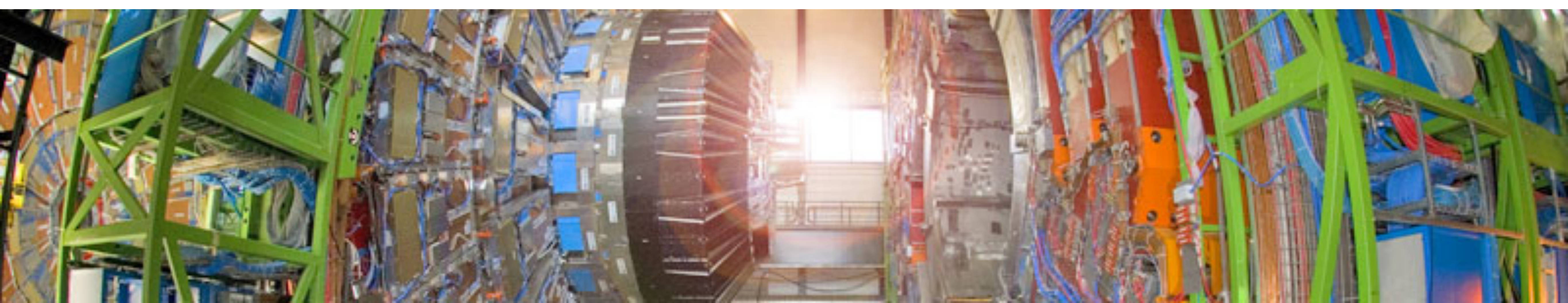
Search for heavy resonances decaying to pairs of vector bosons in the lvqq final state with the CMS detector in proton-proton collisions at $\sqrt{s}$= 13 TeV

Huang Huang, Xudong Lyu

June 20th 2018



outline

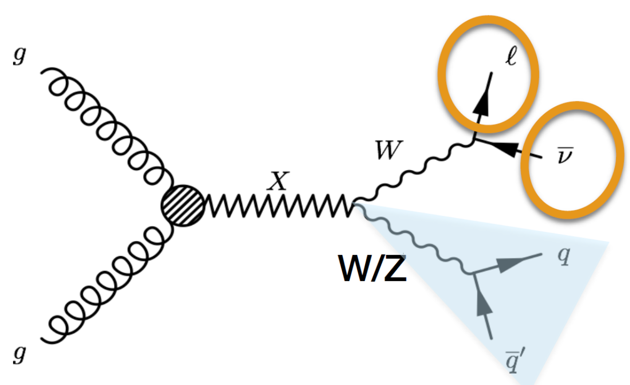
- Motivation
- Boost techniques
- Samples and preselections
- Control plots
- Background estimation
- Systematic uncertainties
- Results
- Summary

Motivation

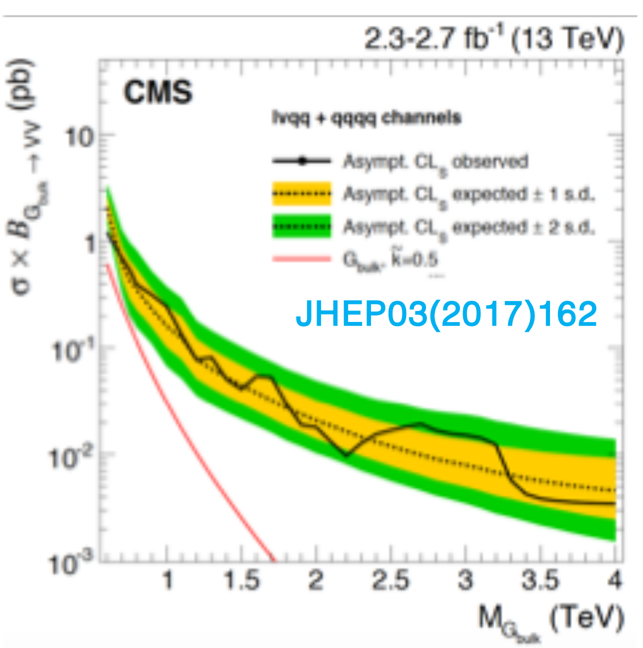
Beyond Standard Model

- Many unification attempts
- Hierarchy problem

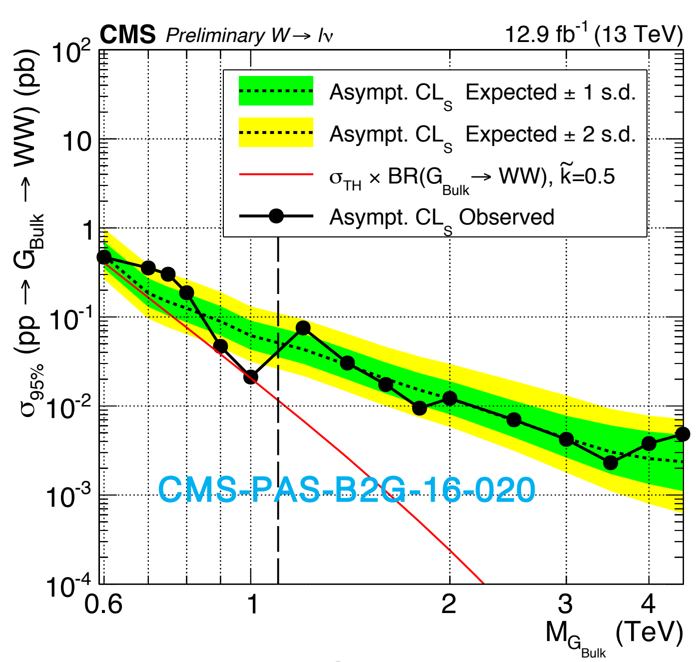
Motivate the existence of heavy EXOTIC resonances



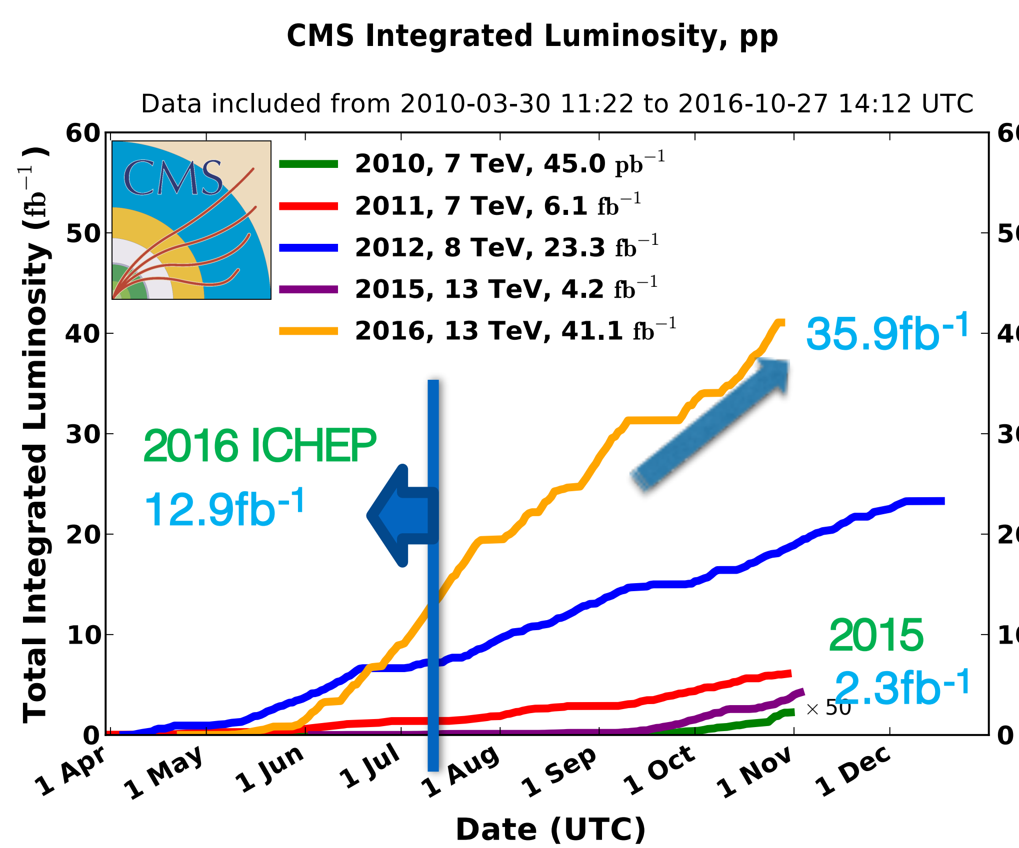
	Channel	Models
EXOTIC resonance X→ Diboson	WW	Spin-2 **Bulk Graviton**¶
	WZ	Spin-1 **HVT** ¶ (charged)



