GLD Concept Study Summary

Y. Sugimoto for the GLD concept study team
KEK, Tsukuba, Ibaraki 305-0801, Japan

GLD is a large detector concept based on a large gaseous tracker. Among the three proposed detector concepts, GLD has the largest size. Activity of the GLD detector concept working group in this workshop consisted of study reports on detector simulation and sub-detector R&D, actual "work" for detector optimization, and reports on the progress at Snowmass. In this paper, we summarize the progress on these activities and show the future prospects.

1. INTRODUCTION

In experiments at the ILC, it is essential 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 of e^+e^- collisions or as decay daughters of heavy particles (SUSY particles, Higgs boson, top quark, etc.). The detectors at the ILC have to have capability of efficient identification and precise measurement of four-momenta of these fundamental particles. The design study of GLD is being carried out to achieve these performances. Accelerator design and the machine parameters also give impact on the detector design through the crossing angle, l^*, and beam background.

This workshop gave us an opportunity to make progress towards the optimized baseline design of GLD with close contact and discussion with accelerator physicists and members of other detector concepts. Actual progress was made during the workshop, particularly on machine-related issues, PFA (see below) study, and sub-detector designs. In this report, we summarize the progress in the GLD detector concept study and show the future prospects of the study. Details of each sub-detector technology is not discussed extensively in this paper to avoid the duplication with other summary talks of detector sub-system working groups.

2. GLD OVERVIEW

The basic design of GLD has a calorimeter with fine segmentation and large inner radius to optimize it 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 a TPC (Time Projection Chamber) and hit clusters in the calorimeter. The solenoid magnet is located outside of the calorimeter. Because the detector volume is huge, a moderate magnetic field of 3 Tesla has been chosen.

Jet energy resolution is one of the most important issues for ILC detectors. Precise mass reconstruction and separation of W and Z in their hadronic decay mode are essential in many physics channels. The PFA (Particle Flow Algorithm) is a method to get the best jet-energy resolution. In this method, each particle in a jet is measured separately; charged particles by the tracker, photons by the EM (electromagnetic) calorimeter ECAL, and neutral hadrons by the hadron calorimeter HCAL. The ultimate PFA performance can be achieved by complete separation of charged-particle hit clusters from neutral hit clusters in the calorimeter. Actual jet energy resolution is dominated by a contribution from confusion between charged and neutral clusters. Optimization of algorithm and calorimeter design for PFA is necessary to get better jet energy resolution. In all three detector concepts (SiD, LDC, and GLD), optimization for PFA is the major concern. Thus detector optimization for PFA was one of the most topical issues in this workshop.

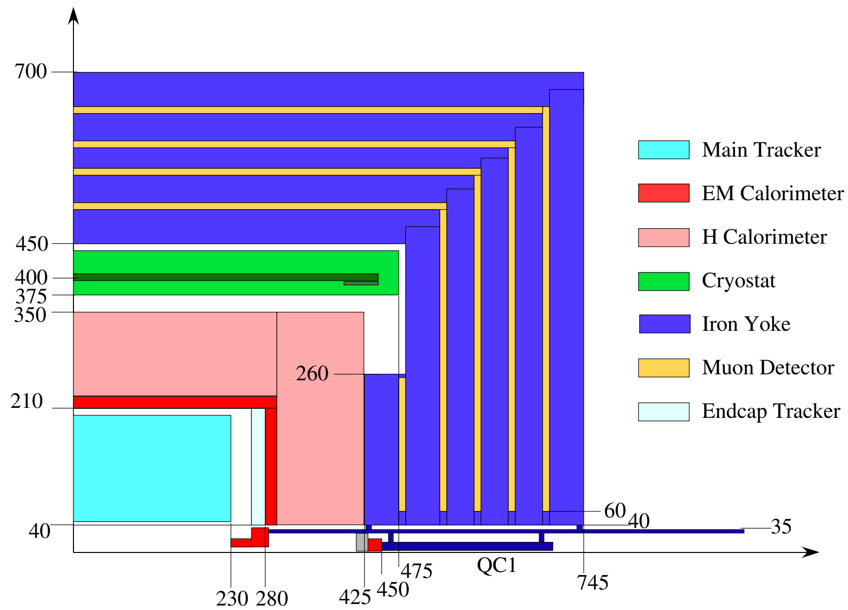

Figure 1: Schematic view of a quadrant of the baseline design of GLD. Dimensions are in cm. The vertex detector and the silicon inner tracker are not shown here.

