CERN-TH.5526/89

BU-TH-89/6

ON THE FEASABILITY OF NO-TAG TWO-PHOTON EXPERIMENTS

ON THE Z - POLE

M. Drees

CERN - Geneva

and

R.M. Godbole

Bombay University, Bombay, India

A B S T R A C T

The feasibility of studying the hadronic structure of the photon in the process $\gamma\gamma \rightarrow \text{high-}P_T \text{ jets} + X$ at e^+e^- -colliders with $\sqrt{s} \approx M_Z$ using no-tag experiments is studied. It is shown that at least on the parton level the background from annihilation multijet events with one or more jets in forward/backward direction can be removed by cutting on the angle and P_T -balance of the high- P_T jets, at least in the region of small invariant mass of the high- P_T jets, $M_{jj} \lesssim 20\text{-}25 \text{ GeV}$, where the signal is sizeable. Hadronization effects are expected to be small if one restricts oneself to the region $M_{jj} \gtrsim 10 \text{ GeV}$.

CERN-TH.5526/89
September 1989

There has been a lot of interest in recent years in processes that allow to study the hadronic structure of the photon. The "classical" way [1] is to measure the electromagnetic structure function of the photon F_2^Y using "single tag" events at e^+e^- colliders, where one photon is highly off-shell ($Q^2 \geq 1 \text{ GeV}^2$) so that the corresponding electron or positron emerges at an angle that is large enough to allow for its detection. Although this leads to a rather clean signature, event rates are low due to the $1/Q^2$ photon propagator suppression; furthermore, F_2^Y is sensitive mainly to the quark content q_i^Y of the photon. As a result, very little can be learnt about the gluon content G^Y of the photon from such measurements. Experimental information on G^Y would be invaluable not only for the purpose of testing various theoretical models [2] of the hadronic structure of the photon; the hadronic structure of the photon in general and its gluon content in particular also play an important or even dominant role whenever (almost) real photons of sufficiently high energy collide with nucleons, be it in fixed target photoproduction experiments [3,4], at the ep collider HERA [5] or in γ -initiated cosmic air showers [6].

In this note we focus therefore on the second class of inclusive two photon reactions at e^+e^- colliders, where both photons are (almost) on-shell; in this "no tag" situation both the electron and the positron go down the beam pipe, so that only the hadronic jets produced in the hard $\gamma\gamma$ collision can be detected. In lowest order in QED, three classes of processes, depicted in Fig. 1, contribute: in the "direct" contribution (Fig. 1a), both photons couple pointlike, leading to a $q\bar{q}$ final state; in the "single resolved" contribution (Fig. 1b), one photon couples to the quarks and gluons inside the other photon; and in the "double resolved" case, the partons within the first photon interact with the partons inside the second photon.

These three classes of processes are all of the same order in α_s , since the parton densities inside the photon $\hat{q}^Y = (q_j^Y, G^Y)$ receive a contribution $\sim 1/\alpha_s$. Indeed, it has recently been shown [7] that already in the TRISTAN energy range the resolved processes, which are sensitive to the hadronic structure of the photon, start to dominate over the direct process for $P_T(\text{jet}) < 5\text{--}7 \text{ GeV}$ or $M_{jj} < 15\text{--}20 \text{ GeV}$, depending on the parametrization used for $\hat{q}^Y(x, Q^2)$. Since both the total hard two photon cross section and the ratio of resolved to direct contributions increase with the beam energy $E = \sqrt{s}$, one might conclude that LEP and SLAC are even better suited than TRISTAN to study hard two photon scattering in general and resolved processes in particular. However, due to the large increase of the e^+e^- annihilation cross section around the Z-pole, a major new background arises at those machines: annihilation events with several jets in the final state where a large part of the energy is lost, in particular in the holes of the detectors

around the beam pipes. Since the total hadronic cross section right on the Z-pole is about 25 nb and hence some 3 or 4 orders of magnitude bigger than the two-photon cross section in the relevant region, one could be led to the conclusion that it is impossible to perform inclusive no-tag two photon experiments at $\sqrt{s} \sim M_Z$, or that at best the cleaner but perhaps less interesting direct process can be studied. The main purpose of this note is to point out that such a conclusion might be overly pessimistic. It seems possible to find a realistic set of cuts that reduces the annihilation background to insignificant levels in the region $M_{jj} \lesssim 20 \text{ GeV}$, without reducing the two photon signal by more than a factor of two or three, at least in the region $M_{jj} \gtrsim 10 \text{ GeV}$.

