



Institute of High Energy Physics  
Chinese Academy of Sciences

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# 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

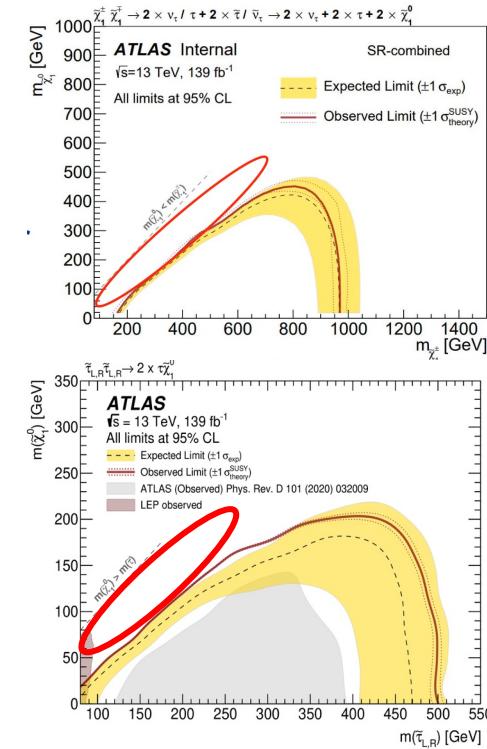
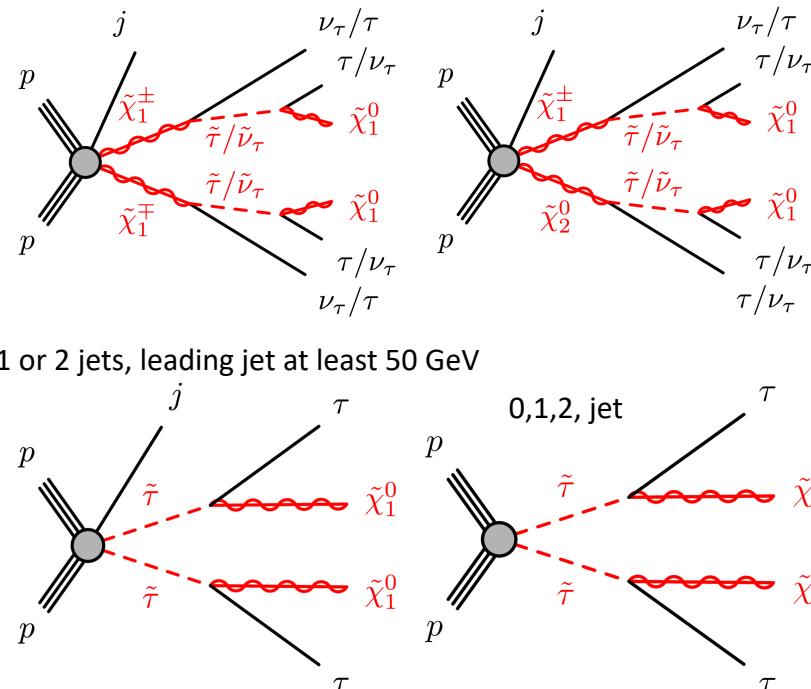
Previous paper: [JHEP 05 \(2024\) 150](#)

## Motivation:

an explanation for observed excess in the Muon g-2 experiment and the observed dark matter relic density  
ISR can boost the SUSY system and improve the sensitivity in compressed region

Glance Analysis entry: [ANA-HMBS-2024-07](#)

Internal Note: [ANA-HMBS-2024-07-INT1](#)



# Ntuple setup

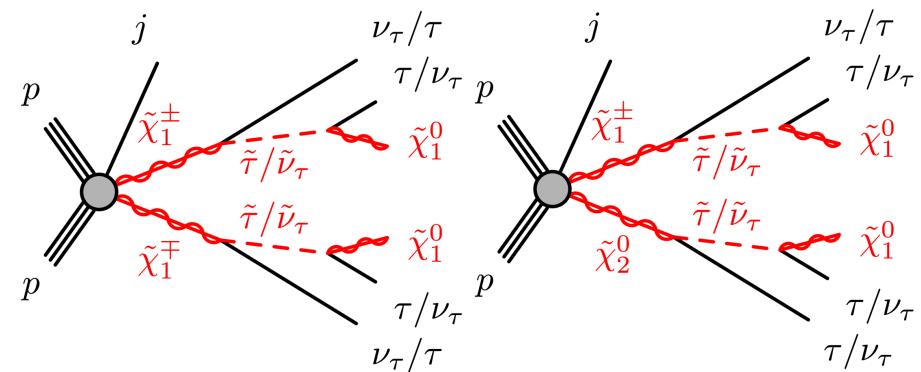
- [MelAnalysis framework](#)
- DAOD PHYS
- ptag: signal p6244, bkg p6490/p6491, data p6479/p6269
- background list: [mc20](#), [mc23](#)

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_NNPDF30_AZNLO_WmH125j_MINLO_lvbb_VpT
	345054	PowhegPythia8EvtGen_NNPDF30_AZNLO_WpH125j_MINLO_lvbb_VpT
	345055	PowhegPythia8EvtGen_NNPDF30_AZNLO_ZH125j_MINLO_llbb_VpT
	345056	PowhegPythia8EvtGen_NNPDF30_AZNLO_ZH125j_MINLO_vvbb_VpT
	345057	PowhegPythia8EvtGen_NNPDF30_AZNLO_ggZH125_llbb
	345098	PowhegPythia8EvtGen_NNPDF30_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_NNPDF30_AZNLO_WmH125j_MINLO_lvcc_VpT
	345110	PowhegPythia8EvtGen_NNPDF30_AZNLO_WpH125j_MINLO_lvcc_VpT
	345111	PowhegPythia8EvtGen_NNPDF30_AZNLO_ZH125j_MINLO_llcc_VpT
	345112	PowhegPythia8EvtGen_NNPDF30_AZNLO_ZH125j_MINLO_vvcc_VpT
	345113	PowhegPythia8EvtGen_NNPDF30_AZNLO_ggZH125_llcc
	345211	PowhegPythia8EvtGen_NNPDF30_AZNLO_WmH125j_Winc_MINLO_tautau
	345212	PowhegPythia8EvtGen_NNPDF30_AZNLO_WpH125j_Winc_MINLO_tautau
	345217	PowhegPythia8EvtGen_NNPDF30_AZNLO_ZH125j_Zinc_MINLO_tautau
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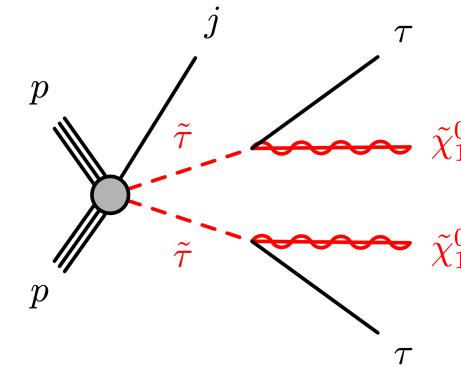
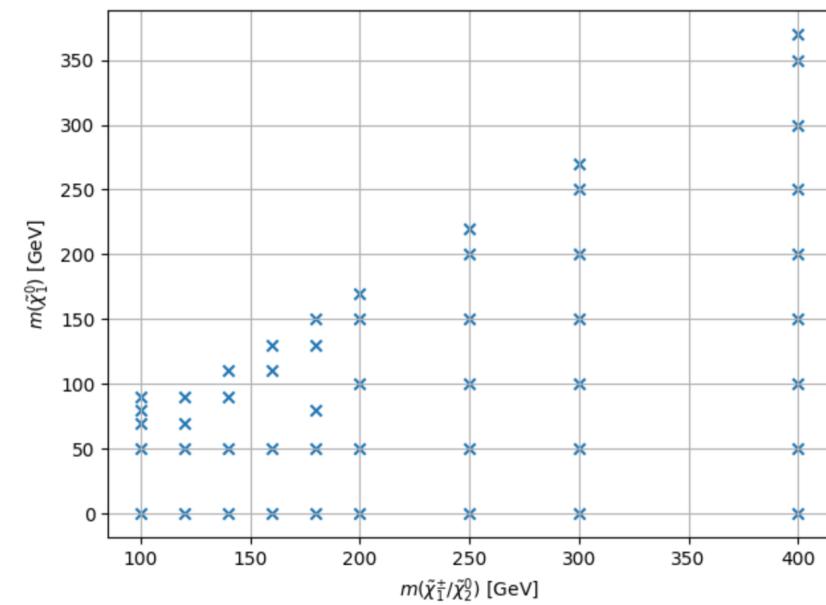
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Z+jets	700320-700322, 700467-700469	Sh_2211_Zee_maxHTpTV2
	700323-700325, 700470-700472	Sh_2211_Zmumu_maxHTpTV2
	700792-700794, 700901-700903	Sh_2214_Ztautau_maxHTpTV2
	700358	Sh_2211_Zee2jets_Min_N_TChannel
	700359	Sh_2211_Zmm2jets_Min_N_TChannel
	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*lvW*qq
	700600	Sh_2212_lll
	700601	Sh_2212_lllv
	700602,700603	Sh_2212_llvv_*
	700604	Sh_2212_lvvv
	700605	Sh_2212_llvvv
	701000	Sh_2214_lllljj
	701005	Sh_2214_lllvjj
	701010,701015	Sh_2214_llvvjj_*
	701020	Sh_2214_lllljj_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
	364242	Sherpa_222_NNPDF30NNLO_WWW_3l3v_EW6
	364243-364244	Sherpa_222_NNPDF30NNLO_WWZ
	364245-364246	Sherpa_222_NNPDF30NNLO_WZZ
	364247-364249	Sherpa_222_NNPDF30NNLO_ZZZ

# Signal samples



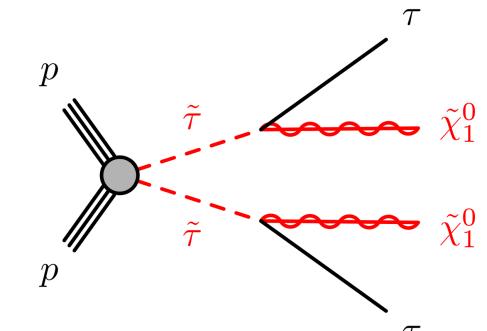
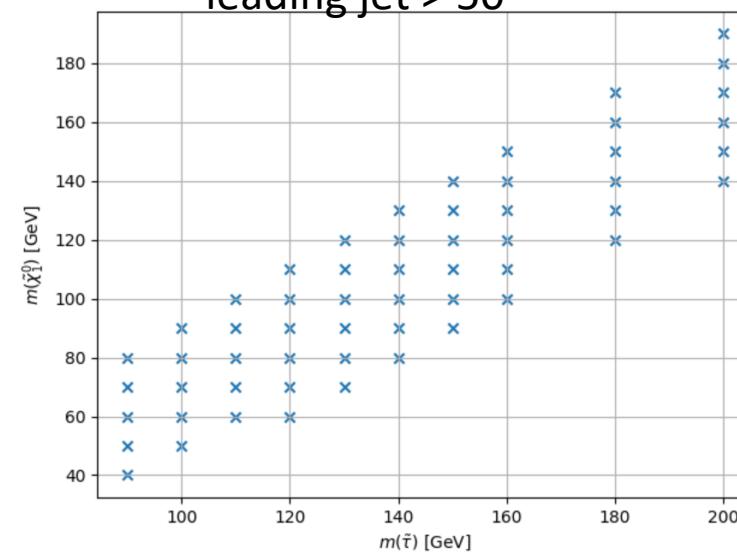
$\tilde{\chi}_1^\pm$  and  $\tilde{\chi}_2^0$  mass degenerate and pure wino

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



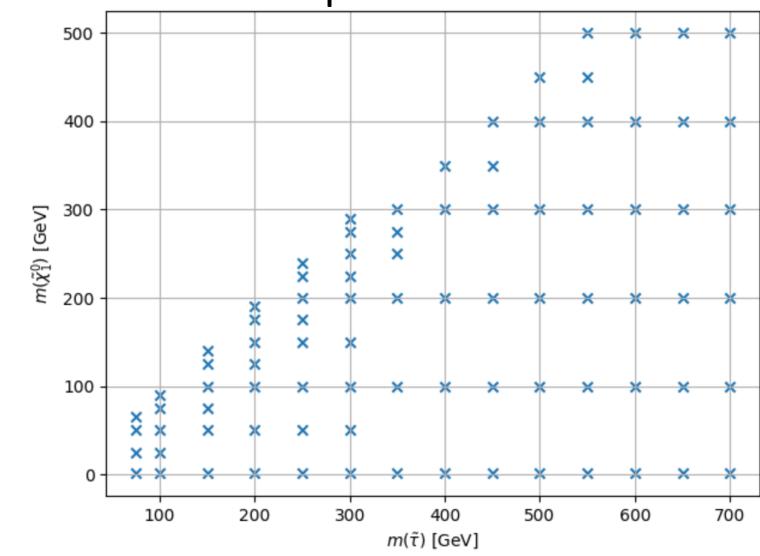
$\tilde{\tau}_L/\tilde{\tau}_R$  mass degenerate  
Bino-like  $\tilde{\chi}_1^0$

leading jet  $> 50$



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

1 lepton 20GeV



# Object Definition

- Full ST config: [Run2](#), [Run3](#)
- Follow the CP recommendation

Selection	Electron	Muon	Tau	Jet
Baseline	$p_T > 4.5 \text{ GeV}$ $ \eta  < 2.47$ $ z_0 \cdot \sin \theta  < 0.5 \text{ mm}$ ID: LooseAndBLayerLLH impact parameter	$p_T > 5 \text{ GeV}$ $ \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: FixedEffPt 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 MET  $\geq 200$ ,

Single lepton trigger for MET  $\leq 200$

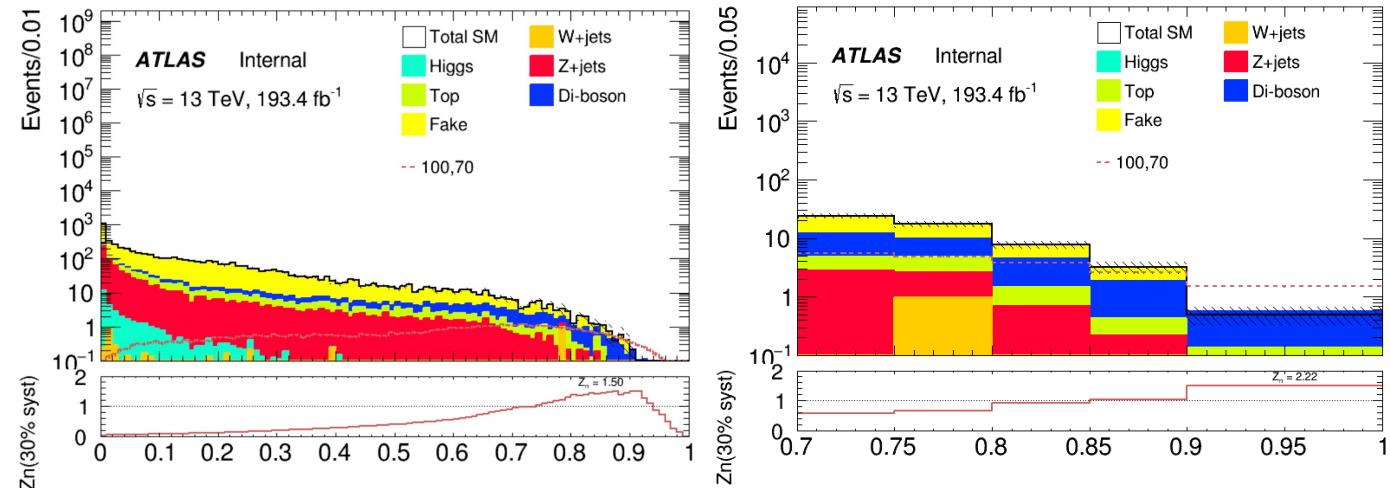
C1C1/C1N2: MET trigger

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	
	HLT_xe65_cell_xe90_pfopufit_L1XE50	2022,2023	90	
single electron trigger	HLT_e24_lhmedium_L1EM20VH	2015	24	25
	HLT_e60_lhmedium	2015	60	61
	HLT_e120_lhloose	2015	120	121
	HLT_e26_lhtight_nod0_ivarloose	2016-2018	26	27
	HLT_e60_lhmedium_nod0	2016-2018	60	61
	HLT_e140_lhloose_nod0	2016-2018	140	141
	HLT_e26_lhtight_ivarloose_L1EM22VHI	2022-2023	26	27
	HLT_e60_lhmedium_L1EM22VHI	2022-2023	60	61
	HLT_e140_lhloose_L1EM22VHI	2022-2023	140	141
single muon trigger	HLT_mu20_iloose_L1MU15	2015	20	21
	HLT_mu26_ivarmedium	2016-2018	26	27.3
	HLT_mu50	2015-2018	50	52.5
	HLT_mu24_ivarmedium_L1MU14FCH	2022-2023	24	25.2
	HLT_mu50_L1MU14FCH	2022-2023	50	52.5

# Direct Stau ISR signal region definition(HH)

- Preselection

HH Pre-selection	
=> 2 medium taus (OS)	
0 base lepton	
bveto	
MET trigger	
MET $\geq 200$ GeV	
$M_{\tau\tau}^{\text{reco}} < 40$ GeV or $M_{\tau\tau}^{\text{reco}} > 130$ GeV	



- SR selection using neuron network score

- Fake tau estimation using fake factor method
- DNN signal score  $> 0.7$

SR	
Pre-selection	
DNN score $> 0.7$	

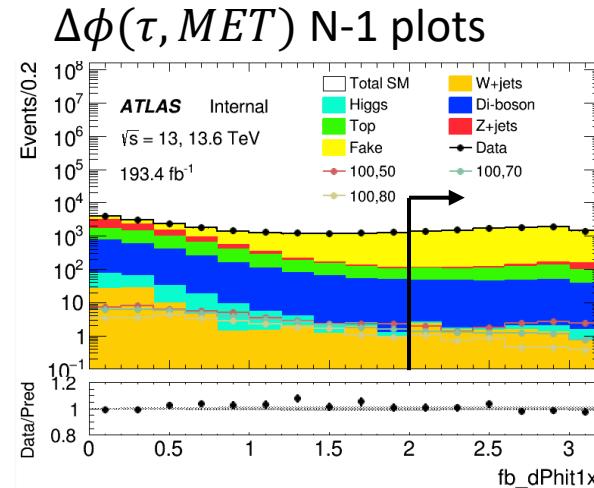
- Background composition

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

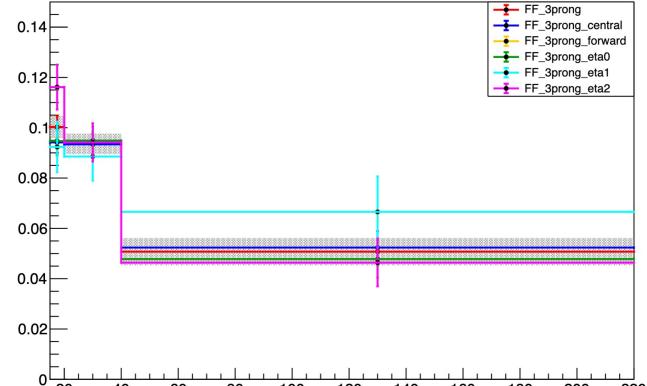
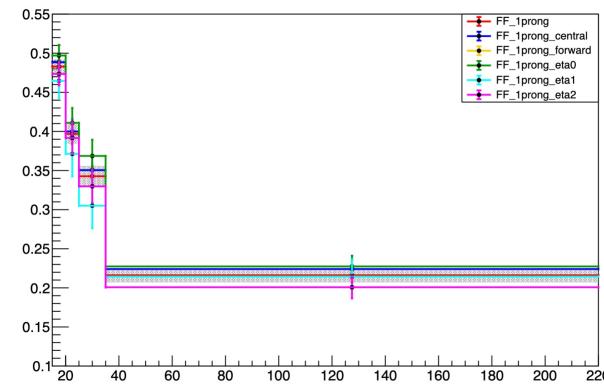
Dominate

# Direct Stau ISR fake estimation

- CRs (fake factor computation)
  - METtrig
  - MET $\geq 200$
  - bveto
  - 1 signal lepton
  - $\Delta\phi(\tau, MET) > 2$  improve fake purity
  - ID:  $\geq 1$  medium tau
  - antiID:  $\geq 1$  VeryLoose tau, 0 medium tau
- SRs
  - preselection
  - 2ID:  $\geq 2$  medium tau
  - 1ID1antiID:  $\geq 2$  VeryLoose tau , 1 medium tau
  - 2antiID:  $\geq 2$  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



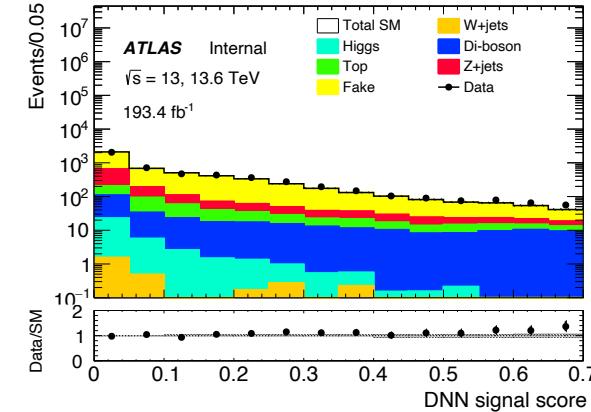
FF determination Data	FF application Data
CR Pass ID	SR Pass ID
SR but 1 tau Fail ID	SR but 2 tau Fail ID
CR Fail ID	SR but 2 tau Fail ID



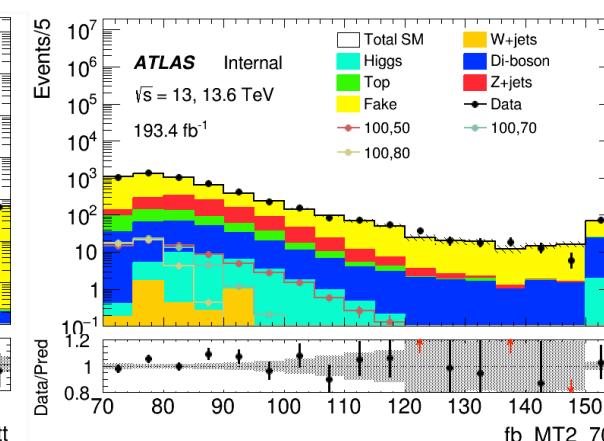
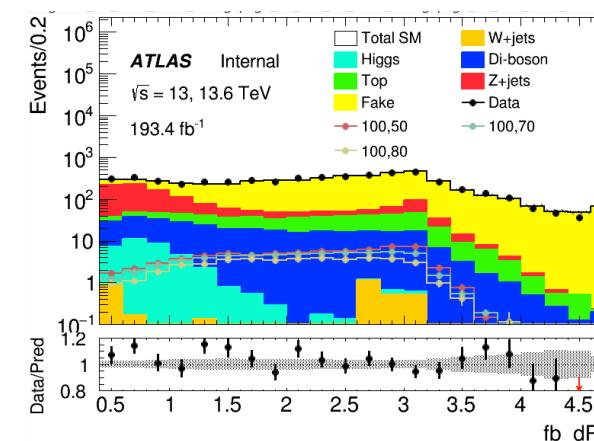
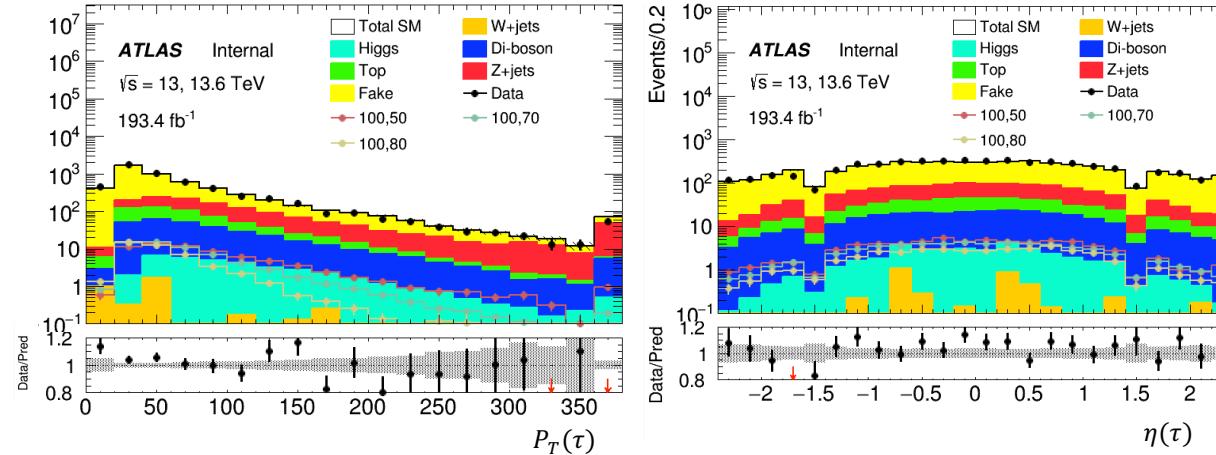
# Direct Stau ISR fake estimation validation(HH)

