中国科学院高能物理研究所
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Search for the direct production of charginos and neutralinos in final states with tau leptons in 13 TeV pp collisions with the ATLAS detector

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on behalf of the ATLAS Collaboration

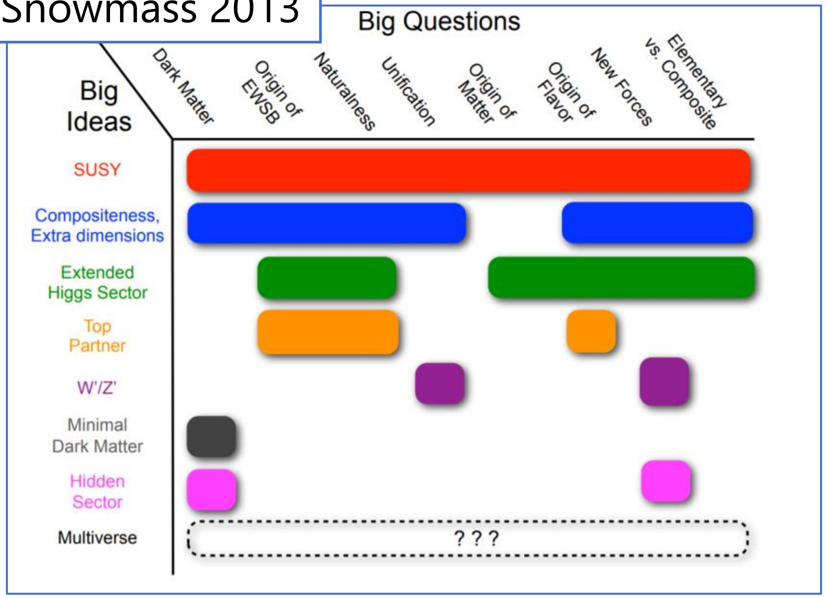
Chinese High Energy Conference 2022

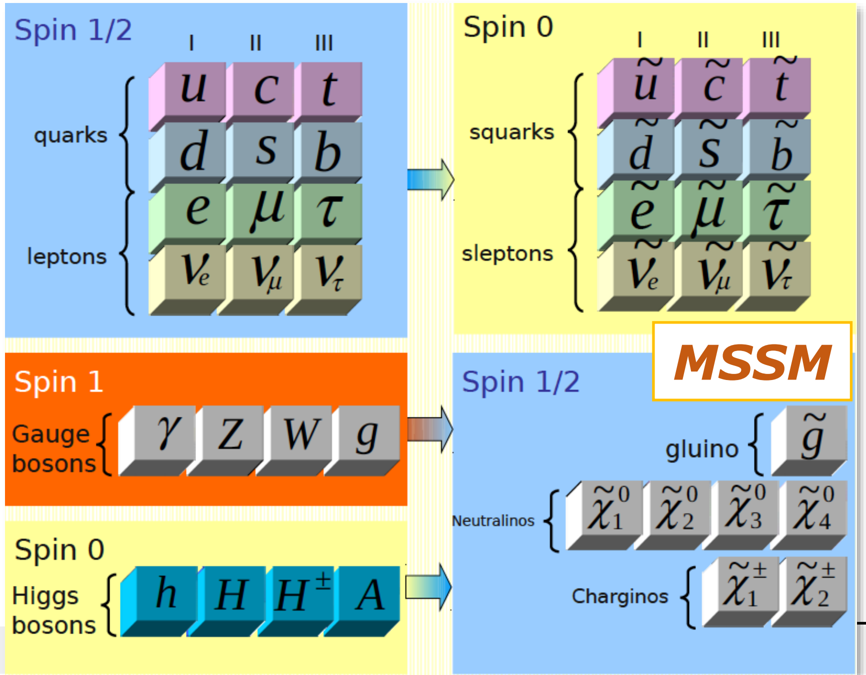
Aug 10th, 2022

ATLAS EXPERIMENT

We are still searching for SUSY…

Snowmass 2013



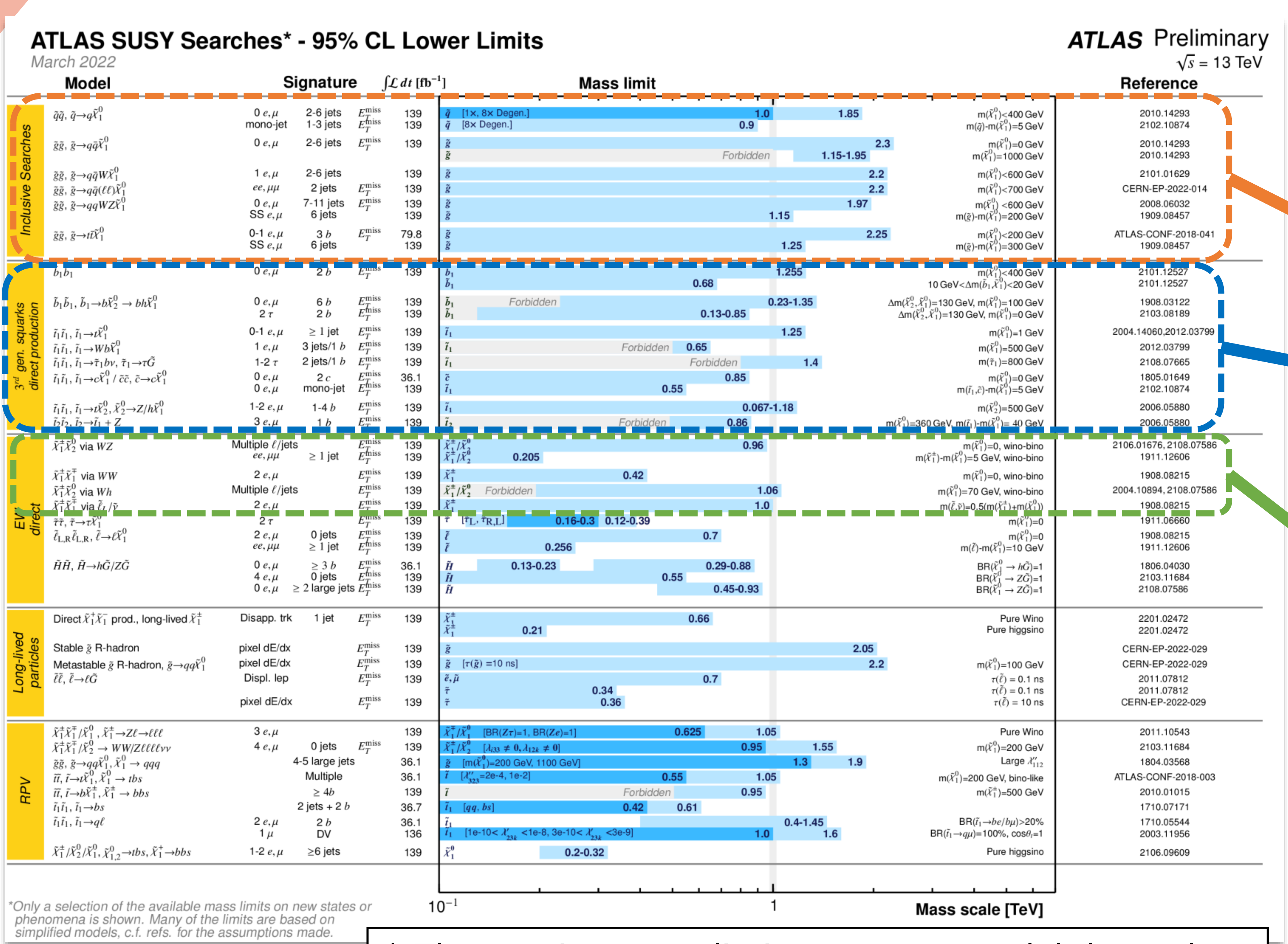


- The Standard Model (SM) described the fundamental elements of the matter and the interactions between them precisely.

- Despite the huge success of SM, SUSY is strongly motivated by:
  - *Hierarchy problem*: transfer to little hierarchy problem.
  - *Dark matter*: if R-parity is conserved, SUSY will provide the LSP, a compelling candidate for DM particle.
  - *the GUT*: predict the SM forces unification at the high scale.
  - *muon g-2 or W boson mass*: the loop corrections from SUSY particle can explain the excess.

- The minimal supersymmetric extension of the SM (MSSM)
  - Assume one partner for each SM particle.
  - We use Simplified Models signal in the searches to reduce the huge number of degrees of freedom in MSSM.

Exclusion limits on ATLAS



- [ATLAS-SUSY-Exclusion-Limits]()

***Squark & Gluino** are above 2 TeV*

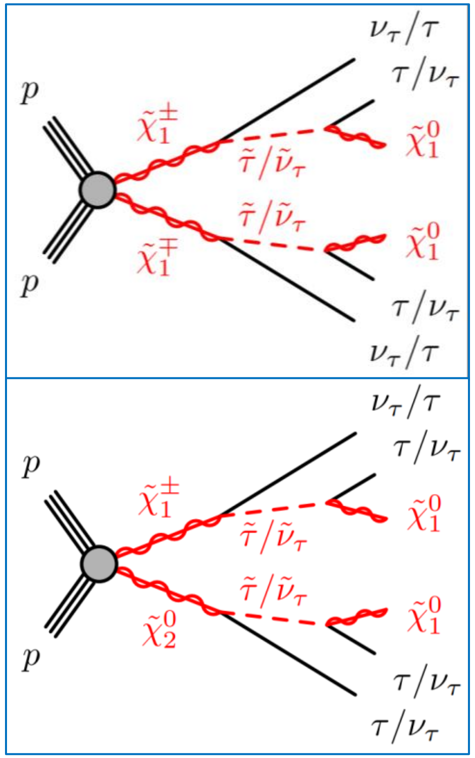
***Stop & Sbottom** are above 1 TeV*

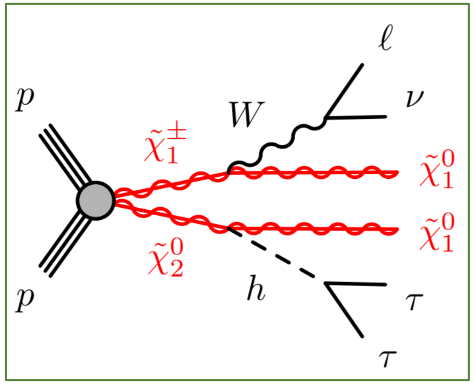
***Electroweakinos** can be lighter*

- Search for direct production of Electroweakinos (charginos & neutralinos) with ≥ 2 *two hadronic taus final state.*

* The precise mass limits are very model dependent

Analysis Overview





■ Conference Note→ [ATLAS-COM-CONF-2022-045]()

