NLC Accelerator Physics

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@Parameters
*Present Status
*Optics and tools
State of the NLC design

- Optimized parameters to reduce rf system costs
- Established common parameters with KEK
- 1st pass at ZDR optics -- improvements started -- there are a few places with real problems
- Updating and completing ZDR calculations
- Making engineering layouts and costing components for CD1
- Looking at schedules and requirements for CDR
Parameter Optimization

- Improved accelerator structure design
- Reduced average current and lengthened bunch train
- Reduced # of klystrons/modulators required at 1 TeV by about 30%
- Adopted efficient DLDS (Delay-Line Distribution System)
- Improved 500 GeV cms parameters with easier DR, looser linac requirements for faster commissioning, and full utilization of 1 TeV hardware
- Optimizing luminosity spectrum at 500 GeV and 1 TeV
JLC / NLC Parameters

- DLDS $\rightarrow$ higher efficiency than SLED-II and easier than Binary Pulse Compression (BPC)
- $a/h / L_{\text{acc}} \rightarrow$ longer structures lead to looser alignment tolerances and lower costs if they can be constructed
- RDDS $\rightarrow$ clearly better provided costs are comparable
- $\Delta \epsilon \rightarrow$ NLC assumed no global $\epsilon$ correction which has been used very successfully at SLC
- Energy $\rightarrow$ overhead clearly needed
- Rep. Rate? NLC is designed for 120 Hz-JLC for 100 Hz
- Maximum energy? NLC has room for 1.5 TeV upgrade in final focus—JLC does not.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>500 GeV</th>
<th>1 TeV</th>
<th>1.5 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMS Energy (GeV)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Luminosity ($10^{33}$)</td>
<td></td>
<td></td>
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<tr>
<td>Repetition Rate (Hz)</td>
<td></td>
<td></td>
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<tr>
<td>Bunch Charge ($10^{10}$)</td>
<td></td>
<td></td>
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<tr>
<td>Bunches/RF Pulse</td>
<td></td>
<td></td>
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<tr>
<td>Bunch Separation (ns)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Injected $\gamma_x/\gamma_y$ ($10^{-8}$)</td>
<td></td>
<td></td>
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<tr>
<td>$\gamma_y$ at IP ($10^{-8}$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\beta_x/\beta_y$ at IP (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma_x/\sigma_y$ at IP (nm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma_z$ at IP (um)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yave</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Pinch Enhancement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beamstrahlung $\delta B$ (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Photons per $e^+/e^-$</td>
<td></td>
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</tr>
</tbody>
</table>

- Range of $N, \epsilon, \sigma^*$ with similar $\epsilon$'s and tol.
- 1.5 TeV parameters based on 40% increase in gradient ($2x P_{RF}$) or 50% increase in length.
Electron and Positron Sources

- Charge limit/current limit effect limits polarized e- current to 20% of NLC goal -- looking at solutions
- Positron system still based on conventional target -- looking at damage thresholds -- also looking at polarized e+ option for future
- Large charge and emittance overheads included in design but worried about beam halos and radiation damage
- System still based on 714 MHz for 1.4ns option
Damping Rings

- Damping rings need major re-design because of parameter change -- longer trains
- Lattice still based on TME cells but with more relaxed combined-function dipole magnets
- Include more wiggler (25m → 40m) to increase momentum compaction and allow for additional 714 MHz rf
- Increased vacuum and ante-chamber apertures for reduced impedance and easier beam handling
- Investigate possibility of off-frequency operation to compensate transient beam-loading
- Studying ALS impedance for comparison
NLC MDR TME Cell – 6/11/98
Instabilities

- Longitudinal microwave (SLC DR sawtooth) – single bunch instability from impedance due to small discontinuities in vacuum chamber – use large aperture and very smooth chamber

- Transverse and longitudinal coupled-bunch instabilities – use damped rf cavity and feedback (Pi-mode cavity in SLC DR)

