Beam-Gas-Bremsstrahlung and Coulomb Scattering in the NLC Beam Delivery System

Conditions for Calculation:

1. Program is DECAY TURTLE modified for BGB and Coulomb scattering. Used at PEP-I, SLC, PEP-II, and PEP-N. Now called Lost Particle TURTLE (LPTURTLE).

2. BDS model is P. Raimondi, BDS112, with $E_{\text{beam}} = 500$ GeV.

3. Residual gas is 62% H$_2$, 22% CO, 16% CO$_2$ by pressure (L. Eriksson). This gives a radiation length of 771 m at 1 atm.

4. Start with $P = 50$ nTorr $\Rightarrow L_{\text{rad}} = 1.17 \times 10^{13}$ m, $N_{e^-} = 1.4 \times 10^{12}$ / pulse train

5. LPTURTLE forces BGB and coulomb scattering uniformly along the 1433 m beam line.

6. Output histograms in PAW (T. Fieguth format, modified for NLC BDS). Make separate histograms for BGB electrons, BGB photons, and coulomb scattered electrons. All histograms are arbitrary units. Tables 1 and 2 are actual rates.

7. Apertures (radius):

- Octupoles 0.8 cm, 1.0 cm
- Sextupoles 1.0 cm
- Quadrupoles 1.0 cm, 2.0 cm
- Dipoles 5.0 cm
- 3 absorbers in FF 0.3-0.9 cm
- Vertex detector 1.2 cm
- Energy slit 0.34 cm (1.7%)
- New coll. at Z=55m, 0.5 cm
Conditions for calculation (cont.):

8. Octupoles off, apertures in place.

9. “Final doublet” includes two quadrupoles, two sextupoles, one octupole. All final doublet apertures and 1st quadrupole in dump line are 1.0 cm radius.
**Rough Estimate of Rates**

**BGB**

\[
N_{\text{BGB}}/\text{pulse train} = t \ln\left(\frac{E_2}{E_1}\right) N_{e^-},
\]

where,

\[
E_2 = \text{maximum photon energy} = E_{\text{beam}}
\]

\[
E_1 = \text{minimum photon energy} = 0.01 \ E_{\text{beam}}
\]

\[
t = \# \text{ of radiation lengths in 1500 m beam line at 50 nTorr} = (1500/1.17 \times 10^{13}) = 1.28 \times 10^{-10} \text{ rl}
\]

\[
N_{e^-} = 1.4 \times 10^{12} / \text{pulse train}
\]

\[
N_{\text{BGB}} = 825 \text{ electrons and photons/pulse train in the BDS}
\]

**Coulomb Scattering**

\[
N_{\text{coul}} = 4.52 \times 10^{-11} P(\text{Torr}) \ N_{e^-} \left(\frac{1}{E_{\text{beam}}}\right)^2(L_{\text{beam}})(1/\Theta_{\text{min}}^2 - 1/\Theta_{\text{max}}^2)
\]

where,

\[
\Theta_{\text{min}} = 10^{-5} \text{ rad},
\]

\[
\Theta_{\text{max}} = 2 \times 10^{-3} \text{ rad}
\]

\[
E_{\text{beam}} = 500 \text{ GeV}
\]

\[
L_{\text{beam}} = 1500 \text{ m}
\]

\[
N_{\text{coul}} = 190 \text{ electrons/pulse train in the BDS, @ 500 GeV/electron}
\]
Inverse Compton Scattering from Thermal Photons

\[ N_{\text{thermal}} / \text{pulse train} = \sigma_T n_\gamma N_{e-} L_{\text{beam}}, \]

where,

\[ \sigma_T (\Delta E > 0.01E_{\text{beam}}) \approx 1.2 \text{ barns} \quad @ \quad E_{\text{beam}} = 500 \text{ GeV} \]

\[ n_\gamma \approx 20T^3 \gamma/\text{cm}^3 = 5 \times 10^8 \gamma/\text{cm}^3, \quad T = 300 \text{ K} \]

\[ N_{e-} = 1.4 \times 10^{12} / \text{pulse train} \]

\[ L_{\text{beam}} = 1500 \text{ m} \]

\[ <E_\gamma> = 0.07 \text{ ev} \quad @ \quad T = 300 \text{ K} \]

\[ N_{\text{thermal}} = 126 \text{ electrons/pulse train} \]

