



**Moriond 2018 Electroweak Sessions**

# **Search for heavy resonances decaying to pairs of vector bosons in the $lvqq$ final state with the CMS detector in proton-proton collisions at $\sqrt{s} = 13$ TeV**



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**on behalf of the CMS collaboration**

2018/3/14

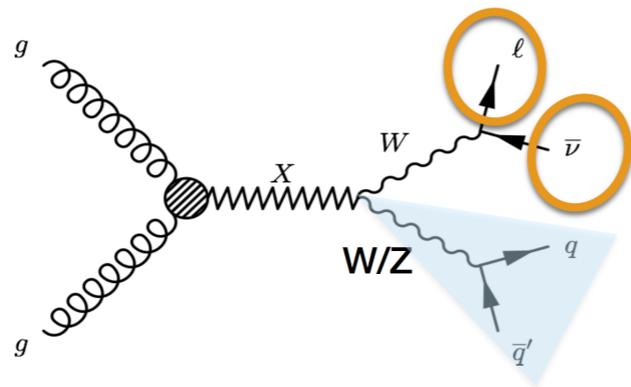
# Motivation

## Beyond Standard Model

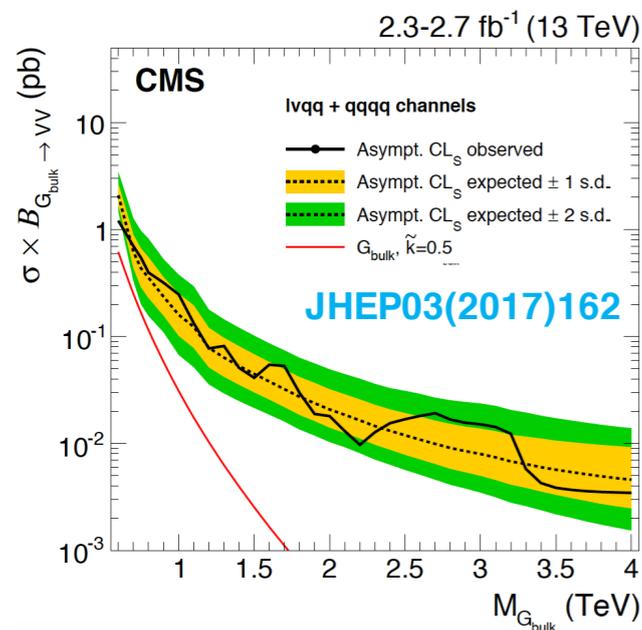
Many unification attempts

Hierarchy problem

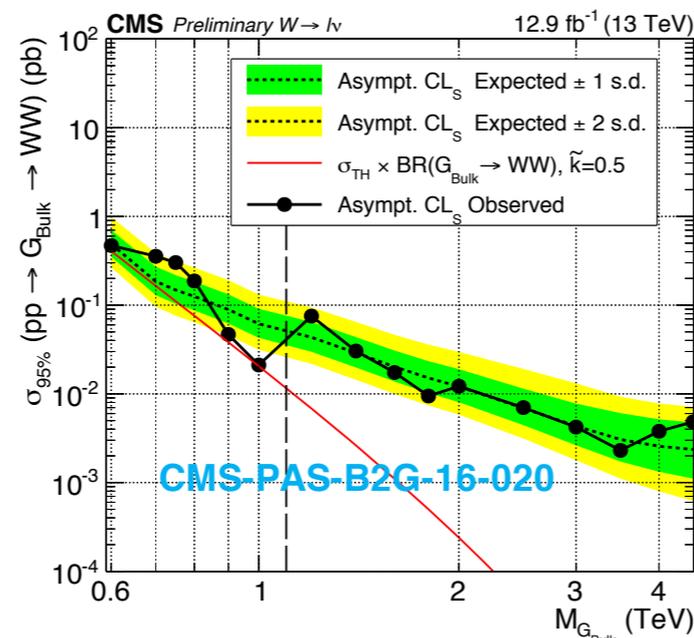
## Motivate the existence of heavy EXOTIC resonances



	Channel	Models
EXOTIC resonance $X \rightarrow$ Diboson	WW	Spin-2 <b>Bulk Graviton</b> <sup>fl</sup>
	WZ	Spin-1 <b>HVT</b> <sup>fl</sup> (charged)

