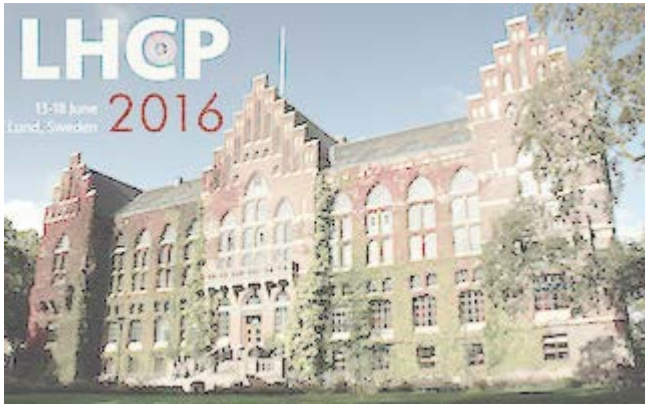


Searches for diboson resonances with the CMS experiment

Jordan Damgov (Texas Tech University)
on behalf of the CMS Collaboration

LHCP 2016, Lund, Sweden, June 13–18, 2016

Outline

Resonance searches with boosted topologies at 13 TeV (m_X above 800 GeV)

- Reconstruction techniques for studies with boosted topologies
- VH → llbb,lvbb,vvbb (CMS-PAS-B2G-16-003)
- VV → lvqq, qqqq (CMS-PAS-EXO-15-002)
- VW → lvqq, low mass extension (CMS-PAS-B2G-16-004)
- VV and VH combination 8 and 13 TeV (CMS-PAS-B2G-16-007)

Resonance searches with non-boosted topologies (m_X in 250-1200 GeV)

- Zγ → llγ, qqγ (CMS-PAS-EXO-16-019, CMS-PAS-EXO-16-020)
- ZZ → 2l2ν (CMS-PAS-HIG-16-001)
- HH → bbbb (CMS-PAS-HIG-16-002)
- HH → WWbb → lνlνbb (CMS-PAS-HIG-16-011)
- HH → ττbb (CMS-PAS-HIG-16-013)

**More recent results*

Theory models (typical benchmark):

- Spin-0: Radion; two Higgs doublet model (2HDM), etc.-
- Spin-1: Heavy Vector Triplet (model B)
- Spin-2:Bulk scenario of RS Wrapped Extra Dimensions

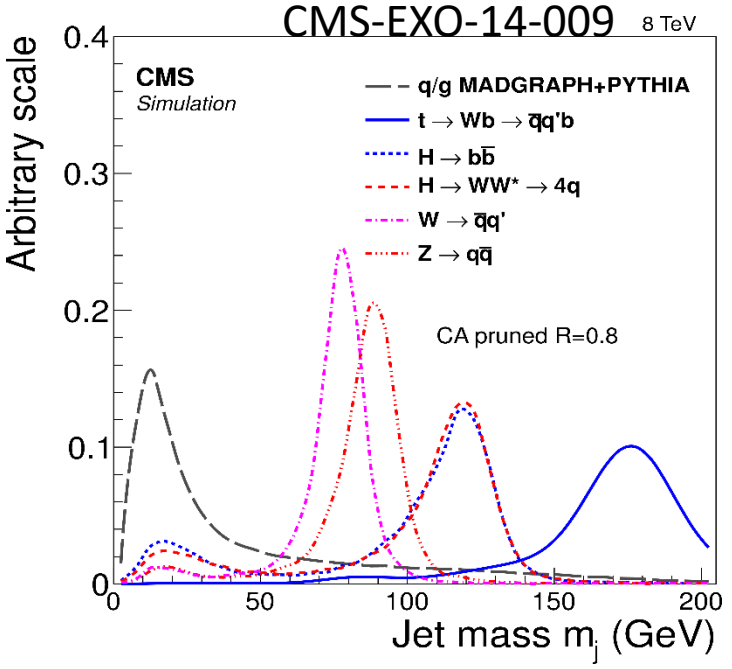
Reconstruction of boosted W/Z/H

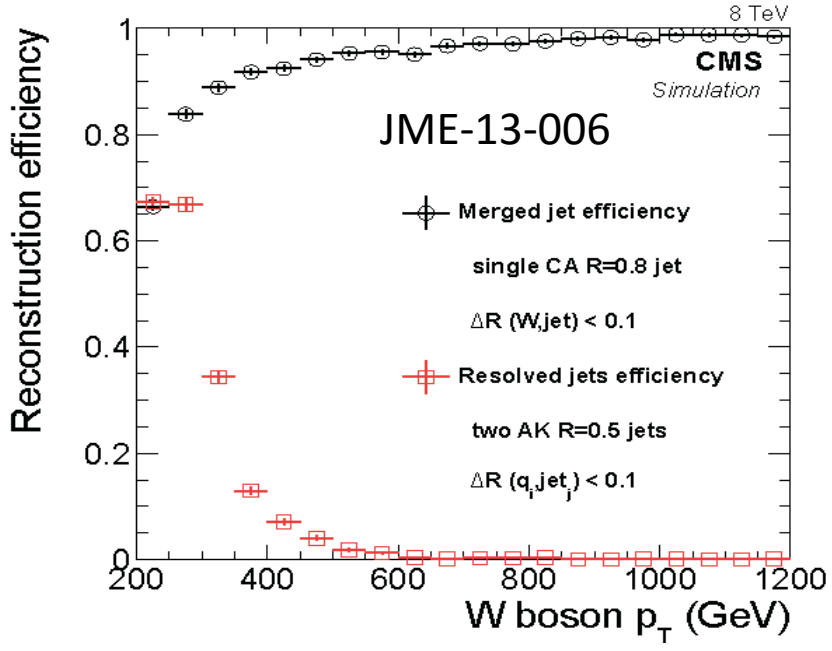
Heavy resonances decay results in boosted di-bosons, hadronic decays enhancing the rates

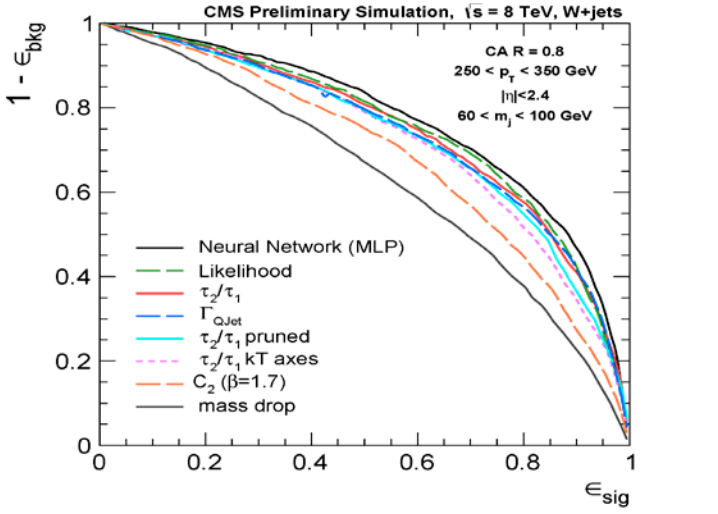
➢ it is crucial to identify boosted V -> qq decays

❖ Anti-k_t jets with R = 0.8, pruned with CA re-clustering with p_T^{min} fraction of 10%

❖ Substructure exploited mainly with N-subjettiness (τ_2/τ_1), other variables studied







Zγ ->llγ

CMS-PAS-EXO-16-019

Event selection:

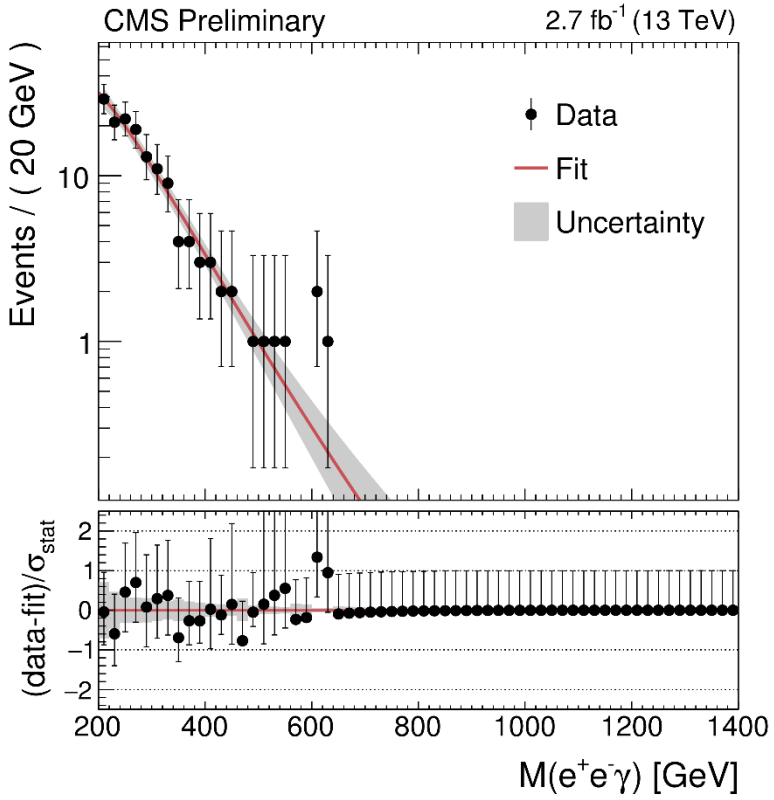
- two opposite sign leptons (e,μ)
- p_T^l > 25,20 GeV, p_T^γ >40 GeV
- 50 < mll < 130
- p_T^γ > 40/150 $m_{Z\gamma}$ – reduces further the background

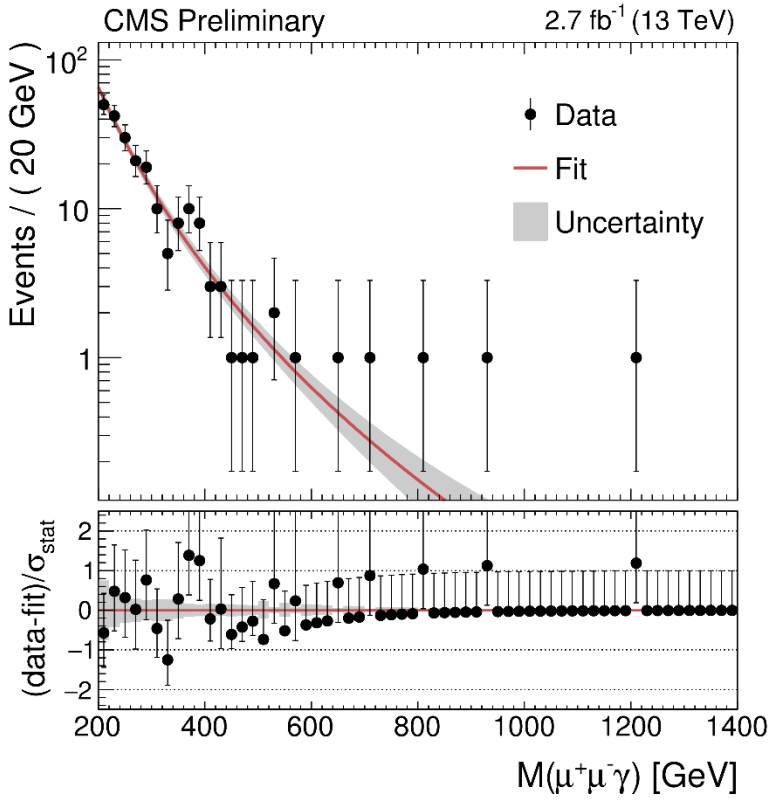
Background: Zγ (90%), Z+jets (10%)

✓ Described by parametric function

$$f(m_{Z\gamma}) = m_{Z\gamma}^{a+b\log m_{Z\gamma}}$$

✓ Checks with simulation.





