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Simulation Study of the Hybrid ECAL for ILD

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A highly granular calorimeter is required for a future linear collider experiment in order to optimally utilize Particle Flow Algorithms. An electromagnetic calorimeter (ECAL) read out by silicon sensors is a promising candidate to realize such fine granularity. Another option to make the ECAL at a lower cost, while keeping the performance as much as possible, would be to use a mixture of silicon and scintillator-strip layers. In this paper, we evaluated the performance of three cases of the hybrid configurations using the dedicated simulation software.

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1. Introduction

The International Linear Collider (ILC) is a future energy-frontier electron-positoron collider currently being designed by a world-wide collaboration. For the ILC experiment, a highly granular calorimeter is desired to achieve good Jet Energy Resolution (JER) using Particle Flow Algorithm (PFA) [1]. International Large Detector (ILD), which is one of the detector concept being developed for ILC , has been designed for PFA [2]. An electromagnetic calorimeter (ECAL) of the ILD detector is a sandwich calorimeter whose absorber material is tungsten. There are two candidates for sensitive layer; High resistivity silicon sensor, whose cell size is 5mm×5mm and thickness is 0.5mm, is one of the candidate. Left figure of Figure 1 shows a silicon sensors produced by Hamamatsu Photonics K.K.. They are suitable for PFA because of the high granularity, but it's also a large fraction of detector cost. The scintillator-strip with Multi-pixel photon counter (MPPC) readout is another option for the sensitive layer. The scintillator size is $45\times5\times2\text{mm}^3$. Right figure of Figure 1 is a picture of a scintillator strip and a MPPC. Scintillator strips in odd layers are orthogonal with respect to those in even layers in order to realize the 5mm×5mm effective granularity. We can expect a cost reduction compared to the silicon sensor option, however, special algorithm to extract the effective granularity from the strip structure should be developed. An another option to make ECAL with a lower cost while keeping the performance as much as possible would be a mixture of silicon and scintillator-strip layers (Hybrid ECAL option). Therefore we are studying the performance of the Hybrid ECAL for various configurations by using the dedicated simulation software which is developed for the ILD detector.

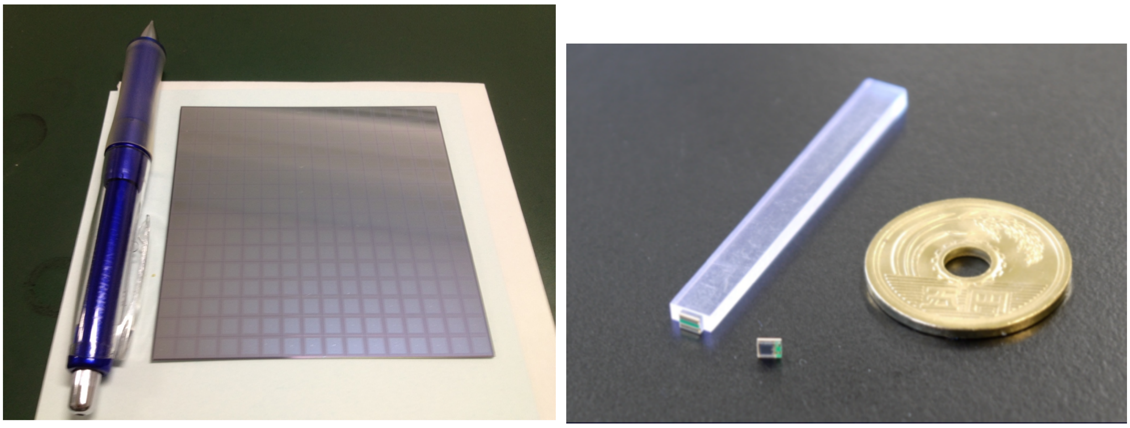


Figure 1: [*left*] Picture of the silicon sensor. The sensor has 16×16 cells and each cell size is 5mm×5mm. [*right*] Picture of the scintillator-strip(45mm×5mm×2mm) and MPPC.

