Indirect constraints on poorly constrained SMEFT operators

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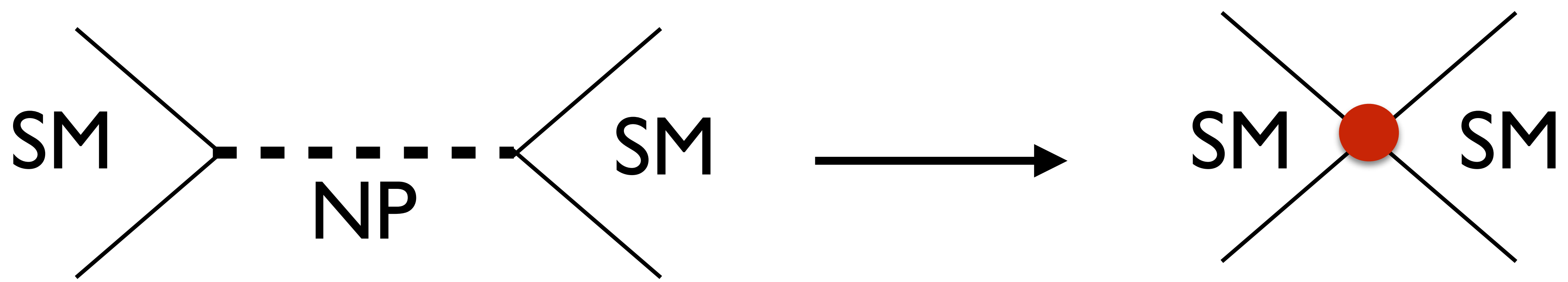
Effective Field Theories are an useful tool in our search for physics beyond the SM



We can exchange the unknown NP with a known EFT

Assume the SM is low energy limit of an EFT

$$\mathscr{L}_{SMEFT} = \mathscr{L}_{SM} + \sum_{k=5} \sum_{i} \frac{\mathscr{C}_i^k}{\Lambda^{k-4}} \mathscr{O}_i^k$$

Scale of new physics

Operators respect SM gauge symmetries

Assumptions: no "light" particles; Higgs is part of a SU(2) doublet.

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Scale of new physics (Λ^{k-4})

Operators respect SM gauge symmetries ($\mathscr{O}_i^k$)

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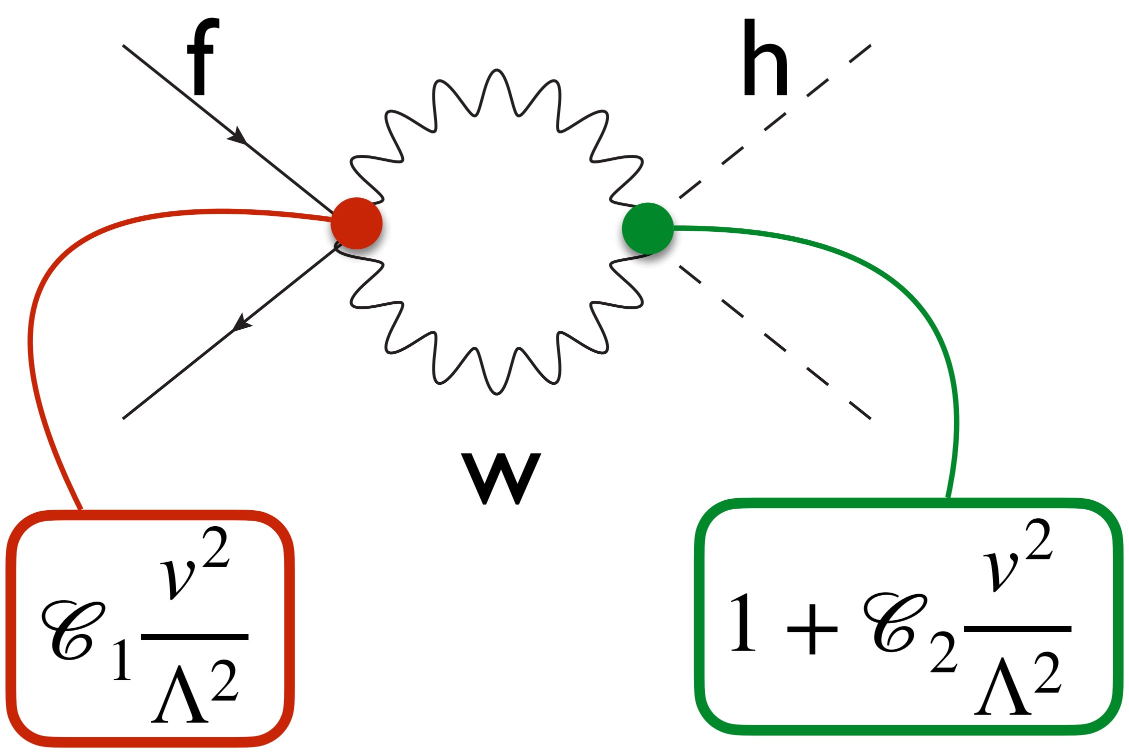
The theory is renormalizable order by order in Λ

There is a definition of renormalization that allows to calculated loop corrections in SMEFT



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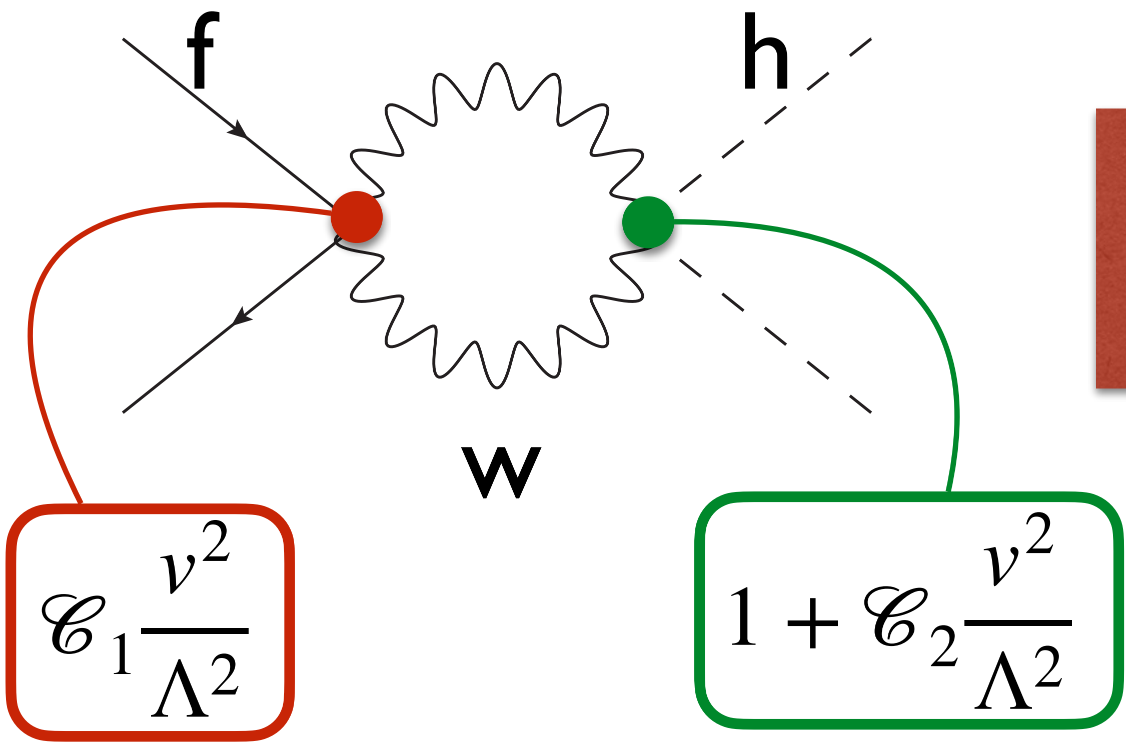
Operatively that means to fix the power of Λ and throw away anything that carries higher powers of Λ



$\propto \mathscr{C}_1 \frac{v^2}{\Lambda^2}$

The term $\mathscr{C}_1 \mathscr{C}_2 \frac{v^4}{\Lambda^4}$ is simply thrown away

A generic process can be expressed as:

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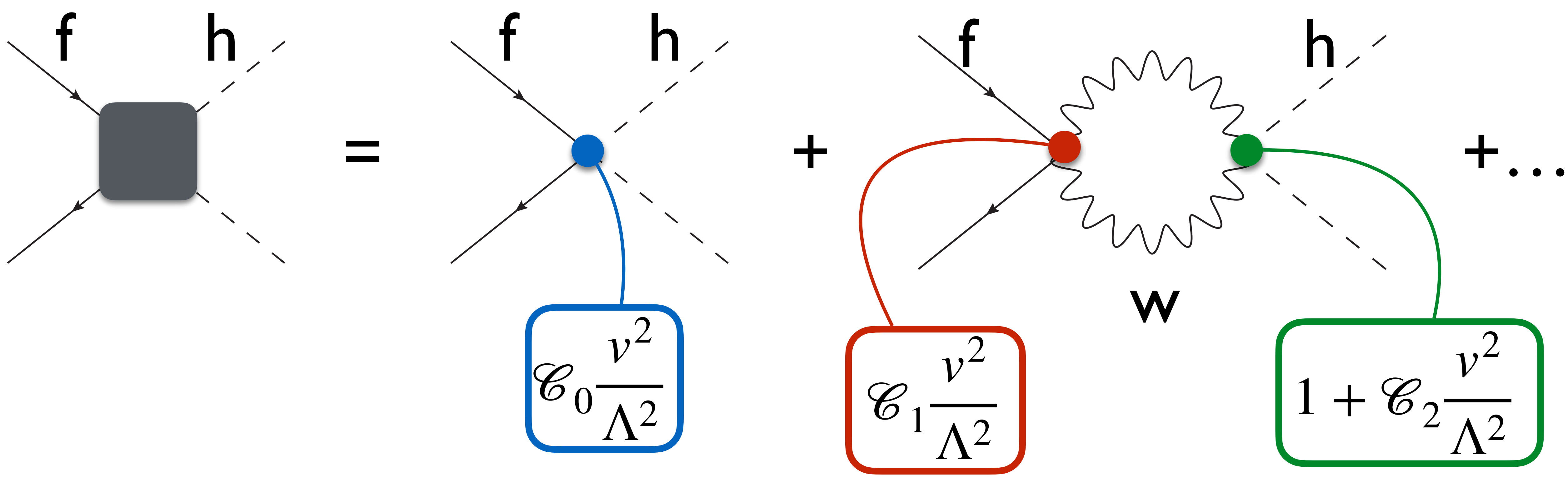

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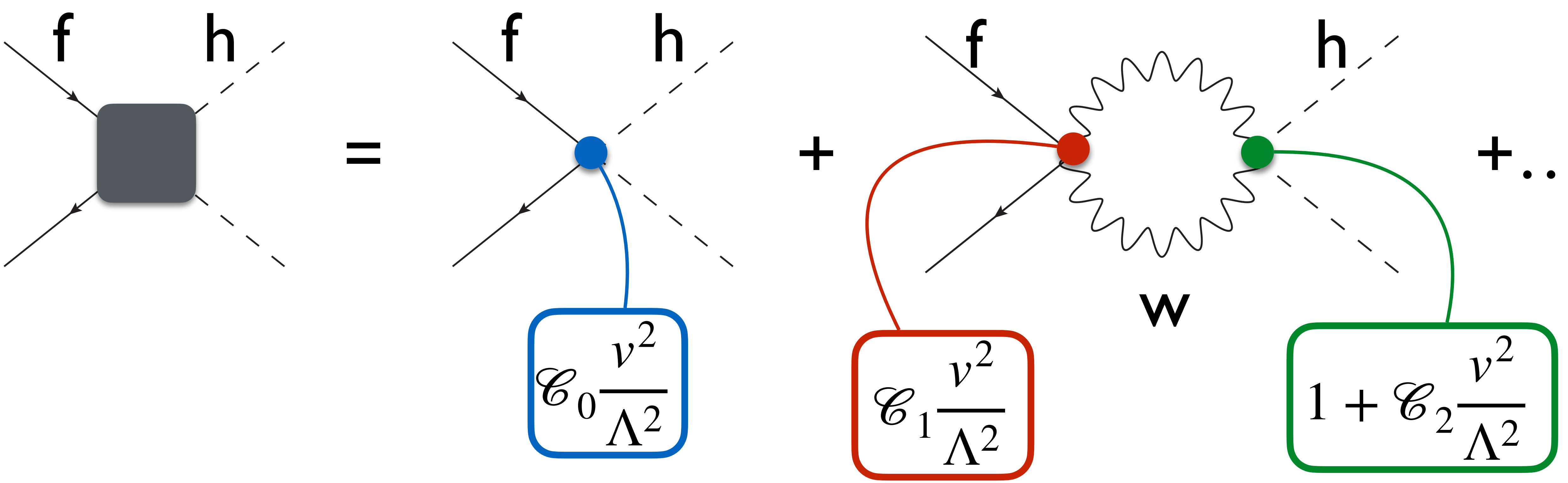
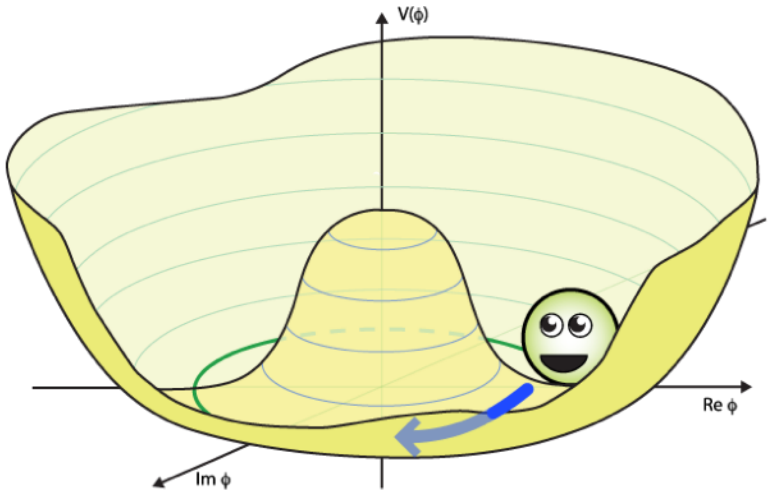


