Beyond Standard Model $R \rightarrow WW$ with the ATLAS Detector at the LHC

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Introduction

Today will overview my thesis which has been performed with the ATLAS collaboration at the LHC.

- An overview of the theoretical interpretations considered in the analysis will be given.
  - Four theoretical models are used to give five resonant interpretations.
- A brief overview of the experimental apparatus will be shared highlighting the areas sensitive to the analysis.
- An in-depth discussion of the physics analysis which is the focus of the thesis.
  - A beyond-Standard Model search for resonances decaying to a pair of W bosons in the different flavor $\ell\nu\ell\nu$ final state.

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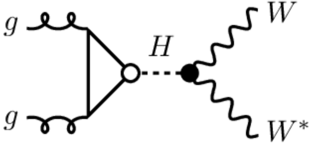
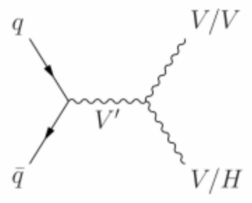
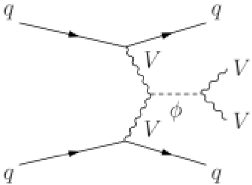
Theory Models - Overview

- BSM search for heavy scalar/vector bosons decaying to WW with the $\ell\nu\ell\nu$ final state.
- Multiple signal interpretations:
  - Scalars: Narrow Width Approximation (NWA), Georgi-Machacek (GM), Radion (ϕ)
  - Neutral vector bosons: Heavy Vector Triplet (HVT Z')
  - Spin-2: RS Graviton ($G*$)

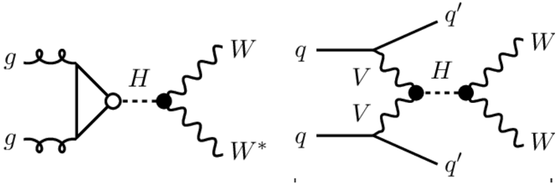






Theory Models - Narrow Width Approximation

- Narrow width approximation (NWA) uses the existence of a heavy-Higgs particle with a width much smaller than the detector resolution.
  - Specifically use the SM higgs boson's width of 4 MeV.
- The simplicity of this toy model makes it ideal for a baseline sample to use for optimization purposes.
- Two production modes are considered independently: gluon-gluon fusion (ggF) and vector-boson fusion (VBF)



Theory Models - Georgi-Machacek

- Georgi-Machacek (GM) model expands the Higgs sector by adding a real and complex $SU(2)_L$ triplet.
- Preserves the SM value of $\rho = M_W^2/(M_Z^2 \cos^2\theta_W) = 1$.
- The five physical states, defined by their charge H_5^0, $H_5^{\pm}$, $H_5^{\pm\pm}$, combine to make a Higgs fiveplet.
- The preferential coupling of the fiveplet members to vector bosons V allows for a lesser constraint of the VBF production mode.
- The analysis considers the neutral heavy-higgs (H_5^0) member of the fiveplet with the VBF production mode.

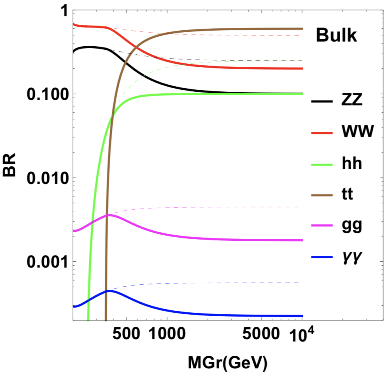
Theory Models - Bulk Randall Sundrum Model

- Bulk Randall Sundrum (RS) postulates the existence of a warped extra dimension in which both gravity and all SM fields propagate into the "bulk".
- Propagation in the extra dimension leads to a tower of Kaluza–Klein (KK) excitations of gravitons.
- KK gravitons are produced via both quark–antiquark annihilation and gluon–gluon fusion , with the latter dominating due to suppressed couplings to light fermions.

- The couplings to the SM fields are inversely proportional to:

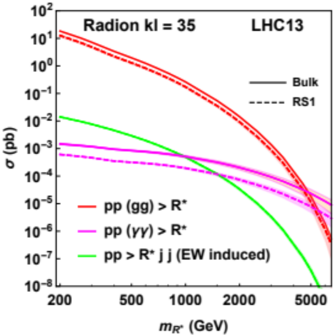
$$\Lambda_R = \sqrt{g} \times k \times e^{-k\pi r_c} \times \sqrt{M_5^3/k^3}$$

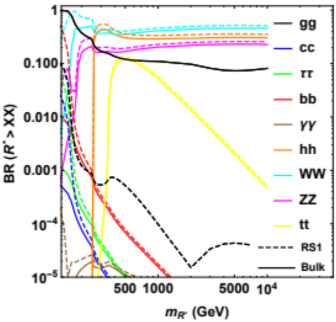
- The analysis considers G_{KK} produced by ggF.



Theory Models - Bulk Randall Sundrum Model

- The initial RS model did not allow for stability of the r_c of the ED.
- Introducing a massive scalar that propagates into the bulk allows for the stabilization of r_c.
- The radion field, ϕ, can be produced by ggF and VBF production and both are considered in the analysis.

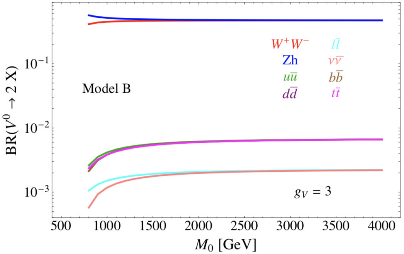




Theory Models - Heavy Vector Triplet

- Heavy Vector Triplet (HVT) introduces a triplet $\mathcal{W}$ of colorless vector bosons with zero hypercharge.
- The triplet leads to a set of nearly degenerate charged, $W'^{\pm}$, and neutral, Z', states.
- The analysis considers both Drell-Yan (DY) and VBF production of Z'.

$$\mathcal{L}_{\mathcal{W}}^{\text{int}} = - g_q \mathcal{W}_\mu^a \bar{q}_k \gamma^\mu \frac{\sigma_a}{2} q_k - g_\ell \mathcal{W}_\mu^a \bar{\ell}_k \gamma^\mu \frac{\sigma_a}{2} \ell_k - g_H \left(\mathcal{W}_\mu^a H^\dagger \frac{\sigma_a}{2} iD^\mu H + \text{h.c.} \right)$$



Theory Models - Physics Impact

- While the SM is fairly complete, some significant holes still exist from physically evident phenomena:
  - Hierarchy problem, dark matter, matter-antimatter asymmetry, neutrino masses, particle generations
- Many models considered in the $R \to WW$ search attempt to address one of these problems.
  - RS Model proposes ED to solve hierarchy problem
  - GM proposes an explanation of neutrino masses with triplet states interacting with the Higgs doublet $\to$ non-evidence of H also limits the h–V opposite sign coupling which is currently allowed by SM h measurements
  - HVT Model provides a probe to higher order generations of bosons
- Many of these models have lots of free parameters, making it difficult to compare directly to the data. $\to$ Encourage phenomenologists to produce simplified Lagrangians to probe mass resonances.
- Searches in other aspects at the LHC can become more specific (such as monopole searches) or are already generic ("invisible" resonances).

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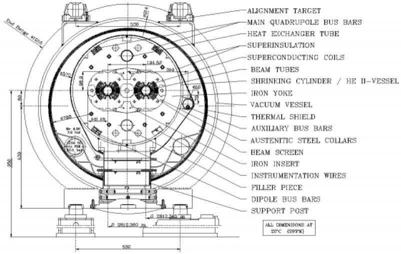
The LHC - Overview

- The Large Hadron Collider (LHC) is a 27 km circumference synchotron built about 100 m below the countryside near the city of Geneva, Switzerland.
- The accelerator complex provides proton bunches traveling with individual proton energies up to 6.5 TeV, allowing for the production of proton–proton (pp) collisions to be studied at 4 main collision points.

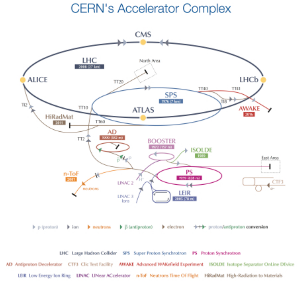
- Superconducting dipole magnets with field strengths of $\tilde{8}$ T are used to steer the proton bunches around the large ring.
- At the collision points quadropole magnets are used to focus the beams to ensure proton collisions.



The LHC - Accelerator Complex

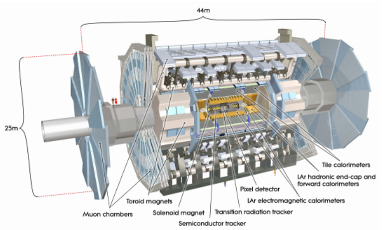
- Prior to acceleration, hydrogen atoms have their electrons removed by first adding an additional electron and bombarding the H^- ions with hydrogen gas to form a plasma which then has the electrons removed by a strong electric field.
- The Large Hadron Collider (LHC) accelerator complex is comprised of 4 individual accelerators that are then used to feed the primary LHC ring.

- The feeding accelerator system is composed of one linear accelerator and 3 synchotron systems.
- The electromagnets step-wise accelerate the proton clusters up to 450 GeV prior to injection to the LHC ring, where they reach 6.5 TeV.



ATLAS - Overview

- The ATLAS (**A** **T**oroidal **L**HC **A**pparatu**S**) experiment uses a general purpose particle detector located 100 m underground at LHC's point 1
- The detector's original design optimization was for the search and measurement of the Higgs Boson and its related properties as well as for searching for evidence of supersymmetry (SUSY) and other BSM processes
- The detector is comprised of three sub-detectors:
  1. Inner detector (ID) surrounded by superconducting solenoid.
  2. Electromagnetic and hadronic calorimeters (eCal, hCal)
  3. Muon spectrometer (MS)

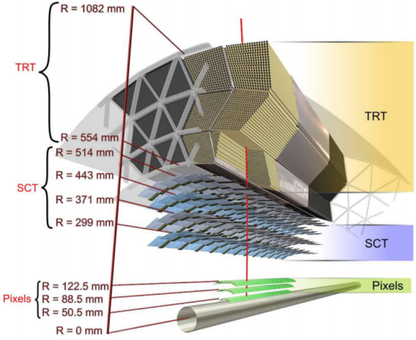


ATLAS - Inner Detector

- The center most portion of the ATLAS detector is the Inner Detector.
- The ID's primary purpose is to track charged particles' trajectories as they travel outwards from the collision point, while also measuring their momentum and the precise location of the primary vertex of the collision.

