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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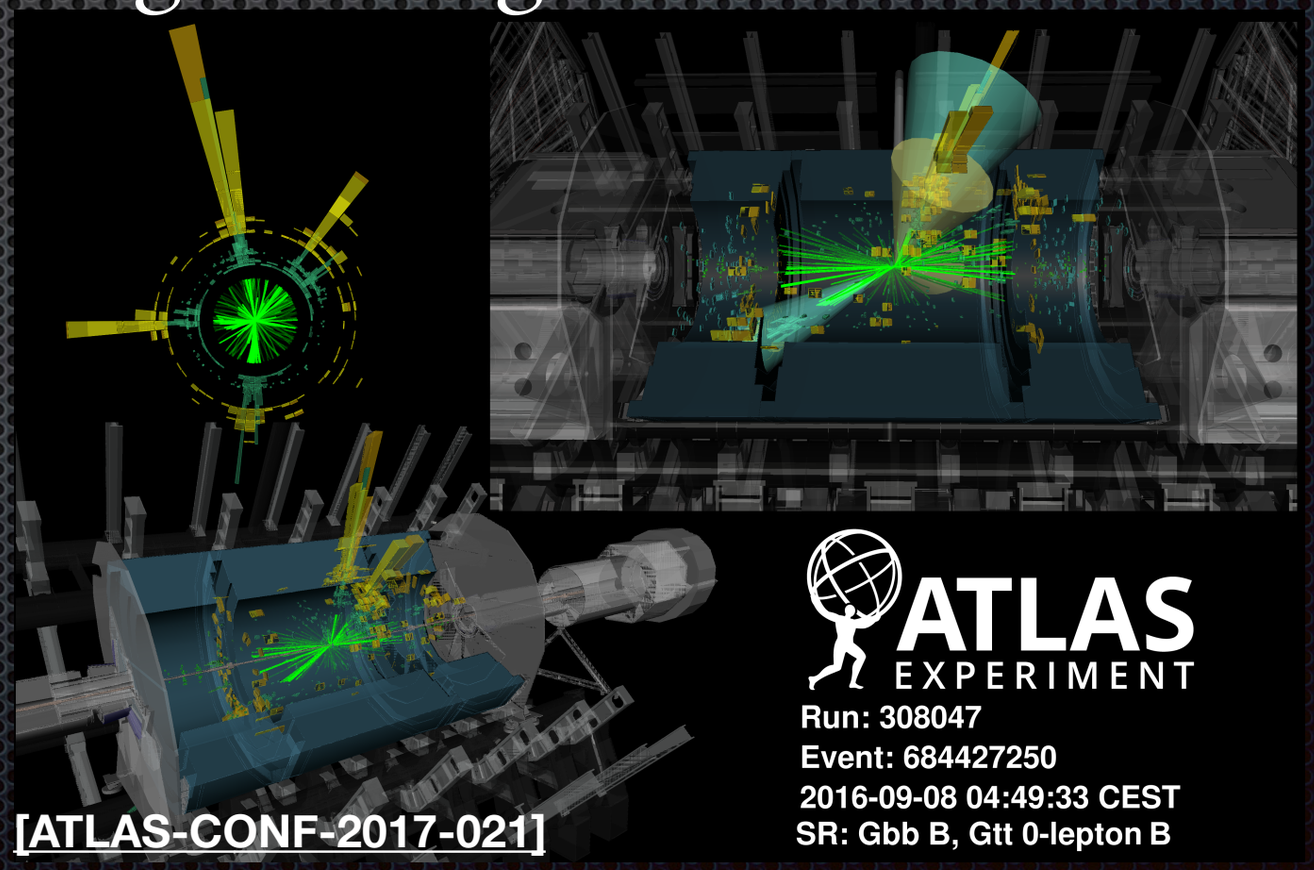
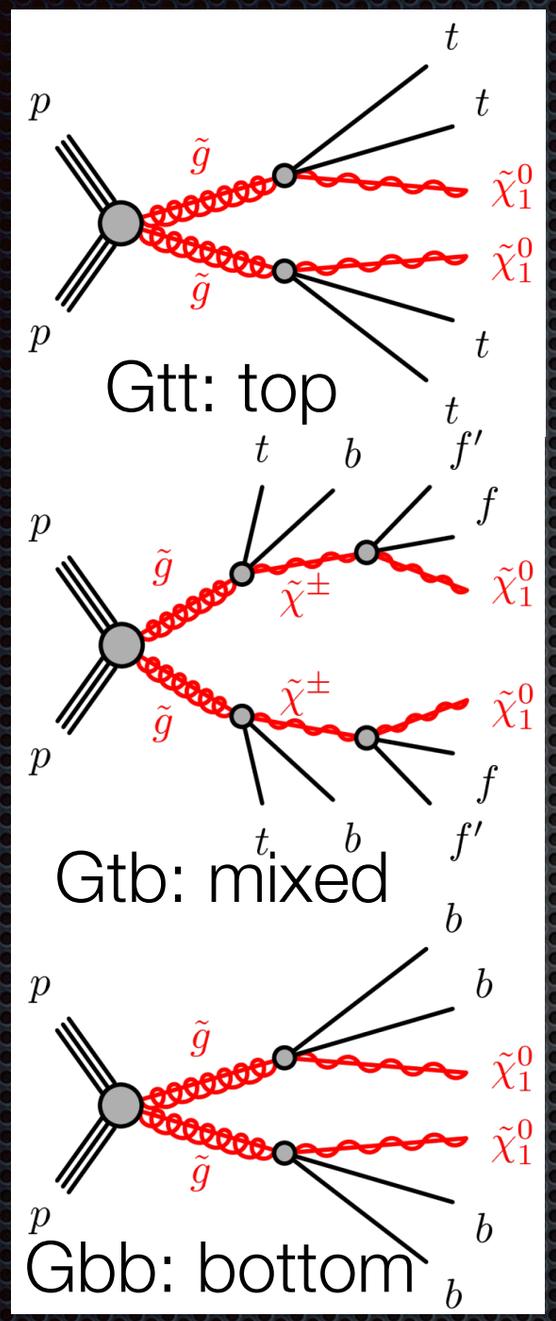


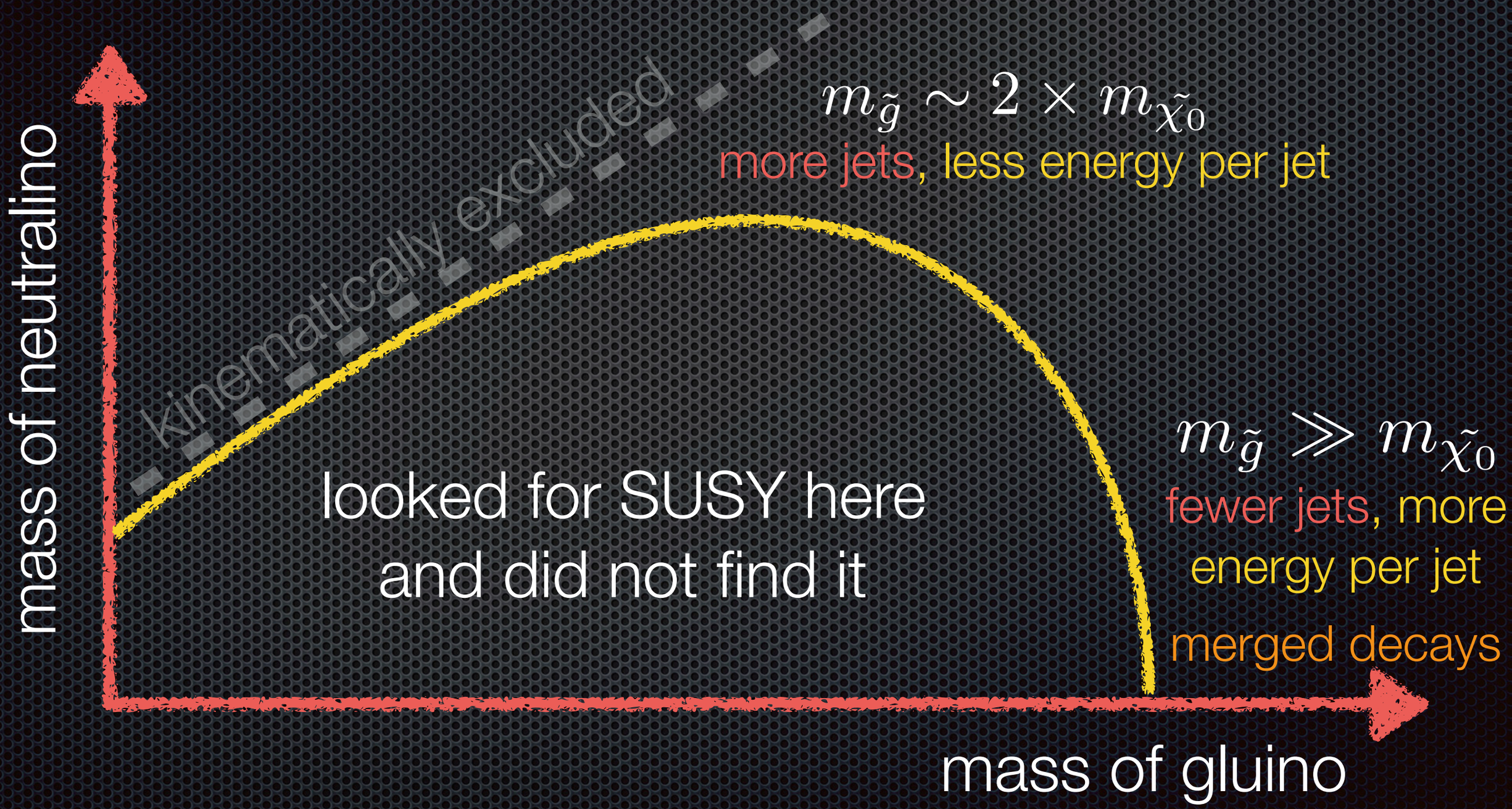
[ATLAS-CONF-2017-021]

