Searches for electroweak supersymmetry in final states containing one lepton, two b-jets and missing transverse energy at the ATLAS experiment

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Introduction

- Electroweak SUSY searches at ATLAS
  - Motivation
  - $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ pair-production
- $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ search with 2015-2016 data
  - Signal selection
  - Background estimation
  - Results
- $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ discovery prospects at HL-LHC
  - HL-LHC prospects overview
  - Signal selection with BDTs
  - HL-LHC projected limits
- Current R&D - MVA classification in small ΔM scenarios

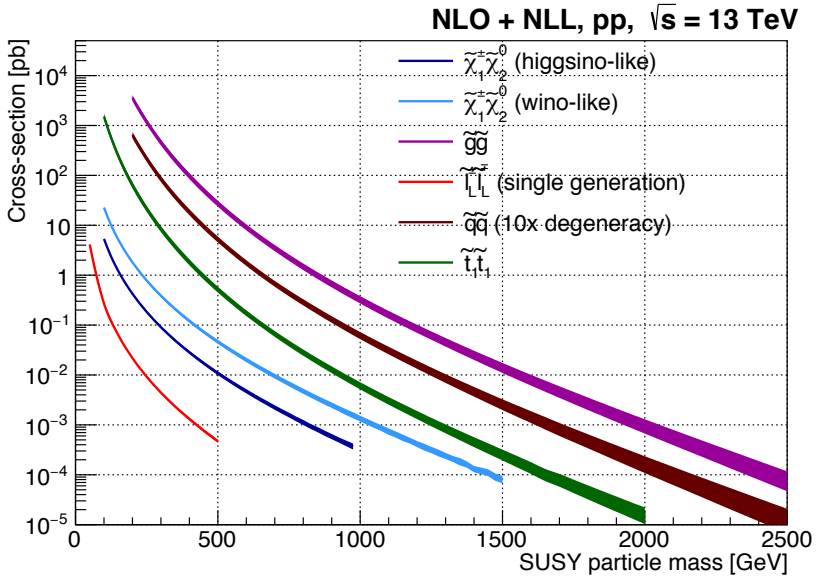
Motivation

Electroweak SUSY searches usually involve direct production of 'EWK-inos' and sleptons:

- EWK-inos: mixtures of SUSY partners to EWK gauge bosons and Higgs

Motivation:

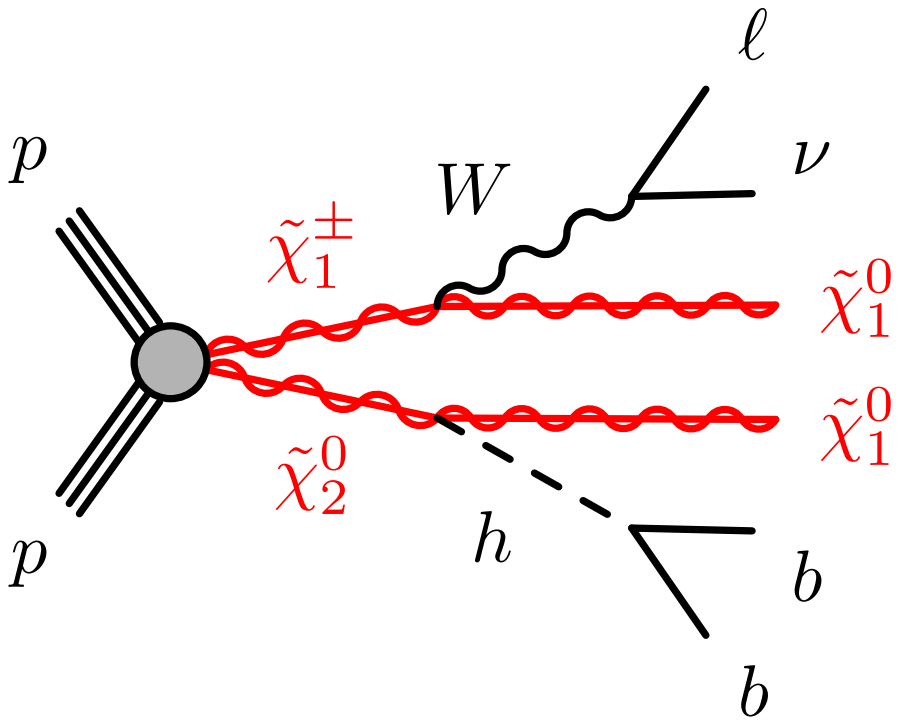
- Low mass EWK-inos may address various open questions (DM, hierarchy problem...)
- EWK SUSY could be dominant SUSY process at LHC if squarks & gluinos are decoupled
- Large CoM energies and datasets → Necessary for EWK SUSY searches