In order to avoid the confusion and to get good jet energy resolution, separation of particles in the calorimeter is important. Therefore, the calorimeter should have a small effective Moliere length, fine segmentation, and a large distance from the interaction point. Stronger solenoid field is preferable to spread out the charged particles more. The figure of merit which is often quoted for the cluster separation in ECAL is expressed as $BR_{\mathrm{in}}^2/R_M^{\mathrm{eff}}$, where B is the solenoid field, R_{in} is the inner radius of the barrel ECAL and R_M^{eff} is effective Moliere length of the ECAL. However 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 $\sim R_{\mathrm{in}}^{-2}$. In any case, larger inner radius of the calorimeter is favorable for achieving good PFA performance.

Figure 1 shows a schematic view of a quadrant of the baseline design of GLD as of August 2005. It has the following sub-detectors:

- a large gaseous central tracker, presumably TPC [1],
- a large-radius medium/high-granularity ECAL with tungsten-scintillator sandwich structure [2],
- a large-radius thick ($\sim 6\lambda$) medium/high-granularity HCAL with lead-scintillator sandwich structure [2],
- forward EM calorimeters (FCAL and BCAL, see Figure 2) down to 5 mrad,
- a precision silicon micro-vertex detector [3],
- silicon inner/forward/endcap trackers [4],
- a beam profile monitor in front of BCAL [5],
- a muon detector interleaved with iron the return yoke [6], and
- a moderate magnetic field of 3 T [7].

The baseline design listed here is just a working assumption. Detailed full simulation and results of detector R&D could modify the parameters of the detector and the sub-detector technologies where necessary.

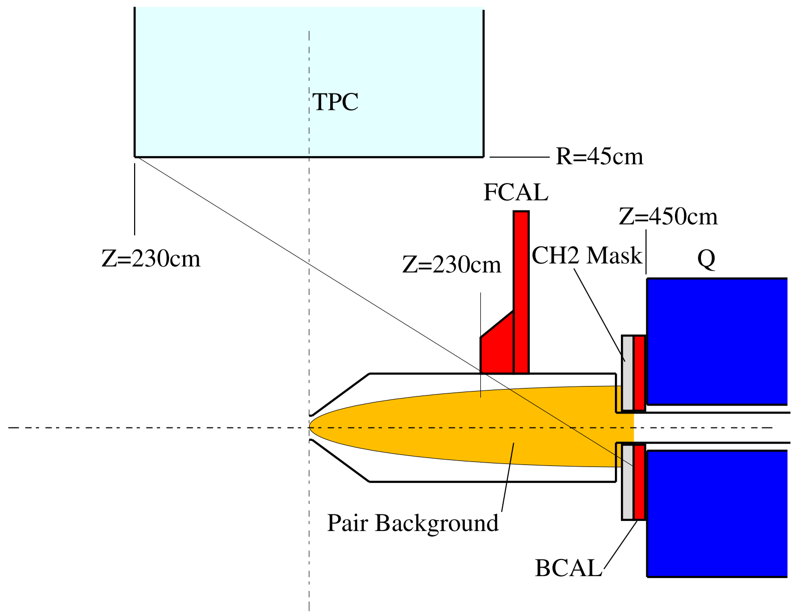

Figure 2: Schematic view of relative location of TPC and very forward detectors of GLD.

3. MACHINE PARAMETER IMPACT ON GLD

Impact of the ILC accelerator design on the GLD detector design has been discussed at this workshop. Machine parameter dependence of radii of the beam pipe and the vertex detector, results of study on background hitting the very forward calorimeter (BCAL), and impact of detector integrated dipole (DID) on GLD design have been reported. Luminosity requirements for Z-pole for detector calibration has also been discussed.

