Search for new physics with $ee \to \gamma\gamma$ at CLIC

Is electron a point-like particle?

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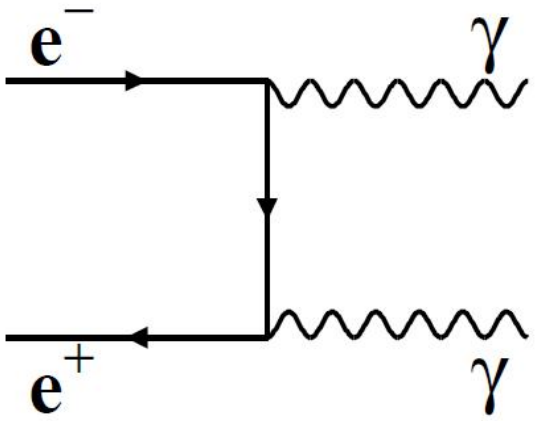
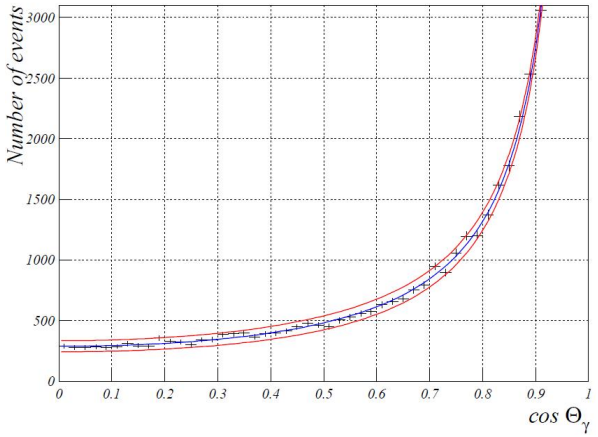
$e^+e^- \to \gamma\gamma$

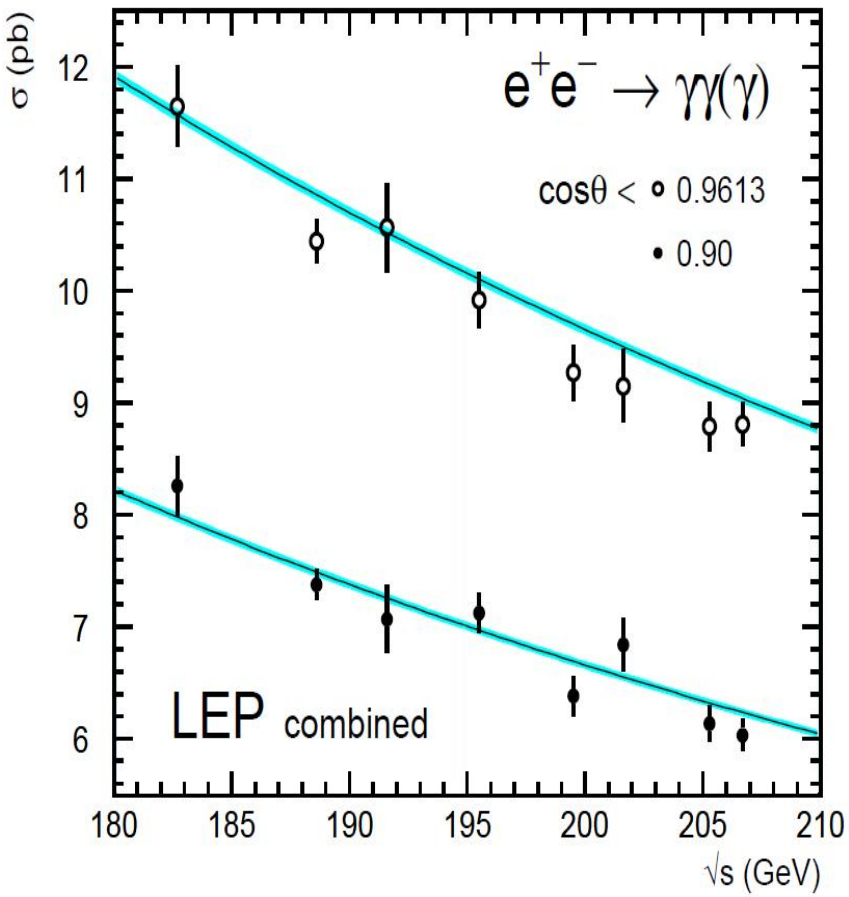
- Simplest annihilation process, easily calculated
- Experimentally very clean, hard back-to-back photons, no tracks
- Provides possibility to test various QED extensions, in particular to probe a finite size of the electron
- Need to measure absolute cross-section and angular spectrum of $\gamma\gamma$