Cross-sections for a number of SUSY pair-production processes at $\sqrt{s} = 13$ TeV
Ref: B. Fuks, M. Klasen, D. R. Lamprea, and M. Rothering, Eur. Phys. J. C 73, 2480 (2013)

$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ pair-production

- Simplified model of $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ pair-production

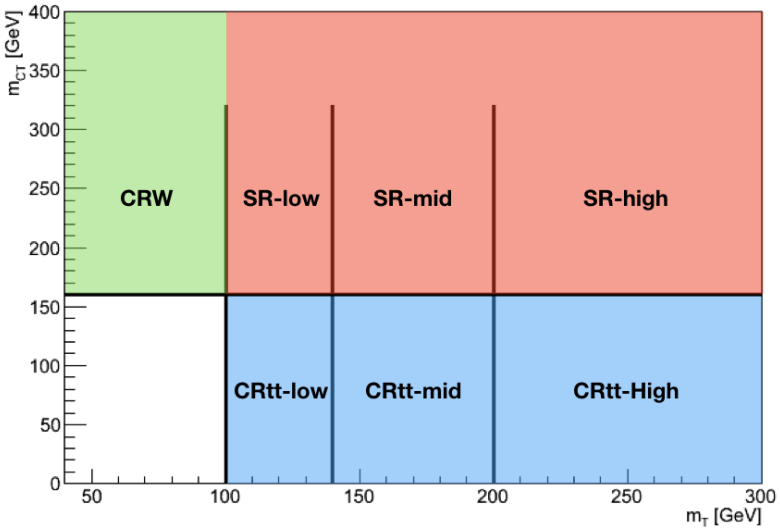


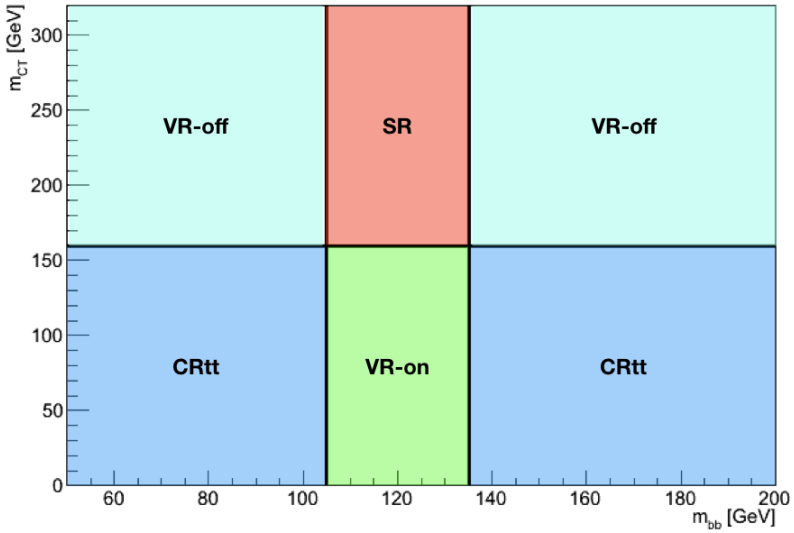
Model assumptions:

- BR($\tilde{\chi}_1^{\pm} \rightarrow W\ \tilde{\chi}_1^0$) = 100%
- BR($\tilde{\chi}_2^0 \rightarrow h\ \tilde{\chi}_1^0$) = 100%
- $m(\tilde{\chi}_1^{\pm}) = m(\tilde{\chi}_2^0)$
- The Higgs, h, is the lightest SUSY Higgs, with SM-like mass and couplings:
  - $m_h = 125$ GeV
  - BR($h \rightarrow b\bar{b}$) = 58%

- For 500 GeV $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$, massless $\tilde{\chi}_1^0$: $\underline{\sigma = 46.4\text{fb}}$
- For comparison: Higgs production via ggF: $\sigma = 43.92$pb
- This talk shows analyses targetting $W \rightarrow \ell\nu$, $h \rightarrow b\bar{b}$ channel.

