Limitations on the LCD VXD Inner Radius due to Backgrounds

Tom Markiewicz/SLAC
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The Experts

- Takashi Maruyama (SLAC)
  - Pairs and Neutron Backgrounds
- Jeff Gronberg (LLNL)
  - Pair and Neutron Backgrounds
- Stan Hertzbach (U. Mass)
  - Synchrotron Radiation
Background Sources Important to the VXD

• **Charged Particles**
  – Direct Hits from $e^+e^-$ pairs produced in the beam-beam interaction
  – Charged secondaries made when beam-beam $e^+e^-$ pairs hit something else

• **Neutrons**
  – Beam Dump
  – Lost Particles
    • Pairs
    • Radiative Bhabhas
    • Disrupted Beam

• **Photons**
  – Synchrotron radiation from final focus, especially the final doublet
  – Photons made when beam-beam $e^+e^-$ pairs hit something else
Caveats and Excuses

• Almost all quantitative work done for:
  – ZDR final focus
  – $L^* = 2$
  – Small Detector
  – 1 TeV c.o.m.

• Current Model
  – Raimondi Final Focus
    • Integrate local chromaticity correction into final quad doublet by interleaving sextupoles
    – $L^* = 4.3$ m
      • Chosen because it would place QD0 (first quad) OUTSIDE the (closed) door of the Small Detector
  – Large Detector
    • Once charged secondaries from pairs splattering on QD0 are absorbed by low Z mask, don’t need 6 Tesla to control VXD hit density
    – 500 GeV c.o.m.
      • Politics
Pinch makes beamstrahlung photons:
1.5E10 per bunch @ \( <E> = 30.3 \text{ GeV} \) (0.83 Mw)

Particles that lose a photon are off-energy

- Physics problem: luminosity spectrum
- Extraction line problem:
  - 1 TeV design has 77 kW of beam with < 50% \( E_{\text{nom}} \), 4kW lost (0.25% loss)
  - Working plan: Ignore for now- not a problem @ 500 GeV; @ 1 TeV either measure Pol, E upstream, steal undisrupted pulses for diagnostics, calibrate other

Photons themselves go straight to dump

- Not a background problem, but angular dist. (1 mrad) limits extraction line length

Photons interact with opposing e,\( \gamma \) to produce e+,e- pairs and hadrons

\[ \gamma \gamma \rightarrow \text{e+e- (Breit-Wheeler)} \]
\[ e\gamma \rightarrow \text{ee+e- (Bethe-Heitler)} \]
\[ ee \rightarrow \text{eee+e- (Landau-Lifshitz)} \]
\[ \gamma \gamma \rightarrow \text{hadrons} \]
e+, e- pairs from beams. $\gamma\gamma$ interactions
44K per bunch per side @ $<E>=10.5$ GeV (0.85 W)
Direct Pairs

Pt of e+e- from given bunch = Sum of
- Pt from individual pair creation process
  - small
- Pt from collective field of opposing bunch
  - large
  - limited by finite size of the bunch

Same-sign focused
Opposite-sign ejected
Dead-Cone Formalism

For Helix:

\[ R = 2\rho \sin \frac{\phi}{2}, \]

where \( \rho(m) = \frac{p_{\perp} (GeV)}{0.3B(Tesla)} \)

and \( \phi = \frac{p_{\perp} l}{p_z \rho} = \frac{0.3Bl}{p_z} = \frac{0.3Bl}{p \cos \theta_{\max}} \approx \frac{0.3Bl}{p} \)

then

\[ p_{\text{max}} \Rightarrow \phi = \pi \]

\[ \varepsilon E_{\text{beam}} = p_{\text{max}} \]

\( \theta_{\text{max}} \) is calculated from Disruption parameter

\[ \theta_{\text{max}} \propto \frac{\sigma_x}{\sigma_z} \sqrt{\frac{D_x}{\varepsilon}} \]

and

\[ R_{\text{max}} = 2\rho = 2 \frac{p \sin \theta_{\text{max}}}{0.3B} \]

\[ \theta_{\text{dead}} = \frac{R_{\text{max}}}{l_{\text{mask}}} \]
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e+e- Pair $p_T$ vs. theta Distribution

Hard edge from finite beam size

“High” $p_T$ inside cone

$e^+, e^-$ with high intrinsic $p_T$ can hit small radius VXD

Low $p_T$/high angle curl in field

50 mrad
Pair Stay-Clear from Guinea-Pig Generator and Geant

Maximum Radius of Pairs vs. Z

- 6 Tesla
- No crossing angle

- vxd 3
- vxd 2
- vxd 1
Another View of the Pairs

Beam-beam Pairs in Solenoid with 10 mrad Crossing Angle

- 6 Tesla
  - $Z = 6.5 \text{ cm}$, $R = 2.6 \text{ cm}$

- 4 Tesla
  - $Z = 4.4 \text{ cm}$, $R = 3.2 \text{ cm}$
Pair Stay-Clear from Analytic Formalism
(NLC-1000A Beam Parameters)
e, γ, n secondaries made when pairs hit high Z surface of LUM or Q1

