TESLA Status
(A Biased Opinion)

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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

1st TESLA 9-cell cavity reached ~ 30 MV/m

Etching Average 24 MV/m

Electropolishing Average 35.7 MV/m
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

<table>
<thead>
<tr>
<th></th>
<th>Stage 1</th>
<th>Stage 2</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>NLC</td>
<td>TESLA</td>
</tr>
<tr>
<td>CMS Energy (GeV)</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td><strong>Luminosity</strong> (10^{33})</td>
<td>20</td>
<td>34</td>
</tr>
<tr>
<td>Repetition Rate (Hz)</td>
<td>120</td>
<td>5</td>
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<tr>
<td><strong>Bunch Charge</strong> (10^{10})</td>
<td>0.75</td>
<td>2</td>
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<tr>
<td>Bunches/RF Pulse</td>
<td>190</td>
<td>2820</td>
</tr>
<tr>
<td>Bunch Separation (ns)</td>
<td>1.4</td>
<td>337</td>
</tr>
<tr>
<td><strong>Eff. Gradient (MV/m)</strong></td>
<td>50.2</td>
<td>23.4</td>
</tr>
<tr>
<td>Injected γεₓ / γεᵧ (10^{-8})</td>
<td>300 / 2</td>
<td>1000 / 2</td>
</tr>
<tr>
<td>γεₓ at IP (10^{-8} m-rad)</td>
<td>360</td>
<td>1000</td>
</tr>
<tr>
<td>γεᵧ at IP (10^{-8} m-rad)</td>
<td>3.5</td>
<td>3</td>
</tr>
<tr>
<td>βₓ / βᵧ at IP (mm)</td>
<td>8 / 0.10</td>
<td>15 / 0.4</td>
</tr>
<tr>
<td>σₓ / σᵧ at IP (nm)</td>
<td>245 / 2.7</td>
<td>553 / 5</td>
</tr>
<tr>
<td>σ₂ at IP (um)</td>
<td>110</td>
<td>300</td>
</tr>
<tr>
<td>Γave</td>
<td>0.11</td>
<td></td>
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<tr>
<td>Pinch Enhancement</td>
<td>1.43</td>
<td>2.1</td>
</tr>
<tr>
<td>Beamstrahlung δB (%)</td>
<td>4.7</td>
<td>3.2</td>
</tr>
<tr>
<td>Photons per e+/e-</td>
<td>1.2</td>
<td>2</td>
</tr>
<tr>
<td>Linac Length (km)</td>
<td>6.3</td>
<td>30</td>
</tr>
</tbody>
</table>

- 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

<table>
<thead>
<tr>
<th></th>
<th>NLC/JLC</th>
<th>ATF</th>
<th>ALS</th>
<th>TESLA</th>
<th>LEP</th>
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<tr>
<td>circumference m</td>
<td>300</td>
<td>140</td>
<td>200</td>
<td>17,000</td>
<td>26,000</td>
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<tr>
<td>energy GeV</td>
<td>2</td>
<td>1.3</td>
<td>1.9</td>
<td>5</td>
<td>46</td>
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<tr>
<td>emittance $\varepsilon_x$ nm</td>
<td>0.56</td>
<td>1.4</td>
<td>5.6</td>
<td>0.9</td>
<td>-</td>
</tr>
<tr>
<td>ratio $\varepsilon_y/\varepsilon_x$ %</td>
<td>0.5</td>
<td>1 – 3 (0.5?)</td>
<td>0.5 – 3</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>damping time ms</td>
<td>5</td>
<td>12 (no wigg.)</td>
<td>15</td>
<td>28</td>
<td>26</td>
</tr>
<tr>
<td>wiggler length m</td>
<td>45</td>
<td>8</td>
<td>6?</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>space charge $\Delta Q$</td>
<td>0.05</td>
<td>~0.02</td>
<td></td>
<td>0.23 $\rightarrow$ 0.04 (x-y bump)</td>
<td>0.2 (4 IP)</td>
</tr>
</tbody>
</table>
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% $\Delta \varepsilon$
  - 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 endpoints with remotely controlled movers

- TESLA cavities must be aligned with 500 µm rms for 15% $\Delta \varepsilon$
  - Achieved +/- 250 µm alignment within cryostat
  - But effects add $\rightarrow$ tolerance for 12 cavities in cryostat $\sim$ 140 µm
  - Effect is worst at $\frac{1}{4}\lambda_{\beta} = 150$ m $\rightarrow$ tolerance for cryostats $\sim$ 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% $\Delta \varepsilon$
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 moveable 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

- TESLA 500 GeV
- NLC 500 GeV
- CLIC 3 TeV
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 $\rightarrow$ single bunch kink instability
  - Sensitive to IP position and angle offsets (IP feedback)
  - Sensitive to position correlations along the bunch, i.e. $\Delta \epsilon$
  - 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

<table>
<thead>
<tr>
<th></th>
<th>Uncorr. $\Delta \epsilon$</th>
<th>Corr. $\Delta \epsilon$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{\text{design}}$ ($\Delta \epsilon = 50%$)</td>
<td>$3.4 \times 10^{34}$</td>
<td></td>
</tr>
<tr>
<td>$L_0$ ($\Delta \epsilon = 0%$ i.e. from DR)</td>
<td>$4.1 \times 10^{34}$</td>
<td>$4.1 \times 10^{34}$</td>
</tr>
<tr>
<td>$L_{\text{sim}}$ ($\Delta \epsilon = 10%$)</td>
<td>$3.9 \times 10^{34}$</td>
<td>$3.2 \times 10^{34}$</td>
</tr>
<tr>
<td>$L_{\text{sim}}$ ($\Delta \epsilon = 20%$)</td>
<td>$3.7 \times 10^{34}$</td>
<td>$2.7 \times 10^{34}$</td>
</tr>
</tbody>
</table>

- 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!
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