Search for Diboson Resonance in the semi-leptonic final state(lvqq) at $\sqrt{s}$ =13 TeV

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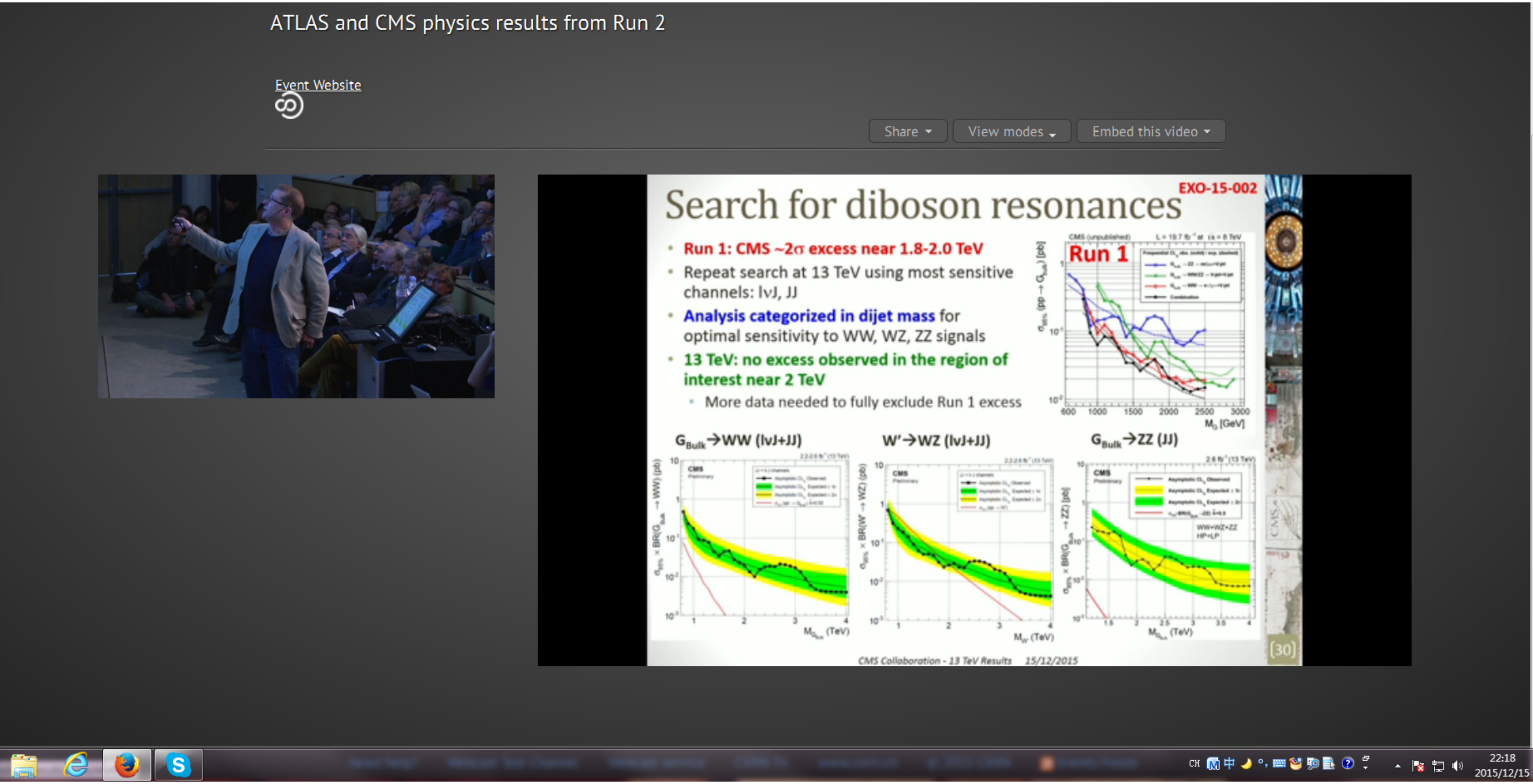
2015/12/20

Results Publication

p1



Outline

- Introduction
- Pre-selection
- Control plots
- V-tagger validation
- Background estimation
- Systematic uncertainties
- Final limit

Motivation for Diboson Search

Beyond Standard Model

- Many unification attempts

  Hierarchy problem

  - Why is gravity so much weaker?

Motivate the existence of heavy EXOTIC resonances

	Channel	Models
EXOTIC resonance X→ Diboson	WW	Spin-0 Radion Spin-1 HVT (neutral) Spin-2 **Bulk Graviton**¶
	WZ	Spin-1 **HVT** ¶ (charged)
	ZZ	Spin-0 Radion Spin-2 **Bulk Graviton** ¶

Samples and Preselections

Background samples

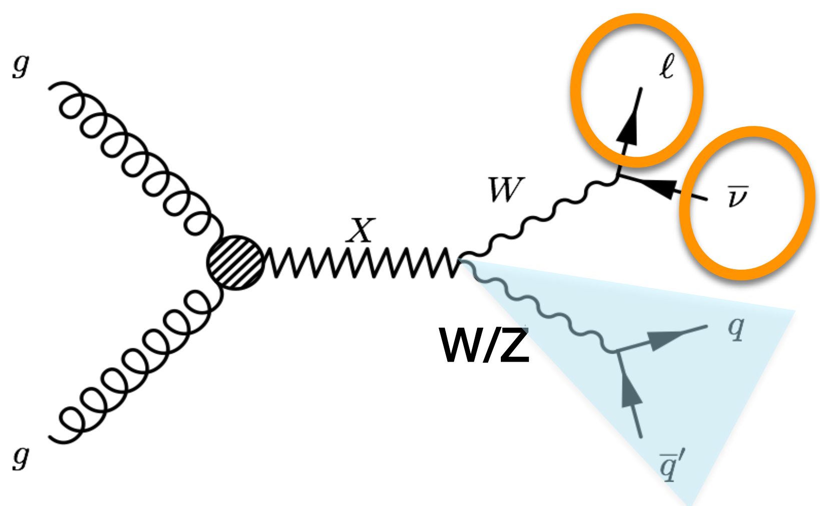
- W+Jets(main background)
- TTbar+jets
- Single top
- WW, WZ, ZZ

Signal samples

- Bulk graviton, W'

Data

- 2.198 fb-1



Muon channel

- HLT
- Tight muon: p_T > 53 GeV , |η|<2.1,
- Loose muon (for veto):
  p_T > 20 GeV , |η|<2.4
- Missing E_T > 40 GeV (type I)

Electron channel

- HLT
- Tight electron: HEEP v6.0, p_T > 120 GeV
- Loose electron (for veto): HEEP v6.0
- Missing E_T > 80 GeV (type I)

Both channels

Noise cleaning filters
AK8 jets, p_T > 200 GeV, Loose ID
AK4 jets (for b-veto), Loose ID
Leptonic W pT > 200 GeV

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

Analysis Strategy

Background knowledge

Jet pruning algorithm

"soft":(i) p_T^i or p_T^j is small compared to the p_T of their combination

(ii) the separation angle between i and j is large

→ (i)$\min(p_T^i, p_T^j)/p_T$<0.1

(ii)$\Delta R_{ij} > m^{orig}/p_T^{orig}$

N-*subjettiness*

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

With the normalization factor d_0

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

R0 is the cluster parameter of the origin jet

$$\Delta R_{n,k} = \sqrt{(\Delta\eta_{n,k})^2 + (\Delta\phi_{n,k})^2}$$

define

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

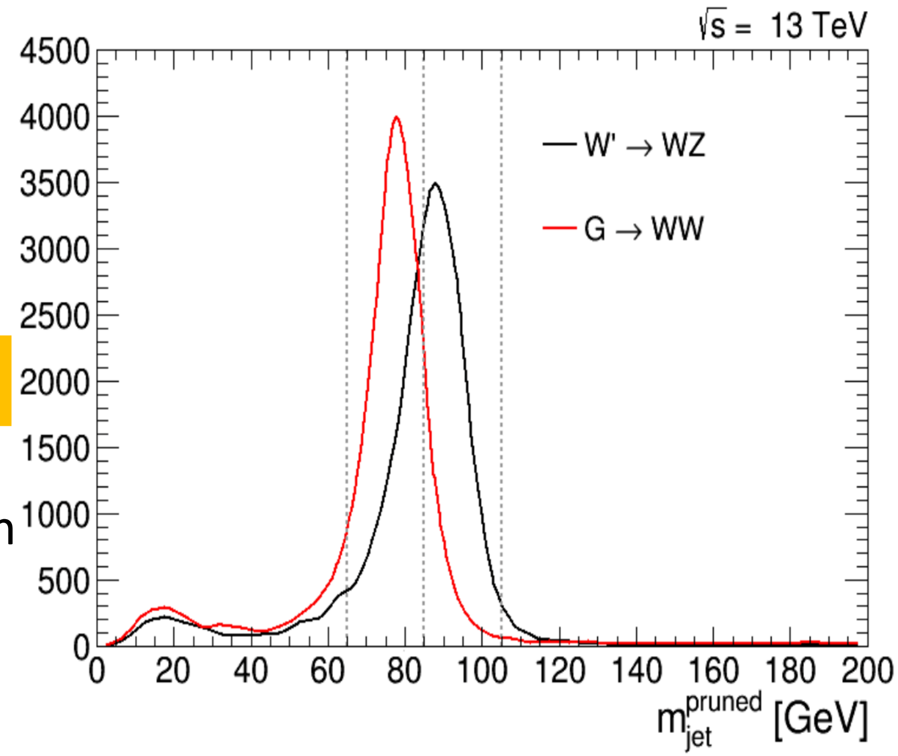
Analysis Strategy

"Bump" search: looking for an excess over the Mvw distributions

Jet pruning

- V-boson mass window
  - 65< M_{pruned} < 105 GeV
  - W-enriched:65-85 GeV
  - Z – enriched:85-105 GeV

Higgs signal region (105-135 GeV) kept blind



Jet substructure

- Discriminate against quark and gluon jet background
- N-subjettiness

HP: $\tau_{21} < 0.6$ LP: $0.6 < \tau_{21} < 0.75$

How to estimate the background contributions

- Minor background: taken from simulation, corrected with scale factors from data
- Wjets: extracted from data

