University of Glasgow

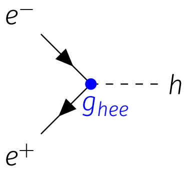
THE PRICE OF A LARGE ELECTRON YUKAWA MODIFICATION

...and what we would learn from a Higgs pole run at FCC–ee

Ben Smith
(based on arXiv:2511.02642 w/ L. Allwicher, M. Mccullough, S. Renner, D. Rocha)

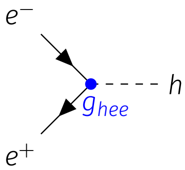
17th December 2025, **YTF 2025**

THE ELECTRON YUKAWA COUPLING



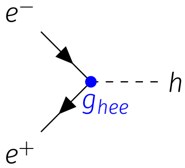
- The smallest fundamental coupling in the Standard Model (SM) $\rightarrow$ easily overcome by new physics (NP) effects.

THE ELECTRON YUKAWA COUPLING



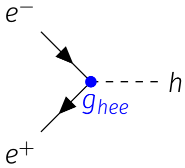
- The smallest fundamental coupling in the Standard Model (SM) $\rightarrow$ easily overcome by new physics (NP) effects.
- In the SM: $g_{hee} \propto m_e$ $\rightarrow$ NP can break this relationship.

THE ELECTRON YUKAWA COUPLING



- The smallest fundamental coupling in the Standard Model (SM) $\rightarrow$ easily overcome by new physics (NP) effects.
- In the SM: $g_{hee} \propto m_e$ $\rightarrow$ NP can break this relationship.
- Parametrise deviations in terms of $\kappa_e = \frac{g_{hee}}{g_{hee}^{SM}}$

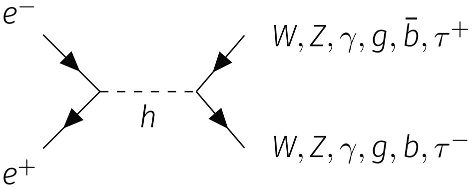
THE ELECTRON YUKAWA COUPLING



- The smallest fundamental coupling in the Standard Model (SM) $\rightarrow$ easily overcome by new physics (NP) effects.
- In the SM: $g_{hee} \propto m_e$ $\rightarrow$ NP can break this relationship.
- Parametrise deviations in terms of $\kappa_e = \frac{g_{hee}}{g_{hee}^{SM}}$
- Constraints:
    - $\kappa_e^{\text{LHC}} < 240$ (Tumasyan et al. 2023)
    - $\kappa_e^{\text{HL-LHC}} < 120$ (Cepeda et al. 2019)

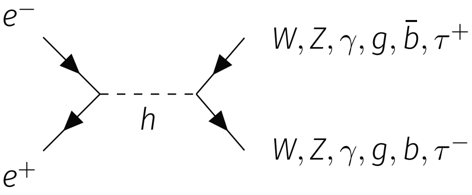
FCC-ee PROSPECTS

- Projected $|\kappa_e| < 1.6$ @ 95% C.L from a dedicated run at the Higgs pole ($\sqrt{s} = m_h$) (d'Enterria, Poldaru, and Wojcik 2022) .



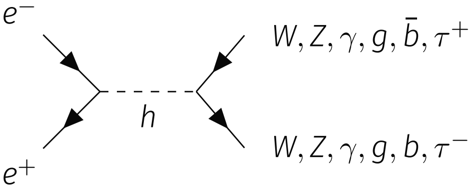
FCC-ee PROSPECTS

- Projected $|\kappa_e| < 1.6$ @ 95% C.L from a dedicated run at the Higgs pole ($\sqrt{s} = m_h$) (d'Enterria, Poldaru, and Wojcik 2022) .



- Challenges:
    - Need high precision on Higgs mass (few MeV).
    - Need monochromatised beams.
    - Large backgrounds.

- Projected $|\kappa_e| < 1.6$ @ 95% C.L from a dedicated run at the Higgs pole ($\sqrt{s} = m_h$) (d'Enterria, Poldaru, and Wojcik 2022) .



- Challenges:
  - Need high precision on Higgs mass (few MeV).
  - Need monochromatised beams.
  - Large backgrounds.

⟹ What do we learn (EFT/Models)?
Other observables?

