

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 \rightarrow W'/Z' boson
 - * New dynamics $\rightarrow \rho'$ resonance
- Their mass scale is expected to be around TeV scale.

Extra spin-1 particles (V')

There are many models

PHYSICAL REVIEW D VOLUME 22, NUMBER 3 1 AUGUST 1980
Gauge model with light W and Z bosons

V. Berger and W. Y. Keung
Physics Department, University of Wisconsin at Madison, Madison, Wisconsin 53706
Ernest Ma
Physics Department, University of Hawaii at Manoa, Honolulu, Hawaii 96822
 (Received 7 March 1985)

show how the standard electroweak model can be naturally generalized to SU(2) \times U(1). It has the number of gauge bosons $N = 5$. All known fermions are included. The theory is renormalizable. Spontaneous symmetry breaking is achieved with a scalar quark which looks like a standard doublet. The interaction Hamiltonian at low energy reproduces the low-energy limit of the standard model. The lightest particle in the theory is explored. One can also consider the mass spectrum of the standard model. These light particles are produced by a resonance at 50-500 MeV. Results for light Z and W bosons are $e^+ e^-$ collisions and hadron-hadron collisions as low as 22 GeV is compatible with existing measurements; the most stringent present cross section.

mixes with the W and Z bosons in the strong sector, the Standard Model is modified. We study the constraints from the LHC experiments, and the

the LHC experiments, and
DOI: [10.1103/PhysRevD.98.034016](https://doi.org/10.1103/PhysRevD.98.034016)

Ranindra Mehantra Pati (1074)

Raihanulha-Mohapatra-Pali (1974)

Mohantra-Pati (1974)

Monapatri-Fati (1974)

Barger-Keung-Ma (1980)

Burger, Reuter, Ma (1988)

Mohapatra-Senjanovic (1980)

Banda Kusa Yamawaki (1987)

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)

Ryo Nagai (Nagoya U.)

Contents

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

Our strategy

We focus on the ratio:

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

Our strategy

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

Two important parameters:

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

$V'ff$ coupling

$V'VV$ coupling

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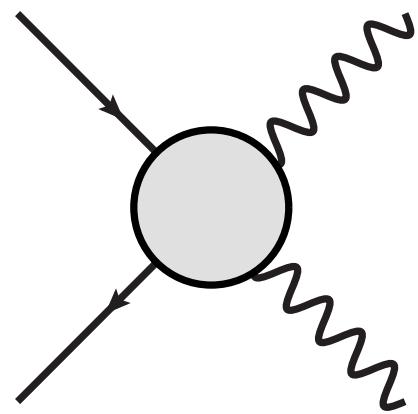
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Let us impose perturbative unitarity and custodial symmetry
in the V' models.

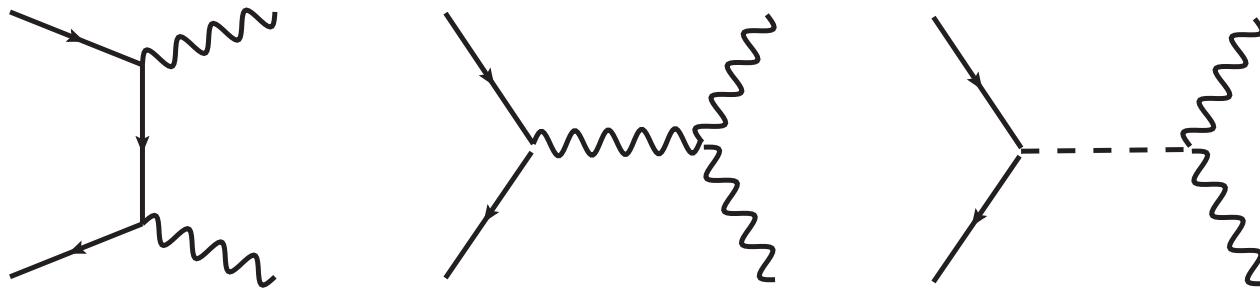
V' and perturbative unitarity

Let us focus on vector / fermion scattering



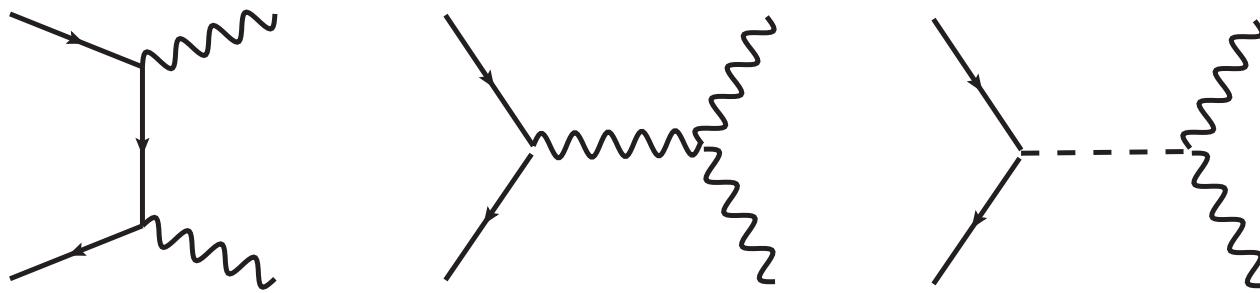
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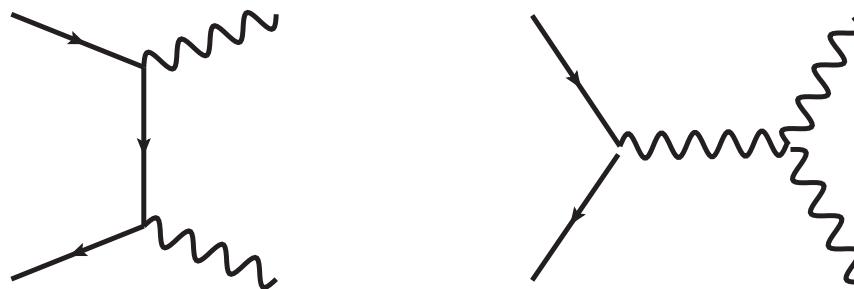


