LECTURES ON ELECTROWEAK SYMMETRY BREAKING

Roberto Contino

Università di Roma La Sapienza

Lecture 3

Higgs couplings: present status and future strategies

Effective Lagrangian for a light Higgs-like boson

RULES:

- Do not assume $SU(2)_L x U(1)_Y$ is linearly realized at high energy
- Do not assume h(x) forms a doublet of $SU(2)_L$ with longitudinal W,Z
- each extra derivative costs a factor $1/\Lambda$
- each extra power of h(x) costs a factor g_*/Λ

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VALIDITY:

- must be used as an effective Lagrangian: some quantities are calculable, some others are not
- no problem to use it at loop-level

Effective Lagrangian for a light Higgs-like boson

$$\mathcal{L} = \frac{1}{2}(\partial_\mu h)^2 - \frac{1}{2}m_h^2 h^2 - \frac{d_3}{6}\left(\frac{3m_h^2}{v}\right)h^3 - \frac{d_4}{24}\left(\frac{3m_h^2}{v^2}\right)h^4 \ldots$$

$$- \left(m_W^2\, W_\mu W_\mu + \frac{1}{2}m_Z^2\, Z_\mu Z_\mu\right)\left(1 + 2a\,\frac{h}{v} + b\,\frac{h^2}{v^2} + \ldots\right)$$

$$- \sum_{\psi=u,d,l} m_{\psi^{(i)}}\,\bar{\psi}^{(i)}\psi^{(i)}\left(1 + c_\psi\frac{h}{v} + c_{2\psi}\frac{h^2}{v^2} + \ldots\right)$$

$$+ \frac{g^2}{16\pi^2}\left(c_{WW}\, W^+_{\mu\nu}W^-_{\mu\nu} + c_{ZZ}\, Z^2_{\mu\nu} + c_{Z\gamma}\, Z_{\mu\nu}\gamma_{\mu\nu}\right)\frac{h}{v} + \ldots$$

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$$+ \frac{g^2}{16\pi^2}\left[\frac{c_{hhgg}}{\Lambda^2}\,G^2_{\mu\nu}\frac{(\partial_\rho h)^2}{v^2} + \frac{c'_{hhgg}}{\Lambda^2}\,G_{\mu\rho}G_{\rho\nu}\frac{\partial_\mu h\partial_\nu h}{v^2} + \ldots\right]$$

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RC, Grojean, Moretti, Piccinini, Rattazzi, JHEP 1005 (2010) 089

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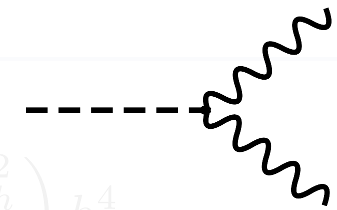
Controls the *hWW*, *hZZ* couplings



$$= a \cdot g^{SM}_{hWW}$$

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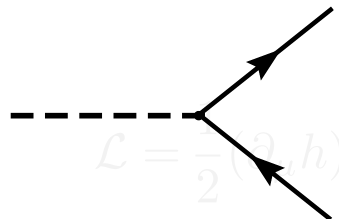

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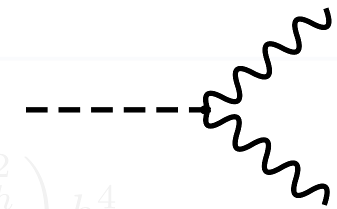

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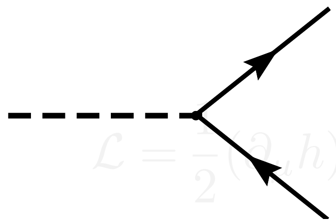

$$= c_\psi \cdot g_{h\psi\psi}^{SM}$$

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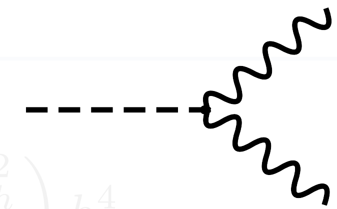

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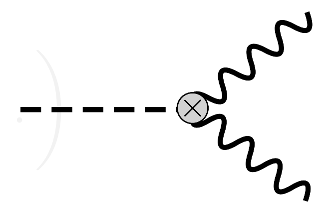
E[2] correction to hVV couplings



$$c_{ij} \sim \left(\frac{g_* v}{\Lambda}\right)$$

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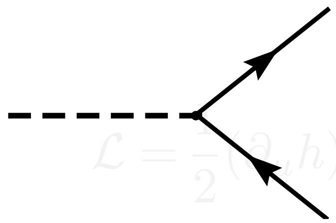

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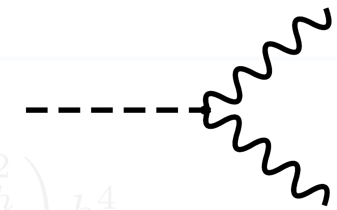

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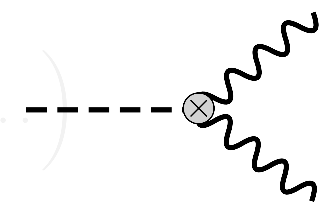

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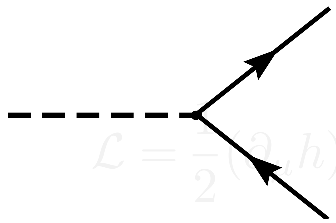

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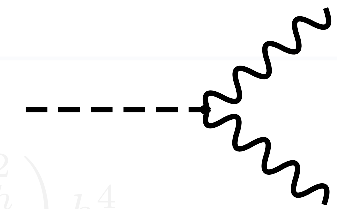

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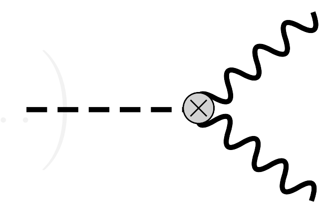

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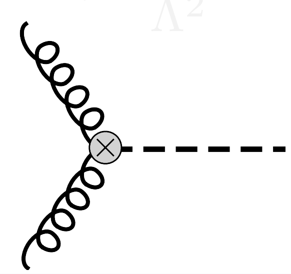

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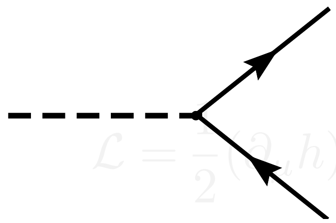

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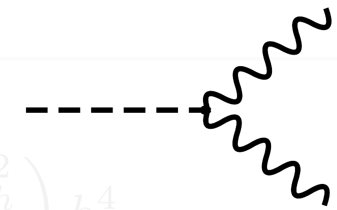

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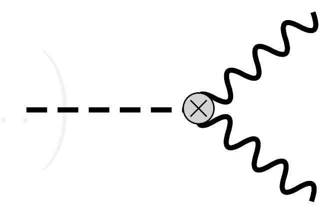

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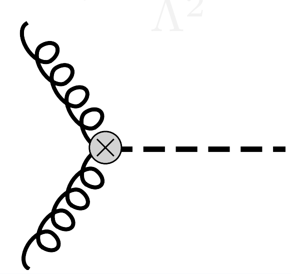

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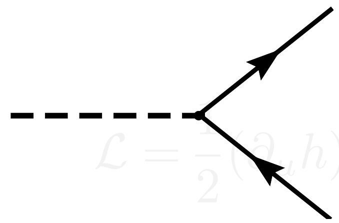

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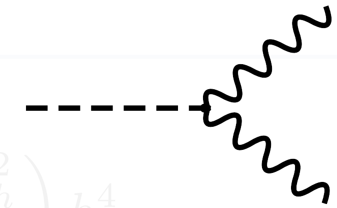

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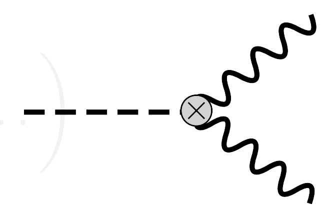

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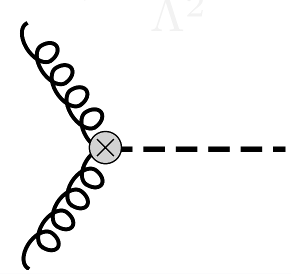

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← extra suppression for a pNG Higgs

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$$+ \frac{g^2}{16\pi^2}\left[\frac{c_{hhgg}}{\Lambda^2}\, G^2_{\mu\nu}\frac{(\partial_\rho h)^2}{v^2} + \frac{c'_{hhgg}}{\Lambda^2}\, G_{\mu\rho}G_{\rho\nu}\frac{\partial_\mu h \partial_\nu h}{v^2} + \ldots\right]$$

$$+ \ldots$$

RC, Grojean, Moretti, Piccinini, Rattazzi, JHEP 1005 (2010) 089

Effective Lagrangian for a light Higgs-like boson

$$\mathcal{L} = \frac{1}{2}(\partial_\mu h)^2 - \frac{1}{2}m_h^2 h^2 - \frac{d_3}{6}\left(\frac{3m_h^2}{v}\right)h^3 - \frac{d_4}{24}\left(\frac{3m_h^2}{v^2}\right)h^4 \dots$$

$$- \left(m_W^2\, W_\mu W_\mu + \frac{1}{2}m_Z^2\, Z_\mu Z_\mu\right)\left(1 + 2a\,\frac{h}{v} + b\,\frac{h^2}{v^2} + \dots\right)$$

$$- \sum_{\psi=u,d,l} m_{\psi^{(i)}}\, \bar{\psi}^{(i)}\psi^{(i)}\left(1 + c_\psi \frac{h}{v} + c_{2\psi}\frac{h^2}{v^2} + \dots\right)$$

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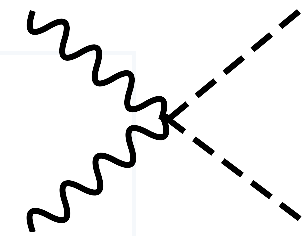
$$+ \dots$$

Contributes to *WW→hh*



RC, Grojean, Moretti, Piccinini, Rattazzi, JHEP 1005 (2010) 089

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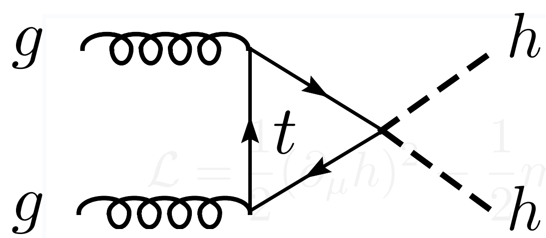

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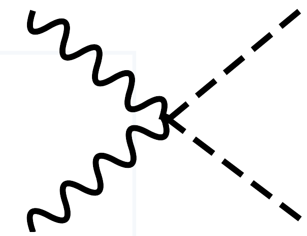

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- \left(m_W^2\, W_\mu W_\mu + \frac{1}{2} m_Z^2\, Z_\mu Z_\mu\right)\left(1 + 2a\,\frac{h}{v} + b\,\frac{h^2}{v^2} + \ldots\right)
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- \sum_{\psi = u,d,l} m_{\psi^{(i)}}\, \bar{\psi}^{(i)} \psi^{(i)} \left(1 + c_\psi \frac{h}{v} + c_{2\psi} \frac{h^2}{v^2} + \ldots\right)
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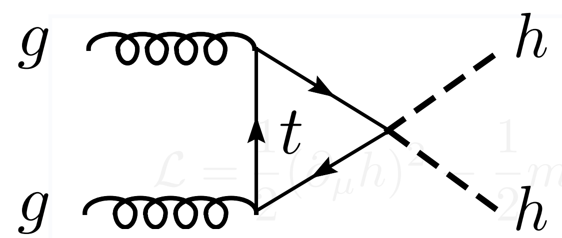
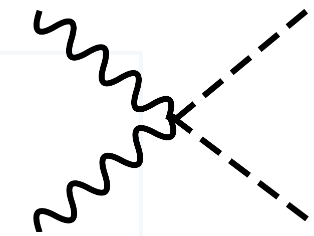
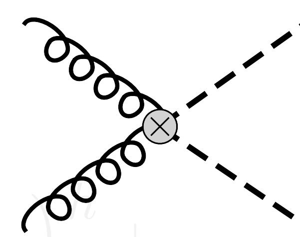


Contributes to $WW \to hh$



E^2 contribution to $gg \to hh$



$$c_{2gg} \sim \left(\frac{g_*^2 v^2}{\Lambda^2}\right)^2\left(\frac{\lambda^2}{g_*^2}\right)$$

RC, Grojean, Moretti, Piccinini, Rattazzi, JHEP 1005 (2010) 089

Effective Lagrangian for a light Higgs-like boson

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$$

$$
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$$
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$$

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$$

$$
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$$

$$
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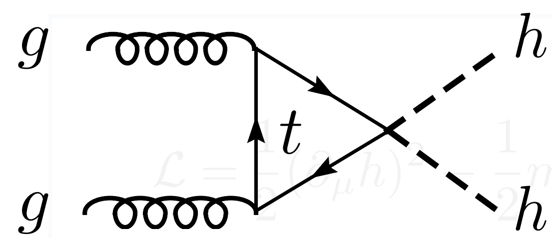
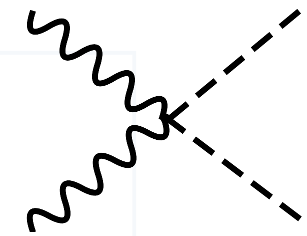
$$

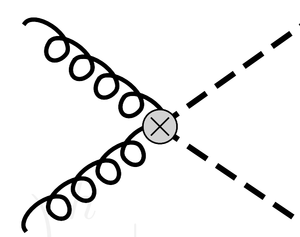
Contributes to *gg→hh*



Contributes to *WW→hh*

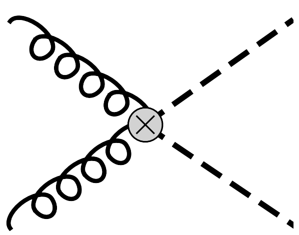


E² contribution to *gg→hh*



$$c_{2gg} \sim \left(\frac{g_*^2 v^2}{\Lambda^2}\right)^2 \left(\frac{\lambda^2}{g_*^2}\right)$$

E⁴ contribution to *gg→hh*



$$c_{hhgg} \sim \left(\frac{g_*^2 v^2}{\Lambda^2}\right)$$

RC, Grojean, Moretti, Piccinini, Rattazzi, JHEP 1005 (2010) 089

Benchmark scenario: composite Higgs

- Possibly large shifts to tree-level couplings a, c due to Higgs non-linearities

Ex: MCHM5 $a = \sqrt{1-\xi}$ for $\xi = 0.25$ $a = 0.87$

$c = 0.58$

$$c = \frac{1-2\xi}{\sqrt{1-\xi}}$$

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$c = \frac{1-2\xi}{\sqrt{1-\xi}}$ $c = 0.58$

- Analyticity and crossing symmetry imply a sum rule on a

$$1 - a^2 = \frac{v^2}{6\pi} \int_0^\infty \frac{ds}{s} \left(2\,\sigma^{tot}_{I=0}(s) + 3\,\sigma^{tot}_{I=1}(s) - 5\,\sigma^{tot}_{I=2}(s)\right)$$

$a > 1$ only if I=2 channel dominates.
Ex: doubly charged scalar resonance

Falkowski, Rychkov, Urbano, JHEP 1204 (2012) 073
Low, Rattazzi, Vichi, JHEP 1004 (2010) 126

Benchmark scenario: composite Higgs

- Leading local contributions to *ggh* and $\gamma\gamma h$ suppressed due to the Higgs shift symmetry

$$g = e^{i\alpha T^{\hat{4}}} \in SO(5) \qquad h(x) \to h(x) + \alpha\, f$$

[NG bosons couple derivatively]

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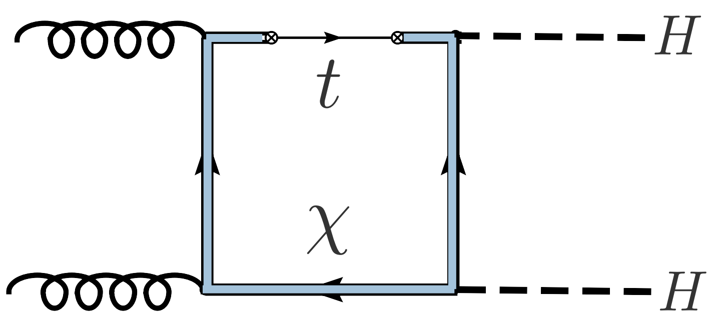
Shift symmetry not broken by $SU(3)_c \times U(1)_Q$: two powers of weak couplings needed to generate $G_{\mu\nu}^2 H^\dagger H$, $\gamma_{\mu\nu}^2 H^\dagger H$

Giudice, Grojean, Pomarol, Rattazzi, JHEP 0706 (2007) 045



$$G_{\mu\nu}^2 H^\dagger H \, \frac{\alpha_s}{4\pi} \frac{Y_*^2}{m_*^2} \times \frac{\lambda^2}{g_*^2}$$

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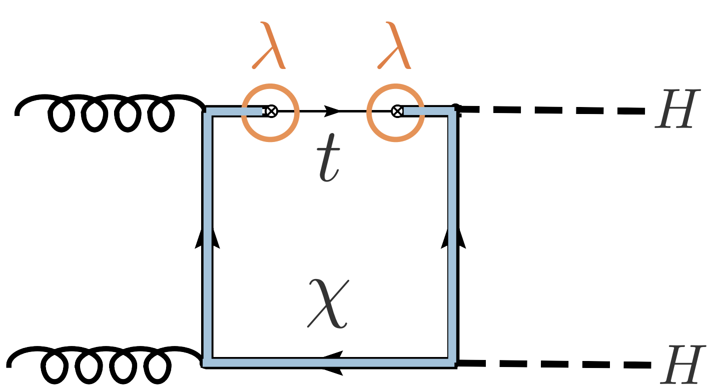

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Benchmark scenario: composite Higgs

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Ellis, Gaillard, Nanopoulos, NPB 106 (1976) 292
Shifman et al., Sov. J. Nucl. Phys. 30 (1979) 711
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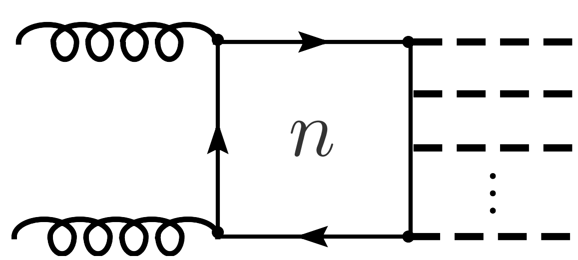
Kniehl, Spira Z. Phys. C69 (1995) 77
Gillioz et al. arXiv:1206.7120

$\sum_n$ 

In the limit of soft Higgs emissions

(soft Higgs = vanishing Higgs mass and momentum)

$$A(gg \to h^n) \propto \left(\frac{\partial^n}{\partial h^n} \log\det\left[\mathcal{M}^\dagger(h)\mathcal{M}(h)\right]\right)_{h=v}$$

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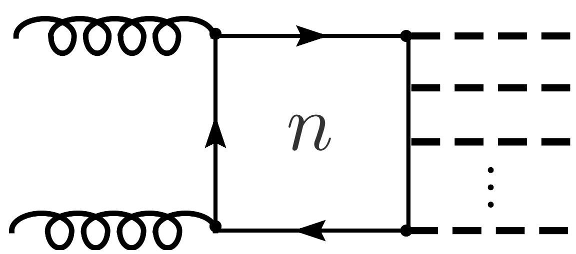

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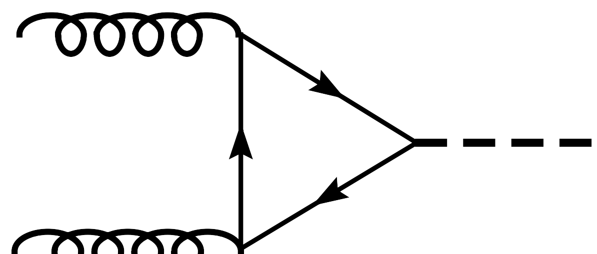
In minimal composite Higgs models with partial compositeness

$$\det \left[\mathcal{M}^\dagger(h) \mathcal{M}(h) \right] \propto \lambda_L(h) \lambda_R(h) \quad \Rightarrow \quad \boxed{A(gg \to h^n) = A(gg \to h^n)_{SM} \times F(\xi)}$$

Falkowski, PRD 77 (2008) 055018
Rattazzi, Vichi, JHEP 1004 (2010) 126
Azatov, Galloway, PRD 85 (2012) 055013

No dependence upon masses of heavy fermions

Benchmark scenario: composite Higgs



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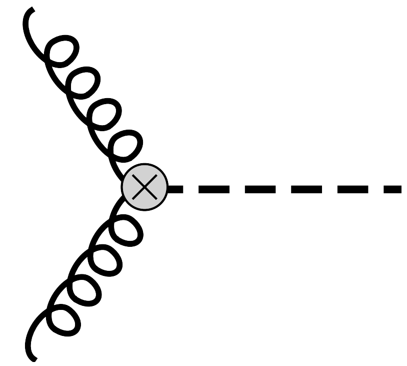

$$c_t \, \frac{m_h^2}{v} \, \frac{g_s^2}{16\pi^2} \, F\left(\frac{m_h^2}{m_t^2}\right)$$

$$c_{gg} \, \frac{m_h^2}{v} \, \frac{g_s^2}{16\pi^2}$$

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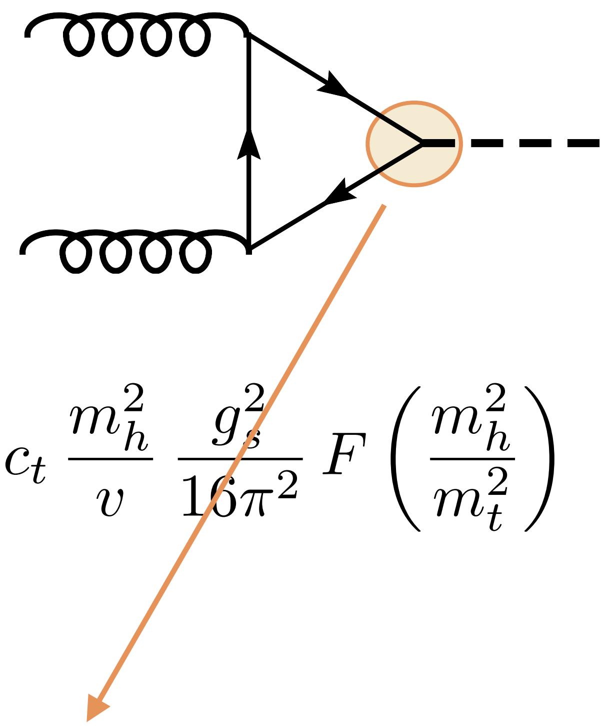

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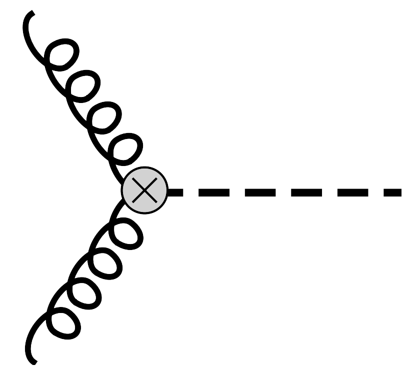

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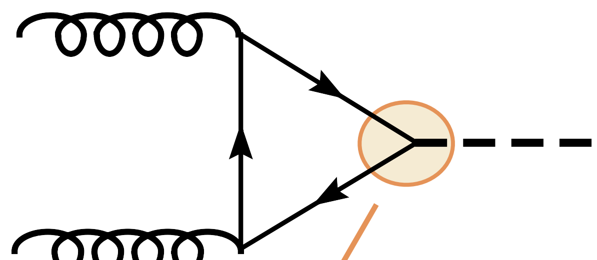

