NLC - The Next Linear Collider Project

“I hear the roar of the big machine…”

X-Band Linear Collider (JLC/NLC): Luminosity Issues

2002 Linear Collider Meeting Monday Plenary

P. Tenenbaum
The Basics

• JLC/NLC linear collider design uses:
  – 11.424 GHz (“X-Band”) RF acceleration...
  – 70 MeV/m unloaded gradient...
  – $0.75 \times 10^{10}$ e$^+/e^-$ per bunch...
  – 192 bunches per RF pulse with 1.4 nsec spacing (268 nsec total train length)...
  – 120 RF pulses per second...
  – IP spot sizes approx. 250 nm x 2.5 nm...

• To achieve 2.0 – 3.5 x $10^{34}$ luminosity @ 0.5 – 1.0 TeV CM
Parameter List

- **Unified JLC/NLC parameter list**
  - some variation due to different line frequencies!
  - Other variations (bunch spacing and charge) conceivable

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Stage 1</th>
<th>Stage 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMS Energy (GeV)</td>
<td>500</td>
<td>1000</td>
</tr>
<tr>
<td>Site</td>
<td>US</td>
<td>Japan</td>
</tr>
<tr>
<td>Luminosity ($10^{33}$)</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>Repetition Rate (Hz)</td>
<td>120</td>
<td>150</td>
</tr>
<tr>
<td>Bunch Charge ($10^{10}$)</td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>Bunches/RF Pulse</td>
<td>192</td>
<td>192</td>
</tr>
<tr>
<td>Bunch Separation (ns)</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Eff. Gradient (MV/m)</td>
<td>48.5</td>
<td>48.5</td>
</tr>
<tr>
<td>Injected $\gamma \varepsilon_x / \gamma \varepsilon_y$ ($10^{-8}$)</td>
<td>300 / 2</td>
<td>300 / 2</td>
</tr>
<tr>
<td>$\gamma \varepsilon_x$ at IP ($10^{-8}$ m-rad)</td>
<td>360</td>
<td>360</td>
</tr>
<tr>
<td>$\gamma \varepsilon_y$ at IP ($10^{-8}$ m-rad)</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>$\beta_x / \beta_y$ at IP (mm)</td>
<td>8 / 0.11</td>
<td>13 / 0.11</td>
</tr>
<tr>
<td>$\sigma_x / \sigma_y$ at IP (nm)</td>
<td>243 / 3.0</td>
<td>219 / 2.3</td>
</tr>
<tr>
<td>$\theta_x / \theta_y$ at IP (nm)</td>
<td>32 / 28</td>
<td>17 / 20</td>
</tr>
<tr>
<td>$\sigma_z$ at IP (um)</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>$\gamma_{ave}$</td>
<td>0.14</td>
<td>0.29</td>
</tr>
<tr>
<td>Pinch Enhancement</td>
<td>1.51</td>
<td>1.47</td>
</tr>
<tr>
<td>Beamstrahlung $\delta B$ (%)</td>
<td>5.4</td>
<td>8.9</td>
</tr>
<tr>
<td>Photons per $e^+ / e^-$</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Two Linac Length (km)</td>
<td>12.6</td>
<td>25.8</td>
</tr>
</tbody>
</table>
NLC - The Next Linear Collider Project

Layout

- Two interaction regions (sequential, not simultaneous, operation)
  - HEIR: minimal bending, 20 mrad crossing angle (set by linac lines)
    - up to 3-5 TeV CM (someday!)
  - LEIR: more bending, 25-30 mrad crossing angle
    - Luminosity okay up to about 1 TeV CM
- Bypass lines for running below max energy
  - Most flexible for operation and installation
- Linac tunnels sized for 1 TeV CM
  - stage 1: fill 50%, run thru bypass lines to beam delivery system
  - populate 2nd half of each linac over time to reach 1 TeV CM
Electron Source

- Polarized Photocathode
- DC gun (not RF)
- Based on the SLAC source used for SLC and E-158
- Two sources planned for redundancy
- High charge/current, 80% polarization, stability (by bunch and by bunch train)
- Excellent recent results by GTL, Nagoya U, SLAC E-158 / Accelerator Dept.
Positron Source

- “Conventional” (6 GeV e\(^-\) on 4 R.L. W-Re target)
- Based on improved SLAC design
  - L-band capture (larger acceptance)
  - multiplexed targets (reduce peak shock load)
  - Bigger targets (reduce avg heat/shock/radiation damage)
- Also considering TESLA-style source (undulator in main e\(^-\) beam and thin target)

Images stolen from D. Schultz and J. Sheppard
Damping Rings

- **Main damping rings:**
  - similar to 3rd generation light sources
    - energy (1.98 GeV)
    - emittance ($\gamma \varepsilon = 3 \times 0.02 \text{ mm.mrad}$)
  - Single-turn injection and extraction of bunch trains (challenging!)

