Single-photon events and Search for DM at CLIC

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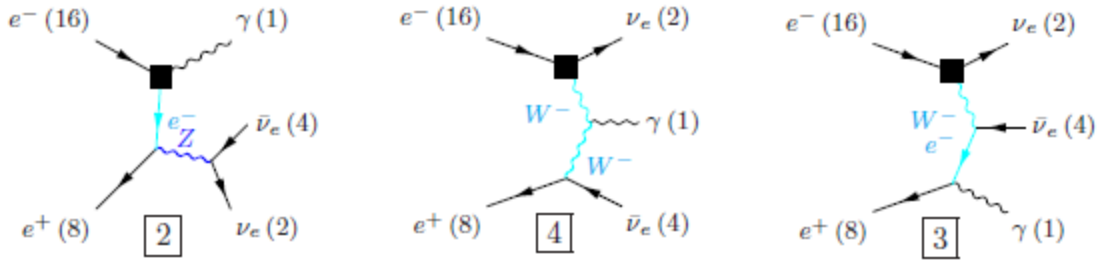
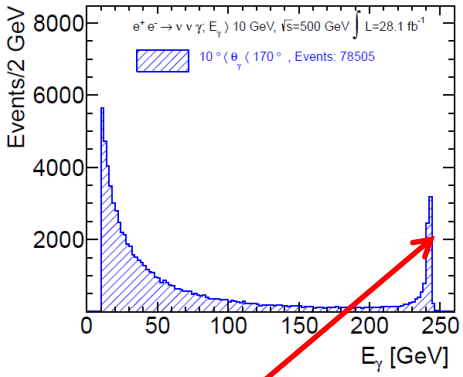
- SM Background reduction methods
- Cross section measurement Requirements
- Summary and prospects

SM Single or Multi-photon Production

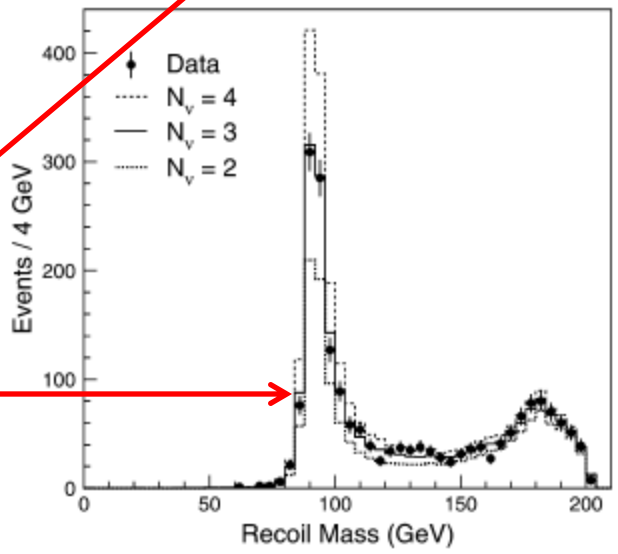




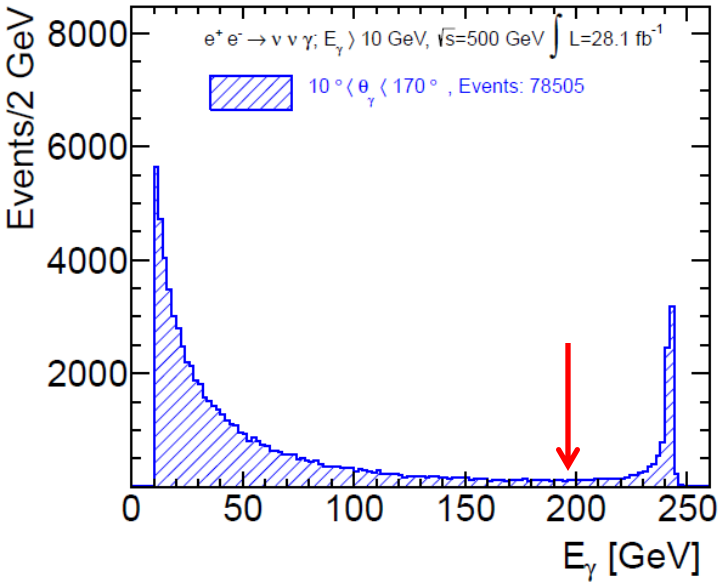
In the SM single or multi-photon events with missing energy are produced in the process: $e^+ e^- \rightarrow \nu\,\nu\,\gamma\,(\gamma)$; $\nu = \nu e\ , \nu\mu\ , \nu\tau$ through:

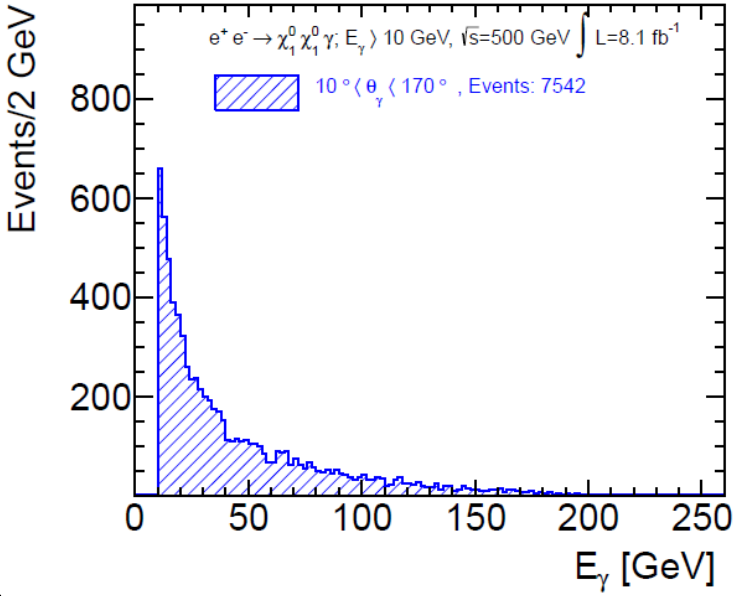
- s-channel Z exchange (2)
- t-channel W exchange (4)
- t-channel W fusion (small) (3)

At LEP with $\int L = 0.62\ fb^{-1}$ the number of Light ν was determined (high Eγ),
Limits on BSM parameters were set (Low Eγ)



Motivation





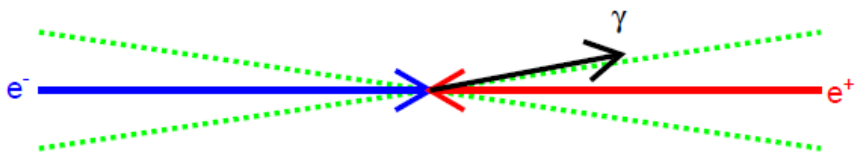
At CLIC at 500 GeV, with $\int L=500$ fb^{-1} could perform a high precision measurement of the $e^+ e^- \to \nu \nu \gamma$ cross section.

Left plot dN/dE: $e^+ e^- \to \nu \nu \gamma$; the Z exchange events (s-channel) are removed requiring $E\gamma < 200$ GeV.

A discrepancy between the measured cross section and the SM expected value would be a hint of BSM physics, e.g Susy, or large ED.

Right plot dN/dE: $e^+ e^- \to \tilde{\chi}^0_1 \tilde{\chi}^0_1 \gamma$, (model III, $m\tilde{\chi}^0$=100 GeV)

Goal and Event Selection



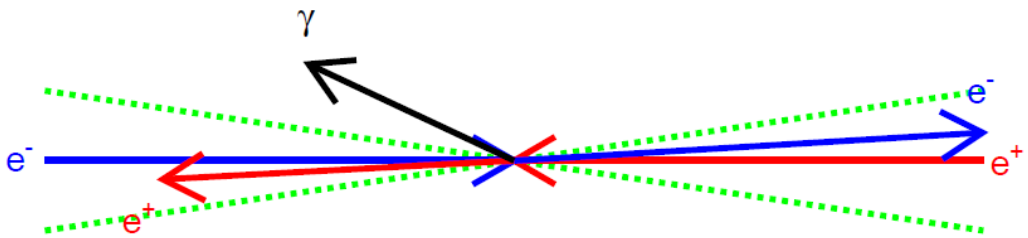
$e^+ e^- \to \nu\,\nu\,\gamma$, $10° < \theta_\gamma < 170°$
E_γ=14.68 GeV

The goal of this study is to:

- Characterize the requirements for a precise measurement of the differential cross sections dN/dEγ of the process: $e^+ e^- \to \nu\,\nu\,\gamma$.
- Estimate the minimum cross section of the process $e^+ e^- \to X\,X\,\gamma$ (X is invisible), which could be measured with 5σ significance.

