New Physics in the Higgs sector

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collaboration with Prof. Seungwon Beak (KIAS)

NCTS

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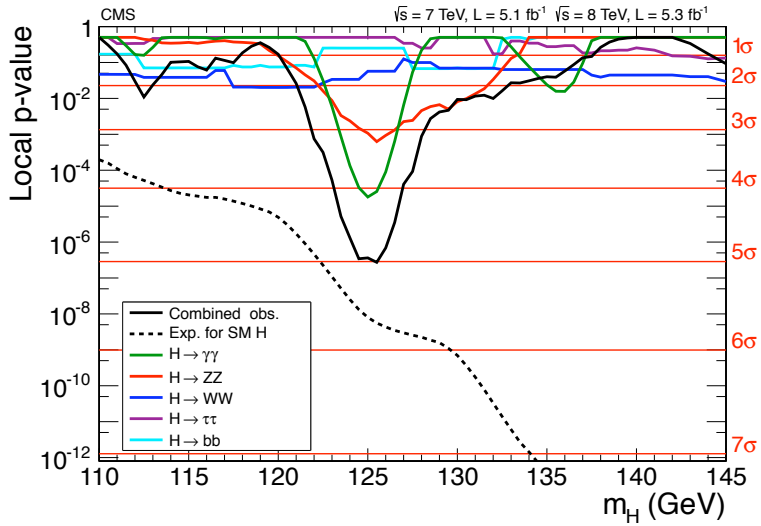
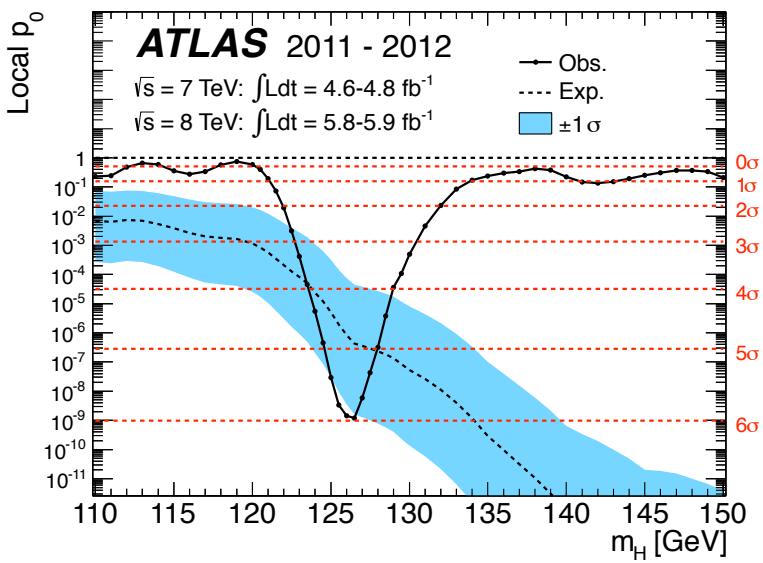
Higgs discovery





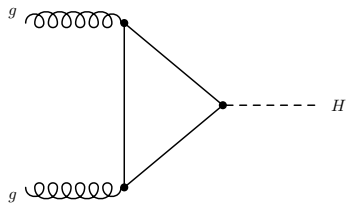
LHC Run I

- mass: $m_h = 125\,\mathrm{GeV}$ ☺
- spin ☺
- party ☺
- Yukawa coupling ☺
- gauge coupling ☺

