ASSESSING THE VALIDITY OF THE EFFECTIVE FIELD THEORY DESCRIPTION

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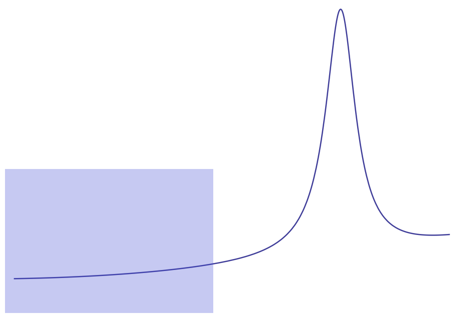
On the use of Effective Field Theory

- EFT ideal framework for low-energy machines with high precision (ex: e^+e^-)

Cannot access directly the new states → probe their tail effects with high-precision measurements



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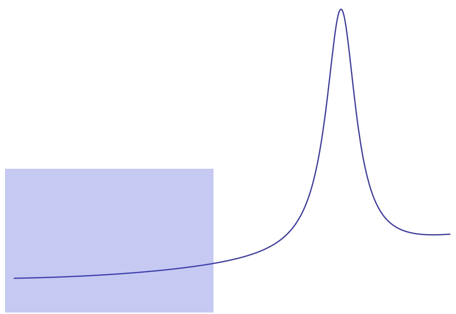

- In fact, even if energy is sufficient to discover (some of the) new particles, EFT can be useful to study the Higgs properties near threshold (low energy)

☞ EFT useful to give universal effective description of the contribution from new states in terms of a few local operators

No need of complete and accurate knowledge of mass spectrum, couplings etc.

- Going above threshold helps extracting the NP contribution

Effects from heavy New Physics naively scale like:

on-shell single production $$\frac{\delta c}{c} \sim \frac{g_*^2}{g_{SM}^2}\frac{m_h^2}{m_*^2}$$

2→2 processes $$\frac{\delta \mathcal{A}}{\mathcal{A}} \sim \frac{g_*^2}{g_{SM}^2}\frac{E^2}{m_*^2}$$

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Assessing the validity of the EFT is crucial to derive meaningful results and fully exploit the experimental data

- The validity of the EFT can be assessed *without* referring to specific UV models

- Specifying a power-counting is sufficient (and <u>necessary</u>)

The SILH power counting

Giudice et al. JHEP 0706 (2007) 045

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For a strongly-interacting light Higgs (SILH):

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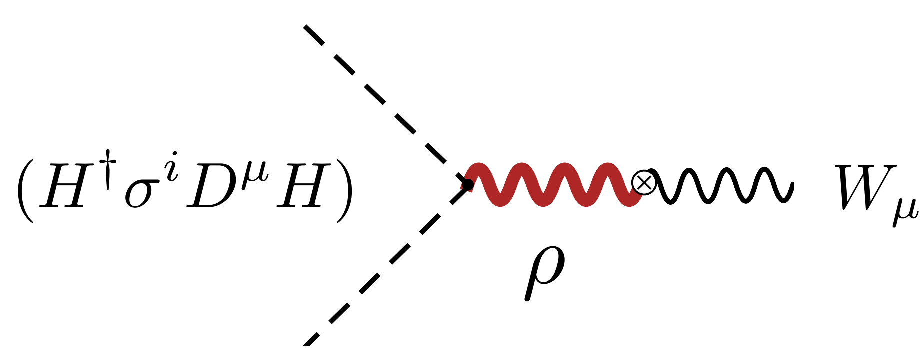
For a strongly-interacting light Higgs (SILH):

$$g_* \gg 1 \quad \Rightarrow \quad \frac{1}{f} \gg \frac{1}{m_*}$$

Example: $O_W = \frac{ig}{2m_W^2} \left(H^\dagger \sigma^i D^\mu H\right) \left(D^\nu W_{\mu\nu}\right)^i$

$$\bar{c}_W \sim \left(\frac{m_W^2}{m_*^2}\right)$$



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Expansion parameters: $$\frac{\partial_\mu}{m_*}, \qquad \frac{v}{f}, \qquad \frac{\alpha_{SM}}{4\pi}$$

derivative expansion

expansion in powers of the Higgs field H/f

expansion in powers of the SM couplings

Secondary Assumptions:

1. The Higgs is a pseudo Nambu-Goldstone boson

☞ operators that break the shift symmetry are suppressed

ex: $(H^\dagger H)^3$, $H^\dagger H G^a_{\mu\nu} G^{a\mu\nu}$

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3. (light) SM fermions are weakly coupled to the UV dynamics

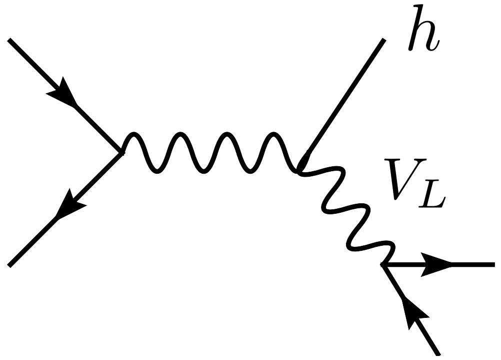
Equivalent to assuming "universality" of NP effects, easier to comply with LEP

☞ current-current operators subdominant

Assessing the validity of the EFT

Example #1: Higgs associated production ($q\bar{q} \to V_L h$)

$$A = g^2 + O\left(g^2 \frac{E^2}{m_W^2}\, \bar{c}_{i=HB,(W-B)}\right) + O\left(g^2 \frac{E^2}{m_W^2}\, \bar{c}_{H\psi}\right)$$



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$$O_{H\psi} = \frac{i}{v^2}\left(\bar{\psi}\gamma^\mu\psi\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right)$$

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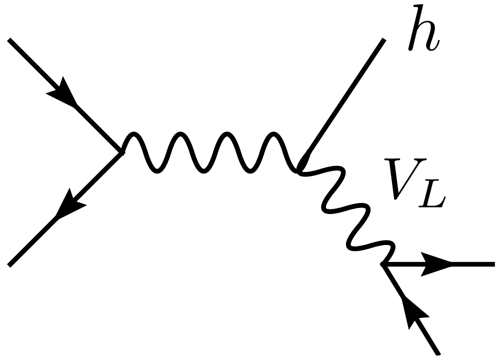

Estimates from SILH power counting (1 scale m_* and 1 coupling strength g_*)

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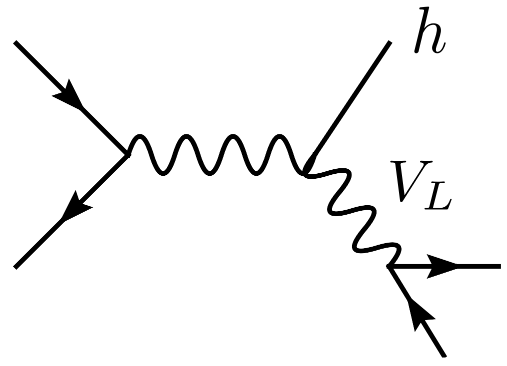

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Riva et al.
arXiv:1406.7320

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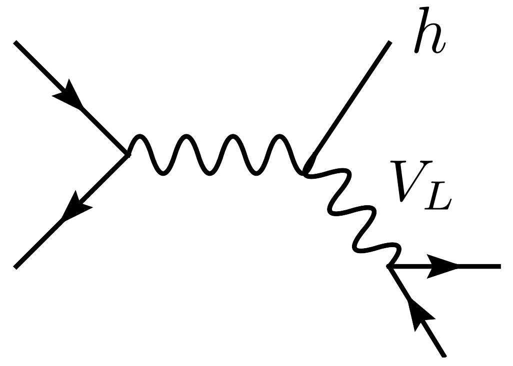