- **Pre-damping ring**
  - positrons only
  - reduces huge emittance from target to level acceptable to MDR ($\gamma \varepsilon \sim 150 \text{ mm.mrad}$)

Images stolen from T. Raubenheimer and A. Wolski
Damping Rings (2)

- Need low emittance and short damping times
  - lots of wigglers – 46 m in MDRs, 50 m in PPDR)
  - Still need to store trains for multiple machine cycles (1 cycle ~ 8 msec)
    - 3 trains stored in MDR
    - 2 trains stored in PPDR
    - gaps for kickers

- Alignment of DR elements crucial for low emittance
  - Achievable with hi-res BPMs, magnet movers, skewquad trims on sextupoles

Images stolen from A. Wolski
Damping Rings (3)

- Lots of fun storage ring issues
  - Ions
  - electron clouds
  - HOM instabilities
  - Path length control
  - Dynamic aperture (esp. with wigglers)
  - Intra-beam Scattering
  - Non-invasive beam size diagnostics
  - etc etc etc

Images stolen from A. Wolski
Bunch Compressors

- Reduce $\sigma_z$ from $\sim 5$ mm (DR) to 110 µm (linac)

- 2-stage design
  - stage 1: $5$ mm $\rightarrow$ 600 µm @ 1.98 GeV
  - Stage 2: 600 µm $\rightarrow$ 110 µm @ 8 GeV

- Prevents DR phase errors from becoming IP Energy errors

- Be careful of coherent synchrotron radiation!
Main Linacs

- About 12 km long each
- Use 0.6 m or 0.9 m X-band RF structures
- Strong wakefields drive ML design
- Short-range: cause beam break-up
  - cure with energy spread along bunch ("BNS Damping")
  - Leads to tight quad alignment tolerances
Main Linac Module

Quad with BPM:
0.3 μm x/y resolution

RF structures, each with
2 BPMs (1 each end),
5 μm x/y resolution

Quad with BPM:
0.3 μm x/y resolution

Remote-controlled magnet
translation stage, x/y degrees of
freedom, 50 nm step size

Remote-controlled girder
translation stage, x/y degrees of
freedom each end
Main Linac: Long Range Wakefields

- Address by detuning (different HOM freqs in different cells) and direct damping
  - Implies tolerance on HOM freqs, structure straightness
- Short structs: need to interleave 2-3 structure types on a girder
  - Implies tolerance on alignment of structures on girder
- Additional reduction via sub-train feedback
  - Relies on deflections within train being constant from train to train
## Main Linac Emittance Budget

<table>
<thead>
<tr>
<th>Effect</th>
<th>Tolerance</th>
<th>$\Delta \gamma \varepsilon_y$, mm.mrad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam-to-Quad Offsets</td>
<td>2.0 µm</td>
<td>0.005</td>
</tr>
<tr>
<td>Quad Strength Errors</td>
<td>0.1%</td>
<td>0.00001</td>
</tr>
<tr>
<td>Struc-to-Girder Misalignments</td>
<td>30 µm</td>
<td>0.0014 (single-bunch) 0.0002 (multi-bunch)*</td>
</tr>
<tr>
<td>Struc-to-Girder Tilts</td>
<td>30 µrad</td>
<td>0.0008</td>
</tr>
<tr>
<td>Struc BPM Resolution</td>
<td>5 µm</td>
<td>0.0006</td>
</tr>
<tr>
<td>Quad Rotations</td>
<td>200 µrad</td>
<td>0.0008</td>
</tr>
<tr>
<td>Mover Steering Interval</td>
<td>30 minutes</td>
<td>0.0004</td>
</tr>
<tr>
<td>Structure Bow</td>
<td>50 µm</td>
<td>0.0002*</td>
</tr>
<tr>
<td>Cell-to-Cell Errors</td>
<td>3.5 µm</td>
<td>0.0002*</td>
</tr>
<tr>
<td>HOM Freq Errors</td>
<td>1 MHz</td>
<td>0.0002*</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0.0099 (50%)</strong></td>
<td></td>
</tr>
</tbody>
</table>
Both IRs use short “Raimondi/Seryi” design with integrated collimation
- Cancel coll aberrations in FF

Principal challenges:
- Delicate cancellation of aberrations
- Stability – both position and strength – of magnets, esp. final doublet
- Collimation – wakefields, protection of BDS, protection of collimators
Stabilization of BDS

- Steering feedbacks
- IP optimization fbcks
  - “dither” waist, eta, coupling and tune on luminosity signal
- IP Collision steering feedback
  - tune beam-beam offset on deflection signal
- Sub-train IP Collision feedback?
- Fast active final doublet position control

Images stolen from L. Hendrickson, T. Himel, S. Smith, TESLA-TDR

P. Tenenbaum
Stabilization of BDS (2)

- Longer term: driven by diffusive ground motion

- Tools to preserve luminosity
  - IP collide feedback
  - steering feedback through sextupoles
  - Adjust aberrations via dither feedbacks

- Only 1 overall realign needed per year
**BDS Energy Scaling**

- Lower energy – aberrations get worse
- Higher energy – SR dilutions get worse
- Can be addressed by scaling BDS bends – changes geometry
- In practice, little improvement seen at lower energies

Plot data courtesy Y. Nosochkov
Conclusion and Provocation

• **JLC/NLC pushes X-band technology to the state of the art (and maybe a bit past)**
  - gradient issues – see next talk!
  - wakefields make linac more challenging, requires more/better diagnostic and control

• **JLC/NLC damping rings are not too far from existing light sources**

• **JLC/NLC BDS is reasonable extrapolation from SLC and FFTB**
  - not too different from CLIC, TESLA BDS for similar energies

• **It’s been an exciting and productive couple of years since LC99!**