- Data-driven fakes in preselection region

**Score distribution**

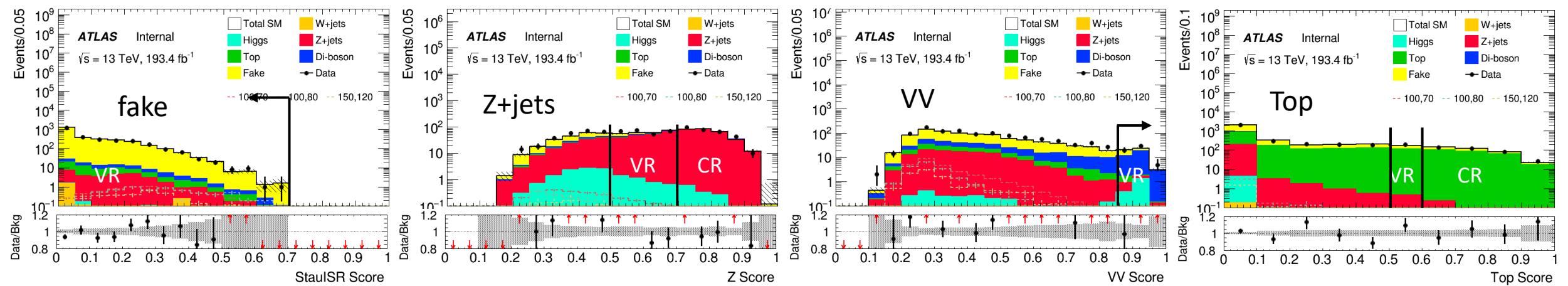


**Kinematic distribution**



# Direct Stau ISR background estimation (HH)

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



# Direct Stau ISR signal region definition(LH)

- Preselection

LH Pre-selection

$\geq 1$  medium taus

1base lepton, 1 signal lepton

Opposite-sign

bveto

MET trigger

$\text{MET} \geq 200$

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

$M_{T2,70} < 100$

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

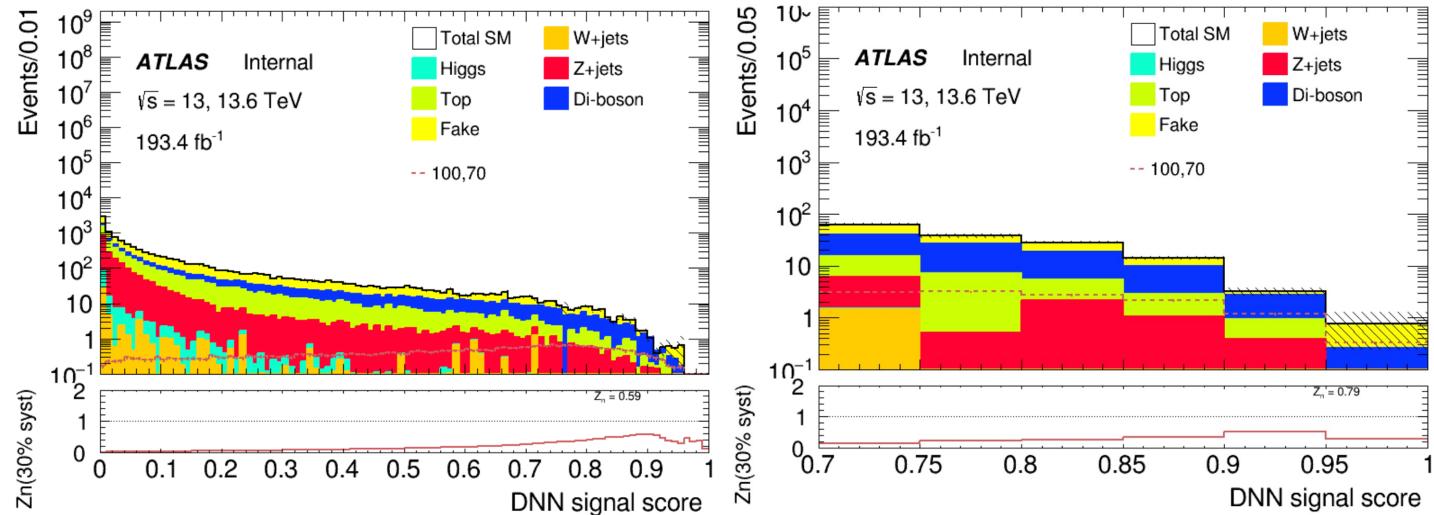
- SR selection using neuron network score

- Fake tau estimation using fake factor method
- DNN signal score  $> 0.7$

SR

Pre-selection

DNN score  $> 0.7$



- Background composition

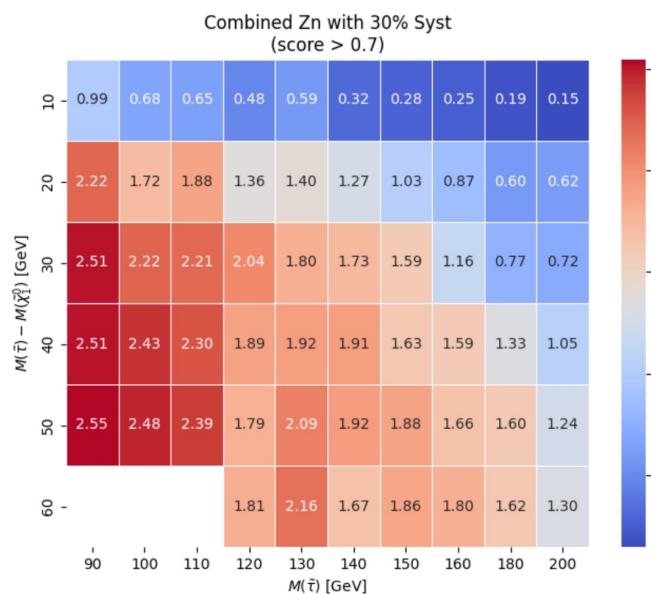
Dominate

Process	[0.70,0.75]	[0.75,0.80]	[0.80,0.85]	[0.85,0.90]	[0.90,0.95]	[0.95,1.00]	Combined
TotalBkg	$63.19 \pm 3.25$	$38.56 \pm 3.70$	$28.54 \pm 2.06$	$14.29 \pm 1.34$	$3.17 \pm 0.54$	$0.75 \pm 0.51$	$148.50 \pm 5.56$
VV	$25.27 \pm 0.86$	$19.64 \pm 0.81$	$12.90 \pm 0.63$	$6.97 \pm 0.45$	$1.77 \pm 0.24$	$0.21 \pm 0.04$	$66.76 \pm 1.43$
Fake	$22.41 \pm 2.65$	$11.87 \pm 1.87$	$10.13 \pm 1.85$	$4.40 \pm 1.16$	$0.45 \pm 0.40$	$0.49 \pm 0.51$	$49.75 \pm 3.96$
Top	$9.28 \pm 1.05$	$6.53 \pm 0.86$	$3.32 \pm 0.60$	$1.86 \pm 0.48$	$0.56 \pm 0.26$	$0.00 \pm 0.00$	$21.56 \pm 1.58$
Zjets	$4.74 \pm 0.29$	$3.33 \pm 0.25$	$2.16 \pm 0.24$	$1.03 \pm 0.16$	$0.37 \pm 0.10$	$0.05 \pm 0.02$	$11.68 \pm 0.49$
Higgs	$0.06 \pm 0.03$	$0.11 \pm 0.04$	$0.03 \pm 0.01$	$0.03 \pm 0.01$	$0.00 \pm 0.00$	$0.00 \pm 0.00$	$0.22 \pm 0.06$
Wjets	$1.44 \pm 1.28$	$-2.92 \pm 2.95$	$0.00 \pm 0.00$	$0.00 \pm 0.00$	$0.01 \pm 0.01$	$0.00 \pm 0.00$	$-1.47 \pm 3.22$
StauStauISR-100-70	$3.13 \pm 0.07$	$3.17 \pm 0.07$	$2.75 \pm 0.07$	$2.17 \pm 0.06$	$1.18 \pm 0.04$	$0.32 \pm 0.02$	$12.71 \pm 0.15$
ZnSignificance	0.15	0.23	0.26	0.36	0.53	0.29	0.79

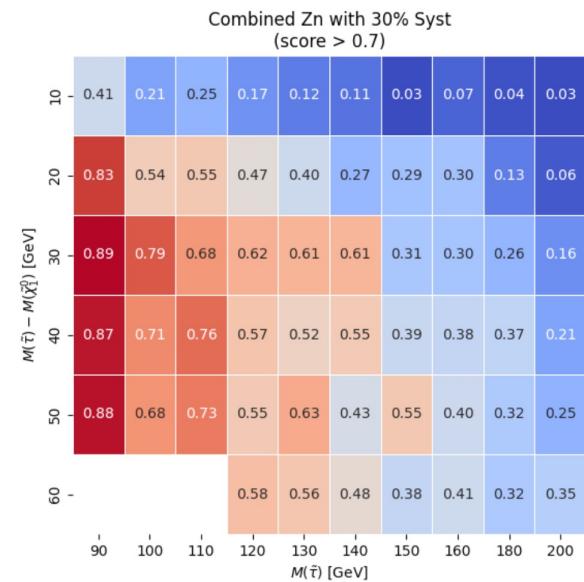
# Direct Stau ISR signal region definition

- Expected sensitivity
  - 30% flat systematic uncertainty

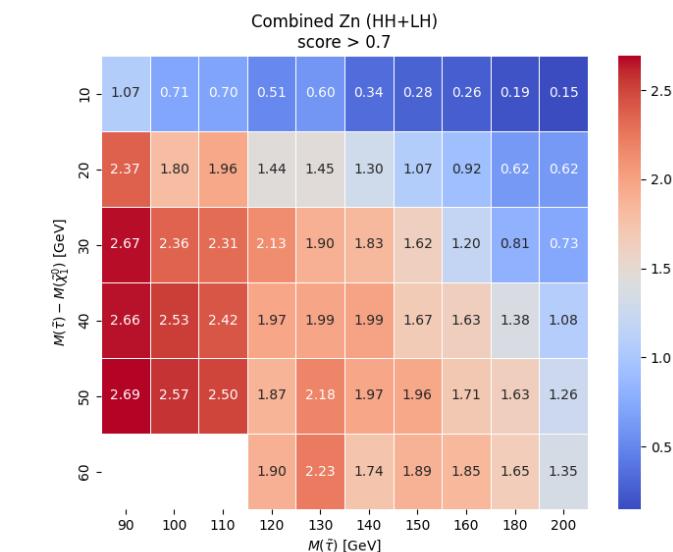
HH channel



LH channel



Combined channel



# Direct Stau single-lep trigger SR definition(LH)

LH Pre-selection

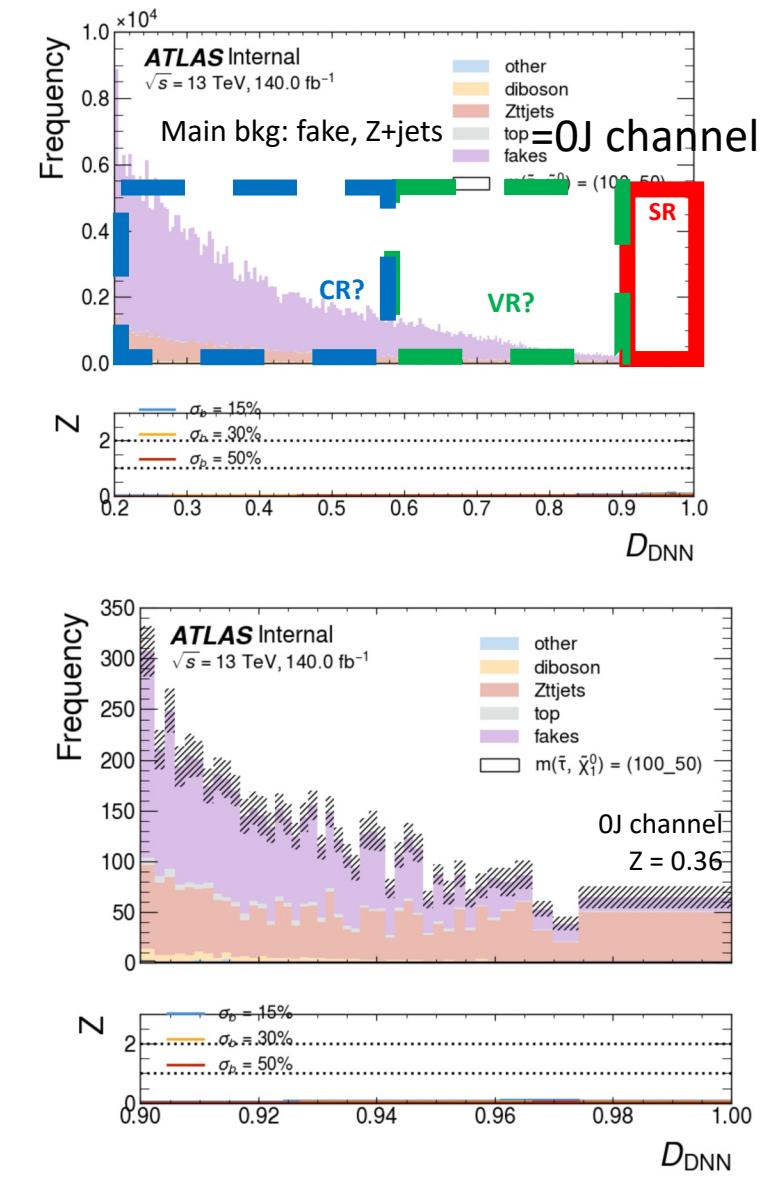
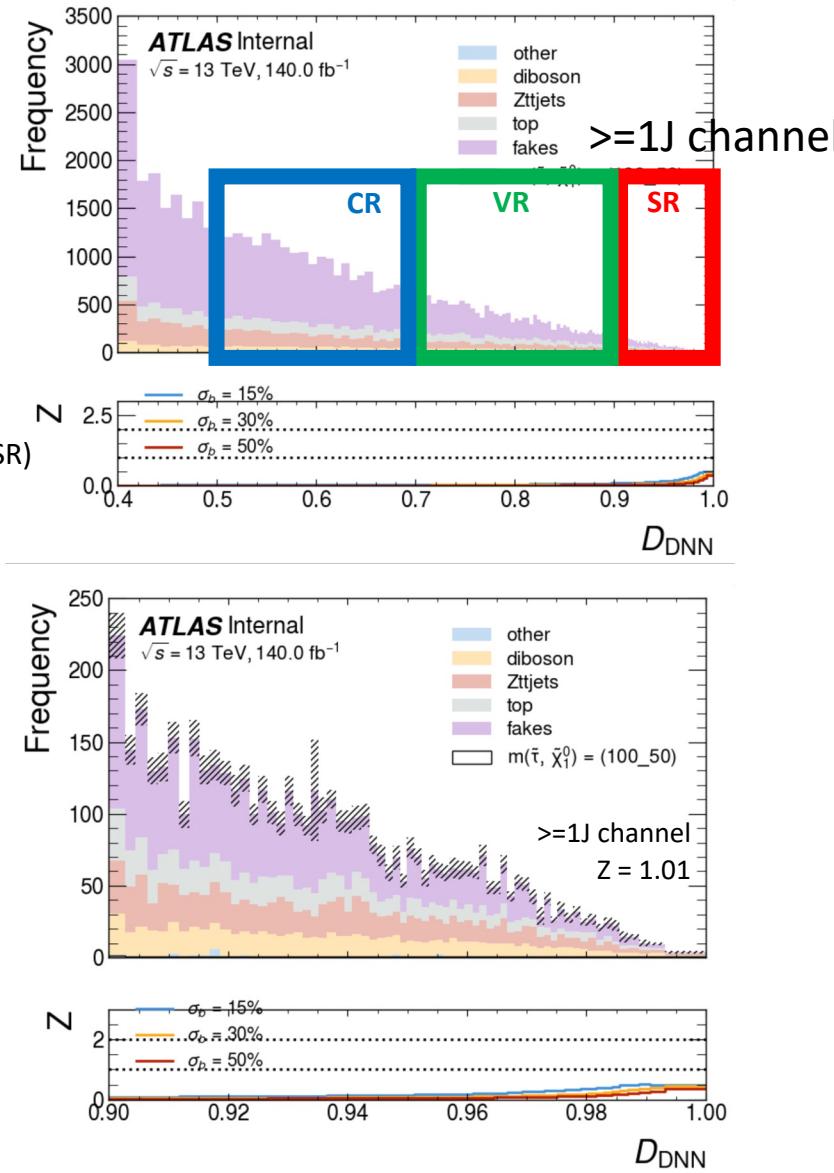
- 1 Tight taus
- 1 signal lepton
- OS
- bveto
- Single-lepton trigger
- 15 GeV < MET < 200 GeV** (orthogonal with ISR SR)
- METSig > 2
- MT2 < 90
- $dR(\text{lep}, \tau) < 3.6$
- custom MT cut\*
- $\phi_{\{1,2\}} \text{ cut}^*$

---

SR

Pre-selection

- $\geq 1$  Jet
- $= 0$  Jet
- DNN score > 0.9



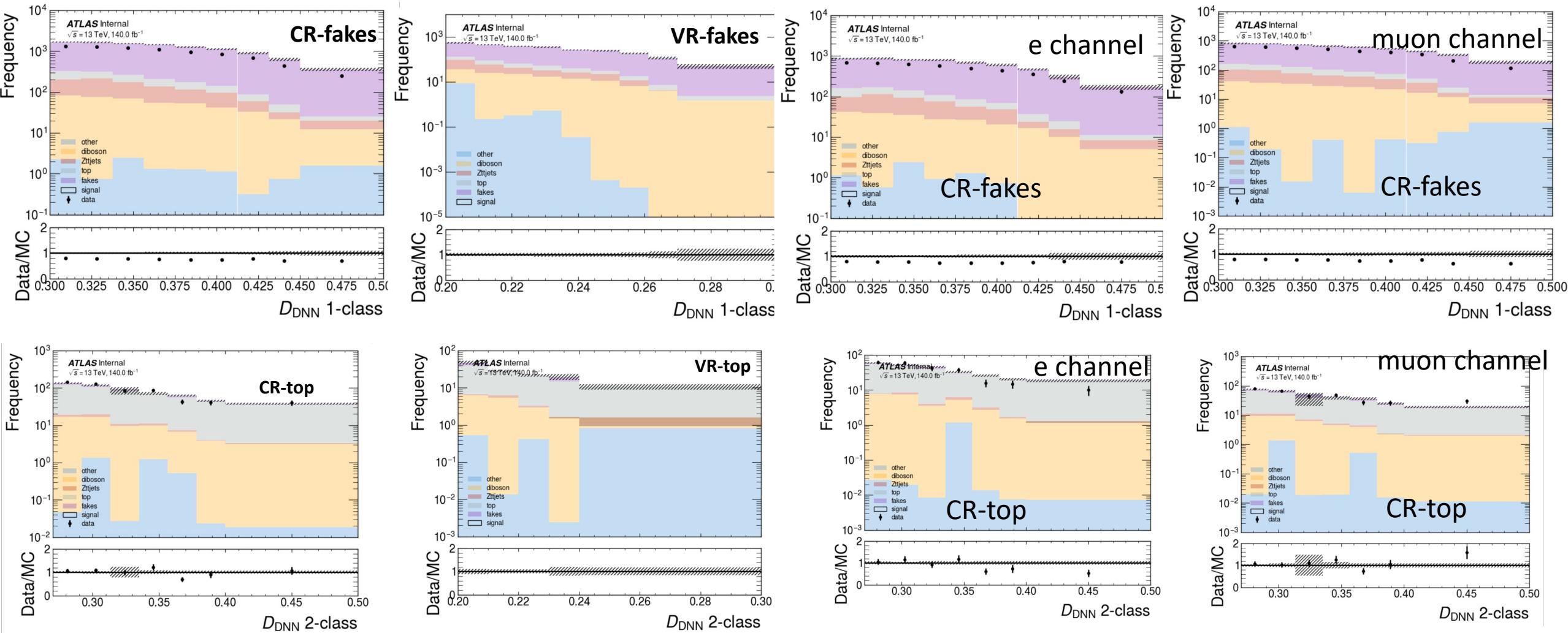
# Direct Stau single-lep trigger background estimation(LH)

$\geq 1J$  channel

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

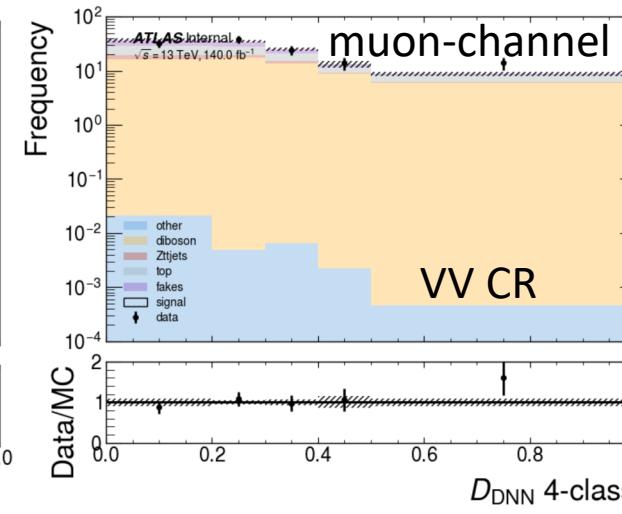
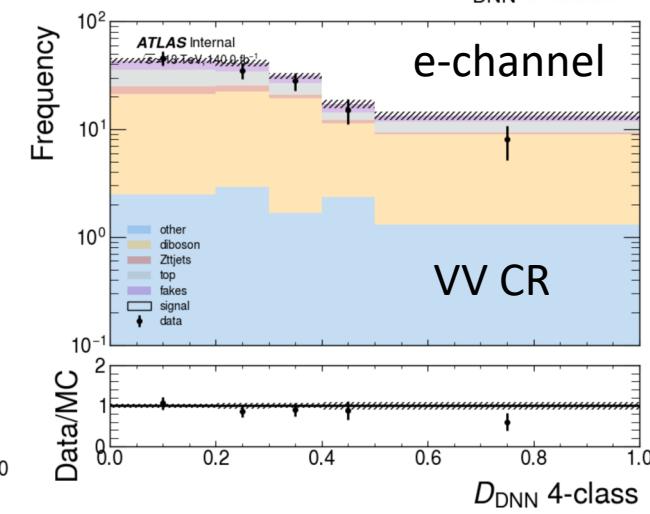
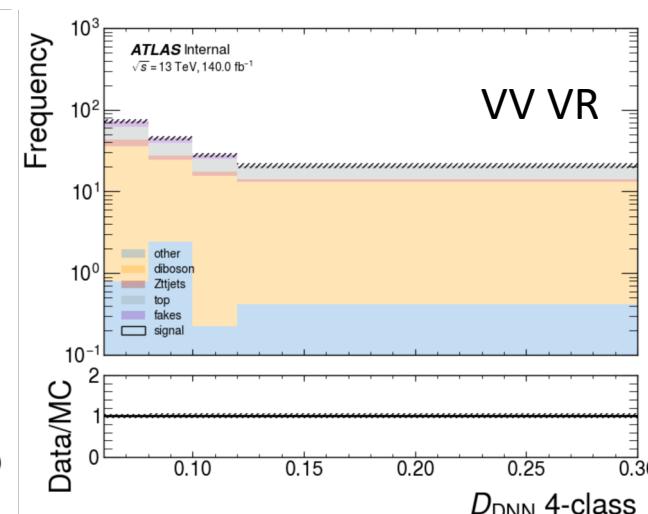
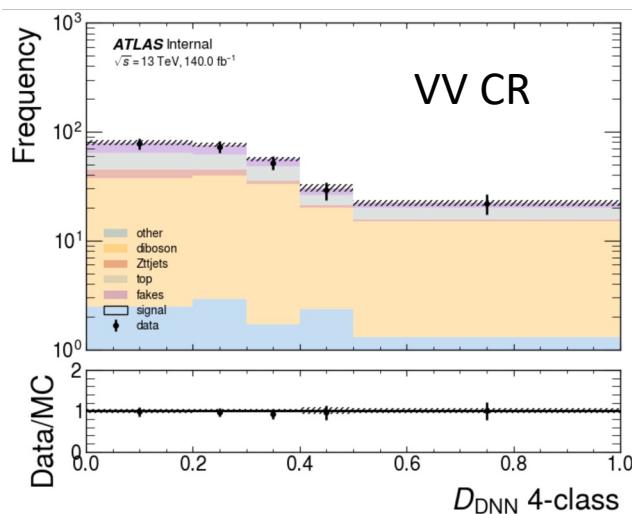
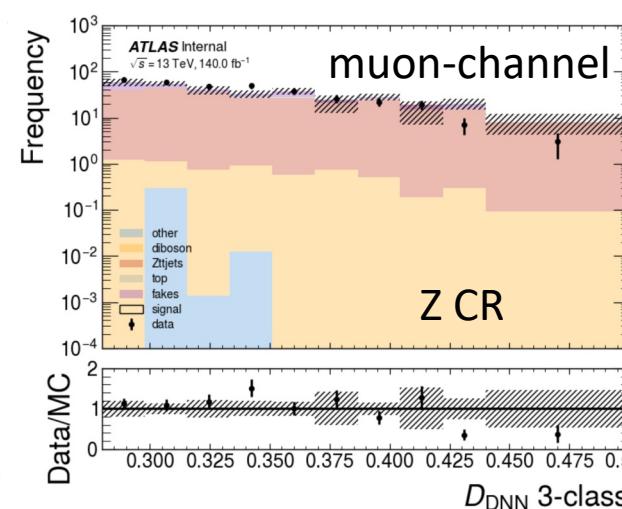
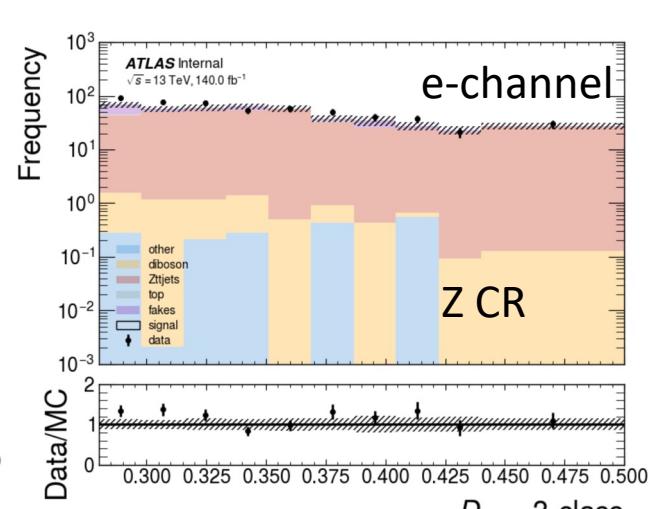
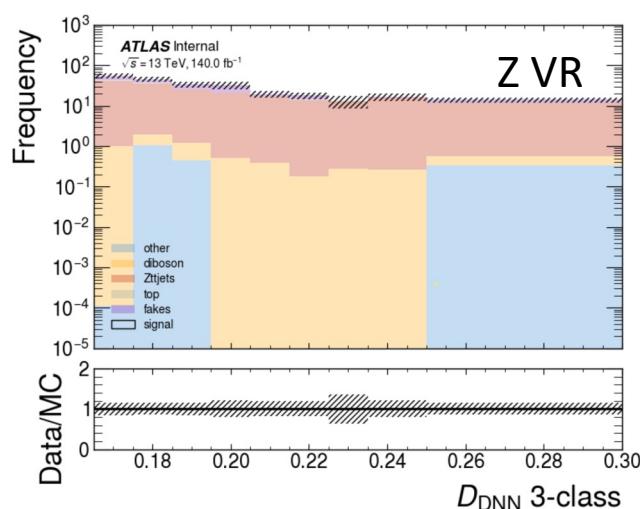
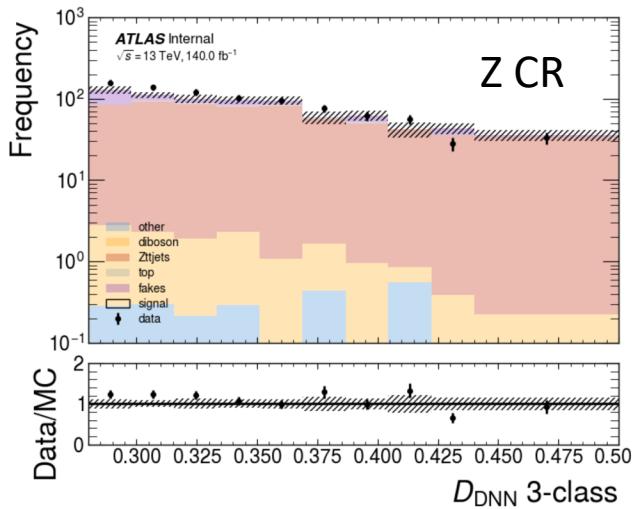
**\*Note: MC fakes are only place holders, will be replaced with data driven background in final fit and CR will be added to VR)**