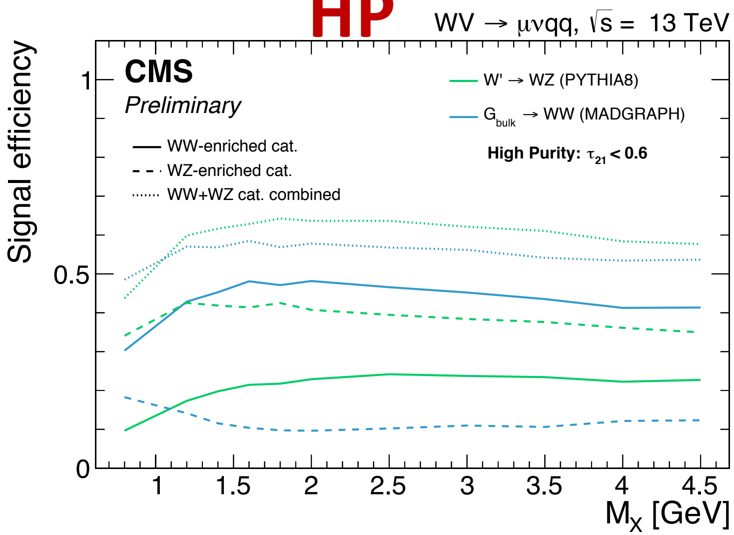
8 signal categories: HP/LP, WW/ WZ, el and muon

Signal Efficiency(WV in each category)

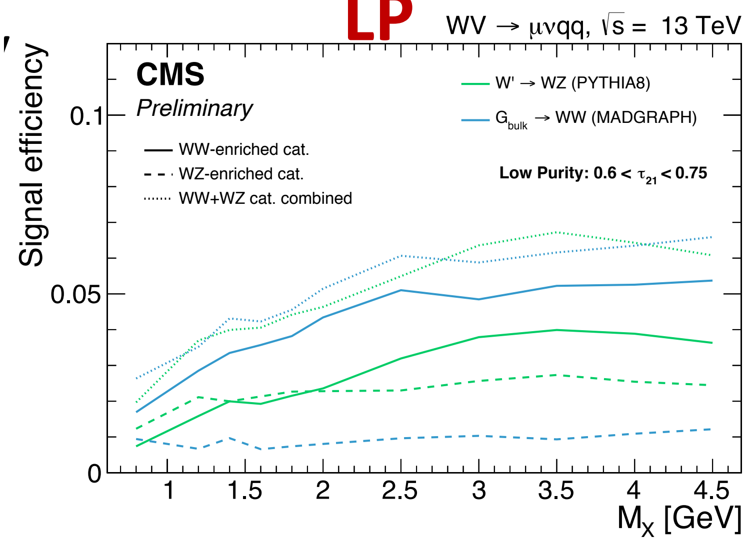
p7

muon

HP



LP



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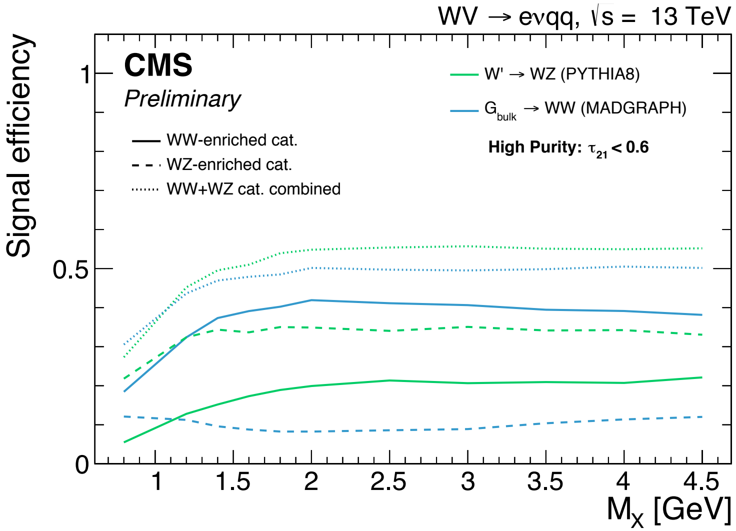
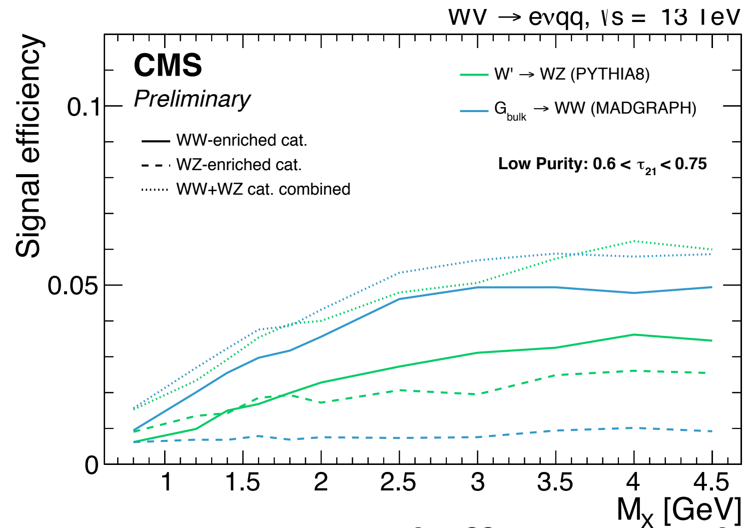


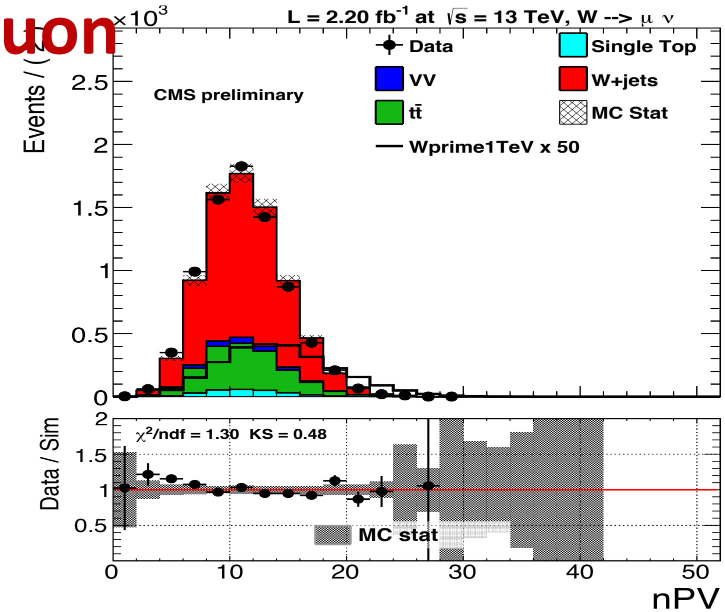


Efficiency of spin-2 G_{bulk} in WW category ~ 2× W'
Efficiency of spin-1 W' in WZ category ~ 3× G_{bulk}

Low signal efficiency in the LP category
-> gain from the combining with HP at high masses where expected background is low

Control Plots in W+jets

muon



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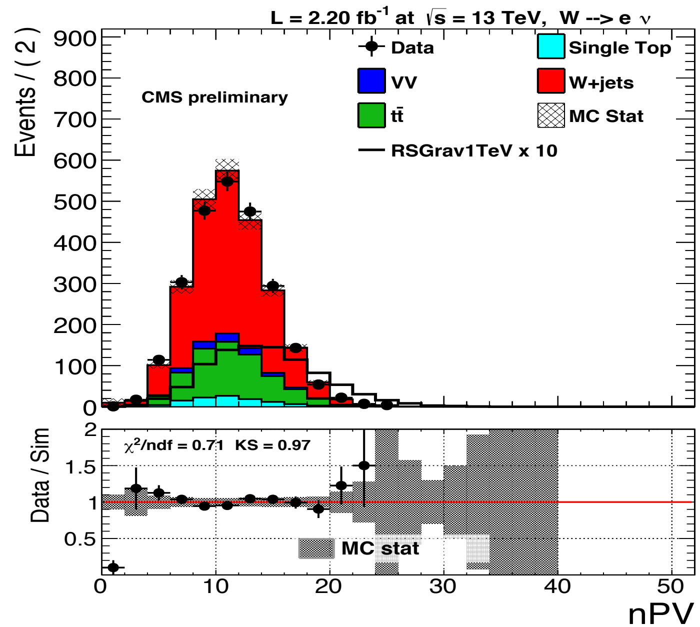