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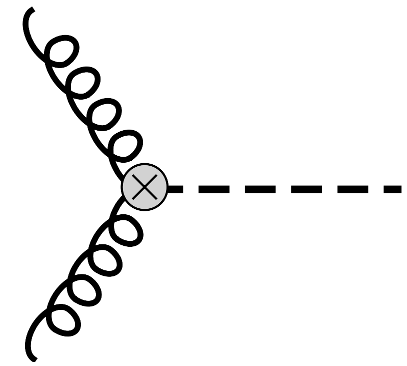

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from Higgs
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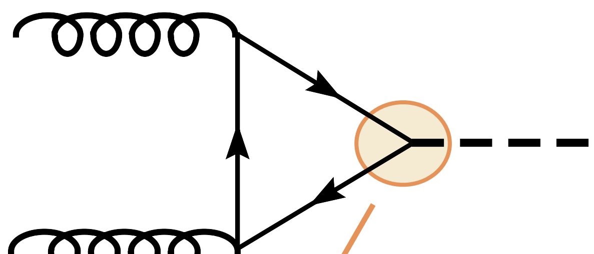

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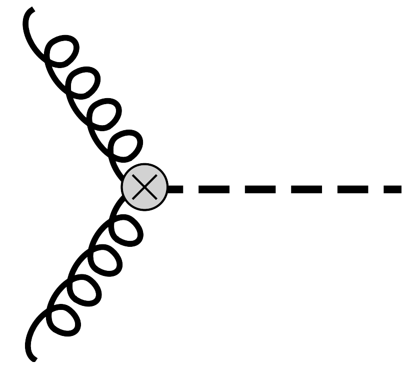

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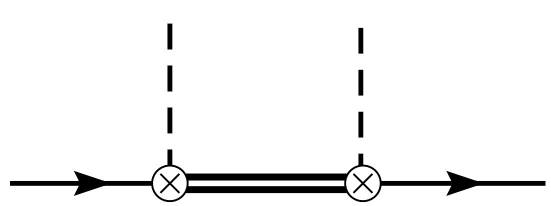
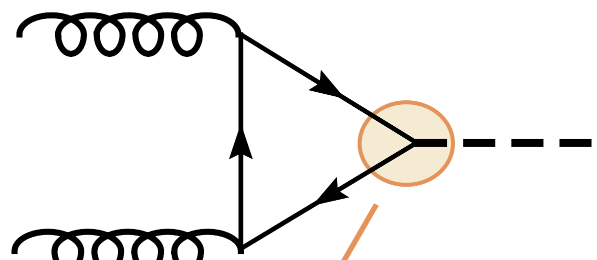
from Higgs non-linearities

from corrections to wave-function



Benchmark scenario: composite Higgs



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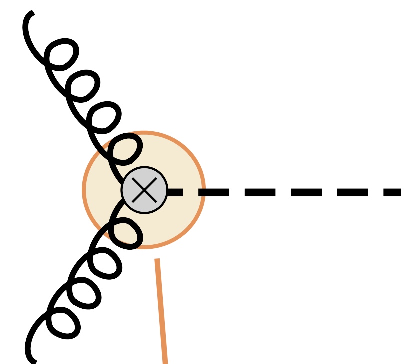

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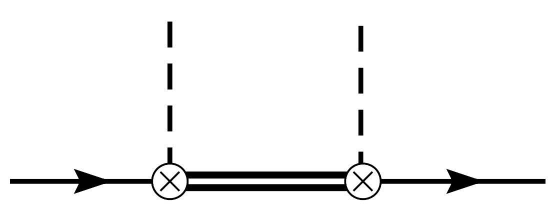

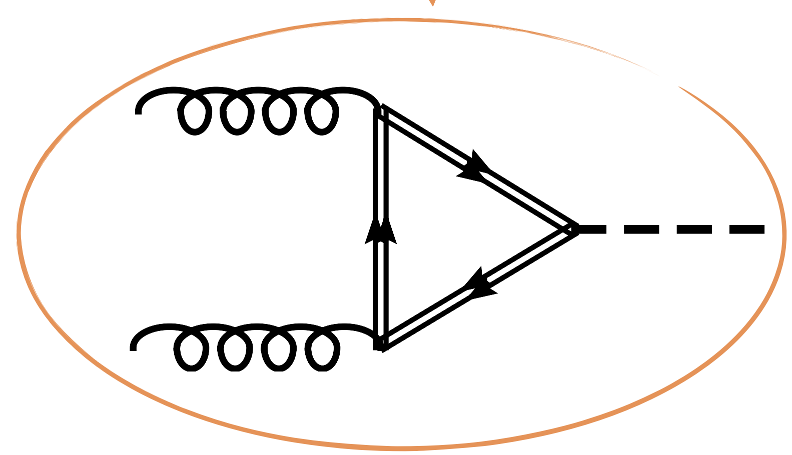

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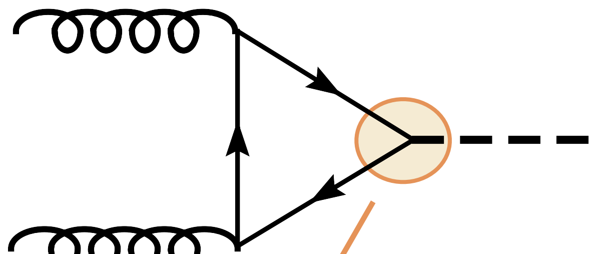
Benchmark scenario: composite Higgs



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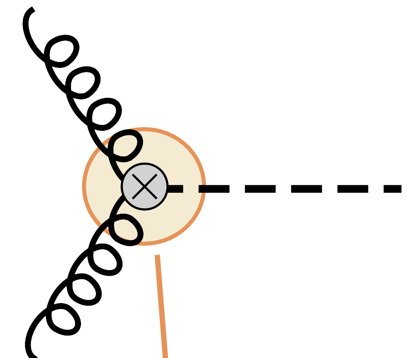

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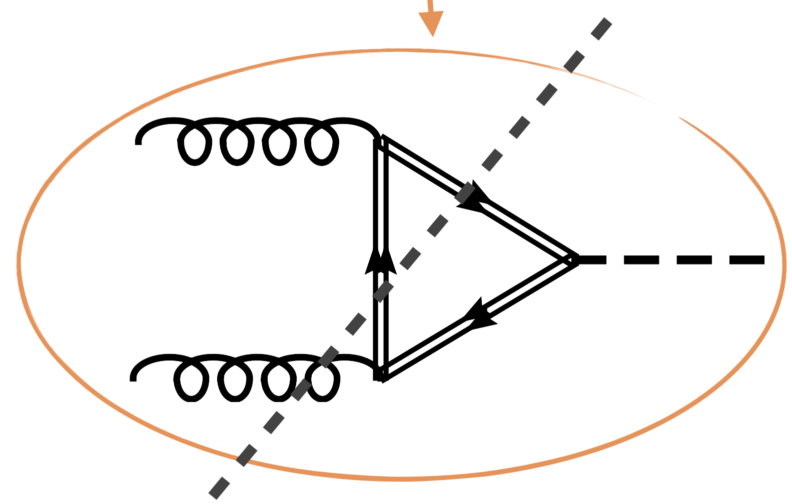
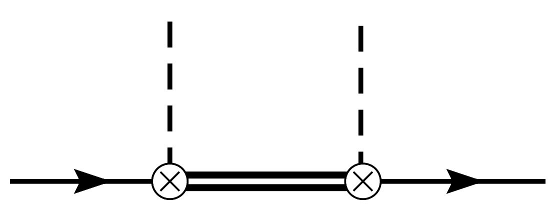
from Higgs non-linearities

from corrections to wave-function





$$c_{gg} \sim \left(\frac{g_*^2 v^2}{M^2}\right)\left(\frac{\lambda^2}{g_*^2}\right)$$

with partial compositeness: loops of heavy fermions exactly cancel the wave function correction

Benchmark scenario: composite Higgs

- In the case of $gg \to h$ and $h \to \gamma\gamma$ the soft limit is a good approximation ($m_h \ll 2m_t, m_*$)

$$A(gg \to h) = A(gg \to h)_{SM} \times c_t(\xi)$$

$$A(h \to \gamma\gamma) = A(h \to \gamma\gamma)^{(t)}_{SM} \times c_t(\xi) + A(h \to \gamma\gamma)^{(W)}_{SM} \times a(\xi)$$

➡ shifts in $gg \to h$ and $h \to \gamma\gamma$ controlled by tree-level couplings

Benchmark scenario: MSSM (Type II 2HDMs)

- Shifts to tree-level couplings due to mixing with heavier Higgs

$$a = \sin(\beta - \alpha) \qquad c_t = \frac{\cos\alpha}{\sin\beta} \qquad c_b = -\frac{\sin\alpha}{\cos\beta}$$

$$\begin{pmatrix} h^0 \\ H^0 \end{pmatrix} = \begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} \mathrm{Re}\, H_u^0 \\ \mathrm{Re}\, H_d^0 \end{pmatrix}$$

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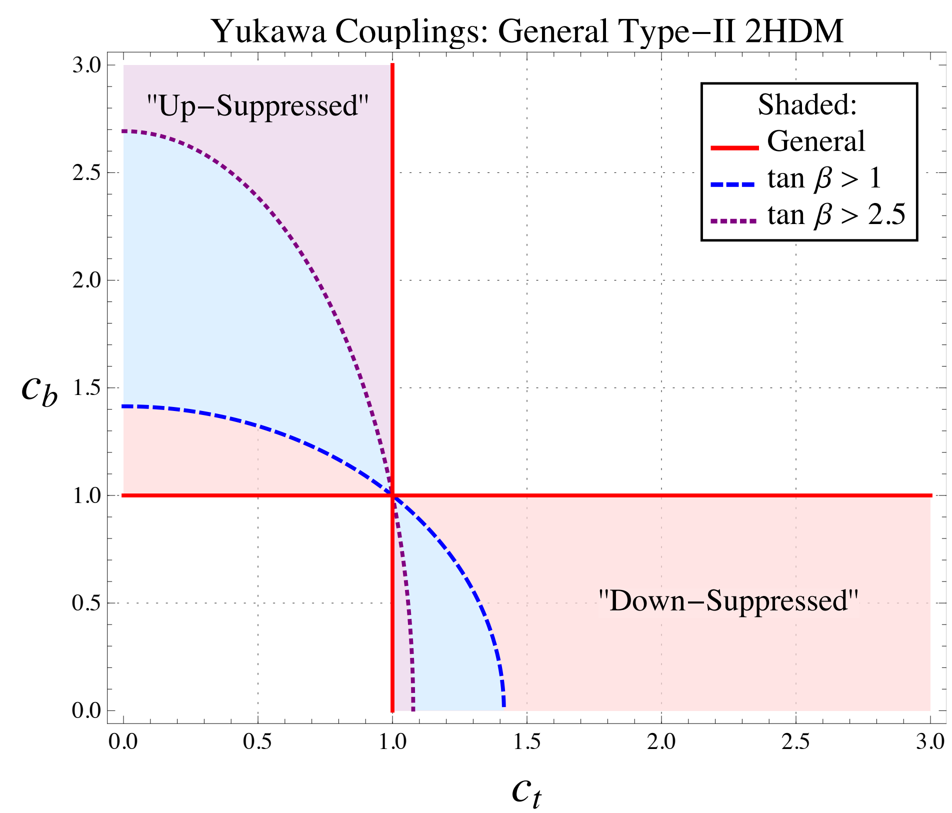
Only two regions in the (c_t, c_b) plane accessible

Down-Suppressed region mostly inaccessible at large $\tan\beta$

see: Azatov, Chang, Craig, Galloway arXiv:1206.1058



Decoupling limit: $\alpha \to \beta - \pi/2$ $\quad (a, c_{t,b} \to 1)$

Benchmark scenario: MSSM (Type II 2HDMs)

- Contributions to *ggh* (c_{gg}) and *γγh* ($c_{\gamma\gamma}$) from loops of stops

By virtue of the low energy theorem ($m_{\tilde{t}} \gg m_h/2$)

$$A(gg \to h), A(h \to \gamma\gamma) \propto \left(\frac{\partial}{\partial h} \log \det \mathcal{M}^2(h) \right)_{h=v}$$

$$\mathcal{M}^2 = \begin{bmatrix} \tilde{m}_L^2 + y_t^2 |H_u^0|^2 & y_t(H_u^0 A_t - \mu H_d^0) \\ y_t(H_u^{0\dagger} A_t - \mu H_d^{0\dagger}) & \tilde{m}_R^2 + y_t^2 |H_u^0|^2 \end{bmatrix}$$

$$c_{gg} = \frac{9}{2} c_{\gamma\gamma} = \frac{1}{4} \left(\frac{m_t^2}{m_{\tilde{t}_1}^2} + \frac{m_t^2}{m_{\tilde{t}_2}^2} - \frac{m_t^2 X_t^2}{m_{\tilde{t}_1}^2 m_{\tilde{t}_2}^2} \right)$$

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$$X_t = |A_t - \mu \cot \beta|$$

if mixing is small: $c_{gg} = 9/2\, c_{\gamma\gamma} > 0$ ⇒ $\Gamma(gg \to h)$ enhanced, $\Gamma(h \to \gamma\gamma)$ suppressed

large mixing can flip the sign ⇒ $\Gamma(gg \to h)$ suppressed, $\Gamma(h \to \gamma\gamma)$ enhanced

Naive expectation:

- Composite Higgs models:

$$(a-1), (c-1) \sim O(\xi)$$

$$c_{gg}, c_{\gamma\gamma} \simeq 0$$

- Natural SUSY:

$$a, c \simeq 1$$

$$c_{gg}, c_{\gamma\gamma} \neq 0$$

Higgs couplings: present status

- After the discovery, the main goal now is to understand the properties of the new particle
- Several theoretical studies have discussed what can be the best ways to determine the Higgs properties and understand its role in EWSB

Ideas put forward include:

- Use of effective Lagrangians for a model-independent determination of the Higgs couplings
- Use of exclusive analyses as a way to increase the sensitivity on individual couplings
- Study of systematic uncertainties
- Operative definition of quantities of interest

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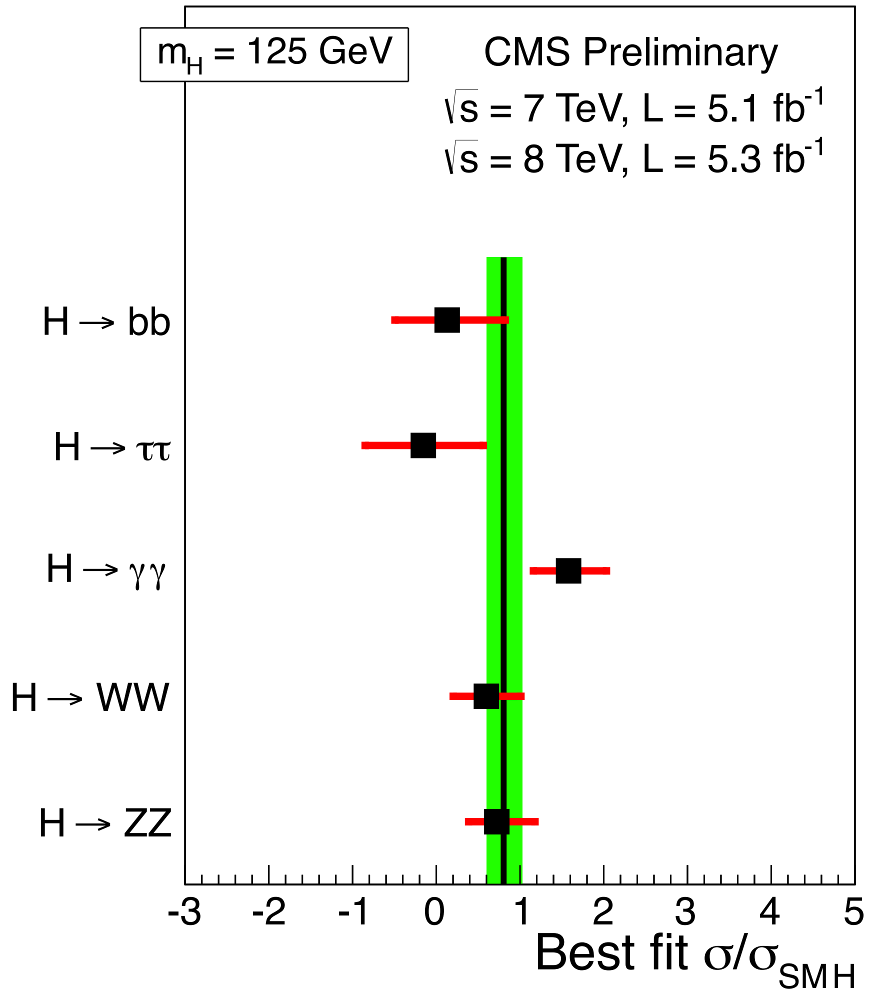
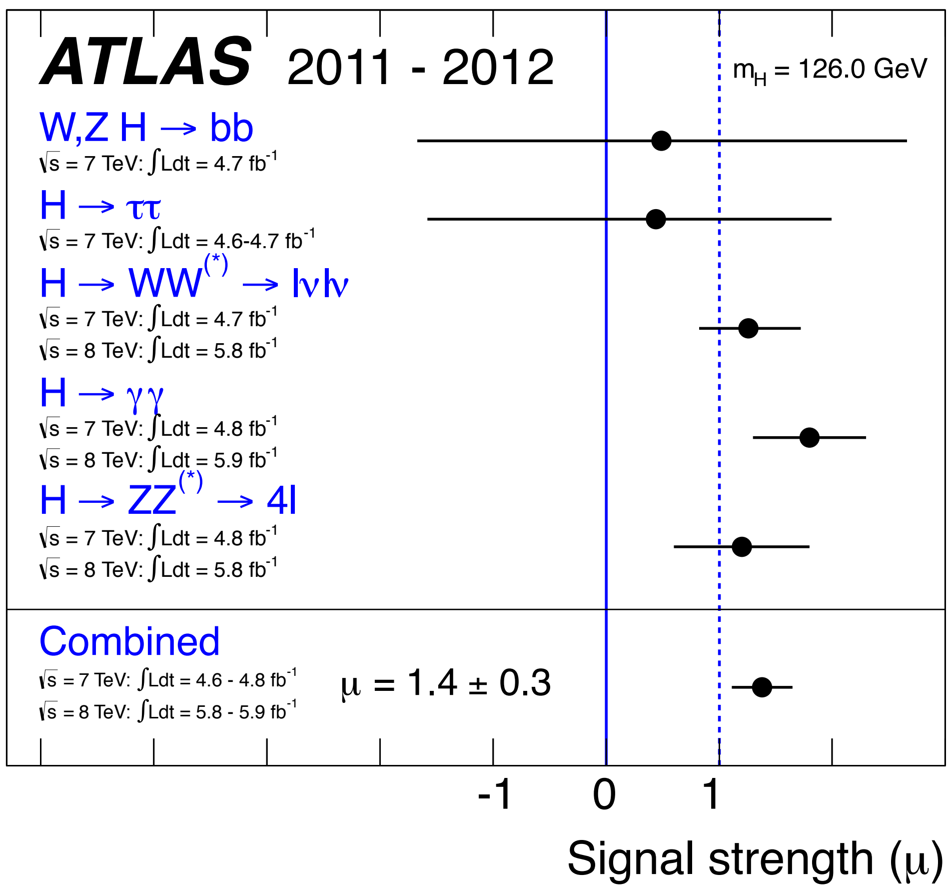
Zeppenfeld et al. PRD 62 (2000) 013009
Duhrssen et al. PRD 70 (2004) 113009
Giudice, Grojean, Pomarol, Rattazzi, JHEP 0706 (2007) 045
Lafaye et al. JHEP 0908 (2009) 009
R.C. et al. JHEP 1005 (2010) 089
Bock et al. PLB 649 (2010) 44
Englert, Plehn, Rauch, Zerwas, Zerwas, PLB 707 (2012) 512
Carmi, Falkowski, Kuflik, Volansky, JHEP 1207 (2012) 136
Azatov, R.C., Galloway JHEP 1204 (2012) 127
Espinosa, Grojean, Muhlleitner, Trott, JHEP 1205 (2012) 097
Giardino, Kannike, Raidal, Strumia JHEP 1206 (2012) 117
Ellis, You JHEP 1206 (2012) 140
Azatov et al. JHEP 1206 (1021) 134
Klute et al. arXiv:1205.2699
Azatov, Chang, Craig, Galloway, arXiv:1206.1058
Corbett, Eboli, Gonzalez-Fraile, Gonzalez-Garcia, arXiv:1207.1344
Low, Lykken, Shaughnessy, arXiv:1207.1093
Giardino, Kannike, Raidal, Strumia arXiv:1207.1347
Baglio, Djouadi, Godbole, PLB 716 (2012) 203
Ellis, You, arXiv:1207.1693
Espinosa, Grojean, Muhlleitner, Trott, arXiv:1207.1717
Espinosa, Grojean, Sanz, Trott, arXiv:1207.7355
Djouadi, arXiv:1208.3436
.....

