Introduction to Di-Tau analysis

Focus on C1C1

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Di-Tau: C1C1 via stau

ATLAS Note

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

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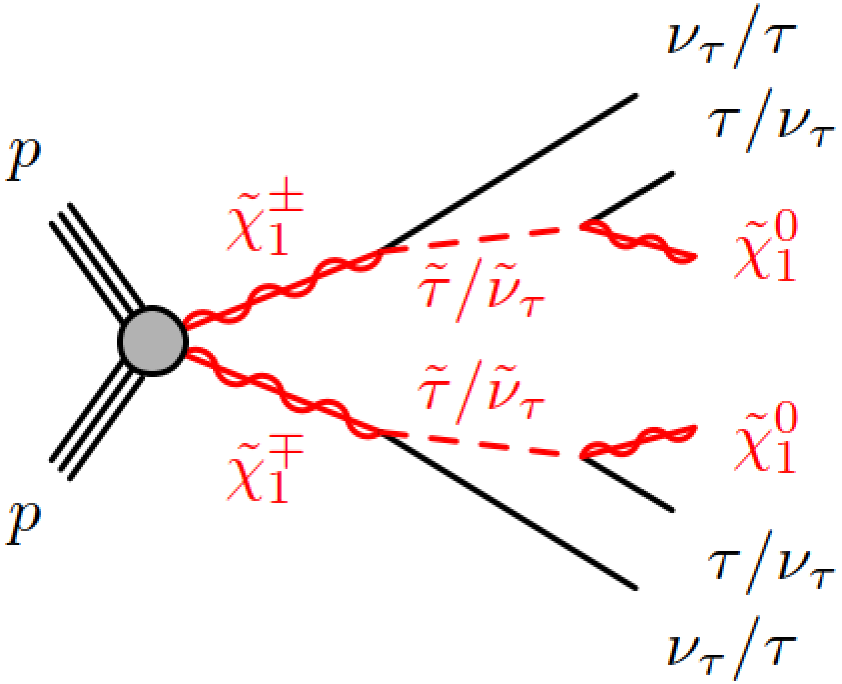
This note contains the supporting material of the search for direct electroweakino and stau production in events with at least two hadronic taus in the final state. The search uses the full Run-2 dataset which includes 139 fb^{-1} of integrated luminosity of pp collisions at $\sqrt{s} = 13$ TeV collected by the ATLAS detector from 2015 to 2018. Three scenarios are included: $\tilde{\chi}^{+}{}_{1}\tilde{\chi}^{-}{}_{1}$ and $\tilde{\chi}^{\pm}{}_{1}\tilde{\chi}^{0}{}_{2}$ production via stau decay, $\tilde{\chi}^{\pm}{}_{1}\tilde{\chi}^{0}{}_{2}$ produciton via wh decay, direct stau production with two hadronic taus.