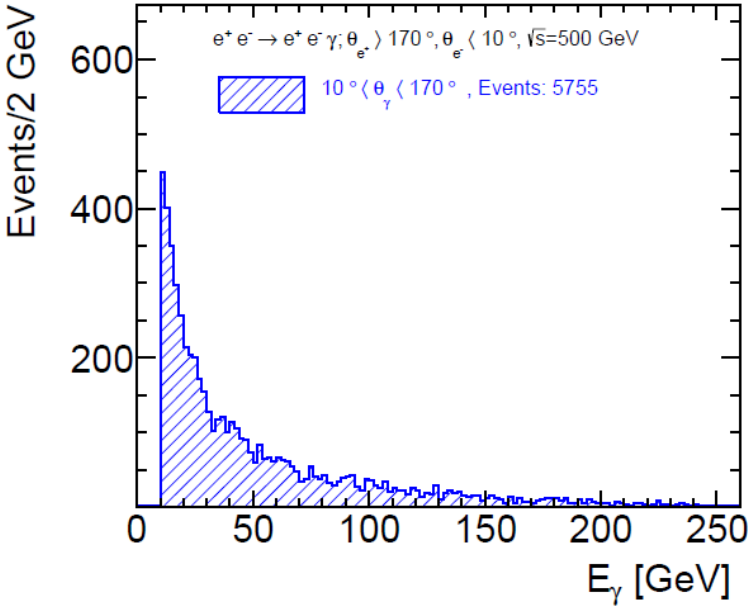
Event generation: Whizard1 with Beamstrahlung, ISR and FSR.
Event Selection:
Select single-γ events with and $10^o < \theta\gamma < 170^o$; the angular region where the tracking system allows an effective γ identification.
For Eγ>10 GeV σ $(e^+ e^- \to \nu\,\nu\,\gamma)$ = 2790 fb
Remove Z exchange events: Eγ < 200 GeV => σ=2414 fb.

Background $e^+ e^- \rightarrow e^+ e^- \gamma$



$e^+ e^- \rightarrow e^+ e^- \gamma, \theta_{e^+} \rangle 170\,^\circ, \theta_{e^-} \rangle 10\,^\circ$

E_{e^+}=242.25, E_γ=8.01, E_{e^-}=250.88



$e^+ e^- \rightarrow e^+ e^- \gamma$ can mimic single-photon events:

For $E\gamma > 10$ GeV and $10^o < \theta\gamma < 170^o$, $\sigma = 7.69\ 10^5$ fb (right plot)

The γ energy spectrum is similar to the ν ν γ spectrum.

For $E\gamma < 200$ GeV, $\sigma = 7.50\ 10^5$ fb

To remove these events the energy measurement in the Ecal end cap, LumiCal and BeamCal detectors is used.

