Unitarity sum rules, three site moose model and the ATLAS 2TeV diboson anomalies

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based on arXiv : 1507.01185

with Tomohiro Abe (KEK) , Shohei Okawa (Nagoya U.)
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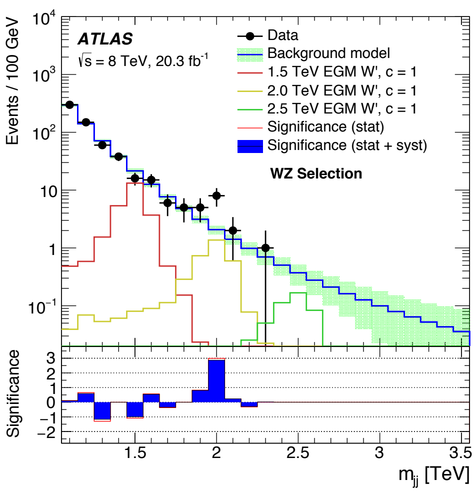
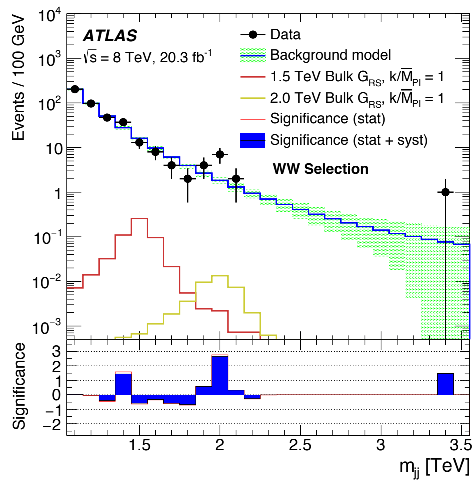
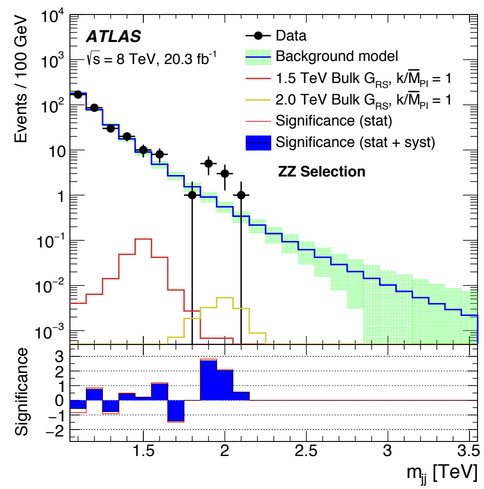
Kavli-IPMU-Durham-KIAS workshop:
New particle searches confronting the first LHC run-2 data 7-11 Sep 2015

The ATLAS 2TeV diboson anomalies

arXiv:1506.00962







The reported local significance :

WZ → JJ : 3.4σ WW → JJ : 2.6σ ZZ → JJ : 2.9σ

The ATLAS 2TeV diboson anomalies

In this talk, we investigate spin-1 (W') interpretations for the ATLAS 2TeV diboson anomalies.