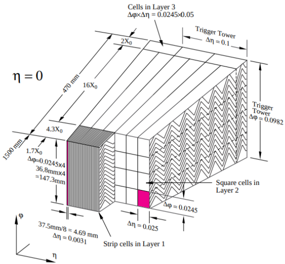
- The ID is comprised of three sub-detectors:

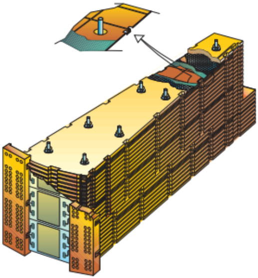
  1. The pixel detector and insertable b-layer (IBL)
  2. The semiconductor tracker (SCT)
  3. Transition radiation tracker (TRT)



ATLAS - Calorimetry

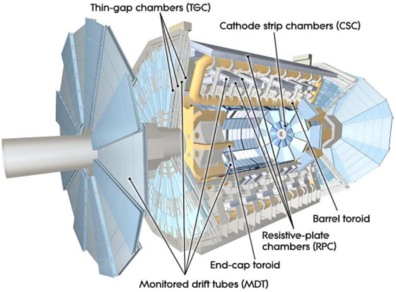
- Surrounding the ID and solenoid magent of the ATLAS detector is the calorimetry system.
- The eCal, a sampling calorimeter using liquid-argon (LAr) as a scintillator and lead plates as absorbers, is the first calorimeter radiating outwards from the beampipe. $\rightarrow$ Measure energy deposits of charged particles
- Residing outside the eCal is the hCal, consisting of scinitillating tiles interleaved with steel plate absorbers in the barrel region, and LAr with copper absorbers in the endcap regions. $\rightarrow$ Measure energy deposits of hadronic activity





ATLAS - Muon Spectrometer

- The muon spectromer (MS) is the outermost layer of the ATLAS detector and is focused to measure muon momentum and trajectories.
- The MS hosts three large magnets to bend the muon trajectory to allow for charge identification and momentum measurements.
- The MS is comprised of:
  1. Monitored drift tubes
  2. Cathode strip containers
  3. Resistive plate and thin gap chambers



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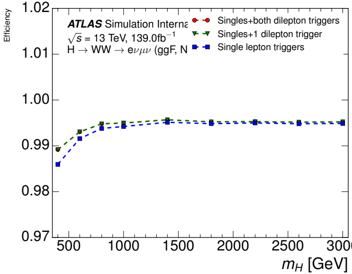
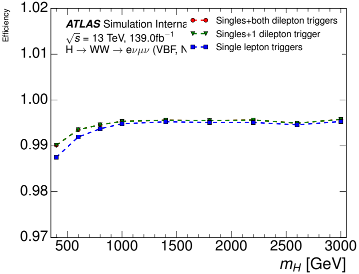
Samples - Data

- The data used in the analysis corresponds to the 139 fb^{-1} taken from the ATLAS detector during the full Run-II data-taking period.
- Data events are required to pass data quality requirements provided in the form of good runs lists (GRLs).
- Events are selected if they are matched to firing one of the single-lepton triggers available in ATLAS's high-level trigger (HLT) menu.





Samples - Monte-Carlo Signal

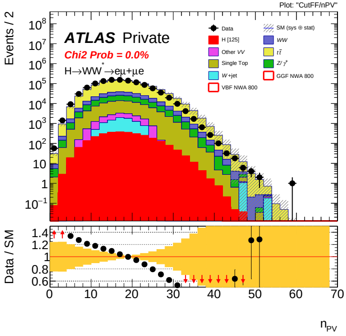
- Monte-Carlo generation is used to produced the signal samples for each of the five interpretations in the analysis.

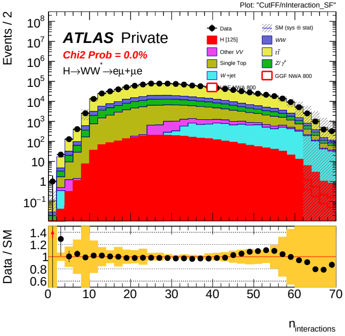
Signal	Production Mode	Pole Masses [Step Size] in TeV
NWA	ggF	0.2, 0.25, 0.3-1.0 [0.1], 1.0-4.0 [0.2]
	VBF	0.2, 0.25, 0.3-1.0 [0.1], 1.0-4.0 [0.2]
Radion	ggF	0.3, 0.7, 1.0-6.0 [1.0]
	VBF	0.3, 0.7, 1.0-6.0 [1.0]
GM	ggF	x
	VBF	0.25, 0.3-1.0 [0.1]
HVT V'	qqA	0.3-1.0 [0.1], 1.0-3.0 [0.2], 3.0-5.0 [0.5], 5.0-8.0 [1.0]
	VBF	0.3-0.8 [0.1], 0.8, 1.0, 1.2, 1.5, 1.8, 2.0, 2.4, 2.6, 3.0, 3.5, 4.0
G_{KK}	ggF	0.6-2.0 [0.2]
	VBF	x

- The signal samples are required to pass the trigger selection and are scaled to the full integrated luminosity of the data-set considered.

Samples - Monte-Carlo Background

- The SM background for the analysis is estimated using Monte-Carlo generated samples for the processes decaying to pair of different flavor leptons and missing energy.
- To correctly model the effect of multiple *pp* interactions in the same and neighbouring bunch crossings (pile-up), corrections need to be applied.
- The rate of these pile-up collisions are dependent on the luminosity and $\sqrt{s}$ energy of the collision, and takes two types: in-time (same bunch crossing) and out-of-time (neighbouring bunch crossing)





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Object Selections

Lepton	Level-1 Trigger	High-Level Trigger (HLT)
Year 2015		
e	20 GeV	24M OR 60M OR 120L GeV
μ	15 GeV	20i OR 50 GeV
Year 2016-18		
e	20 GeV	26Ti OR 60M OR 140L GeV
μ	15 GeV	26i OR 50 GeV

- Electrons:
  - Medium LH, $|\eta| < 2.5$, exclude crack region
  - FixedCutTight Isolation: ptvarcone20_TightTTVA_pt1000/pT < 0.06
- Muons:
  - Tight Quality, $|\eta| < 2.4$
  - FixedCutTight Isolation: ptvarcone30_TightTTVA_pt1000/pT < 0.04
- Jets:
  - AntiKt4EMPFlow Jets, $p_T >$ 30 GeV, JVT Tight WP
  - BTagging: DL1r, 85% WP
- Overlap Removal:
  - b-tag aware OR: Prioritize keeping b-jets.
  - e - ΔR 0.2 jet rejection
  - μ - ΔR 0.2 jet rejection + p_T dependence rejection

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Optimization - Overview

- A significant portion of the analysis work comes into the event selection optimization.
- Signal regions are optimized to select the largest amount of expected signal events with respect to the SM background.
- Control regions are optimized for target process purity and close orthogonality to the signal regions.
- The analysis used five optimization studies to further optimize the results using the previous 36 fb^{-1} analysis's selection as a baseline:

1. Tighter selection
2. E_T^{miss} Significance cuts
3. VBF common selection
4. Kinematic ratio cuts
5. $m_{\tau\tau}$ FOM

Optimization - Baseline Signal Region Selections

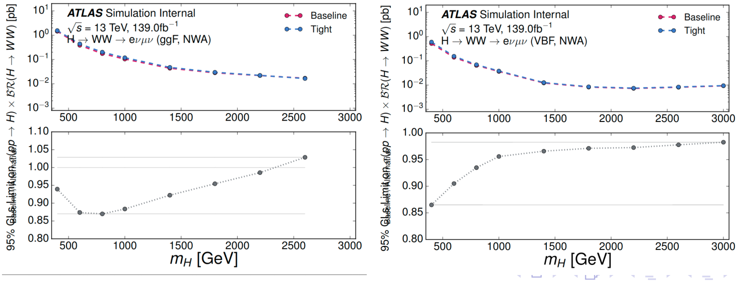
Pre-Selection		
Two Different Flavour, Opposite Sign Leptons, $p_T^\ell > 25$ GeV Third lepton veto, $p_T^\ell > 15$ GeV		
SR_{ggF}	SR_{VBF1J}	SR_{VBF2J}
Common Selection		
$N_{b-tag} = 0$ $\|\Delta\eta_{\ell\ell}\| < 1.8$ $m_{\ell\ell} > 55$ GeV $p_T^{\ell,\text{lead}} > 45$ GeV $p_T^{\ell,\text{sublead}} > 30$ GeV veto if $p_T^{\ell,\text{other}} > 15$ GeV $\max(m_T^W) > 50$ GeV		
ggF phase space	VBF1J phase space	VBF1J phase space
Inclusive in N_{jet} but excluding VBF1J and VBF2J phase space	$N_{jet} = 1$ and $\|\eta_j\| > 2.4$, $\min(\|\Delta\eta_{j\ell}\|) > 1.75$	$N_{jet} = 2$ and $m_{jj} > 500$ GeV, $\|\Delta y_{jj}\| > 4$

Optimization - Baseline Control Region Selections

Pre-Selection			
Two Different Flavour, Opposite Sign Leptons, $p_T^{\ell} > 25$ GeV Third lepton veto, $p_T^{\ell} > 15$ GeV			
WW CR_{ggF}	Top CR_{ggF}	WW CR_{VBF1J}	Top CR_{VBF}
$N_{b-tag} = 0$	$N_{b-tag} = 1$	$N_{b-tag} = 0$	$N_{b-tag} \geq 1$
$\lvert\Delta\eta_{\ell\ell}\rvert > 1.8$	$\lvert\Delta\eta_{\ell\ell}\rvert < 1.8$	$(\lvert\Delta\eta_{\ell\ell}\rvert > 1.8$ or	–
$m_{\ell\ell} > 55$ GeV		10 GeV $< m_{\ell\ell} <$ 55 GeV)	$m_{\ell\ell} > 10$ GeV
$p_T^{\ell,\text{lead}} > 45$ GeV		$p_T^{\ell,\text{lead}} > 25$ GeV	
$p_T^{\ell,\text{sublead}} > 30$ GeV		$p_T^{\ell,\text{sublead}} > 25$ GeV	
$\max(m_T^W) > 50$ GeV		–	
Excluding VBF1/2J phase space		VBF1J phase space	VBF1/2J phase space

Optimization - Tighter Selection

- The previous 36 fb^{-1} analysis used a relatively loose signal region selection in terms of lepton kinematics.
- Tighter selection was explored using a gridscanning technique $\rightarrow$ scanning a range of values for specific kinematic cuts in a grid-like fashion.
- Significant gain was seen when selecting tighter values in the integrated significance ($\frac{s}{\sqrt{b}}$), but the binned m_T significance did not lead to improved statistics results.

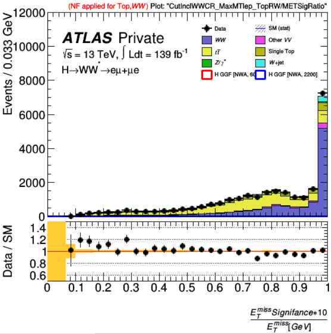


Optimization - E_T^{miss} Significance Cuts

- E_T^{miss} Significance is objected-based value that quantifies the amount of "fake" E_T^{miss} in an event.
- While the cuts showed good promise of removing unwanted backgrounds such as Z/W+jets, no statistical improvement was shown due to a cut on E_T^{miss} Significance also adding a pseudo-cut on E_T^{miss}.
- To remove this pseudo-cut, an exploration of using the ratio of E_T^{miss} Significance and E_T^{miss} was made.

- While no improvement in the SRs was seen with such a cut, significant separation between the $t\bar{t}$ and WW backgrounds was observed.

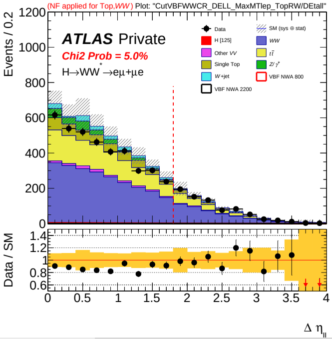
- A cut of $\frac{E_T^{\text{miss}}\text{Significance}}{E_T^{\text{miss}}\times 10} \geq 0.8$ is applied to the region.



Optimization - VBF Common Selection

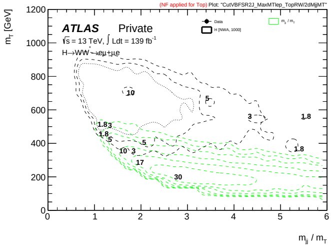
- Previous 36 fb^{-1} analysis used a loose selection in the VBF control regions than the selection in the SRs.
- With increased statistics from the 139 fb^{-1} dataset, the analysis tries to match the lepton selections to that of the signal regions.
- No issues were found when doing this for the top CR, so the tightened selection is then used as the baseline.

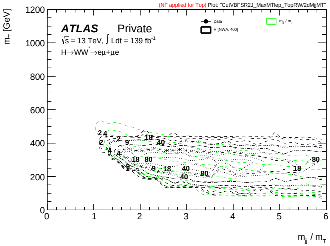
- For the *WW* CR, a large change in normalization factor (NF) was observed when tightening the selection.
- Further study showed this comes from the poor modeling of the $|\Delta\eta_{\ell\ell}|$ distribution which is used to define the region.
  - Looser CR selection is used.

