Search for Supersymmetry at ATLAS

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Les Rencontres de Physique de la Vallée d'Aoste

23 February-1 March 2014

Outline

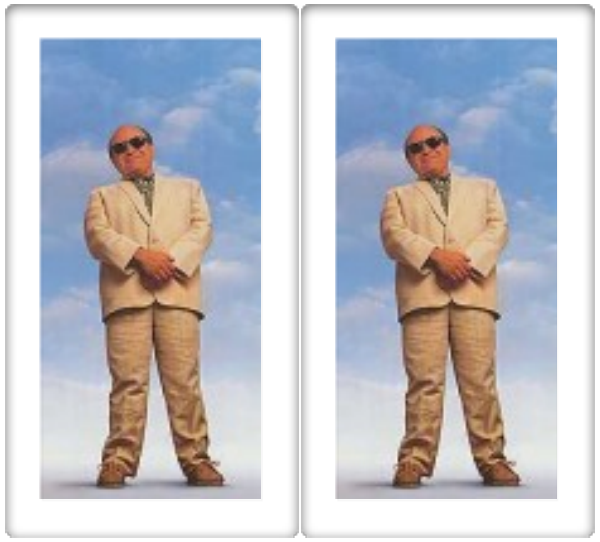
- Supersymmetry searches at LHC
- ATLAS strategy
- Strong production results
  - 1-*lepton*+[3-6] *jets* + E_T^{miss} searches
- Third generation production results
  - E_T^{miss} + *jets stop* search
- Electroweak production results
  - *New*: 3-*lepton*+ E_T^{miss} searches
  - *New*: *di-photon*+ E_T^{miss} searches
- Long Lived particles results
  - Stopped *gluino* search
- Mass limits summary

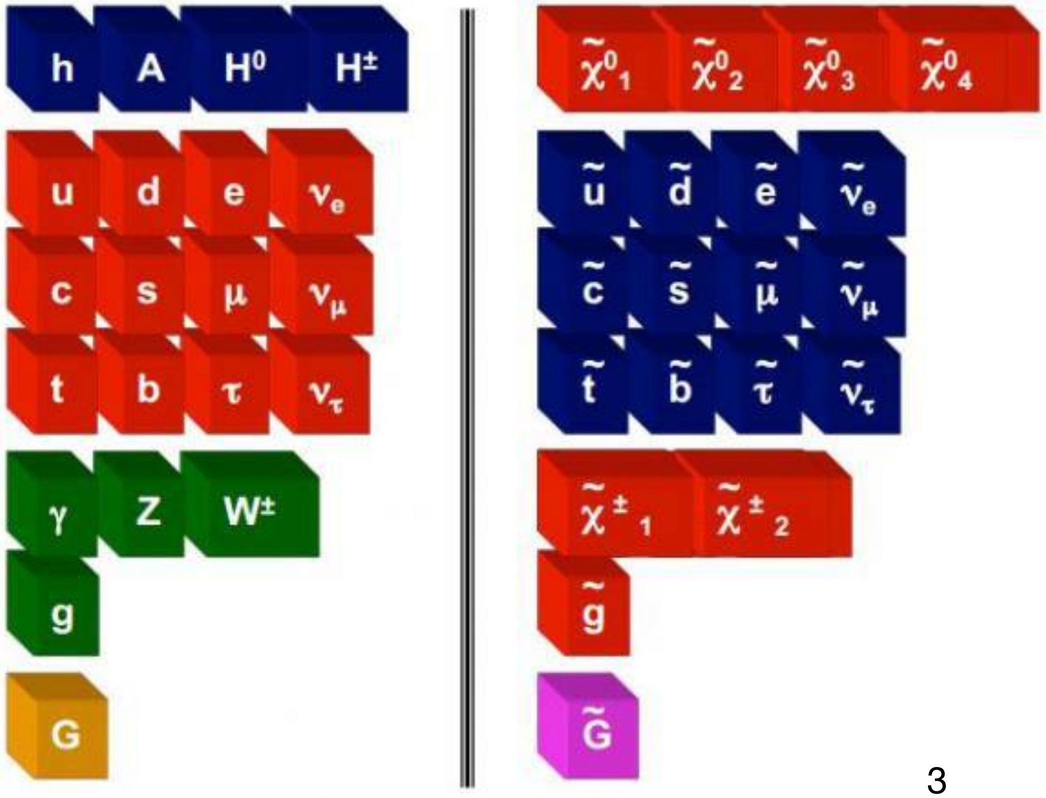
SUSY: a reminder

Supersymmetry (SUSY) is a fermion - bosons symmetry

For each Standard Model (SM) particle, a superpartner exists having the same quantum numbers but the spin.

The MSSM is the Minimal SUSY extensions of the SM (~105 parameters!)





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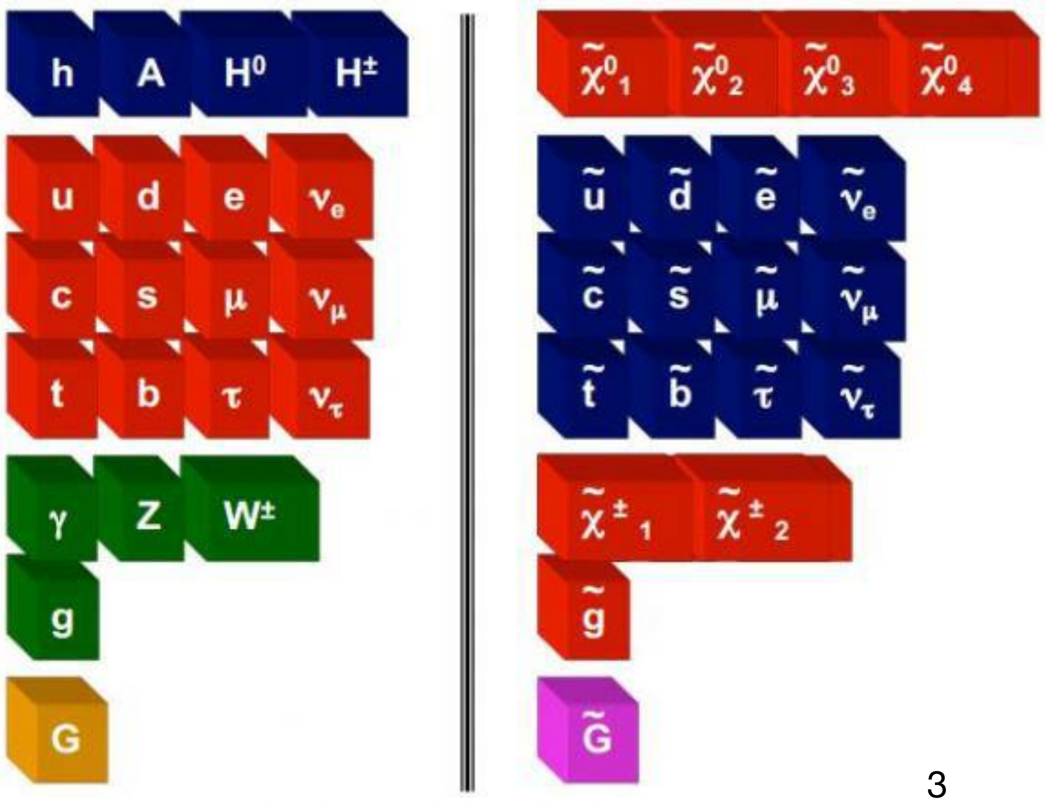

