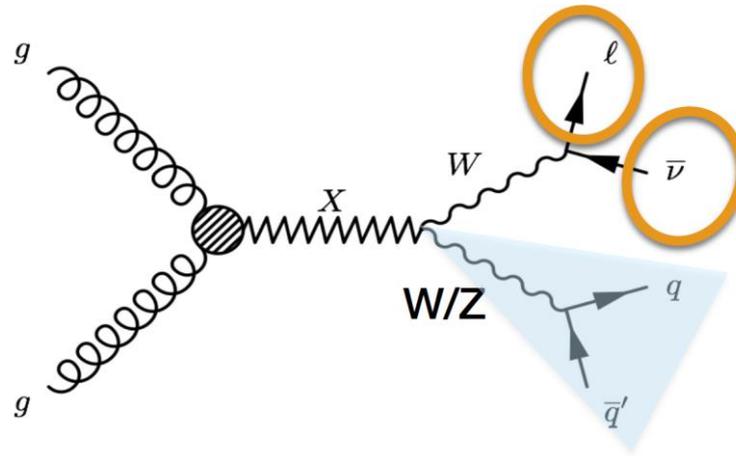




北京大学



Search for Heavy Resonances

$$X \rightarrow WV \rightarrow l\nu qq$$

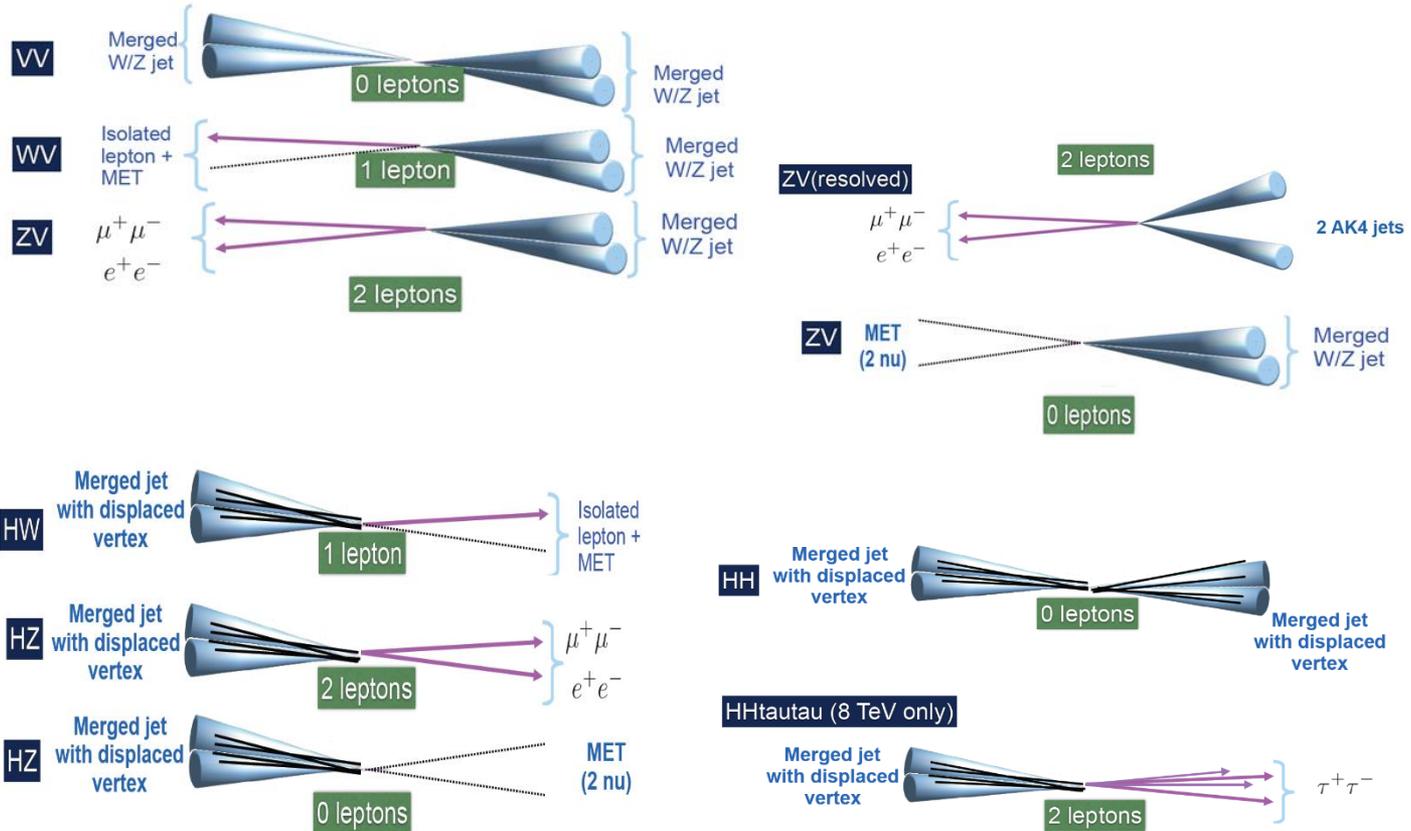
Zijun Xu

Peking University

2016 Dec

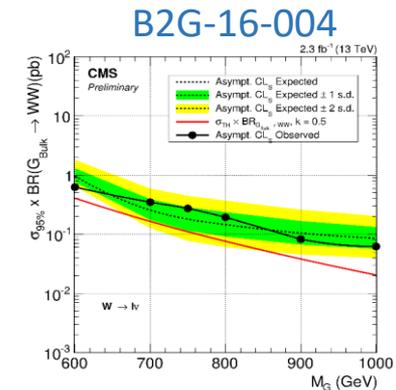
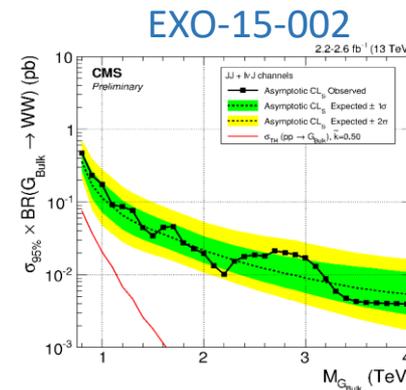
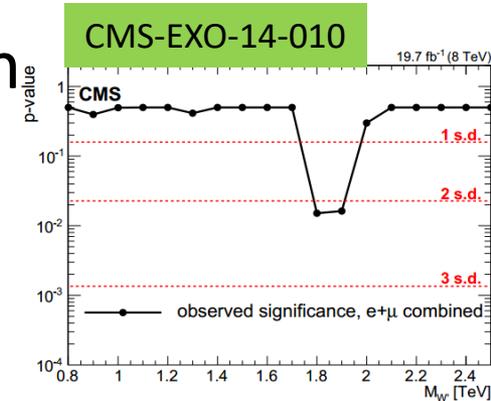
Diboson Resonance searches

Spin-0, Heavy Higgs, Radion
 Spin-1, Heavy Vector Triplet W' , Z'
 Spin-2, RS/Bulk Graviton



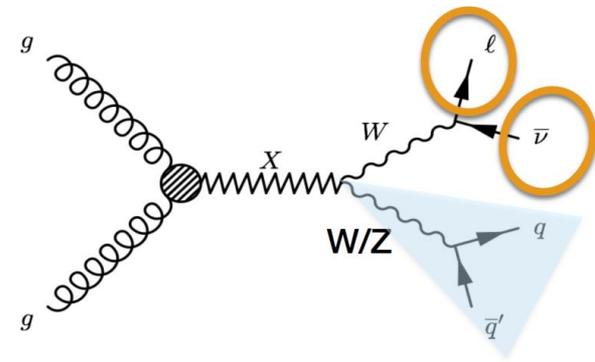
Diboson Resonance searches

- In Run1, excess of events around 2 TeV in diboson analyses
 - ATLAS: largest excess in WZ all-hadronic
 - CMS: largest excess in WH semileptonic
- From Run1 to Run2: 8 TeV \rightarrow 13 TeV
 - For 2 TeV signal, parton luminosity scaling by ~ 15
- $X \rightarrow WV \rightarrow l\nu qq$
 - 2015 data: 2.3/fb, $\sqrt{s}=13\text{TeV}$
 - EXO-15-002: 800 - 4000 GeV
 - B2G-16-004: 600 - 1000 GeV
 - **2016 data: 12.9/fb, $\sqrt{s}=13\text{TeV}$**
 - **B2G-16-020: 600 - 4500 GeV**



(<http://cds.cern.ch/record/2205880>)

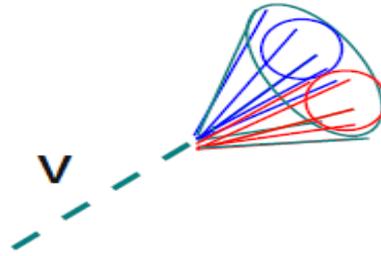
CMS B2G-16-020



- Heavy Resonance decaying to WV in the semi-leptonic final state
 - Bulk Graviton to WW to lep, MET, and Fat-Jet
 - W prime to WZ to lep, MET, and Fat-Jet
- Signal Mass coverage: 600 – 4500 GeV
 - Low mass analysis [600-1000] with M_{WV} 600-1500 GeV
 - High mass analysis (1000- 4500] with M_{WV} 0.8-5 TeV

