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Review of the Gamma-Gamma and Electron-Gamma Options at a Linear Collider

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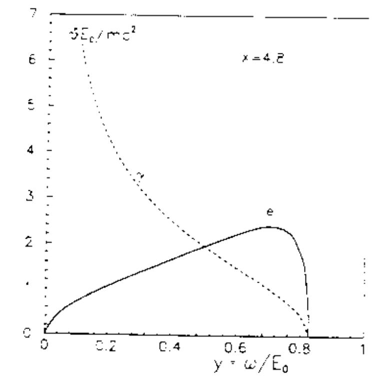


Fig. 2. Electron and photon scattering angles vs. photon energy for x = 4.8.

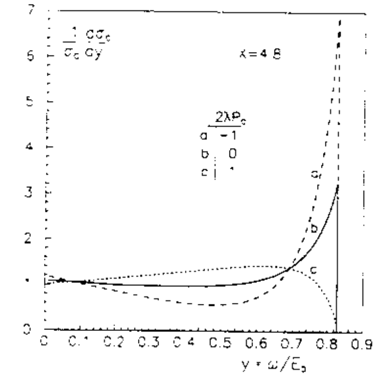


Fig. 3. Energy spectra of scattered photons for different polarizations

If the laser beams and the electron beams can all be polarised there is good control over the spectrum of the primary backscattered photons. Figure 3 shows the energy of primary photons produced in scatters between full energy electrons and laser photons. But the remaining lower energy electrons can scatter from the laser pulse again, producing low energy secondary backscattered photons. For a "thick" laser pulse, offering more than one interaction length to the incident electrons, figure 4 shows how the number of lower energy secondary photons can far exceed the number of primaries. Lower energy primary photons, and the secondary photons, are at larger angles to the beam direction than the high energy primaries, so it is possible to reduce

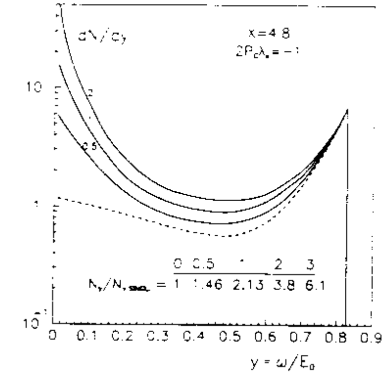


Fig. 4. Normalized (to maximum) photon spectra for different numbers of interaction lengths in a laser target (these numbers mark the solid curves); dashed curve is photon spectra without secondary scatterings.

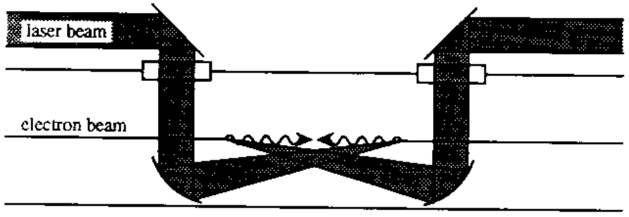


Figure 5. schematic design for a photon linear collider [6].

the contribution of low energy photons to the collision rate by intersecting the laser beams with the incident electrons at a finite distance from the collision point; see figure 5 [6]. Figure 6 shows $\gamma\gamma$ luminosities for collisions of primary photons with either no spacing between the conversion and the interaction points, "ρ=0", or with a finite spacing, "ρ=1". Here $\rho = b/\gamma a_e$, with b the distance from the conversion points to the interaction point, a_e the r.m.s radius of the colliding electron beams at the i.p. and $\gamma = E_0/m_e$. For 250 GeV beams with a_e=20 nm (say), ρ=1 corresponds to b = 10 mm. If both laser beams have opposite helicity to their electron beams, as in the lower dashed curve in figure 6, it would be possible to reduce the effective width of the peak to $\Delta W_{\gamma\gamma}/W_{\gamma\gamma} \cong 10\%$. This is often called the monochromatic $\gamma\gamma$ collider. It will be particularly attractive for dedicated Higgs studies, if any neutral Higgs bosons are found with masses of less than about 350 GeV/c^2 (see section 4 below). Since both high energy beams need to be highly polarised for the monochromatic collider it is likely to be operated in e^-e^- mode rather than e^+e^-.

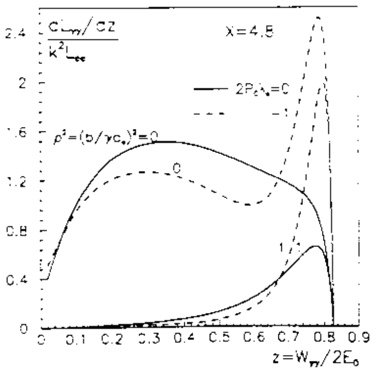


Figure 6. Spectral luminosity of γγ collisions.

