$\gamma\gamma$, $e\gamma$, and e^-e^- Physics and Technology

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Physics in $\gamma\gamma$, $e\gamma$, and e^-e^- options expand opportunities at the ILC. It is important for the ILC program to keep the expendabilities and to explore feasibility of options both in physics and technological aspects. Since the decision of using the "Cold" technology gave great impact on the laser related technology for $\gamma\gamma$ and $e\gamma$ options, we spent more time on the technology for options than what we did in previous workshops. In this paper we report current status and plans toward realization of the options.

1. INTRODUCTION

If we switch the positron beam of the ILC e^+e^- collider to the electron beam, two electron beams are brought to the interaction region of the ILC. The idea of the e^-e^- option is to use two electron beams as its initial state where both beams are expected to be $\approx 90\%$ polarized. The polarized positron beam may be possible but not expected to be 90% level. Technical issues for this option is not critical as it can be achieved by simply switches the positron beam to the electron beam. Detail of the physics and technology for e^-e^- option has been discussed in previous workshops[1].

The $\gamma\gamma$ and $e\gamma$ options, on the other hand, the electron beam is converted to the photon beam by backward Compton scattering a few mm before the interaction points. Physics opportunities and technical feasibility has been studied and recent progress was summarized in [2, 3]. The polarizability of the electron beam plays important role for properties of the generated beam: i.e., the polarization and the spectrum of the photon beam is controllable by polarization of the electron and the beam. Therefore, the initial state of the photon collider can be a helicity eigen state or a CP eigen state depending on our choice.

This workshop is the first LCWS after the technical recommendation in August 2004. The decision of using the superconducting RF technology for the ILC put large impact on the laser technology for $\gamma\gamma/e\gamma$ collider. In addition, efforts on the ILC design has become very active since the decision. The design of the interaction region of the ILC, such as the beam crossing angle, is tightly connected with the feasibility of the $\gamma\gamma/e\gamma$, one has to start realistic design of the option as early as possible. Regarding these situation, technical issues were important topic of the workshop.

We had four sessions during the workshop. Three sessions were for physics discussion and two of the three were joint session with the Higgs working group. One full session was devoted to the discussion on the technical issues. In Physics discussion, there were night contributions; seven talks were Higgs related work and other three were discussions on the search for signature from new physics via standard model processes. In technical session, there were two topics to be discusses; i.e., how to accommodate options in the ILC interaction region, impact of the "Cold" decision on the laser technologies.

2. PHSICS DISCUSSIONS

Although current concerns for options are technological feasibility, physics must always be main driving force for the facility. Discussion in the workshop can be categorized in two aspects. One is the improvement of previous analysis and/or study of physics feasibility with more realistic condition. The others are discussions on new ideas and possibilities with $\gamma\gamma$ and $e\gamma$ interactions.

Niezurawski discussed feasibility of measuring $\Gamma(\gamma\gamma \to h)Br(h \to b\bar{b})$ for both the Standard Model and the MSSM cases. It considered effects of all possible conditions such as hadron backgrounds, the beam crossing angle, overlapping events and background from W pair events. Rosca also discussed two photon decay width for the Standard Model higgs. It took into account the QCD radiative correction for $\gamma\gamma \to q\bar{q}(g)$ by SHERPA[4] and utilized b-tagging by a neural network technique. These study showed that we could expect accuracy of $\Gamma(\gamma\gamma \to h)Br(h \to b\bar{b})$ about 2% which was consistent with previous works.

Dittamier showed the calculation for $\gamma\gamma \to W^+W^- \to 4fermions$ including the radiative correction. The photon collider can be regarded as a W factory above its threshold and is useful to investigate properties of W bosons such as the anomalous coupling to photons while the W bosons can be a background source for other processes. Therefore the precise estimation for this process is very important for the photon collider. It is reported that a new event generator, COFFER$\gamma\gamma$, including the radiative correction, $\gamma\gamma H$ coupling, and anomalous coupling is tested and ready to use now.

All these contributions showed that the photon collider has potential to explore physics for standard processes Higgs analysis which is one of the most important and tools for the precise study is getting ready.