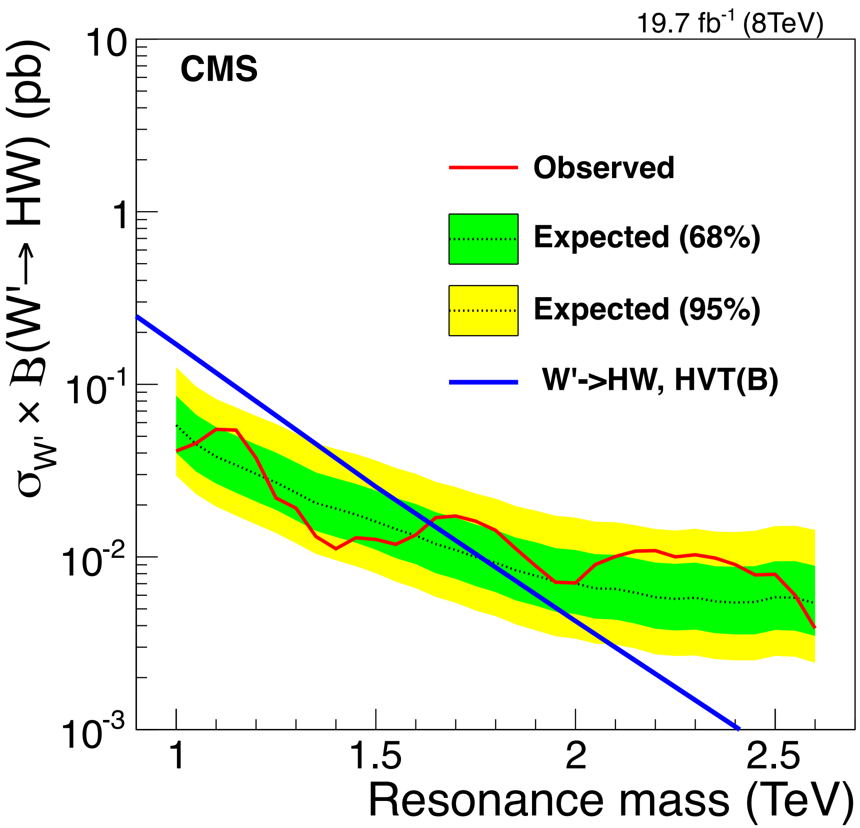
If we explain the ATLAS VV → JJ anomaly in W' model, we need

$$\sigma(pp \to W'; \sqrt{s} = 8\mathrm{TeV}) B_{W'}(WZ) \simeq 14\mathrm{fb}$$

with $M_{W'}$ = 2TeV and $\Gamma_{W'}$ < 100GeV.

Challenge in W' models

The CMS results for W' → Wh → JJ arXiv:1506.01443



Upper limit @ $M_{W'}$ = 2TeV :

$$\sigma(pp \to W')B_{W'}(Wh) < 7\text{fb}$$

$$\sqrt{s} = 8\text{TeV}$$

Challenge in W' models

- The ATLAS anomaly : $\sigma(pp \to W')B_{W'}(WZ) \sim 14\text{fb}$
- The CMS constraint : $\sigma(pp \to W')B_{W'}(Wh) < 7\text{fb}$

- Typical W' model with $M_{W'}$ = 2TeV predicts

$$\Gamma_{W'}(WZ) = \Gamma_{W'}(Wh)$$

Challenge in W' models

Can we relax the relation in the perturbative W' model ?

$$\Gamma_{W'}(WZ) = \Gamma_{W'}(Wh)$$

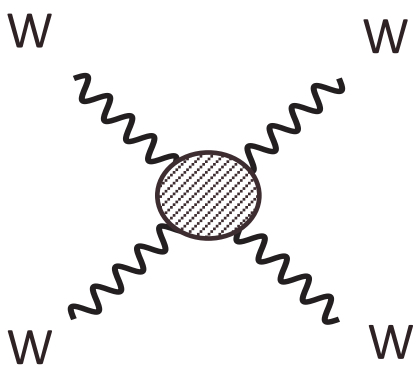
We reconsider the condition from the viewpoint of the perturbative unitarity of W / W' scattering amplitudes.

Perturbative unitarity requirements and the ATLAS diboson anomalies

Ryo Nagai (Nagoya U.)

$W_L W_L$ scattering in W' model

The longitudinal polarization vector grows as energy.

