Physics of High-Energy $\gamma\gamma$, $e\gamma$, and e^-e^- Collisions*

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ABSTRACT

Recent developments in linear collider and laser technology should make it possible to construct an interaction region at the Next Linear Collider where high energy photon beams, produced by Compton backscattering laser photons off linac electrons, are brought into collision with electron beams or with other photon beams. High luminosities, along with control over both the energy distribution and polarization of the photon beams, will give such a facility the potential for a very interesting physics program. In particular, such a *Photon Linear Collider* (PLC) offers a unique environment for the study of Higgs bosons and discovery of new particles such as excited electron states, supersymmetric particles, heavy charged particle pairs, or any particles with appreciable two-photon couplings. Precision electroweak tests also benefit from such a machine, allowing a test of the three-gauge-boson WWγ vertex and it would serve as an excellent laboratory for Quantum Chromodynamics studies involving photon structure functions, jet and hadron production, and resonance production. In this paper we briefly review these physics prospects, detail some new studies of the potential for precision measurement of the two-photon coupling of Higgs bosons and describe some ideas for obtaining physics from the $\gamma\gamma$, eγ, and e^-e^- reactions simultaneously.

I. PHOTON LINEAR COLLIDER

The next linear collider will likely have both high energy ($\sqrt{s} > 500$ GeV) and high luminosity ($> 10^{33}/cm^2/s$). Hopefully, it will also have the ability to produce both e^+e^- and e^-e^- collisions. One of the interaction regions at such a machine could be configured as a Photon Linear Collider by using a dense optical laser pulse to convert one or both of the electron beams to photon beams, resulting in $e\gamma$ or $\gamma\gamma$ collisions. The basic ideas have been detailed in many papers [1]; we will mention them briefly as context for the physics studies in the next section.

A. Compton Scattering

In the collision of a laser beam of frequency ω_o and circular polarization λ_γ with a linac electron beam of energy E_b and longitudinal polarization λ_e a few centimeters upstream of the interaction point (IP), a high energy photon of energy ω and circular polarization λ is emitted at an angle θ_γ to the original direction of the electron beam, along with the scattered electron of energy $E = E_b - \omega$, emitted at an angle θ_e. The Compton kinematics are fully characterized by the polarization of the linac electrons and laser photons and by the dimensionless variable x:

$$x \equiv \frac{4E_b\omega_o}{m_e^2}\cos^2(\alpha/2) \approx 15.3\left(\frac{E_b}{\text{TeV}}\right)\left(\frac{\omega_o}{\text{eV}}\right), \qquad (1)$$

where α is the angle between the linac and laser beams, assumed to be $\ll 1$.

The photon energy distribution, given by

$$\omega < \omega_{\max} = E_b\frac{x}{x+1}, \qquad (2)$$

becomes harder as x increases up to the point, $\omega_{\max}\omega_o = m_e^2$, where pair conversion begins ($x \approx 4.83$). The photon scattering angle is given (for θ small) by:

$$\theta_\gamma(\omega) = \theta_o\sqrt{\frac{\omega_{\max}}{\omega} - 1}$$

$$\theta_o = \frac{m_e\sqrt{x+1}}{E_b} \approx \frac{0.511\sqrt{x+1}}{E_b/\text{TeV}}\,\mu\text{rad}, \qquad (3)$$

and $E_{\min} = E_b\frac{1}{x+1}$ is the minimum electron energy. Note that for beam energies of a few hundred GeV, a typical photon scattering angle is a few μrad, with the lowest energy photons scattering at the highest angles. The electrons scatter forward into a cone of opening angle $\sim \theta_o$.

Polarizing the linac electrons and laser photons not only provides polarized backscattered photons, but also allows one to tailor the photon energy distribution to one's needs. Colliding like-handed electrons and photons results in a flat distribution of backscattered photons; colliding oppositely-handed electrons and photons results in a peaked distribution of backscattered photons with energy up to about 82% of the original electron beam energy. In both cases the resulting photons are highly polarized, with the $J_z = 0$ state preferred over $J_z = 2$ by at least a factor of 20.