$$\mathcal{M} \simeq A \frac{E^2}{m^2} + B \frac{E}{m}$$

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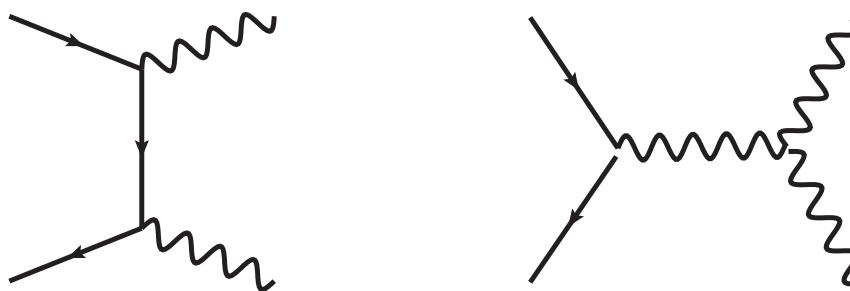
Requiring $A = 0$ in $ff \rightarrow VV$, we obtain

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

V' and perturbative unitarity

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



Requiring $A = 0$ in $ff \rightarrow VV, VV', V'V'$, we obtain

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

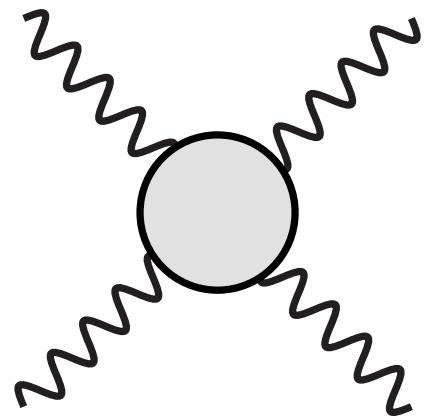
$\nearrow \xi_V$ $\swarrow g_{Vff}$
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\nearrow \nwarrow
V'VV coupling V'ff coupling

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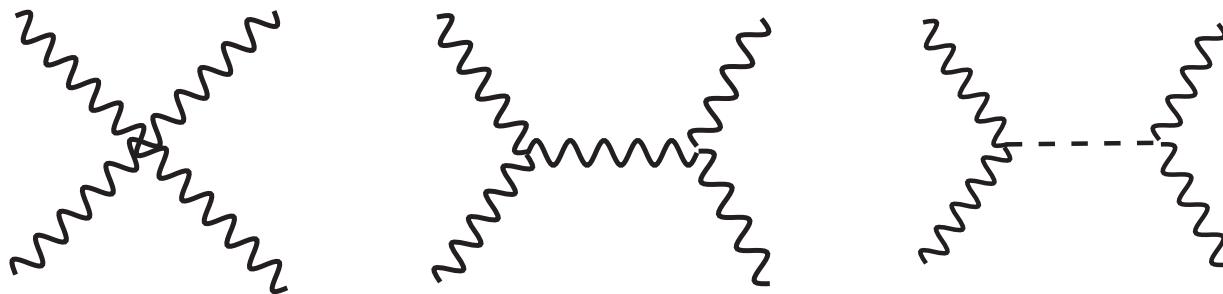
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V' and perturbative unitarity

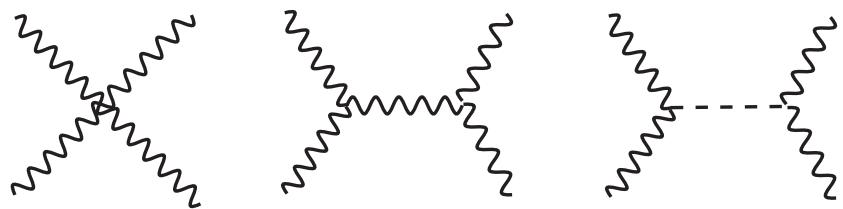
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$$\mathcal{M} \simeq C \frac{E^4}{m^4} + D \frac{E^2}{m^2}$$

V' and perturbative unitarity

Let us next focus on vector scattering



The diagram shows three Feynman diagrams for vector scattering. The first two are vertices where a wavy line (vector boson) enters from the left and another wavy line exits to the right. The third diagram shows a wavy line entering from the left and a dashed line exiting to the right.

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

- “D” in $VV \rightarrow VV, VV', V'V'$ depend on Higgs couplings.
- From $D = 0$ in $VV \rightarrow V'V'$, we 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.

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

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

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

$$g_{V'ff} = -\xi_f g_{Vff}$$

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

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$$R \simeq 4N_c^2$$

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V' mainly decays into
Fermion
(type-F)

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V' mainly decays into
Boson
(type-B)

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

V' mainly decays into
Boson
(type-B)

Summary so far

What we found:

- V' models are classified into 2 categories

This is only based on the unitarity argument,
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Next to do:

- To find bench-mark models in each categories

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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

- New particles

- One CP-even scalar: h'
- New vectors: W', Z'

