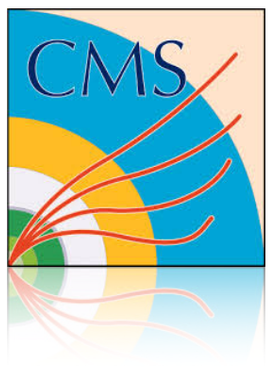
Searches for diboson resonances at CMS

Cristina Mantilla Suarez (JHU) on behalf of CMS



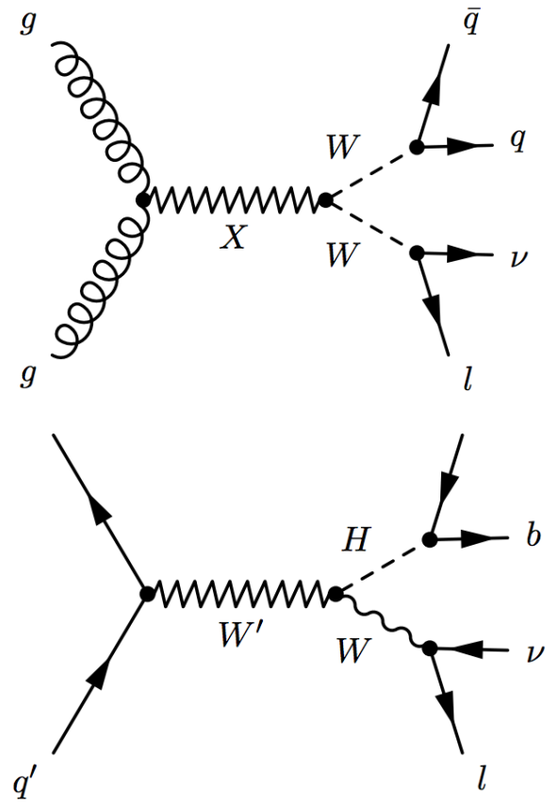
JOHNS HOPKINS UNIVERSITY

SUSY 2019

Diboson resonances

Many BSM theories predict them, e.g.:

- Bulk RS Graviton (warped extra dim)
  - BG->ZZ/WW/HH
- Heavy Vector Triplet (HVT) models, e.g. **Heavy Z', W'** (spin-1)
  - Z' -> WW/ZH, W'-> WZ/WH



Signatures at the LHC:

X → VV qqqq,vvqq, lvqq, llqq

X → VH

H → bb: lvbb,llbb,vvbb,bbbb

H → ττ: qqττ

X → HH: bbbb,bbWW,bbττ

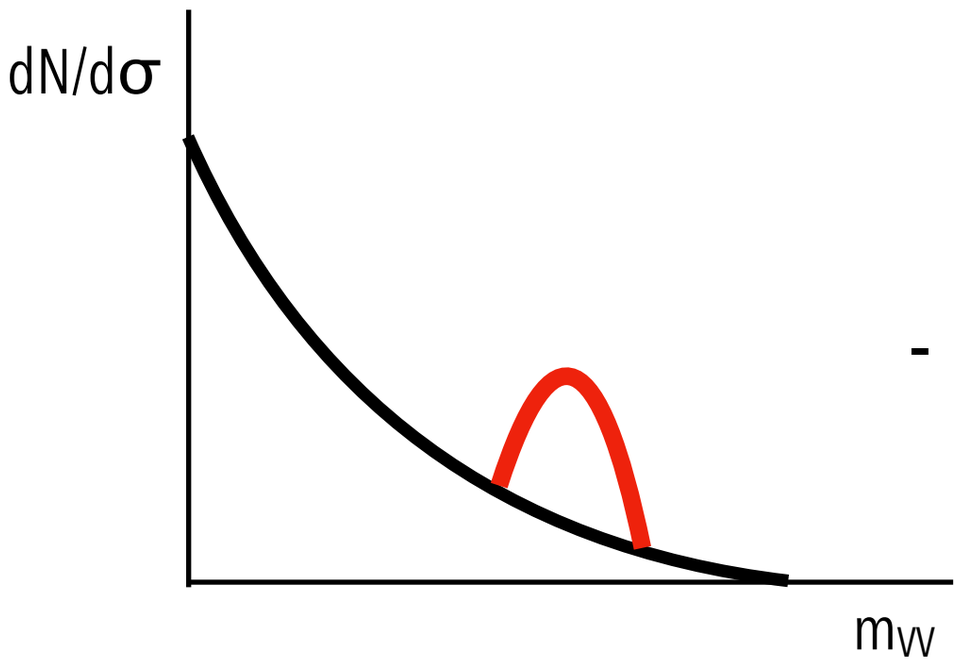
X can be Z',W',BulkGrav

arXiv:hep-ph.0701186
arXiv:hep-ph.9905221
arXiv:1402.4431

Analysis strategy

Search for X in data:

- Reconstruct diboson invariant mass (1D fit)
- Also have explored 2D fit e.g. m_X + m_{Jet}
- Or even 3D fit!

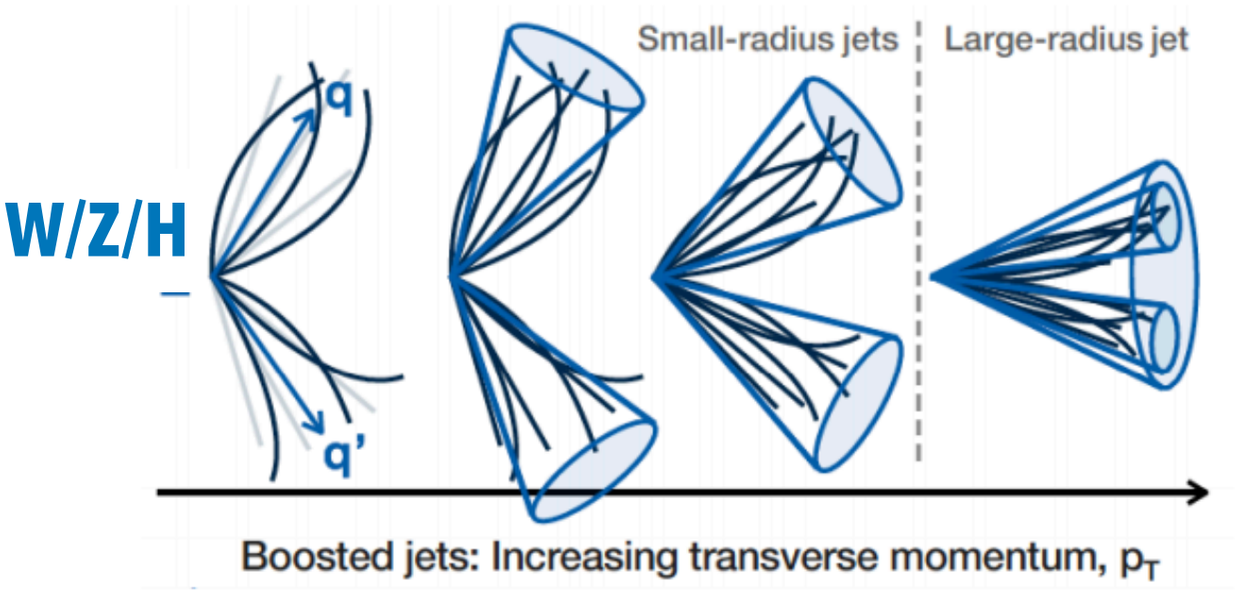


- "bump hunt"-like strategy
  - data-driven background methods
  - 2D/3D fit or parametric fit to data (signal region)
  - sideband-assisted (control regions)
- Background processes:
  - **QCD** (dominant for **hadronic searches**)
  - **W/Z+jets and ttbar** (dominant for **semi-leptonic**)

Analysis strategy

Searches in both **hadronic** and **semi-leptonic** final states.