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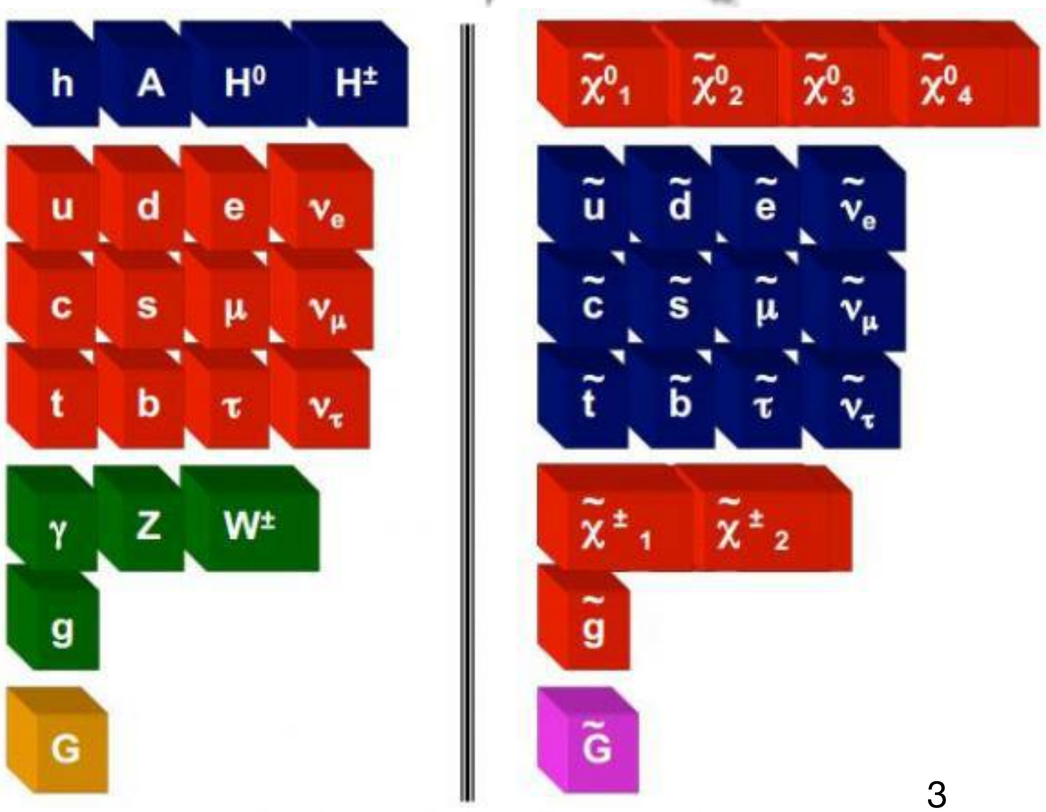
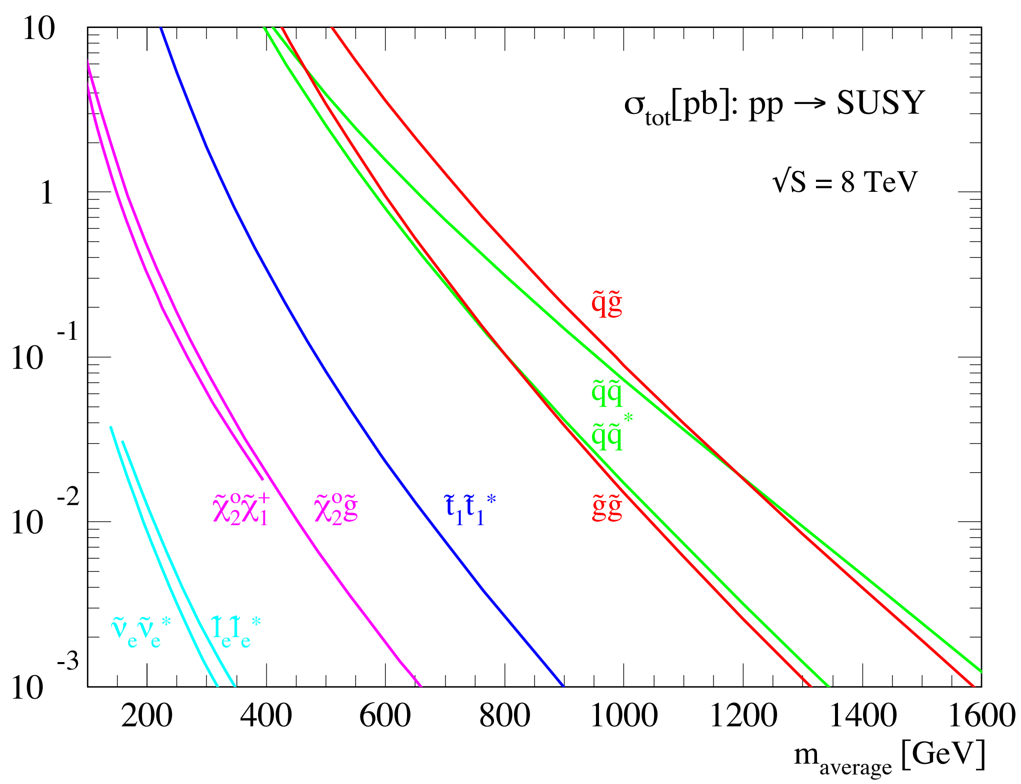
Some SUSY features:

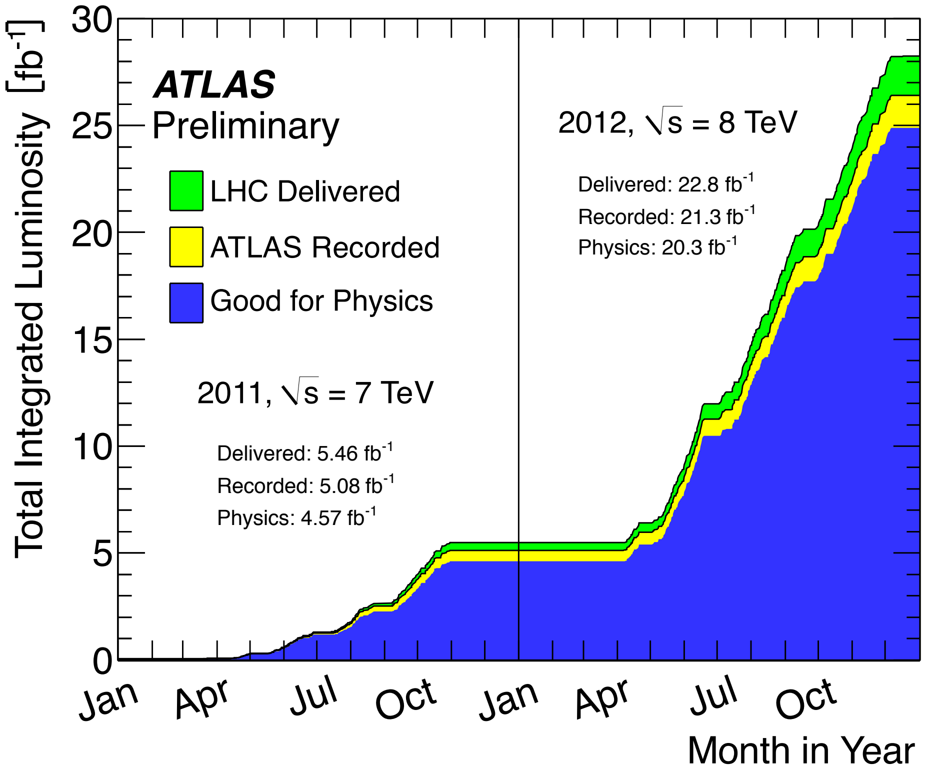
- ✳ Includes the SM as an effective theory
- ✳ Can predict coupling constants unification at GUT scale $O(10^{16})$
- ✳ Can solve the hierarchy problem of the Higgs mass
- ✳ In some scenarios:
  - ✳ R-parity = $(-1)^{3(B-L)+2S}$ is conserved and the Lightest Supersymmetric Particle (LSP) is stable
  - ✳ $\tilde{\chi}^0_1$ is a Dark Matter candidate



SUSY production @ LHC

General approach: reduce number of parameters, simplify models





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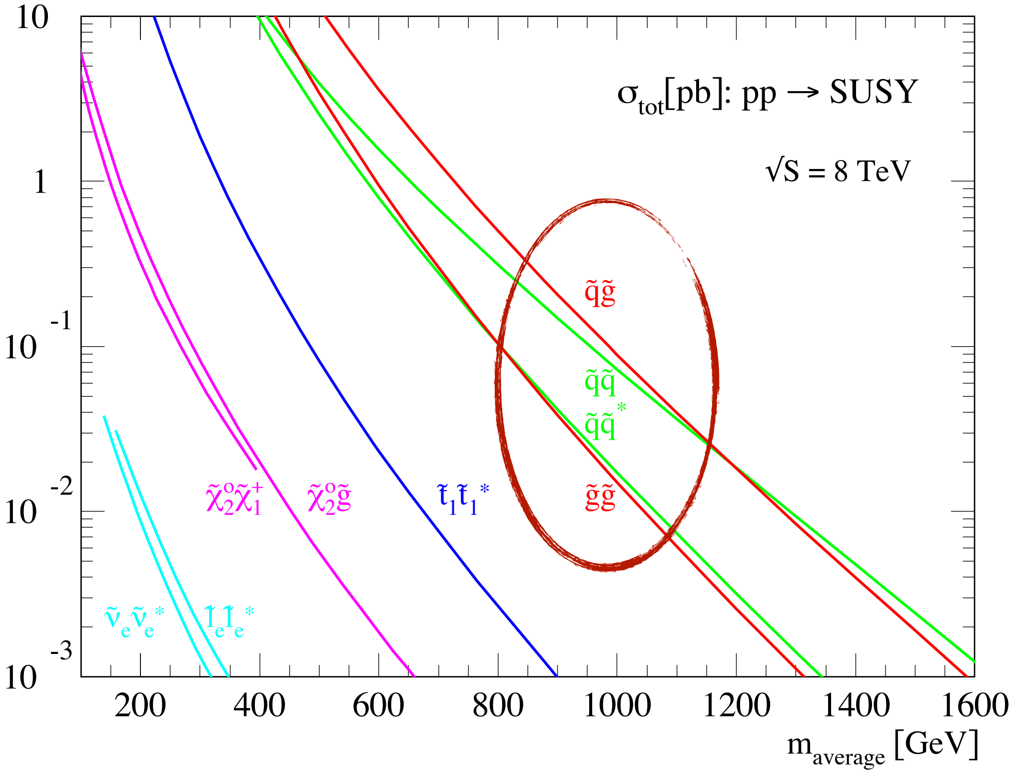
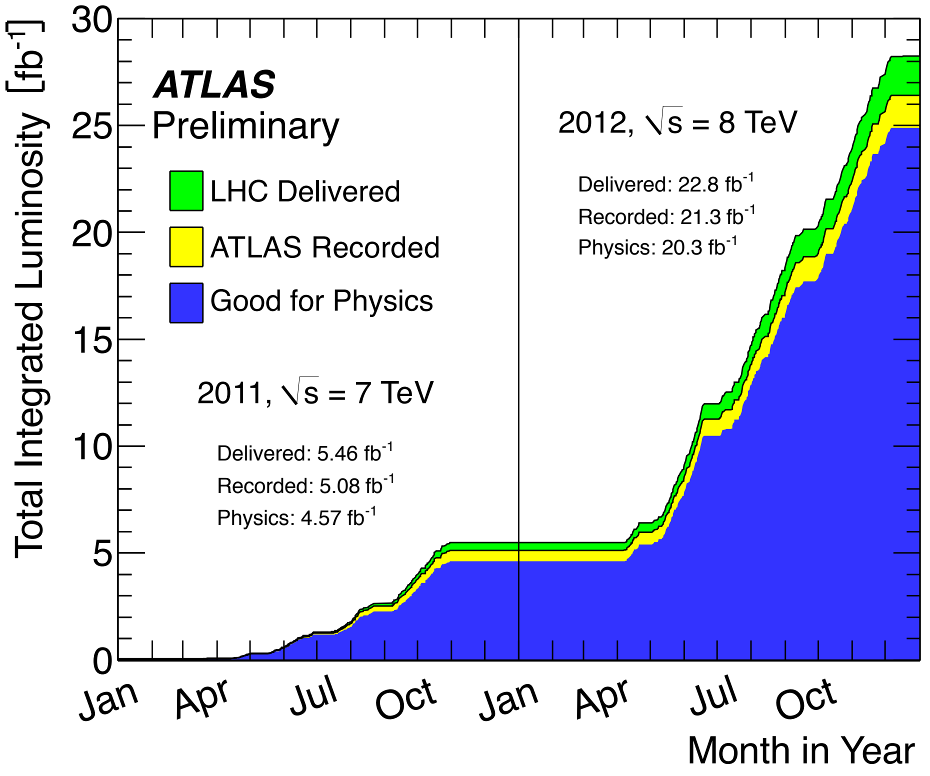