In a recent presentation of the monochromatic scenario, using the beam spot sizes of current e^+e^- collider designs, Telnov [7] estimated that the γγ luminosity in the peak would be 1/10 of the geometric lepton-lepton luminosity (i.e. neglecting disruption). His optimised laser pulses would present a thickness of one interaction length to the incoming electron beam at the conversion point. He pointed out that e^+e^- beamspots at the intersection point have a very large ratio between the horizontal and vertical r.m.s. in order to achieve good luminosity with low disruption and beamsstrahlung. The damping rings, linacs and final focus are all optimised for e^+e^- operation. Discussion with machine designers at LC'95 and at the TESLA workshop in Gran Sasso confirmed that it may be possible to reduce the horizontal to vertical ratio by building special γγ intersection-region optics, bringing the effective luminosity up to about 1/5 of geometric. If the highest possible γγ luminosity were required then it would be necessary to redesign the damping rings and the linac itself to produce the smallest possible beamspot cross-section (though a truly round spot will never be optimal, for optical reasons). In this case the γγ luminosity might be as much as 1/2 of geometric.

With a different combination of beam and laser helicities, and a reduced value of ρ, a γγ collider could be operated in an alternative wide-band mode, e.g. the upper solid curve in figure 6. This would be useful in searching for narrow resonances with large cross sections - though it is unlikely that a Higgs boson would be found first in this way (but see [6] for discussion). Either LEP2, the LHC or the parent e^+e^- linear collider are likely to have found the Higgs already if it is in the available mass range up to 350 GeV/c^2 where a γγ collider could resolve it from background (see section 4 below).

As a lower cost demonstrator for the principles of γγ colliders, a low energy γγ collider [5, 8] could use the wide-band mode to study resonances in the mass range from 1 to 4 GeV (say), including measurements of the "stickiness" of glueball candidates and precise determination of γγ partial widths for η_c and the χ_cs. Yurkov and colleagues [9] have even suggested using the SLC with very intense laser pulses, presenting much more than one interaction length to the incoming electrons, to generate very large numbers of low energy gammas (c.f. uppermost curve in figure 4). This is the only scenario known to this author in which might just be possible to produce enough η_b particles to be worthwhile [10].

3. Intersection Region Problems.

Some specially awkward questions arise:

a) How do we get the laser beams to focal spots only a few wavelengths wide at the conversion points, which are a few millimetres from the interaction point, buried deep inside a large detector?

b) Do we need very localised high magnetic fields to deflect the electrons after the conversion point so that they do not collide at the intersection point?

Both of these questions were tackled at the LBL worskhop [10,11,12]. A further important question related to b) was posed very clearly at Gran Sasso:

c) Must a γγ collider have a large beam-crossing angle?

The following discussion reviews what was said about these questions by participants in the workshops but does not pretend to give the final answers.

Question a) The laser beams will need focussing elements close to the conversion points, probably inside the machine vacuum. These could be mirrors, but to acheive waists of a few microns they will need to be inside the last last low beta quadrupole of the linac and to be some centimetres in diameter. Figure 7 is a sketch of a possible layout. To maintain the required optical performance the mirrors must be kept out of the zones of intense particle radiation associated with the outgoing disrupted (or deflected) electron beams (see discussion of question c). The incoming laser beams will have to be brought past the low beta quadrupoles, inside the conical tungsten masks which stop soft scattered radiation which hits the front of the quadrupoles from splashing back into the central tracking detectors. To make room for the laser beams the mask for γγ experiments may need to have a larger half-angle than for e^+e^-, giving a loss of physics acceptance in the forward regions. Experimenters would be very unhappy for the laser beams to be brought in a right angles to the linac, through the detectors. Such a geometry would interfere seriously with the hermetic coverage which is needed for much of the physics to be done at a γγ collider. For linacs with a separation of only a few nanoseconds between bunches it has been suggested that the laser beams could be multiply reflected through the conversion points. This would require mirrors with superb reflectivity to survive for long periods in the very hostile environment of the vaccum chamber [11].

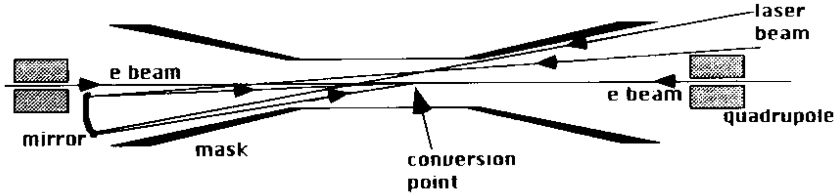


Figure 7. Sketch of a layout for laser optics in the intersection region. Two such systems would be needed for gg collisions.