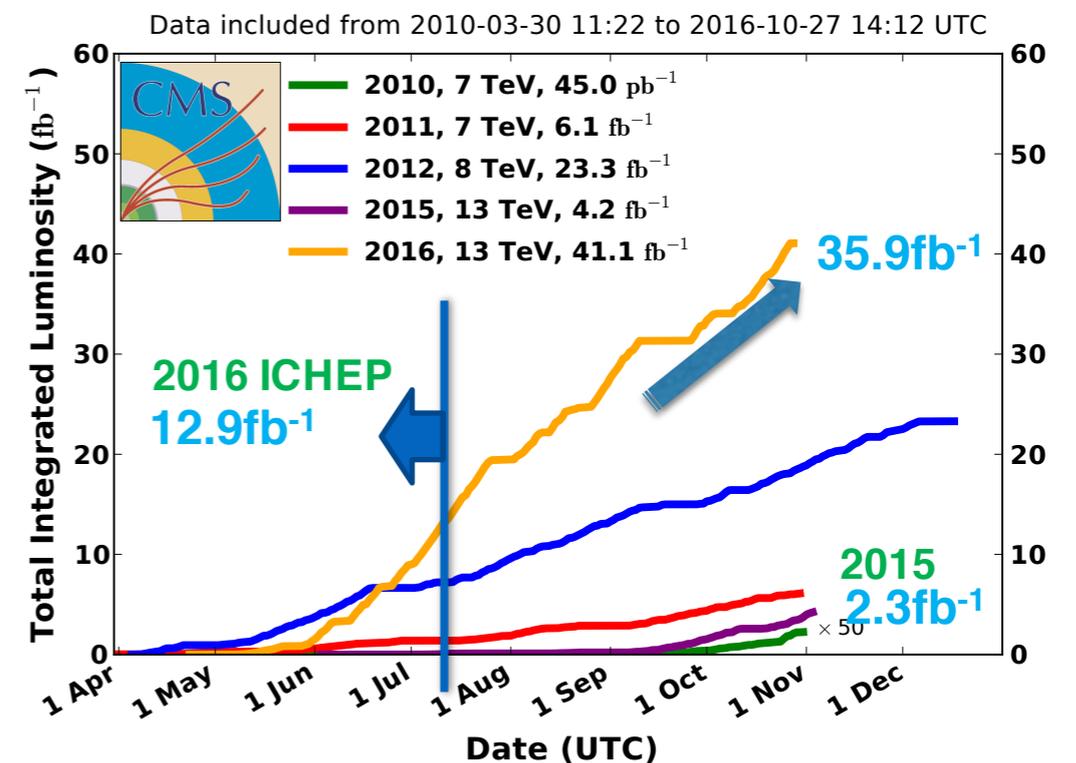


2015 Data



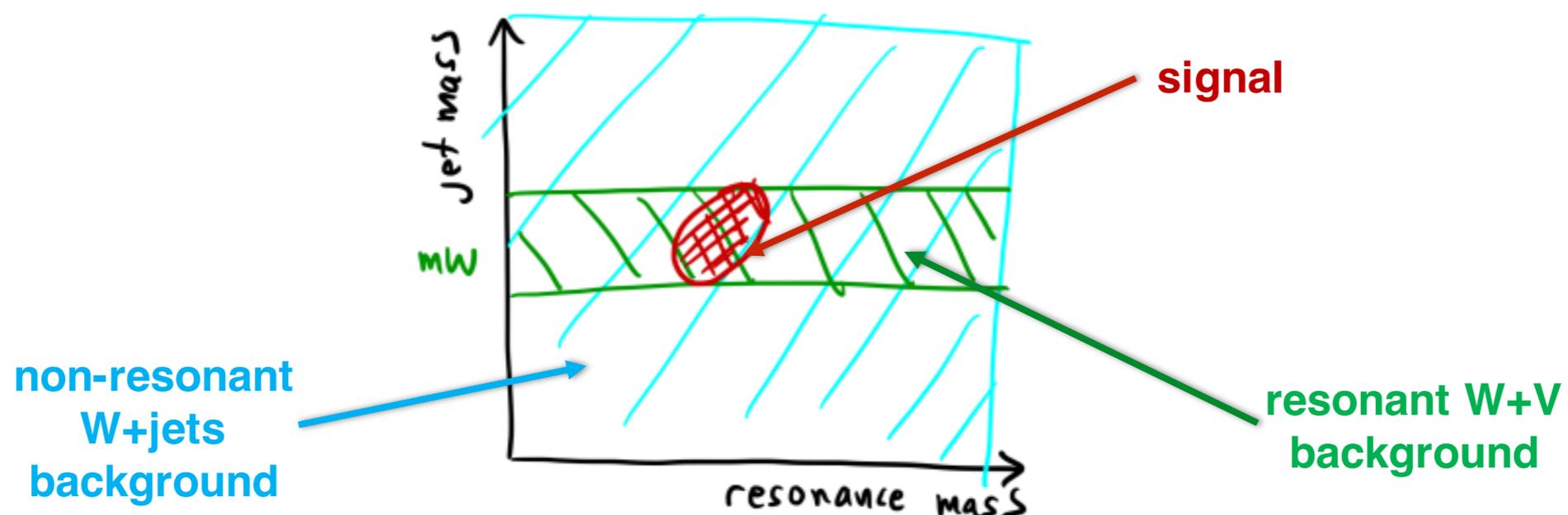
2016 ICHEP Data

## CMS Integrated Luminosity, pp



# Background estimation

- **New method: 2D fit** in  $(m_{WV}, m_{jet})$  plane - use full V jet mass range:  $30 < m_{jet} < 210$  GeV
  - Make better use of correlations between  $m_{WV}$  and  $m_{jet}$
  - Much more sideband statistics - use full line-shape of jet mass
  - Become less dependent on simulation - learn from data
- **Boost techniques**
  - PUPPI ([JHEP10\(2014\)059](#)) + Softdrop ([JHEP05\(2014\)146](#))
  - N-subjettiness ([arXiv:1011.2268](#))
- **2D fit**: distinguish between
  - non-resonant W+jets ( $W(l\nu)+jets$ ,  $t\bar{t}$  with non-W V jet)
  - resonant W+V ( $t\bar{t}$ , diboson) background processes



# Background estimation

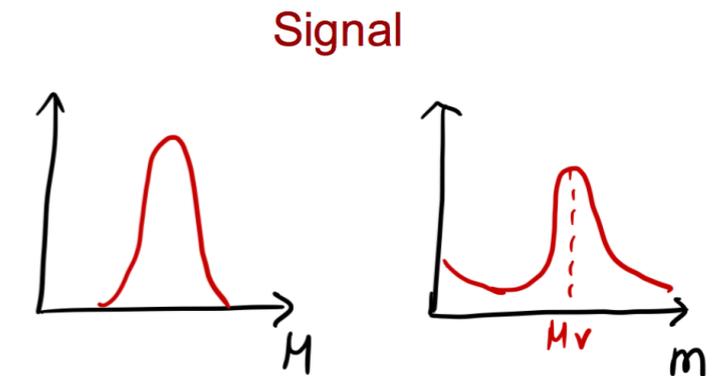
**Signal** peaks in both  $m_{WV}$  and  $m_{jet}$

$$P_{sig}(m_{WV}, m_{jet} | \theta(M_X)) = P_{WV}(m_{WV} | \theta_1(M_X)) \times P_j(m_{jet} | \theta_2(M_X))$$

- Fit both dimensions

double crystal-ball functions, for LP additional exponential is used for  $m_{jet}$  mass tail

- Interpolate using polynomials as a function of the resonance mass hypothesis ( $M_X$ )

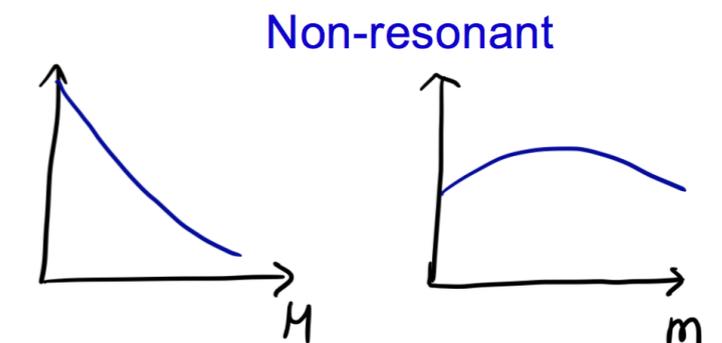


## Non-resonant background: W+jets

Conditional probability of  $m_{WV}$  as function of  $m_{jet}$ :

$$P_{W+jets}(m_{WV}, m_{jet}) = P_{WV}(m_{WV} | m_{jet}, \theta_1) \times P_j(m_{jet} | \theta_2)$$