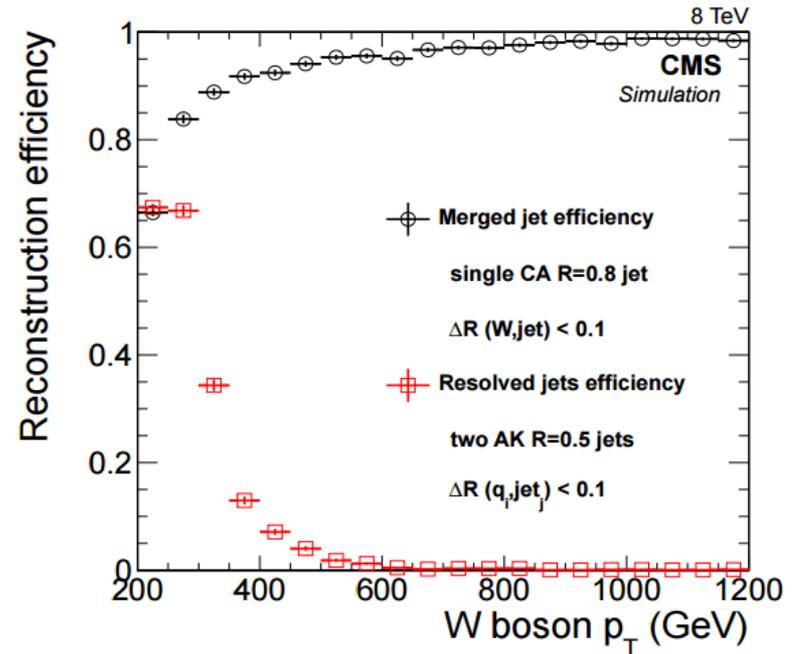
High p_T W Boson Hadronic Decay

- $\Delta R_{jj} \sim 2M_w/pT_w$



- For $p_T(W) > 200$ GeV, 1 CA8 jet is more efficient than 2 AK5 jets

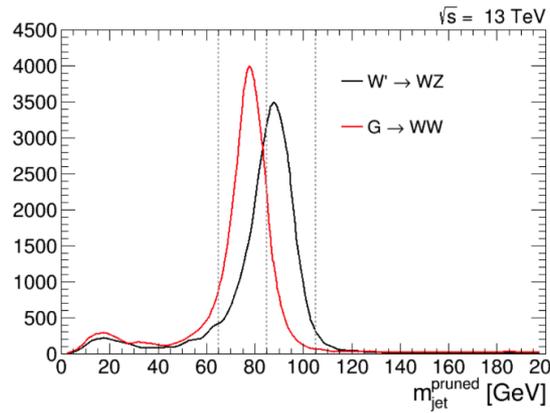
- AK5: Anti-Kt with cone=0.5
- CA8: Cambridge-Aachen with cone=0.8



W/Z Tagging

Jet pruning

- V-boson mass window
Bulk Graviton: 65-95GeV
W': 75-105GeV

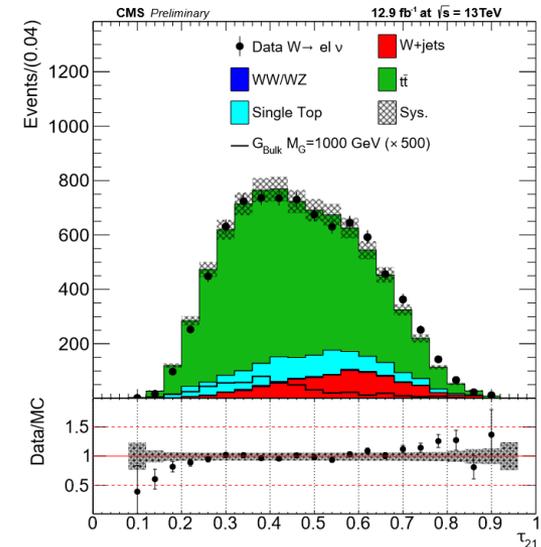
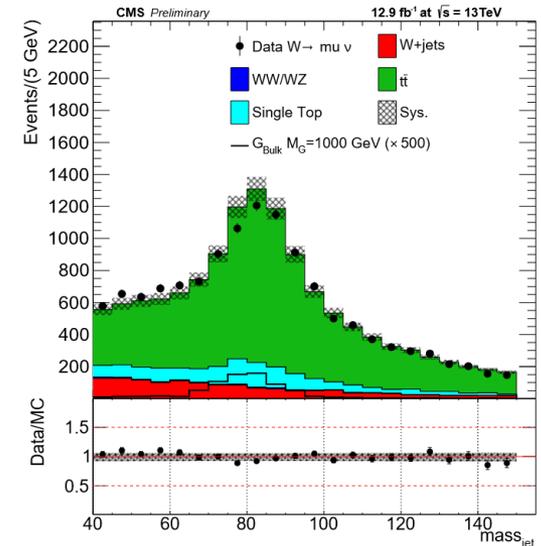


Jet substructure

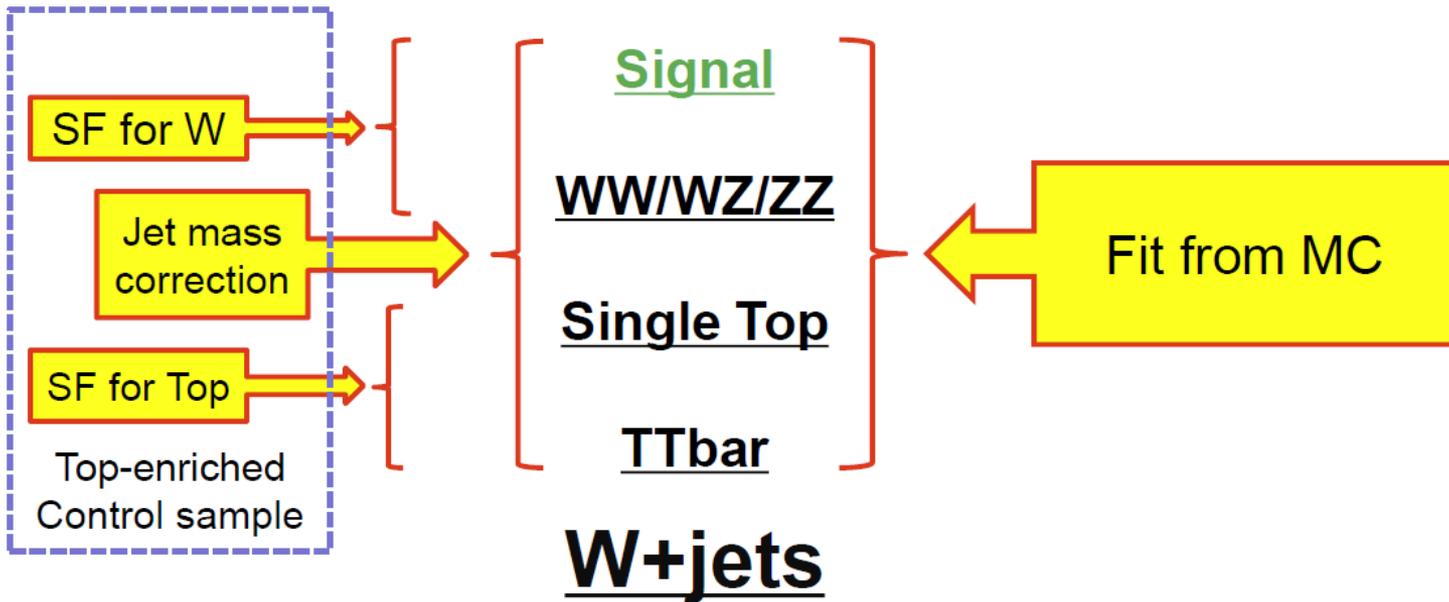
- N-subjettiness
- $\tau_{21} < 0.45$ for low Mass & $\tau_{21} < 0.6$ for high Mass

Top-Enriched Control Sample:

- Reverse the b veto selection
- The back-to-back angular selection is removed



Signal and Bkg Estimation

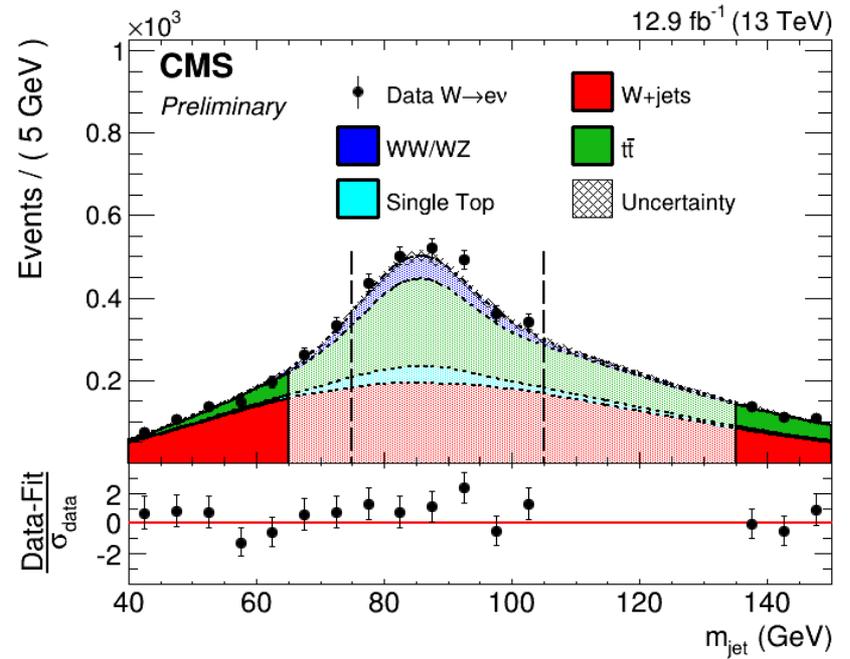
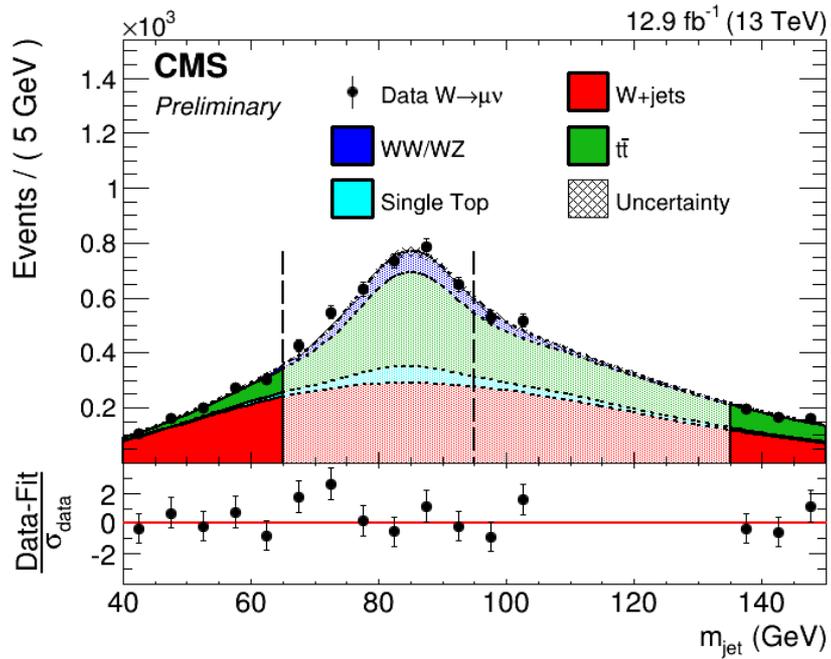


