Search for direct stop quark production in semi-leptonic $t\bar{t}$ events at ATLAS

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Physik bei höchsten Energien mit dem ATLAS-Experiment am LHC
FSP 103
ATLAS

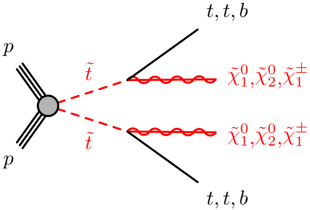
Introduction

Search for direct stop quark production in semi-leptonic $t\bar{t}$ events

1. Introduction and Motivation
2. Event Selection
3. Background Estimate
4. Results

Based on publication: [ATLAS-CONF-2017-037]

Stop Quarks



search for direct stop quark production, stop decays into LSP

1. Bino LSP
   - decay via $\tilde{t} \rightarrow t\tilde{\chi}_1^0$
   - intermediate to high stop quark masses (tN_med and tN_high)
2. Higgsino LSP
   - 3 light states for $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^{\pm}$
   - stop can decay in all 3 states
   - small mass splitting between $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_1^0 \Rightarrow \tilde{\chi}_1^{\pm} \rightarrow W^*\tilde{\chi}_1^0$ with low momentum objects
   - dedicated soft lepton selections (bC_soft)

Signal Selection – tN

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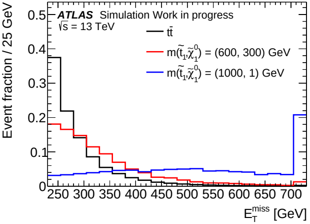
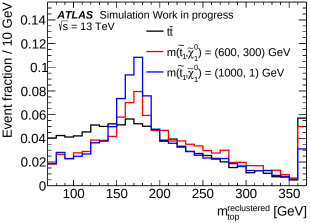
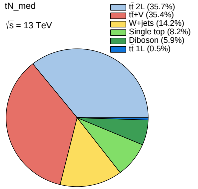




$m_{\mathrm{T}} > 120\ \mathrm{GeV}$ cut applied
$\rightarrow$ dominated by di-leptonic $t\bar{t}$

- dominant background: $t\bar{t}$, W+jets, $t\bar{t}+V$, single top
- semi-leptonic and di-leptonic $t\bar{t}$ differ $\rightarrow$ split $t\bar{t}$ into 1L and 2L

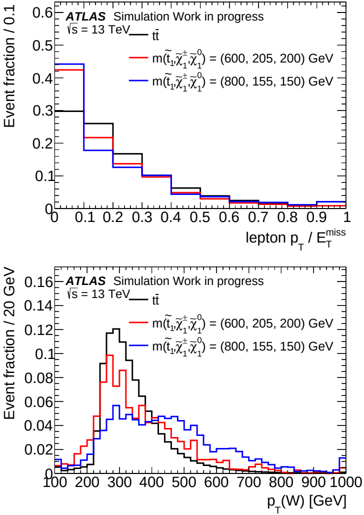


- discriminant variables: $E_{\mathrm{T}}^{\mathrm{miss}}$, am_{T2}, m_{T}, $\Delta R(b, \ell)$, reco. top mass

$\rightarrow$ design two signal regions

  - tN_high: single bin
  - tN_med: 4 $E_{\mathrm{T}}^{\mathrm{miss}}$ bins

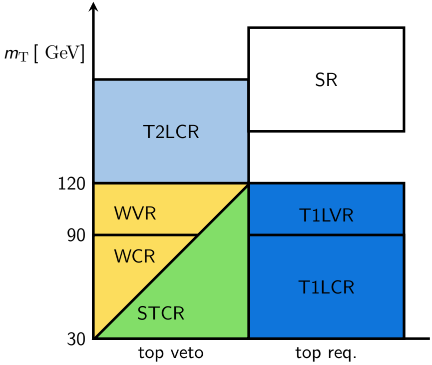
Signal Selection – bC_soft



- dominant background: $t\bar{t}$, W+jets and single top
- $t\bar{t}$ mainly semi-leptonic events
- discriminant variables: $E_{\mathrm{T}}^{\mathrm{miss}}$, m_{T}, p_{T}^{W}, lepton $p_{\mathrm{T}}/E_{\mathrm{T}}^{\mathrm{miss}}$, am_{T2}
- selection orthogonal to tN regions due to m_{T} cut