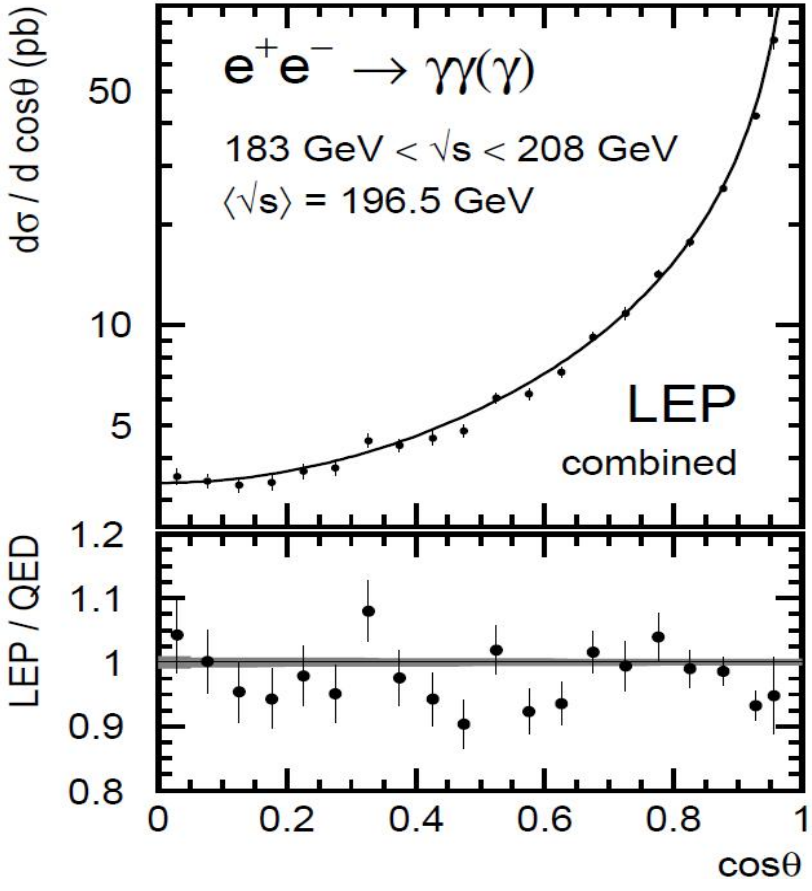


$$\left(\frac{d\sigma}{d\Omega}\right)_{\text{Born}} = \frac{\alpha^2}{s}\left[\frac{1+\cos^2\theta}{1-\cos^2\theta}\right]$$