2. Calibration

First of all, we should determine the calibration constants for the silicon layers and the scintillator-strip layers, respectively. They were determined with 10 GeV single photon events. Left figure of Figure 2 shows energy distribution for pure silicon ECAL (SiECAL), pure scintillator ECAL (ScECAL) and Hybrid ECAL, and right figure of Figure 2 shows scatter plot of the deposited energy in

ECAL and hadron calorimeter. Then we evaluated the energy resolution and linearity using 1 to 50 GeV photons as shown in Figure 3 in order to confirm whether our calibration method is correct or not. Both energy resolution and linearity of Hybrid ECAL are almost same as those of SiECAL and ScECAL. We note that in these plots the configuration of Hybrid ECAL is silicon layers for inner half, and scintillator-strip layers for outer half. We also calibrated e/h compensation parameter and MIP calibration parameter for each ECAL. We used 10GeV single π^+ for e/h compensation, and 10GeV single μ^+ for MIP calibration.

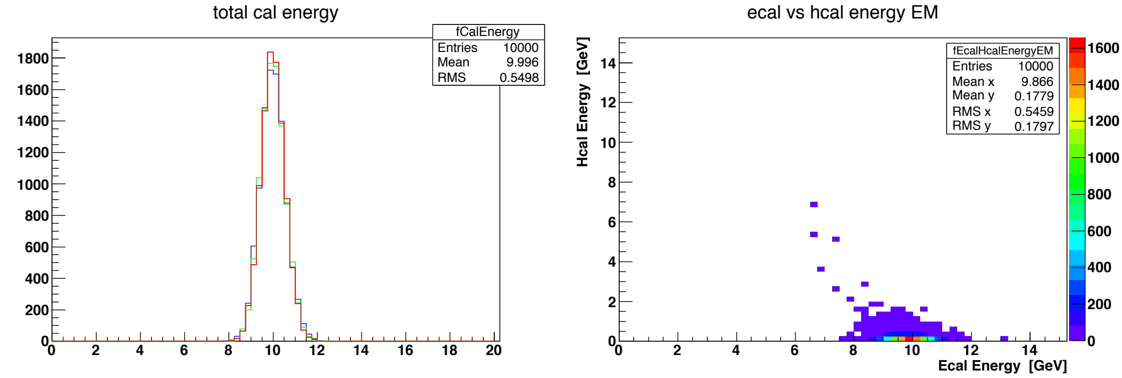


Figure 2: [*left*] Energy distribution of 10GeV photon events in SiECAL(blue), ScECAL(green), and Hybrid ECAL(red). [*right*] Scatter plot of the deposited energy in ECAL and hadron calorimeter.

