Vector Resonances in Composite Higgs Models

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LHC2TSP/WG1
Cern, March 29th 2012

Outline

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- motivations for vector resonances in EWSB

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- EFT for Higgs + spin-1 resonance

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- limits on vector resonances
- conclusions

The Standard Model

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$$\mathcal{L}_{gauge} \supset \quad B_{\mu\nu}^2 \,, \quad W_{\mu\nu}^2 \,, \quad G_{\mu\nu}^2 \,, \quad \bar{\Psi}\gamma^\mu D_\mu \Psi$$

$$\mathcal{L}_{mass} \supset \quad m_W^2 W_\mu^2 \,, \quad m_Z^2 Z_\mu^2 \,, \quad (\Psi_i M_{ij} \Psi_j + h.c.)$$

symmetry breaking spectrum

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symmetry breaking spectrum

3 Goldstone bosons $Z_L\,, W_L^{\pm}$

$$\rho - 1 = 0.00\ldots$$

Custodial symmetry

$$SU(2)_L \times SU(2)_R / SU(2)_{L+R}$$

Restore the symmetry

SM=EWChiral Lagrangian

$$\mathcal{L} = \mathcal{L}_{gauge} + |D_\mu \Sigma|^2 + \ldots$$

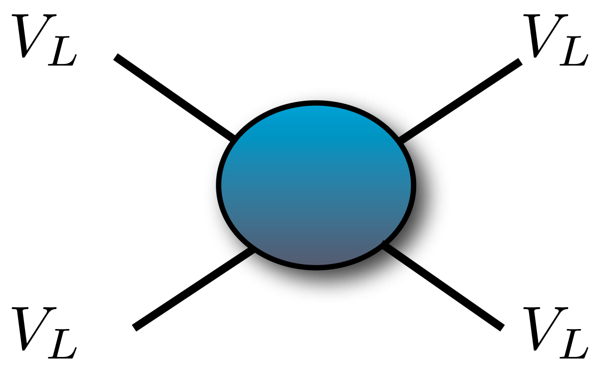
$$\Sigma \longrightarrow L \Sigma R^\dagger$$

$$\Sigma = e^{i\pi}$$

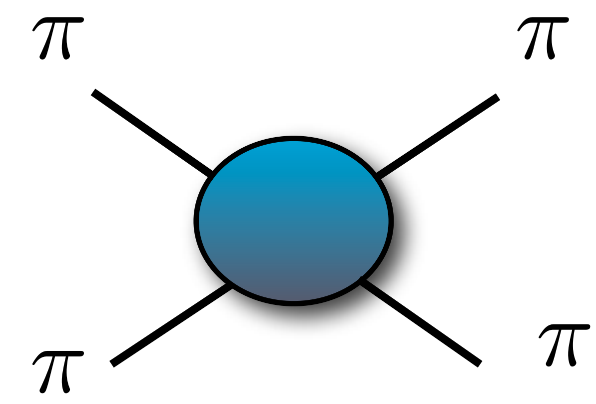
put the pions back

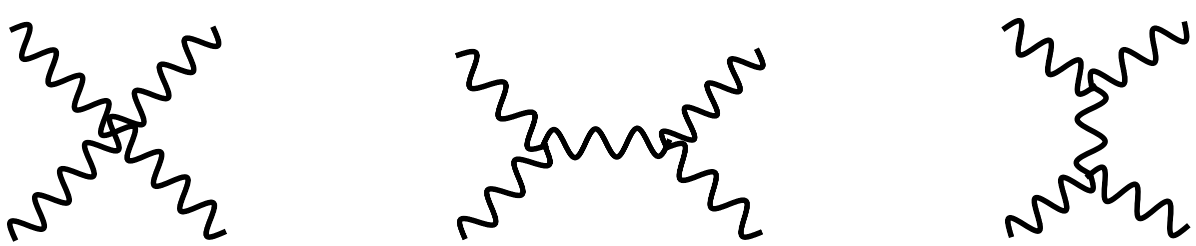
$$V_\mu^2 \longrightarrow \left(V_\mu + D_\mu \pi + \frac{1}{6}[[\pi, \partial_\mu \pi], \pi] + \ldots \right)^2 = |D_\mu \Sigma|^2$$

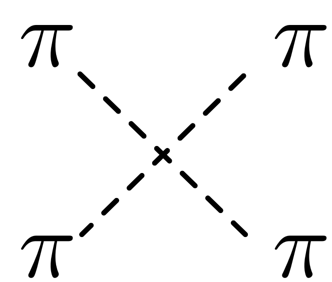
UV behavior



$E \gg v$







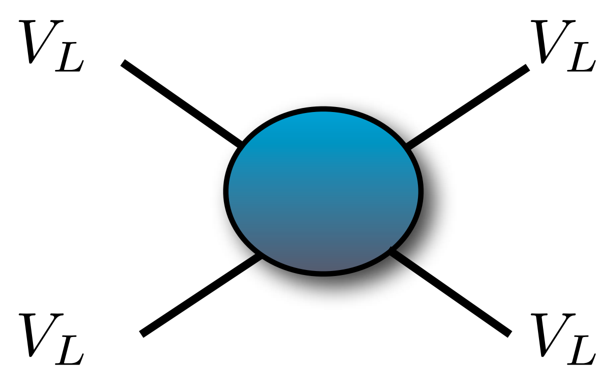
$\sim \left(\frac{E}{v}\right)^2$

$$\Lambda \sim 4\pi v$$

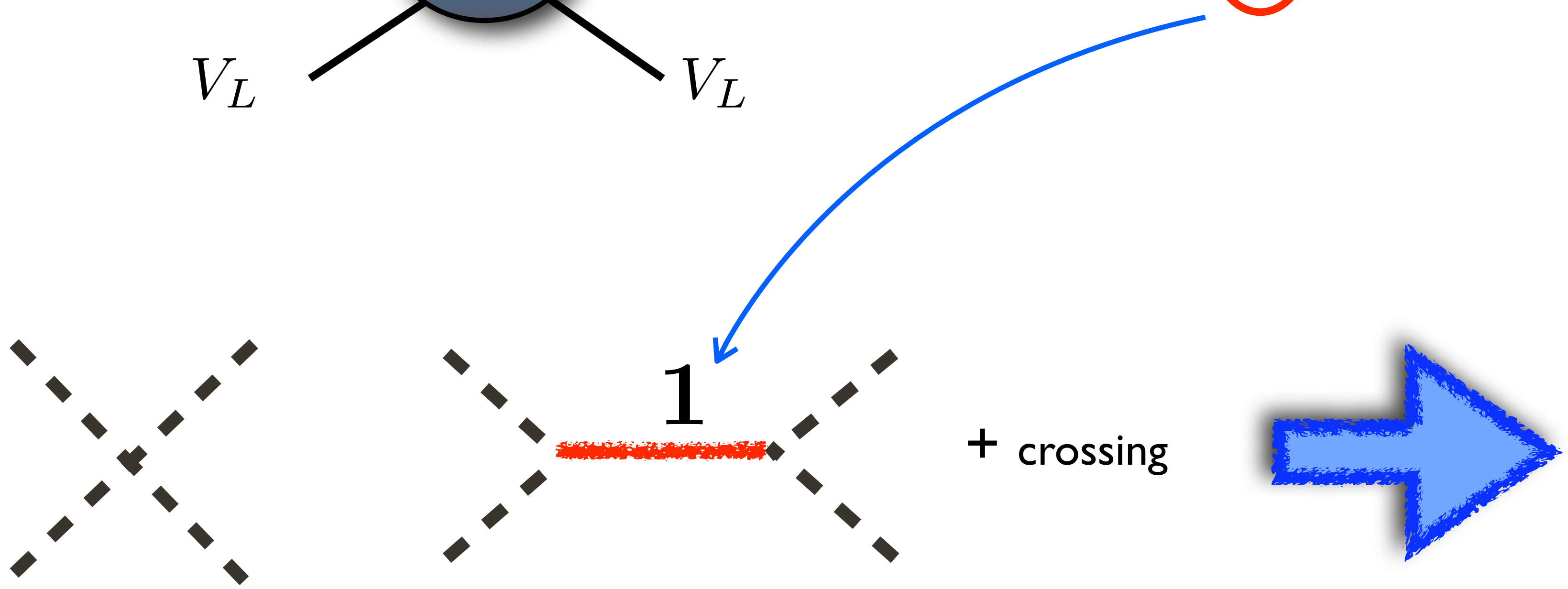
$$\left(V_\mu + \partial_\mu \pi + \frac{1}{6}[[\pi, \partial_\mu \pi], \pi] + \dots\right)^2 \longrightarrow \frac{1}{6}\left[(\vec{\pi}\partial_\mu \vec{\pi})^2 - \vec{\pi}^2(\partial_\mu \vec{\pi})^2\right]$$

Equivalence theorem

UV-Moderators I



$$\mathbf{3} \times \mathbf{3} = \mathbf{1} + \mathbf{3} + \mathbf{5}$$



$$(1 - a_h^2)\frac{s}{v^2}$$

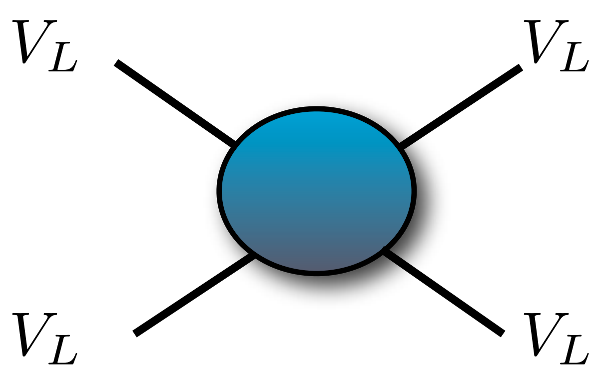
$$|D_\mu \Sigma|^2 \left(1 + 2a_h \frac{h}{v} + b_h^2 \frac{h^2}{v^2} + \dots\right)$$

Contino et al.1002.1011 [hep-ph]

Examples

- SM-Higgs $$a_h^2 = 1 \qquad \Lambda = \infty$$
- THDM $$a_{h1}^2 + a_{h2}^2 = 1 \qquad \Lambda = \infty$$
- pGB $$a_h^2 = 1 - \frac{v^2}{f^2} \qquad \Lambda = 4\pi f$$
- Dilaton $$a_h^2 = \frac{v^2}{f^2} \qquad \Lambda = \frac{4\pi v}{\sqrt{1 - v^2/f^2}}$$

UV-Moderators II



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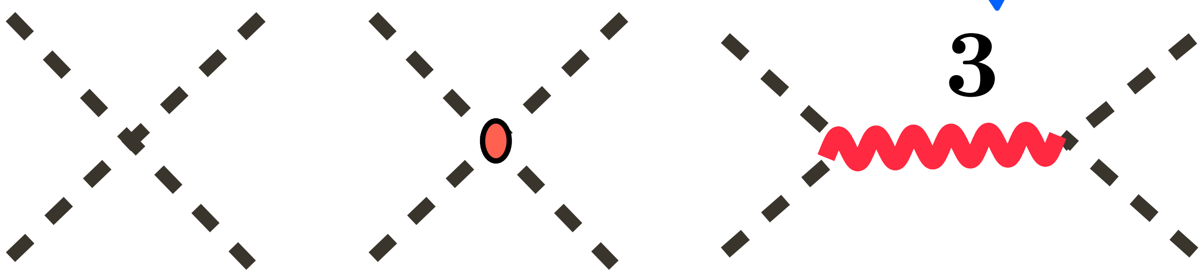


+ crossing

$$(1 - \frac{3}{4} a_\rho^2) \frac{s}{v^2} + o(\log s)$$

$$-\frac{1}{4g_\rho^2}\rho_{\mu\nu}^2 + a_\rho^2 \frac{v^2}{2}\left[\rho_\mu^2 + (\vec{\rho}_\mu \times \partial_\mu \vec{\pi}) \cdot \vec{\pi} + \frac{1}{2}(\vec{\pi} \times \partial_\mu \vec{\pi})^2 + \ldots\right]$$

more later...