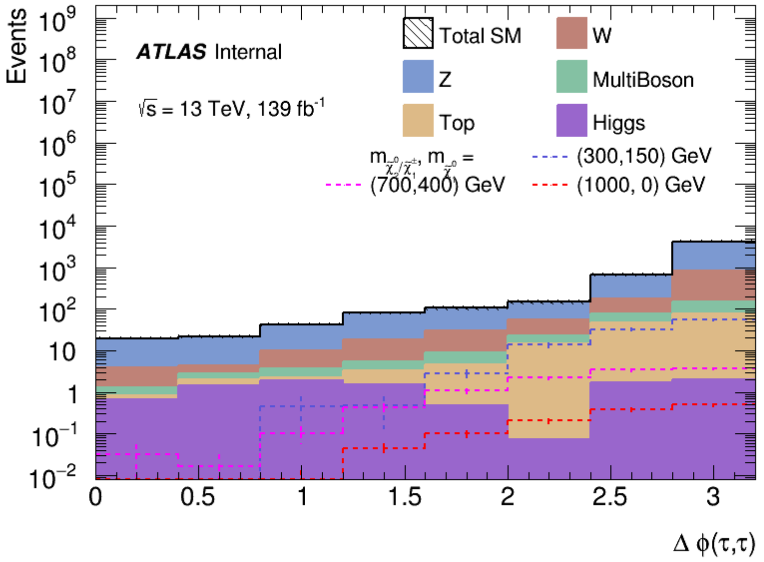
/01 Preselection

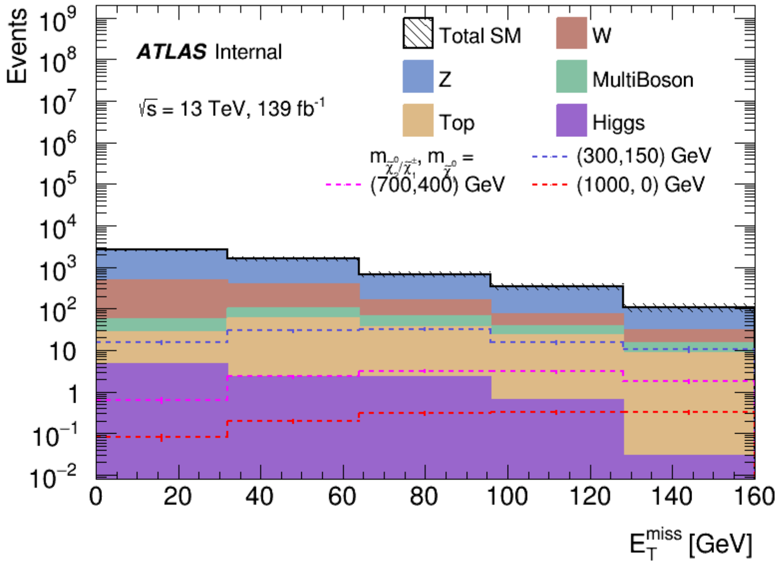
Preselection

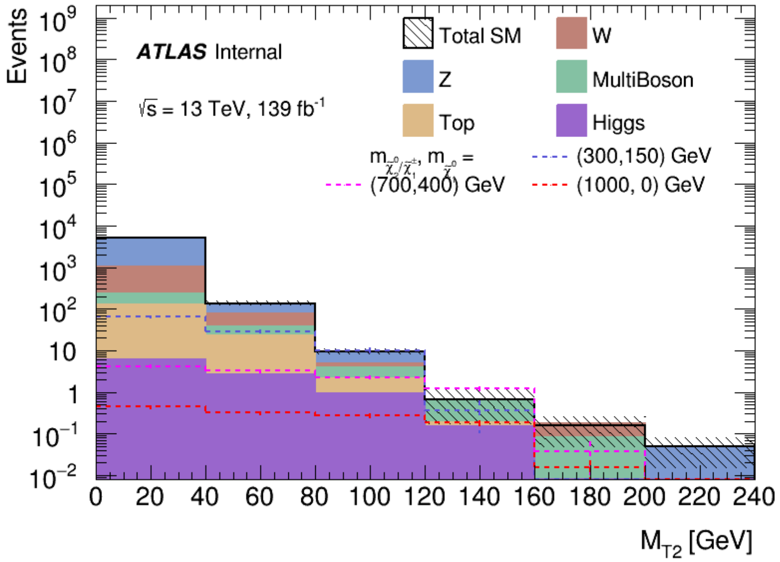
Preselection of low E_T^{miss} SR	Preselection of high E_T^{miss} SR
>=2 medium taus	
b-jet veto	
Z/H-veto ($m(\tau_1, \tau_2) > 120$ GeV) (only for OS channel)	
asymmetric di-tau trigger	di-tau+E_T^{miss} trigger
$E_T^{miss} < 150$ GeV	$E_T^{miss} > 150$ GeV
τ_1 and τ_2 p_T requirements described in Table 8 in Section 4.3	

Table 20: Preselection before low and high E_T^{miss} SR optimization for both C1C1 and C1N2

Preselection







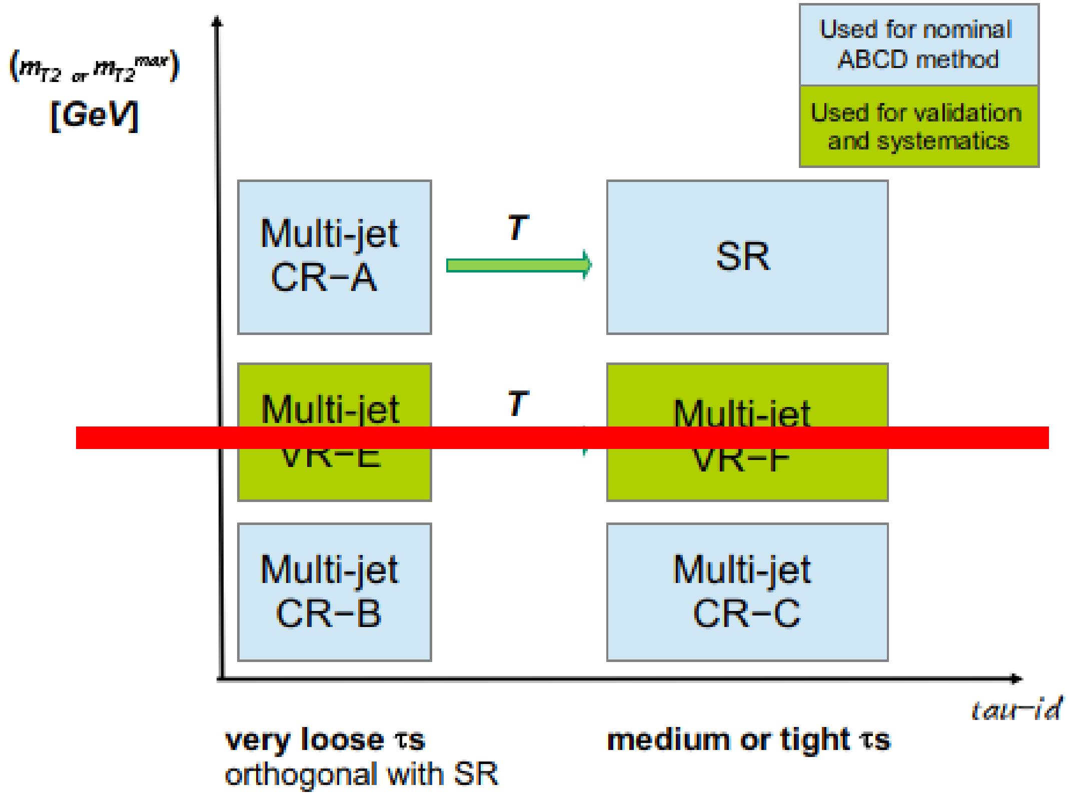
/02 Signal region optimization

Simplified ABCD method

Cut & Count

Simplified ABCD method

preCR – A (lowMass)	preSR – lowMass
≥ 2 veryloose τs; $m_{T2} > 35$ GeV $10 < E_T^{miss} < 150$ GeV	≥ 2 Medium >= 1 tight τs (OS) $m_{T2} > 35$ GeV $10 < E_T^{miss} < 150$ GeV
preCR – B (lowMass)	**preCR – C** (lowMass)
≥ 2 veryloose τs; $15 < m_{T2} < 35$ GeV $10 < E_T^{miss} < 150$ GeV	≥ 2 Medium >= 1 tight τs (OS) $15 < m_{T2} < 35$ GeV $10 < E_T^{miss} < 150$ GeV



The multi-jet are estimated by simplified ABCD method.