$e^+ e^- \rightarrow e^+ e^- \gamma$ veto

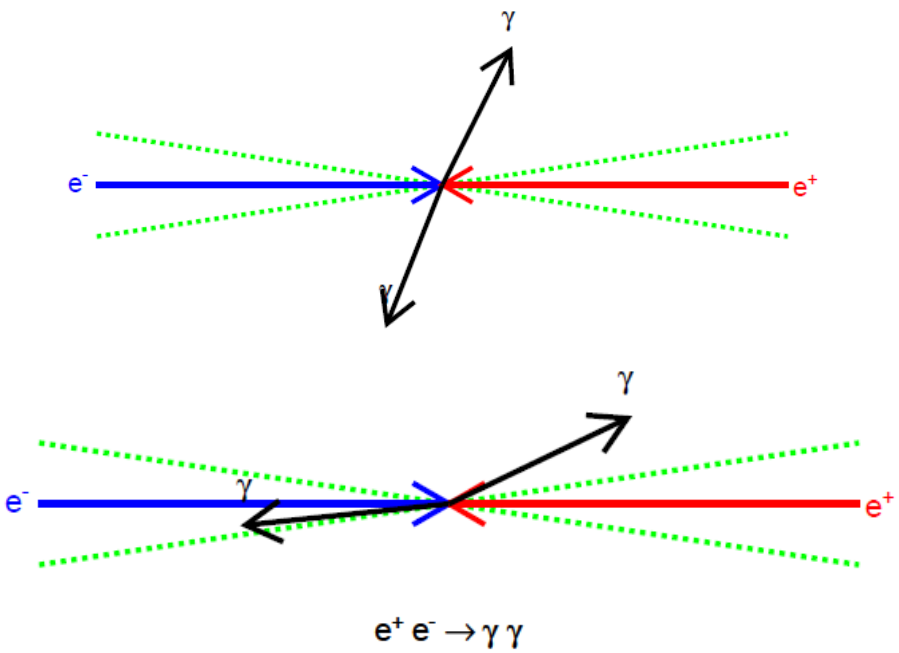
e± tagging

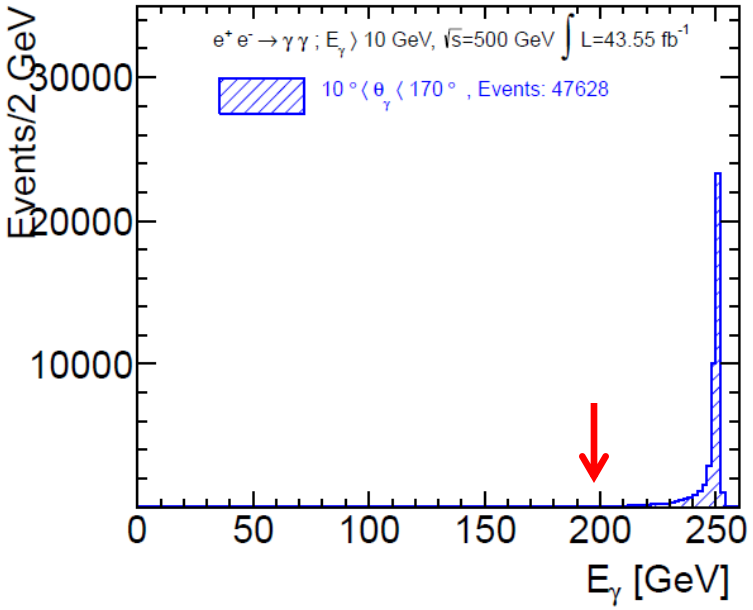
The tagging efficiency was estimated using full simulation:
for θ > 40 mrad; LumiCal and EndCap, single tag efficiency=0.99
for θ < 40 mrad; BeamCal, the tag efficiency =F(θ, E) ; takes into account the inefficiency coming from the energy deposition of Beamstrahlung pair background (Andre Sailer). EvTag inefficiency is (1-tag1)(1-tag2) : Table: EvTag inefficiency for 3 event samples:

	√s GeV	500 %Events	500 EvTag inefficiency ε
Eγ > 10	e^+ and e^- < 40 mrad	0.14	0.024
	e^+ or e^- < 40 mrad	0.59	0.001
	e^+ and e^- > 40 mrad	0.27	0.0001
	Whole detector		0.004

The veto inefficiency at very low angle contributes 85% of σ.
Tagging reduces σ ($e^+ e^- \rightarrow e^+ e^- \gamma$) from 7.50 10^5 fb ↘ 3000 fb.

Background $e^+ e^- \rightarrow \gamma\gamma$





$e^+ e^- \rightarrow \gamma\gamma$ can also fake $\nu\nu\gamma$ events.

For $E\gamma > 10$ GeV and $10^o < \theta\gamma < 170^o$ $\sigma = 2416$ fb

Requiring $E\gamma < 200$ GeV ↘ $\sigma = 32.7$ fb

Using the energy measurement in the LumiCal reduces the cross section down to 1 fb.

