Search for heavy WW/WZ/ZZ resonances in semi-leptonic final states at ATLAS

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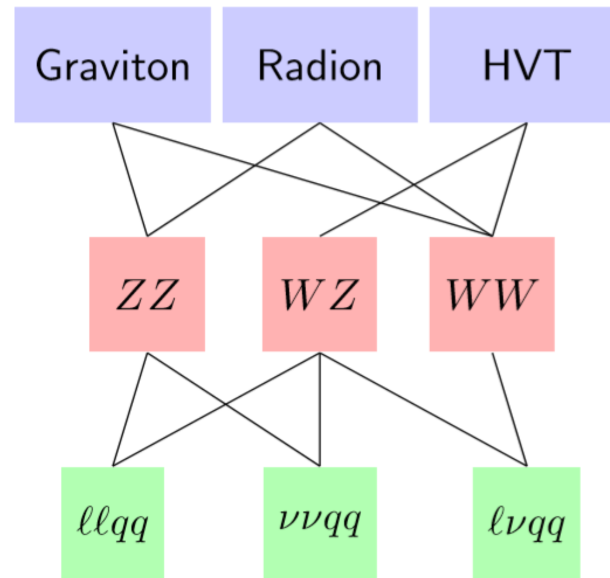
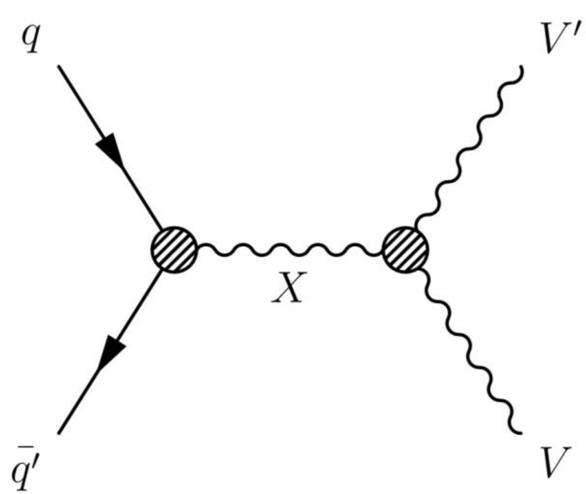
Motivation

- Searching for heavy VV resonances in semileptonic final states
  - One hadronic V decay:
    - Two small-R jets or one large-R jet
  - One leptonic V decay:
    - $l\bar{l}$, $l + E_{T,miss}$, or large $E_{T,miss}$
  - Can appear as resonant detector signature in invariant mass of the bosons





- Three benchmark models for different spin:

Spin-0: Radion from Randall-Sundrum models
- Phenomenology similar to heavy higgs

Spin-1: W'/Z' from Heavy Vector Triplet Model
- Couplings can be chosen to look like Extended Gauge Sector or Composite Higgs

Spin-2: Graviton from Randal-Sundrum
- "Bulk" extension where coupling to light-fermions suppressed

Overview

ATLAS EXPERIMENT

JHEP 03 (2018) 042
DOI: 10.1007/JHEP03(2018)042

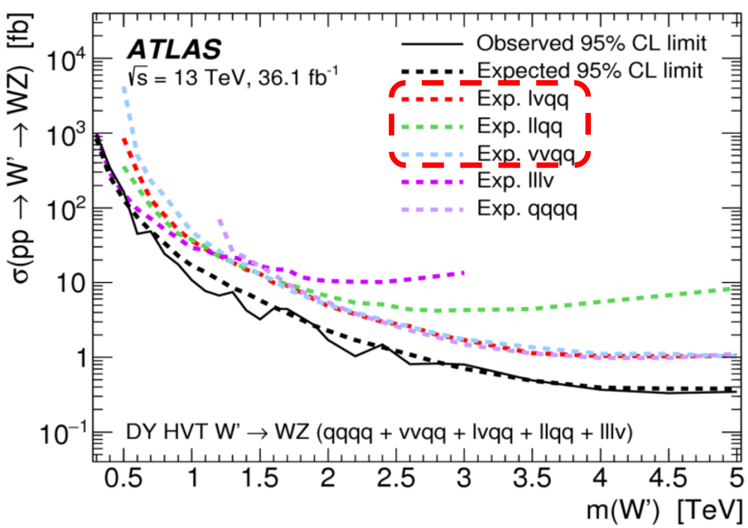
CERN-EP-2017-223
23rd March 2018

Search for WW/WZ resonance production in $\ell\nu qq$ final states in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

JHEP 03 (2018) 009
DOI: DOI:10.1007/JHEP03(2018)009

CERN-EP-2017-146
13th March 2018

Searches for heavy ZZ and ZW resonances in the $\ell\ell qq$ and $\nu\nu qq$ final states in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector



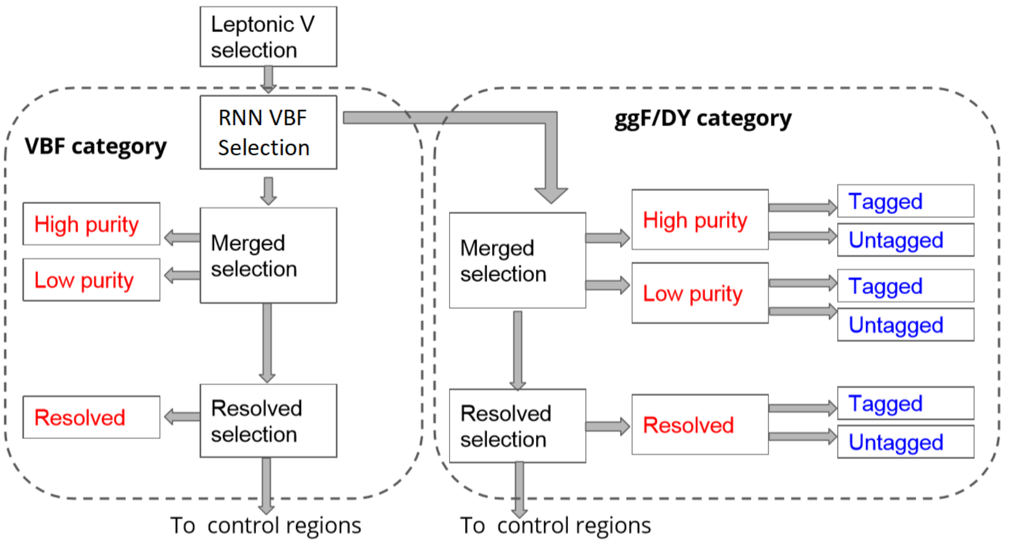
Previously two separate publications:
- Based on 2015+2016 data
- $l\nu q\bar{q}$ and $llq\bar{q} + \nu\nu q\bar{q}$ separated

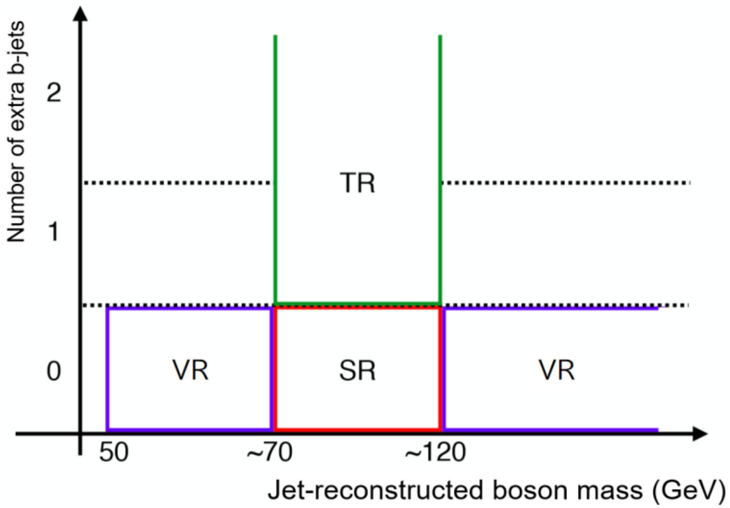
- Update in this round:
  - Full Run-2 data
  - Analysis harmonizations
  - Z → bb with VR-jets
  - Track-CaloCluster jets
  - Radion and VBF Graviton
  - RNN GGF/VBF classifications

Analysis strategy

Cut strategy similar with preivous rounds:

- Three orthogonal channels in lepton multiplicity
- ggF/VBF classification
- Merged selection based on high/low-purity V-tagging
- Merged first strategy
- Categorize Z → qq/bb





Use side-band regions to constrain major backgrounds:

- W+jets CR (WR) / Z+jets CR (ZR): Mass sidebands of 1/2-lepton channel
- Validation Region (VR): Mass sidebands of 0-lepton channel
- $t\bar{t}$ CR (TR) : Additional b-jets in 1-lepton channel

Analysis strategy

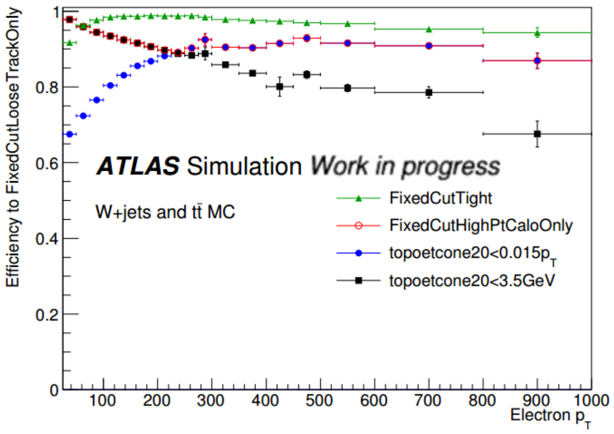
Background estimation:

- W/Z + jets: Sherpa 2.2.1
- ttbar: PwPy8
- single-top : PwPy8
- diboson : Sherpa 2.2.1
- multijet : estimated in data-driven method, used only in 1-lepton channel resolved regime.

Regions			Spin-1 triplet fit model ($W' \to ZW$ and $Z' \to WW$)					
			Merged HP		Merged LP		Resolved	
			Tagged	Untagged	Tagged	Untagged	Tagged	Untagged
0-lepton	ggF	SR	✓	✓	✓	✓	–	
	VBF	SR	✓		✓		–	
1-lepton	ggF	SR	✓	✓	✓	✓	✓	✓
		WCR	✓	✓	✓	✓	✓	✓
		TopCR	✓	✓	✓	✓	✓	✓
	VBF	SR	✓		✓		✓	
		WCR	✓		✓		✓	
		TopCR	✓		✓		✓	
2-lepton	ggF	SR	✓	✓	✓	✓	✓	✓
		ZCR	✓	✓	✓	✓	✓	✓
		TopCR	–	–	–	–	✓	–
	VBF	SR	✓		✓		✓	
		ZCR	✓		✓		✓	

Object selection

Jet: small-R jets, large-R jets, VR jets
Lepton: electron and muon ID,
MET: reconstruction by negative sum
B-tagging: MV2c10 85%
Overlap removal



Lepton selection

- 1-lepton:
  Tight ID, pT > 7GeV, |η|<2.47 (2.5)
- 2-lepton:
  Loose ID, pT > 30 GeV, |η|<2.47 (2.5)

Isolation:

FixedCutHighPtCaloOnly FixedCutTightTrackOnly

FCLoose (pT <100GeV)

