Searches for resonant di-boson production at CMS

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on behalf of the CMS collaboration

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Introduction

- 16 analyses highlighting resonant di-boson production

  → Using data from 2016 onwards

X → WW
HIG-17-033

X → HH
B2G-16-026
B2G-17-019
HIG-17-006
HIG-17-008
HIG-17-009
B2G-18-008

X → ZZ
B2G-16-023
HIG-17-012

X → VV
B2G-16-029
B2G-17-005
B2G-17-013
B2G-18-002

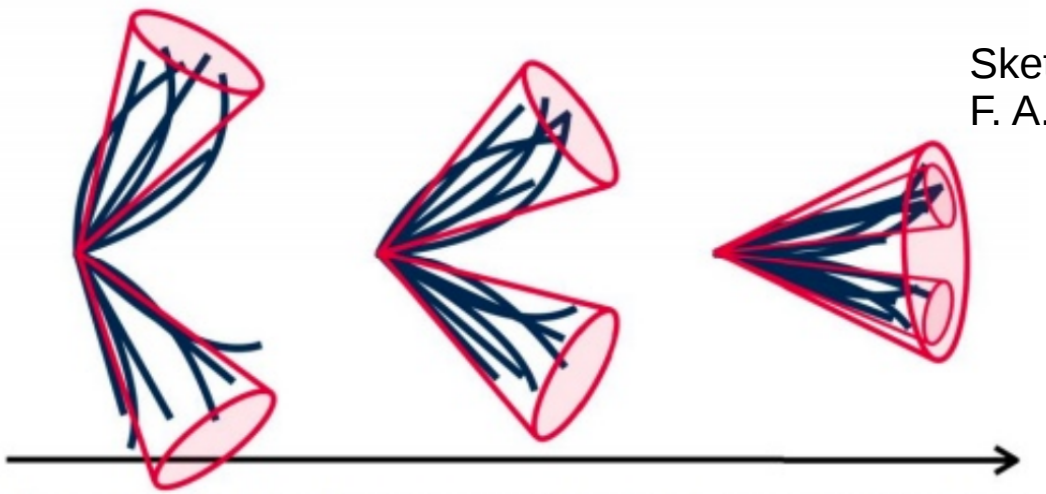
X → VH
B2G-17-002
B2G-17-004
B2G-17-006

Motivation

- High mass VV resonances can be interpreted as new particles predicted by BSM theories, for example:
  - Extended Higgs-like EW sector
  - Two-Higgs-Doublet Model (2HDM) / Minimal Supersymmetric SM (MSSM)
  - Bulk Graviton
  - Heavy vector triplet (HVT)

Hadronic jet reconstruction

- Bosons from high mass resonance decay have large Lorentz boost
  - Jets from hadronically decaying bosons are collimated
  - Reconstructed as AK8 jets (Anti-k_T with R=0.8)



Sketch by F. A. Dias

Boosted jets: Increasing transverse momentum

Used by all analyses reconstructing hadronically decaying bosons from high mass resonances

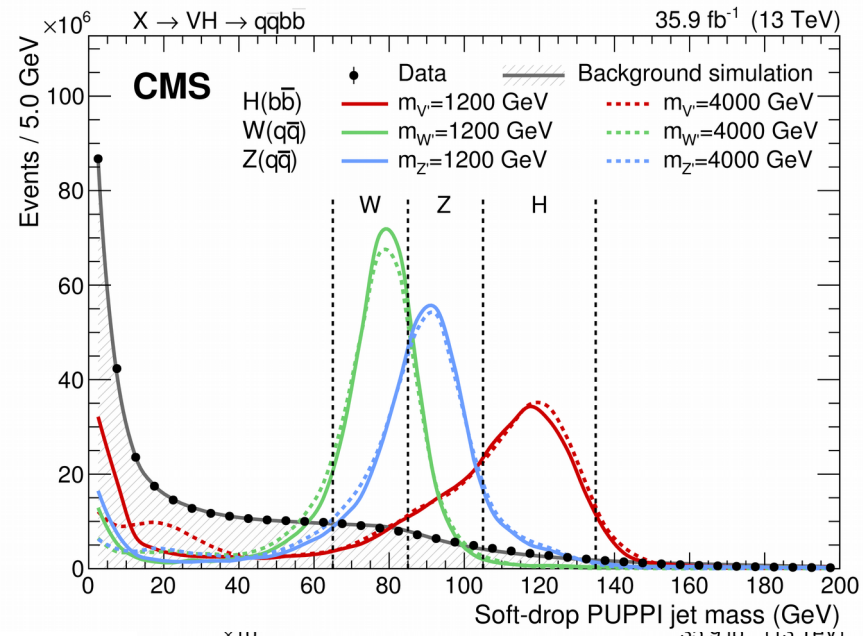
- In case of lower mass resonance: Can still use low p_T AK4 jets

  → Split into Resolved and Boosted/Merged categories

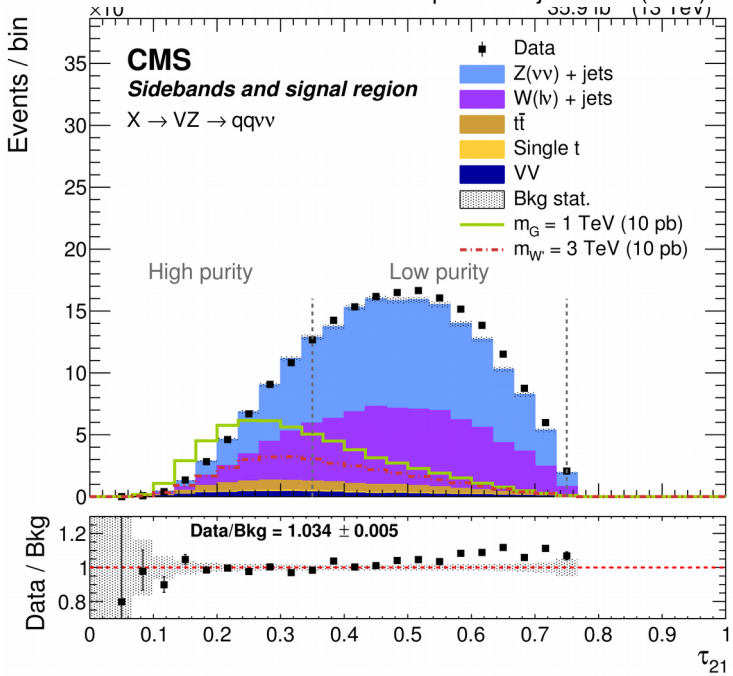
Hadronic jet reconstruction

B2G-17-002
B2G-17-005

- Jets are groomed using soft-drop (modified mass-drop tagger) algorithm, removing further constituents from soft radiation
  - Jet mass calculated from four-momentum of groomed jet



- N-subjettiness $\tau_{21} = \tau_2 / \tau_1$ is used as discriminating variable for jet substructure

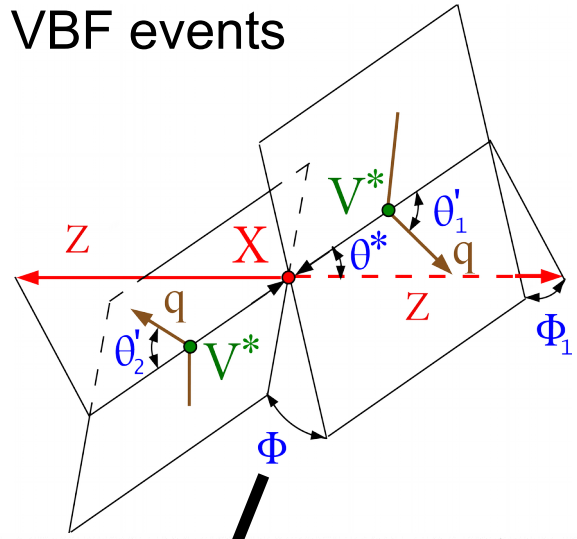


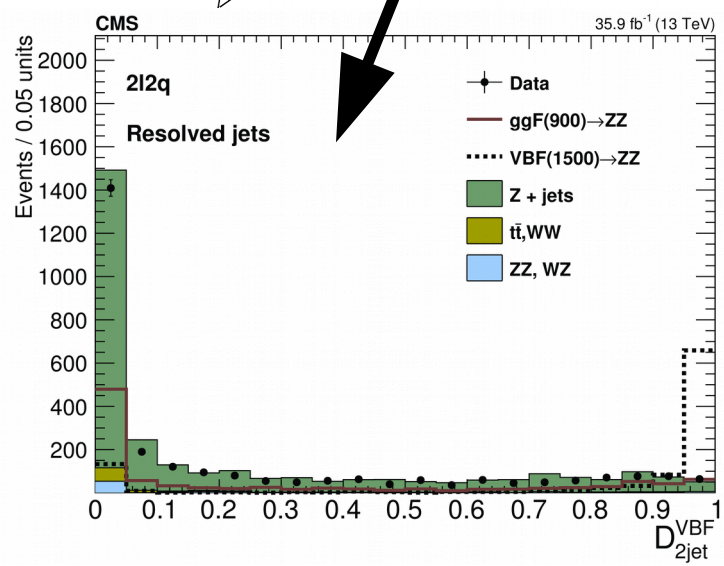
X → WW/ZZ

HIG-17-033
HIG-17-012

- Channels:
  - **WW** → 2l2ν, **<u>lνqq</u>**
  - **ZZ** → 4l; 2l2ν; **<u>2l2q</u>**
- Categorization:
  - VBF
  - ggH-tagged (**WW**) / b-tagged (**ZZ**)
  - Untagged
  - Each divided into „Resolved“ and „Merged“
- Signal selection, i.a.:
  - 65/70 GeV < m($\mathbf{W}_{had}$/$\mathbf{Z}_{had}$) < 105 GeV
- Major background:
  - W/Z + Jets (for **WW**/**ZZ**)

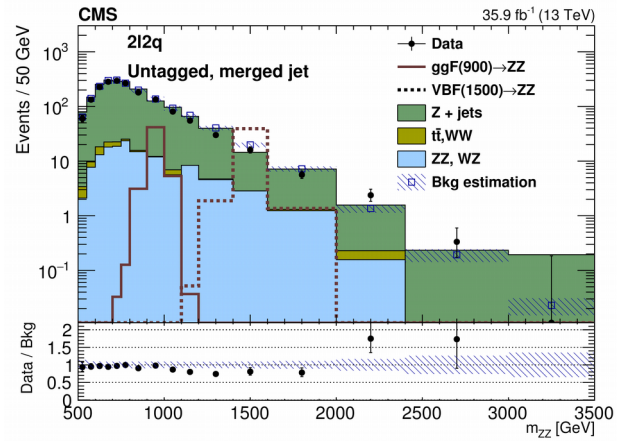
- Uses kinematics of decay products as input for MELA to discriminate signal from background or categorize VBF events

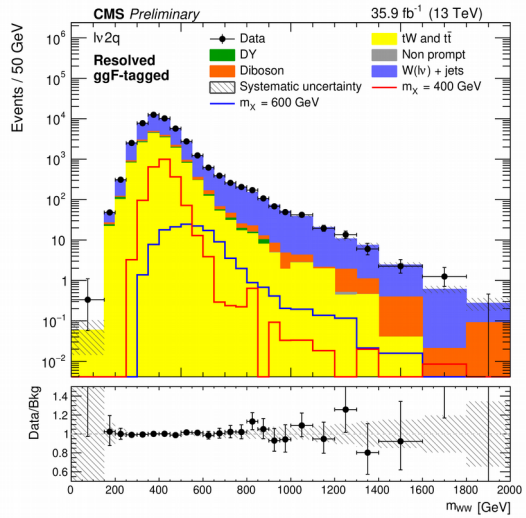


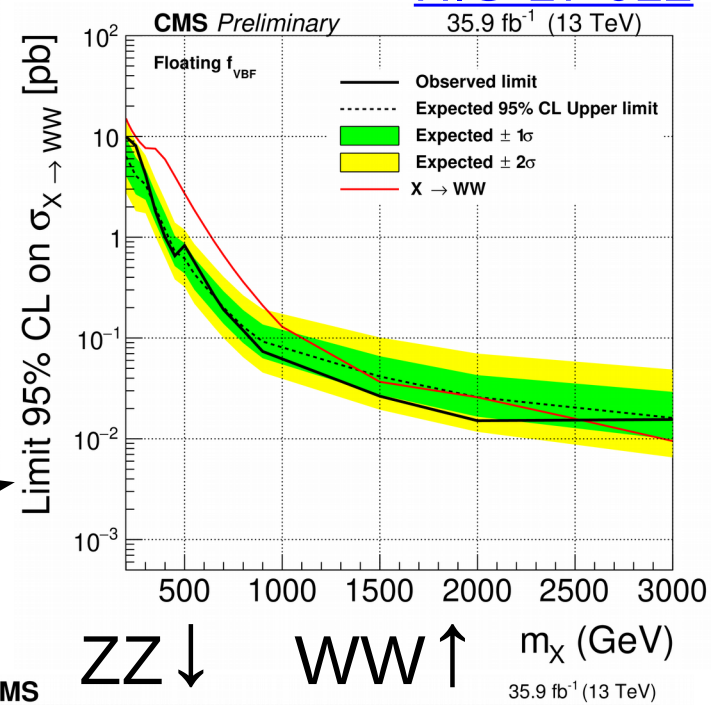


X → WW/ZZ

HIG-17-033
HIG-17-012



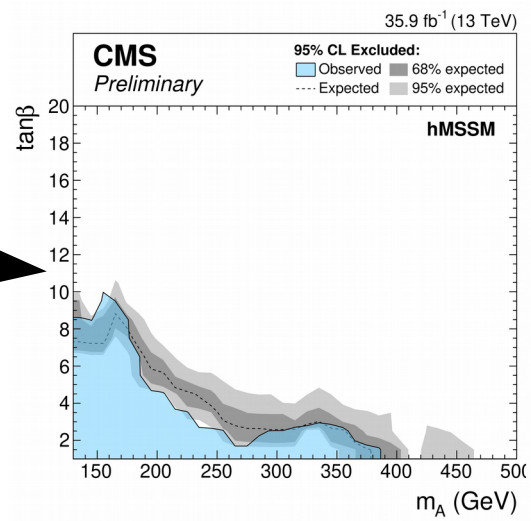


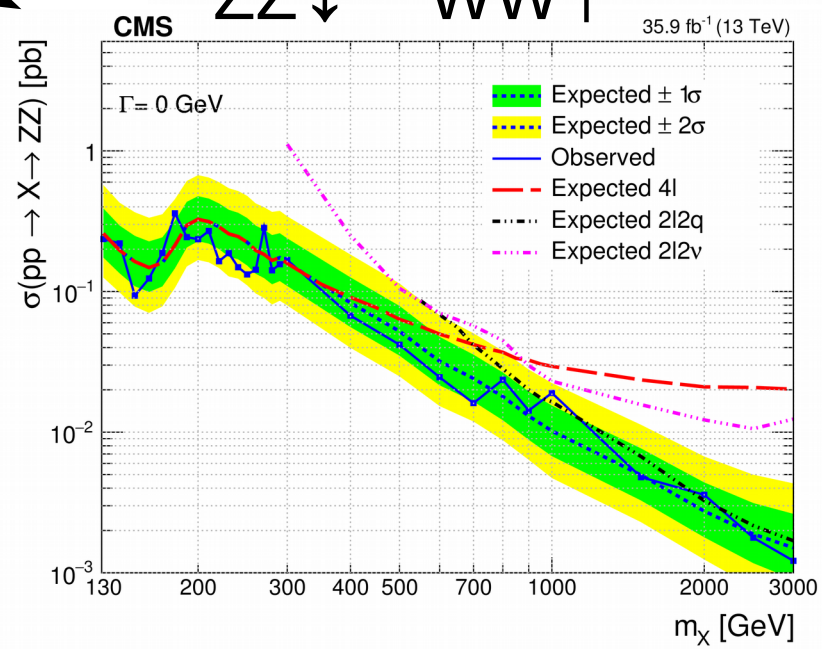


- Results shown as upper limit at 95% CL on cross section times branching fraction