PF(purity factor) = #QCD / #data

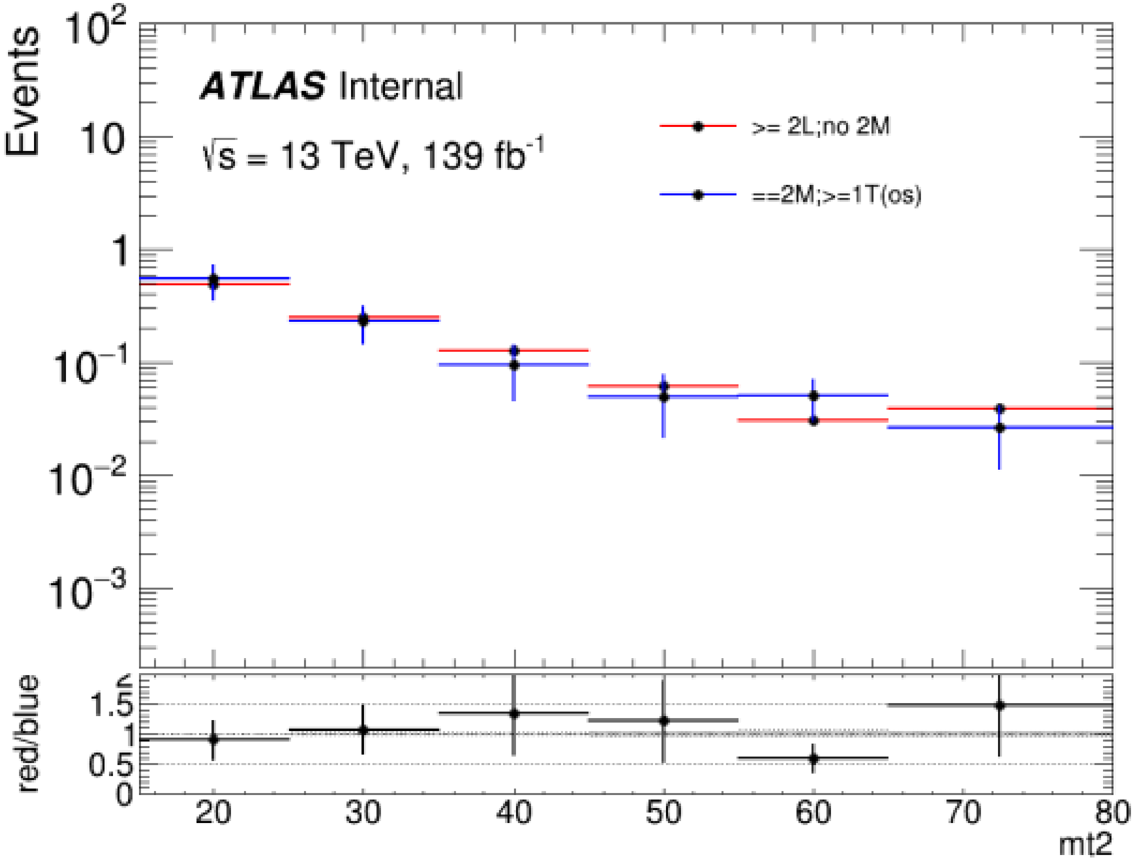
Multi-jet events yields in a region → data * PF