The minimum inner radius of the vertex detector R_{VTX} has been estimated based on pair-background simulations using CAIN [8] for several machine parameters for 3, 4, and 5 T solenoid field [9]. The radii of the beam pipe and the inner radius of the vertex detector have been determined using the following design criteria:

- The dense core of the pair background should not hit the beam pipe. It should have ~ 5 mm clearance at $z = 350$ mm and ~ 2 mm clearance at the junction of the central beryllium part and the conical part.
- The silicon wafer is 2 mm longer than what is required to cover $|\cos\theta| < 0.95$.
- The ladder length is longer than the silicon wafer by 15 mm. The clearance between the ladder and the conical part of the beam pipe is 2 mm.

Since the distribution of the dense core of the pair background largely depends on the machine parameters [10], R_{VTX} also depends on the machine parameters. It was found that the effect of the machine-parameter difference between the nominal and the high-luminosity options is larger than the effect of the magnetic-field difference between 3 T and 5 T. The high-luminosity option [10] requires larger R_{VTX} than the nominal option by 5 mm or more for all detector concepts. New high-luminosity options at 1 TeV proposed by A. Seryi [11] allow significantly smaller R_{VTX} than the original high-luminosity option. His approach should also be used at 500 GeV if possible.

Background in the very forward calorimeter (BCAL) has been studied using CAIN. Figure 2 shows a schematic view of the GLD forward region. BCAL is located just in front of the final quadrupole magnet and covers polar angle of down to ~ 5 mrad. This detector plays a crucial role in SUSY searches by tagging $e^{\pm}$ from 2-photon background [12, 13]. The dense core of the pair background hits BCAL. Another forward calorimeter FCAL functions also as a mask against back-scattered photons from BCAL to protect the TPC. Energy deposited in BCAL by pair-background particles has been estimated for several machine parameters. The results are listed in Table I. As can

Table I: Energy deposit E_{dep} per bunch crossing in BCAL by pair background for various machine parameter options [10]. High Luminosity A-I and High Luminosity A-II options are new parameter sets proposed by A. Seryi [11].

$\mathbf{E_{CM}}$	**Option**	**Crossing angle (mrad)**	$\mathbf{E_{dep}}$ (TeV/BX)
500 GeV	Nominal	2	20.8
		20	44.3
	High Luminosity	2	119
		20	184
	Low Q	2	6.1
		20	15.7
1 TeV	Nominal	2	53.9
		20	98.1
	High Luminosity	2	303
		20	416
	Low Q	2	16.3
		20	34.9
	High Luminosity A-I	2	141
	High Luminosity A-II	2	106

be seen from this table, the energy deposit has a large machine-option dependence. This background has to be taken into account in the BCAL design.

In case of 20 mrad crossing angle, a dipole magnetic field could be implemented inside the detector in order to cancel the transverse field component of the solenoid magnet for the incoming beam and allow the electron and positron beams collide head-on. This dipole field could be produced by a so-called detector-integrated dipole (DID) which would also distort the solenoid field. The DID cancels the transverse field component for the incoming beam but doubles it for the outgoing beam. As a consequence, backscattered low energy $e^{\pm}$ particles from BCAL or the final quadrupole magnet are guided to the large radius region at the IP along the field lines. The radius is about 8 cm so that they could hit the silicon intermediate tracker (IT) [14]. The radius of silicon layers of IT should be chosen avoiding the backscattered particles. Another possible problem caused by DID is non-uniformity of the field in the TPC volume and degradation of the spatial resolution of the TPC. It could be avoided by careful B-field mapping and calibration runs at the Z-pole. The goal of the precision of the field mapping would be 1×10^{-4} for the LC TPC (the achieved precision for the ALEPH TPC was 5×10^{-4} [15]).

Luminosity on Z pole largely depends on the design option of the ILC accelerator. Each detector concept team was requested to give a necessary luminosity for detector calibration at the Z pole. The TPC and the calorimeters of GLD require about 10 pb^{-1} per run-period for calibration; the values are based on the experience at LEP2. The requirement for the TPC is to collect 15000 muon pairs and for the calorimeters to collect 100 pions per calorimeter segment (scintillator strip). The ILC accelerator could deliver more than 10 pb^{-1} within a few days.

