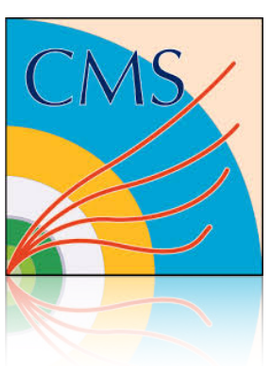
Searches for diboson resonances at CMS

Cristina Mantilla Suarez (JHU) on behalf of CMS



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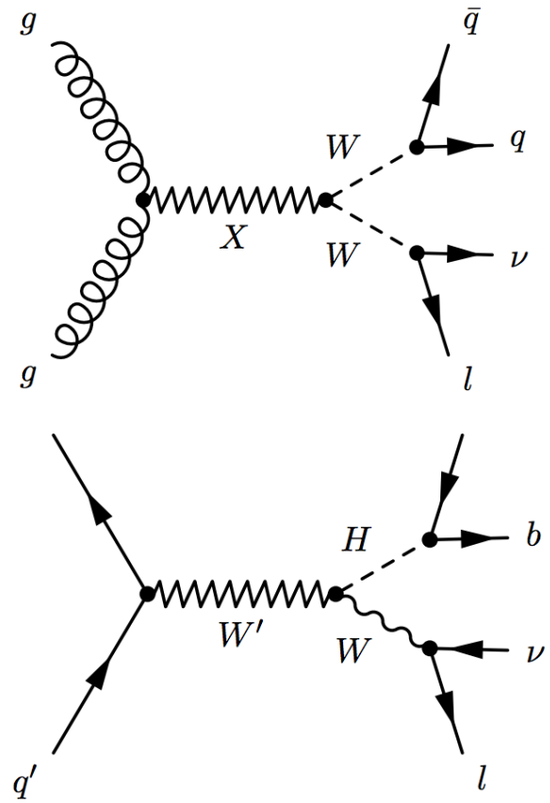
PHENO 2019

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

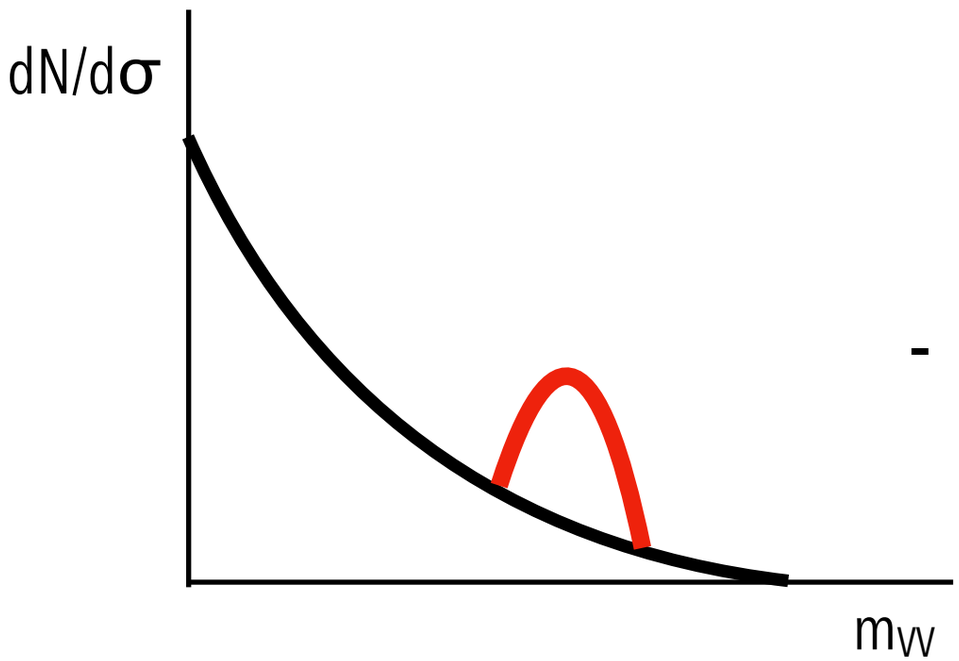
X can be Z',W',BulkGrav

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!

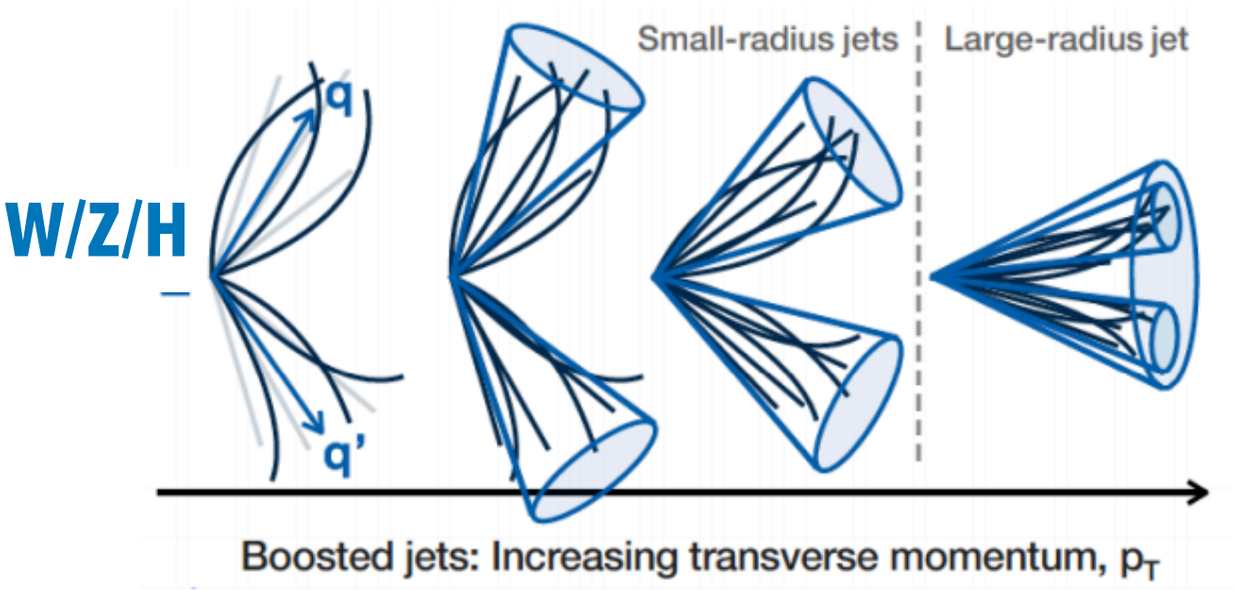


- "bump hunt"-like strategy
  - data-driven background methods
  - 2D/3D fit or parametric fit to data (signal region)
  - sideband-assisted (control regions)
- Background processes:
  - **QCD** (dominant for **hadronic searches**)
  - **W/Z+jets and ttbar** (dominant for **semi-leptonic**)