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$\delta A / A_{SM} \gg 1$

if $\lambda \gg g$

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Experimental searches not yet sensitive to SM Higgs signal

ATLAS-CONF-2013-079
PRD 89 (2014) 012003 (CMS)
D0, PRL 109 (2012) 121802

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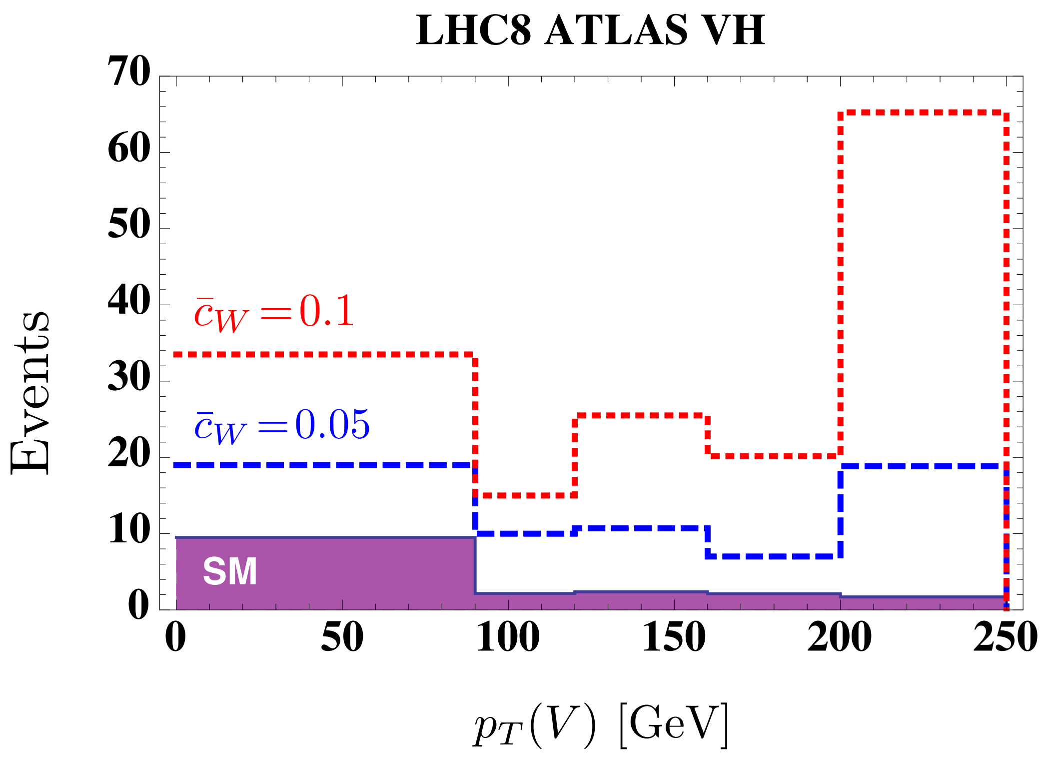

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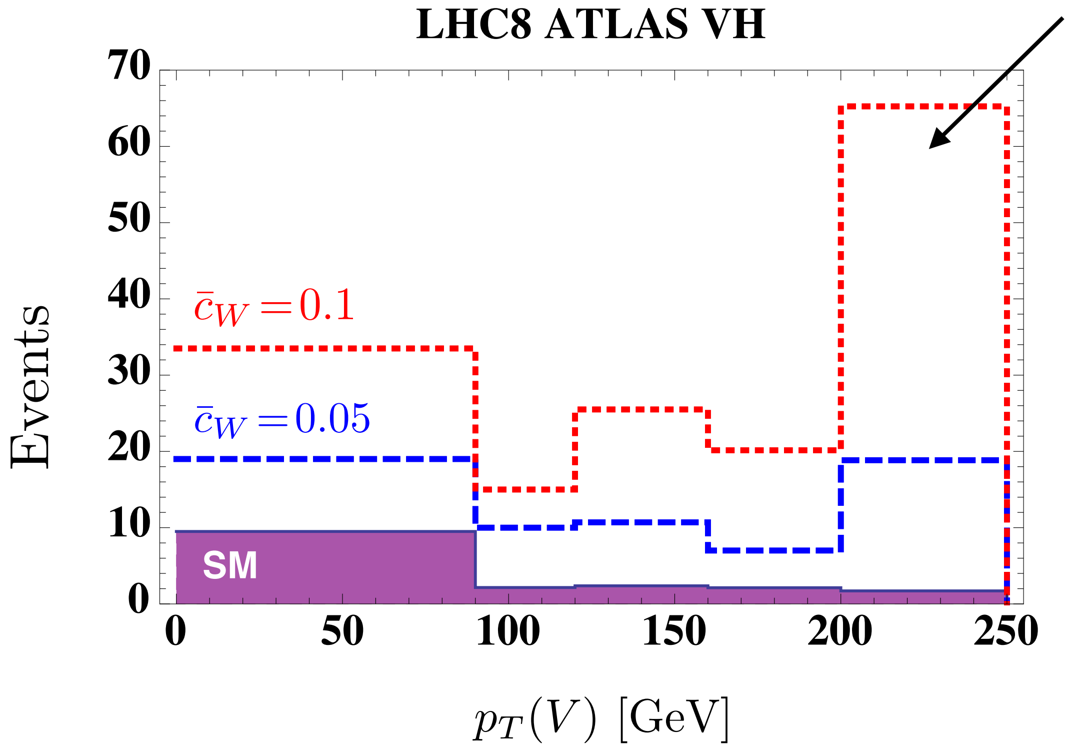

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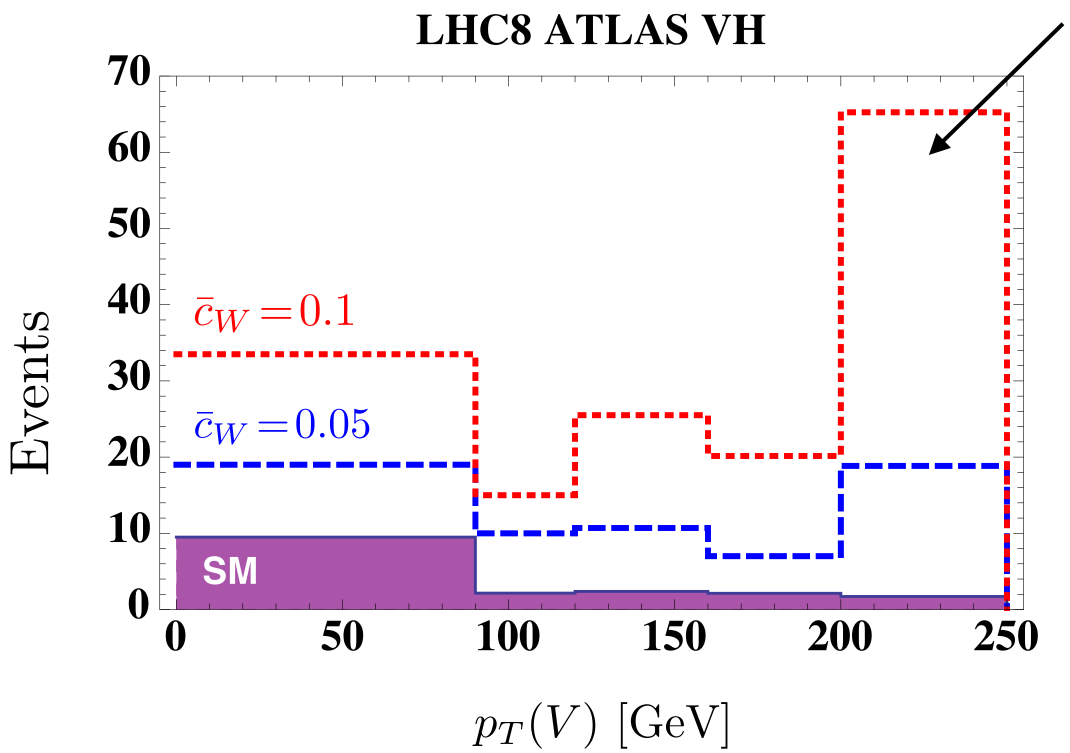
Compare with LEP2 (TGCs):
weaker bounds but EFT valid