4. PROGRESS AT SNOWMASS TOWARDS THE OPTIMIZED BASELINE DESIGN

4.1. Detector Simulation

The GEANT4 based full simulator "JUPITER" is used for the study of GLD. At this workshop, a revised detector geometry of GLD has been implemented into JUPITER as shown in Figure 3. Based on this geometry, detailed study will be done for the detector optimization and background simulation [16].

The study of PFA was one of the key issues for the detector concept studies. It has been shown [17] that by using a simple and robust algorithm of PFA for lead/scintillator calorimeter with a reasonable segmentation of 4 cm $\times$ 4 cm

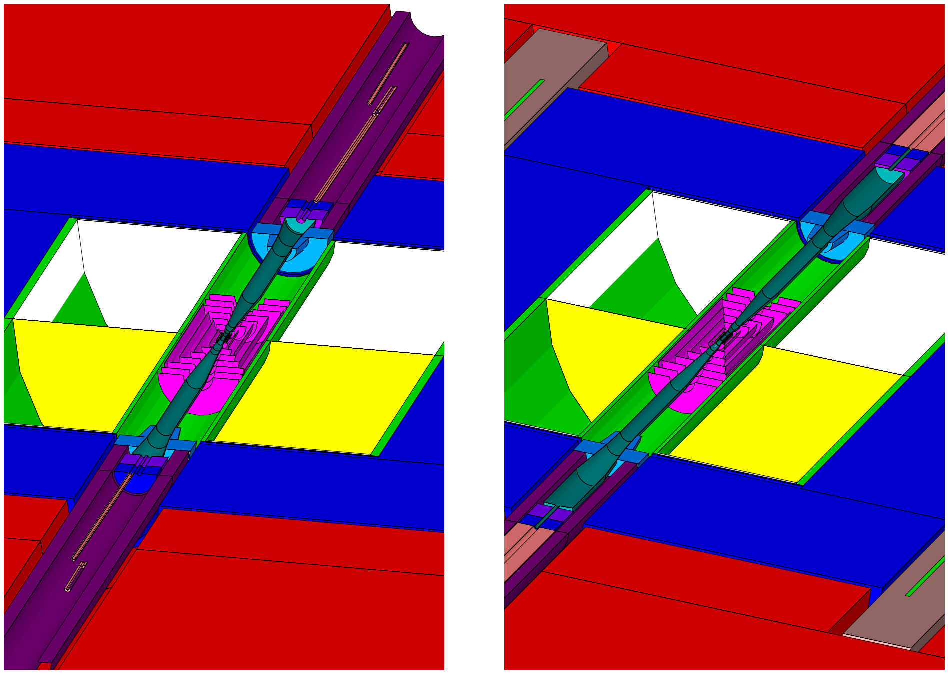

Figure 3: GLD geometry implemented into the full simulator JUPITER for 20 mrad crossing angle with $l^* = 3.5$ m (left) and for 2 mrad crossing angle with $l^* = 4.5$ m (right).

Table II: Granularity dependence of PFA performances.

	1 cm × **1** cm	**2** cm × **2** cm	**4** cm × **4** cm
γ finding efficiency	76.4%	78.8%	78.4%
γ finding purity	95.1%	95.1%	95.2%
Track matching efficiency	83.6%	84.1%	84.2%
Track matching purity	90.9%	91.7%	91.2%

for ECAL and 12 cm × 12 cm for HCAL, Z mass resolution corresponding to $40\%/\sqrt{E}$ can be achieved, while the simple calorimeter energy sum gives the resolution of $60\%/\sqrt{E}$.

Performances of PFA have been studied by changing the segmentation size of the EM calorimeter. Table II shows the results of the study on granularity dependence of efficiency and purity of γ finding and track matching [17, 18]. Naively thinking, it was expected that smaller granularity would give the better performances. However, no significant difference has been found between 4 cm segmentation and 1 cm segmentation of ECAL. The suspected reason, which has to be verified by simulations, is that particles from Z decays at rest are rather well spread out; at higher jet energies the granularity is expected to become inportant.

