
Search for staus and electroweakinos production in compressed region using the final states with two hadronic taus or one hadronic tau one lepton

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Target Signal

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

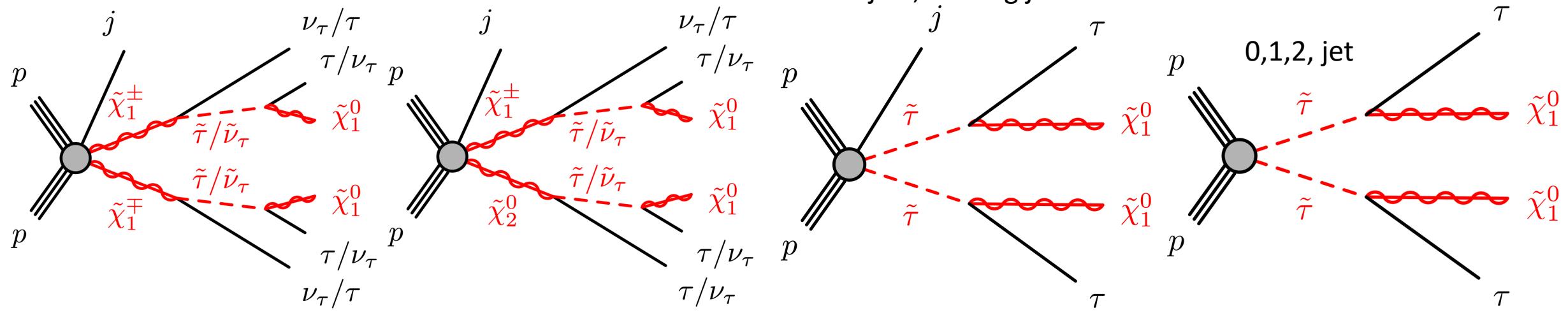
ISR channel and inclusive channel

- Previous paper: [JHEP 05 \(2024\) 150](#)

HadHad channel: SR optimization using neuron network/BDT for full Run-2 + partial Run-3 data

LepHad channel: using single lepton trigger, MET trigger, new final state targeting at compressed region

1 or 2 jets, leading jet at least 50 GeV



Ntuple setup

- [MelAnalysis framework](#)
- DAOD PHYS
- ptag: signal p6244, bkg p6490/p6491, data p6479/p6269
- background list: [mc20](#), [mc23](#)

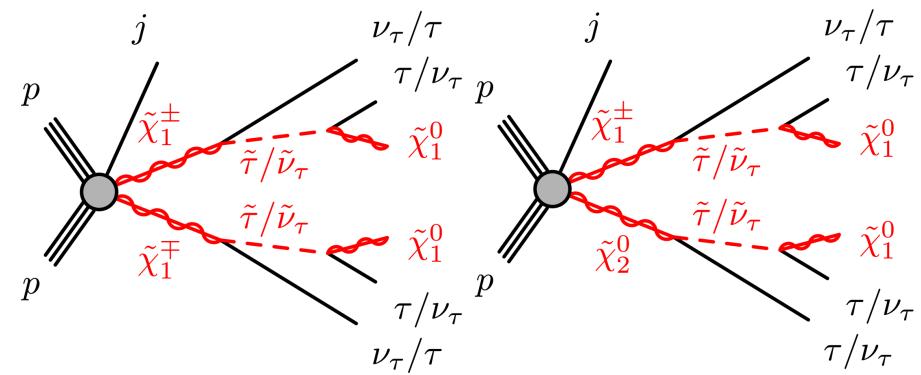
run2 run3

Type	dsid	sample
$t\bar{t}$	410470	PhPy8EG_A14_ttbar_hdamp258p75_nonallhad
	410471	PhPy8EG_A14_ttbar_hdamp258p75_allhad
single top	410644,410645	PowhegPythia8EvtGen_A14_singletop_schan_lept
	410658,410659	PhPy8EG_A14_tchan_BW50_lept
	601352,601355	PhPy8EG_tW_dyn_DR_incl
Rare top	304014	MadGraphPythia8EvtGen_A14NNPDF23_3top_SM
	410276	aMcAtNloPythia8EvtGen_MEN30NLO_A14N23LO_ttee_mll_1_5
	410277	aMcAtNloPythia8EvtGen_MEN30NLO_A14N23LO_ttmmumu_mll_1_5
	410278	aMcAtNloPythia8EvtGen_MEN30NLO_A14N23LO_ttautau_mll_1_5
$t\bar{t}X$	410081	MadGraphPythia8EvtGen_A14NNPDF23_ttbarWW
	504330	aMCPy8EG_NNPDF30NLO_A14N23LO_ttee
	504334	aMCPy8EG_NNPDF30NLO_A14N23LO_ttmmumu
	504338	aMCPy8EG_NNPDF30NLO_A14N23LO_ttZqq
	504342	aMCPy8EG_NNPDF30NLO_A14N23LO_ttautau
	504346	aMCPy8EG_NNPDF30NLO_A14N23LO_ttZnumu

Type	dsid	sample
	346343	PhPySEG_A14NNPDF23_NNPDF30ME_ttH125.allhad
	346344	PhPySEG_A14NNPDF23_NNPDF30ME_ttH125.semilep
	346345	PhPySEG_A14NNPDF23_NNPDF30ME_ttH125.dilep
	345097	PowhegPythia8EvtGen_NNLOPS_mnlo_30_ggfH125.mnumu
	345121	PowhegPythia8EvtGen_NNLOPS_mnlo_30_ggfH125.tautau137
	345121	PowhegPythia8EvtGen_NNLOPS_mnlo_30_ggfH125.tautaul15hp20
	345122	PowhegPythia8EvtGen_NNLOPS_mnlo_30_ggfH125.tautaul15hp20
	345123	PowhegPythia8EvtGen_NNLOPS_mnlo_30_ggfH125.tautau30h20
	345149	PowhegPythia8EvtGen_NNPDF30_AZNLOCTEQ6L1_VBFH125_bb
	346199	PowhegPythia8EvtGen_NNPDF30_AZNLOCTEQ6L1_VBFH125.tautau137
	346191	PowhegPythia8EvtGen_NNPDF30_AZNLOCTEQ6L1_VBFH125.tautaul15hp20
	346192	PowhegPythia8EvtGen_NNPDF30_AZNLOCTEQ6L1_VBFH125.tautaul15hp20
	346193	PowhegPythia8EvtGen_NNPDF30_AZNLOCTEQ6L1_VBFH125.tautaub30h20
	345053	PowhegPythia8EvtGen_NNPDF3_AZNLO_WmH125j_MINLO_lvbb_VpT
	345054	PowhegPythia8EvtGen_NNPDF3_AZNLO_WpH125j_MINLO_lvbb_VpT
	345055	PowhegPythia8EvtGen_NNPDF3_AZNLO_ZH125j_MINLO_llbb_VpT
	345056	PowhegPythia8EvtGen_NNPDF3_AZNLO_ZH125j_MINLO_lvbb_VpT
	345057	PowhegPythia8EvtGen_NNPDF3_AZNLO_ggZH125_llbb
	345098	PowhegPythia8EvtGen_NNPDF3_AZNLO_ggZH125_Hmmnu_Zinc
	345103	PowhegPythia8EvtGen_NNPDF30_AZNLO_ZH125j_Hmmnu_Zinc_MINLO
	345104	PowhegPythia8EvtGen_NNPDF30_AZNLO_WpH125j_Hmmnu_Winc_MINLO
	345105	PowhegPythia8EvtGen_NNPDF30_AZNLO_WpH125j_Hmmnu_Wind_MINLO
	345109	PowhegPythia8EvtGen_NNPDF3_AZNLO_WmH125j_MINLO_lvcc_VpT
	345110	PowhegPythia8EvtGen_NNPDF3_AZNLO_WpH125j_MINLO_lvcc_VpT
	345111	PowhegPythia8EvtGen_NNPDF3_AZNLO_ZH125j_MINLO_llcc_VpT
	345112	PowhegPythia8EvtGen_NNPDF3_AZNLO_ZH125j_MINLO_vvcc_VpT
	345113	PowhegPythia8EvtGen_NNPDF3_AZNLO_ggZH125_llcc
	345211	PowhegPyEG_NNPDF30_AZNLO_WmH125j_Winc_MINLO_tautau
	345212	PowhegPyEG_NNPDF30_AZNLO_WpH125j_Winc_MINLO_tautau
	345217	PowhegPyEG_NNPDF30_AZNLO_ZH125j_Zinc_MINLO_tautau
	346329	PowhegPyEG_NNPDF30_AZNLO_ggZH125_lltautau_file

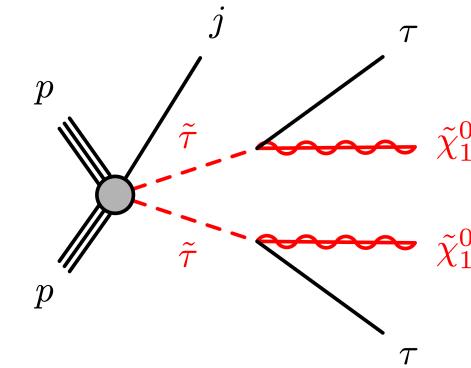
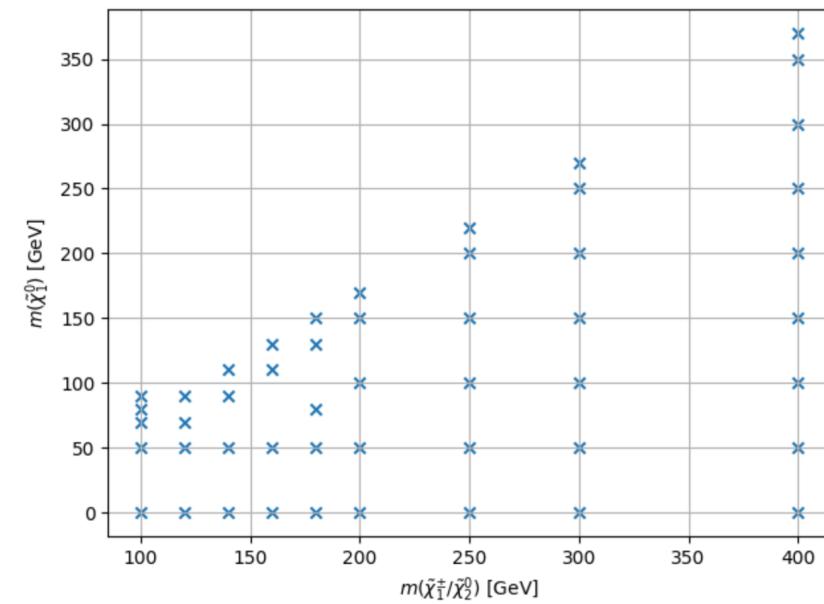
Type	dsid	sample
Z+jets	700320-700322, 700467-700469	Sh_2211_Zee_maxHTpTV2
	700323-700325, 700470-700472	Sh_2211_Zmumu_maxHTpTV2
	700792-700794, 700901-700903	Sh_2214_Ztautau_maxHTpTV2
	700358	Sh_2211_Zee2jets_Min_N_TChannel
	700359	Sh_2211_Zmm2jets_Min_N_TChannel
	700360	Sh_2211_Ztt2jets_Min_N_TChannel
W+jets	700338-700340	Sh_2211_Wenu_maxHTpTV2
	700341-700343	Sh_2211_Wmumu_maxHTpTV2
	700344-700349	Sh_2211_Wtaunu_*_maxHTpTV2
	700362	Sh_2211_Wenu2jets_Min_N_TChannel
	700363	Sh_2211_Wmumu2jets_Min_N_TChannel
	700364	Sh_2211_Wtaunu2jets_Min_N_TChannel
Diboson	345705,345706	Sherpa_222_NNPDF30NNLO_gglill
	345718	Sherpa_222_NNPDF30NNLO_gglvvWW
	345723	Sherpa_222_NNPDF30NNLO_gglvvZZ
	364288	Sherpa_222_NNPDF30NNLO_llll_lowMllPtComplement
	364289	Sherpa_222_NNPDF30NNLO_lllv_lowMllPtComplement
	364290	Sherpa_222_NNPDF30NNLO_llvv_lowMllPtComplement
	364302,364303	Sherpa_222_NNPDF30NNLO_ggZ*Zqq
	364304,364305	Sherpa_222_NNPDF30NNLO_ggW*lW*qq
	700600	Sh_2212_lll
	700601	Sh_2212_lllv
	700602,700603	Sh_2212_llvv_*
	700604	Sh_2212_lvvv
	700605	Sh_2212_lllljj
	701000	Sh_2214_llljj
	701005	Sh_2214_llvjij
	701010,701015	Sh_2214_llvvjj_*
	701020	Sh_2214_llljj_Int
	701025	Sh_2214_llvjj_Int
	701030,701035	Sh_2214_llvjj_*
Triboson	701085	Sh_2214_ZqqZll
	701090	Sh_2214_ZbbZll
	701095	Sh_2214_ZqqZvv
	701100	Sh_2214_ZbbZvv
	701105	Sh_2214_WqqZll
	701110	Sh_2214_WqqZvv
	701115	Sh_2214_WlvZqq
	701120	Sh_2214_WlvZbb
	701125	Sh_2214_WlvWqq

Signal samples

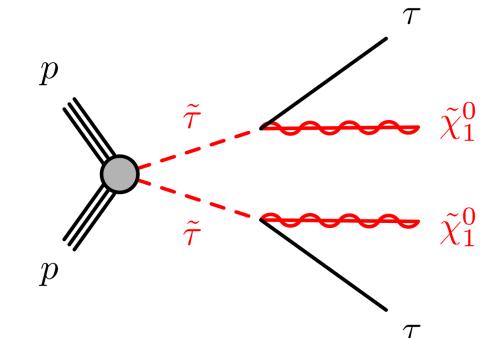


$\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ mass degenerate and pure wino

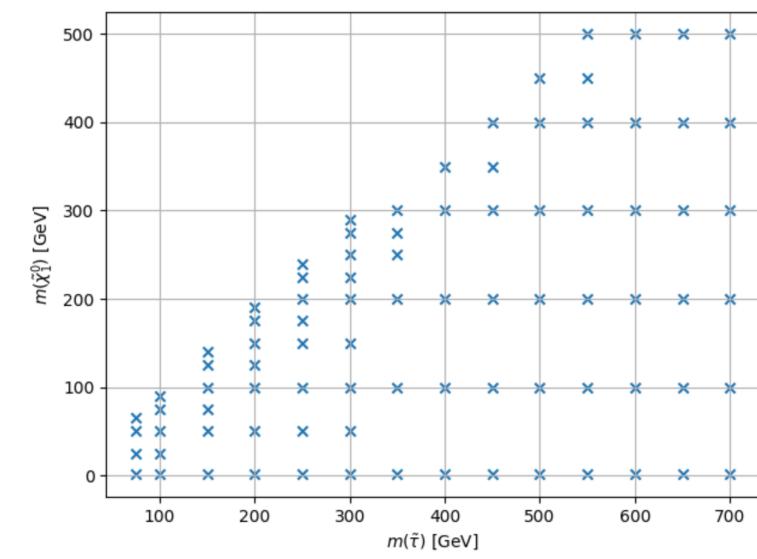
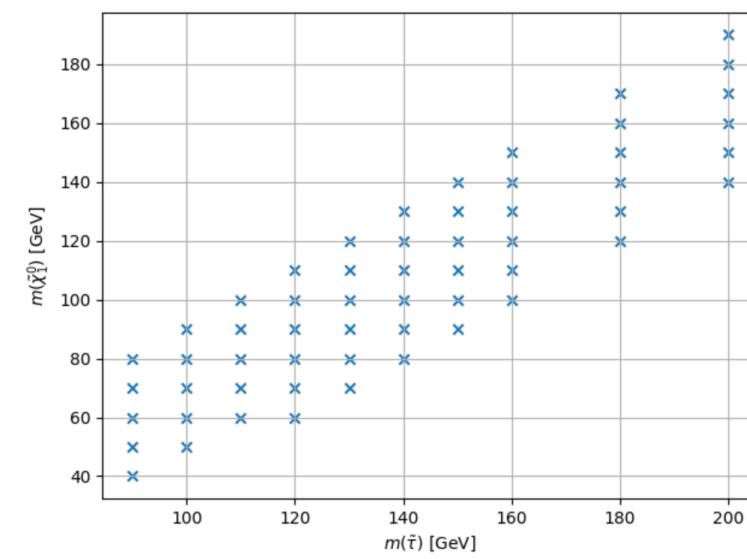
$\tilde{\tau}/\tilde{\nu}$ mass degenerate and lie midway between $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$



$\tilde{\tau}_L/\tilde{\tau}_R$ mass degenerate
Bino-like $\tilde{\chi}_1^0$



$\tilde{\tau}_L/\tilde{\tau}_R$ mass degenerate
Bino-like $\tilde{\chi}_1^0$



Object Definition

- Full ST config: [Run2](#), [Run3](#)

Selection	Electron	Muon	Tau	Jet
Baseline	$p_T > 4.5 \text{ GeV}$ impact parameter $ \eta < 2.47$ $ z_0 \cdot \sin \theta < 0.5 \text{ mm}$ ID: LooseAndBLayerLLH	$p_T > 5 \text{ GeV}$ $ \eta < 2.5$ $ z_0 \cdot \sin \theta < 0.5 \text{ mm}$ ID: Medium	$p_T > 15 \text{ GeV}$ $ \eta < 1.37 \text{ or } 1.52 < \eta < 2.5$ $ Q = 1$ 1 or 3 tracks Ele ID: RNN Loose Tau ID: VeryLoose	AntiKt4EMPFlow $p_T > 20 \text{ GeV}$ $ \eta < 4.5$ JVT: FixedEffPtf if $p_T < 60 \text{ GeV}$ bTag: GN2v01, 77% WP
Signal	ID: TightLLH Run2 ISO: Loose_VarRad, HighPtCaloOnly Run3 ISO: Tight_VarRad $ d_0/\sigma_{d_0} < 5$	ISO: PflowLoose_VarRad $ d_0/\sigma_{d_0} < 3$	Tau ID: Medium	

Overlap Removal

- ST default overlap removal
- Do Tau OLR

Reject	Against	Criteria
electron	electron	shared track, $p_{T1} < p_{T2}$
tau	electron	$\Delta R < 0.2$
tau	muon	$\Delta R < 0.2$
muon	electron	is calo-muon & shared ID track
electron	muon	shared ID track
jet	electron	$\Delta R < 0.2$
electron	jet	$\Delta R < \min(0.4, 0.04 + 10 \text{ GeV}/p_T^{\text{ele}})$
jet	muon	NumTrack < 3 & (ghost-associated or $\Delta R < 0.2$)
muon	jet	$\Delta R < \min(0.4, 0.04 + 10 \text{ GeV}/p_T^{\mu})$
jet	tau	$\Delta R < 0.2$

Trigger Strategy

Stau:

MET trigger for high MET region,
Single lepton trigger for low MET region

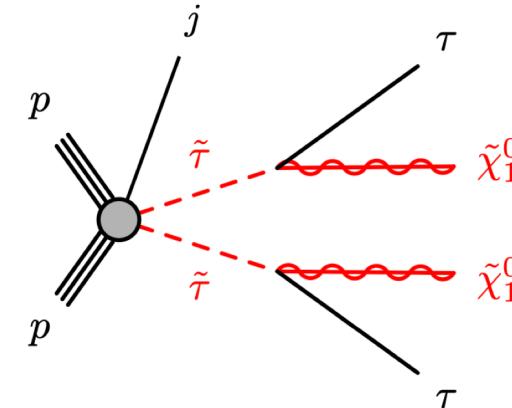
C1C1/C1N2: MET trigger

Trigger	Trigger name	Year	HLT	Offline
MET trigger	HLT_xe70_mht	2015	70	200
	HLT_xe90_mht_L1XE50	2016	90	
	HLT_xe100_mht_L1XE50	2016	100	
	HLT_xe110_pufit_L1XE55	2017	110	
	HLT_xe110_pufit_L1XE50	2017	110	
	HLT_xe110_pufit_xe70_L1XE50	2018	70	
	HLT_xe110_pufit_xe65_L1XE50	2018	65	
single electron trigger	HLT_xe65_cell_xe90_pfopufit_L1XE50	2022,2023	90	
	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
	HLT_e26_lhtight_ivarloose_L1EM22VHI	2022-2023	26	27
	HLT_e60_lhmedium_L1EM22VHI	2022-2023	60	61
single muon trigger	HLT_e140_lhloose_L1EM22VHI	2022-2023	140	141
	HLT_mu20_iloose_L1MU15	2015	20	21
	HLT_mu26_ivarmedium	2016-2018	26	27.3
	HLT_mu50	2015-2018	50	52.5
	HLT_mu24_ivarmedium_L1MU14FCH	2022-2023	24	25.2
	HLT_mu50_L1MU14FCH	2022-2023	50	52.5

Direct stau ISR motivation

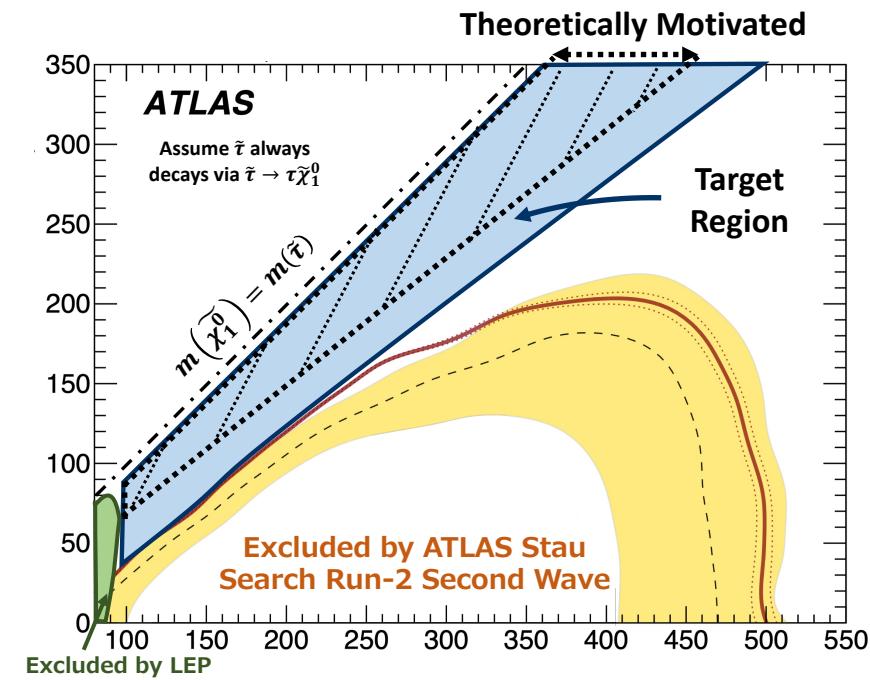
Direct stau with $2\tau + E_T^{miss} + \text{ISR}$

Boosted by ISR and has a large MET due to two missing $\tilde{\chi}_1^0$



Basic Strategy:

- Trigger: MET Trigger
- Search channel:
 - had-had channel
 - lep-had channel
- Follow the NN approach for samples
 - Reference point $(\tilde{\tau}, \tilde{\chi}_0) = (100, 70)$



Direct Stau ISR signal region definition(HH)

- Preselection
- SR selection using neuron network score
 - Fake tau estimation using fake factor method
 - DNN signal score > 0.7
- Background composition

HH Pre-selection

≥ 2 medium taus (OS)

0 base lepton

bveto

MET trigger

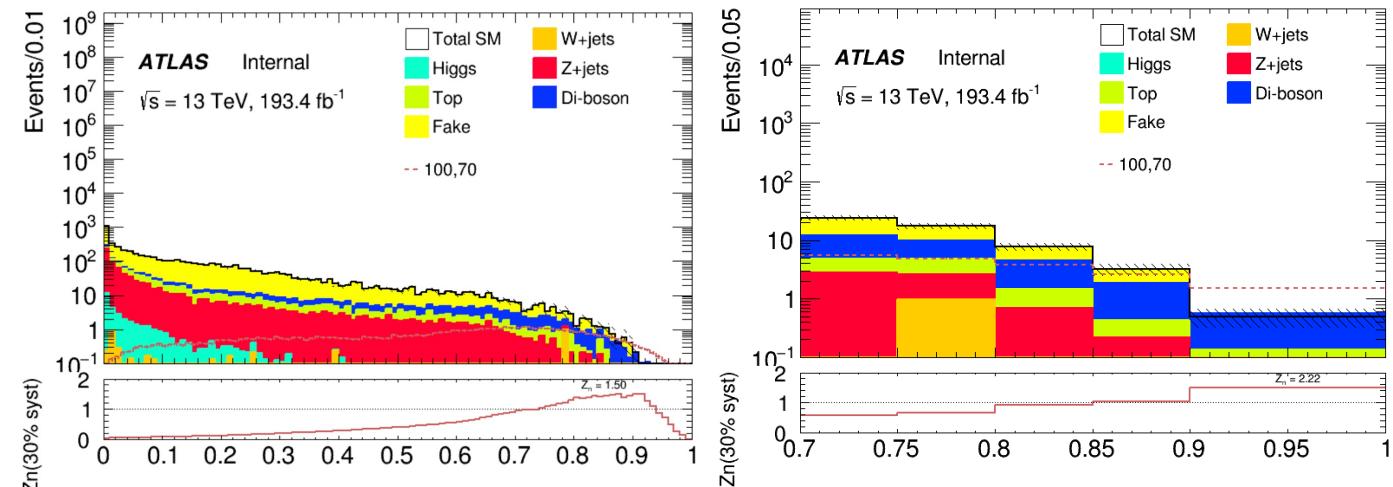
$\text{MET} \geq 200 \text{ GeV}$

$M_{\tau\tau}^{\text{reco}} < 40 \text{ GeV or } M_{\tau\tau}^{\text{reco}} > 130 \text{ GeV}$

SR

Pre-selection

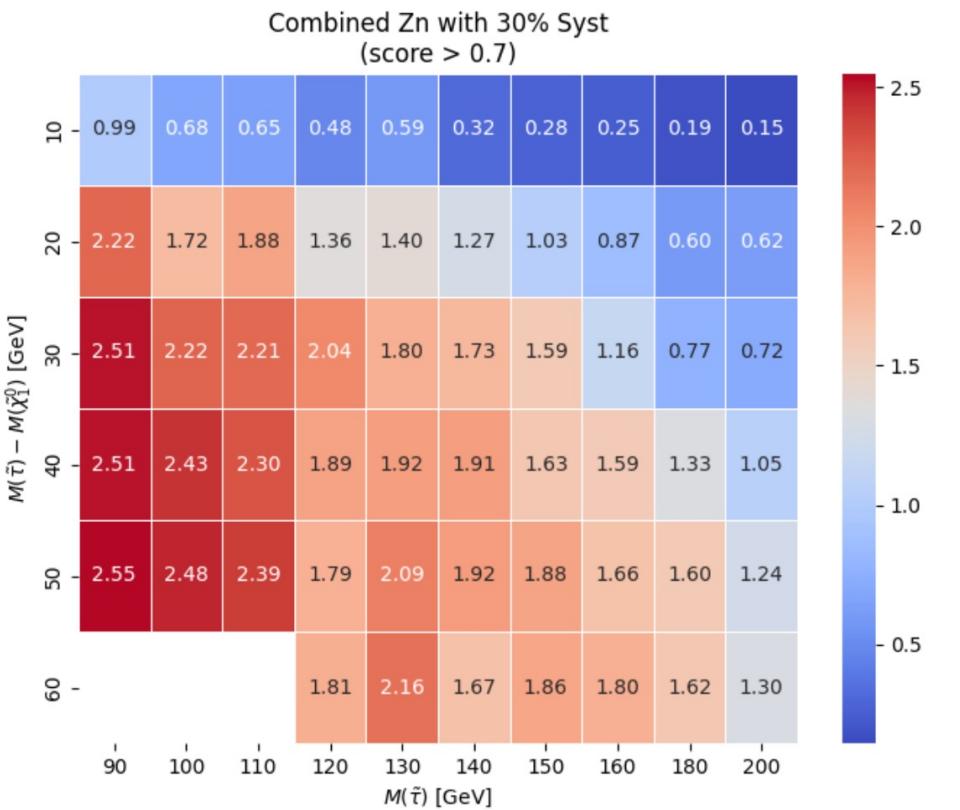
DNN score > 0.7



Process	[0.70,0.75]	[0.75,0.80]	[0.80,0.85]	[0.85,0.90]	[0.90,1.00]	Combined
TotalBkg	24.17 ± 2.35	17.35 ± 2.07	7.69 ± 1.13	3.20 ± 0.77	0.49 ± 0.17	52.90 ± 4.84
Fake	11.95 ± 2.23	7.35 ± 1.66	3.24 ± 1.04	1.33 ± 0.72	-0.07 ± 0.09	23.80 ± 3.05
VV	7.32 ± 0.52	5.18 ± 0.52	2.97 ± 0.27	1.45 ± 0.22	0.42 ± 0.08	17.33 ± 0.82
Top	2.12 ± 0.49	2.23 ± 0.52	0.80 ± 0.31	0.21 ± 0.14	0.11 ± 0.10	5.47 ± 0.80
Zjets	2.69 ± 0.23	1.61 ± 0.21	0.66 ± 0.17	0.20 ± 0.08	0.02 ± 0.07	5.18 ± 0.38
Wjets	0.00 ± 0.00	0.98 ± 0.98	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.98 ± 0.98
Higgs	0.09 ± 0.03	0.00 ± 0.00	0.02 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.14 ± 0.03
StauStauISR-100-70	5.61 ± 0.10	4.90 ± 0.09	3.84 ± 0.08	2.59 ± 0.07	1.53 ± 0.05	18.48 ± 0.18
ZnSignificance	0.58	0.65	0.91	1.03	1.50	2.22