Data-driven for Dominant bkg:

- Normalization: fit m_J sideband
- Shape: $F_{\text{data,SR}}(m_{lvj}) = \alpha_{\text{MC}}(m_{lvj}) \times F_{\text{data,SB}}(m_{lvj})$

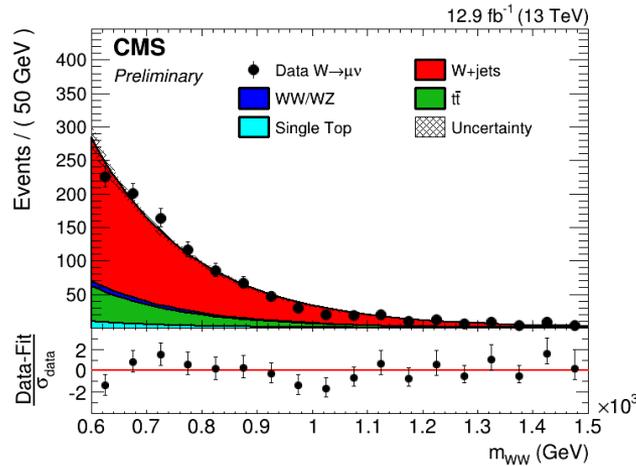
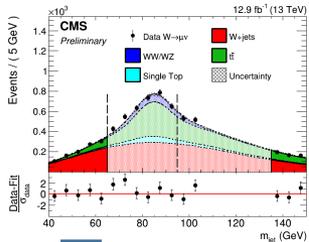
$$\alpha_{\text{MC}}(m_{lvj}) = \frac{F_{\text{MC,SR}}(m_{lvj})}{F_{\text{MC,SB}}(m_{lvj})}$$

W+Jets Norm: Fit Jet Mass in Sideband



- Fit on data in the sidebands to extract the W+jets normalization in signal region
- TTbar, VV, Single Top: Norm. and shape in Pruned jet mass from MC, and corrected by Top-enriched control region

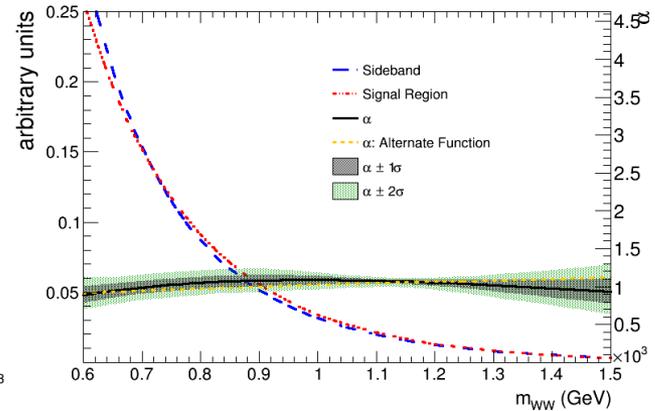
W+jets m_{WW} Shape: alpha-method



Correlation between m_{lvj} and m_j

$$\alpha_{MC}(m_{lvj}) = \frac{F_{MC,SR}(m_{lvj})}{F_{MC,SB}(m_{lvj})}$$

CMS Preliminary, 12.9 fb⁻¹ at $\sqrt{s} = 13\text{TeV}$, $W \rightarrow \mu \nu$



$$F_{\text{data,SB}}(m_{lvj}) \times \alpha_{MC}(m_{lvj}) = F_{\text{data,SR}}(m_{lvj})$$

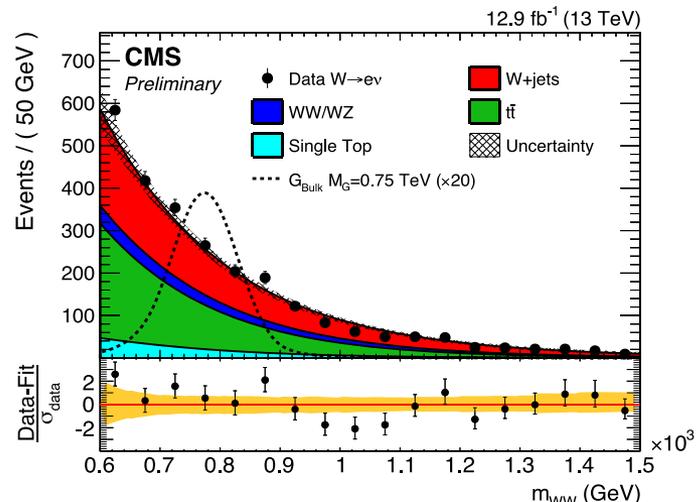
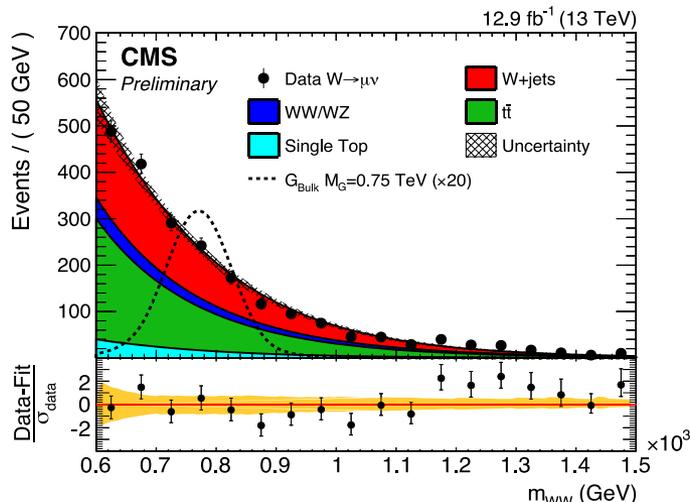
M_{WW} in Signal Region

Bulk Graviton

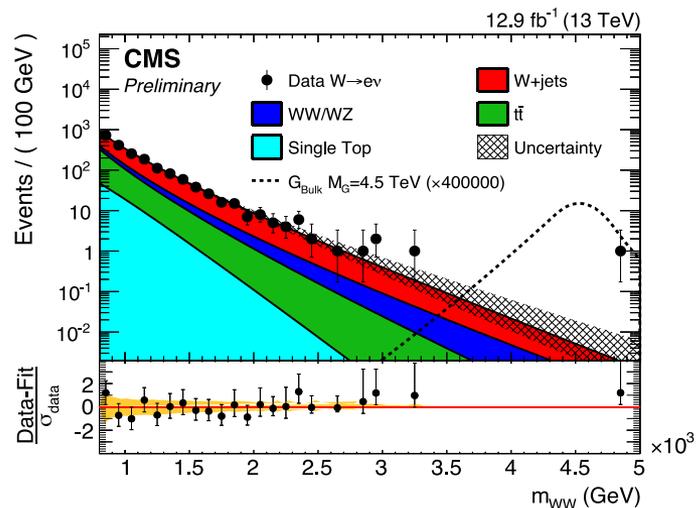
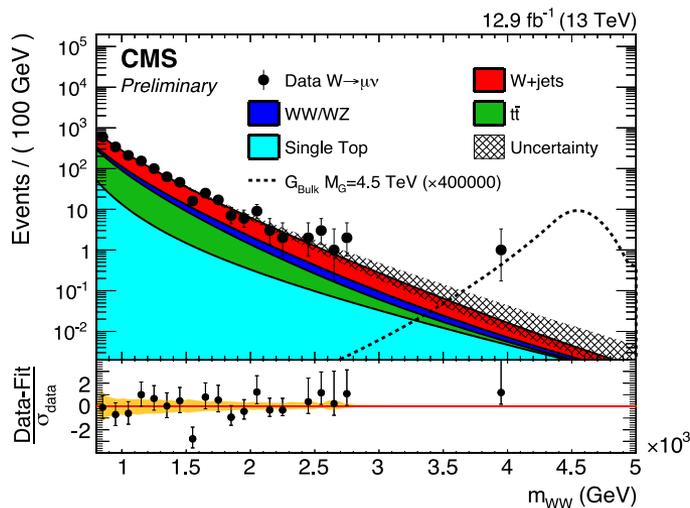
$W \rightarrow \mu\nu$

$W \rightarrow e\nu$

0.6-1.5 TeV



0.8-5 TeV



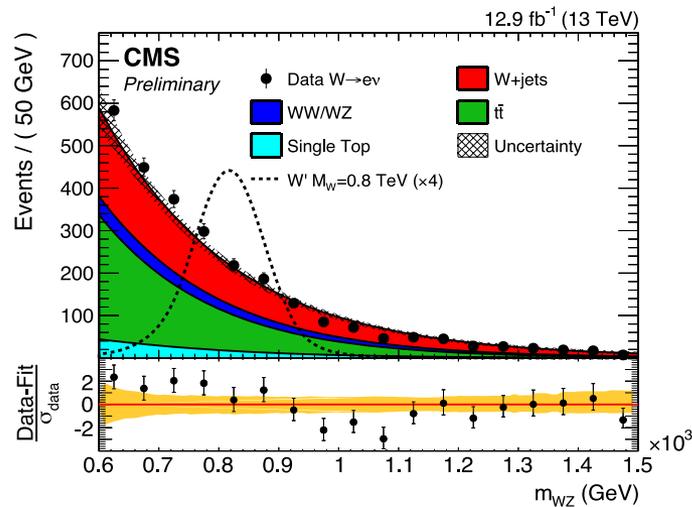
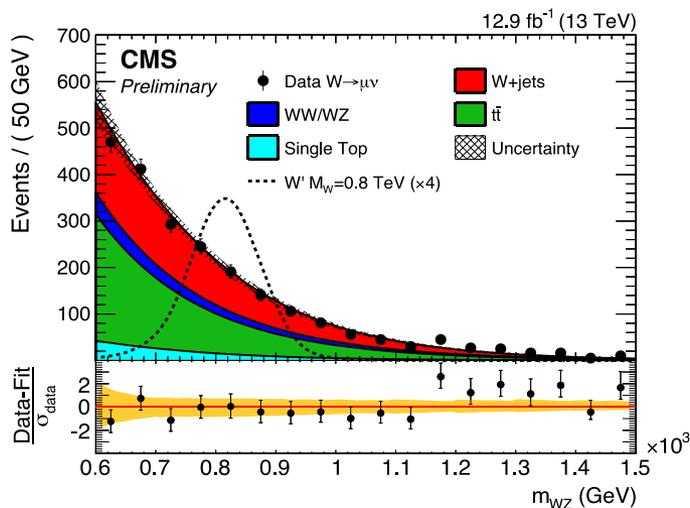
M_{WZ} in Signal Region

