Search for direct electroweakino production in events with at least two hadronic taus with the ATLAS detector

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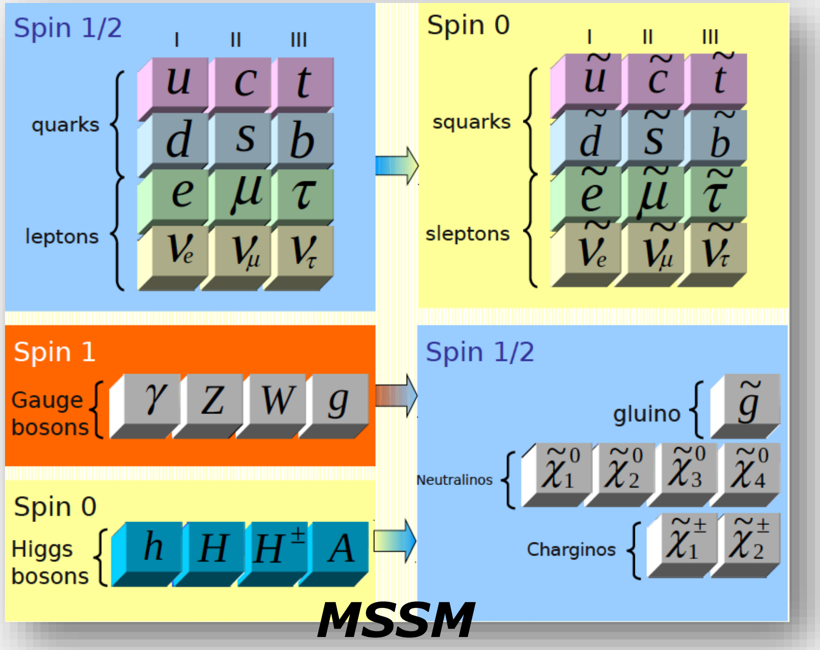
CLHCP (2021)

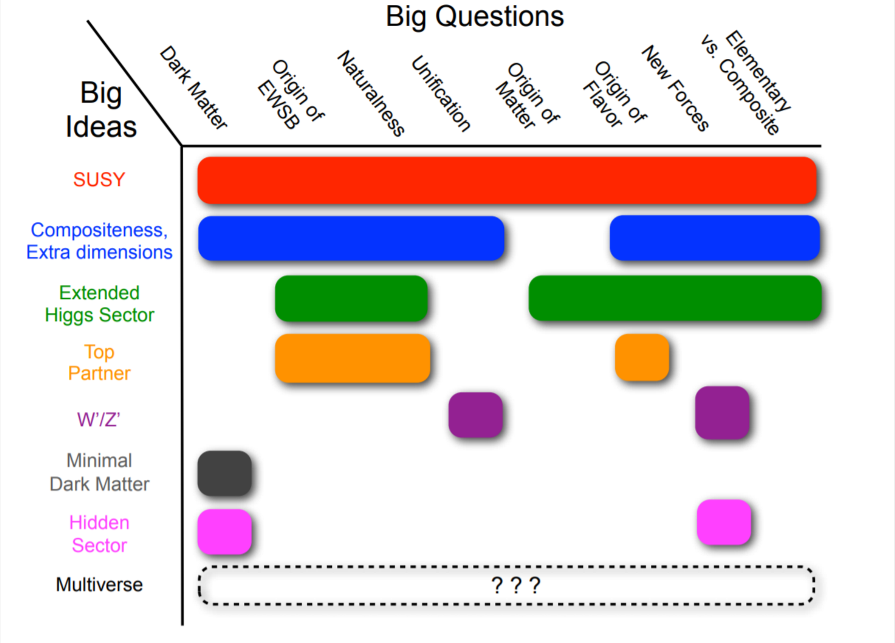
It is about SUSY…

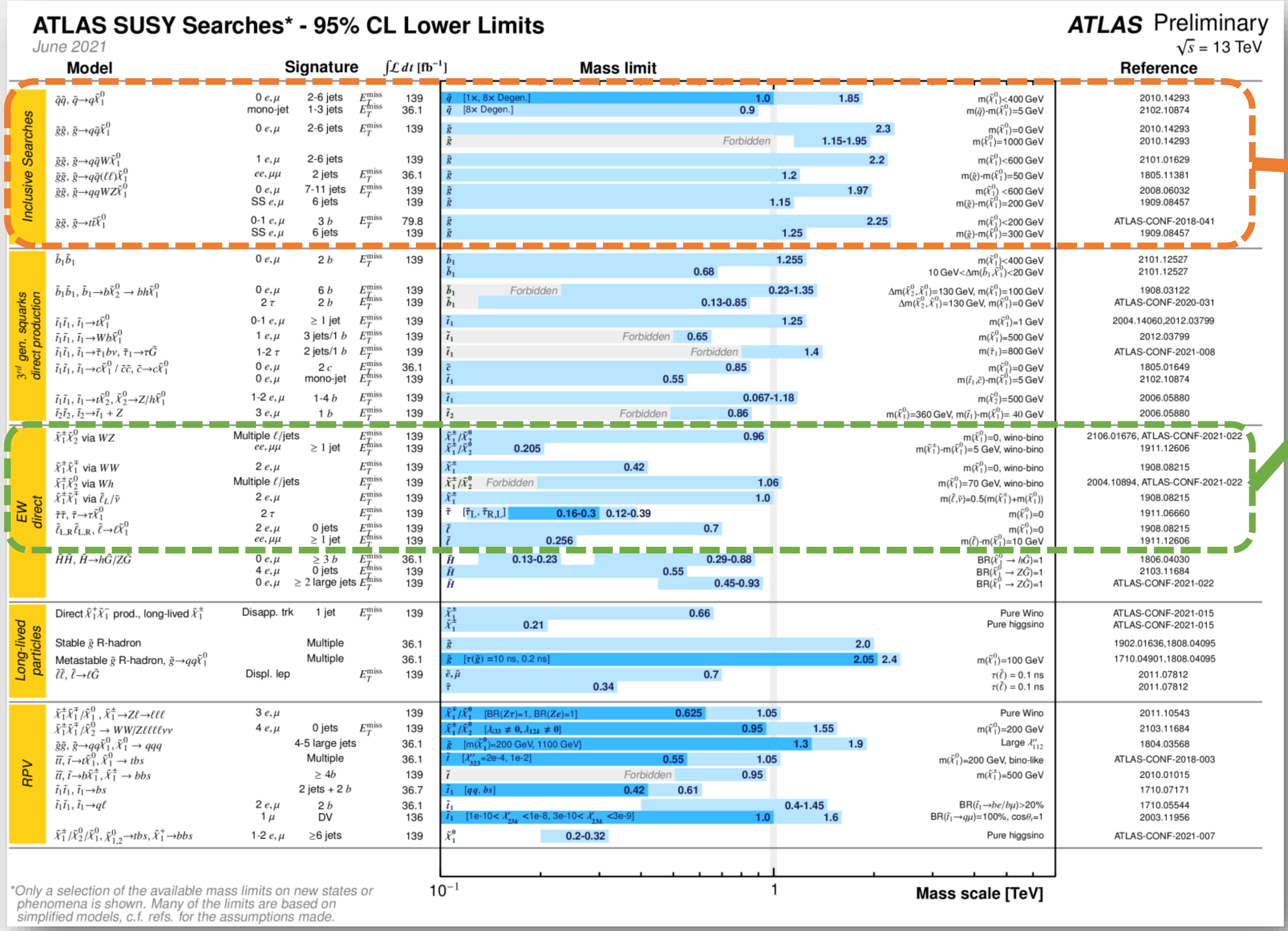
- The Standard Model (SM) of particle physics Precisely described the fundamental elements of the matter and the interactions between them

- Despite the huge success of the SM theory, BSM is strongly motivated:
  - Hierarchy problem, dark matter, the GUT, quantum description of gravity, muon g-2, e.t.c…

- **SUSY advantage:**







- **SUSY…**
  - *The exclusion limit…*

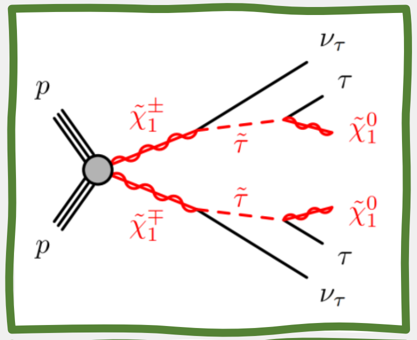
squark & gluino *is above 2 TeV*

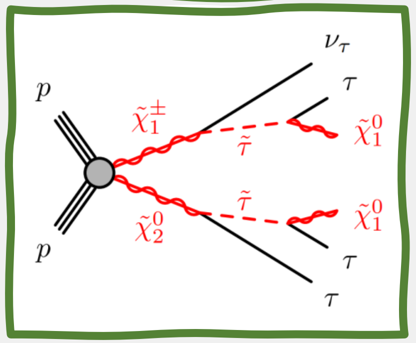
light gauginos & stau *can be lighter*

- **Electroweak Direct Production to $\geq$ 2 *two hadronic taus under R-parity Conserving***

Outline

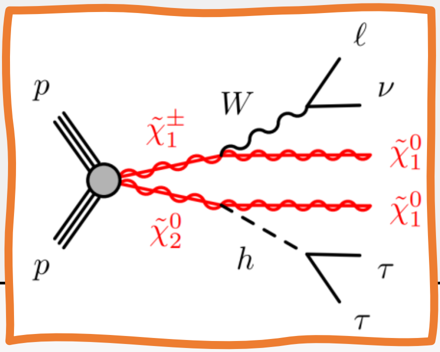
- Glance Analysis entry: ANA-SUSY-2019-17
- **Naming:**
  - *Lightest chargino* ($\tilde{\chi}_1^{\pm}$): C1
  - *Lightest neutralino* ($\tilde{\chi}_1^{0}$): N1
  - *Next-to-lightest neutralino*($\tilde{\chi}_2^{0}$):N2



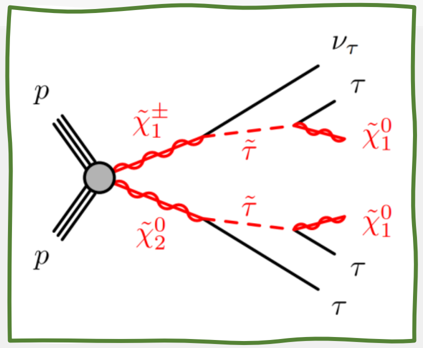


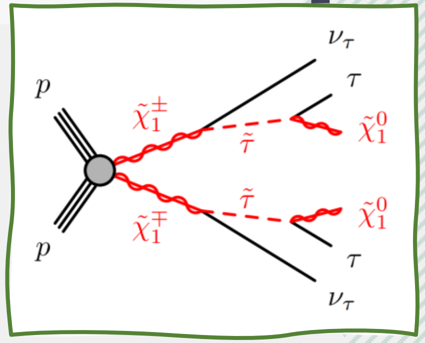
- **C1C1, C1N2 via stau with $\geq 2\tau + E_T^{miss}$**
  - Previous paper with 2015-2016 data : Eur. Phys. J. C 78, 154 (2018)
    - OS final state: Re-optimize based on **full Run-2 data**
    - SS final state: **New final state** for C1N2 production
  - A new **OS-SS combine** result is also included

- **C1N2 via Wh with $\geq 2\tau + 1lep + E_T^{miss}$**
  - **New final state** study for C1N2 via Wh



Gaugino pair – OS channel

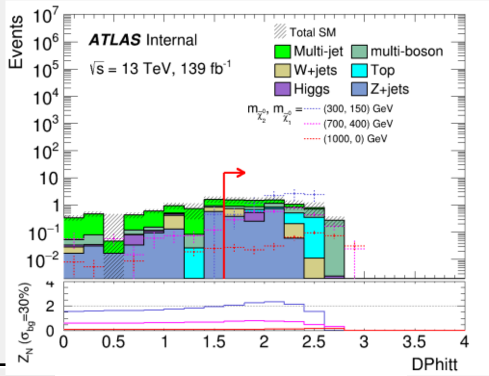




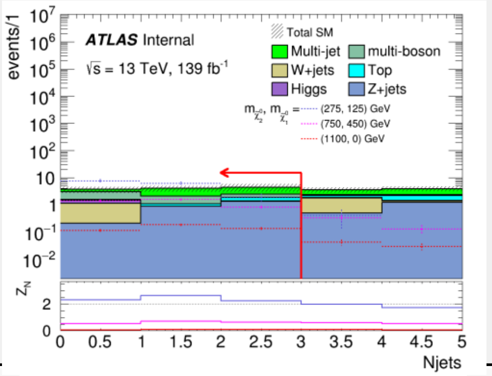
- **SR optimization**: **cut-based** search algorithm
  - The kinematic distributions of ***C1C1*** and ***C1N2*** are different
  - The kinematic distributions of ***tau*** and ***MET*** are different for different SUSY particle mass & mass spliting.
  - *Four SRs:*

SR-C1C1-LM	SR-C1N2OS-LM	SR-C1C1-HM	SR-C1N2OS-HM
== 2 medium taus (OS)	>= 2 medium taus (OS)	== 2 medium taus (OS)	>= 2 medium taus (OS)
>= 1 tight tau		-	
b-jet veto			
Z/H veto ($m(\tau_1, \tau_2)$ > 120 GeV)			
$\lvert\Delta\phi(\tau_1, \tau_2)\rvert > 1.6$	$N_{jets} < 3$	-	
$E_{\mathrm{T}}^{\mathrm{miss}}$ > 60 GeV		$m_{T\,sum}$ > 400 GeV	
m_{T2} >80 GeV	$m_{T2}^{\max}$ > 70 GeV	m_{T2} > 85 GeV	$m_{T2}^{\max}$ > 85 GeV
asymmetry di-tau Trigger		di-tau + $E_{\mathrm{T}}^{\mathrm{miss}}$ Trigger	
$E_{\mathrm{T}}^{\mathrm{miss}}$ < 150 GeV		$E_{\mathrm{T}}^{\mathrm{miss}}$ > 150 GeV	
τ_1 and τ_2 p_{T} requirements described in Table 11 in Section 4.3			

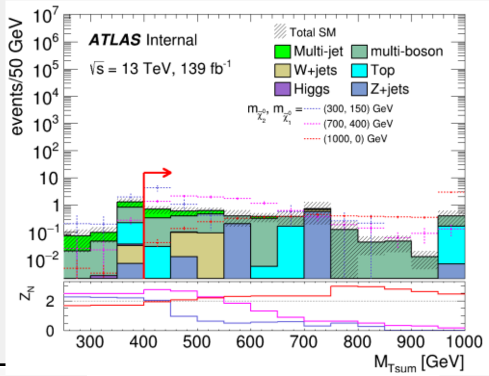
  - LM and HM are split by MET.