The simulation study of the PFA has just begun for the GLD detector. The following issues have to be studied as soon as possible:

- energy-dependent calibration factors,
- improvement of γ finding method including modification of small clustering, removal of low momentum hadrons, and use of H-Matrix method, and
- improvement in track matching methods including MIP finder and improvement of track-matching purity for low momentum (> 1 GeV/c) tracks.

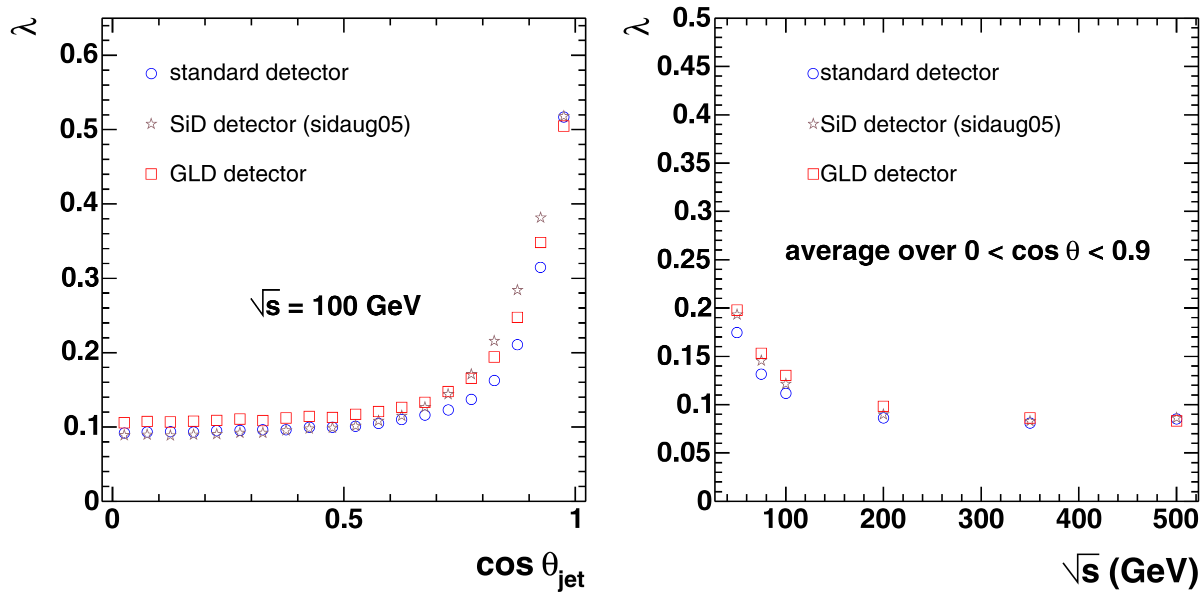

Figure 4: Comparison of the current vertex detector designs of the LDC, SiD and GLD concept studies in terms of λ, the probability for reconstructing a neutral B decay vertex as charged. The left figure shows the polar angle dependence for 50 GeV jets, and the right figure the energy dependence obtained when averaging over the polar angle range $0 < |\cos\theta| < 0.9$.

4.2. Optimization of Sub-detectors

Optimization study has been done for some of the sub-detectors of GLD during this workshop. For the vertex detector, the inner radius R_{VTX} is the key parameter which determines the impact-parameter resolution. The study of R_{VTX} has been done based on the beam-background consideration as described in Section 3. A discussion on R_{VTX} from a viewpoint of physics has also been shown [19]. Impact of R_{VTX} on vertex charge determination was discussed and the importance of small R_{VTX} was stressed. Performance of the vertex charge determination has been compared for three detector concepts, LDC, SiD, and GLD, as shown in Figure 4. It was found that GLD has a worse performance than other two detector concepts because the inner radius of GLD VTX is larger than the others. However the difference is very small.

