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Detector Questions for a Gamma-Gamma Collider

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ABSTRACT

The working group reviewed the main difficulties foreseen in doing physics at a gamma-gamma collider. They discussed the requirements for the detector, calculated some of the signal and background rates, compared methods of measuring luminosity, looked at how to get the laser beams in, investigated ways of sweeping aside the electrons and considered ways of disposing of the used beams. No overwhelming obstacles were found but important questions still need to be answered.

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1. Introduction

The "Detectors" working group did not attempt to design a dedicated detector. It looked at the performance required from a detector to tackle the major physics topics at gamma-gamma colliders [1, 2, 3, 4, 5, 6], especially at high energies (hundreds of GeV). It reviewed the expected event rates for heavy-quarkonium production at a low energy gamma-gamma collider (3 to 11 GeV). It discussed the problem of normalising the effective luminosities in the $J = 0$ and $J = 2$ states, and spent much of the rest of its time on the problems of fitting the detectors, laser mirrors and other essential equipment into the very constrained interaction region of a linear e^-e^- or e^+e^- collider. Other papers in these proceedings (by F.C.Richard, D.O.Caldwell, V.Telnov, V.Balakin and others) address some of the same questions and make important points which are not repeated here. Our conclusions include a set of "homework tasks" to be undertaken before the next workshop.

2. Demands of Physics

Prime physics channels for high energy gamma-gamma colliders are:

$$\gamma\gamma \rightarrow \text{Higgs} \rightarrow b\bar{b},$$

or $\gamma\gamma \rightarrow \text{Higgs} \rightarrow ZZ,$

and $\gamma\gamma \rightarrow WW$ precision studies.

At low energy colliders ([5] and section 3, below) there is special interest in

$$\gamma\gamma \rightarrow \eta_b, \gamma\gamma \rightarrow \eta_c, \chi_c,$$

$$\gamma\gamma \rightarrow \text{resonances},$$

and $\gamma\gamma \rightarrow \text{exclusive hadron pairs}.$

These are enough to establish that the detector must be like the best of the LEP and SLC detectors. (Other possible channels are discussed elsewhere in these proceedings [7, 8] and in the literature [3, 4, 5, 9]). The group concluded that there were no known obstacles to building a detector with the required performance. It must be as close to hermetic as possible, covering

the largest possible part of 4π steradians. Despite the possible peak in the gamma-gamma luminosity spectrum at 80% of the colliding lepton energy, there will always be a significant continuum of lower energy collisions. To resolve these from the interesting channels with missing neutrinos needs the best possible measurement of the transverse energy, as well as of the total visible energy and momentum flow. Complete hermeticity will be impossible to achieve close to the beam direction. Even at an e^+e^- linear collider, without the complications of backscattered laser beams, soft electrons from the interaction region will spiral along the solenoidal field lines of the detector and hit the faces of the first quadrupoles, giving intense soft photon backscatter towards the detectors. It has been proposed [10] that this soft background be cut off by conical tungsten masks which project to within a few centimetres of the interaction point at an angle of 10° to the beams (See Figure 1). The soft background may be worse at the gamma-gamma collider where there are extra conversion collisions taking place very close to the interaction point (see discussion in section 5 below) , so similar masks will be necessary - with high radiation levels inside them and little room for inner-forward detectors or laser-mirrors (section 7 below).

To identify beauty decays (especially from the Higgs boson) the detector will need good resolution on the decay-vertices of short-lived particles, using a microvertex detector mounted at 1 to 2 cms inner radius. Developments from current CCD pixel detectors [11] will have the required position resolution, readout performance and background rejection capacity. The inner radius at the gamma-gamma collider may have to be larger than for e^+e^- to avoid radiation damage to the detectors .

Particle identification is needed, both at the high energy collider to give flavour tagging for Higgs studies, and at the low energy collider where

identified final states must be fully reconstructed in order to resolve the narrow mass peaks of charmonium and beautionium decays, as in the recent L3 study of η_c at LEP [12]. Jet chambers offer the best combination of position resolution and dE/dX measurement, so long as they can be screened effectively from soft background radiation.

The calorimeters must have fine granularity and good $\Delta E/E$ resolution for jets, especially in Higgs studies where mass resolution in the final state is crucial. Muon detectors will be very important, not only for heavy-flavour identification, and in Z or W decays, but also for luminosity monitoring (section 4 below). Muons from W decays and from the 4μ luminosity channel will be copiously produced at small angles to the beam direction. They will be measurable in forward toroid detectors (see Figure 2) even when they go inside the protective tungsten masks.