Examples

- QCD/ Technicolor(?) $a_\rho^2 \approx 2$ $\Lambda \sim m_\rho$

- Higgsless $\sum_N \frac{3}{4} a_{\rho_N}^2 = 1$ $\Lambda \gg 4\pi v$

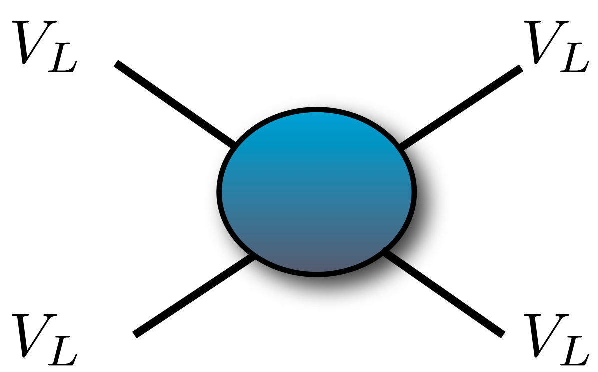
  Csaki et al. hep-ph/0305237

$$\Lambda_{NDA} \sim \Lambda_{unitary}$$

$$\sqrt{s} \lesssim 2m_\rho$$

inelastic threshold

UV-Moderators III



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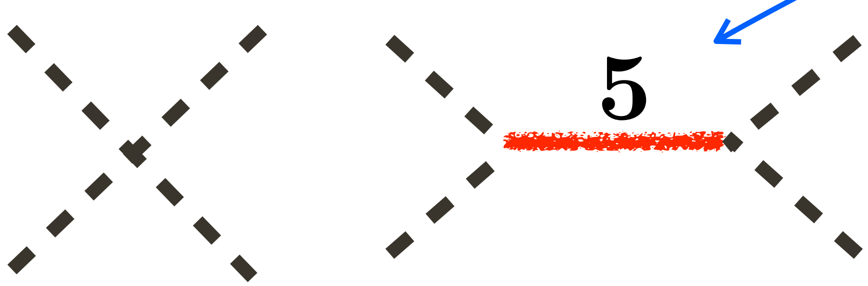


+ crossing

$$\left(1 + \frac{5}{6} a_Q^2\right) \frac{s}{v^2}$$

doesn't unitarize alone

see e.g. Falkowski, Rychkov and Urbano 1202.1532 [hep-ph]

Higgs + Spin-1

one single spin-1 below the cutoff (techni-rho, KK-W,...)

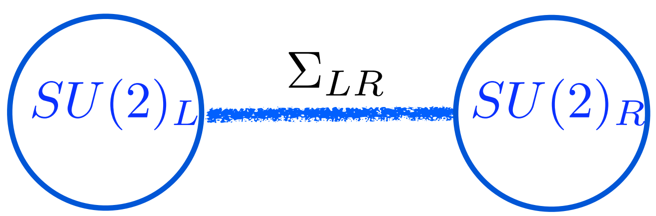
ρ_μ as gauge vector $\rho \longrightarrow h\rho h^\dagger - ih\partial_\mu h$

- UV-behavior $\rho_L \longrightarrow \partial\eta$
- no weird NDA $\mathcal{L} \not\supset \frac{\mathcal{O}}{m_\rho^\#}$
- perturbative limit $\Sigma = e^{i\pi} \longrightarrow e^{i\pi}(1 + \frac{h}{v})$
- easy to implement on MC

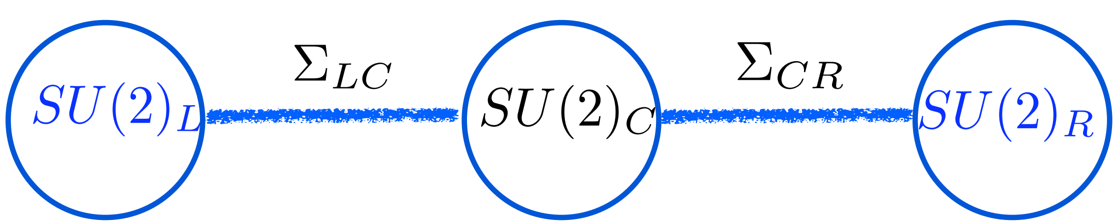
Examples

non-linear

2-sites



3-sites



$H\ (h)$ is $P_{LR} - odd\,(-even)$

linear

sm-Higgs

$$\Sigma_{LR} = e^{i\pi} \longrightarrow e^{i\pi}(1 + \frac{h}{v})$$

$$\Lambda = \infty$$

weak 3-site

$$\Sigma_{LC} \longrightarrow e^{i(\pi-\eta)}(1 + \frac{h-H}{2v})$$

$$\Sigma_{CR} \longrightarrow e^{i(\pi+\eta)}(1 + \frac{h+H}{2v})$$

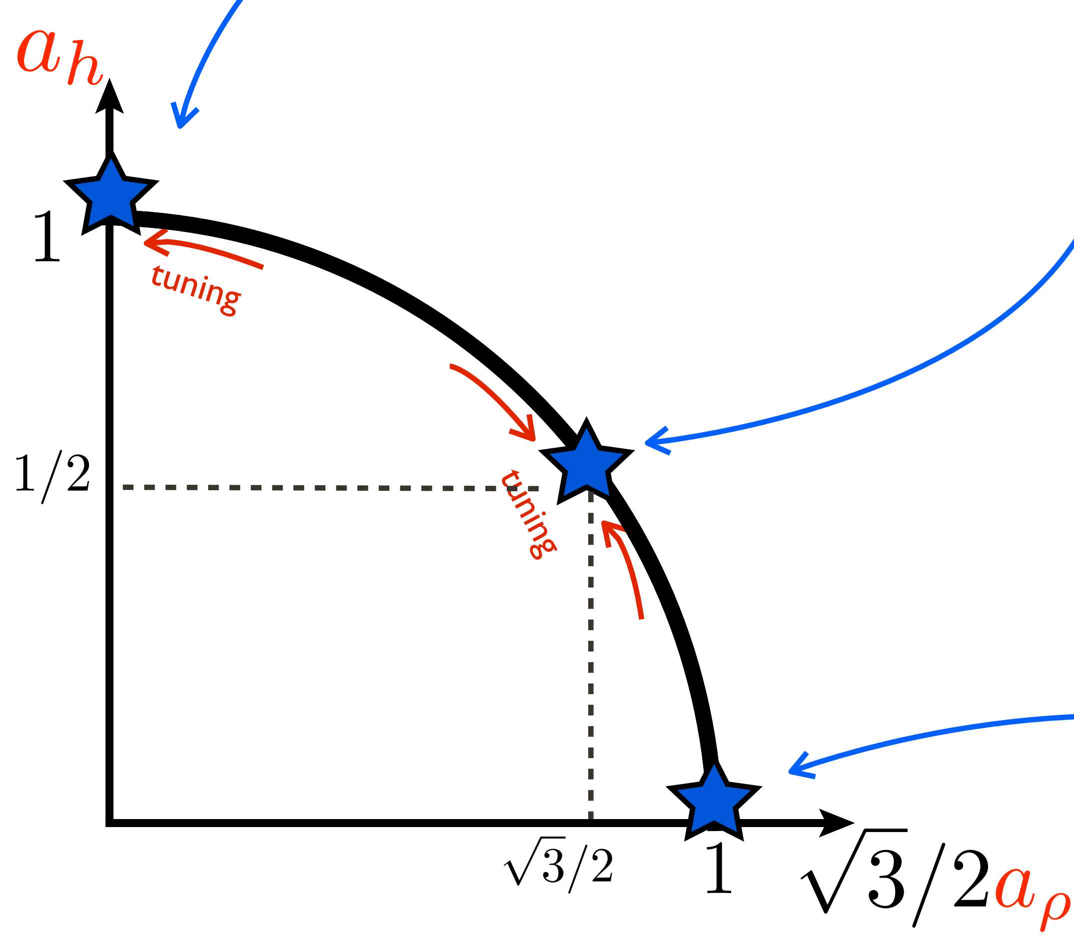
$$\Lambda \sim \infty\,(\gg 2m_\rho)$$

see e.g. Carcamo, Torre 1005.3809 [hep-ph]