$Wh\ 1\ell b\bar{b}$ - Search strategy





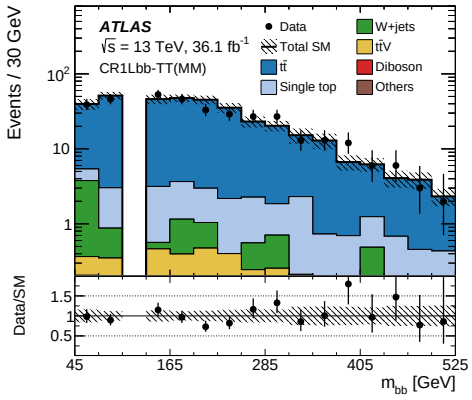
- SR: Region designed to target a particular signal parameter space while suppressing background
- CR: Background control region used to estimate dominant backgrounds in semi-data-driven method:
  - $t\bar{t}$, single top, W+jets
- Use validation regions (VRs) to prove validity of estimation

$Wh\ 1\ell b\bar{b}$ - Signal selection

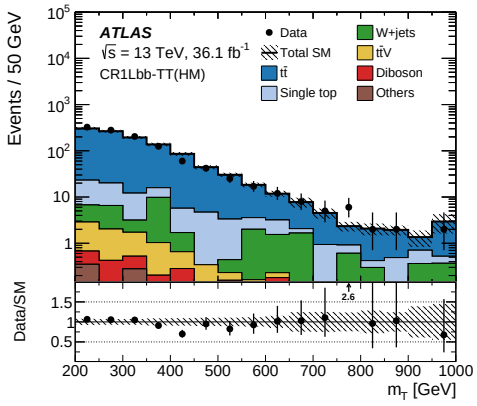
- Make preliminary selection using lepton and jet multiplicity:

	Pre-selection
n_{leptons}	1
n_{jets}	$2-3$
$n_{\text{b-jets}}$	2

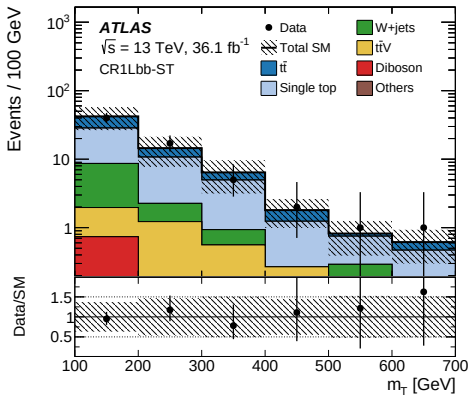
- Use E_T^{miss}, m_T, m_{bb} and m_{CT} to define 3 signal regions (SRs)
- Data/MC agreement in control regions (CRs) is good! (Plots: arXiv:1812.09432)