- $P_{WV}$  templates created using kernel method starting from particle level, clustering as for reconstructed jets
- Determine scale and resolution as function of true jet  $p_T$  (encode uncertainties by varying those)
- Populate templates as sums of 2D gaussian templates in bins of  $m_{jet}$
- Smoothen  $m_{WV}$  from 2.5 TeV as function of  $m_{WV}$  fitting exponential from 2 TeV to avoid empty bins



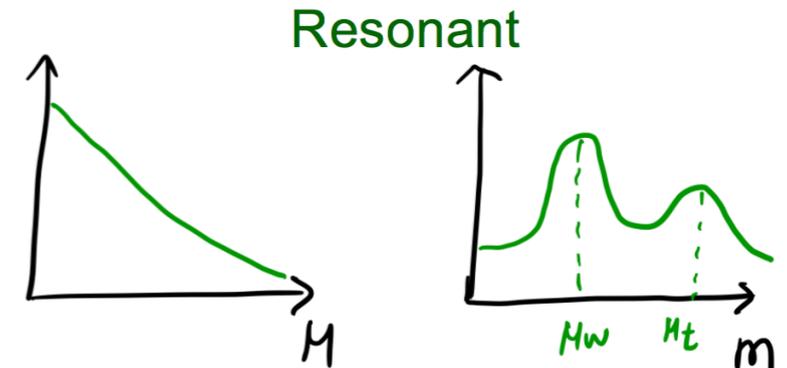
# Background estimation

## Resonant background: W+V

Conditional probability of  $m_{jet}$  as function of  $m_{WV}$ :

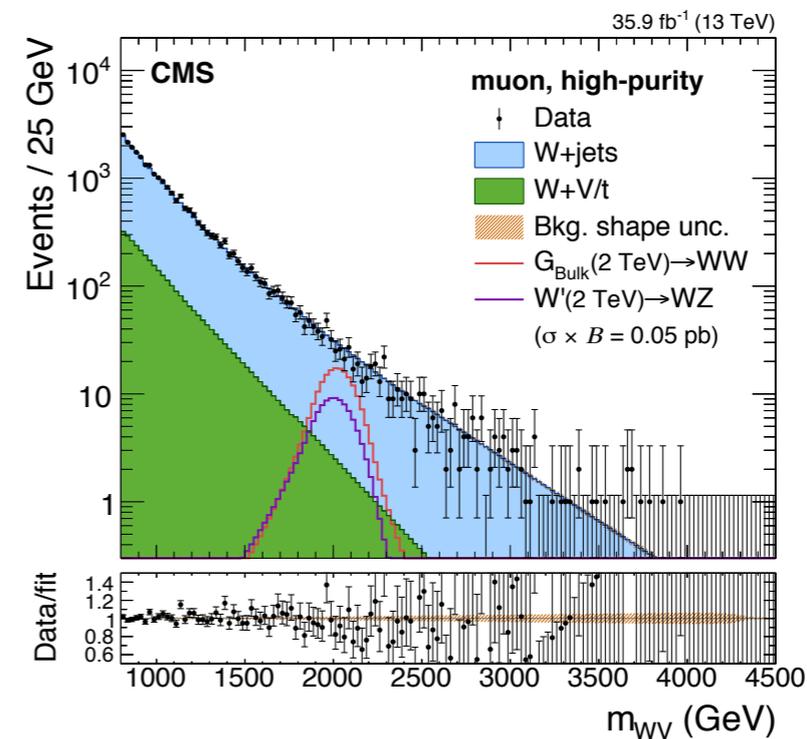
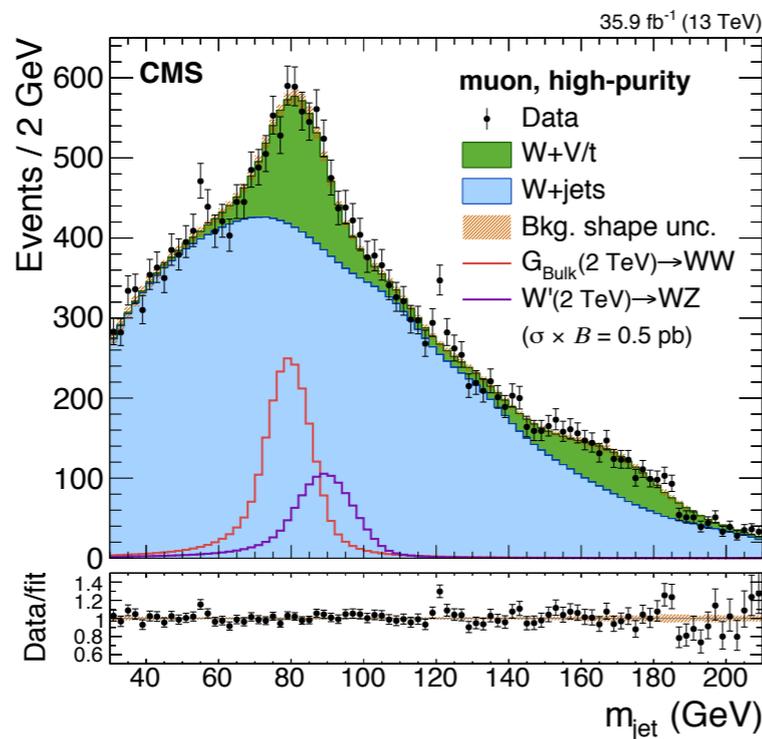
$$P_{W+V}(m_{WV}, m_{jet} | \theta) = P_{WV}(m_{WV} | \theta_1) \times P_j(m_{jet} | \theta_2(m_{WV}))$$

- $P_{WV}$  templates created using kernel method as for W+jets (1D)
- Smoothen  $m_{WV}$  from 1.2 TeV as function of  $m_{WV}$  fitting exponential
- $m_{jet}$  template described by W and top mass peaks

