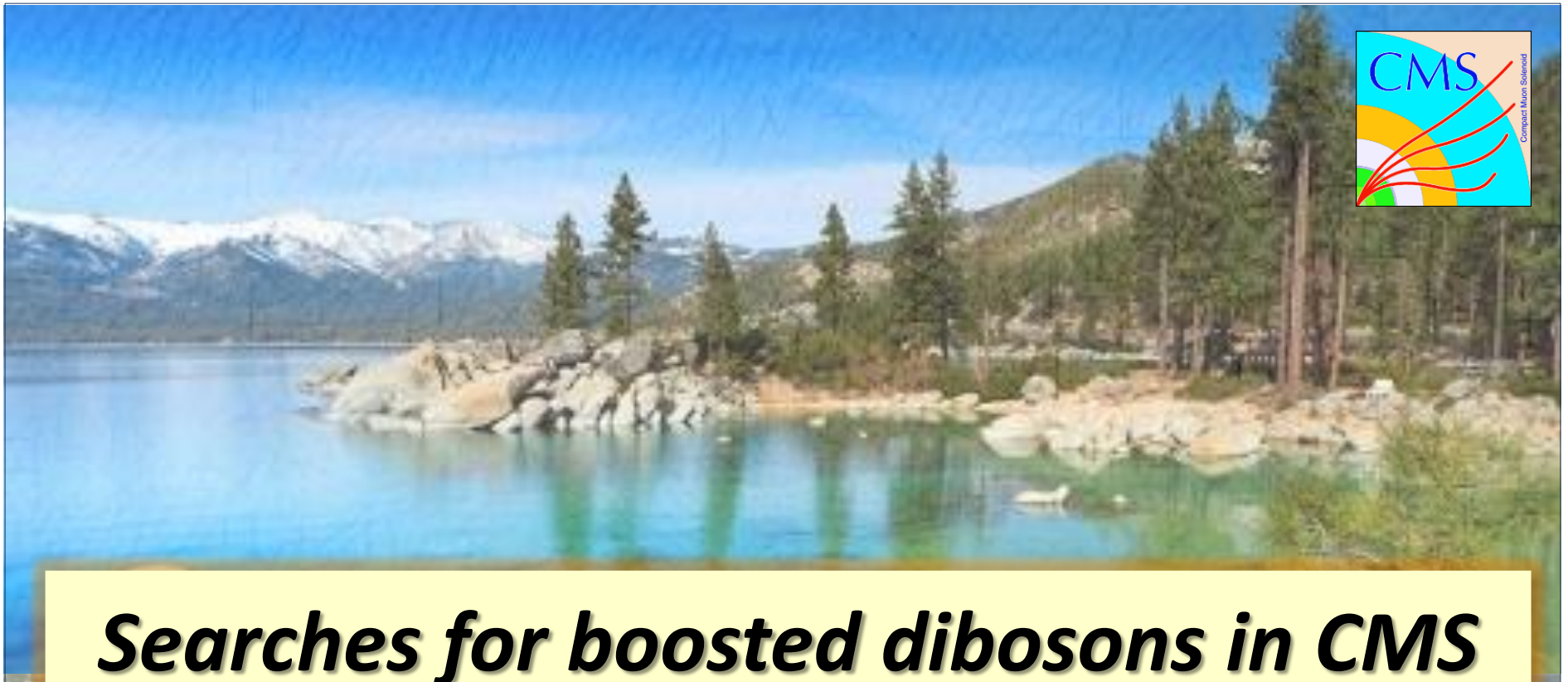


Searches for boosted dibosons in CMS

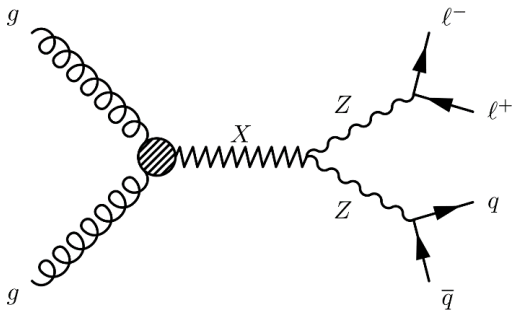
Jordan Damgov (TTU)
on behalf of the CMS Collaboration

SUSY 2015, Lake Tahoe, California, August 23 – 29

Overview

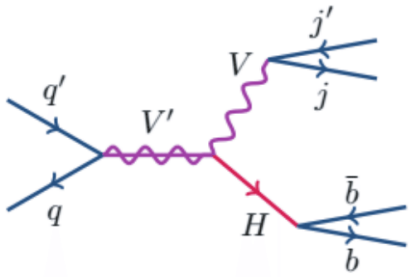
Many extensions of the Standard Model predict existence of new particles decaying into vector-boson pairs.

Few of them are used as benchmarks for heavy narrow resonance searches in di-boson final state by CMS.



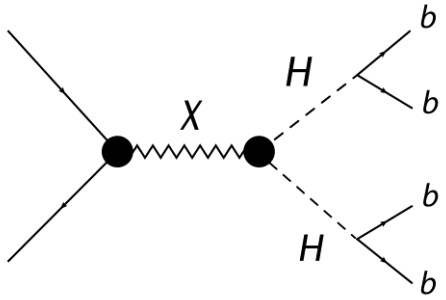
Extra dimensions

- Bulk scenario of RS model
- spin-2 gravitons, spin-0 radions



Heavy spin-1 vector bosons.

- Heavy Vector Triplet (scenario B)
- spin-1 W'± and Z'

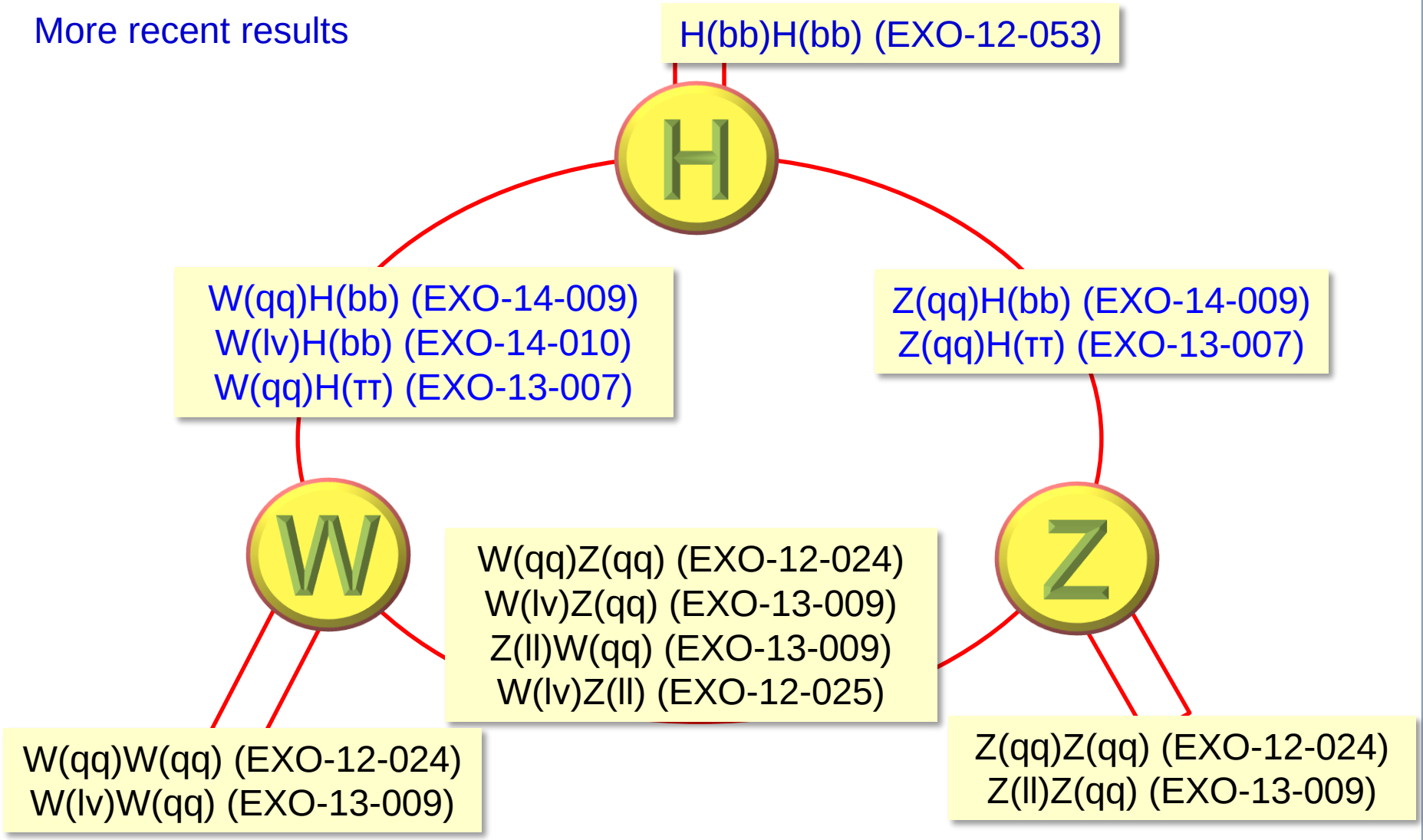


Final state with boosted V:

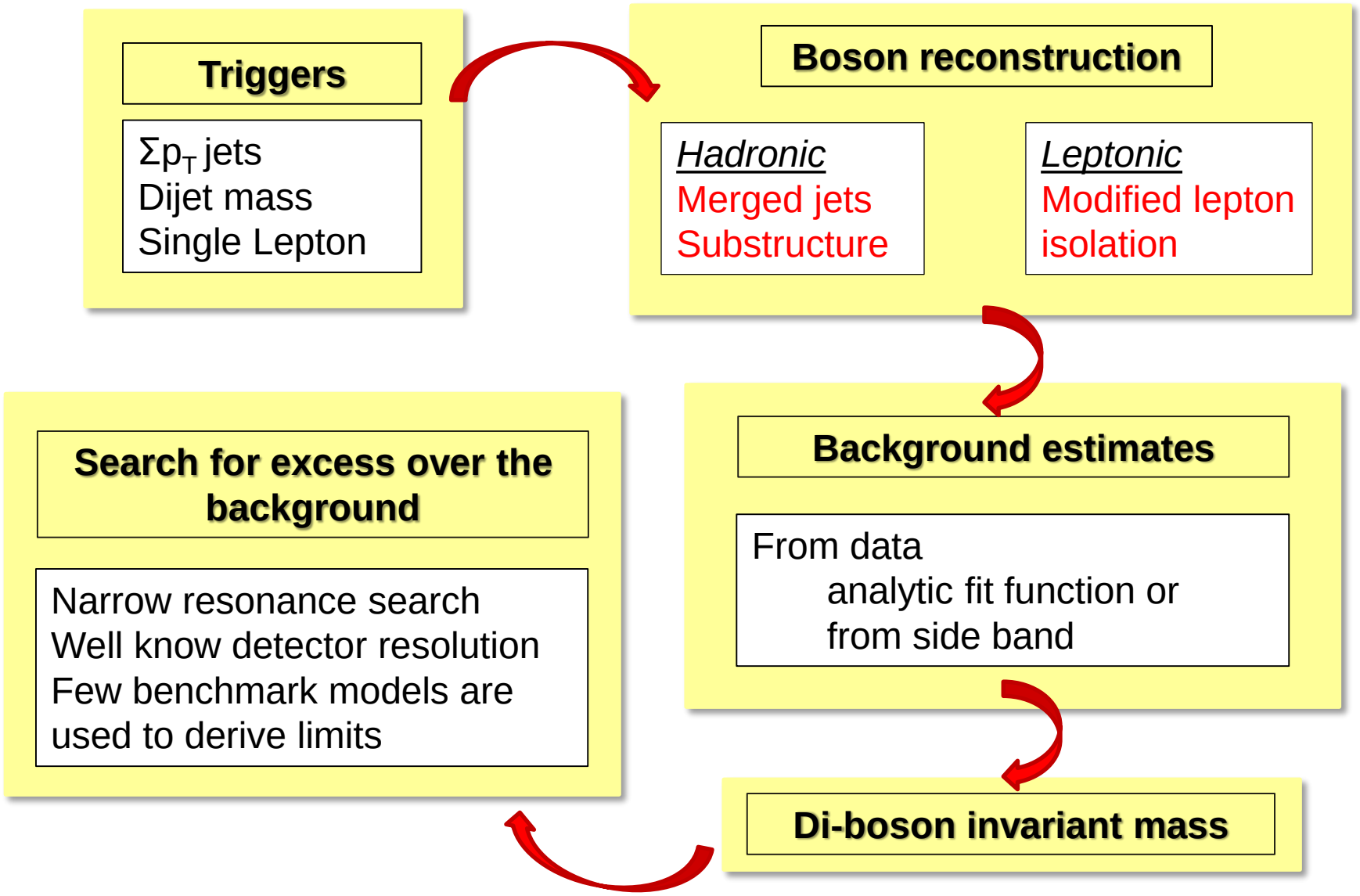
- ✓ WW, WZ, ZZ resonances
- ✓ WH and ZH resonances search
- ✓ HH resonances

Di-boson final states - map

More recent results



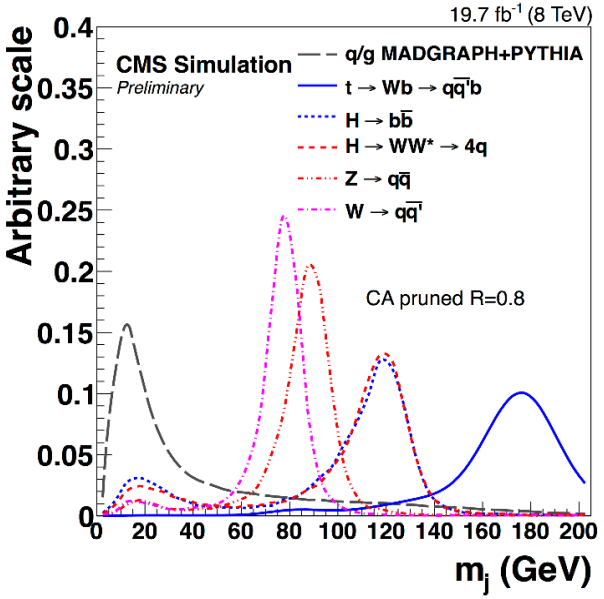
Analysis Strategy at a Glance



WW/WZ/ZZ

Reconstructing boosted W/Z/H

Above W,Z(H) p_T>200(300) GeV quarks merge into R=0.8 jet



- Reconstruct W/Z/H with CA R=0.8 jet
- Pruned jet mass (arXiv:0912.0033)
  Better resolution by elimination soft, large angle radiation and
  - expected at W/Z/H mass

- N-subjettiness (τ_2/τ_1) – provide additional discrimination. Should look like composed of two smaller jets

$$\tau_N = \frac{1}{d_0}\sum_k p_{T,k}\min\{\Delta R_{1,k}, \Delta R_{2,k}, ..., \Delta R_{N,k}\}$$ arXiv:1011.2268

✓ *Calibrated in semi-leptonic ttbar sample containing real boosted Ws.*

Fully hadronic WW/WZ/ZZ

10.1007/JHEP08(2014)173

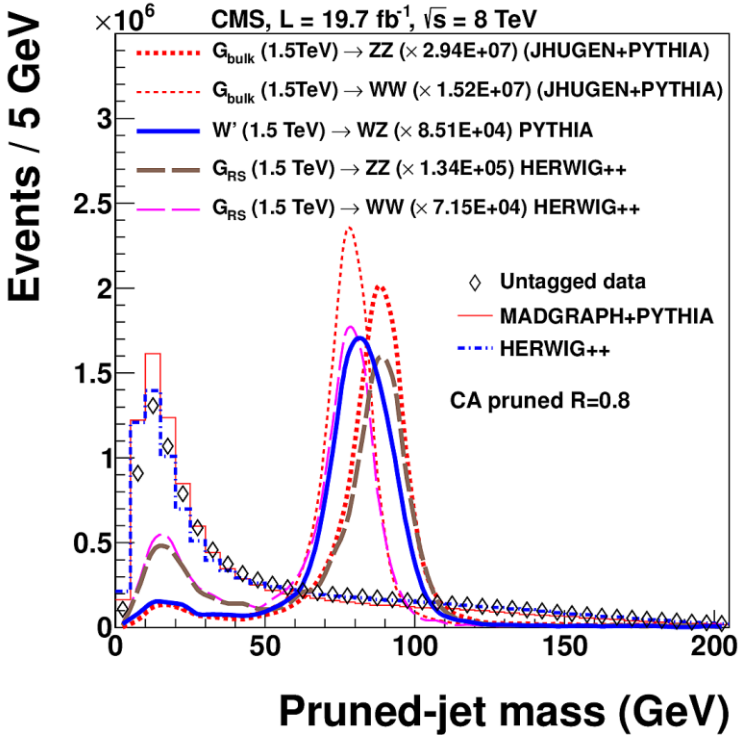
Trigger $\Sigma p_{T\,jets}$>650 GeV OR dijet mass>750 GeV

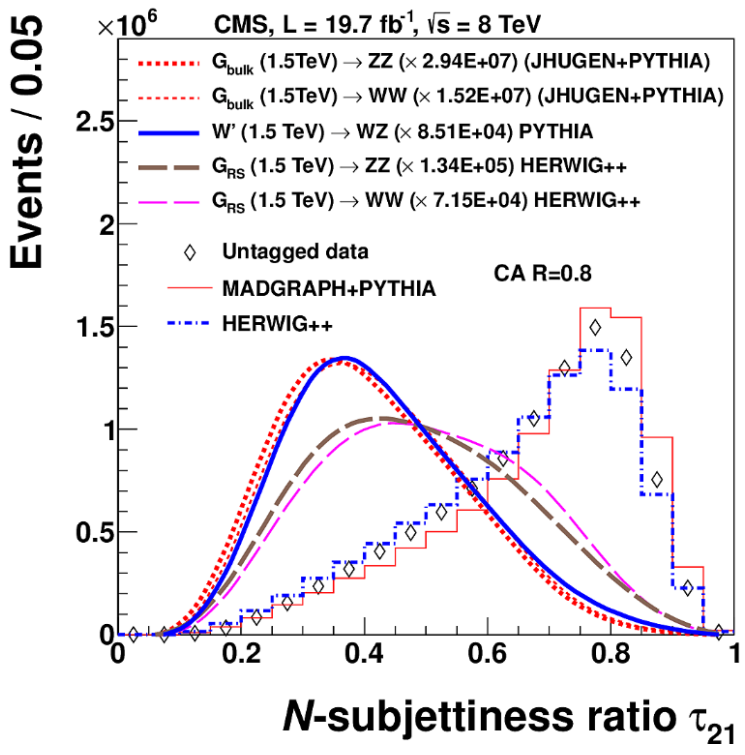
Event selection: two R=0.8 jets with

$|\eta 1-\eta 2|<1.3$ (suppress QCD multijet background)

$70<m_{pruned}<100$ GeV to select both W and Z

$\tau 2/\tau 1 <0.5$ for highest purity, $0.5< \tau 2/\tau 1 <0.75$ for lower purity