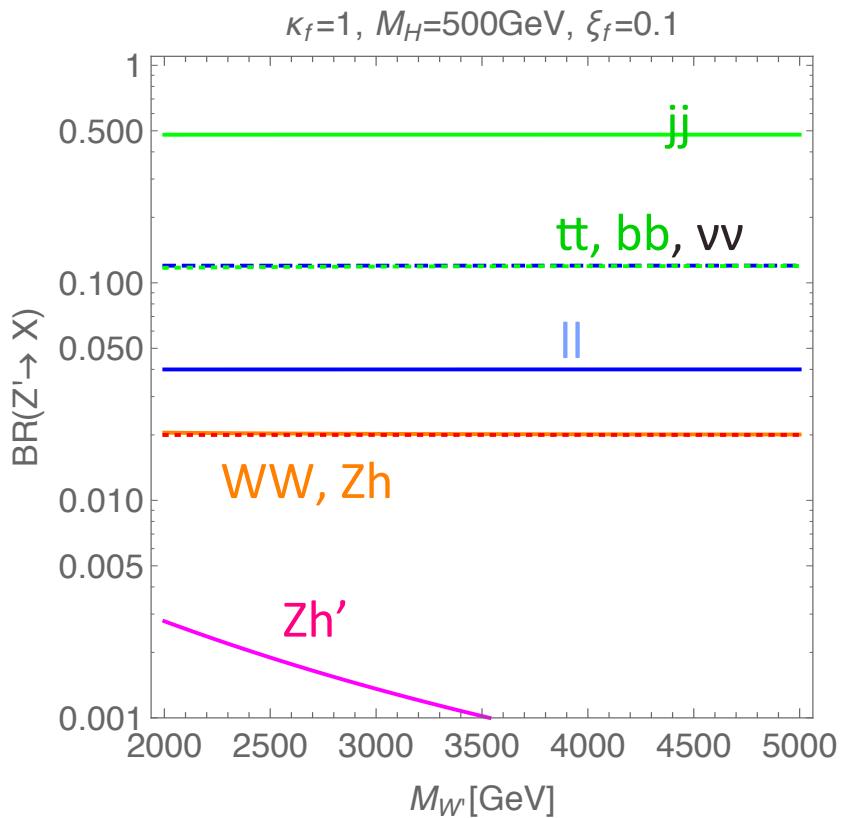
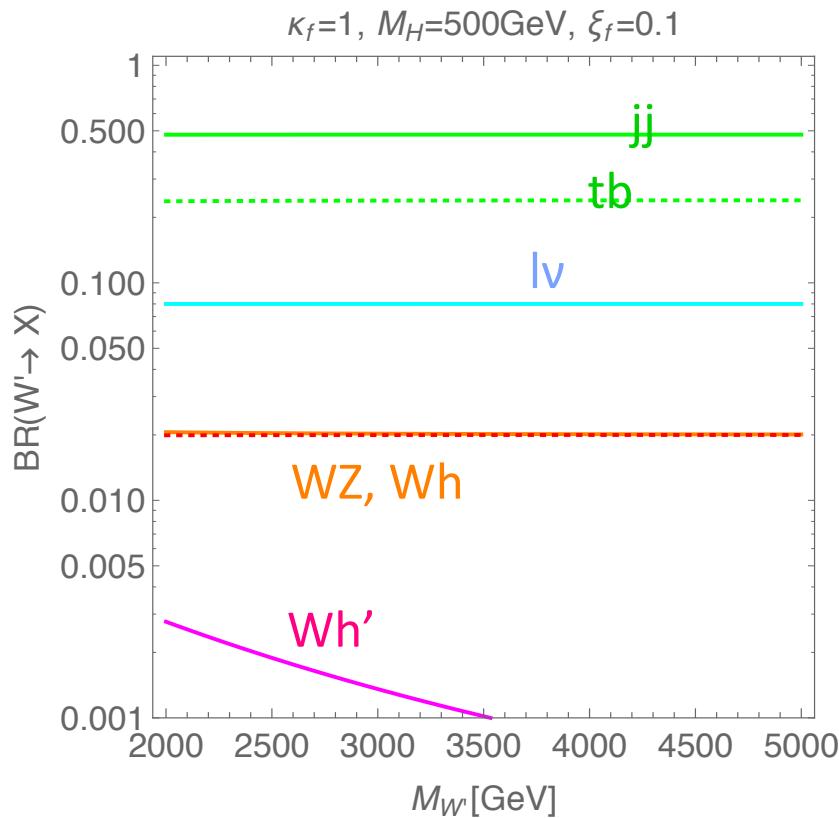
- $V'VH$ coupling is suppressed

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

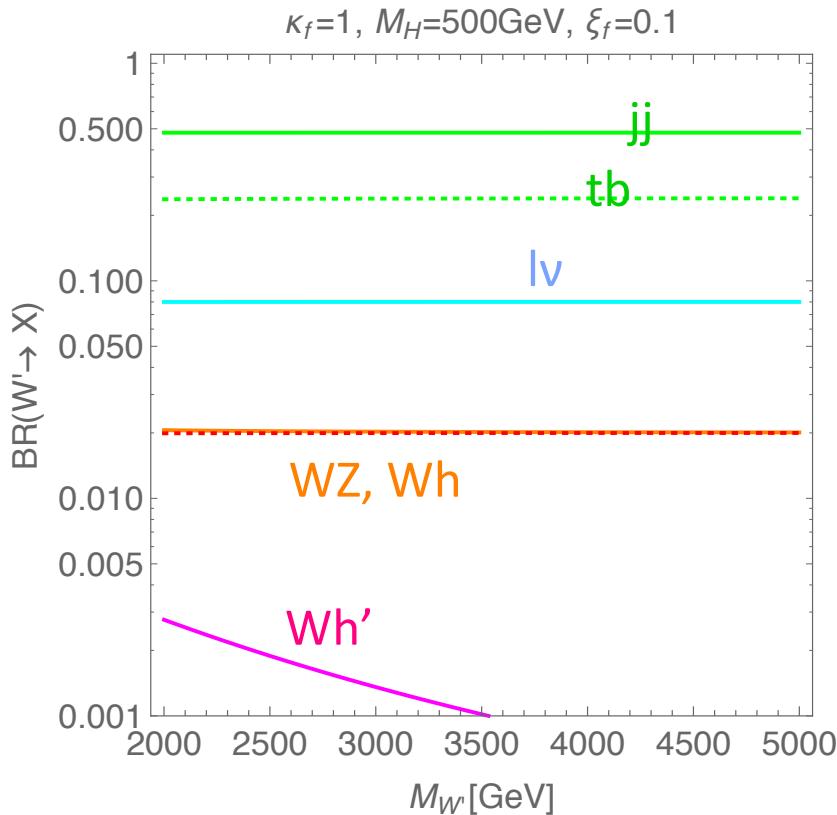
- $BR(V' \rightarrow VH)$ is suppressed even for $m_H < m_{V'}$

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

BR of W'/Z'



