

# INVESTIGATION OF CLIC 380 GeV POST-COLLISION LINE

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## Abstract

It has been proposed that the Compact Linear Collider (CLIC) be commissioned in stages, starting with a lower-energy, 380 GeV version for the first stage, and concluding with a 3 TeV version for the final stage. In the Conceptual Design Report (CDR) [1] published in 2012, the post-collision line is described for the 3 TeV and 500 GeV stages. However, the post-collision line for the 380 GeV design was not investigated. This work will describe the simulation studies performed in BDSIM [2] for the 380 GeV post-collision line.

## GOALS

The goal of any post-collision line study is to make sure that both collided and uncollided beams can be safely guided to a dump. These beamlines must be able to account for large energy spreads, wrong-charge particles, and minimize deposition on beamline components.

This work was performed for the CLIC Project Implementation Plan [3], which was presented to the European Strategy Update in December of 2018. For this work, the goal was to confirm that the post-collision line design previously investigated for the 3 TeV phase of CLIC [4–6] will work for the initial 380 GeV phase. It is important to note that the design of the dump itself is not included in this work.

## PREVIOUS WORK

Previous studies of the CLIC post-collision line (PCL) focused almost entirely on the 3 TeV version of the machine. Mentions of lower-energy versions were briefly discussed, but no in-depth, detailed studies were performed. Several versions of the 3 TeV post-collision line have been made [4–6], and while overall the layouts are similar, they differ in various details.

For the present work, the authors generally endeavored to use the same design as that described in the CDR [1]. Occasionally, design aspects from other sources were used instead. Additionally, minor changes were made when it improved the overall design, or when designs were inconsistent with each other.

## OVERVIEW OF PRESENT DESIGN

The majority of the overall layout remains the same as those found in [4–6]. The distances remain the same from the interaction point (IP), as well as between the magnets and intermediate dump (ID). The authors opted to use the 50 m

version of the final drift to the dump, as in [4]. All of the geometries in this study were created using a python-based Boolean geometry toolkit, `pyg4ometry` [7, 8].

One change involved the first set of window-frame magnets. Described in the CDR and elsewhere, these magnets were to have lengths of 0.5 m and 3.5 m, respectively. However, this is inconsistent with the designs made by the magnet group [9]. Here, each magnet was 2 m in length. Both versions were tested in BDSIM, and the results were identical for both 3 TeV and 380 GeV. The authors opted to use the 2 m versions, as this is what the magnet group designed.

Minor changes were also required with the carbon-based masks in between each window-frame magnet. The aperture sizes of these masks were not consistently reported, so the authors chose for this initial study to match the aperture size to the beampipe size at each location. This may not be optimal, but for the purposes of this initial study it is sufficient.

All of the beampipes upstream of the intermediate dump are elliptical cones which gradually increase in size from the IP to the ID. Most of this growth occurs in the y-plane, as the beam is highly divergent in this plane after the IP. These shapes are consistent with previous designs.

The window-frame magnets are also consistent with previous design studies. A new beampipe shape was added to the BDSIM functionality to take into account the elliptical beampipes inside of these magnets.

The intermediate dump remains geometrically the same as previous designs. The geometry allows for wrong-charge particles to be deposited into the upper part of the ID, lower-energy particles to be deposited in the lower part of the ID, and particles close to nominal energy to pass through the aperture. The geometry for the intermediate dump is shown in Fig. 1.

The beampipes downstream of the ID match previous descriptions as well. At the end closest to the ID, the beampipe has a two-half-ellipse design, which can be shown in Fig. 2. As the beampipe continues past the C-shaped dipoles to the main dump (MD), this shape gradually changes to a racetrack shape just before the main dump. The C-shaped magnets allow for this two-half-ellipse beampipe shape. The main dump geometry is based on that described [10].

Figure 3 shows the overall 3D layout of the PCL.

## BDSIM SIMULATIONS

To begin the simulation process, the settings are tested interactively in BDSIM. This is done with a fewer number of particles (approximately 1000) in order to make sure that

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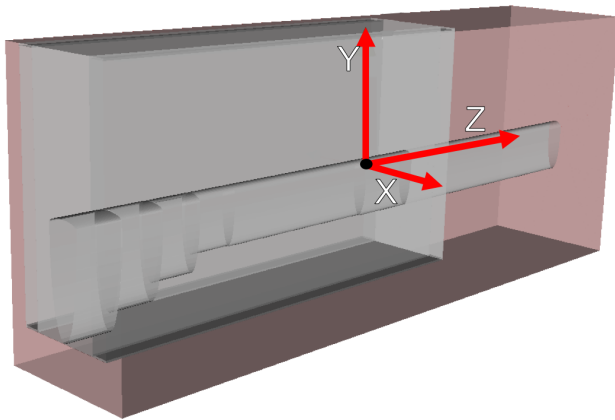


Figure 1: Side-angle view of the intermediate dump.