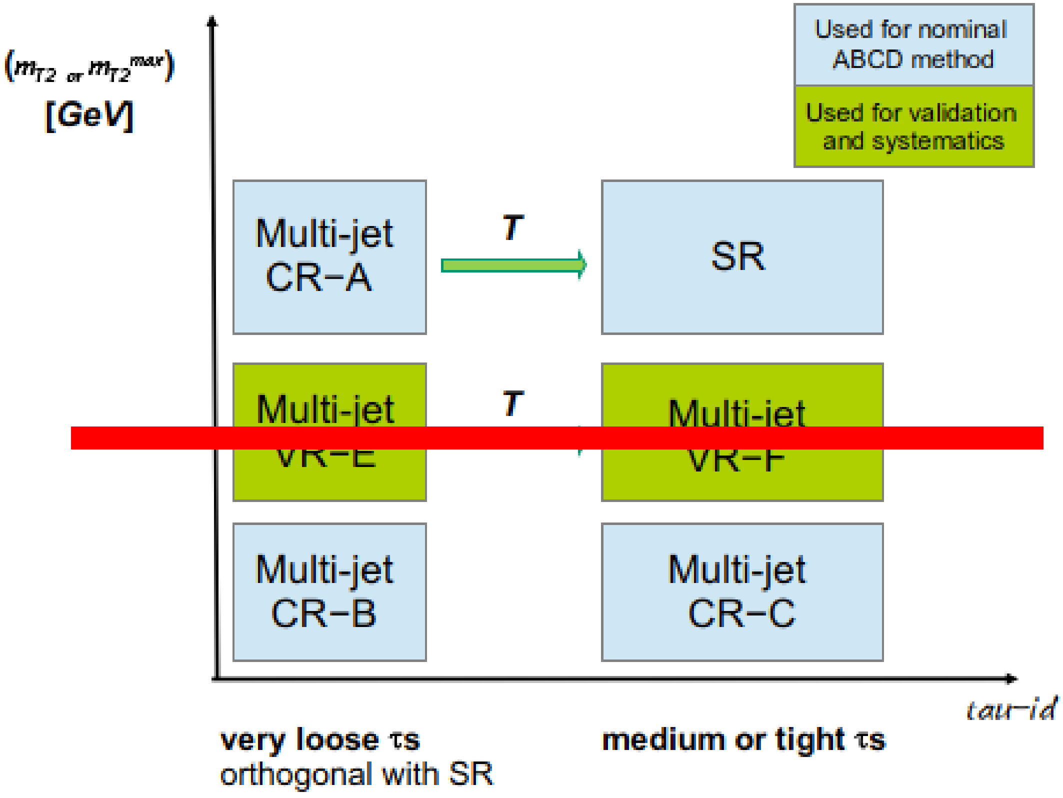
TF = #multi-jet in C / #multi-jet in B

#multi-jet in SR = #multi-jet in A × TF

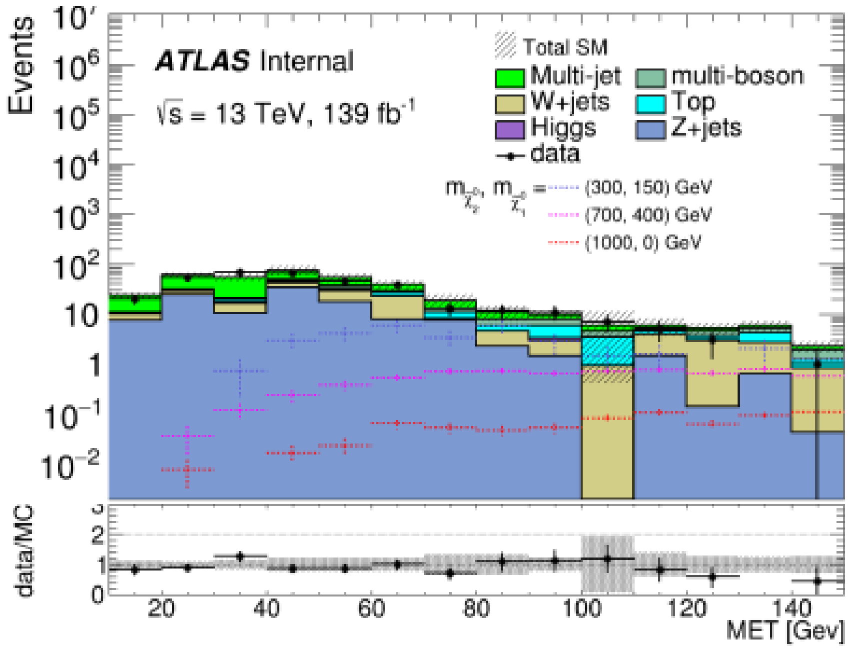
M_{T2} ~ τ quality correlation

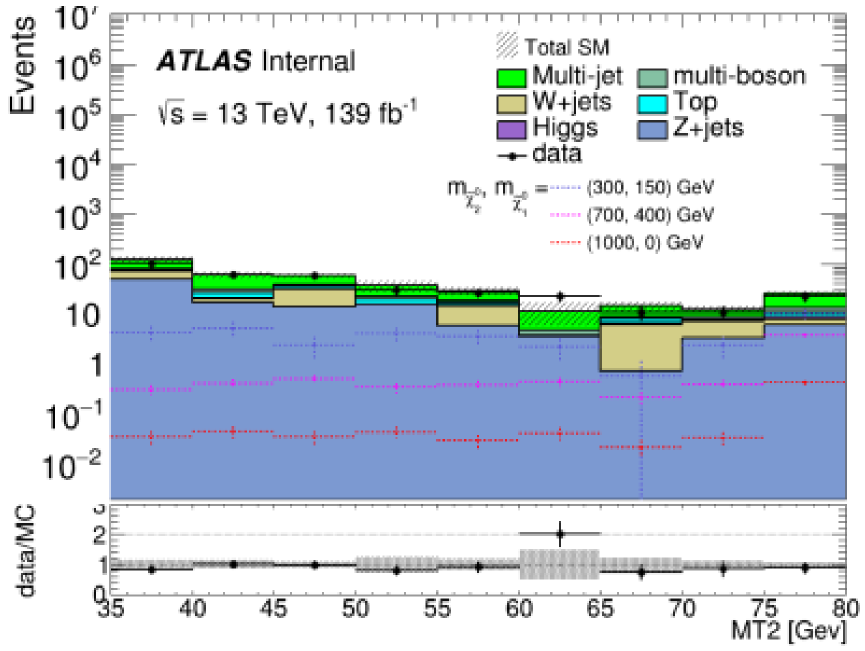
Use QCD events in CR-B, C(after remove MT2 < 35 GeV cut).





Kinematic distribution in the preSR-C1C1-lowMass





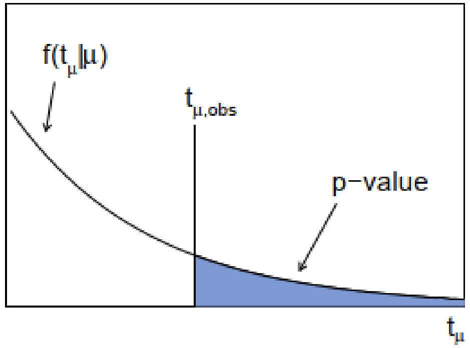
Cutcount

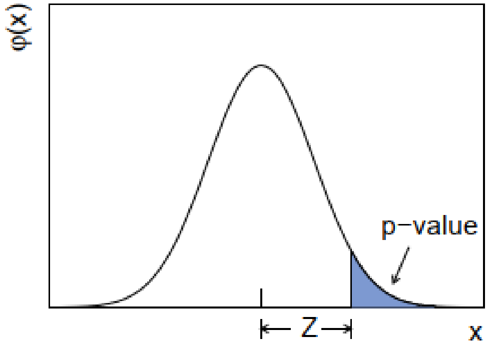
Cut candidates

variables	cut values of low E_T^{miss} SR	cut values of high E_T^{miss} SR
tau quality	>= 2 medium taus, 1 medium 1 tight taus, 2 tight taus	
$E_T^{miss} \geq$	30, 50, 60, 75, 80, 90, 100 GeV	150, 160, 170, 180, 200 GeV
$m_{T2} \geq$	40, 50, 60, 70, 80, 90, 100 GeV	
$m_{Tsum} \geq$	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	
$p_T(\tau_1) \geq$	95, 100, 110, 120, 130, 140, 150 GeV	50, 55, 60, 65, 70, 80, 90, 100, 120 GeV
$p_T(\tau_2) \geq$	60, 70, 80, 90, 100 GeV	40, 45, 50, 55, 60, 70, 80, 90, 100 GeV