The experimental situation in a nutshell





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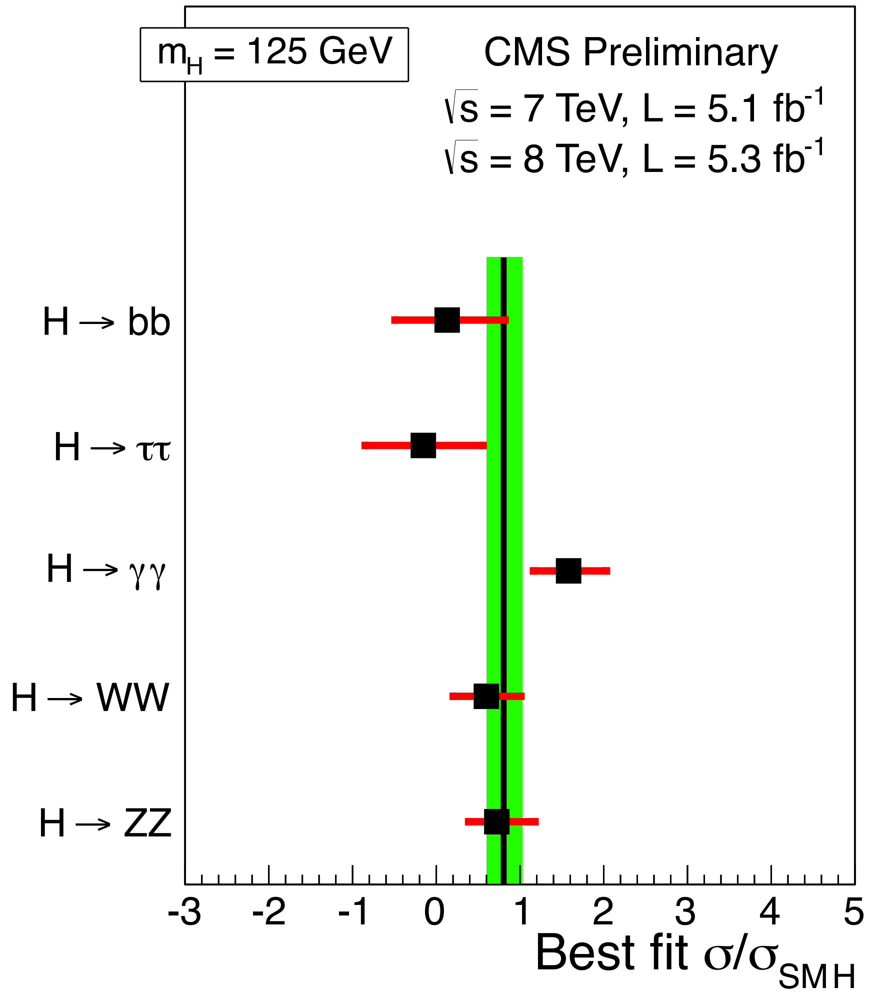
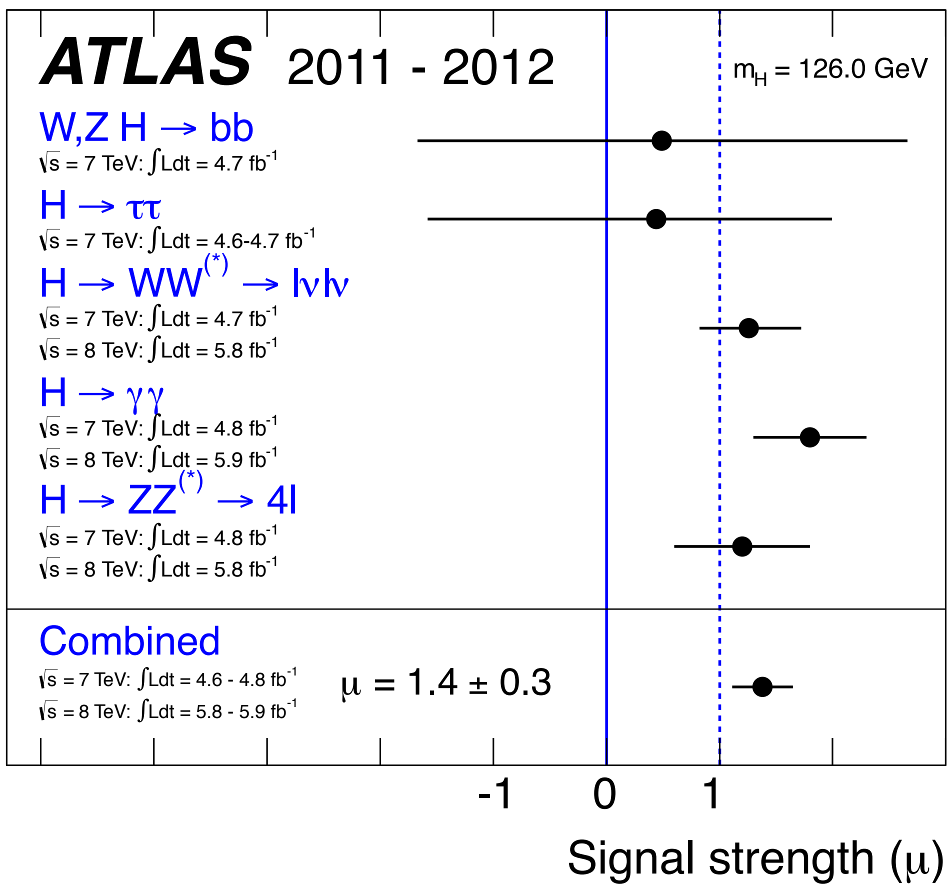
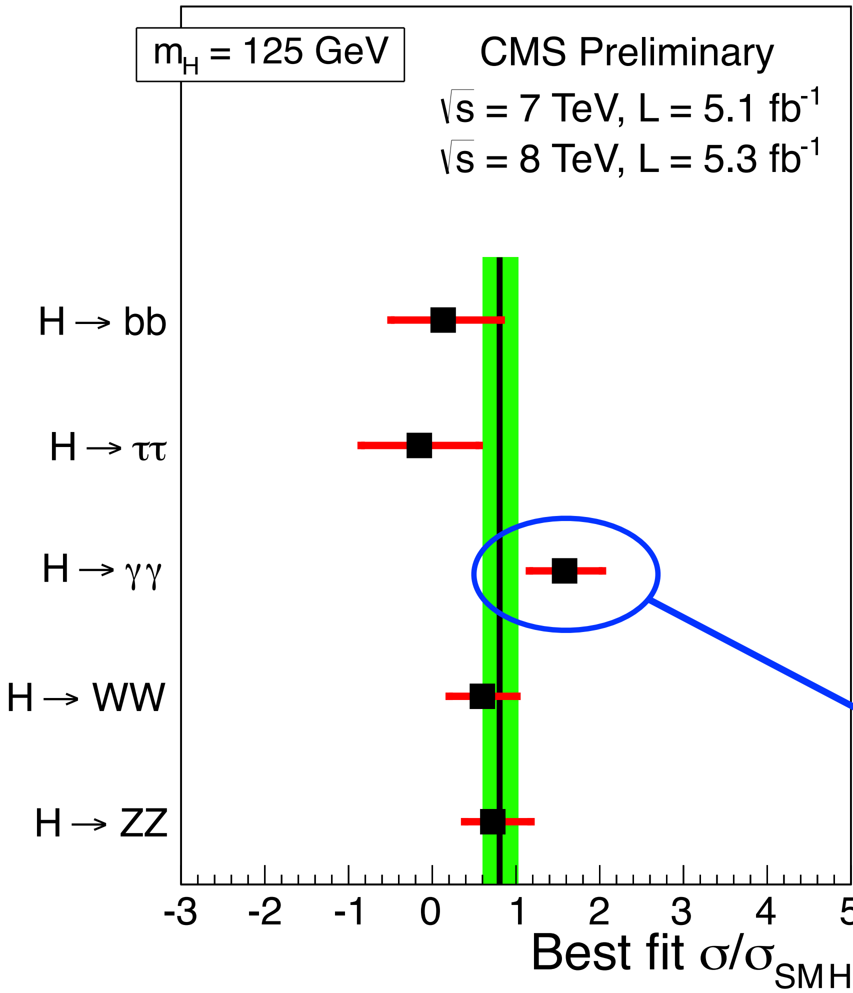


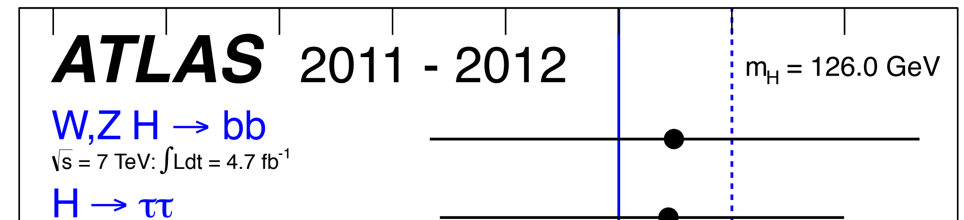


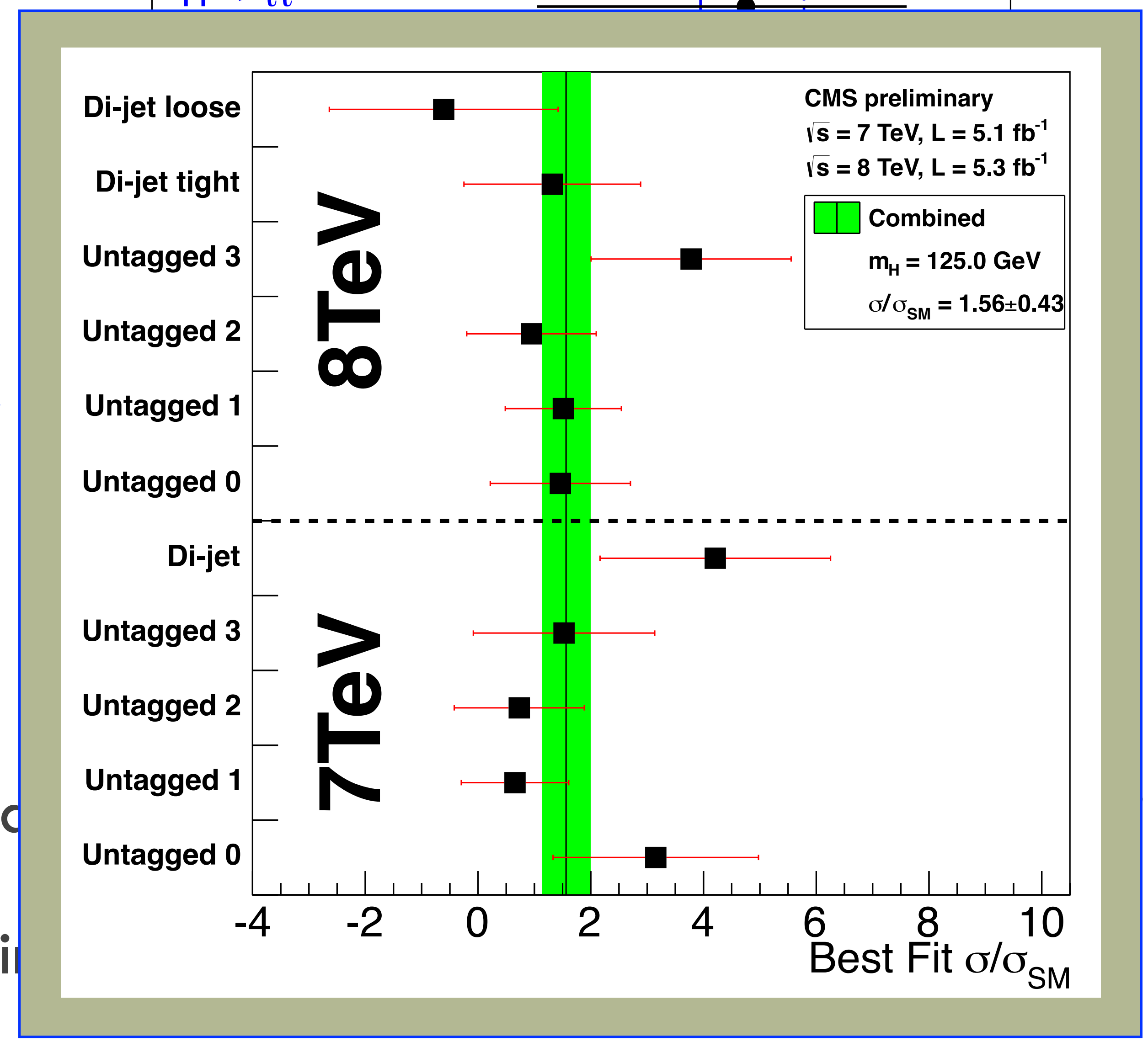
- Is there a pattern ? ... not quite apparently, just values scattered around 1 ?

  Only 'feature': mild excess in γγ channel. Too early to say if interesting

The experimental situation in a nutshell







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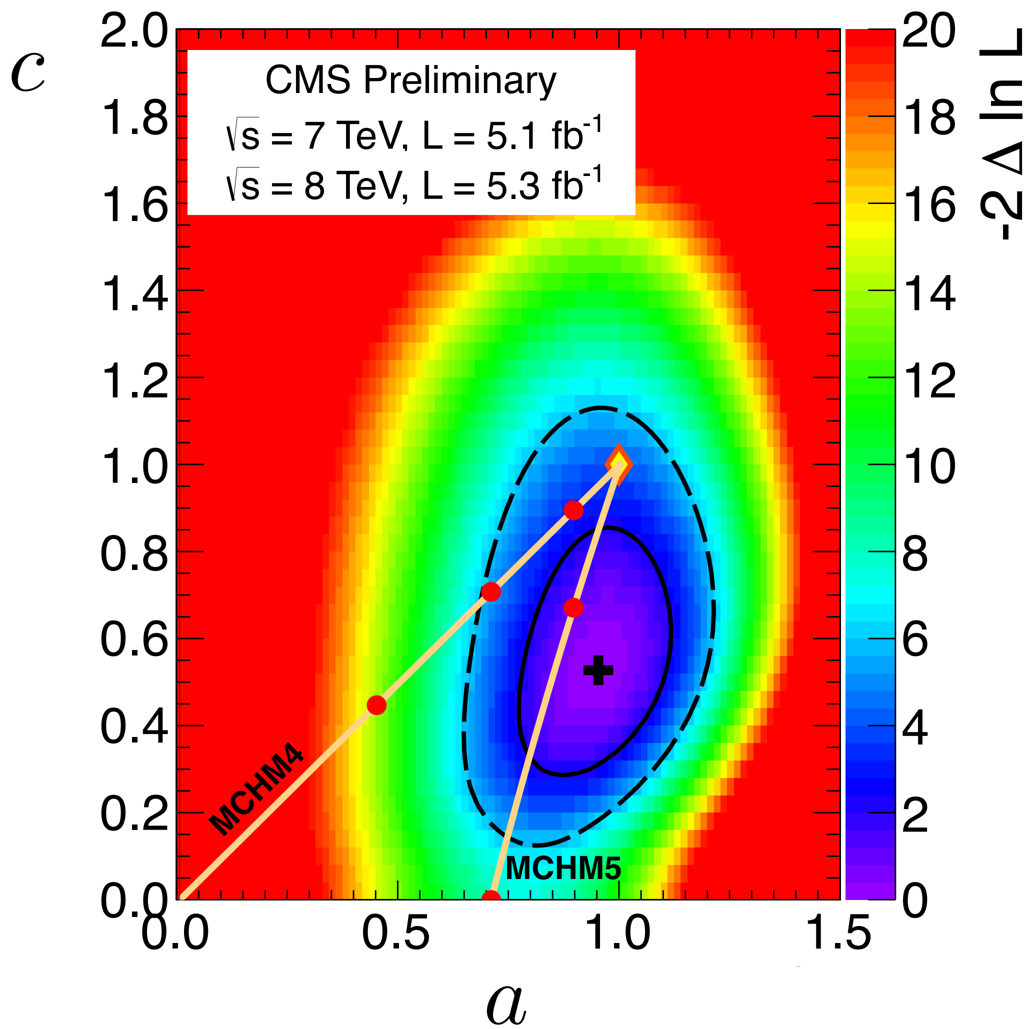
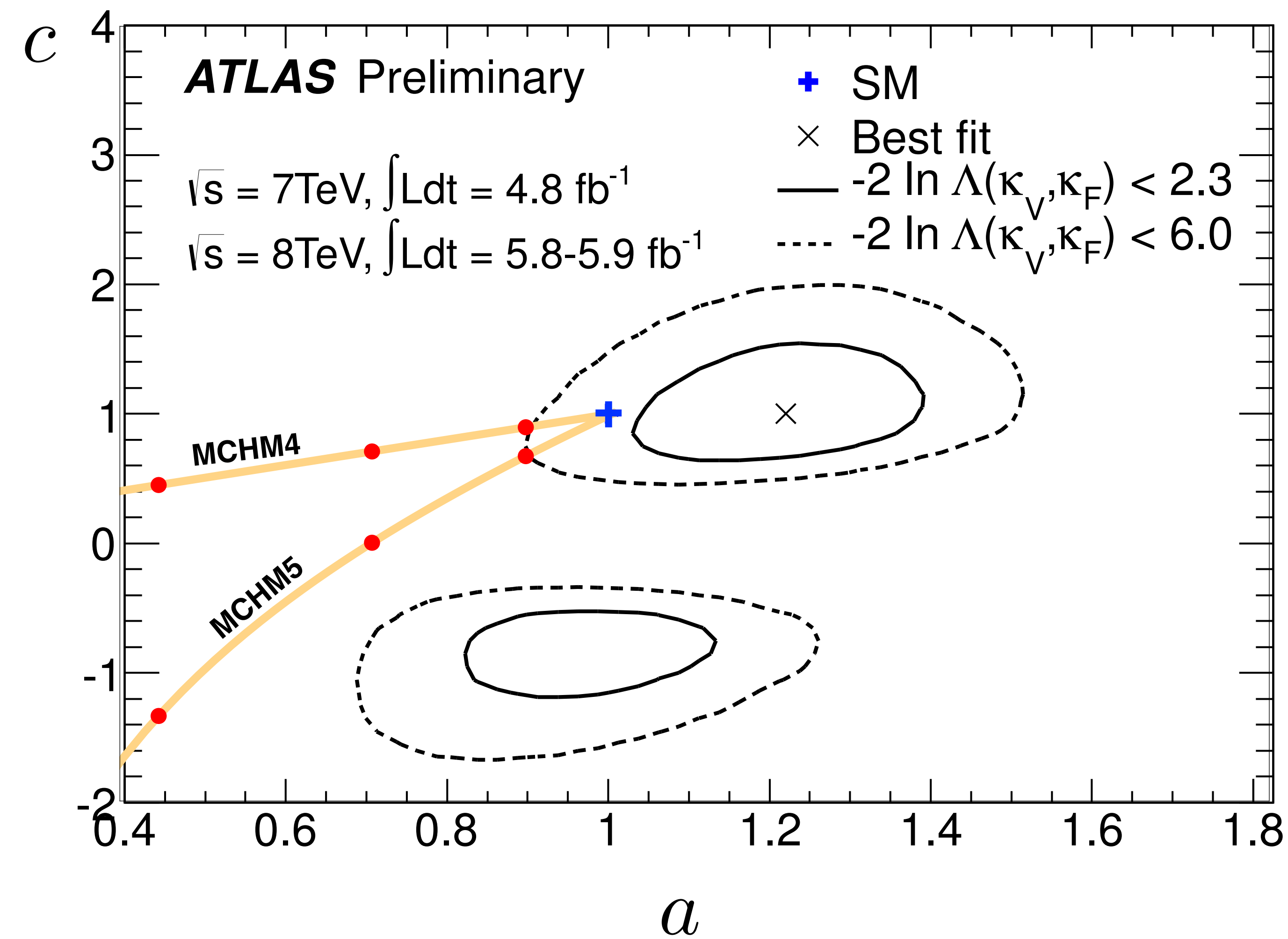
- Warning: much more elaborate and complex analyses behind these plots

Testing Composite Higgs models

Red points at $\xi = 0.2,\ 0.5,\ 0.8$



CMS



ATLAS

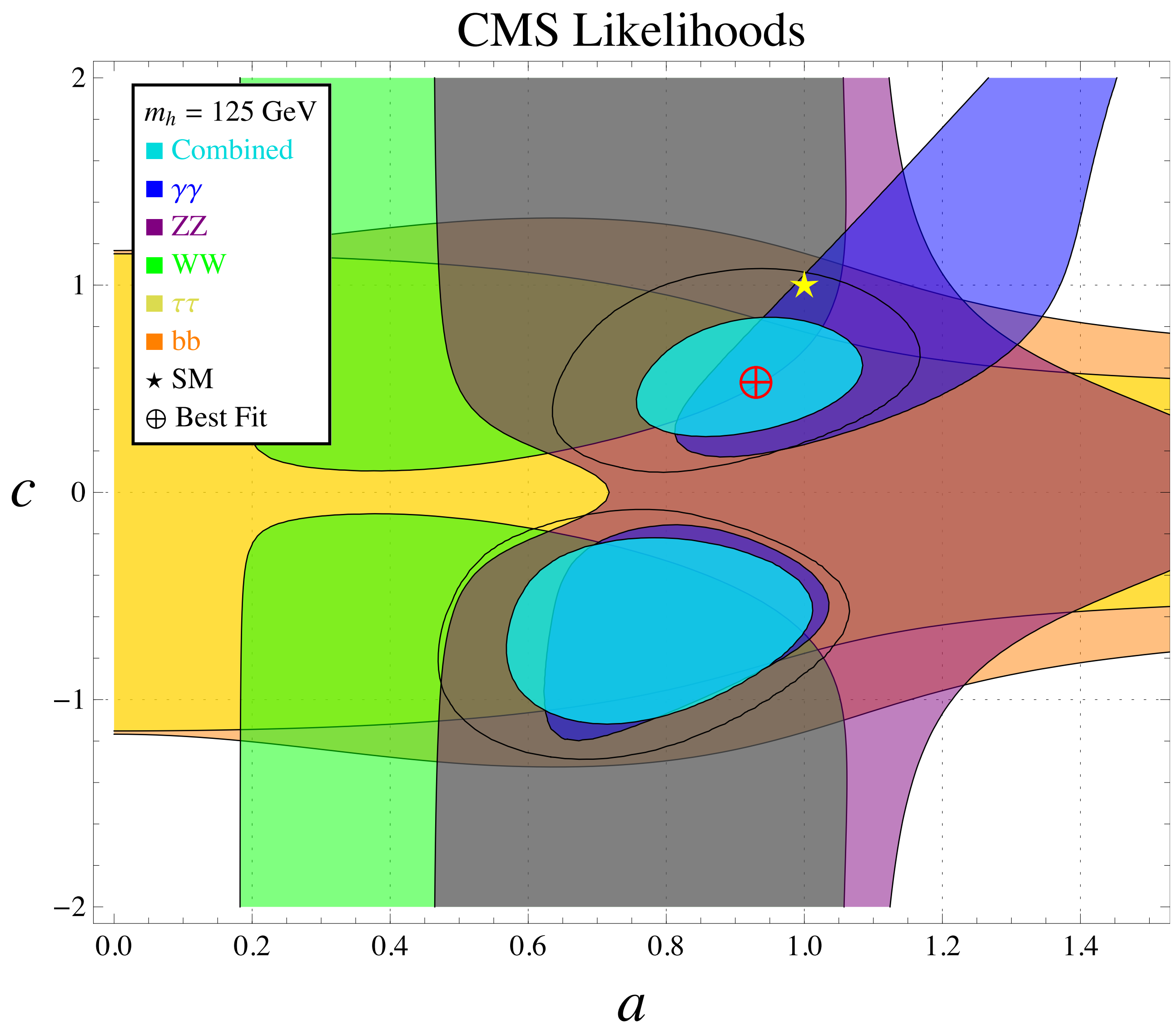
prefers $c < 1, a \simeq 1$

deeper minimum at $c < 0$ (not shown)

prefers $a > 1, c \simeq 1$

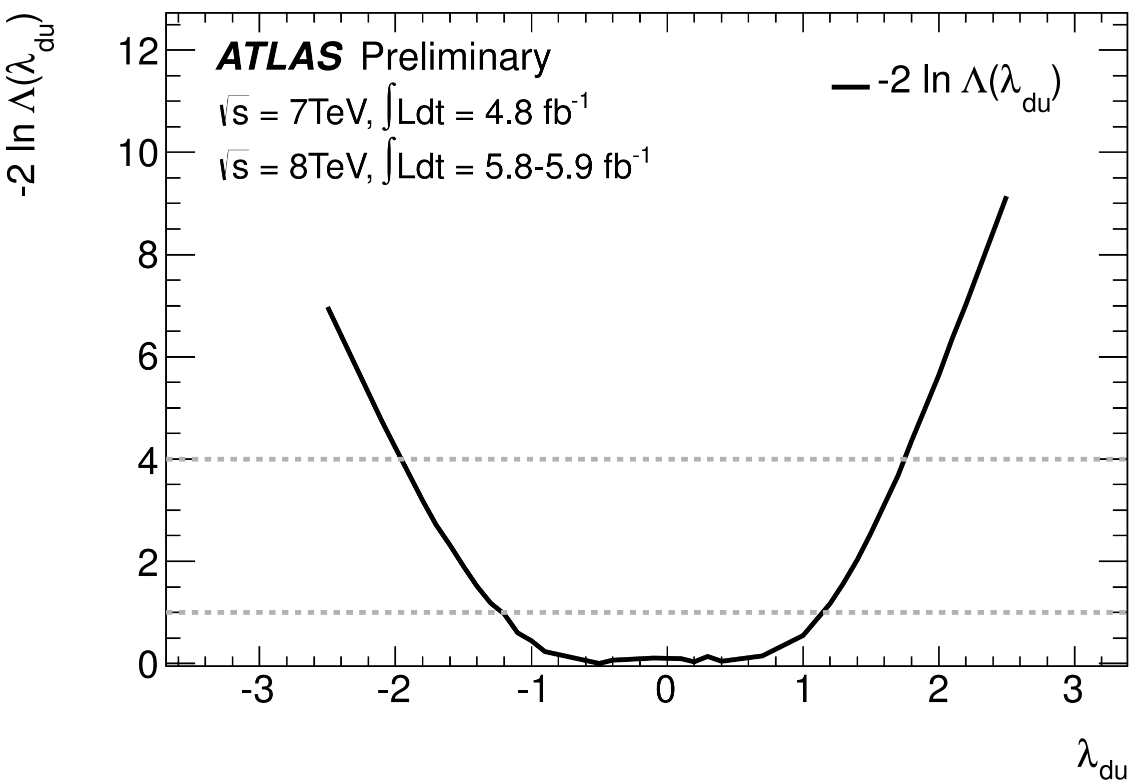
Testing Composite Higgs models: channel breakdown

Best fit location is determined by several channels



J. Galloway et al. work in progress

Testing Type II 2HDMs (incl. MSSM)



