HALO AND TAIL GENERATION STUDIES FOR LINEAR COLLIDERS

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Abstract

Halo particles in linear colliders can result in significant losses and serious background which may reduce the overall performances. We present a study of various halo generation processes with numerical estimates. The aim is to allow to predict and minimize the halo throughout the accelerator chain including the final focus up to the experimental detectors. We include estimates for the planned CLIC beam line.
1 Introduction

Halo particles can potentially cause significant background to the experiments [1]. Even if most of these particles will be stopped in the collimation, the muon background may still be significant [2]. We consider the following halo generation processes:

- Beam Gas elastic scattering, multiple scattering
- Beam Gas inelastic scattering, Bremsstrahlung
- Synchrotron radiation (coherent and incoherent)
- Intrabeam scattering
- Touschek scattering
- Scattering off thermal photons

Here, we will mainly discuss results for the first two of these processes. Generators for these processes have been written and interfaced to detailed optics tracking programs. Optics effects like mismatch, coupling, dispersion and non-linearities further generate and enhance tails. We further plan to include various equipment related tail generating and enhancing processes like noise and vibration, dark currents, wake-fields and beam-loading and we already started to include a simulation of the scattering in thin spoilers.

2 Beam Gas scattering

2.1 Elastic scattering

In the elastic process of Mott scattering, the incident beam particle is deflected by the Coulomb potential of the particles in the residual gas. Elastic scattering changes the direction of the beam particle while its energy is not affected. Elastic scattering can lead to large betatron amplitudes and loss of particles at collimators or any other aperture restriction.

The cross section as a function of the minimum scattering angle $\theta_{\text{min}}$ is [3]

$$\sigma_{\text{el}} = \pi \left( \frac{\alpha \hbar c Z}{E} \right)^2 \left[ \frac{1}{1 - c_m} - c_m - \log(1 - c_m) \right],$$

where $c_m = \cos \theta_{\text{min}}$. Relevant for halo production are scattering angles which exceed the beam divergence, or roughly $\theta_{\text{min}} = \sqrt{\varepsilon/\beta_y}$. The angular distribution of the scattered electron is given by [3]

$$\frac{d\sigma_{\text{el}}}{d\Omega} \approx \frac{1 - \beta^2}{\frac{7}{4}(1 - \cos \theta)^2}. \quad (2)$$

Note that $\beta$ is here the velocity in units of the speed of light. The distribution is shown in the Fig. 1.
2.2 Inelastic scattering

At high energy, the dominating process relevant for energy loss or inelastic scattering is Bremsstrahlung in which the incident electron interacts with the field of the nucleus and radiates photons. The differential cross section is

$$\frac{d\sigma}{dk} = \frac{A}{N_A X_0} \frac{1}{k} \left( \frac{4}{3} - \frac{4}{3} k + k^2 \right),$$

(3)

where $k$ is the photon energy in units of the beam energy, $N_A$ the Avogadro constant, $X_0$ and $A$ are the radiation length and the mass of the material. This equation diverges for very small energy losses $k \rightarrow 0$, which however will have no visible effect. We therefore introduce a minimum energy loss parameter $k_{\text{min}}$. Integration over $k$ (from $k = k_{\text{min}}$ to $k = 1$) yields

$$\sigma_{\text{in}} \sim \frac{A}{N_A X_0} \left( -\frac{4}{3} \log k_{\text{min}} - \frac{5}{6} + \frac{4}{3} k_{\text{min}} - \frac{k_{\text{min}}^2}{2} \right).$$

(4)

The angular cross section is given by:

$$\frac{d\sigma_{\text{in}}}{d\Omega} \sim \frac{\theta}{(1 - \cos \theta + \gamma^{-2})^2}$$

(5)

