Centre National pour la Recherche Scientifique et Technique

كلية العلوم - القنيطرة
Faculté des Sciences - Kenitra

Search for heavy diboson resonances in semileptonic final states in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

Yassine El Ghazali

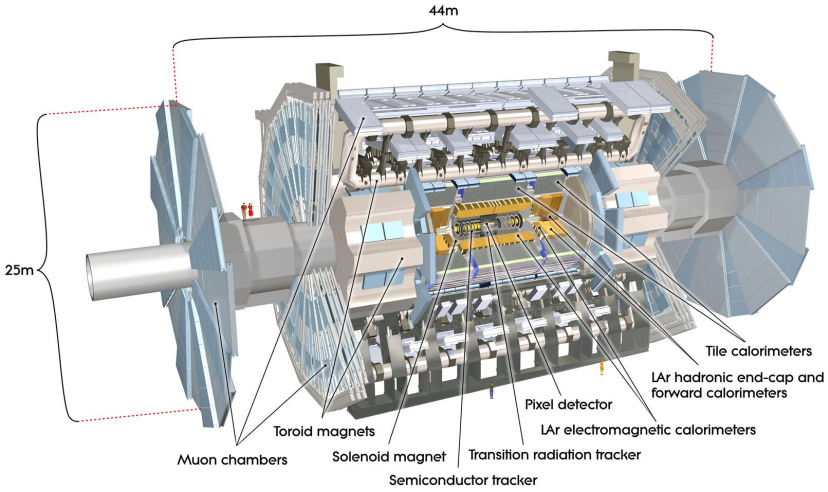
Ibn Tofail University in Kenitra
Beyond Standard Model: From Theory to Experiment (BSM-2021 Conference), Egypt

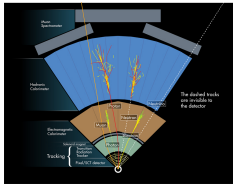
April 2, 2021

Outline

1. ATLAS experiment
2. Motivation
3. Benchmark Models
4. Object definition
5. Analysis strategy
6. Results
7. Summary

ATLAS detector

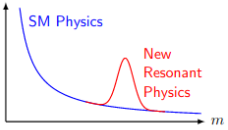




Motivation

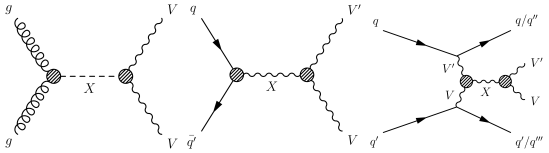
Various BSM models predict new particles decaying to pairs of $V = W/Z$

- Extended Gauge, Higgs sectors, RS models
- Can appear as resonant detector signature in invariant mass of the bosons



Searches for new resonances in semileptonic VV final stats

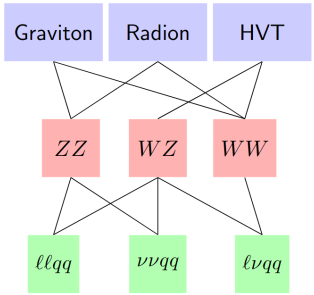
- One V decays leptonically and the other hadronically
- Compromise between competing effects
  - Hadronic decays $\rightarrow$ high BR
  - Leptonic decays $\rightarrow$ Low Bkgs



Benchmark Models

Three benchmark models correspond to different spin have been used

- Spin 0: Radion in Randall-Sundrum models
- Spin 1: W'/Z' for Heavy vector Triplets
- Spin 2: Graviton in Randall-Sundrum



Production through ggF/DY and VBF for all models

Object definition

The building objects for this search are: leptons(*Electrons* or *Muons*), E_T^{miss} and *jets*

- Priority is given to Merged regime, if failed then resolved $V \to jj$
- E_T^{miss} = negative sum
- $\mathcal{R}_{p_T/m} = \frac{min(p_{T,\ell\nu}, p_{T,J})}{m_{WV}}$