If we have $\mathscr{C}_0$ "under control" we can obtain info on $\mathscr{C}_1$ from $ff \to HH$ without measuring $ff \to WW$

Indirect measurements help constrain the Higgs trilinear from single-Higgs processes:



$$V(H) = \frac{1}{2}M_H^2 H^2 + \frac{M_H^2}{2v}H^3 + \frac{M_H^2}{8v^2}H^4$$

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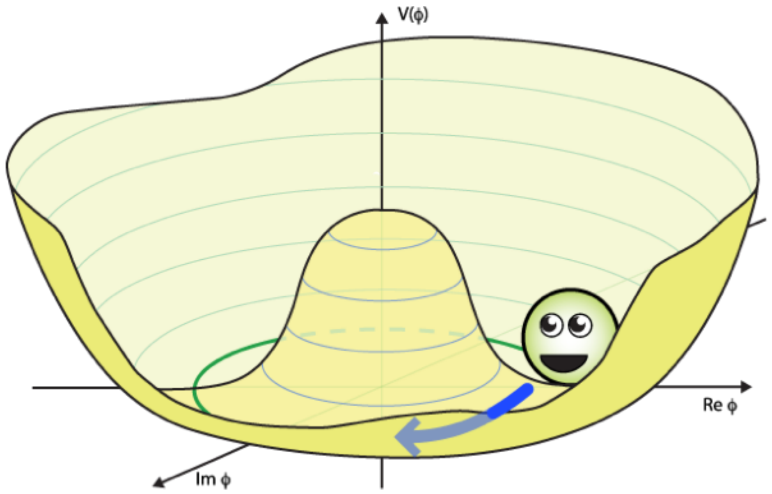

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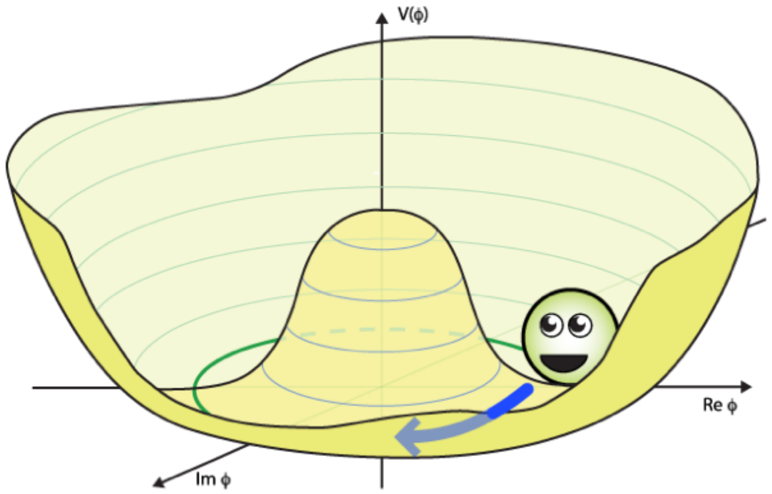

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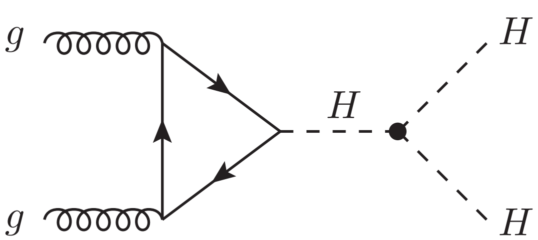
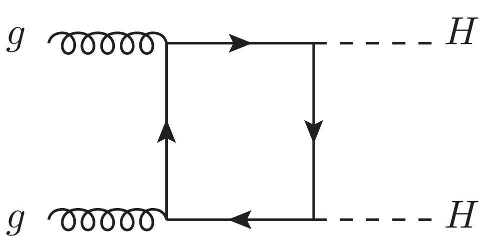
This is not the same EFT of SMEFT but it is related

Measuring the Higgs potential

Modifications to the Higgs trilinear can appears in different channels

Extraction of λ_3 from direct searches





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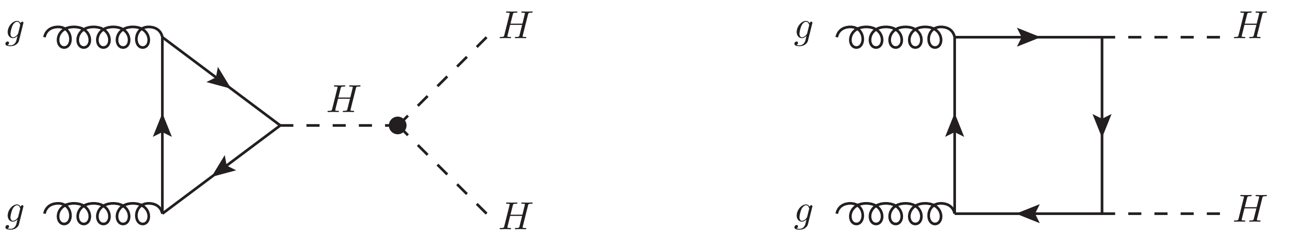

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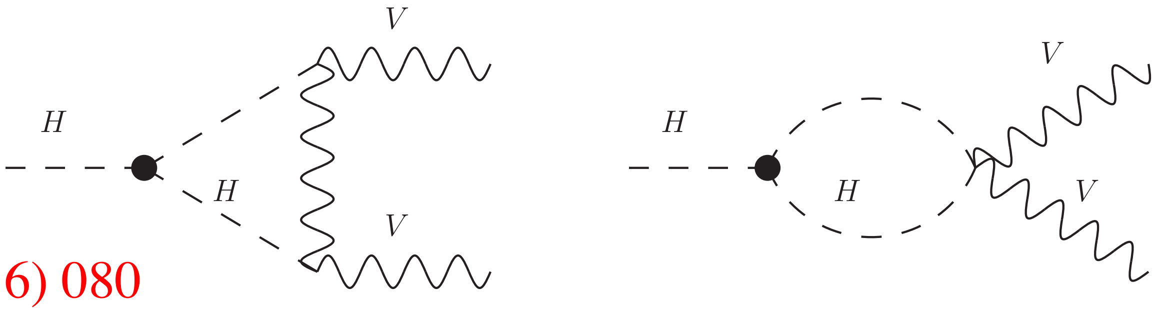
G. Degrassi, **PPG**, F. Maltoni, D. Pagani, JHEP 1612 (2016) 080



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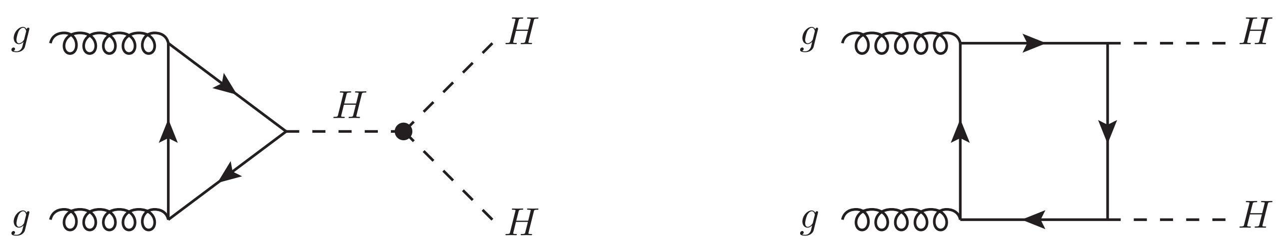

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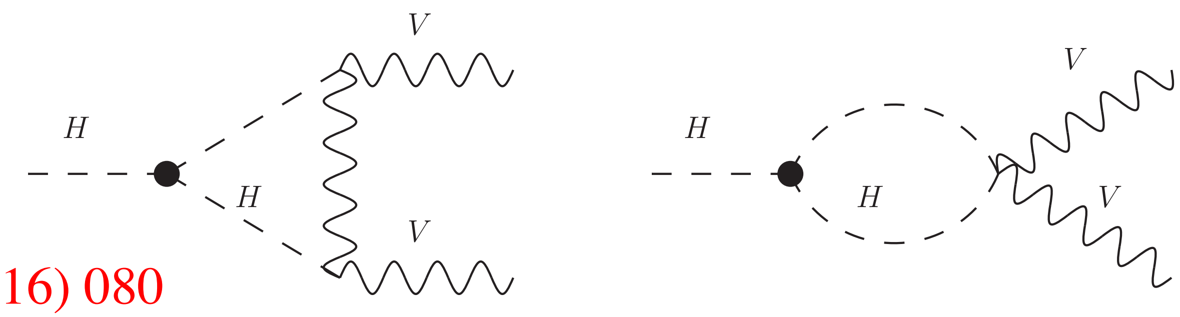

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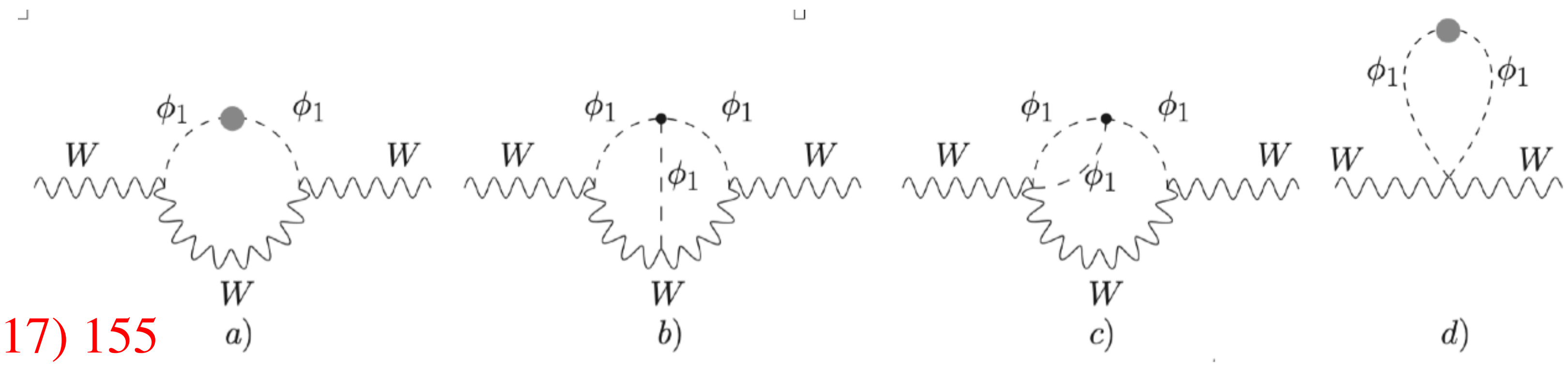
Extraction of λ_3 from precision observables