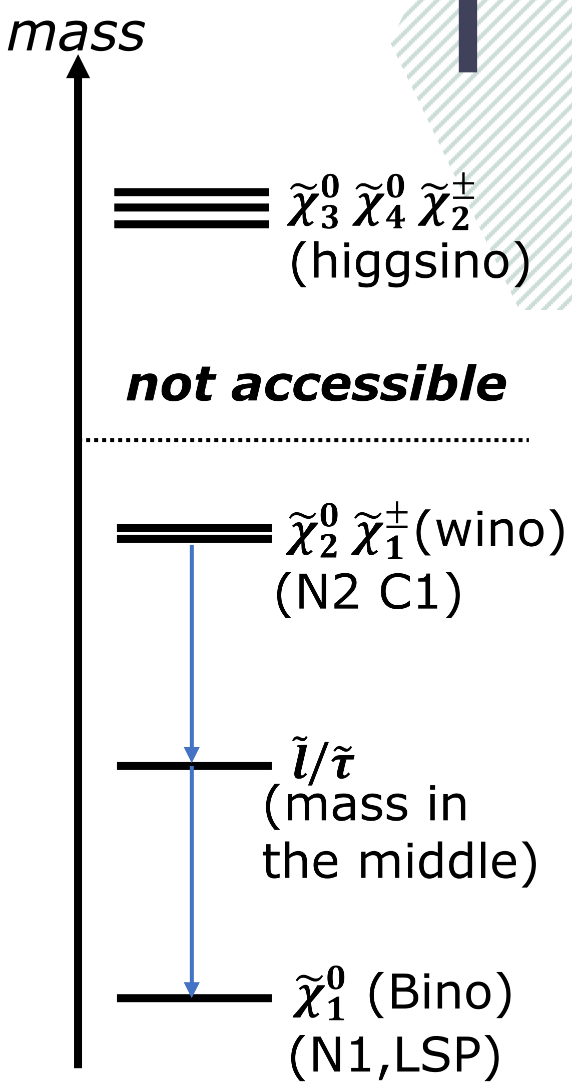
1、 $\tilde{\chi}_1^{+}\tilde{\chi}_1^{-}, \tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$ **via stau deacy with** $\geq 2\tau + E_T^{miss}$

Large MET is from LSP.

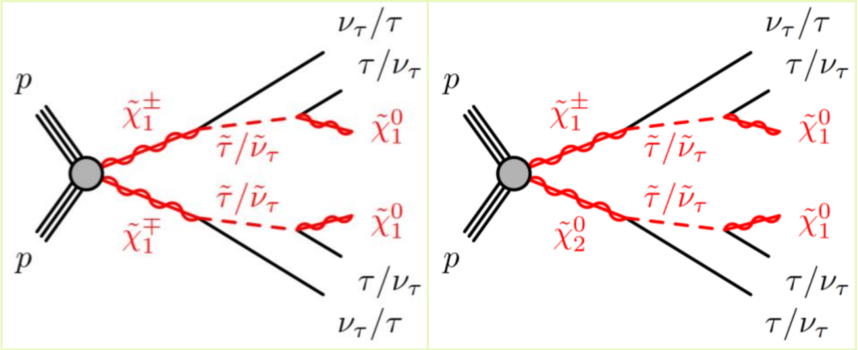
Published work with 2015-2016 data: [Eur. Phys. J. C 78, 154 (2018)](). Add C1N2 SS channel.

2、 $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$ **via Wh decay with** $2\tau + 1lep + E_T^{miss}$

2 had-τ are from the Higgs decay; 1l is from the W boson decay. → first time in the ATLAS.



$\tilde{\chi}_1^{+}\tilde{\chi}_1^{-}$, $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$ via stau deacy with $\geq 2\tau + E_T^{miss}$



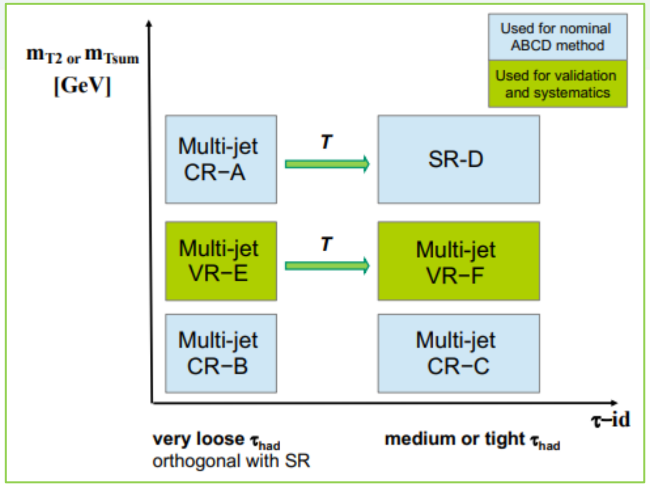
SR-C1C1-LM	SR-C1N2OS-LM	SR-C1N2SS-LM
$= 2$ medium τ (OS)	≥ 2 medium τ (OS)	≥ 2 medium τ (SS)
≥ 1 tight τ		-
asymmetric di-τ Trigger		
$E_T^{miss} < 150$ GeV		
b-jet veto		
Z/h veto ($m(\tau_1, \tau_2) > 120$ GeV)		-
$\lvert\Delta\phi(\tau_1, \tau_2)\rvert > 1.6$	-	$\lvert\Delta\phi(\tau_1, \tau_2)\rvert > 1.5$
-	$N_{jets} < 3$	
$E_T^{miss} > 60$ GeV		$m_{Tsum} > 200$ GeV
$m_{T2} > 80$ GeV	$m_{T2} > 70$ GeV	$m_{T2} > 80$ GeV

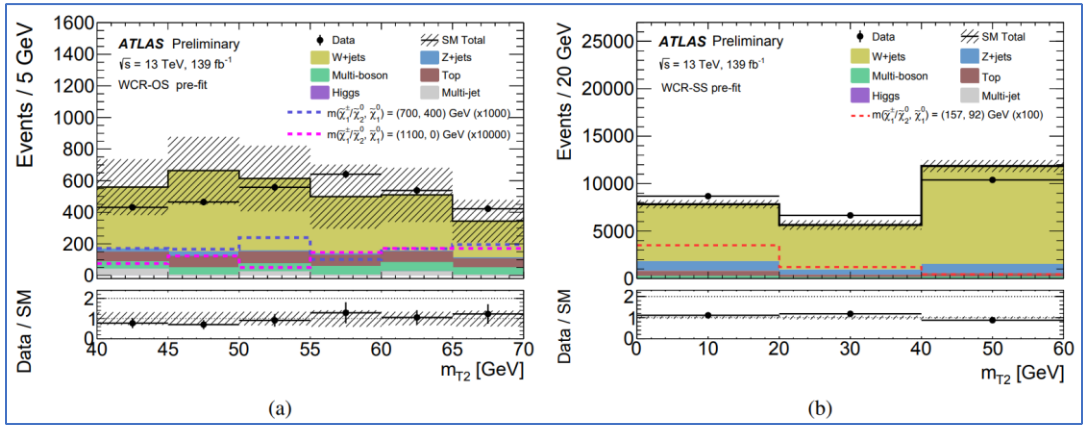
SR-C1C1-HM	SR-C1N2OS-HM	SR-C1N2SS-HM
$= 2$ medium τ (OS)	≥ 2 medium τ (OS)	≥ 2 medium τ (SS)
di-τ + E_T^{miss} Trigger		
$E_T^{miss} > 150$ GeV		
b-jet veto		
Z/h veto ($m(\tau_1, \tau_2) > 120$ GeV)		-
$m_{Tsum} > 400$ GeV		$m_{Tsum} > 450$ GeV
$m_{T2} > 85$ GeV		$m_{T2} > 80$ GeV

- **SR definition**:
  - C1C1, C1N2OS, and C1N2SS are optimized separately with cut & count method.
  - Each channel has one LM and one HM region, which are separated by E_T^{miss} (=150 GeV) for the orthogonality, targeting at low or high C1/N2 mass regions.
  - The main BKGs components are different in OS and SS channel. The methods of BKG estimations are different.

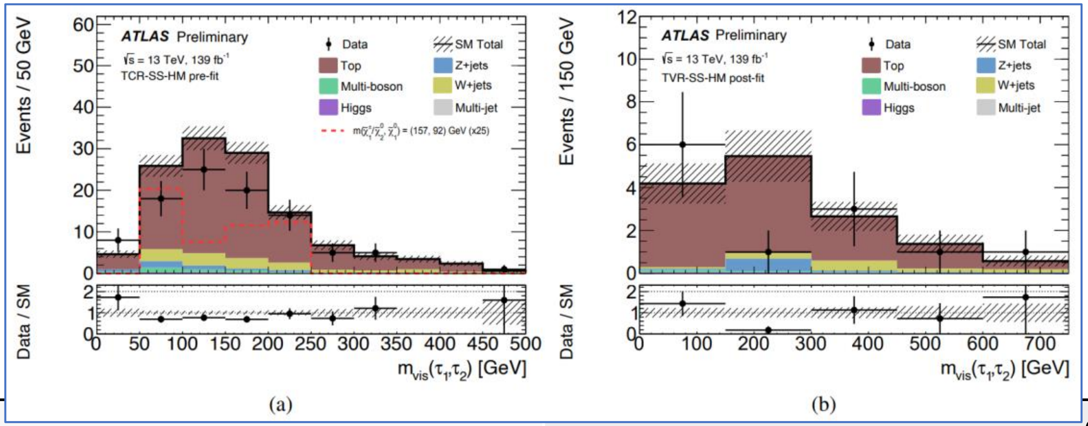
Background estimation

- BKG estimation strategy: Multi-jets, W+jets, Z+jet, Multi-boson, Top.
  - **Multi-jet**: mostly fake τ.
    - Data-driven ABCD method.
    - Use “very loose” τ-ID to define CR-B, VR-E, CR-A, use m_{T2} and m_{Tsum} to define CRs and VRs.
  - **W+jets**: One real + at least one fake τ
    - WCR for SS/OS separately: normalization factor are obtained from CRs, validated in VRs.
  - **Top**: Components are different in OS and SS channel.
    - SS: ≥ 1 fake τ contribution from $t\bar{t}$ and Wt , using TCR for normalization and validate in TVR.
    - OS: Use MC simulation directly and validate in VRs.
  - **Z+jets**, **Multi-Boson**: real τ dominates (85-90%). Use MC simulation directly and validate in VRs.