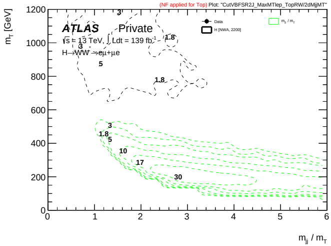


Optimization - Kinematic Ratio Cuts

- Similar to the tightened cut selection, a study of ratio's of different kinematics with the m_T distribution were explored.
- Again, integrated significance in the SRs showed some gain, but no bin-by-bin significance was observed.

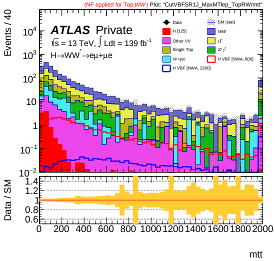


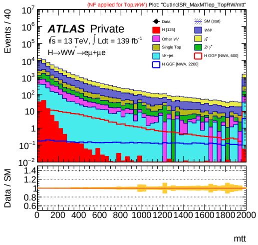


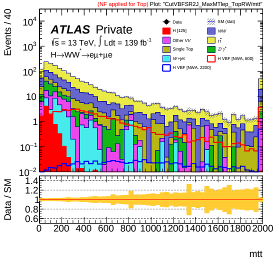


Optimization - $m_{\tau\tau}$ Figure of Merit

- The observable $m_{\tau\tau}$ makes use of the Collinear Approximation Method, assuming the charged leptons seen are the products of the decay of a pair of τ leptons.
- In this case the neutrinos emitted are collinear with the charged leptons, and these neutrinos are the only source of the observed E_T^{miss} in the event, allowing for direct calculation of the neutrino energy fractions.







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Analysis - Event Selection

- Preselection:
  - Two Different Flavor, Opposite Sign Leptons, $p_T^\ell > 25$ GeV
  - Third lepton veto, $p_T^\ell > 15$ GeV
- Figure of merit: Transverse mass, m_T:

$$m_T = \sqrt{(E_T^{\ell\ell} + E_T^{\mathrm{miss}})^2 - |p_T^{\ell\ell} + E_T^{miss}|^2}$$

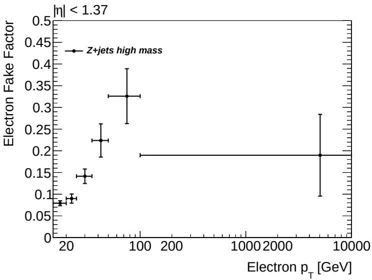
- Main Backgrounds: $t\bar{t}$, Wt, WW
  → Tight Selection to reduce background:
  - b-jet veto to reduce top backgrounds
  - $|\Delta\eta_{\ell\ell}| < 1.8$
  - $m_{\ell\ell} > 55$ GeV
  - $p_T^{\ell,\mathrm{lead}} > 45$ GeV, $p_T^{\ell,\mathrm{sublead}} > 30$ GeV
  - $\max(m_T^W) > 50$ GeV

Analysis - Non-prompt Background

- Non-prompt (fake) background primarily from W+jets processes
- Due to the poor modeling of fake electrons from W+jets processes in simulation, a data-driven fake factor method is used to estimate this background.

$$N^{\text{fake}}_{\text{id+id}} = N^{\text{fake}}_{\text{id+anti-id}} \cdot f$$
$$= (N_{\text{id+anti-id}} - N^{\text{EW}}_{\text{id+anti-id}}) \cdot f$$

- The extrapolation factor f is measured in Z+jets events in a three-lepton selection.
- The non-Z matched lepton is considered as the fake candidate.
- Fake factors are binned in η, p_T, and lepton flavour e, μ

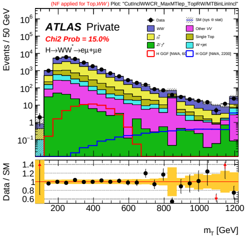


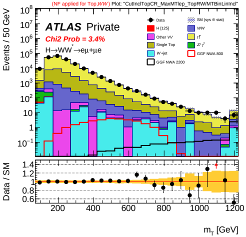
Analysis - Control Regions

Control regions optimized for the major backgrounds ($t\bar{t}$, WW) in each production phase space (ggF, VBF)

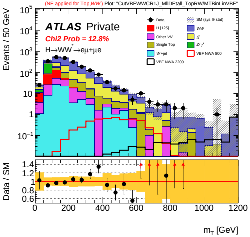
- *WW* regions orthogonal to SRs with reverse of $|\Delta\eta_{\ell\ell}|$ cut
  - ggF *WW* also has METSig / MET cut
- Top-quark regions orthogonal to SRs with *b*-tag requirement

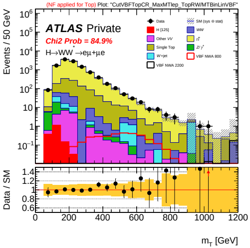
ggF Space





VBF Space



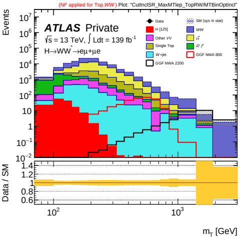


Analysis - Signal Regions

Signal regions optimized for rejection the major backgroundsin each production phase space (ggF, VBF)

- VBF 1-jet Selection:
  - $|\eta_j| > 2.4$, $\min(\Delta\eta_{j,\ell}) > 1.75$
- VBF 2+ jet Selection:
  - $m_{jj} > 500$ GeV, $\Delta y_{jj} > 4$
- ggF Selection: Orthogonal to VBF Selections

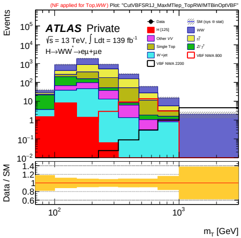
ggF Space

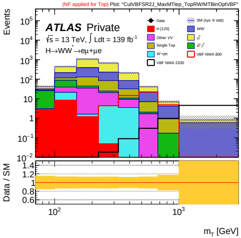


Common Selections:

- b-jet veto
- $|\Delta\eta_{\ell\ell}| < 1.8$
- $m_{\ell\ell} > 55$ GeV
- $p_T^{\ell,\text{lead}} > 45$ GeV
- $p_T^{\ell,\text{sublead}} > 30$ GeV
- $\max(m_T^W) > 50$ GeV

VBF Space





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Experimental Uncertainties

- The evaluation of the experimental systematic uncertainties is performed by closely adhering to the recommendations of the individual combined performance (CP) groups of the ATLAS experiment
- Each CP group is responsible for one or more of the reconstructed objects' calibrations and efficiency calculations.
- The analysis considers two distinct types of experimental systematic uncertainties:
  1. Four-vector (P4) systematics - Uncertainties which are evaluated as $\pm 1\sigma$ variations on the four-momentum calculation of a reconstructed object.
  2. Scale factor (SF) systematics - Uncertatines which are evaluated as $\pm 1\sigma$ variations on the weight applied to physics event, which are applied to either the unique reconstructed objects or the event as a whole.

W+jets

Systematics for W+jets are applied individually to the data-driven estimate:

1) **Statistical uncertainty**: straightforward propagation of unc. in FF plots
2) **Electroweak subtraction**: vary normalization of bkg samples
   - $Z\gamma$, ZZ: generator, QCD scale, PDF, PSUE (7.7%, 10%)
   - WZ: 1) normalization estimated in CR, uncertainty small ($<$1%),
     2) modelling unc. for extrapolation from CR to FF region (7%)
   - others: flat 10%

   $\rightarrow$ produce FFs with varied bkgs and propagate to analysis
3) **Flavour correction**: Difference between correction factors for Powheg- and MadGraph-generated samples.

Theory Uncertainties

- The modeling uncertainties arising from the parton showering (PS), choice of scale, and choice of the PDF set used in the generation of the major MC backgrounds (top-quark and $ggWW$) are also to be considered.
- Each individual process is handled separately and receives its own NP in the fit.
- NPs are also decorrelated across VBF and ggF regions to avoid over-constraints of the NPs.
- Shape contributions are considered for the WW and $t\bar{t}$ backgrounds in both ggF and VBF space. Wt has the shape portion of it's NPs removed for the VBF regions due to low statistics at higher values of m_T.

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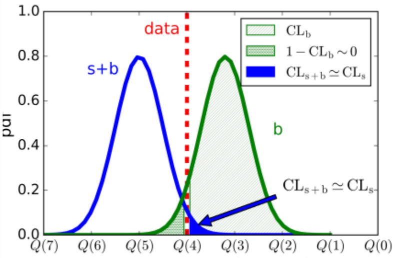
Statistical Analysis - Overview

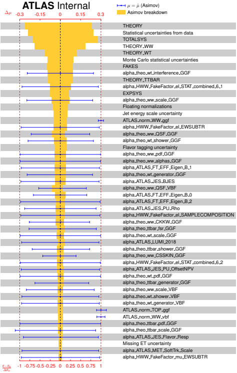
- Individual likelihood fits of each signal model, mass point, and production mode made simultaneously in the 3 SRs and 4 CRs.
- WW and top-quark normalizations are left floating and decorrelated between ggF and VBF phase-space.
- Theoretical uncertainties are taken as nuisance parameters (NPs) $qqWW$, Wt, and $t\bar{t}$ decorrelated between the ggF and VBF phase-spaces.
- Detector systematics provided from object reconstruction and calibration groups receive individual NPs.
- 95% CL_s limits with asymptotic approximation are obtained for each signal sample independently.

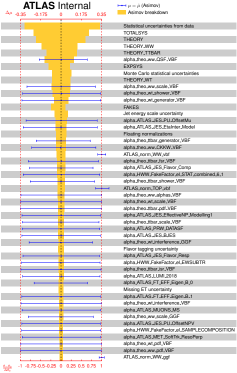


Statistical Analysis - Ranking of Systematic Uncertainties

- Breakdown method is used to calculate grouped and individual NP's uncertainty on signal strength μ.
- Pull values of individual NPs obtained from an unconstrained fit.

GGF NWA





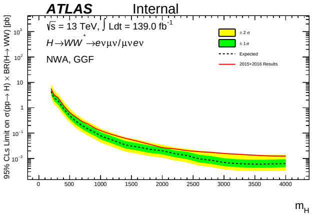
VBF NWA

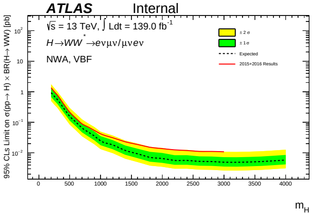
Statistical Analysis - NWA Results

The analysis is still under review, so for the time being expected limits are computed and compared to the previous 36 fb^{-1} results.

- Improvements over previous 36 fb^{-1}
  - Decreased systematic uncertainties
  - Improved statistics
  - Improved region definition

ggF Production





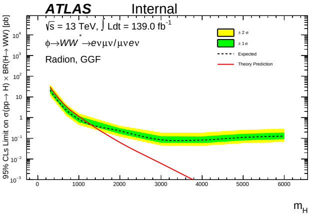
VBF Production

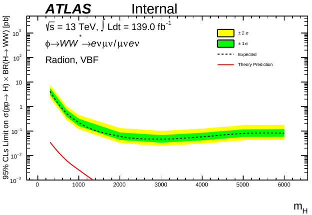
Statistical Analysis - Radion Results

The analysis is still under review, so for the time being expected limits are computed and compared to the previous 36 fb^{-1} results.

- Improvements over previous 36 fb^{-1}
  - Decreased systematic uncertainties
  - Improved statistics
  - Improved region definition

ggF Production





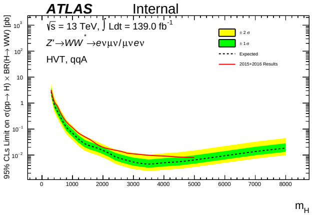
VBF Production

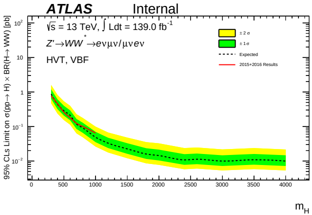
Statistical Analysis - HVT Results

The analysis is still under review, so for the time being expected limits are computed and compared to the previous 36 fb^{-1} results.

