Looking for leptophilic Z’ at the FCC-ee

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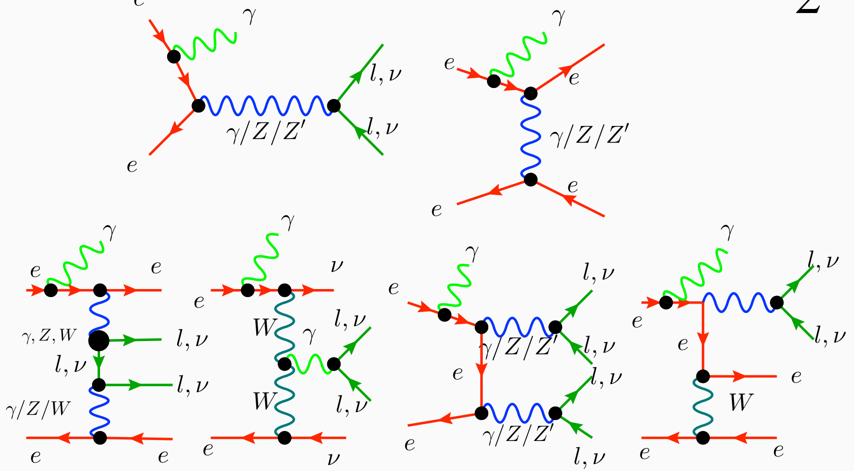
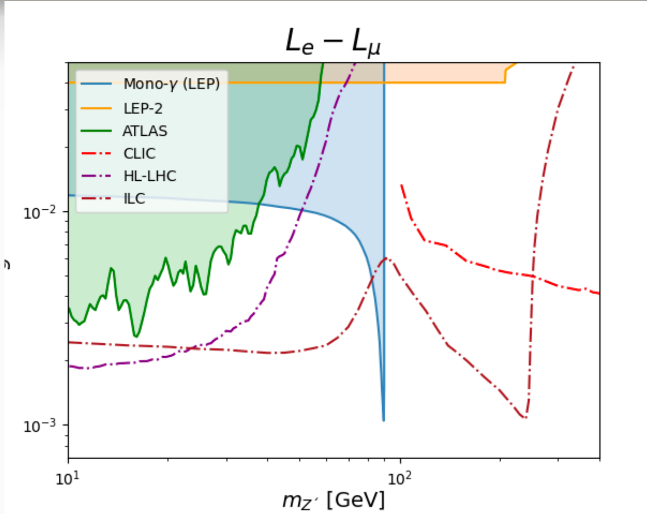
Leptophilic Z’

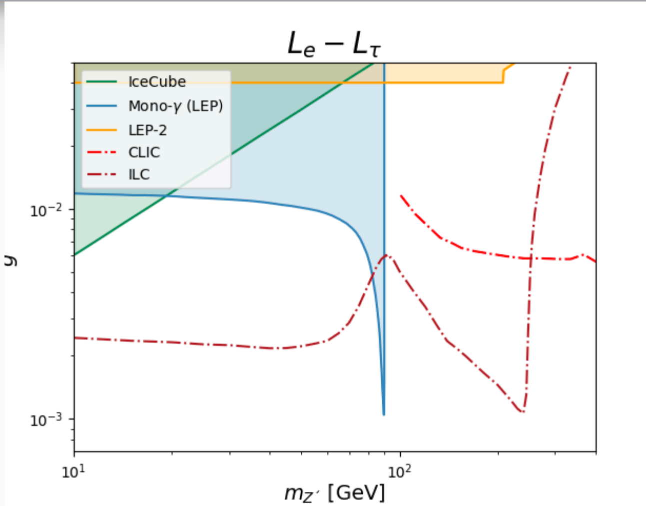
- Arises from an additional U(1) symmetry [Dasgupta et al (2308.12804), Goudelis et al (2312.14103)]
- Electrically neutral, couples only to SM leptons
- Does not show up at hadron colliders at tree level
- We focus on the anomaly free $Le - L\mu$ and $Le - L\tau$ models

$$\mathscr{L} \supset -g'(\bar{L}_i\gamma^\mu L_i - \bar{L}_j\gamma^\mu L_j + \bar{l}_{i,R}\gamma^\mu l_{i,R} - \bar{l}_{j,R}\gamma^\mu l_{j,R})Z'_\mu + \frac{1}{2}(m_{Z'})^2 Z'^\mu Z'_\mu$$



Existing constraints





- $m_{Z'} \lesssim 10$ GeV, $g' \lesssim 10^{-4}$ BaBar, other low energy experiments [not shown].
- LEP searches (mono-γ, $e^+e^- \rightarrow e^+e^-$).
- LHC: Leading bounds from ATLAS search $pp \rightarrow W^{(\star)} \rightarrow Z'\mu\nu \rightarrow \mu\mu\mu\nu$, 140 fb^{-1} (2402.15212)
- IceCube constrains non-standard ν interactions in matter ($L_e - L_\tau$).

Pipeline

- Calculate signal and background cross-sections on MG5_aMC@NLO
- Use PYTHIA8 and DELPHES to take showering and detector effects into account
- Cuts and object efficiencies taken from DELPHES IDEA card used for analysis:

$$e, \mu : p_T > 0.5 \text{ GeV}, |\eta| \leq 2.5, \Delta\text{R}(\text{l}, \text{X}) > 0.5$$

$$\gamma : E > 2\text{GeV}, \text{p}_\text{T} > 0.5 \text{ GeV}, |\eta| \leq 3.0, \Delta\text{R}(\gamma, \text{X}) > 0.5$$

$$\tau : p_T > 1 \text{ GeV}, |\eta| \leq 3.0, \Delta\text{R}(\tau, \text{X}) > 0.5$$

$$\epsilon_{e,\mu,\gamma} = 0.99, \ \epsilon_\tau = 0.6$$

Pipeline (contd.):

Background inclusion

- Preliminary kinematic distributions obtained using MadAnalysis; further cuts imposed
- Final analysis is performed using these cuts
- Invariant mass of dilepton pair data used to obtain signal and background event count for charged lepton searches. For invisible search channels recoil mass used.