Pair distribution at z=200

High momentum pairs mostly in exit beampipe

Low momentum pairs trapped by detector solenoid field
Charged Secondaries

- Spiral in detector field back to VXD
- To remove:
  - Shield the field lines which direct secondaries back to VXD layer with low Z absorber
- For L* = 2m case:
  - 10cm long x 2mm thick Be “RING Mask” at z = 65cm
    - inside vacuum pipe
    - 15cm behind tip of M1 so secondaries that it itself produces are shielded
    - becomes the limiting aperture for SR radiation; the further away from the IP it is, the worse a limit it becomes
    - perhaps fine tuning solenoid fringe field will help
New Masking

Small Reryllium Shield

<table>
<thead>
<tr>
<th></th>
<th>No Shield</th>
<th>With Shield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>50</td>
<td>68</td>
</tr>
<tr>
<td></td>
<td>11%</td>
<td>84%</td>
</tr>
<tr>
<td>BPEX</td>
<td>293</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>64%</td>
<td>16%</td>
</tr>
<tr>
<td>Flange</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11%</td>
<td></td>
</tr>
<tr>
<td>Q1</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3%</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>454</td>
<td>81</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>
1.2 cm VXD L1 in BOTH L & S Detectors

With few backscattered hits, LCD group currently feels aggressive 1.2 cm VXD is also possible for Large Detector (3-4 T) detector

\[ \text{Hits / bunch} \]

- Black: Layer 1
- Turquoise: Layer 2
- Green: Layer 3
- Blue: Layer 4
- Red: Layer 5

\[ \sim 3.5 \times \text{more} \]
Layer 1 hits at 3 Tesla

2.0 hits/mm\(^2\)/train
84% from multiple hits by primary pair electrons
New Large Detector model

- Update the Large detector model:
  - Change VXD to same design as the small detector.
  - Assume 4T B-field
  - Move inner edge of M1 out to respect the pair edge.
  - Add a second ring to shield SVX layer 2
SVX Backgrounds for new LCDs

Hit Density in VXD and Central Tracker

- $e^+e^-$ (Small Detector)
- $e^+e^-$ (Large Detector)
- Photons (Small Detector) converted $\sigma=0.01$
Masking Charged Secondaries When $L^* = 4.3m$

For LCD-S 1.2cm field line is outside all relevant apertures by $z = 4.3m$

For LCD-L -1.2cm field line falls on Q1, where it is easy to put shielding, other lines fall in apertures. We need to study if this is a problem, but for now assume that a low Z mask position can be found that does not interfere with SR or beam and is far from the IP.
Total VXD Neutron Backgrounds

• Neutron Sources:
  • $e^+/e^-$ pairs and radiative bhabhas hitting beam-pipe, luminosity monitor, masks and magnets in the extraction line: 1cm radius aperture beginning at 6m
  • Disrupted beam lost in the extraction line.
    • 0.25% beam loss in recent redesign
  • Beam (~10 MW @ 1 TeV) and beamstrahlung photons (1 MW @ 1 TeV) in the dump

Neutron hit density in VXD @ 1.2 cm

(2m L* Design, 1 TeV c.o.m.)

<table>
<thead>
<tr>
<th>Source</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam-Beam pairs (small det.)</td>
<td>$1.9 \times 10^9$ hits/cm$^2$/yr</td>
</tr>
<tr>
<td>Beam-Beam pairs (large det.)</td>
<td>$4.4 \times 10^9$ hits/cm$^2$/yr</td>
</tr>
<tr>
<td>Radiative Bhabhas</td>
<td>$0.01 \times 10^9$ hits/cm$^2$/yr</td>
</tr>
<tr>
<td>Beam loss in extraction line</td>
<td>$0.01 \times 10^9$ hits/cm$^2$/year</td>
</tr>
<tr>
<td>Backshine from dump</td>
<td>$0.25 \times 10^9$ hits/cm$^2$/yr</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$2.2-4.7 \times 10^9$ hits/cm$^2$/yr</strong></td>
</tr>
</tbody>
</table>
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Neutrons produced by Pairs and Rad. Bhabhas

Neutron Background

Neutron Sources

\( e^+ e^- \) pairs

Radiative Bhabhas
Neutrons produced by Pairs and Rad. Bhabhas that hit the VXD

• Neutrons which reach the IP are produced close to the IP, mainly in the luminosity monitor