B. $e\gamma$ and $\gamma\gamma$ Collisions

A machine operating as an $e\gamma$ or $\gamma\gamma$ collider can, in principle, have a much higher luminosity than one operating as an e^+e^- or e^-e^- collider, due to the absence of beam-beam effects at the interaction point. Telnov and Chen [2] have derived limits on the $e\gamma$ and $\gamma\gamma$ luminosity of 3×10^{33} cm^{-2} s^{-1} and 10^{34} cm^{-2} s^{-1}, respectively, although more recent work suggests that a $\gamma\gamma$ luminosity of 10^{35} cm^{-2} s^{-1} might be achievable [3]. However, in the case where a second interaction region of a next linear e^+e^- collider is dedicated to such collisions, the luminosities of $\gamma\gamma$, $e\gamma$, and e^-e^- will likely be from $10-30\%$ of the e^+e^- luminosity. Indeed, a preliminary design of such an interaction region already exists [4].

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The luminosity distribution depends sensitively on the conversion distance and on the size and shape the electron beam would have had at the interaction point in the absence of a backscattering laser. Assuming round Gaussian linac beams, the luminosity spectrum is characterized by the geometrical factor ρ, the ratio of the intrinsic transverse spread of the photon beam to that of the original electron beam:

$$\rho \equiv \frac{z\theta_o}{\sqrt{2}\sigma_e} \approx 3.61\sqrt{x+1}\left(\frac{z}{\text{cm}}\right)\left(\frac{E_b}{\text{TeV}}\right)^{-1}\left(\frac{\sigma_e}{\text{nm}}\right)^{-1} \quad (4)$$

where z is the conversion distance. As ρ increases the monochromaticity of the luminosity distribution improves (because the lowest energy photons, scattering at the largest angles, end up outside of the IP), but the total luminosity decreases.

C. Linac Characteristics

There are many proposed designs for the next high energy e^+e^- collider [5], but some of them are better suited for photon collisions than others [6]. The absence of beam-beam effects in $\gamma\gamma$ collisions means that very flat beams are not necessary. In addition, the tight beam energy spread required of linear e^+e^- colliders is not needed for a PLC. Furthermore, since positrons are not required, an e^-e^- collider provides a better platform for $\gamma\gamma$ and $e\gamma$ collisions, because it is easier to produce and transport polarized electrons than positrons and because the polarization is easily reversible. Highly-polarized electrons will be crucial if one is to fully exploit the potential of a photon linear collider. Fortunately, recent advances in electron source technology at SLAC have virtually ensured that highly-polarized e^- beams ($\approx 90\%$) will be available at an NLC. Finally the high beam currents and favorable timing structure of superconducting linacs would make them the best choice for a true Photon Linear Collider.

D. Laser Characteristics

Any laser candidate suitable for use in a Photon Linear Collider must satisfy the following requirements: high power (≈ 2 Joule/pulse), 'optical' wavelength (200—2000 nm), short pulse length (≈ 6 psec), and high repetition rate (0.1—10 kHz). Present-day laser systems do not satisfy all of these requirements simultaneously (especially the repetition rate) but will likely do so in the near future. The two most promising candidates for a PLC laser system are solid state lasers using chirped pulse amplification [7] and free electron lasers [8].

In addition, the laser photon beams must be focused and brought into collision with the linac electron beams within a few centimeters of the interaction point. This requires the introduction of a complicated system of focusing mirrors into the beampipe. Designs for these optical elements are under active development at LLNL [11].

E. Simultaneous $\gamma\gamma$, $e\gamma$ and e^-e^- interactions

In a Photon Linear Collider, following Compton backscattering, the 'spent' electron beams would need to be deflected transversely from the interaction point to avoid colliding with the opposing electron or photon beam. A strong (few Tesla) transverse magnetic field at the interaction point [9] or a thin plasma lens [10] might sweep these electrons out of the way, reducing their electromagnetic field at the IP and eliminating $e\gamma$ and e^-e^- collisions as a background to the $\gamma\gamma$ collisions. However, either option would be technically difficult to accomplish and would likely have a significant impact on detector performance and backgrounds. Thus it is interesting to consider whether the desired $\gamma\gamma$, eγ, and e^-e^- physics can be done simultaneously. Studies of possible interaction region designs suggest that one might achieve comparable luminosities in each reaction, but with different c.m. energies (full energy for e^-e^-, $\approx 90\%$ of full energy for eγ, and $\approx 80\%$ of full energy for $\gamma\gamma$). In the next section, we will examine some possible impacts this might have on the physics.

