NLC Accelerator Physics

NLC Lehman Review
May 24 – 28, 1999
Outline

• State of design—CD-1 Model
• Outstanding accelerator physics issues to be addressed during CDR phase
• Plans for the CDR phase

• Address charge:
  – readiness to begin conceptual design
  – planning and schedule for CDR
  – structure to manage CDR
Luminosity in Linear Colliders

\[ L = \frac{f_{\text{rep}}}{4\pi} \frac{n_b N^2}{\sigma_x \sigma_y} H_D \]

In a linear collider

\[ L = \frac{2P_b}{4\pi E_{\text{cms}}} \frac{N}{\sigma_x} \frac{H_D}{\sigma_y} \]

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

⇒ Three issues for LC: energy, spot size, and beam power
NLC History

- NLC design based on experience from the SLC
- Informal collaboration of ~ 60 people at 16 institutions
- 1st pass at:
  - physics and design verification
  - parameter optimization
  - tolerance and performance specification
- ZDR cost model → route to further optimization
- ZDR → framework for present design → CD-1 Model
NLC Schematic

- Consists of:
  - e+ source and polarized e- source to produce high-current bunch trains
  - damping rings for small emittances
  - bunch compressors for short bunches
  - X-band linacs to attain high gradient acceleration for high energy
  - collimation section to remove large amplitude particles
  - final focus for small spots
  - two IPs for alternate experiments
Energy Upgrade Scenarios

• 500 GeV → 1 TeV (design optimized for 1 TeV)
  – Add rf power sources and acc. structures to 2\textsuperscript{nd} half of linacs
  – Quadrupoles already in place for 1 TeV
  – Collimation and FF designed for 350 GeV → 1 TeV (although permanent magnet FD must be replaced at ~ 750 GeV)
  – 500 GeV parameters have looser linac tolerances for faster commissioning—all components are specified for 1 TeV tolerances

• 1 TeV → 1.5 TeV (lots of options!)
  – Increase gradient or lengthen linacs (many possible routes)
  – FF layout designed for 1.5 TeV (shielding, length, etc.) but need to replace 10\% of magnets and shift beam line by ~ 10 cm
### 500 GeV and 1 TeV Parameters

<table>
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<th>IP Parameters for the JLC / NLC (8/8/98)</th>
<th>500 GeV</th>
<th>1 TeV</th>
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<td><strong>A</strong></td>
<td><strong>B</strong></td>
<td><strong>C</strong></td>
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<tr>
<td>CMS Energy (GeV)</td>
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<td>Repetition Rate (Hz)</td>
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<td>120</td>
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<td><strong>Bunch Charge (10^{10})</strong></td>
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<td>Bunches/RF Pulse</td>
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<td>95</td>
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<td>Bunch Separation (ns)</td>
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<tr>
<td><strong>Eff. Gradient (MV/m)</strong></td>
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<td>55</td>
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<tr>
<td>Injected $\gamma_x / \gamma_y (10^{-6})$</td>
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<td>300 / 3</td>
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<tr>
<td>$\gamma_x$ at IP (10^{8} m-rad)</td>
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<td>$\gamma_y$ at IP (10^{8} m-rad)</td>
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<td>10</td>
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<tr>
<td>$\beta_x / \beta_y$ at IP (mm)</td>
<td>10 / 0.1</td>
<td>12 / 0.12</td>
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<td>120</td>
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<td>$\Upsilon$ ave</td>
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<td>Pinch Enhancement</td>
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<td>Photons per e+/e-</td>
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<td>1.1</td>
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</table>

From Accelerator Physics pages in NLC www area
Design Parameter Space and Margins

• Operating plane over which $L \sim$ constant but current, final focus optics, and spot sizes vary by $\sim 50\%$ (similar to SLC experience)
  – component requirements set by tightest tolerances in range
• Allow for 1.4 ns or 2.8 ns bunch spacing to trade multi-bunch vs. single-bunch $\varepsilon$ dilutions and backgrounds
• Systems are all specified with additional overheads to produce better beams than required—for example:
  – E- injector designed to produce 40% additional charge
  – Linac tolerances do not assume emittance correction
• Luminosity would more than double using overheads
Possible 1.5 TeV Parameters

- Two upgrade paths listed:
  (A) increase linac gradient
  (B) increase linac length
- Limit ac power to ~ 200 MW
- Linac tunnel cross-section sized for Two-Beam Acc. option