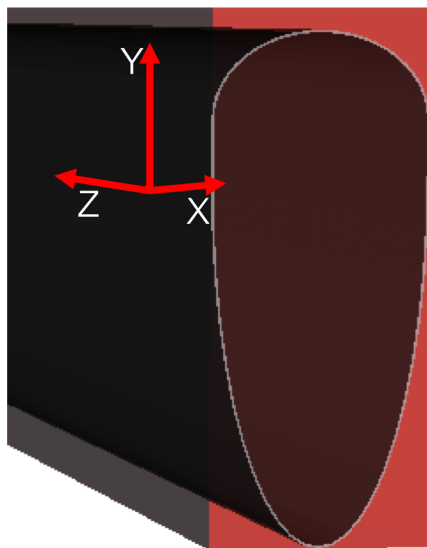


Figure 2: Two-half-ellipse geometry.

the general behavior of the particles is consistent with what is expected given the beamline optics.

Once the interactive simulations are checked, the simulations are then performed using the batch system. Here, approximately 1,000,000 particles are simulated. For the initial beam distributions, we used data provided by the beam-beam interactions group, which was found using GUINEA-PIG [11]. Since BDSIM simulations can produce large amounts of data, certain cuts must be performed to speed up the process. For our simulations, any particle, including secondaries, which had an energy lower than 20 MeV were excluded from analysis since they are unlikely to significantly contribute to the deposition along the beamline. Additionally, any particles that do not travel at least 1 cm were also cut, for the same reasons.

The primary analysis is actually performed during the simulation itself with ROOT. This requires knowing what data is needed, and at which locations. This is done to limit the amount of data which is copied back, since it can easily

be over 1 terabyte. Instead, only the histogram data provided by the ROOT analysis is copied back for further analysis.

To perform this analysis on the histogram data, the pybdsim utilities are used. With these, detailed particle and power deposition plots can be created.

## RESULTS

For the Project Implementation Plan (PIP) study, only the most important aspects were investigated. The focus was on reproducing previous 3 TeV results to check for consistency, and then to study the same setup with reduced magnet strengths at 380 GeV.

We first tested that the 3 TeV setup would behave similarly to previous studies. Some of the results are shown in Table 1 for both the collided (C) and uncollided (U) 3 TeV beams. The power deposited in the intermediate dump, along the final drift, and in the main dump is within expectations, and there were no unexpected "hot spots" along the beamline. The maximum power deposited into the main dump is 13.6 MW, which is below the designed 14 MW capability.

Once we were confident in our 3 TeV simulations, we then scaled the dipole magnet strengths from 0.8 T to 0.1 T for the 380 GeV case (to achieve the same 0.64 mrad kick per dipole as in the 3 TeV case). Some of these results are also shown in Table 1. These results are as expected from previous studies.

Table 1: Power Deposited (MW) in Key PCL Elements for both Uncollided (U) and Collided (C) Beams

	Int. Dump	Final Drift	Main Dump
<b>3 TeV U</b>	$2.10 \times 10^{-4}$	$1.97 \times 10^{-2}$	13.6
<b>3 TeV C</b>	$3.67 \times 10^{-2}$	$2.96 \times 10^{-2}$	10.2
<b>380 GeV U</b>	$5.19 \times 10^{-5}$	$4.08 \times 10^{-3}$	2.91
<b>380 GeV C</b>	$7.77 \times 10^{-5}$	$4.23 \times 10^{-3}$	2.70

What was unknown for the 380 GeV design is whether there would be hot spots or other unexpected behavior by the beam as it passed through the PCL designed for the 3 TeV version of CLIC. Figures 4 and 5 show the deposition along the post-collision line for both the uncollided and collided 190 GeV beams, respectively. There appear to be no unexpected "hot spots" or other anomalies which impact the energy deposition. Additionally, the majority of the beam is deposited at or below the center of the main dump, which is as previously designed.

## CONCLUSION

These studies show that the basic designs previously described for the 3 TeV CLIC machine should be adequate for the 380 GeV version. It should be possible to use the same design with the magnets scaled from 0.8 T to 0.1 T for the 380 GeV case. Further studies can be performed to improve upon this.

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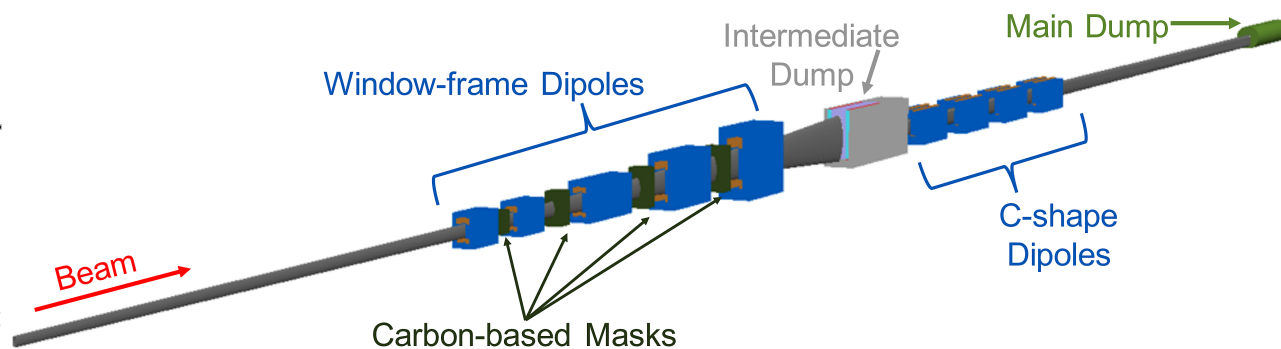


Figure 3: Graphical output of BDSIM showing the post-collision line design.

