Search for direct stau production with the ATLAS detector

Chenzheng Zhu

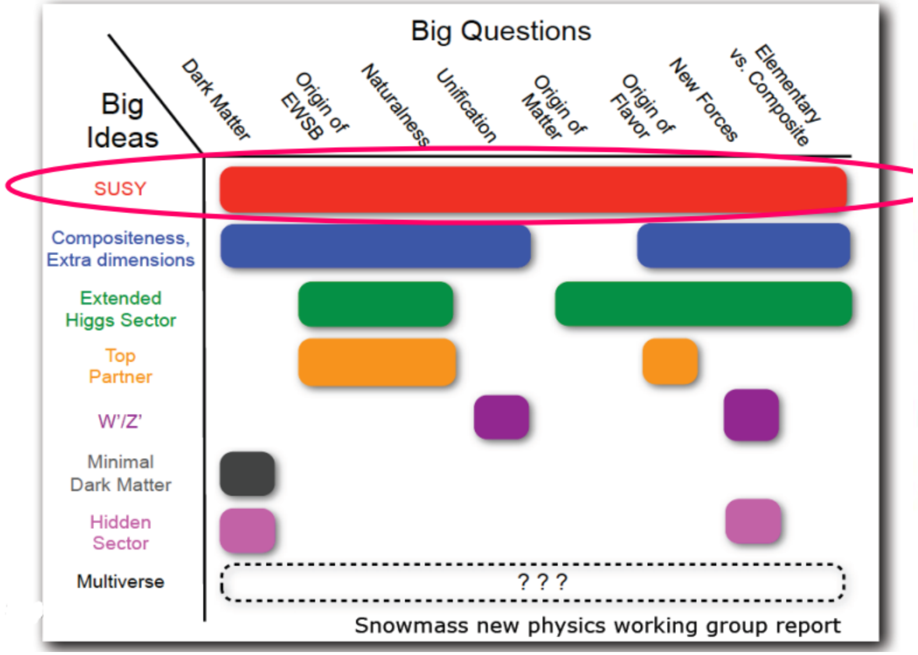
On behalf of ATLAS Collaboration

CLHCP2018, Wuhan

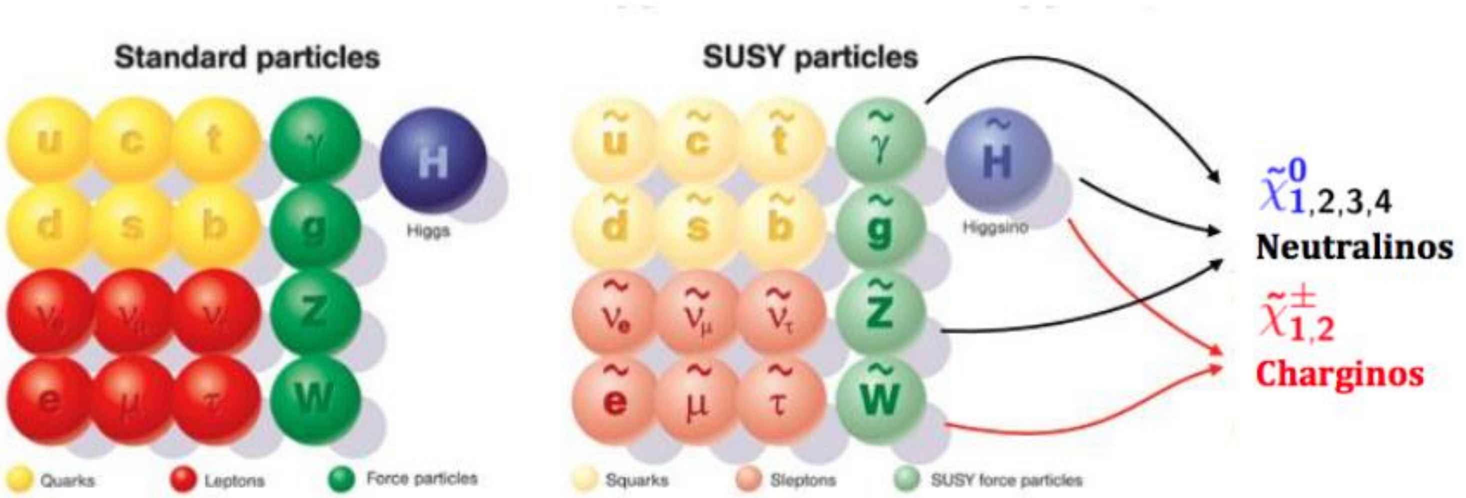
19-22,Dec,2018

中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

Introduction



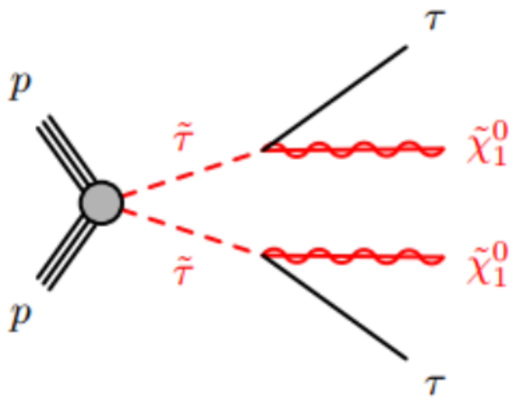
Snowmass new physics working group report



- Supersymmetry: one of the most appealing BSM theories
  - Solve problems such as hierarchy problem, grand unification of gauge couplings, dark matter…
- If SUSY is at TeV scale, it will be produced copiously at LHC
- SUSY search is one of the most hot topics at LHC and beyond

Analysis Overview

- **Motivation**
  - In many SUSY scenarios with large tanβ, the stau is lighter than the selectron and smuon, resulting in tau-rich final states.
  - Direct stau pair production might become one of dominant EWK Prod if charginos and next-to-lightest neutralinos too heavy.

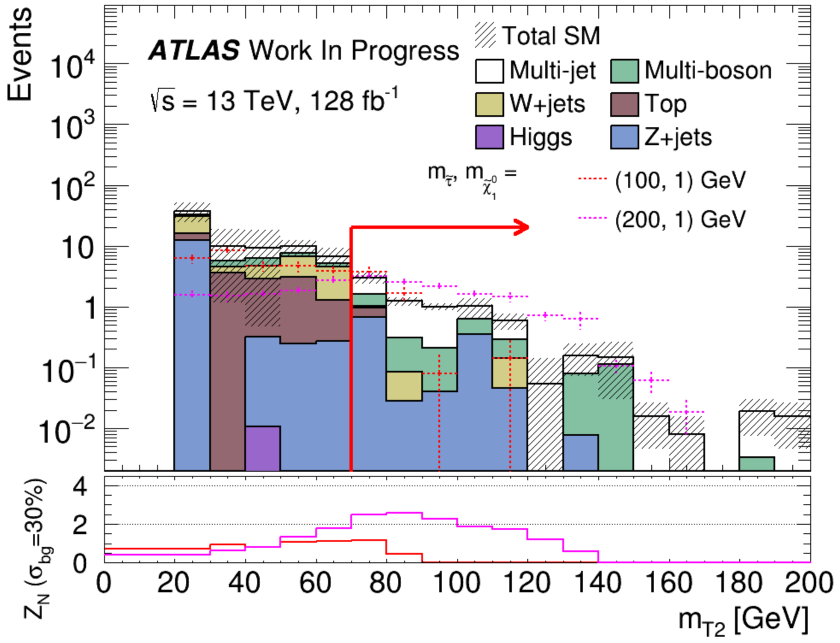


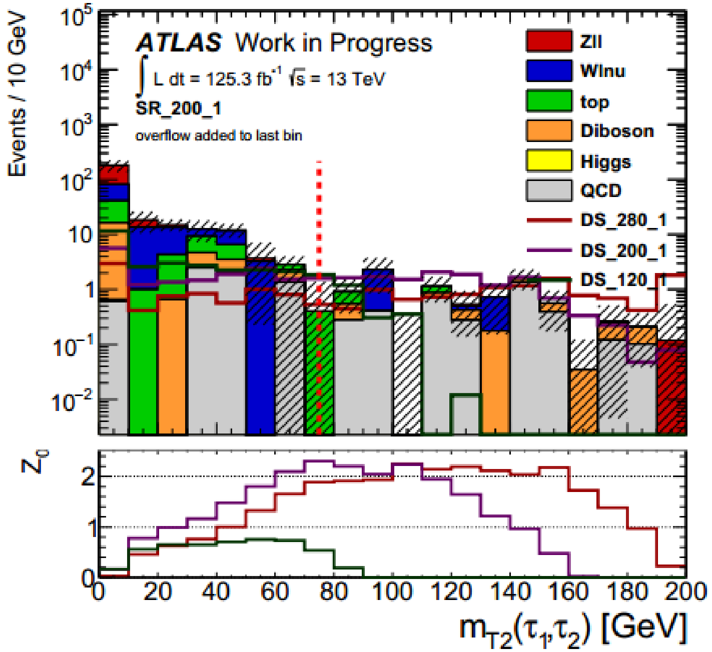
- **Signature**
  - Events with two hadronic taus, low jet activity and MET
- **Goal:**
  - Study the sensitivity of direct stau production using 13TeV pp collision data recorded by ATLAS Detector from 2015-2018 with integrated luminosity of 140 fb^{-1}
  - Study the prospect of sensitivity of direct stau production at the 14TeV HL-LHC with integrated luminosity of 3000 fb^{-1} and upgraded ATLAS Detector