Choice of the strip length is an issue for the silicon inner tracker (IT) discussed at Snowmass. The structure of the IT would be more simple and the material budget would be smaller for the long-strip option. On the other hand, the short-strip option is advantageous for fast timing, which enables bunch tagging of tracks and is indispensable for GLD. Concerning the forward region of the IT (silicon disks), the geometry for the baseline design has been determined at this workshop, and will be implemented in the simulator.

The present design of the muon detector of GLD has only four detector layers inserted into 10 cm gaps between iron plates of the return yoke. In order to see the possibility of increasing the number of layers of the muon detector, the magnetic field of GLD has been calculated for different configurations of iron plates and gaps using a finite element analysis program ANSYS. In cases with two times and four times more number of layers and less thickness of iron plates and gaps, it was found that the field uniformity of

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

can be achieved in the drift region of the TPC.

Design of the experimental hall has been modified at the workshop. Earlier the distance between the beam line and the wall of the experimental hall was assumed to be 20 m. However, it was pointed out that 20 m is too large to be compatible with the two-interaction-point configuration for the ILC accelerator, and a new design with the

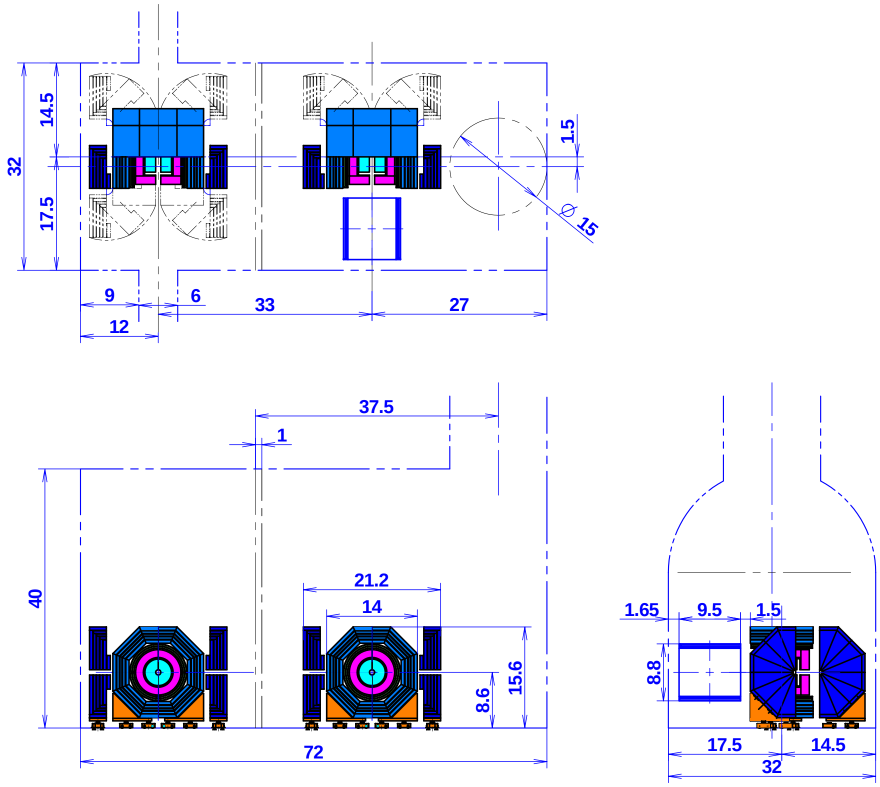

Figure 5: Experimental hall and opening method of the endcaps of the GLD detector. The position of the detector along the beam line is not at the center of the hall in order to keep the space for installation of the 9.5 m-long solenoid.

distance of 12 m was made at the workshop. Because 12 m is not long enough to fully open the endcap of the detector sideway, a sophisticated way of opening the endcap was adopted as shown in Figure 5.

5. CRITICAL R&D FOR GLD

In order to show the feasibility of the GLD detector, there are many critical R&D issues for the sub-detectors. Some of them are common to other detector concepts, and some of them are specific to GLD.

For the vertex detector (VTX), no sensor technology seems to be demonstrated to work satisfactorily under the conditions of an ILC experiment. Thus the sensor development is the most critical issue for VTX. In order to satisfy the required goal for the impact parameter resolution of $\sigma_b = 10 \oplus 5/p \sin^{3/2}\theta$ [20], wafers of VTX have to be thinned down to much less than 100 μm. The wafer thinning and the support structure for the thinned wafers are important R&D items.