- Highest cross sections dominated by strong production of $\tilde{g}$ and first/second $\tilde{q}$ generation ⟶ early searches focus

- ✴ main SUSY signatures: high-p_T *jets* + Missing Transverse Energy (E_T^{miss}) + (0,1,2+) leptons
- ✴ main SM background: *top, Z+jets, W+jets* events



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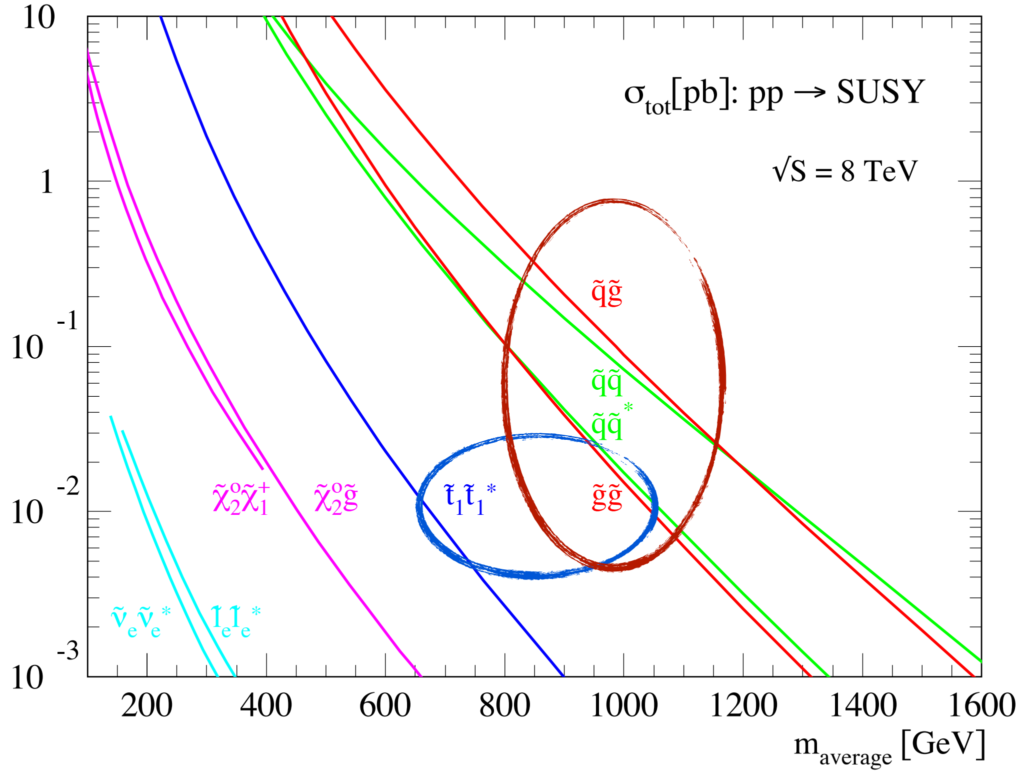

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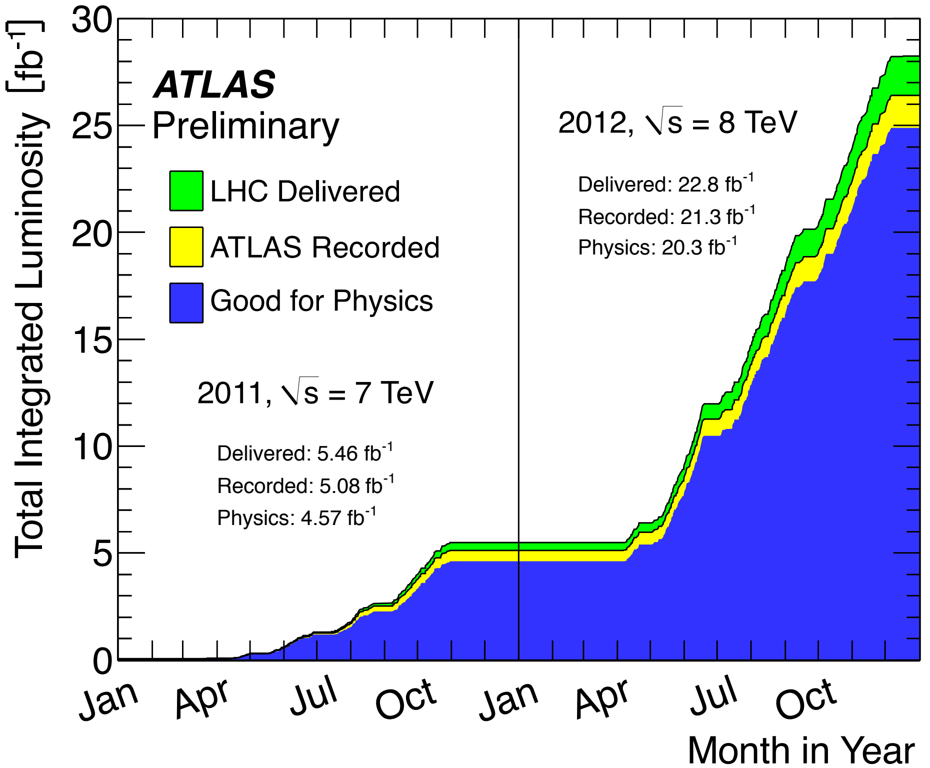
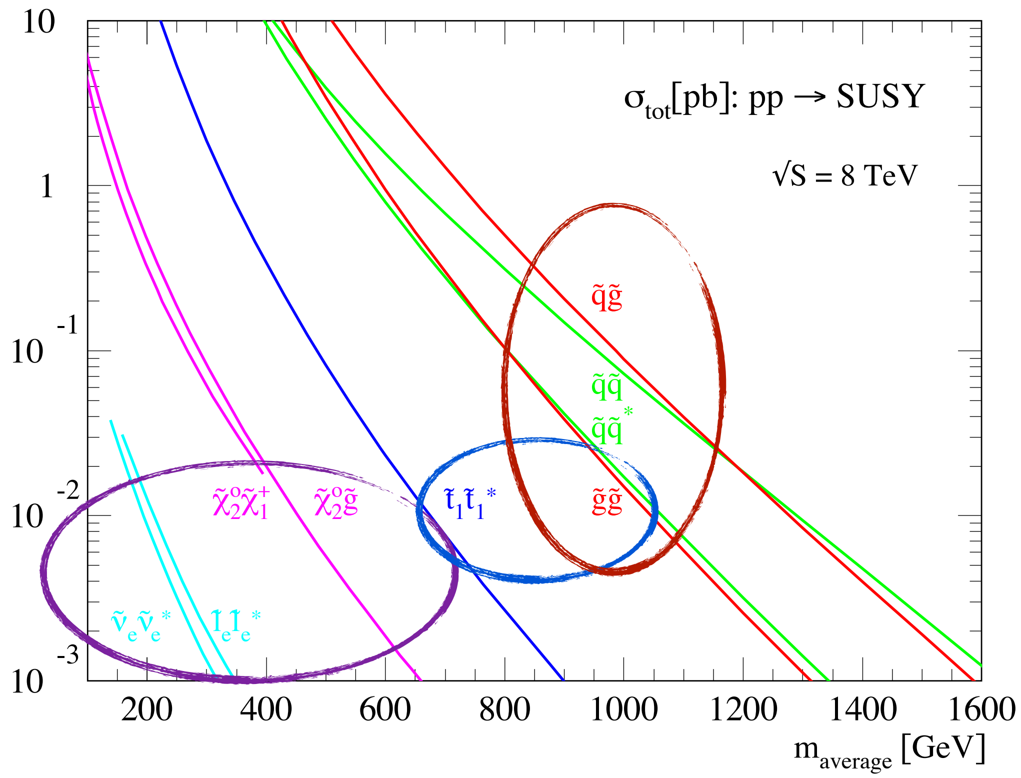


-Third $\tilde{q}$ generation ⟶ major LHC focus

- ✶ need to be light for naturalness argument
- ✶ main SUSY signatures: *b-jets* + E_T^{miss} +leptons
- ✶ main SM background: *top* events