• At z~0, the flux of these neutrons is independent of r. While detailed simulations are needed, we anticipate rate will go down by a factor of 4 as L* doubles.
Extraction Line Beam Loss: Not a VXD Problem
150 m long with common γ and e- dump

Problem: Handling the large low E tail on the disrupted beam cleanly enough to allow extraction line diagnostics

2.1% of beam with 77 kWatts has E<250 GeV
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Neutrons from the Beam Dump

Geometric fall off of neutron flux passing 1 mrad aperture [parent distribution for next slide]
Dump-produced Neutron flux at z=0 as a function of radius

- 1.2E10 neutrons hit the beampipe within +/-5cm at r>1.0 cm
- 30% scatter into VXD
- Divide by area of VXD L1 to get quoted hit density = 0.25E9/cm^2/y
- Fall off for r>1.0 cm due to limiting aperture of EXTRACTION LINE QUAD DOUBLET (currently 10-11 mm from L=6-10.8 m from the IP; SR concerns MAY require larger aperture)
- Fall off as r -> 0cm comes from reduced solid angle view of the dump
- As r is reduced need to integrate more of this curve.
As VXD inner radius is reduced by x2

- Flux from dump up x10
- Hit density up by x40 from 0.25E9 to 10E9
- dump becomes dominant source of neutron hits

- All numbers are from OLD simulation and may change if extraction line aperture increases
Synchrotron Radiation at SLC/SLD

- SR from triplet WOULD have directly hit beam-pipe and VXD
- Conical masks (M2) were installed to shadow the beam pipe inner radius and geometry set so that photons needed a minimum of TWO bounces to hit a detector
- Small cylindrical masks (M4) were placed within the beam pipe close to the IP to close a small “one bounce” window. These were a large source of charged DC hits (presumably due to off energy beam particles which scraped upstream, hit, and made ~6 GeV pions)
- Quantitative measurements of background rates could be fit by a “flat halo” model where it was assumed that between 0.1% and 1% (in the early days) of the beam filled the phase space allowed by the collimator setting.
NLC SR Design Criteria

- No direct SR hits ANYWHERE. Do NOT hit:
  - inner bore of QD0
  - Conical M1 mask
  - Be Ring Mask protecting VXD-L1
  - Beam Pipe at VXD
  - Extraction line beam pipe or magnet aperture
Sources of Beam Halo

- Calculable contributions to the expected halo are SMALL. Per $10^{12}$ particles (1 train), we expect:
  - DR/RTL/Compressor: $?$
  - Main Linac Wakefields: $<10^7$ (Tor)
  - Captured Dark Current: $\sim10^4$ (Brinkmann)
  - Multipoles in main linac: $?$
  - Linac coulomb/compton: $\sim10^4$ (Tor)
  - Linac mistuning: $?$
  - BDS coulomb/compton: $\sim10^3$ (ZDR)

- SLC experience: $\sim0.1\%$ of beam in halo
  - often thought to have come from DR/RTL but Panta says all RTL scans show Gaussian beam. Panta feels SLC problems arose from non-linear nature of the FF itself, and will GO AWAY with the new FF.

- Expect some improvement from pre-linac collimation and new FF
- Present design assumes $10^9$ halo particles per train
  - current (pre-Panta) thinking should try to collimate at $10^{-6}$ level (transmitted halo $\sim$ halo generated by edge scattering of the collimators)
Basic Accelerator Physics
Angular Divergence

\[ \sigma_X = \sqrt{\varepsilon_X \beta_X} \quad \sigma_{X'} = \sqrt{\varepsilon_X / \beta_X} \]

- Emittance is as good as designers can deliver
- Beta function is set to give desired spot size and therefore luminosity
- Current NLC parameters: \( \sigma_x' = 28 \, \mu\text{rad}, \sigma_y' = 40 \, \mu\text{rad} \) at 500 GeV

