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AEC ALBERT EINSTEIN CENTER FOR FUNDAMENTAL PHYSICS

ATLAS EXPERIMENT

Bottom Squark searches in Decay Chains with the Higgs Boson

SPS Annual Conference - Lausanne

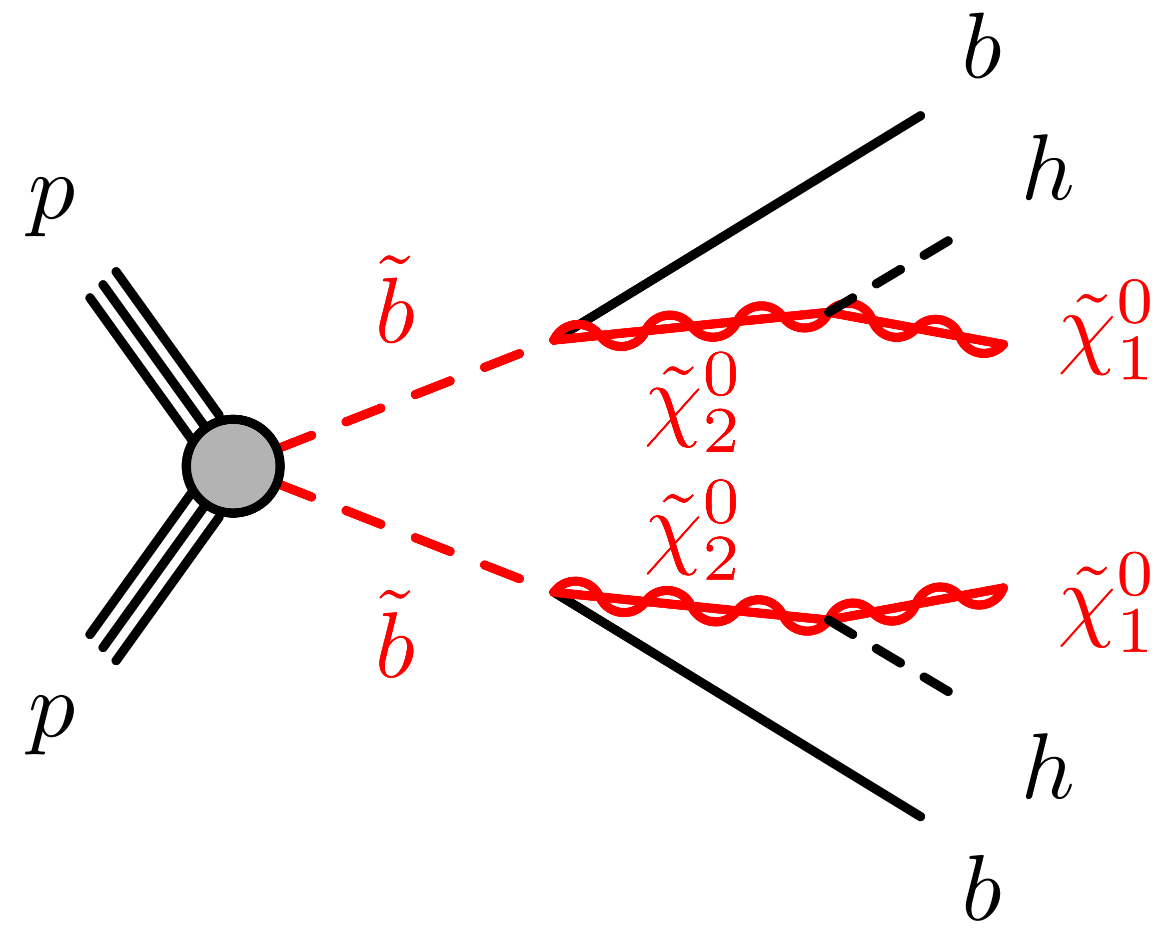
Thomas Weston

https://cds.cern.ch/record/2632345

29.08.18

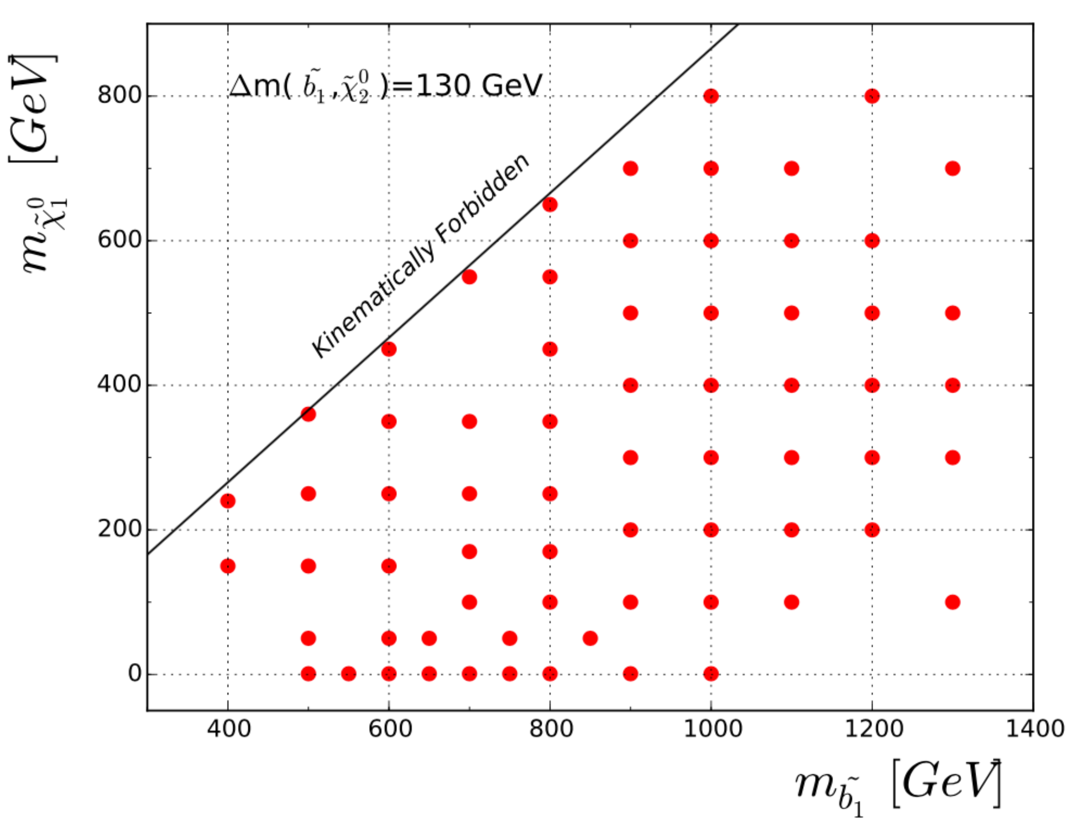
Introduction

- Complex decay chain of sbottom - supersymmetric partner to bottom quark.
- All branching ratios assume 100% apart from SM-like Higgs.
- Exploiting the dominant decay of Higgs:
  - final state with multiple b-jets and E_T^{miss}.

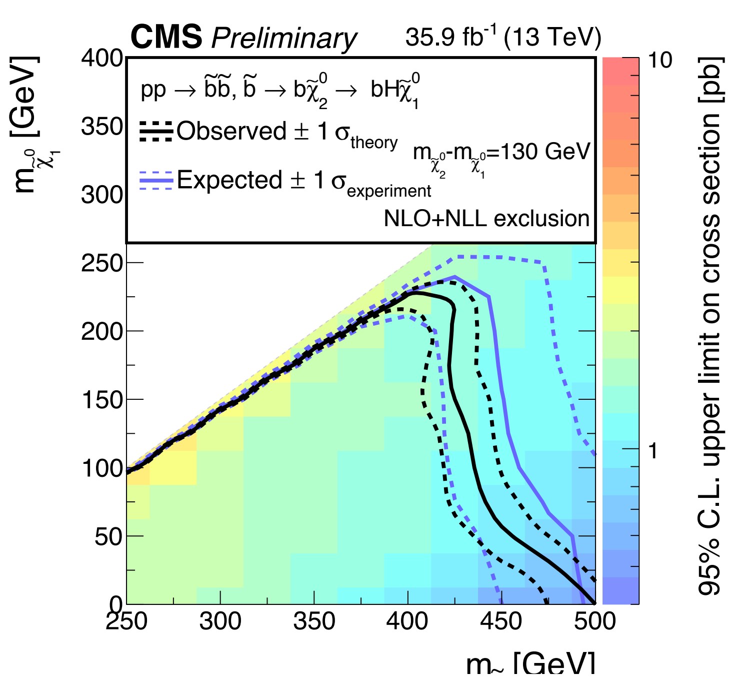


Signal Models and Previous Limits

$$\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) = 130\text{GeV}$$

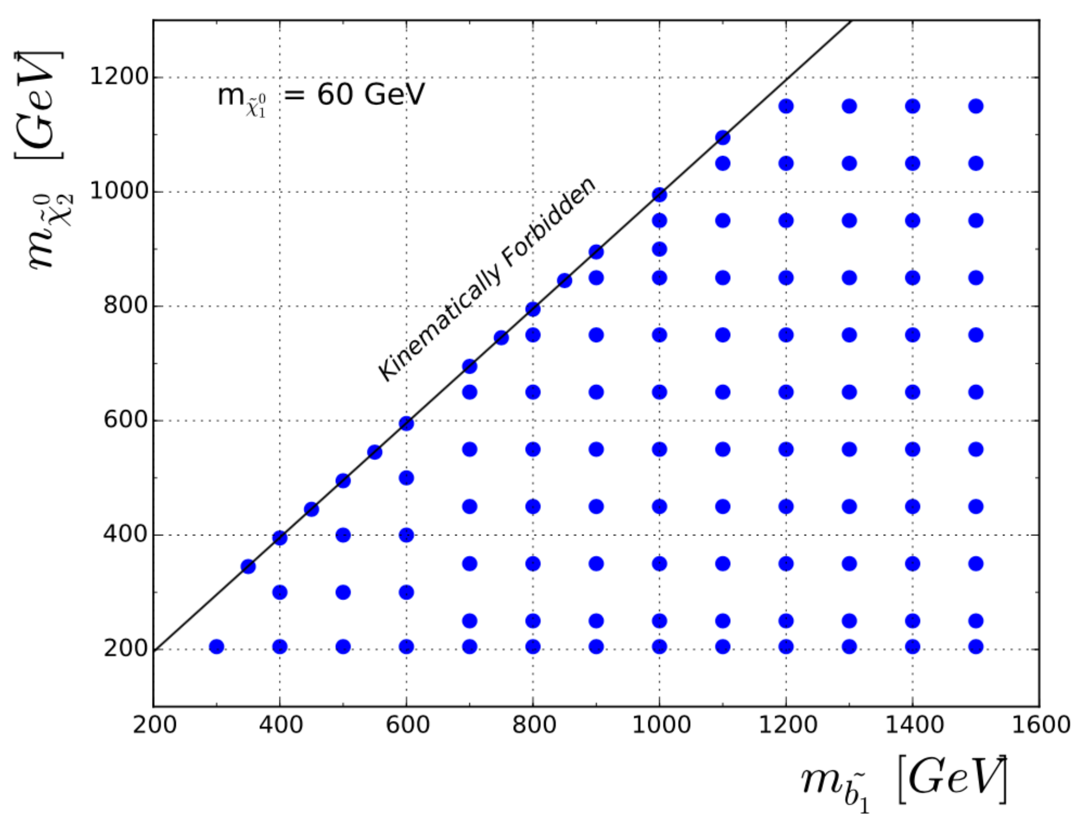


- produces an on-shell Higgs.