- at least 1 hadronic side to be identified
- search for **massive X (≥ 1 TeV)** -> **high pT** (**boosted**)



- Keys for a successful boosted analysis:
  - large radius jets -> **jet substructure**
  - *W/Z(qq) tagging*
    - 2-prong tagging
  - *H(bb)/(ττ) tagging*
    - Simultaneous id of 2 b-quarks (BDT)
    - Dedicated tau reconstruction
  - *Lepton+jets*
    - Special lepton reco/isolation

Overview of the talk

Focusing on **recent** results with **novel background estimates**:

- VV (qqqq) : B2G-18-002 (77 fb^{-1}) -> 2016 + 2017 data!
- HH(bbbb): B2G-16-026 (36 fb^{-1}) -> 2016 only
- HH(bbWW): B2G-18-008 (36 fb^{-1}) -> 2016 only

Wrap up:

- Combination of diboson searches: B2G-18-006 (36 fb^{-1})

For full list of public results (more than 10 for diboson only!) see:
http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/B2G/index.html

X->VV->qqqq

All hadronic: *largest branching fraction*

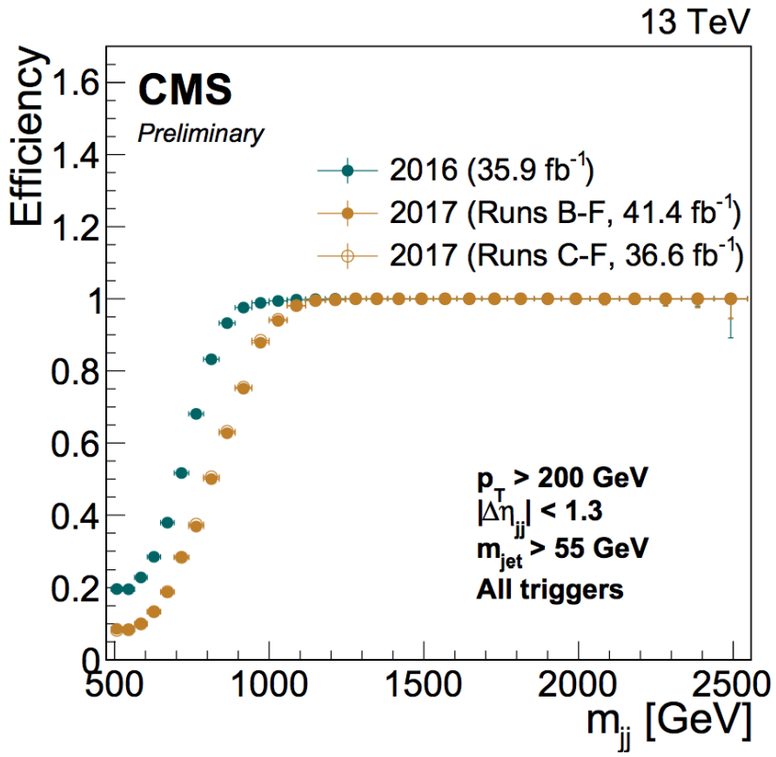
Identifies 2 boosted hadronic jets

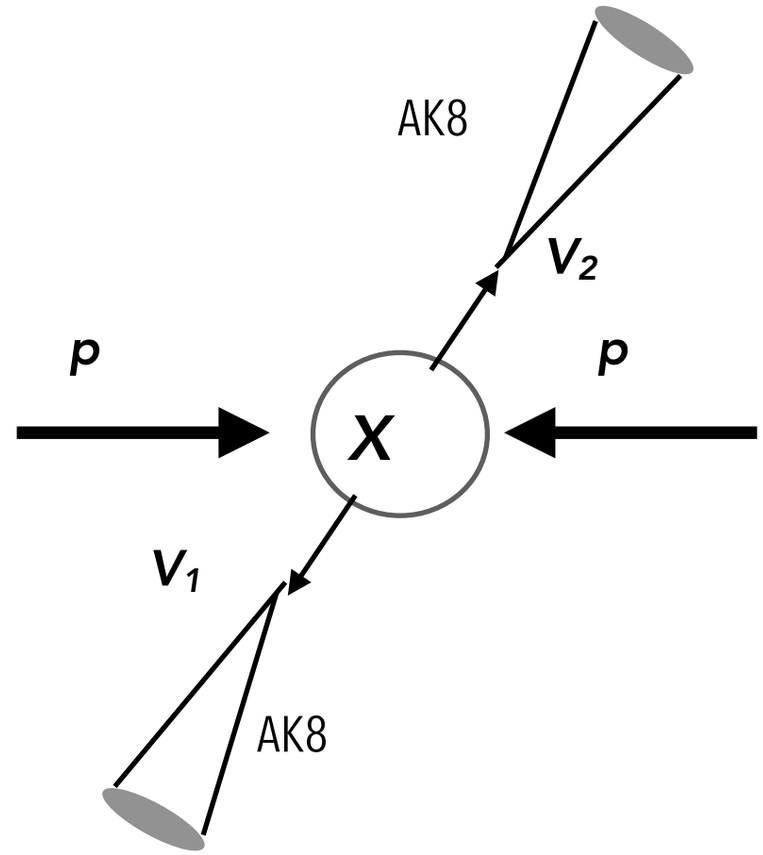
B2G-18-002

At least 2 AK8 jets (R=0.8) p_T> 200 GeV

m_{JJ} > 1126 GeV:

