Searches for supersymmetry in events with photons or tau leptons and missing transverse momentum with the ATLAS detector

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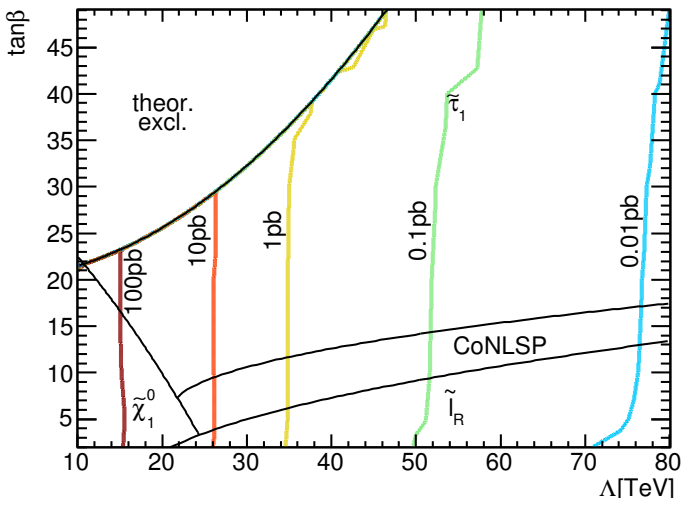
Gauge Mediated Supersymmetry Breaking

- Gauge Mediated Supersymmetry Breaking (GMSB) is one possible theory to introduce SUSY breaking
  - Breaking happens at a high scale in a hidden sector. It is communicated to the weak scale MSSM by messenger fields
  - Messengers couple to SM fields via standard gauge interactions
- In minimal version: six free parameters (two for Higgs sector)
  - In the searches presented here Λ - setting the sparticle mass scale - and $\tan\beta$ - Higgs VEV ratio - are varied
  - Other parameters fixed to ensure one particular signature

Gauge Mediated Supersymmetry Breaking

Phenomenology

- $\tilde{G}$ (Gravitino) is always lightest SUSY particle (LSP)
- $\tilde{G}$ has eV mass, is collider-stable and non-interacting $\Rightarrow \not{E}_T$
- NLSP$\rightarrow\tilde{G}$ decay at the end of every decay chain



- NLSP determines search signatures
- Only short lived NLSP considered here
- Two NLSP possibilities studied:
  - $\tilde{\chi}^0 \rightarrow\gamma\ \tilde{G}$, one photon in every decay chain
  - $\tilde{\tau} \rightarrow\tau\ \tilde{G}$, one tau in every decay chain

- Production modes depend on squark and gluino masses
- Strong production for lower, electroweak production for higher values of Λ

Tau Searches

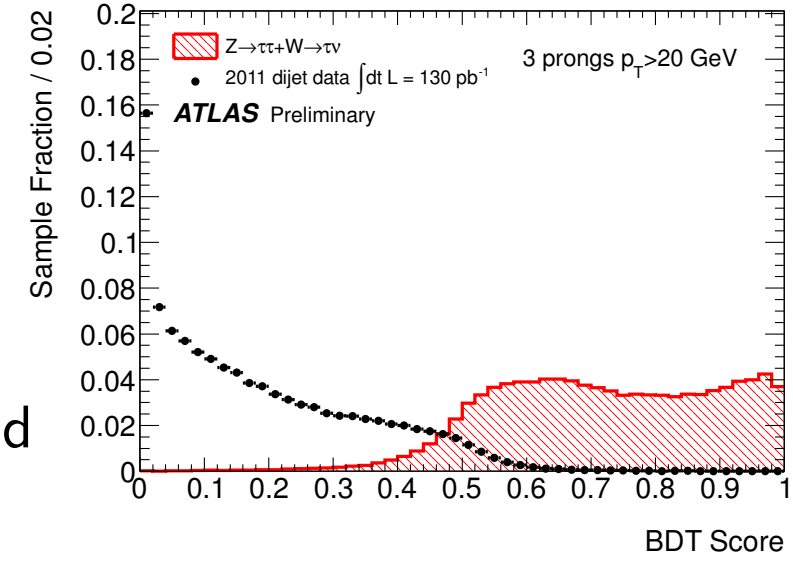
Outline

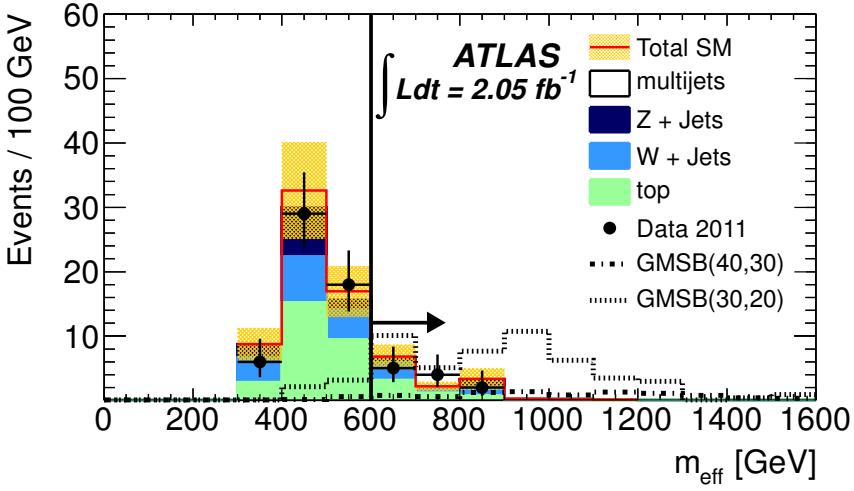
- Two searches based on $2.05\,\mathrm{fb}^{-1}$ of data recorded in 2011
- Target intermediate scale GMSB model with $\widetilde{\tau}$ NLSP and production of colored sparticles
- Trigger on one hard jet ($130\,\mathrm{GeV}$) and large missing transverse energy $\not{E}_T$ ($130\,\mathrm{GeV}$)
- Select events with either one or two reconstructed taus with $p_T > 20\,\mathrm{GeV}$ and no light leptons
- Separation between direction of jets and $\not{E}_T$ used to suppress missing energy due to instrumental effects
- Use $m_{\mathrm{eff}} = \left(\sum_{\text{selected taus/jets}} p_T + \not{E}_T\right)$, $\not{E}_T / m_{\mathrm{eff}}$ and transverse mass m_T^{τ} as main discriminating variables
- Background estimates based on extrapolations from control regions into signal region