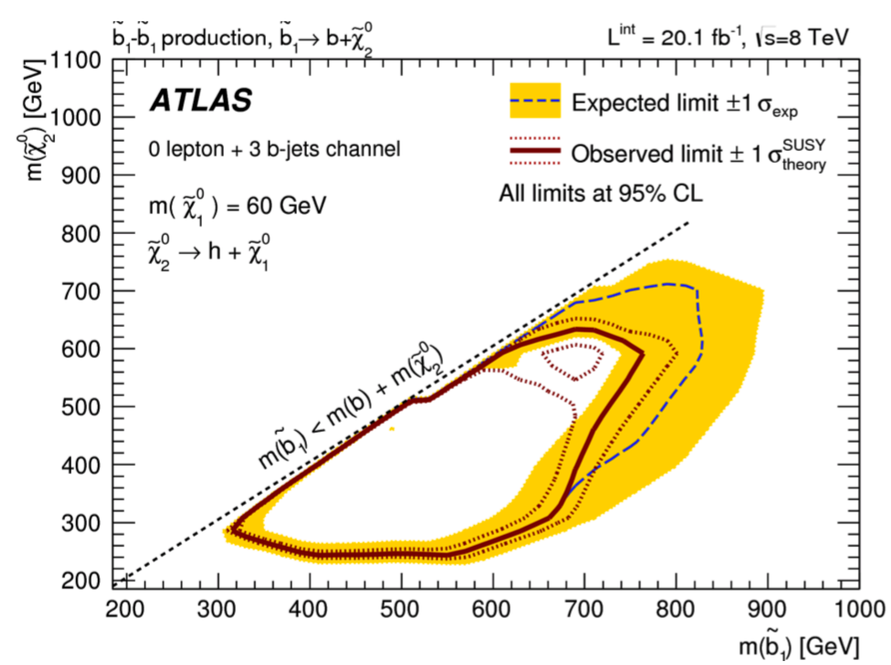


http://cms-results.web.cern.ch/cms-results/public-results/publications/SUS-16-045/

$$m(\tilde{\chi}_1^0) = 60\text{GeV}$$



- limits set by LEP to ~ 60 GeV.



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/SUSY-2013-18/

Analysis Strategy

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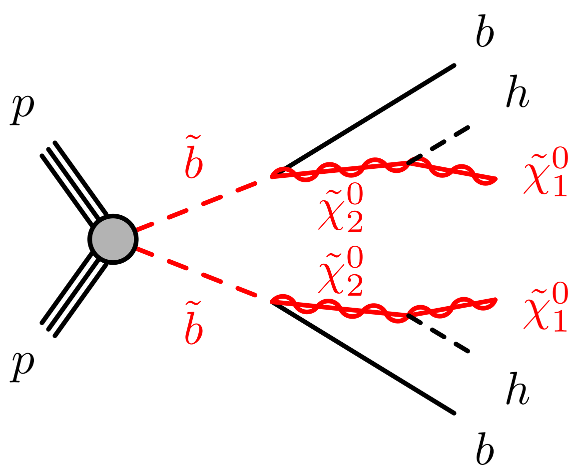
- 3 Signal Regions target different mass hierarchies:
  - Majority of both models (SRA)
  - Compressed regions (SRB & SRC)
- Control and Validation regions model and validate the SM backgrounds.