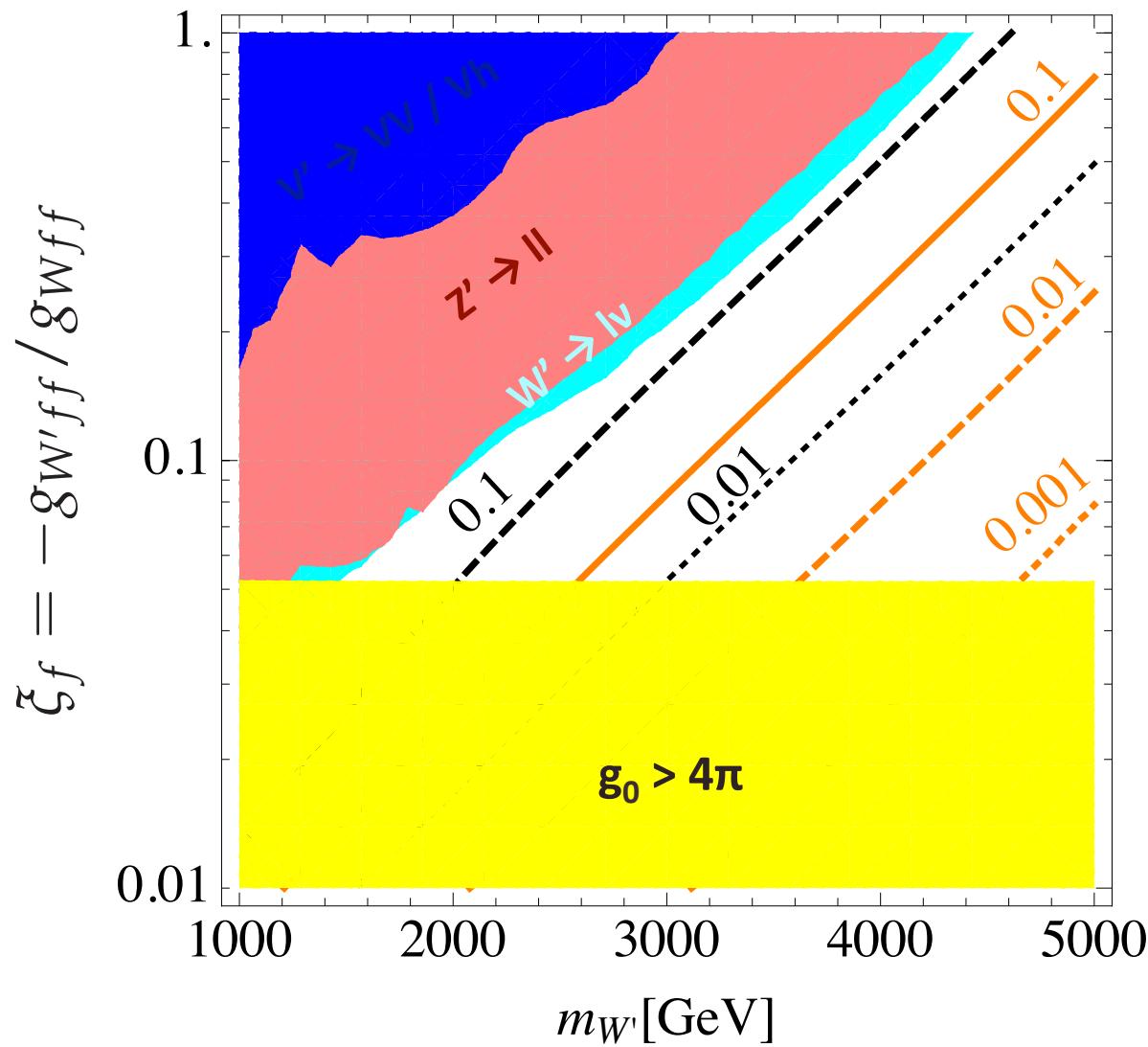
BR of W'/Z'



This model falls into
type-F

- V' mainly decays into fermions

LHC constraint



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)

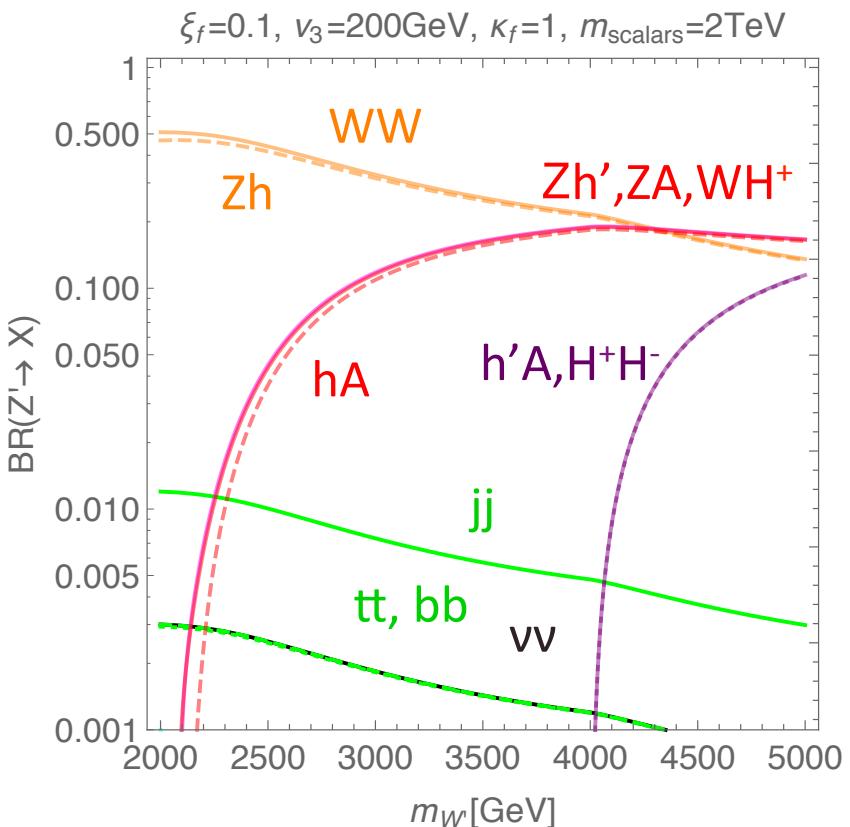
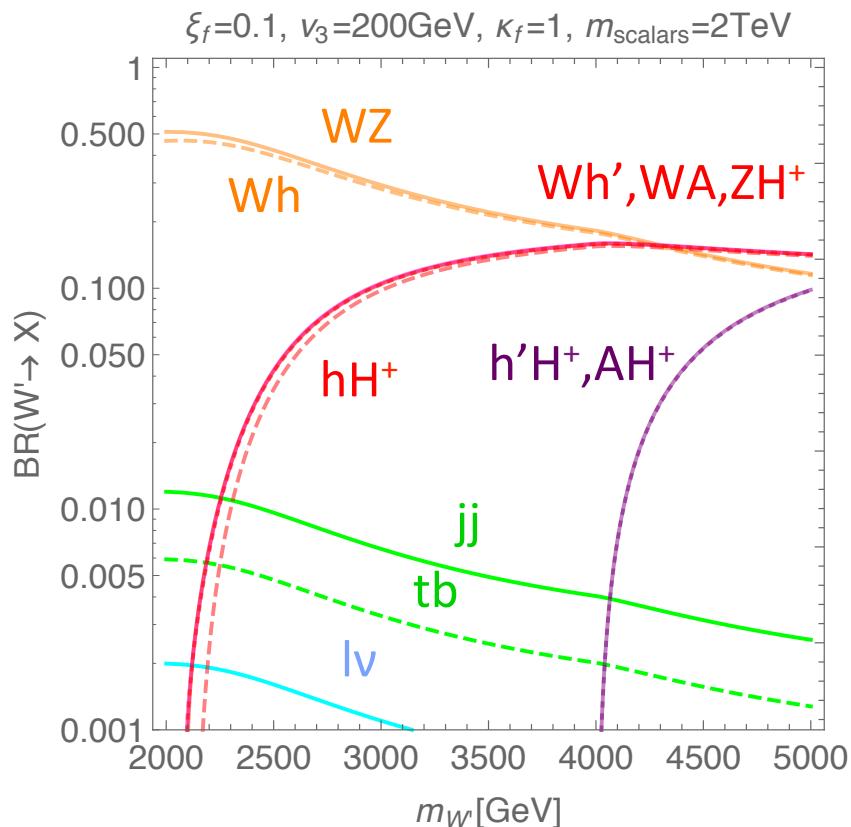
- New particles:

- Two CP-even scalars: h', h''
- One CP-odd scalar: A
- One charged scalar: H^\pm
- New vectors: W', Z'

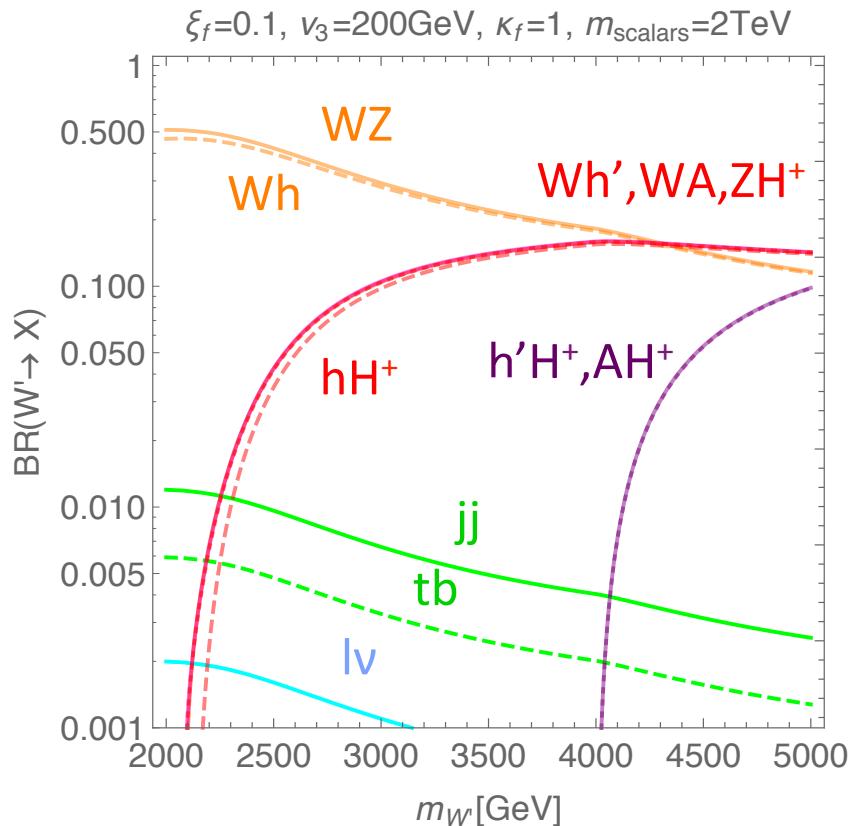
- $V'VX$ (X : heavy scalars) couplings are not suppressed

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

BR of W'/Z'



