GLD Detector Concept Study

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July 28, 2005

Abstract

GLD is a large detector model for ILC experiment based on a large gaseous tracker. In this article, the basic design concept and the baseline design of the GLD detector model are described. Technologies intended to be used for the sub-detectors in the baseline design are shown with possible options. The status and the prospects of each sub-detector R&D are also shown.

1 Introduction

At future high energy e^+e^- linear collider experiments, it is required to reconstruct events at fundamental particle (leptons, quarks, and gauge bosons) level. Most of interesting events includes gauge bosons (W or Z), heavy flavor quarks (b and c), and/or leptons (e, μ, τ) as direct products or as decay daughters of heavy particles (SUSY particles, top quark, higgs boson, etc.). Identification and precise measurement of four-momenta of those fundamental particles are very important. To achieve them, the detector must have the following performances:

- Good jet-energy resolution to separate W and Z in their hadronic decay mode.
- Efficient jet-flavor identification capability.
- Excellent charged-particle momentum resolution.
- Hermetic detector coverage which gives high veto efficiency against 2-photon background.

In order to achieve these performances, we propose a large detector model based on a large gaseous tracker, named “GLD”.

2 Basic design concept of GLD

The best jet-energy resolution is expected by measuring each particle in a jet separately; charged particles by the tracker, photons by the EM calorimeter, and neutral hadrons by the hadron calorimeter. This approach is called “energy flow algorythm” or “particle flow algorythm (PFA)”.

The basic design of GLD has a calorimeter with fine segmentation and large inner radius to optimize for PFA. Charged tracks are measured by a large gaseous tracker with excellent momentum resolution and good pattern recognition capability. The good pattern recognition capability is advantageous for efficient reconstruction of V^0 particles such as K^0, Λ, and new unknown long-lived particles, and for efficient matching between tracks measured by TPC and hit clusters in the calorimeter. The solenoid magnet is located outside of the calorimeter. Because the detector volume is huge, it has a moderate magnetic field of 3 Tesla.

The ultimate PFA performance can be achived by complete separation of charged-particle hit clusters from neutral hit clusters in the calorimeter. The figure of merit for the cluster separation in ECAL can be expressed as $BR_{\mathrm{in}}^2/R_m^{\mathrm{eff}}$, where R_{in} is the inner radius of the barrel ECAL and R_m^{eff} is effective Moliere length of the ECAL. It means large inner radius and strong magnetic field is favorable for PFA. Actually, the things are not so simple. Even with $B = 0$, photon energy inside a certain distance from a charged track in the ECAL scales as $\sim R_{\mathrm{in}}^{-2}$. So, the large inner radius of the ECAL has a peculiar advantage.

The outer radius of the main tracker is also large in GLD. Consequently the lever arm of the tracking is long and the number of sampling can be large. Therefore, we can expect an excellent momentum resolution for the charged particles ($\delta p_t/p_t^2 \propto 1/BL^2\sqrt{n_{\mathrm{sample}}}$), and good particle identification ($\pi/K/p$) capability by dE/dx.

3 Baseline design of the GLD detector

The schematic view of the baseline design of the GLD detector is shown in Figure 1. It consists of the following sub-detectors:

- Silicon pixel vertex detector
- Silicon strip inner tracker
- Large volume gaseous tracker, presumably TPC
- Silicon strip endcap tracker
- Tungusten-scintillator sandwitch EM calorimeter
- Lead-scintillator sandwitch hadron calorimeter
- Solenoid magnet of 3 Tesla
- Iron return yoke interleaved with muon tracker
- Forward silicon disks
- Forward calorimeters for maximum hermeticity

Additional silicon tracker between TPC and EM calorimeter in the barrel region is also proposed to improve the momentum resolution still more. It is also suggested that a TOF counter in front of the EM calorimeter can improve the particle identification capability, but this function could be included in the EM calorimeter.

