Search for gluino-mediated stop and sbottom pair production in events with b-jets and large missing transverse momentum

Chiara Rizzi
On behalf of the ATLAS Collaboration

ALPS 2017
Obergurgl

Introduction

- Supersymmetry (**SUSY**) → fermion-boson symmetry → super-partners for each SM particle
  - gluons → spin-½ **gluinos** ($\tilde{g}$)
  - top/bottom → **stop** ($\tilde{t}$) and **sbottom** ($\tilde{b}$), scalar quarks
  - W/Z/γ/h → spin-½ **charginos** ($\tilde{\chi}^{\pm}$) and **neutralinos** ($\tilde{\chi}^{0}$)

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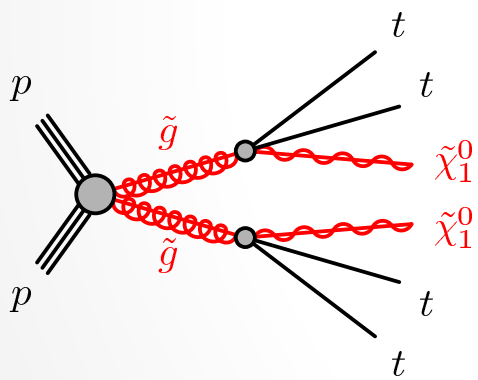
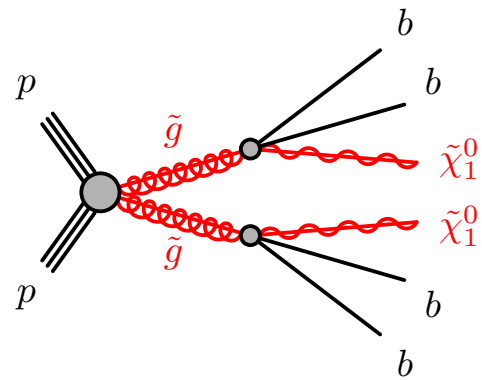
- Model considered in this search: gluino pair production with (off-shell) stop/sbottom in their decay products (ATLAS-CONF-2017-021)



Gtt model

Analysis in 0-lepton and 1-lepton channels



Gbb model

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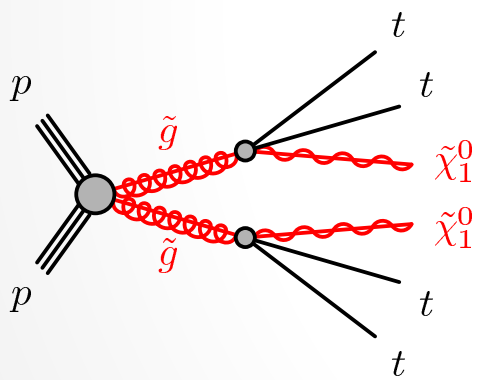

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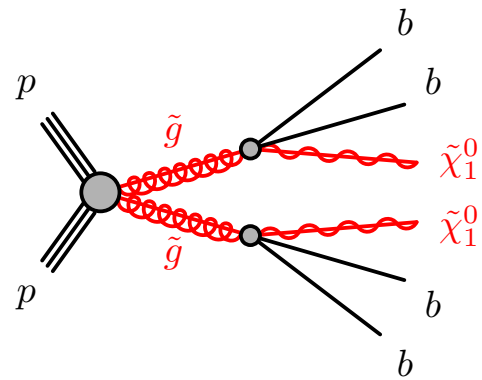


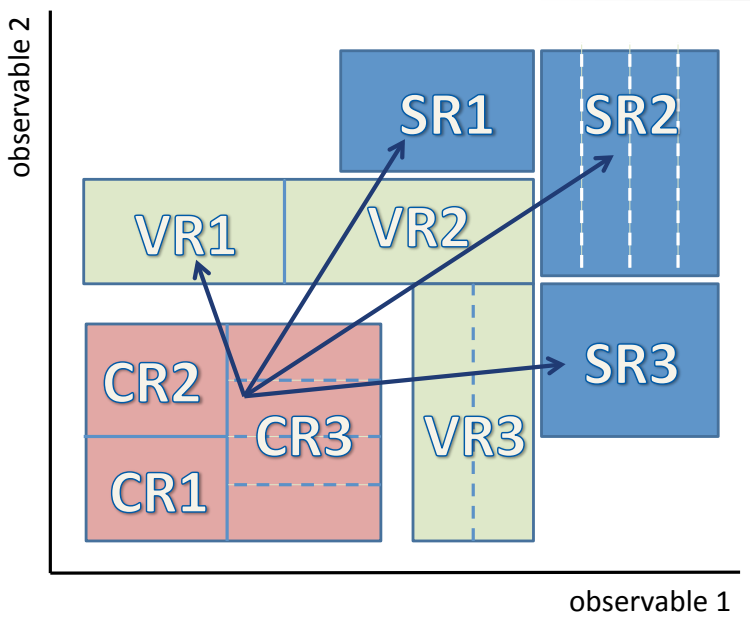
Gbb model

Analysis in 0-lepton channel

- In both cases final state with multiple **(b)-jets** and **missing transverse momentum**
- Main background is $t\bar{t}$ with at least 1 lepton

Analysis Strategy (I)

- Discriminating variables used to define multiple signal-enriched regions (**SR**s), based on specific benchmark models
- **Observed yields** are compared with SM predictions



Analysis Strategy (I)

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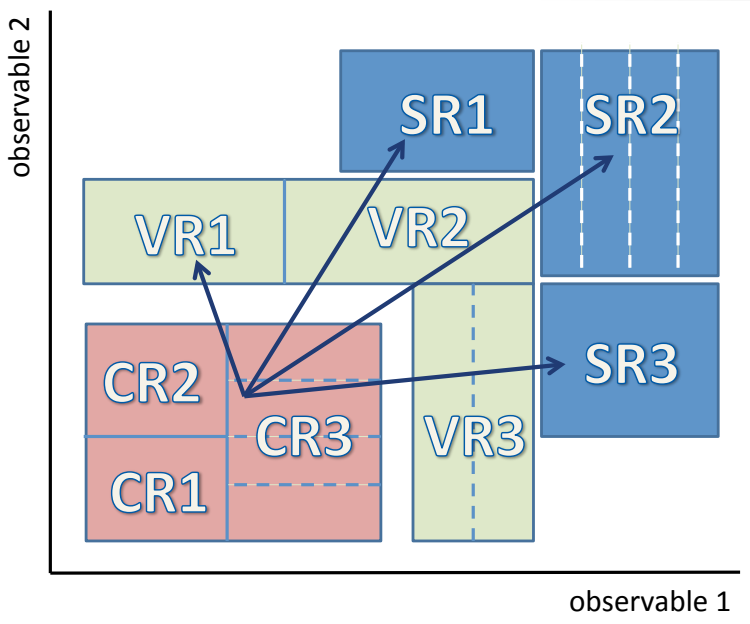
- **Observed yields** are compared with SM predictions

Background estimation

- $t\bar{t}$ normalization derived in control regions (**CR**s) and tested in validation regions (**VR**s)
- Other backgrounds → Monte Carlo Simulation
- Data-driven QCD estimate
- Corresponding SRs, CRs and VRs are **orthogonal**



Analysis Strategy (II)

Two different analysis strategies carried out in parallel

Single-Bin Strategy

- Several **overlapping single-bin SRs**
- Each optimized for **discovery** in a specific region of phase space
- Ideal also to provide **model-independent upper limits** easy to reinterpret

Multi-Bin Strategy

- Several **orthogonal SRs**, designed to be combined
- Each SR individually does not provide great discovery power
- The **combined fit** leads to better model-dependent exclusion

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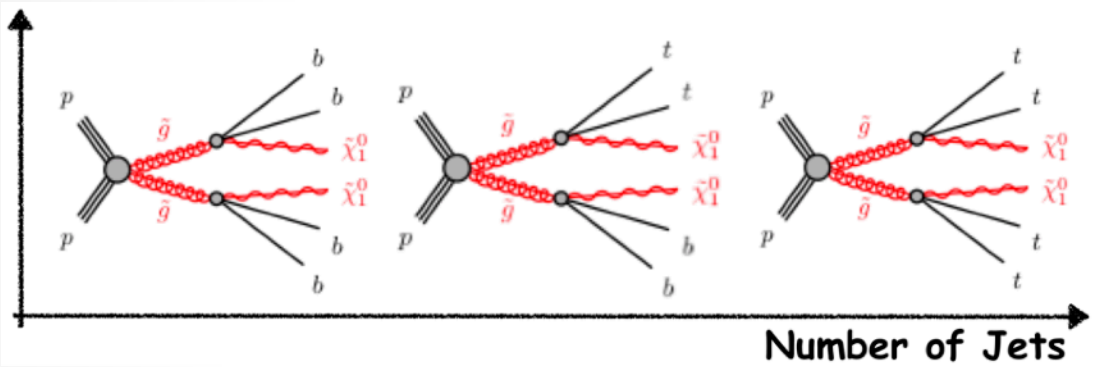
Focus of this talk

Multi-bin Strategy

The phase space is sliced in several bins based on **number of leptons**, **number of jets** (N_{jets}) and **effective mass** (m_{eff})



