CTF3/CLIC Beam Loss Simulations

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CTF3/CLIC Beam Loss Simulations

Compact Linear Collider (CLIC)

- Proposed design for $e^+/e^-$ linear collider based at CERN
- 3-5 TeV CM energy
- $10^{34}-10^{35}$ cm$^{-2}$ s$^{-1}$ max luminosity
- Two beam acceleration scheme
- 150 MV/m acceleration gradient

Third CLIC Test Facility (CTF3)

- Prototype facility that will demonstrate the essential technologies of CLIC
- Critical issues for CTF3:
  - Achieving a high current and high frequency drive beam
  - Stability of drive beam decelerator
  - Achieving 150 MV/m acceleration gradient
Current Status of CTF3

- Housed in the LEP Pre-injector complex (LPI) at CERN
- Drive Beam Accelerator currently under construction
- Scheduled completion in 2008
Development of a Beam Loss Detection System at CTF3/CLIC

- Northwestern University will design and build a beam loss detection system for CTF3 based on the detection of secondary particles.


- Motivation for Beam Loss Detection System:
  - Machine protection
  - Tuning of machine parameters
  - Detailed studies of beam halo and other beam loss mechanisms

- Beam losses also measured with wall current monitors (sensitive to % level) – sufficient for machine protection at CTF3 but beam loss detectors still useful for machine tuning.

- A future CLIC accelerator will have much higher beam current and energy
  - Beam losses will need to be kept at a much lower level than CTF3 ($<\%_{00}$)
  - CLIC will need to rely more heavily on beam loss detectors for machine protection.
Detector chosen for the CTF3 beam loss detection system

Developed at Northwestern University (Mayda Velasco and Anne Dabrowski) in conjunction with Fermilab (Gianni Tassotto) and Richardson Electronics

SIC characteristics:

- Radiation Hard
- Can be operated with gas (ionization) or vacuum (secondary emission)
- Large Dynamic Range \((10^7 - 10^{13} \text{ cm}^{-2} \text{s}^{-1})\)
- Effective detecting surface of 1 cm\(^2\)
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Beam Loss Simulations for CTF3/CLIC

- GEANT 3.21 simulations will be used in the design of the beam loss detection system

- Simplifying Assumptions:
  - Beam loss occurs at a single position in the linac – $\phi = 90^\circ \theta = 1 - 10$ mrad
  - No divergence in beam energy, angle, or position – should average out in secondary fluxes
  - Minimum energy cut on production of secondary particles – 100 keV

- General Observations:
  - Secondary fluxes fall off as $1/r^2$ from the point of beam loss
  - Secondary fluxes scale linearly with beam energy
  - Secondaries are all electrons, positrons, or photons (small hadron component not represented in simulations)
  - Photon fluxes are $\sim 10$ times greater than electron/positron fluxes

- Secondary fluxes normalized with respect to a beam loss of 1 mA
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Drive Beam Accelerator Simulations

- Initial focus on simulations of the CTF3 Drive Beam Accelerator (DBA) where the beam loss detectors will first be installed

- DBA has a modular organization with each module containing:
  - 2 Accelerating Structures
  - 3 Quadrupole Magnets
  - 1 Beam Position Monitor
  - 1 Dipole Magnet (not represented in simulations)

- Some approximate parameters for the CTF3 Drive Beam Accelerator:
  - Initial Beam Energy: 20 MeV
  - Final Beam Energy: 150 MeV
  - Beam Current: 3.5 A
  - Pulse Length: 300 ns (∼ 1.5 μs nominal)
  - Linac Module Length: 4.5 m
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Drive Beam Accelerator

Quadrupole Magnets  Accelerating Structures  Beam Position Monitor

4.5 m

Drive Beam Accelerator Module

Beam size enhancement at Quadrupoles

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Beam Loss Point

Points of Detection

\( e^- \), 100 MeV, 3.5 A

Photon Flux \( E = 100 \text{ MeV} \), Angle \( \pm 10 \text{ mrad} \), \( Z_1 = 0 \text{ cm} \), \( Z_2 = 75 \text{ cm} \)