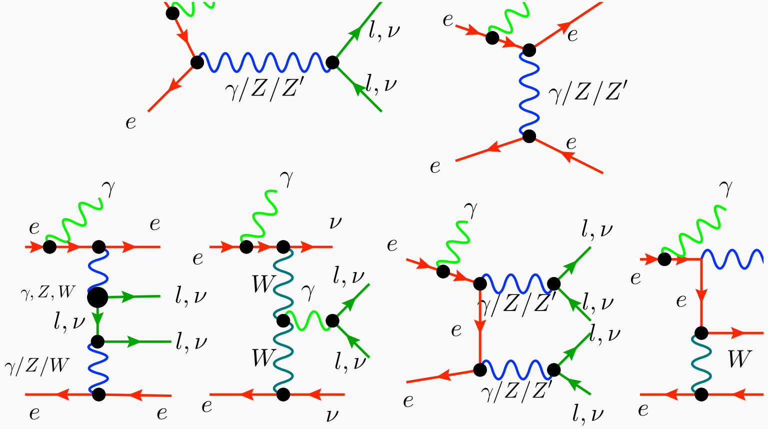
$$Z = \frac{N_s}{\sqrt{N_s + N_b + \lambda^2 N_b^2}}$$

Significance Z =2 (95 % CL)

Cuts: pT(gamma) > 0.5 GeV
E(gamma) > 2 GeV
DeltaR(a,l)

FCC-ee sensitivity

- e+ e- —> Z’ + γ
- Signal: 2 leptons + γ
- Main backgrounds:2 leptons + γ
  4 leptons + γ



Backgrounds

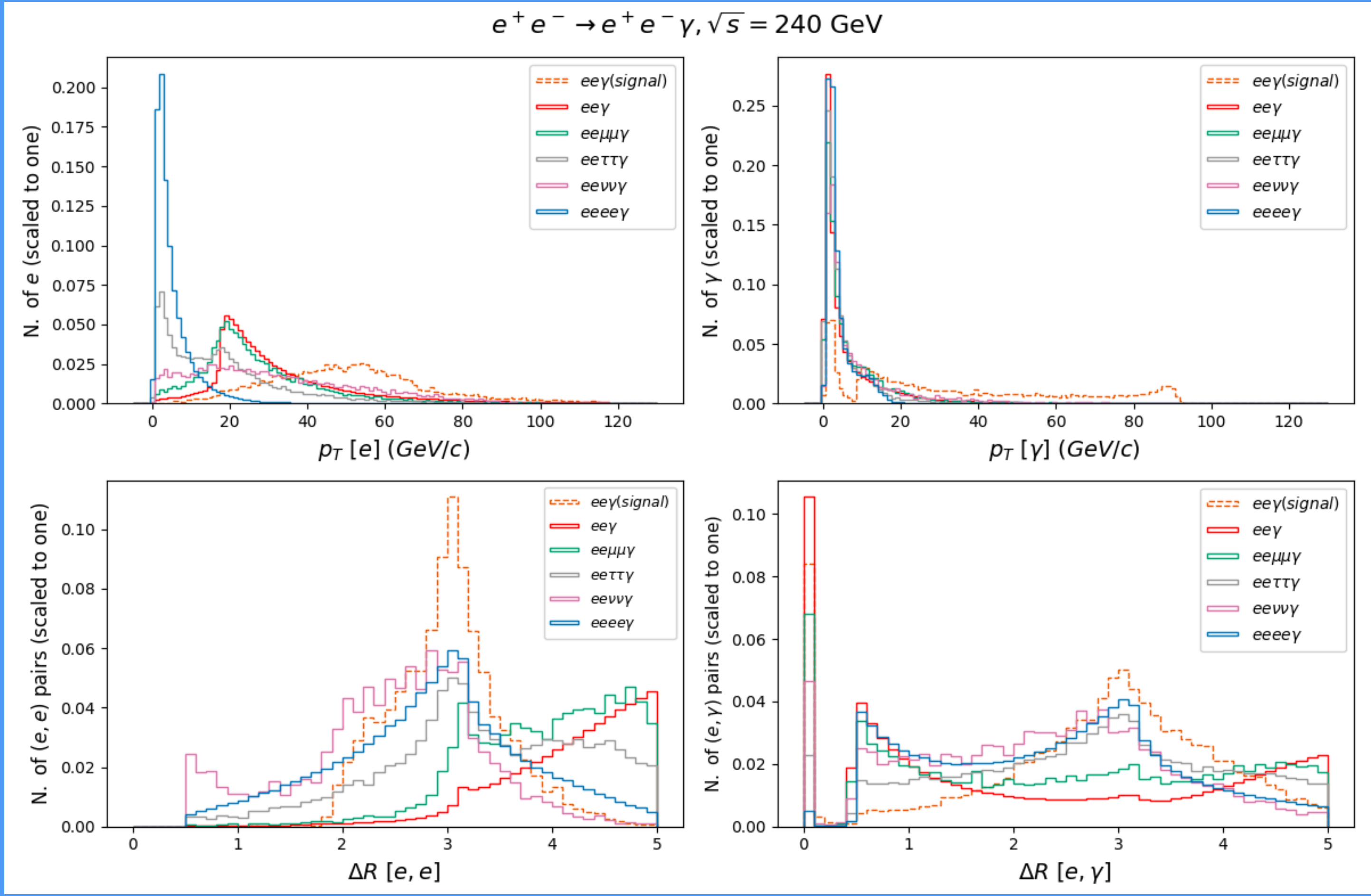
Process $e^+e^- \to \gamma + \ldots$	N_{ev}, Z run	N_{ev}, WW run	N_{ev}, ZH run	N_{ev}, $t\bar{t}$ run
$\mu\mu$	2.3×10^{10}	2.1×10^7	5.5×10^6	8.44×10^5
ee	8.63×10^{10}	1.26×10^9	4.5×10^8	7.9×10^7
$\tau\tau$	2.3×10^{10}	2.1×10^7	5.7×10^6	8.82×10^5
$\nu\nu$	2.2×10^9	5.9×10^7	3.3×10^7	1.35×10^7
$\mu\mu\mu\mu$	1.2×10^5	1.4×10^4	6.3×10^3	1.4×10^3
$\mu\mu ee$	8×10^7	5.03×10^6	4.16×10^6	1.73×10^6
$\mu\mu\tau\tau$	1.43×10^9	9.9×10^6	1.7×10^8	2.3×10^6
$\mu\mu\nu\nu$	8×10^3	1.8×10^4	1.56×10^4	6.7×10^3
$eeee$	7.6×10^7	4.86×10^6	4.04×10^6	1.78×10^6
$ee\tau\tau$	3×10^7	1.1×10^6	8.9×10^5	3.82×10^5
$ee\nu\nu$	1.28×10^4	2×10^4	2.5×10^4	1.16×10^4
$\tau\tau\tau\tau$	5×10^5	6.3×10^3	4.5×10^3	1×10^3
$\tau\tau\nu\nu$	4×10^3	2.3×10^4	1.6×10^5	4×10^4
$\nu\nu\nu\nu$	0.5	1.12×10^4	8.1×10^3	4.6×10^3