Background estimation – fully hadronic

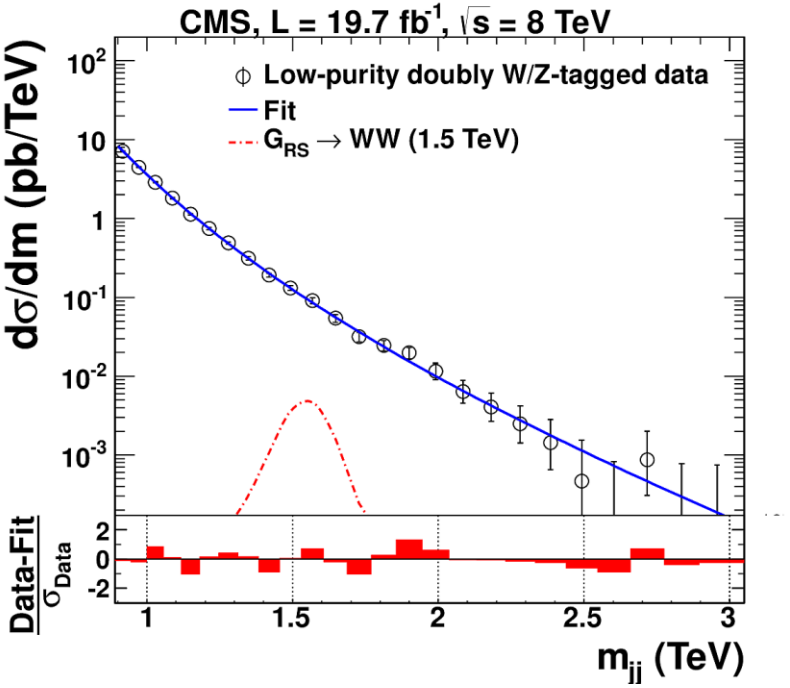
Background has a smooth distribution and can be described by a fit function

Performing simultaneously fit:

- signal yield and background parameters
- No need of detailed simulation for the background processes

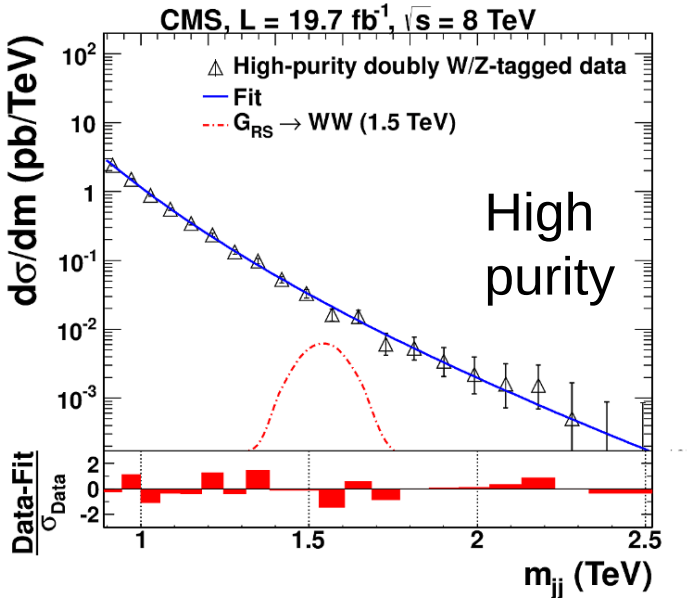
Checks:

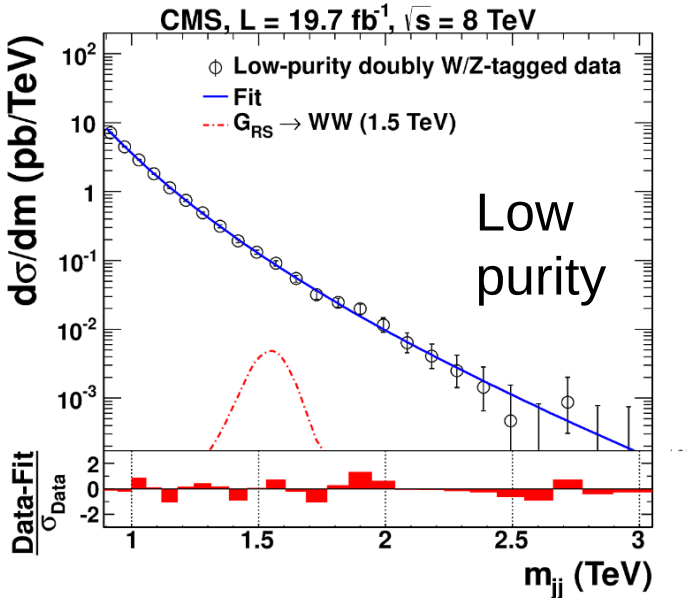
- ***Bias-test***: How much is signal yield mis-fitted when fitting toy spectra of default fit function with alternative functional form
- ***F-test:*** Increase number of parameters until fit shows no significant improvement



V(qq)V(qq) resonances

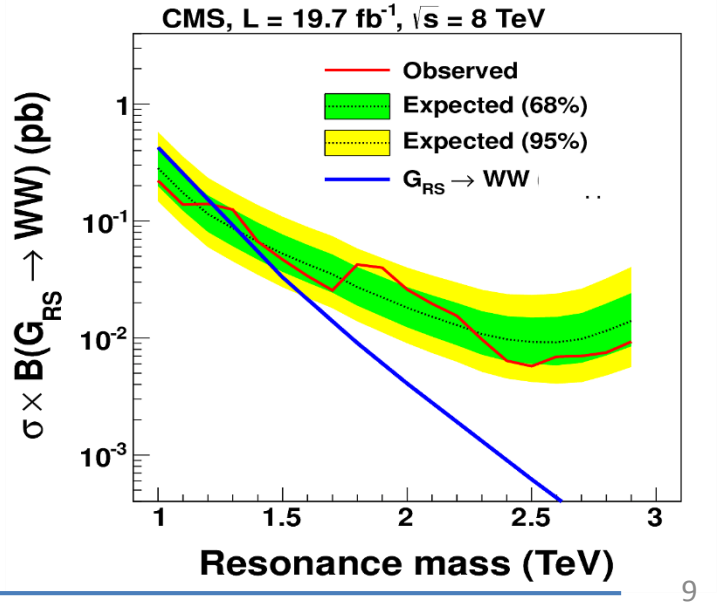
10.1007/JHEP08(2014)173





Two bump hunts in HP and LP samples, like "classic" dijet search

- Randall-Sundrum gravitons
- A *moderate excess (1.3σ)* seen for M_{jj}≈2 TeV
  - ✓ no excess in HP
  - ✓ larger excess in LP

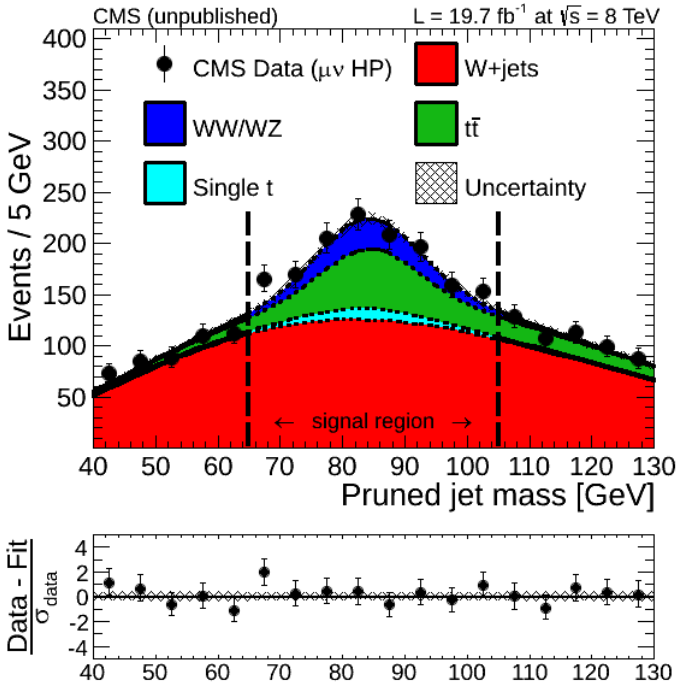


Semi-lepton background estimation

Using observable in signal-depleted sideband closely related to signal region

- Background rate+shape estimated from data in sideband, extrapolated to signal region using simulation

- ✓ Limited use of background simulation
- ✓ Uncertainties associated to extrapolation to signal region sometimes arbitrary



Checks:

- Closure test in simulation and/or other data sideband
- Cross-checked against the estimate from data with fit function for the background

Semi-lepton W(lν)W(qq)

10.1007/JHEP08(2014)174

- Trigger: high p_T lepton: pT>80(40) GeV for e(μ)

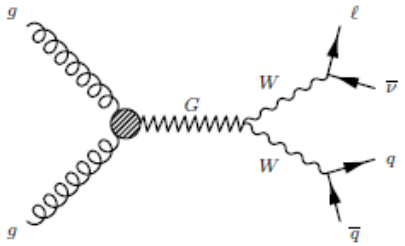
Reconstructed one W from one lepton and E_T^{miss}