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**:

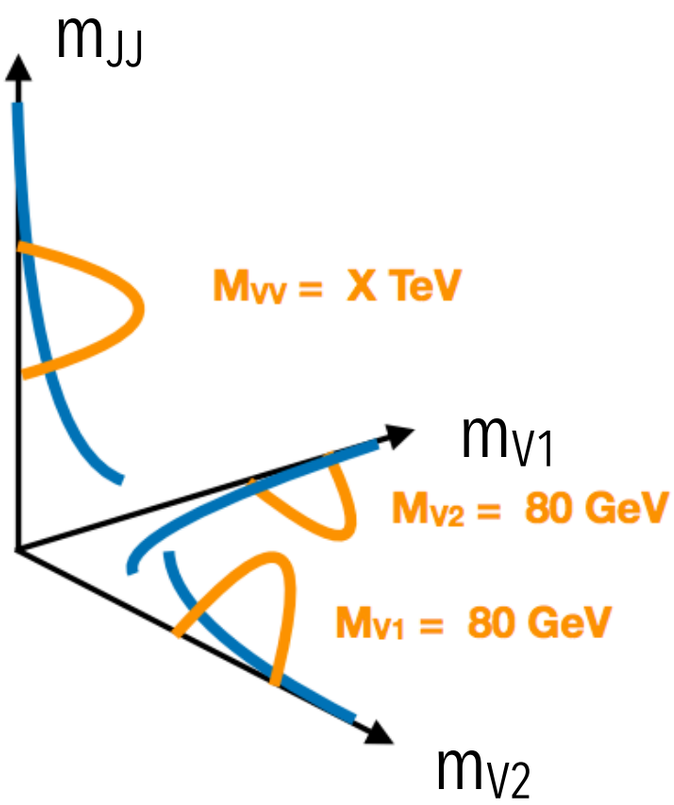
- VV (qqqq) : B2G-18-002 (77 fb^{-1}) -> 2016 + 2017 data!
- HH(bbWW): B2G-18-008 (36 fb^{-1}) -> 2016 only

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

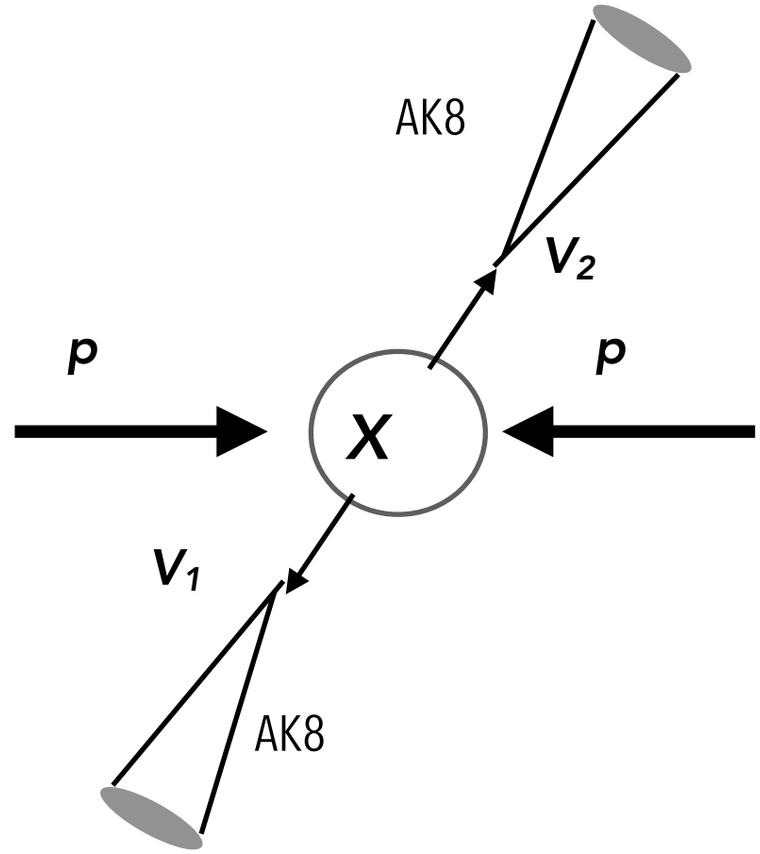
X->VV->qqqq



B2G-18-002

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

Identifies 2 boosted hadronic jets



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

m_{JJ} > 1126 GeV:

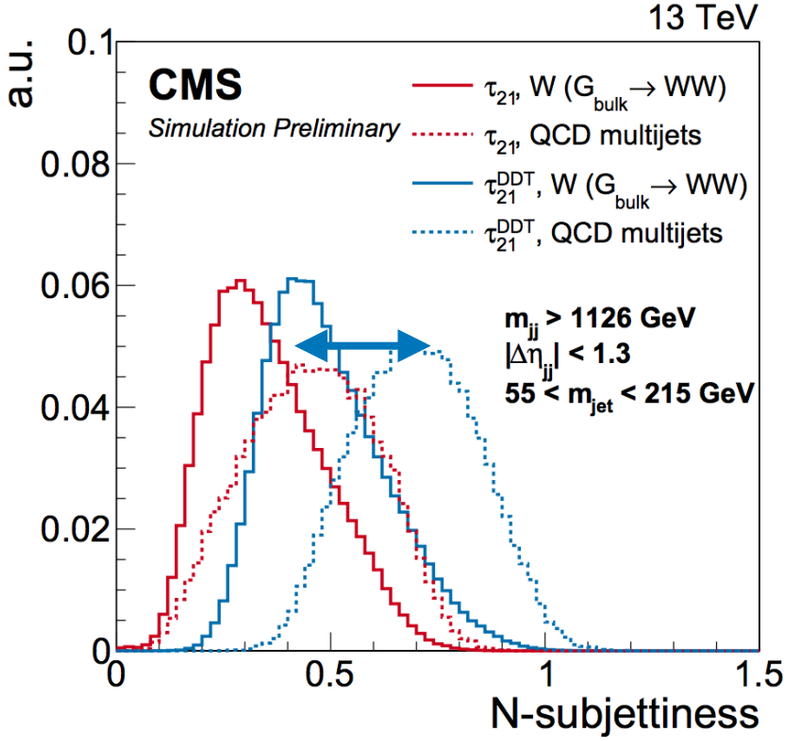
- All hadronic: *largest branching fraction*
- low mass *threshold* set by *hadronic trigger eff.*