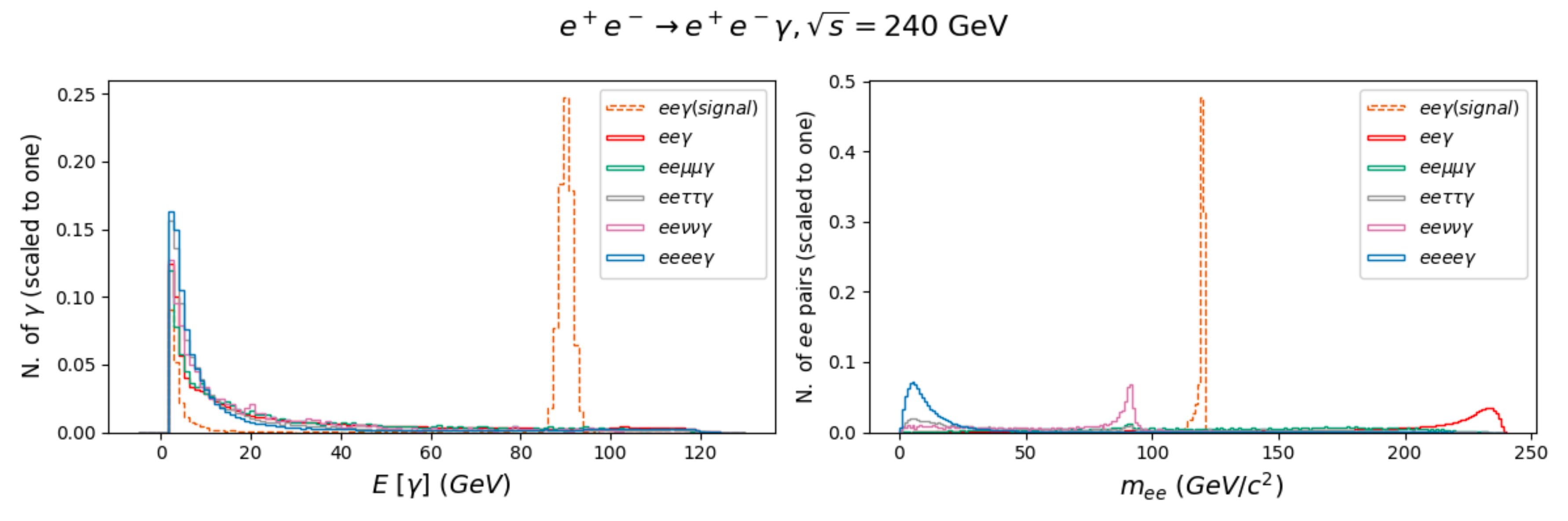
$e^+ e^- \longrightarrow \mu^+ \mu^- \gamma$

Backgrounds:

- SM process
- $\mu^+ \mu^- \mu^+ \mu^- \gamma$, $e^+ e^- \mu^+ \mu^- \gamma$, $\mu^+ \mu^- \tau^+ \tau^- \gamma$, $\mu^+ \mu^- \nu \nu \gamma$
- Obtain events for each process, set preliminary cuts to reject events (Eg: reject events with electrons and taus)

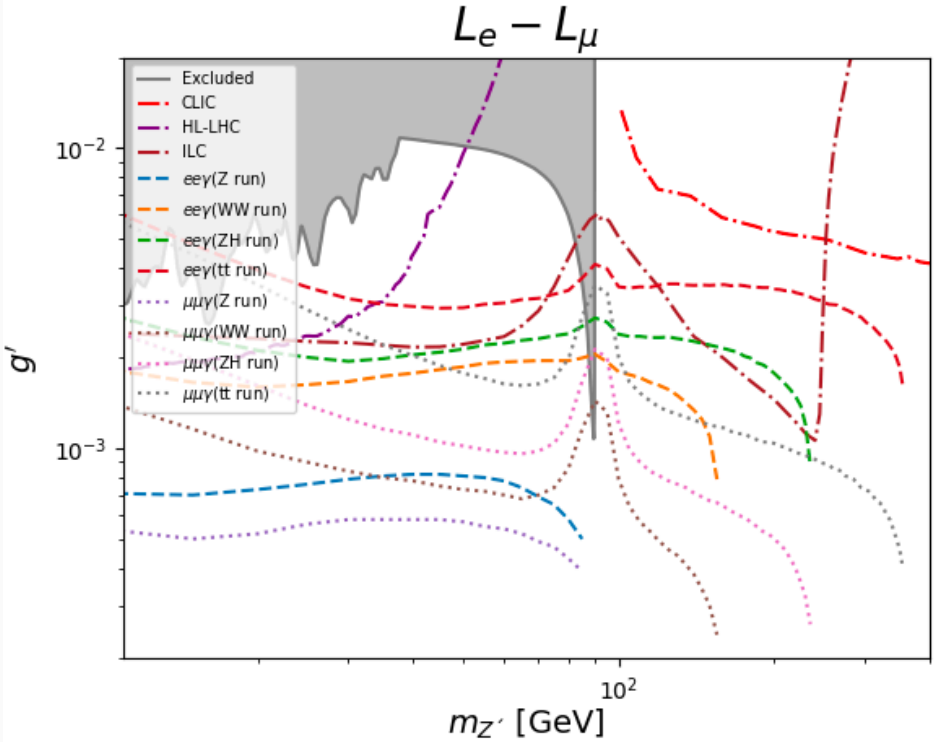
Further cuts imposed based on particle kinematics to effectively reject background