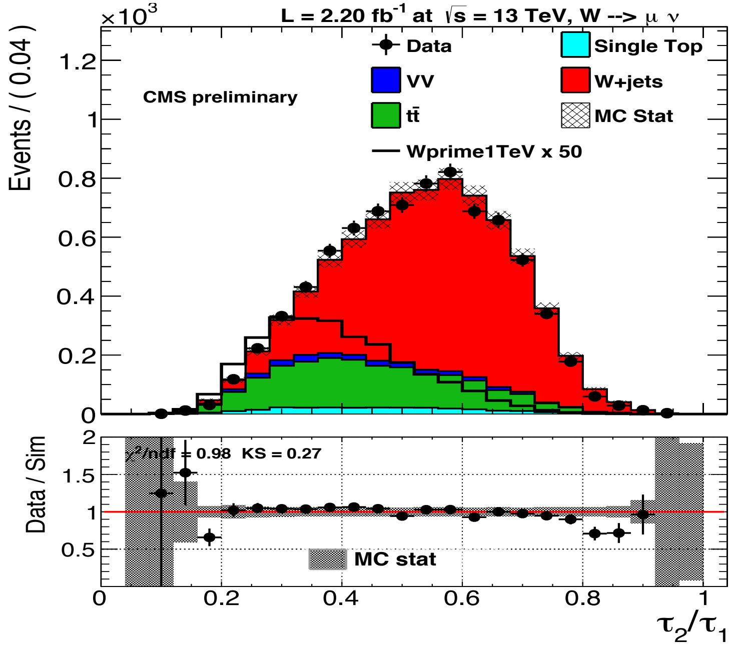

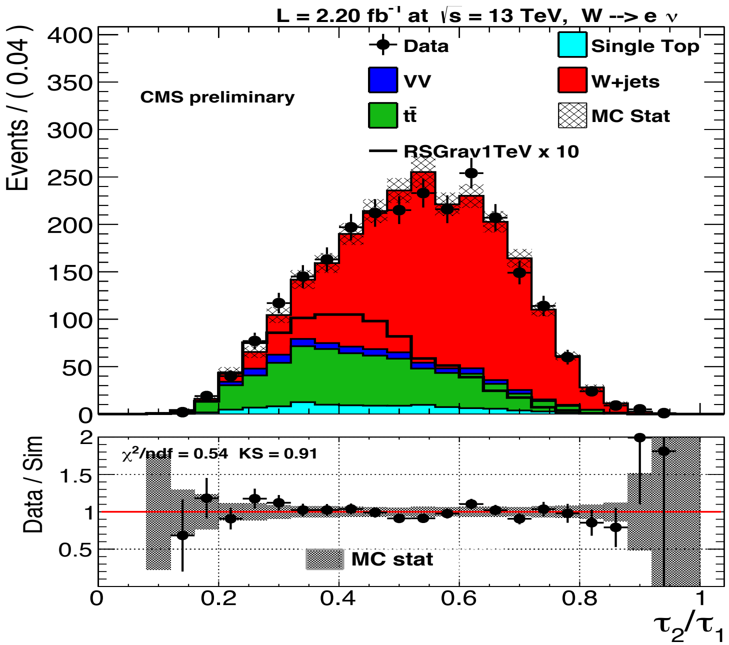

Control Plots in W+jets

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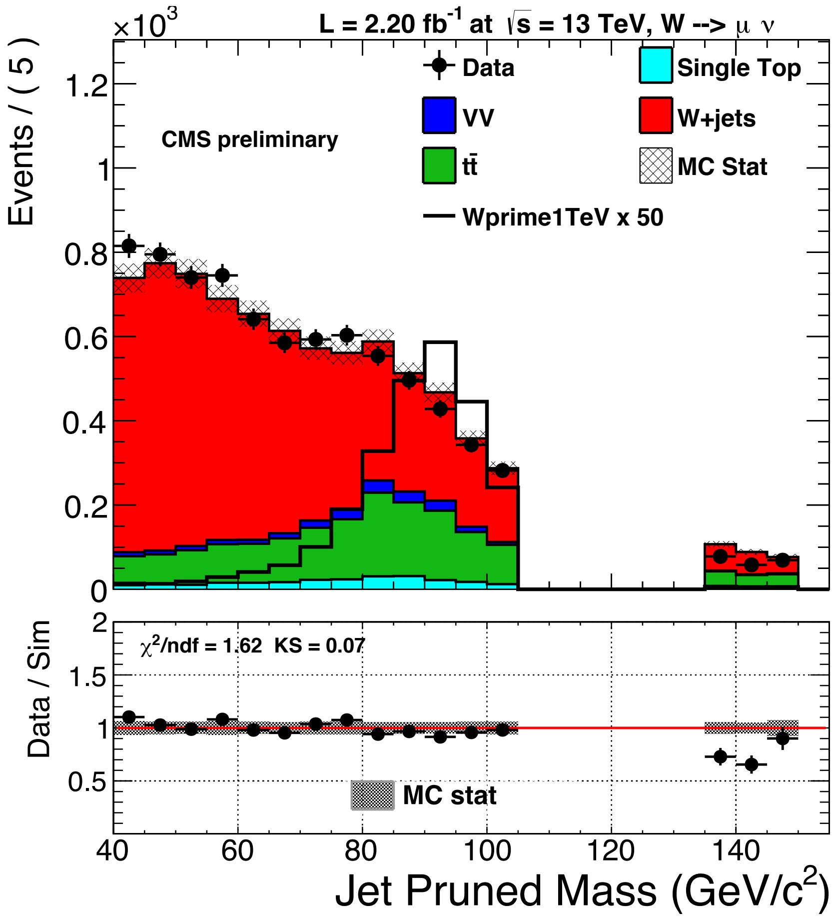

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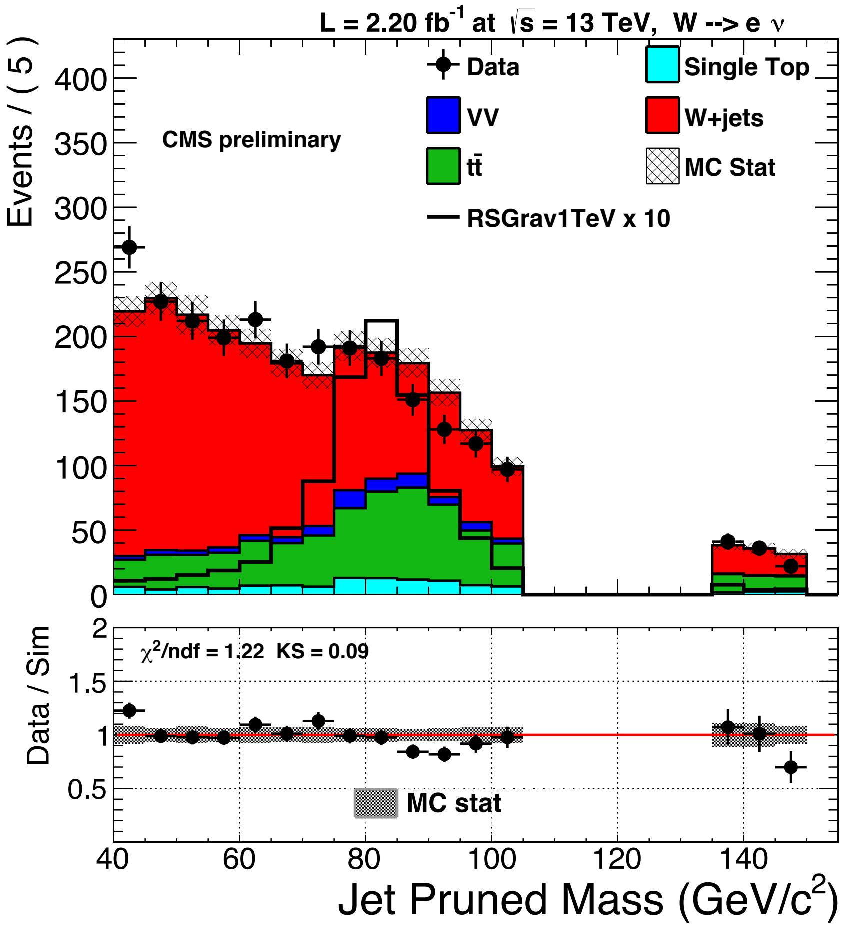
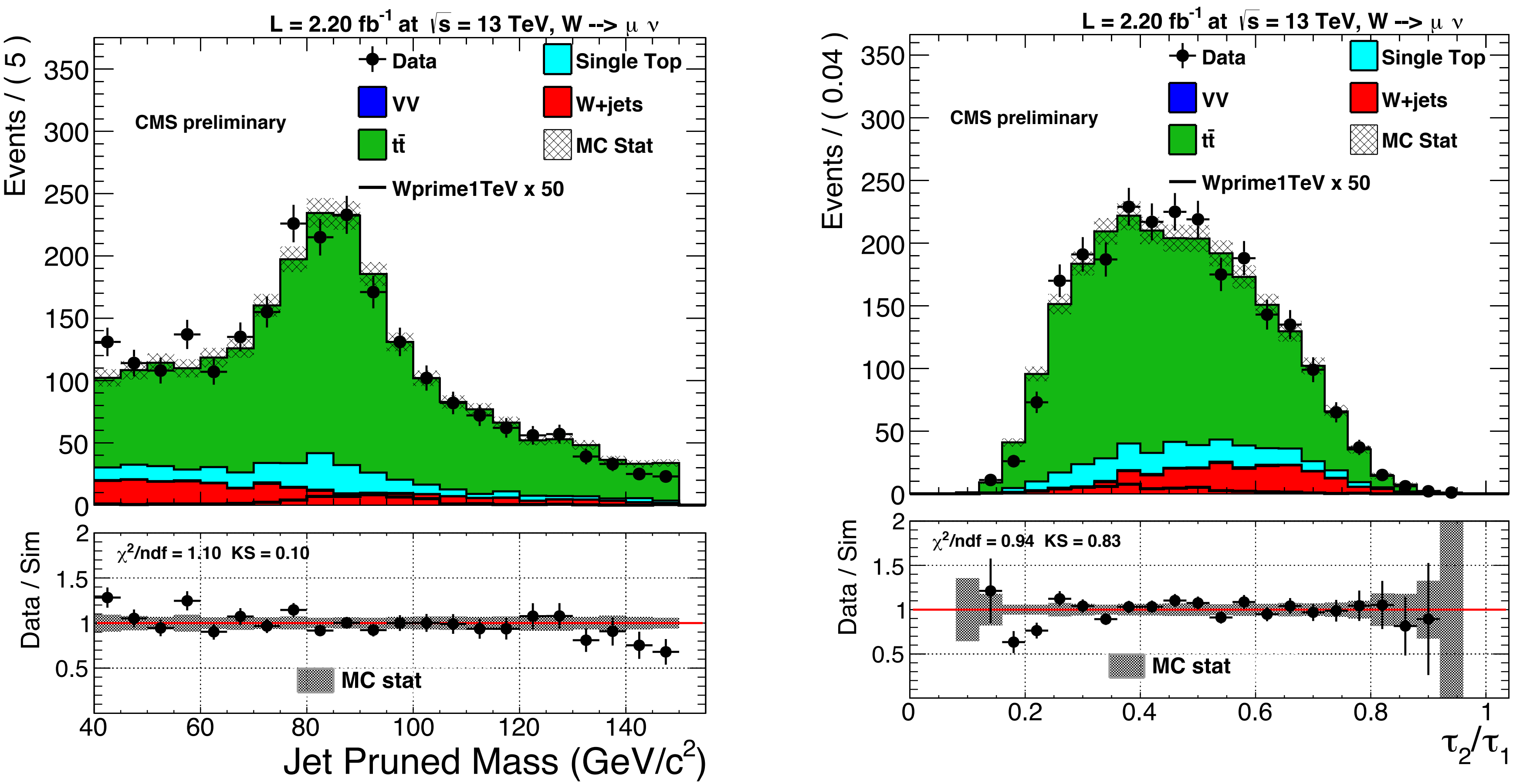