EFT PERSPECTIVE

LEPTON YUKAWAS IN THE SMEFT

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{k,D>4} \mathcal{C}_k^{(D)} \mathcal{O}_k^{(D)}$$

LEPTON YUKAWAS IN THE SMEFT

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{k,D>4} \mathcal{C}_k^{(D)} \mathcal{O}_k^{(D)}$$

- At leading order ($D = 6$), only the Warsaw basis operator $\mathcal{O}_{eH}$ can modify a lepton Yukawa coupling in a manner $\not\propto g_{h\ell\ell}^{SM}$.

$$\mathcal{O}_{eH} = (H^\dagger H)(\bar{l}_L H e_R)$$

LEPTON YUKAWAS IN THE SMEFT

$$\boxed{\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{k,D>4} \mathcal{C}_k^{(D)} \mathcal{O}_k^{(D)}}$$

- At leading order ($D = 6$), only the Warsaw basis operator $\mathcal{O}_{eH}$ can modify a lepton Yukawa coupling in a manner $\not\propto g_{h\ell\ell}^{\text{SM}}$.

$$\boxed{\mathcal{O}_{eH} = (H^\dagger H)(\bar{l}_L H e_R)}$$

- New contributions to lepton flavour conserving and violating Higgs couplings.

$$[g_{h\ell\ell}]_{ij} = \frac{1}{v}[M_\ell]_{ij} - \frac{v^2}{\sqrt{2}}[\mathcal{C}_{eH}^*]_{ji} \Rightarrow g_{H\ell\ell} \not\propto M_\ell!$$

LEPTON YUKAWAS IN THE SMEFT

$$\boxed{\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{k,D>4} \mathcal{C}_k^{(D)} \mathcal{O}_k^{(D)}}$$

- At leading order ($D = 6$), only the Warsaw basis operator $\mathcal{O}_{eH}$ can modify a lepton Yukawa coupling in a manner $\not\propto g_{h\ell\ell}^{SM}$.

$$\boxed{\mathcal{O}_{eH} = (H^\dagger H)(\bar{l}_L H e_R)}$$

- New contributions to lepton flavour conserving and violating Higgs couplings.

$$[g_{h\ell\ell}]_{ij} = \frac{1}{v}[M_\ell]_{ij} - \frac{v^2}{\sqrt{2}}[\mathcal{C}_{eH}^*]_{ji} \Rightarrow g_{H\ell\ell} \not\propto M_\ell!$$

- Assume **'electrophilic'** flavour structure: only $[\mathcal{C}_{eH}]_{11} \neq 0$

INDIRECT CONSTRAINTS ON $\mathcal{C}_{eH}$

INDIRECT CONSTRAINTS ON $\mathcal{C}_{eH}$

- Natural to look at the anomalous magnetic moment of the electron ($g_e - 2$) as it is the only other observable with the same chiral structure as g_{hee}.

INDIRECT CONSTRAINTS ON $\mathcal{C}_{eH}$

- Natural to look at the anomalous magnetic moment of the electron ($g_e - 2$) as it is the only other observable with the same chiral structure as g_{hee}.

- In SMEFT, corrections arise from the EW dipole operators.

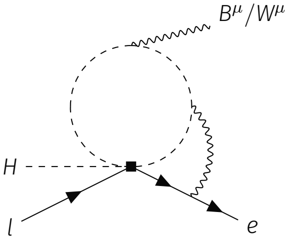
$$\mathcal{O}_{eB} = \bar{l}\sigma_{\mu\nu} e\, H\, B^{\mu\nu}, \quad \mathcal{O}_{eW} = \bar{l}\sigma_{\mu\nu} e\, \tau^I H\, W_I^{\mu\nu}.$$

INDIRECT CONSTRAINTS ON $\mathcal{C}_{eH}$

- Natural to look at the anomalous magnetic moment of the electron ($g_e - 2$) as it is the only other observable with the same chiral structure as g_{hee}.
- In SMEFT, corrections arise from the EW dipole operators.

$$\mathcal{O}_{eB} = \bar{l}\sigma_{\mu\nu}e\,H\,B^{\mu\nu}, \quad \mathcal{O}_{eW} = \bar{l}\sigma_{\mu\nu}e\,\tau^I H\,W_I^{\mu\nu}.$$

- Leading connection $\mathcal{O}_{eH} \to \mathcal{O}_{eW}/\mathcal{O}_{eB}$ is at the two-loop level.



