Classification of simple heavy vector triplet models

Ryo Nagai

(Nagoya U.)

based on

RN and T. Abe arXiv: 1607.03706 [hep-ph]

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Extra spin-1 particles (V')

Well-motivated

- Various BSM predict them.

  * Extension of gauge sym → W'/Z' boson
  * New dynamics → ρ' resonance

- Their mass scale is expected to be around TeV scale.

Extra spin-1 particles (V’)

There are many models

Radindra-Mohapatra-Pati (1974)
Mohapatra-Pati (1974)
Barger-Keung-Ma (1980)
Mohapatra-Senjanovic (1980)
Bando-Kugo-Yamawaki (1987)

Agashe-Davoudiasl-Gopalakrishna-Han-Huang-Perez-Si-Soni (2007)
Agashe-Gopalakrishna-Han-Huang-Soni (2009)
Agache-Azatov-Han-Li-Si-ZHu (2010)
Contino-Pappadopulo-Marzocca-Rattazzi (2011)
Abe-Kitano (2013)

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Extra spin-1 particles (V’)

There are many models

Can we identify the V’ model if V’ is discovered in the future ?

The classification of V’ models is important.

Contents

Our strategy

We focus on the ratio:

$$R = \frac{\Gamma(V' \to ff)}{\Gamma(V' \to VV)}$$

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Two important parameters:

$$g_{V'ff} = -\xi_f g_{Vff} \qquad g_{V'VV} = \xi_V g_{VVV} \frac{m_V^2}{m_{V'}^2}$$

V'ff coupling

V'VV coupling

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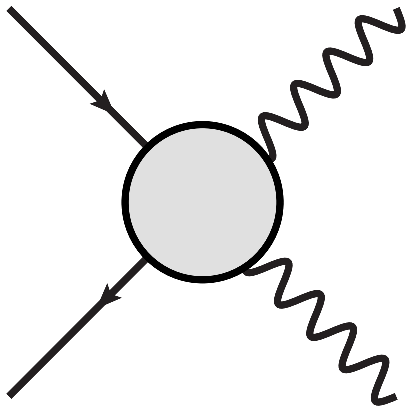
Let us impose perturbative unitarity and custodial symmetry in the V' models.

V’ and perturbative unitarity

Let us focus on vector / fermion scattering



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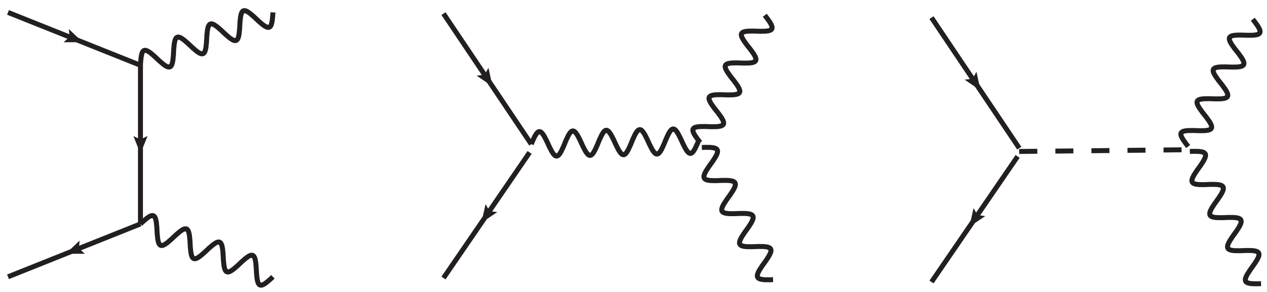

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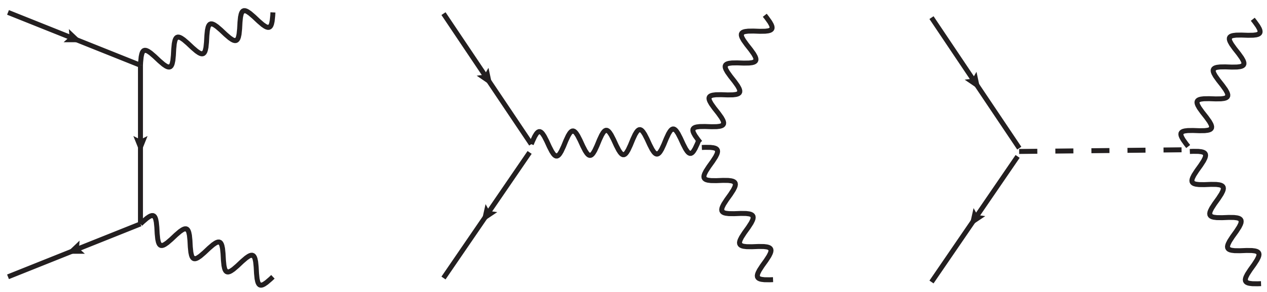

$$\mathcal{M} \simeq A\frac{E^2}{m^2} + B\frac{E}{m}$$

V' and perturbative unitarity

Let us focus on vector / fermion scattering $\mathcal{M} \simeq A\frac{E^2}{m^2} + B\frac{E}{m}$

Requiring A = 0 in ff → VV, we obtain

$$g_{Vff}^2 = g_{Vff}g_{VVV} + g_{V'ff}g_{V'VV}$$

V' and perturbative unitarity

Let us focus on vector / fermion scattering $\mathcal{M} \simeq A\frac{E^2}{m^2} + B\frac{E}{m}$

Requiring A = 0 in ff → VV, VV', V'V', we obtain

$$\xi_V = \frac{1}{\xi_f}\frac{g_{VVV} - g_{Vff}}{g_{VVV}}\frac{m_{V'}^2}{m_V^2}$$

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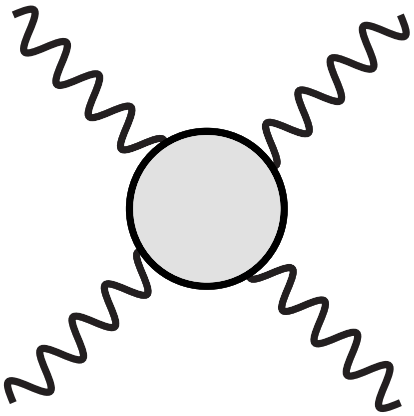

