CERN – EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-AB-2006-054

CLIC Note 668

HALO AND TAIL GENERATION STUDIES FOR LINEAR COLLIDERS

H. Burkhardt, L. Neukermans, J. Resta-Lopez

CERN, Geneva, Switzerland

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.

Presented at
EPAC'06, Edinburgh, UK,
June 26-30, 2006

Geneva, Switzerland
June 2006

HALO AND TAIL GENERATION STUDIES FOR LINEAR COLLIDERS *

H. Burkhardt, L. Neukermans, J. Resta-Lopez (CERN, Geneva)

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.

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 nonlinearities 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.

BEAM GAS SCATTERING

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.

* This work is supported by the Commission of the European Communities under the 6th Framework Programme "Structuring the European Research Area", contract number RIDS-011899.

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

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

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

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

Note that β is here the velocity in units of the speed of light. The distribution is shown in the Fig. 1.

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

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

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

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

The angular cross section is given by:

$$\frac{d\sigma_{\rm in}}{d\Omega} \sim \frac{\theta}{(1-\cos\theta+\gamma^{-2})^2} \quad (5)$$

Fig. 1 shows the angular distribution superimposed to the Mott scattering. For $\rm N_2$ or CO gas and $k_{\rm min} = 1\%$, we have $\sigma_{\rm in} \sim 5.51\,\rm barn$. 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 in the 16.5 km LINAC+BDS system. 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.

Table 1: Spoiler positions and gaps. The last two columns are halo electrons hitting the spoilers originating from beam-gas scattering in the linac and BDS.

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

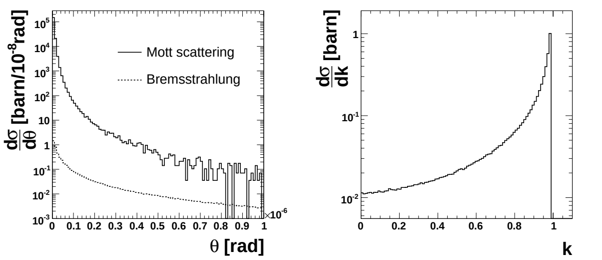

Figure 1: Left: Cross sections as a function of scattering angle for the elastic (full line) and inelastic (dashed line) scattering processes. Right: Cross section as a function of the energy fraction taken by the photon in the inelatic scattering

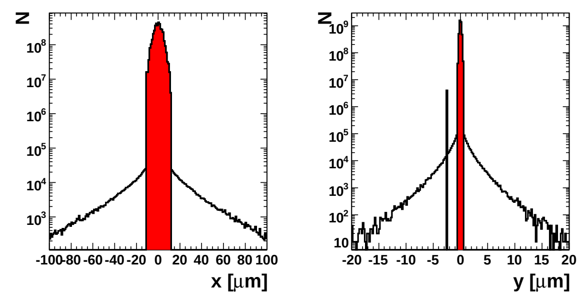

Figure 2: Beam profile at the BDS entrance in the horizontal (left) and the vertical plane (right). The red distribution is the main (unscattered) beam. The tails are from beam-gas scattering.

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.

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 the Mott scattering process is derived from the vertical divergence $\theta_{\min} \simeq \sqrt{\frac{\epsilon_y}{\gamma\beta}}$ taking $\beta = 50\,\mathrm{m}$ and a normalized emittance of $\epsilon_y = 5$ nm. This cutoff ramps down from 8×10^{-8} rad at LINAC entrance to 6×10^{-9} rad. This leads to about 1.6×10^6 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 2×10^{-4} above $5\,\sigma$ and 10^{-4} above $10\,\sigma$. This numbers can be expected to increase a bit due to wakefields, which have not yet been included in this simulation. Table 1 shows where the losses occur in the beam delivery system (BDS). 50% of the scattered particles hit the first energy spoiler and the others in the first and second betatron spoiler.

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 2. For the angular cutoff we found that $\theta_{\min} = 10^{-9}$ rad is sufficiently small to predict reliable loss distributions. For the scattering probability we find $1.9 \times 10^{-7}\,/\,\mathrm{m}$ implying 2×10^6 scattered particles per bunch over the 2.5 km long CLIC BDS. Fig. 3 shows the horizontal and vertical position for beam and halo particles produced in the BDS.

The energy density of the low emittance CLIC beams is very high and damage by beam losses is an issue. In the collimation system it is foreseen to use relatively thin (0.5 to 1 radiation length) low density Carbon or Beryllium spoilers close to the beam followed by longer absorbers. Table 1 give the positions and gaps for energy and betatron collimation spoilers. They are designed to remove particles with amplitudes larger than $10\,\sigma_x$ and $80\,\sigma_y$ and energy deviations exceeding 1%.