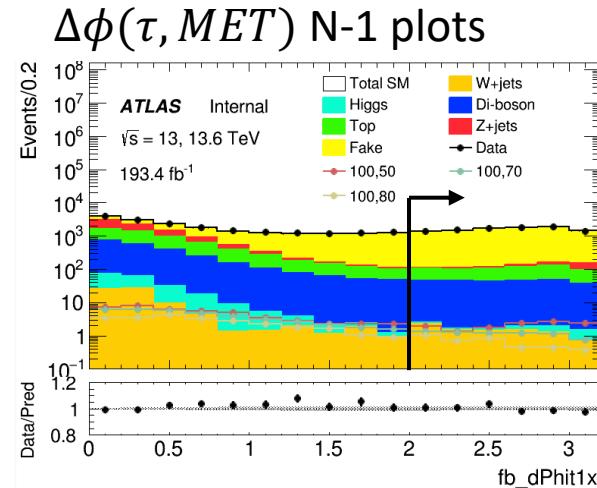
Direct Stau ISR signal region definition(HH)

- Expected sensitivity
 - 30% flat systematic uncertainty

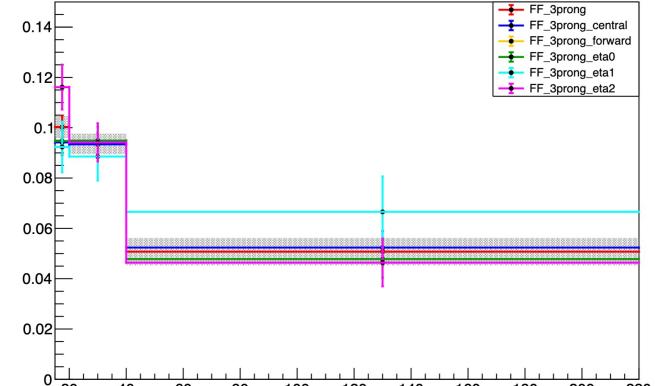
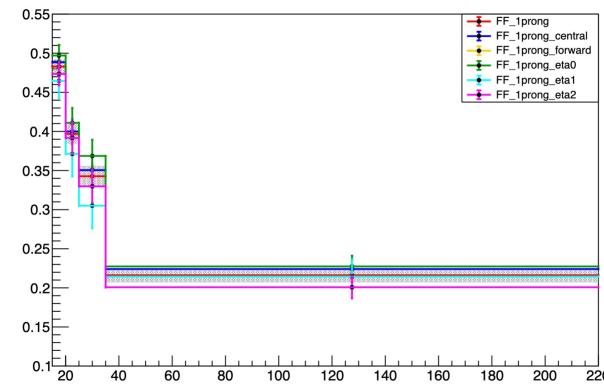


Direct Stau ISR fake estimation

- CRs (fake factor computation)
 - METtrig
 - MET ≥ 200
 - bveto
 - 1 signal lepton
 - $\Delta\phi(\tau, MET) > 2$ improve fake purity
 - ID: ≥ 1 medium tau
 - antiID: ≥ 1 VeryLoose tau, 0 medium tau
- SRs
 - preselection
 - 2ID: ≥ 2 medium tau
 - 1ID1antiID: ≥ 2 VeryLoose tau , 1 medium tau
 - 2antiID: ≥ 2 VeryLoose tau , 0 medium tau
- Binned in prongness, tau eta, tau pT**
 - Eta bins
 - 2 bins: central [0,1.37], forward [1.52,2.5]
 - 3 bins: eta0,1,2 for [0,1), [1, 1.37], [1.52,2.5]
- Auto binning:**
 - > 10% of events in nominator and denominator
 - Add bins to bin i until it is not consistent anymore with bin i - 1
 - Relative stat uncertainty on ratio smaller than 50%
 - >10% events in nominator and denominator



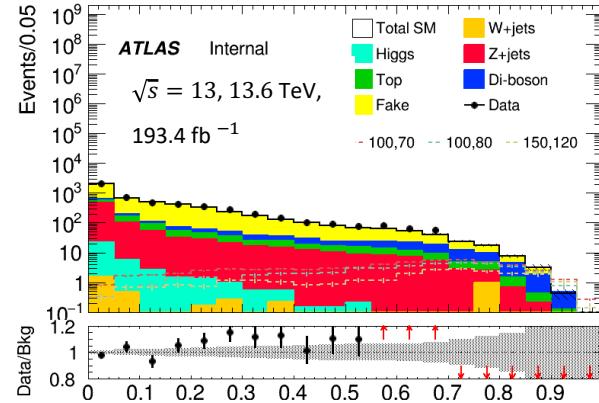
FF determination	FF application
Data	Data
CR Pass ID	SR Pass ID
CR Fail ID	SR but 1 tau Fail ID
	SR but 2 tau Fail ID



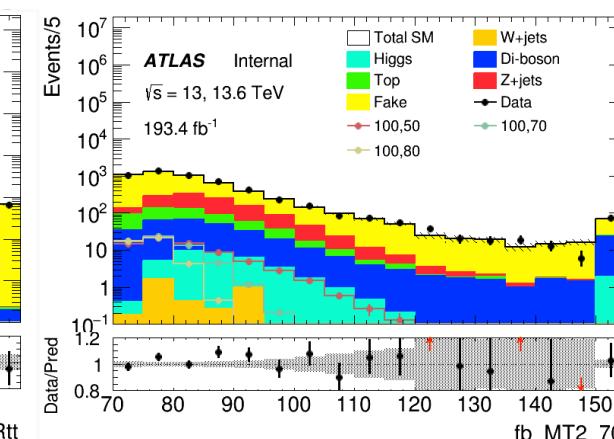
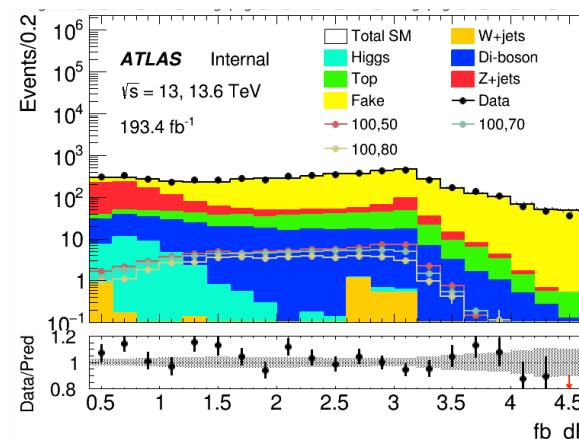
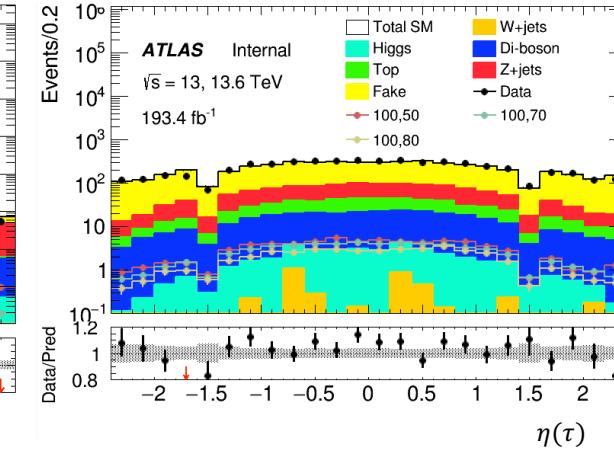
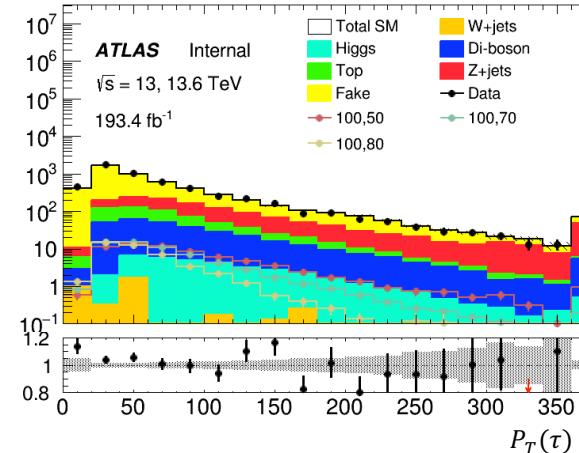
Direct Stau ISR fake estimation validation(HH)

- Data-driven fakes in preselection region

Score distribution

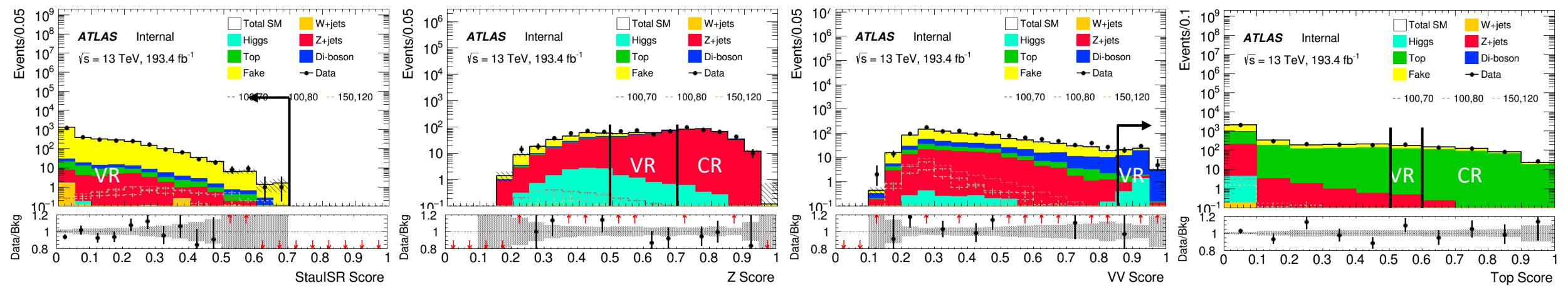


Kinematic distribution



Direct Stau ISR background estimation (HH)

Region	Selections	Total Bkg	Dominant Bkg	Purity	Data	Data/Bkg	
Fake VR	signal score < 0.7, max bkg score: Fake	2870 ± 40	2770 ± 40	0.96	2794	0.972	
Z CR	signal score < 0.7, max bkg score: Z	Z Score > 0.7	276 ± 7	257 ± 6	0.93	295	1.07
Z VR		Z Score $\in (0.5, 0.7)$	251 ± 7	198 ± 5	0.79	264	1.05
VV VR	signal score < 0.7, max bkg score: VV	VV Score > 0.85	48 ± 2.8	30 ± 1.1	0.62	55	1.15
Top CR	HH bTag	Top Score > 0.6	374 ± 9	271 ± 5	0.72	375	1
Top VR		Top Score $\in (0.5, 0.6)$	178 ± 6	178 ± 6	0.64	195	1.09



Direct Stau ISR signal region definition(LH)

- Preselection
- SR selection using neuron network score
 - Fake tau estimation using fake factor method
 - DNN signal score > 0.7
- Background composition

LH Pre-selection

≥ 1 medium taus

1base lepton, 1 signal lepton

Opposite-sign

bveto

MET trigger

$\text{MET} \geq 200$

$\Delta\phi(\tau, \text{MET}) < 2$

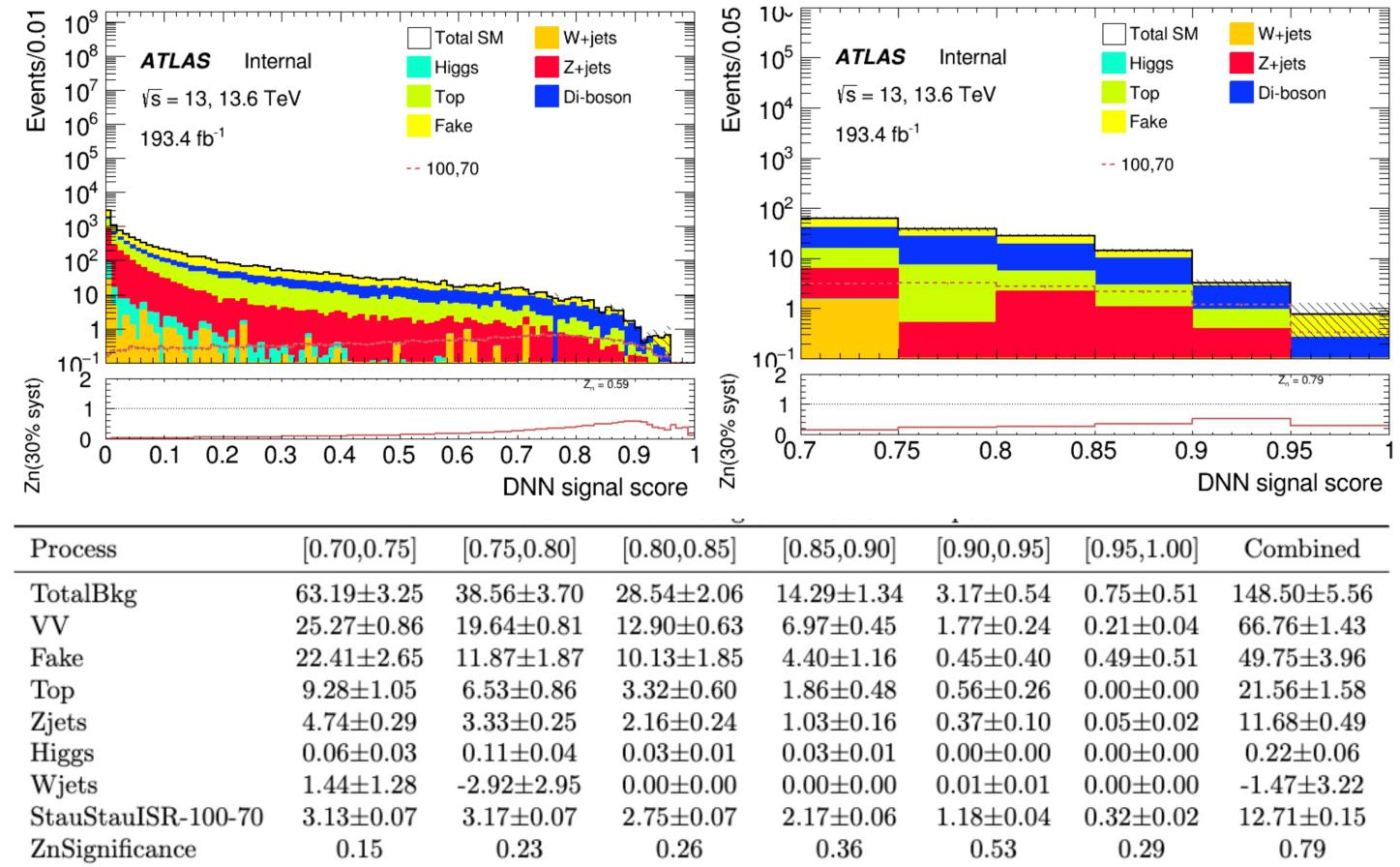
$M_{T2,70} < 100$

$\Delta R_{\tau\ell} \in (0.6, 3.6)$

SR

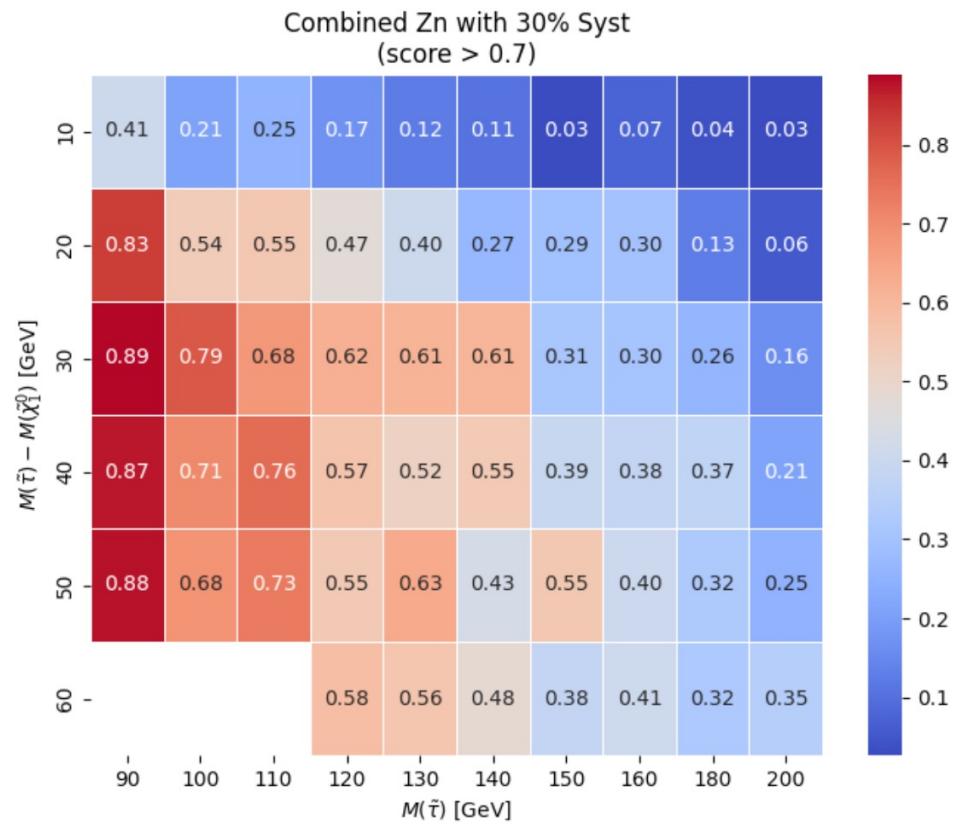
Pre-selection

DNN score > 0.7



Direct Stau ISR signal region definition(LH)

- Expected sensitivity
 - 30% flat systematic uncertainty



Direct Stau ISR Cut and Count(HH)

HH Pre-selection

≥ 2 medium taus (OS)

0 base lepton

bveto

MET trigger

$\text{MET} \geq 200 \text{ GeV}$

Primary Jet pt $> 200\text{GeV}$

$\tau_{pt} > 20\text{GeV}$

Collinear mass($\tau\tau$) $> 250\text{GeV}$

SR before binned

Pre-selection

$$M_{T2}(0) < 5\text{GeV}$$

$$M_{T2}(70) < 85\text{GeV}$$

$$d\phi(\text{MET}, \text{Jet}) > 0.4$$

$$d\eta(\tau_1, \tau_2) < 2.0$$

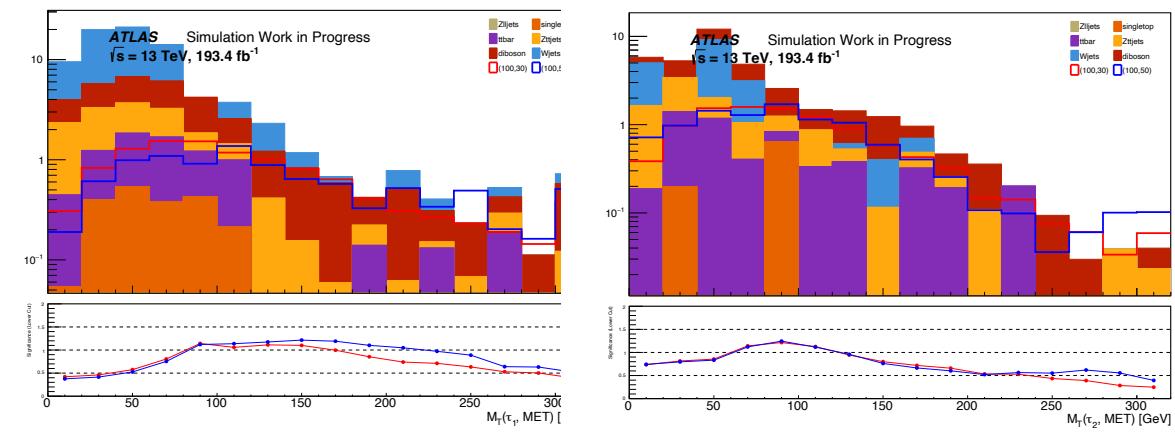
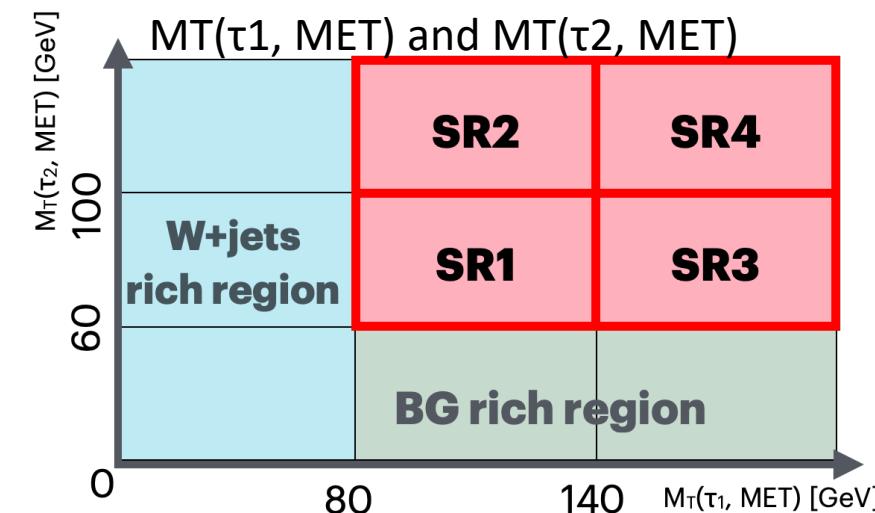
$$dR(\tau_1, \tau_2) < 3.2$$

$$dR(\tau, \text{MET}) > 1$$

$$M_T(\tau_1, \text{MET}) > 80\text{GeV}$$

$$M_T(\tau_2, \text{MET}) > 60\text{GeV}$$

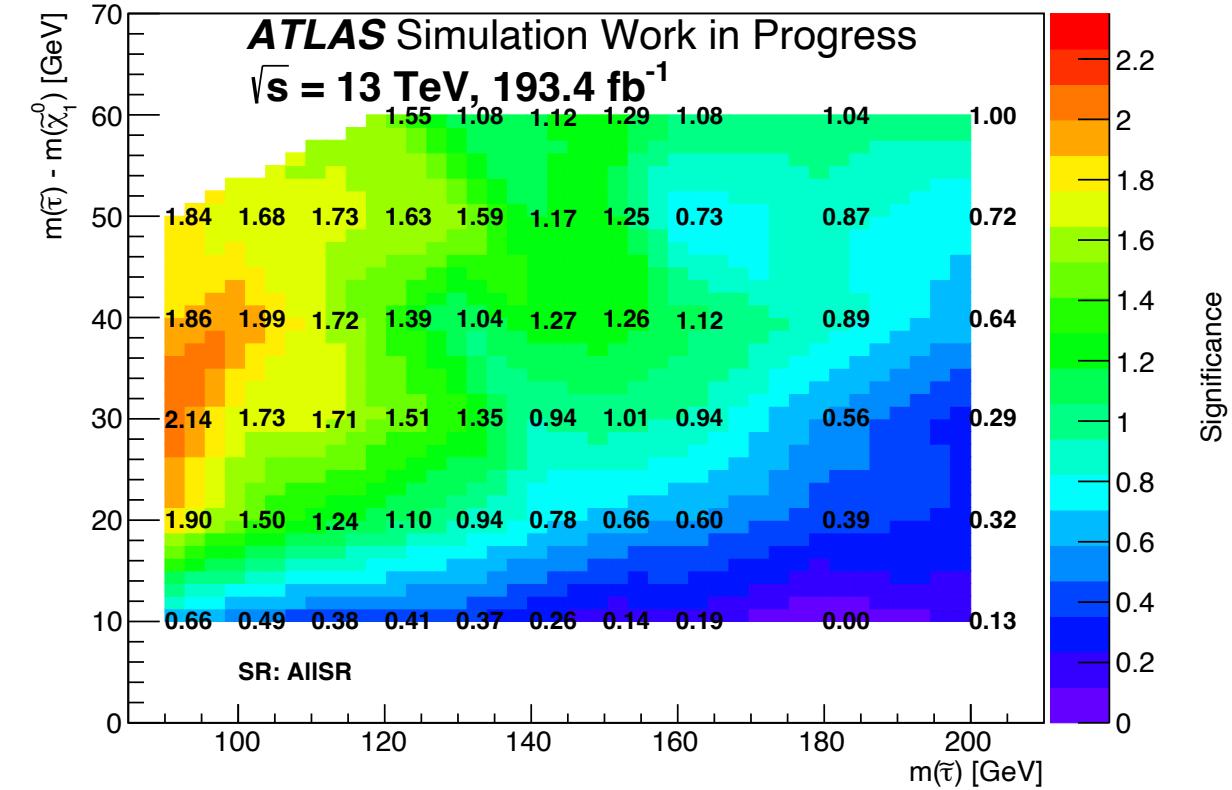
Signal Region definition:
Binned for the combination of
 $M_T(\tau_1, \text{MET})$ and $M_T(\tau_2, \text{MET})$



Direct Stau ISR Cut and Count(HH)

Sensitivity for any pair production of $\tilde{\tau}_l + \tilde{\tau}_R$ pair-production with 30% flat systematic uncertainty

	SR1	SR2	SR3	SR4	All
VV	2.88	2.49	2.58	1.05	9
Top	2.05	1.16	0.20	0.32	3.73
Wjets	0.32	0.40	0.48	0.0	1.2
Zjets	1.06	0.79	0.57	0.32	2.74
BG Sum	6.31	4.84	3.83	1.69	16.67
Signal (100, 70)	2.35	2.15	2.00	1.73	8.23
Significance	0.69	0.75	0.80	1.14	1.73



Direct Stau ISR Cut and Count(LH)

LH Pre-selection

≥ 1 medium taus (OS)

1 base lepton, 1 signal lepton

bveto

MET trigger

$\text{MET} \geq 130 \text{ GeV}$

Primary Jet pt $> 50\text{GeV}$

$\tau_{pt} > 25\text{GeV}$

Collinear mass(τl) $> 130\text{GeV}$

SR

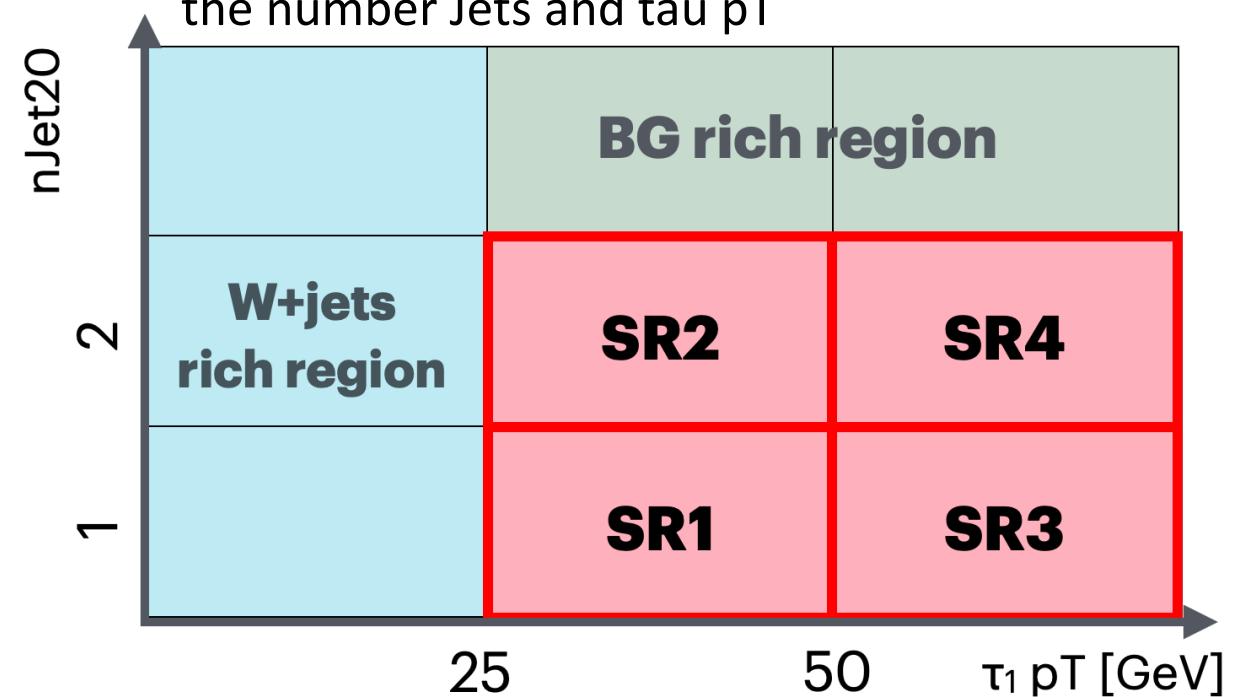
Pre-selection

$M_{T2}(40) < 55\text{GeV}$

$\frac{p_t \text{lep}}{M_T(\tau_1, \text{MET})} < 0.1$

$M_T(\tau_1, \text{MET}) > 90\text{GeV}$

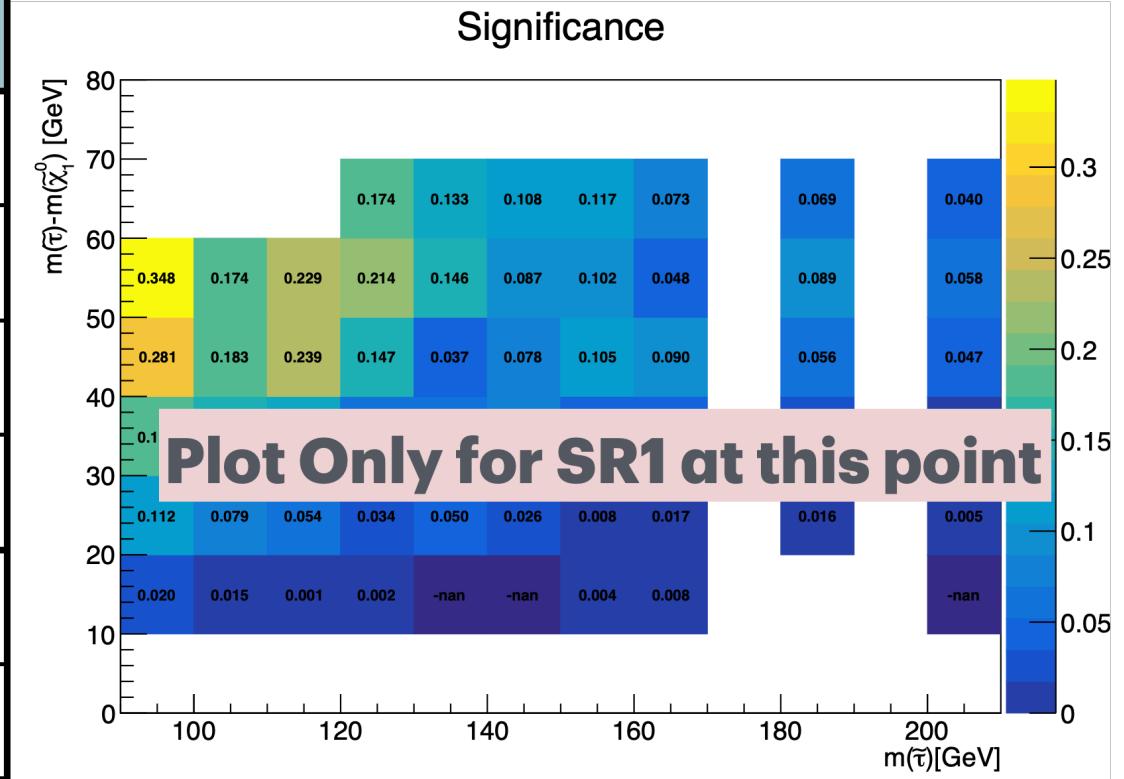
Signal Region definition:
Binned for the combination of
the number Jets and tau pT