Event selection	0-lepton ($ZV \to \nu\nu V_h$)	1-lepton ($WV \to \ell\nu V_h$)	2-lepton ($ZV \to \ell\ell V_h$)
V_ℓ selection	No *Loose* lepton $E_{\mathrm{T}}^{\mathrm{miss}} > 250$ GeV $p_{\mathrm{T}}^{\mathrm{miss}} > 50$ GeV	1 *Tight* electron or 1 *Medium* muon with $p_{\mathrm{T}}^{\ell} > 30$ GeV $E_{\mathrm{T}}^{\mathrm{miss}} > 60$ GeV $p_{\mathrm{T}}^{V_\ell} > 75$ GeV	2 *Loose* leptons with $p_{\mathrm{T}}^{\ell} > 30$ GeV from the $Z \to \ell\ell$ candidate
Event veto	No additional *Loose* leptons		
		Veto events with b-jets not associated with the $V \to qq$ candidate	
Event categorisation	≥ 1 large-R jets or ≥ 2 small-R jets VBF and ggF/DY classification according to RNN score		
V_h selection (Merged)		$E_{\mathrm{T}}^{\mathrm{miss}} > 100$ GeV $p_{\mathrm{T}}^{V_\ell} > 200$ GeV	
	≥ 1 large-R jets The leading jet passing p_{T}-dependent m_J requirement		
		$\mathcal{R}_{p_{\mathrm{T}}/m} > 0.35$ (ggF/DY) $\mathcal{R}_{p_{\mathrm{T}}/m} > 0.25$ (VBF)	$\mathcal{R}_{p_{\mathrm{T}}/m} > 0.35$ (ggF/DY) $\mathcal{R}_{p_{\mathrm{T}}/m} > 0.25$ (VBF)
V_h selection (Resolved)	Not Performed	Failed merged selection ≥ 2 small-R jets with $\lvert\eta\rvert < 2.5$ $62 < m_{jj} < 97$ GeV for $W \to jj$ $70 < m_{jj} < 105$ GeV for $Z \to jj$	
		$\mathcal{R}_{p_{\mathrm{T}}/m} > 0.35$ (ggF/DY) $\mathcal{R}_{p_{\mathrm{T}}/m} > 0.25$ (VBF)	$\mathcal{R}_{p_{\mathrm{T}}/m} > 0.35$ (ggF/DY) $\mathcal{R}_{p_{\mathrm{T}}/m} > 0.35$ (VBF)

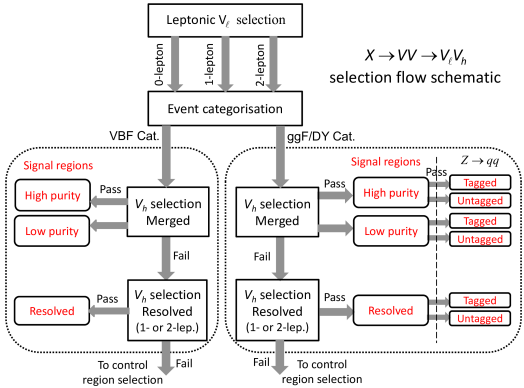
Analysis strategy

Identification of leptonic V decay and hadronic V decay

Leptonic V decay
- $Z \to \nu\nu$
- $W \to \ell\nu$
- $Z \to \ell\ell$

Hadronic V decay
- Merged: One Large-R jet
- Resolved: Two Small-R jets

Further Categorizations
- High purity and Low Purity Pass or fail W/Z tagger
- $Z \to bb$ tagged/untagged regions



Signal and Control region definition

- Signal regions: mass window cut ($V \to qq$)
  - Merged: p_T-dependent cut
  - Resolved: Fixed cut
  - No extra *b-jet*
- Control regions: $W+jets$, $Z+jets$ and $t\bar{t}$
  - WCR/ZCR (W/Z+jets): W/Z mass side-band
  - TCR ($t\bar{t}$): Extra *b-jets* required