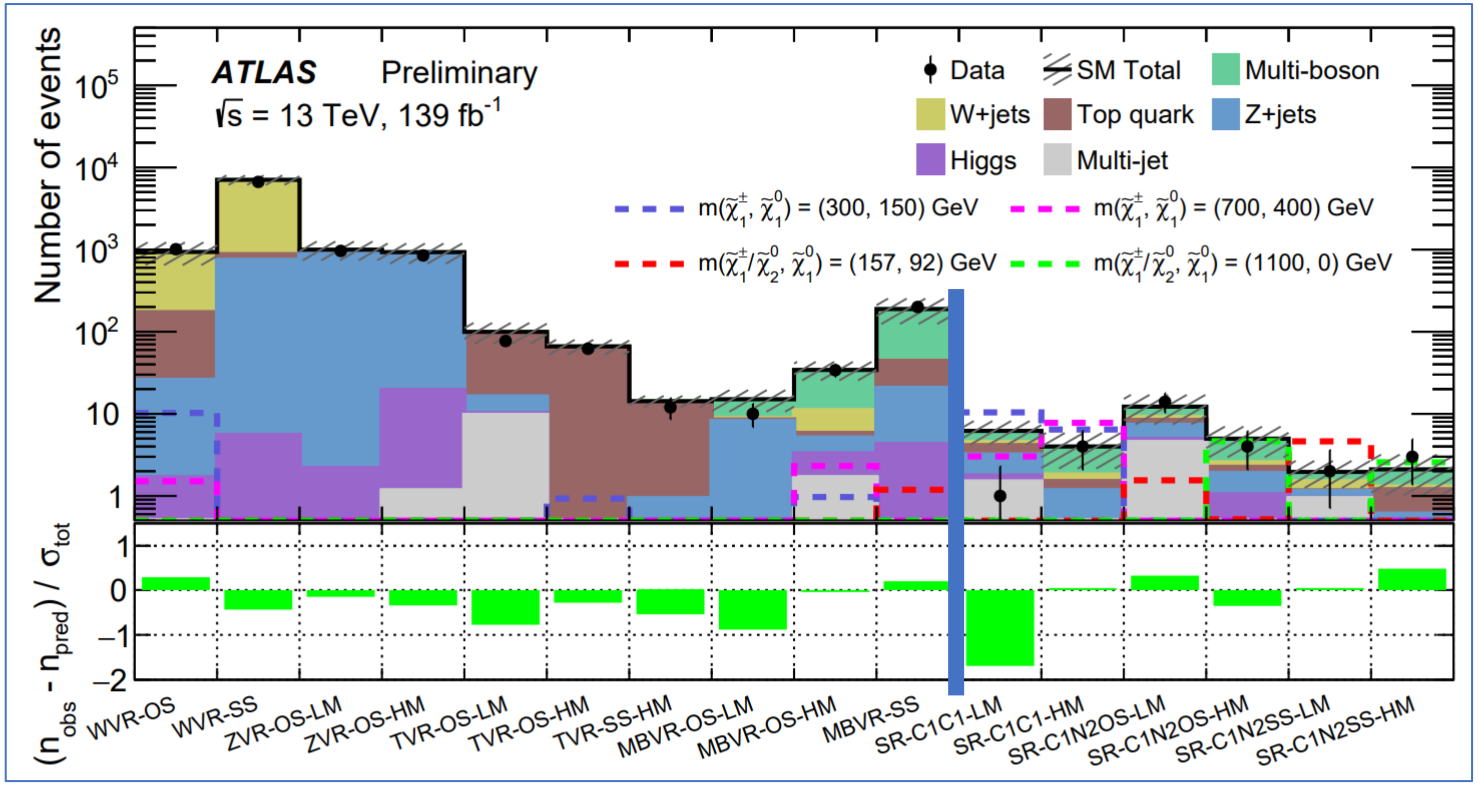


(a) (b)



(a) (b)

■ Post-fit yields in VRs and SRs

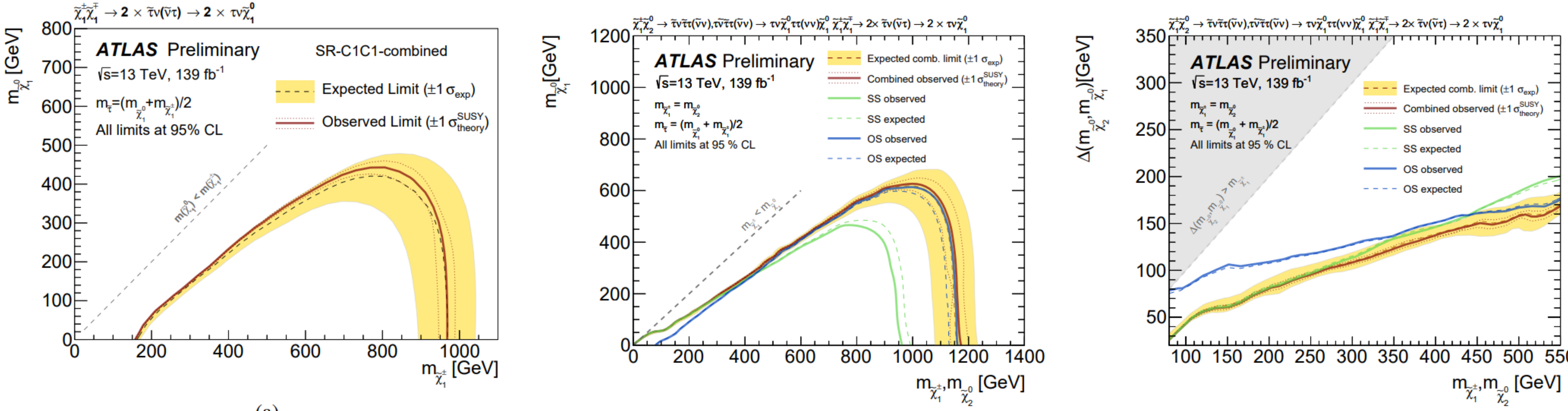


SM process	SR-C1C1-LM	SR-C1C1-HM	SR-C1N2OS-LM	SR-C1N2OS-HM
Multi-boson	1.6 ± 0.6	2.2 ± 1.6	3.2 ± 1.2	2.4 ± 1.6
W+jets	0.4 ± 0.4	$0.29^{+0.35}_{-0.29}$	$0.6^{+2.2}_{-0.6}$	$0.29^{+0.35}_{-0.29}$
Top quark	1.0 ± 0.5	0.36 ± 0.13	$1.1^{+1.2}_{-1.1}$	0.36 ± 0.14
Z+jets	$1.4^{+1.5}_{-1.4}$	0.78 ± 0.34	2.5 ± 1.7	0.9 ± 0.4
Higgs	0.27 ± 0.06	$0.01^{+0.13}_{-0.01}$	0.40 ± 0.22	0.73 ± 0.23
Multi-jet	1.5 ± 0.5	0.37 ± 0.21	4.50 ± 0.97	0.31 ± 0.17
SM total	6.2 ± 2.0	4.0 ± 1.8	12.2 ± 4.8	5.0 ± 2.0
Observed	1	4	14	4
$m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)$ = (700, 400) GeV	3.0 ± 0.6	7.8 ± 1.6	4.69 ± 0.99	14.1 ± 2.8
$m(\tilde{\chi}_1^\pm/\tilde{\chi}_2^0, \tilde{\chi}_1^0)$ = (1100, 0) GeV	0.20 ± 0.05	3.1 ± 0.6	0.39 ± 0.11	4.6 ± 1.0
p_0	0.5	0.5	0.4	0.5
Expected $\sigma^{95}_{\mathrm{vis}}$ [fb]	0.04	0.05	0.10	0.05
Observed $\sigma^{95}_{\mathrm{vis}}$ [fb]	0.02	0.05	0.10	0.05

SM process	SR-C1N2SS-LM	SR-C1N2SS-HM
Multi-boson	0.47 ± 0.20	0.8 ± 0.4
W+jets	0.33 ± 0.25	0.10 ± 0.05
Top quark	$0.01^{+0.02}_{-0.01}$	0.59 ± 0.20
Z+jets	0.20 ± 0.15	$0.6^{+0.8}_{-0.6}$
Higgs	$0.00^{+0.01}_{-0.00}$	0.02 ± 0.01
Multi-jet	0.9 ± 0.5	0.00 ± 0.00
SM total	2.0 ± 0.7	2.1 ± 1.1
Observed	2	3
$m(\tilde{\chi}_1^\pm/\tilde{\chi}_2^0, \tilde{\chi}_1^0)$ = (157, 92) GeV	4.6 ± 1.3	0.00 ± 0.00
p_0	0.4	0.3
Expected $\sigma^{95}_{\mathrm{vis}}$ [fb]	0.03	0.04
Observed $\sigma^{95}_{\mathrm{vis}}$ [fb]	0.03	0.04

- High purity of BKGs in each respective VRs.
- The signal contamination is low in the above VRs.
- Good agreement between data and the SM prediction. No excess in SRs.

$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ via stau deacy with $\geq 2\tau + E_T^{miss}$

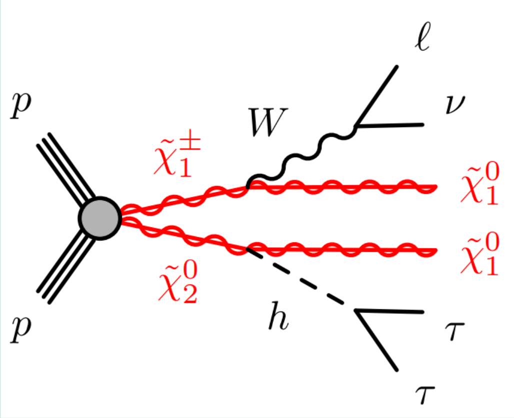


(a) (b) (c)

- (a) **C1C1**: SR-C1C1-LM and SR-C1C1-HM are statistically combined
  - The Chargino masses up to 970 GeV are excluded for decays to a massless neutralino
- (b,c) **C1C1+C1N2**: SR-C1N2OS and SR-C1N2SS are combined for the production of $\tilde{\chi}_1^+\tilde{\chi}_1^-$ and $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$
  - The Chargino masses up to 1160 GeV are excluded for a massless neutralino.
- These limits significantly extend previous results in high C1/N2 mass region. And the SS channel makes an improvement at compressed and low C1/N2 mass region.

$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via Wh decay with $2\tau + 1lep + E_T^{miss}$

SR definition:



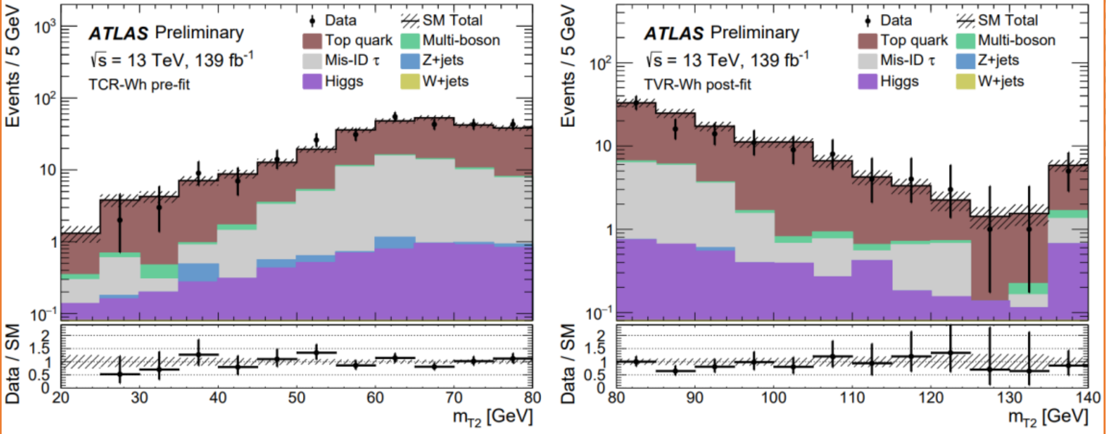
SR-Wh-LM	SR-Wh-HM
= 1 signal light lepton	
$\geq$ 2 medium τ (OS)	
b-jet veto	
$\lvert\Delta\phi(\tau_1,\tau_2)\rvert < 3$	
-	$\Delta R(\tau_1,\tau_2) < 2.2$
$90 < m(\tau_1,\tau_2) < 130$ GeV	$80 < m(\tau_1,\tau_2) < 160$ GeV
$m_{T2} > 100$ GeV	$m_{T2} > 80$ GeV
-	$m_{T,l} > 80$ GeV
-	$m_{Tsum} > 450$ GeV

- Two SRs are defined to cover low and high EWKino mass regions.
- SRs are not orthogonal due to limitations from the available statistics in the dataset.

