SUSY Strong production

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

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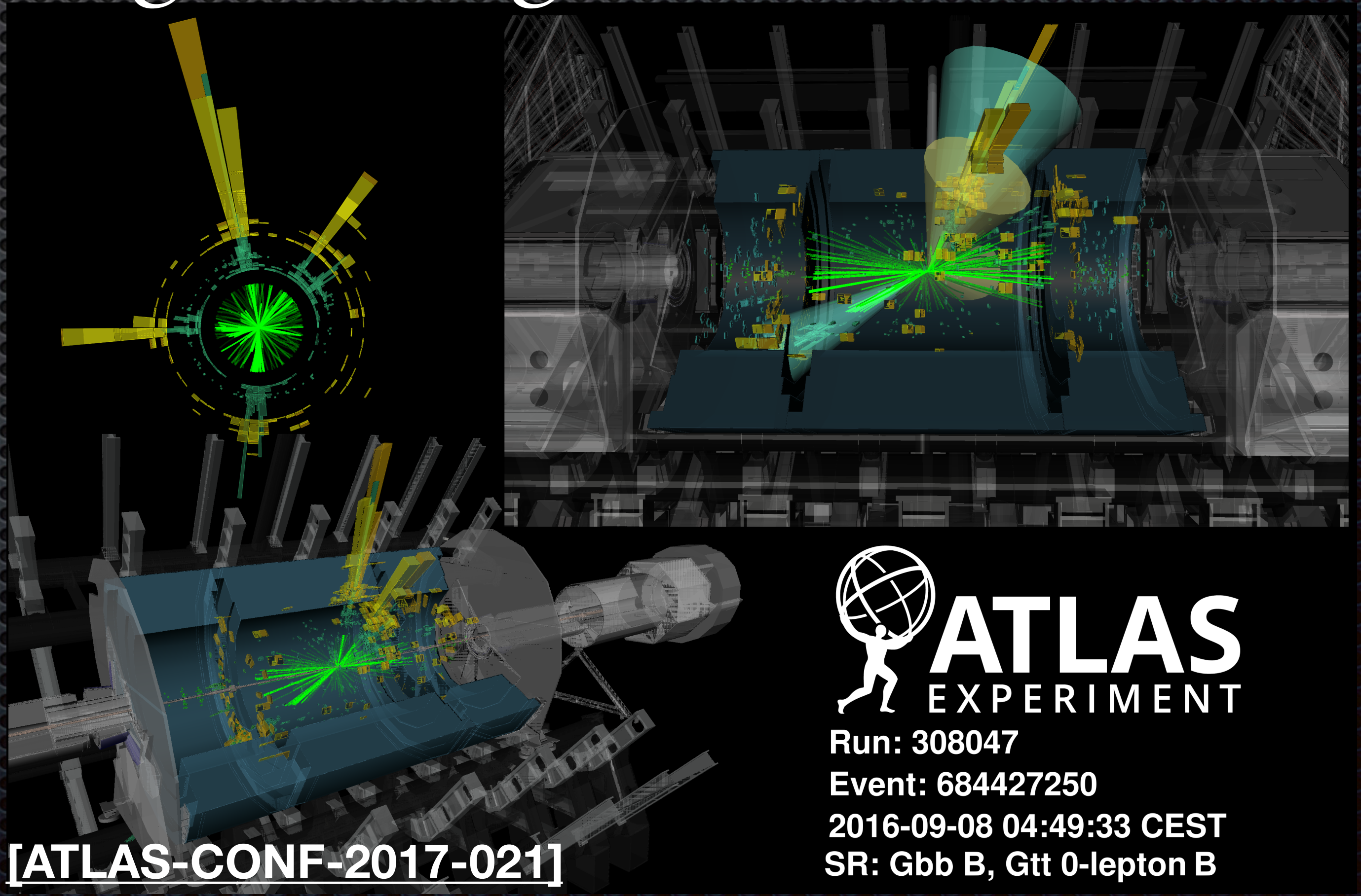
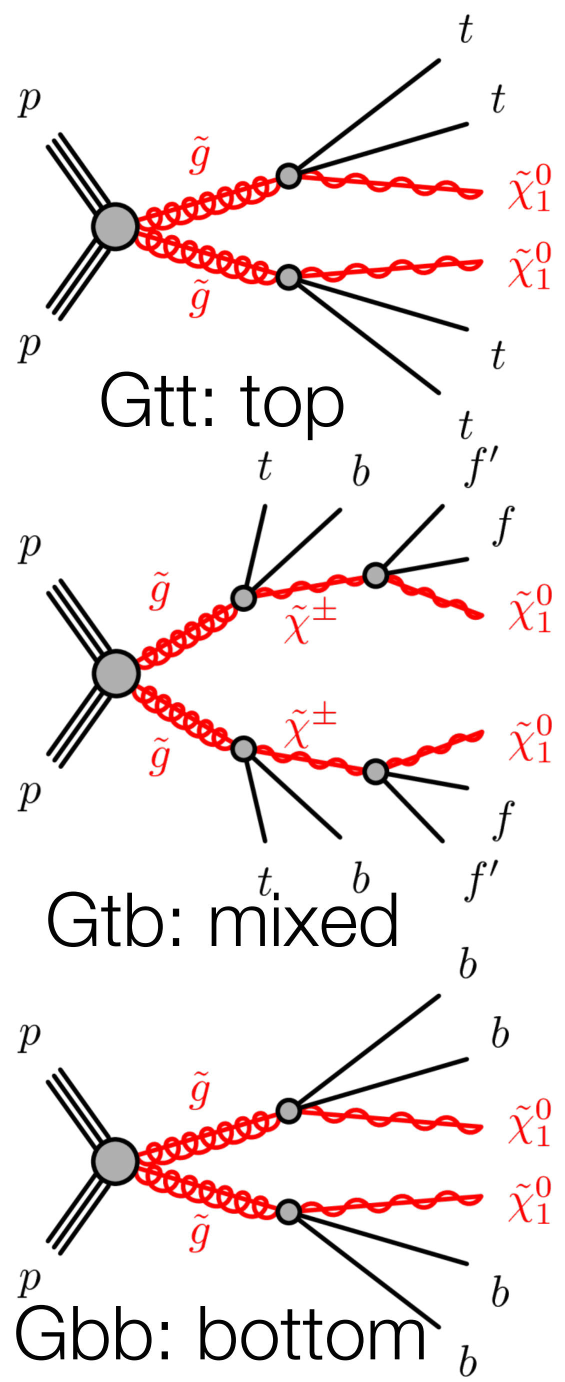


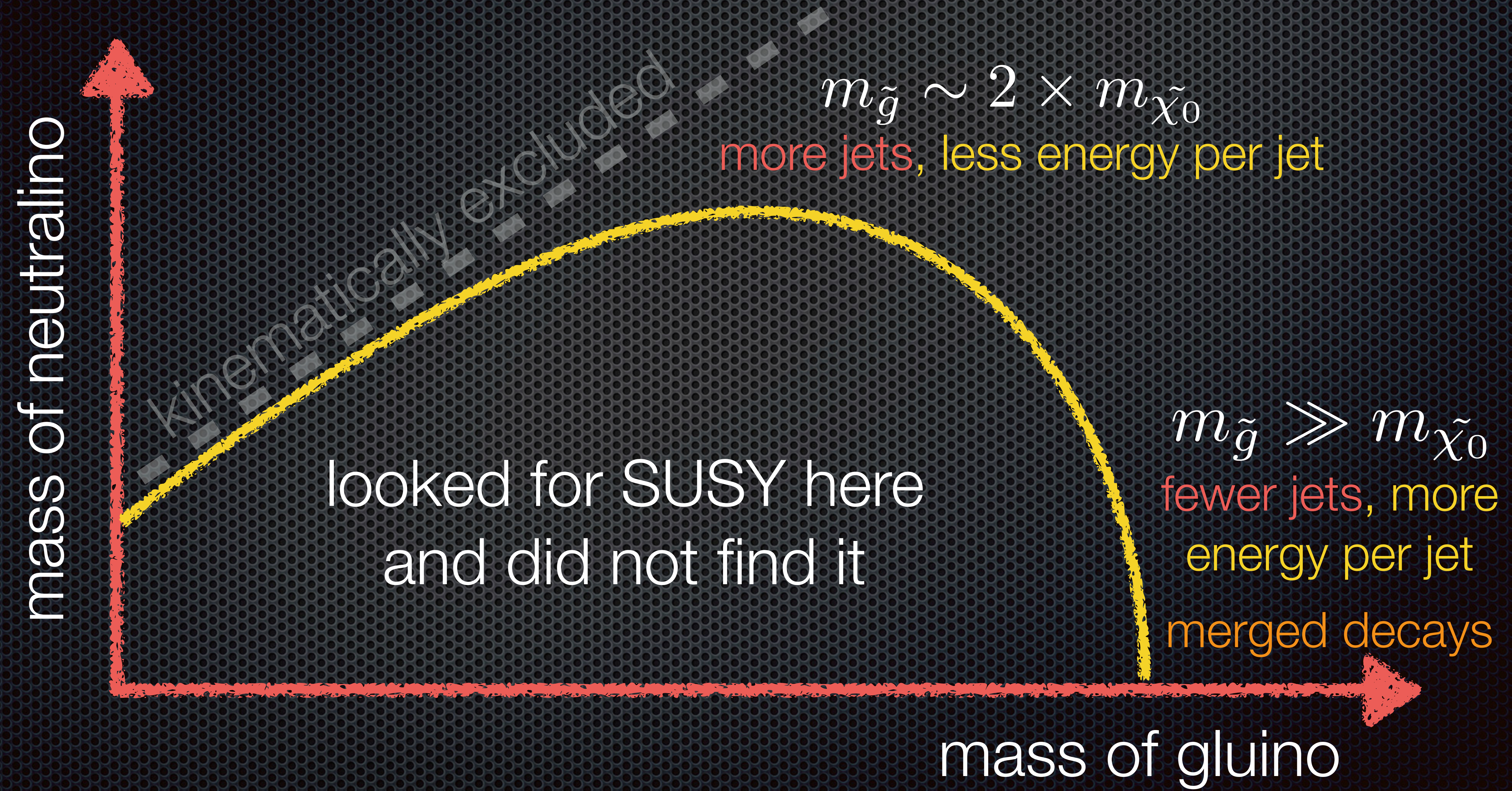
[ATLAS-CONF-2017-021]

Motivation



- Supersymmetry (SUSY) at the LHC: high gluino cross section @ 13 TeV
    - Stops and sbottoms decay to corresponding quark + LSP (neutralino)
- Typical signature for 3rd generation, R-parity conserving, Supersymmetry (3G RPC SUSY) models
    - large number of *b*-jets
    - high missing transverse energy (MET)
    - Lorentz-boosted W bosons and top quarks in certain regions of parameter space
- Prior analyses done: Run 1, 2015 paper, ATLAS-CONF-2016-052, and ATLAS-CONF-2017-021

