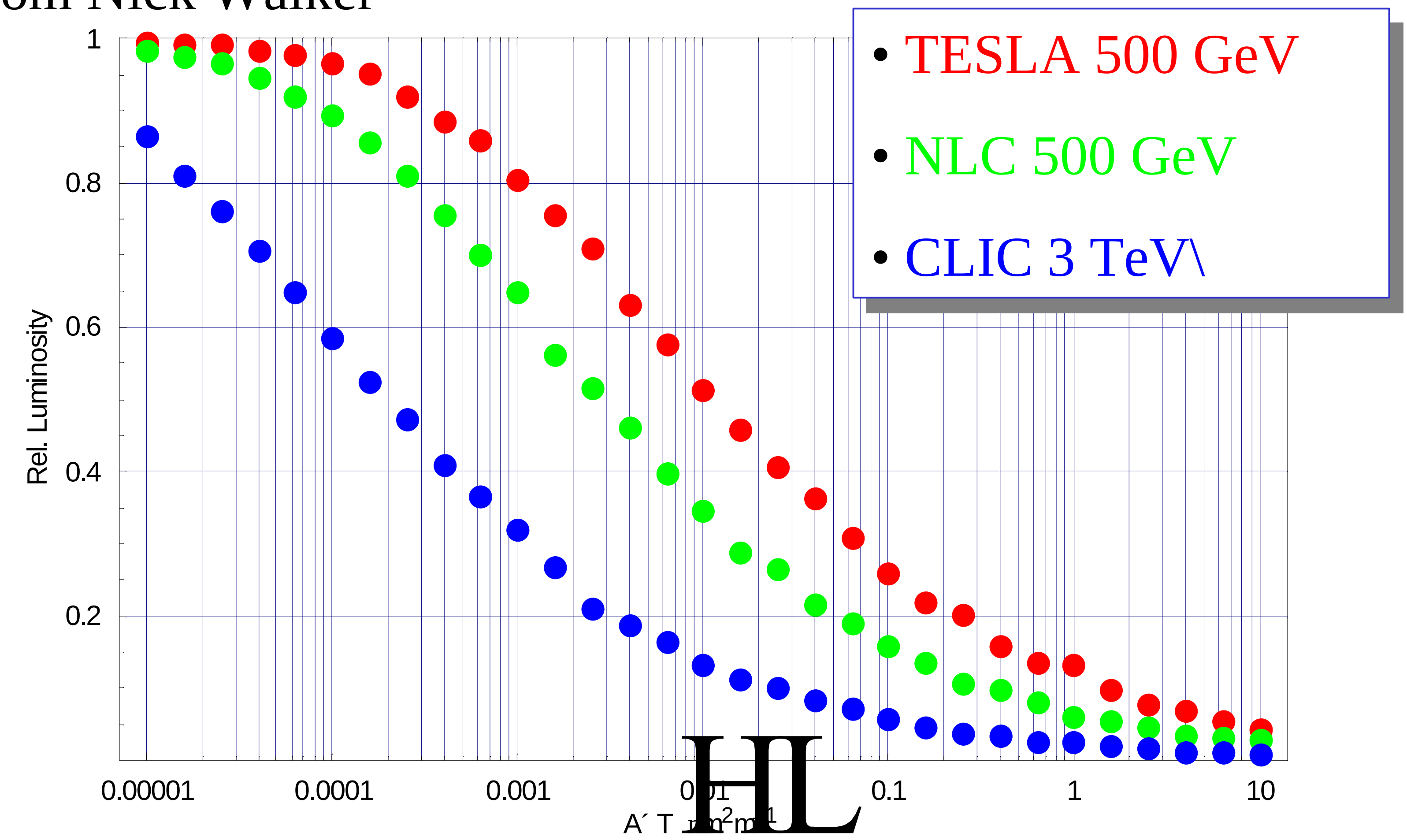


Beam Delivery Systems

- TESLA BDS based on conventional lattice while NLC and CLIC are based on new Pantaleo FFS
- Alignment and jitter tolerances are similar
  - New FFS appears to have better performance but NLC and CLIC demand more from systems
- Low repetition rate makes ground motion a larger problem
  - Fast intra-train feedback at TESLA designed to handle fast beam jitter however does not yet treat spot size variation
  - No plans to test system; possible sensitivity to IR backgrounds
- Collimation system solved for NLC and solution can be applied to TESLA

