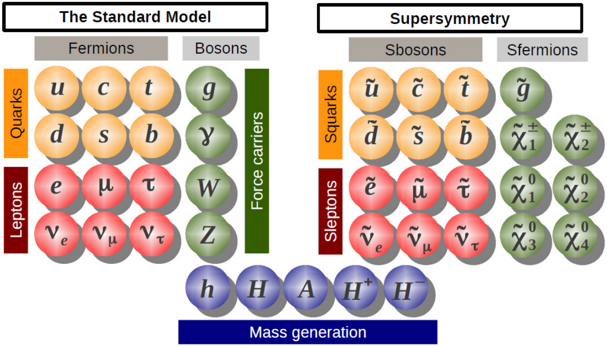
SUSY searches at the LHC

Tina Potter

on behalf of the ATLAS and CMS Collaborations

LCWS15, Whistler, Canada

Supersymmetry



Superpartner for every SM particle

- Spin difers by one half.
- Mostly heavier than SM partners → broken symmetry
- Rich array of signatures to search for at the LHC and future LC.

✔ New superpartners cancel quadratic divergences in Higgs mass corrections.
✔ *R*-parity conserving models offer a stable LSP (usually $\tilde{\chi}_1^0$) → a good dark matter candidate.

To avoid high levels of "unnatural" fine tuning in Higgs mass corrections, some sparticles need to be light. For natural SUSY (low levels of fine tuning)

- Light higgsinos
- Light stop (<1 TeV)
- Light gluinos ($< 1 - 2$ TeV)

SUSY Search Strategy

Search strategy designed to provide coverage for a broad class of SUSY models

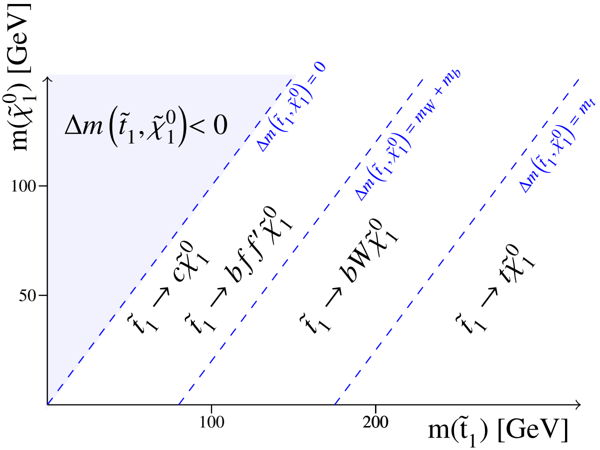
Prompt					Long-lived
R-Parity Conserving			*R*-Parity Violating		RPC or RPV.
Strong gluinos, 1^{st}, 2^{nd} gen. squarks	**3^{rd} gen.** stop, sbottom	**EWK** EWKinos, sleptons	**RPC prod.** RPV decays	**RPV prod.** RPV decays	Various ranges of lifetimes

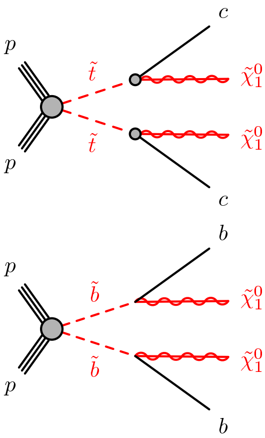
For each search, a number of signal regions is optimised based on a variety of models

Focus today on recent 3^{rd} gen., EWK and γ+X results
+ pMSSM interpretations.

Third Generation SUSY Searches

Expect light stops for natural SUSY.
Example: Compressed scenarios, $\tilde{t}_1 \to c\tilde{\chi}_1^0$, or $\tilde{b}_1 \to b\tilde{\chi}_1^0$





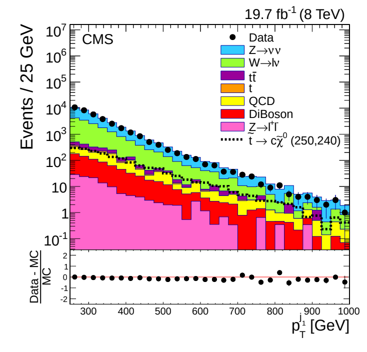
Third Generation SUSY Searches

Example: Compressed scenarios, $\tilde{t}_1 \to c\tilde{\chi}_1^0$, or $\tilde{b}_1 \to b\tilde{\chi}_1^0$

Small $\Delta m = m(\tilde{t}_1) - m(\tilde{\chi}_1^0)$ or $\Delta m = m(\tilde{b}_1) - m(\tilde{\chi}_1^0)$ leave little visible energy in detectors $\Rightarrow$ difficult to distinguish from SM background.