Signal significance

$$Z = \pm\sqrt{2} \times \sqrt{n \ln \frac{n(b+\sigma^2)}{b^2 + n\sigma^2} - \frac{b^2}{\sigma^2} \ln \frac{b^2 + n\sigma^2}{b(b+\sigma^2)}}$$





Assumptions about uncertainty:

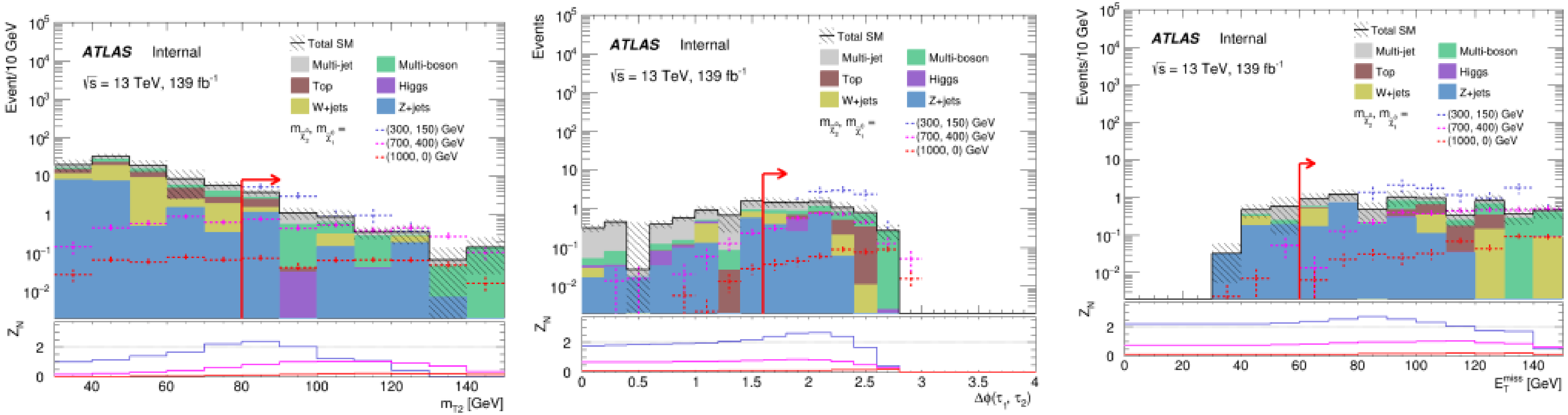
30% flat syst uncertainty on the SM background.
signal stat uncertainty is assumed to be negligible
the dominant bkg multi-boson stat uncertainty < 50%
total bkg stat uncertainty < 30%

CutCount result

Zn	Signal	totalBkg	MET	MT2	MTsum	dRtt	dPhitt	Mtt_12	tau1Pt	tau2Pt
3.31346	14.154 +- 1.7525	4.68716 +- 1.18538(200)	70	70	250	3.0	1.8	130	95	60
3.31346	14.154 +- 1.7525	4.68716 +- 1.18538(200)	70	70	0	3.0	1.8	130	95	60
3.31346	14.154 +- 1.7525	4.68716 +- 1.18538(200)	70	70	200	3.0	1.8	130	95	60
3.31101	14.154 +- 1.7525	4.69915 +- 1.18544(201)	70	70	200	3.0	1.8	120	95	60
3.31101	14.154 +- 1.7525	4.69915 +- 1.18544(201)	70	70	200	3.0	1.8	100	95	60
3.31101	14.154 +- 1.7525	4.69915 +- 1.18544(201)	70	70	200	3.0	1.8	50	95	60
3.31101	14.154 +- 1.7525	4.69915 +- 1.18544(201)	70	70	250	3.0	1.8	100	95	60
3.31101	14.154 +- 1.7525	4.69915 +- 1.18544(201)	70	70	0	3.0	1.8	120	95	60
3.31101	14.154 +- 1.7525	4.69915 +- 1.18544(201)	70	70	250	3.0	1.8	50	95	60
3.31101	14.154 +- 1.7525	4.69915 +- 1.18544(201)	70	70	250	3.0	1.8	120	95	60
3.31101	14.154 +- 1.7525	4.69915 +- 1.18544(201)	70	70	0	3.0	1.8	100	95	60
3.31101	14.154 +- 1.7525	4.69915 +- 1.18544(201)	70	70	0	3.0	1.8	50	95	60

Kinematic distributions

Distribution of a variable with some selections.