Fig. 1 shows the angular distribution superimposed to the Mott scattering. For $N_2$ or CO gas and $k_{\text{min}} = 1\%$, we have $\sigma_{\text{in}} \sim 5.51$ barn. This implies, that about 2000 particles per bunch train will have a significant energy loss by inelastic scattering in a rest-gas of 10 nTorr pressure at a temperature of 300 K. This represents $3. \times 10^{-9}$ fraction of particle losses with $0.4 \times 10^9$ particles per bunch and 154 bunches per train. We find that the inelastic scattering is rare and nearly negligible compared to the halo generation by elastic scattering for the very low emittance beams we consider here.
3 Tracking results

The simulation is done with our halo generators, referred to as HTGEN, interfaced to the lattice and rf-structures tracking program PLACET [4]. We assume a N$_2$ or CO rest gas of 10 nTorr at a temperature of 300 K. The beam used in this simulation consists on a train of 154 bunches, each containing $0.4 \times 10^{10}$ particles.

3.1 Simulation of the linac

We simulate the planned CLIC linac as a 14 km long accelerating structure which accelerates electrons or positrons from 9 GeV to 1.5 TeV. The angular cutoff for Mott scattering process derived from the vertical divergence $\theta_{\text{min}} \simeq \sqrt{\frac{\gamma}{\beta}}$ with betatron value $\beta \sim 50$ assuming a normalized emittance of $\epsilon_y = 5 \text{ nm}$. This leads to about $1.6 \times 10^6$ scattered particles per bunch at the end of the linac.

Fig. 2 shows the beam profiles obtained at the end of the linac. The fraction of particles in the tails is $2 \times 10^{-4}$ above $5\sigma$ and $10^{-4}$ above $10\sigma$. These numbers can be expected to increase a bit due to wakefields, which have not yet been included in this simulation. Table 2 shows where the losses occur in the beam delivery system (BDS). 50% of the scattered particles hit the first energy spoiler and the others the first and second betatron spoiler.

3.2 Simulation of the Beam Delivery System

We use the current CLIC optics for this simulation, which is based on a compact final focus scheme à la Raimondi and described in [5]. The optical parameters have been matched to those listed in Table 1. For the angular cutoff we found that $\theta_{\text{min}} = 10^{-9} \text{ rad}$ is sufficiently small to predict reliable loss distributions. For the scattering probability we find $1.9 \times 10^{-7} \text{ m}^{-1}$ implying $2 \times 10^6$ scattered particles per bunch over the 2.5 km long CLIC BDS. Fig. 3 shows the horizontal and vertical positions for beam and halo particles produced in BDS.

Due to the high intensity of the CLIC beam, the beam impact on a collimator can seriously damage the surface. The proposal is to use a sequence of thin Carbon or Beryllium spoilers ($0.5 \rightarrow 1.X_0$) followed by absorbers. The spoilers increase the beam divergence due to multiple scattering in case of failure which spread the energy deposition on the absorbers. Table 2 gives the positions and gaps for energy and betatron collimation spoilers. They are designed to remove particles with amplitudes larger than $10\sigma_x$ or $80\sigma_y$ and energy deviations exceeding 1%.

84000 of particles per bunch scattered in BDS are lost in collimation system. About 60% hit the first energy spoiler and around 4000 the last betatron spoiler.