Tau Searches

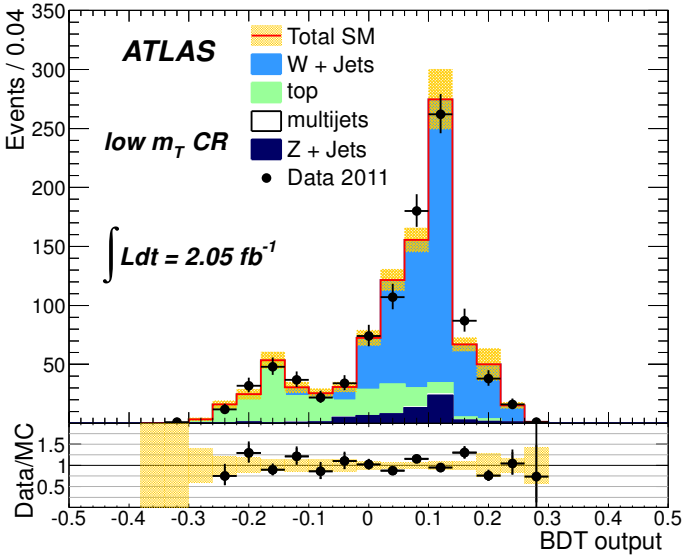
Selection

- Separate hadronic tau decays from jets using multivariate techniques
- Generally smaller track multiplicity and stronger collimation than QCD jets
- Require ≥ 1 "tight" tau for single tau and ≥ 2 "loose" taus for di tau selection





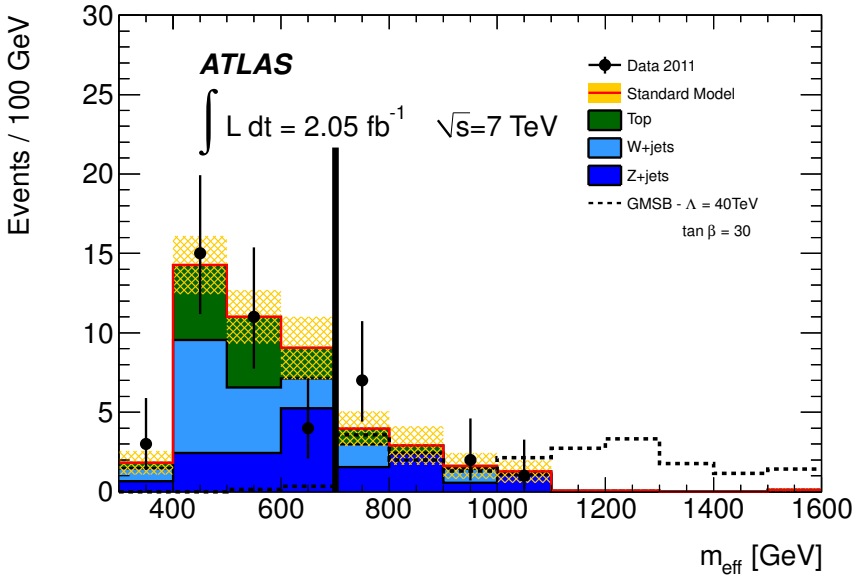
- Individual cuts to suppress single background channels
- Main selection cut on m_{eff} at $600\,\text{GeV}$ ($700\,\text{GeV}$) for the one tau (di tau) selection



- Multijet background estimated by measuring probability of jets to fake taus in control region
- True tau background evaluated from control region with $m_T^\tau < 70\,\mathrm{GeV}$
- . . . separating top from W using a multivariate discriminant

- Additional influence of fake taus studied in control region with $70\,\mathrm{GeV} < m_T^\tau < 110\,\mathrm{GeV}$ or $m_{\mathrm{eff}} < 600\,\mathrm{GeV}$
- Extrapolate to signal region with $110\,\mathrm{GeV} < m_T^\tau$
- Dominant uncertainties from jet energy uncertainties (besides extrapolation, normalization and signal cross section)

Top	W + jets	Z + jets	Multijet	$\sum$SM	Data
5.6 ± 1.4	4.7 ± 1.5	2.4 ± 0.7	0.5 ± 0.6	13.2 ± 4.2	11