Legacy of LEP



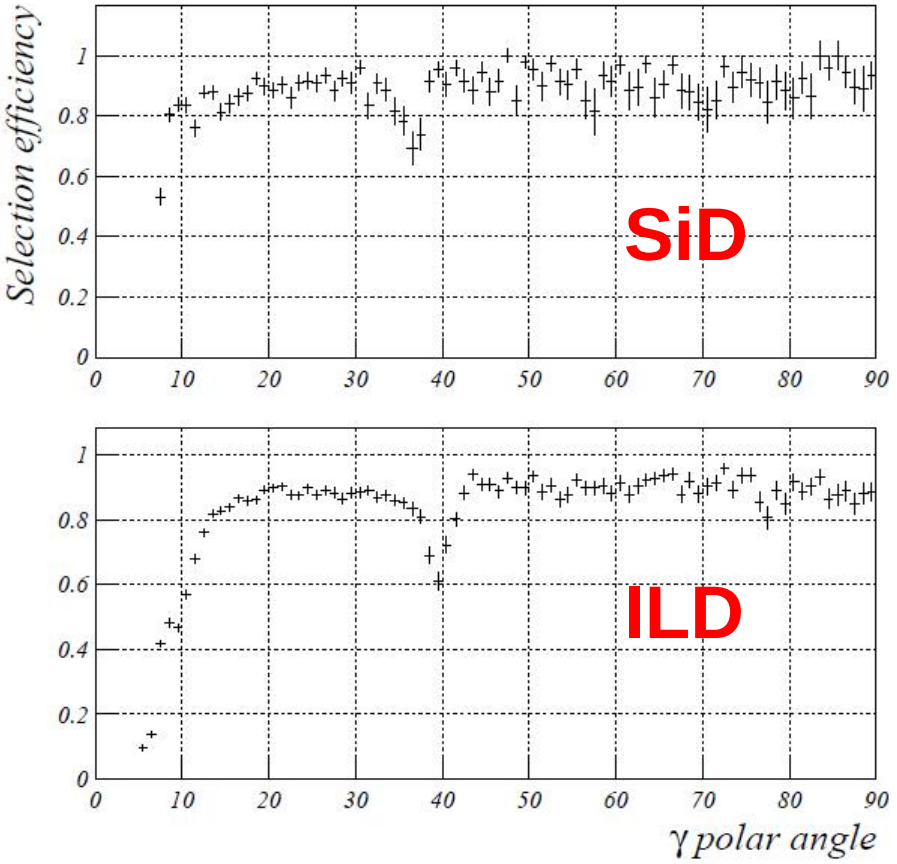


Full simulation study for CLIC

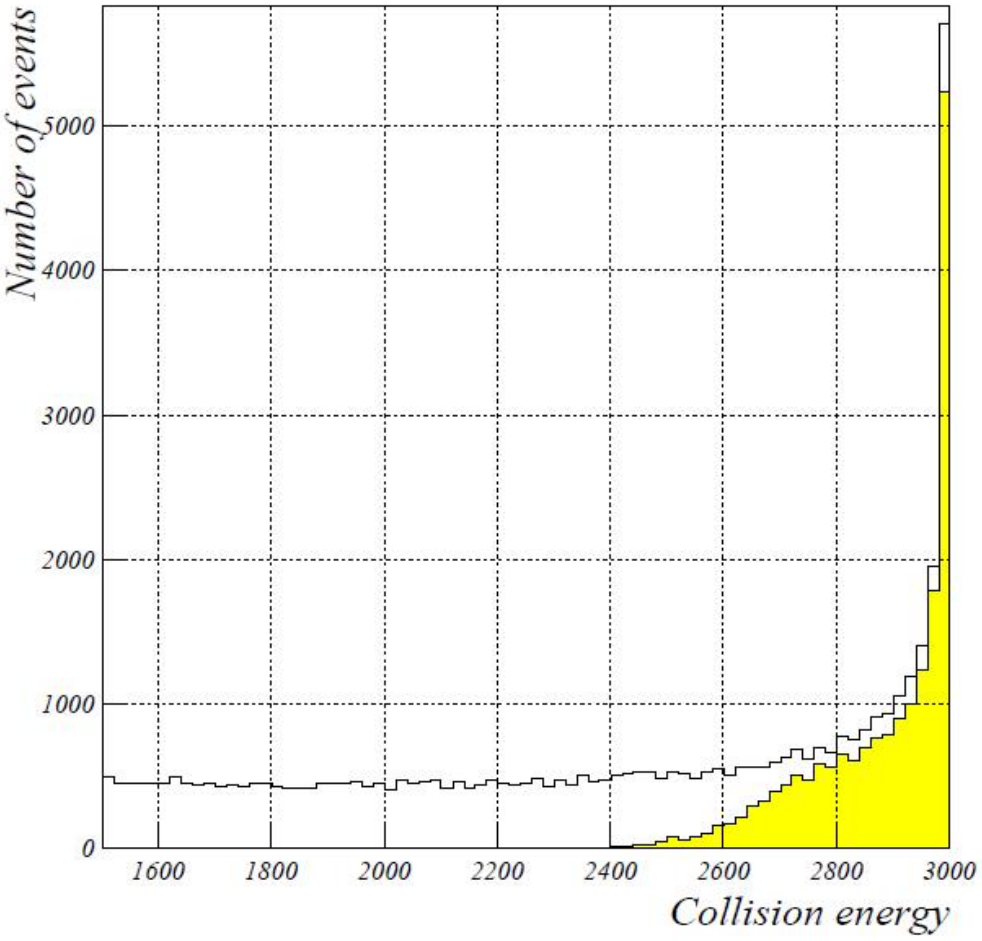
- Simulation of CLIC beams
- Full simulation for two detector options: CLIC_ILD and CLIC_SiD
  - Similar results for the two options
  - Results presented here for CLIC_SiD
  - No result yet for the new model CLICdet
- Assumed 2000 fb^{-1} at 3 TeV
  - Higher the energy, larger the New Physics reach