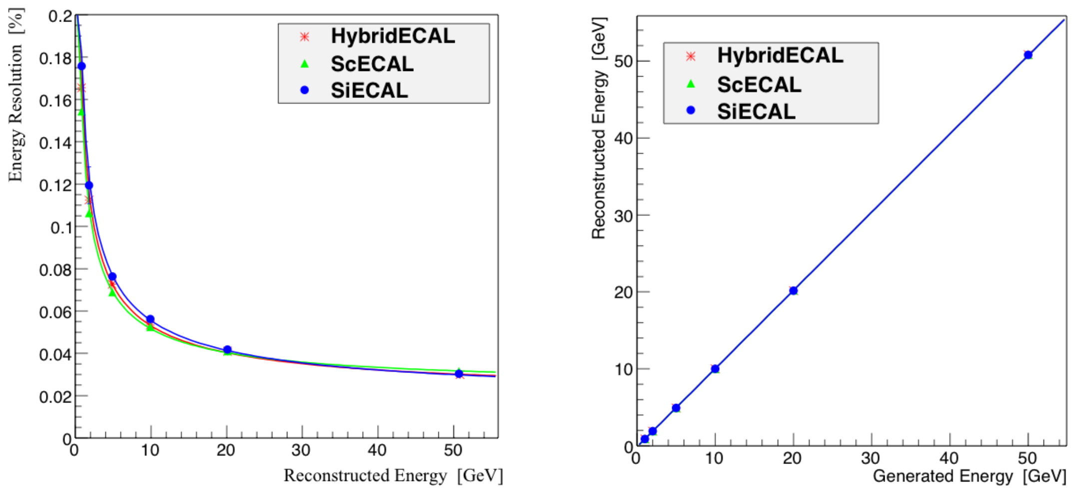


Figure 3: Photon energy resolution[*left*] and Linearity[*right*] in SiECAL(circle), ScECAL(triangle), and Hybrid ECAL(x-mark).

3. Jet Energy Resolution

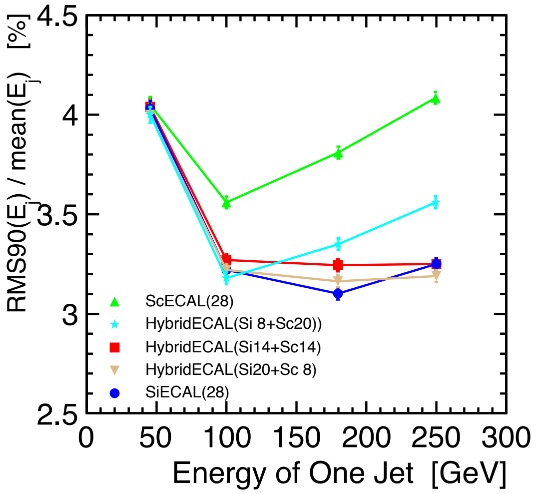
In this study, we evaluated JER in two ways; energy dependence and silicon-scintillator ratio dependence. JER is evaluated using RMS90 method which is the RMS in the smallest region where 90% events are included [1]. $Z \to q\bar{q}$ $(q = u, d, s$ quarks only) events were generated at the interaction point in the ILD detecter with the centre-of-mass energies of 91, 200, 360 and 500 GeV. We only selected the events that both jets were injected to barrel region because the performance in barrel/endcap overlap region and very forward region are worse.

3.1 Same absorber thickness

We keep the absorber thickness in order to evaluate the performance difference between silicon layers and scintillator layers. We simulated five configurations as shown in Table 1. Because of the scintillator-strip thickness is thicker than that of the silicon sensor, the whole ECAL thickness increases as shown in Table 1. Left figure of Figure 4 shows JER as a function of the energy of one jet. JERs become worse from 100 GeV for ScECAL and Hybrid[Si8+Sc20], and the difference of JER from other three configurations becomes bigger as energy increase. Right figure of Figure 4 shows silicon-scintillator ratio dependence. JERs of ECALs which contain more scintillator layers are worse especially at higher energies. But the performance can be kept with 75% of scintillator layers up to 100 GeV jet, and even at 500 GeV up to 50%.

Configuration	Si layer	Sc layer	Tungsten thickness(Inner/Outer)	ECAL thickness
SiECAL[28]	28	0	$2.1\text{mm}\times20/3.5\text{mm}\times7$	165.4mm
Hybrid[Si20+Sc8]	20	8	$2.1\text{mm}\times20/3.5\text{mm}\times7$	176.7mm
Hybrid[Si14+Sc14]	14	14	$2.1\text{mm}\times20/3.5\text{mm}\times7$	185.2mm
Hybrid[Si8+Sc20]	8	20	$2.1\text{mm}\times20/3.5\text{mm}\times7$	193.7mm
ScECAL[28]	0	28	$2.1\text{mm}\times20/3.5\text{mm}\times7$	205.0mm