<table>
<thead>
<tr>
<th>IP Parameters for the JLC / NLC</th>
<th>1.5 TeV</th>
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<tbody>
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<td>Repetition Rate (Hz)</td>
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<tr>
<td>Bunch Charge ($10^{10}$)</td>
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<td>Bunches/RF Pulse</td>
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<td>Bunch Separation (ns)</td>
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<td>Eff. Gradient (MV/m)</td>
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<tr>
<td>Injected $\gamma/e_x / \gamma/e_y$ ($10^{-8}$)</td>
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<td>$\gamma/e_x$ at IP ($10^{-8}$ m-rad)</td>
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<td>$\gamma/e_y$ at IP ($10^{-8}$ m-rad)</td>
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<td>$\beta_x / \beta_y$ at IP (mm)</td>
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<td>$\sigma_z$ at IP (um)</td>
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<td>Yave</td>
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<tr>
<td>Pinch Enhancement</td>
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<tr>
<td>Beamstrahlung $\delta B$ (%)</td>
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<tr>
<td>Photons per e+/$e-$</td>
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</table>
State of Accelerator Physics Design

• ZDR parameters re-optimized to reduce rf system costs
• Collaboration established with KEK: Optimized common parameter set developed together

• Optics designs for roughly 30 miles of beamline
  – specified subsystem requirements
  – designs have all beamline elements (rf structures, magnets, diagnostics, correctors)
  – common ‘toolkit’ for lattice design and simulation, and, process for configuration control
  – have 1st pass on all tolerances—working on next iteration!
  – prioritized further work and problem areas (not too many!)
State of Accelerator Physics Design (2)

- First pass at reviewing and improving ZDR physics models and tolerance calculations $\rightarrow$ CD-1 Model
- Starting to look at further cost and performance optimization
- Test facilities have addressed fundamental questions

$\Rightarrow$ Ready to start CDR!
Accelerator Physics Issues for CDR

- Two issues:
  - Energy (rf technology – Chris Adolphsen)
  - Luminosity (small spots & beam power)

- Beam power (long bunch trains):
  - charge from sources (John Sheppard)
  - long-range wakefields

- Small spot sizes:
  - low emittance damping rings
  - final focus system
  - alignment and jitter tolerances
  - beam-based alignment and feedback

- Both issues: (very high charge densities)
  - beam collimation and machine protection
Injector System Layout

- E+/E- sources to generate required charge but large $\gamma \varepsilon$
- Accelerate in low $f_{rf}$ linacs for low wakes and big apertures
- Damping rings and bunch compressors to generate the required emittances and bunch lengths—also damp transients for stable beam and allow for feed-forward
- Geometry of system allows for polarized positrons or polarized electrons on either side (allow need solenoids)
- Geometry also allows linac expansion in future
- Centralized injector system considered in future to share components and ease maintenance
Damping Rings

• Damping rings like 3rd generation SR sources with similar problems except require faster damping:
• ZDR damping rings needed re-design because of parameter change—longer bunch trains
  – Lattice without combined-function dipole magnets
  – Increase momentum compaction and increase RF voltage by including more wiggler (25m → 45m)
  – Increased vacuum and ante-chamber apertures for reduced impedance and easier beam handling
• R&D started on kickers, wiggler, and RF cavities
• Have not re-done dynamic aperture optimization or instability calculations but ZDR demonstrated feasibility
Main Linac Layout

- Linacs consists of repetitive sectors of roughly 230 meters
- Rf power from klystron gallery
- Three 1.8 meter accelerator structure per rf girder
- Quadrupole magnets spaced by 1, 2, and finally 3 rf girders
- All elements on remote movers for alignment
- Two extra diagnostic regions along linac
Long-Range Wakefields and Accelerator Structure Designs

- Choose parameters to optimize energy transfer to beam at high gradient but beams induce ‘wakefields’ in structures.

- Longitudinal wakefield causes energy variation along bunch train—compensated by adjusting rf pulse amplitude (and phase)—verified in NLCTA!

- Transverse wakefields cause Beam Break-Up instability and can make linac inoperable!

- Careful design of the structures to ensure small transverse wakefields and eliminate problem by design.

- Issues are different in L-band, S-band, and X-band linacs.
Rounded Damped-Detuned X-band Accelerator Structures (RDDS)

- Need to damp or decohere long-range dipole modes to prevent the Beam Break-Up instability
- Each X-band structure has 206 cells, each with a different dipole mode frequency
- Manifolds provide signal for beam-based alignment
- Latest structure design: RDDS has cells with +12% shunt impedance
Accelerator Structures

- (R)DDS structures use detuning combined with weak damping to control dipole modes
- Dipole modes rapid decay due to detuning and damping keeps them that way!
- Structures designed using 3-D field calculations and 2-band circuit model
- Very good agreement between calculation and measurements

← factor of 100 decay in 1st ns
Final Focus and Interaction Region

• Focus beams to the very small spot sizes
• Final focus is a scaled up model of the Final Focus Test Beam (FFTB) beamline—FFTB demonstrated greater demagnification than needed for NLC

• Need to design a stable support for the final magnets with ~1nm vibration at frequencies greater than a few Hz
• Length of system: IP switch, big bend, final focus, is roughly 2.5 km—driven by synchrotron radiation effects at high energy
Alignment and Time Scales