(Panico, Pomarol, and Riembau 2019)

κ_e vs Δa_e

$$\Delta a_e = a_e^{\text{exp}} - a_e^{\text{SM}}, \text{ with: } a_e = (g_e - 2)/2$$

- Δa_e sets indirect constraints on κ_e enhancements.

κ_e vs Δa_e

$$\boxed{\Delta a_e = a_e^{\text{exp}} - a_e^{\text{SM}}, \text{ with: } a_e = (g_e - 2)/2}$$

- Δa_e sets indirect constraints on κ_e enhancements.
- Current constraints are very weak.

κ_e vs Δa_e

$$\boxed{\Delta a_e = a_e^{\text{exp}} - a_e^{\text{SM}}, \text{ with: } a_e = (g_e - 2)/2}$$

- Δa_e sets indirect constraints on κ_e enhancements.
- Current constraints are very weak.
- We assume $|\Delta a_e^{\text{future}}| \lesssim 5 \times 10^{-14}$ @ 95% C.L (Di Luzio et al. 2025) .

κ_e vs Δa_e

$$\boxed{\Delta a_e = a_e^{\text{exp}} - a_e^{\text{SM}},\ \text{with: } a_e = (g_e - 2)/2}$$

- Δa_e sets indirect constraints on κ_e enhancements.
- Current constraints are very weak.
- We assume $|\Delta a_e^{\text{future}}| \lesssim 5 \times 10^{-14}$ @ 95% C.L (Di Luzio et al. 2025) .
- $|\kappa_e| \lesssim 70$$\rightarrow$Better than HL-LHC

κ_e vs Δa_e

$$\boxed{\Delta a_e = a_e^{\text{exp}} - a_e^{\text{SM}}, \ \text{with: } a_e = (g_e - 2)/2}$$

- Δa_e sets indirect constraints on κ_e enhancements.
- Current constraints are very weak.
- We assume $|\Delta a_e^{\text{future}}| \lesssim 5 \times 10^{-14}$ @ 95% C.L (Di Luzio et al. 2025) .
- $|\kappa_e| \lesssim 70$→Better than HL-LHC

Working the SMEFT alone, Δa_e is insufficient to constrain κ_e to $\mathcal{O}(1)$.

UV MODEL PERSPECTIVE

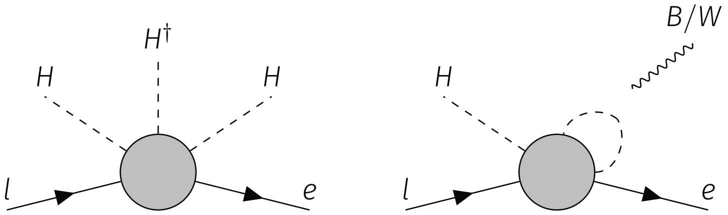
UV MODEL PERSPECTIVE

- We looked at all single- and multi-field extensions which generate $\mathcal{C}_{eH} \not\propto m_e$.

UV MODEL PERSPECTIVE

- We looked at all single- and multi-field extensions which generate $\mathcal{C}_{eH} \not\propto m_e$.
- For these extensions, matching at any loop order, we find you should generally expect to generate $\mathcal{O}_{eB}/\mathcal{O}_{eW}$ at ***most*** one-loop order higher than $\mathcal{O}_{eH}$.

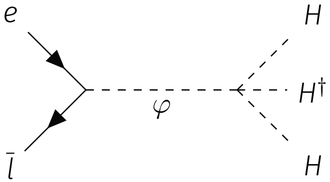
- We looked at all single- and multi-field extensions which generate $\mathcal{C}_{eH} \not\propto m_e$.
- For these extensions, matching at any loop order, we find you should generally expect to generate $\mathcal{O}_{eB}/\mathcal{O}_{eW}$ at ***most*** one-loop order higher than $\mathcal{O}_{eH}$.



Grey blob = diagram of arbitrary loop order involving heavy state exchange.