Control Plots in TTbar

Definition: Top-enriched control sample can be naturally obtained by:

- Asking at least one b-tagged jet outside the W-jet (iCSVM)
- Not requiring back to back topology



V-tagger in TTbar

Top Scale factor(TTbar + single Top yield correction)

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

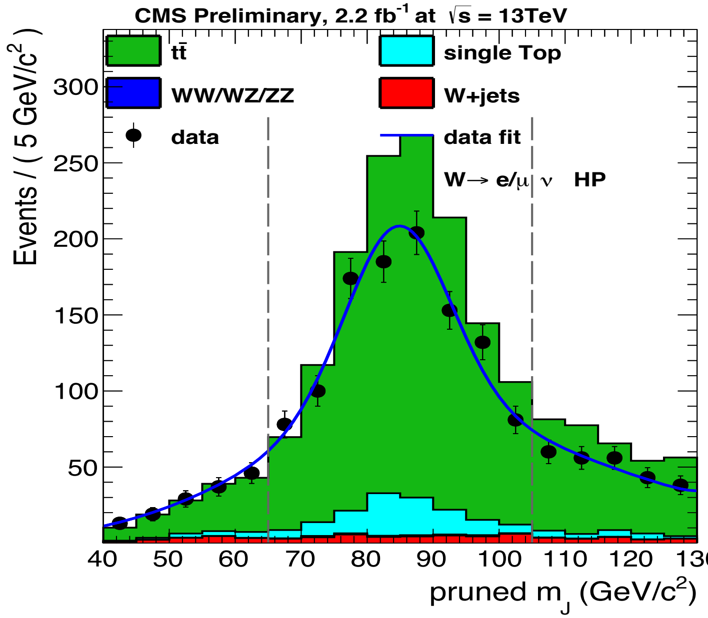
Cut count method: $Sf_{top} = N_{data}/N_{MC}$ (minor background contribution negligible)

Top scale factor	Muon channel	Electron channel	Muon+Electron channels
HP($\tau_{21} < 0.6$)	0.872±0.040	0.833±0.070	0.862±0.035
LP($0.6 < \tau_{21} < 0.75$)	0.787±0.110	0.661±0.200	0.756±0.097
HP($\tau_{21} < 0.45$)	0.847±0.049	0.865±0.084	0.850±0.042
LP($0.45 < \tau_{21} < 0.75$)	0.883±0.059	0.746±0.106	0.870±0.053

Mass scale and resolution

Simultaneous fit of mu and el mJ spectrum

Parameter	Data	simulation	Data/Simulation
$< m >$	84.7±0.4	85.3±0.4	0.992± 0.005
σ	8.2±0.5	7.3±0.4	1.12±0.07

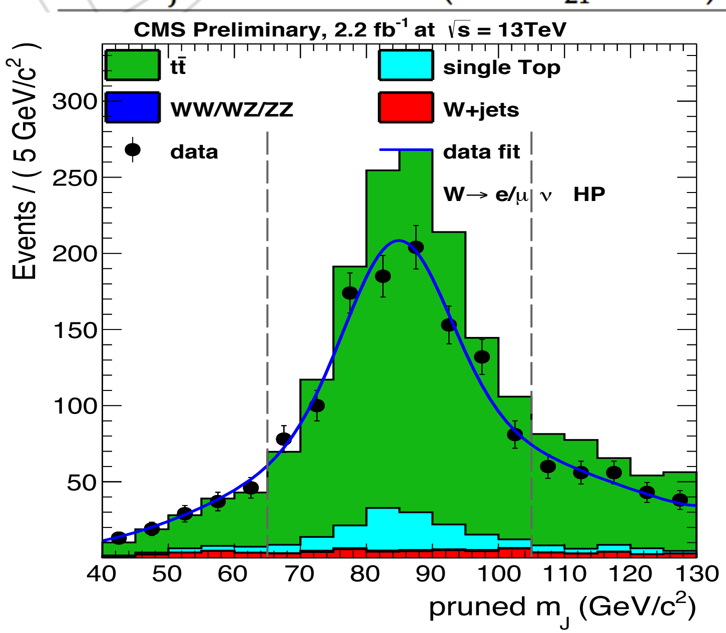


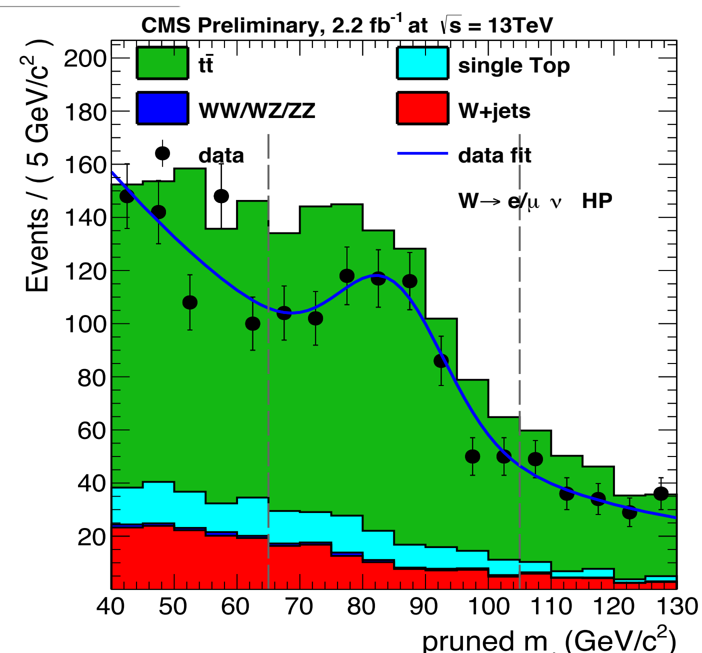
V-tagger in TTbar

W-tagging scale factors

- Consider the TTbar made of ‘real’ W and ‘combinatorial’
- Background(s-top/ WW/ W+jets) are taken from MC
- Pass PDF $f_{pass} = f_{pass}^{W-match} \times \epsilon \times N_W + f_{pass}^{W-nomatch} \times N_2 + F_{pass}^{STop} + F_{pass}^{VV} + F_{pass}^{Wjet}$
- Fail PDF $f_{fail} = f_{fail}^{W-match} \times (1-\epsilon) \times N_W + f_{fail}^{W-nomatch} \times N_3 + F_{fail}^{STop} + F_{fail}^{VV} + F_{fail}^{Wjet}$
- Simultaneous fit data and MC in PASS & FAIL to get SF

Category	Definition	W scale factor
Dijet channel HP	$(\tau_{21} < 0.45)$	0.69 ± 0.14
Dijet channel LP	$(0.45 < \tau_{21} < 0.75)$	1.46 ± 0.38
$\ell\nu$+V-jet channel HP	$(\tau_{21} < 0.6)$	1.03 ± 0.13
$\ell\nu$+V-jet channel LP	$(0.6 < \tau_{21} < 0.75)$	0.88 ± 0.49





W+jets Background Estimation Yields

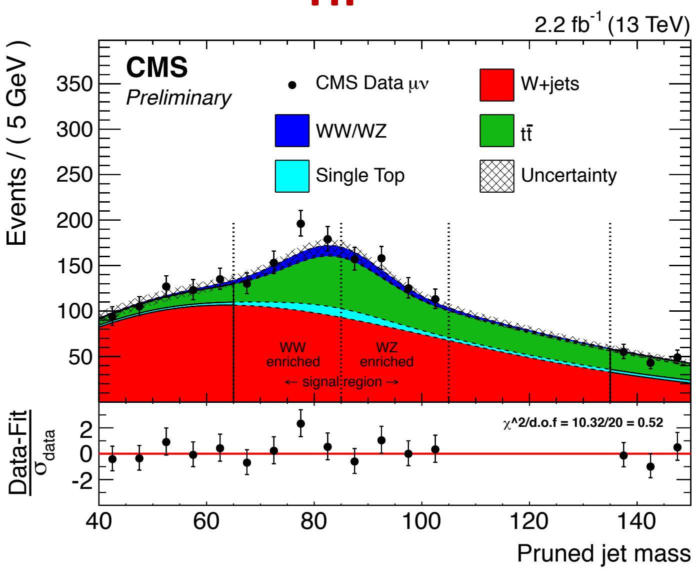
Dominant background is W+jets– Large contribution of ttbar as well

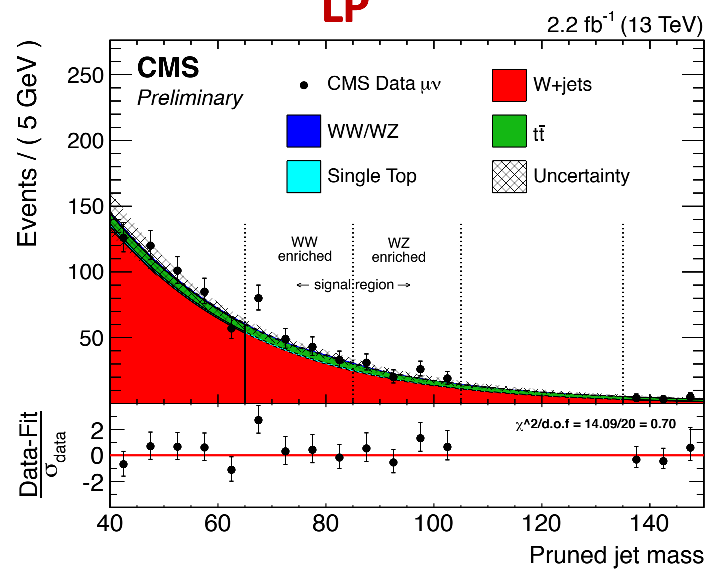
normalization: fit on data sideband in mJ;