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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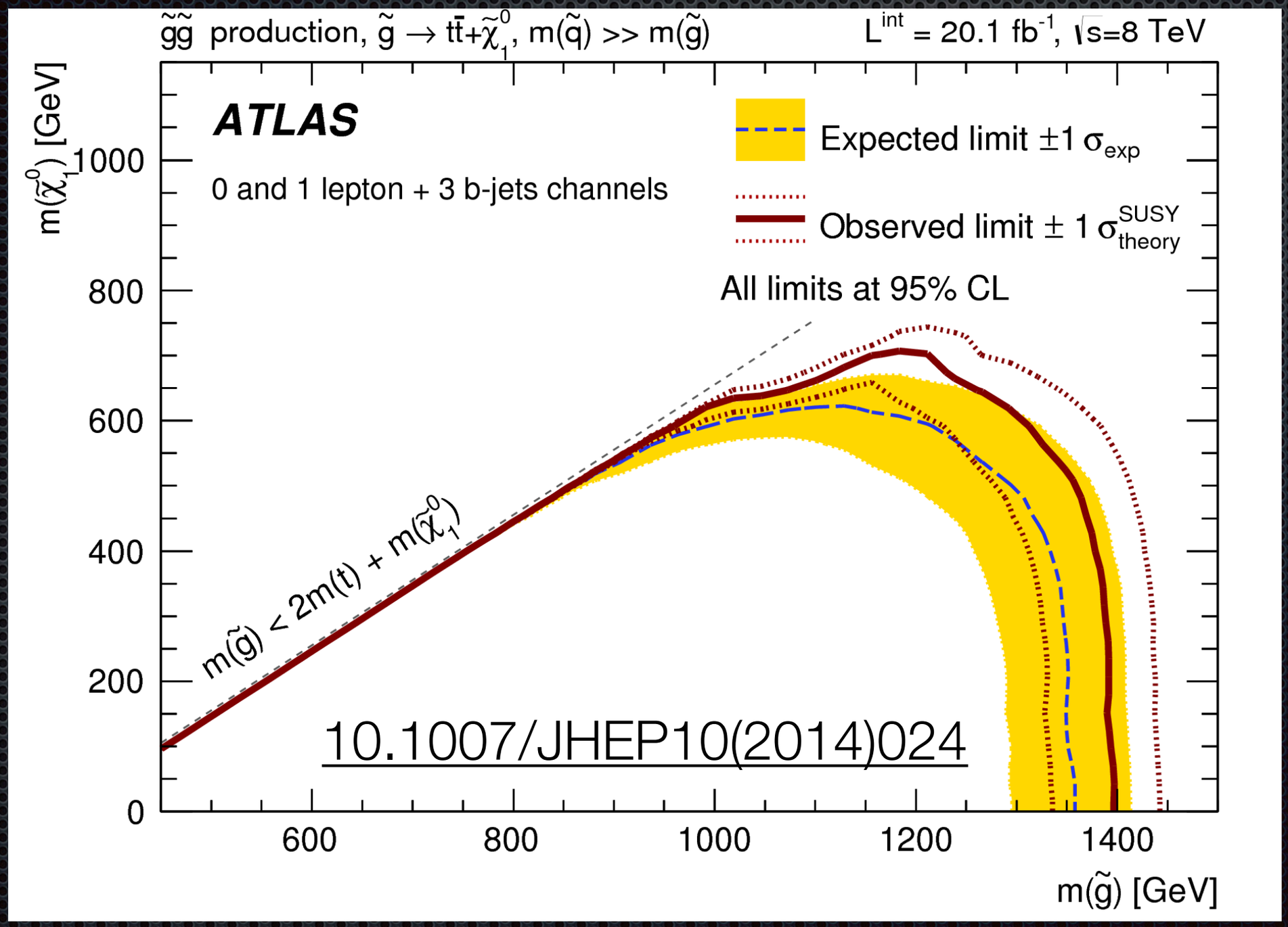
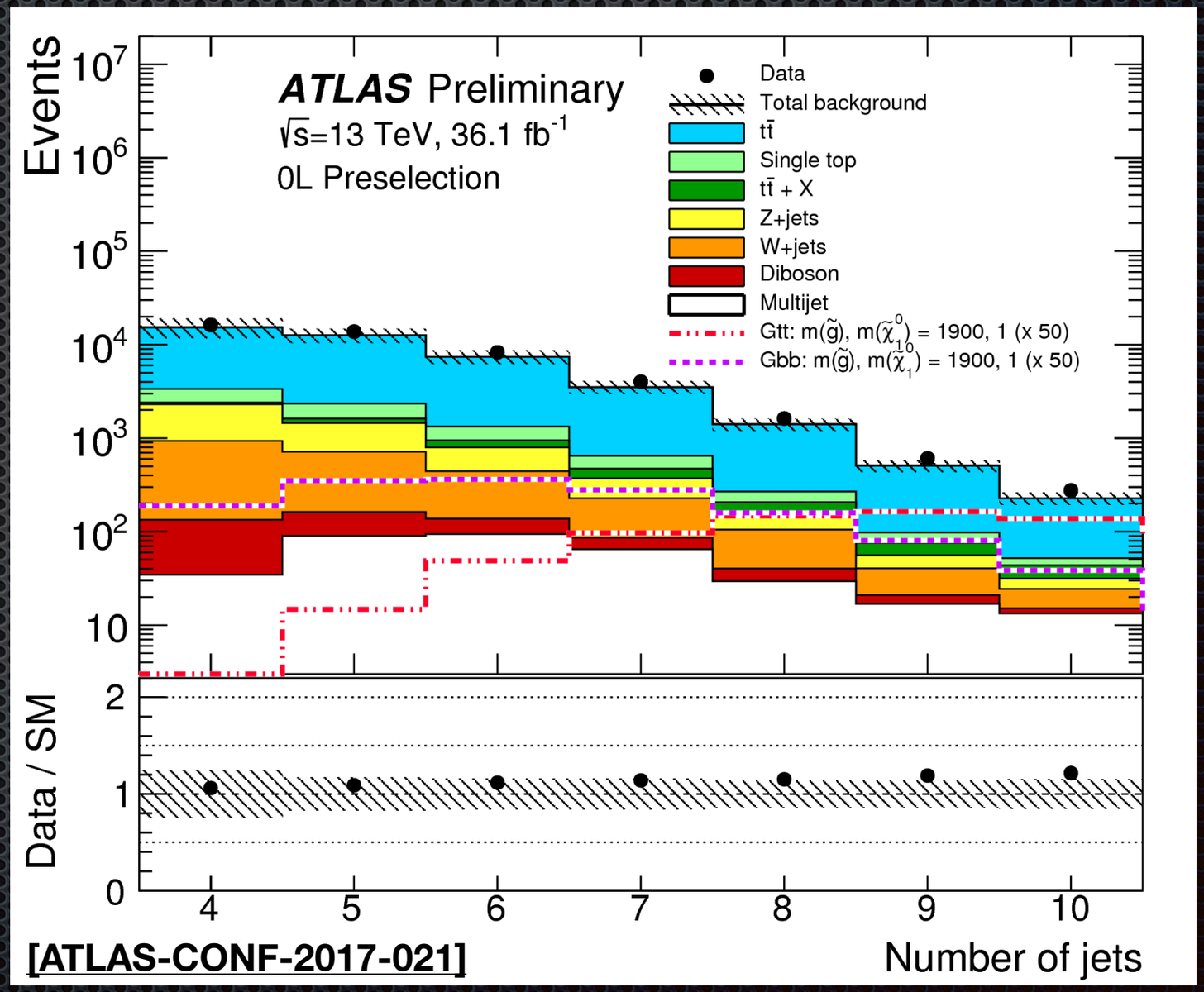