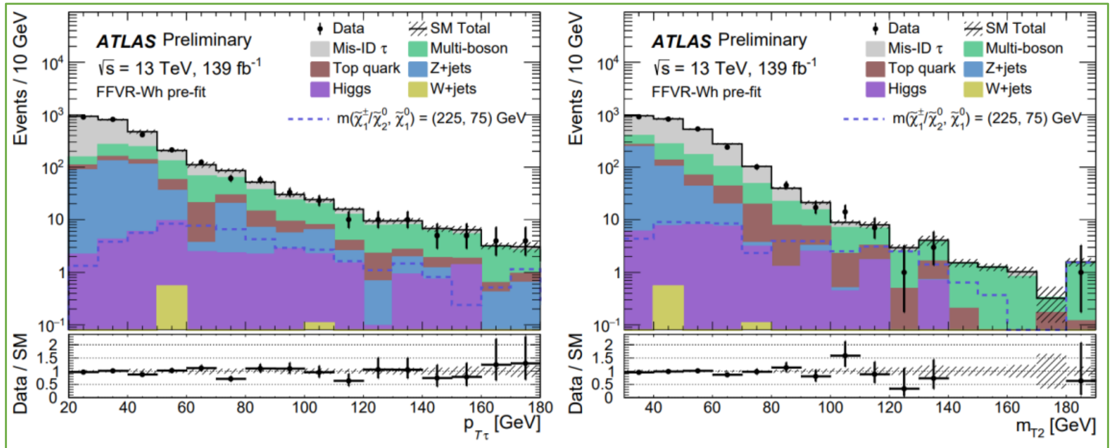
Background estimation

■ BKG estimation strategy:

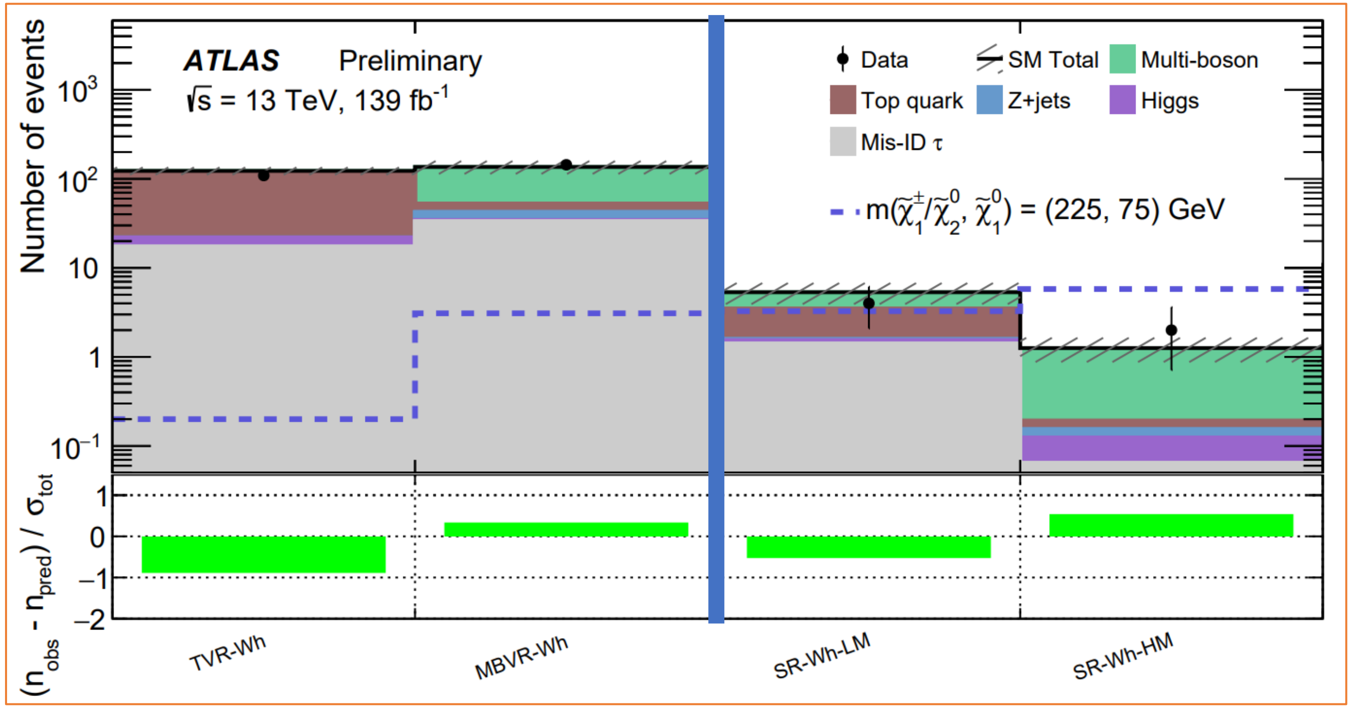
- 1 lep + 2 real tau : Multi-boson(dominates), Higgs.
  - **Multi-boson**: estimated directly from MC simulation and a VR for validation.
- 1 lep + 1 real 1 fake tau : top (dominates), Z+jets.
  - **Top**: use a dedicated CR for normalization, and a VR.
- 1 lep + 2 fake tau : W+jets dominates.
  - **2 fake tau**: Fake Factor method.
    - ◆ Use CRs to extrapolate from two fake-fail-medium (anti-tau,A) taus events to two fake-pass-medium (M) taus events.



(a) (b)



(a) (b)

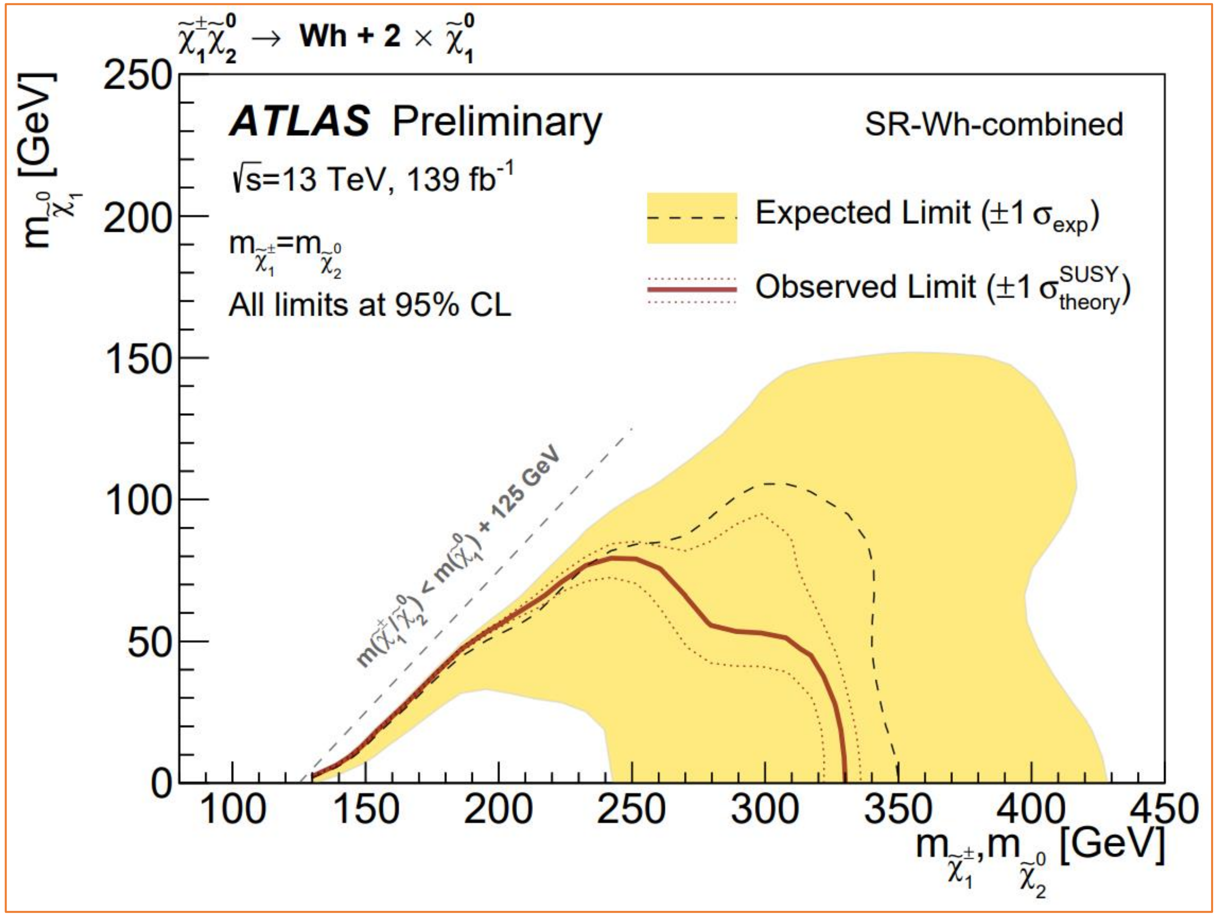


SM process	SR-Wh-LM	SR-Wh-HM
Multi-boson	1.85 ± 0.5	1.1 ± 0.4
Fake processes	1.4 ± 0.6	0.06 ± 0.03
Top quark	1.9 ± 0.6	$0.04^{+0.06}_{-0.04}$
Z+jets	0.05 ± 0.02	0.03 ± 0.01
Higgs	$0.13^{+0.99}_{-0.13}$	0.06 ± 0.02
SM total	5.3± 1.4	1.3 ± 0.4
Observed	4	2
$m(\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0, \tilde{\chi}_1^0)$ = (225, 75) GeV	5.8 ± 1.5	3.3 ± 0.9
p_0	0.5	0.3
Expected σ^{95}_{vis} [fb]	0.05	0.03
Observed σ^{95}_{vis} [fb]	0.04	0.03

■ **Post-fit distribution**:

- The signal contamination is low.
- good agreements in VRs and SRs. No excess in SR

$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via Wh decay with $2\tau + 1lep + E_T^{miss}$



- The best expected limits for SR-Wh-LM and SR-Wh-HM are used to derive limits.
- Gaugino masses up to 330 GeV are excluded for a massless lightest neutralino.