Technologies for sub-detectors are still to be discussed based on detailed performance study. In the following section, we describe the sub-detector technologies assumed at present and their possible options. The technologies and parameters of the baseline design described in the following section are as of July 28, 2005.

MDI issues are also important for the detector design. We assume large distance between the interaction point and the front surface of the final quadrupole magnet ($l^* = 4.1$–4.8 m).

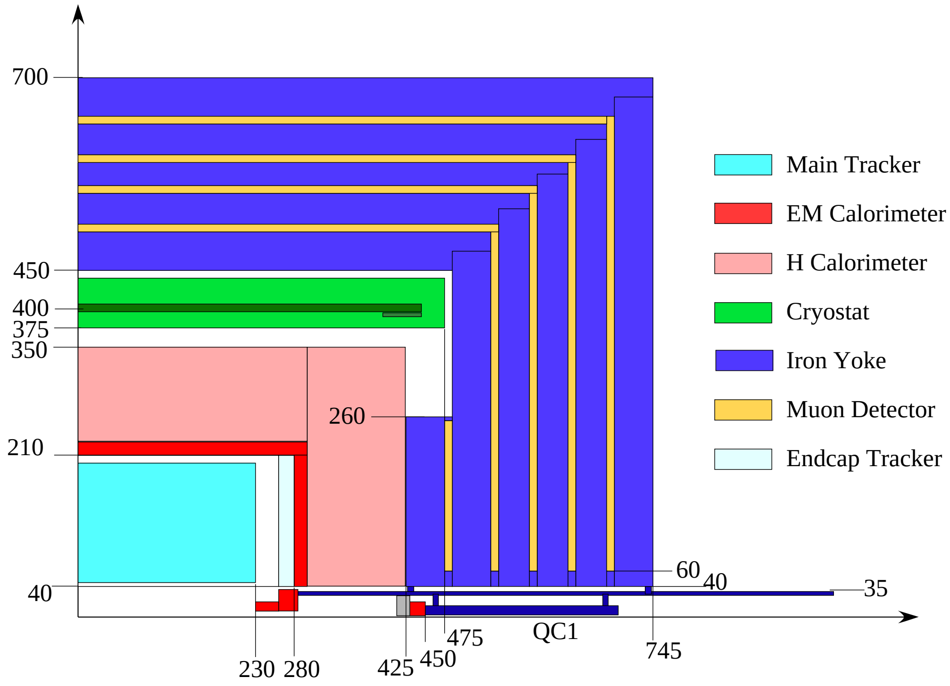

Figure 1: Schematic view of the baseline design of the GLD detector. The vertex detector, the Si inner tracker, and the Si forward disks are not shown.

4 Sub-detector technologies

4.1 Vertex detector

Very good impact parameter resolution for charged tracks is required at ILC for efficient jet-flavor identification. The target value of the impact parameter resolution is

$$\sigma_b = 5 \oplus \frac{10}{p\beta \sin^{3/2}\theta}\ [\mu m].$$

In order to achieve this resolution, the Si pixel vertex detector has to have excellent point resolution and thin wafer thickness.

From a viewpoint of vertex detector concept (not technology), two options of sensors have been proposed for ILC vertex detector; standard pixel option and fine pixel option. In standard pixel option, the sensors have a typical pixel size of 20 μm and the signal is read out about 20 times per beam bunch train in order to reduce the pixel hit occupancy due to the beam background. In fine pixel option, the pixel size is as small as 5 μm and the signal for one bunch-train is accumulated and read out between trains.

For the baseline design of the vertex detector, we envisage fine pixel CCDs (FPCCDs) as the sensors. The inner radius is 20 mm and the outer radius is 50 mm. It consists of three layers of doublets, and a doublet is made by two sensor layers with 2 mm distance. The angular coverage is $|\cos\theta| < 0.95$ with inner two barrel doublets plust a forward doublet (disk), and $|\cos\theta| < 0.90$ with three barrel doublets.

The CCD technology is well-established one and the fine pixel option is completely free from electro-magnetic interfare (EMI) due to the beam current. So it seems that the FPCCD option is the most feasible among various proposed technologies.