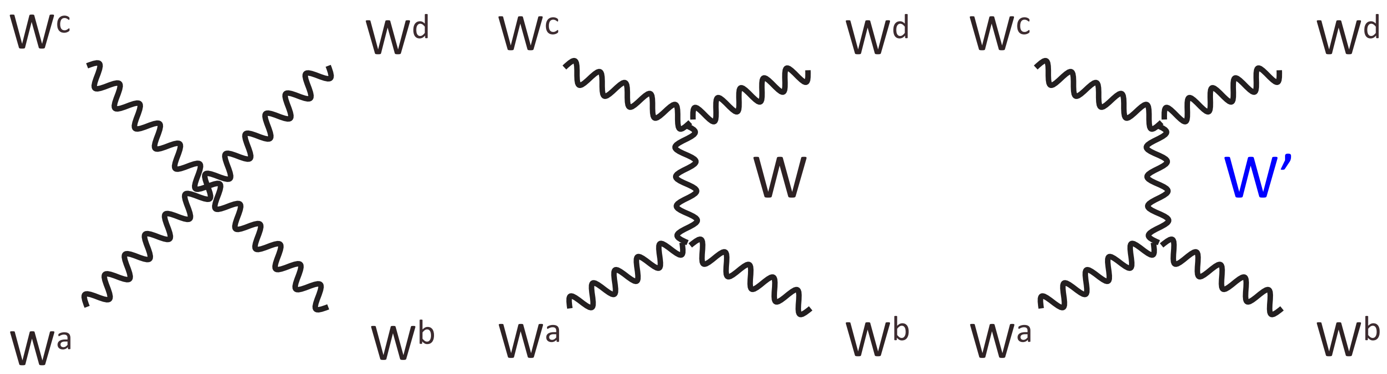


$$\sim \quad |\epsilon_L|^4 \sim \frac{E^4}{M^4} + \frac{E^2}{M^2} + \cdots$$

Let us first focus on WW → WW scattering.

$W_L W_L$ scattering in W' model

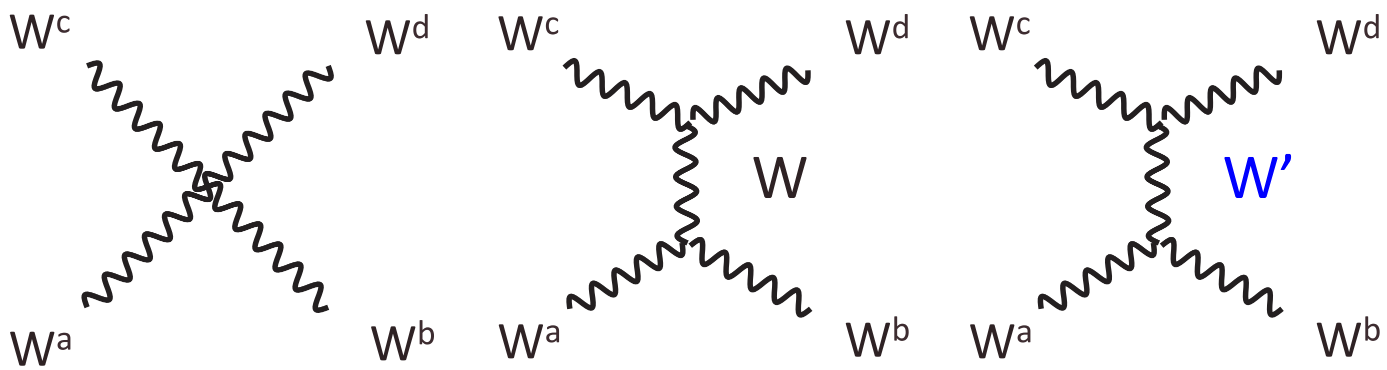
O(E^4) terms in WW → WW scattering amplitude



$$\mathcal{M}_{W_L W_L \to W_L W_L}\Big|_{E^4} \sim \left[\, g_{WWWW} - g_{WWW}^2 - g_{WWW'}^2 \,\right] \frac{E^4}{M_W^4}$$