→ three signal regions, shape fit in lepton $p_{\mathrm{T}}/E_{\mathrm{T}}^{\mathrm{miss}}$

Background Estimate – tN



- define orthogonal regions
  - similar cuts to SR to ensure similar kinematics
  - invert some cuts to enrich specific background processes
- CRs: used in simultaneous fit to estimate data-driven normalisation
- VRs: not part of the fit, only for validation
- $t\bar{t} + Z$: normalisation estimated in a dedicated 3L selection

Background Estimate – tN

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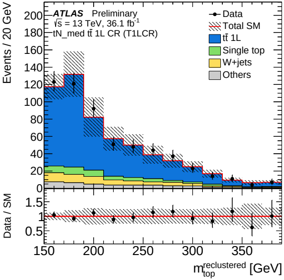
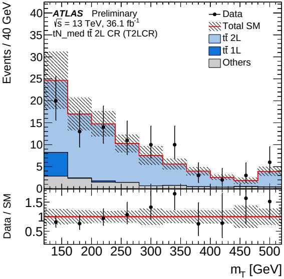
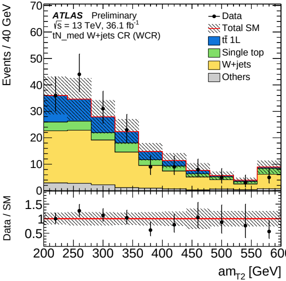
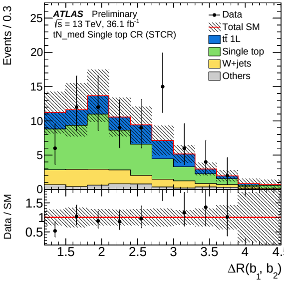




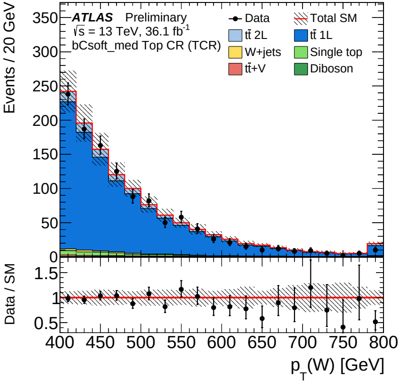


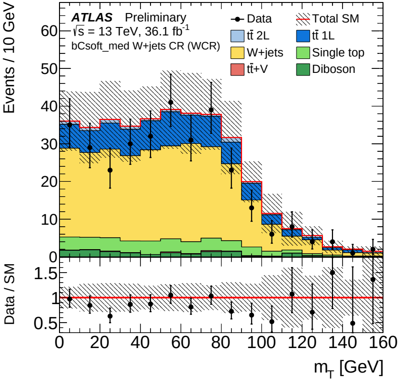


- check agreement in CRs, especially on variables used for the extrapolation
- good modelling observed
- normalisation factors estimated for tN_med agree with unity

$t\bar{t}$ 2L	$t\bar{t}$ 1L	$tt + \bar{W}/Z$	single top	W+jets
1.19 ± 0.13	1.08 ± 0.14	0.98 ± 0.38	0.94 ± 0.37	1.08 ± 0.21

Background Estimate





- similar approach for bC_soft regions
  - combined $t\bar{t}$, as dominated by semi-leptonic $t\bar{t}$
    - keep p_{T}^{W} constant to ensure same kinematic behaviour
    - invert am_{T2}, lepton $p_{\mathrm{T}}/E_{\mathrm{T}}^{\mathrm{miss}}$, number of b-tagged jets
  - good modelling in CRs

