

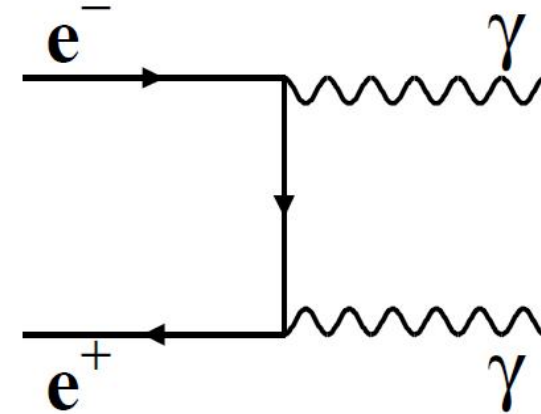
# Search for new physics with $ee \rightarrow \gamma\gamma$ at CLIC

Is electron a point-like particle?

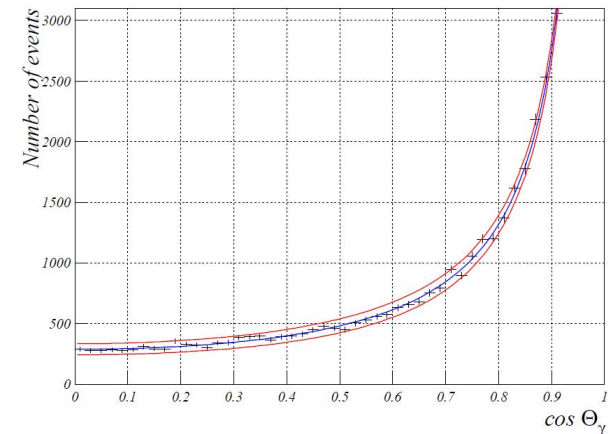
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[CLICdp / JINR](#)