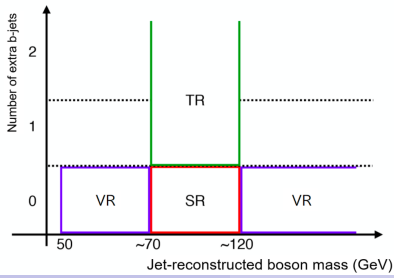


Table: Merged regime

Selection		SR		W CR (WR)		$t\bar{t}$ CR (TR1)	
		HP	LP	HP	LP	HP	LP
$W/Z \to J$	Num of large-R jets	≥ 1					
	D_2 cut	pass	fail	pass	fail	pass	fail
	W/Z mass window cut	pass	pass	fail	fail	pass	pass
	Numb. of associated VR track jets b-tagged	For $Z \to J$: ≤ 1 ($= 2$) for untagged (tagged) category					

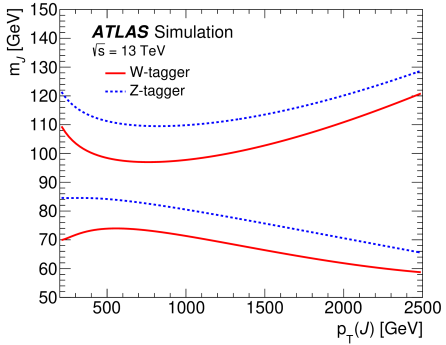
Table: Resolved regime

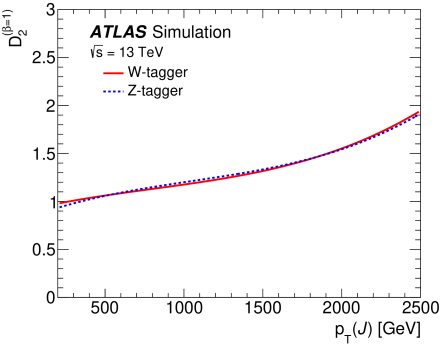
cuts		SR	W CR (WR)	$t\bar{t}$ CR (TR1)
$W/Z \to jj$	Number of small-R jets	≥ 2		
	Leading jet p_T	> 60 GeV		
	Subleading jet p_T	> 45 GeV		
	$Z \to q\bar{q}$	$78 < m_{jj} < 105 GeV$	$50 < m_{jj} < 68$, GeV or	$50 < m_{jj} < 150 GeV$
	$W \to q\bar{q}$	$68 < m_{jj} < 98 GeV$	$150 < m_{jj} < 150$, GeV	
	Num. of b-tagged jets	For $Z \to jj$: ≤ 1 ($= 2$) for untagged (tagged) category		
Topology cuts	$\Delta\sigma(j, \ell)$	> 1.0		
	$\Delta\sigma(j, E^{\ell}_{miss})$	> 1.0		
	$\Delta\sigma(j, j)$	< 1.5		
	$\Delta\sigma(\ell, E^{\ell}_{miss})$	< 1.5		
	$\min(p_T(\nu), p_T(jj))/m_{WV}$	$> 0.35(0.25)$ for DY/ggF (VBF) category		
Top veto	Number of additional b-tagged jets	0		≥ 1

W/Z boson tagger with TCCs

TrackCaloClusters (TCCs) used instead of LCTopo for Large-R jet reconstruction

- Support of ID tracks gives better $D_2^{\beta=1}$ resolution
- 2D re-optimized W/Z tagger working point for optimal signal sensitivity in this channel