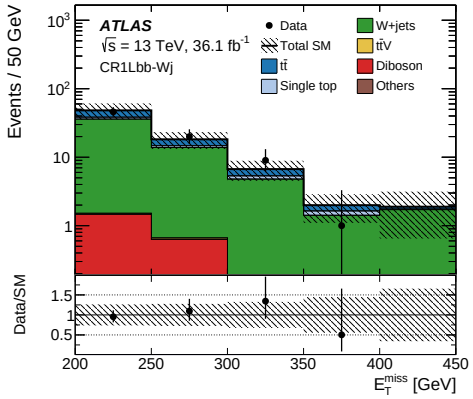
m_{bb}



m_T



m_T



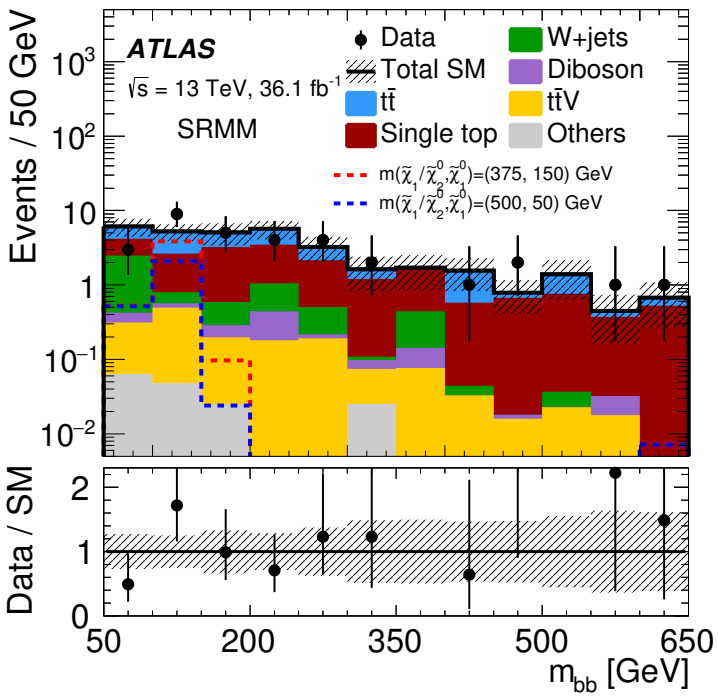
E_T^{miss}

$$m_T = \sqrt{2p_T^{\ell} E_T^{miss} (1 - \cos\Delta\phi)} \quad (1)$$

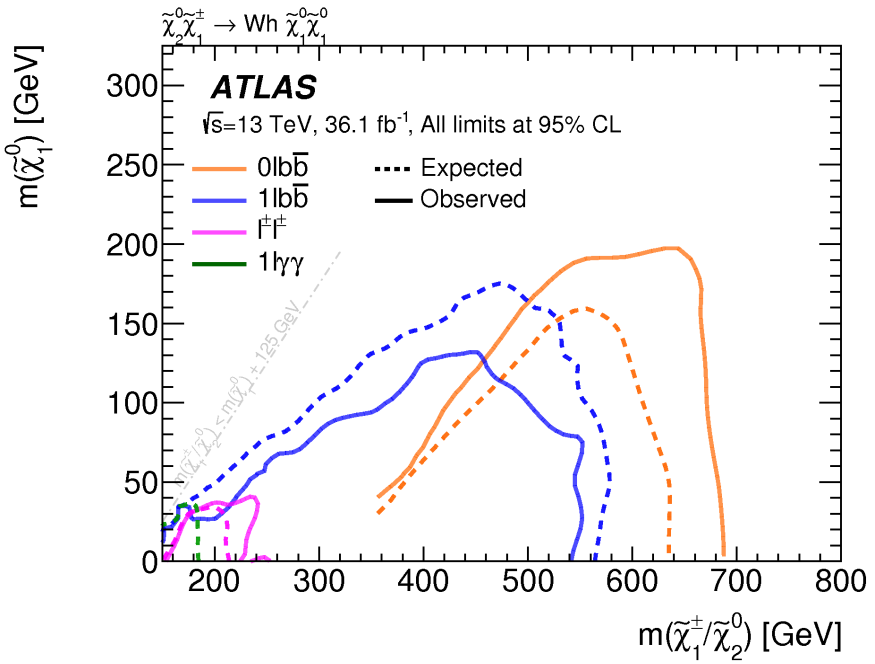
$$m_{CT} = \sqrt{\left(E_T^{b1} + E_T^{b2}\right)^2 - \left(\mathbf{p}_T^{b1} - \mathbf{p}_T^{b2}\right)^2} \quad (2)$$

$Wh\ 1\ell b\bar{b}$ - Results

SR	SR-low	SR-mid	SR-high
Observed events	6	7	5
Fitted bkg events	5.7 ± 2.3	2.8 ± 1.0	4.6 ± 1.2



N-1 plot of m_{bb} in SR-mid



ATLAS early Run 2 result for this production channel

Submitted to arXiv and PRD: arXiv:1812.09432

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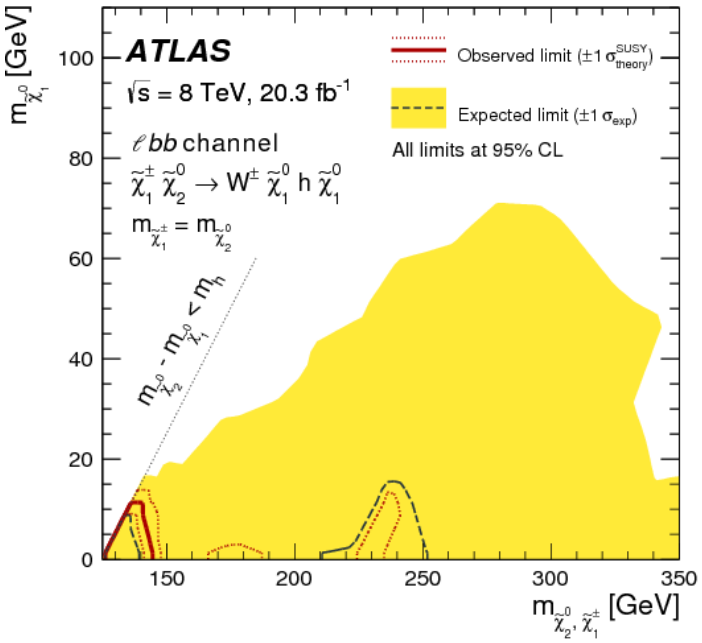
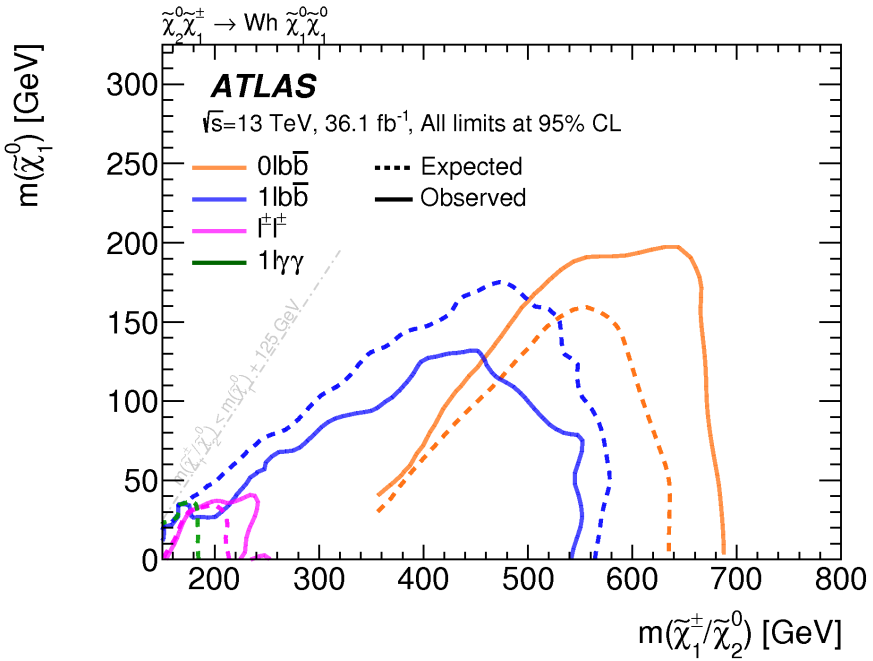