- low mass *threshold* set by *hadronic trigger eff.*



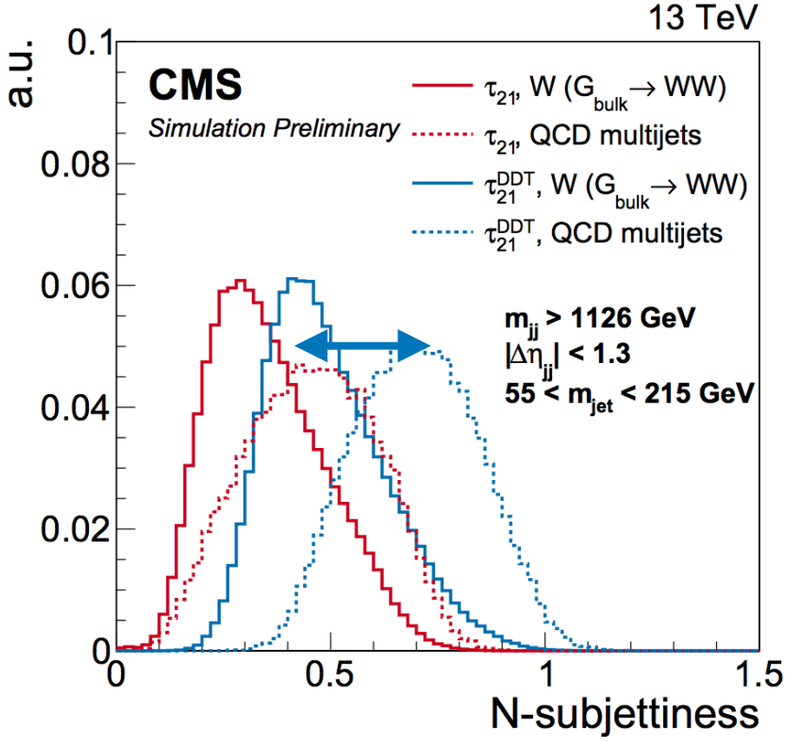


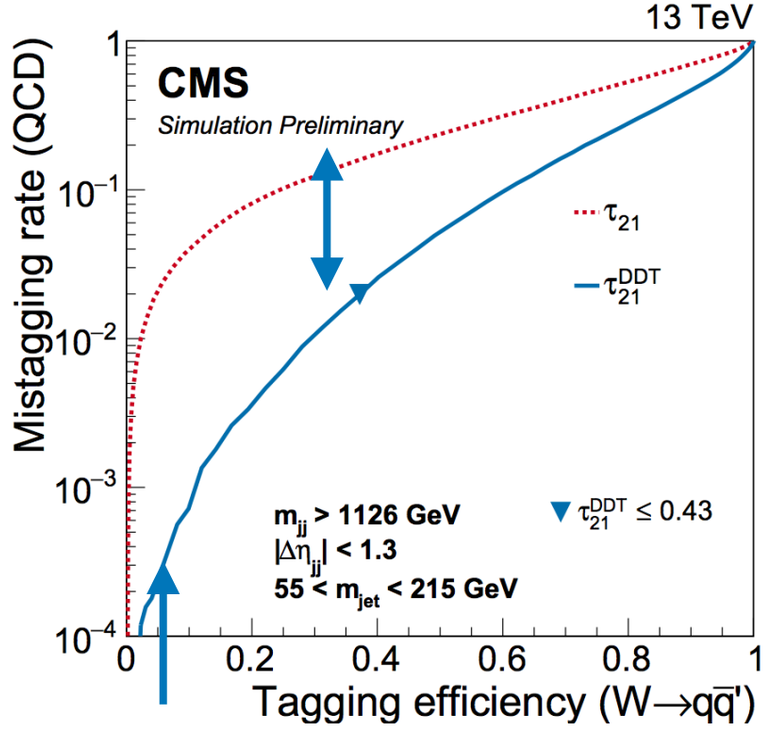
X->VV->qqqq

Boosted V-tagging:

B2G-18-002

- **Jet mass:** PUPPI (pileup mitigation) + soft drop algorithm:
  - pushes QCD bkg. to low mass + improves signal resolution
- 2-prong signal: **N-subjetiness** (τ_{21}) :
  - ***decorrelated from jet mass*** (ensures smooth jet mass shape)





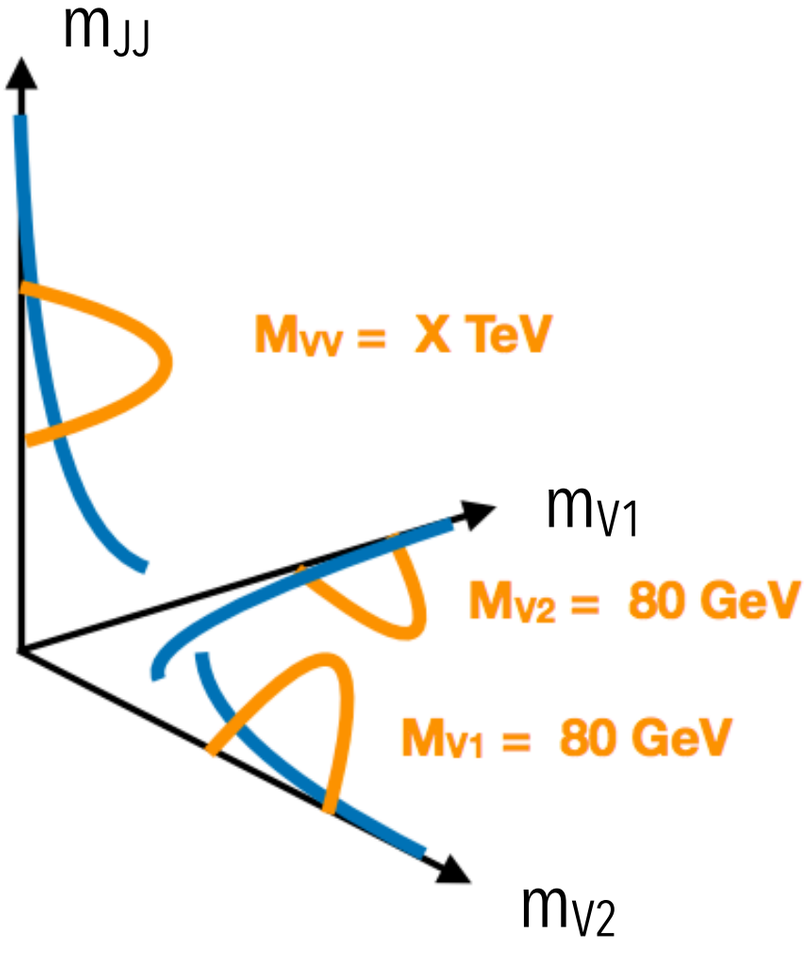
$$\tau_{21}^{DDT} = \tau_{21} + 0.08 \times \log(\frac{m^2}{p_T} 1GeV)$$

← Takes advantage of τ_{21} + ratio mass/p_T

X->VV->qqqq

B2G-18-002

Takes advantage of the fact that **signal is resonant in 3D: mJJ,mV1,mV2**



3D fit:

Modeling of correlations in QCD background from **smooth MC-based template**

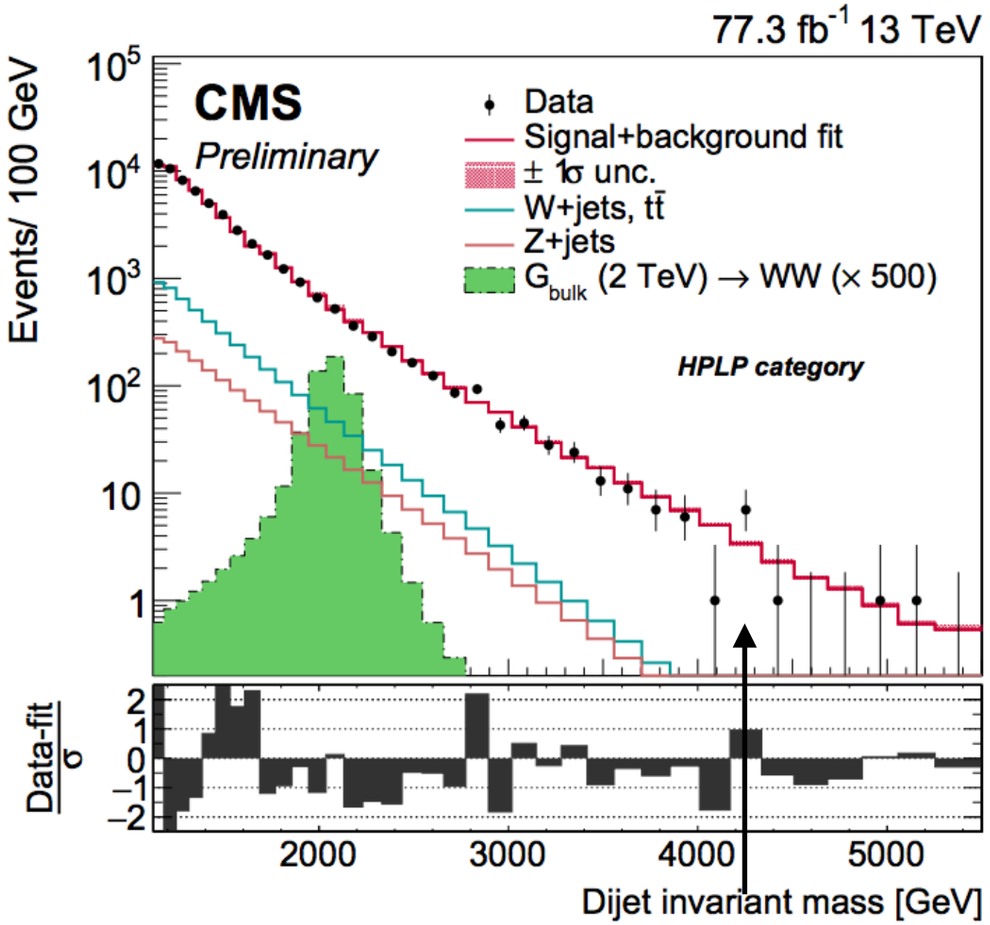
- 3D templates derived from MC (mjj,mj1,mj2)
- **Forward folding kernel approach :**
  - 250K bins -> each event contributing to a 1D/ 2D gaussian kernel defined by detector scale and resolution