Sensitive up to 1.4 TeV

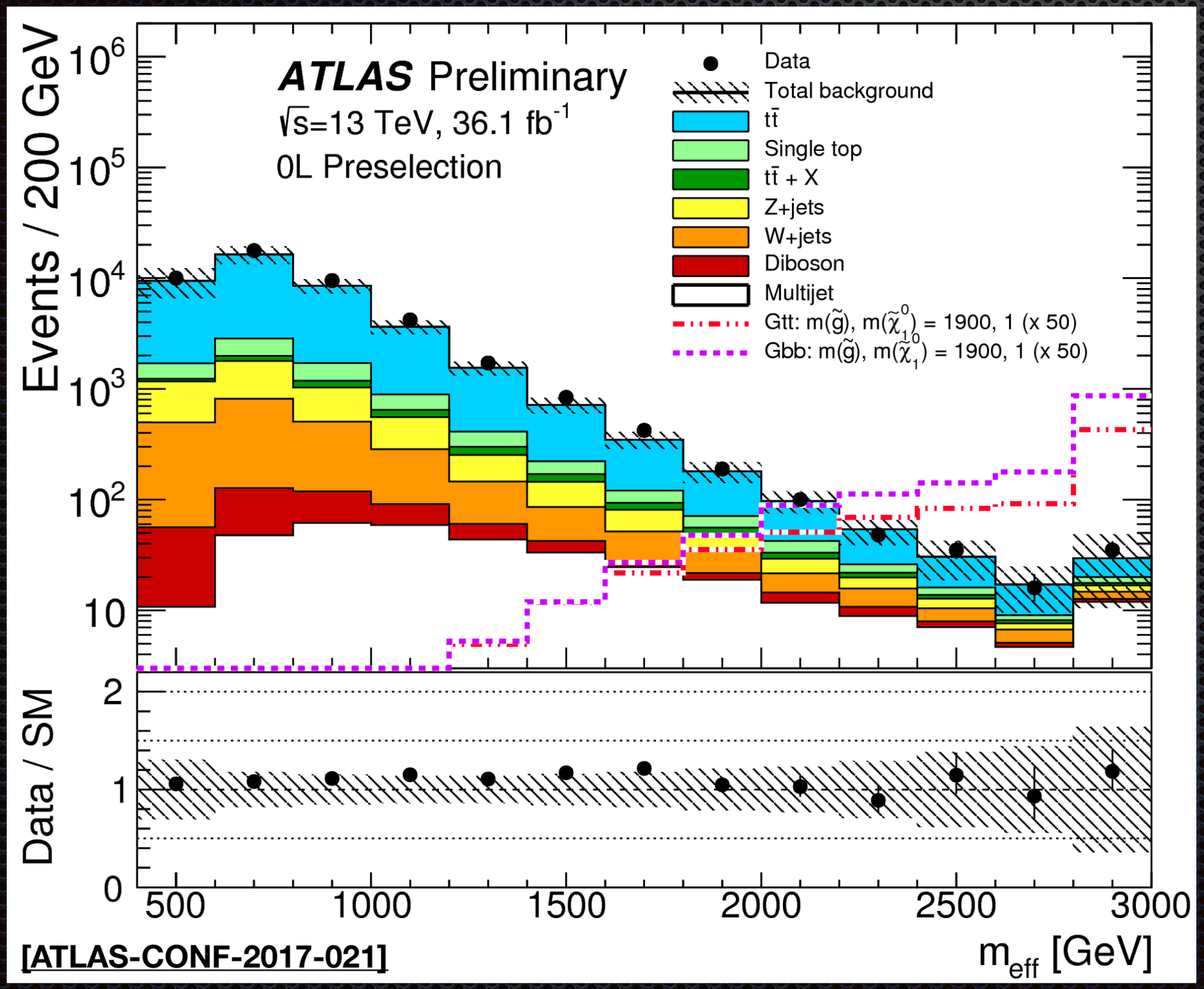
Objects of Interest

Signal: 4 top quarks Background: 2 top quarks

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



Data/Simulation Comparison



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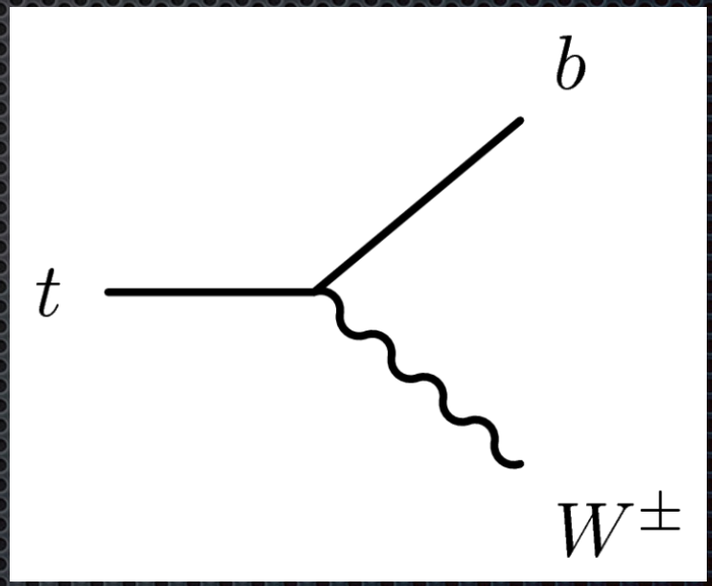


⚠ ttbar-enhanced

MET > 200 GeV

≥4 signal jets

≥2 *b*-jets

0 leptons

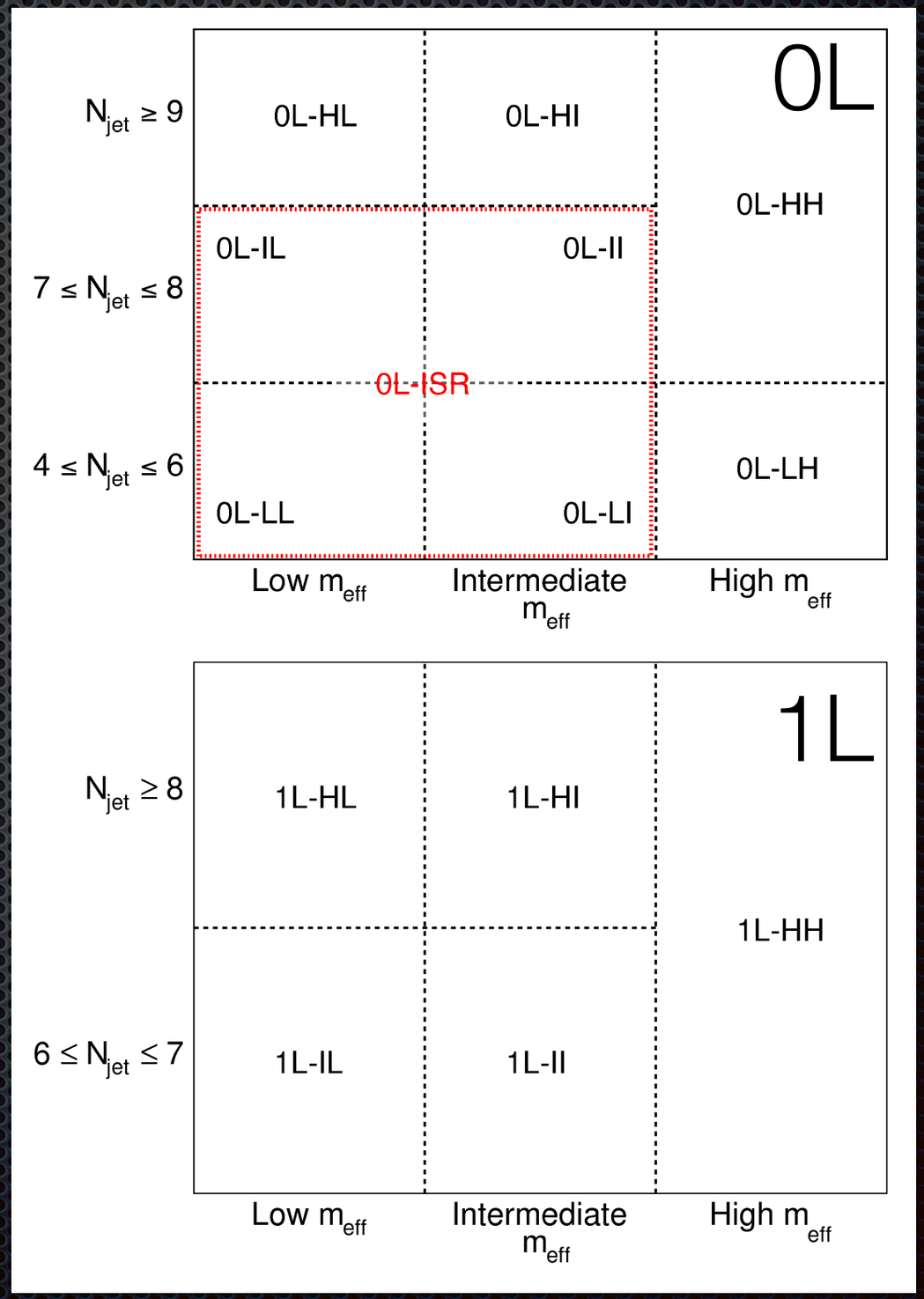
Selections optimized for maximal SUSY sensitivity

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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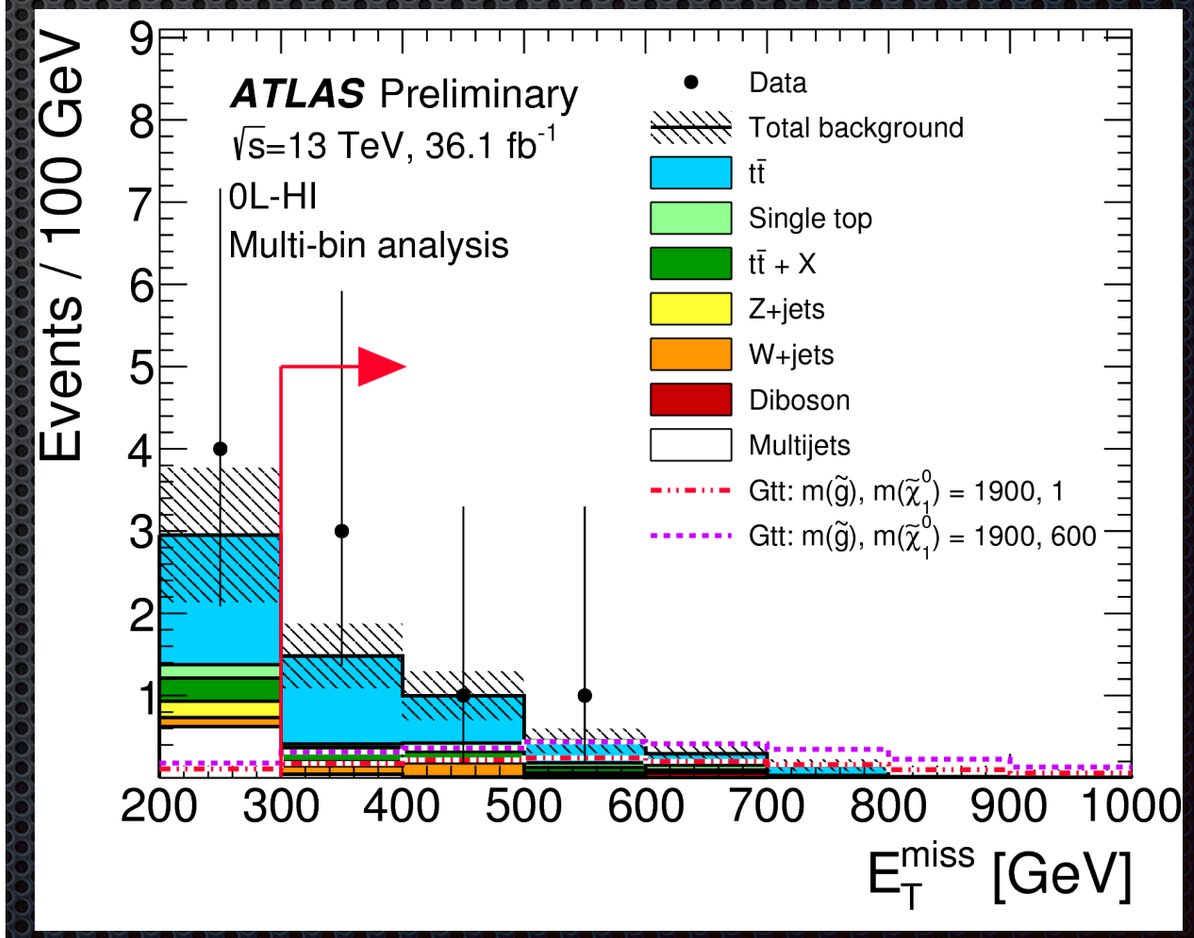
High-jet-multiplicity regions