Parameterizing the model



Run I results

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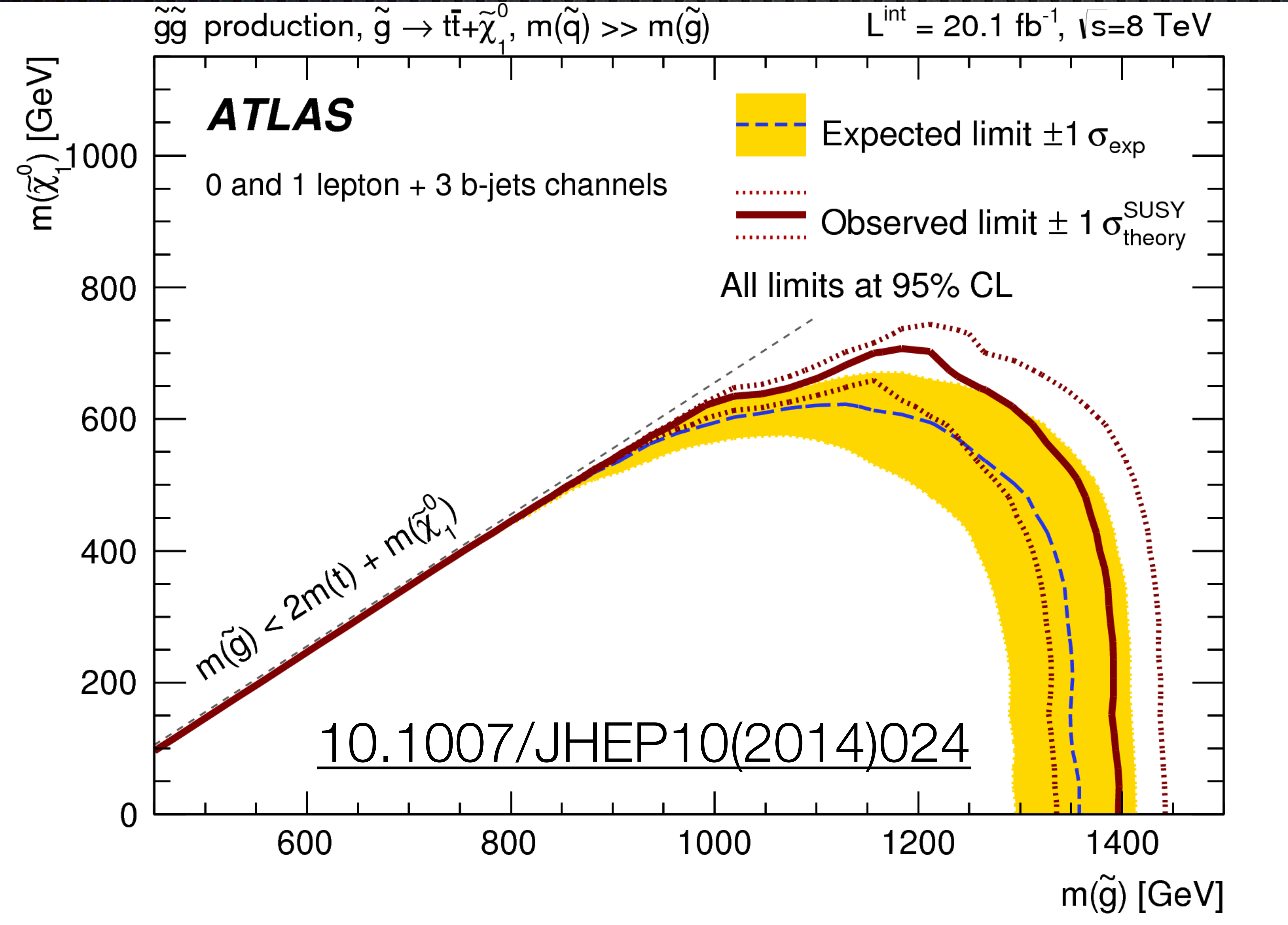


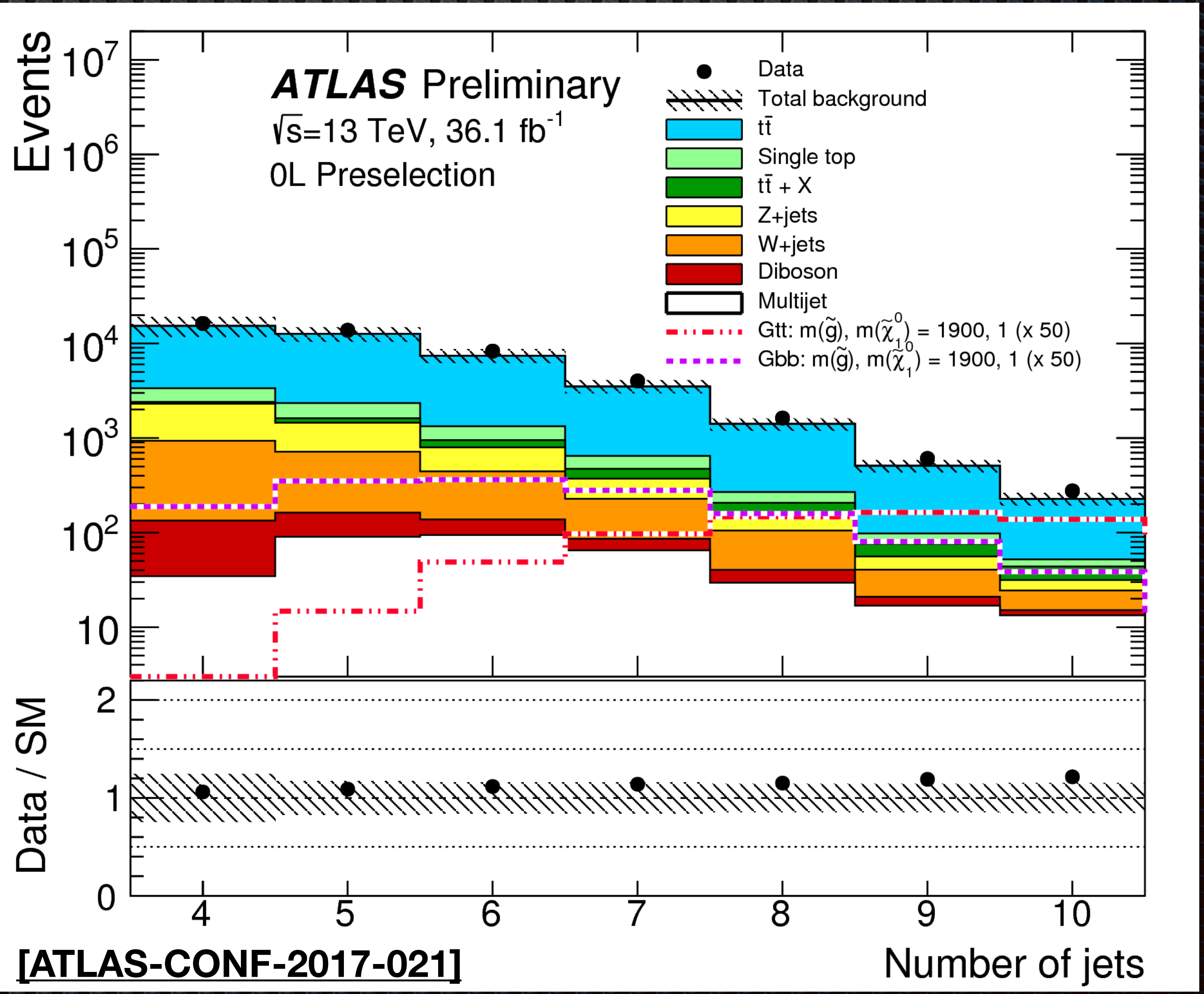
Excluded up to 1.4 TeV

Objects of Interest

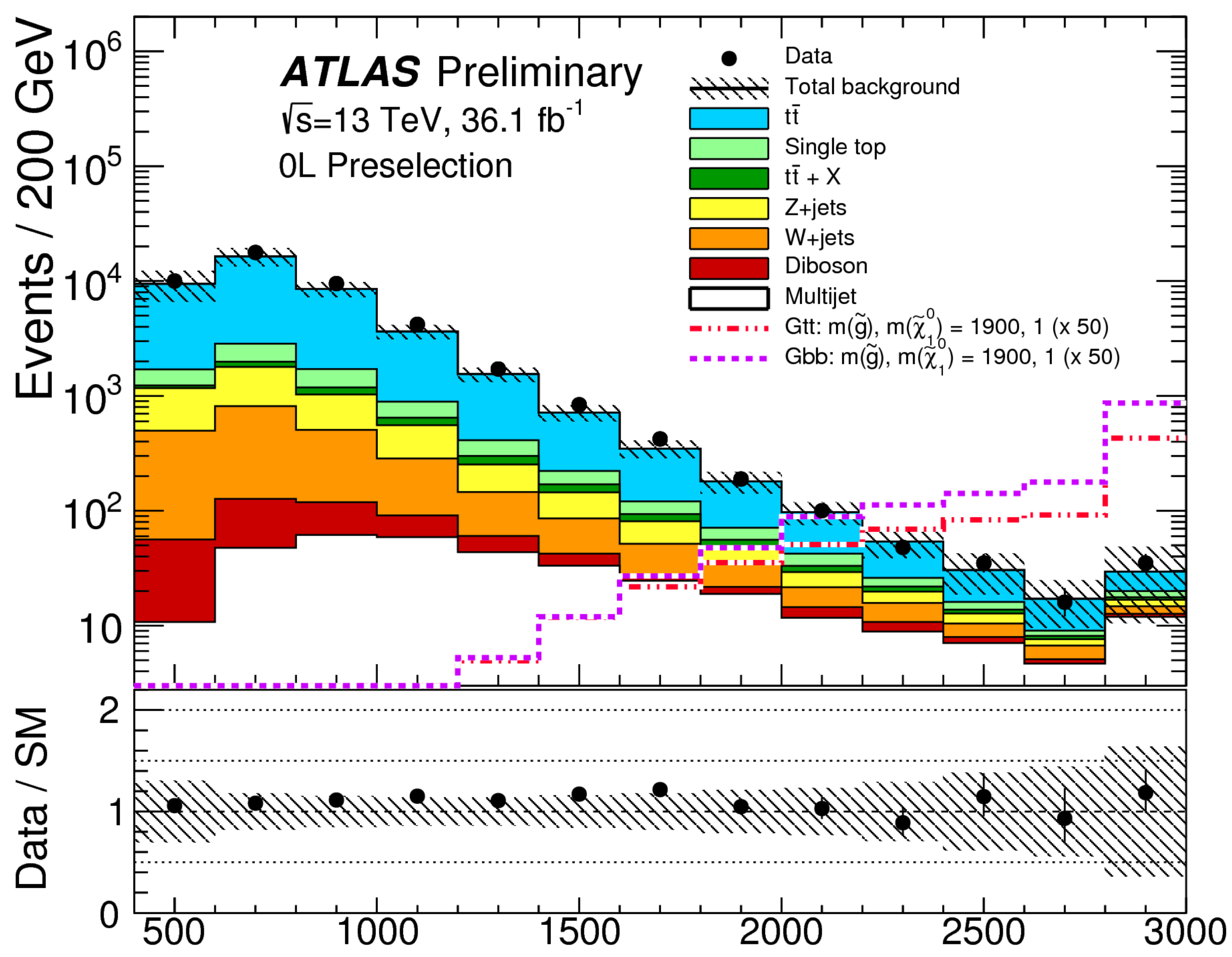
Signal: 4 top quarks

- Small energetic jets
- Large reclustered jets
- Leptons: electrons and muons
- High missing transverse energy
- MET trigger

Background: 2 top quarks



Data/Simulation Comparison



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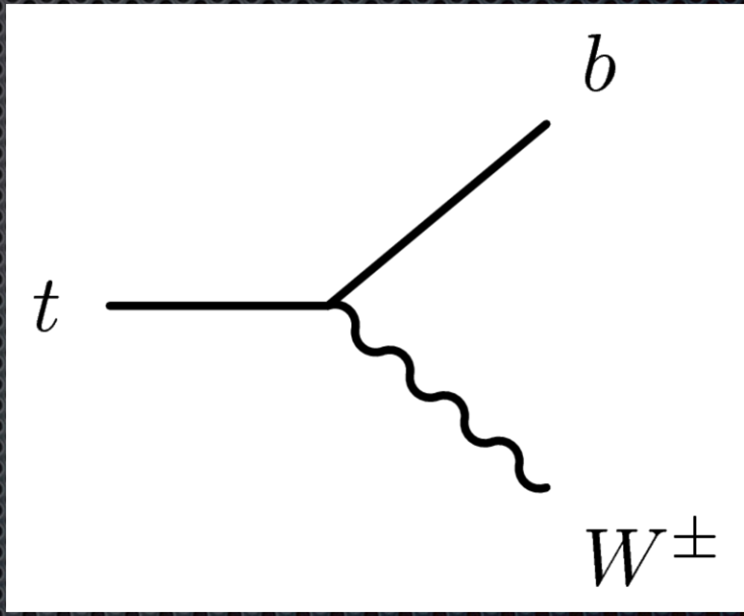


