Search for direct production of supersymmetric charginos with mass splittings close to the electroweak scale in $\sqrt{s} = 13$ TeV collisions with the ATLAS detector

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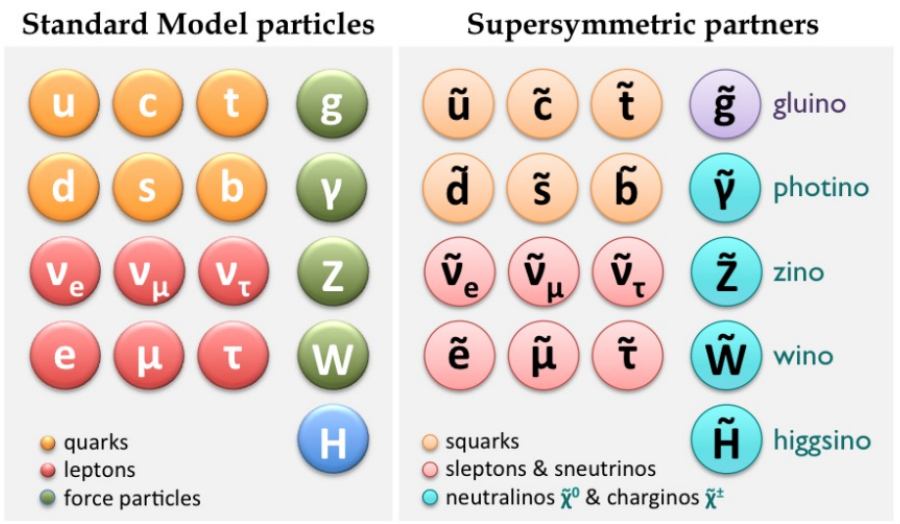
Supersymmetry

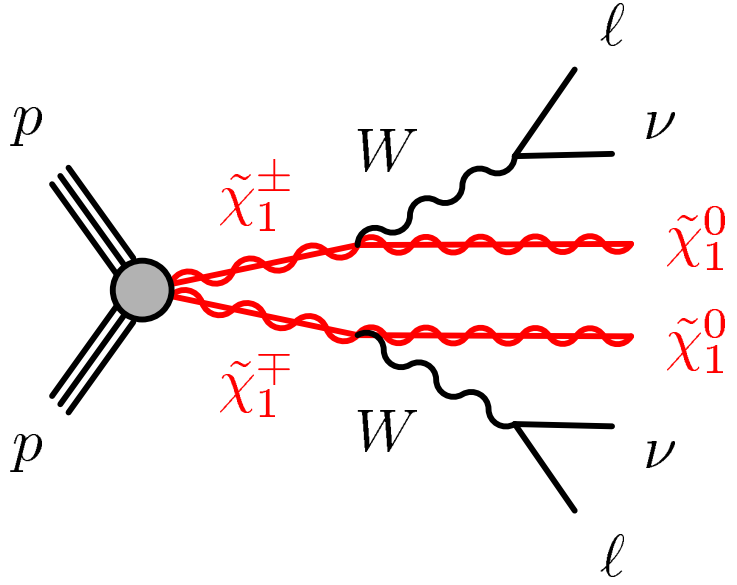
Supersymmetry is an extension of the Standard Model (SM)

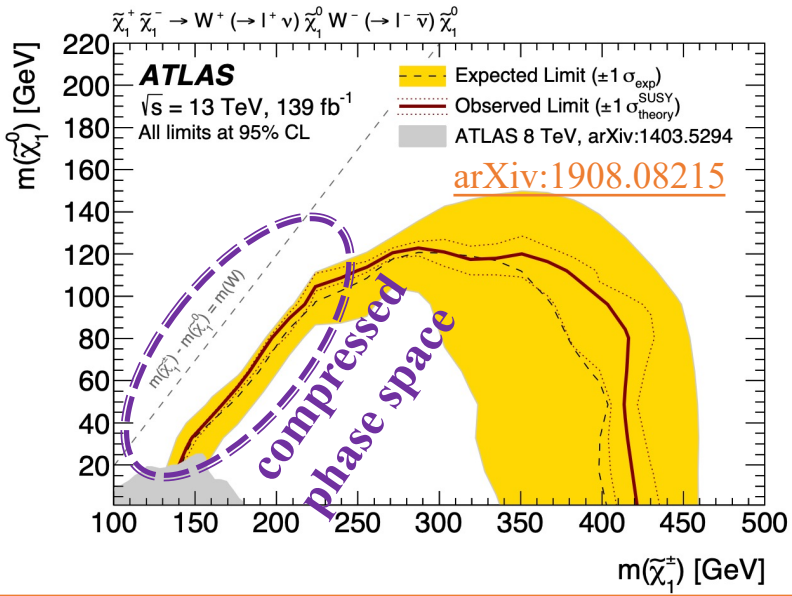
- For each SM particle, a superpartner with spin differing by 1/2 unit is introduced.
- Charginos $\tilde{\chi}_1^{\pm}$ and neutralinos $\tilde{\chi}_1^0$ come from the electroweak mixing of the superpartners of the gauge and the Higgs bosons.