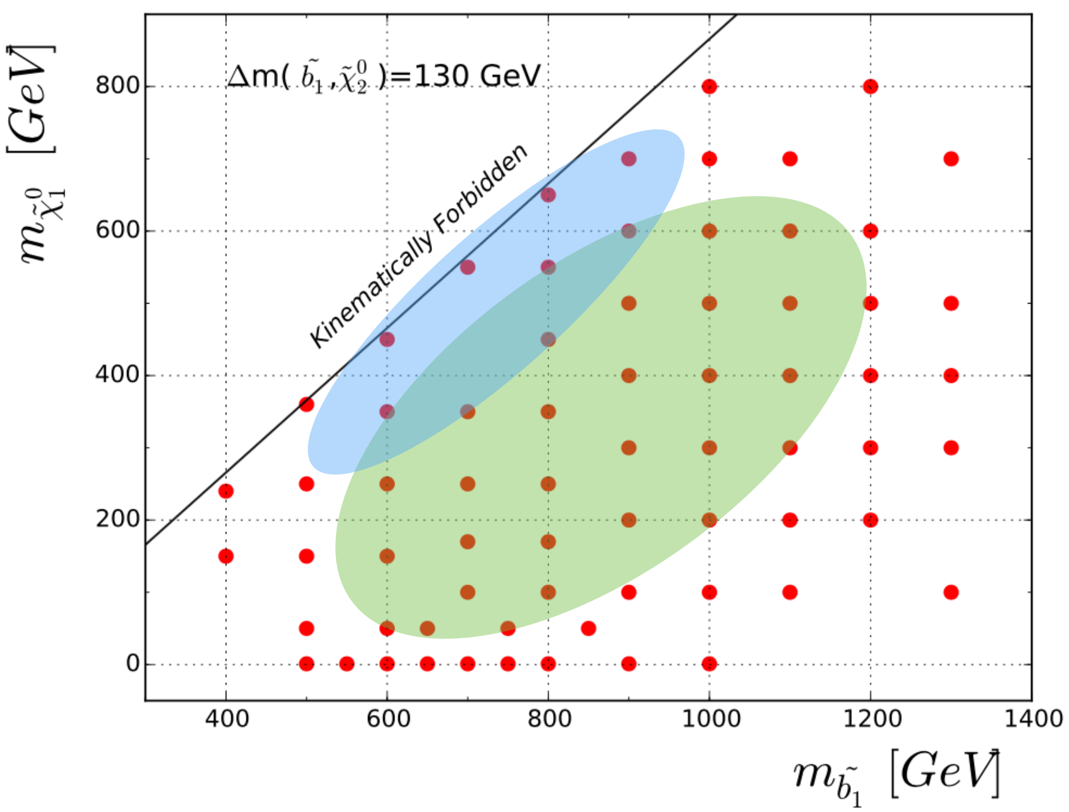
SRA

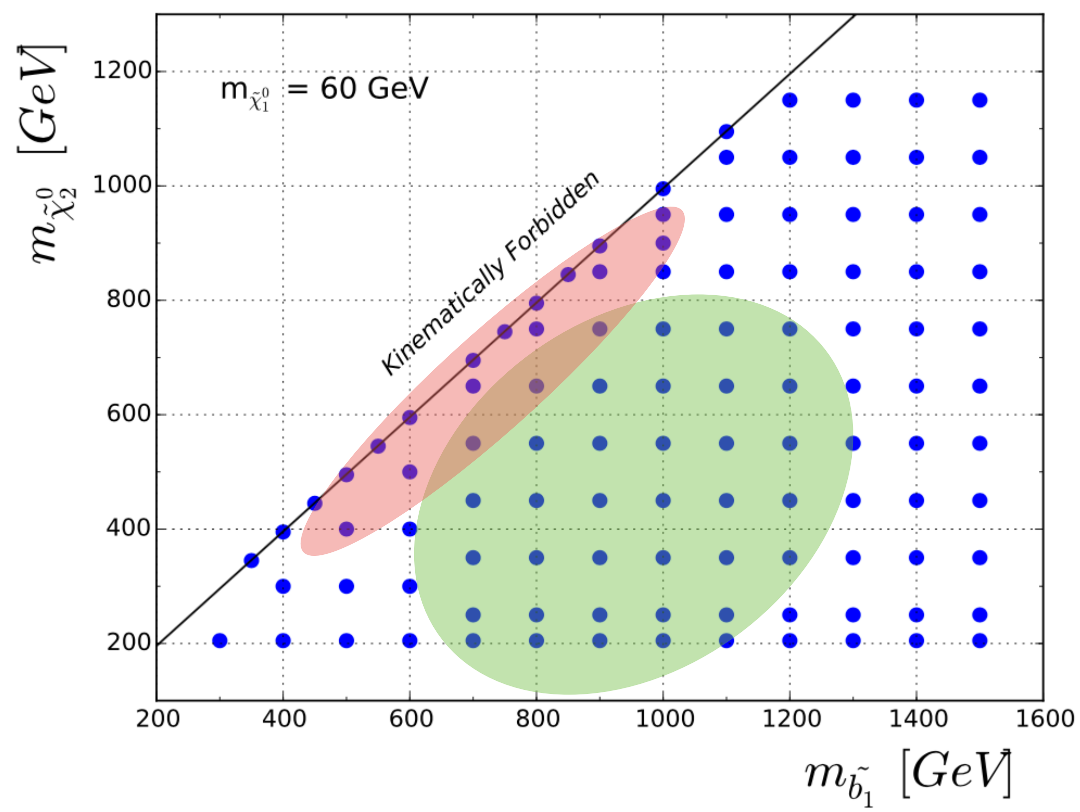
SRB

SRC

$$\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) = 130\text{GeV}$$

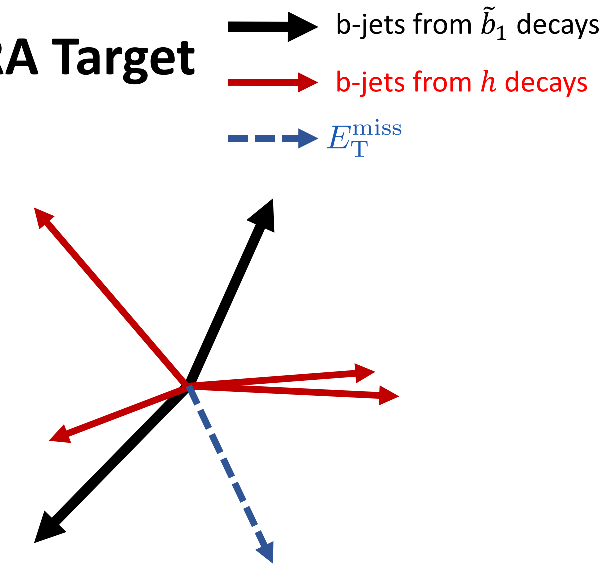
$$m(\tilde{\chi}_1^0) = 60\text{GeV}$$





SRA Overview

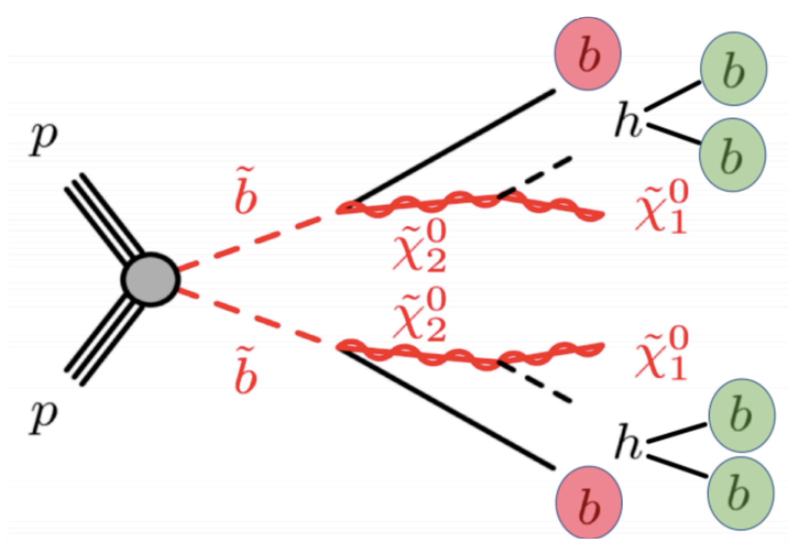
SRA Target

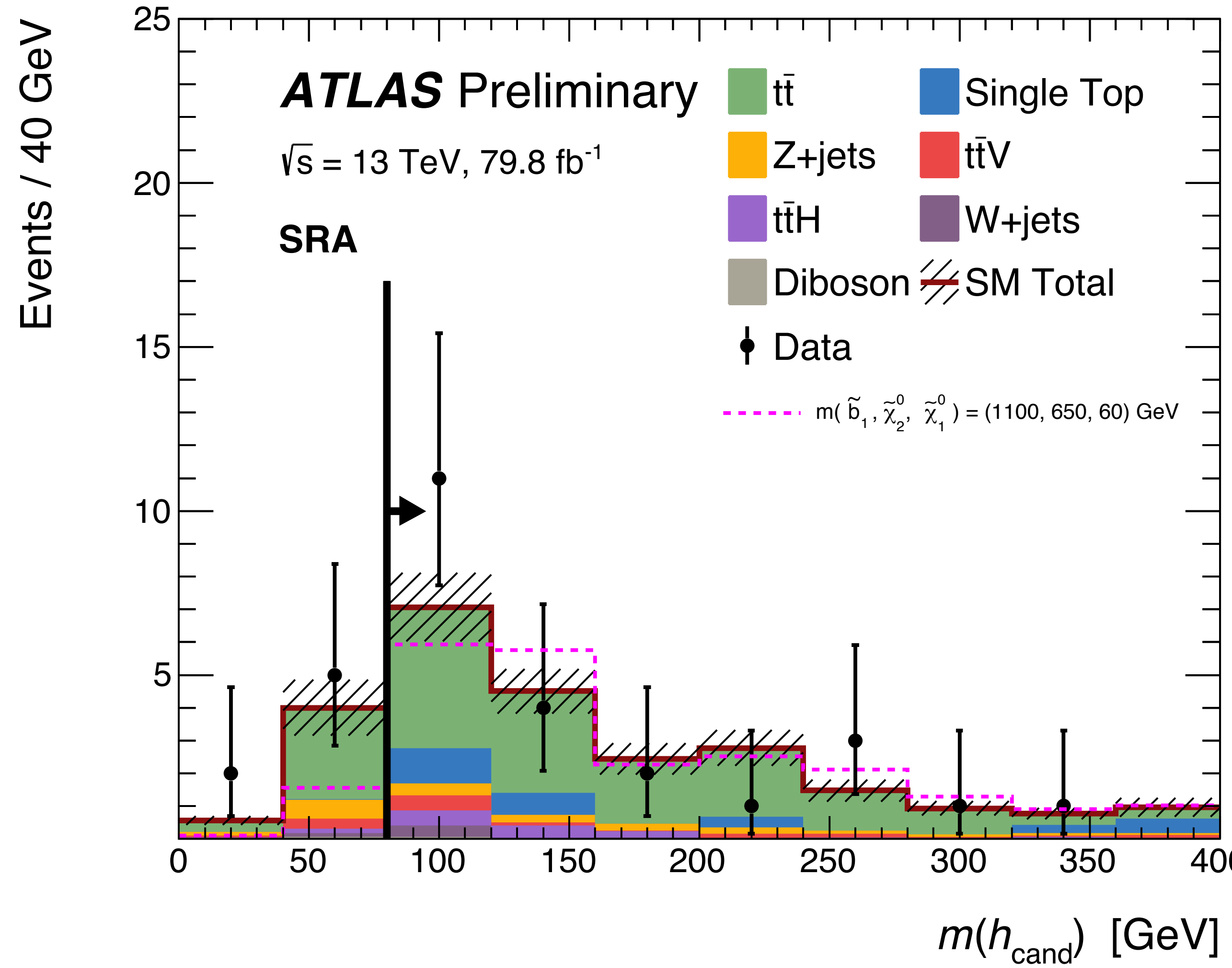


- SRA covers majority phase space of both signal models.
- Designated MaxMin algorithm used to identify one Higgs candidate.

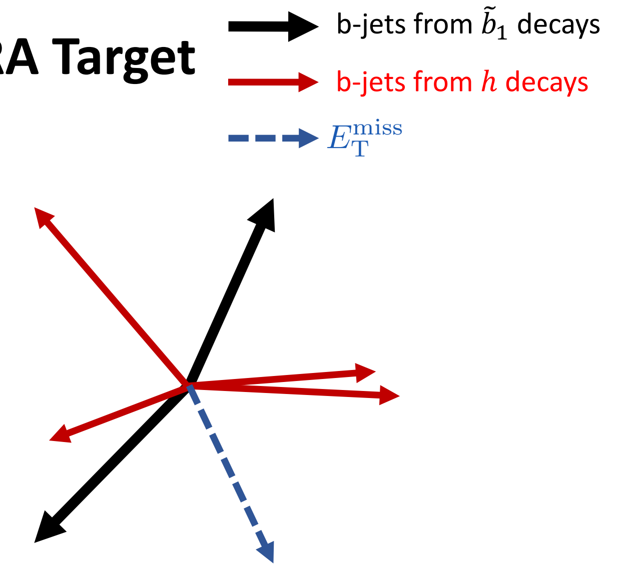
MaxMin Algorithm

- **Requires >= 4 b-jets.**
- **Identify b-jets with max ΔR (SUSY decay) and remove from iteration.**
- **Identify b-jets with min ΔR (Higgs decay) and form a single Higgs candidate.**
- **Apply Higgs-like invariant mass cut m_{bb} > 80 GeV.**



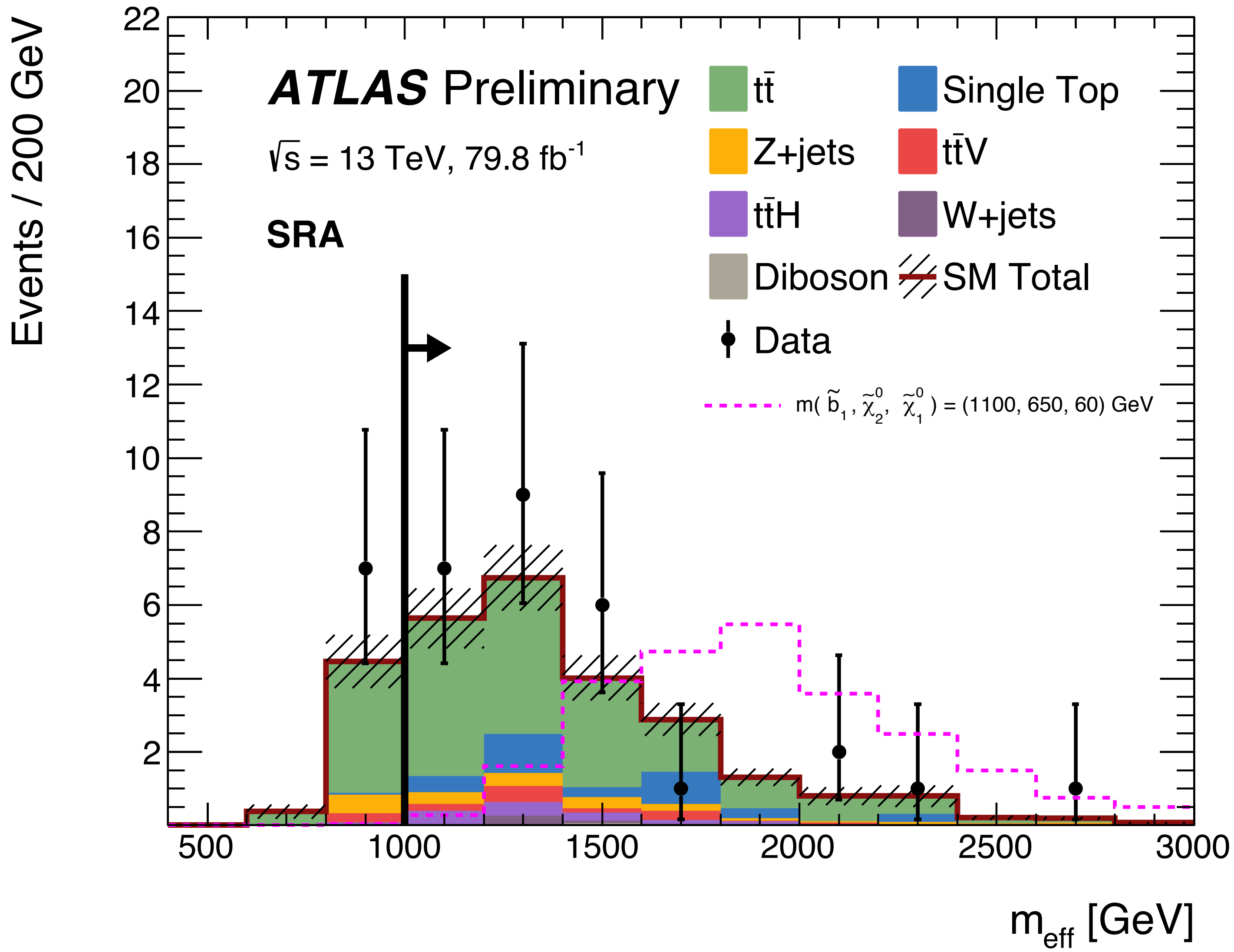


SRA Target



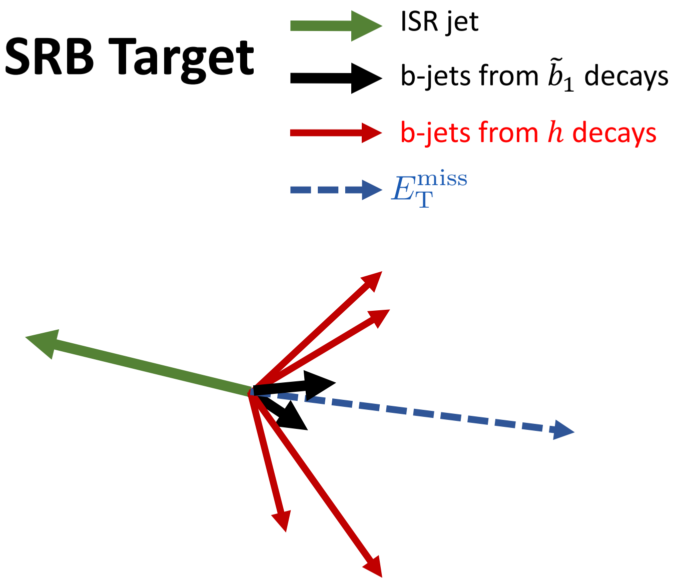
- m_{eff} main discriminating variable.
- m_{eff} phase space split into 3 orthogonal SRs + SR-inclusive.
- Simultaneous fit of these SRs provides exclusion power.