Second V reconstructed from V-tagged CA8 jet

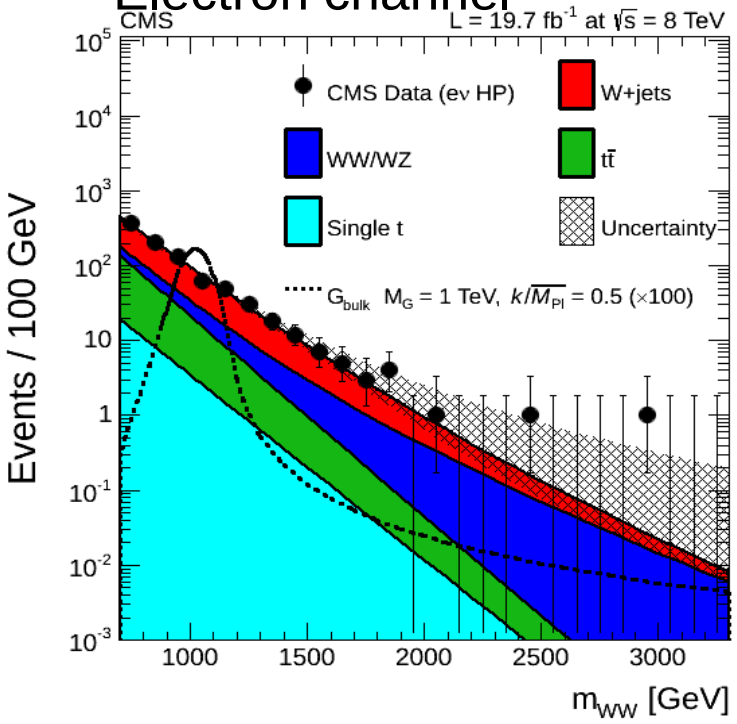
Categorize in purity based on τ2/τ1

W+jets background estimated from jet mass side-band

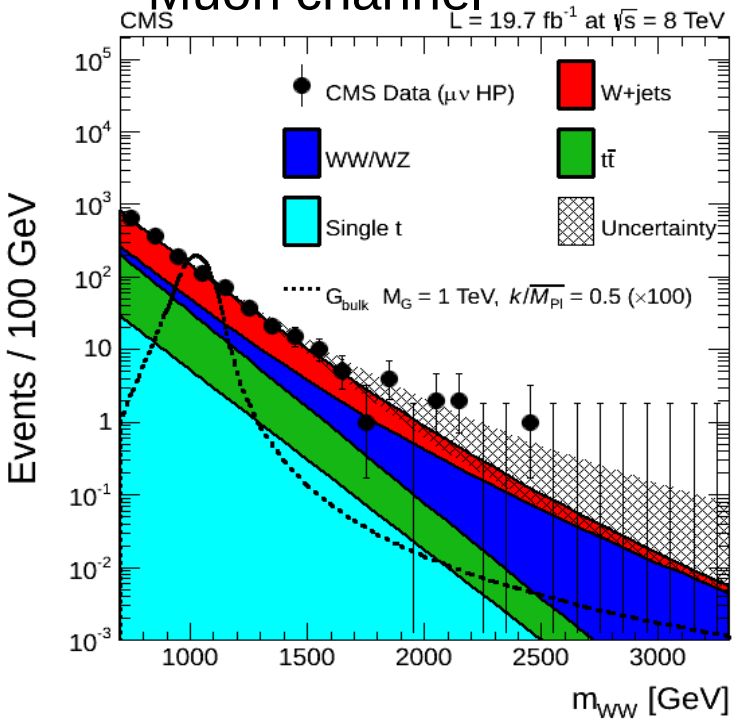
ttbar control region



Electron channel



Muon channel



Semi-lepton Z(ll)Z(qq)

10.1007/JHEP08(2014)174

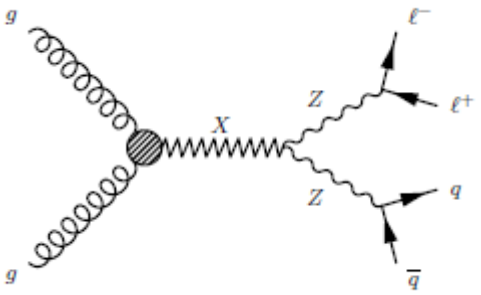
- Trigger two leptons: p_T>33/33 (22/8) GeV for e(μ)

Reconstructed one Z from 2 leptons

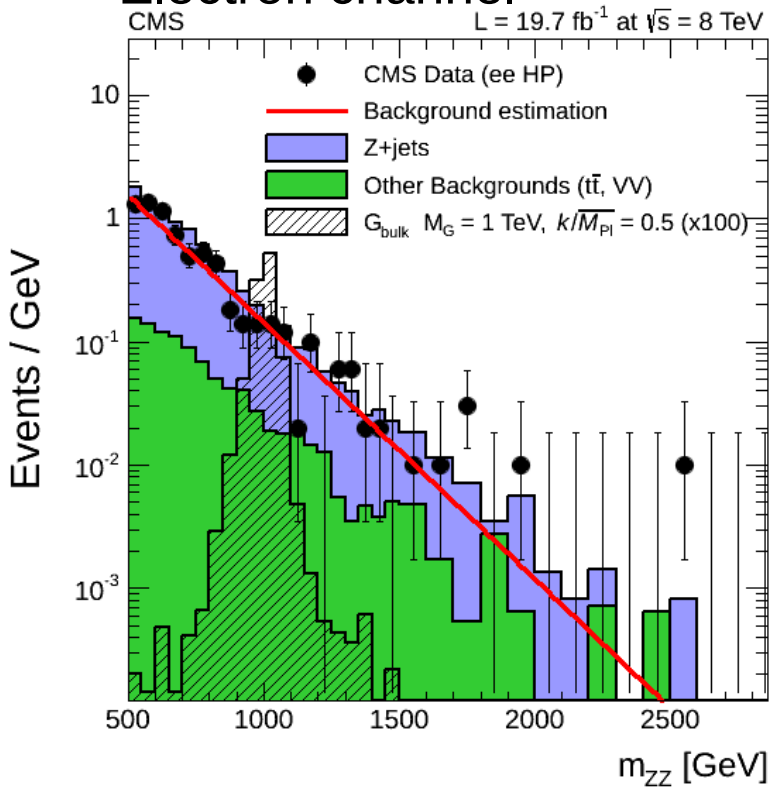
Second V reconstructed from V-tagged CA8 jet

Categorize in purity based on τ2/τ1

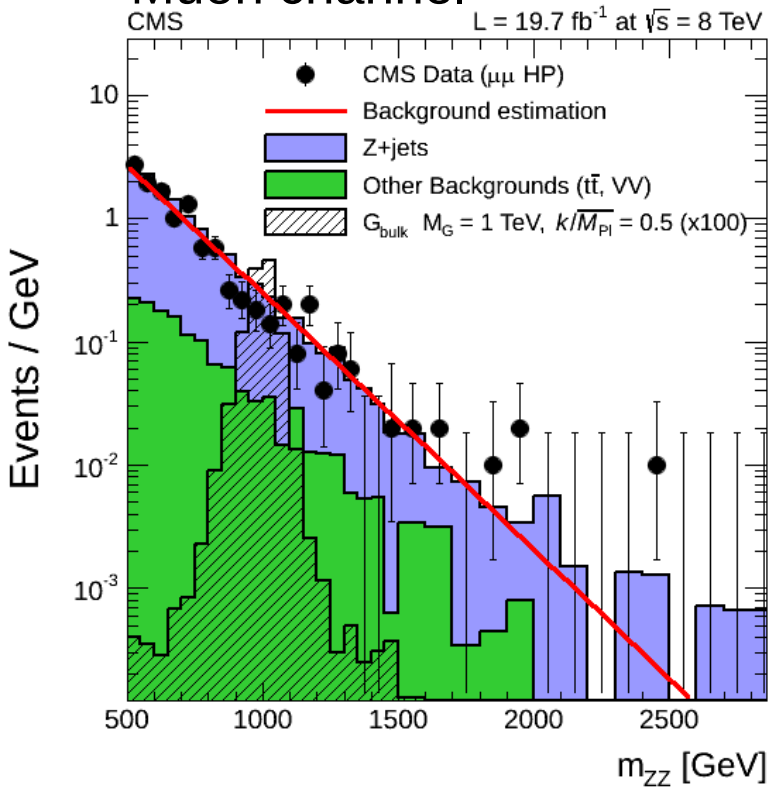
Z+jets background estimated from jet mass side-band