- Electron cloud from photoelectrons and secondaries can couple bunches in the positron rings

- Ion trapping can do the same in the electron rings
Injector Linacs

- Low frequency linacs below 10 GeV for looser tolerances and loading and increased apertures
- ZDR design used combination of At and Af for loading compensation -- present design only uses At to simply rf systems
- Optimized S-band structure parameters for looser tolerances and lower gradient
- Studying BBU effects in S-band systems -- looks like pure detuning of dipole modes is acceptable although more work is needed
- Need integrated rf BPM in structures and movers on components downstream of damping rings
## Low RF Linacs, Compressors

<table>
<thead>
<tr>
<th>Function</th>
<th>Freq</th>
<th>Energy</th>
<th>Average Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^+$ booster</td>
<td>L(1)</td>
<td>250 MeV - 1.98 GeV</td>
<td>$&lt;0.91$ A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$(1.6 \times 10^{10} , 2.8\text{ns})$</td>
</tr>
<tr>
<td>$e^+$ drive</td>
<td>S(1)</td>
<td>6 GeV</td>
<td>$&lt;0.83$ A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$(1.45 \times 10^{10} , 2.8\text{ns})$</td>
</tr>
<tr>
<td>$e^-$ booster</td>
<td>S(1)</td>
<td>80 MeV - 1.98 GeV</td>
<td>$&lt;0.83$ A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$(1.45\times 10^{10} , 2.8\text{ns})$</td>
</tr>
<tr>
<td>Pre-linacs</td>
<td>S(2)</td>
<td>1.98 GeV - 10 GeV</td>
<td>$&lt;0.66$ A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$(1.15 \times 10^{10} , 2.8\text{ns})$</td>
</tr>
<tr>
<td>E compressors</td>
<td>L(2X2)</td>
<td>$\sim 100$ MeV</td>
<td>$&lt;0.83$ A</td>
</tr>
<tr>
<td>BC1</td>
<td></td>
<td></td>
<td>$(1.45 \times 10^{10} , 2.8\text{ns})$</td>
</tr>
<tr>
<td>Bunch</td>
<td>X(2)</td>
<td>1 GeV at 90° phase</td>
<td>$&lt;0.66$ A</td>
</tr>
<tr>
<td>compressors 2</td>
<td></td>
<td></td>
<td>$(1.15 \times 10^{10} , 2.8\text{ns})$</td>
</tr>
</tbody>
</table>
S-band Structure Optimization

- $\Delta T$ beam loading compensation scheme
- ZDR cost model
- Structure-to-structure tolerance: $\propto a^{3.8}/L_{acc}$
- Structure options

<table>
<thead>
<tr>
<th>Type</th>
<th>L (m)</th>
<th>T (mm)</th>
<th>$N_{module}$</th>
<th>Cost</th>
<th>$a_{ave}(\text{mm})$</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>DLWG</td>
<td>3.0</td>
<td>5.878</td>
<td>27</td>
<td>1.0</td>
<td>12.85</td>
<td>---</td>
</tr>
<tr>
<td>DLWG</td>
<td>4.0</td>
<td>7.5</td>
<td>25</td>
<td>1.0</td>
<td>14.69</td>
<td>+29.3%</td>
</tr>
<tr>
<td>RDS$^a$</td>
<td>4.0</td>
<td>5/5.2</td>
<td>25</td>
<td>1.0</td>
<td>15.40</td>
<td>+52.7%</td>
</tr>
<tr>
<td>RDS$^b$</td>
<td>4.0</td>
<td>5/5.2</td>
<td>22</td>
<td>1.09</td>
<td>15.72</td>
<td>+42.9%</td>
</tr>
</tbody>
</table>

$^a$ High gradient design. 4 structures/module, 22 MV/m loaded

$^b$ Low gradient design. 6 structures/module, 17 MV/m loaded

- Current design:
  - RDS$^b$
  - 6 structures/module, 17 MV/m loaded
  - 10% spare modules
Wake envelope [V/pC/m/m] vs s [m]