# 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)

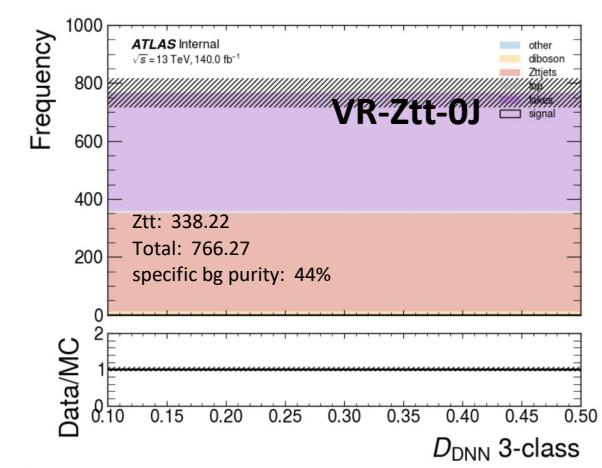
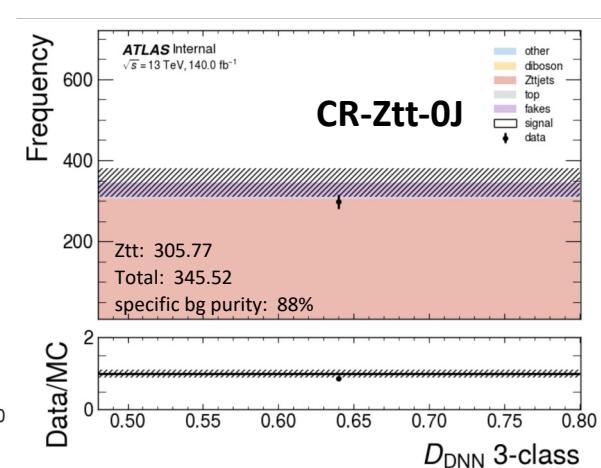
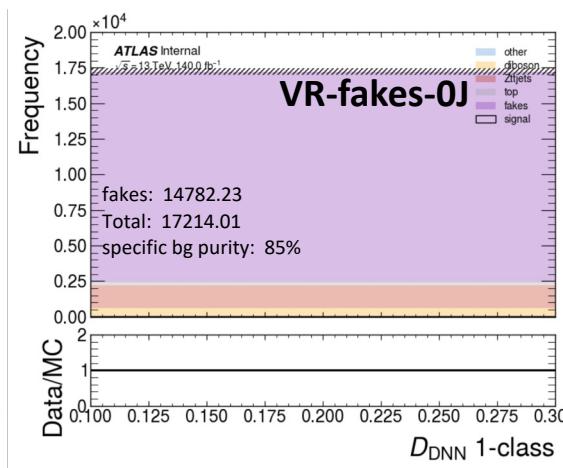
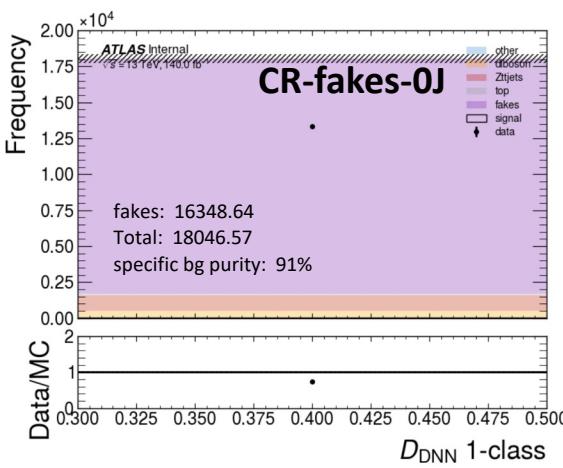


\*(Note: MC fakes are only place holders, will be replaced with data driven background in final fit and CR will be added to VR)

# Direct Stau single-lep trigger background estimation(LH)

= 0J channel

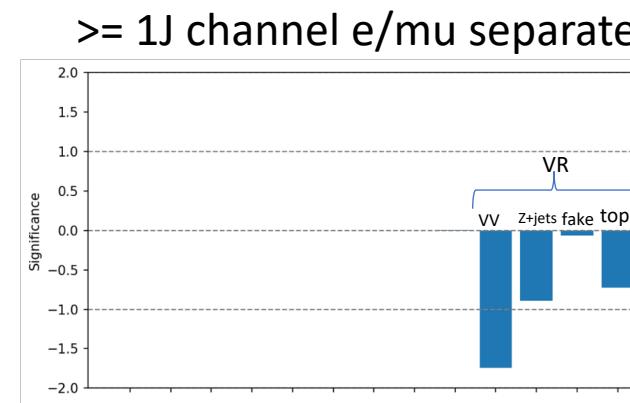
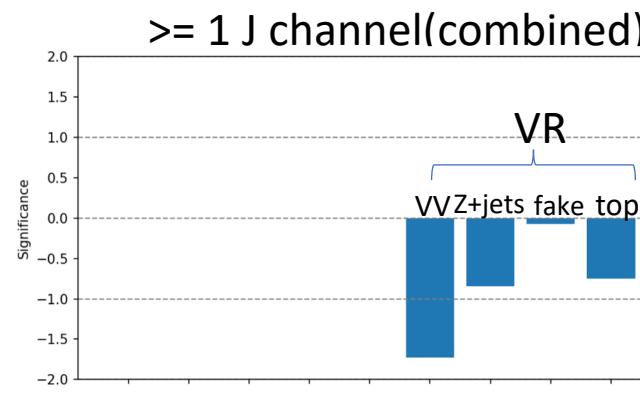
Region	Selections		Total Bkg	Dominant Bkg	Purity
Fake CR	<b>0.5 &lt; signal score &lt; 0.7, max bkg score: Fake</b>	<b>fake score &gt; 0.3</b>	18046	16348	0.91
Z CR	<b>0.2 &lt; signal score &lt; 0.5, max bkg score: Z</b>	<b>Z score &gt; 0.48</b>	345	305	0.88
Fake VR	<b>0.7 &lt; signal score &lt; 0.9,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



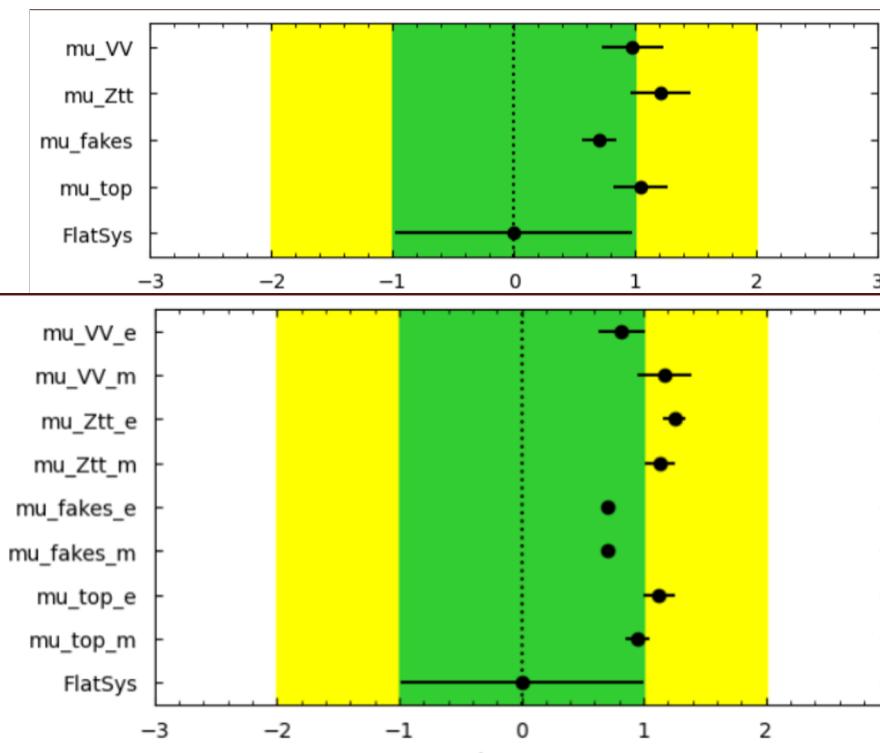
\*(Note: MC fakes are only place holders, will be replaced with data driven background in final fit and CR will be added to VR)

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

Norm Factor	results	Norm Factor	results
mu_VV	0.9763+-0.2523	mu_VV_e	0.8181+-0.1909
mu_Ztt	1.2063+-0.2497	mu_Ztt_e	1.2519+-0.0929
mu_fake	0.7051+-0.1398	mu_fakes_e	0.7060+-0.0259
mu_top	1.0451+-0.2208	mu_top_e	1.1251+-0.1277
FaltSys	-0.0009+-0.9745	FaltSys	0.0008+-0.9934

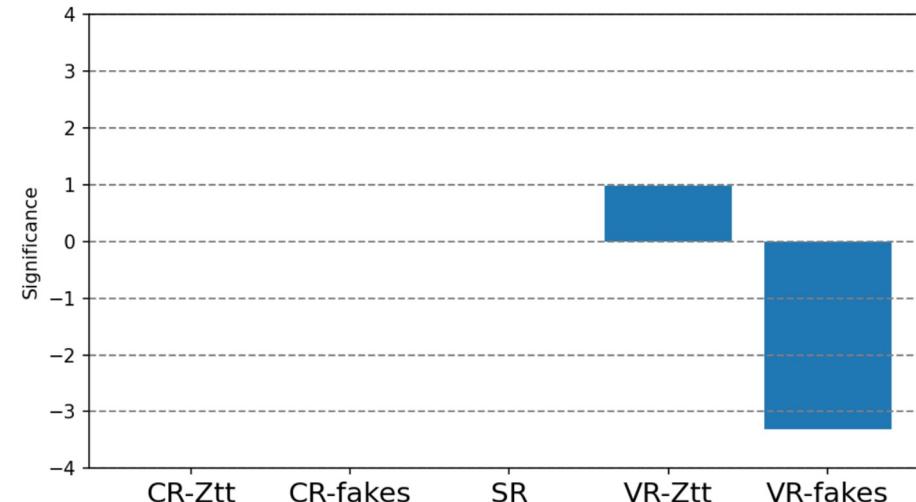
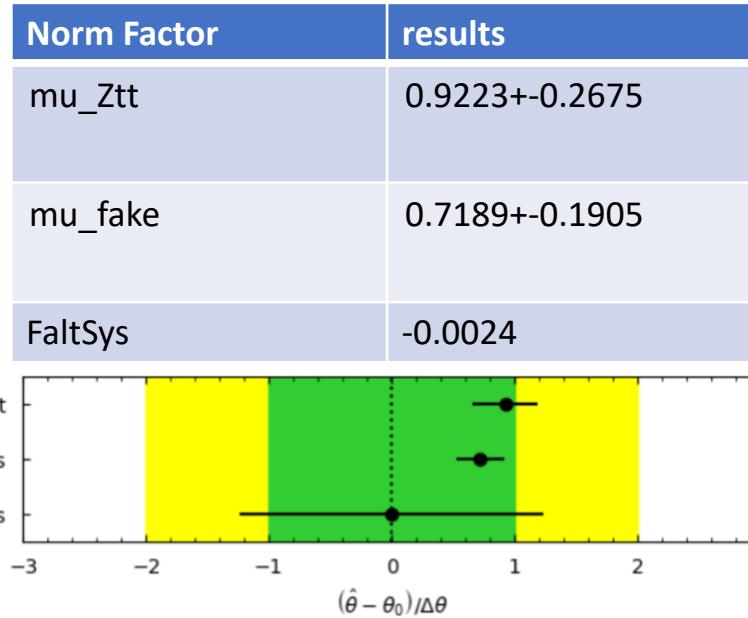


- Norm factors indicate overprediction for fake
  - Hence data-driven method
- VRs have slight over prediction (but all under 2-sigma)



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

= 0 J channel

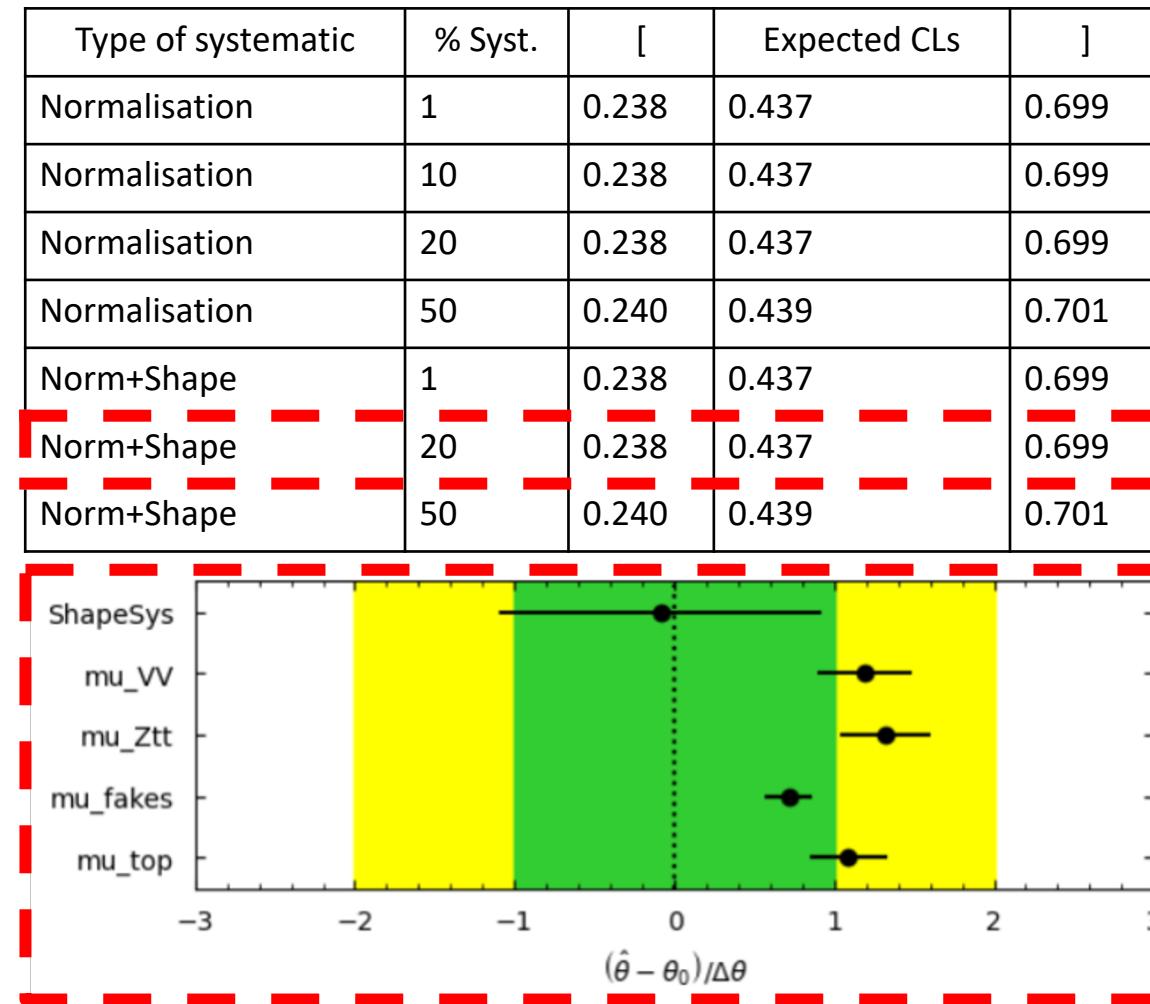


- Observe >3 sigma overestimation for fake
  - Further solidifies need for data-driven fakes
- Z+jets agreement in VR very good
- Top and boson minor backgrounds in this channel

# Direct Stau single-lep trigger Exclusion Fit(LH)

## >= 1J channel

- expected CLs **very robust** to systematics
- Sensitivity worse than estimated from simple Z score formula
- (Mu factors preliminary since dominant fake background MC will be replaced)\*

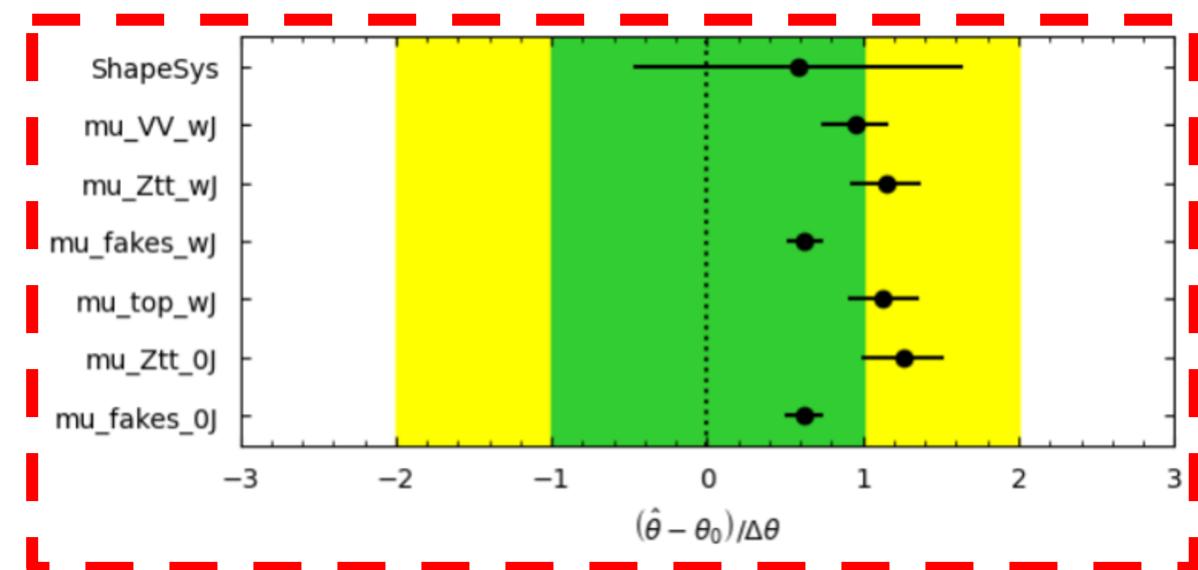


# Direct Stau single-lep trigger Exclusion Fit(LH)

## 0J and >= 1J channel combined

- a slight decrease in the expected CLs, but not much
- DNN studies showed >=1J channel drives sensitivity

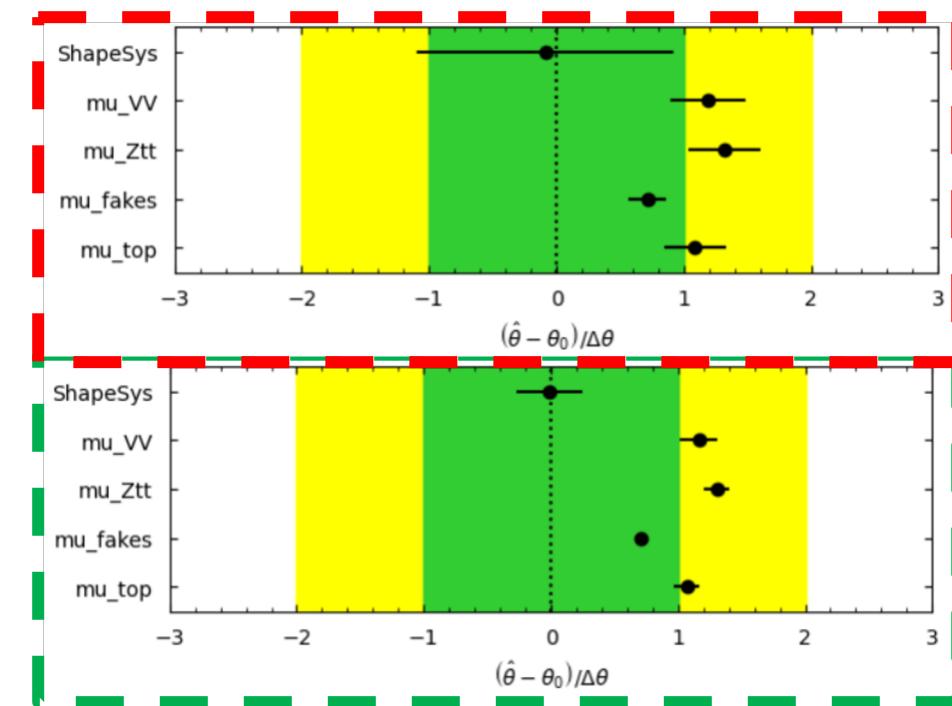
Type of systematic	% Syst.	[	Expected CLs	]
Normalisation	20	0.231	0.429	0.693
Norm+Shape	20	0.231	0.429	0.693



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

- Idea to use same-sign (SS) region in the fit to constrain systematics
- small impact on resulting CLs value