Signal model

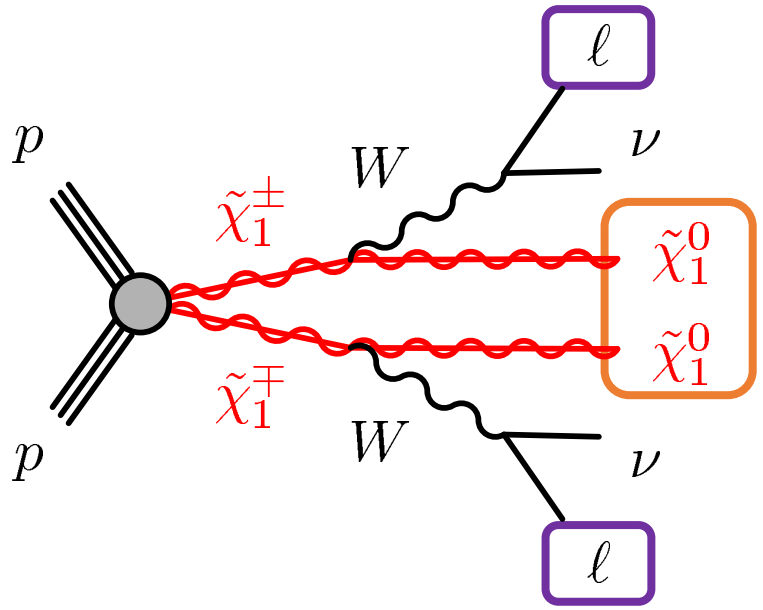
- **New search** for the direct production of $\tilde{\chi}_1^{\pm}$ decaying into $\tilde{\chi}_1^0$ through W bosons of the SM (ATLAS-CONF-2022-006).
- Targeting a phase space where the difference in mass between $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_1^0$ is close to or below the electroweak scale, $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0) \lesssim m_W$, something that we usually refer to as "**compressed mass splitting**".





Preselection

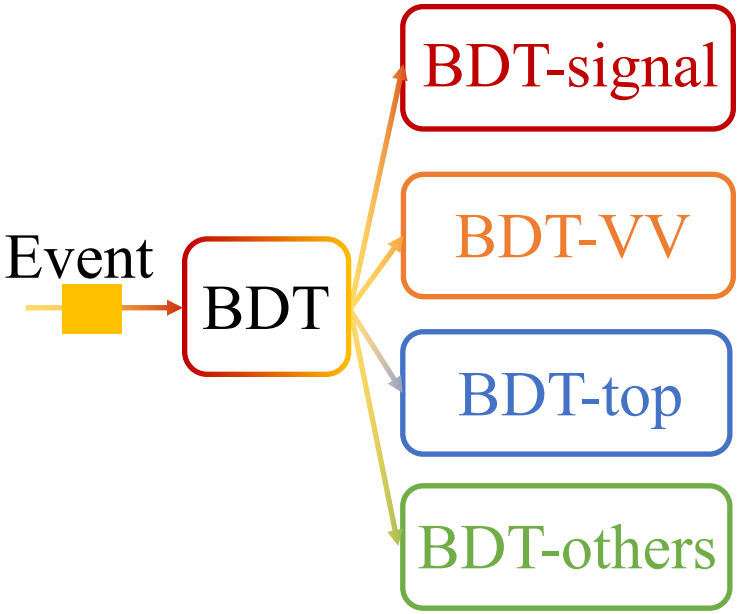
- Topology with **2 leptons** and no hadronic activity.
- Large $\mathbf{E_T^{miss}}$ to account for the presence of neutralinos.



Analysis strategy

Analysis strategy relying on **machine learning techniques**

- Training of Boosted Decision Trees (BDTs) with gradient boosting (LightGBM framework) combining $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0) = 90$ or 100 GeV signal samples.
- Input features: $p_T^{\ell_1}$, $p_T^{\ell_2}$, $\mathrm{E}_T^{\mathrm{miss}}$, $\mathrm{E}_T^{\mathrm{miss}}$ significance, m_{T2}, $m_{\ell\ell}$, $\Delta\phi_{\mathrm{boost}}$, $\Delta\phi_{\mathrm{E}_T^{\mathrm{miss}},\ell_1}$, $\Delta\phi_{\mathrm{E}_T^{\mathrm{miss}},\ell_2}$, $|\cos\theta^*_{\ell\ell}|$.
- Multiclass classification with 4 output categories.
- BDT-signal separates the signal from the backgrounds.



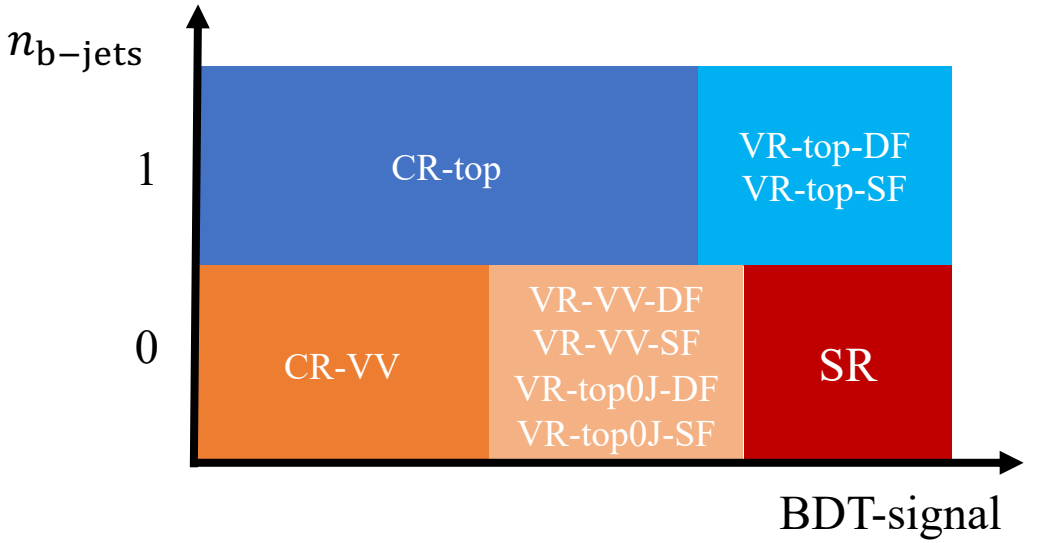
Main backgrounds (VV and top) estimated in dedicated Control Regions (CRs) and validated in Validation Regions (VRs).