Run 1 result for this channel



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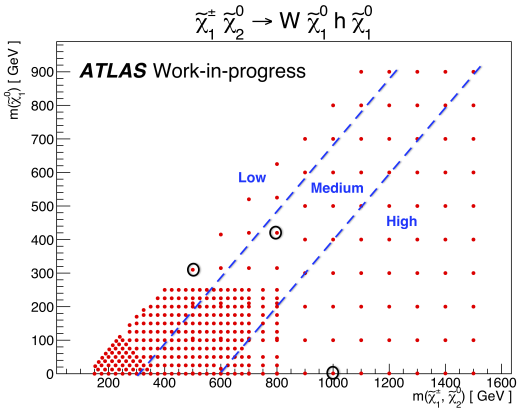
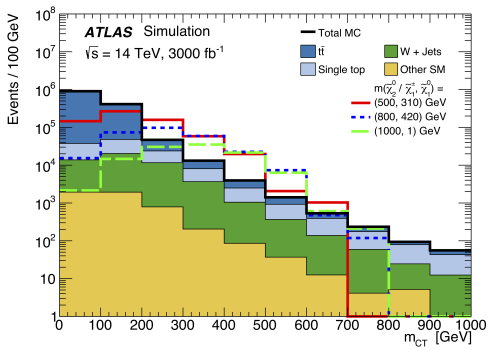
HL-LHC prospects overview

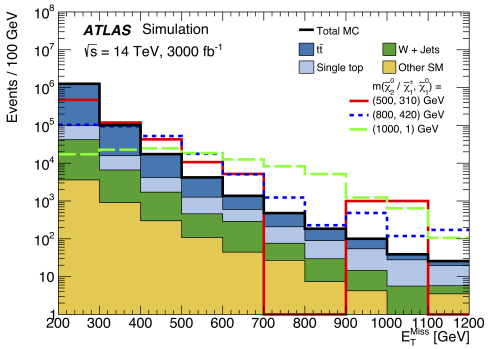
- HL-LHC: $\sqrt{s} = 14$TeV, expected integrated luminosity $= 3000 fb^{-1}$, $< \mu >= 200$, improved tracking (ITk)
- Make preliminary selection requiring 1 lepton, 2 jets from b-quarks + $E_T^{miss} > 200$ GeV
- Separate signal models into 3 regions:



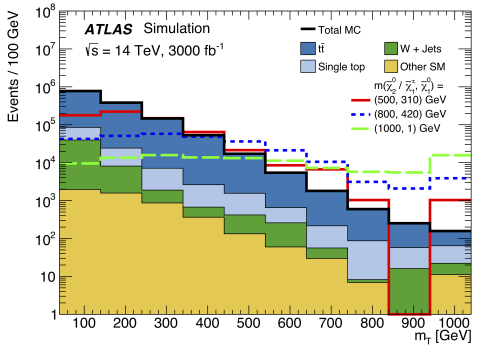
- Train a Boosted Decision Tree (BDT) on signal in each region and $t\bar{t}$ background



