New physics in triboson event topologies

Matthew J. Smylie

Department of Physics, The Ohio State University

May 9, 2022

L. M. Carpenter, M. J. Smylie, J. M. Caridad Ramirez, C. McDowell and D. Whiteson, "New physics in triboson event topologies," Phys. Rev. D **105**, no.7, 075027 (2022) doi:10.1103/PhysRevD.105.075027 [arXiv:2112.00137 [hep-ph]].

Introduction and Outline

- As the LHC dataset grows large, opportunities are created for the study of rare final states, such as those with three or more weak bosons.
- We consider benchmark models of new physics in which a new scalar is produced in association with a vector boson, and the scalar then decays to two bosons.
- We take an effective field theory approach, and allow diboson couplings to serve as portals to new physics.
- We compute sensitivity to these scenarios at the LHC, projecting limits on effective couplings to the full 3 ab^{-1} of the high luminosity run.

Models

- We construct a detailed catalogue of effective operators up to dimension 7 which couple exotic states to pairs of Standard Model gauge bosons.
- Here we only consider exotic spin-zero fields in the singlet, fundamental, and adjoint representations of the Standard Model gauge groups.
- Each effective operator will be suppressed by a new physics scale Λ.
- We may consider scalars which do not couple to gluons, preventing a $pp \to \phi$ production mode.

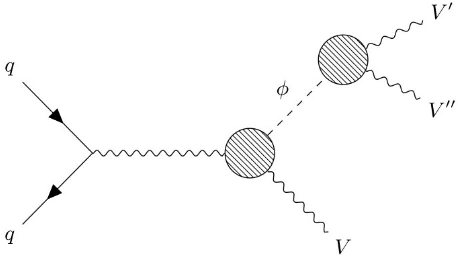
New Field Content

Field	$U(1)_Y$	$SU(2)_L$	$SU(3)_c$
X	0	1	1
Y	1	2	1
T	0	3	1

$$\mathcal{L}_X = \frac{1}{\Lambda_{XBB}} X B^{\mu\nu} B_{\mu\nu} + \frac{1}{\Lambda_{XWW}} X W^{\mu\nu} W_{\mu\nu} + \frac{1}{\Lambda^3_{XBW}} X B^{\mu\nu} [H^\dagger W_{\mu\nu} H]$$

$$\mathcal{L}_Y = \frac{1}{\Lambda^2_{YBB}} [H^\dagger Y] B^{\mu\nu} B_{\mu\nu} + \frac{1}{\Lambda^2_{YWW}} [H^\dagger Y] W^{\mu\nu} W_{\mu\nu} + \frac{1}{\Lambda^2_{YBW}} B^{\mu\nu} [H^\dagger W_{\mu\nu} Y]$$

$$\mathcal{L}_T = \frac{1}{\Lambda_{TWB}} T_i W_i^{\mu\nu} B_{\mu\nu} + \frac{1}{\Lambda^3_{TBB}} [H^\dagger T H] B^{\mu\nu} B_{\mu\nu} + \frac{1}{\Lambda^3_{TWW}} [H^\dagger T H] W^{\mu\nu} W_{\mu\nu}$$



$$pp \to \phi V \to V + V'V''$$

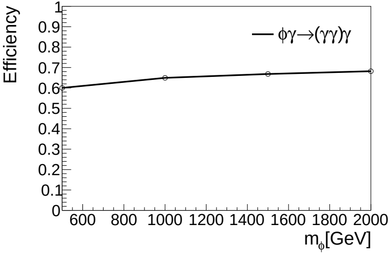
Here the bosons V, V', and V'' can be photons, W bosons, or Z bosons.

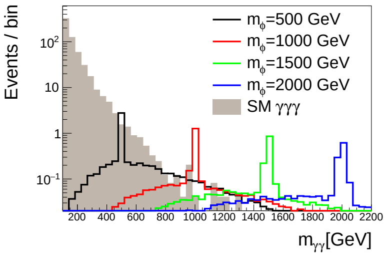
Sensitivity

- First we estimate the sensitivity of the LHC dataset to these hypothetical signals using samples of simulated collisions representing 100 fb^{-1} of proton collisions.
- We investigate 14 different processes which lead to 4 distinct final state channels.