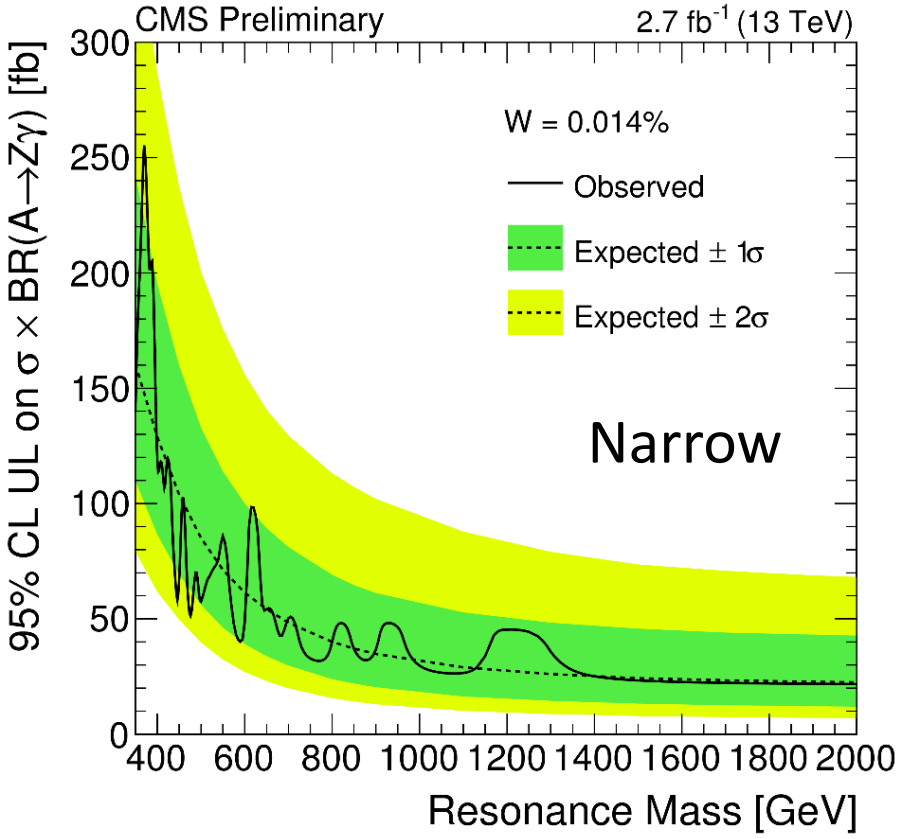
Zγ ->llγ: limits

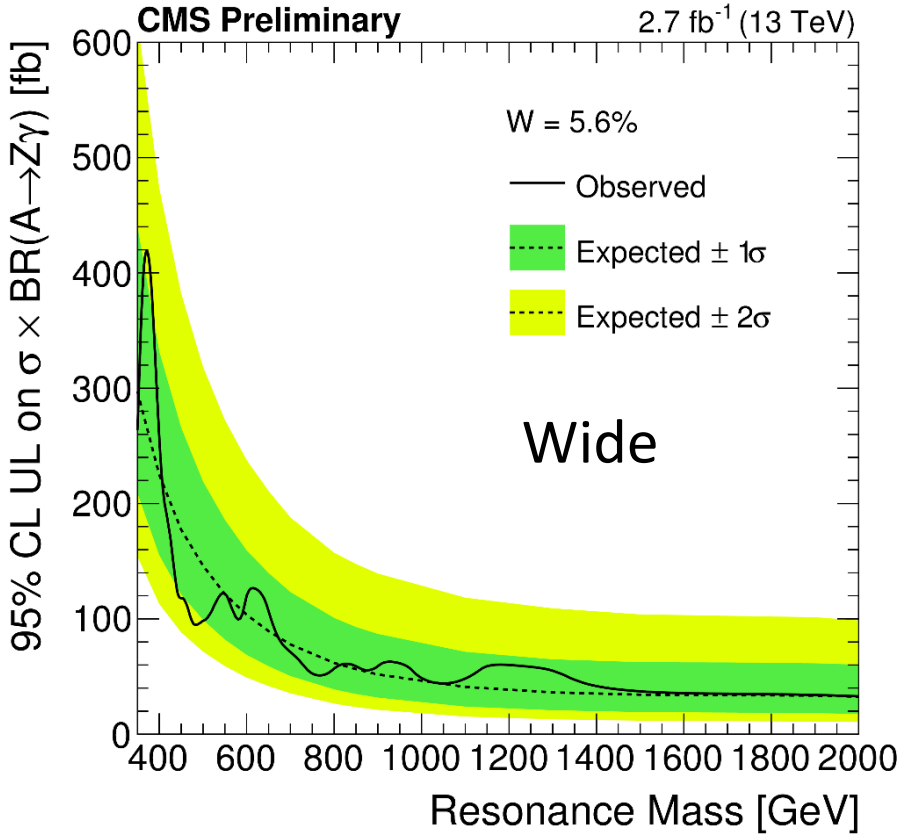
CMS-PAS-EXO-16-019

Scalar resonance decaying to Zγ:

- ✓ Narrow resonance: 0.014%
- ✓ Wide resonance: 5.6%

An alternative cross-check with cut-based analysis has been performed.





Zγ ->qqγ

CMS-PAS-EXO-16-020

Event selection:

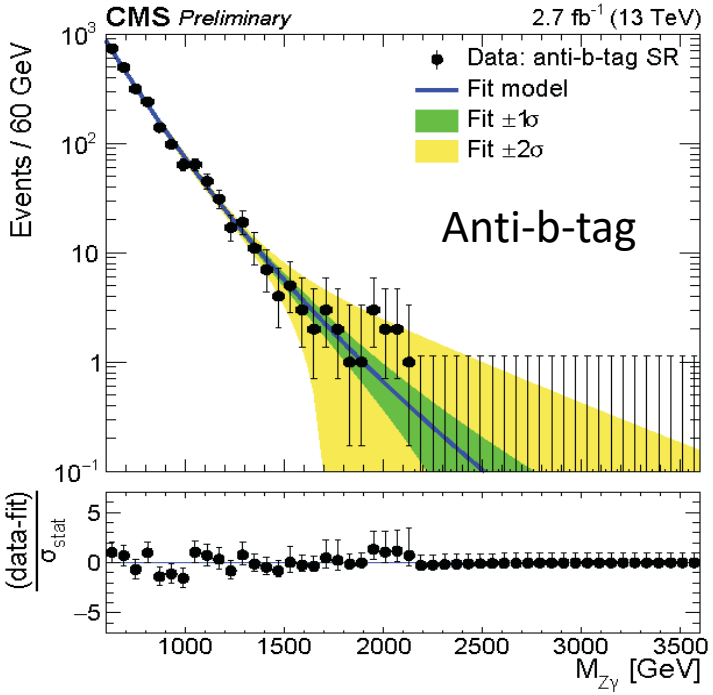
- ✓ Photon p_T >180 GeV, $|\eta|$ <1.4, $p_T^{\gamma} > 0.34\, m_{Z\gamma}$
- ✓ AK8 jet p_T > 200 GeV, 75 < m_J^{prun} < 105 GeV
- ✓ Sub-jet b-tagging
  - ✓ Two categories, anti-b-tagged and b-tagged (20% gain in sensitivity)
- ✓ $m_{J\gamma}$ > 600 GeV

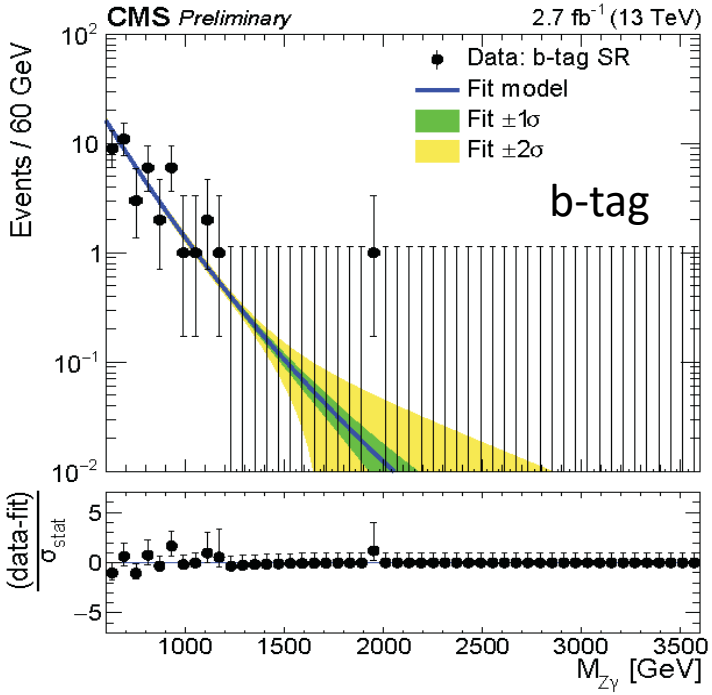
Backgrounds: γ+jets and multi-jets

- Described by parametric function

$$\frac{dN}{dM_{Z\gamma}} = P_0 \times (M_{Z\gamma}/\sqrt{s})^{P_1 + P_2 \times \log(M_{Z\gamma}/\sqrt{s})},$$

- ✓ Cross checks with alternative functions and with and without signal injection.





