Search for direct production of electroweakinos in final states with one lepton, jets and missing transverse momentum with ATLAS detector

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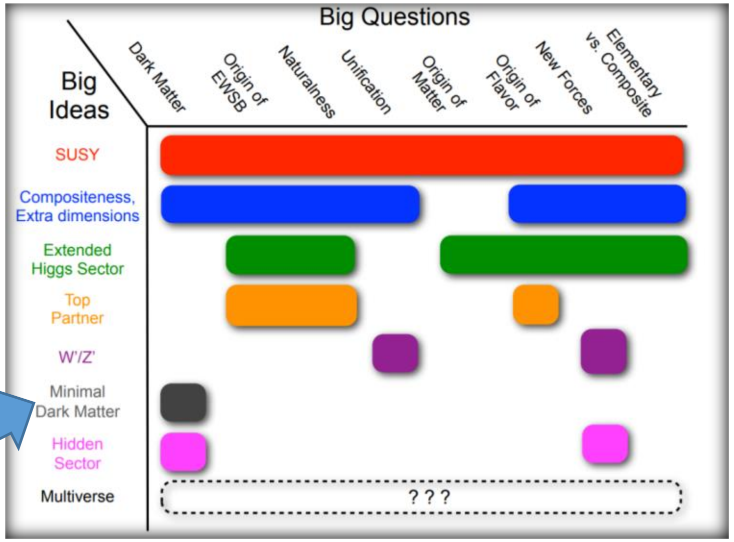
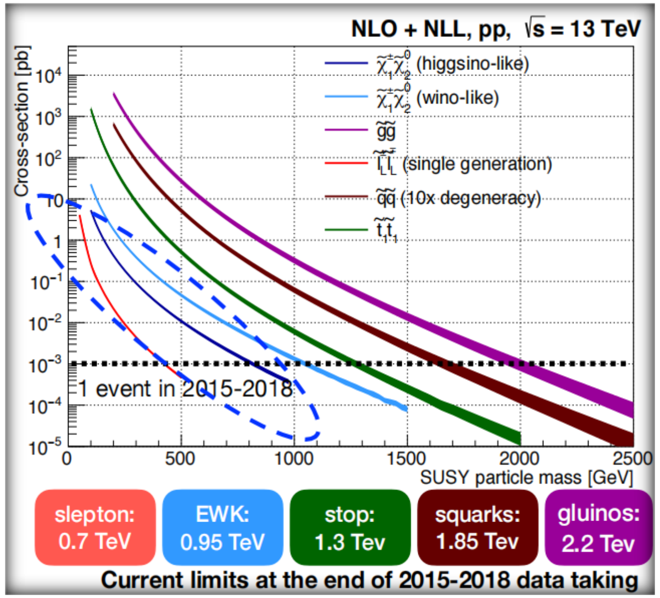
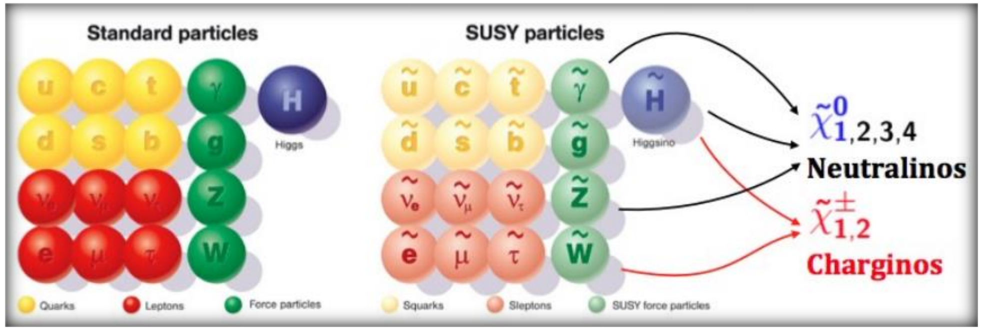
Introduction

- Standard model (SM) :
  - Advantage: Precisely describes the fundamental elements of the matter and the interactions between them.
  - Problems: hierarchy problem, grand unification of gauge couplings, dark matter... -> BSM physics is strongly motivated.
- Supersymmetry (SUSY): one of the most appealing BSM theories.
  - Introduce new symmetry between bosons and fermions.
  - No SUSY particles were discovered so far. -> Limits at LHC.



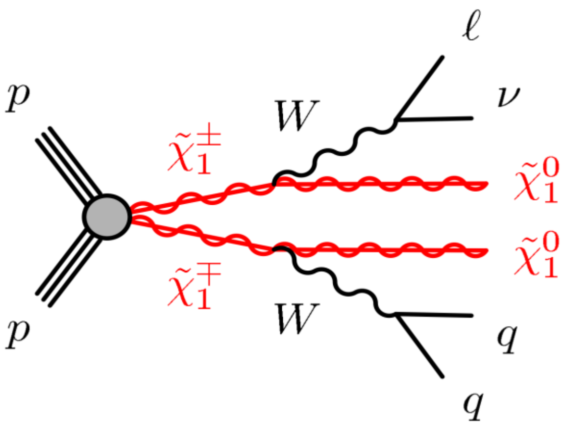




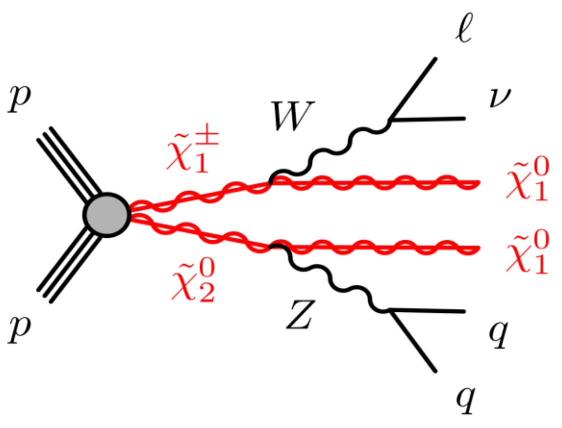
Introduction

- This is the EWK 1L analysis, targeting direct EWK production of **chargino pairs** and **chargino-neutralino pairs**, decaying **into LSP via W/Z boson**.
  - Final state: exactly **one isolated lepton** (ele or mu), **jets** and large **missing transverse momentum**.
  - Targeting **full Run 2 data** of **139 fb^{-1}**.
  - The first time studying C1C1->WW/C1N2->WZ using exactly one lepton final state.
  - Use large-R jet with W/Z boson tagging to improve sensitivity.