Wprime

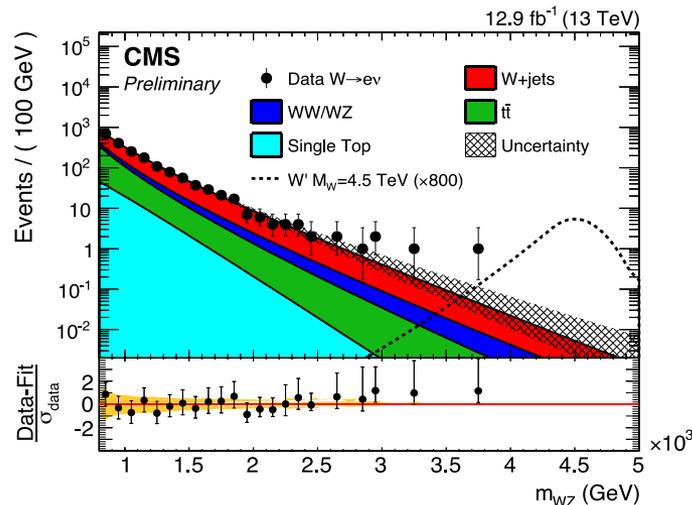
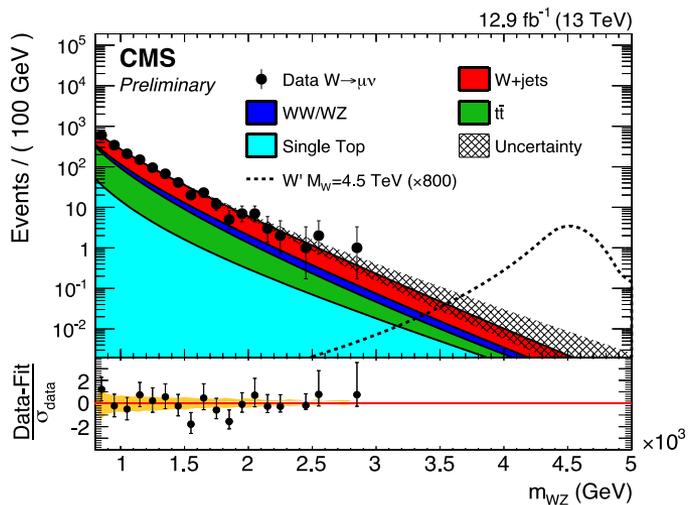
0.6-1.5TeV

$W \rightarrow \mu\nu$

$W \rightarrow e\nu$



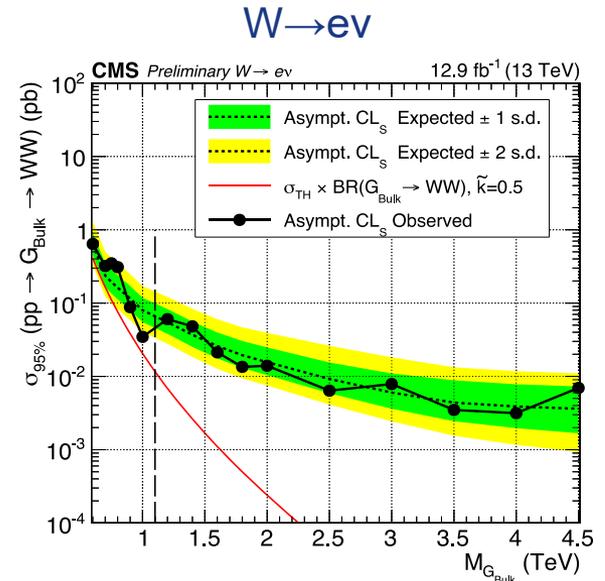
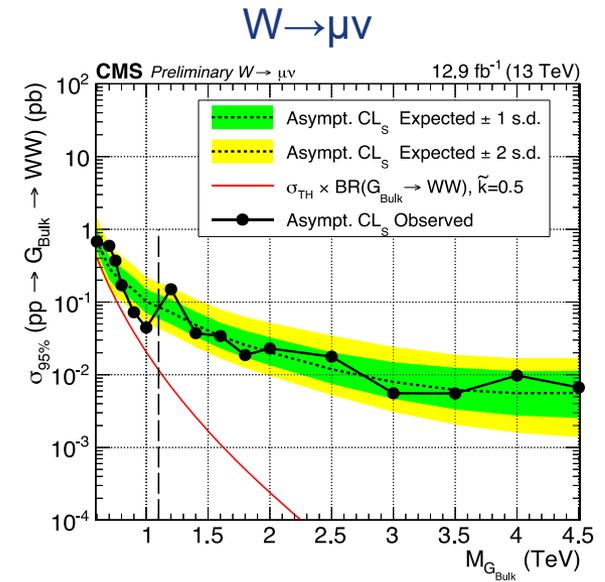
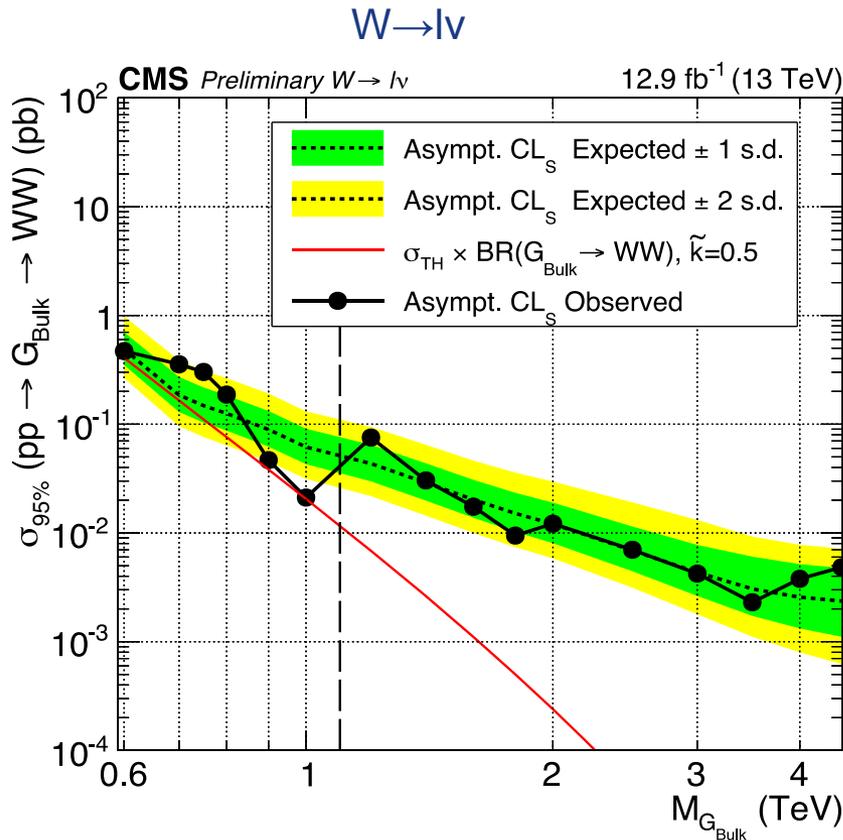
0.8-5TeV



Systematic Uncertainties

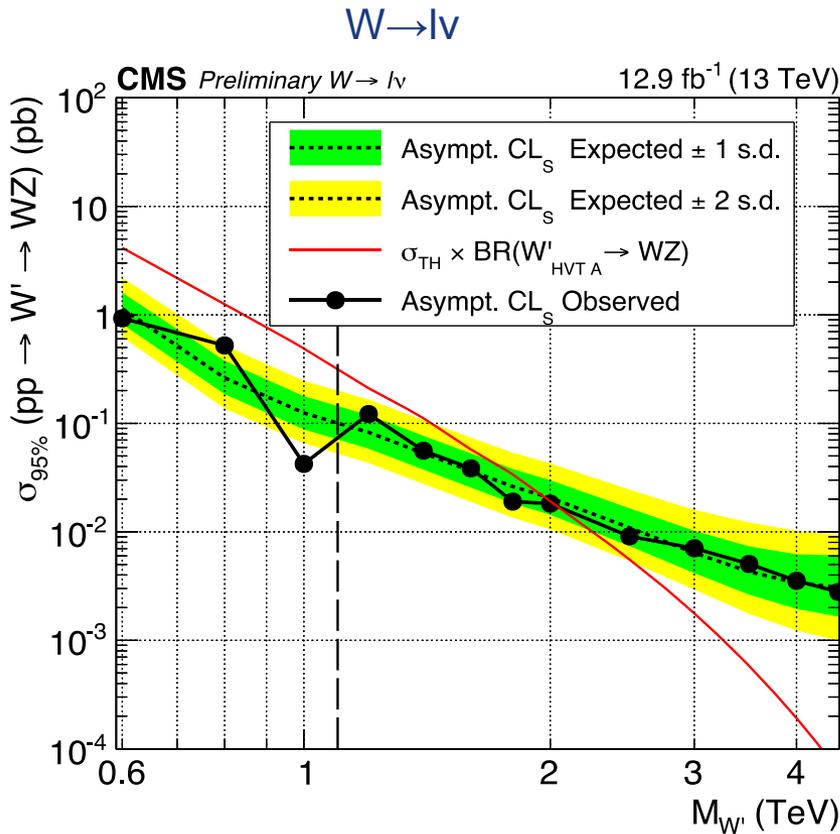
- Brief summary
 - Common terms for signal and backgrounds
 - Integrated lumi, Theory XS, lepton Trigger and ID, V-tagging
 - Signal
 - lepton energy scale/res, jet energy/mass scale/res, btagging, Scale and PDF uncertainties
 - Backgrounds
 - W+jets norm.: stat. of data in sideband, shape function, TTbar
 - W+jets shape: α and $F_{WW}(SB)$ uncertainties inflating by $\sqrt{2}$
 - TTbar and Single Top norm.: SF from Top-enriched control region