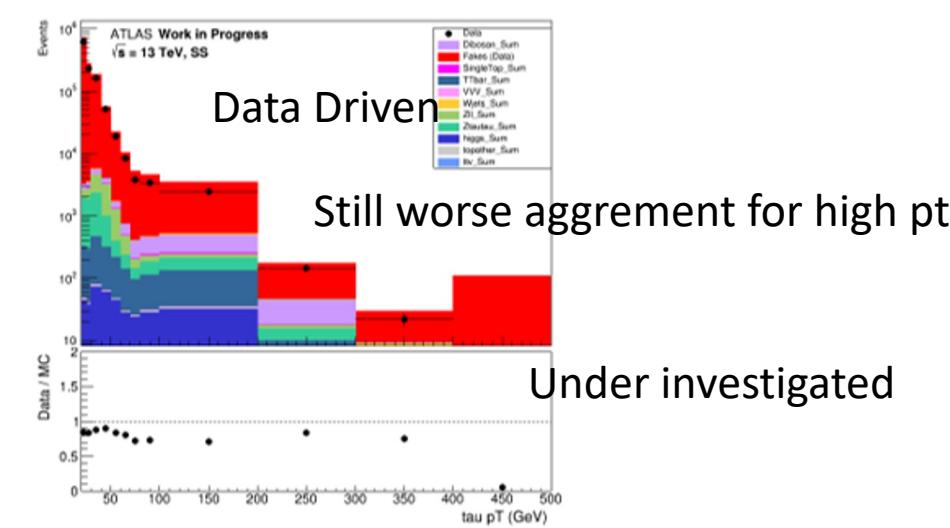
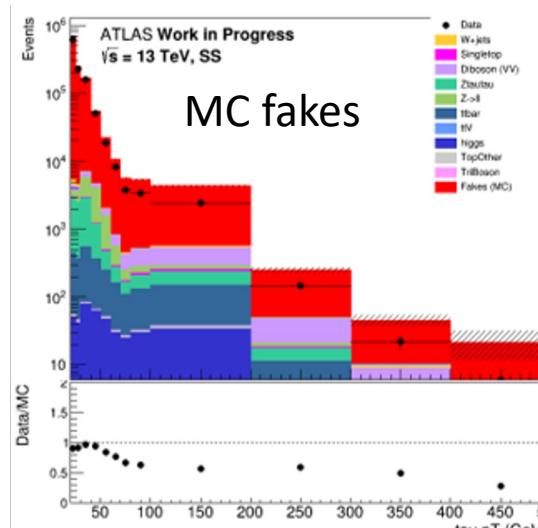
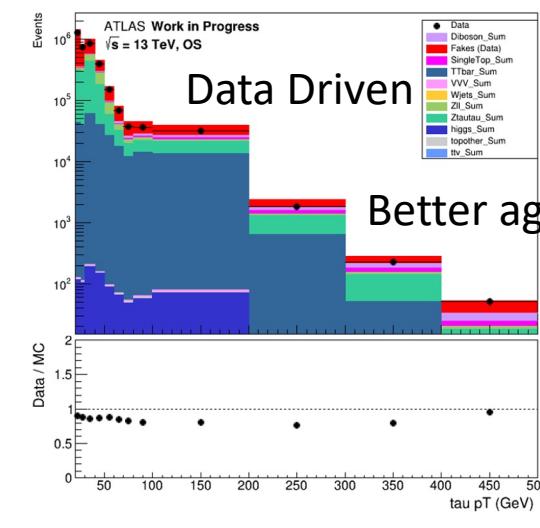
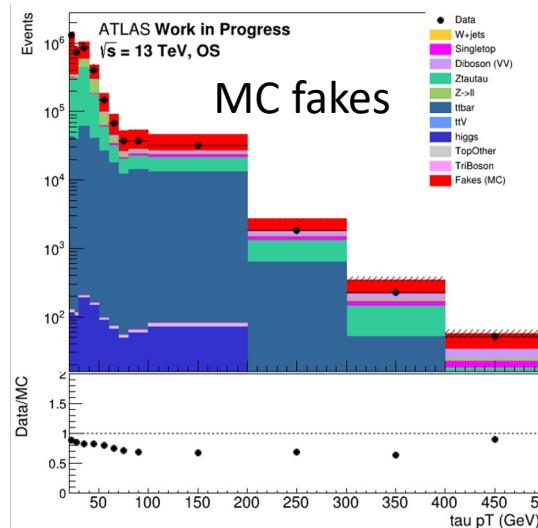
Type of fit	% Syst.	[	Expected CLs	]
OS only	20	0.242	0.442	0.703
OS-SS	20	0.242	0.441	0.702



# Direct Stau single-lep trigger fake estimation(LH)

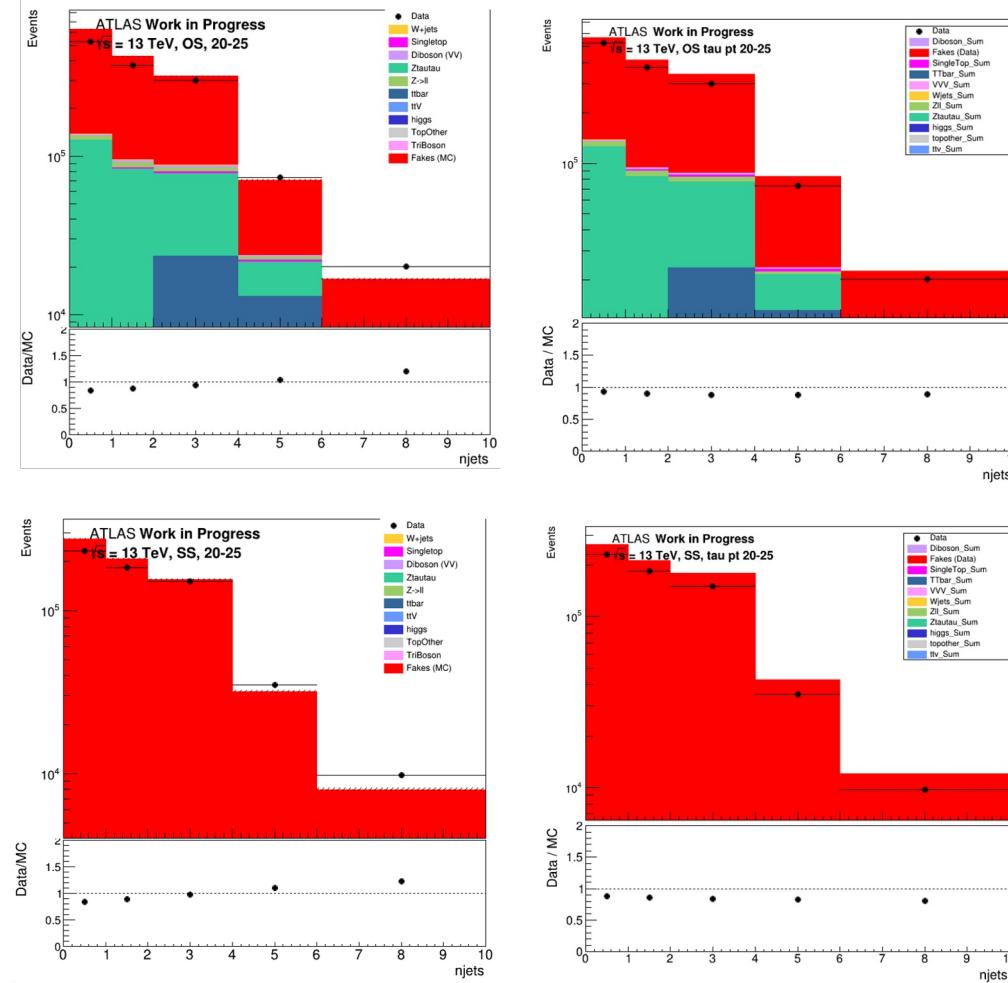
- CRs (fake factor computation)
  - Single lepton trigger
  - OS/SS
  - 1 signal lepton
  - ID:  $\geq 1$  tight tau
  - antiID:  $> 0.05$  RNN score, no tight tau
- SRs
  - Single lepton trigger
  - MET  $> 15\text{GeV}$
  - B-veto
  - OS/SS
  - ID:  $\geq 1$  tight tau
  - antiID:  $> 0.05$  RNN score,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

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



# Direct Stau single-lep trigger 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



# Direct Stau ISR Cut and Count(HH)

HH Pre-selection

$\geq 2$  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

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

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

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

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

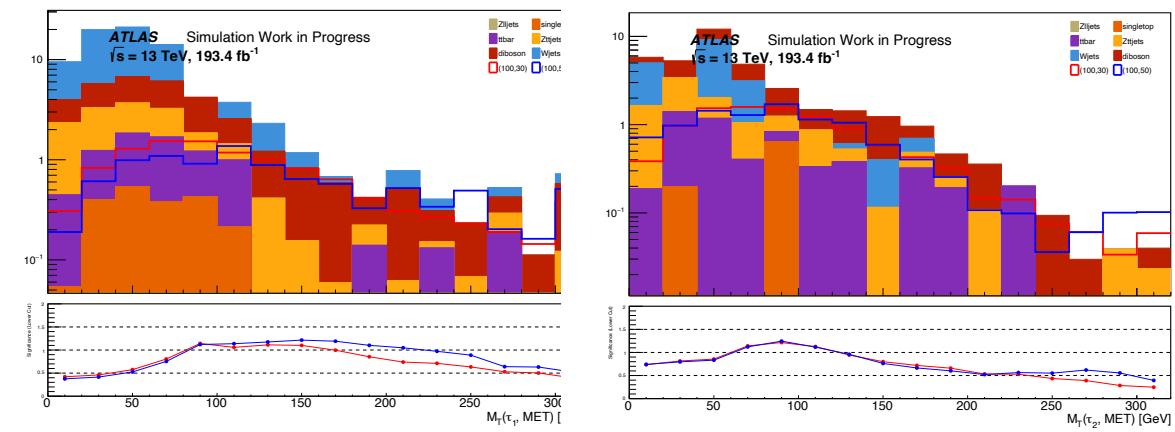
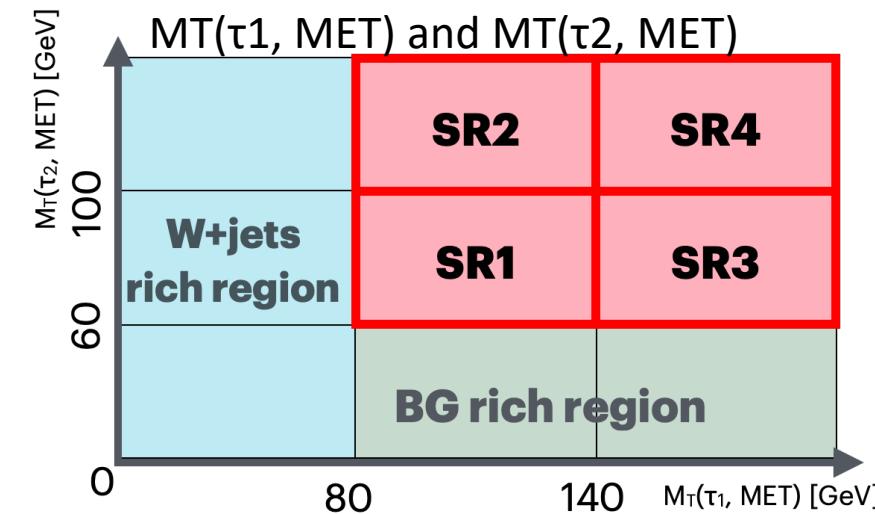
$$dR(\tau_1, \tau_2) < 3.2$$

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

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

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

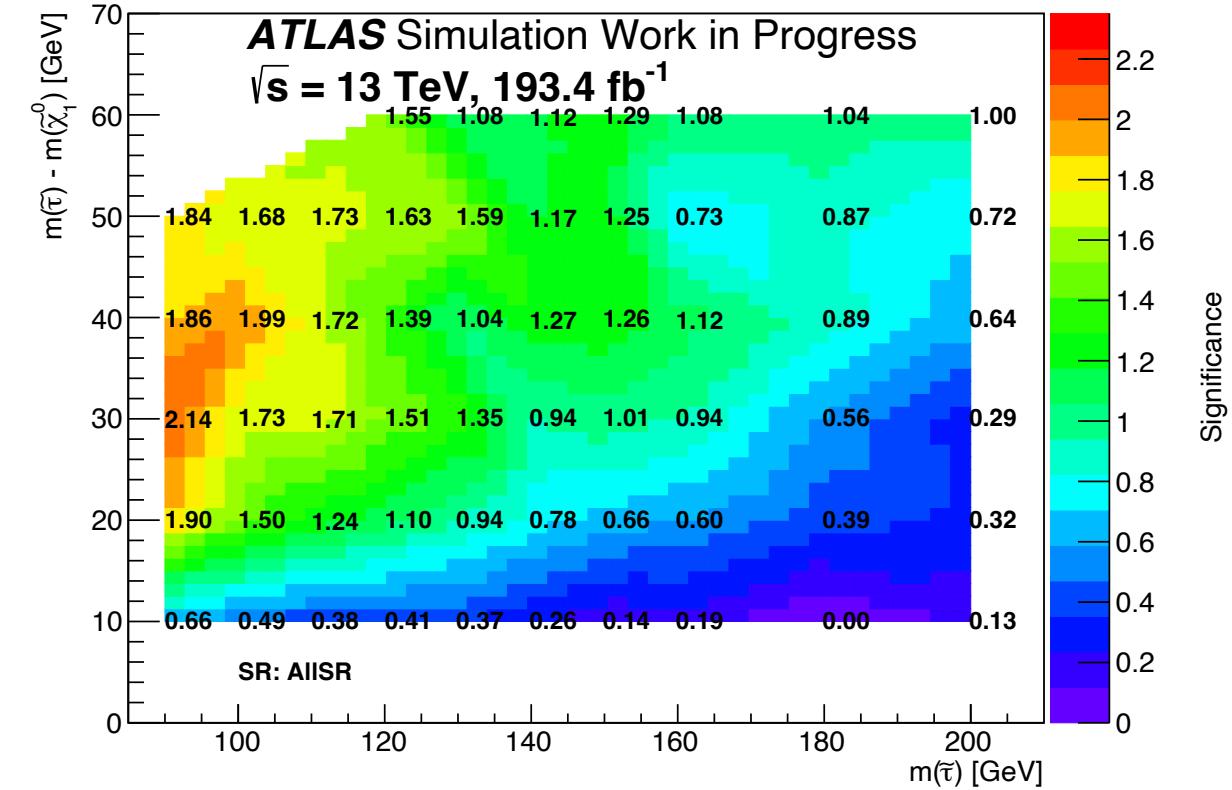
Signal Region definition:  
Binned for the combination of  
 $M_T(\tau_1, \text{MET})$  and  $M_T(\tau_2, \text{MET})$



# 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	<b>16.67</b>
Signal (100, 70)	2.35	2.15	2.00	1.73	<b>8.23</b>
Significance	0.69	0.75	0.80	1.14	<b>1.73</b>



# Direct Stau ISR Cut and Count(LH)

LH Pre-selection

$\geq 1$  medium taus

1 base lepton, 1 signal lepton

OS

bveto

MET trigger

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

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

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

Collinear mass( $\tau l$ )  $> 130 \text{ GeV}$

SR before binned

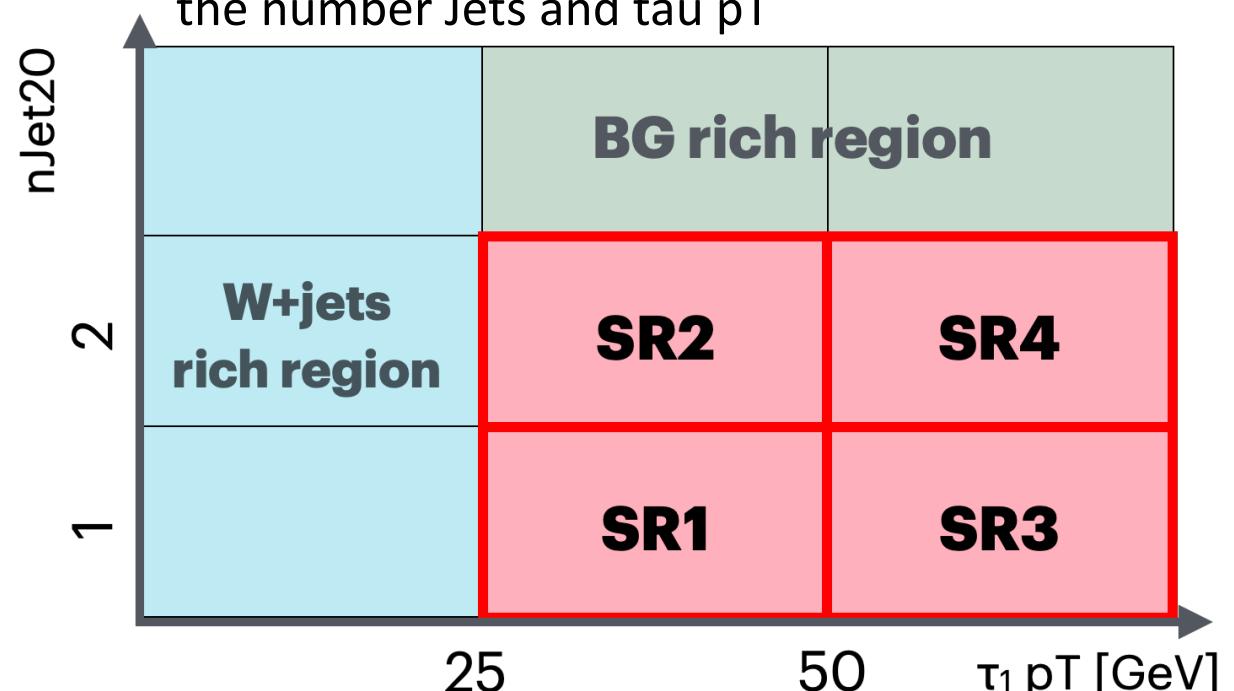
Pre-selection

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

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

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

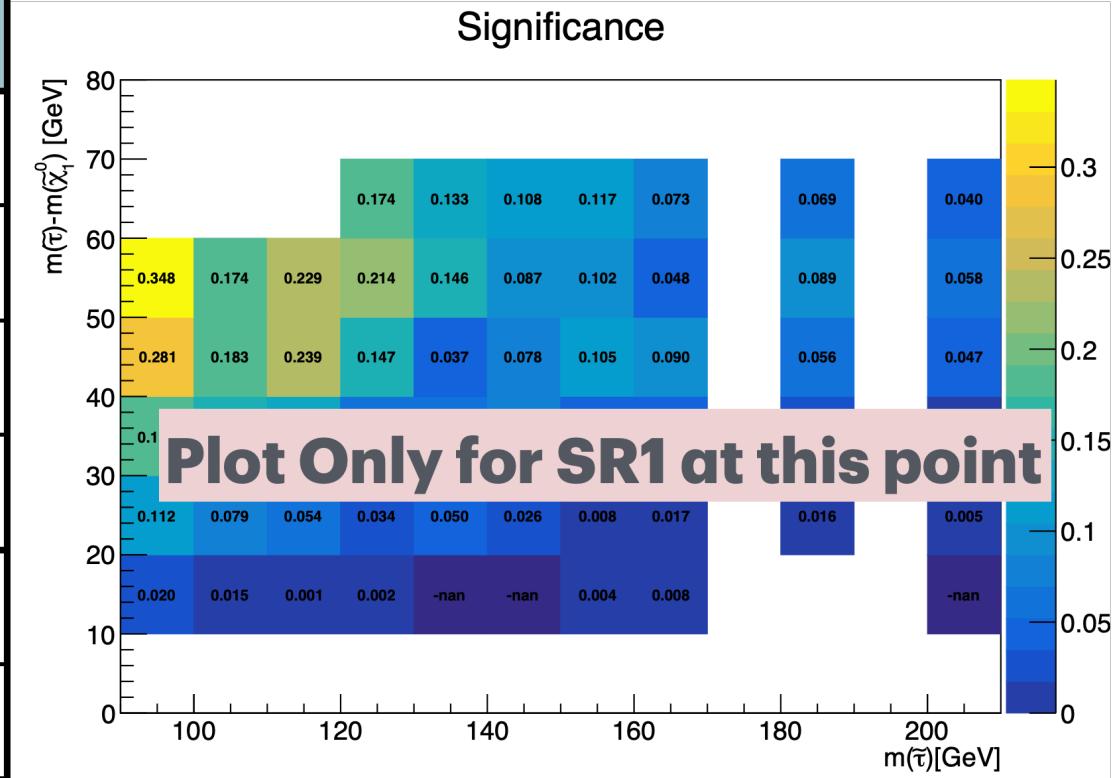
Signal Region definition:  
Binned for the combination of  
the number Jets and tau pT



# Direct Stau ISR Cut and Count(LH)

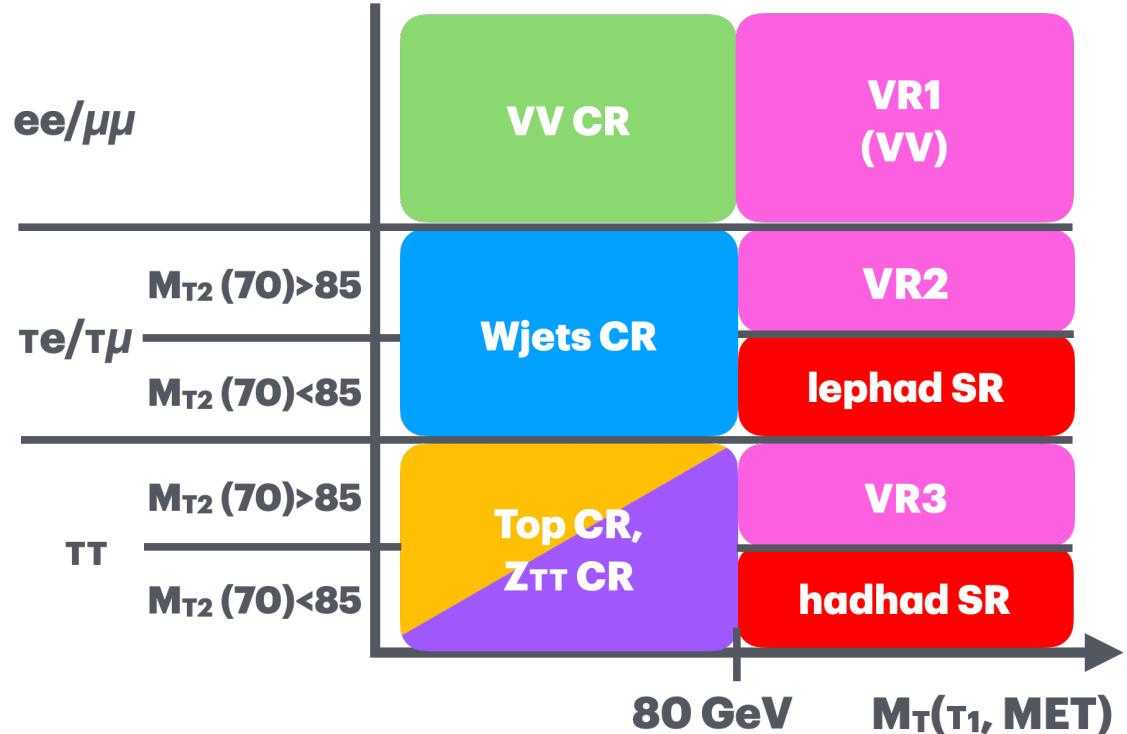
Sensitivity map with 30% systematic uncertainty

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



# 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  $\tau$ ) 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)

	<b>SR (HH)</b>	<b>SR (LH)</b>	<b>CR (VV)</b>	<b>CR (Wjets)</b>	<b>CR (Z<math>\tau\tau</math>)</b>	<b>CR (Top)</b>	<b>VR (VV)</b>	<b>VR (HH)</b>	<b>VR (LH)</b>
<b>MET</b>	> 200 GeV	> 130 GeV			> 200 GeV		> 200 GeV		> 130 GeV
<b>nJet20</b>	<= 4	<= 2			<= 4		<= 4		<= 2
<b>nBJet20 (WP 90%)</b>		= 0			= 0	>= 1		= 0	
<b>Primary Jet pT</b>	> 200 GeV	> 50 GeV			> 200 GeV		> 200 GeV		> 50 GeV
<b>(nLightLeptons, nHadronic Taus)</b>	= (0, 2)	= (1, 1)	= (2, 0)	= (1, 1)	= (0, 2)		= (2, 0)	= (0, 2)	= (1, 1)
<b>tau pT</b>	> 20 GeV	> 25 GeV	-		> 20 GeV		-	> 20 GeV	> 25 GeV
<b>M<math>\tau</math> (<math>\tau_1</math>, MET)</b>	> 80 GeV	> 90 GeV			< 80 GeV		> 80 GeV		> 90 GeV
<b>Collinear mass</b>	> 250 GeV	> 130 GeV		> 250 GeV	$\in [70, 110]$ GeV	> 250 GeV		> 250 GeV	> 130 GeV
<b>M<math>\tau_2(70)</math></b>	< 85 GeV	-			-			> 85 GeV	-
<b>M<math>\tau_2(40)</math></b>	-	< 55 GeV			-		-		> 55 GeV