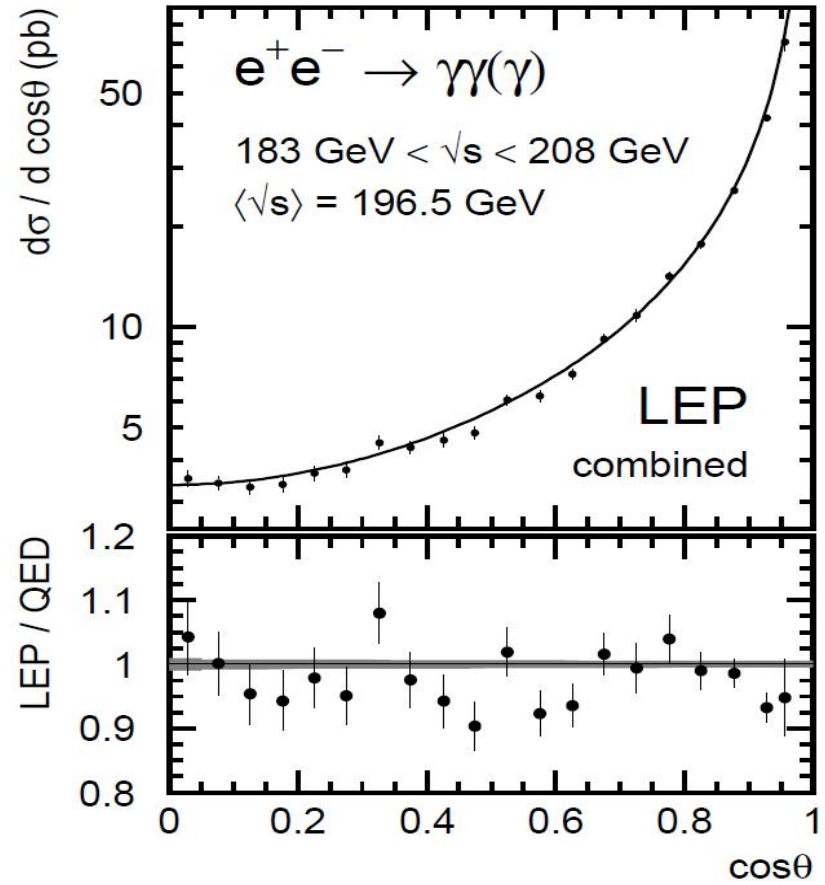
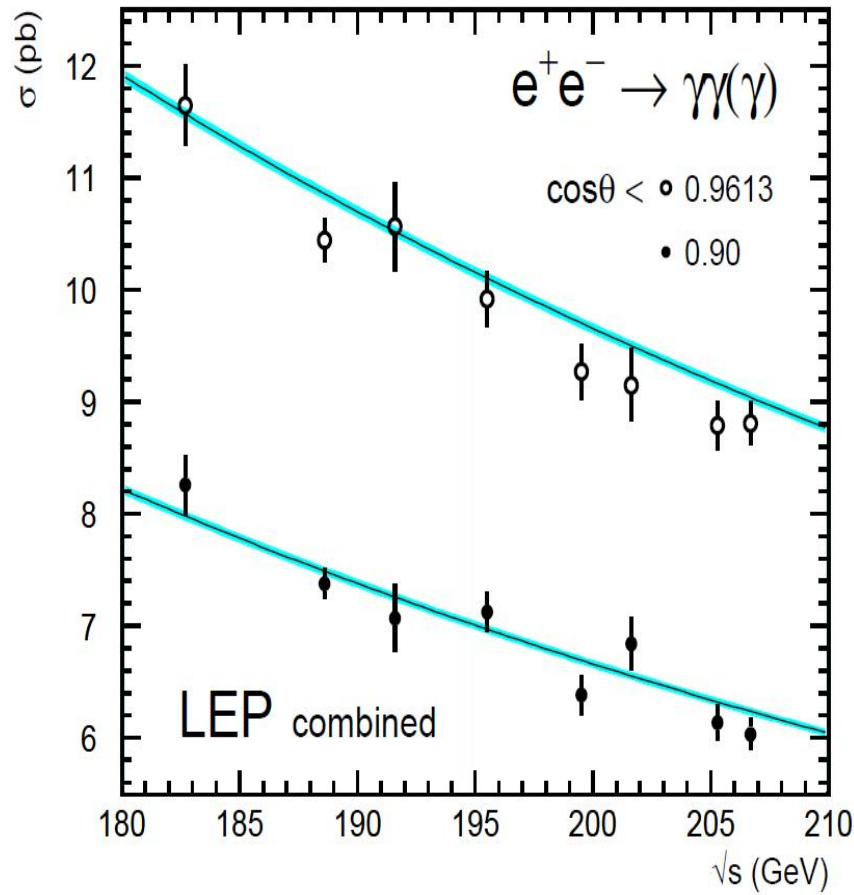
- Simplest annihilation process, easily calculated
- Experimentally very clean, hard back-to-back photons, no tracks
- Provides possibility to test various QED extensions, in particular to probe a finite size of the electron
- Need to measure absolute cross-section and angular spectrum of  $\gamma\gamma$



$$\left(\frac{d\sigma}{d\Omega}\right)_{\text{Born}} = \frac{\alpha^2}{s} \left[ \frac{1 + \cos^2 \theta}{1 - \cos^2 \theta} \right]$$