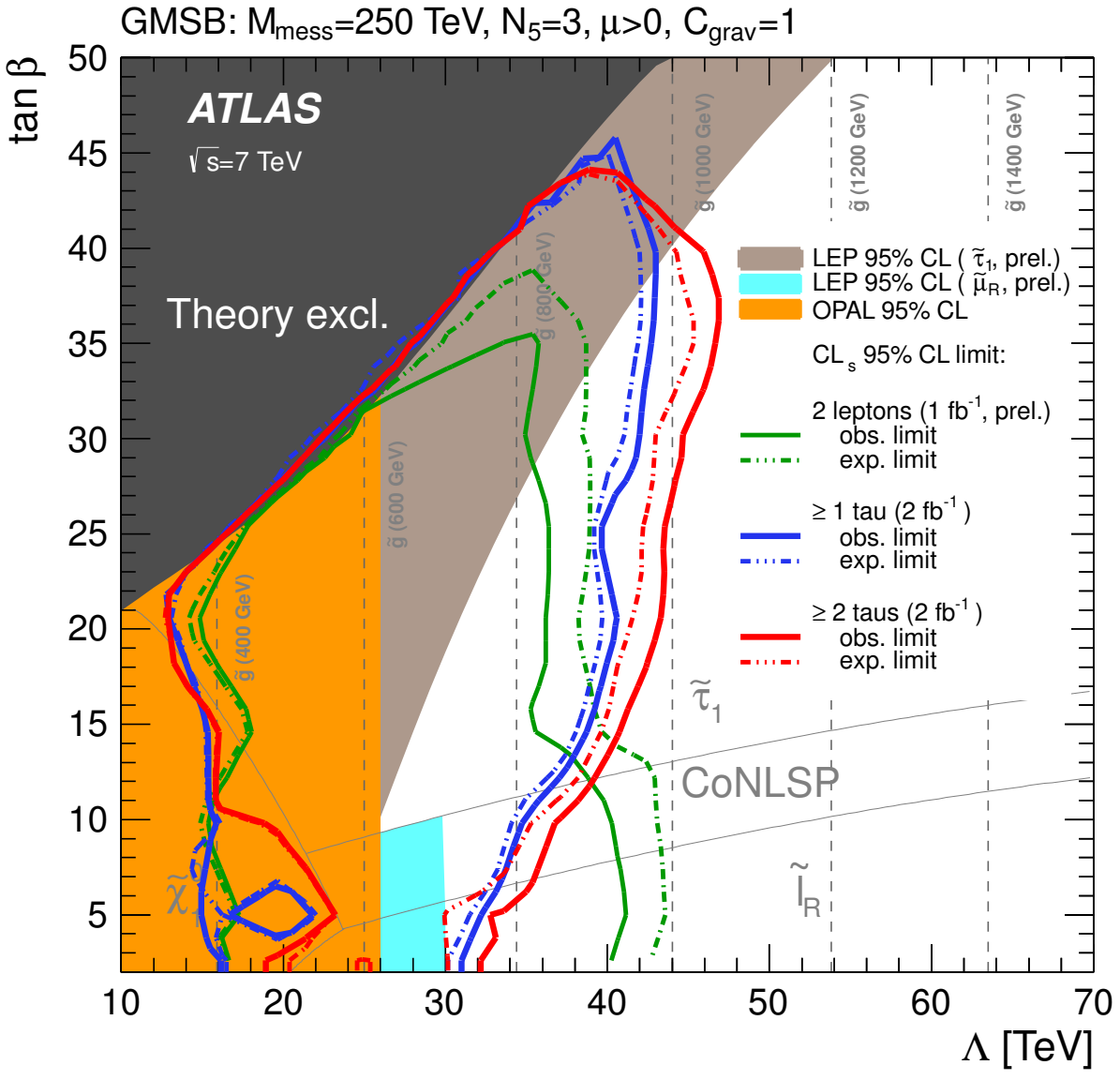
- Multijet background expected to contribute < 0.01 events by extrapolating estimate in sidebands to control region
- Contribution from $Z \rightarrow \tau\tau$ background estimated from simulation
- W and t estimated by extrapolating from dedicated control region to signal region
- Similar uncertainties as in the one tau search

$\sum$SM	Data
$5.3 \pm 1.3(\text{stat}) \pm 2.2(\text{syst})$	3

Top	W + jets	Z + jets	DiBosons
$1.57 \pm 0.42 \pm 0.75$	$2.5 \pm 1.0 \pm 1.2$	$1.08 \pm 0.70 \pm 0.63$	$0.14 \pm 0.05 \pm 0.03$

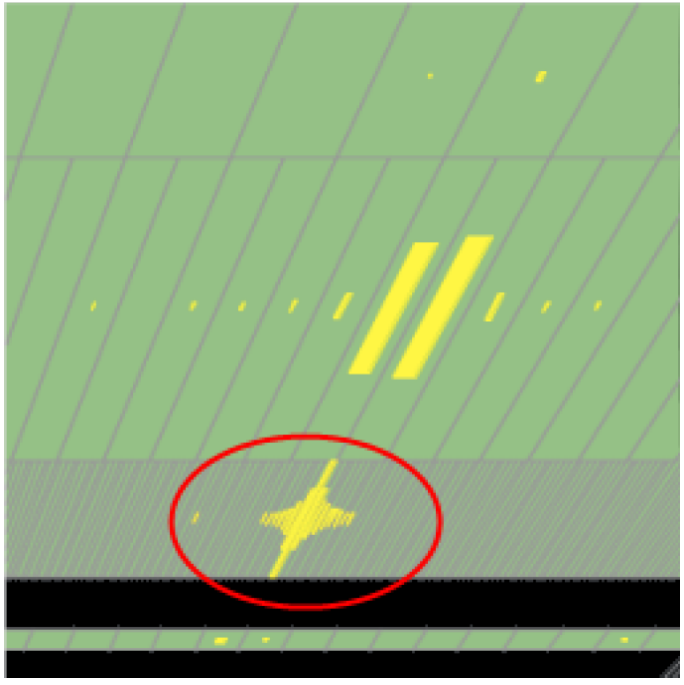
Tau Searches

Exclusion



- Upper limits on non-SM events of 8.5 (7) are set at 95% CL by single (di) tau search
- Limit interpreted as exclusion contour in (Λ, $\tan\beta$) plane
- Translates into limit on gluino mass of $m_{\tilde{g}} > 920(990)\,\mathrm{GeV}$ for $\tan\beta > 20$