SUSY production @ LHC

General approach: reduce number of parameters, simplify models



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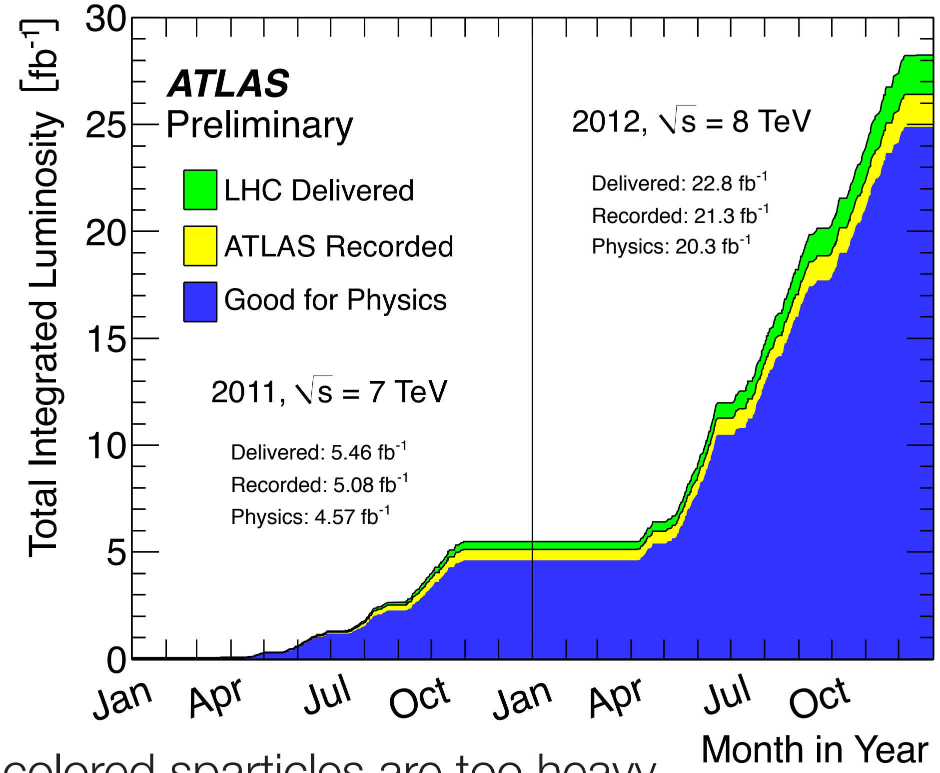

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✶ need to be light for naturalness argument

✶ main SUSY signatures: *b-jets* + E_T^{miss} +leptons

✶ main SM background: *top* events

- ElectroWeak (EW) production ⟶ high luminosity focus

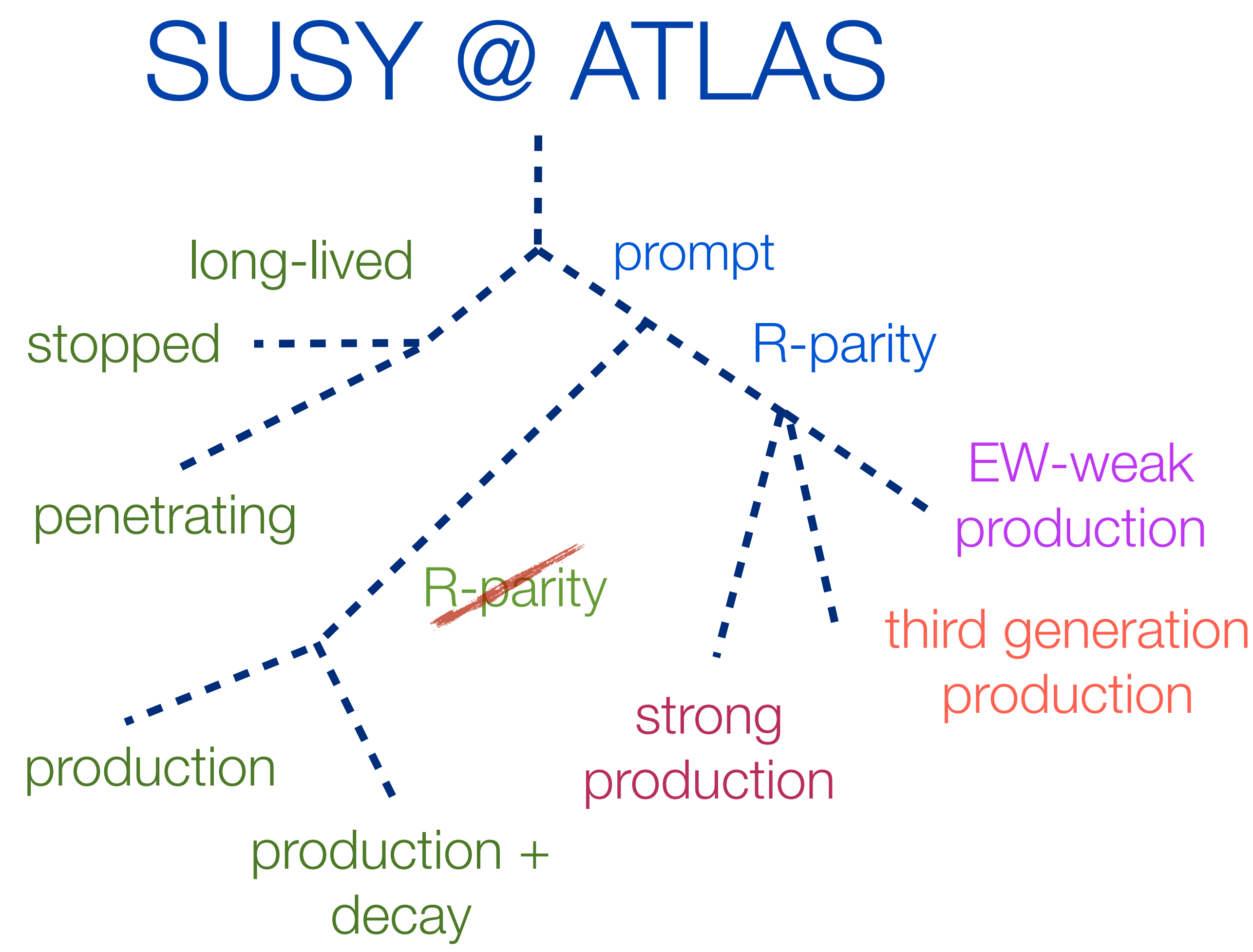
✶ low cross sections but can be the dominant production mechanism if colored sparticles are too heavy

✶ different signatures depending on gauginos composition and sleptons masses

✶ multi-lepton + E_T^{miss} signatures : very low SM background

ATLAS SUSY searches

- Search strategy designed to cover broad spectra of different SUSY models
- For every search: signal regions are optimized individually based on the variety of the models/decay chains
- Assume 100% BR for the simplified model grids



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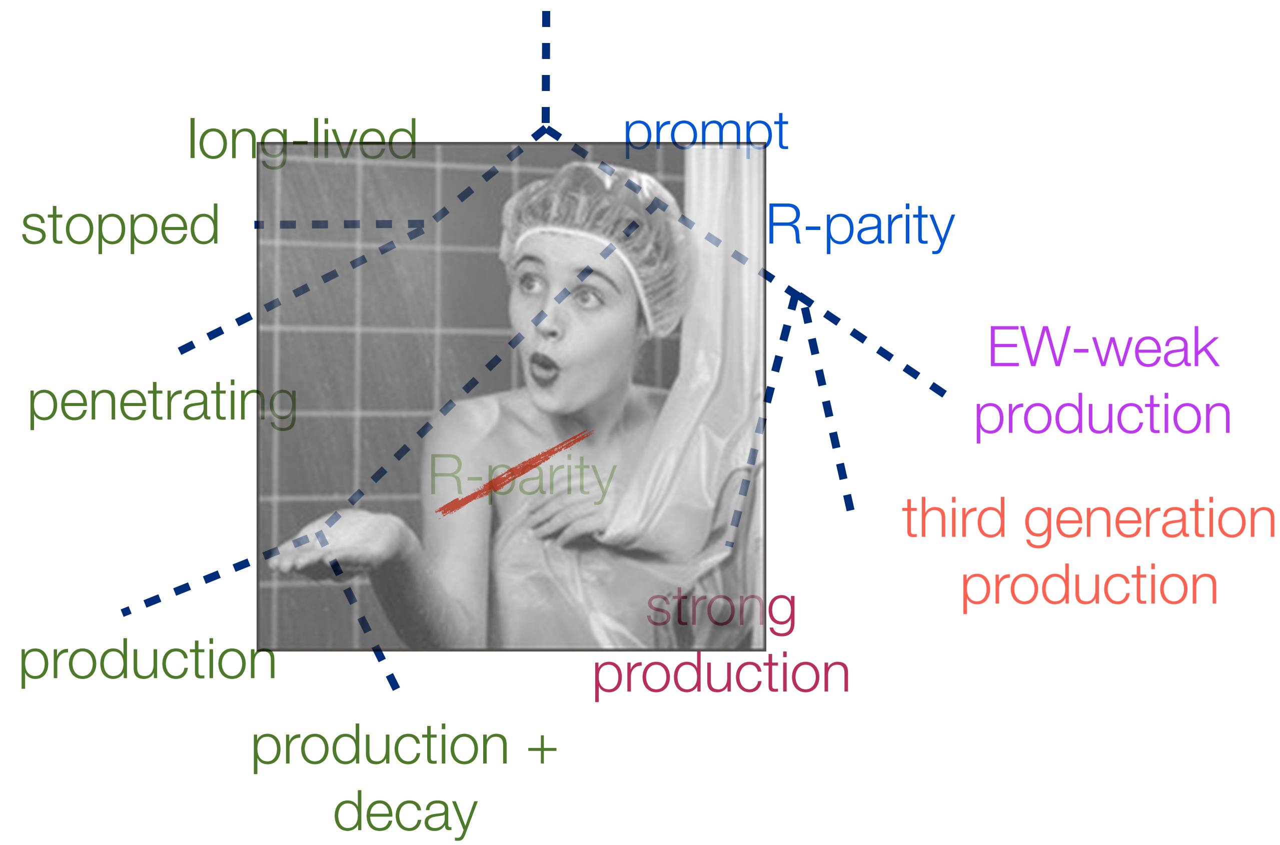