$W_L W_L$ scattering in W' model

<u>$O(E^4)$ terms in WW → WW scattering amplitude</u>

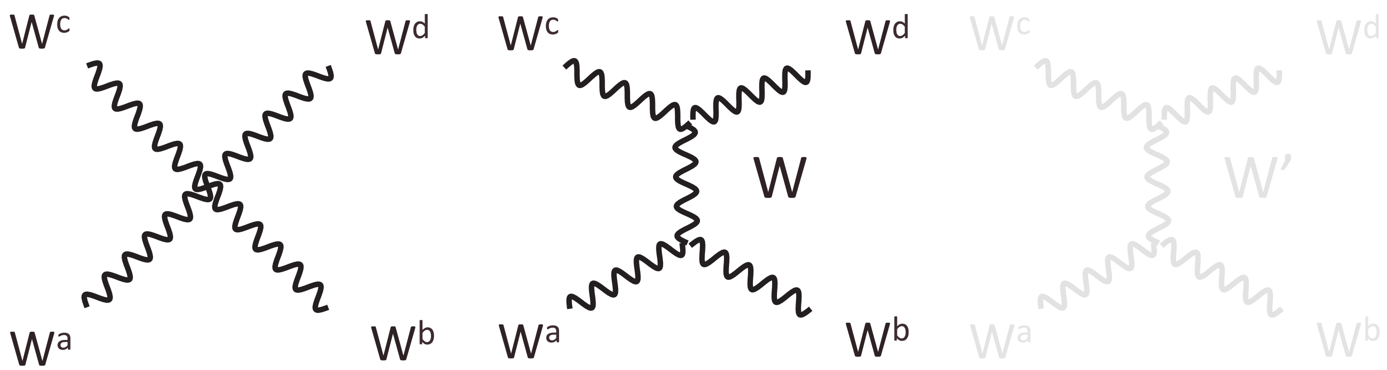


In order to cancel $O(E^4)$ term, WWW and WWWW couplings should satisfy

$$g_{WWWW} = g^2_{WWW} + g^2_{WWW'}$$

$W_L W_L$ scattering in W' model

O(E^4) terms in WW → WW scattering amplitude

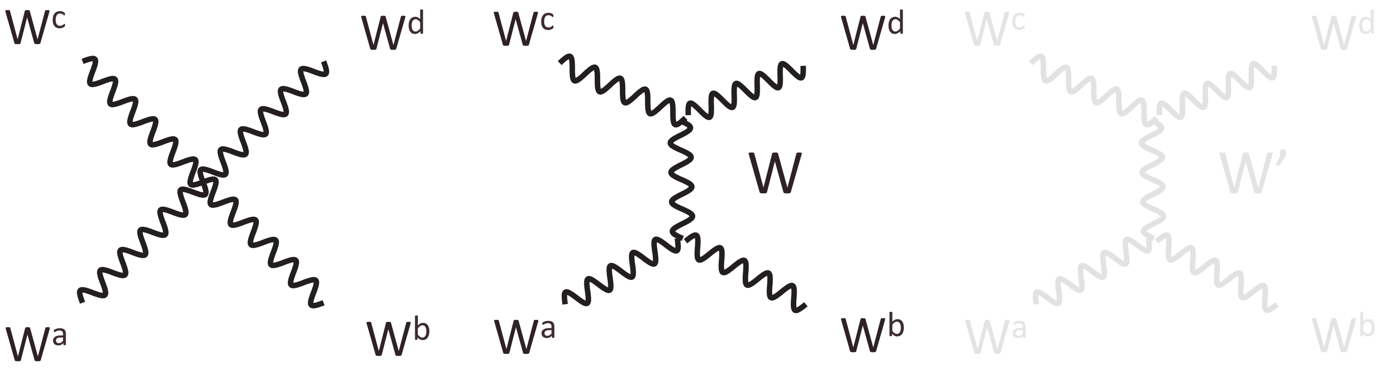


At $M_W << E \leq M_{W'}$, the sum rule is not enough to keep perturbative unitarity

$$\mathcal{M}_{W_L W_L \to W_L W_L}|_{E^4} \sim \left[\, g_{WWWW} - g^2_{WWW} \,\right] \frac{M^4_{W'}}{M^4_W}$$