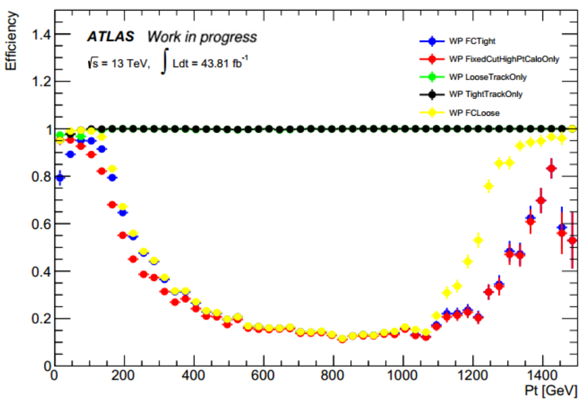


Table 3: Summary of electron selection

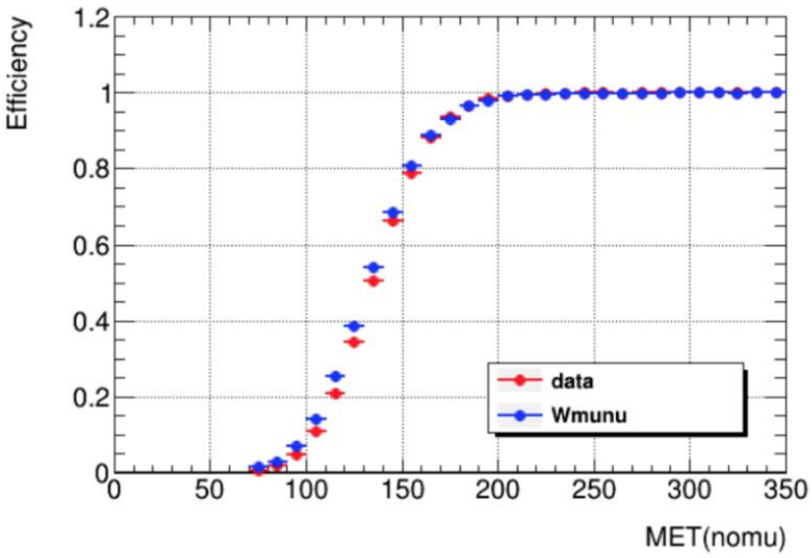
Feature	*Loose*	*Tight*
Pseudorapidity range	$\|\eta\| < 2.47$	
Energy calibration	"es2017_R21_v0" (ESModel)	
Transverse momentum	$p_T > 7$ GeV	> 30 GeV
Object quality [44]	Not from a bad calorimeter cluster (BADCLUSELECTRON)	
	Remove clusters from regions with EMEC bad HV (2016 data only)	
Track to vertex association	$\|d_0^{BL}(\sigma)\| < 5$	
	$\|\Delta z_0^{BL} \sin\theta\| < 0.5$ mm	
Identification	Loose	Tight
Isolation	FCLoose at $p_T < 100$ GeV and no isolation requirement at > 100 GeV	FixedCutHighPtCaloOnly

Table 4: Summary of muon selections

Criteria	*Loose*	*Tight*
Pseudorapidity range	$\|\eta\| < 2.5$	
Momentum Calibration	Sagitta Correction Used	
Transverse momentum	$p_T > 7$ GeV	$p_T > 30$ GeV
d_0 Significance Cut	$\|d_0^{BL}(\sigma)\| < 3$	
z_0 Cut	$\|z_0^{BL} \sin\theta\| < 0.5$ mm	
Selection Working Point	Loose	Medium
Isolation Working Point	FCLoose at $p_T < 100$ GeV and no isolation requirement at > 100 GeV	FixedCutTightTrackOnly

Event selection

- Trigger requirement
  - Single(double) lepton trigger is selected for 1(2) lepton channel
  - MET trigger for 0-lepton channel
  - $\mu v q\bar{q}$ channel found low efficiency for high pT events, so MET trigger is specifically used for $\mathrm{pT}(\mu v) > 150\mathrm{GeV}$



Data-taking period	$e\nu qq$ and $eeqq$ channels	$\mu\nu qq$ ($p_{\mathrm{T}}(\mu\nu) < 150$ GeV) and $\mu\mu qq$ channels	$\mu\nu qq$ ($p_{\mathrm{T}}(\mu\nu) > 150$ GeV) and $\nu\nu qq$ channels
2015	HLT_e24_lhmedium_L1EM20 OR HLT_e60_lhmedium OR HLT_e120_lhloose	HLT_mu20_iloose_L1MU15 OR HLT_mu50	HLT_xe70
2016a (run < 302919) ($L < 1.0 \times 10^{34}\ cm^{-2}\ s^{-1}$)	HLT_e26_lhtight_nod0_ivarloose OR HLT_e60_lhmedium_nod0 OR HLT_e140_lhloose_nod0 HLT_e300_etcut	HLT_mu26_ivarmedium OR HLT_mu50	HLT_xe90_mht_L1XE50
2016b (run ≥ 302919) ($L < 1.7 \times 10^{34}\ cm^{-2}\ s^{-1}$)	same as above	same as above	HLT_xe110_mht_L1XE50
2017	same as above	same as above	HLT_xe110_pufit_L1XE55
2018	same as above	same as above	HLT_xe110_pufit_xe70_L1XE50

Event selection

- 0-lepton
  - Merged only

    $Z \rightarrow vv$: No loose lepton, $E_T^{miss} > 250GeV$

    $Z/W \rightarrow qq$: One large-R jet

    Anti-QCD: $p_T^{miss} > 250GeV, \min(\Delta\phi(E_T^{miss}, j)) > 0.4,$
    $\Delta\phi(E_T^{miss}, p_T^{miss})$ <1.0

Selection	SR		VR	
	HP	LP	HP	LP
Number of Loose leptons	0			
E_T^{miss}	> 250 GeV			
p_T^{miss}	> 50 GeV			
$\min(\Delta\Phi(E_T^{miss}$,small-R jets))	> 0.4			
$\Delta\Phi(E_T^{miss}, p_T^{miss})$	< 1			
Number of large-R jets	$\geqslant$ 1 large-R jets			
D_2 cut	pass	fail	pass	fail
W/Z mass window cut	pass	pass	m_J > 50 GeV, fail mass window cut	
Numb. of associated VR track jets b-tagged	For $Z \rightarrow J$: ≤ 1 (= 2) for untagged (tagged) category			

Event selection

- 1-lepton
  - Merged(Resolved) common selection:
    $W \rightarrow l\nu$: One tight lepton
    Anti-QCD: $E_T^{miss} > 100(60)GeV,$
    $p_{T,l\nu} > 200(75)GeV$
  - Separated selection
    - Merged: ggF(VBF)
      One large R jet
      $\min(p_{T,l\nu}, p_{T,J})/m_{WV} > 0.35(0.25)$ boson relative pT cut

Selection		SR HP	SR LP	W CR (WR) HP	W CR (WR) LP	$t\bar{t}$ CR (TR1) HP	$t\bar{t}$ CR (TR1) LP
$W \rightarrow \ell\nu$	Num of Tight leptons	1					
	Num of Loose leptons	0					
	E_T^{miss}	> 100 GeV					
	$p_T(\ell\nu)$	> 200 GeV					
$W/Z \rightarrow J$	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 $Z \rightarrow J$: ≤ 1 ($= 2$) for untagged (tagged) category					
Topology cut	$\min(p_{T,\ell\nu}, p_{T,J})/m_{WV}$	$> 0.35(0.25)$ for DY/ggF (VBF) category					
Top-quark veto	Num of b-tagged jets outside of large-R jet	0				≥ 1	
Pass VBF selection		no (yes) for DY/ggF (VBF) category					

Event selection

1-lepton

Separated selection

- Resolved: ggF(VBF)
  Two small jets
  $\Delta\phi(l, E_T^{miss}) < 1.5$, $\Delta\phi(j1, j2) < 1.5$, $\Delta\phi(l, j1{,}2) < 1.5$, $\Delta\phi(E_T^{miss}, j1{,}2) > 1.0$ for topology requirement
  $\min(p_{T,lv}, p_{T,jj})/m_{WV} > 0.35(0.25)$ boson relative pT to enhance signal

cuts		SR	W CR (WR)	$t\bar{t}$ CR (TR1)
$W \to \ell\nu$	Number of Tight leptons	1		
	Number of Loose leptons	0		
	E_T^{miss}	> 60 GeV		
	$p_T(\ell\nu)$	> 75 GeV		
$W/Z \to jj$	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	$105. < m_{jj} < 150.$ GeV	
	Num. of b-tagged jets	For $Z \to jj$: ≤ 1 (= 2) for untagged (tagged) category		
Topology cuts	$\Delta\phi(j, \ell)$	> 1.0		
	$\Delta\phi(j, E_T^{miss})$	> 1.0		
	$\Delta\phi(j, j)$	< 1.5		
	$\Delta\phi(\ell, E_T^{miss})$	< 1.5		
	$\min(p_{T,\ell\nu}, p_{T,jj})/m_{WV}$	$> 0.35(0.25)$ for DY/ggF (VBF) category		
Top veto	Number of additional b-tagged jets	0		≥ 1
Pass VBF selection		no (yes) for DY/ggF (VBF) category		

Event selection

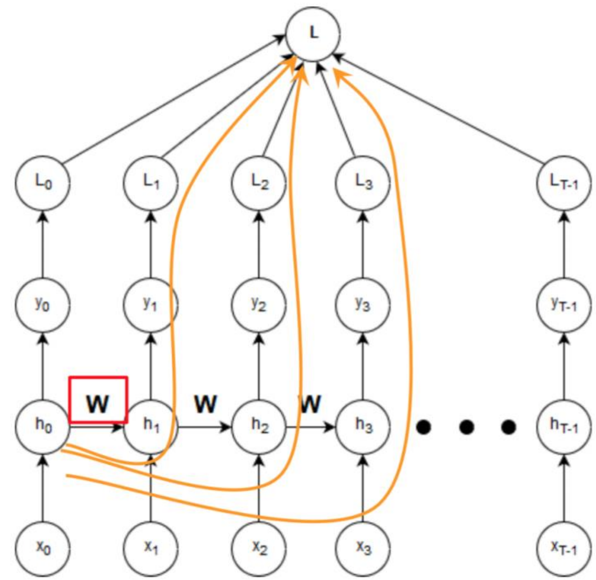
2-lepton

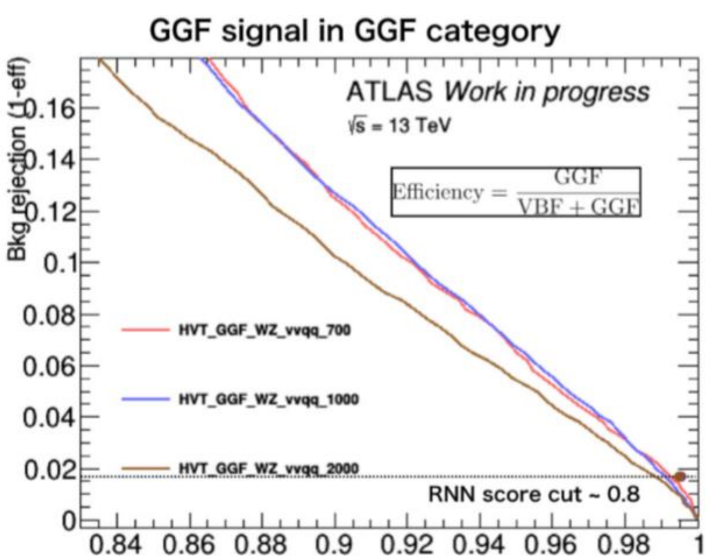
- Merged(Resolved) shared selection:
  $Z \rightarrow ll$: Two loose leptons
  $p_{T,sublep} > 30GeV$
- Separated selection
  - Merged: ggF(VBF)
    One large R jet
    $\min(p_{T,lv}, p_{T,J})/m_{WV} > 0.35(0.25)$ boson relative pT cut

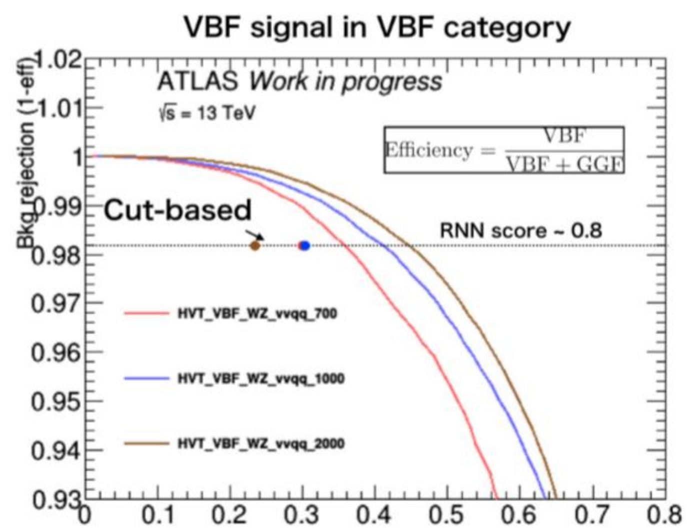
Selection		SR		W CR (WR)		$t\bar{t}$ CR (TR1)	
		HP	LP	HP	LP	HP	LP
$W \rightarrow \ell\nu$	Num of Tight leptons	1					
	Num of Loose leptons	0					
	$E_{\mathrm{T}}^{\mathrm{miss}}$	> 100 GeV					
	$p_{\mathrm{T}}(\ell\nu)$	> 200 GeV					
$W/Z \rightarrow J$	Num of large-R jets	≥ 1					
	D_2 cut	pass	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 $Z \rightarrow J$: ≤ 1 (= 2) for untagged (tagged) category					
Topology cut	$\min(p_{\mathrm{T},\ell\nu}, p_{\mathrm{T},J})/m_{WV}$	> 0.35(0.25) for DY/ggF (VBF) category					
Top-quark veto	Num of b-tagged jets outside of large-R jet	0				≥ 1	
Pass VBF selection		no (yes) for DY/ggF (VBF) category					