Direct Stau ISR Cut and Count(LH)

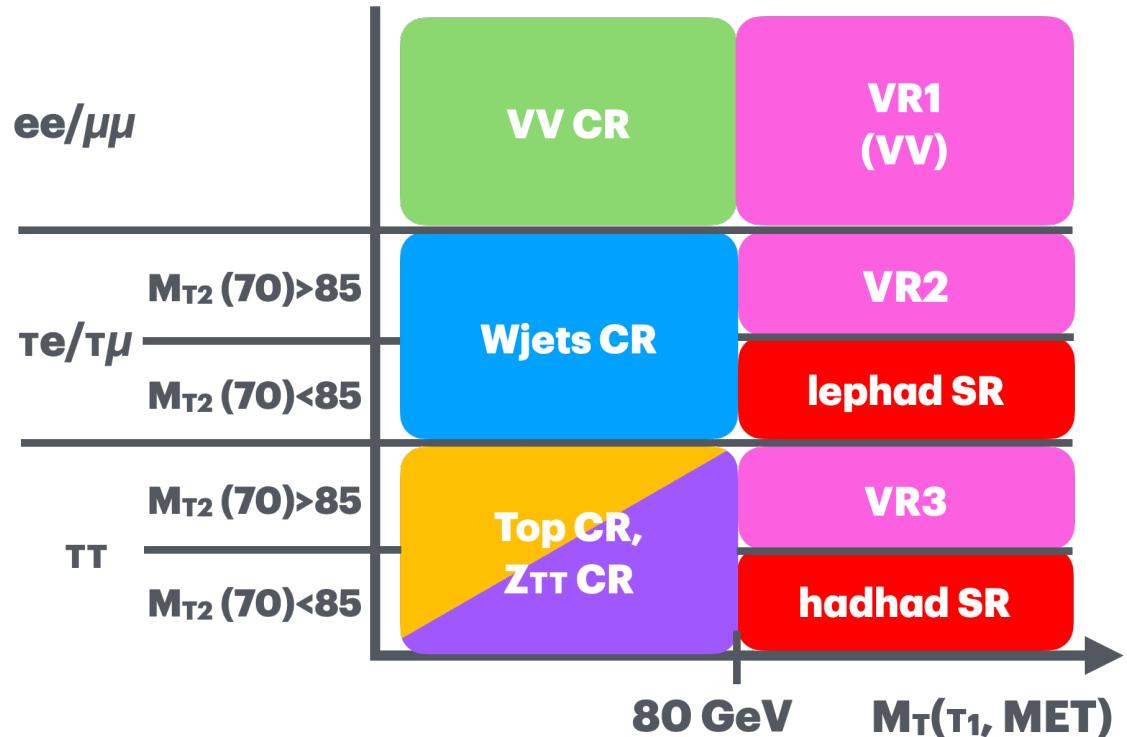
Sensitivity map with 30% systematic uncertainty

	SR1	SR2	SR3	SR4	All
VV	6.24	11.01	4.27	5.83	27.35
Top	5.93	11.02	4.48	7.80	29.23
Wjets	13.48	28.78	13.60	18.49	74.35
Zjets	5.71	7.67	1.71	4.17	19.26
BG Sum	31.36	58.49	24.06	36.29	150.2
Signal (100, 70)	1.70	1.22	1.08	0.84	4.84
Significance	0.15	0.06	0.12	0.07	0.4



Direct Stau ISR Background Estimation

- Common estimation for both had-had and lep-had
- No large difference in distributions of $M_T(\tau_1, \text{MET})$
- Prepare CR for each of the BG
 - Use leplep / lephad mode
 - W decay and lepton ID (including τ) are modeled well in MC
 - $M_T(\tau_1, \text{MET})$ distribution matches as well
→ Extrapolation along M_T and lepton flavor
 - Reverse b-veto or colinear mass to obtain top/Z rich CRs
- VR: Reverse MT2 cut
- Fake estimation:
 - Estimation using MC, setting Wjets CR
 - Validation with Fake Factor method planned

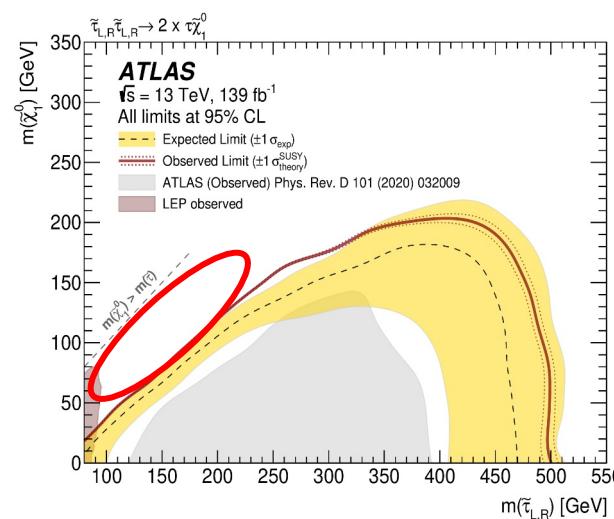
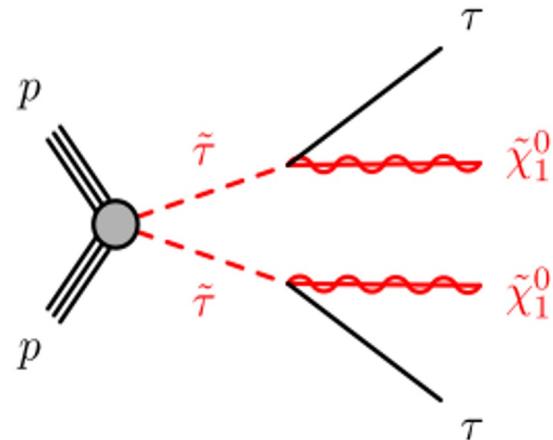


Direct Stau ISR Background Estimation

- Common Preselection: Pass MET Trigger
- Each SR is binned and has specific cuts (see SR definitions)

	SR (HH)	SR (LH)	CR (VV)	CR (Wjets)	CR (Z$\tau\tau$)	CR (Top)	VR (VV)	VR (HH)	VR (LH)
MET	> 200 GeV	> 130 GeV			> 200 GeV		> 200 GeV		> 130 GeV
nJet20	<= 4	<= 2			<= 4		<= 4		<= 2
nBJet20 (WP 90%)		= 0			= 0	>= 1		= 0	
Primary Jet pT	> 200 GeV	> 50 GeV			> 200 GeV		> 200 GeV		> 50 GeV
(nLightLeptons, nHadronic Taus)	= (0, 2)	= (1, 1)	= (2, 0)	= (1, 1)	= (0, 2)		= (2, 0)	= (0, 2)	= (1, 1)
tau pT	> 20 GeV	> 25 GeV	-		> 20 GeV		-	> 20 GeV	> 25 GeV
Mτ (τ_1, MET)	> 80 GeV	> 90 GeV			< 80 GeV		> 80 GeV		> 90 GeV
Collinear mass	> 250 GeV	> 130 GeV		> 250 GeV	$\in [70, 110]$ GeV	> 250 GeV		> 250 GeV	> 130 GeV
M$\tau_2(70)$	< 85 GeV	-			-			> 85 GeV	-
M$\tau_2(40)$	-	< 55 GeV			-		-		> 55 GeV

Direct Stau single-lep trigger motivation



Sensitivity to direct stau production is difficult

- Low cross-sections
- Hadronically-decaying taus are difficult objects

Possible final states

$\tau_{\text{had}} \tau_{\text{had}}$	BR = 42%
$\tau_{\text{had}} \tau_{\text{lep}}$	BR = 46%
$\tau_{\text{lep}} \tau_{\text{lep}}$	BR = 12%

... and problems

- trigger on 2x high pT taus, large Δm
- large W+jets background
- leptons are soft (Ben H study)

$\tau_{\text{had}} \tau_{\text{had}}$ has been the main focus for ATLAS so far, with potential improvements at low mass from Dom's ML efforts.

2-tau triggering 95,75 or 75,40+MET 150 kills moderate Δm signals.

Huge uncovered region from moderate $\Delta m \rightarrow$ low Δm .

Target with the $\tau_{\text{had}} \tau_{\text{lep}}$ channel and use single lep triggers

Direct Stau signle-lep trigger SR definition(LH)

LH Pre-selection

≥ 1 Tight taus (OS)

1 signal lepton

bveto

Single-lepton trigger

$15 \text{ GeV} < \text{MET} < 200 \text{ GeV}$

$\text{METSig} > 2$

$\text{MT2} < 90$

$dR(\text{lep}, \text{tau}) < 3.6$

custom MT cut*

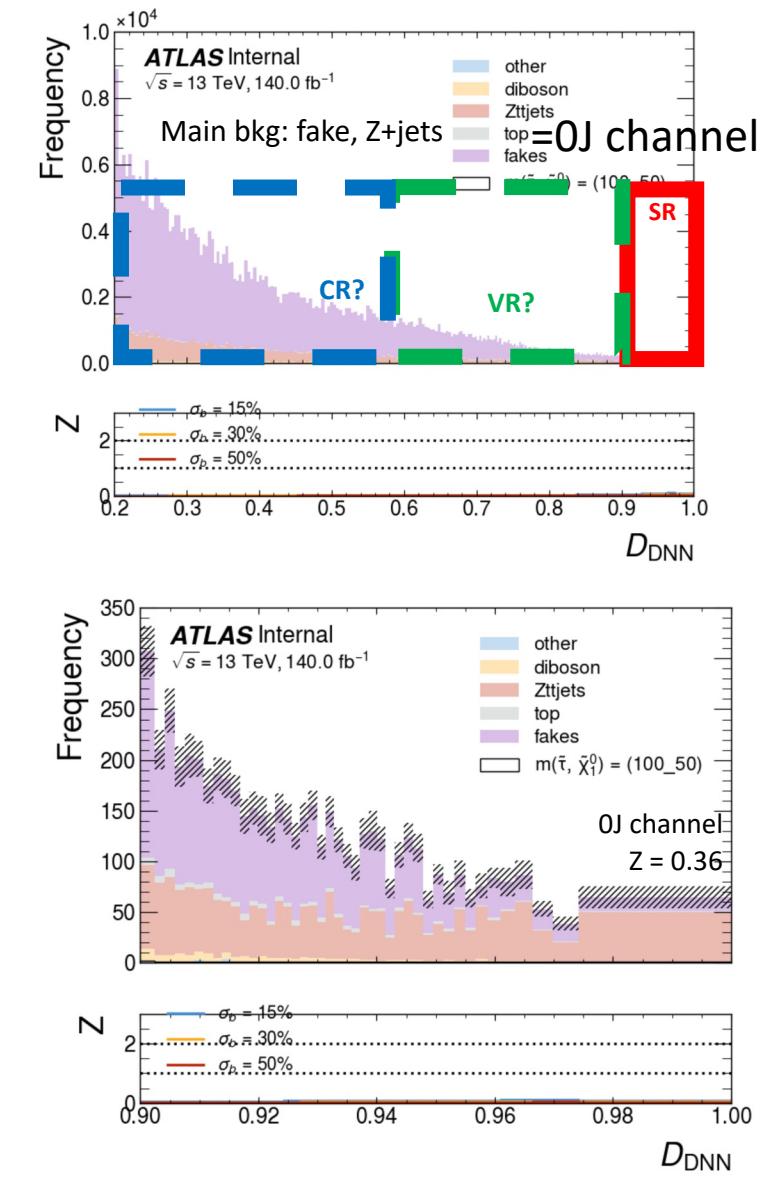
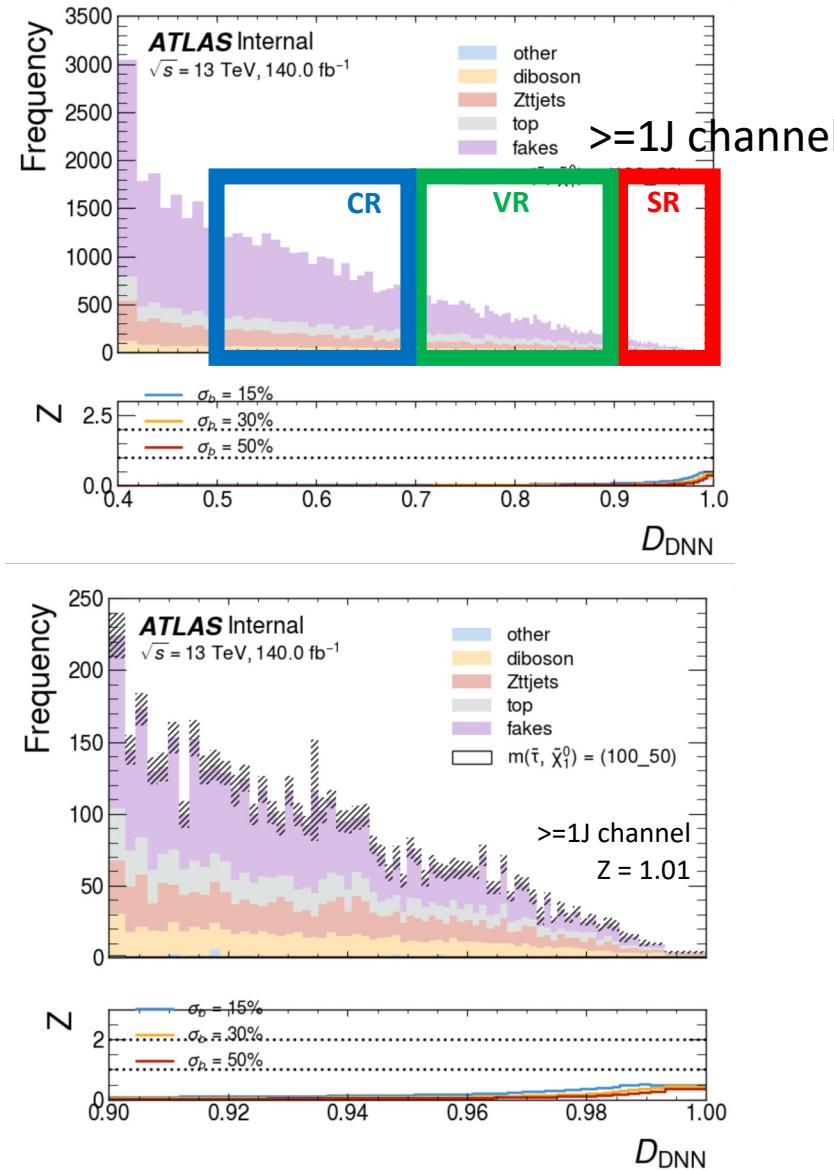
$\phi_{\{1,2\}} \text{ cut}^*$

SR

Pre-selection

≥ 1 Jet ≥ 0 Jet

DNN score > 0.9



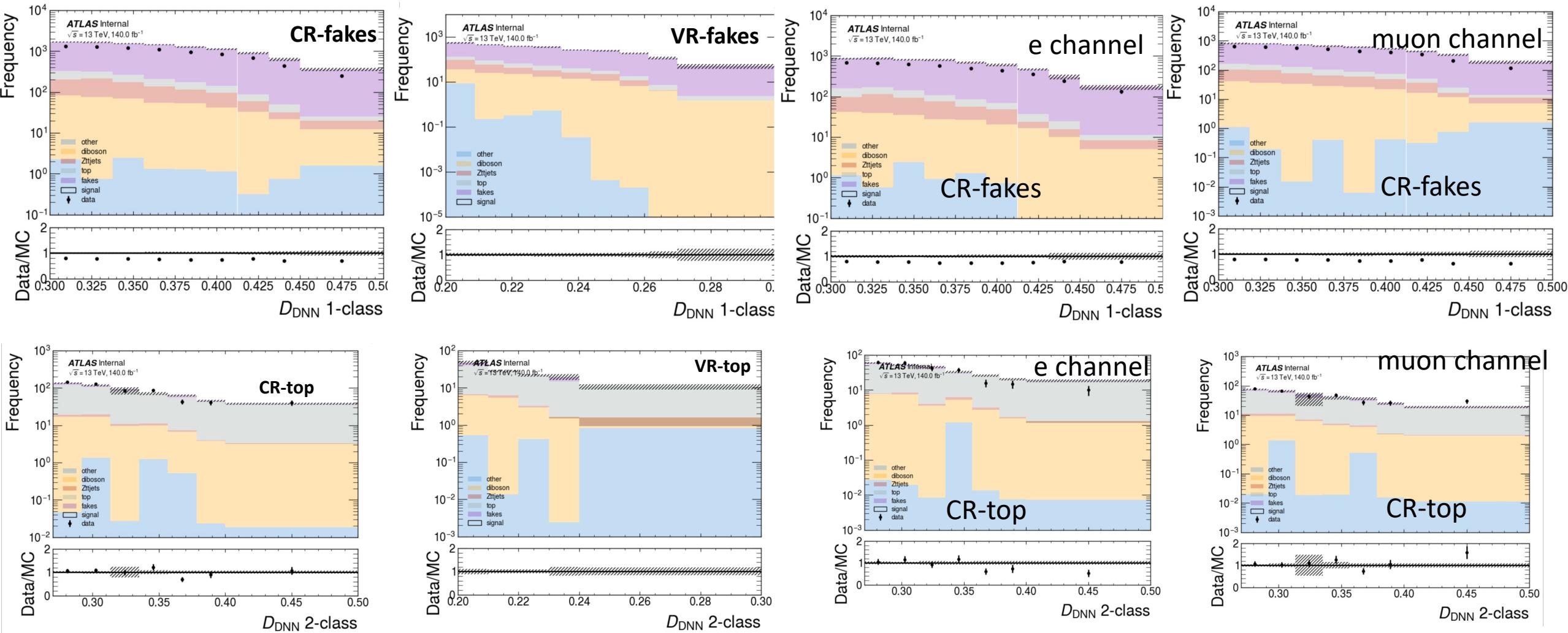
Direct Stau single-lep trigger background estimation(LH)

$\geq 1J$ channel

Region	Selections		channel	Total Bkg		Dominant Bkg		Purity		
Fake CR	0.5 < signal score < 0.7, max bkg score: Fake	fake score > 0.3	e-channel	5557	10628	4746	9029	0.85	0.85	
			muon-channel	4283		4283		0.84		
Top CR	0.5 < signal score < 0.7, max bkg score: Top	Top score > 0.27	e-channel	256	555	203	449	0.79	0.82	
			muon-channel	299		245		0.82		
Z CR	0.5 < signal score < 0.7, max bkg score: Z	Z score > 0.28	e-channel	457	775	374	631	0.82	0.82	
			muon-channel	317		256		0.81		
VV CR	0.0 < signal score < 0.7, max bkg score: VV	VV Score > 0	e-channel	145	264	72	134	0.50	0.50	
			muon-channel	118		61		0.52		
Fake VR	0.7 < signal score < 0.9, max bkg score: Fake	fake score > 0.2	--	2601	2166		0.83			
Top VR	0.7 < signal score < 0.9, max bkg score: Top	Top score > 0.2	--	128	95		0.74			
Z VR	0.7 < signal score < 0.9, max bkg score: Z	Z score > 0.165	--	247	189		0.76			
VV VR	0.7 < signal score < 0.9, max bkg score: VV	VV score > 0.06	--	166	84		0.51			

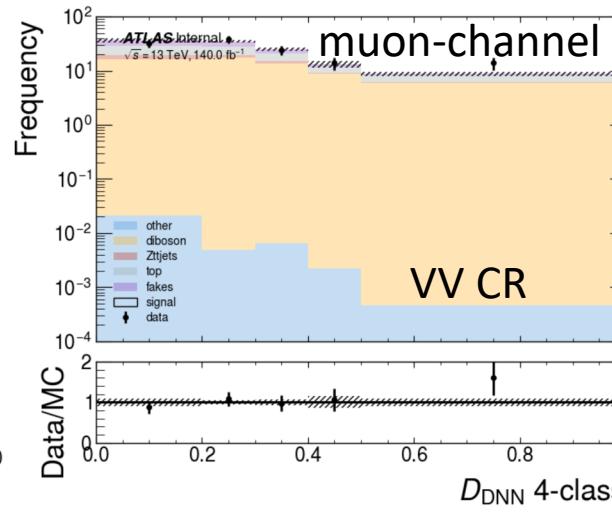
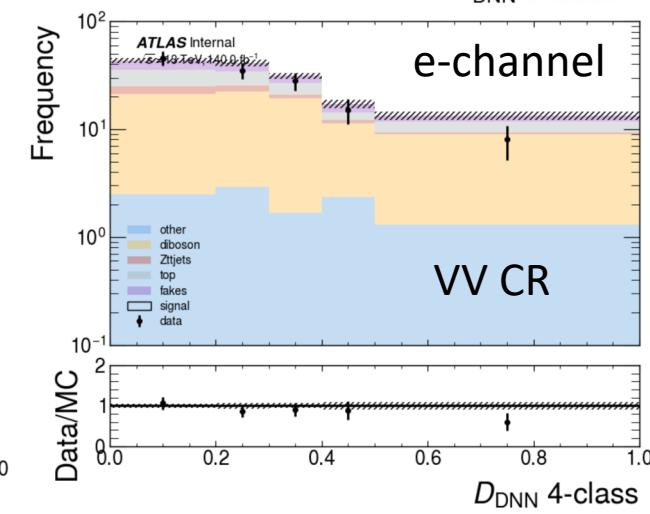
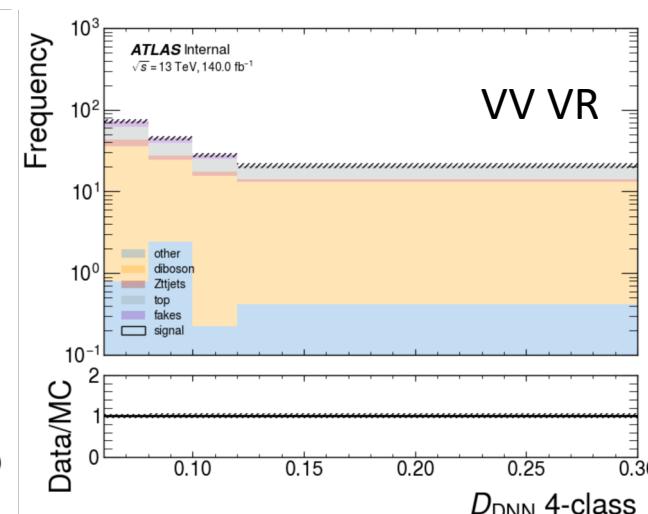
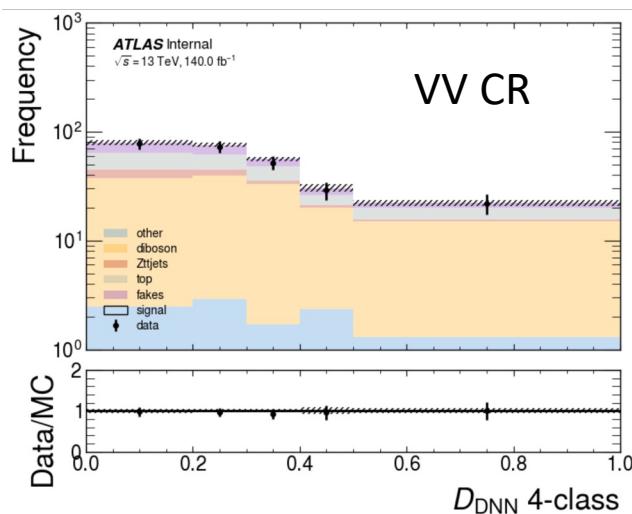
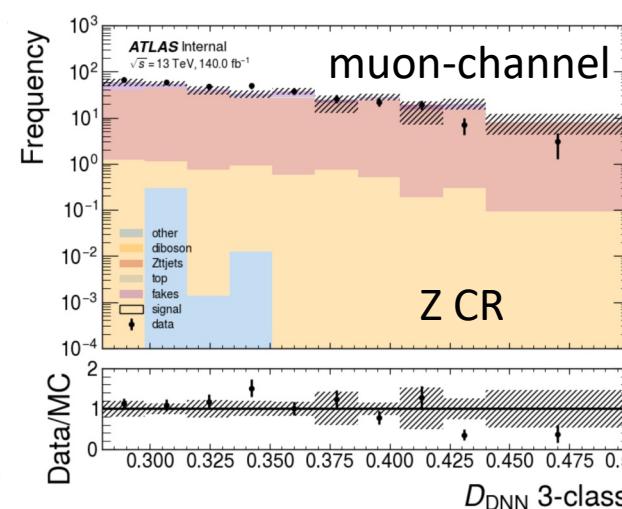
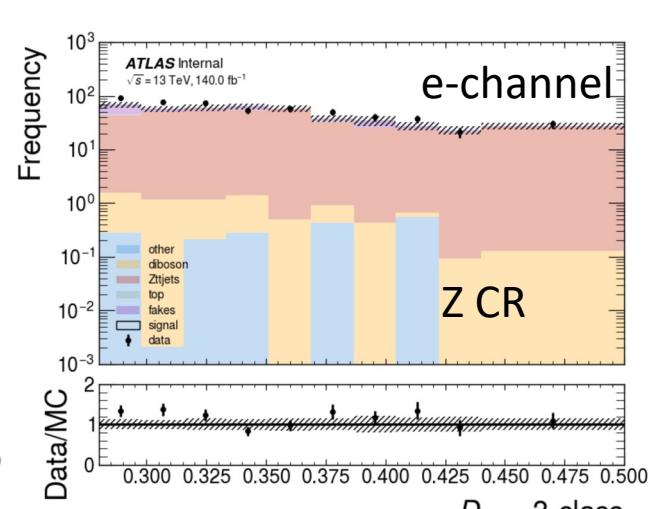
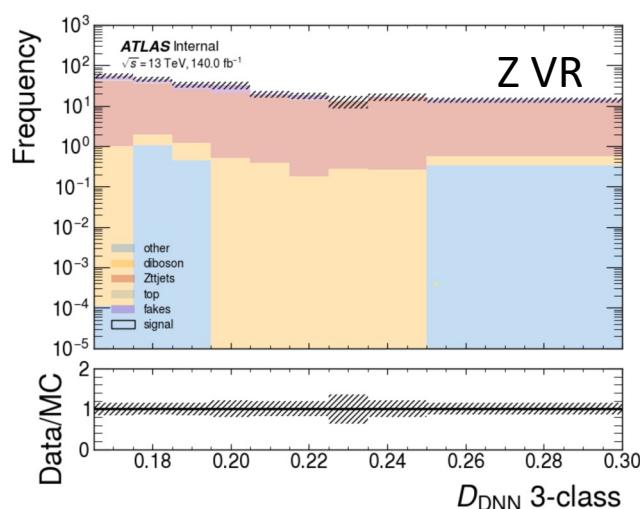
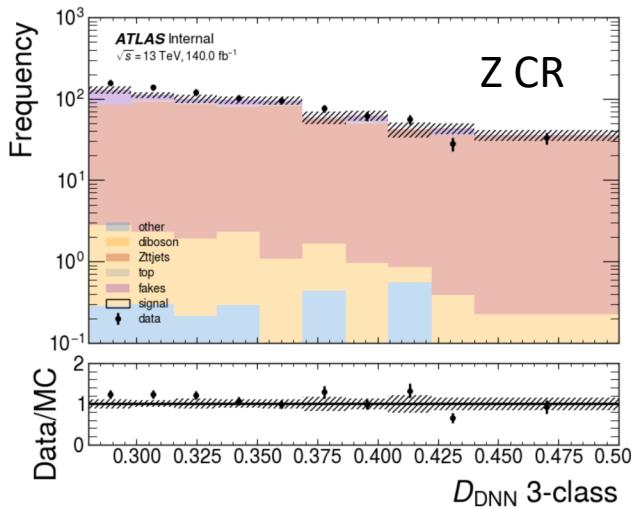
***Note: MC fakes are only place holders, will be replaced with data driven background in final fit and CR will be added to VR)**