II. PHYSICS WITH COLLIDING ELECTRONS AND PHOTONS

One of the main goals of the Next Linear Collider is a thorough exploration of the Higgs sector of the Standard Model (or beyond). Although e^+e^- collisions can perform much of this work, adding $\gamma\gamma$, $e\gamma$, and e^-e^- collisions gives complementary access to the Higgs and provides determination of parameters such as the two-photon width and spin/parity assignments which are difficult to determine with only one initial state. Supersymmetry is another area where the alternative reactions can provide sensitive probes and may even exceed the mass reach of an e^+e^- machine. Precision electroweak measurements and new particle searches can also be done in a complementary way. Finally, $e\gamma$ and $\gamma\gamma$ collisions provide a unique testbed for QCD.

A. Higgs Boson Physics

A Photon Linear Collider provides a clean method to search for an intermediate mass Higgs boson, through resonant $\gamma\gamma \to H \to \bar{b}b$ or ZZ production. It is complementary to searches using hadron and e^+e^- machines, being sensitive to different models and couplings. More importantly, a $\gamma\gamma$ linear collider permits a direct measurement of the two-photon width of the Higgs. The coupling of the Higgs to two photons involves loops where any charged fermion or boson with couplings to the Higgs must contribute. A measurement of the two-photon width is then quite sensitive to new physics even at higher mass scales. Supersymmetric models, technicolor models, and other extensions of the standard model with more complicated Higgs sectors all predict Higgs spectra and two-photon couplings which are generally different from those of the standard model. Indeed, $e\gamma$ and $\gamma\gamma$ machines may be the only approaches to study Higgs with "invisible" decay modes [12]. In the minimal supersymmetric model (MSSM), the added appearance of a CP-odd neutral A is best studied in the $\gamma\gamma$ and $e^-\gamma$ modes [13]. Finally, it may even be possible to study CP-violation in the Higgs sector at a Photon Linear Collider [14].

For a standard model Higgs boson with mass below about 300 GeV, the beam energy spread of a $\gamma\gamma$ collider is much greater than the total width of the Higgs boson, and so the num-

ber of $H \to X(=\bar{b}b, WW, ZZ)$ events expected is

$$N_{H\to X} = L\,\frac{4\,\pi^2\,\Gamma(H\to\gamma\gamma)\,B(H\to X)\,(1+\lambda_1\lambda_2)}{M_H^2}\,, \quad (5)$$

where

$$L = \left.\frac{dL_{\gamma\gamma,J_z=0}}{dW_{\gamma\gamma}}\right|_{M_H}\,, \quad (6)$$

and $W_{\gamma\gamma}$ is the two-photon invariant mass. Note that since the Higgs boson has spin zero, the initial photons must be in a $J_Z = 0$ state.

In the intermediate mass region (< 150 GeV) the Higgs decays dominantly to $\bar{b}b$, so the relevant backgrounds are from continuum production of heavy quarks (vertexing techniques can be used to eliminate backgrounds from light quarks). These backgrounds are quite large, but can be actively suppressed by exploiting the polarization dependence of their cross-sections ($\propto (1-\lambda_1\lambda_2)$) and by the use of angular cuts. Additional event shape and jet width cuts must be used to suppress radiative processes [15].

Several potential backgrounds might fake the presence of a ≈ 90 GeV Higgs boson. The dominant potential background is due to the presence of the residual electrons left over from the original Compton backscatter undergoing the reaction $e\gamma\to eZ \to e\bar{b}b$. If the Higgs is known to be near the Z mass, there would be a compelling reason to sweep these spent electrons away from the interaction point. The process $\gamma\gamma\to f\bar{f}Z$, where the $f\bar{f}$ go down the beampipe and the Z decays to $\bar{b}b$ provides a background of the same order of magnitude as that of a ≈ 90 GeV Higgs signal [16].

Above ≈ 150 GeV the dominant Higgs decay is to WW, with one of the W's virtual below 162 GeV. However, the large continuum cross section is not easily suppressed so the WW final state will be a difficult one to use for doing Higgs physics. Fortunately, the ZZ (or ZZ^*) decay channel can be utilized. The Higgs has a branching fraction into this channel of approximately 1/3 (for real Z's), while the standard model cross section for $\gamma\gamma\to ZZ$ is small. Hadronic decays of the Z bosons predominate, but the huge $\gamma\gamma\to WW$ cross section results in a large number of 'fake ZZ' events (both W's being misidentified as Z's), so that unambiguous tagging of the ZZ state requires at least one Z to decay leptonically. For Higgs masses above about 350 GeV, the ZZ continuum background makes detection of the Higgs very difficult [17].