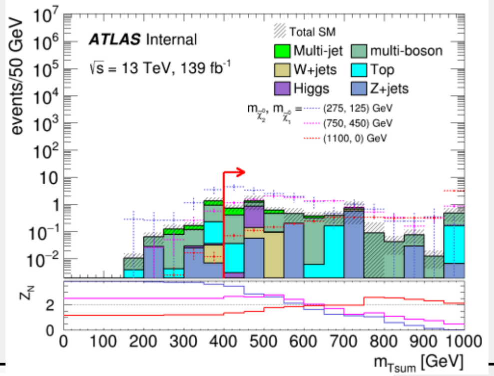
SR-C1C1-LM



SR-C1N2-OS-LM



SR-C1C1-LM

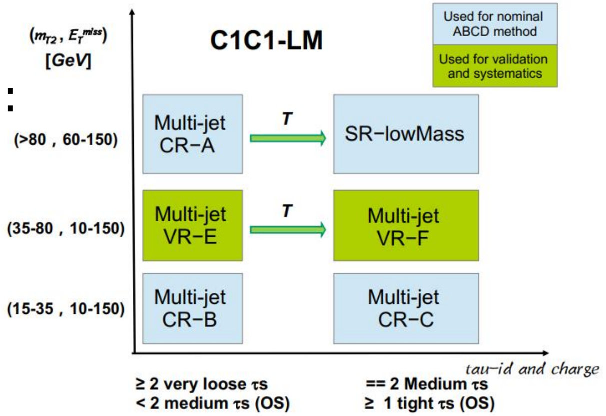


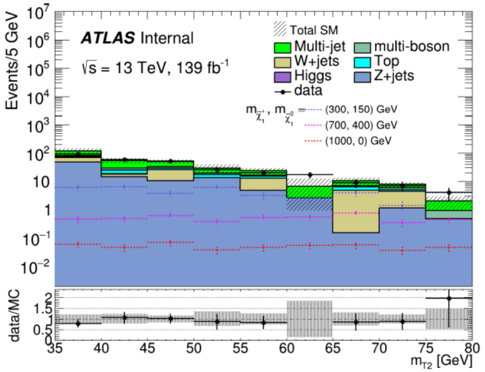
SR-C1N2-OS-LM

Gaugino pair – OS channel – BKG estimation

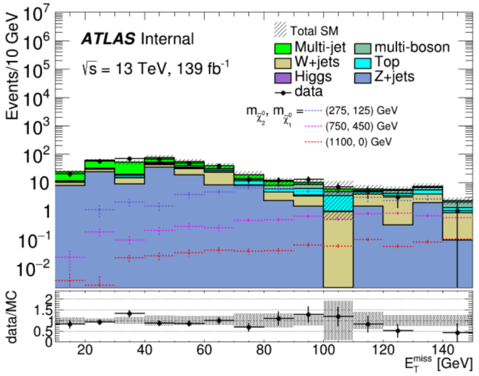
- ***Multijet*** estimation: **ABCD method** for each SR

Example:





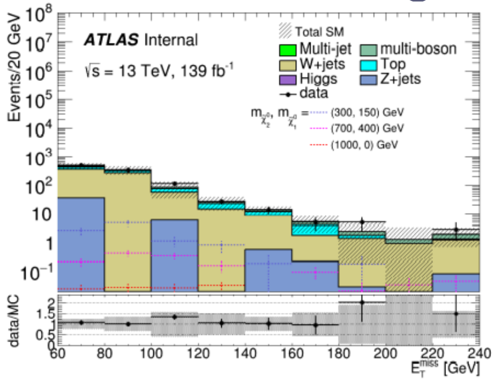
VR-C1C1-LM



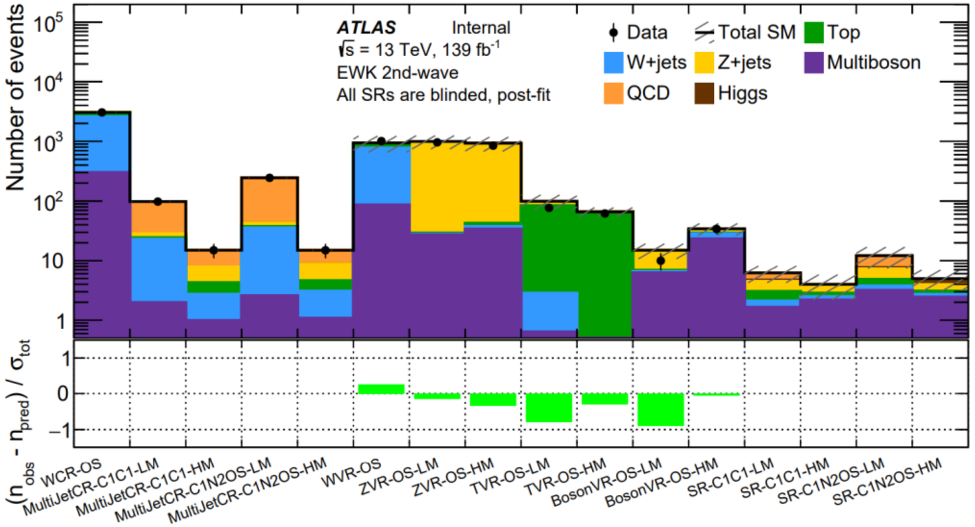
VR-C1N2OS-LM

- ***W+jets***: dedicate *Control Region & Validation Region*

WCR:

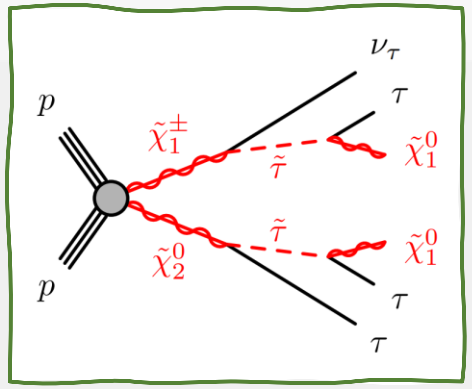


- ***Top***, ***Z***, ***Multiboson***: validation regions



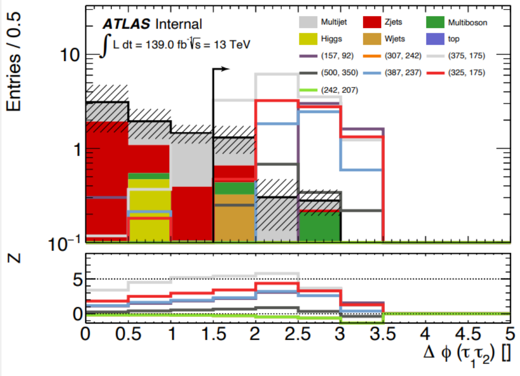
Gaugino pair – SS channel

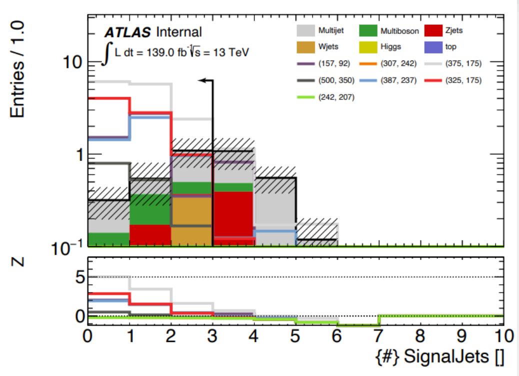
- *Gaugino pair Direct Production!* **Only C1N2** has SS channel



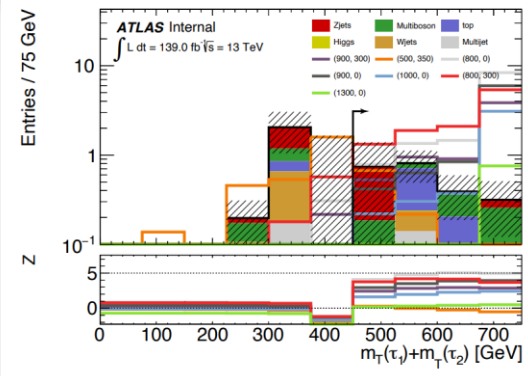
- **SR optimization**: **cut-based** search algorithm
  - Also split by MET for different SUSY particle mass splitting

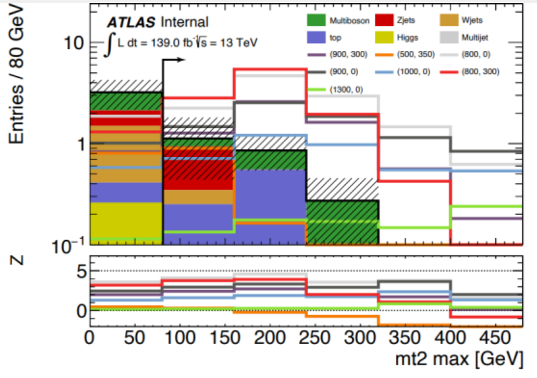
SR-C1N2SS-LM	SR-C1N2SS-HM
>= 2 medium taus (SS)	
b-jet veto	
$\Delta\Phi(\tau_1, \tau_2) > 1.5$	-
N_{jets} <3	-
$m_{T\,sum} > 200$ GeV	$m_{T\,sum} > 450$ GeV
$m_{T2}^{\max} > 80$ GeV	
asymmetric di-tau trigger	di-tau+$E_{\mathrm{T}}^{\mathrm{miss}}$ trigger
$E_{\mathrm{T}}^{\mathrm{miss}} < 150$ GeV	$E_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV
τ_1 and τ_2 p_{T} requirements described in Table 11 in Section 4.3	





SR-C1N2SS-LM





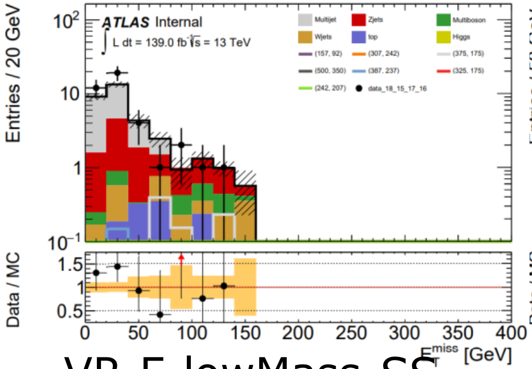
SR-C1N2SS-HM

Gaugino pair – SS channel – BKG estimation

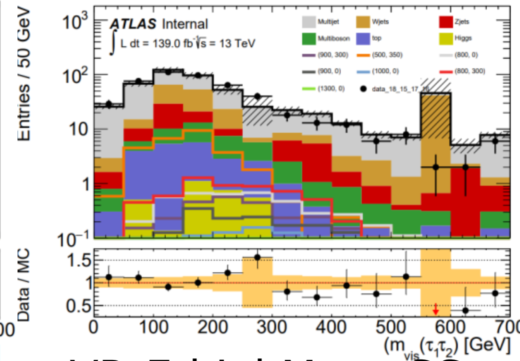
■ *Multijet* estimation: **ABCD method**

CR – A (lowMass-SS)	SR – C1N2SS – LM
≥ 2 very loose or loose τs	≥ 2 medium τs (SS)
< 2 medium τs	–
$m_{T\,sum} \geq 200$ GeV	$m_{T\,sum} \geq 200$ GeV
$\Delta\Phi(\tau_1,\tau_2) \geq 1.5$	$\Delta\Phi(\tau_1,\tau_2) \geq 1.5$
VR – E (lowMass-SS)	**VR – F (lowMass-SS)**
≥ 2 very loose or loose τs	≥ 2 medium τs (SS)
< 2 medium τs	–
$m_{T\,sum} \in [100, 200]$ GeV	$m_{T\,sum} \in [100, 200]$ GeV
$\Delta\Phi(\tau_1,\tau_2) \leq 1.5$	$\Delta\Phi(\tau_1,\tau_2) \leq 1.5$
CR – B (lowMass-SS)	**CR – C (lowMass-SS)**
≥ 2 very loose or loose τs	≥ 2 medium τs (SS)
< 2 medium τs	–
$m_{T\,sum} < 100$ GeV	$m_{T\,sum} < 100$ GeV
$\Delta\Phi(\tau_1,\tau_2) \leq 1.5$	$\Delta\Phi(\tau_1,\tau_2) \leq 1.5$

CR – A (highMass-SS)	SR – C1N2SS – HM
≥ 2 very loose or loose τs	≥ 2 medium τs (SS)
< 2 medium τs	–
$m_{T\,sum} \geq 450$ GeV	$m_{T\,sum} \geq 450$ GeV
$E_T^{miss} \geq 50$ GeV	$E_T^{miss} \geq 150$ GeV
VR – E (highMass-SS)	**VR – F (highMass-SS)**
≥ 2 very loose or loose τs	≥ 2 medium τs (SS)
< 2 medium τs	–
$m_{T\,sum} \in [200, 450]$ GeV	$m_{T\,sum} \in [200, 450]$ GeV
$E_T^{miss} \geq 50$ GeV	$E_T^{miss} \geq 50$ GeV
CR – B (highMass-SS)	**CR – C (highMass-SS)**
≥ 2 very loose or loose τs	≥ 2 medium τs (SS)
< 2 medium τs	–
$m_{T\,sum} \in [100, 200]$ GeV	$m_{T\,sum} \in [100, 200]$ GeV
$E_T^{miss} \geq 50$ GeV	$E_T^{miss} \geq 50$ GeV