Different number of top quarks → different jet multiplicities

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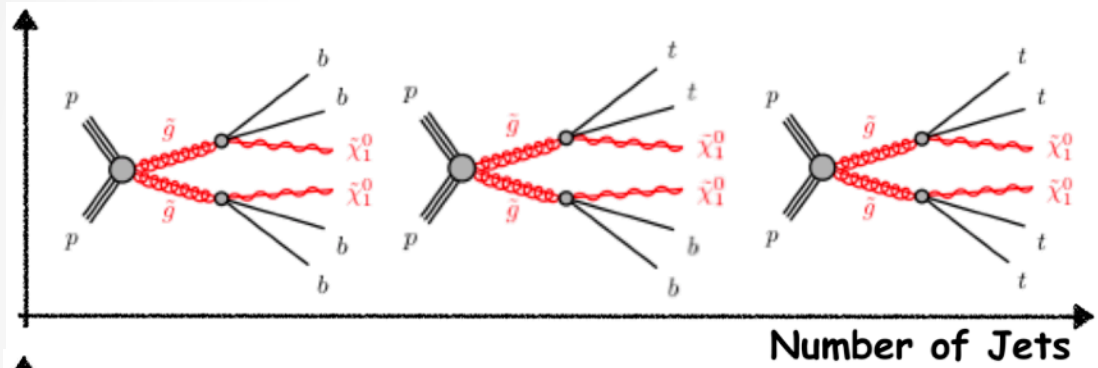

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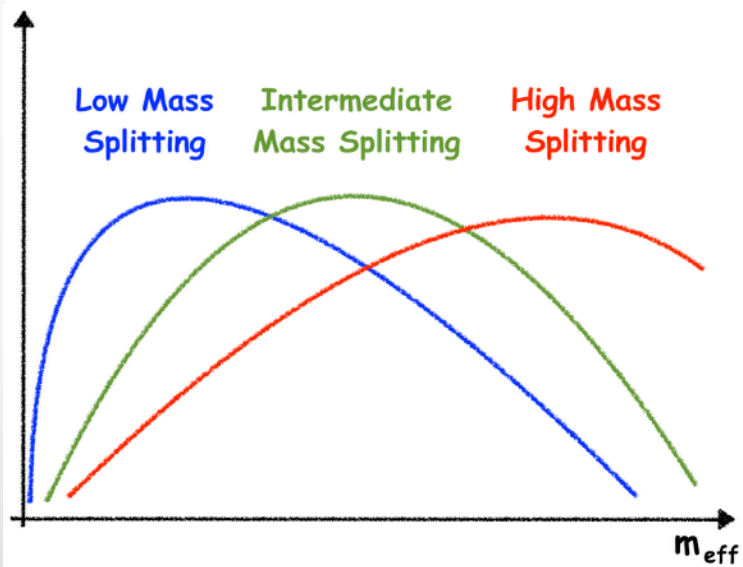
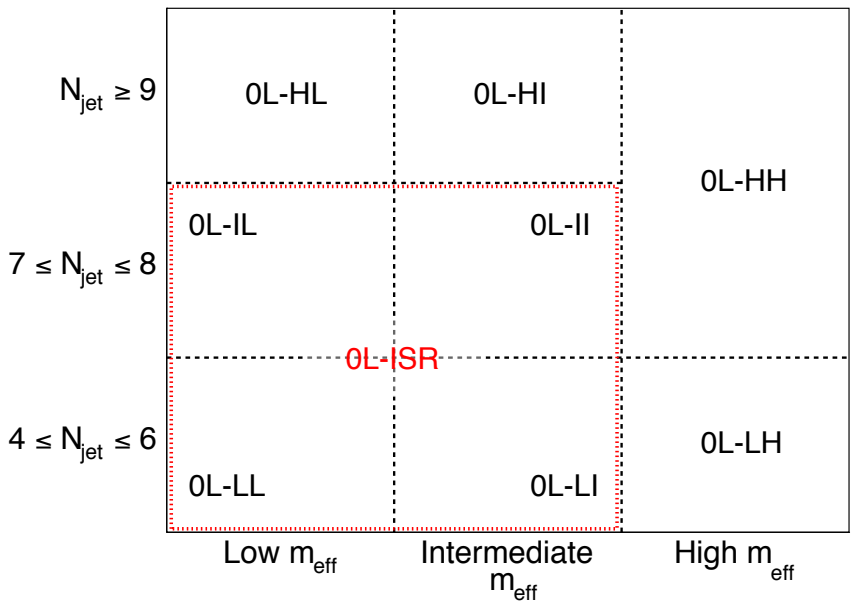


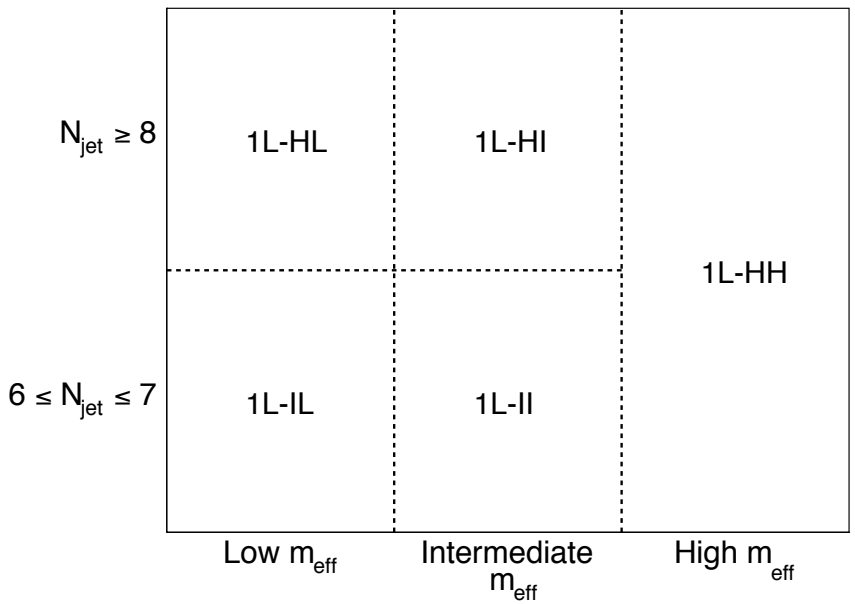
$$m_{\mathrm{eff}} = \sum_i p_{\mathrm{T}}^{\mathrm{jet}_i} + \sum_j p_{\mathrm{T}}^{\ell_j} + E_{\mathrm{T}}^{\mathrm{miss}}$$

m_{eff} → sensitive to different $m(\tilde{g})$-$m(\tilde{\chi}^0)$ splitting

Region Definition

14 **orthogonal** regions





- In each region, selections over other kinematic variables are **optimized**
- All regions require ≥ 3 b-jets (b-tagged with a 77% efficiency)
- One CR defined for each pair of 1L-0L SRs corresponding to the same N_{jet}-m_{eff} bin
- Dedicated 0L region to target Initial State Radiation (ISR) topology in Gbb models

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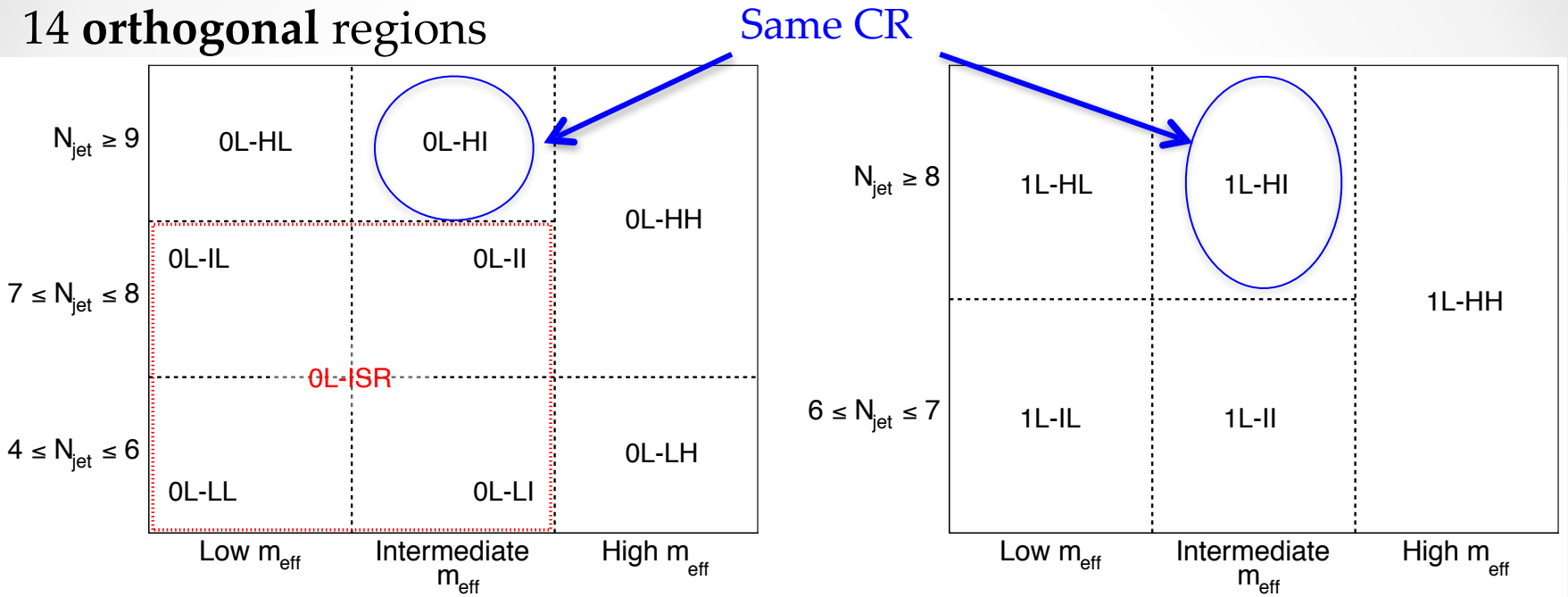