- Improvements over previous 36 fb^{-1}
  - Decreased systematic uncertainties
  - Improved statistics
  - Improved region definition

qqA Production





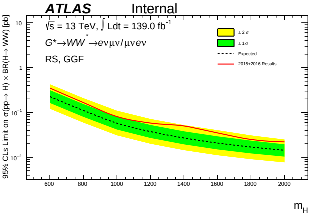
VBF Production

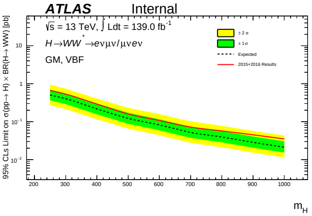
Statistical Analysis - RS+GM Results

The analysis is still under review, so for the time being expected limits are computed and compared to the previous 36 fb^{-1} results.

- Improvements over previous 36 fb^{-1}
  - Decreased systematic uncertainties
  - Improved statistics
  - Improved region definition

RS Graviton





GM Heavy Higgs

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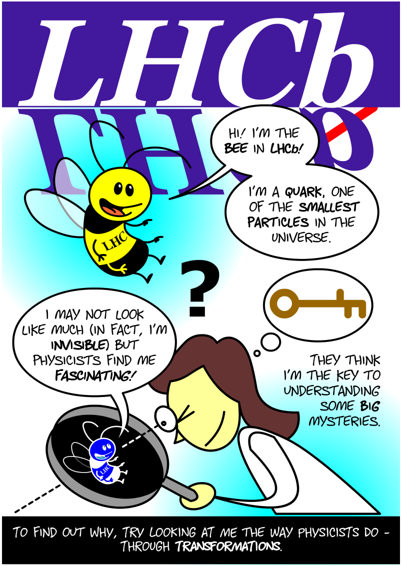
Conclusions

- A search for heavy resonances decaying to a pair of W bosons has been performed.
- No statistically significant excess is expected to be seen $\rightarrow$ Expected limits are calculated.
- Expectation to improve theoretical limits on ggF Radion production.
- Analysis continues to move forward desiring unblinding of data in the signal regions to calculate observed limits.

Special thanks to Dr. Mike Strauss, Dr. David Shope, Joseph Lambert, and the full ATLAS Higgs and HWW analysis group for close collaboration

The search continues in Run-III..



BACKUP

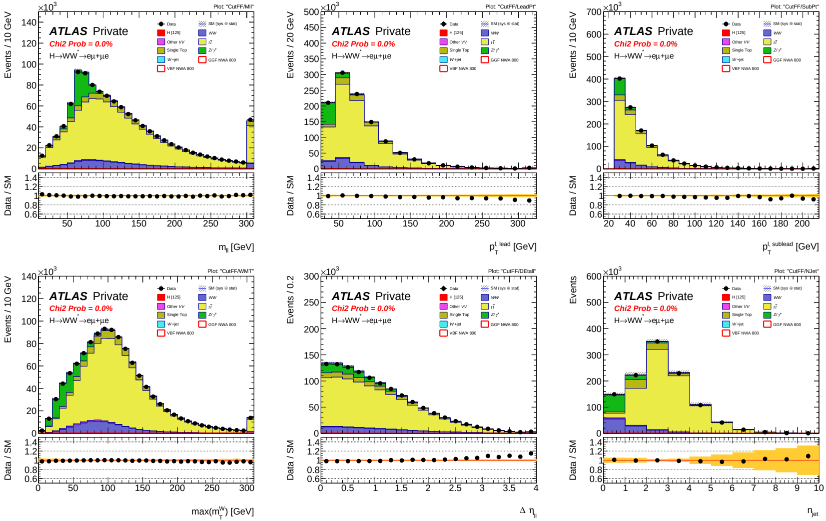
Optimization - Baseline Signal Region Selections

Pre-Selection		
Two Different Flavour, Opposite Sign Leptons, $p_T^\ell > 25$ GeV Third lepton veto, $p_T^\ell > 15$ GeV		
$\mathrm{SR_{ggF}}$	$\mathrm{SR_{VBF1J}}$	$\mathrm{SR_{VBF2J}}$
Common Selection		
$N_{b-tag} = 0$ $\lvert\Delta\eta_{\ell\ell}\rvert < 1.8$ $m_{\ell\ell} > 55$ GeV $p_T^{\ell,\mathrm{lead}} > 45$ GeV $p_T^{\ell,\mathrm{sublead}} > 30$ GeV $\max(m_T^W) > 50$ GeV		
ggF phase space	VBF1J phase space	VBF1J phase space
Inclusive in N_{jet} but excluding VBF1J and VBF2J phase space	$N_{jet} = 1$ and $\lvert\eta_j\rvert > 2.4$, $\min(\lvert\Delta\eta_{j\ell}\rvert) > 1.75$	$N_{jet} = 2$ and $m_{jj} > 500$ GeV, $\lvert\Delta y_{jj}\rvert > 4$

Optimization - Baseline Signal Region Selections

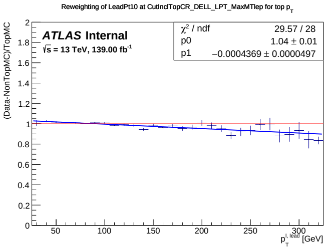
Pre-Selection			
Two Different Flavour, Opposite Sign Leptons, $p_T^{\ell} > 25$ GeV Third lepton veto, $p_T^{\ell} > 15$ GeV			
WW CR_{ggF}	Top CR_{ggF}	WW CR_{VBF1J}	Top CR_{VBF}
$N_{b-tag} = 0$	$N_{b-tag} = 1$	$N_{b-tag} = 0$	$N_{b-tag} \geq 1$
$\lvert\Delta\eta_{\ell\ell}\rvert > 1.8$	$\lvert\Delta\eta_{\ell\ell}\rvert < 1.8$	$(\lvert\Delta\eta_{\ell\ell} > 1.8$ or	$\lvert\Delta\eta_{\ell\ell}\rvert < 1.8$
$m_{\ell\ell} > 55$ GeV		10 GeV $< m_{\ell\ell} <$ 55 GeV)	$m_{\ell\ell} > 55$ GeV
$p_T^{\ell,\text{lead}} > 45$ GeV		–	$p_T^{\ell,\text{lead}} > 45$ GeV
$p_T^{\ell,\text{sublead}} > 30$ GeV		–	$p_T^{\ell,\text{sublead}} > 30$ GeV
$\max(m_T^W) > 50$ GeV		–	$\max(m_T^W) > 50$ GeV
METSigRatio > 0.8	–	–	
Excluding VBF1/2J phase space		VBF1J phase space	VBF1/2J phase space

- Modeling of the data by the MC background is considered at the preselection level. Begin to see mismodeling of the $p_T^{\ell,\text{lead}}$ distribution, but no other modeling issues stand out.



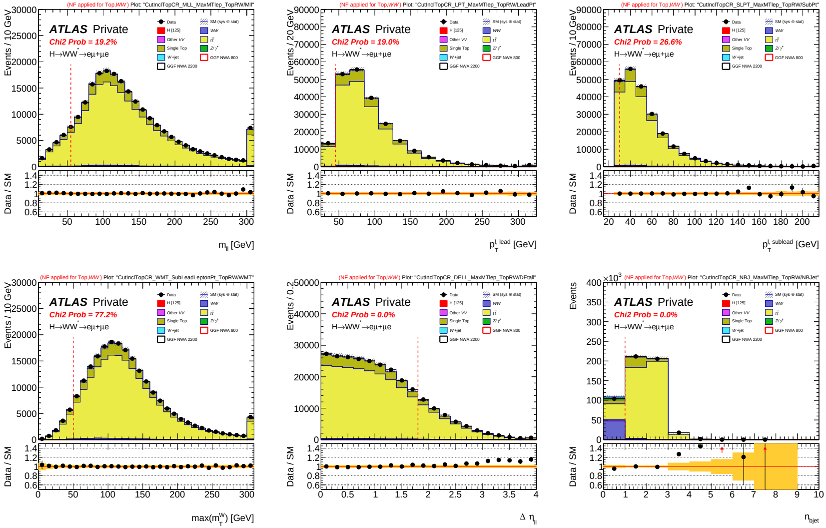
Top p_T Reweighting

- Values of the top lead lepton p_T derived in ggF (left) and VBF (right):

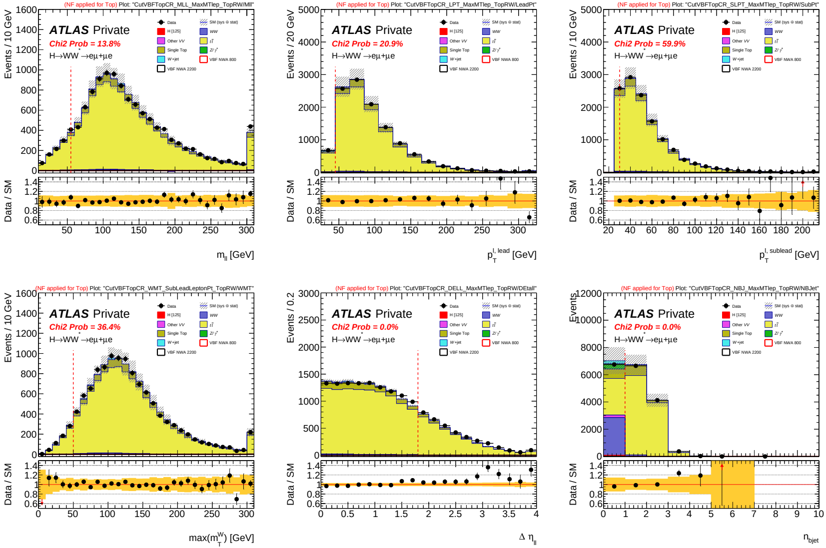


- Because the values of the reweighting function are similar and within statistical uncertainties between the two regions, we use the ggF value in all regions.

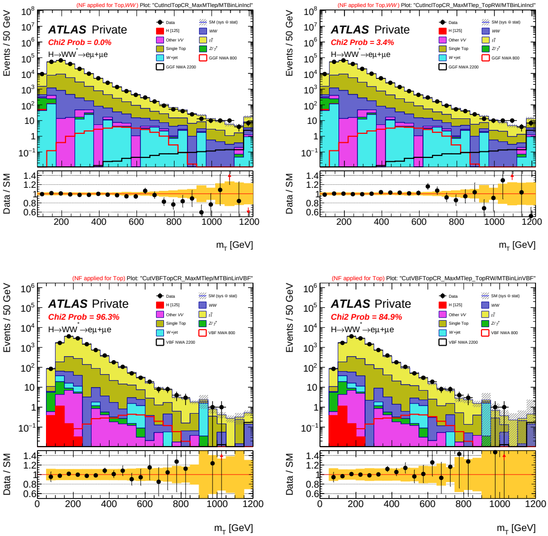
- Top-quark modeling in the ggF quasi-inclusive control region where the cut on the specific kinematic has been removed after the top-quark reweighting has been applied.



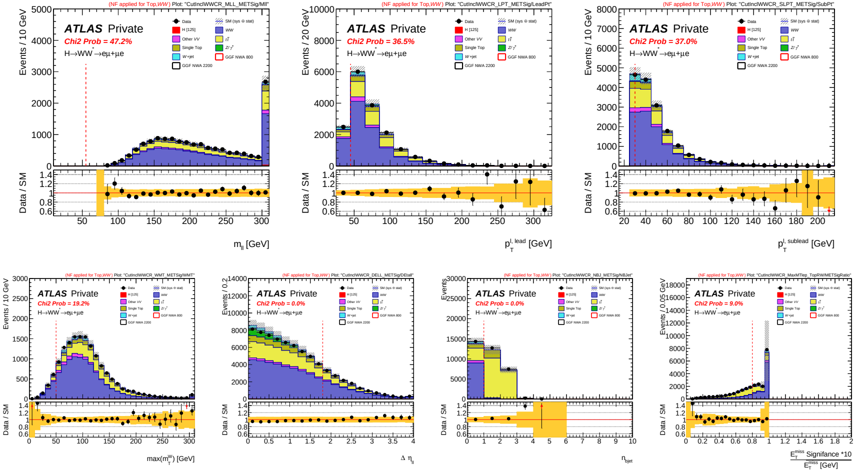
- Top-quark modeling in the VBF control region after the top-quark reweighting has been applied.