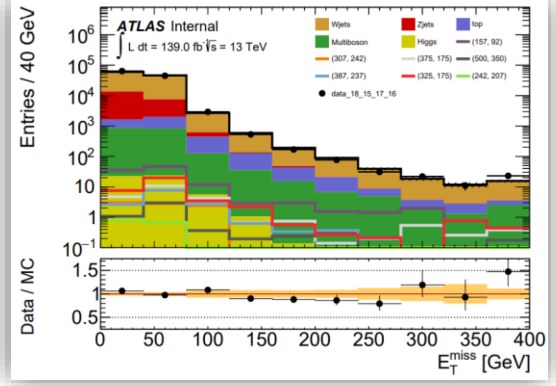


VR-F-lowMass-SS

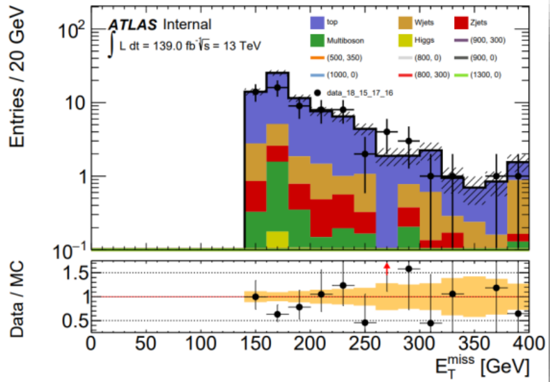


VR-F-highMass-SS

■ ***W+jets*** and ***Top*** : dedicate *Control Region & Validation Region*



WCR

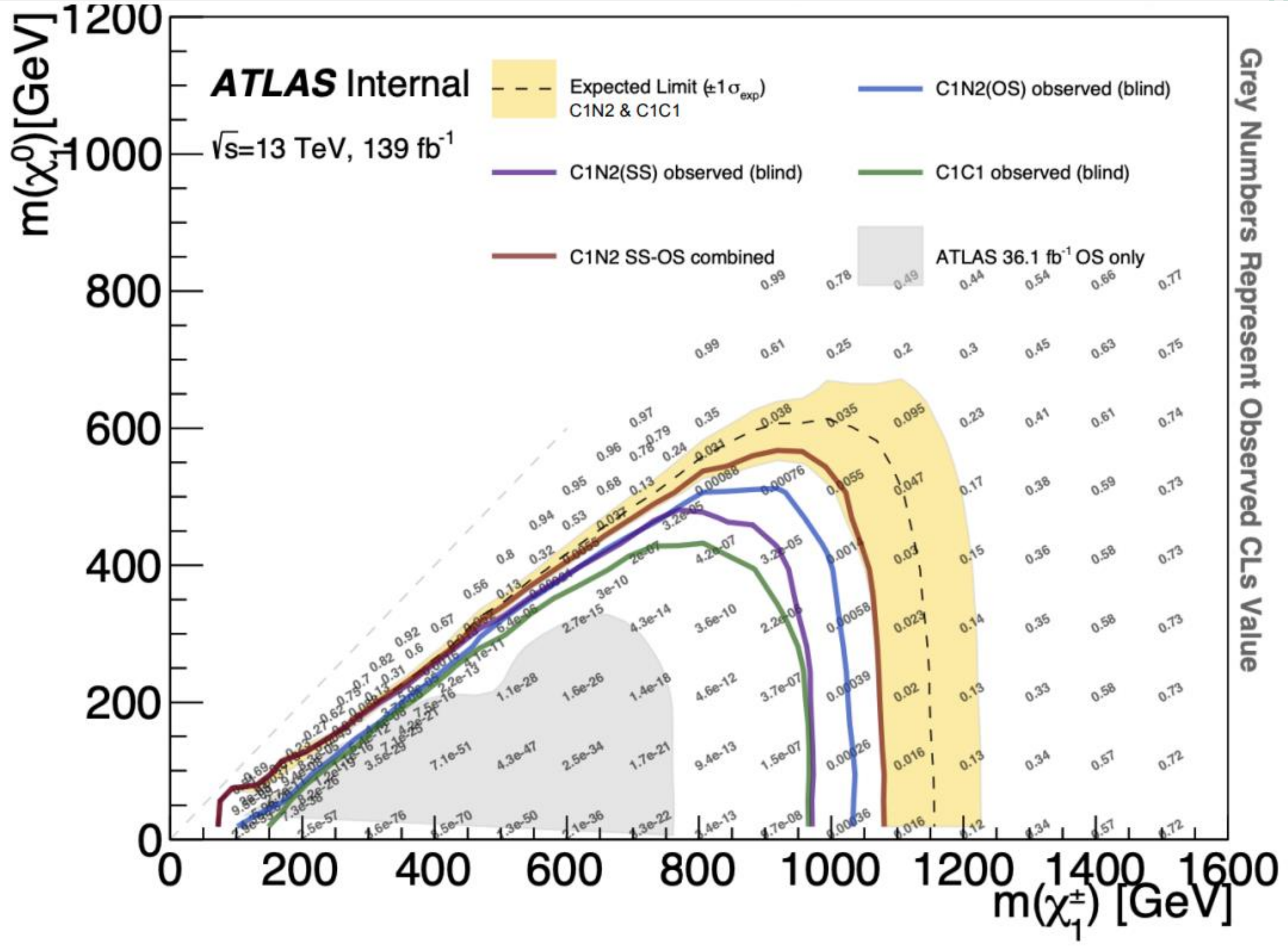


TCR

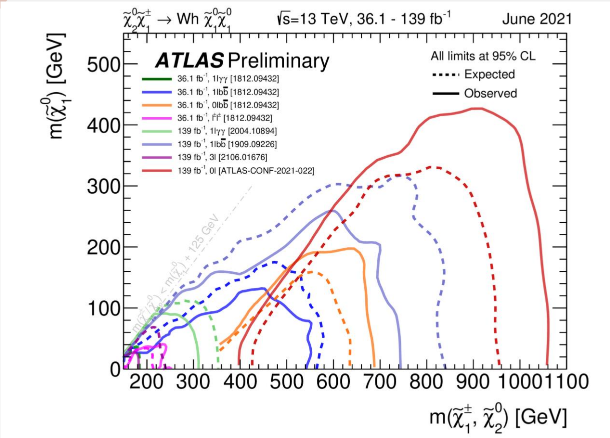
■ ***MultiBoson***: validation region

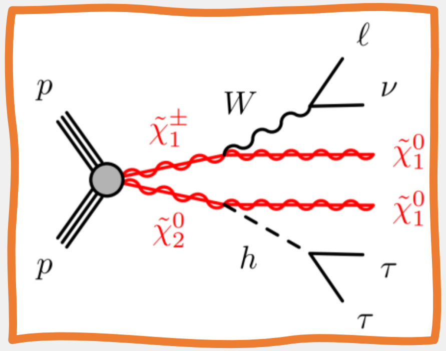
Gaugino pair – Results

- ***Still Blinded!***
  - **Grey: 36 ifb results**
  - **Green:** C1C1
  - **Purple:** C1N2-SS
  - **Blue:** C1N2-OS
  - **C1N2 SS-OS *statistical* combination. SS-channel** has a contribution of 50 GeV improvement.
  - **C1C1-C1N2 yields combination**: Merge C1C1 & C1N2 samples, use C1N2 SR definition. **C1C1-channel** contributes a lot.



C1N2 via Wh with 1-lep 2-tau final state

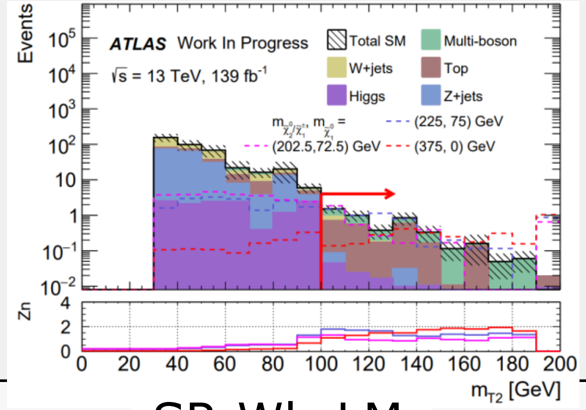




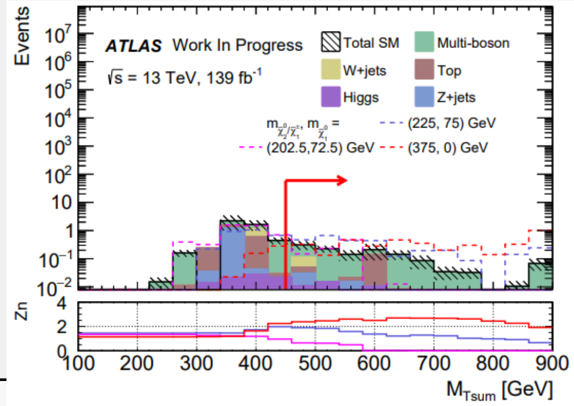
- New channel for C1N2 via Wh: make contribution in EWK-combination.
- **SR definition**: **cut-based** search algorithm
  - ***Two SRs*** are defined to cover low (high) gaugino.

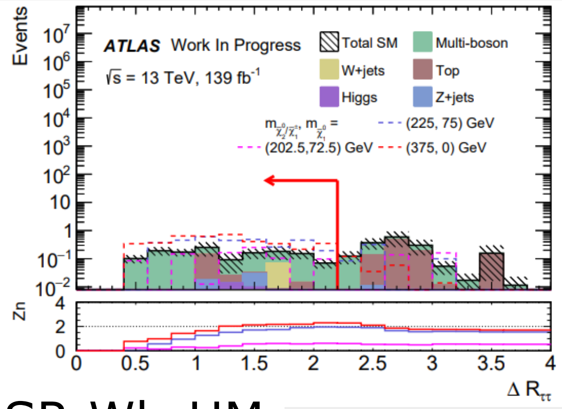
<table>
<tr><th>SR-Wh-LM</th><th>SR-Wh-HM</th></tr>
<tr><td colspan="2">==1 signal light lepton</td></tr>
<tr><td colspan="2">>= 2 medium taus (OS)</td></tr>
<tr><td colspan="2">b-jet veto</td></tr>
<tr><td colspan="2">$|\Delta\phi(\tau_1,\tau_2)| < 3$</td></tr>
<tr><td></td><td>$\Delta R(\tau_1,\tau_2) < 2.2$</td></tr>
<tr><td>$90GeV < m(\tau_1,\tau_2) < 130GeV$</td><td>$80GeV < m(\tau_1,\tau_2) < 160GeV$</td></tr>
<tr><td>$m_{T2}^{max} > 100GeV$</td><td>$m_{T2}^{max} > 80GeV$</td></tr>
<tr><td></td><td>$M_{Tlep} > 80GeV$</td></tr>
<tr><td></td><td>$M_{Tsum} > 450GeV$</td></tr>
</table>

  - *They are not orthogonal!*



SR-Wh-LM

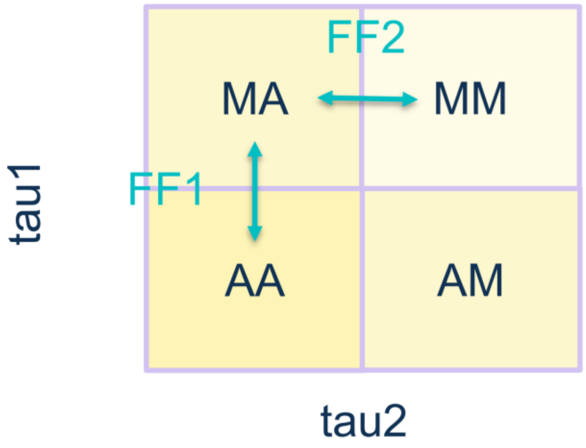




SR-Wh-HM

Wh – BKG estimation

- Fake estimation: **FakeFactor method**
  - W+jets: 2 jet fake Tau + W decay lepton

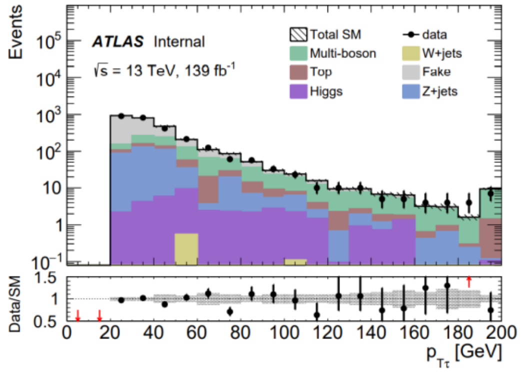


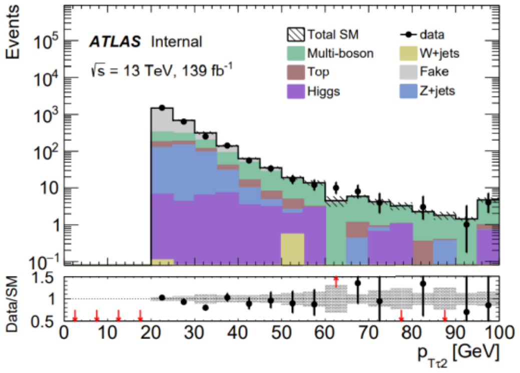
$$FF^{CR}_{\tau 1} = \frac{N^{CR}_{AA,fakebkg}}{N^{CR}_{MA,fakebkg}}$$

$$FF^{CR}_{\tau 2} = \frac{N^{CR}_{MA,fakebkg}}{N^{CR}_{MM,fakebkg}}$$

Split by Leading tau & Next-Leading tau ID (Medium)

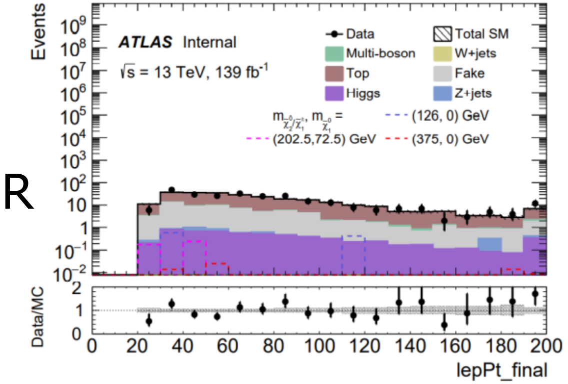
  - Also need a SR-like region to apply FFs.



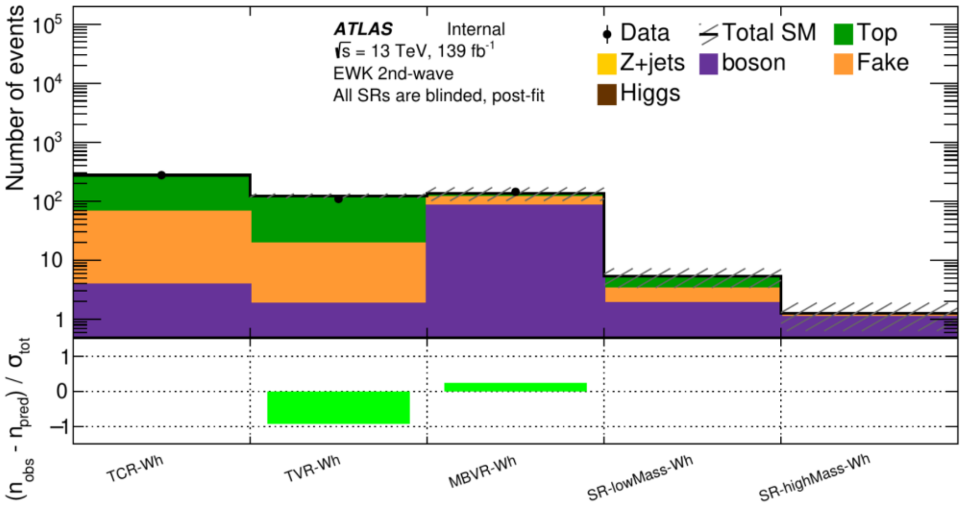


- ***Top***: dedicate *Control Region* & *Validation Region*

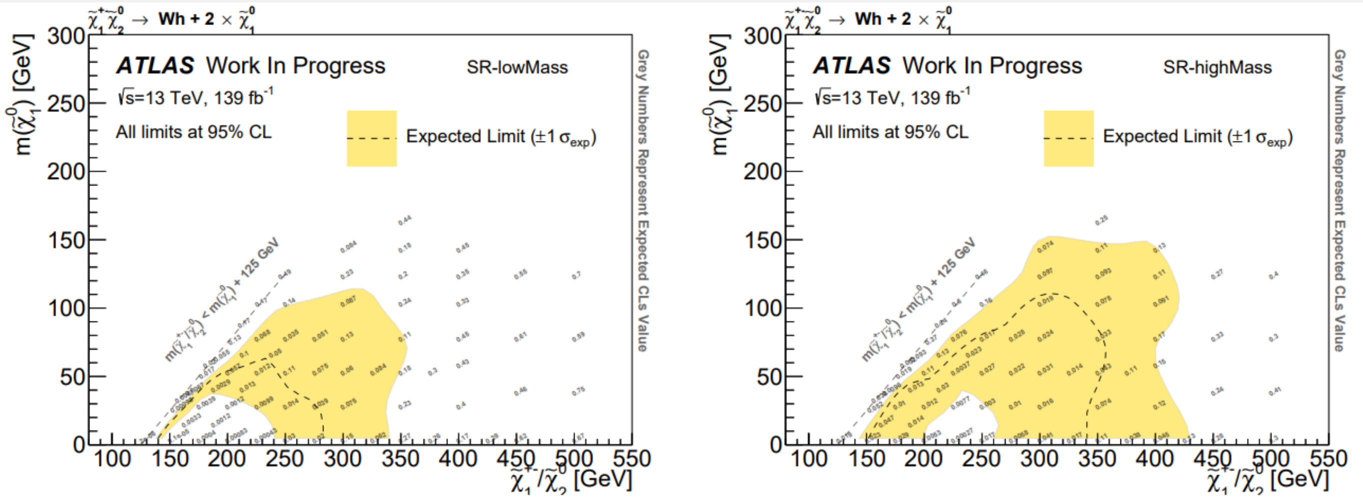
TCR



- ***Multiboson***: *Validation Region*



Wh – Results

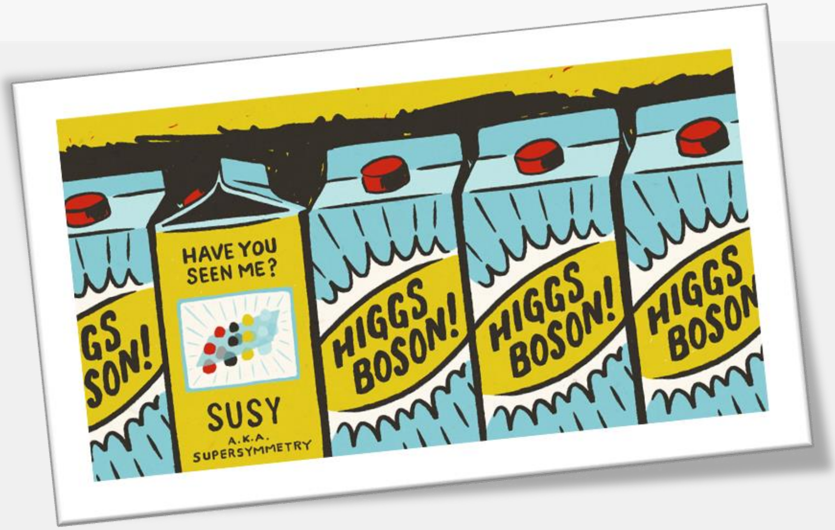


(a) SR-lowMass (b) SR-highMass

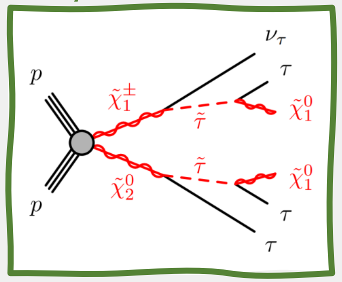
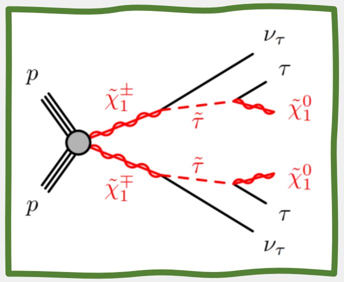
(c) Combined SRs

- ***Still Blinded!***
- We can see the two SRs are ***targeting @ different Region*** clearly.
- LM & HM are combined by choosing best.