Bulk Graviton

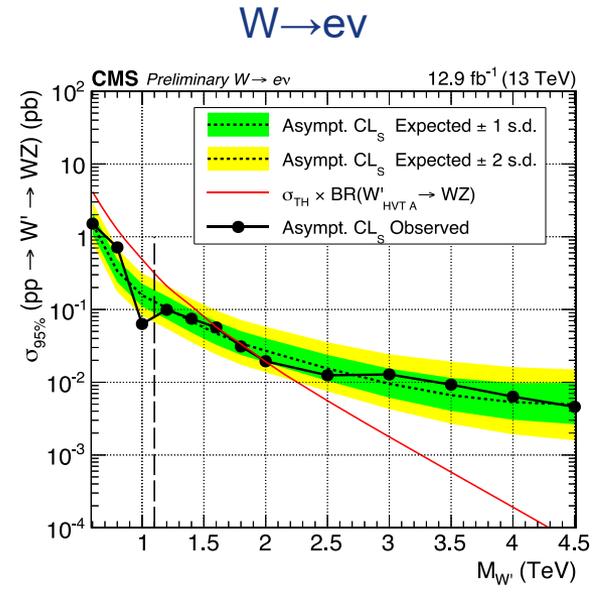
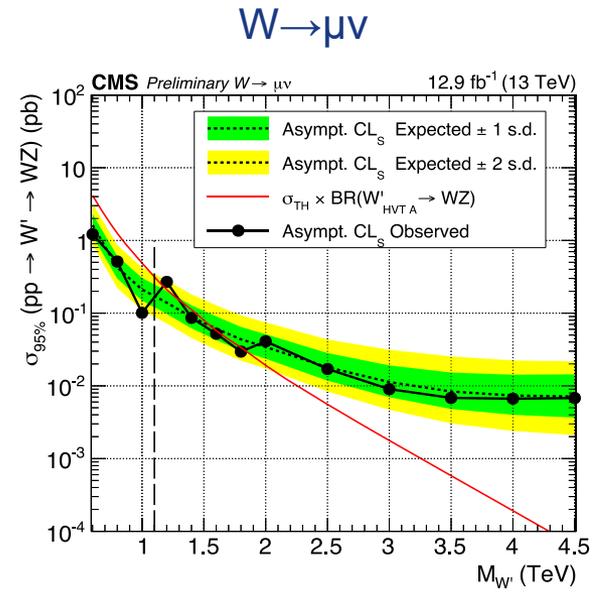


- Higgs Combination Tool and Asymptotic CLs
- No significant excess from 600 GeV to 4.5 TeV

W' HVT model A



- No significant excess from 600 GeV to 4.5 TeV
- W' is excluded by 2 TeV



Summary

- [600-4500 GeV] analysis of the $X \rightarrow WV \rightarrow l\nu J$
 - No significant excess with 12.9/fb 13TeV data
 - In the model of HVT A, we set a limit on the W' mass of 2.0 TeV
- PAS-PUB & ICHEP2016
 - B2G-16-020
- More data will definitely tell us more
 - 28/fb 13 TeV data
 - Aiming for 2017 Moriond

Incomplete List of Diboson Searches from PKU Group

CMS PAS	PKU Authors
8TeV, $H \rightarrow WW$, HIG-13-008	Z. Xu
8TeV, $X \rightarrow WW$, EXO-12-021	S. Liu, Z. Xu
8TeV, $X \rightarrow WH$, EXO-14-010	M. Wang, Z. Xu
13TeV, $X \rightarrow WV$, EXO-15-002	Q. Wang, Z. Xu
13TeV, $X \rightarrow WW$, B2G-16-004	Q. Wang, H. Huang, Z. Xu
13TeV, $X \rightarrow WV$, B2G-16-020	H. Huang, Z. Xu

Shuai Liu(2010)



PhD

Mengmeng Wang(2011)



PhD

Qun Wang(2013)



PhD
Candidate

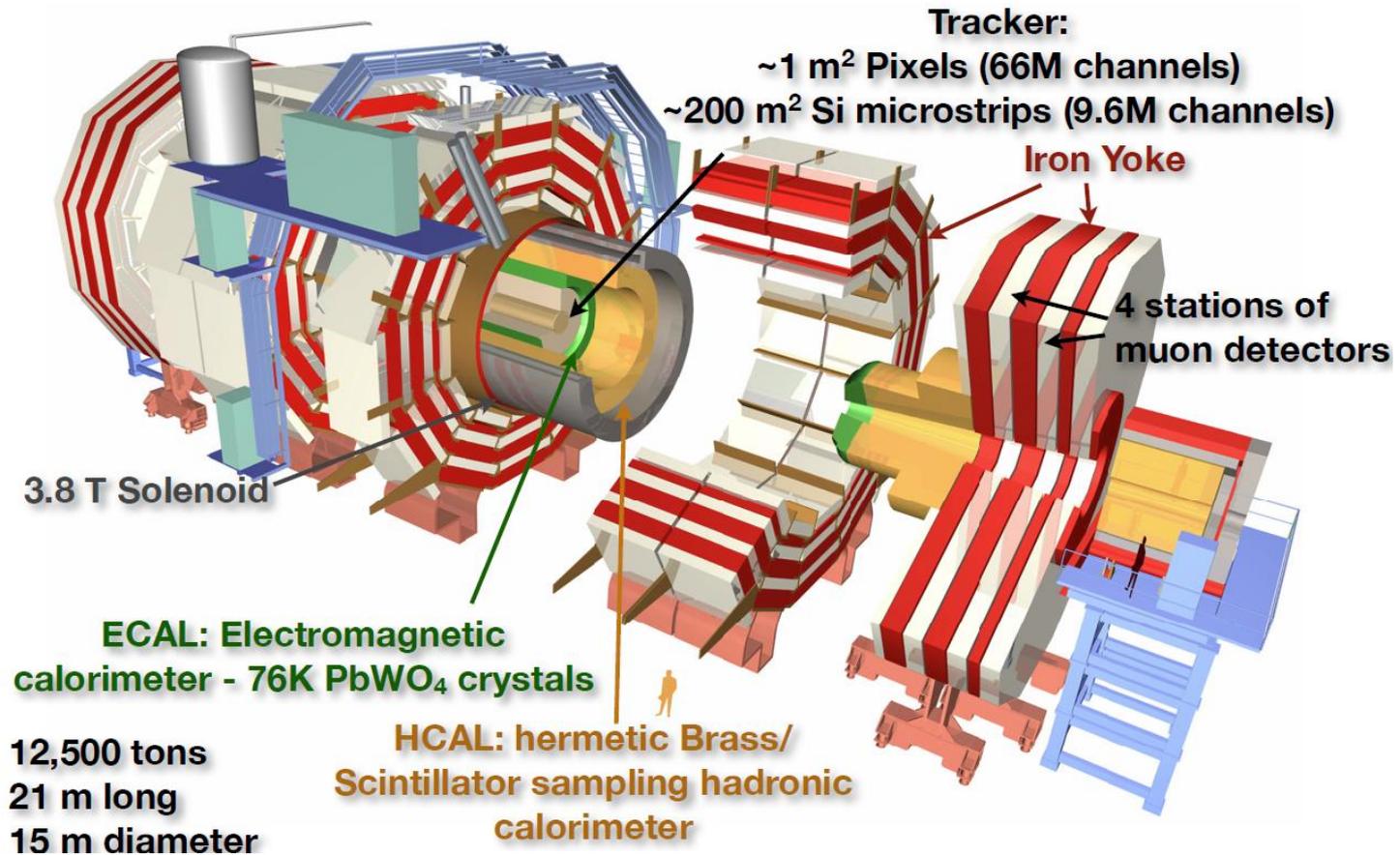
Huang Huang(2014)