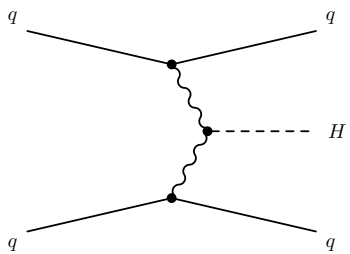
LHC Run II/HL

Higgs production and decay at the LHC

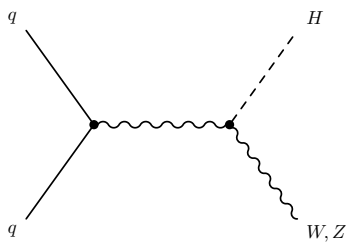
- gluon-gluon fusion



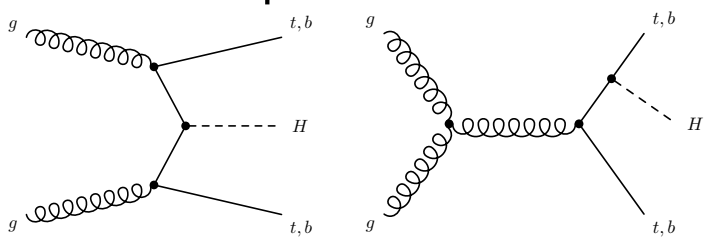
- vector boson fusion



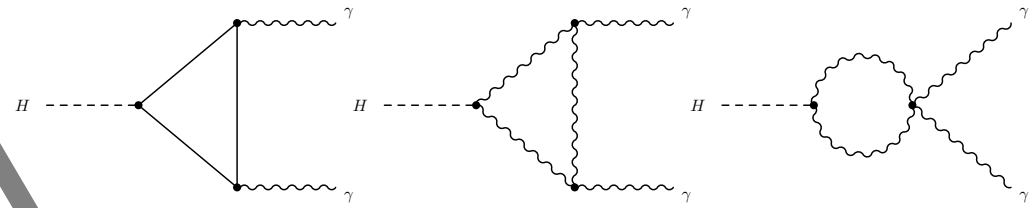
- associated production with W/Z



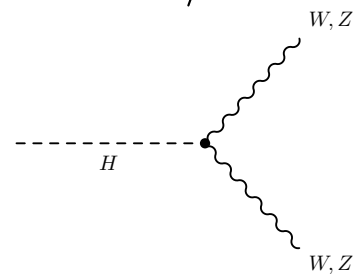
- associated production with $t\bar{t}$



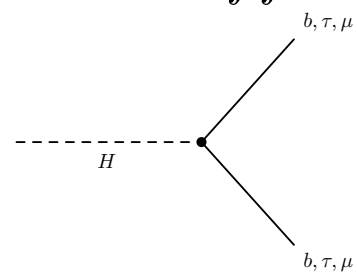
$h \to \gamma\gamma$



$h \to WW/ZZ$

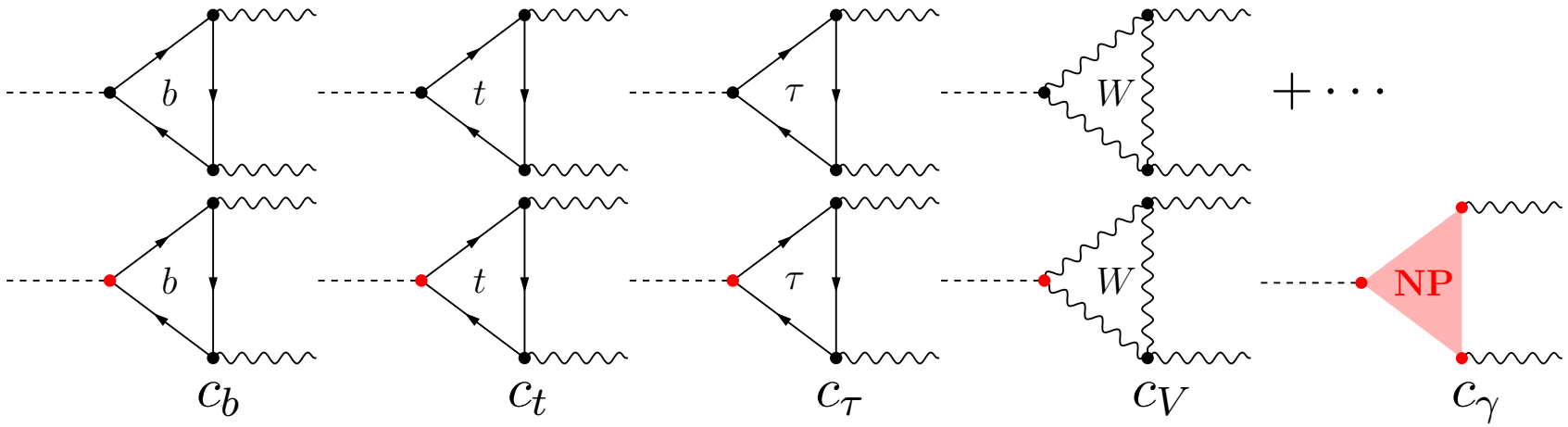


$h \to ff$



$h \to \gamma\gamma$ in the SM and beyond

- SM
- BSM



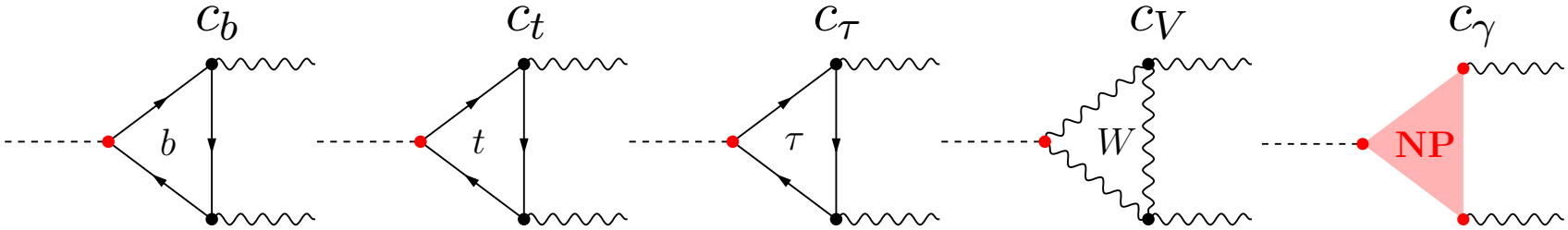
If deviations of $\mathcal{B}(h \to \gamma\gamma)$ or $\sigma_{gg\mathrm{F}}$ from the SM were observed at the future LHC, where is the New Physics?

Scenario I: $c_f, c_V \neq 1$ and $c_\gamma, c_g = 0$
Hgg and $H\gamma\gamma$ couplings are affected only through the triangle diagrams in the SM.

Scenario II: $c_f, c_V \neq 1$ and $c_\gamma, c_g \neq 0$
New particles also enter the loop diagrams and affect the Hgg or $H\gamma\gamma$ coupling directly.

How to distinguish between these two scenarios?

Higgs with EFT



- effective Lagrangian

$$\mathcal{L} = 2c_V\left(m_W^2 W_\mu^+ W^{-\mu} + \frac{1}{2}m_Z^2 Z_\mu Z^\mu\right)h + c_\gamma \frac{\alpha_e}{\pi} F_{\mu\nu}F^{\mu\nu}\frac{h}{v} + c_g \frac{\alpha_s}{12\pi} G^a_{\mu\nu}G^{a\mu\nu}\frac{h}{v}$$