We have estimated the annihilation background using the LUND program package with all hadronizations switched off; i.e., we performed our calculations on the parton level. However, we tried to include the effects of measurement errors, and restricted ourselves to regions of phase space where hadronization effects should not be big.

As mentioned earlier, annihilation events can only be mistaken as two-photon events if a substantial amount of energy is lost. In praxis this can occur if the event contains one or more jets close to the beam pipe. Note that the jet does not actually have to coincide with the beam pipe, since detectors typically have difficulties measuring jets in a finite cone around the beam pipe. The ALBPH detector will, e.g., not be able [8] to reconstruct jets with angles less than 10 (or bigger than 170) degrees. We therefore define a forward or backward jet as a parton with angle ϕ between 0 and 10° or 170° and 180° , respectively, i.e.,

$$|\cos\theta(\text{forward jet})| > 0.985 \quad (1)$$

Even though the energy of these jets can probably not be determined with any accuracy, we assume that their presence or absence can still be detected; analogously, we assume that one can tag on or against the presence of spectator jets stemming from resolved photons. Consequently, we treat annihilation events with one forward or backward jet and two high- P_T jets as the only background to the once-resolved signal, while 4 jet annihilation events with one forward and one backward jet together with two high- P_T jets are assumed to be the sole background to the double-resolved signal.

This procedure obviously necessitates that high- P_T jets and spectator or forward jets are sufficiently well separated. We therefore require the high- P_T jets to have angles larger than 20 degrees with respect to the beam pipes [9], i.e.,

$$|\cos \Theta(\text{high-}P_T \text{ jet})| < 0.94; \quad (2)$$

this corresponds to a rapidity cut (for massless partons) of $|y| < 1.7$. Notice also that for smaller angles the measurement of jets may start to become difficult [8]. The angular cuts (1) and (2) are illustrated in Fig. 2.

Recall that we are interested in no-tag experiments where both photons are (nearly) on-shell, i.e. have almost no transverse momentum. Since the partons inside the photons also only have transverse momenta of a few hundred MeV, the transverse momenta of the two high- P_T jets of the signal must (almost) balance. This is not necessarily true for the background, since here the forward/backward jet(s) can have a finite angle to the beam pipe and thus carry some transverse momentum. Since even our high- P_T jets have $P_T \lesssim 10$ GeV (otherwise the signal cross section is too small), the imbalance can indeed be quite large for the background. We therefore imposed the following cut on the vectorial sum of the transverse momenta of the two high- P_T jets:

$$|\vec{p}_{T_1} + \vec{p}_{T_2}| < \Delta_P \cdot \min(|\vec{p}_{T_1}|, |\vec{p}_{T_2}|). \quad (3)$$

Obviously the appropriate choice of Δ_P depends on how precisely jet transverse momenta in the region between 3 and 10 GeV can be measured. This is not yet entirely clear. If the transverse momentum is derived from a measurement of the angle and energy of the jet, the relative error of P_T will be similar to the jet energy E , i.e., about $80\%/P_T$ (P_T in GeV). On the other hand, most tracks in these jets will be rather soft, since we are interested in the region $M_{jj} \lesssim 20$ GeV; a good measurement of the momentum of the charged particles inside the jet from the curvature of the corresponding tracks should thus be possible. The electromagnetic component of the jet (mostly photons from neutral pions or eta's) can also be measured quite accurately. The big problem of this approach, however, is the treatment of neutral long-lived hadrons (K^0, n).

In view of this uncertainty we do not try to smear out the Lund-generated transverse momenta according to some error function. Rather, we implement the cut (3) on the parton momenta, but include results for an optimistic value $\Delta_P = 0.2$ as well as the more conservative choice $\Delta_P = 0.5$. Notice that, as discussed later on, the cut (3) with $\Delta_P = 0.2$ will eliminate as much as 65-75% of the signal if P_T is determined from the total energy of the jet.

Having implemented the cuts (1)-(3) we found that the background to the once-resolved signal is a steeply rising function of the invariant mass M_{jj} of the two high- P_T jets. This is not surprising, since this background has only one small angle jet, the longitudinal momentum of which has to be balanced by the two high- P_T jets. Recall that the opening angle between these two jets is at least 40° degrees due to the cut (2); for the case of perfect P_T -balance of the two high- P_T jets this implies $M_{jj} > 16$ GeV. Furthermore, the cut (3) is effective only in the region of low M_{jj} , since for large M_{jj} the forward/backward jet has to be soft and can thus not carry a significant transverse momentum. Such a steep spectrum can obviously be distorted quite severely if experimental errors on M_{jj} are included; in particular, some events with large M_{jj} will, due to mismeasurement, contribute to the background in the more interesting region of low M_{jj} . In order to estimate the importance of this effect, we have smeared the M_{jj} -spectrum of both signal and background assuming a Gaussian error distribution with

$$\sigma(M_{jj}) = 1.0 \sqrt{M_{jj}} \quad (M_{jj} \text{ in GeV}), \quad (4)$$

which can be considered to be a quite conservative choice; an error of $80\%/M_{jj}$ should be achievable, at least in the central region of the detector.