Models on a circle

$$a_h^2 + \frac{3}{4}a_\rho^2 = 1$$

sm-higgs
$\Lambda = \infty$



weak 3-site

$\Lambda \sim m_H \lesssim 2m_\rho$ Integrate-out H

$\Lambda \gg 2m_\rho$ Integrate-in H

no change in
$\pi\pi \longrightarrow \pi\pi$

Higgsless
$\Lambda \sim 2m_\rho$

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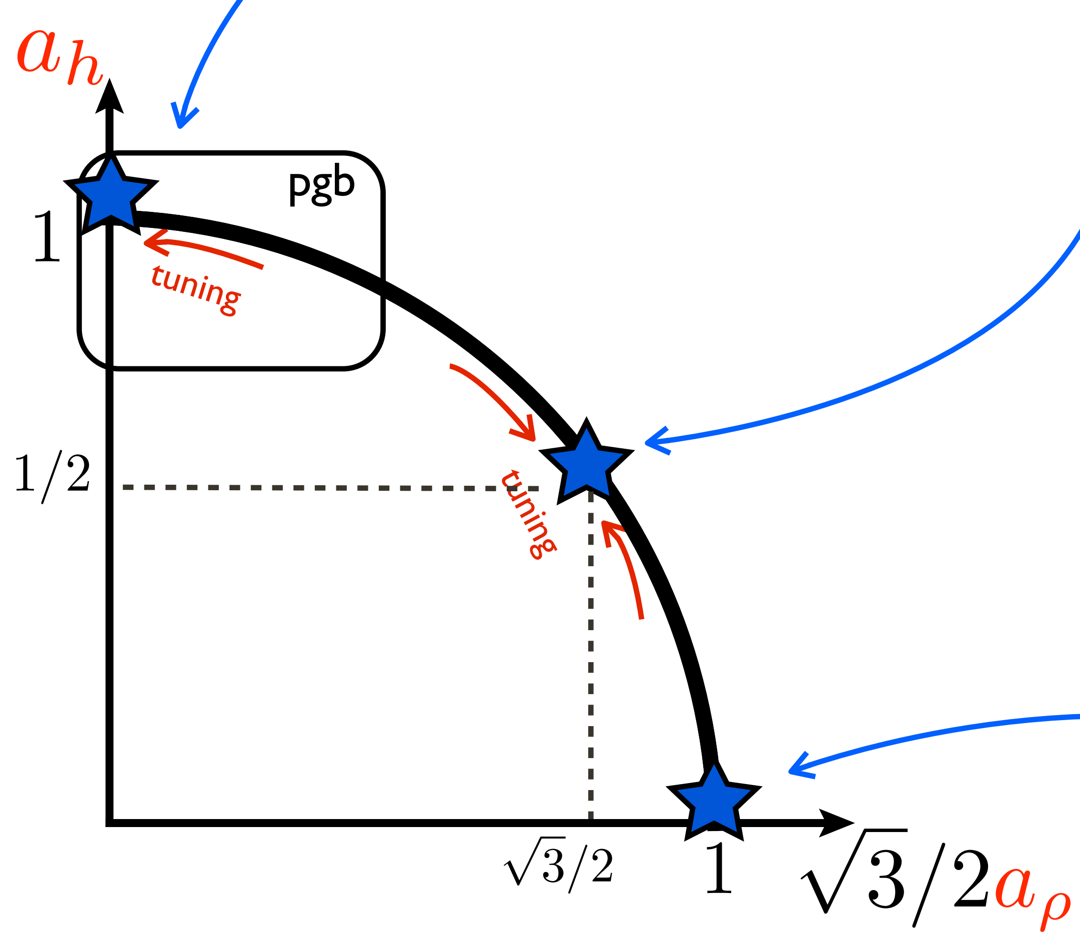

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Higgs+vector: effective lagrangian

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Higgs

$$\mathcal{L}_{eff} = a_h \left(\frac{m_Z^2}{v} Z_\mu^2 + \frac{2m_W^2}{v} W_\mu^2 \right) h + c_f \frac{m_f}{v} \bar{f} f h + c_\gamma \frac{\alpha}{8\pi v} h F_{\mu\nu}^2 + c_g \frac{\alpha_s}{8\pi v} h G_{\mu\nu}^2$$

Higgs+vector: effective Lagrangian

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spin-1

$$-\frac{1}{4g_\rho^2} \rho_{\mu\nu}^2 + \frac{v^2}{2} \left(\rho_\mu^a + \ldots \right)^2 \left[a_\rho^2 + 2c_\rho \frac{h}{v} + \ldots \right]$$

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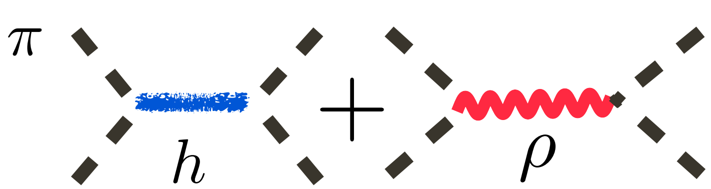
$$a_h^2 + \frac{3}{4} a_\rho^2 = 1$$



$$\pi\pi \longrightarrow \pi\pi$$

Higgs+vector: effective Lagrangian

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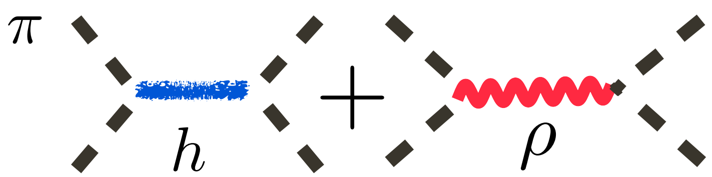

$$\pi\pi \longrightarrow \pi\pi$$

2+2 parameters

$a_h \quad c_{top} \quad m_\rho \quad c_\rho$

Higgs+vector: effective Lagrangian

Higgs

$$\mathcal{L}_{eff} = a_h \left(\frac{m_Z^2}{v} Z_\mu^2 + \frac{2m_W^2}{v} W_\mu^2 \right) h + c_f \frac{m_f}{v} \bar{f} f h + c_\gamma \frac{\alpha}{8\pi v} h F_{\mu\nu}^2 + c_g \frac{\alpha_s}{8\pi v} h G_{\mu\nu}^2$$

spin-1

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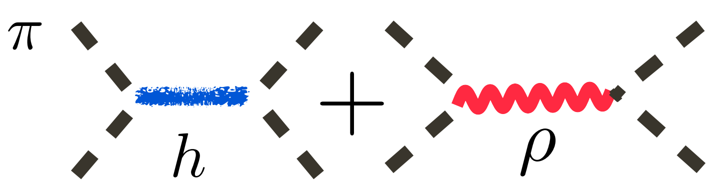
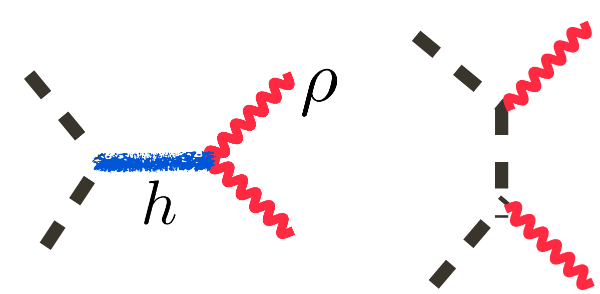