While we have to investigate feasibility of the physics study with more and more realistic condition, it is also important to keep searching for new possibilities with options. Heinemeyer compared sensitivity of LHC, ILC and photon colliders to the complex MSSM for some scenarios. He reported that the photon collider would have good prospect for parameter determination in CPX scenario. Choi reported the case in which the Higgs potential has CP violating phase in THDM or equivalently the phase is effectively induced in MSSM. It was indicated that a large H/A mixing can be expected when H and A is degenerated. The signal in the photon collider is a CP asymmetry using the linearly polarized initial state or the top quark polarization. He emphasized a necessity of experimental studies with realistic conditions. Asakawa discussed on the charged higgs production via A decay, $\gamma\gamma \to A \to H^{\pm}W^{\mp}$. This process is not significant in the MSSM, however, is allowed to have relatively large cross section in THDM. For example, when $m_A = 400GeV$ and $m_H^{\pm} = 300GeV$, the cross section for this process in the photon collider could have a few fb depending on $tan\beta$.

A calculation for $\gamma\gamma \to \mu^+\mu^-\nu\bar{\nu}$ via single/double W resonant or Z pole was reported by Ginzburg. The motivation is that this process includes effect of intermediate state and the charge asymmetry could be a good signature of new physics, if any. He also showed calculation for charge asymmetry for the W bosons in $e\gamma \to eW^+W^-$. The asymmetry seems to be good observable for the strong interacting Higgs sector.

3. TECHNOLOGY

There are two aspects in technologies for the $\gamma\gamma$ and the $e\gamma$ options. One is issues for beam parameters such as the beam emittance, the final focus optics and the beam crossing angle. These issues are, in other word, to find a way to accommodate options with e^+e^- operation of the ILC. The second is the laser technology as we have to bring high power $O(5J/pulse)$ laser pulses into the interaction region with the repetition rate of 3000×5 per second. The issues were reviewed by Gronberg at the beginning of the technology session.

The beam parameters for several proposal for the $\gamma\gamma$ option are summarized in table. I. In the table, the column of "ILC optimistic" is a set of parameters which tried to maximize $\gamma\gamma$ luminosity. It assumes a modification of the dumpling ring of the ILC. The "ILC e^+e-" parameters are the same as the e^+e- operation except for the horizontal β function at the interaction point. For references, parameter sets for the TESLA $\gamma\gamma$ collider and current ILC e^+e- parameters are shown in the table. In the discussion, we reached a consensus that base lines for options should use standard ILC parameters.

The beam crossing angle at the interaction point is one of the most important issue to accommodate $\gamma\gamma/e\gamma$ options. The situation is illustrated in fig. 1. The electron beam after passing through an intense laser pulse has large energy spread from the original beam energy down to as low as about 5 GeV. Therefore the outgoing electron beam will have a large disruption angle due to the strong beam-beam interaction at the interaction point. According to the beam simulation by CAIN[5], the low energy electrons have the disruption angle θ_d of about 10 mr. Since these

Table I: Beam Parameters for $\gamma\gamma$ option

		ILC optimistic	w/ ILC e^+e^-	NLC $\gamma\gamma$	TESLA e^+e^-
f_{rep}	Hz	5	5	120	5
n_b		2820	2820	150	2820
σ_x^*/σ_y^*	nm	88/4.3	175/4.3	166/3.0	553/5
β_x/β_y	mm	1.5/0.3	1.5/0.3	4./0.08	11/0.4
$\gamma\varepsilon_x/\gamma\varepsilon_y$	$\mu mrad$	2.5/0.03	10/0.03	3.6/0.071	10/0.03
L_{geom}^{ee}	$cm^{-2}s^{-1}$	11.8×10^{34}	5.9×10^{34}	4.0×10^{34}	1.6×10^{34}

disrupted beam should not hit the final focus magnet which will be placed at L^* from the interaction point, we have to set a finite beam crossing angle $\theta_x = \theta_d + \theta_Q$ where θ_Q is the solid angle of the final focus magnet. The situation to determine the beam crossing angle is illustrated in fig. 1. The beam disruption angle can be estimated by the

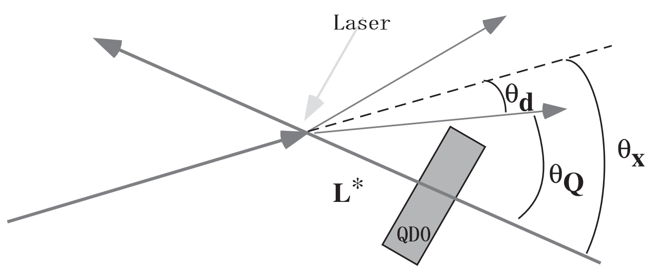

Figure 1: Factors to determine the beam crossing angle for $\gamma\gamma$ colliders.

laser-Compton and the beam-beam simulation, however, the angle θ_Q depends on the L^*(and therefore the final focus beam optics) as well as physical dimension of the final focus magnet. There is an idea to set beam crossing angle at 20 mr using a superconducting magnet with the $L^* = 3.8m$ [6]. However, detail simulation for the beam interaction and the study of the final focus optics to achieve enough luminosity for the $\gamma\gamma$ option is required. Telnov discussed possibility of larger beam crossing angle of 25 mr. He studied the effect of beam crossing angles to the e^+e- collision such as synchrotron radiation due to the detector solenoid. He claimed that there are no difference for e^+e- luminosity between 20 mr and 25 mr and even 30 mr may be tolerable with some optimization.