In Figs. 3a-b we show the signal cross-section, where in addition to the cut (2) we have required $P_T(\text{jet}) > 2$ GeV, in order to guarantee the applicability of perturbative QCD. The two figures differ only in the parametrization used for $q\bar{q}$. In Fig. 3a, the parametrization of Ref. [10] has been used, while Fig. 3b is valid if $q\bar{q}$ is given by the sum of the parametrization of Ref. [4] and a VMD-inspired part. We have used the Weizsäcker-Williams approximation in the form given in Ref. [11]. The momentum scale Q^2 in α_s and $q\bar{q}$ is chosen as M_{jj}^2 , and we have used $\Lambda_{\text{QCD}} = 0.4$ GeV. Further information about the parametrizations used as well as details of the signal calculation (without M_{jj} -smearing) can be found in Ref. [7].

Since the signal is always a steeply falling function of M_{jj} the smearing depletes the signal at small M_{jj} , but increases it at larger values of M_{jj} by roughly a factor of two at $M_{jj} \approx 25$ GeV. Note that we have cut off the Gaussian below $M_{jj} = 5$ GeV (as well as above $\sqrt{s} = 91$ GeV); without this cut-off the depletion of the signal in the region $M_{jj} \lesssim 10$ GeV would be much stronger. However, for reasons to be discussed later, the region $M_{jj} \lesssim 10$ GeV might not be accessible at $\sqrt{s} \approx M_Z$ anyway. Finally it should be pointed out that the background [7,12] from single hard bremsstrahlung is below 0.1 pb/GeV everywhere after the cuts $|y| < 1.7$ and $M_{jj} < 30$ GeV have been applied.

Notice that the DO + VMD parametrization of Fig. 2b always leads to larger

signal rates, by as much as a factor of two at low M_{jj} . Notice also that the double-resolved contribution actually dominates the total two-photon signal in the region $M_{jj} \lesssim 15-25$ GeV, depending on the parametrization used for q^2 . (The direct contribution, $\gamma\gamma \rightarrow q\bar{q}$, is of course independent of q^2 and thus the same in both figures.) The main objective of studying resolved two-photon events would, of course, be to decide which (if any) of the parametrizations used in Fig. 3 is the correct one.

In Figs. 4 and 5 we compare the once-resolved and double-resolved signal respectively, with the corresponding backgrounds from 3- and 4-jet annihilation events. The cuts (1)-(3) and the smearing in M_{jj} according to eq. (4) have been implemented; the 4-jet background has then to be multiplied by a "K-factor" of two, in order to account for a known [13] deficiency of the Lund program when compared to existing 4-jet data.

As discussed earlier, the 3-jet background rises sharply with M_{jj} in the relevant region, while the 4-jet background is much flatter. In both cases changing Δp from 0.5 to 0.2 reduces the background by a factor of three or more in the interesting region of low M_{jj} ; as mentioned earlier, for large M_{jj} the two high- P_T jets automatically have more or less balancing transverse momenta. Recall, however, that the cut (3) has been applied at the parton-level. A similar cut on the measured transverse momentum of the high- P_T jets might have similar effects on the background at low M_{jj} , but will also affect the background at larger M_{jj} , since there is always a finite probability that jets that are in reality perfectly balanced appear to be imbalanced. More importantly, the measured signal (as opposed to our "partonic" signal) will also suffer from this cut; if $\sigma(P_T(\text{jet})) = 80\%/P_T$ (P_T in GeV), about 2/3 (1/3) of the signal will be lost by the cut (3) with $\Delta p = 0.2$ (0.5), assuming a Gaussian distribution of $P_T(\text{jet})$. However, as discussed earlier, the true error in P_T might well be smaller; and even with this big error the stronger cut reduces the background more than the signal.

From Figs. 4 and 5, we can thus tentatively conclude that the once-resolved and double-resolved signal should dominate the background for $M_{jj} \lesssim 15$ GeV and $M_{jj} \lesssim 20$ GeV, respectively; if the stronger cut $\Delta p = 0.2$ can be used, the useful region of M_{jj} can be extended by another five GeV or so. For even higher values of M_{jj} the signal event rate would be less than 10 ev./yr, assuming an integrated luminosity of 100 pb/yr, and thus too low to be useful anyway.