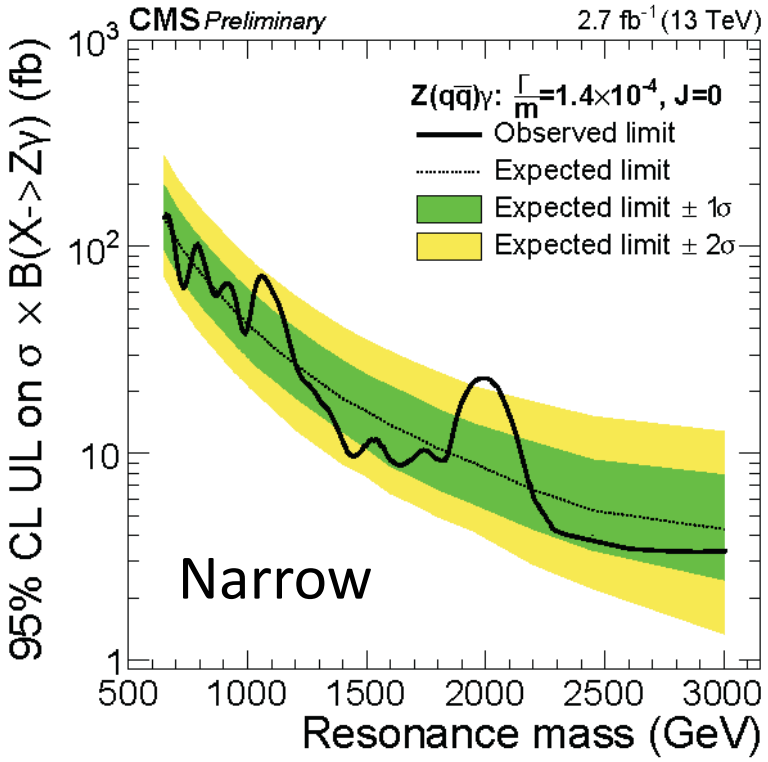
Zγ-> qqγ, limits

CMS-PAS-EXO-16-020

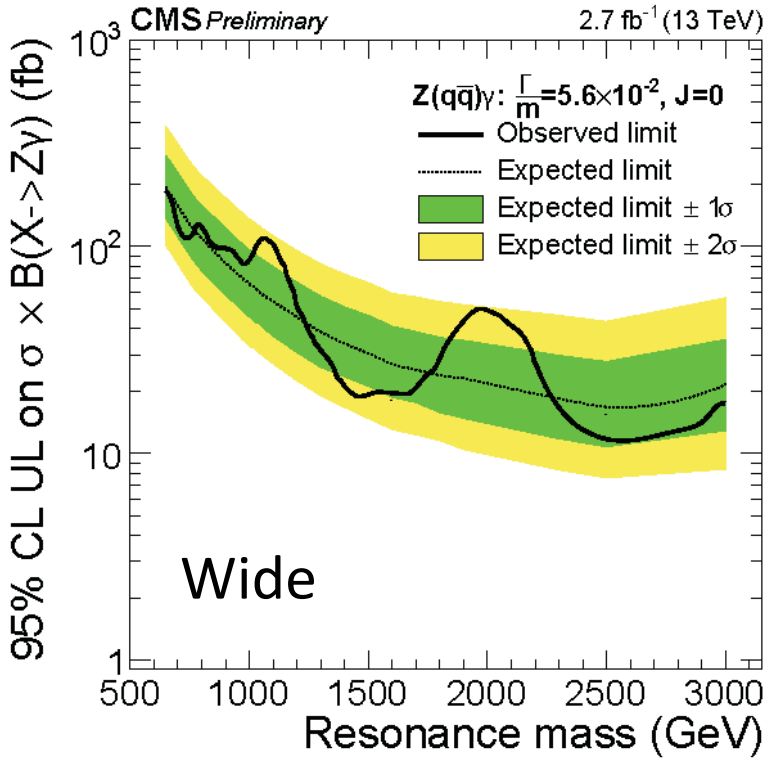
Scalar resonance decaying to Zγ:

- ✓ Narrow resonance: 0.014%
- ✓ Wide resonance: 5.6%

Zγ- the leptonic channel is twice more sensitive around 750 GeV, while the hadronic channel dominates at higher masses.



(a) $\frac{\Gamma}{m}$ = 0.014%: combined limit



(b) $\frac{\Gamma}{m}$ = 5.6%: combined limit

ZZ-> 2l2ν

CMS-PAS-HIG-16-001

Event selection:

- ✓ e^+e^- or $\mu^+\mu^-$ with $p_T > 25$ GeV
- ✓ $|m_Z - m_{ll}| < 30$ GeV, $p_T^{ll} > 55$ GeV
- ✓ $E_T^{miss} > 125$ GeV, b-jet veto, 3rd lepton veto

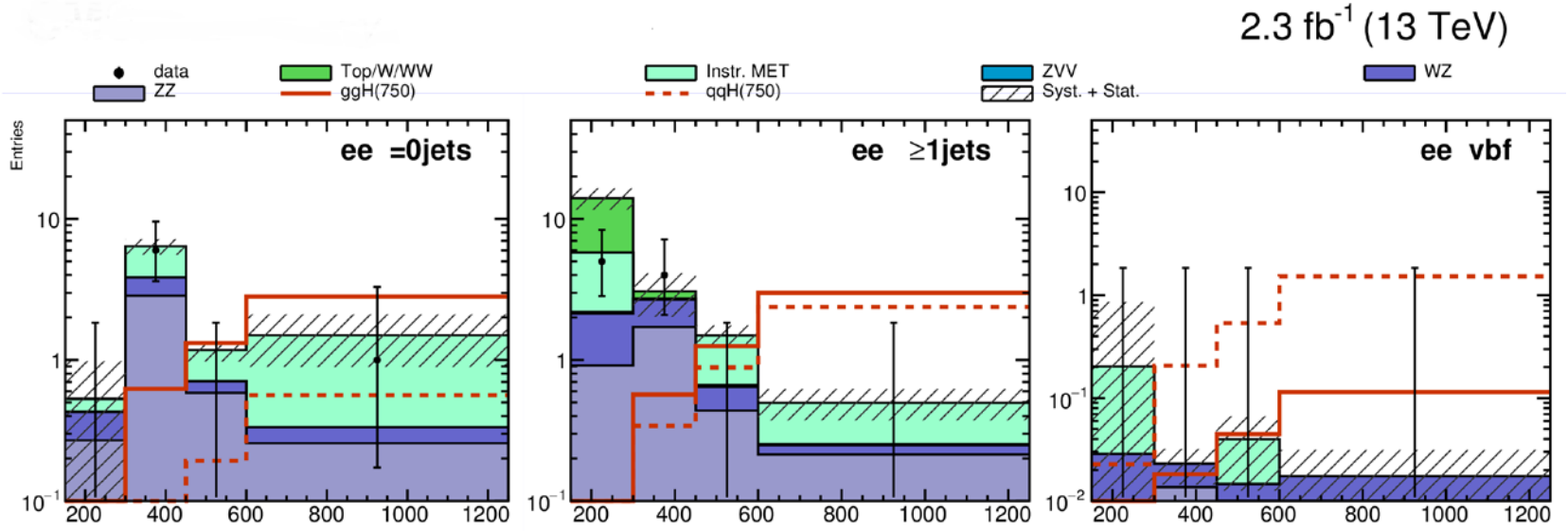
Three categories:

- ➢ VBF: at least 2 forward jets, $|\Delta\eta| > 4$, $m_{jj} > 500$ GeV, no central jets
- ➢ ≥ 1 jet: $p_T > 30$ GeV failing VBF selection
- ➢ 0 jets: no jets with $p_T > 30$ GeV

Backgrounds:

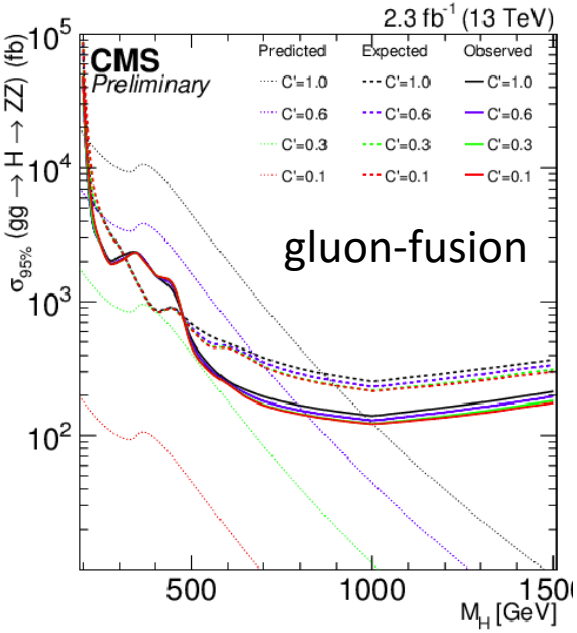
- ✓ Z+jets – modeled with γ+jets
- ✓ Top production and WW – modeled with eμ using $40 < m_{ll} < 70$ GeV sideband
- ✓ ZZ, WZ – taken from the simulation (NNLO,NLO)

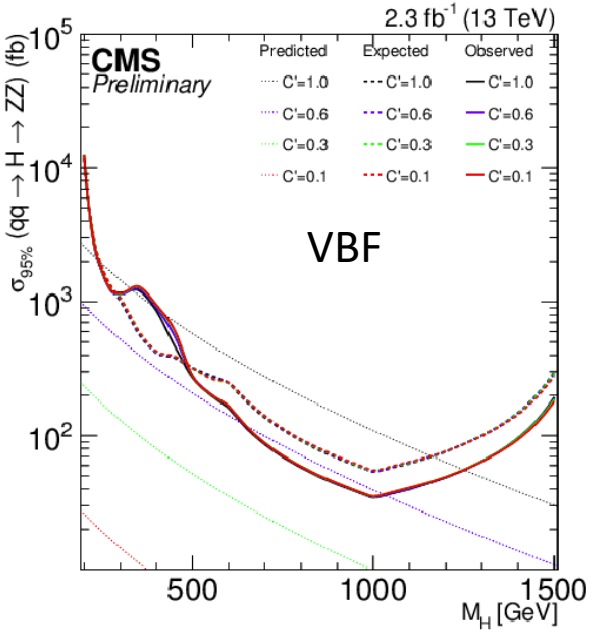
Transverse mass distribution is used as observable in shape-based analysis



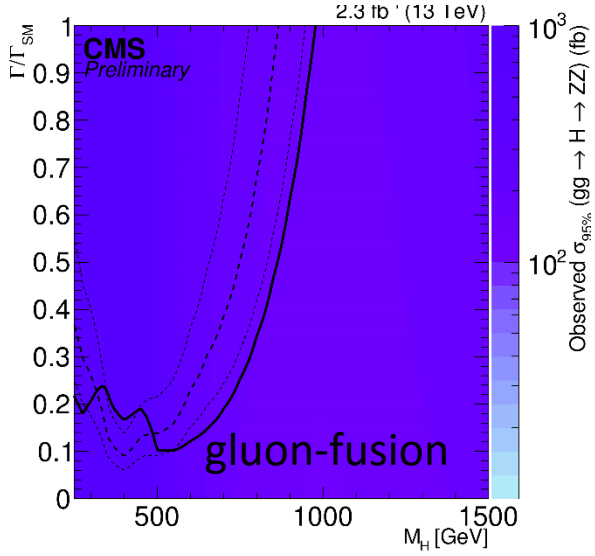
ZZ-> 2l2ν

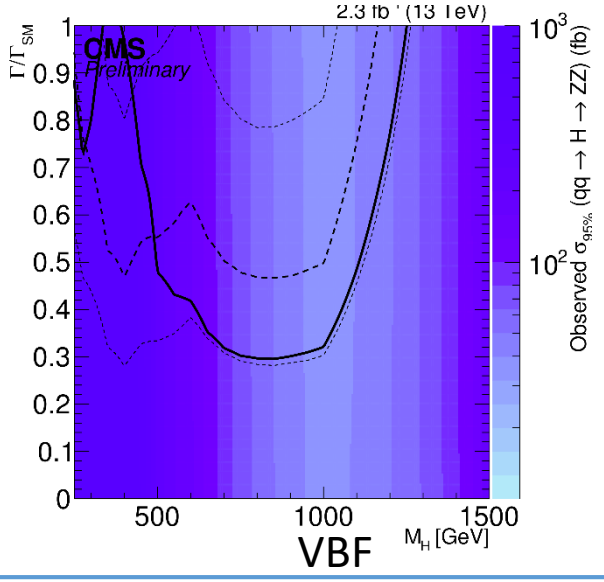
CMS-PAS-HIG-16-001

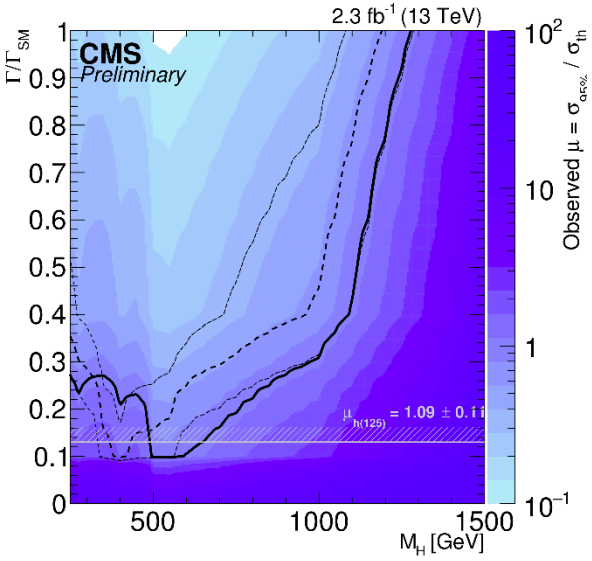




Generic scalar of variable mass and width, modelled as an electroweak singlet mixing with Higgs boson.