# C1C1 ISR signal region optimization

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

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

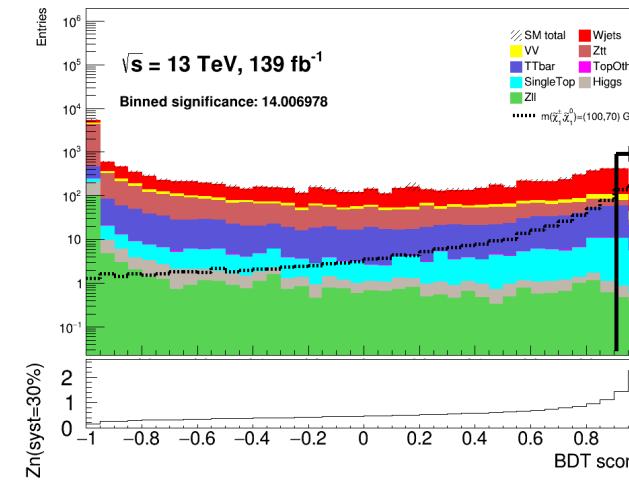
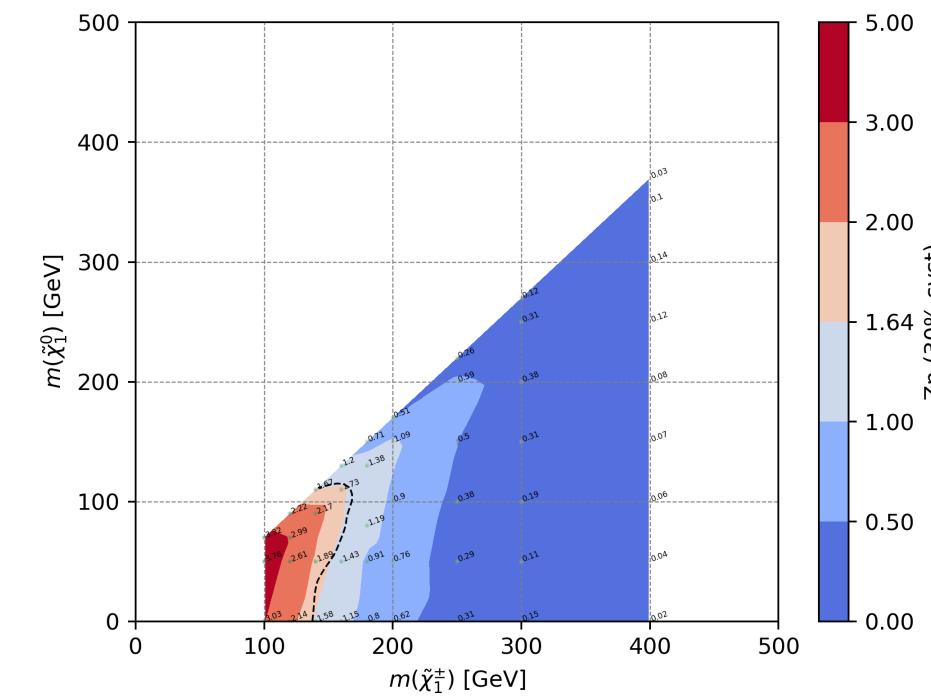
Table 3: Best performance for HH and LH channel after grid search

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

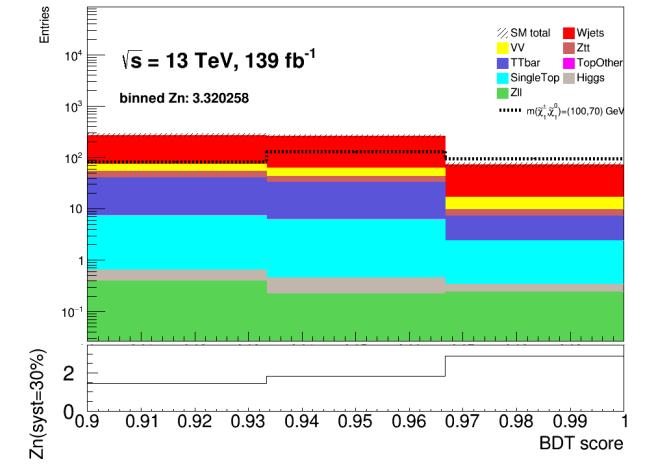
# C1C1 ISR signal region definition(HH)

SR  
Pre-selection  
BDT score > 0.9

Sensitive map



Binned significance: 3.32

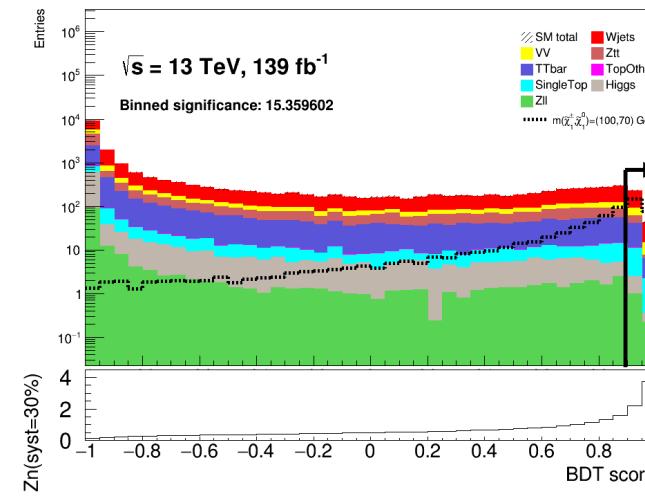
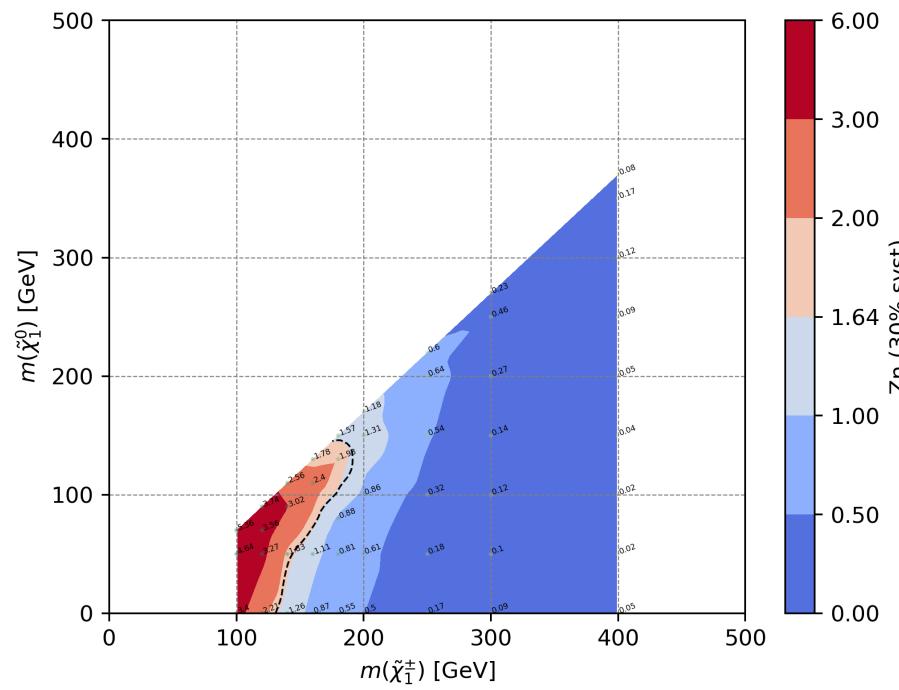


SM process	SR2	SR2-Bin1	SR2-Bin2	SR2-Bin3
Wjets	$448 \pm 28$	$197 \pm 18$	$55 \pm 9$	$197 \pm 19$
VV	$49.1 \pm 1.2$	$20.7 \pm 0.9$	$7.4 \pm 0.4$	$21.0 \pm 0.9$
Ztt	$25.3 \pm 2.9$	$9.8 \pm 1.6$	$2.3 \pm 1.1$	$13.1 \pm 2.1$
TTbar	$64.5 \pm 3.1$	$26.7 \pm 2.0$	$4.9 \pm 0.9$	$32.9 \pm 2.2$
TopOther	$0.38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

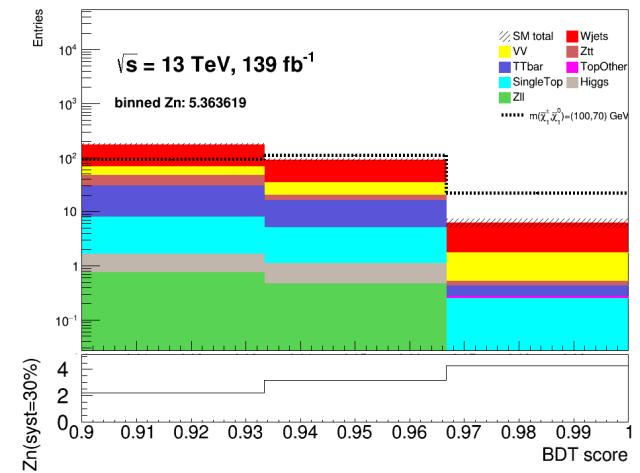
# C1C1 ISR signal region definition(LH)

SR  
Pre-selection  
BDT score > 0.9

Sensitive map



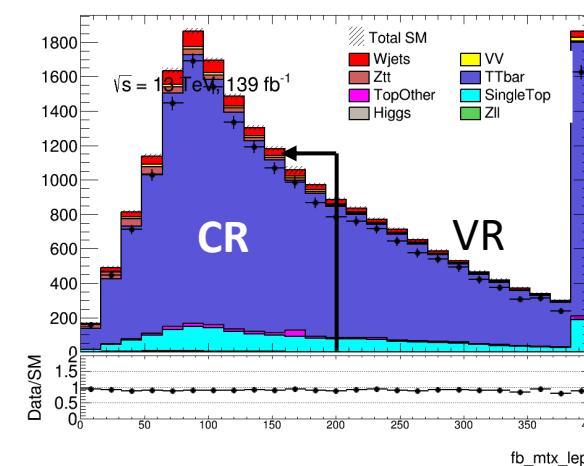
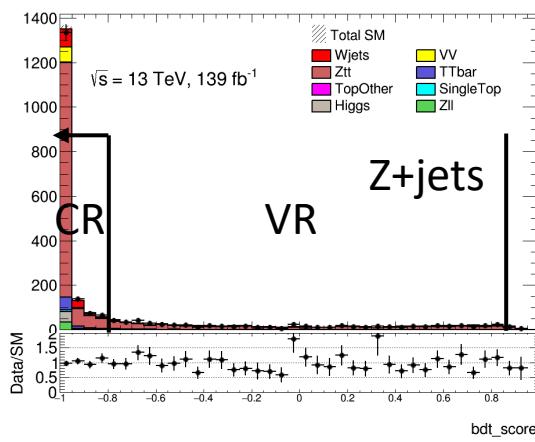
Binned significance: 5.36



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

# C1C1 ISR Z+jets estimation(LH)

Region	Selections		Total Bkg	Dominant Bkg	Purity	Data	Data/Bkg
Top CR	pre-selection(b-veto->bTag)	$M_T(l_{ep}, MET) > 200$	8367+-34	8043+-34	0.96	7404	0.89
Z CR	Pre-selection $40 < M_{\tau\tau}^{reco} < 100$	BDT score < -0.8	1615+-16	1272+-15	0.79	1611	0.99
Top VR	pre-selection(b-veto->bTag)	$120 < M_T(l_{ep}, MET) < 200$	5674+-35	5345+-34	0.94	5141	0.90
Z VR	Pre-selection $40 < M_{\tau\tau}^{reco} < 100$	-0.8 < BDT score < 0.9	623+-12	472+-10	0.76	619	0.99



# C1N2 ISR signal region optimization

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

HH Pre-selection	LH Pre-selection
$\geq 2$ medium taus	$\geq 1$ medium taus
0 base lepton	$\geq 1$ base lepton, $\geq 1$ signal lepton
$\text{MET} \geq 200$ ; pass MET trigger	$\text{MET} \geq 200$ ; 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 $\text{pt} > 100$ GeV	jet $\text{pt} > 100$ 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

$$\mathcal{F} = \text{AUC}_{\text{validation}} - 0.3 \times \text{AUC}_{\text{gap}}$$

$$\text{AUC}_{\text{gap}} = |\text{AUC}_{\text{train}} - \text{AUC}_{\text{validation}}|$$

# 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

$\geq 2$  medium taus

0 base lepton

MET  $\geq 150$ ; 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

---

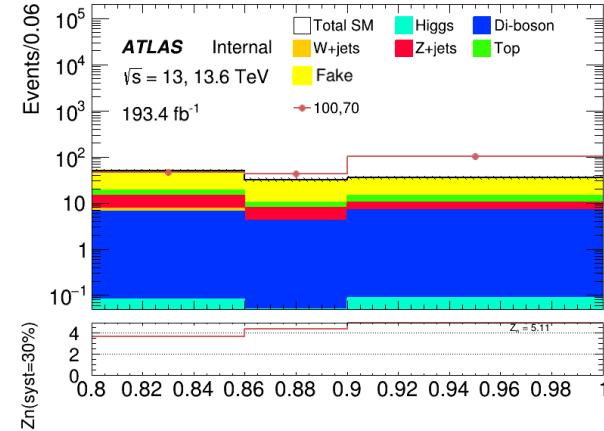
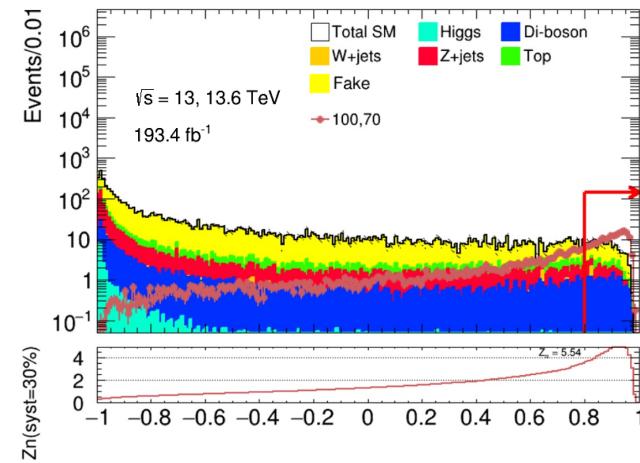
SR

---

Pre-selection

---

BDT score  $> 0.8$

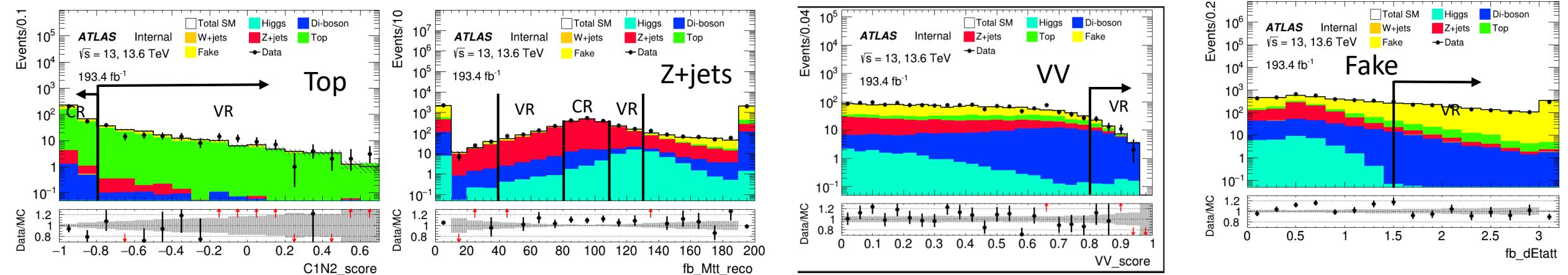


SM Process	[0.80, 0.86]	[0.86, 0.90]	[0.90, 1.00]
VV	$6.508 \pm 0.368$	$4.124 \pm 0.341$	$6.855 \pm 0.398$
Top	$4.719 \pm 0.686$	$2.663 \pm 0.546$	$4.331 \pm 0.731$
Fake	$31.456 \pm 3.898$	$21.525 \pm 3.292$	$20.438 \pm 2.976$
Higgs	$0.080 \pm 0.023$	$0.045 \pm 0.019$	$0.086 \pm 0.031$
Z+jets	$6.659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

# C1N2 ISR background estimation(HH)

## Selection for control region and validation region

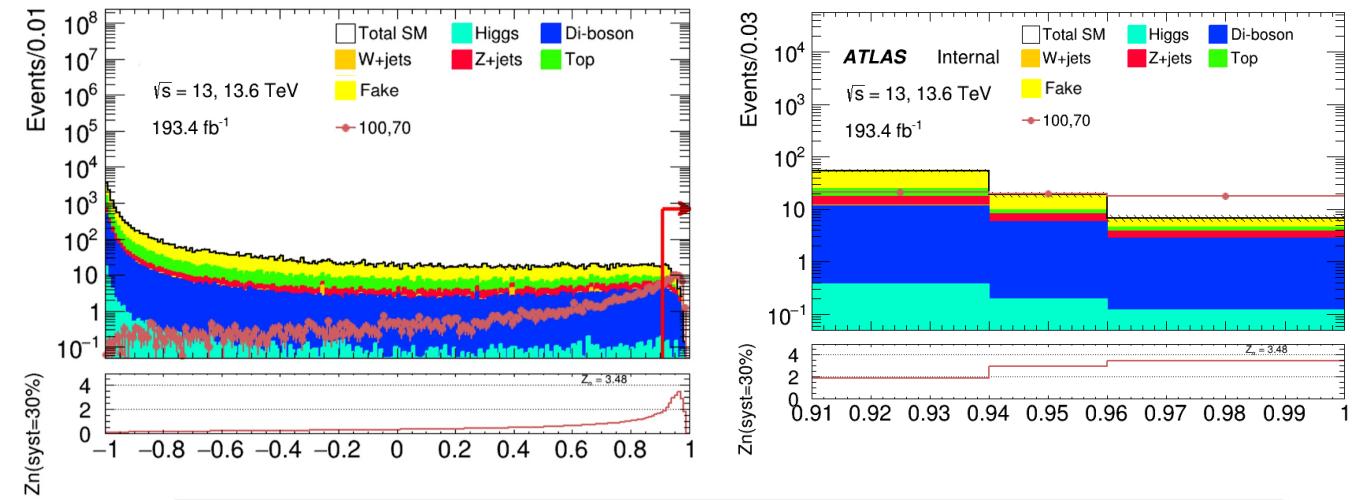
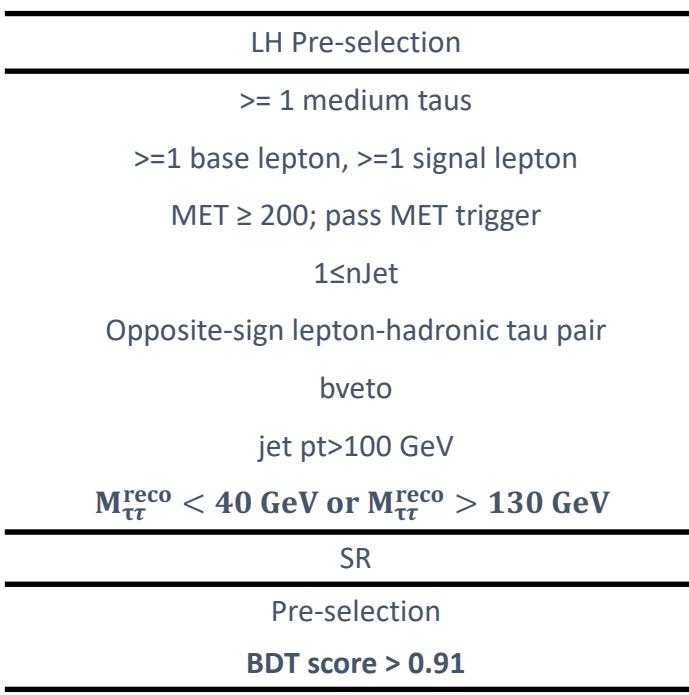
Process	Top		Z+jets		Multi-bosons		Fake
	TCR	TVR	ZCR	ZVR	MBVR	FakeVR	
Charge combination							
Trigger			OS MET trigger, $E_T^{\text{miss}} \geq 200\text{GeV}$				
N medium $\tau$							$\geq 2$
N lep							$= 0$
$n_{\text{BaseJet}}$							$\geq 1$
Jet $p_T[\text{GeV}]$							$\geq 100$
N b-jets							$\geq 1$
$m(\tau_1, \tau_2) [\text{GeV}]$			$\leq 40$ or $\geq 130$	[80,110]	[40,80] or [110,130]		$= 0$
$M_T(\tau_1, E_T^{\text{miss}})$			$\geq 200$	—	—		$\leq 40$ or $\geq 130$
$d\eta(\tau_1, \tau_2)$			—	—	—		$\geq 1.5$
C1N2 score	[-1, -0.8]	[-0.8, 0.7]				$\leq 0.7$	
VV score	—	—	—	—		$\geq 0.80$	—
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  
 $[0.91, 0.94], [0.94, 0.96], [0.96, 1.00]$

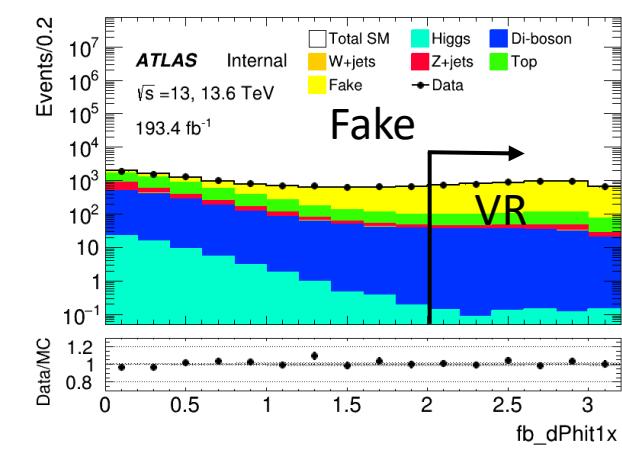
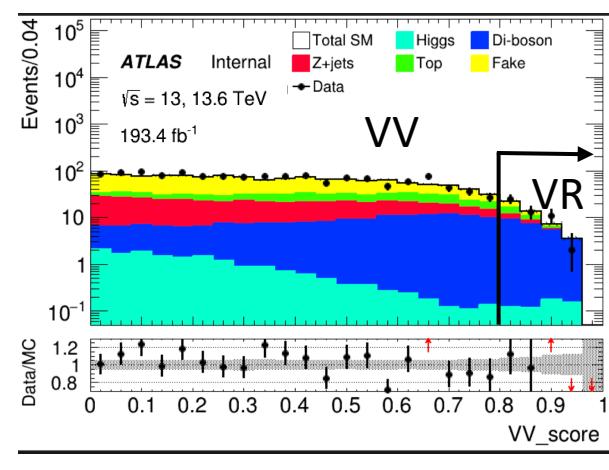
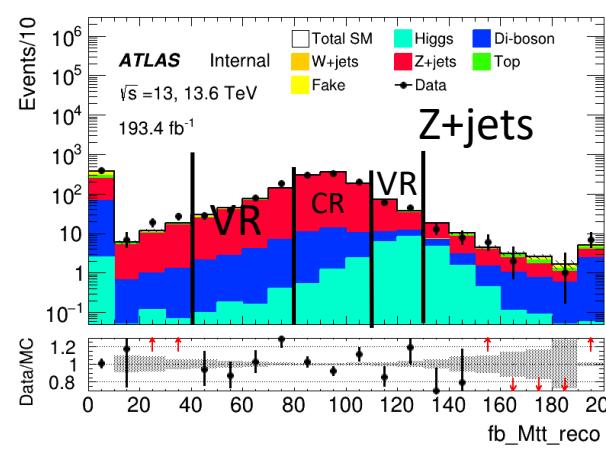
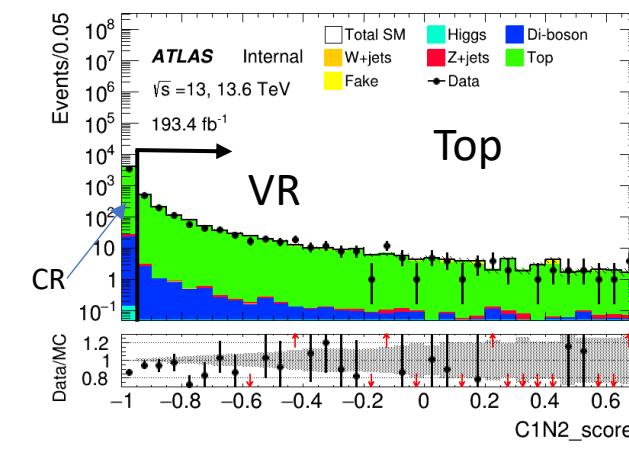