ATLAS made a 3-parameter fit:

$$a/c_t,\ c_t^2/c_{tot},\ \lambda_{du} \equiv c_b/c_t$$

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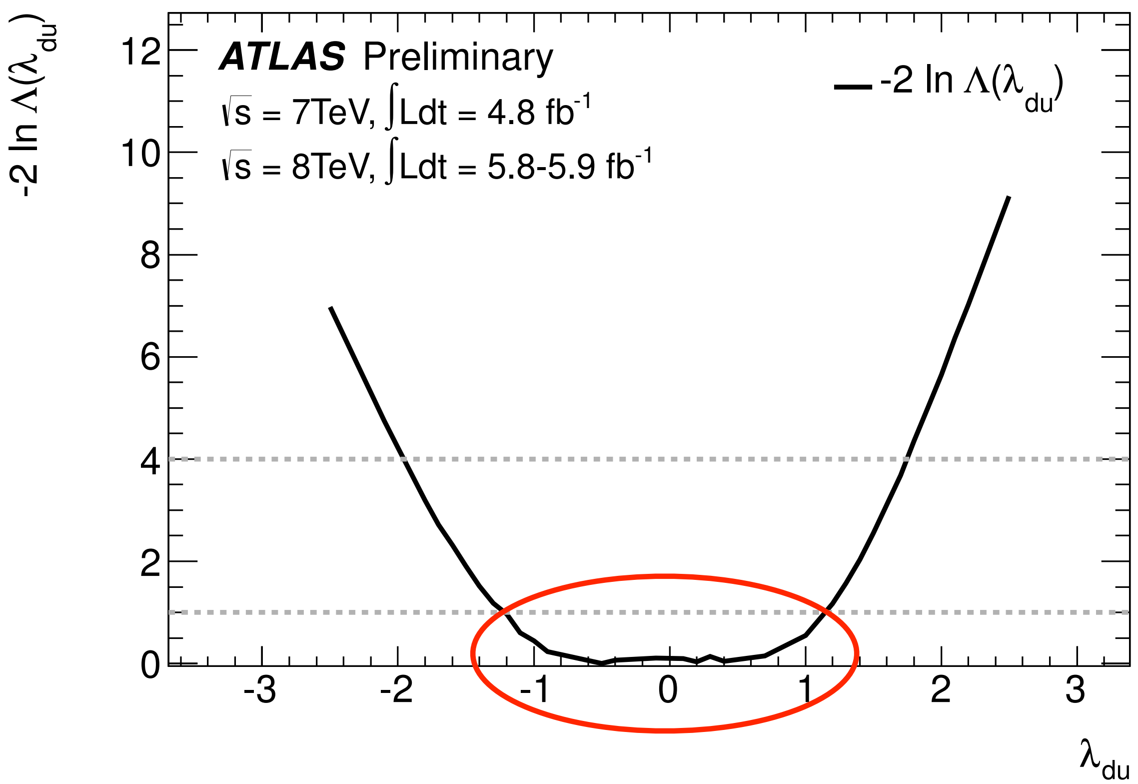

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Likelihood for λ_{du} rather shallow between -1 and +1: limited sensitivity on $c_b = c_\tau$

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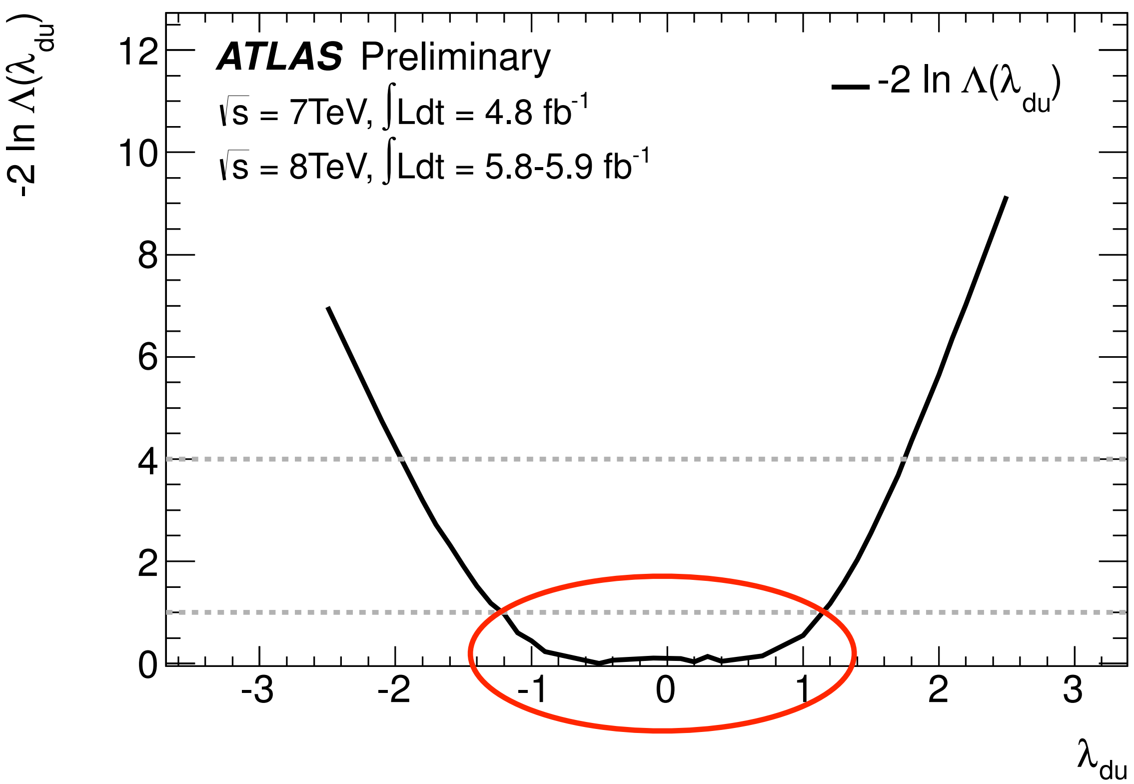

Use (c_b, c_t) plane to test Type II 2HDMs

Fixing the total width to the SM value can help to increase the sensitivity on

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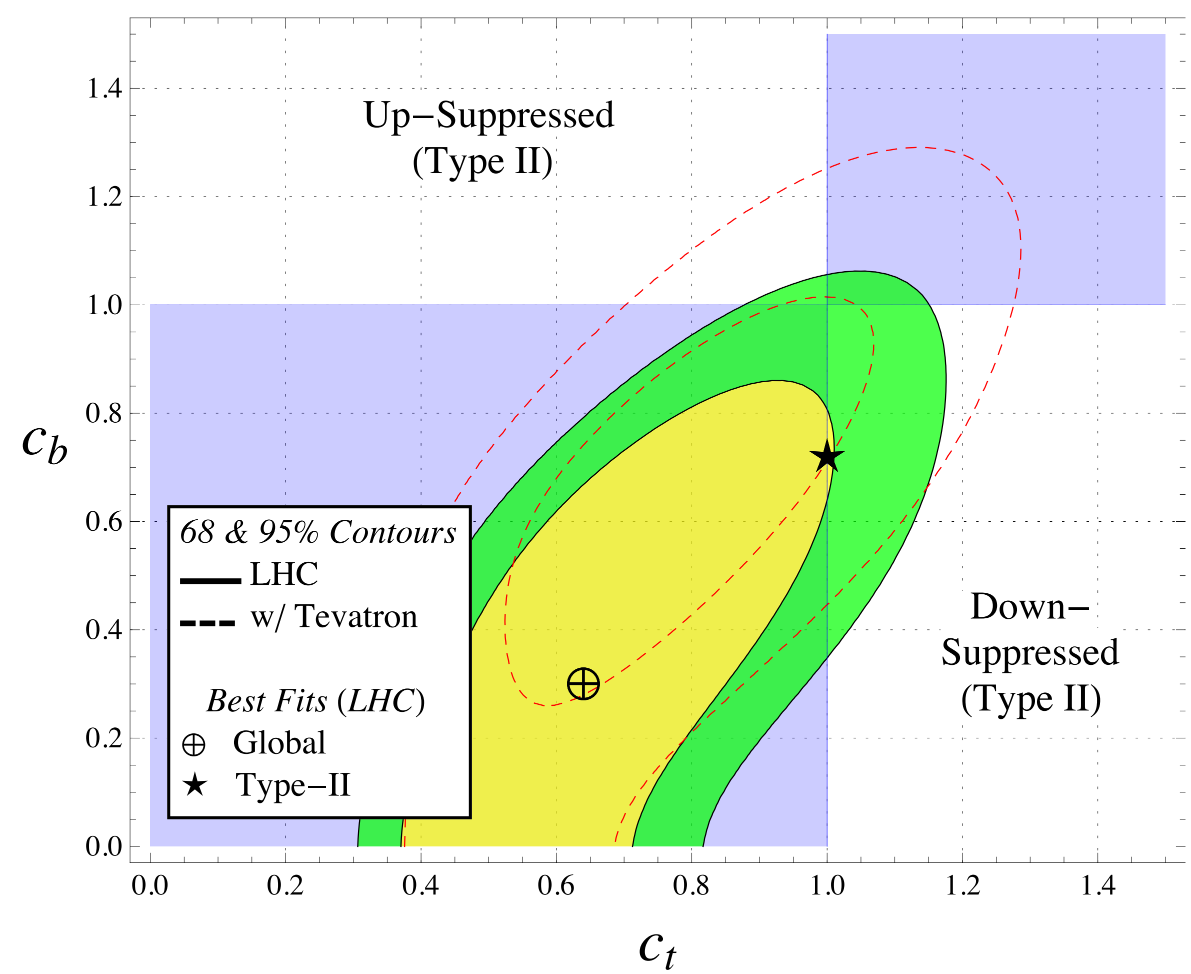
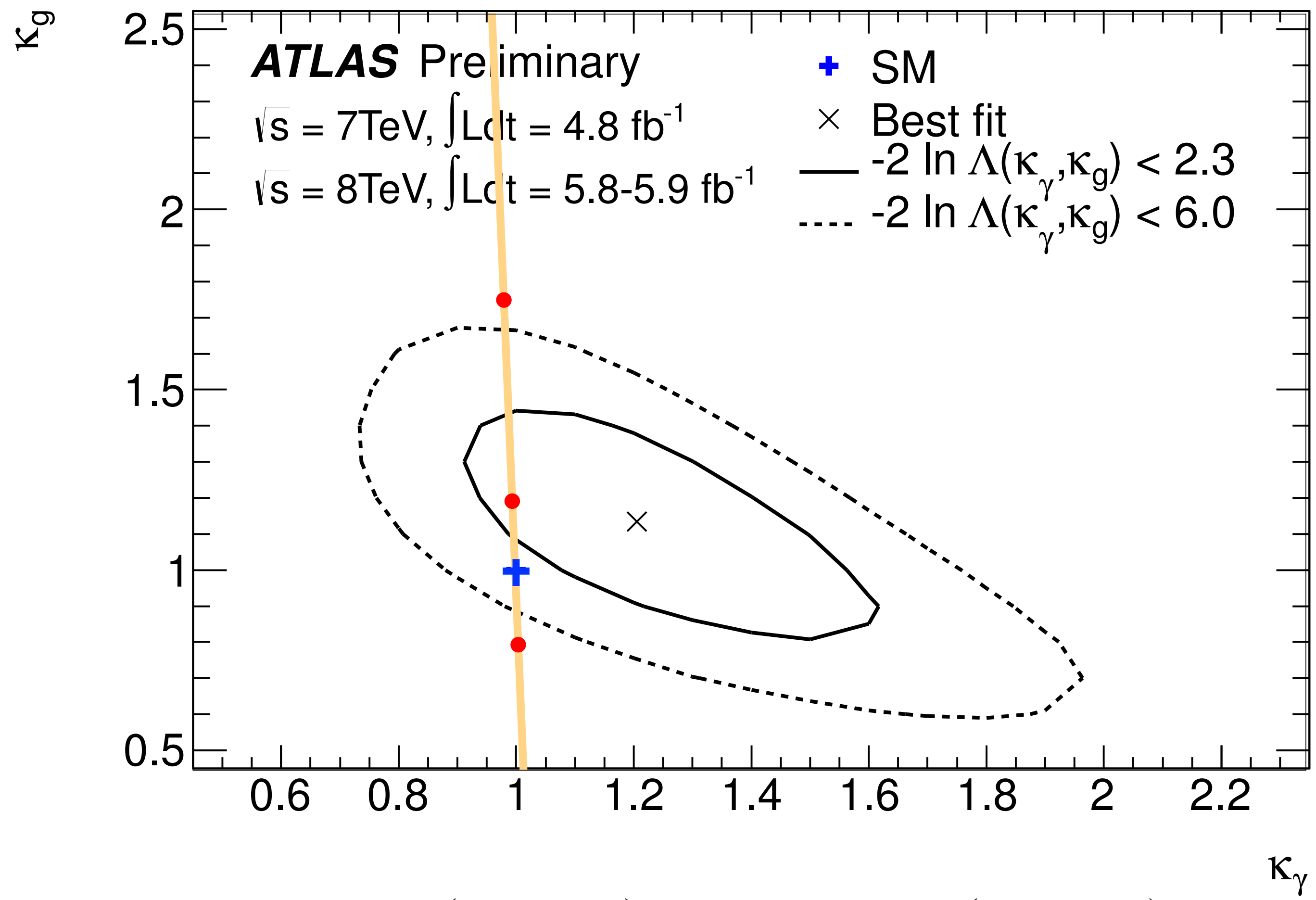
λ_{du} alone does not test Type II 2HDMs

Marginalizing over $0 < a < 1$



Azatov, Chang, Craig, Galloway, arXiv:1206.1058v3

Testing New Light Physics in Loops (incl. SUSY)



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Yellow = MSSM trajectory $c_{\gamma\gamma} = 2/9 c_{gg}$

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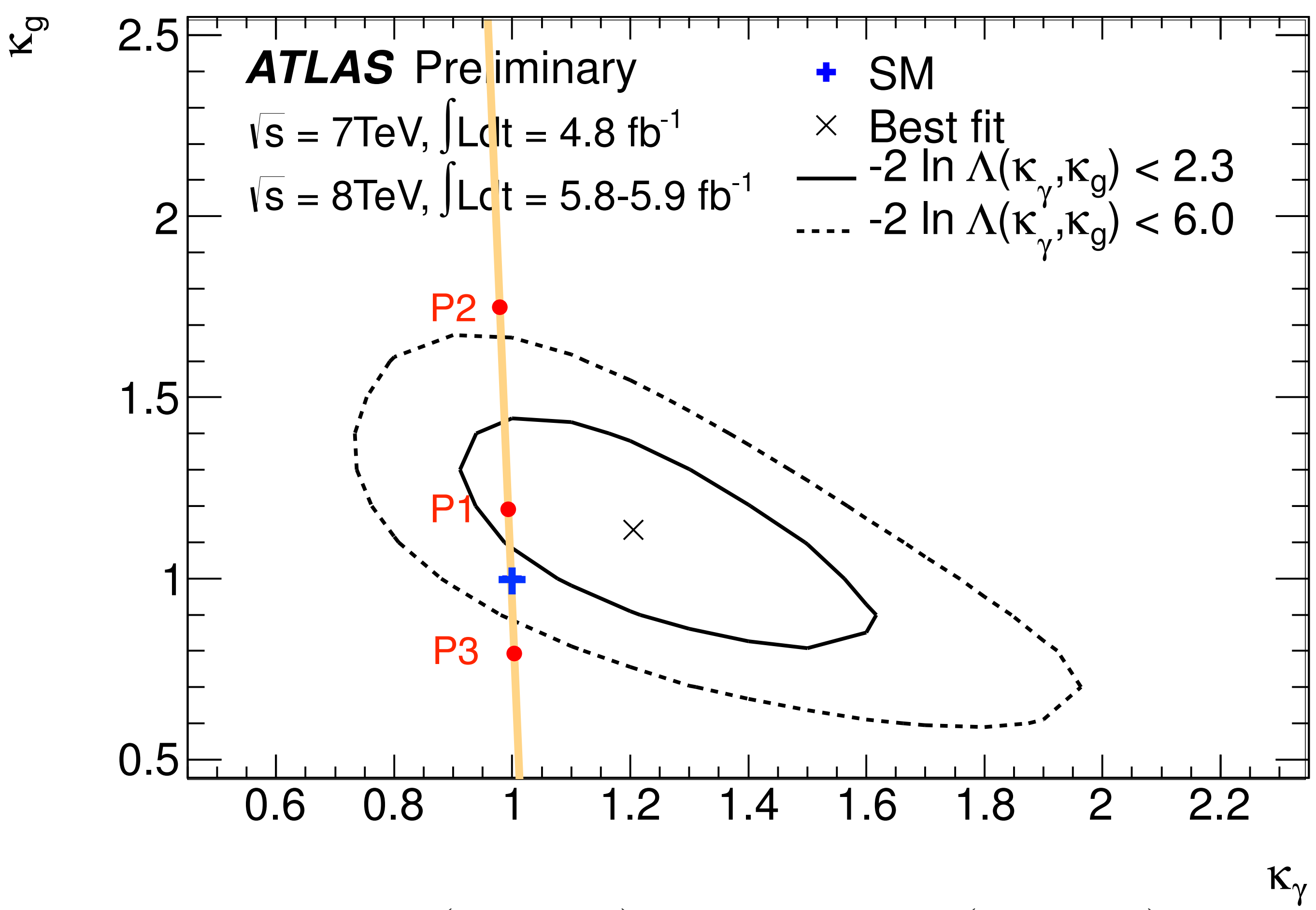

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P1: $m_{\tilde{t}_1} = 100\,\mathrm{GeV},\ m_{\tilde{t}_2} = 300\,\mathrm{GeV},\ \theta_t = 0$

P2: $m_{\tilde{t}_1} = 200\,\mathrm{GeV},\ m_{\tilde{t}_2} = 500\,\mathrm{GeV},\ \theta_t = 0$

P3: $m_{\tilde{t}_1} = 400\,\mathrm{GeV},\ m_{\tilde{t}_2} = 1000\,\mathrm{GeV},\ \theta_t = \pi/4$

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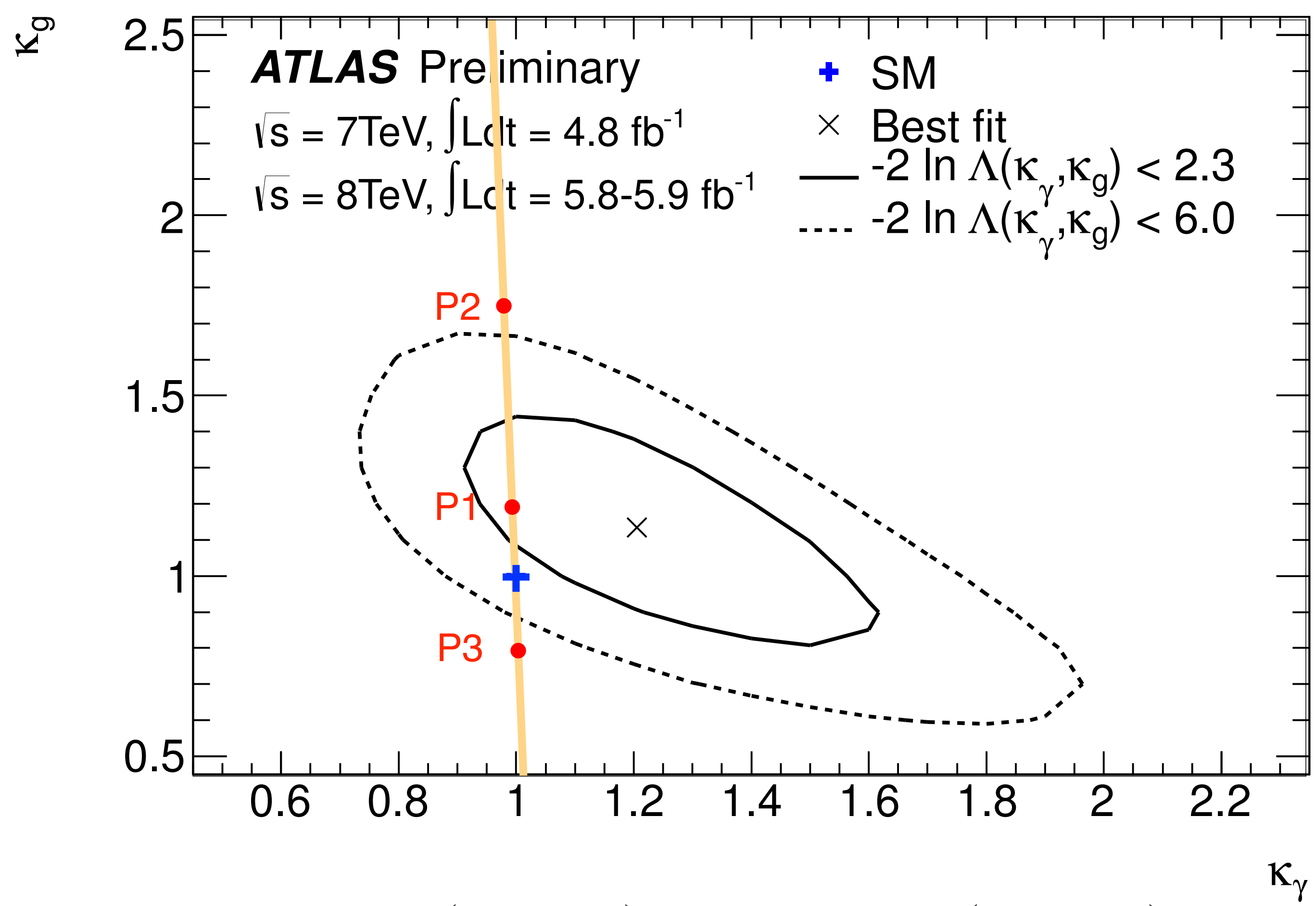