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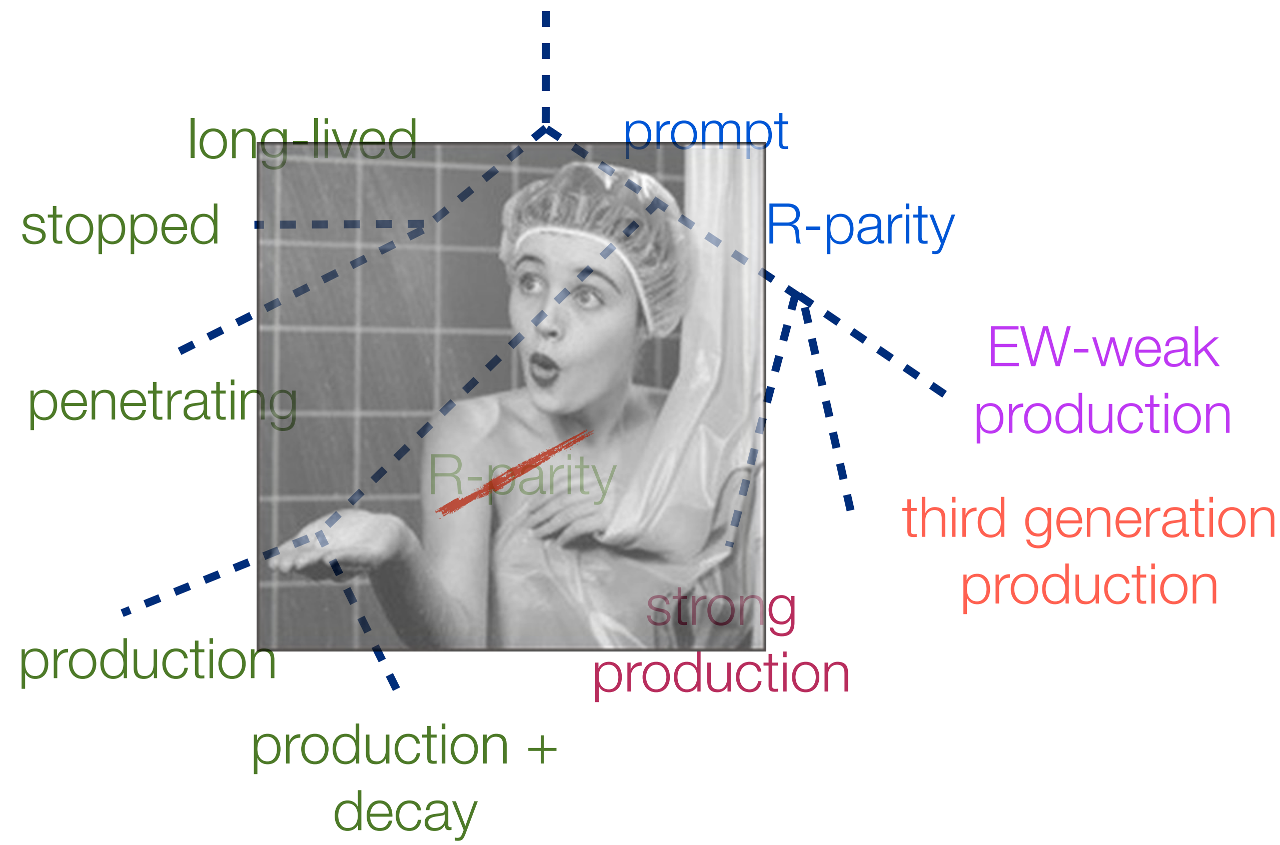
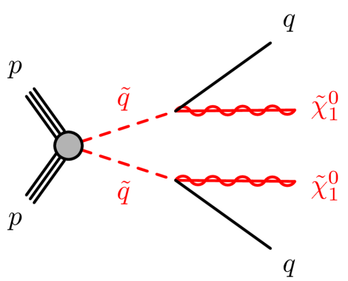


Notes:

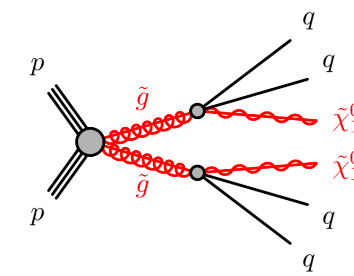
- I will not be able to cover all the ATLAS SUSY analysis, so I will focus on latest (2013/2014) results: please visit our ATLAS SUSY Public Results page for further info
- All limits quoted are at 95%CL