Nominal shape allowed to adjust to data among large alternative shapes

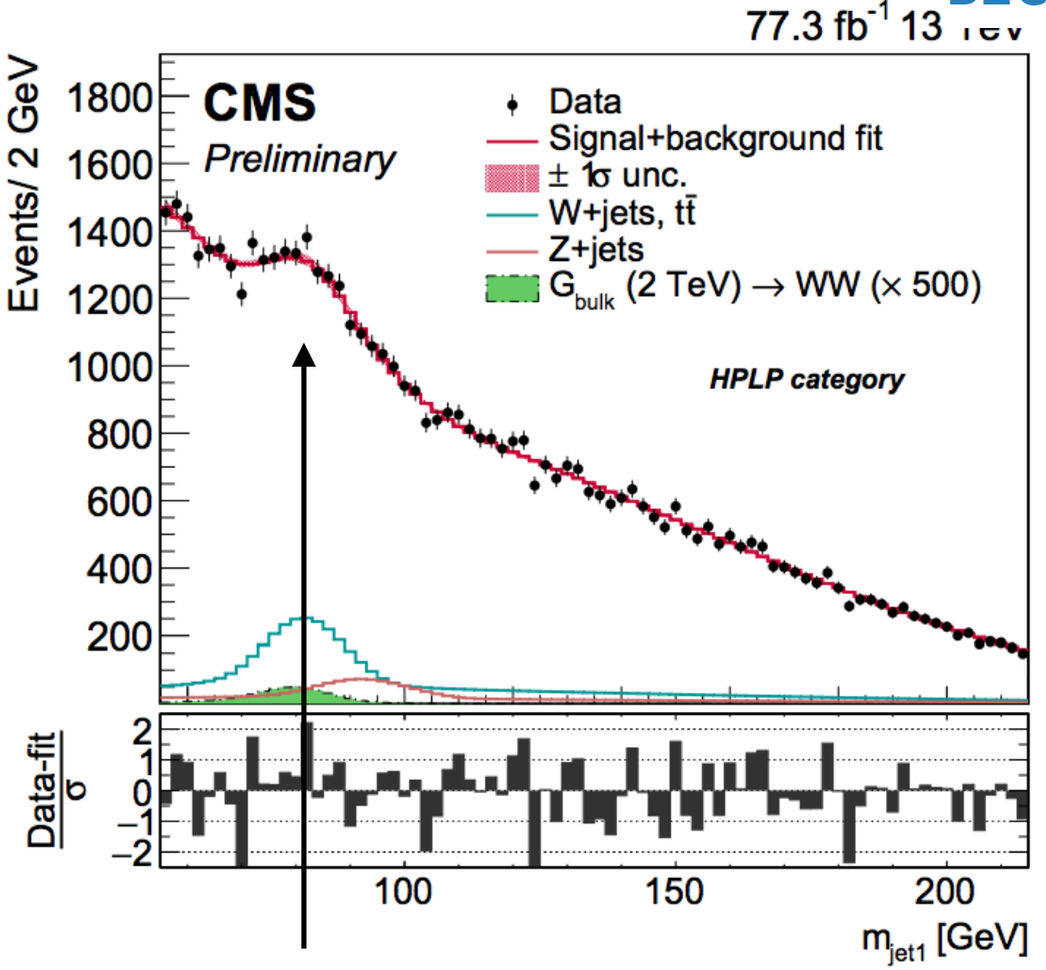
Method can be *generalized to any 3D resonant search!*

X->VV->qqqq

B2G-18-002



Overcomes limitation from high mass statistics!



SM V->qq peak:

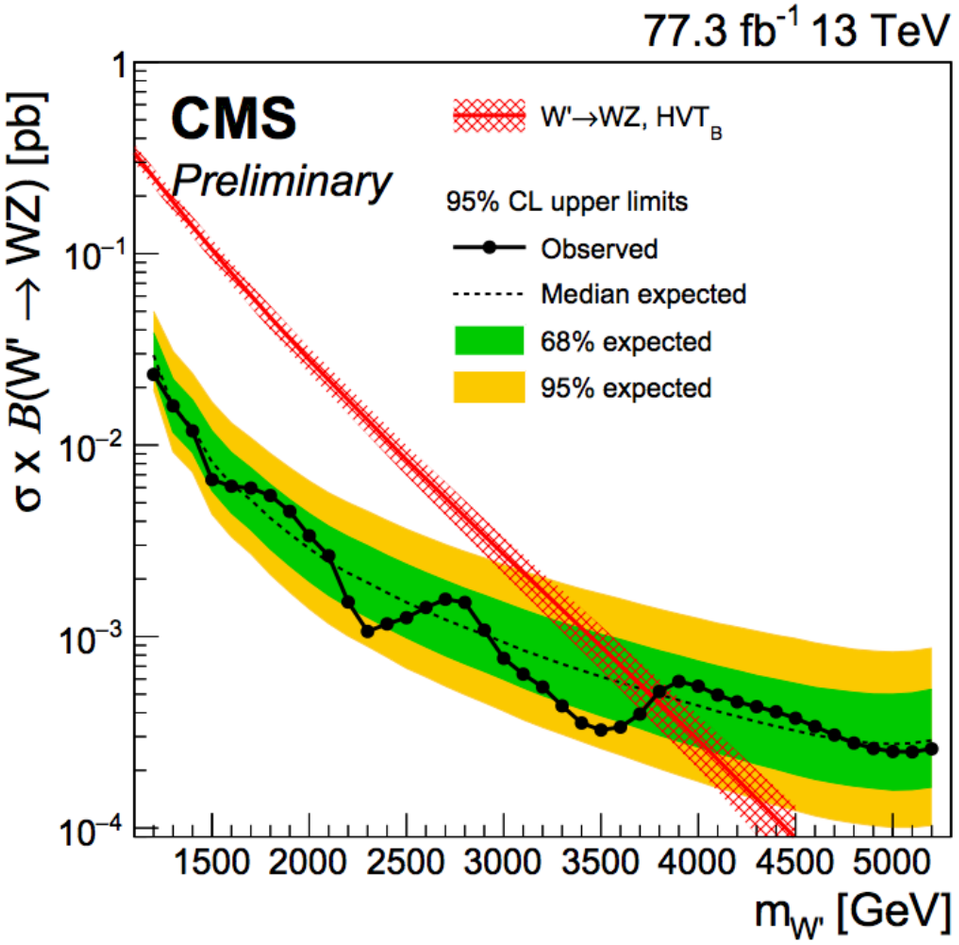
- allows to constrain signal sys. unc. on jet mass *scale* and *resolution*