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

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
	$\Delta\phi^{4\text{j}}_{\text{min}}$	> 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



Apply all selections for a signal region, except for MET

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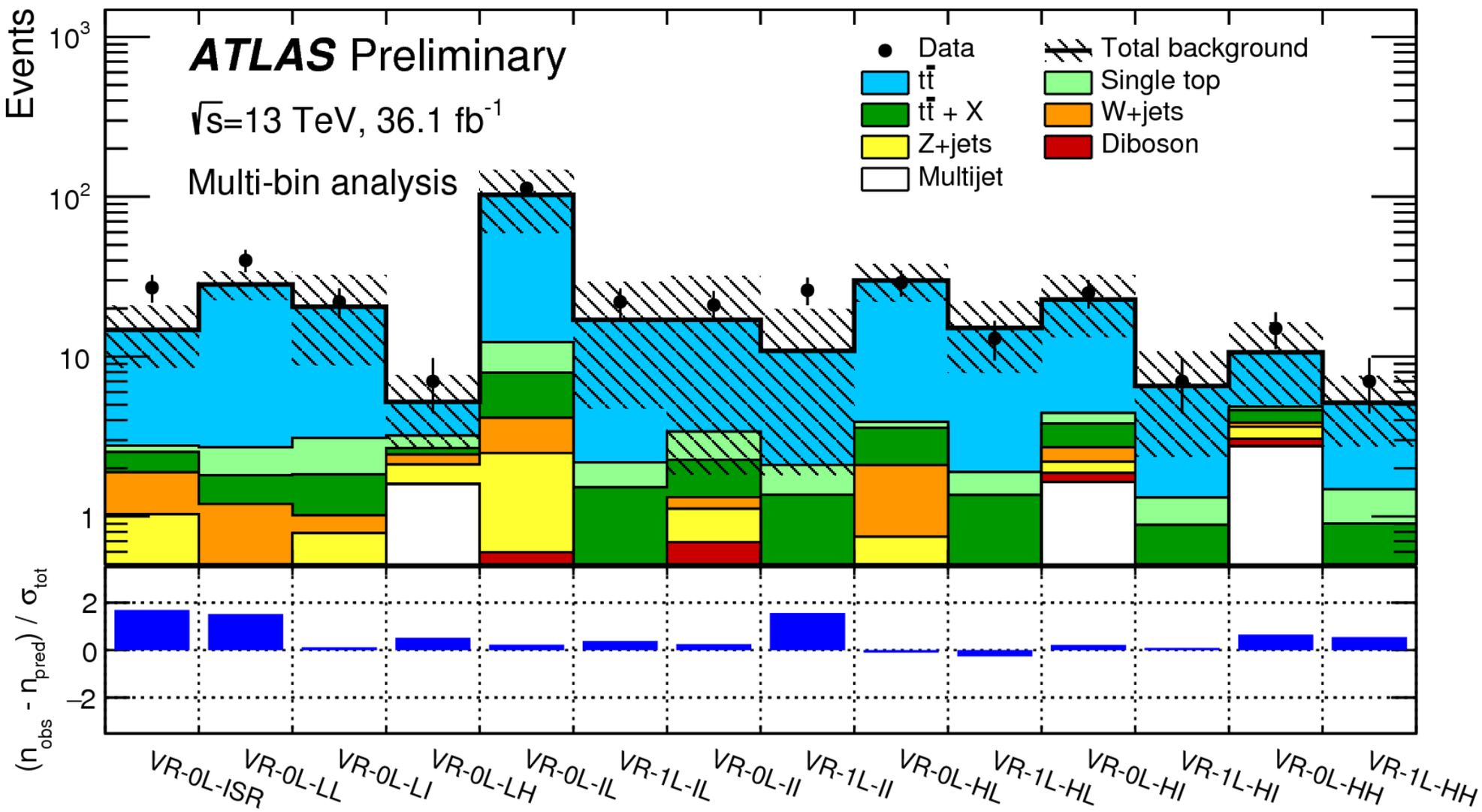
Systematic Uncertainties

- **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 simulation 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



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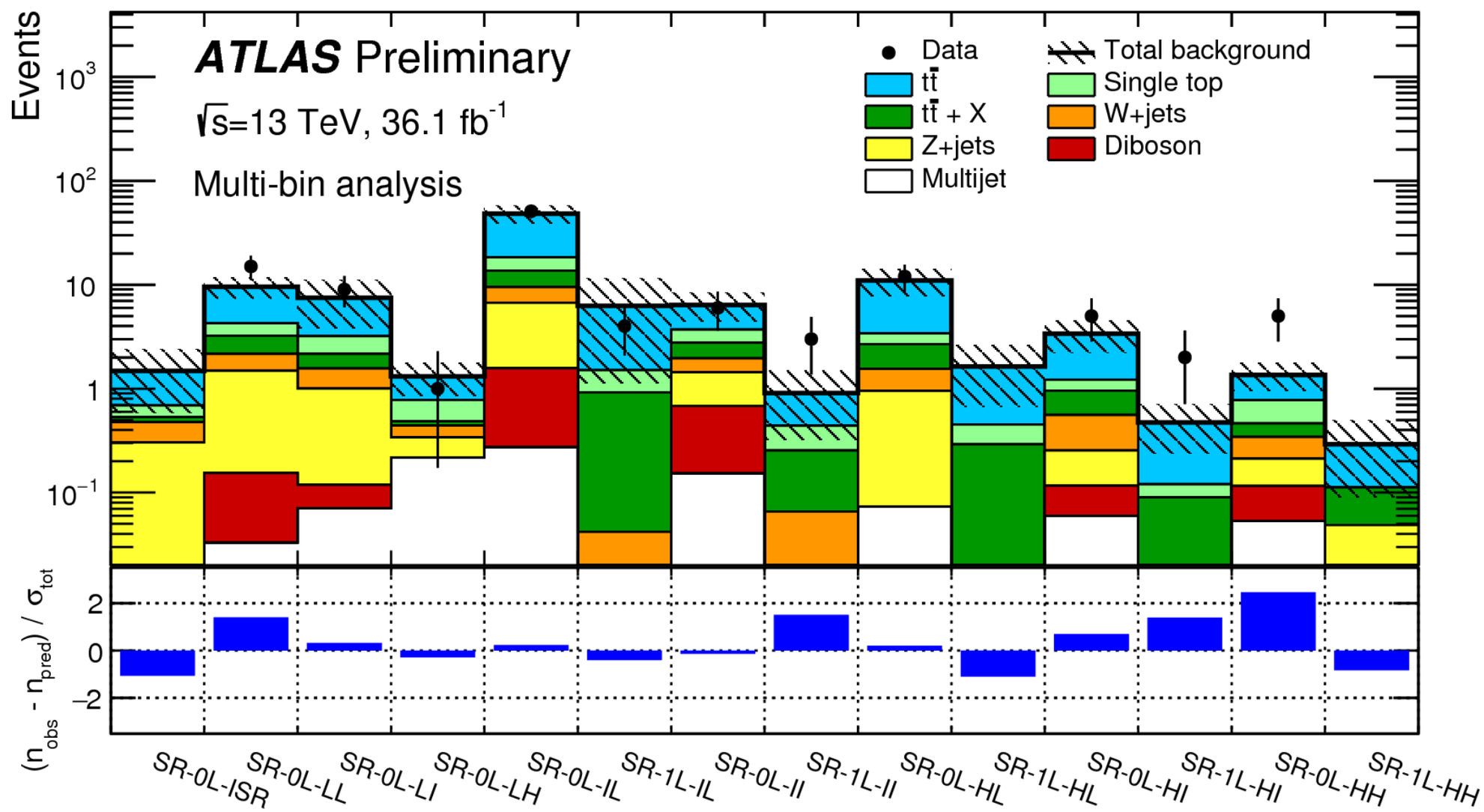
no significant mismodeling between observation and theory