$$- c_t \frac{m_t}{v}\bar{t}th - c_b\frac{m_b}{v}\bar{b}bh - c_c\frac{m_c}{v}\bar{c}ch - c_\tau\frac{m_\tau}{v}\bar{\tau}\tau h$$

- effective coupling

$$C_f = c_f$$
$$C_V = c_V$$
$$C_\gamma = c_\gamma - \frac{1}{8}\left(\sum c_f N_{c,f} Q_f^2 \mathcal{A}_{\frac{1}{2}}(x_f) + c_V \mathcal{A}_1(x_W)\right)$$
$$C_g = c_g - \frac{3}{4}\sum c_q \mathcal{A}_{\frac{1}{2}}(x_q)$$

S.I: $C_\gamma = 0.23c_t - 1.04c_V$

$C_g = 1.04c_t - (0.05 - 0.07i)c_b$

S.II: $C_\gamma = c_\gamma + 0.23c_t - 1.04c_V$

$C_g = c_g + 1.04c_t - (0.05 - 0.07i)c_b$

- Higgs production and decay

$gg\mathrm{F}$	$: gg \to h$	$: C_g$
$V\mathrm{BF}$	$: qq \to qqh$	$: C_V$
VH	$: qq \to W/Zh$	$: C_V$
ttH	$: qq/gg \to tth$	$: C_t$

$h \to \gamma\gamma$	$: C_\gamma$
$h \to WW/ZZ$	$: C_V$
$h \to bb/\tau\tau$	$: C_b, C_\tau$

Measurements of the Higgs boson at the LHC

- Higgs signal strength

$$\mu_i = \frac{\sigma_i}{\sigma_i^{\rm SM}} \qquad \mu^j = \frac{\mathcal{B}_j}{\mathcal{B}_j^{\rm SM}} \qquad \mu_i^j = \mu_i \cdot \mu^j$$

$$i \to h \to j$$

$$i = gg{\rm F}, VBF, WH, ttH$$
$$j = ZZ, WW, \gamma\gamma, \tau\tau, bb$$

- ratios

$$r^j_{1,V} = \frac{\mu^j_{gg{\rm F}}}{\mu^j_V} \qquad r_{2,i} = \frac{\mu_i^{\gamma\gamma}}{\mu_i^{VV}} \qquad r_3^j = \frac{\mu^j_{gg{\rm F}}}{\mu^j_{ttH}}$$