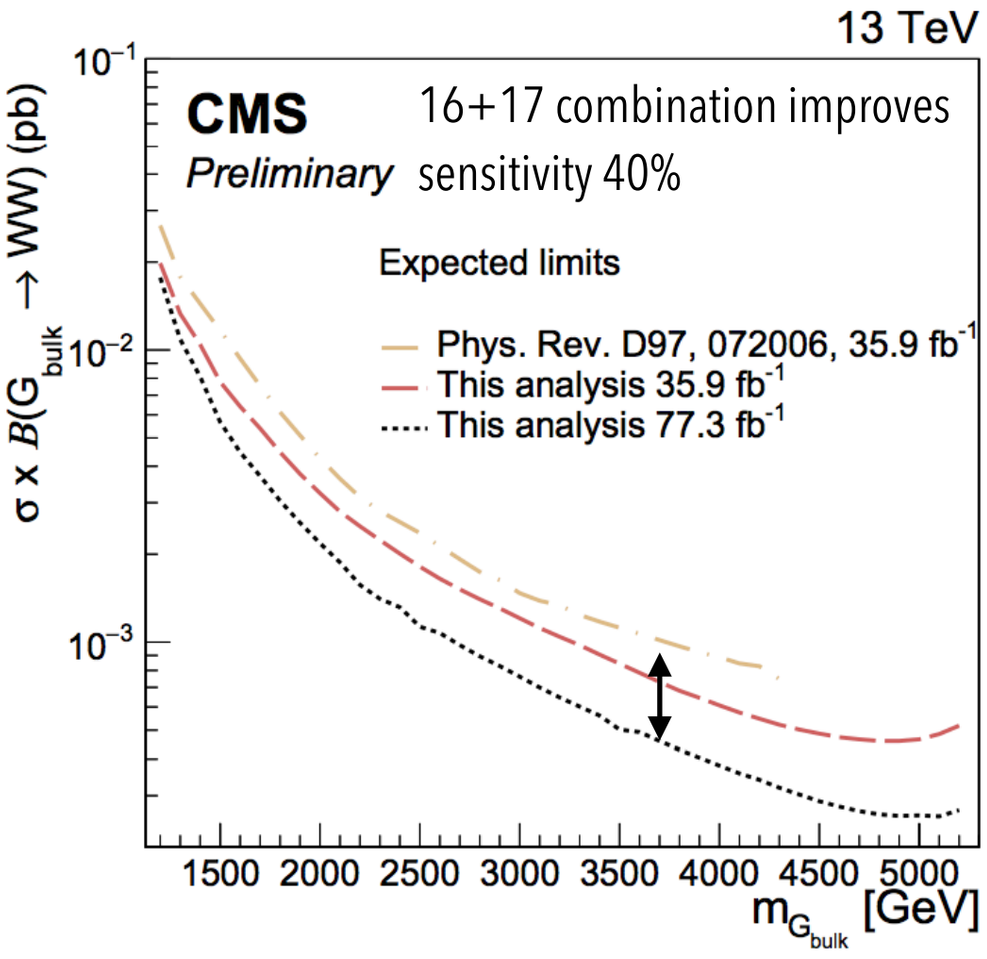
- W+Z cross section compatible with SM

X->VV->qqqq

- **No significant excess** observed for all models (W′,Z′,BG)
- Limits set up to 5 TeV:
  - HVT excluded, e.g W′:1.2-3.8 TeV (CMS),
- **20-30% improvement** with respect to the previous method

B2G-18-002

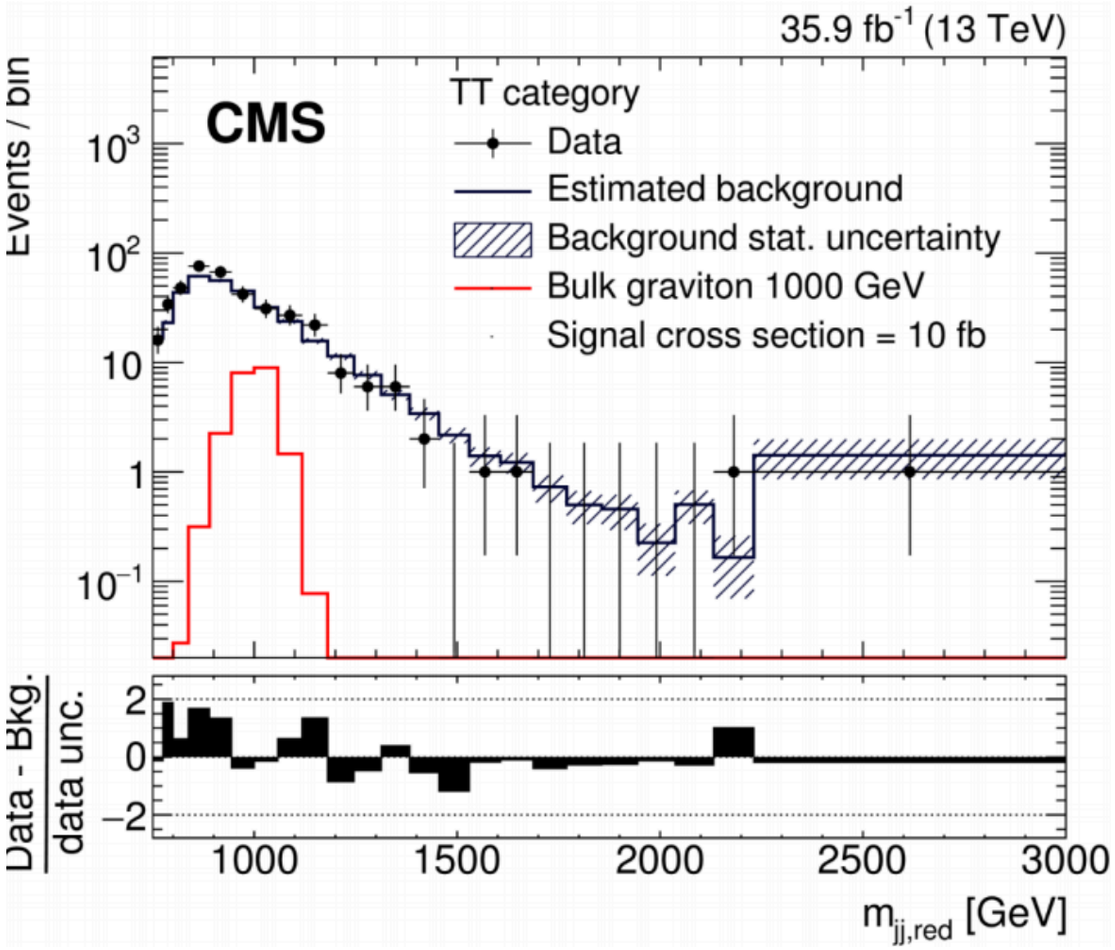


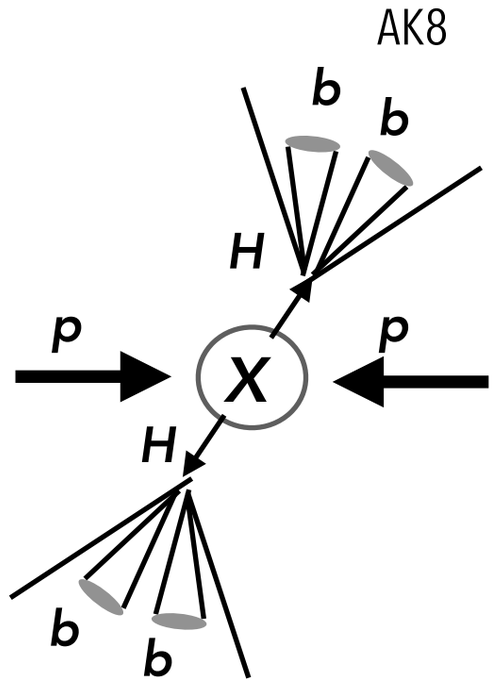


X->HH->bbbb

B2G-16-026

- Simultaneous identification of two b-quarks in the same AK8 jet
- QCD background estimated from data using Rp/f alphabet -assisted method