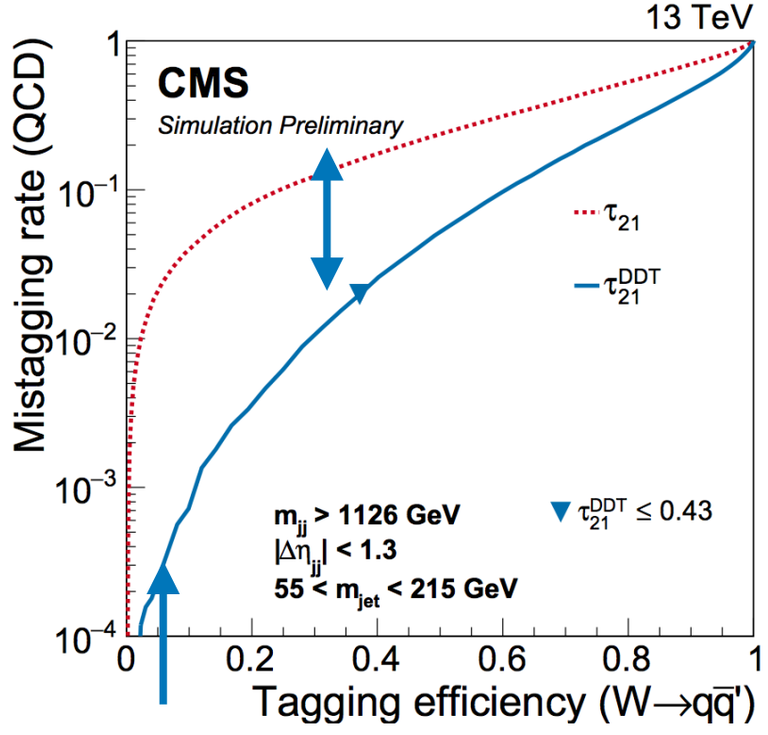
X->VV->qqqq

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)

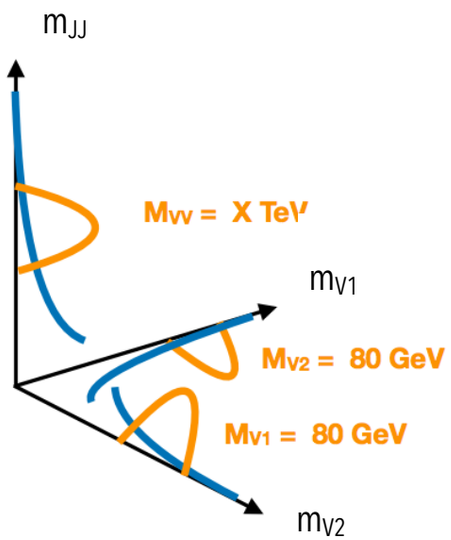




$$\tau_{21}^{DDT} = \tau_{21} + 0.08 \times \log(\frac{m^2}{p_T} 1GeV)$$

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

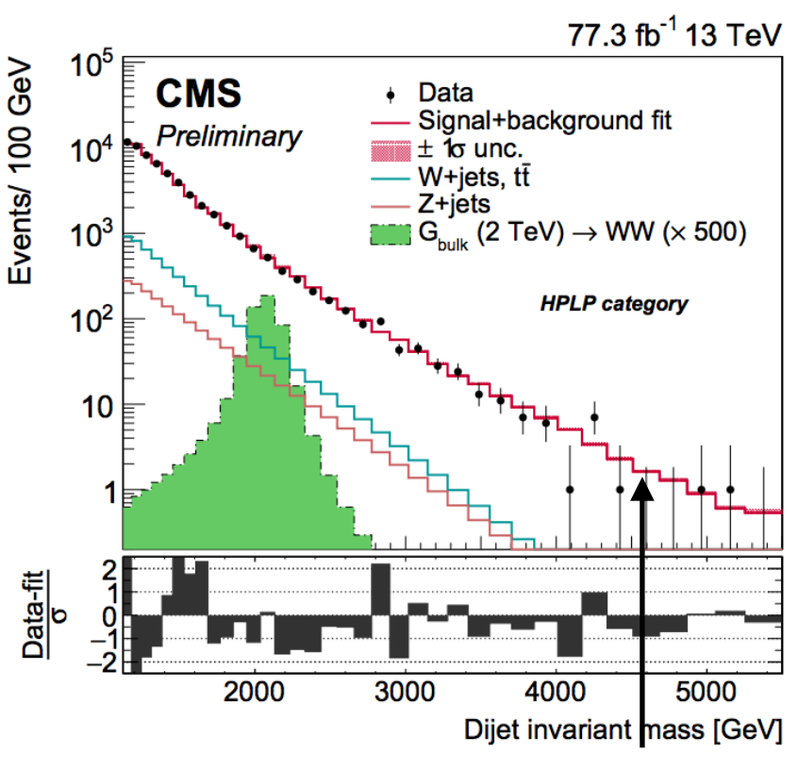
X->VV->qqqq

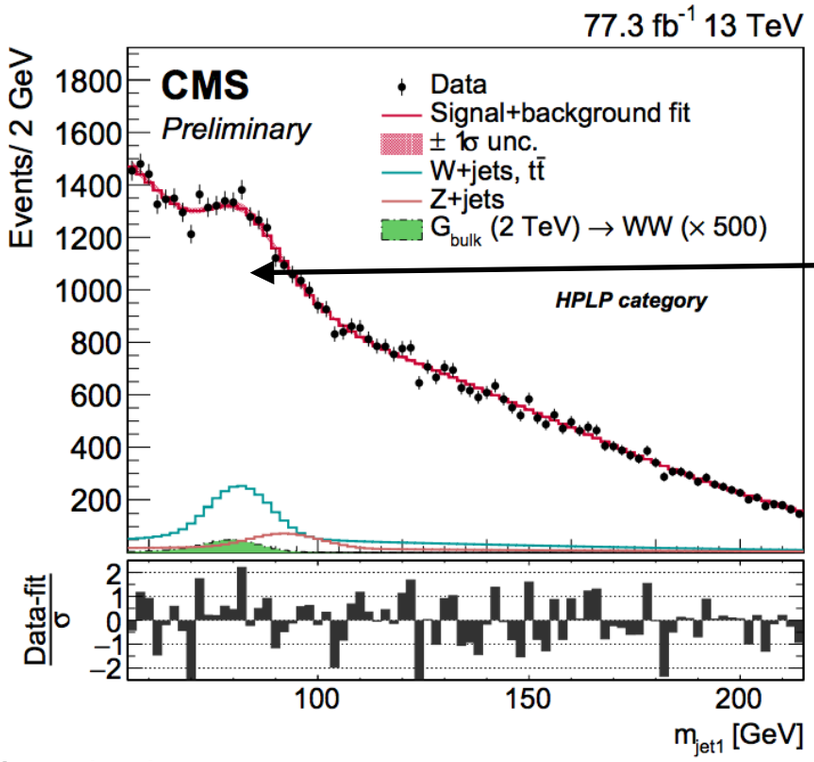


3D fit:

B2G-18-002

- **Forward folding kernel approach** to ensure smooth QCD templates
  - 3D templates derived from MC
  - Particle-level evts smeared using detector resolution
  - same procedure for resonant bkg. (W/Z)
- Method can be generalized to any 3D resonant search!





