Optimisation studies for the CLIC vertex-detector geometry

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ABSTRACT: A new detector concept is currently under development for the proposed multi-TeV linear $e^+e^-$ Compact Linear Collider (CLIC). The impact of the detector geometry on the physics performance of the CLIC vertex detector is being investigated. Different options for the barrel detector and alternative layouts of the endcap regions fulfilling engineering requirements while minimising the material budget are considered. This study is based on a full detector simulation using GEANT4. The beauty and charm flavour-tagging performances for different jet energies and polar angles are the key observables used to compare the different investigated detector configurations.

KEYWORDS: Performance of High Energy Physics Detectors; Simulation methods and programs
1 Introduction

The precision physics requirements and experimental conditions at CLIC [1] set challenging demands for the vertex detector: excellent spatial resolution ($\sim 3\mu$m single-point resolution per layer), time slicing of hits with $\sim 10$ ns precision, geometrical coverage extending down to low polar angles ($\theta_{\text{min}} \approx 8^\circ$), extremely low mass ($\sim 0.2\% X_0$ per detection layer, including readout, support and cabling) and efficient heat removal from sensors and readout. Airflow cooling is considered as a strategy to significantly reduce the amount of material in the vertex detector. However, in previous physics simulation studies [1], simplified geometries were used which contained disks in the endcap region and did not allow for airflow through the vertex detector. Moreover, the geometries did not consider detailed models for the cabling and support and therefore contained a total amount of material per detection layer of only approximately $0.1\% X_0$.

In a recent study [2], a spiral arrangement of the sensors in the vertex endcap regions is implemented, allowing for airflow through the vertex-detector volume [3]. Geometries with double-sided arrangements are compared to single-sided layouts. Finally, a geometry with increased material budget is implemented based on engineering studies for supports and cabling.

Based on full detector simulations using GEANT4, the performance of the implemented geometries are evaluated and compared by investigating the beauty and charm flavour-tagging efficiencies for different jet energies and polar angles.

2 Vertex-detector layouts

Several engineering studies are in progress to limit the material, e.g. the cables, the mechanical support and also the cooling for the CLIC vertex detector. Cooling solutions with pipes and liquids increase significantly the material budget. The aim is therefore to use airflow cooling for the CLIC vertex detector. As illustrated in figure 1a, a spiral arrangement for the modules in the endcap regions can be used instead of disks, allowing the air to flow through the vertex detector. The physics performance of the geometries described in table 1 and illustrated in figure 1 have been studied in simulations.
Table 1. Geometries implemented in simulations.

| Geometry                  | Barrel layers | Endcap layers | Material budget          |
|---------------------------|---------------|---------------|--------------------------|
| disks (Figure 1b), spirals (Figure 1c) | 5 single-sided | 4 single-sided | 0.1%\(X_0\) per single-sided layer |
| double_spirals (Figure 1c) | 3 double-sided | 3 double-sided | 0.2%\(X_0\) per double-sided layer |
| double_spirals_v2 (Figure 1c) | 3 double-sided | 3 double-sided | 0.4%\(X_0\) per double-sided layer |

Figure 1. (a) airflow cooling within the vertex detector [3]. (b): simulation layout for the disks geometry. (c) simulation layouts for the spirals and double_spirals(v2). The double_spirals_v2 with the same layout as double_spirals has twice more material for the mechanical support. A double-sided layer is implemented as two silicon sensors on top of each other, each 50µm thick.

3 Flavour-tagging performance

The different geometries described in section 2 are compared based on their flavour-tagging performance with the LCFIPlus package [4]. The performance of the flavour tagging depends on the jet energy and polar angle: dijet events with different center-of-mass energies, \(\sqrt{s}\), having polar angles of \(10^\circ \leq \theta \leq 90^\circ\) with a uniform distribution in \(\phi\) angles are considered. Initial state radiation and beamstrahlung were switched off during the event generation and hence the final-state quarks are in a back-to-back configuration. For each jet flavour, energy and angle, 80000 events are used for the following processes: \(e^+e^- \rightarrow b\bar{b}, c\bar{c}, u\bar{u}, d\bar{d}, s\bar{s}\). The boosted decision trees are trained using 50% of the generated events and the other 50% are used for testing the performance of the flavour tagging.

The performance of the different geometries for dijet events at 200GeV is shown in figure 2. Similar results were found for other jet energies [2]. The spirals and disks have a similar flavour-tagging performance except for jets at \(\theta = 40^\circ\) (figure 2a), which corresponds to the transition between the vertex endcaps and the barrel region, where the beauty-tagging performance is up to 20% worse using the spirals geometry (compared to disks). With the spiral configuration, the number of sensitive layers becomes dependent on the azimuthal angle \(\phi\) and less layers can be hit in certain ranges of \(\phi\). The performance of the spirals and the double_spirals is very similar (figure 2b). The double_spirals_v2 geometry is a more realistic version of the double_spirals geometry, taking into account the material used for the mechanical support of the sensors and also for the cables. As shown in figure 2c, the misidentification probability increases by \(\sim 35\%\) due to the increased material.
Figure 2. Beauty-tagging performance for dijet events at 200 GeV. (a) comparison between disks and spirals in terms of the ratio of the misidentification probabilities for charm background in the forward region. (b) comparison of the beauty-tagging performance between the spirals and double_spirals geometries. (c) comparison of the beauty-tagging performance between the double_spirals and double_spirals_v2 geometries. For (b) and (c), dijet events with a mixture of polar angles between 10° and 90° are considered.

4 Conclusions

A new detector model for CLIC is under development which takes into account the progressing engineering studies. The spiral arrangement of the modules in the vertex endcaps allows to use airflow cooling which has the potential to reduce the material budget significantly. Double-sided modules provide more sensitive layers with the same amount of support material as single-sided modules. The overall results show that the implemented geometries are similar in terms of the flavour-tagging performance for simulated dijet events. The amount of material, on the other hand, was found to have a large impact on the performance.

References

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