CMS — JHEP 06 (2015) 116

- Monojet selection targets $\tilde{t}_1\tilde{t}_1$ and $\tilde{b}_1\tilde{b}_1$
- Single jet (ISR) + $E_{\mathrm{T}}^{\mathrm{miss}}$
- 7 SR: jet $p_{\mathrm{T}} > 250 - 550$ GeV
- $Z(\nu\bar{\nu})$+jets and $W(\ell\nu)$+jets from $Z(\mu\mu)$ and $W(\mu\nu)$ in data.
- VV, multijet and $t\bar{t}$ from simulation corrected to data.



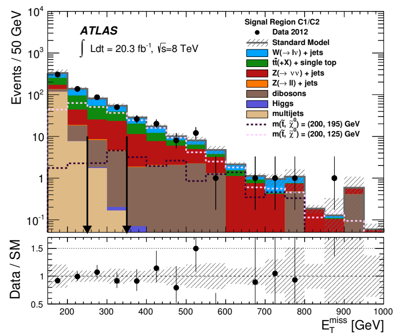
Third Generation SUSY Searches

Example: Compressed scenarios, $\tilde{t}_1 \to c\tilde{\chi}_1^0$, or $\tilde{b}_1 \to b\tilde{\chi}_1^0$

Small $\Delta m = m(\tilde{t}_1) - m(\tilde{\chi}_1^0)$ or $\Delta m = m(\tilde{b}_1) - m(\tilde{\chi}_1^0)$ leave little visible energy in detectors $\Rightarrow$ difficult to distinguish from SM background.

ATLAS — Phys. Rev. D 90, 052008 (2014)

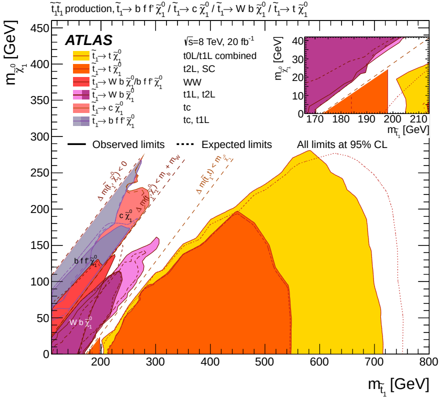
- Monojet selection targets $\tilde{t}_1\tilde{t}_1$ and $\tilde{b}_1\tilde{b}_1$
  - Single jet (ISR) + E_T^{miss}
  - 3 SR: large jet p_T and E_T^{miss}
- c-tagging selection targets $\tilde{t}_1\tilde{t}_1$
  - 4 jets, $\geq$1 c-tagged jet
  - 2 SR: large jet p_T and E_T^{miss}
- $Z(\nu\bar{\nu})$+jets and $W(\ell\nu)$+jets from simulation corrected to data.
- $t\bar{t}$ from simulation (corrected to data for c-tagged SR).
- Others from simulation.



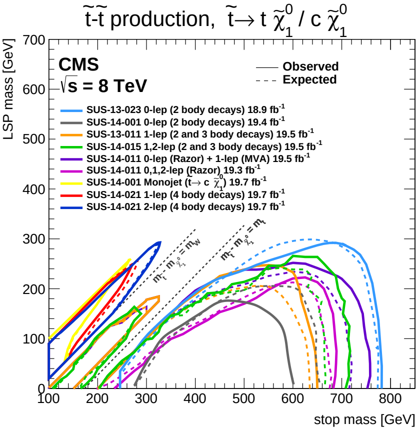
Third Generation SUSY Searches

Exclusion limits $\tilde{t}_1 \to c\tilde{\chi}_1^0$

arXiv:1506.08616



JHEP 06 (2015) 116

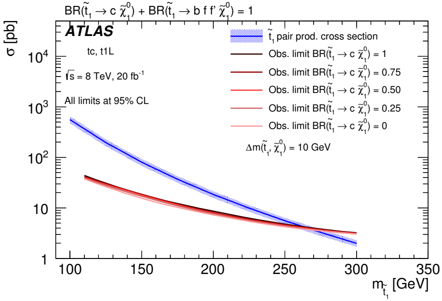


$\tilde{t}_1$ masses below ∼250 GeV are excluded for $m(\tilde{t}_1) - m(\tilde{\chi}_1^0) < 85$ GeV.