⚠ ttbar-enhanced

MET > 200 GeV

≥4 signal jets

≥2 *b*-jets

0 leptons

! Selections optimized for SUSY exclusion

Multi-bin Strategy

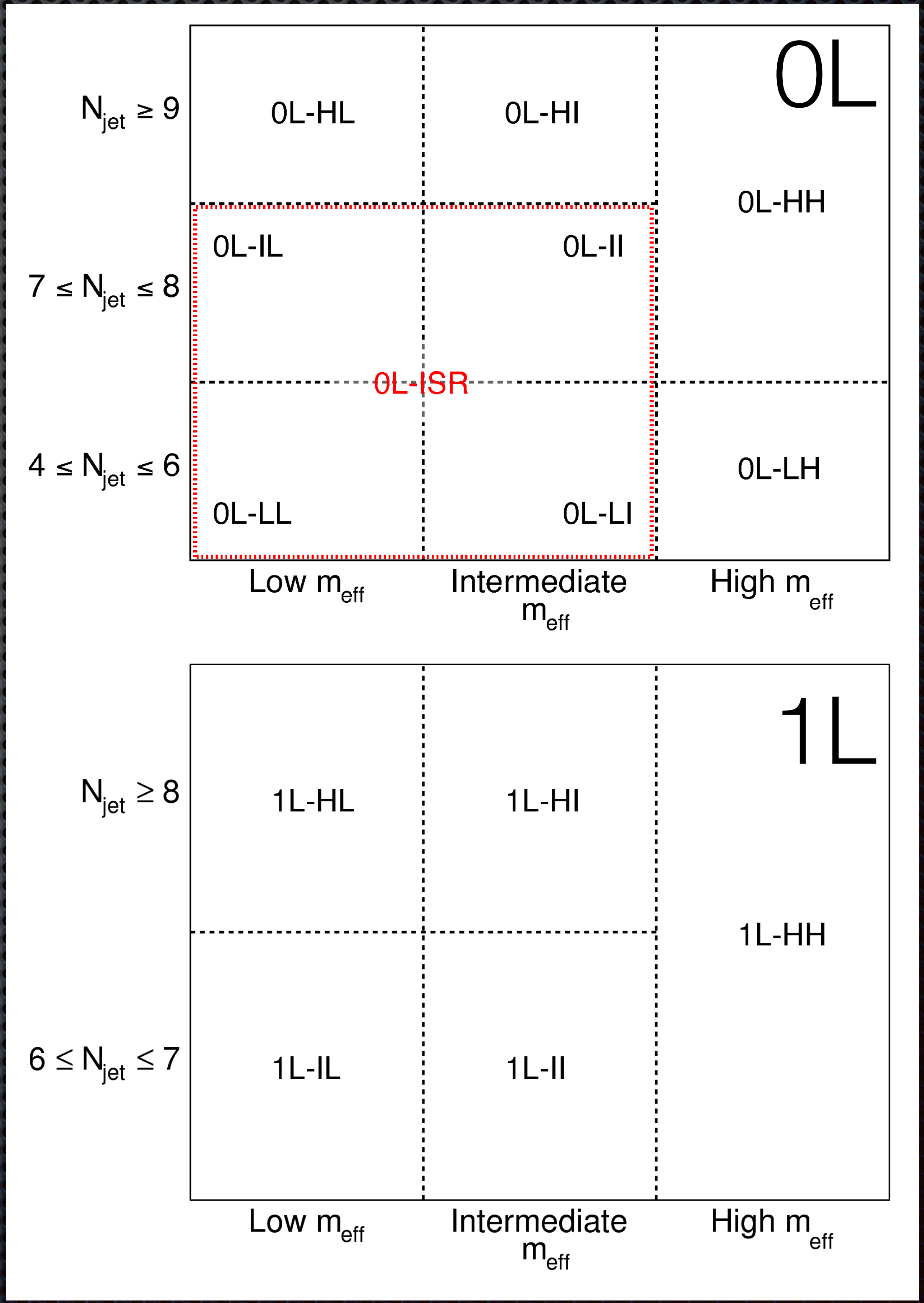
simultaneously fit multiple parts of phase space together

Define orthogonal **signal** regions using jet multiplicity and effective mass

- allow for model-dependent interpretations (e.g. low jet multiplicity probes Gbb-like models)

- Then define orthogonal regions dominated by ttbar: **control**
  - Likelihood fit using MC
  - Derive normalization factors by fitting to data
- Lastly, define orthogonal regions: **validation**
  - Verify that our control region derives normalization correctly
  - Check variable extrapolations between **signal** and **control**

Open the box (unblind)!



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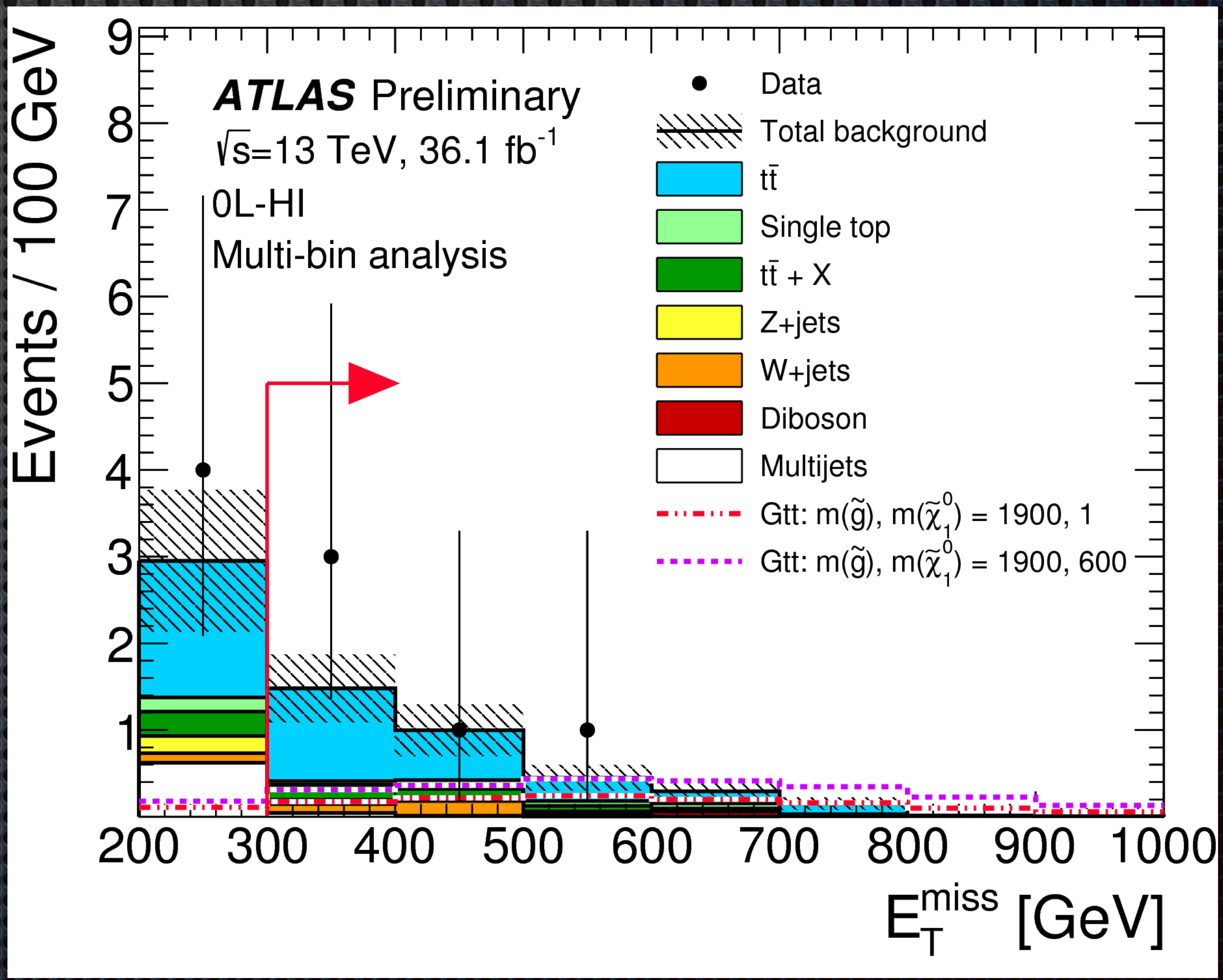
High-jet-multiplicity regions

Criteria common to all high-N_{jet} regions: $N_{b\text{-jets}} \geq 3$				
	Variable	SR-0L	SR-1L	CR
Criteria common to all regions of the same type	N_{lepton}	0	≥ 1	≥ 1
	$\Delta\phi^{4j}_{\text{min}}$	> 0.4	–	–
	m_{T}	–	> 150	< 150
High-m_{eff} (HH) (Large Δm)	N_{jet}	≥ 7	≥ 6	≥ 6
	m_{eff}	> 2500	> 2300	> 2100
	$m^{b\text{-jets}}_{\text{T,min}}$	> 100	> 120	> 60
	$E^{\text{miss}}_{\text{T}}$	> 400	> 500	> 300
Intermediate-m_{eff} (HI) (Intermediate Δm)	N_{jet}	≥ 9	≥ 8	≥ 8
	m_{eff}	[1800,2500]	[1800,2300]	[1700,2100]
	$m^{b\text{-jets}}_{\text{T,min}}$	> 140	> 140	> 60
	$E^{\text{miss}}_{\text{T}}$	> 300	> 300	> 200
Low-m_{eff} (HL) (Small Δm)	N_{jet}	≥ 9	≥ 8	≥ 8
	m_{eff}	[900,1800]	[900,1800]	[900,1700]
	$m^{b\text{-jets}}_{\text{T,min}}$	> 140	> 140	> 130
	$E^{\text{miss}}_{\text{T}}$	> 300	> 300	> 250

- Signal regions are orthogonal using lepton multiplicity
- Control regions flip the transverse mass cut to be **orthogonal** to 1-lepton SRs



Apply all selections for a signal region, except for MET

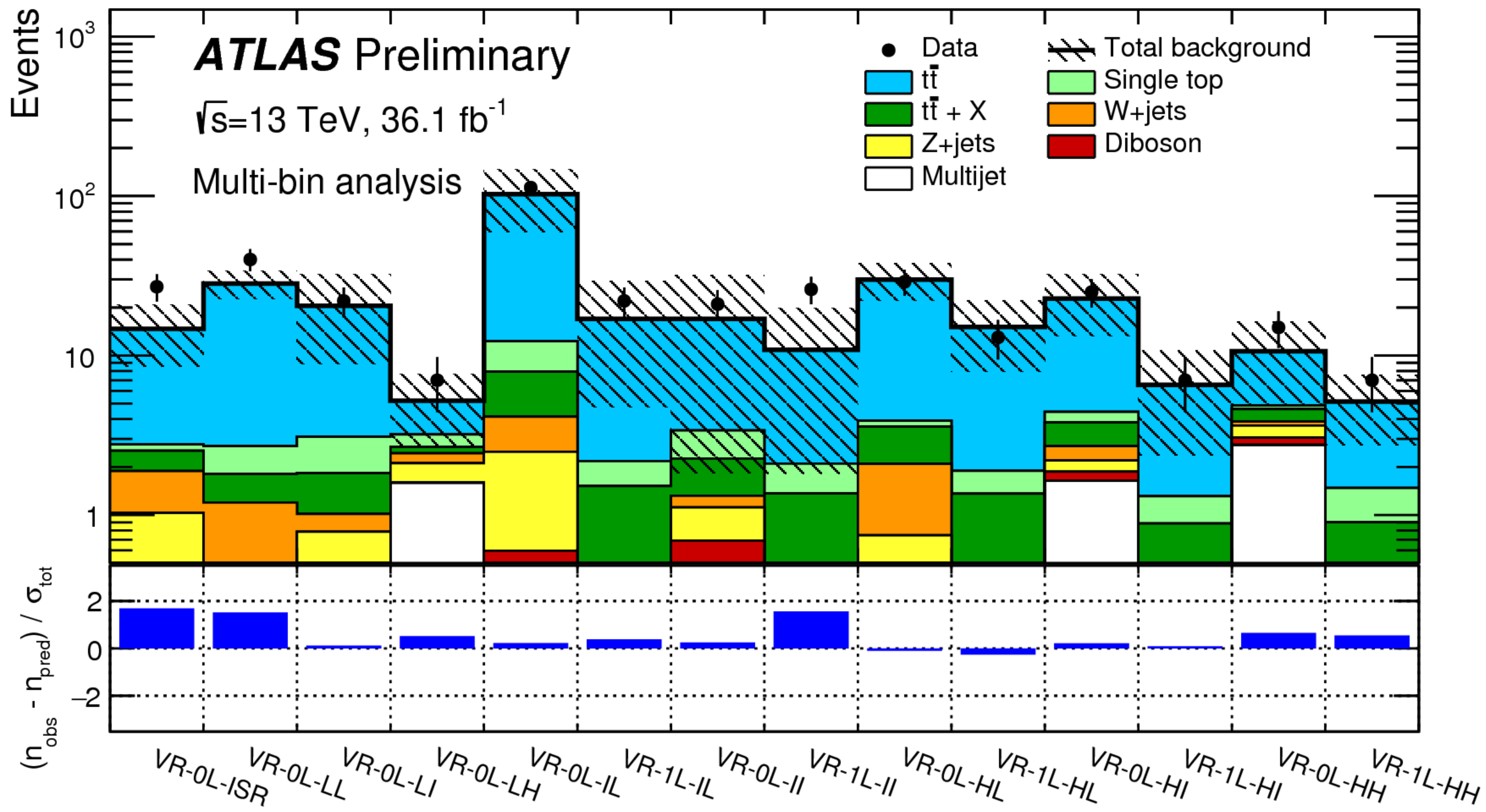
[ATLAS-CONF-2017-021]

