PRAMANA
— journal of
physics

© Indian Academy of Sciences

Vol. xx, No. x
xxxx xxxx
pp. 1–4

Performance of GLD Detector

T. Yoshioka
ICEPP, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, JAPAN

Abstract. Most of the important physics processes to be studied in the International Linear Collider (ILC) experiment have multi-jets in the final state. In order to achieve better jet energy resolution, the so-called Particle Flow Algorithm (PFA) will be employed and there is a general consensus that PFA derives overall ILC detector design. Four detector concepts for the ILC experiment have been proposed so far in the world; the GLD detector that has a large inner calorimeter radius, which is considered to have an advantage for a PFA, is one of them. In this paper, general scheme and performance of the GLD-PFA will be presented.

Keywords. ILC, GLD, PFA

PACS Nos 2.0

1. Introduction

Most of the important physics processes to be studied in the International Linear Collider (ILC) experiment have multi-jets in the final state [1]. Since the momentum resolution of the charged particle measured by trackers is much better than the energy resolution measured by calorimeters, the best jet energy resolution is obtained by reconstructing momenta of individual particles avoiding double counting among trackers and calorimeters; charged particles, whose energy fraction in a jet is about 60%, are measured by trackers, photons, whose energy fraction in a jet is about 30%, are measured by electromagnetic calorimeter (ECAL) and neutral hadrons, whose energy fraction in a jet is about 10%, are measured by both ECAL and hadron calorimeter (HCAL). This is known as a Particle Flow Algorithm (PFA) and there is a general consensus that PFA derives overall ILC detector design. In a PFA, separation of particles in calorimeter (i.e. reducing the density of charged and neutral particles at calorimeter surface) is important. In order to represent quantitatively, Figure of Merit (F.O.M.) is often quoted as

$$\text{F.O.M.} = \frac{BR^2}{\sqrt{\sigma^2 + R_M^2}}, \tag{1}$$

where B is magnetic field, R is calorimeter inner radius, σ is calorimeter granularity and R_M is effective Moliere length. Four detector concepts for the ILC experiment have been proposed so far in the world [2]; the GLD detector [3] that has a large inner calorimeter radius, which is considered to have an advantage for a PFA as can be seen from the F.O.M., is one of them.

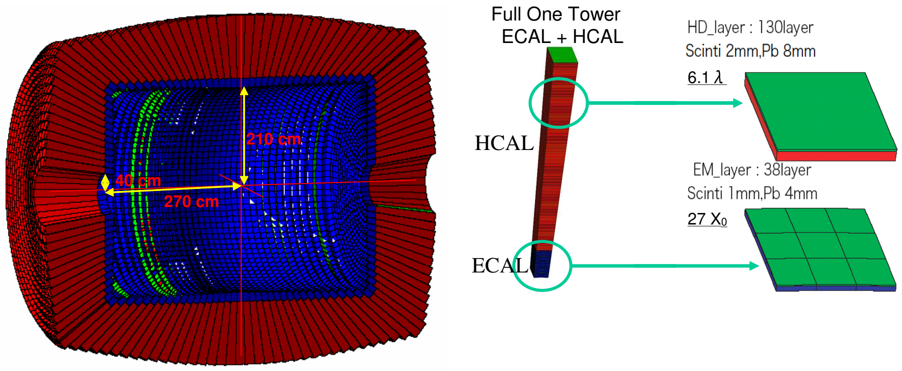

Figure 1. Schematic cross section of the GLD calorimeter currently implemented in the Jupiter (left). The calorimeter consists of tower structure (middle) and one tower consists of electromagnetic calorimeter and hadron calorimeter (right). See text for more details.

We have been studied the PFA for the GLD detector [4,5] using the GEANT4 [6]-based full simulator named Jupiter [7]. Left most figure in Figure 1 shows a schematic cross section of the GLD calorimeter that is currently implemented in the Jupiter [1] . The calorimeter is cylindrical shape with a half length of 270 cm in the beam direction and a inner radius of 210 cm. The calorimeter consists of tower structure (see middle part of Figure 1): One tower consists of ECAL and HCAL. The ECAL is a sandwich-type calorimeter made of 38 layers of 1 mm-thick plastic scintillator and 4 mm-thick lead. The length in the radial direction is 27 radiation lengths in total. The HCAL is a sandwich-type calorimeter, as well as the ECAL, made of 130 layers of 2 mm-thick plastic scintillator and 8 mm-thick lead. The length in the radial direction is 6.1 interaction lengths in total. The size of plastic scintillator sheet (called "cell" hereafter) can be changed easily in the Jupiter and current cell size is set to be 4 cm $\times$ 4 cm and 12 cm $\times$ 12 cm for the ECAL and HCAL, respectively. One layer in a tower containers 9 ECAL cells (3 $\times$ 3) as shown in the right most figure of Figure 1.

2. Particle Flow Algorithm for GLD

The GLD-PFA mainly consists of four part: photon finding, charged hadron finding, neutral hadron finding and "satellite" hit finding. Here satellite hit means a calorimeter hit cell which is not belonged to a cluster core. Note that neutral hadron finding and satellite hit finding are performed simultaneously. The photon finding is based on a hit cluster in the ECAL. A "small cluster" is formed by the so-called nearest-neighbor clustering method.