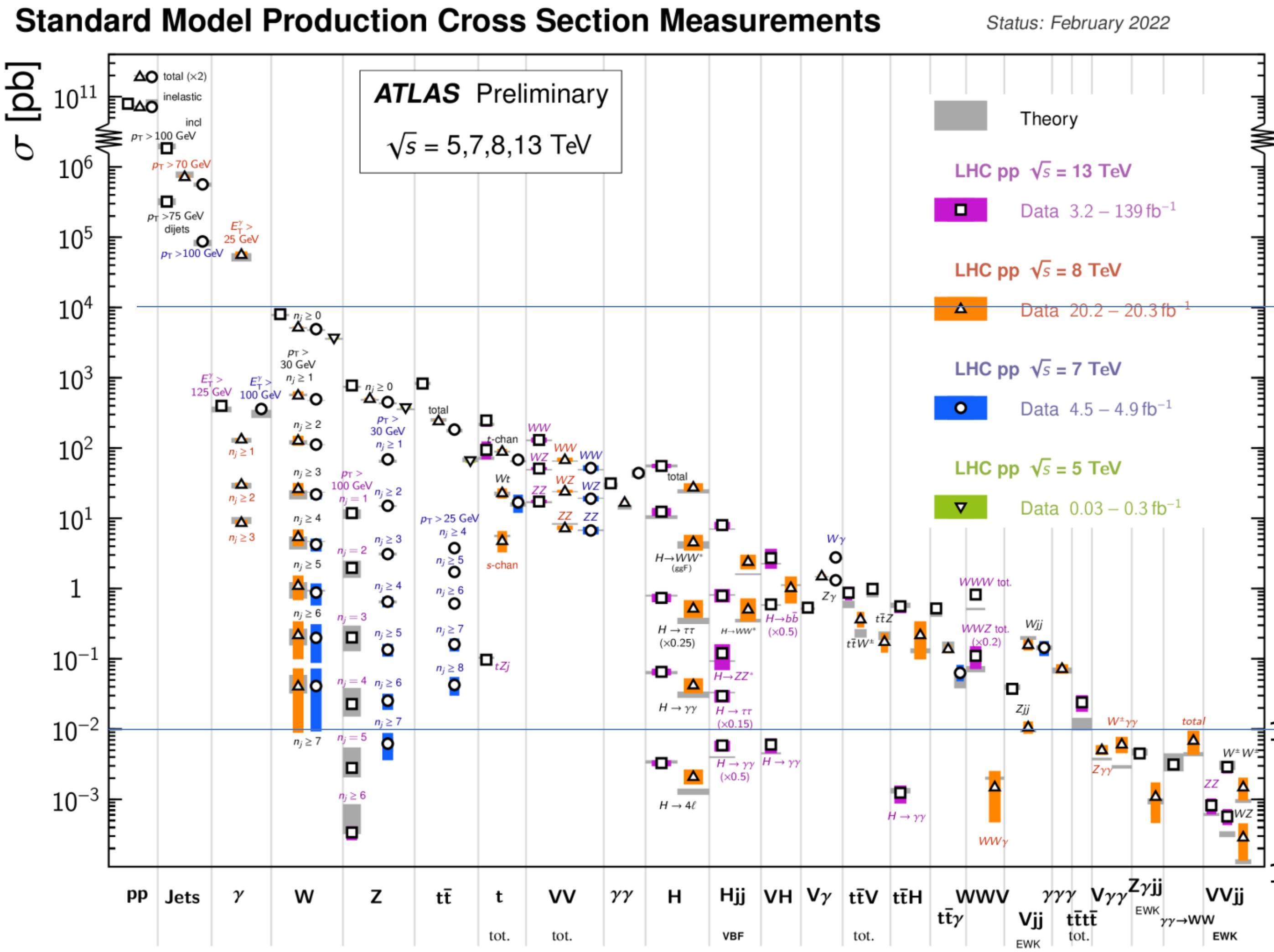
Summary

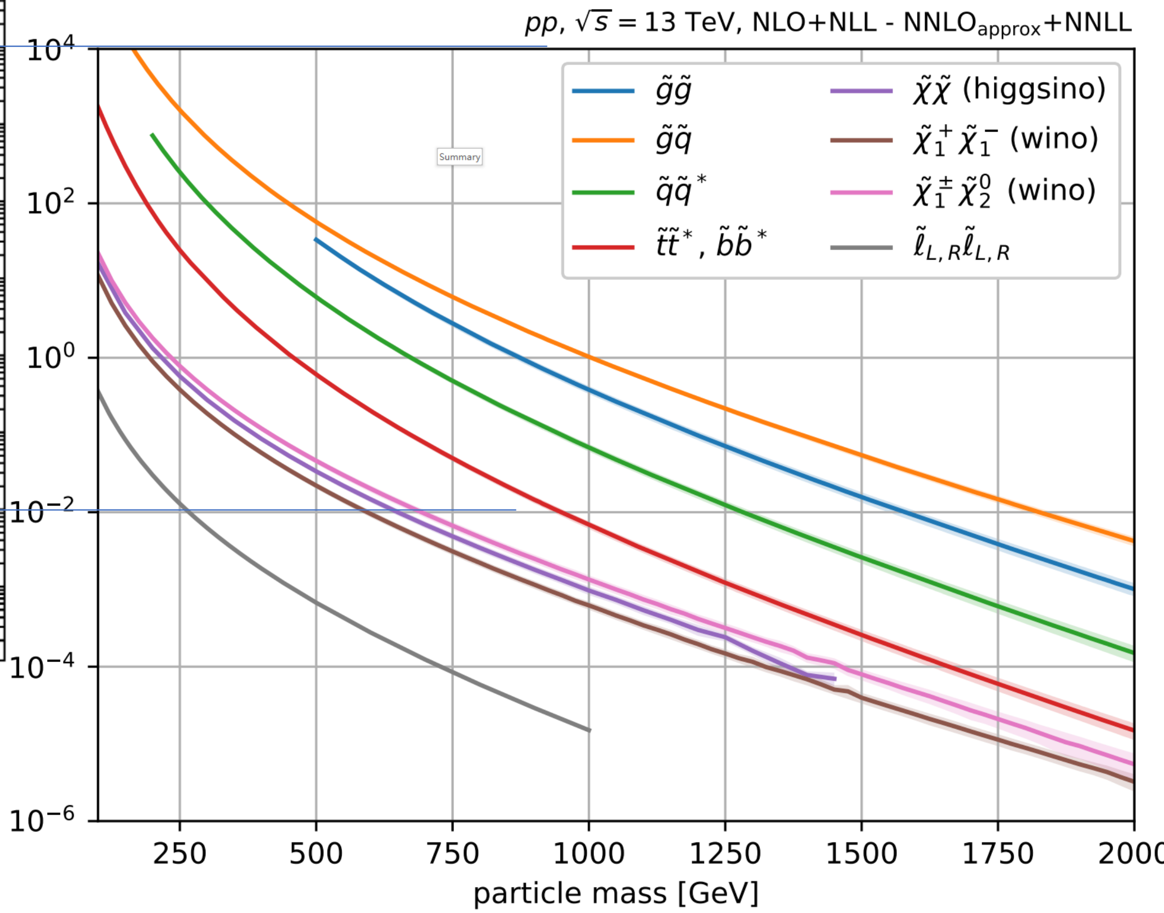
- Searches for direct Ewkino pair production decaying via stau or Wh with at least two hadronically decaying taus in the final state have been presented. No excess is found.

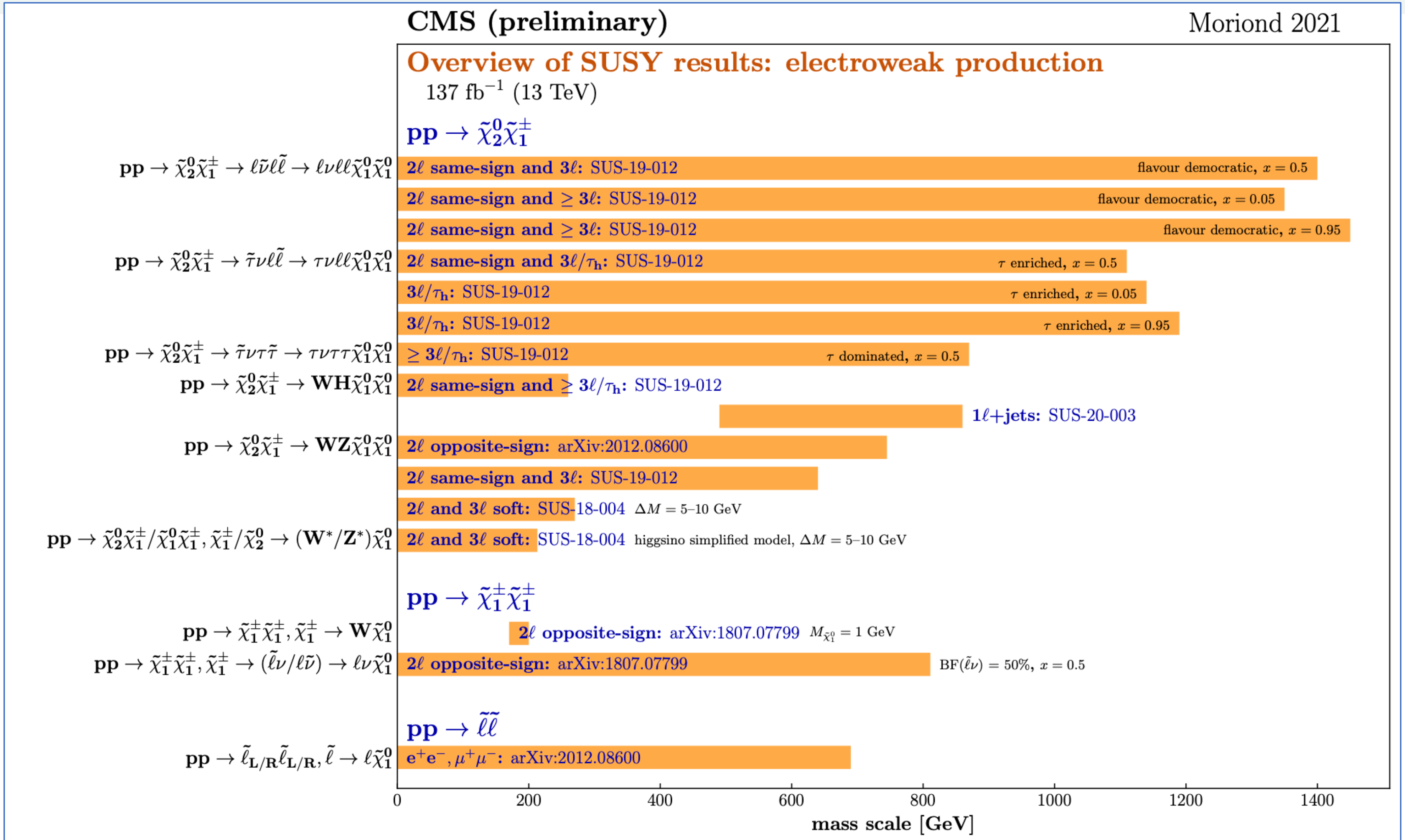
- **$\tilde{\chi}_1^{+}\tilde{\chi}_1^{-}$, $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$ via stau deacy with $\geq 2\tau + E_T^{miss}$:**
  - With the full Run-2 dataset, the exclusion limits for high C1/N2 masses could be improved by 340–400 GeV compared to the previous result.
  - And the sensitivity at compressed C1/N2 mass region is also improved by the addition of the C1N2SS channel.

