Diboson resonance searches including HH in ATLAS and CMS in Run2

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Overview

- General strategy
- $V V \rightarrow JJ$ ($V=W, Z$)
- $H H \rightarrow b b b b$
- $V V \rightarrow$ leptons+jets
- $V H \rightarrow$ leptons+bb
- $H H \rightarrow W W + b b$
- $H H \rightarrow \tau \tau b b$
- $V V \rightarrow$ leptons
- $H H \rightarrow b b \gamma \gamma$
- Combinations of results
Motivation and General Strategy

• Heavy resonances of vector bosons or Higgs bosons would be a sign of new physics at LHC
  • Many different models predicted, often motivated by hierarchy or naturalness arguments
  • Examples: extended Higgs sector (2HDM), heavy vector triplets (HVT - $W'$, $Z'$), Kaluza-Klein graviton from bulk Randall-Sundrum model

• Search Strategy:
  • Select events based on final state of interest (leptons, missing $E_T$, jets, etc)
  • Categorise events based on signal purity (based on (di-)jet mass, jet substructure, b-tagging, number of leptons, etc)
  • Look at invariant mass of dibosons or output from multivariate analysis to search for resonant signal
  • Perform statistical analysis
Final state: 2 high pT large-R anti-kT jets  
(R=1.0 ATLAS, R=0.8 CMS) 

Boson tagging used to distinguish signal from multijet background 

Jet mass consistent with W/Z mass 

\( \tau_{21} \): ratio of how well jet can be divided into 2 sub-jets vs 1 sub-jet
New ATLAS result on full Run 2 dataset
Improvements in boson tagging leads to
better sensitivity than increase in luminosity
alone (see Sofia's talk for more info)

Exclusion regions:
HVT: 1.3-4.4 TeV (ATLAS)
  1.2-3.8 TeV (CMS)

Graviton: 1.3-2.8 TeV (ATLAS, k/M_\text{Pl}=1)
  0.6-36 fb (CMS, k/M_\text{Pl}=0.5)
**HH → 4b**

ATLAS-EXOT-2016-31, CMS-B2G-017-019

**Final state:** 4 small-R (R=0.4) or 2 large-R jets (ATLAS)

2 small-R and 1 large-R, or 2 large-R jets (CMS)

**Multijet Background**

Estimate of dominant multijet background (ATLAS):
- Templates with fewer b-tags used to reweight events
- Weights derived based on comparison of kinematics in sideband region

**Signal models:**
- KK graviton
- Radion
- 2HDM

**Multivariate techniques used to identify b-jets**
- CMS double b-tagger:
  - Uses information about b-hadron lifetime and mass to determine probability of large-R jet to contain bb pair
HH → 4b

Local significance, m=280 GeV: 3.6σ
Global significance: 2.5σ

Exclusion regions:
Scalar: ~1-5000 fb (ATLAS)
Radion: 1.6-67 fb (CMS)
Graviton: 1.4-43.9 fb (CMS, k/M_{Pl}=0.5)
313-1362 GeV (ATLAS, k/M_{Pl}=1)
VV $\rightarrow$ leptons+jets

Final state: 2 leptons (e, mu) + 2 small-R or 1 large-R jet, 1 lepton + missing ET + 2 small-R or 1 large-R jet, missing ET + 1 large-R jet

Signal models: HVT ($W'$, $Z'$) RSG

HVT signals excluded up to $M(W')$, $M(Z')$ $\sim$3-3.5 TeV

Graviton signals excluded up to $M(G)$ $\sim$1-1.5 TeV
VH → leptons + bb

Similar to VV searches, but with H decaying to bb.

Events categorised based on number and flavour of leptons, and number of b-tagged jets.
VH $\rightarrow$ leptons + bb

Exclusion regions:

HVT: 0.8-60 fb (CMS)
    0.9-280 fb (ATLAS)

Scalar: 0.01-1 pb (CMS, $M<1$ TeV only)
        0.002-0.8 pb (ATLAS, 500 GeV $M<5$ TeV)
HH → bb + WW


Final state: ATLAS: 1 lepton + MET + 4 small-R jets (2 b-jets) or 1 large-R b-jet + 2 small-R jets
CMS: 1 lepton + MET + 1 large-R b-jet + 1 large-R jet

New result from CMS

Backgrounds defined in 4 generator level categories with distinct m(bb) shapes. Templates of m(bb) modelled as a function of m(HH).