Question b) If the remains of the converted electron beams are allowed to continue undeflected to the intersection point there are at least two unwanted effects:

i) the electron beams will disrupt one-another and produce a very large range of angles in the outgoing beam;

ii) there will be a significant rate of eγ collisions providing background to the γγ channels (e⁻e⁻ background in the eγ mode may not be so serious).

Telnov has suggested [4] that small superconducting sweeping magnets could be mounted close to the intersection point to provide a few Tesla-millimetres of bending between conversion and interaction, sufficient to make the electrons miss the interaction point by by a few hundred nanometers. No one has produced a satisfactory design for such a magnet [10,12]. It should present a negligible thickness of material to tracks going out towards a vertex detector (especially important for Higgs decaying to beauty pairs). It must be mechanically strong enough to withstand the magnetic forces. It must give zero field at and before the conversion points to avoid deflecting the photon spots. Balakin [13] showed at LBL that, for the ultra high current beams of the VLEPP collider, the coherent fields of the two e⁻ spots would be strong enough to deflect one another and avoid direct collisions, but this would not happen for any of the other linear colliders at present under discussion. Norem [14] suggested that a plasma lens, of the kind discussed also by Chen and colleagues for eγ physics [15], could be formed by puffing gas jets between the conversion and interaction points. The plasma would overfocus the electrons before the interaction point so that they would have diverged before they reached it. Experimenters worry about how the gas from the jets can possibly be pumped away without serious obstruction of the interaction region.

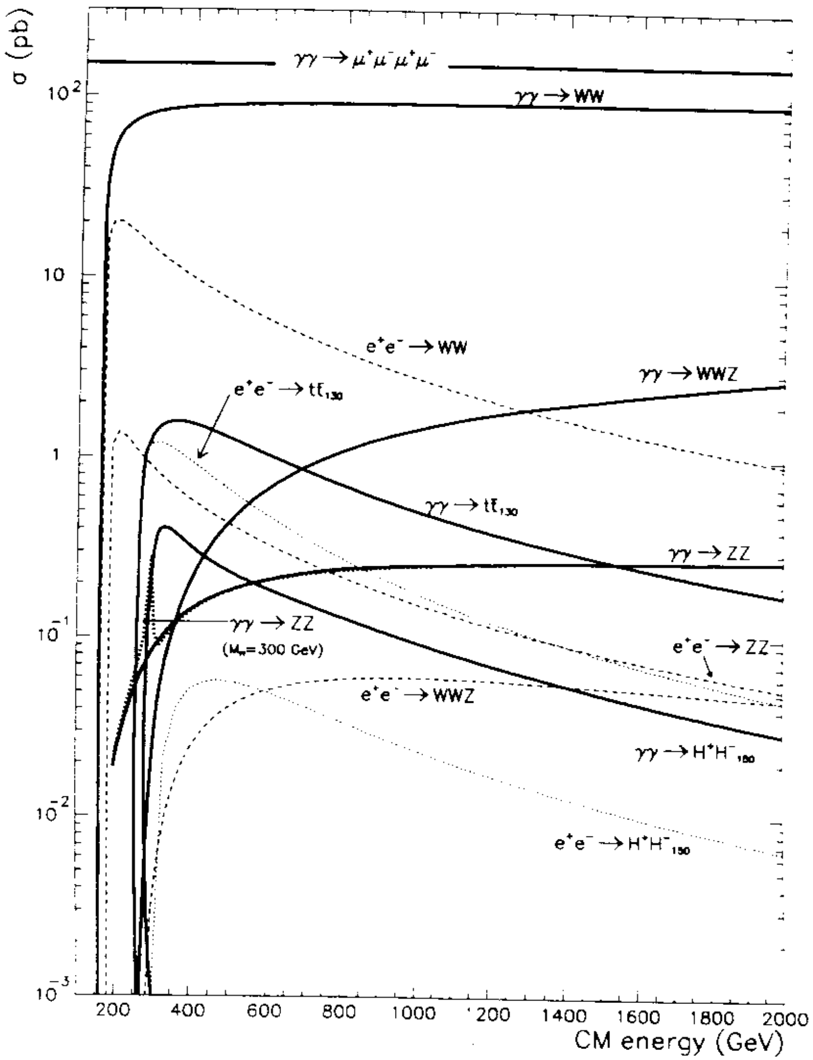
Question c) The reader will have noted that in every scenario discussed above in connection with question b) the spent electrons are - in one way or another - bent aside or disrupted. For example, in Telnov's optimised monochromatic collider the energies of these electrons would be double-peaked, at beam energy (for the 35% unconverted), and at about 20 % of beam energy. To sweep away the full energy electrons it will be necessary to sweep the converted electrons a factor of 5 further away. But there will also be a large number of electrons which have made multiple collisions and these will be swept to even larger angles. There will be a considerable amount of energy in this outgoing shower of electrons. Not only must they not be allowed to hit the laser mirrors, they must also be kept away from any superconducting or permanent magnets - the two most likely technologies for low beta quadrupoles. The only way to do this will be to have a significant beam-crossing angle in the γγ and eγ collider modes, which would be incompatible with current final-focus plans for the e⁺e⁻ mode at some of the planned colliders - at TESLA, for instance, as reported at Gran Sasso.