Background Validation

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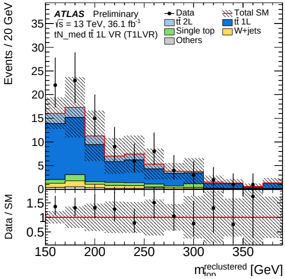
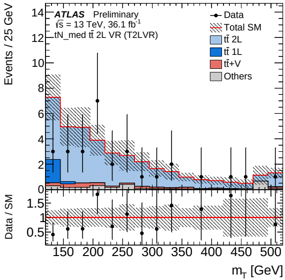
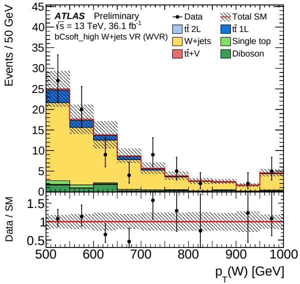
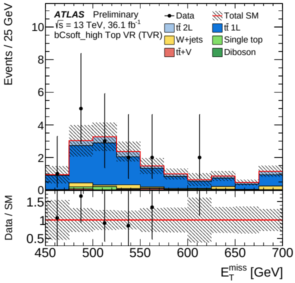








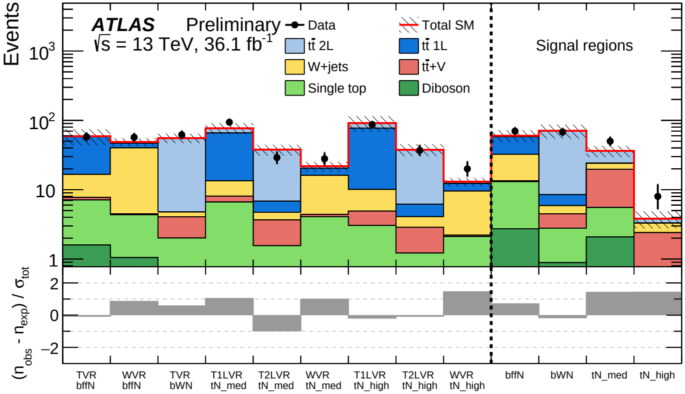
- overall good agreement in the various VR for all SRs
- test extrapolation of the background estimate from CR to SR

Systematic Uncertainties

ATLAS Work in progress	tN_med
total background expectation	36.31
total statistical ($\sqrt{N_{\mathrm{exp}}}$)	± 6.03
total background systematic	± 6.61 [18.21%]
$\mu_{t\bar{t}+V}$	± 4.00 [11.0%]
$t\bar{t}+V$ modelling	± 3.83 [10.6%]
$\mu_{t\bar{t}2\mathrm{L}}$	± 1.70 [4.7%]
$t\bar{t}$ radiation	± 1.55 [4.3%]
$t\bar{t}$ MC generator	± 1.31 [3.6%]
MC stat. (nominal samples)	± 1.28 [3.5%]
$\mu_{\mathrm{single\ top}}$	± 1.09 [3.0%]
jet energy resolution	± 1.01 [2.8%]
jet energy scale (1^{st} component)	± 1.01 [2.8%]
pileup reweighting	± 0.92 [2.5%]
$\mu_{W+\mathrm{jets}}$	± 0.92 [2.5%]
$t\bar{t}$ fragmentation	± 0.89 [2.5%]
flavour tagging c-jet mistag rate	± 0.83 [2.3%]
flavour tagging light-jet mistag rate	± 0.72 [2.0%]
diboson cross-section	± 0.43 [1.2%]
diboson modelling	± 0.40 [1.1%]

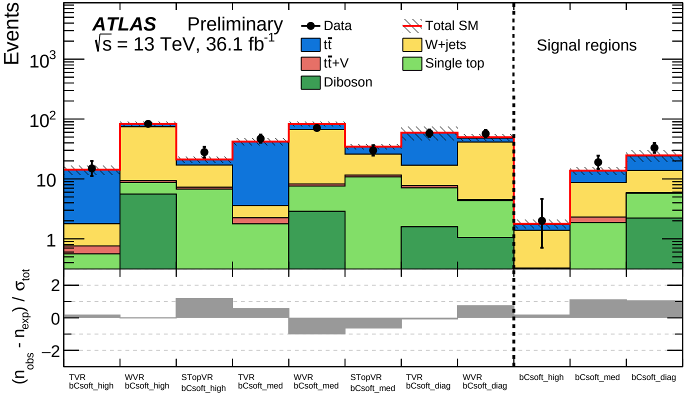
- systematic uncertainties as nuisance parameter in profile likelihood fit
- similar size for statistical and systematic uncertaintiy
- dominant theoretical uncertainty: $t\bar{t}+V$ modelling
  - dominant background
- dominant experimental uncertaintiy: jet energy resolution
  - influences m_T resolution