We have been warned that soft hadronic background interactions could give "underlying events" at a high energy e^+e^- or gamma-gamma collider. It was suggested [13] that the cross-section for "minijet" production in gamma-gamma scattering would rise by large factors in going from LEP to a 500 GeV collider, but unitarity arguments [14] show that this rise should be damped, and recent data on photoproduction at HERA [15] confirm that the photon does not grow rapidly into a kind of hadron as the energy increases. It is reasonable to assume that the hadronic part of the gamma-gamma total cross section stays below 400nb ($4 \times 10^{-31} \text{ cm}^2$) even at the highest energies. A collider with a gamma-gamma luminosity of $\mathcal{L} = 10^{34} \text{ cm}^{-2} \cdot \text{sec}^{-1}$ would have 4000 hadronic events per second. If the collider is based on the TESLA design [16] there will be 8000 beam crossings per second, separated by at least 1 μsec , so every second signal event would have an underlying hadronic background event. Single events with soft hadrons would not seriously

confuse signals like $\gamma\gamma \rightarrow Higgs \rightarrow b\bar{b}$ which can be recognised both by their characteristic jets with large transverse momentum and by tagged decay-vertices. Such clear signals could probably still be resolved at $\mathcal{L} = 10^{35} \text{ cm}^{-2} \text{ sec}^{-1}$. But at $\mathcal{L} = 10^{36} \text{ cm}^{-2} \text{ sec}^{-1}$ (which Palmer and Chen suggested might be possible with a plasma lens[17]) there would be 50 background events per bunch filling the detectors with soft tracks and it is not obvious that the signals would survive.

3. Heavy-Quarkonia at Low Energy Gamma-Gamma Colliders.

With electron energies in the region of 10 or 20 GeV, some of us [5] have claimed that a gamma-gamma collider can be built with $\mathcal{L} = 2.3 \times 10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$ for $\gamma\gamma$ invariant masses in the range of 3 to 4 GeV/c². The physics rates would be comparable with the Weizsäcker-Williams $\gamma\gamma$ rates from a beauty factory. Spencer has recently gone farther and claimed [18] that a $\gamma\gamma$ -collider based on SLC could reach $\mathcal{L} = 5 \times 10^{31}$. That would give about 8,000 completely reconstructed η_c events per year - ten times Ern's expected rate [19] from all four detectors together at LEP 2. This number is calculated by assuming 50% efficiency per linear collider beam for conversion of electrons to backscattered γ s, a luminosity ratio $\frac{dL_{\gamma\gamma} / dW_{\gamma\gamma}}{L_{ee}} = 0.15 \text{ GeV}^{-1}$ at $W_{\gamma\gamma} = 3 \text{ GeV}$, and Ern's conservative estimate [19] that only 5% η_c final states can be reconstructed. Ern's calculation has recently been shown [20] to be in good agreement with the new L3 result [12] at LEP1. There would be very useful rates for χ_c too.

The really difficult channel is $\gamma\gamma \rightarrow \eta_b$. The expected $\gamma\gamma$ partial width is $\sim 1/12$ of that for η_c , the cross-section goes like $1/\text{mass}^2$ and Ern [19] only expects about 1.5% of the decays to be fully reconstructed. If Spencer's hoped-for $\mathcal{L} = 5 \times 10^{31}$ can be achieved, and we assume

$$\frac{dL_{\gamma\gamma} / dW_{\gamma\gamma}}{L_{ee}} = 0.05 \text{ GeV}^{-1} \text{ at a } \gamma\gamma \text{ mass of } 10 \text{ GeV}/c^2, \text{ then we predict 8 fully}$$

reconstructed $\gamma\gamma \rightarrow \eta_b$ per year; not enough to justify building a special experiment. To make it worthwhile we would need the magical increase in SLC luminosity promised by Yurkov [21].

4. Normalisation of the J = 0 and J = 2 luminosity spectra.

Two approaches were presented at the workshop. Both need to be studied further with detector Monte Carlos, simulated linac performance and realistic backgrounds.