ZZ↓ WW↑

- **WW**: Interpretations on MSSM and 2HDM scenarios are also given





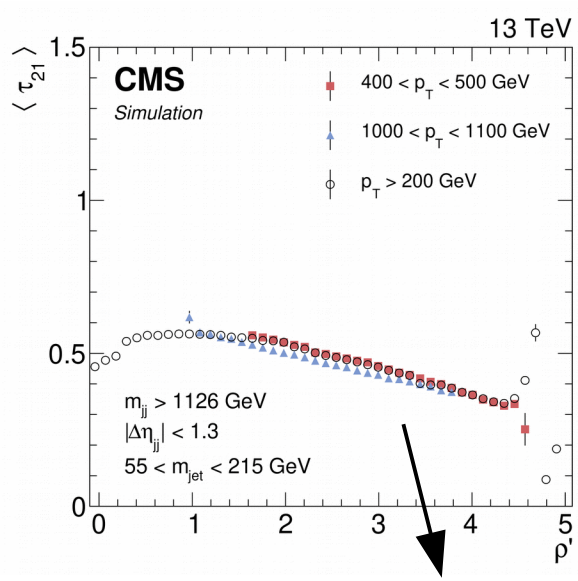
X → VV

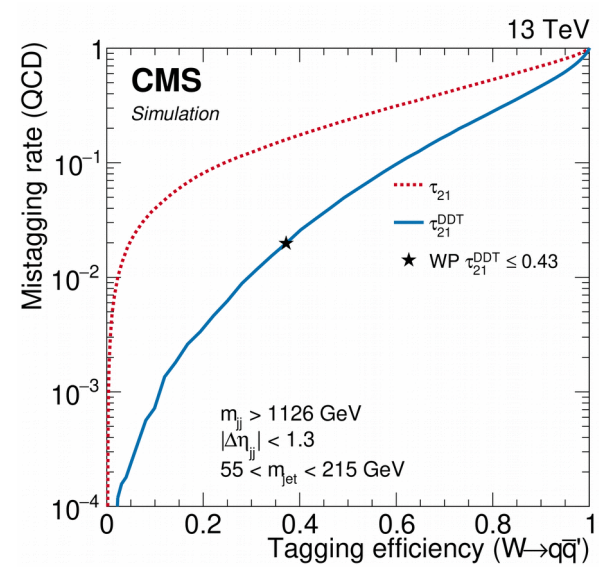
- Semileptonic and **full hadronic** analyses
- Categorization:
  - High purity $\tau_{21}^{DDT} < 0.43$
  - Low purity $0.43 < \tau_{21}^{DDT} < 0.79$
- Signal selection, i.a.:
  - Jet $p_T > 200$ GeV
  - $m_{JJ} > 1126$ GeV
- Major background:
  - QCD multijet

- Decorrelate τ_{21} from jet mass and p_T through „designed decorrelated tagger“ (DDT) method

$$\tau_{21}^{DDT} = \tau_{21} - M \cdot \rho'$$

$$\rho' = \log\left(m_J^2 / p_T\right)$$

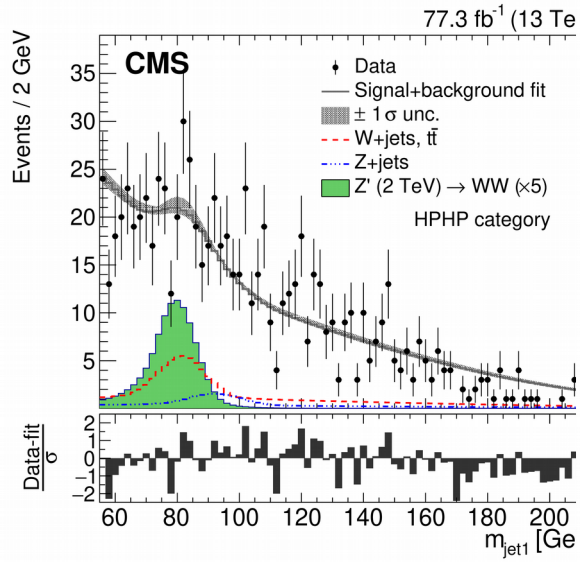


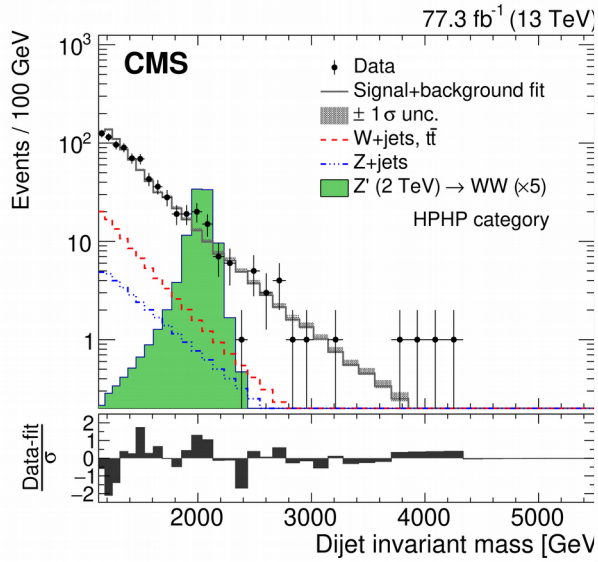


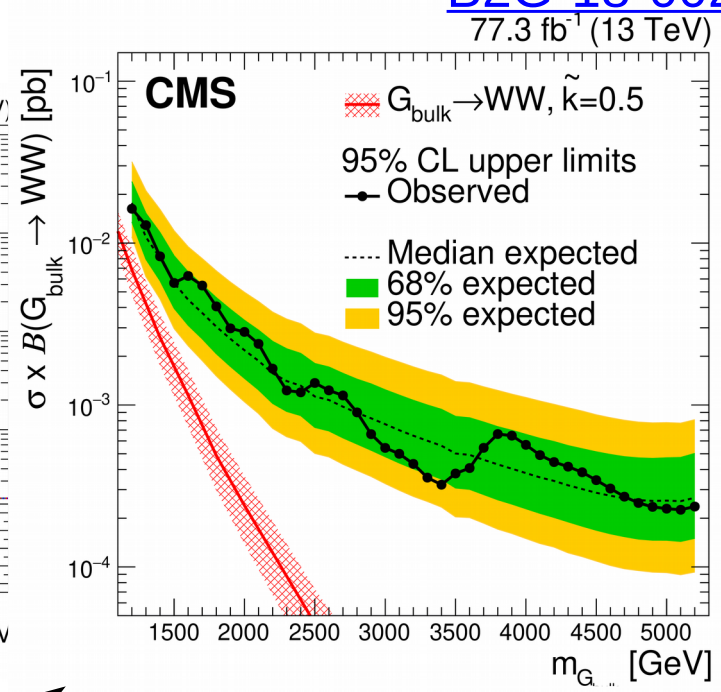
M = -0.08

X → VV

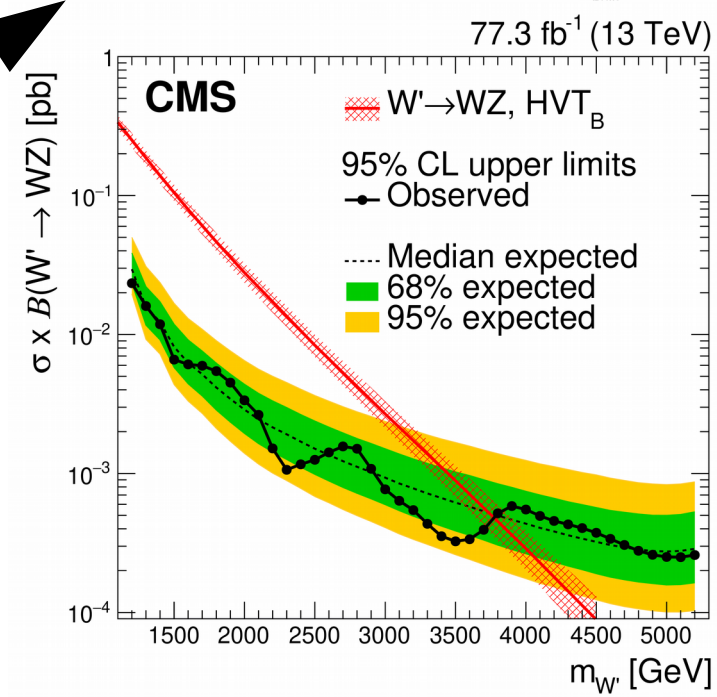
B2G-18-002







- No excess observed over expectation
- Upper limits on cross section for:
  - Bulk graviton
  - HVT model B



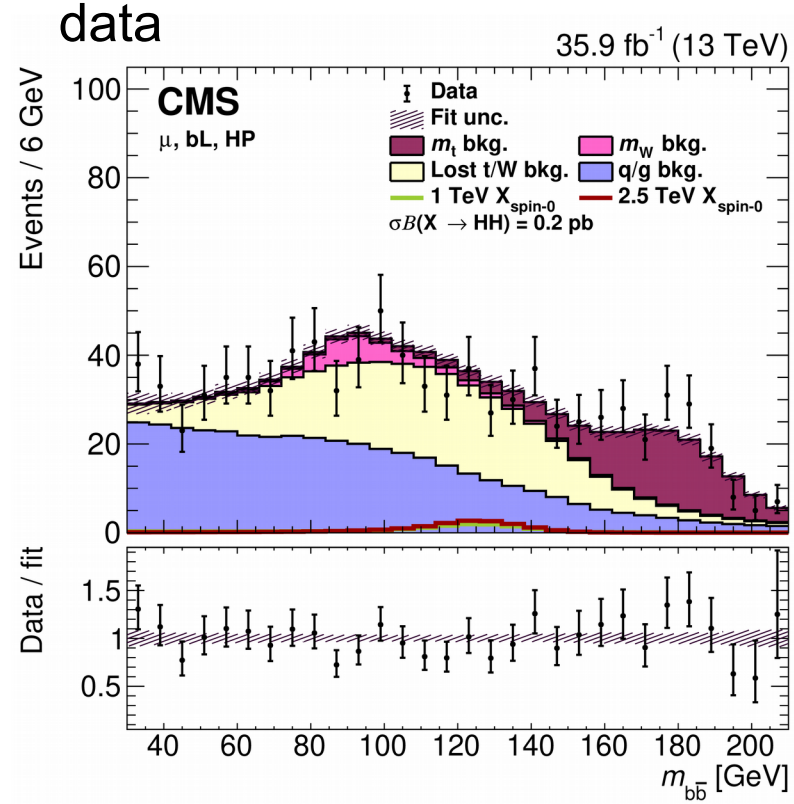
X → HH → bbWW

- Final state:
  - bbWW → **bbqqlν**
- 12 Categories:
  - Electron / Muon
  - B-tagged subjets (loose / medium / tight)
  - τ_{21} (loose / tight)
- Signal selection, i.a.:
  - H_T > 400 GeV
  - 2. Lep. p_T < 20 GeV
- Major background: $t\bar{t}$

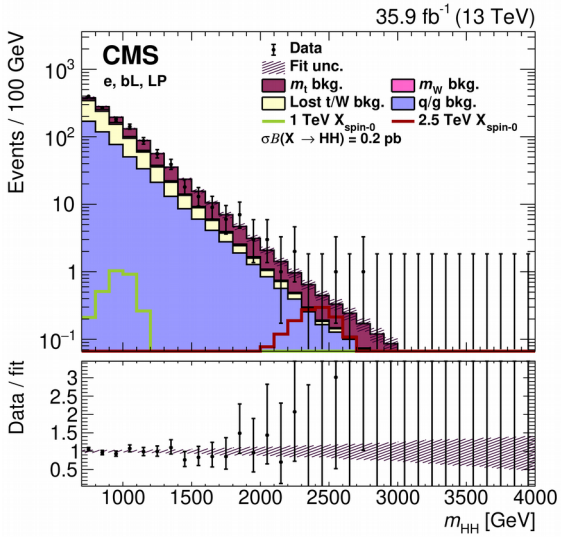
- Backgrounds are split into 4 categories based on number of generator-level quarks

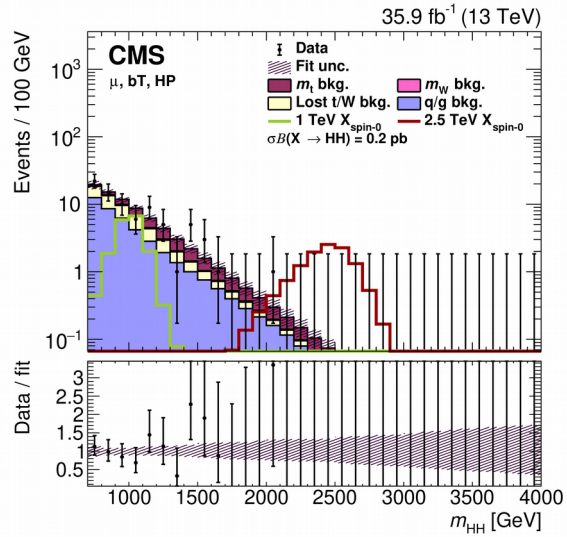
  → each has distinct m_{bb} shape

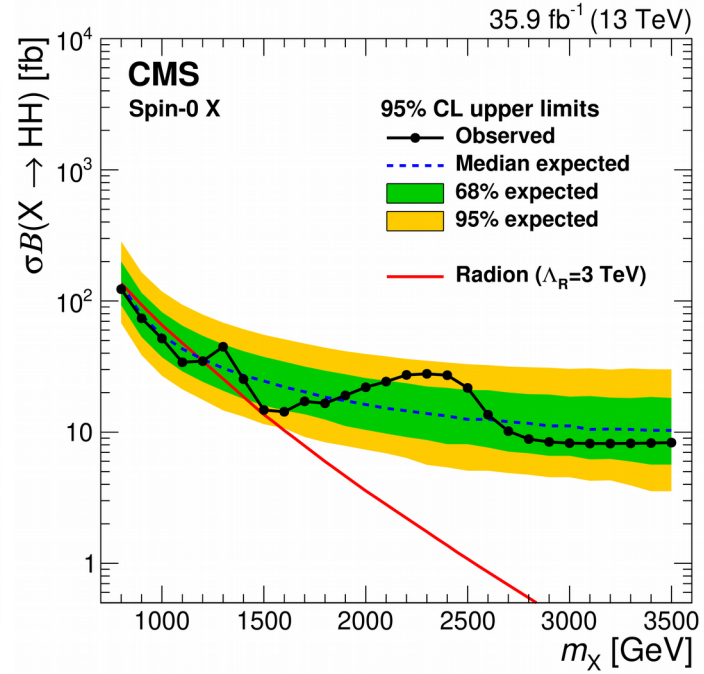
  → Signal and background yields estimated simultaneously from data



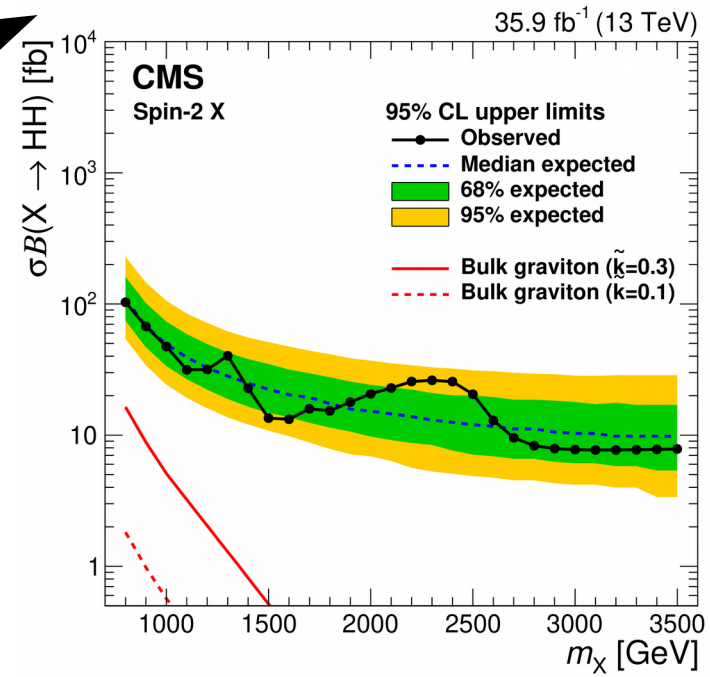
X → HH → bbWW







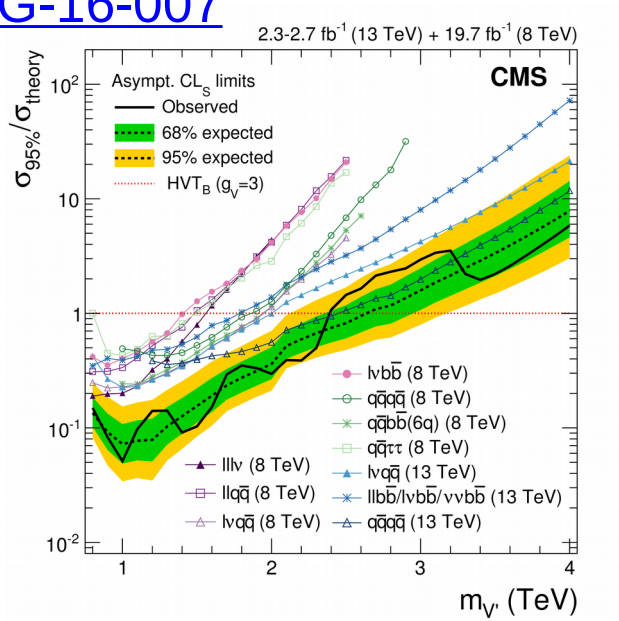
- No excess observed over expectation
- Upper limits on cross section for:
  - Spin 0 resonance
  - Spin 2 resonance