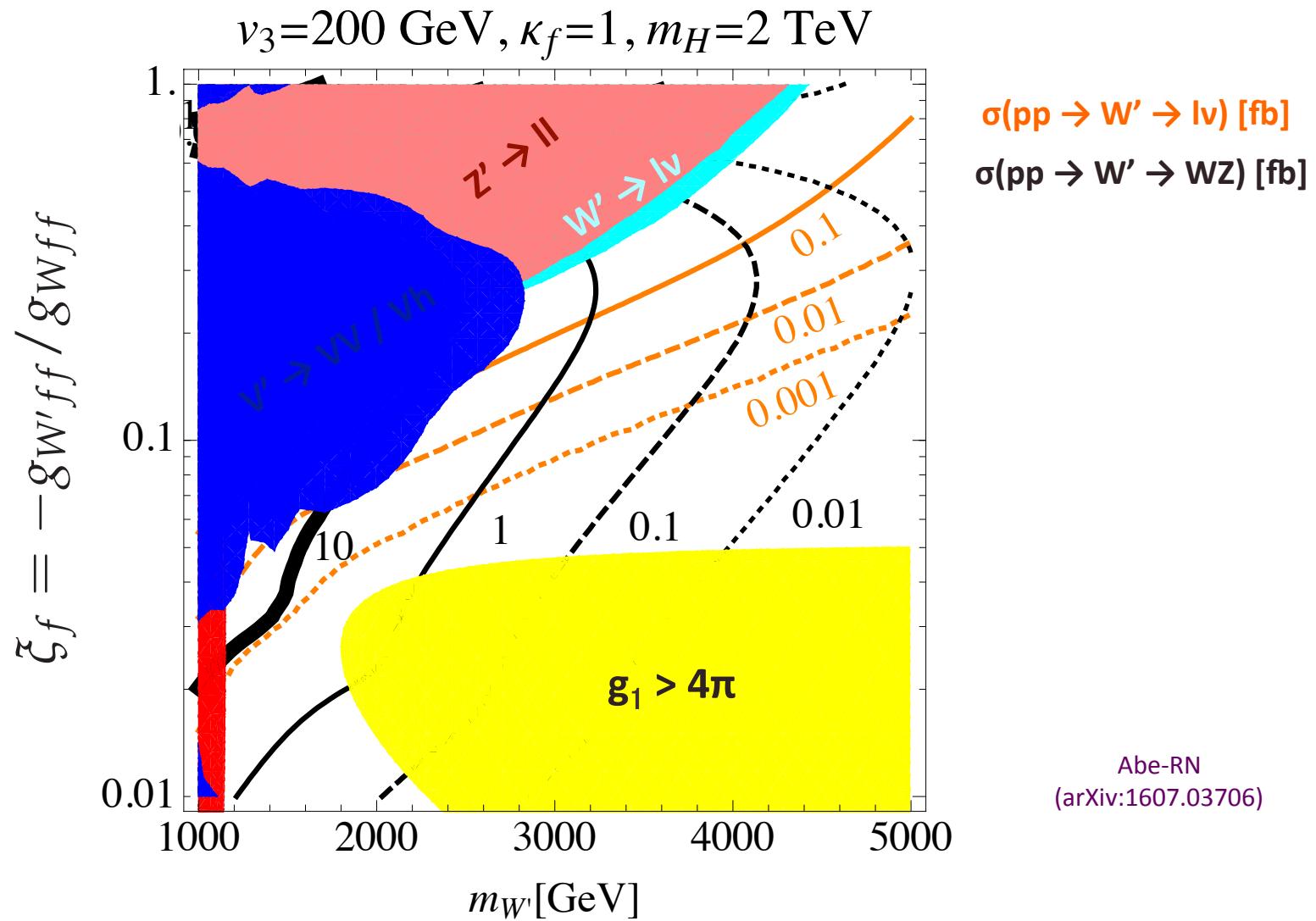
BR of W'/Z'



This model falls into
type-B

- V' mainly decays into bosons

LHC constraint



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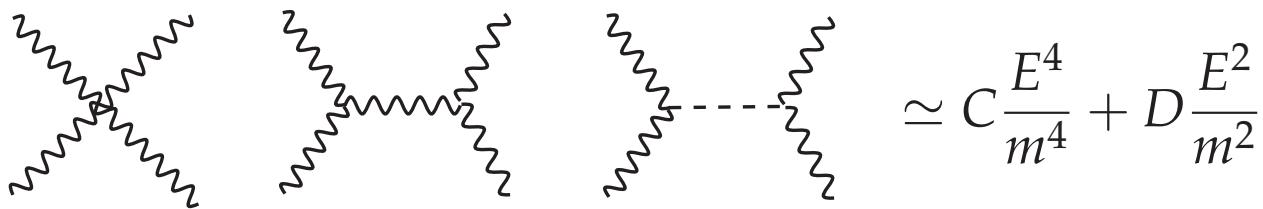
Summary

- 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



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

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

Classification of V'

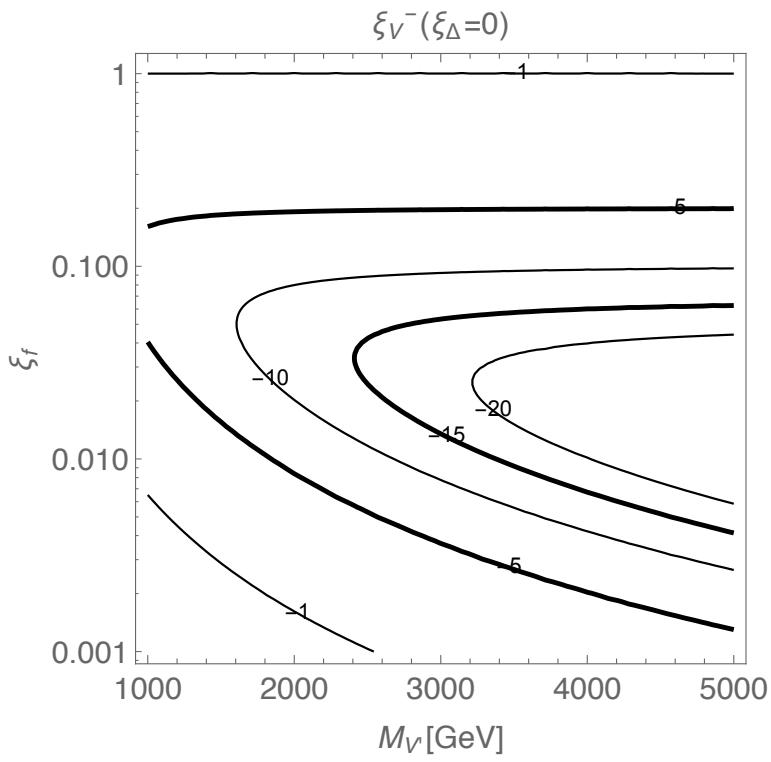
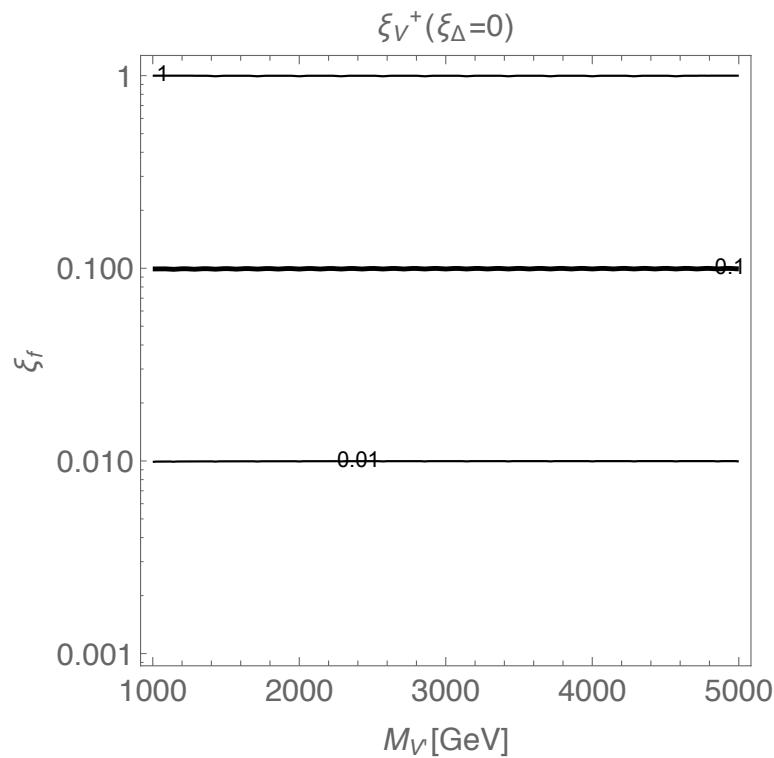
We find two solutions.