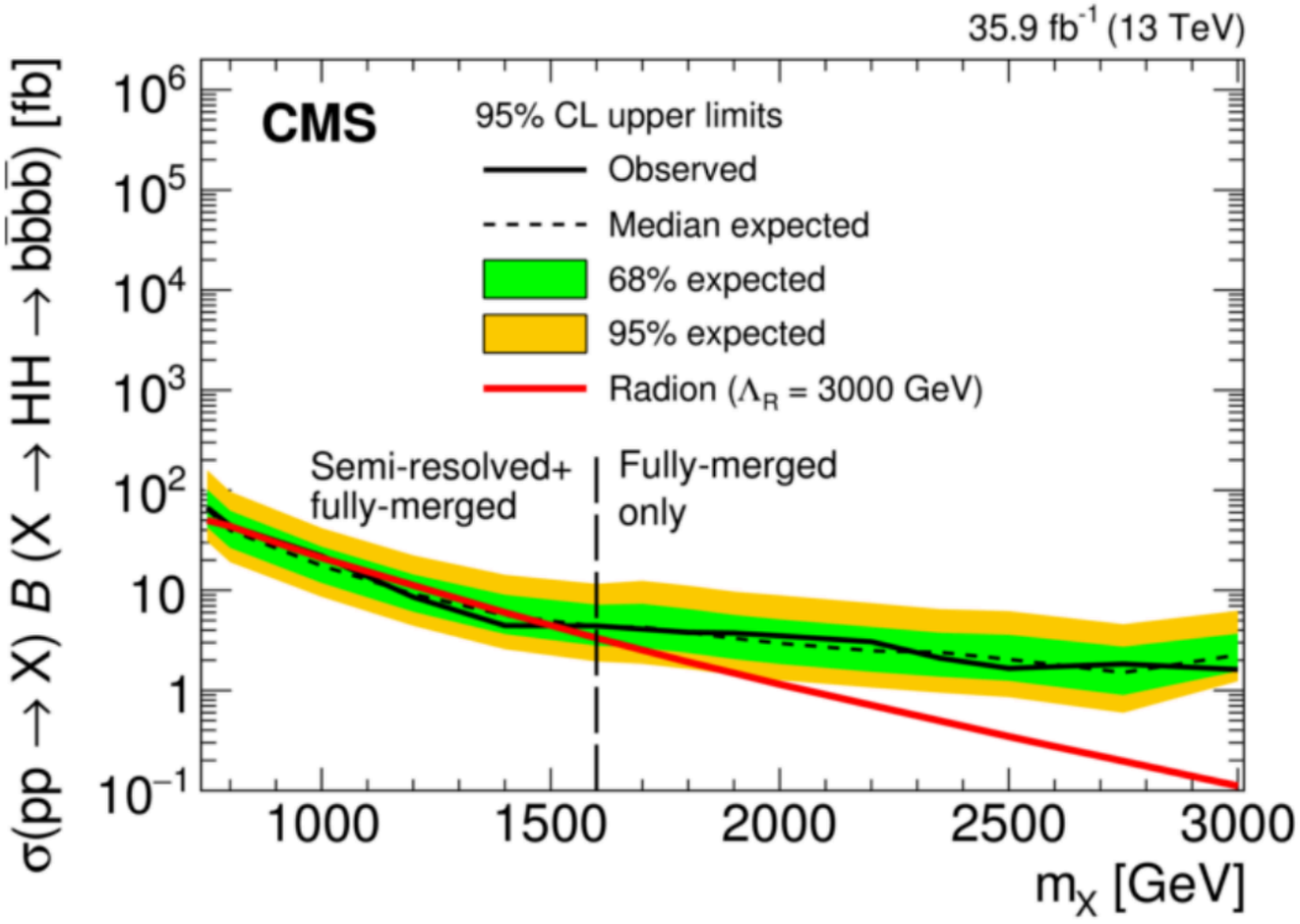


Boosted and semi-boosted categories

X->HH->bbbb

B2G-16-026

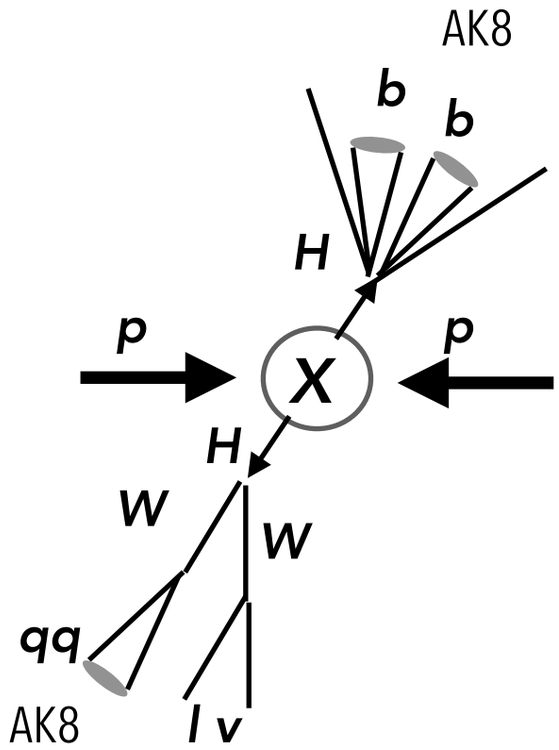
- No significant excess observed, stringent limits on Radion models:
  - Radion: 1.6 GeV -67 fb
  - Graviton: 1.4-43.9 fb



X->HH->bbWW

B2G-18-008
arXiV.1904.04913

- HH->bbWW->bb**lvqq**:
  - ***Lepton suppresses QCD***, while maintaining most of the branching fraction
  - Challenging ***lepton-in-jet reconstruction***: p_T dependent cone isolation + lepton subtraction from the AK8 jet
- Event categorization:
  - W→qq: n-subjettiness
  - H→bb: sub-jet b-tagging