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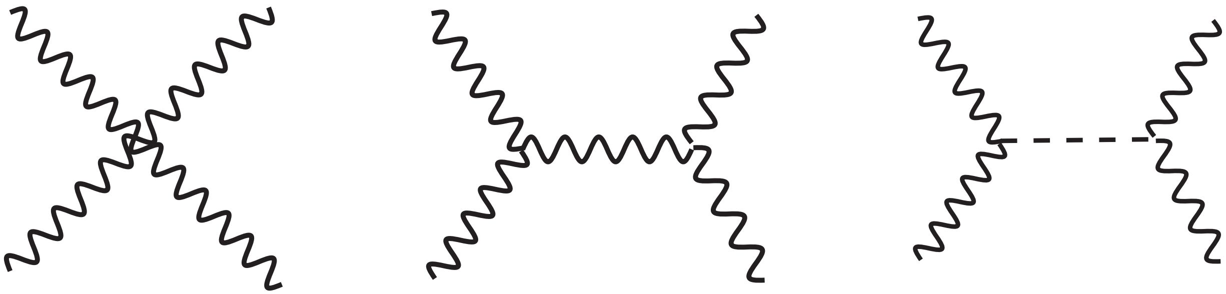

$$\mathcal{M} \simeq C\frac{E^4}{m^4} + D\frac{E^2}{m^2}$$

V’ and perturbative unitarity

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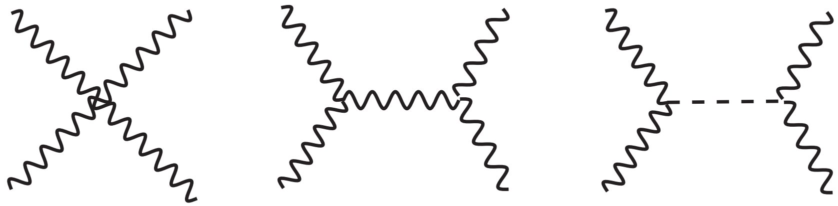

$$\simeq C\frac{E^4}{m^4} + D\frac{E^2}{m^2}$$

- “D” in VV → VV, VV’, V’V’ depend on Higgs couplings.

- From D = 0 in VV → V’V’, we find find some relations which are independent from custodial singlet Higgs coupling.

V’ and perturbative unitarity

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Classification of V'

We find two solutions.

$$R = \frac{\Gamma(V' \to ff)}{\Gamma(V' \to VV)} \simeq 4N_c \frac{\xi_f^2}{\xi_V^2}$$

$$\xi_V^+ = \xi_f \left[1 - (1 - \xi_f^2)\frac{m_V^2}{m_{V'}^2}\right]^{-1}$$

$$\xi_V^- = -\frac{1}{\xi_f} \left[1 - (1 - \xi_f^{-2})\frac{m_V^2}{m_{V'}^2}\right]^{-1}$$

$$g_{V'ff} = -\xi_f g_{Vff} \qquad g_{V'VV} = \xi_V g_{VVV} \frac{m_V^2}{m_{V'}^2}$$

* Here we assume there is no scalars other than custodial singlets

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$$R \simeq 4N_c^2$$

$$R \simeq 4N_c^2 \xi_f^4$$

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V’ mainly decays into Fermion

(type-F)

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V' mainly decays into Fermion **(type-F)**

$$R \simeq 4N_c^2 \xi_f^4$$

V' mainly decays into Boson **(type-B)**

* Here we assume there is no scalars other than custodial singlets

Summary so far

What we found:

- V' models are classified into 2 categories

This is only based on the unitarity argument,
not rely on specific models.

$$\xi_V^+ = \xi_f \left[1 - (1 - \xi_f^2)\frac{m_V^2}{m_{V'}^2}\right]^{-1}$$

V' mainly decays into
Fermion
(type-F)

$$\xi_V^- = -\frac{1}{\xi_f} \left[1 - (1 - \xi_f^{-2})\frac{m_V^2}{m_{V'}^2}\right]^{-1}$$

V' mainly decays into
Boson
(type-B)

Summary so far

What we found:

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not rely on specific models.

Next to do:

- To find bench-mark models in each categories

Contents

Strategy

We focus on

- $SU(2)_0 \times SU(2)_1 \times U(1)_2$ gauge model
- Renormalizable
- without extra fermions

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The models contains at least two scales (two VEVs)

- Models with two VEVs

Model 1

$SU(2)_0 \times SU(2)_1 \times U(1)_2 \rightarrow U(1)_{EM}$

	$SU(2)_0$	$SU(2)_1$	$U(1)_2$
q_L	**1**	**2**	1/6
u_R	**1**	**1**	2/3
d_R	**1**	**1**	- 1/3
l_L	**1**	**2**	- 1/2
e_R	**1**	**1**	- 1
H_1	**2**	**2**	0
H_2	**1**	**2**	1/2

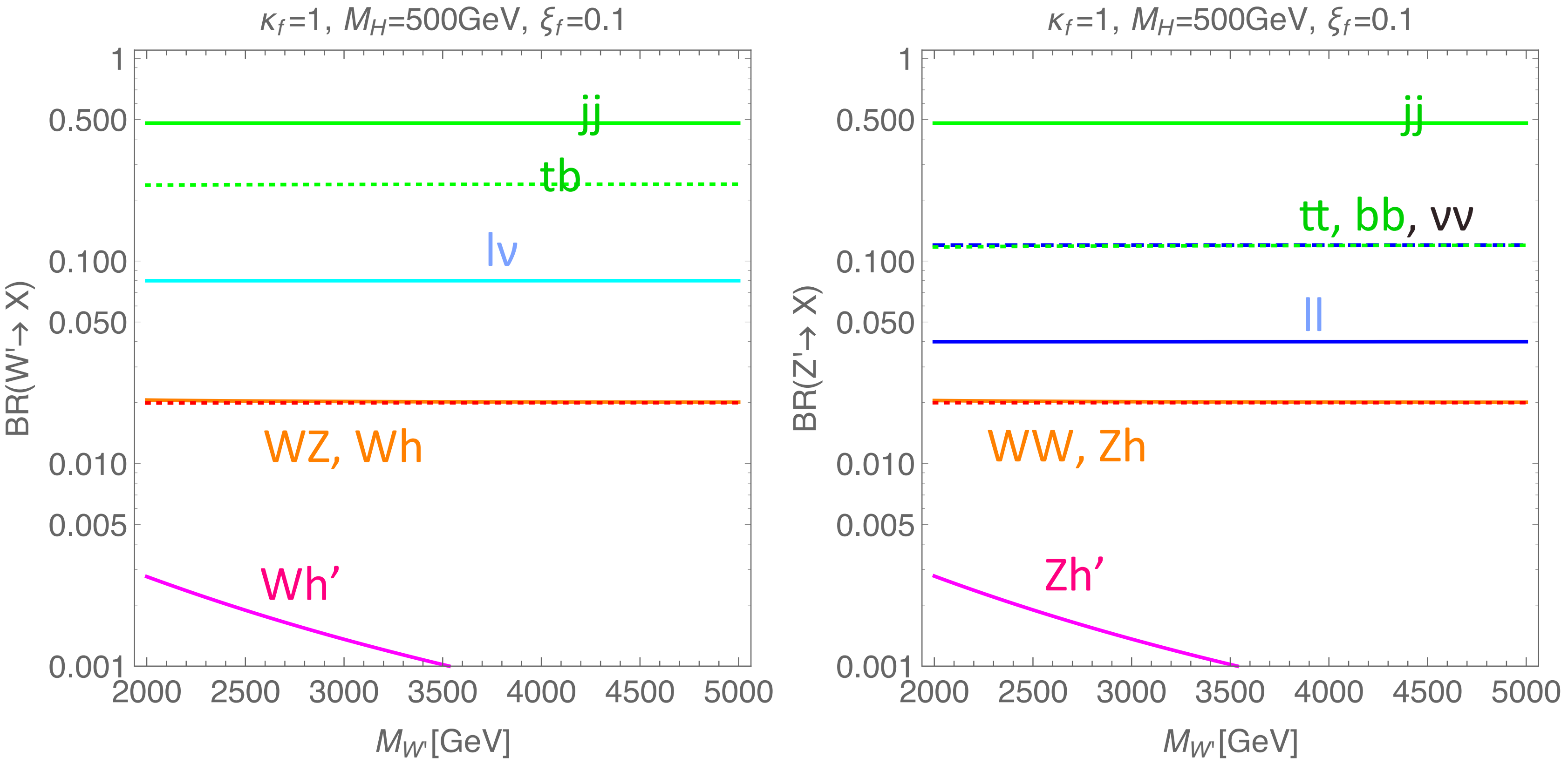
Barger-Keung-Ma (1980)
Pappadopulo-Thamm-Torre-Wulzer (2014)