# Legacy of LEP

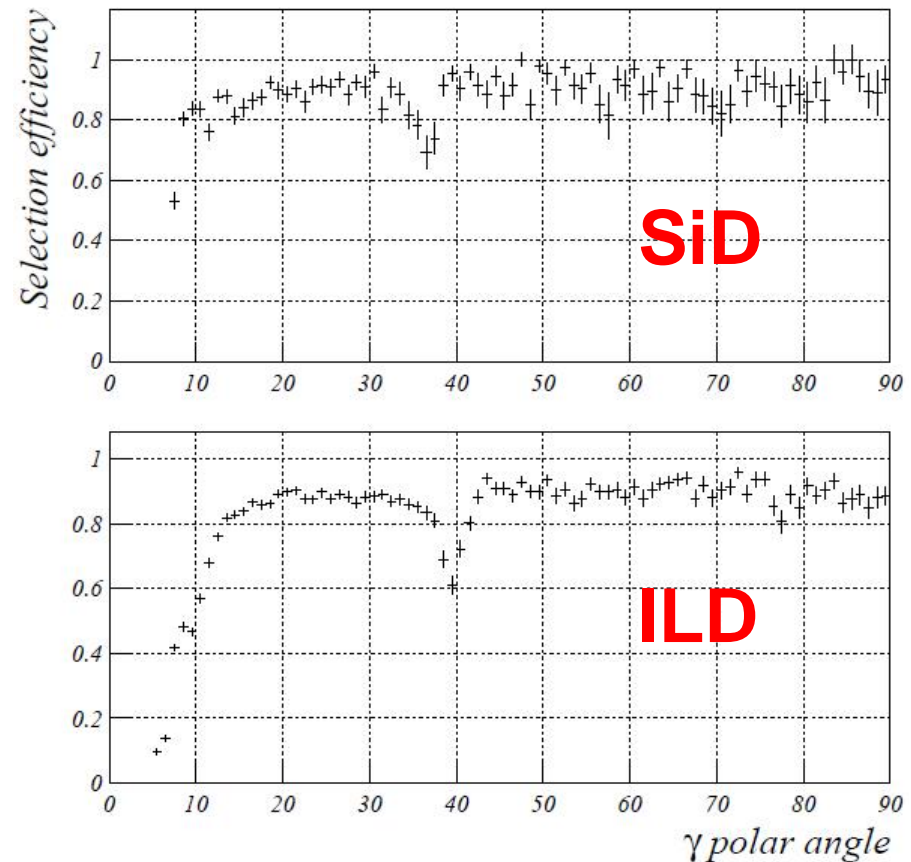


# Full simulation study for CLIC

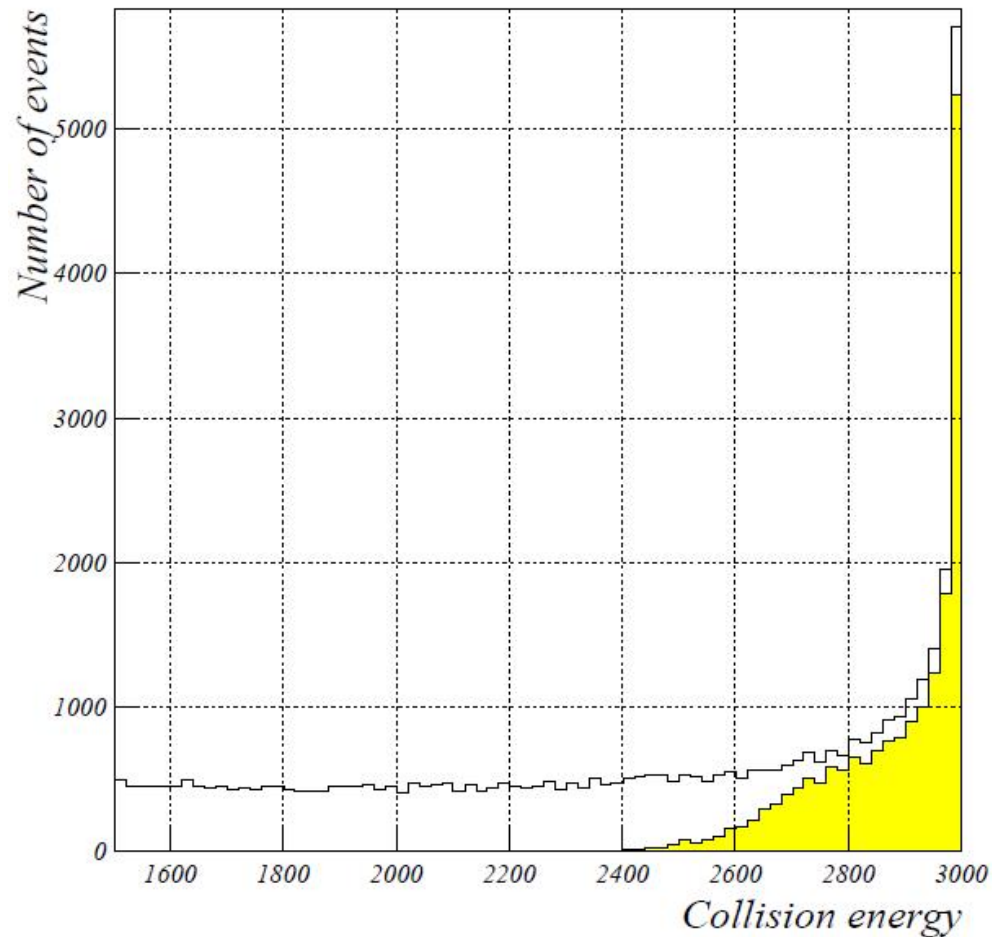
- Simulation of CLIC beams
- Full simulation for two detector options: **CLIC\_ILD** and **CLIC\_SiD**
  - Similar results for the two options
  - Results presented here for CLIC\_SiD
  - No result yet for the new model CLICdet
- Assumed **2000 fb<sup>-1</sup>** at **3 TeV**
  - Higher the energy, larger the New Physics reach