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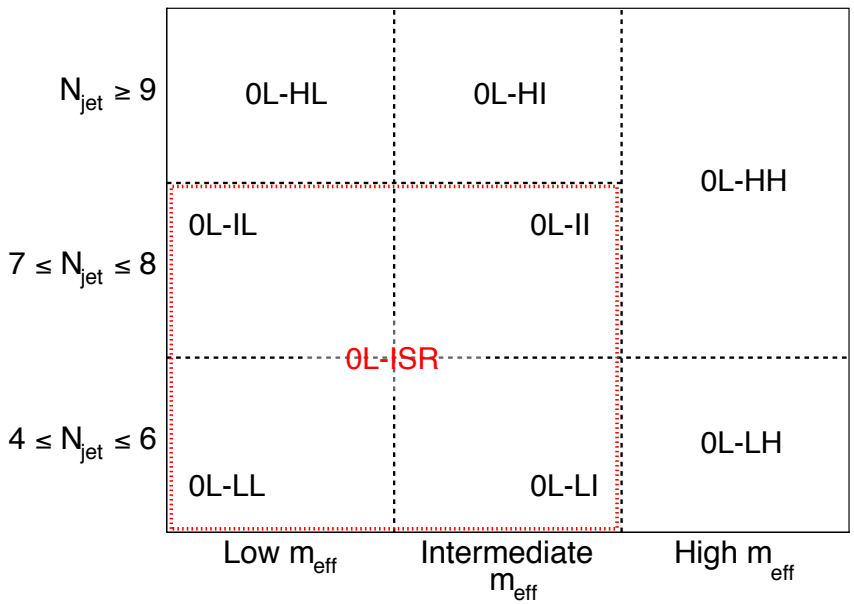
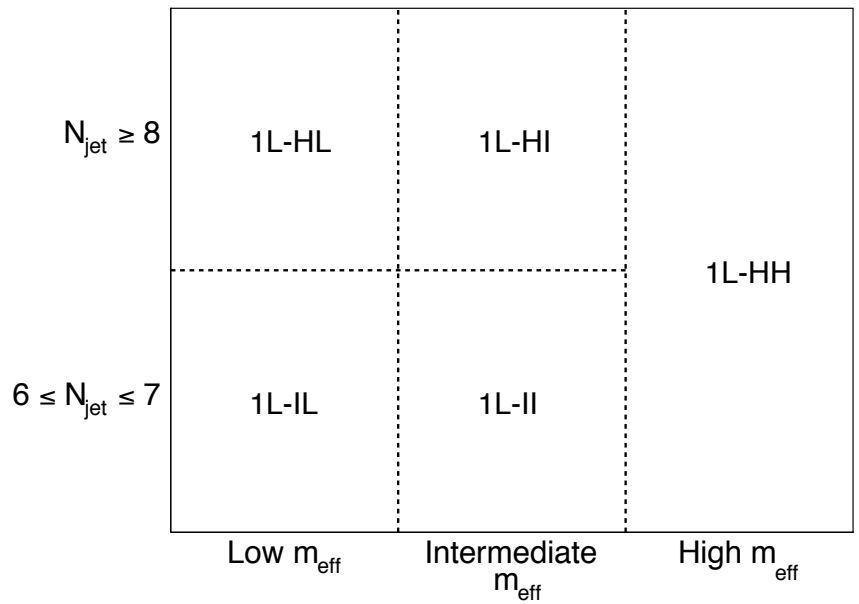
- All regions require ≥ 3 b-jets (b-tagged with a 77% efficiency)
- One CR defined for each pair of 1L-0L SRs corresponding to the same N_{jet}-m_{eff} bin (e.g. 0L-HI and 1L-HI share the same CR)
- Dedicated 0L region to target Initial State Radiation (ISR) topology in Gbb models

Region Definition

14 **orthogonal** regions





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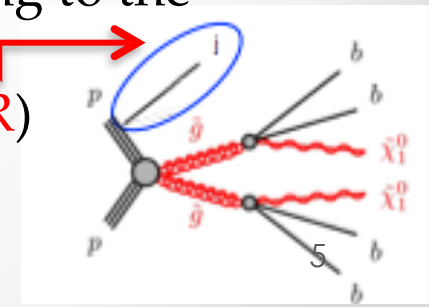
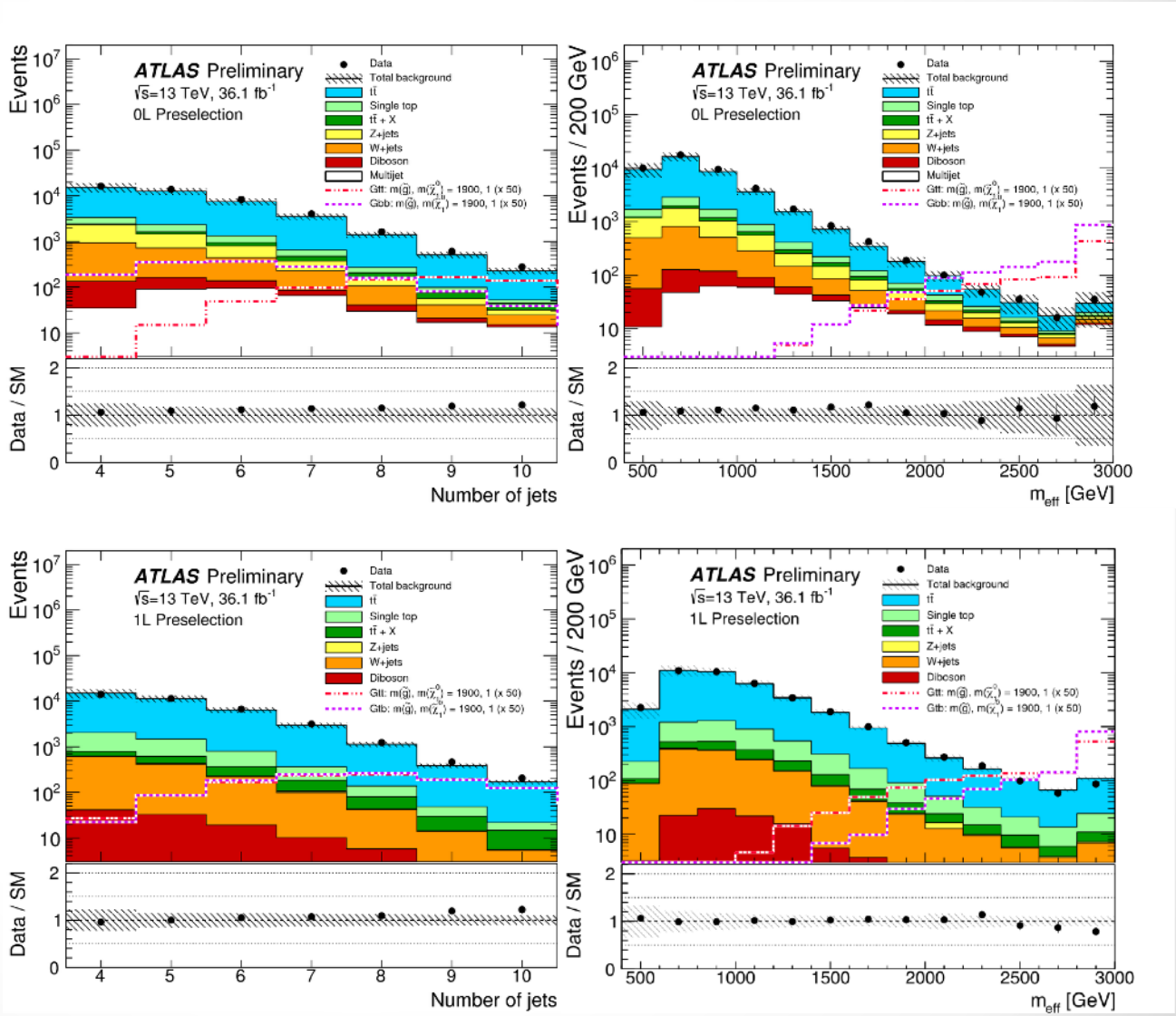


How These Variables Look in Data

Preselection requirements		
	0-lepton	1-lepton
Trigger	E_T^{miss} trigger	
E_T^{miss}	$E_T^{miss} > 200$ GeV	
N_{lepton}	$= 0$	≥ 1
$\Delta\phi_{min}^{4j}$	> 0.4	–
N^{jet}	≥ 4	
N^{b-tag}	≥ 2	



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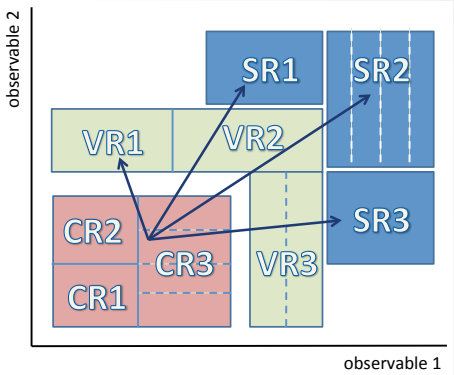
Background Fit Results