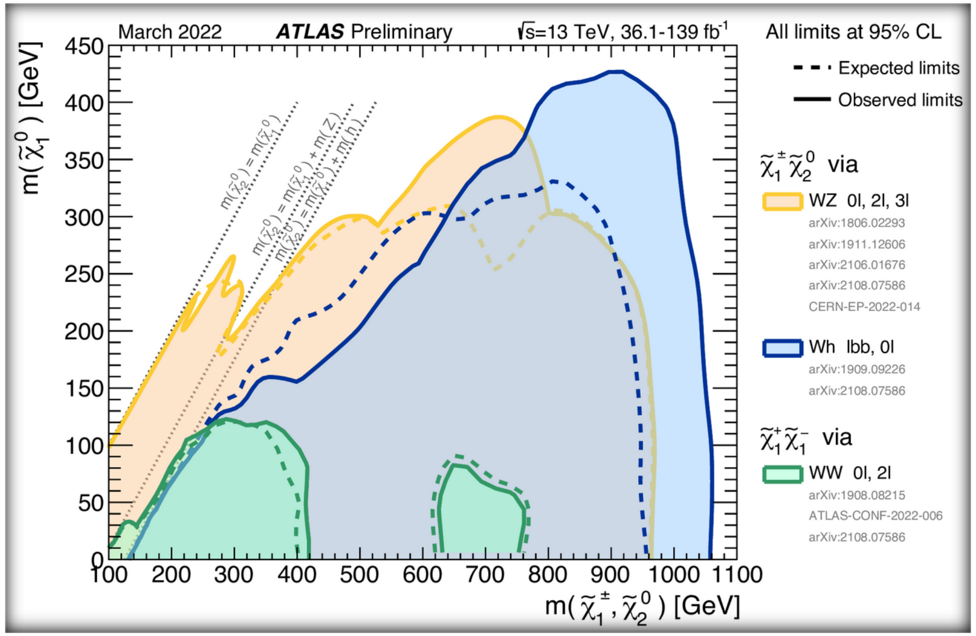
C1C1_WW



C1N2_WZ



Existing results



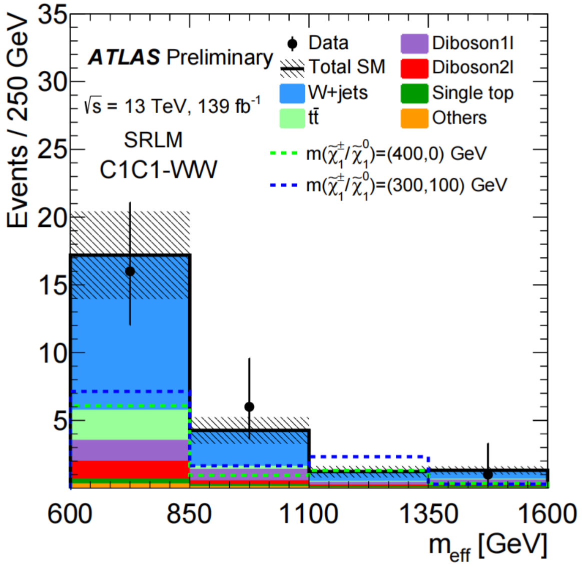
Event selection

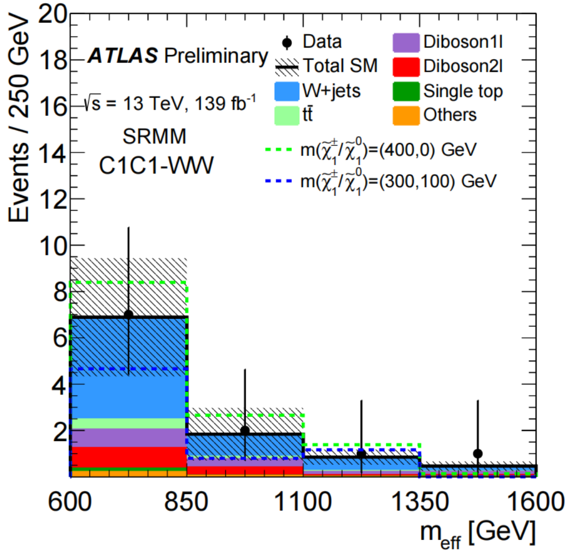
Variable	C1C1-WW model			C1N2-WZ model		
	SRLM	**SRMM**	**SRHM**	**SRLM**	**SRMM**	**SRHM**
N_{lep} ($p_T > 25$ GeV)	1					
N_{jet} ($p_T > 30$ GeV)	1 – 3					
$N_{large-Rjet}$ ($p_T > 250$ GeV)	≥ 1					
E_T^{miss} [GeV]	> 200					
$\Delta\phi(\ell, E_T^{miss})$	< 2.6					
large-R jet type	W-tagged			Z-tagged		
m_T [GeV]	120–200	200–300	> 300	120–200	200–300	> 300
	Exclusion SR					
m_{eff} [GeV] (excl.)	[600–850, > 850]			[600–850, > 850]		
m_{jj}[GeV] (excl.)	[70–90, -]			[80–100, -]		
$\sigma_{E_T^{miss}}$ (excl.)	[> 12, > 15]			[> 12, > 12]		
	Discovery SR					
m_{eff} [GeV] (disc.)	> 600	> 600	> 850	> 600	> 850	> 850
m_{jj}[GeV] (disc.)	-	-	-	80–100	-	-
$\sigma_{E_T^{miss}}$ (disc.)	> 15	> 15	> 15	> 12	> 12	> 12

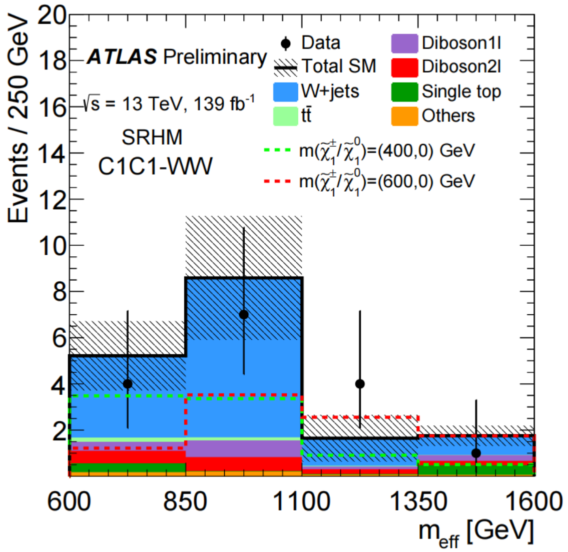
- ✓ The main difference between C1C1 and C1N2 signal scenarios is the **large-R jet boson tagging** type. For each model, LM, MM, HM SRs are defined using m_T
- ✓ **Exclusion SRs** are designed for setting **model-dependent exclusion limits. Two-dimensional multi-bin SR of m_T and m_{eff}** are defined targeting the **different mass differences** between C1/N2 and LSP.
- ✓ **Discovery SRs** are constructed for **model-independent limits**. **Meff bins are merged** for each SR.

Event selection

C1C1_WW_SR

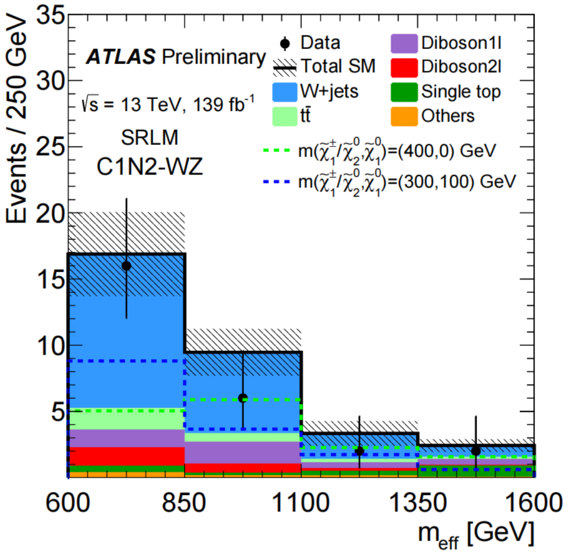


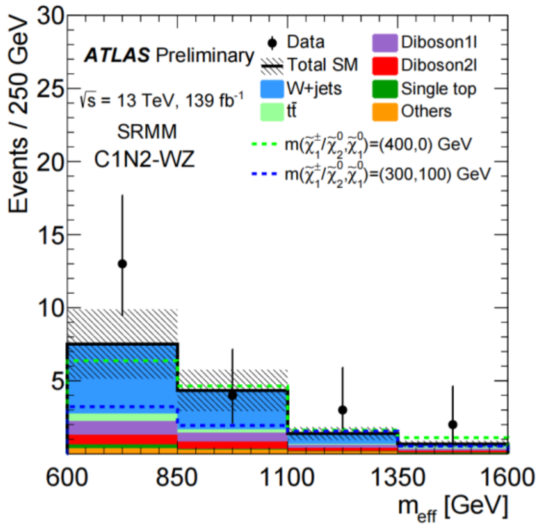


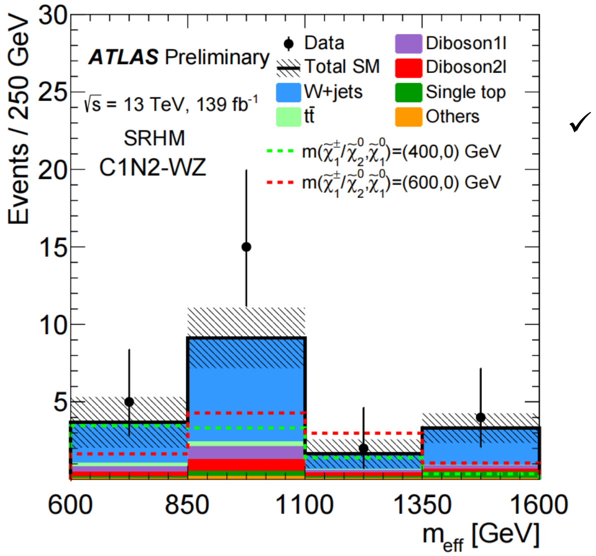


- ✓ Based on different m_T selections, SRLM, SRMM and SRHM target the signal models with low, medium and high mass differences between C1 and LSP, respectively.

C1N2_WZ_SR







- ✓ Based on different m_T selections, SRLM, SRMM and SRHM target the signal models with low, medium and high mass differences between C1/N2 and LSP, respectively.

Background estimation

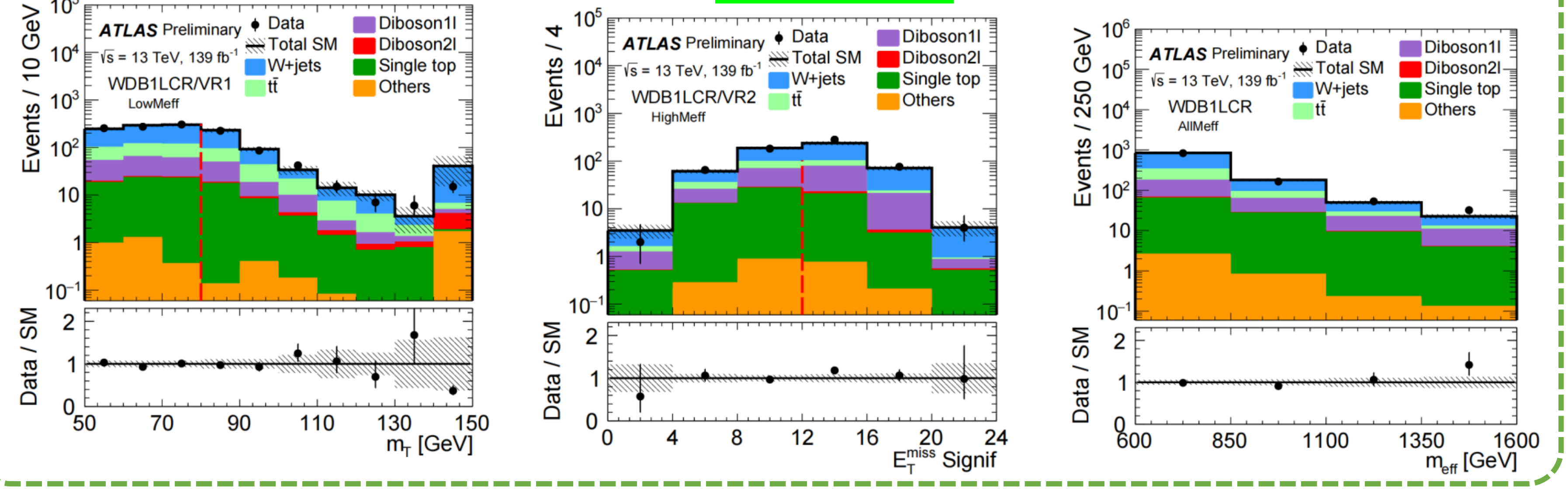
- Dominant background: W+jets (46-73%),diboson(16-39%) and $t\bar{t}$ processes(2-17%).
  - Define dedicated CRs, validated in VRs.
  - W+jets and Diboson1L (lvvv) are estimated in the same WDB1LCR (similar behavior)
  - ttbar is estimated in TCR (similar to WDB1LCR but different Nbjet)
  - Diboson 2L (llvv) is estimated in a DB2L CR
- Small background: Z+jets, single-top, multiboson, $t\bar{t}$ +V, $t\bar{t}$ + H and VH.