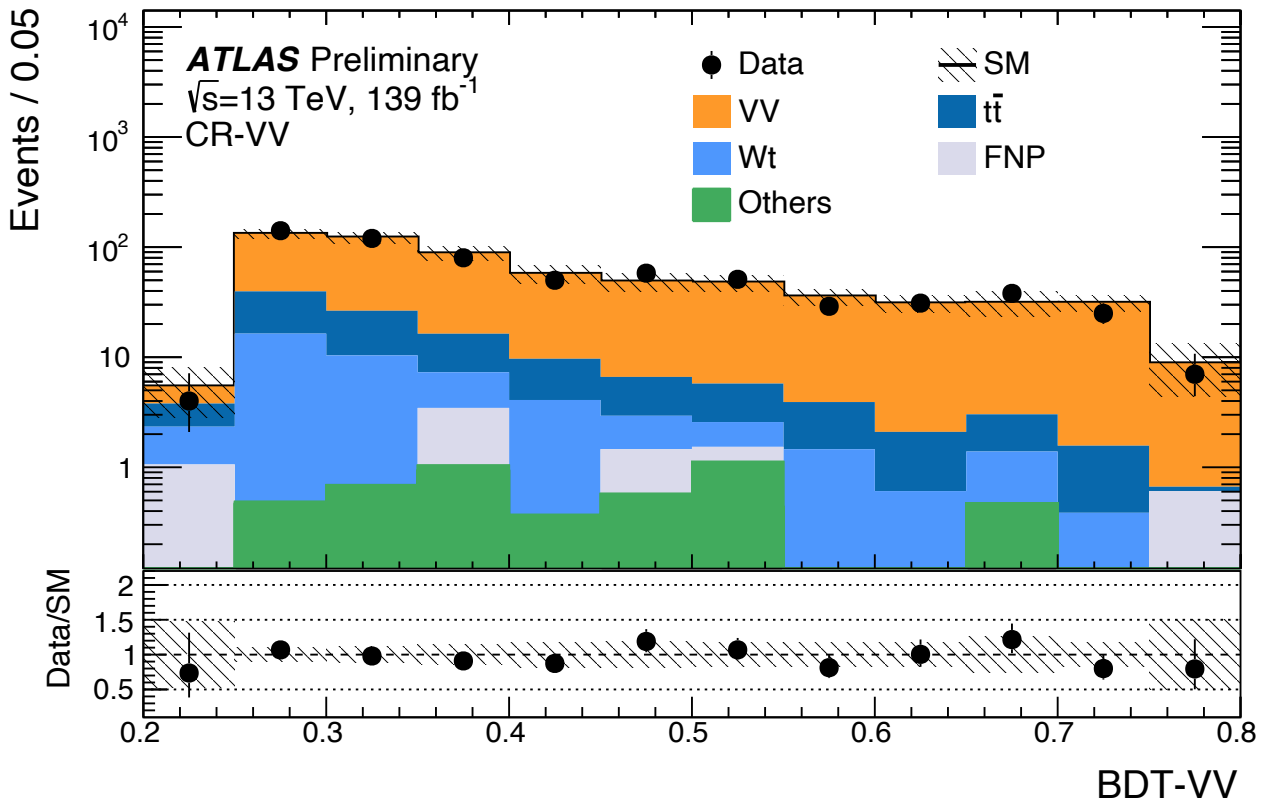
- Dedicated cuts on BDT-VV, BDT-top and BDT-others to increase the purity of specific backgrounds in CRs and VRs.

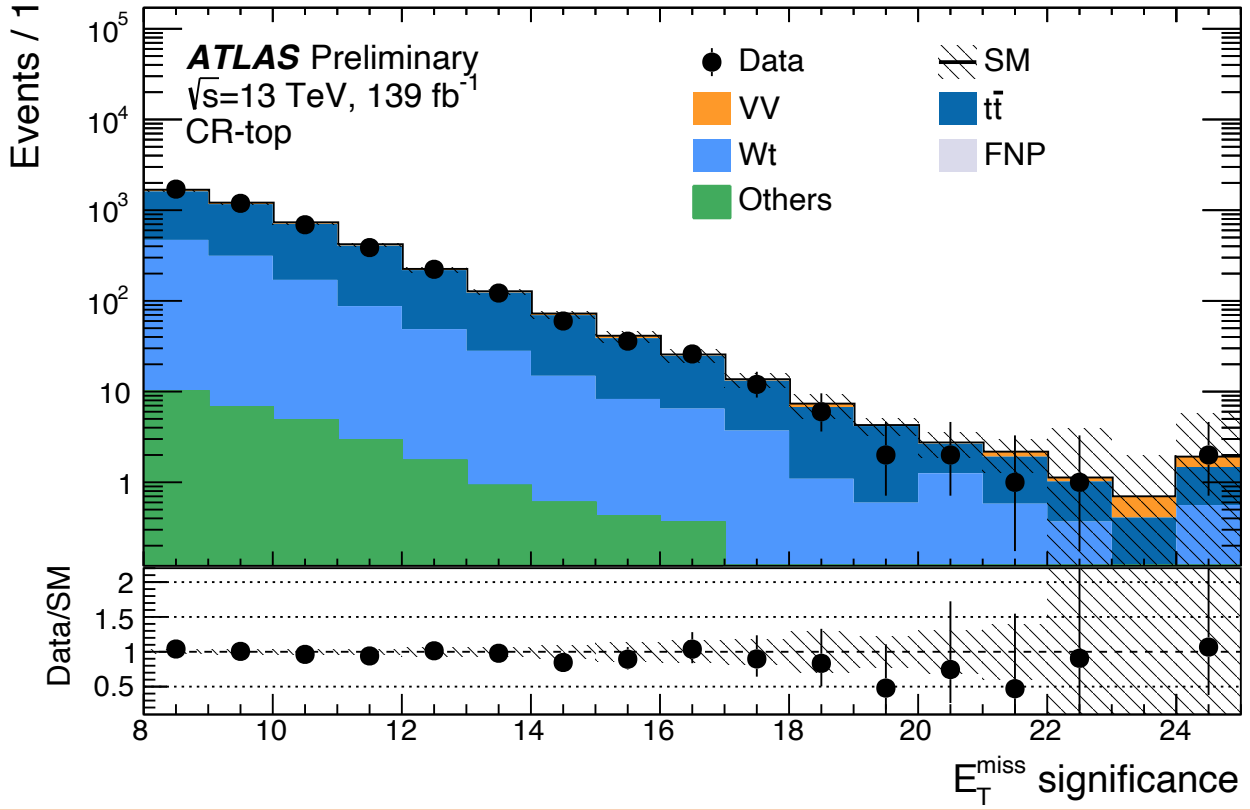
Background estimation

Backgrounds estimated in CRs by normalizing Monte Carlo simulated backgrounds to data:

- 2 CRs defined, CR-VV and CR-top.
- CR-top in $n_{\mathrm{b-jets}} = 1$ phase space to reach high purity of top backgrounds.