Direct Stau Run-2: Signal region Optimization

- Method: **Cut and Count** method for each benchmark point based on **Zn**
  - $Z_n = \sqrt{2}\,\mathrm{erf}^{-1}(1-2p)$ where $p \propto \int_0^{\infty} db\, G(b; N_b, \delta b) \sum_{i=N_{s+b}}^{\infty} \frac{e^{-b} b^i}{i!}$

- Two SRs are designed to improve the sensitivity of signal models with for different mass difference between the $\tilde{\tau}$ and $\tilde{\chi}_1^0$





(a) m_{T2}

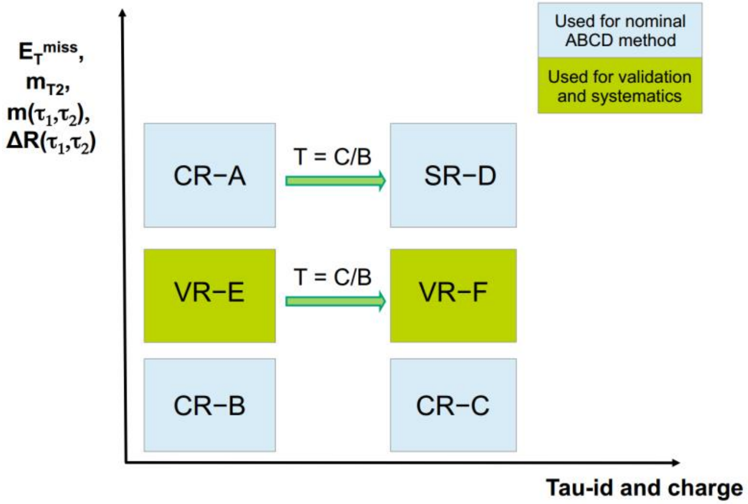
The m_{T2} distribution in the SR-lowMass and SR-highMass for each background process and signal benchmark points

Direct Stau Run-2: Background estimation

- Reducible backgrounds: (>= 1 fake tau)
  - **Multi-jet background**: Using Data-driven ABCD method and fake factor method
  - **W+jets**: Using a dedicated control region (W-CR) to normalize it to data

- Irreducible background estimation
  - mainly from $t\bar{t}$, single top quark, $t\bar{t}$+V, Z+jets, and diboson (WW, WZ and ZZ)
  - Estimated based on MC simulation
  - Using a dedicated validation region to validate the MC production

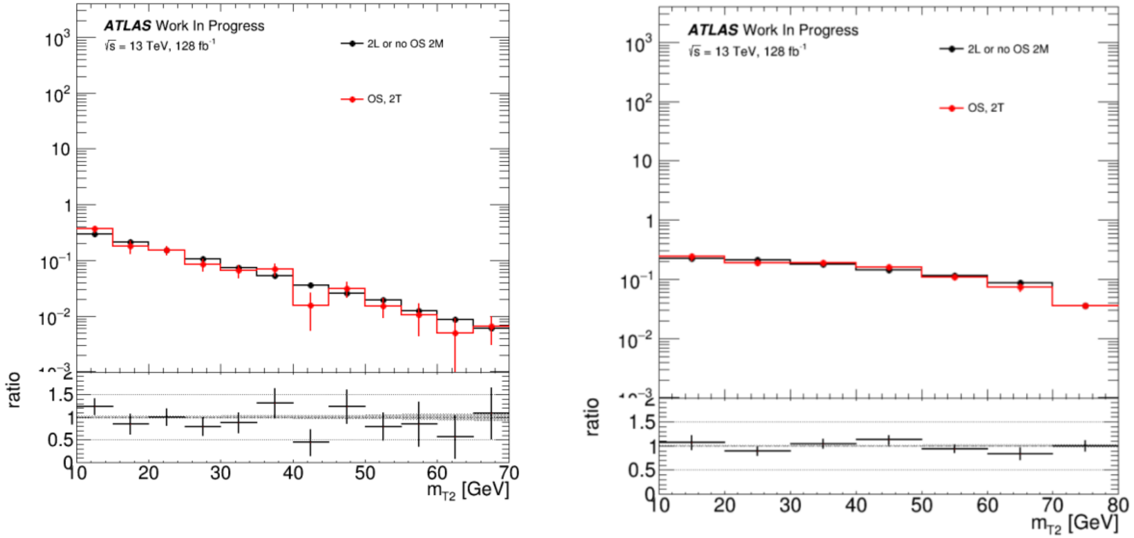
Direct Stau Run-2: Multi-jet estimation



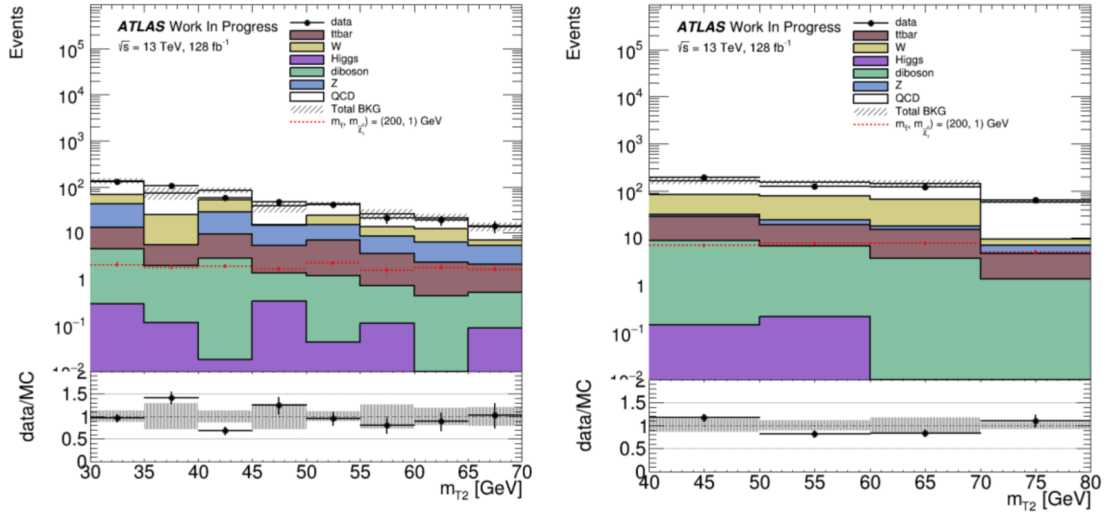
ABCD Method

- Four exclusive regions, labelled as A, B, C, and D are defined in a two-dimensional plane as a function of two (or more) uncorrelated discriminating variables
- Multi-jet in SR_D: $N_D = N_A \times TF$ while $TF = N_C/N_B$
- Two sets of validation regions (VR), are defined to verify the extrapolation of the ABCD estimation to the SRs and estimate the systematic uncertainty

• Also used another method: Fake factor method as another method/cross check



The m_{T2} correlation check for ABCD method in the SR-lowmass(left) and SR-highmass(right)



The m_{T2} distributions in the VR-F lowmass(left) and VR-F highmass (right) regions