Recall, however, that our calculation has been performed on the parton level. The difference between partons and jets should not be too drastic as far as the angular cuts (1) and (2) are concerned [although the signal depends quite strongly on the value used in the cut (2), so that a change of a factor of two cannot be excluded]; since we already incorporated smearing in the dijet invariant mass M_{jj}

the shape of the background distributions in Figs. 4 and 5 should also not change too much when hadronization effects are included. Nevertheless at least one significant effect of hadronization cannot be mimicked by the cuts we used so far: the occurrence of soft hadrons that fill the regions between jets. The cross section for two-jet events where both jets have an angle of less than 10 degrees to the beam pipe is 100 pb or more, depending on the jet definition used. In these events the only hadrons inside the inner cone specified by the cut (2) are soft hadrons; these contribute about 1 GeV or, if "minijets" from the radiation of fairly soft gluons are included, as much as 2 GeV of transverse energy per unit of rapidity, i.e., some 6 or 7 GeV inside the cone $|\eta| < 1.7$. Without further information on the forward/backward jets, this background might well resemble two-photon events where the partonic M_{jj} is too small to allow for the formation of well-defined jets. In other words, this background forces one to throw away all events that do not have two well-defined jets. This will make it very hard, if not impossible, to study the region $M_{jj} \lesssim 10$ GeV, at least for the double-resolved signal. From Fig. 3, we see that in precisely this region double-resolved events are most dominant, and predictions using different parametrizations of q^2 differ most strongly. On the other hand, for $M_{jj} \gtrsim 10$ GeV the requirement of two well-defined jets should not lead to a large further reduction of the signal, since here jet-reconstruction should already be [14] quite efficient.

Finally we should mention that the multijet annihilation events studied in this paper are not a background to the direct signal from $\gamma\gamma \rightarrow q\bar{q}$. This process is, however, both theoretically and experimentally quite well understood, although it might be worthwhile to try and extend the region where this process has been studied towards larger P_T or M_{jj} .

In conclusion we have shown that multijet annihilation events should not be an unsurmountable background to the study of high- P_T jet production in no-tag two-photon experiments; even the interesting subclass of events where one or both photons are resolved into quarks and gluons should be clearly detectable in the region $M_{jj} \lesssim 15-20$ GeV or $M_{jj} \lesssim 20-25$ GeV, respectively. Although we performed our calculation on the parton level we do not believe that hadronization would change these upper boundaries of the accessible regions of M_{jj} drastically; note also that for much larger M_{jj} , the signal rates become uninterestingly low anyway. Soft hadrons in two-jet annihilation events where both jets are close to the beam pipe may, on the other hand, make the study of double-resolved processes very hard or even impossible in the region $M_{jj} \lesssim 10$ GeV; they might also force one to discard all events which do not have two well-defined high- P_T jets. This is somewhat of a pity, since lower M_{jj} mean lower 8-jet α_s^8 , and thus larger differences between different model predictions and larger effects due to the hitherto unobserved gluon content of the photon.

However, this note is definitely not a definitive study of no-tag two photon physics at or close to the Z-pole. More detailed Monte Carlo studies including both hadronization effects and detector simulation are clearly needed. In particular, it would be very interesting to know how well the transverse momentum of jets in the region $3 \text{ GeV} < p_T \leq 10 \text{ GeV}$ can be measured. It would also be very helpful if one could get at least a rough estimate of the energy of forward/backward jets; among other things, discriminating between 15 GeV jets and 40 GeV jets would be sufficient to make the region $M_{jj} < 10 \text{ GeV}$ accessible again.

One could, of course, avoid all the trouble with annihilation backgrounds by going away from the Z-pole; increasing the beam energy by 3 GeV would be sufficient. However, this will not happen at LEP in the next couple of years, and might never happen at the SLC; and even two years with design luminosity should be sufficient to accumulate thousands of two-photon events even after cuts, which might enable us to gain further insight into the hadronic structure of the photon.

ACKNOWLEDGEMENTS

We are indebted to T. Sjöstrand for providing us with a copy of the Lund program package as well as for many helpful discussions and suggestions. We also thank M. Schmelling and A. Finch for discussions on experimental considerations. One of us (R.G.) wishes to thank the CERN theory division for providing a hospitable environment. This work was partially supported by the Board for Research in Nuclear Sciences, India.