sensitivity comes from last bin where EFT breaks down



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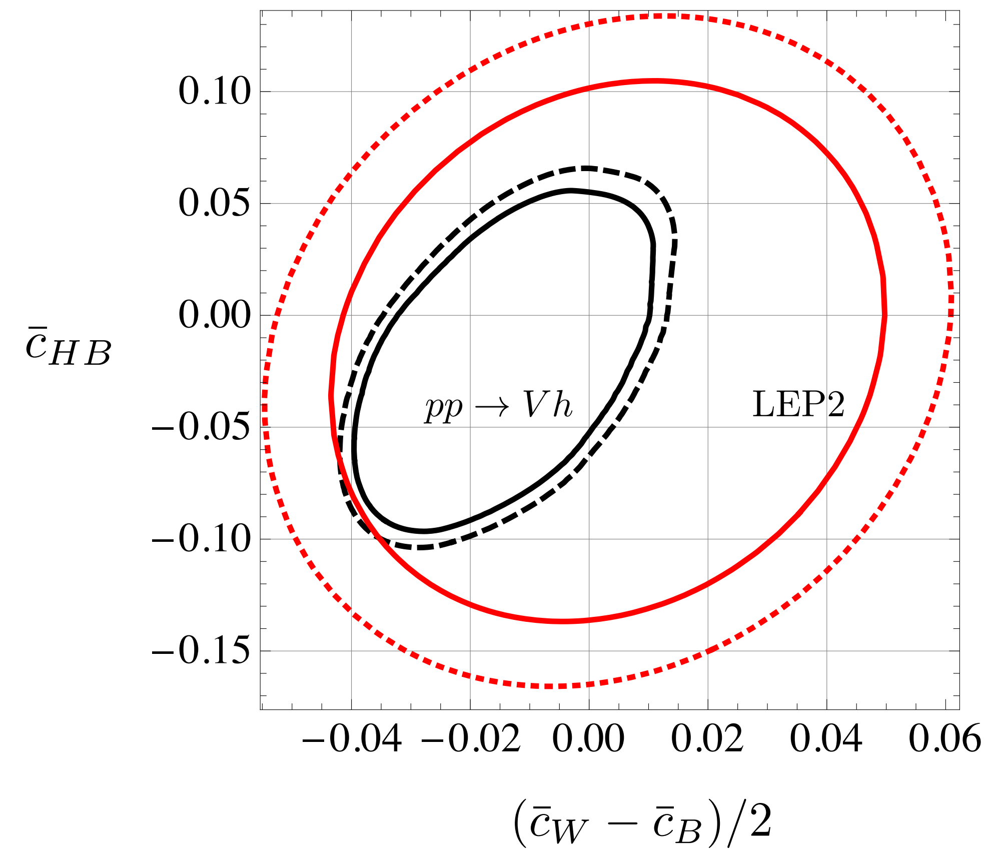

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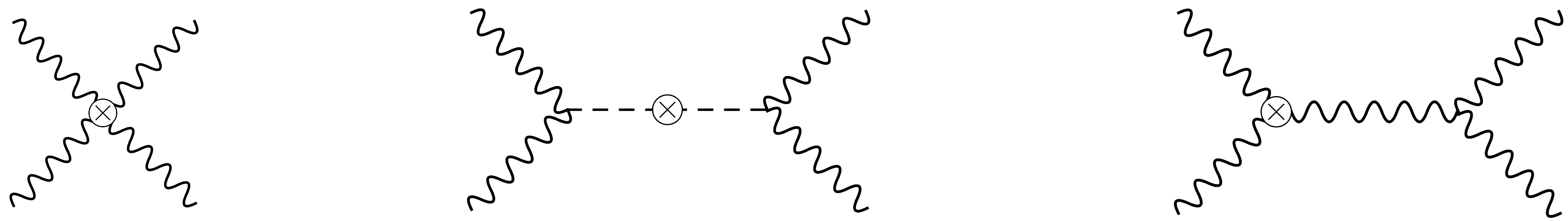
Example #2: WW scattering



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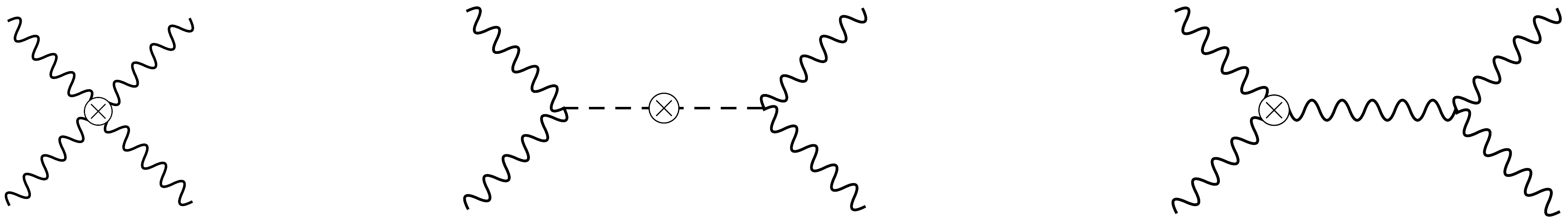

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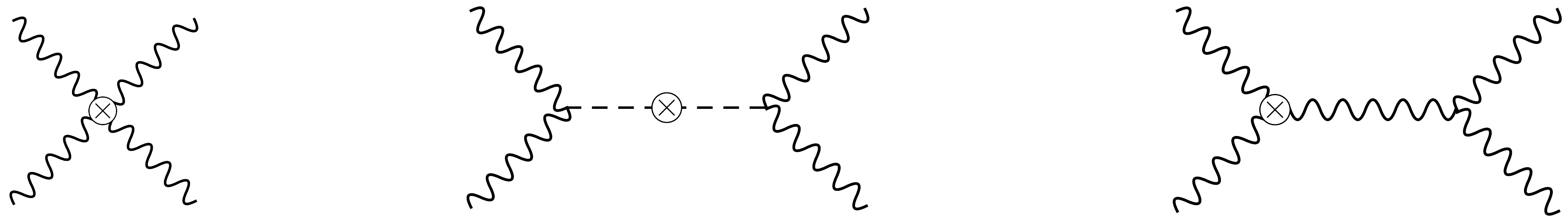