- New particles
  - One CP-even scalar: h'
  - New vectors: W' , Z'
- V'VH coupling is suppressed

$$\left| \frac{g_{W'Wh'}}{g_{WWh}} \right| \sim \mathcal{O}(0.01)$$

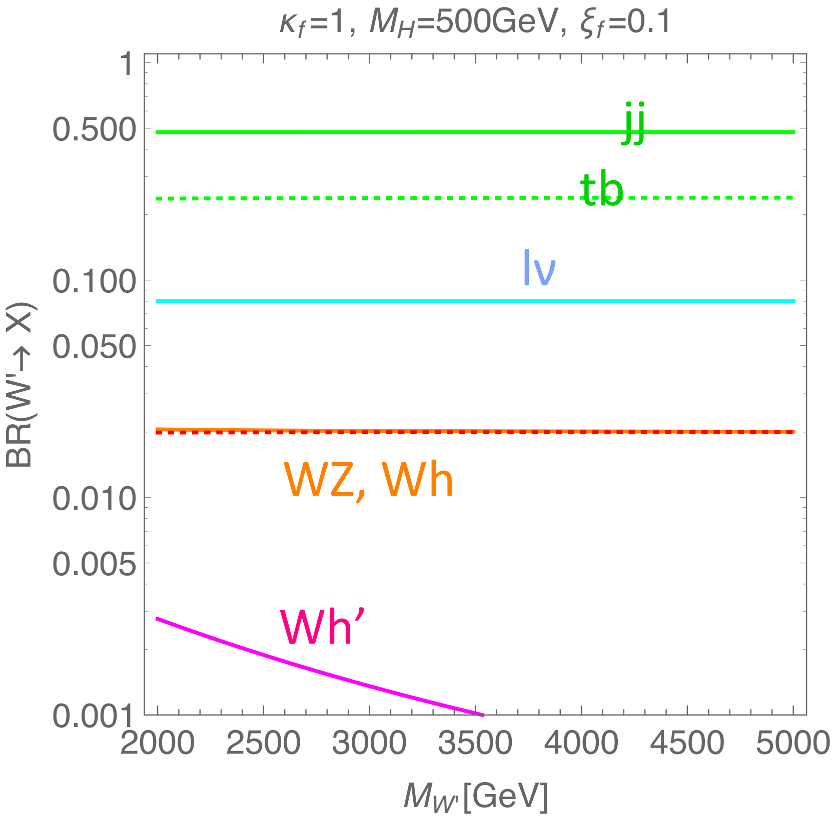
- BR(V'→VH) is suppressed even for $m_H < m_{V'}$

BR of W'/ Z'



κ_f=1, M_H=500GeV, ξ_f=0.1
1
0.500
0.100
0.050
0.010
0.005
0.001
2000
2500
3000
3500
4000
4500
5000
$M_{W'}$[GeV]
BR(W'→ X)
jj
tb
lν
WZ, Wh
Wh'
κ_f=1, M_H=500GeV, ξ_f=0.1
BR(Z'→ X)
jj
tt, bb, νν
ll
WW, Zh
Zh'
$M_{W'}$[GeV]