Detailed Monte Carlo studies using detector simulations [18] indicated that it should be possible to measure the two-photon width of a Higgs to a statistical precision of 10% for most of the mass range < 250 GeV. These results have been updated at this workshop to incorporate the effects of systematic errors and new decay modes and backgrounds. The resulting measurement, shown in Figure 1, would still be made to a precision better than 10% over a large portion of the intermediate mass range, which should distinguish amongst many of the competing models for Higgs production. Further discrimination will be supplied if several Higgs bosons can be detected and their $\Gamma_{\gamma\gamma}$ values obtained.

Several ideas for extending the mass range of these measurements of the two-photon width of the Higgs were explored at this workshop. It may be possible to exploit the fact that $\gamma\gamma \to H \to ZZ$ produces longitudinally- polarized Z's while the standard model background tends to produce transversely-polarized Z's. This might extend the mass reach up to about 400 GeV. A more-promising alternative for measuring the two-photon width at higher mass would make use of the reaction $\gamma\gamma \to$ H $\to \bar{t}t$. We estimate that the production rate would be about 4000 $\bar{t}t$ pairs/10 GeV/year of running at a luminosity of 2×10^{33}. A thorough study of $\bar{t}t$ production in e^+e^- collisions [19] concludes that one can detect the $\bar{t}t$ pairs with 63% efficiency in the 6-jet mode while reducing the large standard model background from W pairs by nearly three orders of magnitude. This would yield a statistical error on $\Gamma_{\gamma\gamma}\times B(H\to\bar{t}t)$ of 5% for Higgs masses greater than about 400 GeV. Systematic errors, particularly on the branching ratio, would likely raise this to the $15-20\%$ level but this is still quite sufficient to distinguish between model predictions and identify contributions from higher mass scales.

For $m_H > 200$ GeV, the process $e^-e^- \to e^-e^-H$ via ZZ fusion becomes an interesting discovery channel because it overtakes the $e^+e^- \to ZH$ process in cross-section with rising $\sqrt{s}$, and is preferable to $e^+e^- \to H\nu\nu$ via WW fusion because background rejection is much more effective: there is no missing momentum, and both final-state electrons are detectable [20]. In the MSSM, charged Higgs bosons are readily pair produced and lead to good experimental signatures for like-sign states from e^-e^-[21]. Finally, the chances of finding doubly-charged H^{--} states from extensions of the Higgs sector [22] should be seen as a bonus possibility in e^-e^- collisions. In all

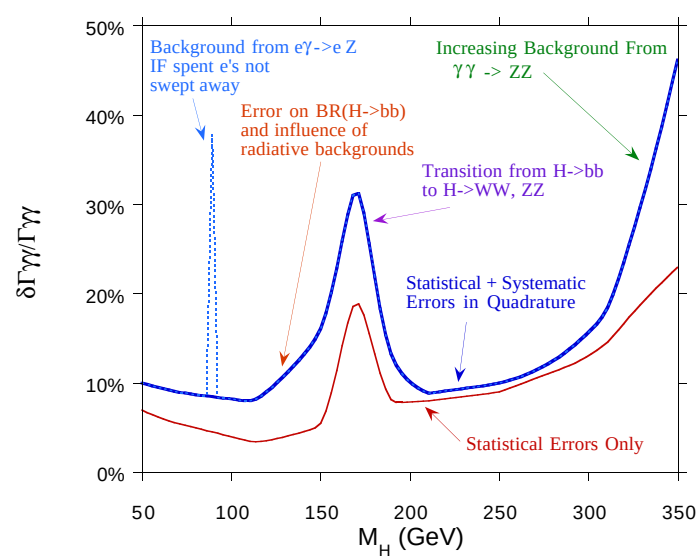

Figure 1: Fractional error on $\Gamma_{\gamma\gamma}$ for the standard model Higgs boson of various masses using a Photon Linear Collider. The lower curve shows the effect of statistical errors only, while the upper curve reflects the inclusion of systematic errors in quadrature.

of these cases, the required large c.m. energy (2-3 times the Higgs mass) and the necessary detection of e^-e^- in the final state virtually eliminates any chance of confusion with reactions involving photons.