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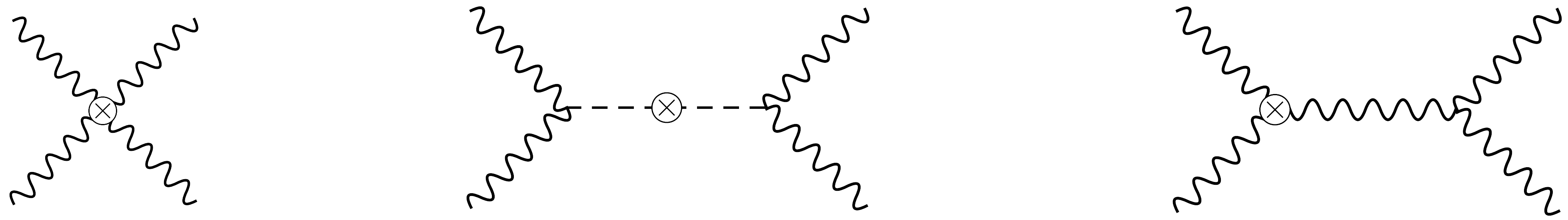

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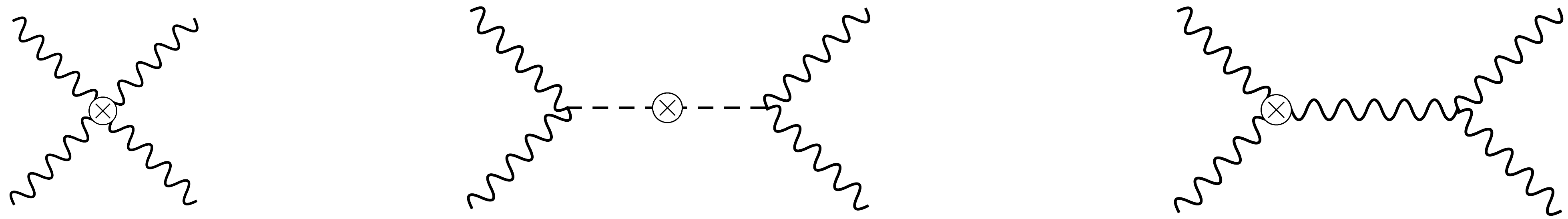

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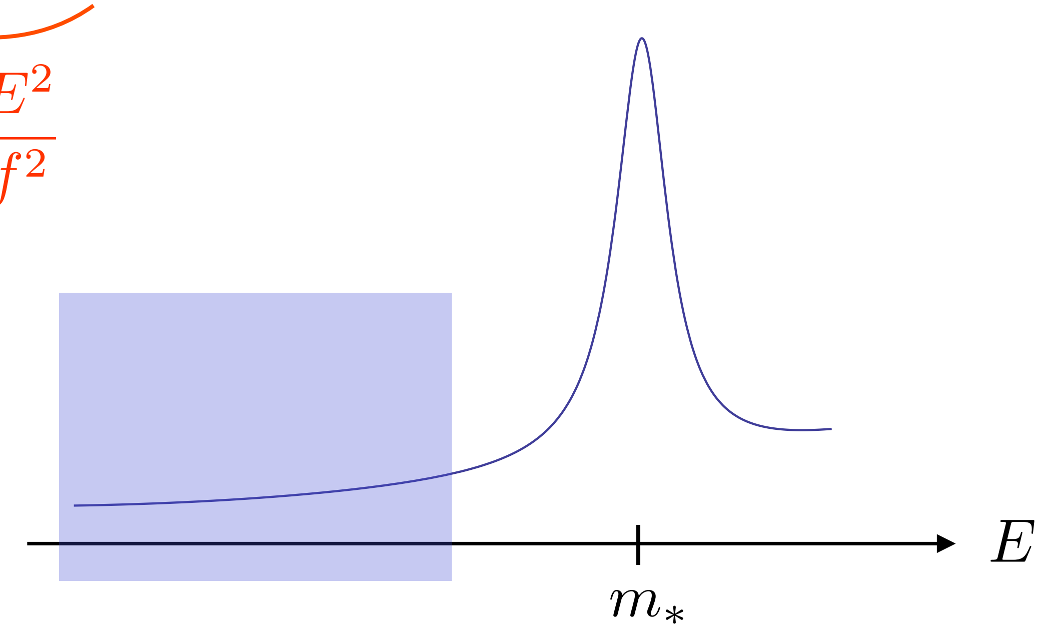
Interesting energy window: $g_{SM}\, f < E < m_*$



$$\frac{\delta\mathcal{A}}{\mathcal{A}_{SM}} \sim \frac{E^2}{g_{SM}^2 f^2} \lesssim \frac{g_*^2}{g_{SM}^2}$$

can be > 1 if NP dynamics is *strongly coupled* ($g_* > g_{SM}$)

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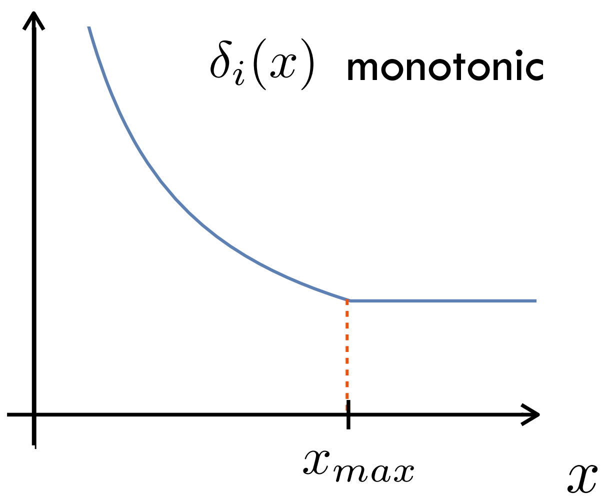

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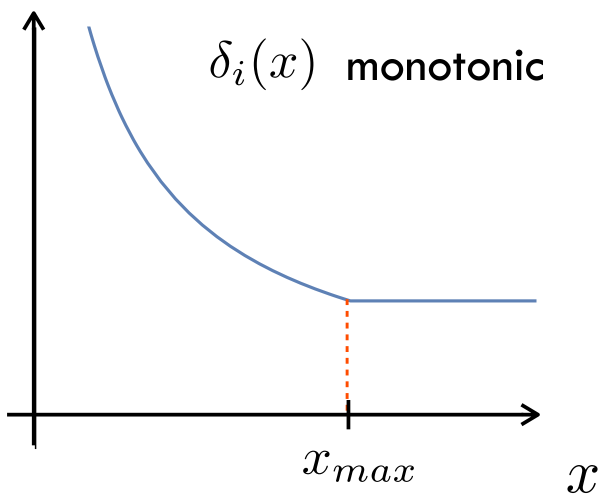