HH -> bb bb

CMS-PAS-HIG-16-002

Event selection:

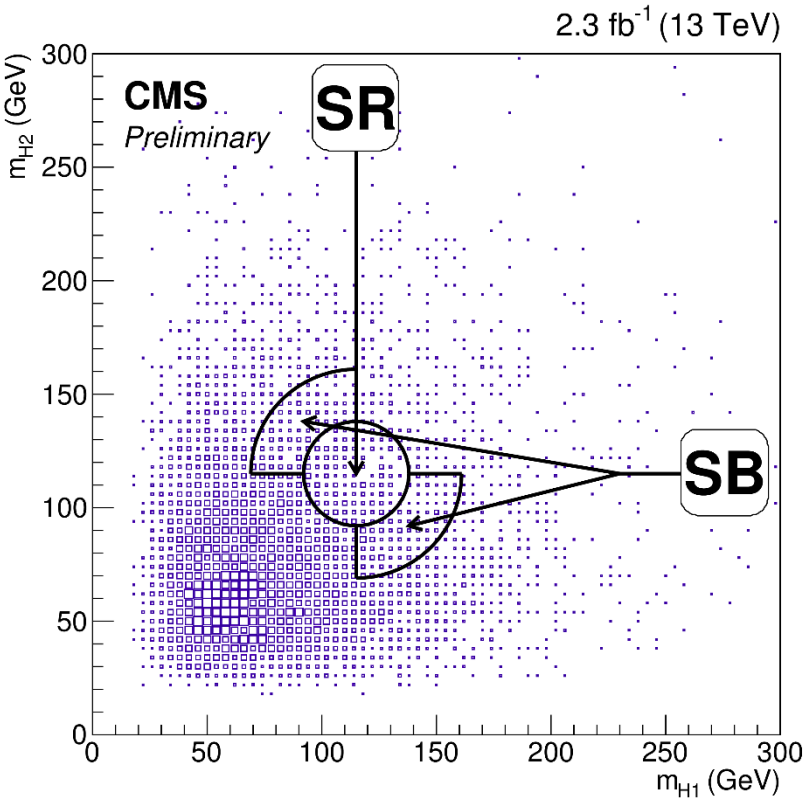
4 resolved jets, p_T > 30 GeV, b-tagged

Two region in resonance mass
Low Mass Candidate (LMR)260-400 GeV
Medium Mass Candidate(MMR) 400-1200 GeV

- Require $\Delta R<1.5$ for jets from same H in MMR

$$\chi^2 = \left(\frac{m_{H1} - 115}{\sigma}\right)^2 + \left(\frac{m_{H2} - 115}{\sigma}\right)^2$$

σ = 17 GeV for LMR,
23 GeV for MMR



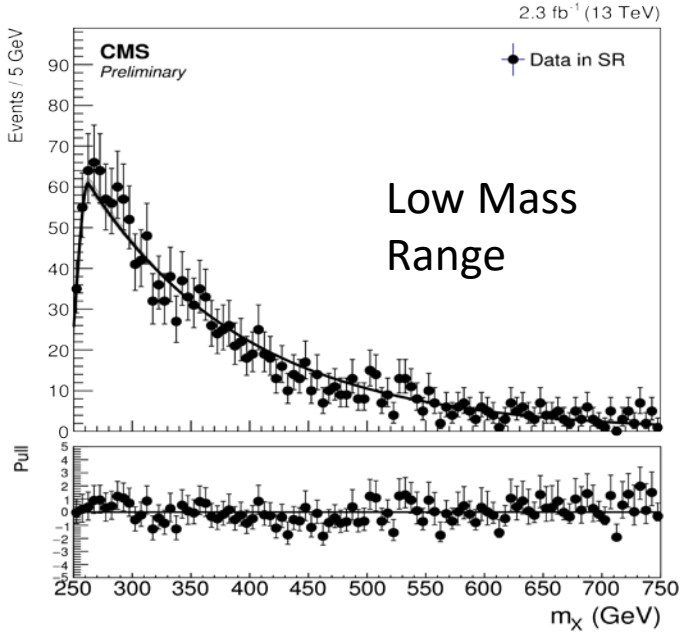
σ Is optimized for sensitivity.

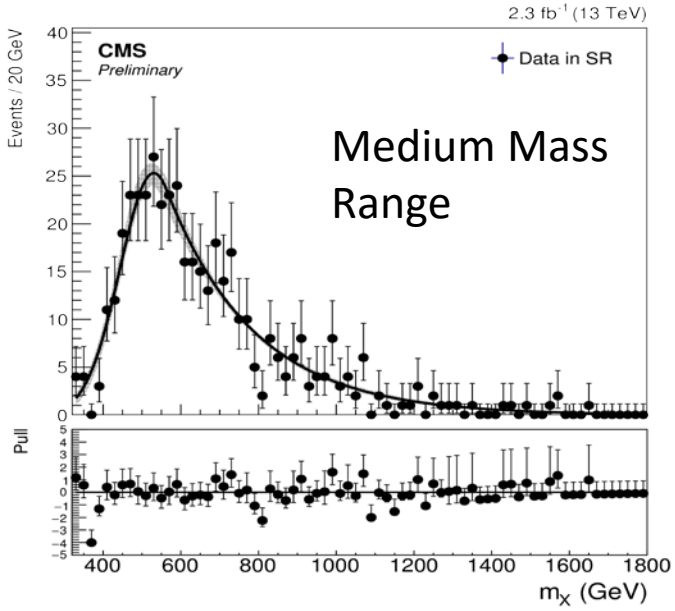
Signal region: $\chi < 1$
Sideband region: $1<\chi<2$, and
$(m_{H1}\text{-}115).(m_{H2}\text{-}115) < 0$

Background modeling: **shape** of the m_X distribution for multi-jets and top are estimated from sideband. Validated in control region (SR,SB) with inverted b-tag.

HH -> bb bb, limits

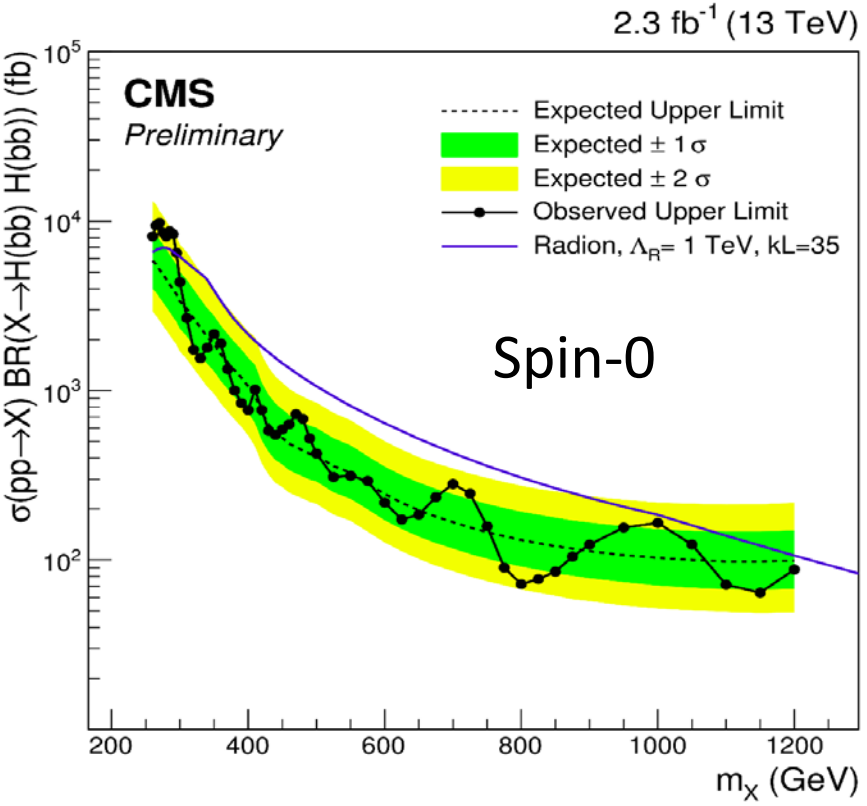
CMS-PAS-HIG-16-002





No significant excess is observed.

Upper limits on the production cross section for narrow-width resonance decaying into two Higgs bosons in the mass range from 260 to 1200 GeV, are set.



HH->WW bb->lvlvbb

CMS-PAS-HIG-16-011

Event election:

two opposite sign leptons

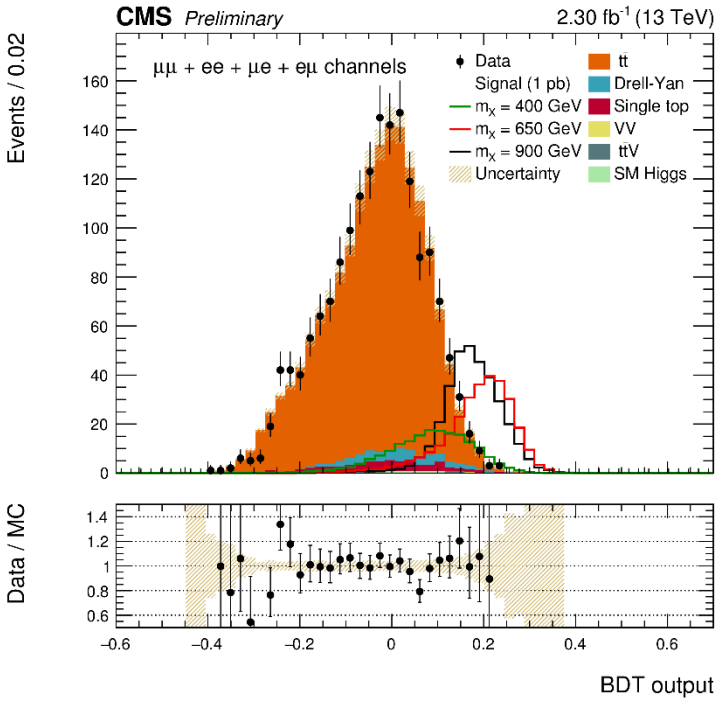
μ p_T > 20/10 GeV; e p_T >20/15 GeV

12< m_{ll}< 76 GeV

two b-tagged jets p_T > 20 GeV

ΔR_{ll} <2.2, ΔR_{jj} < 3.1 and $\Delta\varphi_{ll,jj}$ >1.5

Backgrounds: top-pair production is the dominant.



Boosted decision trees(BDTs) discriminants are used to further improve signal-to-background separation.