Variable	SRA	SRA-L	SRA-M	SRA-H
m_{eff} [TeV]	> 1.0	∈ [1.0, 1.2]	∈ [1.2, 1.5]	> 1.5



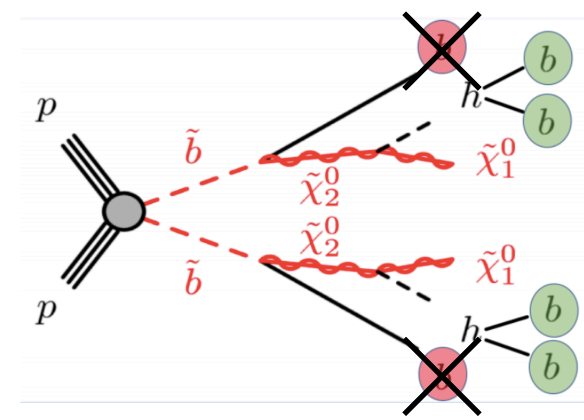
SRB Overview

SRB Target

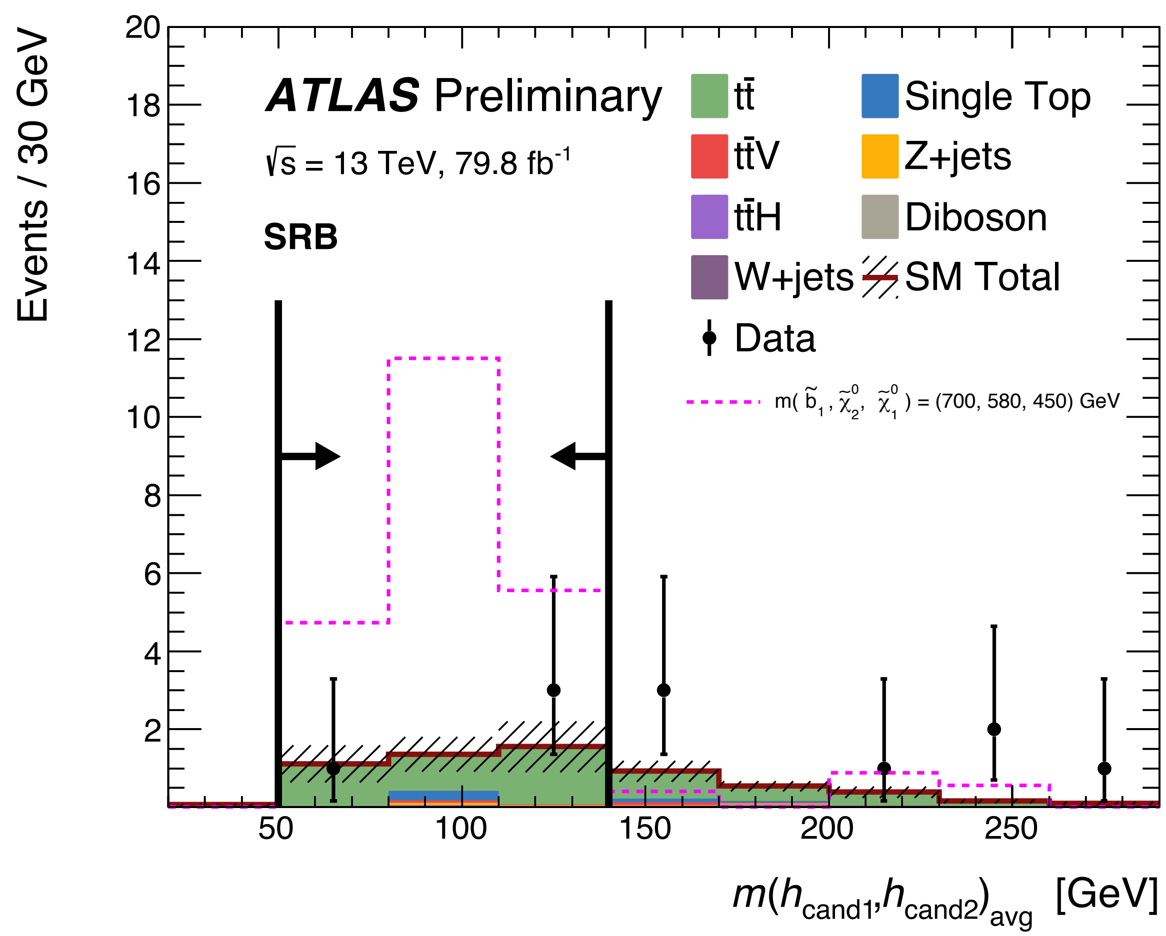


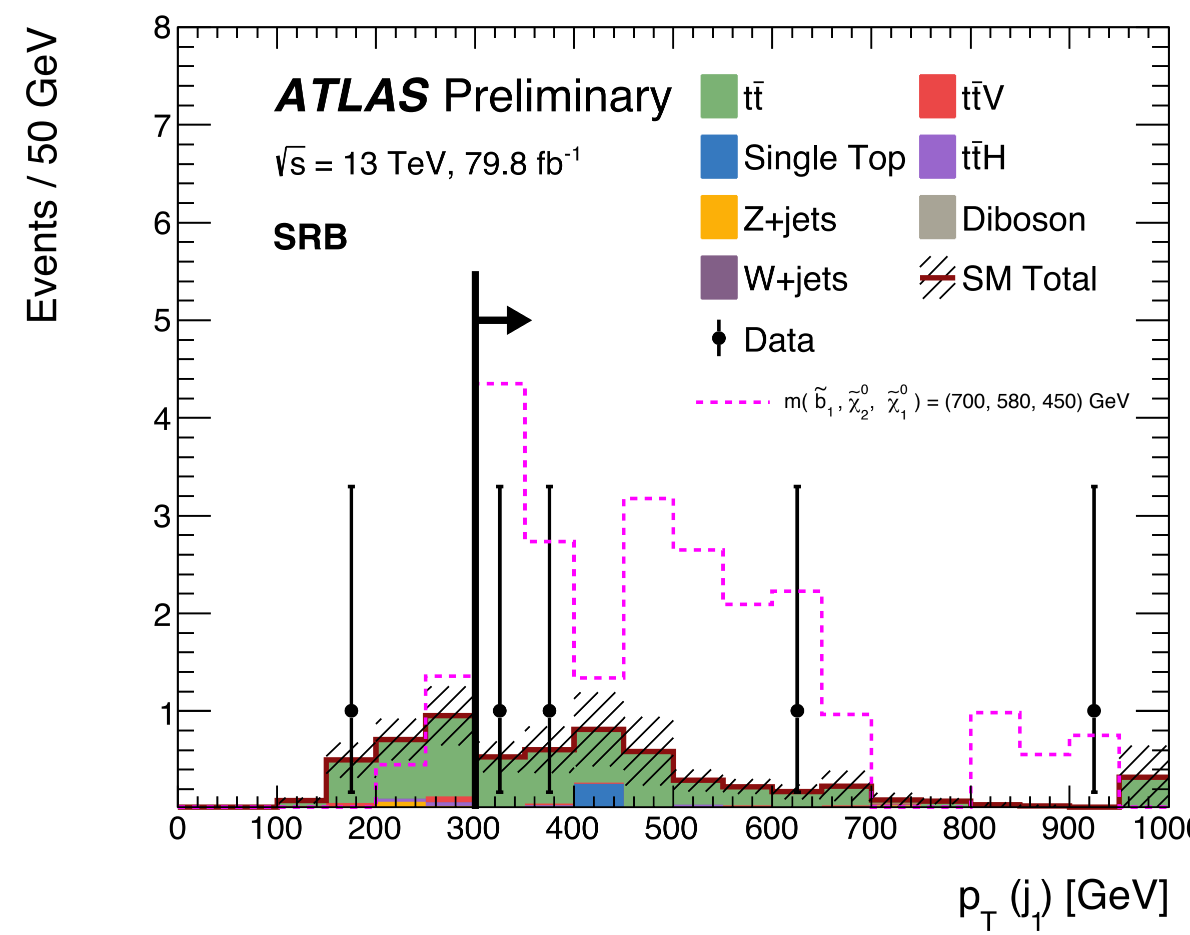
Modified MaxMin Algorithm

- Loop over all combinations.
- minimise max ΔR of both b-jet pairs.
 i.e. minimises maxΔR(b_1,b_2; b_3,b_4)



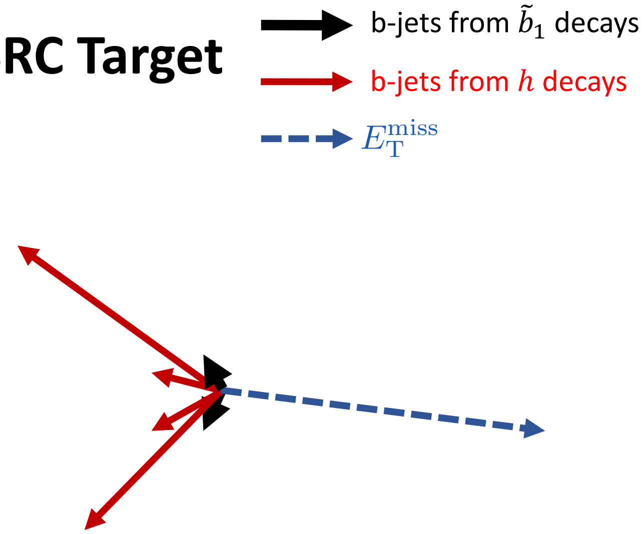
- Targets compressed region of $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) = 130\mathrm{GeV}$ model using ISR scenario.
- Due to soft (5-20 GeV) b-jets, don't pass p_T > 30 GeV requirement.
- loss of two b-jets requires modification of MaxMin algorithm.