Event selection

- RNN for VBF/ggF Classification
- Developed ML technique
  - Using a RNN with jet 4-momenta as inputs
  - RNN architecture since N(jets) is variable
  - WP optimized for same background rejection as the cut-based
  - Significant efficiency gain

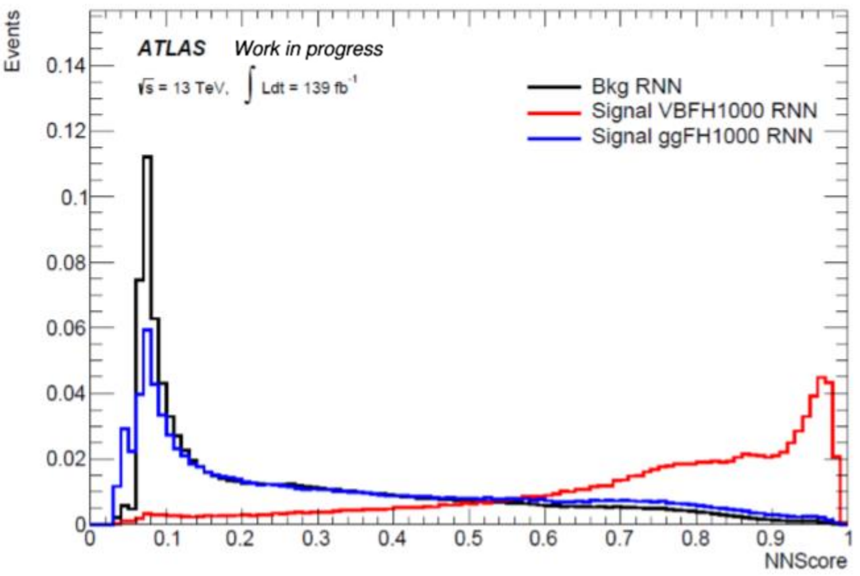


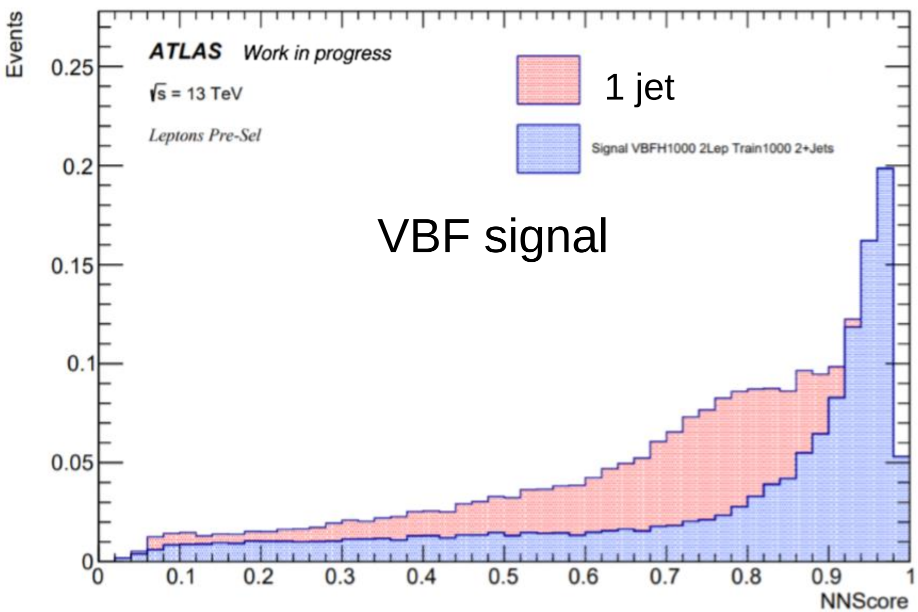


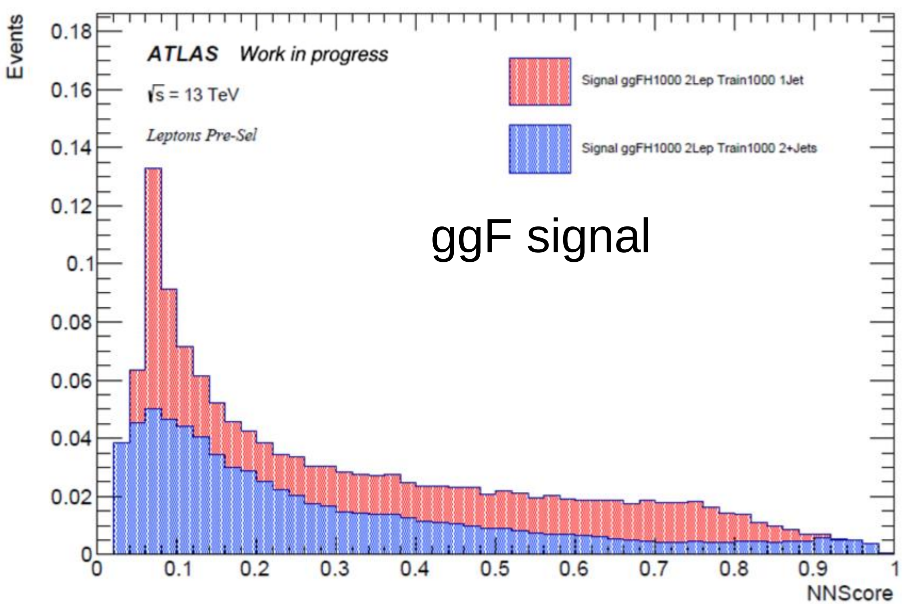


ggF/VBF categorization

- **RNN for VBF/ggF Classification**
  - Can select VBF events even one of VBF jets is too soft to reconstructed
  - Good discriminant power on signal
  - Optimized RNN ggF cut : >0.8
  - Significant senvivtity gain





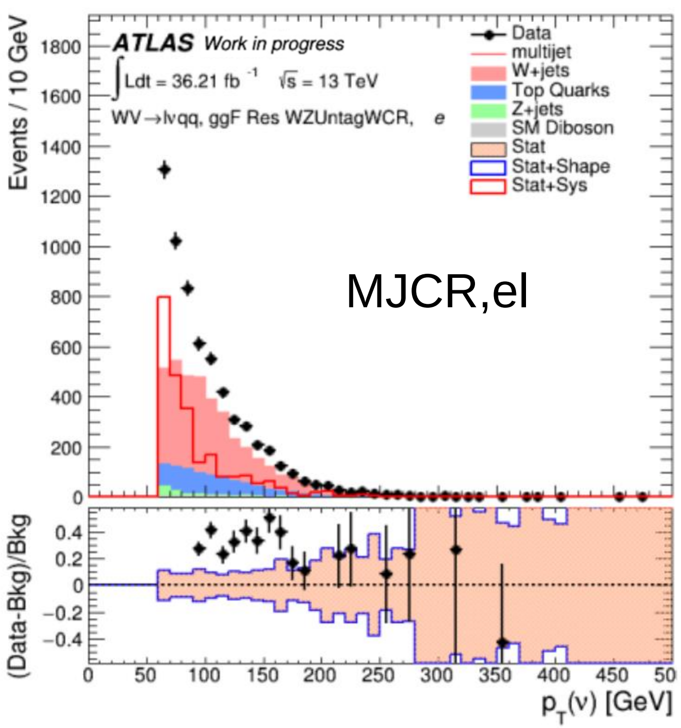


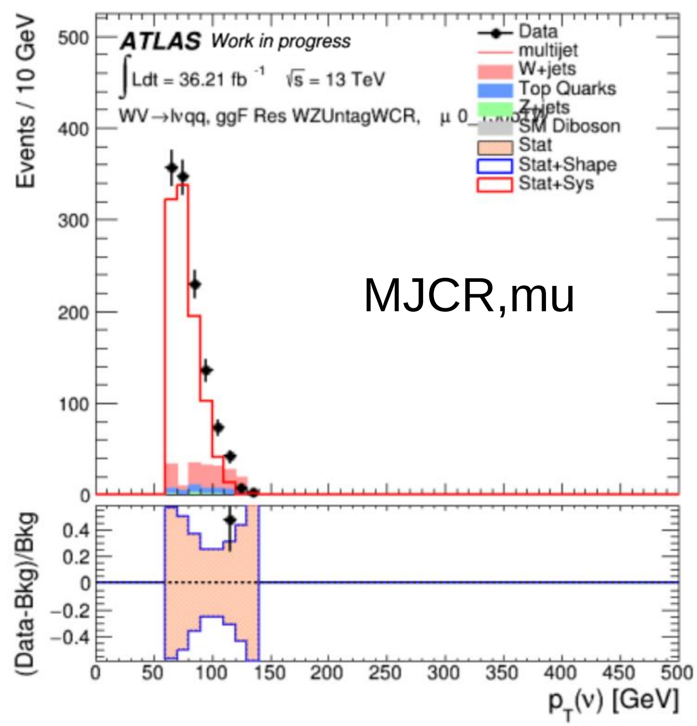
Fake Lepton Estimation

Fake lepton estimation in lvqq from template method

- Shape derived in MJ-enriched region with inverted lepton ID
  only estimate events with single lepton trigger
- Data

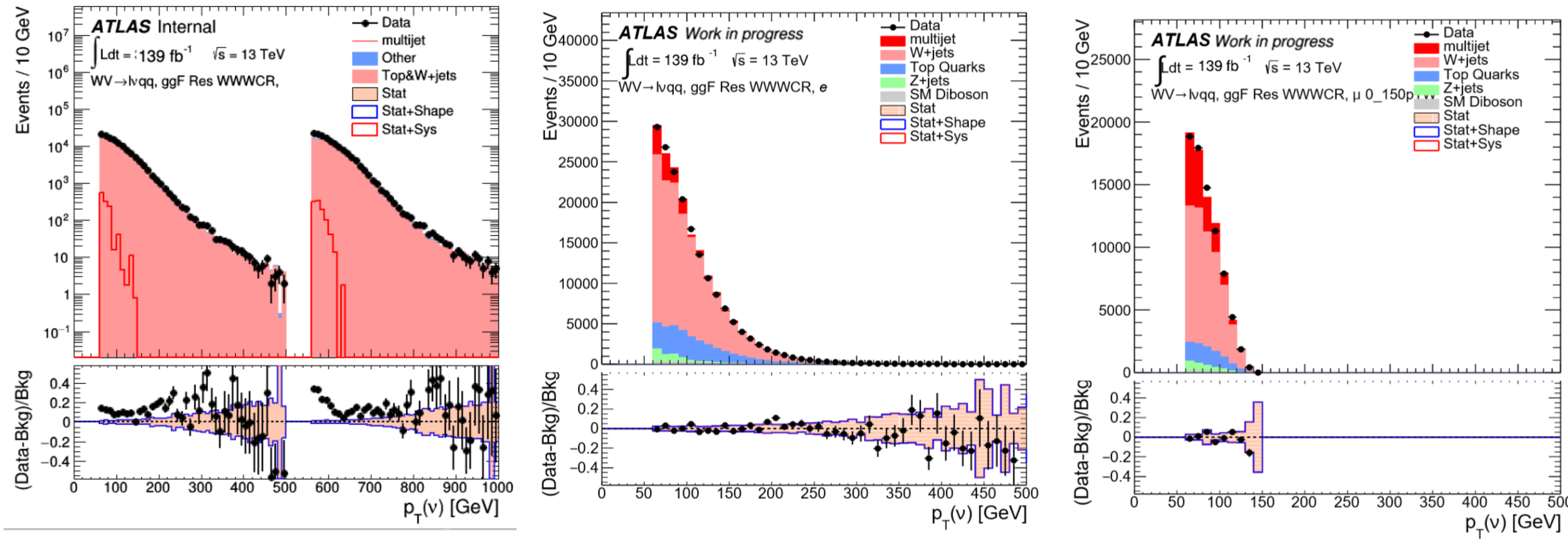
	Criterion	signal lepton	inverted lepton
Electron	ID	TightLH	MediumLH !TightLH
	Calo Isolation	FixedCutHighPtCaloOnlyIso	FixedCutHighPtCaloOnlyIso
Muon	ID	WHSignalMuon	WHSignalMuon
	Track Isolation	FixedCutTightTrackOnlyIso	!FixedCutTightTrackOnlyIso $ptvarcone30/pt < 0.07^*$
	*Only applied to events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