THE φ (2HDM) EXCEPTION

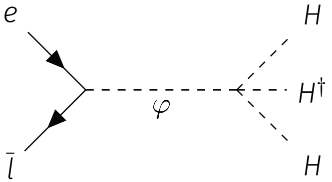
- If extension is a scalar doublet $\varphi \sim (1, 2, \frac{1}{2})$, can generate $\mathcal{O}_{eH}$ at tree level.



$$\Longrightarrow \mathcal{C}_{eH} = \frac{\lambda_\varphi (y^e_\varphi)^*}{M^2_\varphi}.$$

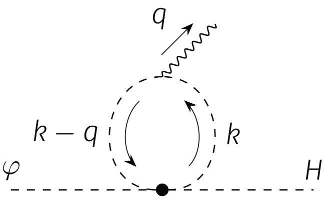
THE φ (2HDM) EXCEPTION

- If extension is a scalar doublet $\varphi \sim (1, 2, \frac{1}{2})$, can generate $\mathcal{O}_{eH}$ at tree level.



$$\Longrightarrow \mathcal{C}_{eH} = \frac{\lambda_\varphi (y^e_\varphi)^*}{M^2_\varphi}.$$

- However, we do *not* generate $\mathcal{O}_{eB}/\mathcal{O}_{eW}$ at one loop.



$$\propto \; q^\mu \epsilon^*_\mu(q) = 0.$$

SCHEMATIC BOUNDS

$$\mathcal{C}_{e\gamma} = (\cos(\theta_W)\mathcal{C}_{eB} - \sin(\theta_W)\mathcal{C}_{eW}) = \frac{e}{16\pi^2}\left(\frac{g^2}{16\pi^2}\right)^{N_{\text{loops}}-1}\mathcal{C}_{eH}$$

N_{loops}	$\lvert\kappa_e\rvert$ $(\Delta a_e^{\text{future}})$
0	< 1.01
1	< 3
2	< 300

cf. $\lvert\kappa_e^{\text{FCC-ee}}\rvert < 1.6$

SCHEMATIC BOUNDS

$$\boxed{\mathcal{C}_{e\gamma} = (\cos(\theta_W)\mathcal{C}_{eB} - \sin(\theta_W)\mathcal{C}_{eW}) = \frac{e}{16\pi^2}\left(\frac{g^2}{16\pi^2}\right)^{N_{\text{loops}}-1}\mathcal{C}_{eH}}$$

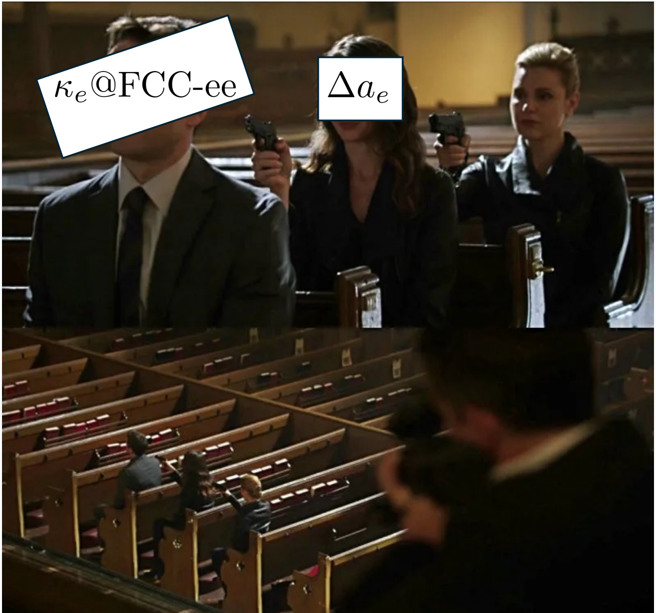
N_{loops}	$\lvert\kappa_e\rvert$ $(\Delta a_e^{\text{future}})$
0	< 1.01
1	< 3
2	< 300

cf. $\lvert\kappa_e^{\text{FCC-ee}}\rvert < 1.6$

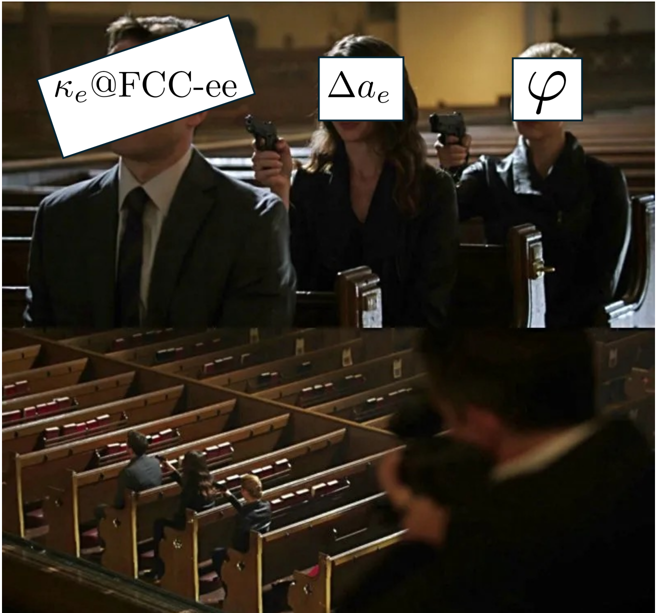
$\Longrightarrow$ Two loop suppression between κ_e and Δa_e required for large enhancements.