Production and decay	Final state
$\phi\gamma \to (\gamma\gamma)\gamma$	3γ
$\phi\gamma \to (ZZ)\gamma \to (J(ee))\gamma$ $\phi\gamma \to (ZZ)\gamma \to (J(\mu\mu))\gamma$	$J, 2\ell, \gamma$
$\phi\gamma \to (ZZ)\gamma \to ((ee)(ee))\gamma$ $\phi\gamma \to (ZZ)\gamma \to ((ee)(\mu\mu))\gamma$ $\phi\gamma \to (ZZ)\gamma \to ((\mu\mu)(\mu\mu))\gamma$ $\phi Z \to (Z\gamma)Z \to ((ee)\gamma)(ee)$ $\phi Z \to (Z\gamma)Z \to ((ee)\gamma)(\mu\mu)$ $\phi Z \to (Z\gamma)Z \to ((\mu\mu)\gamma)(ee)$ $\phi Z \to (Z\gamma)Z \to ((\mu\mu)\gamma)(\mu\mu)$	$4\ell, \gamma$
$\phi\gamma \to (\gamma Z)\gamma \to (\gamma(\mu\mu))\gamma$ $\phi\gamma \to (\gamma Z)\gamma \to (\gamma(ee))\gamma$ $\phi Z \to (\gamma\gamma)(ee)$ $\phi Z \to (\gamma\gamma)(\mu\mu)$	$2\ell, 2\gamma$

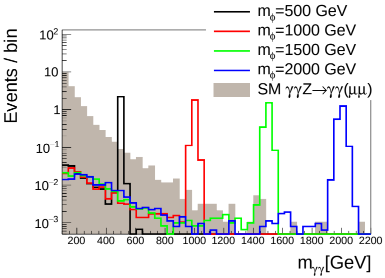
$\gamma\gamma\gamma$





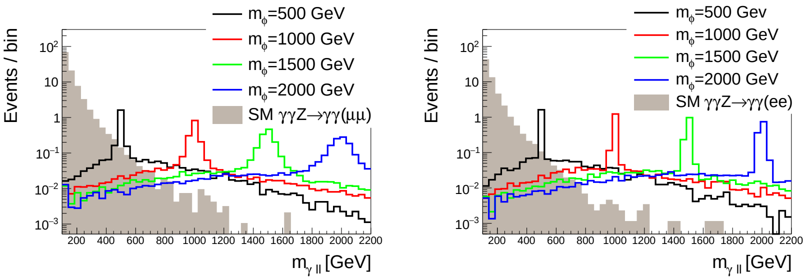
(Left) Efficiency of three-photon selection as a function of the hypothetical ϕ mass for the $\gamma\gamma\gamma$ final state. (Right) Distributions of reconstructed m_ϕ in simulated signal and background samples, normalized to integrated luminosity of 100 fb^{-1}.

$\gamma\gamma\ell^+\ell^-$

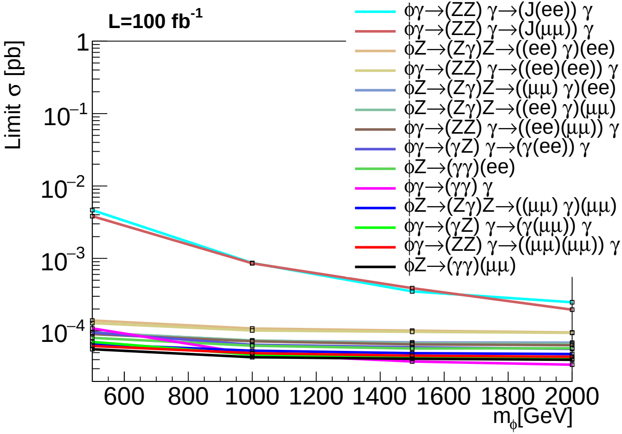


Distributions of reconstructed m_ϕ in simulated signal and background samples in $\gamma\gamma\ell^+\ell^-$ final states, normalized to integrated luminosity of 100 fb^{-1}. Here the scalar is produced in association with a Z and decays to $\gamma\gamma$.

$\gamma\gamma\ell^+\ell^-$



Distributions of reconstructed m_ϕ in simulated signal and background samples in $\gamma\gamma\ell^+\ell^-$ final states, normalized to integrated luminosity of 100 fb^{-1}. Here the scalar is produced in association with a γ and decays to $Z\gamma$.



Summary of expected upper limits at 95% CL on the production cross-sections as functions of the ϕ mass in integrated luminosity of 100 fb^{-1} for the fourteen production and decay modes.