None of these questions is a real show-stopper. It may be necessary to live with the backgrounds due to unswept electrons; there will still be clear physics signals. It may be necessary to have a special γγ intersection region with a finite crossing angle and its own optimised detector. And it may be necessary to use a free electron laser [16] to match the linac pulse structure so that multiple reflections are not needed. The conclusion at Gran Sasso was that solutions will be found - if the γγ physics programme is good enough.

4. γγ physics at a 500 GeV collider.

Where γγ produces the same final states as e⁺e⁻ the γγ cross sections are often significantly larger due to the exchange of bosons in the t-channel, see figure 8 [17]; though the observable rates can be an order of magnitude lower because the processes are peaked forward-backward and the high energy collider detectors may have dead regions within ± 10° of the beam direction due to shielding masks. The Physics programme was discussed in some detail at LBL [18,19], at the Linear Collider Workshop in Hawaii [20] and at Photon '95 [21].

Figure 8. Comparison of the sizes of γγ and e⁺e⁻ cross sections with the same final states (from [17]). Bold curves are for γγ processes. The subscripts refer to the assumed Higgs boson and top quark masses. In the case of ZZ production the dotted line shows the resonant peak of a Higgs boson with 300 GeV mass while the plain curve is for infinite Higgs mass.



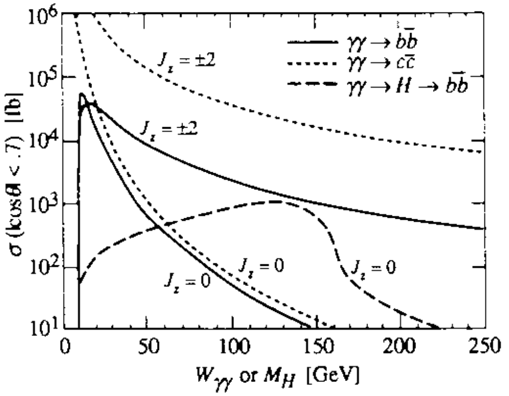


Figure 9. Cross sections from [22] for the continuum production of beauty and charm pairs, and for Higgs to beauty-antibeauty.

The most important channel is $\gamma\gamma \to$ Higgs, *if it is there.* Borden at Hawaii [22] (enlarging upon [6]) discussed the backgrounds and analysis techniques in Higgs studies with a near monochromatic beam (90% polarisationision of the incident electrons, ρ=3). For a standard model H^0 (or lightest MSSM h^0) with mass less than about 130 GeV/c^2 the main search channel would be $H \to b\bar{b}$. Figure 9 shows how selection of the J_z=0 combination of gamma helicities cuts down the background from direct γγ production of charm pairs and beauty pairs. Borden concludes that an effective integrated luminosity of 20 fb-1, with a good pixel vertex detector [24], would give 5% precision on the γγ width of such an intermediate mass Higgs For a Higgs mass close to the *WW* threshold things are more difficult since the Higgs signal can only be distinguished from the $\gamma\gamma \to W^+W^-$ background by resolving the Higgs peak. There Borden estimates an error of 20% on the partial width. Above the *ZZ* threshold things improve again. On figure 8 the resonance curve for a 300 GeV/c^2 standard model Higgs boson has been drawn on top of Jikia's curve for the continuum background from $\gamma\gamma \to ZZ$ [25] (actually $\gamma\gamma \to Z_t Z_t$, while the Higgs signal is $H \to Z_l Z_l$). The continuum swamps the signal for a Higgs mass above about 350 GeV/c^2.

Once a Higgs boson of any kind has been found in some channel at LEP, LHC or an e$^+$e$^-$ linear collider, the main goal will be to identify what kind of Higgs it is (SM, MSSM, etc etc.). One of the most important tools for doing this is to check its partial widths. Over most of the mass range below 350 GeV/c^2 measuring the γγ partial width at a γγ collider will be one of most accurate of all possible measurements. If the value disagrees with the standard model the result will be extremely interesting; but the interpretation will not be simple because of the possible contributions from charged loops due to hitherto unknown heavy particles. These may interfere constructively or destructively with the standard model contribution which is driven by $t\bar{t}$ and W$^+$W$^-$ loops. (N.B. $H \to \gamma\gamma$ is not an accessible channel in e$^+$e$^-$ mode [23], for any Higgs mass, unless a very anomalous set of heavy charged loops generates an order of magnitude higher partial width than the standard model predicts.) If the MSSM is true, for some combinations of parameters it may also be possible at a γγ collider to observe the heavier scalar Higgs boson and even the CP-odd A^0 [18].