Signal Regions Unblinded



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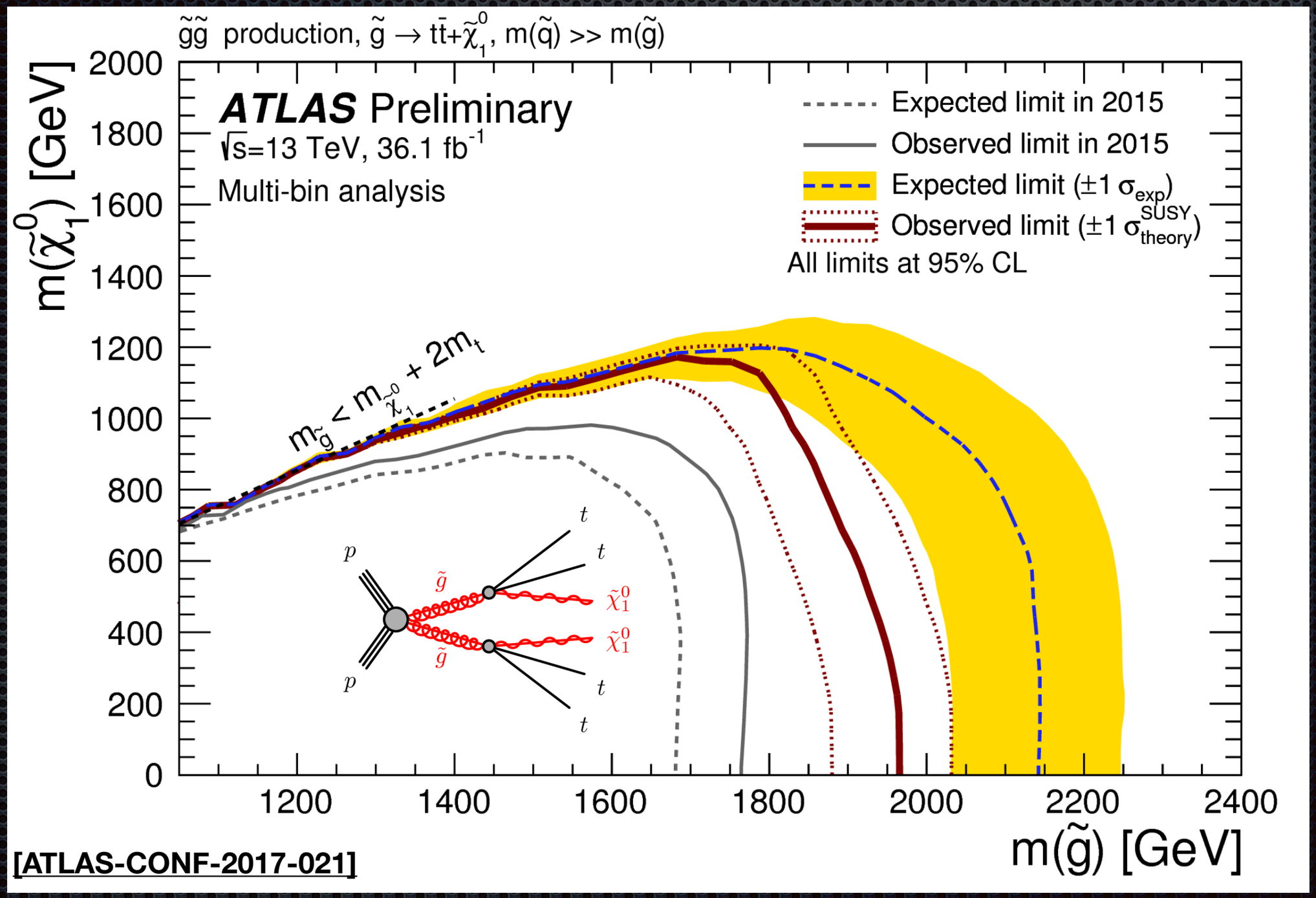
no large difference between observation and theory

Set strong limits given no large difference

The limits



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sensitive 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, a multi-bin analysis was optimized for maximal sensitivity
  - No excess was observed, so the multi-bin analysis was used to set stronger limits
- Stronger limits were set on gluino masses (1.4 TeV to 1.95 TeV) and more sensitive in simplified models involving the pair production of gluinos that decay via top (bottom) squark

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

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

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

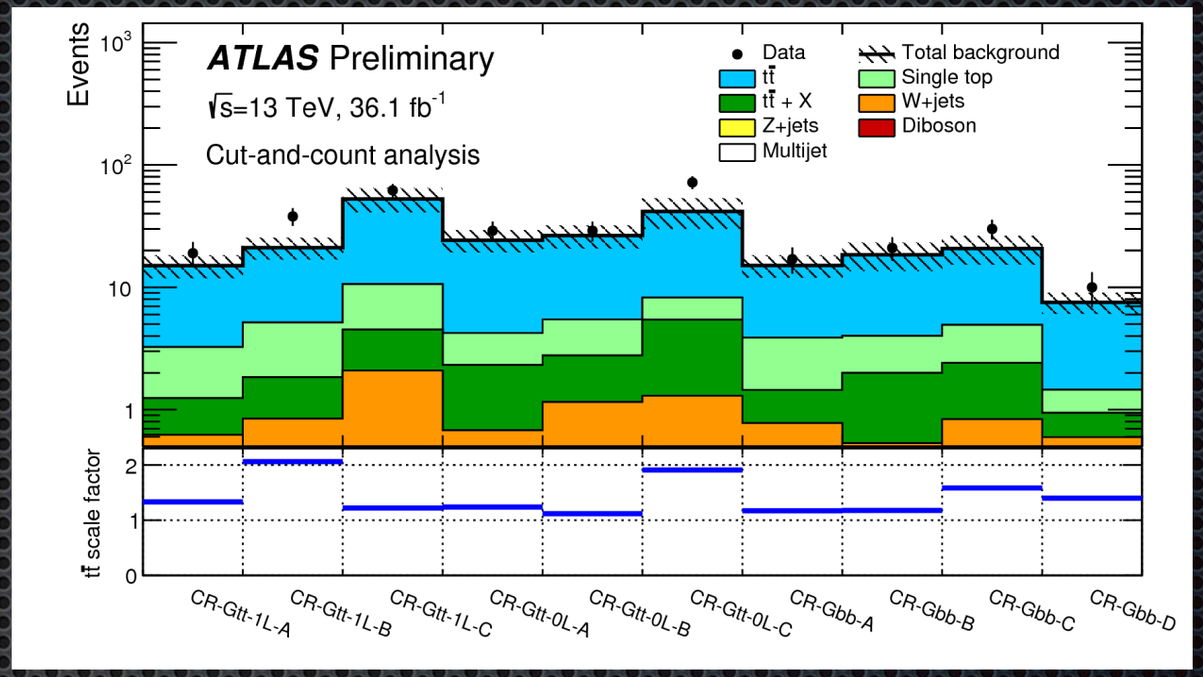
Transverse mass leptonic W

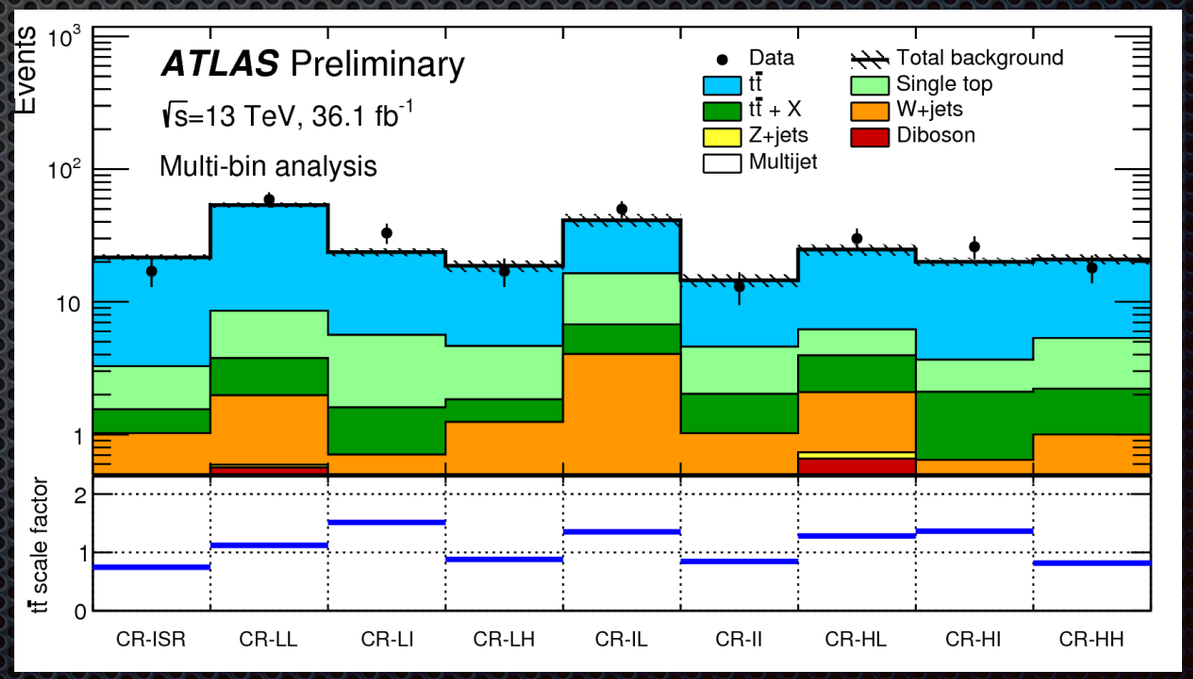
$M_J^{\Sigma,4} = \sum_{i \leq 4} m_{J,i}$ *Sum of 4 leading reclustered jets*