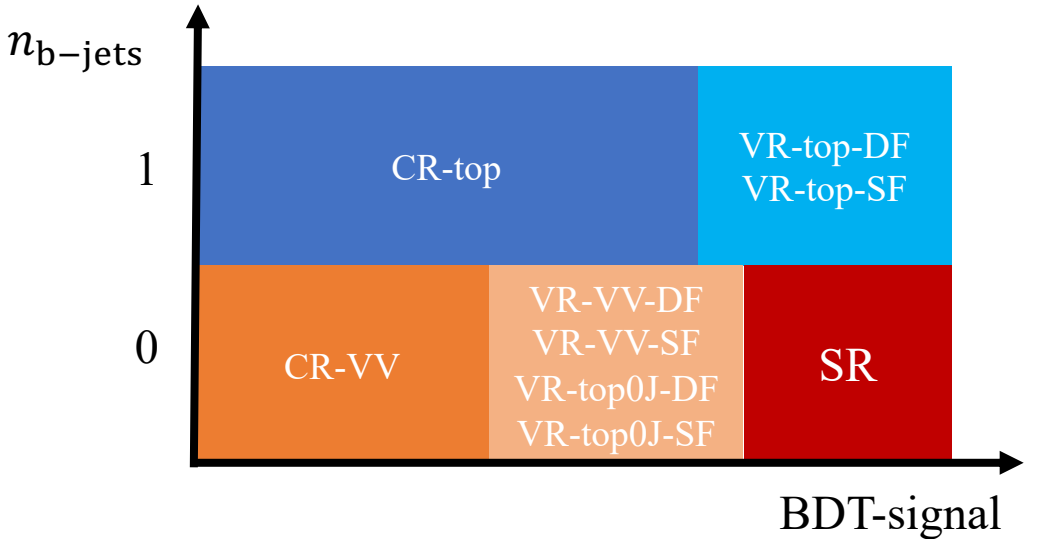


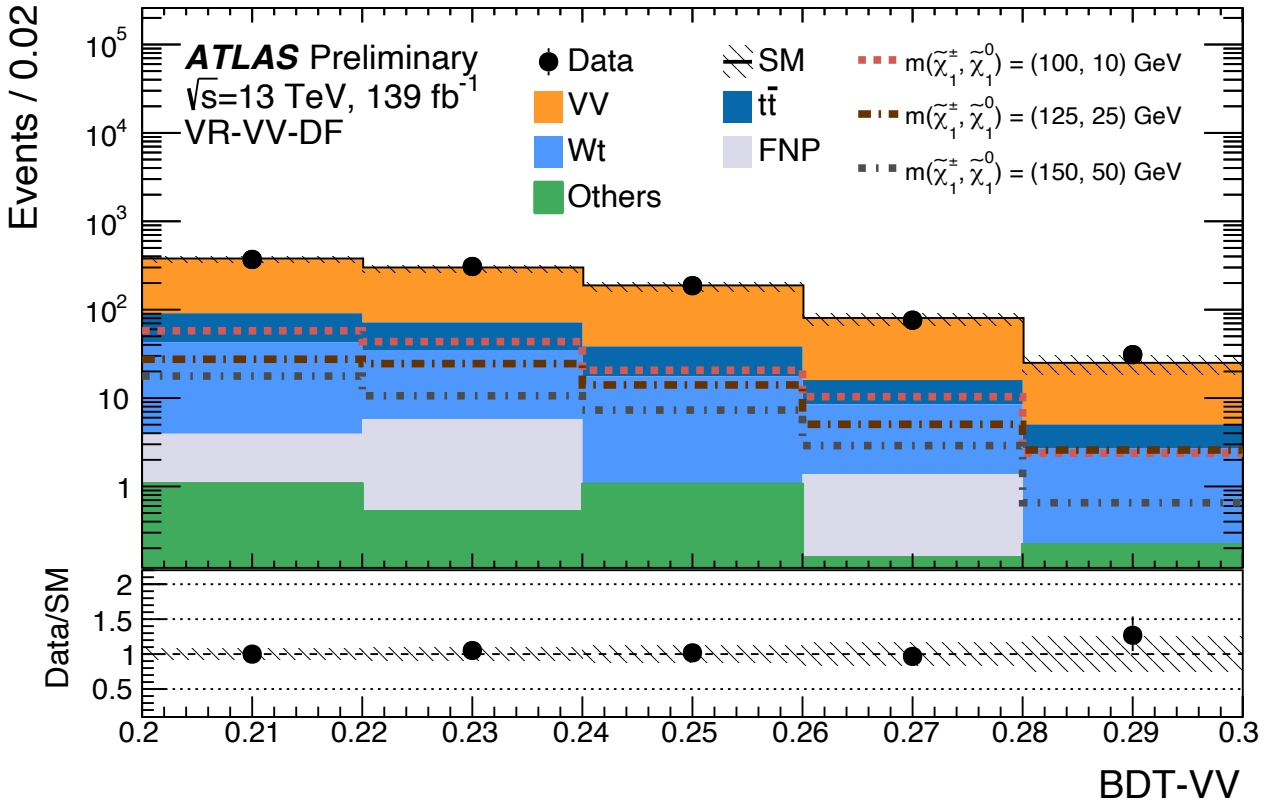


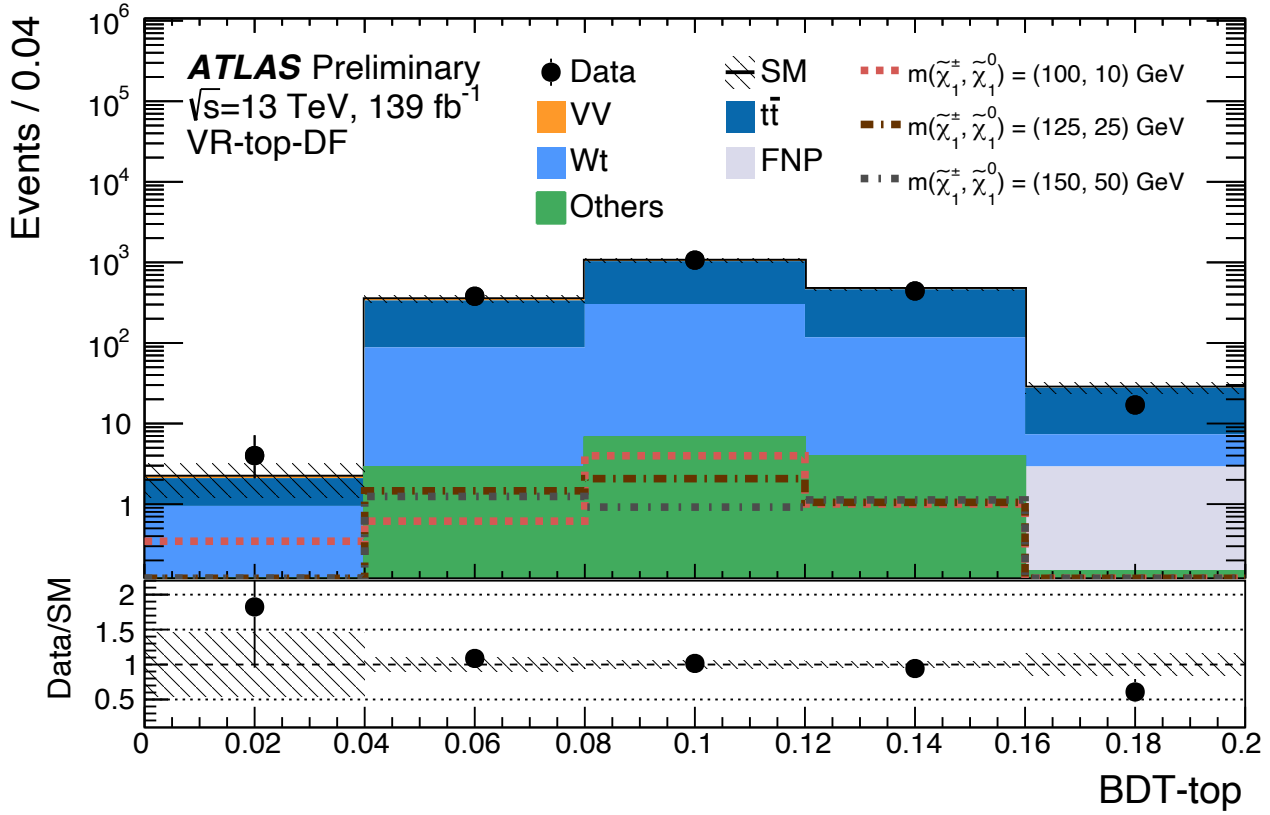
Background validation

Background estimation validated in VRs separated by Different/Same Flavour (DF/SF) of the 2 leptons:

- 2 top VRs defined close to CR-top.
- 2 VV VRs and 2 top0J VRs defined close to the Signal Region (SR).