- Scale factors for $t\bar{t}$ are derived in CRs and applied to VRs and SRs

Background Fit Results

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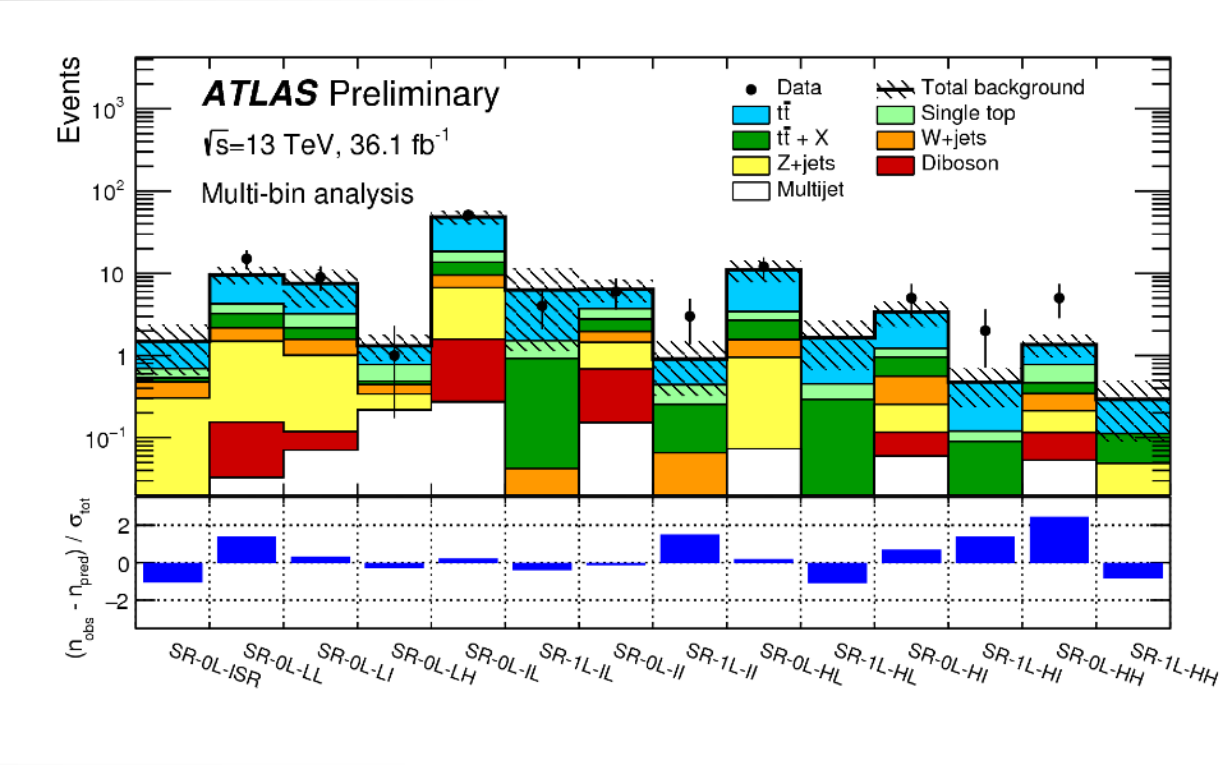
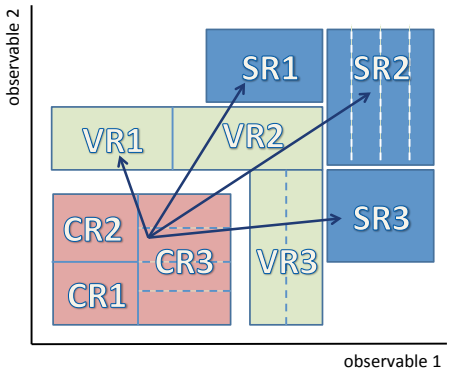


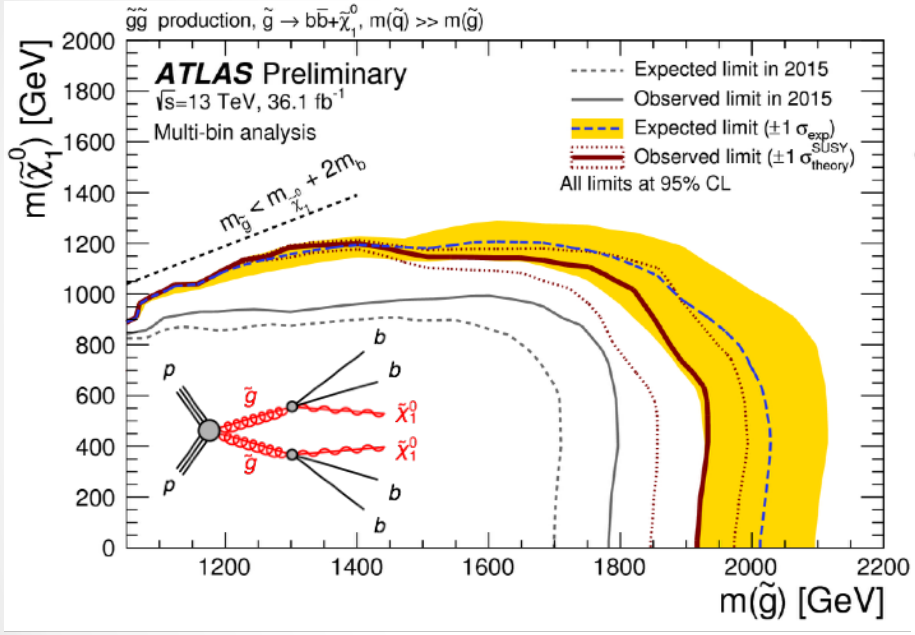


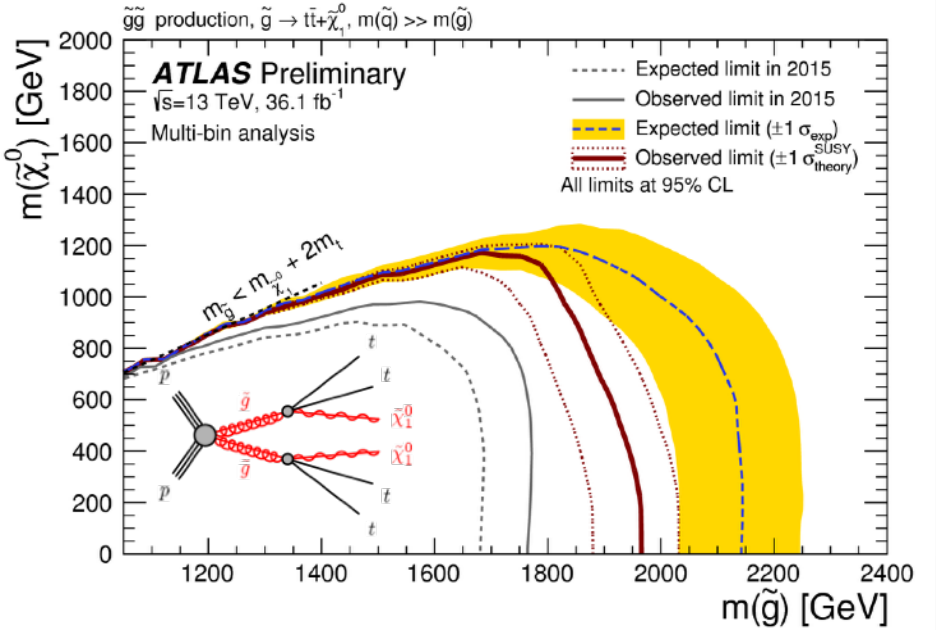
- Scale factors for $t\bar{t}$ are derived in CRs and applied to VRs and SRs

- SRs → no significant excess in the SRs
- Small excess at high m_{eff} and high N_{jets}

Model Dependent Limits

The results of the multi-bin strategy are used to set limits on the Gbb and Gtt simplified models





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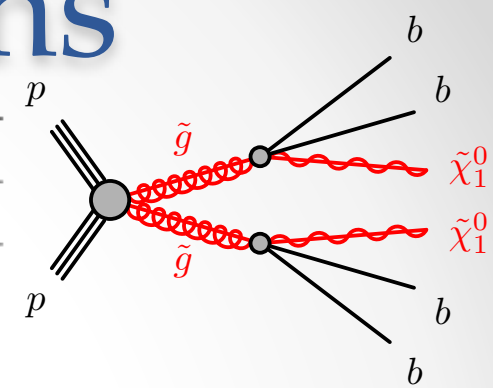
Observed limit weaker than expected due to the small excess in the high m_{eff} and high N_{jet} region

Conclusion

- I have presented a search for gluino pair production, decaying via stop/sbottom, in final states with:
  - Multiple (b-)jets
  - Missing transverse momentum
  - 0 or at least 1 lepton
- 2015+2016 data (36 fb^{-1}) collected by the ATLAS detector have been analyzed
- These results have been made public for Moriond EW 2017 (ATLAS-CONF-2017-021)
- No significant excess has been observed, thus limits are set on simplified models. Gluino limits for massless neutralino:
  - Gbb → 1.92 TeV
  - Gtt → 1.97 TeV
- The limits set considerably extend the ones from 2015