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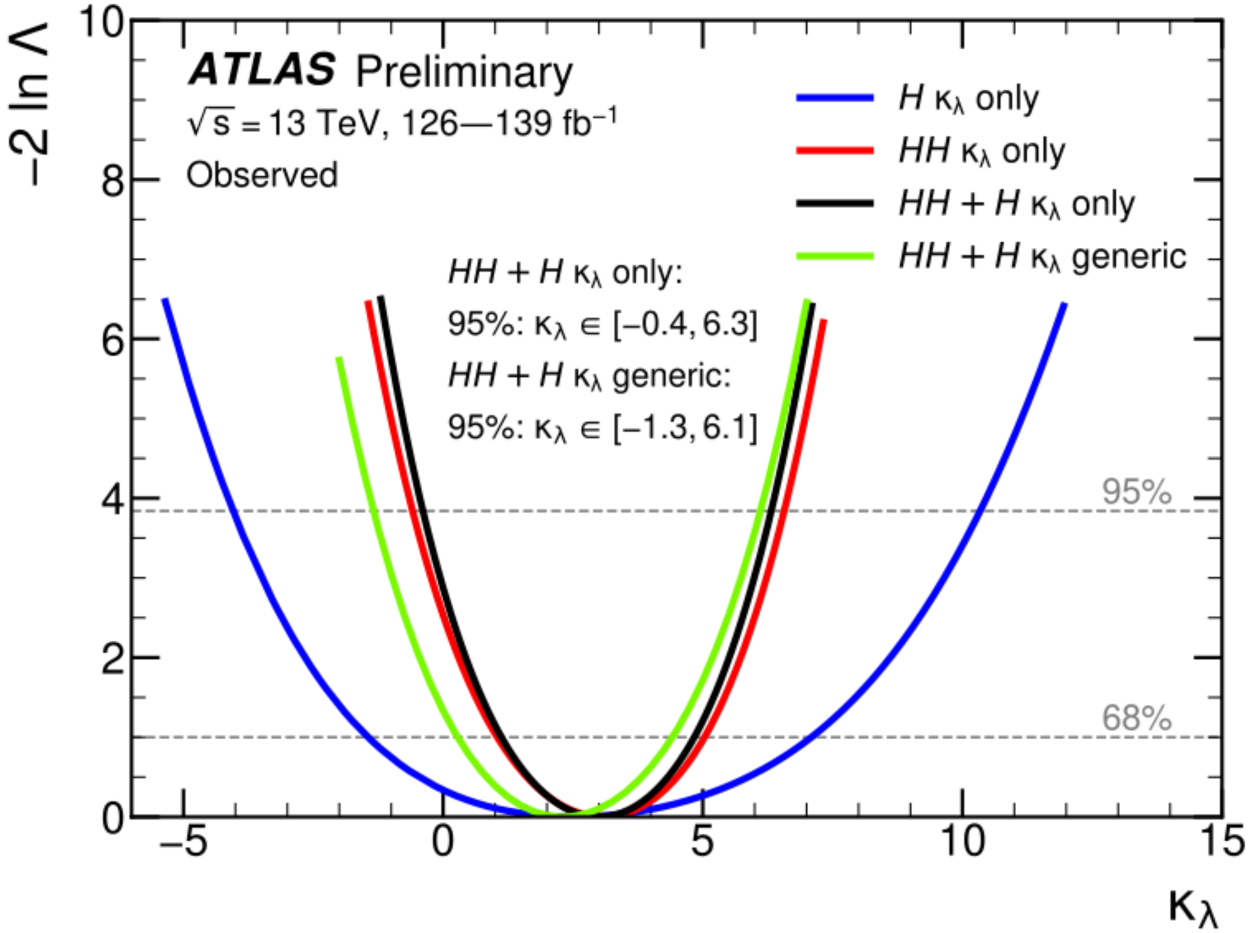
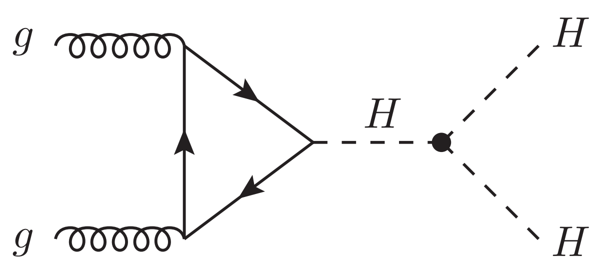
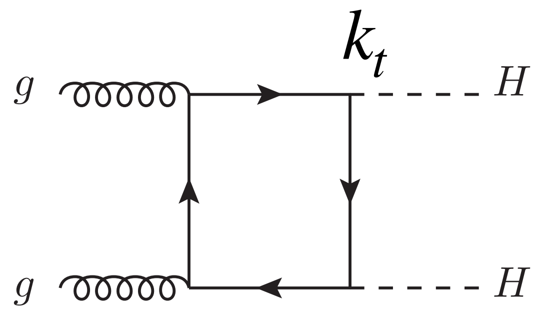


Nowadays the HH bounds are stronger than H bounds

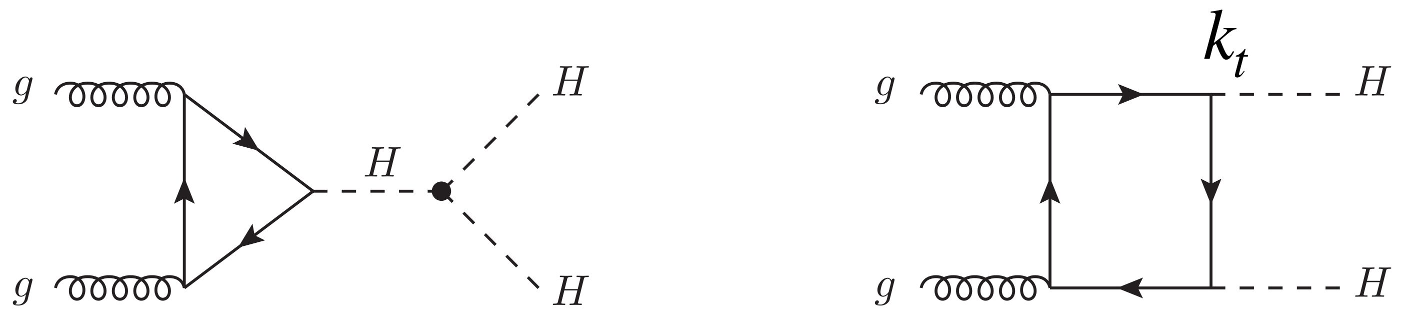
Single-H helps improving the HH bounds

Combination assumption	Obs. 95% CL	Exp. 95% CL	Obs. value$^{+1\sigma}_{-1\sigma}$
HH combination	$-0.6 < \kappa_\lambda < 6.6$	$-2.1 < \kappa_\lambda < 7.8$	$\kappa_\lambda = 3.1^{+1.9}_{-2.0}$
Single-H combination	$-4.0 < \kappa_\lambda < 10.3$	$-5.2 < \kappa_\lambda < 11.5$	$\kappa_\lambda = 2.5^{+4.6}_{-3.9}$
HH+H combination	$-0.4 < \kappa_\lambda < 6.3$	$-1.9 < \kappa_\lambda < 7.5$	$\kappa_\lambda = 3.0^{+1.8}_{-1.9}$
HH+H combination, κ_t floating	$-0.4 < \kappa_\lambda < 6.3$	$-1.9 < \kappa_\lambda < 7.6$	$\kappa_\lambda = 3.0^{+1.8}_{-1.9}$
HH+H combination, κ_t, κ_V, κ_b, κ_τ floating	$-1.3 < \kappa_\lambda < 6.1$	$-2.1 < \kappa_\lambda < 7.6$	$\kappa_\lambda = 2.3^{+2.1}_{-2.0}$





Higgs Pair production is sensitive to anomalous top couplings.



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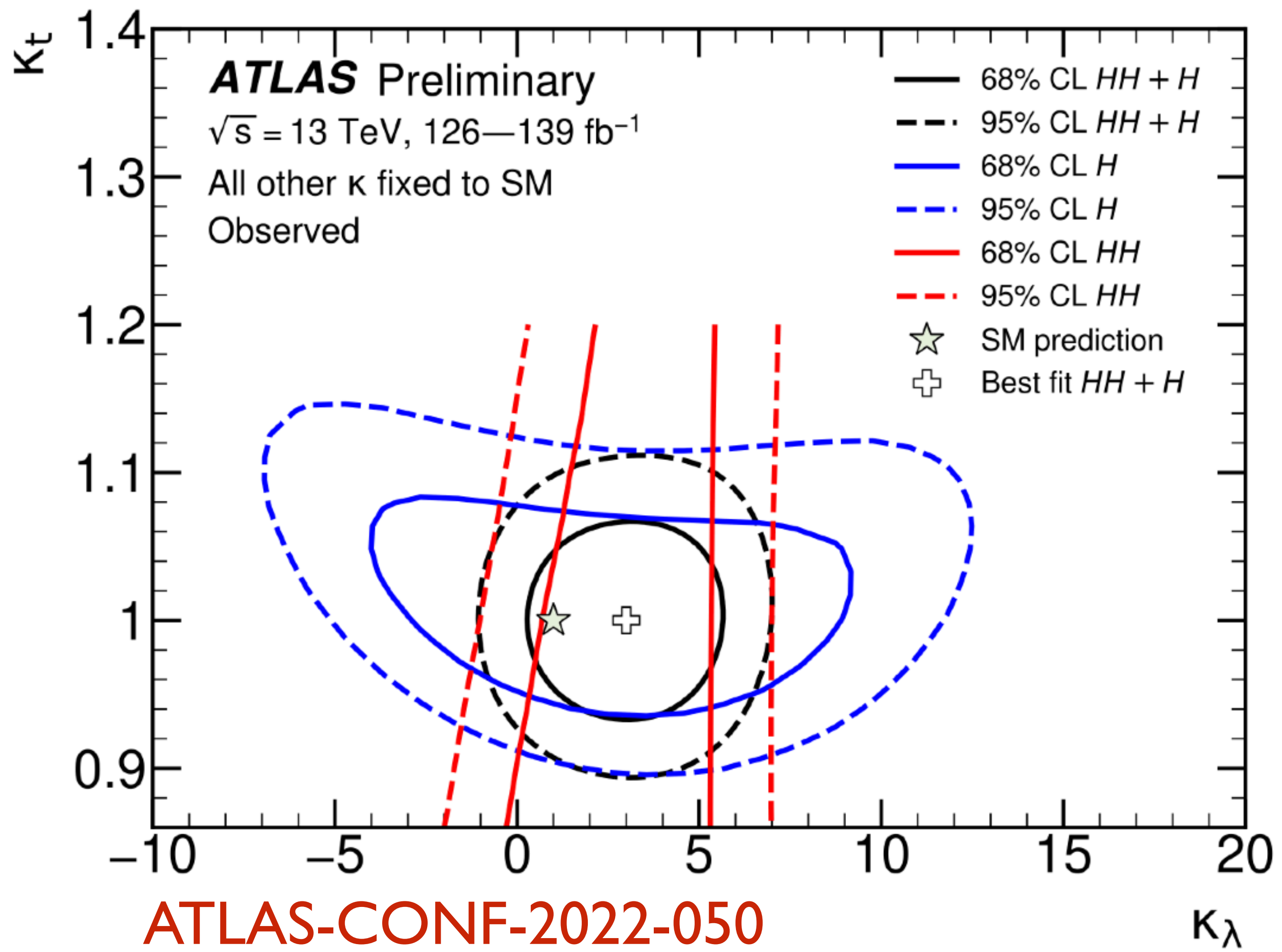

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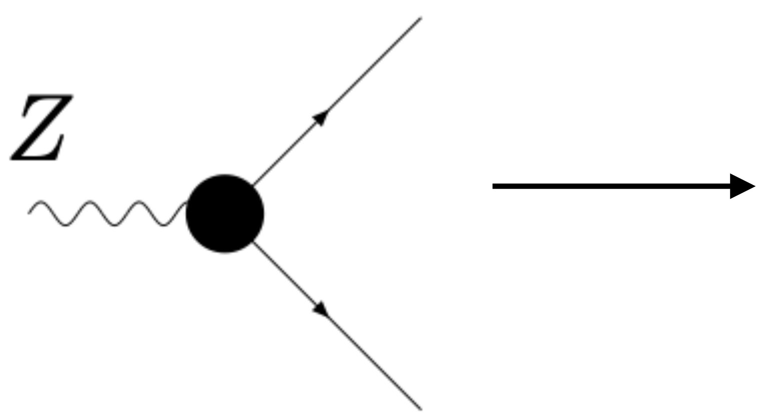
Bounds from single Higgs measurements give information on other directions in parameter space