2015 Data



2016 ICHEP Data



Boost techniques

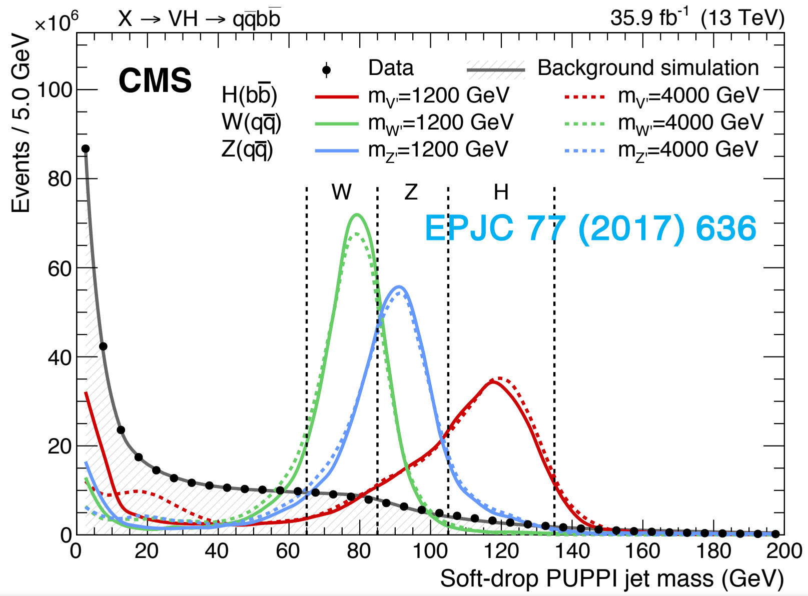
- ## Grooming and jet mass

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 ($V \rightarrow \bar{q}q$)

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

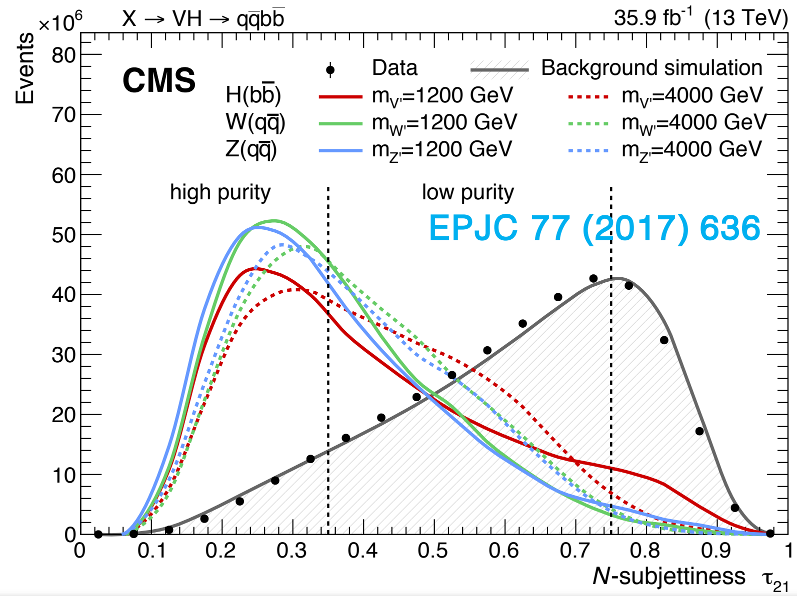
Distinguish: Boosted W/Z jets (2-prong) vs. QCD q/g jets (1-prong)

- **N-subjettiness** (arXiv:1011.2268): how likely is a jet to have "N" subjets

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

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

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



Samples and preselections

- Data: 35.9/fb (2016 full year)
- Signal: BulkGraviton, Wprime
- Backgrounds: WJetsToLNu, TT, SingleTop, WW/WZ/ZZ

Muon channel
• High_pT muon: $p_T > 55$ GeV , $\lvert\eta\rvert<2.4$, • Loose muon (for veto): $p_T > 20$ GeV , $\lvert\eta\rvert<2.4$ • Missing $E_T > 40$ GeV (type I)
Electron channel
• HEEP electron: $p_T > 55$ GeV, $\lvert\eta\rvert<2.5$, • Loose electron: $p_T > 35$ GeV • Missing $E_T > 80$ GeV (type I)

p_T(MET+lep) >200GeV

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

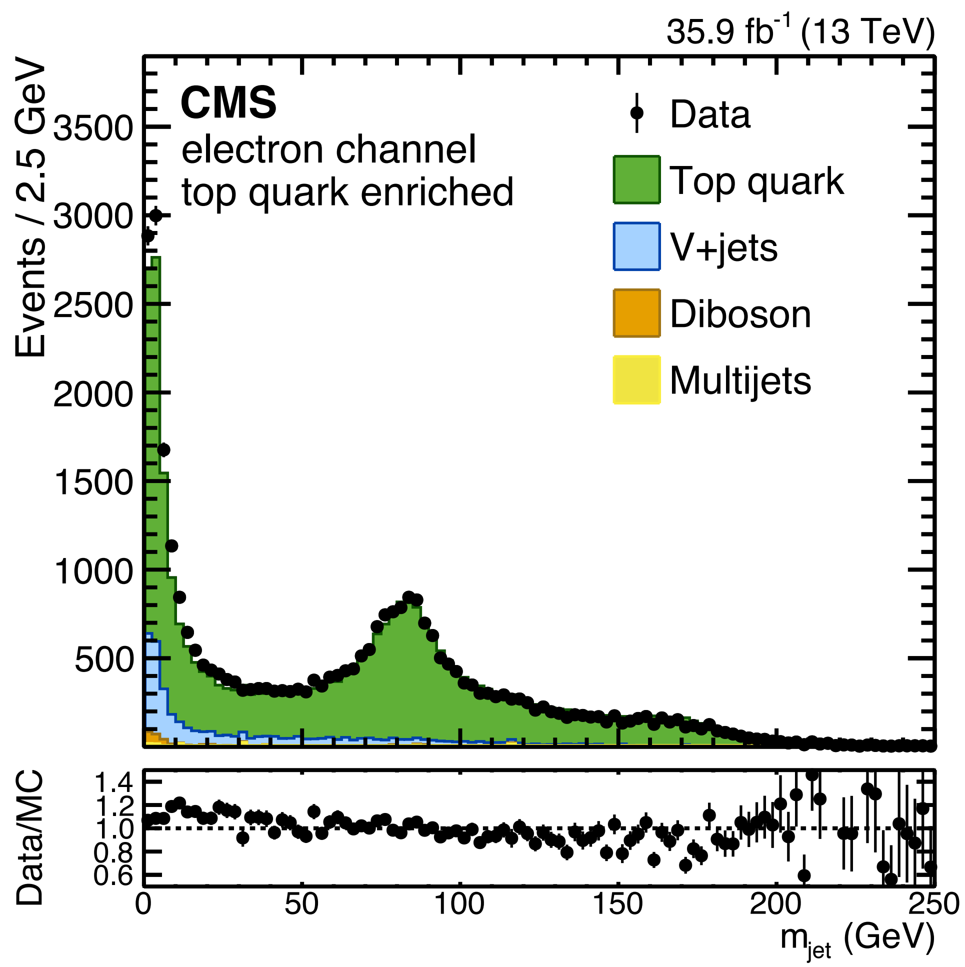
Reconstruct leptonic W: constrain mass, solve quadratic equation, choose
smallest magnitude solution (imaginary solution: take real part only