PhD
Candidate

Backup

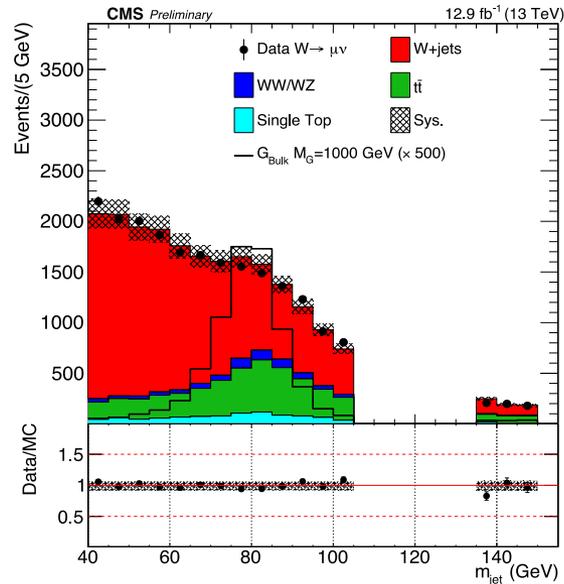
THE COMPACT MUON SOLENOID



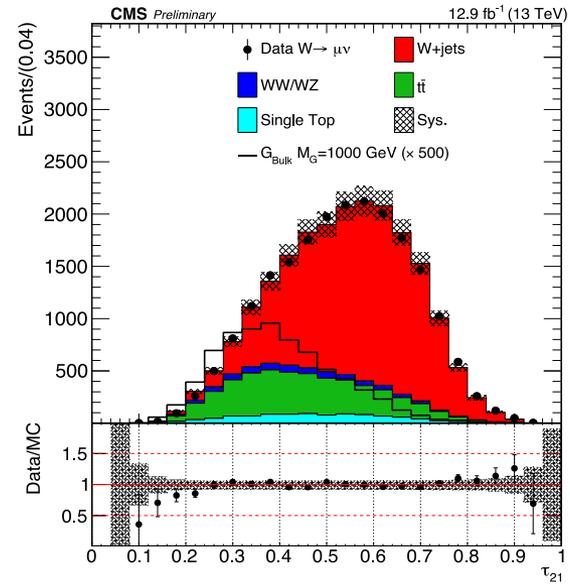
Data/MC Comparison

muon

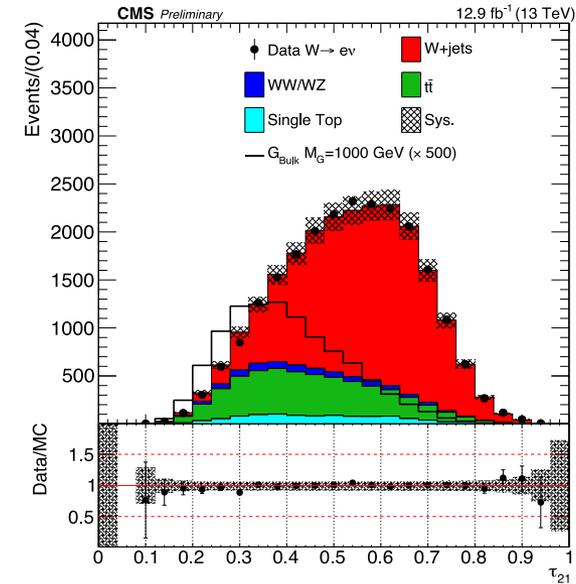
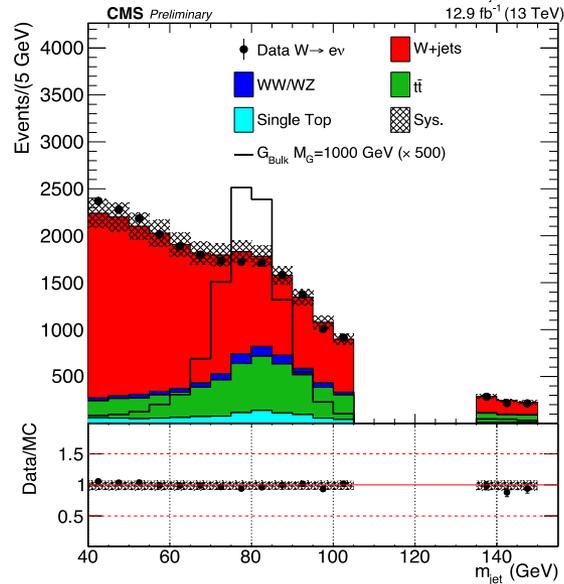
Pruned jet mass



tau21

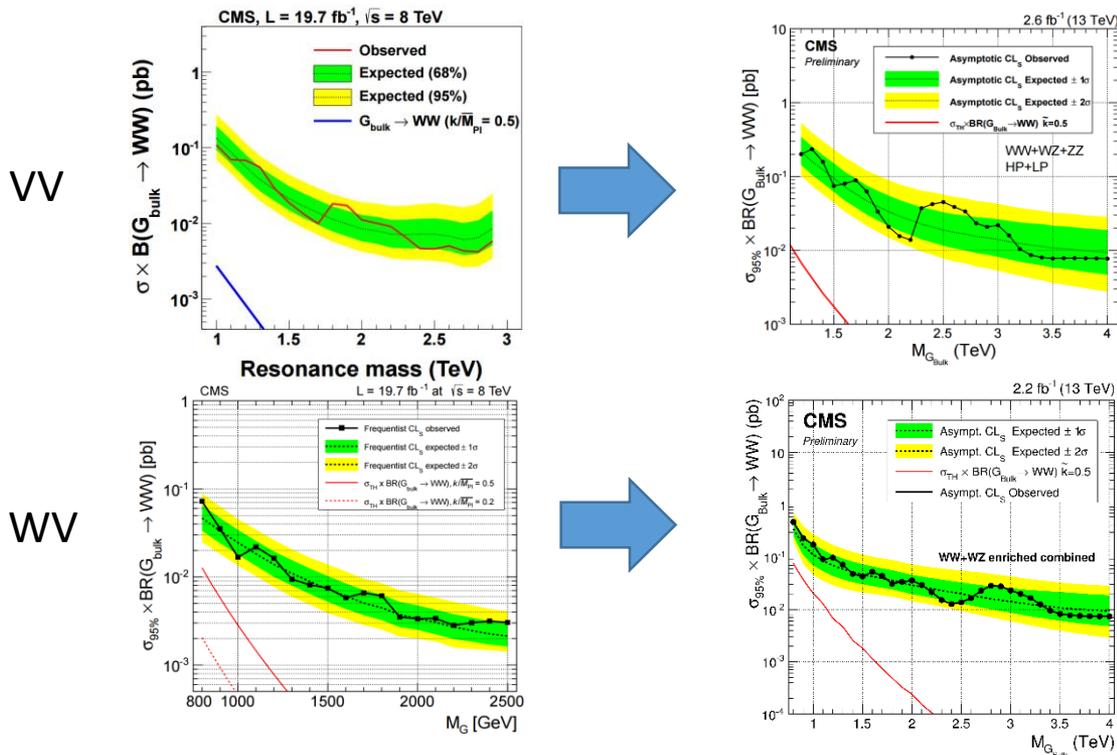


electron



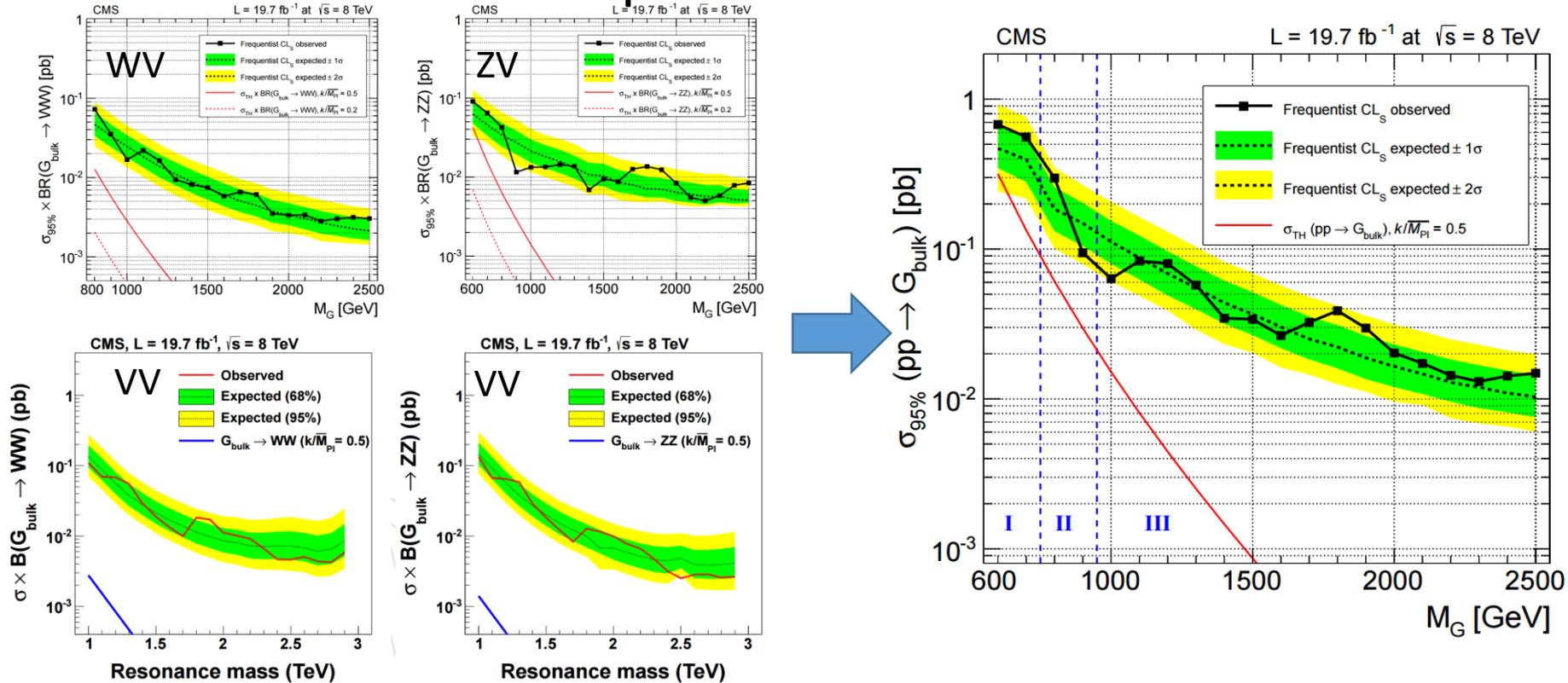
CMS Run1 \rightarrow Run2

- Sensitivity higher for 13 TeV analysis due to parton luminosity and cut optimizations
- New for 13 TeV: Sensitivity improved when splitting into W/Z mass categories



CMS Run1: VV+WV+ZV

- No significant excesses observed combining all-hadronic and semileptonic channels



Results Publication

- **PAS-PUB**
- [CMS Collaboration, “Search for new resonances decaying to \$WW/WZ \rightarrow \ell\nu qq\$ ”, CMS Physics Analysis Summary CMS-PAS-B2G-16-020, 2016.](#)
- **ICHEP2016**
- <http://indico.cern.ch/event/432527/contributions/2207066/>

Search for new resonances involving Higgs, W or Z boson at CMS (15' + 5')

🕒 5 Aug 2016, 15:10
📍 Chicago 7 ()

Oral Presentation

Beyond the Standard ...

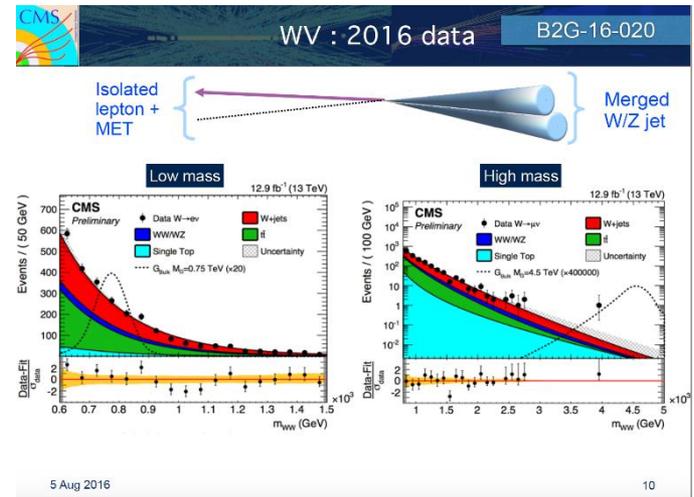
Beyond the Standard Mo...