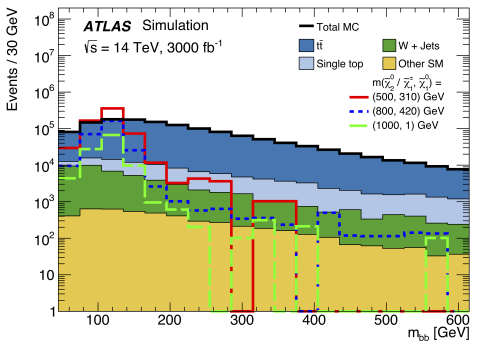
m_{CT}



E_T^{miss}



m_T

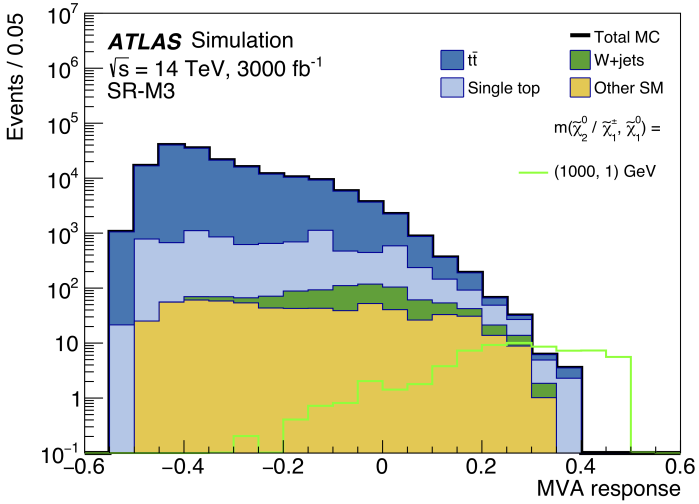


m_{bb}

Signal yield $\times 1000$. All backgrounds estimated directly from Monte Carlo.
Plots: arXiv:1812.07831

Signal selection with BDTs

- BDT classifies event as signal or background with prediction $\in [-1, 1]$
  - Prediction $\rightarrow$ 1 = signal-like
  - Prediction $\rightarrow$ -1 = background-like
- Optimise cut on output of BDT using significance (assume 15% uncertainty)

