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Hadronic backgrounds from two photon processes at e^+e^- colliders

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Summary. — Hadronic backgrounds coming from two photon processes are studied at CLIC energies and beam parameters. We determine these backgounds as predicted by various models and fits to experimental data and show that the beamstrahulng-induced backgrounds at CLIC are considerably large.

PACS 13.60.Hb – Total and inclusive cross-sections (including deep-inelastic processes).
PACS 13.66.Bc – Hadron production in e^-e^+ interactions.
PACS 41.60.-m – Radiation by moving charges.
PACS 12.38.-t – Quantum Chromodynamics.

1. – Introduction

The world of particle physics is right now at a very interesting juncture. The Large Hardon Collider (LHC) has started delivering interesting information about the Standard Model (SM) of particle physics. The experiments at the LHC are expected to close in on the Higgs sector of the SM in the coming months and then one hopes to get glimpses of the physics beyond the SM in these experiments. After this project has provided particle physicists with a broad overview of the landscape of particle physics in the TeV range, the community expects to embark on the construction of e^+e^- linear colliders [1, 2] to probe the same energy range with high precision. Historically, progress in particle physics has been achieved by the working of a hadronic and a leptonic collider in tandem. The required high precision for the studies at the e^+e^- colliders has been made possible due to the very clean environment that they have traditionally provided. However, at high energy and high luminosity linear colliders, the "cleanliness" of this environment may be threatened by large hadronic two-photon interaction rates [3]. In addition to the beamstrahlung spectra giving the energy distribution of the photons participating in the two photon interactions, a good knowledge of the energy dependence of $\sigma^{\rm tot}(\gamma\gamma \to \text{hadrons})$ is of utmost importance to be able to assess the issue. These backgrounds are under control at the International Linear Collider (ILC) for the energies and the designs under consideration [1, 3, 4]. The Compact Linear Collider (CLIC) is a machine that has been proposed to be built to study e^+e^- collisions at centre-of-mass energies of about 1–5 TeV [2]. These backgrounds are expected to be larger for an e^+e^- collider operating in this higher-energy range. It is therefore important to revisit the issue and obtain an estimate of the range of expected backgrounds, based on the current understanding of the energy dependence of $\sigma^{\rm tot}(\gamma\gamma \to \text{hadrons})$. In the following we estimate the contributions from $\gamma\gamma \to$ hadrons to backgrounds at CLIC. We first review the current status of data and models on the total photon-photon cross-sections and the predictions for these cross-sections at the nominal CLIC centre of mass energy of 3 TeV. We then determine the number of hadronic events per bunch crossing expected at CLIC from these processes. It may be mentioned here that a good understanding of hadron production in two photon processes may play a role also in the context of either the heavy ion collisions [5] or the two photon processes to be studied at the high-luminosity LHC [6].

2. – Status of currently available data and models for $\sigma^{\rm had}_{\gamma\gamma}$

The currently available experimental information on total hadronic cross-sections for photon-induced processes comes from the e^+e^- colliders PEP [7], PETRA [8] and LEP [9, 10] as well as HERA [11]. The most important of these are the LEP2 data from the L3 [9] and OPAL [10] experiments. Experimentally, all total cross-sections rise asymptotically with energy, but it is not clear whether the rate of increase is the same for all processes. Phenomenologically, the LEP data seem to indicate that the slope with which the total $\gamma\gamma$ cross-section rises is not the same as in the proton case [12]. This difference would spoil the simplicity of the so-called Regge-pomeron model, in which the high-energy rise is described through a single universal term [13]. Of course, all total cross-sections do rise with energy and to appreciate it at a glance, we show in fig. 1 a compilation of data on $pp/\bar{p}p$ [14, 15], γp [11] and $\gamma\gamma$ [9] scattering together with expectations from the BN model [16-18] for protons. Since the data span an energy range of four orders of magnitude, with the cross-sections in the millibarn range for proton-proton/ proton-antiproton, microbarn range for photoproduction and nanobarns for photon-photon, to plot them all on the same scale, one needs a normalization factor. The data suggest to multiply the γp cross-section by a factor ≈ 330 and the $\gamma\gamma$ by $(330)^2$ [17], as shown in fig. 1.