Event selection

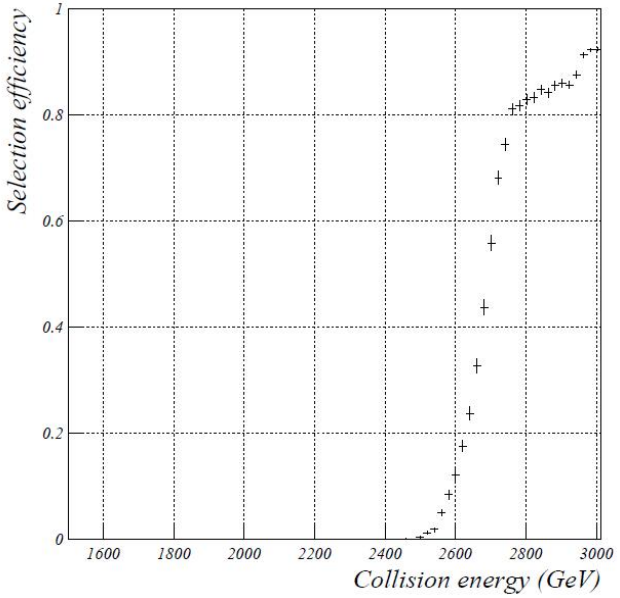
- Two photons, the most energetic above 1300 GeV, another above 1200 GeV
- No third photon above 50 GeV
- Back-to-back photons: ±10º in θ, ±10º in φ
- Track veto: no tracks with |p|>300 GeV/c within 20º from a photon candidate