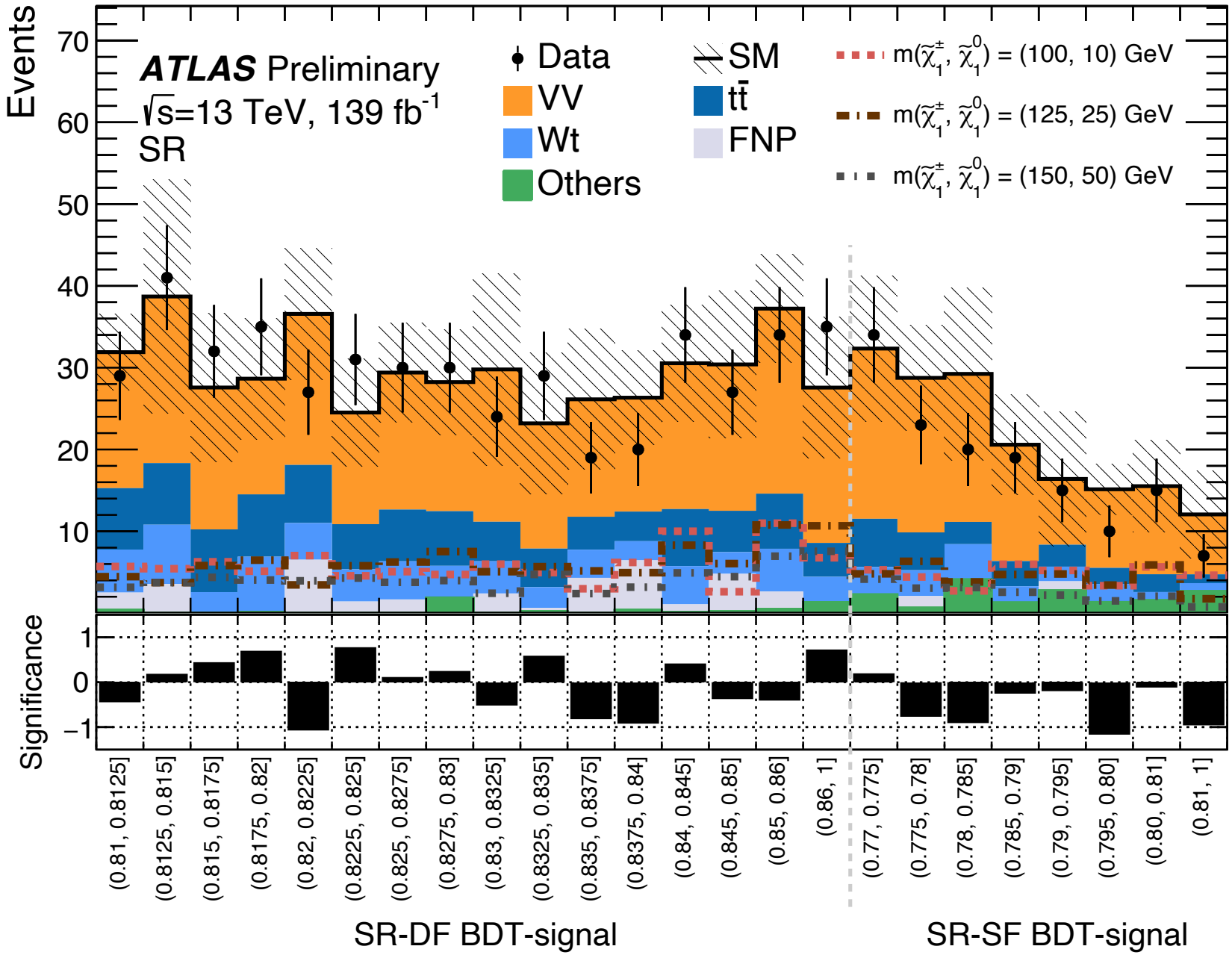




Signal Region

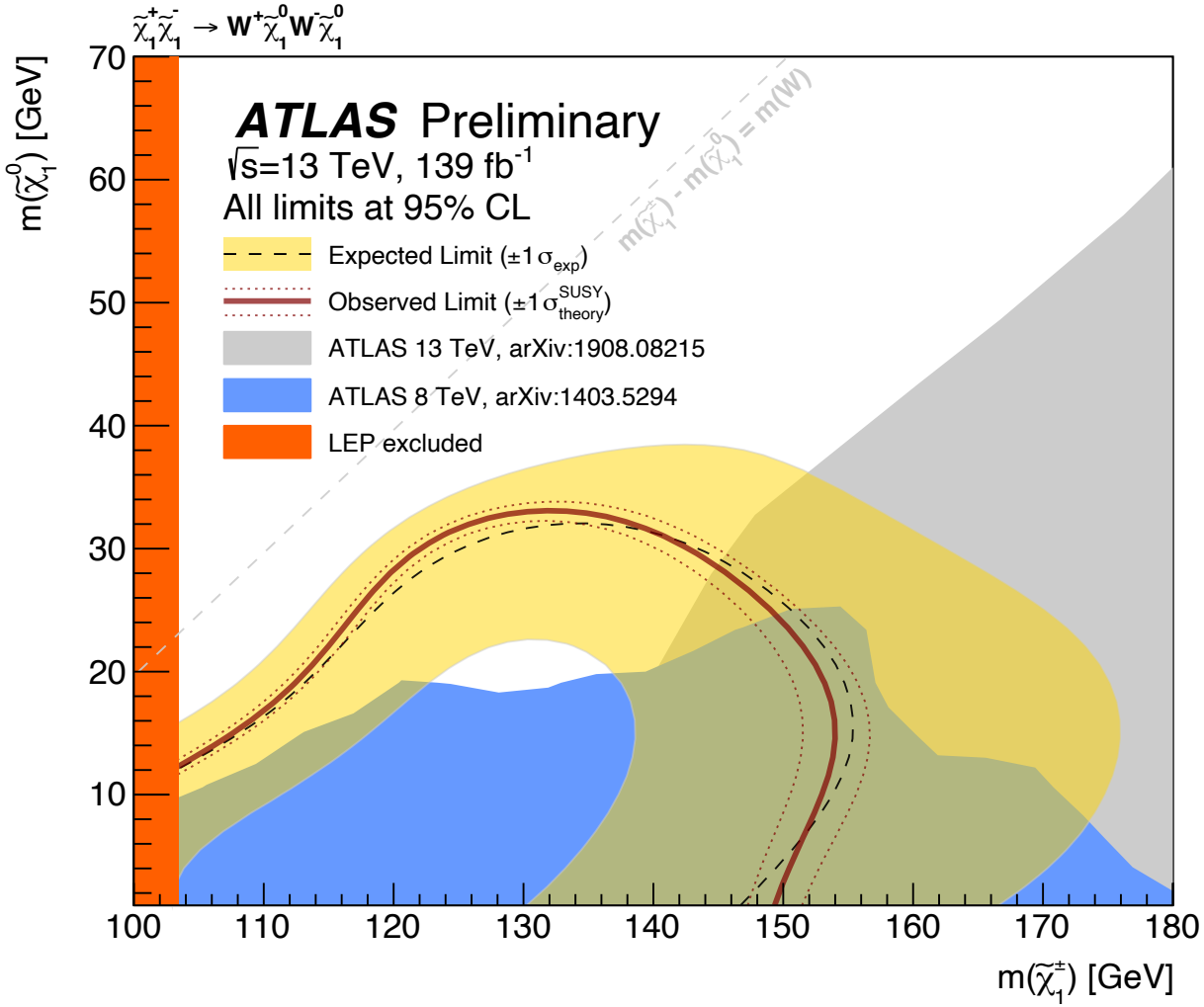
- SR defined for high values of BDT-signal to maximise signal significance:
  - SF and DF channels combined together in a likelihood fit.
  - Shape-fit in BDT-signal bins performed to increase sensitivity.