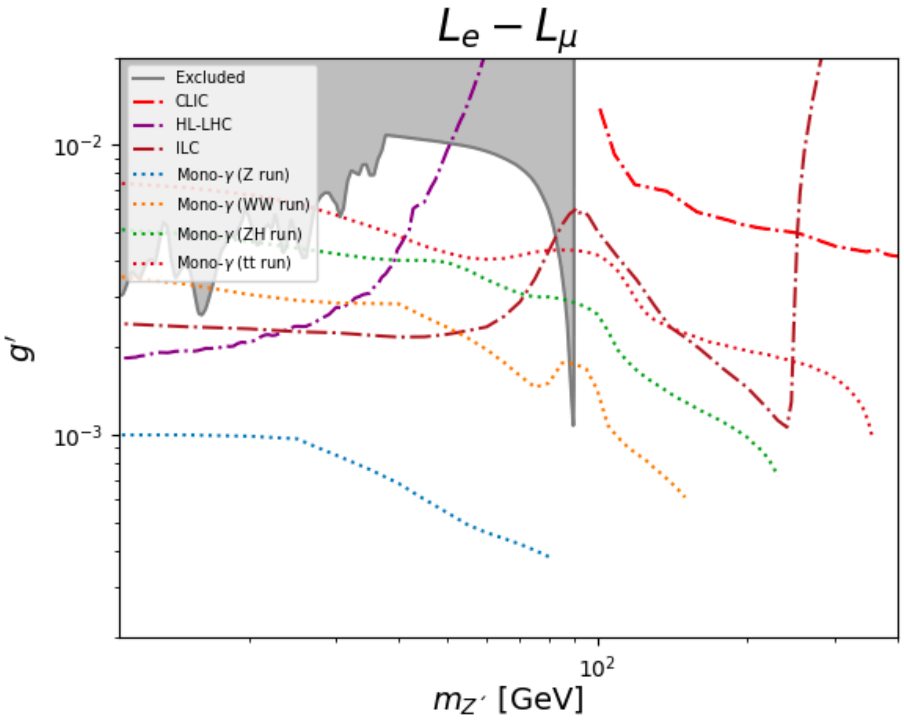

$e^+e^- \to e^+e^-\gamma, \sqrt{s} = 240$ GeV
eeγ(signal)
eeγ
eeμμγ
eeττγ
eeννγ
eeeeγ
N. of e (scaled to one)
p_T [e] (GeV/c)
N. of γ (scaled to one)
p_T [γ] (GeV/c)
N. of (e, e) pairs (scaled to one)
ΔR [e, e]
N. of (e, γ) pairs (scaled to one)
ΔR [e, γ]



$e^+e^- \rightarrow e^+e^-\gamma, \sqrt{s} = 240$ GeV
N. of γ (scaled to one)
E [γ] (GeV)
N. of ee pairs (scaled to one)
m_{ee} (GeV/c^2)
eeγ(signal)
eeγ
eeμμγ
eeττγ
eeννγ
eeeeγ