The γγ collider could be used as a *W* factory for the study of *W* decays and final states. The cross sections in figure 8 are too optimistic because, as we get away from threshold both $\gamma\gamma \to W^+W^-$ and $e^+e^- \to W^+W^-$ become increasingly forward-backward peaked. With a realistic cut to eliminate $|\cos\theta_w| > 0.8$ the accepted cross section for $\gamma\gamma \to W^+W^-$ with $\sqrt{s_{ww}} = 400$ GeV drops to 11.5 pb, compared with only 1.2 pb for $|\cos\theta_w| > 0.8$ and the same $\sqrt{s_{ww}}$ in $e^+e^- \to W^+W^-$ [17]. There is a clear advantage for the γγ machine if its luminosity is close to 1/2 of the effective linac luminosity, which could be the case for an optimised linac (see discusion in section 2 above). With 50 fb^{-1} of γγ luminosity we would get over a million *W* decays. Boudjema's studies [17] also showed that the constraints on at least one of the possible anomalous electroweak couplings of the *W* could be determined more precisely from $\gamma\gamma \to W^+W^-$ than from $e^+e^- \to W^+W^-$ at an equivalent machine. At a higher energy linac the $\gamma\gamma \to W^+W^-Z$ cross section rises (see figure 8) to more than 20 times $e^+e^- \to W^+W^-Z$. This will be another important channel for measuring anomalous weak couplings, if the γγ luminosity can be kept higher than 1/10 of the e$^+$e$^-$ luminosity.

There will be some interest in studying $\gamma\gamma \to t\bar{t}$ close to threshold, but with $\Delta W_{\gamma\gamma} / W_{\gamma\gamma} \cong 10\%$ γγ studies offer no significant competition to the threshold scan at an e$^+$e$^-$ linac where the top quark mass should be measurable to better than ± 500 MeV/c^2, if the beamsstrahlung is kept reasonably low [26].

5. eγ physics at a 500 GeV linear collider.

The photon structure function $F_2^\gamma(x,Q^2)$ will be measured better at a high energy eγ collider than anwhere else[19]. Figure 10 shows the kinematics. There are two important QCD tests to be made, studying the evolution of F_2^γ to high Q^2 and to low x. We are trying to do them now at LEP, but the soft Weiszäcker-Williams spectrum of virtual photons means that even LEP2 will only reach Q^2 of about 1000 GeV^2.

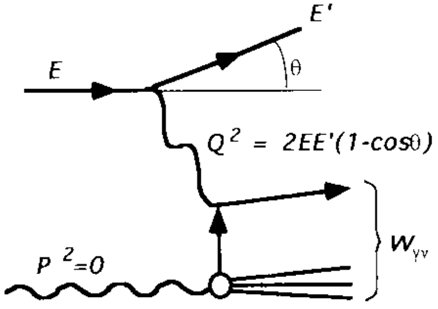


Figure 10. Kinematics for deep inelastic scattering of an electron from a real target photon.

barely enough to be able to measure the magnitude of Λ_{QCD} [27, 28]. Tagged electrons in the main detector (at $>10^\circ$ to the beam) will give data starting at $Q^2 = 200 GeV^2$ and going up to Q^2 values of tens of thousand GeV^2, much better than could be done at the 500 GeV e$^+$e$^-$ machine, even with beamsstrahlung assistance [29]. This would be sufficient for a truly model independent and accurate measurement of Λ_{QCD}, as commended by Frazer [30]. (N.B. F_2^γ reflects the quark structure of the photon. Its gluonic structure can be extracted at a γγ collider by looking at the rapidity distributions for heavy quark pairs [19, 32]).

The evolution of F_2^γ to low x may involve a sharp rise for as has been seen for the proton at HERA and as is predicted in some QCD based approaches [41,42], or it might be quite different if the photon does not behave entirely like a hadron in this kinematic region. In current LEP and TRISTAN experiments the true value of Bjorken x is particularly difficult to measure well when the target photon is virtual [28, 31] because $x = Q^2 \big/ \left(Q^2 + W_{\gamma\gamma}^2\right)$. Q^2 can be well measured, from the tagged electron, but the mass of the hadronic system $W_{\gamma\gamma}$ is biased by the loss of hadrons in the forward region of the detector, and this effect is worst when x is very small. At the eγ collider, however, with gammas produced in the narrow-band mode, $W_{\gamma\gamma}$ can be calculated directly from the invariant mass of the virtual and the real gammas, both of which are well determined. To get large statistics at low x (<.01) it will be necessary to tag electrons inside the forward shielding mask. For very low x a special tagger will have to be provided which can identify and measure scattered electrons at extremely small angles among the flux of disruption-products and radiation in the spent beam. For such tags, if they could be made at 10 mr on 250 GeV electrons, $Q^2 \approx 7.5$ GeV^2, safely deep inelastic, and the minimum accessible value of x would be $\approx 2 \times 10^{-5}$.

