Hadronic backgrounds at CLIC from two photon processes

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Introduction

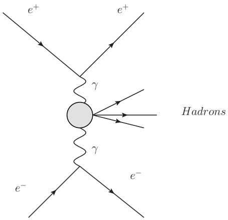
- High energy photons can fluctuate into fermion pairs or even to bound states
- These quantum fluctuations mean that a high energy photon behaves like a hadron and has a structure
- This means that there are processes of the type ($\gamma\gamma \rightarrow$ *hadrons*)
- The "clean" environment of these colliders threatened by ($ee \rightarrow \gamma\gamma \rightarrow$ *hadrons*) due high density of particle bunches required for high luminosity.(M. Drees, R. Godbole Phys. Rev. Lett 67, 1189 1991)
- Estimating these backgrounds is important

Outline

- Backgrounds and their sources
- How to estimate these backgrounds
- Results

Backgrounds (Bremsstrahlung)

- Backrounds to e^+e^- processes at linear colliders comes from bremsstrahlung processes such as



Calculation of Backgrounds: n (number of events per bunch crossing)

- Calculating the background requires knowledge of:
  - The energy spectrum of the photons at the collider
  - The total photon-photon cross-section $\sigma_{tot}(\gamma\gamma \rightarrow hadrons)$

$$n(e^- e^+ \rightarrow \gamma\gamma \rightarrow hadrons) = \int_0^1 dx_1 \int_0^1 dx_2 L_{\gamma\gamma}(x_1, x_2) \times \sigma\left[\gamma(x_1 p_1)\gamma(x_2 p_2) \rightarrow hadrons\right] \quad (1)$$

- Luminosity function $L_{\gamma\gamma}$ is the product of the energy spectrum of the bremsstrahlung photons from the two beams.

$$L_{\gamma\gamma}(x_1, x_2) = f_{\gamma/e}^{brem1} \times f_{\gamma/e}^{brem2} \times \text{Luminosity/bunch crossing} \quad (2)$$

We use the Weizsacker-Williams (EPA) approximation for bremsstrahlung photons.

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

Entire kinematical range of the photon virtuality is used.
One could also incorporate anti-tagging of electrons and include effects due to photon virtuality

$$f_{\gamma/e}(z) = \frac{\alpha_{\rm em}}{2\pi z}\left[(1+(1-z)^2)\ln\frac{P_{max}^2}{P_{min}^2} - 2(1-z)\right], \quad (4)$$

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

We use the anti-tagging conditions $\theta_{tag} = 0.025$, $E_{min}^e = 0.2E_{beam}$.
50 $\text{GeV}^2 < s_{\gamma\gamma} < 0.64 s_{ee}$
M. Drees and R. Godbole ZPC 59 1993

Bremsstrahlung Spectrum

$$f_{\gamma/e}(z) = \frac{\alpha_{\rm em}}{2\pi z}\left[(1+(1-z)^2)\ln\frac{s}{m_e^2}\right] \tag{5}$$

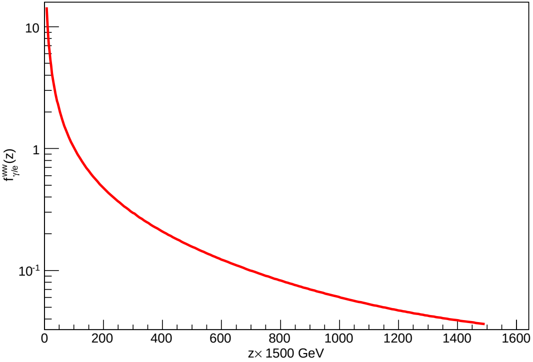


Figure: Normalized bremsstrahlung spectrum at CLIC energies: 3 TeV

But there is more...