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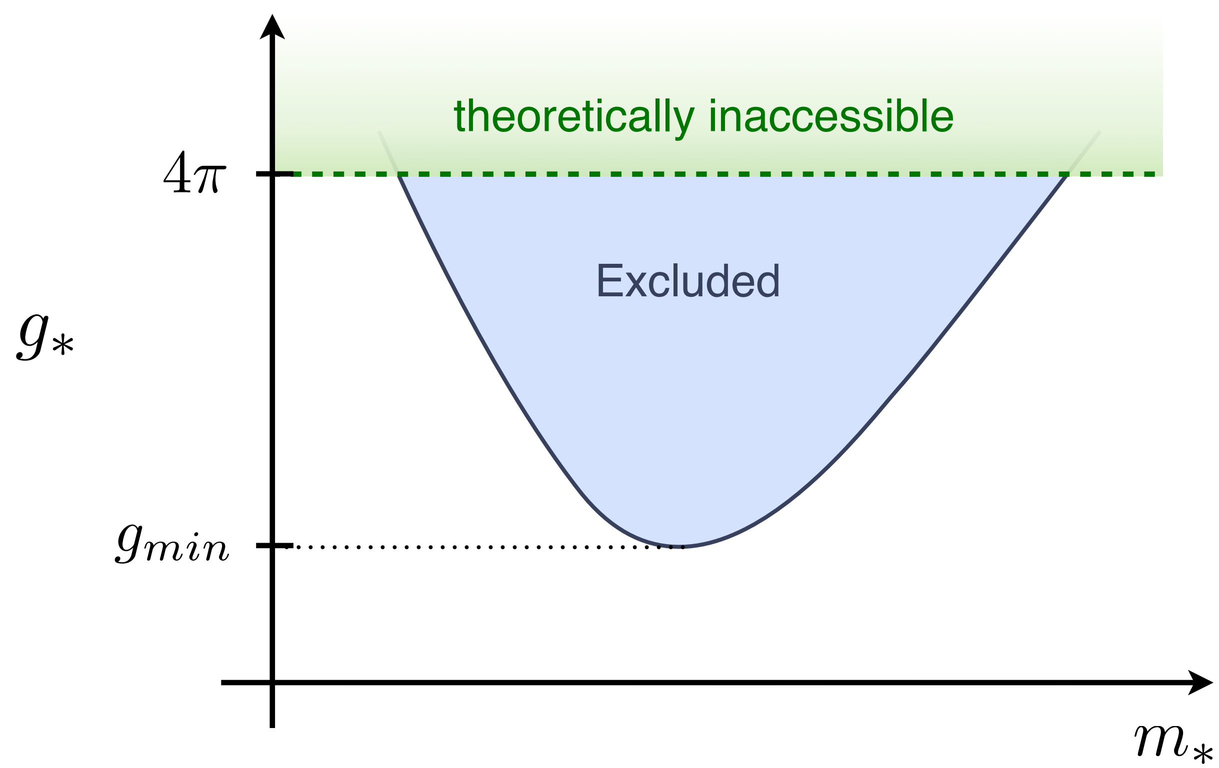
3. Specify a power counting to express $\bar{c}_i = \bar{c}_i(m_*, g_*)$ and set $M_{cut} = m_*$ (optimal value compatible with EFT)

Bounds in the plane (m_*, g_*) follow from the inequalities

$$\bar{c}_i(m_*, g_*) \leq \delta_i(m_*)$$

Example: $\bar{c}_H = \dfrac{v^2 g_*^2}{m_*^2} \leq \delta_H(m_*)$ $\Rightarrow$ $g_* \leq \dfrac{m_*}{v}\sqrt{\delta_H(m_*)}$



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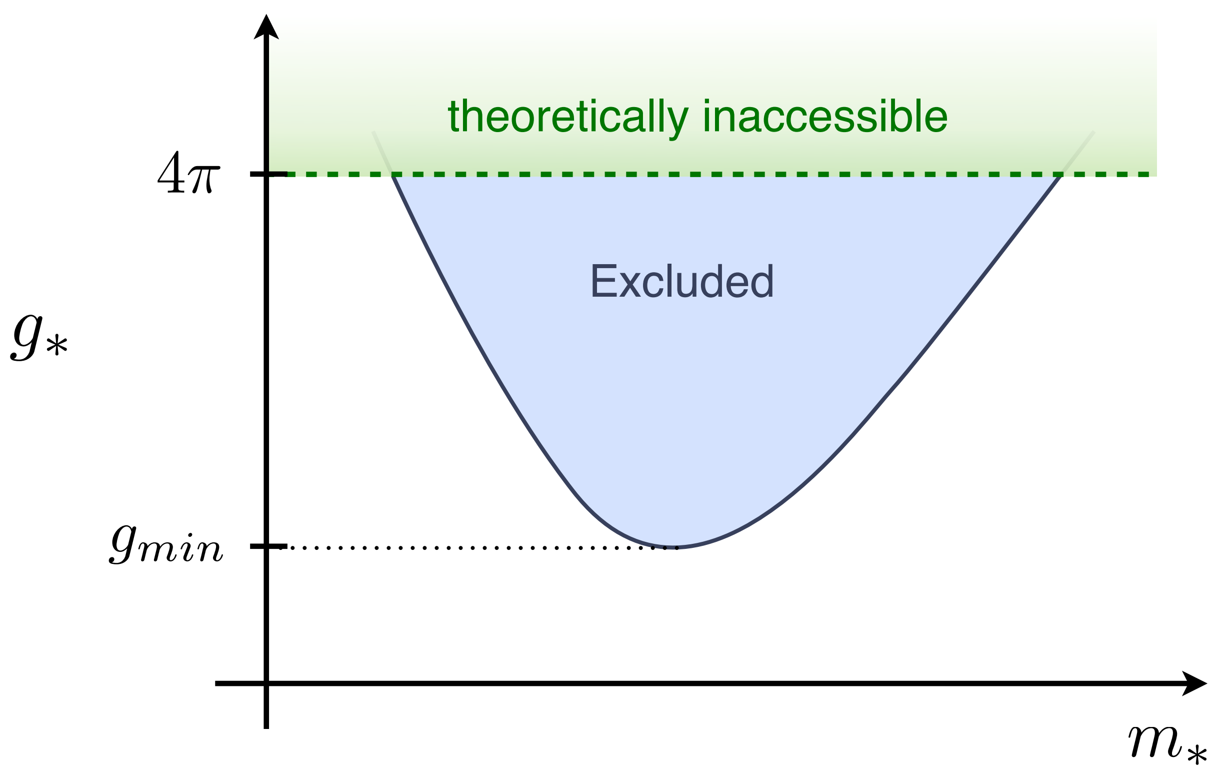

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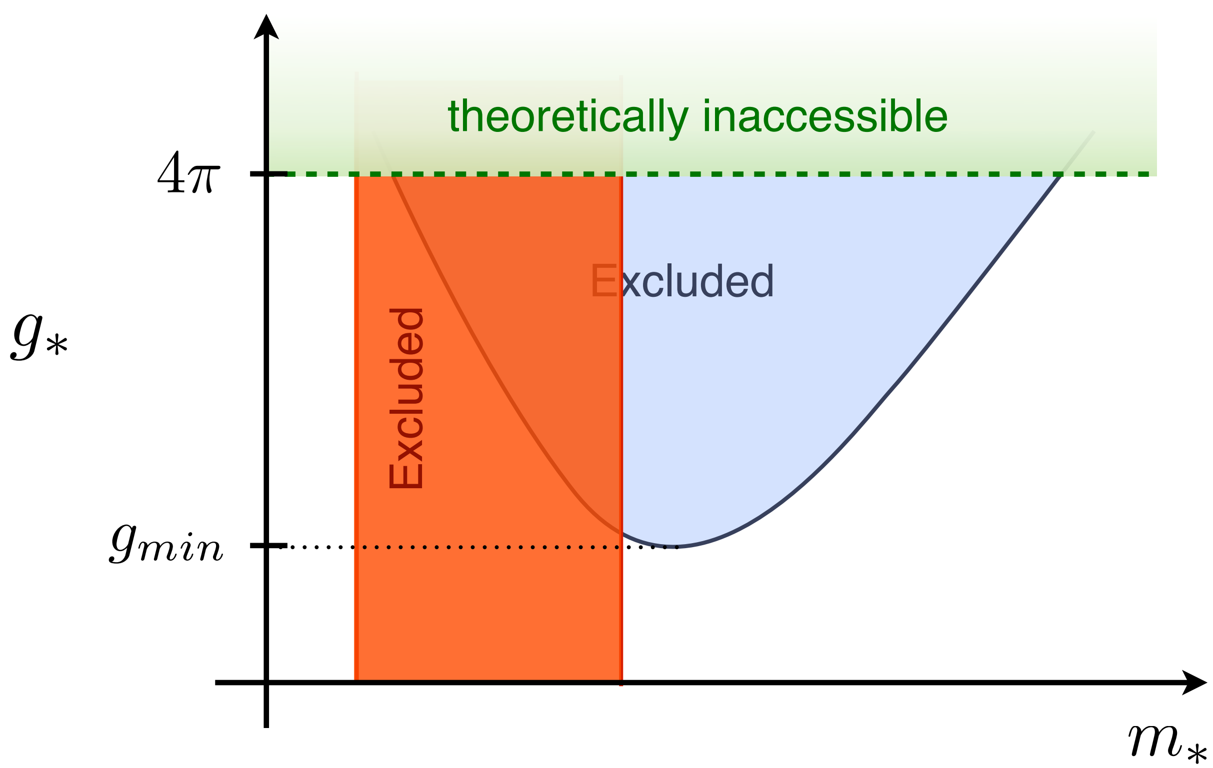