Top observables in Electroweak precision observables

In the SMEFT* the EWPO depend on a set of 10 operators at LO



$\mathcal{O}_{ll}$	$(\bar{l}\gamma_\mu l)(\bar{l}\gamma^\mu l)$	$\mathcal{O}_{\phi WB}$	$(\phi^\dagger\tau^a\phi)\, W^a_{\mu\nu}B^{\mu\nu}$	$\mathcal{O}_{\phi D}$	$(\phi^\dagger D^\mu\phi)^*\,(\phi^\dagger D_\mu\phi)$
$\mathcal{O}_{\phi e}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\,\phi)(\bar{e}_R\gamma^\mu e_R)$	$\mathcal{O}_{\phi u}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\,\phi)(\bar{u}_R\gamma^\mu u_R)$	$\mathcal{O}_{\phi d}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\,\phi)(\bar{d}_R\gamma^\mu d_R)$
$\mathcal{O}^{(3)}_{\phi q}$	$(\phi^\dagger i\overleftrightarrow{D}^a_\mu\,\phi)(\bar{q}\tau^a\gamma^\mu q)$	$\mathcal{O}^{(1)}_{\phi q}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\,\phi)(\bar{q}\tau^a\gamma^\mu q)$	$\mathcal{O}^{(3)}_{\phi l}$	$(\phi^\dagger i\overleftrightarrow{D}^a_\mu\,\phi)(\bar{l}\tau^a\gamma^\mu l)$
$\mathcal{O}^{(1)}_{\phi l}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\,\phi)(\bar{l}\tau^a\gamma^\mu l)$				

Mostly include modifications of the Z verteces

*in the Warsaw basis

At NLO EWPO give us indirect info on 4-fermion interactions

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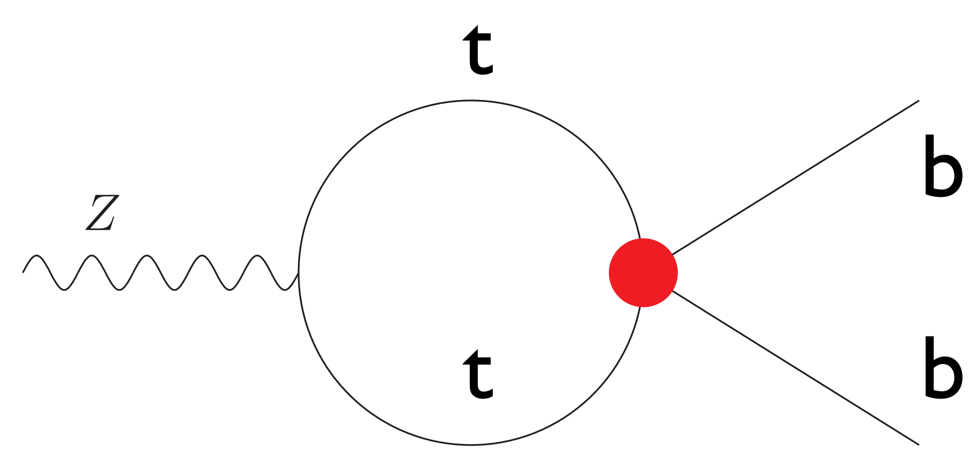

$$\mathcal{O}^{(1)}_{qq,[rstp]} \quad (\bar{q}_{L,r}\gamma_\mu q_{L,s})(\bar{q}_{L,t}\gamma^\mu q_{L,p})$$

$$\mathcal{O}^{(3)}_{qq,[rstp]} \quad (\bar{q}_{L,r}\gamma_\mu \sigma^A q_{L,s})(\bar{q}_{L,t}\gamma^\mu \sigma^A q_{L,p})$$

4-fermion interactions involving tops are particularly relevant

Direct searches

Operator	EWPO	$t\bar{t}(1/\Lambda^2)$	$t\bar{t}(1/\Lambda^4)$
$\frac{C^{(1)}_{QQ}}{\Lambda^2} \equiv 2\frac{C^{(1)}_{qq,[3333]}}{\Lambda^2} - \frac{2}{3}\frac{C^{(3)}_{qq,[3333]}}{\Lambda^2}$	[-1.61,2.68]	[-6.132, 23.281]	[-2.229,2.019]
$\frac{C^{(8)}_{QQ}}{\Lambda^2} \equiv 8\frac{C^{(3)}_{qq,[3333]}}{\Lambda^2}$	[-15.23,25.41]	[-26.471,57.778]	[-6.812,5.834]
$\frac{C^{(1)}_{Qt}}{\Lambda^2} \equiv \frac{C^{(1)}_{qu,[3333]}}{\Lambda^2}$	[-2.24,1.35]	[-195,159]	[-1.830,1.862]

S. Dawson, PPG; Phys.Rev.D105(2022)7, 073006

SMEFiT Collaboration; arXiv: 2105.00006

CP violating operators in the Higgs sector

K. Asteriadis, S. Dawson, P.P.G, R. Szafron; arXiv:2406.

CP violating operators in the Higgs sector

In particular we concentrate on 3 operators

$$\mathcal{O}_{\phi\tilde{W}} = \phi^\dagger\phi\tilde{W}_{\mu\nu}W^{\mu\nu} \qquad \mathcal{O}_{\phi\tilde{B}} = \phi^\dagger\phi\tilde{B}_{\mu\nu}B^{\mu\nu}$$

$$\mathcal{O}_{\phi\tilde{W}B} = \phi^\dagger\tau^i\phi\tilde{W}^i_{\mu\nu}B^{\mu\nu}$$

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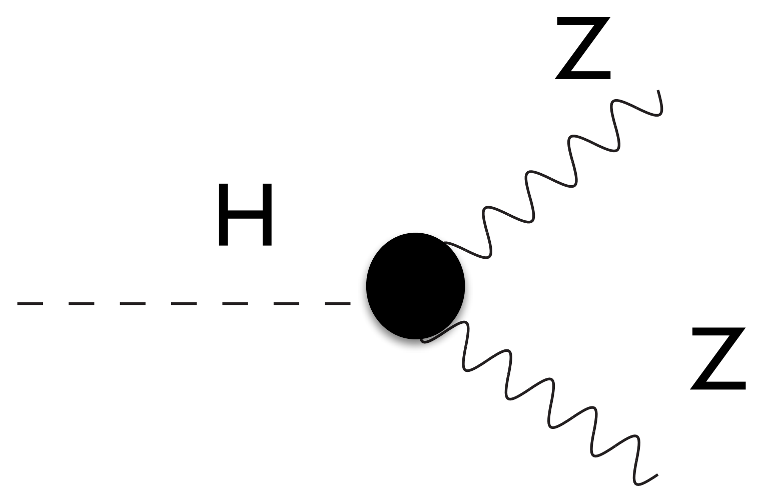
That appear in HVV couplings



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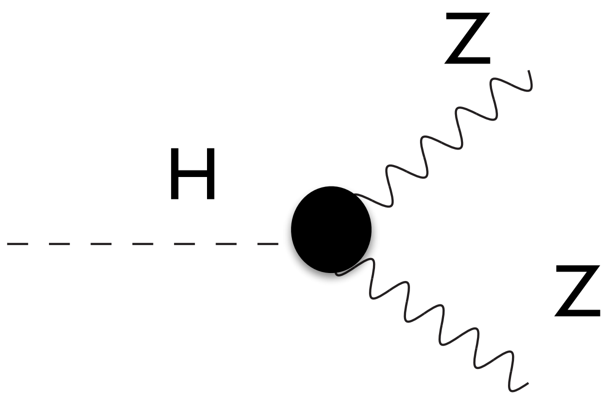
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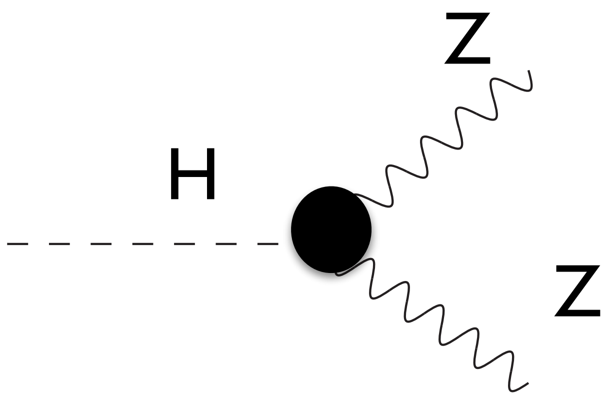
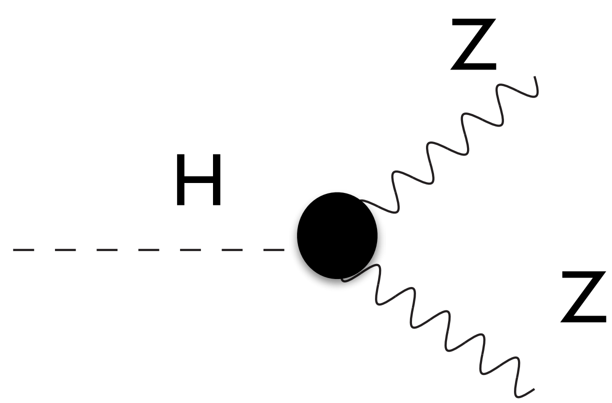


$$\mathscr{A} \sim SM(g^{\mu\nu} - p^{\mu}p^{\nu}) + \mathcal{O}_{CP_V}\epsilon^{\mu\nu\rho\sigma}p_{\rho}p_{\sigma}$$

No interference between SM and EFT



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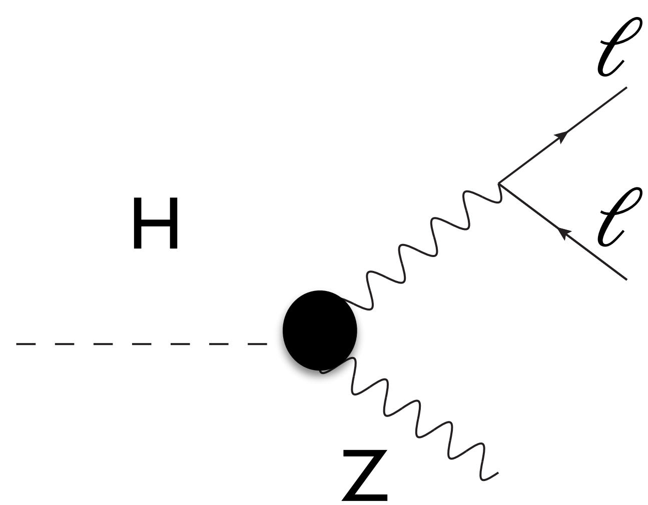
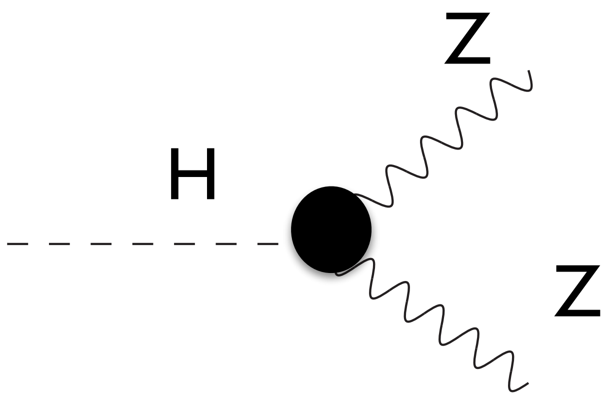


$$\sim Tr[\gamma^{\mu}\gamma^{\nu}\gamma^{\rho}\gamma^{\sigma}\gamma_5] \sim i\epsilon^{\mu\nu\rho\sigma}$$

$$\mathscr{A} \sim SM + i\mathscr{O}_{CP_V}$$

The interference disappears in the square



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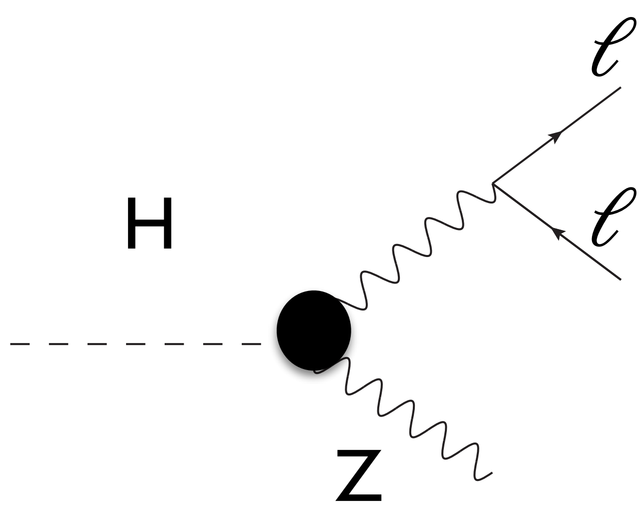