# Event selection

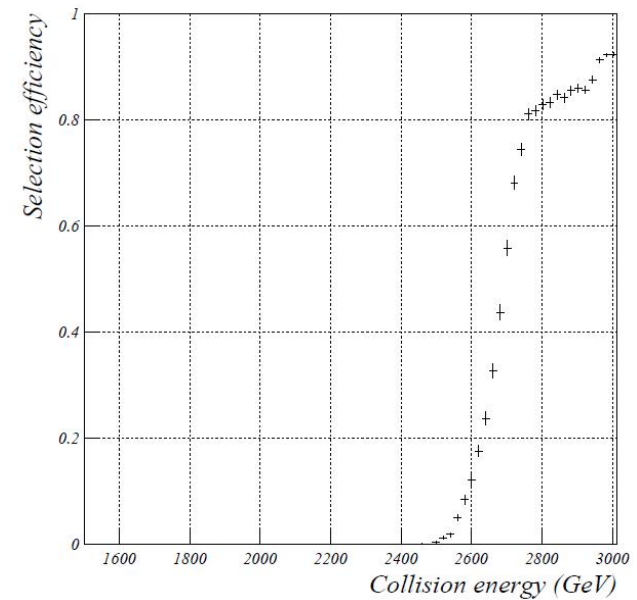
- Two photons, the most energetic above **1300 GeV**, another above **1200 GeV**
- No third photon above **50 GeV**
- Back-to-back photons:  $\pm 10^\circ$  in  $\theta$ ,  $\pm 10^\circ$  in  $\varphi$
- **Track veto**: no tracks with  $|p| > 300 \text{ GeV}/c$  within  $20^\circ$  from a photon candidate