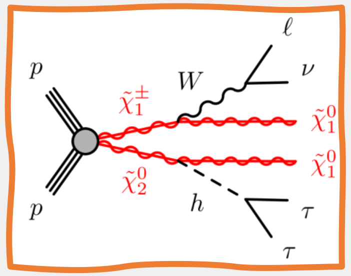
Summary



- C1C1, C1N2 via stau with $\geq 2\tau + E_T^{miss}$

- C1N2 via Wh with $\geq 2\tau + 1lep + E_T^{miss}$



- We have search for the **Direct Gaugino pair production** via stau decay or Wh decay for **at least two tau final state**…
  - Preliminary results shows: Exclusion limit has improved a lot comparing to 36 ifb.
  - New final state will contribute in EWK combination (*Combined search for electroweakinos*)
- Outlook:
  - Unblinding
  - Paper publication in next year

Backups

CMS Results

- Table 1: Brief description of the categories used to classify events in the search.

Category	Requirements
2lSS	Two light leptons with the same charge
3lA	Three light leptons with at least an OSSF pair
3lB	Three light leptons with no OSSF pair
3lC	A pair of light leptons forming an OSSF pair and a τ_h
3lD	A pair of light leptons of different flavor and opposite charge and a τ_h
3lE	A pair of light leptons of same charge and a τ_h
3lF	A light lepton and two τ_h
4lG	Four light leptons with two OSSF pairs
4lH	Four light leptons with less than two OSSF pairs
4lI	Three light leptons and a hadronically decaying tau
4lJ	Two light leptons and two hadronically decaying taus, two OSSF pairs
4lK	Two light leptons and two hadronically decaying taus; one or zero OSSF pairs

- They have the splitting x= 0.05 and 0.95.

Definitions

Object

Cut	Selection
Signal Tau	
Acceptance	p_T > 20.0 GeV , $\|\eta\|$ < 2.5 and crack veto
AbsCharge	1
NTracks	1 or 3
EleBDTWP	ELEIDBDTMEDIUM
JetIDWP	JETIDRNNMEDIUM
Quality	
IP	$\Delta z_0 sin(\theta) < 0.5mm$

Cut	Selection
Baseline Electron	
Acceptance	p_T > 4.5 GeV , $\|\eta\|$ < 2.47
Quality	LooseAndBLayerLLH
IP	$\Delta z_0 sin(\theta) < 0.5mm$
Signal Electron	
Acceptance	p_T > 25 GeV , $\|\eta\|$ < 2.47
Quality	TightLLH
Isolation	FCLoose (< 200 GeV), FCHighPtCaloOnly (>200 GeV)
IP	$d_0/\sigma(d_0) < 5$

Cut	Selection
Baseline Muon	
Acceptance	p_T > 3.0 GeV , $\|\eta\|$ < 2.7
Quality	Medium
IP	$\Delta z_0 sin(\theta) < 0.5mm$
Signal Muon	
Acceptance	p_T > 25 GeV , $\|\eta\|$ < 2.7
Quality	Medium
Isolation	Loose_VarRad
IP	$d_0/\sigma(d_0) < 3$

Cut	Selection
Signal Jet	
Acceptance	p_T > 20.0 GeV , $\|\eta\|$ < 2.8
Type	PFlow
Uncertainty	Full JER
JetVertexTagger	Default (Tight) for p_T < 60.0 GeV , $\|\eta\|$ < 2.5
b tag	
Acceptance	p_T > 20.0 GeV , $\|\eta\|$ < 2.8
Algorithm	DL1r FixedCutBEff@77%
TimeStamp	201903

Trigger

Trigger	Trigger leg	Year	HLT	Offline
di-tau + E_T^{miss} trigger	leading tau p_T [GeV]	2015-2017	35	50
		2018	60	75
	2nd leading tau p_T [GeV]	2015-2018	25	40
	E_T^{miss} [GeV]	2015-2018	50	150
asymmetric di-tau trigger	leading tau p_T [GeV]	2015-2018	80	95
	2nd leading tau p_T [GeV]	2015-2017	50	60
		2018	60	75

Trigger	Trigger name	Year	HLT p_T cut [GeV]	Offline p_T 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

C1N2OS

- C1N2OS

SM process	SR-C1C1-LM	SR-C1N2OS-LM	SR-C1C1-HM	SR-C1N2OS-HM
Top	0.95 ± 0.38	1.08 ± 0.40	0.36 ± 0.22	0.36 ± 0.22
W+jets	0.43 ± 0.50	0.62 ± 1.18	0.30 ± 0.17	0.30 ± 0.17
Z+jets	1.42 ± 0.51	2.46 ± 1.43	0.78 ± 0.56	0.86 ± 0.56
Multi-boson	1.65 ± 0.36	3.18 ± 0.47	2.19 ± 0.42	2.43 ± 0.44
Higgs	0.27 ± 0.26	0.39 ± 0.27	0.011 ± 0.003	0.73 ± 0.72
Multi-jet	1.86 ± 0.19	4.51 ± 0.29	0.77 ± 0.20	0.72 ± 0.19
SM total	6.58 ± 0.95	12.24 ± 2.00	4.41 ± 0.78	5.40 ± 1.07
Ref. point (300, 150)	10.81 ± 1.56	12.53 ± 1.67	6.74 ± 1.33	10.68 ± 1.74
Ref. point (750, 450)	2.65 ± 0.21	4.40 ± 0.31	6.77 ± 0.35	12.16 ± 0.53

SR-C1C1-LM	SR-C1N2OS-LM	SR-C1C1-HM	SR-C1N2OS-HM
== 2 medium taus (OS)	>= 2 medium taus (OS)	== 2 medium taus (OS)	>= 2 medium taus (OS)
>= 1 tight tau		-	
b-jet veto			
Z/H veto ($m(\tau_1,\tau_2) > 120$ GeV)			
$\lvert\Delta\phi(\tau_1,\tau_2)\rvert > 1.6$	$N_{jets} < 3$	-	
$E_{\mathrm{T}}^{\mathrm{miss}} > 60$ GeV		$m_{T\,sum} > 400$ GeV	
$m_{\mathrm{T2}} > 80$ GeV	$m_{T2}^{\mathrm{max}} > 70$ GeV	$m_{\mathrm{T2}} > 85$ GeV	$m_{T2}^{\mathrm{max}} > 85$ GeV
asymmetry di-tau Trigger		di-tau + $E_{\mathrm{T}}^{\mathrm{miss}}$ Trigger	
$E_{\mathrm{T}}^{\mathrm{miss}} < 150$ GeV		$E_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV	
τ_1 and τ_2 p_{T} requirements described in Table 12 in Section 4.3			

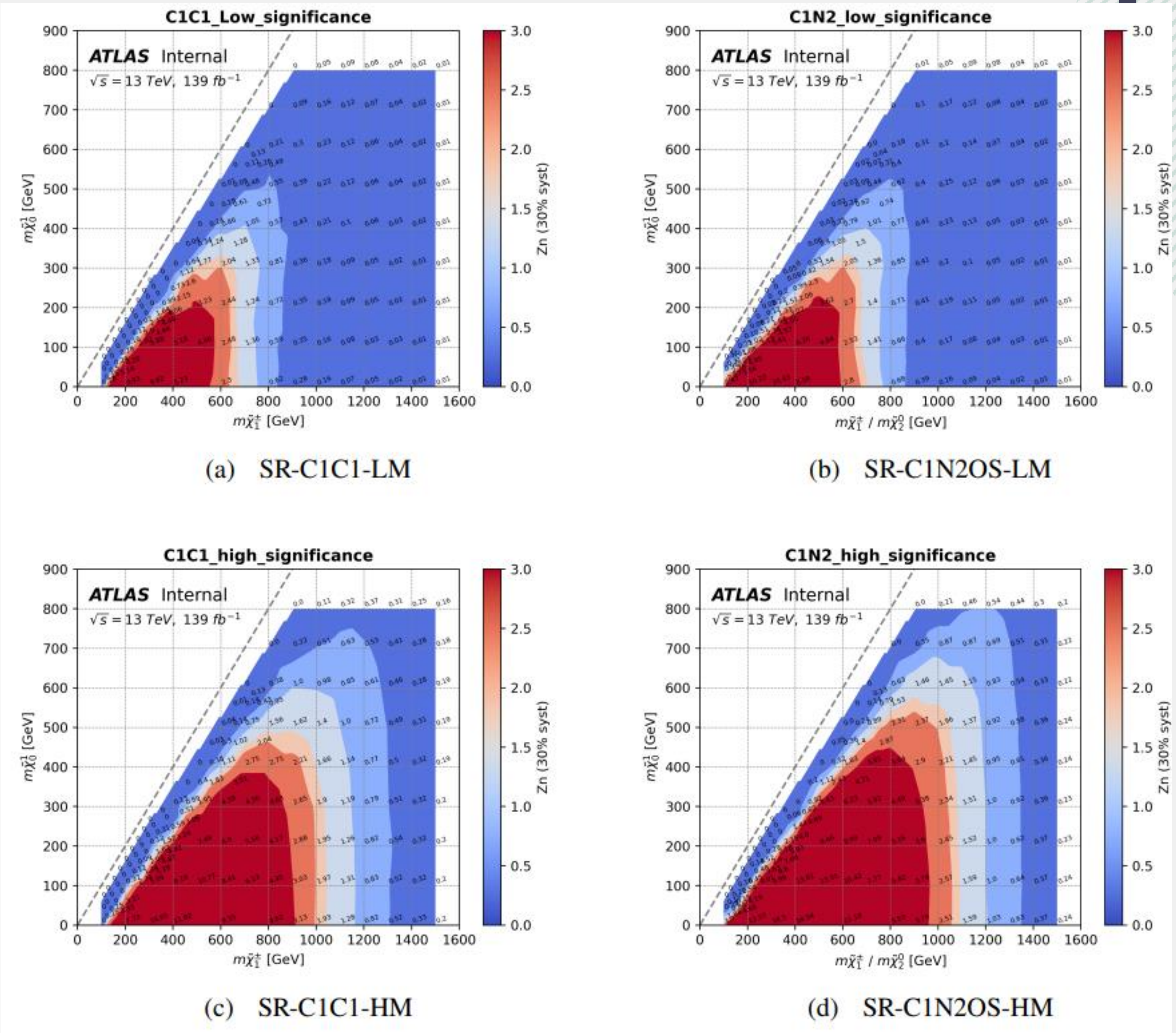
variables	cut values of low $E_{\mathrm{T}}^{\mathrm{miss}}$ SR	cut values of high $E_{\mathrm{T}}^{\mathrm{miss}}$ SR
tau quality	>= 2 medium taus, 1 medium 1 tight taus, 2 tight taus	
$E_{\mathrm{T}}^{\mathrm{miss}} \geq$	30, 50, 60, 75, 80, 90, 100 GeV	150, 160, 170, 180, 200 GeV
$m_{\mathrm{T2}} \geq$	40, 50, 60, 70, 80, 90, 100 GeV	
$m_{T\,sum} \geq$	200, 250, 300, 350, 400, 450, 500,550 GeV	
$\Delta R(\tau_1,\tau_2) \leq$	2.4, 2.6, 2.8, 3.0, 3.2, 6	
$\lvert\Delta\phi(\tau_1,\tau_2)\rvert \geq$	0.4, 0.5, 0.6, 0.8, 1, 1.2,1.4	
$m(\tau_1,\tau_2) \geq$	120, 130, 140, 150 GeV	
$p_{\mathrm{T}}(\tau_1) \geq$	95, 100, 110, 120, 130, 140, 150 GeV	50, 55, 60, 65, 70, 80, 90, 100, 120 GeV
$p_{\mathrm{T}}(\tau_2) \geq$	60, 70, 80, 90, 100 GeV	40, 45, 50, 55, 60, 70, 80, 90, 100 GeV

C1N2OS

- MultiJet

CR – A (C1C1-LM)	SR – C1C1 – LM	CR – A (C1N2OS-LM)	SR – C1N2OS – LM
≥ 2 very loose τs $60 < E_{\mathrm{T}}^{\mathrm{miss}} < 150\ GeV$ $m_{\mathrm{T2}} > 80$ GeV	$== 2$ Medium ≥ 1 tight τs (OS) $60 < E_{\mathrm{T}}^{\mathrm{miss}} < 150\ GeV$ $m_{\mathrm{T2}} > 80$ GeV	≥ 2 very loose τs $60 < E_{\mathrm{T}}^{\mathrm{miss}} < 150\ GeV$ $m_{T\,sum} > 70$ GeV	≥ 2 Medium $>= 1$ tight τs (OS) $60 < E_{\mathrm{T}}^{\mathrm{miss}} < 150\ GeV$ $m_{T\,2max} > 70$ GeV
VR – E (C1C1-LM)	**VR – F** (C1C1-LM)	**VR – E** (C1N2OS-LM)	**VR – F** (C1N2OS-LM)
≥ 2 very loose τs $10 < E_{\mathrm{T}}^{\mathrm{miss}} < 150\ GeV$ $35 < m_{\mathrm{T2}} < 80$ GeV	$== 2$ Medium ≥ 1 tight τs (OS) $10 < E_{\mathrm{T}}^{\mathrm{miss}} < 150\ GeV$ $35 < m_{\mathrm{T2}} < 80$ GeV	≥ 2 very loose τs $10 < E_{\mathrm{T}}^{\mathrm{miss}} < 150\ GeV$ $35 < m_{T\,2max} < 70$ GeV	≥ 2 Medium ≥ 1 tight τs (OS) $10 < E_{\mathrm{T}}^{\mathrm{miss}} < 150\ GeV$ $35 < m_{T\,2max} < 70$ GeV
CR – B (C1C1-LM)	**CR – C** (C1C1-LM)	**CR – B** (C1N2OS-LM)	**CR – C** (C1N2OS-LM)
≥ 2 very loose τs $10 < E_{\mathrm{T}}^{\mathrm{miss}} < 150\ GeV$ $15 < m_{\mathrm{T2}} < 35$ GeV	$== 2$ Medium ≥ 1 tight τs (OS) $10 < E_{\mathrm{T}}^{\mathrm{miss}} < 150\ GeV$ $15 < m_{\mathrm{T2}} < 35$ GeV	≥ 2 very loose τs $10 < E_{\mathrm{T}}^{\mathrm{miss}} < 150\ GeV$ $15 < m_{T\,2max} < 35$ GeV	≥ 2 Medium ≥ 1 tight τs (OS) $10 < E_{\mathrm{T}}^{\mathrm{miss}} < 150\ GeV$ $15 < m_{T\,2max} < 35$ GeV