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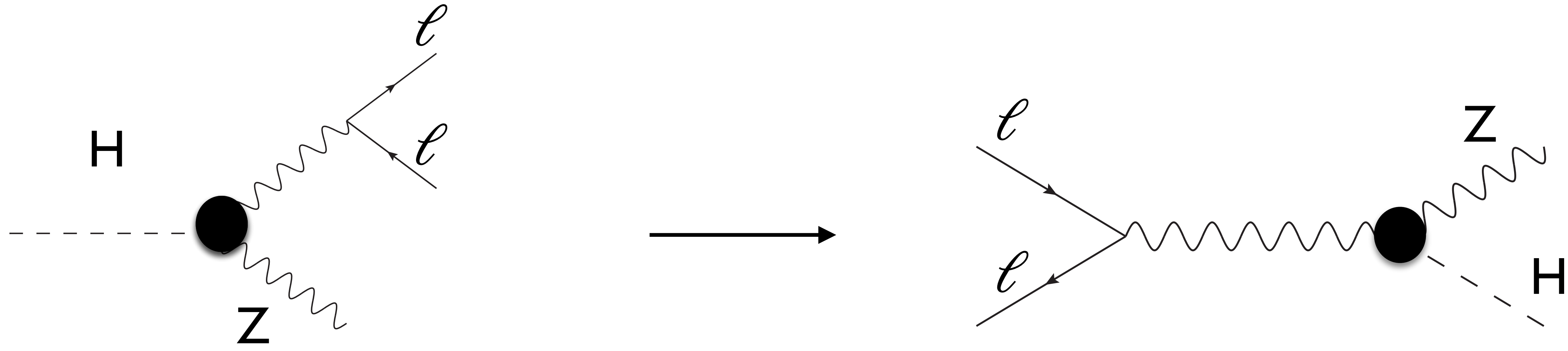
Only quadratic terms in $\mathscr{O}_{CP_V}$ possible

More info on $\mathcal{O}_{CP_V}$ can be ontained if we "rotate" $H \to Z\ell\ell$



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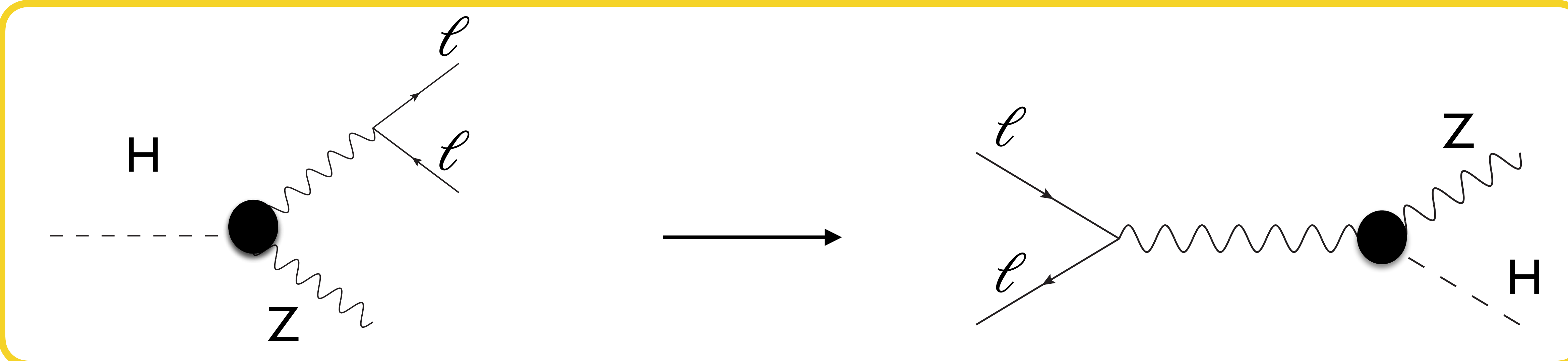
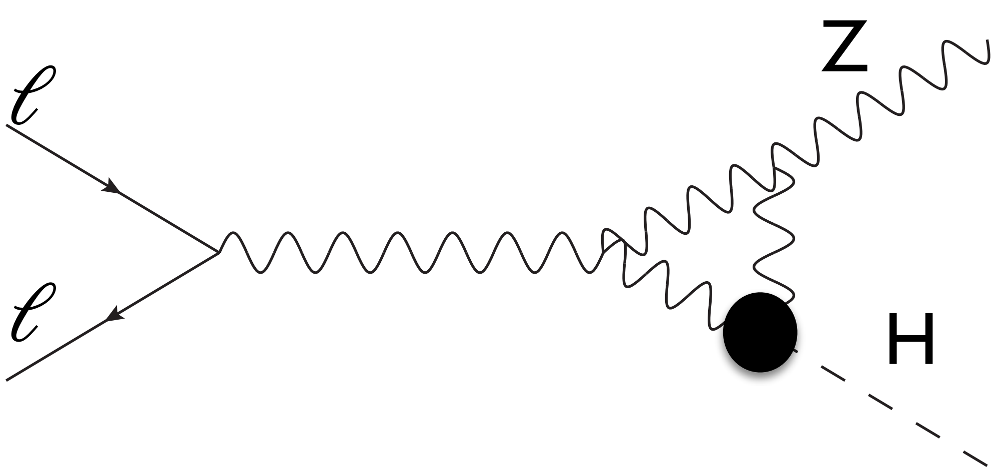


Loop corrections to $\ell\ell \to HZ$ have imaginary parts



$$\mathscr{A} \sim \mathrm{SM}(1 + \mathfrak{R}_{\mathrm{SM}} + \mathrm{i}\mathfrak{I}_{\mathrm{SM}}) + i\mathcal{O}_{CP_V}(1 + \mathfrak{R}_{\mathcal{O}_{CP_V}} + i\mathfrak{I}_{\mathcal{O}_{CP_V}})$$

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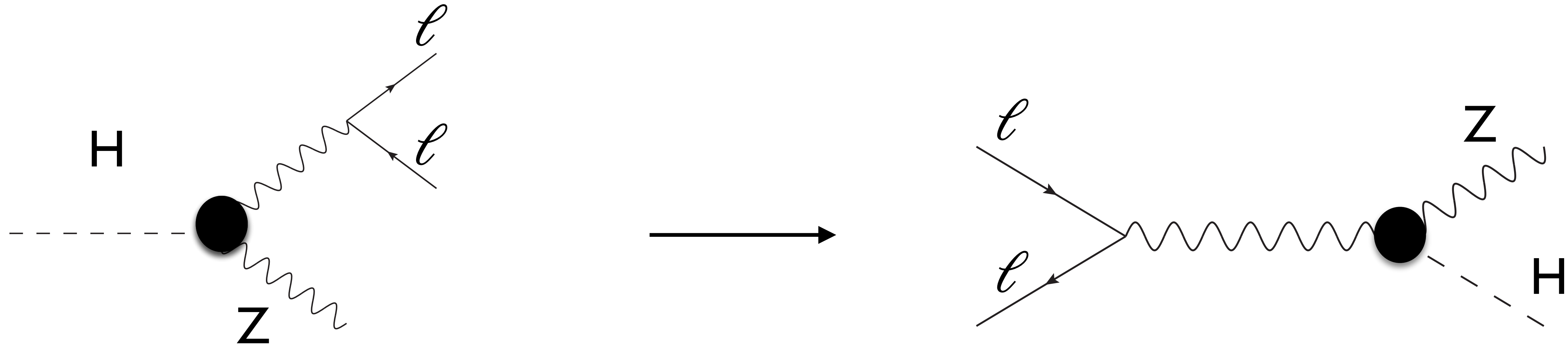

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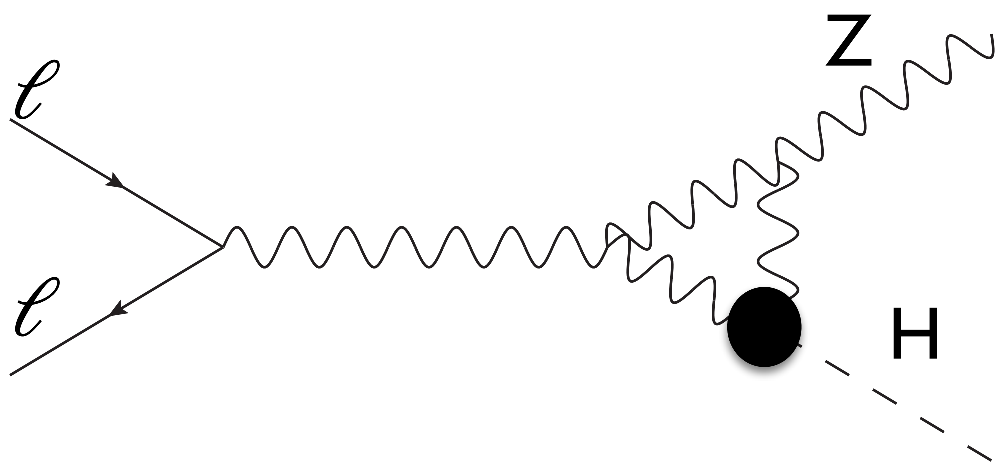


$$\mathscr{A} \sim \mathrm{SM}(1 + \mathfrak{R}_{\mathrm{SM}} + \mathrm{i}\mathfrak{I}_{\mathrm{SM}}) + i\mathcal{O}_{CP_V}(1 + \mathfrak{R}_{\mathcal{O}_{CP_V}} + i\mathfrak{I}_{\mathcal{O}_{CP_V}})$$

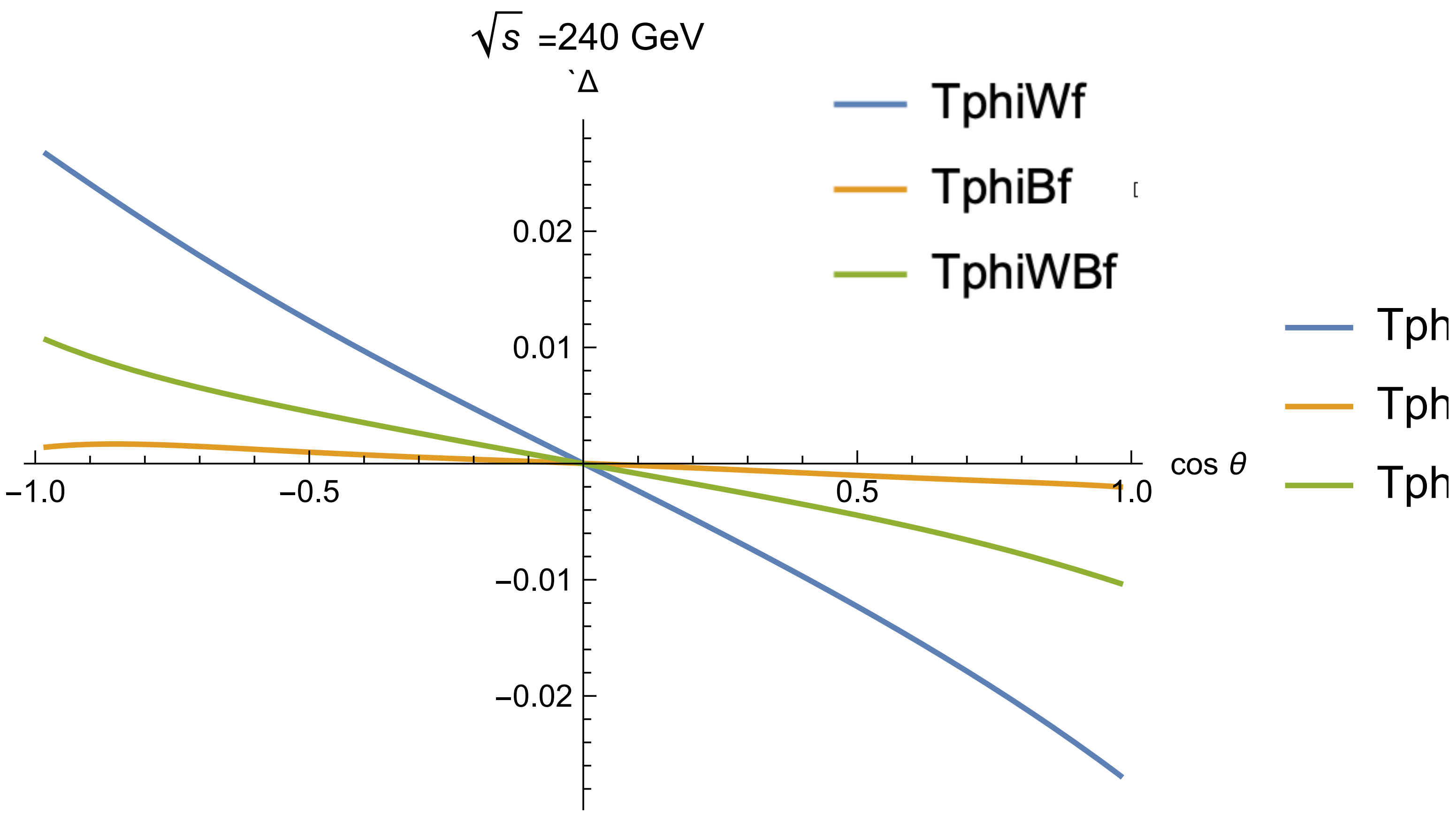
$$|\mathscr{A}|^2 \sim SM^2(1 + 2\mathfrak{R}_{\mathrm{SM}}) + 2SM\mathcal{O}_{CP_V}(\mathfrak{I}_{\mathrm{SM}} - \mathfrak{I}_{\mathcal{O}_{CP_V}})$$