$W_L W_L$ scattering in W' model

<u>$O(E^4)$ terms in WW → WW scattering amplitude</u>

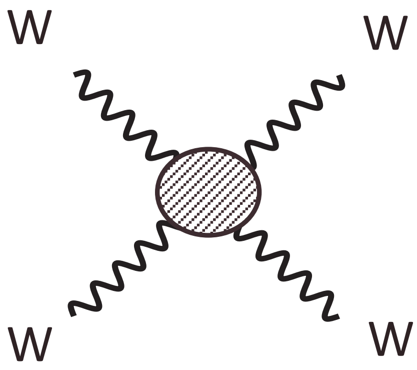


Requiring the amplitude is still consistent with perturbative unitarity,

$$g_{WWW'} \equiv \xi_V g_{WWW} \frac{M_W^2}{M_{W'}^2}, \qquad |\xi_V| \le 15$$

$W_L W_L$ scattering in W' model

The longitudinal polarization vector grows as energy.



$$\sim \quad |\epsilon_L|^4 \sim \frac{E^4}{M^4} + \underline{\frac{E^2}{M^2}} + \cdots$$

hWW and hWW' couplings are controlled by
O(E²) perturbative unitarity conditions.

$W_L W_L$ scattering in W' model

In order to cancel $O(E^2)$ term, hVV couplings should satisfy

WW → WW :

$$\sum_h g_{hWW}^2 = M_W^2 g_{WWW}^2 + (4M_W^2 - 3M_{W'}^2) g_{WWW'}^2$$

WW → WW' :

$$\sum_h g_{hWW} g_{hWW'} = M_{W'}^2 g_{WWW} g_{WWW'} + (3M_W^2 - 2M_{W'}^2) g_{WWW'} g_{WW'W'}$$

WW → W'W' :

$$\sum_h g_{hWW'}^2 = \frac{M_{W'}^4}{M_W^2} g_{WWW'}^2 + \frac{M_W^4}{M_{W'}^2} g_{WW'W'}^2$$

Our finding

Combining WW → WW, WW → WW’, and WW → W’W’ unitarity sum rules, we obtain

$$g_{hWW'}^2 = \zeta_V^2 g_{hWW}^2$$

hWW’ coupling WWW’ coupling hWW’ coupling

- Perturbative unitarity requires that hWW’ coupling should relate with WWW’ coupling and hWW coupling !

Our finding

Combining WW → WW, WW → WW', and WW → W'W' unitarity sum rules, we obtain

$$\Gamma_{W'}(Wh) = \kappa_V^2 \Gamma_{W'}(WZ) \qquad \kappa_V \equiv \frac{g_{hWW}}{g_{hWW}^{\rm SM}}$$