B. Supersymmetry

An $e\gamma$ collider provides a very clean environment for studying selectrons [23] via the reaction $e\gamma\to\ \tilde{e}\tilde{\gamma}\ \to\ e\tilde{\gamma}\tilde{\gamma}$. The experimental signature is a single electron in the detector, with substantial missing energy. In the case where e^-e^- collisions are also allowed, one would need to require that the missing momentum be well away from the beamline to avoid the large Møller scattering background. Study of the reactions $e\gamma\to\ W\nu\ \to\ \mu\bar{\nu}\nu$ and $e\gamma\to\ eZ\ \to\ e\mu^+\mu^-$ should provide direct measurements of the $W\nu\ \to\ e\bar{\nu}\nu$ and $eZ\ \to\ e\bar{\nu}\nu$ backgrounds. It appears possible to detect selectrons with masses up to nearly the beam energy minus the photino mass in this way.

$\gamma\gamma$ colliders may also play a significant role in discovering supersymmetric particles via pair production [24]. Although the mass reach is smaller than for $e\gamma$, the production mechanism is cleaner and detection of the lepton pair may allow better background rejection. The experimental signatures are different enough that little confusion will arise from simultaneous operation with $e\gamma$ or e^-e^- collisions.

Finally, for the case where the selectron is the lightest slepton, and the Higgsino the lightest of the neutralinos, the reaction $e^-e^-\ \to\ \tilde{e}\tilde{e}$ is the most promising detection channel for the slepton, with backgrounds considerably reduced below the competing e^+e^- reaction. Again the necessary detection of e^-e^- in the final state makes this a unique signature.

C. Electroweak Physics

For the study of the potential non-standard behavior of the triple or quartic gauge boson couplings, the values of which are firmly fixed in the Standard Model, only a complete combination of a number of dedicated studies in the e^+e^-, e^-e^-, $e^-\gamma$, and $\gamma\gamma$ initial states [25] is likely to give us a good determination of potential deviations. $\gamma\gamma\to\ WW$ and $\gamma\gamma\to\ ZZ$ probe anomolous quartic couplings of the electroweak gauge bosons while $e\gamma\to\ eZ$ probes anomalous $\gamma\gamma Z$ and γZZ couplings. e^-e^- interactions allow the use of combined information from LL and LR beam polarizations as a sensitive probe of κ_γ [25]. A recent analysis of the $e^-\gamma$ reaction [26] exploits the sensitivity to λ_γ of a zero-crossing in the polarization asymmetry.

There are substantial issues involved in simultaneous operation of $\gamma\gamma$, eγ, and e^-e^- collisions for such precision electroweak measurements which can only be resolved with detailed Monte Carlo studies involving jet confusion and acceptance. Clearly the missing momentum and angular dependence in $e\gamma\to W\nu$ and $e^-e^-\to e^-e^-W^+W^-$ will be the best handles for distinguishing these reactions from the more-frequent $\gamma\gamma\to\ W^+W^-$ process.

D. Strong WW Scattering

If no elementary Higgs boson is discovered at energies up to 0.5-1 TeV, this will signal the onset of strong scattering among the W and Z bosons. This is a new dynamic, and will need to be investigated in detail in the different angular momentum and isospin channels, so that both e^-e^- and the $\gamma\gamma$ collisions will be needed for a full exploration [27]. For example, the I=2 channel is not even accessible to e^+e^- annihilation, but e^-e^- production is allowed. Similarly, angular momentum states different from 1 are not produced in the e^+e^- channel, but do result from $\gamma\gamma$ interactions. At the highest energy NLC (1.5 TeV), the modes $\gamma\gamma\to WWWW, WWZZ$ (i.e. longitudinal W scattering) seem to be quite promising in this regard [28].

If technicolor is responsible for EW symmetry breaking, $\gamma\gamma$ production of the "light" technieta' would be feasible at a 1 TeV linear collider [29].

E. Searches for New Particles

A PLC also provides opportunities to search for new particles. Heavy charged particles (such as charged Higgs bosons or charged superpartners) are an obvious example, produced through $\gamma\gamma\to\ X^+X^-$. Other interesting possibilities include excited fermions [30] via $e\gamma\to e^*\to e\gamma$ or $\gamma\gamma\to e^*e^*\to ee\gamma\gamma$, dileptons [31] via $e^-\gamma\ \to\ X^{--}e^+$, leptoquarks [32] in either $e^-\gamma$ and $\gamma\gamma$ production modes, or resonances with anomalous γWV couplings in strongly-interacting weak symmetry breaking models [33] via the reaction $e\gamma\to\ V\gamma W$.