Results – VRs and SRs



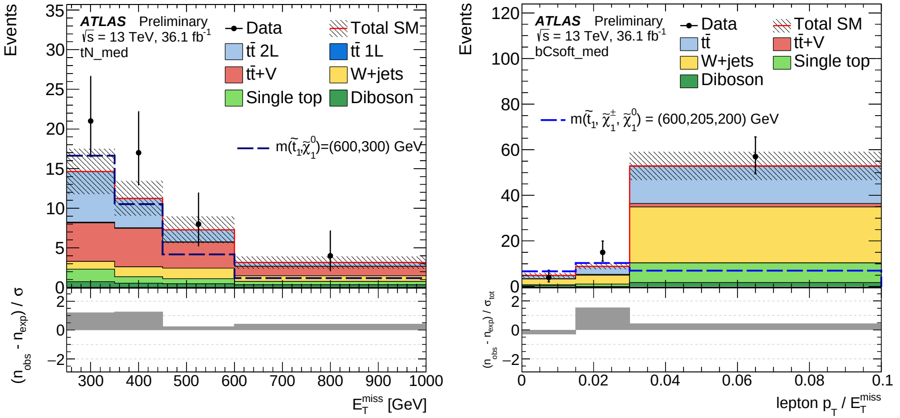
- VR and SR for tN_med and tN_high
- largest differences: T2LV for tN_med, WVR for tN_high
- overall good agreement in VRs
- small excess in tN_med and tN_high, but not significant

Results – VRs and SRs



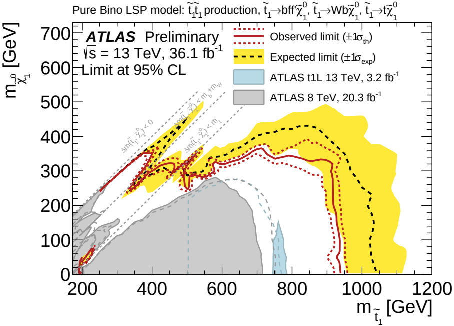
- VR and SR for bC_soft regions
- largest differences: STVR_high, WVR_med
- overall good agreement in VRs
- small excess in bCsoft_med and bCsoft_diag, but not significant

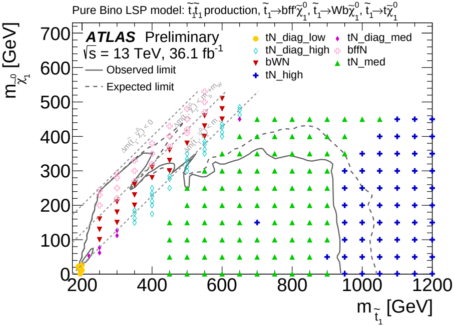
Results



- exclusion fits: using shape information
- $E_{\mathrm{T}}^{\mathrm{miss}}$ shape for tN_med
- lepton $p_{\mathrm{T}}/E_{\mathrm{T}}^{\mathrm{miss}}$ shape for the bC_soft regions

Results





- exclusion limits using all regions in analysis
  - additional regions will be covered in the next talk
- stop quark masses are excluded to 950 GeV for massless neutralinos
- for intermediate stop quark masses (around 800 GeV): neutralino masses up to 320 GeV excluded