- Interested in alignment at micron level
- Sounds small but motion at high frequency >10 Hz is in nanometer range
- In few cases, high frequency stability might be provided with active stabilization
- Use beam to diagnose low frequency alignment errors
- Relies on accurate diagnostics and correction  
  ⇒ We have them!
Beam-Based Alignment

- Movers developed for Final Focus Test Beam (FFTB) have steps \( \sim 0.5\mu m \)

- Stripline Beam Position Monitors (BPMs) for FFTB have \(<1\mu m\) resolution and rf cavity BPMs have 40nm resolution

- All elements from damping rings downstream have independent power supplies and are on magnet movers
Collimation System and MPS

- Collimation system and machine protection (MPS) intimately related (see discussion tomorrow)
- Collimation system consists of two parts:
  - Pre-linac collimation at the end of the pre-linac (10 GeV)
  - Main collimation at end of main linac
- Pre-linac system is ‘easy’
- Main collimation system is hard because high density beams will destroy materials (linac beam: $\Delta T \sim 8 \times 10^5 ^\circ C$!)
  \[ \Rightarrow \text{increase beam size but makes optics difficult!} \]
- ZDR system was designed to have passive protection but had very tight tolerances—working on new design
Post-Linac Collimation System

- **Single Pulse Collimator Damage**
  - Never
  - Seldom
  - Always

- **Optics Tolerances**
  - Tighter
  - Looser

- **Consumable Collimators**
  - Damaged $\sim 1000 \times$ per year

- **Renewable Collimators**
  - Damaged each pulse

- **Conventional Collimators**
  - Not damaged

- **ZDR**
Accelerator Physics Tasks for CDR

• Additional lattice design work:
  – Collimation system
  – Final extraction line
  – Damping rings

• Tuning optimization:
  – All quads and sextupoles have independent power supplies—is this necessary?
  – Verify BPM specifications for feedback and tuning and performance with jitter and errors
Accelerator Physics Tasks for CDR (2)

• Update Component Specification and Tolerances:
  – Balance emittance, charge, and jitter budgets
  – Update detailed tolerance calculations

• System Cost Optimization:
  – Central injector
  – Radiation levels from halos
  – Damping rings and bunch compressors
  – Linac structures and rf system
  – Beam delivery
Accelerator Physics Tasks for CDR (3)

• **Beam Physics:**
  – Update damping ring impedance calculations
  – Update simulations of instabilities in beam lines and damping rings
  – Finalize RDDS structure wakefields and tolerances
  – Update ground motion measurements and models
  – Further study of beam-based feedback systems
  – Evaluate failure scenarios for MPS
  – Beam tails, material limits, wakefield calculations for collimators
  – Model backgrounds from beam in final focus and dump line

• **Documentation!**
Accelerator Physics Process

- System requirements
- Physics verification and system concept
- Preliminary design
- Optimized design – cost, risk, reliability
- Final conceptual design

Multi-step process
- Performance model
- Cost model
- Risk evaluation
- Reliability optimization

Close interaction of engineers, systems managers, and accelerator physicists

Starting this stage now!

Using web to enhance communication and make information accessible
Accelerator Physics Group

- Karl Bane
- John Corlett
- Paul Emma
- Linda Hendrickson
- Roger Jones
- Kiyoshi Kubo
- Zenghai Li
- Cho Ng
- Yuri Nosochkov
- Nan Phinney
- Tor Raubenheimer
- Gennady Stupakov
- Peter Tenenbaum
- Kathy Thompson
- Mark Woodley
- Kaoru Yokoya
Schedule for CDR

- Accelerator physics milestones defined to provide information to area managers
- R&D programs designed to produce results needed for accelerator physics design decisions
- Schedule driven by annual reviews when CDx Model is updated
- Component layout and specifications completed by 5/01—one year before CDR
- Detailed tuning studies and optimization during final year
High-level schedules in Appendix

More detail to be discussed tomorrow in breakout sessions
# High-level Milestones for CDR

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<th>Date</th>
<th>Milestones</th>
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<td>11/99</td>
<td>Central injector option</td>
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<td>DR &amp; BC energy choice</td>
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<td>S- &amp; L-band structure</td>
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<td>DR wiggler &amp; rf cavity</td>
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<td>S- &amp; L- rf layout</td>
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<td>S- &amp; L-band linac optics</td>
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Summary

- Ready to begin CDR:
  - System requirements are defined
  - 95% of beamline lattices exist
  - Tools are in place for lattice design and control
  - Design has sufficient flexibility and ‘overhead’ so facility can be used beyond NLC goals!
  - Cost optimization has begun based on cost model and reviews with area physicists and engineers
  - Plans to address outstanding R&D are clear and backup solutions exist if necessary!

⇒ It is time to start!