Optimization of layer composition for ILD ECAL

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Abstract

International Large Detector (ILD) adopts Particle Flow Algorithm (PFA) for precise measurement of multiple jets. The electromagnetic calorimeter (ECAL) of ILD has two candidates sensor technologies for PFA, which are pixelized silicon sensors and scintillator-strips with silicon photomultipliers. Pixelized silicon sensors have higher granularity for PFA, however they have an issue of cost reduction. In contrast, scintillator-strips have an advantage of relatively low cost and a disadvantage of degradation of position resolution by ghost hits, which are generated by orthogonal arrangement. Hybrid ECAL using both candidates is proposed to supplement these disadvantages. In this paper, we report an optimization study of the hybrid ECAL using detector simulation.

1 Introduction

International Linear Collider (ILC) is a future lepton collider which is expected to be constructed in Japan [1]. It can measure higgs boson and top quarks precisely. This measurement is useful to search for new particles and physics. International Large Detector (ILD) [2], which is one of the detector concepts in ILC, have to have suitable structures for Particle Flow Algorithm (PFA) because ILD needs to measure multiple jets contained in final states of these physics processes of ILC precisely.

PFA is a method to identify particles in a jet individually and to measure momentum and energy at optimal detectors for each particle. Jet energy is measured by mainly trackers, ECAL and hadron calorimeter (HCAL). At the trackers, momentum of charged particles is measured, where energies of photons and neutral hadrons are measured at ECAL and HCAL, respectively.

ILD ECAL has two candidates of sensitive detectors (Figure 1). One is silicon semiconductor sensor with 5.5 × 5.5 mm$^2$ pixels which has high granularity for PFA, however its cost reduction is an important issue. The other is scintillator-strips with silicon photomultipliers as photon detectors. Its cost is relatively low, however jet energy resolution is worse by ghost hits which are made by orthogonal arrangement of 45 × 5 mm$^2$ strip when there are more than two hits on 45 × 45 mm$^2$ area spontaneously.

We optimized a hybrid ECAL concept, which uses both silicon and scintillator detectors to reduce ECAL cost and maintain its performance.
2 Optimization of hybrid ECAL

Recent baseline design of the ILD ECAL is described in the Detailed Baseline Design (DBD) report. The structure uses pixelized silicon semiconductor as sensitive detectors which can reach high energy resolution. However, it causes high occupation of cost ratio in the whole ILD cost. To deal with this problem, two ideas are proposed. One is to reduce the whole size of ILD, and the other is to use hybrid ECAL instead of ECAL with all silicon semiconductor.

This paper describes optimization study of hybrid structure with detector simulation.

2.1 Simulation framework

ILCSoft v01_16_02 is a software suite including numerous packages for physics analysis and detector optimization of ILC, used for the following analysis. For the event generation, Whizard and Pythia packages are used for di-jet events. Single particles are generated within the detector simulation software with particle guns. Mokka is a detector simulation package based on GEANT4. ILD_o1_v5 geometry in the Mokka framework is used for the detector simulation. After the simulation, we performed the ILD standard event reconstruction, including digitization of the hits, tracking and track fitting, and PandoraPFA for particle flow.

2.2 Setup of simulation

This study focuses on the hybrid ECAL with reasonable cost and performance. As an example, we set the silicon sensors in first 14 detector layers (inner region) and scintillator-tiles in the rest of layers (outer region) (Figure 2). The number of silicon layers is fixed because we would like to restrict the cost of silicon. For the scintillator, we adopt $15 \times 15$ mm$^2$ tiles. Comparison between tiles and strips is not in the scope of this study and should be studied separately.
In this study, we change the boundary between inner and outer region and the number of scintillator layers, but whole thickness of absorber layers is fixed ($22.8X_0 = 79.8$ mm). Considered configurations are listed in Figure 3 and Table 1-4.

As a performance comparison, we investigated energy resolution of di-jet ($e^+e^- \rightarrow Z \rightarrow q\bar{q}$) events of various center-of-mass energies. We use RMS90 energy resolution obtained by PandoraPFA [3], and PerfectPFA which utilizes MC information for clustering instead of real particle flow. Confusion term is defined as squared difference of PandoraPFA and PerfectPFA.
| Configuration   | Boundary | Si     | Sc     | Absorber (Inner/Outer)                  |
|-----------------|----------|--------|--------|----------------------------------------|
| Hybrid (1-1)    | $8.4X_0$ | 14 layers | 20 layers | 2.1 mm×14 layers/2.653 mm×19 layers  |
| Hybrid (1-2)    | $8.4X_0$ | 14 layers | 22 layers | 2.1 mm×14 layers/2.4 mm×21 layers    |
| Hybrid (1-3)    | $8.4X_0$ | 14 layers | 24 layers | 2.1 mm×14 layers/2.191 mm×23 layers  |
| Hybrid (1-4)    | $8.4X_0$ | 14 layers | 26 layers | 2.1 mm×14 layers/2.016 mm×25 layers  |