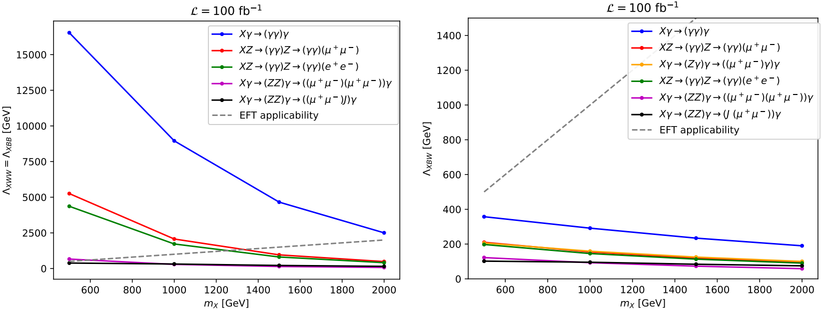
Interpretation

- Expected limits on cross sections are translated to limits on the effective mass scales Λ_i.
- Six benchmark scenarios are chosen to analyze. For each, we take all other couplings to zero:

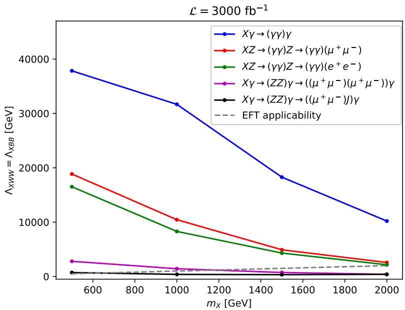
Label	Description	$\mathcal{L}$
A	singlet dim 5	$\frac{1}{\Lambda_{XBB}} X B^{\mu\nu} B_{\mu\nu} + \frac{1}{\Lambda_{XWW}} X W^{\mu\nu} W_{\mu\nu}$
B	singlet dim 7	$\frac{1}{\Lambda^3_{XBW}} X B_{\mu\nu} [H^\dagger W_{\mu\nu} H]$
C	doublet I	$\frac{1}{\Lambda^2_{YBB}} [H^\dagger Y] B^{\mu\nu} B_{\mu\nu} + \frac{1}{\Lambda^2_{YWW}} [H^\dagger Y] W^{\mu\nu} W_{\mu\nu}$
D	doublet II	$\frac{1}{\Lambda^2_{YBW}} B_{\mu\nu} [H^\dagger W_{\mu\nu} Y]$
E	adjoint dim 5	$\frac{1}{\Lambda_{TWB}} T_i W_i^{\mu\nu} B_{\mu\nu}$
F	adjoint dim 7	$\frac{1}{\Lambda^3_{TBB}} [H^\dagger T H] B^{\mu\nu} B_{\mu\nu} + \frac{1}{\Lambda^3_{TWW}} [H^\dagger T H] W^{\mu\nu} W_{\mu\nu}$

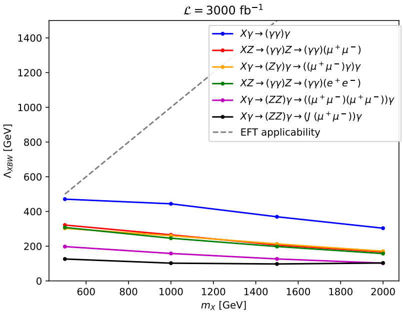
Interpretation

- We specialize to the points where $\Lambda_{XBB} = \Lambda_{XWW}$, which causes the $X \to Z\gamma$ branching fraction to vanish and reduces destructive interference in production.
- Associated production cross sections have a simple dependence on the effective couplings.
- The widths of the scalars are computed to be narrow compared to their masses.
- The EFT approach breaks down if the scalar mass exceeds the scale Λ.

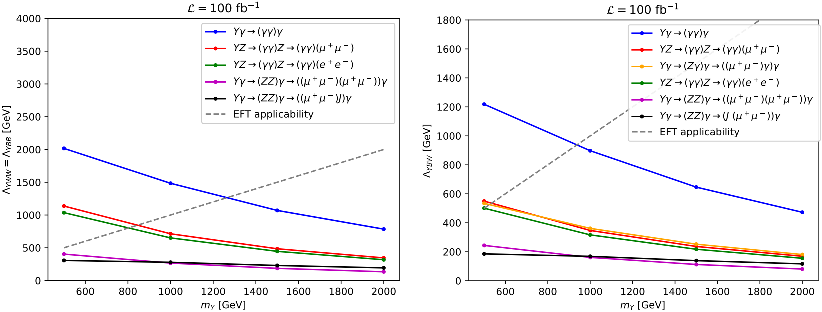


Exclusions of effective cut-offs vs scalar mass for 100 fb^{-1} for dimension 5 singlet (left) and dimension 7 singlet (right) models in various final states.