$$\pi\pi \longrightarrow \pi\pi$$

2+~~2~~ 1 parameters

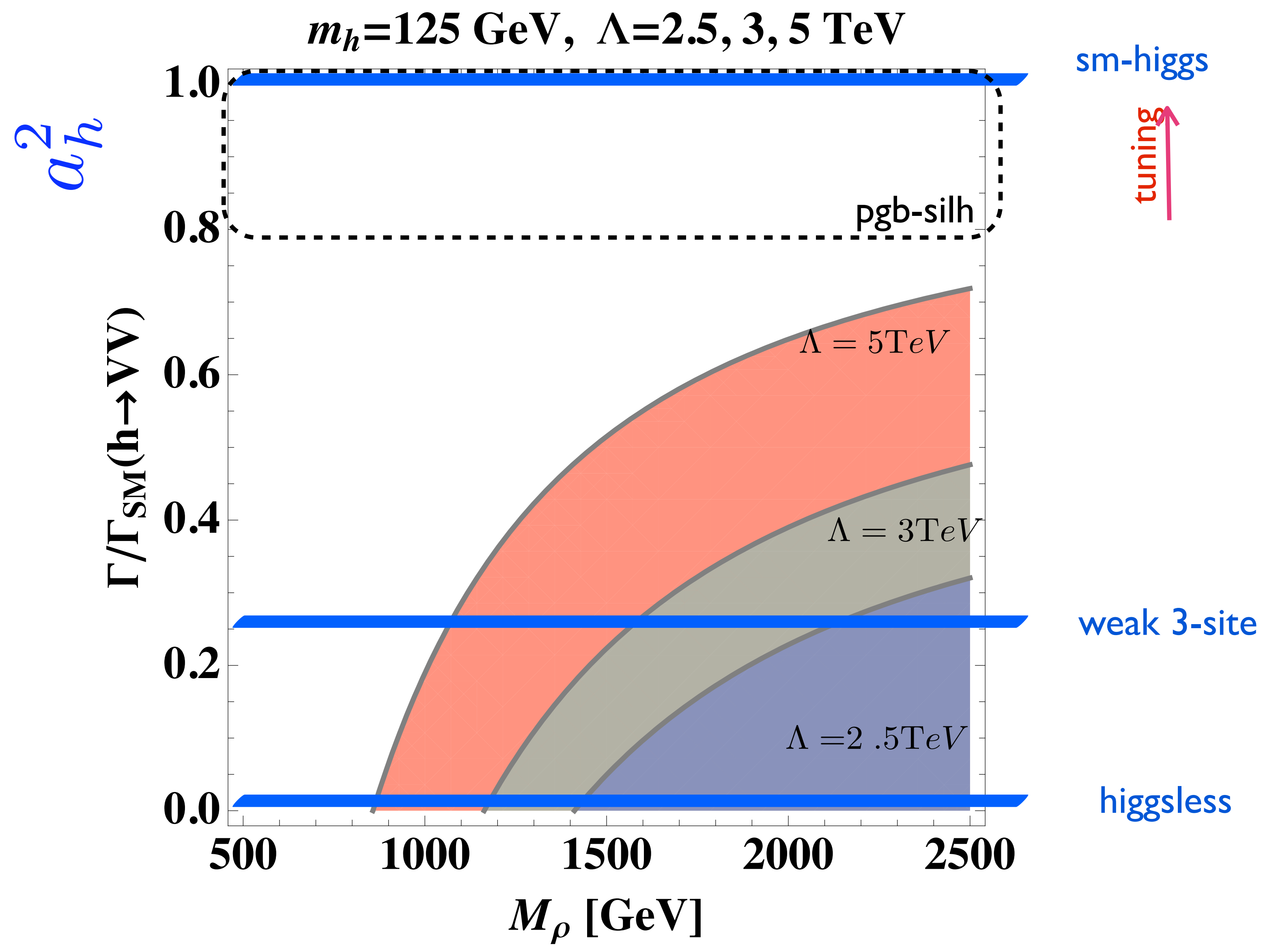
a_h c_{top} m_ρ ~~c_ρ~~

$$4c_\rho a_h = a_\rho^2$$



$$\pi\pi \longrightarrow \rho_L \rho_L$$

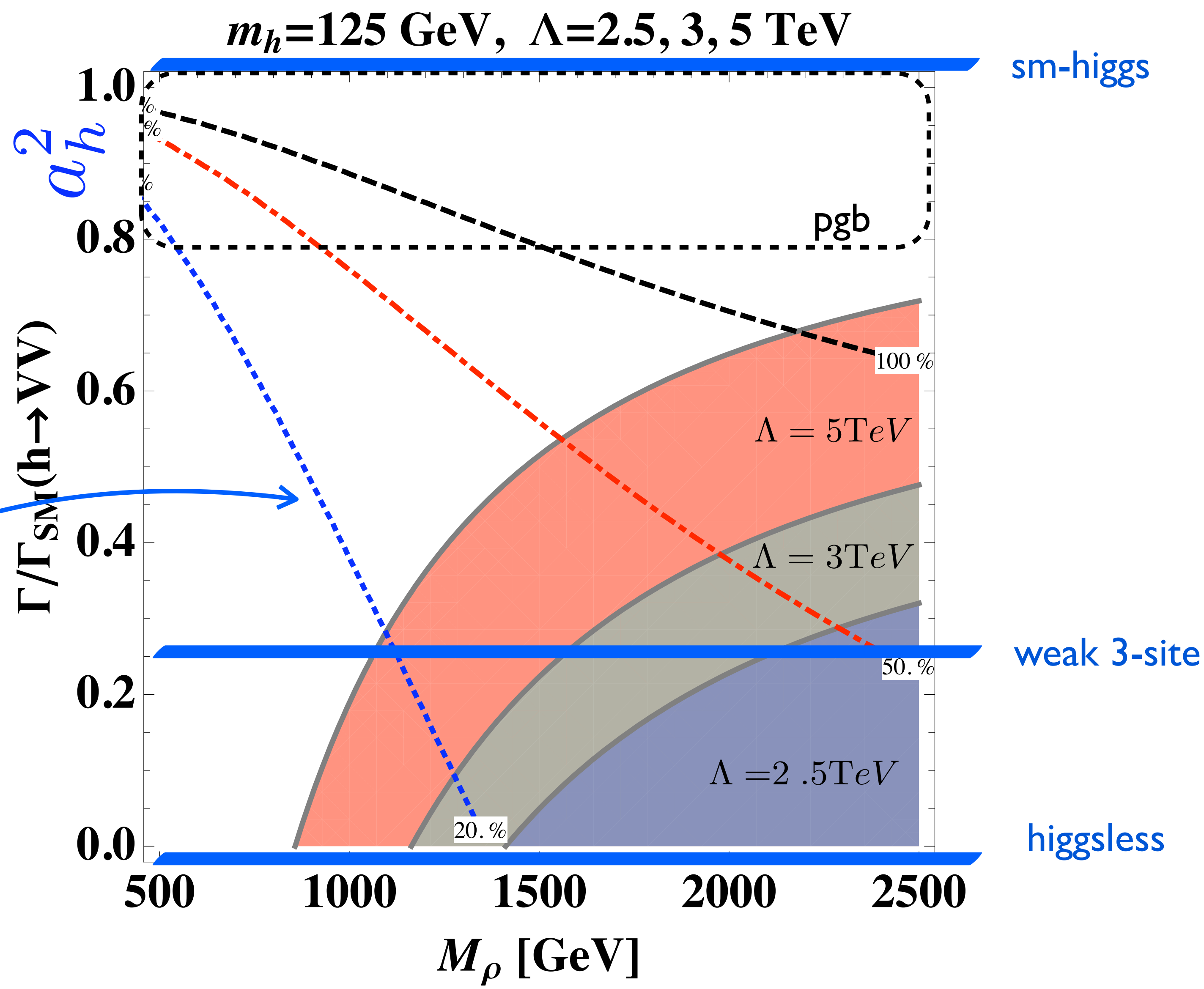
Higgs decay into VV



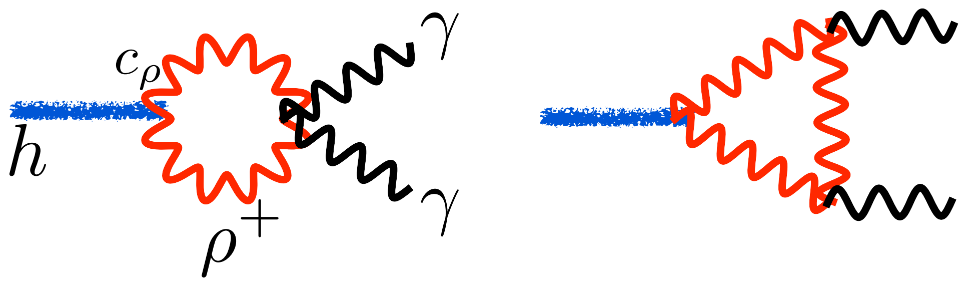
S-parameter

tree-level
contribution

cancellations?
(axial vectors...)



Higgs into gammas



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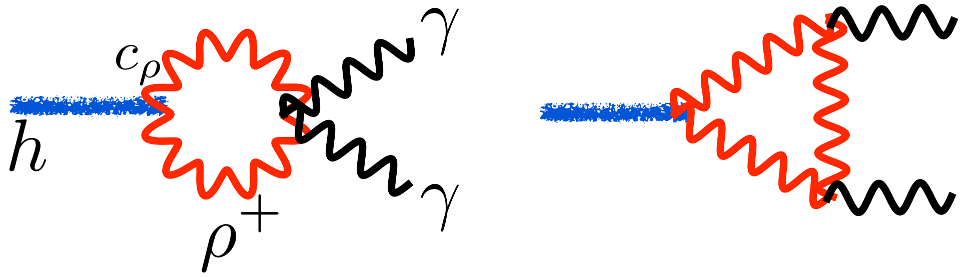
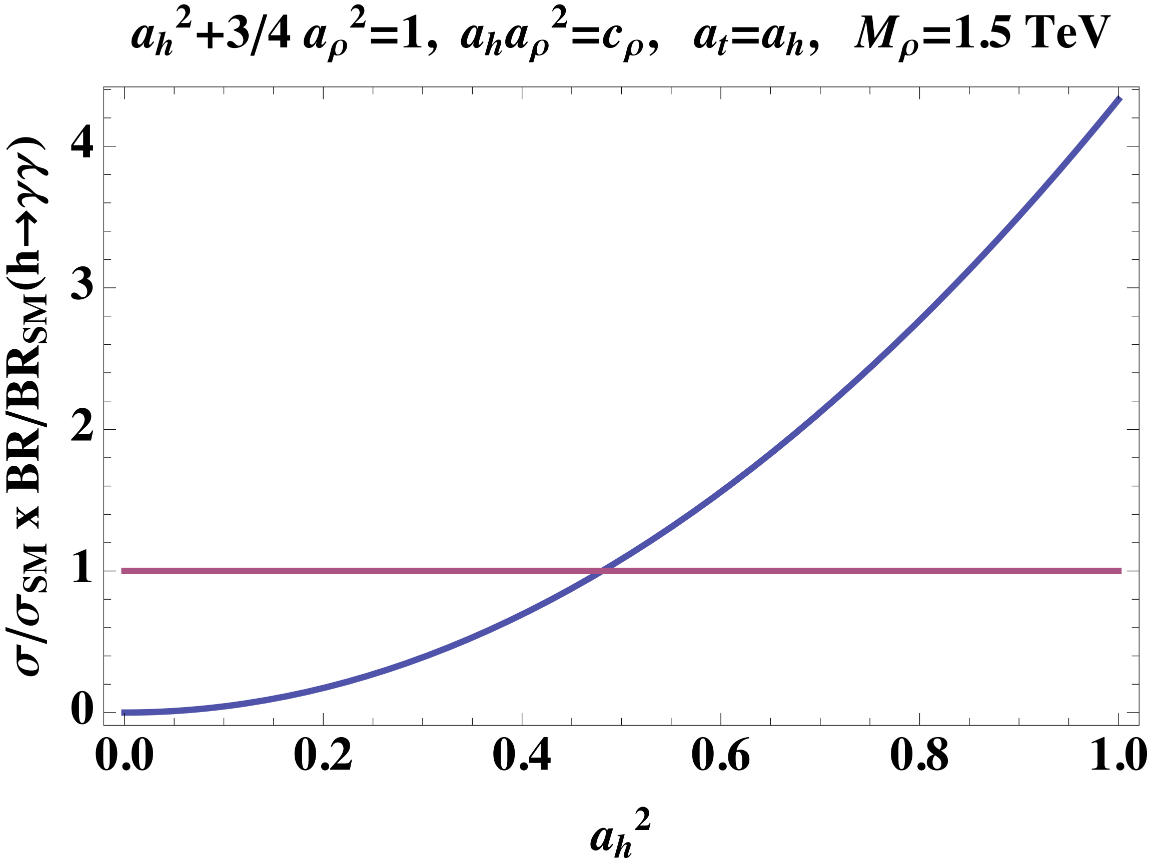
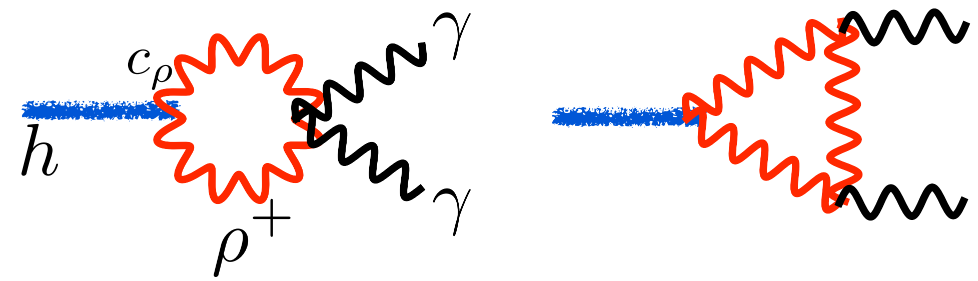
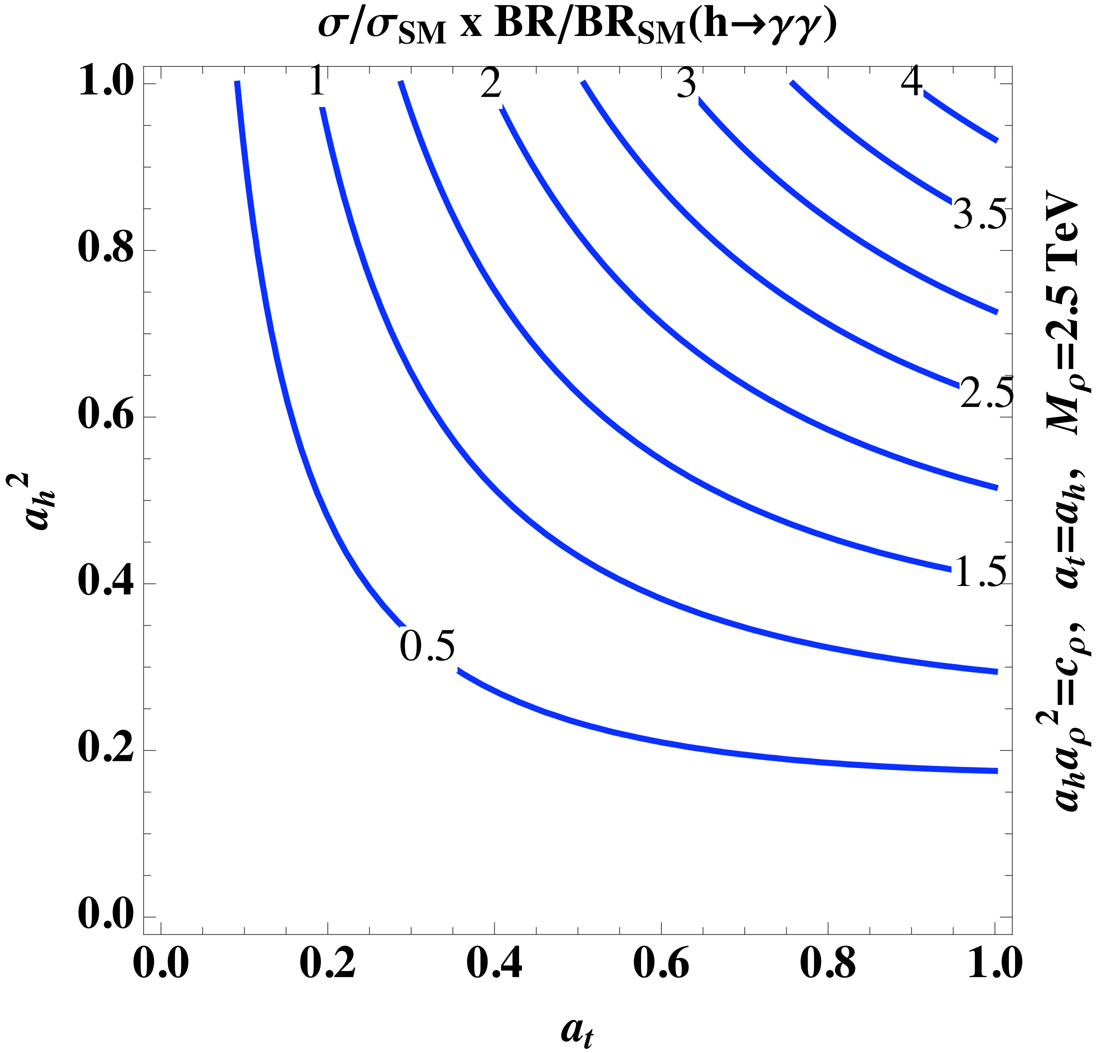