<table>
<thead>
<tr>
<th>Variable</th>
<th>NLC0500A</th>
<th>NLC0500B</th>
<th>NLC0500C</th>
<th>NLC1000A</th>
<th>NLC1000B</th>
<th>NLC1000C</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EmitX</td>
<td>7.641E-04</td>
<td>8.930E-04</td>
<td>1.022E-03</td>
<td>3.909E-04</td>
<td>4.562E-04</td>
<td>5.225E-04</td>
<td>(10^{-8} , \text{m-rad})</td>
</tr>
<tr>
<td>EmitY</td>
<td>1.146E-05</td>
<td>1.984E-05</td>
<td>2.862E-05</td>
<td>5.863E-06</td>
<td>1.014E-05</td>
<td>1.463E-05</td>
<td>(10^{-8} , \text{m-rad})</td>
</tr>
<tr>
<td>Sig_x</td>
<td>276</td>
<td>327</td>
<td>365</td>
<td>198</td>
<td>234</td>
<td>261</td>
<td>nm</td>
</tr>
<tr>
<td>Sig_y</td>
<td>3.39</td>
<td>4.88</td>
<td>7.57</td>
<td>2.71</td>
<td>3.90</td>
<td>5.41</td>
<td>nm</td>
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<tr>
<td>Oide_y</td>
<td>1.18</td>
<td>1.70</td>
<td>2.16</td>
<td>1.74</td>
<td>2.50</td>
<td>3.18</td>
<td>nm</td>
</tr>
<tr>
<td>Sig_x'</td>
<td>27.6</td>
<td>27.3</td>
<td>28.0</td>
<td>19.8</td>
<td>19.5</td>
<td>20.0</td>
<td>(\mu\text{rad})</td>
</tr>
<tr>
<td>Sig_y'</td>
<td>33.9</td>
<td>40.7</td>
<td>37.8</td>
<td>21.7</td>
<td>26.0</td>
<td>27.0</td>
<td>(\mu\text{rad})</td>
</tr>
</tbody>
</table>
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1 TeV Ray Plots

X vs S for 8.00 σ * 20. μrad

Y vs S for 40.00 σ * 27. μrad
Photons from QF1 are the problem.

Magnet apertures on input side very generous.

Extraction Line aperture filled.
IP Close-Ups of SR Fans

280 µrad

200 µrad
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**Stan’s SR Results**

Assumes 1E-3 halo

$E_{\gamma} \sim 3-4$ MeV

Sextupoles not yet included

Effective vs. Ideal accounts for 1% beam energy spread and planar collimation

### Collimation Depth

<table>
<thead>
<tr>
<th>Beam Pipe Radius (mm)</th>
<th>Max. allowed x'</th>
<th>Max allowed y'</th>
<th>Ideal x coll. Depth</th>
<th>Ideal y coll. Depth</th>
<th>Effective x coll.depth</th>
<th>Effective y coll. Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.50</td>
<td>280 $\mu$rad</td>
<td>1000 $\mu$rad</td>
<td>10 sigma</td>
<td>25 sigma</td>
<td>5.6 sigma</td>
<td>16.6 sigma</td>
</tr>
<tr>
<td>9.25</td>
<td>240 $\mu$rad</td>
<td>1000 $\mu$rad</td>
<td>8.57 sigma</td>
<td>25 sigma</td>
<td>4.6 sigma</td>
<td>16.6 sigma</td>
</tr>
<tr>
<td>9.00</td>
<td>200 $\mu$rad</td>
<td>1000 $\mu$rad</td>
<td>7.14 sigma</td>
<td>25 sigma</td>
<td>3.6 sigma</td>
<td>16.6 sigma</td>
</tr>
</tbody>
</table>

### Hits @ BF

<table>
<thead>
<tr>
<th>Beam Pipe Radius (mm)</th>
<th>Hits/ $mm^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flare</td>
<td>Min. R</td>
</tr>
<tr>
<td>9.50</td>
<td>3.4E+04</td>
</tr>
<tr>
<td>9.25</td>
<td>4.0E+05</td>
</tr>
<tr>
<td>9.00</td>
<td>1.7E+06</td>
</tr>
<tr>
<td>8.75</td>
<td></td>
</tr>
<tr>
<td>8.50</td>
<td></td>
</tr>
<tr>
<td>8.25</td>
<td></td>
</tr>
<tr>
<td>8.00</td>
<td></td>
</tr>
</tbody>
</table>
Collimator Phase Space

• How tightly you can collimate is a very slippery question
  – Limiting apertures at the IP
  – Minimum collimation apertures in the collimation section
    • Lost particle heating
    • Image current heating
    • Wakefields
  – Maximum number of muons generated (for a given halo)
  – Radiation in the collimation section (for a given halo)
Limits to Collimator Phase Space

- Available aperture is reduced by effects not yet considered in detail:
  - New FF has large angular dispersion \( \left( \frac{x'}{\Delta E/E} \right) \equiv \eta' = 5.9 \) mrad at IP
    - Allow for 1% energy spread at the IP = 59 \( \mu \)rad
    - Reduce aperture by \( \sqrt{2} \) to account for rectangular collimation in \( x, x', y, y' \)
    - 200 mrad in \( x \) is effectively \( \frac{200 - 59}{28/1.4} = 3.6 \)sigma
    - At this level, the GAUSSIAN part of the beam distribution will start to contribute, so it is hard to imagine collimating any tighter than this
Conclusion

A VXD beam pipe of about 10mm is probably as aggressive as you want to get, especially before we understand the beam halo, energy spread, and backgrounds in more detail.