Systematic Uncertainties

- **Systematics on objects**
  - For example, the measurement of a jet's momentum
- **Statistical uncertainties**
  - For example, statistical uncertainty on the normalization of ttbar in the control regions
- **Theory uncertainties**: systematic comparisons with alternatively-produced samples
  - radiation (two-sided), parton shower, generator
  - combine in quadrature for each region
- Total background systematics are between 30-50% for all regions
- Dominant uncertainties:
  - normalization — due to our data/MC fit in the control region for ttbar normalization
  - theory systematics — sensitive to radiation effects and MC generator chosen
  - jet energy scale/resolution (JES/JER) — due to corrections in energy/momentum of jets measured in the calorimeter [JES = 13-25%, JER=6-16%]
  - statistical

Results

Validating our work

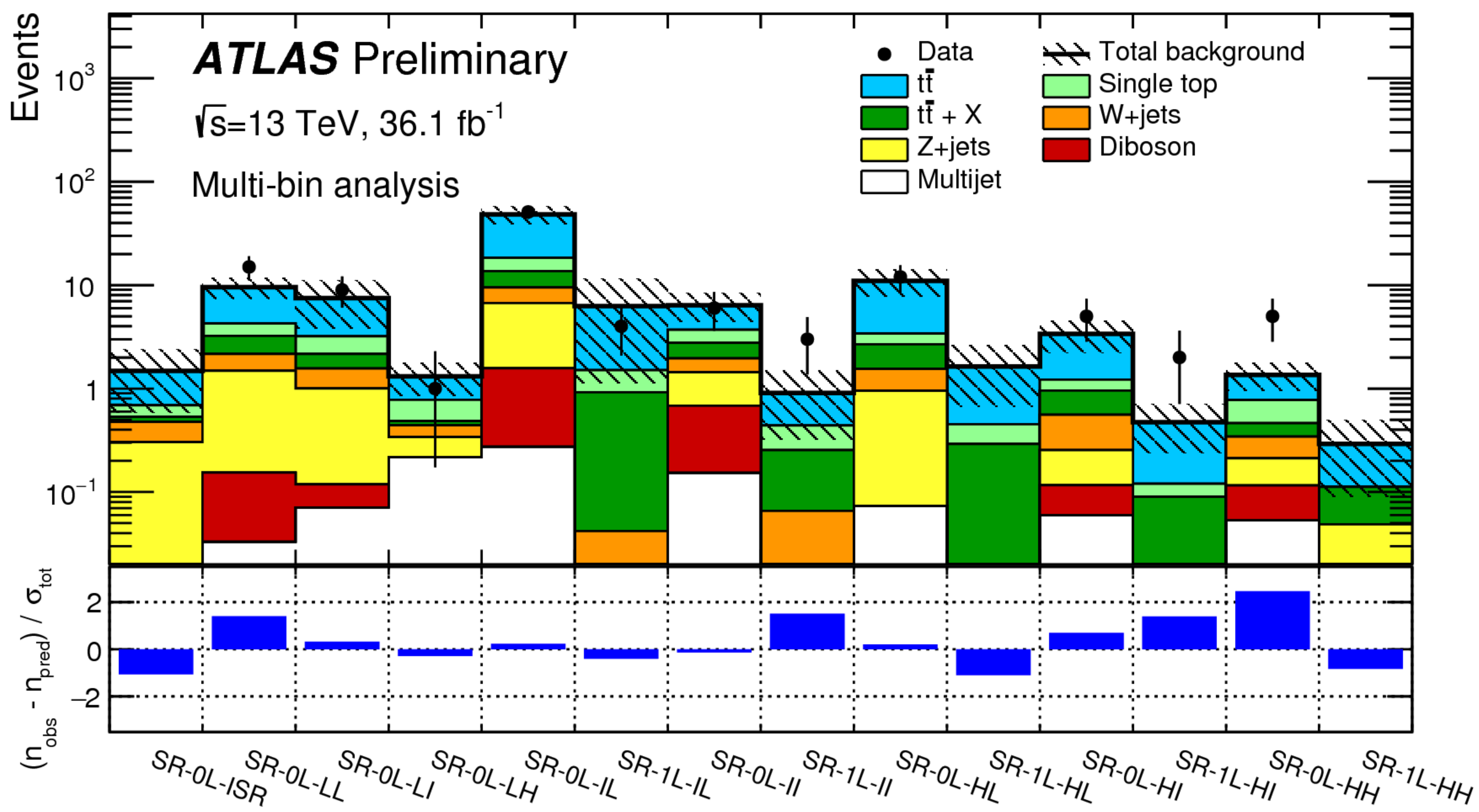


[ATLAS-CONF-2017-021]

no significant mismodeling between observation and theory

multi-bin

Signal Regions Unblinded

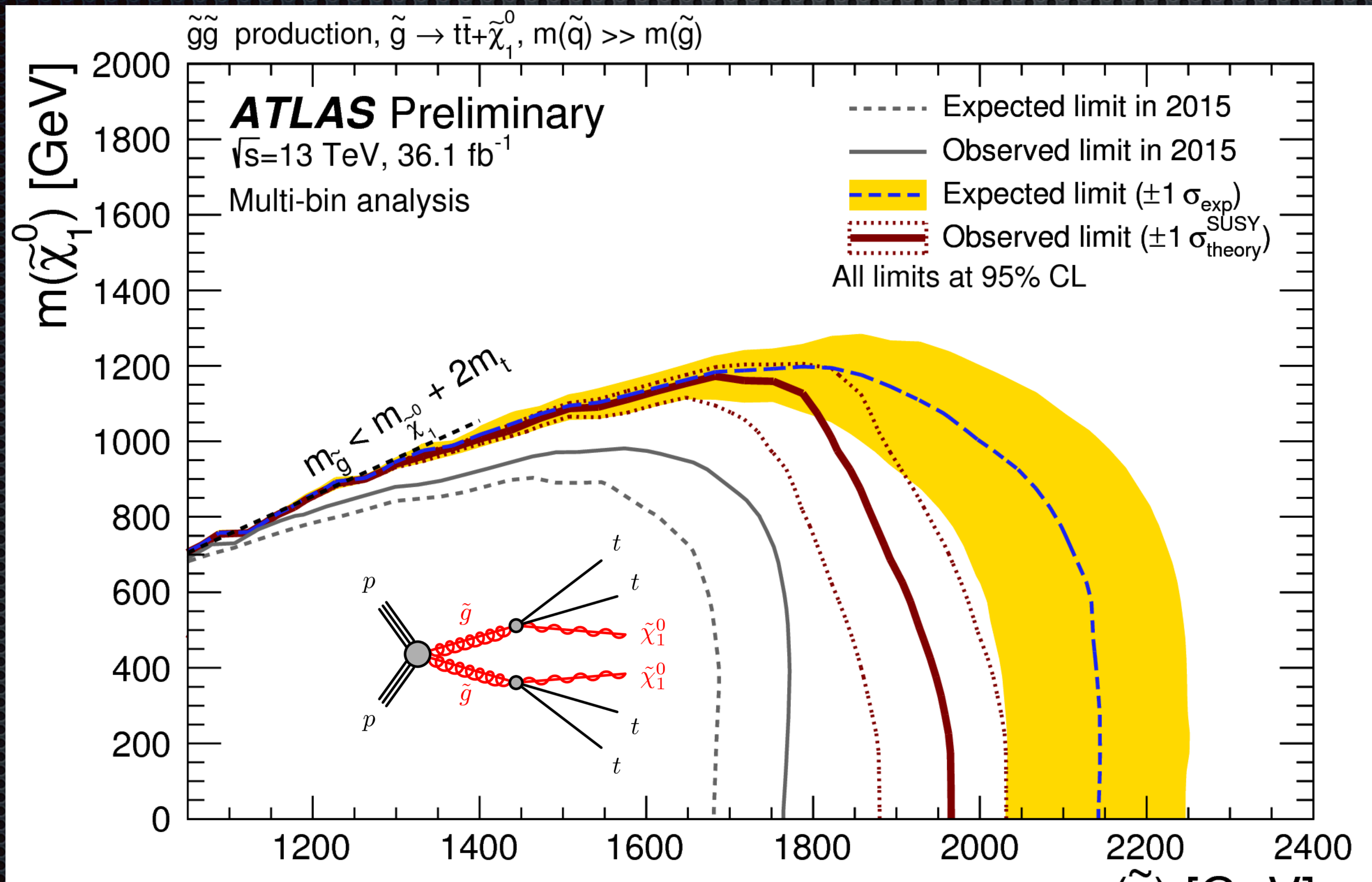


[ATLAS-CONF-2017-021]

no large difference between observation and theory

❗ *Set strong limits given no large difference*

The limits



[ATLAS-CONF-2017-021]

❗ exclude up to ~1.95 TeV

Conclusion

- A search for supersymmetry at the ATLAS detector was performed and no excess was observed above the predicted background
  - A cut-and-count analysis was optimized for discovery
  - No excess was observed, so the multi-bin analysis was performed and optimized for exclusion
- Stronger limits were set on gluino masses excluded at the 95% CL in simplified models involving the pair production of gluinos that decay via top (bottom) squark

Next paper coming out soon!

[ATLAS-CONF-2017-021]

Backup

Objects

Jets

Baseline small-R

R=0.4, pT > 20 GeV, |η| < 2.8
Calibrated: EM+JES+GSC
JVT > 0.59 & pT < 60 GeV & |η| < 2.4

Signal
OR'ed
pT > 30 GeV

***b*-jets**
MV2c10, 77% OP
|η| < 2.5

Baseline large-R

Signal
reclustered from signal small-R jets
Anti-Kt, R=0.8, f_{cut} = 10%*
pT > 100 GeV

**remove subjets with pT < 10% of total jet pT*

Leptons

Baseline Electrons

ID: LooseLHBLayer
pT > 20 GeV, |η| < 2.47

Signal
Overlap Removal, ID: MediumLLH
LooseTrackOnly isolation
$|z_0 \sin\theta| < 0.5\ mm$, $|d_0/\sigma_{d_0}| < 5$

Baseline Muons

ID: Medium Track
pT > 20 GeV, |η| < 2.5

Signal
Overlap Removal
LooseTrackOnly isolation
$|z_0 \sin\theta| < 0.5\ mm$, $|d_0/\sigma_{d_0}| < 3$

Trigger and MET

MET reconstructed using Track Soft Terms
2015 trigger: HLT_xe70 *2016 trigger:* HLT_xe(100|110)_mht_L1XE50

Variables of Interest

$$\Delta\phi^{4j}_{\mathrm{min}} = \min(|\phi_1 - \phi_{E_{\mathrm{T}}^{\mathrm{miss}}}|, \ldots, |\phi_4 - \phi_{E_{\mathrm{T}}^{\mathrm{miss}}}|)$$ *QCD suppression*

minimum ΔΦ between leading 4 jets and MET

$$\mathrm{m}_{\mathrm{eff}}^{\mathrm{incl}} = \sum_{i \leq n} p_{\mathrm{T}}^{j_i} + \sum_{j \leq m} p_{\mathrm{T}}^{\ell_j} + E_{\mathrm{T}}^{\mathrm{miss}}$$ *Only signal objects used*

Inclusive effective mass

$$\mathrm{m}_{\mathrm{T,min}}^{b\mathrm{-jets}} = \min_{i \leq 3} \sqrt{\left(E_{\mathrm{T}}^{\mathrm{miss}} + p_{\mathrm{T}}^{j_i}\right)^2 - \left({E_{\mathrm{T}}^{\mathrm{miss}}}_x + p_x^{j_i}\right)^2 - \left({E_{\mathrm{T}}^{\mathrm{miss}}}_y + p_y^{j_i}\right)^2}$$

Transverse mass of MET and *b*-jets *(leading 3 b-jets)*

$$\mathrm{m}_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}} E_{\mathrm{T}}^{\mathrm{miss}} \left(1 - \cos\Delta\phi\left(E_{\mathrm{T}}^{\mathrm{miss}}, \mathrm{lepton}\right)\right)}$$ *Regions with ≥1 lepton*