In FPCCD option, pixel occupancy is expected less than 0.5% for the inner most layer (R=20 mm) at B=3 T for the ILC nominal machine parameters [1]. The hit density is, however, as high as $20/\mathrm{mm}^2$. Therefore, very thin wafer (much less than 100 μm) is required in order to keep wrong-tracking probability due to multiple scattering reasonably low [2]. The R&D effort on the wafer thinning is very important, as well as the fabrication of the small pixel sensors.

If the wrong-tracking probability cannot be low with the FPCCD option, other options have to be seriously considered. Fortunately, there are many R&D activities on various vertex detector technologies all over the world. The technologies such as CMOS, CMOS with SOI technology, In-Situ storage Image Sensor (ISIS), etc., are possible options.

4.2 Si inner tracker

The Si inner tracker (IT) is located between the vertex detector and main tracker. The roles of the IT are to improve the linking efficiency between the main tracker and the vertex detector, and to reconstruct and measure momenta of low p_t charged particles. Time stamping capability to separate bunches (307.7 ns or 153.8 ns interval) is necessary as well as good spatial resolution.

Silicon strip detectors will be used for the IT. Four layers of Si strips is being considered for stand-alone tracking capability. The innermost and outermost layers are located at the radii of 9 cm and 30 cm, respectively. The number of layers, the thickness of the wafers, inner- and outer radii, etc., are still to be optimized by simulation studies.

4.3 Forward Si disks

Forward Si disks should cover the angular range down to ~ 150 mrad which corresponds to the coverage of the endcap calorimeter. Few layers of Si disks should be put in front of forward calorimeter covering down to ~ 40 mrad.

The technologies used for the forward Si disks depends on the background level (beam background and 2-photon background). Detailed background simulation is necessary to determine the technology.

4.4 Main tracker

A large gaseous tracker will be used for GLD as the main tracker. In the baseline design, a TPC (Time Projection Chamber) with 40 cm inner radius and 200 cm outer radius is assumed. The maximum drift length in z-direction is 230 cm.

The requirement for the performance of the TPC in GLD is to achieve the momentum resolution of $\delta p_t/p_t^2 < 5 \times 10^{-5}$ combined with SIT and VTX at the high p_t limit.

TPCs have been used in a number of large collider experiments in the past and have performed excellently. These TPCs were read out by multi-wire proportional chambers (MWPCs). The thrust of R&D is to develop a TPC based on novel micro-pattern gas detectors (MPGDs), which promise to have better point and two-track resolution than wire chambers and to be more robust in high backgrounds than wires.

Systems under study at the moment are Micromegas[4] meshes and GEM (Gas Electron Multiplier)[5] foils. Both operate in a gaseous atmosphere and are based on the avalanche amplification of the primary produced electrons. The gas amplification occurs in the large electric fields in MPGD microscopic structures with sizes of the order of 50 μm. MPGD lend themselves naturally to the intra-train un-gated operation at the ILC, since, when operated properly, they display a significant suppression of the number of back-drifting ions.

In a previous document [3] LC-TPC groups proposed to investigate the feasibility of designing and testing the TPC technology for this collider. To this end an R&D program was started during the last couple of years. The present scope of the R&D work has been extended to all Asian, American and European TPC groups. Some of the points being address are:

- Operate MWPC in a small test TPC and compare with MPGDs to prove that they can be used reliably in an LC TPC.
- Study the behaviour of GEM and Micromegas with and without magnetic fields.
- Study the achievable resolution of a MPGD-TPC for different gas mixtures.

To enable an objective comparison of MPGD options with the well-tested MWPC technology, one goal of the present studies is to compare all three technologies with the same test set-up. The performance of a MWPC TPC was measured in the $\pi 2$ test beam at KEK. The chamber was then coverted to GEM and finally to Micromegas technologies and measured in the beam; these results will be reported in subsequent papers.