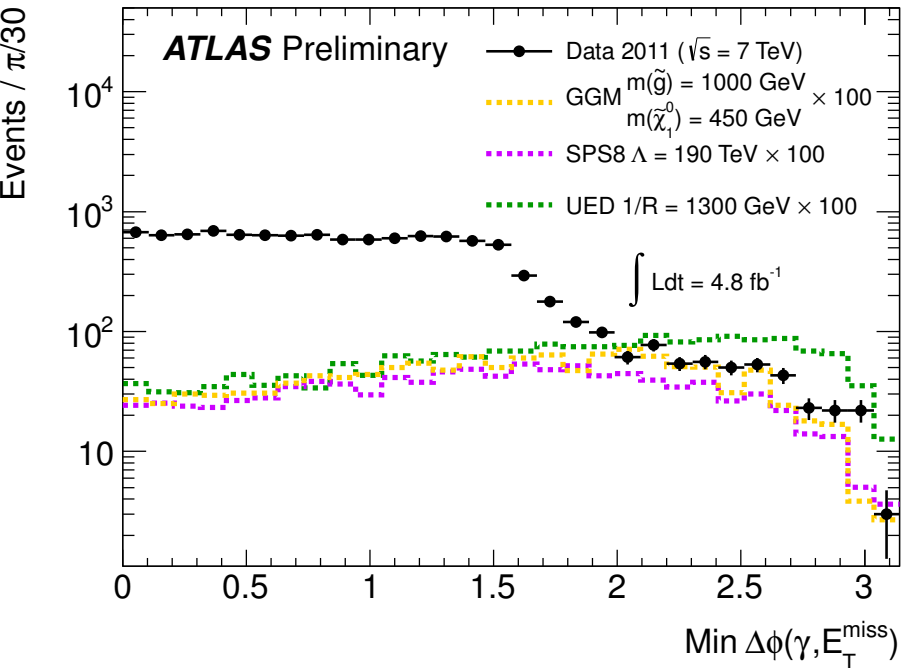
- Search uses $4.8\,\mathrm{fb}^{-1}$ of data recorded in 2011
- Target two classes of GMSB models
  - High-scale colored sparticle production with bino NLSP
  - Intermediate-scale gaugino production with bino-like NLSP
- Use diphoton trigger to select events with two photon candidates
- Require two $50\,\mathrm{GeV}$ photons and $\not{E}_T$
- Special care taken to reduce the amount of photons faked by electrons
- Use $\not{E}_T$, $H_T := \sum_{\text{photons/jets/leptons}} p_T$ and the isolation between $\not{E}_T$ and photons $\Delta\phi_{\text{min}}(\gamma, \not{E}_T)$ as main signal selection variables

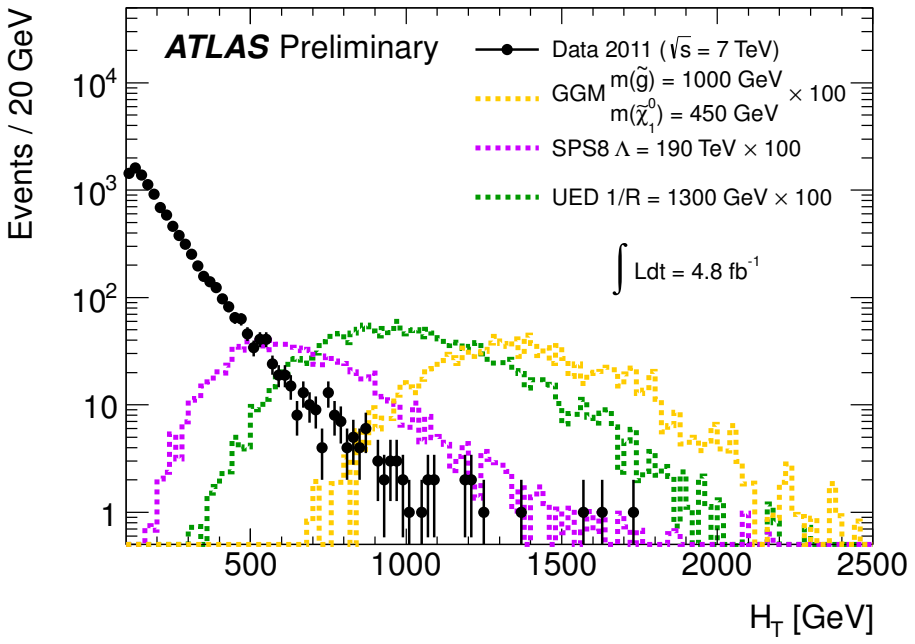


- Identification by shower shape in calorimeter, exploiting the high granularity of the ATLAS electromagnetic calorimeter
- ATLAS TRT capability allows reconstructing converted photons very efficiently
- Photon selection depends on conversion type (0/1/2 tracks)
- Large suppression of fakes by requiring one-track conversions to have no hits in the Pixel detector
- Reconstructed electrons always precede overlapping photons
- Strongly improved suppression of electron fakes offers optimized control over backgrounds compared to former analyses

Photon Searches

Signal Optimization





- Three different signal regions (SR) constructed
- SR A and B for colored production, SR C for electroweak production

	SR A	SR B	SR C
$\not{E}_T >$	200 GeV	100 GeV	125 GeV
$H_T >$	600 GeV	1100 GeV	-
$\Delta\phi_{\min}(\gamma, \not{E}_T) >$	0.5	-	0.5