[1]Note that this calorimeter geometry is idealistic structure and is not the GLD baseline.

Further clustering is performed by collecting the small clusters within a certain tube region around a mother cluster which has a relatively high energy among the small clusters. A cluster due to photon is then identified by using the cluster information such as longitudinal energy profile, and the ECAL energy is used for that cluster. After the photon finding, the charged hadron finding is performed. A charged track is extrapolated to the calorimeter, and distance between a calorimeter hit cell and the extrapolated track is calculated. The distance is calculated for any track/calorimeter cell combination. The calorimeter hit cells within a certain tube radius are connected to form a charged hadron cluster. Note that the tube radius for the ECAL and HCAL can be changed separately. Charged track information is used instead of the calorimeter energy for a charged hadron cluster. After the charged hadron finding, the remaining calorimeter hits are classified into a hit due to a neutral hadron or a satellite hit due to a charged hadron by using a TOF and energy density information. Calorimeter energy is used for a neutral hadron hit and calorimeter energy of satellite hits are subtracted from total energy.

3. Results

Performance of the GLD-PFA is studied by using $e^+e^- \to Z \to q\bar{q}$ process at the center of mass energy of 91.2GeV. Performance of each tool is summarized in Table 1. The left most column shows a particle type identified by the GLD-PFA. The energy weighted efficiency (E_{XXX}) for the photon finding, charged hadron finding and neutral hadron finding are 85.2%, 84.4% and 60.5%, respectively. The energy weighted purity (P_{XXX}) for the photon finding, charged hadron finding and neutral hadron finding are 92.2%, 91.9% and 62.2%, respectively. Definition of efficiency and purity is as follows:

$$E_{XXX} \equiv \frac{\text{Total XXX energy in collected hits}}{\text{True XXX energy in calorimeter}} \tag{2}$$

$$P_{XXX} \equiv \frac{\text{Total XXX energy in a cluster}}{\text{Total energy of the cluster}} \tag{3}$$

Note that if satellites hits are included in the charged hadron, we gain 10% efficiency at a cost of 3% purity loss for the charged hadron finding. Right histogram of Figure 2 shows the energy sum of these events when the GLD-PFA is applied. $38\%/\sqrt{E}$ energy resolution is achieved by using the PFA while that of energy sum in the calorimeter is $60\%/\sqrt{E}$ as shown in the left histogram of Figure 2.

4. Summary and Future

We studied a PFA for the GLD detector and checked the performance with $e^+e^- \to Z \to q\bar{q}$ process at the center of mass energy of 91.2GeV. We found the jet energy resolution is $38\%/\sqrt{E}$ by using the GLD-PFA. However, the world-wide consensus of the performance goal for jet energy resolution is $30\%/\sqrt{E}$. By looking at Table 1, there is still some room for the improvement in the efficiency and purity. We therefore expect we can achieve the ILC goal of $30\%/\sqrt{E}$ in near future.

Table 1. Energy weighted efficiency (E_{XXX}) and purity (P_{XXX}) for each particle type identified by the GLD-PFA. CHD and NHD represents charged hadron and neutral hadron, respectively.

	E_{Photon}	E_{CHD}	E_{NHD}	P_{Photon}	P_{CHD}	P_{NHD}
Photon	85.2	0.626	8.19	92.2	2.03	5.11
CHD	4.59	84.4	16.4	1.67	91.9	3.44
NHD	6.27	4.51	60.5	11.2	24.1	62.2
Satellite	3.94	10.5	14.9	8.90	70.9	19.4
CHD + Satellite	8.53	94.9	31.3	2.67	89.0	5.64

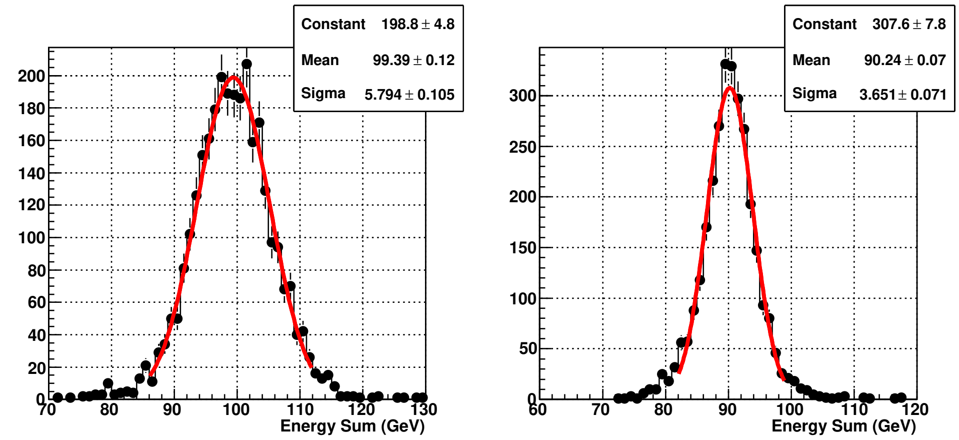

Figure 2. Energy sum for $e^+e^- \rightarrow Z \rightarrow q\bar{q}$ process at the center of mass energy of 91.2GeV. $38\%/\sqrt{E}$ energy resolution is achieved by using the PFA (right) while that of energy sum in the calorimeter is $60\%/\sqrt{E}$ (left).

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