New feature!

SM V->qq peak:

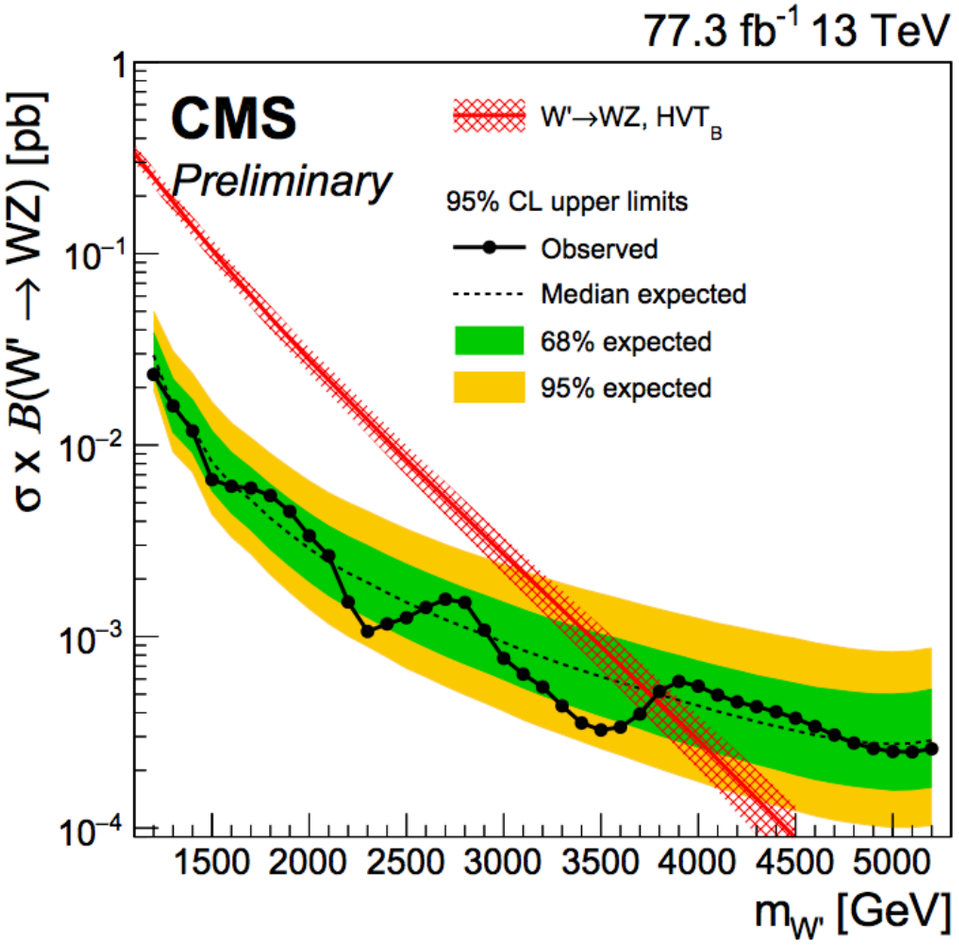
- allows to constrain signal sys. unc. on jet mass *scale* and *resolution*
- **W+Z cross section compatible with SM**

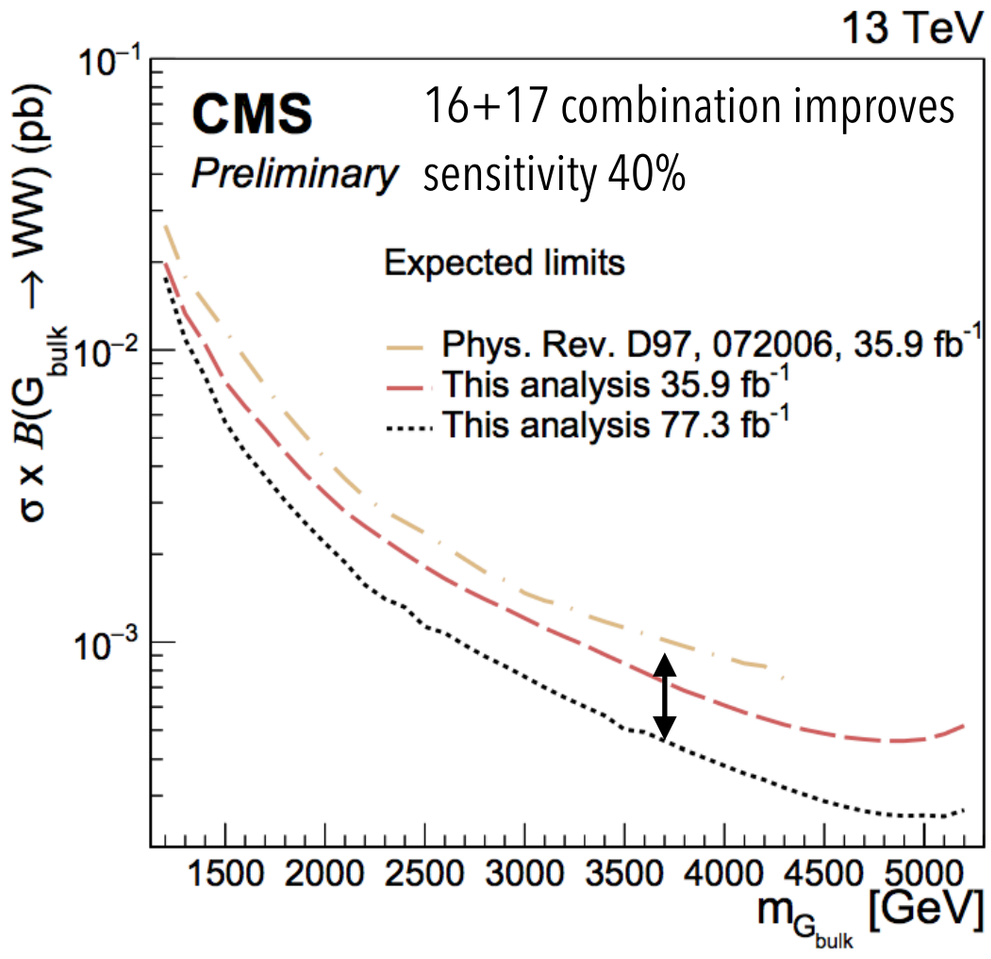
Overcomes limitation from high mass statistics!