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

where

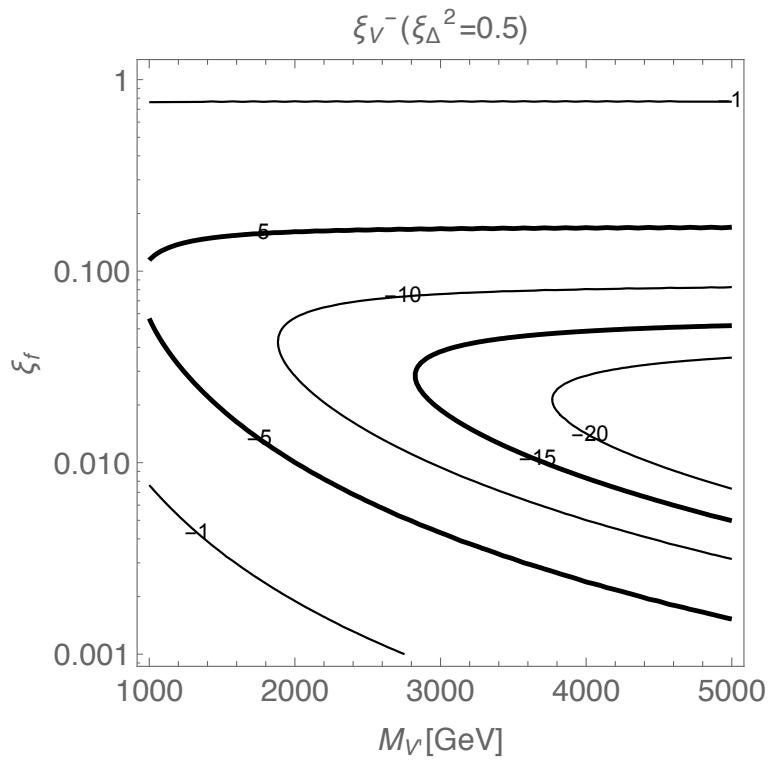
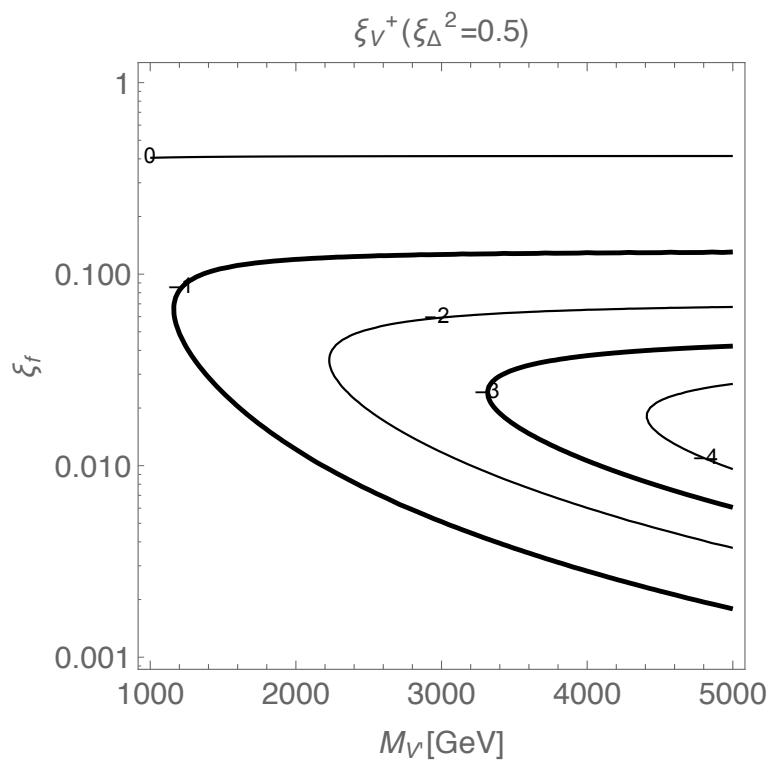
$$r = \frac{m_V^2}{m_{V'}^2} \quad \text{and} \quad \sum_\Delta g_{VV'\Delta}^2 = \frac{1}{4} g_{Vff}^2 \frac{m_V^2 m_{V'}^2}{m_V^2 + m_{V'}^2 \xi_f^2} (1 + \xi_f^2)^2 \xi_\Delta^2$$

Classification of V'