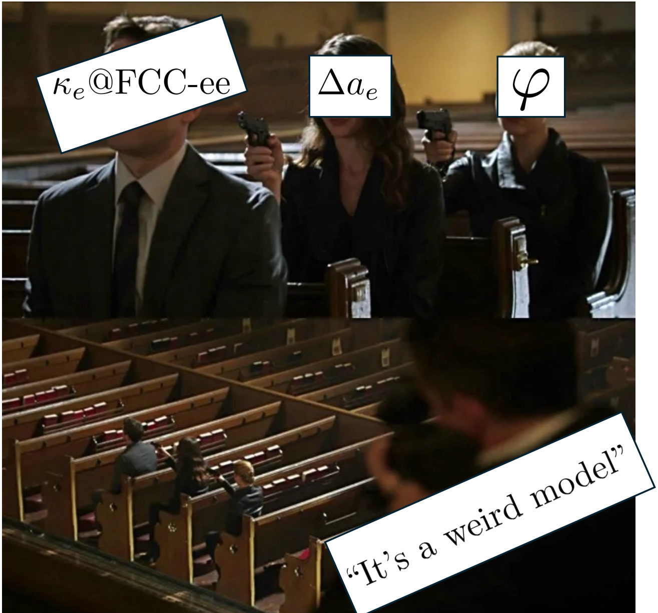
VISUAL SUMMARY

VISUAL SUMMARY


κ_e@FCC-ee
Δa_e

VISUAL SUMMARY




κ_e@FCC-ee
Δa_e
φ
"It's a weird model"

Thank you!

BACKUP SLIDES

UV MODEL PERSPECTIVE

State	Spin	SM charges	$\mathcal{C}_{eH}$	$\mathcal{C}_{eB}/\mathcal{C}_{eW}$
$\mathcal{S}$	0	$(1,1,0)$	tree	1 loop
φ (with Higgs coupling)	0	$(1,2,\frac{1}{2})$	tree	2 loop
Ξ	0	$(1,3,0)$	tree	1 loop
Ξ_1	0	$(1,3,1)$	tree	1 loop
E	$\frac{1}{2}$	$(1,1,-1)$	tree	1 loop
Δ_1	$\frac{1}{2}$	$(1,2,-\frac{1}{2})$	tree	1 loop
Δ_3	$\frac{1}{2}$	$(1,2,-\frac{3}{2})$	tree	1 loop
Σ	$\frac{1}{2}$	$(1,3,0)$	tree	1 loop
Σ_1	$\frac{1}{2}$	$(1,3,-1)$	tree	1 loop
φ (with top coupling)	0	$(1,2,\frac{1}{2})$	1 loop	2 loop
ω_1	0	$(3,1,-\frac{1}{3})$	1 loop	1 loop
Π_7	0	$(3,2,\frac{7}{6})$	1 loop	1 loop
$\mathcal{U}_2$	1	$(3,1,\frac{2}{3})$	1 loop	1 loop
$\mathcal{Q}_5$	1	$(3,2,-\frac{5}{6})$	1 loop	1 loop

Blue = non-renormalisable interaction required to match to $\mathcal{C}_{eH}, \mathcal{C}_{eB}, \mathcal{C}_{eW} \Rightarrow$ See (Erdelyi, Gröber, and Selimovic 2025) .