There are many other TPC R&D projects addressing the above and other goals by the LC TPC groups. See for example reference [6].

4.5 Endcap Si tracker

Several layers of Si strip detectors are placed in the relatively large gap between the TPC and the endcap EM calorimeter. This endcap Si tracker (ET) improves momentum resolution for charged particles which have small number of TPC hits. Another role of the ET is to improves matching efficiency between TPC tracks and shower clusters in the EM calorimeter. This function is important particularly for low momentum tracks.

4.6 Calorimeter

As mentioned in section 2, the calorimeter of GLD should have large radius and fine 3D segmentation in order to get excelent jet energy resolution by PFA. The target value of the jet energy resolution is

$$\sigma(E_j)/E_j = 30\%/\sqrt{E_j(GeV)}.$$

4.6.1 EM calorimeter

The EM calorimeter (ECAL) should have small effective Moliere length in order to suppress the shower spread and minimize the deterioration of the jet-energy resolution due to confusion of γs and charged tracks. For this reason, tungsten will be used for the absorber material.

Because the size of EMCAL is quite large ($\sim$ 100 m^2/layer), it would not be practical to use Si pad as the sensor due to the cost problem. Therefore, the baseline design adopts scintillator strip and tile with wavelength-shifter fiber readout. The combination of strip and tile resolves overlapping problem, thus reduces the cost effectively. As the photon sensor, the use of MPC (Multipixel Photon Counter) is considered. It consists of 33 sampling layers of tungsten/scintillator with the thicknesses of 3 mm/2 mm and 1 mm gap for readout. The effective segmentation cell size is 1 cm×1 cm with orthogonal strips and combination of tile.

The cell size is not yet optimized, because we do not have powerful PFA in our hands. The detector full simulation and application of realistic PFA are necessary to determine the cell size. If it turned out that much smaller segmentation should be used, the strip length and width must be tuned as far as the cost limit. The use of Si layers for the first several radiation lengths is also an option.

4.6.2 Hadron calorimeter

The hadron calorimeter (HCAL) of GLD, as a baseline design, consists of 50 layers (48 layers for the endcap region) of lead/scintillator sandwiches with 20 mm/5 mm thickness. This configuration is thought as a "hardware compensation" configuration which gives the best energy resolution for a single particle. The effective cell size is 1 cm square to be achieved by a 1 cm x 20 cm strip and 4 cm x 4 cm tile. As the photon sensor, the use of MPC (Multipixel Photon Counter) is considered to read scintillating lights through a wave length shifting fiber. This is also to be determined by simulations studies. Another option of "digital hadron calorimeter" is also considered for HCAL so as to reduce the read out electronics. For the digital HCAL, the base line design consists of scintillator strip may have shower overlap problem. With a realistic PFA model, we need to clarify this, so as to determine the optimal width and length of the strips.

4.7 Muon tracker

Because calorimeters of GLD has enough thickness of 7 interaction length to contain the hadron showers, the muon detector of GLD is not required to work as a tail catcher. Therefore, the baseline design of GLD has just 4 or 5 layers of muon detectors interleaved with the iron return yoke. As a baseline design, two-dimensional array of scintillator strips with wavelength-shifter fiber plus multi-pixel photon counter readout is proposed.

4.8 Forward calorimeter

Forward calorimeter of GLD consists of two parts; FCAL and BCAL. The z-position of FCAL is close to that of endcap ECAL, and it locates outside of the dense core of the pair background in R direction. BCAL is located just in front of the final quadrupole magnet (~ 4.5 m). The inner radius of FCAL and BCAL depends on the machine parameters. In case of small crossing angle of 2 mrad, the inner radius of the BCAL can be as small as 20 mm and the minimum veto angle for the electrons of 2-photon processes is ~ 5 mrad.

Since BCAL is hit by the dense core of the pair background, it creates a lot of backscattered $e^{\pm}$ and photons. A mask made by low-Z material with the same inner radius as the BCAL should be put in front of BCAL to absorb low energy backscattered $e^{\pm}$. The z-position of FCAL should be chosen so that FCAL works as a mask for the backscattered photons from BCAL and they cannot hit TPC directly.