Spectrum of collision energy

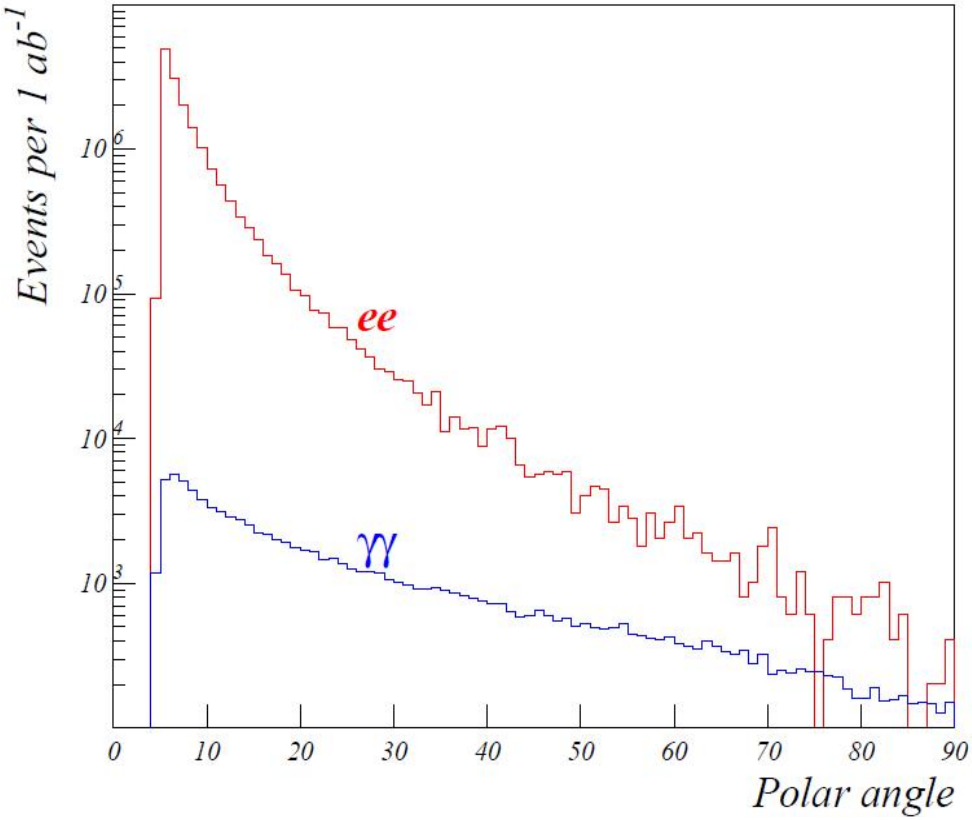


- Selection cuts ensure nearly nominal collision energy
- Average √s: 2878 GeV

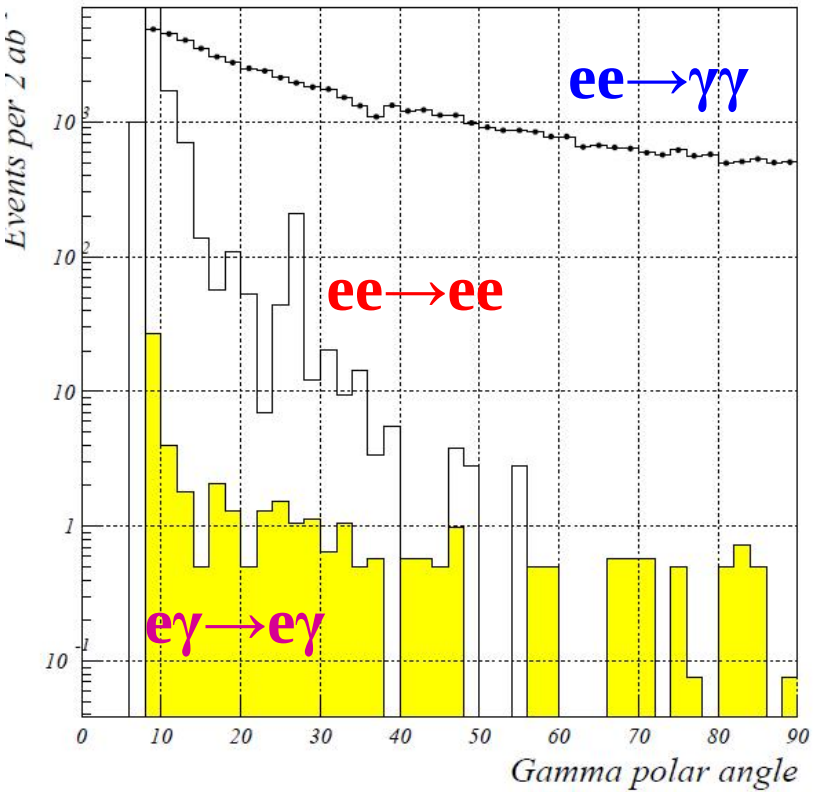


Signal versus ee→ee background

Before selection



After selection



Sensitivity to New Physics

- Interpret results in terms of 4 different New Physics models
- All results assuming 2000 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 in not point-like
- Charge distribution is exponential, with slope parameter Λ_{QED}
- LEP combined limit: $\Lambda_+ > 431$ GeV, $\Lambda_- > 339$ 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 $1/\Lambda^4_{QED}$