Fake Lepton Estimation

- Validation of MJ estimation by WCR combined fit
  - Electron and muon share background normalization.
  - Electron and muon MJ normalization is uncorrelated
  - Fitting result is promising



Sample	Yield	R.U.	SF
Top&W	645040 ± 1971.68	0.31%	0.998
Z&VV	24075.9	fixed	
MJ_el	24156.3 ± 1224.62	5.06%	3.973
MJ_mu	35528.5 ± 923.94	2.60%	9.019

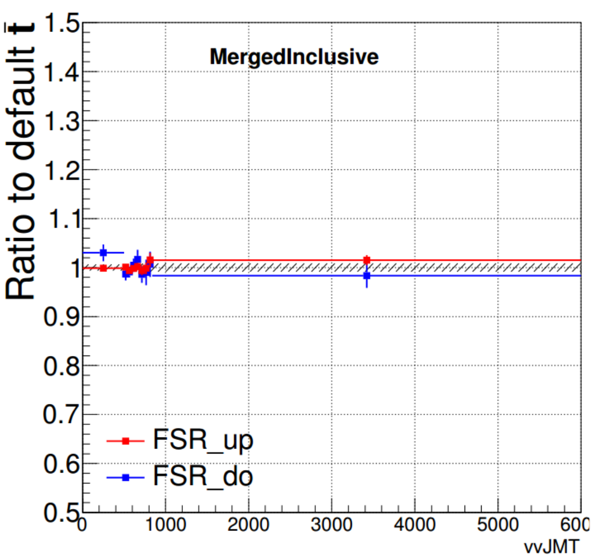
Systematics

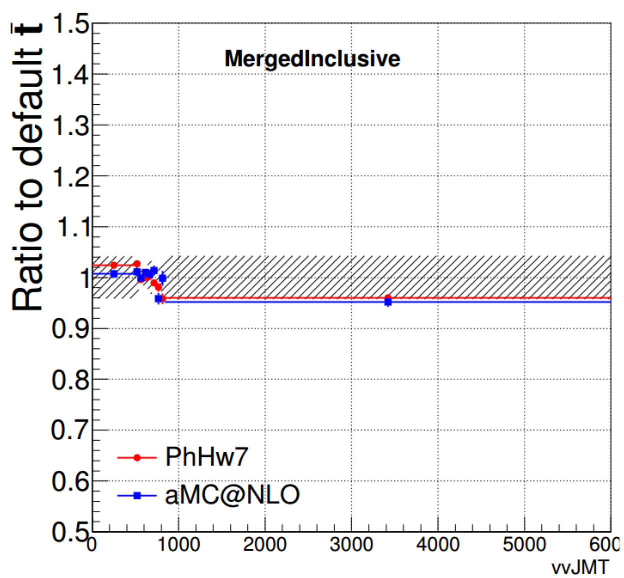
- Expermental Systematics: lepton, jets, MET, b-tagging, lumi
- Background modeling uncertainties:-Vjets, MJ, VV, singlet, ttbar
- Signal modeling

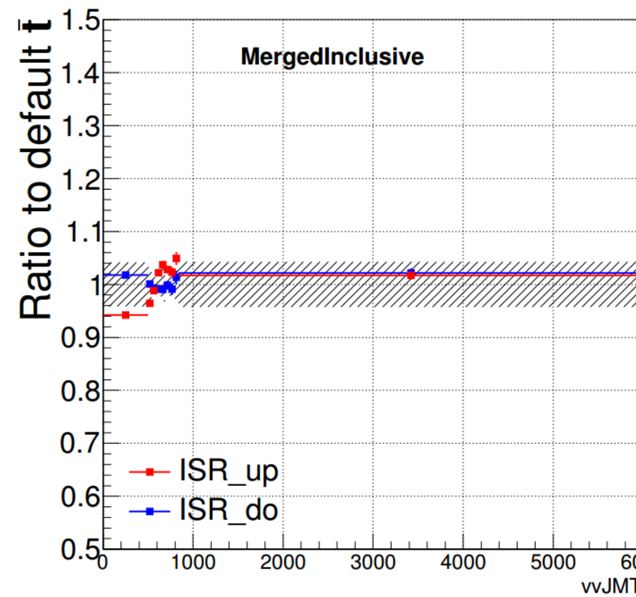
ttbar modeling:

More details in backup

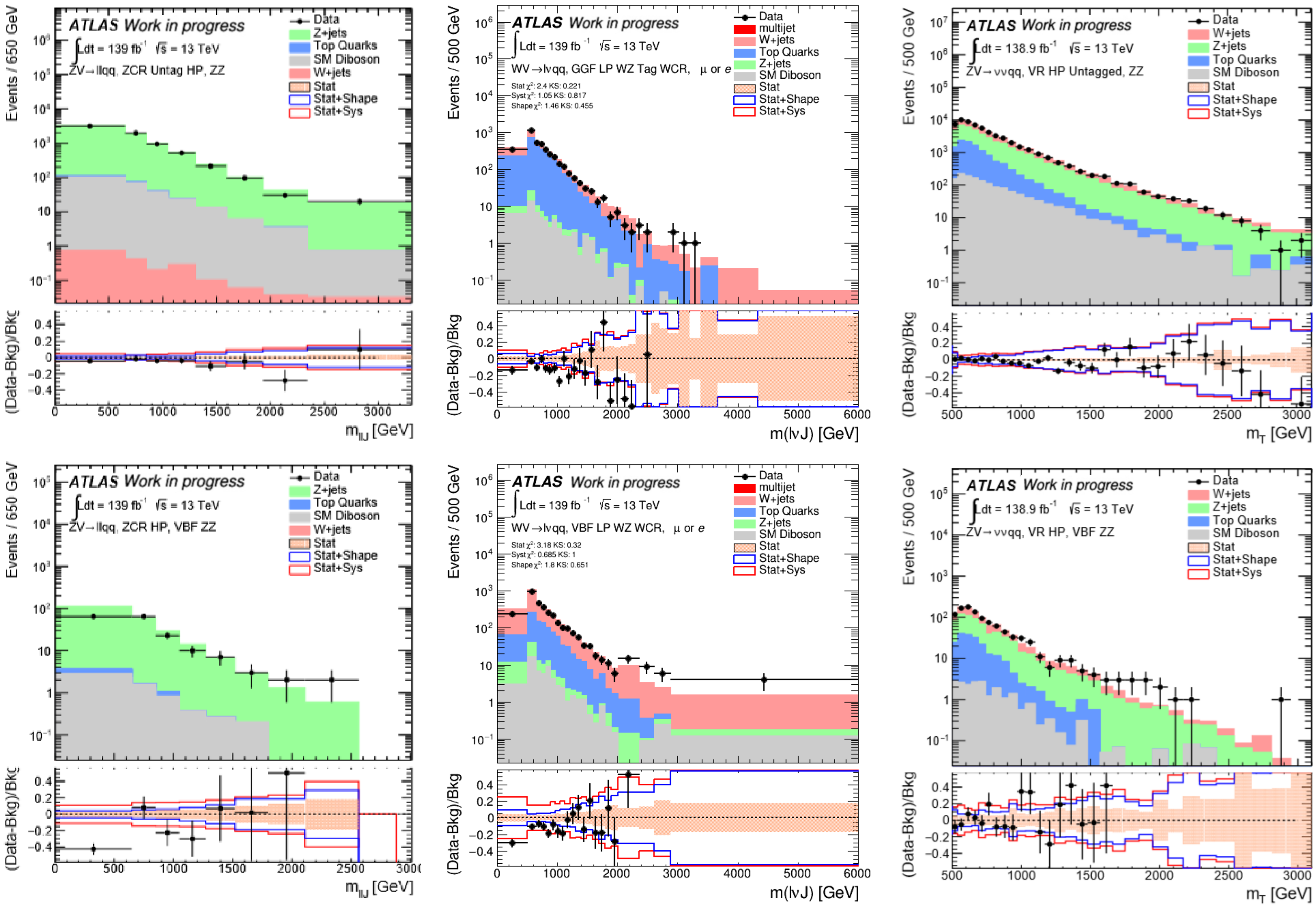
Variation of hadronization: Pythia8 -> Herwig7
Variation of generator: Powheg -> AcerMC@NLO
Variation of ISR and FSR: different weight





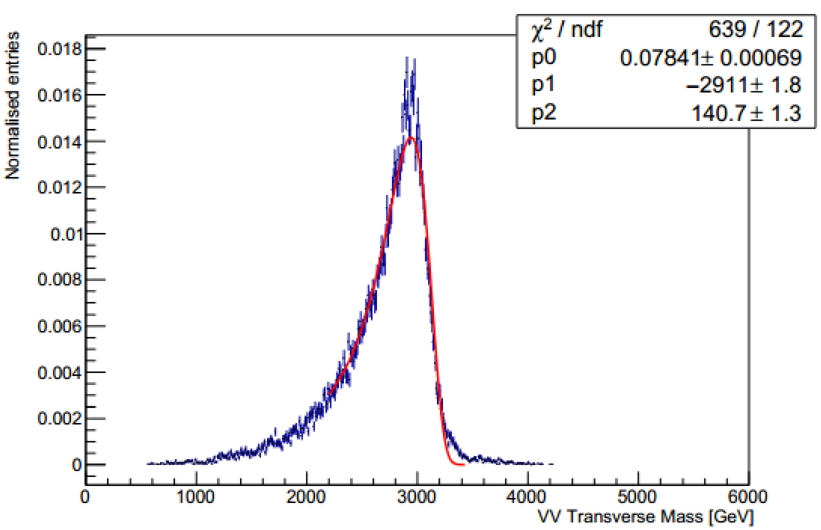


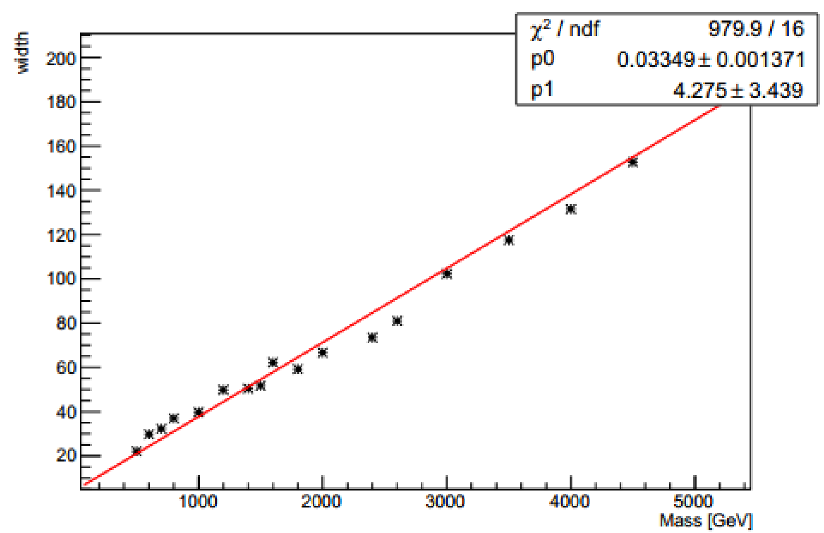
Prefit CR Distributions



Fit strategy

- Fit binning:
  - Signal resolution is checked for each mass point
    - Resolution defined as σ of Gaussian fit for 1 and 2 lepton signals
    - For 0 lepton used width from fit with Landau function
  - Bin edges defined such that:
    - Width is larger than resolution
    - Number of background events is greater than 0
    - Fractional error on the background is less than 75%*