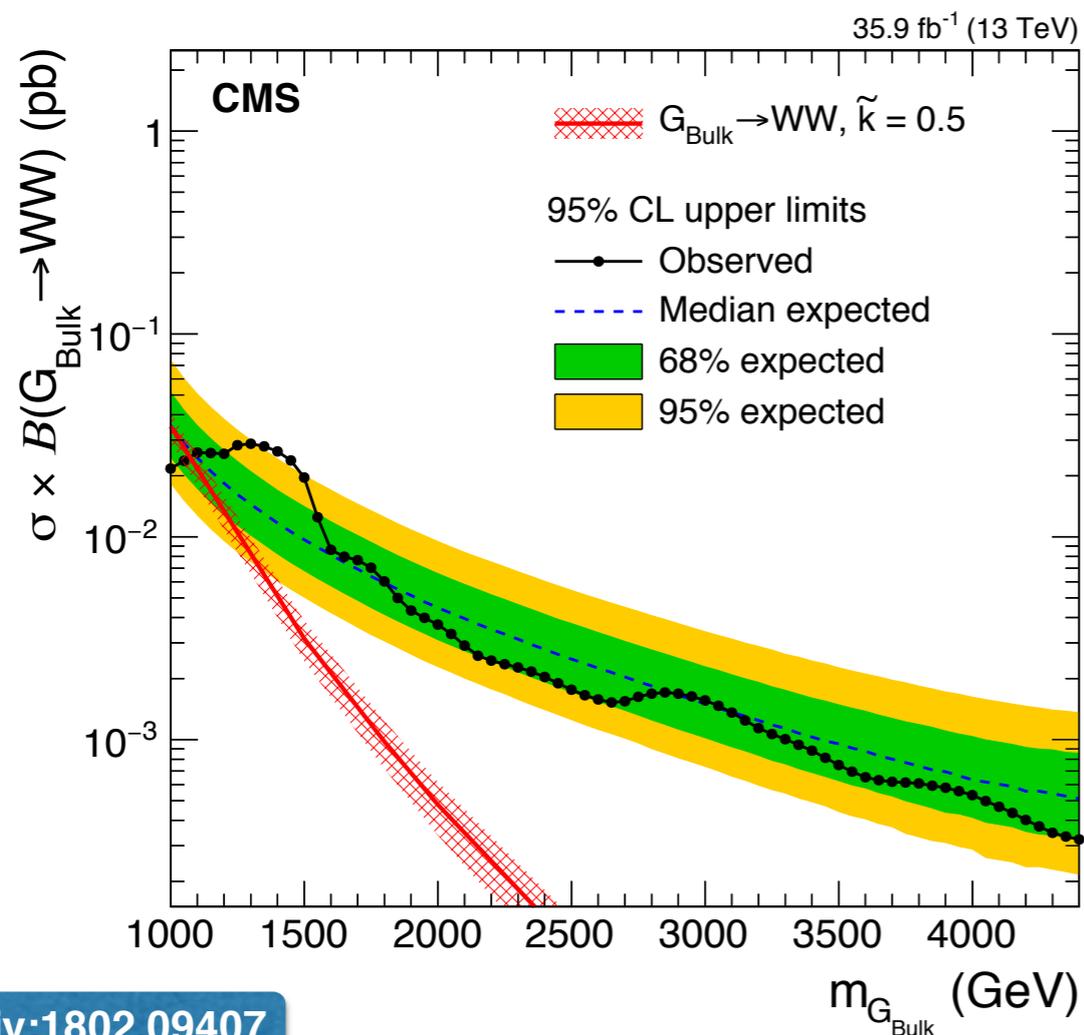


HP muon

arXiv:1802.09407

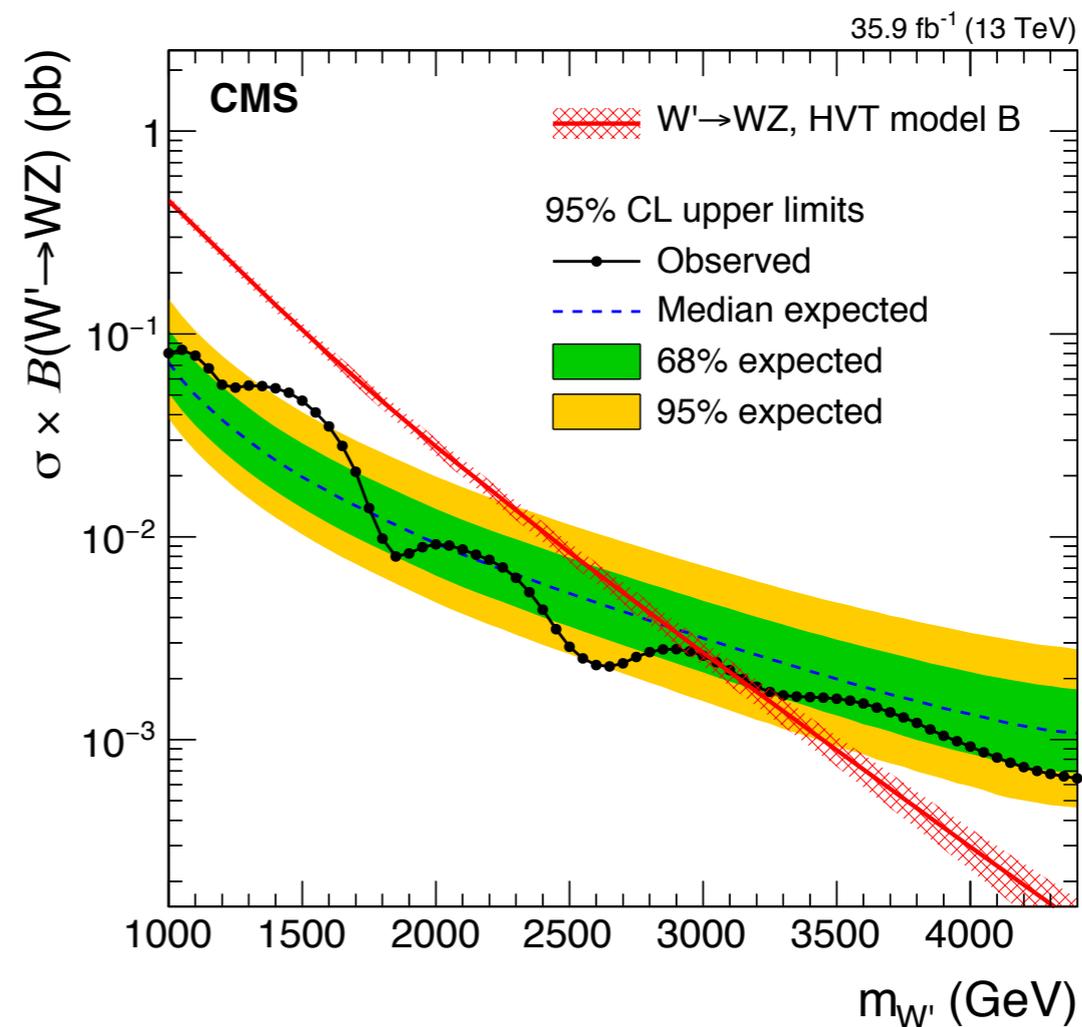


# Results **limit**



arXiv:1802.09407

**BulkGraviton**



**W'**

No strong evidence of a new signal is found.