Electron channel



Muon channel



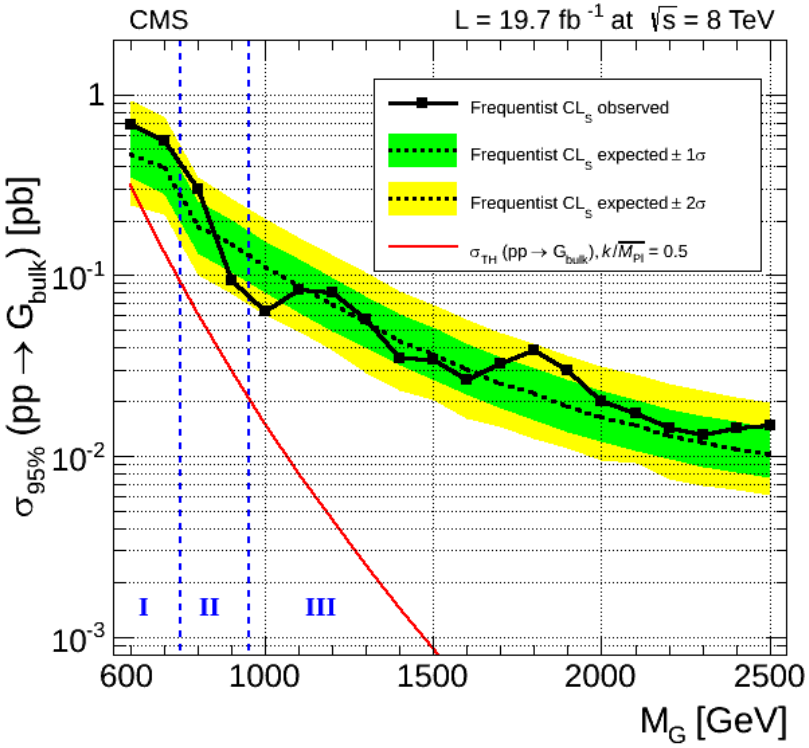
Limits on spin-2 WW/ZZ resonances

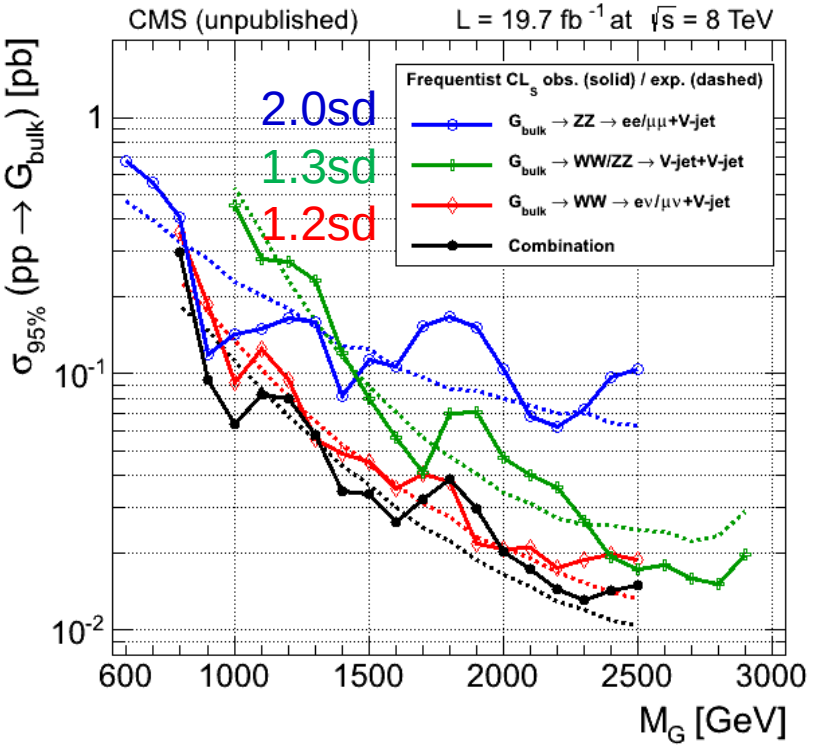
10.1007/JHEP08(2014)174

Combined results for WW/ZZ searches at √s = 8 TeV

Cross section and width related to coupling parameter k/M_{Pl} (narrow <0.5)

Narrow width for $k/M_{Pl} \leq 0.5$, Bulk Graviton model



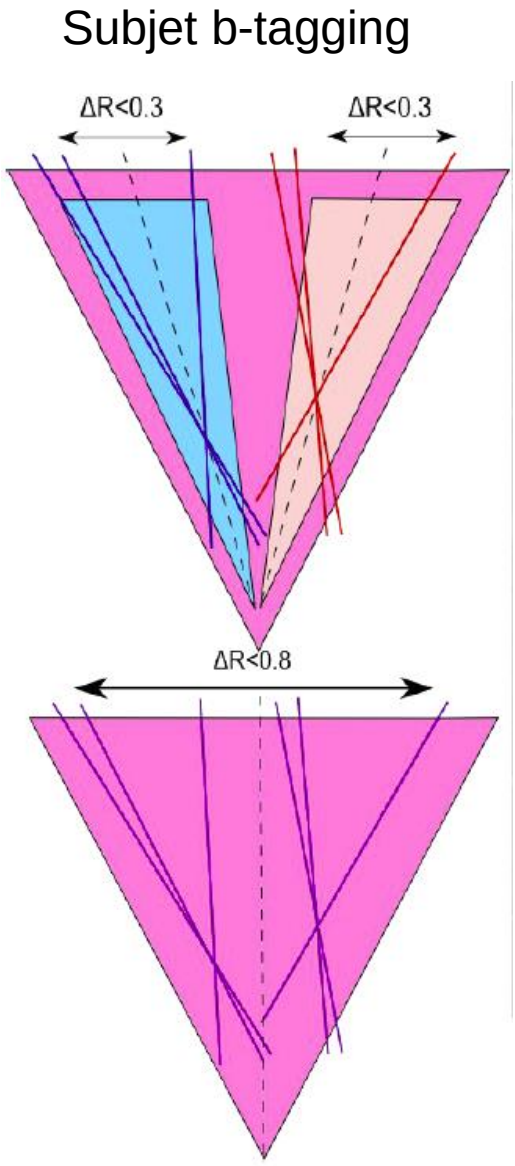


VH,HH resonance

Reconstructing H(bb)

Pruned jet mass is used as main discriminator

- Identify b-quark initiated jets with multivariate discriminant based on secondary vertices from B-hadron decay and associated tracks
- Modified b-tag algorithm - 2 steps procedure
  - Sub-jet: Undo last iteration of jet clustering to obtain two subjets corresponding to the b-quarks from Higgs decay. If subjets angular separation is larger than 0.3, apply b-tagging on subjets. Otherwize:
  - Fat-jet: apply b-tagging on R=0.8 jet

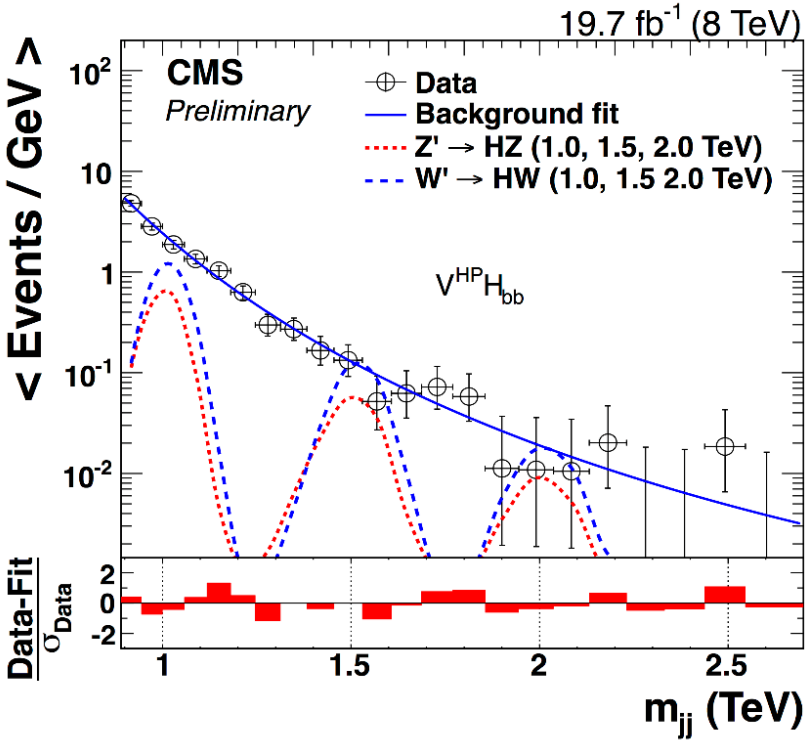


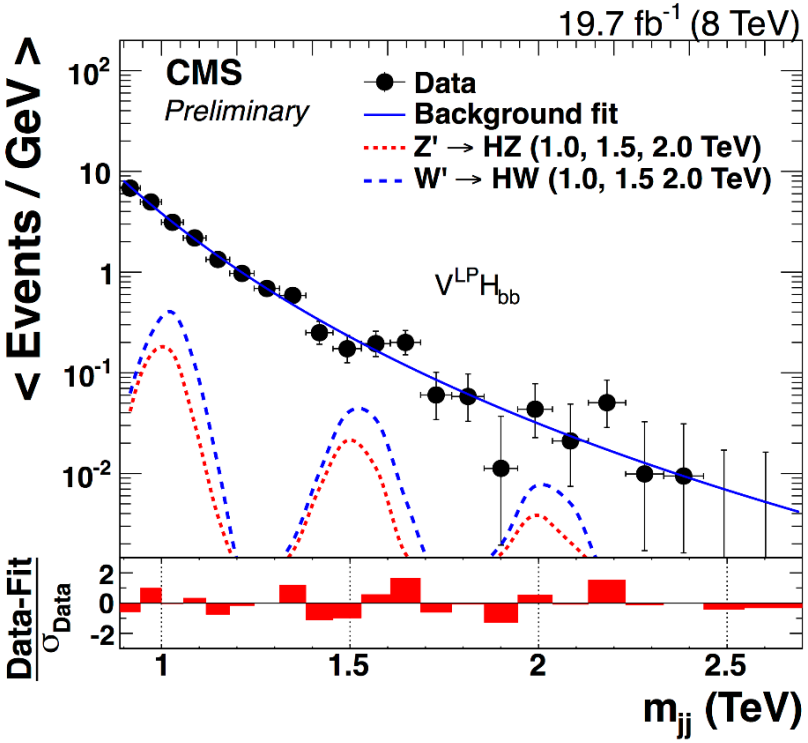
V(qq)H(bb) resonances

arXiv:1506.01443

- Using the same search techniques as V(qq)V(qq) search

Better S/B ratio due to better background rejection of H(bb)-tagger compared to W(qq)/Z(qq)-tagger