SRC Overview

SRC Target



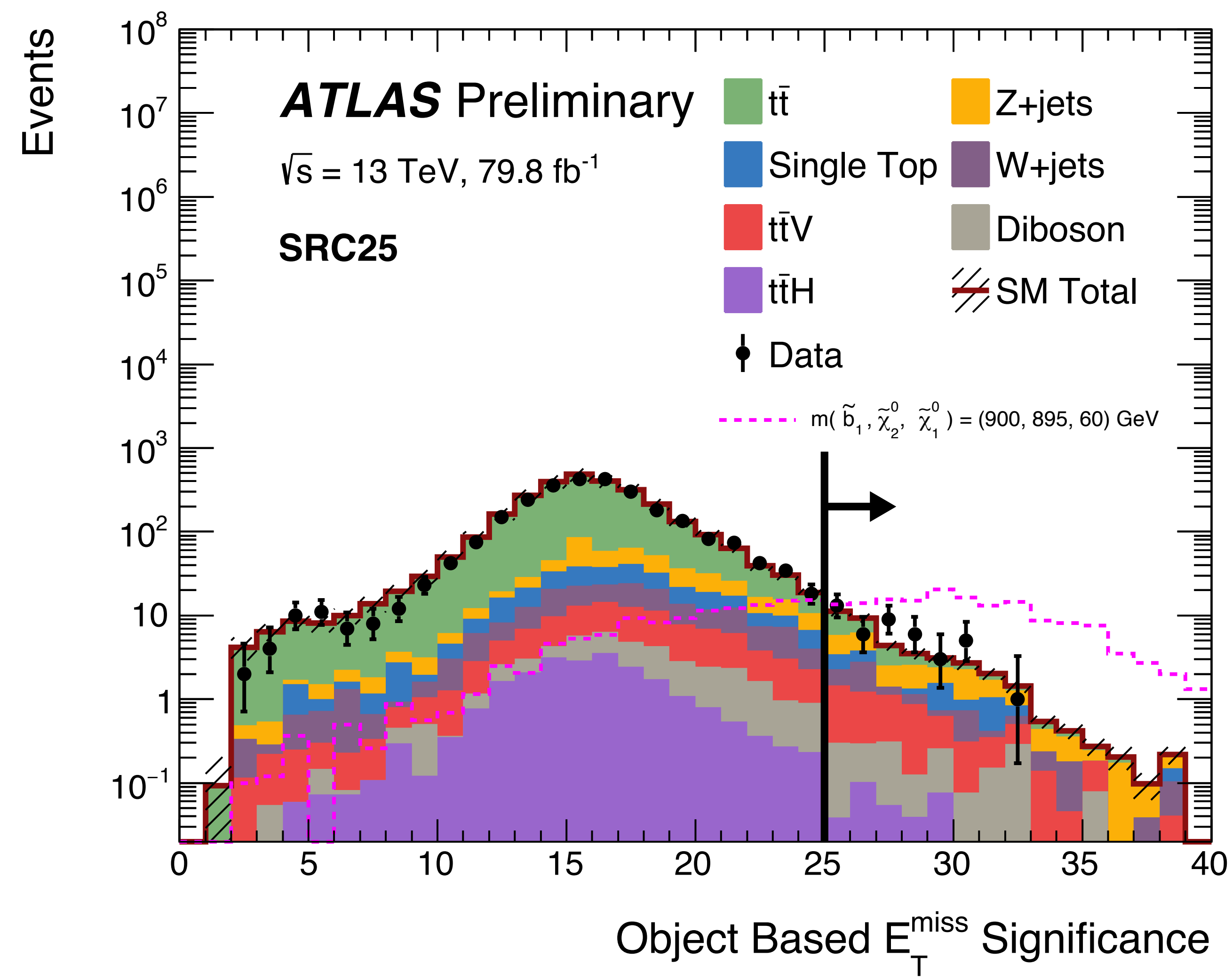
- Targets compressed region of $m(\tilde{\chi}_1^0) = 60\mathrm{GeV}$ model.
- Highly boosted scenario.
- Object based MET significance variable becomes key!

object-based MET Significance Variable

$$S^2 = 2\ \ln\left(\frac{\mathcal{L}(\overrightarrow{E_{\mathrm{T}}^{\mathrm{miss}}} = \sum_i \overrightarrow{E_{\mathrm{T}\ i}^{\mathrm{miss Reco}}})}{\mathcal{L}(\overrightarrow{E_{\mathrm{T}}^{\mathrm{miss Truth}}} = 0)}\right)$$

- log likelihood ratio which accounts for the differing resolutions.

https://cds.cern.ch/record/2630948/files/ATLAS-CONF-2018-038.pdf



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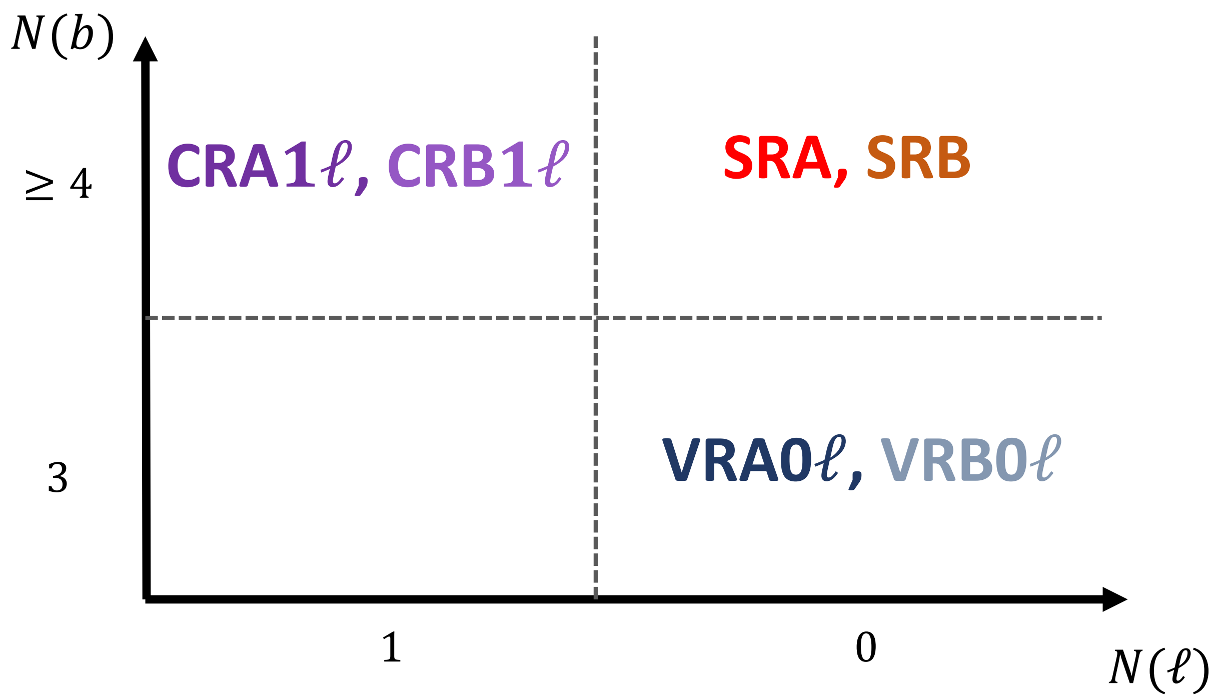
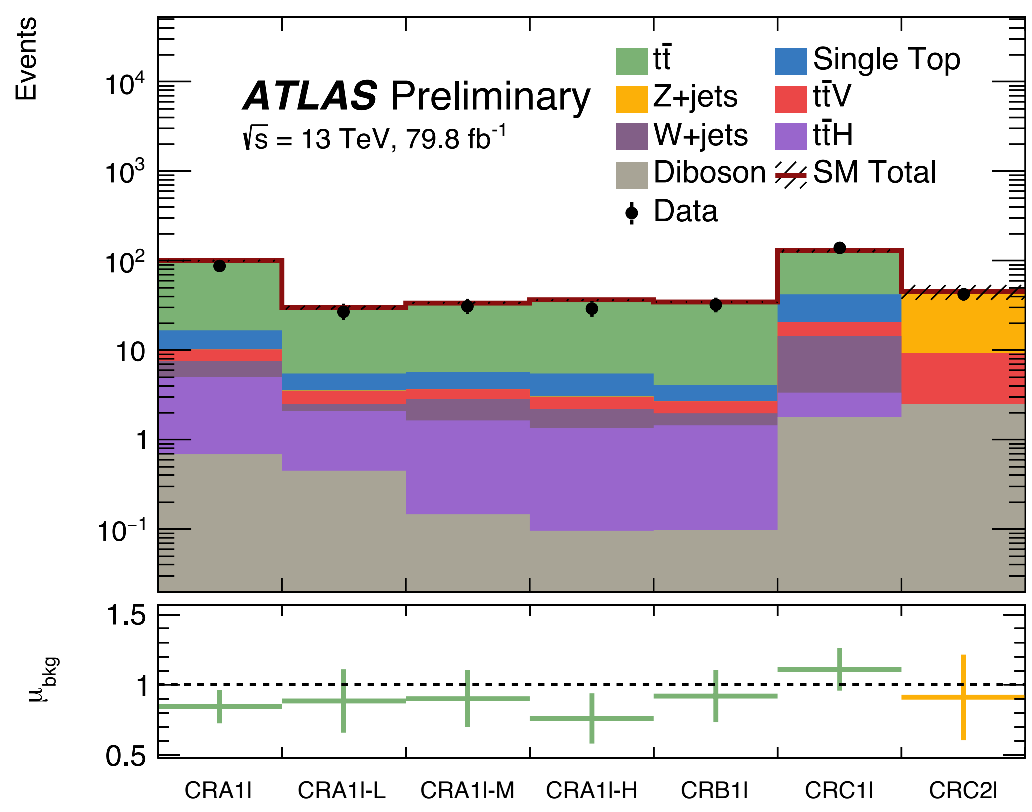
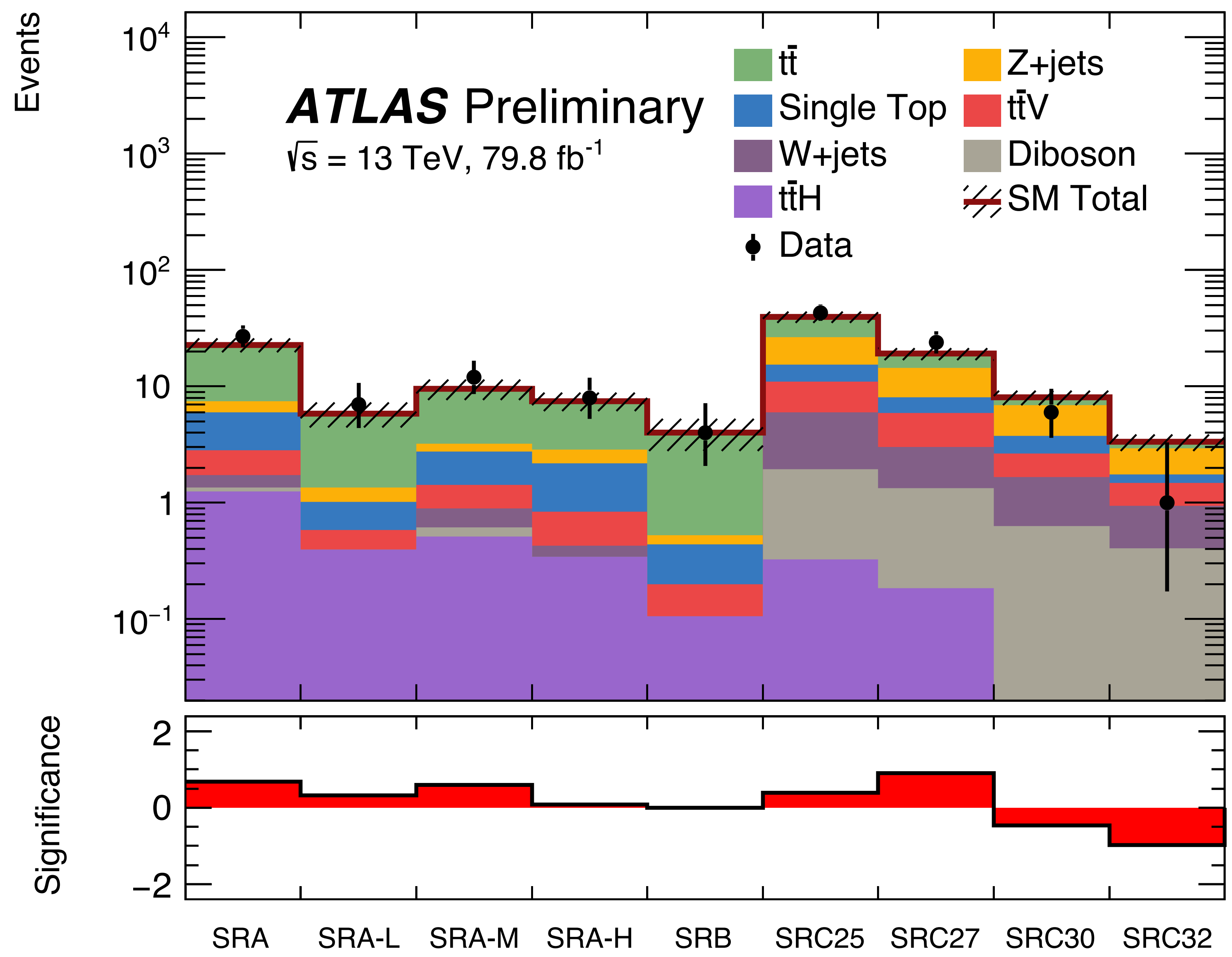
- SRA and SRB ttbar is dominant.
- Orthogonal through lepton and b-jet multiplicity.
- Background-only fit is performed using the CRs and scale factors are used to normalise the SRs.





