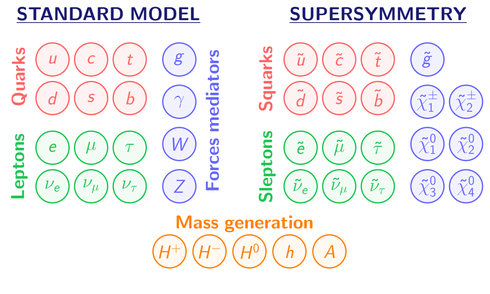
SEARCH FOR THE DIRECT PRODUCTION OF CHARGINO PAIRS DECAYING VIA W BOSON IN $\sqrt{s} = 13$ TeV pp COLLISIONS WITH THE ATLAS DETECTOR

Introduction

Supersymmetry (SUSY) is one of the most interesting extension of the Standard Model (SM).

- To each SM particle it associates a superpartner with spin (S) which differs by 1/2.
- In the Minimal Supersymmetric Standard Model (MSSM), R-parity, $R = (-1)^{3(B-L)+2S}$, is conserved.
- **Neutralinos** ($\tilde{\chi}_i^0$, with $i = 1, 2, 3, 4$) and **charginos** ($\tilde{\chi}_j^{\pm}$, with $j = 1, 2$) → combination of the neutral or charged supersymmetric partners of the gauge and Higgs bosons.
- $\tilde{\chi}_1^0$ represents the Lightest Supersymmetric Particle (LSP) and a good dark matter candidate.



Searching strategy

The general strategy used in this search consists in:

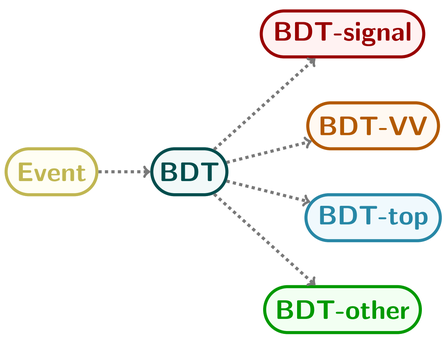
1. Considering "simplified" SUSY models (few new particles with masses as free parameters).
2. Optimization of the event selection to define **Signal Regions (SRs)**, where the signal from background discrimination is maximized.
3. Background estimate with semi data driven techniques, by normalizing Monte Carlo (MC) to data in **Control Regions (CRs)** chosen for a specific background. Normalization is validated in **Validadon Regions (VRs)**, kinematically close to SRs.
4. Comparing data to expected backgrounds in SRs:

evidence/discovery of signal if a significant excess of data over the expected background is observed or setting **upper limits** on the SUSY cross section and on the tested model parameters if data are compatible with the SM expectation.

Machine learning approach

In order to improve analysis sensitivity a **machine learning** technique has been applied, using the **Boosted Decision Tree (BDT)**:

- Training uses, for both signal and background samples, a set of kinematic variables relevant for the signal-background discrimination.



- A multiclass classification is performed → the classifier is trained to separate events into four classes:
  - **signal**,
  - **diboson** (VV),
  - **top** ($t\bar{t}$ and Wt),
  - **other** (Z+jets, $Z(\to \tau\tau)$+jets, VVV, and minor backgrounds).

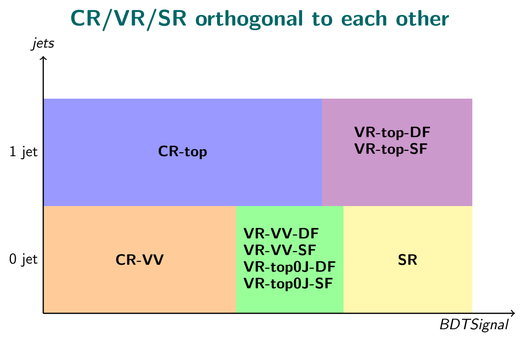
  } **main SM backgrounds**

For each event, the four scores BDT-signal, BDT-VV, BDT-top and BDT-other provide the probability for the event to belong to each class, and sum to one.