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

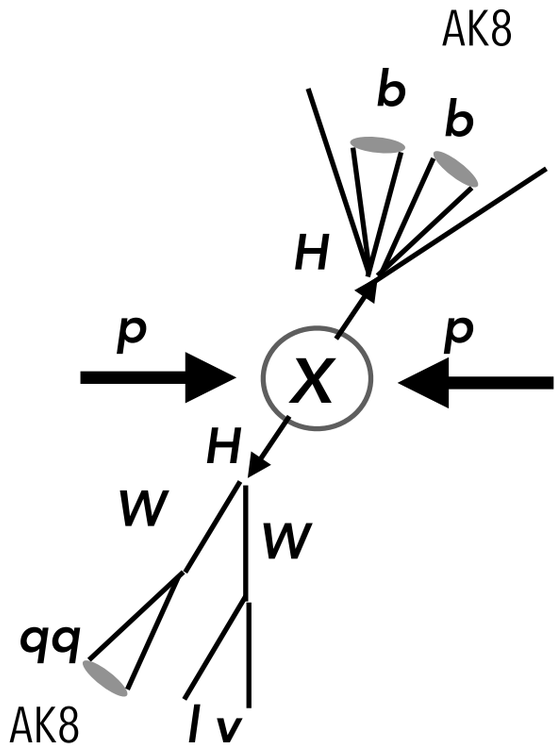




X->HH->bbWW

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

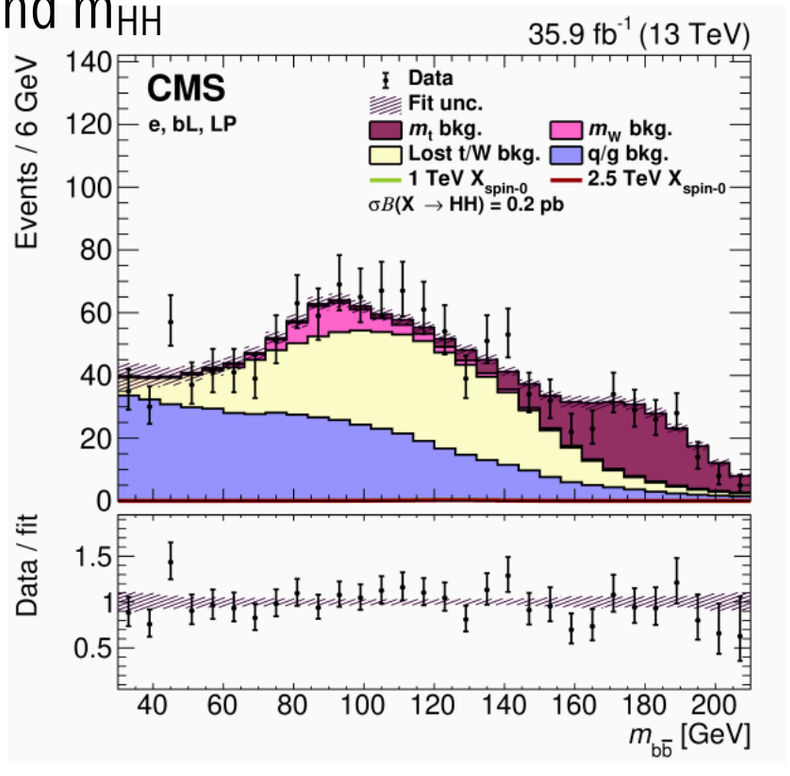


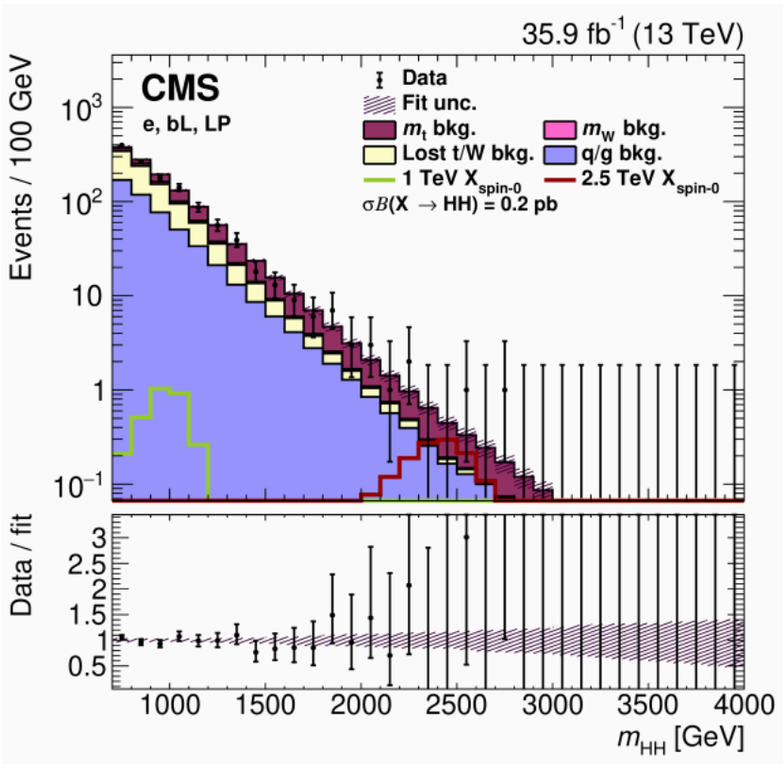
Non-isolated lepton close to jet!