Some unique Electroweak channels are available at an eγ collider. The γWW coupling can be studied very cleanly in $e\gamma \rightarrow W\nu$ The cross section is large, 30 pb at 500 GeV, though it is very peripheral and many events will be badly measured because the W decay products will be lost in the forward region. Cline and colleagues [15] have even suggested that this channel would be worth studying soon at the SLC, if the energy and luminosity could be somewhat enhanced. Another unique channel is $e^-\gamma \rightarrow \nu \bar{t} b$. The cross section at a 500 GeV collider is estimated to be 1.5x10^{-2} pb, giving 400 events after notional experimental cuts, enough to make a worthwhile measurement of $|V_{tb}|$. Supersymmetry may show itself first in the channel $e\gamma \rightarrow \tilde{e}\tilde{\gamma}$ [34], though HERA physicists at the Gran Sasso workshop commented that the limits on the mass of $\tilde{e}$ from H1 and ZEUS are rising fast.

6. Higher energy γγ colliders.

If no Higgs boson is discovered with a mass below about 600 GeV/c^2, then there could be a strongly interacting Electroweak sector at the TeV scale. New effects should be seen most clearly in $W_l W_l$ and $Z_l Z_l$ scattering - that is, when virtual Ws or Zs scatter at a central vertex (e.g. figure 11). According to Jikia [35] the equivalent rates from γγ are significantly higher than from e$^+$e$^-$ at the same energy and luminosity:

$$\frac{e^+e^- \rightarrow \nu\bar{\nu}WW}{\gamma\gamma \rightarrow WWWW} \cong \frac{4*10^{-3}\,pb}{15*10^{-2}\,pb} \text{ and } \frac{e^+e^- \rightarrow \nu\bar{\nu}ZZ}{\gamma\gamma \rightarrow WWZZ} \cong \frac{1.5*10^{-3}\,pb}{4*10^{-2}\,pb} \text{ at 1.5 TeV C. of M.,}$$

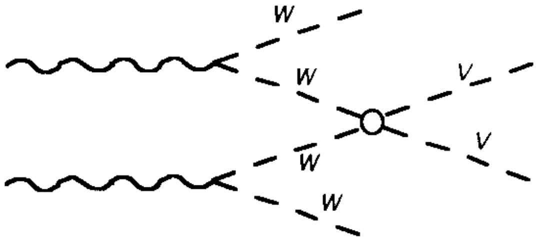


Figure 11. $\gamma\gamma \rightarrow WWVV$ with strong $W_l W_l \rightarrow W_l W_l$ or $W_l W_l \rightarrow Z_l Z_l$ scattering at the central vertex.

but the expected reduction in luminosity at the γγ machine (discussed in section 2 above) removes any clear advantage it may appear to have. Cheung [36] concludes that more than 100 fb^{-1} would be needed to make such a study worthwhile. If the strong interaction gives hadron-like resonances [37] then all possible I-spins must be looked for in the scattered WW state. The e$^+$e$^-$ collider could only produce I= 0 or 1, but a γγ (or an e$^-$e$^-$) collider would also see I=2 states.

Higher energies also extend the range for discovery physics; e.g. for $\tilde{e}\tilde{\gamma}$, for stop and for the heavier neutral supersymmetric Higgses, as well as for compositeness effects, but the relatively large cross section for $\gamma\gamma \rightarrow t\bar{t}$ will give background problems. The total $\gamma\gamma \rightarrow VVV$ cross sections all rise with energy [17, 38] because of t-channel boson exchange, unlike the equivalent e$^+$e$^-$ cross-sections, but more and more hadrons from the upper and lower vertices get lost in the forward region. Again, the two alternative colliders may actually see about the same number of useful events.

7. Conclusions

With our present understanding, Richard's comment at LC'95 still holds;

"The γγ collider has no absolute priority reasons to be built first. It has no 'star channels'; unlike the e$^+$e$^-$ collider which is definitely needed to do two major jobs:
    i) to kill or confirm the MSSM by finding or not finding a Higgs boson with mass less than 130 GeV/c^2[39, 40];
and ii) to do clean $t\bar{t}$ physics at and near the threshold[26]"

Nevertheless, there are important things to do with a γγ machine, especially if $\mathcal{L}_{\gamma\gamma} \sim \mathcal{L}_{ee} \sim 5 \times 10^{33}$cm^{-2}s^{-1}. It would be a prolific W factory and it would shed new light on Electroweak triple-gauge-boson couplings. It would be especially important if a Higgs boson were found with a mass below 350 GeV/c^2. Measuring $\Gamma_{H\gamma\gamma}$ would then be one of the highest priorities in particle physics. The eγ programme will also be rich, though it too has no star channels.