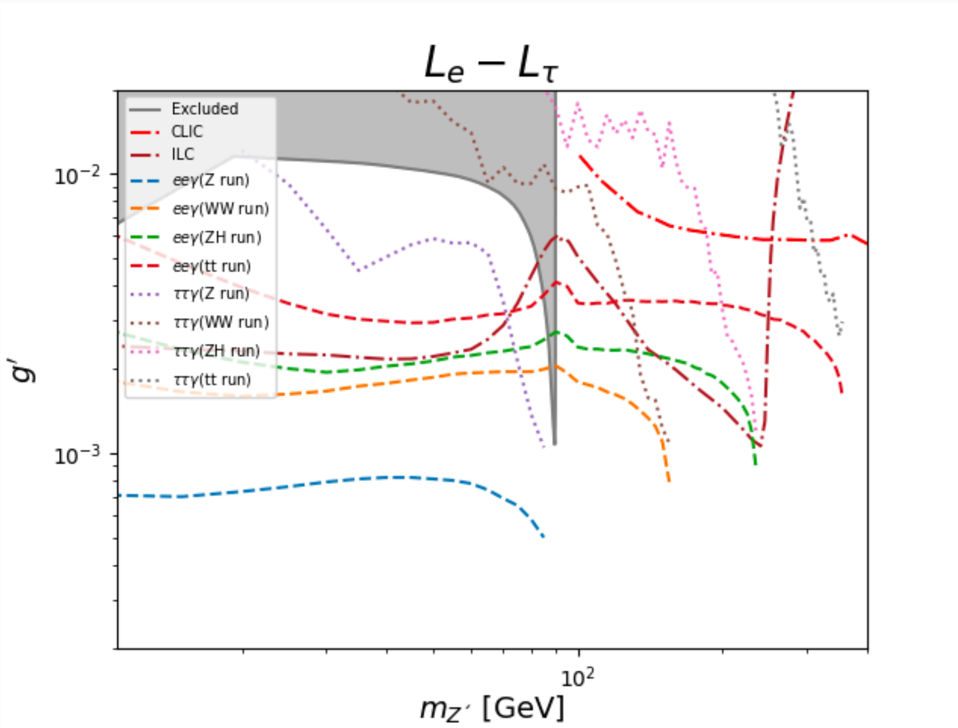
Sensitivity plots

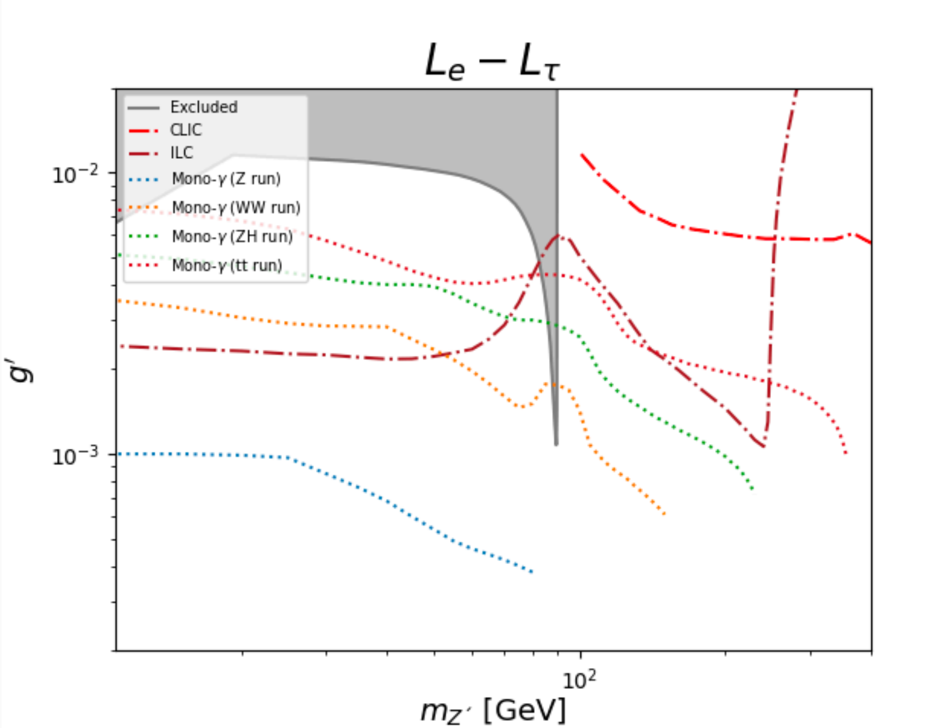




Plots shown for an invariant mass window (photon energy/recoil mass window) of 5 GeV