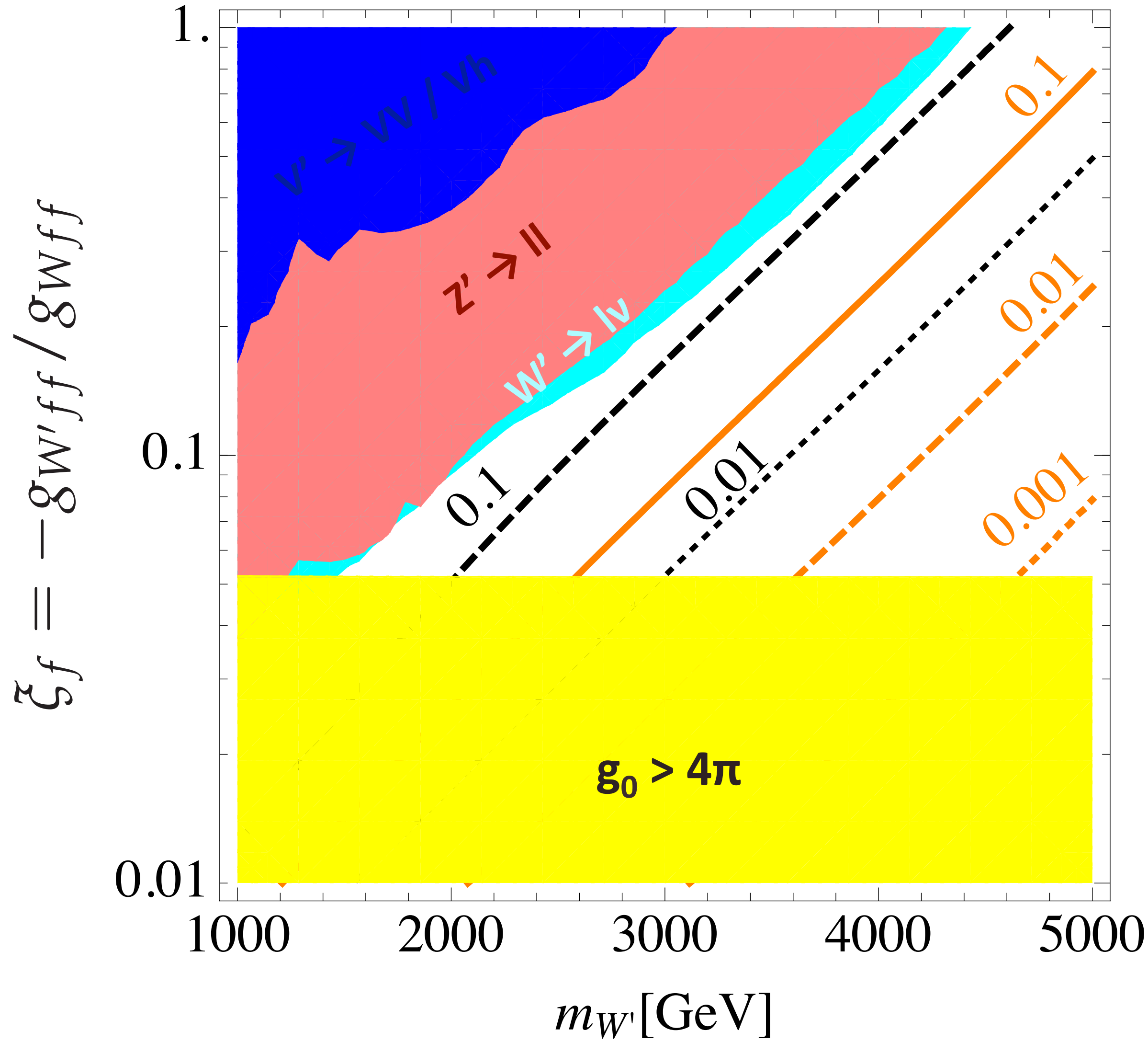
BR of W'/ Z'



This model falls into type-F

- V' mainly decays into fermions

LHC constraint



σ(pp → W' → lν) [fb]

σ(pp → W' → WZ) [fb]

Abe-RN
(arXiv:1607.03706)

Strategy

We focus on

- $SU(2)_0 \times SU(2)_1 \times U(1)_2$ gauge model
- Renormalizable
- without extra fermions

The models contains at least two scales (two VEVs)

- Models with two VEVs
- Models with three VEVs

Model 2

$SU(2)_0 \times SU(2)_1 \times U(1)_2 \rightarrow U(1)_{EM}$

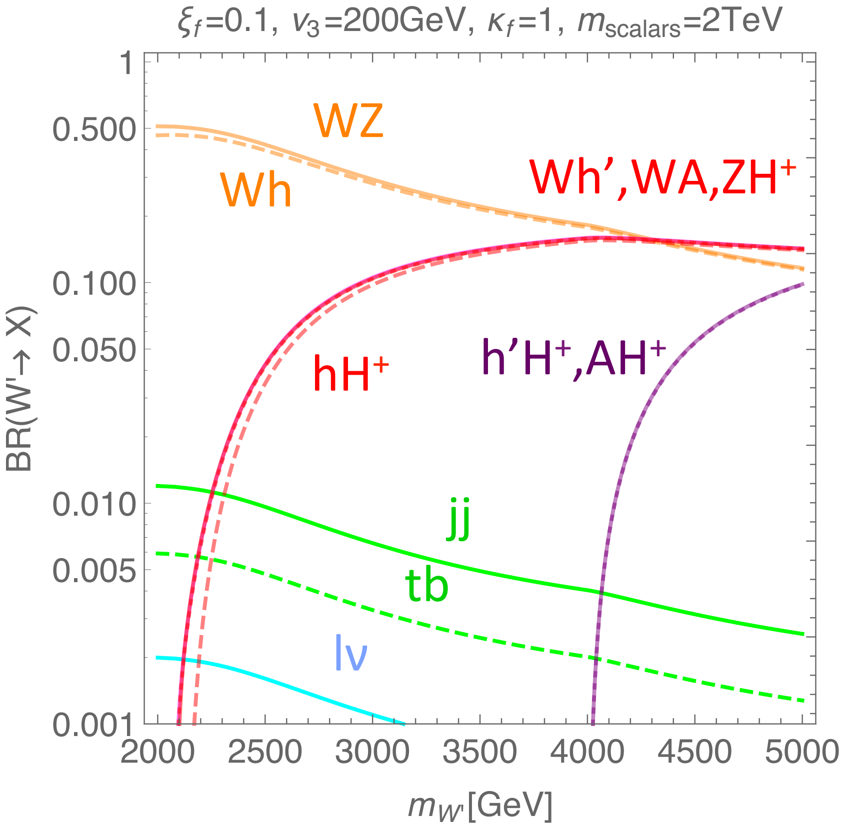
	$SU(2)_0$	$SU(2)_1$	$U(1)_2$
q_L	**2**	**1**	1/6
u_R	**1**	**1**	2/3
d_R	**1**	**1**	- 1/3
l_L	**2**	**1**	- 1/2
e_R	**1**	**1**	- 1
H_1	**2**	**2**	0
H_2	**1**	**2**	1/2
H_3	**2**	**1**	1/2