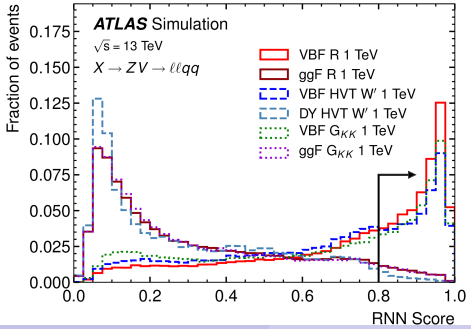


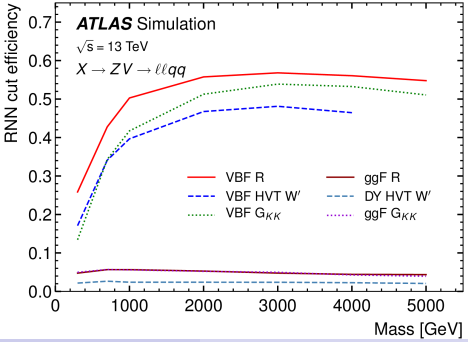
- 30% improvements for $m(VV) > 3$ TeV

RNN for VBF/ggF classification

Machine Learning technique to categorize ggF/VBF

- Using RNN with jet 4-momenta (p_T, E, η, ϕ) as inputs
- ggF(DY) vs. VBF signal training
- Exclude jets from hadronic boson candidate decay
- Up to 2 jets used for training
- WP optimized for same background rejection as previous cut-based strategy





Background modeling

Electroweak backgrounds:

- W/Z+jets: W/Z production associated with jets
- Top quark: both top-quark pair ($t\bar{t}$) & single-top quark
- SM Diboson: Non resonant diboson production (WW/WZ/ZZ)

W/Z+jets and $t\bar{t}$ use data from CRs to constraint normalization

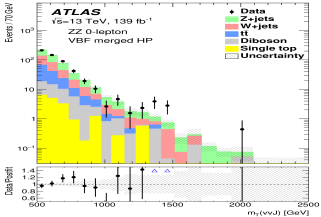
Multijet: Non resonant QCD multijet production:

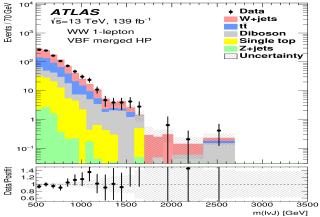
- Considered only in 1-lepton channel
- Shape derived from MJ-enriched region with inverted lepton ID
- Normalization derived from fit on MET distribution in WCR

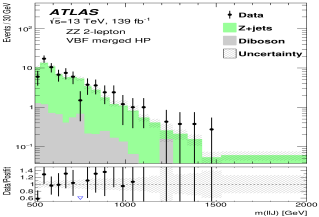
	Criterion	signal lepton	inverted lepton
Electron	ID	TightLH	MediumLH !TightLH
	Calo Isolation	FixedCutHighPtCaloOnlyIso	FixedCutHighPtCaloOnlyIso
Muon	ID	WHSignalMuon	WHSignalMuon
	Track Isolation	FixedCutTightTrackOnlyIso	!FixedCutTightTrackOnlyIso $ptvarcone30/p_T < 0.07$*
	*Only applied to events with $p_T(W) < 150 GeV$		

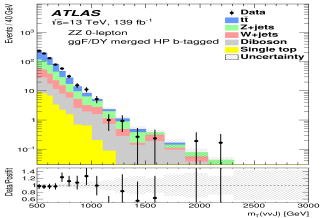
- For events with $p_T(W \to \mu\nu) > 150$ GeV, E_T^{miss} trigger is used