- However the story is not so simple there is another process through which photons can be generated: Beamstrahlung (P. Chen,T. L. Barklow, M. E. Peskin, PRD. 49, 94 3209)
- Luminosity function $L_{\gamma\gamma}$ recieves contributions from two sources
  - Bremsstrahlung radiation of the colliding electrons
  - "Beamstrahlung" radiation from disruption of the beams as they pass through each other
- Assuming these two sources are independent of each other

$$L_{\gamma\gamma}(x_1, x_2) = \left[f_{\gamma/e}^{beam1} + f_{\gamma/e}^{brem1}\right] \times \left[f_{\gamma/e}^{beam2} + f_{\gamma/e}^{brem2}\right] \times \text{Luminosity/bunch crossing} \tag{6}$$

- For small transverse deviations (and also neglecting interfernces from successive photon emissions) there is an analytic form of the spectra (P. Chen PRD 46,3 1992)

$$\begin{aligned} f^{\text{beam}}_{\gamma/e}(x) &= \frac{1}{\Gamma\left(\frac{1}{3}\right)}\left(\frac{2}{3\Upsilon}\right)^{\frac{1}{3}} x^{-\frac{2}{3}}(1-x)^{-\frac{1}{3}} e^{-2x/[3\Upsilon(1-x)]} \\ &\times \left\{ \frac{1-\sqrt{\frac{\Upsilon}{24}}}{g(x)}\left[1-\frac{1}{g(x)N_\gamma}\left(1-e^{-g(x)N_\gamma}\right)\right]\right. \\ &+ \left.\sqrt{\frac{\Upsilon}{24}}\left[1-\frac{1}{N_\gamma}\left(1-e^{-N_\gamma}\right)\right]\right\} \qquad (7) \end{aligned}$$

- The analytic spectrum is controlled by the beamstrahlung parameter

$$\Upsilon = \frac{5 r_e^2 E_e N}{6\alpha\sigma_z(\sigma_x+\sigma_y)m_e}, \qquad (8)$$

- The validity of this analytic expression characterized by the beamstrahlung parameter $\Upsilon < 5$
- For CLIC energies and beam parameters (CLIC Report 2008):
  $\sigma_x = 0.45 \times 10^{-4}$mm
  $\sigma_y = 0.9 \times 10^{-5}$mm
  $\sigma_z = 0.03$mm
  Number of electrons/positrons per bunch $N = 4 \times 10^9$
  $\Upsilon = 6.5$
- Hence we also use spectrum generated by simulations
  GUINEAPIG
  M. Battaglia, B. Dalena
  http://clic-beam-beam.web.cern.ch/clic-beam-beam
  Also see talk by Tony Hartin

Beamstrahlung Spectra

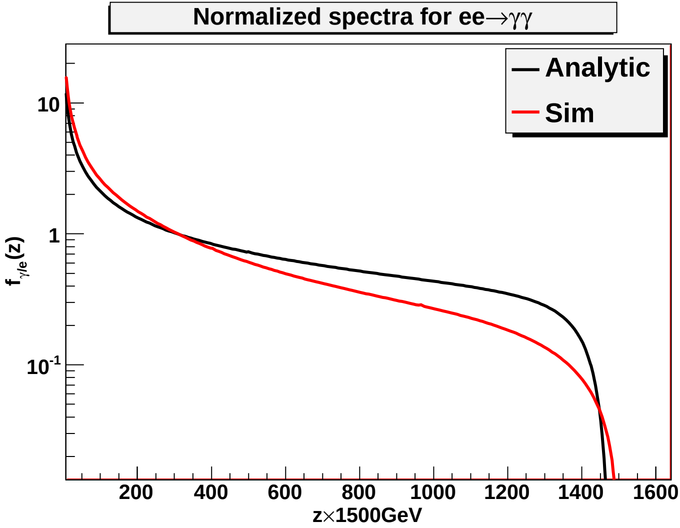


Figure: Comparison of normalized spectra of simulation with analytic spectrum for beamstrahlung photons

The Total Photon Cross-section

- We now look at the second input to calculating the hadronic background : $\sigma_{tot}(\gamma\gamma \rightarrow hadrons)$
- Data for this process exists in the energy range of a few GeV to 160 GeV
- Most consistent and widest range of data comes from L3 and OPAL experiments at LEP.
- In order to calculate the background we need to know the cross-section upto 3 TeV
- We try to fit the data from these experiments to forms inspired from S-Matrix Theory.
- We also use various model predictions for $\gamma\gamma$ cross-sections.
- We compare the results obtained when using theoretical model predictions with fits to the experimental data.

