

## THE CLIC POST-COLLISION LINE\*

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### Abstract

The 1.5 TeV CLIC beams, with a total power of 14 MW per beam, are disrupted at the interaction point due to the very strong beam-beam effect. As a result, some 3.5 MW reach the main dump in form of beamstrahlung photons. About 0.5 MW of  $e^+e^-$  pairs with a very broad energy spectrum need to be disposed of along the post-collision line. The conceptual design of this beam line will be presented. Emphasis will be on the optimization studies of the CLIC post-collision line design with respect to the energy deposition in windows, dumps and absorbers, on the design of the luminosity monitoring for a fast feedback to the beam steering and on the background conditions for the luminosity monitoring equipment.

### INTRODUCTION

The Compact Linear Collider (CLIC) study aims at  $e^+e^-$  collisions with a centre of mass energy of 3 TeV. In order to reach the required luminosity, the incoming beams must be focused to extremely small spot sizes (see Table 1). The resulting strong beam-beam effects at the interaction point lead to an emittance growth for the outgoing beam as well as to the production of beamstrahlung photons and  $e^+e^-$  pairs.

Table 1: Beam parameters at the interaction point of the 3 TeV CLIC accelerator

Centre of mass energy [GeV]	3000
Luminosity $L_{99\%}$ [ $\text{cm}^{-2}\text{s}^{-1}$ ]	$2 \cdot 10^{34}$
Bunch train frequency [Hz]	50
Bunch spacing [ns]	0.5
# Particles per bunch	$3.72 \cdot 10^9$
# Bunches per train	312
Bunch train length [ns]	156
Beam power per beam [MW]	14
Crossing angle [mrad]	20
Core beam size at IP horiz/vert $\sigma_{x/y}$ [nm]	45 / 1
Beamstrahlung energy loss	29%
Number of photons per beam particle	2.2
Number of coherent pairs per bunch-crossing	$3.8 \cdot 10^8$

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The post-collision line must be designed to transport both the un-collided beam with its extremely small size as well as the disrupted beam (charged particles and photons) with increased momentum spread and angular divergence from the interaction point to the main dump. In addition, the post-collision line should be able to cope with a possible initial CLIC operation at lower c.m. energy, e.g. 500 GeV. The implications of such a scenario for the post-collision line are described below.

### LAYOUT AND OPTICS

The baseline layout of the post-collision beam line is shown in Fig. 1. Details are described in [1]. The design philosophy of the extraction line is to provide an early separation of the outgoing charged beam from the low energy products of the strong beam-beam interaction (photons, pairs). This will eventually allow an effective monitoring of the luminosity from the beamstrahlung photons and assure the transport of the beam-beam products to suitable collimators and dumps.

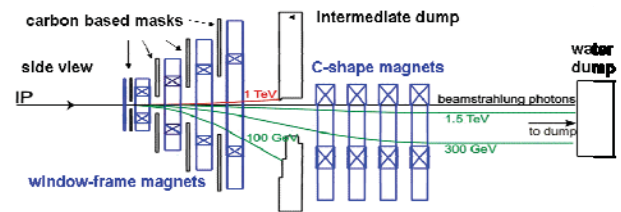


Figure 1: Baseline layout of the post-collision line.

The line ends with a dump 273 m from the IP, designed to dump the main beam particles, the high energy tail of the beam-beam charged particles (pairs) and the beamstrahlung photons. A significant portion of the pairs are stopped in an intermediate dump, located 67 m from the IP. The post-collision line contains eight dipoles - four located on the IP-side of the intermediate dump, and four located in the region after the intermediate dump, with the first set of dipoles protected from particle loss by a set of interleaved absorbers.

While the CLIC baseline is designed for 3 TeV and 20 mrad total beam crossing angle, for the 500 GeV scenario a crossing angle of 18.6 mrad is required [2]. It is assumed that the position of the IP, the intermediate and main dumps and the eight magnets is fixed and that the current in the vertical dipoles will be lowered and

horizontal dipoles will be added to steer the beam to the fixed position at the dump. For 500 GeV operation the beamstrahlung photon spot shifts by 19.1 cm at the dump window and is, due to the reduced beam-beam interaction, reduced in size. This change is absorbed into the dump window design. In summary, the impact of the 500 GeV scenario on the post-collision line design is minimal.