Direct Stau single-lep trigger background estimation (LH)



***(Note: MC fakes are only place holders, will be replaced with data driven background in final fit and CR will be added to VR)**

Direct Stau single-lep trigger background estimation(LH)

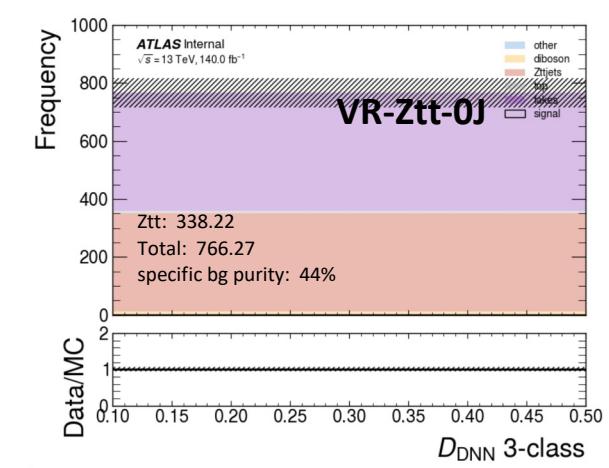
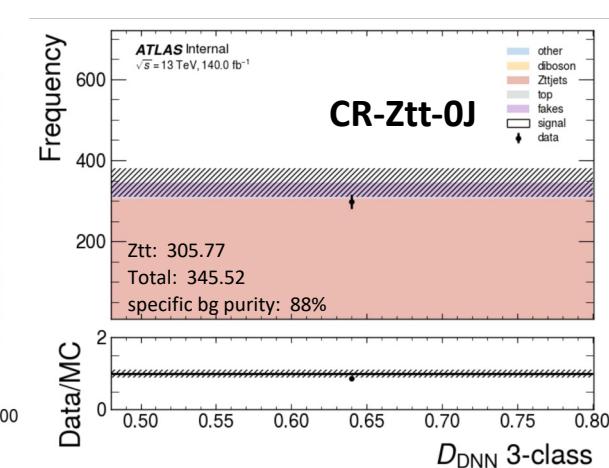
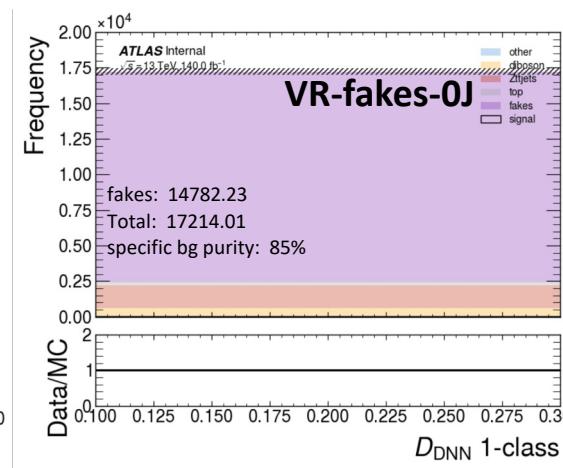
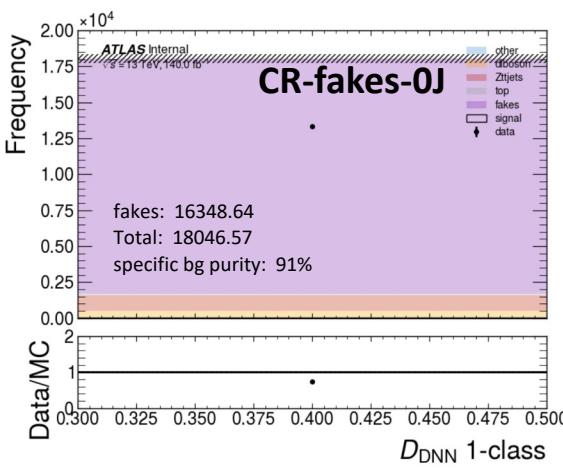


*(Note: MC fakes are only place holders, will be replaced with data driven background in final fit and CR will be added to VR)

Direct Stau single-lep trigger background estimation(LH)

= 0J channel

Region	Selections		Total Bkg	Dominant Bkg	Purity
Fake CR	0.5 < signal score < 0.7, max bkg score: Fake	fake score > 0.3	18046	16348	0.91
Z CR	0.2 < signal score < 0.5, max bkg score: Z	Z score > 0.48	345	305	0.88
Fake VR	0.7 < signal score < 0.9, max bkg score: Fake	fake score > 0.1	17214	14782	0.85
Z VR	0.5 < signal score < 0.9, max bkg score: Z	Z score > 0.1	766	338	0.44

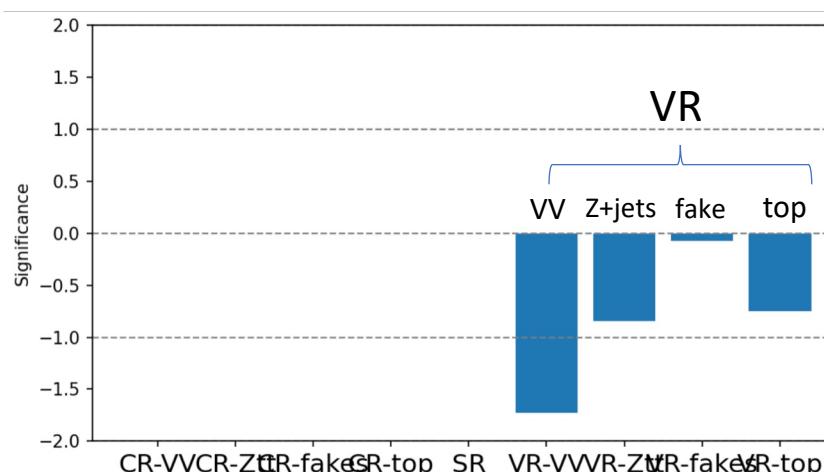
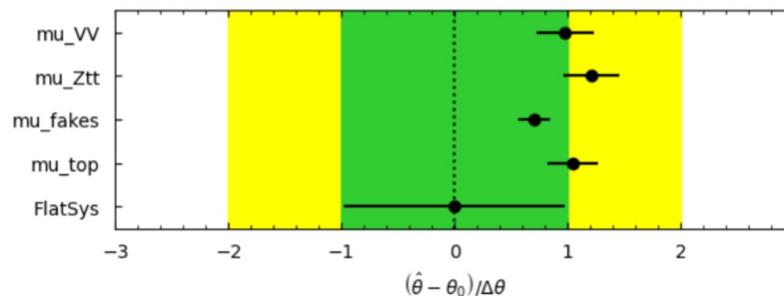


*(Note: MC fakes are only place holders, will be replaced with data driven background in final fit and CR will be added to VR)

Direct Stau single-lep trigger background only fit (LH)

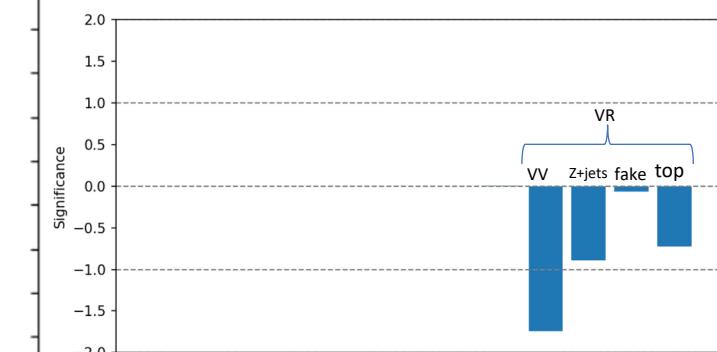
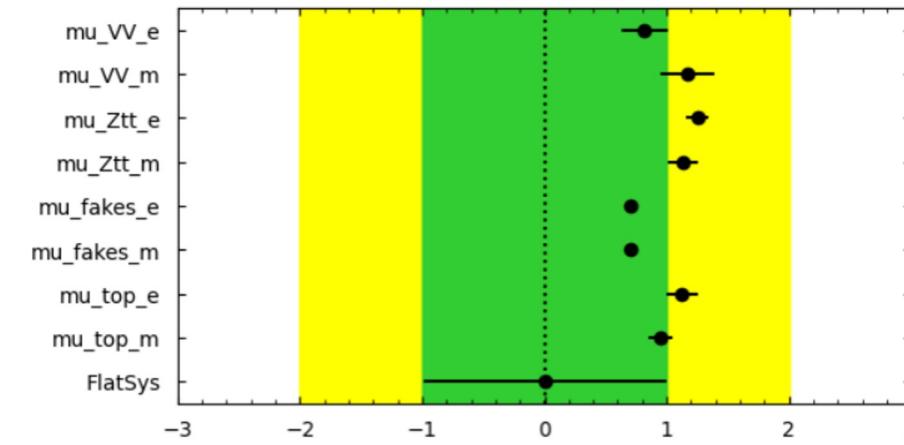
≥ 1 J channel(combined)

```
INFO - cabinetry.fit - fit results (with symmetric uncertainties):
INFO - cabinetry.fit - mu_VV          = 0.9763 +/- 0.2523
INFO - cabinetry.fit - mu_Ztt         = 1.2063 +/- 0.2497
INFO - cabinetry.fit - mu_fakes       = 0.7051 +/- 0.1398
INFO - cabinetry.fit - mu_top         = 1.0451 +/- 0.2208
INFO - cabinetry.fit - FlatSys        = -0.0009 +/- 0.9745
INFO - cabinetry.fit - staterror_CR-VV[0] = 1.0000 +/- 0.0252
INFO - cabinetry.fit - staterror_CR-Ztt[0] = 1.0000 +/- 0.0413
INFO - cabinetry.fit - staterror_CR-fakes[0] = 1.0000 +/- 0.0145
INFO - cabinetry.fit - staterror_CR-top[0] = 1.0000 +/- 0.0002
INFO - cabinetry.visualize.utils - saving figure as figures/pulls.pdf
```



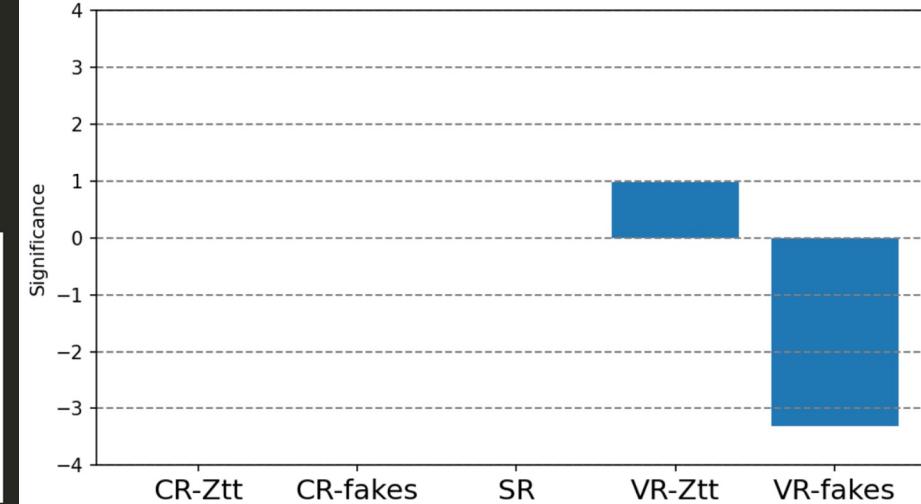
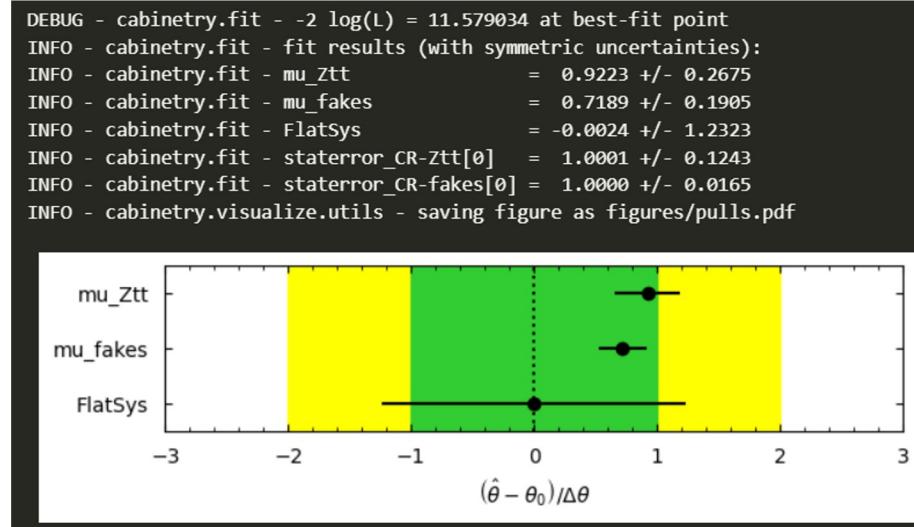
≥ 1 J channel e/mu separate

```
INFO - cabinetry.fit - fit results (with symmetric uncertainties):
INFO - cabinetry.fit - mu_VV_e          = 0.8181 +/- 0.1909
INFO - cabinetry.fit - mu_VV_m          = 1.1690 +/- 0.2165
INFO - cabinetry.fit - mu_Ztt_e         = 1.2519 +/- 0.0929
INFO - cabinetry.fit - mu_Ztt_m         = 1.1379 +/- 0.1224
INFO - cabinetry.fit - mu_fakes_e       = 0.7060 +/- 0.0259
INFO - cabinetry.fit - mu_fakes_m       = 0.7044 +/- 0.0268
INFO - cabinetry.fit - mu_top_e         = 1.1251 +/- 0.1277
INFO - cabinetry.fit - mu_top_m         = 0.9486 +/- 0.0945
INFO - cabinetry.fit - FlatSys          = 0.0008 +/- 0.9934
INFO - cabinetry.fit - staterror_CR-VV-e[0] = 0.9999 +/- 0.0315
INFO - cabinetry.fit - staterror_CR-VV-m[0] = 1.0001 +/- 0.0407
INFO - cabinetry.fit - staterror_CR-Ztt-e[0] = 1.0002 +/- 0.0479
INFO - cabinetry.fit - staterror_CR-Ztt-m[0] = 1.0001 +/- 0.0735
INFO - cabinetry.fit - staterror_CR-fakes-e[0] = 1.0000 +/- 0.0211
INFO - cabinetry.fit - staterror_CR-fakes-m[0] = 1.0000 +/- 0.0199
INFO - cabinetry.fit - staterror_CR-top-e[0] = 0.9999 +/- 0.0705
INFO - cabinetry.fit - staterror_CR-top-m[0] = 1.0000 +/- 0.0282
INFO - cabinetry.visualize.utils - saving figure as figures/pulls.pdf
```



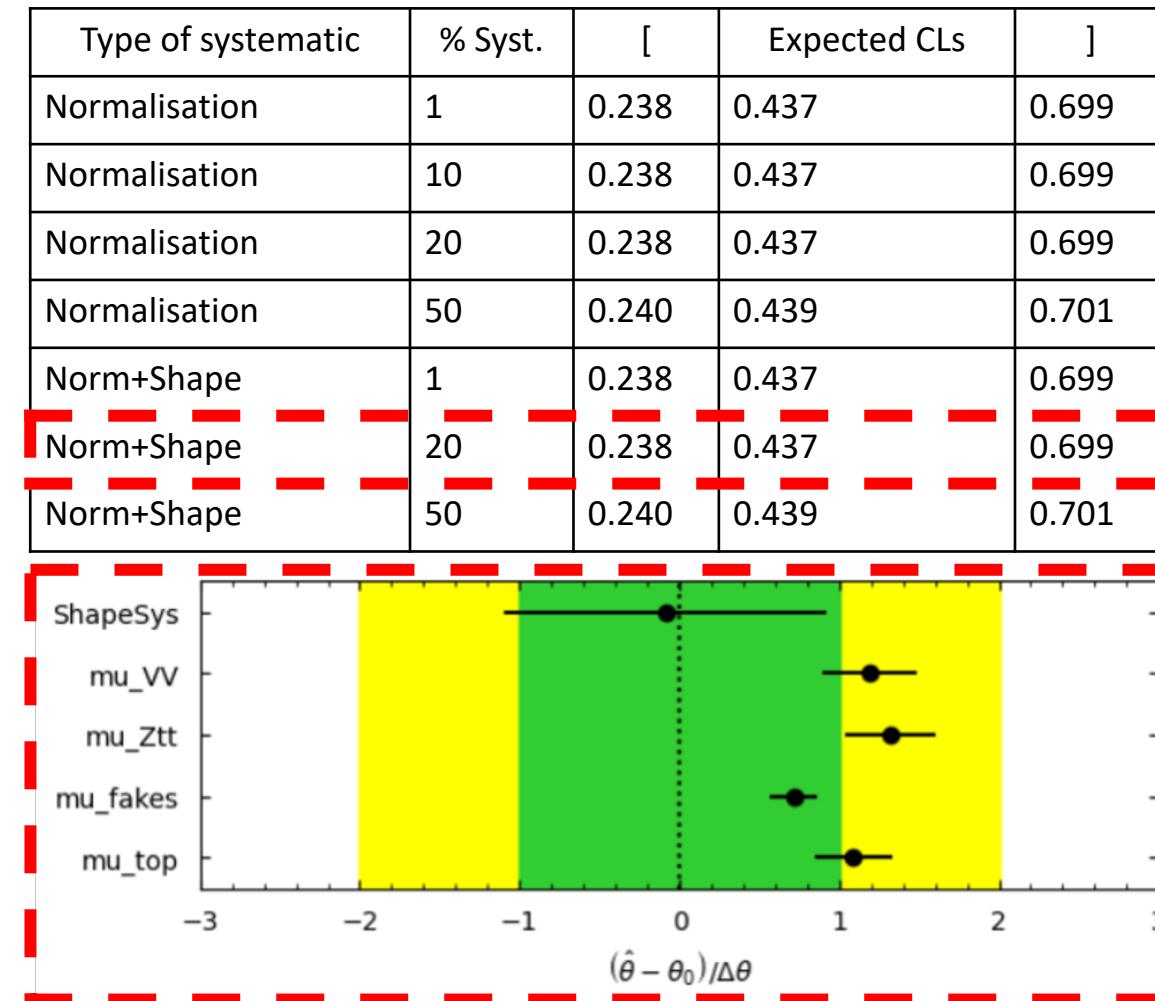
Direct Stau single-lep trigger background only fit (LH)

= 0 J channel



Direct Stau single-lep trigger background only fit (LH)

- Experimented running exclusion fit with Asimov data using different systematics (both FlatSys and ShapeSys).
- Overall, expected CLs very robust to size of systematics, limited by signal statistics
- Sensitivity worse than estimated from simple Z score formula
- (Mu factors preliminary since dominant fake background MC will be replaced)*

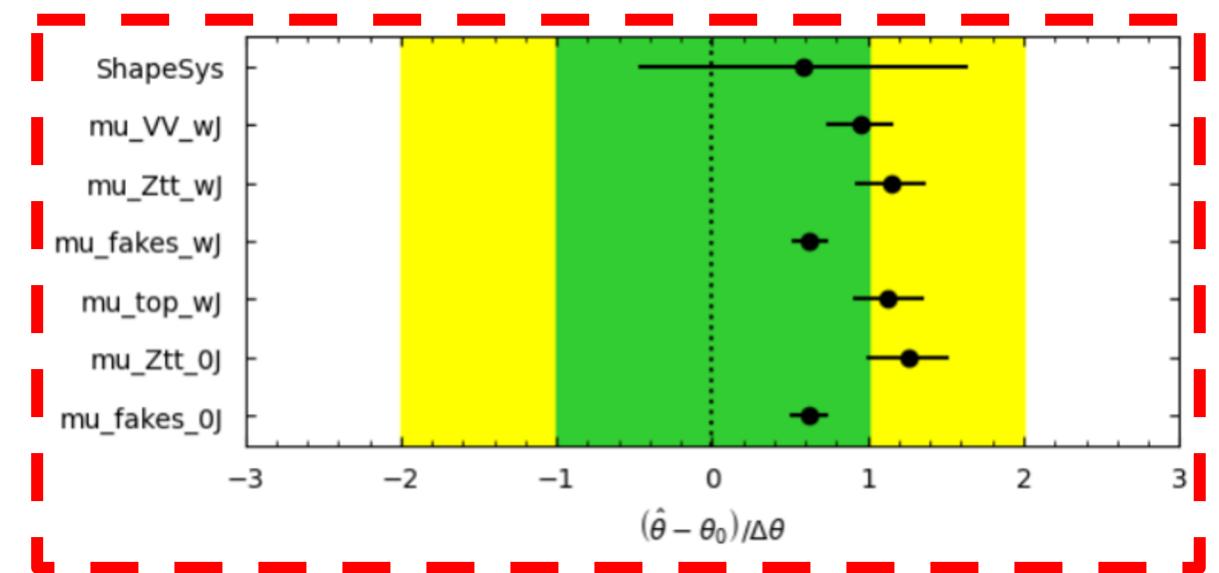


Direct Stau single-lep trigger Exclusion Fit(LH)

0J and $\geq 1J$ channel combined

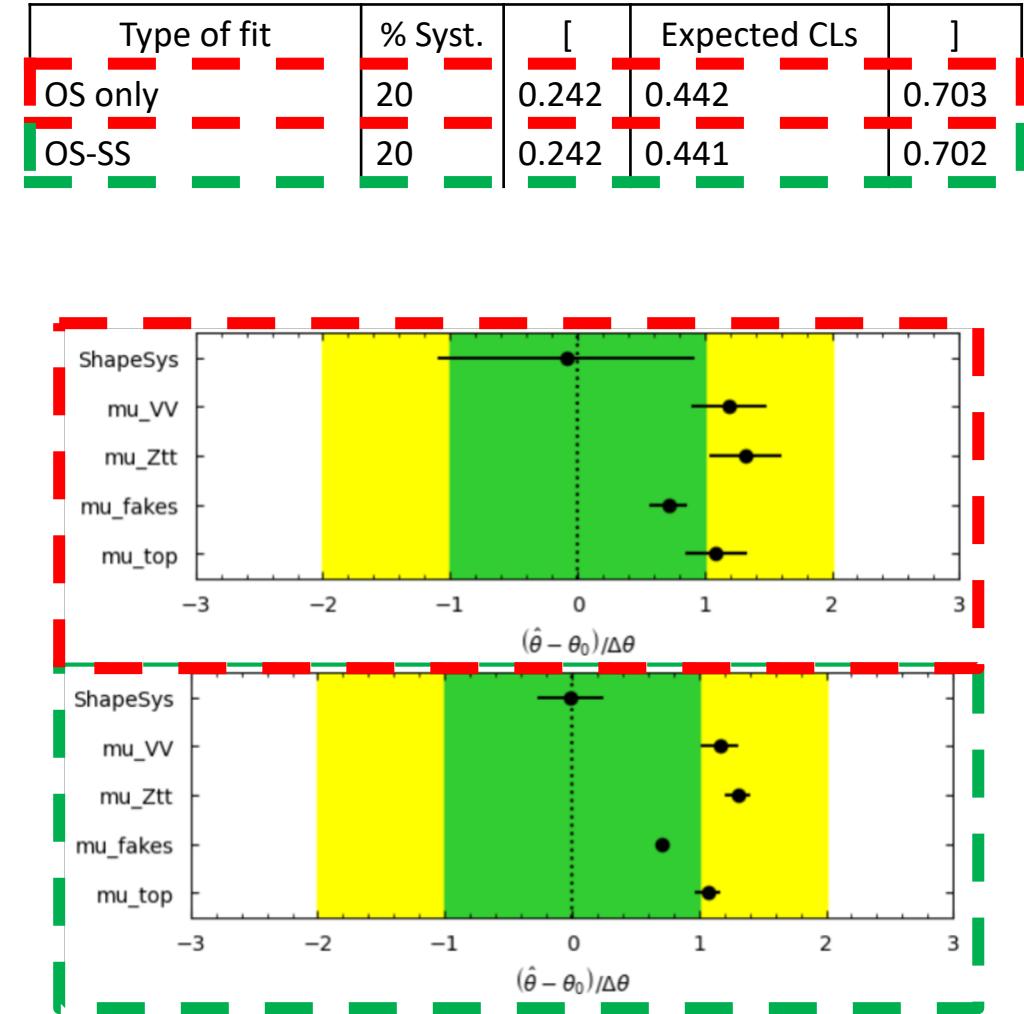
- Including the 0J and $\geq 1J$ channel together in the exclusion fit, we get a slight decrease in the expected CLs, but not much
- Not that surprising, DNN studies showed $\geq 1J$ channel drives sensitivity
- ShapeSys further away from zero (~ 0.58)

Type of systematic	% Syst.	[Expected CLs]
Normalisation	20	0.231	0.429	0.693
Norm+Shape	20	0.231	0.429	0.693



Direct Stau single-lep trigger OS-SS Fit(LH)

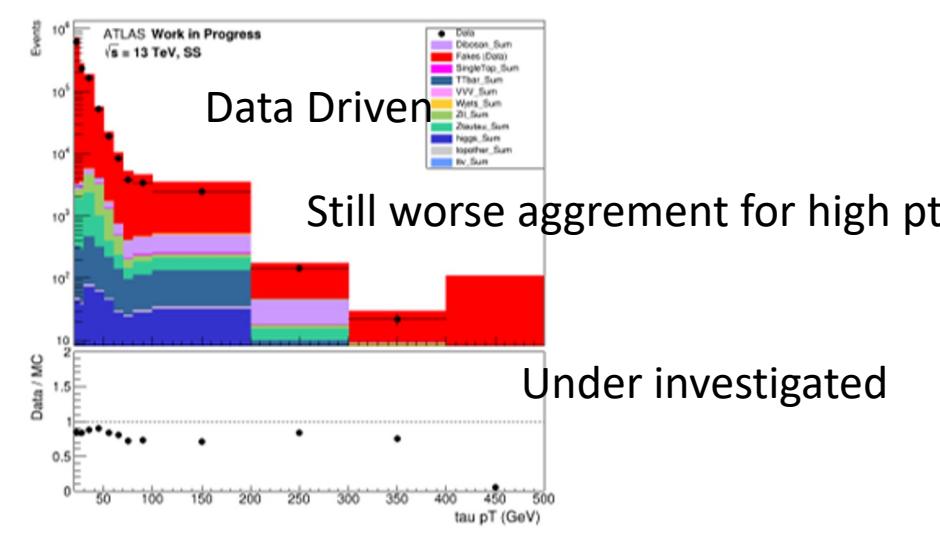
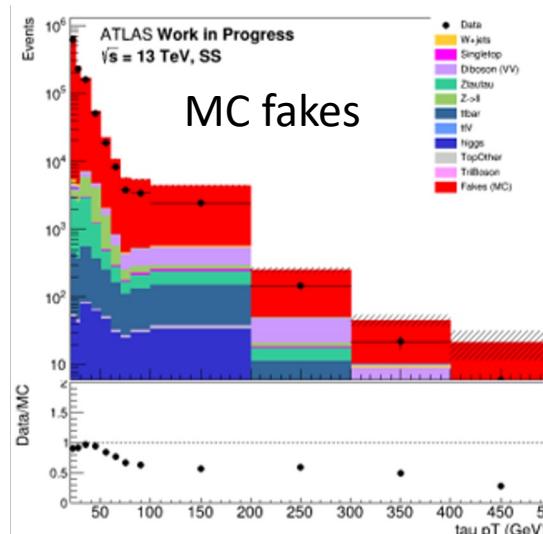
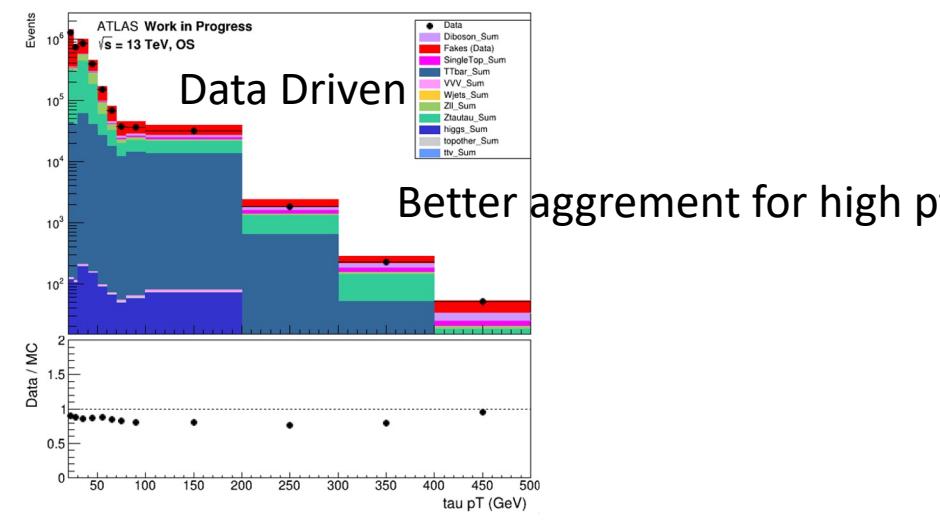
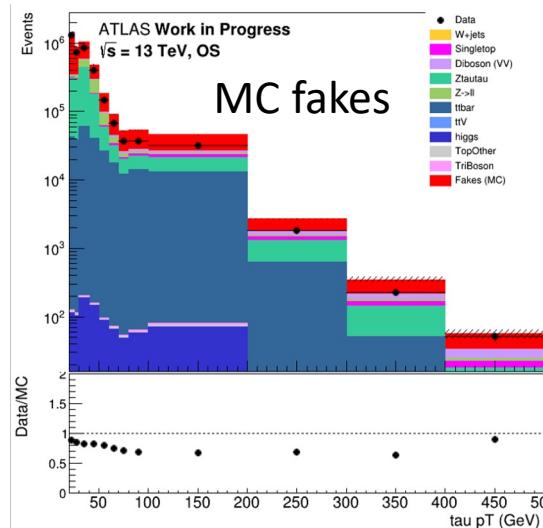
- Idea to use same-sign (SS) region in the fit to constrain systematics
- Can model any differences between the extrapolation
- Applied this as a simultaneous fit of the OS and SS data with a floating common component
- Ran test with much simpler SR with fewer (16) bins in $\geq 1J$ channel
- Systematics significantly more constrained, but as seen before, we are not systematics limited, so small impact on resulting CLs value
- Small signal statistics remains main issue