Presently, the $\gamma\gamma$ cross-section data indicate a very clear rise, which may be even stronger than in hadron-hadron collisions. This can be shown through Regge inspired fits of the type [12]

$$\sigma^{\rm had}_{\gamma\gamma}(s_{\gamma\gamma}) = A\ s^{\epsilon}_{\gamma\gamma} + B\ s^{-\eta}_{\gamma\gamma}, \tag{1}$$

where ϵ and η are expected to be process independent, *i.e.* the same in pp, $p\bar{p}$, γp and $\gamma\gamma$ collisions. A well-motivated argument of the form of the above total cross-section is given in [16]. Note that $s_{\gamma\gamma}$ is infact $s/(1\,\text{GeV}^2)$ and is therefore dimensionless.

Since the power of the Regge term and its size cannot be both determined from the LEP data alone, we take the value measured in pp and γp interactions as given in the PDG [19] namely $\eta = 0.358$. Table I and fig. 2 show results of fits to the measurements in the form of eq. (1), leading to $\sigma^{\rm had}_{\gamma\gamma}$ in nanobarns, for three different cases:

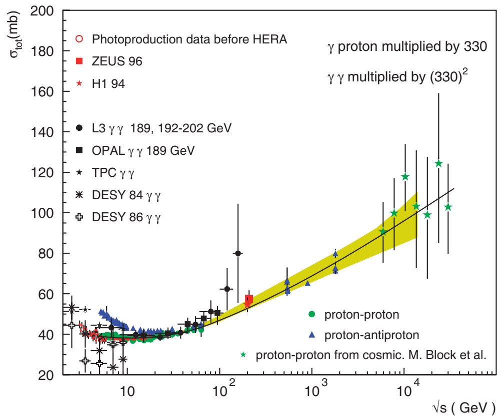

Fig. 1. – Proton [15] and photon [11, 9] normalized total cross-sections with the band expected from our BN model for $pp/\bar{p}p$ [16-18] and one typical curve from this model. Cosmic ray data are from [20].

– Fit1: All parameters A, B and ϵ are left free.

– Fit2: ϵ is fixed to 0.093, as measured in pp and $\bar{p}p$ collisions, the other parameters are left free.

– Fit3: ϵ is fixed to 0.093, but a second pomeron term of the form $Cs_{\gamma\gamma}^{\epsilon_1}$ as proposed in [21] was added with $\epsilon_1 = 0.418$ and the normalization (C) fitted.

We see that when the value of ϵ is allowed to vary, then it is much larger for $\gamma\gamma$ cross-section as compared to $pp/\bar{p}p$ cross-section, hence indicating the rise with energy in $\gamma\gamma$ collisions is faster than in $pp/\bar{p}p$ collisions.

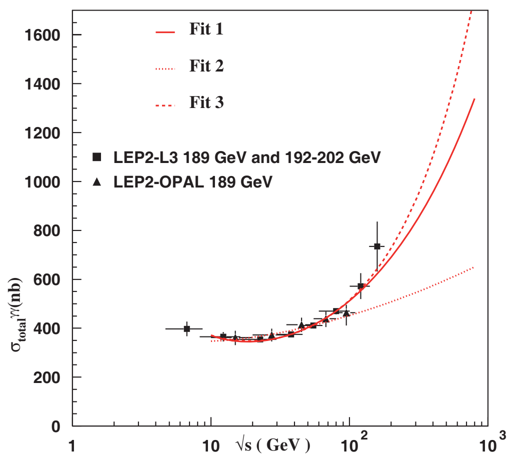

Fig. 2. – Data from OPAL and L3, shown with combined statistical and systematic error apart from the model dependence error, together with results from fits. In Fit 1 all parameters of eq. (1) are free. In Fit 2, ϵ is fixed at the $pp/\bar{p}p$ value of 0.093, other parameters are free and in Fit 3 a second pomeron term Cs^{ϵ_1}, with $\epsilon_1 = 0.418$ is added.