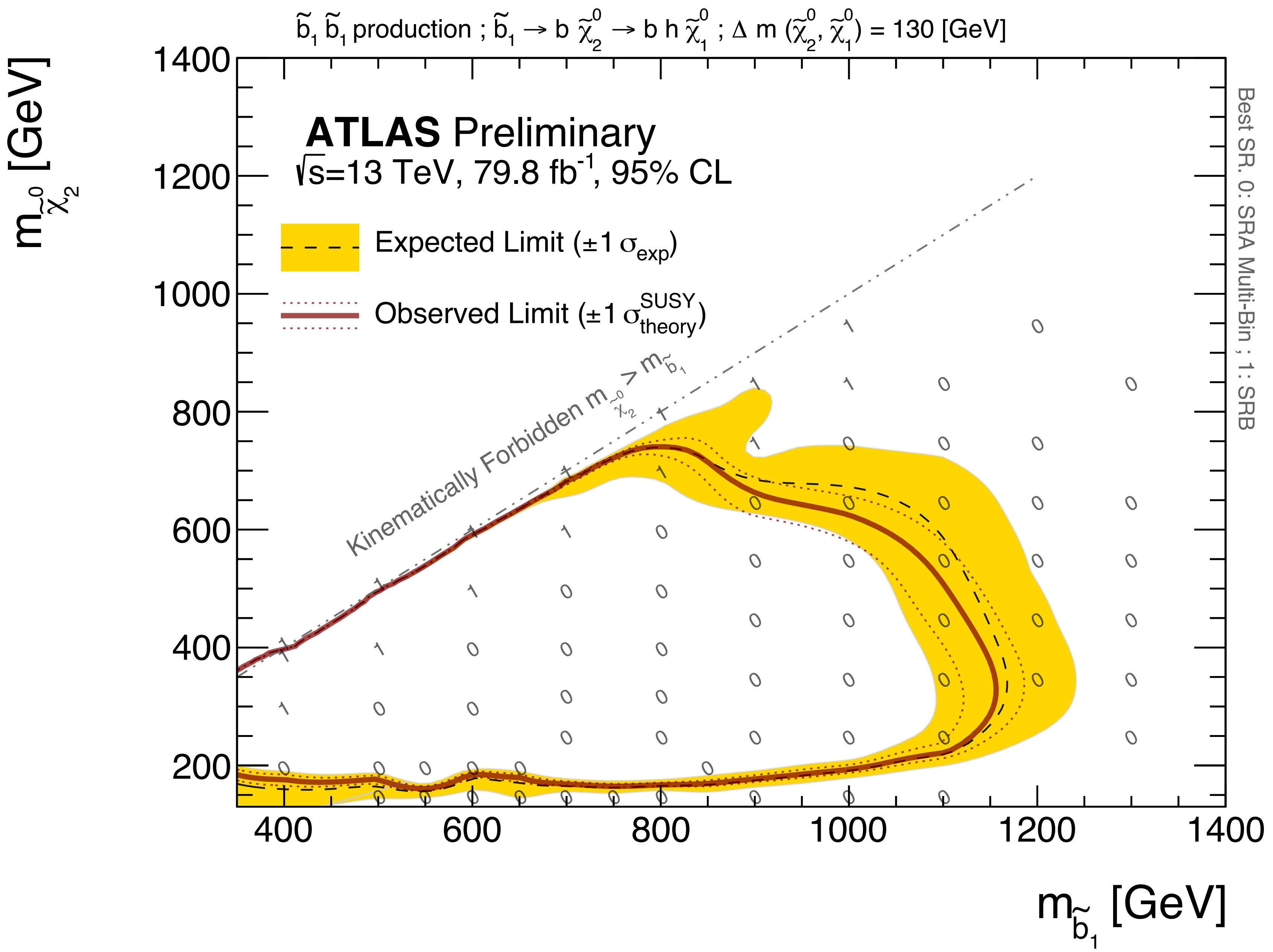
- Control region event yields compared to SM MC predictions.
- All scale factors are consistent with 1, suggesting good modelling.
- All uncertainties include statistical and systematics.

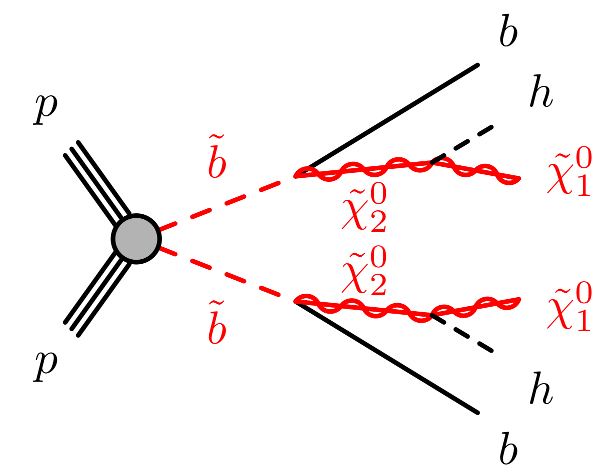
Results



- Results of background-only fit extrapolated to all signal regions.
- Normalisations calculated from scale factor in control regions.
- No significant excess found in any signal region.

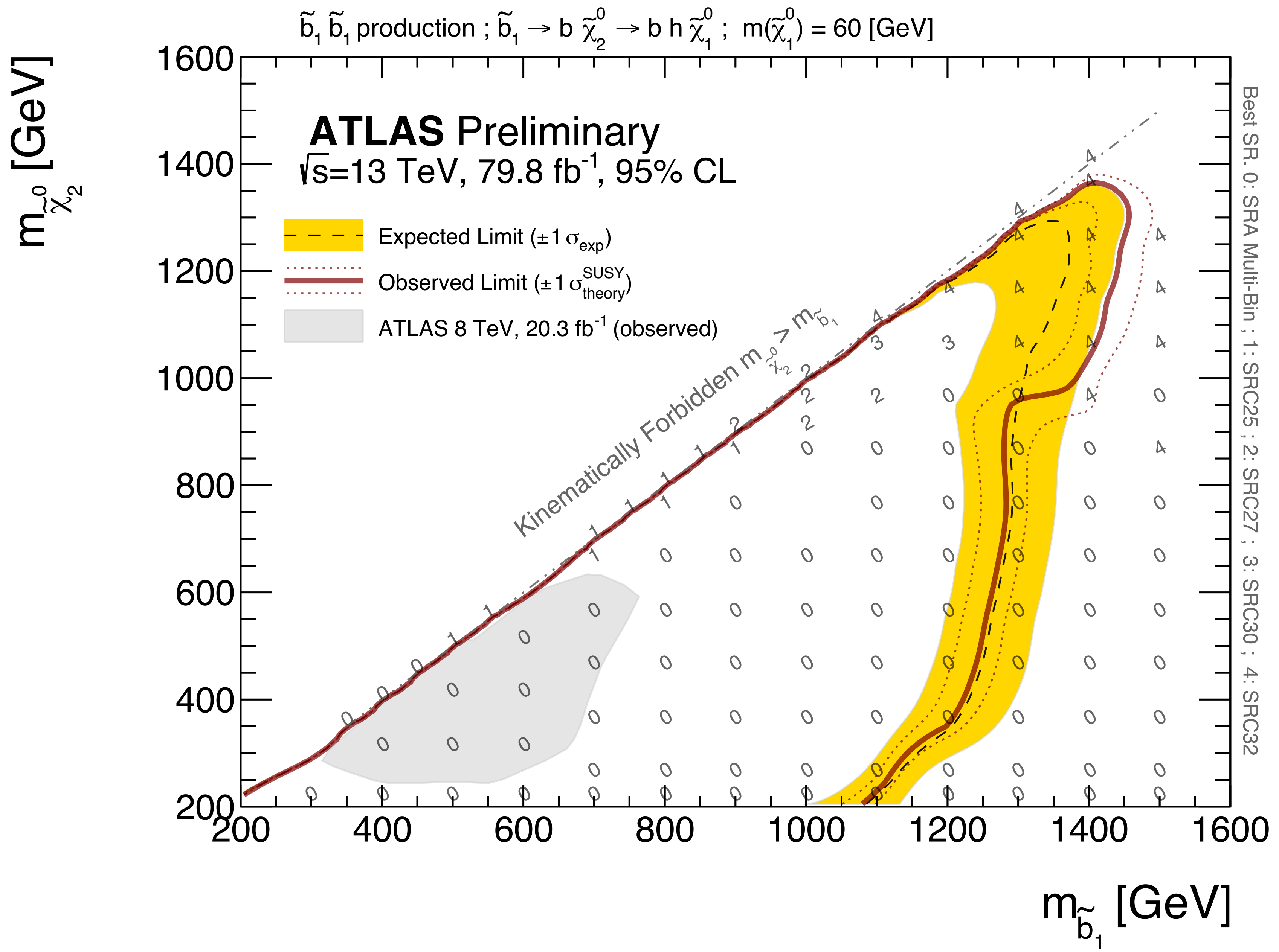
Exclusion Limits $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) = 130\text{GeV}$

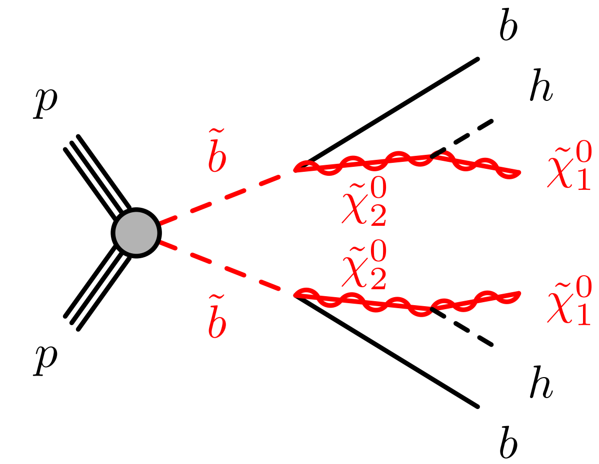




- Combined exclusion contour at 95% CL on DM130 signal scenario.
- Observed limit up to 1.15 TeV in sbottom mass.
- Previous result (CMS) up to 0.5 TeV in sbottom mass.
- SRA optimal in bulk; SRB optimal in compressed scenarios.