Reconstructed H→WW→qqqq

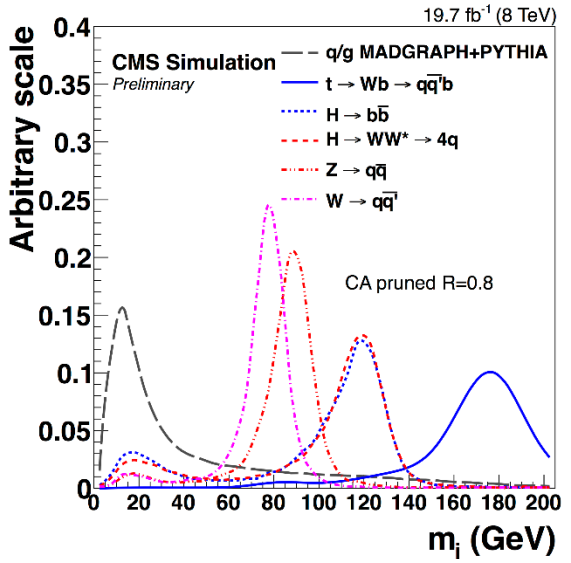
arXiv:1506.01443

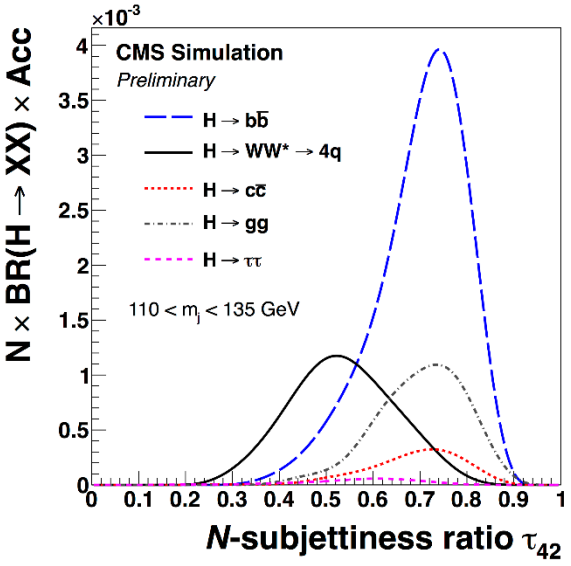
H → WW → qqqq has second highest BR after H→ bb . Imposing the same requirement on the pruned jet mass selection as H->bb jets

- τ4/τ2 is the best discriminating variable between H->WW->qqqq jet (initiated from 4 partons) and quark/gluon/W/Z/H(bb) jets (initiated from 1 or 2 partons)

Since BR(H → bb)>>BR(H →WW→qqqq), fraction of H->bb event failing b-tagging, but passing τ4/τ2 selection is non-negligible

- Need to consider all possible Higgs decays simultaneously in the analysis





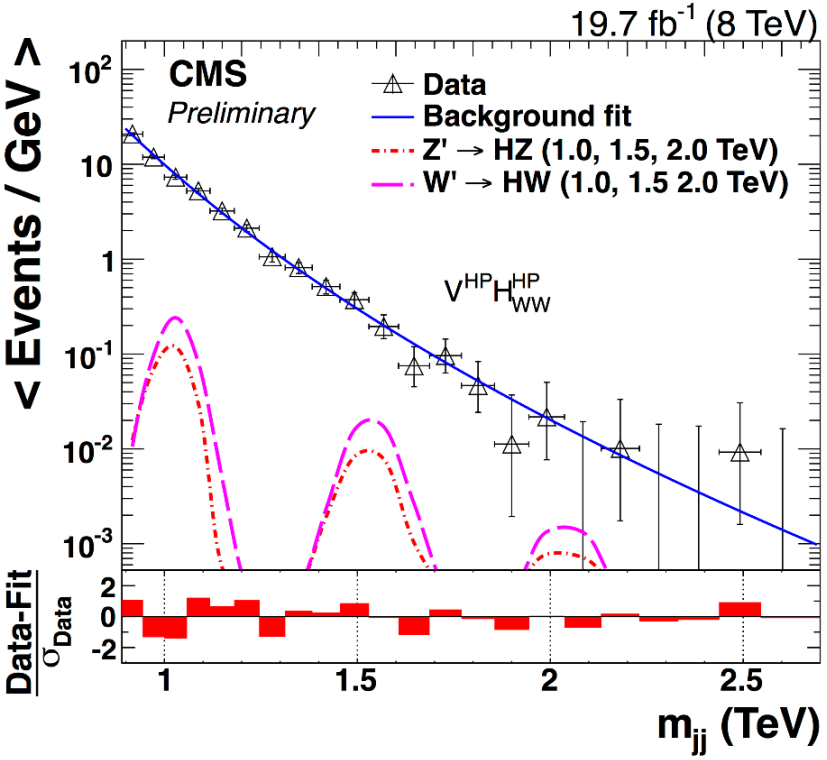
V(qq) H(WW->qqqq) resonances

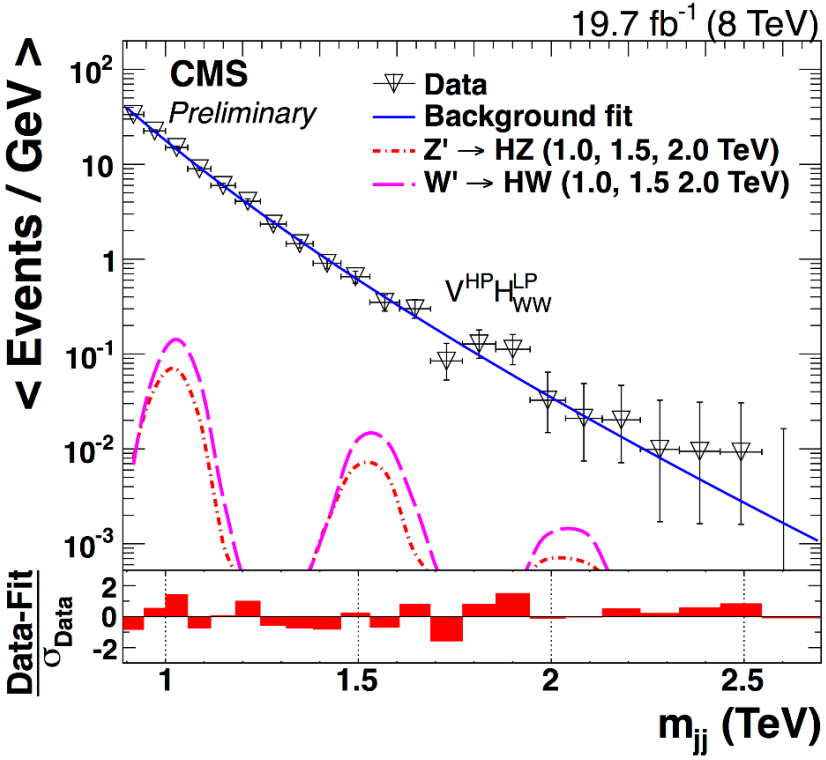
arXiv:1506.01443

Exclusive search channel: Only events that fail H(bb) tagger

Factor 4 less stringent limits on cross section than H(bb) channel

Improves the sensitivity by 10% when combined with H(bb)