Cross Sections, √s =500 GeV
No Polarization

√s (GeV)		500 σ (fb) Eγ>10	500 σ (fb) 10< Eγ<200 GeV	500 σ (fb) 10< Eγ<200 GeV Energy Tag
Process 1	$e^+ e^- \to \nu \nu \gamma$	2.79 E+03	2.41E+03	2.41E+03 ± 2.2
2	$e^+ e^- \to e^+ e^- \gamma$	7.69 E+05	7.57 E+05	3.00E+03 ± 2.5
3	$e^+ e^- \to \gamma \gamma$	2.42 E+03	8.03E+01	1.01E+00 ± 0.04
Total				5.41E+03 ± 3.3

Table: Cross section values for $10^o < \theta\gamma < 170^o$ and different selection cuts, no polarization.

After selection, the $e^+ e^- \gamma$ background is larger than the $\nu \nu \gamma$ process. With $\int L=500$ fb^{-1}, ignoring syst errors, the sum of SM processes could be measured with a statistical accuracy $\Delta\sigma=3.3$ fb; the minimal cross section excess which could be measured with 5 σ CL is 16.5 fb.

Systematic Error Requirements at 500 GeV

To assess the physics potential of such measurement requires taking into account the systematic errors. $\Delta\sigma_{(syst)} = F(\Delta\sigma_{Th} , \Delta\varepsilon\gamma, \Delta\varepsilon v , \Delta L)$
Table: σ, εγ, εv and assumptions to keep the total systematic error close to the statistical error (3.3 fb).

√s (GeV) Process	500 σ (fb)	εγ %	εv %	Δσth/σth	Δε/ε	σ fb	Δσ fb
$e^+ e^- \rightarrow \nu \nu \gamma$	2.79 E+03	86.4		10^{-3}	10^{-3}	2.41E+03	3.4
$e^+ e^- \rightarrow e^+ e^- \gamma$	7.69 E+05	97.5	0.4	10^{-3}	10^{-3}	3.00E+03	5.2
$e^+ e^- \rightarrow \gamma \gamma$	2.49 E+03	3.32	1.	10^{-3}	10^{-3}	1.01E+00	0.01
Sum						5.41E+03	6.2

$\Delta\sigma_{Th}/\sigma_{Th} = 10^{-3}$, $\Delta\varepsilon/\varepsilon = 10^{-3}$ $(\varepsilon\gamma, \varepsilon v)$ $\Delta L/L = 5.10^{-4}$.

To reach such small errors is very challenging.

With polarization the total systematic error could be reduced to 5.4 fb; => 5 σ cross section limits of 31 fb and 27 fb respectively.

Systematic Errors at 500 GeV

With more realistic selection efficiency errors $\Delta\varepsilon/\varepsilon = 10^{-2}$ and $\Delta\sigma_{Th}/\sigma_{Th} = 10^{-3}$ and $\Delta L/L = 0.5\ 10^{-3}$.

√s (GeV) Process	500 σ (fb)	εγ %	εν %	Δσth/σth	Δε/ε	σ fb	Δσ fb
$e^+ e^- \rightarrow \nu \nu \gamma$	2.79 E+03	86.4		10^{-3}	10^{-2}	2.41E+03	24.2
$e^+ e^- \rightarrow e^+ e^- \gamma$	7.69 E+05	97.5	0.4	10^{-3}	10^{-2}	3.00E+03	42.6
$e^+ e^- \rightarrow \gamma \gamma$	2.49 E+03	3.32	1.	10^{-3}	10^{-2}	1.01E+00	0.01
Sum						5.41E+03	49.0

The total error increases to 49.0 fb, the 5 sigma cross section limit increases to 245 fb; poor measurement; 218 fb with e^- polarization.
It shows that a good estimation of the th and exp errors is crucial to obtain a realistic picture of the physics potential of this channel.
It is also essential to measure accurately εγ and εν.

Summary

The control of the experimental systematic errors is a major issue for this measurement; to reach a low cross section limit requires; all relative errors to be << 10^{-2}.