Technology of FCAL and BCAL is still open question. For FCAL, W/Si sampling calorimeter will work well. For BCAL, more radiation hard sensors, such as diamond, would be the option.

4.9 Solenoid coil and iron structure

The detector magnetic field is generated by a super-conducting solenoid with correction winding at both end. The radius of the coil center is 4.0 m and the length is 8.9 m. The total size of the iron structure has a height of 14 m and a length of 14.9 m. Additional serpentine winding for the ditector integrated dipole (DID) might be necessary to compensate the radial component due to finite crossing angle.

The integrated field uniformity at the tracker region with this configuration satisfies

$$\left| \int_0^{z_{max}} \frac{B_r}{B_z} dz \right| < 2 \text{ mm}$$

without DID. This value is good enough for TPC.

4.10 R&D groups for sub-detectors

R&D projects of the technologies relevant for the baseline design and possible options of the GLD sub-detectors are listed in Table 1 with the institutes of the R&D collaborations and their status of funding and manpower. This table is based on the contents of the WWS detector R&D panel web page[7].

References

[1] T. Raubenheimer, "Suggested ILC Beam Paraneter Range", http://www-project.slac.stanford.edu/ilc/acceldev/beamparameters.html

[2] Y. Sugimoto, talk at LCWS2005, Stanford, Mar. 2005.

[3] Proposal PRC R&D-01/03 to the DESY Physics Review Committee and LC Note LC-DET-2002-008 (http://www-flc.desy.de/lcnotes).

[4] Y.Giomataris et al, Micromegas: A High Granularity Position Sensitive Gaseous Detector for High Particle Flux Environments, Nucl.Instrum.Meth. A376(1996)29.

[5] F.Sauli, GEM: A New Concept for Electron Amplification in Gas Detectors, Nucl.Instrum.Meth. A386(1997)531.

[6] http://www.mppmu.mpg.de/~settles

[7] https://wiki.lepp.cornell.edu/wws/bin/view/Projects/WebHome

Table 1: Technology options for the sub-detectors. For funding and manpower, the first column shows those approved in the past few years, the second column showns those approved or expexted for next few years, and the third column shows those needed in the next few years to complete the work. All values are averaged one during the period shown above each value.

Technology	Collaboration	Funding (/y)			Manpower (FTE)		
Vertex Detector							
Fine Pixel CCD	KEK, Tohoku, Tohoku-Gakuin	–	–	–	–	–	–
		$	$	$			
ISIS	RAL, Bristol, Liverpool, Oxford						
SOI	AGH, IET, INFN						
MAPS	IReS, DAPNIA						
DEPFET	Bonn, Mannheim, MPI						
Si Inner/Forward Tracker							
Si microstrip	Kyungpook, Korea, Chonnam, Seoul	–	–	–	–	–	–
		$	$	$			
Thin Si sensor	Purdue						
Main Tracker							
TPC	MPI, KEK, Tsukuba, TUAT, Kinki, Hiroshima, Saga, Mindanao, Victoria, Berkley, Orsay, Saclay	–	–	–	–	–	–
		$	$	$			
ECAL/HCAL							
Scinti. based	KEK, Kobe, Konan, Niigata, Shinshu, Tsukuba, JINR, Kyungpook, Seoul, Sunkyunkwan, Mindanao	–	–	–	–	–	–
		$	$	$			
Offset tile	Colorado						
Digital HCAL with RPC	Argonne, Boston, Chicago, FNAL, Iowa						
Digita HCAL with GEM	UTA, Washington, Tsinghua, Changwon						
Tile HCAL	CALICE						
Muon system							
Scinti. based	Colorado S., FNAL, Indiana, N.Illinois, Rice, UCD, Nortre Dame, Texas Austin, Wayne S.						
Glass RPC	INFN						