- Two different selections considered: **DF0J** and **SF0J**, characterized by different flavour (DF) and same flavour (SF) leptons respectively and no hadronic jets in the final state.

Control and Validation Regions

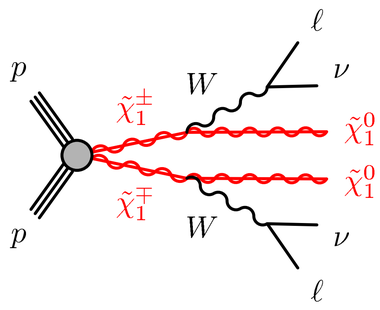
- CRs have been defined, from where **scale factors** are extracted, validated in some VRs, and then applied to the SRs,
- CRs and VRs defined by reversing the BDT-signal cut applied to the SRs,
- CR-VV targets the diboson background and CR-top targets the top-quark background,
- Six VRs are used to verify the agreement of data and SM predictions.



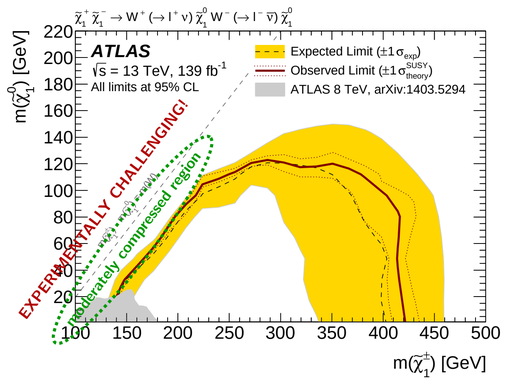
	Control regions (CRs)				Validation Regions (VRs)					
	CR-VV		CR-top		VR-VV-DF	VR-VV-SF	VR-top-DF	VR-top-SF	VR-top0J-DF	VR-top0J-SF
E_T^{miss} significance	> 8				> 8					
m_{T2} [GeV]	> 50				> 50					
$n_{\text{non-}b\text{-tagged jets}}$	$= 0$				$= 0$					
Lepton Flavour	DF	SF	DF	SF	DF	SF	DF	SF	DF	SF
$n_{b\text{-tagged jets}}$	$= 0$	$= 0$	$= 1$	$= 1$	$= 0$	$= 0$	$= 1$	$= 1$	$= 0$	$= 0$
BDT-other	-	< 0.01	-	< 0.01	-	< 0.01	-	< 0.01	-	< 0.01
BDT-signal	$\in (0.2, 0.65]$	$\in (0.2, 0.65]$	$\in (0.5, 0.7]$	$\in (0.7, 0.75]$	$\in (0.65, 0.81]$	$\in (0.65, 0.77]$	$\in (0.7, 1]$	$\in (0.75, 1]$	$\in (0.5, 0.81]$	$\in (0.5, 0.77]$
BDT-VV	> 0.2	> 0.2	-	-	> 0.2	> 0.2	-	-	< 0.15	< 0.15
BDT-top	< 0.1	< 0.1	-	-	< 0.1	< 0.1	-	-	-	-

Chargino direct production

- Direct production of $\tilde{\chi}_1^+\tilde{\chi}_1^-$, where each chargino decays into $\tilde{\chi}_1^0$ and a W-boson (which decays leptonically) in the pp collision at LHC.
- The analysis uses data collected by the ATLAS experiment during full **Run 2** (2015-2018), at $\sqrt{s} = 13$ TeV, corresponding to **139 fb^{-1}**.



Final state:
- 2 opposite signed leptons ($\ell = e, \mu$)
- E_T^{miss} ($\tilde{\chi}_1^0$ and ν)
- No hadronic activity



- A previous analysis [1] has produced exclusion limits at 95% CL in kinematic regions with large mass-splitting:

$$\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0) = m(\tilde{\chi}_1^{\pm}) - m(\tilde{\chi}_1^0) > m(W).$$

- The current analysis targets the **"moderately compressed region"**:

$$\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0) = m(\tilde{\chi}_1^{\pm}) - m(\tilde{\chi}_1^0) \lesssim m(W).$$

Signal Regions

- Firstly, an event preselection applies cuts on lepton transverse momentum, dilepton invariant mass and E_T^{miss} significance.
- Then, a further selection is applied for the SRs.