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

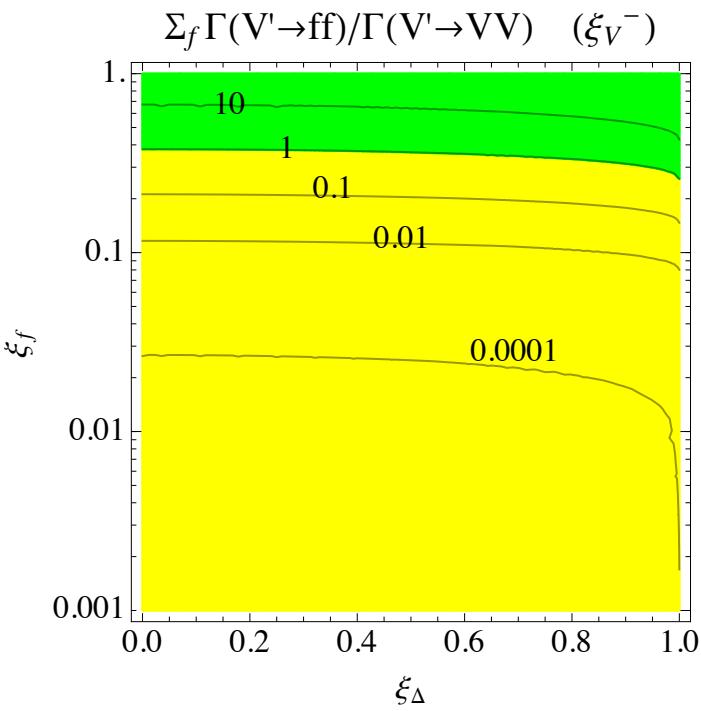
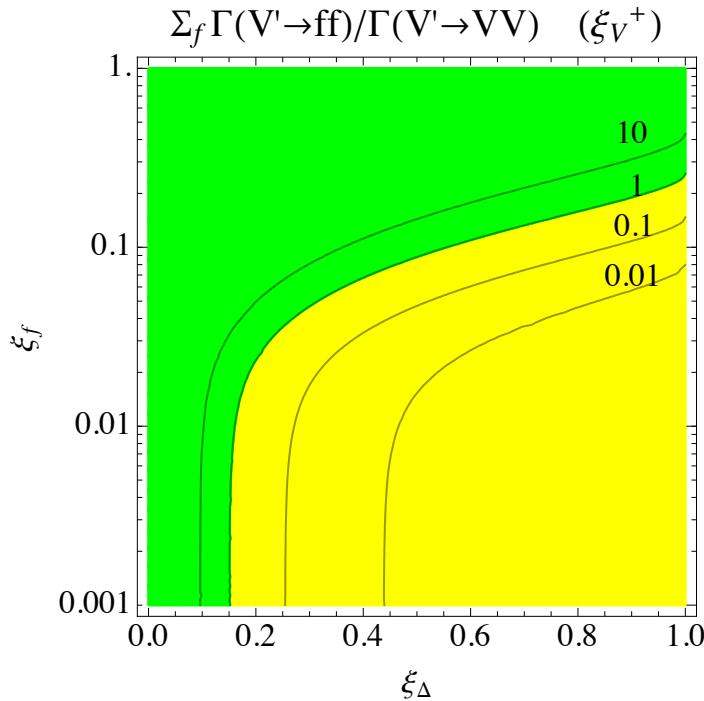
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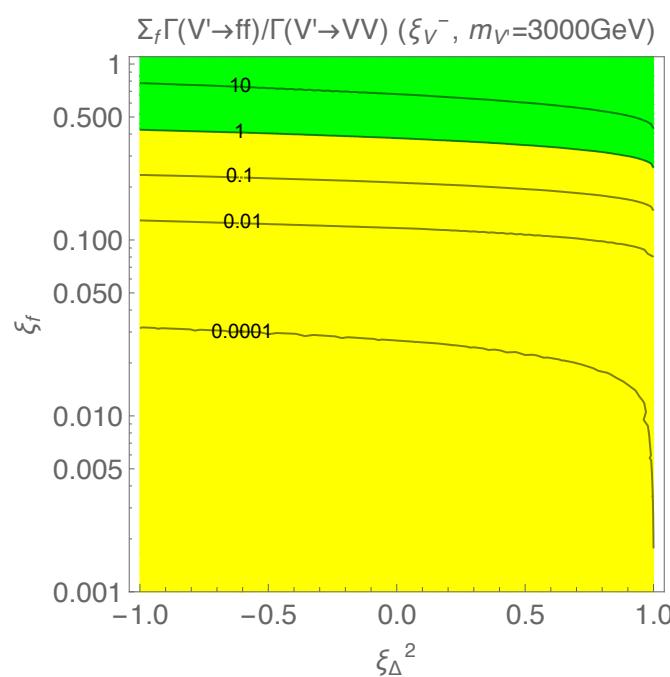
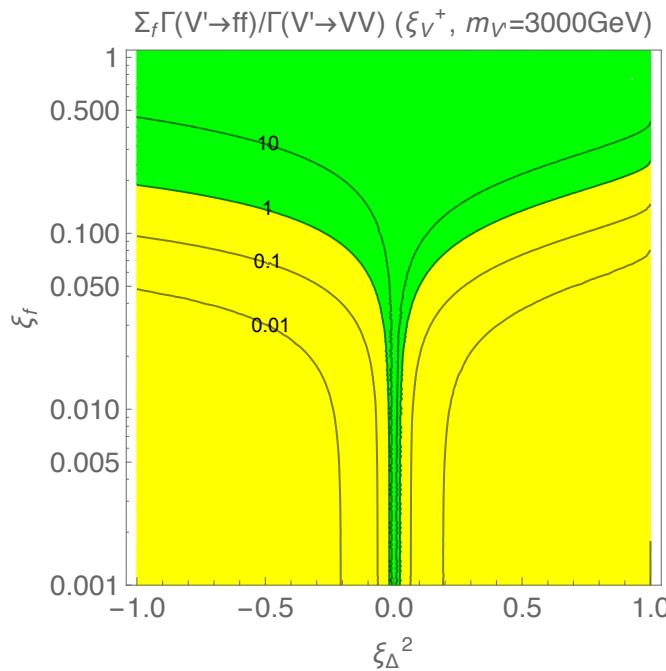
Remark If triplets (Δ) exist, ξ_V depends on $V'V\Delta$ coupling



- If ξ_Δ is non-zero, our classification still valid. $\xi_\Delta : V'V\Delta$ coupling ($|\xi_\Delta| \leq 1$)

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