Comparing the excluded cross section values and the expectation from theoretical calculations, WW resonances lighter than 1 TeV and WZ resonances lighter than about 3 TeV are excluded at 95% confidence level.

# Summary

- Searching for heavy resonances is one of the most direct ways to find new physics at TeV scale
- Significant development in boosted object techniques
- [1-4.5 TeV] analysis of  $X \rightarrow WV \rightarrow lvq\bar{q}$
- New background estimation method: 2D-fit
- No significant excess.
- More data and high energy will definitely tell us more



# Backup

# Boost techniques

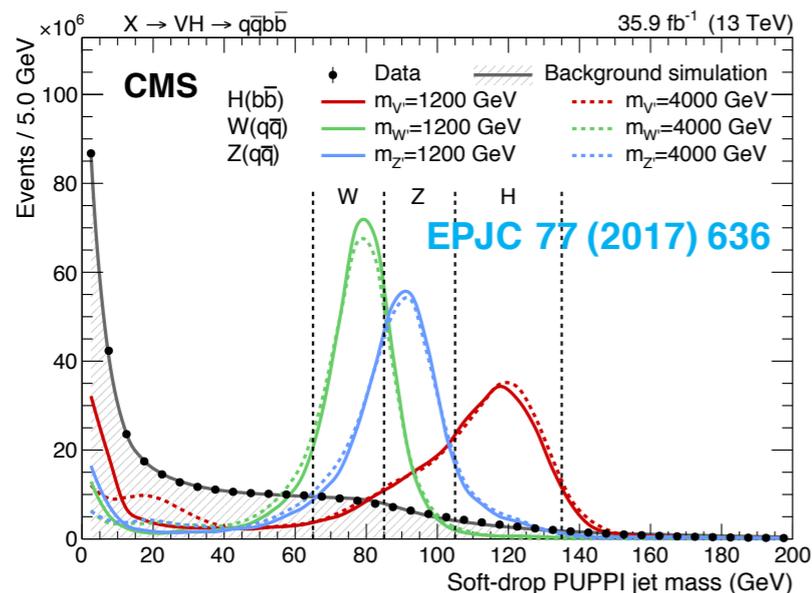
- Grooming and jet mass**

Boosted large-R jets ( $R=0.8$ ) can be easily contaminated by pileup interactions.

“Grooming” is to remove those pileup contaminations, to achieve stronger discrimination power for boosted jets.

- PUPPI algorithm** ([JHEP10\(2014\)059](#)): pileup mitigation algorithm identifying and assigning small weights to the pileup particles served as input to jet clustering.

- Softdrop algorithm** ([JHEP05\(2014\)146](#)): dropping soft jet constitution particles.



- Vector boson tagging ( $V \rightarrow q\bar{q}$ )**

The  $V$ -jets tagging variables and  $V/H$ -jet mass are calculated based on the ***groomed jets***

Distinguish: Boosted  $W/Z$  jets (2-prong) vs. QCD  $q/g$  jets (1-prong)

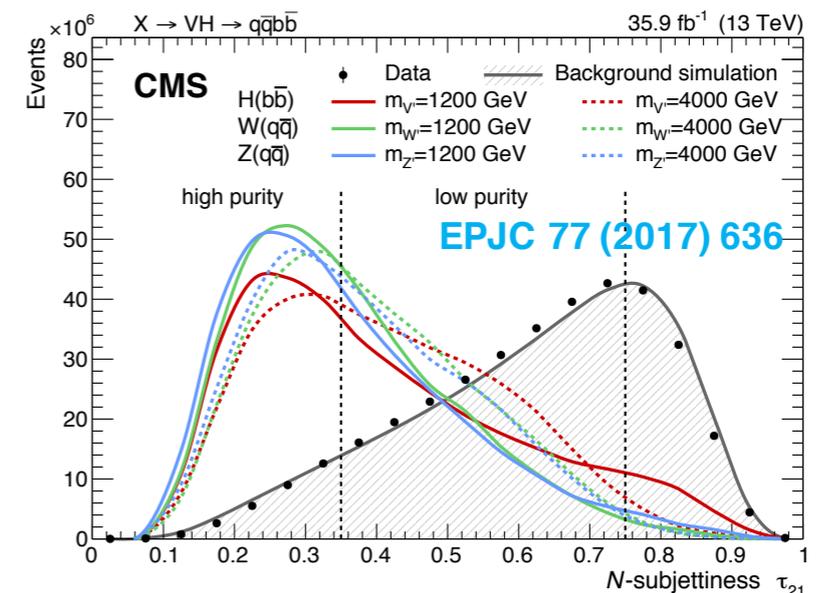
- N-subjettiness** ([arXiv:1011.2268](#)): how likely is a jet to have “N” subjets

$$\tau_N = \frac{1}{d_0} \sum_k p_{T,k} \times \min(\Delta R_{1,k}, \Delta R_{2,k}, \dots, \Delta R_{N,k})$$

$$d_0 = \sum_k p_{T,k} \times R_0$$

**Wjet tagger**

$$\tau_2 / \tau_1 = \tau_{21}$$



# Samples and preselections

- Data: 35.9/fb (2016 full year)
- Signal: BulkGraviton, Wprime
- Backgrounds: WJetsToLNu,  $T\bar{T}$ , SingleTop, WW/WZ/ZZ

## Muon channel

- High\_pT muon:  $p_T > 55 \text{ GeV}$ ,  $|\eta| < 2.4$ ,
- Loose muon (for veto):  $p_T > 20 \text{ GeV}$ ,  $|\eta| < 2.4$
- Missing  $E_T > 40 \text{ GeV}$  ( type I)

## Electron channel

- HEEP electron:  $p_T > 55 \text{ GeV}$ ,  $|\eta| < 2.5$ ,
- Loose electron:  $p_T > 35 \text{ GeV}$
- Missing  $E_T > 80 \text{ GeV}$  ( type I)

$p_T(\text{MET} + \text{lep}) > 200 \text{ GeV}$

Single lepton triggers, use logical OR with **MET triggers** to recover muon trigger inefficiency at high  $p_T$

**Reconstruct leptonic W:** constrain mass, solve quadratic equation, choose smallest magnitude solution (imaginary solution: take real part only)