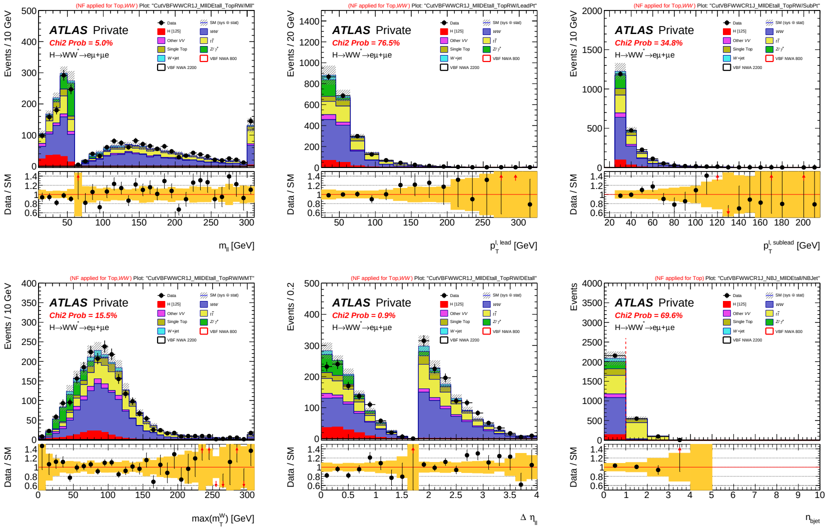
- The affect of the correction can clearly be seen in the shape of the m_T distribution for both ggF (top) and VBF (bottom) control regions.



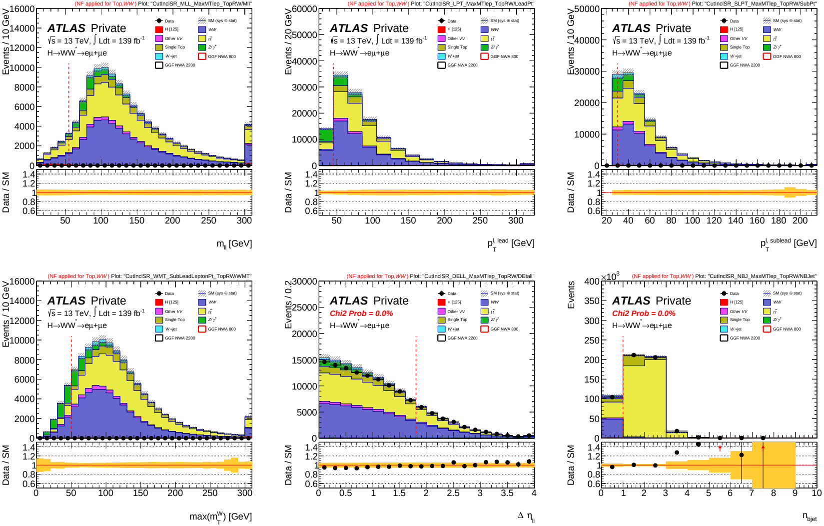
- *WW* modeling in the ggF quasi-inclusive control region with the cut on the kinematic shown removed. NF $= 1.09 \pm 0.02$



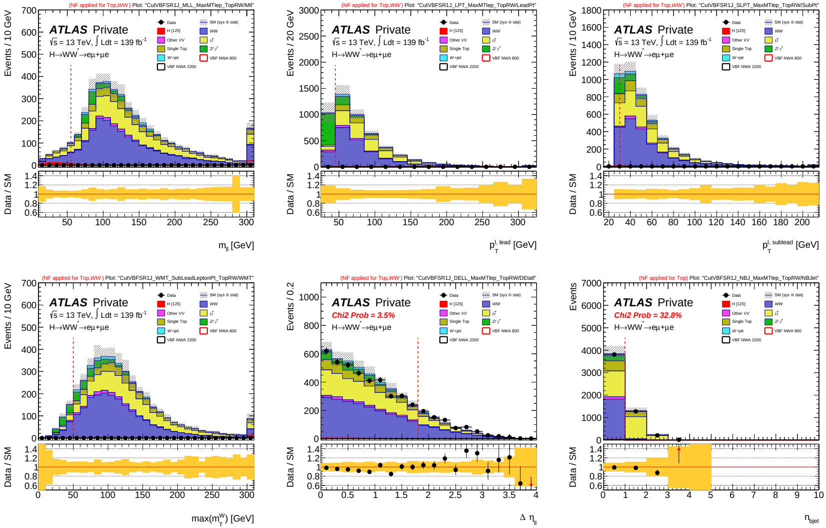
- *WW* modeling in the VBF control region with the cut on the kinematic shown removed. NF $= 1.08 \pm 0.05$



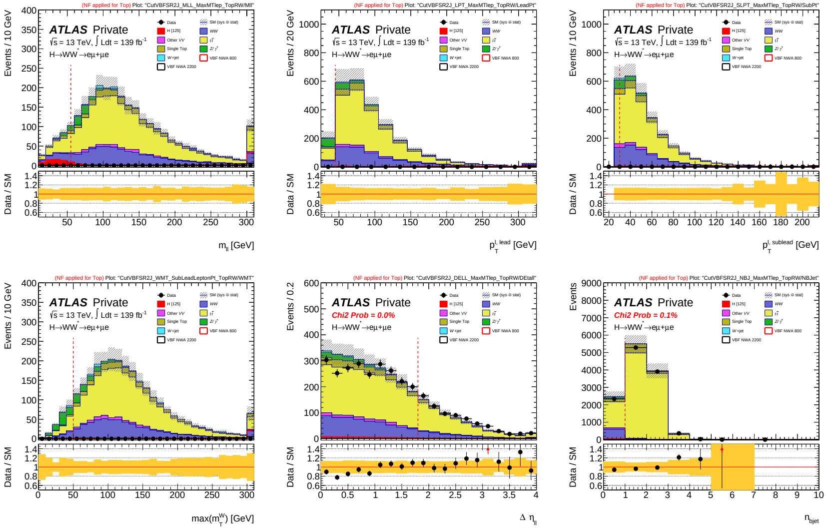
- SM background and select NWA mass points in the ggF quasi-inclusive signal region.



- SM background and select NWA mass points in the VBF 1-jet signal region.



- SM background and select NWA mass points in the VBF 2+ jets signal region.



W+jets

- Due to the poor modeling W+jets processes in simulation, a data-driven fake factor method is used to estimate this background.
- The number of events with misidentified leptons (in short "fake events") is estimated from a control region, where exactly one lepton does not meet the lepton identification criteria but instead satisfies a looser set of criteria designed to select fake leptons:

$$\begin{aligned} N^{\mathrm{fake}}_{\mathrm{id+id}} &= N^{\mathrm{fake}}_{\mathrm{id+anti-id}} \cdot f \\ &= (N_{\mathrm{id+anti-id}} - N^{\mathrm{EW}}_{\mathrm{id+anti-id}}) \cdot f \end{aligned} \quad (1)$$

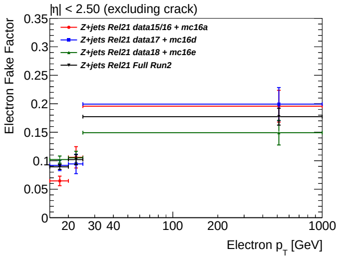
- The extrapolation factor f is measured in Z+jets events in a three-lepton selection where the two electrons or muons of opposite charge are taken as Z decay particles if they are in an invariant-mass window of [80, 110] GeV or [70, 110] GeV, respectively.
- The remaining lepton is the fake candidate, which can be identified or anti-identified.

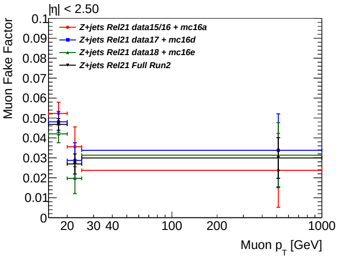
- The fake factor is measured to be the ratio of identified over anti-identified leptons:

$$f = \frac{N^{\mathrm{Z+jets}}_{\mathrm{i,i,i}}}{N^{\mathrm{Z+jets}}_{\mathrm{i,i,a}}}$$

Electron		Muon	
identified	anti-identified	identified	anti-identified
$p_{\mathrm{T}} > 15$ GeV		$p_{\mathrm{T}} > 15$ GeV	
$\lvert\eta\rvert < 2.47$,excluding $1.37 < \lvert\eta\rvert < 1.52$		$\lvert\eta\rvert < 2.45$	
$\lvert z_0 \sin\theta\rvert < 0.5$ mm		$\lvert z_0 \sin\theta\rvert < 0.5$ mm	
$\lvert d_0\rvert/\sigma(d_0) < 5$		$\lvert d_0\rvert/\sigma(d_0) < 3$	$\lvert d_0\rvert/\sigma(d_0) < 15$
Pass LHMedium	Pass LHLoose	Pass Quality Tight	Pass Quality Medium
Pass FCTight isolation		Pass FCTight isolation	
AUTHOR = 1			
	Veto against identified electron		Veto against identified muon

- The fake factor calculated in bins of p_T of the fake candidate due to p_T dependence. Due to the similar yields of data and MC background at high transverse momenta in the ID region, the fake factor is only split at small p_T with bin boundaries at $\{15, 20, 25, \inf\}$ GeV.
- For electrons, where a split of the high-p_T bin at 35 GeV would be feasible, the fake factors are observed to be the same within statistical uncertainties.





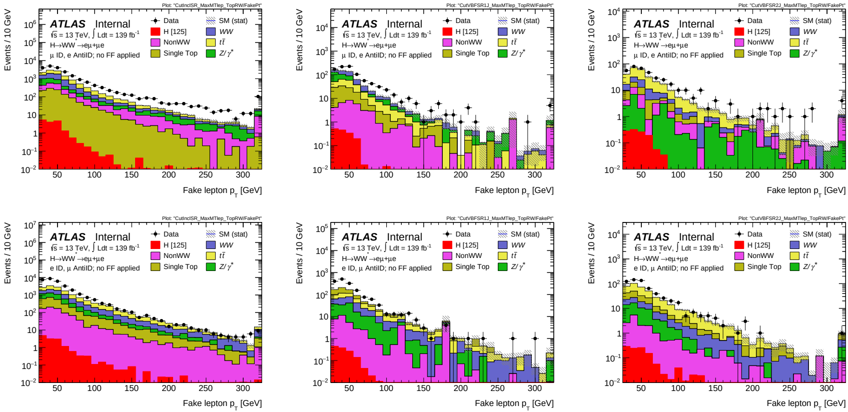
- Corrections to the fake factor are also necessary due to the compositional differences between the region the fake factor is estimated (Z+jets) and the region the fake factor is applied (W+jets).
- A further correction is applied due to the trigger requirement in the control region being more stringent than the anti-id selection:

$$N_{\mathrm{i,i}}^{\mathrm{W+jets}} = f(N_{\mathrm{i^T,a^T}}^{\mathrm{W+jets}} + N_{\mathrm{i^T,a^{!T}}}^{\mathrm{W+jets}}) + f^{\mathrm{T}} N_{\mathrm{i^{!T},a^T}}^{\mathrm{W+jets}} \quad \text{with } f^{\mathrm{T}} = \frac{N_{\mathrm{i}}}{N_{\mathrm{a^T}}}$$

- A final correction is applied to account for the double counting of fakes coming from multi-jet backgrounds.

ID-AntiID Fake Lepton p_T

- Very little real fakes contributing at high p_T:



Systematic Uncertainties - Uncertainty Overview

- Individual experimental uncertainties considered in the analysis.