Direct Stau fake estimation(LH)

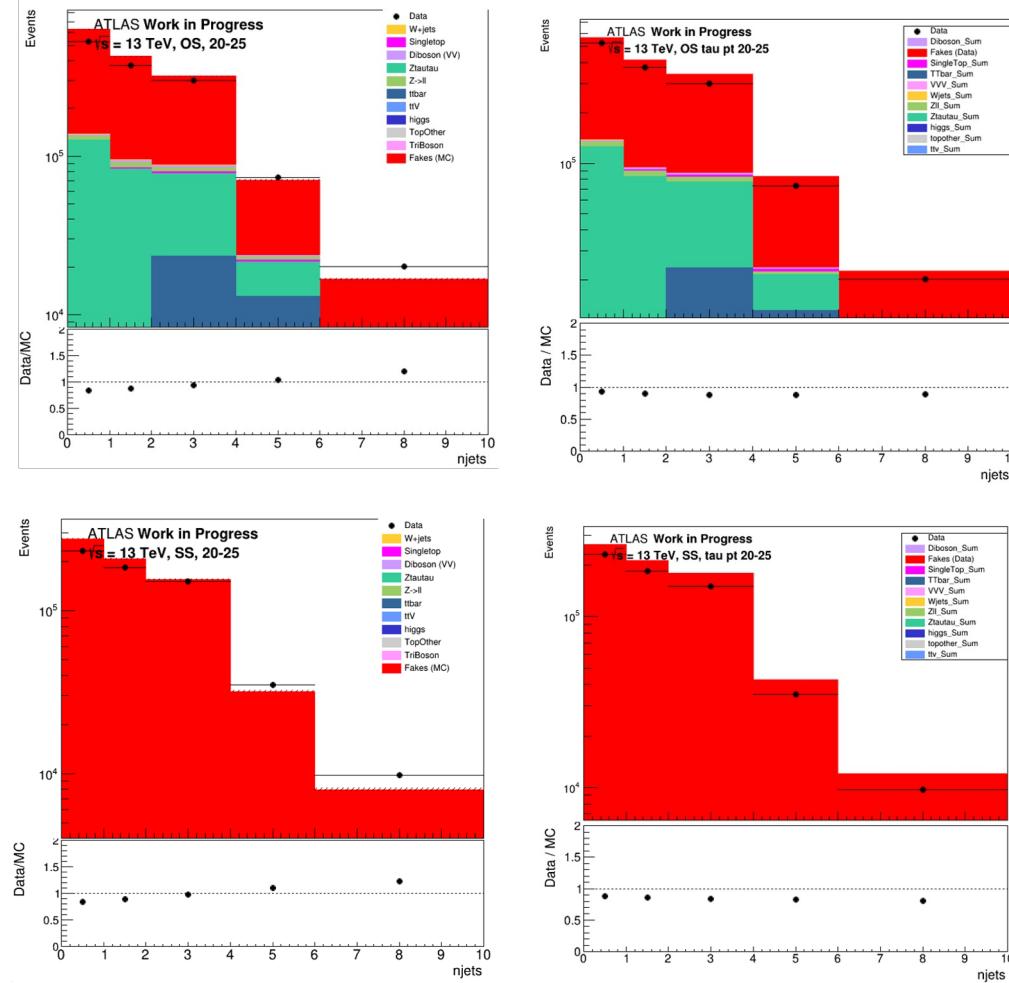
- CRs (fake factor computation)
 - Single lepton trigger
 - OS/SS
 - 1 signal lepton
 - ID: ≥ 1 tight tau
 - antiID: > 0.05 RNN score, no tight tau
- SRs
 - Single lepton trigger
 - MET $> 15\text{GeV}$
 - B-veto
 - OS/SS
 - ID: ≥ 1 tight tau
 - antiID: > 0.05 RNN score, no tight tau
- Focus on W+jets and ttbar
- **Binned in prongness, tau pT**

FF determination	FF application
Data	Data
CR Pass ID	SR Pass ID
CR Fail ID	SR Fail ID



Direct Stau fake estimation(LH)

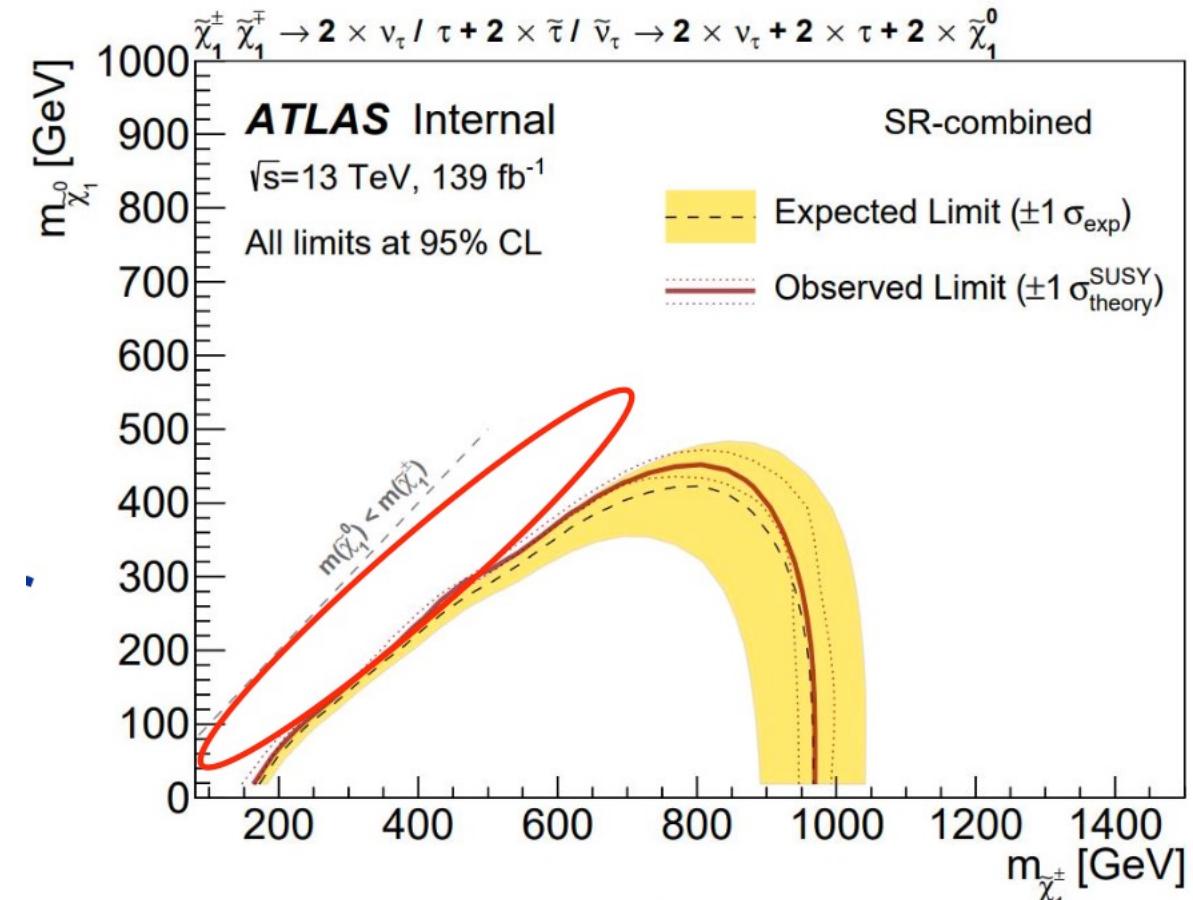
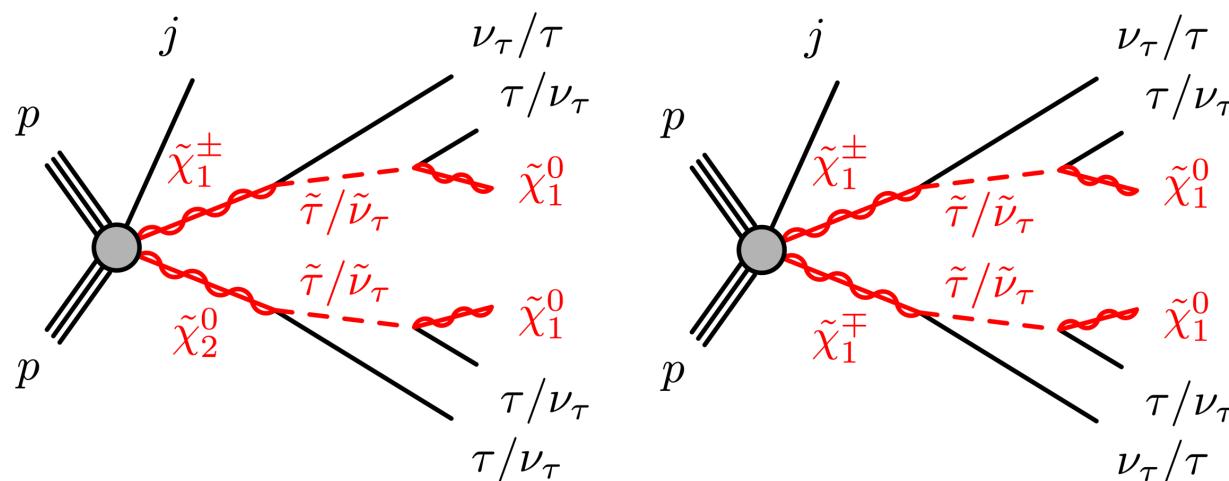
- Focus on events with taus with pT 20-25 GeV
- Top: OS
- Bottom: SS
- Better agreement with data-driven fake taus compared to MC for different numbers of jets in the event



C1C1/C1N2 Motivation

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

Boosted by ISR and has a large MET due to two miss $\tilde{\chi}_1^0$



C1C1 ISR signal region optimization

- BDT method for signal region optimization
 - 30% flat systemic uncertainty
 - Figure of merit: Z_n
 - 5fold to Train(Cross-Validation)
 - Preselection based on final state($\tau \tau$ or τl)

	HH Pre-selection	LH Pre-selection
	≥ 2 medium taus	≥ 1 medium taus
	0 base lepton	1 base lepton, 1 signal lepton
	MET ≥ 150 ; pass MET trigger	MET ≥ 200 ; pass MET trigger
	$1 \leq n_{\text{jet}}$	$1 \leq n_{\text{jet}}$
	Opposite-sign hadronic-hadronic tau pair	Opposite-sign lepton-hadronic tau pair
	bveto	bveto
	jet pt > 100 GeV	jet pt > 100 GeV

Table 3: Best performance for HH and LH channel after grid search

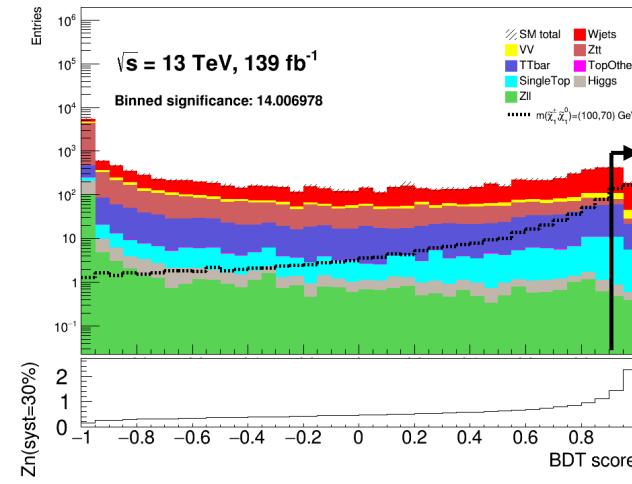
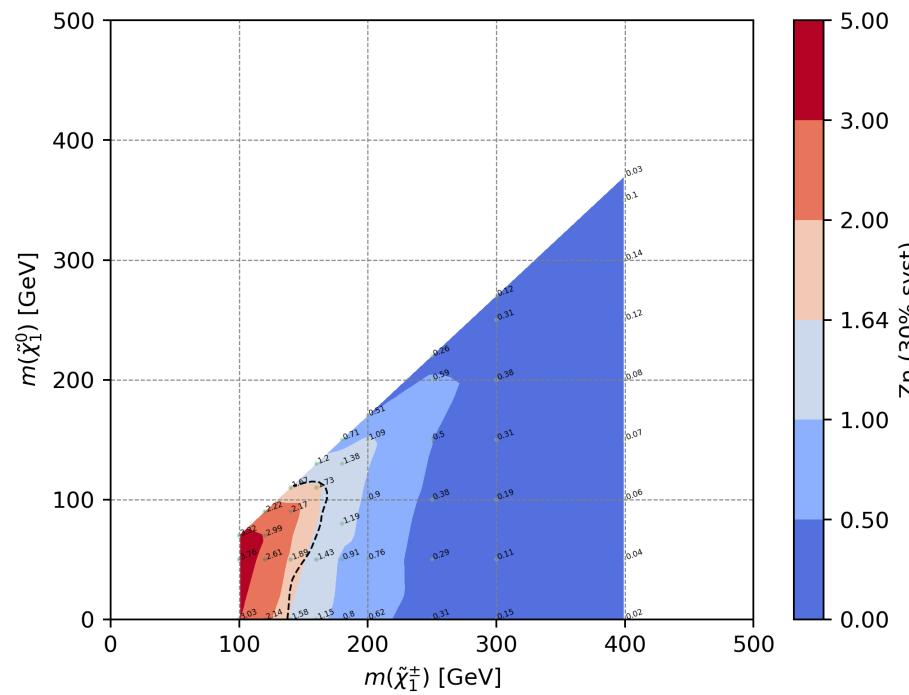
Channel	Ntrees	MaxDepth	MinNode	Learning rate
had-had channel	400	8	1	0.1
lep-had channel	300	6	1	0.05

C1C1 ISR signal region definition(HH)

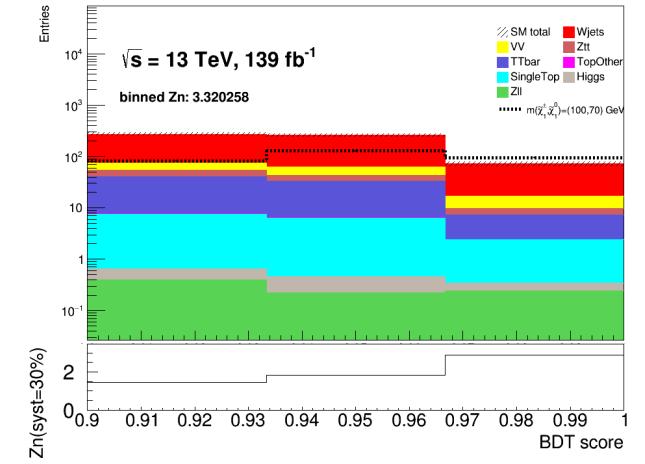
SR

Pre-selection
BDT score > 0.9

Sensitive map



Binned significance: 3.32

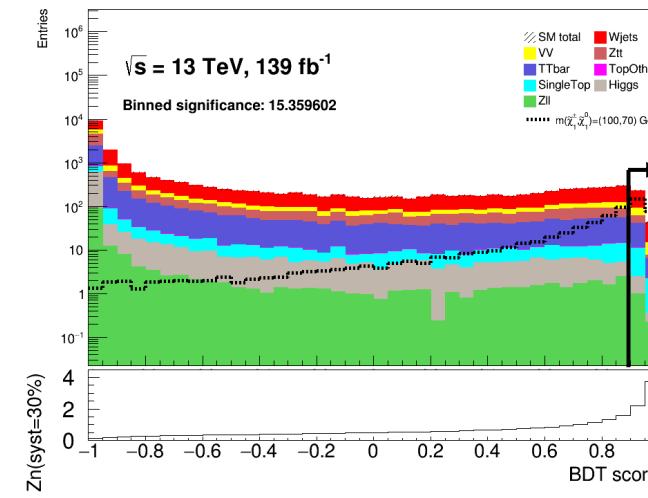
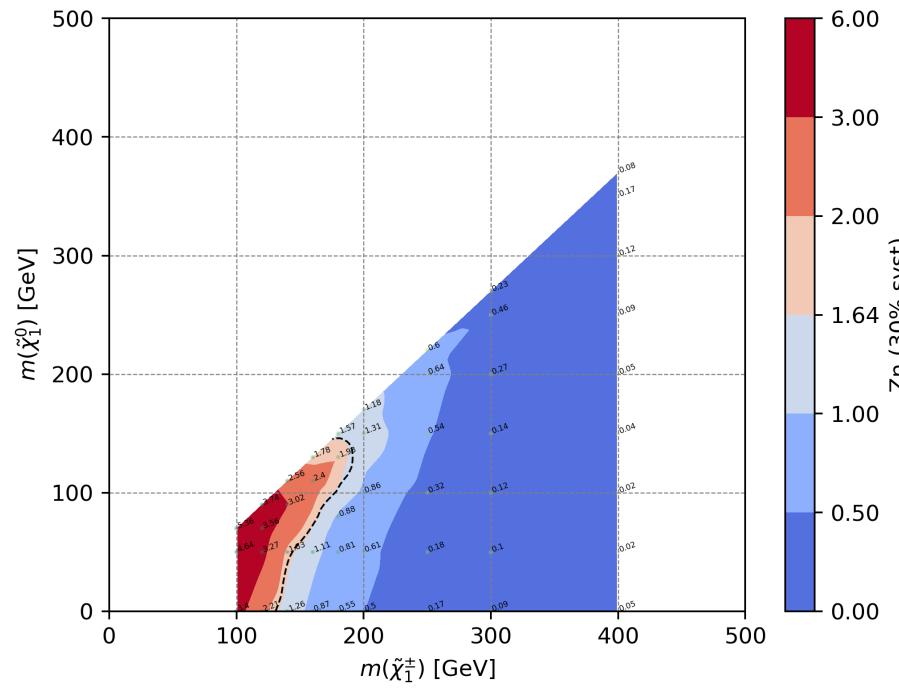


SM process	SR2	SR2-Bin1	SR2-Bin2	SR2-Bin3
Wjets	448 ± 28	197 ± 18	55 ± 9	197 ± 19
VV	49.1 ± 1.2	20.7 ± 0.9	7.4 ± 0.4	21.0 ± 0.9
Ztt	25.3 ± 2.9	9.8 ± 1.6	2.3 ± 1.1	13.1 ± 2.1
TTbar	64.5 ± 3.1	26.7 ± 2.0	4.9 ± 0.9	32.9 ± 2.2
TopOther	0.38 ± 0.07	0.15 ± 0.04	0.031 ± 0.028	0.21 ± 0.05
SingleTop	14.7 ± 1.3	5.8 ± 0.8	2.1 ± 0.5	6.8 ± 0.9
Higgs	0.60 ± 0.06	0.24 ± 0.04	0.100 ± 0.026	0.26 ± 0.04
Zll	0.86 ± 0.29	0.22 ± 0.07	0.24 ± 0.18	0.40 ± 0.20
SM total	603 ± 28	271 ± 19	260 ± 19	72 ± 9
$m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0) = (100, 70)$	307.3 ± 2.4	82.9 ± 1.2	129.1 ± 1.5	95.3 ± 1.3

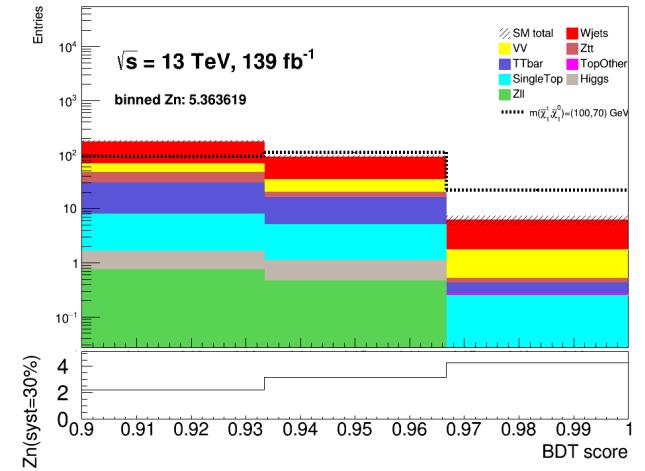
C1C1 ISR signal region definition(LH)

SR
Pre-selection
BDT score > 0.9

Sensitive map



Binned significance: 5.36



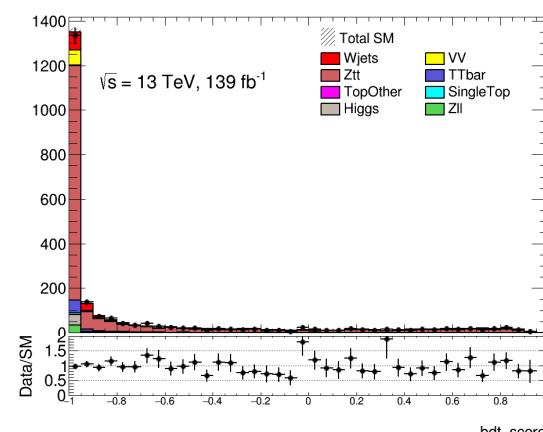
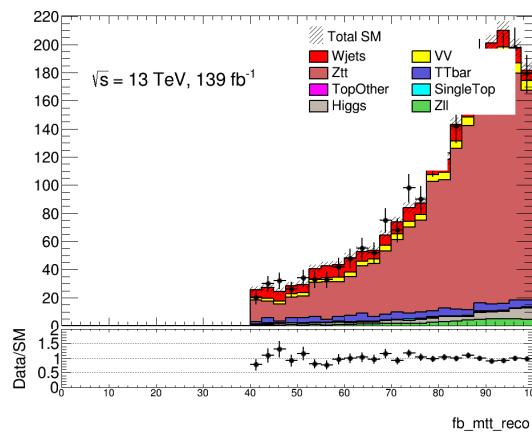
SM process	SR1	SR1-Bin1	SR1-Bin2	SR1-Bin3
Wjets	167 ± 8	56 ± 4	4.4 ± 1.1	106 ± 7
VV	35.90 ± 0.95	13.81 ± 0.54	1.25 ± 0.17	20.8 ± 0.8
Ztt	22.4 ± 2.6	4.5 ± 0.7	0.10 ± 0.04	17.8 ± 2.6
TTbar	33.2 ± 2.3	11.0 ± 1.3	0.15 ± 0.15	22.0 ± 1.8
TopOther	0.27 ± 0.05	0.061 ± 0.025	0.022 ± 0.019	0.18 ± 0.04
SingleTop	10.5 ± 1.0	4.0 ± 0.7	0.24 ± 0.11	6.3 ± 0.8
Higgs	1.59 ± 0.29	0.66 ± 0.19	0.008 ± 0.005	0.92 ± 0.22
Zll	1.22 ± 0.20	0.46 ± 0.13	0.007 ± 0.005	0.75 ± 0.16
SM total	272 ± 9	175 ± 7	91 ± 5	6.2 ± 1.2
$m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0) = (100, 70)$	226.0 ± 2.0	92.9 ± 1.3	110.6 ± 1.4	22.5 ± 0.6

C1C1 ISR Z+jets estimation(LH)

selections highlighted in green make SR and CR/VR orthogonal

	selection	purity	Total Bkg	Dominant Bkg	Data	Data/Bkg
ZCR	Pre-selection $40 \text{ GeV} < M_{\tau\tau}^{\text{reco}} < 100 \text{ GeV}$ BDT score<-0.8	0.79	1615+-16	1272+-15	1611	0.99
ZVR	Pre-selection $40 \text{ GeV} < M_{\tau\tau}^{\text{reco}} < 100 \text{ GeV}$ -0.8<BDT score<0.9	0.76	623+-12	472+-10	619	0.99

Distributions after pre-selection and $40 \text{ GeV} < M_{\tau\tau}^{\text{reco}} < 100 \text{ GeV}$

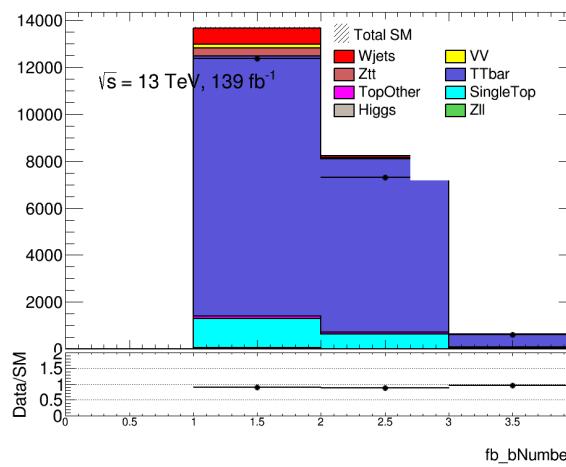
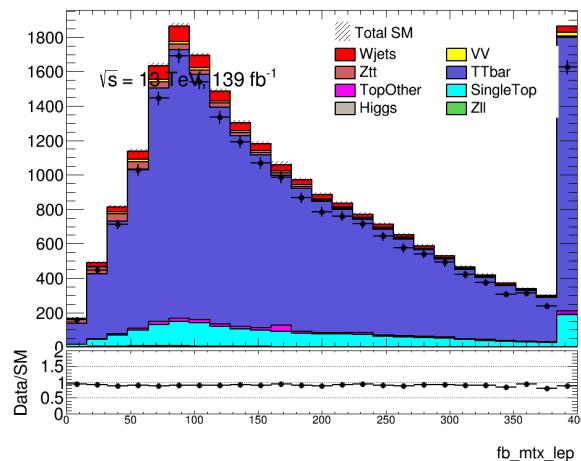


C1C1 ISR Top estimation(LH)

selections highlighted in green make SR and CR/VR orthogonal

	selection	purity	Total Bkg	Dominant Bkg	Data	Data/Bkg
topCR	Pre-selection without bVeto Number of B jets > 0 $M(\text{lep}, \text{met}) > 200 \text{ GeV}$	0.96	8367+34	8043+34	7404	0.89
topVR	Pre-selection without bVeto Number of B jets > 0 $120 \text{ GeV} < M_{\text{int}}(\text{lep}, \text{met}) < 200 \text{ GeV}$	0.94	5674+35	5345+34	5141	0.90

Distributions after pre-selection with bTag



C1N2 ISR signal region optimization

- BDT method for signal region optimization
 - 30% flat systemic uncertainty
 - Figure of merit: Z_n
 - 5fold to Train(Cross-Validation)
 - Preselection based on final state($\tau \tau$ or τl)

HH Pre-selection	LH Pre-selection
≥ 2 medium taus	≥ 1 medium taus
0 base lepton	≥ 1 base lepton, ≥ 1 signal lepton
MET ≥ 200 ; pass MET trigger	MET ≥ 200 ; pass MET trigger
$1 \leq n_{\text{Jet}}$	$1 \leq n_{\text{Jet}}$
Opposite-sign hadronic-hadronic tau pair	Opposite-sign lepton-hadronic tau pair
bveto	bveto
jet pt > 100 GeV	jet pt > 100 GeV
$M_{\tau\tau}^{\text{reco}} < 40$ GeV or $M_{\tau\tau}^{\text{reco}} > 130$ GeV	$M_{\tau\tau}^{\text{reco}} < 40$ GeV or $M_{\tau\tau}^{\text{reco}} > 130$ GeV

Grid Search for the best model

Hyperparameter	Scan Range
NTrees	200, 300, 400
MaxDepth	4, 6, 8
MinNode	1, 3, 5
Learning rate	0.01, 0.03, 0.05, 0.08, 0.1

Penalty function to balance the AUC and overfit

$$\mathcal{F} = AUC_{validation} - 0.3 \times AUC_{gap}$$

$$AUC_{gap} = |AUC_{train} - AUC_{validation}|$$

C1N2 ISR signal region definition(HH)

SR definition using BDT score(HH)

- Fake tau estimation using fake factor method
- Three bins
[0.80, 0.86], [0.86, 0.90], [0.90, 1.00]
- Fake estimation is same with direct stau
only change signal lep to at least signal lep