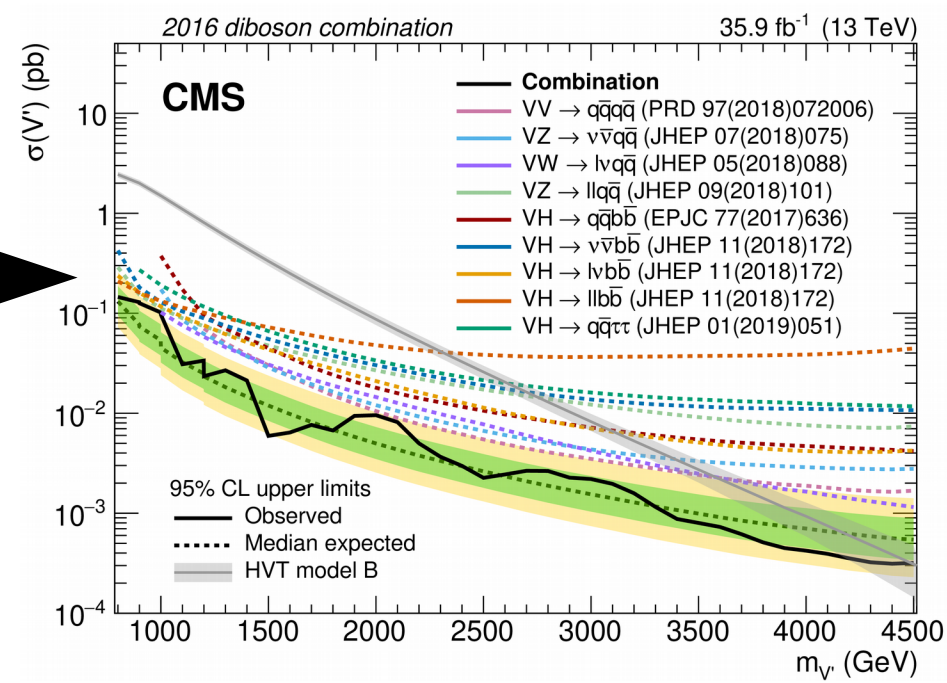
Conclusion

- Only covered a few out of 16 total analyses
- No high mass resonance observed
- Significantly improved upper limits on signals w.r.t Run 1 analyses
  - Example: Combined upper limit on HVT model B: 2.4 GeV → 4.5 GeV