$\mathcal{O}_{CP_V}$ and SM have different dependence on θ_h

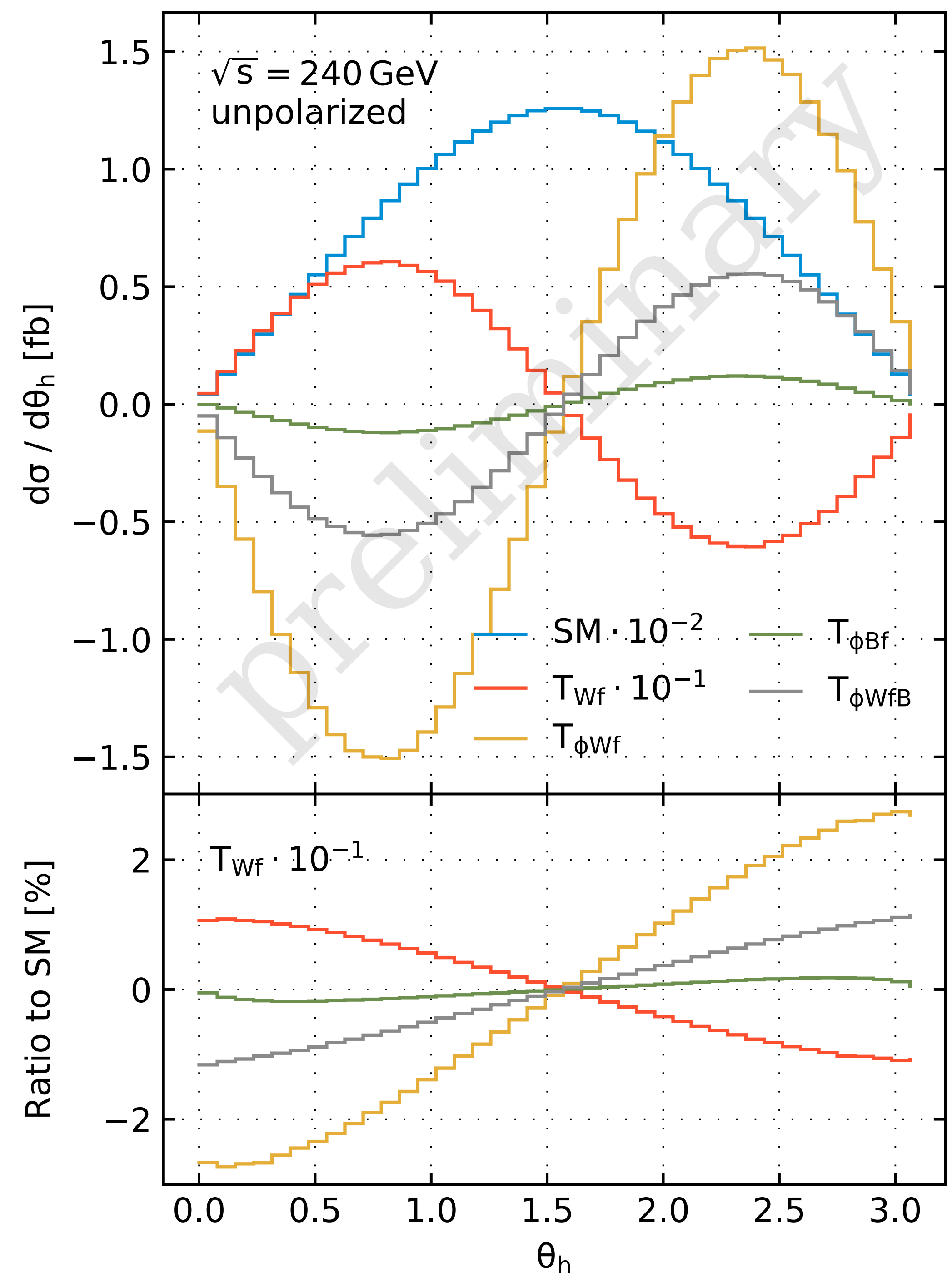
*preliminary study: K. Asteriadis, S. Dawson, P.P.G, R. Szafron; arXiv:2406.

$\mathcal{O}_{CP_V}$ and SM have different dependence on θ_h

Assuming $\Lambda = 1\,\text{TeV}$ and $\mathscr{C} \sim 1$
$\sim 2-3\,\%$ differences* at small angles



Ratio $(d\sigma_{\text{EFT}}/d\cos\theta)/(d\sigma_{\text{SM}}/d\cos\theta)$



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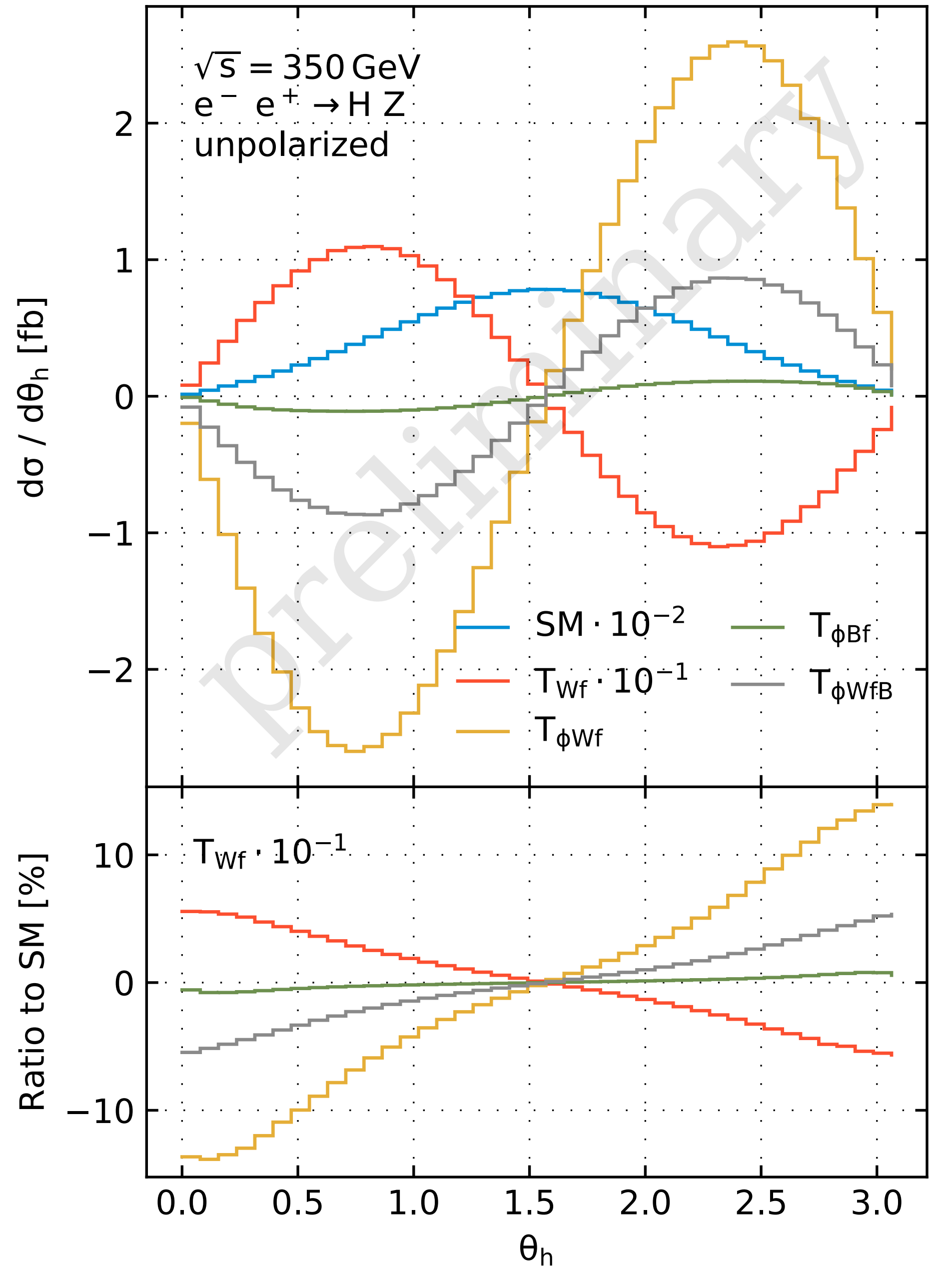
$\mathcal{O}(10\%)$ differences at $\sqrt{s} = 350\,\mathrm{GeV}$