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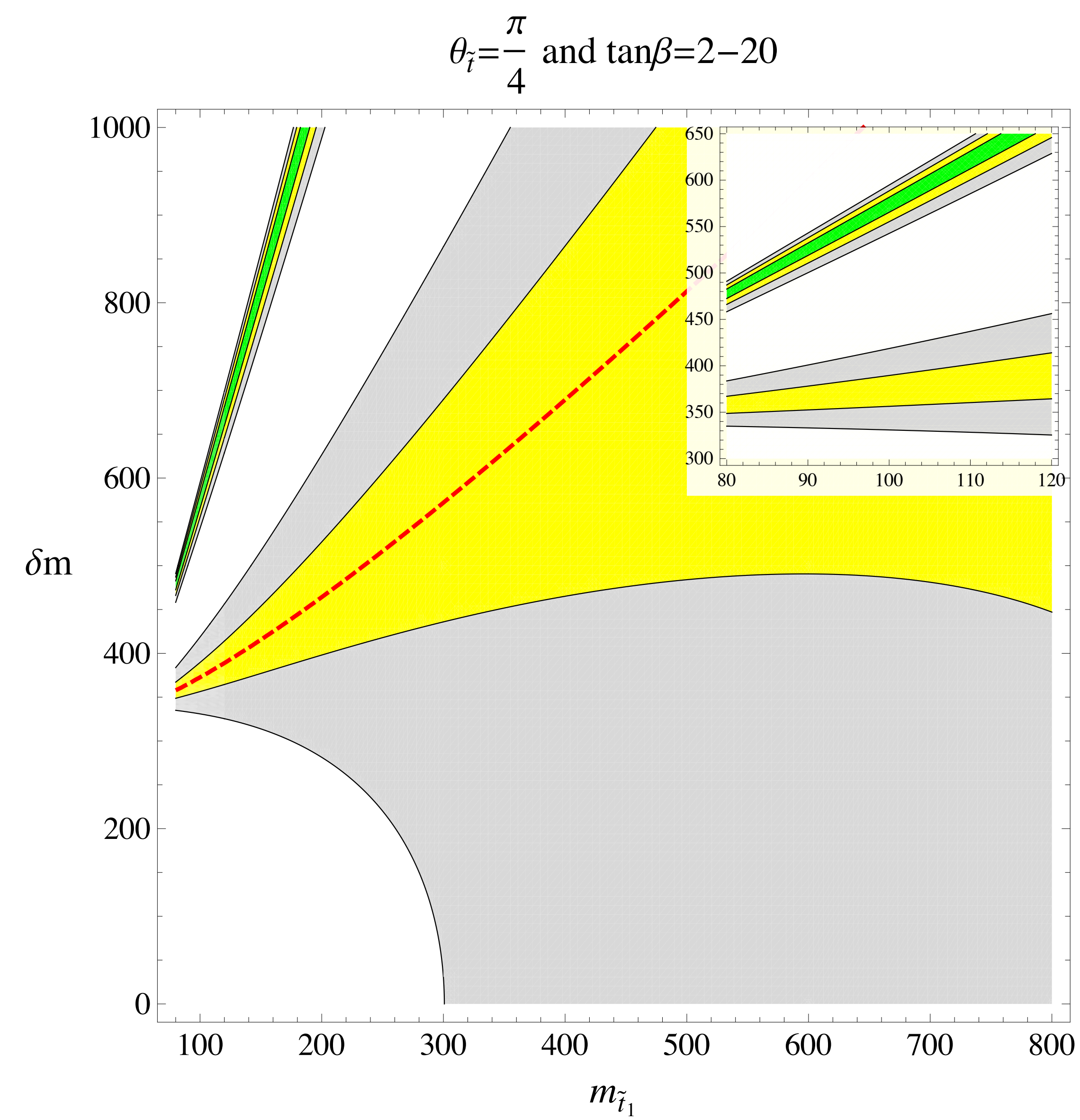
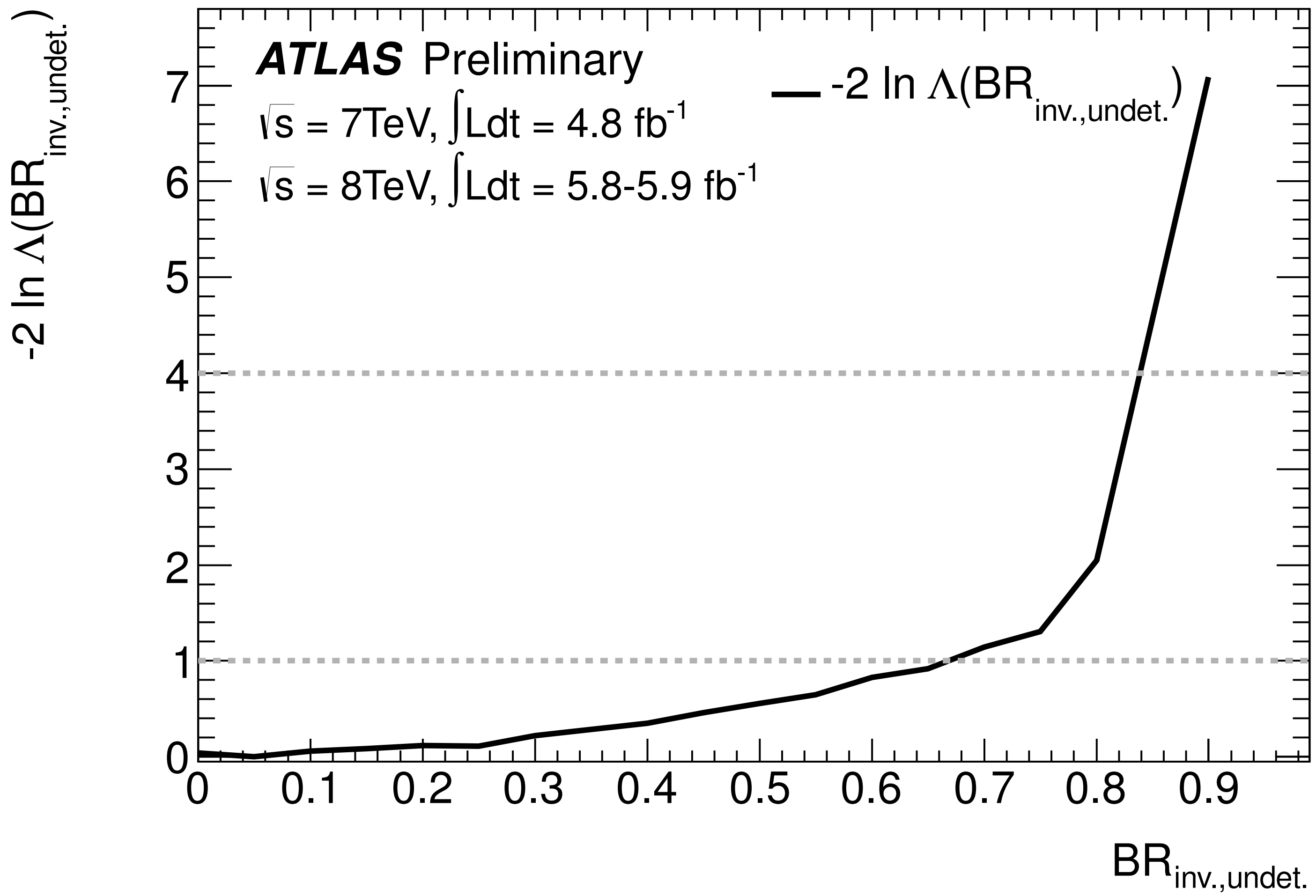


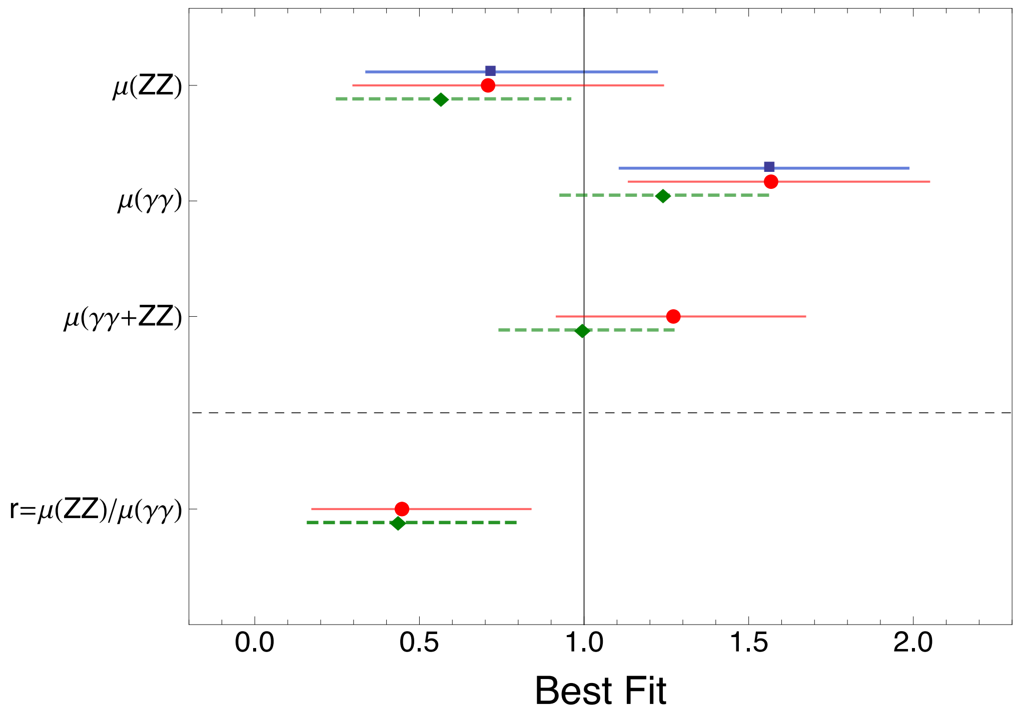
Espinosa, Grojean, Sanz, Trott, arXiv:1207.7355

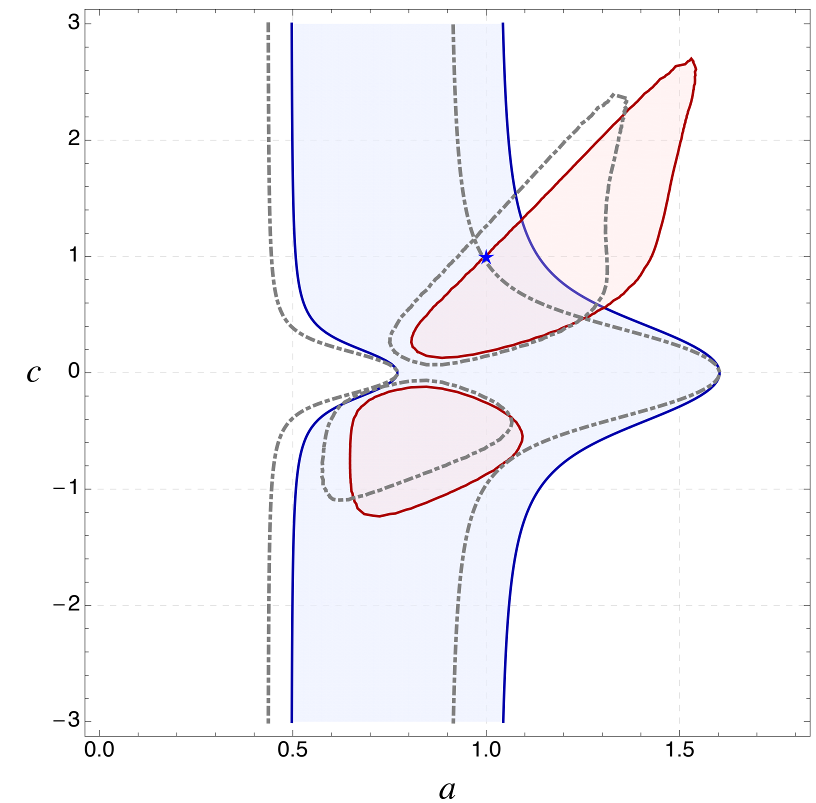
Limits on the Invisible Width



$$BR_{inv} < 0.68\,(0.84) \quad \text{at } 68\% \ (95\%) \text{ CL}$$

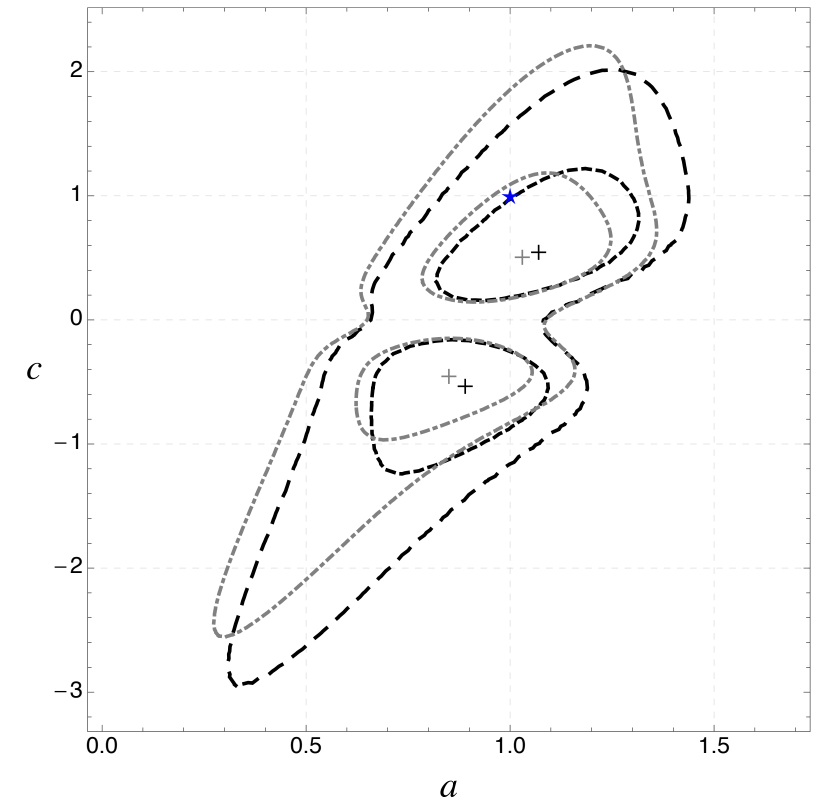
Effect of the theoretical uncertainty





Blue = ZZ

Red = γγ

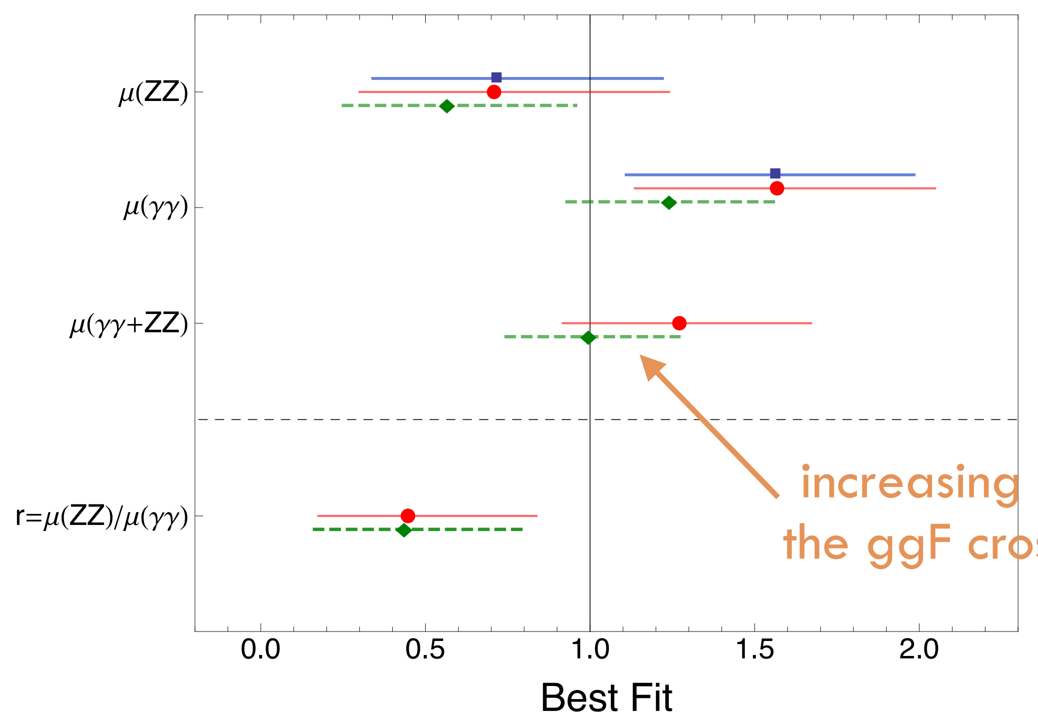


Black = ZZ+ γγ

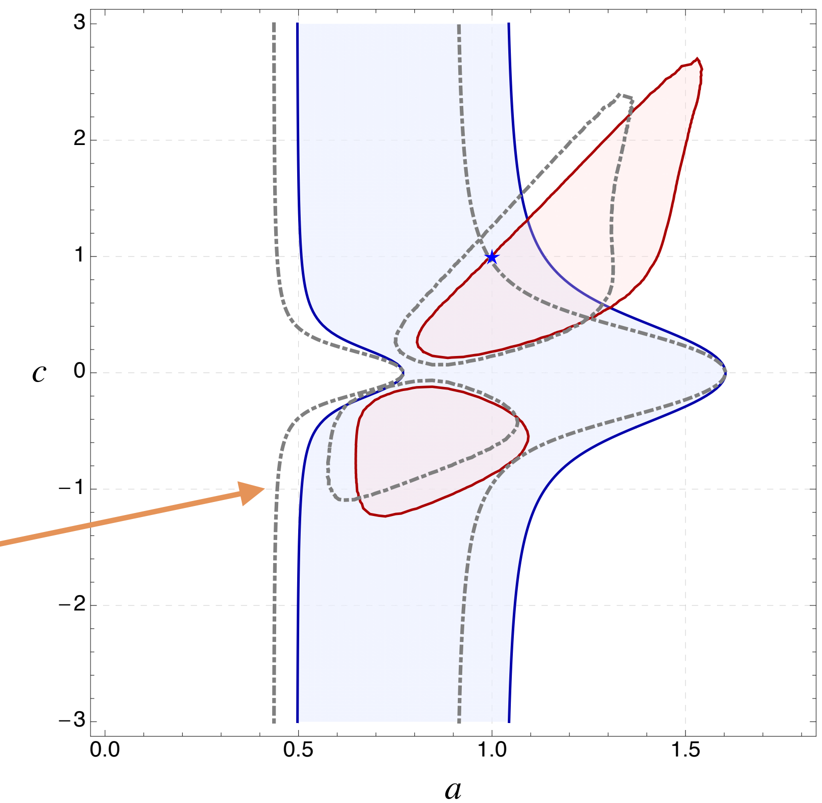
Strong effect in μ_i, much smaller in the (a, c) plane

Azatov, R.C. , DelRe, Galloway, work in progress

Effect of the theoretical uncertainty



increasing by 30% the ggF cross section



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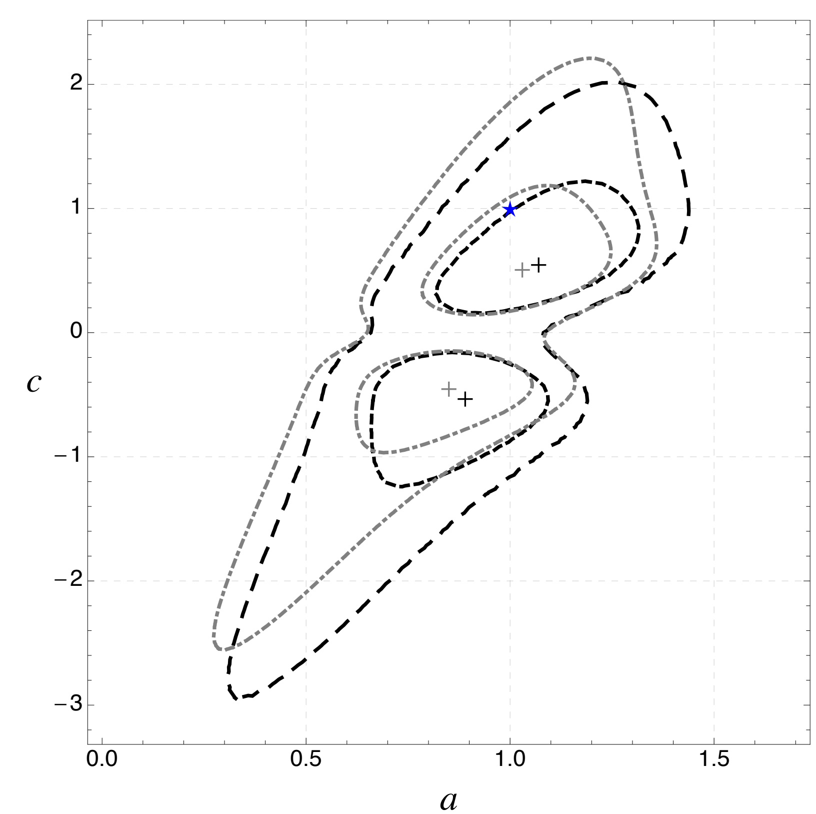

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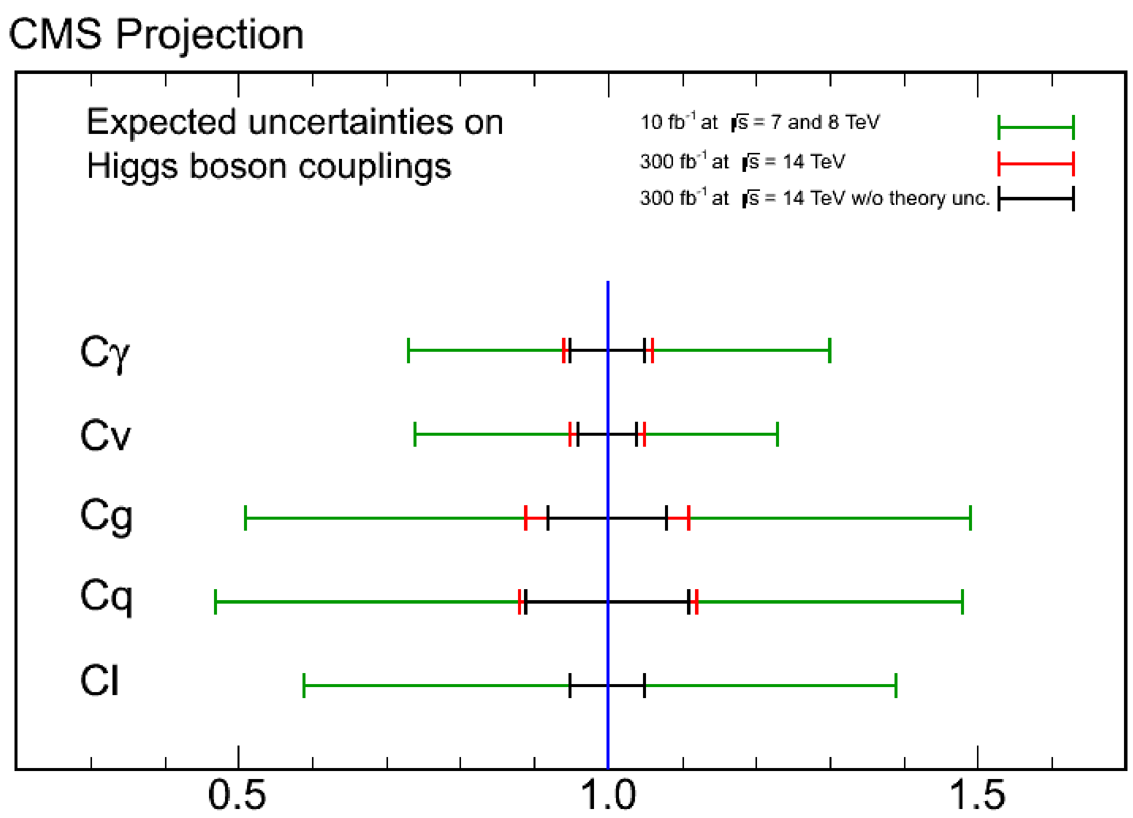
Expected precision on Higgs couplings



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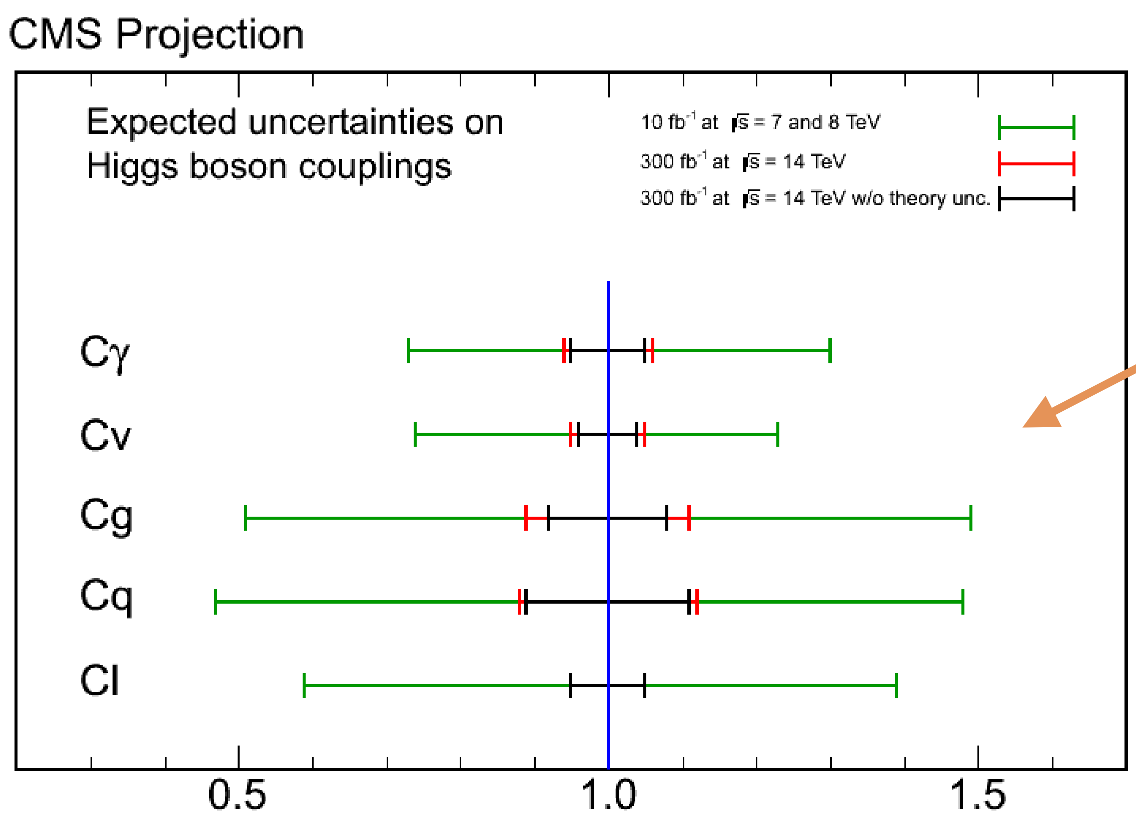