Combination

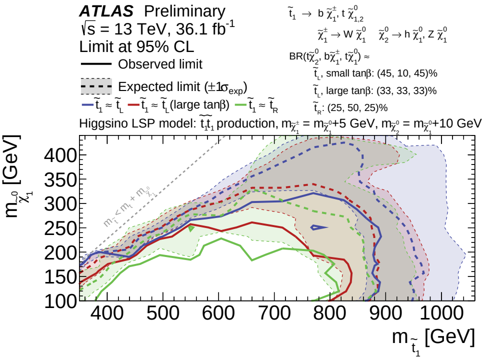
Higgsino LSP: mixture of $\tilde{t} \rightarrow t\tilde{\chi}_1^0$, $\tilde{t} \rightarrow t\tilde{\chi}_2^0$ and $\tilde{t} \rightarrow b\tilde{\chi}_1^\pm$ possible

- tN regions sensitive to $\tilde{t} \rightarrow t\tilde{\chi}_1^0$, $\tilde{t} \rightarrow t\tilde{\chi}_2^0$
- soft lepton regions sensitive to $\tilde{t} \rightarrow b\tilde{\chi}_1^\pm$

$\Rightarrow$ statistical combination of tN_med with the three soft lepton regions

- SR orthogonal (due to m_T requirement), overlap in CRs removed

- small tan β: similar to tN reach, as 90% decay into $t\tilde{\chi}_{1,2}^0$
- right-handed decay: mainly $b\tilde{\chi}_1^\pm$, sensitivity from soft lepton selection
- large tan β: equivalent BRs, largest gain with the combination



Summary and Outlook

- presented search strategy and results for
  - tN signal regions for Bino LSP at intermediate and high stop quark masses
  - soft lepton selection for Higgsino LSP
  - combination of these selections to be sensitive to Higgsino mixtures
- no significant excess observed
  - exclusion limits for Bino and Higgsino LSP models
- further signal regions and more interpretations

  $\rightarrow$ covered in the next talk

Selection – tN

	tN_med	T1LCR/VR	T2LCR/VR	WCR/VR	STCR
Preselection	high-$E_{\mathrm{T}}^{\mathrm{miss}}$ preselection				
Number of (jets, b-tags)	$(\geq 4, \geq 1)$	$(\geq 4, \geq 1)$	$(\geq 4, \geq 1)$	$(\geq 4, \geq 1)$	$(\geq 4, \geq 2)$
Jet p_{T} [GeV]	$> (60, 50, 40, 40)$				
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 250				
$E_{\mathrm{T},\perp}^{\mathrm{miss}}$ [GeV]	> 230				
m_{T} [GeV]	> 160	$[30, 90]$ / $[90, 120]$	> 120	$[30, 90]$ / $[90, 120]$	$[30, 120]$
$H_{\mathrm{T,sig}}^{\mathrm{miss}}$	> 14	> 10	> 10	> 10	> 10
$m_{\mathrm{top}}^{\mathrm{reclustered}}$ [GeV]	> 150	> 150	top veto / > 150	top veto	top veto
am_{T2} [GeV]	> 175	< 200	< 200 / < 130	> 200	> 200
$\Delta R(b, \ell)$	< 2.0	–	–	–	–
$\Delta R(b_1, b_2)$	–	–	–	< 1.2	> 1.2
lepton charge	–	–	–	$+1$	–
$\lvert\Delta\phi(j_{1,2}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})\rvert$	> 0.4				
m_{T2}^{τ} based τ-veto [GeV]	> 80				

	tN_high	T1LCR/VR	T2LCR/VR	WCR/VR	STCR
Preselection	high-$E_{\mathrm{T}}^{\mathrm{miss}}$ preselection				
Number of (jets, b-tags)	$(\geq 4, \geq 1)$	$(\geq 4, \geq 1)$	$(\geq 4, \geq 1)$	$(\geq 4, \geq 1)$	$(\geq 4, \geq 2)$
Jet p_{T} [GeV]	$> (100, 80, 50, 30)$				
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 550	> 350	> 350	> 350	> 350
m_{T} [GeV]	> 160	$[30, 90]$ / $[90, 120]$	> 120	$[30, 90]$ / $[90, 120]$	$[30, 120]$
$H_{\mathrm{T,sig}}^{\mathrm{miss}}$	> 27	> 10	> 10	> 10	> 10
$m_{\mathrm{top}}^{\mathrm{reclustered}}$ [GeV]	> 130	> 130	top veto / > 130	top veto	top veto
am_{T2} [GeV]	> 175	< 200	< 200 / < 130	> 200	> 200
$\Delta R(b, \ell)$	< 2.0	–	–	–	–
$\Delta R(b_1, b_2)$	–	–	–	< 1.2	> 1.2
lepton charge	–	–	–	$+1$	–
$\lvert\Delta\phi(j_{1,2}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})\rvert$	> 0.4				
m_{T2}^{τ} based τ-veto [GeV]	> 80				