HP

LP

muon





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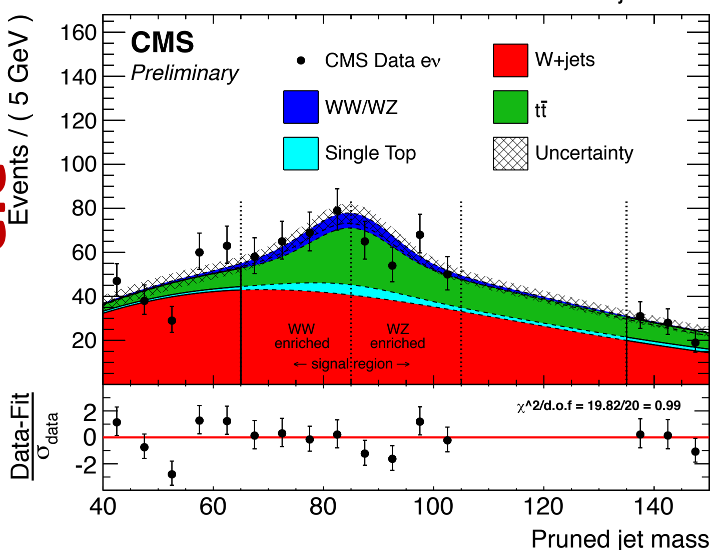
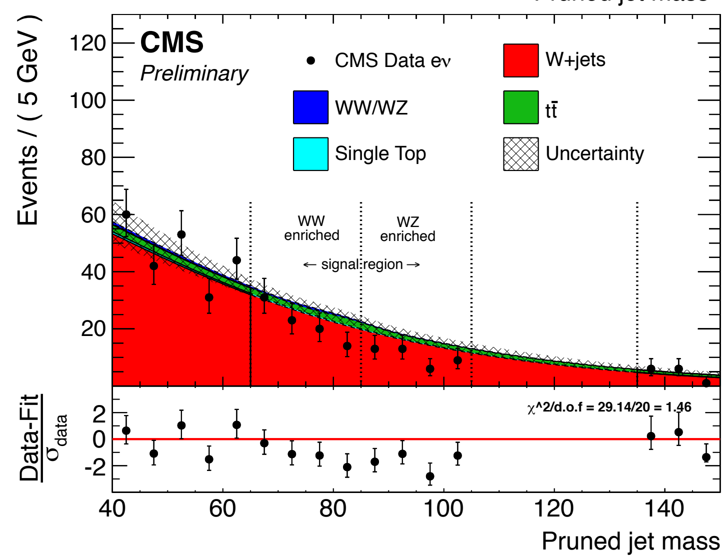


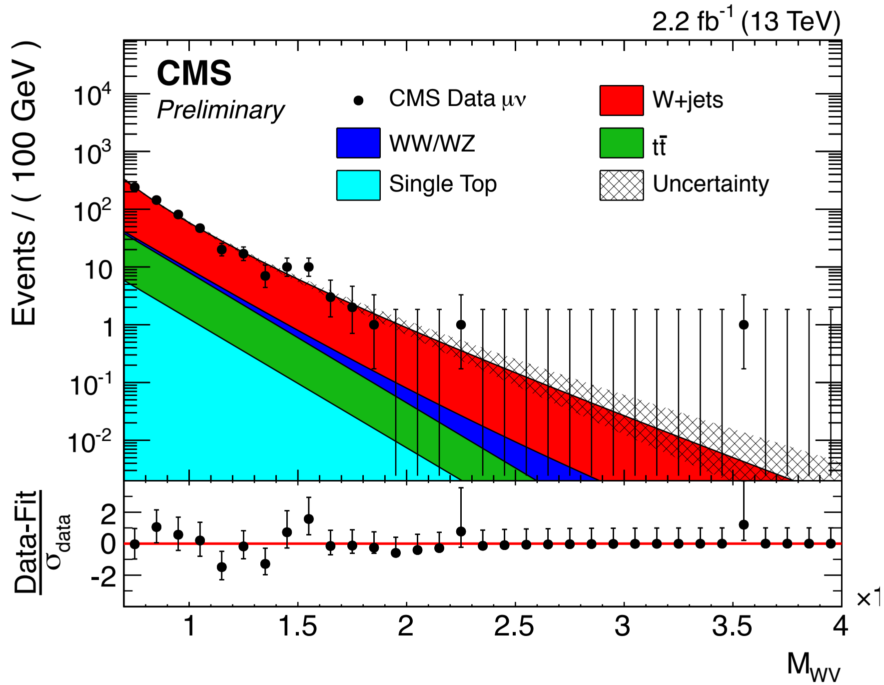


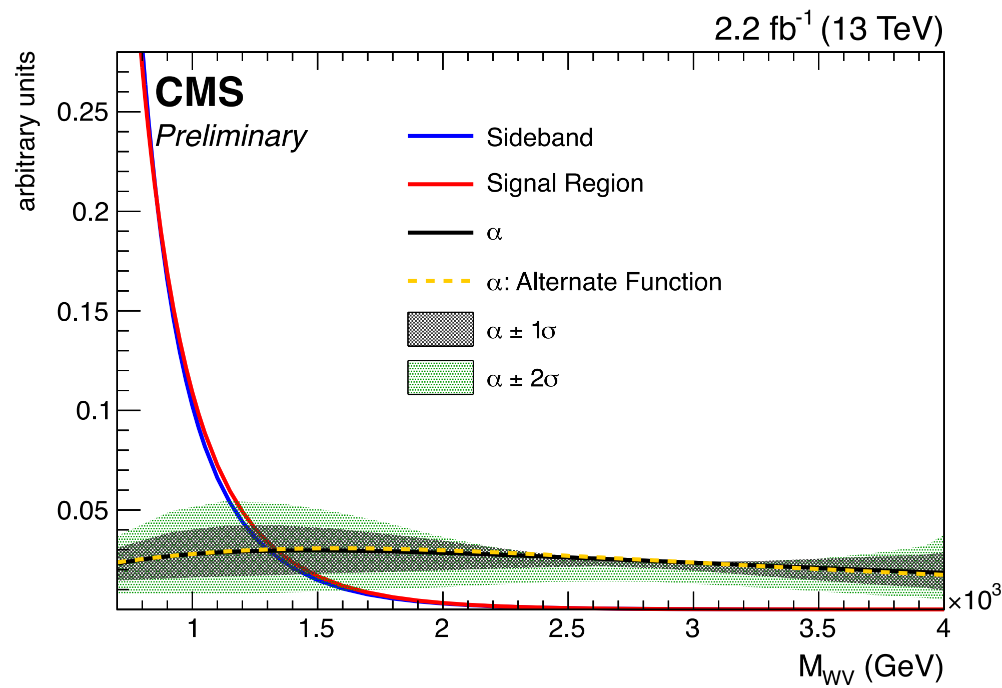
W+jets Background Estimation Shape

Mvw shape: extrapolated from data, from the sideband using alpha function

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

Muon HP



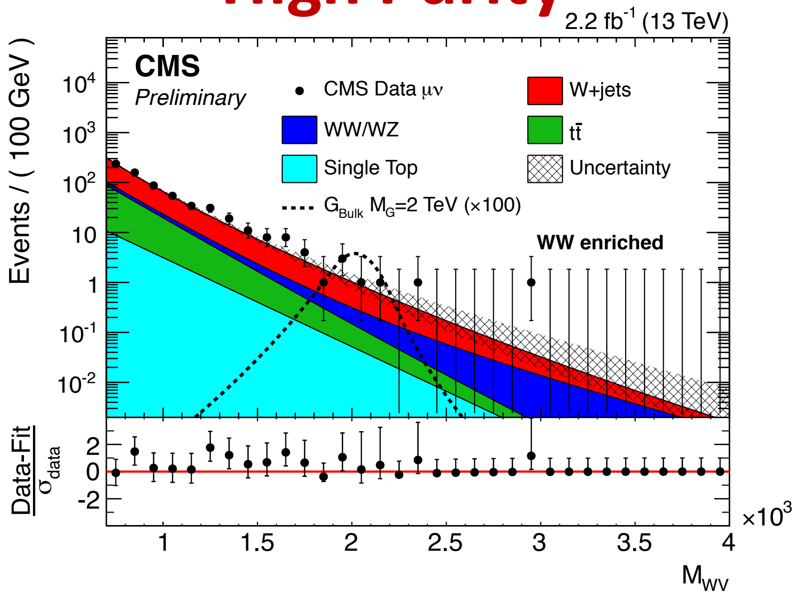


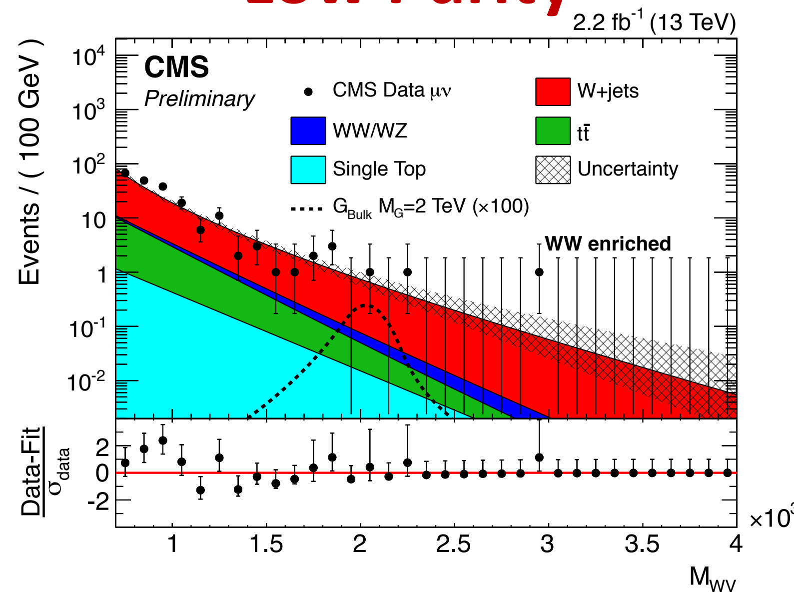
$$F_{ExpN}(x) = e^{c_0 x + n/x}$$

V+jets M_{VV} shape in Signal Region(mu)