- one type
  \( \Delta f/f = 10\% \)
  \( \sigma_f/f = 10.5\% \)

- two types
  \( \Delta f/f = 10\% \)
  \( \sigma_f/f = 15\% \)

prelinac: coupled modes
one type
\( \Delta f/f = 10\% \)
\( \sigma_f/f = 10.5\% \)
\( \Delta \epsilon/\epsilon = 1.6\% \)

two types
\( \Delta f/f = 10\% \)
\( \sigma_f/f = 15\% \)
\( \Delta \epsilon/\epsilon = 0.4\% \)

Prelinac: 114 cells, coupled, systematic freq. errors = 0.1\%
X-band Linac Structures

- Shifted $a/\lambda$ from 0.17 1 back to 0.18 to ease single bunch effects
- Re-calculting long-range wakefields and tolerances based on RDDS 1 structure design with $a/h = 0.18$
  - Decoupling of last cells leads to undamped modes
  - Still need work on BBU but have basic results look good
- Looking at higher dipole and longitudinal bands, rf deflections, etc.
- Need to start translating tolerances into engineering specifications
Short-range Wakefields

- Calculated short-range wakefields for RDDS structure
- Found 15% error in ZDR transverse wakefield — the wrong way!
- Have confidence in present calculations — three different codes yield same result
- Net result: present transverse wakefield is 40~50% larger and BNS is difficult
- Looking at options to ease BNS problems: stronger focusing (increases length and tightens quad. tolerances), rf quads (tight alignment tolerances), and increasing a/λ (eases tolerances and rf phase for energy spread)
BNS profiles for RDDS1 wake, $\lambda/a=0.18$
Vert. emit. growth due to 1 μ quad offset, λ/a=0.171
Cost Optimized Low Emittance Linac vs a/\lambda (L_s=1.8\,m)

Wake Function (V/μC/mm/m)

Distance (m)

Manifold Transition Reflection Coefficient

Frequency (MHz)

RMJ, NMK, RHM, JW, GS & TR(10-98)
Envelope of Wake Function via Spectral Fn. Method: RDDS (VSWR 1.0)

R M Jones, N.M. Kroll, R.H. Miller, Z Li, J.W. Wang, T. Raubenheimer & J. Irwin(6-98)
RDDSC 14 Cells Decoupled and a VSWR of 1.05 Throughout the Band.
Random Walk Cell Offsets, rms Step=1
X-band Linac Operation

- Modified linac lattice for 3 structures/girder with 86% filling factor and diagnostic stations
- Studied improved linac steering techniques (without emittance correction) to preserve emittance within budget
- Need more work on stability of quadrupole center -- very important for beam-based alignment of BPM to quadrupole center
- Starting study of linac feedback systems including wakefield effects -- conjectured to be the major limitation in the SLC feedback operation
- MPS system is being re-defined because of limitations in collimation system and previous calculations of damage
NLC linac: Diagnostics section 2.

$L_c = 8 \text{ m}$
Emittance Dilution versus Mover Step Size

- FC Algorithm
- Standard Algorithm
- Standard + Micado

mover stepsize (nm)
"FC" Algorithm with ATL: Emittance Dilution Versus Iterations of Automated Alignment
Step function along the linac: AFTER FEEDBACK

- BPM positions
- Feedback BPM positions

Step at xcor 15

BPM measurement

S position
EGS calculation

Exit of upstream structure

Output Drift Tube

Input Drift Tubes

IRIS Location (cm)

$\Delta T$ (°C pulse)