Selection – bCsoft_diag

	bCsoft_diag/bffN	TCR/VR	WCR/VR
Preselection	soft-lepton preselection		
Number of (jets, b-tags)	$(\geq 2, \geq 1)$	$(\geq 2, \geq 1)$	$(\geq 2, = 1)$
Jet p_{T} [GeV]		$(120,\ 25)$	
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]		> 300	
m_{T} [GeV]	< 50 / < 160	< 160	< 160
$p_{\mathrm{T}}^{\ell}/E_{\mathrm{T}}^{\mathrm{miss}}$	< 0.02	$[0.03, 0.10]$ / < 0.03	$[0.03, 0.10]$ / < 0.03
$m_{\mathrm{top}}^{\mathrm{reclustered}}$ [GeV]	top veto	> 150	top veto
$\min(\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, b\text{-jet}_i))$	< 1.5	< 1.5	> 1.5
$\lvert\Delta\phi(j_{1,2}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})\rvert$		> 0.4	

Selection – bCsoft_med and high

	bCsoft_med	TCR/VR	WCR/VR	STCR/VR
Preselection	soft-lepton preselection			
Number of (jets, b-tags)	$(\geq 3, \geq 2)$	$(\geq 3, \geq 2)$	$(\geq 3, = 1)$	$(\geq 3, \geq 2)$
Jet p_{T} [GeV]	$> (120,\ 60,\ 40,\ 25)$			
b-tagged jet p_{T} [GeV]	$> (120,\ 60)$	$> (120,\ 60)$	> 120	$> (120,\ 60)$
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 230			
m_{T} [GeV]	> 160			
p_{T}^{W} [GeV]	> 400			
$p_{\mathrm{T}}^{\ell}/E_{\mathrm{T}}^{\mathrm{miss}}$	< 0.03	> 0.03 / < 0.03	> 0.20 / $[0.1, 0.2]$	> 0.20 / $[0.1, 0.2]$
am_{T2} [GeV]	> 200	< 200	> 200	> 200
$\min(\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, b\text{-jet}_i))$	> 0.8	–	$[0.8, 2.5]$	> 0.8
$\Delta R(b_1, b_2)$	–	–	–	> 1.2
$\lvert\Delta\phi(j_{1,2}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})\rvert$	> 0.4			

	bCsoft_high	TCR/VR	WCR/VR	STCR/VR
Preselection	soft-lepton preselection			
Number of (jets, b-tags)	$(\geq 2, \geq 2)$	$(\geq 2, \geq 2)$	$(\geq 2, = 1)$	$(\geq 2, \geq 2)$
Jet p_{T} [GeV]	$> (100,\ 100)$			
b-tagged jet p_{T} [GeV]	$> (100,\ 100)$			
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 230			
m_{T} [GeV]	> 160			
p_{T}^{W} [GeV]	> 500			
$p_{\mathrm{T}}^{\ell}/E_{\mathrm{T}}^{\mathrm{miss}}$	< 0.03	> 0.10 / < 0.10	$[0.1, 0.4]$ / < 0.10	> 0.30 / $[0.1, 0.3]$
am_{T2} [GeV]	> 300	< 300	> 300	> 300
$\min(\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, b\text{-jet}_i))$	> 0.4			
$\Delta R(b_1, b_2)$	> 0.8	> 0.8	–	> 0.8
$\Delta R(b, \ell)$	–	–	> 0.8	–
$\lvert\Delta\phi(j_{1,2}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})\rvert$	> 0.4			

Higgsino exclusion – Δm