B2G-16-007



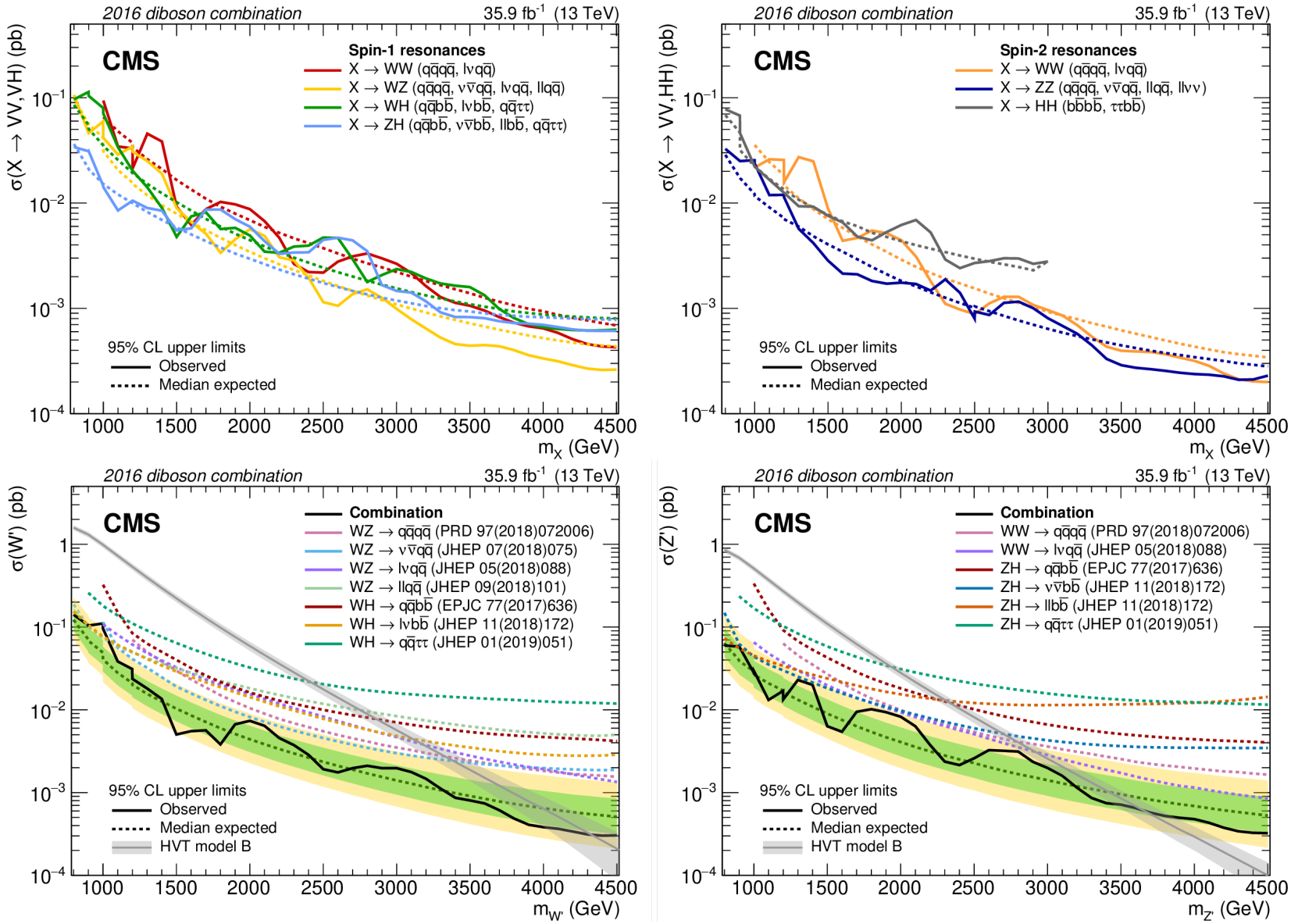
B2G-18-006



Backup

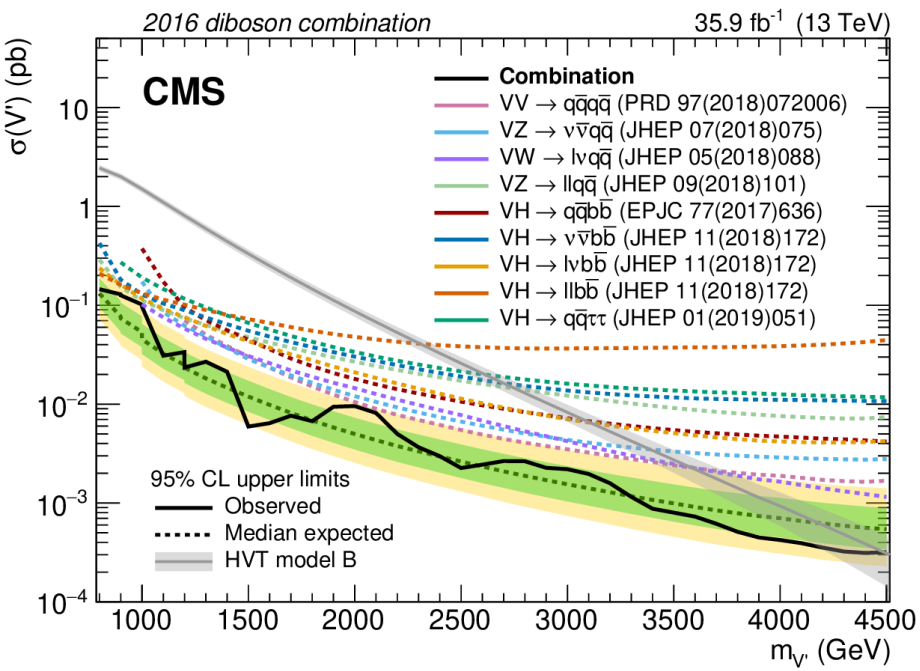
B2G-18-006

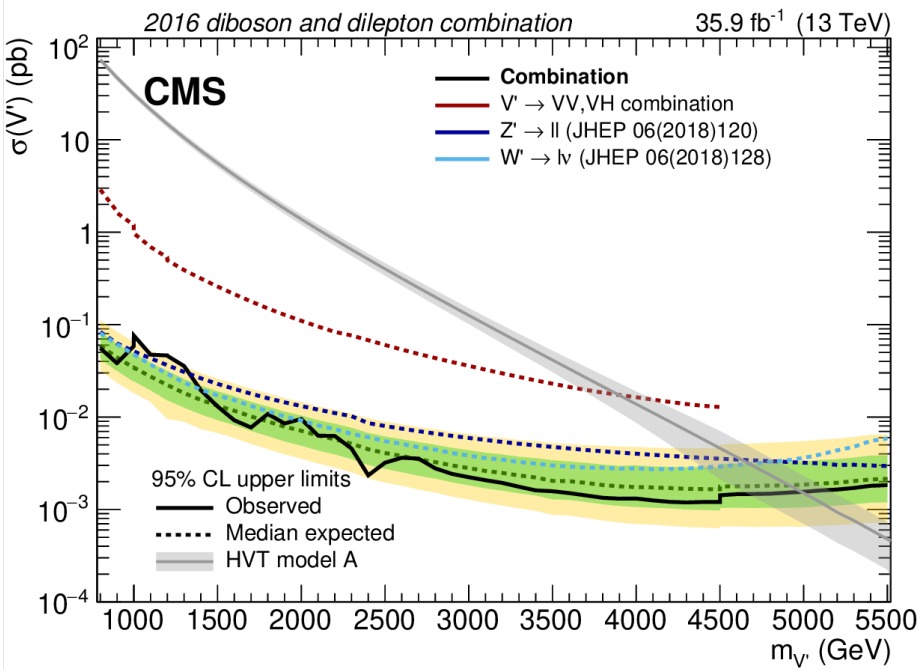
Full X → VV Combination



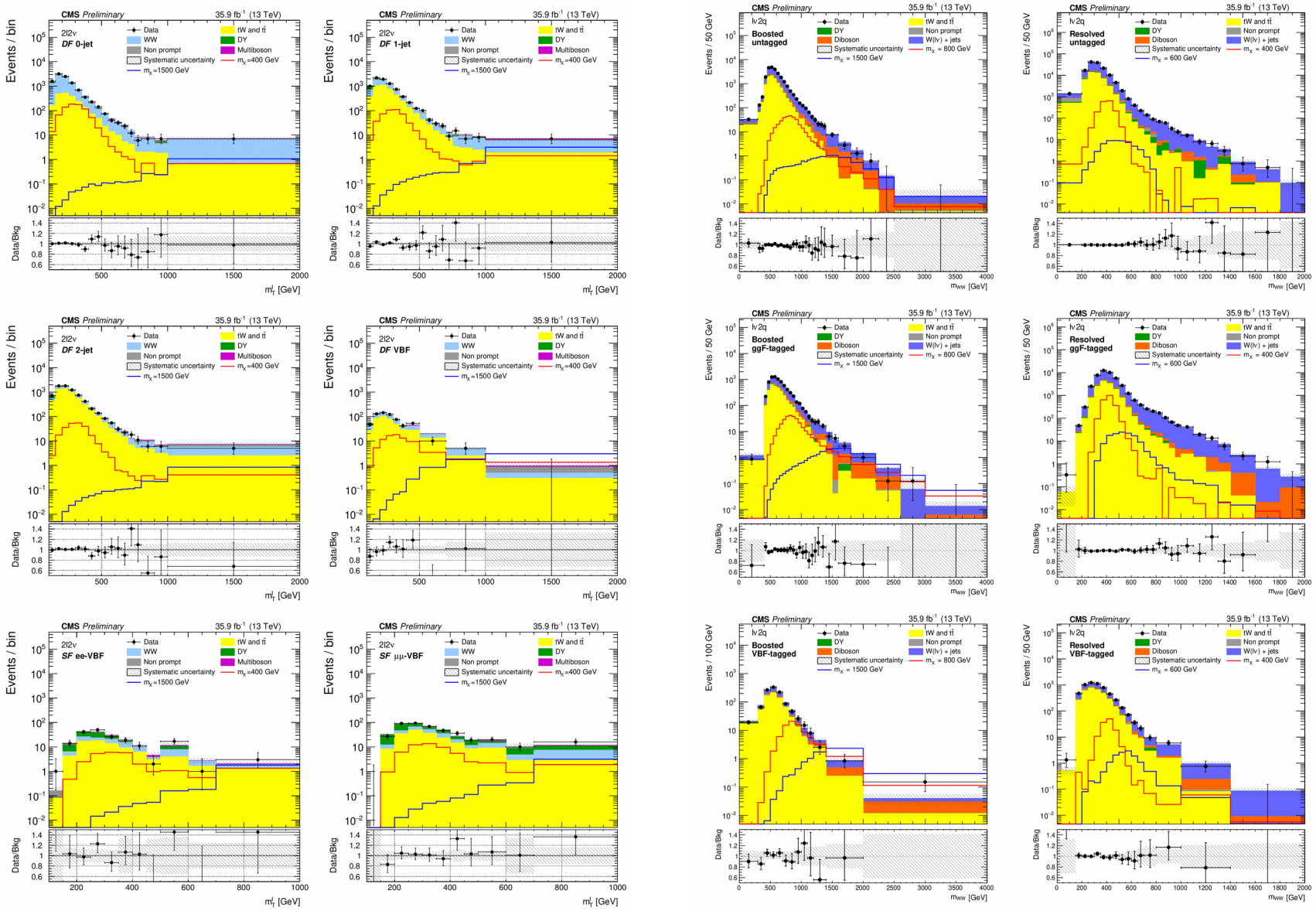
B2G-18-006

Full X → VV Combination

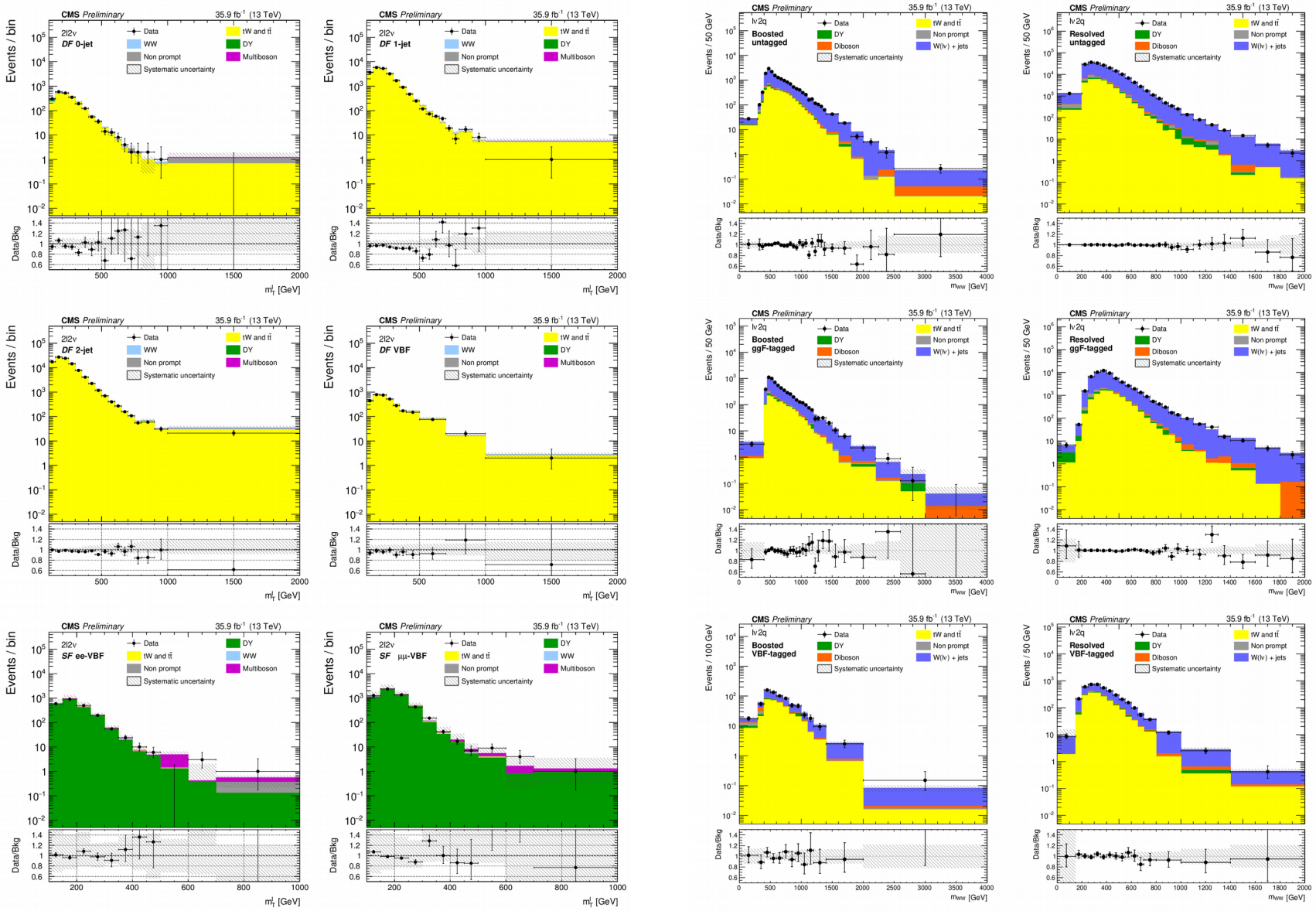




X → WW

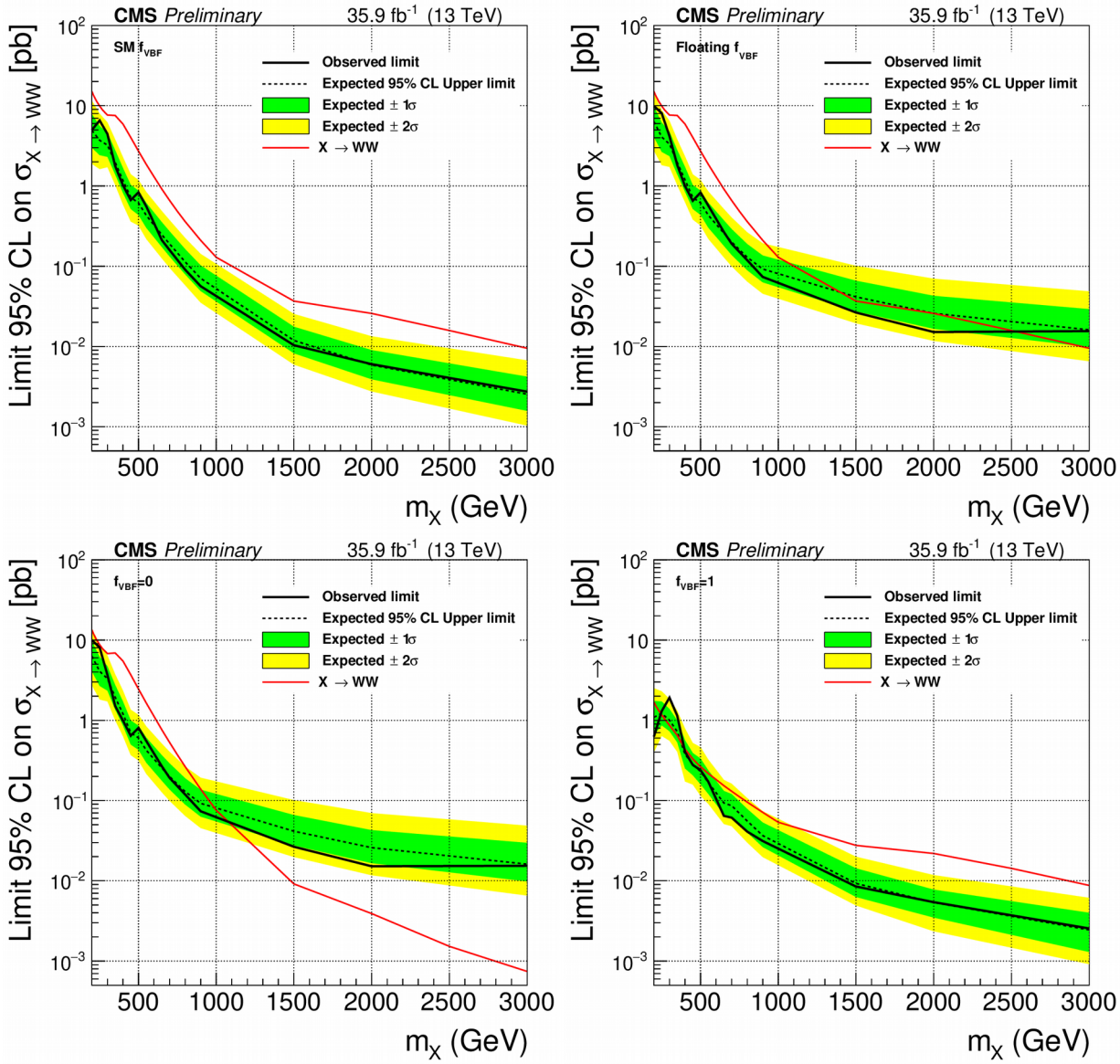

CMS Preliminary
35.9 fb^{-1} (13 TeV)
2l2ν
DF 0-jet
DF 1-jet
DF 2-jet
DF VBF
SF ee-VBF
SF μμ-VBF
Data
WW
Non prompt
Systematic uncertainty
m_X=1500 GeV
tW and tt̄
DY
Multiboson
m_X=400 GeV
Events / bin
Data/Bkg
m_T^l [GeV]
lν2q
Boosted untagged
Resolved untagged
Boosted ggF-tagged
Resolved ggF-tagged
Boosted VBF-tagged
Resolved VBF-tagged
Diboson
W(lν) + jets
m_X = 1500 GeV
m_X = 800 GeV
m_X = 600 GeV
m_X = 400 GeV
Events / 50 GeV
Events / 100 GeV
m_{WW} [GeV]

X → WW


CMS Preliminary
35.9 fb^{-1} (13 TeV)
2l2ν
DF 0-jet
DF 1-jet
DF 2-jet
DF VBF
SF ee-VBF
SF μμ-VBF
Data
WW
Non prompt
Systematic uncertainty
tW and tt̄
DY
Multiboson
Events / bin
Data/Bkg
m_T^l [GeV]
lν2q
Boosted untagged
Resolved untagged
Boosted ggF-tagged
Resolved ggF-tagged
Boosted VBF-tagged
Resolved VBF-tagged
Diboson
W(lν) + jets
Events / 50 GeV
Events / 100 GeV
m_{WW} [GeV]

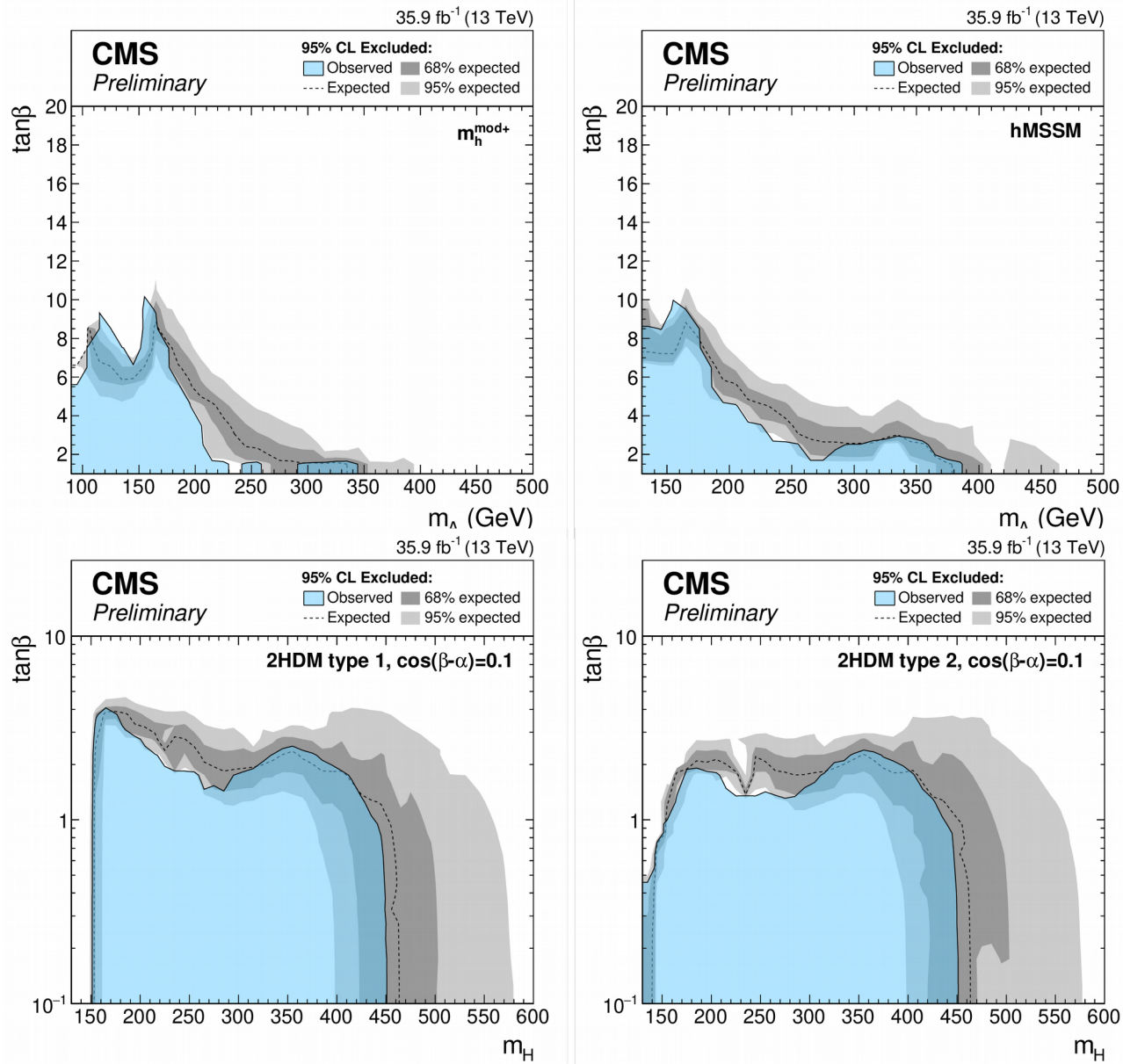
HIG-17-033

X → WW

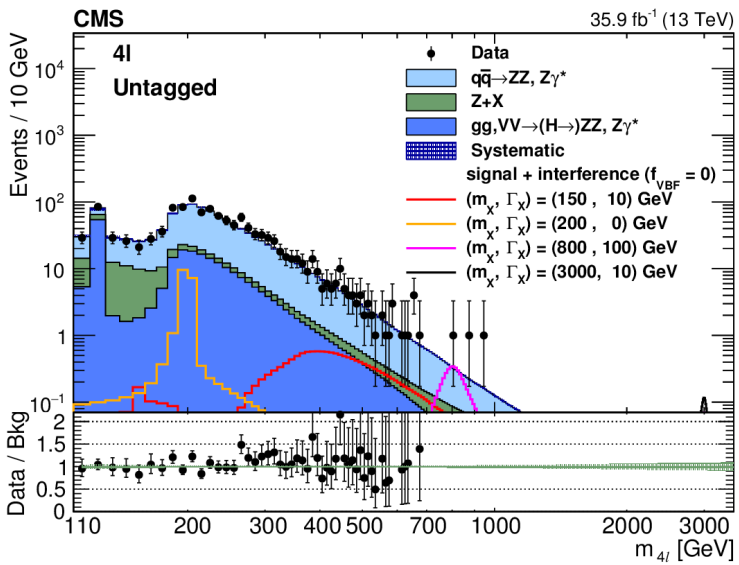


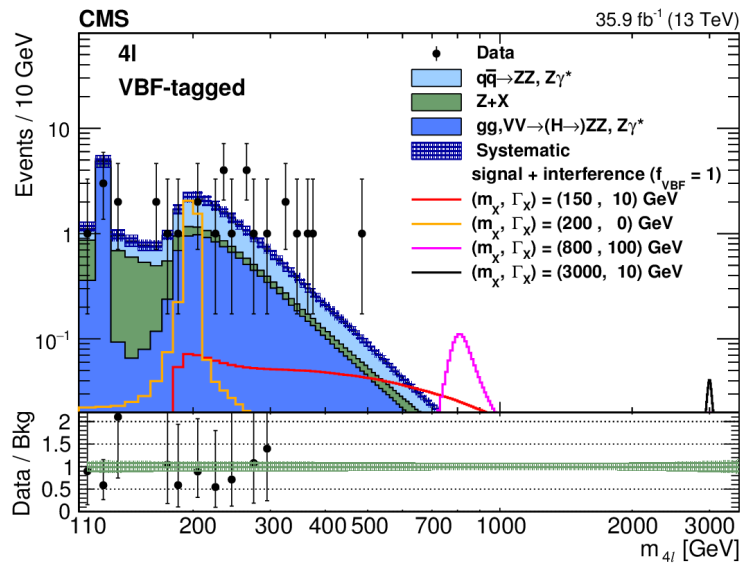
HIG-17-033

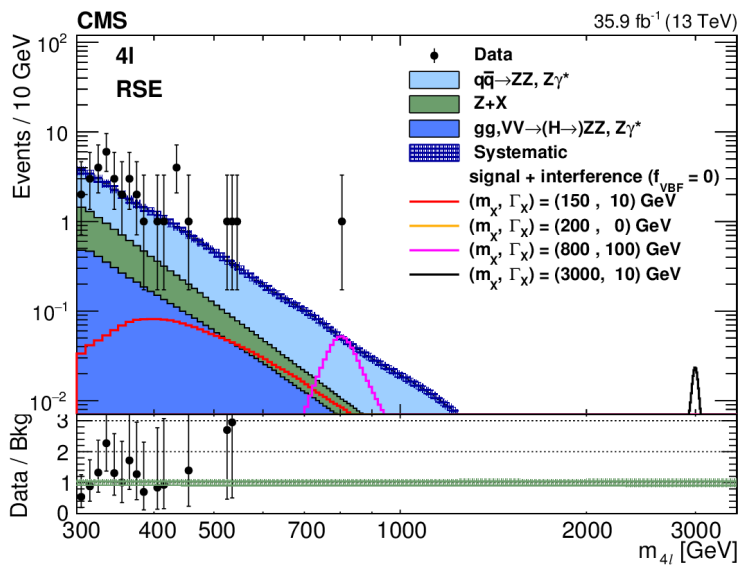
X → WW



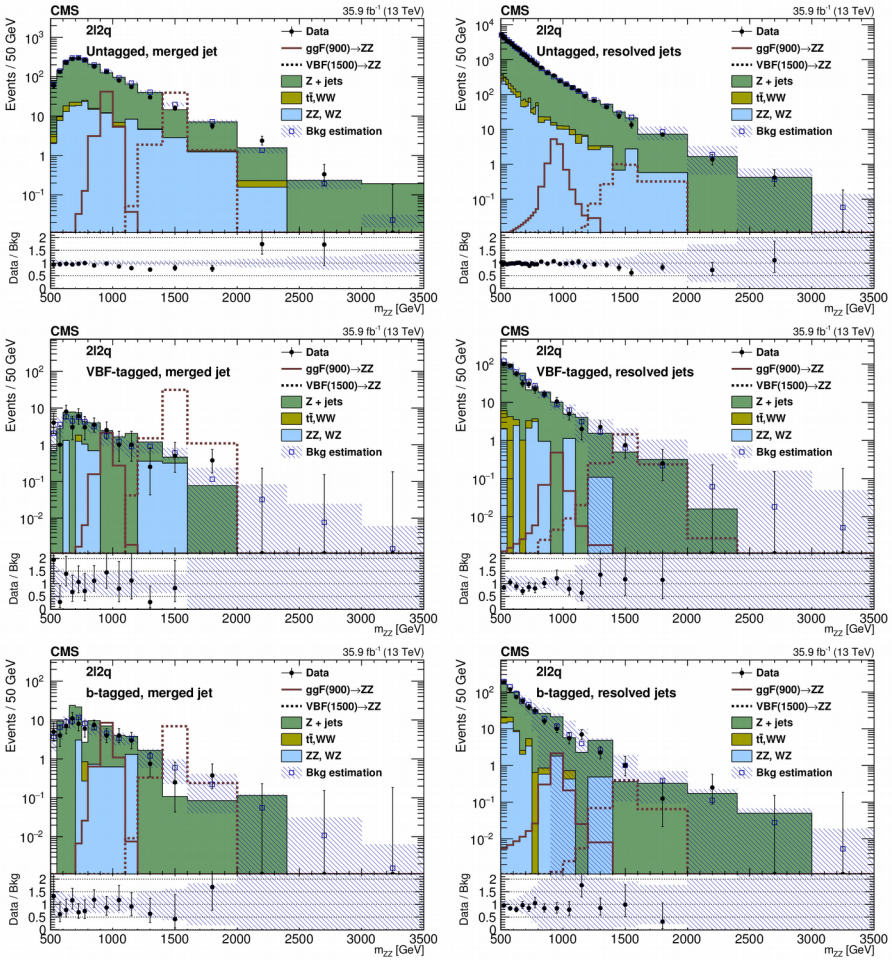
X → ZZ

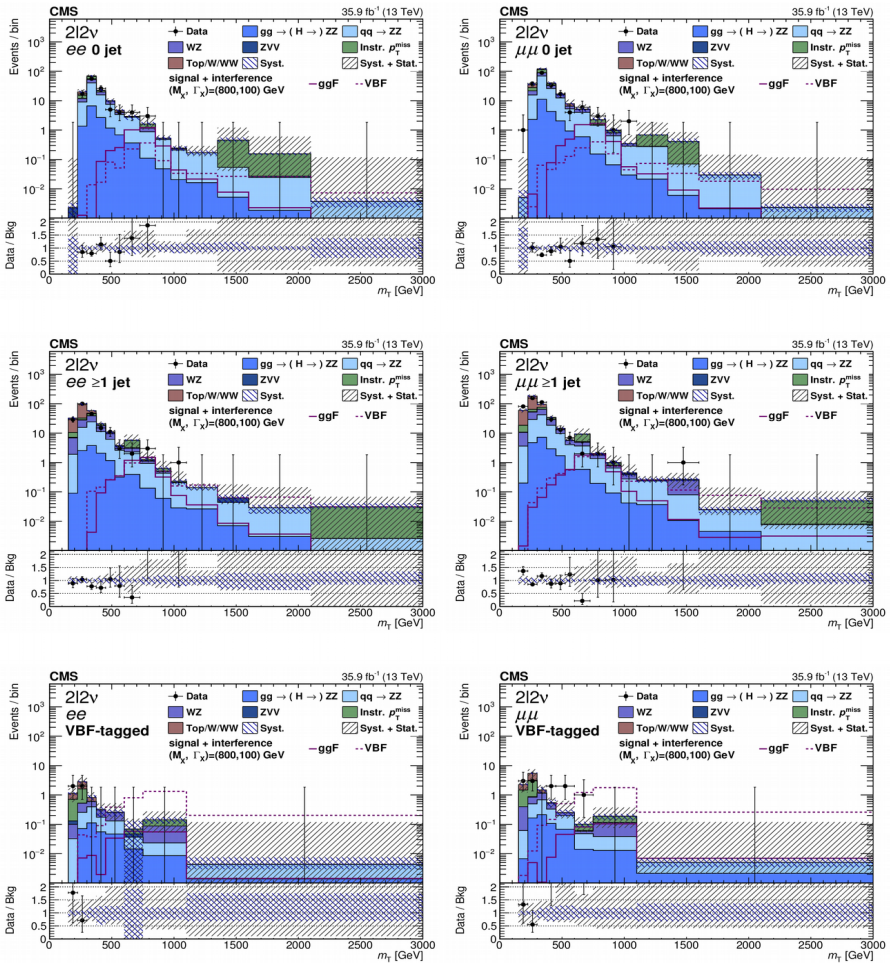

CMS
35.9 fb-1 (13 TeV)
4l
Untagged
Data
qq̄→ZZ, Zγ*
Z+X
gg,VV→(H→)ZZ, Zγ*
Systematic
signal + interference (fVBF = 0)
(mX, ΓX) = (150 , 10) GeV
(mX, ΓX) = (200 , 0) GeV
(mX, ΓX) = (800 , 100) GeV
(mX, ΓX) = (3000, 10) GeV
Events / 10 GeV
Data / Bkg
m4l [GeV]