Direct Stau Run-2: W+jet estimation

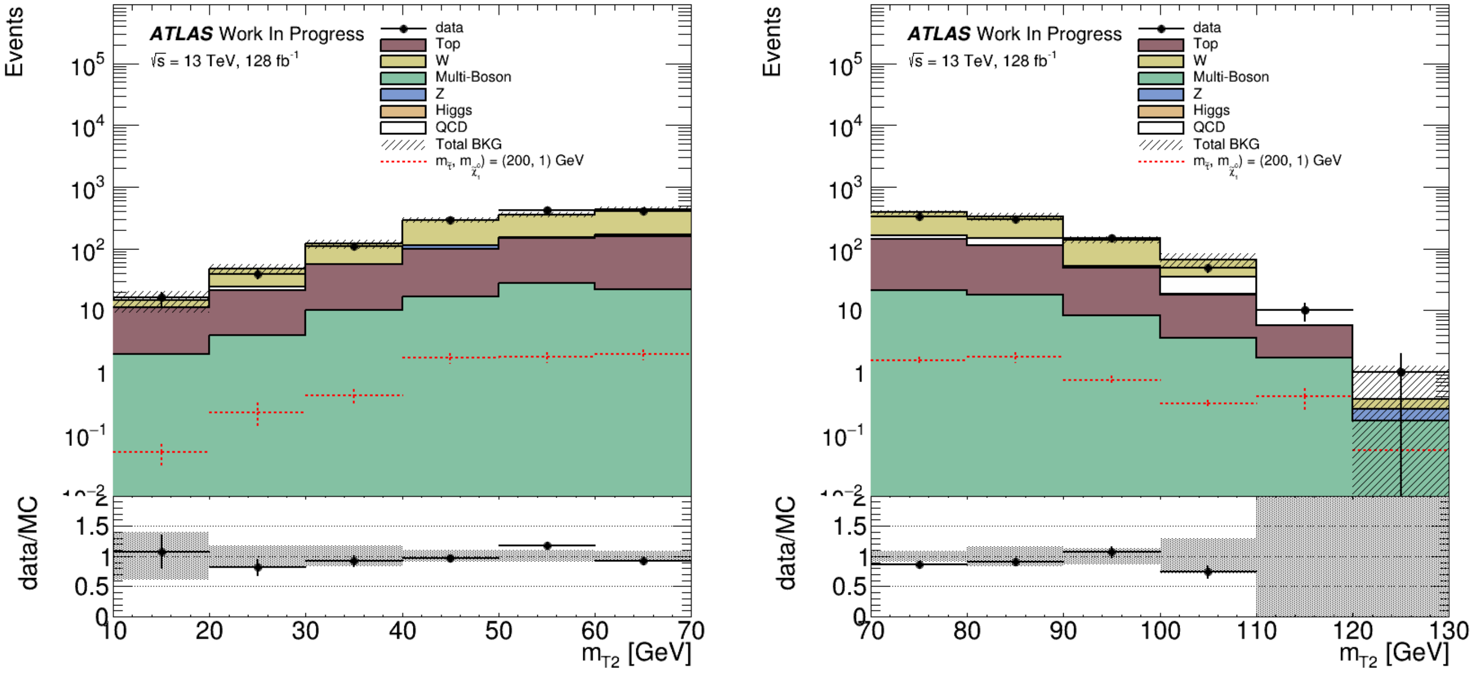
- Derive normalization factor by fitting in W-CR, and apply the NF to W-VR for validation

- Definition:

W-CR	*W*-VR
pass HLT_mu26_ivarmedium	
Exactly one isolated muon and one medium tau lepton with opposite sign	
$p_{inv}(\tau) > 50$ GeV, $p_T(\mu) > 50$ GeV	
b-veto	
$50 < m_T(\mu) < 150$ GeV	
$m(\mu, \tau) > 70$ GeV	
$E_T^{miss} > 60$ GeV	
$m_T(\tau) + m_T(\mu) > 250$ GeV	
$1 < \Delta R(\tau, \mu) < 3.5$	$1 < \Delta R(\tau, \mu) < 4.5$
$10\,\text{GeV} < m_{T2}(\tau, \mu) < 70$ GeV	$m_{T2}(\tau, \mu) > 70$ GeV

- High W+jets purity

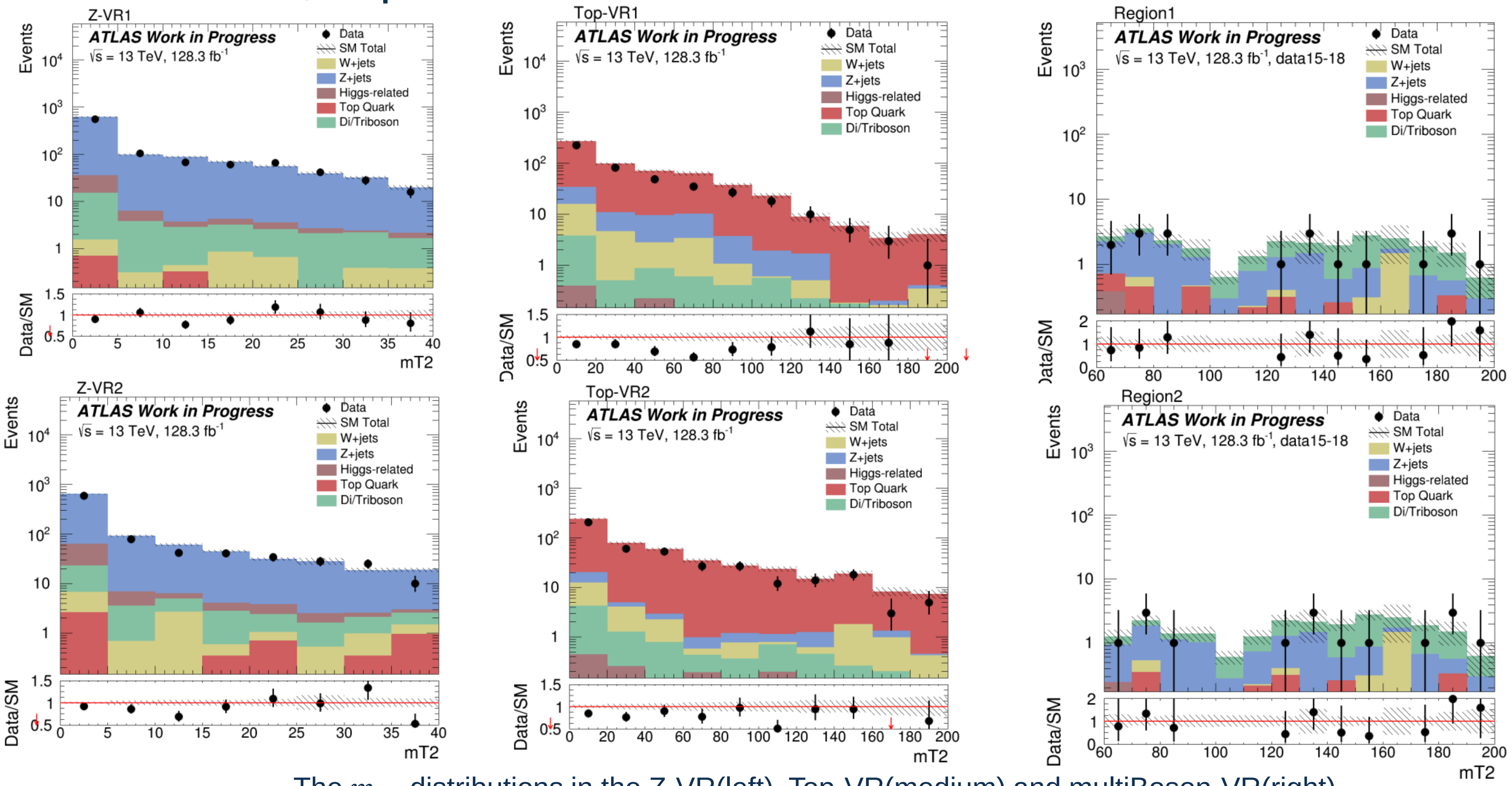
- Reasonable Data/MC agreement



The m_{T2} distributions in the W-CR (left) and W-VR (right) regions after applied the NF derived by WCR

Direct Stau Run-2: Irreducible background estimation

- Use Z-VR, Top-VR and multiBoson-VR to validate them



The m_{T2} distributions in the Z-VR(left), Top-VR(medium) and multiBoson-VR(right)

- High background purity in their validation region
- Agreement between data and SM predictions is observed

Direct Stau Run-2: Systematic uncertainty and Interpretation

- Systematics
  - Uncertainties in ABCD Method is estimated
  - For other systematics, currently use the 30% inclusive systematic from the experience of the previous study

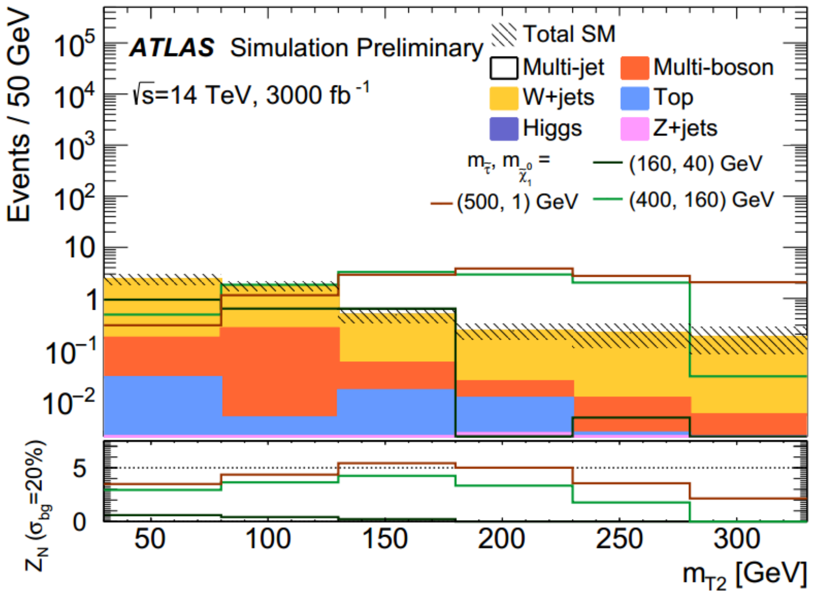
- Get promising result and it will be released soon!