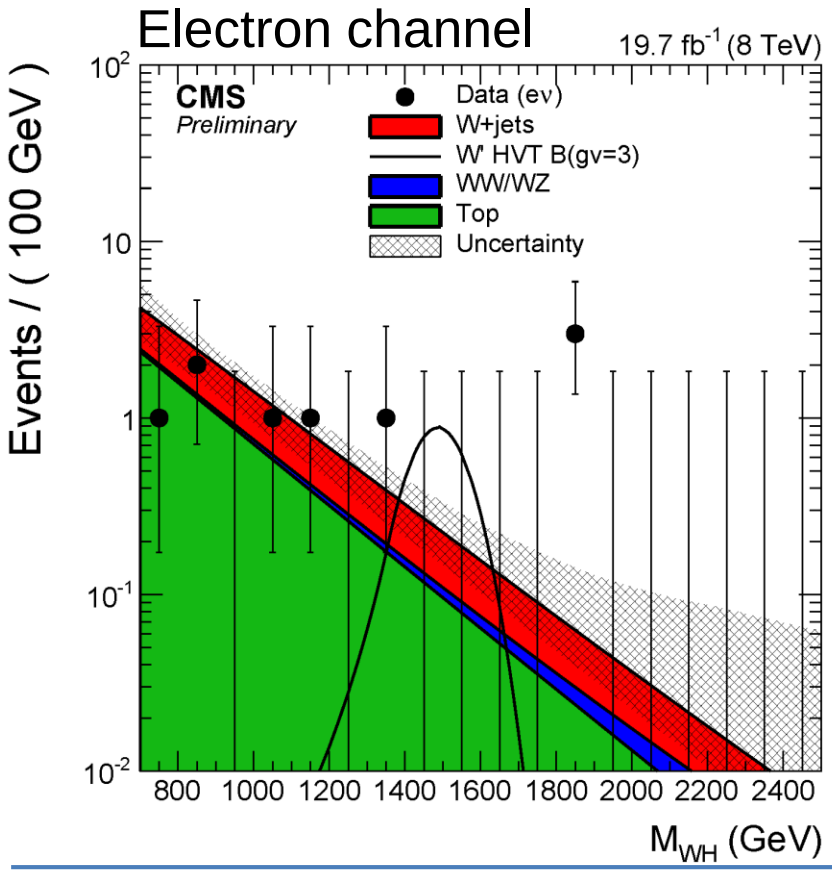
W(lv)H(bb) resonances

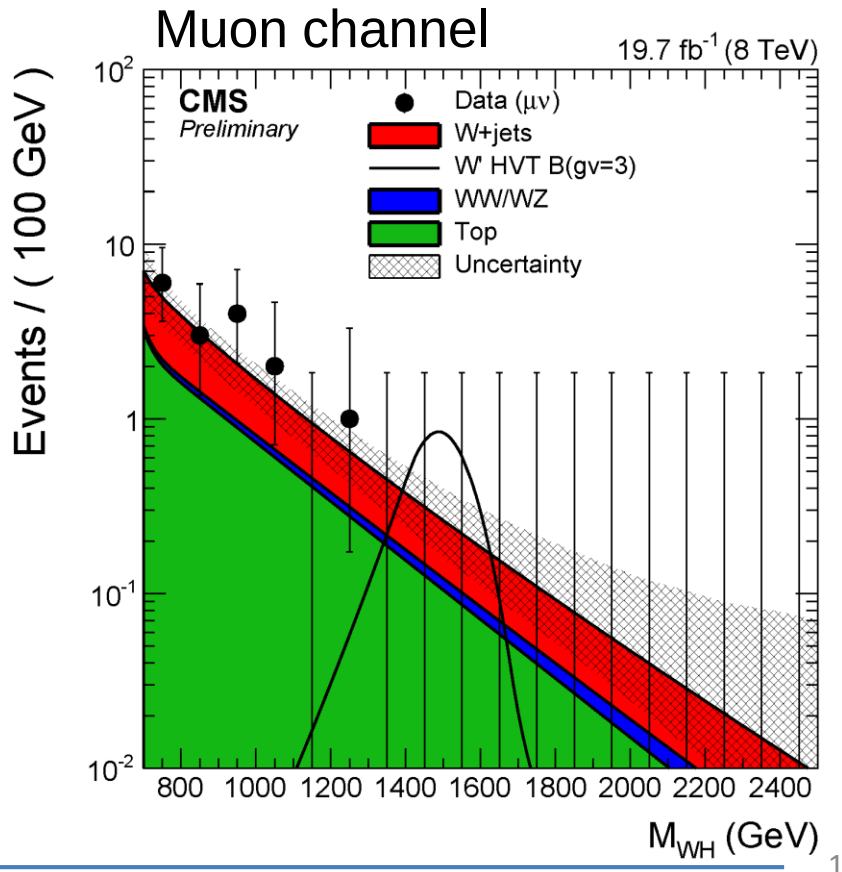
CMS EXO14010

The search techniques is the same as W(lv)V(qq) search

Better background rejection of H(bb)-tagger compared to W(qq)/Z(qq)-tagger

✓ Excess in W(lv)H(bb) at 1.8 TeV has a local significance of 2.2 s.d. for combined electron and muon channel.





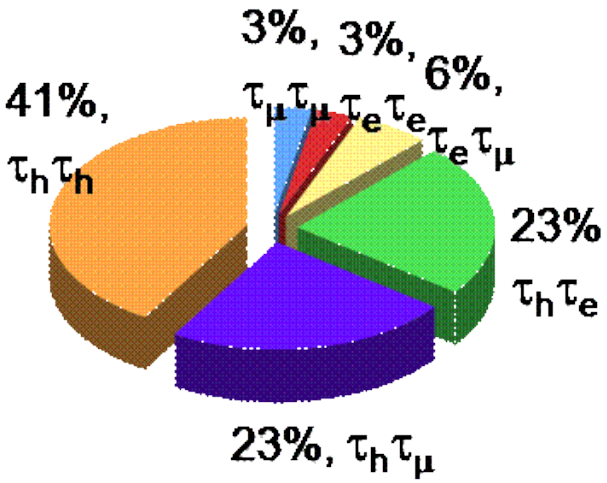
Reconstruction of H->ττ

Special reconstruction for the boosted tau pairs

- ✓ All-leptonic channel – identify by electrons, muons and E_t^{miss}
  Isolation criteria exclude muons and electrons – recover efficiency for the boosted ττ pair.

- ✓ Semi-leptonic channel – modified isolation criteria for τ_h and electrons/muons.

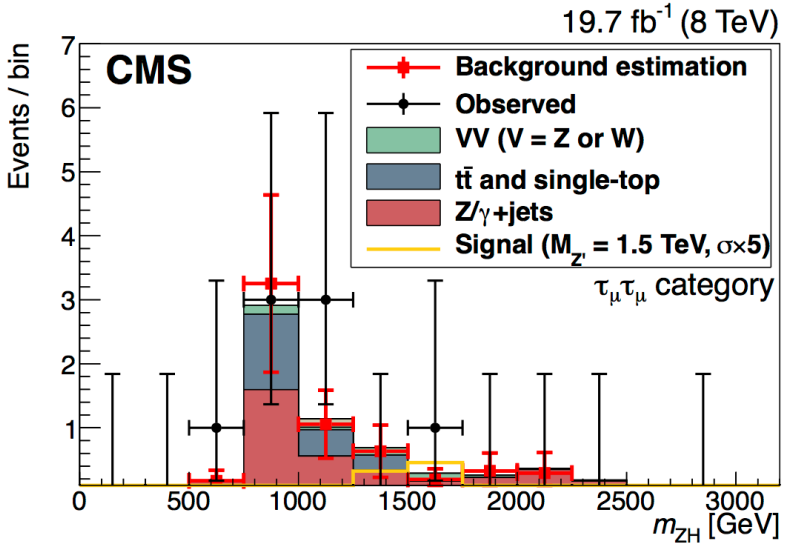
- ✓ All-hadronic channel – start with CA8-jets and apply subjet-searching techniques. Tau identification is applied on sub-jets.



- ✓ Higgs mass is reconstructed from visible tau decay products and missing transverse energy

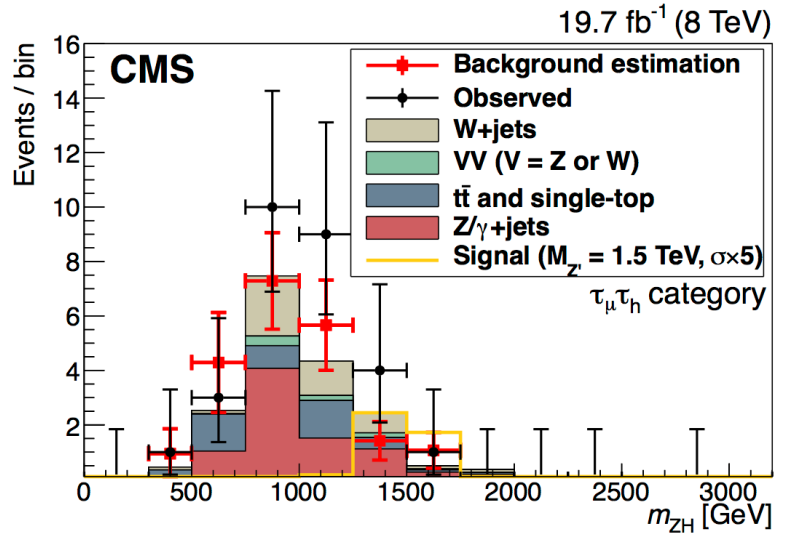
Z(qq) H(ττ) resonances

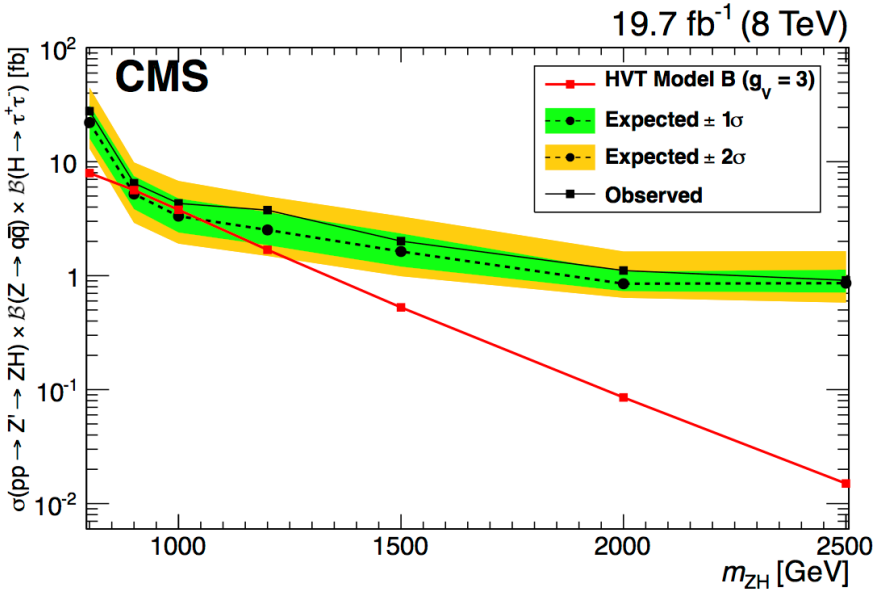
10.1016/j.physletb.2015.07.011



- Events are divided in 6 categories
- Background predicted from data sidebands
  - ✓ Low jet mass window
  - ✓ Di-tau mass window below Z