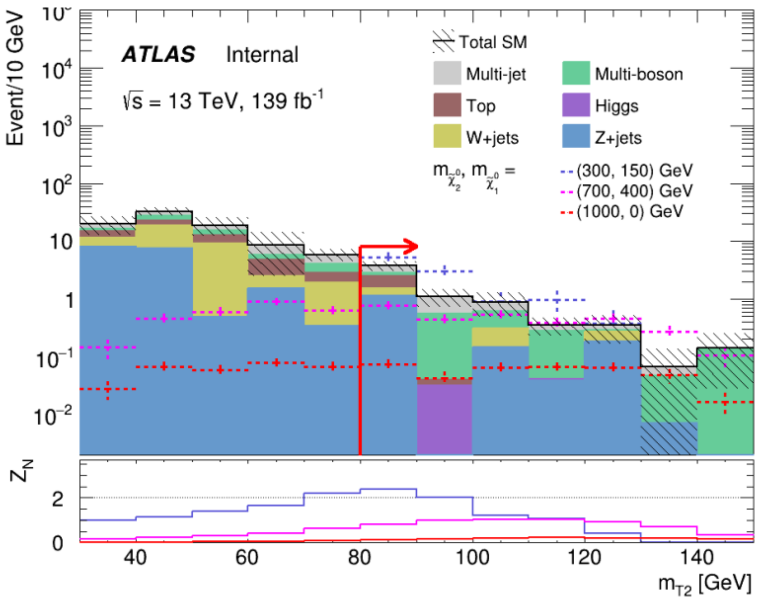


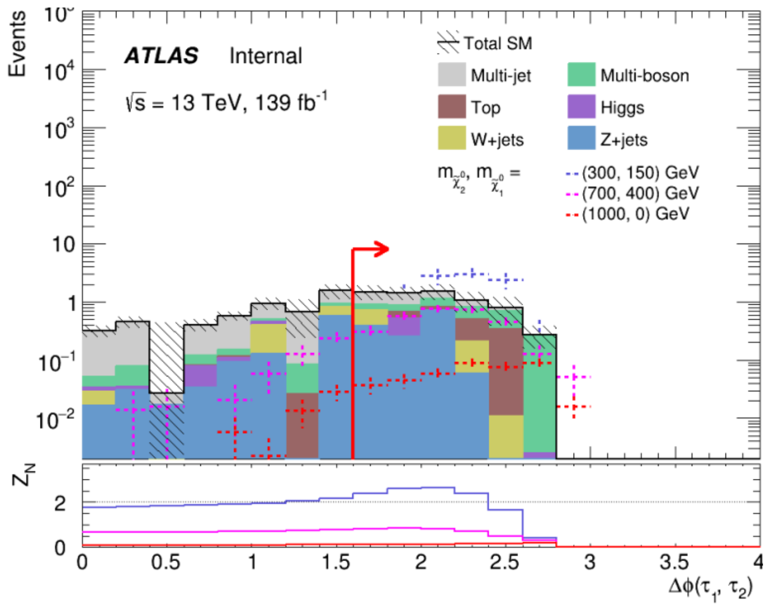
/03 Signal region definition

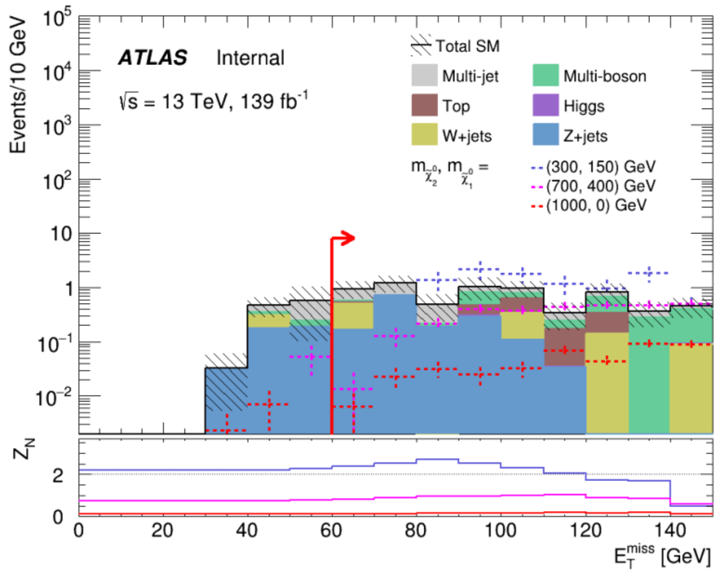
Signal Region Definition

SR-C1C1-LM
== 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
E_T^{miss}>60 GeV
m_{T2}>80 GeV
asymmetry di-tau Trigger
E_T^{miss}<150 GeV
τ_1 and τ_2 p_T requirements

Signal Region N-1 plots







Signal Region Yields

SM process	SR-C1C1-LM
Top	0.95 ± 0.38
W+jets	0.43 ± 0.50
Z+jets	1.42 ± 0.51
Multi-boson	1.65 ± 0.36
Higgs	0.27 ± 0.26
Multi-jet	1.86 ± 0.19
SM total	6.58 ± 0.95
Ref. point (300, 150)	10.41 ± 1.51
Ref. point (750, 450)	2.06 ± 0.17