Variable	**WDB1L and T**		
	CR	**VR1**	**VR2**
N_{lep} ($p_{\mathrm{T}} > 25$ GeV)	1		
N_{jet} ($p_{\mathrm{T}} > 30$ GeV)	1 - 3		
$N_{\mathrm{b-jet}}$ ($p_{\mathrm{T}} > 30$ GeV)	0 for WDB1L; > 0 for Top		
$N_{\mathrm{large-Rjet}}$ ($p_{\mathrm{T}} > 250$ GeV)	≥ 1		
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 200		
$\Delta\phi(\ell, \mathrm{E}_{\mathrm{T}}^{\mathrm{miss}})$	< 2.9		
large-R jet type	W-tagged		
m_{eff} [GeV]	[600-850,> 850]		
$\sigma_{E_{\mathrm{T}}^{\mathrm{miss}}}$	< 12	< 12	> 12
m_{T} [GeV]	50 – 80	> 80	50 – 120

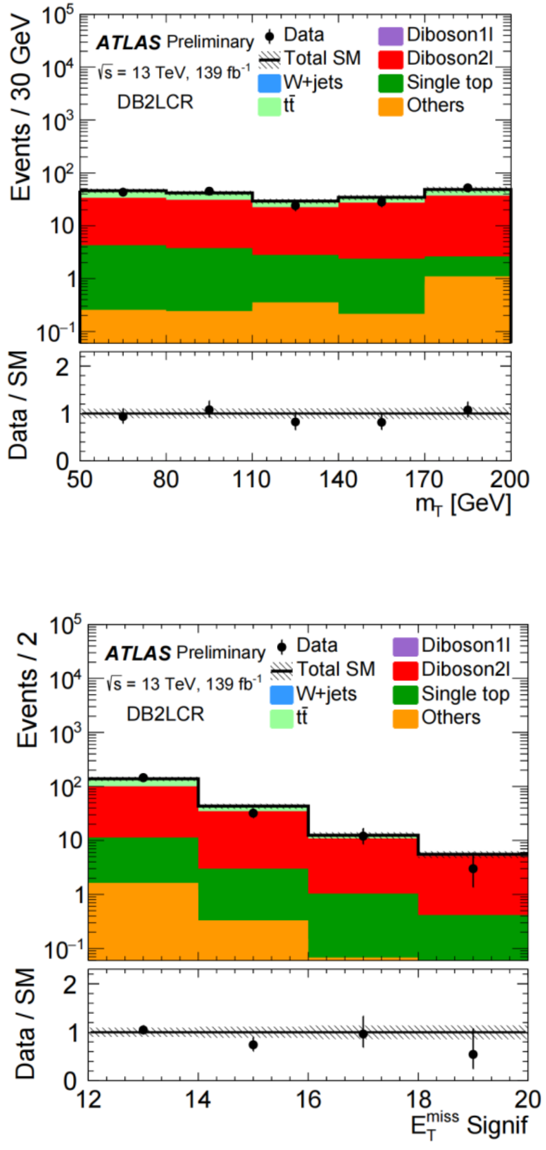
Variable	**DB2L**	
	CR	**VR**
N_{lep} ($p_{\mathrm{T}} > 25$ GeV)	2	
N_{jet} ($p_{\mathrm{T}} > 30$ GeV)	1 - 3	
$N_{\mathrm{b-jet}}$ ($p_{\mathrm{T}} > 30$ GeV)	0	
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 200	
$\Delta\phi(\ell, \mathrm{E}_{\mathrm{T}}^{\mathrm{miss}})$	< 2.9	
$m_{\ell\ell}$ [GeV]	70 – 100	
m_{jj} veto [GeV]	75 – 95	
$\sigma_{E_{\mathrm{T}}^{\mathrm{miss}}}$	> 12	> 10
m_{T} [GeV]	50 – 200	200 – 350

Background estimation

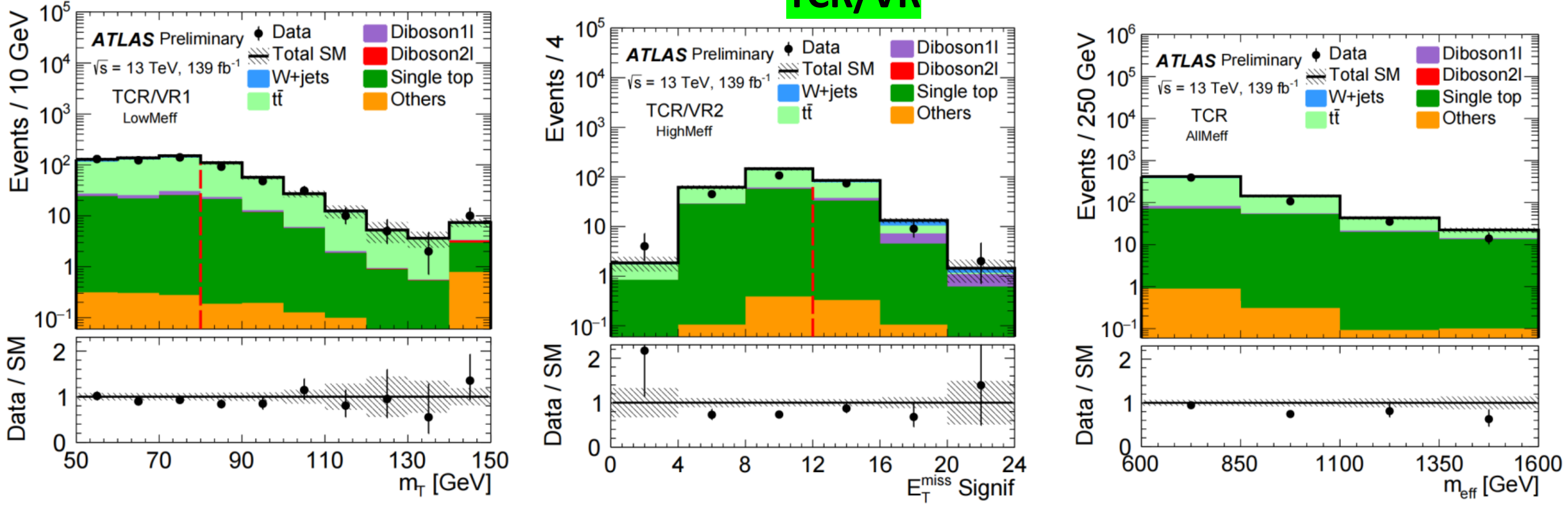
WDB1LCR/VR



DB2LCR/VR



TCR/VR



Systematic Uncertainties

C1C1-WW

C1C1-WW model	SRLM	SRMM	SRHM
Total background expectation	21.96	9.19	15.65
Total background sytematic	±3.19 [14.54%]	±2.51 [27.29%]	±3.04 [19.40%]
Theoretical systematic uncertainties			
$t\bar{t}$	±1.07 [4.88%]	±0.25 [2.71%]	±0.15 [0.96%]
Single top	±0.31 [1.43%]	±0.08 [0.92%]	±0.35 [2.21%]
W+jets	±0.38 [1.73%]	±0.15 [1.59%]	±0.32 [2.04%]
Diboson	±0.29 [1.34%]	±0.24 [2.66%]	±0.26 [1.63%]
Other backgrounds	±0.10 [0.43%]	±0.07 [0.77%]	±0.08 [0.53%]
MC statistical uncertainties			
MC statistics	±2.09 [9.54%]	±1.61 [17.51%]	±2.07 [13.20%]
Uncertainties in the background normalisation			
Normalisation of dominant backgrounds	±1.48 [6.76%]	±0.62 [6.76%]	±1.12 [7.19%]
Experimental systematic uncertainties			
Jet energy resolution	±1.09 [4.99%]	±1.01 [11.03%]	±1.38 [8.81%]
Jet energy scale	±1.65 [7.51%]	±1.52 [16.54%]	±1.12 [7.19%]
$E_{\mathrm{T}}^{\mathrm{miss}}$	±0.51 [2.34%]	±0.26 [2.80%]	±0.59 [3.76%]
Lepton uncertainties	±0.41 [1.88%]	±0.10 [1.04%]	±0.48 [3.08%]
Pile-up/JVT	±0.10 [0.48%]	±0.21 [2.29%]	±0.23 [1.49%]