σ(Lumi)	0.2%	0.5%	1%
σ (stat) 10^{-4} TeV^{-4}	2.70	3.13	3.65
σ (syst) Bckg ±15%	0.35	0.36	1.35
σ (syst) θ ±1mrad	0.72	0.45	0.41
Λ_{QED} (95%CL)	6.52 TeV	6.33 TeV	6.01 TeV

Limit on Λ_{QED} equivalent to electron size $R<3.1\times10^{-18}$cm

eeγγ contact interaction

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

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

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

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

σ(Lumi)	0.2%	0.5%	1%
σ (stat) 10^{-6} TeV^{-6}	0.0050	0.0068	0.0108
σ (syst) Bckg ±15%	0.0032	0.0030	0.0021
σ (syst) θ ±1mrad	0.0025	0.0023	0.0024
Λ' (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. $ee \to \gamma\gamma$ spectrum is distorted by exchange of gravitons propagating in the extra dimensions
- LEP combined limit: $M_s > 868$ GeV, $M_s > 1108$ GeV (for $\lambda = \pm 1$)

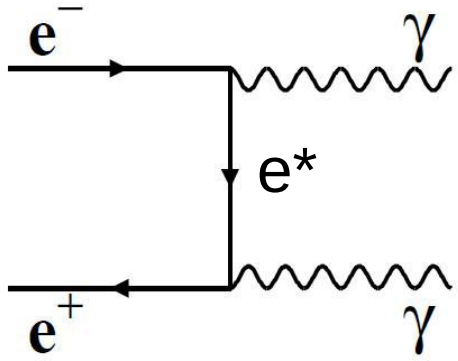
$$\left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{M_s}} = \left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{Born}} - \alpha s \, \frac{\lambda}{M_s^4} \, (1 + \cos^2\theta) + \frac{s^3}{8\pi} \, \frac{\lambda^2}{M_s^8} \, (1 - \cos^4\theta)$$

Extra dimensions: Fit to λ/M_s^4

σ(Lumi)	0.2%	0.5%	1%
σ (stat) 10^{-4} TeV^{-4}	0.0683	0.0783	0.0889
σ (syst) Bckg ±15%	0.0098	0.0067	0.0303
σ (syst) θ ±1mrad	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 $ee \to \gamma\gamma$ spectrum via t-channel exchange
- LEP combined limit: $M_{e^*} > 256$GeV (assuming $M_{e^*} = \Lambda$)



$$\mathcal{L} = \frac{e}{2\Lambda_{e^*}} \overline{\Psi}_{e^*} \sigma^{\mu\nu} (1 \pm \gamma^5) \Psi_e F_{\mu\nu}$$