CR – A (C1C1-HM)	SR – C1C1 – HM	CR – A (C1N2OS-HM)	SR – C1N2OS – HM
≥ 2 very loose τs < 1 medium τs (OS) $E_{\mathrm{T}}^{\mathrm{miss}} > 150\ GeV$ $m_{T\,sum} > 400$ GeV $m_{\mathrm{T2}} > 85$ GeV	$== 2$ medium τs (OS) - $E_{\mathrm{T}}^{\mathrm{miss}} > 150\ GeV$ $m_{T\,sum} > 400$ GeV $m_{\mathrm{T2}} > 85$ GeV	≥ 2 very loose τs < 1 medium τs (OS) $E_{\mathrm{T}}^{\mathrm{miss}} > 150\ GeV$ $m_{T\,sum} > 400$ GeV $m_{T\,2max} > 85$ GeV	≥ 2 medium τs (OS) - $E_{\mathrm{T}}^{\mathrm{miss}} > 150\ GeV$ $m_{T\,sum} > 400$ GeV $m_{T\,2max} > 85$ GeV
VR – E (C1C1-HM)	**VR – F** (C1C1-HM)	**VR – E** (C1N2OS-HM)	**VR – F** (C1N2OS-HM)
≥ 2 very loose τs < 1 medium τs (OS) $E_{\mathrm{T}}^{\mathrm{miss}} > 50$ GeV $200 < m_{T\,sum} < 400$ GeV $60 < m_{\mathrm{T2}} < 85$ GeV	$== 2$ medium τs (OS) - $E_{\mathrm{T}}^{\mathrm{miss}} > 50$ GeV $200 < m_{T\,sum} < 400$ GeV $60 < m_{\mathrm{T2}} < 85$ GeV	≥ 2 very loose τs < 1 medium τs (OS) $E_{\mathrm{T}}^{\mathrm{miss}} > 50$ GeV $200 < m_{T\,sum} < 400$ GeV $60 < m_{T\,2max} < 85$ GeV	≥ 2 medium τs (OS) - $E_{\mathrm{T}}^{\mathrm{miss}} > 50$ GeV $200 < m_{T\,sum} < 400$ GeV $60 < m_{T\,2max} < 85$ GeV
CR – B (C1C1-HM)	**CR – C** (C1C1-HM)	**CR – B** (C1N2OS-HM)	**CR – C** (C1N2OS-HM)
≥ 2 very loose τs < 1 medium τs (OS) $E_{\mathrm{T}}^{\mathrm{miss}} > 50$ GeV $100 < m_{T\,sum} < 300$ GeV $35 < m_{\mathrm{T2}} < 60$ GeV	$== 2$ medium τs (OS) - $E_{\mathrm{T}}^{\mathrm{miss}} > 50$ GeV $100 < m_{T\,sum} < 300$ GeV $35 < m_{\mathrm{T2}} < 60$ GeV	≥ 2 very loose τs < 1 medium τs (OS) $E_{\mathrm{T}}^{\mathrm{miss}} > 50$ GeV $150 < m_{T\,sum} < 300$ GeV $35 < m_{T\,2max} < 60$ GeV	≥ 2 medium τs (OS) - $E_{\mathrm{T}}^{\mathrm{miss}} > 50$ GeV $150 < m_{T\,sum} < 300$ GeV $35 < m_{T\,2max} < 60$ GeV



(a) SR-C1C1-LM
(b) SR-C1N2OS-LM
(c) SR-C1C1-HM
(d) SR-C1N2OS-HM

C1N2OS

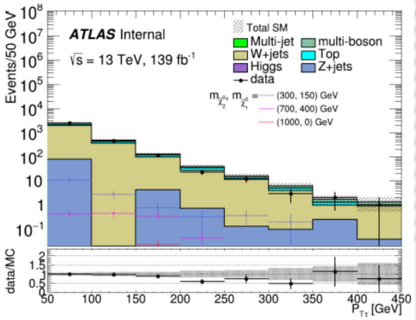
- WCR/VR

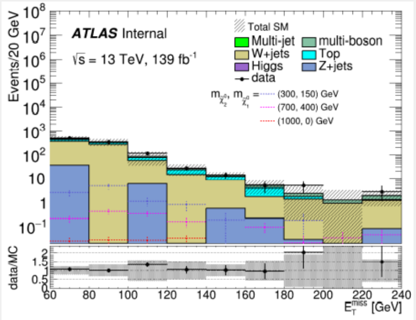
Sample	W-CR	W-VR
Data	**3055**	**1010**
SM total	**3108.90 ± 237.93**	**950.04 ± 145.79**
W+jets	**2322.58 ± 235.77**	**692.62 ± 144.62**
Z+jets	80.17 ± 30.06	24.11 ± 17.55
Multi-boson	300.66 ± 7.26	85.81 ± 2.99
Top	400.27 ± 7.97	145.82 ± 2.99
Higgs	5.22 ± 1.53	1.68 ± 0.84
Multi-jets	0 ± 108.93	0.00 ± 81.80
Ref. point (300, 150)	14.70 ± 2.39	8.79 ± 1.91

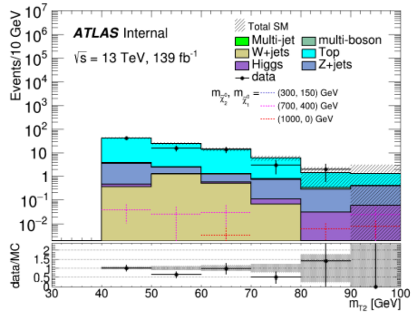
W-CR	W-VR
pass TrigHLT_mu20_iloose_L1MU15 (2015) and HLT_mu26_ivarmedium (2016-2018)	
== 1 medium tau and 1 isolated muon (OS)	
b-veto	
Top-tagged events veto	
$p_{T\tau} > 50$ GeV, $p_{T\mu} > 40$ GeV	
$m_T(\mu) < 140$ GeV	
$E_T^{miss} > 60$ GeV	
$40 < m_{T2}(\tau,\mu) < 70$ GeV	$m_{T2}(\tau,\mu) > 70$ GeV

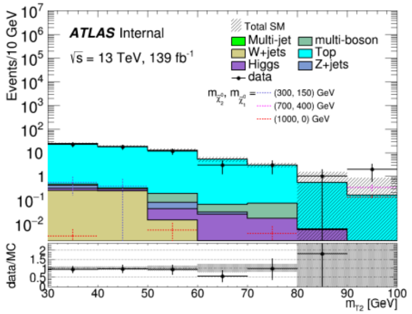
- Other...

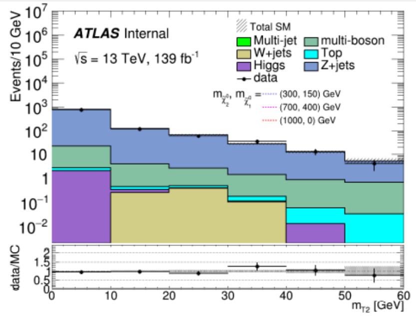
Top-VR1	Top-VR2	Z-VR1	Z-VR2	MB-VR1	MB-VR2
$\tau-\tau$ channel					
$\geq$ 2 medium taus (OS), $\geq$ 1 tight tau					
at least one b-jet		b-jet veto			
$m_{T,\tau_1} + m_{T,\tau_2} > 150$ GeV		–		$m_{T,\tau_1} + m_{T,\tau_2} > 180$ GeV	
$m(\tau_1,\tau_2) > 120$ Gev		$m(\tau_1,\tau_2) < 70$ GeV	$m(\tau_1,\tau_2)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

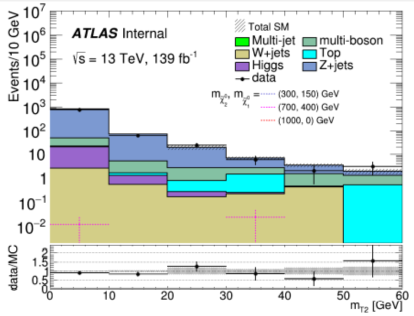


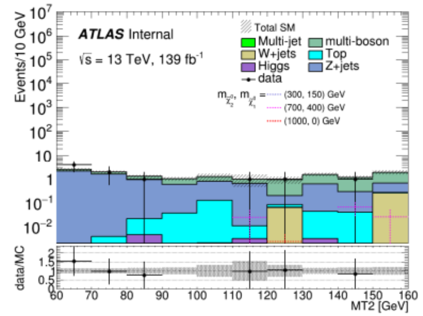


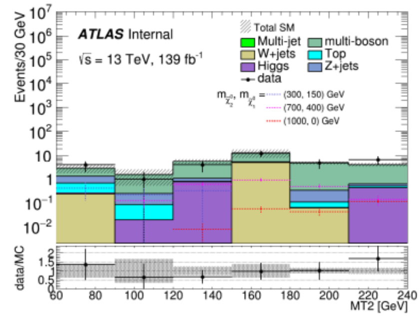








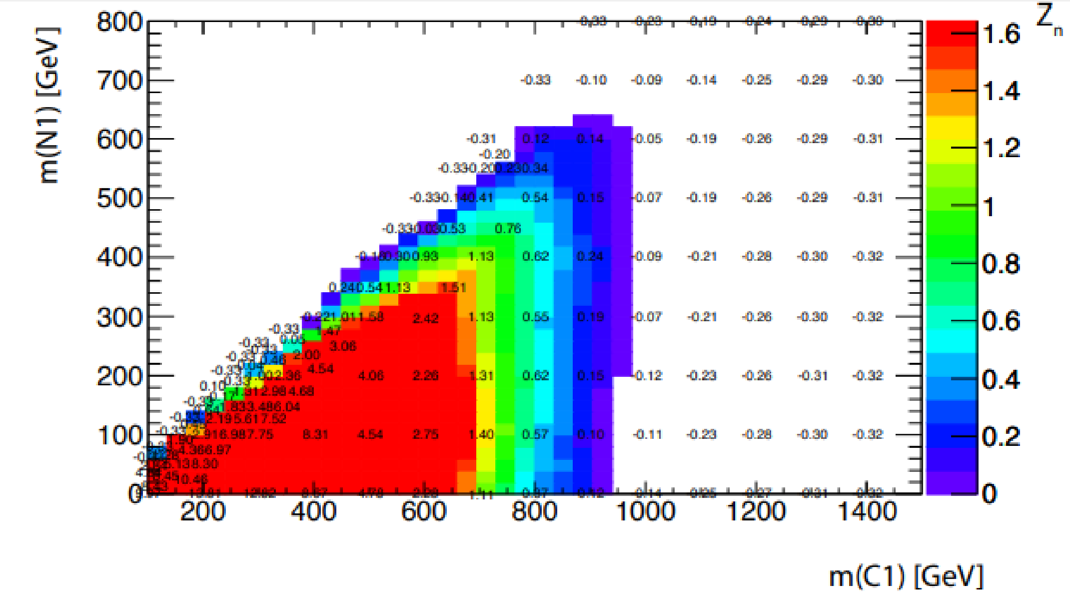


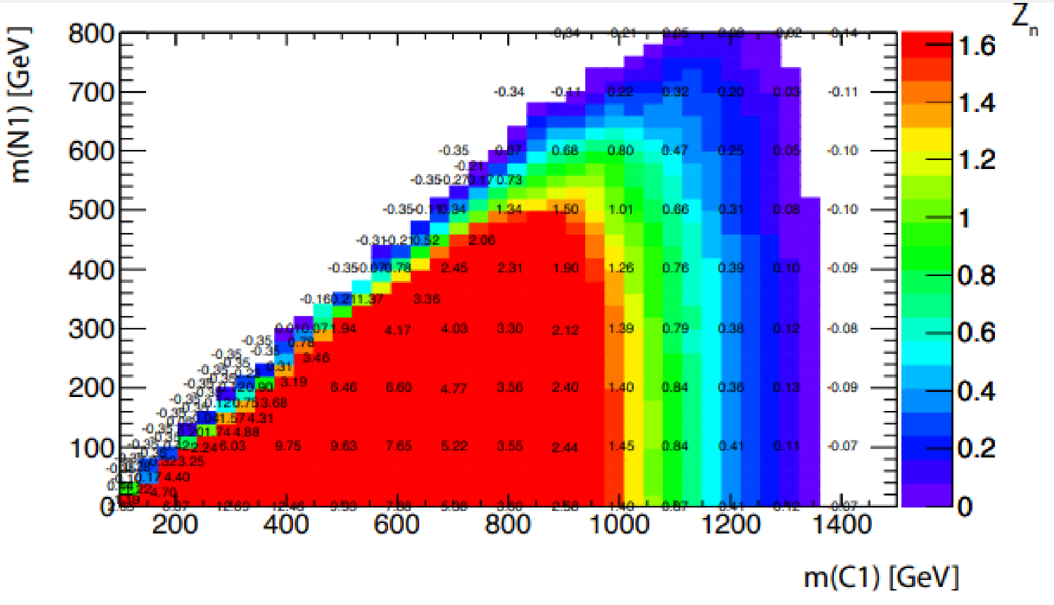


C1N2SS

SM-process	SR-C1N2SS-LM	SR-C1N2SS-HM
Top	0.01 ± 0.01	0.84 ± 0.36
Multi-boson	0.47 ± 0.11	0.81 ± 0.21
Multi-jet	0.94 ± 0.27	−0.086 ± 0.31
W+jets	0.32 ± 0.32	0.10 ± 0.10
Z+jets	0.20 ± 0.20	0.59 ± 0.56
Higgs	0.00 ± 0.00	0.02 ± 0.00
SM total	1.95 ± 0.48	2.35 ± 0.80
Ref. point (325, 175)	7.80 ± 1.27	2.26 ± 0.71
Ref. point (500, 300)	3.78 ± 0.65	5.62 ± 0.88
Ref. point (900, 300)	0.84 ± 0.07	6.23 ± 0.21

SR-C1N2SS-LM	SR-C1N2SS-HM
>= 2 medium taus (SS)	
b-jet veto	
$\Delta\Phi(\tau_1, \tau_2) > 1.5$	-
$N_{jets} < 3$	-
$m_{T\,sum} > 200$ GeV	$m_{T\,sum} > 450$ GeV
$m_{T2}^{max} > 80$ GeV	
asymmetric di-tau trigger	di-tau+E_T^{miss} trigger
$E_T^{miss} < 150$ GeV	$E_T^{miss} > 150$ GeV
τ_1 and τ_2 p_T requirements described in Table 12 in Section 4.3	





W-CR	W-VR
pass TrigHLT_mu20_iloose_L1MU15 (2015) and HLT_mu26_ivarmedium (2016-2018)	
== 1 medium tau and 1 isolated muon (SS)	
baseline electron veto	
b-veto	
$50 < \mathrm{m_T}(\mu) < 150\,\mathrm{GeV}$	
$\mathrm{m_T}(\tau) + \mathrm{m_T}(\mu) > 80\,\mathrm{GeV}$	
$m_{T2}(\mu, \tau) < 60$ GeV	$m_{T2}(\mu, \tau)) \geq 60$ GeV

TopVRLowMass	TopCRHighMass	TopVRHighMass
$n_{\text{at least very loose taus}} \geq 2$		
$n_{\text{at least loose taus}} \geq 1$		
$n_{\text{medium taus}} < 2$		
$n_{BJets} \geq 1$		
asymmetric di-tau trigger	di-tau plus met trigger	
$E_T^{\text{miss}} \geq 100$ GeV	$E_T^{\text{miss}} \geq 150$ GeV	
	$m_{T\,sum} \leq 250$ GeV	$m_{T\,sum} \geq 250$ GeV

C1N2SS

Sample	W-CR	W-VR
W+jets	88688.2 ± 2242.2	6764.4 ± 540.0
Z+jets	17618.9 ± 554.6	857.2 ± 96.4
top	2386.5 ± 18.7	215.7 ± 5.7
Muliboson	1844.5 ± 16.0	148.8 ± 4.1
Higgs	53.1 ± 5.4	5.8 ± 1.8
Multijet	0.00 ± 0.00	0.00 ± 0.00
SM total	110591.2 ± 2309.9	7992.0 ± 548.6
Data	**112976**	**7135**

Sample	**TopVRLowMass**	**TopCRHighMass**	**TopVRHighMass**
W+jets	19.16 ± 13.77	9.75 ± 1.49	4.53 ± 0.95
Z+ jets	4.39 ± 0.99	3.34 ± 0.43	1.78 ± 0.90
top	47.08 ± 2.70	63.08 ± 3.15	58.38 ± 2.98
Multiboson	0.92 ± 0.19	2.66 ± 0.91	0.69 ± 0.13
Higgs	0.63 ± 0.06	0.61 ± 0.03	0.50 ± 0.03
Multijet	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
SM total	72.17 ± 14.07	79.44 ± 3.62	65.88 ± 3.26
Data	**52**	**68**	**40**

- MBVR

MBVR-SS
Two OS signal muons
== 1 signal tau
b-Jet Veto
$E_T^{miss} \geq 100$GeV
$\Delta\Phi(\tau, E_T^{miss}) \leq 1.75$