Exclusion Limits $m(\tilde{\chi}^0_1) = 60\text{GeV}$



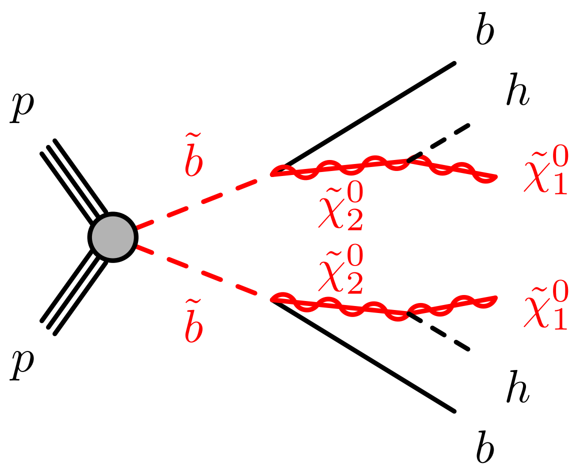


- Combined exclusion contour at 95% CL on M60 signal scenario.
- Observed limit up to 1.4 TeV in sbottom mass.
- Previous result up to 0.75 TeV in sbottom mass.
- SRA optimal in bulk; SRC regions optimal in compressed scenarios.

Conclusions

- Search for complex sbottom decays involving Higgs boson.
- Signal regions developed using Higgs identification algorithm.

- Exclusion limits at 95% CL up to 1.4 TeV sbottom mass on m60 model.
- Exclusion limits at 95% CL up to 1.15 TeV sbottom mass on DM130 model.
- Significant increase in exclusion on both models.



https://cds.cern.ch/record/2632345

Thanks for listening, questions?

Backup

OBJECT DEFINITION

4

Candidate Objects

Jets

- anti-k_T (R=0.4)

Calibration: EM+JES+GSC

- p_T > 20 GeV
- |η|< 2.8
- JVT: Medium WP

Electrons

- ID: *VeryLooseLLH*
- p_T > 7 GeV
- |η|< 2.47
- $|z_0 \sin\theta| < 0.5\,mm$
- $|\frac{d_0}{\sigma_{d_0}}| < 5$

Muons

- ID: *loose*
- p_T > 6 GeV
- |η|< 2.5
- $|z_0 \sin\theta| < 0.5\,mm$
- $|\frac{d_0}{\sigma_{d_0}}| < 3$

Trigger

1. **E_T^{miss}**
   0/1-lepton selections, plateau > 250 GeV
2. **Single-Lepton**
   2-lepton selections, plateau > 27 GeV

Overlap Removal

Baseline Objects

Signal Objects

Jets

- p_T > 30 GeV

b-Jets

- MV2c10, 77% WP
- |η|< 2.5

Electrons

- ID: *TightLLH*
- p_T > 20 GeV
- Isolation: *GradientLoose*

Muons

- ID: *medium*
- p_T > 20 GeV
- Isolation: *GradientLoose*

E_T^{miss}

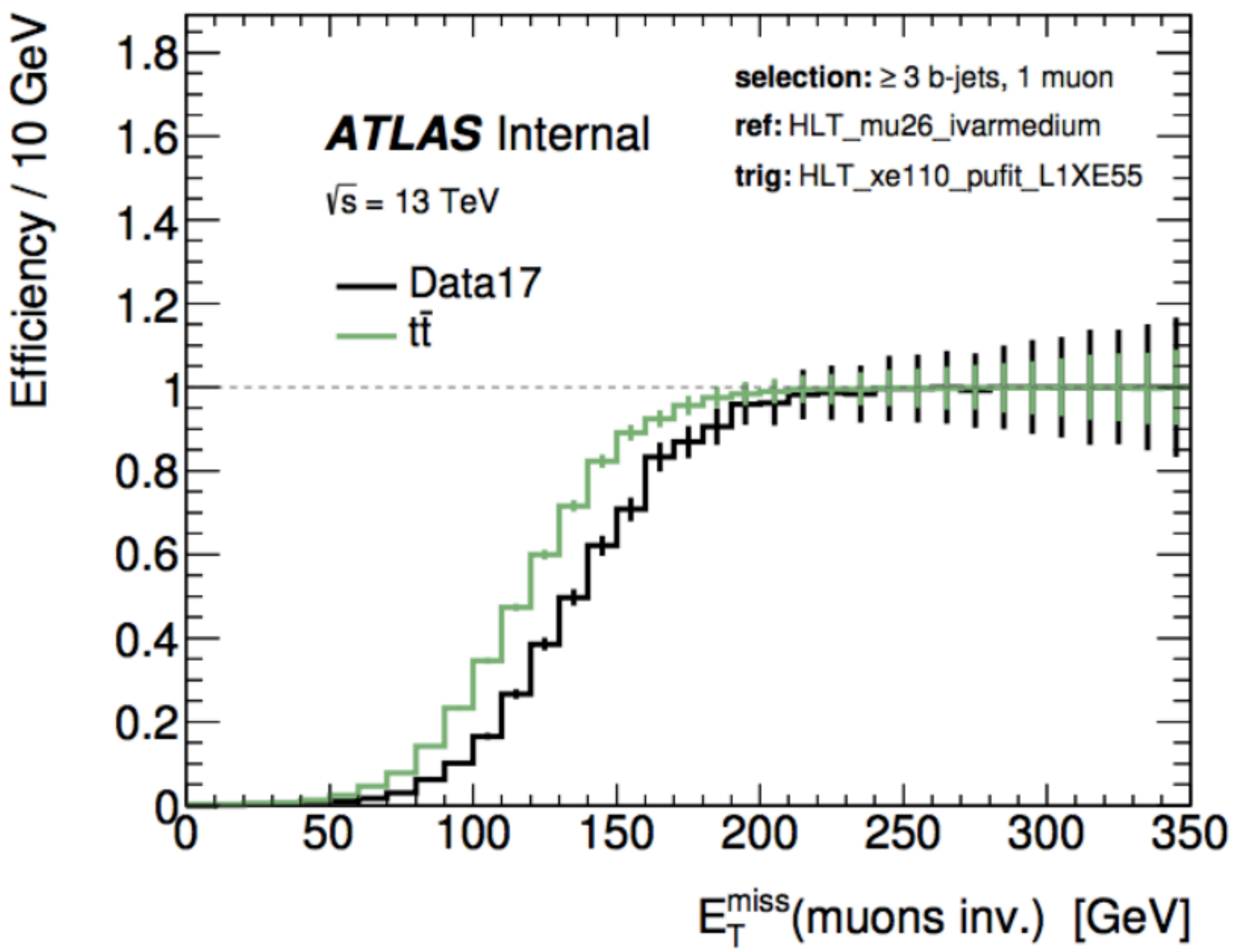
- Track soft terms
- *Tight* WP

Software

AnalysisBase 21.2.31

SUSYTools configuration file

- MET triggers are used for 0-lepton regions.
  - plateau at MET > 250 GeV.
- Single-lepton triggers used for >=1-lepton regions.
  - plateau at pT > 27 GeV.
  - trigger matched.



SRA

Variable	Units	SRA-inclusive,L,M,H	VRA0ℓ,L,M,H	CRA1ℓ,L,M,H
Event Cleaning		✓		
$E_{\mathrm{T}}^{\mathrm{miss}}$ Trigger		✓		
$E_{\mathrm{T}}^{\mathrm{miss}}$	[GeV]	> 250		
$\min[\Delta\phi(\mathrm{jet}_{1-4}, E_{\mathrm{T}}^{\mathrm{miss}})]$	[rad]	> 0.4		-
N_{leptons} (baseline)		0		1
N_{leptons} (signal)		0		1
p_{T}^{1l}	[GeV]	-		> 20
m_{T}	[GeV]	-		> 20
τ veto		✓		-
N_{jets}		≥ 6		
$n_{b-\mathrm{jets}}$		≥ 4	3	≥ 4
$p_{\mathrm{T}}(b_1)$	[GeV]	> 200		> 100
$\mathcal{S}$	[$\mathrm{GeV}^{\frac{1}{2}}$]	-	< 25	-
$\Delta R_{\mathrm{max}}(b, b)$		> 2.5	-	-
$\Delta R_{\mathrm{max-min}}(b, b)$		< 2.5	-	-
$m(h_{\mathrm{cand}})$	[GeV]	> 80	-	-
m_{eff}	[TeV]	$> 1, \in [1, 1.2], \in [1.2, 1.5], > 1.5$		

SRB

Region B Definitions

Variable	Units	SRB	VRB0ℓ	CRB1ℓ
Event Cleaning			✓	
E_T^{miss} Trigger			✓	
E_T^{miss}	[GeV]	> 300	> 250	
$\min[\Delta\phi(\text{jet}_{1-4}, E_T^{miss})]$	[rad]	> 0.4		-
N_{leptons} (baseline)		0		1
N_{leptons} (signal)		0		1
p_T^{1l}	[GeV]	-		> 20
m_T	[GeV]	-		> 20
τ veto		✓		-
N_{jets}			≥ 4	
$n_{b-\text{jets}}$		≥4	3	≥4
leading jet non b-tagged			✓	
$p_T(j_1)$	[GeV]		> 300 GeV	
$\lvert\Delta\phi(j_1, E_T^{miss})\rvert$	[rad]	> 2.8		> 2.2
S	[GeV$^{\frac{1}{2}}$]	-	-	< 25
$m(h_{cand1}, h_{cand2})_{avg}$	[GeV]	∈ [50, 140]	-	-
m_{eff}	[TeV]		> 1000	