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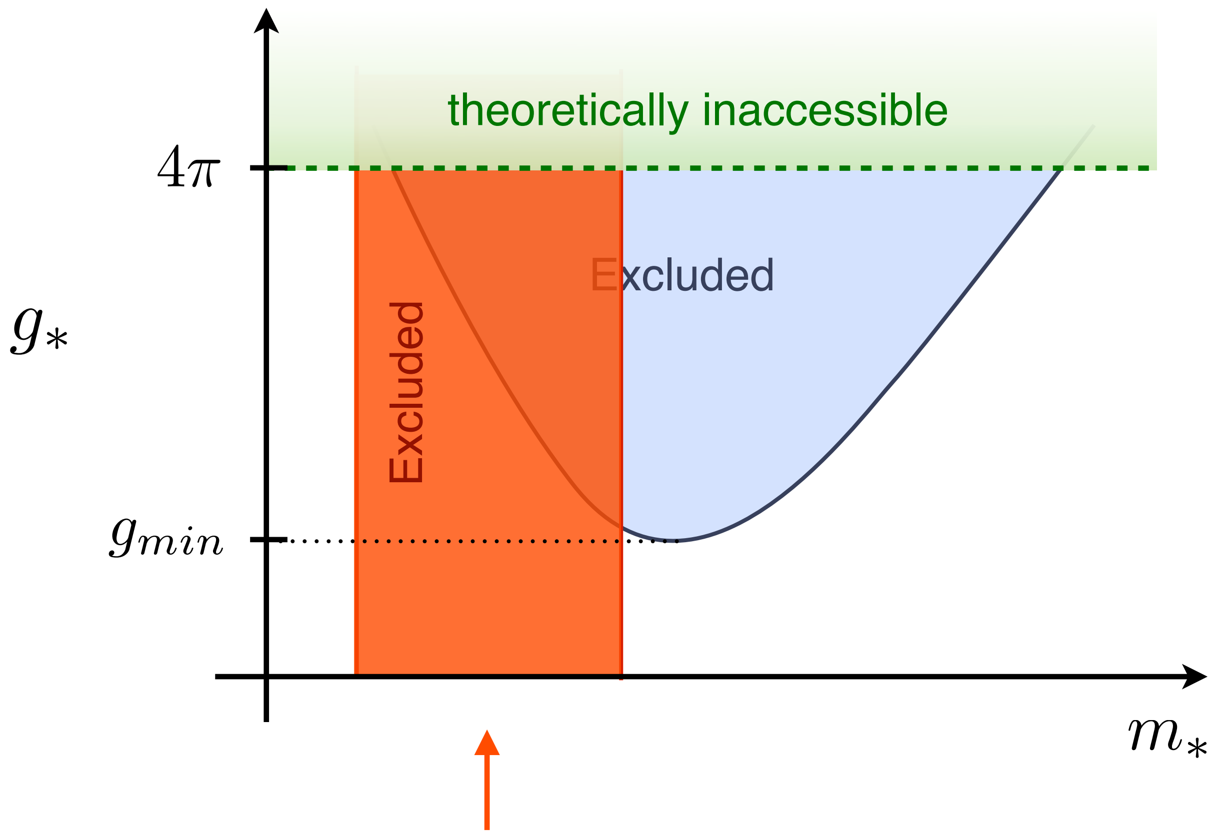

Excluded region is non-vanishing only if analysis is sensitive to SM

Are dim-6 operators sufficient ?

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Examples: RC, C. Grojean, A. Falkowski, F. Goertz, F. Riva, note to appear on Higgs Yellow Report 4

1. symmetry suppression of dim-6

2. observables with no contribution from dim-6

3. dim-6 do not interfere with SM (while dim-8 do)

⋮

Examples of the second kind (observables free from dim-6):

0-Higgs vs 1-Higgs → See talk by Luca Merlo

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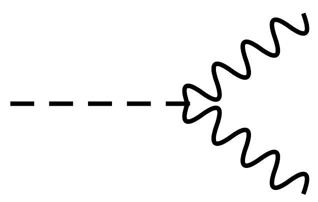
1-Higgs vs 2-Higgs

Ex: couplings of 1 and 2 Higgs bosons to vector bosons

[RC, Grojean, Pappadopulo, Rattazzi, Thamm JHEP 1402 (2014) 006]

$$c_V = 1 - \frac{c_H}{2}\frac{v^2}{f^2} + \left(\frac{3c_H^2}{8} - \frac{c'_H}{4}\right)\frac{v^4}{f^4}$$



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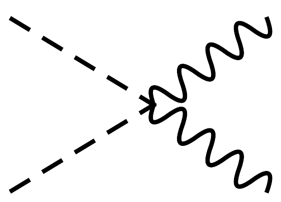

dim 6: $O_H = \frac{c_H}{2f^2}\partial_\mu|H|^2\partial^\mu|H|^2$

dim 8: $O'_H = \frac{c'_H}{2f^4}|H|^2\partial_\mu|H|^2\partial^\mu|H|^2$

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Exp. precision $\sim 1\%$

→ Test dim-8 operators

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(e[+]e[-] at $\sqrt{s} = 3\,\mathrm{TeV}$)

with $L = 2\,\mathrm{ab}^{-1}$

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P. Roloff (CLICdp Coll.), talk at LCWS14

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For an SO(5)/SO(4) Composite Higgs:

$$c_V = \sqrt{1 - (v^2/f^2)}$$

$$c_{2V} = 1 - 2(v^2/f^2)$$

$$\Delta c_{2V} = 2\Delta c_V^2$$

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Example of the first kind (symmetry suppression):

double Higgs production via gluon fusion (assuming Higgs is a pNGB)

Azatov, R.C., Panico, Son   Phys. Rev. D92 (2015) 035001

$$O_g = H^\dagger H \, G^a_{\mu\nu} G^{a\,\mu\nu}$$ suppressed by → $\frac{\lambda^2}{g_*^2}$ (λ = weak spurion breaking the shift symmetry)

$$O_{gD0} = (D_\rho H^\dagger D^\rho H) G^a_{\mu\nu} G^{a\,\mu\nu}$$
$$O_{gD2} = (\eta^{\mu\nu} D_\rho H^\dagger D^\rho H - 4 D^\mu H^\dagger D^\nu H) G^a_{\mu\alpha} G^{a\,\alpha}_{\nu}$$