$10^{-1}$ $10^{2}$ $10^{3}$ $10^{4}$ $10^{5}$

$t=90 \text{ mm}$

$l=340 \text{ mm}$

$t=1300 \text{ mm}$

$T_{\text{MEIT}}=1083^\circ \text{C}$

$T_{\text{STRESS}}=180^\circ \text{C}$
Beam Delivery System

- Considering variation of L* to ease tolerances or to simplify quadrupole support -- depends on detector model
- ZDR final focus modified to include realistic magnets
- Beam line displacement versus energy eliminated
- Looking at diagnostics and feedbacks -- will start study of required tuning procedures
- Improving dump line for better transmission and moved capture magnets out of detector (at least 4m from IP so far)
- Modified IP switch to provide longitudinal IP offset
NLC BD Luminosity Estimates Case "C" Params

Unenhanced Luminosity, 10^{33} cm^{-2} sec^{-1}

- Linear
- Geometric
- Geometric + Chromatic
- Geometric + Chromatic + SR Bends
- Geometric + Chromatic + SR Bends + SR Quads
- 1 TeV Hi
- 0.75 TeV Hi
- 0.75 TeV lo
- 0.5 TeV lo
- 0.35 TeV lo
Aperture Constraints

- Full beam size
- Orbit of low energy particles ($\Delta E/E$ from 0 to -70%)
- Photon flux aperture (max. half angle $6 \times 100 \mu$rad)
Distribution of beam power loss (kW/m)

1) Case 1046A. Total loss: 31.35 kW.

2) Case 9786. Total loss: 35.27 kW.
Beam Collimation and Tails

- Studying new collimation systems with simplified optics
  - laser collimation
  - resonant octupole collimation and octupole beam shaping
  - liquid metal collimators
  - simplified conventional collimation

- Proposed measurement of collimator wakefields

- Studying generation of beam-tails in upstream systems

- Simulated effect of beam-gas and beam-photon scattering through system using modified version of DIMAD with scattering and full chromatic treatment

- Adopting SLC techniques for study of degraded particles
Luminosity Optimization

- Making detailed luminosity spectrum calculations with CAIN and Guinea-Pig
- Studied high-luminosity operation mode at 500 GeV
- Starting luminosity spectrum optimizations for different operation modes based on different physics studies: top threshold, selectron discovery, Higgs production, W scattering
High Luminosity Operation

- 500 GeV and 1 TeV designs have large margins
- Damping ring should be able to produce $\gamma \varepsilon_y = 2 \times 10^{-8}$ with 25$\mu$m alignment which was the spec. for beam-based alignment
- Use emittance bumps to reduce emittance dilution in the linacs by a factor of 3 — based on nominal 1 TeV tolerances
- Shorten bunch by reducing $R_{56}$ in BC2
- Operate with 1.4ns spacing
- Separate waists at IP
- Sensitive to jitter

Pinch acts earlier and is more effective (like plasma lens)
### High luminosity parameters for JLC/NLC and TESLA