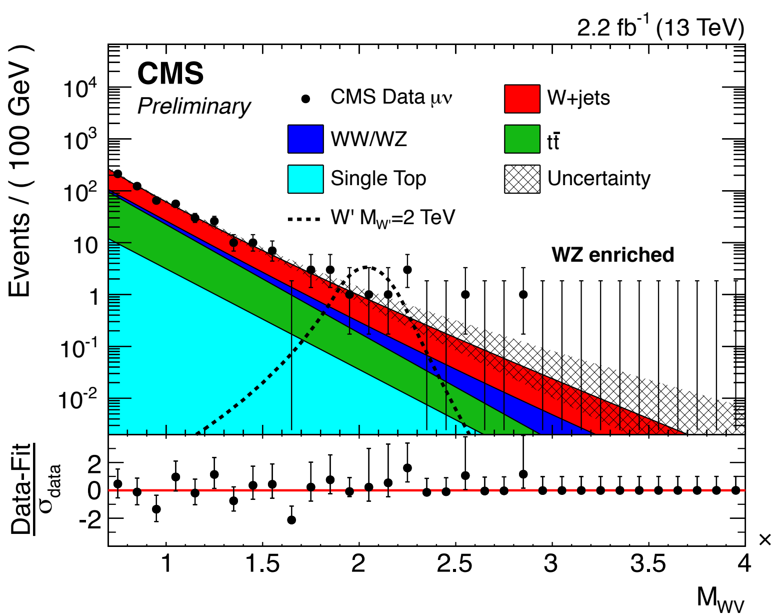
High Purity / Low Purity

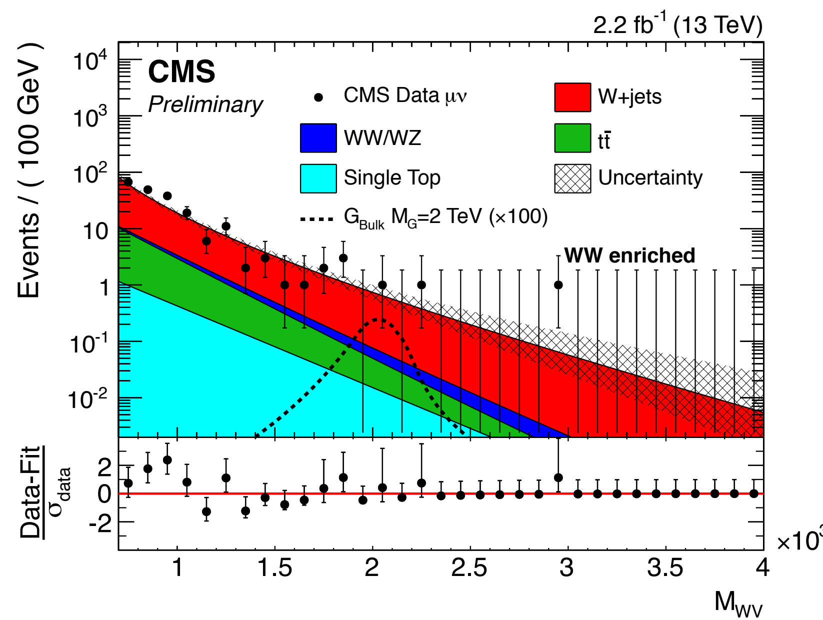
WW category





WZ category

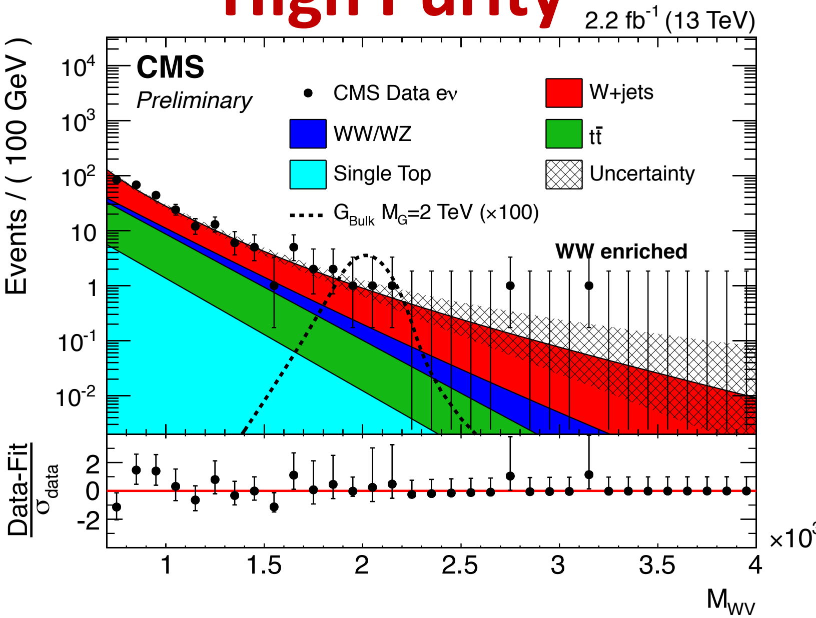




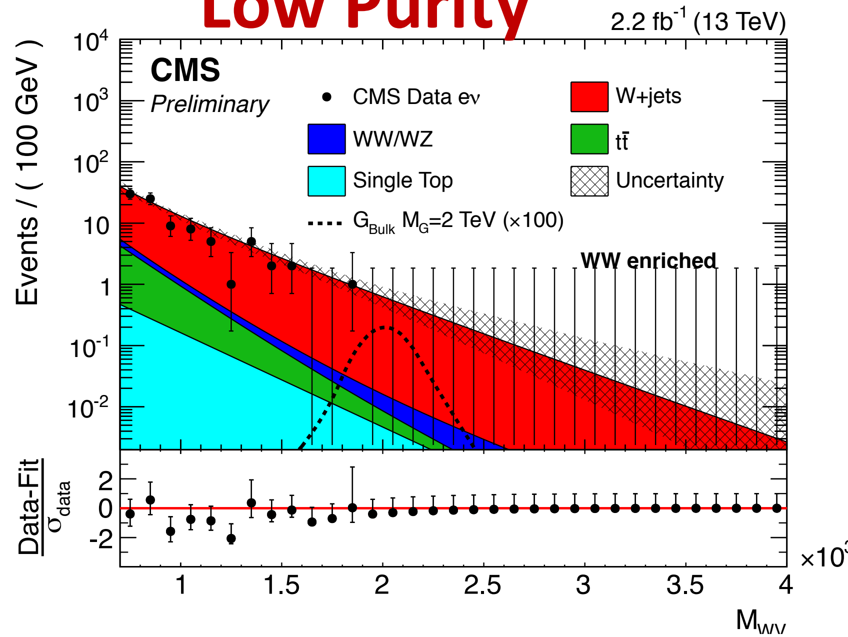
V+jets M_{VV} shape in Signal Region(el)