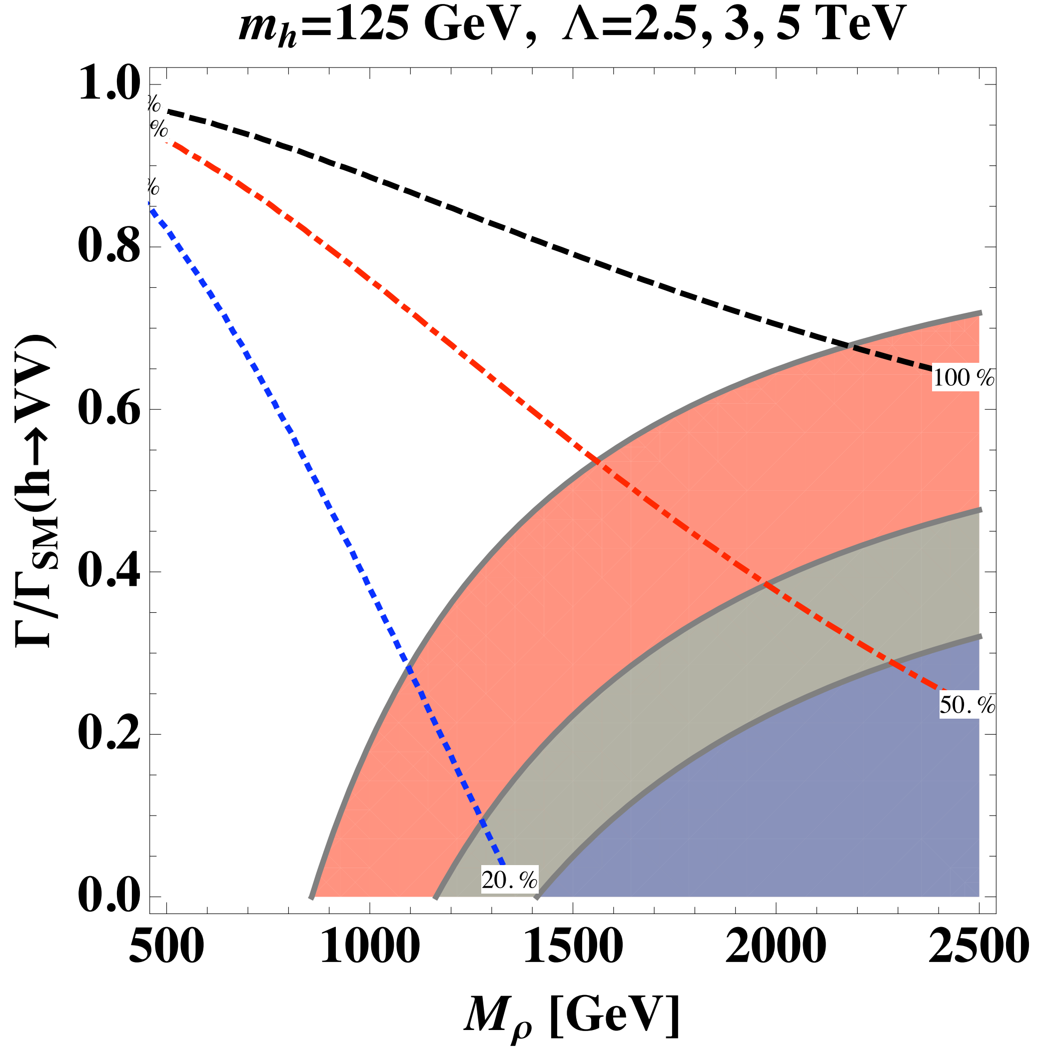


$$\Gamma/\Gamma_{SM}(h \to VV)$$

Higgs into gammas







RHO-COUPLING AND BRs

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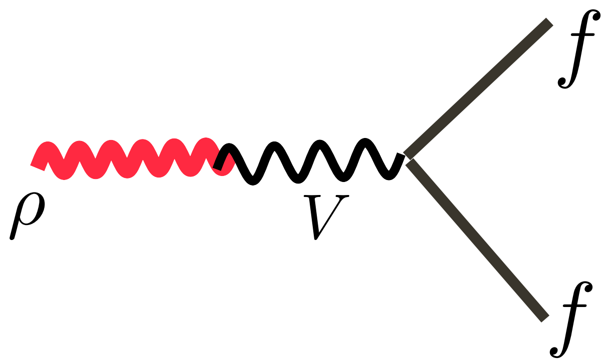
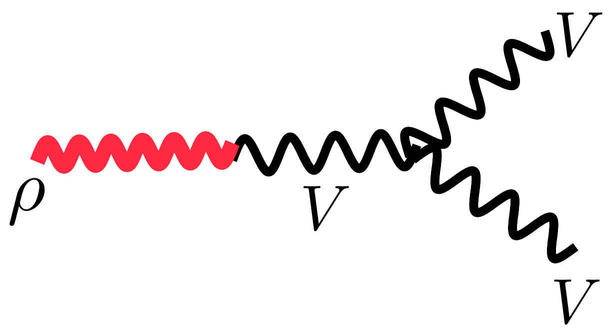


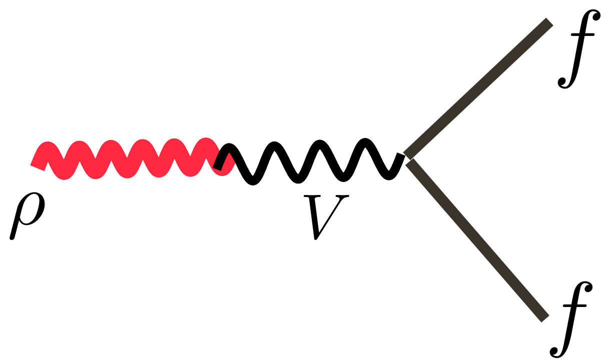
$$g_{\rho^\pm f f'} = g_{SM}\left(a_\rho \frac{m_W}{m_\rho}\right)$$



$$g_{\rho^\pm W^\mp Z} = g_{SM}\left(a_\rho \frac{m_Z}{m_\rho}\right)$$

model independent

RHO-COUPLING AND BRs



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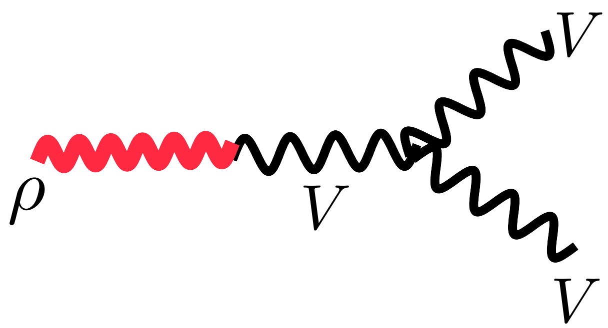