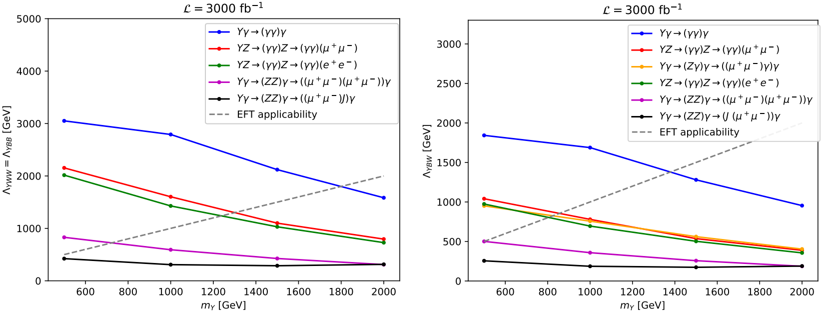




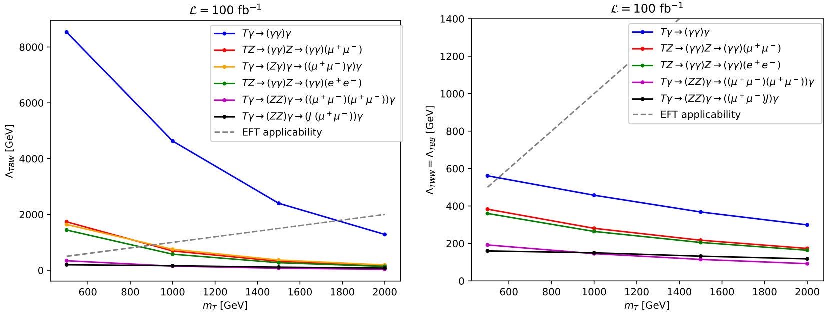
Exclusions of effective cut-offs vs scalar mass for 3 ab^{-1} for dimension 5 singlet (left) and dimension 7 singlet (right) models in various final states.



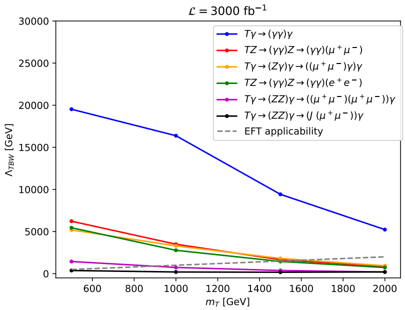
Exclusions of effective cut-offs vs scalar mass for 100 fb^{-1} for the dimension 6 doublet models in various final states.

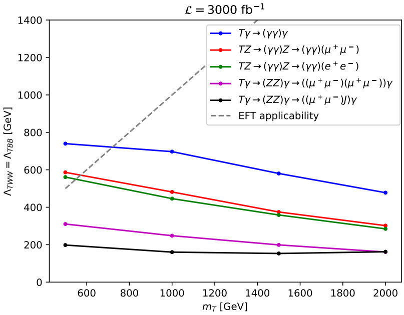


Exclusions of effective cut-offs vs scalar mass for 3 ab^{-1} for the dimension 6 doublet models in various final states.



Exclusions of effective cut-offs vs scalar mass for 100 fb^{-1} for dimension 5 triplet (left) and dimension 7 triplet (right) models in various final states.





Exclusions of effective cut-offs vs scalar mass for 3 ab^{-1} for dimension 5 triplet (left) and dimension 7 triplet (right) models in various final states.

Conclusion

- We have introduced the LHC search topology of triple electroweak gauge bosons to study the production of exotic states that couple to pairs of electroweak gauge bosons.
- We have shown how the presence of multi-photons, multiple leptons, and mass reconstruction of both Z bosons and heavy exotic scalars in the events can give extremely tight constraints on new models, placing cross section limits in the sub-fb region.
- We have analyzed our results in the parameter space of the effective cut-off scales of new EFT models.
- We find several channels capable of probing the multi-TeV effective cut-off regime, with the powerful tri-photon searches reaching as far as 35 TeV in effective cut-off for the full 3 ab^{-1} run of HL-LHC.