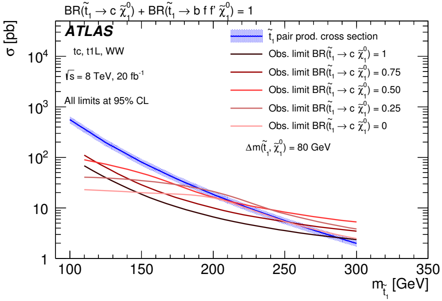
Similar limits on $\tilde{t}_1 \to c\tilde{\chi}_1^0$ set by ATLAS and CMS.

Third Generation SUSY Searches

Exclusion limits $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$ arXiv:1506.08616



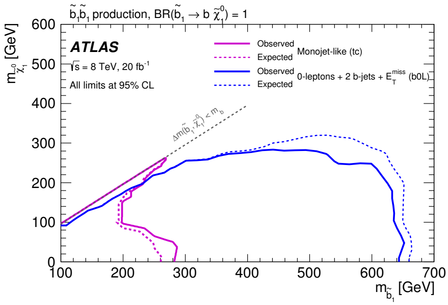
For very small $m(\tilde{t}_1) - m(\tilde{\chi}_1^0)$, the limits do not depend on $\text{BR}(\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0)$.

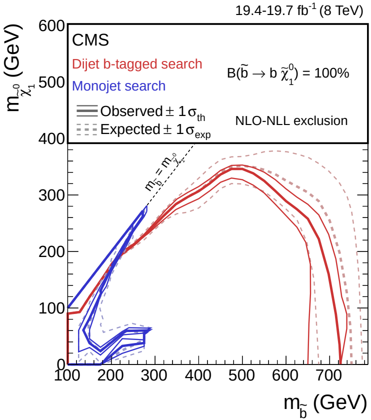


For $m(\tilde{t}_1) - m(\tilde{\chi}_1^0) \sim W$, the limits can vary by ~ 100 GeV depending on BR.

Third Generation SUSY Searches

Exclusion limits $\tilde{b}_1 \to b\tilde{\chi}_1^0$





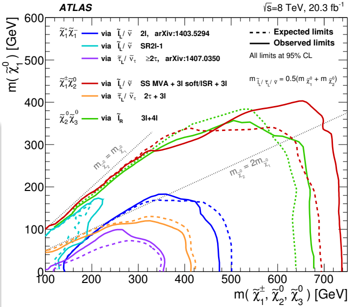
$\tilde{b}_1$ masses below ~280 GeV are excluded for small $m(\tilde{b}_1) - m(\tilde{\chi}_1^0)$.
Similar limits on $\tilde{b}_1 \to b\tilde{\chi}_1^0$ set by ATLAS and CMS.

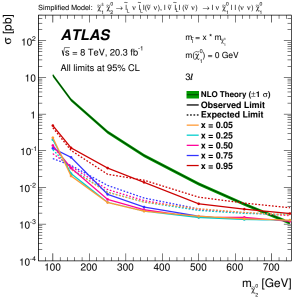
Focus on compressed scenarios and low cross-section processes ($\tilde{\tau}\tilde{\tau}$, VBF prod.)

New analyses

- 2ℓ selections using super-razor variables target compressed $\tilde{\chi}_1^+\tilde{\chi}_1^-$.
- 3ℓ soft leptons/ISR and SS 2ℓ MVA target compressed $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$.
- 2τ MVA target $\tilde{\tau}\tilde{\tau}$.
- SS 2ℓ target VBF $\tilde{\chi}_1^\pm\tilde{\chi}_1^\pm$.

- New analyses + combinations to set limits.
- Little dependence on mass of intermediate slepton for $\tilde{\ell}$-mediated decays.



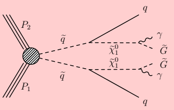


SUSY Searches with photons

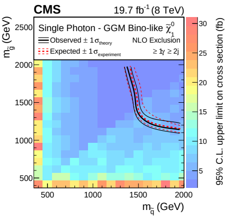
Focus on GGM scenarios with bino-, wino- or higgsino-like $\tilde{\chi}_1^0$ NLSP.