TABLE I. – *Results of fits to the OPAL and L3 total* $\gamma\gamma$ *cross-sections, of the form* $Bs^{-\eta} + As^{\epsilon} + Cs^{\epsilon_1}$.

Data	A (nb)	B (nb)	C (nb)	ϵ, ϵ_1	χ^2
L3+OPAL	51 ± 14	1132 ± 158	–	$\epsilon = 0.240 \pm 0.032$	4.0
L3+OPAL	187 ± 4	310 ± 91	–	$\epsilon = 0.093$ fixed	26
L3+OPAL	103 ± 18	934 ± 156	5.0 ± 1.0	$\epsilon = 0.093$, fixed $\epsilon_1 = 0.418$, fixed	2.8

Various models exist which attempt to explain these total cross-sections. These can be broadly divided into two classes: the "proton-like" models in which the photon is assumed to behave like a proton and QCD and Regge inspired models. Figure 3 shows a collection of data for the total hadronic cross-section $\sigma(\gamma\gamma \to \text{hadrons})$ from the various e^+e^- experiments in comparison with the predictions from a number of theoretical models summarised in ref. [22]. The predictions have been plotted from "proton-like" models, labelled SaS [23], Aspen [24], BSW [25], as well as from QCD and Regge inspired models, like the curve labelled GLMN [26] and the band labelled BKKS [27]. The band labelled EMM covers predictions of two different formulations, inelastic and total. For the EMM, we have used two sets of representative parameters [22], both of which are obtained from the γp cross-section following the procedure outlined in [28]. All models predict a rise of the cross-section with the collision energy $\sqrt{s_{\gamma\gamma}}$, but with very different slopes.

3. – Predictions for CLIC

In linear colliders, if the outgoing and incoming leptons in a hard scattering process are almost collinear, the calculation of the corresponding cross-section can be considerably simplified by use of the Weizsacker-Williams (WW) [29] approximation or equivalent

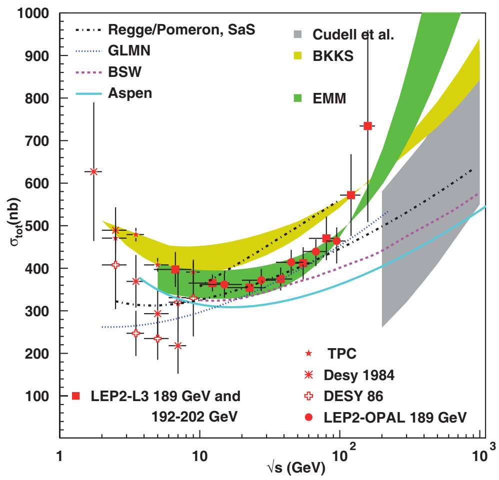

Fig. 3. – The predictions from factorization (proton like) models [23-25] Regge-pomeron exchange [26] and a QCD structure function model [27] together with those from the EMM [22] are compared with the present data.

photon approximation. These photons are in fact bremsstrahlung photons. High-energy linear colliders such as CLIC (3 TeV) [30] require dense particle bunches in order to obtain large luminosities. As a result electrons and positrons experience transverse acceleration and radiate what is known as "beamstrahlung" photons [31]. So both beamstrahlung and bremsstrahlung contributions need to be considered.