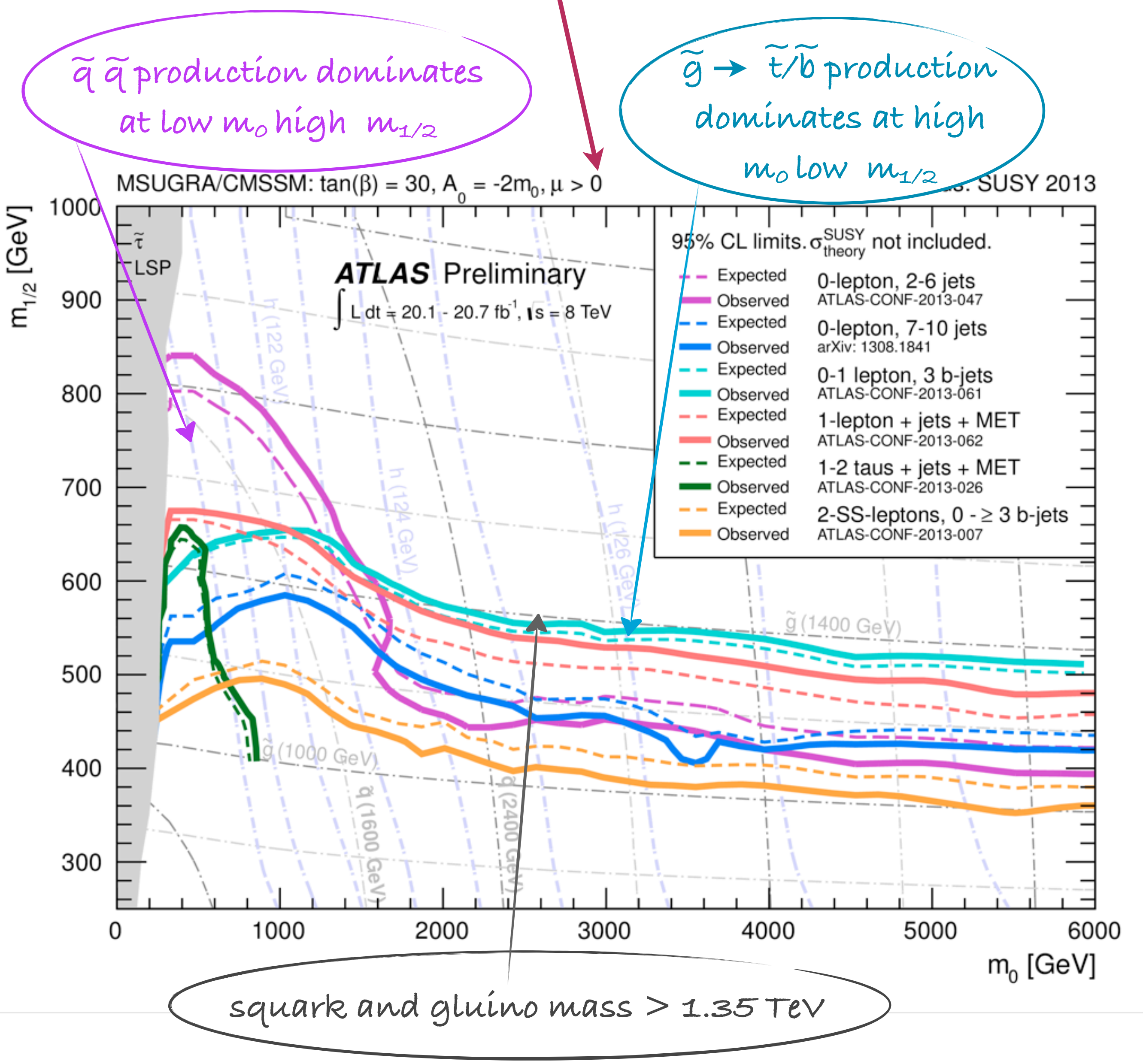
Inclusive strong production



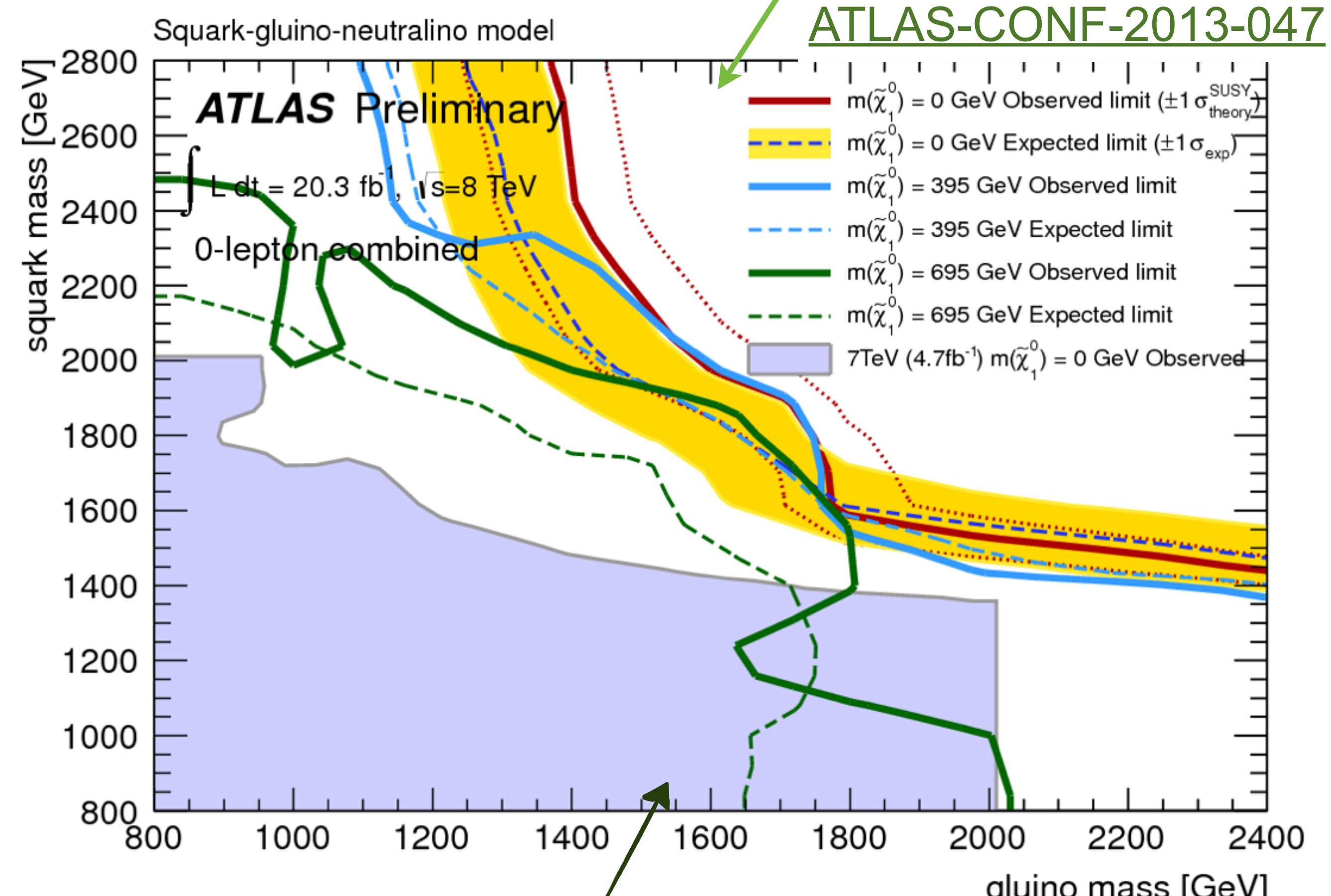
Large yield expected due to high cross sections

Results interpreted within many different SUSY models: Higgs aware constrained models (mSUGRA/CMSSM, GMSB, pMSSM, mUED), simplified models (pMSSM)





ATLAS-CONF-2013-047



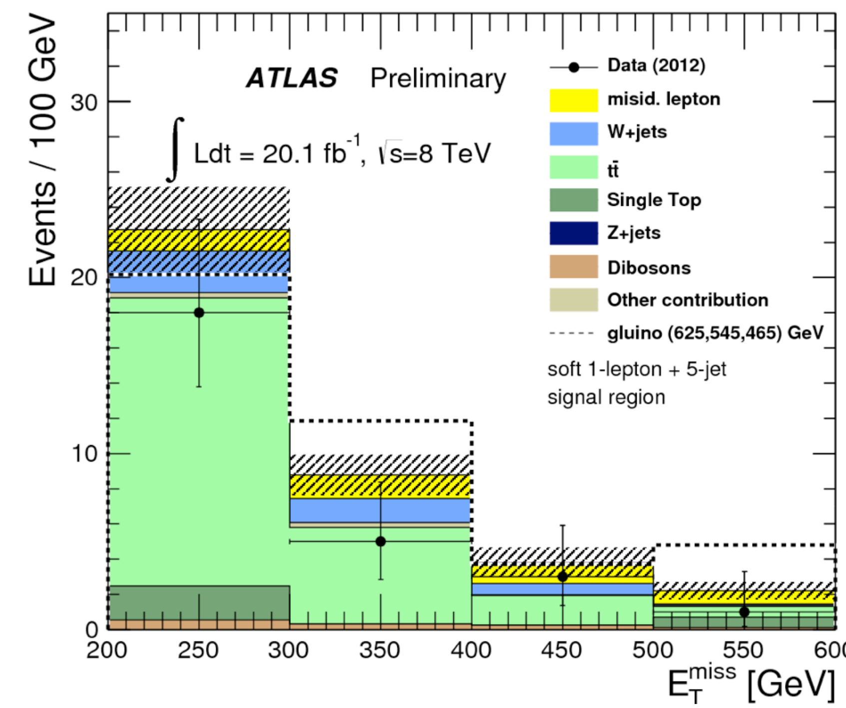
- Only strong production of gluinos and 1st and 2nd generation of squarks (of common mass) with direct decay to the LSP ($\tilde{\chi}^0_1$)
- 10 Signal Regions with different requirements (jets multiplicity, E_T^{miss}..) combined: lines show the best results

$1\ lepton + [3\text{-}6]\ jets + E_T^{miss}$

ATLAS-CONF-2013-062

Mostly targeting pair production of gluinos or squarks (1st and 2nd generation , mass degenerate)

Leptonic decays of $\tilde{\chi}^0_2$, $\tilde{\chi}^\pm_1$, sleptons, sneutrinos directly or through intermediate steps



1-Lepton selection:

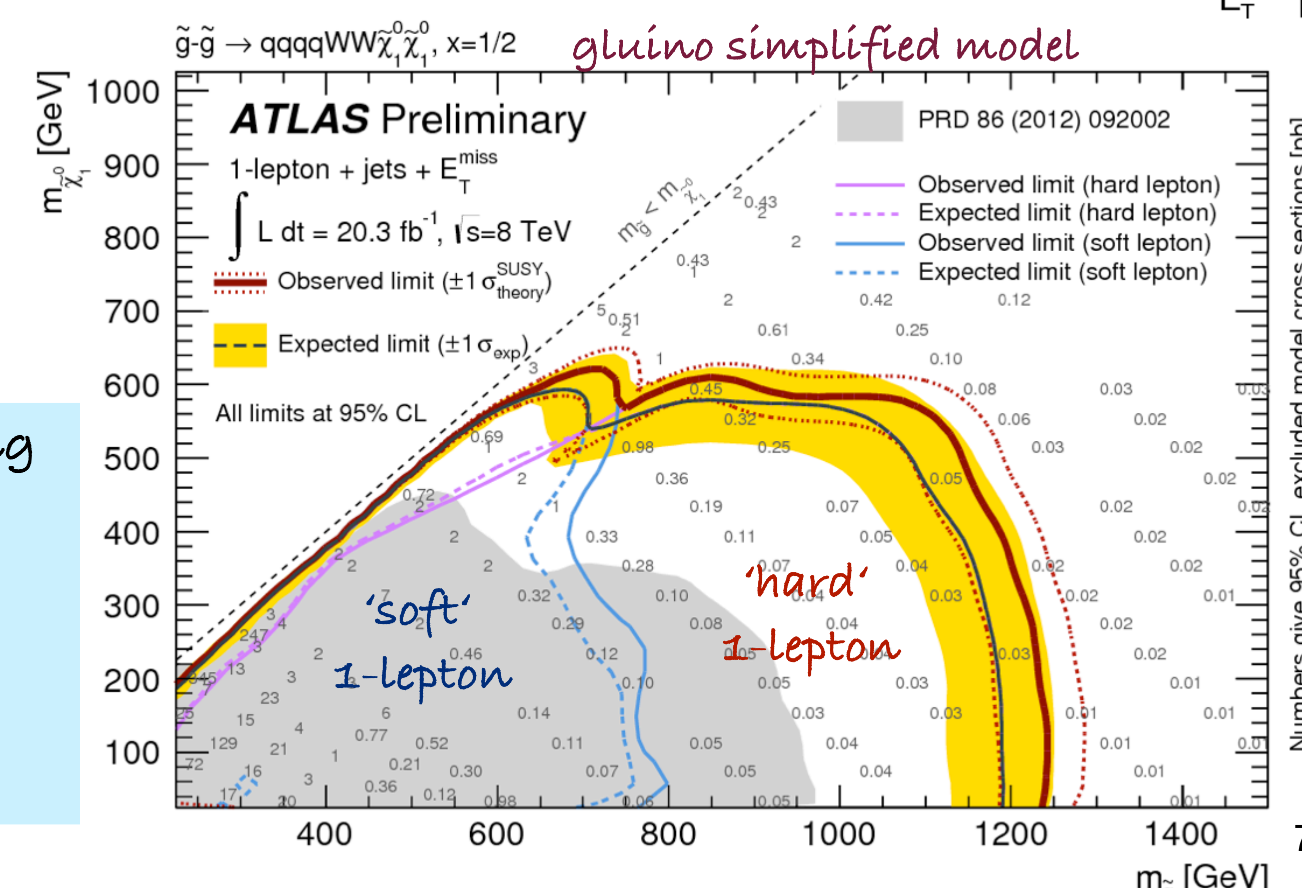
- 'Soft': p_T in range [6-25] GeV, to recover sensitivity for compressed scenarios.
- 'Hard': p_T > 25 GeV, targeting *gluinos* and *squark* production.