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}

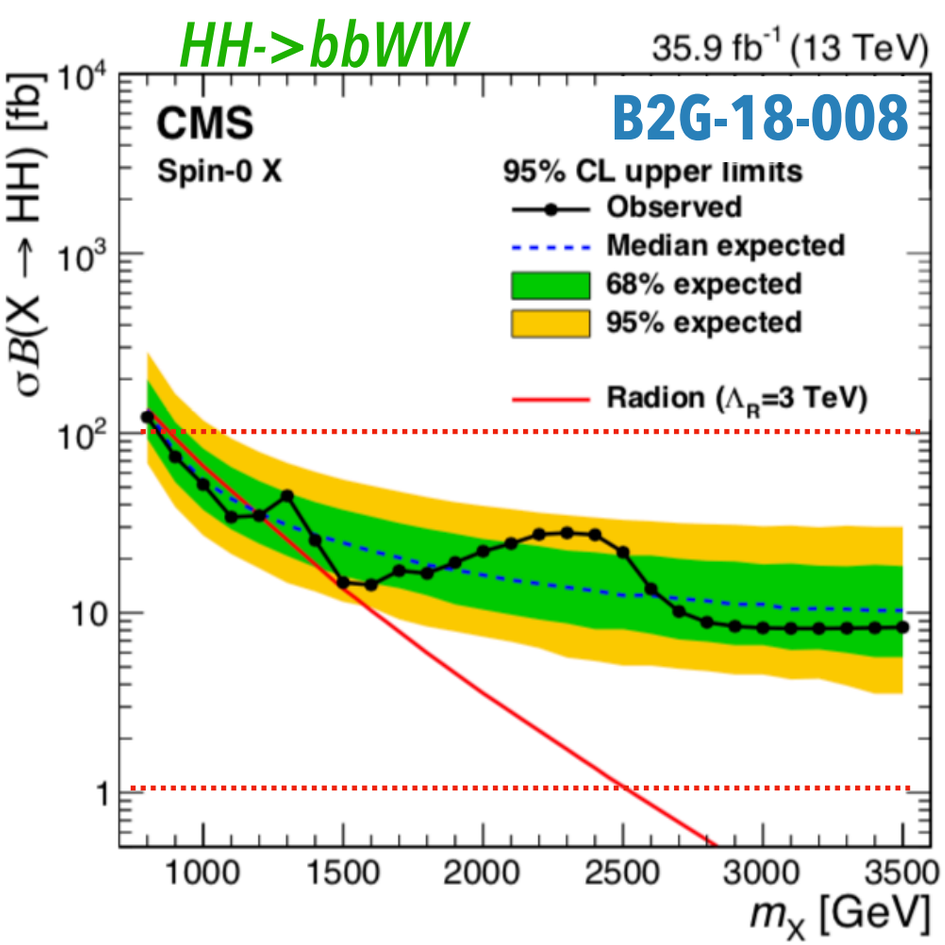
B2G-18-008
arXiV.1904.04913

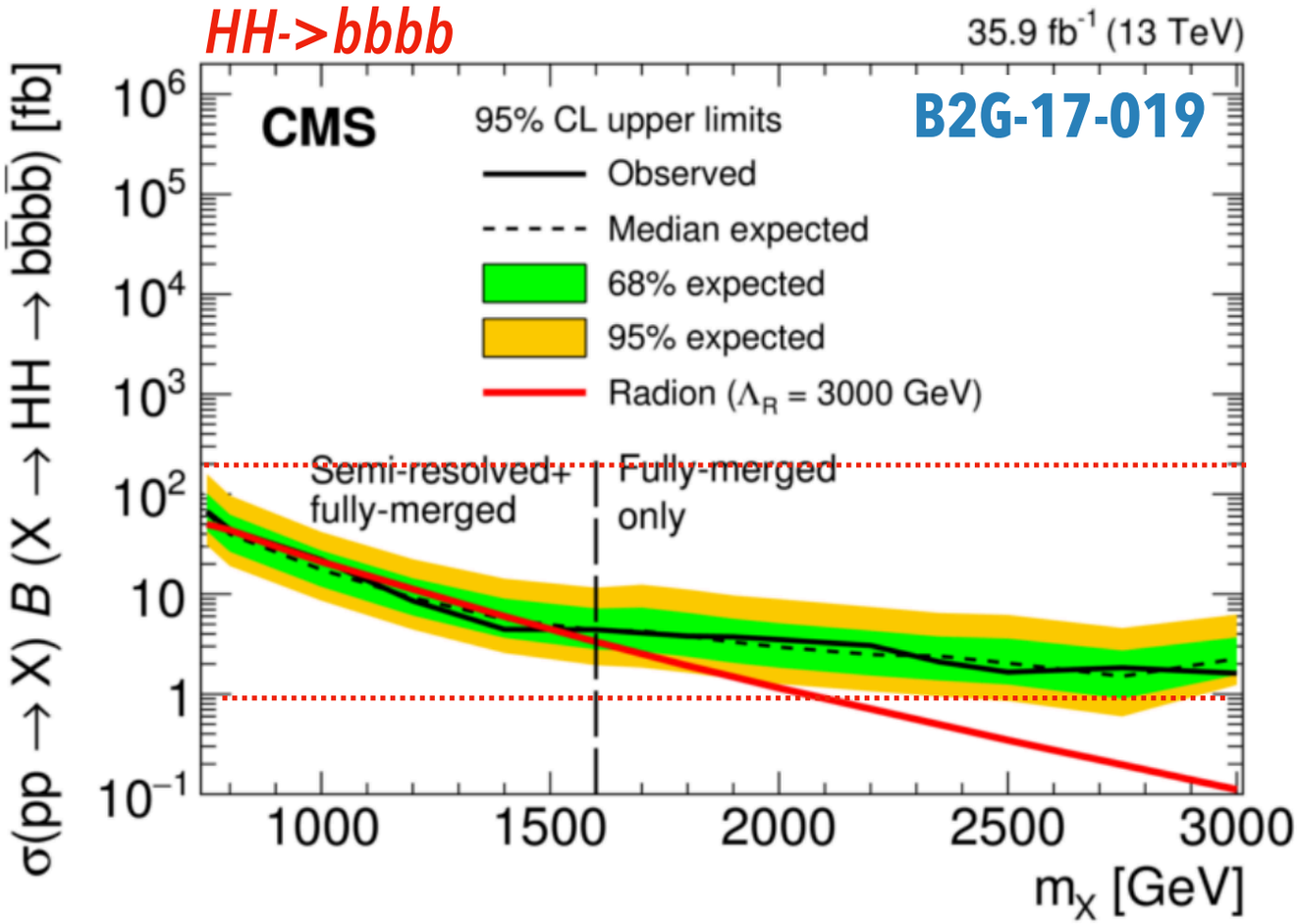




X->HH->bbWW