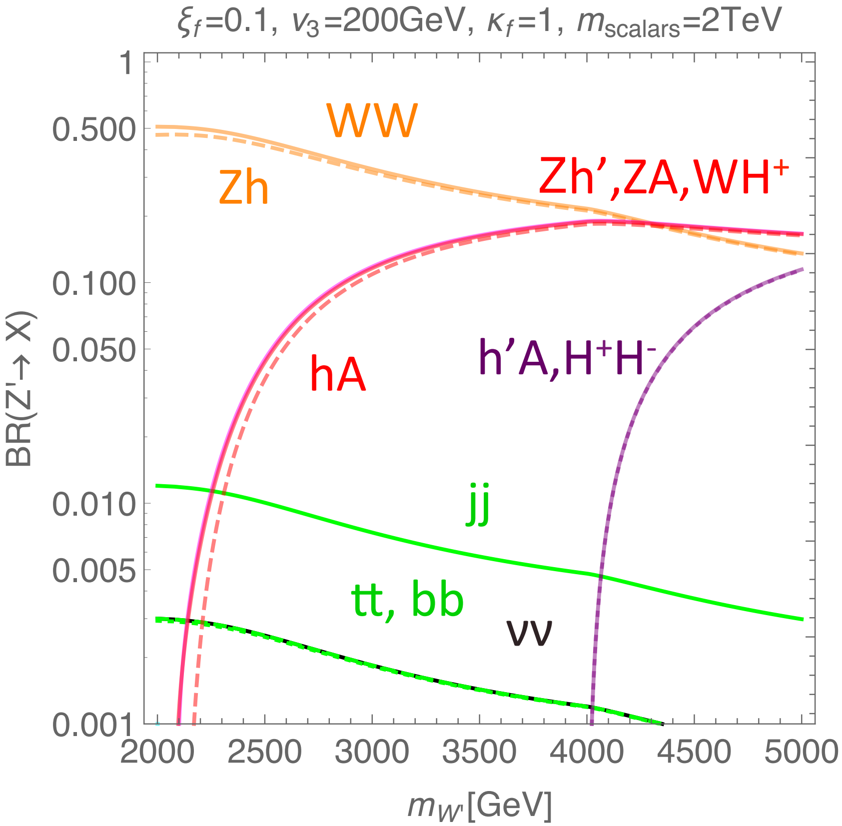
Abe-Kitano (2013)

- New particles:
  - Two CP-even scalars: h', h''
  - One CP-odd scalar: A
  - One charged scalar: $H^{\pm}$
  - New vectors: W', Z'
- V'VX (X : heavy scalars) couplings are not suppressed

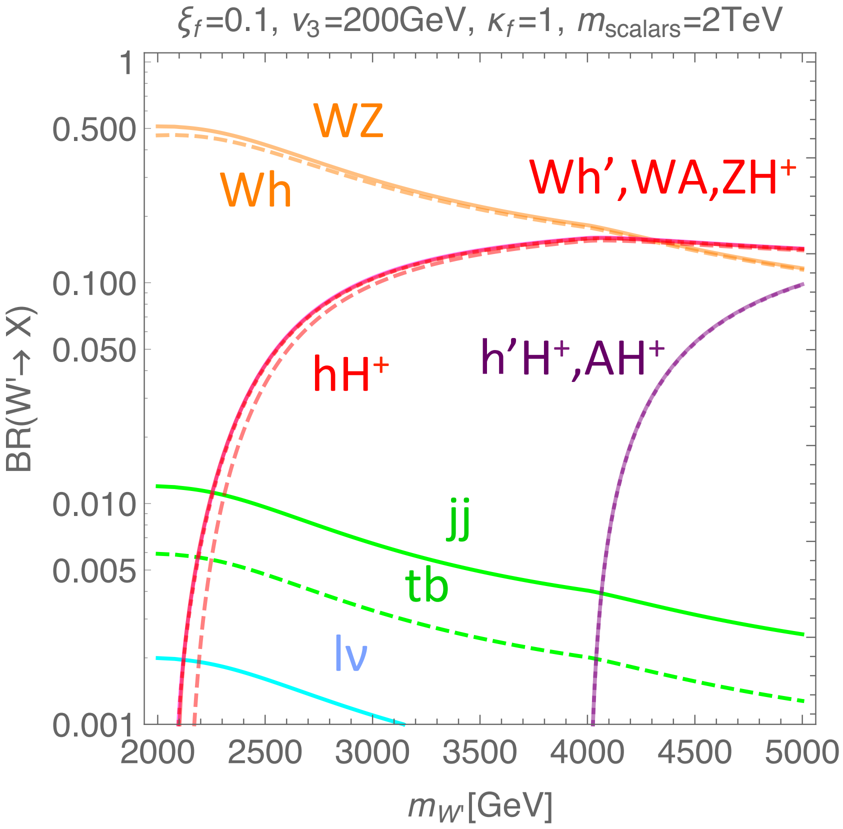
$$\left| \frac{g_{W'Wh'}}{g_{WWh}} \right| \sim 5$$

BR of W'/ Z'


ξ_f=0.1, v_3=200GeV, κ_f=1, $m_{scalars}$=2TeV
BR(W'→ X)
$m_{W'}$[GeV]
WZ
Wh
Wh',WA,ZH+
hH+
h'H+,AH+
jj
tb
lv
1
0.500
0.100
0.050
0.010
0.005
0.001
2000
2500
3000
3500
4000
4500
5000


ξ_f=0.1, v_3=200GeV, κ_f=1, $m_{scalars}$=2TeV
BR(Z'→ X)
$m_{W'}$[GeV]
WW
Zh
Zh',ZA,WH+
hA
h'A,H+H-
jj
tt, bb
νν
1
0.500
0.100
0.050
0.010
0.005
0.001
2000
2500
3000
3500
4000
4500
5000