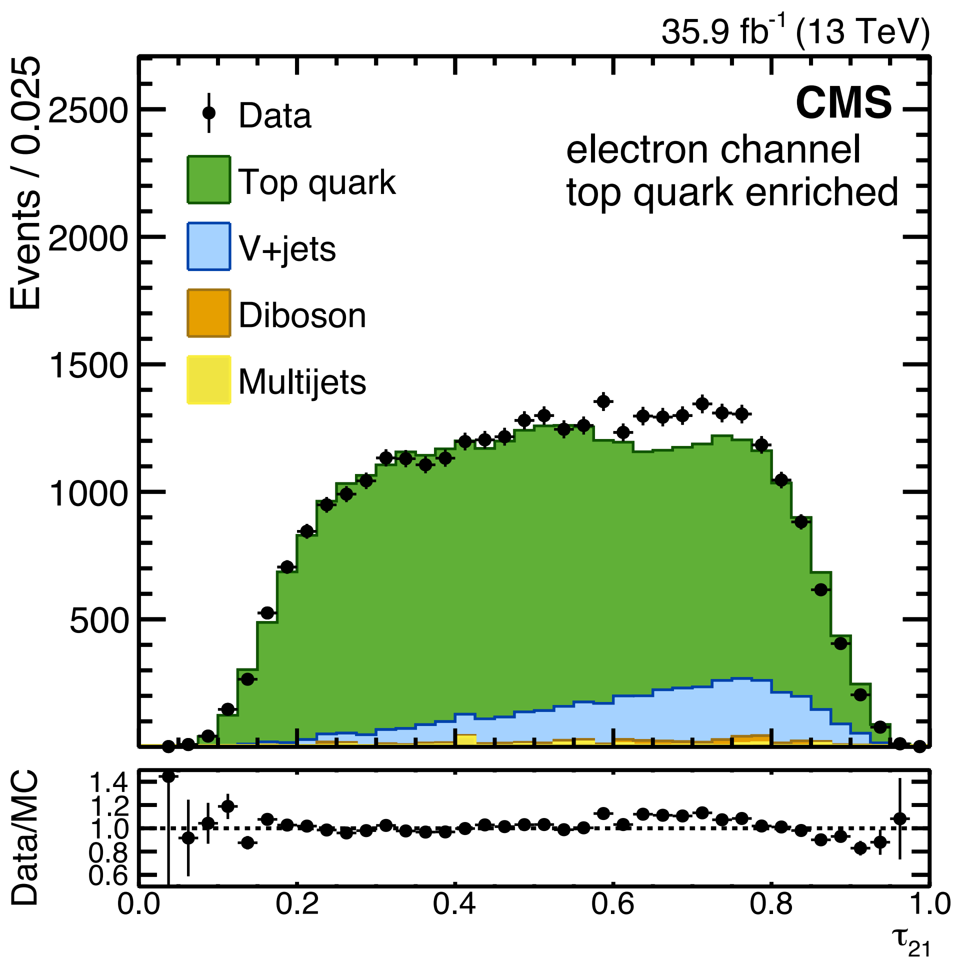
Hadronic
Noise cleaning filters AK8 jets, $p_T > 200$ GeV, Loose ID AK4 jets (for b-veto), $p_T > 30$ GeV, Loose ID
$\Delta R(l,W_{had}) > \pi/2$ $\Delta R(W_{had}, W_{lep}) > 2$ $\Delta R(W_{had}$, missing $E_T) > 2$

V tagging based on PUPPI N-subjettiness ratio τ_{21} and PUPPI soft-drop mass m_{jet}
Two τ_{21} regions: HP ($\tau_{21} < 0.55$) + LP ($0.55 < \tau_{21} < 0.75$)
Soft-drop mass: $30 < m_{jet} < 210$ GeV

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

Control plots

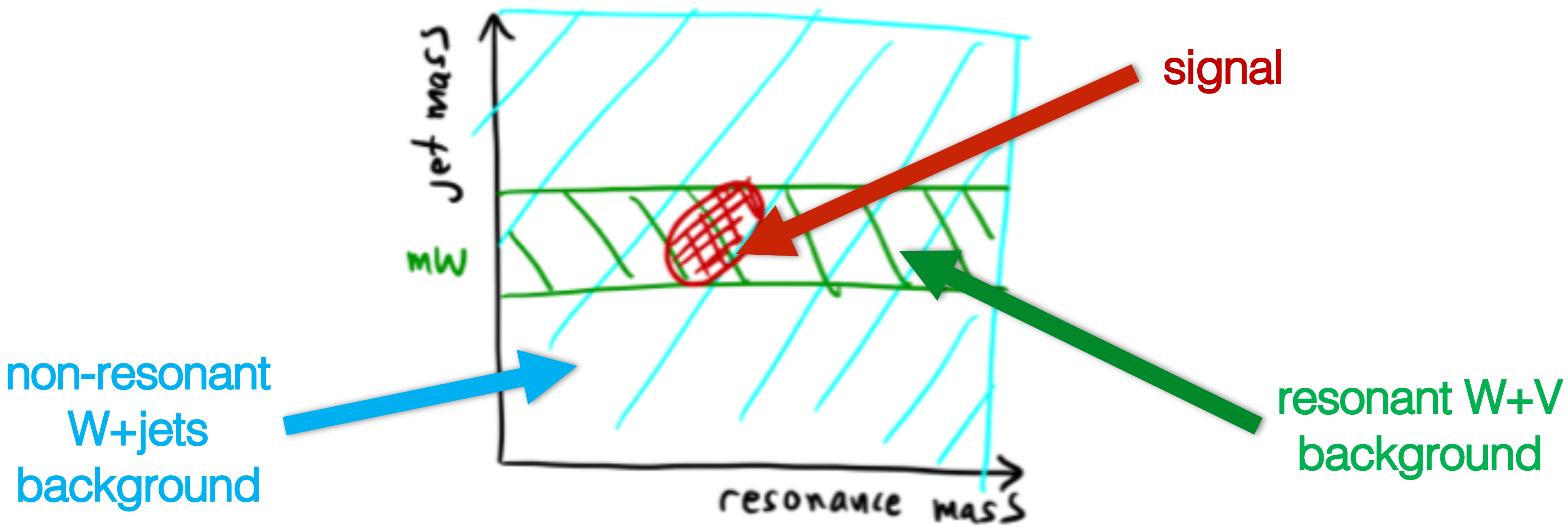




Jet soft-drop mass (left) and N-subjettiness ratio τ_{21} (right) for data and simulated events in the top-enriched region in the electron channel. Data statistics only are shown as uncertainties.