Backup

Low Njet Regions

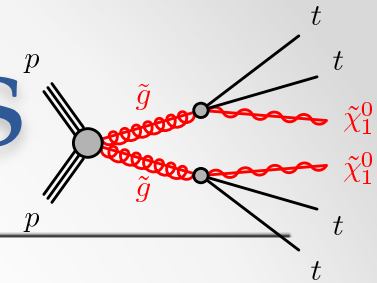


Criteria common to all low-N_{jet} regions: $N_{b\text{-jets}} \geq 3$				
	Variable	SR	CR	VR
Criteria common to all regions of the same type	N^{lepton}	0	≥ 1	0
	$\Delta\phi^{4\text{j}}_{\text{min}}$	> 0.4	–	> 0.4
	m_{T}	–	< 150	–
	N_{jet}	[4,6]	[4,5]	[4,6]
High-m_{eff} (LH) (Large Δm)	m_{eff}	> 2400	> 2100	[2000,2400]
	$E_{\text{T}}^{\text{miss}}$	> 300	> 200	> 200
	$p_{\text{T}}^{\text{j}_4}$	> 90	> 30	< 90 if $E_{\text{T}}^{\text{miss}} < 300$
Intermediate-m_{eff} (LI) (Intermediate Δm)	m_{eff}	[1400,2400]	[1400,2000]	[1250,1800]
	$\text{j}_1 = b$ or $\Delta\phi^{\text{j}_1} \leq 2.9$	✓	✓	✓
	$m_{\text{T,min}}^{b\text{-jets}}$	> 140	-	< 140
	$E_{\text{T}}^{\text{miss}}$	> 350	> 300	> 300
	$p_{\text{T}}^{\text{j}_4}$	> 90	> 70	> 90
Low-m_{eff} (LL) (Low Δm)	m_{eff}	[800,1400]	[800,1400]	[800,1250]
	$\text{j}_1 = b$ or $\Delta\phi^{\text{j}_1} \leq 2.9$	✓	✓	✓
	$m_{\text{T,min}}^{b\text{-jets}}$	> 140	-	< 140
	$E_{\text{T}}^{\text{miss}}$	> 350	> 300	> 300
	$p_{\text{T}}^{\text{j}_4}$	> 90	> 70	> 90

Intermediate Njet Regions

Criteria common to all intermediate-N_{jet} regions: $N_{b\text{-jets}} \geq 3$						
	Variable	SR-0L	SR-1L	CR	VR-0L	VR-1L
Criteria common to all regions of the same type	N^{lepton}	0	≥ 1	≥ 1	0	≥ 1
	$\Delta\phi^{4\text{j}}_{\text{min}}$	> 0.4	–	–	> 0.4	–
	m_{T}	–	> 150	< 150	–	> 150
	N_{jet}	[7,8]	[6,7]	[6,7]	[7,8]	[6,7]
	$\text{j}_1 = b$ or $\Delta\phi^{\text{j}_1} \leq 2.9$	✓	–	✓	✓	–
Intermediate-m_{eff} (II) (Intermediate Δm)	m_{eff}	[1600,2500]	[1600,2300]	[1600,2100]	[1450,2000]	[1450,2000]
	$m^{b\text{-jets}}_{\text{T,min}}$	> 140	> 140	> 110	< 140	< 140
	$E^{\text{miss}}_{\text{T}}$	> 300	> 300	> 200	> 300	> 225
Low-m_{eff} (IL) (Small Δm)	m_{eff}	[800,1600]	[800,1600]	[800,1600]	[800,1450]	[800,1450]
	$m^{b\text{-jets}}_{\text{T,min}}$	> 140	> 140	> 130	< 140	< 140
	$E^{\text{miss}}_{\text{T}}$	> 300	> 300	> 300	> 300	> 300

High Njet Regions

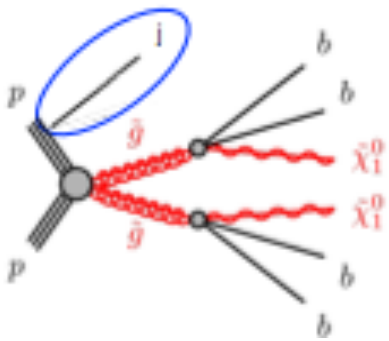


Criteria common to all high-N_{jet} regions: $N_{b\text{-jets}} \geq 3$

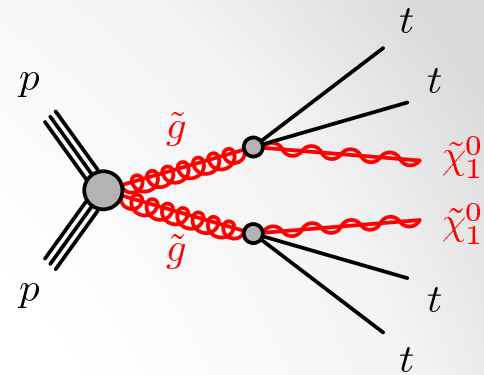
	Variable	SR-0L	SR-1L	CR	VR-0L	VR-1L
Criteria common to all regions of the same type	N^{lepton}	0	≥ 1	≥ 1	0	≥ 1
	$\Delta\phi^{4\text{j}}_{\text{min}}$	> 0.4	–	–	> 0.4	–
	m_{T}	–	> 150	< 150	–	> 150
High-m_{eff} (HH) (Large Δm)	N_{jet}	≥ 7	≥ 6	≥ 6	≥ 7	≥ 6
	m_{eff}	> 2500	> 2300	> 2100	> 2100	> 2100
	$m_{\text{T,min}}^{b\text{-jets}}$	> 100	> 120	> 60	< 100 if $E_{\text{T}}^{\text{miss}} > 300$	< 140 if $m_{\text{eff}} > 2300$
	$E_{\text{T}}^{\text{miss}}$	> 400	> 500	> 300	< 300 if $m_{\text{T,min}}^{b\text{-jets}} > 100$	< 500
Intermediate-m_{eff} (HI) (Intermediate Δm)	N_{jet}	≥ 9	≥ 8	≥ 8	≥ 9	≥ 8
	m_{eff}	[1800,2500]	[1800,2300]	[1700,2100]	[1650,2100]	[1600,2100]
	$m_{\text{T,min}}^{b\text{-jets}}$	> 140	> 140	> 60	< 140 if $E_{\text{T}}^{\text{miss}} > 300$	< 140 if $E_{\text{T}}^{\text{miss}} < 300$
	$E_{\text{T}}^{\text{miss}}$	> 300	> 300	> 200	< 300 if $m_{\text{T,min}}^{b\text{-jets}} > 140$	< 300 if $m_{\text{T,min}}^{b\text{-jets}} > 140$
Low-m_{eff} (HL) (Small Δm)	N_{jet}	≥ 9	≥ 8	≥ 8	≥ 9	≥ 8
	m_{eff}	[900,1800]	[900,1800]	[900,1700]	[900,1650]	[900,1650]
	$m_{\text{T,min}}^{b\text{-jets}}$	> 140	> 140	> 130	< 140	< 140
	$E_{\text{T}}^{\text{miss}}$	> 300	> 300	> 250	> 300	> 225

ISR Region

Criteria common to all ISR regions			
$N_{b\text{-jets}} \geq 3$, $\Delta\phi^{j_1} > 2.9$, $p_T^{j_1} > 400$ GeV, $j_1 \neq b$			
Variable	SR	CR	VR
N^{lepton}	0	≥ 1	0
$\Delta\phi^{4j}_{\text{min}}$	> 0.4	–	> 0.4
m_T	–	> 150	–
N_{jet}	[4,8]	[4,7]	[4,8]
$m^{b\text{-jets}}_{T,\text{min}}$	> 100	–	> 100
E_T^{miss}	> 600	> 400	> 250
m_{eff}	< 2200	> 2000	< 2000

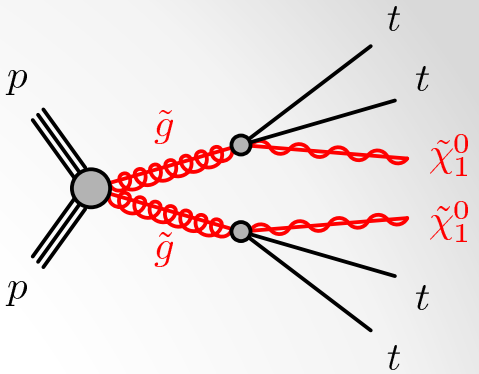


Gtt-1L



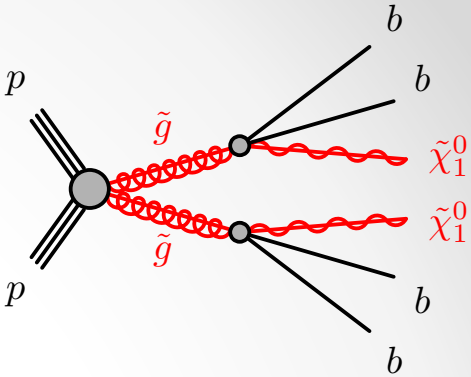
Criteria common to all Gtt 1-lepton regions ≥ 1 signal lepton, $p_T^{jet} > 30$ GeV, $N_{b\text{-jets}} \geq 3$			
	Variable	SR	CR
Region A (Large Δm)	N_{jet}	≥ 5	$= 5$
	m_T	> 150	< 150
	$m_{T,min}^{b\text{-jets}}$	> 120	–
	E_T^{miss}	> 500	> 300
	m_{eff}^{incl}	> 2200	> 1700
	M_J^{Σ}	> 200	> 150
Region B (Moderate Δm)	N_{jet}	≥ 6	$= 6$
	m_T	> 150	< 150
	$m_{T,min}^{b\text{-jets}}$	> 160	–
	E_T^{miss}	> 450	> 400
	m_{eff}^{incl}	> 1800	> 1500
	M_J^{Σ}	> 200	> 100
Region C (Small Δm)	N_{jet}	≥ 7	$= 7$
	m_T	> 150	< 150
	$m_{T,min}^{b\text{-jets}}$	> 160	–
	E_T^{miss}	> 350	> 350
	m_{eff}^{incl}	> 1000	> 1000