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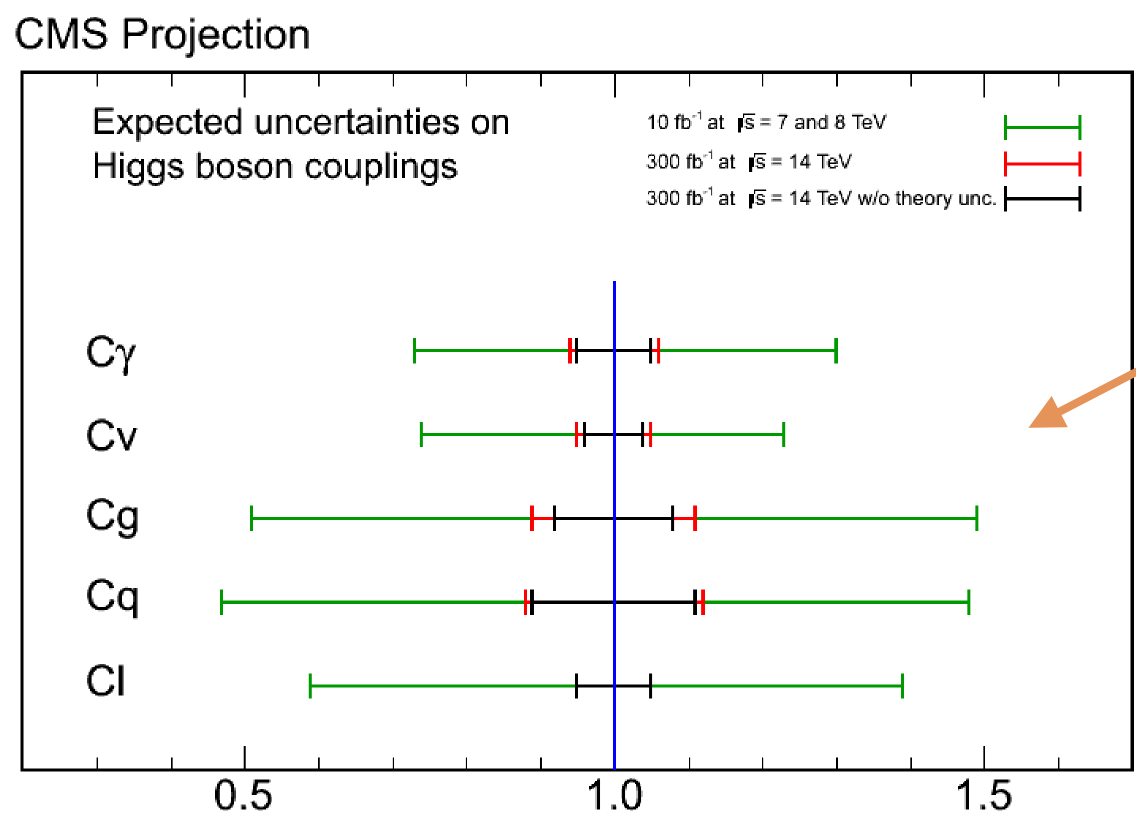

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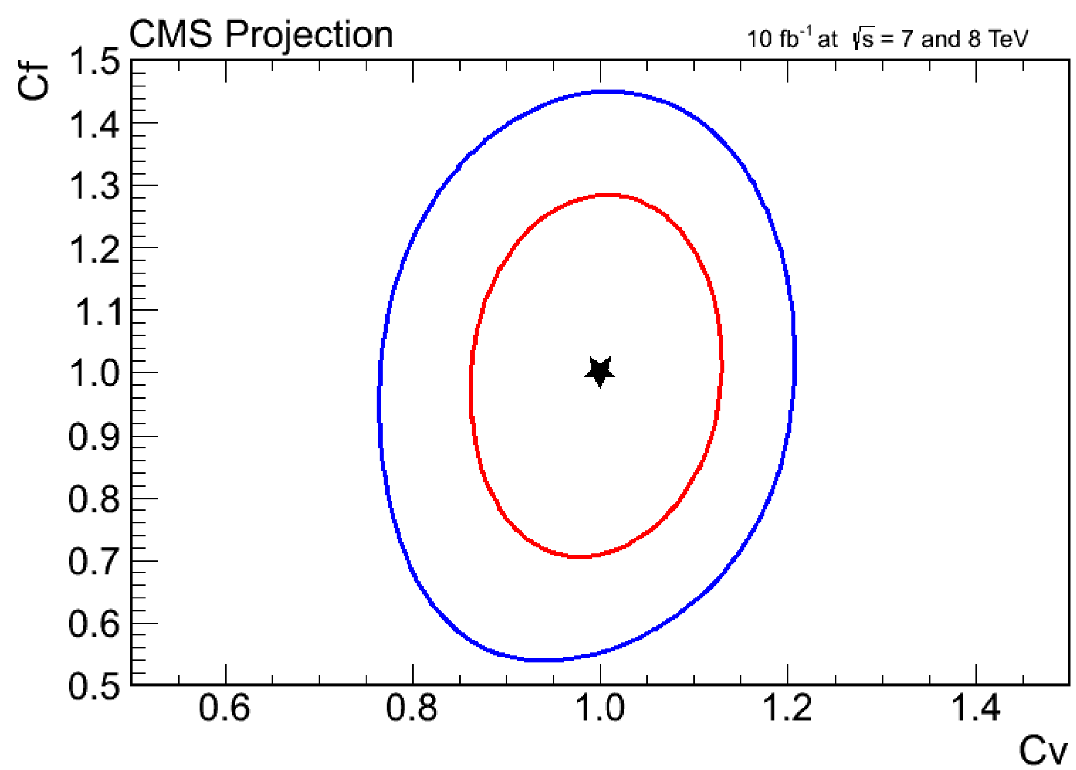
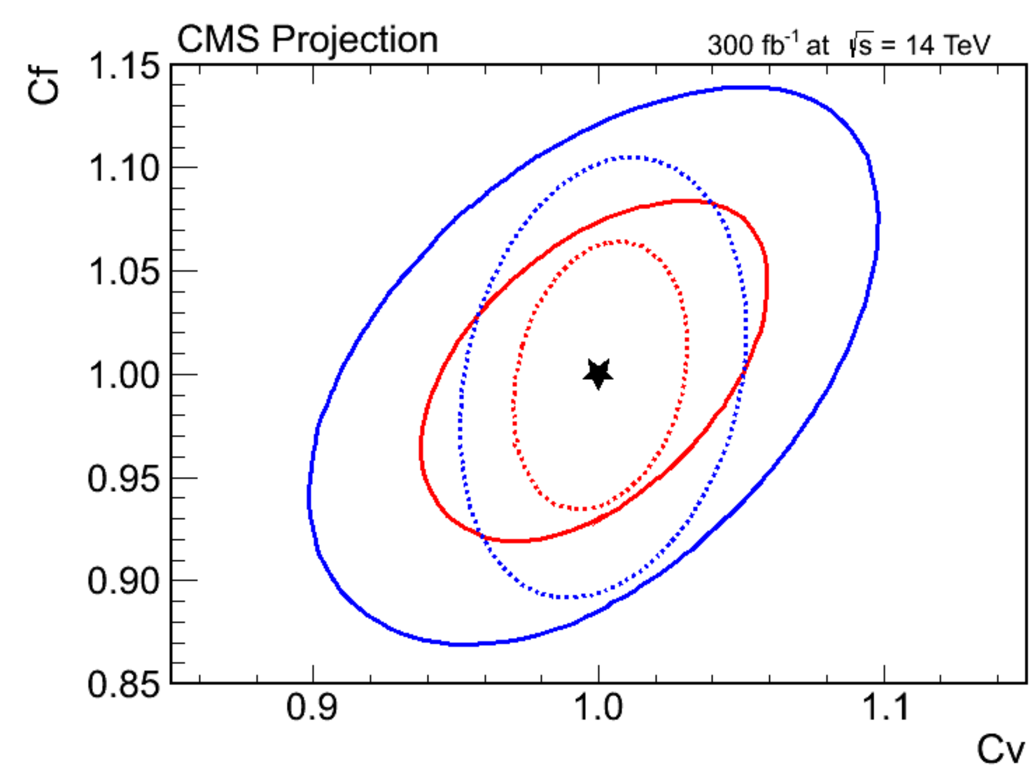




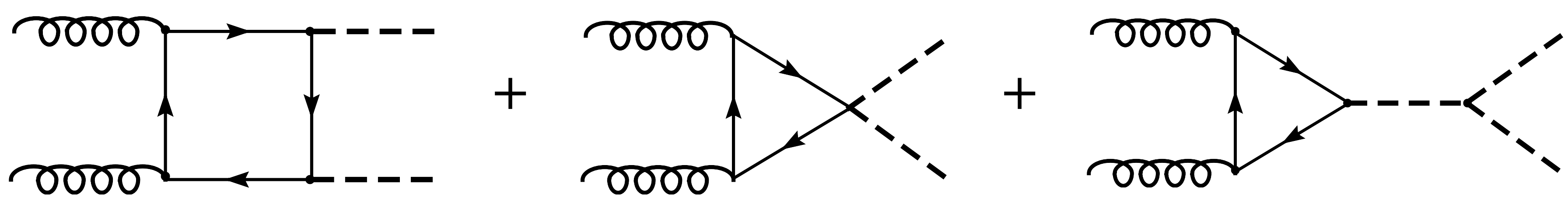
Additional interesting processes

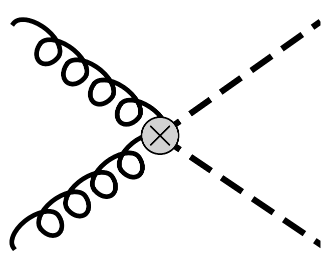
- Double Higgs Production via gluon fusion

- Double Higgs production via Vector Boson Fusion

Double Higgs Production via gluon fusion

in Composite Higgs models



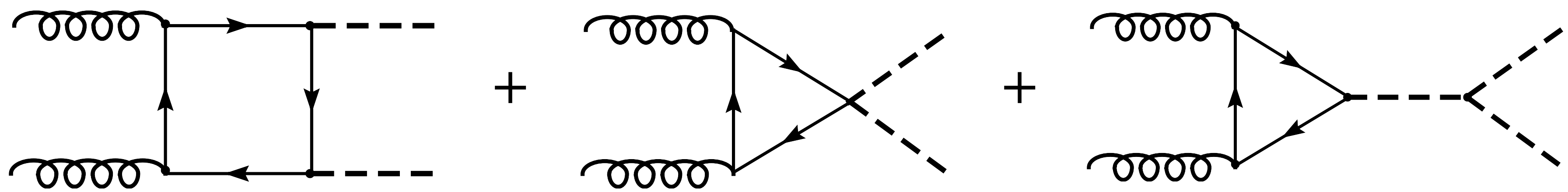


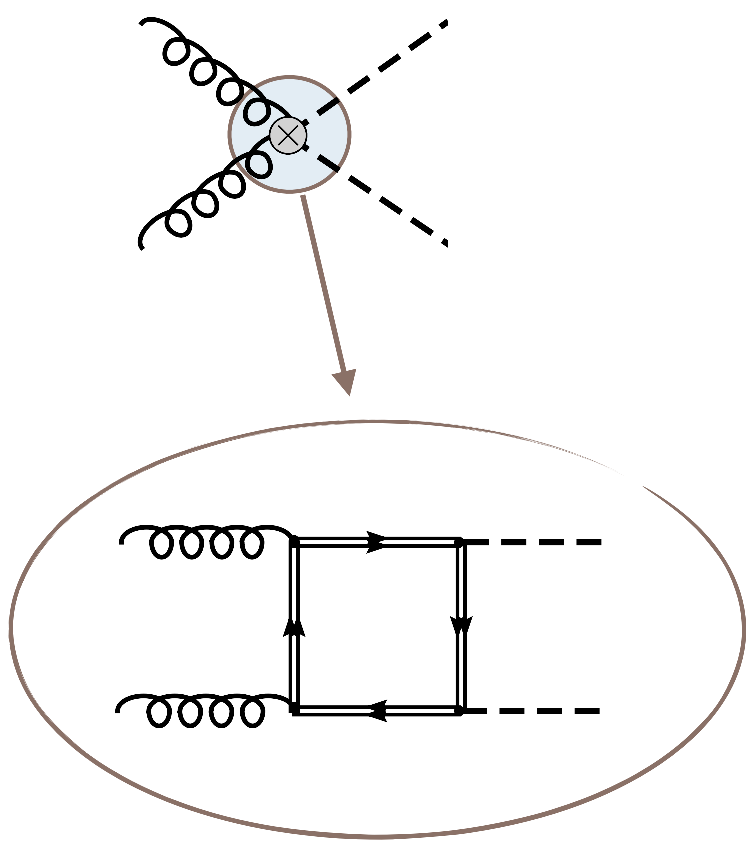
$$G_{\mu\nu}^2 \frac{H^\dagger H}{m_*^2}$$

$$G_{\mu\nu}^2 \frac{(\partial_\rho H)^\dagger (\partial_\rho H)}{m_*^4}$$

Double Higgs Production via gluon fusion

in Composite Higgs models





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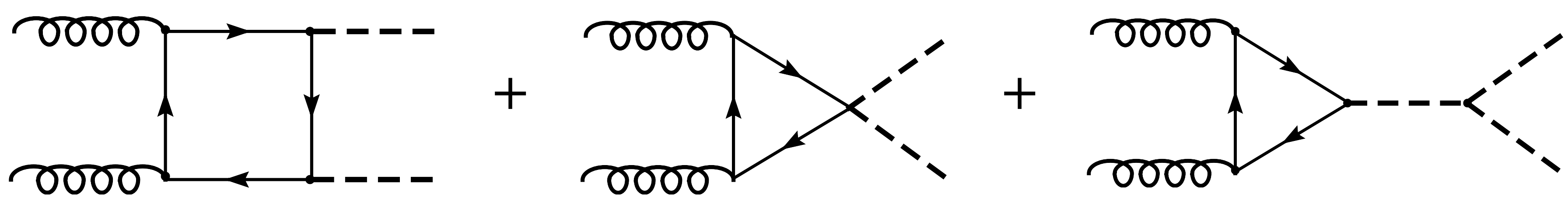
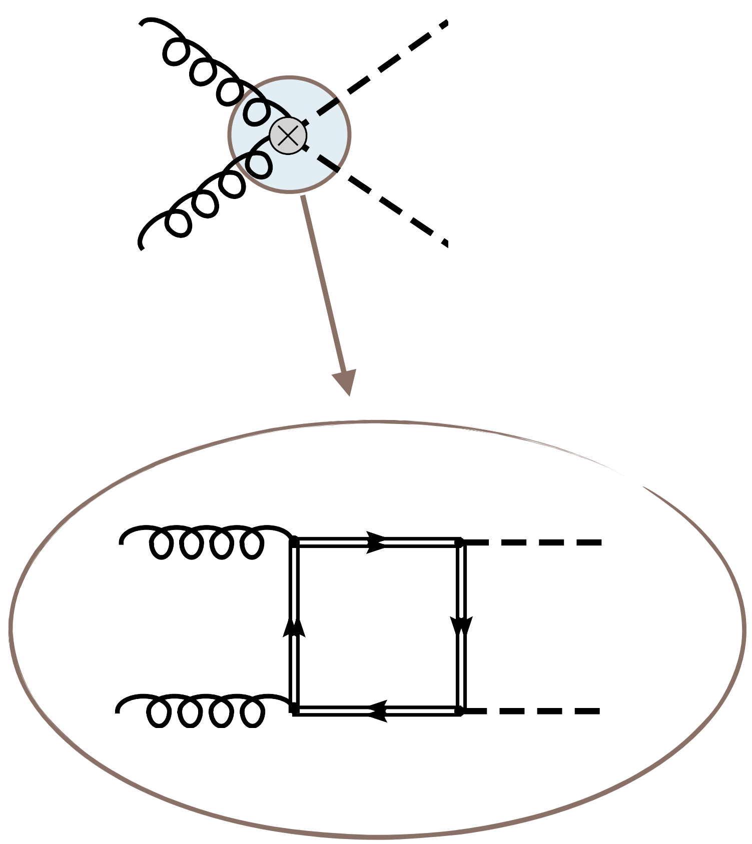
in Composite Higgs models





$$G_{\mu\nu}^2 \frac{H^\dagger H}{m_*^2}$$

Leading operator suppressed by spurion factor $\left(\frac{\lambda}{g_*}\right)^2$

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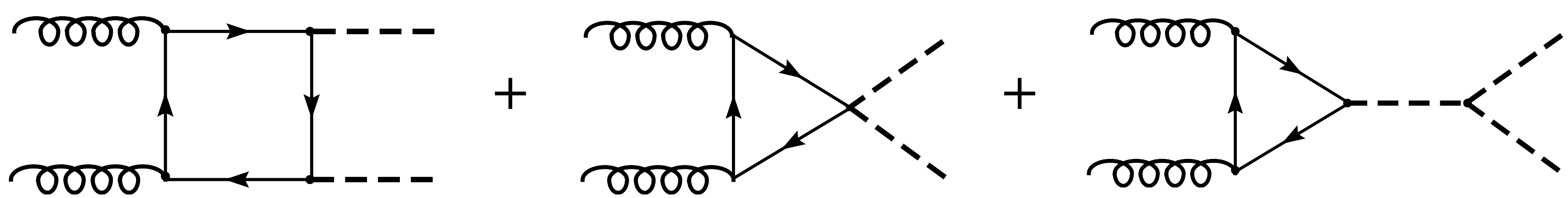
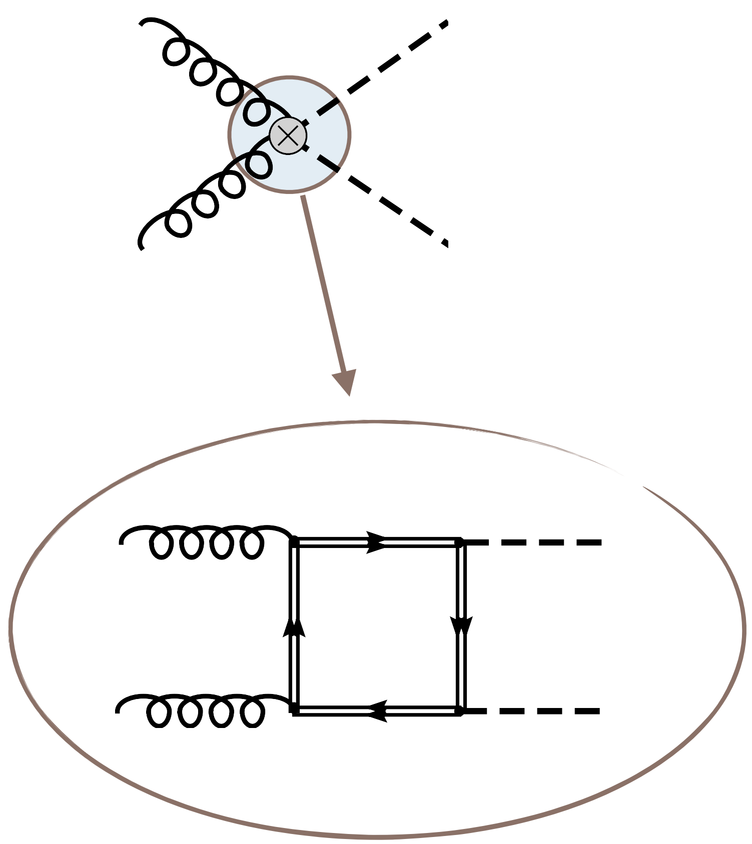
Double Higgs Production via gluon fusion

in Composite Higgs models





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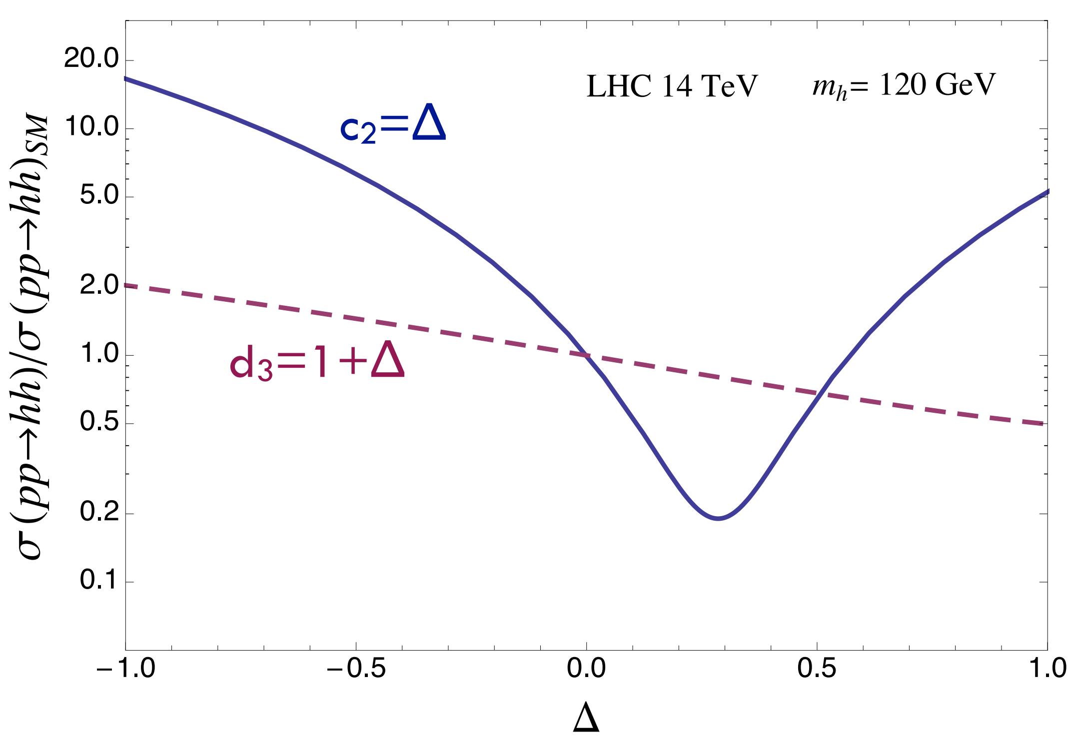
$$G_{\mu\nu}^2 \frac{(\partial_\rho H)^\dagger(\partial_\rho H)}{m_*^4}$$

next-to-leading operator can be important $\frac{m(hh)^2}{m_*^2}$

Double Higgs Production via gluon fusion

- σ(gg→hh) much more sensitive on new tthh couplings c2 than on trilinear d3

[First noticed by:
Dib, Rosenfeld, Zerwekh, JHEP 0605 (2006) 074
Grober and Muhlleitner, JHEP 1106 (2011) 020]