Data for $\sigma_{tot}(\gamma\gamma \to hadrons)$

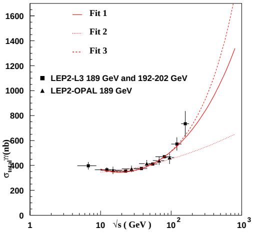


Figure: Data and fits ($\sigma_{tot}^{\gamma\gamma} = Bs^{-\eta} + As^{\epsilon} + Cs^{\epsilon_1}$),($s = s/1GeV$)

- 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 $Cs_{\gamma\gamma}^{\epsilon_1}$ was added with $\epsilon_1 = 0.418$ and the normalization (C) fitted.
- $\eta_1 = 0.358$, $\epsilon = 0.418$ (PDG), for $pp/\gamma p$: inspired from S-matrix theory (Donnachie, Landshoff PLB 437 (1998) 408).

Results of fits

Table: 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

- So we have now have all the ingredients to estimate these Hadronic Backgrounds
  - Bremsstrahlung Spectrum
  - Beamstrahlung Spectrum
  - $\sigma_{tot}(\gamma\gamma \rightarrow \textit{hadrons})$
- Lets look at some estimates of the backgrounds.

Backgrounds at CLIC (Only Bremsstrahlung Photons)

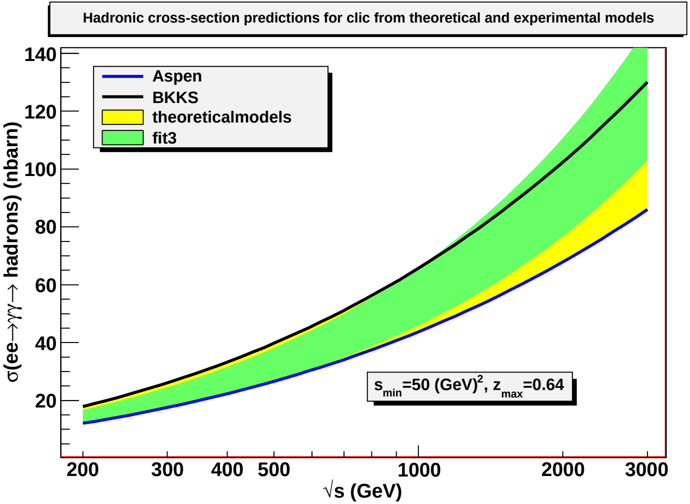
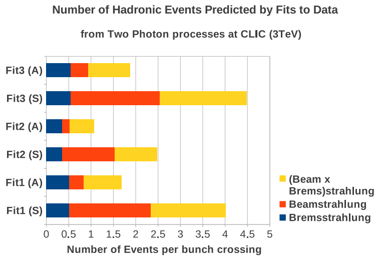
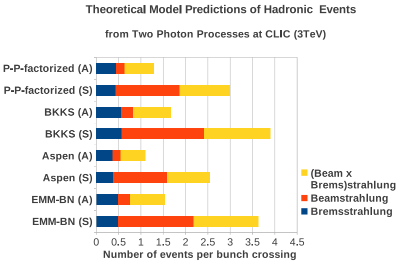


Figure: Including only bremsstrahlung , the backgrounds at CLIC as a function of $\sqrt{s}$, spread of predictions from models and “fit3”

Number of events per bunch crossing





Note that despite having different high energy behaviour the event numbers from “fit1” and “fit3” dont differ too much $\rightarrow$ maximum contribution from the low energy part

Table: Number of events per bunch crossing (with tagging)