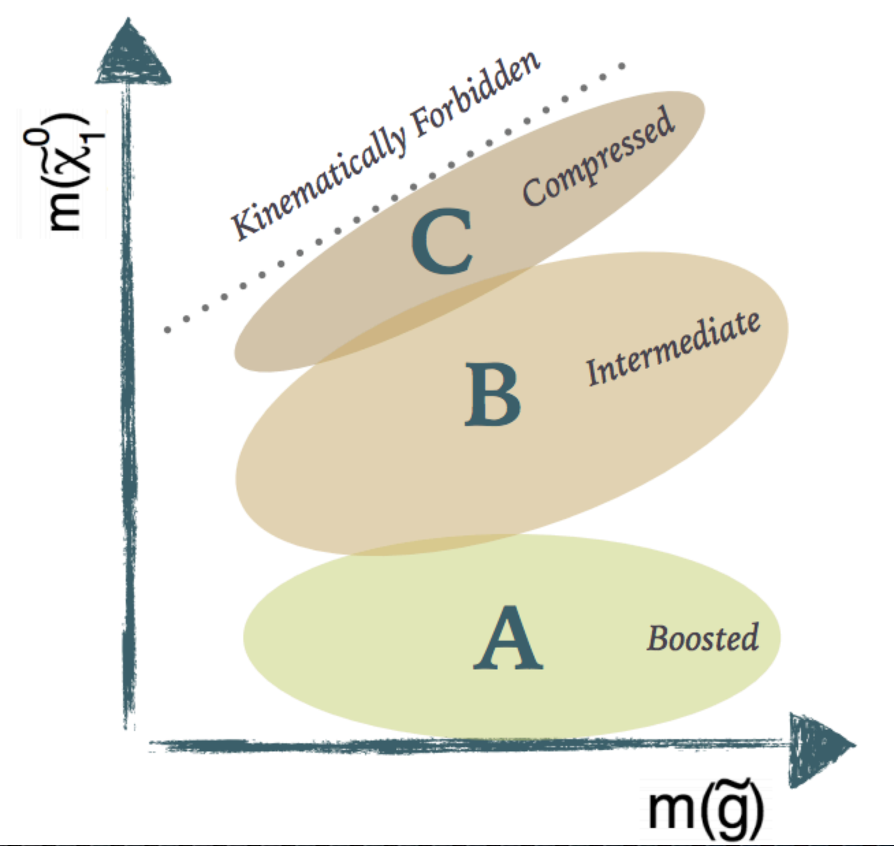
Transverse mass leptonic W

$$M_J^{\Sigma,4} = \sum_{i \leq 4} m_{J,i}$$ *Sum of 4 leading reclustered jets*

Total jet mass

❗ All regions optimized for discovery

Strategy



- Define signal regions based on Gtt/Gbb models
  - Goal: enhance signal/background
- Define ttbar control regions
  - Likelihood fit using MC
  - Derive normalization factors
- Define validation regions
  - Kinematically close
  - Orthogonal to SRs / CRs
  - Validate extrapolations between CR and SR
- Open the box (unblind)!

</> *Used the root_optimize optimization framework*

Systematic Uncertainties

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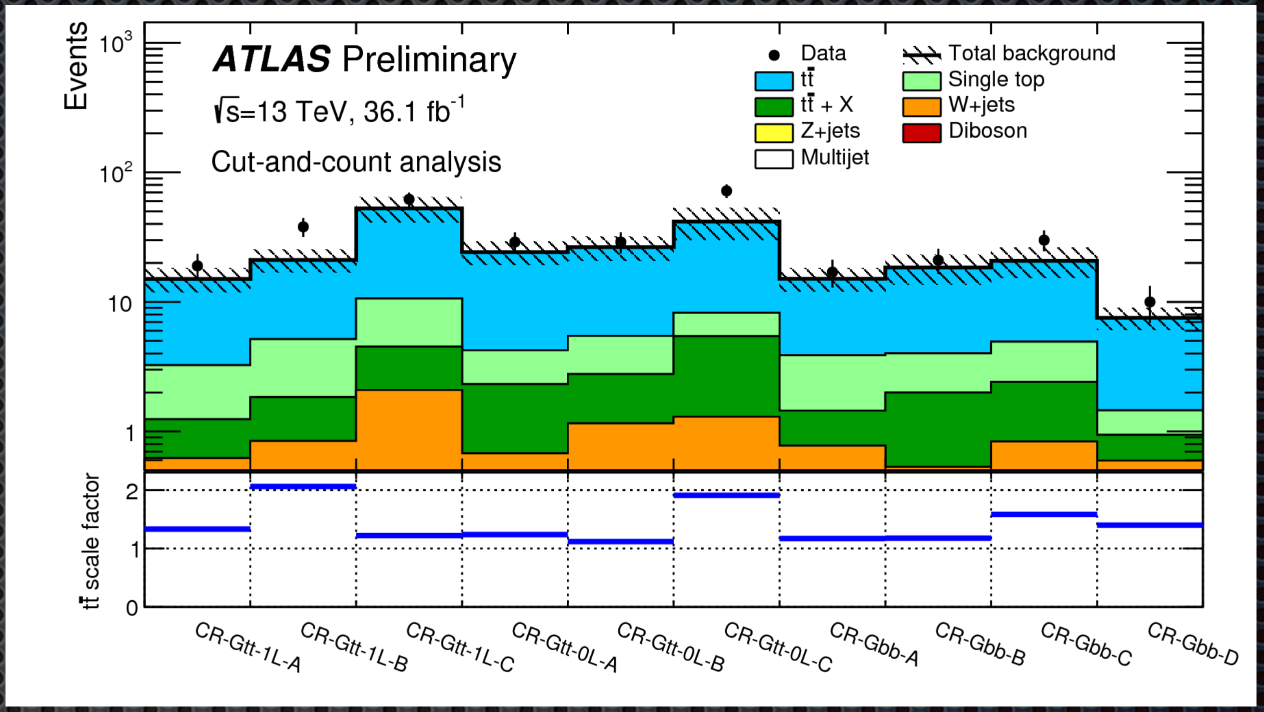
  - statistical

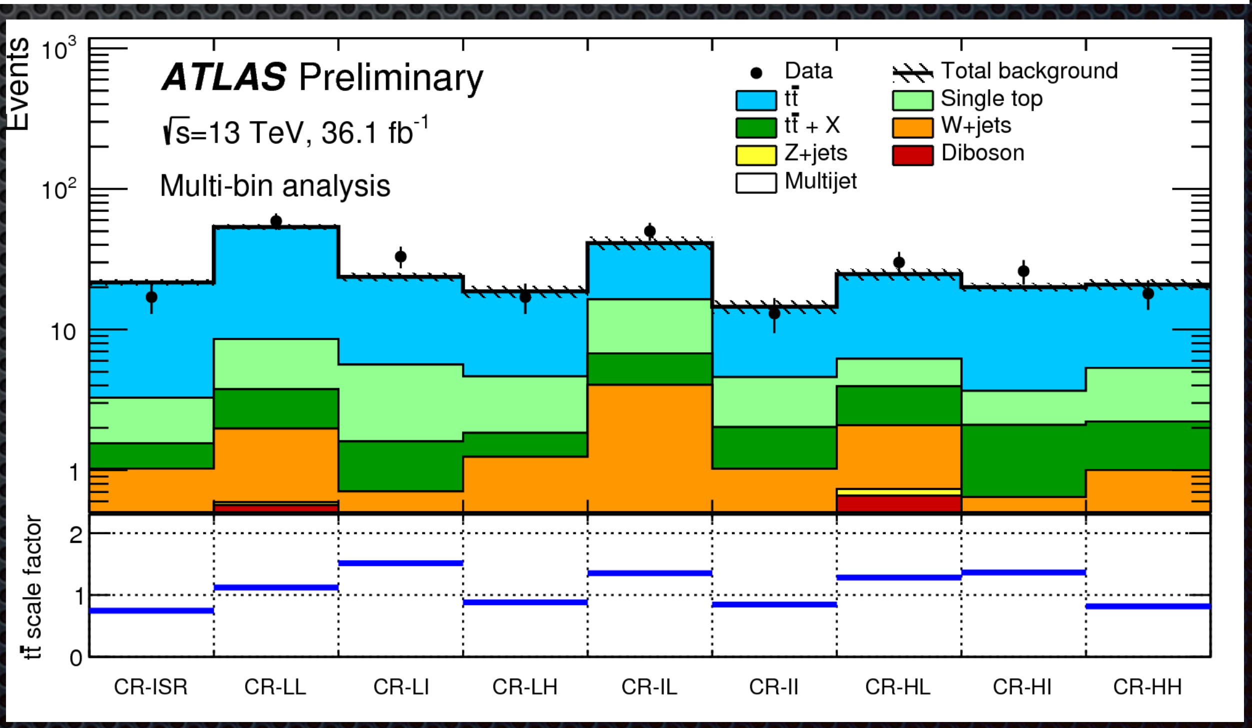
Gtt 0L C

Uncertainty of channel	SR
Total background expectation	36.23
Total statistical ($\sqrt{N_{\text{exp}}}$)	±6.02
Total background systematic	±10.36 [28.59%]
ttbar normalization	±9.60
theory systematics	±9.12
jet energy scale	±6.13

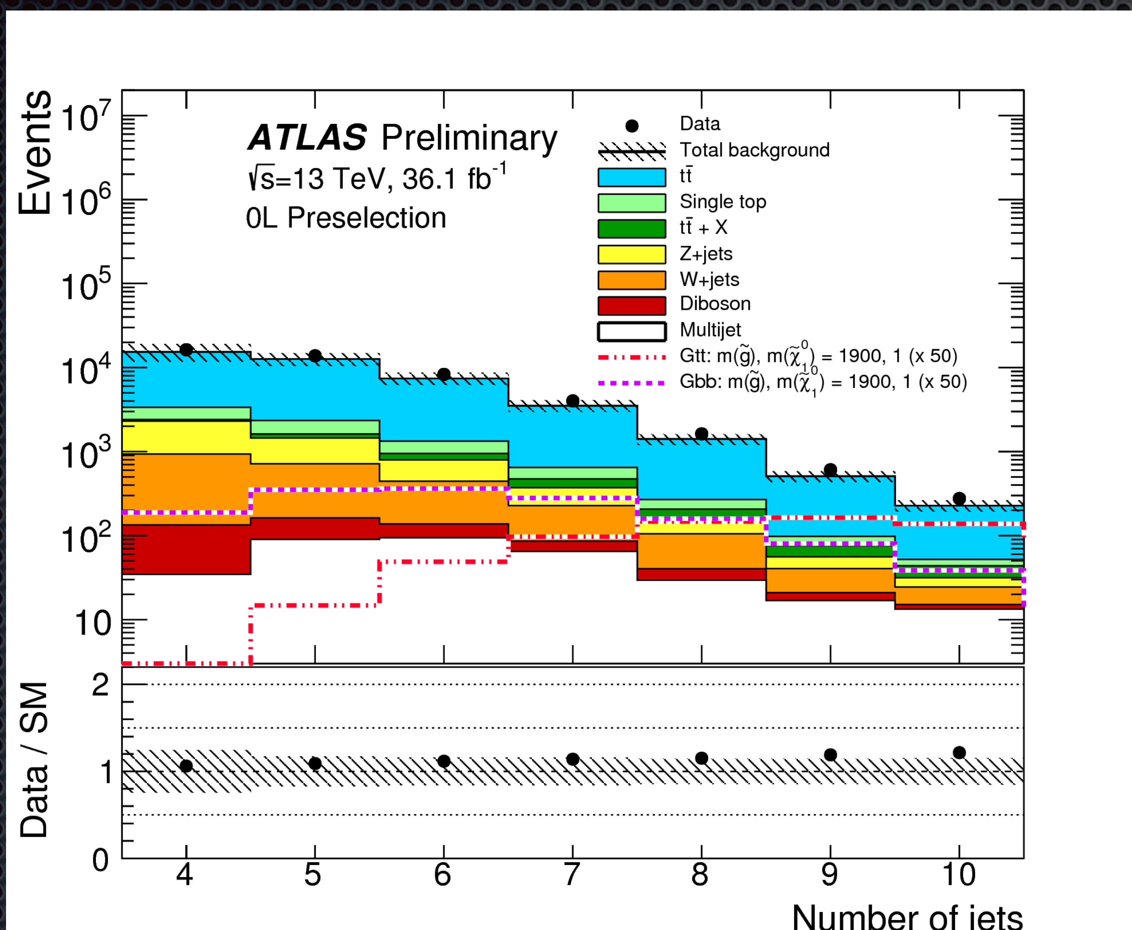
Likelihood fits

- inputs to likelihood fits in control regions of cut-and-count and multi-bin analysis