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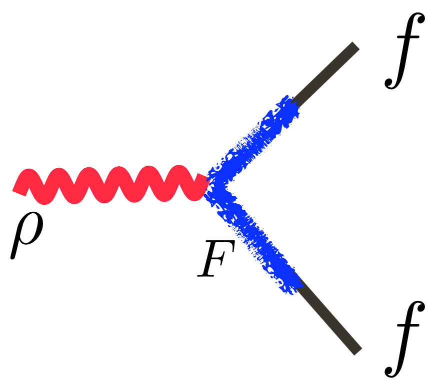
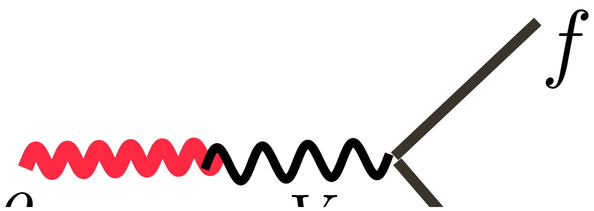


compositeness: model dependent

$$g^{comp}_{\rho f f} \sim g_\rho \sin\theta^2$$

RHO-COUPLING AND BRs



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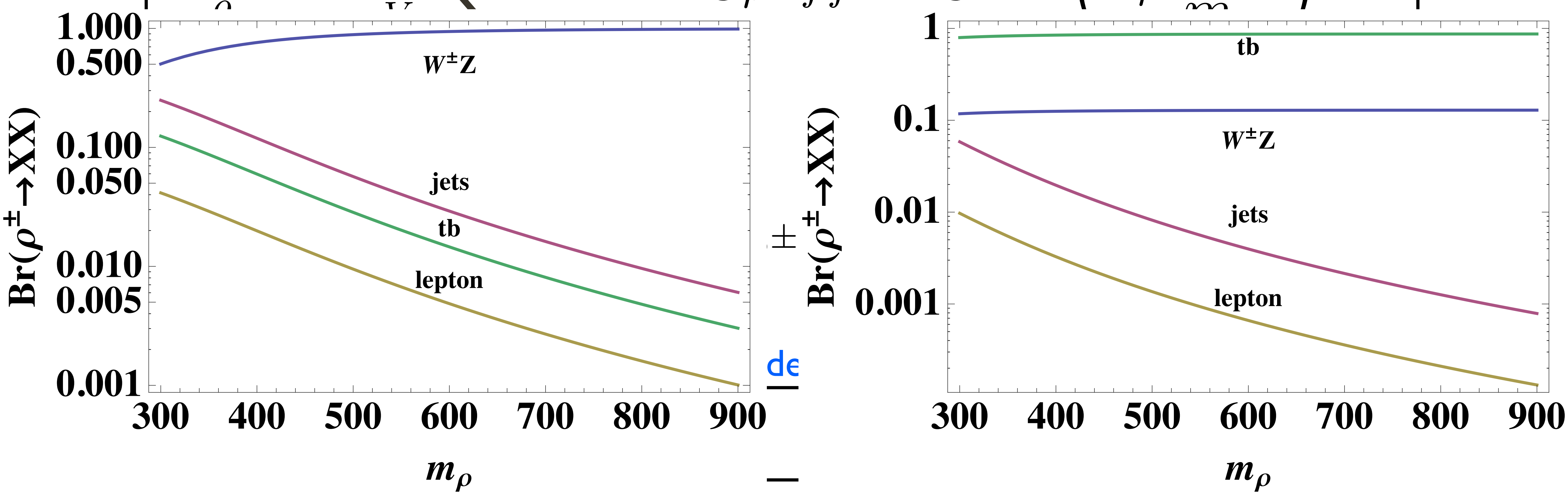

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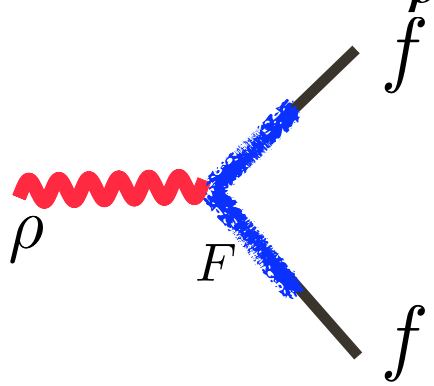

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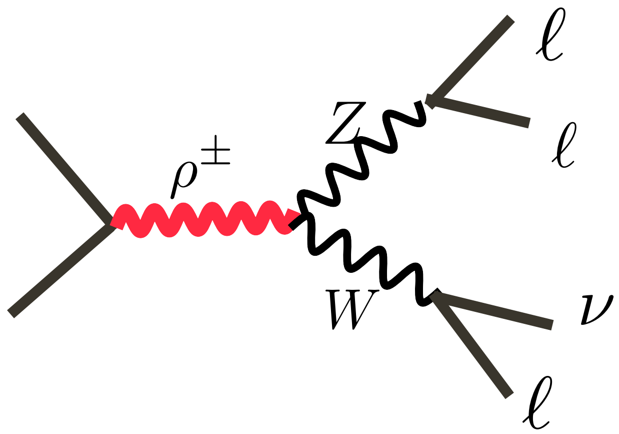
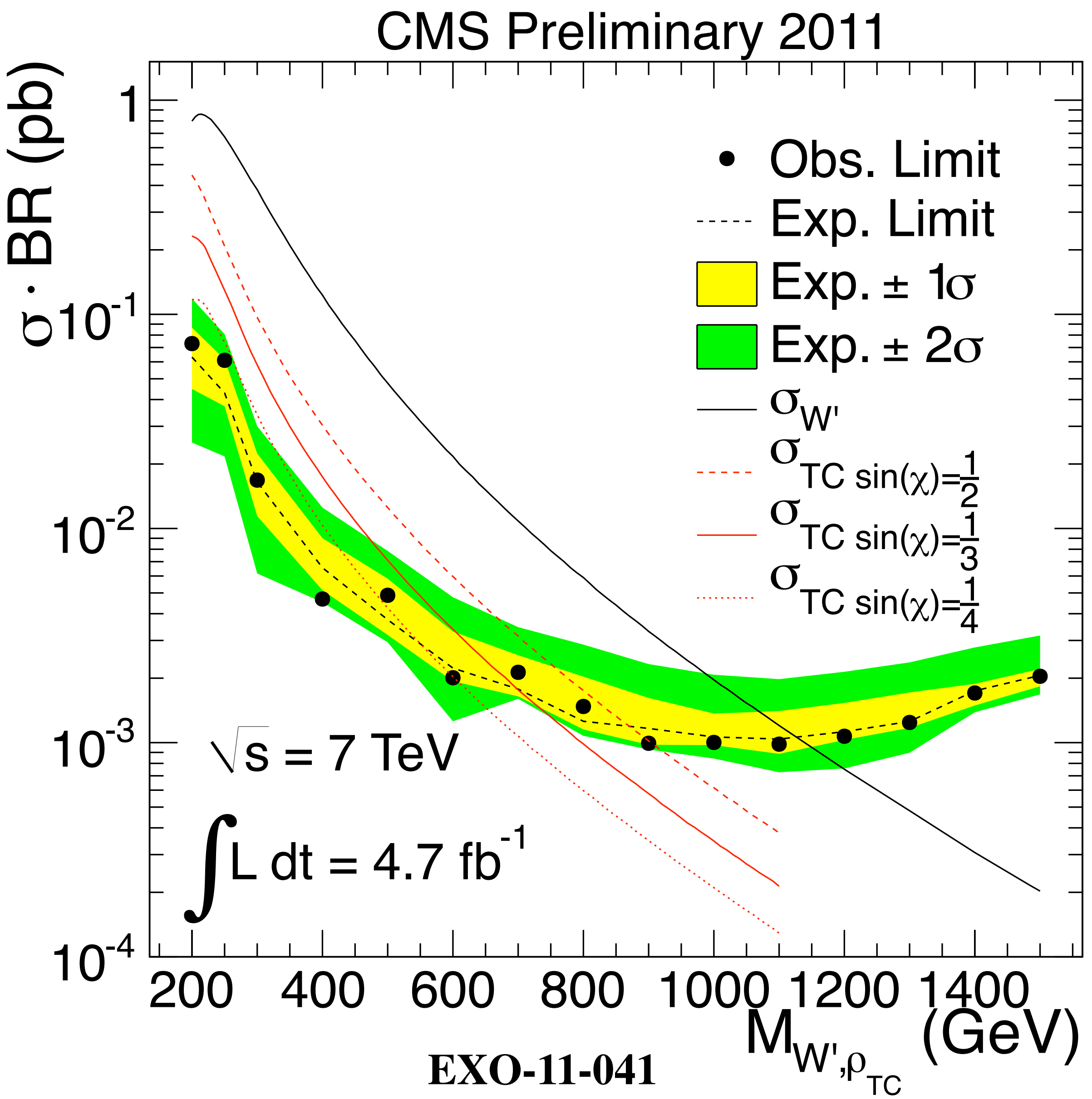
Limits on rho+-