Development of silicon strip sensors with large wafers is necessary to reduce the cost of the silicon trackers, particularly for endcap silicon tracker which has a large area. The silicon inner tracker (IT) plays a crucial role in charged particle tracking by measuring z-coordinate and timing of the tracks. These measurements are necessary because other tracking devices of the GLD, TPC and VTX, do not have absolute z-coordinate measurement (TPC) or absolute time measurement (VTX). In order to achieve enough time resolution to separate beam bunches, R&D for front-end electronics for fast shaping is necessary. The TPC can, however, achieve a time-stamping resolution of 2 ns in combination with the mechanical position of the z-strips of the IT or of the VTX.

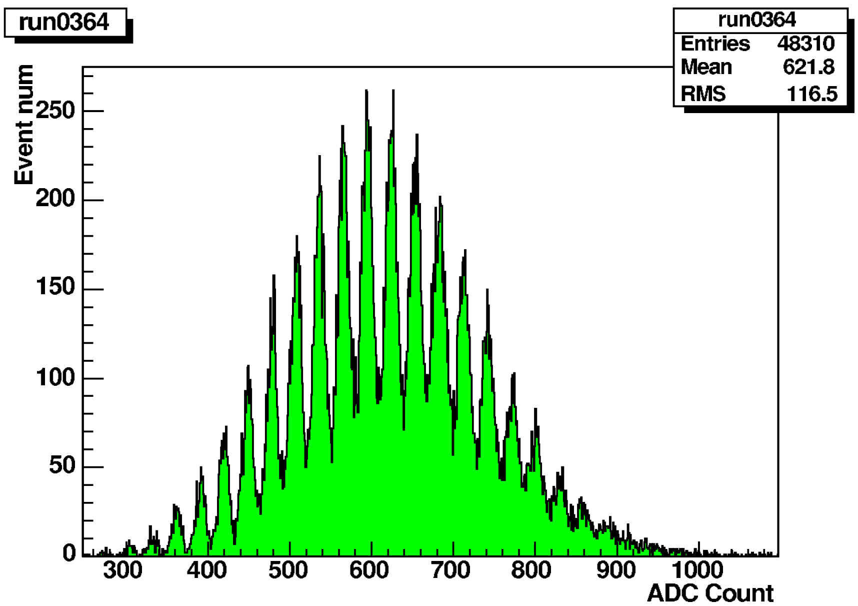

Figure 6: Spectrum of output of a MPPC.

R&D for the TPC is being carried out by a world-wide LC-TPC collaboration, and is common to the LDC detector concept. The first priority of the R&D is to demonstrate the feasibility of a TPC with micro-pattern gas detectors (MPGD). This will be done within one year. The next step will be the study using a large prototype with diameter larger than 75 cm and drift distance larger than 1 m. The time range for this study will be 3 or 4 years.

Because the size of GLD is quite large, scintillator-based calorimeter is adopted for the baseline design to reduce the cost. The scintillation light will be read out by multi-pixel photon counters (MPPCs), which are equivalent to SiPMs, through wavelength-shifting fibers. MPPCs are very attractive devices because the size is very small and they can work in a strong magnetic field. They can count the number of photo-electrons even at room temperature as shown in Figure 6. In order to ensure the dynamic range, R&D for large area MPPC with many (> 1000) pixels is indispensable. The readout electronics for the MPPC is not trivial and requires R&D effort [21].

There are several sub-detectors still to be designed. For the silicon endcap tracker (ET) which will possibly consist of two or three layers of silicon strips, no serious study on the requirement for the performance in GLD has been done, and a detailed design does not exist. For the forward calorimeters (FCAL and BCAL), the layout is considered as described in Section 3, but the detailed design for GLD does not exist yet. Because BCAL is exposed to high-rate pair background, a very careful design and detector R&D will be necessary. Consideration on trigger and DAQ has just started [22].

