The Idea of a Compton-Collider*

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ABSTRACT
A brief overview, from an experimentalist's point of view, of the possibilities and difficulties involved in building a photon-photon collider using beams produced in Compton backscattering from a linear $e^+e^-$ or $e^-e^-$ collider. Some hindsight is included from the successful March 1994 Berkeley workshop on gamma-gamma colliders.

1. Introduction
There is great theoretical interest\textsuperscript{1} in the possibility that a gamma-gamma collider might be built, with high luminosity in a narrow range of $\sqrt{s} \approx 400\text{GeV}$. This is an overview of what was known in February 1994. No insuperable problems were revealed at the Berkeley workshop\textsuperscript{2} on gamma-gamma colliders in March 1994. Telnov\textsuperscript{3}, and the Santa Barbara group\textsuperscript{4}, have given more complete surveys of the technical questions involved and of the physics opportunities. There has also been discussion\textsuperscript{5} of a low energy Compton collider, as a testbed for a high energy machine but with its own programme of worthwhile physics.

2. What is a Compton Collider?
High energy backscattered laser beams were first used at SLAC\textsuperscript{6} to provide a useful flux of high energy photons for bubble chamber experiments. The Novosibirsk group\textsuperscript{7} then suggested that it would be possible to backscatter laser photons from both beams of a high energy $e^+e^-$ or $e^-e^-$ collider (Figure 1). With sufficient laser flux almost all of the incident electrons could be converted. The angle between the initial electron direction and the scattered photon direction is tiny, so if the conversion is

made close to the intersection point the gamma-gamma luminosity will be comparable with the luminosity of the electron collider. A dimensionless variable is defined:

$$x = \left(\frac{4E_e\omega_0}{m_e^2}\right)\cos^2\left(\frac{\alpha}{2}\right) \approx 15.3\left(\frac{E_b}{\text{TeV}}\right)^2\left(\frac{\omega_0}{\text{eV}}\right),$$

where $\alpha$ is the angle between the electron beam and the laser beam (and $\cos^2(\alpha/2) = 1$ for the most probable regime of close to head-on collisions) and $\omega_0$ is the energy of a laser photon. Two simple QED processes will by-pass the production of high energy backscattered photons if $\omega_0$ is allowed to get too big. Denoting the laser photon as $\gamma_0$ and the high energy scattered photon as $\gamma$, if the invariant mass of the $e\gamma_0$ system is too high the process $e + \gamma_0 \rightarrow e + e^+ + e^-$ will occur. This is avoided by keeping $x < 8$. If the invariant mass of the $\gamma\gamma_0$ system is too high we get $\gamma_0 + \gamma \rightarrow e^+ + e^-$, avoided by keeping $x < 4.8$. The latter limit is normally used to set the wavelength of the laser to be used with a particular beam energy $E_b$ [$\lambda_{x=4.8} = 4.2E_b(\text{TeV})\mu m$], and it reduces the peak centre of mass energy of collisions between the backscattered photons to about 80% of the energy of collisions in the parent $e^+e^-$ or $e^-e^-$ collider. For a 500 GeV NLC (someone's "Next Linear Collider" - not necessarily SLAC's - with 250 x 250 GeV beams) $\lambda_{x=4.8} = 1\mu m$. This would be accessible via a number of current laser techniques. For a 5 x 5 GeV low energy collider $\lambda_{x=4.8} = 0.02\mu m$ which will probably require a free-electron-laser.

If the laser beams and the electron beams can all be polarised then there is very good control over the spectrum of photon-photon collisions (Figure 2). Varying the distance between the conversion point and the collision point also affects the spectrum, via the strong correlation between the energy and the angle of the backscattered photons. Experiments may be designed as searches, with a broad spectrum, or focussed on a particular mass region; for instance to study the Higgs boson by its direct production from $\gamma\gamma$, if it turns out to be accessible. Some interactions only happen in the $J=0$ photon-photon state, others in $J=2$, or in both. The balance of the two states can be regulated - and altered in a controlled way from pulse to pulse - by controlling the polarisations of the lasers and the primary beams. A monitoring technique is being devised to measure the effective integrated luminosity collected in each state (see 3.3 below).
3. Practicalities.