WW category

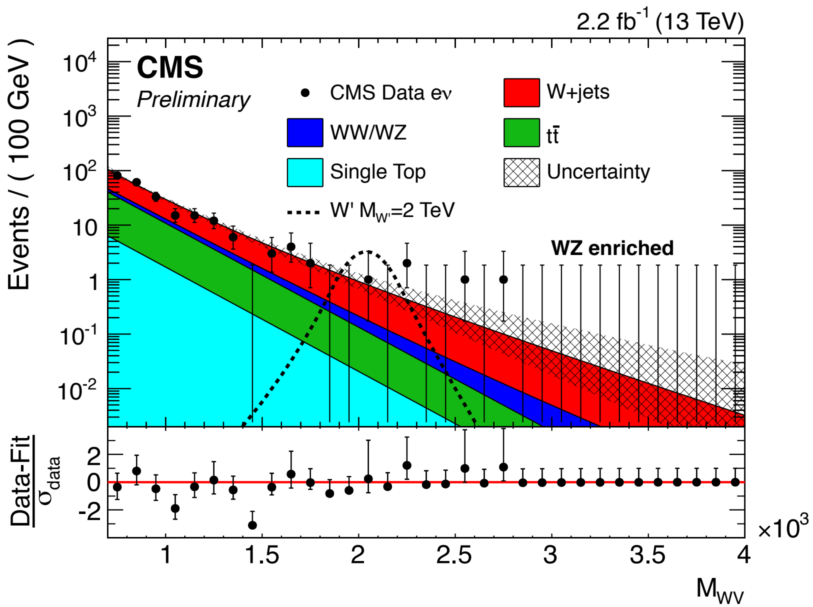
High Purity

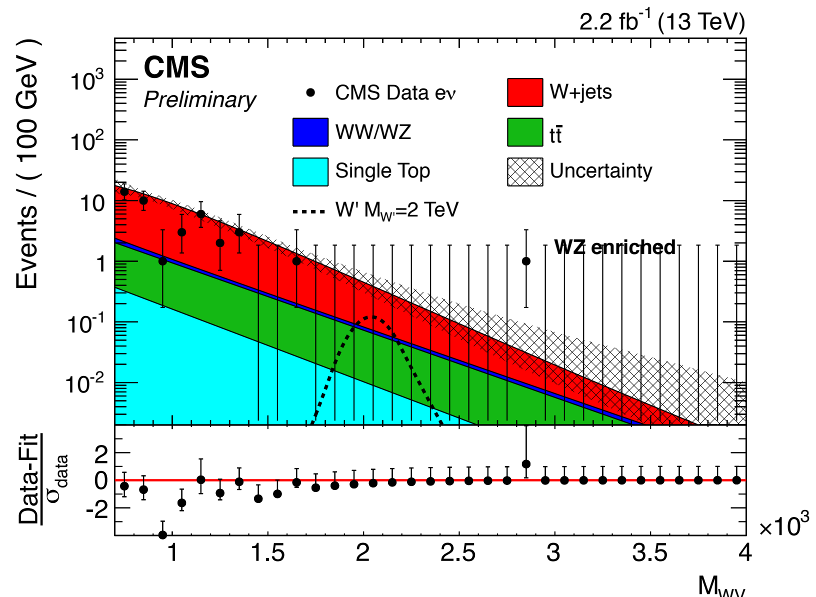


Low Purity



WZ category



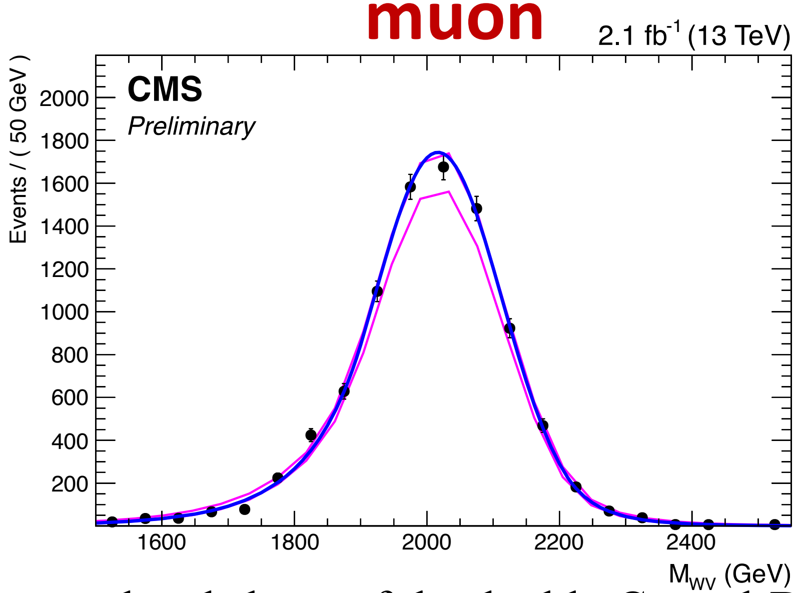


Signal Modelling

Signal fits are performed with double Crystal-ball function.

WW

muon



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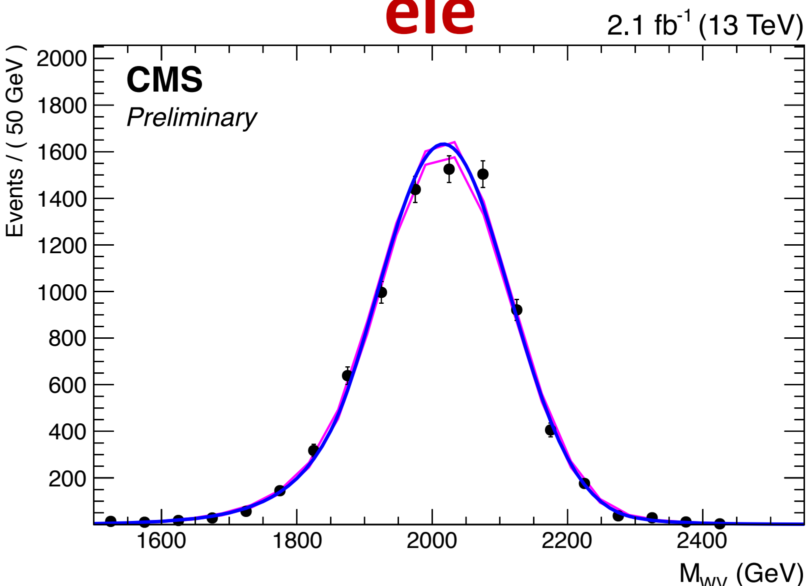
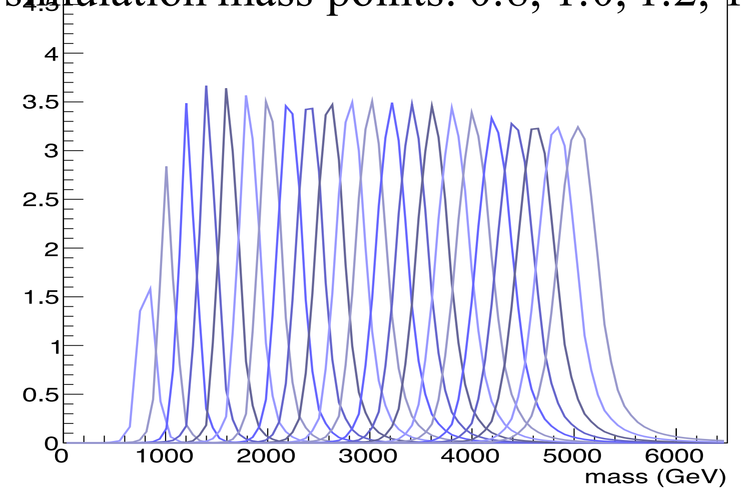
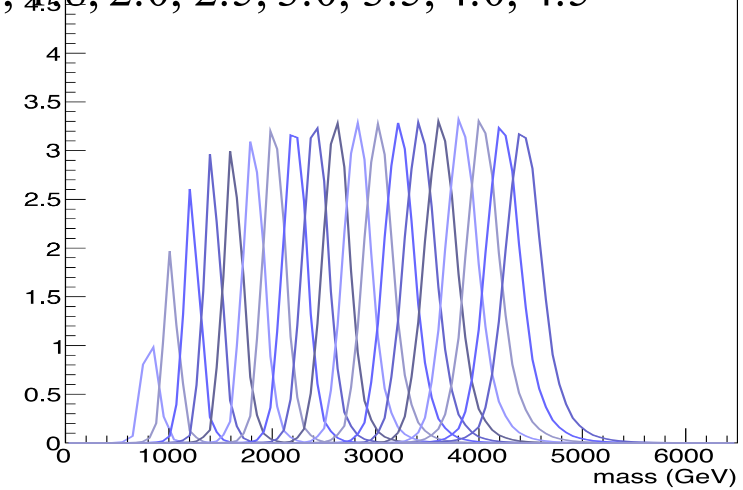


Extrapolated shape of the double Crystal-Ball function for different masses for HP

Full simulation mass points: 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5

WW





Systematic Uncertainties(1)

Background normalization

- W+jets normalization uncertainty —> driven by amount of data in sideband
- TTbar and Single Top normalization —> uncertainty in the scale factor derived in top-enriched control sample
- VV normalization —> uncertainty in the V-tagging scale factor derived in top-enriched control sample

Source	W+jets	$t\bar{t}$	Single Top	VV
Luminosity	-	5%	5%	5%
Cross section	-	-	5%	3%
V-tagging eff. (HP/LP)	-	-	-	13%/49%
W+jets normalization	See Tab.6	-	-	-
W+jets shape	See Sec. 7.1.1	-	-	-
$t\bar{t}$ normalization (HP/LP)	-	5%/14% (μ) 8%/30% (e)	5%/14% (μ) 8%/30% (e)	-
Trigger	-	1% (μ) 1% (e)	1% (μ) 1% (e)	1% (μ) 1% (e)
Lepton identification	-	1% (μ) 3% (e)	1% (μ) 3% (e)	1% (μ) 3% (e)

Summary of background uncertainties

W+jets M_{WV} shape

1. uncertainties in the M_{WV} **shape in sideband** driven by amount of data —> correlated between m_{jet}^{pruned} categories
2. uncertainties in the **alpha shape** driven by W+jets MC statistics —> uncorrelated between m_{jet}^{pruned} categories
3. uncertainties due to the **choice of the function** taken into account inflating 1) and 2) by $\sqrt{2}$

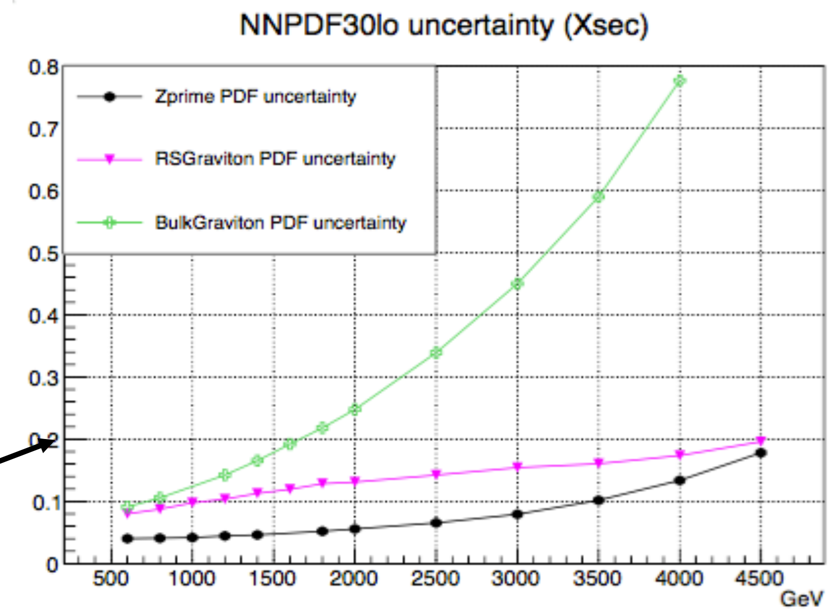
Systematic Uncertainties(2)

- Most important sources for signal normalization:
  - Jet energy scale: 3-12%
  - Jet mass scale: 1-10%
  - Jet mass resolution: 1-5%
  - V-tagging efficiency scale factors: 13/49% for HP/LP

Summary of signal uncertainties

Source	Signal Normalization		Mean m_{WW} Shape		Width m_{WW} Shape	
	$\mu\nu$+jet	$e\nu$+jet	$\mu\nu$+jet	$e\nu$+jet	$\mu\nu$+jet	$e\nu$+jet
Muon Energy Scale	0.7%	–	0.1%	–	0.5%	–
Electron Energy Scale	–	0.2%	–	0.1%	–	0.1%
Muon Energy Resolution	0.1%	–	0.1%	–	0.1%	–
Electron Energy Resolution	–	0.1%	–	0.1%	–	0.1%
Trigger	1%	1%	–		–	
Lepton identification	1%	3%	–		–	
Luminosity	5%				–	
b-tag selection	0.2%				–	
W-tagging eff. (HP/LP)	13%/49%		–		–	
Jet Energy Scale	See Tab. 8				1.3%	[2%-3%]
Jet Energy Resolution	See Tab. 8				0.1%	3%
PDF uncertainties	See Sec. 7.7		–		–	