# Spectrum of collision energy

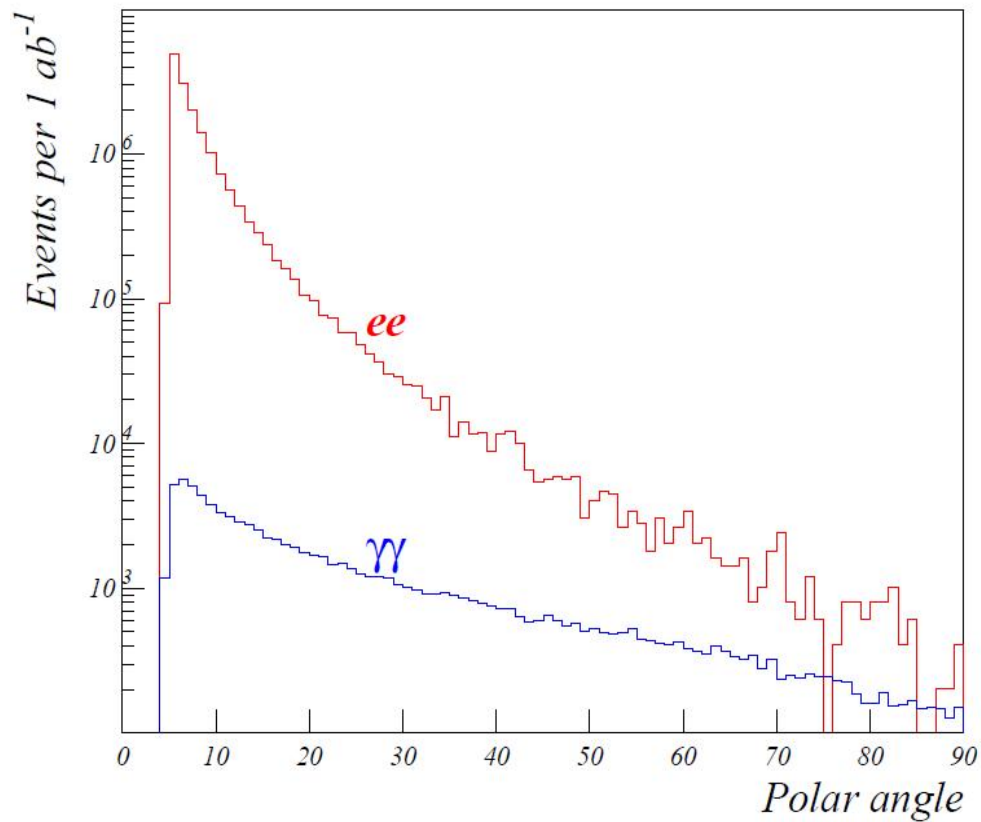


- Selection cuts ensure nearly nominal collision energy
- Average  $\sqrt{s}$ : 2878 GeV