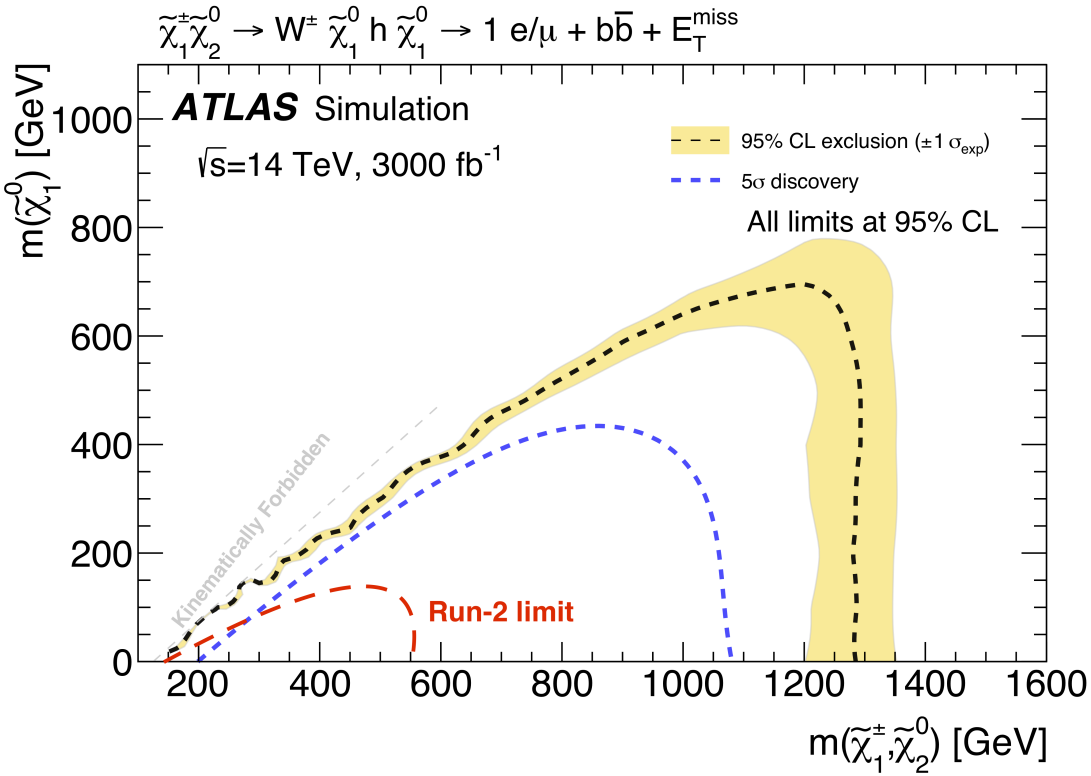


Plot: arXiv:1812.07831

Processes	SR-M1 (>0.25)	SR-M2 (>0.35)	SR-M3 (>0.30)
$t\bar{t}$	38.9 ± 8.4	8.7 ± 3.3	2.5 ± 1.8
single top	28.3 ± 4.8	10.7 ± 3.2	5.4 ± 2.5
W+jets	22.2 ± 5.4	3.0 ± 2.0	2.0 ± 1.8
ttV	5.1 ± 2.4	2.0 ± 1.4	1.0 ± 1.0
Diboson	2.0 ± 2.0	-	-
total background	96.5 ± 11.8	24.4± 5.2	10.9 ± 3.4
m($\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$, $\tilde{\chi}_1^0$) = (500, 300) GeV	20.7 ± 4.8	4.6 ± 2.3	1.0 ± 1.0
m($\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$, $\tilde{\chi}_1^0$) = (800, 420) GeV	44.3 ± 2.3	33.6 ± 2.0	21.2 ± 1.6
m($\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$, $\tilde{\chi}_1^0$) = (1000, 1) GeV	32.2 ± 1.8	31.9 ± 1.8	28.9 ± 1.7

HL-LHC projected limits

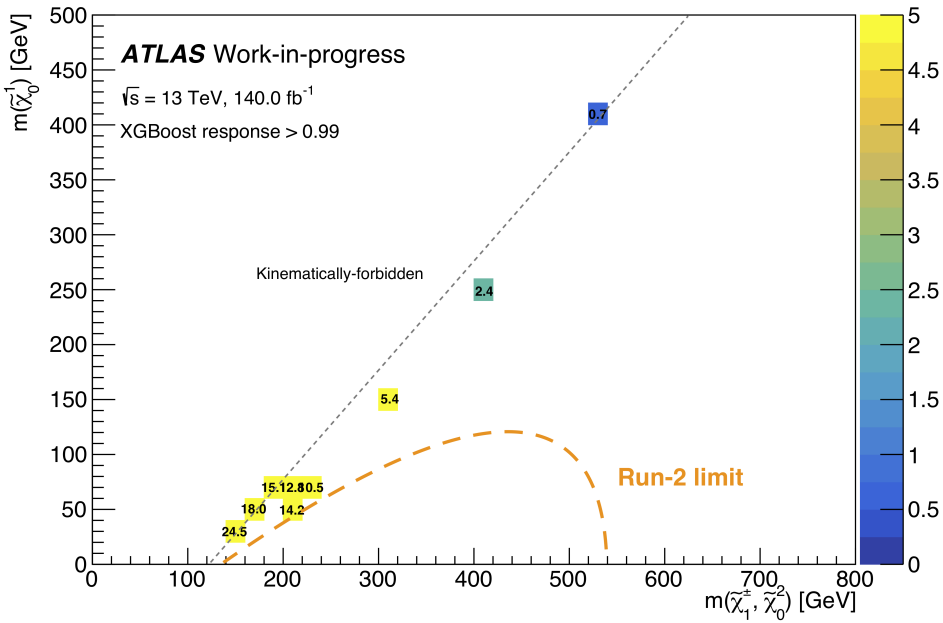
- Systematic uncertainties extrapolated from Run-2:
  - Theory modelling $\times 1/2$
  - Experimental $\times 1/3 - \times 1$
- HL-LHC expected exclusion limit (2σ) up to $m(\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0) = \sim 1280$ GeV
- HL-LHC expected discovery limit (5σ) up to $m(\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0) = \sim 1080$ GeV



This result included in CERN HL/HE-LHC Yellow Report, forming part of the input to the European Strategy for Particle Physics: arXiv:1812.07831

R&D: ML techniques

- Many new packages & techniques gaining interest from HEP community:
  - XGBoost: eXtreme Gradient Boosted decision trees
- Use these techniques to target low mass splitting region (experimentally difficult!)
  - Proof-of-principle: Multiclass classification of signal model vs dominant backgrounds at truth-level
  - Train on m($\tilde{\chi}_1^{\pm}$/ $\tilde{\chi}_2^0$, $\tilde{\chi}_1^0$) = (400, 250) GeV signal point, $t\bar{t}$ & Wt
  - Apply trained model to other signal points and evaluate significance



Expected significance using XGBoost classifier assuming 30% background uncertainty.