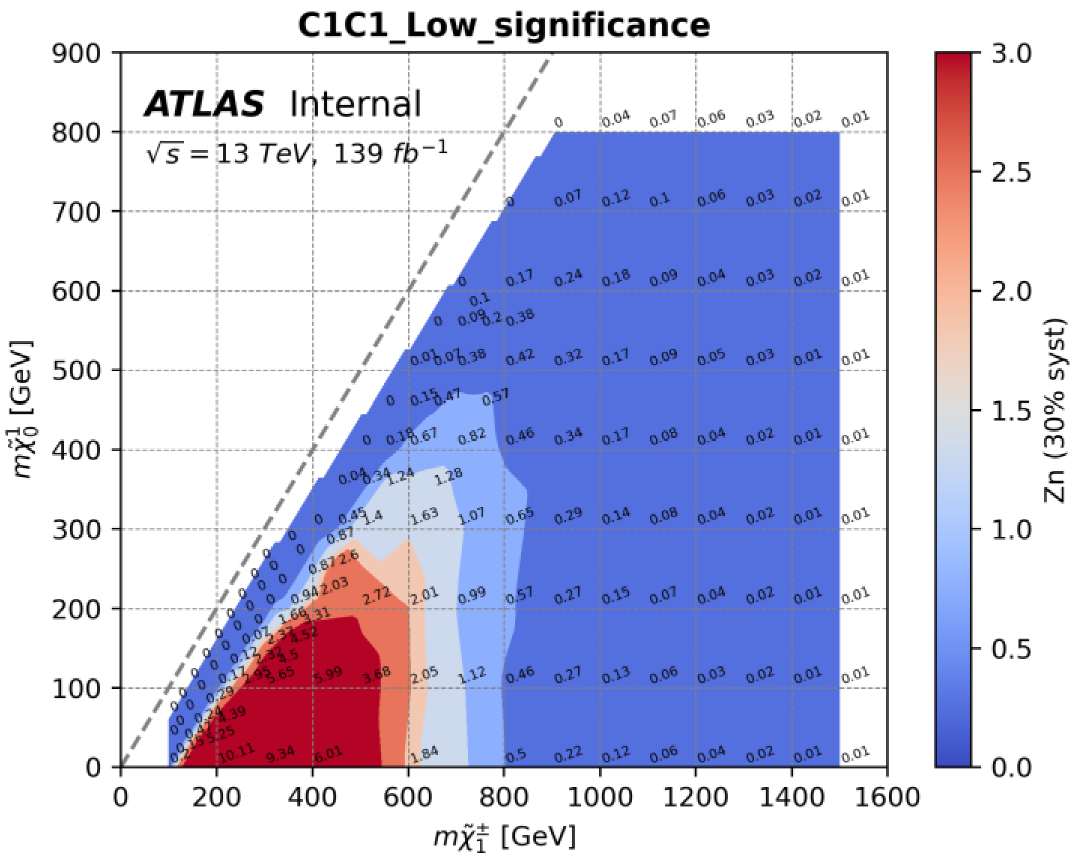
$$Z = \pm\sqrt{2} \times \sqrt{n \ln \frac{n(b+\sigma^2)}{b^2 + n\sigma^2} - \frac{b^2}{\sigma^2} \ln \frac{b^2 + n\sigma^2}{b(b+\sigma^2)}}$$

30% syst

Significance plot

$$Z = \pm\sqrt{2} \times \sqrt{n \ln \frac{n(b+\sigma^2)}{b^2 + n\sigma^2} - \frac{b^2}{\sigma^2} \ln \frac{b^2 + n\sigma^2}{b(b+\sigma^2)}}$$

30% syst



/04

Background Estimation

Reducible: Multi-jet, W+jets

Irreducible background

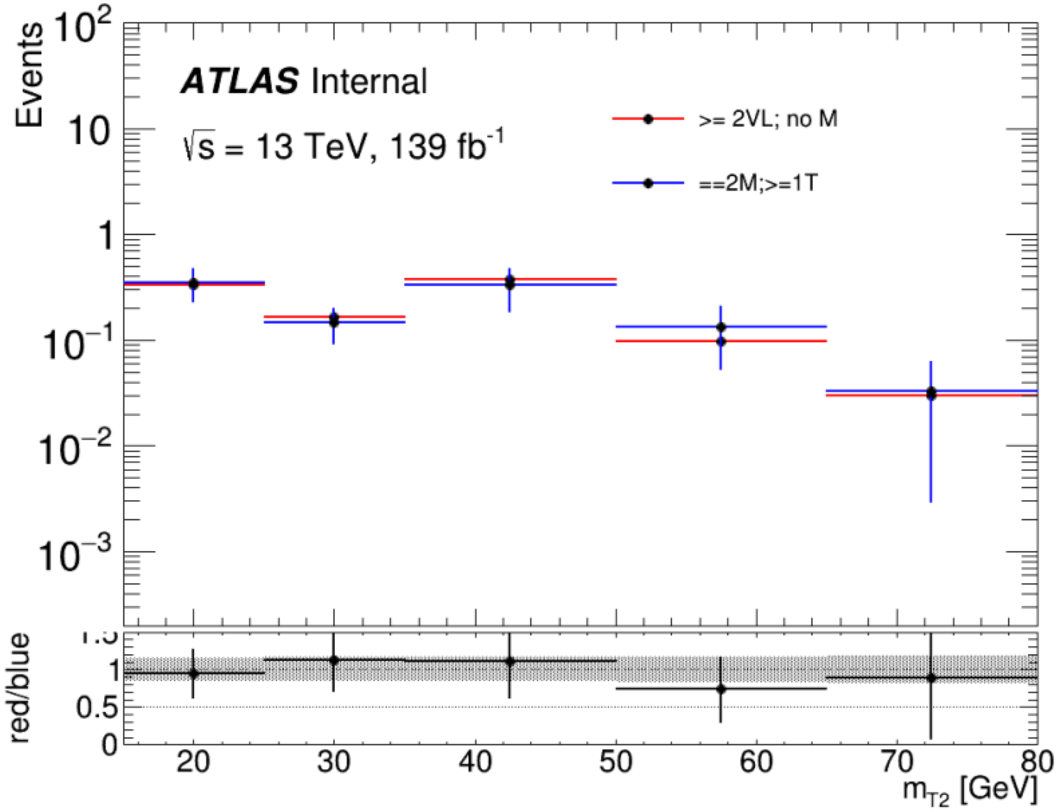
Multi-jet background estimation: regions definition

CR – A (C1C1-LM)	**SR – C1C1 – 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
VR – E (C1C1-LM)	**VR – F** (C1C1-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
CR – B (C1C1-LM)	**CR – C** (C1C1-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