Total jet mass

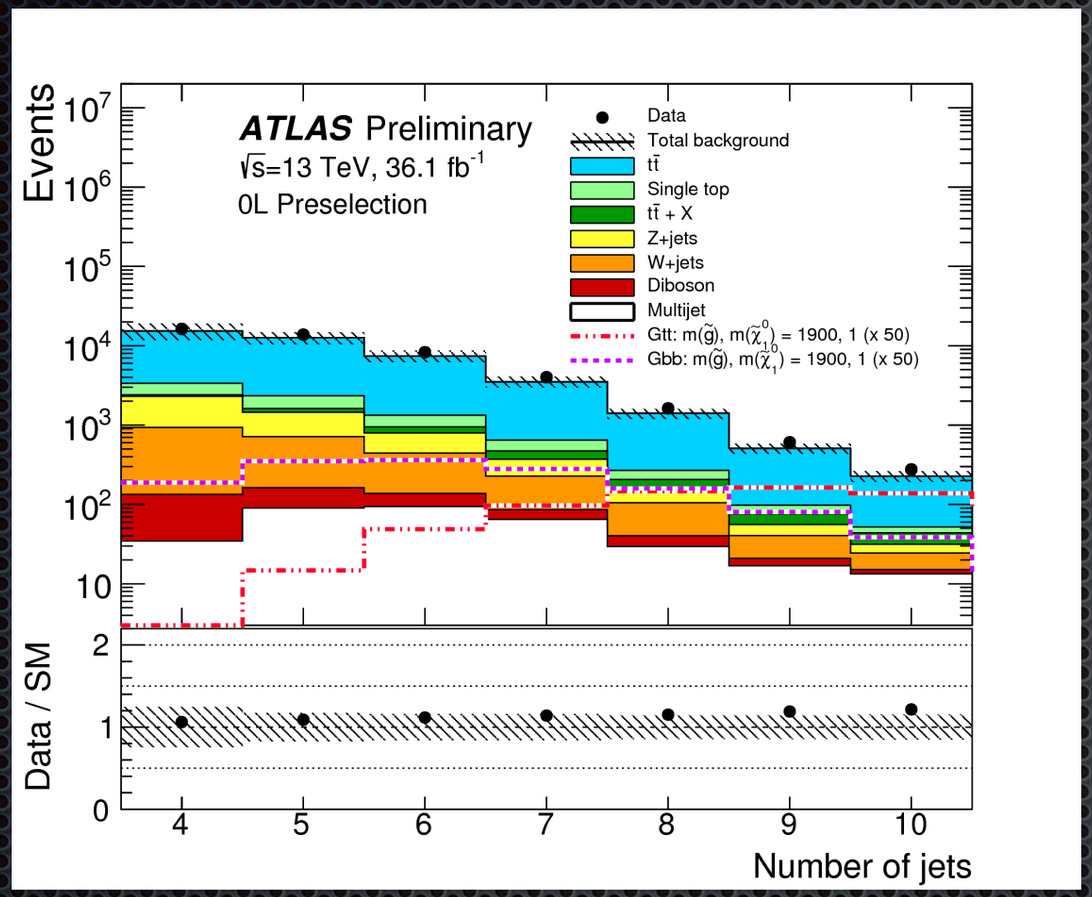
Likelihood fits

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

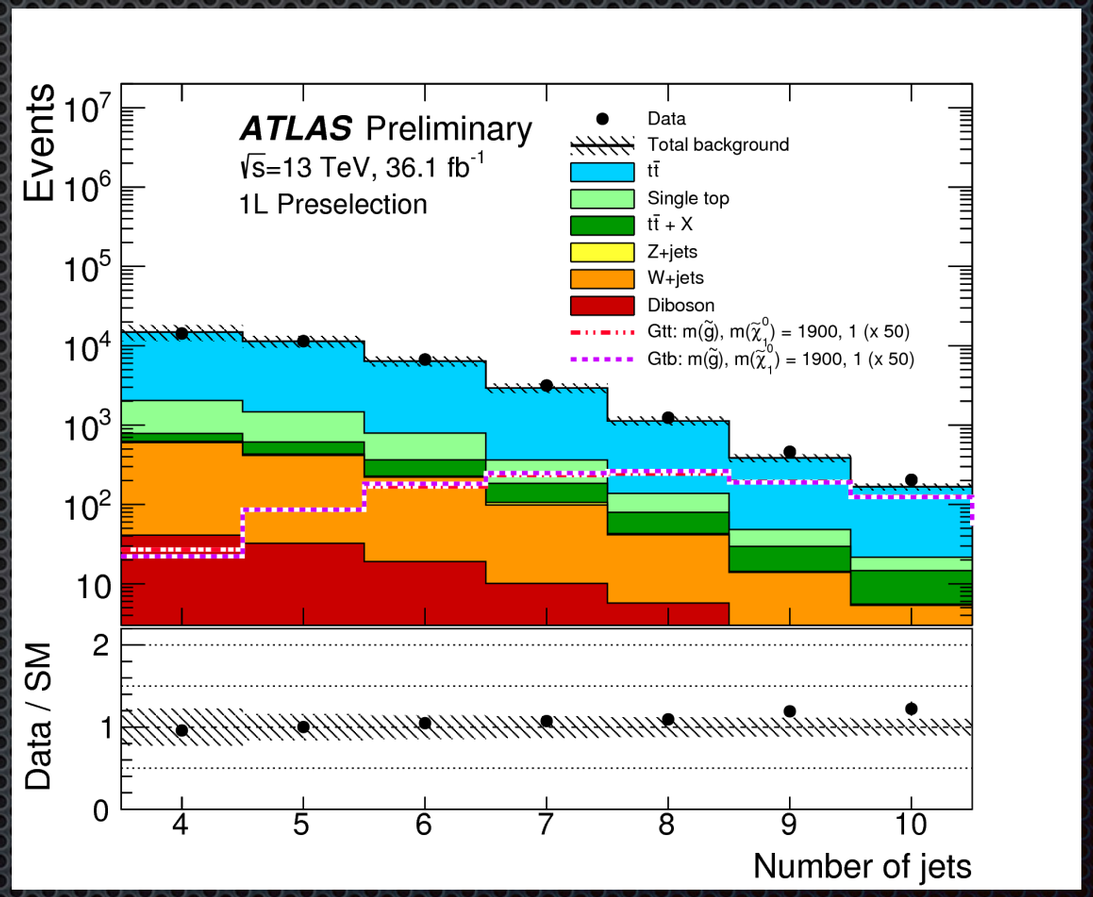




jet multiplicity

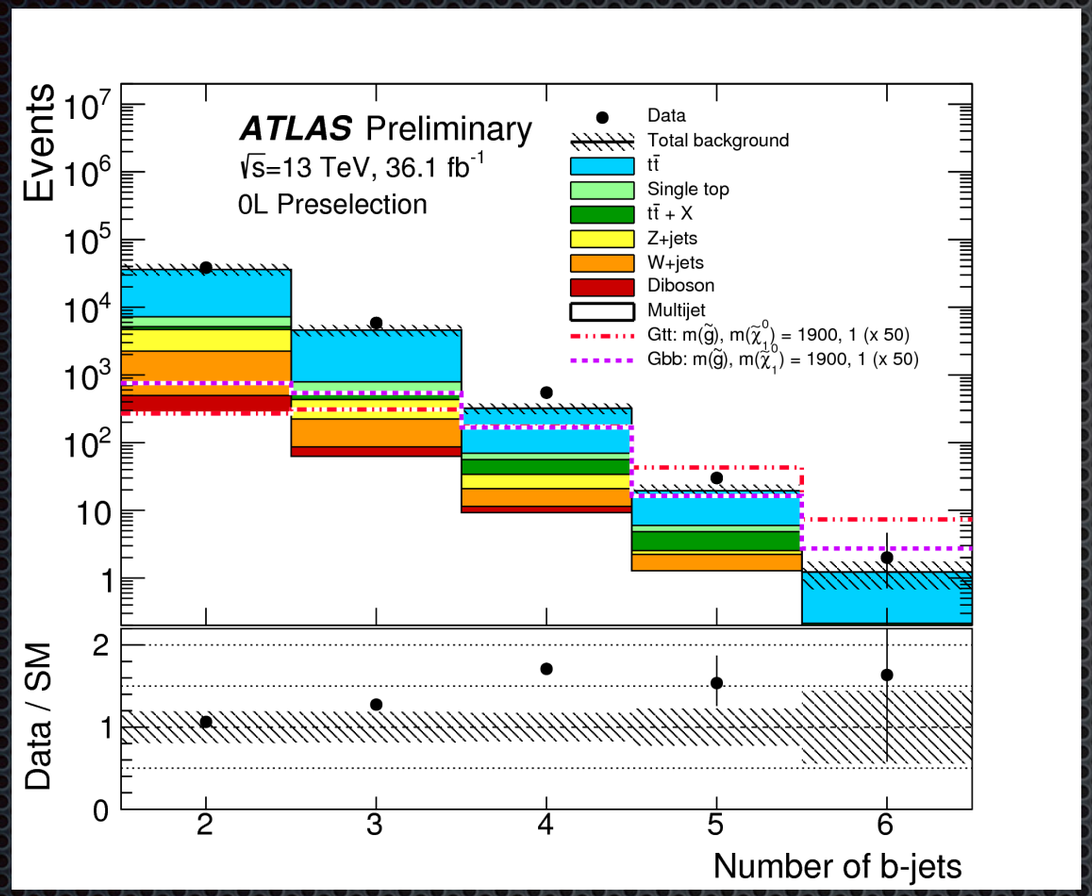


0L



1L

b-jet multiplicity