Table 1: Configuration of ECAL at a boundary of $8.4X_0$

| Configuration   | Boundary | Si     | Sc     | Absorber (Inner/Outer)                  |
|-----------------|----------|--------|--------|----------------------------------------|
| Hybrid (2-1)    | $11.2X_0$| 14 layers | 16 layers | 2.8 mm×14 layers/2.707 mm×15 layers  |
| Hybrid (2-2)    | $11.2X_0$| 14 layers | 18 layers | 2.8 mm×14 layers/2.388 mm×17 layers  |
| Hybrid (2-3)    | $11.2X_0$| 14 layers | 20 layers | 2.8 mm×14 layers/2.137 mm×19 layers  |
| Hybrid (2-4)    | $11.2X_0$| 14 layers | 22 layers | 2.8 mm×14 layers/1.933 mm×21 layers  |

Table 2: Configuration of ECAL at a boundary of $11.2X_0$

| Configuration   | Boundary | Si     | Sc     | Absorber (Inner/Outer)                  |
|-----------------|----------|--------|--------|----------------------------------------|
| Hybrid (3-1)    | $12X_0$  | 14 layers | 16 layers | 3.0 mm×14 layers/2.52 mm×15 layers  |
| Hybrid (3-2)    | $12X_0$  | 14 layers | 18 layers | 3.0 mm×14 layers/2.224 mm×17 layers  |
| Hybrid (3-3)    | $12X_0$  | 14 layers | 20 layers | 3.0 mm×14 layers/1.989 mm×19 layers  |
| Hybrid (3-4)    | $12X_0$  | 14 layers | 22 layers | 3.0 mm×14 layers/1.8 mm×21 layers    |

Table 3: Configuration of ECAL at a boundary of $12X_0$

| Configuration   | Boundary | Si     | Sc     | Absorber (Inner/Outer)                  |
|-----------------|----------|--------|--------|----------------------------------------|
| Hybrid (4-1)    | $14X_0$  | 14 layers | 16 layers | 3.5 mm×14 layers/2.053 mm×15 layers  |
| Hybrid (4-2)    | $14X_0$  | 14 layers | 18 layers | 3.5 mm×14 layers/1.812 mm×17 layers  |
| Hybrid (4-3)    | $14X_0$  | 14 layers | 20 layers | 3.5 mm×14 layers/1.621 mm×19 layers  |
| Hybrid (4-4)    | $14X_0$  | 14 layers | 22 layers | 3.5 mm×14 layers/1.467 mm×21 layers  |

Table 4: Configuration of ECAL at a boundary of $14X_0$
2.3 Optimization of number of scintillator layers

Figure 4-7 shows the dependence on number of scintillator layers in hybrid 1-4 geometries. These plots show that there are no significant differences among the variation of the number of scintillator layers contrary to an expectation that increasing of the number of scintillator layers makes the resolution better. This may caused by calibration procedure or different thicknesses between silicon and scintillator layers. This will be investigated in future studies.

Figure 4: Energy resolution (left) and confusion term (right) of configurations with a boundary of 8.4$X_0$.

Figure 5: Energy resolution (left) and confusion term (right) of configurations with a boundary of 11.2$X_0$.
Figure 6: Energy resolution (left) and confusion term (right) of configurations with a boundary of $12X_0$.

Figure 7: Energy resolution (left) and confusion term (right) of configurations with a boundary of $14X_0$. 
2.4 Comparison with DBD configuration

We compared the jet energy resolution of considered configurations with that of silicon ECAL in DBD. For this comparison, we picked up 4 considered configurations which had the least number of scintillator layers in each boundary (Hybrid(1-1), Hybrid(2-1), Hybrid(3-1), Hybrid(4-1)) because these configurations has a possibility of the biggest cost reduction. Figure 8 shows the result of jet energy resolution and confusion term. It is seen that energy resolutions of PandoraPFA with the boundary in outer direction (Hybrid(2-1), (3-1), (4-1)) are almost same as that of DBD structure at high energy. The reason of degradation of hybrid configurations with respect to DBD configuration is not identified and should be investigated further. The configuration with the boundary of 11.2X_0 (Hybrid(2-1)) has average degradation of energy resolution of 2.7% with reducing the cost of about 30% compared with silicon ECAL in DBD. For the confusion term, DBD configuration has slightly better performance reflecting the difference in the pixel size.

Figure 8: Comparison of jet energy resolution (left) and confusion term (right) between 4 configurations and silicon ECAL in DBD

3 Summary and Plan

We studied the performance of various hybrid ECAL configurations for ILD using ILCSoft v01-16-02. The hybrid ECAL used silicon semiconductor in inner 14 layers and scintillator-tile in outer layers. We also added a requirement that whole thickness of absorber was fixed as 22.8X_0. We changed the number of scintillator layers and a boundary between inner and outer region, then we got a result that an hybrid ECAL with 16 scintillator layers and a boundary of 11.2X_0 had degradation of jet energy resolution by about 2.7% compared with DBD silicon ECAL with 30% cost reduction. Therefore, we guess that this hybrid ECAL is capable to resolve the cost issue of ILD in this study.

Our future plan is to use medium region with alternating structure of silicon and scintillator to partially reduce the effect of confusion.

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