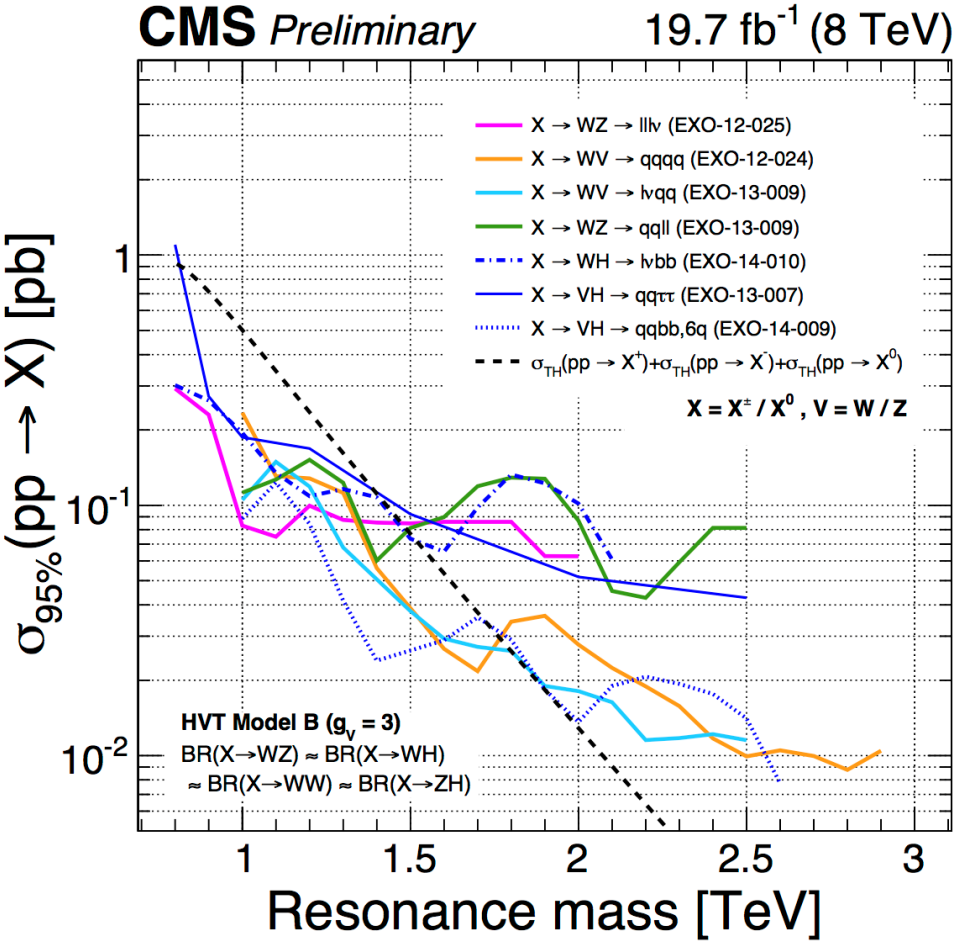
- No excess observed





Limits on spin-1 WW/WZ/ZH/WH resonances

CMS EXO14010



❖ **Heavy Vector Triplet model B (g_V = 3)**

WV(lvqq), VV(qqqq) and VH(qqbb) have best sensitivity at high masses

H(bb)H(bb) resonances

CMS EXO12053

Trigger *$\Sigma p_{T\,jets}$>650 GeV OR dijet mass>750 GeV*

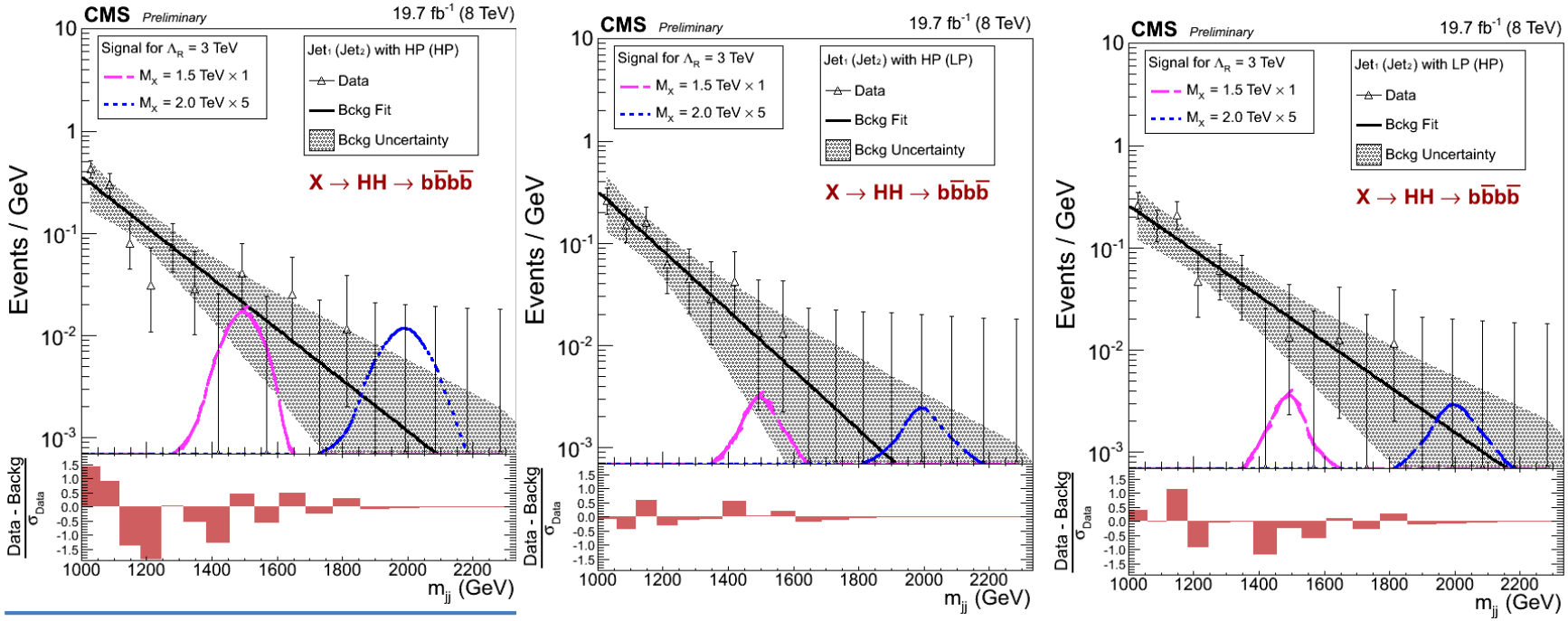
Require ≥3 **b-tagged** subjets in event

- If subjets closer than ΔR<0.3: Require b-tagged fatjet instead

Categorize in purity via τ2/τ1

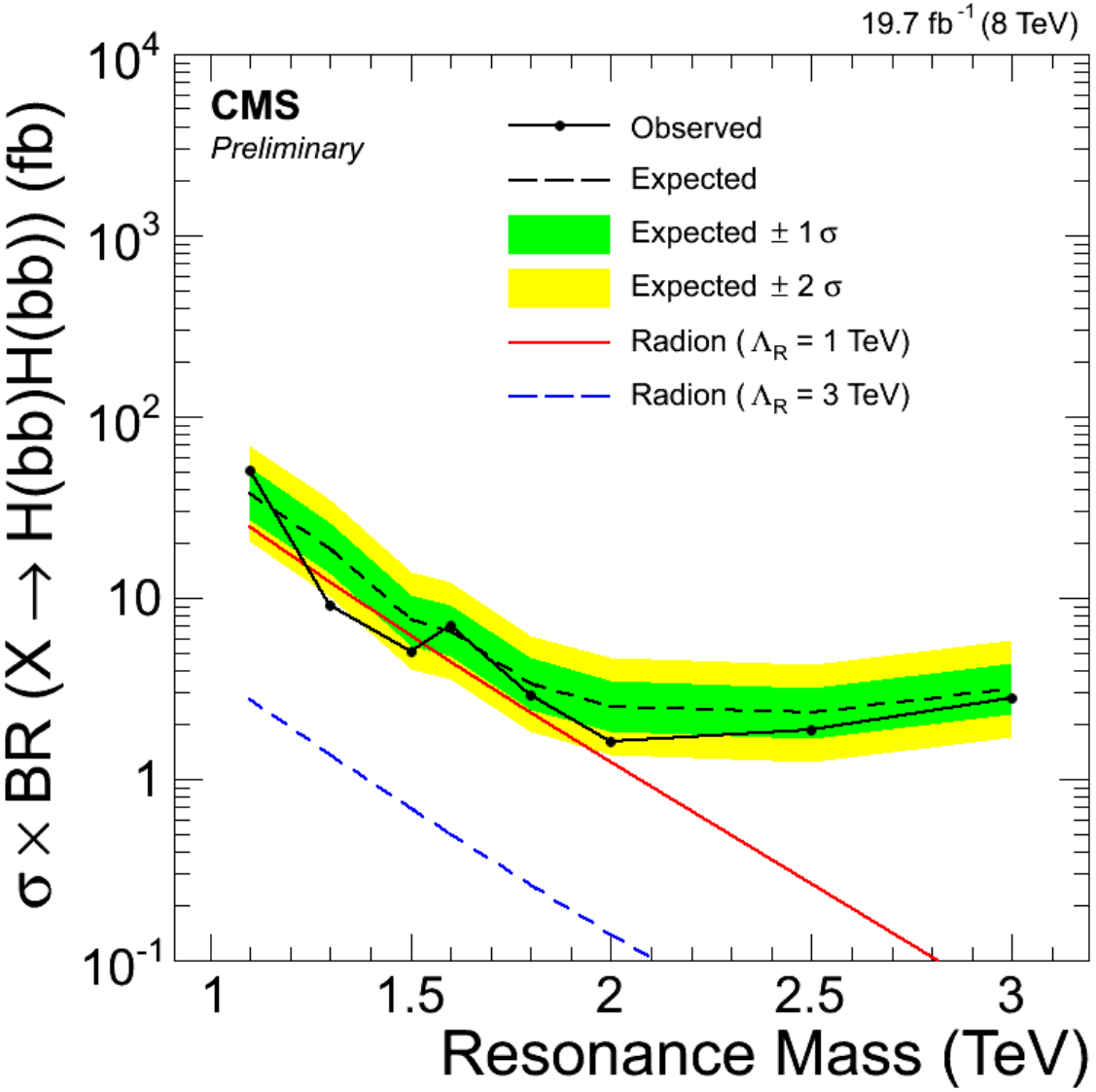
Background estimate is intermediate approach between fitting background shape in signal region and estimation from sideband

Cross-check with low side band and pseudo-signal region (90<m_J<100GeV)



spin-0 HH resonances

CMS EXO12053



Extra dimension spin-0 radion (Λ_R=1 TeV) excluded around 1.2-1.5 TeV

- *This model is at edge of validity of narrow width approximation.*

Summary

Searches for heavy resonances in di-boson final states have been performed with Run1 data with the CMS detector

- direct probe for new physics at TeV scale
- sensitivity is dramatically enhanced with dedicated jet substructure algorithms

No significant excess observed in data

- small deviations observed in different channels at ~1.8 TeV

Need Run II to clarify the interesting situation

Already the first few fb^{-1} from Run2 can exceed the Run1 sensitivity for heavy resonances discovery in di-boson final states.