Direct Stau Upgrade: Signal region Optimization

- Method:
  - **Cut and Count** method for each benchmark point based on **Zn**
  - The **multi-bin fit** method is also used to better explore the sensitivity at the high mass split region
- Signal region Definition
  - Three SRs and one multi-bin SR are designed to improve the sensitivity

Common Selection				
exactly two tight taus with opposite sign				
e/μ veto, b-jet veto				
$m_{\tau\tau} > 100$ GeV (Z-veto)				
$E_{\mathrm{T}}^{\mathrm{miss}} > 200$ GeV				
$p_{\mathrm{T}\tau2} > 75$ GeV				
$\Delta R(\tau1, \tau2) < 3$				
$\Delta\phi(\tau1, \tau2) > 2$				
Selection	**SR-low**	**SR-med**	**SR-high**	**SR-exclHigh**
jet veto threshold	$p_{\mathrm{T\,jet}} > 40$ GeV	$p_{\mathrm{T\,jet}} > 40$ GeV	$p_{\mathrm{T\,jet}} > 20$ GeV	$p_{\mathrm{T\,jet}} > 100$ GeV
$p_{\mathrm{T}\tau1} >$	150 GeV	200 GeV	200 GeV	200 GeV
$m_{\mathrm{T}\tau1} + m_{\mathrm{T}\tau2} >$	500 GeV	700 GeV	800 GeV	800 GeV
$m_{\mathrm{T2}}(\tau1, \tau2)$	$\in$ [80 GeV, ∞]	$\in$ [130 GeV, ∞]	$\in$ [130 GeV, ∞]	$\in$ [80 GeV, 130 GeV] $\in$ [130 GeV, 180 GeV] $\in$ [180 GeV, 230 GeV] $\in$ [230 GeV, ∞]

Signal region definition used for the direct stau upgrade study



The m_{T2} distribution in the SR-high for each background process and signal benchmark points

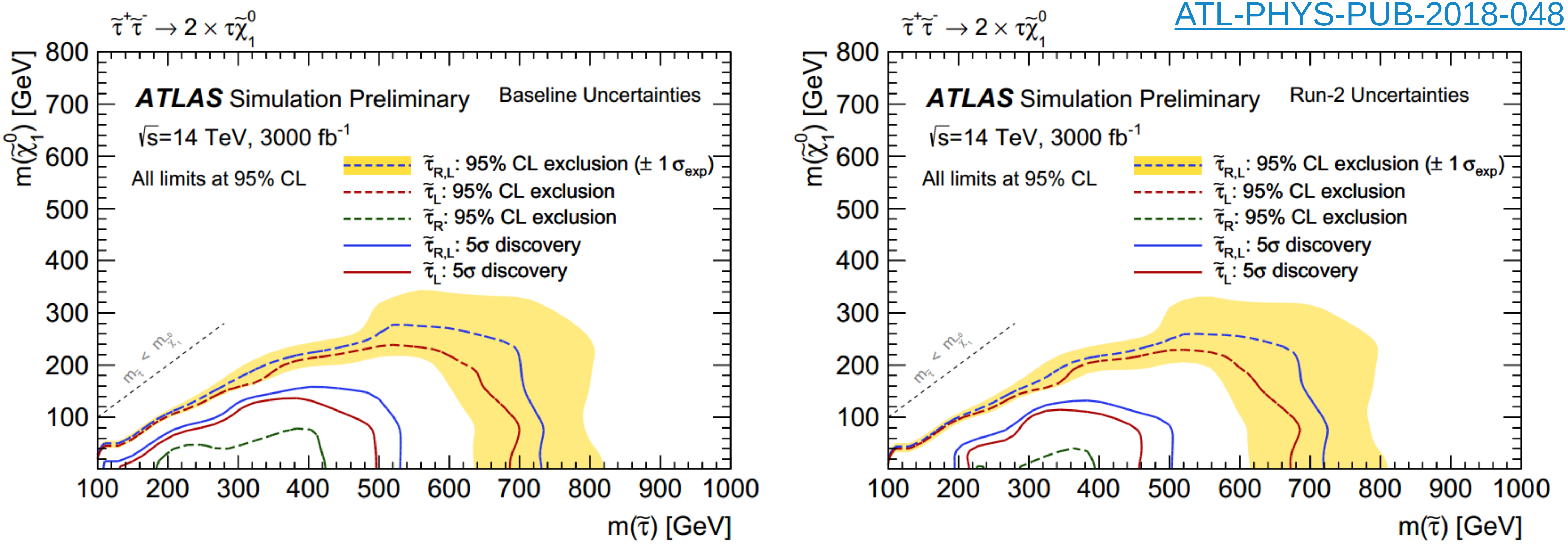
Direct Stau Upgrade: Systematic uncertainty

- Two kinds of assumption are used.

- baseline assumption:
  - The dominant systematic uncertainties are scaled/using the upgrade recommended treatment value
  - Total background systematic uncertainties ~21% and Total signal systematic uncertainties ~ 14%
- Run-2 assumption
  - Assume no improvement in upgrade layout and take the Run-2 value
  - Total background systematic uncertainties ~38% and Total signal systematic uncertainties ~ 21%

Direct Stau Upgrade: The 95% Confidence level exclusion limit

ATL-PHYS-PUB-2018-048



(a) Baseline Uncertainties

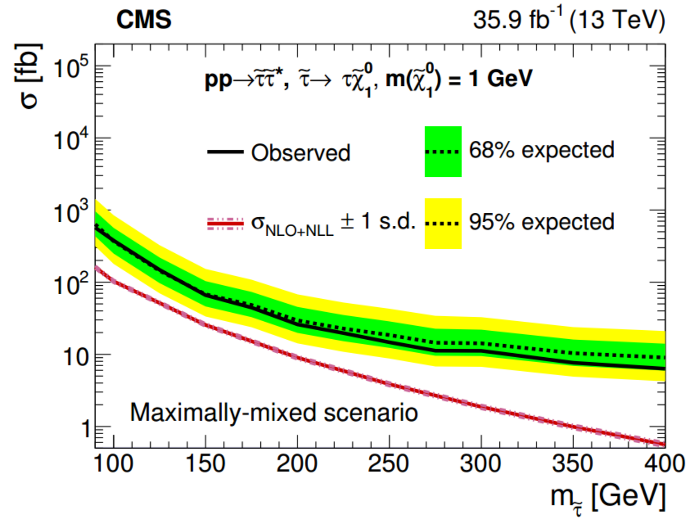
(b) Run-2 Uncertainties

- There is a discovery potential from 120 to 530 GeV with a massless LSP for the combined production, while 140 – 500 GeV for LH production only.
- The exclusion limit reaches to 730 GeV for the combined production while 690 GeV for the LH production and 420 GeV for RH production
- Slightly decrease for the limits for the result of Run-2 uncertainties.

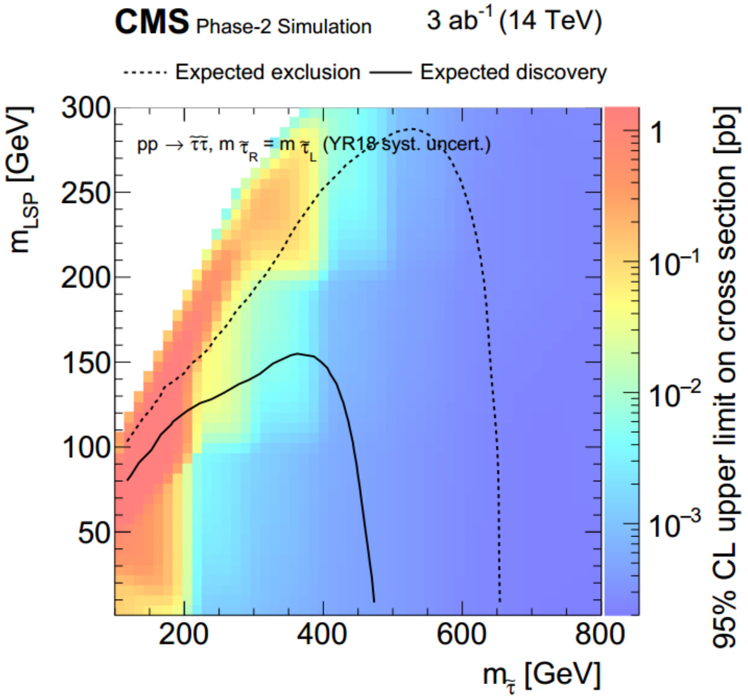
Direct Stau: CMS results

- Run-2: Got some results using the 2016 data. No exclusion yet.