In the WW approximation, the energy spectrum of the exchanged photons can be taken to be [32]

$$f_{\gamma/e}(z) = \frac{\alpha_{\rm em}}{2\pi z}\left[(1+(1-z)^2)\ln\frac{P^2_{\rm max}}{P^2_{\rm min}} - 2(1-z)\right], \tag{2}$$

where

$$P^2_{\rm max} = s/2 * (1-\cos\theta_{\rm tag})(1-z), \qquad P^2_{\rm min} = m_e^2\frac{z^2}{(1-z)}\,.$$

Here, using $\theta_{\rm tag}$ the maximal scattering angle for the outgoing electron, we have taken anti-tagging into account and have included the suppression of the photonic parton densities due to its virtuality following ref. [3].

To select $e^+e^- \to e^+e^-$hadrons events, a minimum value of $s_{\gamma\gamma}$ is required, selecting a region such that the value of $s_{\gamma\gamma}$ can be corrected for smearing and losses with sufficient precision. Also a maximum value is imposed, because the events resemble annihilation events for too large a value of $s_{\gamma\gamma}$ and cannot be easily separated. Additionally an anti-tagging condition for the scattered electrons is imposed. We choose the region $50\,{\rm GeV}^2 < s_{\gamma\gamma} < 0.64 s_{ee}$ and the anti-tagging conditions $\theta_{tag} = 0.025$, $E^e_{\rm min} = 0.2E_{\rm beam}$ following ref. [12]. For a more general overview, we also study the case where we do not use any tagging cuts and use the spectra

$$f_{\gamma/e}(z) = \frac{\alpha_{\rm em}}{2\pi z}\left[(1+(1-z)^2)\ln\frac{s}{m_e^2}\right], \tag{3}$$

following the discussion in ref. [3].

For the beamstrahlung contributions we use two different spectra of photons:

– An analytic form of the beamstrahlung photons [33].

– Spectrum generated by simulation using GUINEAPIG, which we refer to as Sim [34].

For the analytic spectrum we use machine parameters given in ref. [2]. Note that the analytic spectrum does not include nonlinear effects that have been accounted for in the simulation. We show the folded cross-sections for various energies and models using only the bremsstrahlung contribution in fig. 4. We see that there is a broad range of predictions but the experimental data are not precise enough to rule out any of the models.

We calculate the number of events in the following way; if $b1$ = beamstrahlung spectra of beam1, $b2$ = beamstrahlung spectra from beam2, $w1$ = *bremsstrahlung* spectra from beam1, and $w2$ = bremsstrahlung spectra for beam2, then, we calculate the following event numbers:

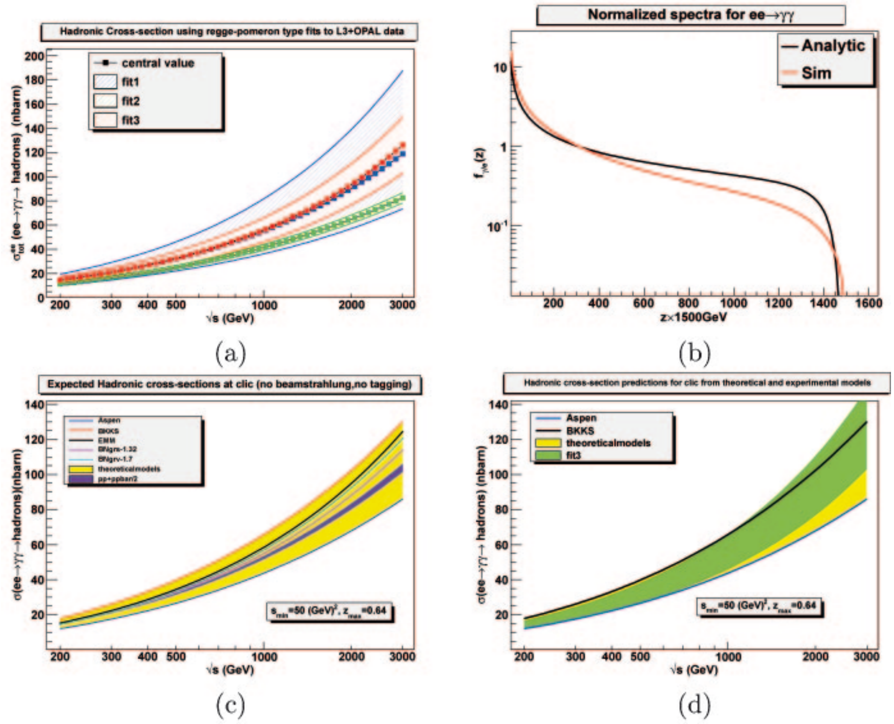

Fig. 4. – Panel (a) shows the predictions of the total cross-sections at CLIC using the Regge-pomeron like fits. Panel (b) shows the two photon spectra that were used [33, 34]. Panel (c) is a plot of the band of predictions coming from various theoretical models. The top curve corresponds to the prediction for $\sigma\gamma\gamma$ of the BKKS model [27] and the lower curve corresponds to the prediction of the Aspen model [24]. The $(pp{+}p\bar{p})$ corresponds to using a naive factorization of the proton-proton cross-sections by a factor of (330^2) [17]. Panel (d) is a comparison of the predictions coming from models and that from experimental fits to data.

Including only bremsstrahlung contribution: $n_{\mathrm{brem}} = \mathcal{L}_{ee} \times w1 \times w2$,

Including only beamstrahlung contribution: $n_{\mathrm{beam}} = \mathcal{L}_{\gamma\gamma} \times b1 \times b2$,

Including beamstrahlung and bremsstrahlung: $n_{bb} = \left(\frac{\mathcal{L}_{\gamma e}+\mathcal{L}_{e\gamma}}{2}\right)(b1\times w2+b2\times w1)$.

Where, $\mathcal{L}_{ee} = 4.3146609 \times 10^{34}\,\mathrm{m}^{-2}$, $\mathcal{L}_{\gamma\gamma} = 2.9678426 \times 10^{34}\,\mathrm{m}^{-2}$, $\mathcal{L}_{\gamma e} = 3.37706 \times 10^{34}\,\mathrm{m}^{-2}$, $\mathcal{L}_{e\gamma} = 3.3754 \times 10^{34}\,\mathrm{m}^{-2}$, are the integrated luminosities per bunch crossing [34].

Tables II-VI present the expected number per bunch crossing of hadronic events from $\gamma\gamma$ collisions at CLIC energies (3 TeV), for various model predictions and fits. The beamstrahlung spectra given by simulations and available from ref. [34], have been normalised to unity and the necessary normalisation information is contained in the $\mathcal{L}_{\gamma\gamma}$ and $\mathcal{L}_{e\gamma}$ factors. When one uses the analytic expression for these spectra instead, then the necessary normalisation is included in the spectrum itself and hence use of $\mathcal{L}_{ee}$ gives the necessary event rates.

TABLE II. – *Number of events per bunch crossing (no tagging).*

Model	Spectrum	n_{brem}	n_{beam}	n_{bb}	n_{tot}
EMM(BN) grs ($p_{t\,\mathrm{min}} = 1.32$)	Sim	0.492	1.691	1.454	3.637
	Analytic	0.492	0.268	0.778	1.539
EMM(BN) grv ($p_{t\,\mathrm{min}} = 1.7$)	Sim	0.520	1.822	1.617	3.960
	Analytic	0.520	0.301	0.842	1.663
EMM	Sim	0.537	1.889	1.703	4.131
	Analytic	0.537	0.326	0.878	1.742
Aspen	Sim	0.371	1.219	0.961	2.551
	Analytic	0.371	0.172	0.555	1.098
BKKS	Sim	0.561	1.857	1.480	3.899
	Analytic	0.561	0.265	0.846	1.673
$\frac{pp+p\bar{p}}{2}$lo	Sim	0.438	1.435	1.123	2.997
	Analytic	0.438	0.200	0.653	1.291
$\frac{pp+p\bar{p}}{2}$hi	Sim	0.458	1.518	1.216	3.193
	Analytic	0.458	0.218	0.692	1.368