Systematic uncertainty	Short description
	Event
Luminosity	uncertainty on total integrated luminosity
Pileup Reweighting	uncertainty on pileup reweighting
	Electrons
EL_EFF_Trigger_Total_1NPCOR_PLUS_UNCOR	trigger efficiency uncertainty
EL_EFF_Reco_Total_1NPCOR_PLUS_UNCOR	reconstruction efficiency uncertainty
EL_EFF_ID_TotalCorrUncertainty	ID efficiency uncertainty
EL_EFF_ID_CorrUncertaintyNP (0 to 15)	ID efficiency uncertainty splits in 16 components
EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP (0 to 17)	ID efficiency uncertainty splits in 18 components
EL_EFF_Iso_Total_1NPCOR_PLUS_UNCOR	isolation efficiency uncertainty
EG_SCALE_ALL EG_SCALE_AF2	energy scale uncertainty
EG_RESOLUTION_ALL	energy resolution uncertainty
	Muons
MUON_EFF_TrigStatUncertainty MUON_EFF_TrigSystUncertainty	trigger efficiency uncertainty
MUON_EFF_RECO_STAT MUON_EFF_RECO_SYS	reconstruction and ID efficiency uncertainty for muons with p_T ¿ 15 GeV
MUON_ISO_STAT MUON_ISO_SYS	isolation efficiency uncertainty
MUON_TTVA_STAT MUON_TTVA_SYS	track-to-vertex association efficiency uncertainty
MUON_ID	momentum resolution uncertainty from inner detector
MUON_MS	momentum resolution uncertainty from muon system
MUON_SCALE	momentum scale uncertainty
MUON_SAGITTA_RHO MUON_SAGITTA_RESBIAS	charge dependent momentum scale uncertainty

Systematic Uncertainties - Uncertainty Overview

- Individual experimental uncertainties considered in the analysis.

Systematic uncertainty	Short description
Jets	
JET_EffectiveNP_Detector (1 to 2) JET_EffectiveNP_Mixed (1 to 3) JET_EffectiveNP_Modelling (1 to 4) JET_EffectiveNP_Statistical (1 to 6)	energy scale uncertainty from the in situ analyses splits into 8 components
JET_EtaIntercalibration_Modeling	energy scale uncertainty on eta-intercalibration (modeling)
JET_EtaIntercalibration_TotalStat	energy scale uncertainty on eta-intercalibrations (statistics/method)
JET_EtaIntercalibration_NonClosure_highE JET_EtaIntercalibration_NonClosure_negEta JET_EtaIntercalibration_NonClosure_posEta	energy scale uncertainty on eta-intercalibrations (non-closure)
JET_Pileup_OffsetMu	energy scale uncertainty on pile-up (mu dependent)
JET_Pileup_OffsetNPV	energy scale uncertainty on pile-up (NPV dependent)
JET_Pileup_PtTerm	energy scale uncertainty on pile-up (pt term)
JET_Pileup_RhoTopology	energy scale uncertainty on pile-up (density ρ)
JET_Flavor_Composition	energy scale uncertainty on flavour composition
JET_Flavor_Response	energy scale uncertainty on samples' flavour response
JET_BJES_Response	energy scale uncertainty on b-jets
JET_PunchThrough_MC16	energy scale uncertainty for punch-through jets
JET_SingleParticle_HighPt	energy scale uncertainty from the behaviour of high-p_T jets
JET_JER_DataVsMC_MC16 JET_JER_EffectiveNP (1 to 11) JET_JER_EffectiveNP_12restTerm	energy resolution uncertainty, each for both MC and pseudo-data
JET_JvtEfficiency	JVT efficiency uncertainty
FT_EFF_Eigen_B FT_EFF_Eigen_C FT_EFF_Eigen_L	*b*-tagging efficiency uncertainties ("BTAG_MEDIUM"): 3 components for *b* jets, 3 for *c* jets and 4 for light jets
FT_EFF_Eigen_extrapolation	*b*-tagging efficiency uncertainty on the extrapolation to high-p_T jets
FT_EFF_Eigen_extrapolation_from_charm	*b*-tagging efficiency uncertainty on tau jets
MET	
MET_SoftTrk_ResoPara	track-based soft term related longitudinal resolution uncertainty
MET_SoftTrk_ResoPerp	track-based soft term related transverse resolution uncertainty
MET_SoftTrk_Scale	track-based soft term related longitudinal scale uncertainty

Systematic Uncertainties - Top Exp. Uncertainties

	Prefit Value [%]						
Source	Jet	Flavor Tagging	Pile-up	Muons	Electrons	MET	Total
ggF SR	3.517	7.609	2.538	1.01	0.298	0.050	8.821
VBF SR 1J	6.433	3.738	4.264	0.973	0.316	0.099	8.636
VBF SR 2J	9.853	6.686	4.128	1.082	0.301	0.010	12.652
ggF Top CR	1.267	1.821	0.911	0.987	0.300	0.058	2.611
ggF WW CR	9.462	6.509	7.408	1.192	0.358	1.713	13.829
VBF Top CR	9.806	1.519	4.133	0.973	0.282	0.111	10.797
VBF WW CR	6.703	3.615	4.102	1.113	0.381	0.000	8.729

Systematic Uncertainties - WW Exp. Uncertainties

	Prefit Value [%]						
Source	Jet	Flavor Tagging	Pile-up	Muons	Electrons	MET	Total
ggF SR	1.257	0.409	0.940	1.040	0.328	0.106	1.957
VBF SR 1J	13.542	0.208	6.172	1.221	0.275	0.176	14.937
VBF SR 2J	14.402	0.739	9.486	0.942	0.327	0.140	17.290
ggF Top CR	-	-	-	-	-	-	-
ggF WW CR	3.769	0.218	2.465	1.182	0.314	1.313	4.852
VBF Top CR	-	-	-	-	-	-	-
VBF WW CR	13.428	0.209	6.518	0.932	0.343	0.000	14.960

Systematic Uncertainties - NWA Exp. Uncertainties

	Prefit Value [%]						
Source	Jet	Flavor Tagging	Pile-up	Muons	Electrons	MET	Total
	ggF Production						
ggF SR	1.359	0.580	0.743	1.088	0.863	0.014	2.159
VBF SR 1J	3.625	0.209	1.67	1.198	0.839	0.037	4.256
VBF SR 2J	9.996	0.677	5.013	1.464	0.856	0.030	11.330
	VBF Production						
ggF SR	3.773	0.462	1.902	1.324	0.857	0.037	4.533
VBF SR 1J	3.510	0.103	1.903	1.108	0.852	0.067	4.232
VBF SR 2J	4.635	0.320	2.265	1.020	0.897	0.022	5.344

$t\bar{t}$ Theory Uncertainties - Overview

- All $t\bar{t}$ variations are taken at reco level following the PMG recommendations, with the nominal as the PowPy8 $t\bar{t}$ dilepton sample 410472.
- **Generator** - Two-point comparison of AFII PowPy8 and aMC@NLO+Pythia8 generators, symmetrized.
- **Shower** - Two-point comparison of AFII PowPy8 and Powheg+Herwig generators, symmetrized.
- **Scale** - Bin-by-bin envelope calculation of 7-point μR and μF variations.
- **ISR** - Variation of strong coupling in initial shower using Var3c eigentune.
- **FSR** - Variation of μRfac (0.5,2.0) in the final state radiation.
- **PDF** - Standard deviation of NNPDF3.0 PDF set.

$t\bar{t}$ Theory Uncertainties - Integrated Values

- Each uncertainty is evaluated by comparing the integrated value difference at each CR/SR cut to obtain the OverallSyst to be used in the fit.

	Impact high / low [%]			
Systematic	ggF Top CR	ggF *WW* CR	ggF Incl SR	$\Delta\alpha$ [%]
Shower	±6.9	±6.2	±8.4	±1.4
Generator	±9.6	±8.9	±13.7	±3.8
Scale	11.6 / -11.6	13.6 / -13.2	11.7 / -11.6	0.1 / -0.1
ISR	-0.2 / 0.2	-0.8 / 0.7	-0.2 / 0.2	-0.0 / 0.0
FSR	-0.9 / 1.2	-4.9 / 9.1	-4.0 / 6.4	-3.2 / 5.2
PDF	±1.5	±1.6	±1.6	±0.4

	Impact high / low [%]					
Systematic	VBF Top CR	VBF *WW* CR	VBF 1J SR	VBF 2J SR	$\Delta\alpha$ [%] (1J)	$\Delta\alpha$ [%] (2J)
Shower	±10.1	±6.0	±3.5	±13.9	±6.0	±3.4
Generator	±16.6	±17.9	±20.6	±17.9	±3.5	±1.2
Scale	14.5 / -13.1	14.0 / -13.2	11.6 / -11.6	13.8 / -13.8	2.5 / -2.5	0.6 / -0.6
ISR	1.9 / -1.7	-1.3 / 1.2	-1.0 / 0.9	2.7 / -2.5	-2.8 / 2.7	0.8 / -0.8
FSR	2.3 / -3.2	-2.3 / 2.9	-1.5 / 4.0	-0.6 / 0.6	-3.7 / 7.4	-2.8 / 3.9
PDF	±1.6	±1.6	±1.6	±2.1	±0.2	±1.0

Wt Theory Uncertainties - Overview

- All Wt variations are taken at reco level following the PMG recommendations, with the nominal as the PowPy8 Wt dilepton samples 410648,9.
- **Generator** - Two-point comparison of AFII PowPy8 and aMC@NLO+Pythia8 generators, symmetrized.
- **Shower** - Two-point comparison of AFII PowPy8 and Powheg+Herwig generators, symmetrized.
- **Scale** - Bin-by-bin envelope calculation of 7-point μR and μF variations.
- **ISR** - Variation of strong coupling in initial shower using Var3c eigentune.
- **FSR** - Variation of μRfac (0.5,2.0) in the final state radiation.
- **PDF** - Standard deviation of NNPDF3.0 PDF set.
- **Interference** - Two-point comparison of fullsim PowPy8 DR (nominal) and DS (variation) samples.

Wt Theory Uncertainties - Integrated Values

- Each uncertainty is evaluated by comparing the integrated value difference at each CR/SR cut to obtain the OverallSyst to be used in the fit.

	Impact high / low [%]			
Systematic	ggF Top CR	ggF WW CR	ggF Incl SR	$\Delta\alpha$ [%]
Shower	±12.0	±20.5	±25.4	±11.9
Generator	±11.2	±15.5	±17.1	±5.2
Scale	4.4 / -4.5	4.3 / -4.4	4.4 / -4.4	0.4 / -0.4
ISR	-0.4 / 0.4	-0.8 / 0.8	4.4 / -4.4	-0.3 / 0.1
FSR	0.6 / -0.4	-3.2 / 3.1	-2.8 / 4.5	-3.4 / 5.0
Interference	±1.9	±2.5	±0.0	±1.6
PDF	±1.9	±1.9	±1.9	±0.3

	Impact high / low [%]					
Systematic	VBF Top CR	VBF WW CR	VBF 1J SR	VBF 2J SR	$\Delta\alpha$ [%] (1J)	$\Delta\alpha$ [%] (2J)
Shower	±10.3	±14.3	±14.8	±29.7	±4.1	±17.6
Generator	±19.8	±24.5	±22.6	±28.4	±2.3	±7.2
Scale	5.2 / -5.0	5.1 / -5.0	4.3 / -4.4	4.9 / -4.8	2.1 / -2.1	0.5 / -0.5
ISR	2.9 / -2.6	-0.0 / 0.4	-0.4 / 0.3	2.6 / -2.1	-3.3 / 3.0	-0.3 / 0.6
FSR	1.6 / -4.5	-3.2 / 2.9	-1.5 / -0.8	0.4 / 0.7	-3.1 / 3.9	-1.2 / 5.4
Interference	±2.5	±6.8	±6.4	±2.6	±9.1	±5.7
PDF	±1.9	±1.8	±1.9	±2.3	±0.3	±1.0

WW Theory Uncertainties - Overview

- WW uncertainties are taken only on $qqWW$, following the PMG recommendations, with the nominal as the Sherpa $qqWW$ dilepton sample 364254.
- **PDF** - Standard deviation of NNPDF3.0 PDF set.
- **Scale** - Bin-by-bin envelope calculation of 7-point μR and μF variations.
- α_S - Variation of the fine-structure constant compared to the nominal PDF set.
- **Shower** - Two-point comparison of truth PowPy8 to Powheg+Herwig7, symmetrized.
- **CKKW** - Variation of the CKKW matching scale on the Sherpa generation at truth level.
- **QSF** - Variation of the resummation scale on the Sherpa generation at truth level.
- **CSSKIN** - Two-point comparison of truth Sherpa with variations on the parton shower recoil scheme, symmetrized.