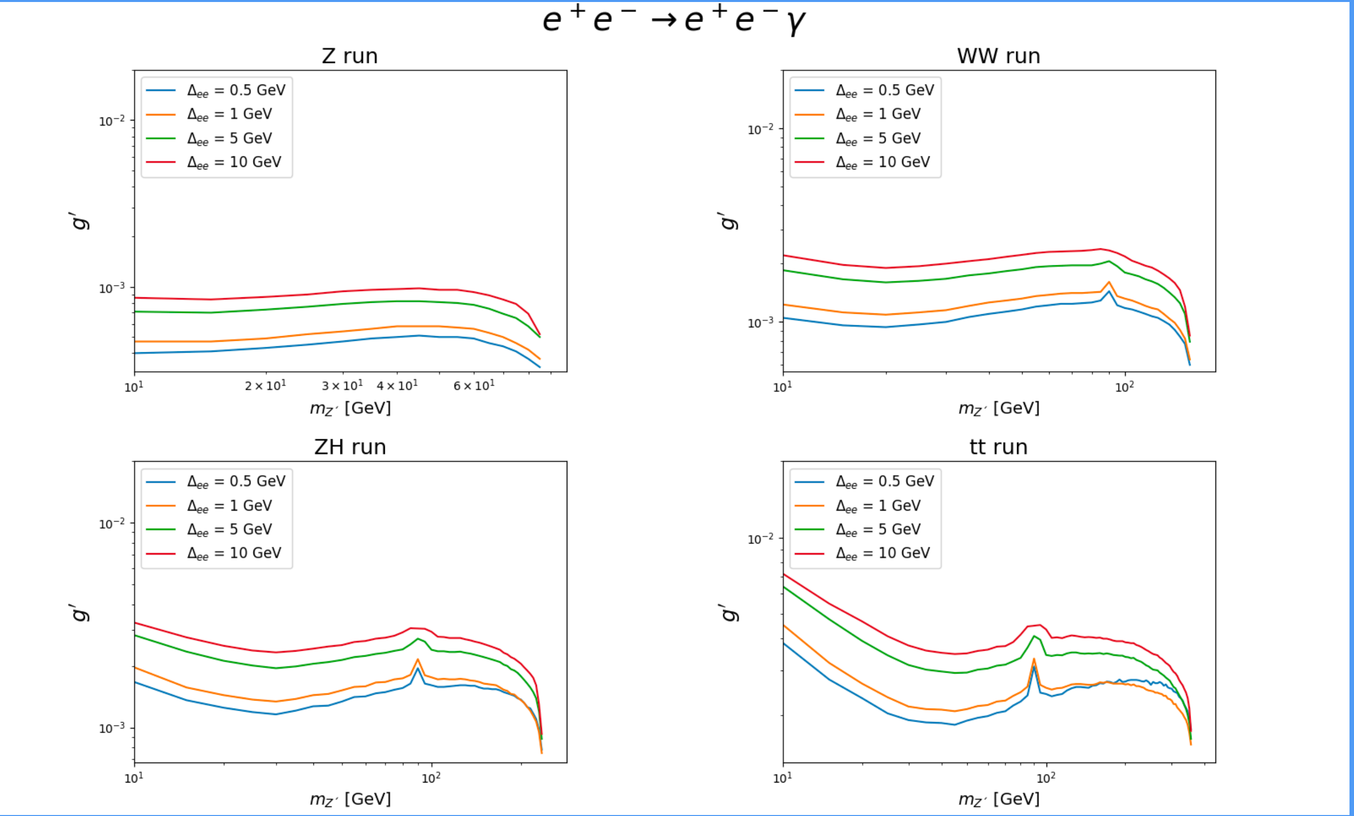
Sensitivity plots





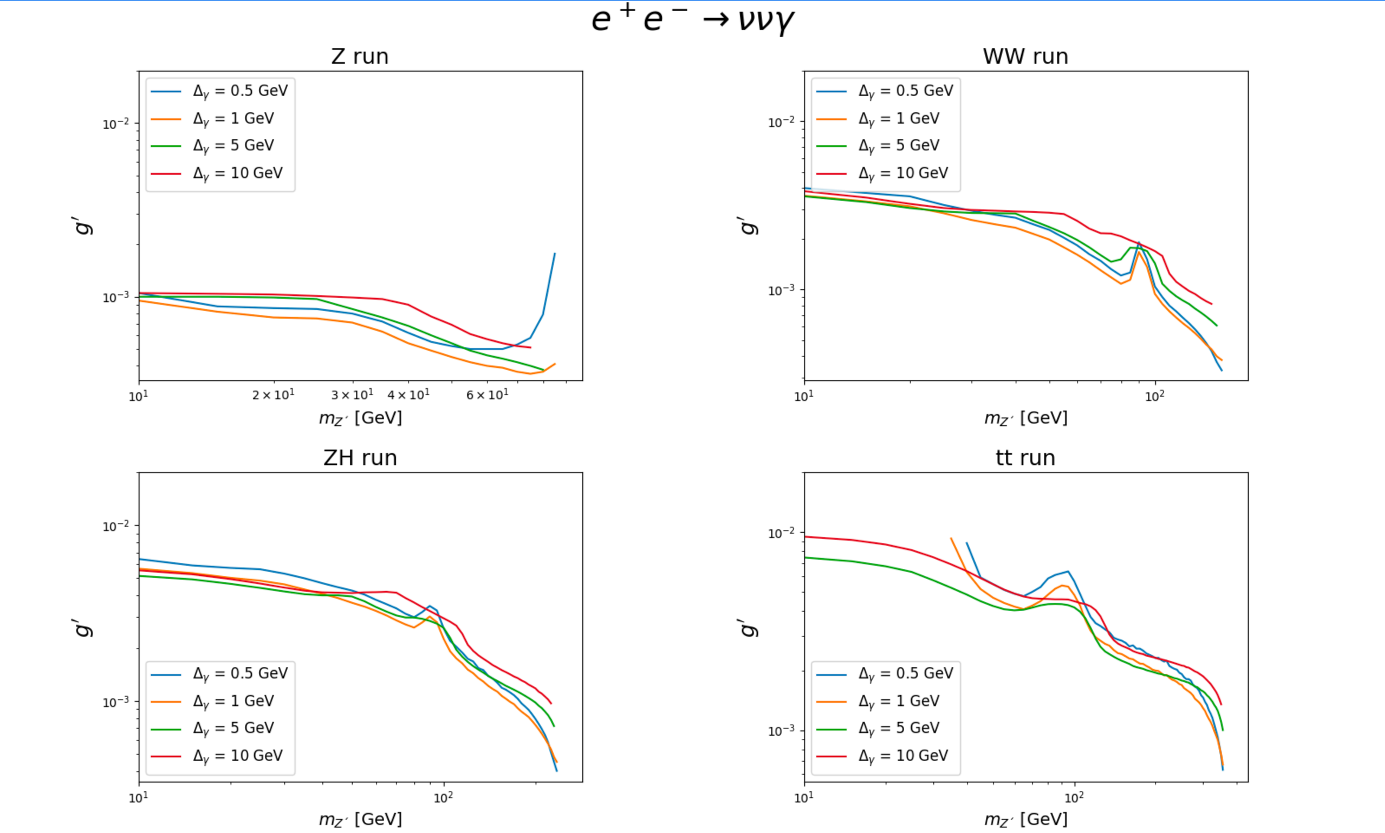
Plots shown for an invariant mass window (photon energy/recoil mass window) of 5 GeV

Sensitivity dependence (invariant mass window)



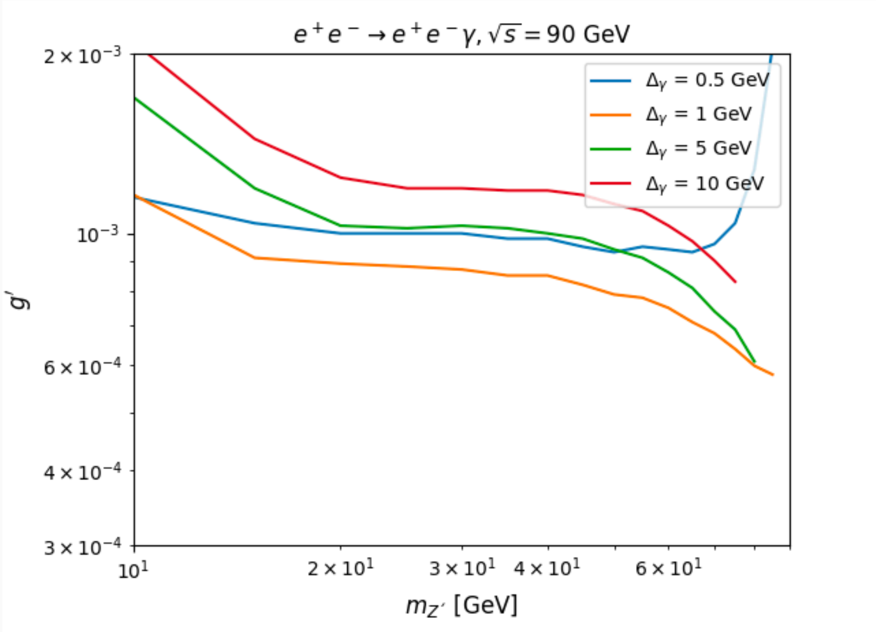
Narrower the invariant mass window, better the sensitivity

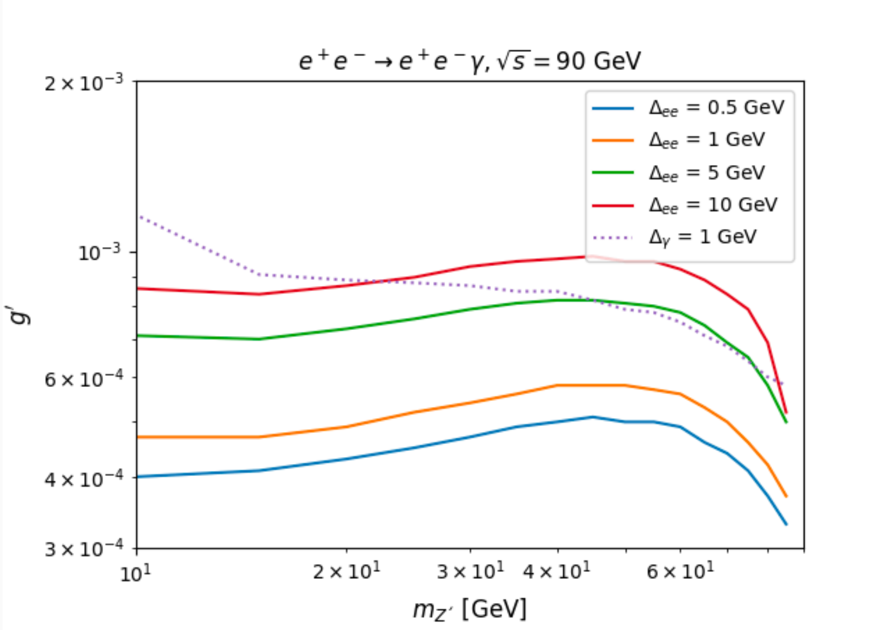
Sensitivity dependence (energy window)