Gtt-0L



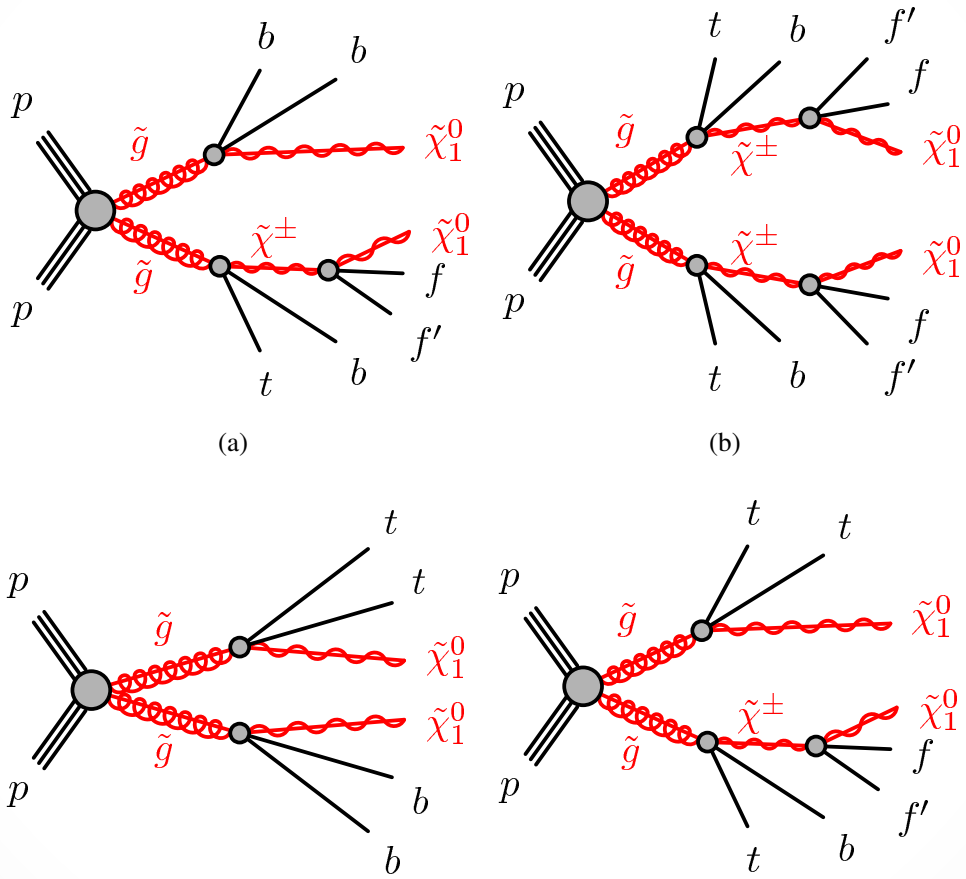
Criteria common to all Gtt 0-lepton regions: $p_T^{jet} > 30$ GeV			
	Variable	SR	CR
Criteria common to all regions of the same type	N_{lepton}	$= 0$	$= 1$
	$\Delta\phi_{min}^{4j}$	> 0.4	–
	m_T	–	< 150
Region A (Large Δm)	$m_{T,min}^{b\text{-jets}}$	> 60	–
	$N_{b\text{-jets}}$	≥ 3	≥ 3
	N_{jet}	≥ 7	≥ 6
	E_T^{miss}	> 350	> 275
	m_{eff}^{incl}	> 2600	> 1800
	M_J^{Σ}	> 300	> 300
Region B (Moderate Δm)	$m_{T,min}^{b\text{-jets}}$	> 120	–
	$N_{b\text{-jets}}$	≥ 3	≥ 3
	N_{jet}	≥ 7	≥ 6
	E_T^{miss}	> 500	> 400
	m_{eff}^{incl}	> 1800	> 1700
	M_J^{Σ}	> 200	> 200
Region C (Small Δm)	$m_{T,min}^{b\text{-jets}}$	> 120	–
	$N_{b\text{-jets}}$	≥ 4	≥ 4
	N_{jet}	≥ 8	≥ 7
	E_T^{miss}	> 250	> 250
	m_{eff}^{incl}	> 1000	> 1000
	M_J^{Σ}	> 100	> 100

Gbb



Criteria common to all Gbb regions: $N_{\text{jet}} \geq 4$, $p_T^{\text{jet}} > 30$ GeV			
	Variable	SR	CR
Criteria common to all regions of the same type	$N^{\text{Signal Lepton}}$	0	= 1
	$\Delta\phi_{\min}^{4j}$	> 0.4	–
	m_T	–	< 150
Region A (Large Δm)	$N_{b\text{-jets}}$	≥ 3	≥ 3
	E_T^{miss}	> 400	> 400
	m_{eff}	> 2800	> 2500
Region B (Moderate Δm)	$N_{b\text{-jets}}$	≥ 4	≥ 4
	E_T^{miss}	> 450	> 300
	$m_{T,\min}^{b\text{-jets}}$	> 90	–
	m_{eff}	> 1600	> 1600
Region C (Small Δm)	$N_{b\text{-jets}}$	≥ 4	≥ 4
	E_T^{miss}	> 450	> 375
	$m_{T,\min}^{b\text{-jets}}$	> 155	–
Region D (Very small Δm)	$N_{b\text{-jets}}$	≥ 3	≥ 3
	E_T^{miss}	> 600	> 600
	$m_{T,\min}^{b\text{-jets}}$	> 100	-
	$p_T^{j_1}$	> 400	> 400
	$j_1 \neq b$	✓	✓
	$\Delta\phi^{j_1}$	> 2.5	> 2.5

Gtb Models


p
p
$\tilde{g}$
$\tilde{g}$
$\tilde{\chi}^{\pm}$
$\tilde{\chi}_1^0$
$\tilde{\chi}_1^0$
b
b
f
f′
t
b
(a)
p
p
$\tilde{g}$
$\tilde{g}$
$\tilde{\chi}^{\pm}$
$\tilde{\chi}^{\pm}$
$\tilde{\chi}_1^0$
$\tilde{\chi}_1^0$
t
b
f′
f
t
b
f′
(b)
p
p
$\tilde{g}$
$\tilde{g}$
$\tilde{\chi}_1^0$
$\tilde{\chi}_1^0$
t
t
b
b
p
p
$\tilde{g}$
$\tilde{g}$
$\tilde{\chi}^{\pm}$
$\tilde{\chi}_1^0$
$\tilde{\chi}_1^0$
t
t
f
f′
t
b

MC Samples

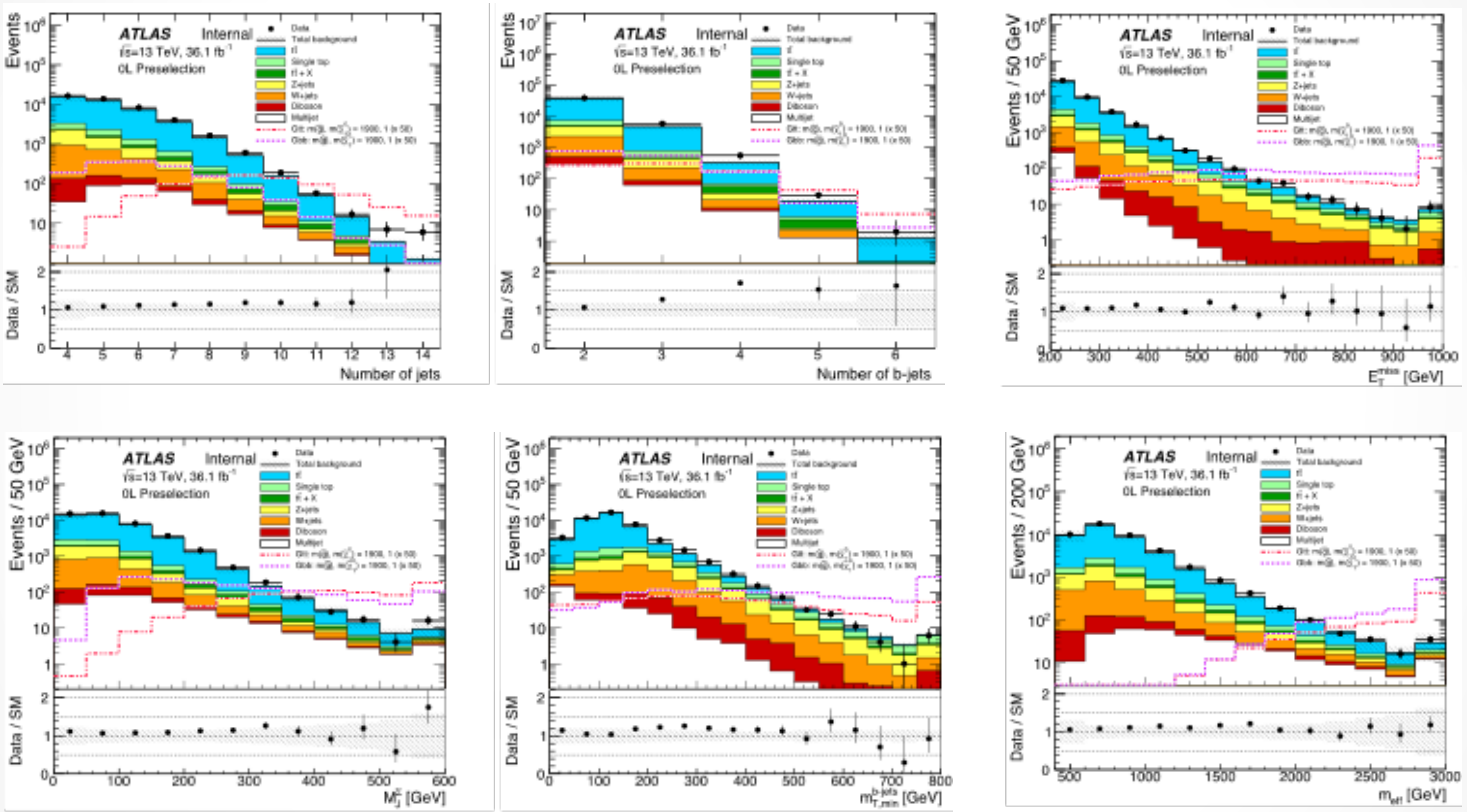
Process	Generator + fragmentation/hadronization	Tune	PDF set	Cross-section order
SUSY signal	MadGraph5_aMC@NLO v2.2.2 + Pythia v8.186	A14	NNPDF2.3	NLO+NLL [54–59]
$t\bar{t}$	Powheg-Box v2 + Pythia v6.428	PERUGIA2012	CT10	NNLO+NNLL [61]
Single top	Powheg-Box v1 or v2 + Pythia v6.428	PERUGIA2012	CT10	NNLO+NNLL [62–64]
$t\bar{t}W/t\bar{t}Z$**/4-tops**	MadGraph5_aMC@NLO v2.2.2 + Pythia v8.186	A14	NNPDF2.3	NLO [32]
$t\bar{t}H$	MadGraph5_aMC@NLO v2.2.1 + Herwig++ v2.7.1	UEEE5	CT10	NLO [65]
Diboson WW, WZ, ZZ	Sherpa v2.1.1	Default	CT10	NLO [46]
W/Z**+jets**	Sherpa v2.2	Default	CT10	NNLO [66]