Flux \( \left( \text{1/cm}^2 \text{s} \right) \) per mA Beam Loss

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Hypothetical System for DBA

- One set of detectors per DBA module
- Detectors are 1 cm\(^2\) (detecting surface of SIC)
- Detect only electrons (SEM-mode) or photons and electrons (ionization-mode)

- Place all detectors at a single zed and different $\phi$ positions
  - Sensitive to $\phi$ of beam loss
  - Less sensitive to $z$ and intensity of beam loss
- Place detectors at a single $\phi$ and different zed positions
  - No sensitivity to $\phi$ of beam loss
  - More sensitive $z$ and intensity of beam loss

<table>
<thead>
<tr>
<th>Detector</th>
<th>$\phi$</th>
<th>$z$</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>$45^\circ$</td>
<td>213.5 cm</td>
</tr>
<tr>
<td>D2</td>
<td>$135^\circ$</td>
<td>98.5 cm</td>
</tr>
<tr>
<td>D3</td>
<td>$225^\circ$</td>
<td>47 cm</td>
</tr>
<tr>
<td>D4</td>
<td>$315^\circ$</td>
<td>-47 cm</td>
</tr>
</tbody>
</table>
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- Goals for Beam Loss System
  - Intensity of beam loss
  - Position of beam loss \((z, \phi)\)
  - Time structure of beam loss → not relevant for simulations

- Challenges for Beam Loss System
  - Disentangling intensity from position of beam loss
  - Beam loss at multiple positions
  - Beam loss in accelerating structures (hard to detect)
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Detectors at $z = 213.5$ cm

Electron/Positron Flux $E = 50$ MeV $R = 30$ cm $Z = 213.5$ cm

- $D_1$ ($\phi = 45^\circ$)
- $D_2$ ($\phi = 135^\circ$)
- $D_3$ ($\phi = 225^\circ$)
- $D_4$ ($\phi = 315^\circ$)

Photon Flux $E = 50$ MeV $R = 30$ cm $Z = 213.5$ cm

- $D_1$ ($\phi = 45^\circ$)
- $D_2$ ($\phi = 135^\circ$)
- $D_3$ ($\phi = 225^\circ$)
- $D_4$ ($\phi = 315^\circ$)
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Detectors at multiple zed positions $\phi = 90^\circ$

Electron/Positron Flux $E = 50$ MeV $R = 30$ cm $\phi = 90^\circ$

Photon Flux $E = 50$ MeV $R = 30$ cm $\phi = 90^\circ$
Method of Analysis

- Zed of the beam loss can be parameterized as a function of the relative signals on the detectors in the module

\[ z = \alpha_0 + \sum_i \alpha_i \frac{D_i}{S}, \quad i = 1, \ldots, N \]  \hspace{1cm} (1)

where S is the sum of the detector signals and N is the number of detectors in a module

- Intensity is then calculated directly from simulations knowing the zed position, beam energy, and magnitude of the detector signals

- Free parameters \( \alpha_i \) are obtained from a straightforward minimization with GEANT data

- This method can be applied to any arrangement of detectors

- Parameterization could also include other variables such as \( \phi \), beam energy, and beam angle
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Conclusions and Future Plans

• Placing detectors at a single zed position
  – Difficult to distinguish losses in the accelerating structure from those in the quads
  – Determining $\phi$ of loss is not straightforward – depends on $z$
  – Difficult to separate effects of $z$ and $I \rightarrow 1$ mA loss at $x$ looks like 10 mA loss at $y$

• Placing detectors at multiple zed positions
  – Can determine $z$ independently of $I$
  – No information on $\phi$ but this is ultimately less important for machine protection

• Compare results with another simulation code – GEANT4

• Do more comparisons with data obtained in controlled tests at CTF3
  – Several beam tests with ACEM detectors run in November 2003
  – GEANT simulations and data generally agreed well