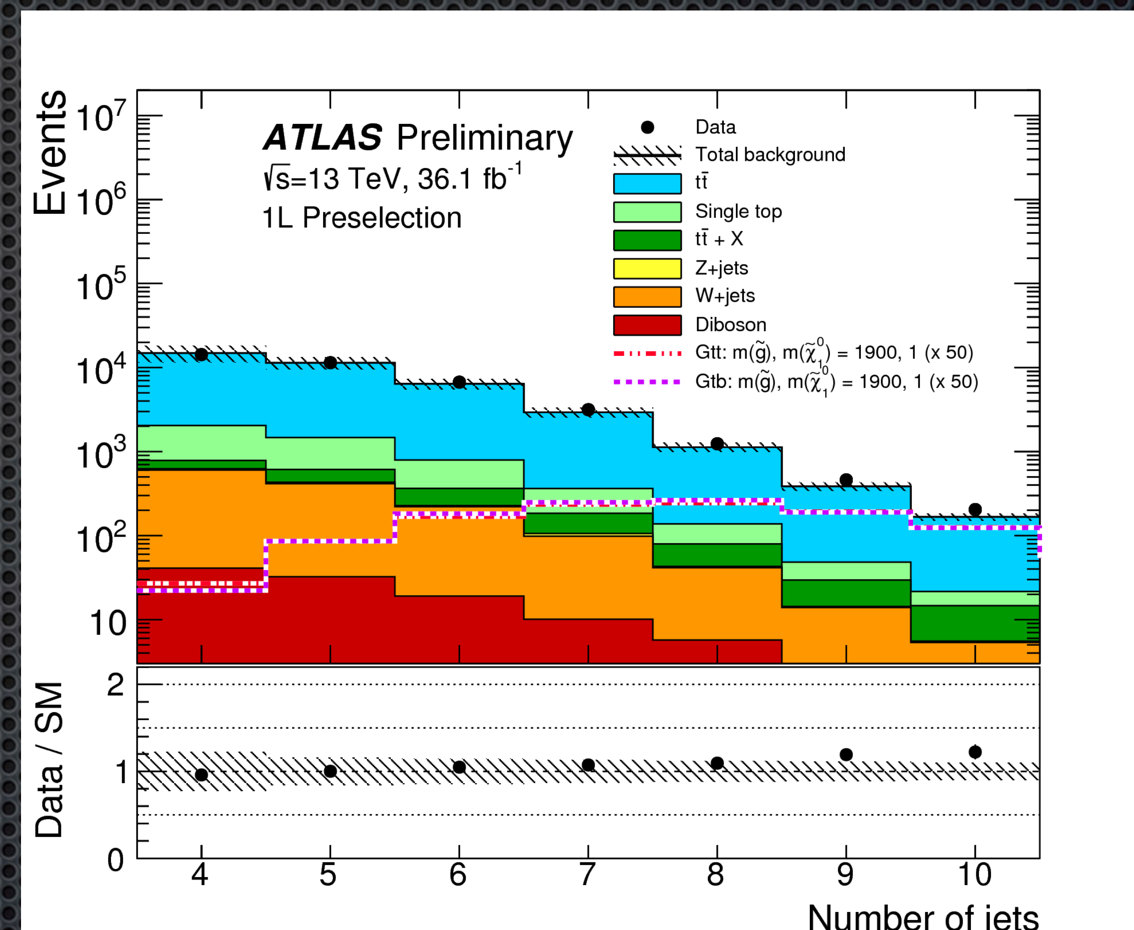




jet multiplicity

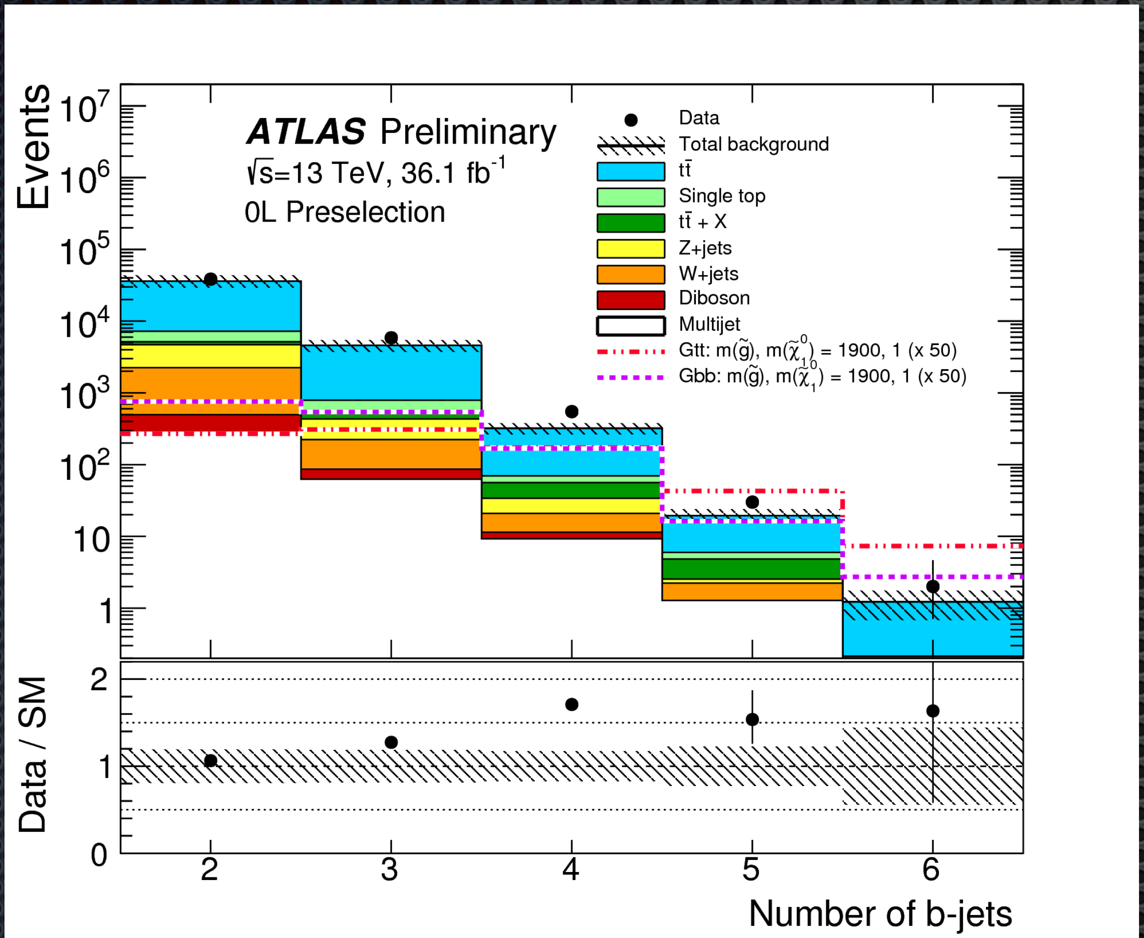


0L



1L

b-jet multiplicity



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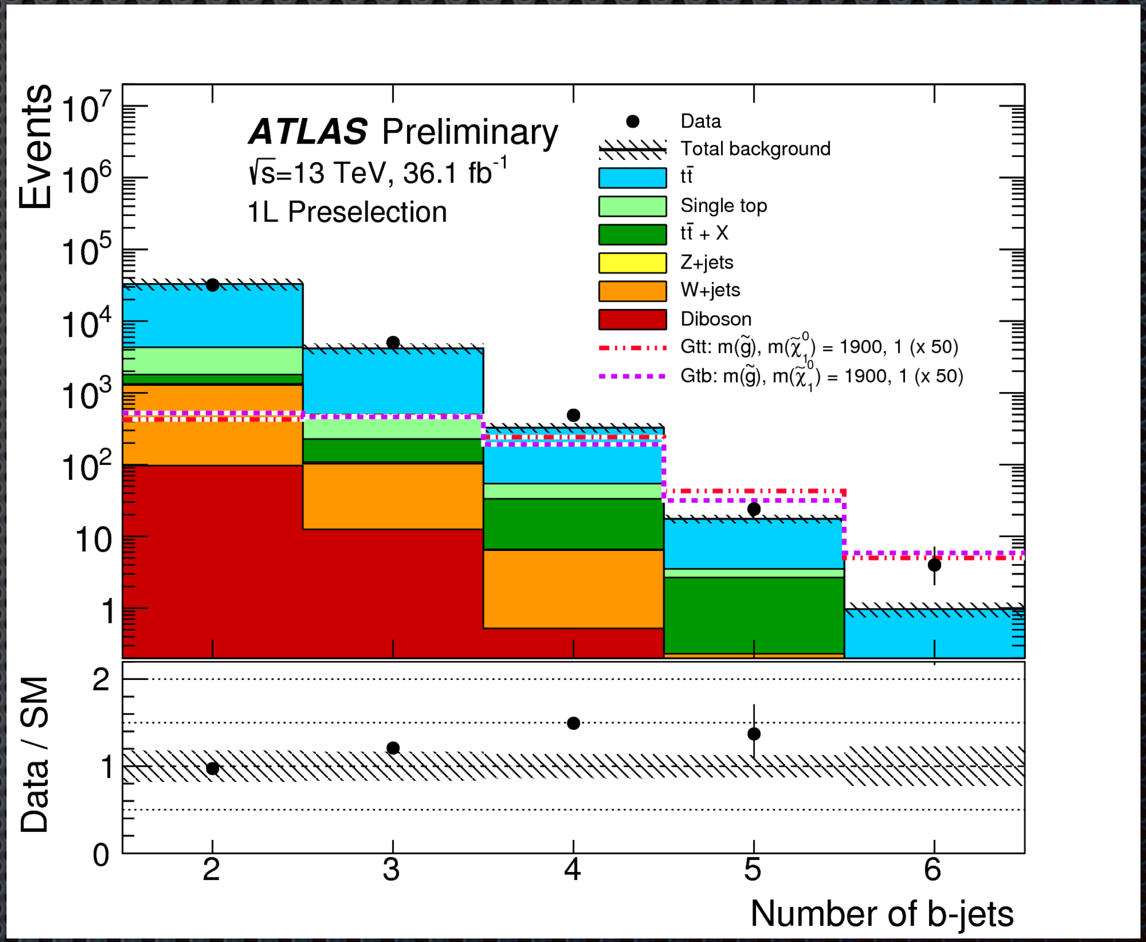
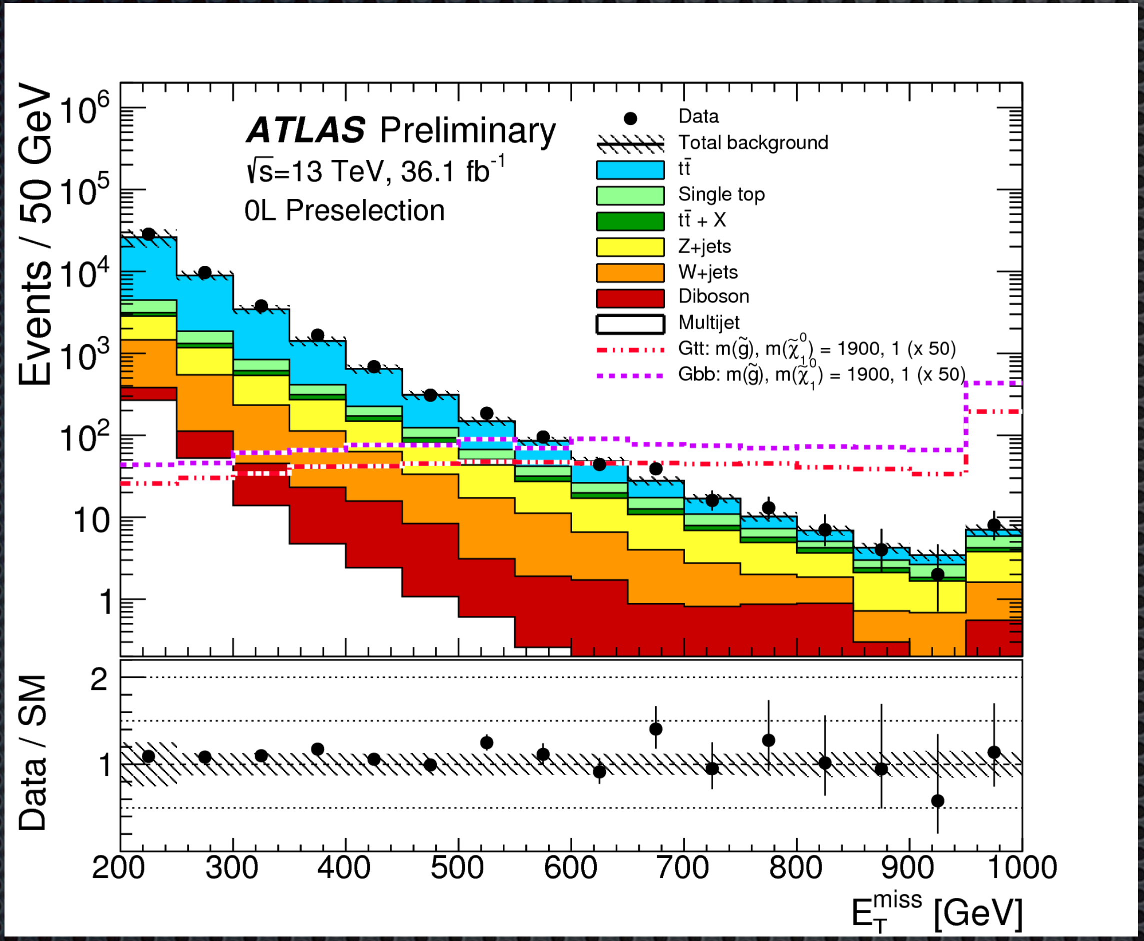