Process	[0.91, 0.94]	[0.94, 0.96]	[0.96, 1.00]
VV	$11.105 \pm 0.565$	$5.550 \pm 0.367$	$2.666 \pm 0.263$
Top	$7.432 \pm 0.956$	$1.524 \pm 0.441$	$0.578 \pm 0.237$
Fake	$28.625 \pm 3.295$	$9.404 \pm 1.929$	$2.400 \pm 1.009$
Higgs	$0.376 \pm 0.057$	$0.189 \pm 0.052$	$0.118 \pm 0.040$
Z+jets	$5.515 \pm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

# C1N2 ISR background estimation(LH)

Selection for control region and validation region

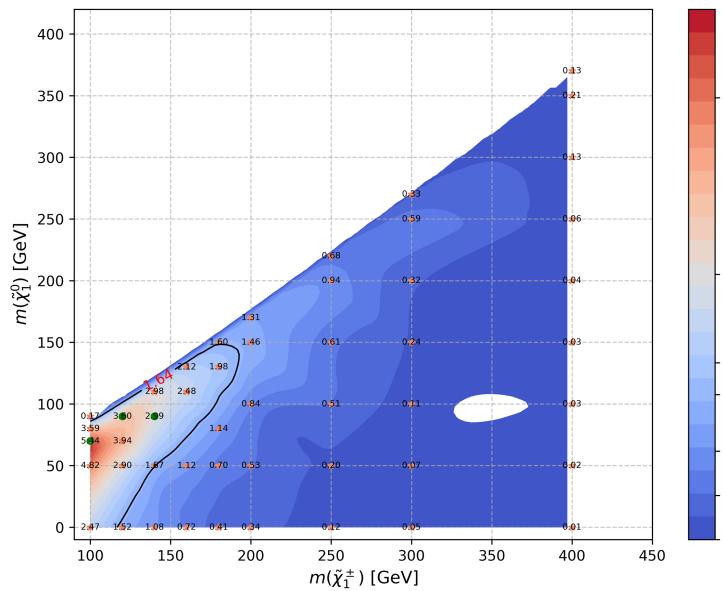
Process	Top		Z+jets		Multi-bosons	Fake
	TCR	TVR	ZCR	ZVR	MBVR	FakeVR
Charge combination						
Trigger OS MET trigger, $E_T^{miss} \geq 200\text{GeV}$						
N medium $\tau$			$\geq 1$			
N lep			$\geq 1$			
nBaseJet			$\geq 1$			
Jet $p_T[\text{GeV}]$			$\geq 100$			
N b-jets	$\geq 1$			$= 0$		
$m(\tau_1, l)$ [GeV]	$\leq 40$ or $\geq 130$		[80,110]	[40,80] or [110,130]	$\leq 40$ or $\geq 130$	
$M_{inv}(l, \text{MET})$	$\geq 300$		—	—	—	—
$\Delta\phi(\text{MET}, \tau_1)$	—	—	—	—	—	$\geq 2$
$dR(\tau, l)$	—	—	$\leq 0.6$	—	—	—
C1N2 score	[-1, -0.95]	[-0.95, 0.7]			$\leq 0.7$	
VV score	—	—	—	—	$\geq 0.80$	—
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



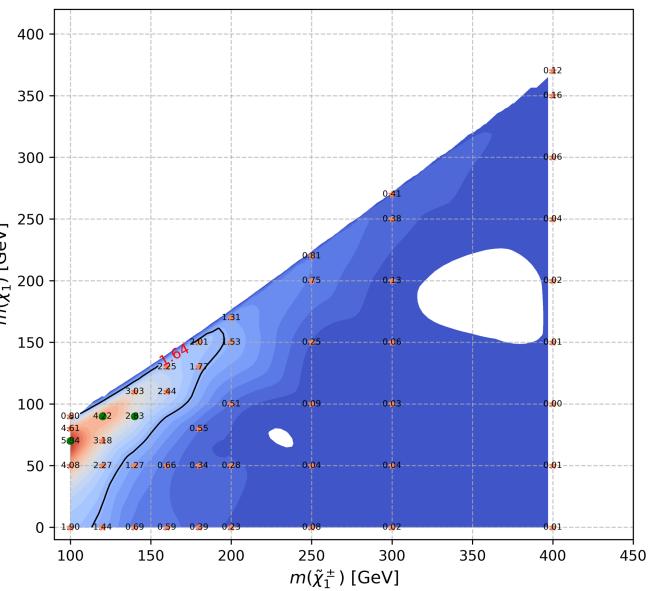
# C1N2 ISR signal region definition

- Expected sensitivity
  - 30% flat systematic uncertainty
  - gap caused by interpolation algorithm
  - Result only for full run2 sample, will update to full run2 + partial run3 sample later

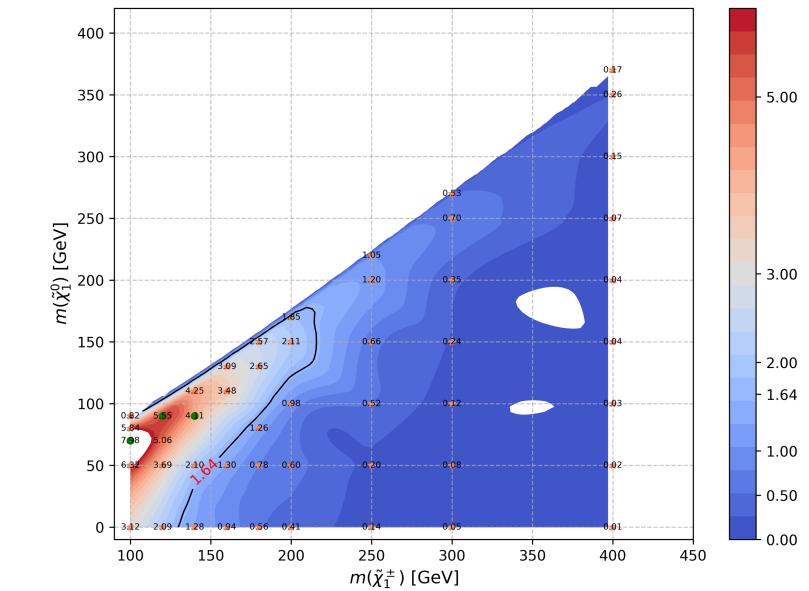
HH channel



LH channel



Combined channel





Institute of High Energy Physics  
Chinese Academy of Sciences

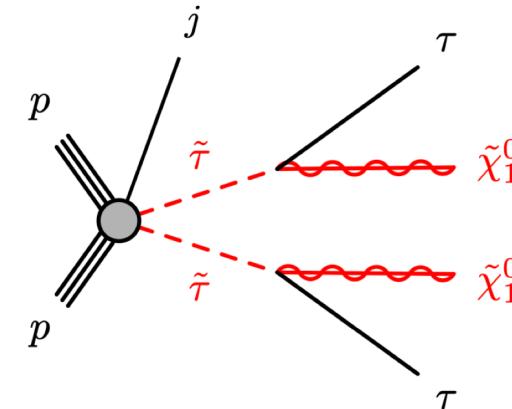
# Backup



# Direct stau ISR motivation

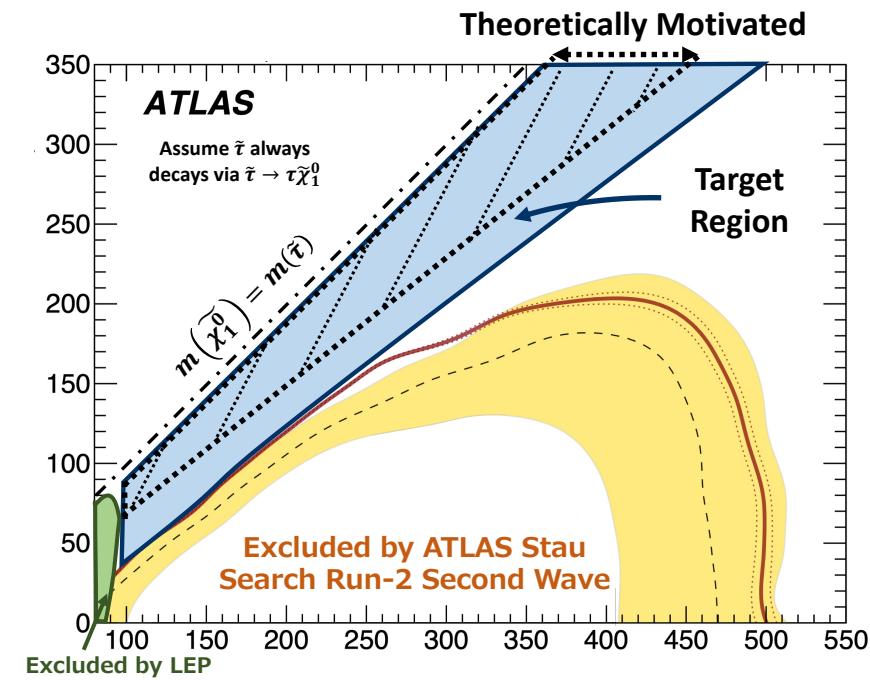
Direct stau with  $2\tau + E_T^{miss} + \text{ISR}$

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



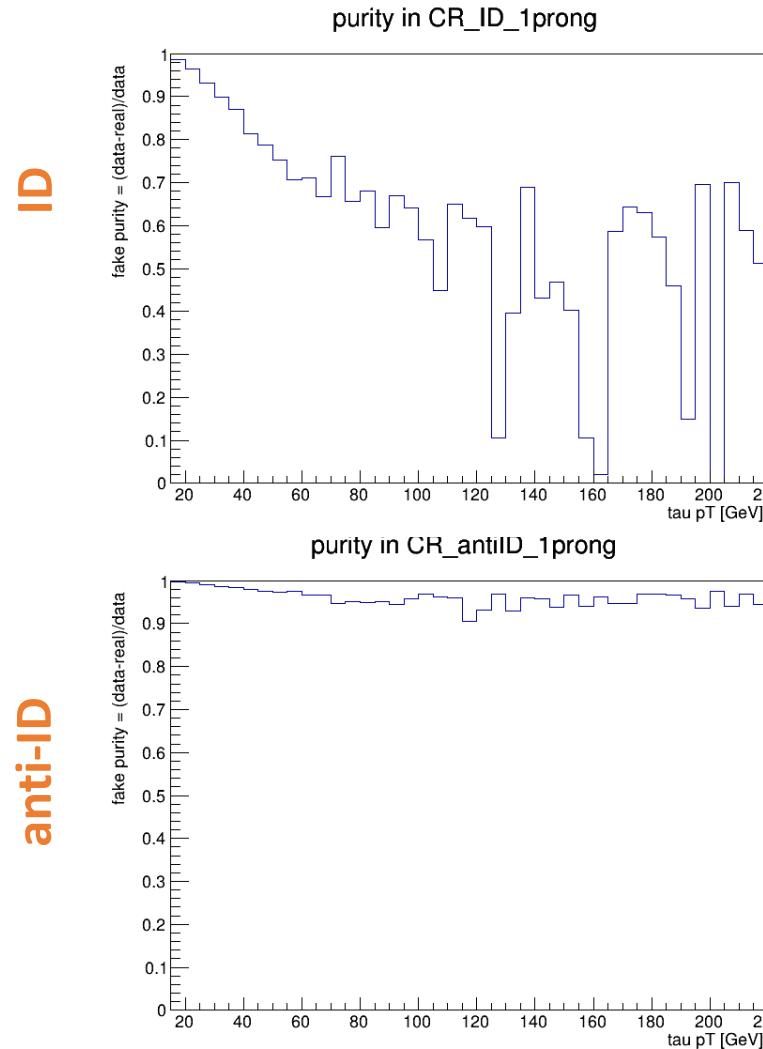
Basic Strategy:

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

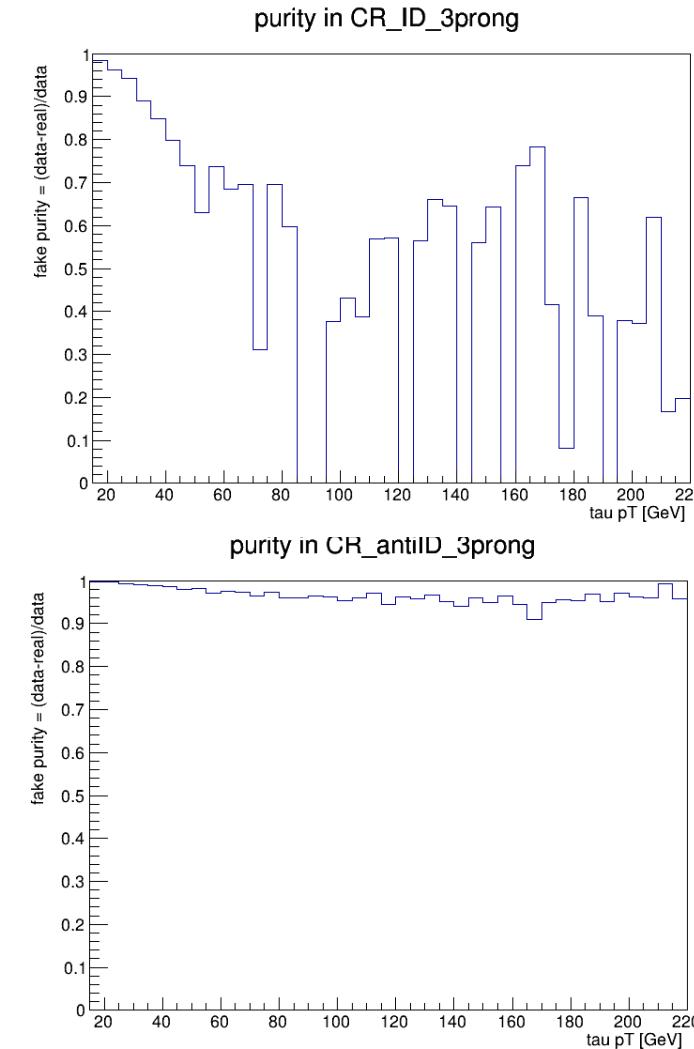


# Direct Stau ISR Fake purity in CR

1-prong

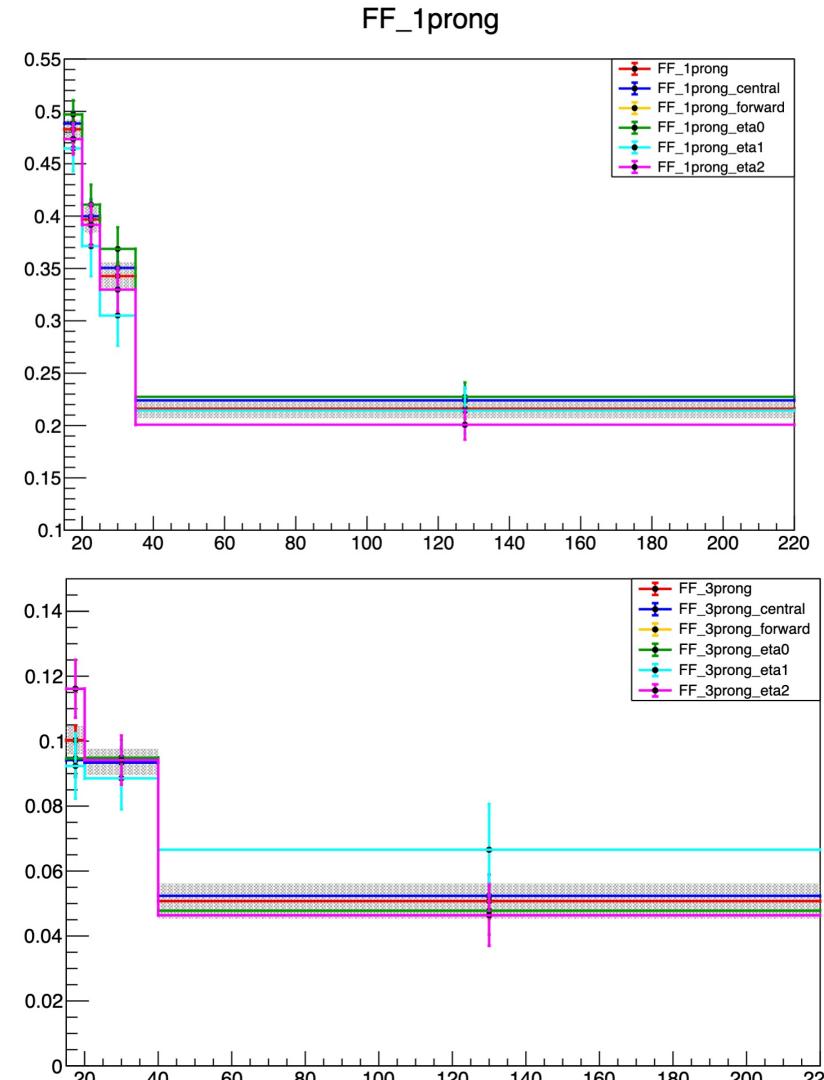


3-prong



# 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

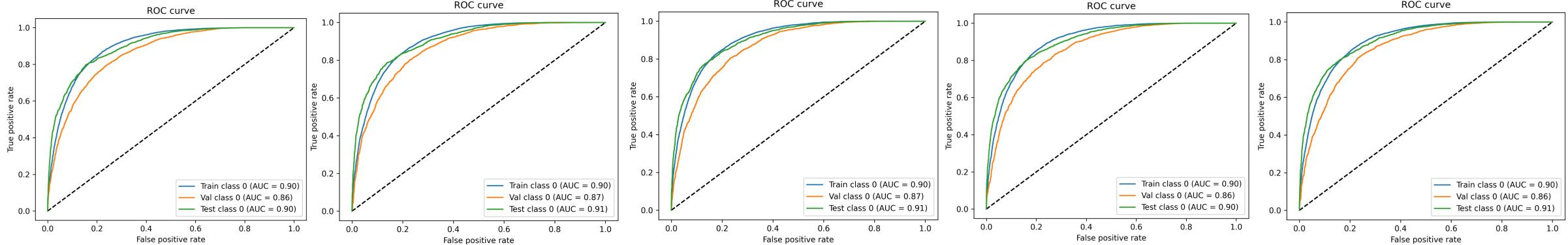
- **Neurons:** [256, 128, 128, 64, 32]
- **Activation Function:** Leaky ReLU
- **Batch Normalization**
- **Dropout Rate:** 0.3
- **L2 Regularization ( $\lambda$ ):** 1e-4

## • Training Configuration

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

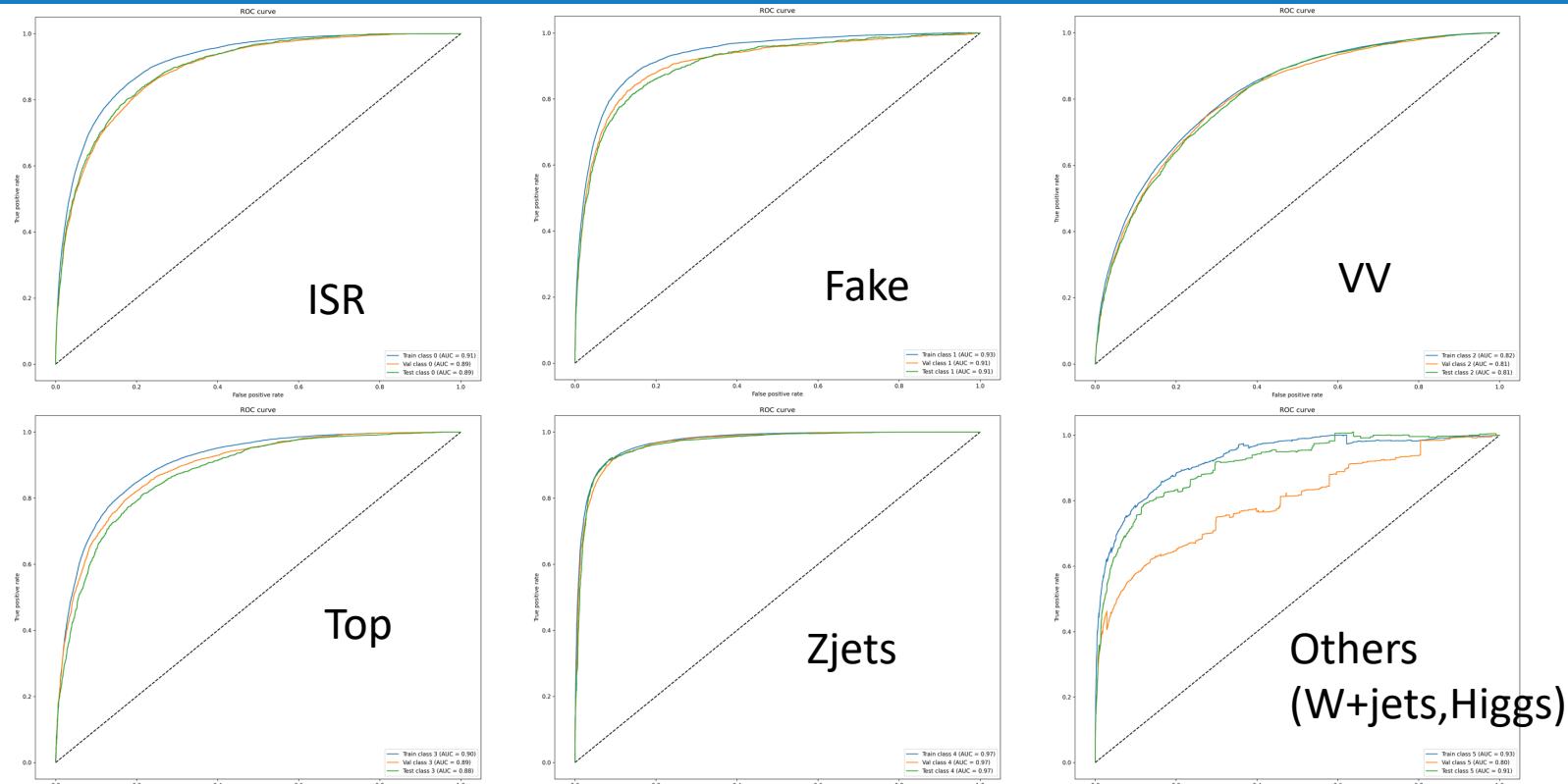
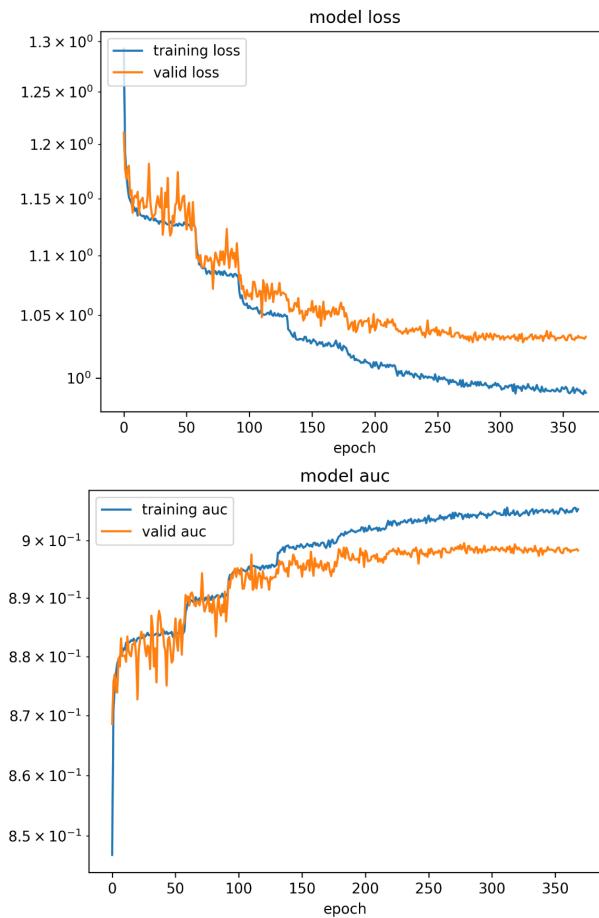
- **Reduce Learning Rate on Plateau:**

- 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  $\geq 1$  (GN2v01, WP 90)**
  - Colinear mass ( $\tau, \tau$ )  $> 250$  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 ( $\tau, \tau$ ) < 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  $\leq 2$
  - 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)**

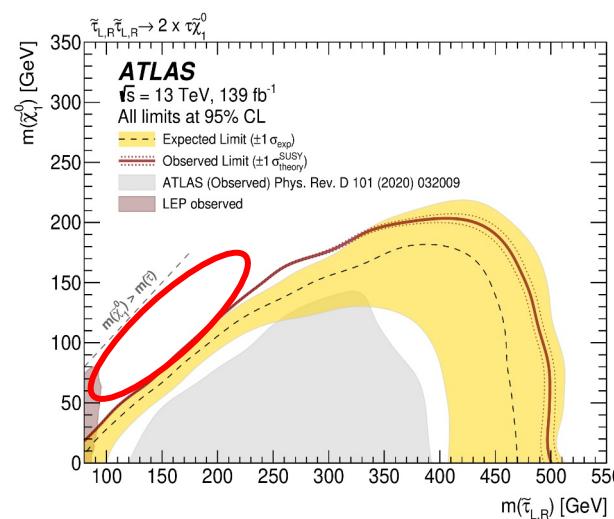
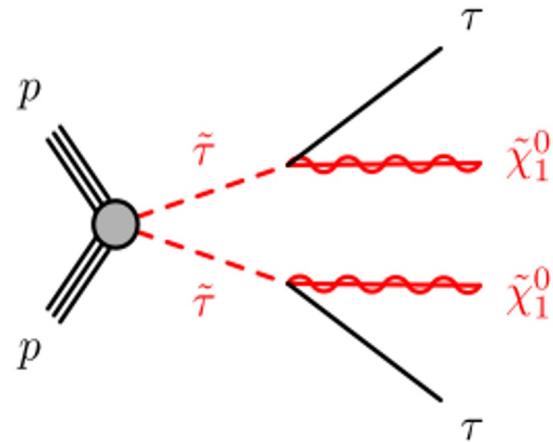
**Yield, purity table  
(VR2)**

**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 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  $\Delta m$
- 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.