Recoil mass window/photon energy window of 1 GeV typically yields best bounds

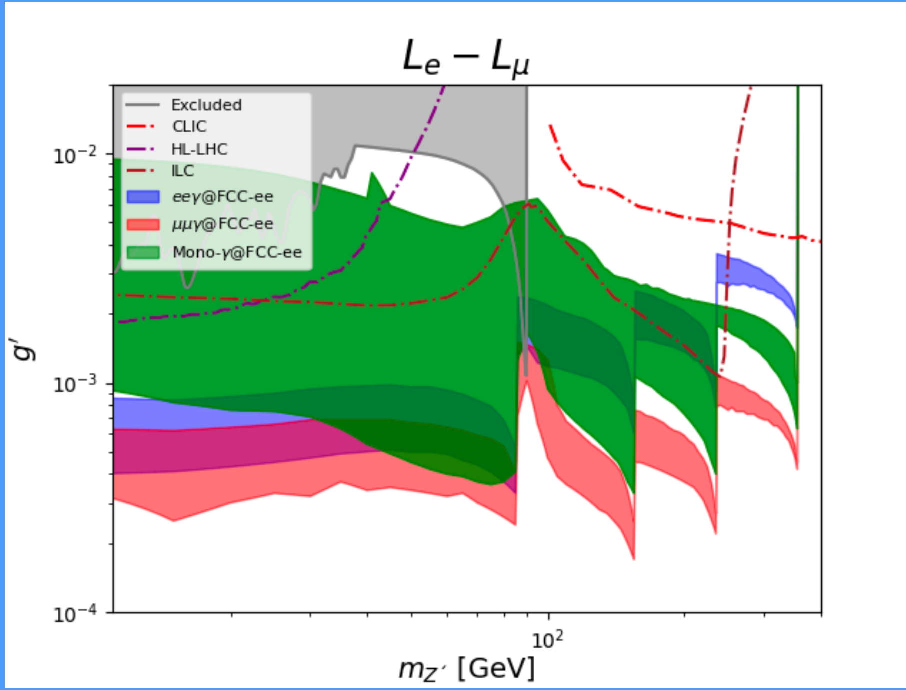
Recoil mass or invariant mass?

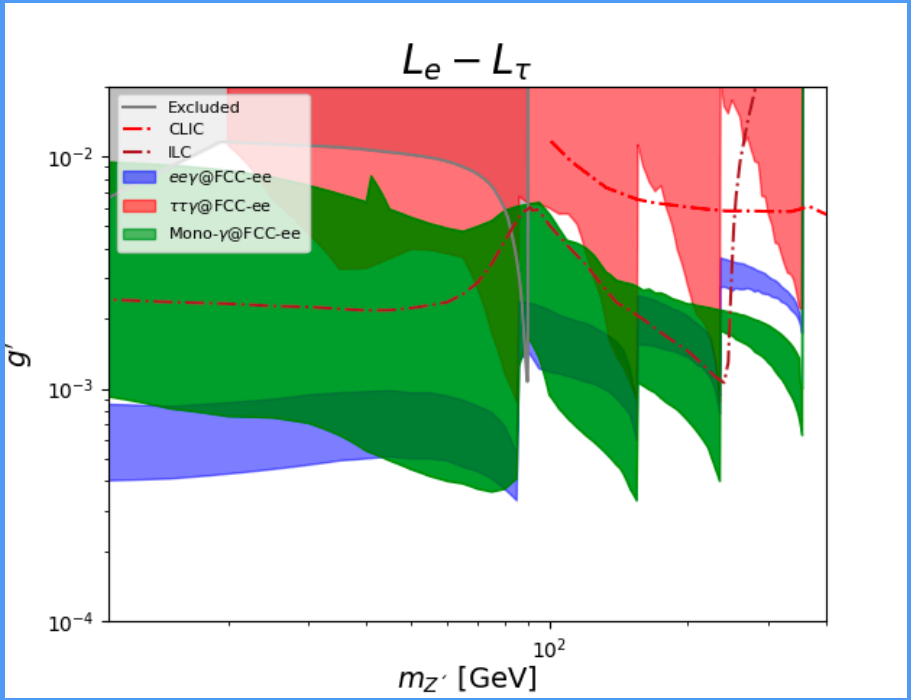




Using the recoil mass (photon energy) leads to weaker sensitivity compared to using the invariant mass.