WW Theory Uncertainties - Integrated Values

- Each uncertainty is evaluated by comparing the integrated value difference at each CR/SR cut to obtain the OverallSyst to be used in the fit.

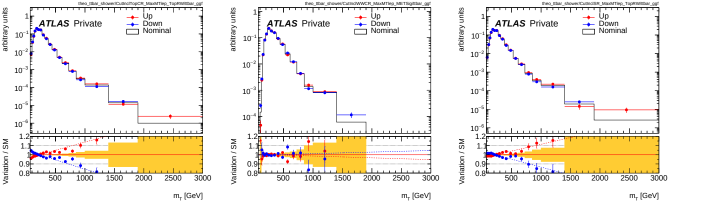
	Impact high / low [%]			
Systematic	ggF Top CR	ggF *WW* CR	ggF Incl SR	$\Delta\alpha$ [%]
PDF	$\pm$1.0	$\pm$1.9	$\pm$1.5	$\pm$0.7
Scale	20.00 / -14.9	3.1 / 3.9	7.5 / -6.8	4.9 / -4.9
α_S	2.1 / -2.1	1.2 / -1.2	1.4 / -1.4	0.1 / -0.1
Shower	$\pm$8.3	$\pm$3.8	$\pm$3.5	$\pm$0.4
CKKW	0.4 / 0.6	-1.2 / 0.4	-2.1 / 0.9	-0.9 / 0.5
QSF	-1.1 / 0.2	0.2 / 2.2	-1.0 / 1.9	-1.2 / -0.2
CSSKIN	$\pm$0.0	$\pm$1.9	$\pm$0.6	$\pm$0.2

	Impact high / low [%]					
Systematic	VBF Top CR	VBF *WW* CR	VBF 1J SR	VBF 2J SR	$\Delta\alpha$ [%] (1J)	$\Delta\alpha$ [%] (2J)
PDF	$\pm$1.1	$\pm$1.4	$\pm$1.4	$\pm$1.0	$\pm$0.3	$\pm$1.0
Scale	20.1 / -14.9	6.9 / -6.5	5.8 / -5.7	21.8 / -15.4	1.1 / -1.1	15.3 / -15.3
α_S	1.9 / -1.9	1.4 / -1.4	1.4 / -1.4	2.0 / -2.0	-0.1 / 0.1	0.6 / -0.6
Shower	$\pm$9.8	$\pm$13.0	$\pm$12.6	$\pm$13.6	$\pm$0.5	$\pm$30.6
CKKW	-10.4 / 11.9	-6.5 / 3.2	-3.3 / 2.0	-12.6 / 9.0	3.4 / -1.2	-6.5 / 5.7
QSF	-7.6 / 6.5	2.3 / 1.6	-1.1 / -0.9	-1.9 / 3.3	-3.3 / -2.5	-4.1 / 1.7
CSSKIN	$\pm$0.0	$\pm$8.7	$\pm$0.0	$\pm$0.0	$\pm$6.2	$\pm$6.1

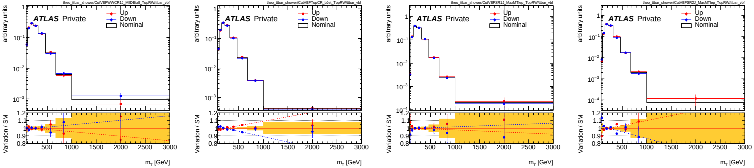
$t\bar{t}$ Theory Uncertainties - Shower

- HistoSys to be included for shape part in the fit for each CR/SR:

GGF



VBF

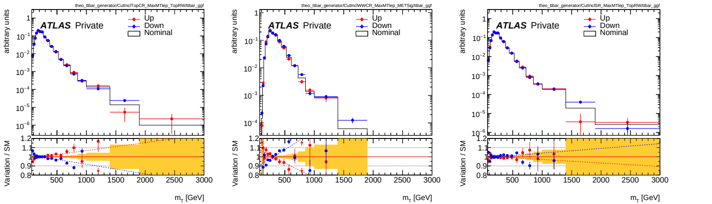


- Small to no shape effects.

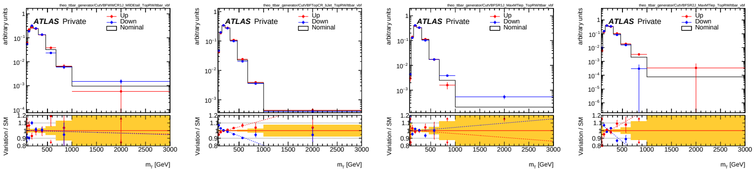
$t\bar{t}$ Theory Uncertainties - Generator

- HistoSys to be included for shape part in the fit for each CR/SR:

GGF



VBF

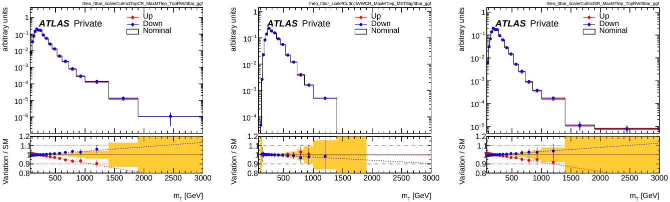


- Significant shape effects in VBF, very low stats in tails though.

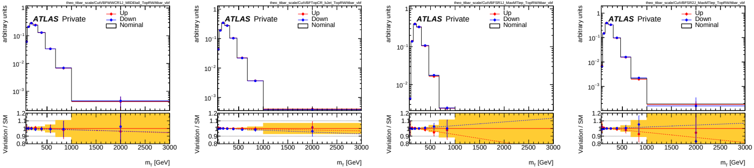
$t\bar{t}$ Theory Uncertainties - Scale

- HistoSys to be included for shape part in the fit for each CR/SR:

GGF



VBF

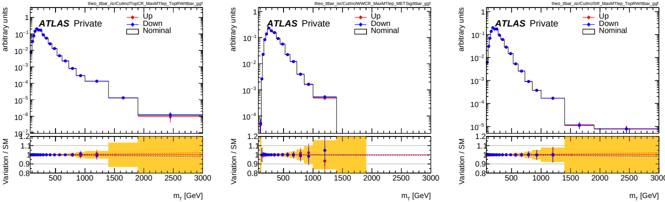


- Small to no shape effects.

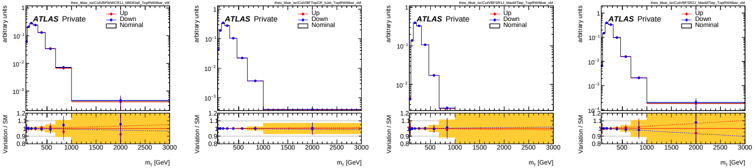
$t\bar{t}$ Theory Uncertainties - ISR

- HistoSys to be included for shape part in the fit for each CR/SR:

GGF



VBF

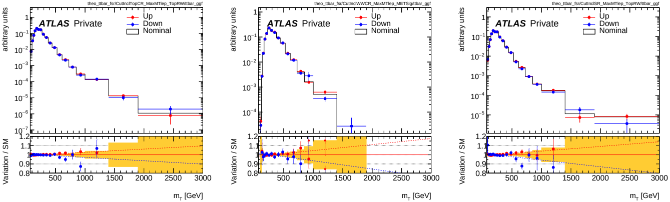


- Small to no shape effects.

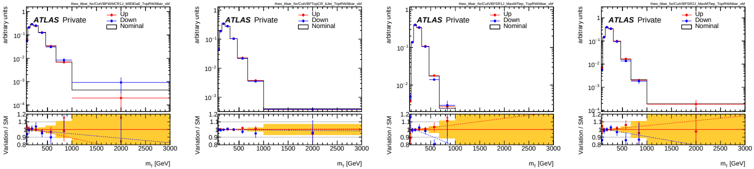
$t\bar{t}$ Theory Uncertainties - FSR

- HistoSys to be included for shape part in the fit for each CR/SR:

GGF



VBF

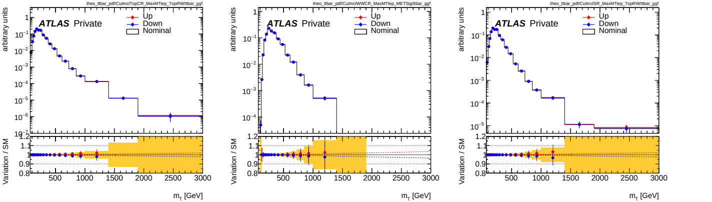


- Small to no shape effects.

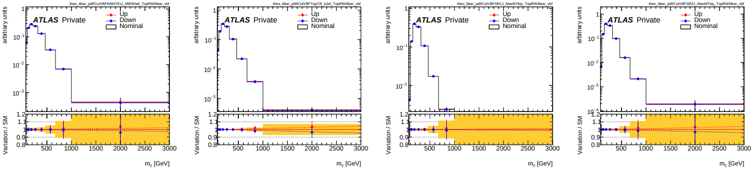
$t\bar{t}$ Theory Uncertainties - PDF

- HistoSys to be included for shape part in the fit for each CR/SR:

GGF



VBF

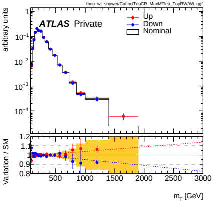


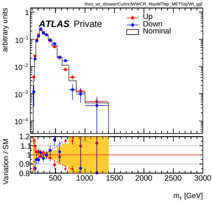
- No shape effects.

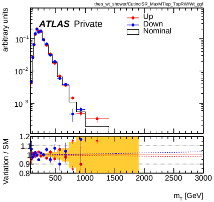
Wt Theory Uncertainties - Shower

- HistoSys to be included for shape part in the fit for each CR/SR:

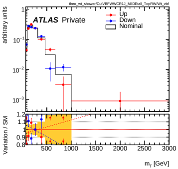
GGF

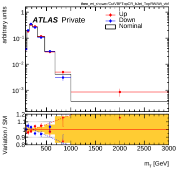


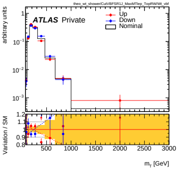


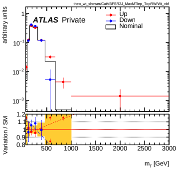


VBF







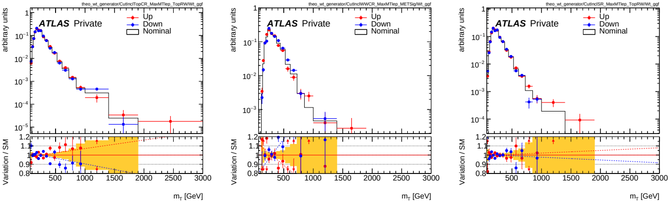


- Small shape effects, generally under stat uncertainties.

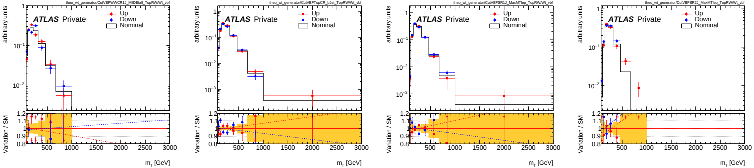
Wt Theory Uncertainties - Generator

- HistoSys to be included for shape part in the fit for each CR/SR:

GGF



VBF

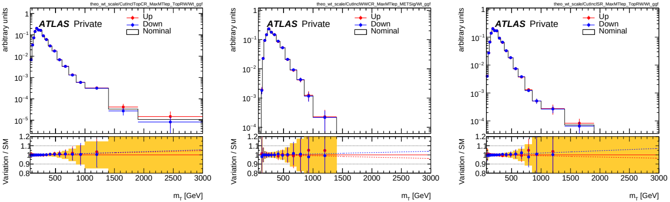


- Significant shape effects in VBF, still generally under stat uncertainties.