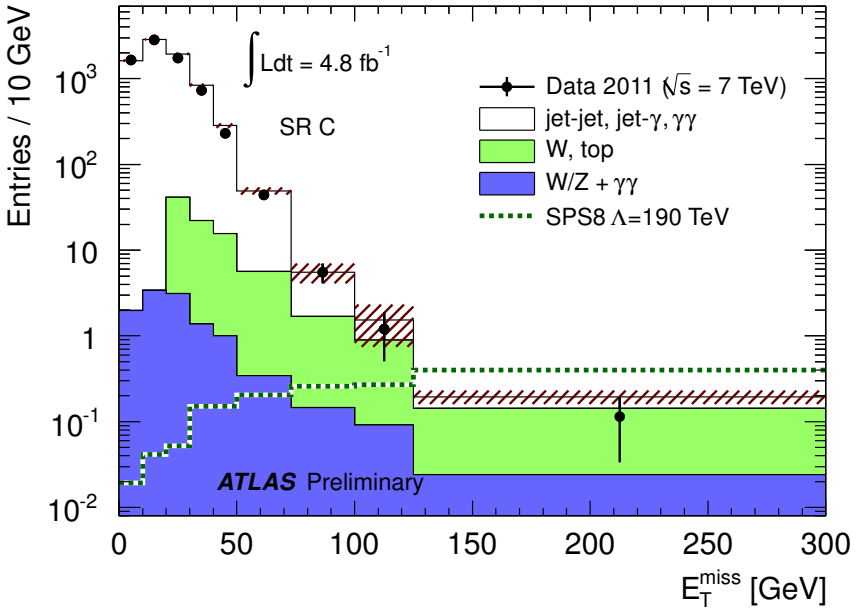
- Three classes of backgrounds

  QCD containing all backgrounds with jets being reconstructed as photons and fake $\not{E}_T$

  Electroweak containing all backgrounds with true $\not{E}_T$ from neutrinos and fake photons from electrons or jets

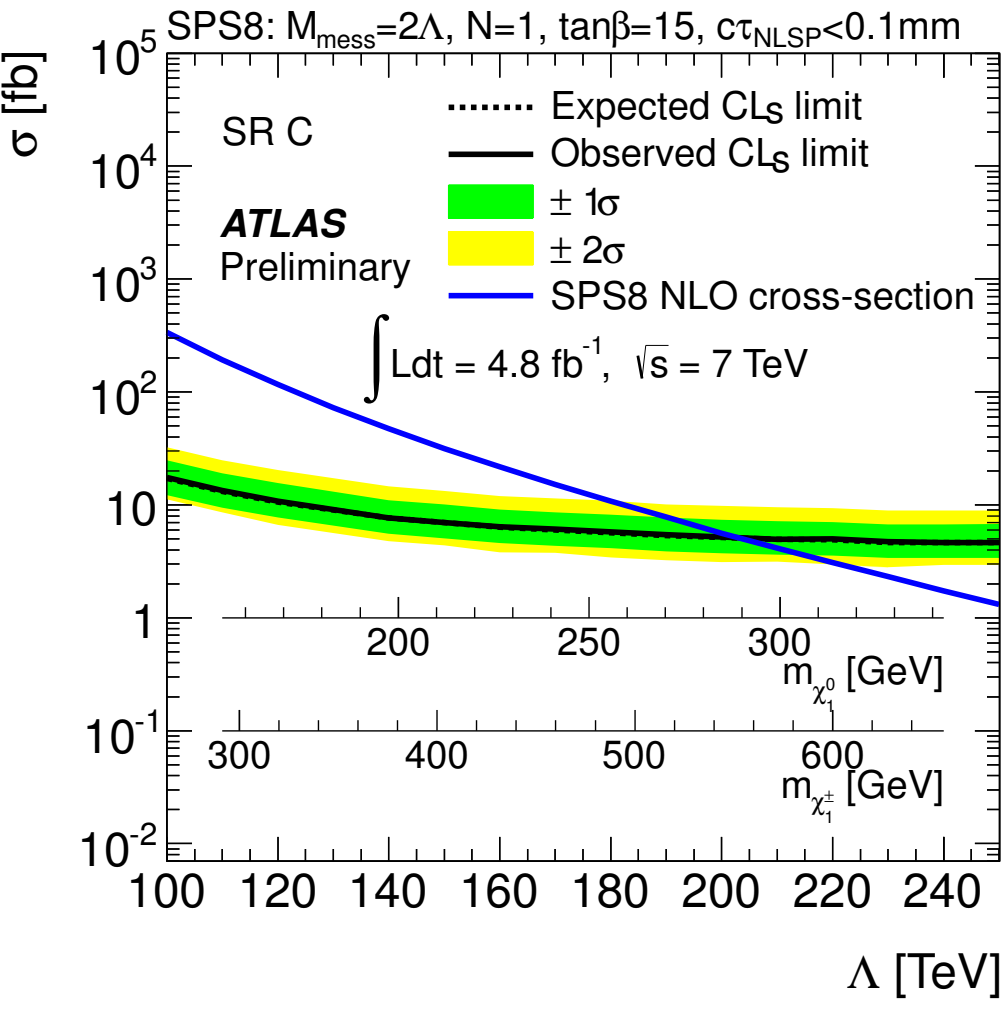
  Irreducible containing two true photons and $\not{E}_T$ from neutrinos, dominantly $\mathrm{W}(\to \ell\nu) + \gamma\gamma$ and $\mathrm{Z}(\to \bar{\nu}\nu) + \gamma\gamma$

- QCD estimated by constructing three templates from events that pass "loose" identification but fail "tight" and applying H_T and $\Delta\phi$ cuts according to each signal region
- Expected number of events obtained by normalizing templates to data in region $\not{E}_T < 20\,\mathrm{GeV}$