REFERENCES

- [1] For a review, see Ch. Berger and W. Wagner, Phys. Rep. 146 (1987) 1.
- [2] The first QCD computation, valid in the limit of infinite Q^2 , has been performed by E. Witten, Nucl. Phys. B120 (1977) 189, and has been extended to two-loop order by W. A. Bardeen and A.J. Buras, Phys. Rev. D20 (1979) 166; Erratum, Phys. Rev. D21 (1980) 2041. However, these solutions diverge as $x \rightarrow 0$, as discussed by D.W. Duke and J.F. Owens, Phys. Rev. D22 (1980) 2280; G. Rossi, Phys. Lett. B130 (1983) 105. A procedure that regularizes these $x \rightarrow 0$ divergences has been suggested by I. Antoniadis and G. Grunberg, Nucl. Phys. B213 (1983) 445; I. Antoniadis and L. Marleau, Phys. Lett. 161B (1985) 163. An alternative procedure that uses regular input distribution functions $q(x, Q_0^2)$ has been suggested by M. Glück and E. Reya, Phys. Rev. D28 (1983) 2749; M. Glück, K. Grassie and E. Reya, Phys. Rev. D30 (1984) 1447. For more recent work on photon structure functions, see J.H. Field, F. Kapusta and L. Poggioni, Phys. Lett. B181 (1986) 362 and Z. Physik C36 (1987) 121; M. Glück and E. Reya, Nucl. Phys. B311 (1988) 519.
- [3] J.F. Owens, Phys. Rev. D21 (1979) 54; P. Aurenche, R. Baier, A. Douiri, M. Fontannaz and D. Schiff, Nucl. Phys. B286 (1987) 553; H. Baer, J. Ohnemus and J.F. Owens, Univ. Florida preprint FSU-HEP 890523 (1989).
- [4] D.W. Duke and J.F. Owens, Phys. Rev. D26 (1982) 1600.
- [5] M. Drees and R.M. Godbole, Phys. Rev. Lett. 61 (1988) 683 and Phys. Rev. D39 (1989) 169; W.J. Stirling and Z. Kunszt, in "Proceedings of the HERA Workshop", Hamburg, Oct. 1987, edited by R.D. Peccei; A.C. Bawa and W.J. Stirling, same proceedings; H. Baer, J. Ohnemus and J.F. Owens, Z. Physik C42 (1989) 657.
- [6] M. Drees and F. Halzen, Phys. Rev. Lett. 61 (1988) 275; M. Drees, K. Hikasa and F. Halzen, Phys. Rev. D39 (1989) 1310.
- [7] M. Drees and R.M. Godbole, CERN preprint TH.5458/89, University of Bombay preprint BU-TH-89/4.
- [8] M. Schmelling, private communication.
- [9] Strictly speaking, this cut would not be necessary for the once-resolved case, if the spectator (or forward) jet and the high- p_T jets are in opposite hemispheres.
- [10] M. Drees and K. Grassie, Z. Physik C28 (1985) 451.
- [11] S.J. Brodsky, T. Kinoshita and H. Terazawa, Phys. Rev. D4 (1971) 1532.
- [12] K. Kajantie and R. Raitio, Nucl. Phys. B159 (1979) 528. For another early calculation of jet production in $\gamma\gamma$ collisions, see: S.J. Brodsky, T.A. DeGrand, J.F. Gunion and J. Weis, Phys. Rev. Lett. 41 (1978) 672; Phys. Rev. D19 (1979) 1418.
- [13] T. Sjöstrand, private communication.
- [14] A. Finch, private communication.

FIGURE CAPTIONS

Fig. 1 : Feynman diagrams (left) and depictions of the final state topology (right) for the three classes of two-photon reactions considered in this paper, i.e., direct (a), once-resolved (b) and double-resolved (c) processes.

Fig. 2 : Illustration of the angular cuts (1) and (2).

Fig. 3 : The invariant mass spectrum expected for the signal at $\sqrt{s} = M_Z = 91$ GeV for two different parametrizations of the parton content of the photon. In addition to the cuts (1)-(3) described in the text we have required the high- P_T jets to have $P_T > 2$ GeV. Gaussian smearing in M_{jj} has been implemented, with the condition $M_{jj} > 5$ GeV.

Fig. 4 : The three-jet background to the once-resolved signal after the cuts (1) and (2), for two different choices of the P_T -balance cut parameter Δp (see Eq. (3)). Gaussian smearing in M_{jj} has been implemented, with the condition $5 \text{ GeV} < M_{jj} < 91 \text{ GeV}$. For comparison, the dotted curve shows the once-resolved signal as predicted by the DG parametrization.

Fig. 5 : The four-jet background to the double resolved signal. Cuts and notations are as in Fig. 3.

Fig. 1

Fig. 3a

Fig. 2

Fig. 3b

Fig. 4

Fig. 5