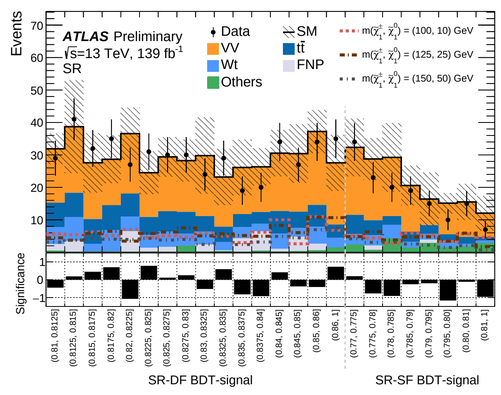
SRs are defined as bins with high values in BDT-signal.

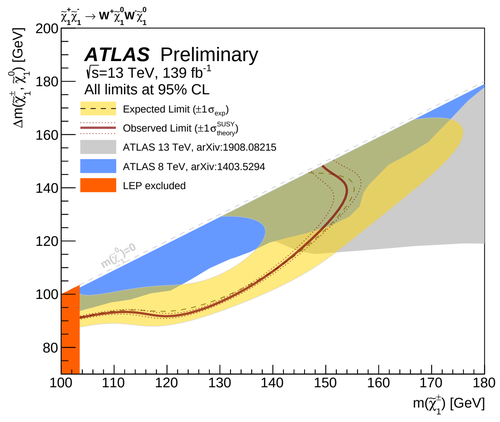
Signal region (SRs)	SR-DF	SR-SF
$n_{b\text{-tagged jets}}$	$= 0$	
$n_{\text{non-}b\text{-tagged jets}}$	$= 0$	
E_T^{miss} significance	>8	
m_{T2} [GeV]	>50	
BDT-other	< 0.01	
BDT-signal	$\in(0.81, 0.8125]$	$\in(0.77, 0.775]$
	$\in(0.8125, 0.815]$	$\in(0.775, 0.78]$
	$\in(0.815, 0.8175]$	$\in(0.78, 0.785]$
	$\in(0.8175, 0.82]$	$\in(0.785, 0.79]$
	$\in(0.82, 0.8225]$	$\in(0.79, 0.795]$
	$\in(0.8225, 0.825]$	$\in(0.795, 0.80]$
	$\in(0.825, 0.8275]$	$\in(0.80, 0.81]$
	$\in(0.8275, 0.83]$	$\in(0.81, 1]$
	$\in(0.83, 0.8325]$	
	$\in(0.8325, 0.835]$	
	$\in(0.835, 0.8375]$	
	$\in(0.8375, 0.84]$	
	$\in(0.84, 0.845]$	
	$\in(0.845, 0.85]$	
	$\in(0.85, 0.86]$	
	$\in(0.86, 1]$	

Results and conclusions

- No significant deviations in data from the SM predictions have been observed in any of the SRs. Exclusion limits at 95% CL are set on the masses of the chargino and the neutralino which extend the limits set by previous analyses on the same search:

chargino masses up to 135 GeV are excluded at 95% CL in the case of a mass splitting between chargino and neutralino up to 100 GeV.





References

[1] ATLAS Collaboration, *Search for electroweak production of charginos and sleptons decaying into final states with two leptons and missing transverse momentum in $\sqrt{s}$=13 TeV pp collisions using the ATLAS detector*, Eur. Phys. J. C 80 123, 2020, arXiV:1908.08215

[2] ATLAS Collaboration, *Search for direct pair production of sleptons and charginos decaying to two leptons and neutralinos with mass splittings near the W boson mass in $\sqrt{s}$=13TeV pp collisions with the ATLAS detector*, ATLAS-CONF-2022-006, 2022

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