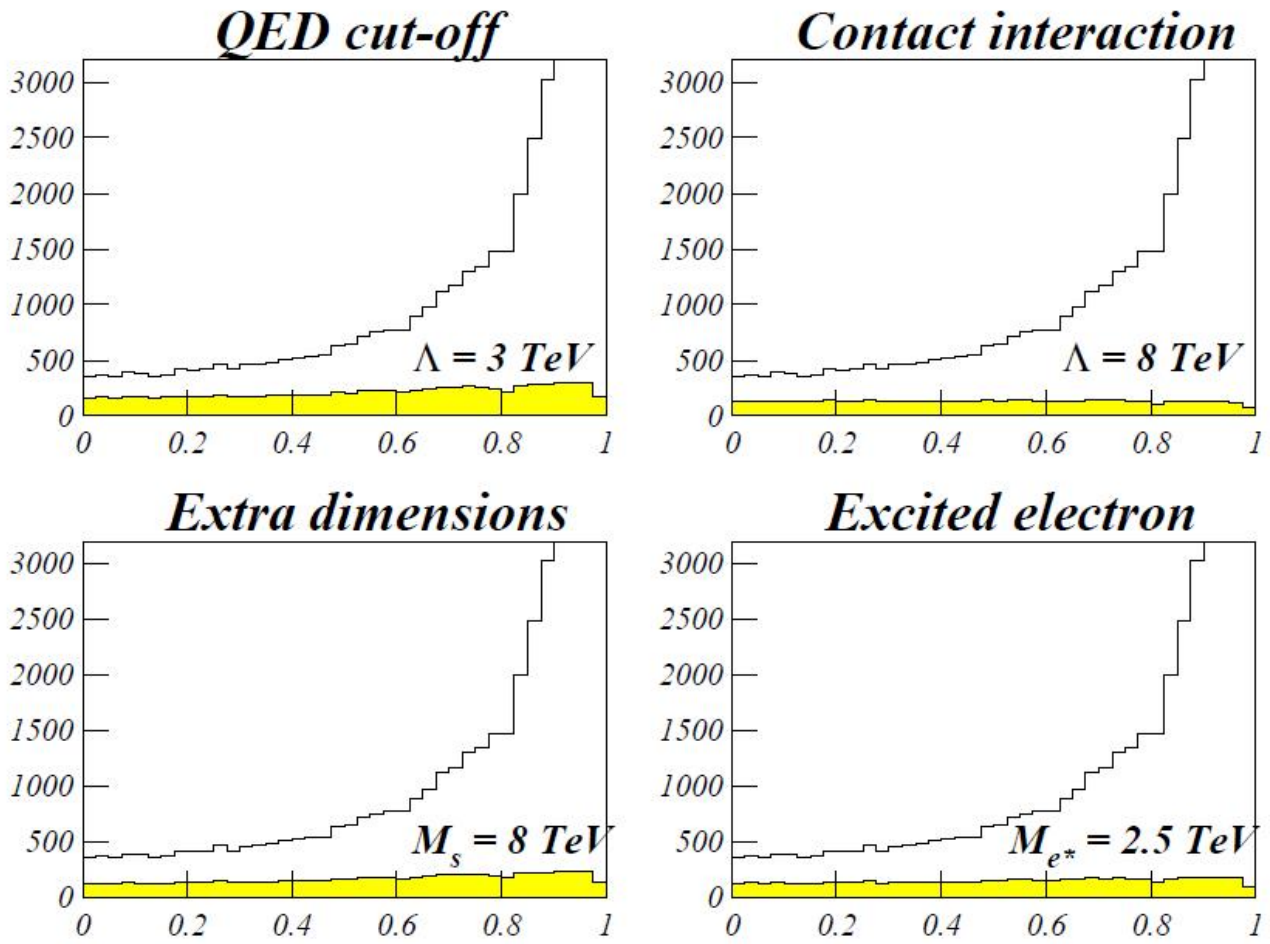
$$\left(\frac{d\sigma}{d\Omega}\right)_{e^*} = \left(\frac{d\sigma}{d\Omega}\right)_{\text{Born}} + \frac{\alpha^2 \pi}{2} \frac{f_\gamma^4}{\Lambda^4} M_{e^*}^2 \left[\frac{p^4}{(p^2 - M_{e^*}^2)^2} + \frac{q^4}{(q^2 - M_{e^*}^2)^2} + \frac{\frac{1}{2} s^2 \sin^2\theta}{(p^2 - M_{e^*}^2)(q^2 - M_{e^*}^2)}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

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

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

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

BSM contributions to cosθ 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 ab^{-1} results still not systematics-limited