CMS
35.9 fb-1 (13 TeV)
4l
VBF-tagged
Data
qq̄→ZZ, Zγ*
Z+X
gg,VV→(H→)ZZ, Zγ*
Systematic
signal + interference (fVBF = 1)
(mX, ΓX) = (150 , 10) GeV
(mX, ΓX) = (200 , 0) GeV
(mX, ΓX) = (800 , 100) GeV
(mX, ΓX) = (3000, 10) GeV
Events / 10 GeV
Data / Bkg
m4l [GeV]


CMS
35.9 fb-1 (13 TeV)
4l
RSE
Data
qq̄→ZZ, Zγ*
Z+X
gg,VV→(H→)ZZ, Zγ*
Systematic
signal + interference (fVBF = 0)
(mX, ΓX) = (150 , 10) GeV
(mX, ΓX) = (200 , 0) GeV
(mX, ΓX) = (800 , 100) GeV
(mX, ΓX) = (3000, 10) GeV
Events / 10 GeV
Data / Bkg
m4l [GeV]

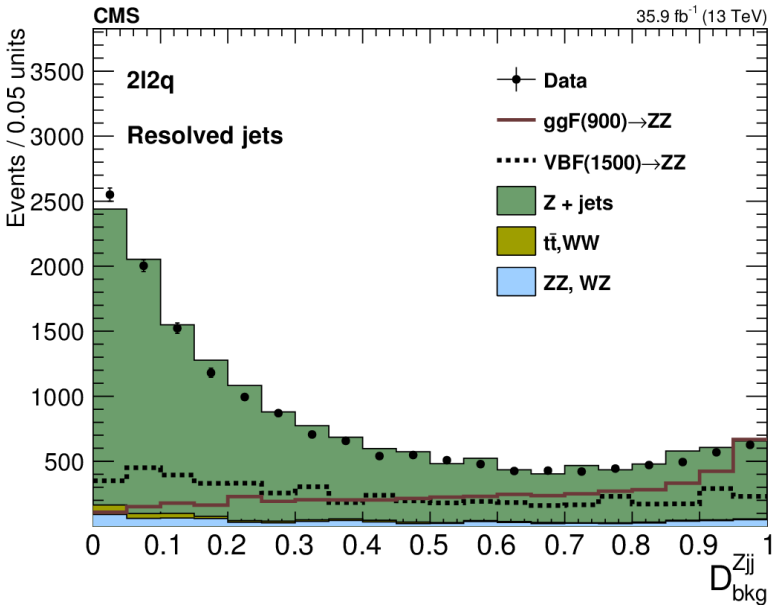
X → ZZ

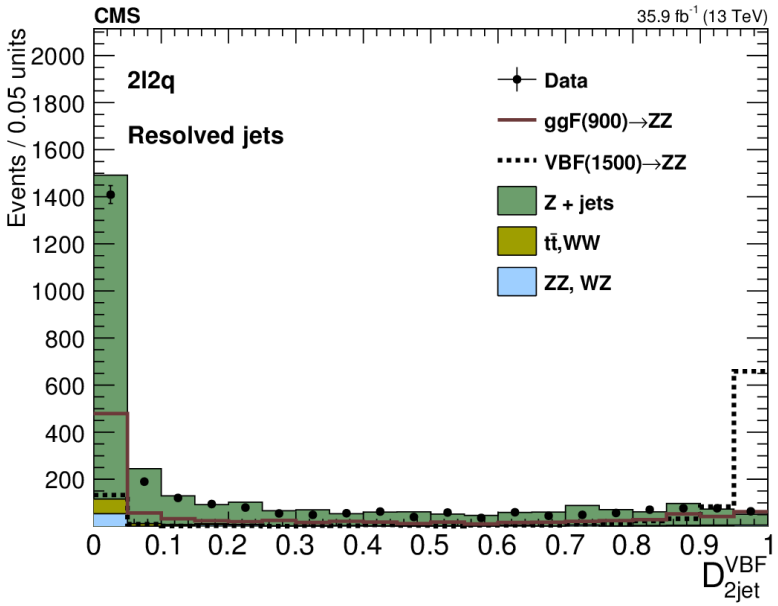

CMS
35.9 fb^{-1} (13 TeV)
2l2q
Untagged, merged jet
Untagged, resolved jets
VBF-tagged, merged jet
VBF-tagged, resolved jets
b-tagged, merged jet
b-tagged, resolved jets
Data
ggF(900)→ZZ
VBF(1500)→ZZ
Z + jets
tt̄,WW
ZZ, WZ
Bkg estimation
Events / 50 GeV
Data / Bkg
m_{ZZ} [GeV]


CMS
35.9 fb^{-1} (13 TeV)
2l2ν
ee 0 jet
μμ 0 jet
ee ≥1 jet
μμ ≥1 jet
ee
μμ
VBF-tagged
Data
gg → (H →) ZZ
qq → ZZ
WZ
ZVV
Instr. p_T^{miss}
Top/W/WW
Syst.
Syst. + Stat.
signal + interference
(M_X, Γ_X)=(800,100) GeV
ggF
VBF
Events / bin
Data / Bkg
m_T [GeV]