- Upgrade: Also got fine exclusion/discovery potential limit. Some differences in the limit which due to:
  - Included the lep-had tau decay channel
  - Different definition of the tau object
  - Defined many search bins based on different M_{T2} category
  - The parameterization of the detectors response and the methods used for reconstructing….



JHEP 11 (2018) 151



CMS-PAS-FTR-18-010

Summary and Outlook

- Summary
  - The SUSY search for the direct stau production with at least two hadronically decaying taus in the final state using 2015-2018 Run-2 data are in progress and the prospect study at HL-LHC are done (pubNote: ATL-PHYS-PUB-2018-048)
  - Limits on the direct stau are significantly extended compared with previous study and there is a discovery potential for this production at the HL-LHC
- Outlook
  - Direct stau Run-2 study: We'll have first LHC sensitivity, the results coming soon, stay tuned please!

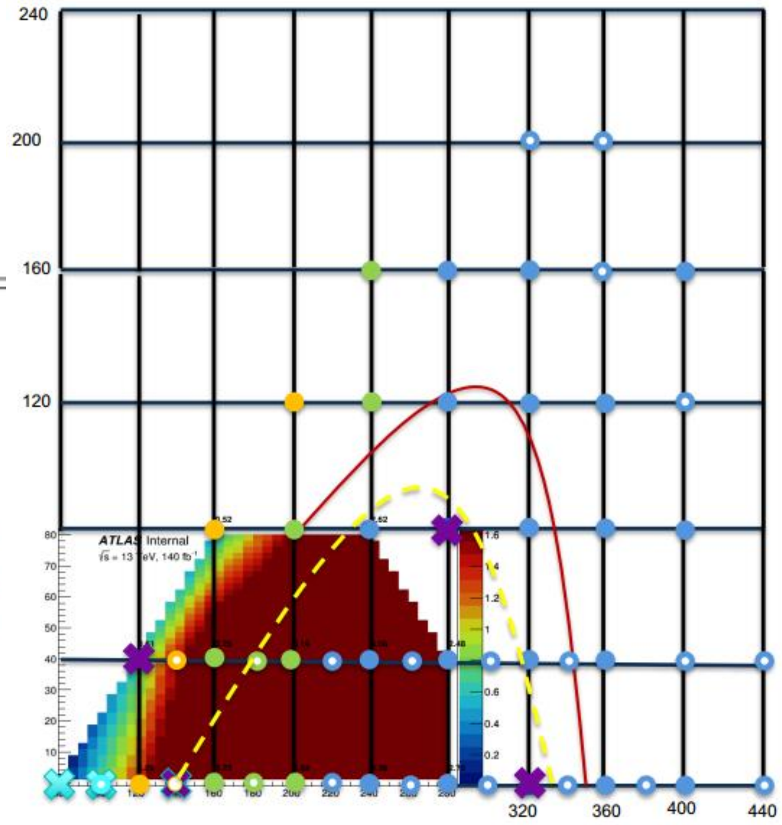
BackUp

Direct Stau Run-2: Signal and background samples

- Signal samples:
  - Use point (140,1), (200,1) and (320,1) as benchmark for the Signal Region Optimization
- Background samples: Use MC16a+MC16d+MC16e with p3529

Table 1: List of SM MC generators used for the background modelling.

Process	ME Generator	Parton Shower	PDF	Tune
$t\bar{t}W$	MG5_aMC	Pythia 8	NNPDF 2.3 LO	A14
$t\bar{t}(Z/\gamma^*)$	MG5_aMC	Pythia 8	NNPDF 2.3 LO	A14
$t\bar{t}$	Powheg-BOX	Pythia 8	CT10/CTEQ6L1	Perugia2012
s-, t-channel, Wt single top	Powheg-BOX	Pythia 6	CT10/CTEQ6L1	Perugia2012
VV, $qqVV$, VVV	Sherpa 2.2.1	Sherpa	CT10	Sherpa default
$Z \rightarrow \ell^+\ell^-$	Sherpa 2.2.1	Sherpa	CT10	Sherpa default
$W \rightarrow \ell\nu$	Sherpa 2.2.1	Sherpa	CT10	Sherpa default



Signal grid

Direct Stau Run-2: Object definitions & Overlap removal

- Following the corresponding performance groups recommendations for the Run 2 analyses
- Object definition :
  - Baseline taus
    - medium, pt > 20 GeV, $|\eta|$ < 2.5, exclude 1.37 < $|\eta|$ < 1.52, 1 or 3 tracks (prongs) and a total track charge equals ± 1
  - Baseline electrons
    - pt > 27 GeV, $|\eta|$ < 2.47, MediumLH or TightLH, $|z_0 sin\theta| < 0.5mm$, $\left|\frac{d_0}{\sigma(d_0)}\right| < 5$
  - Baseline muons
    - pt > 27 GeV, $|\eta|$ < 2.5, medium, $|z_0 sin\theta| < 0.5mm$, $\left|\frac{d_0}{\sigma(d_0)}\right| < 3$, ptvarcone < 1.25GeV
  - Baseline jets
    - anti-kt4 jets, pt > 25 GeV, $|\eta|$ < 2.5, JVT > 0.59 (or pt > 60GeV, or 2.4 < $|\eta|$ < 2.5). For b-tag, use MV2c10 @ 70%OP
- The Overlap Removal is based on the SUSY recommendation

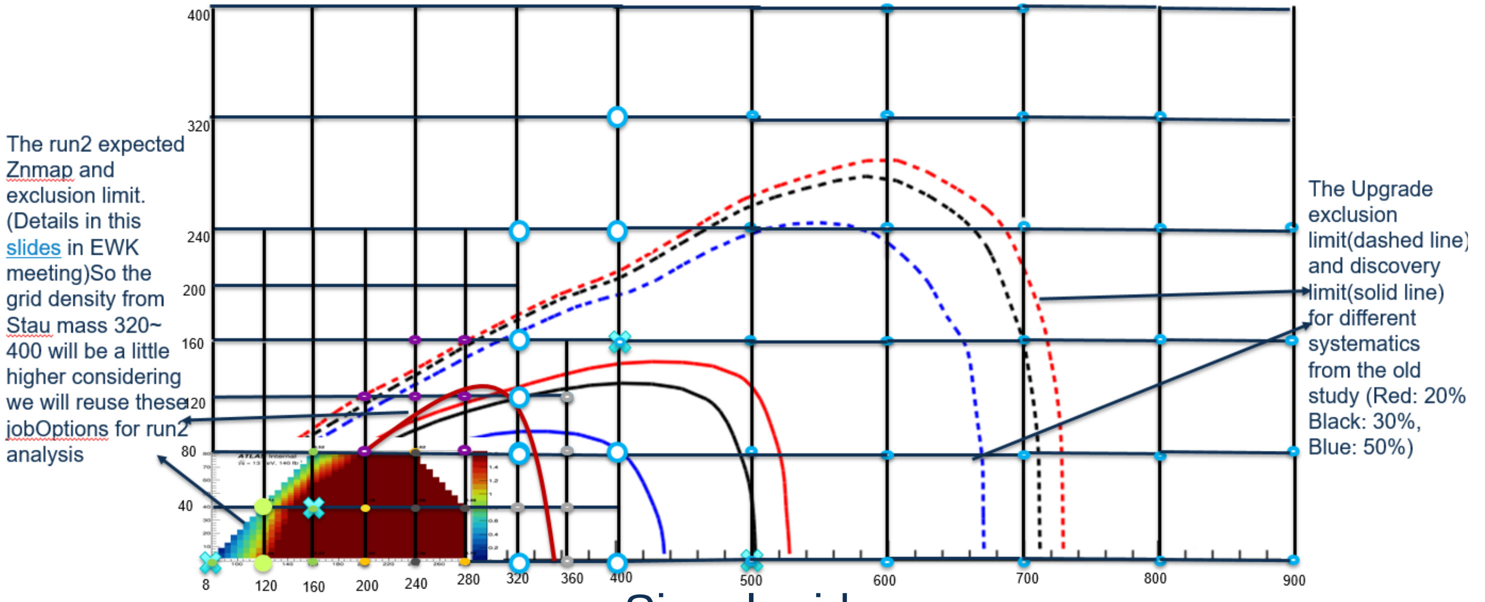
Direct Stau Run-2: Trigger

- The trigger used in direct stau Run-2 study
- To ensure that only events in the plateau region of the trigger are selected, additional requirements are applied