CMS arXiv:1507.02898

- γ + 2 jets + large E_T^{miss}
- $\gamma\gamma$ + 1 jets + super-razor variables
- Interpretations for gluino production with bino- or wino-like NLSP

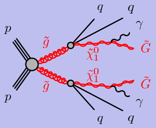


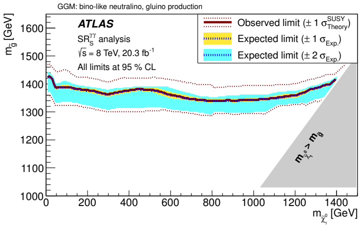
$m(\tilde{\chi}_1^0)$=375 GeV



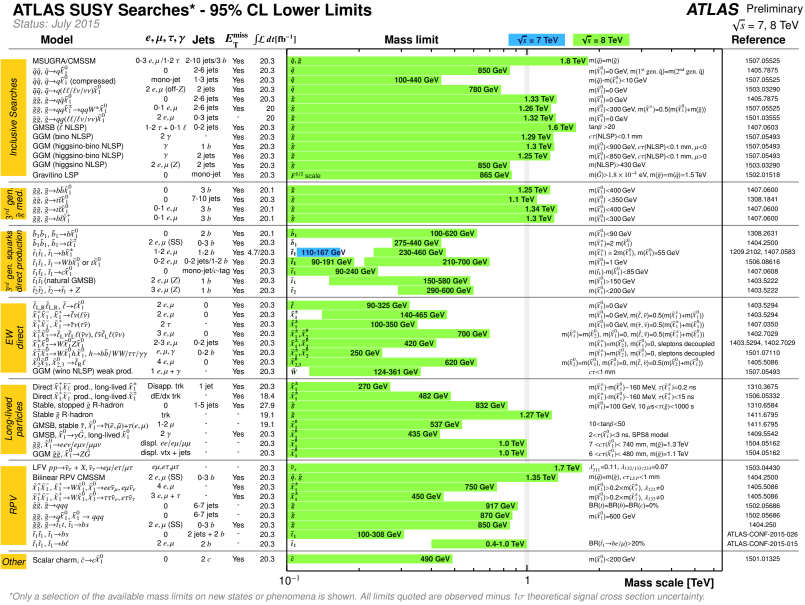
ATLAS arXiv:1507.05493

- $\gamma\gamma$, $\gamma\ell$, γb or γj.
- Selections on E_T^{miss}, m_{eff}, H_T, m_T^{ℓ} ($\gamma\ell$), m_{bb} and m_T^{γ} (γb), jet momentum balance R_T^4 (γj).
- Interpretations for wino or gluino(+higgsino) production, with bino-, wino- or higgsino/bino-like NLSP.