1L

missing transverse momentum



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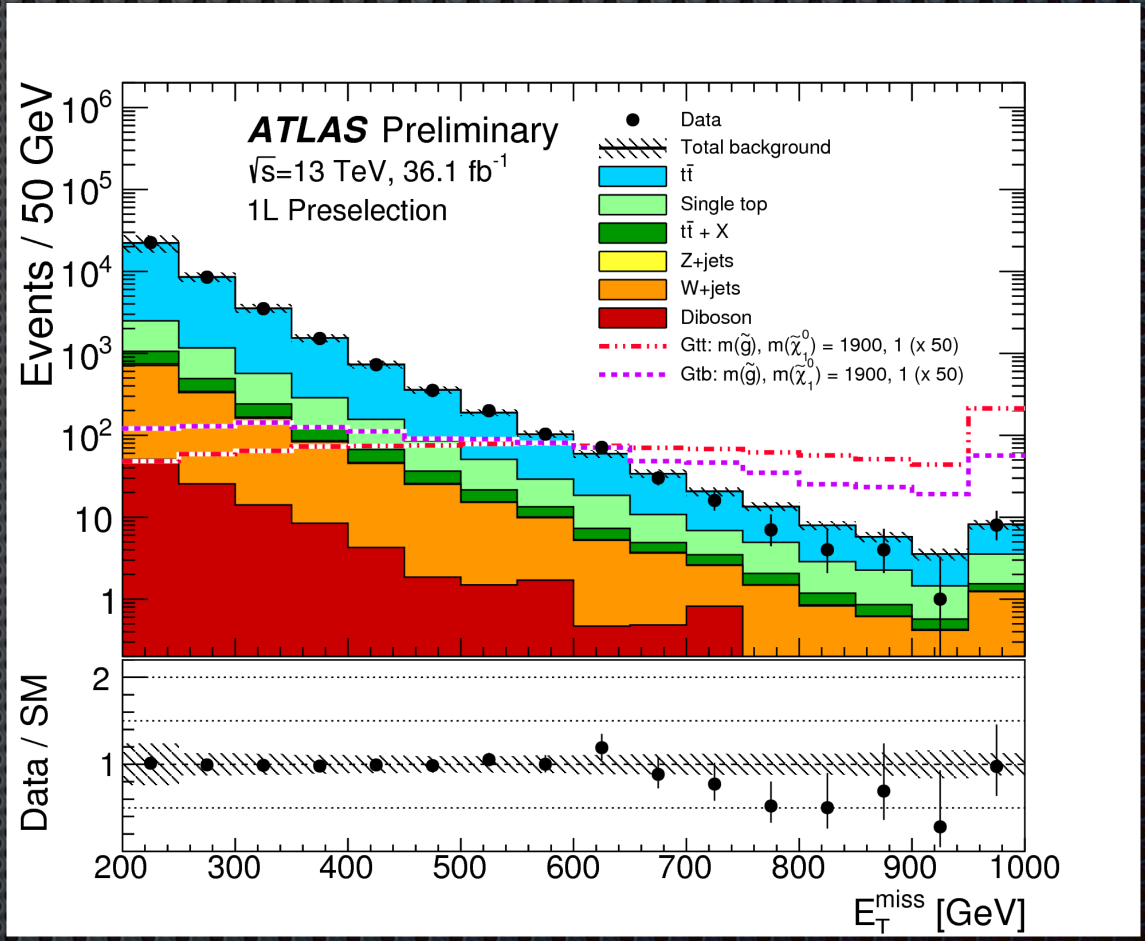
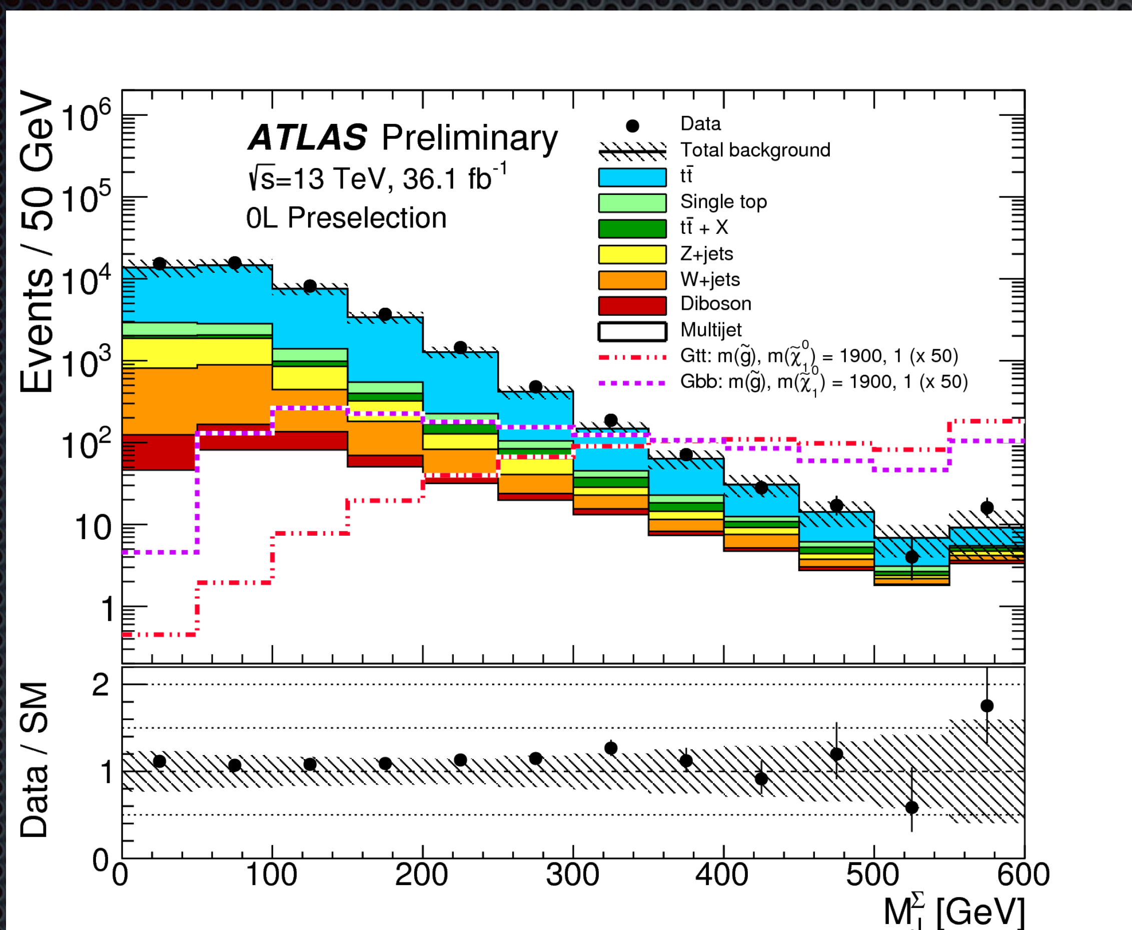


1L

total jet mass



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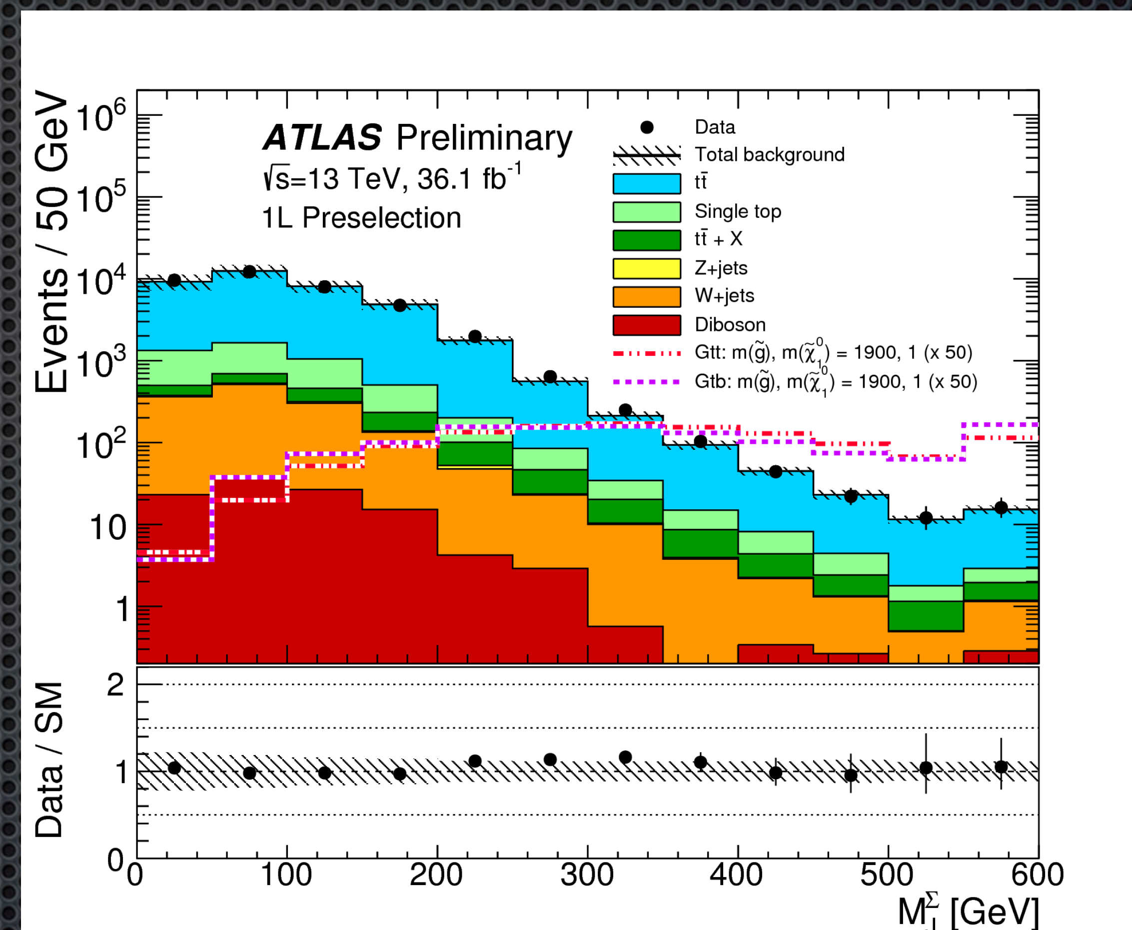
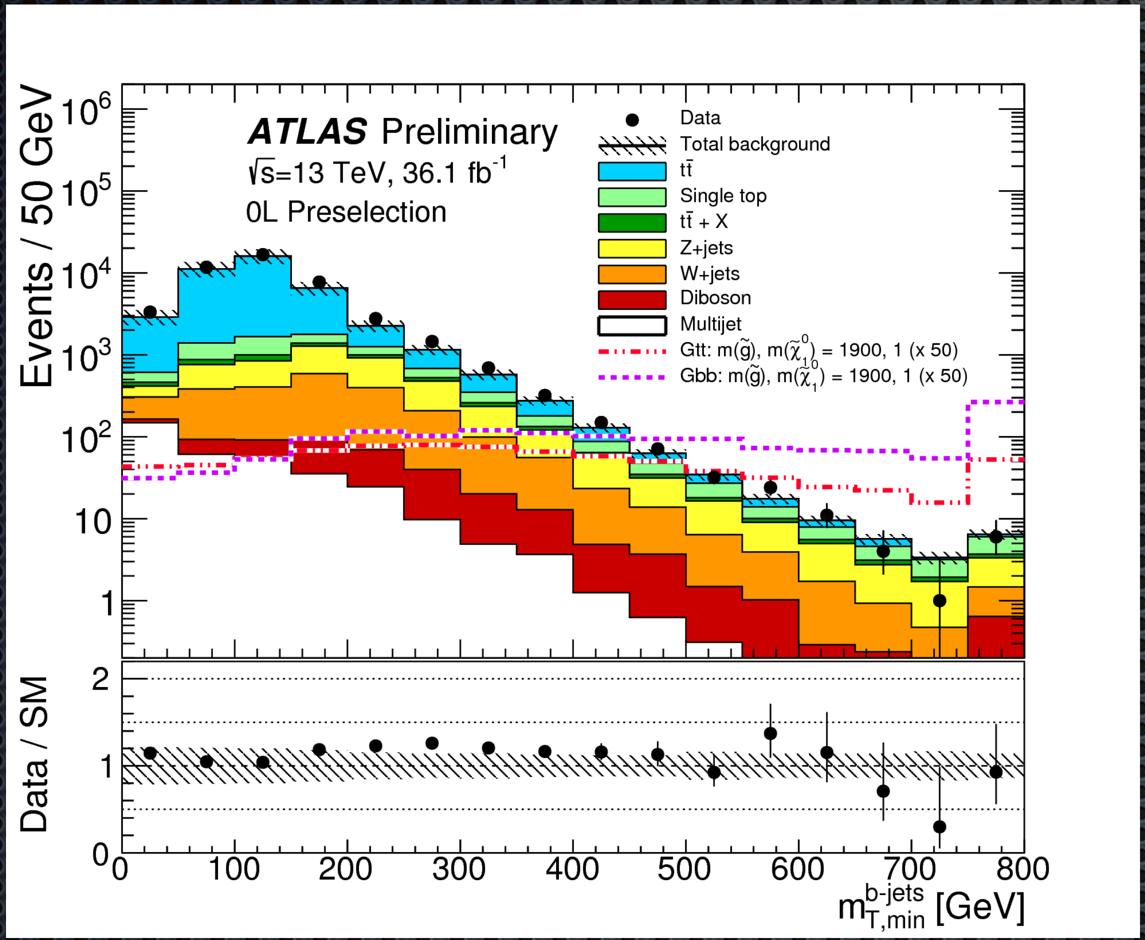