HIG-17-012

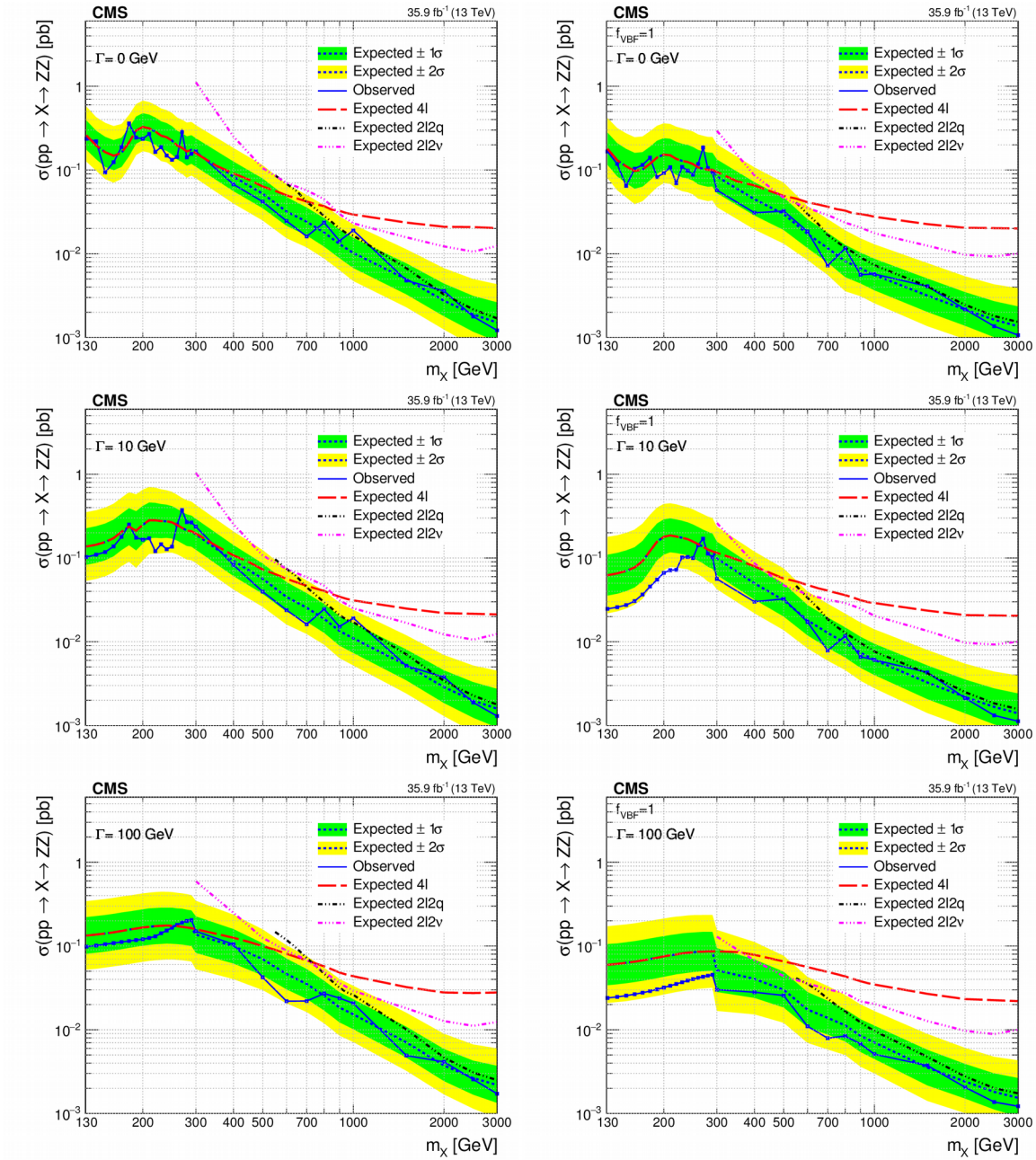
X → ZZ





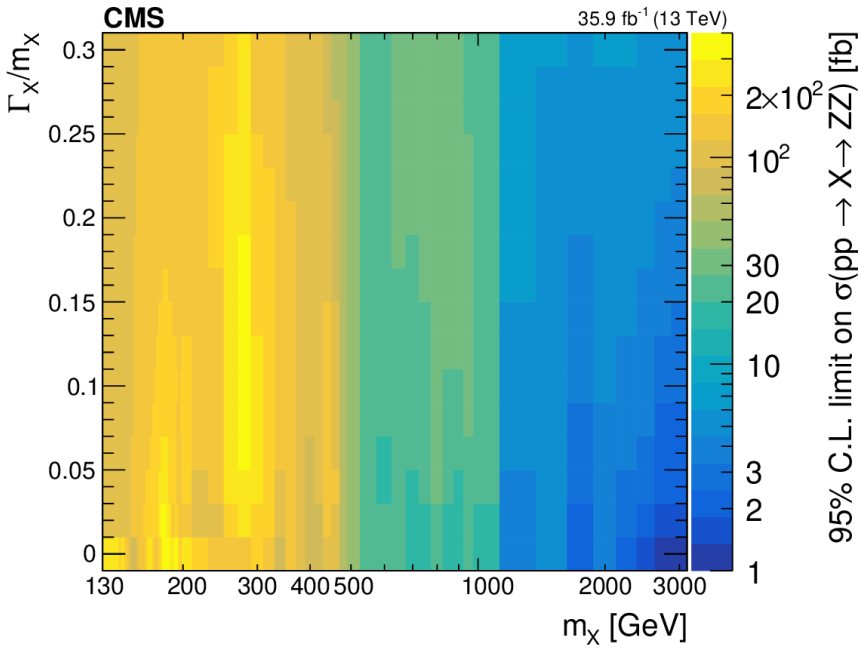
X → ZZ

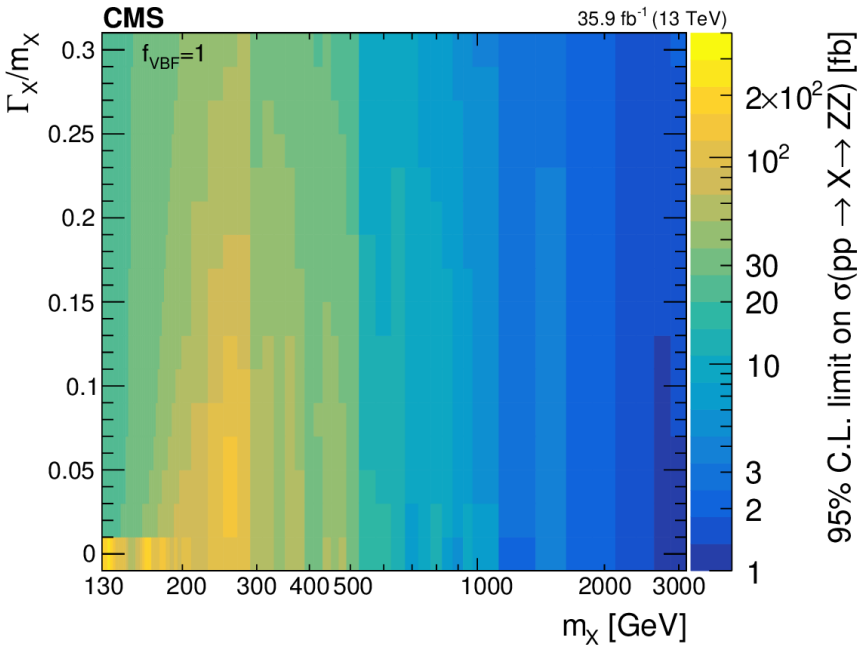
HIG-17-012



HIG-17-012

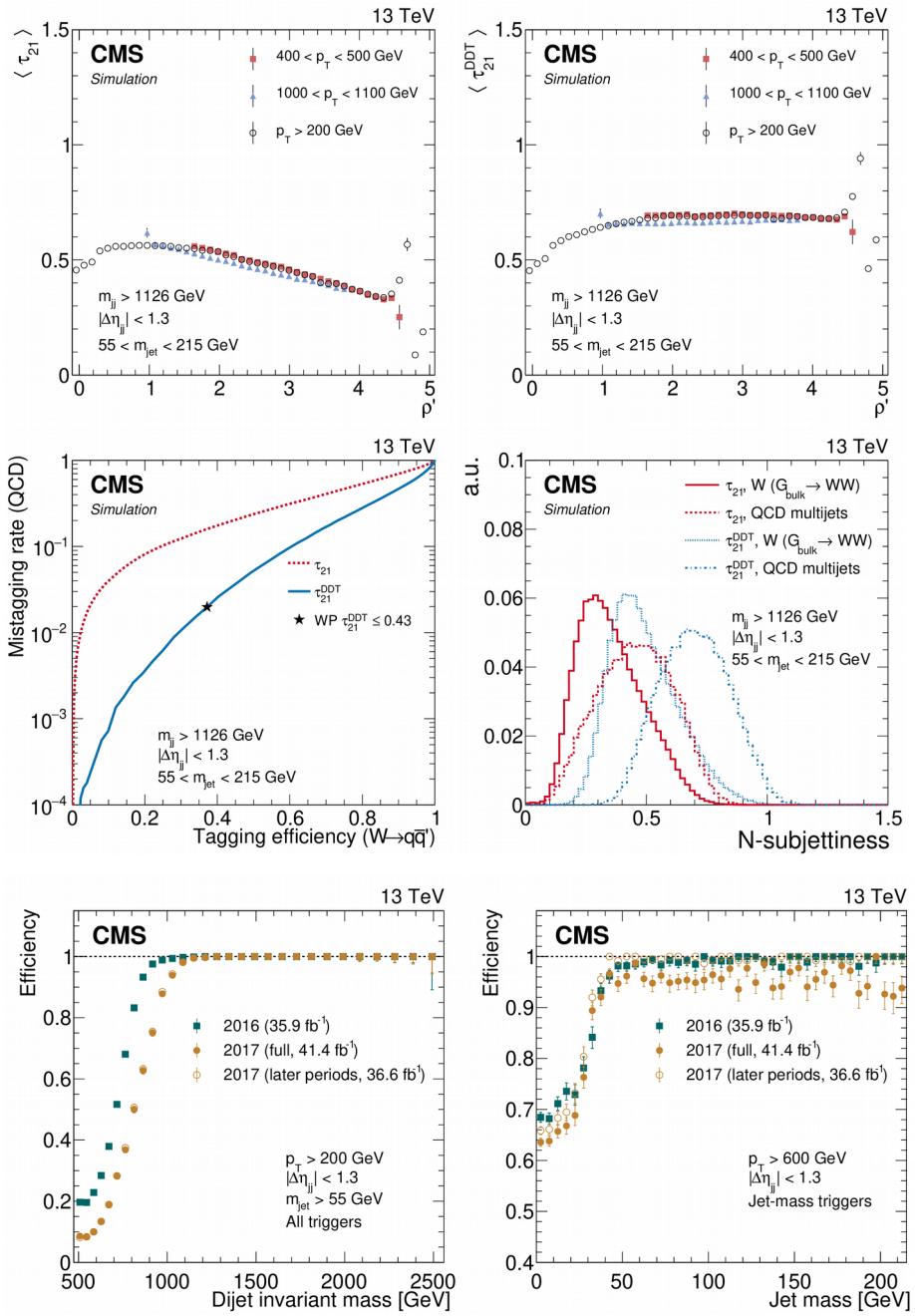
X → ZZ



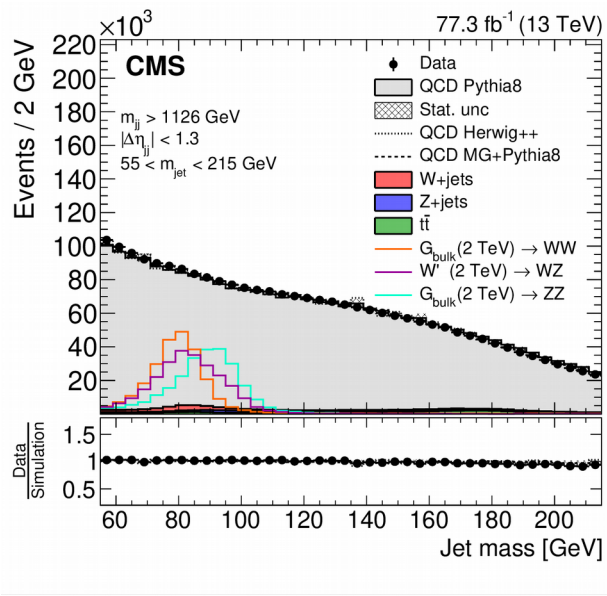


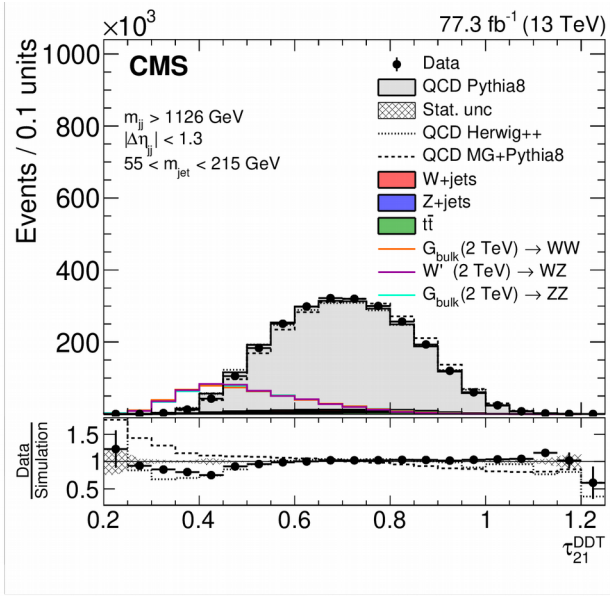
X → VV

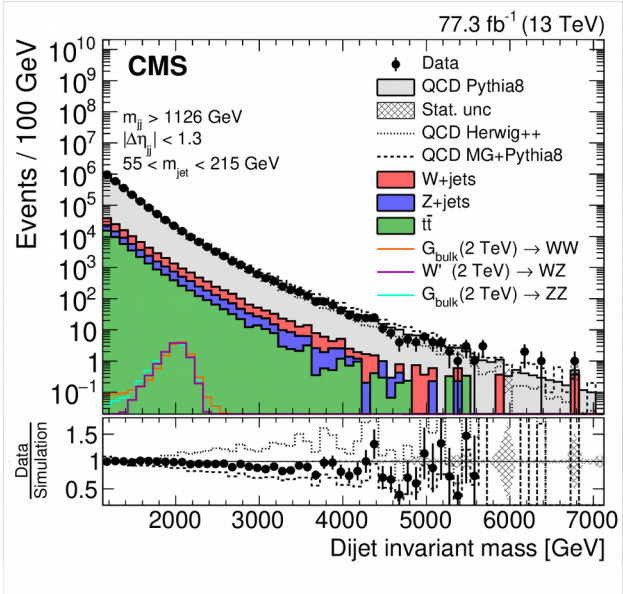
B2G-18-002



X → VV

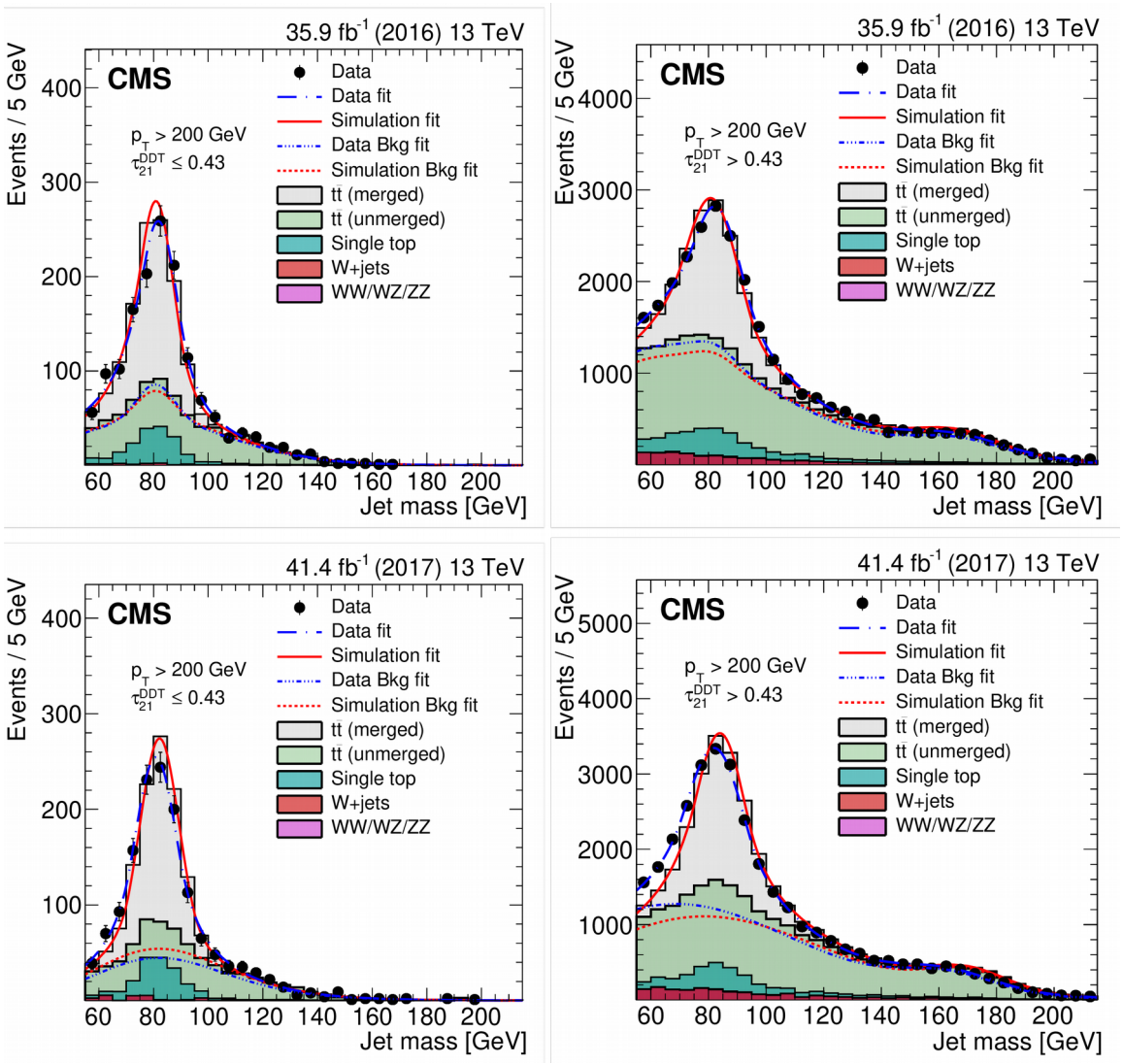

77.3 fb^{-1} (13 TeV)
CMS
m_{jj} > 1126 GeV
$|\Delta\eta_{jj}|$ < 1.3
55 < m_{jet} < 215 GeV
Data
QCD Pythia8
Stat. unc
QCD Herwig++
QCD MG+Pythia8
W+jets
Z+jets
$t\bar{t}$
G_{bulk}(2 TeV) → WW
W' (2 TeV) → WZ
G_{bulk}(2 TeV) → ZZ
Events / 2 GeV
Data / Simulation
Jet mass [GeV]


77.3 fb^{-1} (13 TeV)
CMS
m_{jj} > 1126 GeV
$|\Delta\eta_{jj}|$ < 1.3
55 < m_{jet} < 215 GeV
Data
QCD Pythia8
Stat. unc
QCD Herwig++
QCD MG+Pythia8
W+jets
Z+jets
$t\bar{t}$
G_{bulk}(2 TeV) → WW
W' (2 TeV) → WZ
G_{bulk}(2 TeV) → ZZ
Events / 0.1 units
Data / Simulation
τ_{21}^{DDT}


77.3 fb^{-1} (13 TeV)
CMS
m_{jj} > 1126 GeV
$|\Delta\eta_{jj}|$ < 1.3
55 < m_{jet} < 215 GeV
Data
QCD Pythia8
Stat. unc
QCD Herwig++
QCD MG+Pythia8
W+jets
Z+jets
$t\bar{t}$
G_{bulk}(2 TeV) → WW
W' (2 TeV) → WZ
G_{bulk}(2 TeV) → ZZ
Events / 100 GeV
Data / Simulation
Dijet invariant mass [GeV]