The first approach, presented by Telnov [22], is an elegant technique which exploits the fact that $\gamma\gamma \rightarrow e^+e^-$ only has a significant cross-section in the J = 2 wave. Data is taken throughout a running period with bunch-to-bunch changes between four different combinations of circular polarisation in the four input laser beams (the two electron gun lasers and the two backscatter lasers). The detected events are divided into bins of $W_{\gamma\gamma}$ and rapidity. The sum of data for all four polarisation combinations in a bin gives the product of the integrated luminosity times $\sigma_{\gamma\gamma \rightarrow e^+e^-}$. The normalised differences between pairs of combinations $\{(++++) \text{ and } ----) - (++-- \text{ and } --++)\}$ give the ratio of J = 0 to J = 2. As a check on the geometrical assumptions, within each of the given pairs there should be equal numbers of events.

The normalisation channels have relatively small cross sections compared with some of the interesting physics channels, especially WW ;

$$\sigma_{WW} \approx 90 \text{ pb for all } W_{\gamma\gamma} > 300 \text{ GeV} \quad (1)$$

$$\sigma_{\gamma\gamma \rightarrow e^+e^-} (|\cos \theta| < 0.9) \approx 1 \text{ pb /s (TeV}^2\text{)}, \quad (2)$$

$$\text{where } W_{\gamma\gamma} = \sqrt{s}.$$

For some of the physics it will be sufficient to normalise to the WW rate, but many analyses will depend upon knowing the ratio of $J = 0$ to $J = 2$, and for large experimental runs the helicity-variation technique should work. For instance, 10 fb^{-1} of running at $W\gamma\gamma = 400 \text{ GeV}$ gives about 62,500 $\gamma\gamma \rightarrow e^+e^-$ events within the very conservative angular cut given in (2), to be divided into four helicity combinations and (say) 16 $W\gamma\gamma$ and rapidity bins with an average of 1000 events per sample. This should be sufficient to measure the luminosity spectrum and angular momentum ratio to a few percent in each bin. The rate would be improved in a detector with good forward electron tracking and calorimetry. If the shielding masks work well it should be possible to measure $\gamma\gamma \rightarrow e^+e^-$ events down to $\sim 10^\circ$ from the beam (c.f. Figure 2), approximately doubling the rate, and it could be doubled yet again by adding the $\gamma\gamma \rightarrow \mu^+\mu^-$ channel; not measured quite as well as e^+e^- but easier to separate from background at low $W\gamma\gamma$, and with the same cross section and polarisation properties. (If the detector is also used for e^+e^- collider physics it will have to be built with good endcap tracking and calorimetry for electrons in order to measure the luminosity spectrum via Bhabha scattering acollinearity [23])

The second approach, which was considered by the working group, also uses the dilepton final states but adds the four-lepton final states $\gamma\gamma \rightarrow \mu^+\mu^-\mu^+\mu^-$, $\mu^+\mu^-e^+e^-$ and $e^+e^-e^+e^-$. In an ideal world where we could measure particles arbitrarily close to the beam direction the four-lepton total cross sections are even larger than the WW cross-section, and they rise slowly with energy, but when realistic cuts are applied they become very similar to the accepted dilepton cross sections in equation (2):

$$\begin{aligned}\sigma_{\gamma\gamma \rightarrow \mu^+\mu^-\mu^+\mu^-} &= \sigma_{\gamma\gamma \rightarrow e^+e^-e^+e^-} \\ &\approx 0.5\sigma_{\gamma\gamma \rightarrow \mu^+\mu^-e^+e^-} \approx 0.9 \text{ pb/s (TeV}^2\text{)},\end{aligned}\tag{3}$$

for $\theta_{lepton} > 10^\circ$ from beam, $E_{lepton} > 5 \text{ GeV}$ [24].

The four-lepton channels have contributions from both $J = 0$ and $J = 2$, so combining with the $J = 2$ dilepton data will give an independent measurement of the ratio of the angular momentum states, to be compared with the measurement from the laser polarisation approach mentioned above. Four-lepton final states can be well recognised and well measured. If two or three of the leptons are measured in the central part of the detector it should be possible to use events with either one or two of the muons going inside the 10° shielding mask, as shown in Figure 2. Endcap muon-solenoids would give good momentum measurements down to about 5° and the events would be selected by constraining to zero transverse momentum. This reduced acceptance cut would give a substantial increase in the four-lepton cross-section. Background in the endcap solenoids from beam-halo muons must be rejected by the trigger and if we are using muons scattered into the difficult 5° to 10° range it is much safer to trigger on four-lepton events than dimuon events because the four-lepton events can be required to have more than one good track in the central region.