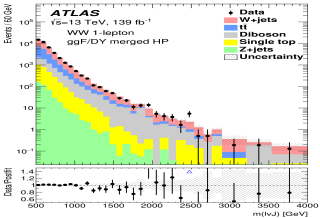
Postfit SR distribution

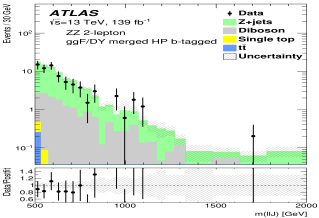






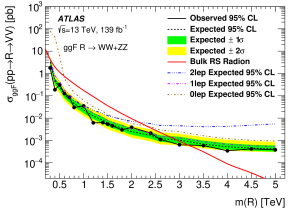


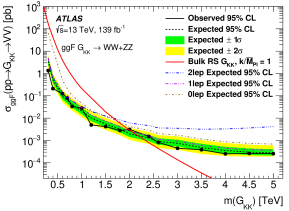


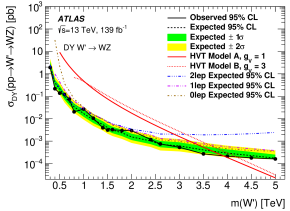


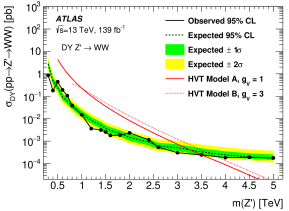
Results

Observed limits









Production process	RS radion	HVT			RS graviton
			W'	Z'	
ggF/DY	3.2 (2.9)	Model A	3.9 (3.8)	3.5 (3.4)	2.0 (2.2)
		Model B	4.3 (4.0)	3.9 (3.7)	
VBF	–	Model C	–	–	0.76 (0.77)

$m(G_{KK}) = 600$ GeV		$m(G_{KK}) = 2$ TeV	
Uncertainty source	$\Delta\mu/\mu$ [%]	Uncertainty source	$\Delta\mu/\mu$ [%]
Total	50	Total	59
Statistical	29	Statistical	48
Systematic	41	Systematic	34
Large-R jet	18	Large-R jet	24
MC statistics	16	MC statistics	17
Background normalisations	15	W/Z+jets modelling	15
Diboson modelling	12	Flavour tagging	5.5
W/Z+jets modelling	11	$t\bar{t}$ modelling	4.2
Small-R jet	9.7	Diboson modelling	3.9
$t\bar{t}$ modelling	8.1	Single-t modelling	3.3

Large-R jet relevant systematics have the largest impact

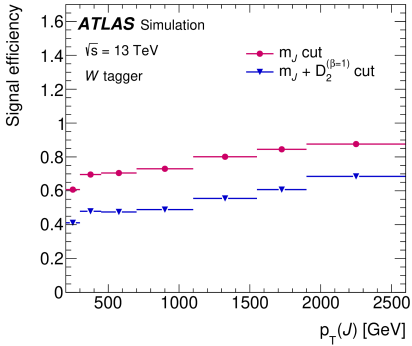
Summary

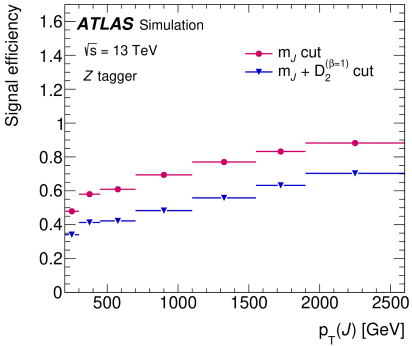
- Full Run-2 analysis in VV semi-leptonic
- Several new ideas for signal sensitivity improvements
  - TCC V boson tagger
  - ML-based ggF/VBF categorization
- No significant excess observed
- Limits set on several benchmark models (Radion, G_{kk}, W' and Z')
- Results published in Eur. Phys. J. C (2020) 80:1165