SRC

Region C Definitions

<table>
<tr><th>Variable</th><th>Units</th><th>SRC</th><th>VRC0ℓ-T</th><th>VRC0ℓ-Z</th><th>CRC1ℓ</th><th>CRC2ℓ</th></tr>
<tr><td>Event Cleaning</td><td></td><td colspan="5">✓</td></tr>
<tr><td>$E_{\mathrm{T}}^{\mathrm{miss}}$ Trigger</td><td></td><td colspan="4">✓</td><td>-</td></tr>
<tr><td>Lepton Triggers</td><td></td><td colspan="4">-</td><td>✓</td></tr>
<tr><td>N_{leptons} (baseline)</td><td></td><td colspan="3">0</td><td>1</td><td>2</td></tr>
<tr><td>N_{leptons} (signal)</td><td></td><td colspan="3">-</td><td>1</td><td>2 (SFOS)</td></tr>
<tr><td>$p_{\mathrm{T}}(\ell_1)$</td><td>[GeV]</td><td colspan="3">-</td><td>> 20</td><td>> 27</td></tr>
<tr><td>$p_{\mathrm{T}}(\ell_2)$</td><td>[GeV]</td><td colspan="3">-</td><td>> 20</td><td>-</td></tr>
<tr><td>m_{T}</td><td>[GeV]</td><td colspan="3">-</td><td>> 20</td><td>-</td></tr>
<tr><td>$\mathrm{m}_{\ell\ell}$</td><td>[GeV]</td><td colspan="4">-</td><td>$\in [86, 106]$</td></tr>
<tr><td>N_{jets}</td><td></td><td colspan="5">≥ 4</td></tr>
<tr><td>$n_{b\mathrm{-jets}}$</td><td></td><td colspan="2">≥ 3</td><td>2</td><td colspan="2">≥ 3</td></tr>
<tr><td>$\min[\Delta\phi(\mathrm{jet}_{1-4}, E_{\mathrm{T}}^{\mathrm{miss}})]$</td><td>[rad]</td><td>$> 0.4$</td><td>$\in [0.2, 0.4]$</td><td>$> 0.8$</td><td colspan="2">-</td></tr>
<tr><td>$E_{\mathrm{T}}^{\mathrm{miss}}$</td><td>[GeV]</td><td colspan="4">> 250</td><td>-</td></tr>
<tr><td>$\tilde{E}_{\mathrm{T}}^{\mathrm{miss}}$</td><td>[GeV]</td><td colspan="4">-</td><td>> 250</td></tr>
<tr><td>$\mathcal{S}$</td><td>[$\mathrm{GeV}^{\frac{1}{2}}$]</td><td>$> 25, > 27, > 30, > 32$</td><td>$\in [19, 22]$</td><td>$\in [23, 24]$</td><td>$> 20$</td><td>-</td></tr>
<tr><td>m_{CT}</td><td>[GeV]</td><td colspan="4">-</td><td>> 200</td></tr>
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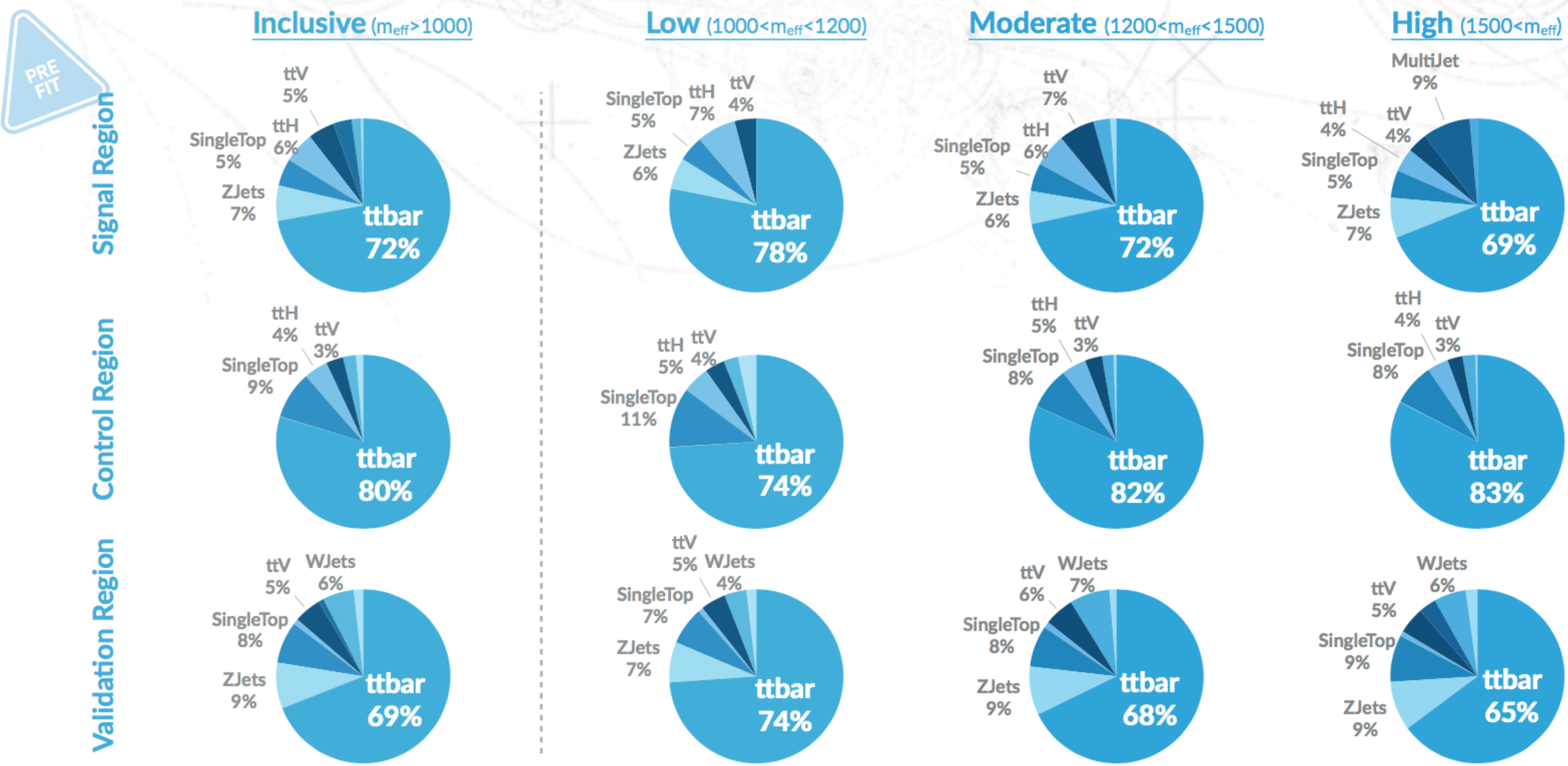
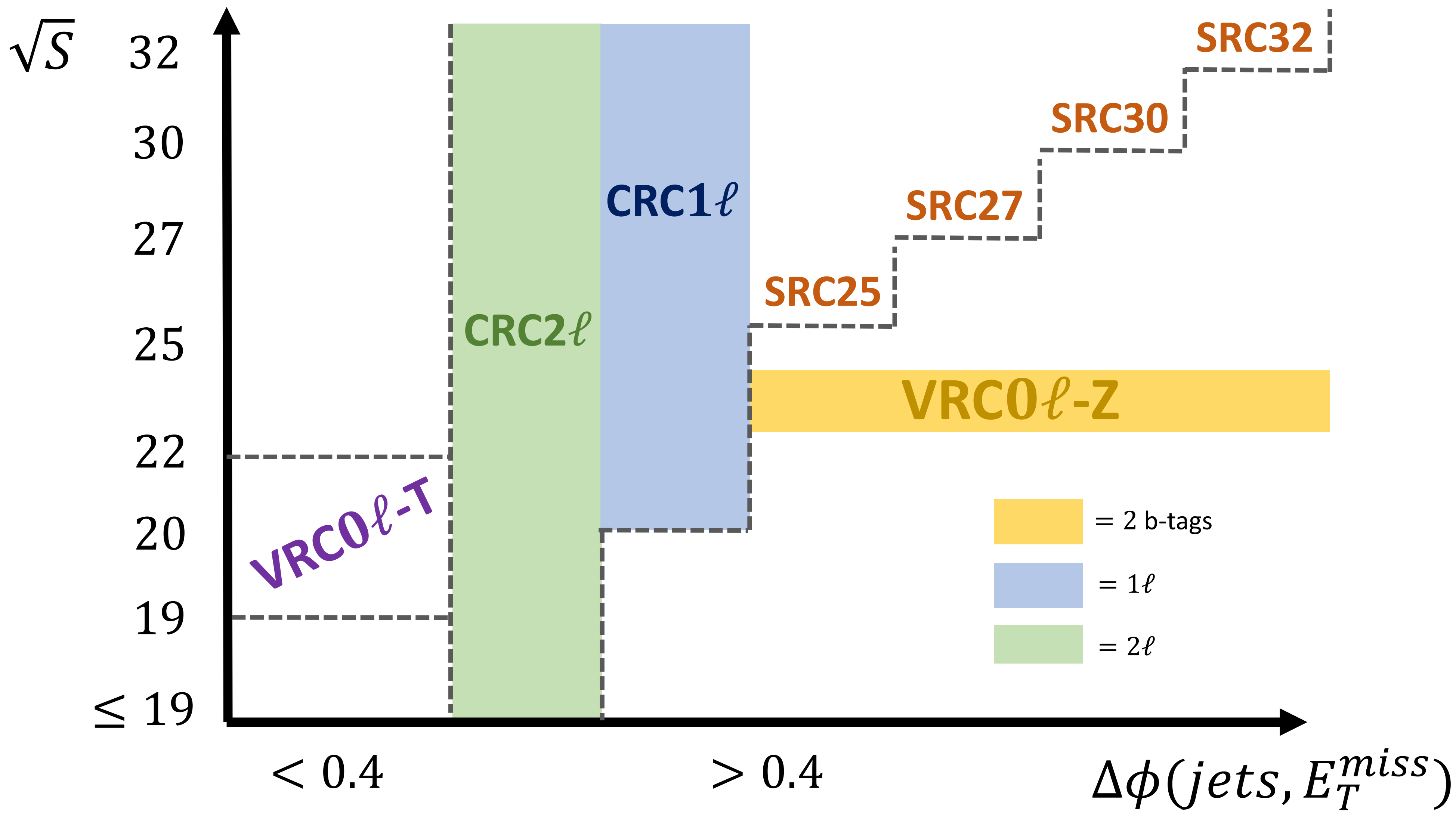
Background Estimation

- Background is $t\bar{t}$ dominated in all bins with similar composition:



Background Estimation - Region C



- SRC dominated by ttbar (CRC1L) and Z+jets (CRC2L).
- orthogonal through MET sig, lepton multiplicity and dPhiJetMET.

Results

SR Yields

	SRA	SRA-L	SRA-M	SRA-H	SRB
Observed events	27	7	12	8	4
Fitted SM bkg events	22.8 ± 3.2	5.8 ± 1.5	9.5 ± 2.0	7.5 ± 1.4	4.0 ± 1.1
$t\bar{t}$	15.3 ± 2.7	4.5 ± 1.4	6.3 ± 1.7	4.7 ± 1.3	3.5 ± 1.2
Z+jets	1.5 ± 0.9	0.3 ± 0.2	0.5 ± 0.2	0.7 ± 0.4	0.09 ± 0.08
Single-top	3.1 ± 0.8	0.4 ± 0.3	1.4 ± 0.5	1.3 ± 0.3	$0.24^{+0.26}_{-0.24}$
$t\bar{t}+W/Z$	1.1 ± 0.2	0.2 ± 0.1	0.5 ± 0.2	0.4 ± 0.2	0.09 ± 0.07
$t\bar{t}+h$	1.3 ± 0.2	0.4 ± 0.1	0.5 ± 0.1	0.3 ± 0.1	0.11 ± 0.03
W+jets	0.4 ± 0.3	−−	$0.28^{+0.33}_{-0.28}$	0.09 ± 0.02	−−
Diboson	0.10 ± 0.05	$0.00^{+0.02}_{-0.00}$	0.10 ± 0.04	−−	−−

	SRC25	SRC27	SRC30	SRC32
Observed events	43	24	6	1
Fitted SM bkg events	39.8 ± 3.9	19.1 ± 2.3	8.1 ± 1.5	3.3 ± 0.7
$t\bar{t}$	13.1 ± 2.6	4.7 ± 0.9	1.2 ± 0.3	0.4 ± 0.1
Z+jets	11.3 ± 3.0	6.3 ± 1.8	3.1 ± 0.9	1.2 ± 0.4
Single-top	4.3 ± 0.5	2.2 ± 0.2	1.1 ± 0.3	0.3 ± 0.1
$t\bar{t}+W/Z$	5.0 ± 1.6	2.9 ± 0.9	1.0 ± 0.4	0.5 ± 0.2
$t\bar{t}+h$	0.33 ± 0.05	0.18 ± 0.03	$0.01^{+0.02}_{-0.01}$	$0.01^{+0.01}_{-0.01}$
W+jets	4.1 ± 0.4	1.7 ± 0.3	1.0 ± 0.3	0.5 ± 0.1
Diboson	1.6 ± 0.4	1.2 ± 0.2	0.6 ± 0.2	0.4 ± 0.3