C1N2-WZ

C1N2-WZ model	SRLM	SRMM	SRHM
Total background expectation	28.53	12.67	17.03
Total background sytematic	±3.68 [12.91%]	±2.54 [20.06%]	±2.85 [16.71%]
Theoretical systematic uncertainties			
$t\bar{t}$	±0.85 [2.97%]	±0.29 [2.33%]	±0.20 [1.18%]
Single top	±1.06 [3.73%]	±0.24 [1.90%]	±0.52 [3.07%]
W+jets	±0.56 [1.97%]	±0.22 [1.76%]	±0.36 [2.10%]
Diboson	±0.48 [1.67%]	±0.24 [1.87%]	±0.58 [3.39%]
Other backgrounds	±0.15 [0.54%]	±0.18 [1.41%]	±0.09 [0.51%]
MC statistical uncertainties			
MC statistics	±2.53 [8.88%]	±1.44 [11.39%]	±2.10 [12.32%]
Uncertainties in the background normalisation			
Normalisation of dominant backgrounds	±1.96 [6.86%]	±0.83 [6.55%]	±1.16 [6.83%]
Experimental systematic uncertainties			
Jet energy resolution	±1.10 [3.85%]	±1.27 [10.03%]	±0.79 [4.63%]
Jet energy scale	±1.28 [4.47%]	±0.99 [7.80%]	±1.25 [7.37%]
$E_{\mathrm{T}}^{\mathrm{miss}}$	±0.49 [1.70%]	±0.57 [4.47%]	±0.07 [0.39%]
Lepton uncertainties	±0.34 [1.18%]	±0.23 [1.79%]	±0.20 [1.17%]
Pile-up/JVT	±0.06 [0.20%]	±0.79 [6.24%]	±0.11 [0.63%]

- ✓ **The uncertainties in the Normalization of dominate background contribute 6 - 7% for each SR.**
- ✓ **The largest individual experimental uncertainty amounts to 4 - 16% depending on the SR.**
- ✓ **The MC statistical uncertainties contribute 8 - 17% depending on the SR.**

Fit strategy

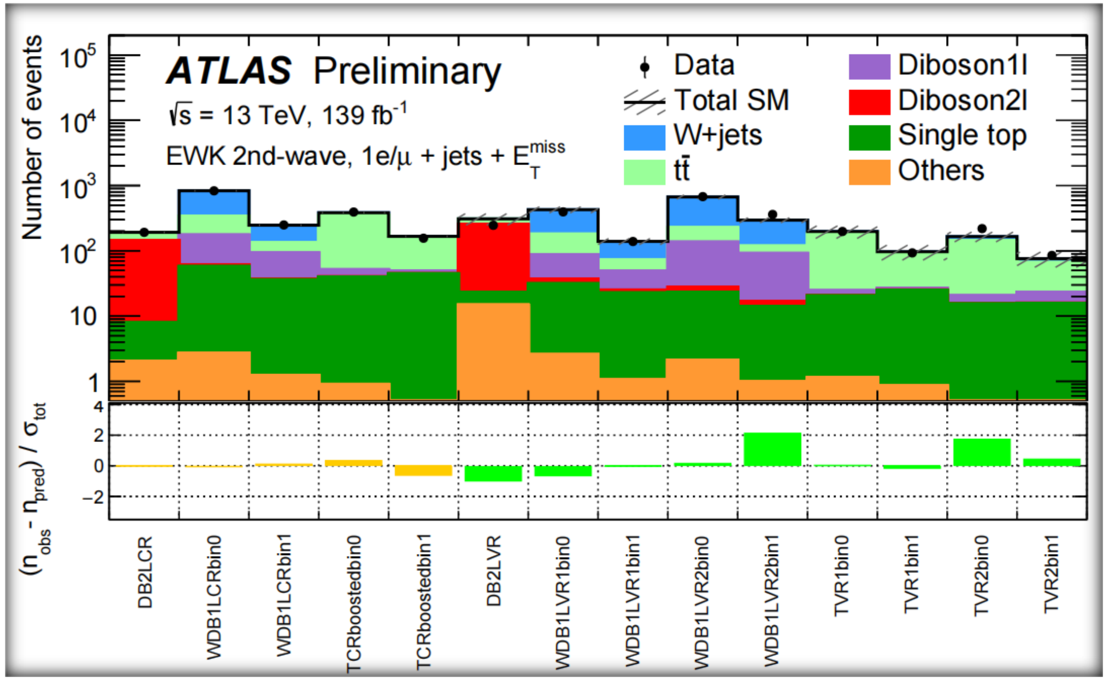
- **Background only fit**:
  - Only the CRs are used to constrain the fit parameters. Any potential signal contribution is neglected everywhere. -> To calculate background estimation in SRs and VRs.

- **Model-dependent fit**:
  - Both CRs and SRs are used in the fit. The signal contribution is taken into account as predicted by the tested model in all the regions. -> To calculate the exclusion limits.

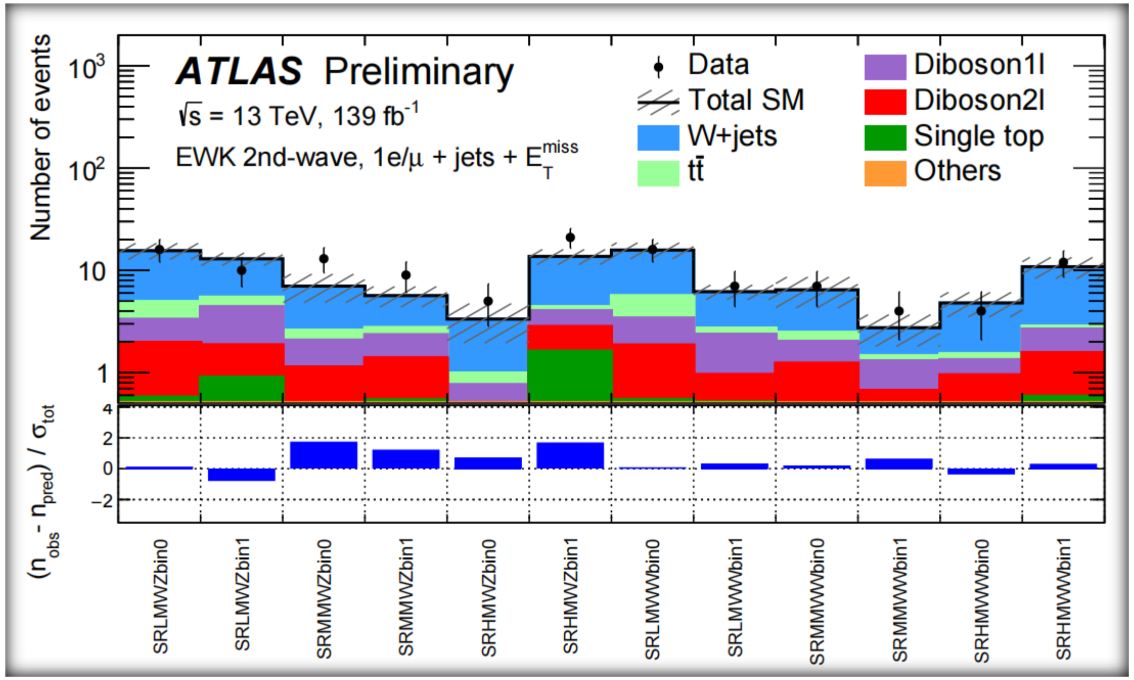
Results --- Region pull plots

Fit parameter: **mu_DB2L** $= 1.22^{+0.18}_{-0.18}$; **mu_ttbar** $= 0.81^{+0.10}_{-0.09}$; **mu_WDB1L** $= 1.05^{+0.09}_{-0.09}$