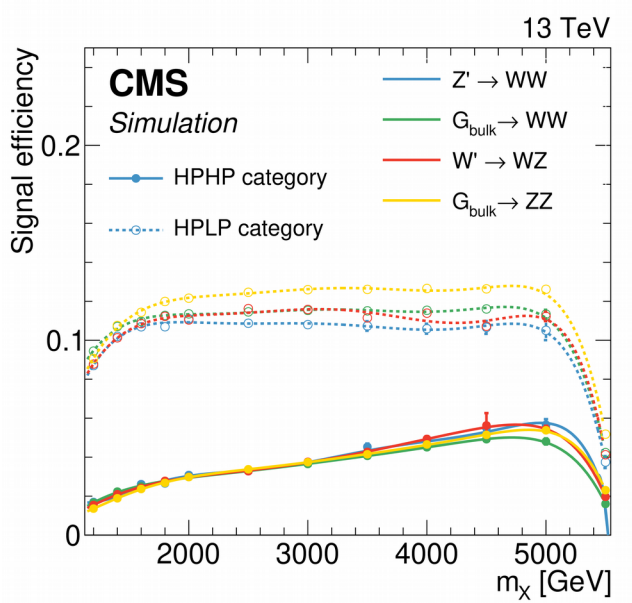
X → VV

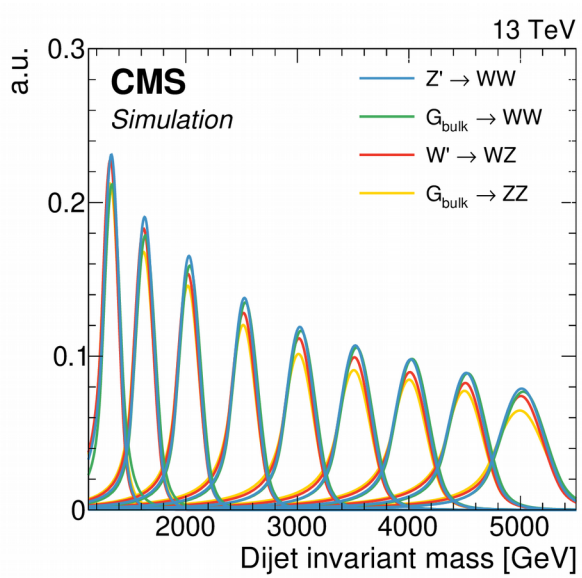
B2G-18-002

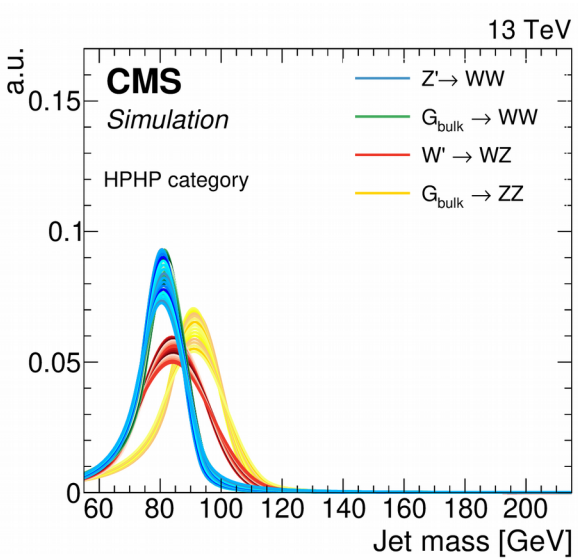


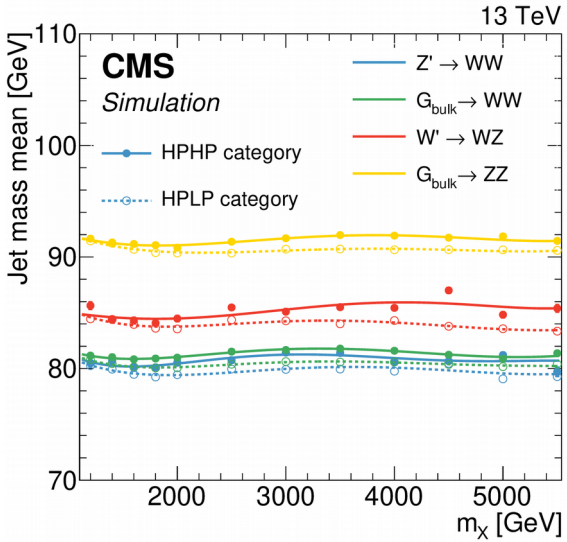
X → VV

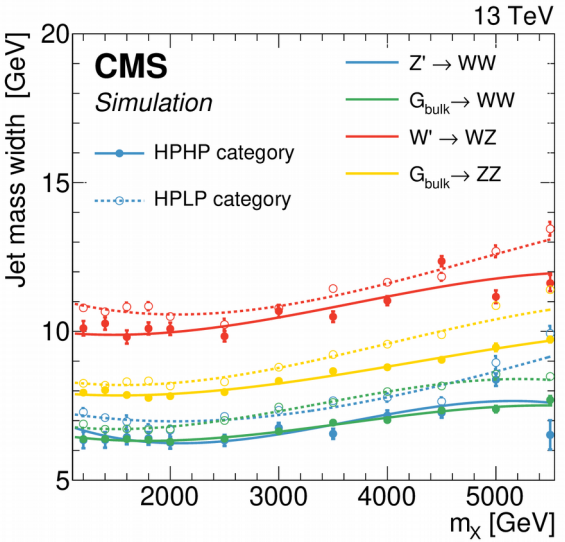
B2G-18-002



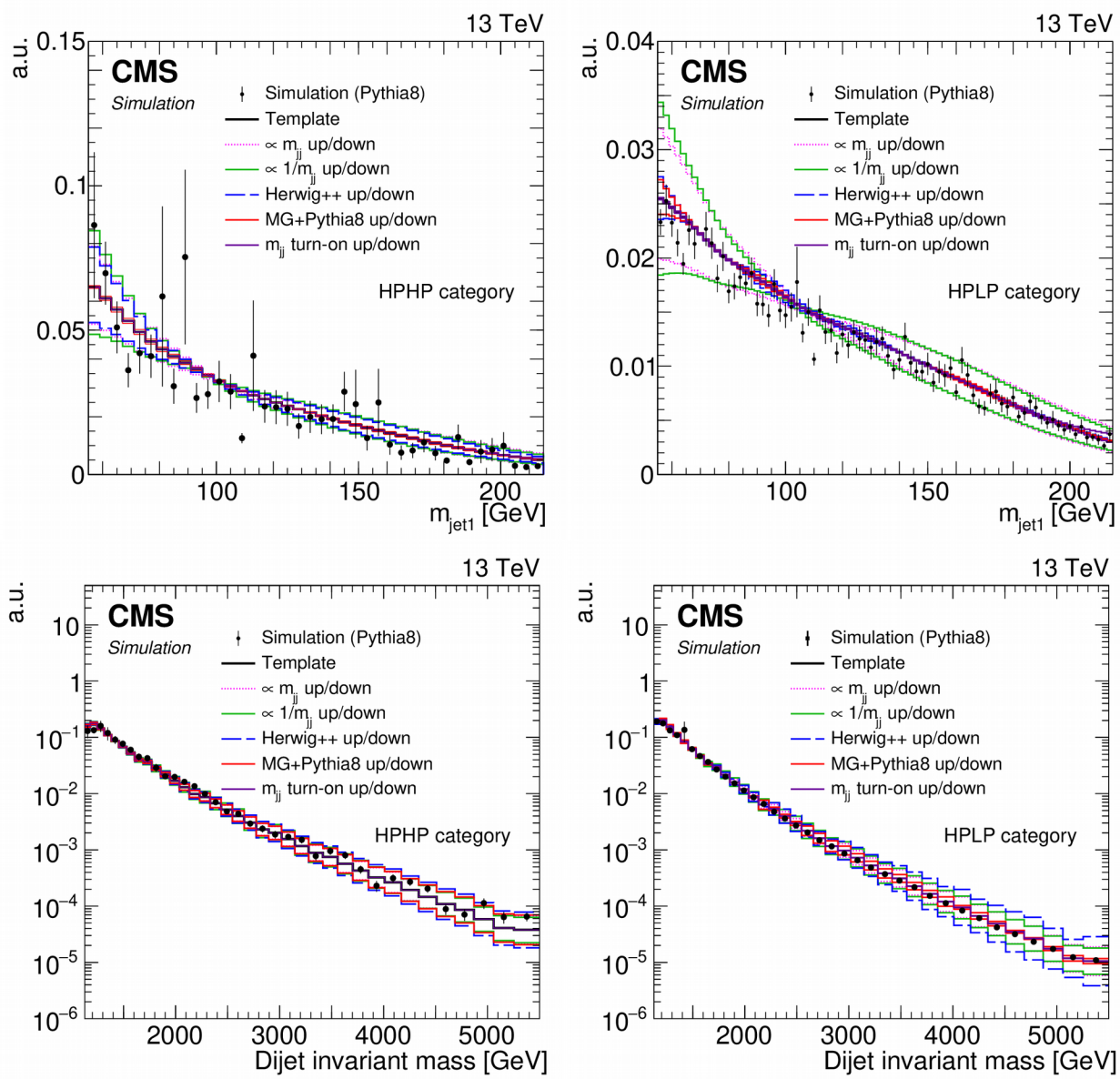




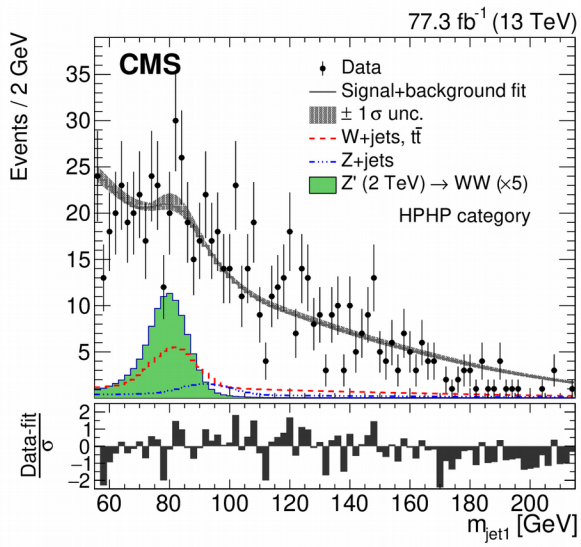


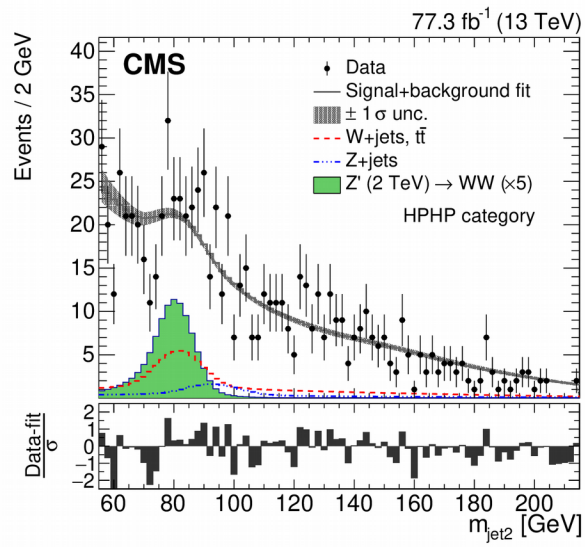


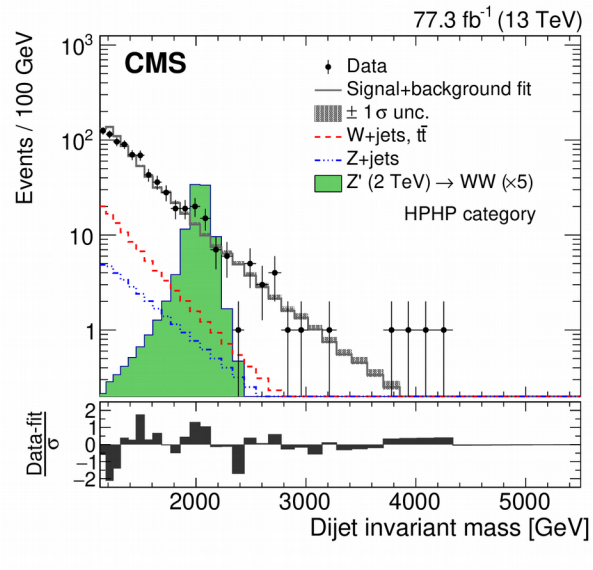
X → VV


13 TeV
CMS
Simulation
Simulation (Pythia8)
Template
∝ m_jj up/down
∝ 1/m_jj up/down
Herwig++ up/down
MG+Pythia8 up/down
m_jj turn-on up/down
HPHP category
HPLP category
a.u.
m_jet1 [GeV]
Dijet invariant mass [GeV]

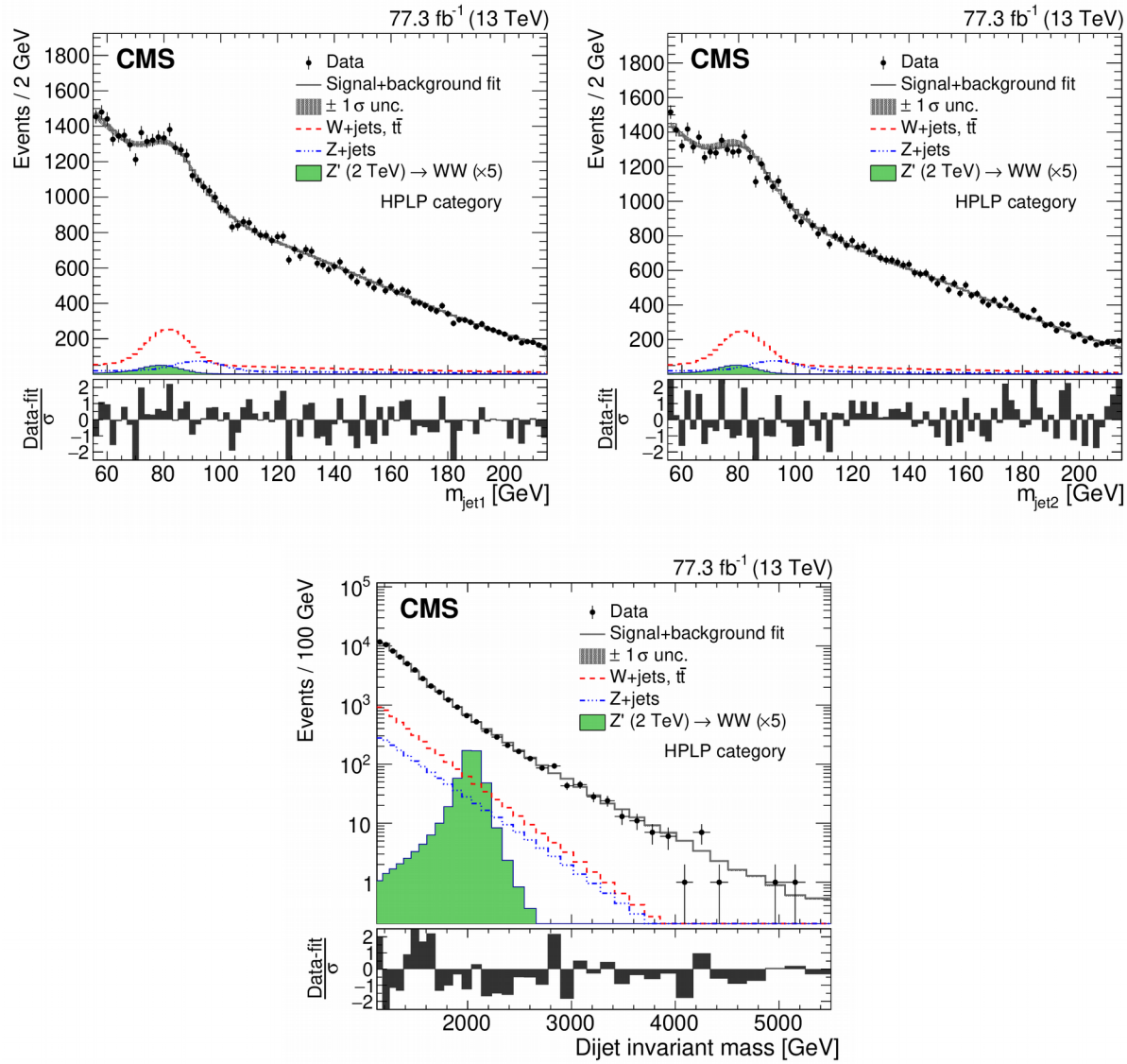
X → VV


77.3 fb^{-1} (13 TeV)
CMS
Data
Signal+background fit
± 1 σ unc.
W+jets, tt̄
Z+jets
Z' (2 TeV) → WW (×5)
HPHP category
Events / 2 GeV
Data-fit / σ
m$_{jet1}$ [GeV]


77.3 fb^{-1} (13 TeV)
CMS
Data
Signal+background fit
± 1 σ unc.
W+jets, tt̄
Z+jets
Z' (2 TeV) → WW (×5)
HPHP category
Events / 2 GeV
Data-fit / σ
m$_{jet2}$ [GeV]

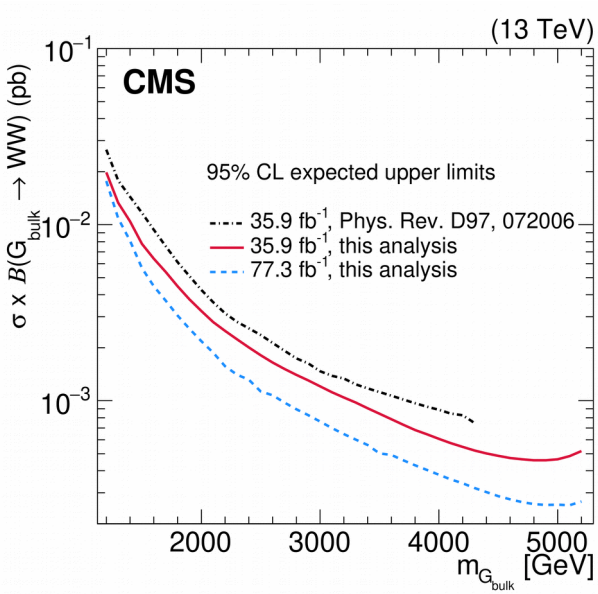

77.3 fb^{-1} (13 TeV)
CMS
Data
Signal+background fit
± 1 σ unc.
W+jets, tt̄
Z+jets
Z' (2 TeV) → WW (×5)
HPHP category
Events / 100 GeV
Data-fit / σ
Dijet invariant mass [GeV]

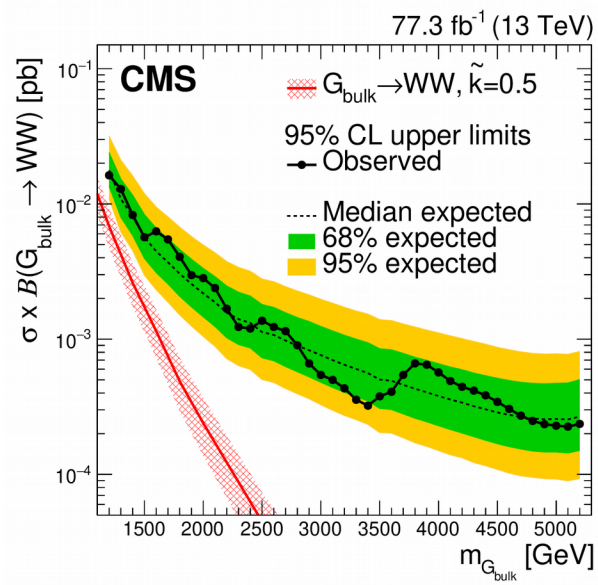
X → VV

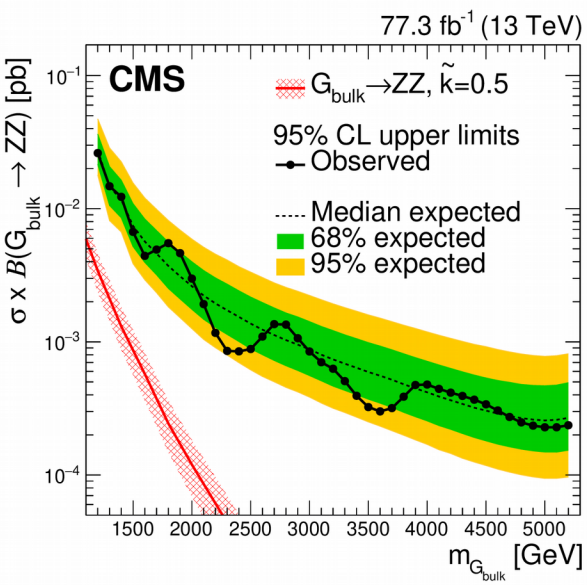

77.3 fb^{-1} (13 TeV)
CMS
Data
Signal+background fit
± 1 σ unc.
W+jets, tt̄
Z+jets
Z' (2 TeV) → WW (×5)
HPLP category
Events / 2 GeV
Data-fit / σ
m$_{jet1}$ [GeV]
m$_{jet2}$ [GeV]
Events / 100 GeV
Dijet invariant mass [GeV]