Thank you for your attention

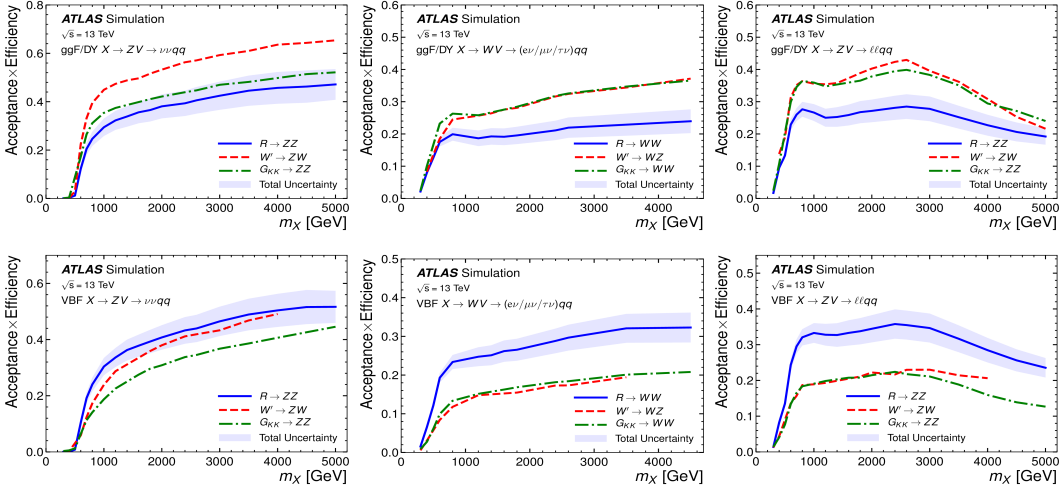
Backup

Boson tagger with TCCs





Acceptance × Efficiency



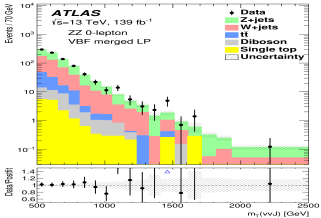
Large differences are due to the different spins of resonances

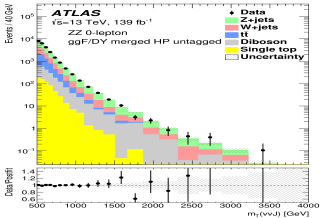
- Radion is produced with isotropic angular distributions
- HVT and RSG are produced more centrally (more forward) for ggF/DY (VBF)

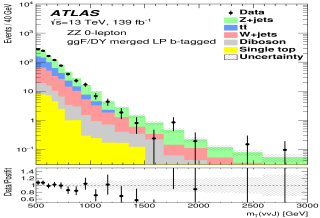
Expected background events

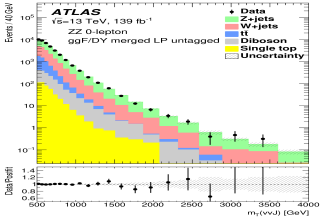
Channel	$V \to qq$ recon.	Signal regions			Background estimates					
					W+jets	Z+jets	$t\bar{t}$	Diboson	Single-t	Multijet	Total
					VBF category						
0-lepton (ZZ)	Merged	HP			169 ± 12	228 ± 16	102 ± 10	51 ± 10	24 ± 4	-	574 ± 25
		LP			370 ± 23	411 ± 20	75 ± 8	30 ± 4	21 ± 4	-	906 ± 33
					ggF/DY category						
	Merged	HP	Tag		133 ± 14	270 ± 40	437 ± 31	100 ± 10	45 ± 7	-	982 ± 60
			Untag		7600 ± 400	14 300 ± 600	6030 ± 270	2300 ± 180	840 ± 110	-	31 100 ± 800
		LP	Tag		259 ± 28	560 ± 50	342 ± 24	67 ± 7	43 ± 7	-	1270 ± 70
			Untag		16 300 ± 900	28 600 ± 1100	5040 ± 220	1760 ± 150	600 ± 80	-	52 400 ± 1500
					VBF category						
1-lepton (WW)	Merged	HP			530 ± 28	8.3 ± 0.5	321 ± 22	141 ± 27	113 ± 21	-	1110 ± 50
		LP			1380 ± 40	24.5 ± 1.1	228 ± 17	150 ± 33	83 ± 16	-	1870 ± 60
	Resolved				11 360 ± 190	530 ± 10	4060 ± 130	590 ± 80	1070 ± 210	960 ± 110	18 570 ± 340
					ggF/DY category						
	Merged	HP			24 820 ± 170	463 ± 5	13 890 ± 220	4910 ± 250	2800 ± 400	-	46 900 ± 500
		LP			60 270 ± 240	1095 ± 8	11 050 ± 160	3950 ± 210	1970 ± 250	-	78 300 ± 400
	Resolved				443 500 ± 1800	12 480 ± 40	126 000 ± 1500	16 800 ± 1200	21 200 ± 2800	27 200 ± 1400	647 000 ± 4000
					VBF category						
2-lepton (ZZ)	Merged	HP			0	87 ± 6	0.081 ± 0.009	9.6 ± 1.2	0	-	97 ± 6
		LP			0.133 ± 0.011	170 ± 8	0.85 ± 0.07	9.9 ± 1.2	0.43 ± 0.07	-	181 ± 8
	Resolved				0.272 ± 0.012	1566 ± 29	17.0 ± 0.7	72 ± 10	0.48 ± 0.32	-	1656 ± 31
					ggF/DY category						
	Merged	HP	Tag		0.0135 ± 0.0043	85 ± 6	0.283 ± 0.035	21.1 ± 2.3	0.34 ± 0.05	-	107 ± 7
			Untag		0.772 ± 0.010	3300 ± 40	4.27 ± 0.08	361 ± 32	0.58 ± 0.11	-	3670 ± 50
		LP	Tag		0.0135 ± 0.0043	138 ± 8	0.313 ± 0.034	12.8 ± 1.4	0.30 ± 0.04	-	152 ± 8
			Untag		2.341 ± 0.017	5920 ± 50	10.16 ± 0.16	278 ± 26	2.03 ± 0.29	-	6220 ± 60
	Resolved	Tag			-	1323 ± 26	110 ± 10	159 ± 12	4.7 ± 0.8	-	1600 ± 30
		Untag			4.681 ± 0.026	42 750 ± 160	110.6 ± 1.5	1800 ± 100	13.4 ± 2.0	-	44 650 ± 190