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suppressed by $\longrightarrow \dfrac{1}{m_*^2}$

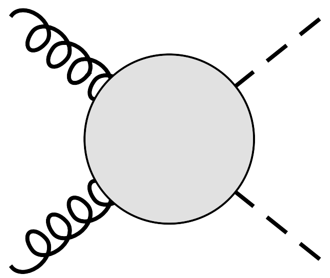
$$\frac{\delta A_8}{\delta A_6} \sim \frac{E^2}{m_*^2} \frac{g_*^2}{\lambda^2}$$

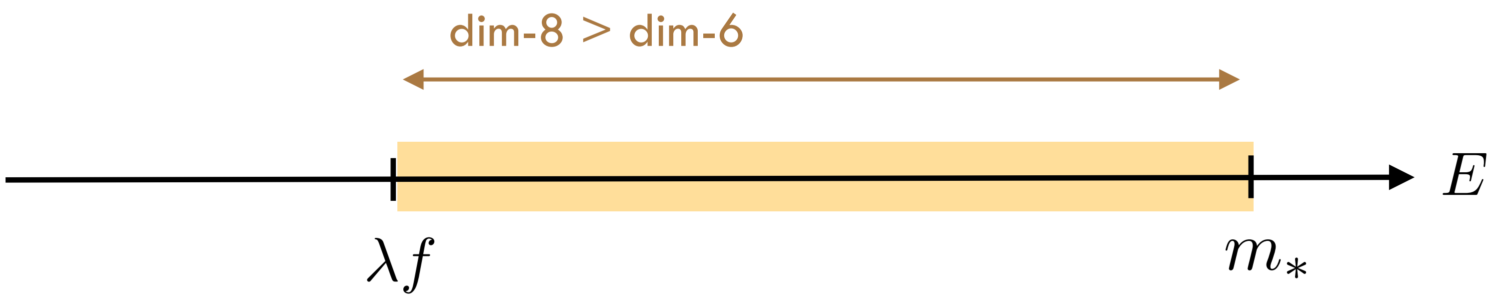
dim-8 dominate over dim-6 for:

$$\lambda f < E < m_*$$

Example: $\lambda = y_t$, $(v^2/f^2) = 0.1$ $\longrightarrow$ $\lambda f \sim 500\,\mathrm{GeV}$

However: double Higgs production has a very low rate, dim-8 are unobservable at the LHC unless bigger than SM





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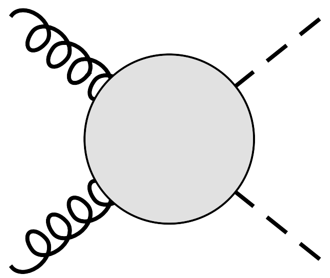

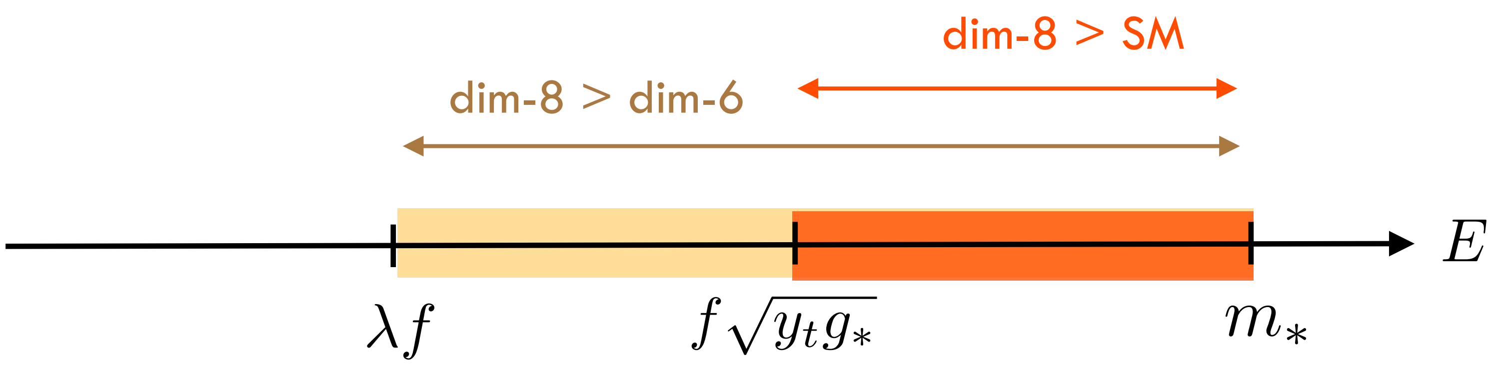

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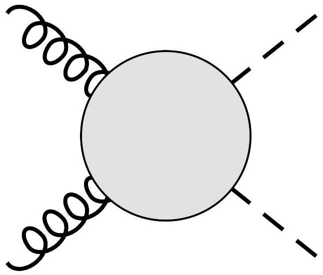

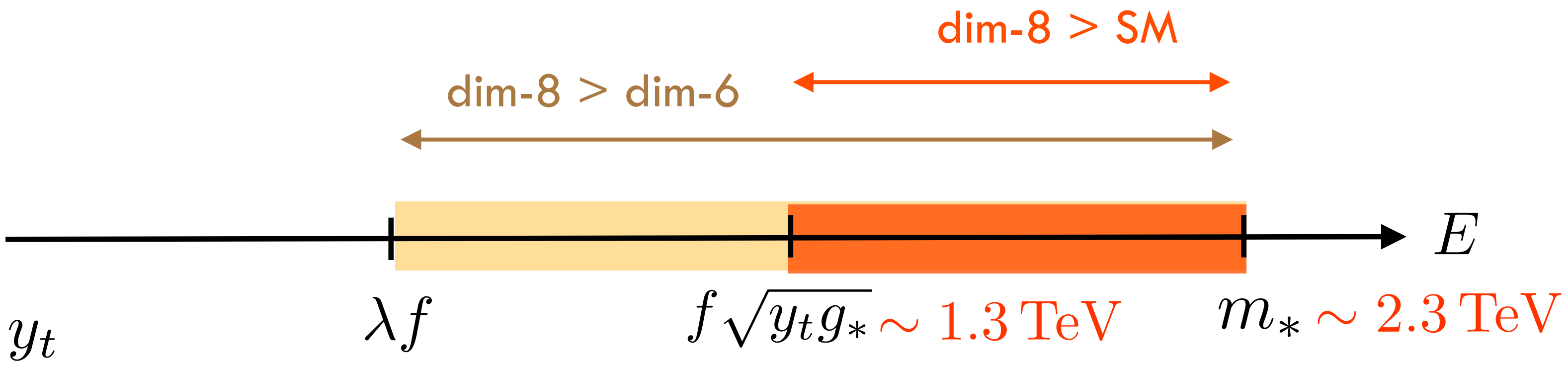

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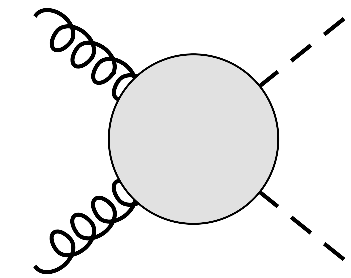