Background:

- *MAIN*: $t\bar{t}$ and *W/Z+jets* events (estimated from data in Control Regions (CR))
- misidentified-lepton background estimated from data (matrix method)

No excess is observed

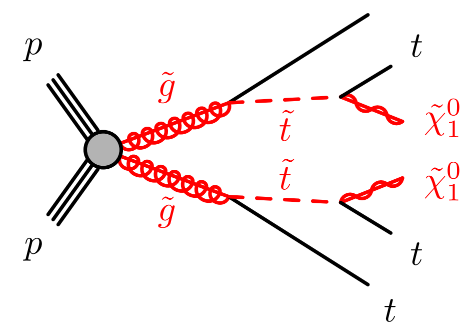
- Soft single-lepton analysis: extremely powerful along the diagonal (gluino /squark and the lightest neutralino nearly mass degenerate), gluino mass excluded up to 700 Gev.
- Hard-lepton analysis: gluino mass up to 1.18 TeV excluded



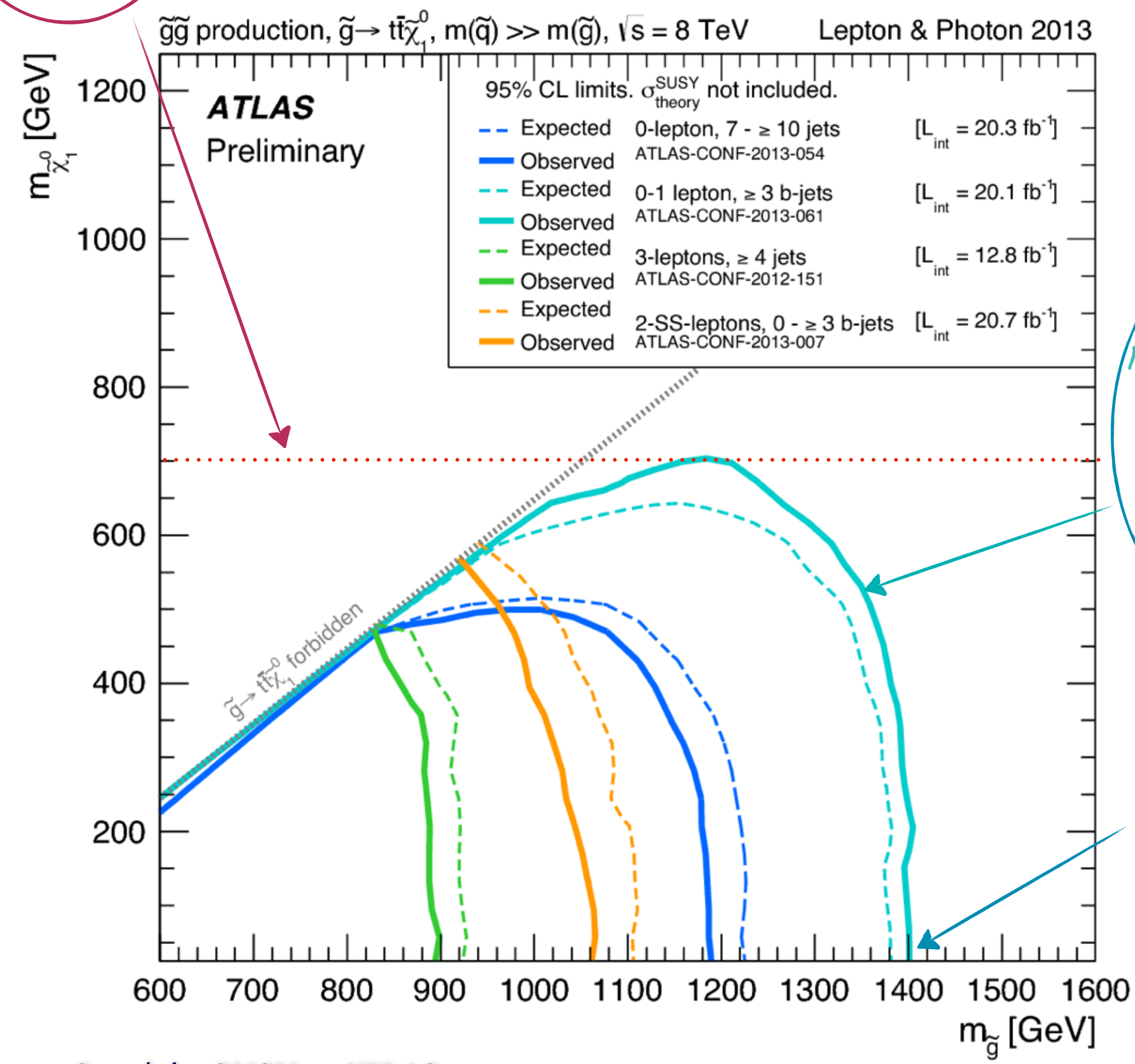
Third generation: *stop*

Results mainly interpreted in the natural SUSY framework, where:

- 1[st] and 2[nd] generation squarks are allowed to be very heavy
- $\tilde{t}/\tilde{b}$ produced via light $\tilde{g}$ *or* directly