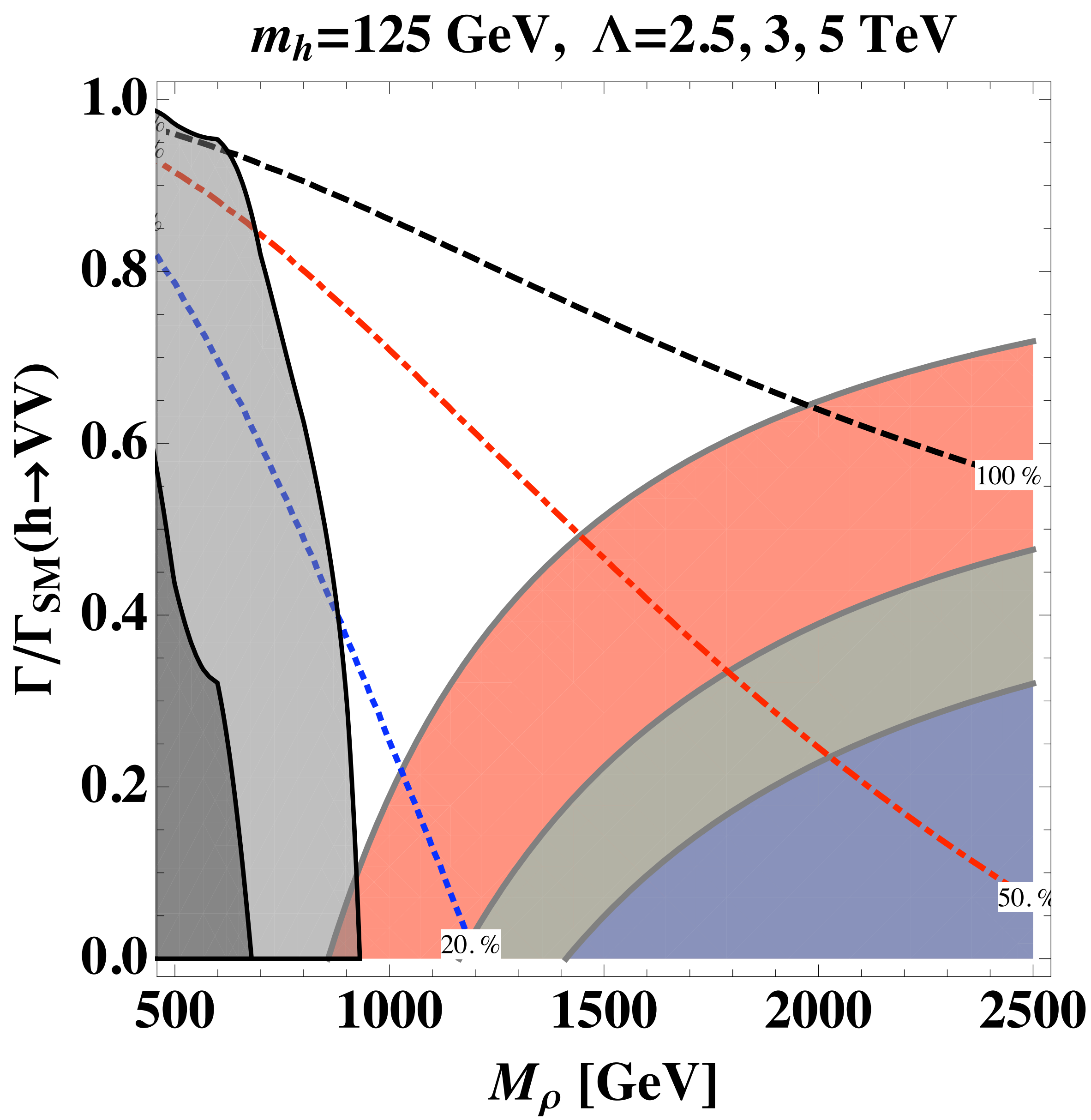


$$\Gamma_{min}/m_\rho \sim 0.04 \left(\frac{m_\rho}{1\ \mathrm{TeV}}\right)^2$$

$$\sigma \sim 50\ \mathrm{fb\ at\ 1\ TeV}$$



EXO-11-041



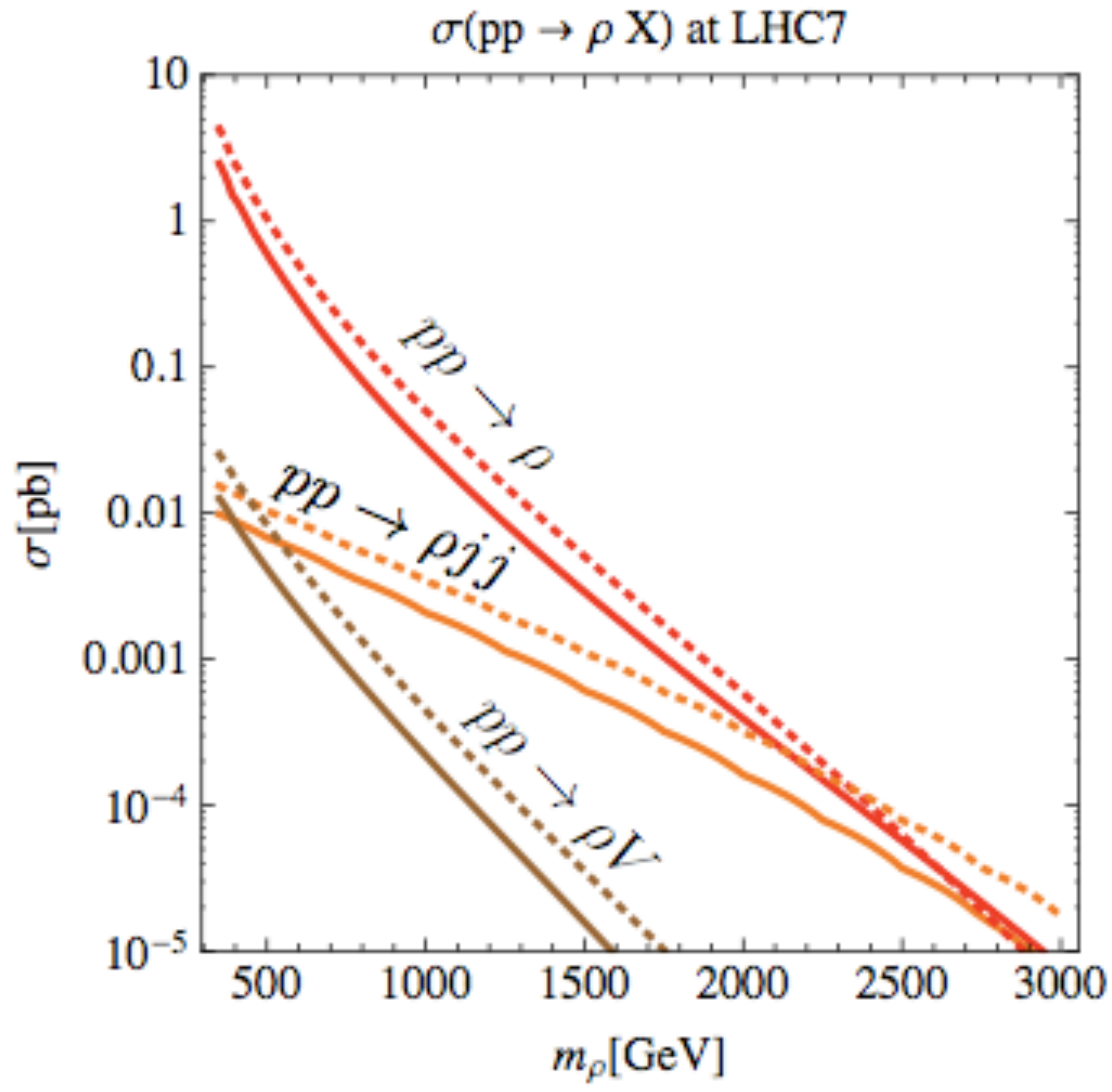
conclusions

- fine-tuning -> non standard higgs couplings
  -> new resonances
- Effective theory of Higgs + spin-1
  just 2 parameters ($c_\rho \,, m_\rho$) more than SM
- smaller h->VV but larger h->2gamma
- CMS-bound on rho+- up to 900 GeV
- experimental searches in di-boson resonances
  (rather than sequential Z') extremely valuable

Thank you!

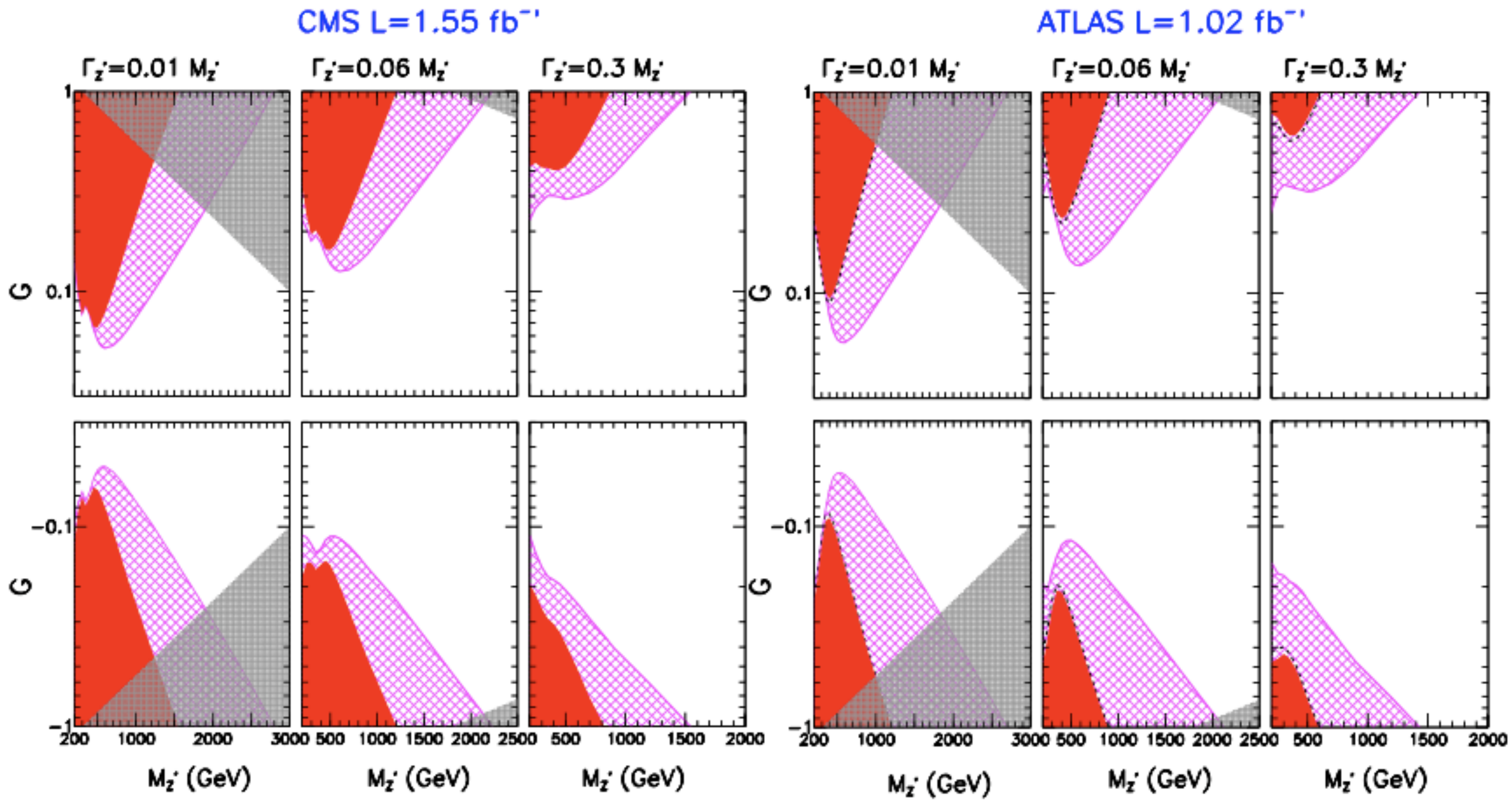
BACKUP SLIDES

resonances production



Falkowski et al. 1108.1183 [hep-ph]