## Hadronic

Noise cleaning filters  
 AK8 jets,  $p_T > 200 \text{ GeV}$ , Loose ID  
 AK4 jets (for b-veto),  $p_T > 30 \text{ GeV}$ , Loose ID

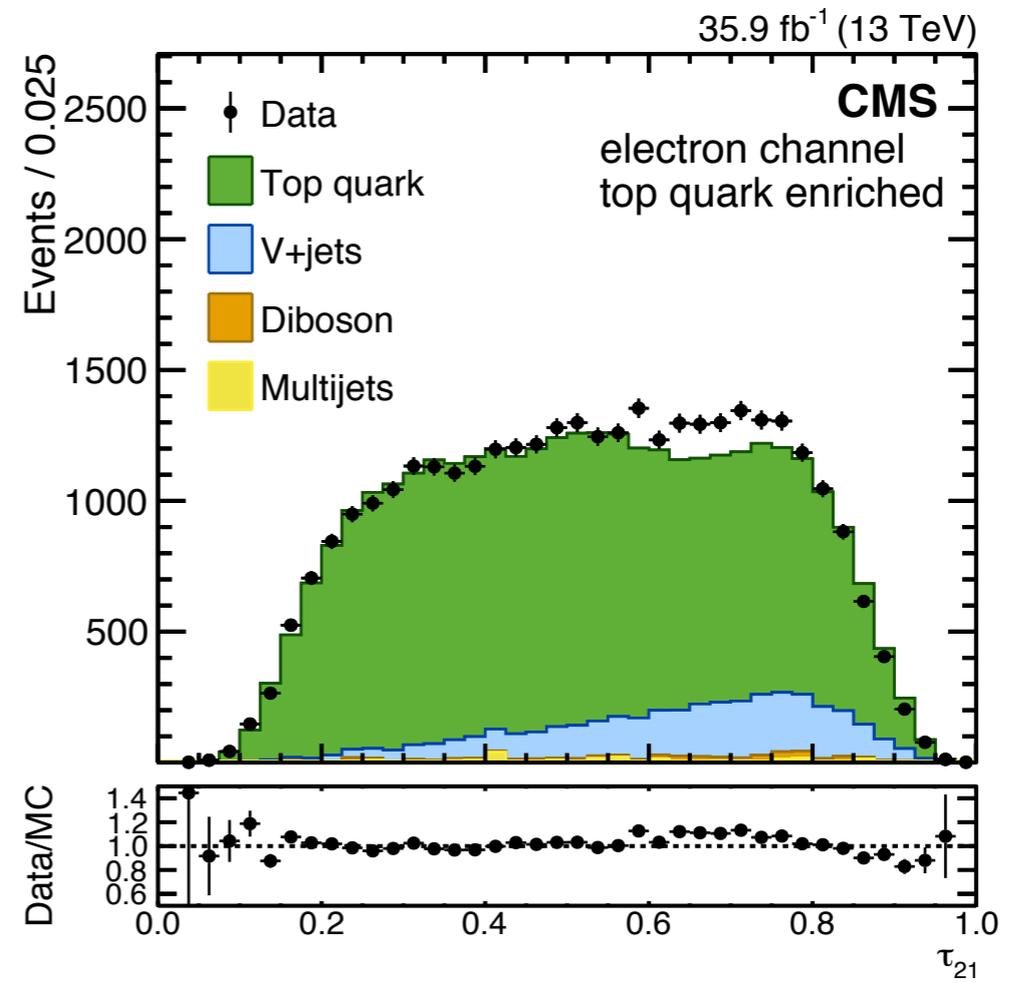
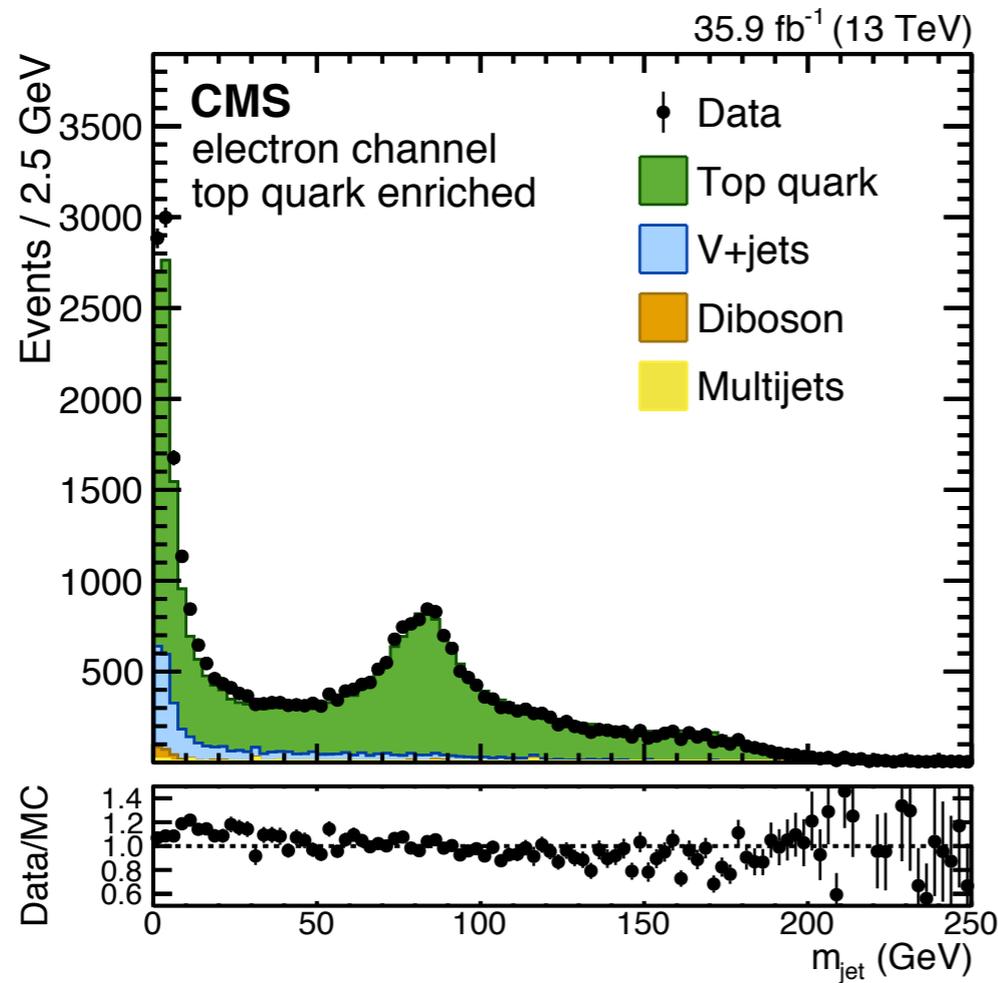
$\Delta R(l, W_{\text{had}}) > \pi/2$   
 $\Delta R(W_{\text{had}}, W_{\text{lep}}) > 2$   
 $\Delta R(W_{\text{had}}, \text{missing } E_T) > 2$