<table>
<thead>
<tr>
<th></th>
<th>ILC-Ib</th>
<th>ILC-IHa</th>
<th>ILC-IHb†</th>
<th>TESLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal CMS Energy (TeV)</td>
<td>0.5</td>
<td></td>
<td>-0.5</td>
<td></td>
</tr>
<tr>
<td>Luminosity without pinch (10^{33})</td>
<td>3.9</td>
<td>10.4</td>
<td>15.8</td>
<td>16.2</td>
</tr>
<tr>
<td>Pinch Enhancement (H_D)‡</td>
<td>1.42</td>
<td>1.36</td>
<td>1.30</td>
<td>1.61</td>
</tr>
<tr>
<td>(H_D) (w/) waist shift *</td>
<td>1.46</td>
<td>1.50</td>
<td>1.90</td>
<td>1.93</td>
</tr>
<tr>
<td>(H_D) (w/) waist shift and offset \¶</td>
<td>1.32</td>
<td>-12.4</td>
<td>11.8</td>
<td>0.98</td>
</tr>
<tr>
<td>Luminosity (10^{33})§</td>
<td>6.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repetition Rate (Hz)</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>5</td>
</tr>
<tr>
<td>Bunch Charge (10^{10})</td>
<td>1.0</td>
<td>1.0</td>
<td>0.75</td>
<td>2.0</td>
</tr>
<tr>
<td>Bunches/RF Pulse</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>2820</td>
</tr>
<tr>
<td>Bunch Separation (ns)</td>
<td>2.8</td>
<td>2.8</td>
<td>1.4</td>
<td>3.3</td>
</tr>
<tr>
<td>(\gamma \varepsilon_{z,y}) at DR (10^{-8})-m-rad</td>
<td>300 / 3</td>
<td>300 / 2</td>
<td>300 / 2</td>
<td>800 / 2</td>
</tr>
<tr>
<td>(\gamma \varepsilon_{z,y}) at IP (10^{-8})-m-rad</td>
<td>500 / 10</td>
<td>400 / 3</td>
<td>400 / 3</td>
<td>1000 / 3</td>
</tr>
<tr>
<td>(\beta_z/\beta_y) at IP (mm)</td>
<td>12/0.125</td>
<td>13/0.100</td>
<td>10/0.080</td>
<td>15/0.400</td>
</tr>
<tr>
<td>(\sigma_z/\sigma_y) at IP (nm)</td>
<td>350/5.1</td>
<td>324/2.5</td>
<td>287/2.2</td>
<td>553/5.0</td>
</tr>
<tr>
<td>(\sigma_z) at IP ((\mu)m)</td>
<td>125</td>
<td>115</td>
<td>85</td>
<td>4 0</td>
</tr>
<tr>
<td>Linac Tolerances II ((\mu)m)</td>
<td>14.6</td>
<td>7.1</td>
<td>10.5</td>
<td>500</td>
</tr>
<tr>
<td>(T) (Beamstrahlung Param.)</td>
<td>0.10</td>
<td>0.13</td>
<td>0.3 4</td>
<td>0.05</td>
</tr>
<tr>
<td>Beamstrahlung (\delta_B) (%)</td>
<td>4.0</td>
<td>5.1</td>
<td>4.6</td>
<td>3.1</td>
</tr>
<tr>
<td># Photons per (e^+)/(e^-)</td>
<td>1.2</td>
<td>1.3</td>
<td>1.1</td>
<td>1.9</td>
</tr>
</tbody>
</table>

† For the same cms energy, the ILC-IHb is 10% longer than the nominal ILC design because of the higher beam loading.

‡ Guinea Pig simulation for the luminosity enhancement — the analytic result is very close to these values.

* Enhancement from Guinea Pig simulations assuming that the \(e^+\)/\(e^-\) waists are offset by 1.6\(\sigma_z\) — this optimizes the enhancement.

\(\Rightarrow\) ¶ Enhancement with waist shift and a vertical offset of la, which allows an estimation of the kick instability.

\(\Rightarrow\) § Luminosity including waist shift and jitter offset; note that the TESLA luminosity listed here is based on same calculation procedure as for JLC/NLC however the value is 45% smaller than listed in the TESLA parameters.

|| Tolerances calculated assuming that 50% of the total emittance budget is used by dilutions from short-range transverse wakefields.
Luminosity Spectrum \((e^-, e^+)\)

Total luminosity \(9.779 \pm 0.027\text{(stat.1\sigma)}\) plotted range \(9.779 \times 10^{29}/\text{cm}^2/\text{s}\)
(beamstrahlung only)
Total Lum in 2% (arb. scale) for 1 TeV NLC

$\eta \gamma \sim 2.1$

$S_0 \sim 18\%$

$\delta \% \sim 98\%$
Summary

- Design is in pretty good shape except:
  - Long-range X-band wakefield needs work -- recent design changes
  - Collimation systems and machine protection system need work
  - Damping rings need to be re-designed
  - Final focus options need exploration
  - Polarized source limited by current limit
  - High peak rf power limitations need to be understood

- Need to start looking at operational issues: feedback, tuning, vibration, and reliability in detail

- Discussion of optics status and simulation/calculation tools will follow