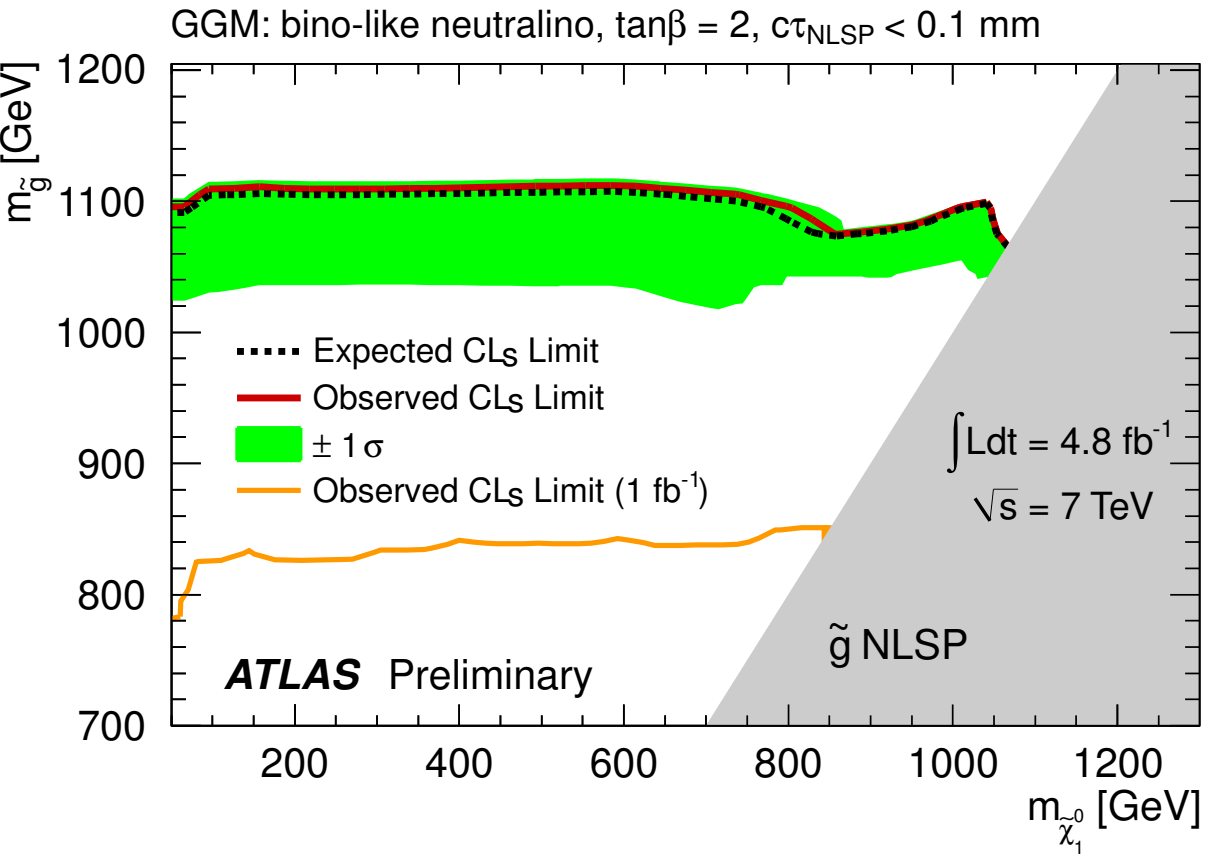


- Electroweak background estimated from events containing one photon and one electron passing signal cuts
- Prediction has to be scaled by electron to photon fake probability measured in $Z \rightarrow ee$ events
- Irreducible background estimated from Monte Carlo simulation
- Systematic uncertainties from alternative background estimate

	SR A	SR B	SR C
QCD	$0.07 \pm 0.00 \pm 0.07$	$0.27 \pm 0.00 \pm 0.27$	$0.85 \pm 0.30 \pm 0.71$
EW	$0.03 \pm 0.03 \pm 0.01$	$0.09 \pm 0.05 \pm 0.02$	$0.80 \pm 0.16 \pm 0.22$
$W(\rightarrow \ell\nu) + \gamma\gamma$	0.0	0.0	$0.18 \pm 0.13 \pm 0.18$
$Z(\rightarrow \bar{\nu}\nu) + \gamma\gamma$	0.0	0.0	$0.27 \pm 0.09 \pm 0.04$
Total	$0.10 \pm 0.03 \pm 0.07$	$0.36 \pm 0.05 \pm 0.27$	$2.11 \pm 0.37 \pm 0.77$
Observed	0	0	2



- Minimal GMSB scenario "SPS8" with full particle spectrum
- Λ is the only free parameter determining mass scales
- A lower limit of 203 TeV is set on the SPS8 breaking scale Λ
- . . . using signal region C
- In studied range of Λ dominantly direct EW gaugino production
- Corresponding limits on $m_{\tilde{\chi}_1^0} \gtrsim 290\,\mathrm{GeV}$ and $m_{\tilde{\chi}_1^\pm} \gtrsim 560\,\mathrm{GeV}$



- GGM (General Gauge Mediation) simplified model with Bino like $\widetilde{\chi}_1^0$
- Only gluino production
- $m_{\widetilde{g}}$ and $m_{\widetilde{\chi}_1^0}$ as free parameters
- All other masses decoupled

- A lower limit on $m_{\widetilde{g}}$ of $1.07\,\mathrm{TeV}$ is determined for $m_{\widetilde{\chi}_1^0} > 50\,\mathrm{GeV}$
- . . . using signal regions A and B depending on the neutralino masses

Summary

- Gauge mediation is an attractive theory of SUSY breaking
- Special properties lead to particular interesting signatures
- Photons and taus can exploit GMSB signatures for sensitive low background searches for SUSY
- Stringent limits on gauge mediated SUSY production set