CR/VR



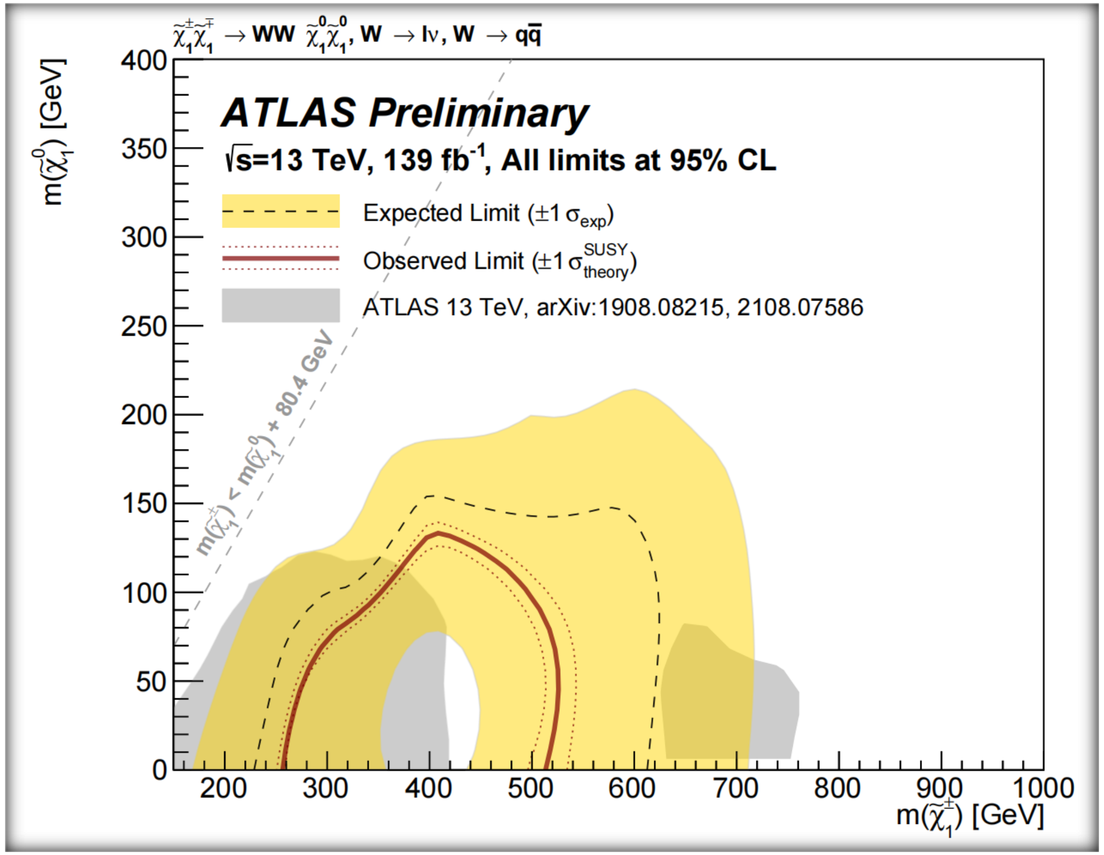
SR



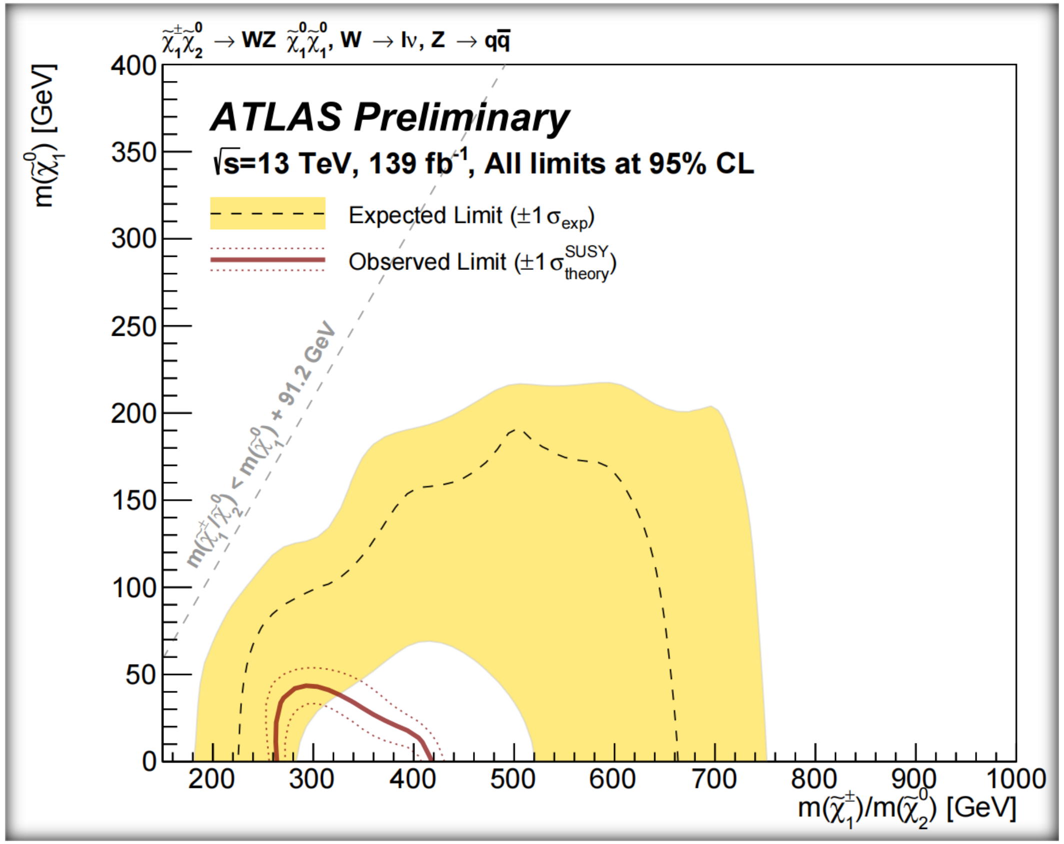
- ✓ **No significant excess over the SM prediction is observed in SRs targeting the C1C1-WW model.**
- ✓ **Mild excesses are seen in some SRs targeting the C1N2-WZ model.**
- ✓ **Combining the low and high meff bins of SRMM for C1N2-WZ model leads to a significance of around 2.1 σ.**

Results --- Limit

C1C1-WW



C1N2-WZ

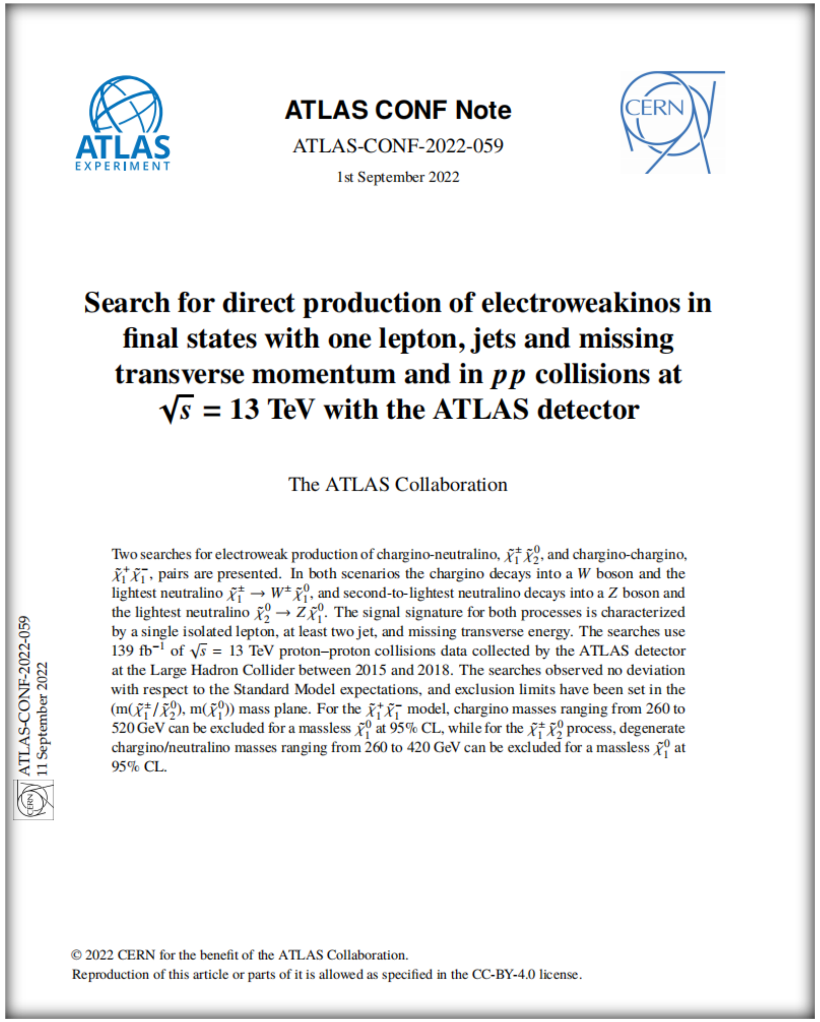


- ✓ The $\tilde{\chi}_1^{\pm}$ mass of about 260 – 520 GeV is excluded for massless $\tilde{\chi}_1^0$.
- ✓ Limits improve about 100GeV for m($\tilde{\chi}_1^{\pm}$) compared to previous ATLAS limits.

- ✓ The observed limit is weaker than expected limit.
- ✓ The $\tilde{\chi}_1^{\pm}$/ $\tilde{\chi}_2^0$ mass of about 260 – 420 GeV is excluded for massless $\tilde{\chi}_1^0$.

Summary

- Presented a search for direct EWK production of **C1C1/C1N2**, decaying to **1L** via **W/Z** and **LSP.**
- The search is performed in events with one isolated lepton, jets and E_T^{miss} based on full Run-2 data.
- No significant deviation from the expected Standard Model background is observed.
- **A chargino/neutralino of mass 260 - 520GeV** can be excluded in C1C1_WW scenario and **260 - 420GeV** can be excluded for C1N2_WZ scenario with massless LSP at 95% CL.
- The current search improves on the previous ATLAS limit by around 100GeV in m($\tilde{\chi}_1^{\pm}$) for a massless $\tilde{\chi}_0^{\pm}$ (C1C1_WW scenario).
- More details in CONF-NOTE (https://cds.cern.ch/record/2826702).