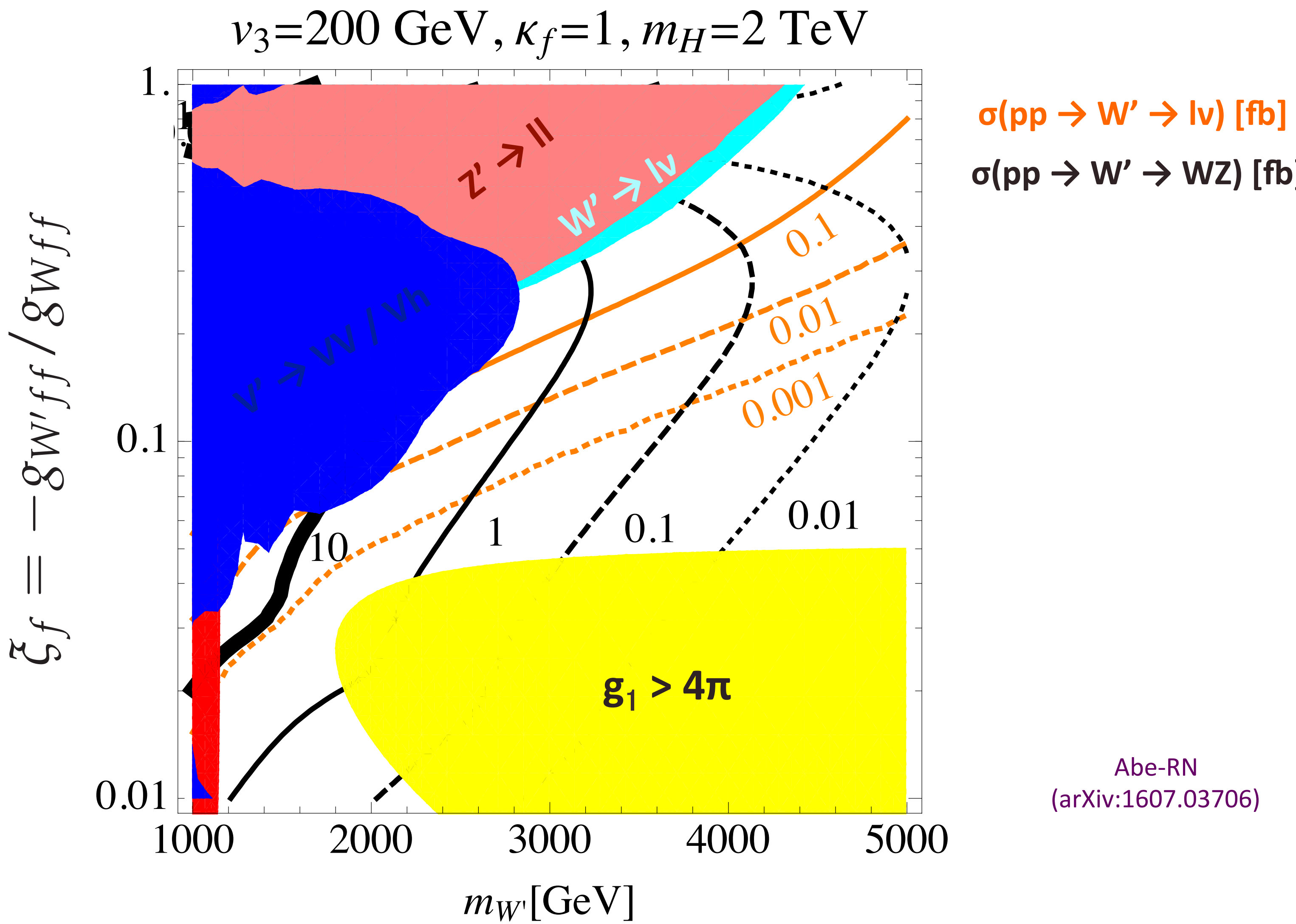
BR of W'/ Z'



This model falls into type-B

- V' mainly decays into bosons

LHC constraint



Abe-RN
(arXiv:1607.03706)

Contents

- Introduction
- Classification of V' models
- Explicit models
- Summary

Summary

- We classify V' models in model-independent manner.

  focusing on their dominant decay mode

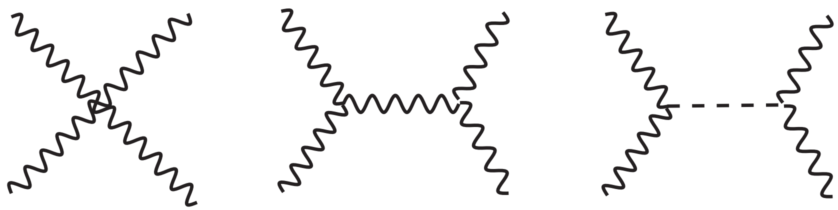
- We find two categories, Type-F (V' mainly decays into fermions) and Type-B (V' mainly decays into bosons).

- Scalars other than custodial singlets are needed for renormalizable type-B models.

BACK UP SLIDES

V' and perturbative unitarity

Let us next focus on vector scattering



$$\simeq C\frac{E^4}{m^4} + D\frac{E^2}{m^2}$$

- Requiring D = 0 in VV → VV, VV', V'V', we find find some relations which are independent from custodial singlet Higgs coupling.

$$\frac{(m_V^2 - m_{V'}^2)^2}{m_V^2} g_{V'VV}^2 + \frac{(m_V^2 - m_{V'}^2)^2}{m_{V'}^2} g_{V'V'V}^2$$
$$-m_V^2 (g_{V'VV}^2 - g_{VVV} g_{V'V'V}) - m_{V'}^2 (g_{V'V'V}^2 - g_{V'VV} g_{V'V'V'}) = -\sum_{\Delta} g_{VV'\Delta}^2$$

Classification of V'

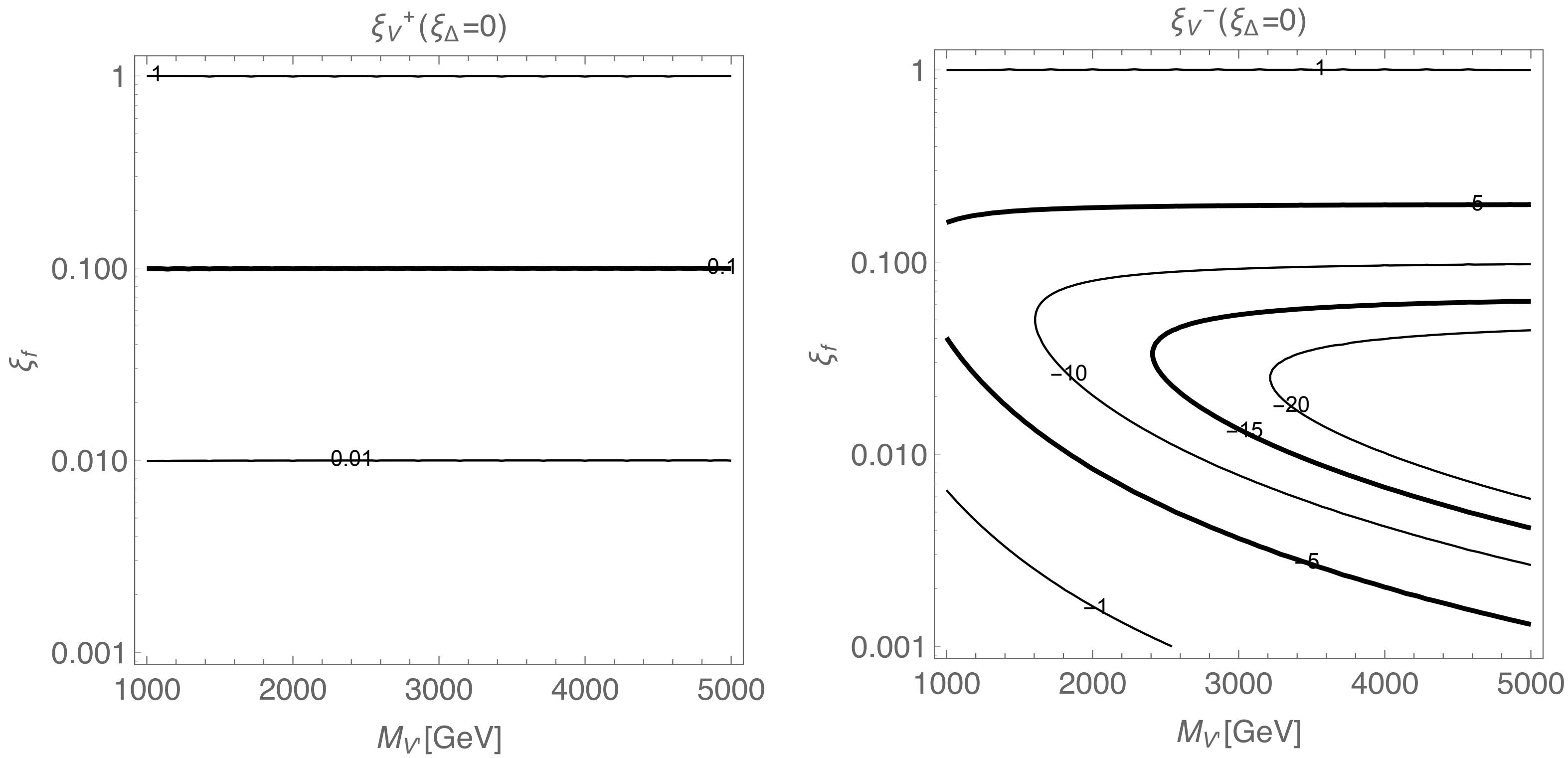
We find two solutions.