Sample	MBVR-SS
Multiboson	148.26 ± 2.01
top	34.35 ± 2.19
Zjets	17.30 ± 29.65
Higgs	4.43 ± 1.31
Wjets	0.08 ± 0.08
Total Bkg	204.42 ± 29.83
data	200.00 ± 14.14
(325, 175)	0.46 ± 0.33
(375, 175)	1.09 ± 0.40

process	subprocess	DSID	SR-C1N2SS-LM
Diboson fully leptonic	$\ell\ell\ell\nu$	364253	0.2514 ± 0.0959
	$\ell\ell\ell\ell$	364250	0.1493 ± 0.0466
	$\ell\ell\nu\nu$	364254	0.0498 ± 0.0244
Diboson VVjj	$\ell\ell\ell\nu jj$	364284	0.0070 ± 0.0029
	$gg\ell\ell\ell\ell$	345706	0.0062 ± 0.0039
Triboson	$4l2\nu$	407313	0.0021 ± 0.0021
	$5\ell1\nu$	407312	0.0016 ± 0.0011
Diboson VVjj	$\ell\ell\ell\ell jj$	364283	0.0011 ± 0.0011
Triboson	$6\ell0\nu$	407311	0.0001 ± 0.0001
Total Multiboson			0.4686 ± 0.1095

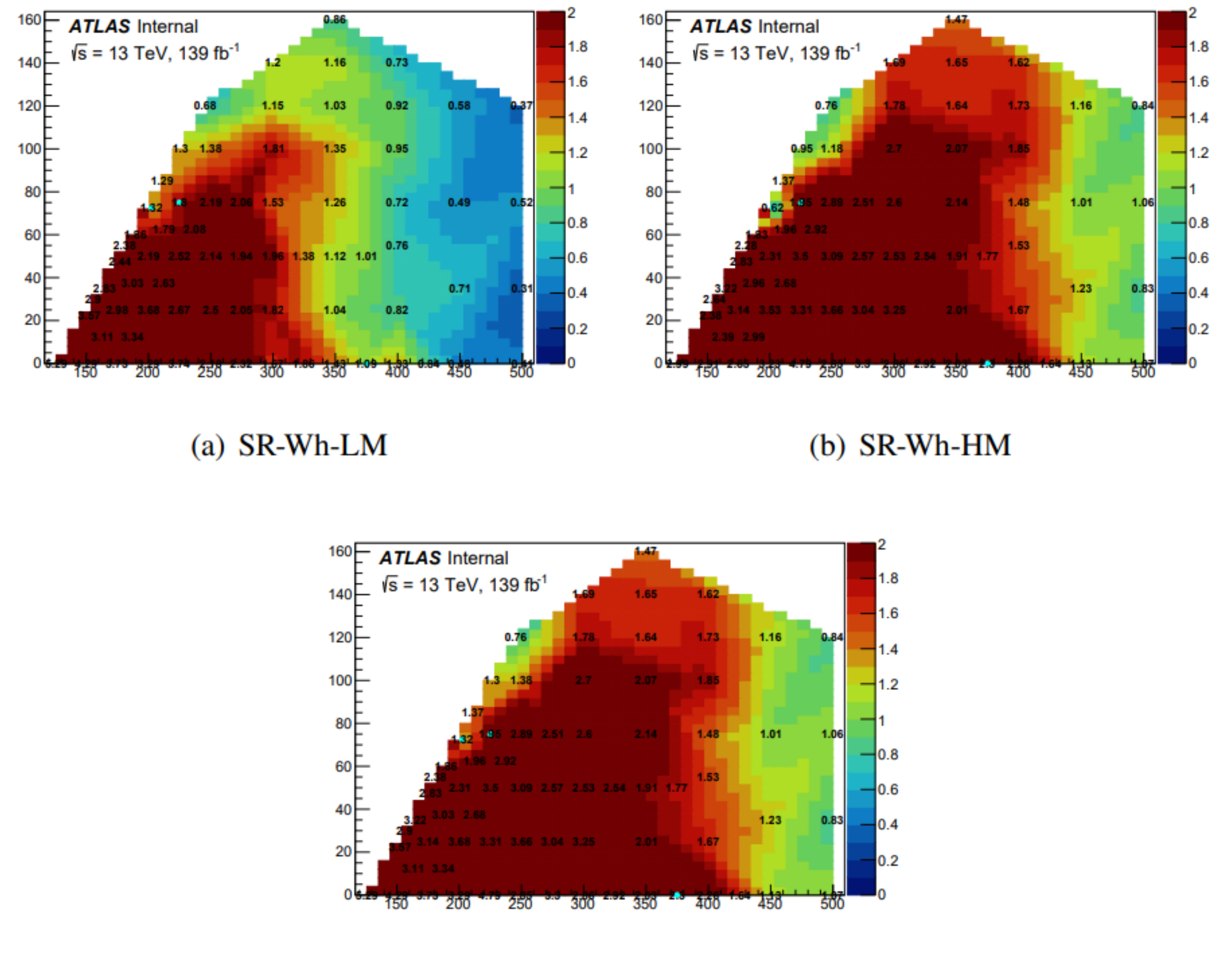
process	subprocess	DSID	SR-C1N2SS-HM
Diboson fully leptonic	$\ell\ell\nu\nu$	364254	0.3783 ± 0.1888
	$\ell\ell\ell\nu$	364253	0.2709 ± 0.0909
	$\ell\ell\ell\ell$	364250	0.0540 ± 0.0167
Triboson	$4l2\nu$	407313	0.0403 ± 0.0137
Diboson fully lep.	$\ell\nu\nu\nu$	364255	0.0163 ± 0.0099
Diboson VVjj	$\ell\ell\ell\nu jj$	364284	0.0135 ± 0.0042
Triboson	$3\ell3\nu$	407314	0.0122 ± 0.0122
Diboson VVjj	$gg\ell\ell\nu\nu ZZ$	345723	0.0079 ± 0.0046
	$gg\ell\ell\ell\ell$	345706	0.0033 ± 0.0033
	$\ell\ell\nu\nu jj$	364287	0.0027 ± 0.0027
	$\ell\ell\nu\nu jjSS$	364286	0.0011 ± 0.0011
Total Multiboson			0.8005 ± 0.2113

process	subprocess	DSID	MBVR-SS
Diboson fully leptonic	$\ell\ell\ell\nu$	364253	120.6694 ± 1.8871
	$\ell\ell\ell\ell$	364250	13.8055 ± 0.3555
	$\ell\ell\nu\nu$	364254	5.2136 ± 0.5509
Diboson VVjj	$\ell\ell\ell\nu jj$	364284	4.0025 ± 0.0650
Triboson	$4l2\nu$	407313	0.9863 ± 0.0660
Triboson	$3\ell3\nu$	407314	0.8989 ± 0.1192
Diboson VVjj	$gg\ell\ell\ell\ell$	345706	0.8629 ± 0.0366
	$\ell\ell\ell\ell jj$	364283	0.5151 ± 0.0287
Diboson semileptonic	$WqqZ\ell\ell$	363358	0.4553 ± 0.1171
	$ZqqZ\ell\ell$	363356	0.3016 ± 0.1040
Diboson VVjj	$\ell\ell\nu\nu jj$	364285	0.2470 ± 0.0564
Triboson	$5\ell1\nu$	407312	0.1180 ± 0.0083
Diboson VVjj	$gg\ell\ell\nu\nu Int$	345715	0.0945 ± 0.0552
	$gg\ell\ell\nu\nu ZZ$	345723	0.0497 ± 0.0115
	$ggZ\ell\ell Zqq$	364302	0.0114 ± 0.0114
	$gg\ell\ell\ell\ell 0M4l130$	345705	0.0045 ± 0.0041
Diboson full leptonic	$\ell\ell\nu\nu jjSSEW4$	364286	0.0032 ± 0.0032
Tribosons	$2\ell4\nu$	407315	0.0127 ± 0.0080
Diboson VVjj	$\ell\ell\nu\nu jjjSSEW6$	364287	0.0022 ± 0.0022
Triboson	$6\ell0\nu$	407311	0.0080 ± 0.0009
Total Multiboson			148.2624 ± 2.0118

Wh

variables	cut values
$m(\tau_1,\tau_2)$	$\geq$ 40., 50., 60., 70., 80., 90., 100., 110. GeV
$m(\tau_1,\tau_2)$	$\leq$ 80., 90., 100., 110. , 120., 130., 140., 150., 160. GeV
m_{T2}^{max}	$\geq$ 30., 40., 50., 60., 70., 80., 90., 100., 110. GeV
$p_T(\tau_1)$	$\geq$ 20., 30., 40., 50., 60., 70., 80. GeV
$p_T(\tau_2)$	$\geq$ 20., 30., 40., 50. GeV
$M_T(\tau_1)$	$\geq$ 0., 20., 30., 40., 50. GeV
$M_T(\mathrm{lep})$	$\geq$ 0., 20., 40., 60., 80., 100. GeV
M_{Tsum}	$\geq$ 0., 300., 350., 400., 450., 500., 550. GeV
$N_{TightTau}$	$\geq$ 0, 1, 2
$\Delta R(\tau_1,\tau_2)$	$\leq$ 2.0, 2.2, 2.3, 2.4, 2.5, 2.6, 3., 100.

SM process	SR-Wh-LM	SR-Wh-HM
Top	2.16 ± 0.60	0.16 ± 0.12
Multiboson	1.87 ± 0.28	1.07 ± 0.16
Wjets	0.23 ± 0.22	0.062 ± 0.062
Higgs	0.131 ± 0.013	0.059 ± 0.0082
Zjets	0.061 ± 0.030	0.030 ± 0.022
total Bkg	4.45 ± 0.70	1.38 ± 0.21
(202.5, 72.5)	4.01 ± 0.80	
(225.0, 75.0)	5.79 ± 0.82	
(375.0, 0)		4.02 ± 0.33



(a) SR-Wh-LM

(b) SR-Wh-HM

(c) SR-Combined

	TCR-Wh	TVR-Wh
Z+jets	1.06 ± 0.37	0.036 ± 0.085
W+jets	-	-
Top	201.67 ± 5.27	98.73 ± 3.63
Multiboson	3.76 ± 0.28	1.81 ± 0.19
Higgs	6.14 ± 0.092	4.64 ± 0.20
Fakes	62.02 ± 3.14	17.21 ± 1.86
Total BG	274.66 ± 6.15	122.43 ± 4.09
Data	276	109
Wh 126_0	1.00 ± 0.72	2.04 ± 0.92
Wh 200_0	0.43 ± 0.15	0.69 ± 0.18
Wh 375_0	0.06 ± 0.03	0.32 ± 0.11

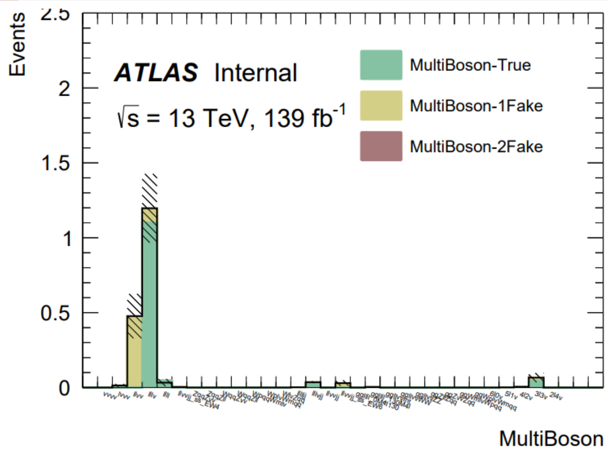
TCR-Wh	TVR-Wh
== 1 signal lepton	
single lepton trigger and offline p_{T} requirement described in Table 12	
>= 2 medium taus	
$1 \leq N_{b\text{−jets}} \leq 2$	
$\|\Delta\phi(\tau_1, \tau_2)\| < 3$	
40 GeV $< m(\tau_1, \tau_2) <$ 160 GeV	
$\mathrm{m_{Tsum}} >$ 250GeV	
20 GeV $< m_{T2}^{max} <$ 80 GeV	$m_{T2}^{max} >$ 80 GeV

Sample	MB-VR-Wh
Z+jets	7.88 ± 2.27
W+jets	-
Top	10.08 ± 1.21
Multiboson	83.43 ± 1.59
Higgs	1.19 ± 0.69
Fakes	33.17 ± 2.13
Total BG	135.75 ± 3.76
Data	144
Wh 126_0	16.04 ± 2.56
Wh 200_0	5.61 ± 0.53
Wh 375_0	0.38 ± 0.10

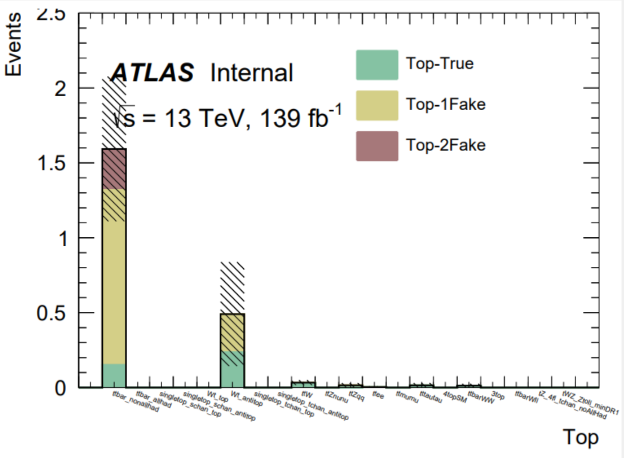
MB-VR-Wh
== 1 signal lepton
pass single lepton trigger and offline p_{T} requirement described in Table 12
>= 2 medium taus (OS)
b-jet veto
$\|\Delta\phi(\tau_1, \tau_2)\| < 3$
$p_{T\,\tau_2} > 30\ GeV$
$40\ GeV < m(\tau_1, \tau_2) < 70\ GeV$
$\mathrm{M_{Tlep}} > 70\ GeV$
$m_{T2}^{max} < 80\ GeV$

Wh FF control region
1 baseline light lepton passing the signal lepton requirements
>= 2 very loose (JetRNNSigTransMin > 0.05) taus (SS)
b-jet veto
$m(\tau_1, \tau_2) > 20GeV$
$\|\Delta\phi(\tau_1, \tau_2)\| < 3$
m_{T2}^{max}>$20GeV$
single lepton trigger and offline p_{T} requirement described in Table 12