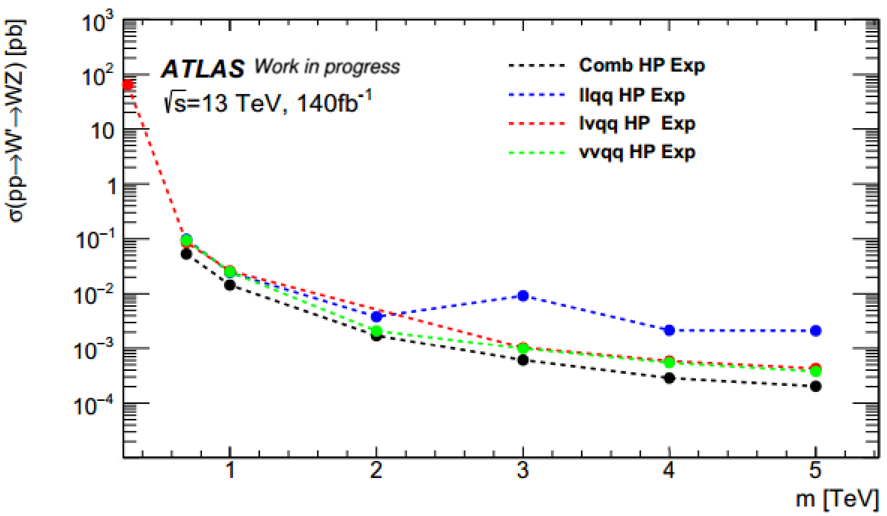


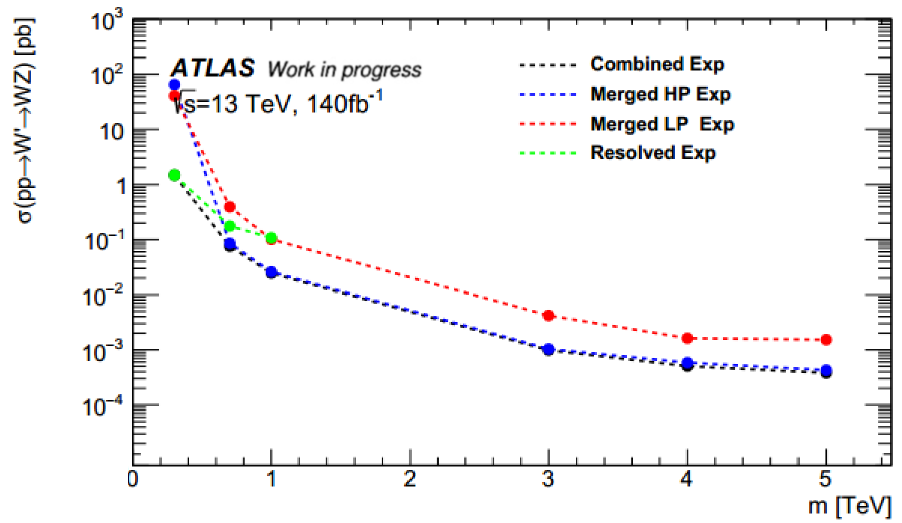


*WIP

Fit result

- Working on Blinded fit (CR/VR only) result





Both combined and individual fit result looks fine, but llqq 3TeV points result is under investigation.

Summary

- DBL VV Semileptonic analysis with Full Run 2 data.
- Analysis strategy stays similar with 2015+16 analysis but with further optimization.
- Most parts of analysis (selection optimization, systematics study, fake lepton estimation) finalized.
- Statistical study is under investigation.
- Aiming for publication soon

Backup

Object selection

Lepton selection

- 1-lepton:
  Tight ID, pT > 7GeV, |η|<2.47 (2.5)
- 2-lepton:
  Loose ID, pT > 30 GeV, |η|<2.47 (2.5)

Isolation:

FixedCutHighPtCaloOnly

FCLoose

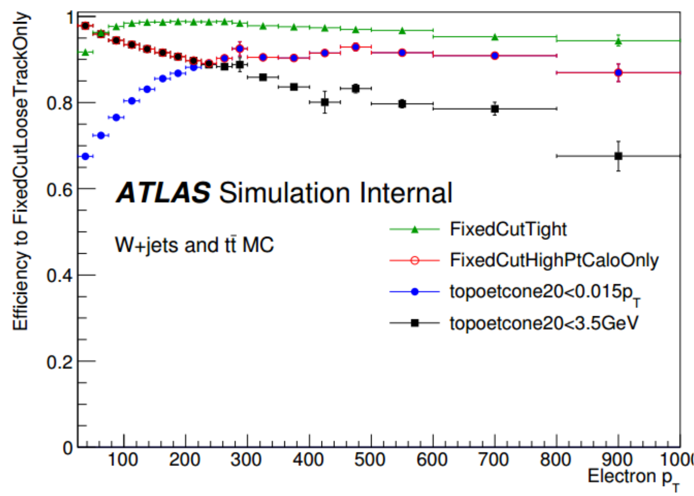
(pT <100GeV)

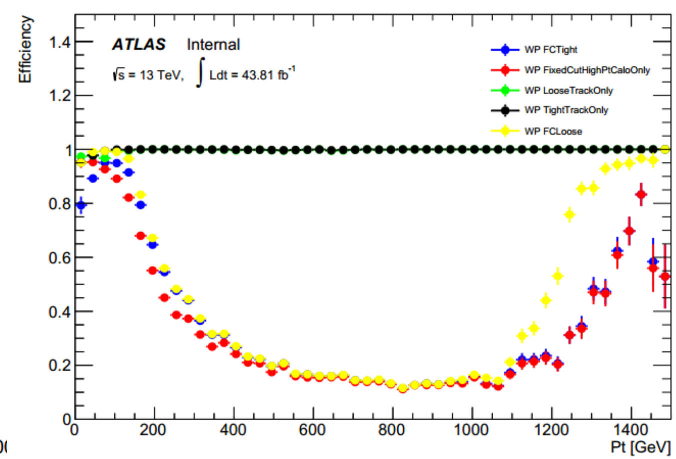
Table 3: Summary of electron selection

Feature	*Loose*	*Tight*
Pseudorapidity range	$\|\eta\| < 2.47$	
Energy calibration	"es2017_R21_v0" (ESModel)	
Transverse momentum	$p_T > 7$ GeV	> 30 GeV
Object quality [44]	Not from a bad calorimeter cluster (BADCLUSELECTRON)	
	Remove clusters from regions with EMEC bad HV (2016 data only)	
Track to vertex association	$\|d_0^{BL}(\sigma)\| < 5$	
	$\|\Delta z_0^{BL} \sin\theta\| < 0.5$ mm	
Identification	Loose	Tight
Isolation	FCLoose at $p_T < 100$ GeV and no isolation requirement at > 100 GeV	FixedCutHighPtCaloOnly

Table 4: Summary of muon selections

Criteria	*Loose*	*Tight*
Pseudorapidity range	$\|\eta\| < 2.5$	
Momentum Calibration	Sagitta Correction Used	
Transverse momentum	$p_T > 7$ GeV	$p_T > 30$ GeV
d_0 Significance Cut	$\|d_0^{BL}(\sigma)\| < 3$	
z_0 Cut	$\|z_0^{BL} \sin\theta\| < 0.5$ mm	
Selection Working Point	Loose	Medium
Isolation Working Point	FCLoose at $p_T < 100$ GeV and no isolation requirement at > 100 GeV	FixedCutTightTrackOnly





Object selection

Jet selection

- Small-R jet selection
  - AntiKt4EMTopoJets
  - $|\eta|<2.5$
  - Medium JVT WP

- Large-R jet selection
  - AntiKt10TrackCaloClusterTrimmedPtFrac5SmallR20Jets
  - $|\eta|<2.0$
  - pT>200GeV, mass > 50GeV
  - WZ Tagger

Table 5: Summary of small-R jet selection and calibration

Jet reconstruction parameters		
Parameter	Value	
algorithm	anti-k_T	
R-parameter	0.4	
input constituent	EMTopo	
Analysis Release Number	21.2.66	
CalibArea tag	00-04-81	
Calibration configuration	JES_data2017_2016_2015_Consolidated_EMTopo_2018_Rel21.config	
Calibration sequence (Data)	JetArea_Residual_EtaJES_GSC_Insitu_Smear	
Calibration sequence (MC)	JetArea_Residual_EtaJES_GSC_Smear	
Selection requirements		
	"Signal" jet	**"VBF" jet**
Observable	Requirement	
Jet cleaning	LooseBad	
BatMan cleaning	No	
p_T	>30 GeV	
$\|\eta\|$	<2.5	< 4.5
JVT	> 0.59 for p_T <120 GeV and $\|\eta\|$ < 2.4 > 0.11 for p_T <120 GeV and 2.4 < $\|\eta\|$ < 2.5 (Medium working point)	
b-tagging (See Sec. 4.7)	Tagged, or not tagged	Not tagged

Table 6: Summary of large-R jet selection and calibration

Jet reconstruction parameters	
Parameter	Value
algorithm	anti-k_T
R-parameter	1.0
input constituent	TrackCaloCluster
grooming algorithm	Trimming
f_{cut}	0.05
R_{trim}	0.2
Analysis Release Number	21.2.47
Calibration configuration	JES_MC16recommendation_FatJet_TCC_JMS_calo_30Oct2018.config
Calibration sequence (Data& MC)	EtaJES_JMS
Selection requirements	
Observable	Requirement
p_T	>200 GeV
$\|\eta\|$	<2.0
mass	> 50 GeV
SmoothedWZTagger	
Object	Working point
W/Z	Optimized working point

Object selection

MET reconstruction:

- reconstructed by negative sum of the all physics objects and ID tracks not associated with them

B-tag requirement:

- MV2c10 algorithm
- Working point 85%

- Variable-radius jet
  For boosted b-tag
  pT-dependent cone size
  |η|<2.5

Table 8: Summary of E_T^{miss} reconstruction configuration.

MET reconstruction parameters	
Parameter	Value
Algorithm	Calo-based
Soft term	Track-based (TST)
MET operating point	Tight

Table 9: Summary of *b*-tag requirement in the resolved category

Jet collection	AntiKt4EMTopoJets
Jet selection	"Signal jet" selection in Table 5
Algorithm	MV2c10
Operating point	Fixed Eff = 85%
CDI	boosted-CDI-30-07-2019

Table 10: Summary of *b*-tag requirement in the merged category.

Jet collection	AntiKtVR30Rmax4Rmin02
Algorithm	MV2c10
Operating point	Fixed Eff = 85%
CDI	boosted-CDI-30-07-2019

Table 7: Summary of VR track jet selection.

Jet reconstruction parameters	
Parameter	Value
algorithm	anti-k_T
R-parameter	–
input constituent	TrackParticles
Observable	Requirement
p_T	>10 GeV
$\|\eta\|$	<2.5

No calibration is available for VR track jets.