Two BDTs are trained

- On m_X = 400 for m_X < 450 GeV region
- On m_X = 650 for m_X >450 GeV region

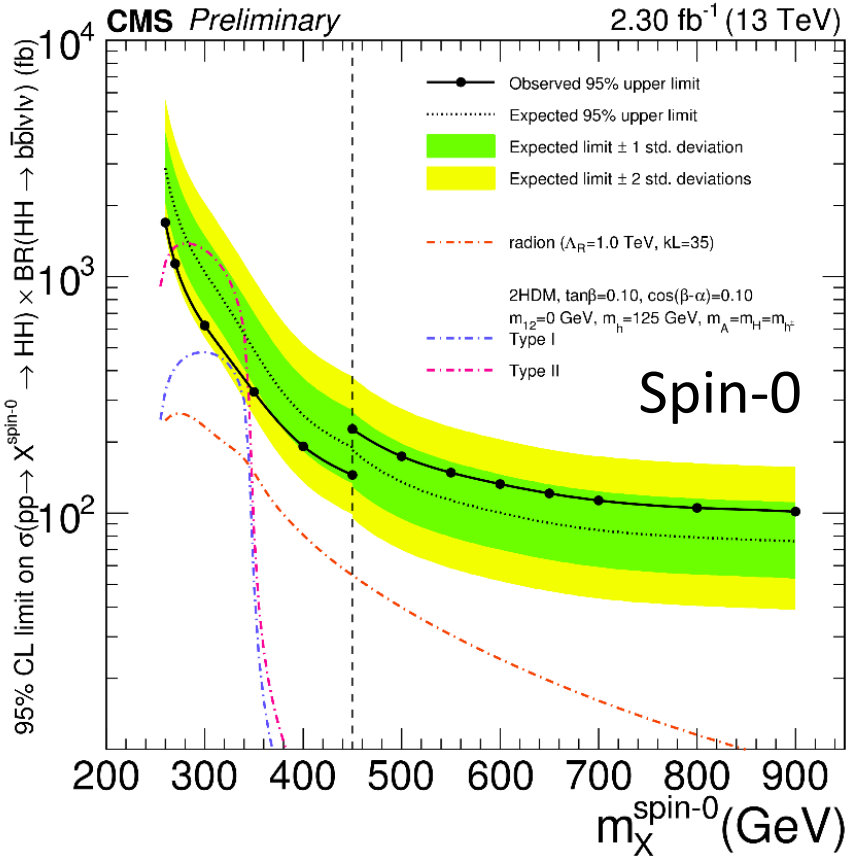
Applying m_{jj} cut around 125 GeV

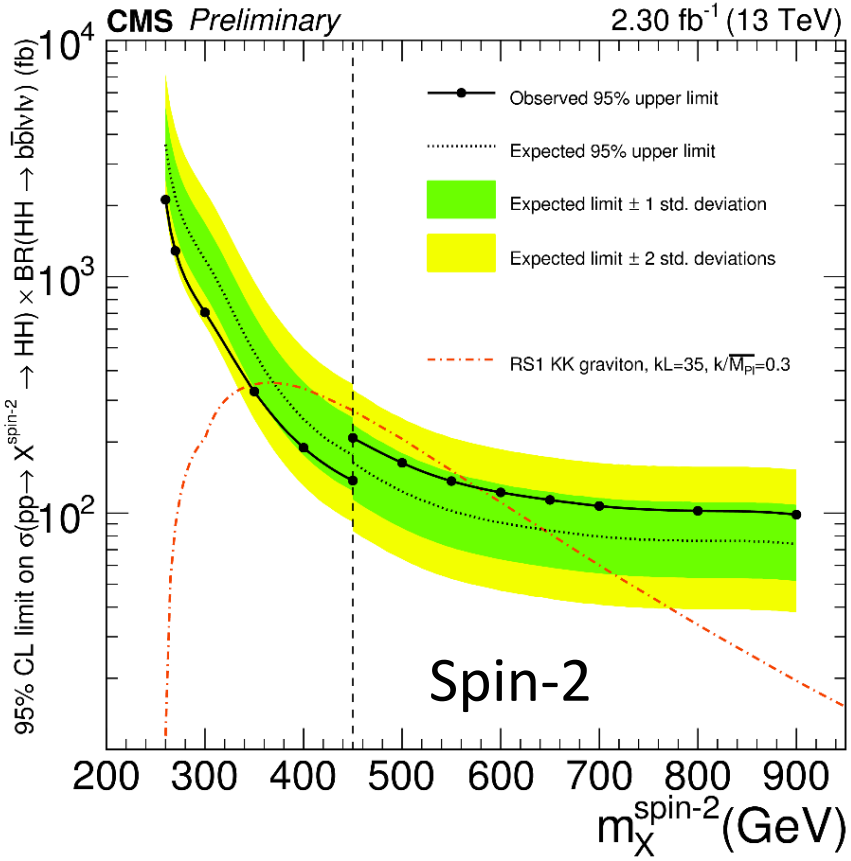
Signal-depleted regions are used to define the background normalization.

HH->WW bb->lvlvbb

CMS-PAS-HIG-16-011

No significant excess is observed. Upper limit on the narrow-width resonance production cross section is imposed for mass range 260-900 GeV.

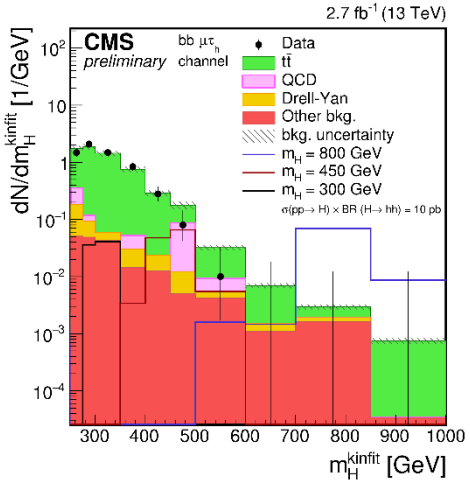


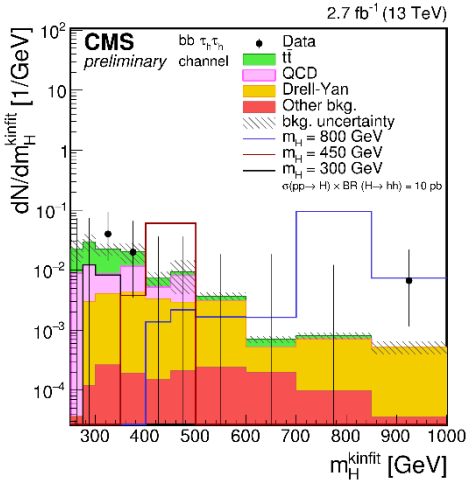


HH->ττbb

CMS-PAS-HIG-16-013

Event selection: $\mu\tau_h$, $e\tau_h$, $\tau_h\tau_h$
two opposite charge leptons
$\mu\tau_h$, $e\tau_h$: $\mu(e)$ p_T> 19(24) GeV
and τ_h p_T> 20 GeV
$\tau_h\tau_h$: p_T> 45 GeV
two b-tagged jets p_T> 30 GeV
80 GeV <$m_{\tau\tau}(m_{bb})$<160 GeV

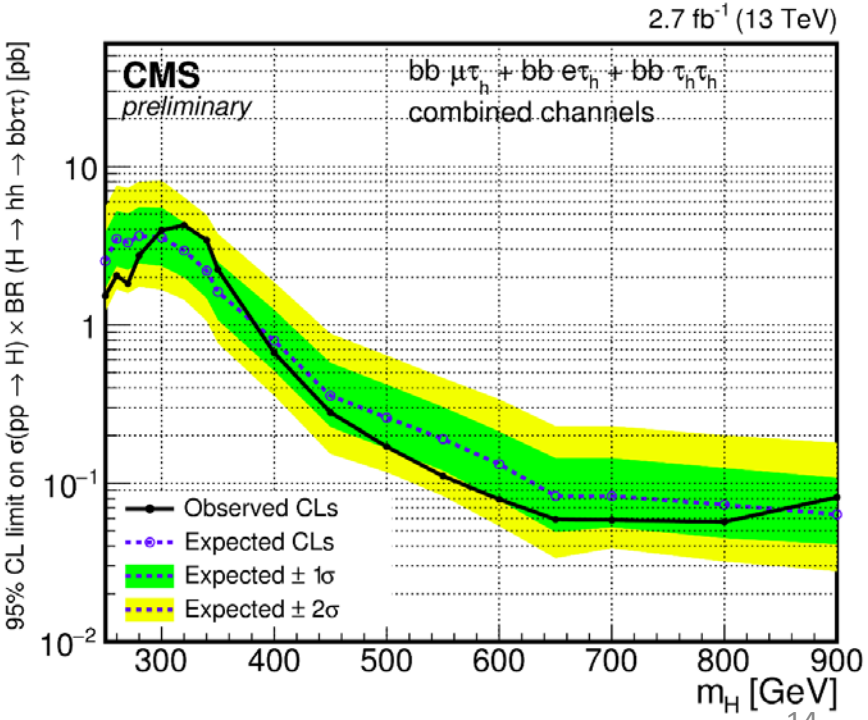




Backgrounds:
Top-pair-normalized to NNLO. A kinematic re-weighting is applied to match better the p_T in the data. Multi-jets is determined from data using jet-enriched region.

M_{hh} is reconstructed using kinematic fit, using hypothesis of two 125 GeV Higgs bosons.

Model independent resonance search.



VH -> llbb, lvbb, vvbb

CMS-PAS-B2G-16-003

Event selection:

vvbb: E_T^{miss}>200 GeV, Δφ(jet, E_t^{miss}) > 2, b-jet veto

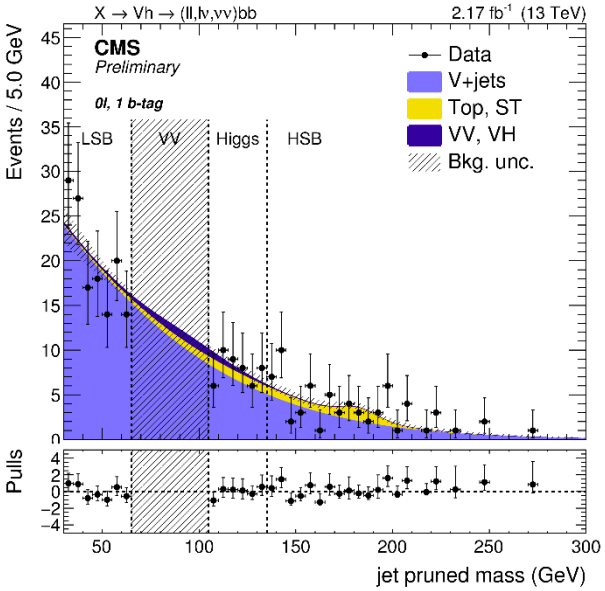
lvbb: μ (el) p_T > 55 (135) GeV, veto extra leptons, E_T^{miss}>80 GeV (el), p_T^W > 200 GeV

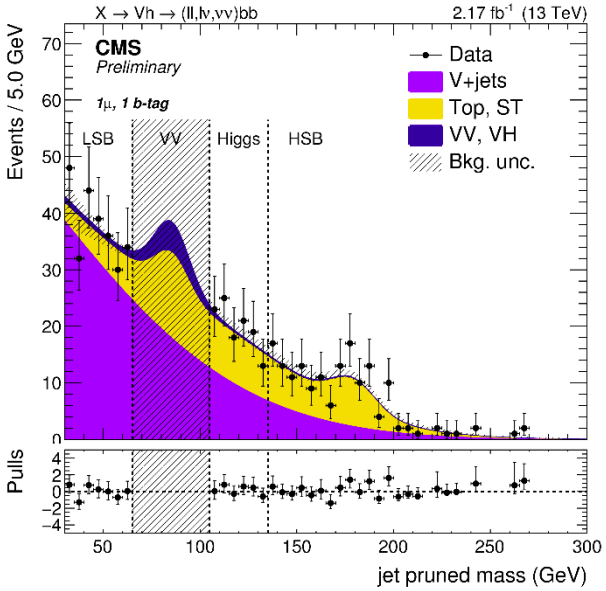
llbb: μ (el) p_T > 55 (135) GeV, 70<m_{ll}< 110, p_T^Z > 200 GeV, |Δη(ll,jet)|<5, Δφ (ll,jet) >2.5

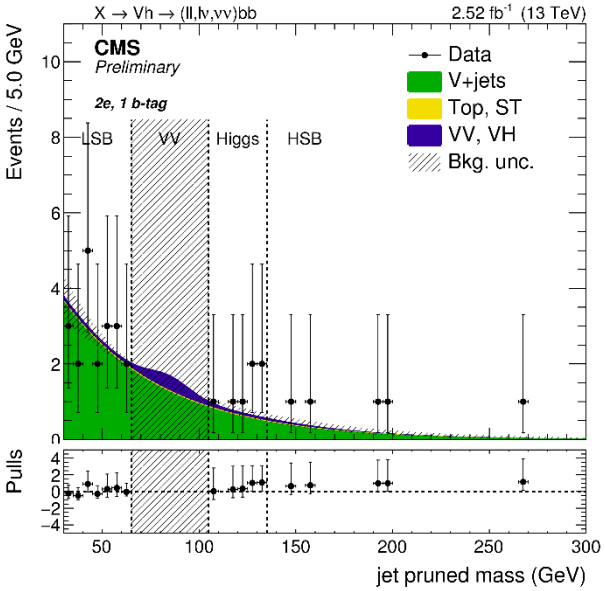
Higgs identification: AK8 jet p_T>200 GeV, 105<m_J<135 GeV, 1 or 2 b-tag sub-jets.