- **$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$ via Wh decay with $2\tau + 1lep + E_T^{miss}$:**
  - The C1/N2 masses up to 330 GeV are excluded for a massless lightest neutralino.
  - Corporate with other Wh decay modes for a combined fit.

BACKUP


Standard Model Production Cross Section Measurements
Status: February 2022
ATLAS Preliminary
$\sqrt{s}$ = 5,7,8,13 TeV
Theory
LHC pp $\sqrt{s}$ = 13 TeV
Data 3.2 – 139 fb^{-1}
LHC pp $\sqrt{s}$ = 8 TeV
Data 20.2 – 20.3 fb^{-1}
LHC pp $\sqrt{s}$ = 7 TeV
Data 4.5 – 4.9 fb^{-1}
LHC pp $\sqrt{s}$ = 5 TeV
Data 0.03 – 0.3 fb^{-1}
σ [pb]
pp
Jets
γ
W
Z
$t\bar{t}$
t
VV
$\gamma\gamma$
H
Hjj
VH
Vγ
$t\bar{t}$V
$t\bar{t}$H
WWV
$t\bar{t}\gamma$
Vjj
$\gamma\gamma\gamma$
$t\bar{t}t\bar{t}$
V$\gamma\gamma$
Zγjj
$\gamma\gamma\to$WW
VVjj


pp, $\sqrt{s}$ = 13 TeV, NLO+NLL - NNLO$_{approx}$+NNLL
$\tilde{g}\tilde{g}$
$\tilde{g}\tilde{q}$
$\tilde{q}\tilde{q}^*$
$\tilde{t}\tilde{t}^*$, $\tilde{b}\tilde{b}^*$
$\tilde{\chi}\tilde{\chi}$ (higgsino)
$\tilde{\chi}_1^+\tilde{\chi}_1^-$ (wino)
$\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ (wino)
$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$
particle mass [GeV]

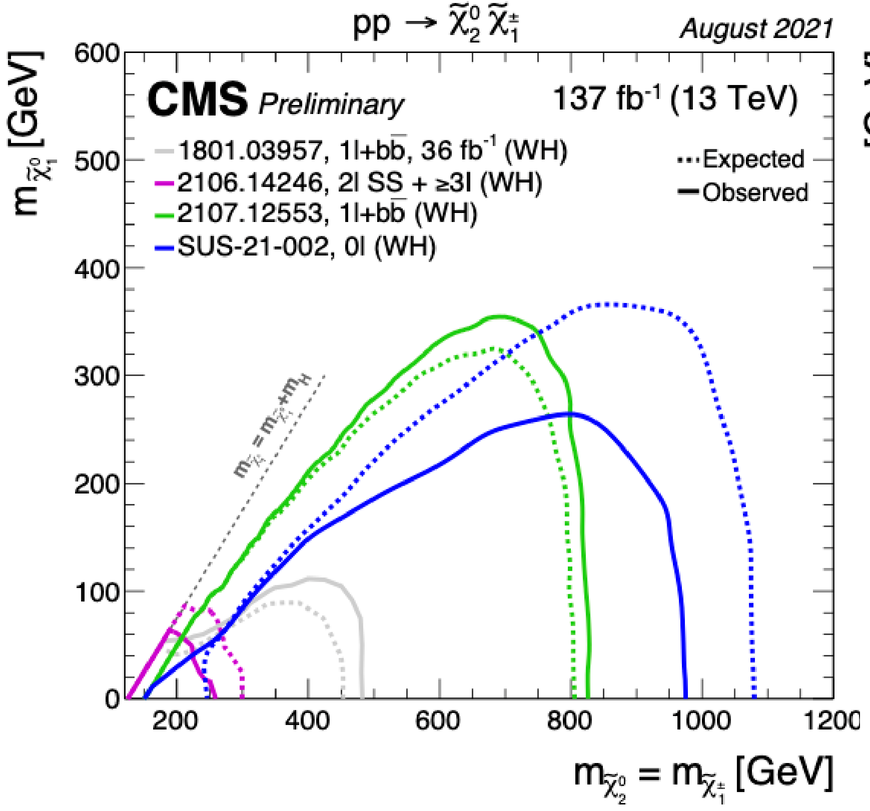


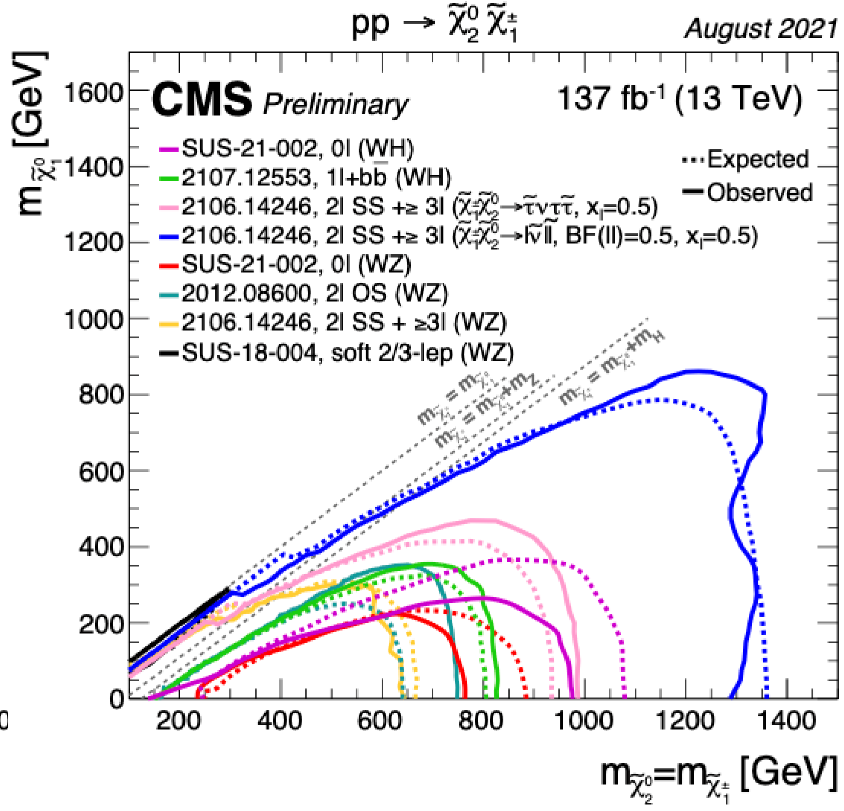
Selection of observed limits at 95% C.L. (theory uncertainties are not included). Probe **up to** the quoted mass limit for light LSPs unless stated otherwise. The quantities ΔM and x represent the absolute mass difference between the primary sparticle and the LSP, and the difference between the intermediate sparticle and the LSP relative to ΔM, respectively, unless indicated otherwise.

CMS results

- [arxiv:2106.14246](https://arxiv.org/abs/2106.14246)

- The "τ-dominated" scenario with both $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ decays mediated by τ sleptons because the other slepton flavors are heavy and decoupled [6]. In this case both $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ decay exclusively to τ leptons.





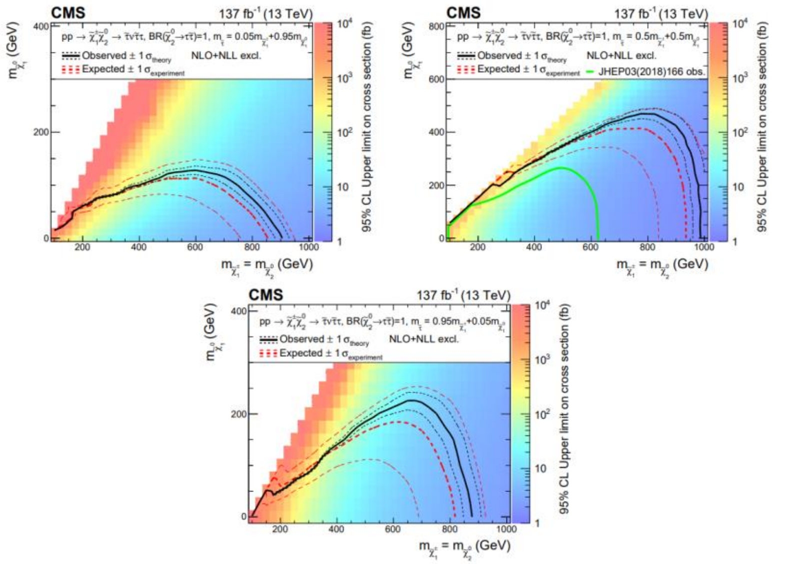


Figure 18: Interpretation of the results for $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ production with τ-dominated slepton-mediated decays, and the parameter governing the mass splittings being $x = 0.05$ (upper left), $x = 0.5$ (upper right) and $x = 0.95$ (lower). The shading in the $m_{\tilde{\chi}_1^0}$ versus $m_{\tilde{\chi}_2^0}$ plane indicates the 95% CL upper limits on the $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ production cross sections. The contours delineate the mass regions excluded at 95% CL when assuming cross sections computed at NLO plus NLL. The observed, observed $\pm 1\sigma_{\text{theory}}$ (± 1 standard deviation of the theoretical cross sections), median expected, and expected $\pm 1\sigma_{\text{experiment}}$ bounds are shown in black and red. The median expected bound obtained with the search region strategy is shown in blue. The observed limits obtained in the CMS analysis using 2016 data [20] are shown in green, which only included interpretations in the $x = 0.5$ case.

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Variables

- the "stransverse mass", m_{T2}, which has a kinematic endpoint for events where two massive pair produced particles each decay to two objects, one of which is detected (the lepton in our case) and the other escapes undetected (the neutralino) [78, 79]. It is defined as:

$$m_{\mathrm{T2}} = \min_{\mathbf{q}_{\mathrm{T}}} \left[\max \left(m_{\mathrm{T1}}(\mathbf{p}_{\mathrm{T1}}, \mathbf{q}_{\mathrm{T}}), m_{\mathrm{T2}}(\mathbf{p}_{\mathrm{T2}}, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}} - \mathbf{q}_{\mathrm{T}}) \right) \right],$$

- m_{Tsum}, the sum of the transverse mass values of the leading and next-to-leading τ-lepton candidates with the $E_{\mathrm{T}}^{\mathrm{miss}}$ for $\tilde{\chi}_1^+\tilde{\chi}_1^-$ and $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ with decays to an intermediate stau channels. In the $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ with decays to an intermediate Wh scenario, m_{Tsum} also includes $m_{\mathrm{T}\ell}$.

"top-tagged". The contransverse mass variable [81], m_{CT}, is used to identify events that are kinematically compatible with $t\bar{t}$ pair production. Furthermore, top-tagged events must have at least two jets with $p_{\mathrm{T}} > 20$ GeV, and the scalar sum of the p_{T} of at least one combination of two jets and the two leptons in the event must exceed 100 GeV. Events passing the top-tagged selection are vetoed in the WCR-OS and WVR-OS regions to reduce the top backgrounds in these regions.