Speaker

👤 Salvatore Rappoccio (State University of N...)

Description

Beyond the standard model theories like composite Higgs models predict resonances with large branching fractions in a Higgs boson and a vector boson with negligible branching fractions to light fermions. We present an overview of searches for new physics containing a Higgs boson and a W or Z boson in the final state, using proton-proton collision data collected with the CMS detector at the CERN LHC. For high-mass resonances decaying to intermediate bosons, the large boost for hadronic decays gives rise to one single "merged" jet, which can be identified through a study of its substructure consistent with the presence of two quarks, enhancing the sensitivity due to the large branching ratios for hadronic decays. B-quark identification algorithms are used in addition to identify the hadronic H decays.



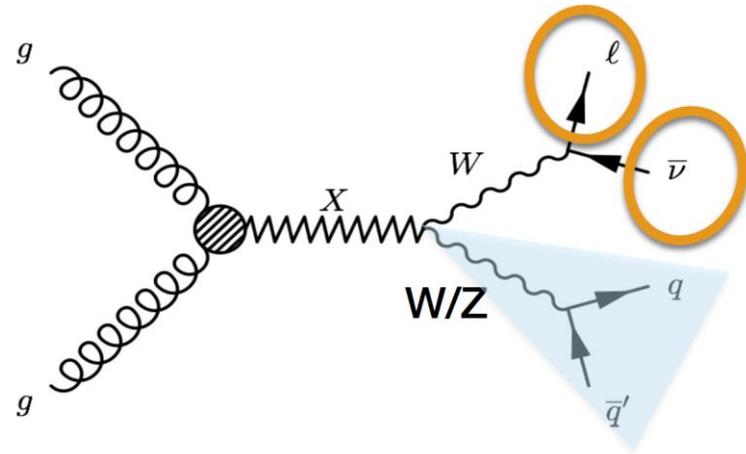
Samples and Pre-selections

- Data: 12.9/fb (2016)
- Signal
 - Bulk Graviton
 - Wprime
- Backgrounds
 - W+Jets
 - TTbar
 - Single Top
 - WW/WZ/ZZ

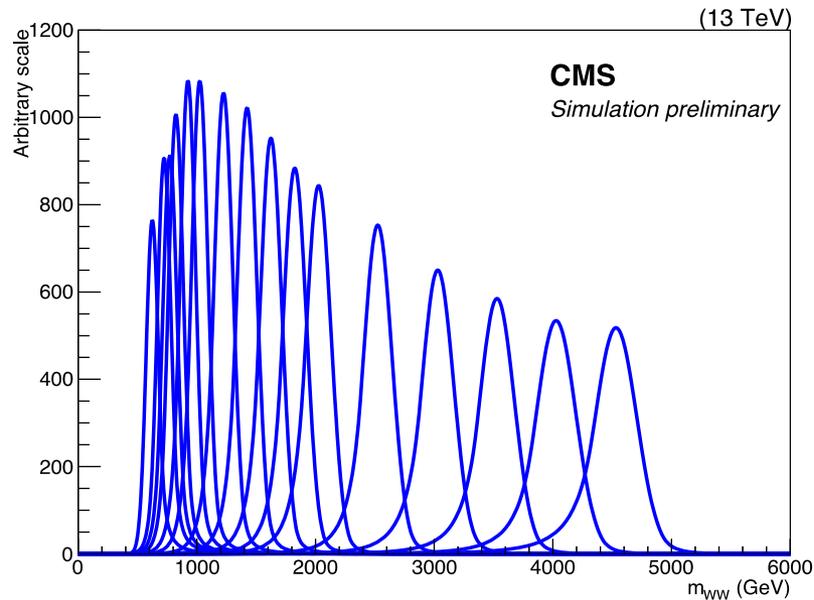
Muon channel
<ul style="list-style-type: none"> • Tight muon: $p_T > 50 \text{ GeV}$, $\eta < 2.1$, • Loose muon (for veto): $p_T > 20 \text{ GeV}$, $\eta < 2.4$ • Missing $E_T > 40 \text{ GeV}$ (type I) • Transverse mass $> 40 \text{ GeV}$
Electron channel
<ul style="list-style-type: none"> • Tight electron: $p_T > 55 \text{ GeV}$ • Loose electron: Veto ID • Missing $E_T > 80 \text{ GeV}$ (type I)
Both channels
Noise cleaning filters AK8 jets, $p_T > 200 \text{ GeV}$, Loose ID AK4 jets (for b-veto), Loose ID Leptonic W $p_T > 200 \text{ GeV}$
$\Delta R(l, W_{\text{had}}) > \pi/2$ $\Delta R(W_{\text{had}}, W_{\text{lep}}) > 2$ $\Delta R(W_{\text{had}}, \text{missing } E_T) > 2$

Analysis Selection

- Leptonic W
 - one charged Lepton
 - Loose lepton veto
 - Large Missing transverse energy: 80(40) GeV for Ele(Mu) channel
 - Leptonic W $p_T > 200$ GeV
- Hadronic W/Z
 - Leading AK8 jet $p_T > 200$ GeV
 - B-tag veto to reduce $T\bar{T}$ and Single Top backgrounds
 - Tau21 0.45(0.60) for low(high) mass analysis
 - Jet mass windows [65-95] for W, [75-105] for Z
- Angular selections for a back-to-back diboson event
 - $\Delta R(\ell, W_{\text{had}}) > \pi/2$
 - $\Delta\phi(W_{\text{had}}, E_T^{\text{miss}}) > 2$
 - $\Delta\phi(W_{\text{had}}, W_{\text{lep}}) > 2$
- Noise Filters from the MET POG



Signal Modeling



Double CB

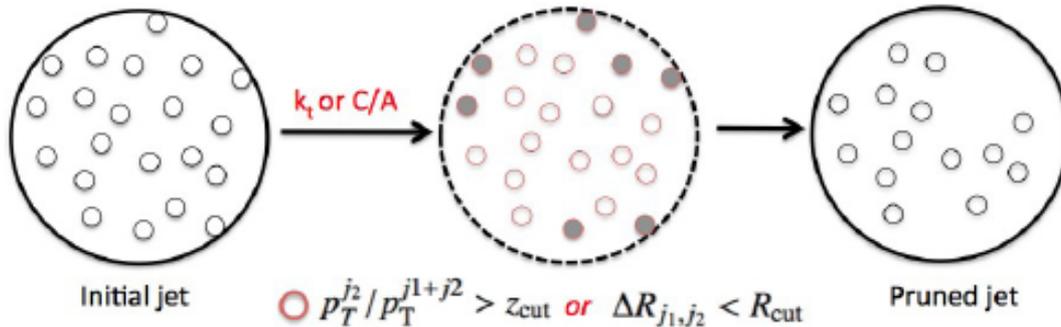
The area of each shape is proportional to the total signal efficiency of the corresponding mass point

- Signal mass from 600 GeV to 4.5 TeV
- Bulk Graviton ($k=0.5$) for WW analysis
- Wprime HVT model A for WZ analysis
- Signal shape is modeled with double Crystal-Ball function

Analysis Strategy

- “Pruning” <http://arxiv.org/abs/0912.0033> (S. Ellis, C. Vermilion, J. Walsh)

- Recombine jet constituents with C/A or kt while vetoing wide angle (R_{cut}) and softer (Z_{cut}) constituents. Does not recreate subjects but prunes at each point in jet reconstruction



Tuned parameters:
 R_{cut} and Z_{cut}

α and z_{cut} are 0.5 and 0.1,

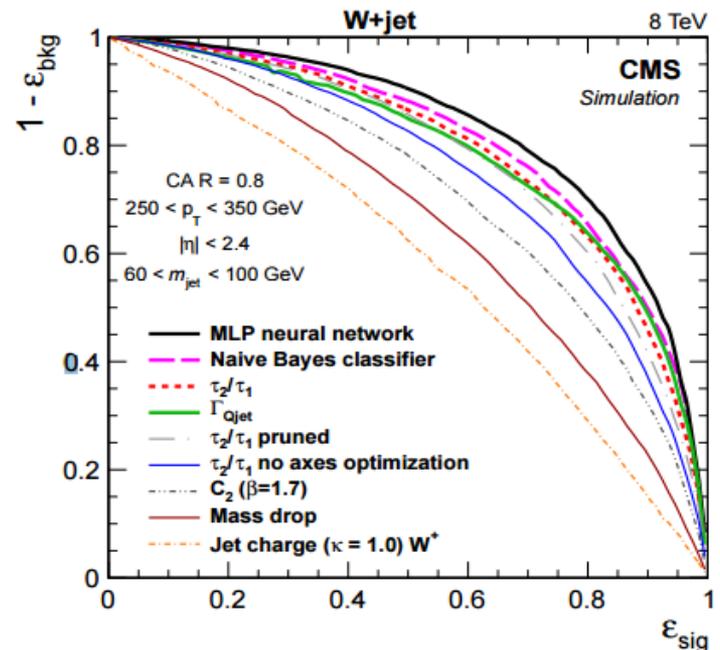
N-subjettiness (arXiv:1011.2268):

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



W-Tagging

High purity



tau21 0.45: 0.81 ± 0.2
0.6: 0.83 ± 0.1

tau21 0.45: 0.976 ± 0.048
0.6: 1.002 ± 0.018

The **Top scale factors** are just derived by DATA/MC in the signal region.