HH Pre-selection

≥ 2 medium taus

0 base lepton

MET ≥ 150 ; pass MET trigger

1 $\leq n_{\text{Jet}}$

Opposite-sign hadronic-hadronic tau pair

bveto

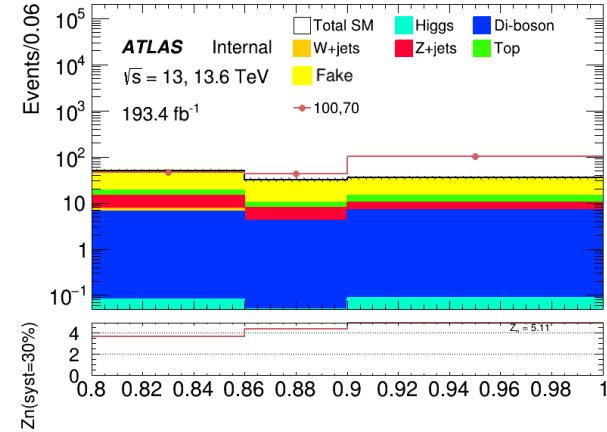
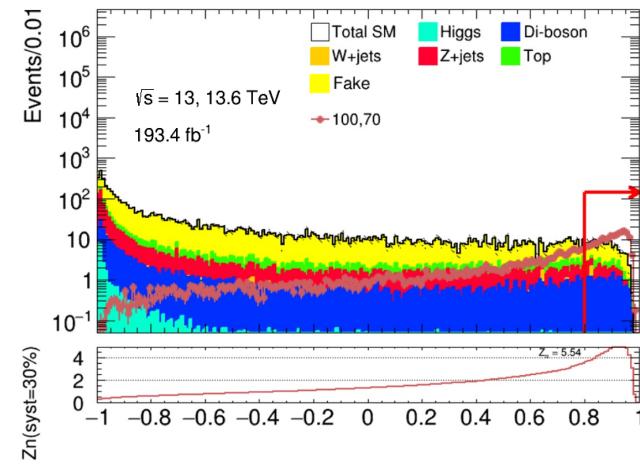
jet pt > 100 GeV

$M_{\tau\tau}^{\text{reco}} < 40$ GeV or $M_{\tau\tau}^{\text{reco}} > 130$ GeV

SR

Pre-selection

BDT score > 0.8

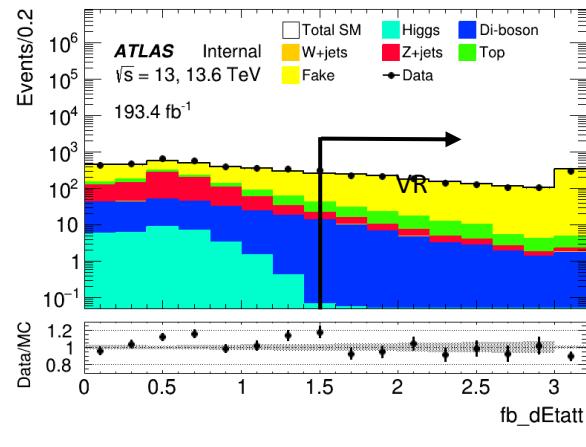
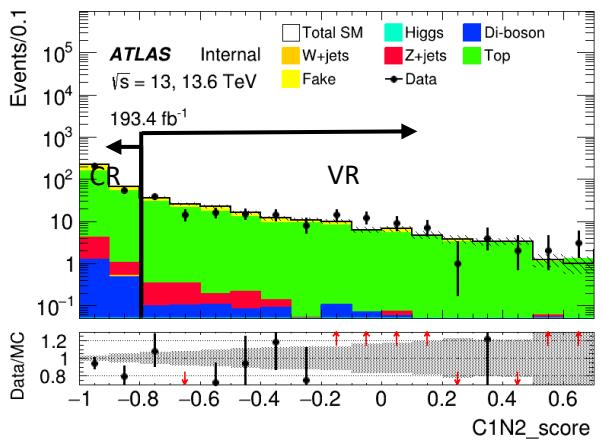
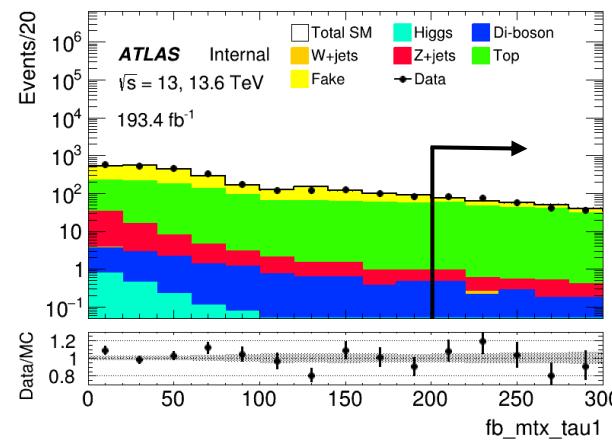
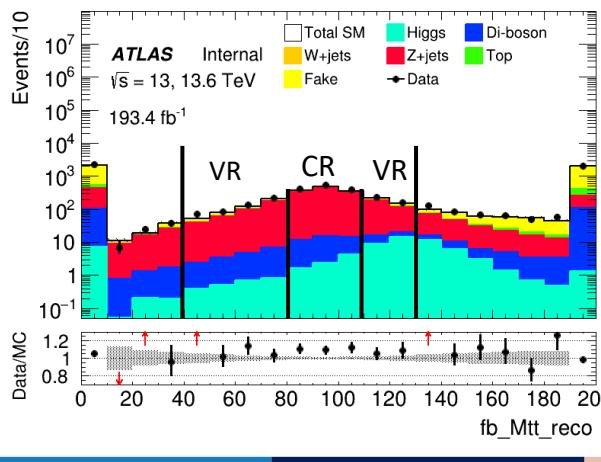
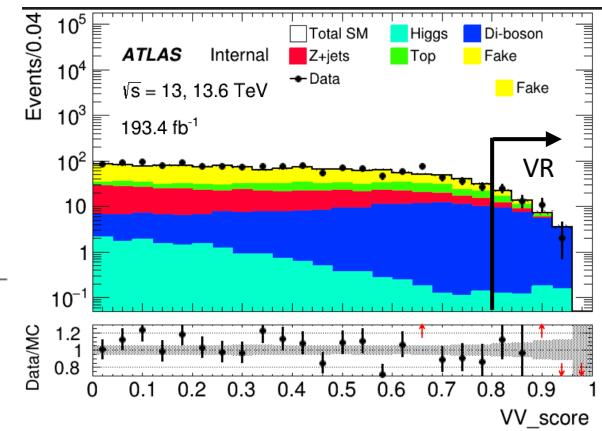


SM Process	[0.80, 0.86]	[0.86, 0.90]	[0.90, 1.00]
VV	6.508 ± 0.368	4.124 ± 0.341	6.855 ± 0.398
Top	4.719 ± 0.686	2.663 ± 0.546	4.331 ± 0.731
Fake	31.456 ± 3.898	21.525 ± 3.292	20.438 ± 2.976
Higgs	0.080 ± 0.023	0.045 ± 0.019	0.086 ± 0.031
Z+jets	6.659 ± 0.416	3.564 ± 0.286	3.207 ± 0.250
W+jets	0.978 ± 0.978	0.000 ± 0.000	0.000 ± 0.000
Total Bkg	50.402 ± 4.042	31.921 ± 3.354	34.917 ± 3.118
$m(\tilde{\chi}_1^\pm, \tilde{\chi}_2^0) = (100, 70)$	46.569 ± 1.327	43.128 ± 1.283	101.059 ± 1.961
Z_n	3.65	4.37	5.11

C1N2 ISR background estimation(HH)

Selection for control region and validation region

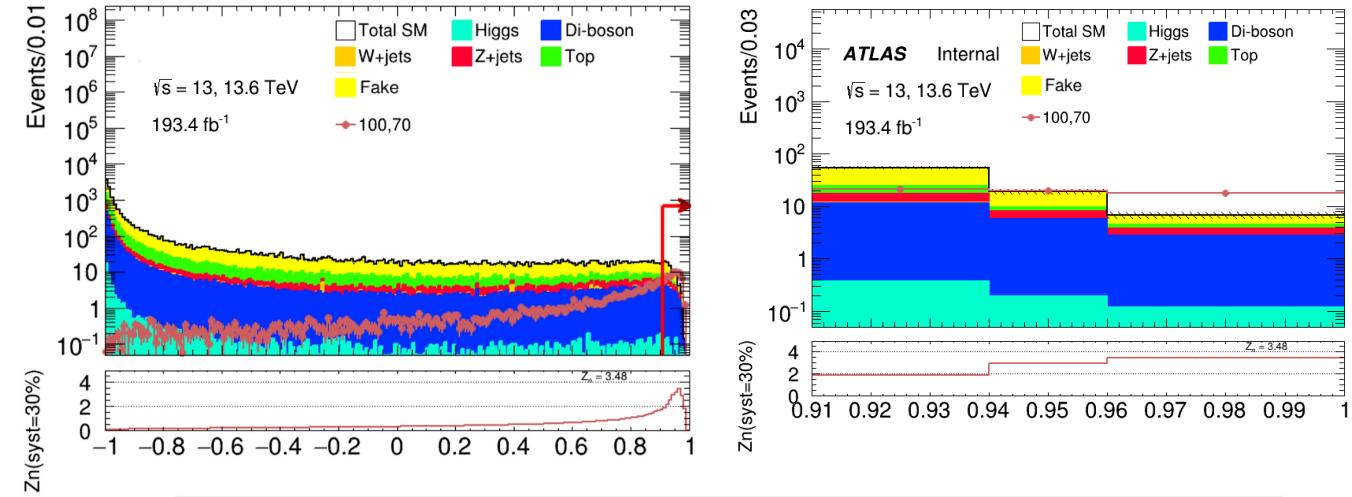
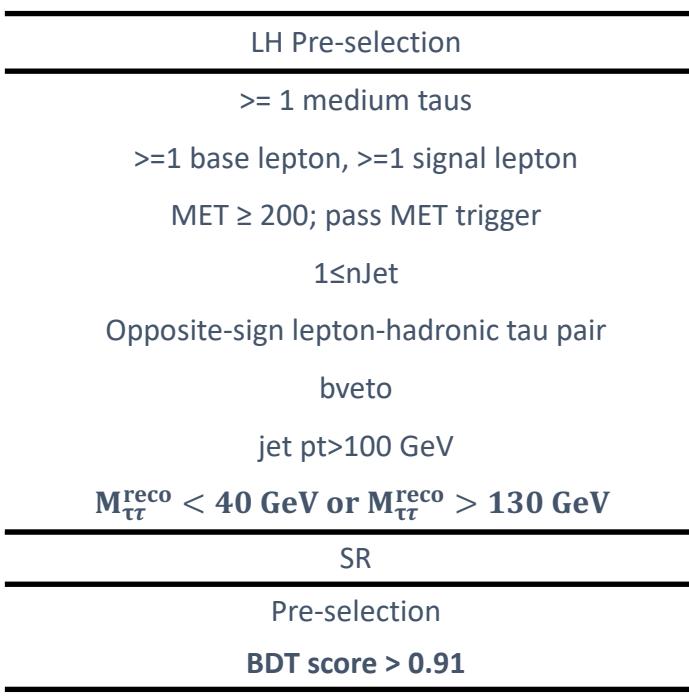
Process	Top		Z+jets		Multi-bosons	Fake		
	TCR	TVR	ZCR	ZVR				
Charge combination								
Trigger								
N medium τ			OS MET trigger, $E_T^{\text{miss}} \geq 200\text{GeV}$					
N lep					≥ 2			
n_{BaseJet}					$= 0$			
Jet $p_T[\text{GeV}]$					≥ 1			
N b-jets					≥ 100			
$m(\tau_1, \tau_2) [\text{GeV}]$			≥ 1					
$M_T(\tau_1, E_T^{\text{miss}})$	≤ 40 or ≥ 130		[80,110]	[40,80] or [110,130]		$= 0$		
$d\eta(\tau_1, \tau_2)$	≥ 200					≤ 40 or ≥ 130		
C1N2 score	[-1, -0.8]	[-0.8, 0.7]				≤ 0.7		
VV score	-	-				≥ 0.80	-	
Total bkg	290+7	162+5	1420+10	1286+11	46+2	2000+28		
Dominant Bkg	206+4	131+3	1221+5	993+4	24+1	1851+28		
Purity	0.71	0.80	0.86	0.77	0.52	0.93		
Data	264	161	1559	1427	51	1950		
Data/MC	0.91	0.99	1.09	1.10	1.10	0.98		



C1N2 ISR signal region definition(LH)

SR definition using BDT score(LH)

- Fake tau estimation using fake factor method
- BDT score > 0.9
- Three bins
 $[0.91, 0.94], [0.94, 0.96], [0.96, 1.00]$

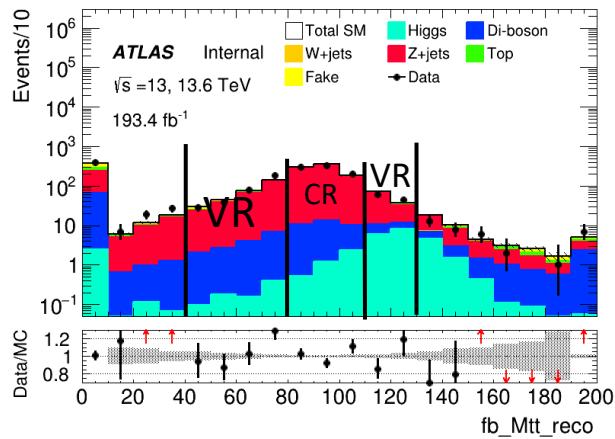
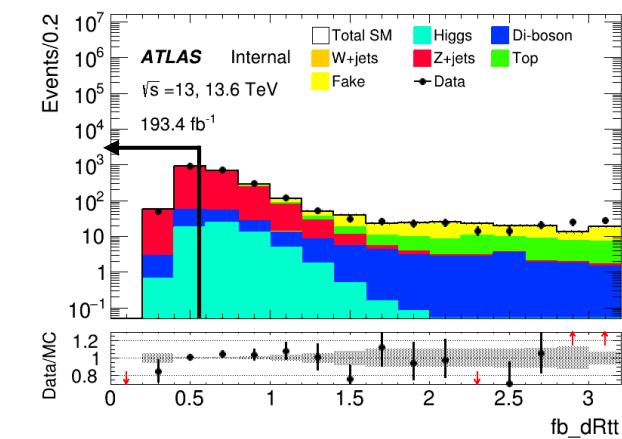
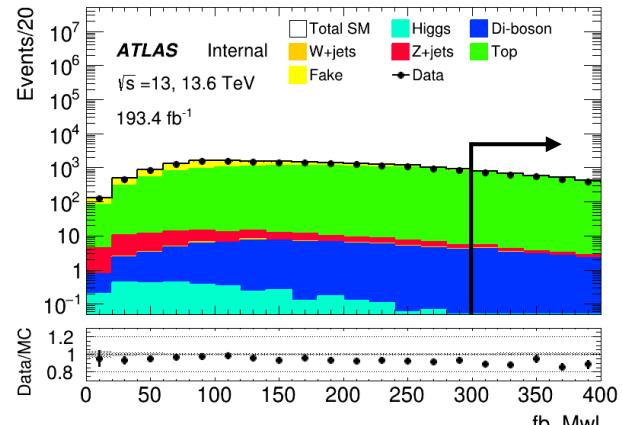
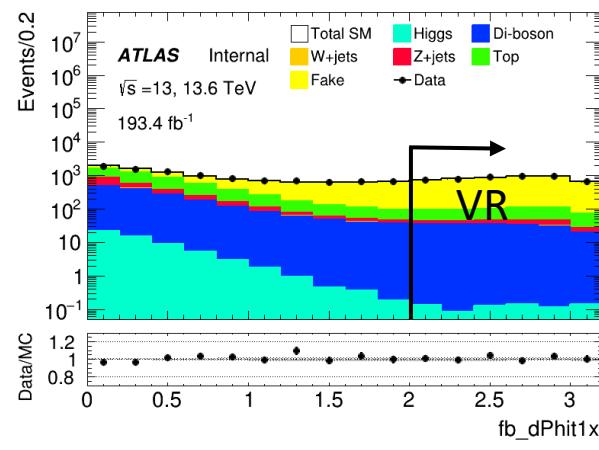
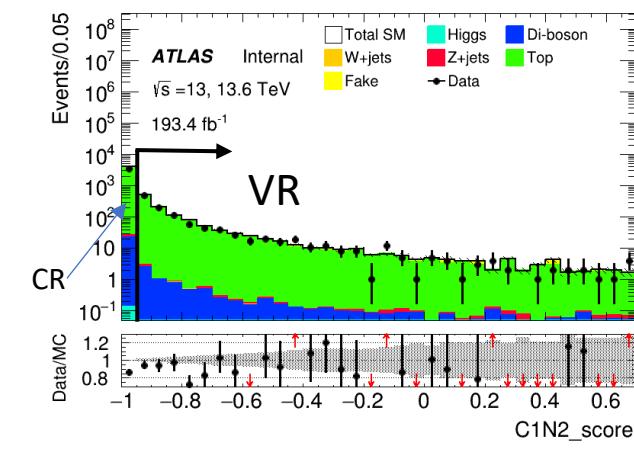


Process	[0.91, 0.94]	[0.94, 0.96]	[0.96, 1.00]
VV	11.105 ± 0.565	5.550 ± 0.367	2.666 ± 0.263
Top	7.432 ± 0.956	1.524 ± 0.441	0.578 ± 0.237
Fake	28.625 ± 3.295	9.404 ± 1.929	2.400 ± 1.009
Higgs	0.376 ± 0.057	0.189 ± 0.052	0.118 ± 0.040
Z+jets	5.515 ± 0.357	2.251 ± 0.222	1.026 ± 0.118
W+jets	0.173 ± 0.142	0.000 ± 0.000	0.000 ± 0.000
Total Bkg	53.226 ± 3.497	18.918 ± 2.018	6.788 ± 1.067
C1N2 (100,70)	21.447 ± 0.901	19.678 ± 0.874	17.543 ± 0.820
Z_n	1.90	2.94	3.47

C1N2 ISR background estimation(LH)

Selection for control region and validation region

Process	Top		Z+jets		Multi-bosons		Fake
	TCR	TVR	ZCR	ZVR	MBVR	FakeVR	
Charge combination							
Trigger OS MET trigger, $E_T^{miss} \geq 200\text{GeV}$							
N medium τ					≥ 1		
N lep					≥ 1		
nBaseJet					≥ 1		
Jet p_T [GeV]					≥ 100		
N b-jets					≥ 1		
$m(\tau_1, l)$ [GeV]	≤ 40 or ≥ 130		[80,110]	[40,80] or [110,130]		$= 0$	
$M_{inv}(l, MET)$	≥ 300		—	—			
$\Delta\phi(MET, \tau_1)$	—	—	—	—			
$dR(\tau, l)$	—	—		≤ 0.6			
C1N2 score	[-1, -0.95]	[-0.95, 0.7]			≤ 0.7		
VV score	—	—	—	—	≥ 0.80	—	—
Total bkg	4151 \pm 11	1212 \pm 13	917 \pm 6	823 \pm 4	78 \pm 2	4983 \pm 40	
Dominant Bkg	3781 \pm 20	1102 \pm 11	823 \pm 4	606 \pm 3	53 \pm 1	4390 \pm 40	
Purity	0.91	0.90	0.90	0.84	0.68	0.88	
Data	3626	1119	908	745	72	5043	
Data/MC	0.87	0.91	0.99	1.03	0.92	1.01	



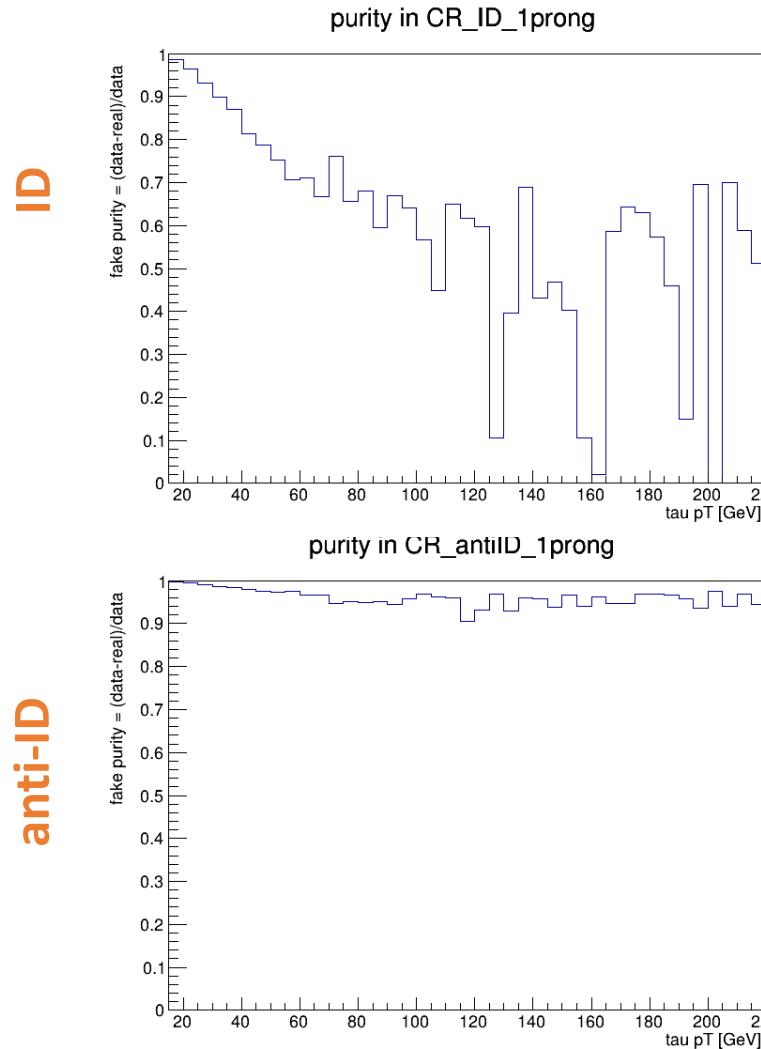


Backup

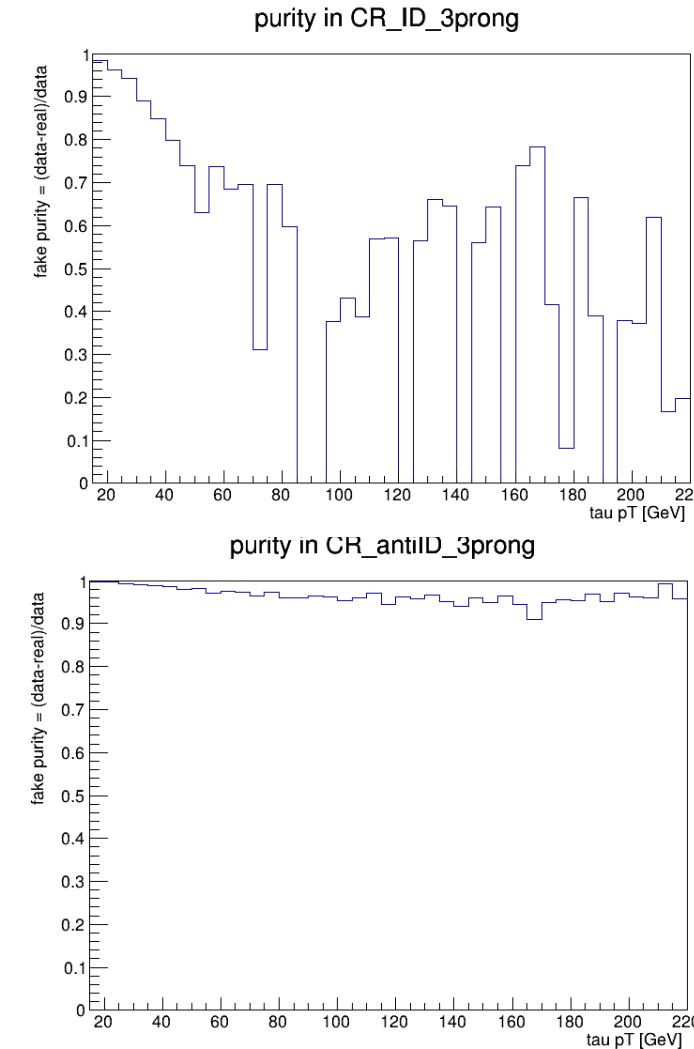


Direct Stau ISR Fake purity in CR

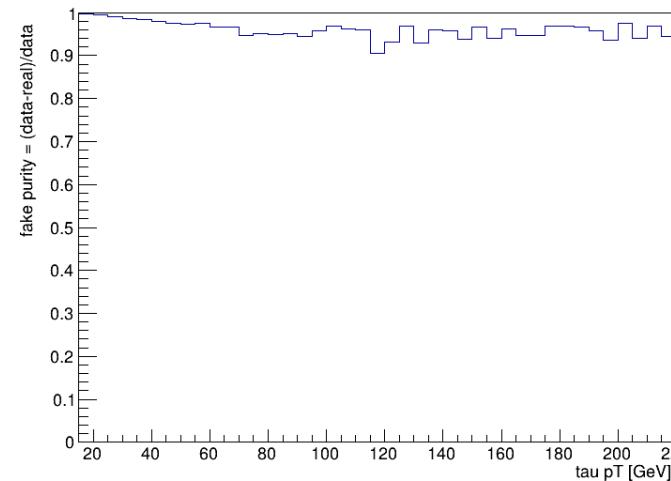
1-prong



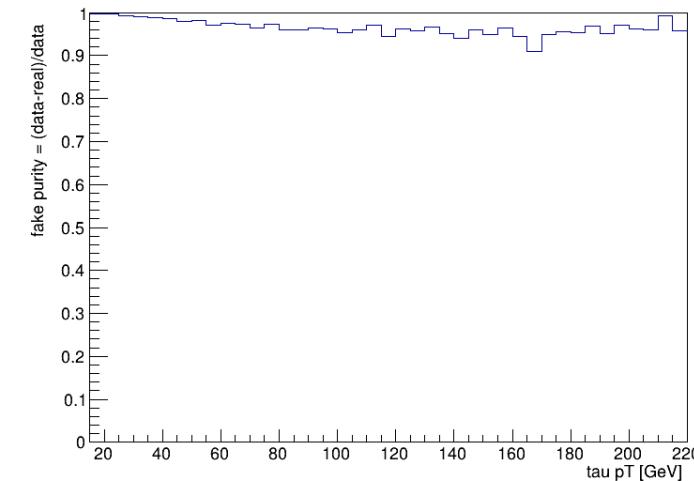
3-prong



anti-ID

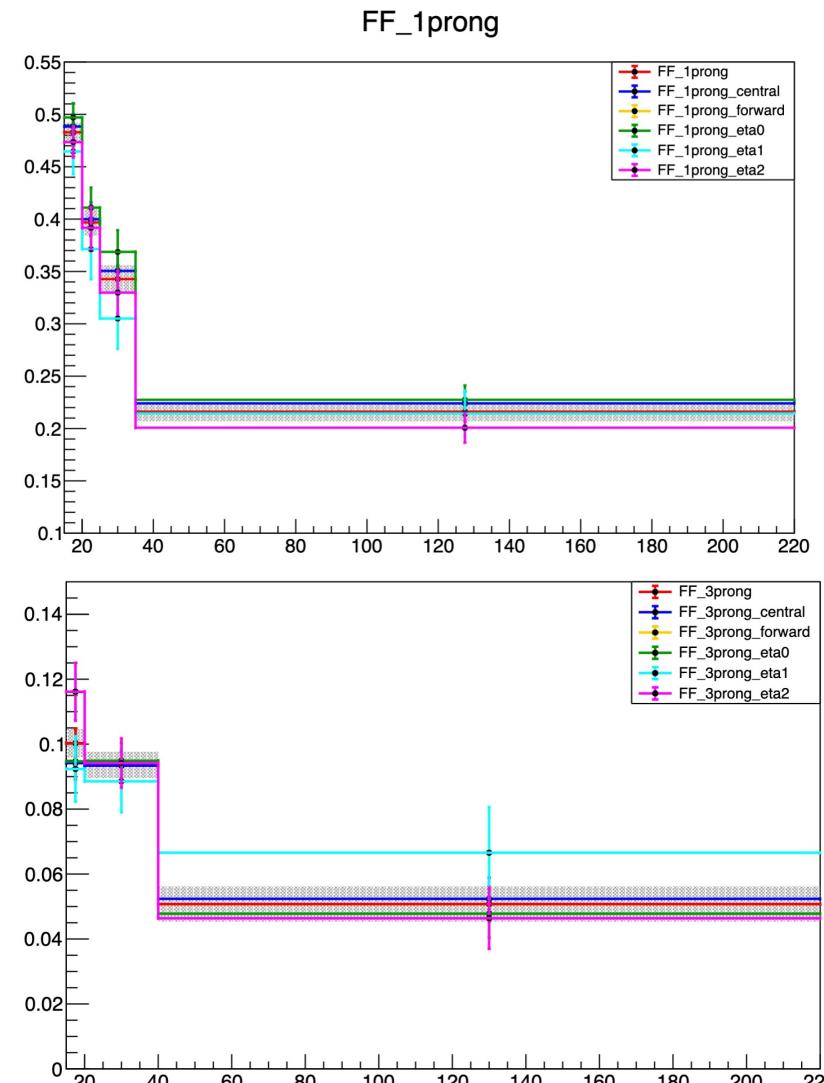


purity in CR_antiID_3prong



Direct Stau ISR Fake Factor

- **Binned in prongness, tau eta, tau pT**
 - Eta bins
 - 2 bins: central [0,1.37], forward [1.52,2.5]
 - 3 bins: eta0,1,2 for [0,1), [1, 1.37], [1.52,2.5]
- **Auto binning:**
 - > 10% of events in nominator and denominator
 - Add bins to bin i until it is not consistent anymore with bin i - 1
 - Relative stat uncertainty on ratio smaller than 50%
 - >10% events in nominator and denominator
- 1-prong: 3 eta bins
- 3-prong: central, forward regions