3.3 Results

Fig. 4 shows the total particle losses along the BDS line. About $1.3 \times 10^6$ particles are lost per bunch or $2 \times 10^7$ per bunch train. Most of these particles lost hit the first two
## BDS entrance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Energy</td>
<td>$E$ 1500 GeV</td>
</tr>
<tr>
<td>Particles/ bunch</td>
<td>$N_{part}$ $4.10^9$</td>
</tr>
<tr>
<td>Bunches per train</td>
<td>$N_{bunch}$ 154</td>
</tr>
<tr>
<td>Energy spread</td>
<td>$\Delta E/E$ 1%</td>
</tr>
<tr>
<td>Hor. beta functions</td>
<td>$\beta_x$ 66.868 m</td>
</tr>
<tr>
<td></td>
<td>$\alpha_x$ -1.721 m</td>
</tr>
<tr>
<td>Vert. beta functions</td>
<td>$\beta_y$ 27.269 m</td>
</tr>
<tr>
<td></td>
<td>$\alpha_y$ 0.785 m</td>
</tr>
<tr>
<td>Norm. emittances</td>
<td>$\epsilon_x$ 680 nm</td>
</tr>
<tr>
<td></td>
<td>$\epsilon_y$ 5 nm</td>
</tr>
<tr>
<td>Bunch length</td>
<td>$\sigma_z$ 35 $\mu$m</td>
</tr>
<tr>
<td>Interaction point</td>
<td></td>
</tr>
<tr>
<td>Beta functions</td>
<td>$\beta^*_x$ 7 mm</td>
</tr>
<tr>
<td></td>
<td>$\beta^*_y$ 90 $\mu$m</td>
</tr>
</tbody>
</table>

**Table 1:** Beam parameters at the entrance and IP of the CLIC BDS.

<table>
<thead>
<tr>
<th>Type</th>
<th>s [m]</th>
<th>x-y gap [mm]</th>
<th>linac halo [$10^3$]</th>
<th>bds halo[$10^4$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESP1</td>
<td>14541</td>
<td>1.3-25.</td>
<td>621</td>
<td>49</td>
</tr>
<tr>
<td>ESP2</td>
<td>14716</td>
<td>2.0-25.</td>
<td>3</td>
<td>14</td>
</tr>
<tr>
<td>YSP1 (XSP1)</td>
<td>15464 (15480)</td>
<td>10-0.17 (0.34-10)</td>
<td>288</td>
<td>1</td>
</tr>
<tr>
<td>YSP2 (XSP2)</td>
<td>15577 (15592)</td>
<td>10-0.17 (0.34-10)</td>
<td>317</td>
<td>18</td>
</tr>
<tr>
<td>YSP3 (XSP3)</td>
<td>15690 (15706)</td>
<td>10-0.17 (0.34-10)</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>YSP4 (XSP4)</td>
<td>15802 (15818)</td>
<td>10-0.17 (0.34-10)</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>total</td>
<td></td>
<td></td>
<td>1232</td>
<td>84</td>
</tr>
</tbody>
</table>

**Table 2:** Spoilers positions and gaps. The two last columns are electrons losses in spoilers for halo particles from linac and BDS.
Figure 2: Beam profile at BDS entrance in horizontal (left) and vertical plane (right). The red distribution is the main beam. The white distribution is halo from beam-gas.

Figure 3: Horizontal and vertical beam profiles as a function of s. Halo particles are in black and core beam particles are in red.
energy spoilers, in region where the betatron functions are at maximum. The fraction of particles lost in the last spoilers is less than 1%. Losses are predominantly in the horizontal plane due to the tighter (10 compared to 80$\sigma$) collimation.

Fig. 5 shows the transverse profiles at the interaction point (IP) in the presence of beam-gas scattering. The horizontal tails have strongly been reduced by the collimation. A fraction of about $5 \times 10^{-5}$ of the particles has amplitudes above $5\sigma$.

## 4 Discussion

Halo particles are a source of unwanted background and radiation. At high energies and small emittances, it will be increasingly difficult to remove these halo particles and the flux of secondary muons produced in the halo collimation becomes significant. From the rather idealistic simulation described here with $3 \times 10^{-4}$ halo particles hitting collimators, we would still expect a flux of 2500 muons in the detector per train crossing\cite{2}. These results have been obtained for a constant pressure of 10 nTorr. We continue to include further halo generation processes and work on a more realistic simulation including non-linearities and imperfections which will likely lead to an increase in background rates.

### Acknowledgement

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Figure 5: Transverse (horizontal on the left, vertical on the right) beam profiles at the IP in presence of beam-gas scattering. The red distribution is the main beam. The white distribution is halo from beam-gas.

References