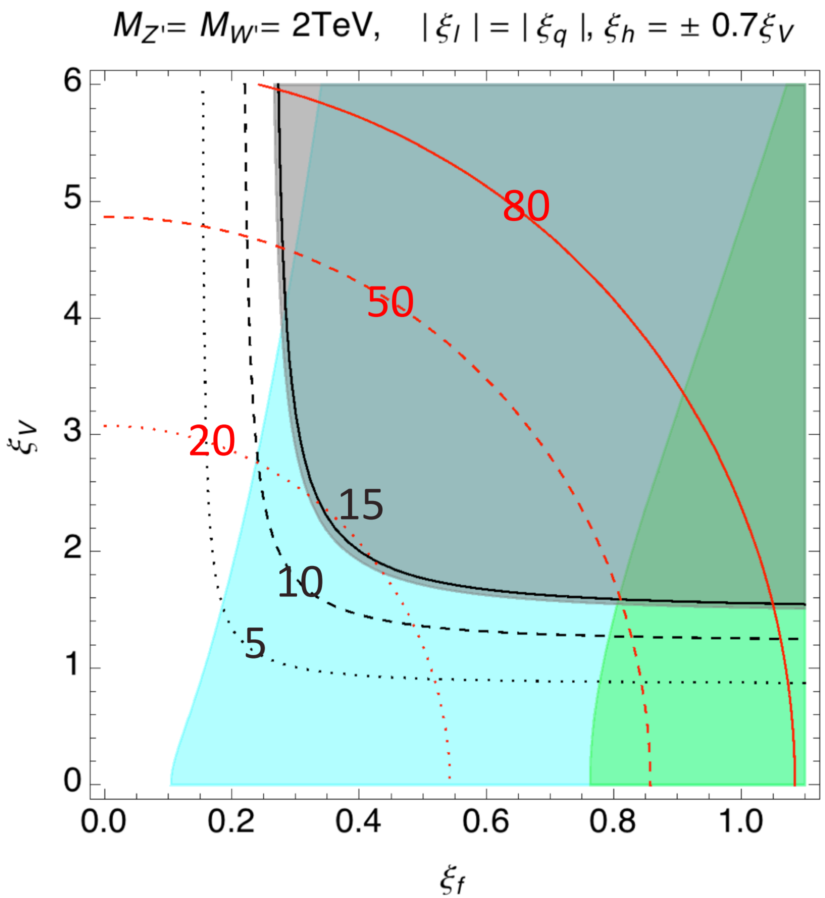
- The ATLAS 2TeV anomalies may be consistent with the CMS limits on Wh decay channel if we consider $\kappa_V < 1$.

The ALTAS 2TeV anomalies : $\sigma(pp \to W')B_{W'}(WZ) \sim 14\text{fb}$

The CMS limit : $\sigma(pp \to W')B_{W'}(Wh) < 7\text{fb}$

$|\xi_q| = |\xi_l|$ and $\kappa_V = 0.7$

e.g. The degenerate model ($M_{W'} = M_{Z'} = 2$TeV)



Black : σB(VV) = 5, 10, 15fb

Gray : Wh/Zh

Blue : lν / ll

Green : 2j

Red : $\Gamma_{W'}$ = 20, 50, 80GeV

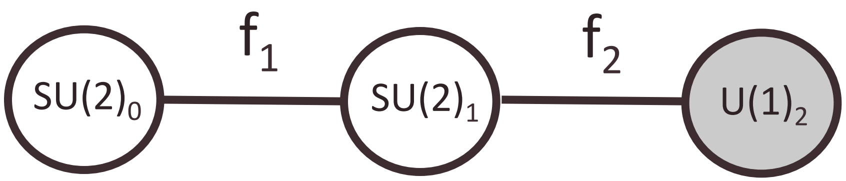
- We obtain σB(VV) = 10fb if $\xi_V = 4$ and $\xi_f = 0.23$

Three site moose model

Three site moose model

<u>Three site Higgs moose model</u>

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



EW interaction :

$$\mathcal{L}_{\rm EW} = -J_W^{a\mu}\left[g_0 W^a_{0\mu}(1-x) + x g_1 W^a_{1\mu}\right] - g_2 J^{Y\mu} B_{2\mu}$$

x : delocalization parameter; 0 < x < 1

Three site moose model

W'/Z' coupling strengths ($f_1 >> f_2$; $M_{W'} = M_{Z'} >> M_Z$)