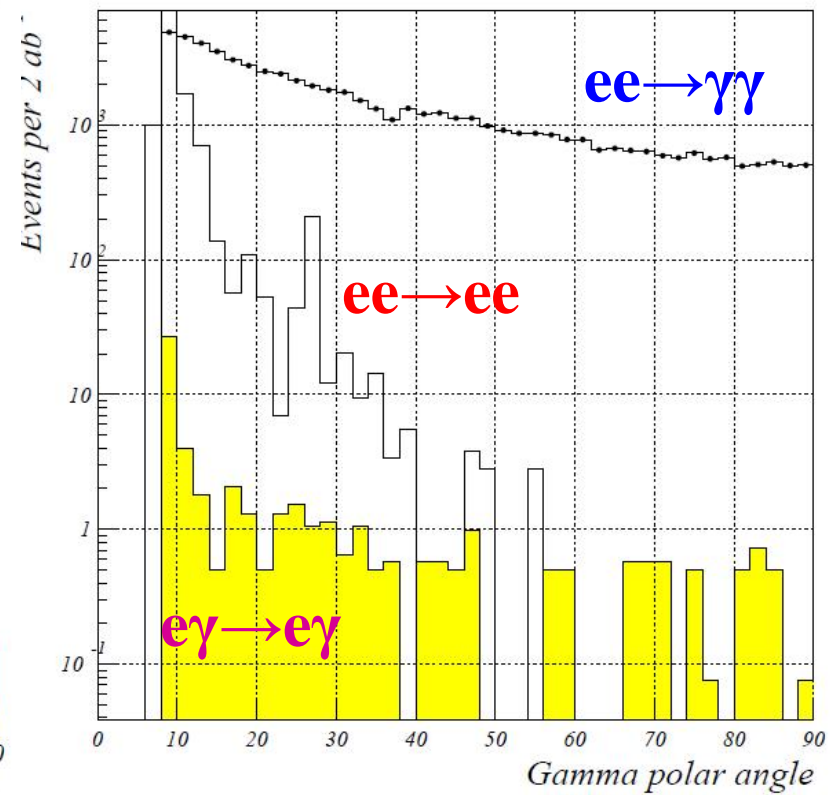


# Signal versus $ee \rightarrow ee$ background

Before selection



After selection



# Sensitivity to New Physics

- Interpret results in terms of 4 different New Physics models
- All results assuming  $2000 \text{ fb}^{-1}$  at 3 TeV, CLIC\_SiD detector full simulation
- Systematic errors:
  - Polar angle misalignment by 1 mrad
  - Mistake in residual background level by 15%
- Luminosity precision: considered 3 scenarios
  - “Pessimistic”,  $\sigma(L)/L=1\%$
  - “Realistic”,  $\sigma(L)/L=0.5\%$
  - “Optimistic”,  $\sigma(L)/L=0.2\%$



# QED cut-off model

- Everything according to Standard Model, but electron is not point-like
- Charge distribution is exponential, with slope parameter  $\Lambda_{\text{QED}}$
- LEP combined limit:  $\Lambda_+ > 431 \text{ GeV}$ ,  $\Lambda_- > 339 \text{ GeV}$

$$\left(\frac{d\sigma}{d\Omega}\right)_{\Lambda_{\pm}} = \left(\frac{d\sigma}{d\Omega}\right)_{\text{Born}} \pm \frac{\alpha^2 s}{2\Lambda_{\pm}^4} (1 + \cos^2 \theta)$$

# QED cut-off: Fit to $1/\Lambda_{\text{QED}}^4$

$\sigma(\text{Lumi})$	0.2%	0.5%	1%
$\sigma(\text{stat})$ $10^{-4} \text{ TeV}^{-4}$	2.70	3.13	3.65
$\sigma(\text{syst})$ Bckg $\pm 15\%$	0.35	0.36	1.35
$\sigma(\text{syst})$ $\theta \pm 1 \text{ mrad}$	0.72	0.45	0.41
$\Lambda_{\text{QED}}$ (95%CL)	6.52 TeV	6.33 TeV	6.01 TeV

Limit on  $\Lambda_{\text{QED}}$  equivalent to electron size  $R < 3.1 \times 10^{-18} \text{ cm}$

# $e e \gamma \gamma$ contact interaction

- Contact interaction can be introduced with dimension-7 lagrangian, effective scale  $\Lambda'$
- Adds angular-independent cross-section term
- Combined LEP limit:  $\Lambda' > 880$  GeV

$$\mathcal{L}_7 = \frac{1}{4} \bar{\psi} (g_7^S F^{\mu\nu} + i g_7^P \gamma_5 \tilde{F}^{\mu\nu}) \psi F_{\mu\nu}$$

$$\left( \frac{d\sigma}{d\Omega} \right)_{\Lambda'} = \left( \frac{d\sigma}{d\Omega} \right)_{\text{Born}} + \frac{s^2}{16} \frac{1}{\Lambda'^6}$$

# Contact interaction: Fit to $(1/\Lambda')^6$

$\sigma(\text{Lumi})$	0.2%	0.5%	1%
$\sigma$ (stat) $10^{-6} \text{ TeV}^{-6}$	0.0050	0.0068	0.0108
$\sigma$ (syst) Bckg $\pm 15\%$	0.0032	0.0030	0.0021
$\sigma$ (syst) $\theta \pm 1 \text{ mrad}$	0.0025	0.0023	0.0024
$\Lambda'$ (95%CL)	20.7 TeV	20.1 TeV	18.9 TeV

# Gravity in extra dimensions

- Plank mass ( $M_s$ ) is in TeV scale. For us it **appears** to be much larger because we **think** that space-time is 4D.
- In fact, there are compactified extra dimensions.  
 $ee \rightarrow \gamma\gamma$  spectrum is distorted by exchange of gravitons propagating in the extra dimensions
- LEP combined limit:  $M_s > 868$  GeV,  $M_s > 1108$  GeV  
(for  $\lambda = \pm 1$ )