- 10 categories - by lepton count (0,1,2), lepton flavor (e,μ) and number of b-sub-jets.

Backgrounds: V+jets (dominant) estimated from data in the sidebands of m_J. The top quark background is evaluated from top-enriched control regions.

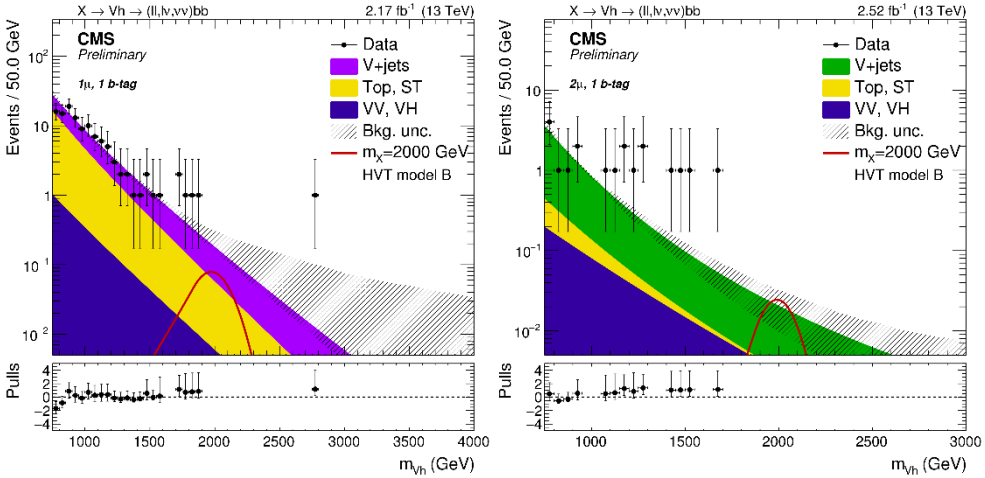






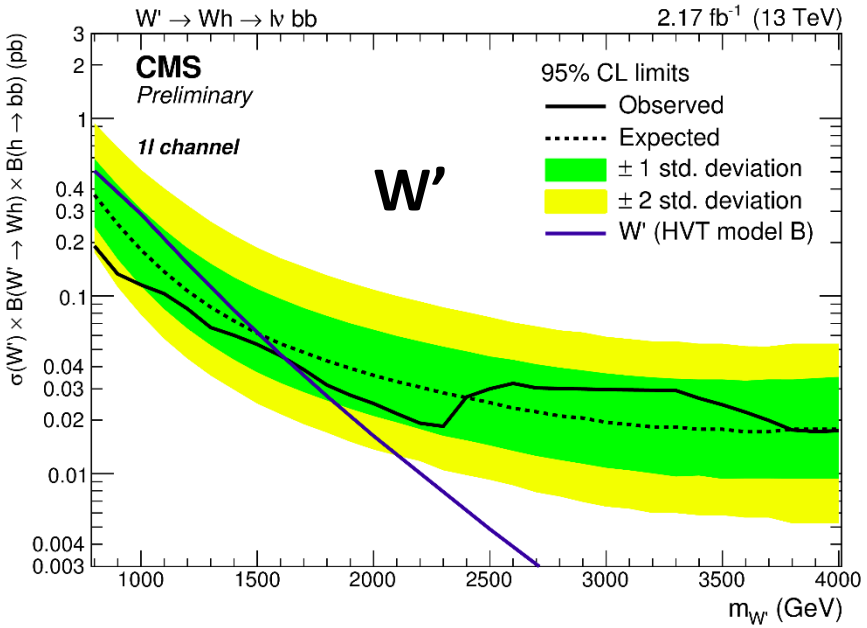
VH -> llbb, lvbb, vvbb

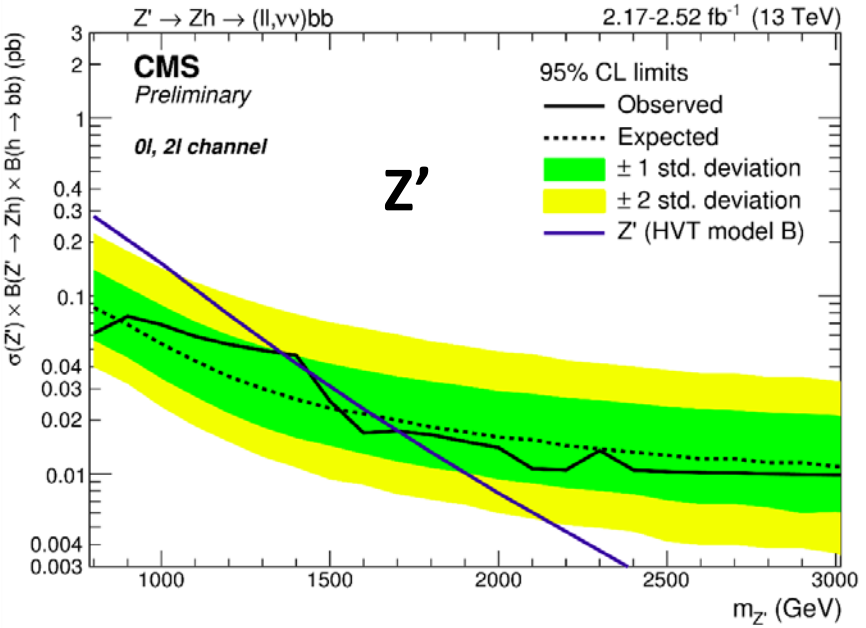
CMS-PAS-B2G-16-003



Interpretation of the results as upper limit on W' and Z' production cross section within HVT model B

Exclusion limits for $m_{W'/Z'} \sim 1.6\text{-}1.7$ TeV





WW/WZ/ZZ->lvqq,qqqq

CMS-PAS-EXO-15-002

Event selection:

lvqq: μ(e) p_T > 53(120) GeV, E_T^{miss}>40 (80) GeV,
veto on extra leptons, b-jet veto, 1 AK8 jet
back-to-back selection

qqqq: 2 AK8 jet, |η1-η2|<1.3

both: AK8 jet, p_T >200 GeV, 65 < m_J < 105GeV

τ2/τ1 categories: HP (0,0.5), LP (0.5,0.7)

W/Z categorization: m_J (65,85) / (85,105) GeV

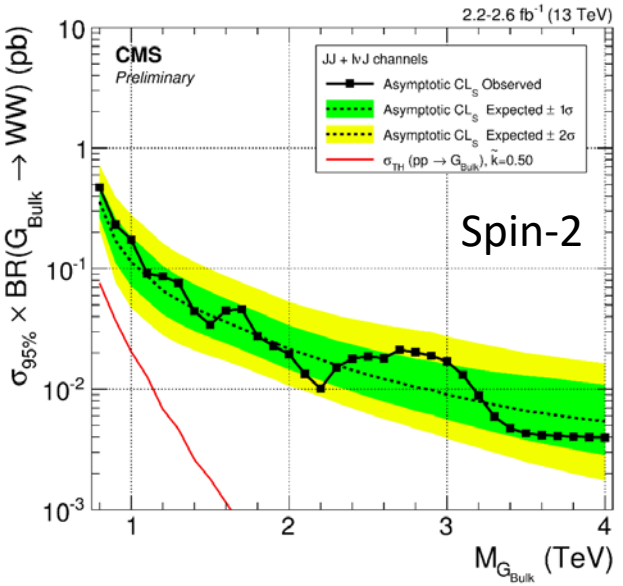
Backgrounds:

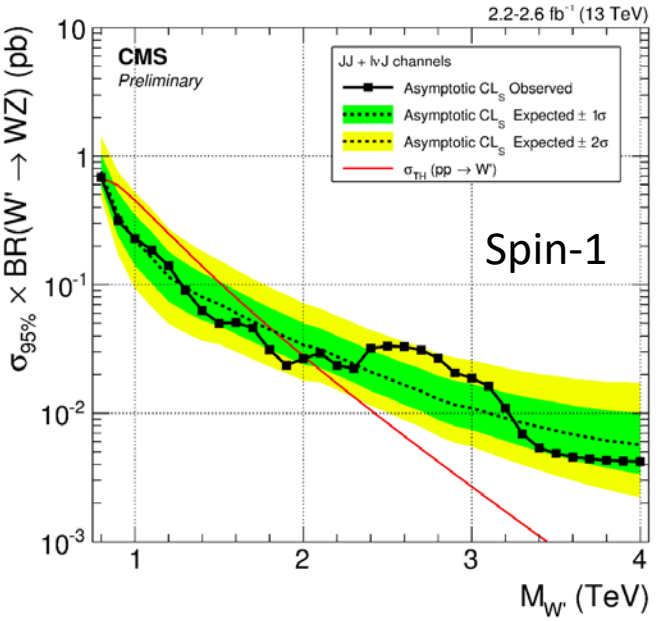
lvqq: W+jets shape and normalization evaluated from data

qqqq: parametric fit to data in the signal region

Upper limits on the production cross section:

- Bulk graviton (Spin-2)
- W' , HVT model B (Spin-1)