$$\xi_V^{\pm} = -\xi_f \frac{\left(2(1-r^2)(1-2r^2)(1-\xi_f^2) - \frac{r^2\xi_f^2(1+\xi_f^2)^2\xi_\Delta^2}{r^2+\xi_f^2}\right) \pm \left(-2(1-r^2)(1+\xi_f^2)\sqrt{1-\xi_\Delta^2}\right)}{4(1-r^2)(\xi_f^2 + r^2(1-r^2)(1-\xi_f^2)^2) + \frac{r^4\xi_f^4(1+\xi_f^2)^2\xi_\Delta^2}{r^2+\xi_f^2}}$$

where

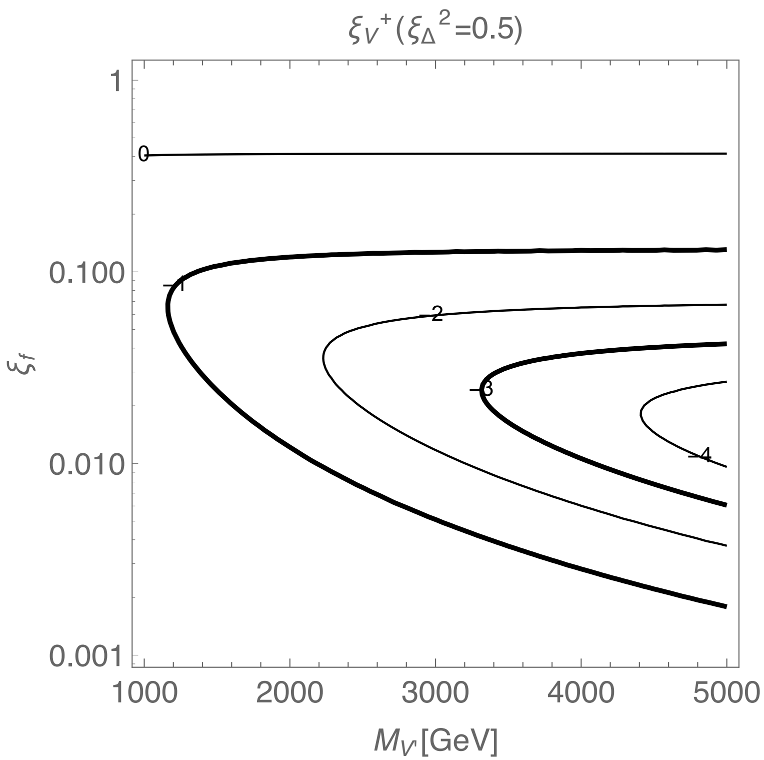
$$r = \frac{m_V^2}{m_{V'}^2} \quad \text{and} \quad \sum_\Delta g_{VV'\Delta}^2 = \frac{1}{4} g_{Vff}^2 \frac{m_V^2 m_{V'}^2}{m_V^2 + m_{V'}^2 \xi_f^2} (1+\xi_f^2)^2 \xi_\Delta^2$$

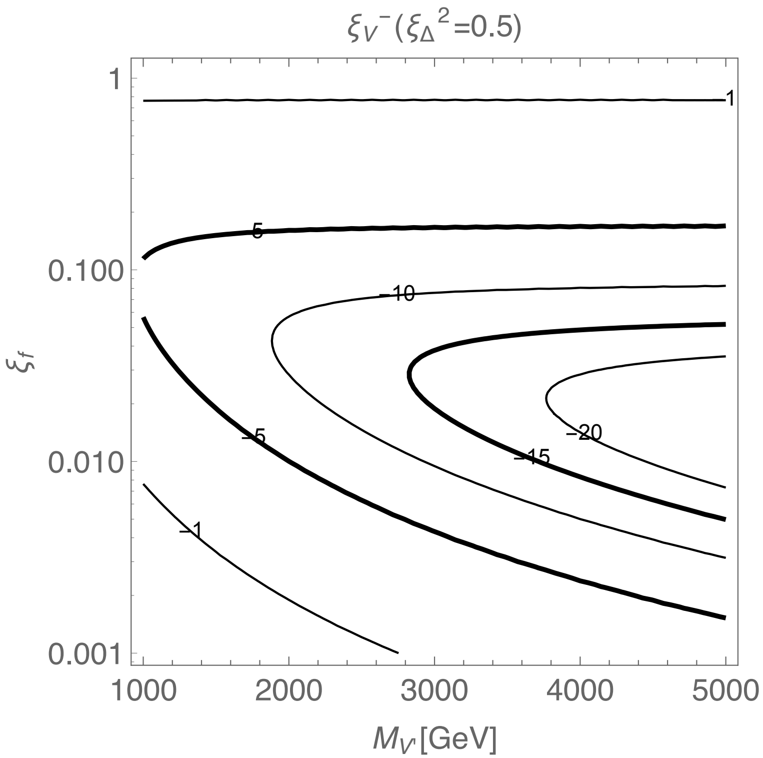
Classification of V'



ξ_Δ : V'VΔ coupling ($|\xi_\Delta| \leqq 1$)