ATLAS CONF Note

ATLAS-CONF-2022-059

1st September 2022

Search for direct production of electroweakinos in final states with one lepton, jets and missing transverse momentum and in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

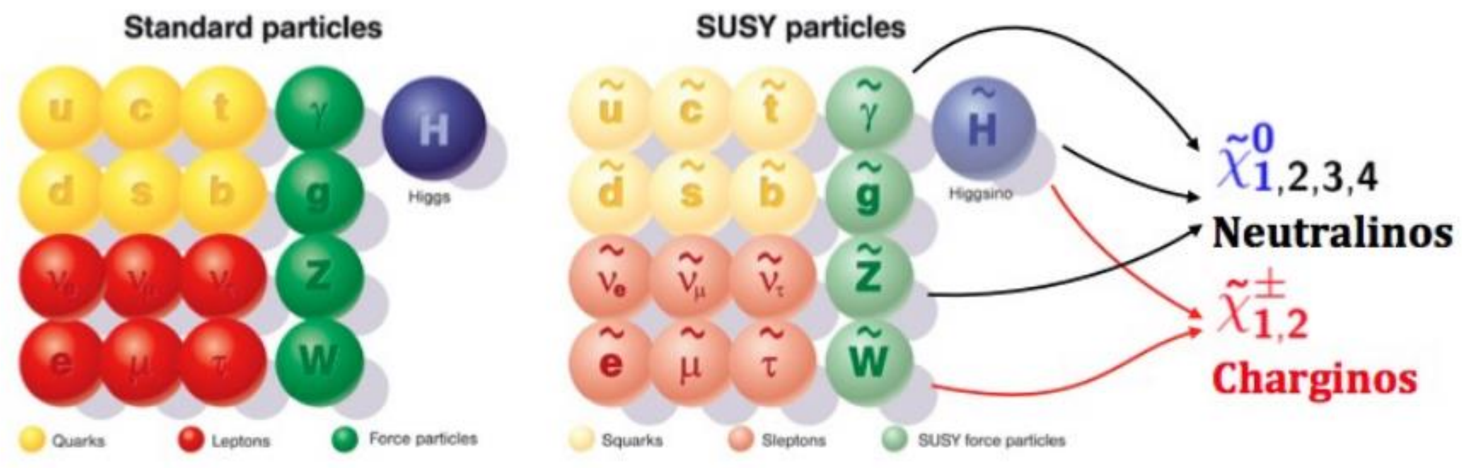
The ATLAS Collaboration

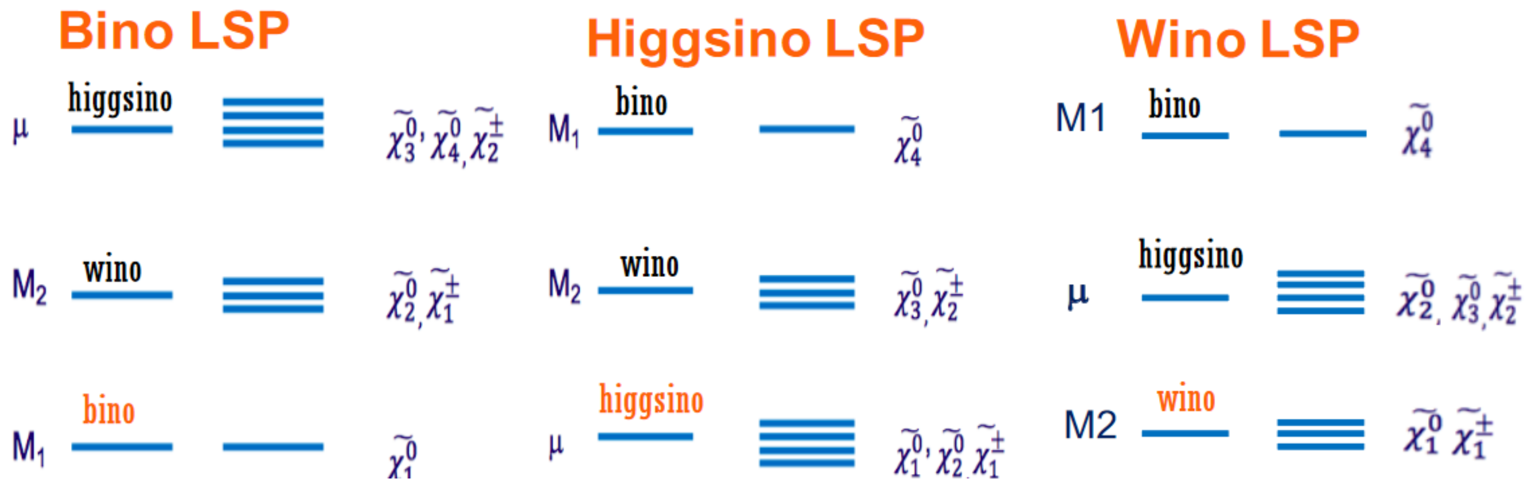
Two searches for electroweak production of chargino-neutralino, $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$, and chargino-chargino, $\tilde{\chi}_1^{+}\tilde{\chi}_1^{-}$, pairs are presented. In both scenarios the chargino decays into a W boson and the lightest neutralino $\tilde{\chi}_1^{\pm} \rightarrow W^{\pm}\tilde{\chi}_1^0$, and second-to-lightest neutralino decays into a Z boson and the lightest neutralino $\tilde{\chi}_2^0 \rightarrow Z\tilde{\chi}_1^0$. The signal signature for both processes is characterized by a single isolated lepton, at least two jet, and missing transverse energy. The searches use 139 fb^{-1} of $\sqrt{s}$ = 13 TeV proton–proton collisions data collected by the ATLAS detector at the Large Hadron Collider between 2015 and 2018. The searches observed no deviation with respect to the Standard Model expectations, and exclusion limits have been set in the (m($\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)) mass plane. For the $\tilde{\chi}_1^{+}\tilde{\chi}_1^{-}$ model, chargino masses ranging from 260 to 520 GeV can be excluded for a massless $\tilde{\chi}_1^0$ at 95% CL, while for the $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ process, degenerate chargino/neutralino masses ranging from 260 to 420 GeV can be excluded for a massless $\tilde{\chi}_1^0$ at 95% CL.

ATLAS-CONF-2022-059
11 September 2022

Backup

SUSY EWK model





Data and simulated samples

- Data: full Run-2 data, corresponding to 139 fb^{-1} data collected between 2015 and 2018.
- Background samples:

Table 1: Simulated background MC samples used in this analysis with the corresponding matrix element and parton shower generators, underlying-event tune, PDF set, and cross-section order in α_s.

Process	Generator	Parton shower and hadronisation	Tune	PDF	Cross-section
$t\bar{t}$	POWHEG BOX v2 [63–66]	PYTHIA 8.230 [43]	A14 [57]	NNPDF2.3LO [44]	NNLO+NNLL [67]
Single top	POWHEG BOX v2 [68–70]	PYTHIA 8.230	A14	NNPDF2.3LO	NLO+NNLL [71]
W/Z+jets	SHERPA 2.2.11 [72]	SHERPA 2.2.11	SHERPA standard	NNPDF3.0NNLO	NNLO [73]
Diboson	SHERPA 2.2.1 [72] & 2.2.2	SHERPA 2.2.1 & 2.2.2	SHERPA standard	NNPDF3.0NNLO	NLO
Multiboson	SHERPA 2.2.1 & 2.2.2	SHERPA 2.2.1 & 2.2.2	SHERPA standard	NNPDF3.0NNLO	NLO
$t\bar{t}+V$	MADGRAPH5_aMC@NLO v2.3.3	PYTHIA 8.210	A14	NNPDF2.3LO	NLO [74]
$t\bar{t}+h$	POWHEG BOX v2	PYTHIA 8.230	AZNLO [75]	CTEQ6L1 [76]	NLO [77]
Vh	POWHEG BOX v2	PYTHIA 8.212	A14	NNPDF2.3LO	NLO [77]

- Signal samples:
  - LSP is bino-like; $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^{0}$ are wino-like and mass-degenerate
  - Generated using **aMC@NLO +Pythia 8**. Cross sections calculated at **NLO+NLL**.
  - The production cross-section of both processes decreases as the mass of the $\tilde{\chi}_1^{\pm}$ increases.
  - The cross-section is 0.62 fb (1.34fb) for C1N2(1000,0) and C1C1(1000,0).

Object reconstruction

Cut	Value/description
Preselected jet	
Algorithm	anti-k_t-4, EMPFlow
Acceptance	$p_T > 20$ GeV, $\|\eta\| < 4.5$
Signal jet	
Acceptance	$p_T > 30$ GeV, $\|\eta\| < 2.8$
JetVertexTagger	JVT @ *tight* working point for $p_T < 60$ GeV and $\|\eta\| < 2.4$
Signal *b*-jet	
b-tagger Algorithm	DL1r @ 77 % PC working point
Acceptance	$p_T > 30$ GeV, $\|\eta\| < 2.8$

Cut	Value/description
Preselected Electron	
Algorithm	AuthorElectron
Acceptance	$p_T >$ 7GeV, $\|\eta^{clust}\| < 2.47$
Quality	LooseAndBLayerLLH
IP	$\|\Delta z_0 \sin(\theta)\|$<0.5 mm
Signal Electron	
Acceptance	$p_T >$ 7GeV, $\|\eta^{clust}\| < 2.47$
Quality	TightLLH
Isolation	PLVLoose for $p_T < 75$ GeV PLVTight for $p_T > 75$ GeV
IP	$d_0/\sigma(d_0) < 5$

Cut	Value/description
Preselected muon	
Acceptance	$p_T > 6$ GeV, $\|\eta\| < 2.7$
Quality	Medium
IP	$\|\Delta z_0 \sin(\theta)\|$<0.5 mm
Signal muon	
Acceptance	$p_T > 6$ GeV, $\|\eta\| < 2.5$
Isolation	PLVLoose for $p_T < 75$ GeV PflowTight_VarRad for $p_T > 75$ GeV
IP	$d_0/\sigma(d_0) < 3$

Large-R Jet

- Anti-k_t algorithm (R = 1.0)
- Trimmed with $f_{cut} = 0.05$ and $R_{sub} = 0.2$
- $p_T > 200$ GeV; $|\eta| < 2.0$
- **W/Z-tagging**: 3-var, 50% WP

Met

- baseline objects + TST.
- Tight WP.