Moller Scattering

\[ N_{\text{Moller}} = 6.4 \times 10^{-12} P(\text{Torr}) N_{e-}(1/E_{\text{beam}})^2(L_{\text{beam}})(1/\Theta_{\text{min}}^2) \]

(for small \( \Theta_{\text{min}} \) and “NLC” gas )

where,

\[ \Theta_{\text{min}} = 10^{-5} \text{ rad}, \]

\[ E_{\text{beam}} = 500 \text{ GeV} \]

\[ L_{\text{beam}} = 1500 \text{ m} \]

\[ N_{\text{Moller}} = 26 \text{ electrons/pulse train} @ \approx 500 \text{ GeV/electron} \]
1 NLC BGB Charged Hits and Energy Deposited vs $Z$, BDS112
2 NLC BGB Interaction Locations for Hits Near IP, BDS112

-20.GT.Zhit.LT.10m

Vertex Detector

Downstream Quadrupole

Final Doublet
NLC BGB Charged Hits and Energy Distribution Near IP, BDS112
5 NLC BGB Energy Distribution Near IP, BDS112

**Vertex Detector**
Collimator Z = 55 m, x = 5 mm

**Downstream Quadrupole**
Collimator Z = 55 m, x = 5 mm
6 NLC BGB Energy Distribution Near IP, BDS112

Final Doublet

Collimator $Z = 55$ m, $X = 5$ mm
1 NLC BGB Photon Hits and Energy Deposited vs Z, BDS112

**Photon Hits**

<table>
<thead>
<tr>
<th>Distance from IP (meters)</th>
<th>Number/20 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1500</td>
<td>8000</td>
</tr>
<tr>
<td>-1000</td>
<td>7000</td>
</tr>
<tr>
<td>-500</td>
<td>6000</td>
</tr>
<tr>
<td>0</td>
<td>5000</td>
</tr>
</tbody>
</table>

**Energy Deposit**

<table>
<thead>
<tr>
<th>Distance from IP (meters)</th>
<th>GeV/20 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1500</td>
<td>8000</td>
</tr>
<tr>
<td>-1000</td>
<td>7000</td>
</tr>
<tr>
<td>-500</td>
<td>6000</td>
</tr>
<tr>
<td>0</td>
<td>5000</td>
</tr>
</tbody>
</table>

**Energy Distribution of Hits**

<table>
<thead>
<tr>
<th>Photon Energy (GeV)</th>
<th>Number/10 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6000</td>
</tr>
<tr>
<td>10</td>
<td>5000</td>
</tr>
<tr>
<td>20</td>
<td>4000</td>
</tr>
<tr>
<td>30</td>
<td>3000</td>
</tr>
<tr>
<td>40</td>
<td>2000</td>
</tr>
<tr>
<td>50</td>
<td>1000</td>
</tr>
<tr>
<td>60</td>
<td>0</td>
</tr>
</tbody>
</table>

Entries: 344110
2 NLC BGB Interaction Locations for Photon Hits Near IP, BDS112

-20.GT.Zhit.LT.10m

Vertex Detector

Downstream Quadrupole

Final Doublet
4 NLC Photon Hits and Energy Distribution Near IP, BDS112

Photon Hits

-20.GT.Zhit.LT.10m
Collimator Z = 55 m, x = 5 mm

Number/meter

Distance from IP (meters)

-20.GT.Zhit.LT.10m
Collimator Z = 55 m, x = 5 mm

Number/meter

Distance from IP (meters)

-20.GT.Zhit.LT.10m
Collimator Z = 55 m, x = 5 mm

Number/10 GeV

Photon Energy (GeV)