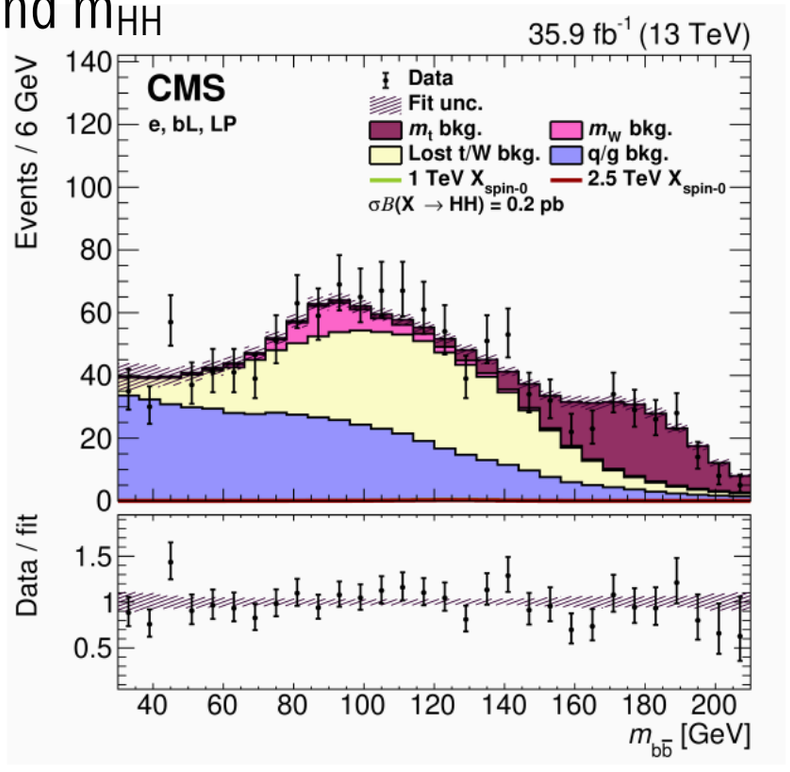


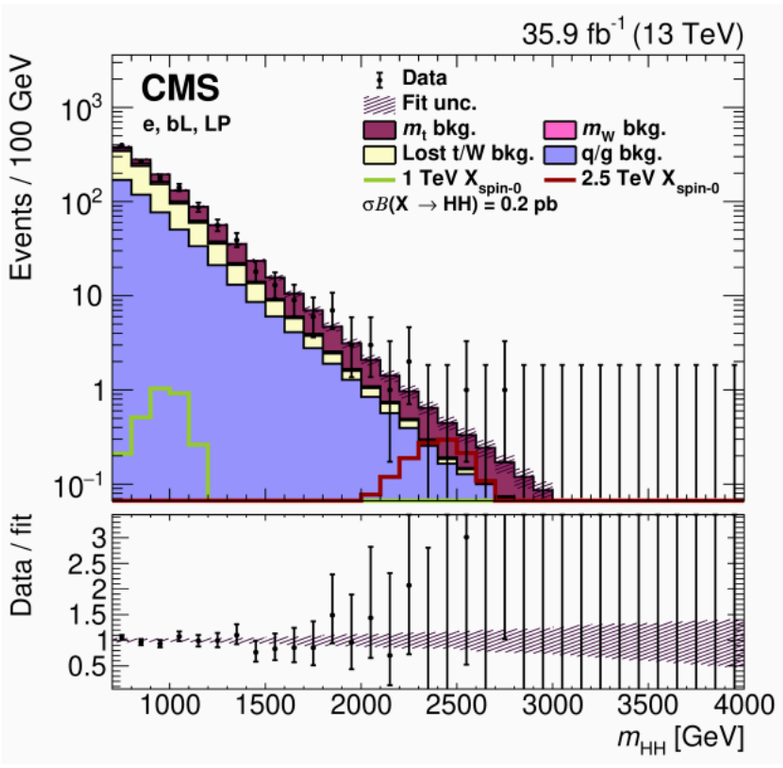
Non-isolated lepton close to jet!

X->HH->bbWW

- Simultaneous fit of 12 independent categories:
  - combinations of **lepton flavor, qq jet purity** and bb jet **b-tagging**
- Background divided into 4 categories by gen-information:
  - Dominated by ttbar with contributions of W+jets
  - Fitting templates taken from MC
  - Data vs MC differences encoded as shape systematics
- 2D fit: $m_{H\to bb}$ and m_{HH}

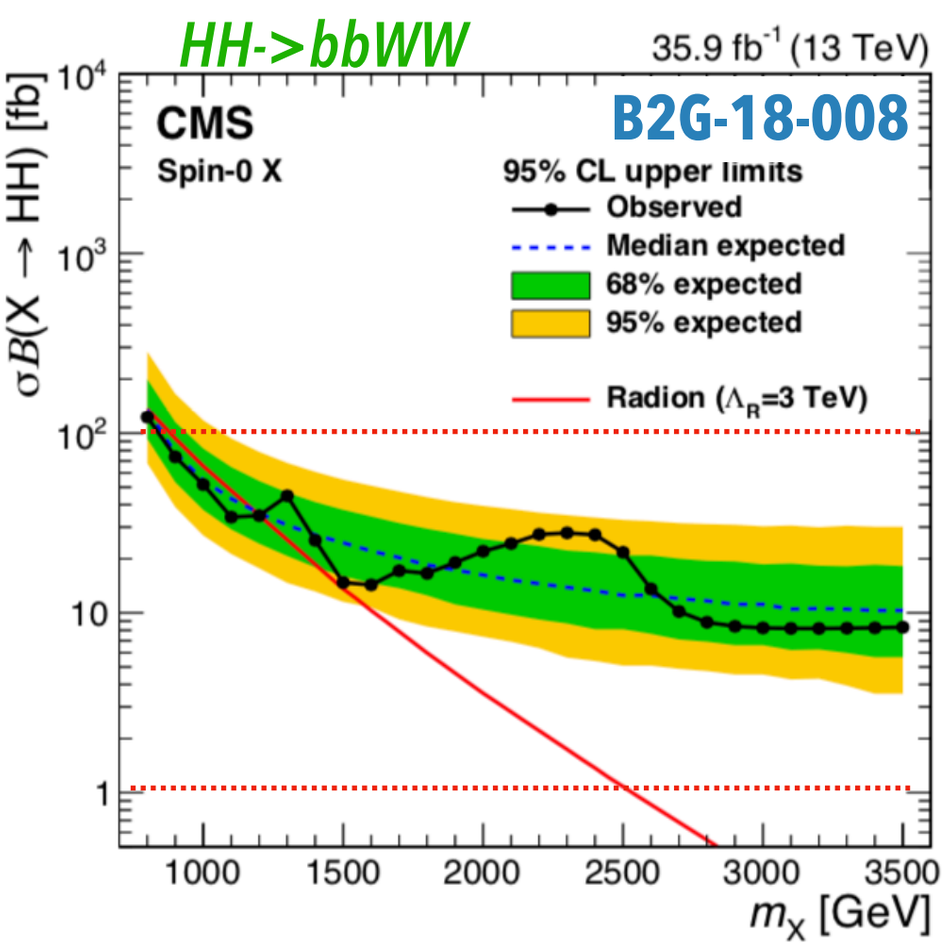
B2G-18-008
arXiV.1904.04913

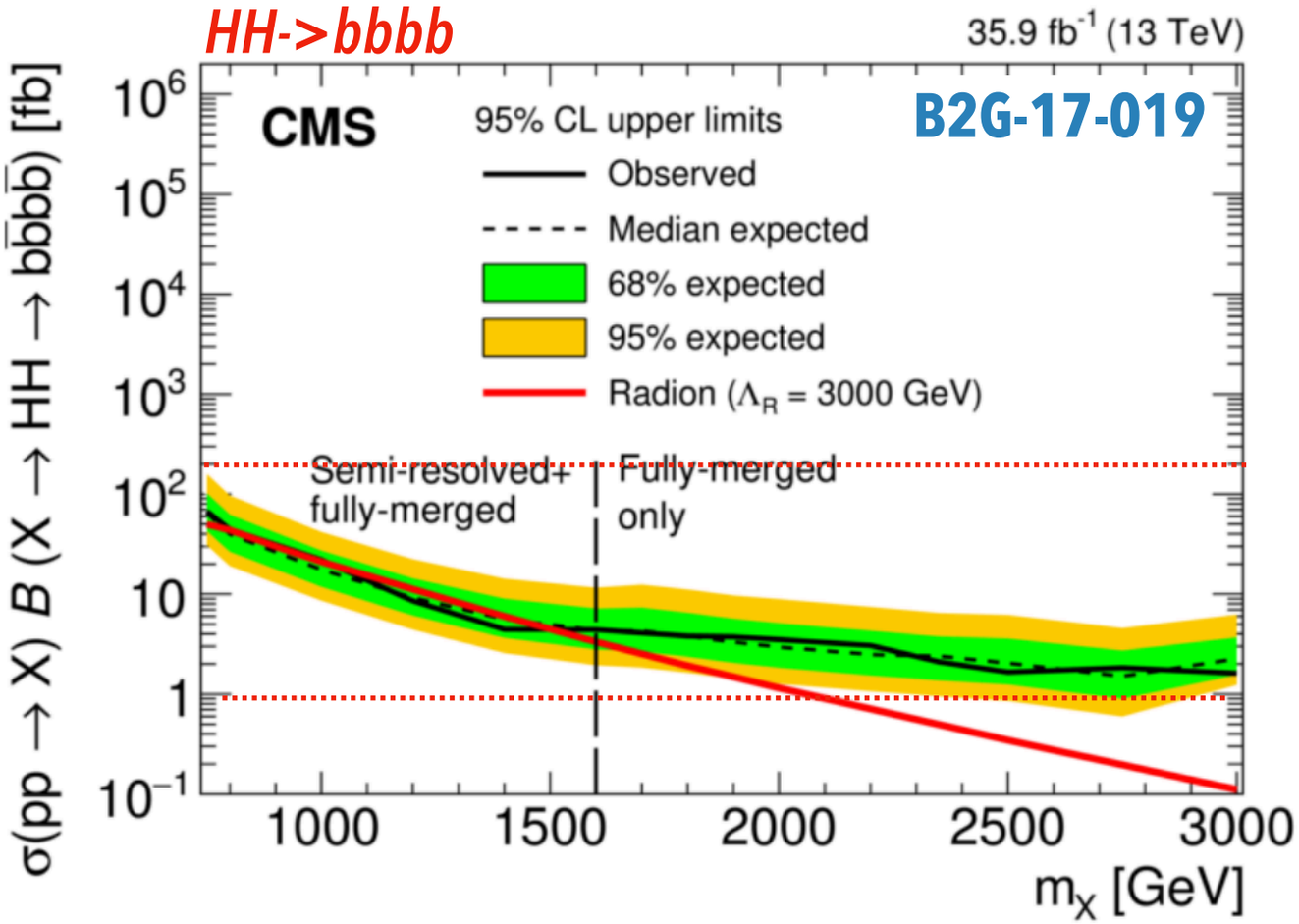




X->HH->bbWW

- No significant excess found
- ***Sensitivity is similar to HH->bbbb*** contrary to the believe of channel being less sensitive