✓ **AnalysisOverlap removal procedure** applied to **baseline objects** and relied on **SUSY background forum recommendation.**

✓ **Dedicated isolation** study performed for **electron/muon identification.**

trigger

- Events are recorded with the ORing of a list of single lepton (electron and muon) triggers.

Trigger	Trigger name	Year	HLT cut [GeV]	Offline cut [GeV]
single electron trigger	HLT_e24_lhmedium_L1EM20VH	2015	24	25
	HLT_e60_lhmedium	2015	60	61
	HLT_e120_lhloose	2015	120	121
	HLT_e26_lhtight_nod0_ivarloose	2016-2018	26	27
	HLT_e60_lhmedium_nod0	2016-2018	60	61
	HLT_e140_lhloose_nod0	2016-2018	140	141
single muon trigger	HLT_mu20_iloose_L1MU15	2015	20	21
	HLT_mu26_ivarmedium	2016-2018	26	27.3
	HLT_mu50	2015-2018	50	52.5

- Key variable:

$$m_{\mathrm{jj}} = \sqrt{2 p_{\mathrm{T}}^{j_1} p_{\mathrm{T}}^{j_2} \left[\cosh\left(\eta_{j_1} - \eta_{j_2}\right) - \cos\left(\phi_{j_1} - \phi_{j_2}\right)\right]}$$

$$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}}^{\ell} E_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos[\Delta\phi(\boldsymbol{p}_{\mathrm{T}}^{\ell}, \boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}})])}$$

$$\sigma_{E_{\mathrm{T}}^{\mathrm{miss}}} = \sqrt{2 \ln \left[\frac{\max_{\boldsymbol{p}_{\mathrm{T}}^{\mathrm{inv}} \neq 0} \mathcal{L}\left(E_{\mathrm{T}}^{\mathrm{miss}} | \boldsymbol{p}_{\mathrm{T}}^{\mathrm{inv}}\right)}{\max_{\boldsymbol{p}_{\mathrm{T}}^{\mathrm{inv}} = 0} \mathcal{L}\left(E_{\mathrm{T}}^{\mathrm{miss}} | \boldsymbol{p}_{\mathrm{T}}^{\mathrm{inv}}\right)}\right]}$$

$$m_{\mathrm{eff}} = p_{\mathrm{T}}^{\ell} + \sum_{\mathrm{jets}} p_{\mathrm{T}} + E_{\mathrm{T}}^{\mathrm{miss}}$$

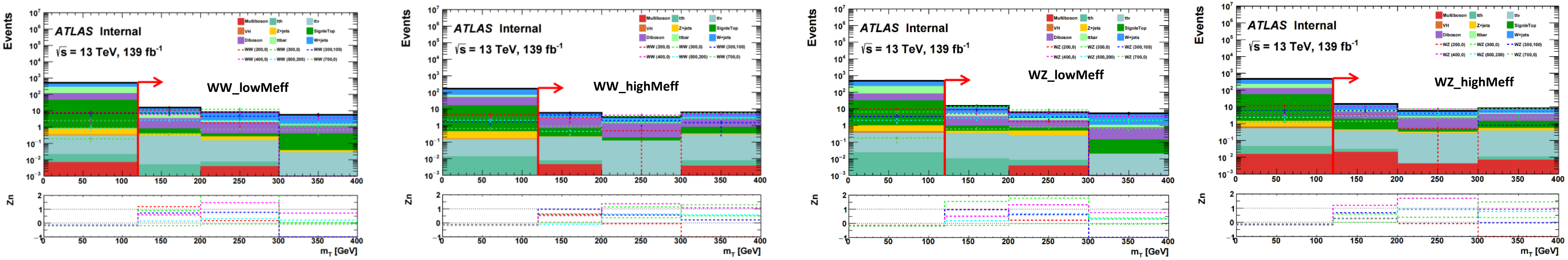
Signal region optimization

- **Step 1**: **Multi-dimensional cut scan** for benchmark signal points is performed to seed the subsequent steps of the optimization procedure. The significance is calculated using *RooStats :: NumberCountingUtils :: BinomialExpZ* considering a combination of 30% systematics and statistical error.

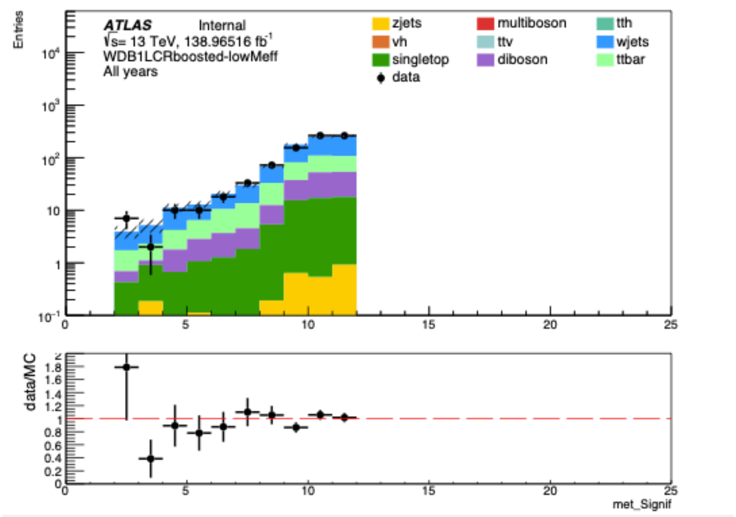
- **Step 2**: **“N-1 plots”** are produced to check and refine the requirements defined at “Step 1” in each proposed SRs.

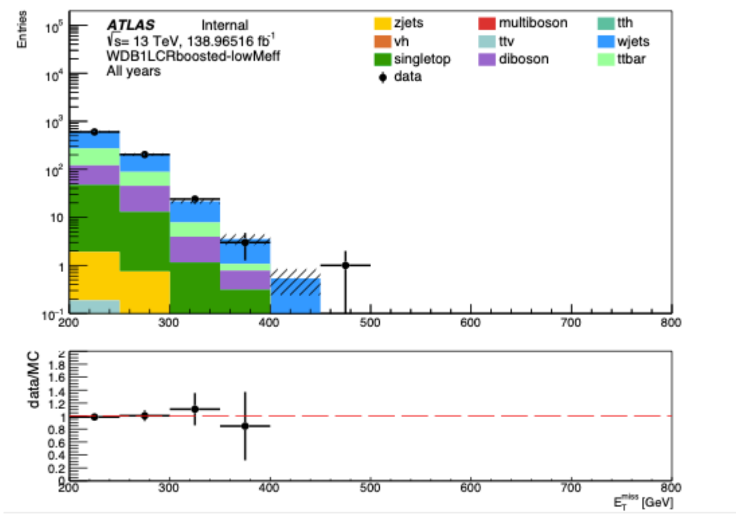
- **Step 3**: **Binned m_T and meff SR** candidates are tested under HF. A combination of 30% systematics and statistical error are used.