Background estimation

- New method: 2D fit in (mWV, mjet) 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
- Cross check with ***alpha method***:
  - sideband: $30 < m_{jet} < 65$ GeV, $135 < m_{jet} < 150$ GeV (excludes top peak)
  - W window: $65 < m_{jet} < 85$ GeV, Z window: $85 < m_{jet} < 105$ GeV
- 2D fit: distinguish between
  - non-resonant W+jets (W(lv)+jets, ttbar with non-W V jet)
  - resonant W+V (ttbar, diboson) background processes



α-method review

CMS-PAS-B2G-16-020

- *α-method background estimation*
- *Shape & normalization*

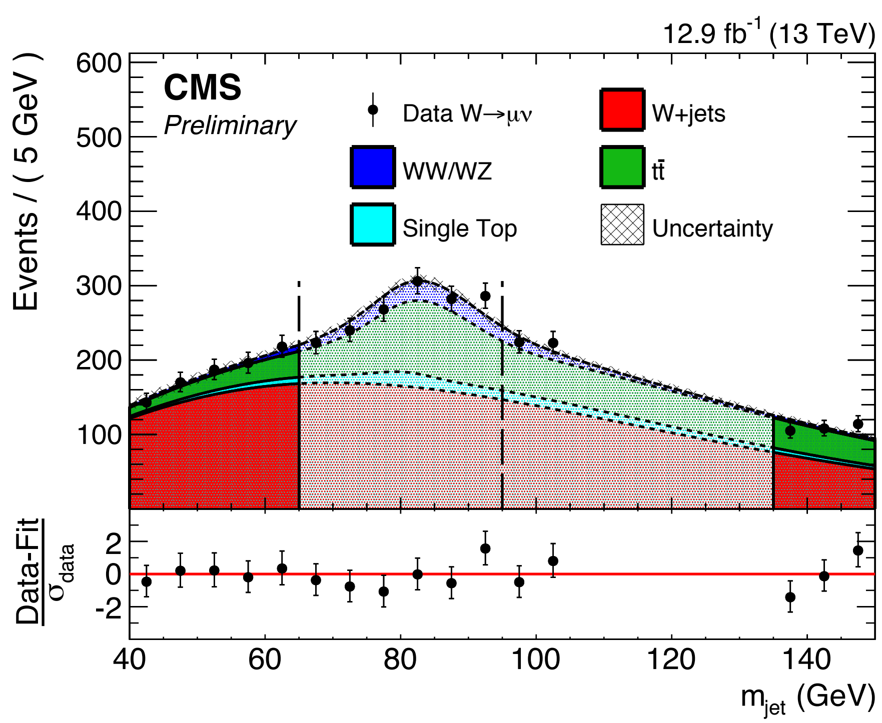
1. transfer function: $\alpha^{MC} = \frac{F_{WW}(SR)^{MC}}{F_{WW}(SB)^{MC}}$
2. Fit data $N_{SB}^{data}(m_X)$ in sideband
3. background expectation in SR

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

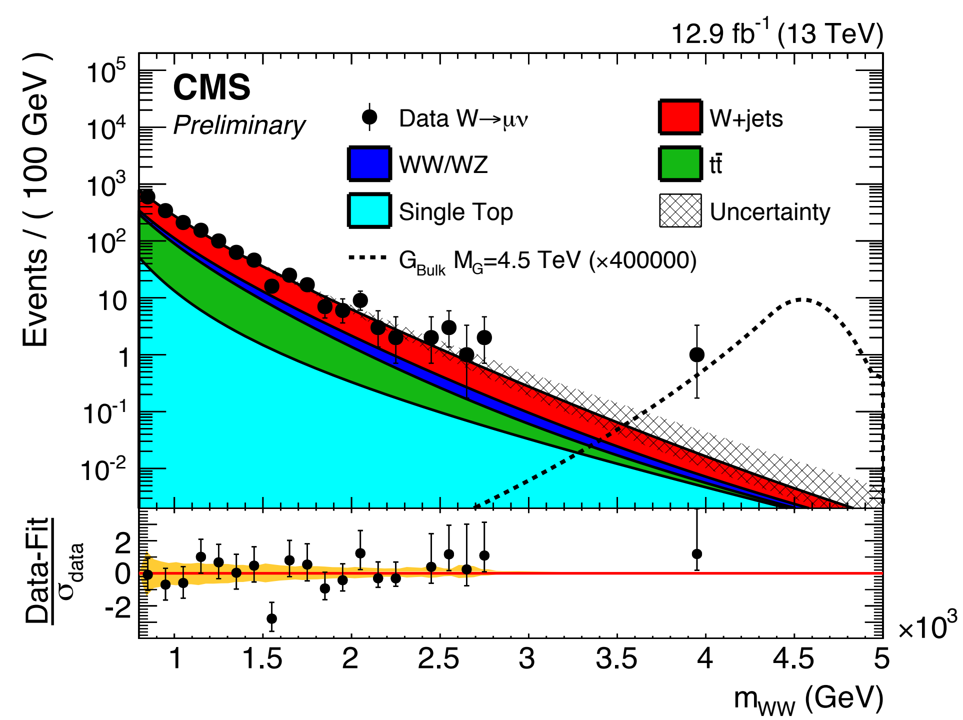
$$\alpha^{MC} = \frac{F_{WW}(SR)^{MC}}{F_{WW}(SB)^{MC}} \Leftrightarrow \alpha^{Data} = \frac{F_{WW}(SR)^{Data}}{F_{WW}(SB)^{Data}}$$