UV MODEL PERSPECTIVE

State	Spin	SM charges	$\mathcal{C}_{eH}$	$\mathcal{C}_{eB}/\mathcal{C}_{eW}$
$\mathcal{S}$	0	$(1,1,0)$	tree	1 loop
φ (with Higgs coupling)	0	$(1,2,\frac{1}{2})$	tree	2 loop
Ξ	0	$(1,3,0)$	tree	1 loop
Ξ_1	0	$(1,3,1)$	tree	1 loop
E	$\frac{1}{2}$	$(1,1,-1)$	tree	1 loop
Δ_1	$\frac{1}{2}$	$(1,2,-\frac{1}{2})$	tree	1 loop
Δ_3	$\frac{1}{2}$	$(1,2,-\frac{3}{2})$	tree	1 loop
Σ	$\frac{1}{2}$	$(1,3,0)$	tree	1 loop
Σ_1	$\frac{1}{2}$	$(1,3,-1)$	tree	1 loop
φ (with top coupling)	0	$(1,2,\frac{1}{2})$	1 loop	2 loop
ω_1	0	$(3,1,-\frac{1}{3})$	1 loop	1 loop
Π_7	0	$(3,2,\frac{7}{6})$	1 loop	1 loop
$\mathcal{U}_2$	1	$(3,1,\frac{2}{3})$	1 loop	1 loop
$\mathcal{Q}_5$	1	$(3,2,-\frac{5}{6})$	1 loop	1 loop

Blue = non-renormalisable interaction required to match to $\mathcal{C}_{eH},\mathcal{C}_{eB},\mathcal{C}_{eW} \Rightarrow$ See (Erdelyi, Gröber, and Selimovic 2025) .

FINE-TUNING

$$\kappa_e = \frac{g_{hee}}{\frac{m_e}{v}} = \frac{\frac{1}{2}(y_e - \frac{3v^2}{\sqrt{2}}\mathcal{C}_{eH})}{\frac{1}{\sqrt{2}}(y_e - \frac{v^2}{2}\mathcal{C}_{eH})} = 1 - \frac{\frac{v^2\mathcal{C}_{eH}}{y_e}}{1 - \frac{v^2\mathcal{C}_{eH}}{2y_e}} = 1 - \frac{\zeta}{1-\zeta/2}$$

Large κ_e requires tuning ζ ($= \frac{v^2\mathcal{C}_{eH}}{2y_e}$) close to 1.

$$\Delta = \left|\frac{\partial \ln \kappa}{\partial \ln \zeta}\right| = \left|\frac{(1-\kappa)(3-\kappa)}{2\kappa}\right| \quad ,$$

which behaves as

$$\lim_{\kappa \gg 1} \Delta = \frac{\kappa}{2} \quad .$$

$\Rightarrow$ $\kappa_e = 10$ requires $\sim 20\%$ tuning.

BIBLIOGRAPHY I

Cepeda, M. et al. (2019). “Report from Working Group 2: Higgs Physics at the HL-LHC and HE-LHC”. In: *CERN Yellow Rep. Monogr.* 7. Ed. by Andrea Dainese et al., pp. 221–584. DOI: *10.23731/CYRM-2019-007.221*. arXiv: *1902.00134 [hep-ph]*.

d’Enterria, David, Andres Poldaru, and George Wojcik (2022). “Measuring the electron Yukawa coupling via resonant s-channel Higgs production at FCC-ee”. In: *Eur. Phys. J. Plus* 137.2, p. 201. DOI: *10.1140/epjp/s13360-021-02204-2*. arXiv: *2107.02686 [hep-ex]*.

Di Luzio, Luca et al. (2025). “Model-Independent Tests of the Hadronic Vacuum Polarization Contribution to the Muon g-2”. In: *Phys. Rev. Lett.* 134.1, p. 011902. DOI: *10.1103/PhysRevLett.134.011902*. arXiv: *2408.01123 [hep-ph]*.

Erdelyi, Barbara Anna, Ramona Gröber, and Nudzeim Selimovic (2025). “Probing new physics with the electron Yukawa coupling”. In: *JHEP* 05, p. 135. DOI: *10.1007/JHEP05(2025)135*. arXiv: *2501.07628 [hep-ph]*.

Panico, Giuliano, Alex Pomarol, and Marc Riembau (2019). “EFT approach to the electron Electric Dipole Moment at the two-loop level”. In: *JHEP* 04, p. 090. DOI: *10.1007/JHEP04(2019)090*. arXiv: *1810.09413 [hep-ph]*.

Tumasyan, Armen et al. (2023). “Search for the Higgs boson decay to a pair of electrons in proton-proton collisions at s=13TeV”. In: *Phys. Lett. B* 846, p. 137783. DOI: *10.1016/j.physletb.2023.137783*. arXiv: *2208.00265 [hep-ex]*.