TABLE III. – *Number of events per bunch crossing (no tagging).*

Fit used	Spectrum	n_{brem}	n_{beam}	n_{bb}	n_{tot}
fit1	Sim	0.513	1.824	1.674	4.012
	Analytic	0.513	0.321	0.849	1.683
fit2	Sim	0.356	1.181	0.945	2.482
	Analytic	0.356	0.169	0.538	1.064
fit3	Sim	0.544	1.995	1.939	4.479
	Analytic	0.544	0.386	0.940	1.871

TABLE IV. – *Number of events per bunch crossing for various values of s_{min} (no tagging).*

Spectra used	s_{min} (GeV)	fit1	fit2	fit3
Sim	5	4.892	2.992	5.315
	25	4.228	2.626	4.690
	50	4.012	2.482	4.479
Analytic	5	2.221	1.374	2.382
	25	1.810	1.149	1.995
	50	1.638	1.064	1.871

TABLE V. – *Number of events per bunch crossing (with tagging).*

Model	Spectrum	n_{brem}	n_{beam}	n_{bb}	n_{tot}
EMM(BN) grs ($p_{t\,\text{min}} = 1.32$)	Sim	0.318	1.454	1.433	3.206
	Analytic	0.318	0.268	0.664	1.250
EMM(BN) grv ($p_{t\,\text{min}} = 1.7$)	Sim	0.334	1.617	1.533	3.484
	Analytic	0.334	0.301	0.712	1.347
EMM	Sim	0.363	1.703	1.585	3.633
	Analytic	0.344	0.326	0.740	1.410
Aspen	Sim	0.244	0.961	1.054	2.259
	Analytic	0.244	0.172	0.484	0.900
BKKS	Sim	0.369	1.480	1.602	3.451
	Analytic	0.369	0.265	0.735	1.369
$\frac{pp+p\bar{p}}{2}$lo	Sim	0.288	1.124	1.242	2.655
	Analytic	0.288	0.200	0.569	1.058
$\frac{pp+p\bar{p}}{2}$hi	Sim	0.300	1.216	1.308	2.825
	Analytic	0.300	0.218	0.601	1.119

Thus we see that depending on which model corresponds to the correct high energy description, we expect between 2 and 5 hadronic events per bunch crossing at CLIC. The spread among these predictions is then the current uncertainty in the predictions of the hadronic events at CLIC. The beamstrahlung photons completely dominate the $\gamma\gamma$ luminosity and its inclusion increases the expected number of events by a factor of 10 more than those calculated from bremsstrahlung photons alone. However, about half of these events come from the cross term between beamstrahlung and bremsstrahlung. We also see that the change in the value of the cut, s_{min}, does not drastically alter the number of hadronic events.

Another important point to notice in the data is that the number of events is dominated by the low-energy part of the photon spectra and hence models and fits that give higher values of the $\gamma\gamma \to$ hadrons cross-sections tend to predict higher values for number of hadronic events. This feature can be easily observed from tables IV and VI where

TABLE VI. – *Number of events per bunch crossing (with tagging).*

Fit used	Spectrum	n_{brem}	n_{beam}	n_{bb}	n_{tot}
fit1	Sim	0.327	1.674	1.524	3.525
	Analytic	0.327	0.321	0.712	1.360
fit2	Sim	0.234	0.945	1.017	2.196
	Analytic	0.234	0.169	0.467	0.870
fit3	Sim	0.342	1.939	1.643	3.924
	Analytic	0.342	0.386	0.776	1.504

fit1 and fit3 have higher low-energy cross-sections than fit2 as can be seen in fig.2. It is therefore imperative to have better parametrizations of the low energy behaviour of photon cross-sections.

* * *

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