Trigger type	offline threashold	Trigger name	data18	data17	data16	data15
tau-tau channel						
Asym di-tau	tau1>95, tau2>65	HLT_tau80_medium1_tracktwo_L1TAU60_tau50_medium1_tracktwo_L1TAU12	L	O	O	O
	tau1>95, tau2>75	HLT_tau80_*medium1_tracktwo_L1TAU60*_tau60_medium1_tracktwo_L1TAU40	O	O(from B1)	X	X
		HLT_tau80_*medium1_tracktwoEF_L1TAU60*_tau60_medium1_tracktwoEF_L1TAU40	O	X	X	X
		HLT_tau80_*mediumRNN_tracktwoMVA_L1TAU60*_tau60_mediumRNN_tracktwoMVA_L1TAU40	O(from K1)	X	X	X
MET	MET>200	HLT_xe70_mht				O
		HLT_xe90_mht_L1XE50			until D3	
		HLT_xe110_mht_L1XE50			from D4	
		HLT_xe110_pufit_L1XE55		O		
		HLT_xe110_pufit_xe70_L1XE50	O			
di-tau+ XE50	tau1>50, tau2>40, MET>130	HLT_tau35_medium1_tracktwo_tau25_medium1_tracktwo_xe50	L	O	O	O
	tau1>75, tau2>40, MET>130	HLT_tau60_medium1_tracktwo_tau25_medium1_tracktwo_xe50	O	O(from B1)	X	X
		HLT_tau60_*medium1_tracktwoEF*_tau25_*medium1_tracktwoEF*_xe50	O	X	X	X
		HLT_tau60_*mediumRNN_tracktwoMVA*_tau25_*mediumRNN_tracktwoMVA*_xe50	O(from K1)	X	X	X

Direct Stau Upgrade: Signal and background samples

- Signal samples:
  - Use point (160,40), (400,160) and (500,1) as benchmark for the Signal Region Optimization



Signal grid

- Background samples:

Process	Generator + fragmentation/hadronisation	Tune	PDF set	Cross-section order
W/Z+jets	Powheg-Box v1 [32] + Pythia 8.186 [33] Sherpa 2.2.1 [30]	AZNLO Default	CTEQ6L1 NNPDF30NNLO [34]	NNLO NNLO
$t\bar{t}$	Powheg-Box v2 + Pythia 8.186	A14	NNPDF23LO [25]	NNLO+NNLL
Single top	Powheg-Box v1 or v2 + Pythia 6.428 [35]	Perugia2012 [36]	CT10 [37]	NNLO+NNLL
Diboson (fully leptonic) (semi leptonic)	Sherpa 2.2.1 Powheg-Box v1 + Pythia 8.186	Default AZNLO [38]	NNPDF30NNLO CTEQ6L1	NLO NLO
Triboson	Sherpa 2.2.2	Default	NNPDF30NNLO	NLO
$t\bar{t}+X$	MadGraph 2.2.2 [22] + Pythia 8.186	A14	NNPDF23LO	NLO
Higgs	Powheg-Box v2 + Pythia 8.186	AZNLO	CTEQ6L1	NNLO+NNLL
Multijet	Pythia 8.186	AU2 [39]	CT10	NLO

Direct Stau Upgrade: Object selection

- Candidate taus
  - hadronically decaying, p_T > 20 GeV, $|\eta|$ <4
- Candidate leptons
  - p_T > 10 GeV, $|\eta|$ < 2.47(2.5) for electron(muon)
- Candidate jets
  - anti-kt4 jets, p_T > 20 GeV, $|\eta|$ < 4

Overlap removeral	
DeltaR(e, e) < 0.05	Drop the e
DeltaR(e, μ) < 0.01	Drop the e
DeltaR(e, jet) < 0.4	Drop the e
DeltaR(μ, jet) < 0.4	Drop the μ
DeltaR(jet, e) < 0.2	Drop the jet
DeltaR(jet,τ) < 0.2	Drop the jet
DeltaR(τ, e) < 0.2	Drop the τ
DeltaR(τ,μ) < 0.2	Drop the τ

- Fake taus from jets are estimated based on the fake rate, using a re-weighting method by applying the fake rate of the jets into event weight. Cases with more than 3 fake taus are not considered due to the negligible probability ($< 10^{-6}$)

- Fake electrons, muons from jets are estimated using a random number method since they don't have large influence.

Direct Stau Upgrade: Event yields and N-1 distributions in SR

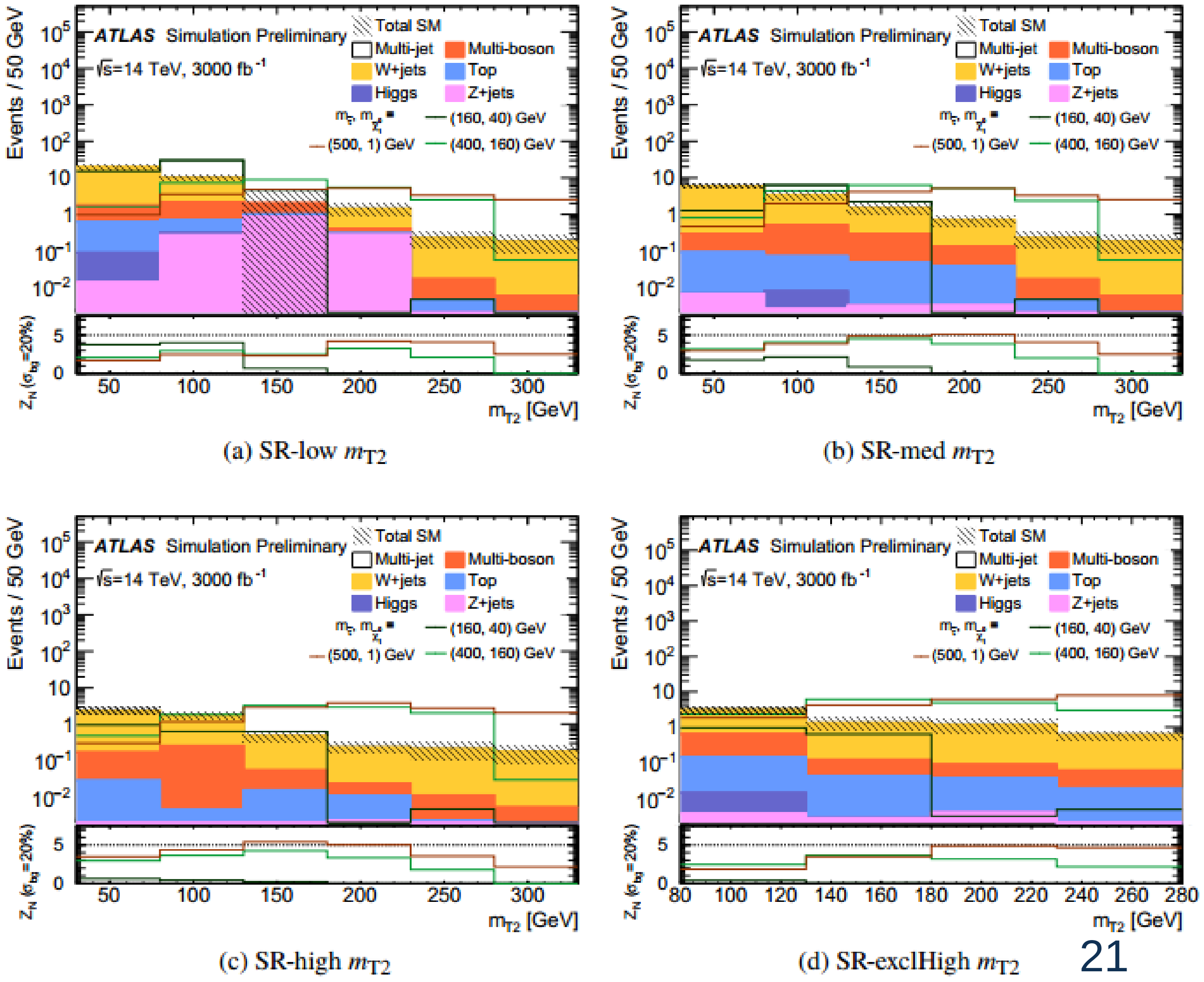
- Yileds in three nominal SR

	SR-low	SR-med	SR-high
W+jets	8.8 ± 2.8	2.12 ± 0.56	1.00 ± 0.21
Multi-boson	2.6 ± 1.3	0.35 ± 0.18	-
Z/γ^* + jets	1.4 ± 1.0	-	-
Other SM	0.98 ± 0.40	-	-
SM total	13.8 ± 3.3	2.57 ± 0.58	1.10 ± 0.21
$m(\tilde{\tau}_L/\tilde{\tau}_R, \tilde{\chi}_1^0)$ = (160, 40) GeV	34.9 ± 7.2	2.2 ± 1.6	0.63 ± 0.44
$m(\tilde{\tau}_L/\tilde{\tau}_R, \tilde{\chi}_1^0)$ = (400, 160) GeV	24.1 ± 1.6	13.8 ± 1.2	8.3 ± 1.0
$m(\tilde{\tau}_L/\tilde{\tau}_R, \tilde{\chi}_1^0)$ = (500, 1) GeV	19.4 ± 1.5	15.0 ± 1.3	11.6 ± 1.2