### INTERFACE BETWEEN DETECTOR AND POST-COLLISION LINE

The vacuum chambers for the incoming beam as well as the spent beam in direction of the post-collision line have to be accommodated in the design of the very forward region of the detectors. The large number of coherent pairs produced at 3 TeV imposes an opening angle for the vacuum chamber of at least 10 mrad around the spent beam axis. Moreover, the short final focusing system chosen for CLIC implies that all or a part of the final quadrupole QD0 is located inside the detector, adding further constraints to the layout.

Detector studies are on-going based on the ILC detector concepts SiD and ILD [3], and first design options have been proposed. The modified SiD concept of the forward region is shown schematically in Fig. 2. Inside the vertex/tracker region, the incoming and spent beams travel in a common, conical vacuum chamber. The Luminosity Calorimeter (LUMICAL), a 40 layer Si-W sandwich calorimeter located at the level of the ECAL end cap, provides a first general aperture limitation to 40mrad around the spent beam axis. Separate vacuum chambers for incoming and spent beams are starting at a distance of 2.8 m from the IP, just upstream of another small calorimeter (BEAMCAL). This second very

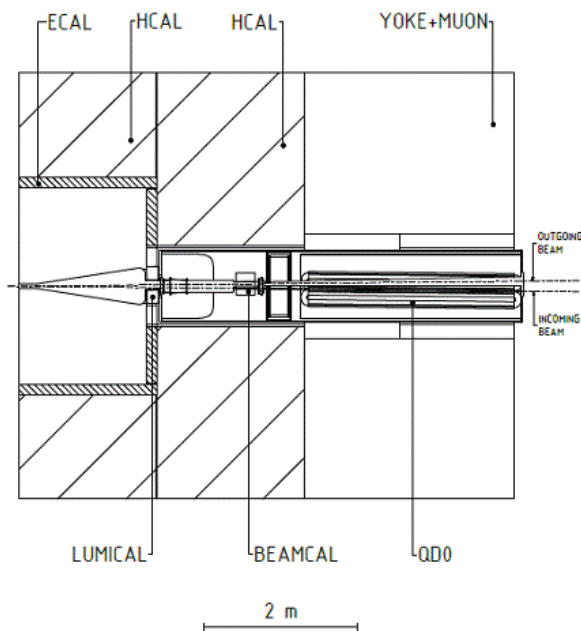


Figure 2: Forward region of a CLIC Detector (courtesy H. Gerwig and N. Siegrist, CERN).

forward calorimeter has the same length as LUMICAL, but is further restricting the aperture to 10 mrad around the spent beam axis. Finally, the QD0 quadrupole itself is, to some extent, an "absorber" for particles backscattering from the post-collision line towards the detector.

Extensive studies have been undertaken to assess the amount of photons backscattering from the post-collision line towards the vertex and tracking region of the CLIC detector [4]. Very preliminary results have also been obtained concerning neutron back-scattering from the CLIC main dump towards the detector. In both cases, the number of background particles "at the outer edge" of the detector ( $L = 7$  m) appears to be low, and QD0, LUMICAL and BEAMCAL should absorb a large fraction of these particles. Nevertheless, space is available in the detector very forward region layout to add additional absorbers, if they should be deemed necessary to shield against photons or neutrons from downstream absorbers and dumps.

### ENERGY DEPOSITION IN ABSORBERS AND DUMPS

A set of four pairs of vertical absorbers with fixed aperture are foreseen in the upstream part of the post-collision line to protect the vertical deflection magnets from the low energy tail of the coherent  $e^+e^-$  pairs. These absorbers are to be mounted outside the post-collision line vacuum. The total power loss in these four absorbers is relatively modest, with 1, 2, 5 and 11 kW respectively.

The intermediate dump is placed asymmetrically around the post-collision line. The upper part of the dump should stop all the "opposite-sign" charged particles up to 1 TeV energy, leading to an estimated power deposited of 170 kW. The lower part intercepts "same-sign" particles up to about 250 GeV, corresponding to 140 kW of deposited power. While a dump with a few-100 kW continuous power deposition is non-trivial equipment, solutions exist. For example, the dumps in neutrino experiments (water-cooled with a graphite core and copper/iron mantle) are to withstand up to 4 MW proton beams [5].