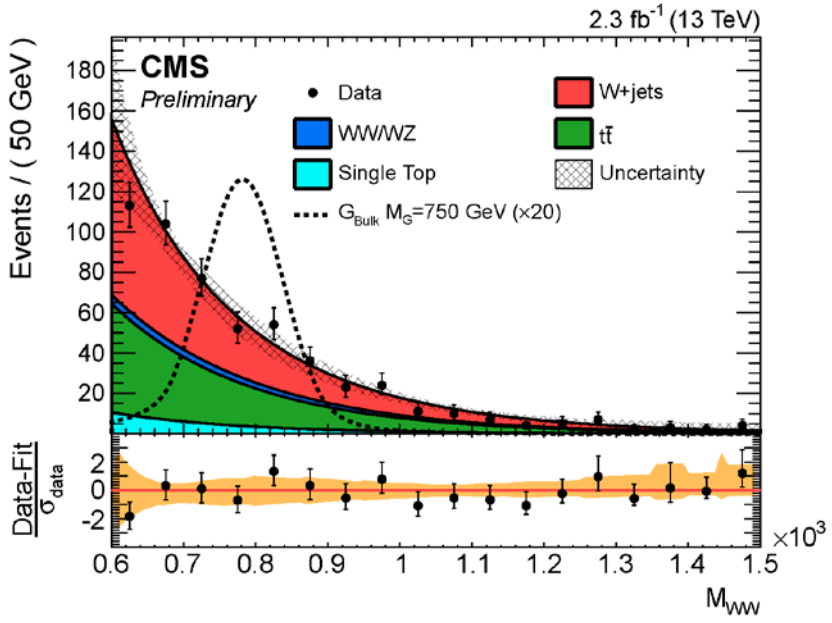
WW -> lvqq, 0.6-1.0 TeV

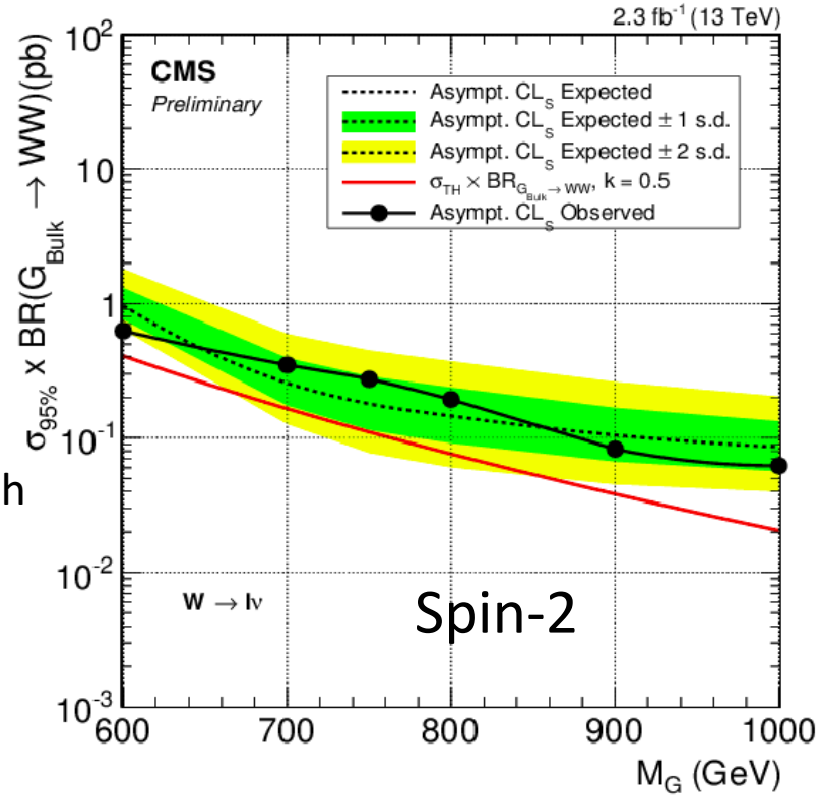
CMS-PAS-B2G-16-004

Event selection:

Lepton: μ(e) p_T > 40(45) GeV,
veto on a second lepton, b-jet veto
E_T^{miss}>40 (80) GeV for μ(e)
AK8 jets, p_T >200 GeV, 65 < m_J < 95 GeV
N-subjettiness: τ2/τ1 < 0.45
Back-to-back topology requirements.

Backgrounds: W+jets estimated from data.
Top-quark contribution normalized from top-enrich control sample in data.





No significant excess is observed

Upper limits on Bulk Graviton production cross section are set.

WW,WZ,ZZ,WH and ZH combination 8+13 TeV

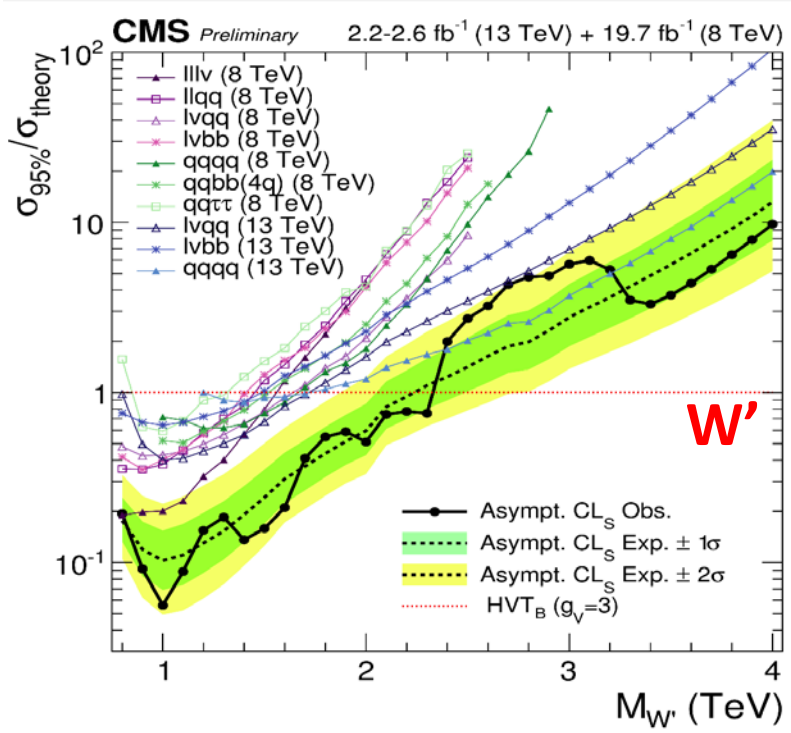
CMS-PAS-B2G-16-007

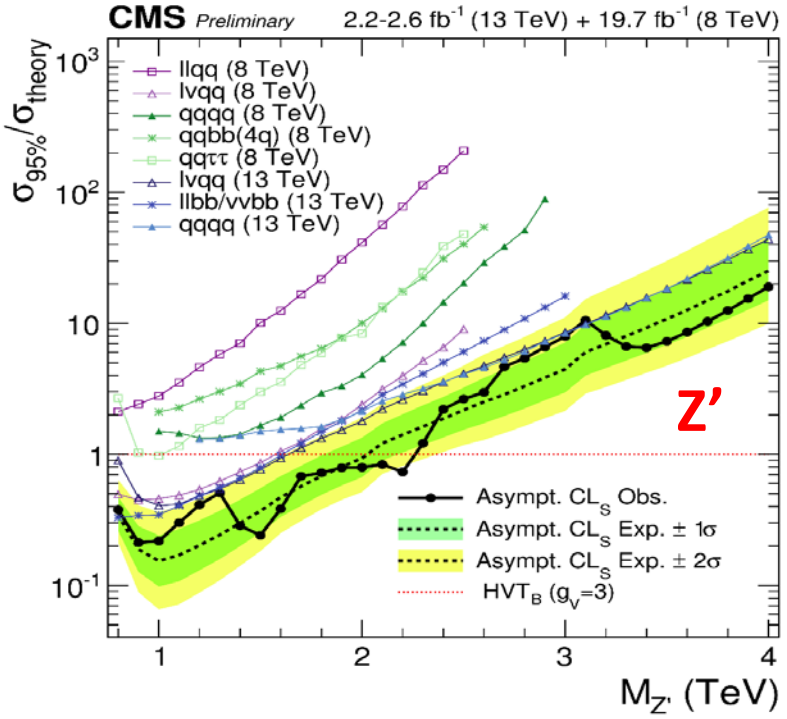
The combination includes:

8 TeV (19.7 fb-1): 3lν, lνqq, llqq, qqqq, lνbb, qqbb/qqqqqq, qqττ

13 TeV (2.2-2.6 fb-1) : lνqq, qqqq, llbb, lνbb, ννbb

Theory models: W', Z' in HVT model B and Bulk graviton



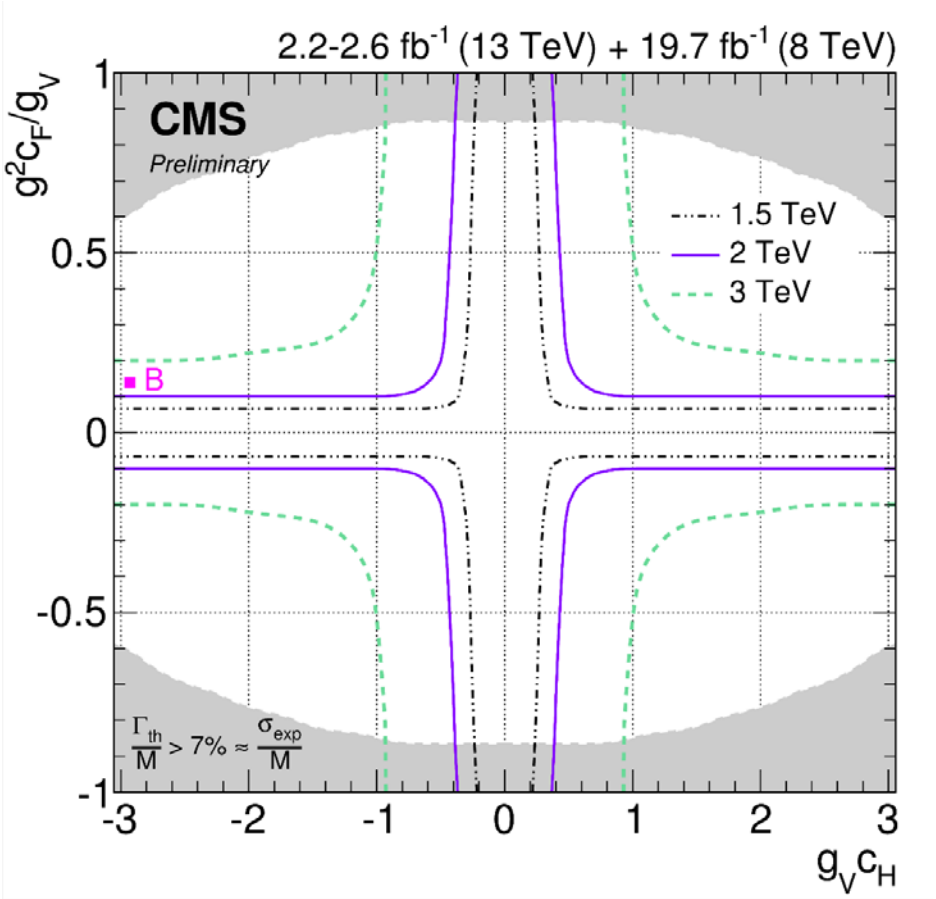


Excluding W' and Z' with masses up to about 2.3 TeV (HVT model B)

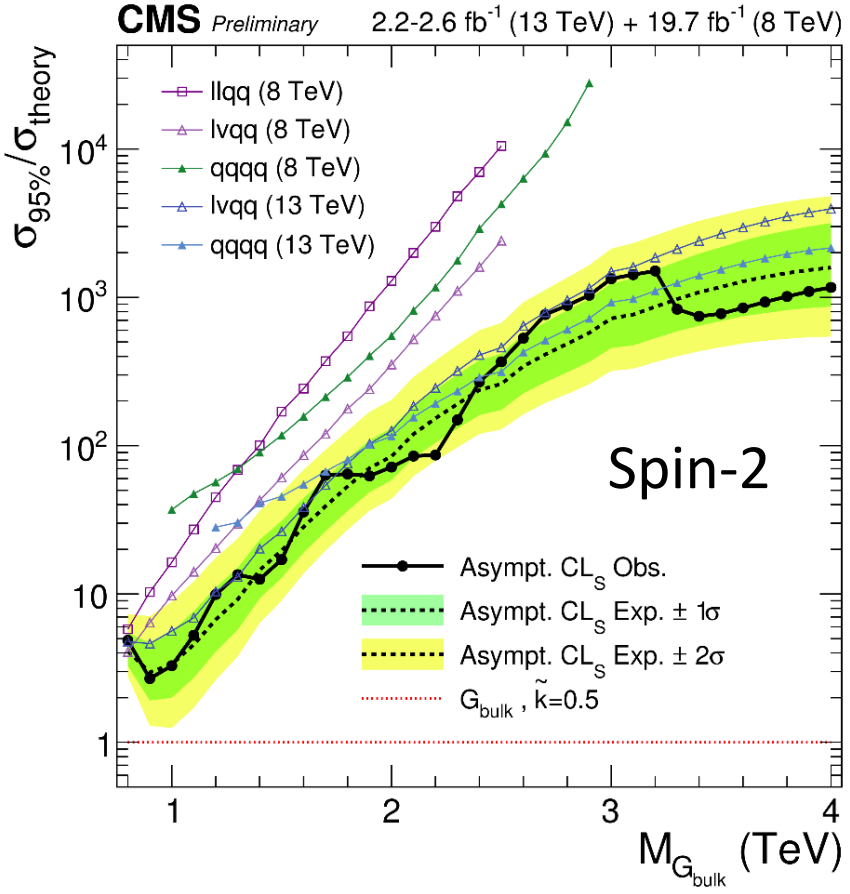
WW,WZ,ZZ,WH and ZH combination 8+13 TeV

CMS-PAS-B2G-16-007

Exclusion in the plain of HVT-model couplings



Limits on Bulk graviton production



WW,WZ,ZZ,WH and ZH combination 8+13 TeV

CMS-PAS-B2G-16-007

Statistical significance of excesses observed at **1.8** TeV in the various searches, expressed in standard deviations.