Conclusions

- Strong motivations for $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ searches
- 2015-2016 search excludes this channel up to 550 GeV
- HL-LHC $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ prospects analysis:
  - Signal selection done with BDTs
  - Exclusion limit: 1280 GeV
  - Discovery limit: 1080 GeV
- Currently studying potential improvements to Run-2 analysis with ML techniques

Backup

Kinematic variable definitions

$$\Delta R = \sqrt{(\Delta\eta^2 + \Delta\phi^2)} \tag{3}$$

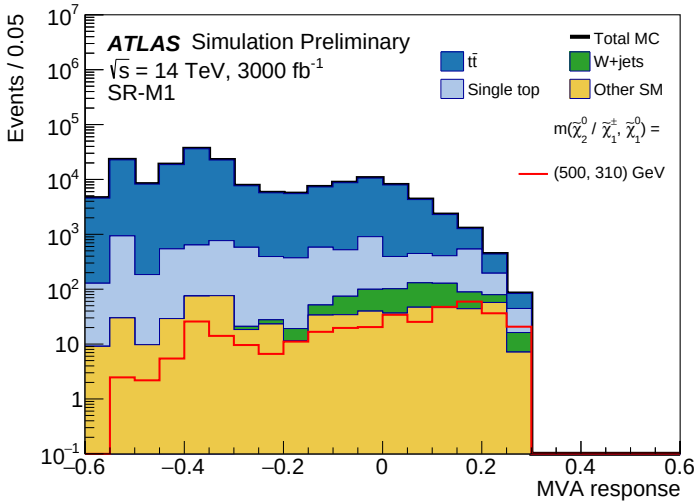
$$m_T = \sqrt{2p_T^{\ell} E_T^{miss} (1 - \cos\Delta\phi)} \tag{4}$$

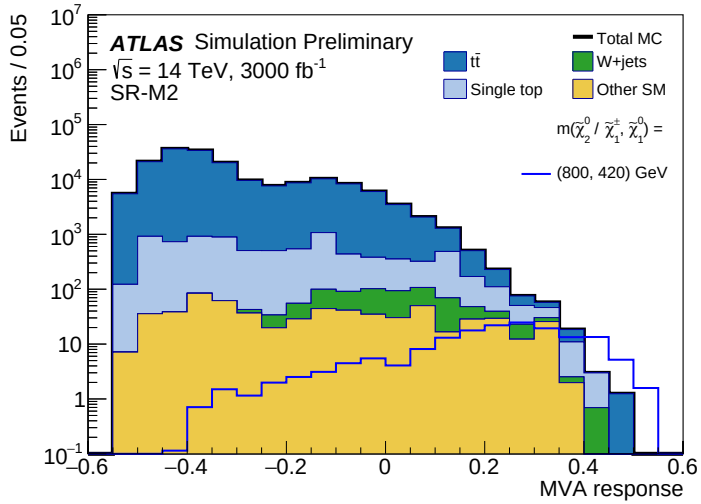
$$m_{CT} = \sqrt{\left(E_T^{b_1} + E_T^{b_2}\right)^2 - \left(\mathbf{p}_T^{b_1} - \mathbf{p}_T^{b_2}\right)^2} \tag{5}$$

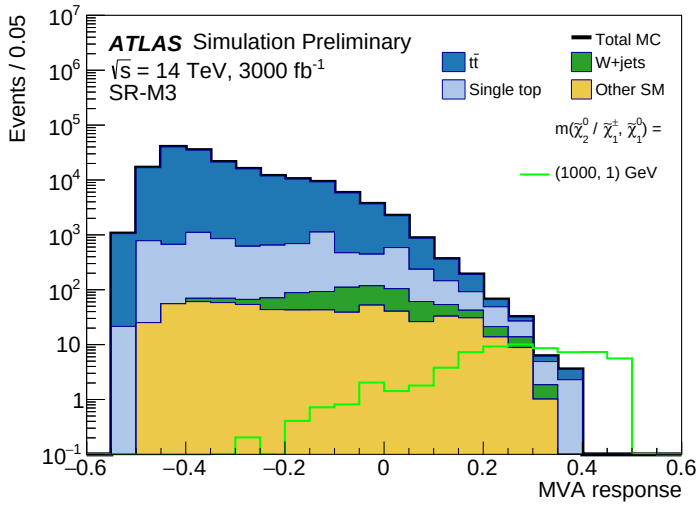
Boost-corrected m_{CT}: https://arxiv.org/abs/0910.0174

$$E_T^{miss} = \left|\mathbf{p}_T^{miss}\right| \tag{6}$$

BDT outputs







Plots: arXiv:1812.07831