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JHEP 1208 (2012) 154

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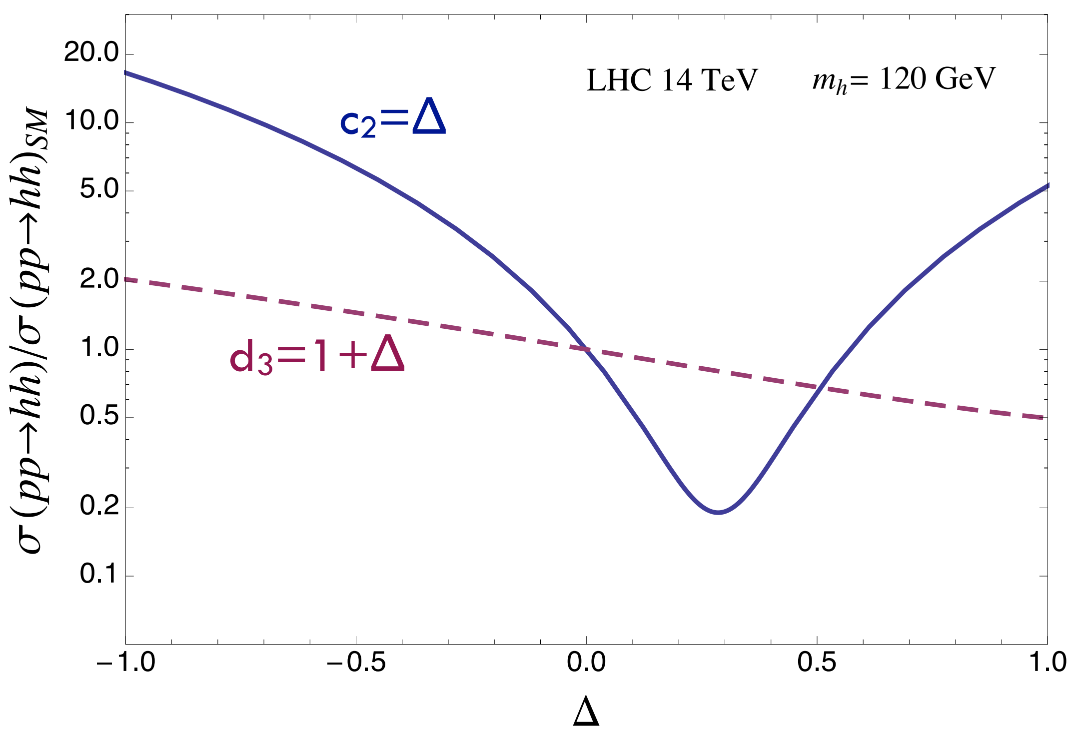

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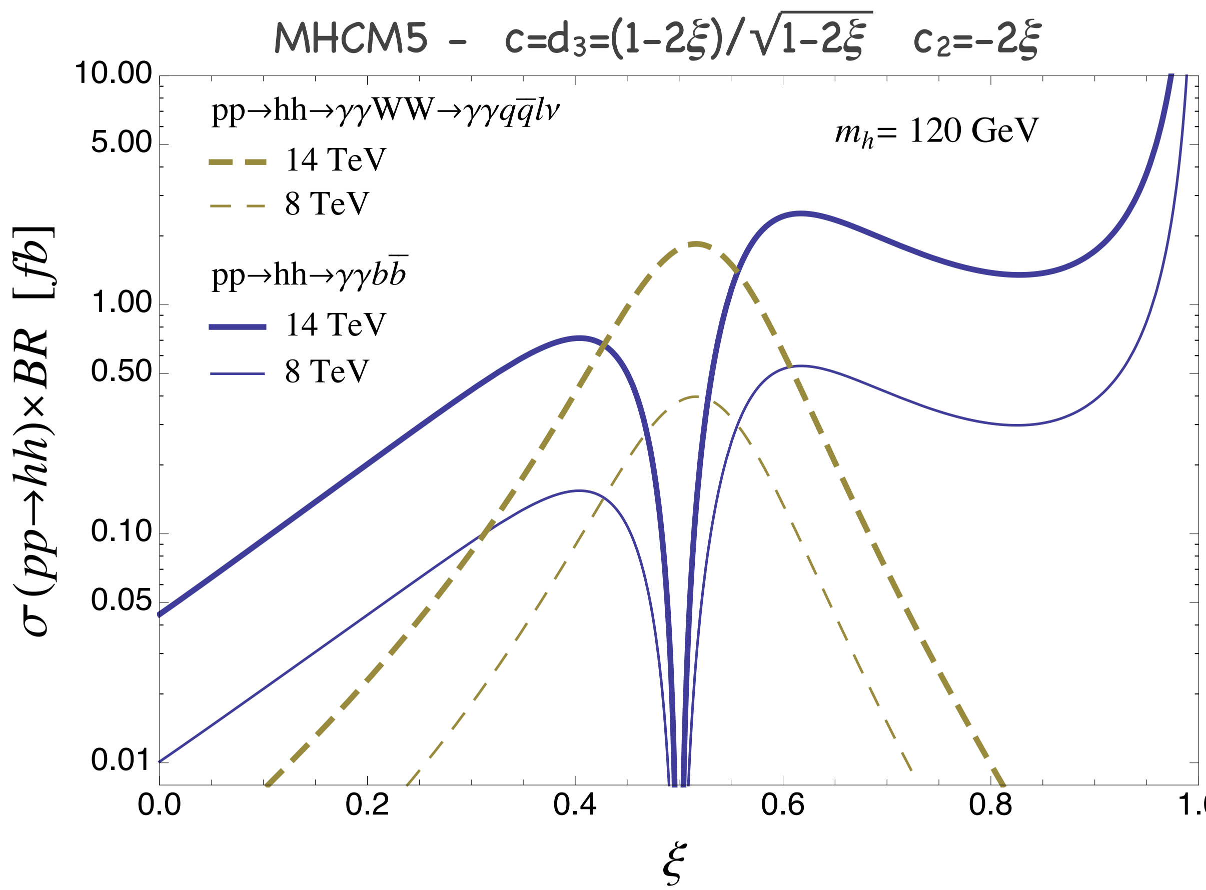


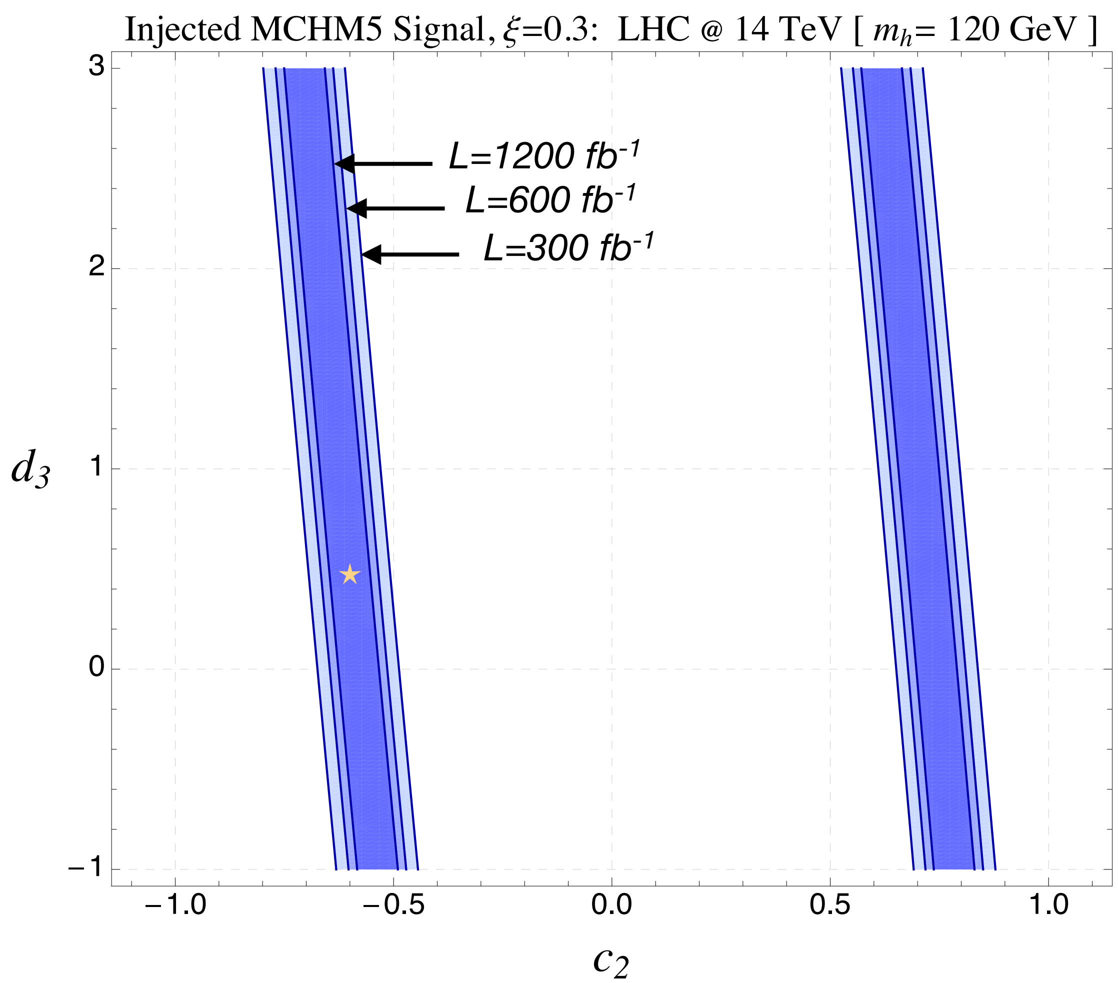
- If $BR(h)\simeq BR(h)_{SM}$ best channel is $hh\to bb\gamma\gamma$

  [Baur, Plehn, Rainwater, PRD 69 (2004) 053004]

ξ=0.15 ➡ $\sigma(gg\to hh)\times BR \sim 3[\sigma(gg\to hh)\times BR]_{SM}$

Double Higgs Production via gluon fusion

Precision on couplings (curves at 68% prob.)



Ex: Injected ξ=0.3 ($c=d_3=0.48$ $c_2=-0.6$)

$\Delta c_2/c_2$ = 15-20%

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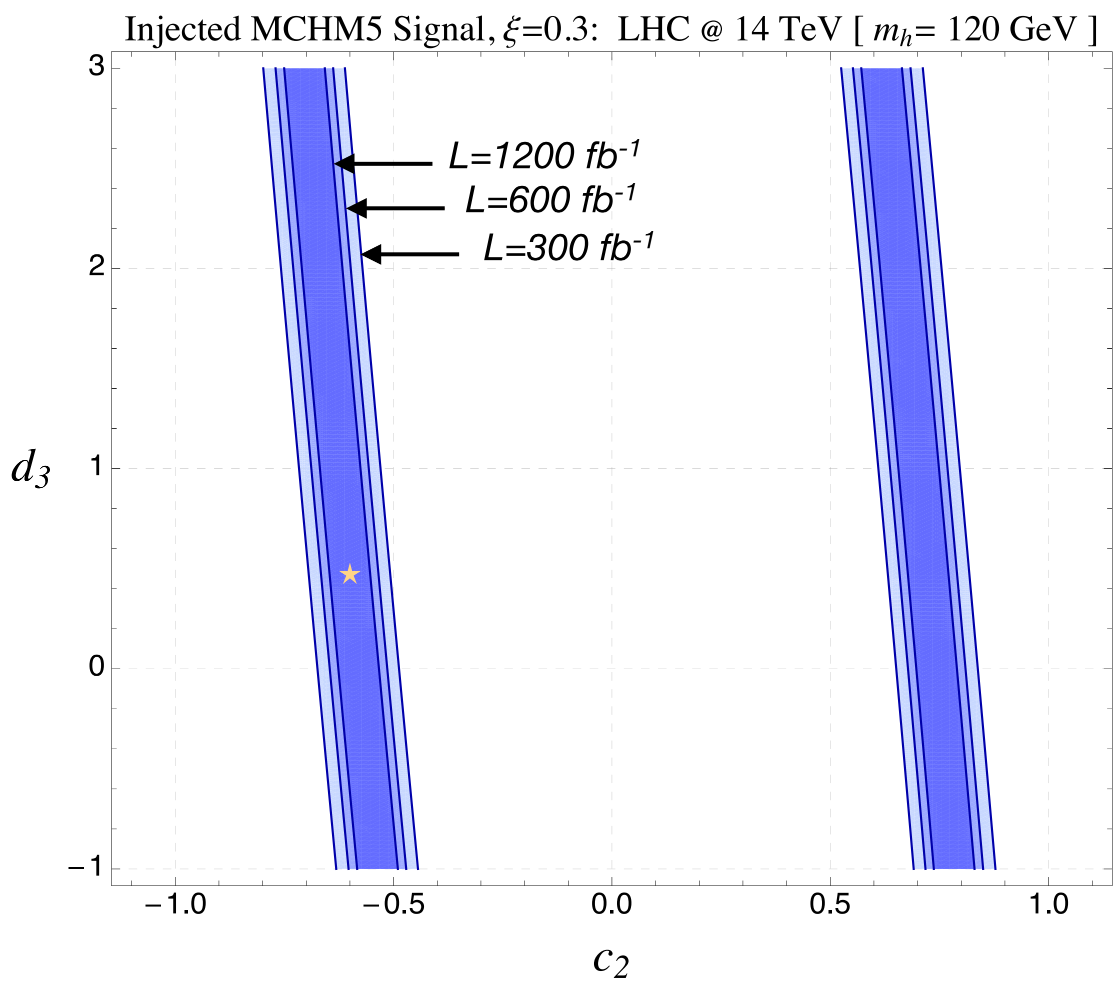
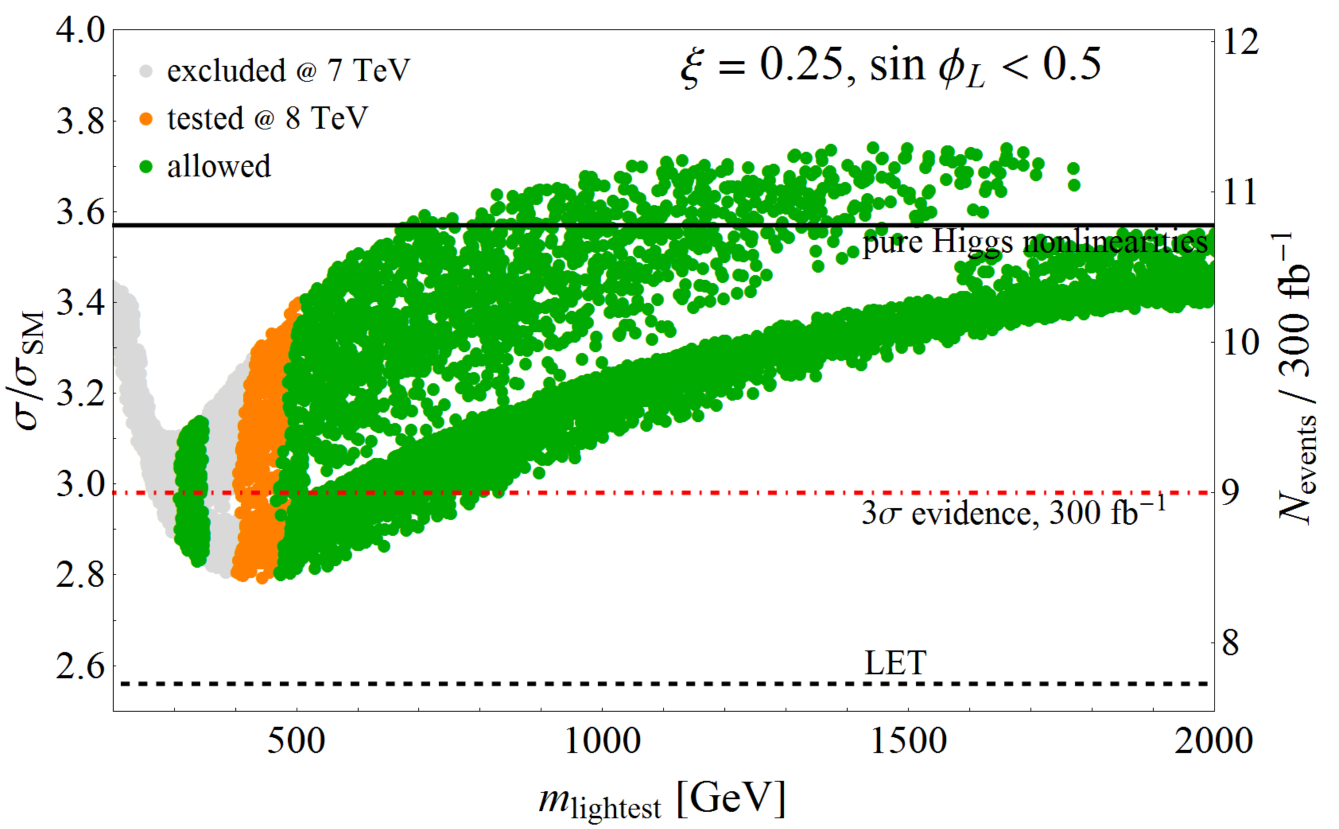


Contribution from heavy fermions can be numerically important



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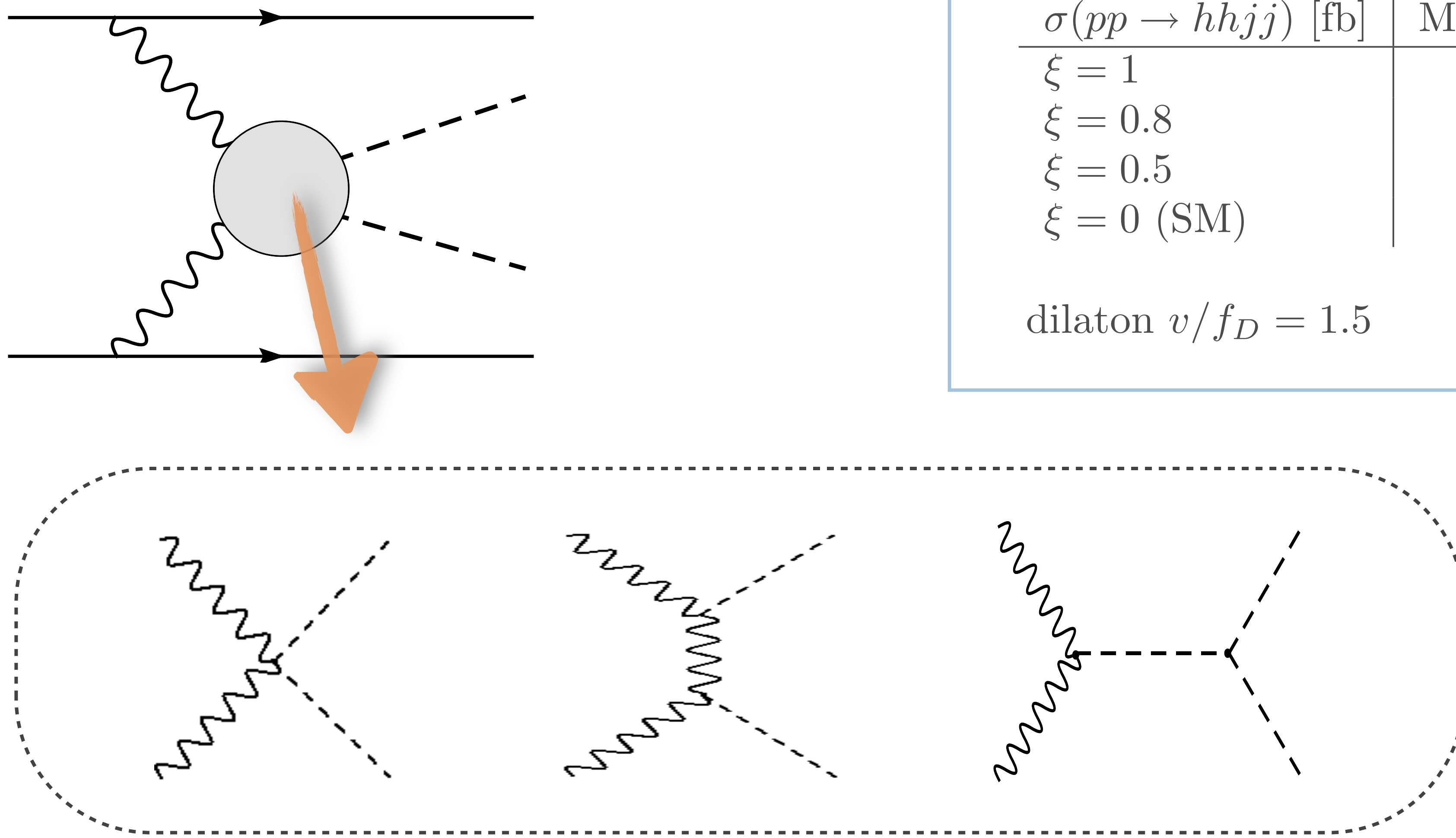
Gillioz, Grober, Grojean, Muhlleitner, Salvioni
arXiv:1206.7120

Double Higgs Production via VBF



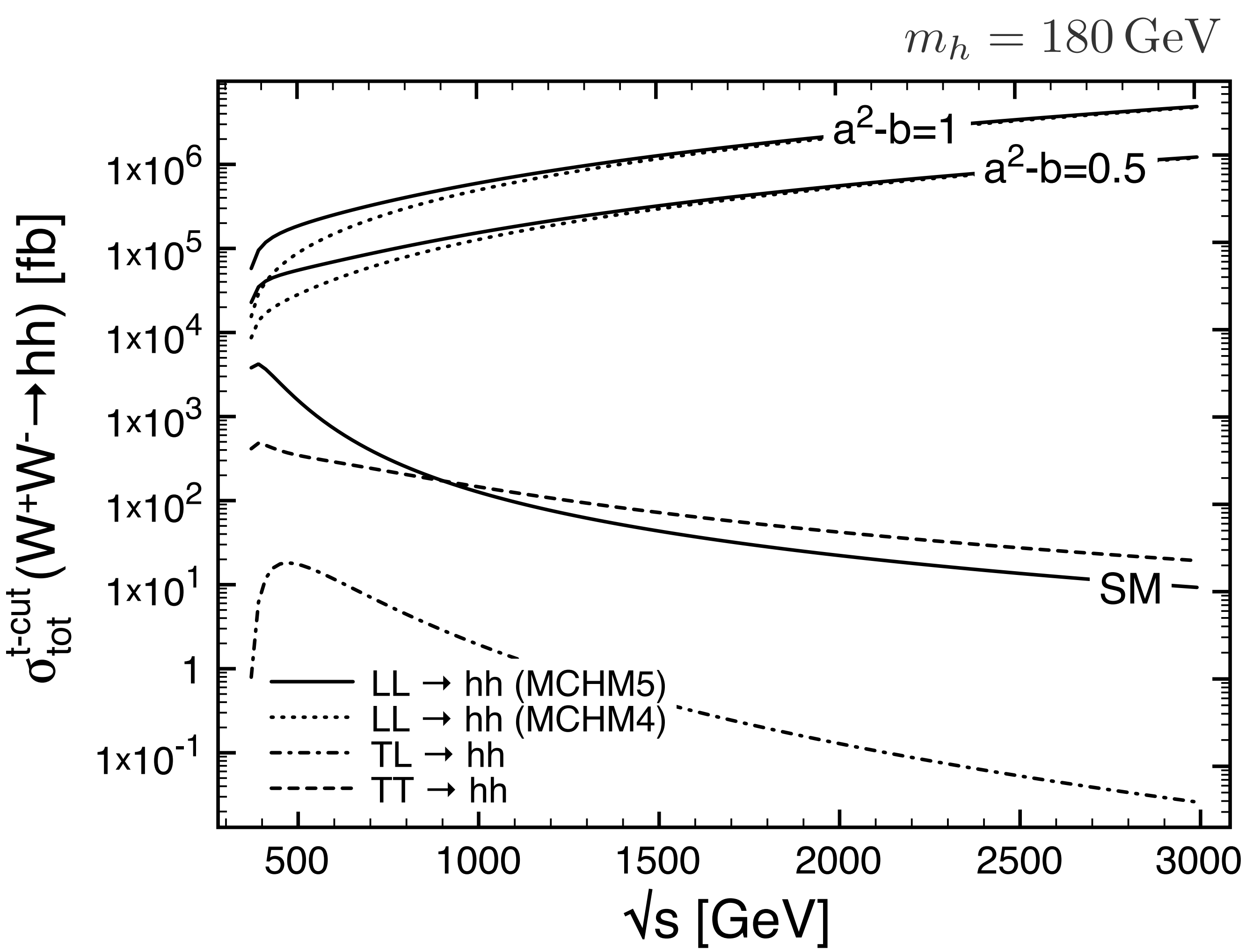
$\sigma(pp \to hhjj)$ [fb]	MCHM4	MCHM5
$\xi = 1$	9.3	14.0
$\xi = 0.8$	6.3	9.5
$\xi = 0.5$	2.9	4.2
$\xi = 0$ (SM)	0.5	0.5
dilaton $v/f_D = 1.5$	3.3	