Classification of V’





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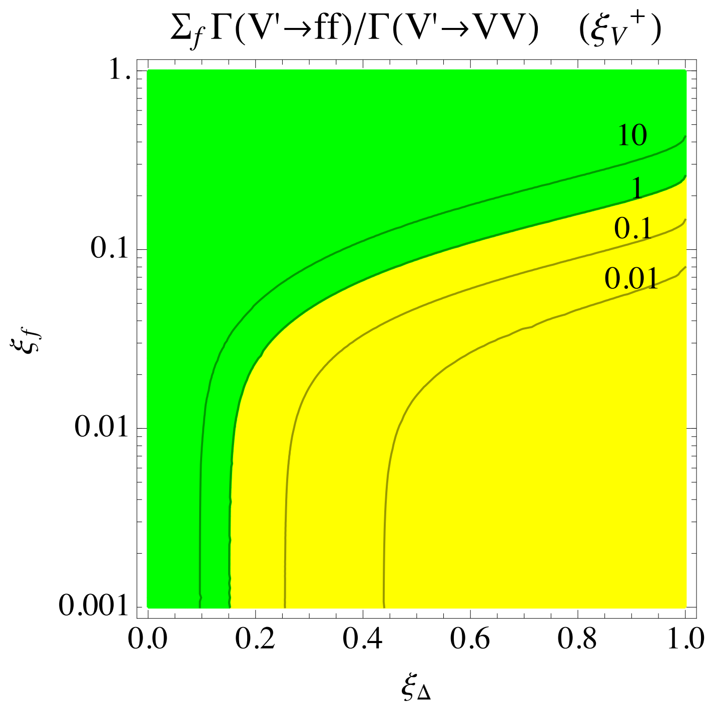
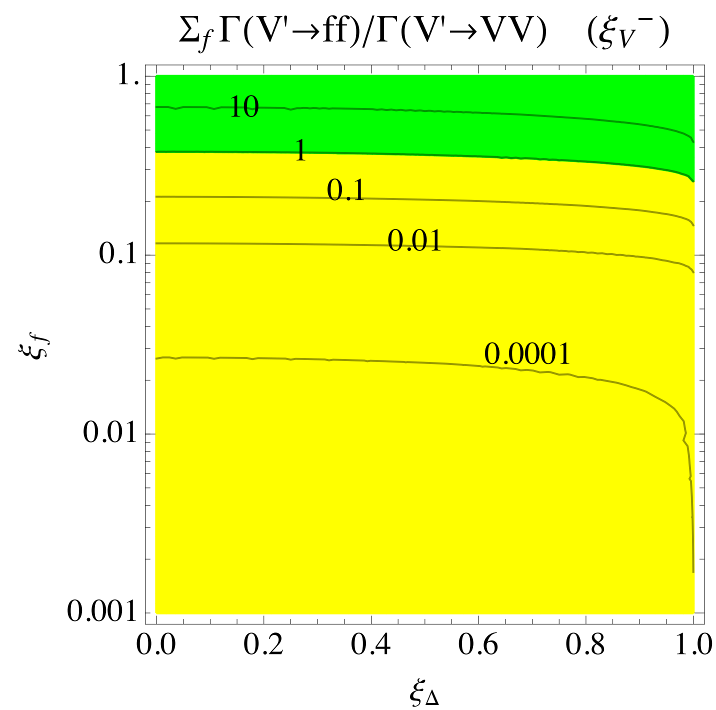
Classification of V’

<u>Remark</u> If triplets (Δ) exist, ξ_V depends on V’VΔ coupling





- If ξ_Δ is non-zero, our classification still valid.

ξ_Δ : V’VΔ coupling ($|\xi_\Delta| \leqq 1$)

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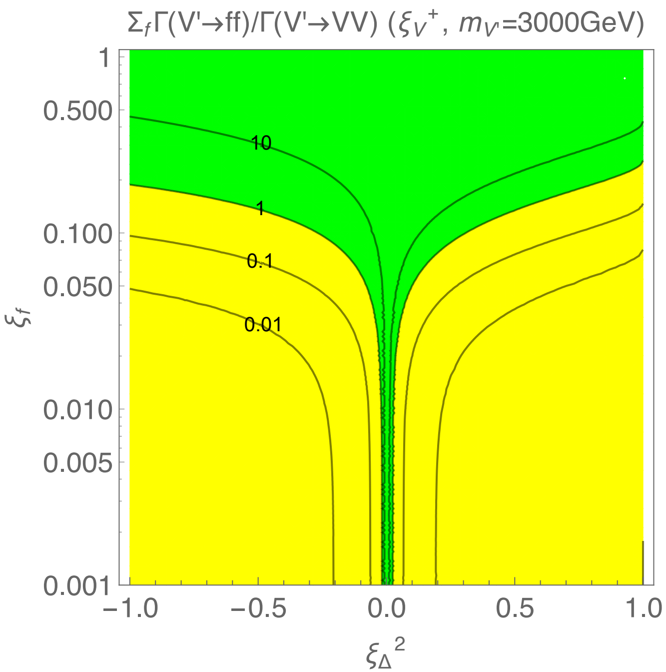

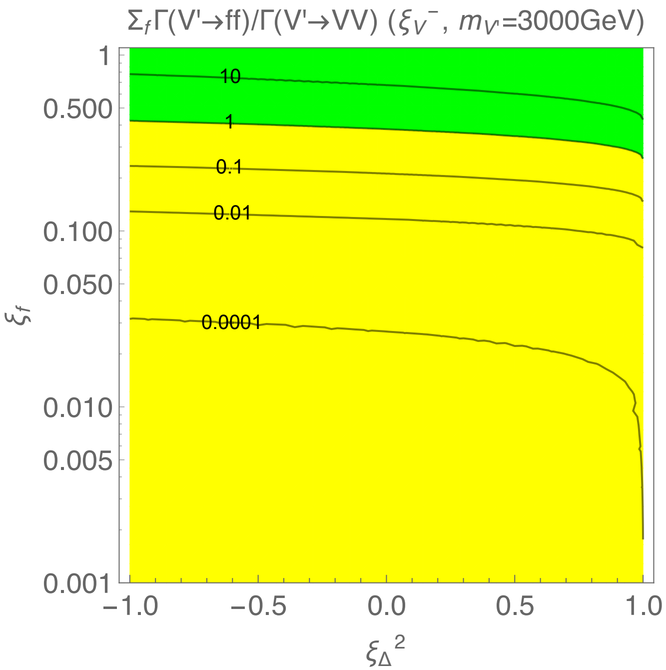

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