Samples

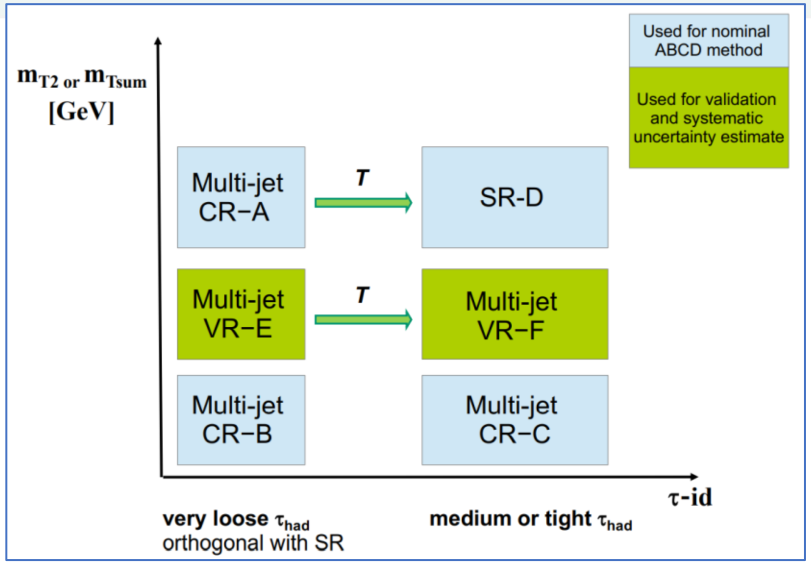
- Data: full Run-2 data, corresponding to 139 fb^{-1} data collected between 2015 and 2018.
- Background samples:

Process	ME Generator	Parton Shower	PDF	Tune
VV, VVV	Sherpa 2.2.1/2.2.2	Sherpa	CT10	Sherpa default
$Z/W+$ jets	Sherpa 2.2.1	Sherpa	CT10	Sherpa default
$t\bar{t}+V, t\bar{t}+H$, 3 top, 4 top	MG5_aMC	Pythia 8	NNPDF 2.3 LO	A14
$t\bar{t}$	Powheg-BOX	Pythia 8	CT10/CTEQ6L1	Perugia2012
s/t-channel and Wt single top	Powheg-BOX	Pythia 8	CT10/CTEQ6L1	Perugia2012
$Z/W+H$	Pythia 8	Pythia 8	NNPDF 2.3 LO	A14
$ttH, VBFH, gg+H$	Powheg-BOX	Pythia 8	NNPDF 3.0/CTEQ6L1	AZN

- Signals:
  - Generated with MadGraph5_aMC@NLO 2.2.3 interfaced to Pythia 8.186 with the A14 tune.
  - bino-like LSP with wino-like C1/N2
  - Assumed $m(\tilde{\tau}) = (m(\tilde{\chi}_0^1) + m(\tilde{\chi}_1^{\pm}))/2$ in the intermediate stau channel.

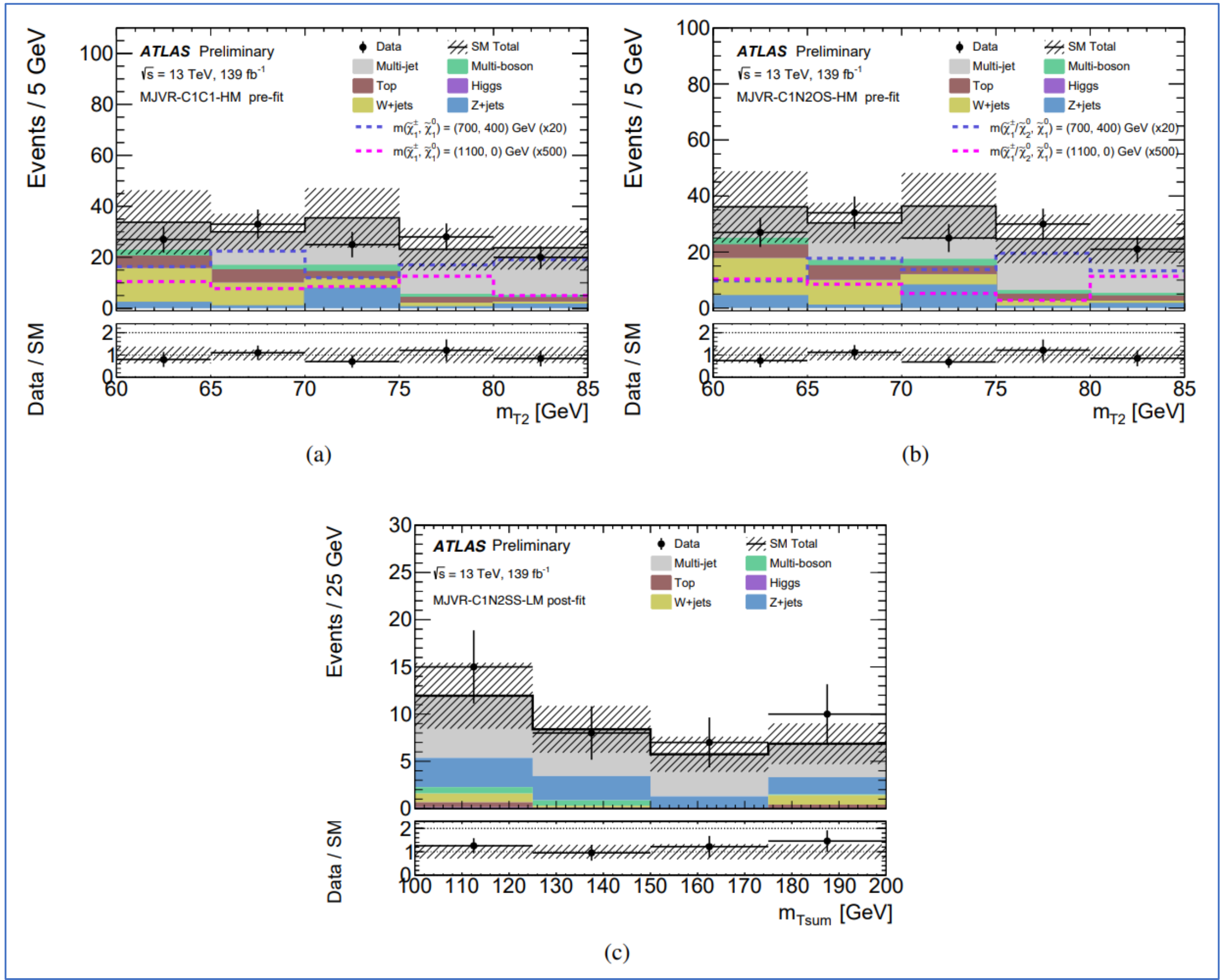
Background estimation (Intermediate Stau channel)

- **Multi-jet** :
  - ABCD-method
    - $T = N_C/N_B$. TF will be verified in VRs and applied on CR-A.
    - $N_{MJ} = N_{Data} - N_{other\ MC}$
    - Use "very loose" τ-lepton identification criterion to define CR-B, VR-E, CR-A
    - Use m_{T2} and m_{Tsum} to define CRs and VRs.



Channel	variable	CR-B / CR-C	VR-E / VR-F	CR-A / SR
C1C1-LM	m_{T2}	$\in$ [15, 35] GeV	$\in$ [35, 80] GeV	> 80 GeV
	E_T^{miss}	$\in$ [10, 150] GeV	$\in$ [10, 150] GeV	$\in$ [60, 150] GeV
C1C1-HM	m_{T2}	$\in$ [35, 60] GeV	$\in$ [60, 85] GeV	> 85 GeV
	m_{Tsum}	$\in$ [100, 300] GeV	$\in$ [200, 400] GeV	> 400 GeV
	E_T^{miss}	> 50 GeV	> 50 GeV	> 150 GeV
C1N2OS-LM	m_{T2}	$\in$ [15, 35] GeV	$\in$ [35, 70] GeV	> 70 GeV
	E_T^{miss}	$\in$ [10, 150] GeV	$\in$ [10, 150] GeV	$\in$ [60, 150] GeV
C1N2OS-HM	m_{T2}	$\in$ [35, 60] GeV	$\in$ [60, 85] GeV	> 85 GeV
	m_{Tsum}	$\in$ [150, 300] GeV	$\in$ [200, 400] GeV	> 400 GeV
	E_T^{miss}	> 50 GeV	> 50 GeV	> 150 GeV
C1N2SS-LM	m_{Tsum}	< 100 GeV	$\in$ [100, 200] GeV	> 200 GeV
	$\lvert\Delta\phi(\tau_1, \tau_2)\rvert$	< 1.5	< 1.5	> 1.5
C1N2SS-HM	m_{Tsum}	$\in$ [100, 200] GeV	$\in$ [200, 450] GeV	> 450 GeV
	E_T^{miss}	> 50 GeV	> 50 GeV	> 150 GeV

- Systematics
  - **Statistical uncertainty**: stat. uncertainty in CRs from the limited number of events and the subtraction.
  - **Experimental uncertainty**: extrapolate from the total systematic uncertainty in CR-A to SR-D.
  - The **correlation** between the tau ID and the kinematics: the difference on TF between N_C/N_B and N_F/N_E.



- VR-F distribution:
  - Good agreement between data and the estimated SM background is found in VR-F.

W+jets

- **W+jets**
  - $W \to \mu\nu$ process is used for WCR definition.
  - Require exactly one muon and one tau.
  - Single muon trigger.

- Multi-jet contribution in WCR/VR
  - OS-SS method:

$$N_{MJ(OS)} = N_{Data(SS)} - N_{otherSM(SS)}$$

- WCR:
  - 73–85% purity in all W control and validation regions.
  - Good data/SM agreement observed in pre-fit distribution.
  - Negligible signal contamination.

Table 3: The definition of the W+jets control (WCR) and validation region (WVR).

WCR-OS	WVR-OS	WCR-SS	WVR-SS
baseline electron veto			
b-jet veto			
$p_{T\,\tau} > 50$ GeV, $p_{T\,\mu} > 40$ GeV			
Exactly one medium τ and one isolated μ (OS)		Exactly one medium τ and one isolated μ (SS)	
Top-tagged events veto		-	
$m_{\mathrm{T},\mu} < 140$ GeV		$50 < m_{\mathrm{T},\mu} < 150$ GeV	
-		$m_{\mathrm{T},\mu} + m_{\mathrm{T},\tau} > 80$ GeV	
$E_{\mathrm{T}}^{\mathrm{miss}} > 60$ GeV		$E_{\mathrm{T}}^{\mathrm{miss}} > 50$ GeV	
$40 < m_{\mathrm{T2}}(\tau,\mu) < 70$ GeV	$m_{\mathrm{T2}}(\tau,\mu) > 70$ GeV	$m_{\mathrm{T2}}(\tau,\mu) < 60$ GeV	$m_{\mathrm{T2}}(\tau,\mu) > 60$ GeV

Top in SS channel

■ Top background estimation for C1N2SS

- one or two fake tau contribution from $t\bar{t}$ and Wt in SR-C1N2SS-HM.
- Dedicated TCR & TVR for HM (high contribution in SR).