3.1 Disposal of the spent primary electrons.

The conversion and intersection points will be separated by something between a few millimetres and a few centimetres, and to achieve high luminosity (~$10^{34}$ at an NLC) the intersection region will have lateral dimensions of a few tens of nanometers. Fears have been expressed that the spent primary electrons, with 20% or more of their initial energy, will still reach the intersection region and will collide with the high energy photons. Telnov had suggested compact high-field coils to sweep these electrons aside by something like 100 nanometers. Such coils could seriously restrict the clear acceptance for the detectors. This problem was one of the main topics discussed by the detectors working group at the Berkeley workshop and a number of possible solutions are now being investigated.

3.2 Laser source.

It must be intense, with $> 2.5 J/pulse$. The repetition rate must be matched to the linac; 100 Hz to many kHz. The wavelength will be fixed by the $\chi < 4.8$ criterion (above) and the angular divergence and spot size must be very small. It is not clear that any conventional gaseous or solid laser can achieve the high repetition rates required. Free-electron lasers look very attractive for this application, in principle, since they are essentially accelerators themselves and can be run in synchronisation with the high energy beams, but the technology is still unproven. Both kinds of laser were considered in detail at Berkeley.

3.3 Flux monitoring.

It is important to have a technique which gives the effective integrated luminosity from the measured rate of actual collisions - rather than relying on machine currents, fluxes etc. The monitoring channel should have a higher event rate than all interesting physics channels, and its cross section should be calculable in QED. Such a technique has been devised for $e^+e^-$ linear colliders, using the acollinearity distribution in Bhabha scattering, but no such ideal monitoring channel exists for the $\gamma\gamma$ collider. The channels which are being further investigated, after Berkeley, are $\gamma + \gamma \rightarrow \mu^+ + \mu^-$ and $\gamma + \gamma \rightarrow \mu^+ + \mu^- + \mu^+ + \mu^-$ (suggested by Gunnion). They can never be ideal because their rates, within a realistic experimental acceptance, are slightly less than the rate for $\gamma + \gamma \rightarrow W^+ + W^-$, one of the interesting physics processes which would be studied at a Compton collider. Nevertheless, it was suggested during the Berkeley workshop that these two channels provide an ideal measurement of the integrated luminosities in the two alignment states, since $\gamma + \gamma \rightarrow \mu^+ + \mu^-$ is purely $J = 0$ and $\gamma + \gamma \rightarrow \mu^+ + \mu^- + \mu^+ + \mu^-$ is a well defined mixture of $J = 2$ and $J = 0$.

3.4 Backgrounds.

There will be intense backgrounds of soft photons, electrons and positrons coming from the conversion and intersection points, as well as synchrotron radiation from any sweeping magnets. The problems associated with these particles will be similar to those encountered in any $e^+e^-$ collider experiment, and one expects to provide a heavy conical shield at about $\pm 10^\circ$ around the beam direction to stop soft scattered gamma-rays from spraying into the central detector region from the front of the first quadrupole. This gives an unavoidable loss of acceptance for final state particles.
Soft hadronic processes may be problem when the luminosity rises above about 10^{33}. The worst fears of rapidly rising "minijet" cross-sections were shown to violate unitarity, and the HERA results on photoproduction have confirmed that photon total cross sections rise gently at high energy. Nevertheless, the total hadronic cross section will be more than 400 pb at 400 GeV, and there could be significant numbers of underlying soft events whose tracks would be difficult to separate from those of the hard physics channels - depending strongly on the time-structure of the beams in the linear collider.

4. Conclusions

Compton colliders look very promising in principle. We do not yet quite know how to make one and we have never thought seriously about how to build the experiments; hence the Berkeley workshop. It might also be attractive to build a lower-energy demonstration machine with its own worthwhile physics programme.

References

1. See talks in the gamma-gamma physics parallel session (organisers Telnov V. and Vernon W.) in Proceedings of the Workshop on Physics and Experiments with Linear e^+e^- Colliders, 26-30 April 1993, Waikoloa, Hawaii, eds. Harris, Olsen, Pakvasa and Tata, World Scientific (Singapore) 1993. Also the talks at this meeting by Boudjema, Veltman, Bambade, Belanger, Zappala and Cuypers.


9. Miller D.J., report from the working group on detectors, in Proceedings of the Workshop on Gamma-Gamma Colliders, Lawrence Berkeley Laboratory; ibid 2.