V tagging based on PUPPI N-subjettiness ratio  $\tau_{21}$  and PUPPI soft-drop mass  $m_{\text{jet}}$   
**Two  $\tau_{21}$  regions:** HP ( $\tau_{21} < 0.55$ ) + LP ( $0.55 < \tau_{21} < 0.75$ )

**Soft-drop mass:**  $30 < m_{\text{jet}} < 210 \text{ GeV}$

Final analysis considers  $m_{\text{WV}} > 800 \text{ GeV}$

# Control plots



Jet soft-drop mass (left) and N-subjettiness ratio  $\tau_{21}$  (right) for data and simulated events in the top-enriched region in the electron channel. Data statistics only are shown as uncertainties.

# $\alpha$ -method review

CMS-PAS-B2G-16-020

- $\alpha$ -method background estimation

- Shape & normalization

1. transfer function:  $\alpha^{MC} = \frac{F_{WW}(SR)^{MC}}{F_{WW}(SB)^{MC}}$

2. Fit data  $N_{SB}^{data}(m_X)$  in sideband

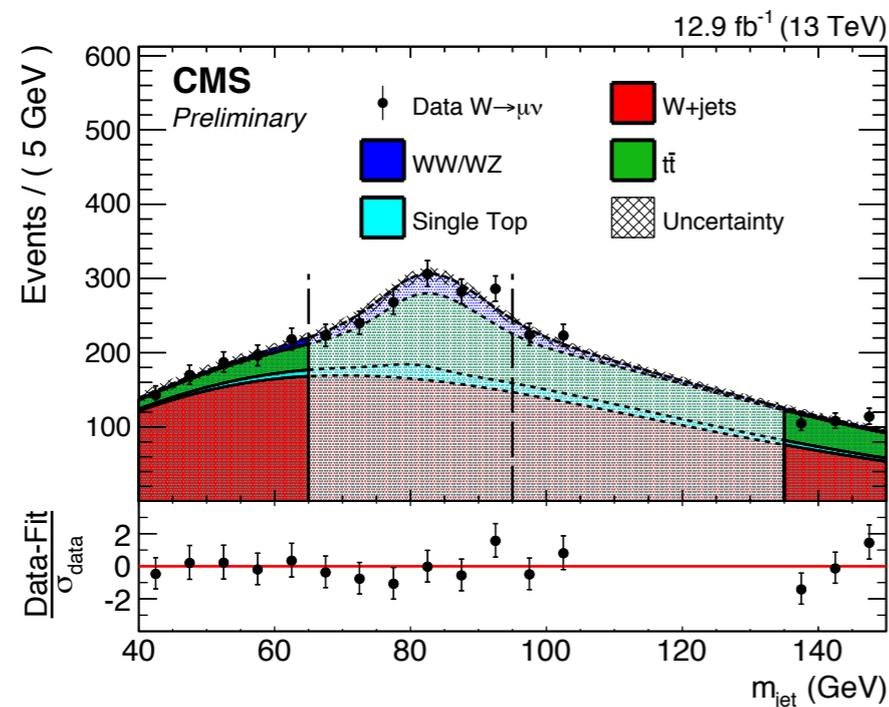
3. background expectation in SR

$$F_{WW}(SR)^{Data} = F_{WW}(SB)^{Data} \times \alpha^{MC}$$

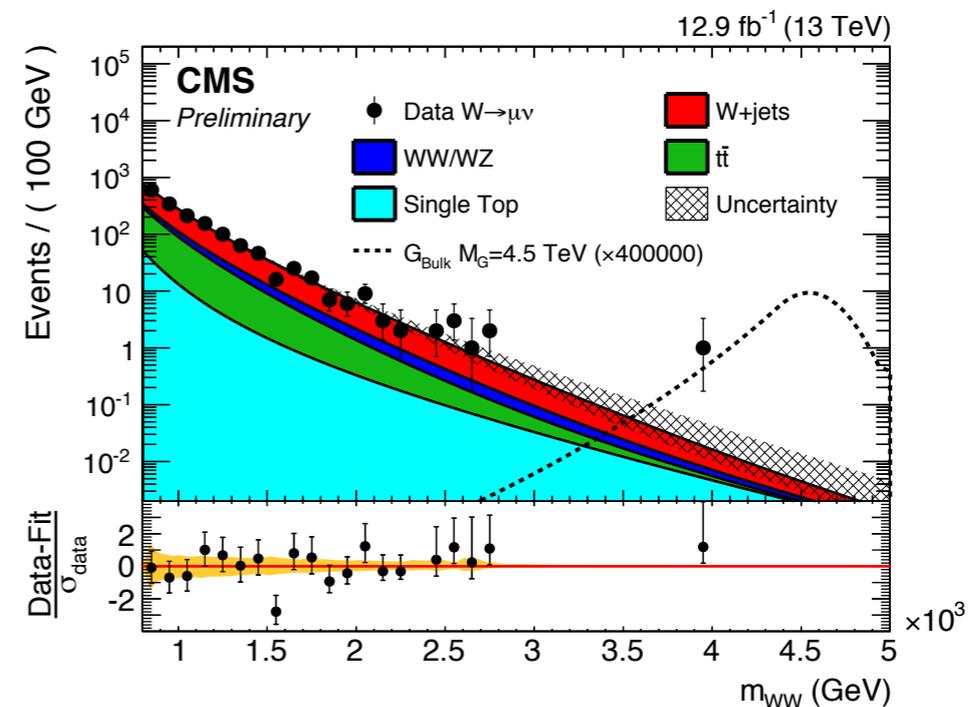
$$\alpha^{MC} = \frac{F_{WW}(SR)^{MC}}{F_{WW}(SB)^{MC}} \longleftrightarrow \alpha^{Data} = \frac{F_{WW}(SR)^{Data}}{F_{WW}(SB)^{Data}}$$