Model	Spectrum	n_{brem}	n_{beam}	n_{bb}	n_{tot}
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

Table: Number of events per bunch crossing (with tagging)

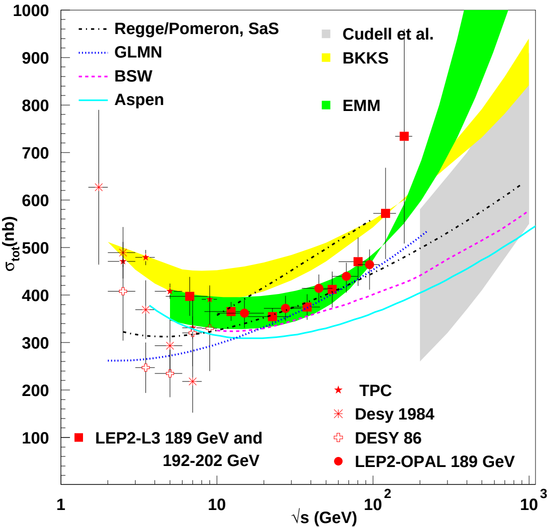
Fit used	Spectrum	n_{brem}	n_{beam}	n_{bb}	n_{tot}
fit1	Sim	0.327	1.674	1.524	3.525
	Analytic	0.327	0.321	0.712	1.360
fit3	Sim	0.342	1.939	1.643	3.924
	Analytic	0.342	0.386	0.776	1.504

Summary

- Hadronic backgounds at CLIC about 2-5 events per bunch crossing.
- Large uncertainty from $\sigma_{total}(\gamma\gamma \to hadrons)$
- Spread of predictions between experimental fits and theoretical models are comparable.
- Both beamstrahlung and bremsstrahlung contributions to the photon spectra of the beams need to be considered
- *brem* $\times$ *beam* contribution is as important as *beam* $\times$ *beam*
- The study of these backgrounds highlight the importance of the low energy part of the cross-section.
- Work in progress taking into account the low energy part of $\sigma_{tot}(\gamma\gamma \to hadrons)$ more carefully.

Backup slides

$\sigma_{tot}(\gamma\gamma \rightarrow hadrons)$: models and data



the beamstrahlung parameter

$$\Upsilon = \frac{5 r_e^2 E_e N}{6 \alpha \sigma_z (\sigma_x + \sigma_y) m_e}, \tag{9}$$

classical electron radius $r_e = \alpha / m_e = 2.818 \cdot 10^{-15}$ m, the beam energy E_e, the total number of particles in a bunch N, and on the r.m.s. sizes of the Gaussian beam σ_x, σ_y, σ_z. For not too large Υ ($\Upsilon \leq 5$), we have the following spectrum.

$$g(x) = 1 - \frac{1}{2} \left[(1 + x) \sqrt{1 + \Upsilon^{\frac{2}{3}}} + 1 - x \right] (1 - x)^{\frac{2}{3}}. \tag{10}$$

The average number of photons radiated per electron throughout the collision is

$$N_\gamma = \frac{5 \alpha^2 \sigma_z m_e \Upsilon}{2 r_e E_e \sqrt{1 + \Upsilon^{\frac{2}{3}}}}. \tag{11}$$

- For the beamstrahlung contributions we use two different spectra of photons.
  - 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;
    Including only bremsstrahlung contribution: $n_{brem} = \mathcal{L}_{ee} \times w1 \times w2$,
    Including only beamstrahlung contribution: $n_{beam} = \mathcal{L}_{\gamma\gamma} \times b1 \times b2$,
    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, $\mathcal{L}_{ee} = 4.3146609 \times 10^{34} m^{-2}, \mathcal{L}_{\gamma\gamma} = 2.9678426 \times 10^{34} m^{-2}, \mathcal{L}_{\gamma e} = 3.37706 \times 10^{34} m^{-2}, \mathcal{L}_{e\gamma} = 3.3754 \times 10^{34} m^{-2}$, are the integrated luminosities per bunch crossing.