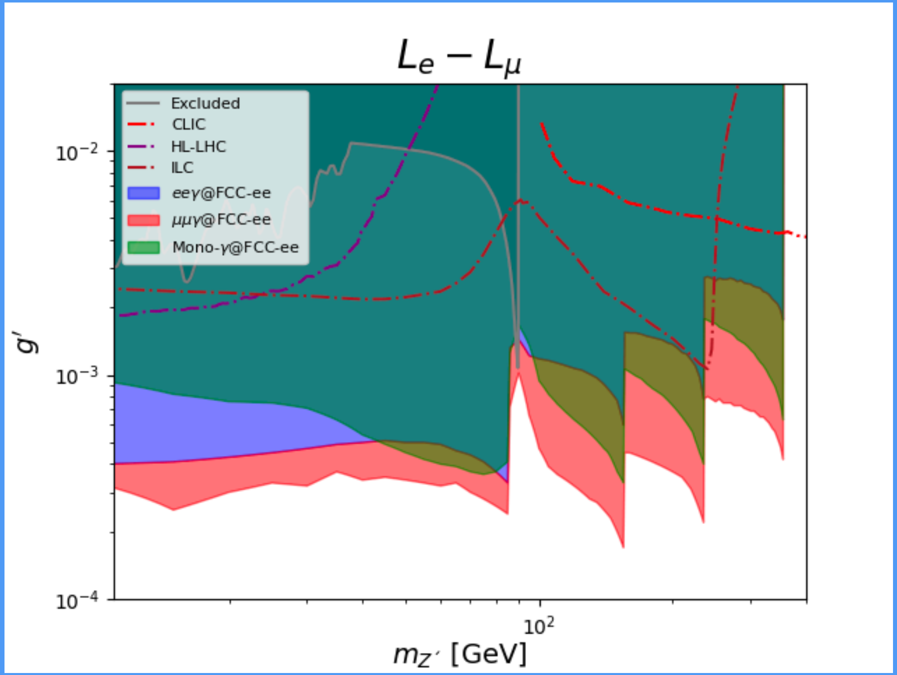
Range of sensitivities

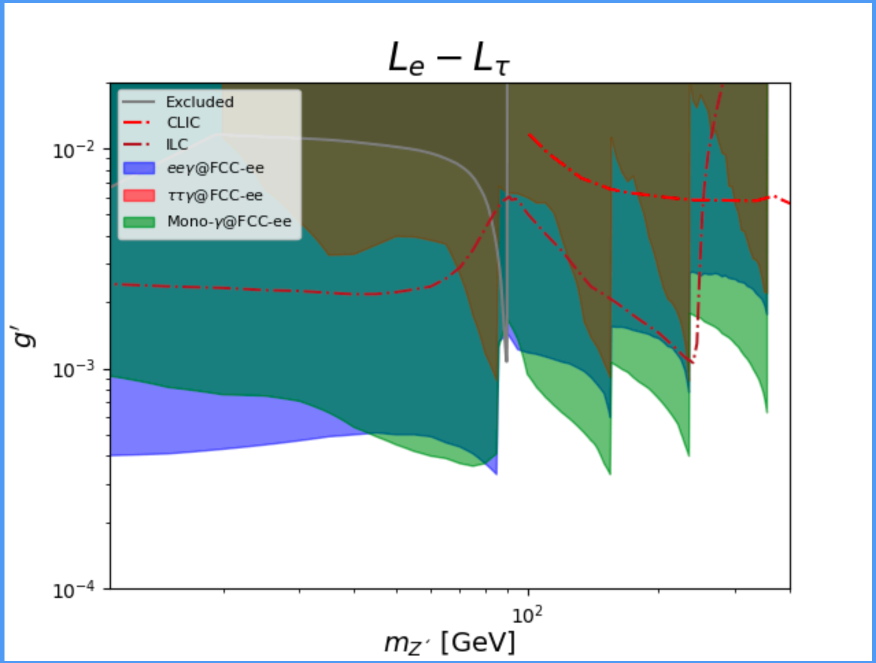




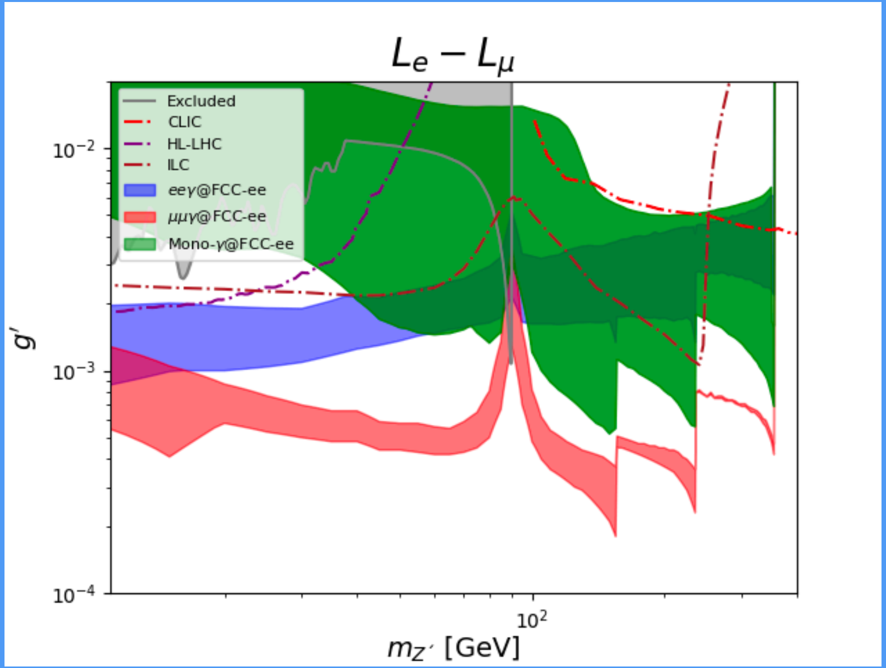
Sensitivities presented for all invariant and recoil mass windows under consideration (as shown in previous slides)

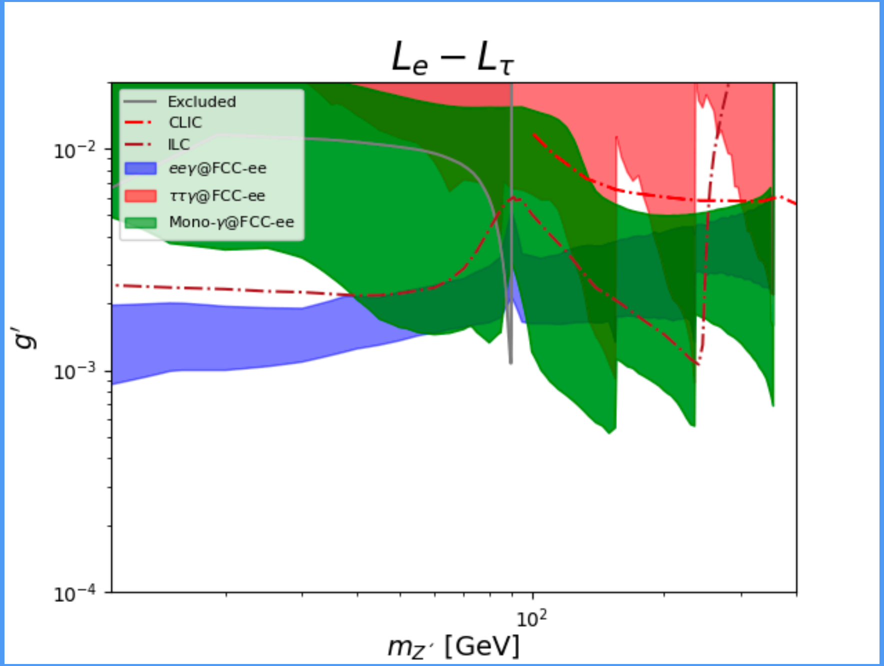
Strongest bounds





Impact of systematics





The bands show the range of sensitivities obtained by using λ= 0.1% and 1% on the strongest bounds shown before

Conclusions

- FCC-ee can provide leading constraints in 10-365 GeV mass range (down to O (10^(-4))
- Our study shows the impact of reconstructed parameters, i.e. invariant mass window and energy window, on the projected sensitivities and the impact of systematics

Future (!) possibilities:

Dark sector portal?

Thank you!