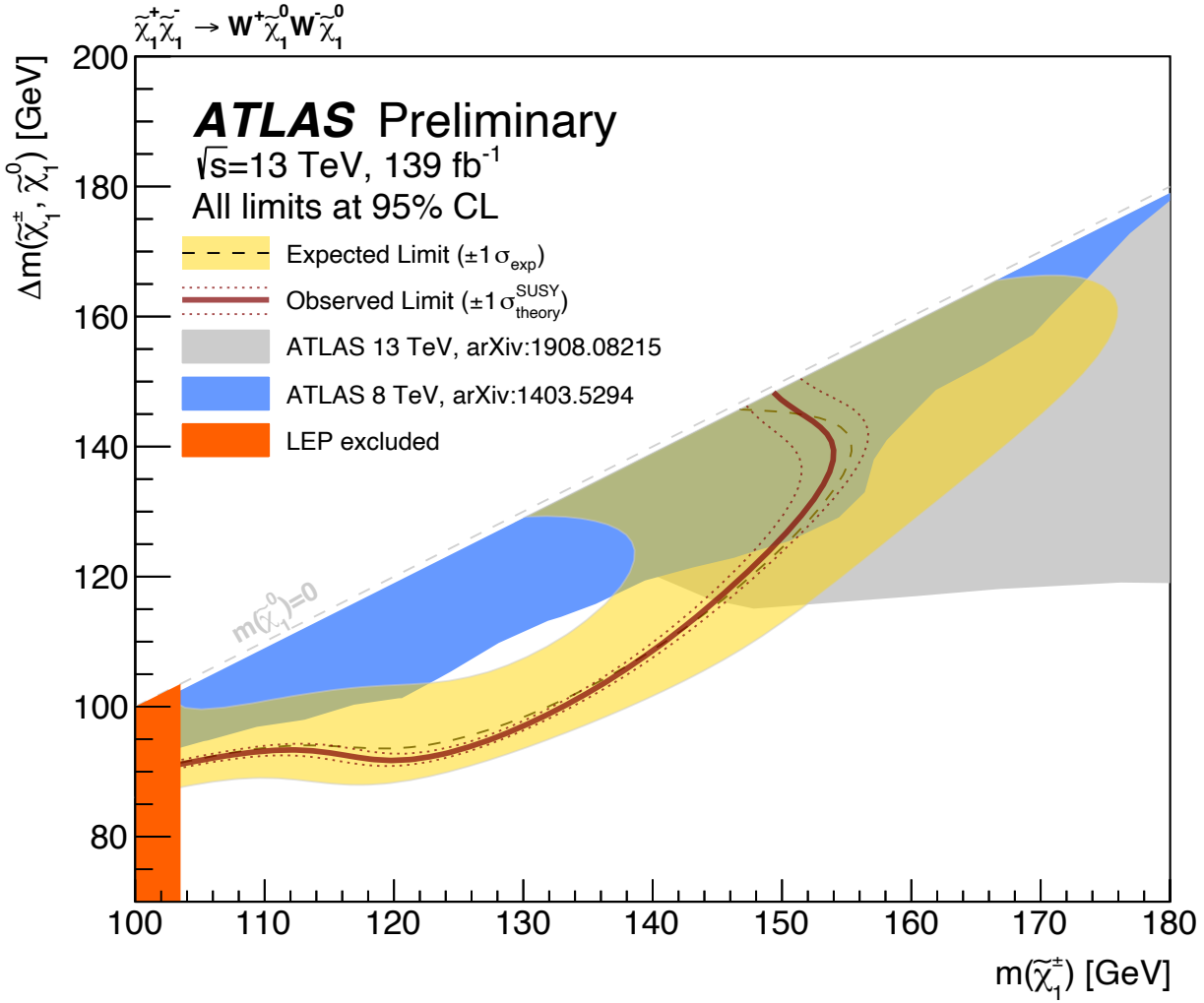
- No significant deviations from the SM observed in SR bins.



Results

Exclusion limits at 95% Confidence Level (CL) are set on the chargino pair production model.





Conclusions

- New search (ATLAS-CONF-2022-006) targeting the **direct production of chargino pairs** at $\sqrt{s}$ = 13 TeV in proton-proton collisions collected by the ATLAS experiment during Run 2 (2015-2018).

- Improved analysis strategy relying on BDTs and reaching an **unprecedented sensitivity**
  - Chargino masses excluded up to 135 GeV at 95% CL for $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0) < 100$ GeV.

- While the SM is surviving our new ATLAS searches, challenging "gaps" in the exclusion contours remain uncovered.
  - Exploring these gaps requires larger datasets, improved data analysis techniques or even dedicated new searches. Essential input for Run 3, which is due to start this year.
  - **Compressed searches** will continue to be a key target of these efforts – stay tuned to see if they lead to future discoveries!

Backup

Definition of analysis variables

- $p_T^{\ell_1}$: the magnitude of the transverse momentum of the leading lepton
- $p_T^{\ell_2}$: the magnitude of the transverse momentum of the subleading lepton
- $\mathrm{E}_T^{\mathrm{miss}}$: the magnitude of the missing transverse momentum
- $\mathrm{E}_T^{\mathrm{miss}}$ significance: the significance of the E_T^{miss} as defined in [1]
- $m_{\ell\ell}$: the invariant mass of the two leptons
- m_{T2}: the stransverse mass as defined in [2, 3]
- $\Delta\phi_{\mathrm{boost}}$: the azimuthal angular separation between E_T^{miss} and the vectorial sum of the two leptons p_T and the E_T^{miss}
- $\Delta\phi_{\mathrm{E}_T^{\mathrm{miss}},\ell_1}$: the azimuthal angular separation between E_T^{miss} and the leading lepton
- $\Delta\phi_{\mathrm{E}_T^{\mathrm{miss}},\ell_2}$: the azimuthal angular separation between E_T^{miss} and the sub−leading lepton
- $p_{\mathrm{T,boost}}^{\ell\ell}$: the module of the vectorial sum of the p_T of the two leptons and the E_T^{miss}
- $|\cos\theta_{\ell\ell}^*| = |\cos(2\tan^{-1}e^{\frac{\Delta\eta_{\ell\ell}}{2}})| = |\tanh e^{\frac{\Delta\eta_{\ell\ell}}{2}}|$, sensitive to the spin of the particles [4]