With realistic selection efficiency errors $\Delta\varepsilon/\varepsilon = 10^{-2}$ and assuming $\Delta\sigma_{Th}/\sigma_{Th} = 10^{-3}$ and $\Delta L/L = 0.5\ 10^{-3}$ the 5 sigma cross section limit is 245 fb.

To improve the physics potential requires:

- A smaller BeamCal veto inefficiency to reduce the $e^+ e^- \gamma$ background.
- Accurate measurement of the γ selection efficiency and of the veto inefficiency.

Prospects

Assuming that

- $\Delta\sigma/\sigma < 10^{-3}$ for theoretical cross section (with BS, ISR, FSR)
- $\Delta L/L < 10^{-3}$ reachable ;

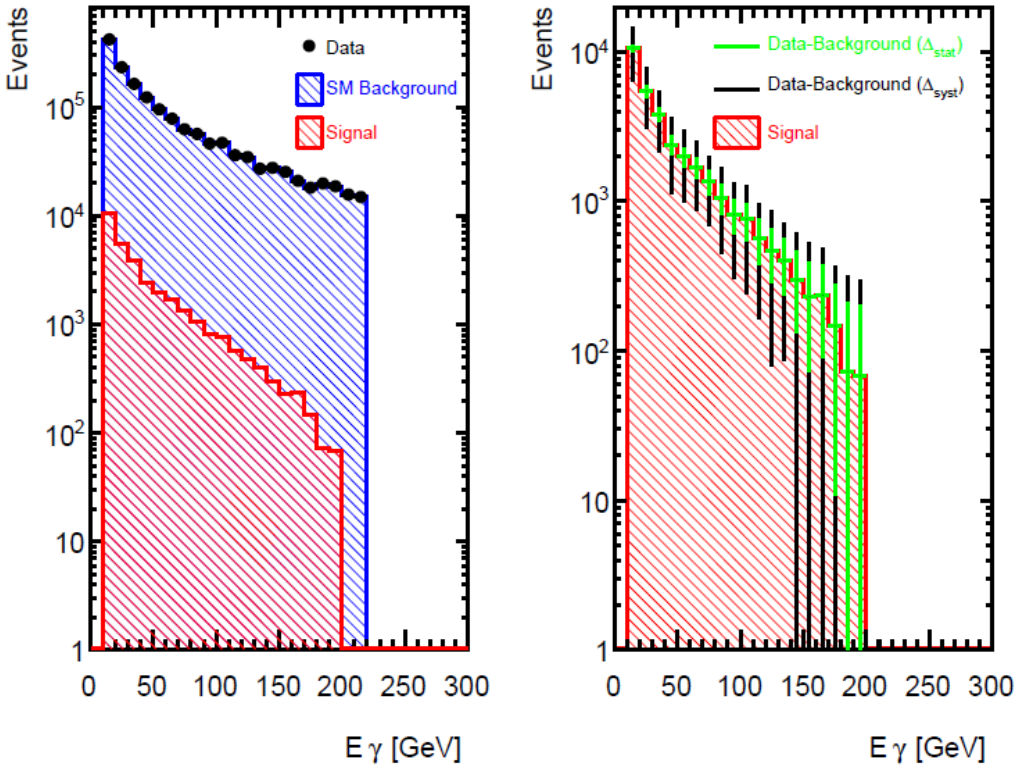
Identify the processes providing the statistics to reach $\Delta\varepsilon/\varepsilon << 10^{-2}$
Demonstrate, with full simulation, that:

- The efficiencies can be measured with $\Delta\varepsilon/\varepsilon << 10^{-2}$
  - Photon selection $\varepsilon\gamma$
  - Veto efficiency, εv

Investigate the possibility to reduce the BeamCal veto inefficiency at 500 GeV. The current inefficiency is obtained using the 3 Tev tag efficiency function $F(\theta, E)$ and scaling the energy E of the $e\pm$ or γ by 3000/500.

Backup

S+B and Data Plots



Signal cross section 55 fb, with polarization (x1.5), $\int L=500\ fb^{-1}$

Left S+B plot

Right, Data = S+B - B ; (stat err, green; syst err, black)