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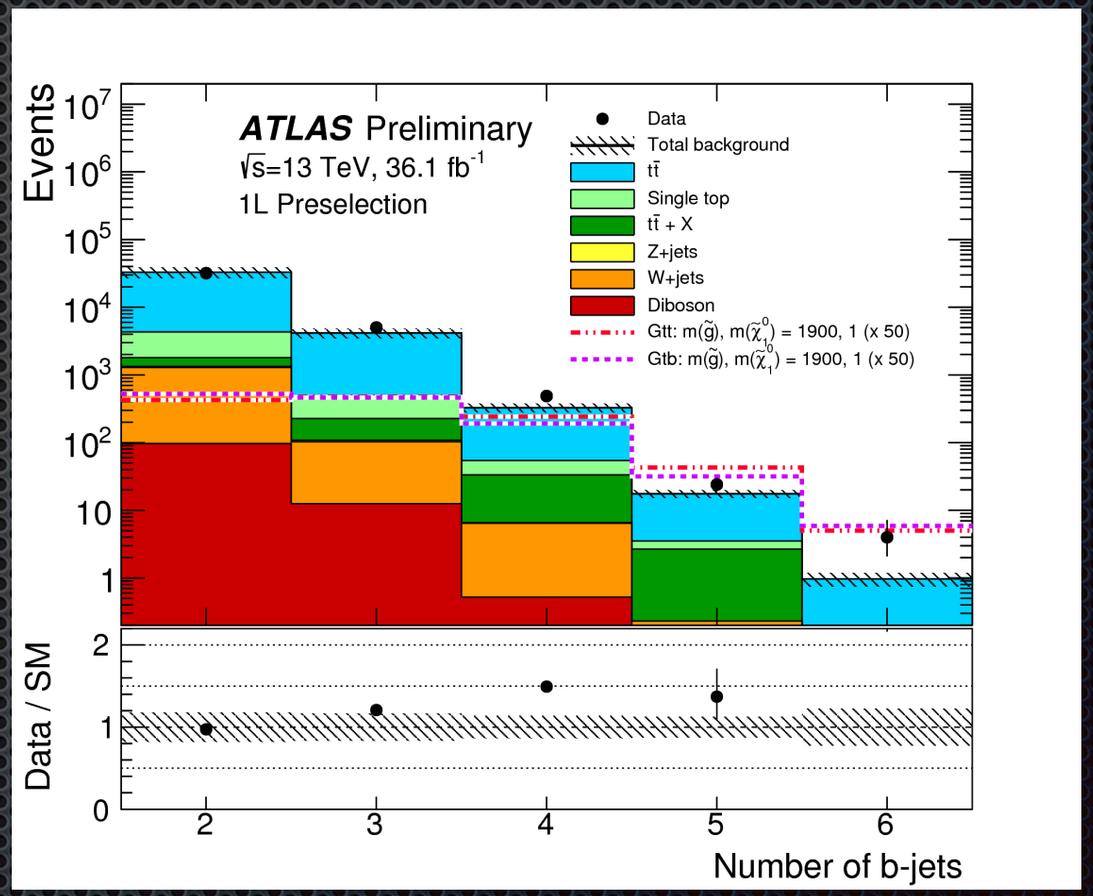
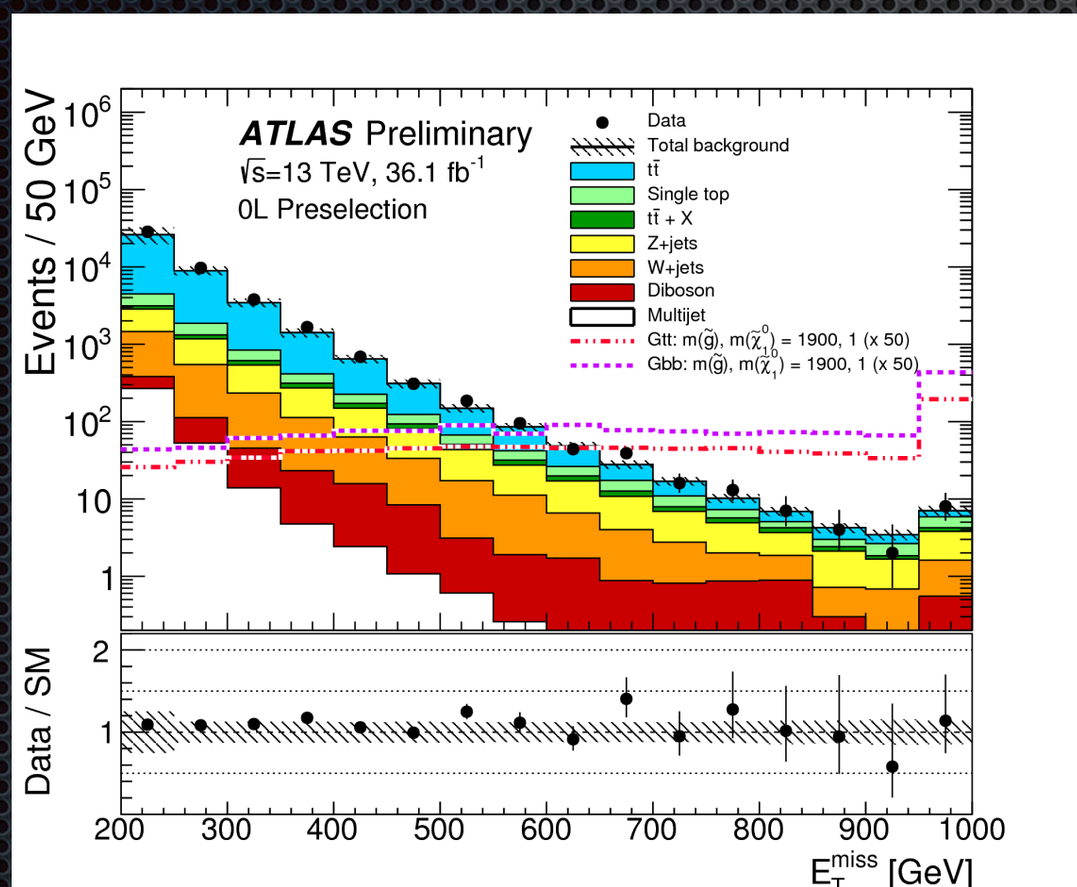


1L

missing transverse momentum



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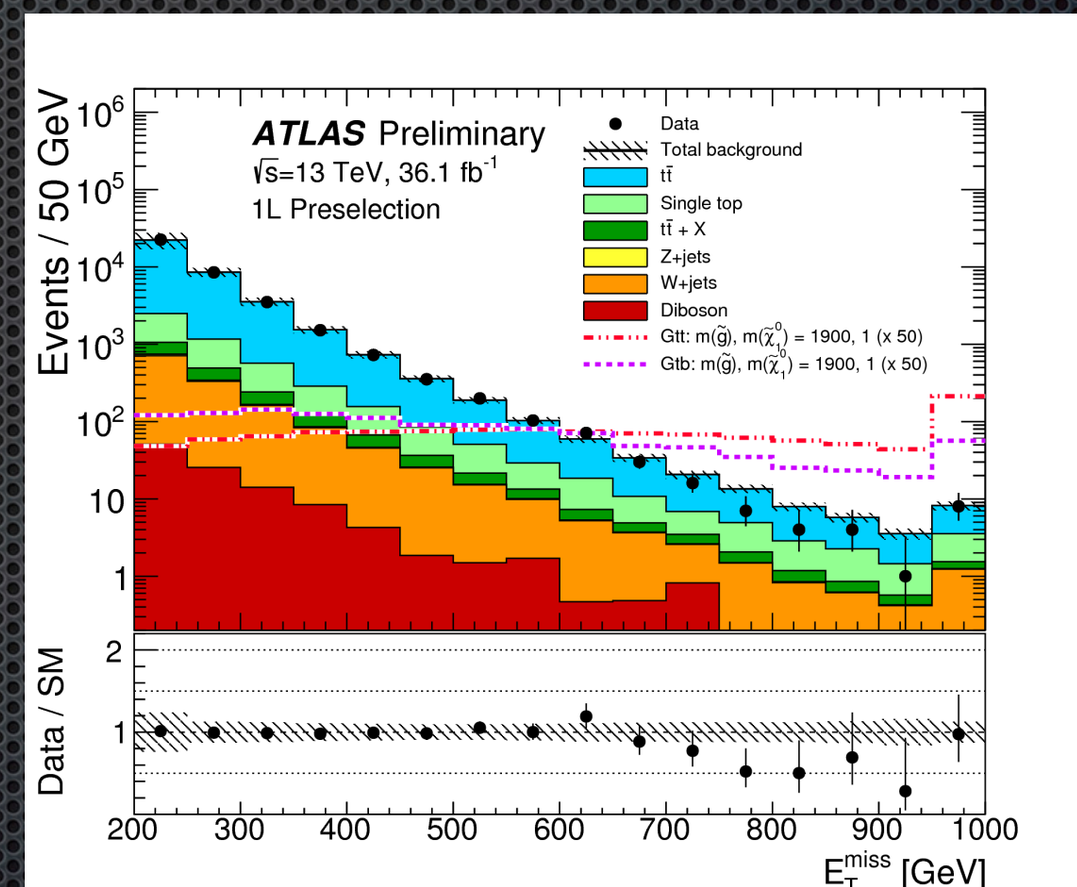
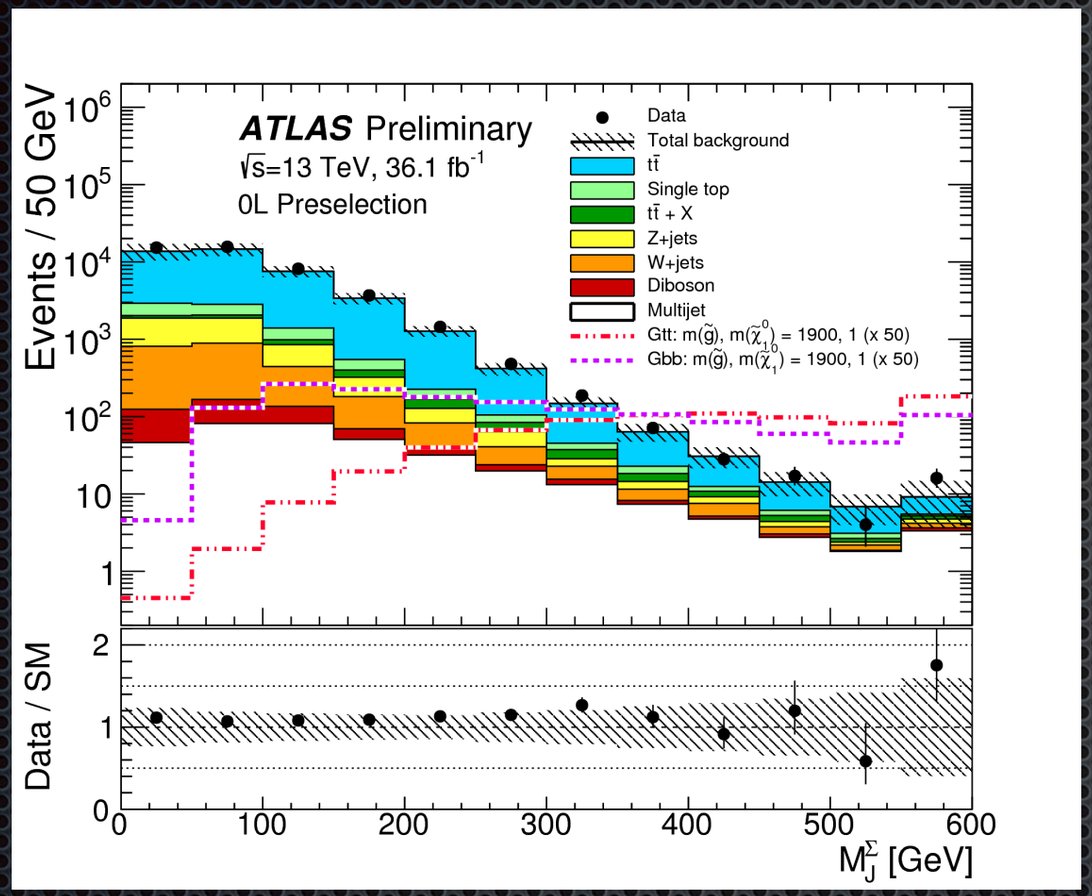