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

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

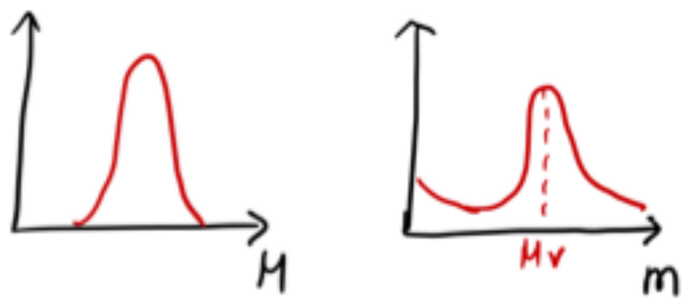


Normalization



shape

Background estimation: Signal parametrisation



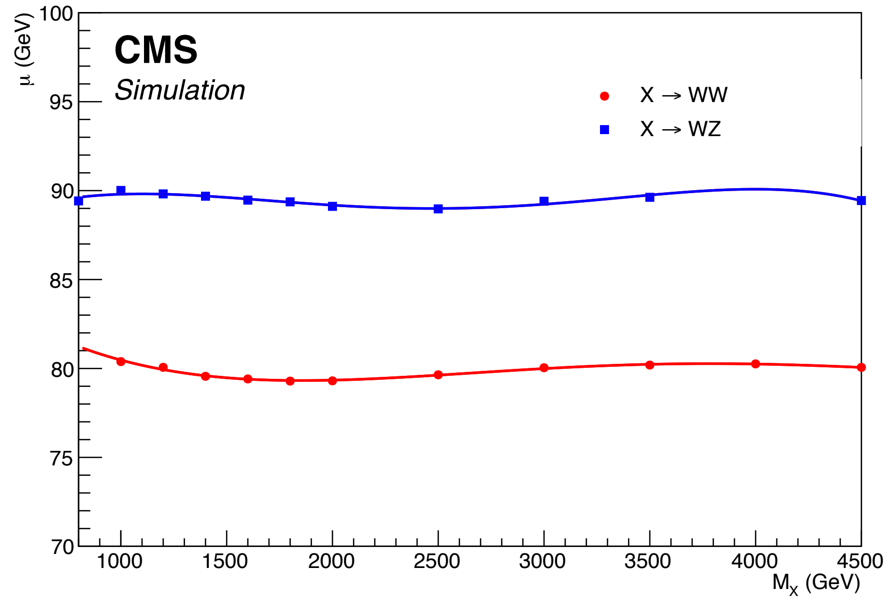
- Signal peaks in both m_{WV} and m_{jet}

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

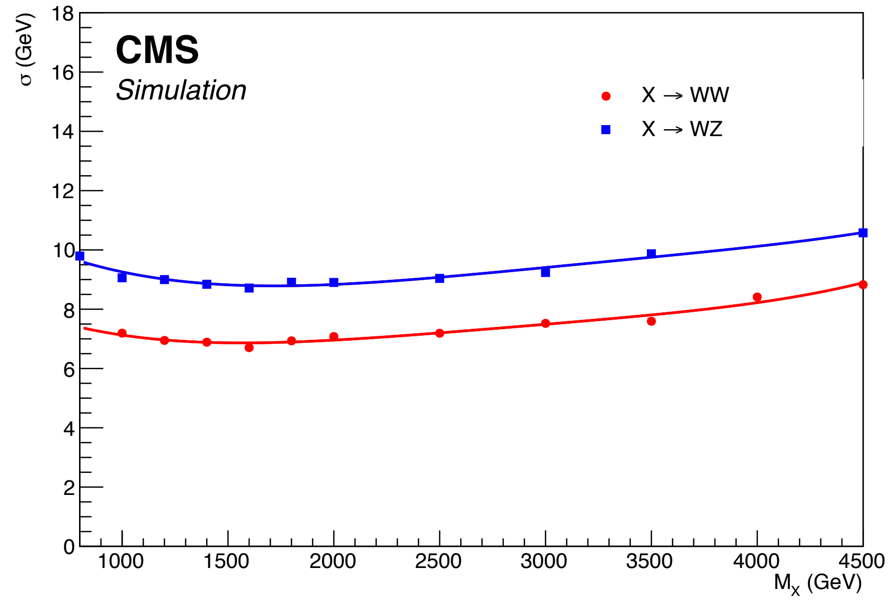
- Fit both dimensions

  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)



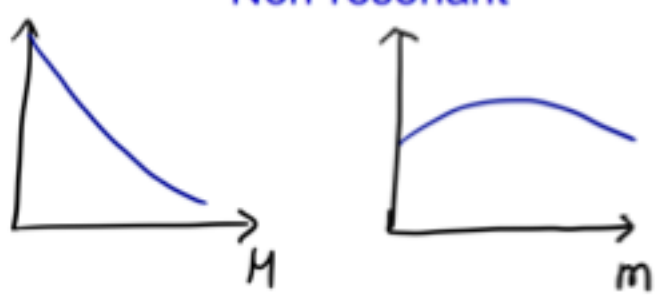
mean



sigma

Background estimation: Non-resonant

- **W+jets background:**

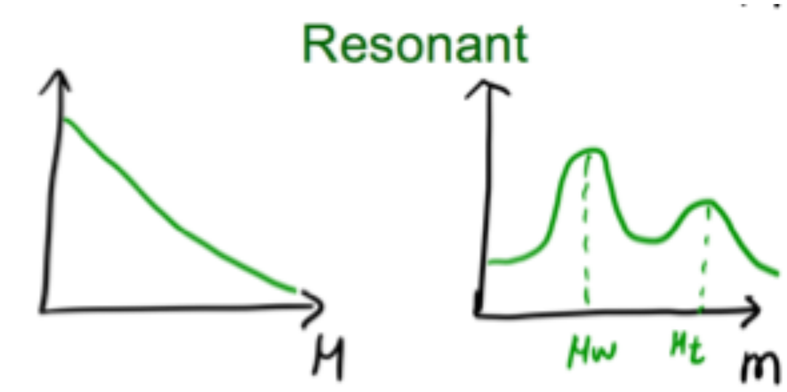


- Conditional probability of m_{WV} as function of m_{jet}:

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

- P_{WV} templates created using kernel method starting from particle level, clustering as tor 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 mWV from 2.5 TeV as function of mWV fitting exponential from 2 TeV to avoid empty bins
- $P_j(m_{jet}|\theta_2)$ template created using fitting splines

Background estimation: resonant

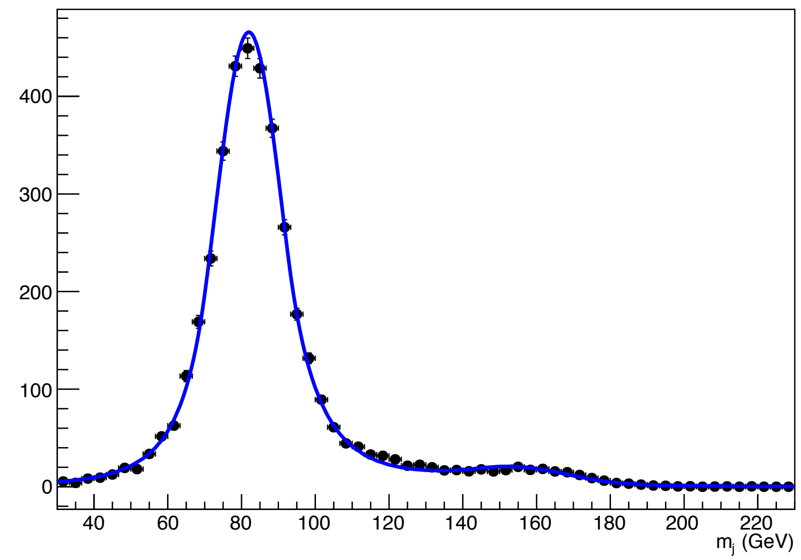


- W+V background:
- Conditional probability of mWV as function of mjet:

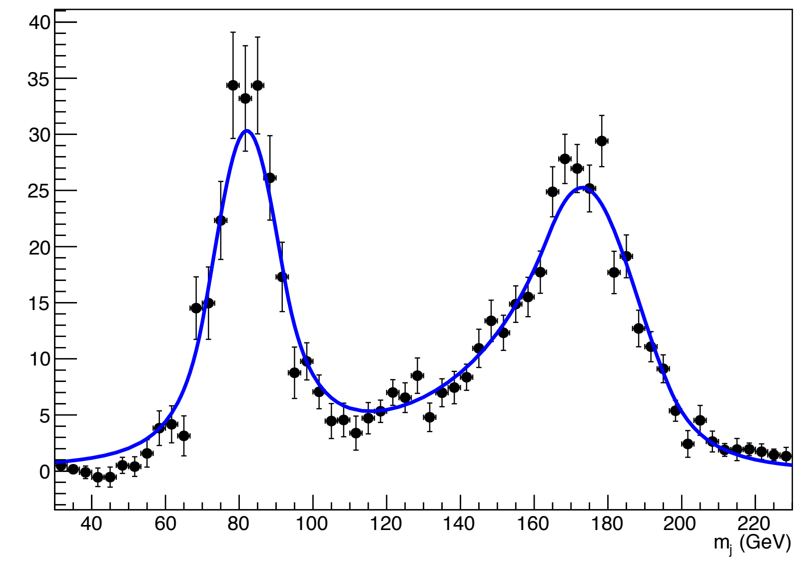
$$P_{W+V}(m_{WV}, m_{jet}|\theta) = P_{WV}(m_{WV}|\theta_1) \times P_j(m_{jet}|\theta_2(m_{WV}))$$