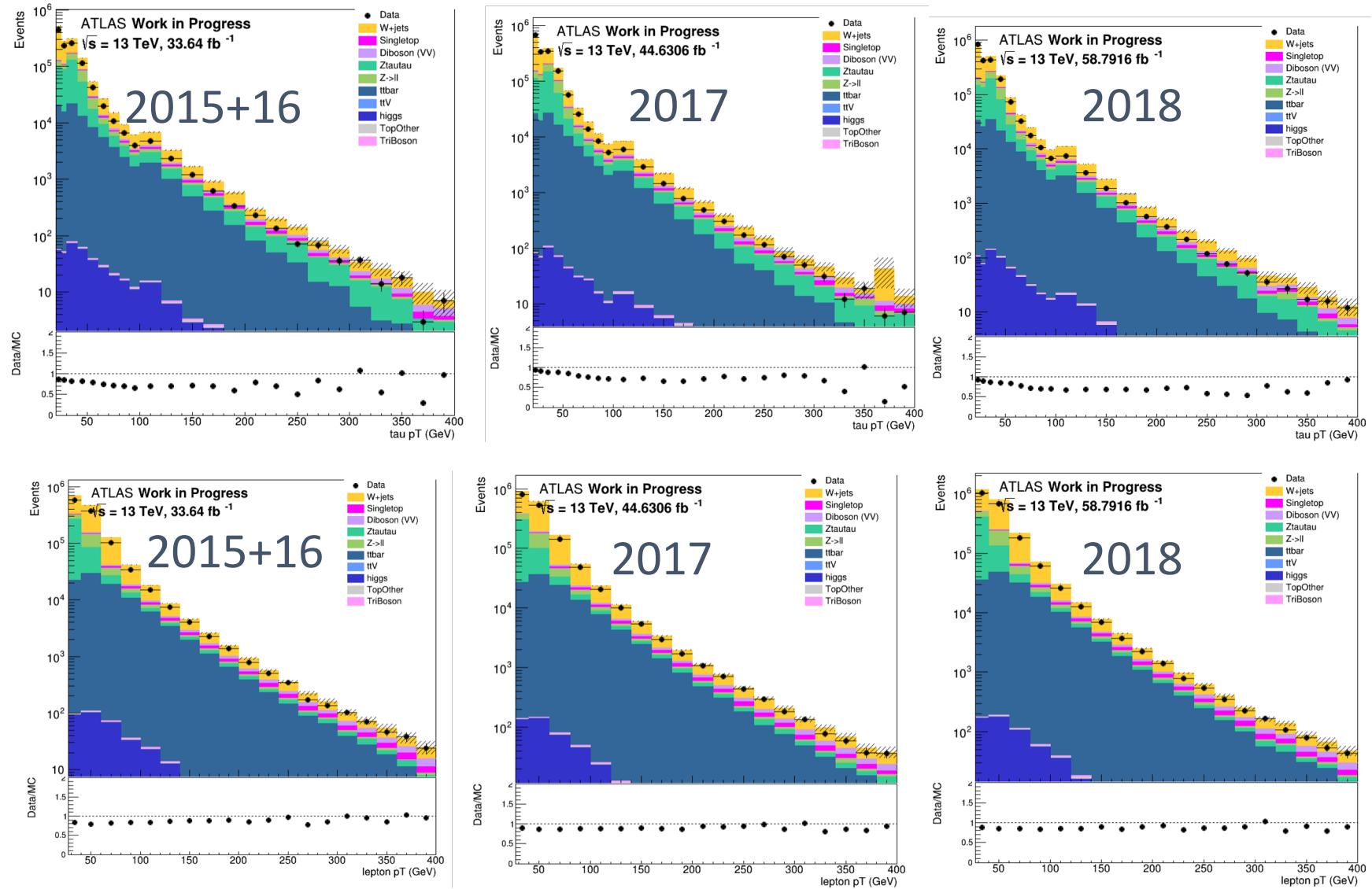
2-tau triggering 95,75 or 75,40+MET 150 kills moderate  $\Delta m$  signals.

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

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

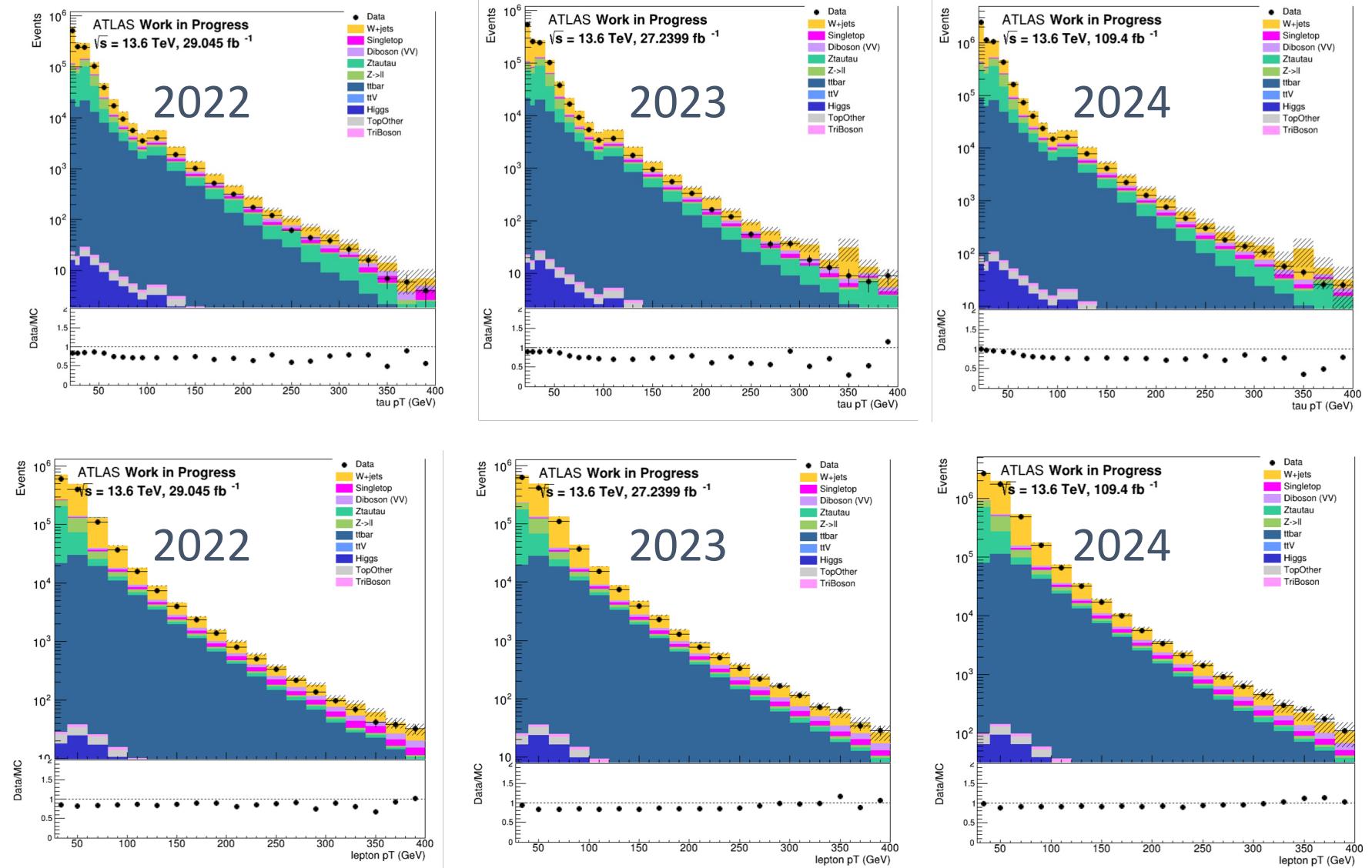
# Direct Stau single-lep trigger MC modeling check

- 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

$\approx 1$  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\*

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

\*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

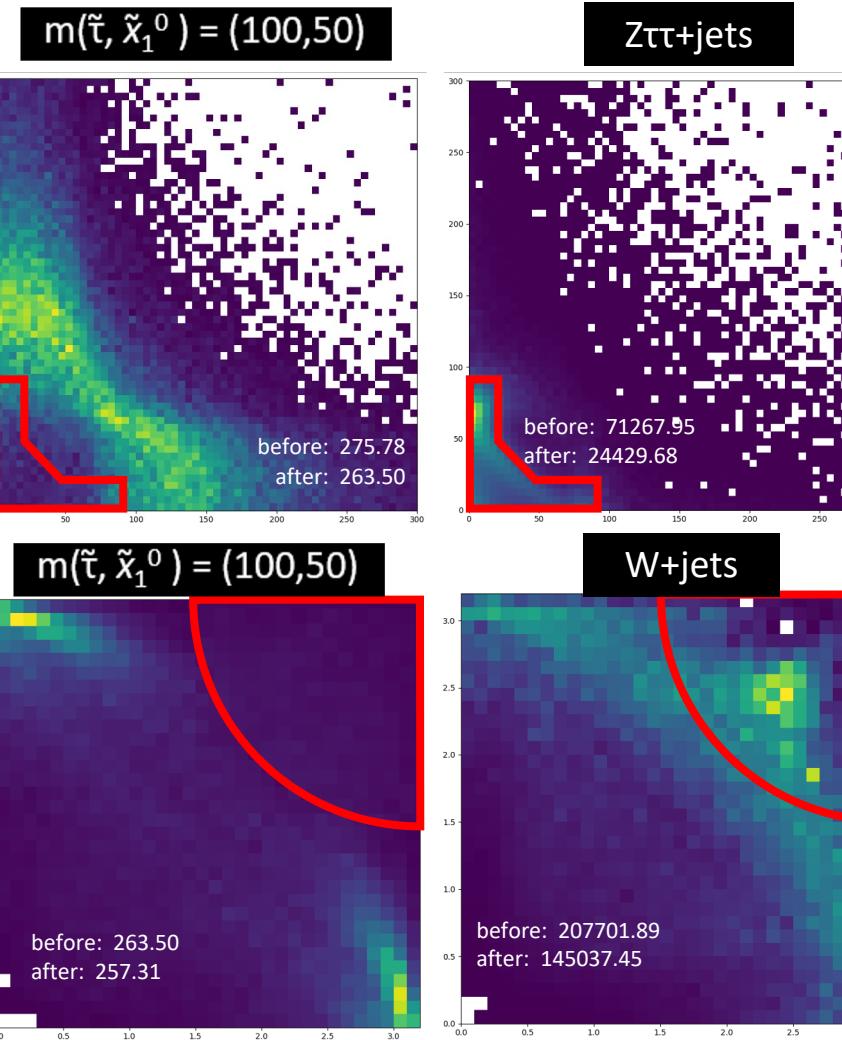
Define:

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

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

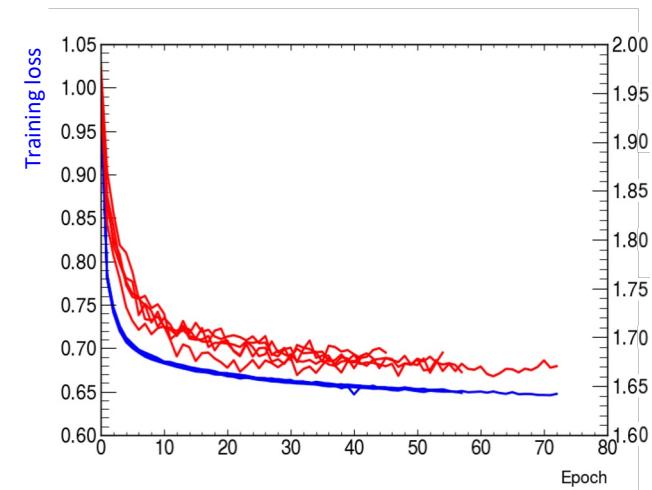
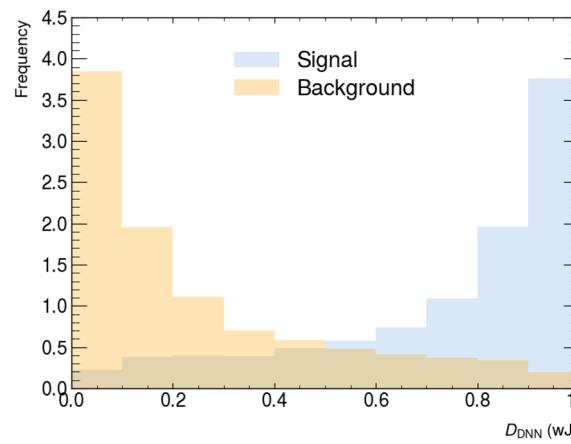
$$(\text{abs}(\phi_1)-a)^{\star 2} + (\text{abs}(\phi_2)-b)^{\star 2} \geq r^{\star 2}$$

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

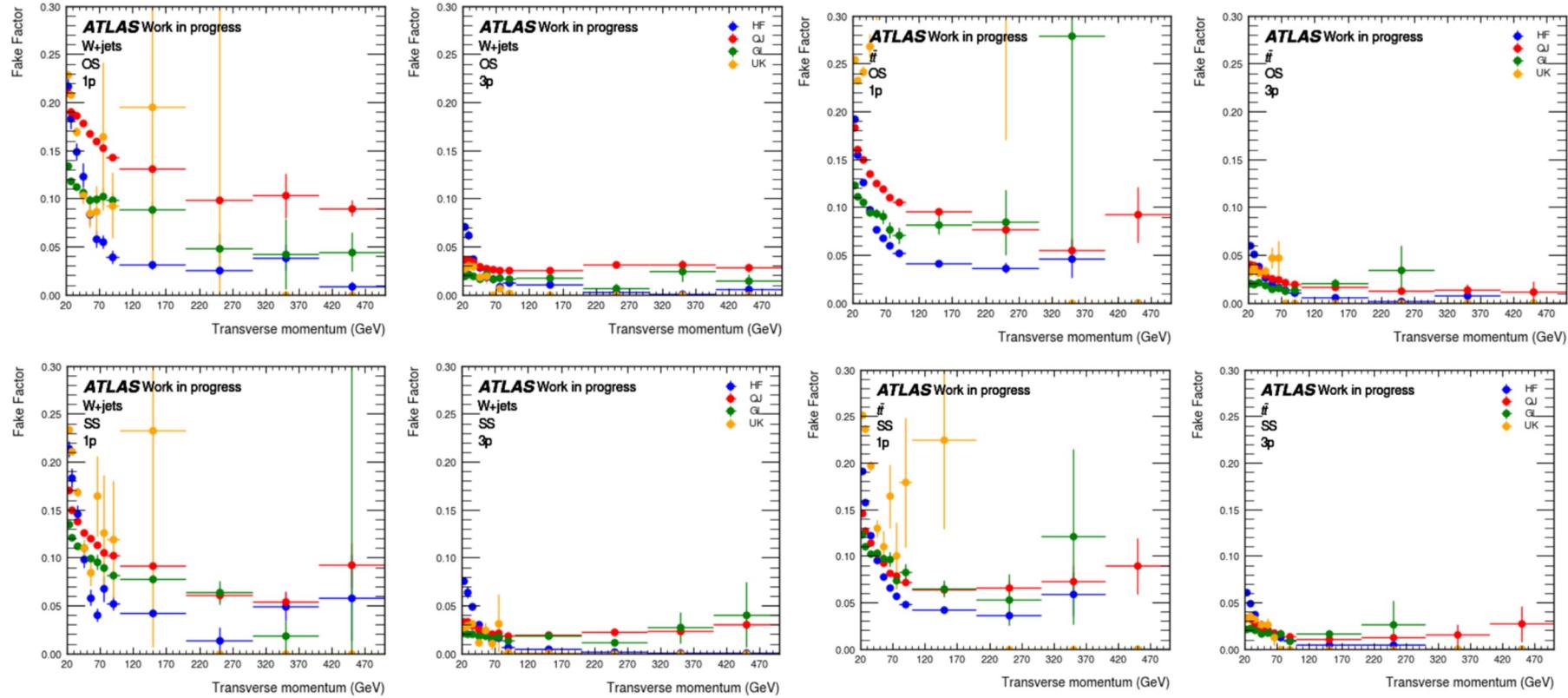


# Direct Stau single-lep trigger DNN Training

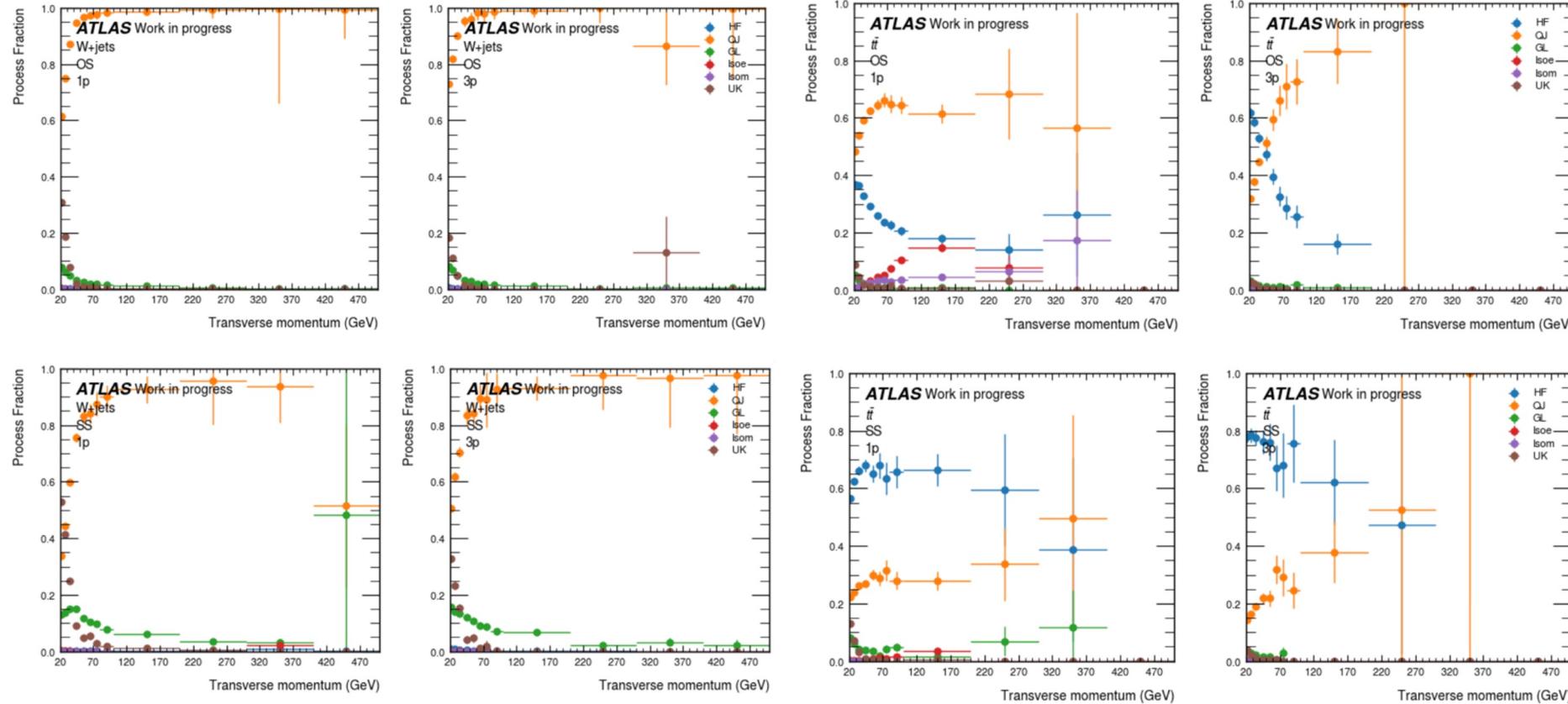
- Train deep neural network (DNN) to separate signal from background and cut on network score targeting (100, 50) & (150,100) mass points (high stats points with 1M events generated) and trained 0J and  $\geq 1J$  channels separately.
  - Training converges well (across all training folds) and very good 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:  $p_T$ ,  $\eta$ , MET, charge etc.
  - High-level variables:  $\Delta R$ ,  $\Delta\eta$ ,  $\Delta\phi$ ,  $m_{T2}$ ,  $M_{\text{eff}}$ ,  $M_{\text{inv}}$ ,  $\Sigma m_T$ ,  $m_{CT}$ , balance + more!



# Direct Stau single-lep trigger Fake Factors



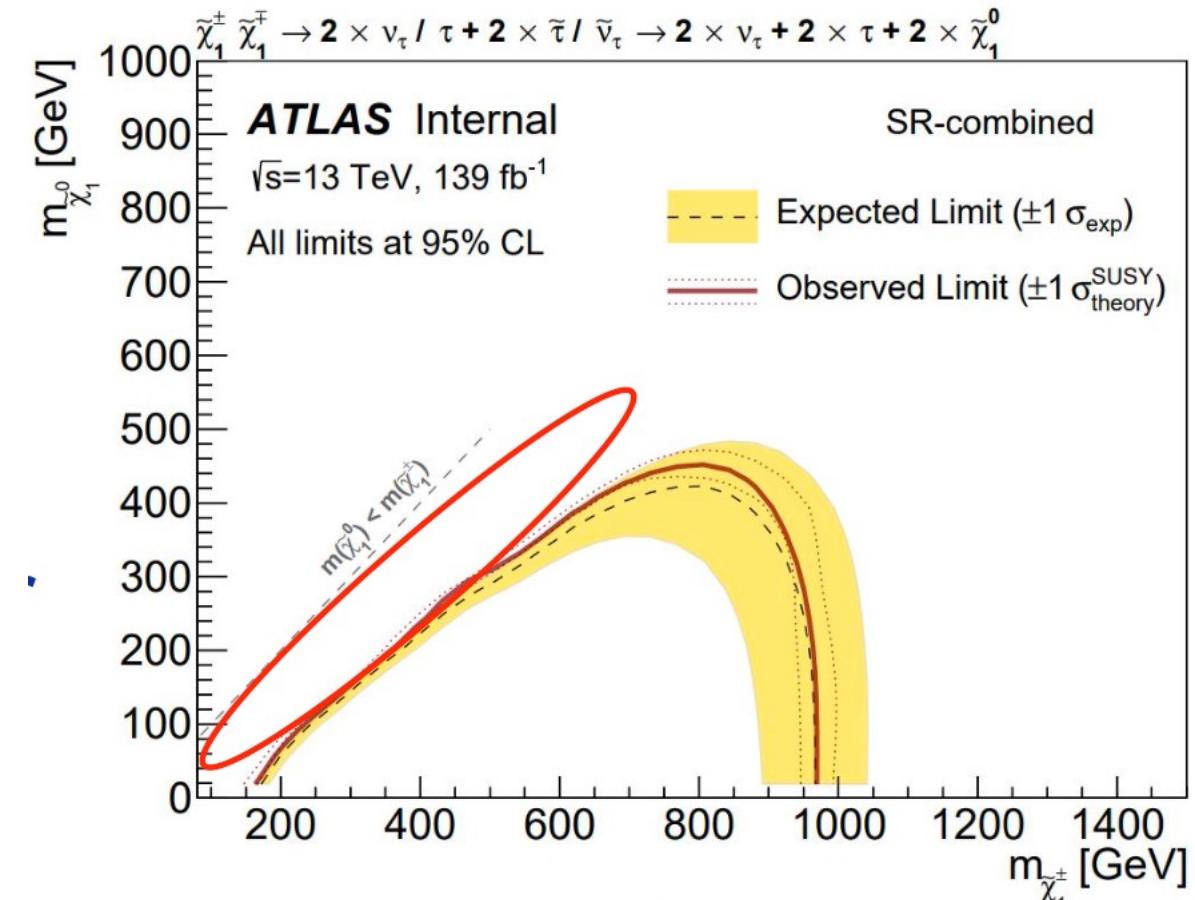
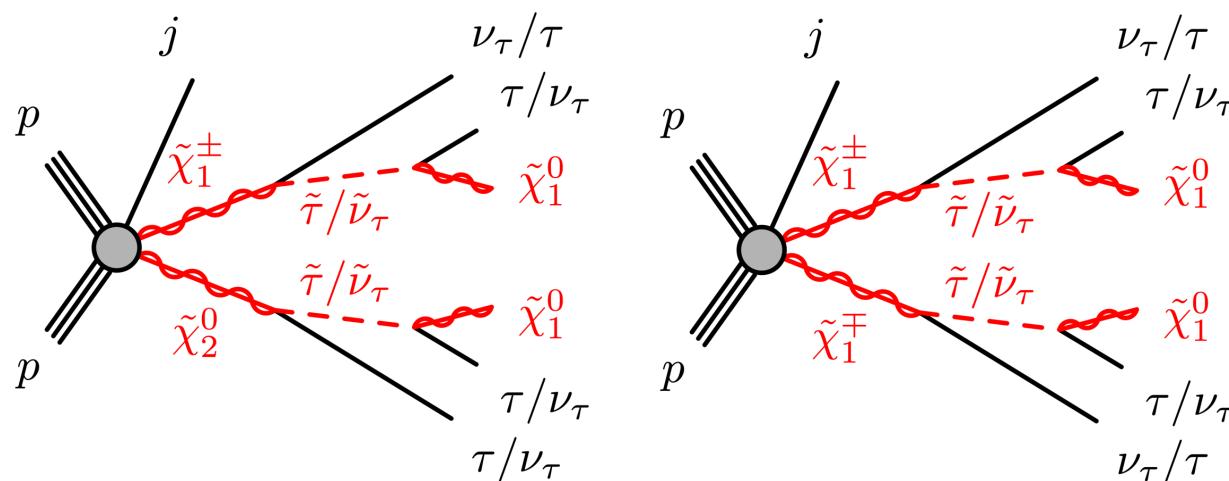
# Direct Stau single-lep trigger Fake Factors