Combination	W'	Z'	HVT ($W'+Z'$)	G_{bulk}
VV 13 TeV	0.00	0.10	0.00	0.00
VV+VH 13 TeV	0.00	0.00	0.00	-
VV 8 TeV	1.22	0.56	1.03	1.61
VV 8+13 TeV	0.20	0.46	0.33	0.35
VH 8 TeV	2.05	0.56	1.79	-
VV+VH 8 TeV	2.22	0.77	1.95	-
VV+VH 8+13 TeV	0.86	0.00	0.83	-

Summary

- Searches for heavy resonances in di-boson final states have been performed with 2.2-2.6 fb^{-1} of data at 13 TeV with the CMS detector.
  - Mass range 250-4000 GeV is explored
- No significant deviation from the SM prediction is observed.
  - Upper limits on production cross section for resonances are derived
- Combination of the searches for VV and VH resonances at 8 and 13 TeV is performed.
  - 2015 13 TeV data disfavors the 2 TeV excess seen in 8 TeV data

New results with 2016 data are coming soon!

BACKUP

WW,WZ,ZZ,WH and ZH combination 8+13 TeV

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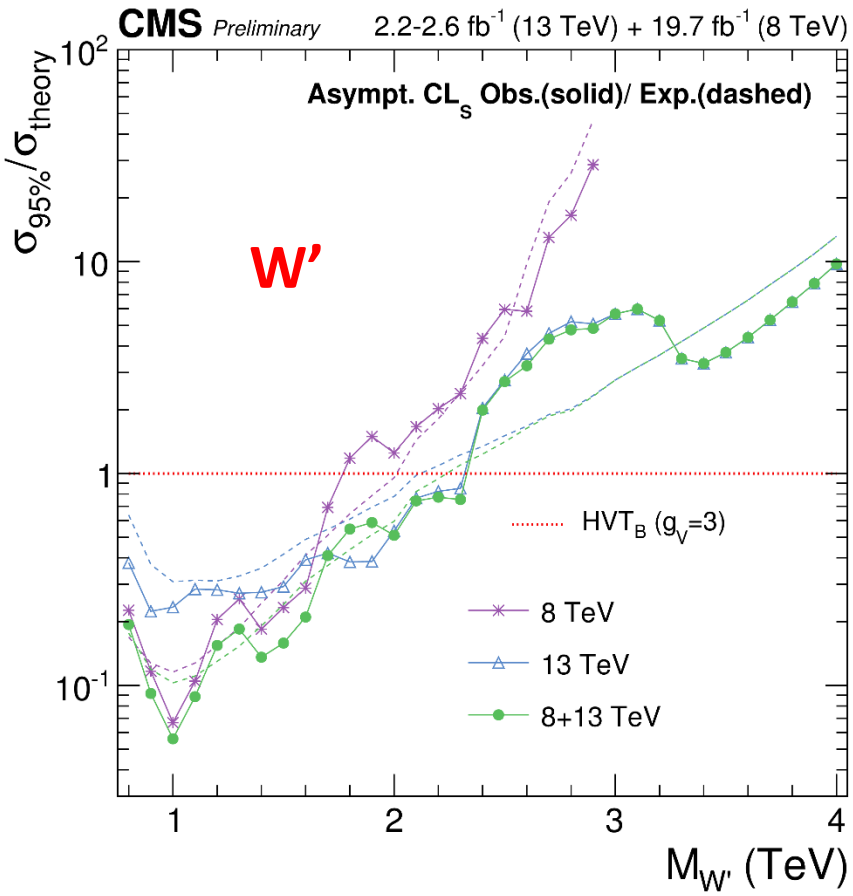
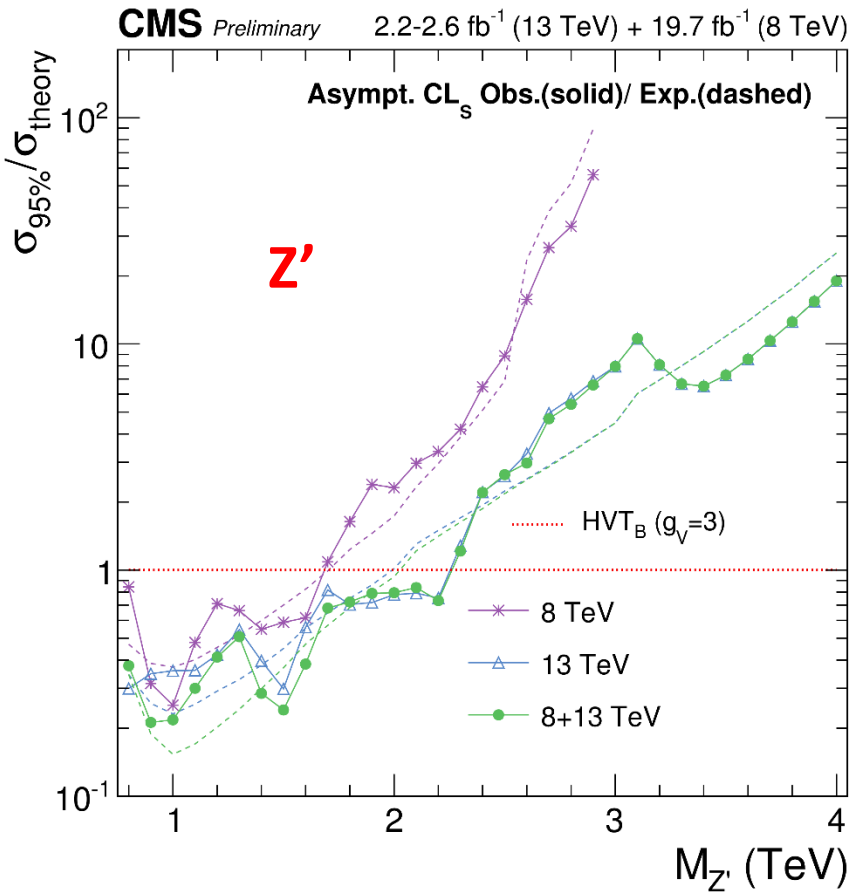
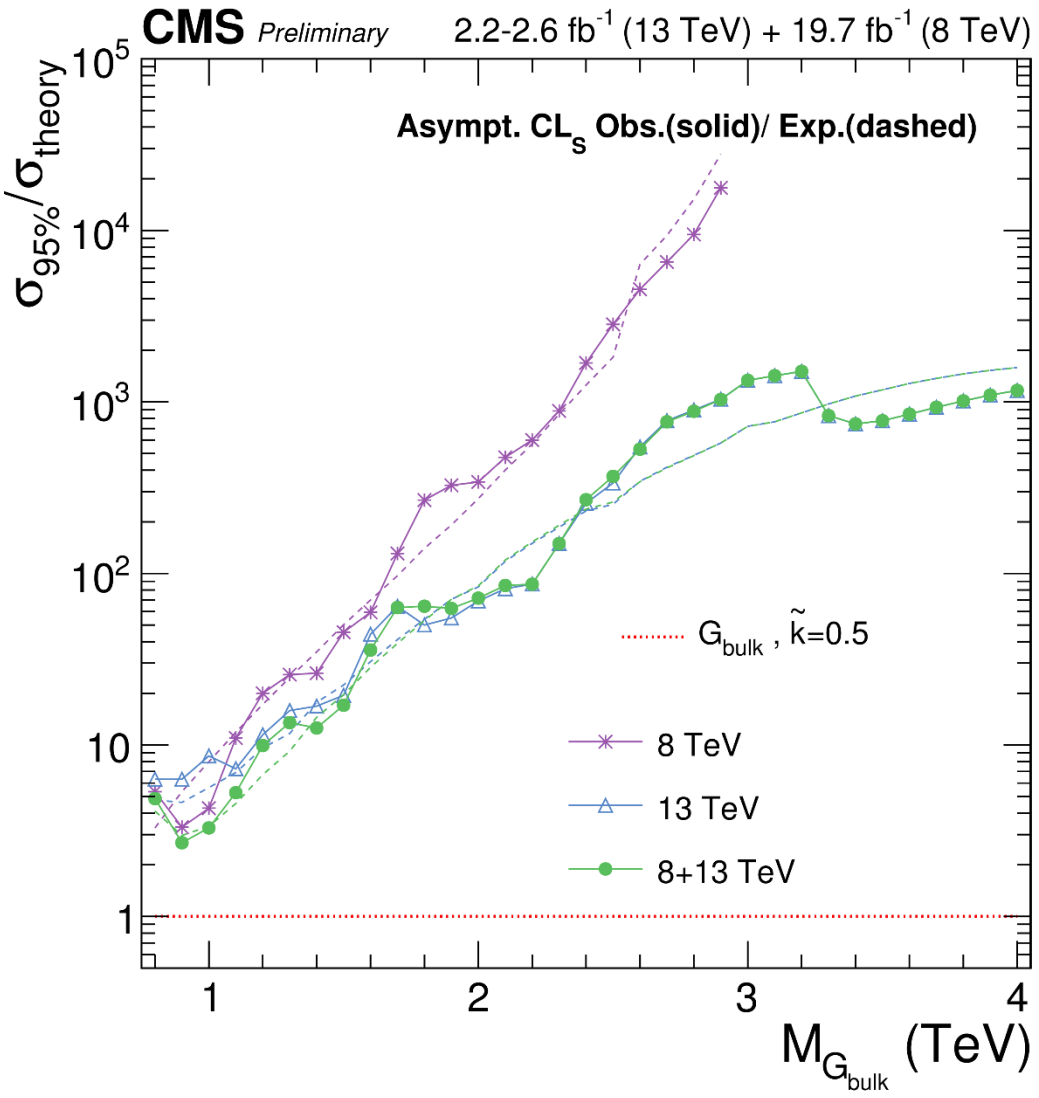




WW,WZ,ZZ,WH and ZH combination 8+13 TeV

CMS-PAS-B2G-16-007



ZZ->2l2l

CMS-PAS-HIG-15-004