Multi-jet background estimation

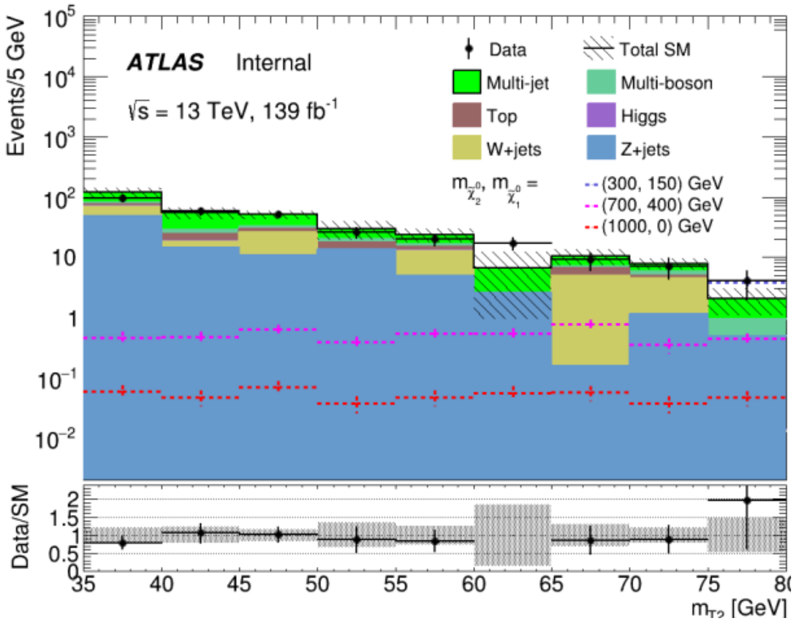
SR	Sample	CR-B	CR-C	VR-E	CR-A	T = C/B	Multi-jet in VR-F	Multi-jet in SR-D
SR-C1C1-LM	**Data**	**20564**	**1040**	**5728**	**98**	0.022 ± 0.006	92.91 ± 31.26	1.50 ± 0.47
	Z+jets	488.92 ± 67.08	363.04 ± 87.69	64.47 ± 23.53	4.17 ± 1.88			
	W+jets	923.94 ± 66.74	193.16 ± 55.82	406.51 ± 38.23	21.20 ± 5.22			
	Multi-boson	29.90 ± 2.00	34.00 ± 2.16	20.18 ± 1.85	1.97 ± 0.33			
	Top	53.21 ± 3.16	36.00 ± 2.47	45.45 ± 2.85	1.36 ± 0.46			
	Higgs	1.92 ± 0.83	1.15 ± 0.80	1.07 ± 0.35	0.02 ± 0.01			
	Multi-jet	*19066.13 ± 171.85*	*412.65 ± 108.89*	*5190.32 ± 88.06*	*69.25 ± 11.36*			
	Ref. point (300, 150)	26.77 ± 2.32	26.94 ± 2.37	36.16 ± 2.71	10.64 ± 1.52			

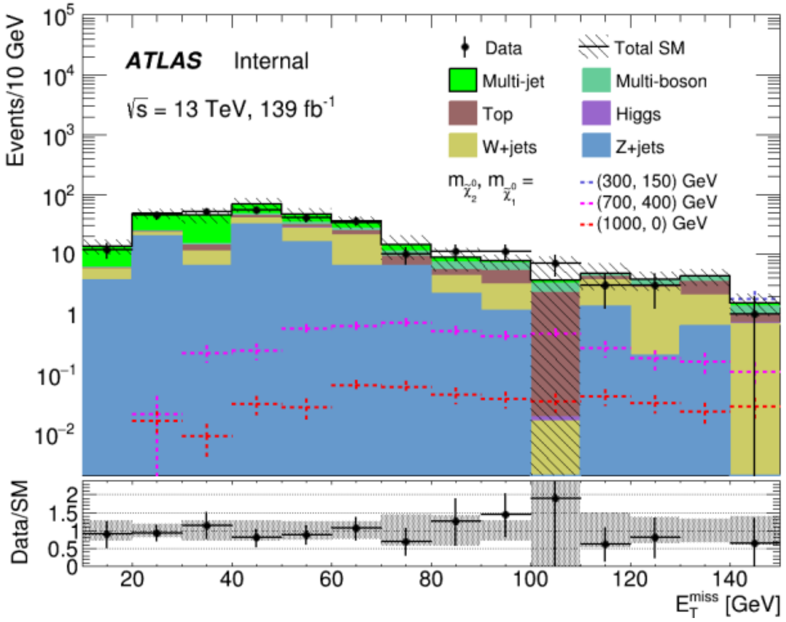
Multi-jet background estimation: correlation plot



Multi-jet background estimation: kinematic distribution in VR-F

Multi-jet events are
transfered from VR-E.





W-jets background estimation

Use W-CR to normalize W+jets, and validate by W-VR

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 $\mathrm{m_T}(\mu) < 140\,\mathrm{GeV}$ $\mathrm{E_T^{miss}} > 60\,\mathrm{GeV}$	
$40 < \mathrm{m_{T2}}(\tau,\mu) < 70\,\mathrm{GeV}$	$\mathrm{m_{T2}}(\tau,\mu) > 70\,\mathrm{GeV}$

Irreducible background estimation

Only validate these bkgs

Top-VR1	Top-VR2	Z-VR1	Z-VR2	MB-VR1	MB-VR2
$\tau - \tau$ channel					
≥ 2 medium taus (OS), ≥ 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					

How to design

- How to design VR
  - orthogonal,
  - close to signal region,
  - the number of bkg to be validated should be large.
- How to design CR
  - 2 uncorrelated arguments for ABCD method,
  - orthogonal,
  - small signal contamination,
  - large statistics(loose cut),
  - high purity for one type of background.

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THE END