References

One tau search arXiv:1204.3852, accepted for publication by PLB

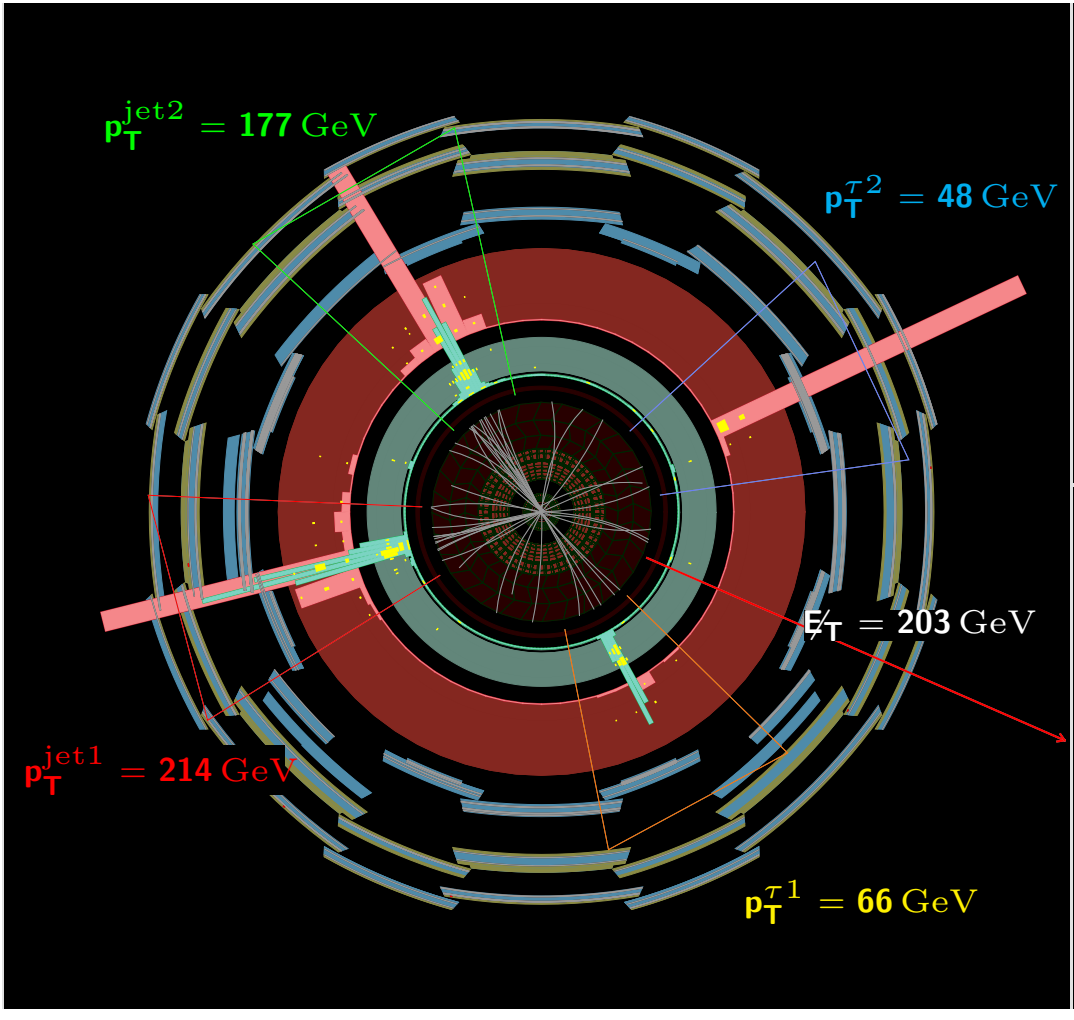
Two tau search arXiv:1203.6580, accepted for publication by PLB