limits on rho->WW from h->WW

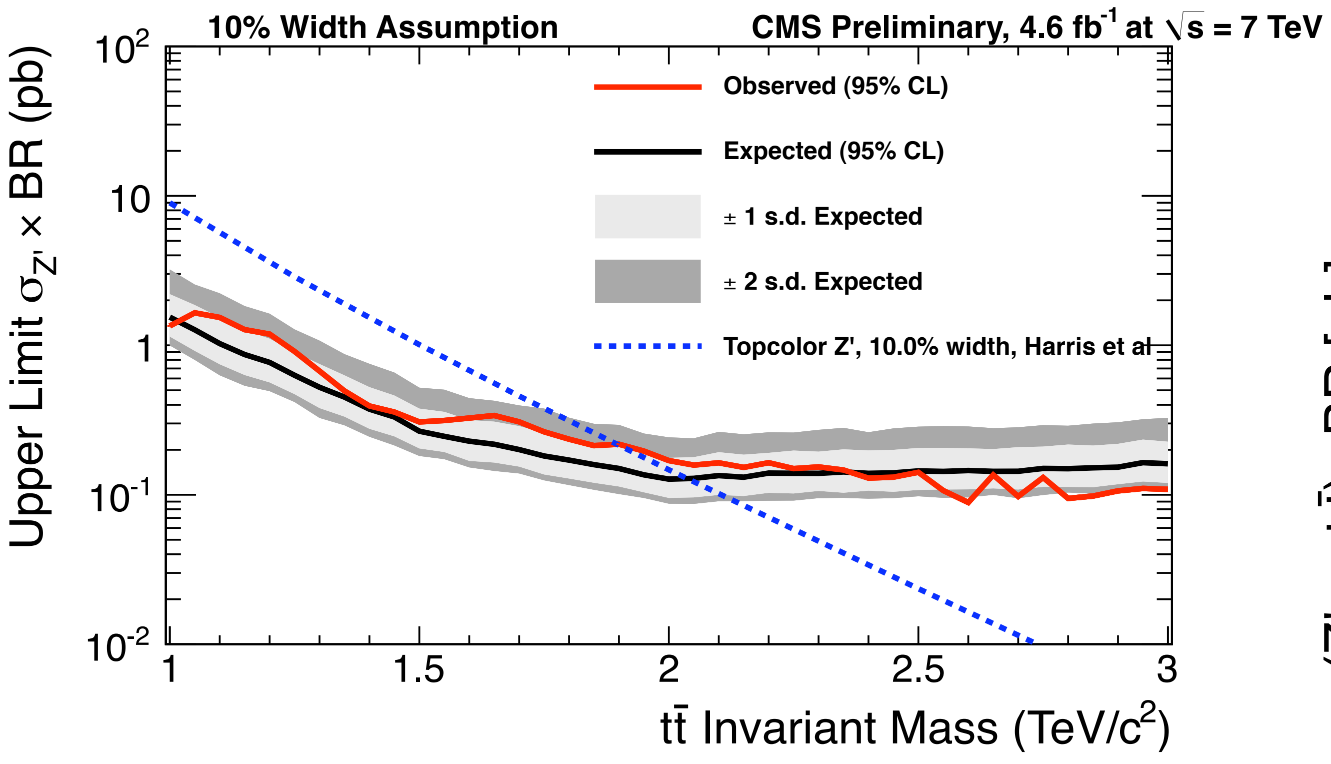


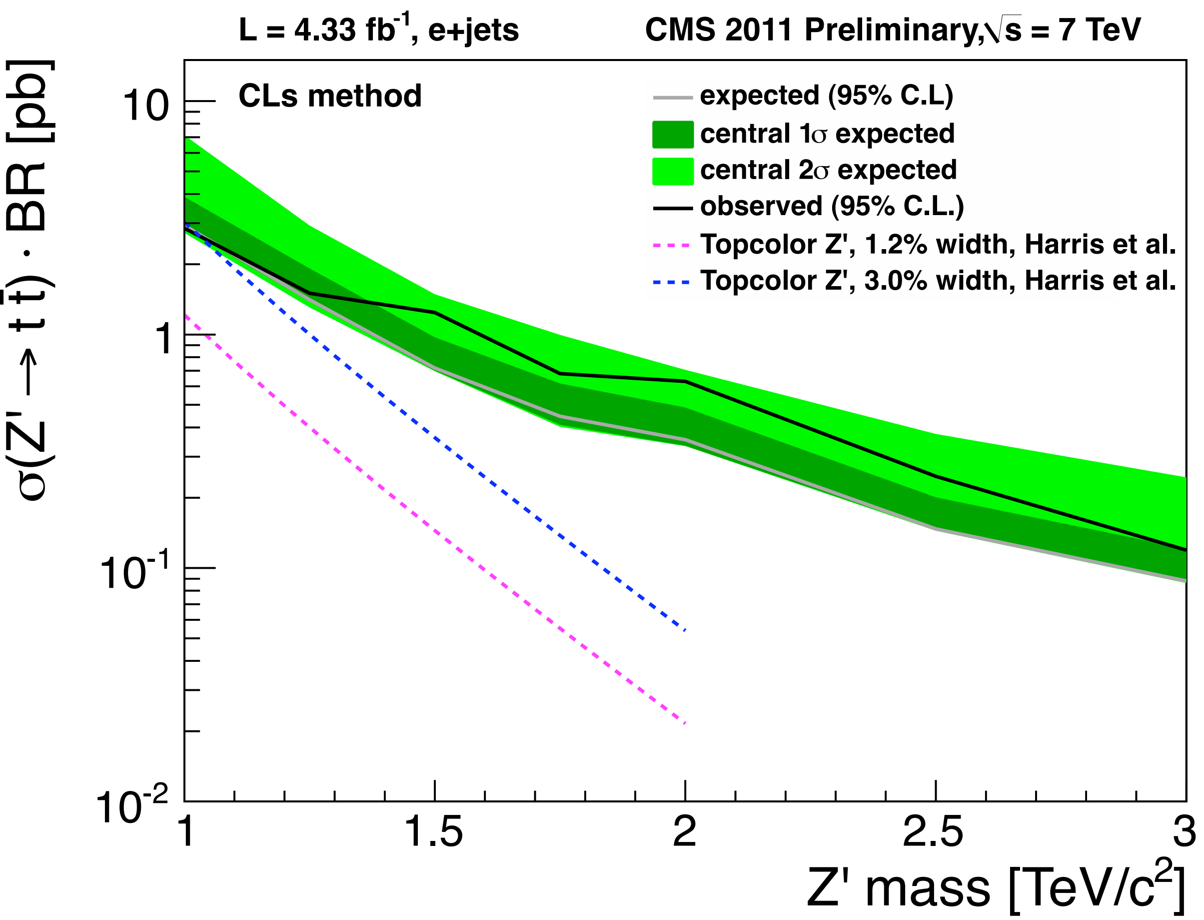
$$G = \left(\frac{g_{Z'q\bar{q}}}{g_{Zq\bar{q}}}\right)\left(\frac{g_{Z'WW}}{g_{Z'WW_{max}}}\right)$$

Eboli et al. 1112.0316 [hep-ph]

rho in DY; h in gluon and VB Fusion
h->WW optimazed for SM couplings

rho->top pairs

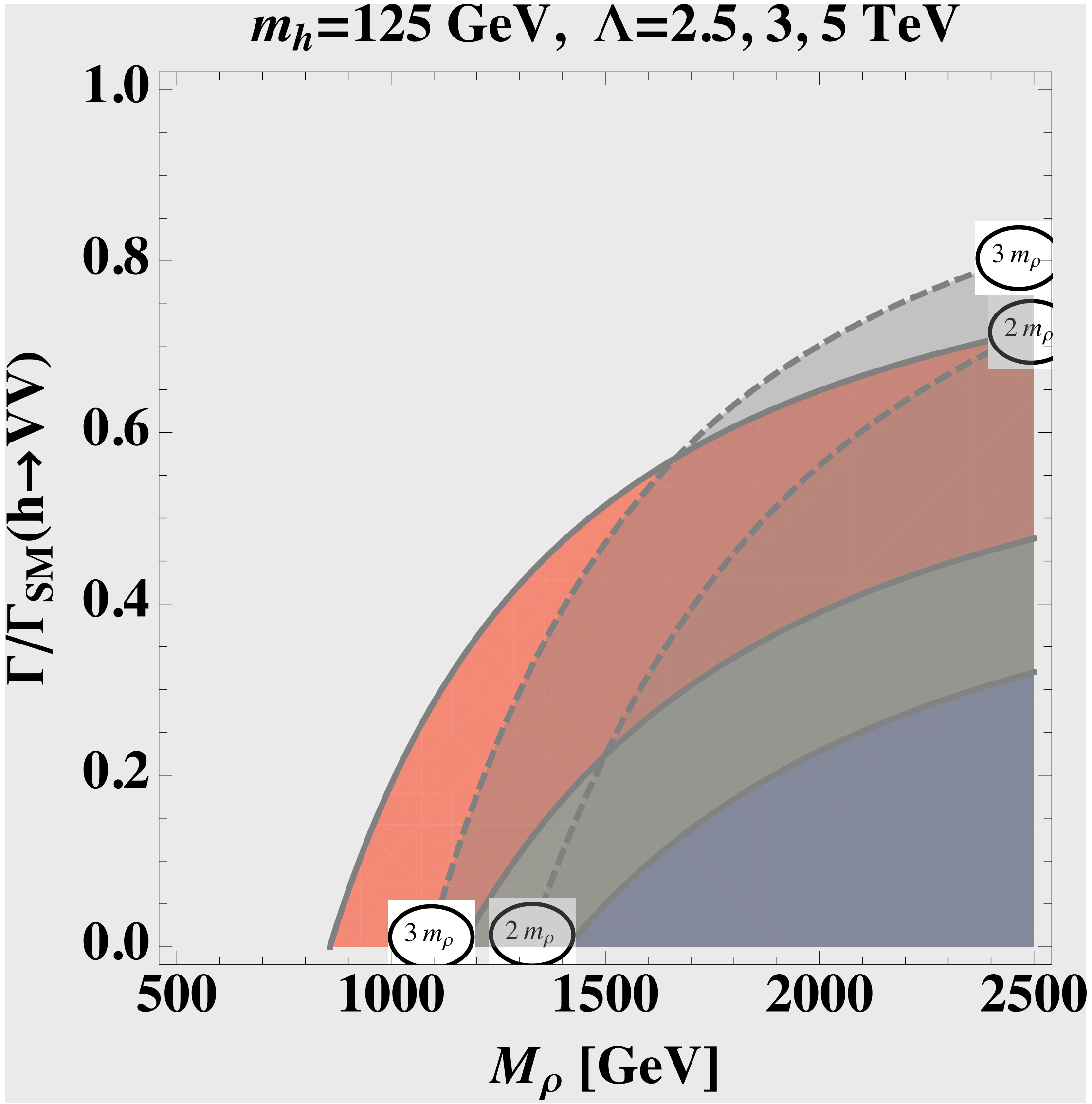




composite top=large BR(rho->tt)

$\sigma \sim 50$ fb at 1 TeV

limits~0.1-1 pb up to 3 TeV



m_h=125 GeV, Λ=2.5, 3, 5 TeV
1.0
0.8
0.6
0.4
0.2
0.0
Γ/Γ_SM(h→VV)
500
1000
1500
2000
2500
M_ρ [GeV]
3 m_ρ
2 m_ρ
3 m_ρ
2 m_ρ

CCWZ-dictionary

$$e^{-i\pi}\partial_\mu e^{i\pi} = d_\mu^{\hat{a}} T^{\hat{a}} + E_\mu^a T^a \qquad E_\mu^a = -\frac{1}{2}\epsilon^{abc}\partial_\mu \pi^b \pi^c + \frac{1}{2}(W_\mu + B_\mu \delta^{a3}) + \dots$$

$$d_\mu \longrightarrow h d_\mu h^\dagger \qquad E_\mu \longrightarrow h E_\mu h^\dagger - i h \partial h^\dagger$$