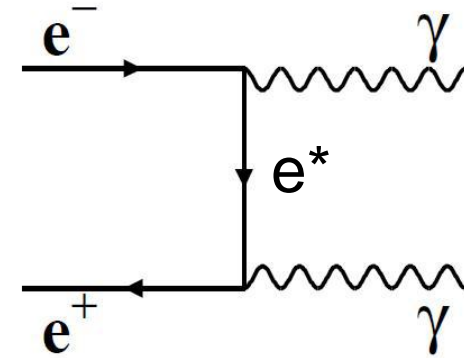
$$\left(\frac{d\sigma}{d\Omega}\right)_{M_s} = \left(\frac{d\sigma}{d\Omega}\right)_{\text{Born}} - \alpha_s \frac{\lambda}{M_s^4} (1 + \cos^2 \theta) + \frac{s^3}{8\pi} \frac{\lambda^2}{M_s^8} (1 - \cos^4 \theta)$$

# Extra dimensions: Fit to $\lambda/M_s^4$

$\sigma(\text{Lumi})$	0.2%	0.5%	1%
$\sigma(\text{stat})$ $10^{-4} \text{ TeV}^{-4}$	0.0683	0.0783	0.0889
$\sigma(\text{syst})$ Bckg $\pm 15\%$	0.0098	0.0067	0.0303
$\sigma(\text{syst})$ $\theta \pm 1 \text{ mrad}$	0.0216	0.0124	0.0034
$M_s/\lambda^{1/4}$ (95%CL)	16.3 TeV	15.9 TeV	15.3 TeV

# Excited electron

- $e^*$  can be directly discovered at CLIC, if kinematically allowed
- Even if unreachable, it would distort  $ee \rightarrow \gamma\gamma$  spectrum via t-channel exchange
- LEP combined limit:  $M_{e^*} > 256 \text{ GeV}$  (assuming  $M_{e^*} = \Lambda$ )



$$\left(\frac{d\sigma}{d\Omega}\right)_{e^*} = \left(\frac{d\sigma}{d\Omega}\right)_{\text{Born}} + \frac{\alpha^2 \pi f_\gamma^4}{2 \Lambda^4} M_{e^*}^2 \left[ \frac{p^4}{(p^2 - M_{e^*}^2)^2} + \frac{q^4}{(q^2 - M_{e^*}^2)^2} + \frac{\frac{1}{2} s^2 \sin^2 \theta}{(p^2 - M_{e^*}^2)(q^2 - M_{e^*}^2)} \right]$$