- Pw templates created using kernel method as for W+jets (1D)
- Smoothen mWV from 1.2 TeV as function of mWV fitting exponential
- mjet template described by W and top mass peaks

m_{jet}



800GeV



2TeV

Systimatics uncertainties

- **General strategy:**

  Each of the two background contributions are allowed to float from expectation for each lepton, and purity sub-category: 50% for W+jets, 20% for W+V (< 10% confirmed in control region)

- **All typical normalisation systematics affect only the signal**

  Luminosity: 2.5%

  Electron/muon efficiency: 10% (account for custom muon ID and high-p_T measurement uncertainty, trigger)

  τ_{21} scale factor using JMAR recommendations (HP 14%, LP 33%), including extrapolation uncertainty (4-13%)

  b tag scale factor (for the b-jet veto): <5%

  PDF effects in acceptance: 1%

- **Signal m_{WV} shape nuisance parameters:**

  Jet p_T scale affecting m_{WV}: 2%

  Jet p_T resolution affecting m_{WV}: 5%

  MET scale and resolution affecting m_{WV}: 2% each

- **Signal and resonant-background jet mass correlated nuisance parameters**

  Groomed jet mass scale (1%) and resolution (2%) - measured in top events in data

Systimatics uncertainties II

- **Resonant-background shape parameters:**

  Top p_T spectrum affecting the W vs. top peak fraction parametrised as $f/f_{MC} = a + b/m_{WV}^2$

  20% uncertainty on a; for b: $\pm$ 25000 GeV^2

- **resonance mass alternative shapes:**

  p_T spectrum affecting m_{WV}: $\pm 0.002 \times m_{WV}$

  general mWV mass scale: $\pm$ 400 GeV / m_{WV}

- **hadronisation/substructure affecting groomed jet mass:**

  shape variation: $\pm 0.04 \times m_{jet}$

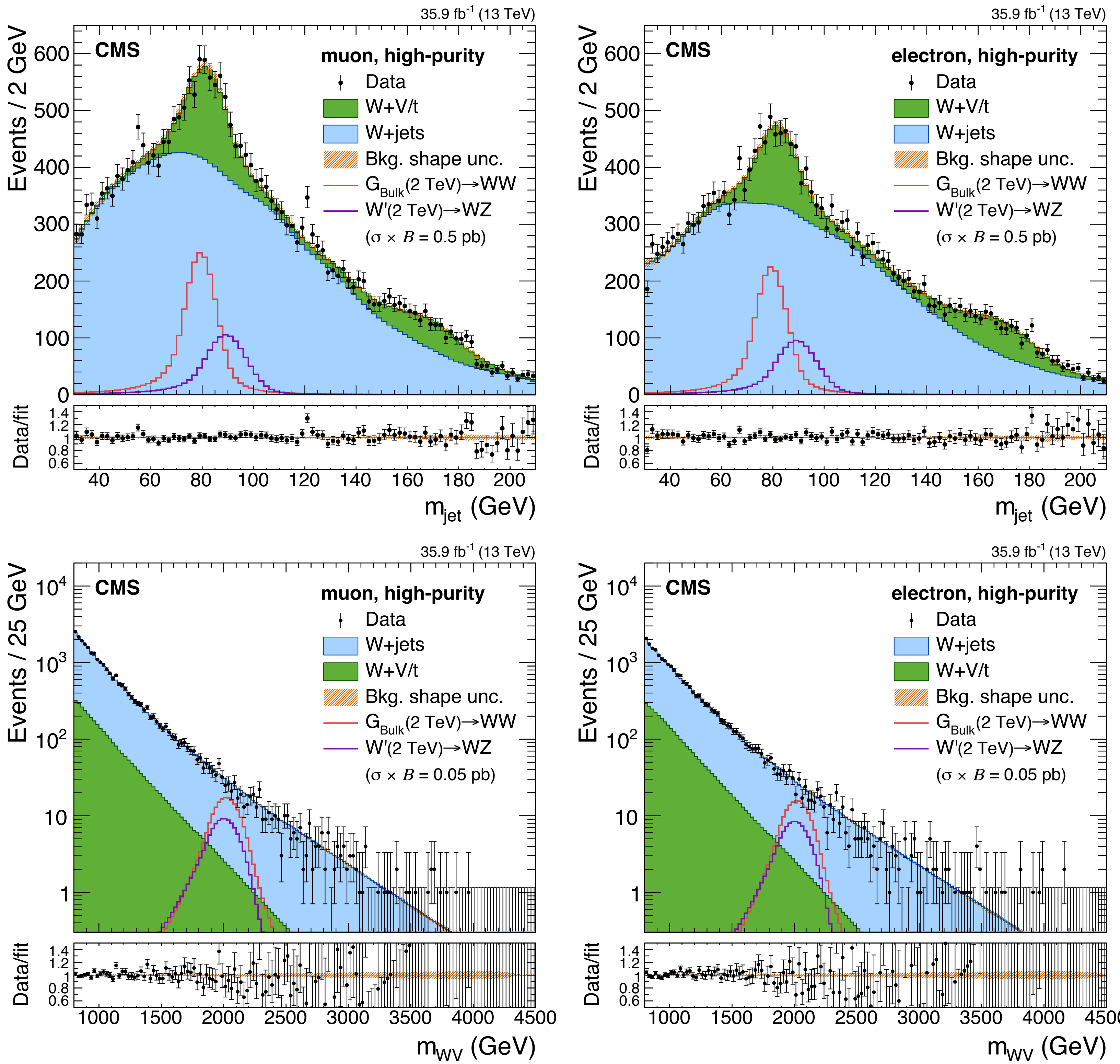
  shape variation: $\pm$ 10 GeV / m_{jet}