Control Regions

Control region (CR)	CR-VV		CR-top	
$E_{\mathrm{T}}^{\mathrm{miss}}$ significance	> 8			
m_{T2} [GeV]	> 50			
$n_{\text{non-}b\text{-tagged jets}}$	$= 0$			
Leptons flavour	DF	SF	DF	SF
$n_{b\text{-tagged jets}}$	$= 0$	$= 0$	$= 1$	$= 1$
BDT-other	-	< 0.01	-	< 0.01
BDT-signal	$\in (0.2, 0.65]$	$\in (0.2, 0.65]$	$\in (0.5, 0.7]$	$\in (0.7, 0.75]$
BDT-VV	> 0.2	> 0.2	-	-
BDT-top	< 0.1	< 0.1	-	-

Region	CR-VV	CR-top
Observed events	634	4468
Fitted backgrounds	634 ± 25	4468 ± 70
Fitted VV	520 ± 27	68 ± 12
Fitted $t\bar{t}$	69 ± 7	3243 ± 100
Fitted single top	40 ± 6	1129 ± 90
Other backgrounds	$4.8^{+5.1}_{-4.8}$	29 ± 5
FNP leptons	$0.02^{+1.4}_{-0.02}$	$0.06^{+12}_{-0.06}$
Simulated VV	376 ± 9	49 ± 7
Simulated $t\bar{t}$	63 ± 8	2974 ± 14
Simulated single top	37 ± 6	1036 ± 110

Validation Regions

Validation region (VR)	VR-VV-DF	VR-VV-SF	VR-top-DF	VR-top-SF	VR-top0J-DF	VR-top0J-SF
$E_{\mathrm{T}}^{\mathrm{miss}}$ significance			> 8			
m_{T2} [GeV]			> 50			
$n_{\text{non-}b\text{-tagged jets}}$			$= 0$			
$n_{b\text{-tagged jets}}$	$= 0$	$= 0$	$= 1$	$= 1$	$= 0$	$= 0$
BDT-other	-	< 0.01	-	< 0.01	-	< 0.01
BDT-signal	$\in (0.65, 0.81]$	$\in (0.65, 0.77]$	$\in (0.7, 1]$	$\in (0.75, 1]$	$\in (0.5, 0.81]$	$\in (0.5, 0.77]$
BDT-VV	> 0.2	> 0.2	-	-	< 0.15	< 0.15
BDT-top	< 0.1	< 0.1	-	-	-	-

Regions	VR-VV-DF	VR-VV-SF	VR-top-DF	VR-top-SF	VR-top0J-DF	VR-top0J-SF
Observed events	972	596	1910	95	810	17
Fitted backgrounds	941 ± 60	668 ± 90	1896 ± 90	101 ± 10	882 ± 40	16 ± 4
Fitted VV	728 ± 50	402 ± 50	32 ± 13	2.2 ± 2.1	427 ± 30	8.1 ± 2.6
Fitted $t\bar{t}$	116 ± 12	111 ± 11	1348 ± 50	67 ± 7	260 ± 21	5.8 ± 1.8
Fitted single top	94 ± 19	75 ± 11	502 ± 60	27 ± 7	168 ± 18	4 ± 1
Other backgrounds	3.1 ± 1.5	71 ± 70	13.6 ± 2.5	0.8 ± 0.4	5.2 ± 1.9	0.05 ± 0.05
FNP leptons	$0.02^{+2.3}_{-0.02}$	7 ± 4	$0.03^{+5}_{-0.03}$	4.2 ± 1.3	21 ± 8	$0.05^{+0.15}_{-0.05}$
Simulated VV	527 ± 27	291 ± 28	23 ± 9	1.6 ± 1.5	309 ± 13	5.9 ± 1.8
Simulated $t\bar{t}$	106 ± 13	102 ± 12	1237 ± 62	61 ± 7	239 ± 20	5.3 ± 1.6
Simulated single top	87 ± 20	69 ± 11	461 ± 64	25 ± 7	154 ± 20	3.2 ± 0.9

Signal Regions

Signal region (SR)	SR-DF	SR-SF
$n_{b\text{-tagged jets}}$	= 0	
$n_{\text{non-}b\text{-tagged jets}}$	= 0	
$E_{\mathrm{T}}^{\mathrm{miss}}$ significance	>8	
m_{T2} [GeV]	>50	
BDT-other		< 0.01

Exclusive SRs	BDT-signal	
BDT-signal	∈(0.81 ,0.8125]	∈(0.77 ,0.775]
	∈(0.8125 ,0.815]	∈(0.775 ,0.78]
	∈(0.815 ,0.8175]	∈(0.78 ,0.785]
	∈(0.8175 ,0.82]	∈(0.785 ,0.79]
	∈(0.82 ,0.8225]	∈(0.79 ,0.795]
	∈(0.8225 ,0.825]	∈(0.795 ,0.80]
	∈(0.825 ,0.8275]	∈(0.80 ,0.81]
	∈(0.8275 ,0.83]	∈(0.81 ,1]
	∈(0.83 ,0.8325]	
	∈(0.8325 ,0.835]	
	∈(0.835 ,0.8375]	
	∈(0.8375 ,0.84]	
	∈(0.84 ,0.845]	
	∈(0.845 ,0.85]	
	∈(0.85 ,0.86]	
	∈(0.86,1]	

Inclusive SRs	BDT-signal	
SR-DF-81-SF-77	∈(0.81,1]	∈(0.77,1]
SR-DF-81	∈(0.81,1]	
SR-DF-82	∈(0.82,1]	
SR-DF-83	∈(0.83,1]	
SR-DF-84	∈(0.84,1]	
SR-DF-85	∈(0.85,1]	
SR-SF-77		∈(0.77,1]
SR-SF-78		∈(0.78,1]
SR-SF-79		∈(0.79,1]
SR-SF-80		∈(0.80,1]