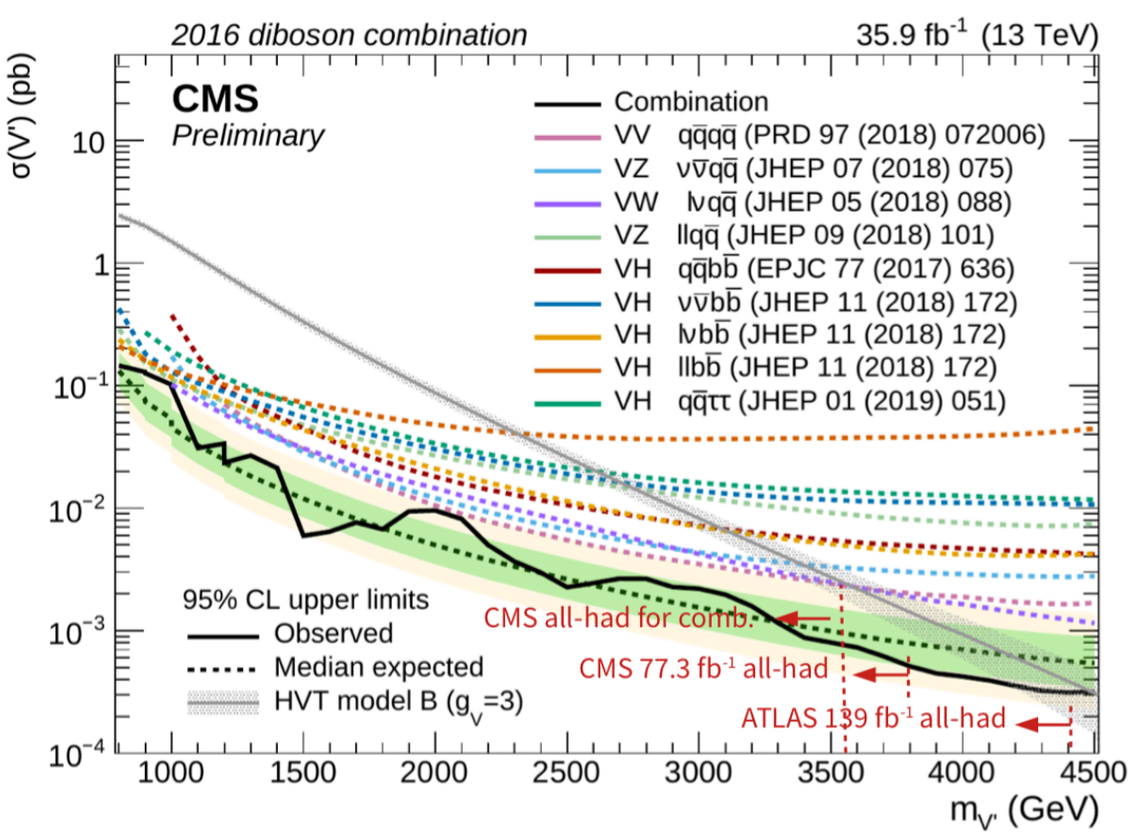


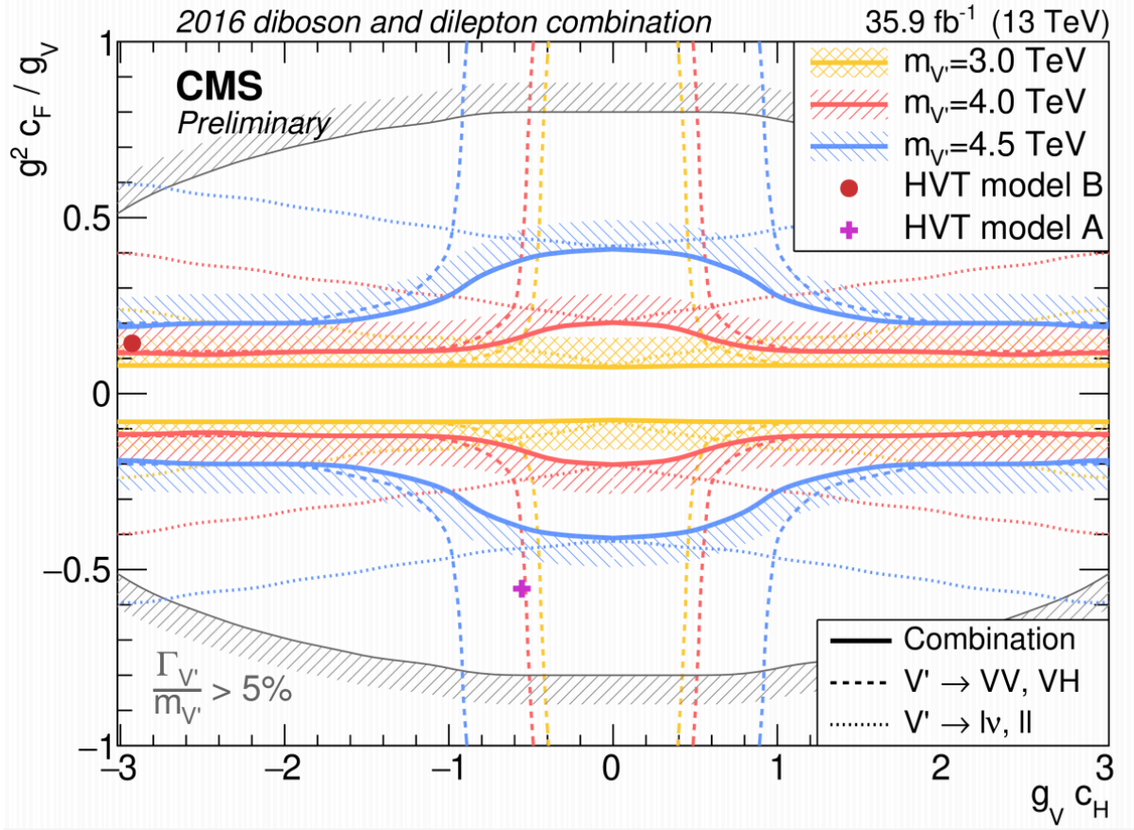
arXiV.1904.04913

Diboson combination

B2G-18-006

- HVT model predicts mass degenerate W′,Z′
- Combination of searches for resonances decaying into bosonic and leptonic final states (36 fb-1)
  - Large gain in statistical combination
  - **Complementary information from dilepton decays** *W->lnu,Z'->ll,* which allow to exclude region of parameter space un-accessible by DIB search





Summary and Outlook

- Rich phenomenology & final states VV, VH, HH:
  - clear experimental signatures
  - allows cross check among different channels
- No significant excess observed in data so far.
- **Stay tuned for results on full Run II dataset** (137fb^{-1})!
- Effort to go beyond the luminosity improvement:
  - exploit state-of-the-art ***tagging techniques*** (e.g. DeepLearning based algorithms in CMS)
  - multiple analysis categories in the same search (e.g include VBF)
  - take advantage of ***3D fit*** for other DIB searches