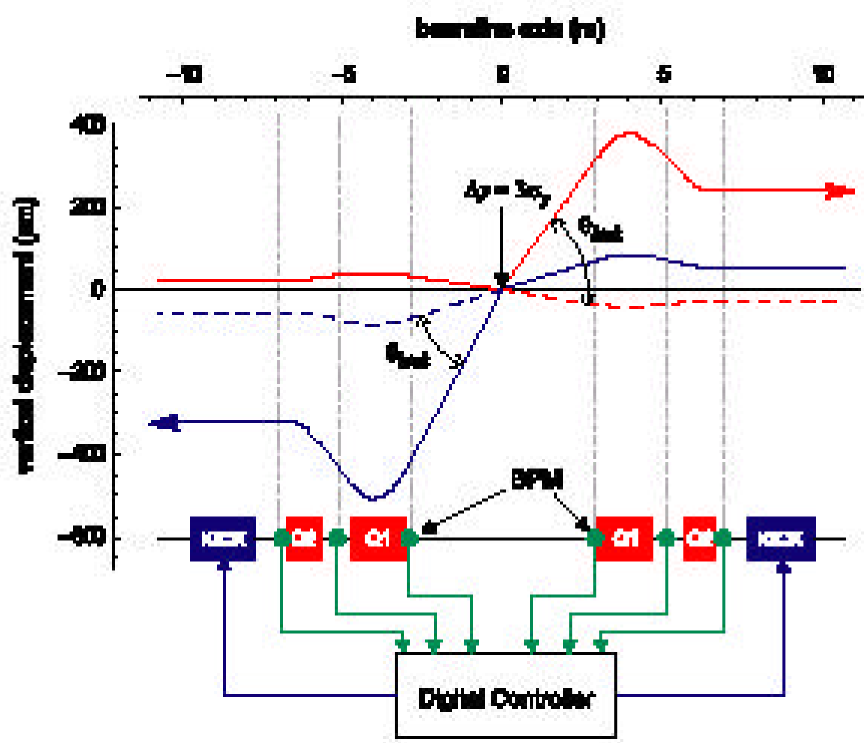
Beam Delivery Systems

From Nick Walker



IP Feedback

- System seems very attractive and simple!
- But design relies on this for 100% of luminosity
- Sensitive to backgrounds, coupling from solenoid, etc



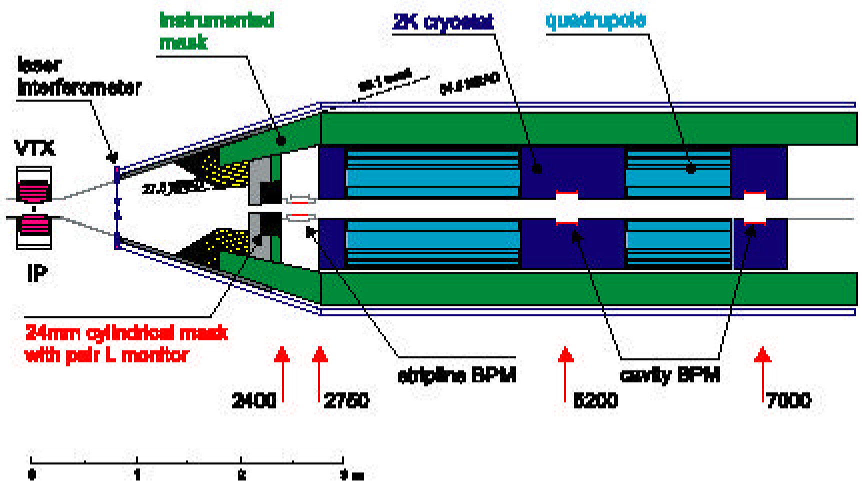


Figure 7.4.6: *Interaction region layout.*

Beam-Beam Issues

- High disruption → single bunch kink instability
  - Sensitive to IP position and angle offsets (IP feedback)
  - Sensitive to position correlations along the bunch, i.e. $\Delta\varepsilon$
  - Fractional luminosity decrease is much larger for correlated errors such as those from the linac or bunch compressor