1L

transverse mass



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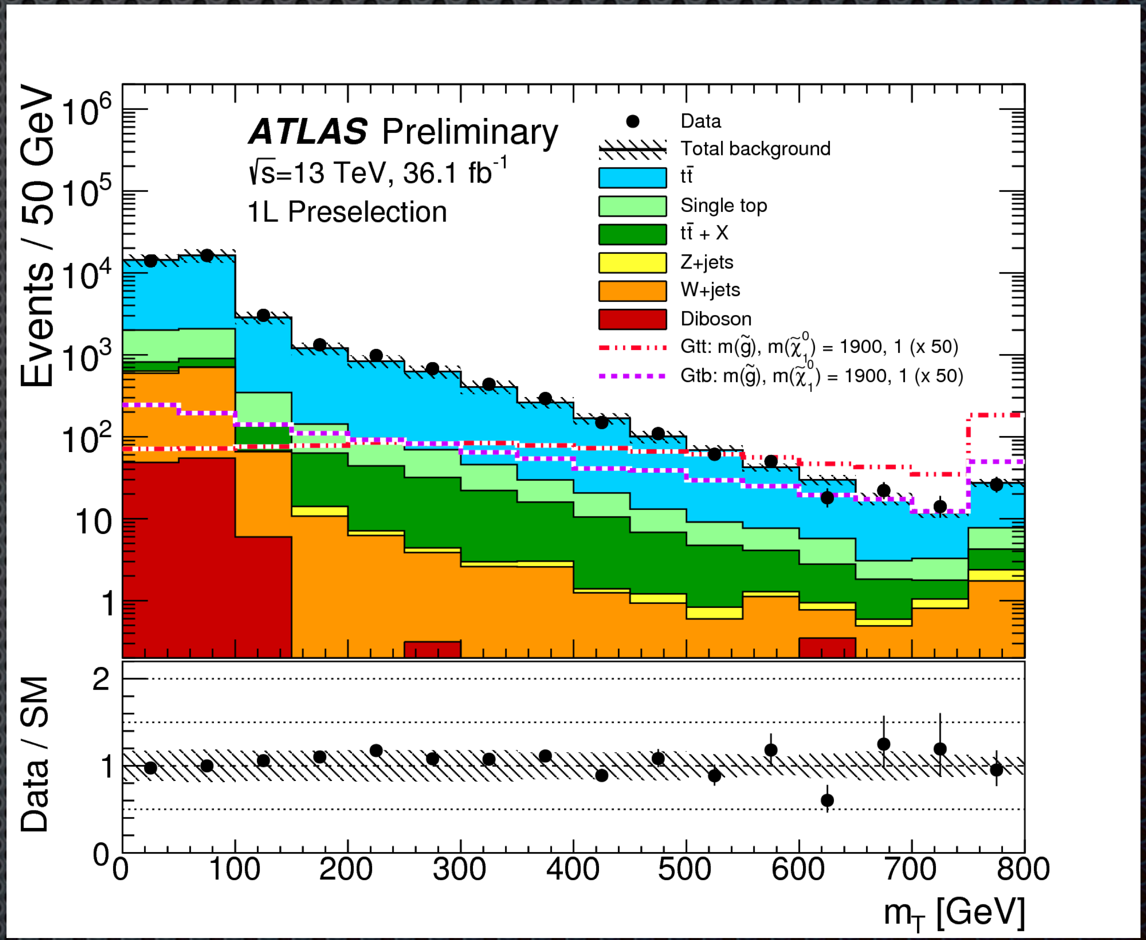
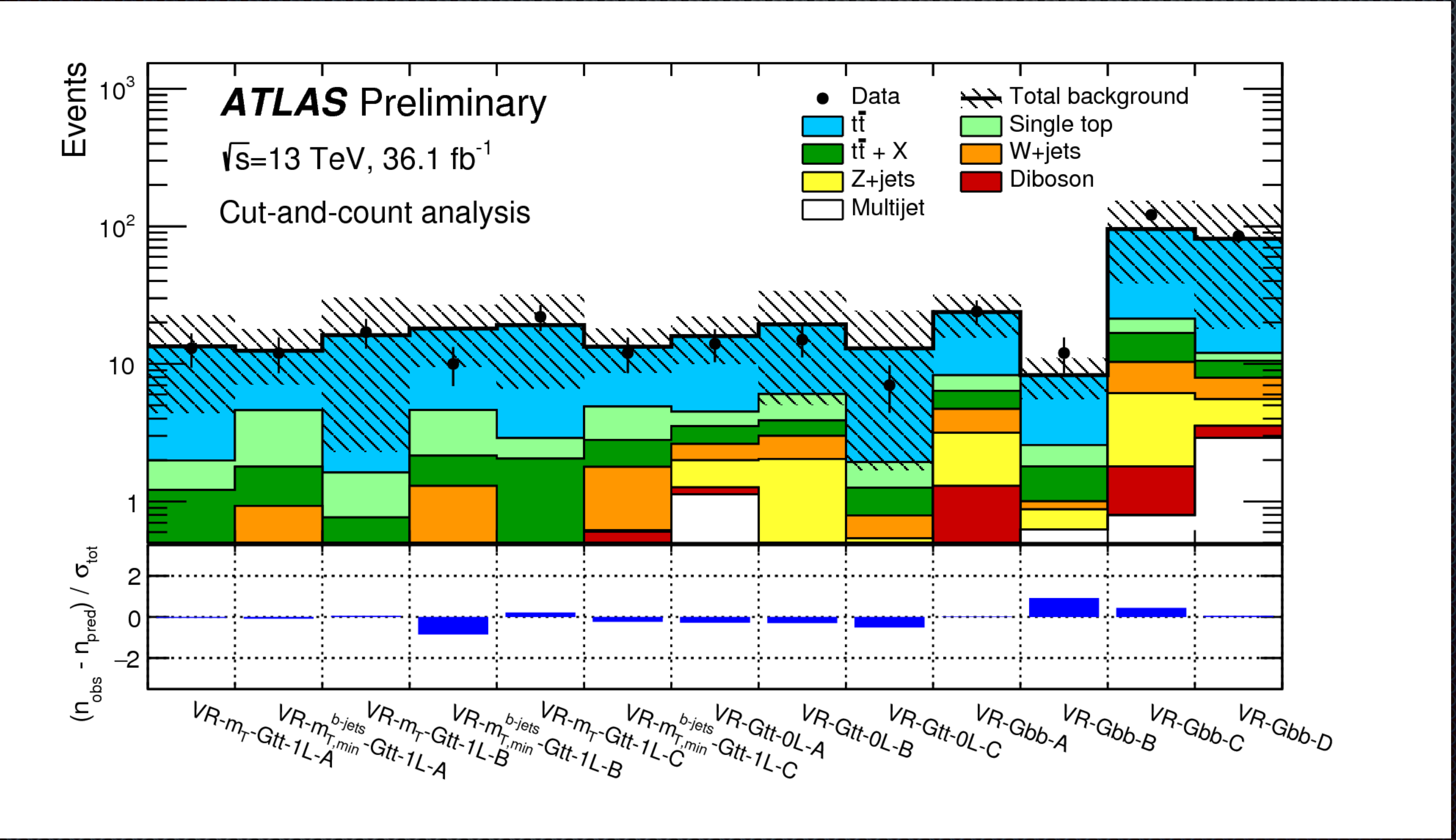


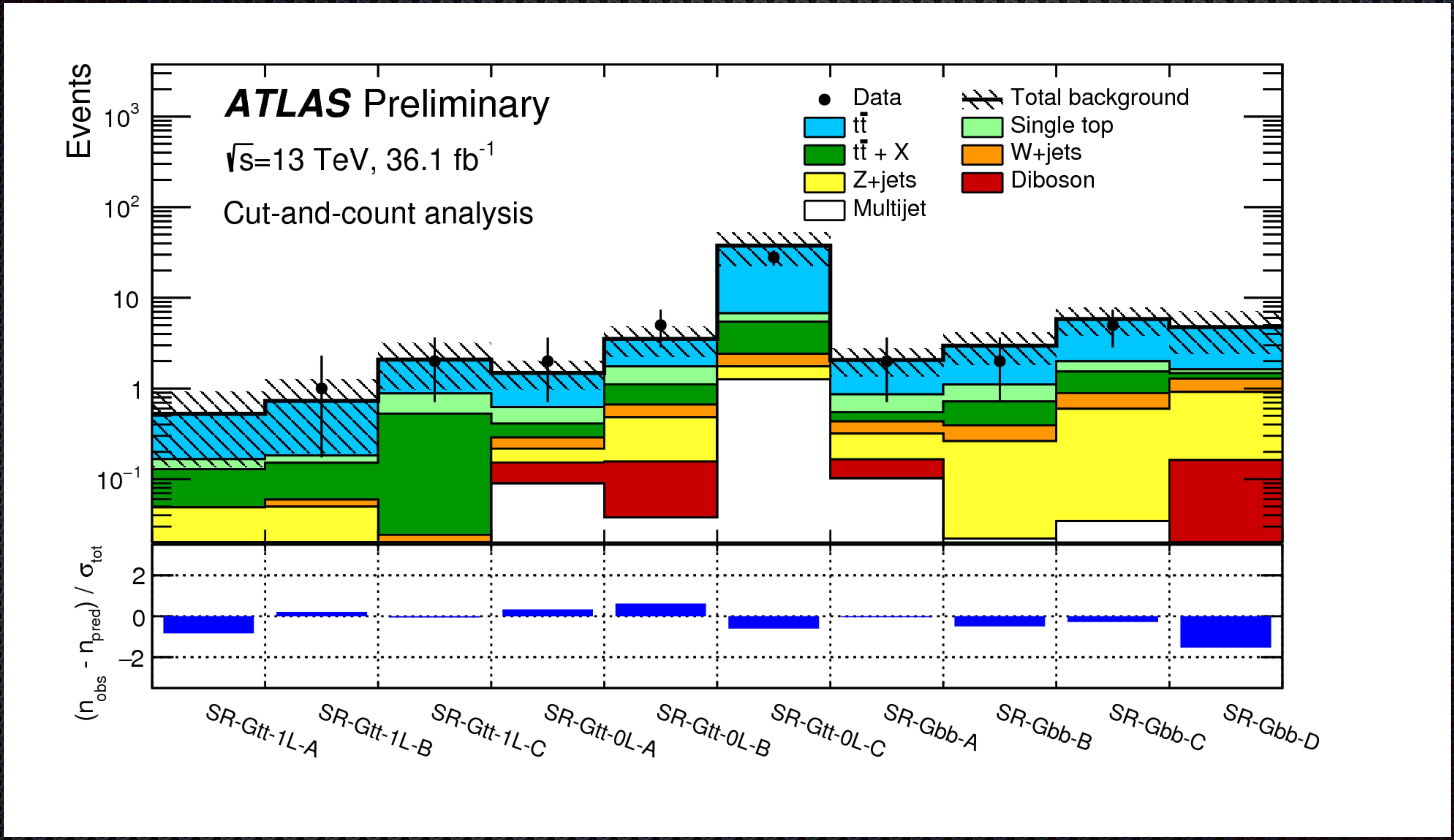
1L

Validating our work



no significant mismodeling between observation and theory

Did we find SUSY? *(no)*



no large difference between observation and theory