Results HP

electron muon

m_{jet}

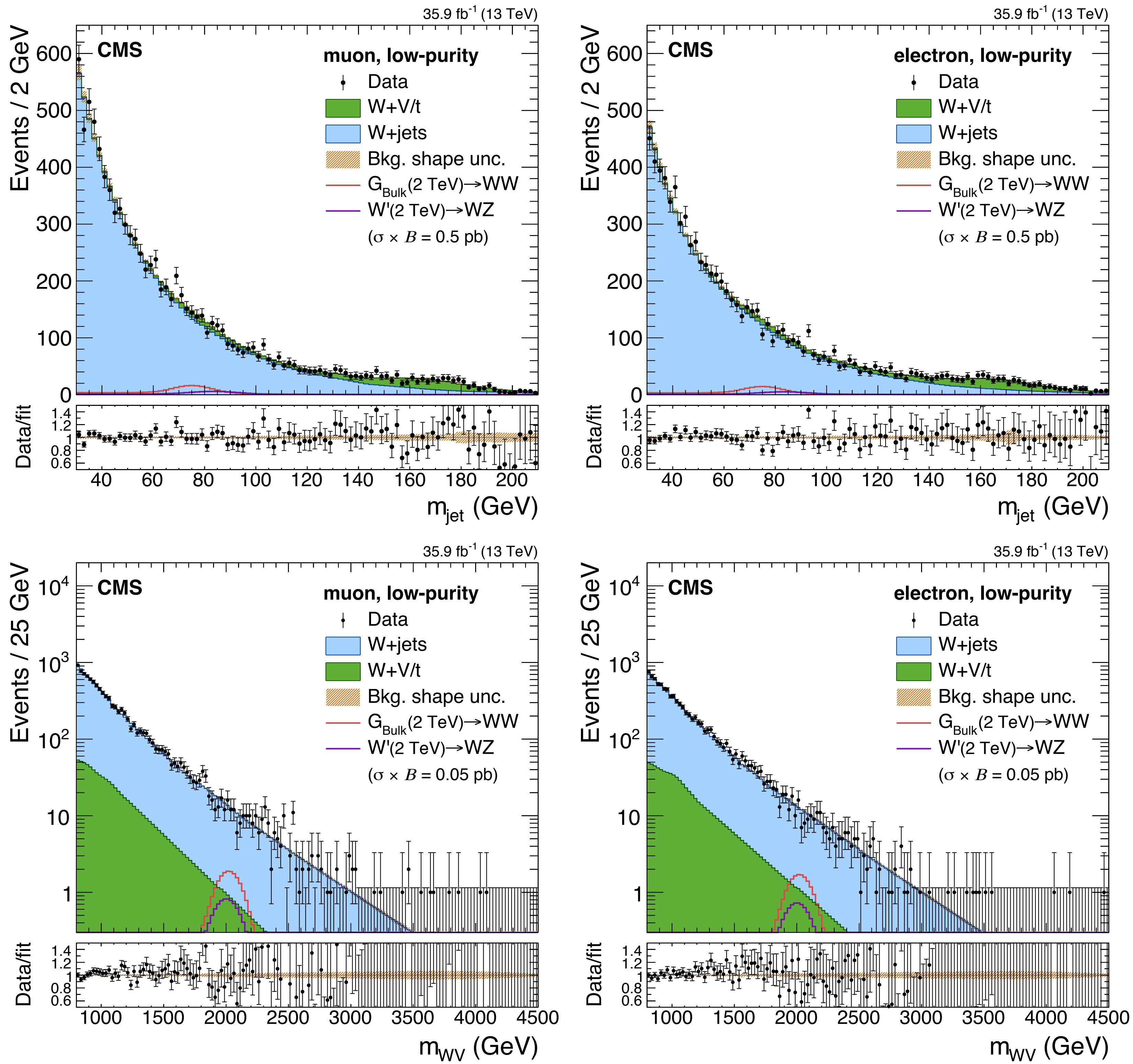
M_{WV}



Results LP

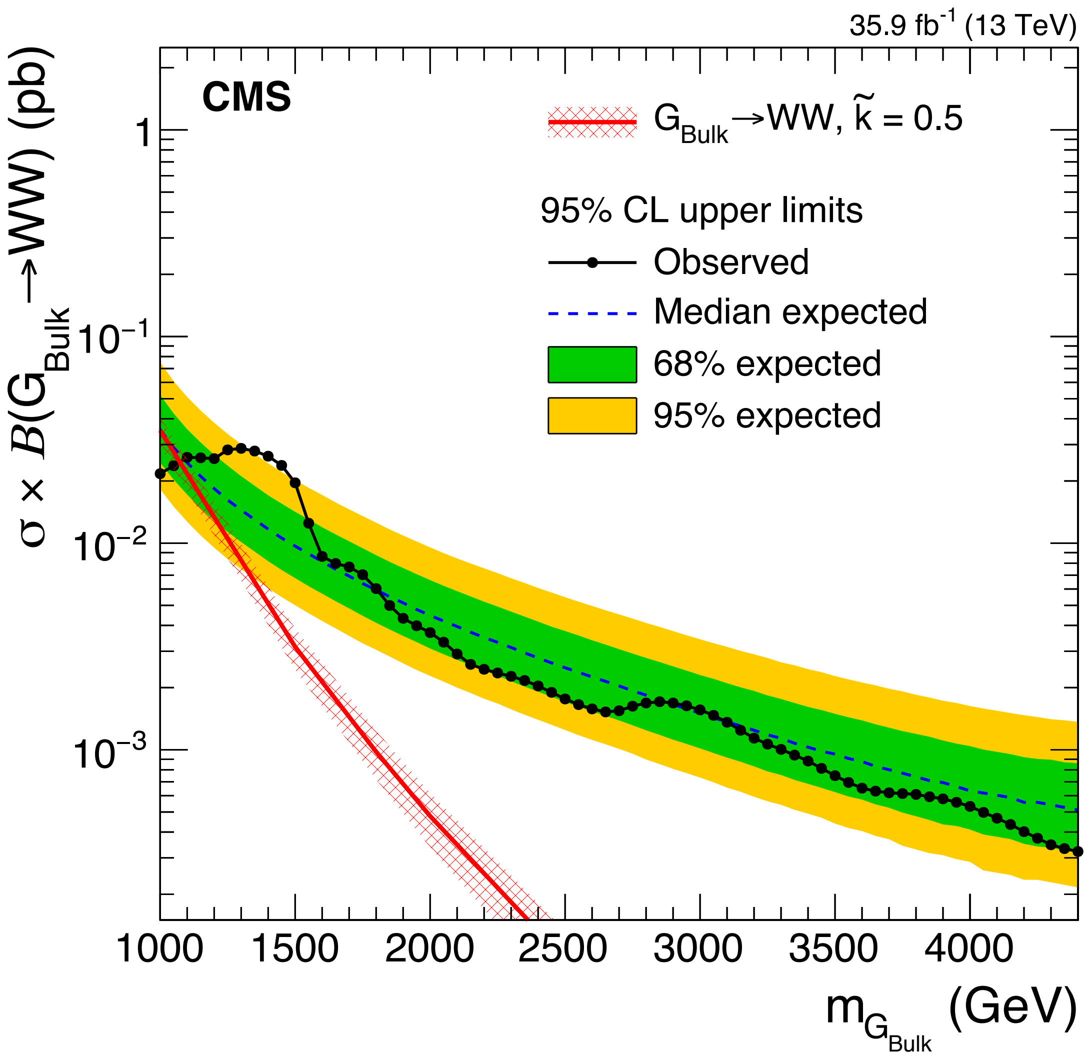
electron muon

m_{jet}

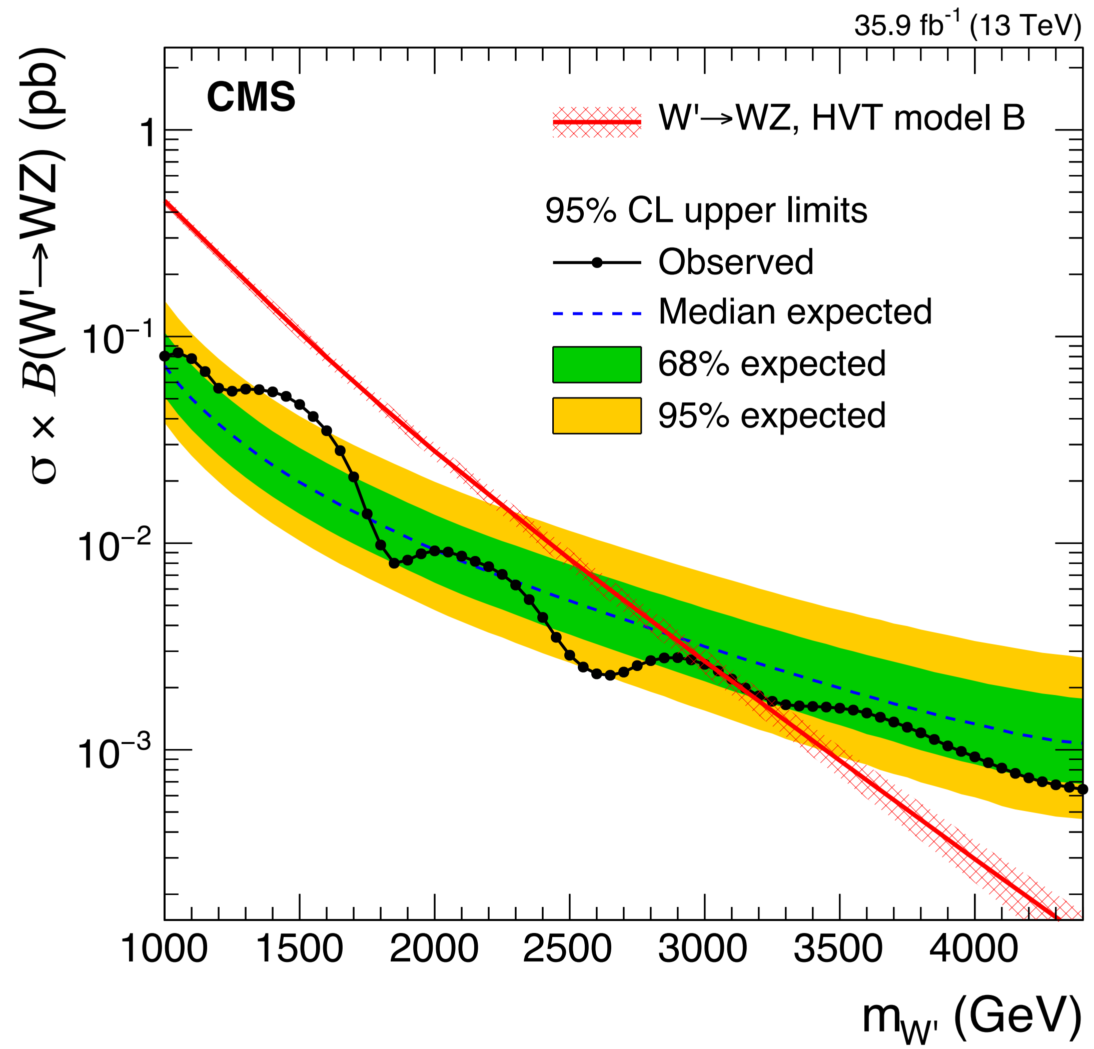


M_{WV}

Results limit



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 develepment in boosted object techniques
- [1-4.5 TeV] analysis of the $X \to WV \to l\nu J$