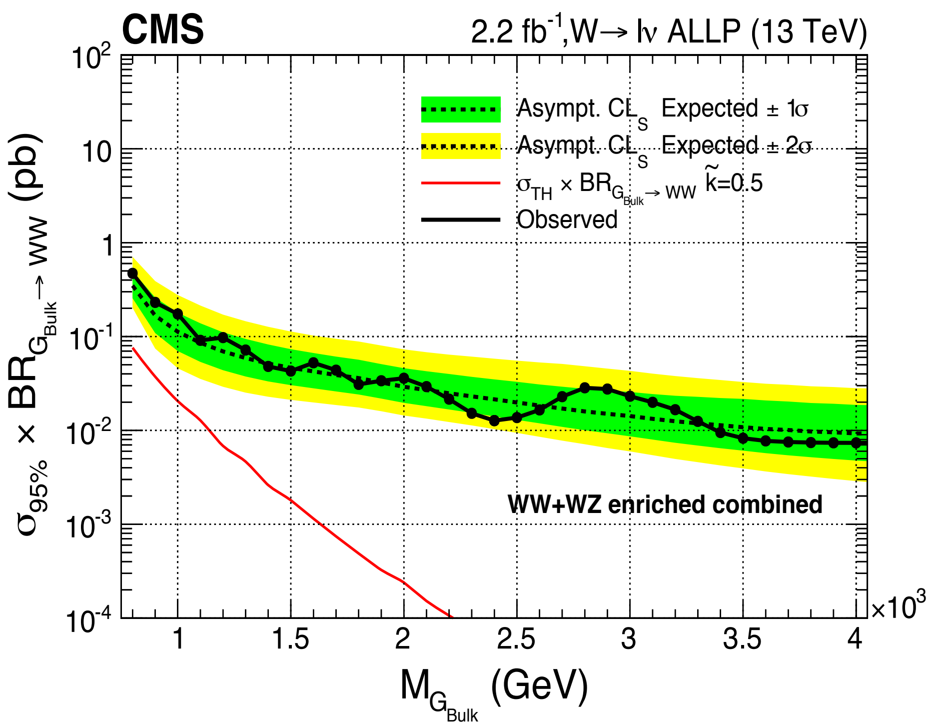
- Extrapolation uncertainties for V-tagging SF at high p_T comparing PYTHIA8 and HERWIG++ signal samples
  - compare selection efficiency of each mass point wrt 600 GeV (p_T 200-300 GeV)
  - Found 1-4% differences in signal efficiency
- PDF uncertainties on signal xsec
  - 10-40% for Bulk Graviton signal in [0.5, 3]TeV



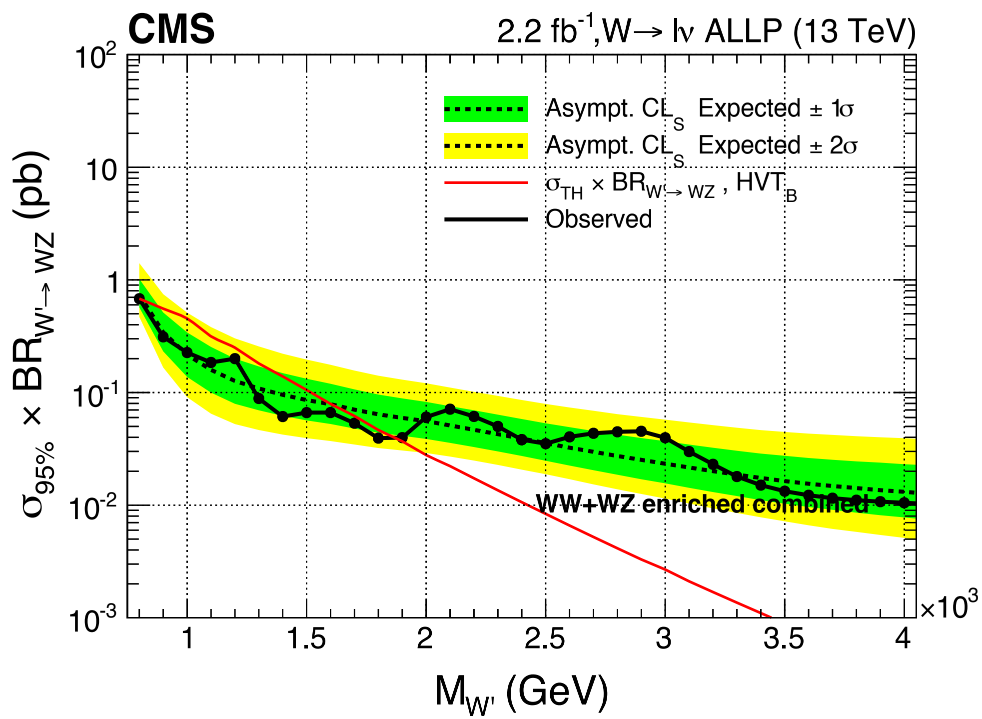
Limits

Combined Limits

Use the Higgs combination tool and Asymptotic CL_s method to compute the upper limits.



Graviton

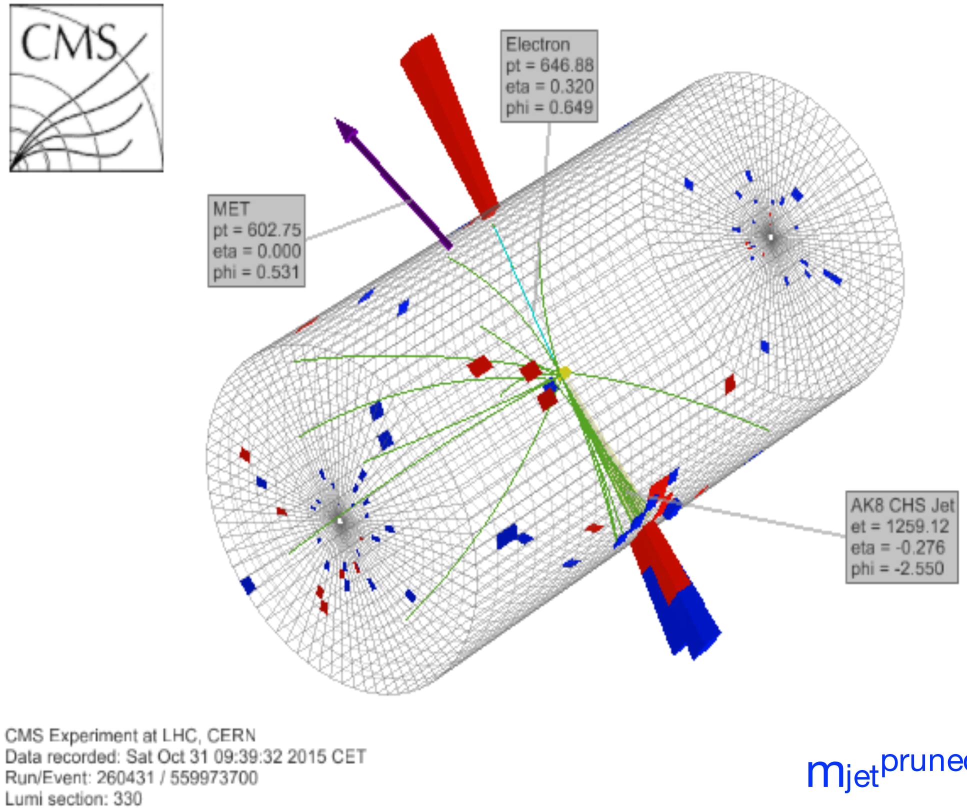


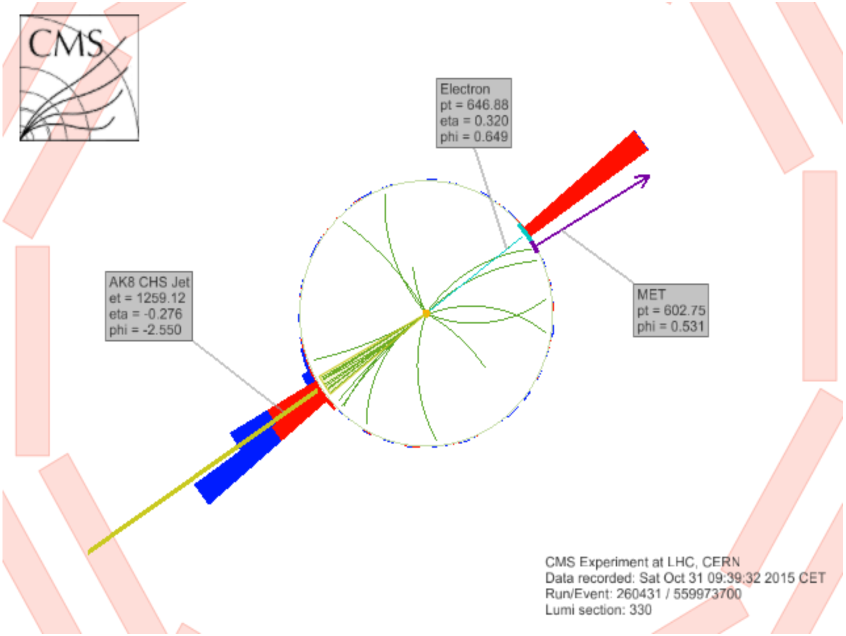
Wprime

The achieved sensitivity is not sufficient to exclude Bulk Graviton model. For HVT model B of a charged spin-1, it's excluded for the masses below 1.8TeV

Event Display

Single Electron HP-WW





m_{jet}^{pruned} = 68.7 GeV

AK8 jet mass = 135.6 GeV

AK8 jet p_T = 1.31 TeV

W_{lept} p_T = 1.34 TeV

M_{WW} = 2.78 TeV

Summary

- Common strategy based on jet substructure methods validated in W+jets and TTbar control samples
  Evaluated V-tagger scale factor and systematics
- No significant deviation from the standard model prediction is observed in the final Mwv distributions in any of the categories
- We set 95% CL upper limits on the two production cross-section of a narrow resonance: Bulk Graviton and W'
- A spin-1 narrow W' resonance is excluded up to a mass of ~1.8TeV
- The final analysis and combination is scheduled as a paper for Moriond.
- The data to be taken in 2016 will finally unravel what is happening around M_{VV} =2 TeV, observed in many channels.