- Yields in the multi-bin SR

	SR-exclHigh			
m_{T2} [GeV]	[80, 130]	[130, 180]	[180, 230]	[230, ∞]
W+jets	2.42 ± 0.52	1.22 ± 0.26	1.10 ± 0.24	0.54 ± 0.12
Multi-boson	0.49 ± 0.10	0.08 ± 0.02	0.05 ± 0.01	0.04 ± 0.01
Z/γ^* + jets	-	-	-	-
Other SM	0.14 ± 0.03	0.04 ± 0.01	0.03 ± 0.01	0.02 ± 0.00
SM total	3.06 ± 0.44	1.34 ± 0.18	1.19 ± 0.15	0.60 ± 0.06
$m(\tilde{\tau}_L/\tilde{\tau}_R, \tilde{\chi}_1^0)$ = (160, 40) GeV	0.96 ± 0.13	0.63 ± 0.09	0.00 ± 0.00	0.00 ± 0.00
$m(\tilde{\tau}_L/\tilde{\tau}_R, \tilde{\chi}_1^0)$ = (400, 160) GeV	4.79 ± 0.67	9.11 ± 1.28	6.43 ± 0.90	2.97 ± 0.42
$m(\tilde{\tau}_L/\tilde{\tau}_R, \tilde{\chi}_1^0)$ = (500, 1) GeV	1.84 ± 0.26	4.21 ± 0.59	5.99 ± 0.84	7.81 ± 1.10

- N-1 distribution for MT2 var In SR



(a) SR-low m_{T2}

(b) SR-med m_{T2}

(c) SR-high m_{T2}

(d) SR-exclHigh m_{T2}

Direct Stau Upgrade: Systematics

- The Run-2 systematic used for the upgrade study. They will be scaled by the recommended treatment

Uncertainty of channel	SRcut_cuts_C1C1_500.0_0.0
Total signal expectation	19.64
Total statistical ($\sqrt{N_{\text{exp}}}$)	±4.43
Total signal systematic	±4.10 [20.85%]
alpha_TAUS_TRUEHADTAU_EFF_JETID_TOTAL	±2.30 [11.7%]
alpha_SigXSec	±1.73 [8.8%]
alpha_TAUS_TES_INSITU	±1.40 [7.1%]
alpha_TAUS_TES_DETECTOR	±1.25 [6.3%]
alpha_Trig_16statdata	±1.04 [5.3%]
alpha_Trig_16statmc	±1.02 [5.2%]
alpha_TAUS_TRUEHADTAU_EFF_RECO_TOTAL	±0.91 [4.6%]
alpha_TAUS_TRUEHADTAU_EFF_ELEOLR_TOTAL	±0.62 [3.1%]
alpha_TAUS_TRUEHADTAU_EFF_JETID_HIGHPT	±0.34 [1.7%]
alpha_JER	±0.27 [1.4%]
alpha_TAUS_TES_MODEL	±0.18 [0.90%]
alpha_Trig_15statdata	±0.16 [0.83%]
alpha_Trig_16syst	±0.14 [0.73%]
alpha_Trig_15statmc	±0.10 [0.48%]
alpha_TAUS_TRUEHADTAU_EFF_RECO_HIGHPT	±0.09 [0.44%]
alpha_JES_Group1	±0.08 [0.39%]
alpha_PRW_DATASF	±0.05 [0.28%]
alpha_MET_SoftTrk_ResoPerp	±0.05 [0.27%]
alpha_JES_Group3	±0.05 [0.24%]
alpha_JvtEfficiency	±0.04 [0.23%]
alpha_MET_SoftTrk_ResoPara	±0.04 [0.18%]
alpha_Trig_15syst	±0.02 [0.08%]
alpha_JET	±0.01 [0.07%]
alpha_JES_Group2	±0.01 [0.05%]

Signal

Uncertainty of channel	SR_highmass
Total background expectation	3.70
Total statistical ($\sqrt{N_{exp}}$)	±1.92
Total background systematic	±1.41 [38.00%]
mu_QCD	±1.15 [31.2%]
gamma_stat_SR_highmass_bin_0	±0.89 [24.2%]
alpha_FakeTauBGQCR	±0.47 [12.6%]
alpha_TAUS_TES_INSITU	±0.31 [8.4%]
alpha_PRW_DATASF	±0.30 [8.1%]
alpha_MET_SoftTrk_ResoPerp	±0.23 [6.2%]
alpha_TAUS_TRUEHADTAU_EFF_JETID_TOTAL	±0.17 [4.7%]
alpha_JES_Group1	±0.16 [4.4%]
alpha_errZjets	±0.16 [4.2%]
alpha_TAUS_TES_MODEL	±0.15 [4.0%]
alpha_TAUS_TES_DETECTOR	±0.15 [3.9%]
mu_W	±0.10 [2.8%]
alpha_DibosonResummationTheo_SR	±0.09 [2.5%]
alpha_DibosonRenormTheo_SR	±0.09 [2.4%]
alpha_TAUS_TRUEHADTAU_EFF_RECO_TOTAL	±0.08 [2.2%]
alpha_WjetsRenormTheo_SR	±0.07 [1.8%]
alpha_errDiboson	±0.06 [1.6%]
alpha_JES_Group3	±0.05 [1.3%]
alpha_Trig_16statmc	±0.04 [1.2%]
alpha_JET	±0.04 [1.2%]
alpha_JER	±0.04 [1.2%]
alpha_Trig_15statdata	±0.04 [1.2%]
alpha_TAUS_TRUEHADTAU_EFF_ELEOLR_TOTAL	±0.03 [0.79%]
alpha_Trig_16statdata	±0.03 [0.73%]
alpha_WjetsResummationTheo_SR	±0.02 [0.64%]
alpha_Trig_15statmc	±0.02 [0.57%]
alpha_TAUS_TRUEELECTRON_EFF_ELEOLR_TOTAL	±0.02 [0.55%]
alpha_MET_SoftTrk_ResoPara	±0.02 [0.53%]
alpha_DibosonFacTheo_SR	±0.01 [0.36%]
alpha_WjetsFacTheo_SR	±0.01 [0.33%]
alpha_JES_Group2	±0.01 [0.30%]
alpha_Trig_15syst	±0.01 [0.26%]
alpha_MET_SoftTrk_Scale	±0.01 [0.21%]
alpha_MUON_ID	±0.01 [0.20%]
alpha_Trig_16syst	±0.01 [0.20%]
alpha_errTop	±0.01 [0.19%]
alpha_MUON_MS	±0.01 [0.16%]
alpha_TAUS_TRUEHADTAU_EFF_RECO_HIGHPT	±0.01 [0.15%]
alpha_JvtEfficiency	±0.01 [0.14%]

Background

Direct Stau Upgrade: Systematics

- The recommended treatment in HL-LHC(details here)

PDF uncertainties HLLHC / Current	10 GeV < M_X < 40 GeV	40 GeV < M_X < 1 TeV	1 TeV < M_X < 6 TeV
gluon-gluon luminosity	0.58 (0.49)	0.41 (0.29)	0.38 (0.24)
quark-gluon luminosity	0.71 (0.65)	0.49 (0.42)	0.39 (0.29)
quark-quark luminosity	0.78 (0.73)	0.46 (0.37)	0.60 (0.45)
quark-antiquark luminosity	0.73 (0.70)	0.40 (0.30)	0.61 (0.50)
up-strange luminosity	0.73 (0.67)	0.38 (0.27)	0.42 (0.38)

Scale factor for PDF systematics

Uncertainty	Expected value at HL-LHC	
b-jet efficiency	1%	for 30<pt<300 GeV; all working points
b-jet efficiency	2-6%	for pt>300 GeV, see parametrization in ROOT file below; all working points
c-jet efficiency	2%	all working points
light-jet mistag	5%	loose working point
light-jet mistag	10%	medium working point
light-jet mistag	15%	tight working point

Value of flavor tagging systematics

Uncertainty	Expected value at HL-LHC	Comments
ID efficiency	5% (2.5%)	baseline (optimistic) floor for ID efficiency, systematic dominated
Energy Scale	2-3%	valid up to pT ~ 200 GeV, if higher pT relevant, contact us

Tau Nuisance Parameter	Scale Factor for HL-LHC	Comments
ATLAS_TAU_EFF_ID_TOTAL	0.9, 0.85	for 1-prong, 3-prongs respectively (baseline), half them for optimistic scenario
ATLAS_TAU_EFF_ID_HIGHPT	1.0	Significant only for pT > 250 GeV; contact us if dominant
ATLAS_TAU_TES_INSITU	0.6	Based on extrapolating stat. uncertainty to zero
ATLAS_TAU_TES_DETECTOR	1.0	Limited by detector/method
ATLAS_TAU_TES_MODEL	1.0	Limited by detector/method
Others	1.0	Rarely dominant, can also be neglected.