$m_h = 180\,\mathrm{GeV}$

$$V(h) = \frac{1}{2} m_h^2 h^2 + d_3 \frac{1}{6}\left(\frac{3m_h^2}{v}\right) h^3 + d_4 \frac{1}{24}\left(\frac{3m_h^2}{v^2}\right) h^4 + \dots$$

Coupling	MCHM4	MCHM5
$a = g_{hWW}/g_{hWW}^{SM}$	$\sqrt{1-\xi}$	$\sqrt{1-\xi}$
$b = g_{hhWW}/g_{hhWW}^{SM}$	$1-2\xi$	$1-2\xi$
$c = g_{hff}/g_{hff}^{SM}$	$\sqrt{1-\xi}$	$\frac{1-2\xi}{\sqrt{1-\xi}}$
$d_3 = g_{hhh}/g_{hhh}^{SM}$	$\sqrt{1-\xi}$	$\frac{1-2\xi}{\sqrt{1-\xi}}$

Double Higgs Production via VBF



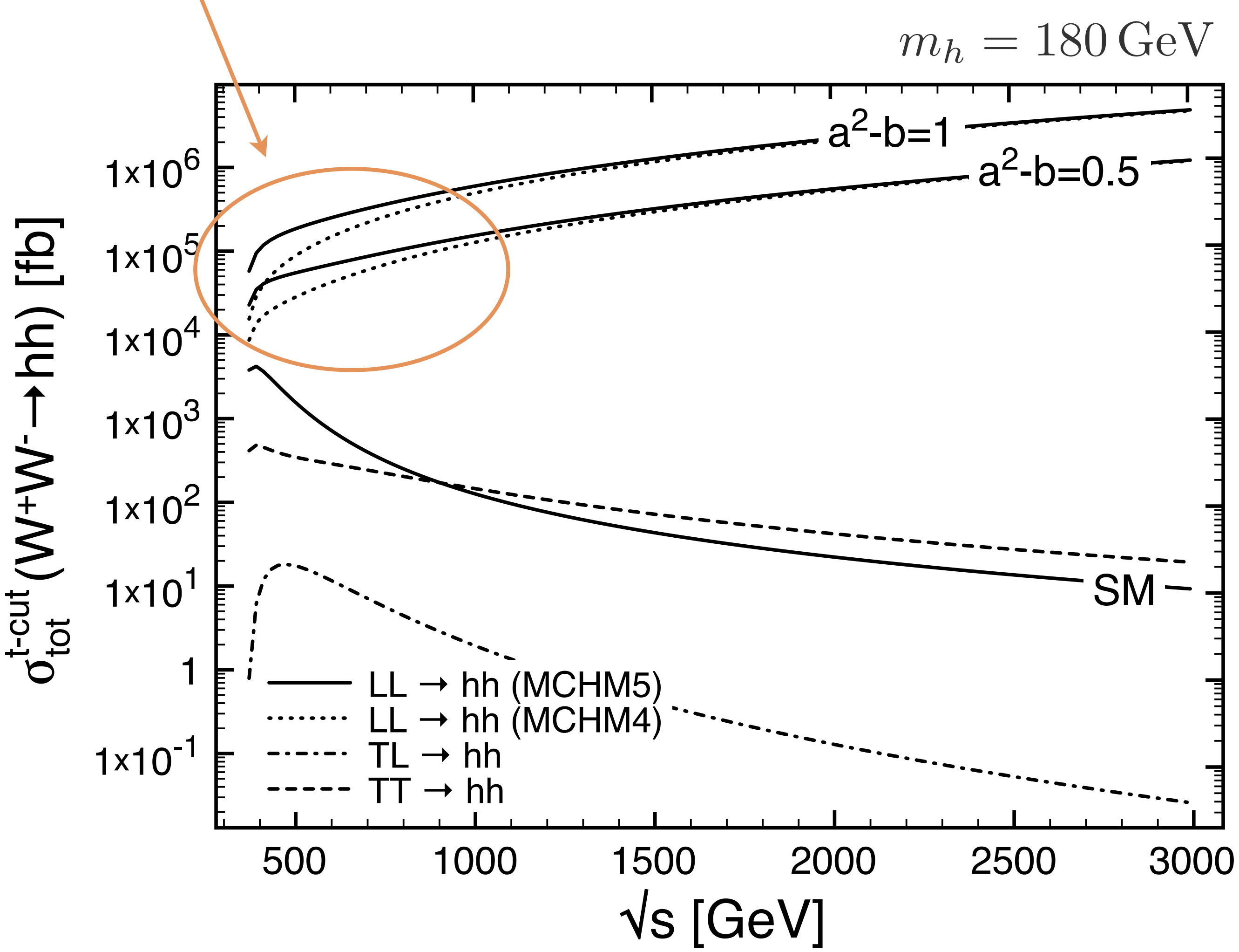
R.C., Grojean, Moretti, Piccinini, Rattazzi, JHEP 1005 (2010) 089

$$\frac{d\sigma_{LL\to hh}/dt}{d\sigma_{TT\to hh}/dt} \sim \frac{1}{8}\,\frac{(b-a^2)^2}{a^4+(b-a^2)^2}\,\frac{s^2}{M_W^4}$$

- No Coulomb singularity enhancement of transverse scattering
- Longitudinal scattering always dominating: cleaner than WW→WW

Double Higgs Production via VBF

model dependency



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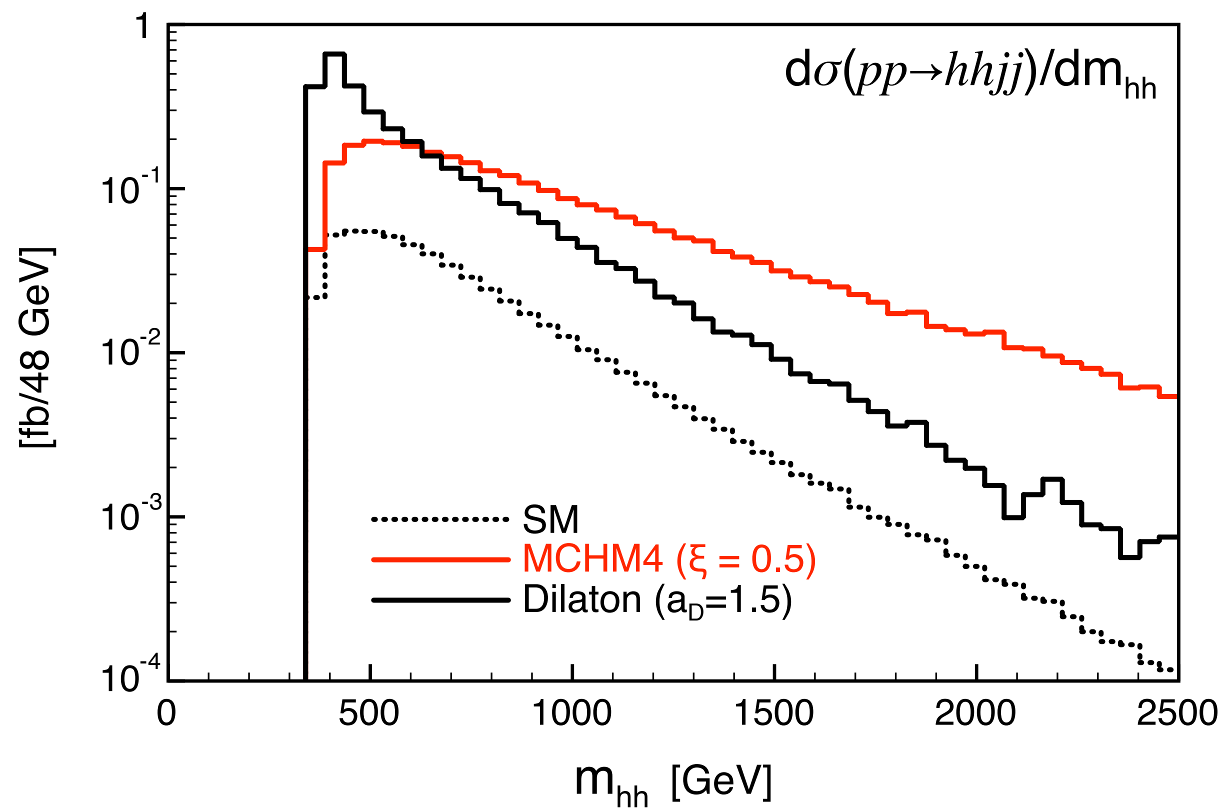
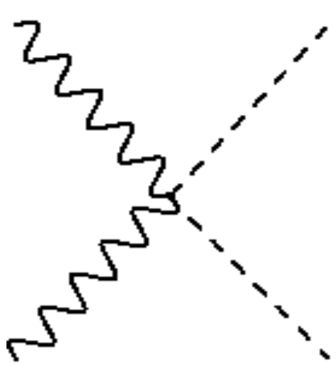
testing the Higgs strong interaction

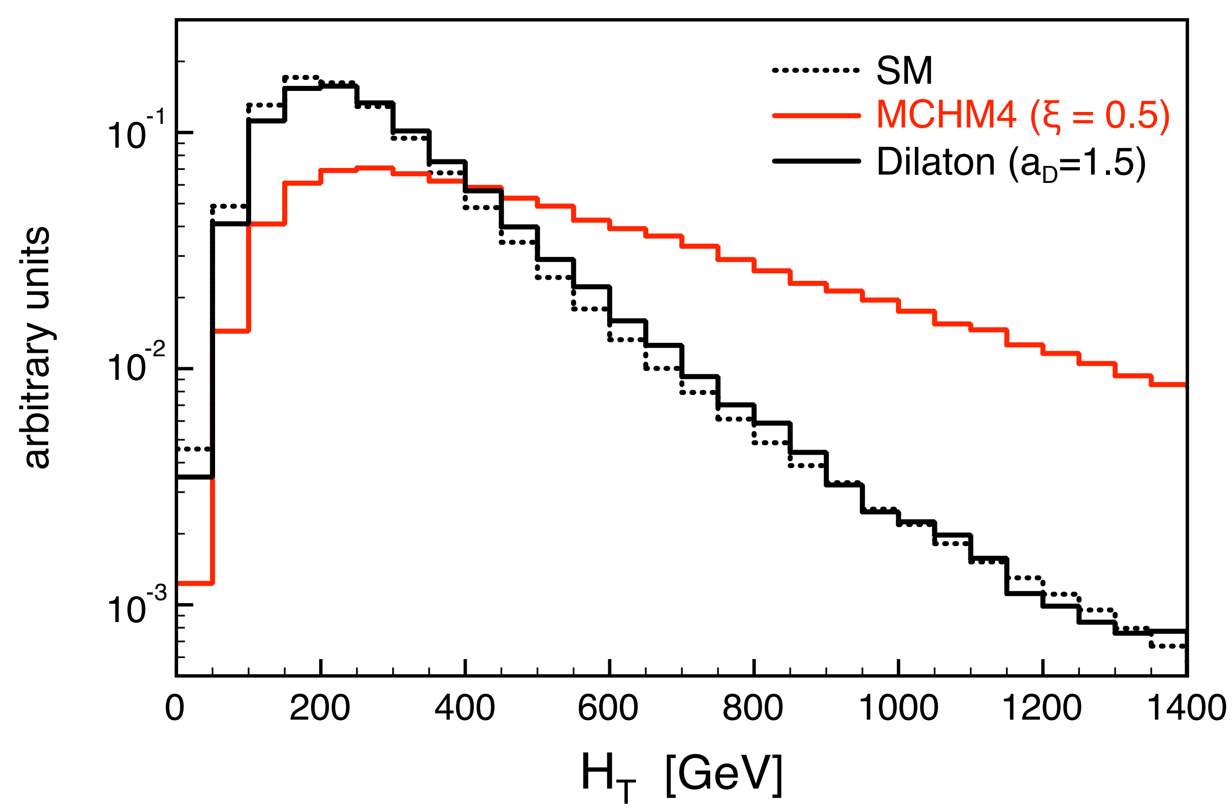




Signal pure s-wave

$$H_T = \sum_{i=1,2} |p_{TH_i}|$$

More central Higgses
(larger HT)



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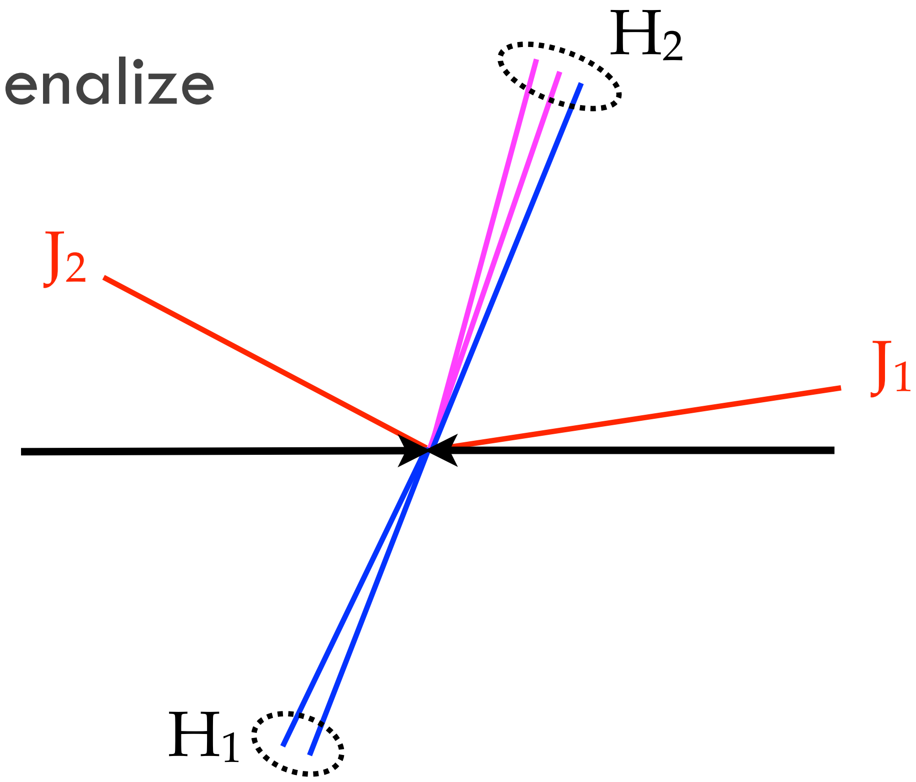

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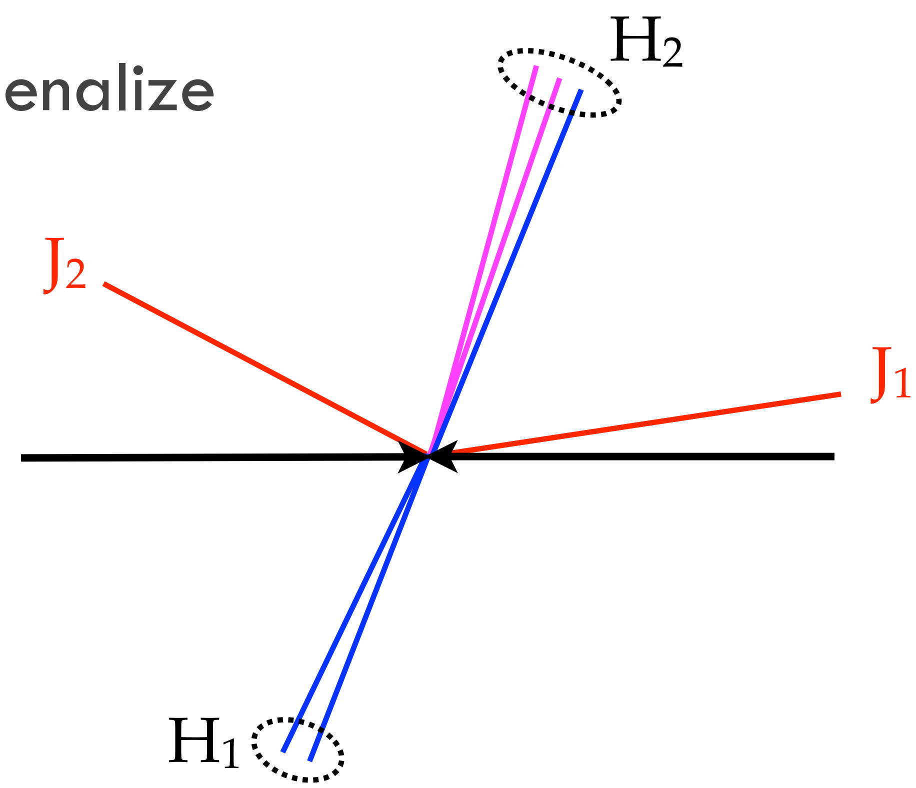

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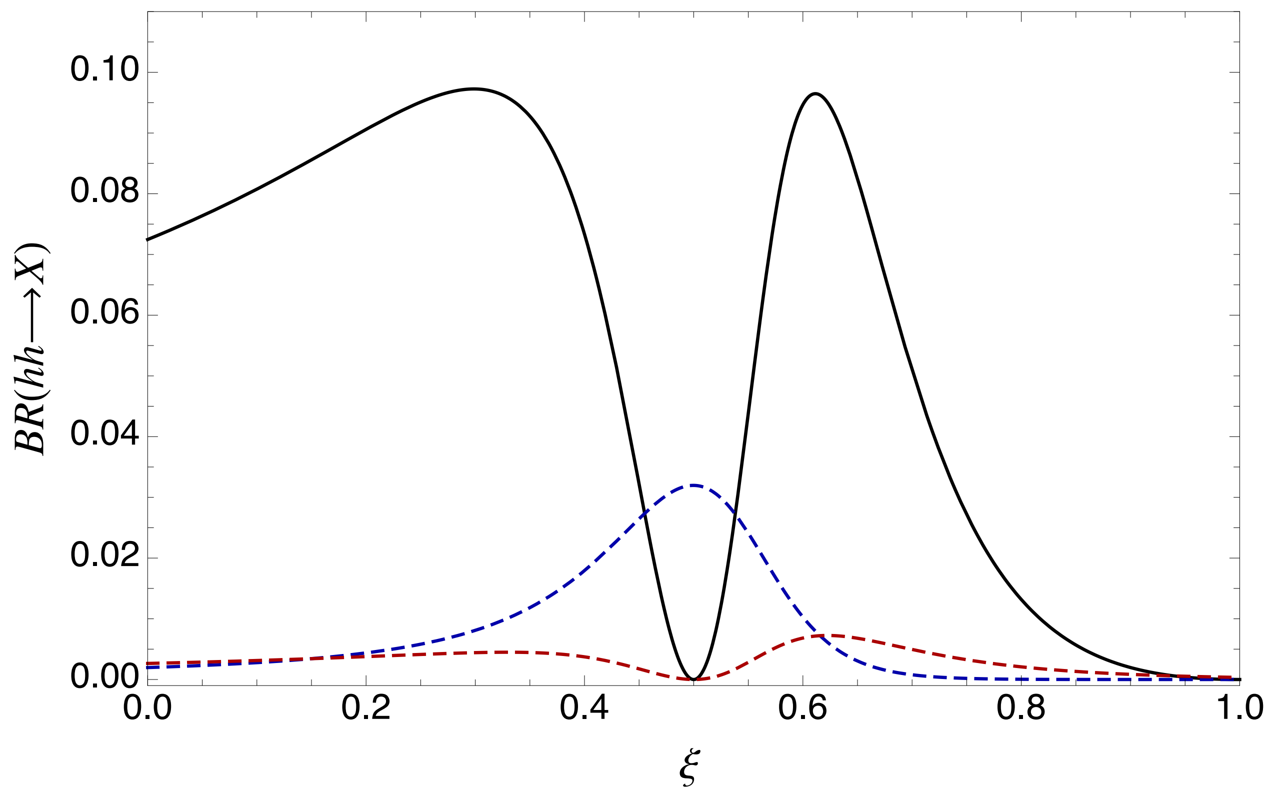
- Naive inspection suggests $hh \to \bar{b}bWW$



Ex: $BR(hh \to \bar{b}b\,WW \to l\nu jj\bar{b}b)|_{125\mathrm{GeV}} \simeq 0.08$

for $\xi = 0.2$

$BR(hh \to 4W \to l^\pm l^\pm \bar{\nu}\nu 4j)|_{180\mathrm{GeV}} \simeq 0.04$

for $\xi \lesssim 0.8$

Black: $hh \to \bar{b}b\,WW \to l\nu jj\bar{b}b$

Blue: $hh \to 4W \to l^\pm l^\pm \bar{\nu}\nu 4j$

Red: $hh \to \bar{b}b\,\gamma\gamma$

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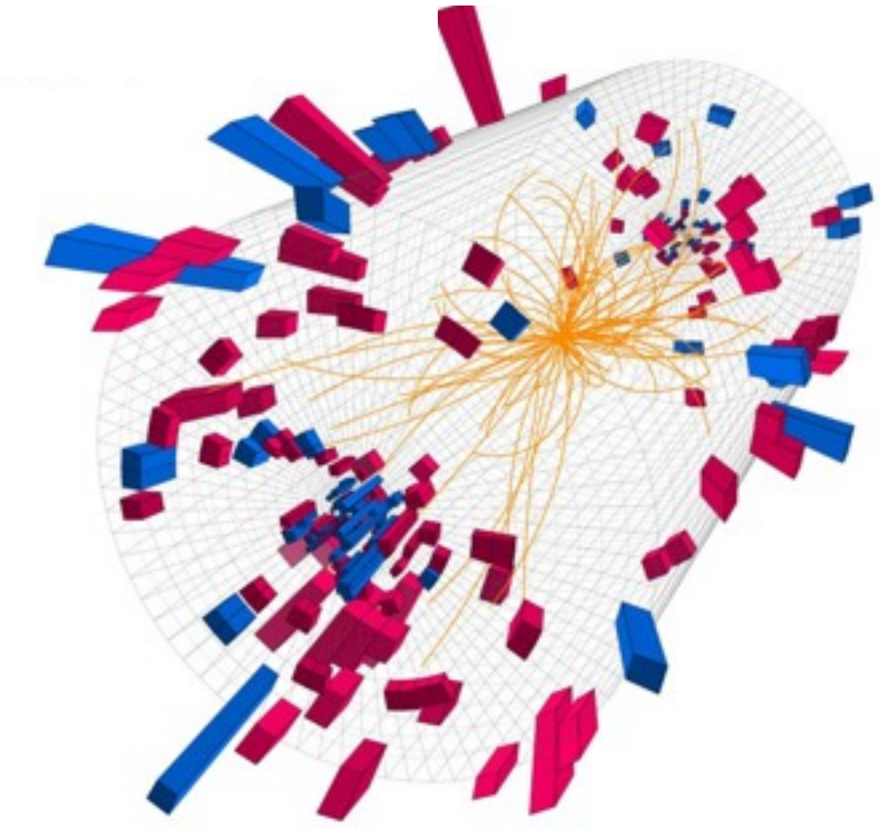
In all these scenarios, the physics behind the mechanism of EWSB will play a crucial role



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Keep on searching !