If there exist heavy neutrinos with TeV masses, the reaction $e^-e^-\ \to\ W^-W^-$ could give convincing and spectacular evidence for their existence (an estimated 150 events/$100fb^{-1}$ at a 1 TeV NLC) [34] - and any signal due to this process should immediately disappear when the initial beam helicities are changed from e_Le_L to any other combination.

In addition to modifications of the Standard Model Lagrangian due to a given substructure scale, Møller scattering is sensitive to the presence of heavier Z' bosons [35]. A recent study [36] has shown that e^-e^- is sensitive to Z' couplings $20-40\%$ smaller than those probed in e^+e^- reactions for $m_{Z'}>1$ TeV. Again, the precise definition of the incoming beams' polarization parameters is of crucial importance.

It is in the area of new particle searches where the confusion in colliding different mixtures of electrons and photons would probably have the greatest impact. For some reactions, such as the formation of excited fermions or Z's, the resonant signature in a simple final state would be clear enough that backgrounds from other initial states would be negligible. However, searching more complicated final states for evidence of dileptons, Majorana neutrinos and the like would rely heavily on precise knowledge of the detector acceptance and would demand low-angle detection of at least e^- to separate some of the signatures.

F. QCD

A PLC provides an extremely powerful tool for the study of the strong sector of the Standard Model via high energy colli-

sions of both real photons (in the $\gamma\gamma$ mode) and virtual photons (in the $e\gamma$ mode). Measurements of interest will include photon structure functions at large x ($\equiv Q^2/(Q^2+W^2)$), and large Q^2, study of jet and inclusive hadron distributions which provide superb tests of perturbative QCD, and the study of exclusive hadron production. Many of these measurements could in fact be accomplished with a low-energy PLC [37]. Separation of the structure function physics requires low-angle e^- detection.

An especially interesting process at higher energy is $e\gamma \rightarrow \nu\bar{t}b$ which provides a direct measurement of the CKM matrix element V_{tb} [38]. The $\gamma\gamma$ initial state will be an aid in the study of the $t\bar{t}$ threshold. In particular, the ability to control the photon polarization will allow a clean separation of S-wave and P-wave production. An extraction of m_t and α_s from P-wave production will provide a good systematic check of results obtained in e^+e^- production [39]. The presence of missing mass and fewer jets in the $e\gamma$ process should make it readily distinguishable from the $\gamma\gamma$ one.

III. SUMMARY

There seems to be no fundamental reason why high-luminosity $\gamma\gamma$, $e\gamma$, and e^-e^- collisions cannot be achieved at the next linear collider. Such interactions would certainly yield exciting physics results, including a thorough study of the Higgs sector with a precision measurement of the fundamental two-photon coupling, supersymmetric particle detection, determination of anomalous electroweak coupling strengths, and further understanding of QCD. Both the accelerator and physics aspects of such a machine will continue to be developed in the near future [40].

IV. REFERENCES

[1] V.I. Telnov, *Nucl. Instrum. Methods* **A294**, 72 (1990); J. Gunion and H. Haber, *Phys. Rev.* **D48**, 5109 (1993); D. Borden, D. Bauer, and D. Caldwell, *SLAC-PUB-5715*(1993) and *Phys. Rev.* **D48**, 4018 (1993).

[2] V.I. Telnov and P. Chen, *Phys. Rev. Lett.* **63**, 1796 (1989).

[3] V. I. Telnov, Proceedings of the Workshop on Gamma-Gamma Colliders, LBL, *Nucl. Instrum. Methods* **A355**, 3 (1995).

[4] Zero Design Report for the NLC, Appendix B; SLAC-PUB-95-7192.

[5] D. Burke, Proceedings of Beyond the Standard Model IV, Granlibakken, CA, 1994, eds. John Gunion, Tao Han, James Ohnemus (World Scientific, Singapore,1995),125.

[6] V.E. Balakin and N.A. Solyak, Proceedings of the Workshop on Gamma-Gamma Colliders, LBL, *ibid.*, 142; also R.B. Palmer, *ibid.*, 150.