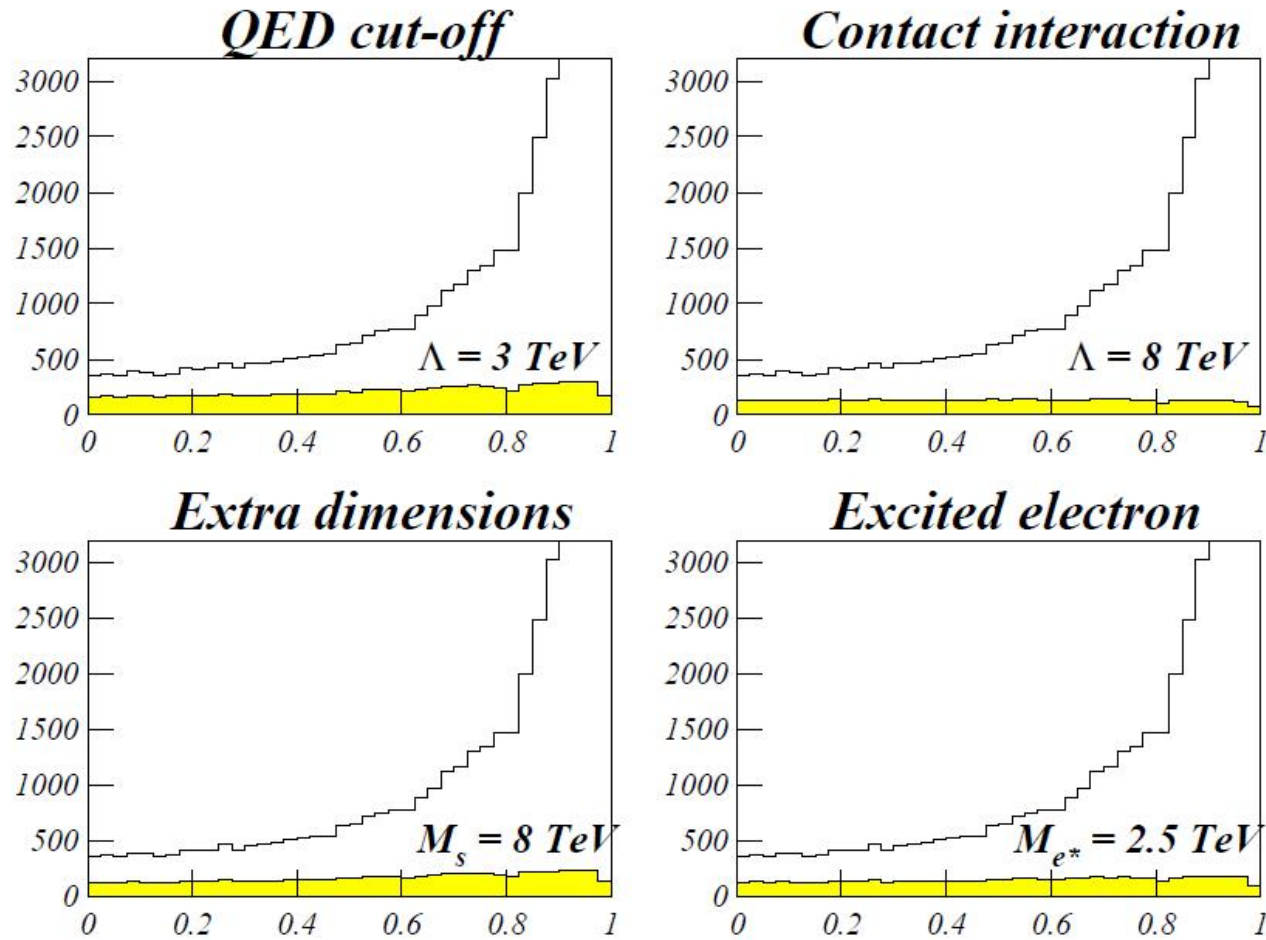
$$p^2 = -\frac{s}{2}(1 - \cos \theta) \text{ and } q^2 = -\frac{s}{2}(1 + \cos \theta)$$

# Excited electron: Fit to $1/M_{e^*}^4=1/\Lambda^4$

$\sigma(\text{Lumi})$	0.2%	0.5%	1%
$\sigma$ (stat) $10^{-4} \text{ TeV}^{-4}$	7.85	9.06	10.35
$\sigma$ (syst) Bckg $\pm 15\%$	0.29	0.33	1.70
$\sigma$ (syst) $\theta \pm 1 \text{ mrad}$	1.28	0.38	0.44
$M_{e^*}$ (95%CL)	5.03 TeV	4.87 TeV	4.70 TeV



# BSM contributions to $\cos\theta$ spectrum



# Summary

- Deviations from QED should be looked at highest possible  $e^+e^-$  energies
- CLIC will be an ideal place to look for such effects
- We estimated CLIC sensitivity for 4 BSM models
  - QED cut-off 6-6.3 TeV (LEP 400 GeV)
  - Contact interaction 19-21 TeV (LEP 800 GeV)
  - Extra dimensions 15-16 TeV (LEP 1000 GeV)
  - Excited electron 4.7-5.0 TeV (LEP 250 GeV)
- With  $2 \text{ ab}^{-1}$  results still not systematics-limited