- basic ratios

$$r_1 = \frac{\mu_{gg{\rm F}}}{\mu_V} \qquad r_2 = \frac{\mu^{\gamma\gamma}}{\mu^{VV}} \qquad r_3 = \frac{\mu_{gg{\rm F}}}{\mu_{ttH}}$$

	Scenario I	Scenario II
$r_1 =$	$\left\lvert 1.06\frac{c_t}{c_V}\right\rvert^2$	$\left\lvert 1.06\frac{c_t}{c_V} + 1.03\frac{c_g}{c_V}\right\rvert^2$
$r_2 =$	$\left\lvert -1.27 + 0.28\frac{c_t}{c_V}\right\rvert^2$	$\left\lvert -1.27 + 0.28\frac{c_t}{c_V} + 1.2\frac{c_\gamma}{c_V}\right\rvert^2$
$r_3 =$	$\lvert 1.06\rvert^2$	$\left\lvert 1.06 + 1.03\frac{c_g}{c_t}\right\rvert^2$

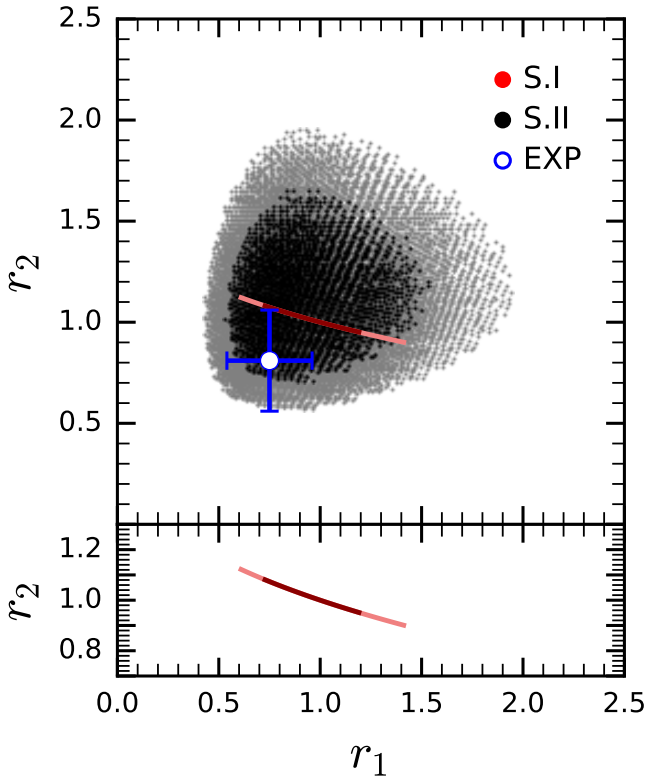
S. I: (c_V, c_F)
S.II: $(c_V, c_F, c_\gamma, c_g)$

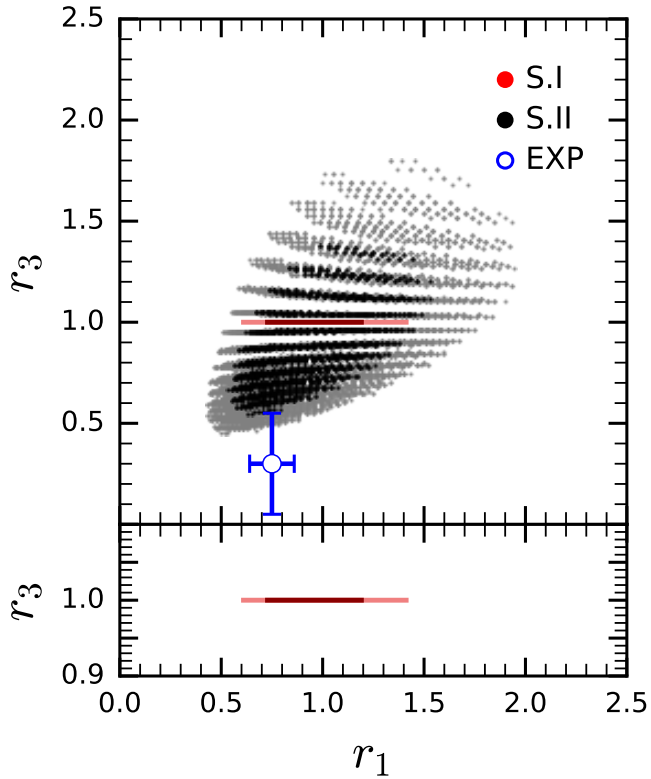
S. I: (c_V, c_b, c_t, c_τ)
S.II: $(c_V, c_b, c_t, c_\tau, c_\gamma, c_g)$