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





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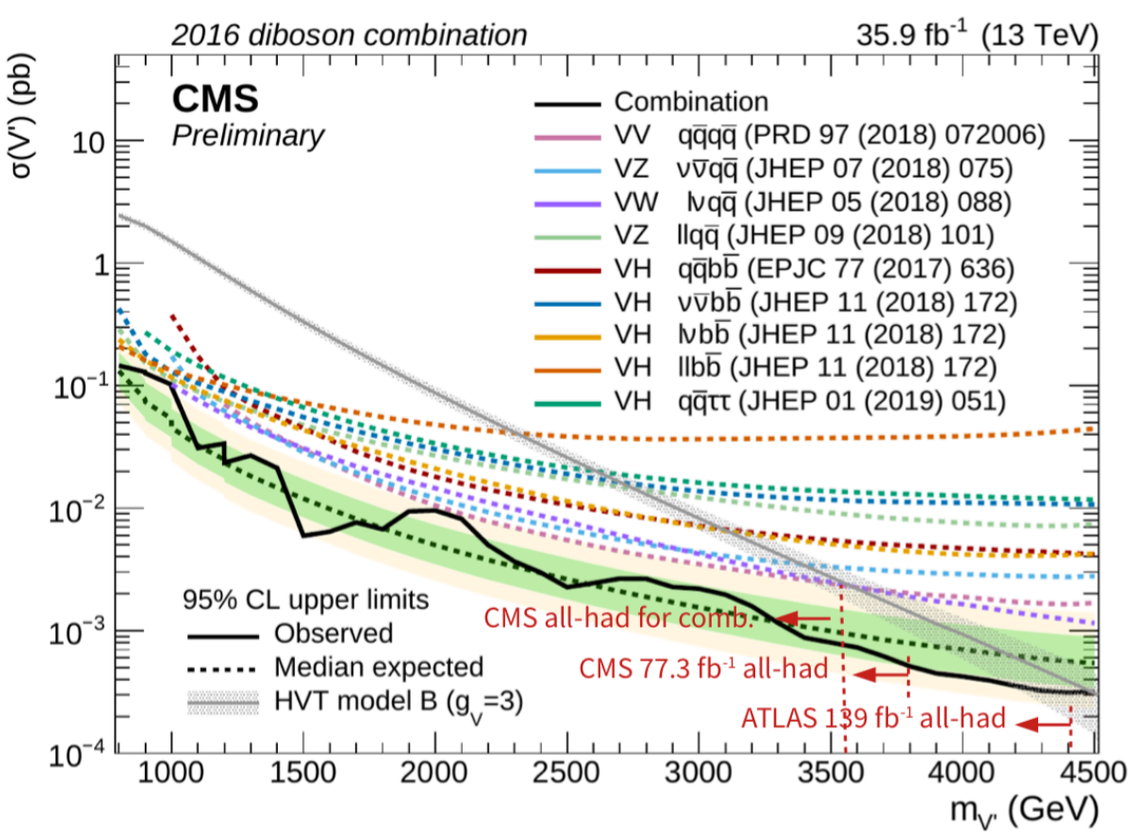
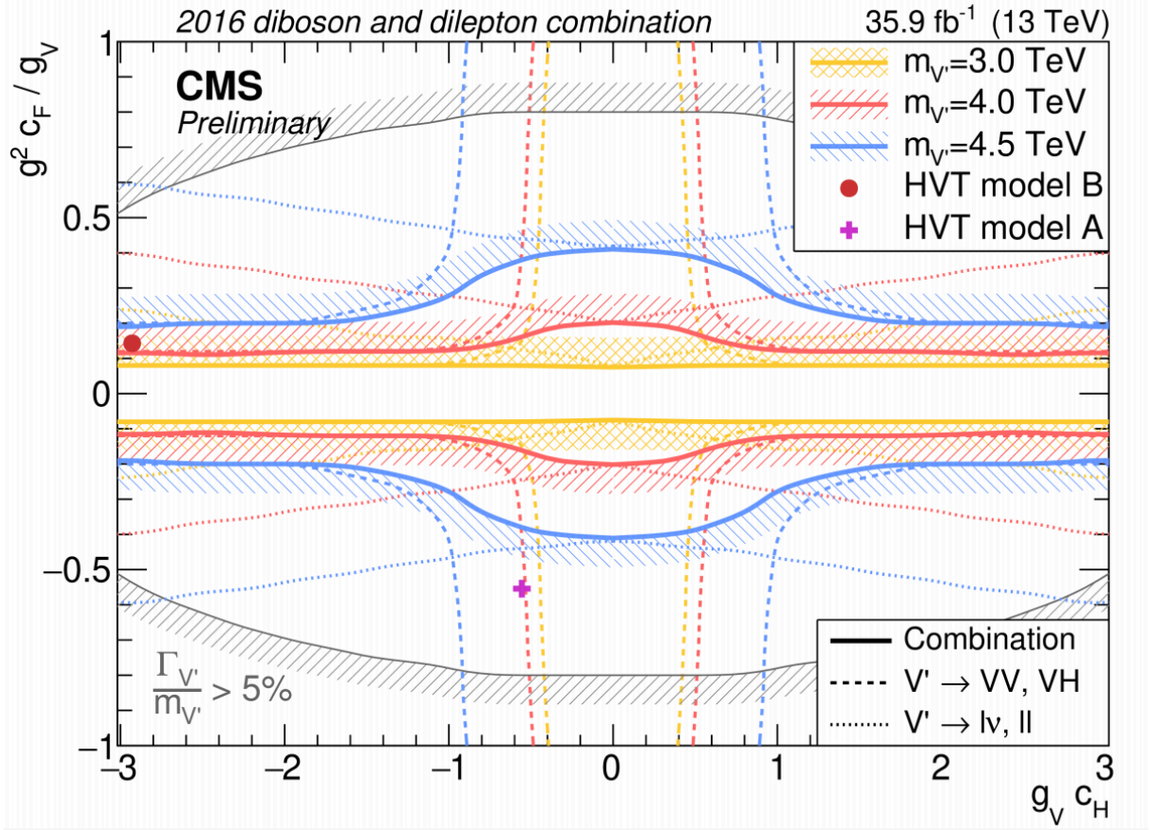
Diboson combination