- Top purity is more than 83% in two regions.
- Negligible signal contamination.

Table 4: The definition of the top control (TCR) and validation region (TVR) for C1N2SS.

TCR-SS-HM	TVR-SS-HM
$\tau-\tau$ channel	
Di-τ + $E_{\mathrm{T}}^{\mathrm{miss}}$ trigger	
≥ 2 very loose τ, ≥ 1 loose τ	
$N_{\text{medium-}\tau} < 2$	
≥ 1 b-jet	
$E_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV	
$m_{\mathrm{T}sum} \leq 400$ GeV	$m_{\mathrm{T}sum} \geq 400$ GeV

■ Top background estimation for C1N2SS

- one or two fake tau contribution from $t\bar{t}$ and Wt in SR-C1N2SS-HM.
- Dedicated TCR & TVR for HM (high contribution in SR).

- Top purity is more than 83% in two regions.
- Negligible signal contamination.

Other Background Estimation

- **Irreducible Backgrounds**:
  - **OS channel**: Top, Z+jets, Multi-boson.

Top-VR1	Top-VR2	Z-VR1	Z-VR2	MB-VR1	MB-VR2
$\tau-\tau$ channel					
$\geq$ 2 medium taus (OS), $\geq$ 1 tight tau					
at least one b-jet		b-jet veto			
$m_{\mathrm{T},\tau_1}+m_{\mathrm{T},\tau_2}>150$ GeV		–		$m_{\mathrm{T},\tau_1}+m_{\mathrm{T},\tau_2}>180$ GeV	
$m(\tau_1,\tau_2)>120$ Gev		$m(\tau_1,\tau_2)<70$ GeV	$m(\tau_1,\tau_2)<60$ GeV	$m(\tau_1,\tau_2)<80$ GeV	$m(\tau_1,\tau_2)<90$ GeV
–		$\Delta R(\tau 1,\tau 2)<1$		$\Delta R(\tau 1,\tau 2)<1.2$	
$\Delta\phi(\tau 1,\tau 2)>1.0$		–		$\Delta\phi(\tau 1,\tau 2)<1.0$	
$m_{\mathrm{T2}}>40$ GeV	$m_{\mathrm{T2}}>30$ GeV	$m_{\mathrm{T2}}<60$ GeV		$m_{\mathrm{T2}}>60$ GeV	
asymmetric di-tau trigger	di-tau+$E_{\mathrm{T}}^{\mathrm{miss}}$ trigger	asymmetric di-tau trigger	di-tau+$E_{\mathrm{T}}^{\mathrm{miss}}$ trigger	asymmetric di-tau trigger	di-tau+$E_{\mathrm{T}}^{\mathrm{miss}}$ trigger
$20<E_{\mathrm{T}}^{\mathrm{miss}}<150$ GeV	$E_{\mathrm{T}}^{\mathrm{miss}}>150$ GeV	$40<E_{\mathrm{T}}^{\mathrm{miss}}<150$ GeV	$E_{\mathrm{T}}^{\mathrm{miss}}>150$ GeV	$70<E_{\mathrm{T}}^{\mathrm{miss}}<150$ GeV	$E_{\mathrm{T}}^{\mathrm{miss}}>150$ GeV
lepton p_{T} and $E_{\mathrm{T}}^{\mathrm{miss}}$ are required at plateau					

    - At least 1M1T tau selection in all VRs.
    - Top-VR: use B-jets to increase purity.
    - Z-VR & MB-VR: use angular requirement, visible mass cut, m_{T2} for orthogonality & purity…

  - **SS channel**: Z+jets, Multi-boson
    - MB-VR definition:
      - Two OS muon, single muon trigger
      - B-jet veto.
      - MET>100 GeV , $\Delta\phi(\mu,\mathrm{MET})\leq 1.75$

Background estimation (Intermediate Wh channel)

- **Fake τ-lepton background**:
  - Fake Factor method
    - Use CRs to extrapolate from two fake-fail-medium (anti-tau,A) taus events to two fake-pass-medium (M) taus events.
    - Workflow: AA->MA->MM

$$\mathrm{FF}_{\tau 1}^{\mathrm{CR}} = \frac{N_{\mathrm{data,AA}} - N_{\mathrm{MC,AA}}^{\geq 1\ \mathrm{truth\ tau}}}{N_{\mathrm{data,MA}} - N_{\mathrm{MC,MA}}^{\geq 1\ \mathrm{truth\ tau}}} \times \mathrm{FF}_{\tau 2}^{\mathrm{CR}} = \frac{N_{\mathrm{data,MA}} - N_{\mathrm{MC,MA}}^{\geq 1\ \mathrm{truth\ tau}}}{N_{\mathrm{data,MM}} - N_{\mathrm{MC,MM}}^{\geq 1\ \mathrm{truth\ tau}}} \Rightarrow N_{\mathrm{fakes}} = N_{\mathrm{AA,\ fakes}} \times \mathrm{FF}_{\tau 1}^{\mathrm{CR}} \times \mathrm{FF}_{\tau 2}^{\mathrm{CR}},$$

$$N_{fakes} = N_{data} - N_{\geq 1\ Truth\ \tau\ MC}$$

- FFCR-Wh: use very loose tau to increase the statistics, two SS tau is used for the orthogonality. FFVR-Wh is a superset of SR.
- FFs for the leading tau and sub-leading tau, for the 1p and 3p are obtained from FFCR-Wh separately.

FFCR-Wh	FFVR-Wh
≥ 2 very loose τ (SS)	≥ 2 medium τ (OS)
$m(\tau_1, \tau_2) > 20$ GeV	$40 < m(\tau_1, \tau_2) < 160$ GeV
$m_{\mathrm{T2}} > 20$ GeV	$m_{\mathrm{T2}} > 30$ GeV
b-jet veto	
$\lvert\Delta\phi(\tau_1, \tau_2)\rvert < 3$	
=1 light lepton (e or μ)	

Table 6: The definition of the fake factor control and validation regions

- Systematic:
  - **Stat. Uncertainty** from the CR and limited stat. in OS AA region.
  - **Systematic uncertainty**: 30% flat syst on the subtracted MC.
  - Check the agreement on the **quark/gluon contribution** between CR & SR.

Top (Intermediate Wh channel)

- **Top**
  - Sub-dominant in LM. Negligible in HM
  - The main contribution is $t\bar{t}$ with one W boson decay to lep and the other to a tau. The second tau is a jet-fake tau.

- TCR & TVR:
  - definition:
    - 1 to 2 b-jets requirement and m_{Tsum} cut.
    - Loose visible mass to increase the statistics.
    - split by m_{T2}
  - The purity in TCR&TVR are **73–81%**.
  - Good data/SM agreement observed in pre-fit distribution in TCR, and post-fit distribution in TVR.
  - Negligible signal contamination.

Table 7: The definition of the top control and validation regions for the intermediate Wh channel.

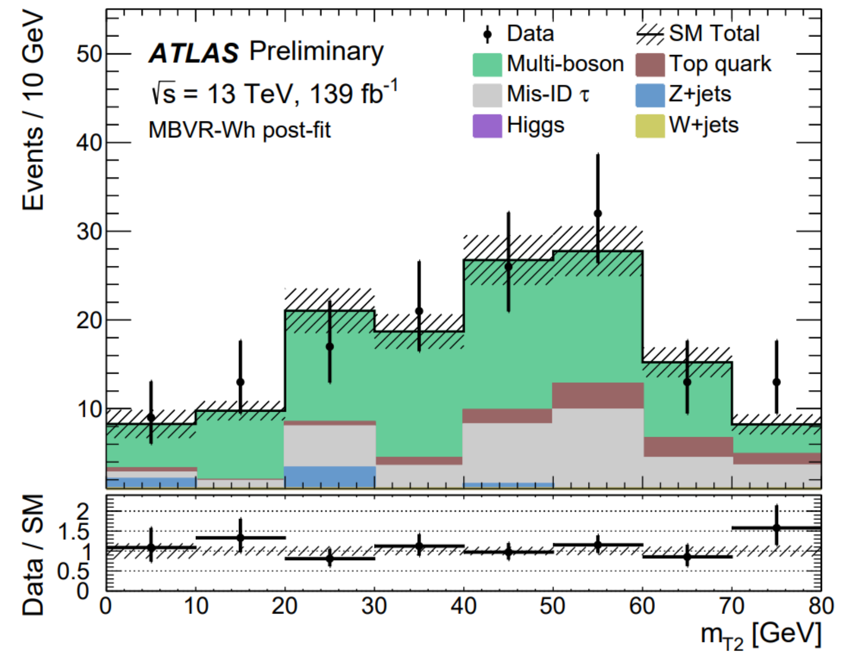
TCR-Wh	TVR-Wh
=1 light lepton (e or μ)	
≥ 2 medium τ	
$40 < m(\tau_1, \tau_2) < 160$ GeV	
$m_{Tsum} > 250$ GeV	
$1 \leq N_{b\text{-jets}} \leq 2$	
$\lvert\Delta\phi(\tau_1, \tau_2)\rvert < 3$	
20 GeV $< m_{T2} <$ 80 GeV	$m_{T2} >$ 80 GeV

Multi-boson (Intermediate Wh channel)

- **Multi-boson**
  - WZ dominates: two real tau in both SRs.
  - estimated from MC simulation and validated in a multi-boson enriched region (MBVR-Wh) with 61% purity.
    - The m_{T2} cut makes MBVR to be orthogonal to SRs.
  - Good agreement in MB-VR.

Table 8: The definition of the multi-boson validation region (MBVR-Wh).

MBVR-Wh
= 1 light lepton (e or μ)
$\geq$ 2 medium τ (OS)
$40 < m(\tau_1, \tau_2) < 70$ GeV
$p_{T\,\tau_2} > 30$ GeV
$m_{\mathrm{T},l} > 70$ GeV
$m_{\mathrm{T2}} < 80$ GeV
b-jet veto
$\lvert\Delta\phi(\tau_1, \tau_2)\rvert < 3$



Systematic Uncertainties

- **Experimental uncertainty** following CP recommendations:
  - Tau lepton and jet energy scale/calibration and resolution, tau ID, pile-up, MET modelling, triggers SF uncertainty, and so on.
  - Wh channel also includes the lep systematics and single lep triggers SF uncertainty.

- **Theoretical uncertainty** following CP recommendations:
  - the renormalization scale, factorization scale, and PDF+α_s uncertainty.
  - ISR, FSR, Hard scattering, and hadronization for Top.
  - X-sec uncertainty.

- **Multi-jet / Fake tau estimation**.

Systematic Uncertainties

- **Statistical uncertainty** from MC.
- **Experimental uncertainty**: tau and jet energy calibration and resolution, tau ID, and MET soft-term resolution.
- **Theoretical uncertainty**: main reducible background in each regions.
- **Multi-jet / Fake estimation**