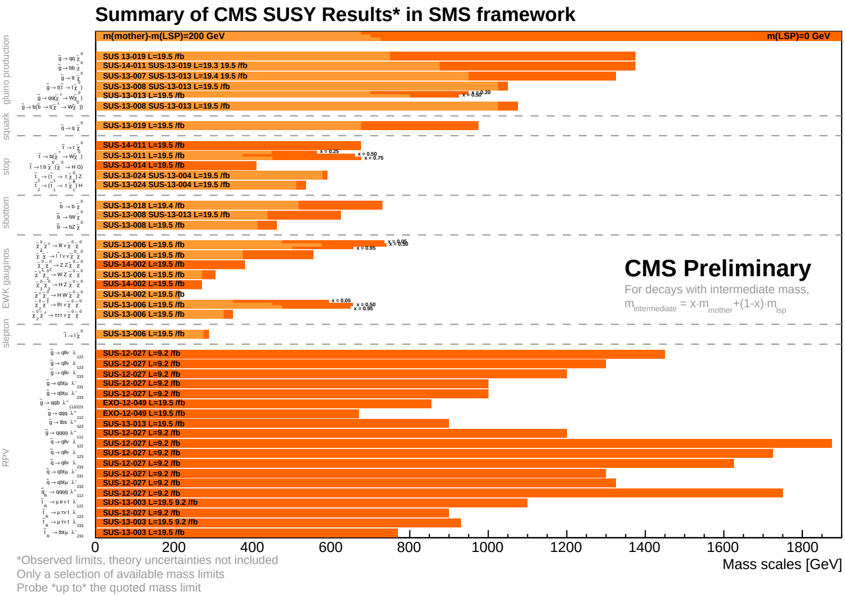




ATLAS Summary



CMS Summary



Summary of CMS SUSY Results* in SMS framework
m(mother)-m(LSP)=200 GeV
m(LSP)=0 GeV
gluino production
squark
stop
sbottom
EWK gauginos
slepton
RPV
SUS 13-019 L=19.5 /fb
SUS-14-011 SUS-13-019 L=19.3 19.5 /fb
SUS-13-007 SUS-13-013 L=19.4 19.5 /fb
SUS-13-008 SUS-13-013 L=19.5 /fb
SUS-13-013 L=19.5 /fb
x = 0.20
x = 0.50
SUS-13-008 SUS-13-013 L=19.5 /fb
SUS-13-019 L=19.5 /fb
SUS-14-011 L=19.5 /fb
SUS-13-011 L=19.5 /fb
x = 0.25
x = 0.50
x = 0.75
SUS-13-014 L=19.5 /fb
SUS-13-024 SUS-13-004 L=19.5 /fb
SUS-13-024 SUS-13-004 L=19.5 /fb
SUS-13-018 L=19.4 /fb
SUS-13-008 SUS-13-013 L=19.5 /fb
SUS-13-008 L=19.5 /fb
SUS-13-006 L=19.5 /fb
x = 0.05
x = 0.50
x = 0.95
SUS-13-006 L=19.5 /fb
SUS-14-002 L=19.5 /fb
SUS-13-006 L=19.5 /fb
SUS-14-002 L=19.5 /fb
SUS-14-002 L=19.5 /fb
SUS-13-006 L=19.5 /fb
x = 0.05
x = 0.50
x = 0.95
SUS-13-006 L=19.5 /fb
SUS-13-006 L=19.5 /fb
SUS-12-027 L=9.2 /fb
SUS-12-027 L=9.2 /fb
SUS-12-027 L=9.2 /fb
SUS-12-027 L=9.2 /fb
SUS-12-027 L=9.2 /fb
EXO-12-049 L=19.5 /fb
EXO-12-049 L=19.5 /fb
SUS-13-013 L=19.5 /fb
SUS-12-027 L=9.2 /fb
SUS-12-027 L=9.2 /fb
SUS-12-027 L=9.2 /fb
SUS-12-027 L=9.2 /fb
SUS-12-027 L=9.2 /fb
SUS-12-027 L=9.2 /fb
SUS-12-027 L=9.2 /fb
SUS-13-003 L=19.5 9.2 /fb
SUS-12-027 L=9.2 /fb
SUS-13-003 L=19.5 9.2 /fb
SUS-13-003 L=19.5 /fb
CMS Preliminary
For decays with intermediate mass,
$m_{intermediate} = x \cdot m_{mother} + (1-x) \cdot m_{lsp}$
0
200
400
600
800
1000
1200
1400
1600
1800
Mass scales [GeV]
*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit

pMSSM Interpretations **ATLAS** JHEP 10 (2015) 134

Study the impact of the full set of ATLAS SUSY searches on the pMSSM.

Use 19-parameter pMSSM

- Minimal flavor violation with no new source of CP violation
- Degenerate 1st and 2nd generation squarks and sleptons
- No RPV and the LSP is the $\tilde{\chi}_1^0$

500×10^6 models in the pMSSM are randomly sampled.
300×10^3 models survive theory and non-LHC constraints *(precision EW, LEP, Higgs, DM)*

22 ATLAS Run 1 RPC SUSY searches are reinterpreted in the pMSSM $\Rightarrow$ **200 SR!**
Best expected SR used for exclusion.
Makes full use of ATLAS simulation, reconstruction and analysis.

$>30\times10^9$ events generated for truth-based analysis.

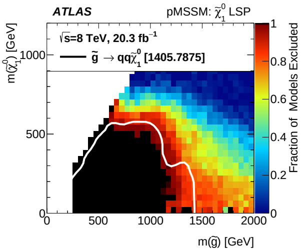
$>600\times10^6$ events simulated & reconstructed.

Most comprehensive results from ATLAS on SUSY to date

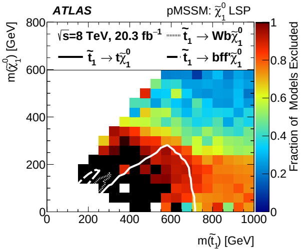
Analysis
0-lepton + 2–6 jets + E_T^{miss}
0-lepton + 7–10 jets + E_T^{miss}
1-lepton + jets + E_T^{miss}
$\tau(\tau/\ell)$ + jets + E_T^{miss}
SS/3-leptons + jets + E_T^{miss}
0/1-lepton + 3b-jets + E_T^{miss}
Monojet
0-lepton stop
1-lepton stop
2-leptons stop
Monojet stop
Stop with Z boson
2b-jets + E_T^{miss}
tb+E_T^{miss}, stop
ℓh
2-leptons
2-τ
3-leptons
4-leptons
Disappearing Track
Long-lived particle
$H/A \to \tau^+\tau^-$