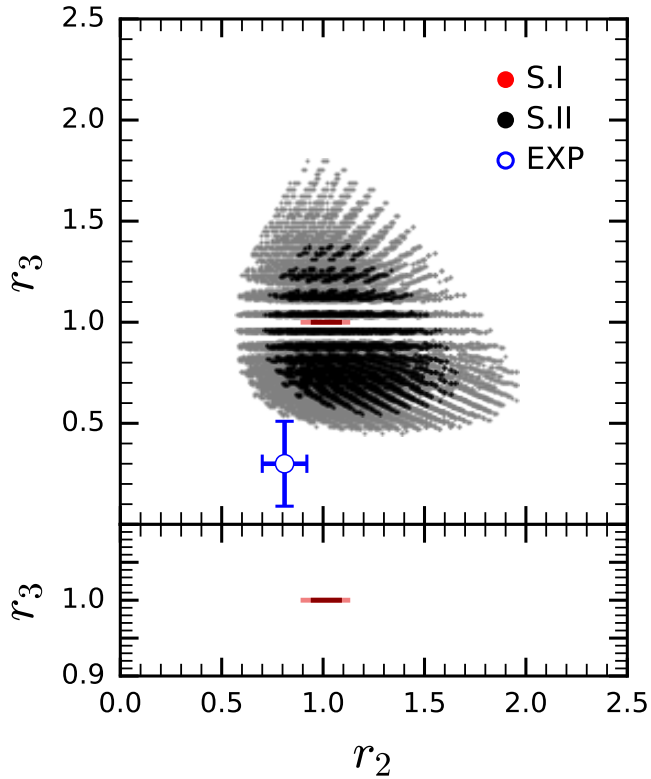
effects of light fermions

LHC Run I data

Correlations between r_i



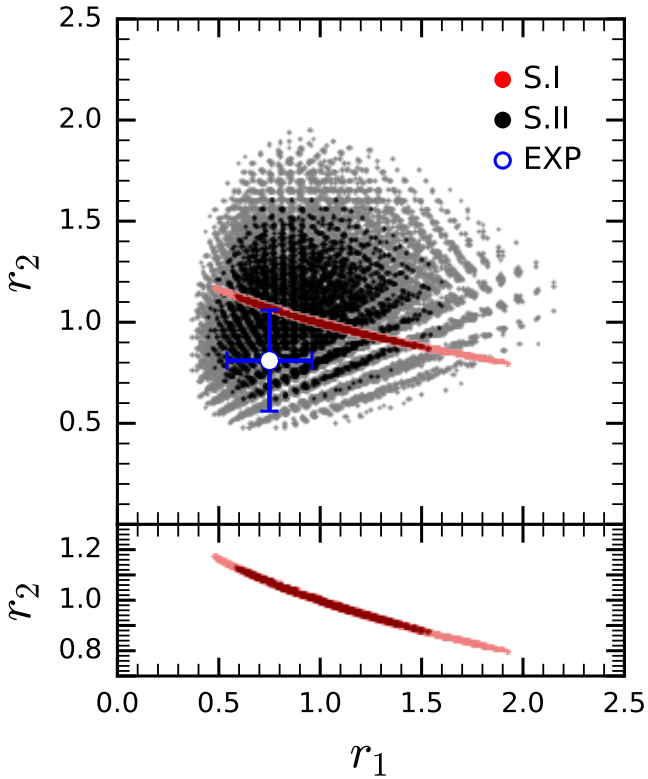


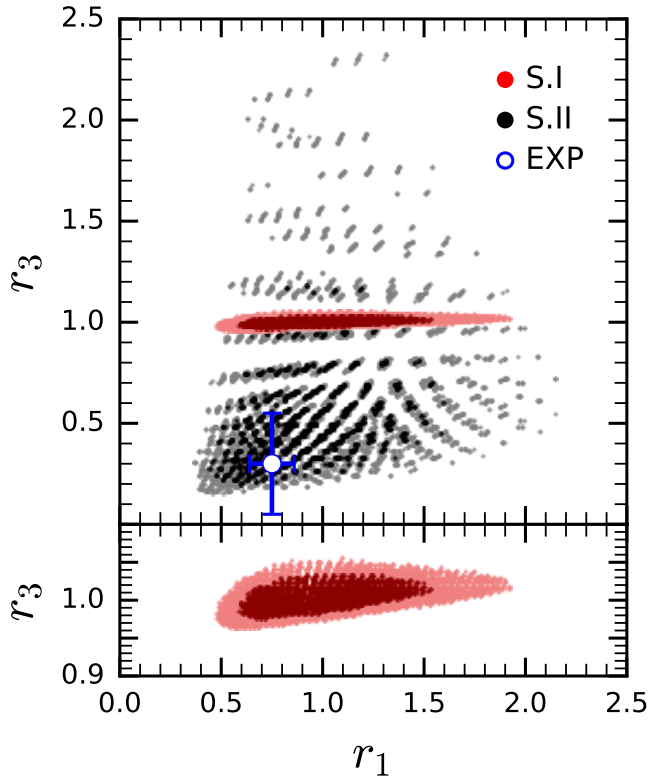


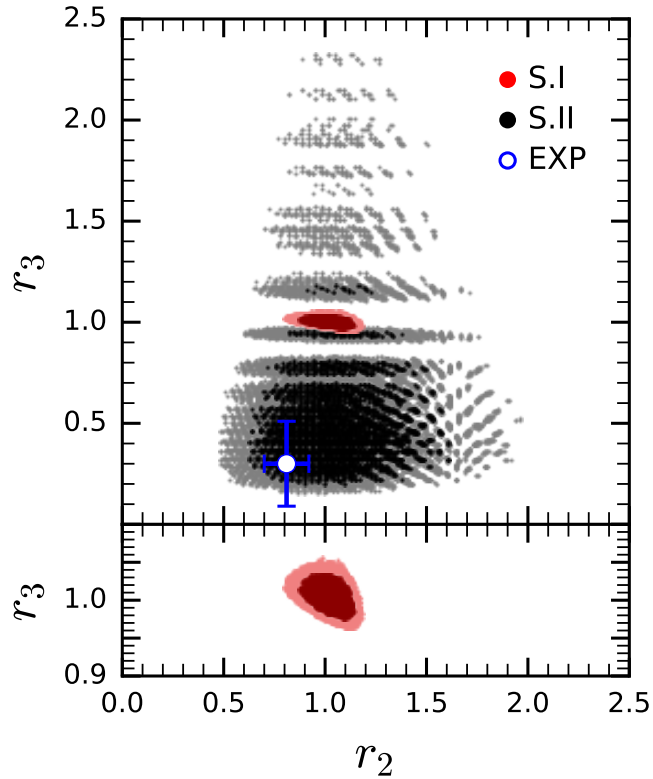
- dark: 68% CL
- light: 95% CL

- Scenario I: (c_V, c_F)
- Scenario II: $(c_V, c_F, c_\gamma, c_g)$

Correlations between r_i







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- Scenario I: (c_V, c_b, c_t, c_τ)
- Scenario II: $(c_V, c_b, c_t, c_\tau, c_\gamma, c_g)$

Summary

If deviations of $\mathcal{B}(h \to \gamma\gamma)$ or $\sigma_{gg\mathrm{F}}$ from the SM were observed at the future LHC, where is the New Physics?

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correlation among $\quad r_1 = \dfrac{\mu_{gg\mathrm{F}}}{\mu_V} \quad r_2 = \dfrac{\mu^{\gamma\gamma}}{\mu^{VV}} \quad r_3 = \dfrac{\mu_{gg\mathrm{F}}}{\mu_{ttH}}$

Thank You !

- `Lilith` pakcage
- LHC Run I measurements: σ_{ggF}/σ_{WH}, $\mathcal{B}^{\gamma\gamma}/\mathcal{B}^{ZZ}$, $\sigma_{ggF}/\sigma_{ttH}$
- associated production with Z