New Physics in double-Higgs production at future lepton colliders.

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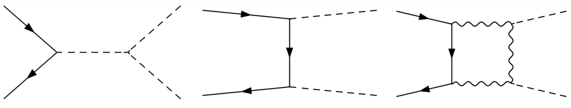
Summary

1. Motivation
2. SMEFT
3. Sommerfeld Enhancement

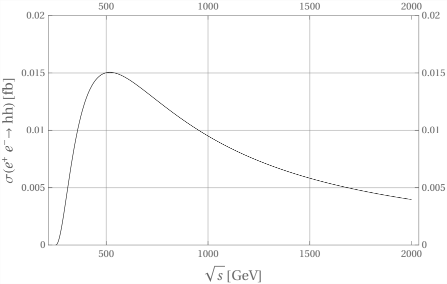
Motivation

Motivation

- $e^+e^- \to hh$ is a loop-induced process.



Tiny SM cross-section



Good place to look for new physics!

SMEFT

SMEFT contribution to di-Higgs

We study the sensitivity of the di-Higgs production to new physics parametrized by the interactions[1]:

$$\mathcal{L} = \frac{c_{e\varphi}}{\Lambda^2}\left(\varphi^\dagger\varphi - \frac{v^2}{2}\right)\bar{l}_L\varphi e_R + \frac{c_{et}}{\Lambda^2}\epsilon_{ij}\left(\bar{l}^i_L e_R\right)\left(\bar{q}^j_L t_R\right) \tag{1}$$

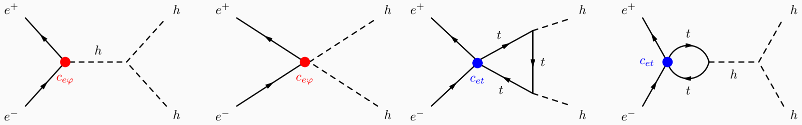


Figure 1: Diagrams contributing to the $e^+e^- \to hh$ process coming from the Lagrangian in eq. 1

[1] [*Vasquez, Degrande, Tonero & Rosenfeld, 2019*]

Bounds on SMEFT operators

We compute the cross-section as:

$$\sigma = \sigma_{SM} + \sigma_{EFT} \tag{2}$$

with

$$\sigma_{EFT} \sim \mathcal{O}(c_{e\varphi}^2) + \mathcal{O}(c_{e\varphi}c_{et}) + \mathcal{O}(c_{et}^2) \tag{3}$$

The exclusion regions are computed through a χ^2-distribution analysis.

The benchmark setups for future colliders taken into account are

Benchmark	Experiment	$\sqrt{s}$ (GeV)	L (ab^{-1})
1	FCC-ee	350	2.6
2	CLIC	380	0.5
3	ILC	500	4
4	CLIC	1500	1.5
5	CLIC	3000	3.0

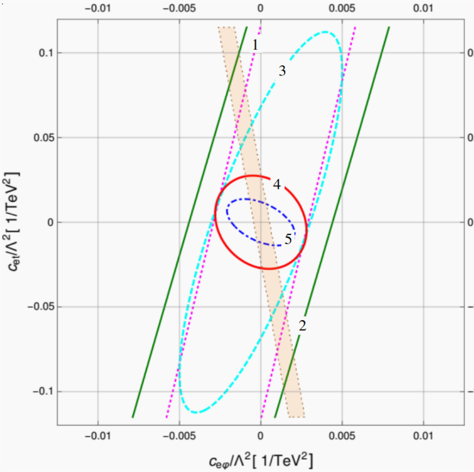


Figure 2: Exclusion regions at 95% CL for the different benchmarks.

Bounds on SMEFT operators

Benchmark	Experiment	$\sqrt{s}$ (GeV)	L (ab^{-1})	$\|c_{e\varphi}/\Lambda^2\|(\mathrm{TeV}^{-2})$	$\|c_{et}/\Lambda^2\|(\mathrm{TeV}^{-2})$
1	FCC-ee	350	2.6	< 0.003 (< 0.004)	< 0.116 (< 0.146)
2	CLIC	380	0.5	< 0.004 (< 0.006)	< 0.143 (< 0.184)
3	ILC	500	4	< 0.003 (< 0.004)	< 0.068 (< 0.083)
4	CLIC	1500	1.5	< 0.003 (< 0.003)	< 0.027 (< 0.035)
5	CLIC	3000	3.0	< 0.002 (< 0.002)	< 0.012 (< 0.015)

Table 1: 95 % CL intervals for each operator coefficients.