Scale factor for tau related systematics

Direct Stau Upgrade: Cutflow

Sample	W+jets	Z+jets	Multi-boson	Top
baseline cut	$3.84 \times 10^6 \pm 11296$	$4.73 \times 10^6 \pm 20056$	47622 ± 369.47	$2.2 \times 10^5 \pm 375.55$
== 2 tight tau	$1.31 \times 10^6 \pm 6598.3$	$2.76 \times 10^6 \pm 15666$	28133 ± 281.64	82244 ± 283.70
OS taus	$6.5 \times 10^5 \pm 4665.0$	$2.67 \times 10^6 \pm 15662$	23262 ± 272.02	54000 ± 274.23
forward jet veto	$5.3 \times 10^5 \pm 4268.2$	$2.28 \times 10^6 \pm 14494$	18017 ± 228.14	37113 ± 229.89
$p_{T\tau 1} > 50$ GeV	$1.9 \times 10^5 \pm 2221.1$	$5.8 \times 10^5 \pm 7258.9$	10101 ± 162.76	23960 ± 177.70
$p_{T\tau 2} > 40$ GeV	72586 ± 1261.3	$1.6 \times 10^5 \pm 3705.5$	4407.50 ± 100.94	11576 ± 120.96
$\lvert\eta\rvert_\tau < 2.5$	44915 ± 835.43	$1.2 \times 10^5 \pm 3319.1$	3677.32 ± 92.37	10076 ± 116.10
Z veto	37293 ± 731.27	60914 ± 2300.3	2008.00 ± 58.54	7712.25 ± 107.25
$m_{T2} > 35$ *GeV*	27134 ± 639.04	26705 ± 1483.2	1392.95 ± 44.86	5590.84 ± 89.31
$m_{T\tau 1} + m_{T\tau 2} > 450$ GeV	888.51 ± 56.78	357.19 ± 165.35	144.99 ± 18.12	218.50 ± 15.85
E_T^{miss} >200 GeV	546.77 ± 49.54	219.75 ± 134.89	74.92 ± 8.46	124.67 ± 11.55
$p_{T jet} < 40$ GeV	314.81 ± 47.72	114.16 ± 96.50	39.48 ± 6.32	34.26 ± 5.86
$\Delta R(\tau 1, \tau 2) < 3$	191.13 ± 47.35	105.77 ± 96.50	27.01 ± 4.54	23.01 ± 4.23
$m_{T2}(\tau 1, \tau 2) > 80$ GeV	64.14 ± 46.94	6.85 ± 2.11	19.37 ± 4.08	12.29 ± 0.79
$p_{T\tau 1} > 150$ GeV	60.54 ± 31.88	5.32 ± 1.88	14.00 ± 3.48	4.28 ± 0.49
$p_{T\tau 2} > 75$ GeV	9.20 ± 4.38	1.48 ± 0.96	5.94 ± 2.58	1.31 ± 0.09
$m_{T\tau 1} + m_{T\tau 2} > 500$ GeV	8.14 ± 4.33	1.48 ± 0.96	5.94 ± 2.58	1.27 ± 0.09
$\Delta\phi(\tau 1, \tau 2) > 2$	8.80 ± 2.81	1.43 ± 0.96	2.59 ± 1.25	0.58 ± 0.06

Sample	(160,40)	(400,160)	(500,1)	Higgs	Multi-jet
baseline cut	5899 ± 92.59	446.1 ± 6.84	202.6 ± 4.60	$2.8 \times 10^5 \pm 2048$	$1.4 \times 10^7 \pm 25579$
== 2 tight tau	3924 ± 75.58	307.2 ± 5.69	143.3 ± 3.90	$1.7 \times 10^5 \pm 1621$	$2.7 \times 10^6 \pm 11449$
OS taus	3909 ± 75.58	306.3 ± 5.69	142.9 ± 3.90	$1.6 \times 10^5 \pm 1620$	$1.3 \times 10^6 \pm 8094$
forward jet veto	3255 ± 68.12	250.6 ± 5.14	119.8 ± 3.58	$1.2 \times 10^5 \pm 1447$	$9.3 \times 10^5 \pm 6800$
$p_{T\tau 1} > 50$ GeV	3042 ± 65.98	249.1 ± 5.13	119.5 ± 3.57	$76546 \pm 1126.$	$7.1 \times 10^5 \pm 5793$
$p_{T\tau 2} > 40$ GeV	2142 ± 55.88	219.2 ± 4.84	112.5 ± 3.48	33397 ± 744.9	$4.0 \times 10^5 \pm 4310$
$\lvert\eta\rvert_\tau < 2.5$	2118 ± 55.64	218.0 ± 4.83	111.9 ± 3.47	30530 ± 715.9	$2.4 \times 10^5 \pm 3217$
Z veto	1939 ± 53.33	199.9 ± 4.63	106.6 ± 3.40	22720 ± 624.4	$2.0 \times 10^5 \pm 2914$
$m_{T2} > 35$ *GeV*	1674 ± 49.63	189.2 ± 4.52	103.6 ± 3.36	13368 ± 474.1	$1.4 \times 10^5 \pm 2378$
$m_{T\tau 1} + m_{T\tau 2} > 450$ GeV	507.7 ± 28.01	152.3 ± 4.08	94.86 ± 3.23	31.61 ± 19.22	284.04 ± 41.54
E_T^{miss} >200 GeV	222.1 ± 18.28	97.58 ± 3.26	75.46 ± 2.89	2.92 ± 0.30	64.79 ± 27.08
$p_{T jet} < 40$ GeV	158.2 ± 14.77	70.33 ± 2.75	53.57 ± 2.43	2.04 ± 0.26	14.11 ± 8.50
$\Delta R(\tau 1, \tau 2) < 3$	133.3 ± 13.58	64.73 ± 2.65	49.86 ± 2.36	0.87 ± 0.18	0.80 ± 0.48
$m_{T2}(\tau 1, \tau 2) > 80$ GeV	89.21 ± 11.43	61.10 ± 2.58	48.00 ± 2.31	0.52 ± 0.14	0.78 ± 0.48
$p_{T\tau 1} > 150$ GeV	62.11 ± 9.59	54.62 ± 2.44	45.70 ± 2.26	0.46 ± 0.14	0.53 ± 0.41
$p_{T\tau 2} > 75$ GeV	35.64 ± 7.24	38.01 ± 2.03	37.87 ± 2.07	0.157 ± 0.077	0.53 ± 0.41
$m_{T\tau 1} + m_{T\tau 2} > 500$ GeV	35.01 ± 7.23	38.01 ± 2.03	37.87 ± 2.07	0.049 ± 0.016	0.38 ± 0.38
$\Delta\phi(\tau 1, \tau 2) > 2$	34.93 ± 7.23	24.05 ± 1.60	19.40 ± 1.47	0.049 ± 0.016	0.38 ± 0.38

Variables Definition

- the "stransverse mass", m_{T2}, which can be shown to have 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) [16, 17]. It is defined as:

$$m_{\mathrm{T2}} = \min_{\mathbf{q}_{\mathrm{T}}} \left[\max \left(m_{\mathrm{T},\tau 1}(\mathbf{p}_{\mathrm{T},\tau 1}, \mathbf{q}_{\mathrm{T}}), m_{\mathrm{T},\tau 2}(\mathbf{p}_{\mathrm{T},\tau 2}, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}} - \mathbf{q}_{\mathrm{T}}) \right) \right],$$

  where $\mathbf{p}_{\mathrm{T},\tau 1}$ and $\mathbf{p}_{\mathrm{T},\tau 2}$ are the transverse momenta of the two taus, and $\mathbf{q}_{\mathrm{T}}$ is the transverse vector that minimises the larger of the two transverse masses $m_{\mathrm{T},\tau 1}$ and $m_{\mathrm{T},\tau 2}$. The latter is defined by

$$m_{\mathrm{T}}(\mathbf{p}_{\mathrm{T}}, \mathbf{q}_{\mathrm{T}}) = \sqrt{2(p_{\mathrm{T}} q_{\mathrm{T}} - \mathbf{p}_{\mathrm{T}} \cdot \mathbf{q}_{\mathrm{T}})}.$$

  In events with more than two taus, m_{T2} is calculated using all possible tau pairs and the largest value is chosen (the reason for this choice can be found in Section H.4);

- $m_{T\tau 1} + m_{T\tau 2}$, the sum of the transverse mass values of the leading and next-to-leading taus;

- m_{eff}, the scalar sum of the missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}}$) and the transverse momenta of the leading and next-to-leading taus;

- $\Delta R(\tau, \tau)$, the cone size between the leading and next-to-leading tau. An upper cut on this variable is powerful to discriminate against back-to-back events such as di-jets or Z decays.