pMSSM Interpretations

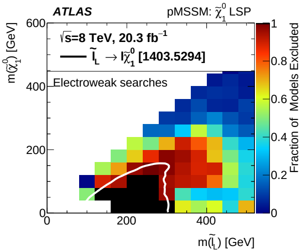
ATLAS JHEP 10 (2015) 134



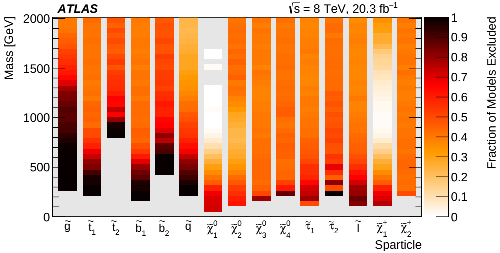
Good agreement with simplified models. Diagonal excluded by mono-jet analysis. Intermediate sparticles reduce exclusion for heavy $\tilde{g}$.



Simplified model overestimates reach (100% BR). Higgs mass constraint excludes light $\tilde{t}_1$ models. Heavy $\tilde{t}_1$ models with long-lived $\tilde{\chi}_1^{\pm}$ excluded by disappearing track analysis.



Good agreement with simplified models.

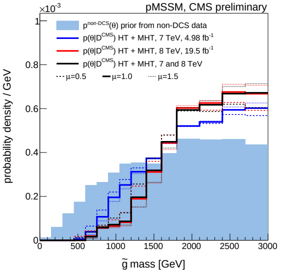


- Highest sensitivity to strong processes.
- Simplified models ↔ pMSSM models (some differences observed).
- Good complementarity between different searches and with direct detection experiments (see paper for details).

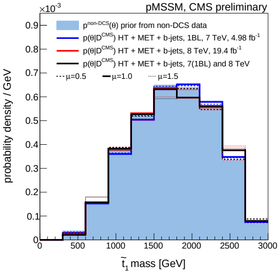
pMSSM Interpretations **CMS** CMS-PAS-SUS-13-020

Combination of 7 TeV and 8 TeV results to scan 19-parameter pMSSM.
Prompt decays only ($\tilde{\chi}_1^{\pm}$ lifetime $<$10 mm).
Bayesian approach (see paper for details).
Likelihood constructed from non-Direct CMS Searches, "non-DCS":
indirect measurements, Higgs, and non-LHC data (not DM).
3 analyses included

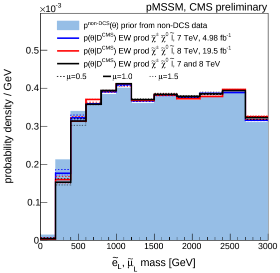
- Hadronic HT+MHT (strong production)
- Hadronic HT+MET + b-jets (3$^{\mathrm{rd}}$ gen.)
- Leptonic EW (SS, 3ℓ, 4ℓ channels)



Strong analyses disfavour $\tilde{g}$ masses $<$1.2 TeV.



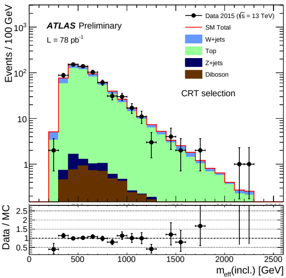
Third gen. analyses have negligible impact on $\tilde{t}$ mass.



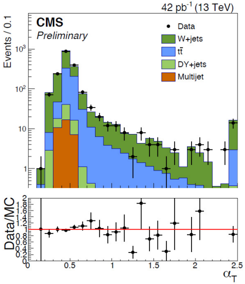
EW analyses slightly disfavour small $\tilde{\ell}$ mass.

Summary

- LHC is searching in many different channels for SUSY.
- Did not find SUSY in 7 TeV and 8 TeV runs.
- Evaluated SUSY searches on a broad set of pMSSM models.
- Strong SUSY production is excluded to high masses.
  More room left in third generation and EWK SUSY scenarios.
- 13 TeV LHC run already begun
  $\rightarrow$ great potential for SUSY discovery!



0ℓ + 2-6 jets + $E_{\mathrm{T}}^{\mathrm{miss}}$.
Top Control Region.



α_{T} search.
Single μ Control Region.