# 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(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	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  $\geq 0.6$

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]



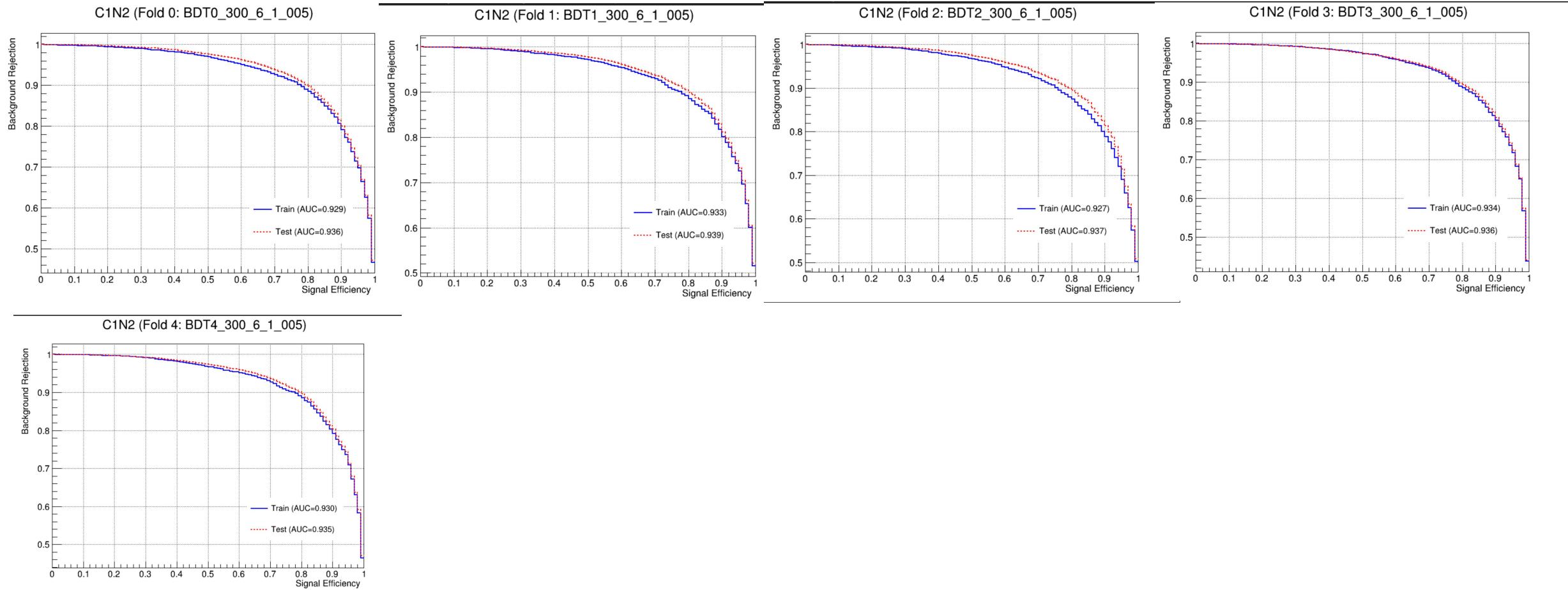
Best one: Ntree=300, MaxDepth=6, MinNode=1%, Learning Rate=0.05



There still have rooms to optimize for lr

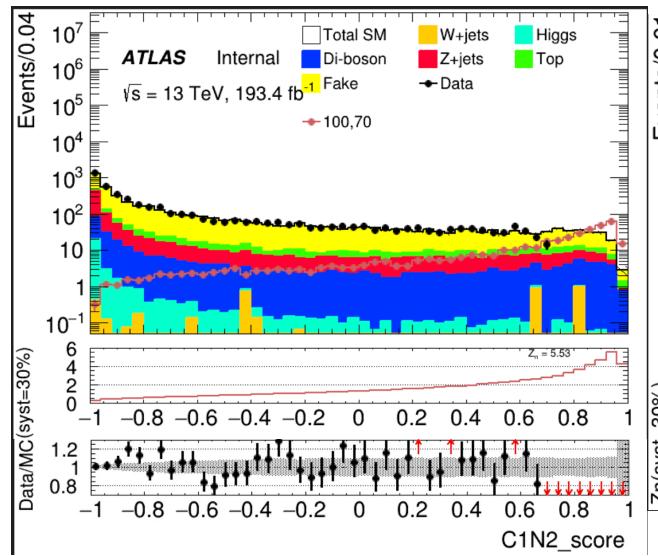
# C1N2 ISR Binary class(HH)

## Overfit Check

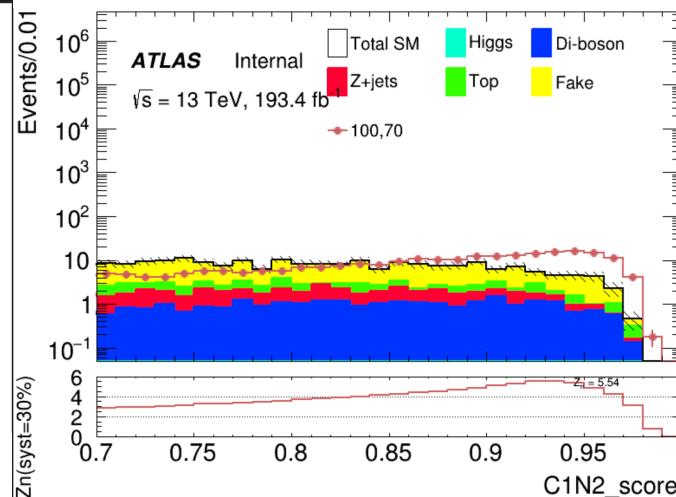


# C1N2 ISR Binary class(HH)

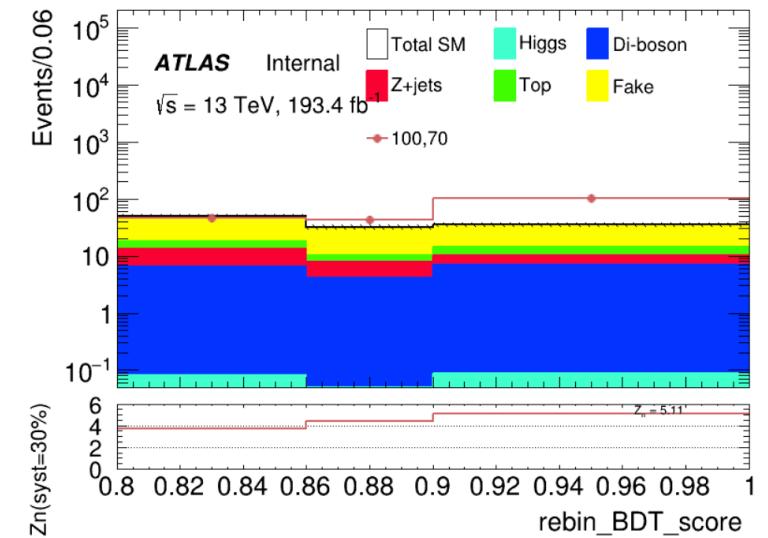
50 bins



Cut at 0.8



rebin



Sum Z<sub>n</sub> = 7.65

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

# 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

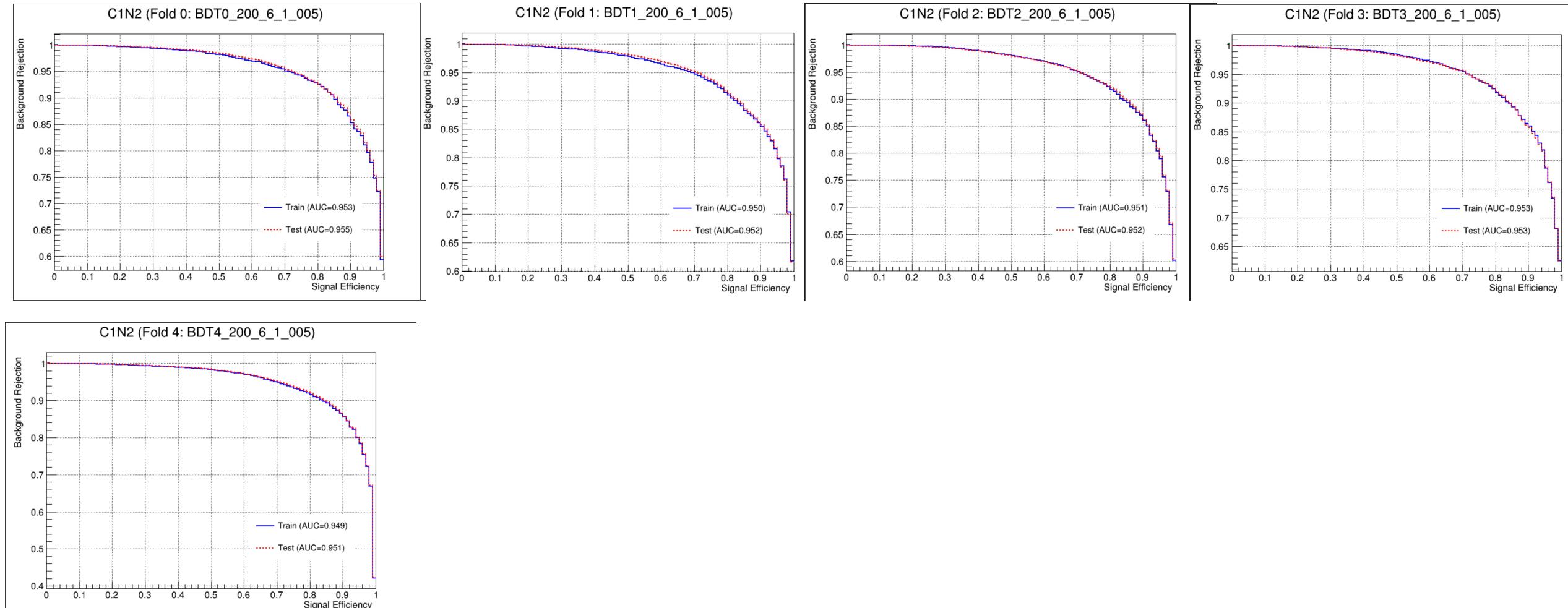
Weight choose: no weight, abs(weight)

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

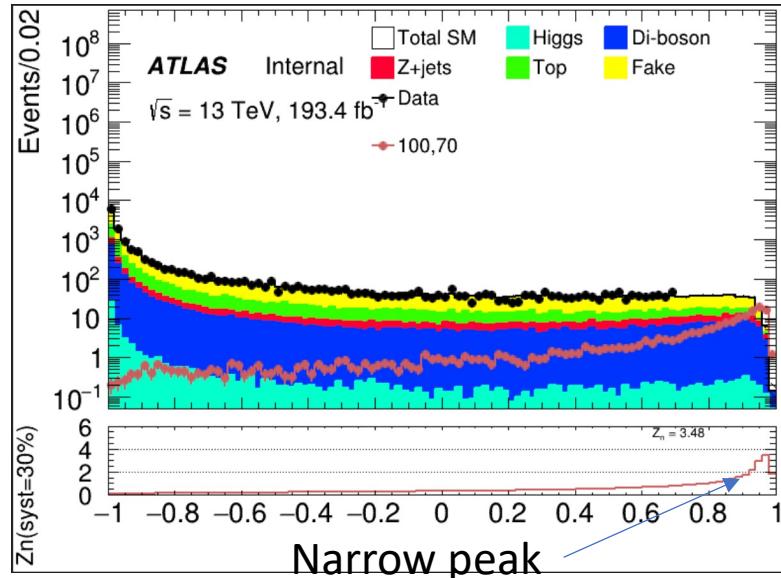
# C1N2 ISR Binary class(LH)

## Overfit Check

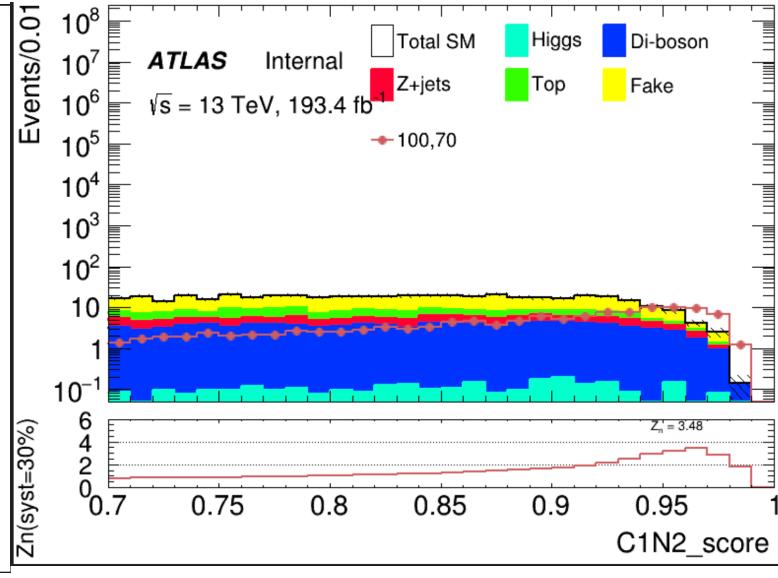


# C1N2 ISR Binary class(LH)

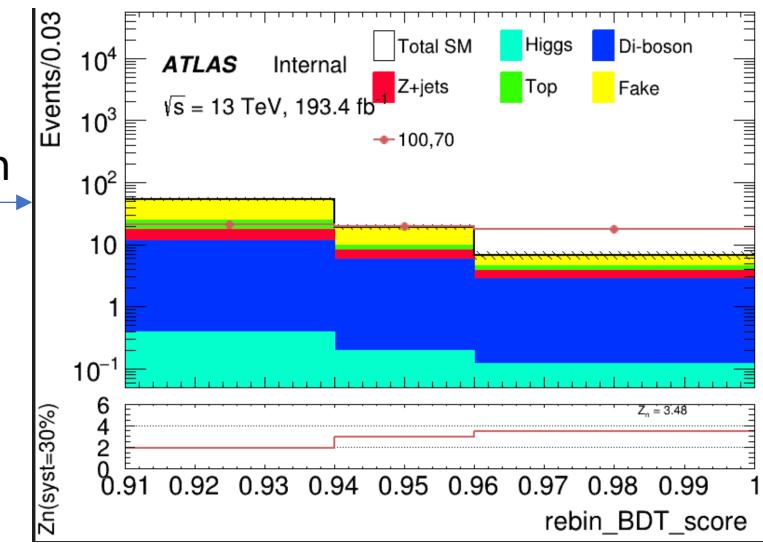
100 bins



Cut at 0.91



rebin

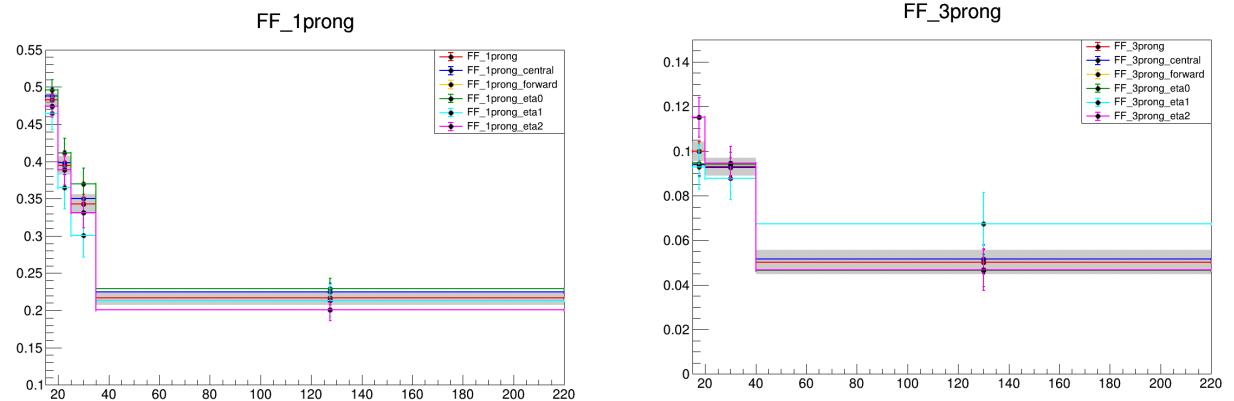
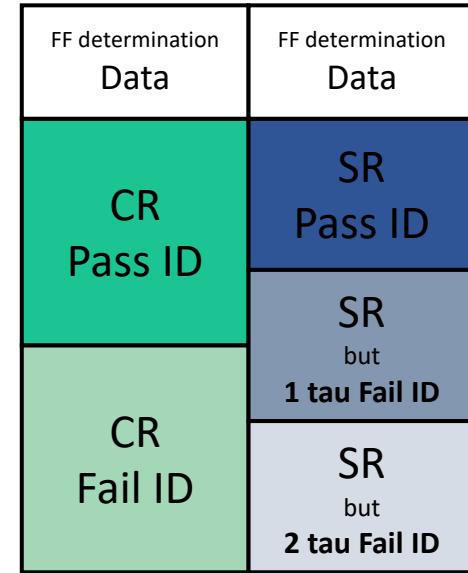


Sum Zn = 4.934

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

# C1N2 ISR fake estimation(HH)

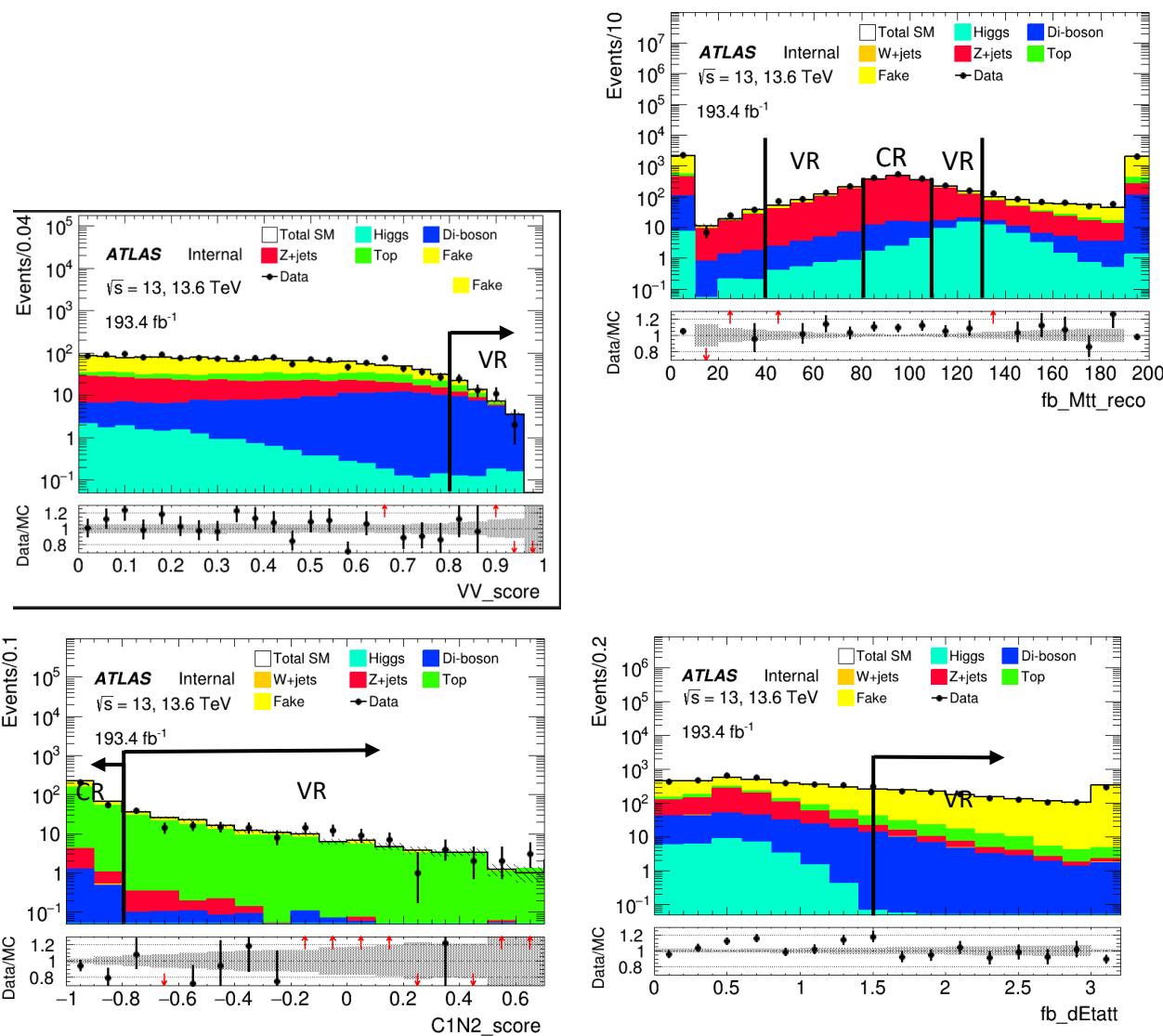
- CRs (fake factor computation)
  - METtrig
  - MET $\geq 200$
  - bveto
  - at least 1 signal lepton
  - $\Delta\phi(\tau, \text{MET}) > 2$
  - **ID:  $\geq 1$  medium tau**
  - **antiID:  $\geq 1$  VeryLoose tau, 0 medium tau**
- SRs
  - preselection
  - 2ID:  $\geq 2$  medium tau
  - 1ID1antiID:  $\geq 2$  VeryLoose tau , 1 medium tau
  - 2antiID:  $\geq 2$  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



# C1N2 ISR background estimation(HH)

## Selection for control region and validation region

Process	Top		Z+jets		Multi-bosons	Fake
	TCR	TVR	ZCR	ZVR	MBVR	FakeVR
Charge combination						
Trigger						
N medium $\tau$			OS MET trigger, $E_T^{\text{miss}} \geq 200\text{GeV}$			
N lep			$\geq 2$			
$n_{\text{BaseJet}}$			$= 0$			
$\text{Jet } p_T [\text{GeV}]$			$\geq 1$			
N b-jets			$\geq 100$			
$m(\tau_1, \tau_2) [\text{GeV}]$	$\leq 40 \text{ or } \geq 130$		$[80, 110]$		$= 0$	
$M_T(\tau_1, E_T^{\text{miss}})$	$\geq 200$		$[40, 80] \text{ or } [110, 130]$		$\leq 40 \text{ or } \geq 130$	
$d\eta(\tau_1, \tau_2)$	–		–		–	
C1N2 score	[-1, -0.8]    [-0.8, 0.7]				$\leq 0.7$	
VV score	–				$\geq 0.80$	
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 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							
N medium $\tau$			$\geq 1$				
N lep			$\geq 1$				
nBaseJet			$\geq 1$				
Jet $p_T$ [GeV]			$\geq 100$				
N b-jets	$\geq 1$				$= 0$		
$m(\tau_1, l)$ [GeV]	$\leq 40$ or $\geq 130$		[80,110]	[40,80] or [110,130]		$\leq 40$ or $\geq 130$	
$M_{inv}(l, MET)$	$\geq 300$		—	—		—	
$\Delta\phi(MET, \tau_1)$	—	—	—	—		$\geq 2$	
$dR(\tau, l)$	—	—		$\leq 0.6$		—	
C1N2 score	[-1, -0.95]	[-0.95, 0.7]			$\leq 0.7$		
VV score	—	—	—	—	$\geq 0.80$	—	
Total bkg	4151+11	1212+13	917+6	823+4	78+2	4983+40	
Dominant Bkg	3781+20	1102+11	823+4	606+3	53+1	4390+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	