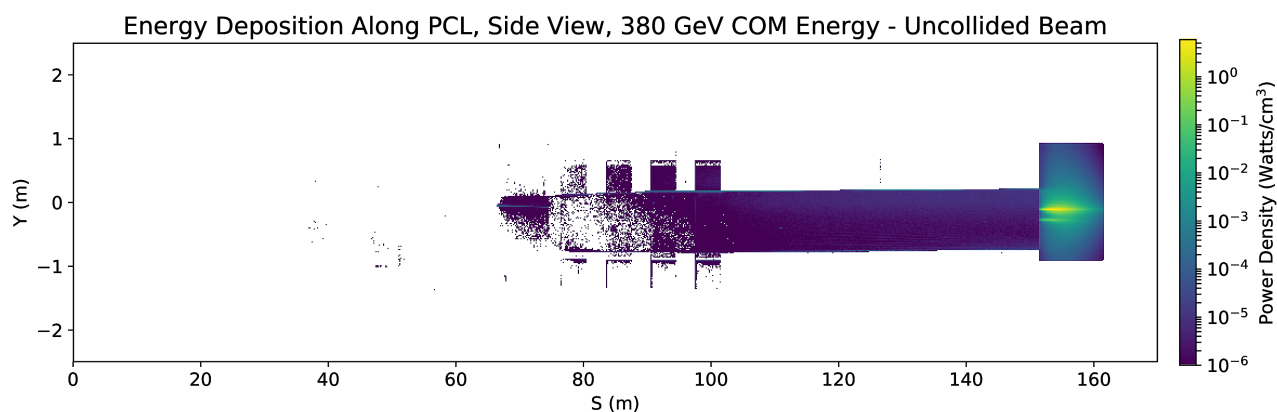


Figure 4: Heat map of deposition for uncollided 190 GeV electron beam.

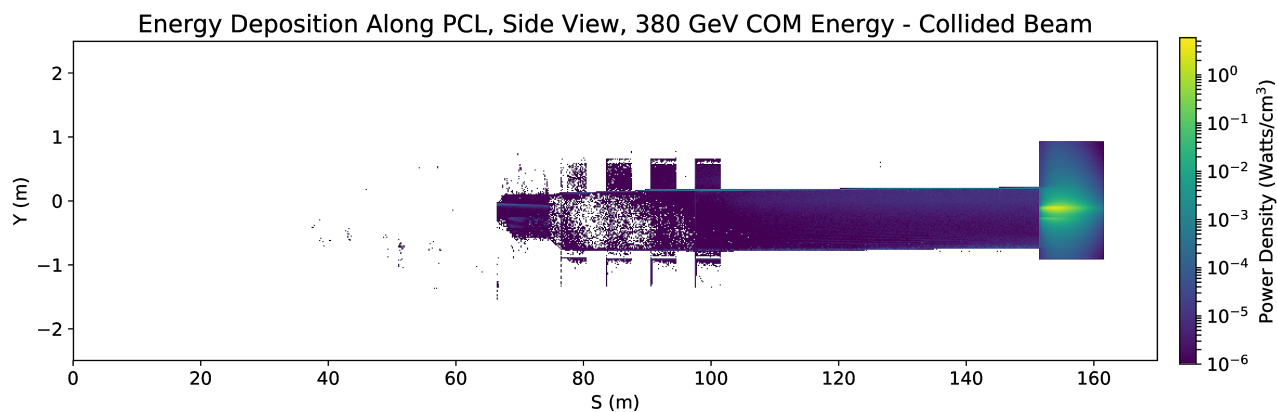


Figure 5: Heat map of deposition for collided 190 GeV electron beam.

## FURTHER STUDIES

To improve the design of both the 3 TeV and 380 GeV PCL, several items should be investigated further. For both cases, the apertures for the carbon-based masks should be optimized to further reduce deposition on the window-frame magnets. Also, including studies of wrong-charge particles, beamstrahlung, incoherent pairs, and muons would be important for completeness. Opportunities for instrumentation should also be investigated.

For the 380 GeV machine, it may be feasible to remove several of the dipoles and scale the strengths accordingly to achieve the same optics and results. This would mean scaling the magnets below 0.8 T, but higher than 0.1 T, aiming for the same total bend angles in each section of the PCL. In the place of the removed dipoles, drift space could remain. When the higher-energy machines are commissioned, the dipoles can simply be added into the drift space. This would be a simple study to perform, and could potentially save cost for the lower-energy designs.

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