Direct Stau ISR Neuron network(HH)

• Model Architecture

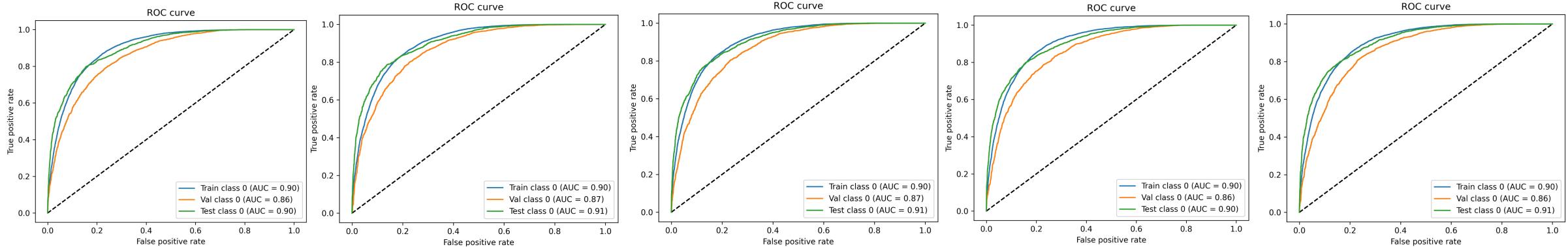
- **Neurons:** [256, 128, 128, 64, 32]
- **Activation Function:** Leaky ReLU
- **Batch Normalization**
- **Dropout Rate:** 0.3
- **L2 Regularization (λ):** 1e-4

• Training Configuration

- **Optimizer:** Adam
 - **Learning Rate:** 1e-3
- **Batch Size:** 128
- **Epochs:** 600

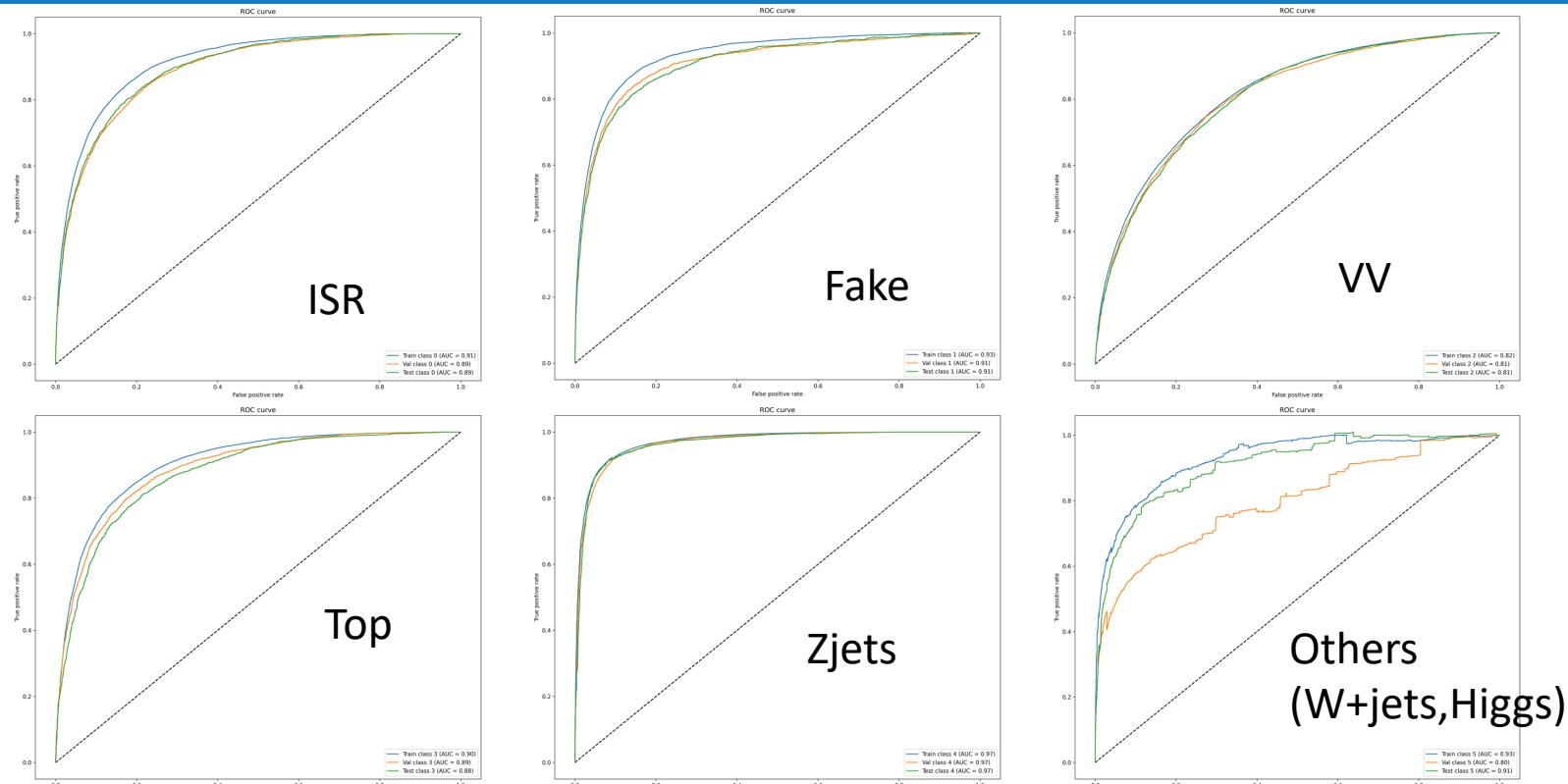
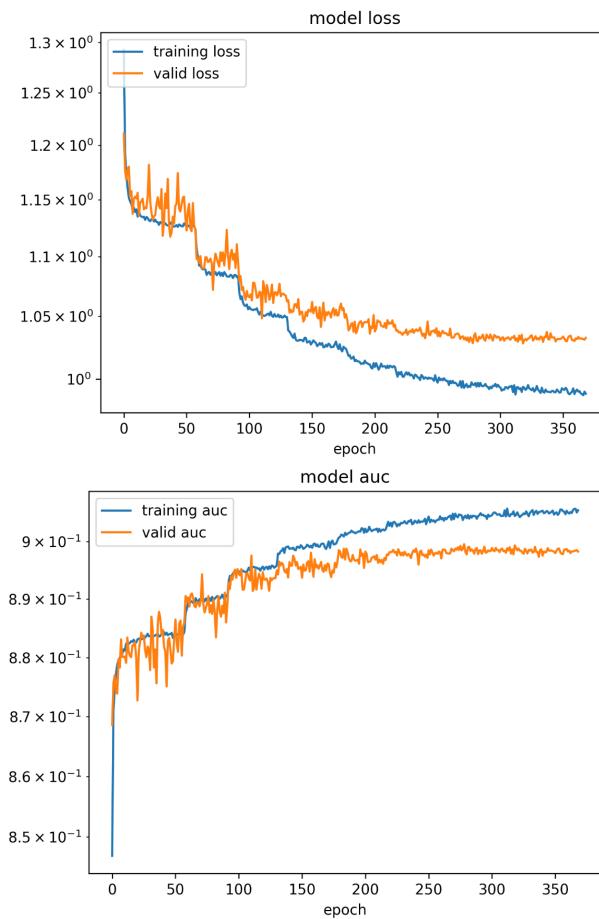
- **Reduce Learning Rate on Plateau:**

- Monitor: *val_loss*
- Factor: 0.5
- Patience: 20
- Class weight to solve imbalance issue
- Normalization before training
 - $\frac{X-\mu}{\sigma}$
- Drop Negative weight



Direct Stau ISR Neuron network(LH)

AUC for 6 output scores



Direct Stau ISR Class Weight

- $w_i = I_i \cdot \frac{N_{all}}{n_{class} \times N_i}$
 - N_{all} : The total sum of weight in the entire dataset (across all classes).
 - N_i : The sum of weight belonging to class i.
 - n_{class} : The total number of distinct classes in the dataset.
 - I_i : importance factor

Direct Stau ISR Top, Ztt CR

- Top CR:
 - **b-jet ≥ 1 (GN2v01, WP 90)**
 - Colinear mass (τ, τ) > 250 GeV

**Yield, purity table
(Top CR)**

**MT or MT2 Data/MC
Comparison plot
(Top CR)**

- Ztautau CR
 - b-veto (GN2v01, WP 90)
 - **70 < Collinear mass (τ, τ) < 110 GeV**

**Yield, purity table
(Ztautau CR)**

**MT or MT2 Data/MC
Comparison plot
(Ztautau CR)**

Direct Stau ISR Diboson CR

- Wjets CR:
 - 1 Medium taus and 1 Tight light lepton with $pT > 20$ GeV
 - OS for tau and light lepton
 - $M_T(\text{lep1}, \text{MET}) < 80$ GeV
- Diboson CR:
 - Tight SFOS light lepton with $pT > 20$ GeV
 - $M_T(\text{lep1}, \text{MET}) < 80$ GeV

**Yield, purity table
Wjets CR**

**MT or MT2 Data/MC
Comparison plot
Wjets CR**

**Yield, purity table
VV CR**

**MT or MT2 Data/MC
Comparison plot
VV CR**

Direct Stau ISR VRs

- VR1 (VV):
 - Two SFOS leptons with $pT > 20$ GeV
- VR2 (LH):
 - MET > 130 GeV
 - nJet ≤ 2
 - Primary Jet $pT > 50$ GeV
 - 1 Medium tau with $pT > 25$ GeV
 - 1 Tight light lepton
 - OS for tau and light lepton
 - $M_{T2}(40) > 55$ GeV
- VR3 (HH):
 - 2 Medium OS taus with $pT > 20$ GeV
 - $M_{T2}(70) > 85$ GeV

**Yield, purity table
(VR1)**

**MT or MT2 Data/MC
Comparison plot
(VR1)**

**Yield, purity table
(VR2)**

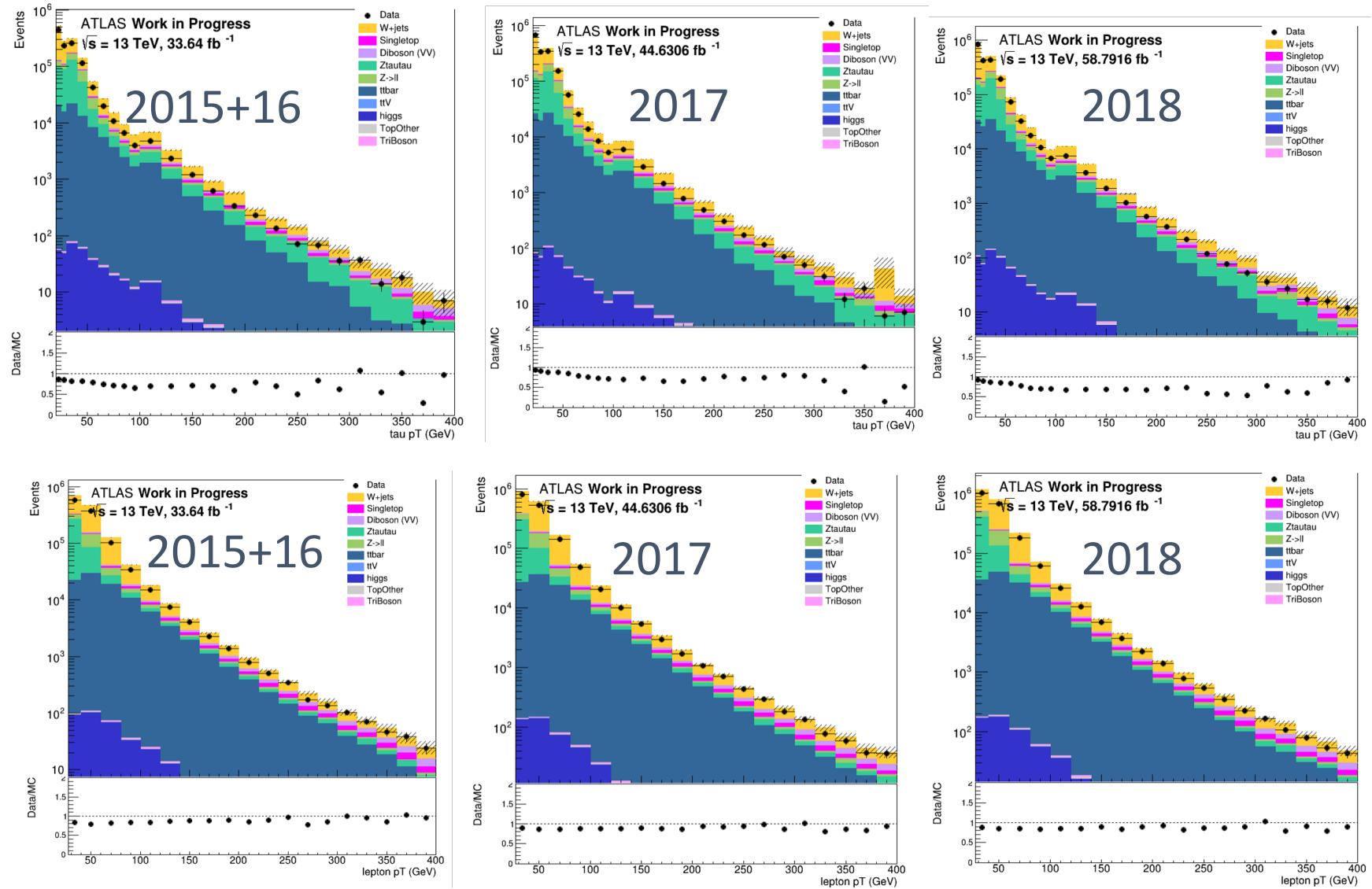
**MT or MT2 Data/MC
Comparison plot
(VR2)**

**Yield, purity table
(VR3)**

**MT or MT2 Data/MC
Comparison plot
(VR3)**

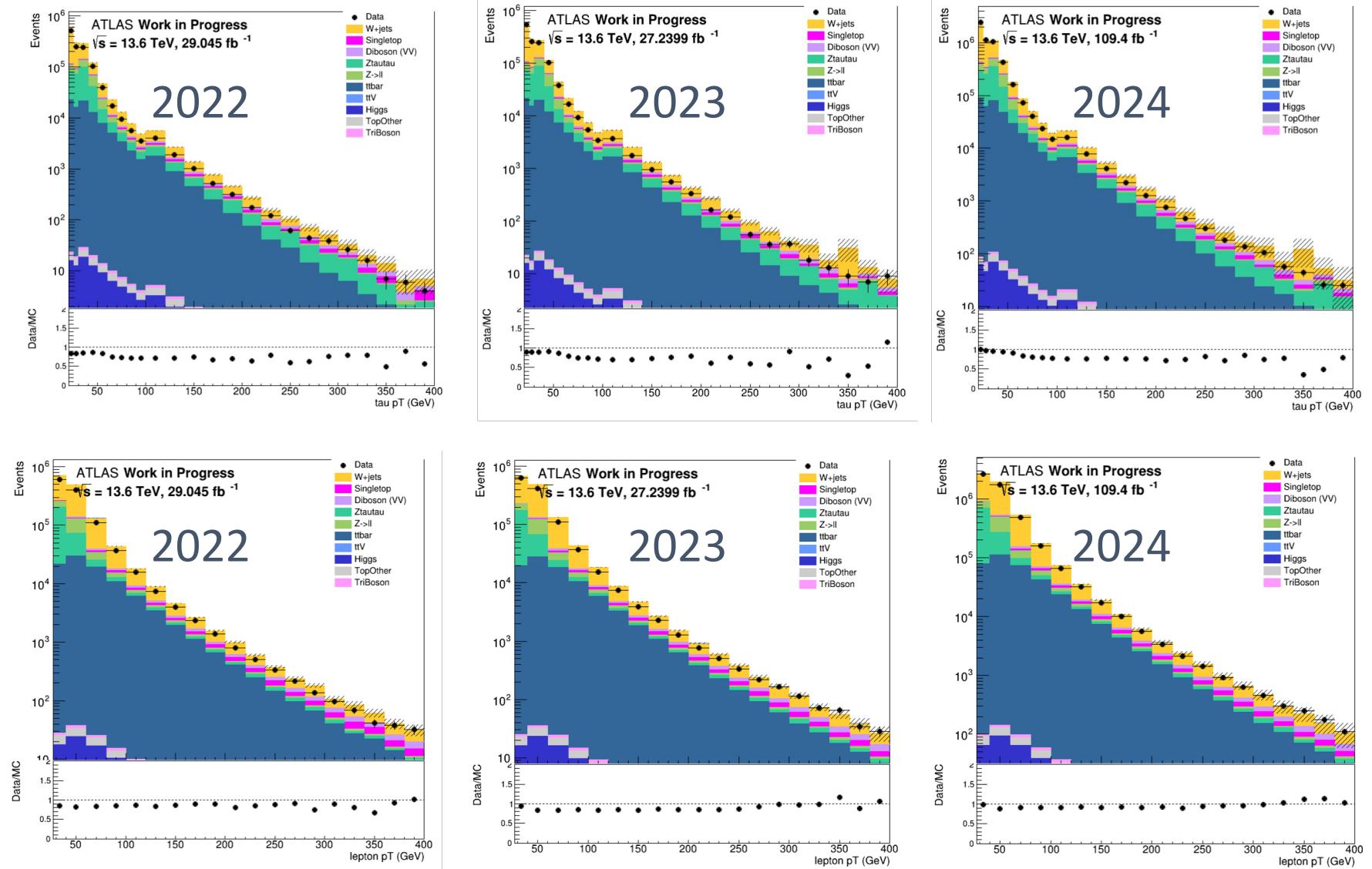
Direct Stau single-lep trigger MC modeling check

- Requirements:
1e/mu passing
trigger, at least 1
tight signal tau
- MC overestimates
data



Direct Stau single-lep trigger MC modeling check

- Requirements:
1e/mu passing
trigger, at least 1
tight signal tau
- MC overestimates
data



Direct Stau single-lep trigger Pre-selection(LH)

LH Pre-selection

≥ 1 Tight taus (OS)

1 signal lepton

bveto

Single-lepton trigger

$15 \text{ GeV} < \text{MET} < 200 \text{ GeV}$

METSig > 2

MT2 < 90

$dR(\text{lep}, \text{tau}) < 3.6$

custom MT cut*

$\phi_{\{1,2\}}$ cut*

*custom MT cut (removes red shape):

- Targets Ztt
- $(mT_{\text{sum}} > 70\,000) \&$
- $((mT_{\text{lep_met}} > 20\,000) \mid (mT_{\text{tau_met}} > 90\,000)) \&$
- $((mT_{\text{lep_met}} > 90\,000) \mid (mT_{\text{tau_met}} > 20\,000))$

* $\phi_{\{1,2\}}$ cut (removes red circle slice):

- Targets fakes

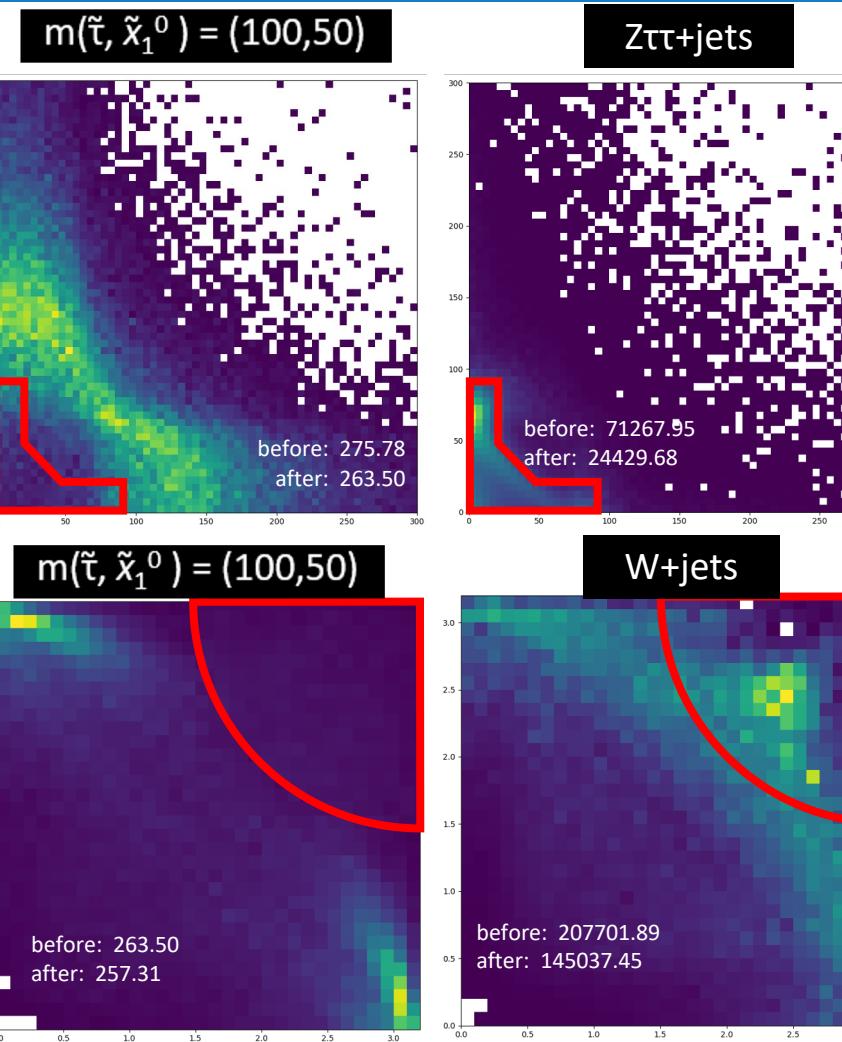
Define:

$$\phi_{\max} = \max(\phi_{\text{lep}}, \phi_{\tau}) \text{ and } \phi_{\min} = \min(\phi_{\text{lep}}, \phi_{\tau})$$

$$\phi_1 = \phi_{\max} - \phi_{\text{MET}} \text{ and } \phi_2 = \phi_{\text{MET}} - \phi_{\min}$$

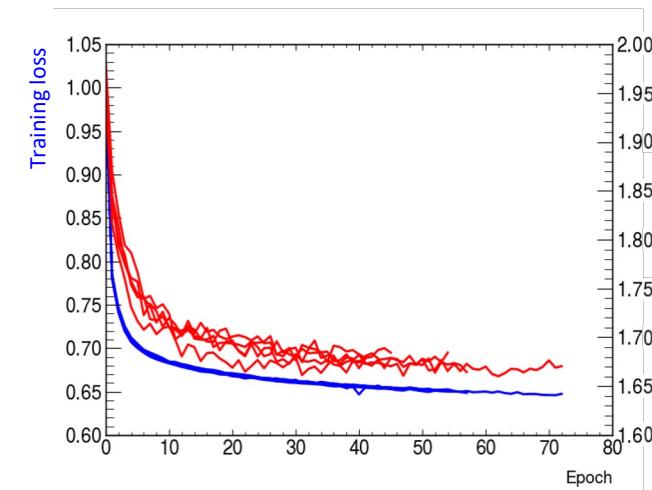
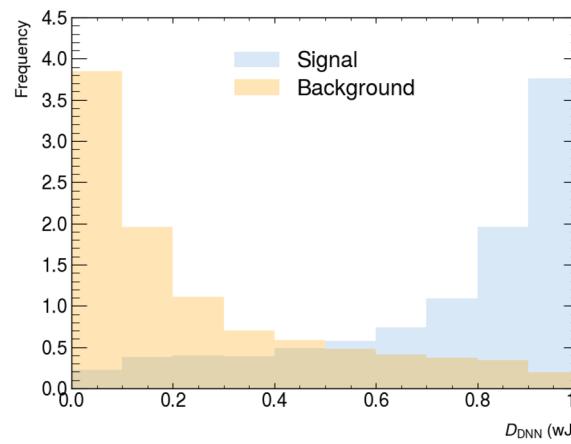
$$(\text{abs}(\phi_1)-a)^{\star 2} + (\text{abs}(\phi_2)-b)^{\star 2} \geq r^{\star 2}$$

where $a=\pi$, $b=\pi$, and $r=\pi/2$

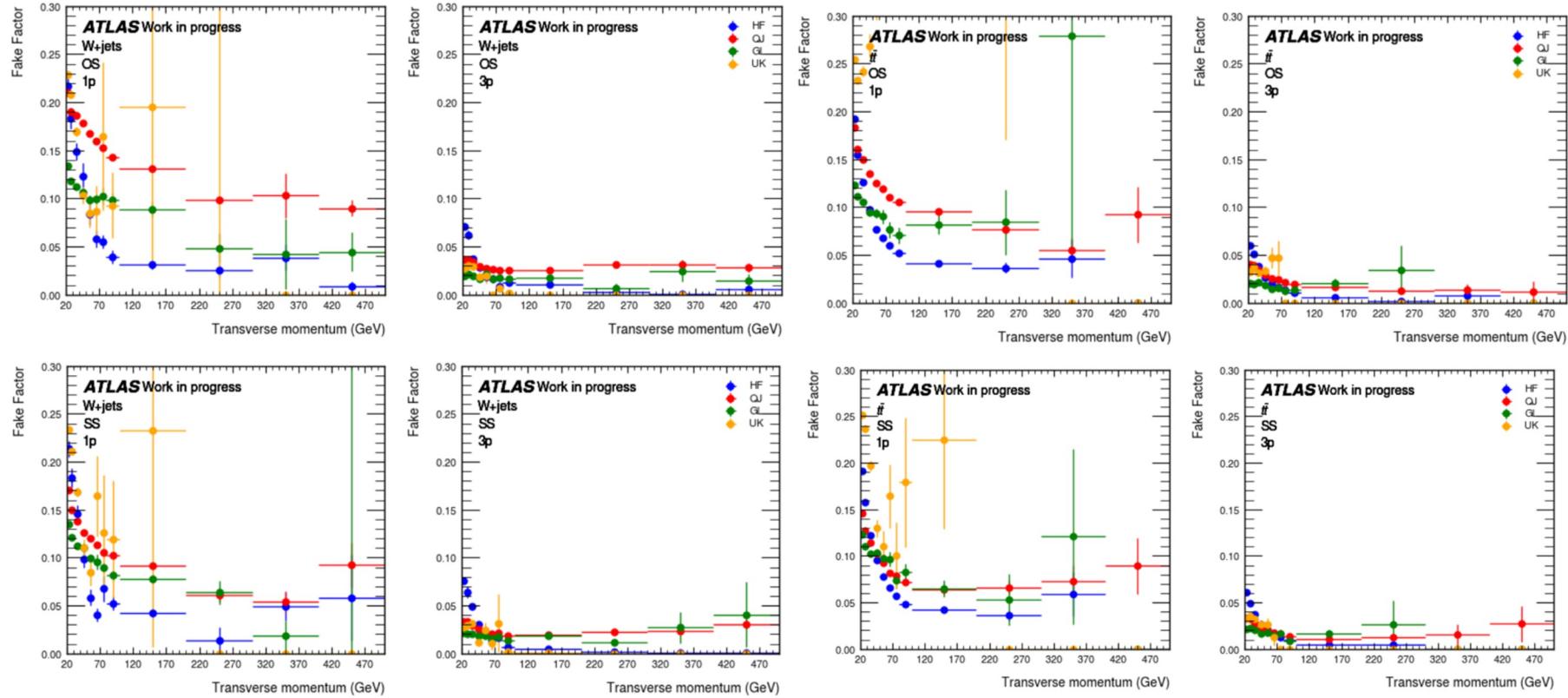


Direct Stau single-lep trigger DNN Training

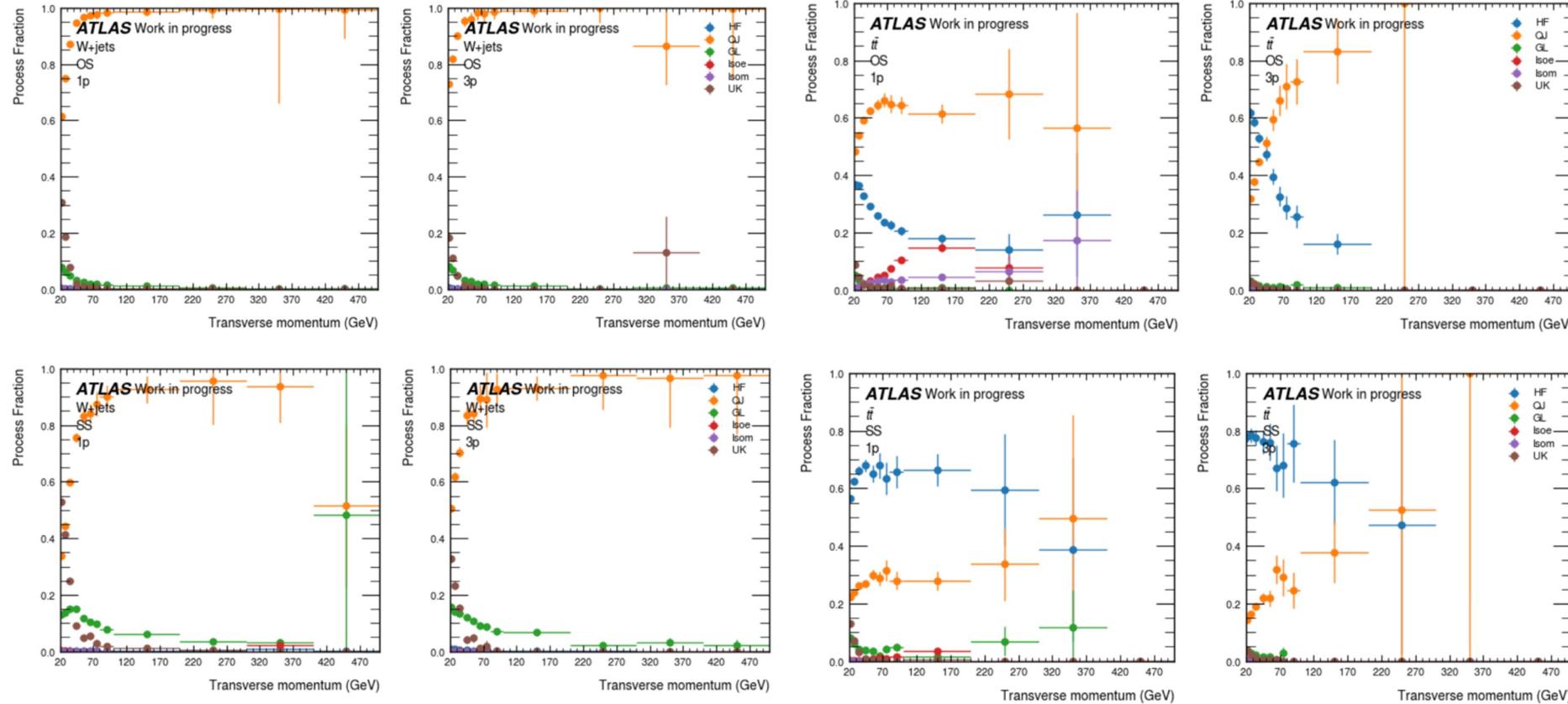
- Train deep neural network (DNN) to separate signal from background and cut on network score targeting (100, 50) & (150,100) mass points (high stats points with 1M events generated) and trained 0J and $\geq 1J$ channels separately.
 - Training converges well (across all training folds) and very good signal/background separation is achieved
- Use multiclass DNN with 6 output classes: Signal, fake-tau background, 4 real-backgrounds (top, Ztt, VV, other)
- Input variables:
 - Basic object variables: p_T , η , MET, charge etc.
 - High-level variables: ΔR , $\Delta\eta$, $\Delta\phi$, m_{T2} , M_{eff} , M_{inv} , Σm_T , m_{CT} , balance + more!