WZW', WWZ' couplings : $\xi_V \simeq \frac{g_1}{g_0}$

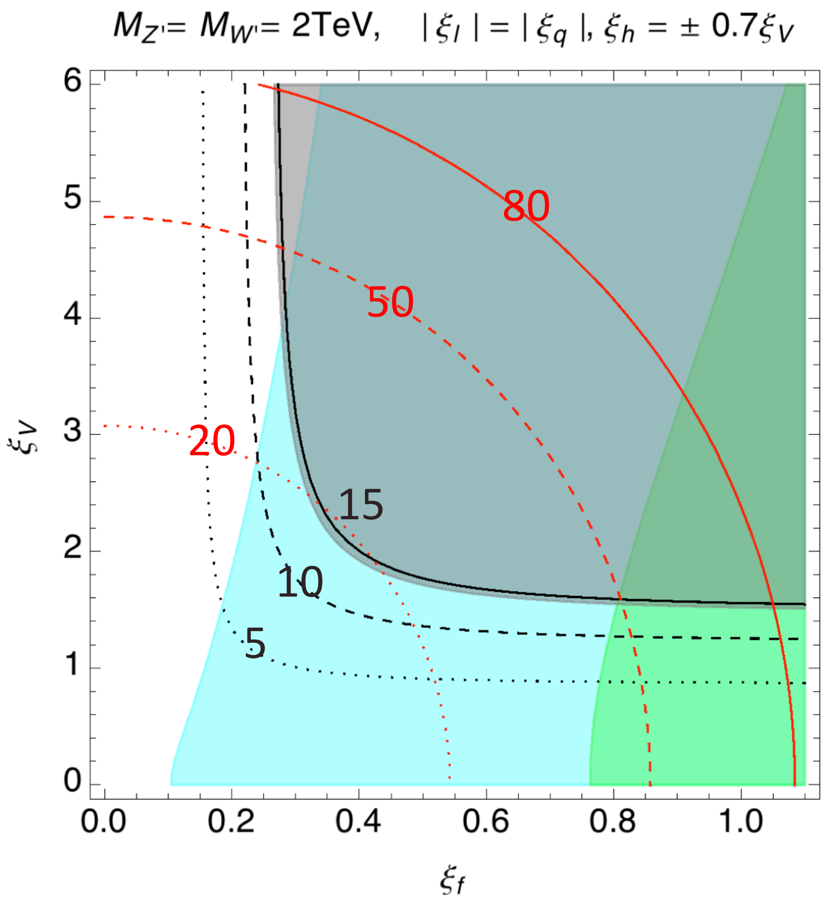
ffW' , ffZ' couplings : $\xi_f \simeq \frac{g_0}{g_1}\left(1 - x - x\frac{g_1^2}{g_0^2}\right)$

hWW, hZZ couplings : $\kappa_V = \sin\alpha \leq 1$

Mixing angle
between Higgs fields

$|\xi_q| = |\xi_l|$ and $\kappa_V = 0.7$

e.g. The degenerate model ($M_{W'} = M_{Z'} = 2$TeV)



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Three site moose model

W'/Z' coupling strengths ($f_1 >> f_2$; $M_{W'} = M_{Z'} >> M_Z$)

WZW', WWZ' couplings : $\xi_V \simeq \frac{g_1}{g_0}$

ffW' , ffZ' couplings : $\xi_f \simeq \frac{g_0}{g_1}\left(1 - x - x\frac{g_1^2}{g_0^2}\right)$

- $g_{W0}/g_{W1} = 4$ gives the reference value cross section for the ATLAS diboson anomalies without causing conflicts with other limits on W'/Z'.

Summary

- We investigate spin-1 (W') interpretation for the ATLAS 2TeV anomalies from the view point of perturbative unitarity and custodial symmetry.

- The anomalies can be explained in a perturbative W' model with non-standard model like 125GeV Higgs boson.

- We find the ATLAS 2TeV anomalies may be interpreted as a W' particle (KK particles of EW gauge bosons) in the three site moose model.

- pp → Wh/Zh channel give us most stringent constraints on W' model. The LHC Run2 experiments are expected to clarify whether the 2TeV resonance is perturbative W'/Z' or not.

Thank you for your attentions.