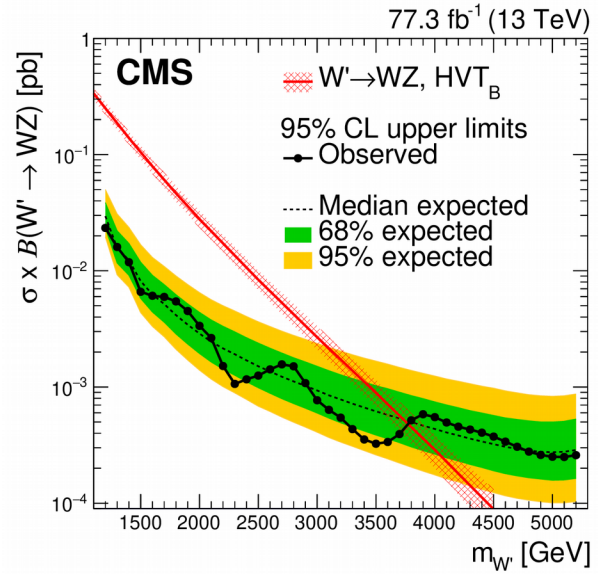
X → VV

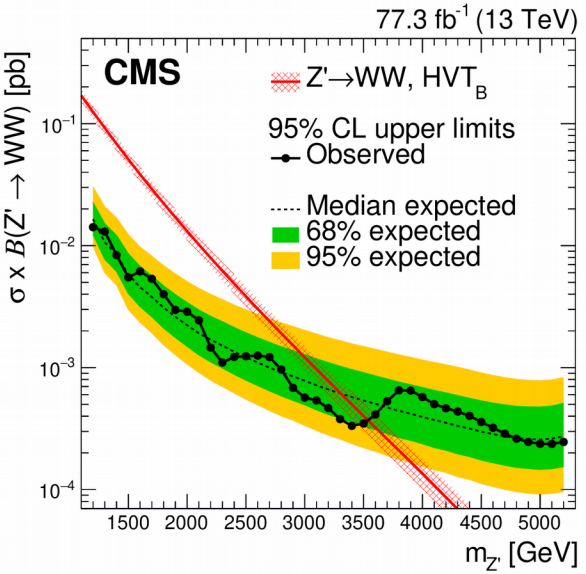
B2G-18-002





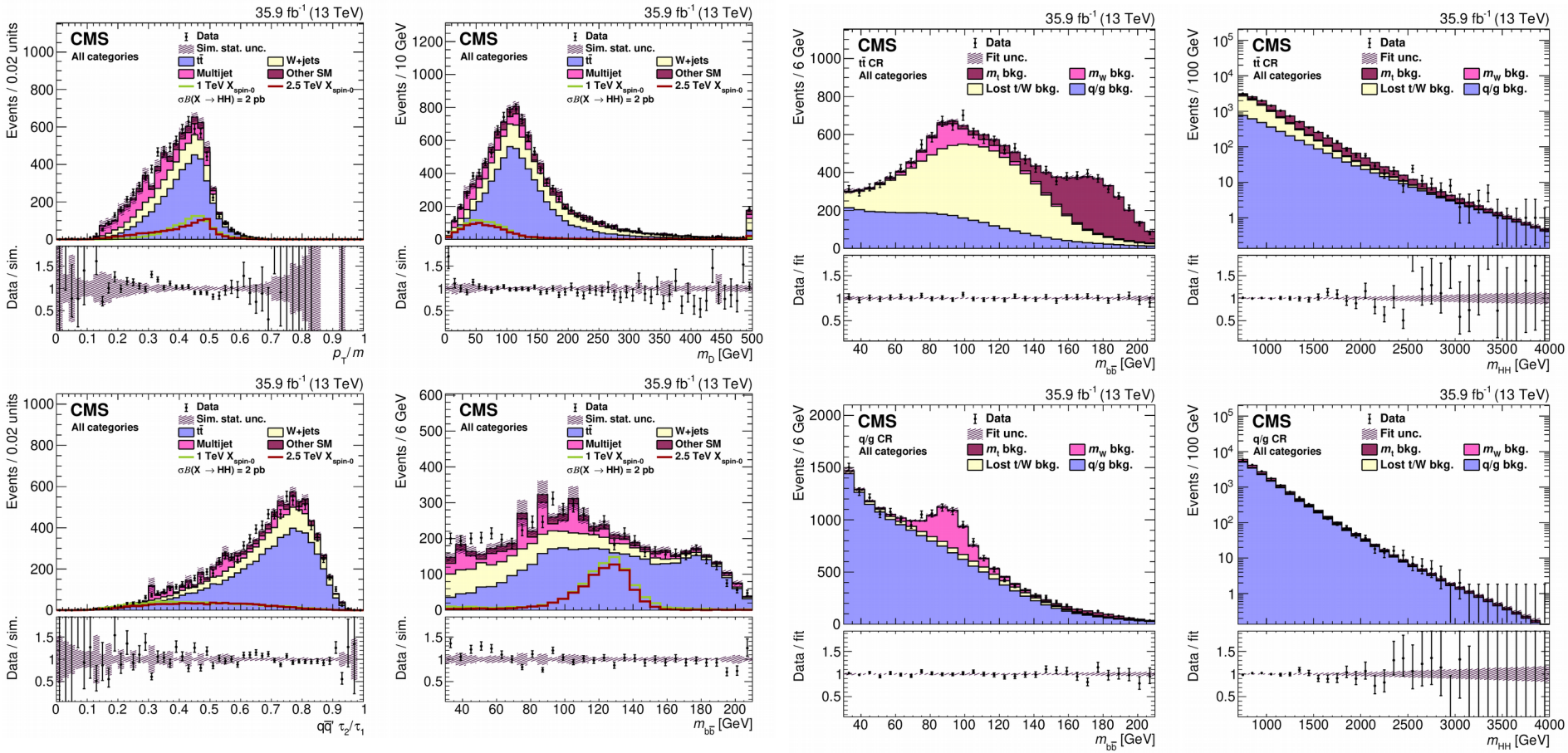






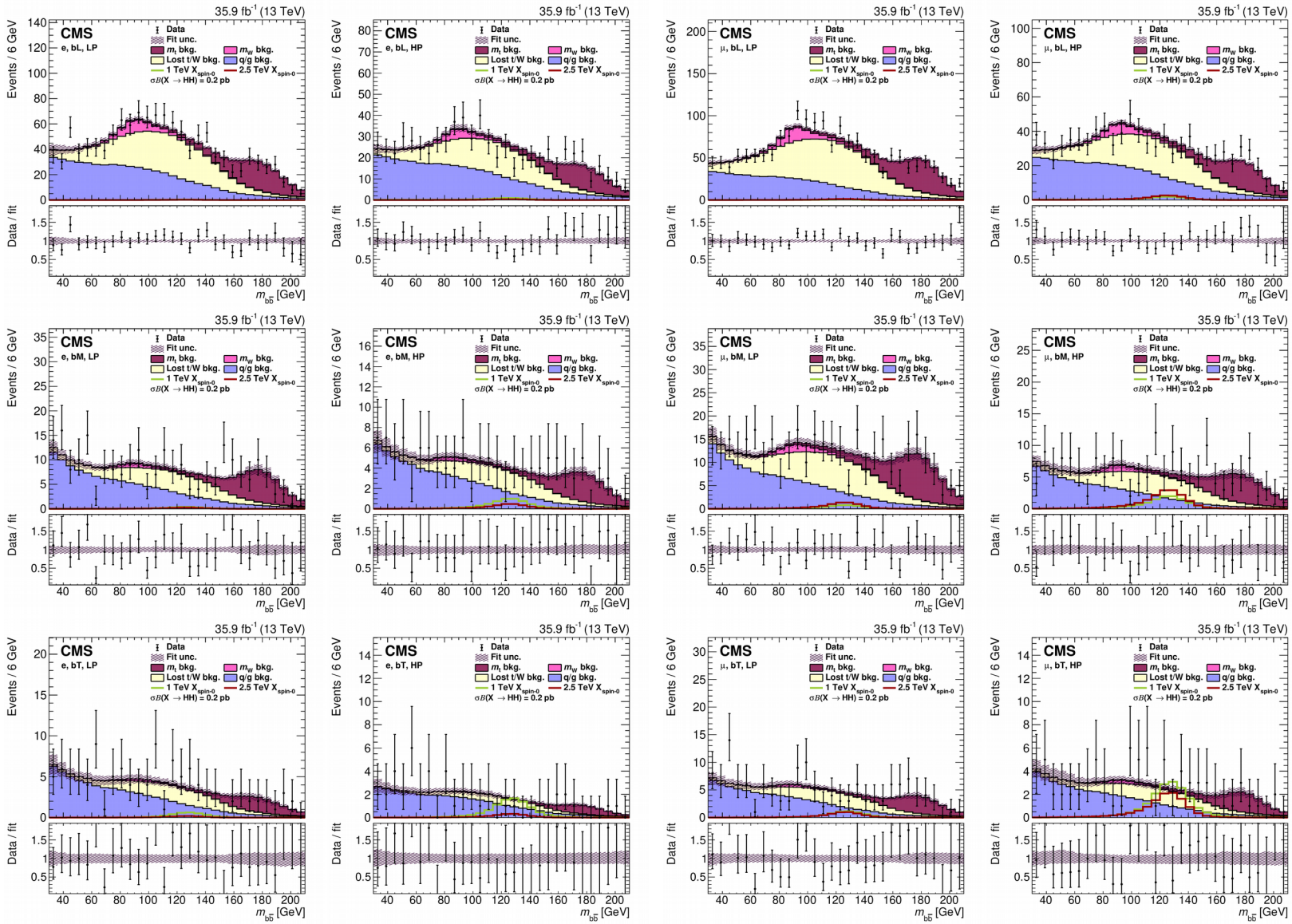
B2G-18-008

X → HH → bbWW



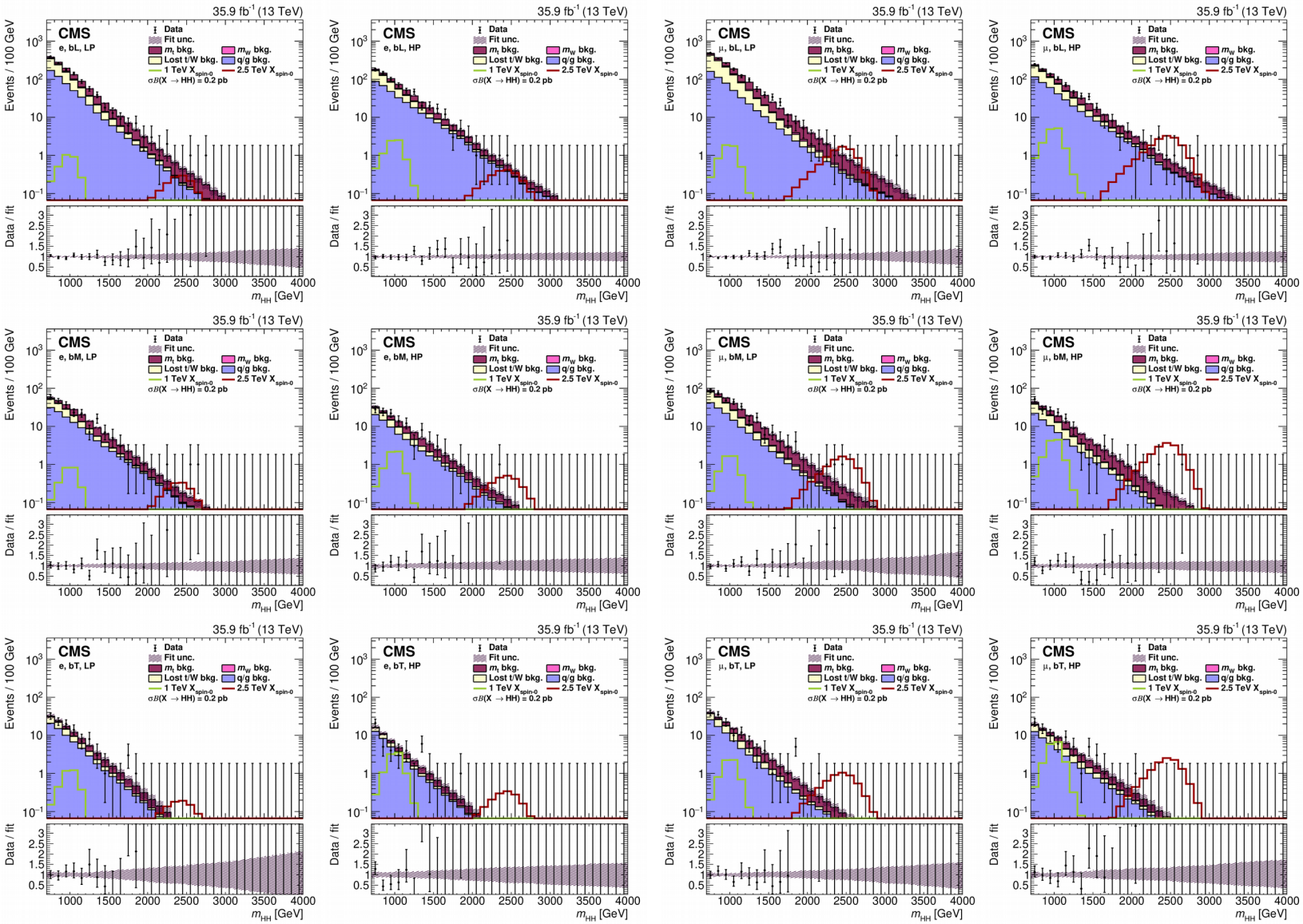
B2G-18-008

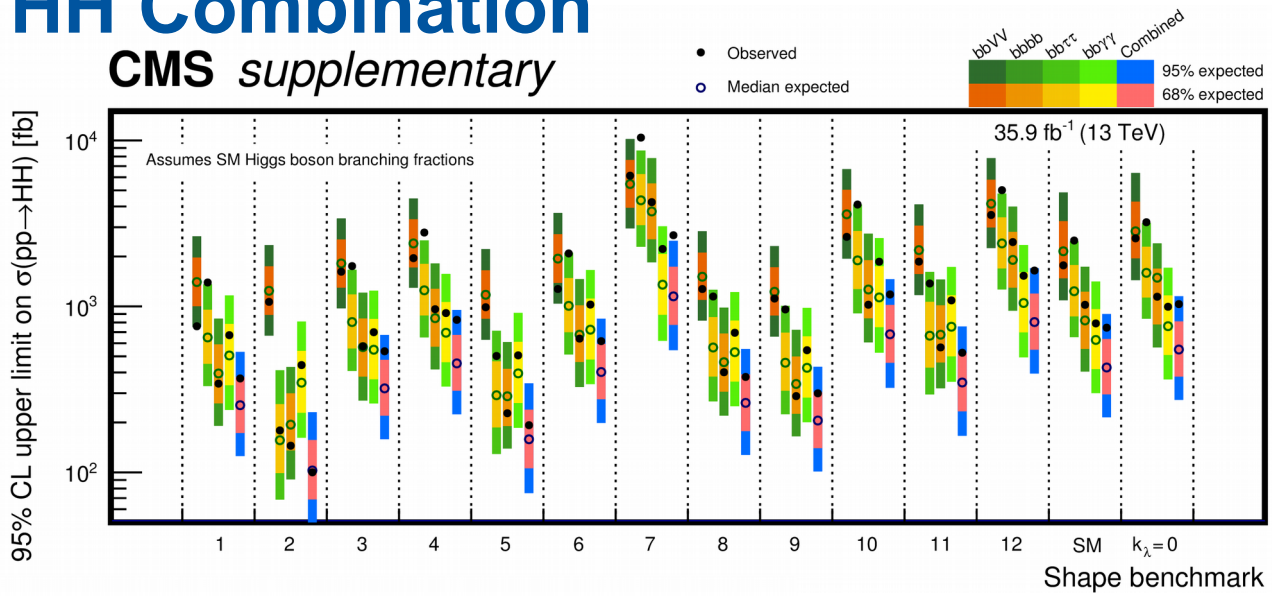
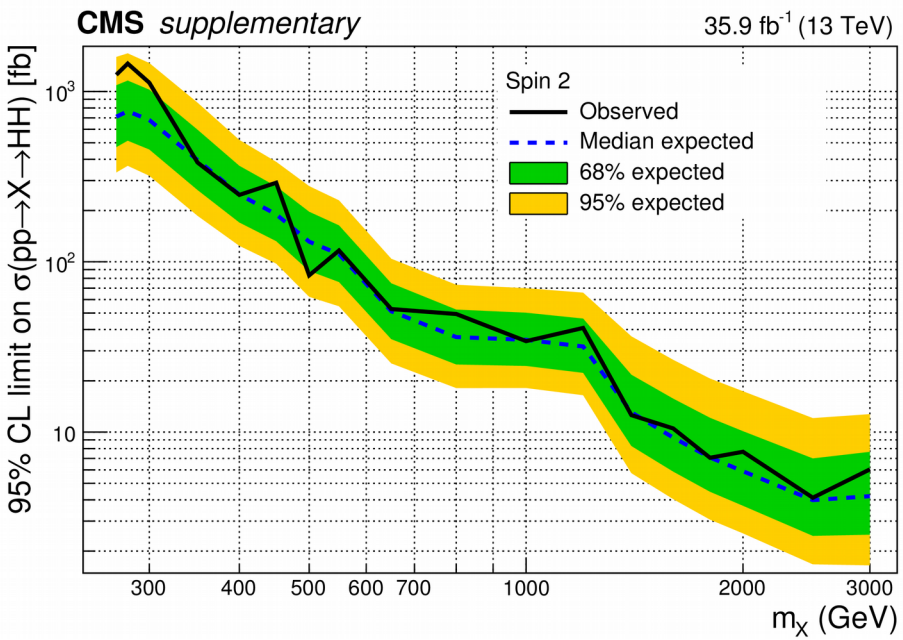
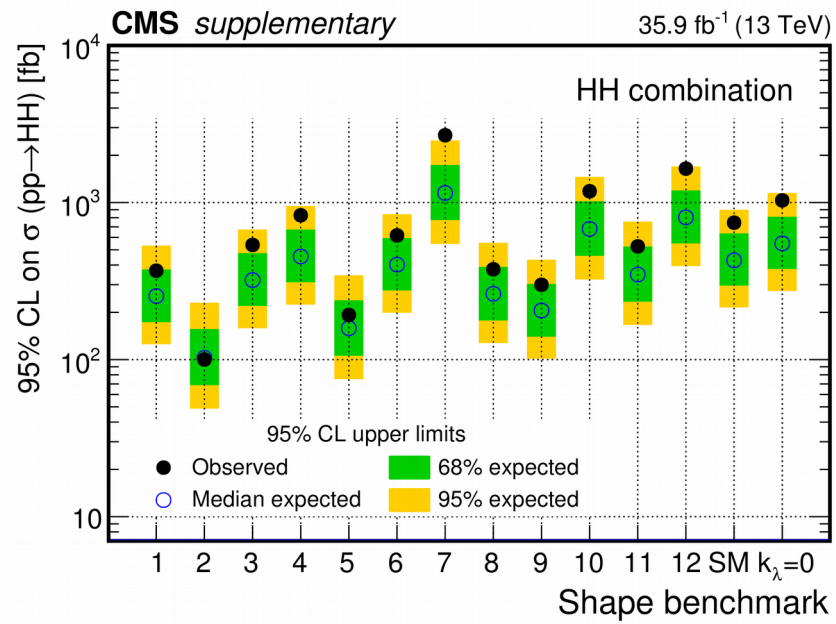
X → HH → bbWW



B2G-18-008

X → HH → bbWW



HIG-17-030

X → HH Combination