Table 1: ECAL Configurations for the case of same absorber thickness



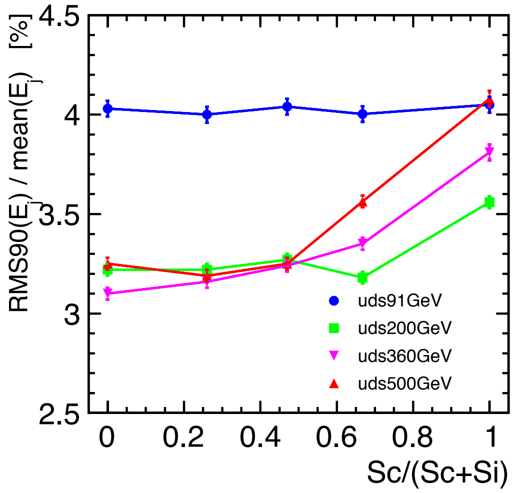


Figure 4: [*left*] Energy dependence of JER for the case of same absorber thickness. [*right*] Ratio dependence of JER for the case of same absorber thickness.

3.2 Same module thickness

In the next, we keep the total ECAL thickness to be 185.0 mm which is the current designed value. Again we simulated also five configurations as shown Table 2. In this case we use 1.0mm thick scintillator to save thickness of scintillator layers. To keep ECAL thickness, we adjusted the absorber layers' thickness for outer 9 layers. Left figure of Figure 5 shows energy dependence of the JER. The performance of SiECAL is much better than that of ScECAL for all over the energies. Hybrid ECALs are in between SiECAL and ScECAL, and their performances seem to depends on the number of silicon layers. Right figure of Figure 5 shows ratio dependence of JER. The performance becomes almost linearly worse as scintillator layers increase, but JERs of Hybrid[Si14+Sc14] at lower energies are better than other hybrid configurations. We are investigating about this behavior.

Configuration	Si layer	Sc layer	Tungsten thickness(Inner/Outer)	ECAL thickness
SiECAL[30]	30	0	2.1mm$\times$20/4.2mm$\times$9	165.4mm
Hybrid[Si22+Sc8]	22	8	2.1mm$\times$20/3.9mm$\times$9	176.7mm
Hybrid[Si16+Sc14]	16	14	2.1mm$\times$20/3.6mm$\times$9	185.2mm
Hybrid[Si10+Sc20]	10	20	2.1mm$\times$20/3.3mm$\times$9	193.7mm
ScECAL[30]	0	30	2.1mm$\times$20/2.9mm$\times$9	205.0mm

Table 2: ECAL Configurations for the case of same module thickness

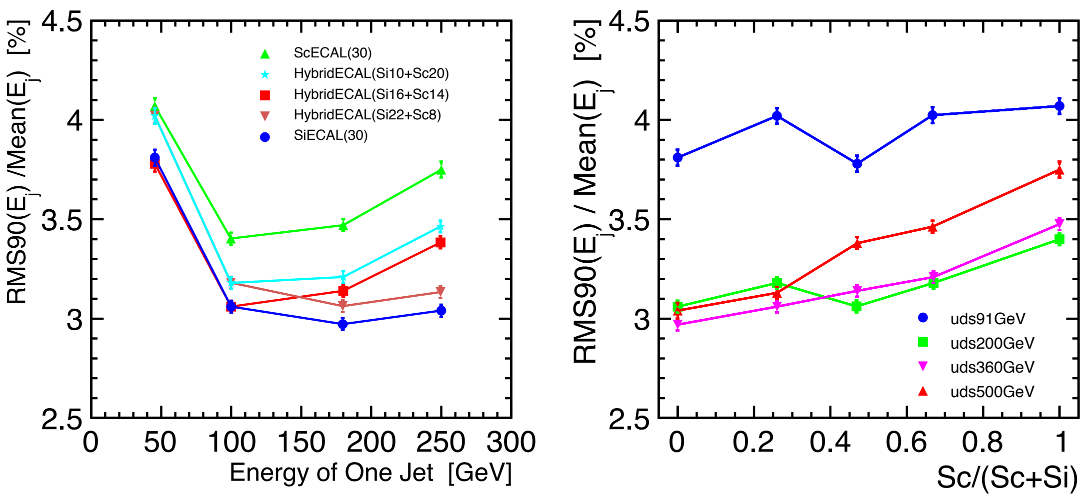


Figure 5: (*left*) Energy dependence of JER for the case of same module thickness. (*right*) Ratio dependence of JER for the case of same module thickness.