At the end of the post-collision line, the CLIC main dump must withstand the full beam power of 14 MW. In the case of non-colliding beams, this power is delivered in a small beam-spot of the order of a few  $\text{cm}^2$ . In nominal conditions with 3 TeV c.m. collisions, about 10 MW of charged particles are dumped in a larger area, while about 3.7 MW by beamstrahlung photons are deposited on the main dump on the geometrical axis with an area of  $\sim 0.3 \text{ m}^2$ .

### CLIC MAIN DUMP

Crucial elements in the CLIC post-collision line are the vacuum window at the exit of the line as well as the main beam dump. Whereas in the case of the colliding beam the main issues are the beam size and thus the large

diameter windows needed (of order 1 m diameter), the issue for non-colliding beams are the small beam spot and consequently the high power density on a small point of impact on the dump window and the dump itself. A conceptual design of the vacuum window at the exit of the post-collision line is described in [1].

The principle of using pressurized water as a dump was first proposed and realized at SLAC for SLC and then taken over for the NLC, TESLA and ILC design studies. The concept of the CLIC main dump is based on the ILC water beam dump, where a beam power of 18 MW must be absorbed [6], [7].

The water dump consists of a 20 mm wall-thickness cylindrical stainless steel vessel of 1.5 m diameter and a length of 10 m. The water is pressurized at 10 bar to prevent boiling. The water is continuously renewed in order to remove the dissipated heat from particle interactions.

The front window of the water vessel is made of a Titanium Alloy, in the ILC case this window has a diameter of 30 cm and a thickness of 1 mm.

The main differences for the CLIC case are the large number of coherent pairs with a wide spectrum of energies, and thus the larger diameter of the entrance window (and possible of the dump itself) needed.

Calculations on the energy deposition, heat flow and mechanical stress in the beam dump and windows have started. Depending on these results a beam dilution system, by using pulsed magnets or tilted dipoles, needs to be foreseen. Fig. 3 shows an estimate of the energy deposition as distributed in the water dump calculated for a non-colliding 1.5 TeV CLIC electron beam with  $\sigma_x/\sigma_y = 1.6 \text{ mm}/1.7 \text{ mm}$  at the dump entrance window. The maximum energy deposition is  $220 \text{ MeV}/\text{cm}^3$ .

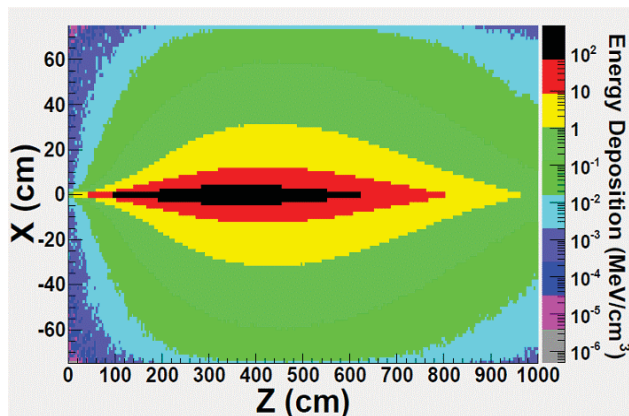


Figure 3: Energy deposition in the main dump for a non-colliding 1.5 TeV electron beam (steel vessel not included in this simulation).

## LUMINOSITY MONITORING

Counting the number of beamstrahlung photons has been found to be an efficient method to monitor luminosity at CLIC. Two methods are envisaged [8]: (a) The photons could be converted into  $e^+e^-$  pairs in a thin foil some 100 metres upstream of the main dump, where the photons are separated from charged particles by more than 10 cm. The  $e^+e^-$  pairs could be observed via a standard Optical Transition Radiation screen (OTR) and photomultiplier; (b) Pair production of muons by the high energy photons travelling inside the main dump could be used. The latter appears more attractive, since there is little background expected downstream of several metres of concrete (dump cavern wall). The muons could be counted e.g. using a Cerenkov detector, which would allow suppressing background muons from the Beam Delivery System (BDS) of the incoming CLIC beam (travelling in the opposite direction) [9].

## OUTLOOK

The baseline design of the 3 TeV CLIC post-collision line has been presented. A possible 500 GeV c.m. collision scenario has only minimal effect on the post-collision design. The photon and neutron background resulting from back-scattering from the post-collision line to the CLIC detector appears to be low. Solutions of the design of masks and intermediate dump for energy depositions at the order of a few 100 kW exist. Detailed studies for the design of the main dump which needs to withstand the full beam power of 14 MW have started. Calculations on luminosity monitoring by muon pair production are ongoing.

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