Likelihood fit done in 2D plane of m(bb) and m(HH).
HH→bb+WW

Exclusion regions (σ*BR):
Graviton: 14-170 fb (ATLAS*)
7.8-103 fb (CMS)

Scalar: 25-280 fb (ATLAS*)
8.3-123 fb (CMS)

*ATLAS numbers multiplied by BR (HH->bblvqq)
**HH → ττbb**

**ATLAS-HIGG-2016-16, CMS-B2G-17-006**

Final state: 2 taus (at least one hadronic decay)  
+ 2 small-R or 1 large-R b-jet

**Signal models:**  
Radion  
KK graviton  
hMSSM scalar

**Boosted decision tree used to improve signal-background separation.**  
BDT trained separately for each mass point.  
Includes masses from neighbouring points in signal model to keep sensitivity between simulated points.
HH → ττbb

Exclusion regions:
hMSSM: 305 < M(X) < 402 GeV (ATLAS)
Radion: M < 2.7 TeV (CMS)
KK Graviton: 325 < M(G) < 885 GeV (ATLAS, k/M_{Pl}=1)
              5-80 fb (CMS, k/M_{Pl}=0.5)
**VV → leptons**

ATLAS-EXOT-2016-11, CMS-B2G-17-023

Final states: 2 or 3 leptons + missing ET (+2 VBF jets)

Signal models:
- KK graviton
- HVT ($W'$)

Neutrino z-momentum estimated using $W$-mass constraint

Exclusion regions:
- $M(W') < 2.3$ TeV (ATLAS)
- $M(G) < 800$ GeV
HH→bbγγ

ATLAS-HIGG-2016-15, CMS-HIG-17-008

Final state: 2 photons + 2 small-R jets
Signal models: 2HDM Radion Graviton

Boosted decision tree trained using b-tagging and helicity variables.
Trained separately for m(X)< 600 GeV and m(X)> 600 GeV

Exclusion regions:
ATLAS σ*BR(X→HH): 0.12-1.1 pb
CMS Radion: m(X)<540 GeV
Graviton: 290<m(X)<810 GeV
Combinations of HH with bbbb, bb\tau\tau, bb\gamma\gamma, and bbVV (*) final states and VV+VH with qqqq, vvqq, lvqq, llll (**) , qqbb, vvbb, lvbb, llbb, qq\tau\tau (*) (*) CMS only, (**) ATLAS only

Exclusion regions HH:
Scalar: 0.02-0.83 pb (ATLAS)
0.003-1 pb (CMS)
Graviton: 0.02-1.89 pb (ATLAS, k/M_{Pl}=1)
0.004-1 pb (CMS, k/M_{Pl}=0.5)

Exclusion regions VV/VH:
HVT: M<5.5 TeV (ATLAS)
M<5 TeV (CMS)
Graviton: M<2.4 TeV (ATLAS, k/M_{Pl}=1)
M<850 GeV (CMS, k/M_{Pl}=0.5)
Summary

- Many results for searches for diboson resonances performed in a wide variety of final states
- No indication of resonances so far
Extra Information

Backup
References

• HH→ bbbb: ATLAS-EXOT-2016-31, CMS-B2G-017-019
• VH→ leptons+bb: ATLAS-EXOT-2016-10, CMS-B2G-17-004, CMS-HIG-18-005
• VV→ leptons: ATLAS-EXOT-2016-11, CMS-B2G-17-023
• HH→ bbγγ ATLAS-HIGG-2016-15, CMS-HIG-17-008
• HH combination: ATLAS-CONF-2018-043, CMS-HIG-17-030
• HH→ WWγγ ATLAS-HIGG-2016-20, CMS-HIG-17-006
• HH→ WWWWW: ATLAS-HIGG-2016-24