5. Electromagnetic Backgrounds.

Equation (2) shows that the $\gamma\gamma \rightarrow e^+e^-$ cross section rises a lower values of $W\gamma\gamma$. There was concern that this might give intolerable fluxes of low transverse-momentum electrons which would swamp the inner detectors. The primary backscattered photons give no problem because they have a very hard spectrum, but there will be many softer photons coming from scatters off secondary electrons. Spectra have been calculated for these photons [4]. They cut off sharply for $W\gamma\gamma < 1$ GeV (with $E_{beam} = 250$ GeV) so we are not worried by the enormous cross sections for very low masses. In a range of 1 GeV about $W\gamma\gamma = 1$ GeV we expect less than 2 events per second for $\mathcal{L}_{ee} = 10^{33}$, and in 10 GeV about $W\gamma\gamma = 10$ GeV we expect about 0.2 events per

second. These are much lower than the hadronic background rates which were discussed in section 2 above and found to be bearable.

No one has yet tried to calculate all of the other processes that could produce soft gammas or soft leptons, though Kushnirenko et al [25] are optimistic. Chen reported to the group that he is producing a new program called "CAIN" (developed from his "ABEL" program for e^+e^- [26]) which will attempt to give a realistic representation of many of these processes. This is one of the most important pieces of homework promised at the workshop, and will be an essential tool for future work on gamma-gamma colliders.

6. Sweeping Magnets; are they needed ?

We want to stop unscattered electrons from the primary beams from continuing straight to the interaction point and producing large numbers of background events. Telnov [3] had suggested that tiny (dimensions ~ 1 cm) superconducting sweeper-coils should be mounted above and below the beams close to the intersection point to bend electrons away, but if these were to be made as Helmholtz coils they would introduce large amounts of material in the paths of final state particles entering the detector, destroying all hopes for good vertex resolution on such channels as Higgs $\rightarrow$ beauty. The discussion in the working group followed the evolution shown in Figure 3, starting from the alternative suggestion of Richard [8] that small current-carrying bars on either side of the beam would obscure much less of the detector acceptance. The two bars developed into a pair of flat coils (Figure 3b), to reduce the DC current required, on either side of and coplanar with the beam. Then three small coils were suggested (Figure 3c), in pairs on either side of the beam, the inner pair providing the sweeping field, and the outer pairs cancelling it at the conversion points. Questions of access for cryogenic lines and conductors and of mechanical support were not tackled in any detail.

One worry was laid to rest. Soft electrons and positrons from pair production will spiral along field lines and there were fears that the transverse sweeping-fields would take them into the detectors. But the detector solenoid field will be of comparable strength and will prevail everywhere except in the sweeping region, so there would just be a sideways step of a centimetre or so due to the sweepers. This might require the first layers of microvertex detectors to be set back a little, but the soft electrons and positrons would all eventually disappear inside the shielding masks.

Two contributions to the workshop challenged the need for sweeping coils at all. Telnov, following a contribution of Balakin[27], suggested that the round high density electron beams needed to give the best possible gamma-gamma luminosity could never be perfectly aligned, and would therefore deflect one another sideways with their intense electromagnetic fields - a sort of coherent disruption effect for like-charge particles. At sufficiently high luminosities the beams would sweep each other far enough apart to avoid collisions without any help from magnets. Then Chen and Raja[28] introduced the concept of a pair of plasma lenses, formed by beam-ionisation of localised gas-jets between the conversion and collision points. They calculated that the overfocusing effects of such lenses would spread the electrons out into such a large area that by the time they reached the collision plane they would be too diffuse to give a significant number of e^-e^- collisions.

The conclusions of the group were

- a) Sweeping the electrons away will be desirable.
- b) Doing it with magnets will be difficult, though not impossible, if that is the only way.

- c) Radically simpler solutions have been suggested but they need further study.