The detector, laser and machine problems are non-trivial, but there are no complete show-stoppers.

Sessler at LC'95 challenged the community to decide what it wants:

a) A machine optimised for e^+e^-, with unmodified final focus. When a low mass Higgs is found the collider could be converted to γγ with $\mathbf{L}_{\gamma\gamma}$~$\mathbf{L}_{ee}$/10. The γγ option would cost nothing extra until it was needed.

b) A machine with a second final focus optimised for γγ collisions, giving $\mathbf{L}_{\gamma\gamma}$~$\mathbf{L}_{ee}$/5. It might add an extra 10% to the cost of the whole machine.

c) A collider designed for γγ physics from the beginning, with alternative damping rings and linac setups. This might acheive $\mathbf{L}_{\gamma\gamma}$~$\mathbf{L}_{ee}$/2, maybe even $\mathbf{L}_{\gamma\gamma}$~$\mathbf{L}_{ee}$. It could increase the cost of the machine by 30%.

If a Higgs boson with mass less than 350 GeV/c^2 is found before the linear collider is built the case for option c) will become much stronger.

References

1. Proceedings of the Workshop on Gamma-Gamma Colliders, LBL, Berkeley, March 28-31 1994; eds S.Chattopadhyay and A.M.Sessler, Nucl. Instr. Meth. **A355** (1995) 1-194.
2. Milburn R.H., *Phys. Rev. Lett.* **10** (1963) 75.
3. Ginzburg I., Kotkin G., Serbo V., Telnov V, *Pizma ZhETF* **34** (1981) 514; *JETP Lett.* **34** (1982) 491.
4. Telnov V., *Principles of Photon Colliders*, in Proceedings of LBL workshop [1] pp 3-18.
5. Bauer D.A., Borden D.L., Miller D.J., Spencer J., *The Use of a Prototype Next Linear Collider for γγ and eγ Collisions*, **SLAC-PUB-5816**, June 1992.
6. Borden D.L., Bauer D.A., Caldwell D.O., *Physics Possibilities at a Photon Linear Collider*, Phys. Rev. **D48** (1993) 4018.
7. Telnov V. contribution to LC'95, Tsukuba.
8. Spencer J., *Use of a prototype NLC/GLC* in Proceedings of LBL workshop [1] pp 184-194.
9. Saldin E.L., Sarantsev V.P., Sceneidmiller E.A., Yurkov M.V., *On the possibility of constructing a high luminosity 2x5 GeV photon collider at SLC*, in Proceedings of LBL workshop [1] pp 171-183.
10. Miller D.J., *Detector Questions for a Gamma-Gamma Collider*, in Proceedings of LBL workshop [1] pp 3-18.
11. Clayton C.E., Kurnit N.A., Meyerhofer D.D. *Application of conventional laser technology to gamma-gamma colliders*, in Proceedings of LBL workshop [1] pp 121-129.
12. Richard F., *Conventional detectors for a photon-photon collider*, in Proceedings of LBL workshop [1] pp 92-100.
13. Balakin V.E. Sery A.A., *VLEPP based photon linear collider 100x100 GeV with ultimate luminosity*, in Proceedings of LBL workshop [1] pp 157-162.
14. Norem J., *Plasma lens formation in eγ and γγ colliders*, in Proceedings of LBL workshop [1] pp 166-168.
15. Rajagopalan S., Cline D.B., Chen P., *Application of a plasma lens to eγ colliders*, in Proceedings of LBL workshop [1] pp 169-170.
16. Morton P., Chattopadhyay S., *Free electron lasers for gamma-gamma colliders - a summary*, in Proceedings of LBL workshop [1] pp 138-141.
17. Baillargeon M., Bélanger G., Boudjema F., *Electroweak Physics Issues at a High Energy Photon Collider*, proceedings of the workshop on Two Photon Physics from DAΦNE to LEP200 and beyond, Paris 2-4 February 1994, eds F.Kapusta and J.Parisi, World Scientific, Sigapore (1994) pp 267-308. (Updated version to be published soon [21]).
18. Brodsky S.J. and Zerwas P.M., *High energy photon-photon collisions*, in Proceedings of LBL workshop [1] pp 19-41.
19. Chanowitz M.S., *Physics at High Energy Photon Colliders*, in Proceedings of LBL workshop [1] pp 42-49.
20. Proceedings of the Workshop on Physics and Experiments with Linear e+e- Colliders, Waikoloa, Hawaii, 26-30 April 1993, eds F.A.Harris, S.L.Olsen, S.Pakvasa, X.Tata, World Scientific, Singapore, 1993.
21. Proceedings of Photon'95, incorporating the Xth workshop on photon-photon collisions, Sheffield, England, 8-13 April 1995, eds Miller D.J., Cartwright S., Khoze V., World Scientific, Singapore, to be published 1995.
22. Borden D., γγ *and eγ physics at linear colliders*, in Proceedings of Waikoloa workshop [20] pp 323-347.
23. Djouadi A., Haidt D., Zerwas P.M., *Higgs Particles - Introduction and Summary*, in e+e- collisions at 500 GeV: the Physics Potential, DESY 92-123A, pp11-30.
24. Bowdery C.K., Damerell C.J.S., *Progress report on a CCD-based vertex detector design and some observations on the microstrip detector operation*, in Proceedings of Waikoloa workshop [20] pp 773-781.
25. Jikia G., Tkabladze A., *Neutral Gauge Boson Pair Production at the Photon Linear Collider:* $\gamma\gamma \rightarrow ZZ, \gamma Z, \gamma\gamma$ in Proceedings of Waikoloa workshop [20] pp 558-562.
26. Bagliesi G. *et al* (European working group on experimental aspects of top quark physics) in e+e- collisions at 500 GeV: the Physics Potential, DESY 92-123A, pp327-378. AND Igo-Kemenes P., *Top quark physics at Next e+e- Linea Collider; Experimental Considerations*, in Proceedings of Waikoloa workshop [20] pp 95-121.
27. Vogt A., Schuler G., contribution to working group on Gamma-Gamma physics at LEP2 1995, to be included in CERN report on the LEP2 working groups. They use the GRV model [41]
28. Miller D.J., *Two photon Physics with OPAL*, in proceedings of workshop on two-photon physics at LEP and HERA, Lund, Sweden, 26-28 May 1994, eds G.Jarlskog and L.Jönsson, published by Fysiska Institutionen, Lund 1994.