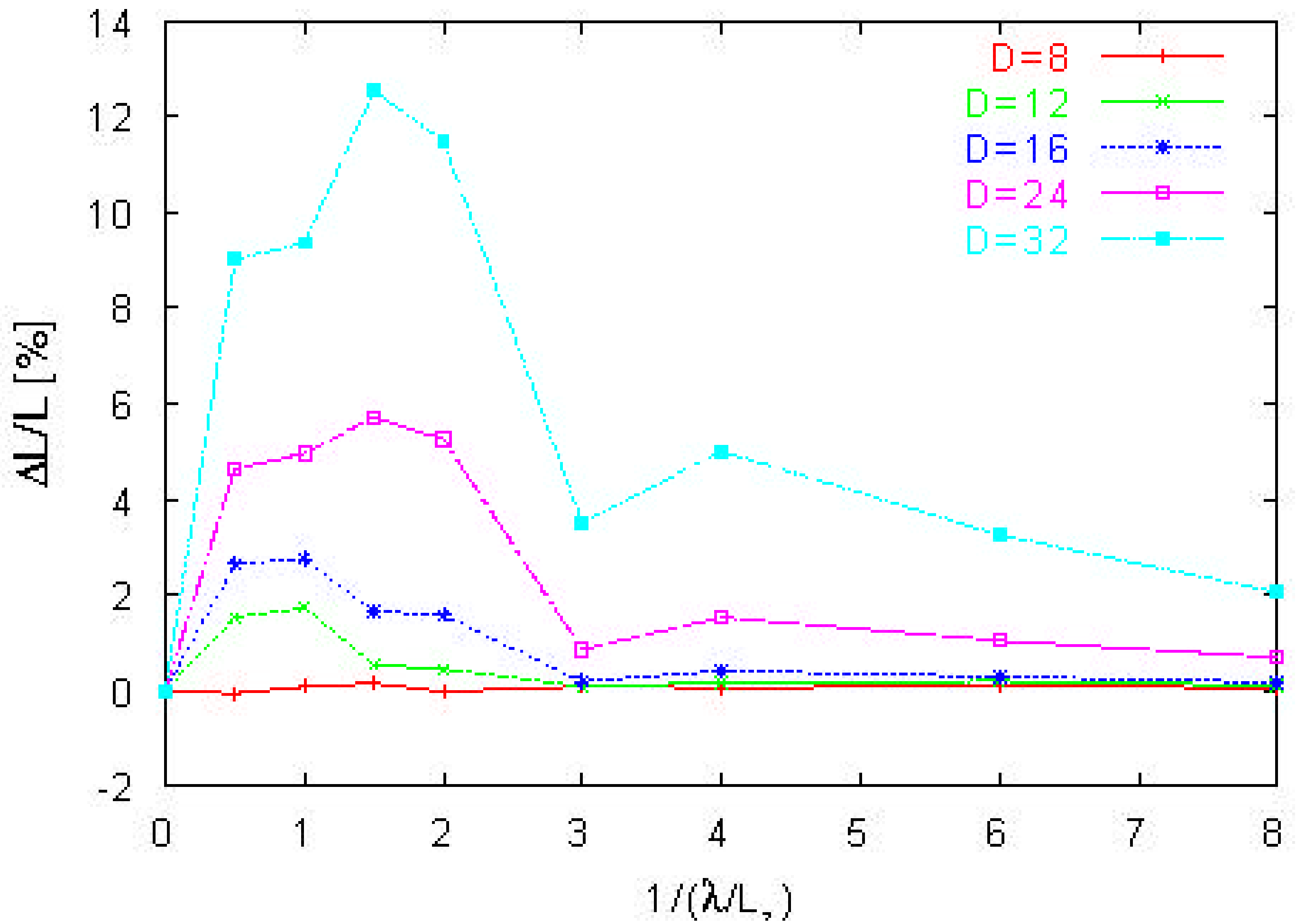
Simulation by R. Brinkmann including IP feedback tuning

	Uncorr. $\Delta\varepsilon$	Corr. $\Delta\varepsilon$
L_{design} ($\Delta\varepsilon$ = 50%)	$3.4\text{x}10^{34}$	
L_0 ($\Delta\varepsilon$ = 0% i.e. from DR)	$4.1\text{x}10^{34}$	$4.1\text{x}10^{34}$
L_{sim} ($\Delta\varepsilon$ = 10%)	$3.9\text{x}10^{34}$	$3.2\text{x}10^{34}$
L_{sim} ($\Delta\varepsilon$ = 20%)	$3.7\text{x}10^{34}$	$2.7\text{x}10^{34}$

  - Effect can be reduced by decreasing bunch length but this increases beamstrahlung energy spread
  - Smaller fractional effect for large emittance dilutions and smaller disruption – initial calcs. suggest smaller problem in NLC design

Banana Effect (single bunch kink)