Object selection

Overlap removal

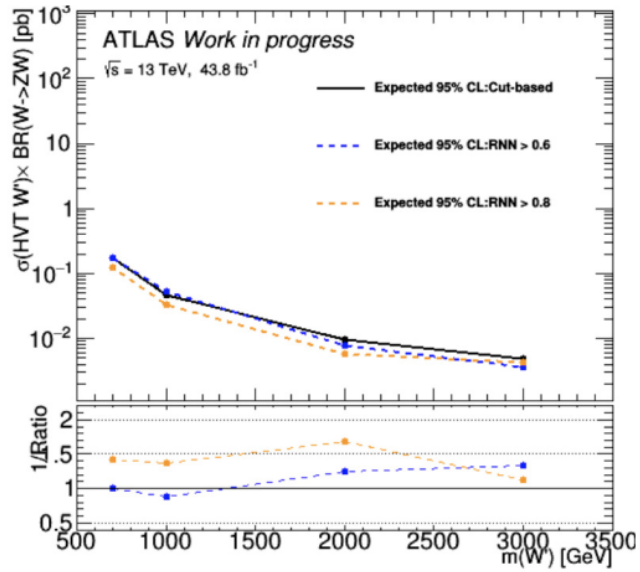
- OR is proceeded to get rid of double counting object (reconstruct same energy deposit as multiple objects)

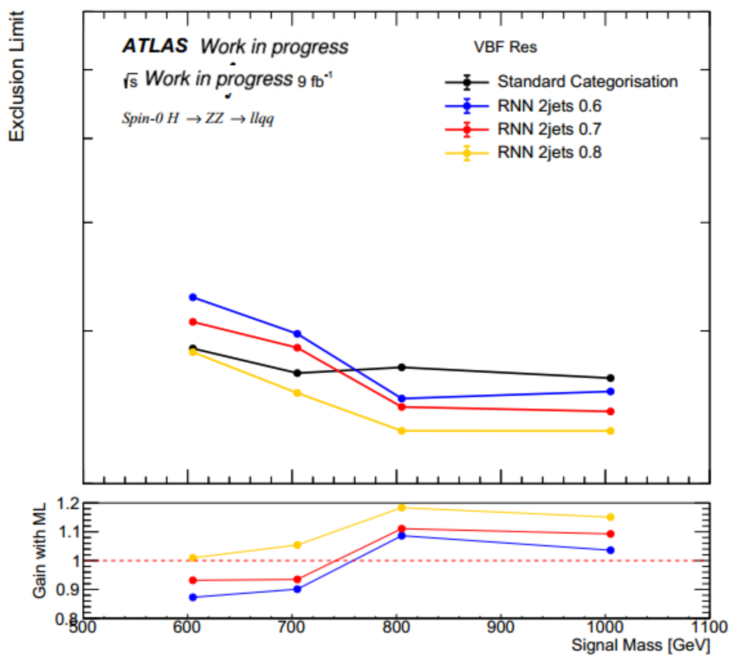
Reject	Against	Criteria
electron	electron	shared track, $p_{T,1} < p_{T,2}$
muon	electron	is calo-muon and shared ID track
electron	muon	shared ID track
jet	electron	$\Delta R < 0.2$
electron	jet	$\Delta R < 0.4$
jet	muon	NumTrack < 3 and (ghost-associated or $\Delta R < 0.2$)
muon	jet	$\Delta R <$ min(0.4, 0.04 + 10GeV/MuPt)
fat-jet	electron	$\Delta R < 1.0$

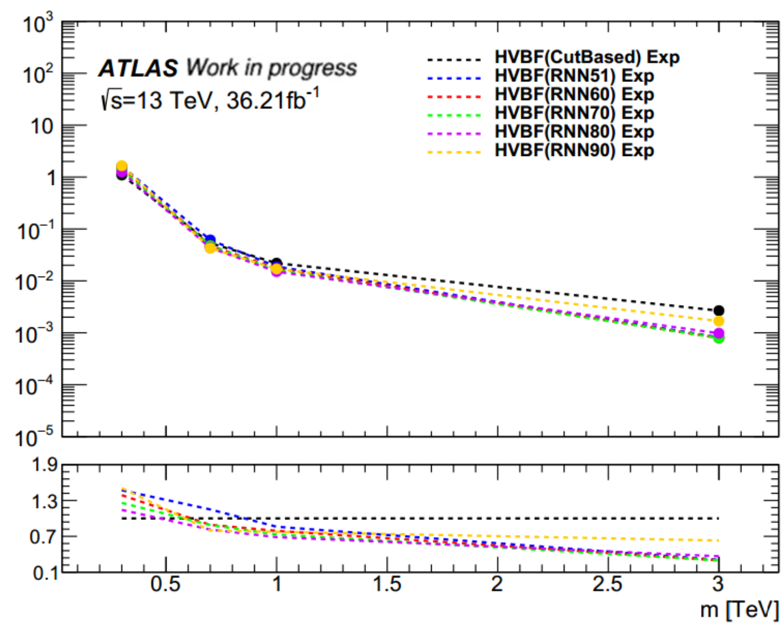
Event selection

RNN for VBF/ggF Classification

- Significant significance gain on all channels
- RNN value 0.8 cut is optimized as final cut







Systematics

Expermental Systematics

- Electron: ES,ER, SFs
- Muon: pT scale, pT resolution, SFs
- MET: Soft term, jet track
- Small-R jets: JES JER
- Large-R jets: pT scale JER
- B-tagging: Flavour tagging SF
- Lumi, PileUp

Source	Description	Analysis Name	Notes
Small-R Jets	JES category reduction	JET_CR_JET_BJES_Response	
Small-R Jets	JES category reduction	JET_CR_JET_EffectiveNP_Detector1	
Small-R Jets	JES category reduction	JET_CR_JET_EffectiveNP_Detector2	
Small-R Jets	JES category reduction	JET_CR_JET_EffectiveNP_Mixed1	
Small-R Jets	JES category reduction	JET_CR_JET_EffectiveNP_Mixed2	
Small-R Jets	JES category reduction	JET_CR_JET_EffectiveNP_Mixed3	
Small-R Jets	JES category reduction	JET_CR_JET_EffectiveNP_Modelling1	
Small-R Jets	JES category reduction	JET_CR_JET_EffectiveNP_Modelling2	
Small-R Jets	JES category reduction	JET_CR_JET_EffectiveNP_Modelling3	
Small-R Jets	JES category reduction	JET_CR_JET_EffectiveNP_Modelling4	
Small-R Jets	JES category reduction	JET_CR_JET_EffectiveNP_Statistical1	
Small-R Jets	JES category reduction	JET_CR_JET_EffectiveNP_Statistical2	
Small-R Jets	JES category reduction	JET_CR_JET_EffectiveNP_Statistical3	
Small-R Jets	JES category reduction	JET_CR_JET_EffectiveNP_Statistical4	
Small-R Jets	JES category reduction	JET_CR_JET_EffectiveNP_Statistical5	
Small-R Jets	JES category reduction	JET_CR_JET_EffectiveNP_Statistical6	
Small-R Jets	JES category reduction	JET_CR_JET_Flavor_Composition	
Small-R Jets	JES category reduction	JET_CR_JET_Flavor_Response	
Small-R Jets	JES category reduction	JET_CR_JET_Pileup_OffsetMu	

Source	Description	Analysis Name
Electrons	Energy scale	EG_SCALE_ALL
Electrons	Energy resolution	EG_RESOLUTION_ALL
Electrons	Trigger	EL_EFF_Trigger_TOTAL_1NPCOR_PLUS_UNCOR
Electrons	ID efficiency SF	EL_EFF_ID_TOTAL_1NPCOR_PLUS_UNCOR
Electrons	Isolation efficiency SF	EL_EFF_Iso_TOTAL_1NPCOR_PLUS_UNCOR
Electrons	Reconstruction efficiency SF	EL_EFF_Reco_TOTAL_1NPCOR_PLUS_UNCOR
Muons	p_T scale	MUONS_SCALE
Muons	p_T scale (charge dependent)	MUON_SAGITTA_RHO
Muons	p_T scale (charge dependent)	MUON_SAGITTA_RESBIAS
Muons	p_T resolution MS	MUONS_MS
Muons	p_T resolution ID	MUONS_ID
Muons	Isolation efficiency SF	MUON_ISO_SYS
Muons	Isolation efficiency SF	MUON_ISO_STAT
Muons	Muon reco & ID efficiency SF	MUONS_EFF_STAT
Muons	Muon reco & ID efficiency SF	MUONS_EFF_STAT_LOWPT
Muons	Muon reco & ID efficiency SF	MUONS_EFF_SYST
Muons	Muon reco & ID efficiency SF	MUONS_EFF_SYST_LOWPT
Muons	Track-to-vertex association efficiency SF	MUON_TTVA_SYS
Muons	Track-to-vertex association efficiency SF	MUON_TTVA_STAT
MET	Soft term	MET_SoftTrk_ResoPerp
MET	Soft term	MET_SoftTrk_ResoPara
MET	Soft term	MET_SoftTrk_Scale
MET	Jet track uncertainties	MET_JetTrk_Scale

Source	Description	Analysis Name	Notes
Large-R Jets	p_T scale	FATJET_Medium_JET_Rtrk_Baseline_pT	
Large-R Jets	p_T scale	FATJET_Medium_JET_Rtrk_Closure_pT	
Large-R Jets	p_T scale	FATJET_Medium_JET_Rtrk_Modelling_pT	
Large-R Jets	p_T scale	FATJET_Medium_JET_Rtrk_TotalStat_pT	
Large-R Jets	p_T scale	FATJET_Medium_JET_Rtrk_Tracking_pT	
Large-R Jets	JER	FATJET_JER	
B-tagging	Flavor tagging scale factors	FT_EFF_Eigen_B_0_AntiKt4EMTopoJets	
B-tagging	Flavor tagging scale factors	FT_EFF_Eigen_B_0_AntiKtVR30Rmax4Rmin02TrackJets	
B-tagging	Flavor tagging scale factors	FT_EFF_Eigen_B_1_AntiKt4EMTopoJets	
B-tagging	Flavor tagging scale factors	FT_EFF_Eigen_B_1_AntiKtVR30Rmax4Rmin02TrackJets	
B-tagging	Flavor tagging scale factors	FT_EFF_Eigen_B_2_AntiKt4EMTopoJets	
B-tagging	Flavor tagging scale factors	FT_EFF_Eigen_B_2_AntiKtVR30Rmax4Rmin02TrackJets	
B-tagging	Flavor tagging scale factors	FT_EFF_Eigen_C_0_AntiKt4EMTopoJets	
B-tagging	Flavor tagging scale factors	FT_EFF_Eigen_C_0_AntiKtVR30Rmax4Rmin02TrackJets	
B-tagging	Flavor tagging scale factors	FT_EFF_Eigen_C_1_AntiKt4EMTopoJets	
B-tagging	Flavor tagging scale factors	FT_EFF_Eigen_C_1_AntiKtVR30Rmax4Rmin02TrackJets	
B-tagging	Flavor tagging scale factors	FT_EFF_Eigen_C_2_AntiKt4EMTopoJets	
B-tagging	Flavor tagging scale factors	FT_EFF_Eigen_C_2_AntiKtVR30Rmax4Rmin02TrackJets	
B-tagging	Flavor tagging scale factors	FT_EFF_Eigen_C_3_AntiKt4EMTopoJets	
B-tagging	Flavor tagging scale factors	FT_EFF_Eigen_C_3_AntiKtVR30Rmax4Rmin02TrackJets	
B-tagging	Flavor tagging scale factors	FT_EFF_Eigen_Light_0_AntiKt4EMTopoJets	
B-tagging	Flavor tagging scale factors	FT_EFF_Eigen_Light_0_AntiKtVR30Rmax4Rmin02TrackJets	
B-tagging	Flavor tagging scale factors	FT_EFF_Eigen_Light_1_AntiKt4EMTopoJets	
B-tagging	Flavor tagging scale factors	FT_EFF_Eigen_Light_1_AntiKtVR30Rmax4Rmin02TrackJets	
B-tagging	Flavor tagging scale factors	FT_EFF_Eigen_Light_2_AntiKt4EMTopoJets	
B-tagging	Flavor tagging scale factors	FT_EFF_Eigen_Light_2_AntiKtVR30Rmax4Rmin02TrackJets	
B-tagging	Flavor tagging scale factors	FT_EFF_Eigen_Light_3_AntiKt4EMTopoJets	
B-tagging	Flavor tagging scale factors	FT_EFF_Eigen_Light_3_AntiKtVR30Rmax4Rmin02TrackJets	
B-tagging	Flavor tagging scale factors	FT_EFF_extrapolation_AntiKt4EMTopoJets	
B-tagging	Flavor tagging scale factors	FT_EFF_extrapolation_AntiKtVR30Rmax4Rmin02TrackJets	
B-tagging	Flavor tagging scale factors	FT_EFF_extrapolation_from_charm_AntiKt4EMTopoJets	
B-tagging	Flavor tagging scale factors	FT_EFF_extrapolation_from_charm_AntiKtVR30Rmax4Rmin02TrackJets	
Pileup reweighting	PRW_DATASF		
Luminosity	LumiNP		