29. Miller D.J., Kennedy B.W., Ward J.J., Forshaw J.R., *Deep inelastic $e\gamma$ scattering, with beamsstrahlung*, in Proceedings of Waikoloa workshop [20] pp 577-580.

30. Frazer W., Phys. Lett. **B194** (1987) 287.

31. Seymour M. and Lonnblad L., contributions to working group on Gamma-Gamma physics at LEP2 1995, to be included in CERN report on the LEP2 working groups. Also contributions to Photon'95, Sheffield [21].

32. Halzen F., University of Wisconsin, Madison, unpublished talk given at LBL workshop [1], also Eboli O., Gonzalez-Garcia, Halzen F., Phys. Lett. B301 (1993) 115.

33. Yehudai E, Godfrey S. and Peterson K.A., *Single top production in eg collisions*, in Proceedings of Waikoloa workshop [20] pp 568-570.

34. Kon T., *Sparticle production in $e\gamma$ and $\gamma\gamma$ collisions*, in Proceedings of Waikoloa workshop [20] pp 822-827.

35. Jikia G., *Production of four weak bosons and heavy Higgs signal in TeV photon-photon collisions*, in proceedings of LBL workshop [1], pp 84-88.

36. Cheung K., *Electroweak symmetry breaking at photon colliders*, in proceedings of LBL workshop [1], pp 57-62.

37. Kurihara Y., *WW scattering with a vector resonance*, in Proceedings of Waikoloa workshop [20] pp 880-883.

38. Ginzburg I.F., *Main stages of a physical program for $e\gamma$ and $\gamma\gamma$ colliders*, in proceedings of LBL workshop [1], pp 63-74.

39. Gunion J.F., *Higgs bosons at an e^+e^- linear collider: theory and phenomenology*, in Proceedings of Waikoloa workshop [20] pp 166-191.

40. Janot P., *Higgs boson search at a 500 GeV e^+e^- collider*, in Proceedings of Waikoloa workshop [20] pp 192-217.

41. Glück M., Reya E., Vogt A., *Photonic parton distributions*, Phys. Rev. **D46** (1992) 1973-1979. See also their closely related predictions for the proton and the pion partonic distributions, respectively Z. Phys. **C53** (1992) 127, and Z.Phys. **C53** (1992) 651. Known as GRV.

42. Balitskij Ya.Ya., Lipatov L.N., Sov. J. Nucl. Phys. **29** (1978) 822; Kuraev E.A., Lipatov, L.N., Fadin V.S., Phys. Lett. **60B** (1975) 50. Known as BFKL.