Assuming  $\alpha^{Data} = \alpha^{MC}$

$$\rightarrow F_{WW}(SR)^{Data} = F_{WW}(SB)^{Data} \times \alpha^{MC}$$



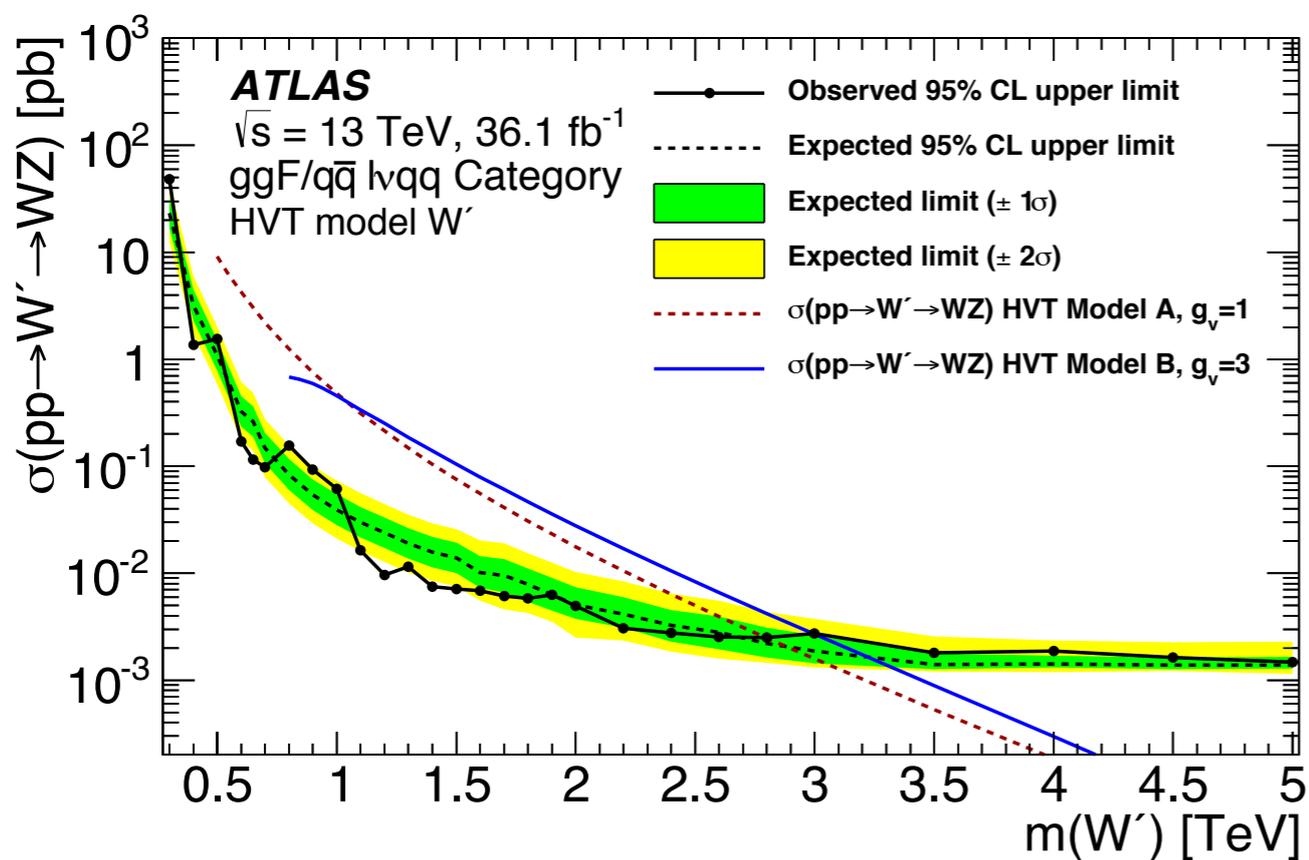
Normalization



shape

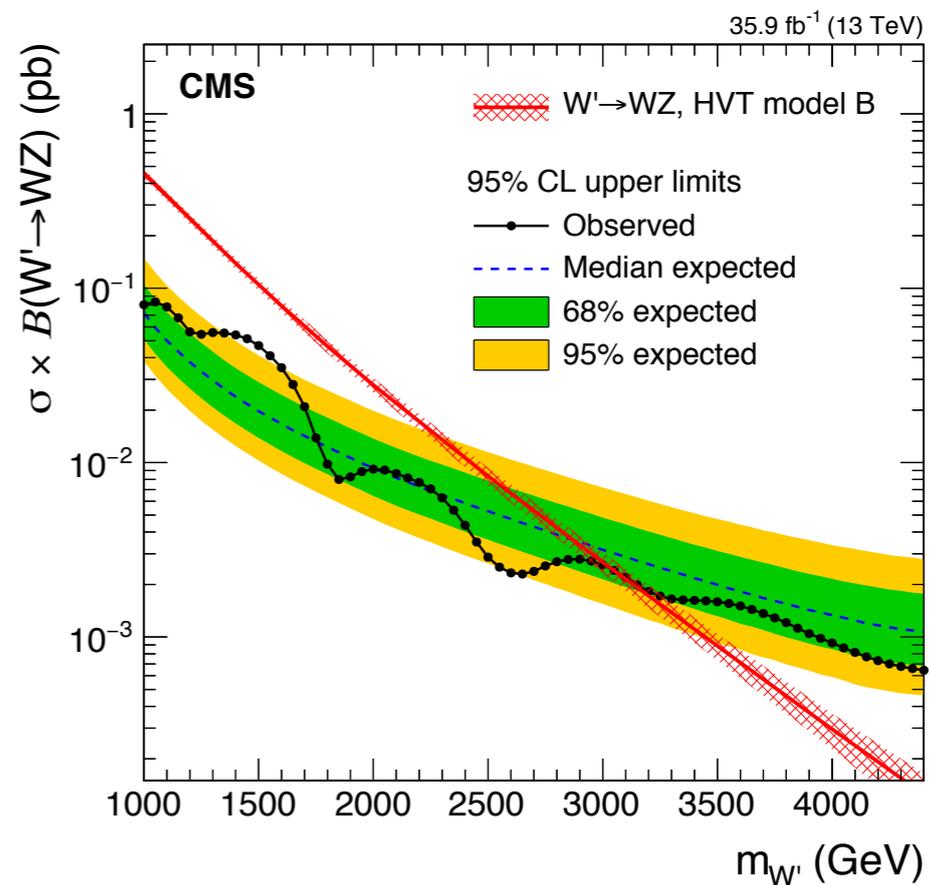
# Results ATLAS vs. CMS

# W'



**ATLAS**

arXiv:1710.07235



**CMS**

arXiv:1802.09407