Kinematic Variables

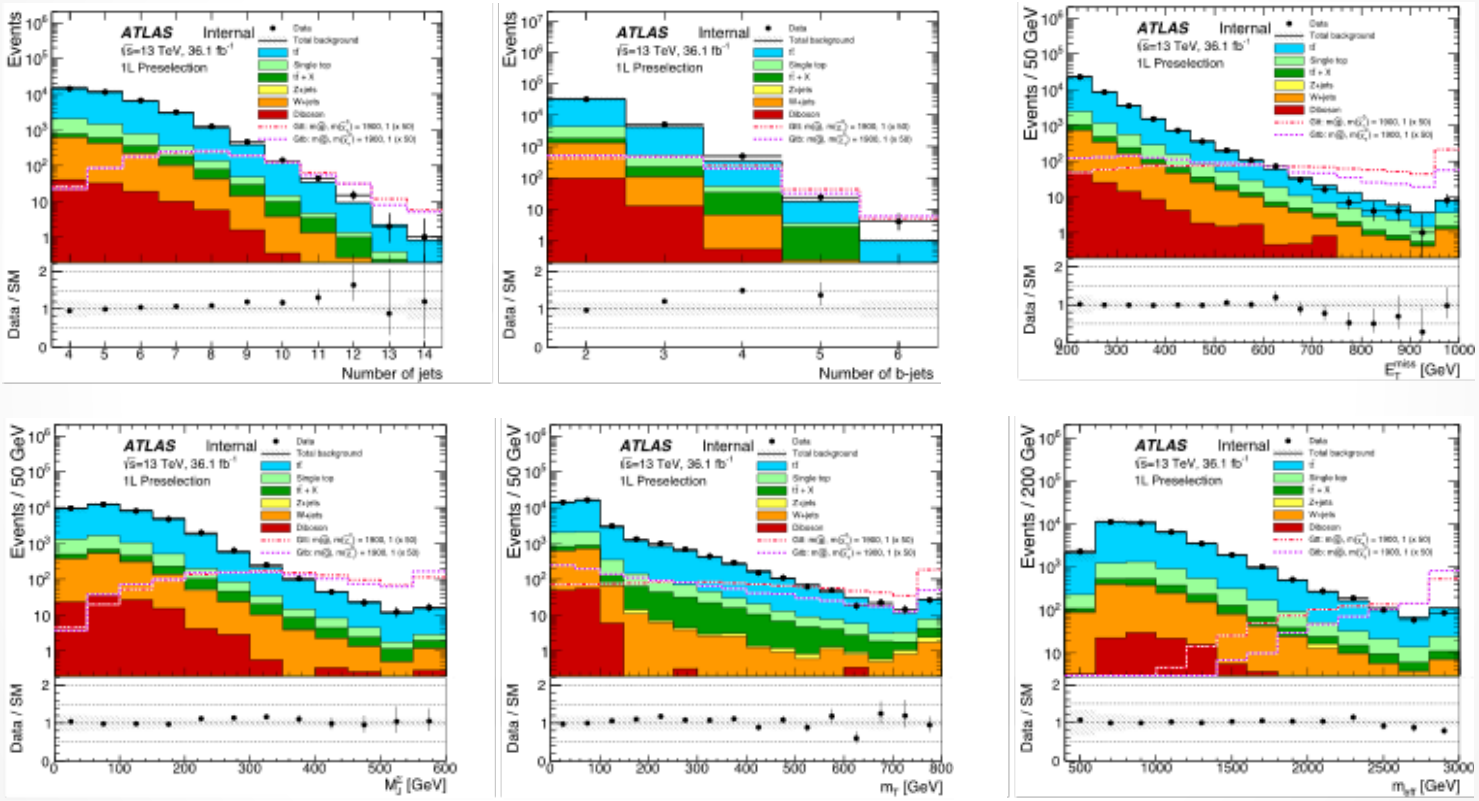
- Effective mass $m_{\mathrm{eff}} = \sum_i p_{\mathrm{T}}^{\mathrm{jet}_i} + \sum_j p_{\mathrm{T}}^{\ell_j} + E_{\mathrm{T}}^{\mathrm{miss}}$
- Transverse mass $m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}}^{\ell} E_{\mathrm{T}}^{\mathrm{miss}} \{1 - \cos[\Delta\phi(\vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}, \vec{p}_{\mathrm{T}}^{\,\ell})]\}}$
- Minimum transverse mass formed by MET and any of the three highest-pT b-tagged jets in the event $m_{\mathrm{T,min}}^{b\text{-jets}} = \min_{i \leq 3} \left(\sqrt{2 p_{\mathrm{T}}^{b\text{-jet}_i} E_{\mathrm{T}}^{\mathrm{miss}} \{1 - \cos[\Delta\phi(\vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}, \vec{p}_{\mathrm{T}}^{\,b\text{-jet}_i})]\}} \right)$
- Total jet mass variable $M_J^{\Sigma} = \sum_{i \leq 4} m_{J,i}$