Systematics

Background modeling uncertainties
- ttbar
- W/Z jets
- Multijet
- VV

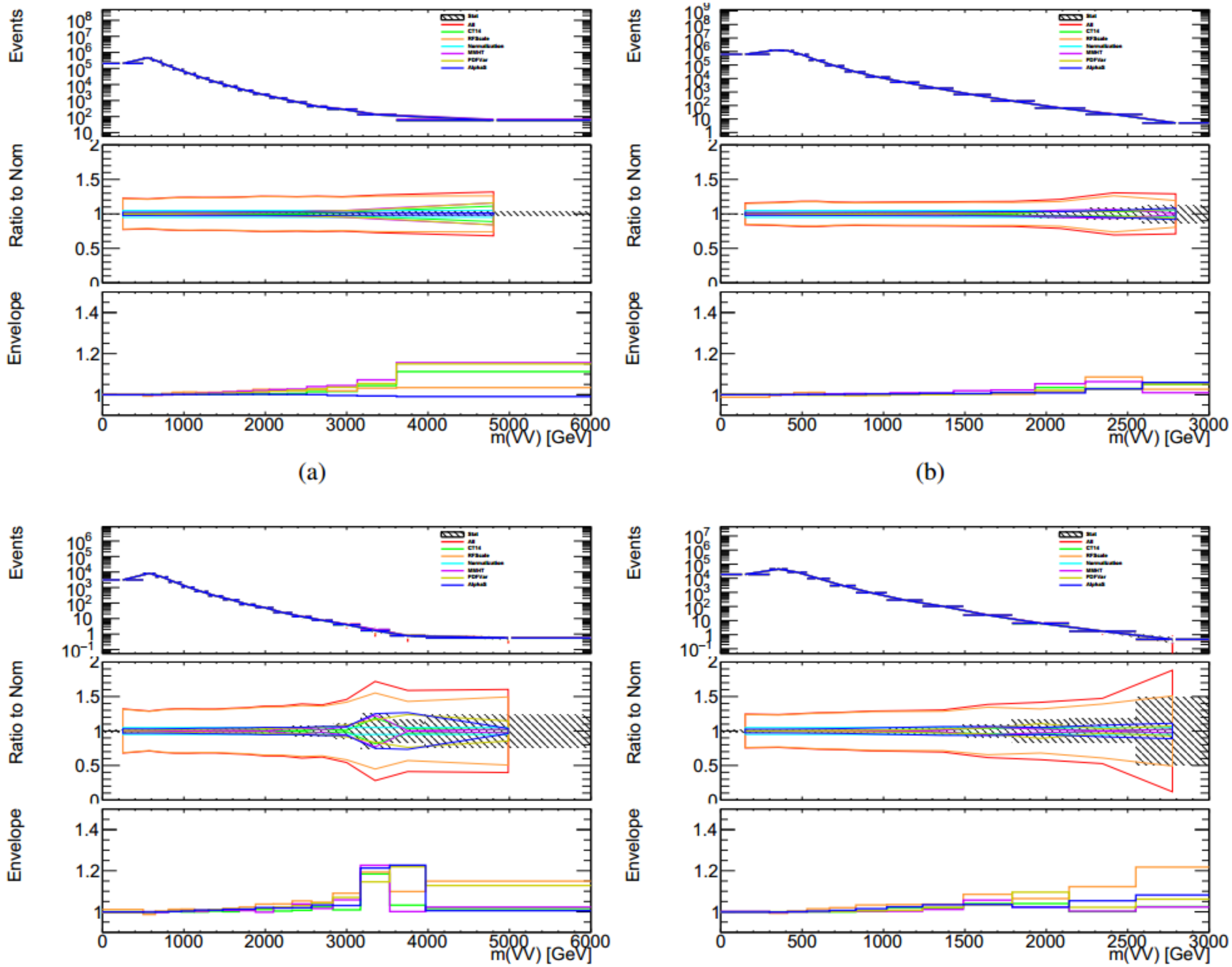
Signal modeling

Source	Description	Analysis Name	Notes
Modeling	Signal	Signal_PDF	
Modeling	Signal	Signal_ISR_FSR	

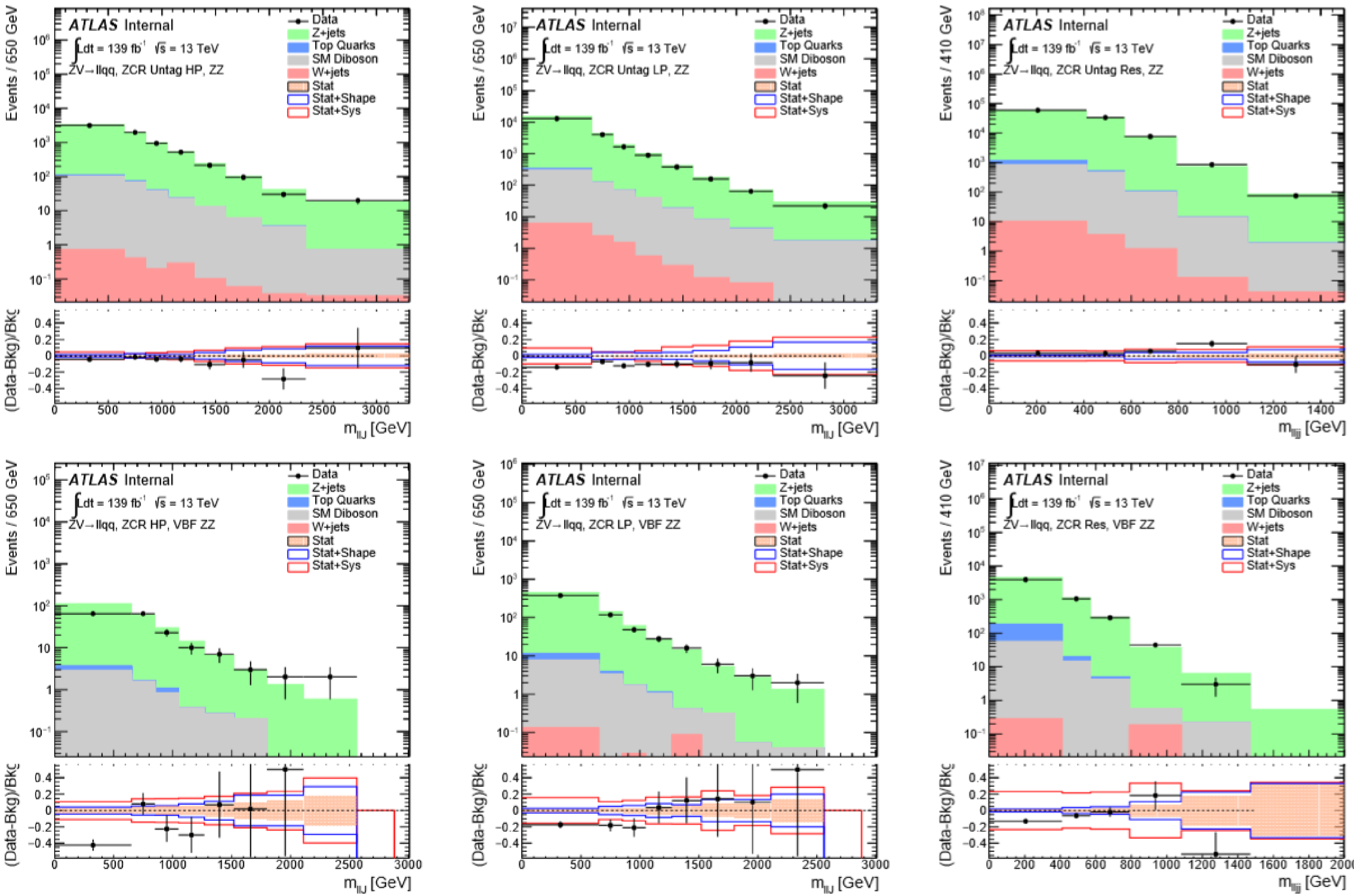
Source	Description	Analysis Name	Notes
Modeling	$t\bar{t}$ aMCaNLO	ttbar_aMC	Generator
Modeling	$t\bar{t}$ Herwig	ttbar_PH7	Parton Shower
Modeling	$t\bar{t}$ ISR	ttbar_ISR	
Modeling	$t\bar{t}$ FSR	ttbar_FSR	
Modeling	W/Z+jets modeling μ_F and μ_R	Vjets_RFScale_lvqq_Merg	
Modeling	W/Z+jets modeling μ_F and μ_R	Vjets_RFScale_lvqq_Res	
Modeling	W/Z+jets modeling PDF	Vjets_PDFVar_lvqq_Merg	
Modeling	W/Z+jets modeling PDF	Vjets_PDFVar_lvqq_Res	
Modeling	W/Z+jets modeling PDF	Vjets_CT14_lvqq_Merg	
Modeling	W/Z+jets modeling PDF	Vjets_CT14_lvqq_Res	
Modeling	W/Z+jets modeling PDF	Vjets_MMHT_lvqq_Merg	
Modeling	W/Z+jets modeling PDF	Vjets_MMHT_lvqq_Res	
Modeling	W/Z+jets modeling α_S	Vjets_AlphaS_lvqq_Merg	
Modeling	W/Z+jets modeling α_S	Vjets_AlphaS_lvqq_Res	
Modeling	W/Z+jets modeling MadGraph	Vjets_GenMG_lvqq_Merg	
Modeling	W/Z+jets modeling MadGraph	Vjets_GenMG_lvqq_Res	
Modeling	multijet modeling	MJ_W_lvqq_Res	
Modeling	multijet modeling	MJ_ttbar_lvqq_Res	
Modeling	multijet normalization	XS_MJ_lvqq_Res	