3.3 Alternating hybrid

The aim of these configurations is resolving ghost hits occurred in scintillator layers using information of silicon layers by putting silicon layers between scintillator layers. We simulated two configurations in this study, single layer alternating and double layers alternating. Single layer alternating is the configuration that one silicon layer and one scintillator layer are in line alternatively. Double layers alternating is the configuration that two silicon layers and two scintillator layers are in line alternatively. For both case, the innermost layer is silicon and we use 2.0mm thickness for scintillator.

Configuration	Si layer	Sc layer	Tungsten thickness(Inner/Outer)	ECAL thickness
SiECAL[30]	30	0	2.1mm×20/4.2mm × 9	185.0mm
Alternating Hybrid[Single]	16	14	2.1mm×20/4.2mm × 9	204.8mm
Alternating Hybrid[Double]	16	14	2.1mm×20/4.2mm × 9	204.8mm
ScECAL[30]	0	30	2.1mm×20/4.2mm × 9	227.4mm

Table 3: ECAL Configurations for the case of same absorber thickness

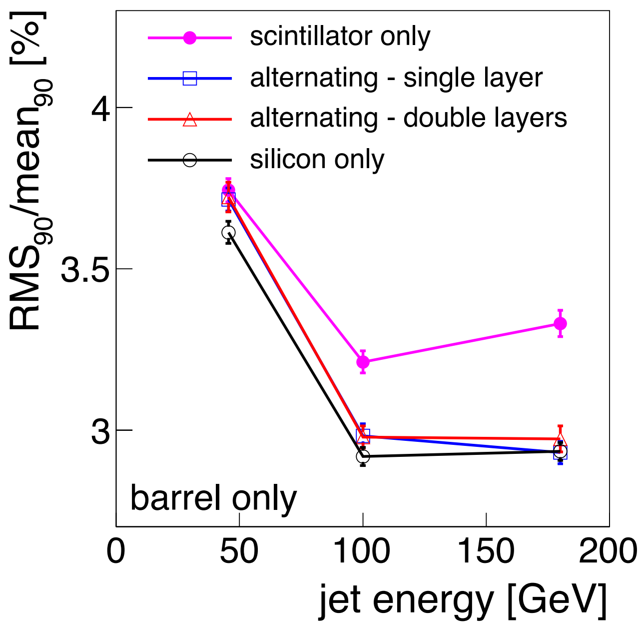


Figure 6: Energy dependence for the case of alternating hybrid

The performances of alternating hybrids are much better than ScECAL, and almost same as SiECAL. And there are no big difference between single layer alternating and double layers alternating.

4. Summary

We evaluated the performance of Hybrid ECALs in three cases for ILD. For the case of same absorber thickness, the performance doesn't degrade up to 50% of scintillator layers. For the case of same module thickness, the performance becomes worse almost linearly, and we can keep the performance up to 30% of scintillator layers. For the case of alternating hybrid, the performance is almost same as pure silicon ECAL. Note that these are slightly different structures to each other, so results cannot be directly compared. For future plan, we will investigate contributions to JER in PFA by using MC information to understand what make resolution worse, and we will study also the structure of absorber layers to optimize the realistic Hybrid ECAL.

References

[1] M. A. Thomson. Particle Flow Calorimetry and the PandoraPFA Algorithm. *Nucl.Instrum.Meth.*, A611:25–40, 2009.

[2] Ilc detailed baseline design. http://ific.uv.es/~fuster/DBD-Chapters/Chapter%204%20ILD.pdf.