-20.GT.Zhit.LT.10m
Collimator Z = 55 m, x = 5 mm

Number/10 GeV

Photon Energy (GeV)
NLC Coulomb Hits and Energy Deposited vs Z, BDS112

**Charged Hits**

- Number/20 m
- Distance from IP (meters)

**Energy Deposit**

- Entries: 1691.3
- x 10^3
- GeV/20 m
- Distance from IP (meters)

**Energy Distribution of Hits**

- Entries: 1691.3
- Number/10 GeV
- Charged Energy (GeV)
2 NLC Coulomb Interaction Locations for Hits Near IP, BDS112

-20 GT ZhitLT. 10m

VerteX Detector

Downstream Quadrupole

Final Doublet
4 NLC Coulomb Hits Near IP, BDS112

Charged Hits

-20.GT.Zhit.LT.10m
Collimator Z = 55 m, X = 5 mm

Entries 504

Number/meter

Distance from IP (meters)
Table 1. Hits and Energy Deposited Near IP (per pulse train)

No new collimator for BGB
P = 50 nTorr

<table>
<thead>
<tr>
<th>Hit Location</th>
<th>BGB charged</th>
<th>BGB photons</th>
<th>Coulomb Scattering</th>
<th>All lost particles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>E$_{dep}$ (GeV)</td>
<td>N</td>
<td>E$_{dep}$ (GeV)</td>
</tr>
<tr>
<td>Downstream Quad</td>
<td>3.8</td>
<td>1000</td>
<td>2.3</td>
<td>206</td>
</tr>
<tr>
<td>Vertex Detector 1.2 cm</td>
<td>2.8</td>
<td>470</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>QD0</td>
<td>1.8</td>
<td>210</td>
<td>0.9</td>
<td>77</td>
</tr>
<tr>
<td>SD0</td>
<td>0.1</td>
<td>~0</td>
<td>0.7</td>
<td>69</td>
</tr>
<tr>
<td>QF1</td>
<td>0.2</td>
<td>~0</td>
<td>1.3</td>
<td>121</td>
</tr>
<tr>
<td>SF1</td>
<td>0.5</td>
<td>225</td>
<td>0.3</td>
<td>36</td>
</tr>
<tr>
<td>Octupole (Z=16m)</td>
<td>4.3</td>
<td>2050</td>
<td>2.7</td>
<td>244</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2. Hits and Energy Deposited Near IP (per pulse train)

New horizontal collimator at 55m from IP, half-aperture = 0.5 cm
P = 50 nTorr

<table>
<thead>
<tr>
<th>Hit Location</th>
<th>BGB charged</th>
<th>BGB photons</th>
<th>Coulomb Scattering</th>
<th>All lost particles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>E\text{\textsubscript{dep}} (GeV)</td>
<td>N</td>
<td>E\text{\textsubscript{dep}} (GeV)</td>
</tr>
<tr>
<td>Downstream</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quad</td>
<td>3.3</td>
<td>834</td>
<td>0.13</td>
<td>13</td>
</tr>
<tr>
<td>Vertex Detector 1.2 cm</td>
<td>2.5</td>
<td>360</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>QD0</td>
<td>1.7</td>
<td>165</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SD0</td>
<td>0.1</td>
<td>~0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>QF1</td>
<td>0.2</td>
<td>~0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SF1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Octupole (Z=16m)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

|          |   |                         |   |                         |   |                         |   |                         |
| Downstream |   |                         |   |                         |   |                         |   |                         |
Table 3. Compare Beam-Gas and $e^+/e^-$ Pair Backgrounds