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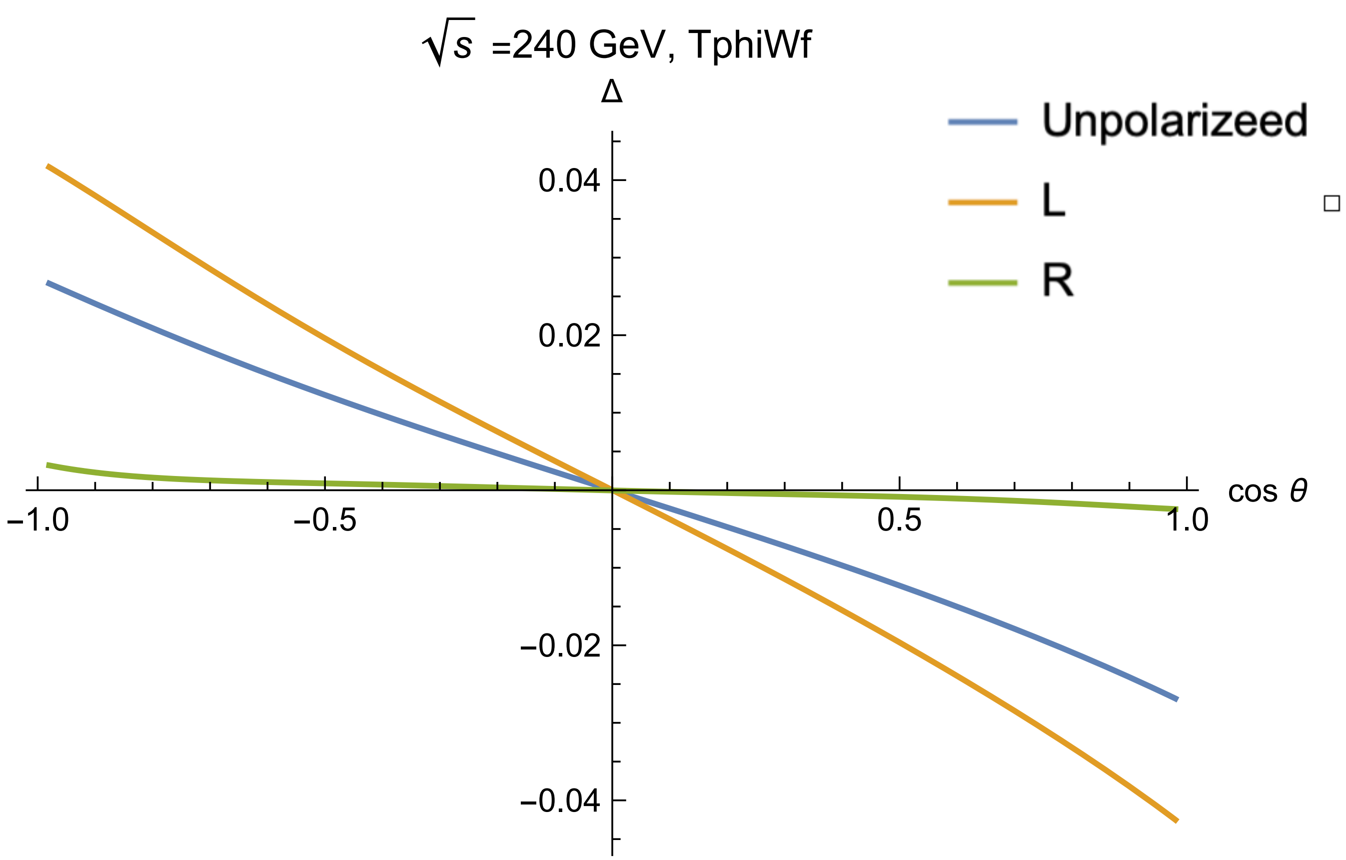
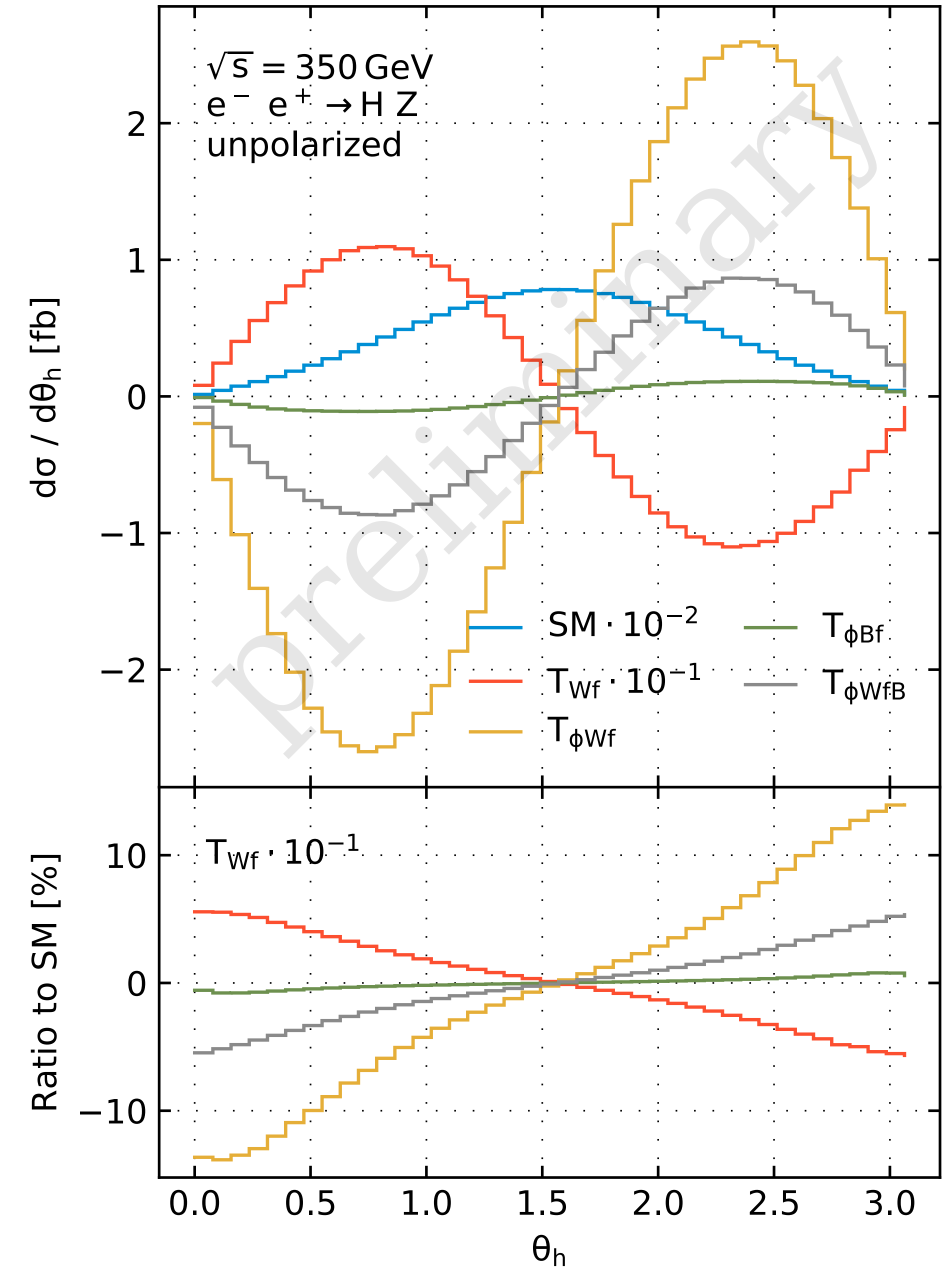
Further info. in polarized-unpolarized σ





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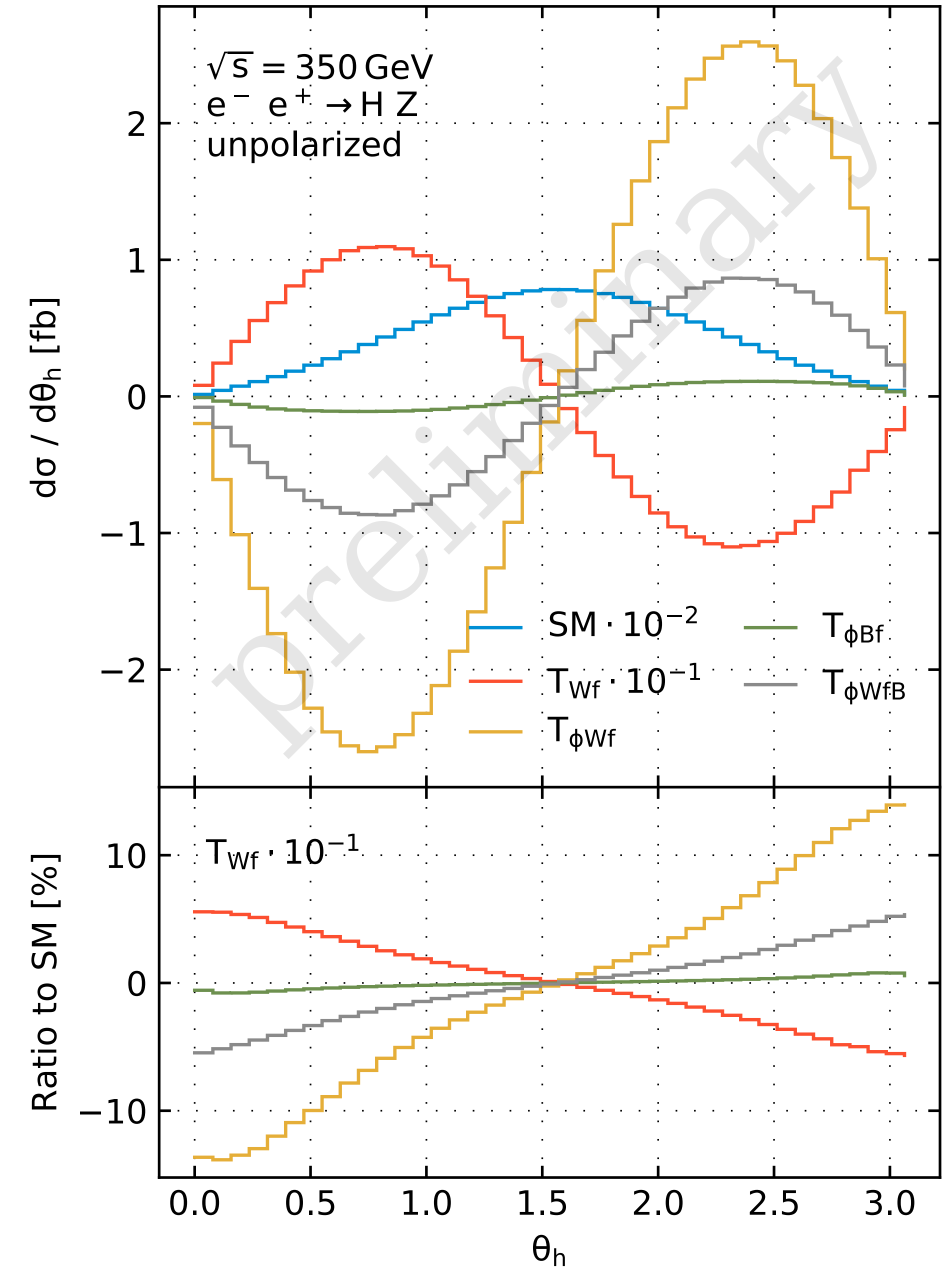
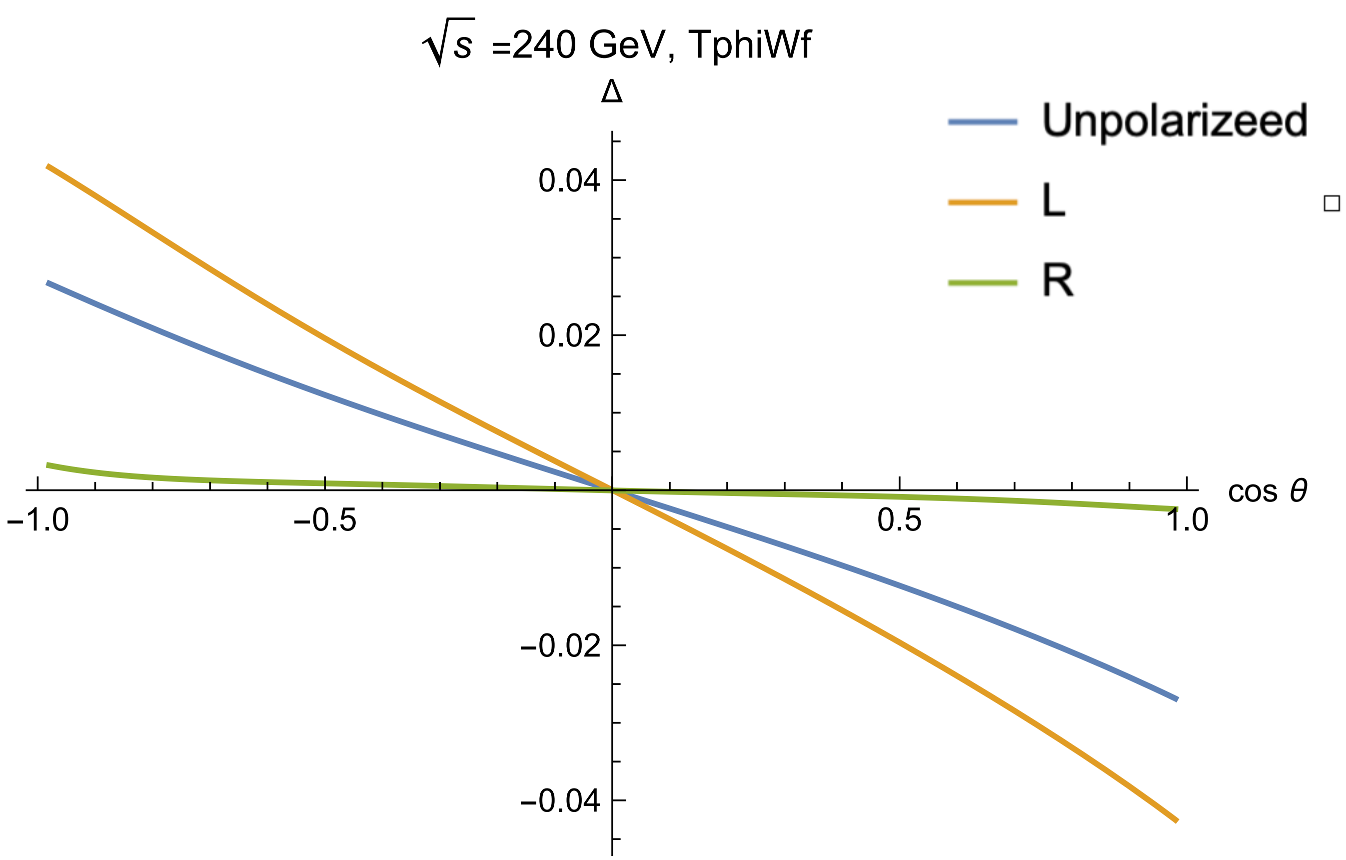
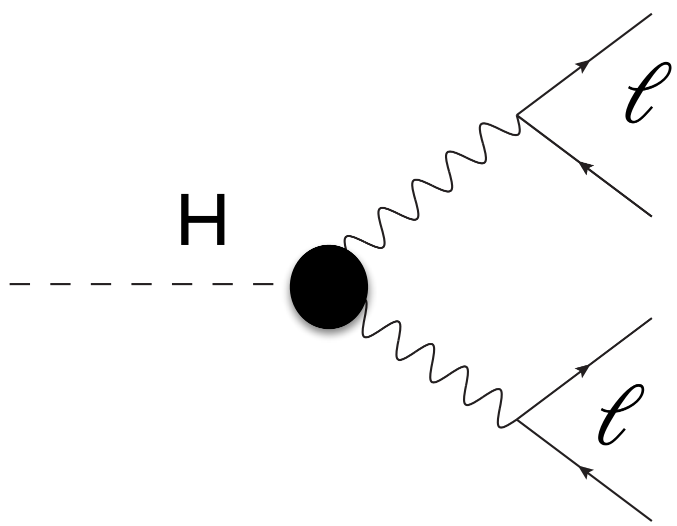