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





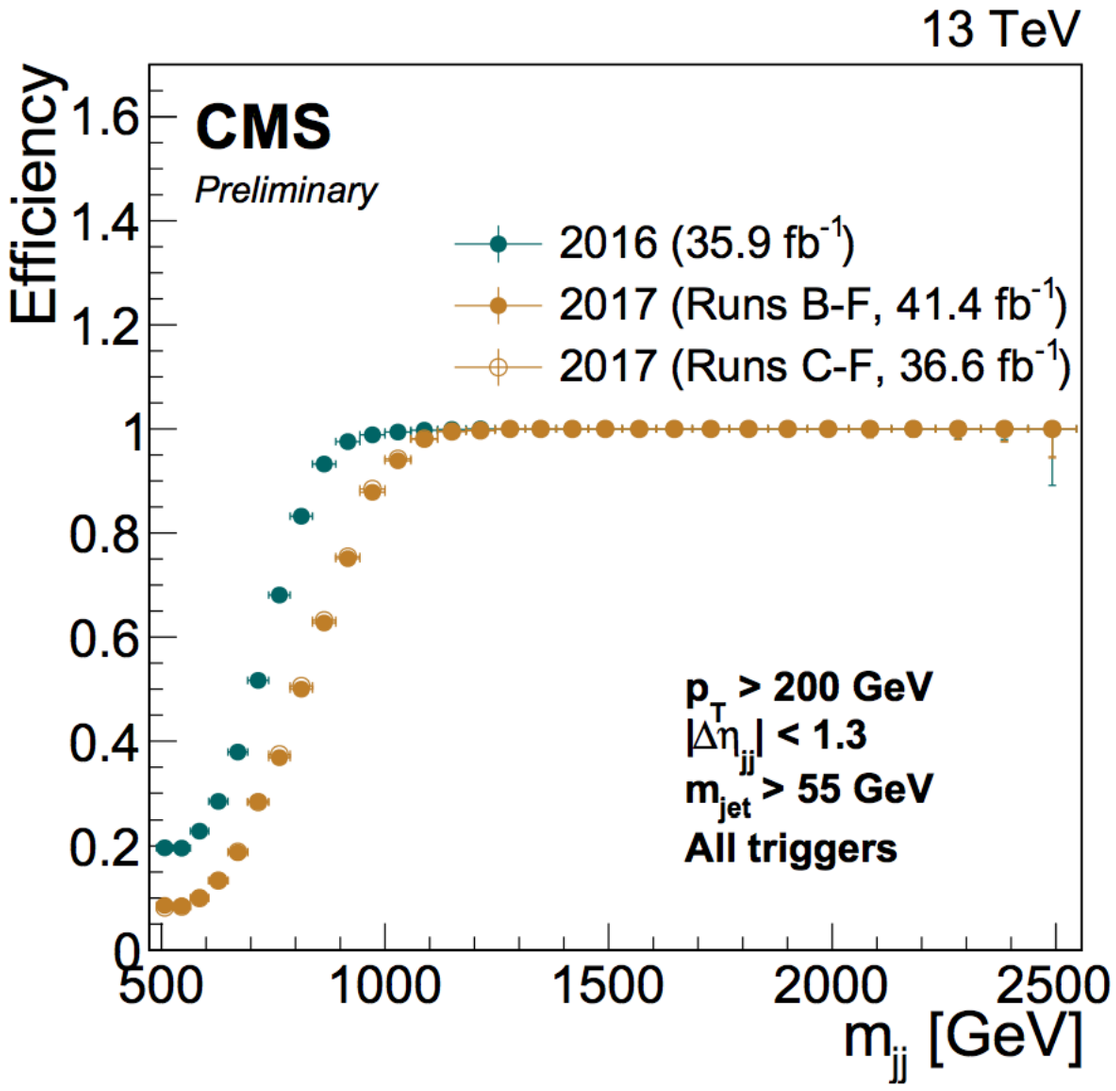
Summary and Outlook

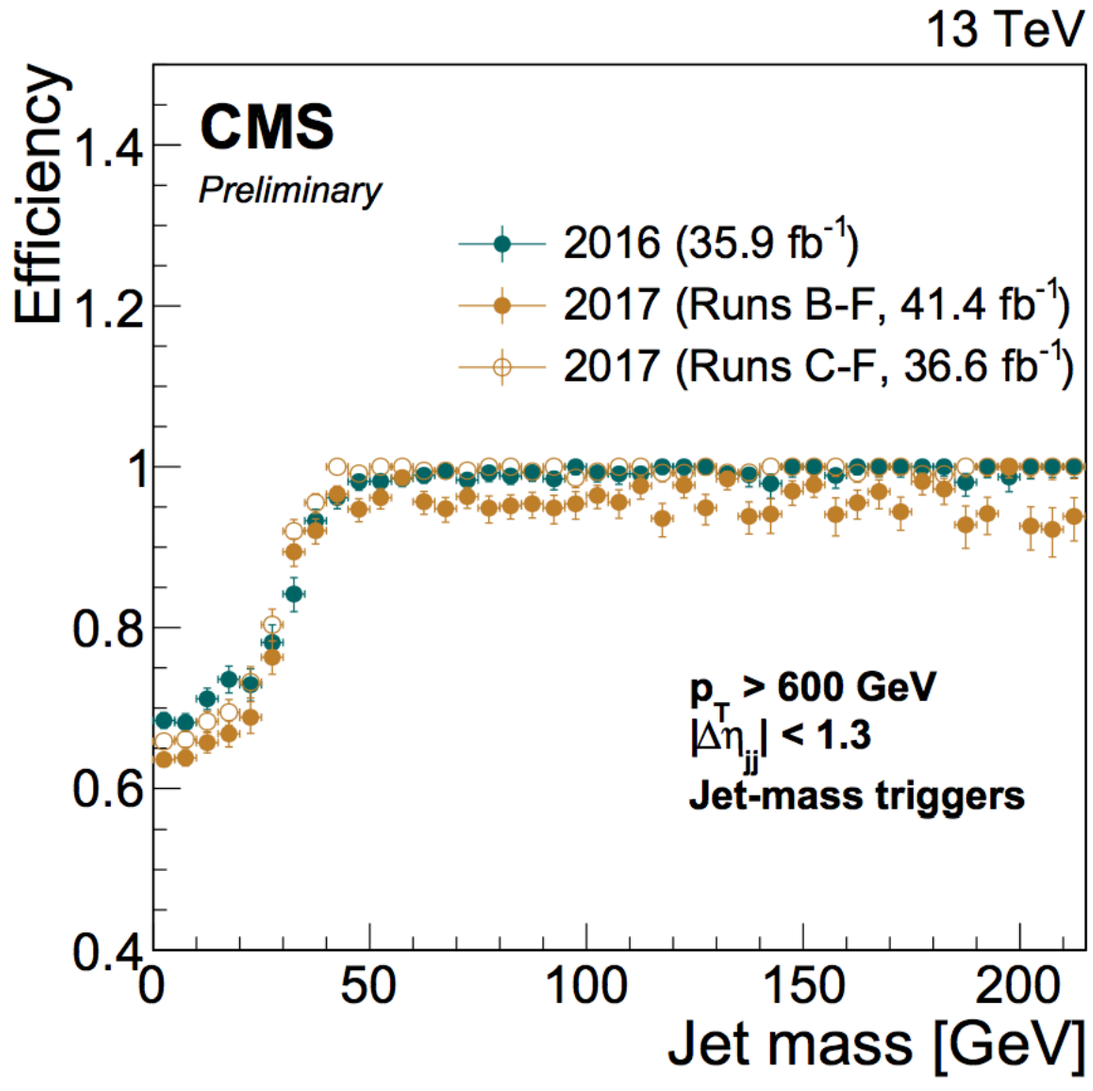
- Rich phenomenology & final states VV, VH, HH:
  - clear experimental signatures
  - allows cross check among different channels
- No significant excess observed in data so far.
- **Stay tuned for results on full Run II dataset** (137fb^{-1})!
  - Effort to go beyond the luminosity improvement:
    - 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

X->VV->qqqq

B2G-18-002

- Trigger efficiency (HT+single jet)





X->VV->qqqq

B2G-18-002

- Multijet background:
  - 3D templates (mjj,mj1,mj2)
  - Account for correlations for Mjet|Mjj -> modeled conditionally
  - 250K bins -> forward folded kernels to ensure smooth and full shape
  - Each event contributing to a 1D/2D gaussian kernel defined by detector scale and res.

$$P(m_{jj}, m_{jet1}, m_{jet2}) = P_{VV}(m_{jj}) \times P_{cond,1}(m_{jet1}|m_{jj}) \times P_{cond,2}(m_{jet2}|m_{jj}).$$

- Resonant backgrounds in Mjet (W/Z/tt):
  - Fit resonant part of Mj with signal function -> fully correlated systematics
  - Model QCD-jet with simple Gaussian
  - Mjj shape, same kernel approach for QCD
  - W+Z NLO QCD + EWK corrections

$$P_{Vjets}\left(M_{jet1}, M_{jet2}, M_{jj}\right) = f \times \left(P_{dijet}\left(M_{jj}\right) \times P_{res}(M_{jet1}) \times P_{non-res}(M_{jet2})\right)$$
$$+(1-f) \times \left(P_{dijet}\left(M_{jj}\right) \times P_{res}(M_{jet2}) \times P_{non-res}(M_{jet1})\right)$$