<table>
<thead>
<tr>
<th>Hit Location</th>
<th>NLC Beam-Gas-Brem, 1 nT</th>
<th>NLC $e^+/e^-$ pairs</th>
<th>BaBar Beam-Gas-Brem, 1 nT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>$E_{ave}$ (GeV/hit)</td>
<td>$E_{tot}$ (Gev/PT)</td>
</tr>
<tr>
<td>Vertex Detector</td>
<td>0.10 150 15</td>
<td>2.9x10^4 0.02 580</td>
<td>10 (7x10^4 GeV/sec)</td>
</tr>
<tr>
<td>Lum. Monitor</td>
<td>0.15 270 40</td>
<td>1.3x10^7 1.0 1.3x10^7</td>
<td>1.6x10^9 GeV/sec</td>
</tr>
<tr>
<td></td>
<td>(1.8x10^3 GeV/sec)</td>
<td></td>
<td>(1x10^7 GeV/sec)</td>
</tr>
</tbody>
</table>
BGB HITS AT IP vs. BEAMPIPE RADIUS

Both Beams

Pressure = 1 nT
**Compare NLC with TESLA TDR**

**TESLA TDR, p. IV-138:**

\[ P = 5 \times 10^{-9} \text{ mbar (of CO)} = 5 \times 10^{-12} \text{ atm} = 3.8 \text{ nTorr of CO} \]

1 R.L. of CO = 304 m @ 1 atm, (NLC used R.L. = 771 m @ 1 atm (different gas))

TESLA Result: “3 x 10⁻³ electrons/bunch crossing leave the beam pipe near the IP” (no information about aperture and beam pipe sizes).

For a TPC with 55 µsec sensitive time (163 bunch crossings) this is

\[ (3 \times 10^{-3})_{163} = 0.5/\text{TPC sensitive time} \]

**Scale NLC Results to TESLA:**

\[
\text{NLC} = \left( \frac{8.5}{\text{pulse train}} \right) \left( \frac{3.8 \text{ nT}}{50 \text{ nT}} \right) \left( \frac{771/304}{2 \times 10^{10}/1.4 \times 10^{12}} \right) = 23 \times 10^{-3}/\text{pulse train (NLC)} \]

vs.

\[ 3 \times 10^{-3}/\text{bunch crossing (TESLA)} \]

Why a factor of \( \approx 8 \) different? Need to understand the TESLA result in detail to make sure we are comparing the same conditions. (If only NLC vertex detector hits are counted, the NLC/TESLA difference is only a factor of two.)
Summary and Conclusions

1. For a residual gas pressure of 50 nT get 8.5 hits/pulse train (1627 GeV) on apertures within ±15 m of the IP, and 2.5 hits/pulse train (360 GeV) on a 1.2 cm radius vertex detector. Rates are for each beam.

2. If the residual gas pressure was reduced to 1 nT in the last 250 m of the BDS, the above rates would be 0.2 and 0.05 hits/pulse train/beam respectively.

3. Adding a new collimator 55 m from the IP intercepts nearly all of the BGB photons and those BGB electrons which would otherwise have hit the outboard end of the final doublet.

4. BGB hits in the vertex detector region are concentrated in the horizontal plane on one side of the IP beampipe. Increasing the beampipe radius from 1.0 to 2.0 cm eliminates about 2/3 of the hits in that region.

5. The energy/pulse train from BGB hits in the vertex detector region is about a factor of 40 less than the energy from e+/e- pairs for a 1 cm radius beampipe. However, the average energy/hit is 150 GeV for BGB and only 20 MeV/hit for e+/e- pairs.

5. There are not enough beam-gas-bremsstrahlung and coulomb scatters to cause a muon problem, even at 50 nT.
**Future Work**

1. Use GEANT for a BGB calculation. Need to make the radiation length of the residual gas large enough to force a statistically significant number of interactions, but small enough to make secondary interactions negligible, probably about 1% r.l.

2. Find out the details of the TESLA BGB calculation and understand the difference between the NLC and TESLA results.

3. For input to the detector GEANT simulation, use LPTURTLE to write out ntuples for particles that hit the vertex detector and other objects near the IP.

4. Put beam-gas-bremsstrahlung, coulomb scattering, inverse Compton scattering, and Moller scattering in the new Woodley/Raimondi version of TURTLE.