- New background estimation method: 2D-fit
- No significant excess.
- More data and high energy will definitely tell us more

- B2G-16-029
- 10.1007/JHEP05(2018)088

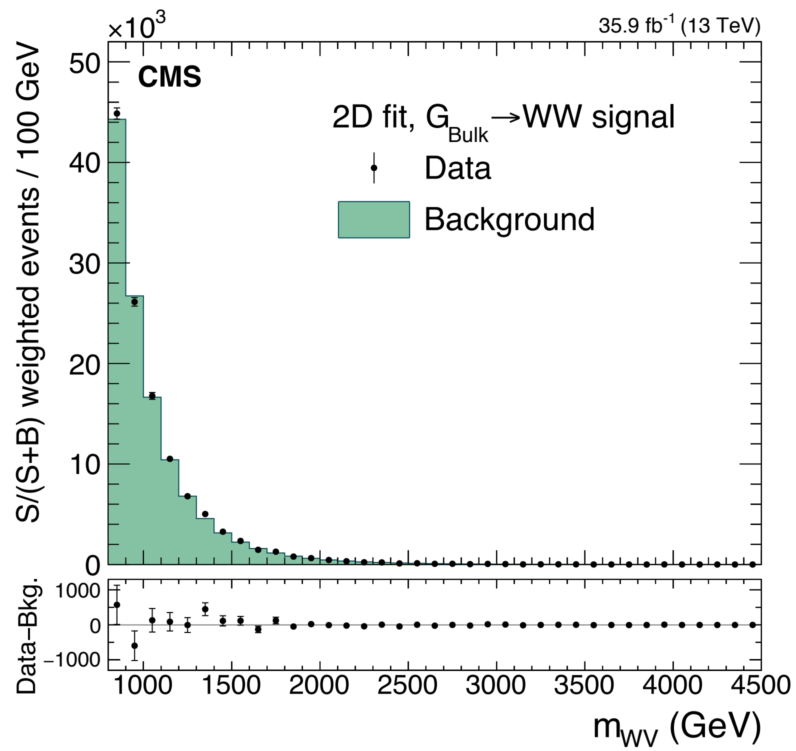
- Backup

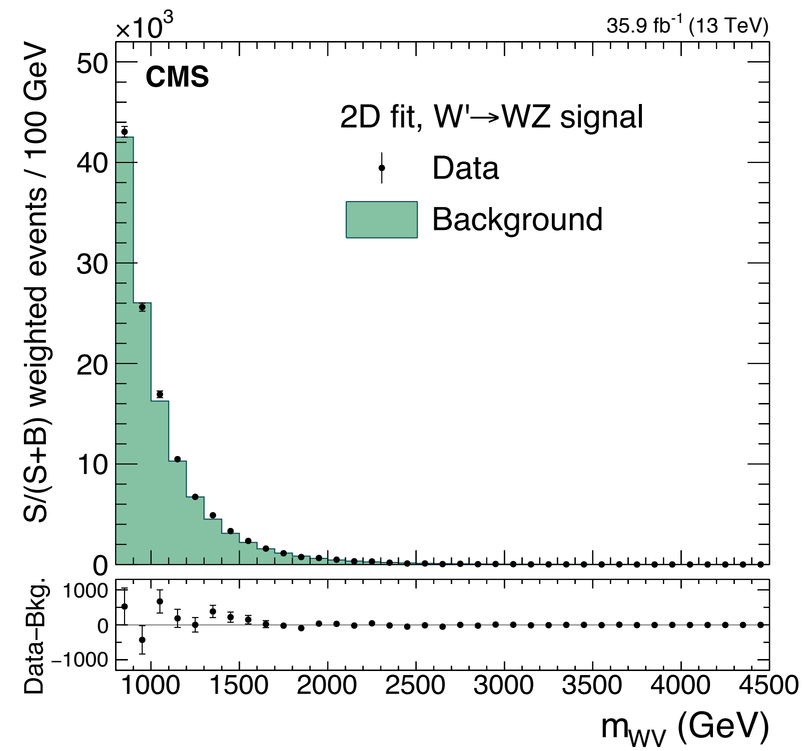
α-method vs 2D-fit S/(S+B)

BulkGraviton

Wprime

α-method





2D-fit