Consider the TTbar made of 'real' W and 'combinatorial'

Cut count method: $Sf_{top} = N_{data}/N_{MC}$
(minor background contribution negligible)

Background(s-top/ WW/ W+jets) are taken from MC

Simultaneous fit data and MC in PASS & FAIL to get SF

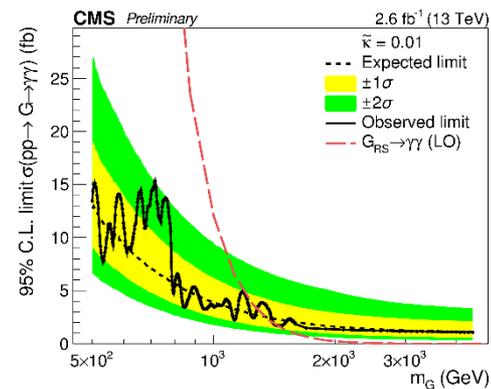
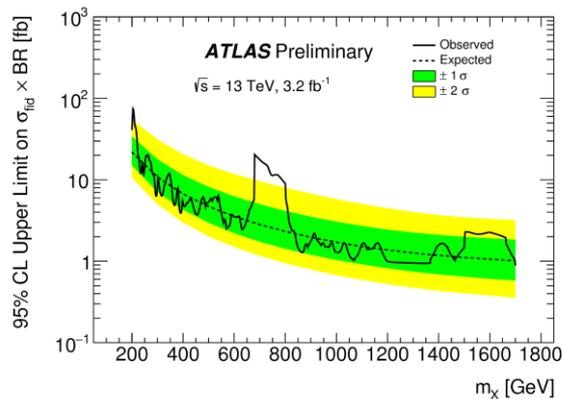
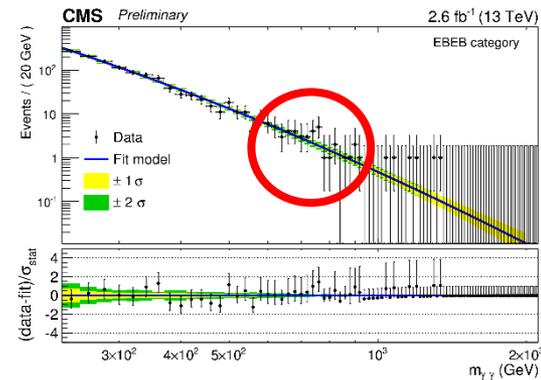
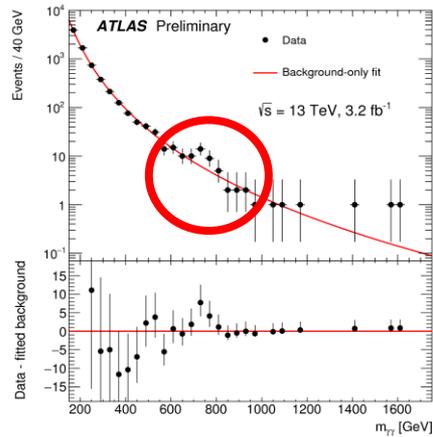
Mass peak shift

Peak shape	Mass[GeV]	σ [GeV]
Data	84.9 ± 0.2	7.9 ± 0.2
MC	83.8 ± 0.2	7.5 ± 0.2

CMS Collaboration, "Identification techniques for highly boosted W bosons that decay into hadrons", JHEP 12 (2014) 017, [doi:10.1007/JHEP12\(2014\)017](https://doi.org/10.1007/JHEP12(2014)017), [arXiv:1410.4227](https://arxiv.org/abs/1410.4227).

750 GeV Mania

- Diphoton resonance search at CERN 2015 Jamboree



ATLAS-CONF-2015-081

3.6 σ local, 2.0 σ global

CMS-EXO-15-004

2.6 σ local, <1.2 σ global

Systematic Uncertainties

- the general and jet-specific uncertainties, respectively, for this analysis

signal

Source	Effect	$\mu\nu$ +jet uncertainty	$e\nu$ +jet uncertainty
Lepton trigger	Yield	5%	5%
Lepton identification	Yield	5%	5%
b tag	Yield		0.6%
Jet energy scale	Yield		[1-2]%
Jet energy scale	Shape (mean)		1.3%
Jet energy scale	Shape (width)		[2%-3%]
Jet mass scale	Yield		[1-4]%
Jet mass resolution	Yield		[0.1-2]%
Jet energy resolution	Yield		<0.1%
Jet energy resolution	Shape (mean)		0.1%
Jet energy resolution	Shape (width)		4%
Integrated luminosity	Yield		6.2%
W' PDF	Yield		[5-30]%
W' Scale	Yield		[1-15]%
Bulk graviton PDF	Yield		[10-100]%
Bulk graviton Scale	Yield		[10-25]%
V tagging τ_{21}	Yield		5%

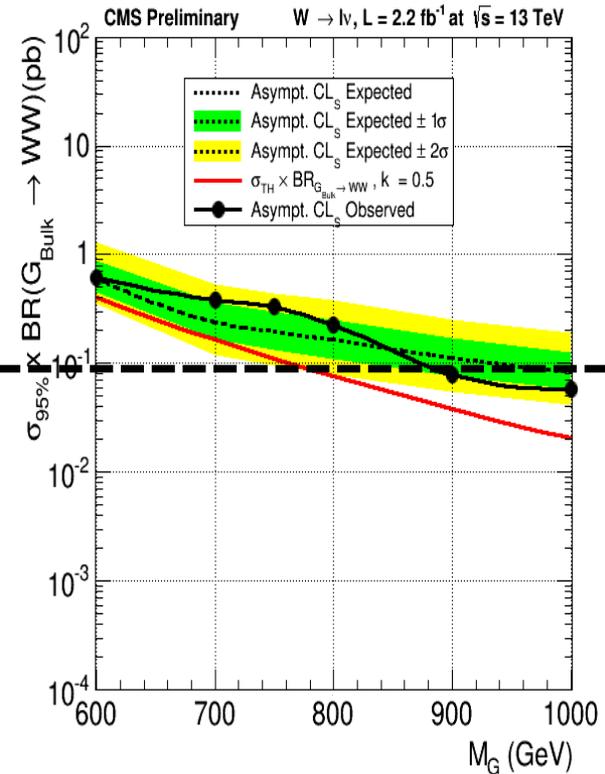
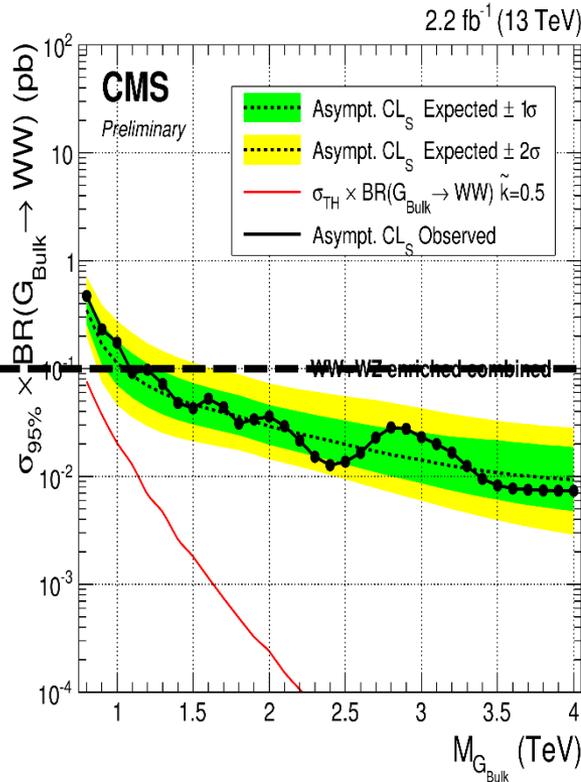
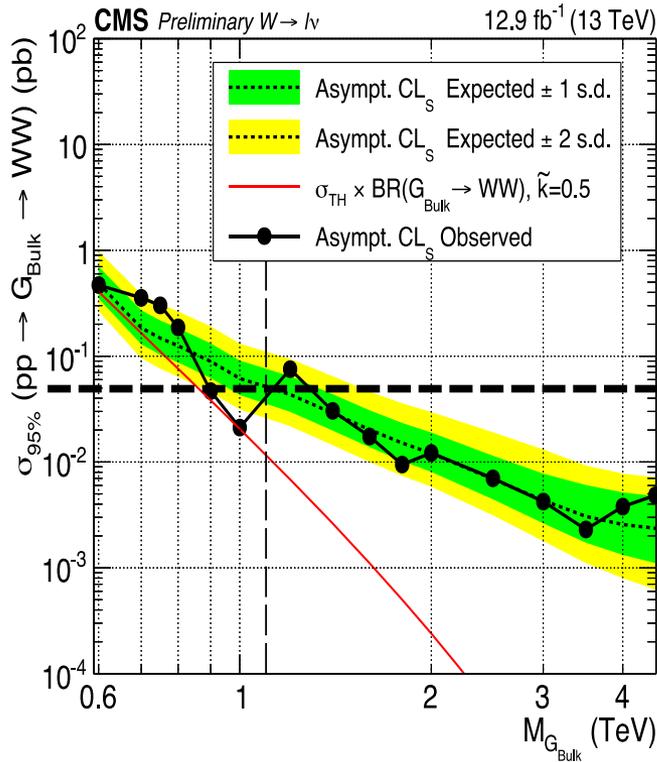
Background

Source	$\mu\nu$ +jet uncertainty	$e\nu$ +jet uncertainty
Lepton trigger	5%	5%
Lepton identification	5%	5%
Integrated luminosity		6.2%
Diboson cross section		20%
$t\bar{t}$ and single top normalization		2%
W+jets normalization, low (high) mass	5%(4%)	5%(3.5%)
Single top b tag		5%
$t\bar{t}$ b tag		6%
Diboson b tag		0.6%
V tagging τ_{21}		5%

Comparisons

High Mass Analysis EXO-15-002

Low Mass Analysis B2G-16-004



- Better sensitivity than EXO-15-002
- Better sensitivity than B2G-16-004 for the 1 TeV mass point (not add BR)
- Larger statistics, low W-tagging uncertainty error,

Aiming for 2017 Moriond

- **Lumi:** $12.9\text{fb}^{-1} \rightarrow 27.66\text{fb}^{-1}$
- Promptreco \rightarrow Rereco
- Higher **Pileup:** CHS+pruning \rightarrow PUPPI+softdrop
- **Jet Mass** Low sideband: $40\text{GeV} \rightarrow 30\text{GeV}$ or lower
- **Single** Mass Window \rightarrow W+Z Mass Window **combine**
- **HP+LP combine**
- **HLT**
- Tighten Mu **Iso** cut to suppress QCD instead of applying MT
- **ID:** Tight ID (Cut based) \rightarrow HighpT/HEEP ID?