7. Getting the laser light in.

A joint session with the laser and intersection region working groups raised many issues which need further study. In order to achieve a compact waist in the laser beams at the conversion points it will be necessary to have large aperture mirrors as the final focusing elements, and these could suffer optical damage from radiation close to the used electron beams. Ideally the laser photons should meet the electrons close to head-on, giving the best conversion rate and good backscattered gamma polarisation. Detector physicists prefer not to have laser paths going through their good acceptance (i.e. outside the 10° shielding masks), but to achieve this the laser beams have an obstacle course to negotiate past the final quadrupoles (Figure 3). It would be better not to have a separate vacuum pipe but rather to use the inner walls of the masks as the vacuum chamber, avoiding inaccessible windows.

Three basic geometries were discussed:

- a) A laser beam comes from one side of the intersection and is focused through the small gaps in the conical masks onto a final spherical mirror close to the last quadrupole on the opposite side. The reflected light crosses the intersection region again before coming to a focus at the conversion point (Figure 4a).
- b) The light comes in down the side of the quadrupole and is reflected sideways by one inclined mirror onto an inclined curved mirror just in front of the quadrupole. This focuses it through to the conversion point at the other side of the intersection (Figure 4b).
- c) The laser beams are brought in at 90° to the beams, through the detector and through windows in the side of the beampipe. An aperture

of f10 might be sufficient. This solution will need more laser power for the same luminosity, unless the laser focus can be made to move sideways with time in a manner analogous to the "crab-crossing" of e^+ and e^- beams in a linear collider. It would disrupt tracking in the detector, especially if long-wire drift chambers were used.

8. Getting rid of the used beams.

It has been suggested that the uninteracted beams from a high energy gamma-gamma collider might be "undumpable", i.e. that no stable controllable technique exists to catch and dissipate their energy. There is alleged to be no such problem for the high intensity electron beams from linacs because they can be spread out magnetically to reduce the local heating effects in a dump. Balakin and Palmer were at first sceptical and suggested that, after a suitable flight path, the beam could be passed through a foil into a high pressure gas or a fountain of water. Chen suggested hitting the photon beam again with a laser beam to reconvert it to electrons. The problem would be the cloud of u.v. photons and x-rays which would accompany the beam and which would burn a hole in any foil. A similar flux of bremsstrahlung photons might also be a problem when dumping the beam from an e^+e^- linac. Miller suggested dumping the beam in a hot chamber with molten lead running over an inclined tungsten plate. The chamber would be connected directly to the end of the vacuum pipe and condensing metal vapour would getter-pump the vacuum.

The group agreed that serious study is needed to see if there is a real problem in disposing of the beams.

9. Conclusions.

The working group did not find any "killer" problem which would prevent a usable gamma-gamma collider from being built and doing physics.

Nevertheless, new problems are still emerging and a great deal of careful study is needed. The "minijet" problem (section 2 above) has been shown to be manageable at all but the highest luminosities. There are a number of other clear "homework" questions which need to be taken away and answered before the next workshop:

- a) What is the best way of measuring the luminosity spectra of the $J = 0$ and $J = 2$ angular momentum states (section 4)? Do we manipulating the laser polarisations, or do we combine dilepton and four-lepton final state data?
- b) How serious will the soft (electron, positron, X-ray and U.V.) backgrounds be? Chen's new CAIN programme (section 5) is needed to calculate all the possible processes. Will conical tungsten masks (section 2, Figure 1, Figure 4) be needed to protect the detector for $\gamma\gamma$ running?
- c) Are tiny sweeping magnets needed to stop the electron beams from colliding, or can the job be done either by beam-beam interactions or by plasma lenses (section 6)? If sweeping magnets are needed, how can they be supported and supplied?
- d) Will the laser mirrors survive the background radiation (section 7), and how can the laser beams be brought into the conversion region?
- e) Can high energy photon beams be dumped without destroying the beam-dump equipment?

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Figure Captions

Figure 1. Conical tungsten masks to prevent soft photons being scattered back into the detector when low energy electrons hit the quadrupoles.

Figure 2. Schematic of a solenoidal detector with forward muon chambers going down to small angles in order to enhance the four-lepton rate for luminosity measurement.

Figure 3. The evolution of ideas for sweeping fields: a) current-carrying bars; b) one pair of flat coils; c) three pairs of flat coils giving zero field at the conversion points. See text for discussion.

Figure 4. Two alternative schemes using mirrors in the beampipe region to focus a laser beam onto the conversion point. For clarity, only one laser beam is shown, sufficient for $e\gamma$ studies. Beams from both sides would be needed for $\gamma\gamma$ operation.

Figure 1

Figure 2

Figure 3

Figure 4