The bounds on c_{et} probe scales of the order $\mathcal{O}(10\,\mathrm{TeV})$ while the $c_{e\varphi}$ operator probes scales of the order $\mathcal{O}(1\,\mathrm{TeV})$.

The operator c_{et} has stringent bounds in the process $e^+e^- \to t\bar{t}$: of the order $\mathcal{O}(10^{-3}\,\mathrm{TeV}^{-2})$[2]. The operator $c_{e\varphi}$ is constrained by using measurements in the $h \to e^+e^-$, of the order of $\mathcal{O}(10^{-4} - 10^{-3})$.

[2] [*Durieux, Perello, Vos & Zhang, 2018*]

Sommerfeld Enhancement

Light singlet SM extension

- If a new light scalar ϕ couples to the Higgs in the low energy:

$$\mathcal{L} \supset \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{m_\phi^2}{2}\phi^2 - \kappa\phi h^2\,. \tag{4}$$

- The exchange of ϕ in the final state generates a yukawa potential in the non-relativistic limit for the Higgs.

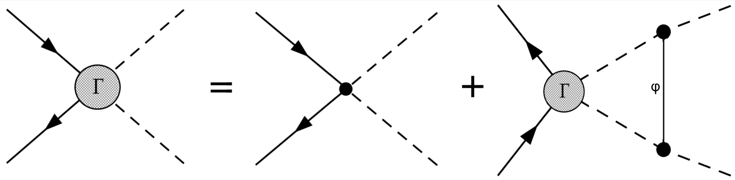


Figure 3: Recursion Relation for the ladder type diagrams for the ϕ exchange.

Sommerfeld Enhancement

This can generate a Sommerfeld like enhancement[3] on the cross-section:

$$\sigma(e^+e^- \to hh) = \sigma_{\rm SM}(e^+e^- \to hh)R(E)\,, \tag{5}$$

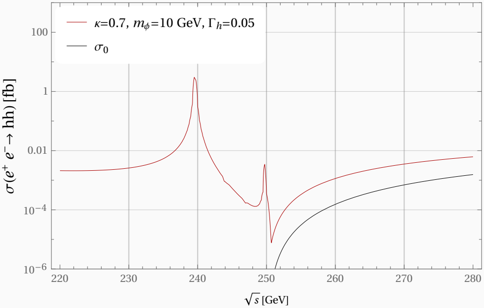


Figure 4: Preliminary plot for the cross-section enhancement.

[3]Similar effect as the one in $e^+e^- \to t\bar{t}$ [*1990, M.Strassler and M.Peskin*] and $e^+e^- \to \tilde{t}\bar{\tilde{t}}$ [*1992, V.Khoze, V.S Fadin and I.I Bigi*]

Phenomenology of this model (on going study)

- The SM $e^+e^- \to hh$ cross-section is so small and a enhancement due to new physics can potentially be probe near threshold. (Relevant for ILC at 250GeV, $L = 4\,\text{ab}^{-1}$)
- We can potentially probe this enhancements in other channels like VBF, Zhh...
- This can be extended to different effective operators for the higgs-electron interaction that would in principle give different enhancement factors.

Backup

Green Function and Green function Equation

The green function equation for the Sommerfeld enhancement in this case is:

$$\left[-\frac{\nabla}{m_h} - E - i\Gamma_h + V(r)\right] \partial^i G(E, |\vec{r} - \vec{r}'|) = i\partial^i \delta^3(\vec{r} - \vec{r}')\,. \qquad (6)$$

$$R(E) = \frac{\nabla^2 \operatorname{Im} G(0,0)}{\nabla^2 \operatorname{Im} G_{\mathsf{free}}(0,0)} \qquad (7)$$

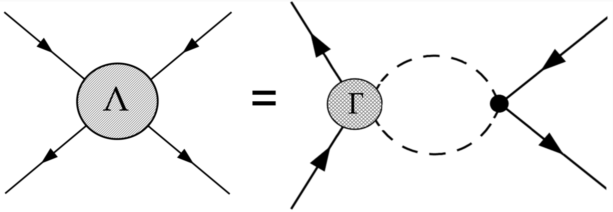


Figure 5: Optical Theorem.