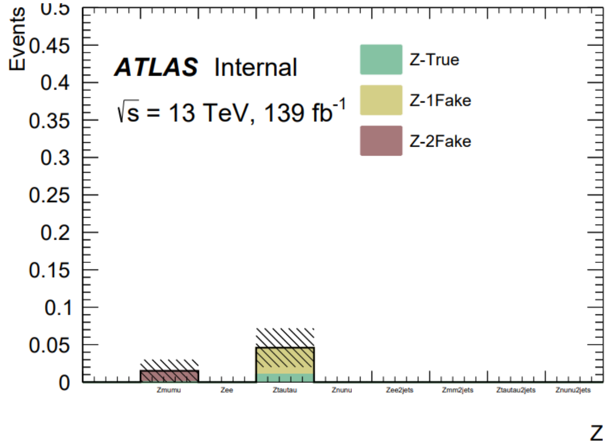
Wh SR



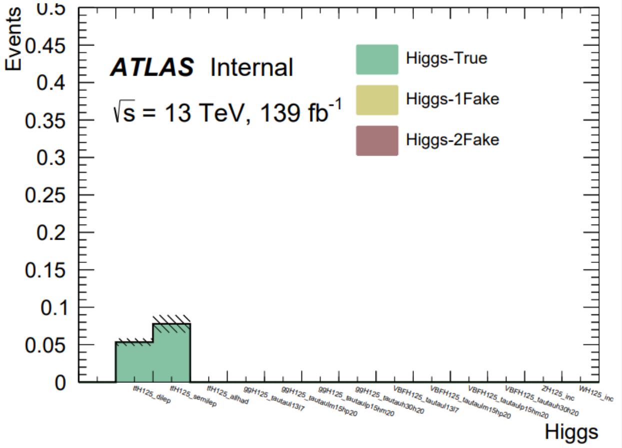
(a) Multiboson



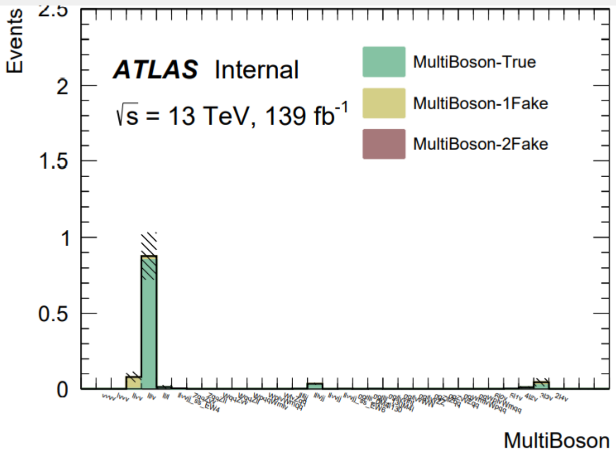
(b) Top



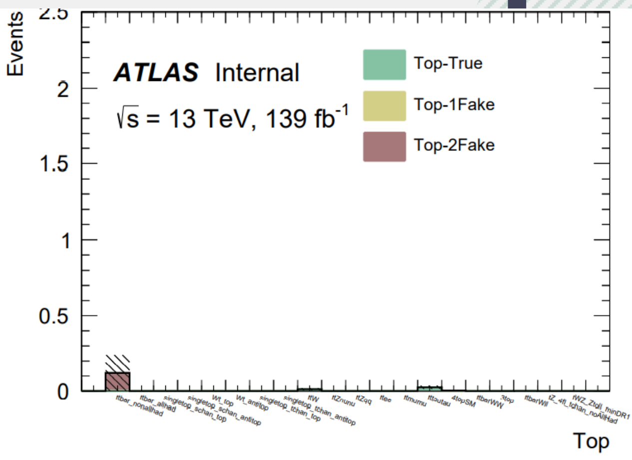
(c) Z



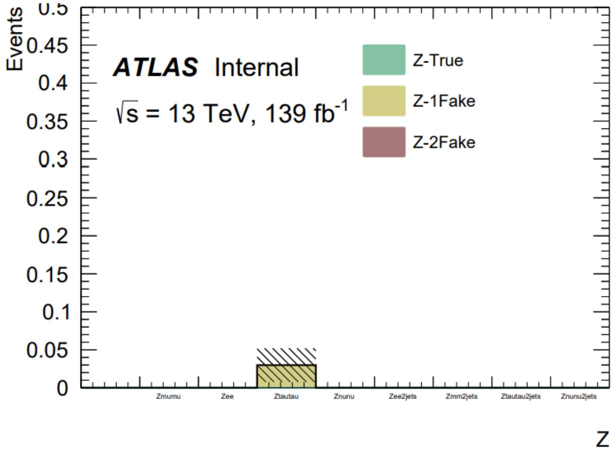
(d) Higgs



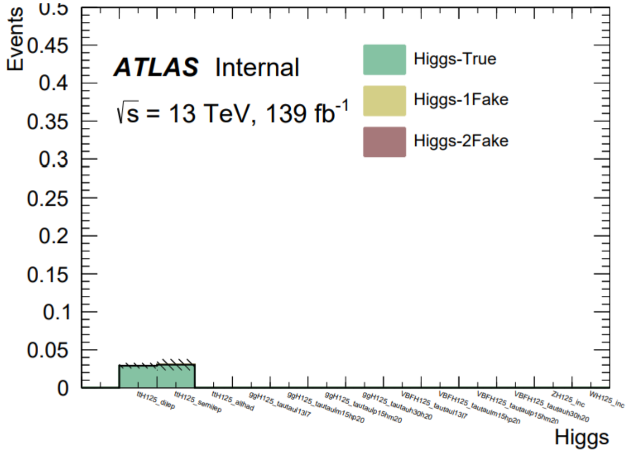
(a) Multiboson



(b) Top

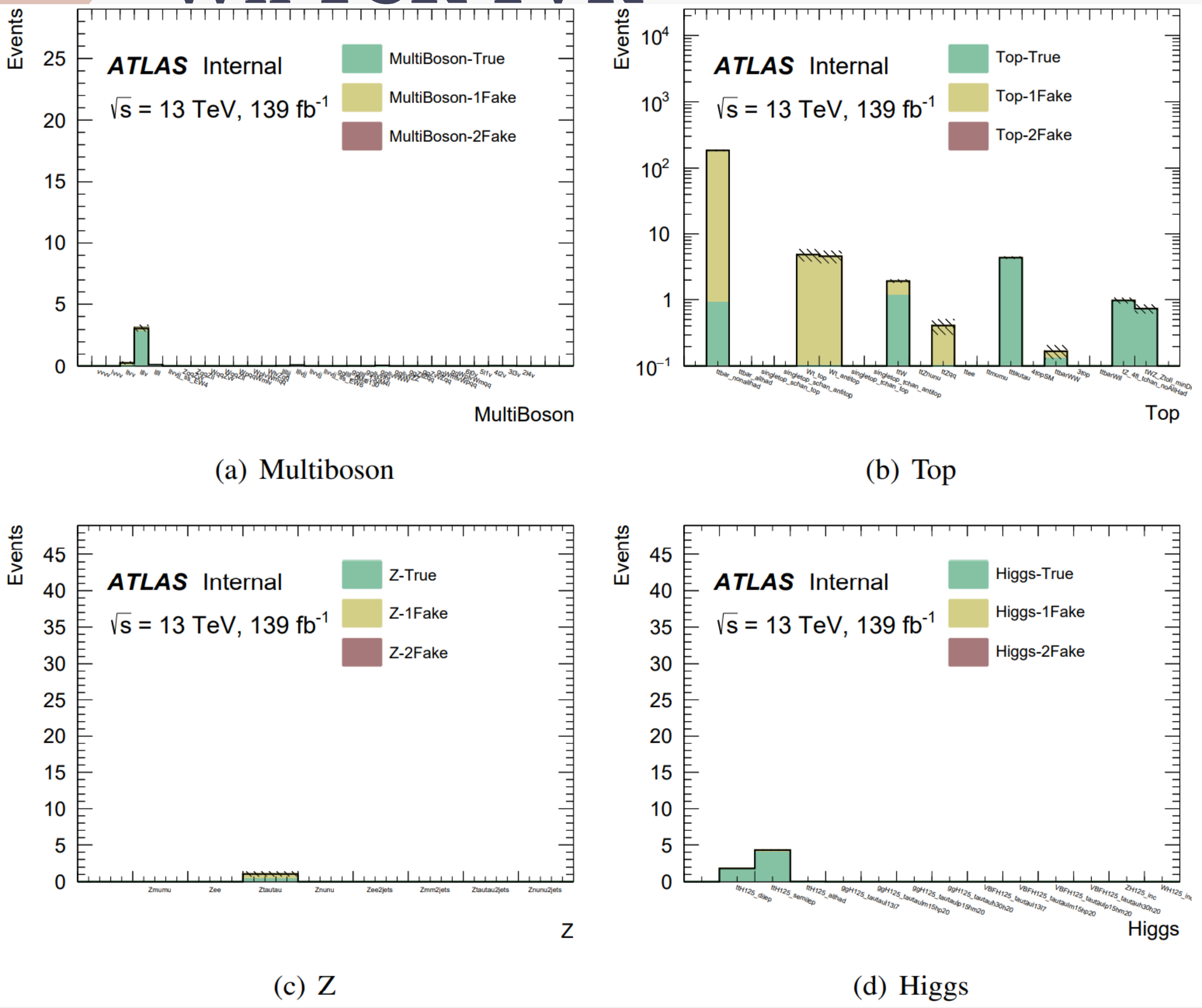


(c) Z



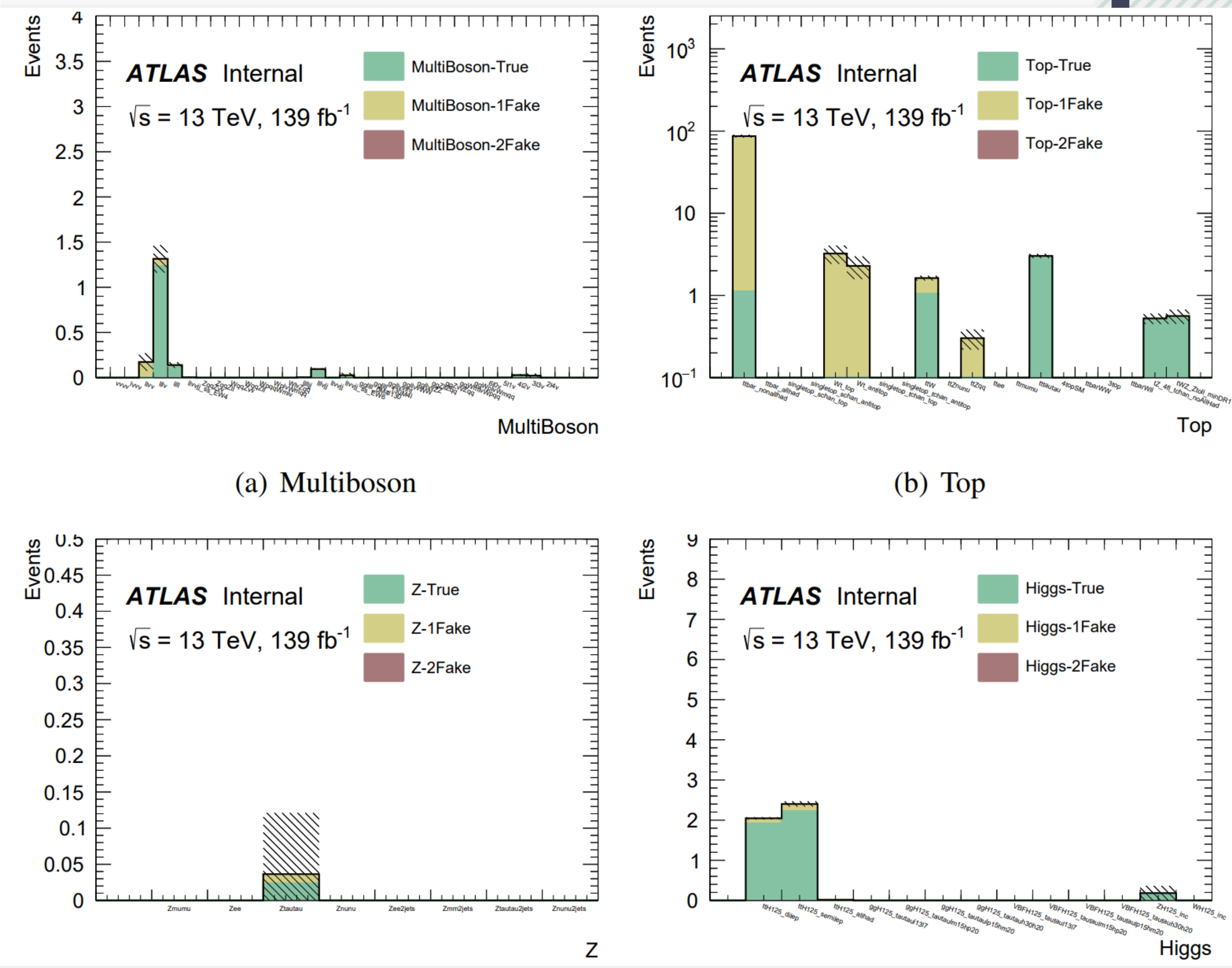
(d) Higgs

Wh TCR TVR



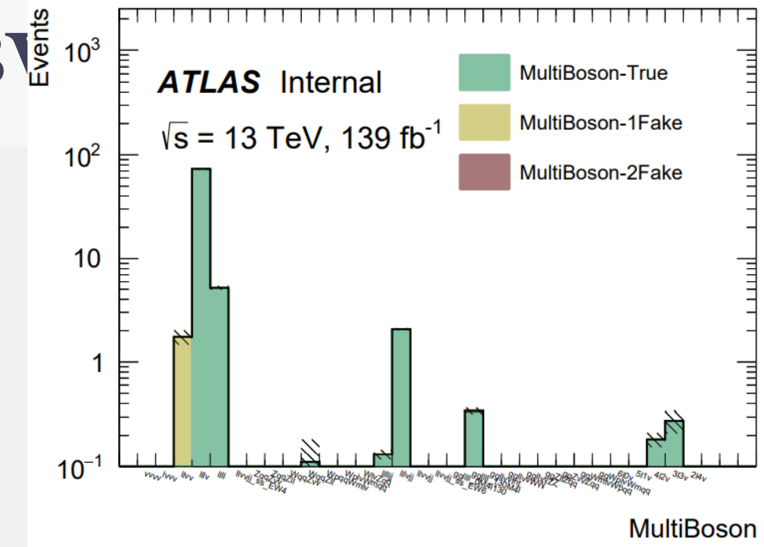
(a) Multiboson (b) Top

(c) Z (d) Higgs

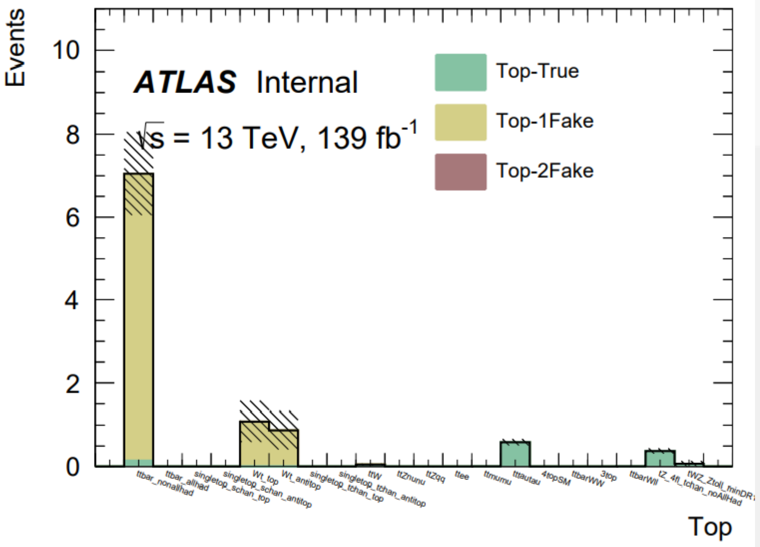


(a) Multiboson (b) Top

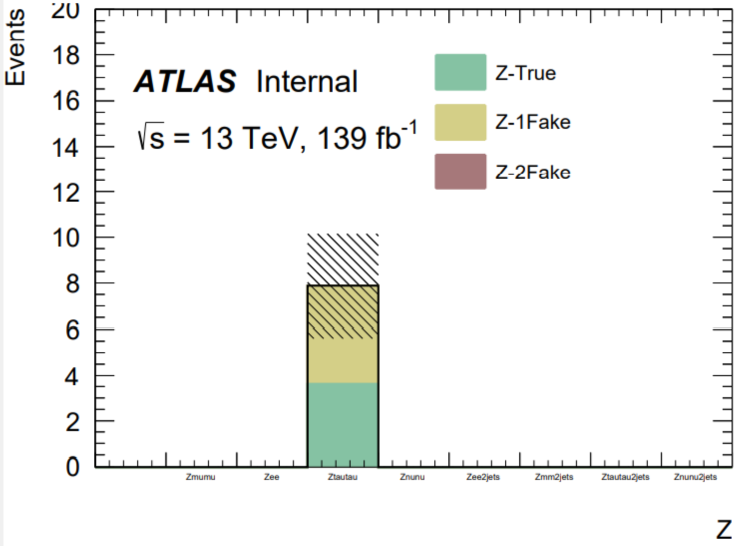
Wh-MBV



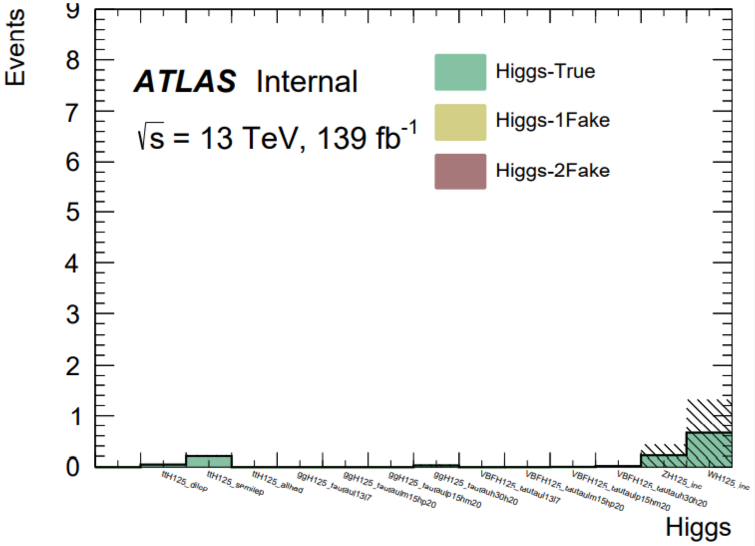
(a) Multiboson



(b) Top



(c) Z