  Using the mass of the large-radius re-clustered jets in the event

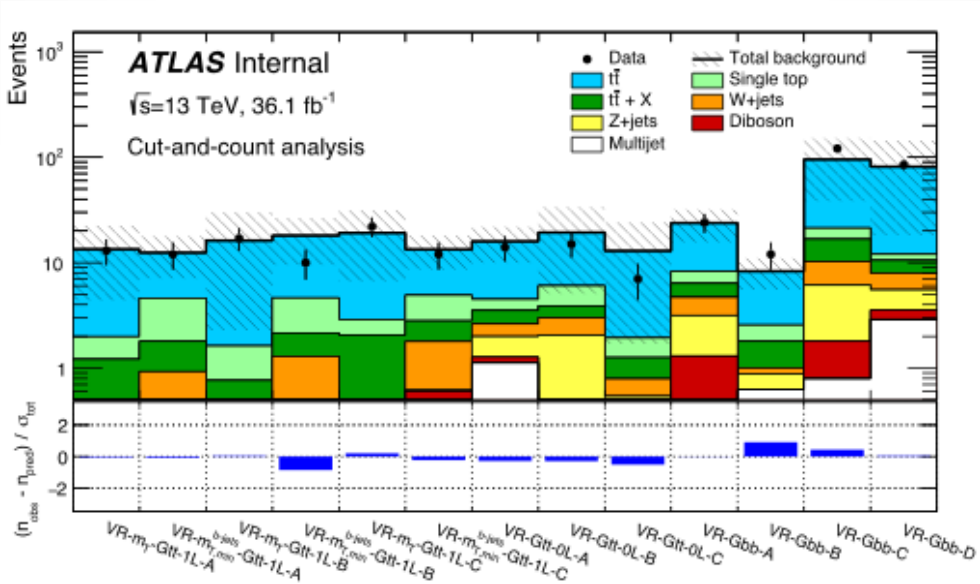
0-L Preselection

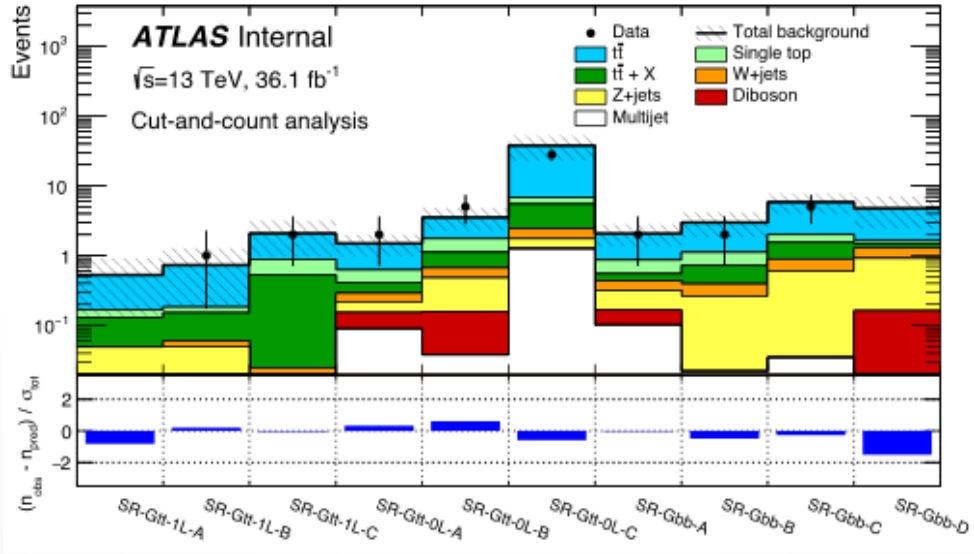


1-L Preselection

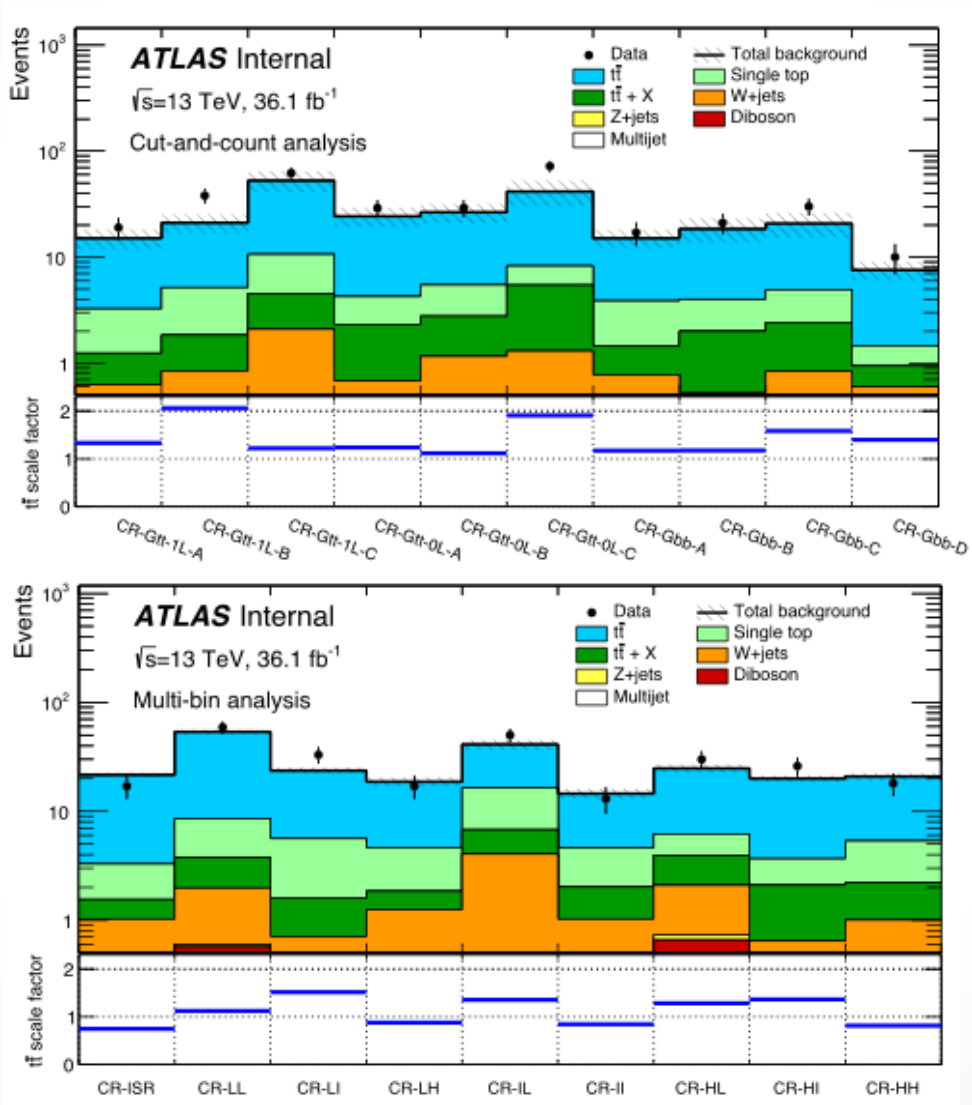


Single-bin Regions

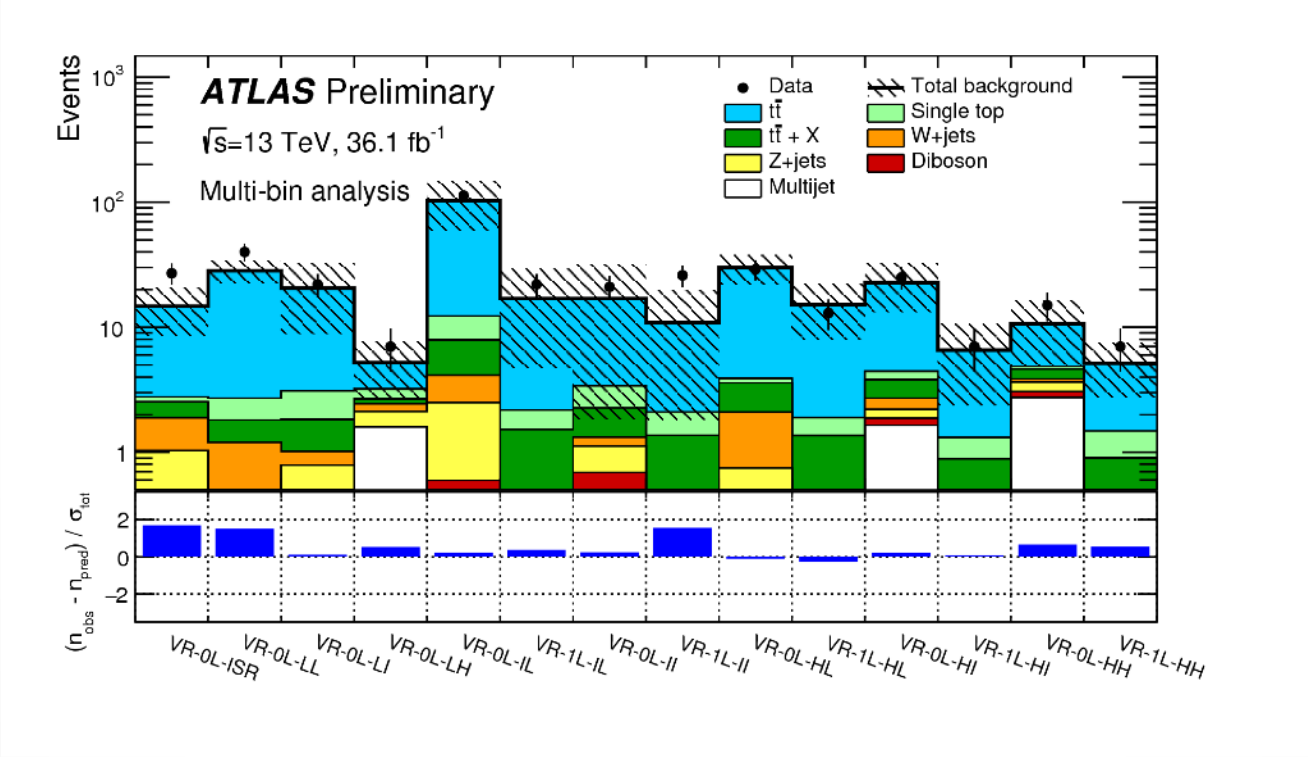




tt Scale Factors



Multi-bin VRs



Model-independent Limits

Signal channel	p_0 (Z)	σ_{vis}[fb]	S^{95}_{obs}	S^{95}_{exp}
SR-Gtt-1L-A	0.50 (0.00)	0.08	3.0	$3.1^{+0.9}_{-0.1}$
SR-Gtt-1L-B	0.34 (0.41)	0.11	3.9	$3.6^{+1.2}_{-0.5}$
SR-Gtt-1L-C	0.50 (0.00)	0.14	4.9	$4.8^{+1.8}_{-1.0}$
SR-Gtt-0L-A	0.32 (0.47)	0.13	4.8	$4.1^{+1.7}_{-0.7}$
SR-Gtt-0L-B	0.25 (0.68)	0.21	7.4	$5.9^{+2.2}_{-1.4}$
SR-Gtt-0L-C	0.50 (0.00)	0.55	20.0	$20.0^{+0.0}_{-2.1}$
SR-Gbb-A	0.50 (0.00)	0.13	4.6	$4.5^{+1.7}_{-0.9}$
SR-Gbb-B	0.50 (0.00)	0.13	4.5	$5.0^{+2.1}_{-1.1}$
SR-Gbb-C	0.50 (0.00)	0.18	6.6	$6.9^{+2.8}_{-1.5}$
SR-Gbb-D	0.50 (0.00)	0.09	3.1	$4.4^{+2.0}_{-1.1}$