The performance goal of the tracking system has long been thought as $\delta p_t/p_t^2 = 5 \times 10^{-5}$ at high p_t limit [20]. This value comes from a consideration of Higgs mass measurement error in $e^+e^- \to ZH,\ Z \to \mu^+\mu^-$ that the error should be dominated by beam energy spread and beam strahlung. Recently, however, reconsideration based on new beam parameters suggests that better resolution than 5×10^{-5} could give better physics outputs. Along this consideration, tracking systems of hybrid tracker such as "sandwich" (Si-TPC-Si) or "club sandwich" (Si-TPC-Si-TPC-Si) scheme have been discussed in this workshop [23]. GLD has an advantage of incorporating this idea because of its large size. The performance and feasibility of this option should be studied in case the better momentum resolution is required.

6. SUMMARY AND OUTLOOK

At the Snowmass workshop, optimization study of the GLD detector has been successfully launched, particularly in PFA study and MDI study. Towards the detector optimization, there are still many issues to be attacked after the workshop. The PFA study has to be pushed forward towards the goal of $\delta E/E = 30\%/\sqrt{E}$ [20] including improvement of algorithm and optimization of detector parameters. Study of machine-parameter impact on the detector performance has to be continued. Particularly effects of crossing angle, DID, and beam background should be studied as soon as possible. The next milestone for the optimization study will be the DOD (detector outline document) which should be ready by the LCWS2006 in March 2006. Throughout the workshop, inter-concept study has been strengthened in the fields of PFA, MDI, simulation, and others. This is a great success of this workshop, and should be continued.

References

[1] R. Settles, "TPC R&D, Tasks towards the Design of the ILC TPC", http://alcpg2005.colorado.edu:8080/alcpg2005/program/detector/GLD/ron_settles20050817183312.ppt

[2] T. Takeshita, "GLD-CAL Review and Tasks", in these proceedings.

[3] Y. Sugimoto, "Vertex Detector for GLD", in these proceedings.

[4] H.J. Kim, "Review of Silicon Inner Tracker", in these proceedings.

[5] H. Yamamoto, et al., "Beam Profile Monitor Using Pixel Detector", in these proceedings.

[6] T. Takeshita, "GLD Muon System R&D", in these proceedings.

[7] H. Yamaoka, "Solenoid Magnet and Return Yoke for GLD", in these proceedings.

[8] K. Yokoya, et al., CAIN home page, http://www-acc-theory.kek.jp/members/cain/.

[9] Y. Sugimoto and T. Tauchi, "B and machine parameter dependence of R_{VTX}", in these proceedings.

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

[11] A. Seryi, "Discussion of ILC high luminosity parameters", http://www-project.slac.stanford.edu/lc/bdir/Meetings/beamdelivery/2005-07-26/high_lumi_pars.ppt

[12] Z. Zhang, et al., "Importance of the Low Angle Beam CAL", in these proceedings.

[13] P. Bambade, M. Berggren, F. Richard, Z. Zhang, hep-ph/0406010.

[14] K. Busser, "Update on Pair Backgrounds in the LDC Detector", in these proceedings.

[15] R. Settles, "On the Magnetic-field Requirements for the LC TPC", https://ilcsupport.desy.de/cdsagenda/askArchive.php?base=agenda&categ=a0545&id=a0545s10t4/moreinfo

[16] A. Sugiyama, "GLD background study with Jupiter", in these proceedings.

[17] T. Yoshioka, "Particle Flow Algorithm for GLD", in these proceedings.

[18] T. Fujikawa, et al., "Gamma Finding Procedure for GLD Detector", in these proceedings.

[19] S. Hillert and C. Danerell, "Physics potential of vertex detector as function of beam pipe radius", in these proceedings.

[20] J. Brau, et al., "Linear Collider Detector R&D", Proceedings of LCWS2002 at Jeju, Korea, p.787.

[21] H. Matsunaga, "Electronics for GLD Calorimeter", in these proceedings.

[22] P. LeDu, "ILC Trigger & DAQ Issues", in these proceedings.

[23] B. Schumm, "General Thoughts about Tracking for the Linear Collider Detector(s)", in these proceedings.