1L

total jet mass



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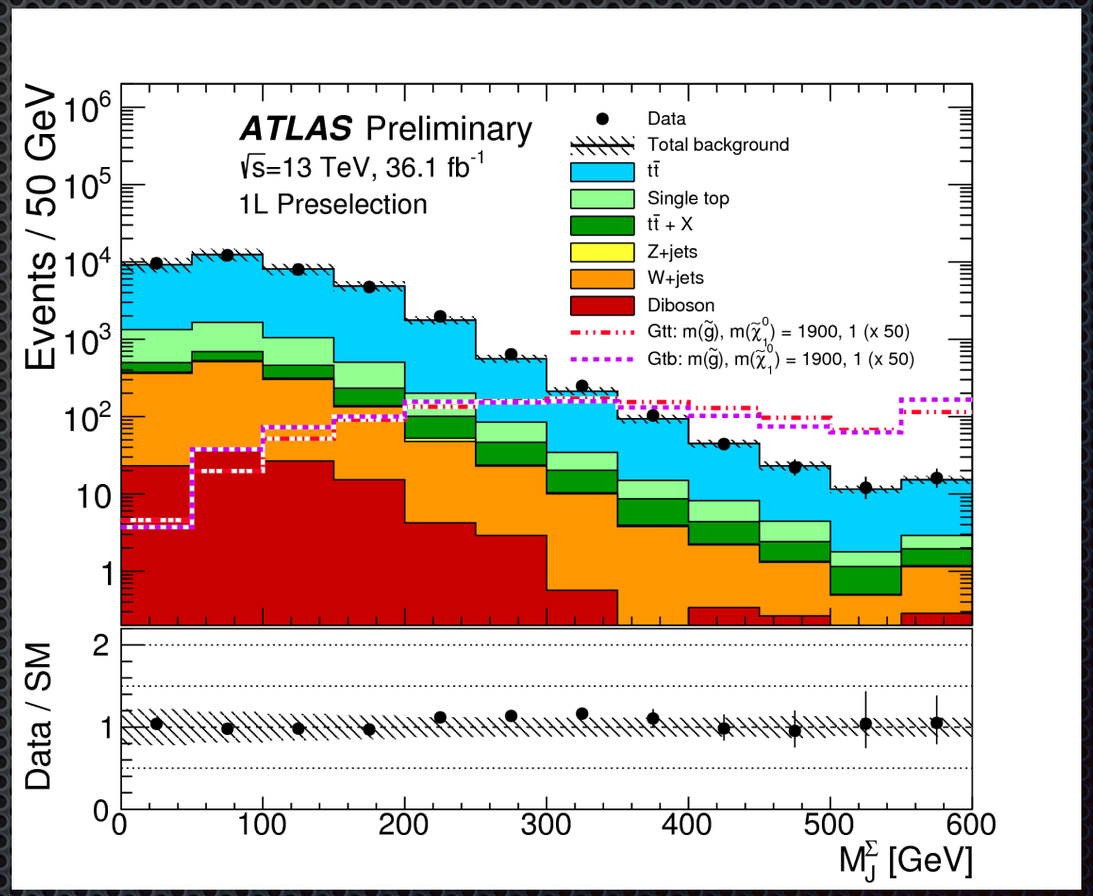

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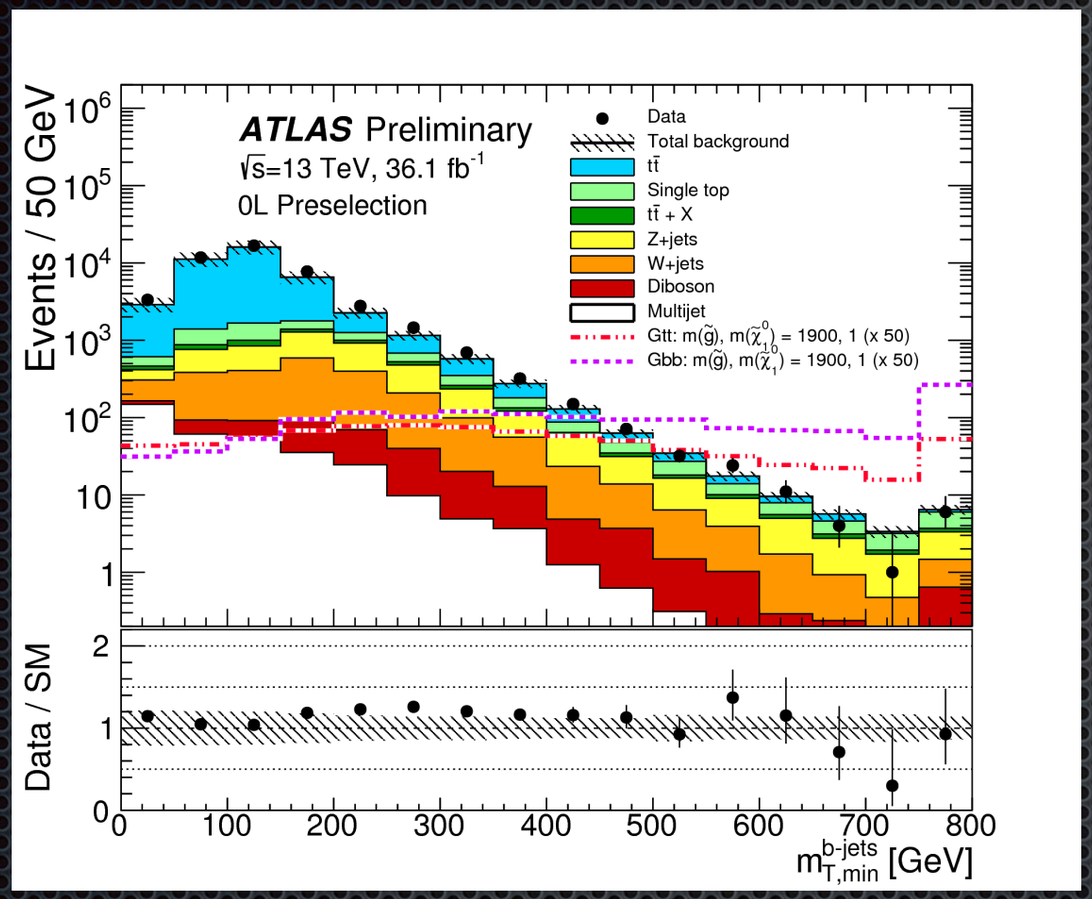
transverse mass



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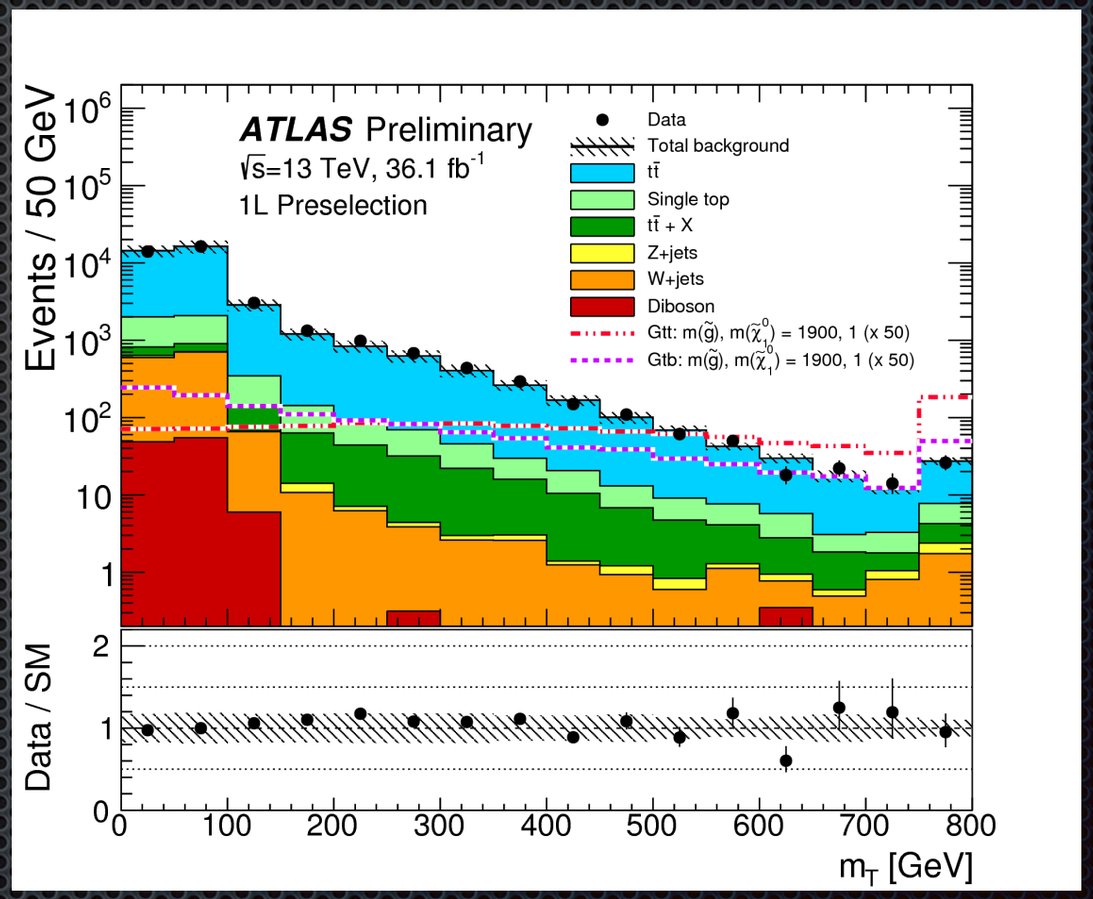

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