84000 particles which have undergone beam gas scattering in the BDS are stopped in the collimation system. About 50000 hit the first energy spoiler and around 4000 the last betatron spoiler.

Table 2: Beam parameters at the entrance and IP of the CLIC BDS.

BDS entrance		
Beam Energy	E	1500 GeV
Particles/ bunch	N_{part}	4.10^9
Bunches per train	N_{bunch}	154
Energy spread	$\Delta E/E$	1%
Hor. beta functions	β_x	66.868 m
	α_x	-1.721 m
Vert. beta functions	β_y	27.269 m
	α_y	0.785 m
Norm. emittances	ϵ_x	680 nm
	ϵ_y	5 nm
Bunch length	σ_z	35 μm
Interaction point		
beta functions	β_x^*	7 mm
	β_y^*	90 μm

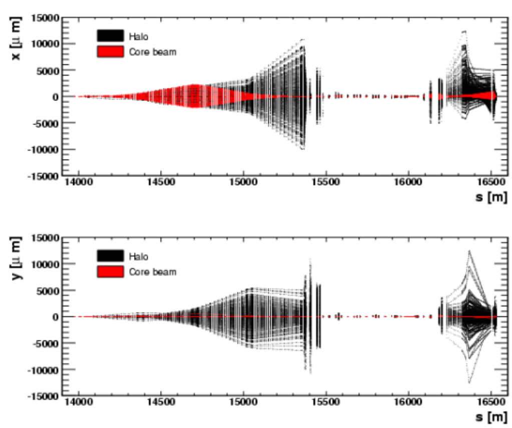

Figure 3: Horizontal and vertical beam trajectories as a function of s. Halo particles are in black and core beam particles are in red.

Results

Fig. 4 shows the total particle losses along the BDS line. About 1.3×10^6 particles are lost per bunch or $2. \times 10^7$ per bunch train. Most of the particles lost hit the first two energy spoilers, in a region where the β functions are maximum. The fraction of particles lost in the last spoilers is less than 10^{-2}. Losses are predominently in the horizontal plane due to the tighter (10 compared to 80 σ) 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 5×10^{-5} of the particles has amplitudes above 10 σ.

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. A muon rate of 2.7×10^4 per train crossing was estimated for fraction of 10^{-3} halo particles[2]. In the rather idealistic simulations described here, we already find a fraction of 3×10^{-4} halo particles hitting collimators, which would still result in a flux of 400 to 2500 muons in the detector per train crossing. 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.

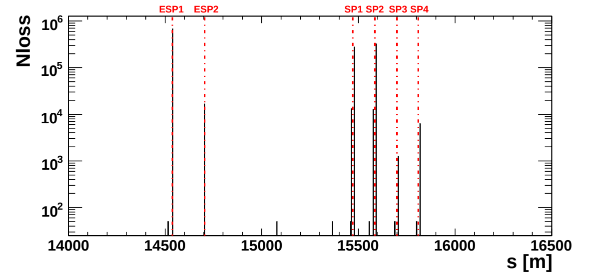

Figure 4: Number of particles lost per bunch along the BDS line.

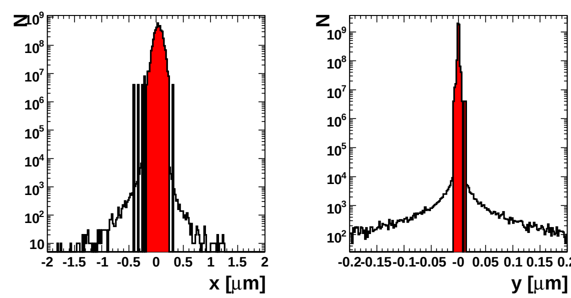

Figure 5: Transverse (horizontal on the left, vertical on the right) beam profiles at the IP in presence of beam-gas scattering. The red distribution is the main beam. The white distribution is halo from beam-gas

REFERENCES

[1] H. Burkhardt, I. Reichel and G. Roy, Phys. Rev. ST Accel. Beams **3** (2000) 091001.

[2] G. A. Blair, H. Burkhardt and H. J. Schreiber. Background simulation for the CLIC beam delivery system with Geant. Proceedings of EPAC 2002, Paris, France, pp. 449-451.

[3] W. S. C. Williams. Nuclear and Particle Physics. Oxford, UK: Clarendon (1991) 385 p. (Oxford science publications).

[4] A. Latina, and al. Recent improvements in PLACET. These proceedings.

[5] R. W. Assmann and al. Collimation for CLIC. *AIP Conf. Proc.*, 693:205–208, 2004.