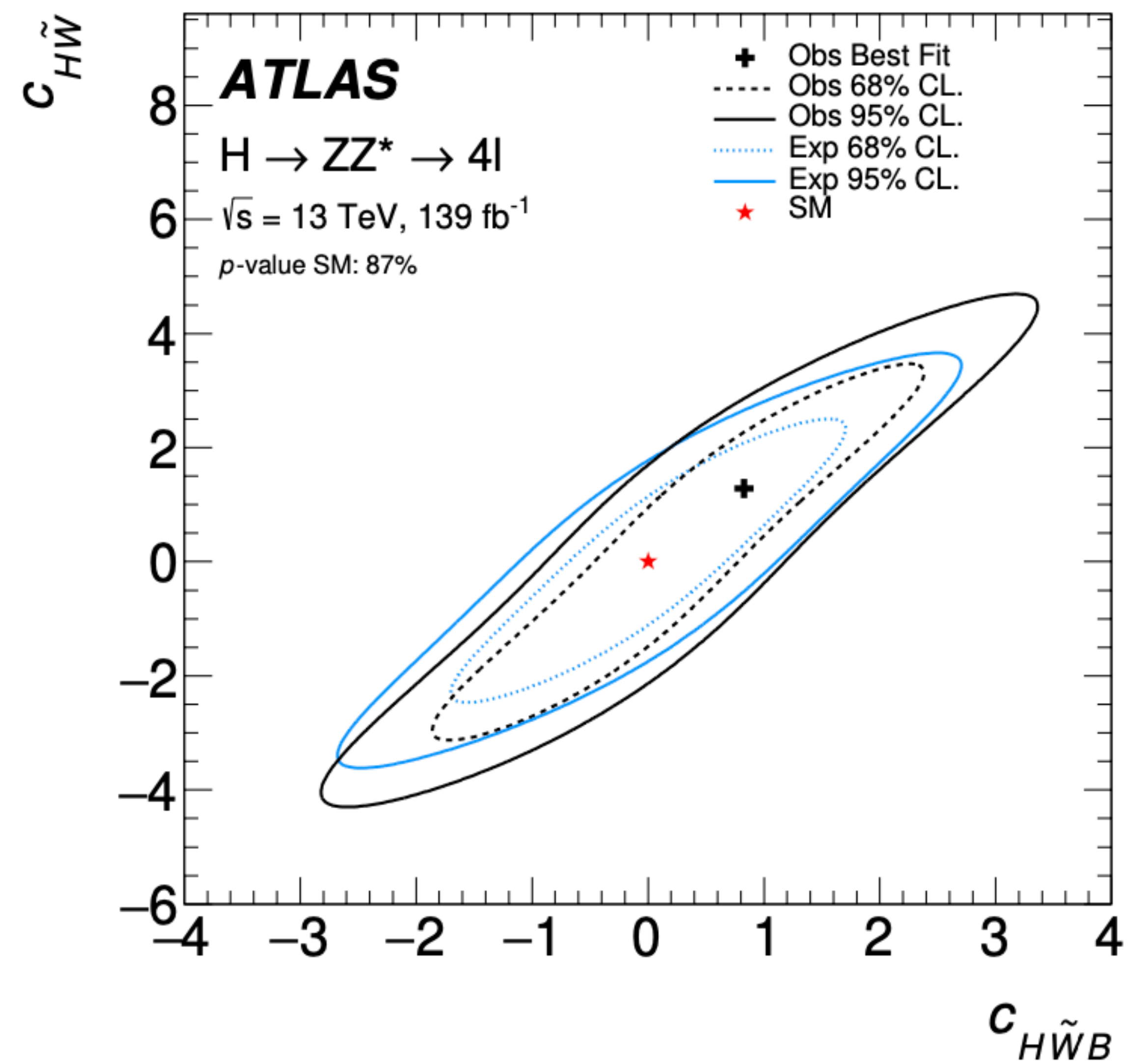


Fcc-ee will be able to put strong* bounds on these operators

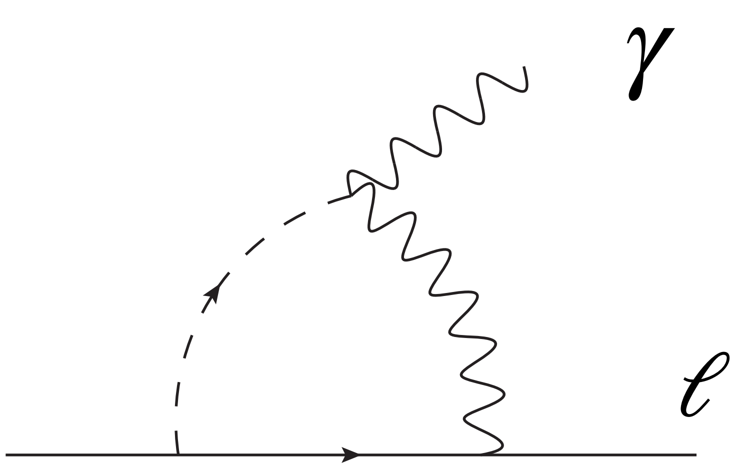
*preliminary study: K. Asteriadis, S. Dawson, P.P.G, R. Szafron; arXiv:2406.

arXiv: 2304.09612



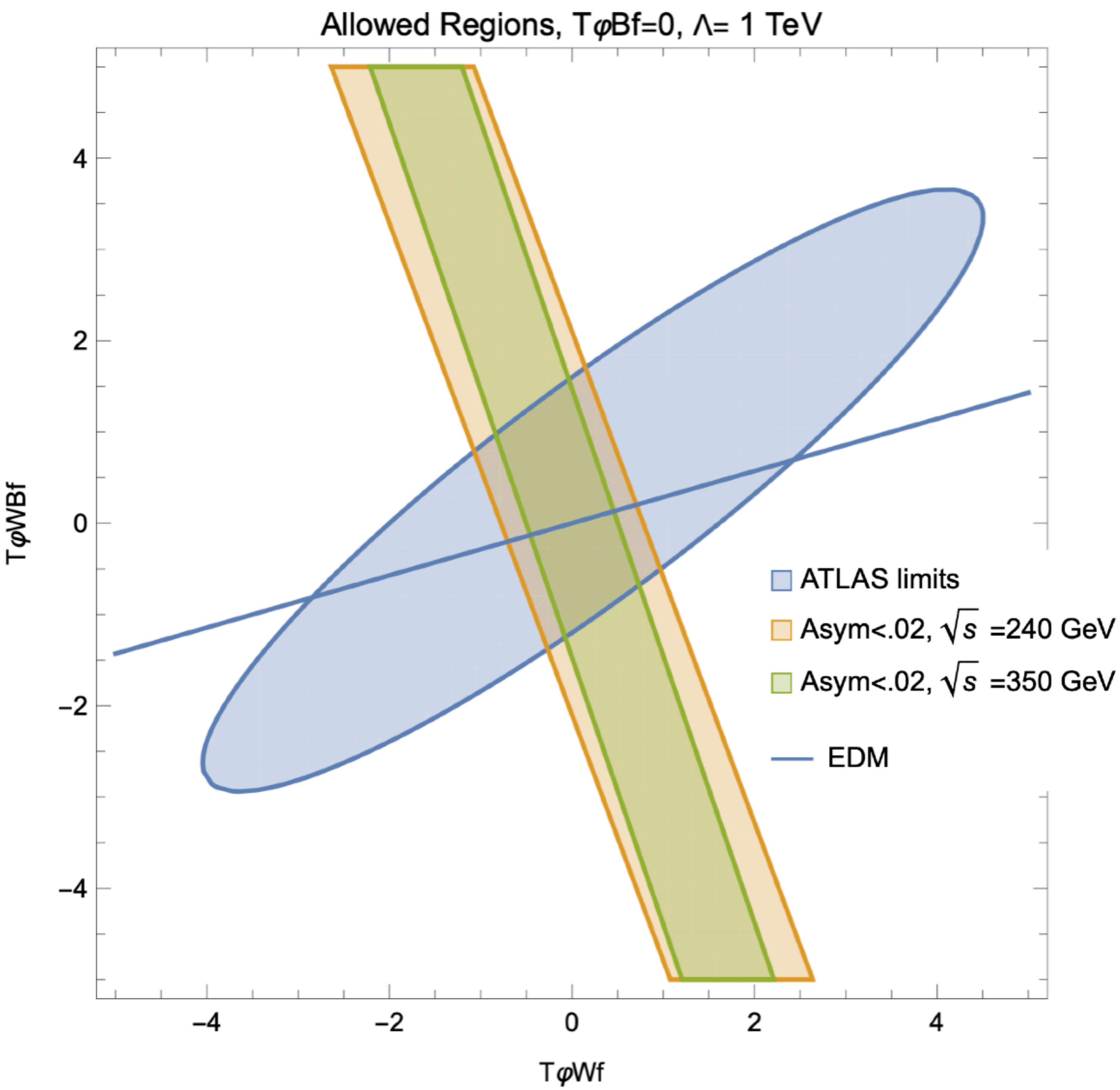


Single limits are $\sim \mathcal{O}(1)$



EDM single Op. limits: $\mathcal{O}_{CP_V} \lesssim 10^{-5}$

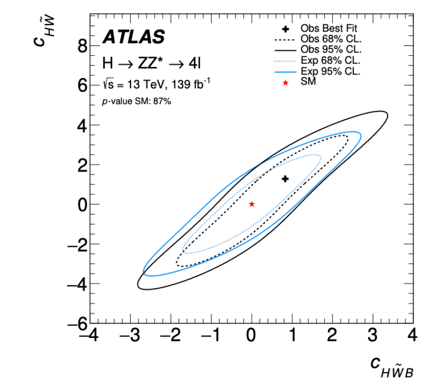
J. Kley, T. Theil, E. Venturini, A. Weiler; arXiv:2109.15085v3 [hep-ph]



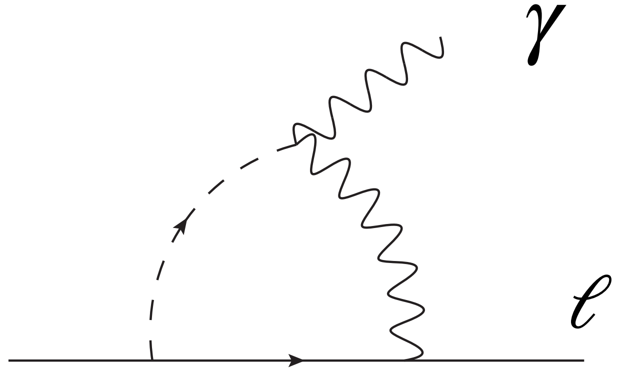
Asym:

$$\frac{\int_{\text{forward}} d\sigma_{ee\to HZ} - \int_{\text{backward}} d\sigma_{ee\to HZ}}{\int d\sigma_{ee\to HZ}}$$

Atlas limits:



EDM:



EDM single Op. limits: $\mathcal{O}_{CP_V} \lesssim 10^{-5}$

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- Loop corrections of SM processes involve EFT operators not present at LO.
- This can be used to find information on NLO operators through indirect searches.
- Bounds from indirect searches can compete with direct searches, or at least help with multi-dimensional bounds.