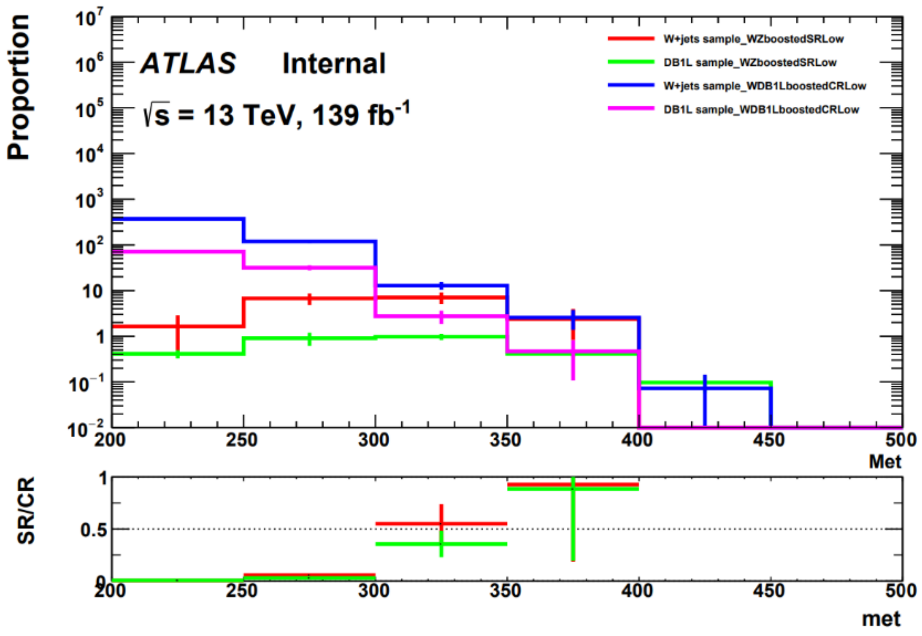
Zn check for exclusion SR

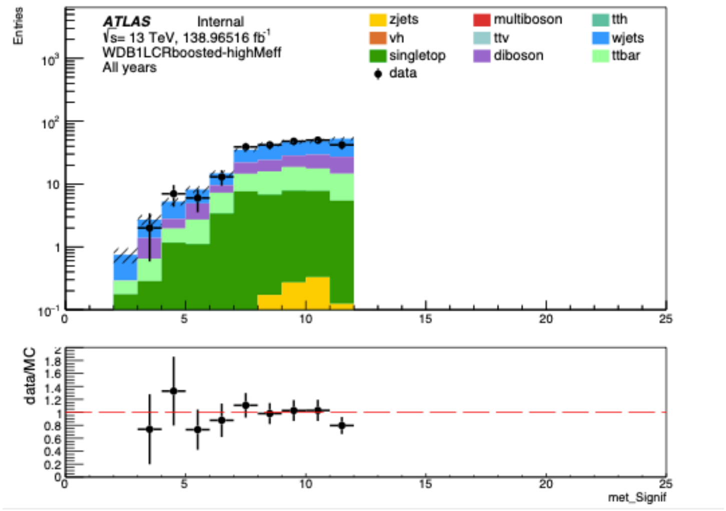


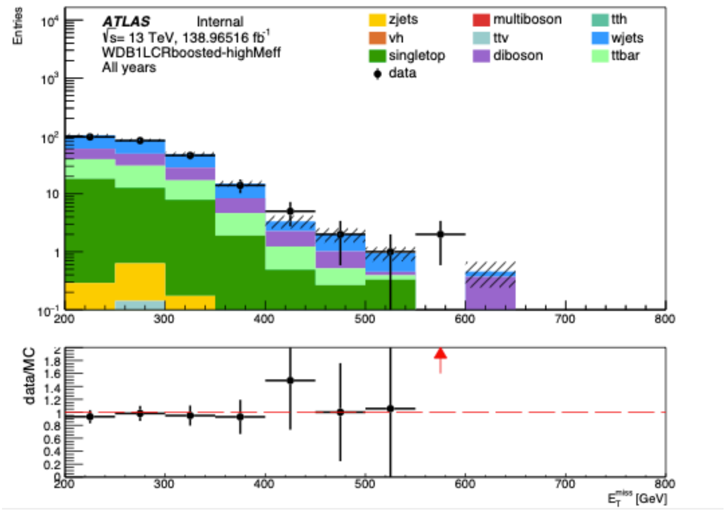
Background estimation: Wjets and DB1L











The extrapolation from CR to SR is identical between Wjets and DB1L --> thus they can share the same CR/VR strategy

Pre-fit kinematic; stats err only

Systematic Uncertainties

- Theoretical uncertainty:
  - Signal:
    - factorization, renormalization, CKKW
  - Ttbar & single-top:
    - Parton Shower, Hard Scattering, ISR, FSR, interference between single-top Wt and ttbar production.
  - Wjets & Zjets:
    - Renorm, Factor, RenormFactor, PDF, CKKW, QSF, EWK correction.
  - Diboson1L & Diboson2L & ttV & tth & Vh:
    - Renorm, Factor, RenormFactor, PDF

- Experimental uncertainty:
  - jet energy scale (JES)
  - jet energy resolution (JER)
  - E_T^{miss} modeling
  - lepton reconstruction and identification
  - pile-up/JVT

✓ For **major bkgs** with dedicated CRs (wjets, ttbar, Diboson1L, Diboson2L): **uncertainty calculated based on transfer factor from CR to SR.**

✓ For **small bkgs** (zjets, Singletop, ttv, tth): Estimated using yields uncertainty. cross-section uncertainties are considered.

Systematic Uncertainties

Table 5: Breakdown of the dominant systematic uncertainties in background estimates in the various exclusion signal regions for the C1C1-WW model. The individual uncertainties can be correlated, and do not necessarily add up in quadrature to the total background uncertainty. The percentages show the size of the uncertainty relative to the total expected background.

C1C1-WW model	SRLM	SRMM	SRHM
Total background expectation	21.96	9.19	15.65
Total background sytematic	±3.19 [14.54%]	±2.51 [27.29%]	±3.04 [19.40%]
Theoretical systematic uncertainties			
$t\bar{t}$	±1.07 [4.88%]	±0.25 [2.71%]	±0.15 [0.96%]
Single top	±0.31 [1.43%]	±0.08 [0.92%]	±0.35 [2.21%]
W+jets	±0.38 [1.73%]	±0.15 [1.59%]	±0.32 [2.04%]
Diboson	±0.29 [1.34%]	±0.24 [2.66%]	±0.26 [1.63%]
Other backgrounds	±0.10 [0.43%]	±0.07 [0.77%]	±0.08 [0.53%]
MC statistical uncertainties			
MC statistics	±2.09 [9.54%]	±1.61 [17.51%]	±2.07 [13.20%]
Uncertainties in the background normalisation			
Normalisation of dominant backgrounds	±1.48 [6.76%]	±0.62 [6.76%]	±1.12 [7.19%]
Experimental systematic uncertainties			
Jet energy resolution	±1.09 [4.99%]	±1.01 [11.03%]	±1.38 [8.81%]
Jet energy scale	±1.65 [7.51%]	±1.52 [16.54%]	±1.12 [7.19%]
$E_{\mathrm{T}}^{\mathrm{miss}}$	±0.51 [2.34%]	±0.26 [2.80%]	±0.59 [3.76%]
Lepton uncertainties	±0.41 [1.88%]	±0.10 [1.04%]	±0.48 [3.08%]
Pile-up/JVT	±0.10 [0.48%]	±0.21 [2.29%]	±0.23 [1.49%]

Table 6: Breakdown of the dominant systematic uncertainties in background estimates in the various exclusion signal regions for the C1N2-WZ model. The individual uncertainties can be correlated, and do not necessarily add up in quadrature to the total background uncertainty. The percentages show the size of the uncertainty relative to the total expected background.

C1N2-WZ model	SRLM	SRMM	SRHM
Total background expectation	28.53	12.67	17.03
Total background sytematic	±3.68 [12.91%]	±2.54 [20.06%]	±2.85 [16.71%]
Theoretical systematic uncertainties			
$t\bar{t}$	±0.85 [2.97%]	±0.29 [2.33%]	±0.20 [1.18%]
Single top	±1.06 [3.73%]	±0.24 [1.90%]	±0.52 [3.07%]
W+jets	±0.56 [1.97%]	±0.22 [1.76%]	±0.36 [2.10%]
Diboson	±0.48 [1.67%]	±0.24 [1.87%]	±0.58 [3.39%]
Other backgrounds	±0.15 [0.54%]	±0.18 [1.41%]	±0.09 [0.51%]
MC statistical uncertainties			
MC statistics	±2.53 [8.88%]	±1.44 [11.39%]	±2.10 [12.32%]
Uncertainties in the background normalisation			
Normalisation of dominant backgrounds	±1.96 [6.86%]	±0.83 [6.55%]	±1.16 [6.83%]
Experimental systematic uncertainties			
Jet energy resolution	±1.10 [3.85%]	±1.27 [10.03%]	±0.79 [4.63%]
Jet energy scale	±1.28 [4.47%]	±0.99 [7.80%]	±1.25 [7.37%]
$E_{\mathrm{T}}^{\mathrm{miss}}$	±0.49 [1.70%]	±0.57 [4.47%]	±0.07 [0.39%]
Lepton uncertainties	±0.34 [1.18%]	±0.23 [1.79%]	±0.20 [1.17%]
Pile-up/JVT	±0.06 [0.20%]	±0.79 [6.24%]	±0.11 [0.63%]

- ✓ **The uncertainties in the Normalization of dominate background contribute 6% -7% for each SR.**
- ✓ **The largest individual experimental uncertainty amounts to 4-16% depending on the SR.**
- ✓ **The MC statistical uncertainties contribute 8 – 17% depending on the SR.**

Model-independent fit

Table 9: Left to right: Observed events, total SM background, 95% CL upper limits on the visible cross section ($\langle\epsilon\sigma\rangle^{95}_{obs}$) and on the number of signal events (S^{95}_{obs}). The fifth column (S^{95}_{exp}) shows the 95% CL upper limit on the number of signal events, given the expected number (and $\pm1\sigma$ excursions on the expectation) of background events. The last three columns indicate the $\mathrm{CL_B}$ value and the discovery p-value ($p(s = 0)$) with the corresponding gaussian significance (Z). $\mathrm{CL_B}$ provides a measure of compatibility of the observed data with the 95% CL signal strength hypothesis relative to fluctuations of the background, and $p(s = 0)$ measures compatibility of the observed data with the background-only (zero signal strength) hypothesis relative to fluctuations of the background. Larger values indicate greater relative compatibility. $p(s = 0)$ is not calculated in signal regions with a deficit with respect to the nominal background prediction.

Signal channel	Observed events	Total SM background	$\langle\epsilon\sigma\rangle^{95}_{\mathrm{obs}}$[fb]	S^{95}_{obs}	S^{95}_{exp}	$\mathrm{CL_B}$	p_0	Z
C1C1-WW model								
SRLM (disc.)	16	11.6 ± 1.6	0.09	13.0	$8.8^{+4.3}_{-1.5}$	0.84	0.14	1.09
SRMM (disc.)	9	9.8 ± 2.0	0.06	7.9	$9.0^{+5.4}_{-1.4}$	0.42	0.50	0.00
SRHM (disc.)	12	10.8 ± 2.5	0.07	10.4	$9.4^{+4.1}_{-3.0}$	0.60	0.39	0.29
C1N2-WZ model								
SRLM (disc.)	17	18.4 ± 2.9	0.08	11.5	$13.7^{+4.0}_{-4.5}$	0.40	0.50	0.00
SRMM (disc.)	9	5.7 ± 1.3	0.07	10.2	$6.8^{+3.1}_{-0.9}$	0.87	0.13	1.11
SRHM (disc.)	21	13.7 ± 2.3	0.13	17.5	$10.5^{+4.4}_{-2.4}$	0.92	0.06	1.54