Direct Stau single-lep trigger Fake Factors



Direct Stau single-lep trigger Fake Factors



C1C1 ISR signal region optimization(HH)

- Input:

- data: MC events passing pre-selection
 - signal: 39382 events C1C1 + ISR, $M(C_1, N_1) = (100, 70)$ GeV
 - Bkg: 1089081 events.

feature:Pzetaj1,Pzetae,MCTtt,m_jet,dPhiSRV,dPhiVI,nS_tau,PtV,dPhit2x,maxdPhit1j,maxdPhit2j,METOPtau2,METOHTtt,METOHTjet,Ptjet1OPtau1,MT2tt_110,mtx_jet,mtx_lep,mt_lep,mt_C1C1,MTtau2met,MTtaumin,MTsum,Mtsum,Mtsumj,MII,MT2,MET,METsig

- Strategy

- TMVA.Types.kBDT
- Cross-Validation(5-fold)
- hyper parameter: NTrees=400, learning rate=0.1, max depth=8, MinNodeSize=1%

other set-up: nCuts=20:BoostType=Grad:UseBaggedBoost=true:BaggedSampleFraction=0.5:NegWeightTreatment=Pray

C1C1 ISR signal region optimization(LH)

- Input:
 - data: MC events passing pre-selection
 - signal: ISRC1C1(with C1 mass=100GeV, N1 mass=70 GeV)(39336 events)
 - bkg(1559557 events).
- feature: dRt1x,dRtt,dPhitt,e_lep,mt_lep,ht_tau,METsig,nBaseJet,mindPhi,j,maxdPhi,t2j,MTtau1met,MTtau2met,MTtaumin,MTtot,MTsum,Minvtt,Minvt2j,MT2tt_110,MCTtt,Pzetaj1,Pzetatt,METOPtau1,METOPtau2,METOHTtt,METOHTjet,Ptjet1OPtau1,Ptjet1OPtau2,Ptjet1OHTtt,PtV
- Strategy
 - TMVA.Types.kBDT
 - 5-fold train
 - hyper parameter: NTrees=300, learning rate=0.05, max depth=6, MinNodeSize=1%
- other set-up: nCuts=20:BoostType=Grad:UseBaggedBoost=true:BaggedSampleFraction=0.5:NegWeightTreatment=Pray

C1N2 ISR Binary class(HH)

Hyperparameters: Ntrees = 200, MaxDepth = 6, MinNodeSize = 2%, Learning rate = 0.03(initial setting)

Feature engineering:

Select a simple model and put all features into model, choose Top 30 vars based on importance list, drop high correlated vars

Final feature list:

: Rank	: Variable	: Variable Importance
: 1	: fb_dEtatt	: 5.153e-02
: 2	: fb_dRtt	: 4.318e-02
: 3	: fb_dRMax_xt	: 4.248e-02
: 4	: fb_dPhitt	: 4.228e-02
: 5	: fb_MIA	: 4.205e-02
: 6	: fb_METsig	: 3.979e-02
: 7	: fb_dPhizxe	: 3.972e-02
: 8	: fb_dPhiztt	: 3.942e-02
: 9	: fb_frac_MET_tau1	: 3.735e-02
: 10	: fb_dPhiMin_xt	: 3.513e-02
: 11	: fb_dPhiMin_tj1	: 3.512e-02
: 12	: fb_MT2_150	: 3.494e-02
: 13	: fb_frac_MET_MeffInc_40	: 3.474e-02
: 14	: fb_dRMin_tj	: 3.467e-02
: 15	: fb_eta_tau2	: 3.454e-02
: 16	: fb_frac_MET_tt	: 3.452e-02
: 17	: fb_frac_MET_Meff	: 3.408e-02
: 18	: fb_dPhit2x	: 3.277e-02
: 19	: fb_dPhiMax_xt	: 3.207e-02
: 20	: fb_dRt2x	: 3.131e-02
: 21	: fb_dPhit1x	: 3.089e-02
: 22	: fb_frac_MET_tau2	: 3.085e-02
: 23	: fb_Mll	: 2.960e-02
: 24	: fb_MET_Jet	: 2.734e-02
: 25	: fb_sum_cos_dphi	: 2.530e-02
: 26	: fb_pt_Vframe	: 2.272e-02
: 27	: fb_Pt_tt	: 1.912e-02
: 28	: fb_MstauA	: 1.881e-02
: 29	: fb_Proj_t1	: 1.594e-02
: 30	: fb_Proj_tt	: 1.427e-02
: 31	: fb_MCT	: 1.345e-02

Weight choose: no weight, abs(weight)

No weight have better performance
but abs(weight) fit our analysis requirement

Split strategy: Separate entries by using mod 5, for Fake bkg, if separate follow sequence, all weighted entry will split into first fold

C1N2 ISR Binary class(HH)

Hyperparameter tune:
use optuna to auto-optmize

constraint:

average of AUC need to ≥ 0.6

penalty function: $\text{score} = \text{test_auc} - 0.3 * \text{auc_gap}$ ($\text{auc_gap} = \text{abs}(\text{train_auc} - \text{test_auc})$)
 $\text{maximum}(\text{score})$

Class: C1N2, bkg

$\text{Test_auc} = \sum \{\text{Test_auc_class}\}$
 $\text{Train_auc} = \sum \{\text{Train_auc_class}\}$

Grid Search

Ntrees: [200, 300, 400]

MaxDepth: [4, 6, 8, 10]

MinNode: [1, 3, 5, 7]

Learning rate: [0.001, 0.005, 0.01, 0.05, 0.1]



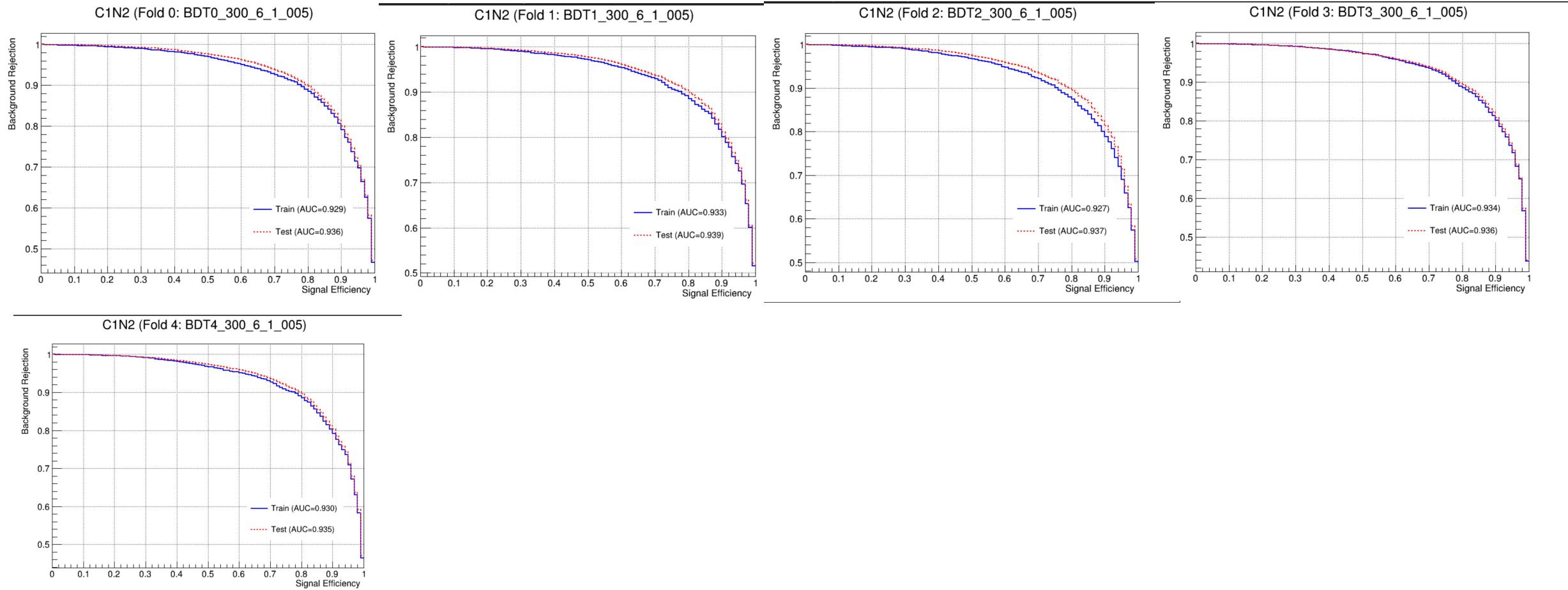
Best one: Ntree=300, MaxDepth=6, MinNode=1%, Learning Rate=0.05



There still have rooms to optimize for lr

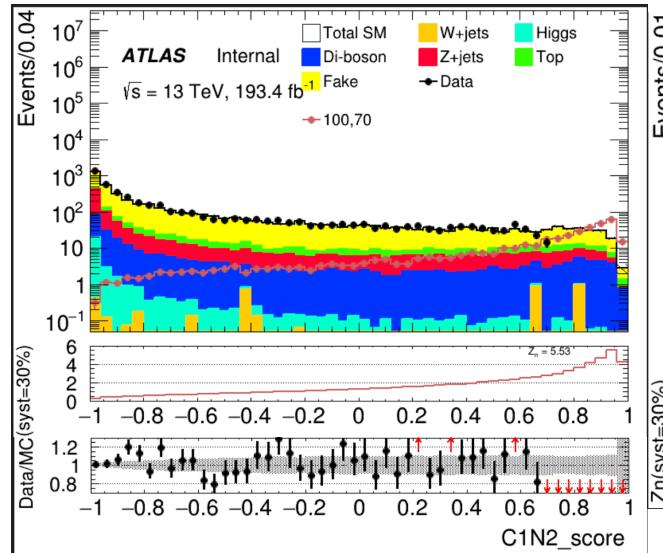
C1N2 ISR Binary class(HH)

Overfit Check

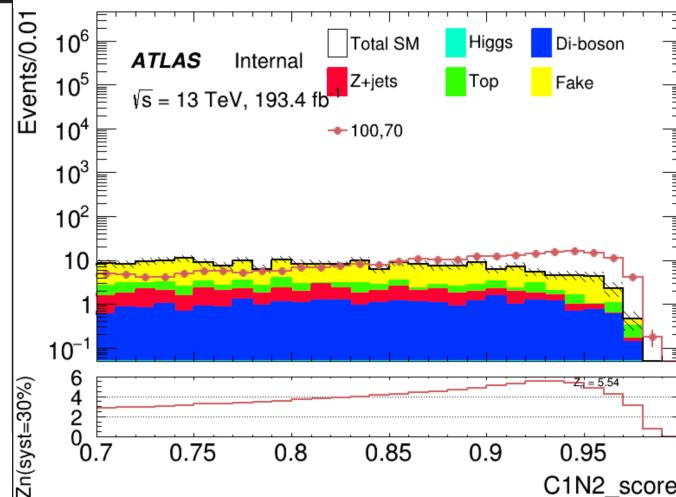


C1N2 ISR Binary class(HH)

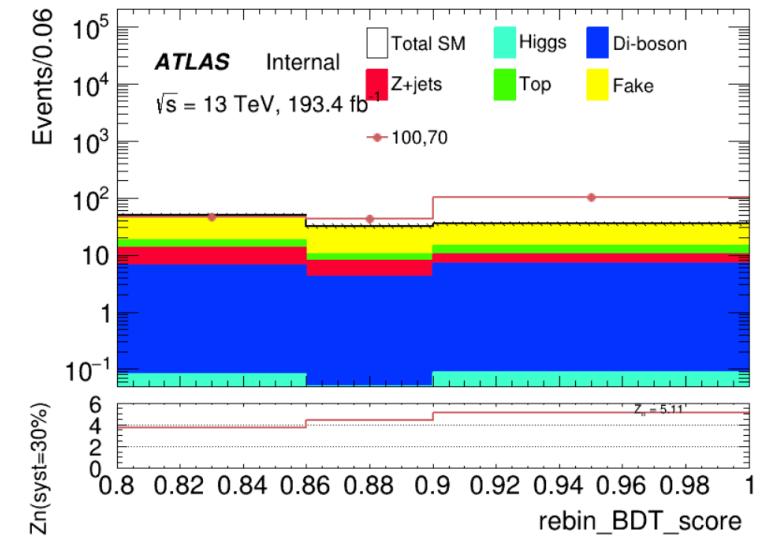
50 bins



Cut at 0.8



rebin



Sum $Z_n = 7.65$

Bin Range	Z_n	C1N2 (100_70) Yield \pm Error	VV Yield \pm Error	Top Yield \pm Error	Fake Yield \pm Error	Higgs Yield \pm Error	Zjets Yield \pm Error	Wjets Yield \pm Error	Total Bkg Yield \pm Error
[0.80,0.85]	3.65	46.569 ± 1.327	6.508 ± 0.368	4.719 ± 0.686	31.458 ± 3.898	0.080 ± 0.023	6.659 ± 0.416	0.978 ± 0.978	50.402 ± 4.042
[0.85,0.90]	4.37	43.128 ± 1.283	4.124 ± 0.341	2.663 ± 0.546	21.525 ± 3.292	0.045 ± 0.019	3.564 ± 0.286	0.000 ± 0.000	31.921 ± 3.354
[0.90,1.00]	5.11	101.059 ± 1.961	6.855 ± 0.398	4.331 ± 0.731	20.438 ± 2.976	0.086 ± 0.031	3.207 ± 0.250	0.000 ± 0.000	34.917 ± 3.118

C1N2 ISR Binary class(LH)

Hyperparameters: Ntrees = 200, MaxDepth = 6, MinNodeSize = 2%, Learning rate = 0.03(initial setting)

Feature engineering:

Select a simple model and put all features into model, choose Top 30 vars based on importance list, drop high correlated vars

Final feature list:

: Rank	: Variable	: Variable Importance
:	1 : fb_frac_MET_tau2	: 8.270e-02
:	2 : fb_dRtt	: 6.684e-02
:	3 : fb_dPhit	: 6.226e-02
:	4 : fb_frac_MET_tt	: 5.197e-02
:	5 : fb_frac_jet_tau2	: 5.179e-02
:	6 : fb_MT2_50	: 5.077e-02
:	7 : fb_dPhiMax_tj	: 4.779e-02
:	8 : fb_dPhiMin_xj	: 4.343e-02
:	9 : fb_mt_taumin	: 3.547e-02
:	10 : fb_Mll	: 3.511e-02
:	11 : fb_mtx_tau1	: 3.408e-02
:	12 : fb_nBaseJet	: 3.146e-02
:	13 : fb_frac_jet_tt	: 3.110e-02
:	14 : fb_mtx_tau2	: 2.941e-02
:	15 : fb_frac_MET_tau1	: 2.898e-02
:	16 : fb_METsig	: 2.824e-02
:	17 : fb_pt_Vframe	: 2.726e-02
:	18 : fb_Mwh	: 2.684e-02
:	19 : fb_Proj_j	: 2.678e-02
:	20 : fb_frac_MET_sqrtHT_40	: 2.560e-02
:	21 : fb_frac_jet_tau1	: 2.518e-02
:	22 : fb_MCT	: 2.254e-02
:	23 : fb_Mwl	: 2.185e-02
:	24 : fb_mt_quad_sum	: 2.165e-02
:	25 : fb_Proj_tt	: 2.038e-02
:	26 : fb_ht_tau	: 1.992e-02
:	27 : fb_e_tau2	: 1.819e-02
:	28 : fb_mt_sum_ttj	: 1.624e-02
:	29 : fb_mt_tau2	: 1.618e-02
:		

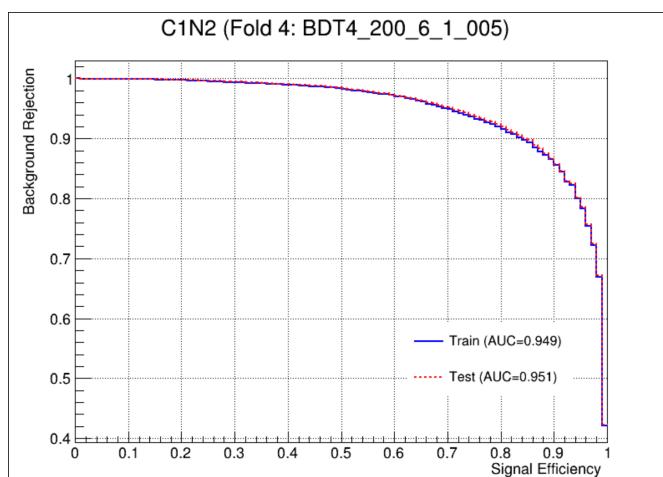
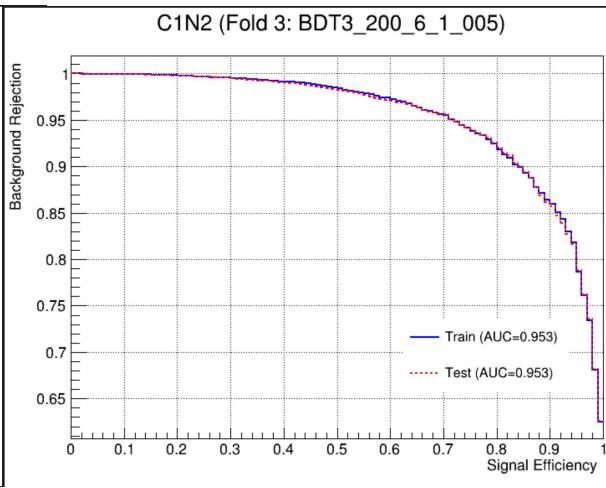
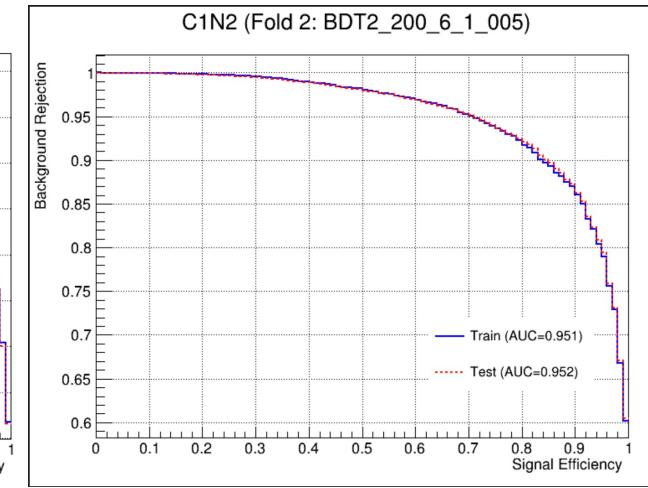
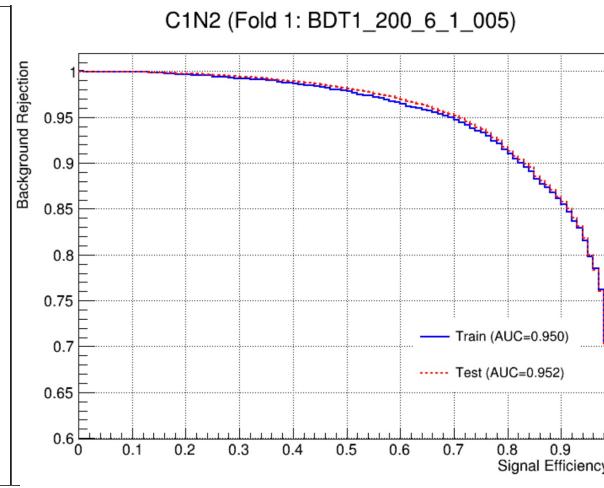
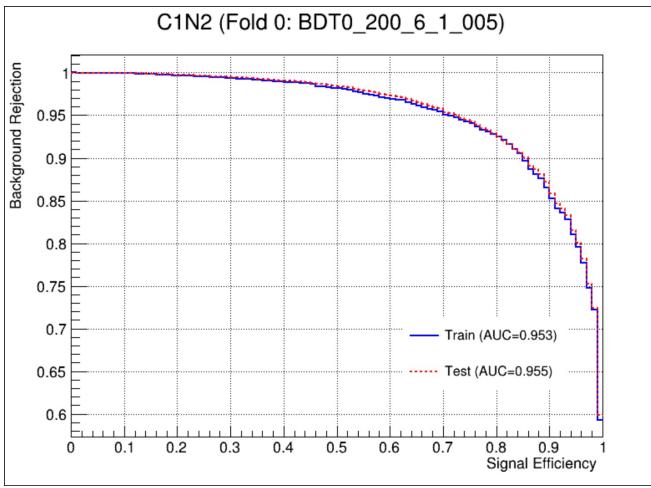
Weight choose: no weight, abs(weight)

No weight have better performance
but abs(weight) fit our analysis requirement

Split strategy: Separate entries by using mod 5, for Fake bkg, if separate follow sequence, all weighted entry will split into first fold

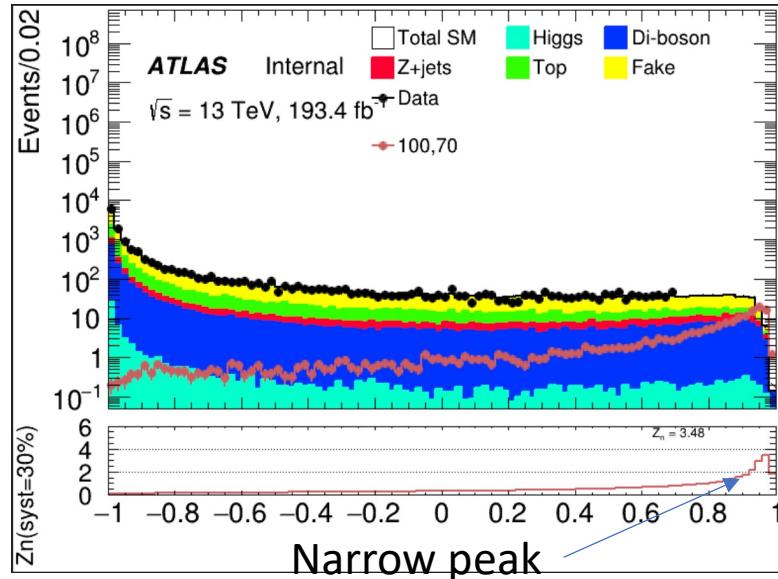
C1N2 ISR Binary class(LH)

Overfit Check

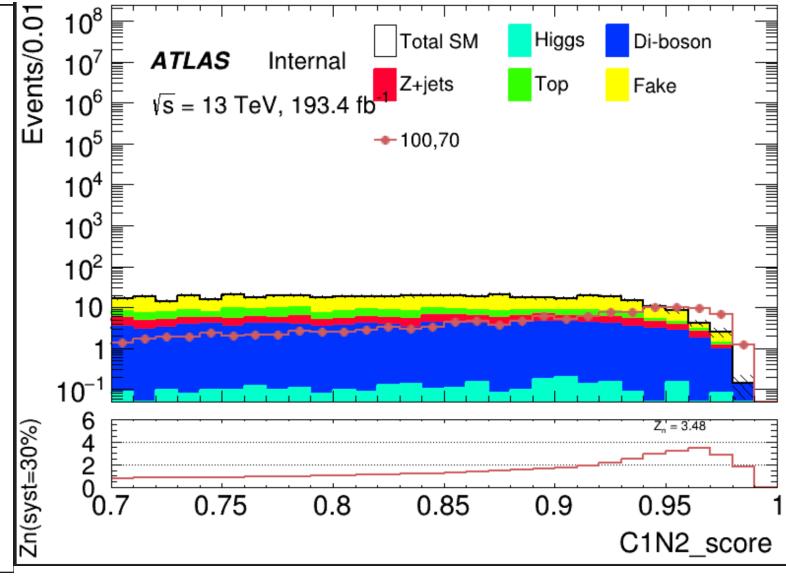


C1N2 ISR Binary class(LH)

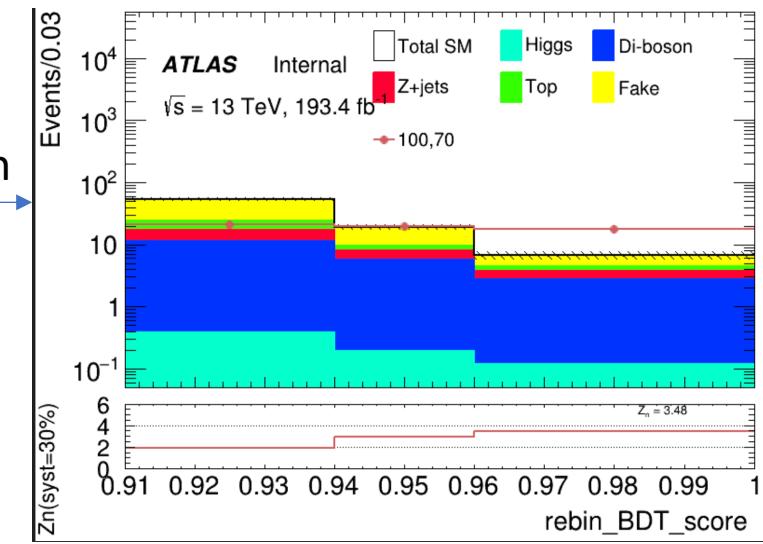
100 bins



Cut at 0.91



rebin



Sum $Z_n = 4.934$

Bin Range	Z_n	C1N2 (100_70) Yield \pm Error	VV Yield \pm Error	Top Yield \pm Error	Fake Yield \pm Error	Higgs Yield \pm Error	Zjets Yield \pm Error	Wjets Yield \pm Error	Total Bkg Yield \pm Error
[0.91,0.94]	1.90	21.447 ± 0.901	11.105 ± 0.565	7.432 ± 0.956	28.625 ± 3.295	0.376 ± 0.057	5.515 ± 0.357	0.173 ± 0.142	53.226 ± 3.497
[0.94,0.96]	2.94	19.678 ± 0.874	5.550 ± 0.367	1.524 ± 0.441	9.404 ± 1.929	0.189 ± 0.052	2.251 ± 0.222	0.000 ± 0.000	18.918 ± 2.018
[0.96,1.00]	3.47	17.543 ± 0.820	2.666 ± 0.263	0.578 ± 0.237	2.400 ± 1.009	0.118 ± 0.040	1.026 ± 0.118	0.000 ± 0.000	6.788 ± 1.067

C1N2 ISR fake estimation(HH)

- CRs (fake factor computation)
 - METtrig
 - MET ≥ 200
 - bveto
 - at least 1 signal lepton
 - $\Delta\phi(\tau, \text{MET}) > 2$
 - **ID: ≥ 1 medium tau**
 - **antiID: ≥ 1 VeryLoose tau, 0 medium tau**
- SRs
 - preselection
 - 2ID: ≥ 2 medium tau
 - 1ID1antiID: ≥ 2 VeryLoose tau , 1 medium tau
 - 2antiID: ≥ 2 VeryLoose tau , 0 medium tau
- **Binned in prongness, tau eta, tau pT**
 - Eta bins
 - 2 bins: central [0,1.37], forward [1.52,2.5]
 - 3 bins: eta0,1,2 for [0,1), [1, 1.37], [1.52,2.5]
- **Auto binning:**
 - $> 10\%$ of events in nominator and denominator
 - Add bins to bin i until it is not consistent anymore with bin i - 1
 - Relative stat uncertainty on ratio smaller than 50%
 - $>10\%$ events in nominator and denominator