0 lepton channel

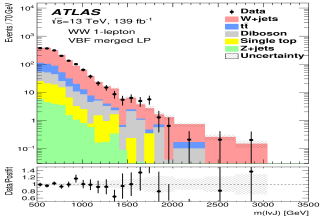


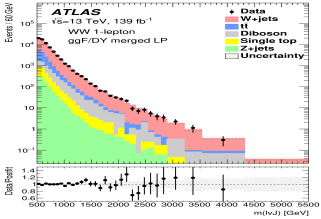


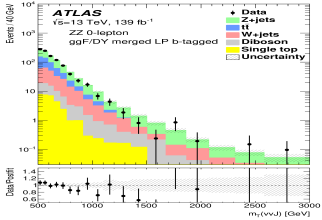


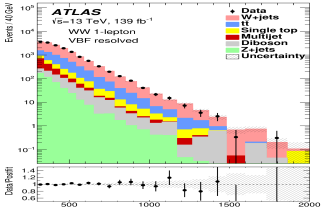


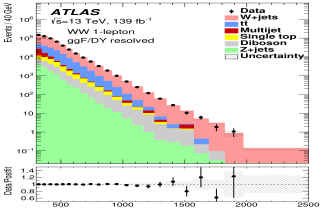
1 lepton channel



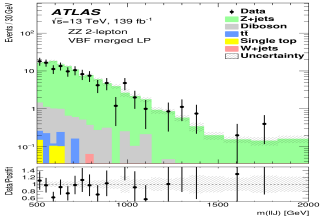


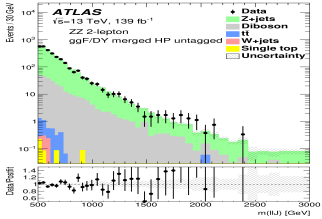


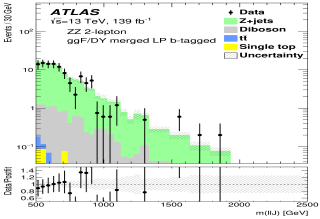


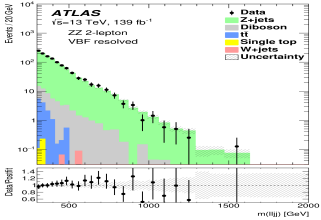


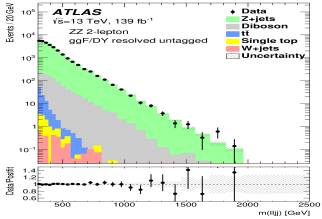
2 lepton channel

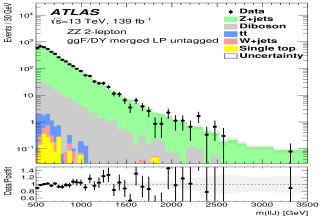












More limit plots