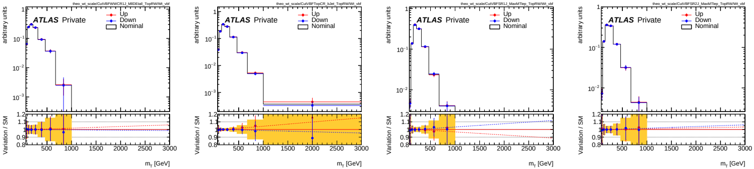
Wt Theory Uncertainties - Scale

- HistoSys to be included for shape part in the fit for each CR/SR:

GGF



VBF

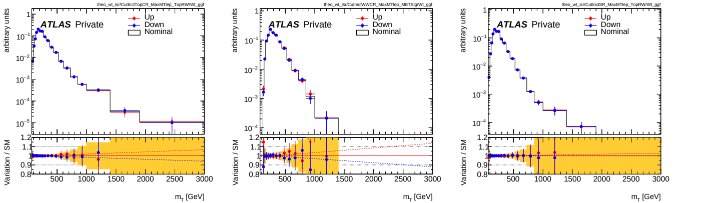


- Small to no shape effects.

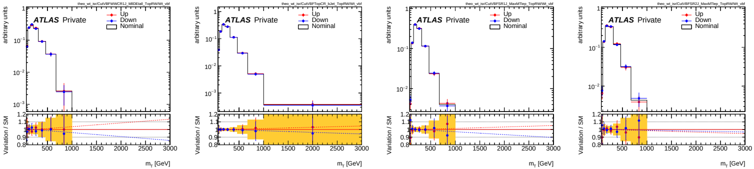
Wt Theory Uncertainties - ISR

- HistoSys to be included for shape part in the fit for each CR/SR:

GGF



VBF

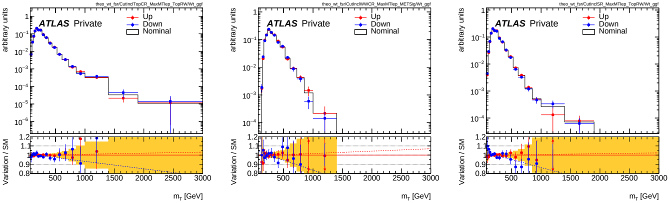


- Small to no shape effects.

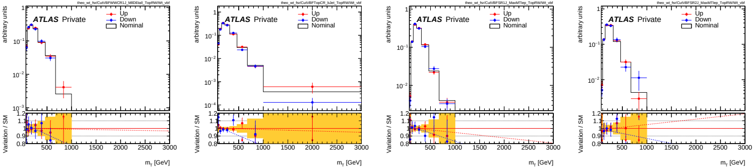
Wt Theory Uncertainties - FSR

- HistoSys to be included for shape part in the fit for each CR/SR:

GGF



VBF

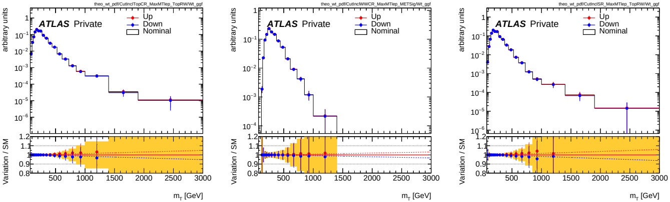


- Significant shape effects in VBF, still generally under stat uncertainties.

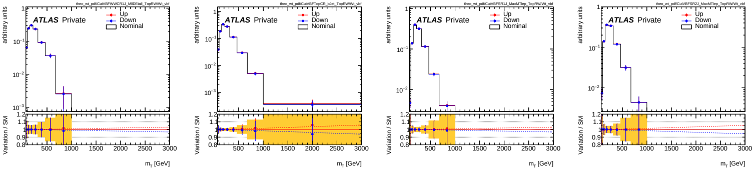
Wt Theory Uncertainties - PDF

- HistoSys to be included for shape part in the fit for each CR/SR:

GGF



VBF

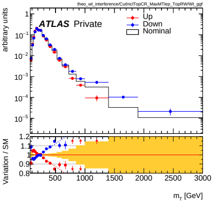


- No shape effects.

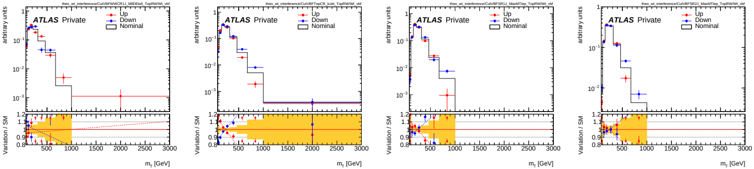
Wt Theory Uncertainties - Interference

- HistoSys to be included for shape part in the fit for each CR/SR:

GGF



VBF

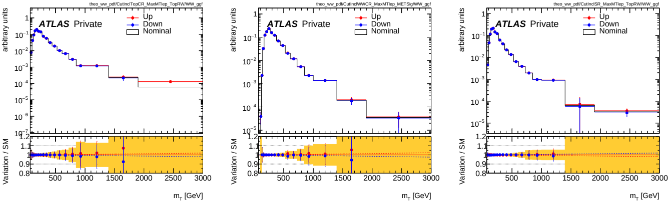


- Significant shape effects, rising above stat uncertainties .

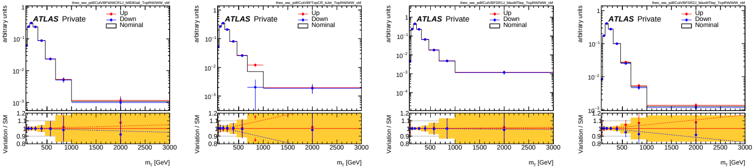
WW Theory Uncertainties - PDF

- HistoSys to be included for shape part in the fit for each CR/SR:

GGF



VBF

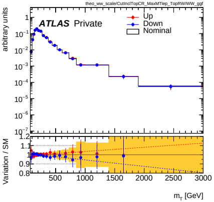


- Small to no shape effects.

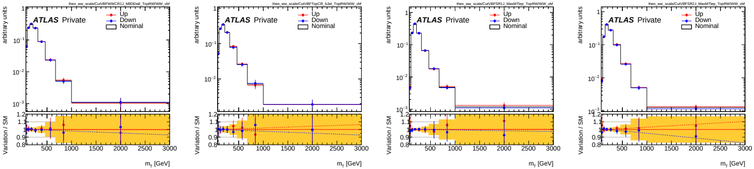
WW Theory Uncertainties - Scale

- HistoSys to be included for shape part in the fit for each CR/SR:

GGF



VBF

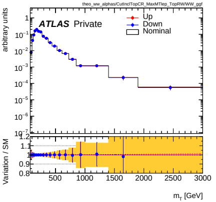


- Small shape effects, generally below stat uncertainties.

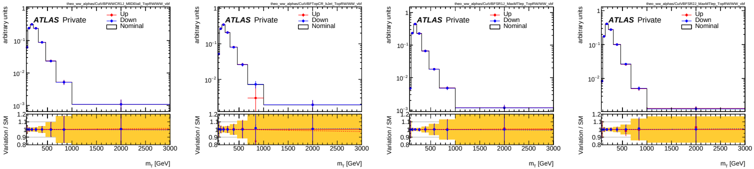
WW Theory Uncertainties - α_S

- HistoSys to be included for shape part in the fit for each CR/SR:

GGF



VBF

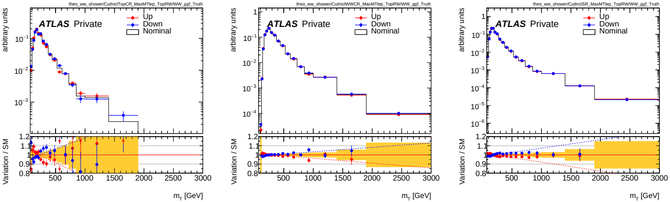


- No shape effects.

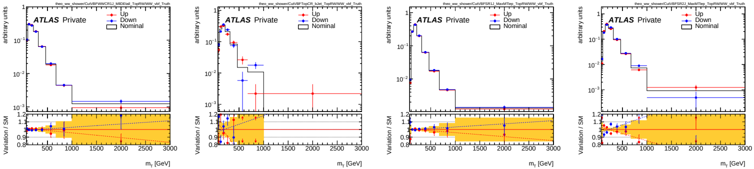
WW Theory Uncertainties - Shower

- HistoSys to be included for shape part in the fit for each CR/SR:

GGF



VBF

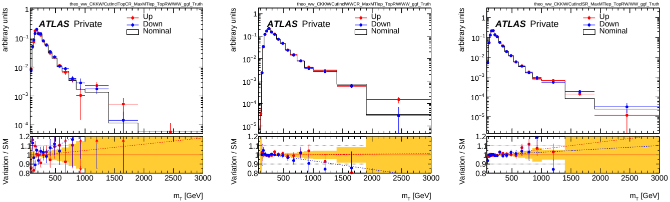


- Moderate shape effects, generally below stat uncertainties.

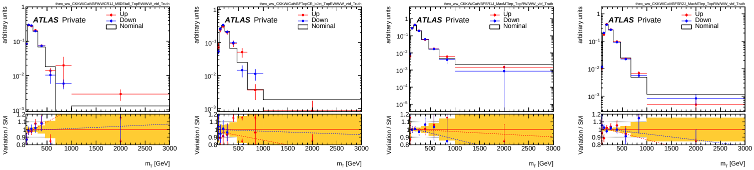
WW Theory Uncertainties - CKKW

- HistoSys to be included for shape part in the fit for each CR/SR:

GGF



VBF

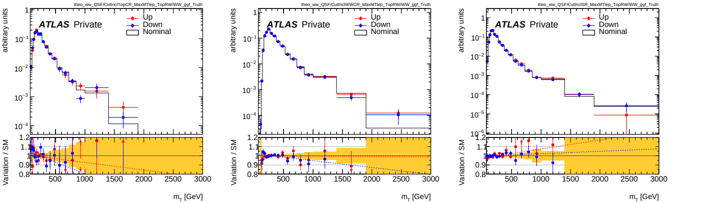


- Significant shape effects, similar to stat uncertainty scale.

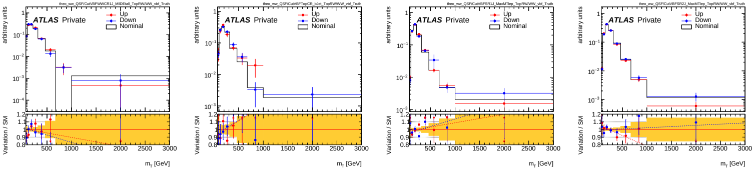
WW Theory Uncertainties - QSF

- HistoSys to be included for shape part in the fit for each CR/SR:

GGF



VBF

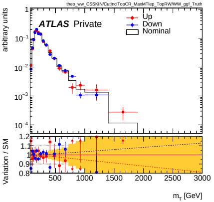


- Small shape effects, generally below stat uncertainties.

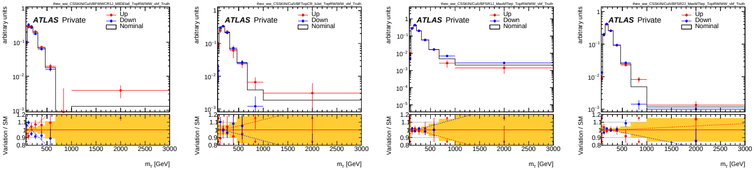
WW Theory Uncertainties - CSSKIN

- HistoSys to be included for shape part in the fit for each CR/SR:

GGF



VBF



- Small shape effects, generally below stat uncertainties.

Statistical Analysis - Correlation Matrices

- Correlation matrices of NPs in the statistical fit for NWA production with $m_H = 800$ GeV.