Mönig discussed a way to deliver polarized electron(and positron) beams to two interaction point simultaneously with a full flexibility. It is possible with at most three spin rotators and a few kickers. There is a CDR level study available but need detailed study for the TDR.

The ILC accelerate 5 bunch trains in a second and each train consists of about 3000 electron bunches of 337 ns separation in time. Laser pulses for the photon conversion have to be synchronized with the electron bunches and each pulse should have $O(J/pluse)$ to achieve high conversion efficiency. The cost for the high power laser is roughly proportional to the cost for the pumping laser, and therefore the pumping power to amplify 3000 pulses in 1 ms. Thus, if we assume to obtain enough laser power directly from laser amplifiers, the cost for the laser system may beyond tolerable level.

A way out is to amplify the laser power outside of the laser system using an optical resonator, i.e., pulse stacking cavity. For example, in case that 100 of laser pulses can be stacked in right phase, the power of a laser pulse will be 100 times larger than those at the laser system. In other word, the output power from the laser system can be reduced to 1/100. In the real system, each laser pulse have to be synchronized with the electron bunches of 337 ns (about 100 m) separation and optical components must be placed outside of the detector, it is necessary to construct the cavity of 100 m circumference. Fig. 2 is an illustration of a detector system with a pulse stacking cavity. Power build up cavities are widely used for CW lasers, however, cavities for pulse lasers are less popular than those for CW lasers. Honda showed a working example of the pulse stacking cavity used for the laser wire monitor at KEK-ATF

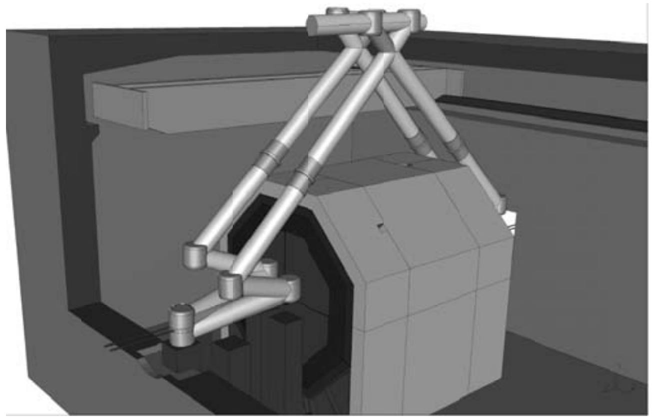

Figure 2: An illustration a detector with pulse stacking cavity for the photon collider

electron ring. They achieved about 1000 power enhancement with 21 cm long cavity.

An example at ATF is encouraging, however, the cavity for photon colliders have is required:

- power enhancement of more than 100
- large scale of about 100 m circumference
- large pulse power of 1-10 J/pulse
- small spot size of $O(\mu m)$ at the conversion point
- long term stabilization

Each item is achieved individually, for example, a large power enhancement with large scale cavity is demonstrated by gravitational wave experiment, Honda showed small scale pulse cavity at KEK. However, the cavity system which fulfill all these requirements simultaneously is unprecedented.

4. Summary

There is no question that optional interaction such as $\gamma\gamma$, $e\gamma$ and e^-e^- expand physics opportunities of the ILC [7]. Unanswered question for physics are:

- when we should plug-in options into the ILC experiments.
- how long we need to run with the options.

It is not possible answer these question now, however, the LHC and the ILC e^+e^- colliders will give us answers by due time. Therefore, the most important issues to be consider for option at this moment are:

- keep expandability of the ILC to optional interactions,
- get them ready when it will be necessary.

Specific items related with the first one are number of interaction points for the ILC and beam crossing angle at the 2nd interaction point(if any). The items for the later issue are, to clarify feasibility of the pulse stacking cavity, beam dump, backgrounds to the detector, final focus optics to achieve enough luminosity.

There have been works on these issues but sill may not be enough to convince the ILC community. Regarding the fact that a few people is working on options, more synergetic work with e^+e- is necessary to accommodate options in the ILC program.

References

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