[7] D.D. Meyerhofer, Proceedings of the Workshop on Gamma-Gamma Colliders, LBL, *ibid.*, 113; also C.E. Clayton et al., *ibid.*, 121.

[8] S. Hiramatsu et al, Proceedings of the Workshop on Gamma-Gamma Colliders, LBL, *ibid.*, 133; also P. Morton and S. Chattapadhyay, *ibid.*, 138.

[9] F. Richard, Proceedings of the Workshop on Gamma-Gamma Colliders, LBL, *ibid.*, 92; also D.J. Miller, *ibid.*, 101.

[10] S. Rajagopalan, D.B. Cline, P. Chen, *Nucl. Inst. Meth.* **A357**, 1 (1996).

[11] D. Klem, these proceedings.

[12] O.J.P. Eboli et al., *Nucl. Phys.* **B421**, 65 (1994).

[13] J. Gunion and J. Kelly, *Phys. Lett.* **B333**, 110 (1994); S. Moretti, *Phys. Rev.* **D50** , 2016 (1994); M. Kramer et al., *Z. Phys.* **C64**, 21, (1994).

[14] H. Anlauf et al., *Phys. Rev.* **D52**, 3803 (1995).

[15] D. Borden et al., *Phys. Rev.* **D50**, 4499 (1994).

[16] I.F. Ginzburg and V.G. Serbo, *Phys. Rev.* **D49**, 2623 (1994).

[17] G. V. Jikia, *Phys. Lett.* **B298**, 224 (1993); *Nucl. Phys.* **B405**, 24 (1993).

[18] D. Borden, Ph.D. thesis, Univ. California, Santa Barbara (1994); unpublished.

[19] K. Fujii, T. Matsui, and Y. Sumino, *Phys. Rev.* **D50,** 4341 (1994).

[20] K.Hikasa, *Phys. Lett.* **B164**, 385, (1985).

[21] T.Rizzo, Proc. of e^-e^- 1995, Santa Cruz, California, 1995 (ed. C. A. Heusch, World Scientific); *Intl. Jour. Mod. Phys.* **11**, 1563 (1996).

[22] J.F.Gunion, Proc. of the Workshop on e^-e^- Physics, *ibid.* , 1551.

[23] D. Choudhury and F. Cuypers, *Nucl. Phys.* **B451**, 16 (1995).

[24] F.Cuypers et al., *Nucl.Phys.* **B409**, 123(1993).

[25] D.Choudhury, F.Cuypers, *Phys.Lett.* **B325**, 500(1994).

[26] S. Brodsky et al., *Phys. Rev.* **D52**, 4929 (1995).

[27] T.Han, Proc. of the Workshop on e^-e^- Physics, *ibid.* , 1541.

[28] K. Cheung, Proc.Workshop on Gamma-Gamma Colliders, *ibid.*, 57; G. Jikia, *ibid.*, 84.

[29] J. Tandean, *Phys. Rev.* **D52**, 1398 (1995).

[30] F. Boudjema et al., *Z. Phys.* **C57**, 425 (1993).

[31] N. Lepore et al, *Phys. Rev.* **D50**, 2031 (1994).

[32] G. Belanger et al, *Phys. Rev.* **D49**, 3140 (1994); H. Nadeau et al., *Phys. Rev.* **D47**, 3742 (1993).

[33] R. Rosenfeld, HEP-PH/9403356.

[34] C.A.Heusch, P.Minkowski, *Nucl.Phys.* **B416**, 1(1994).

[35] D.Choudhury et al., *Phys.Lett.* **B333**, 531(1994).

[36] F. Cuypers, Proc. of the Workshop on e^-e^- Physics, *ibid.* , 1571.

[37] D. Bauer et al., SLAC-PUB-5816 (1992); also see E.L.Saldin et al., Proceedings of the Workshop on Gamma-Gamma Colliders, LBL, *ibid.*, 171 and J.E. Spencer, *ibid.*, 184.

[38] G.V. Jikia, *Nucl. Phys.* **B374**, 83 (1992); also K. Cheung, Proceedings 2nd Int'l Workshop on Physics and Experiments with Linear Colliders, Waikoloa, Hawaii, 1993, eds. F.A. Harris et al. (World Scientific, Singapore, 1995).

[39] I.I. Bigi and F. Gabbiani, *Nucl. Phys.* **B406**, 3, (1993).

[40] The next major forum for discussion will likely be Photons'97 in The Netherlands, April 1997.