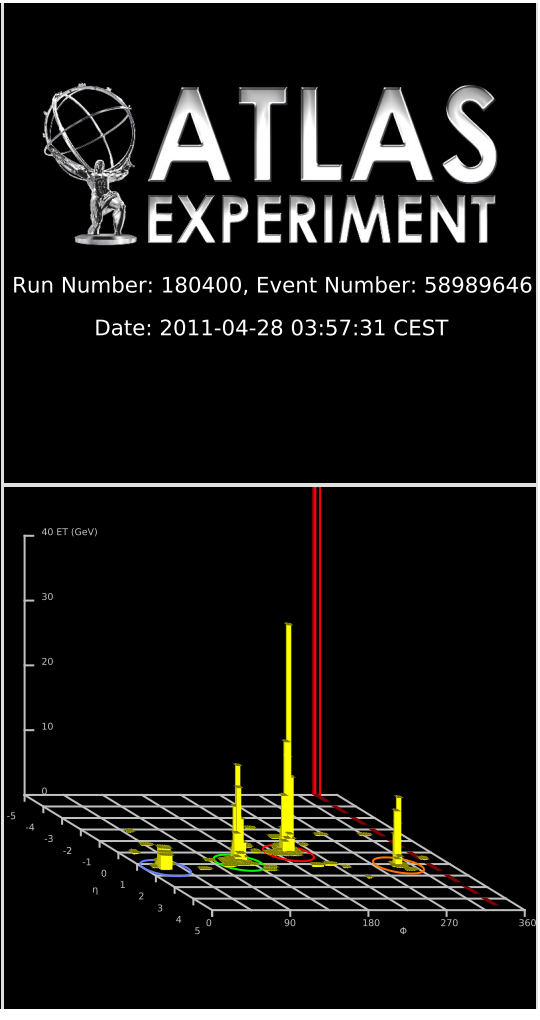
Diphoton search ATLAS-CONF-2012-072

Back Up

Tau Searches

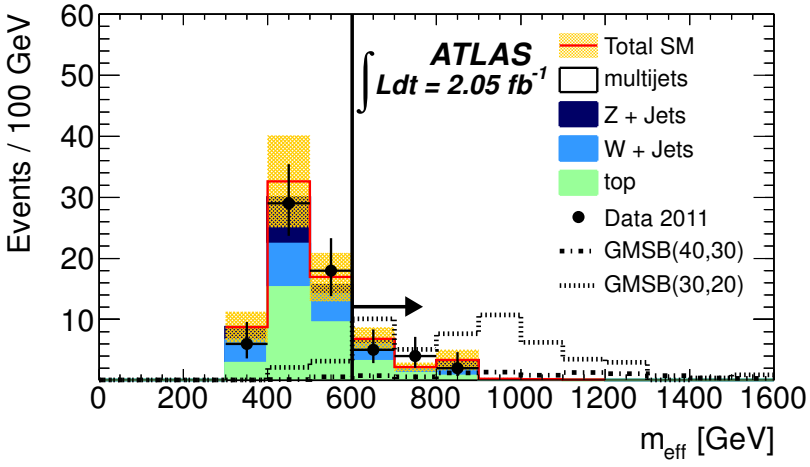
Example Event

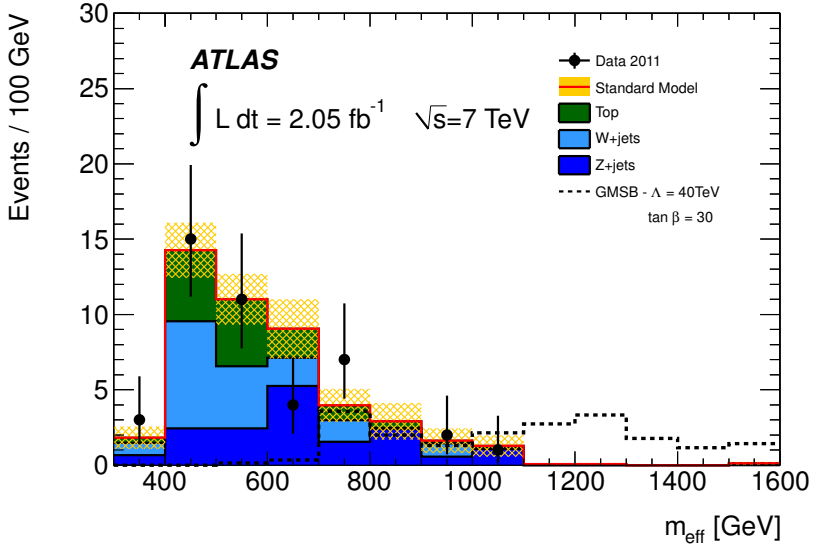




Tau Searches

Selection





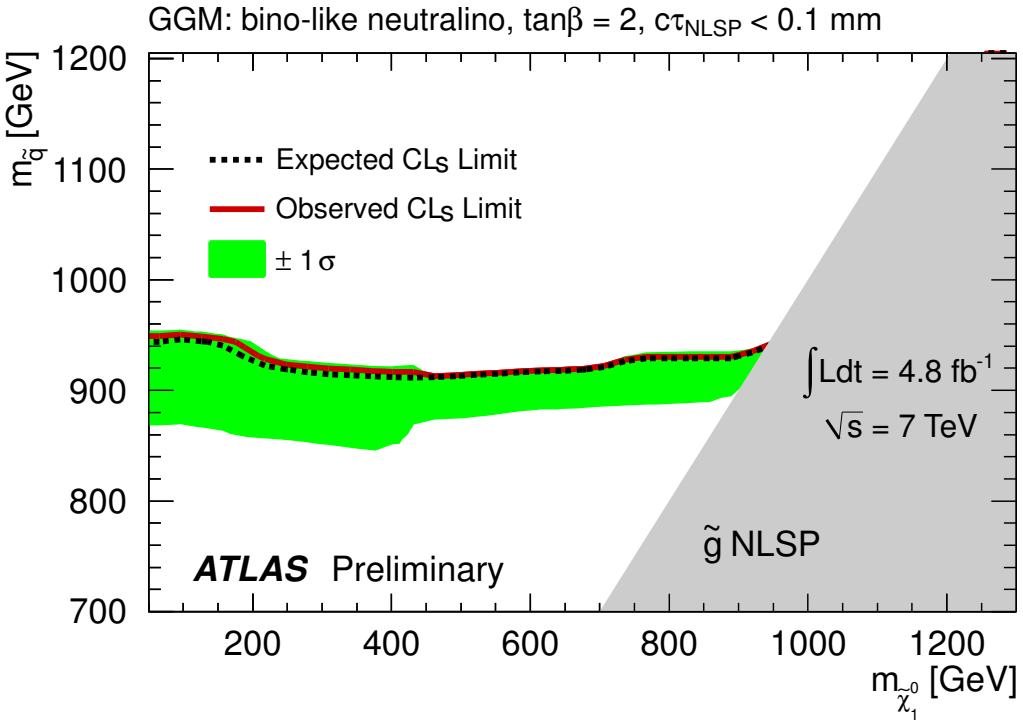
1 tau Selection

- ≥ 1 "tight" tau
- $\frac{\not{E}_T}{m_{\text{eff}}} > 0.25$
- $m_T^{\tau} > 110\,\text{GeV}$
- $m_{\text{eff}} > 600\,\text{GeV}$

2 tau Selection

- ≥ 2 "loose" taus
- $m_T^{\tau 1} + m_T^{\tau 2} > 80\,\text{GeV}$
- $m_{\text{eff}} > 700\,\text{GeV}$

- Identification by shower shape in calorimeter, exploiting the high granularity of the ATLAS electromagnetic calorimeter
- ATLAS TRT capabilities to reconstruct and identify photon conversions leads to three classes of photons
  - Unconverted photons that have no tracks pointing to the photon cluster
  - Single track conversions that have one electron track that does not have hits in the innermost pixel detector
  - Two tracks conversions that have two electron tracks and a conversion vertex consistent with the decay of a zero mass particle
- Reconstructed electrons always precede overlapping photons
- Overall achieve 55% fake rejection at 70% signal efficiency
- Strongly improved suppression of electron fakes offers optimized control over backgrounds



- $\tan\beta = 2$ and $c\tau_{\text{NLSP}} < 0.1\,\text{mm}$
- $m_{\tilde{q}}$ and $m_{\tilde{\chi}^0}$ as free parameters
- All $\tilde{d}$ and $\tilde{u}_L$ masses degenerate, $\tilde{u}_R$ decoupled
- All other masses decoupled
- A lower limit on $m_{\tilde{q}}$ of $0.91\,\text{TeV}$ is determined for $m_{\tilde{\chi}^0} > 50\,\text{GeV}$