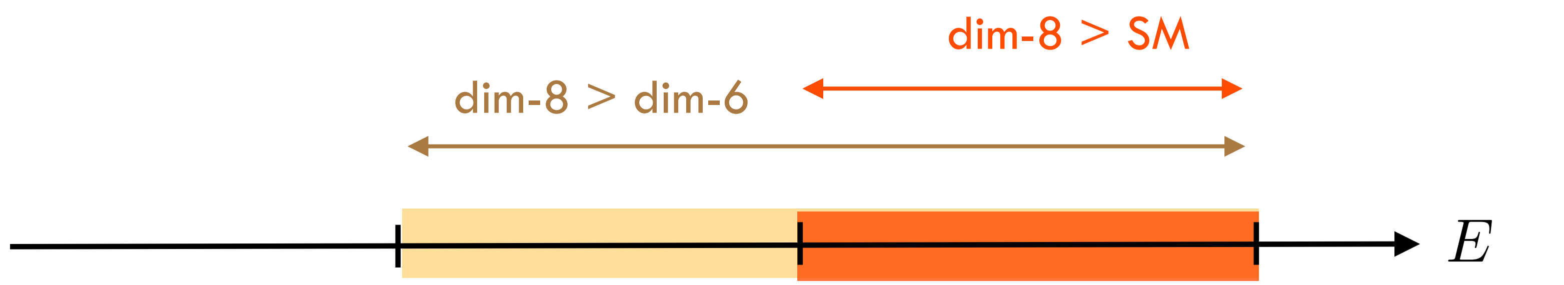

λf $\quad f\sqrt{y_t g_*} \sim 1.3\,\mathrm{TeV}$ $\quad m_* \sim 2.3\,\mathrm{TeV}$

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For a luminosity: $L = 3\,\mathrm{ab}^{-1}$

- requiring at least 5 events
- including 10% efficiency due to kinematic cuts

Largest value of $m(hh)$[GeV]	$b\bar{b}\gamma\gamma$	$4b$
$\sqrt{s} = 14\,\mathrm{TeV}$	550	1550
$\sqrt{s} = 100\,\mathrm{TeV}$	1350	4300

Probing dim-8 operators is very difficult (perhaps possible through $hh \to 4b$ or at 100TeV)

Testing dim-8 operators through angular distributions

- The scattering $gg \to hh$ proceeds through $J_z = 0$ and $J_z = \pm 2$ transitions

$$M_0 \sim const.$$
$$M_2 \sim \sin^2\theta$$

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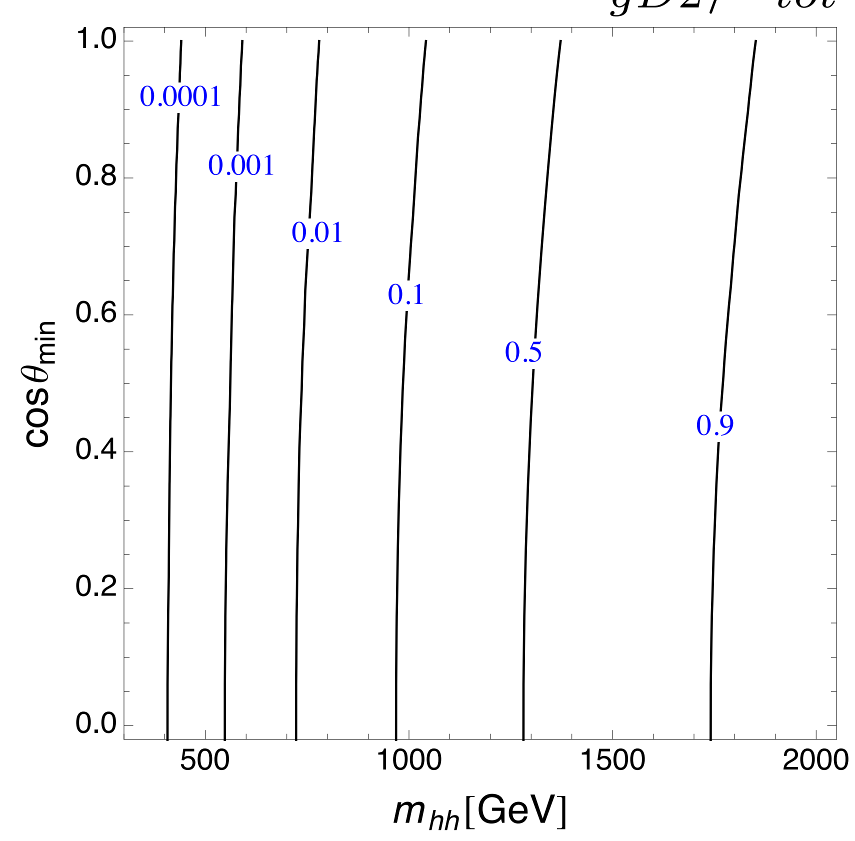
$$r = \sigma_{gD2}/\sigma_{tot}$$



$\bar{c}_{gD2}$ set to its SILH estimate with:

$$(v/f)^2 = 0.15$$
$$g_* = 3$$
$$[m_* = 1.9\,\text{TeV}]$$

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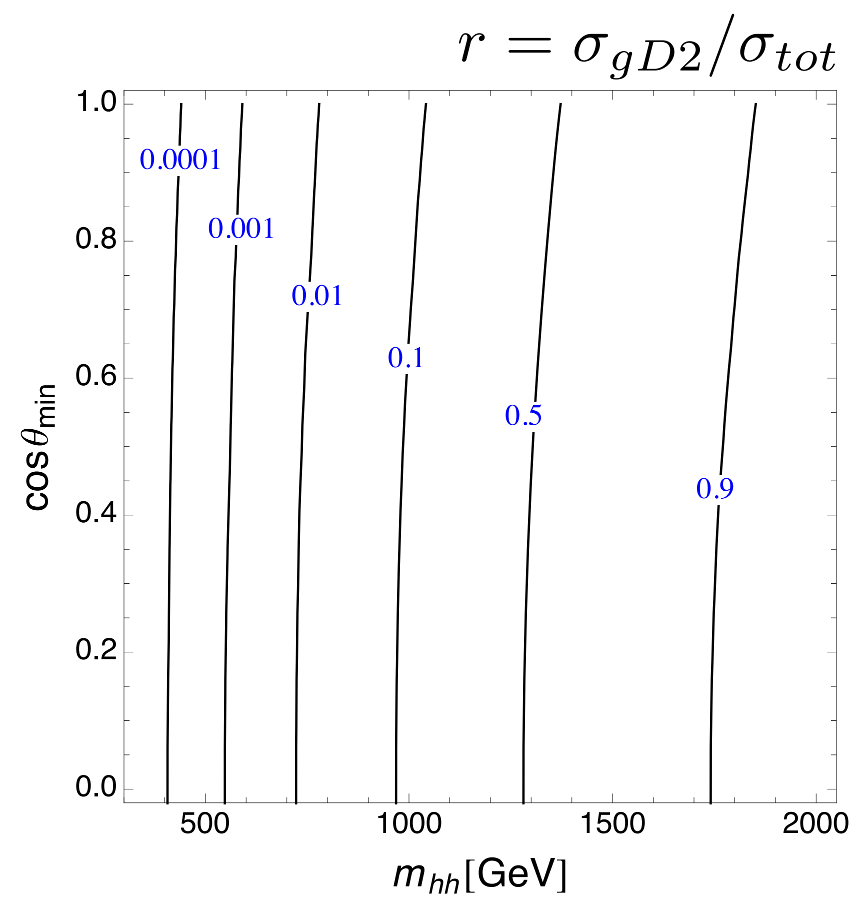
Sensitivity on dim-8 operators only marginally improved by angular analysis



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- Dimension-8 operators can be safely neglected except in few special cases

  Ex: -- dim-6 operators suppressed by symmetry
  -- observables with no contribution from dim-6