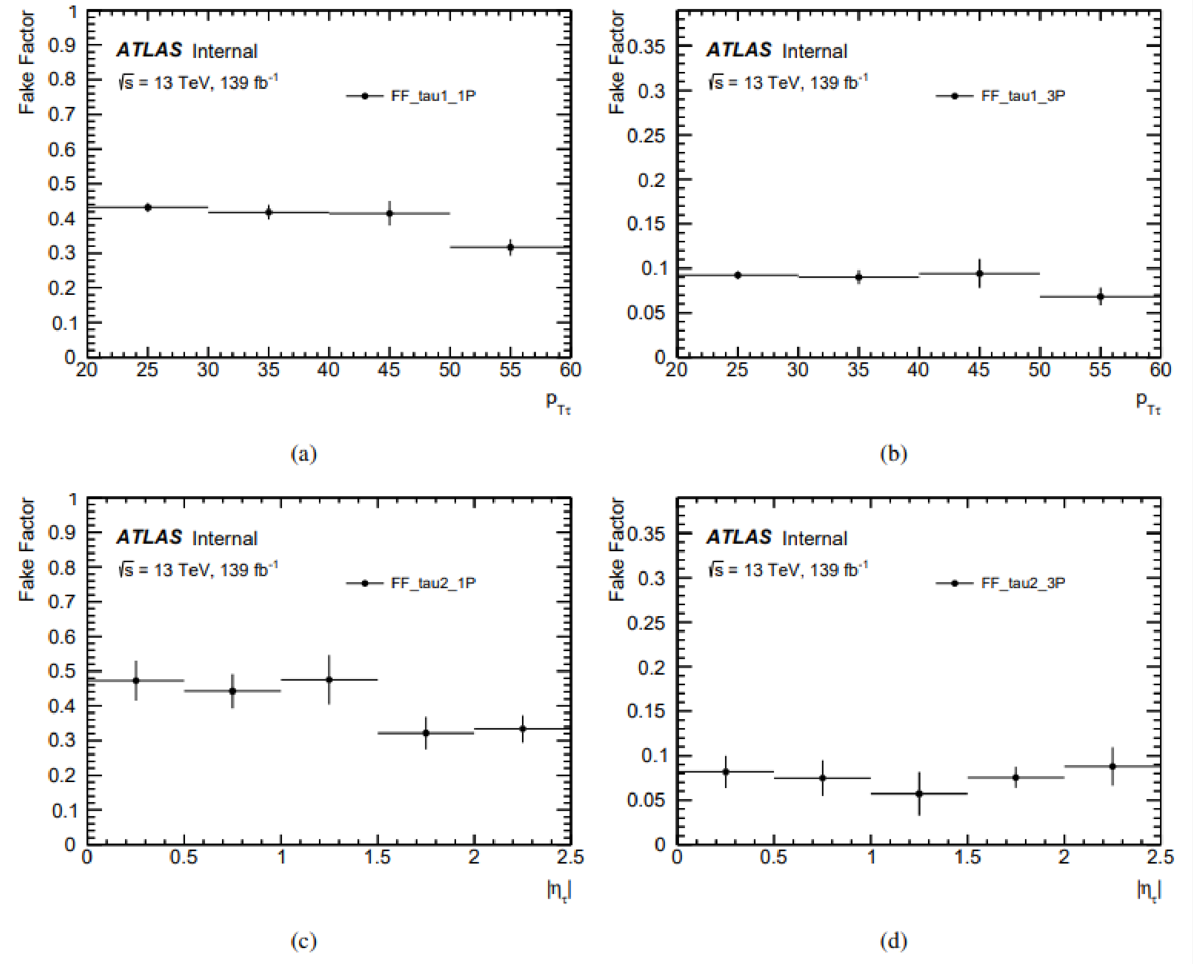


(d) Higgs

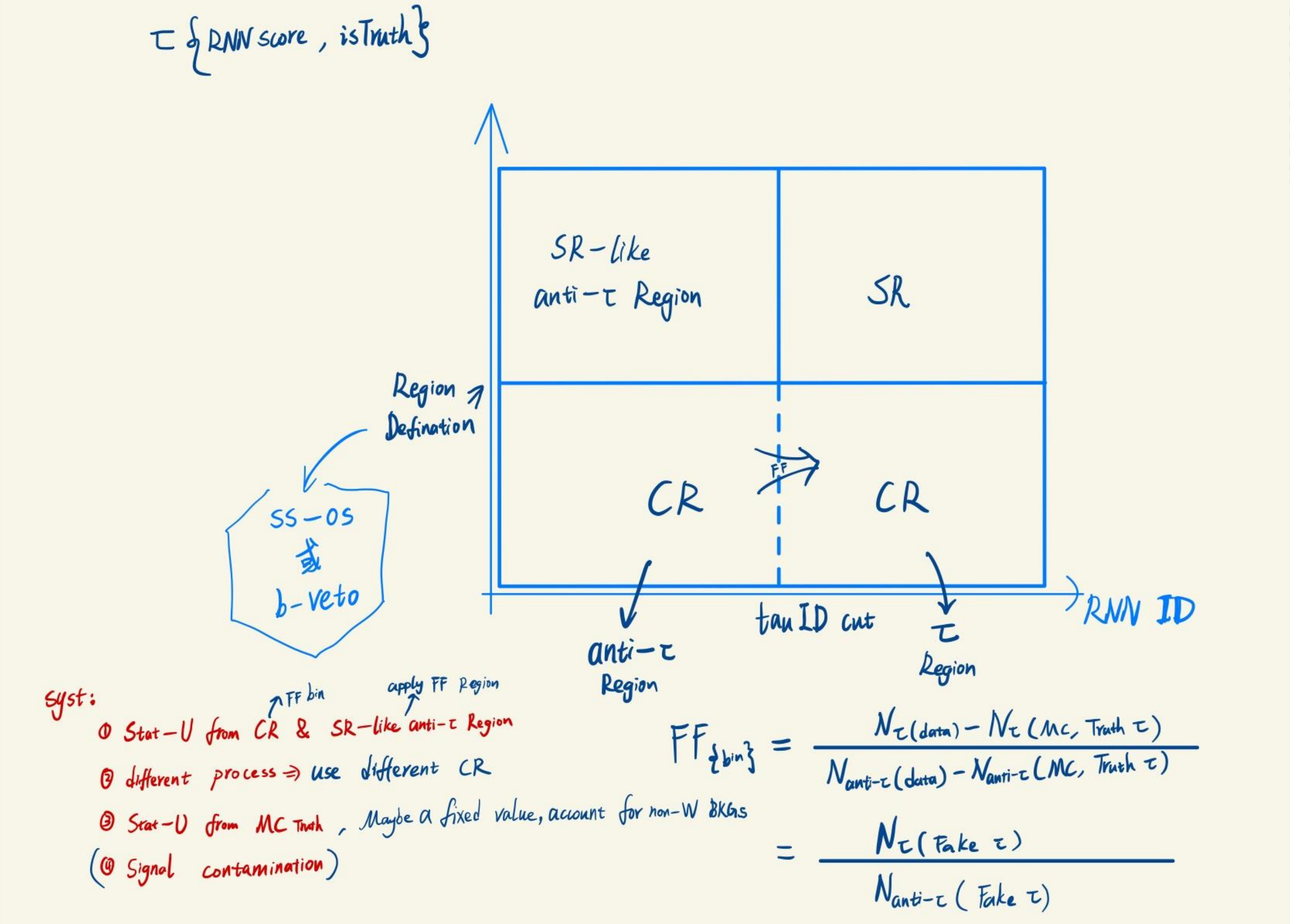
FFs

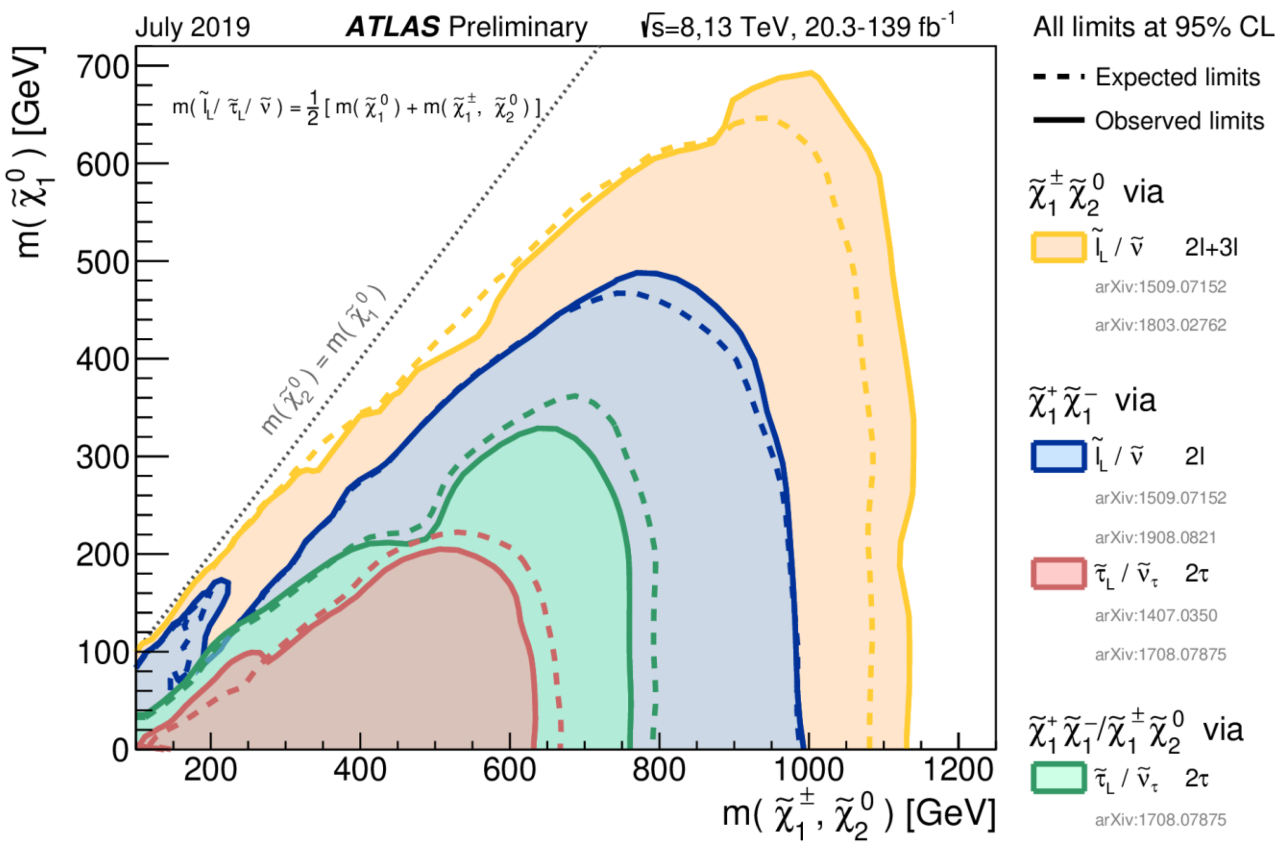
$$N_{fakebkg} = N_{data} - N_{MCbkg}^{\geq 1 truthtau}$$

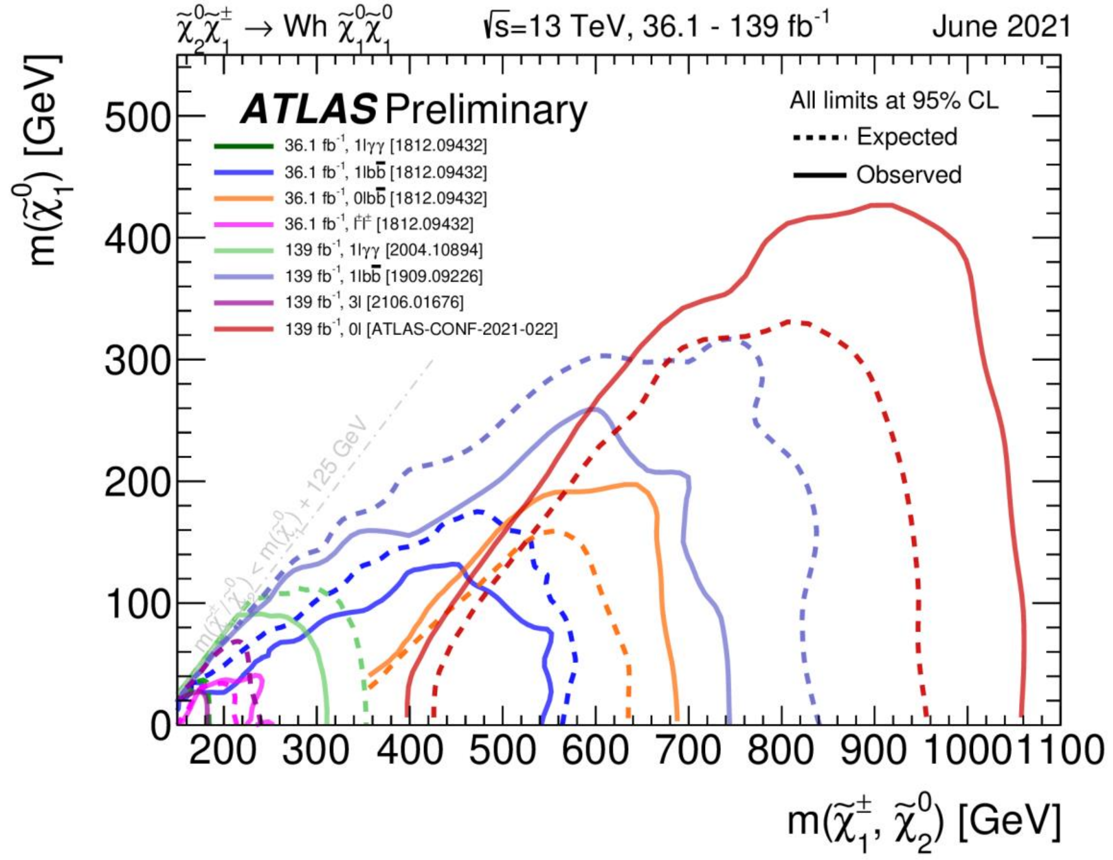
ATLAS Fake Tau Scoping Study : https://cds.cern.ch/record/2300696



(a) (b) (c) (d)




July 2019
ATLAS Preliminary
√s=8,13 TeV, 20.3-139 fb-1
All limits at 95% CL
Expected limits
Observed limits
arXiv:1509.07152
arXiv:1803.02762
arXiv:1908.0821
arXiv:1407.0350
arXiv:1708.07875


√s=13 TeV, 36.1 - 139 fb-1
June 2021
ATLAS Preliminary
All limits at 95% CL
Expected
Observed
36.1 fb-1, 1lγγ [1812.09432]
139 fb-1, 1lγγ [2004.10894]
139 fb-1, 3l [2106.01676]
139 fb-1, 0l [ATLAS-CONF-2021-022]