- Plot from Daniel Schulte



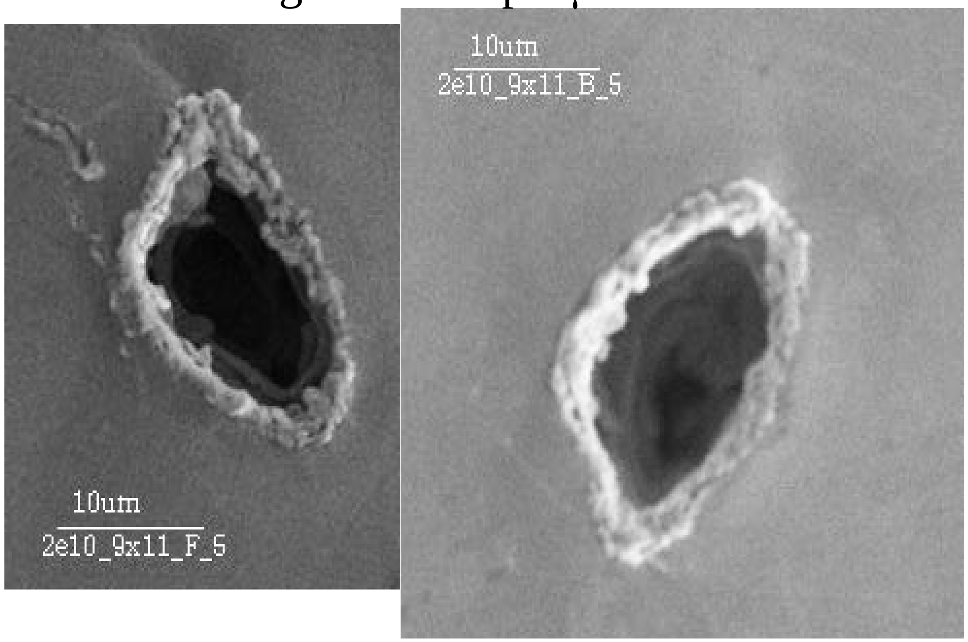
Machine Protection Issues

- Single bunches will likely damage any material at the end of the linac or in the beam delivery
  - Complicated turn-on process to prevent damage
  - Complicated MPS system with diagnostics on many components
    - Anything that can change from pulse-to-pulse

  - Some impact on operation not yet fully quantified

  - Problems are very similar for TESLA and NLC!

Damage from 13 pC/μm^2



Reliability Issues

- Essential to understand!
  - Significant limitation in SLC operation
    - Would take 3 ~ 4 times the length of each down time to recover luminosity!
- New LC are being designed to avoid known problems
  - Multiple (redundant) power supplies
  - Overhead in klystron / modulator populations
  - Redundant electrical / cooling systems
  - Big questions regarding TESLA single tunnel with accesses/10 days
    - radiation levels have only been checked at 17 MV/m (turned off 1 cavity)
    - Operation model based on 40,000 hr klystron lifetime -- only operated for ~2000 hrs at 25% power and 1 Hz
    - modulator cables; temp stability; low level rf electronics
- Must qualify reliability of all components, especially those in the tunnel!

Personal Opinion: XFEL

- First thought of in ’92 (C. Pelegrini and H. Winick)
  - Convergence of LC technology; rf guns; undulators; star wars
- No fundamental advantage of different technologies
  - TTF FEL and APS FEL LCLS and TESLA XFEL

- Great idea however do we/they really want a combined fac.?
  - Cost sharing is minimal (new sources; new compressors; only share 5% of linac) and operating expertise can be transferred!
  - Experimental requirements very different: users need few hours of beam time
  - Real operational issues in sharing linacs and tunnels

- Build user facilities at radiation sources: SSRL at SLAC, APS at Argonne, HASYLAB at DESY

Summary

- TESLA rf system is making great progress
  - Rf system for 500 GeV cms is close to being ready
    - Need to test final prototypes for modules, HOM damping, couplers, and klystrons
    - Need to gain operational time at nominal gradient 22~23 MV/m
  - Rf cavities for 800 GeV cms might be ready in 2004
- Luminosity issues are a larger concern!
  - Linac alignment tolerances are not attainable with proposed conventional systems
  - Damping ring and e+ source novel design with new dynamical issues
  - Beam-beam effects are significant and may force reduction in luminosity
  - The single tunnel design may severely constrain machine operation
- TESLA parameters developed for 500 GeV cms
  800 GeV parameters have not been studied in detail