Systematics

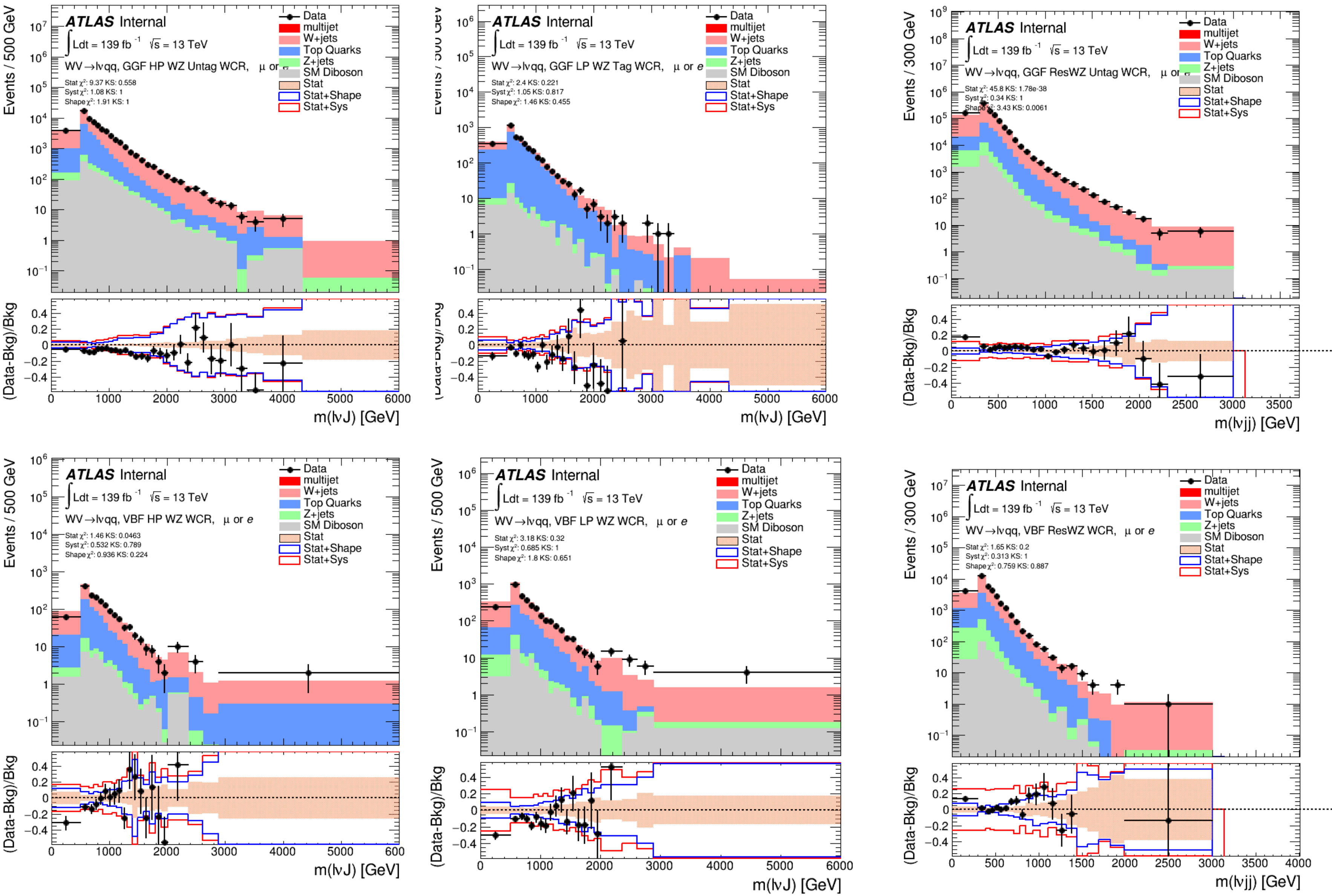
- Vjets



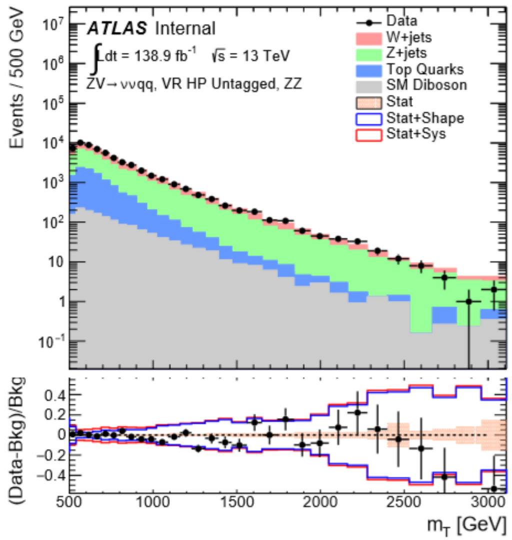
Prefit Distributions: 2-lepton ZCR

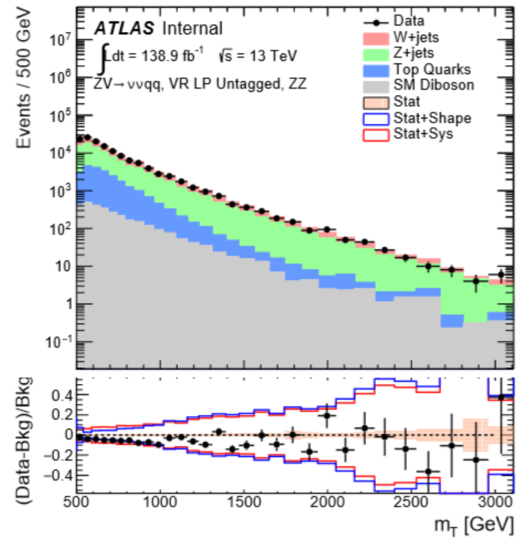


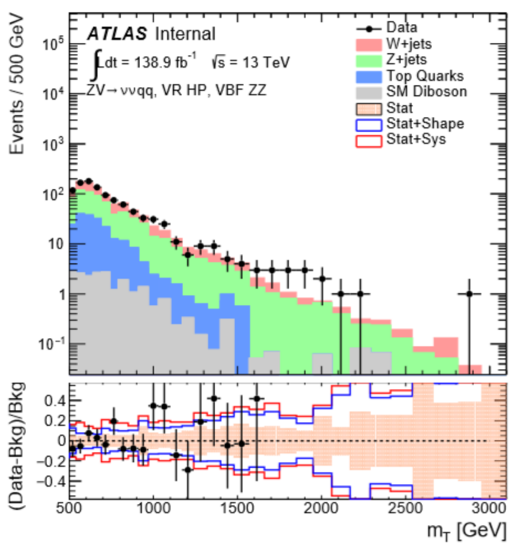
Prefit Distributions: 1-lepton WCR

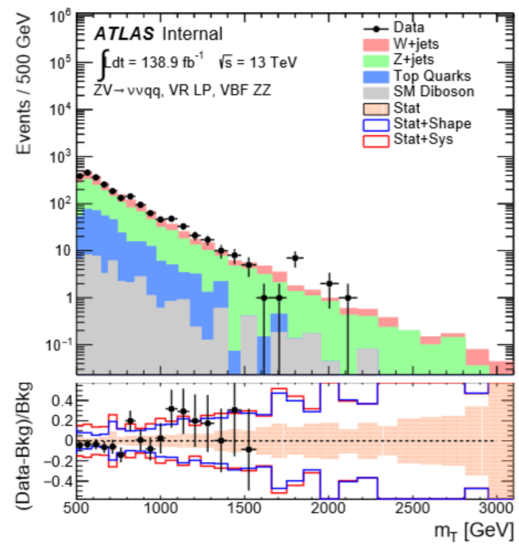


Prefit Distributions: 0-lepton VCR









D2 cut

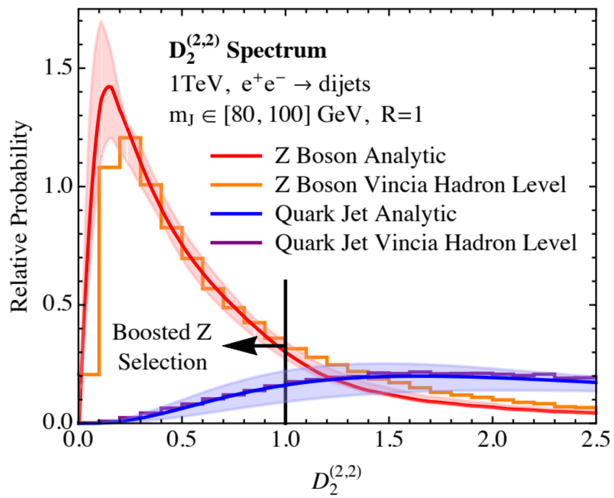
$$D_2^{(\beta=1)} = E_{CF3}\left(\frac{E_{CF1}}{E_{CF2}}\right)^3$$

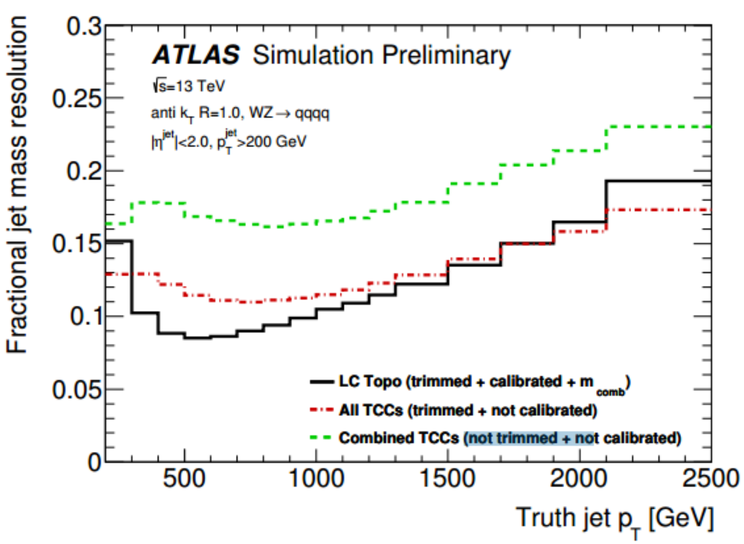
functions (E_{CF}) are defined as:

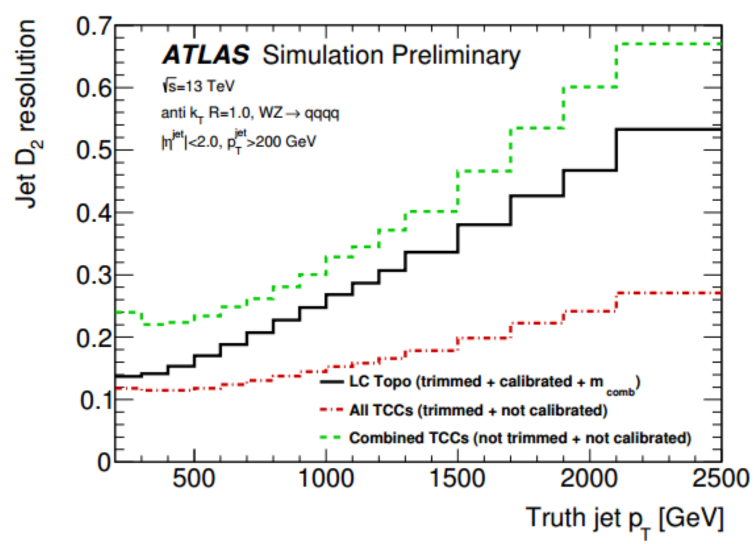
$$E_{CF1} = \sum_i p_{T,i}$$

$$E_{CF2} = \sum_{ij} p_{T,i}p_{T,j}\Delta R_{ij}$$

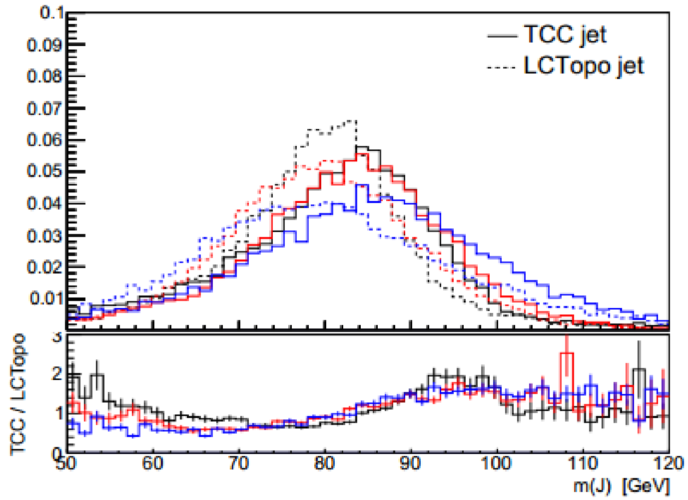
$$E_{CF3} = \sum_{ijk} p_{T,i}p_{T,j}p_{T,k}\Delta R_{ij}\Delta R_{jk}\Delta R_{ki}$$



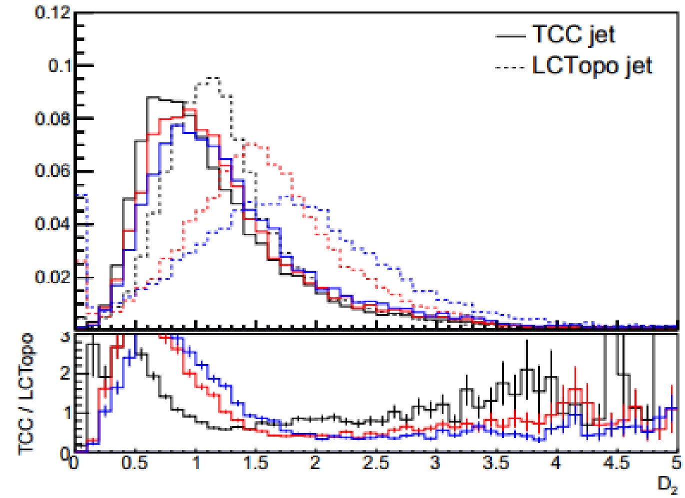




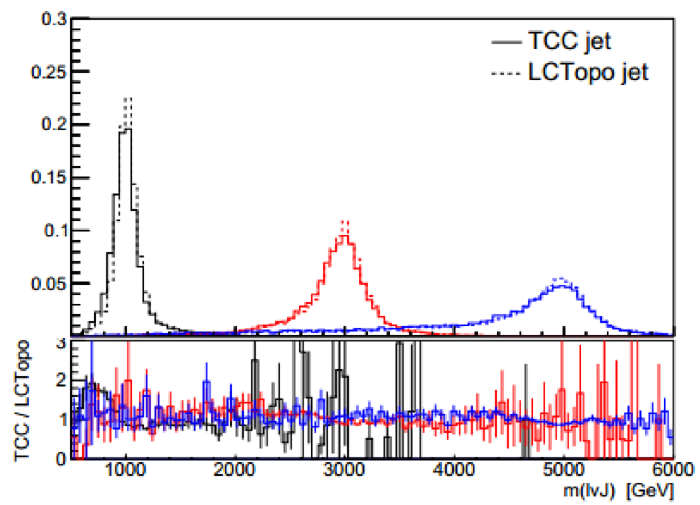
D2


TCC jet
LCTopo jet
TCC / LCTopo
m(J) [GeV]

(a)


TCC jet
LCTopo jet
TCC / LCTopo
D_2

(b)


TCC jet
LCTopo jet
TCC / LCTopo
m(lvJ) [GeV]