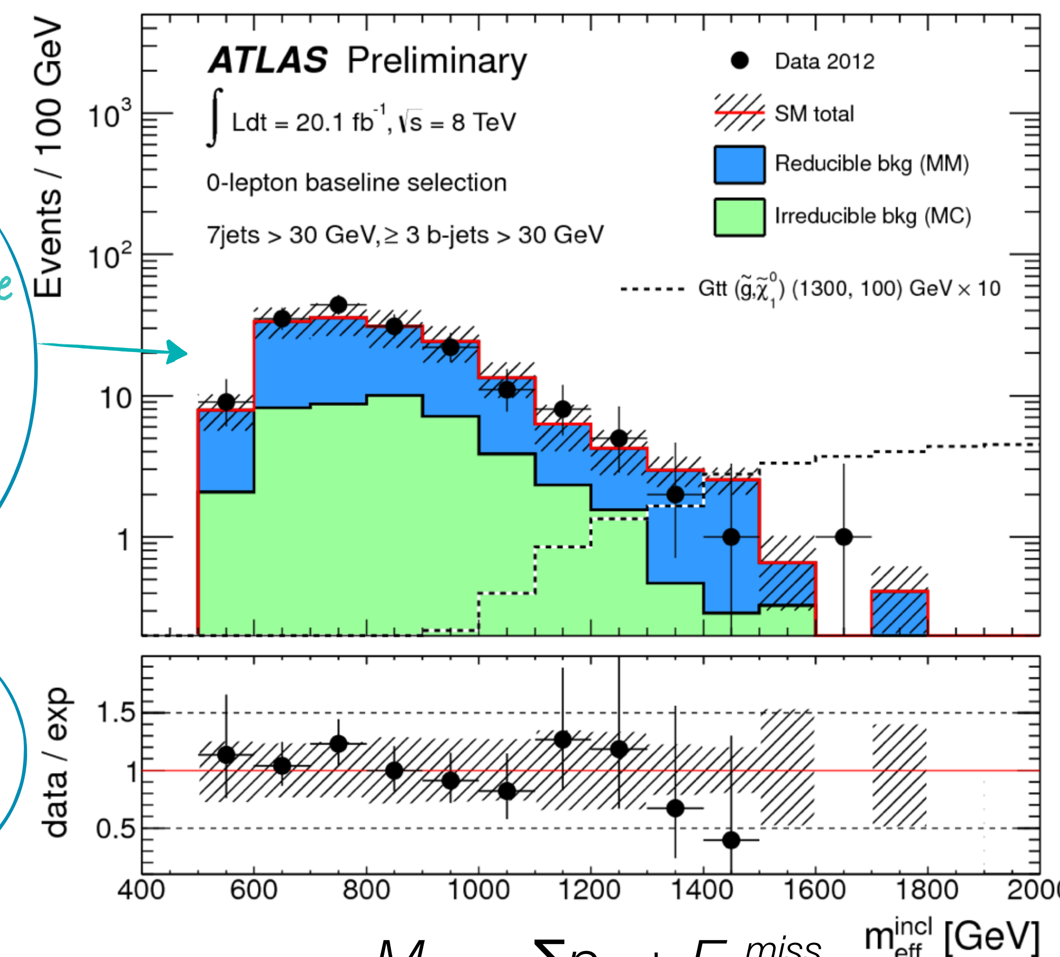


No exclusion for m(LSP) > 700 GeV



Most sensitive channel: ≥ 3 b-jets + 0-1 lepton + E_T^{miss}

m($\tilde{g}$) excluded below 1.4 TeV



$M_{eff} = \Sigma p_T + E_T^{miss}$

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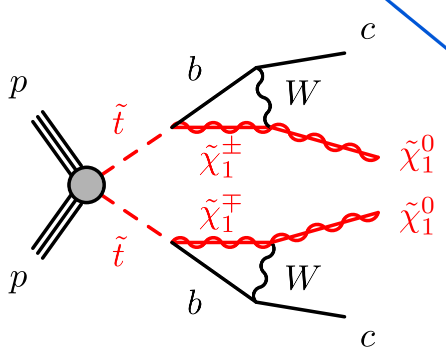
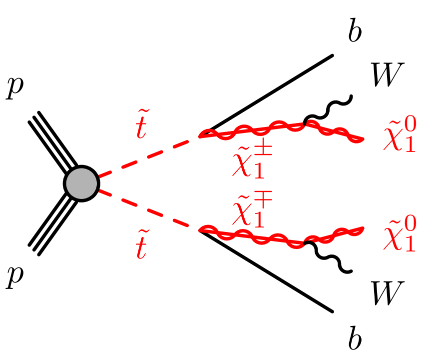
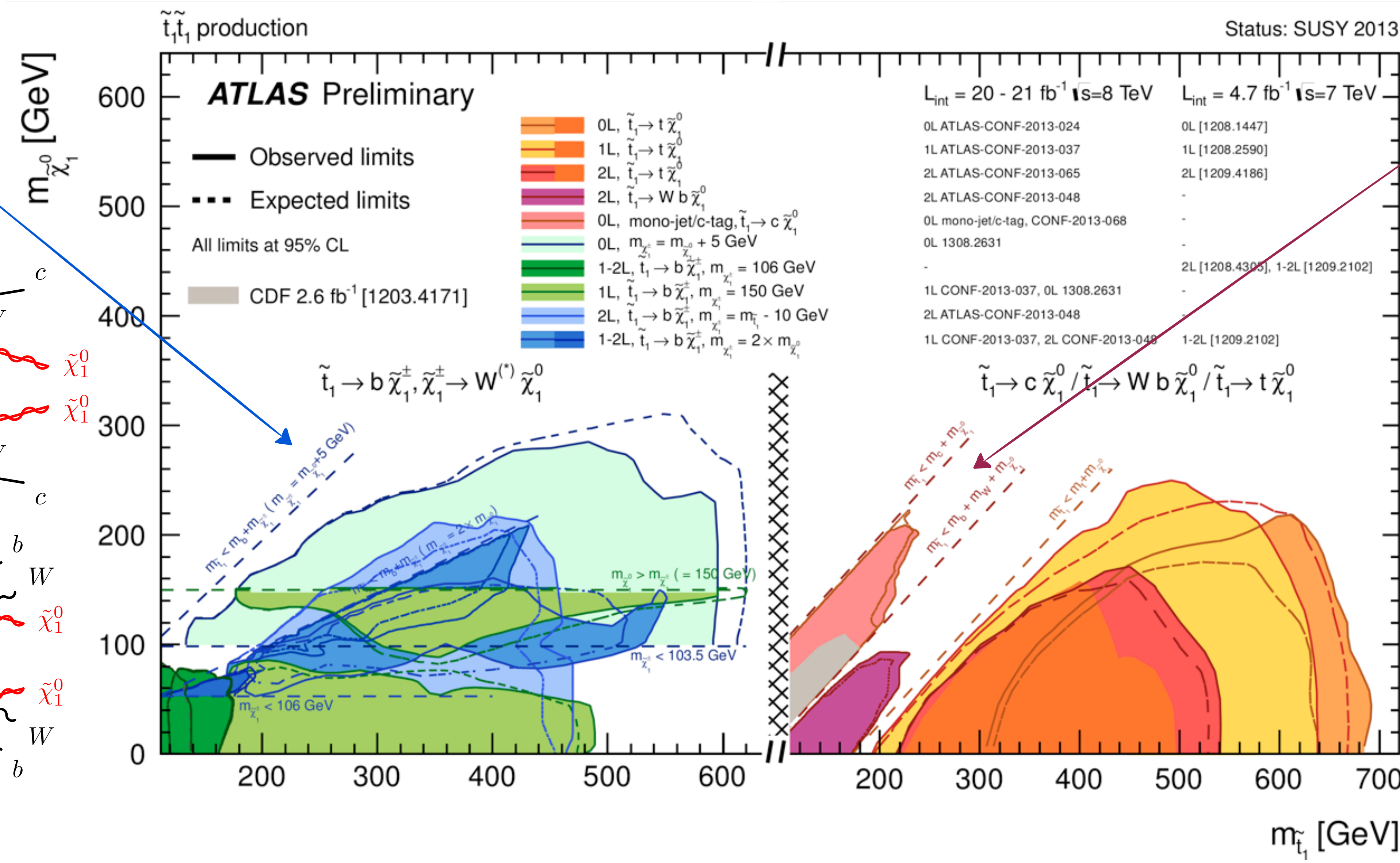
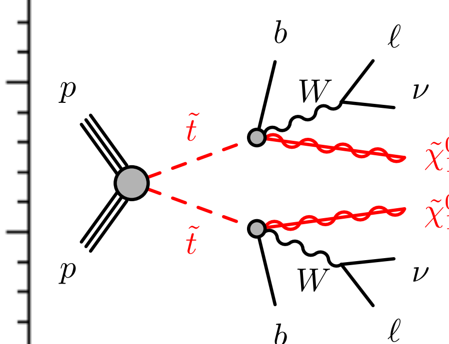
Limits depend on chargino-neutralino mass splitting

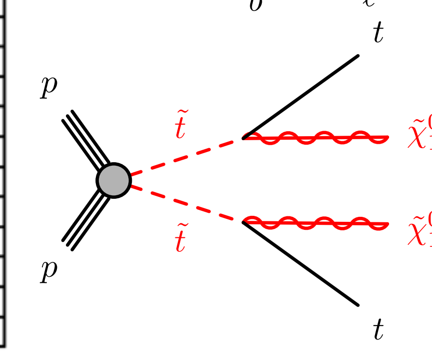
First LHC SUSY search with charm tagging











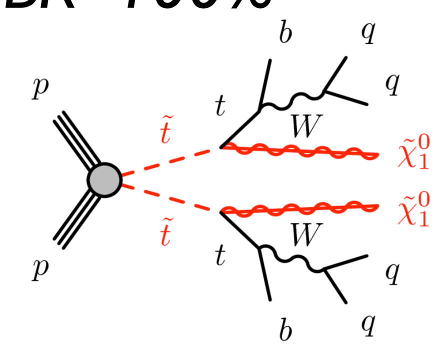
E_T^{miss} + *jets stop* search (1/2)

ATLAS-CONF-2013-024

Search for top squark in $t\bar{t}$ + E_T^{miss} events, where $\tilde{t} \rightarrow t + \tilde{\chi}^0_1$ (LSP) with BR=100%

Consider only final state where both top quarks decay hadronically

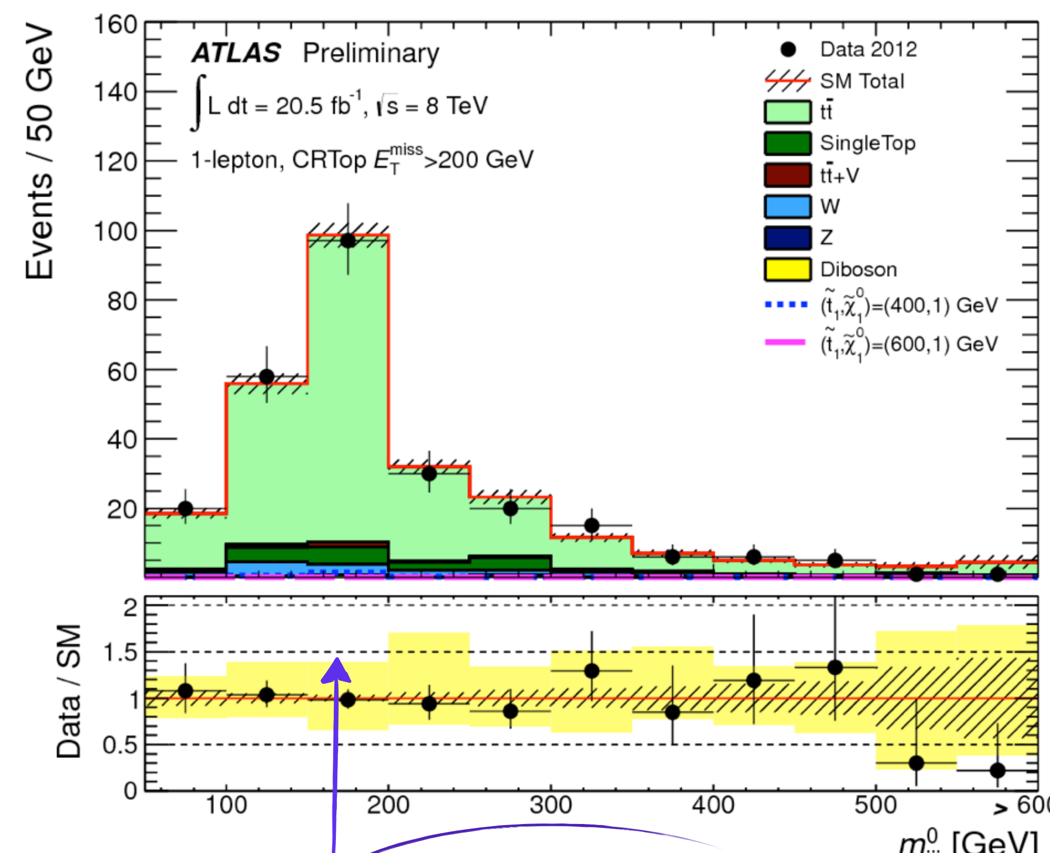
Signature is 6 jets, of which >=2 b-jets, and significant E_T^{miss}



Signal selection:

- E_T^{miss} **trigger**
- **veto events with** μ, e.
- **veto fake** E_T^{miss} **events**
- **Veto events if** E_T^{miss} **and** ***b-jets*** **are consistent with semi-leptonic** $t\bar{t}$
- **Veto events if a** ***jet*** **close to** E_T^{miss} **is consistent with hadronic τ**
- **6** ***jets*** p_T **> 80,80,35,...,35 GeV**
- $\min\left|\Delta\phi\left(\text{jet}^{0-2}, E_T^{miss}\right)\right| > 0.2\,\pi$
- $80\text{ GeV} < m^0_{jjj},\ m^1_{jjj} < 270\text{ GeV}$
- $m_T\left(b_{\min[\Delta\phi(b,E_T^{miss})]}, E_T^{miss}\right) > 175\text{ GeV}$
- $E_T^{miss,track} > 30\text{ GeV and } \left|\Delta\phi\left(E_T^{miss}, E_T^{miss,track}\right)\right| < \frac{\pi}{3}$

3 Signal regions: E_T^{miss} > 200,300,350 GeV



Semileptonic $t\bar{t}$ CR
Lepton treated as jet

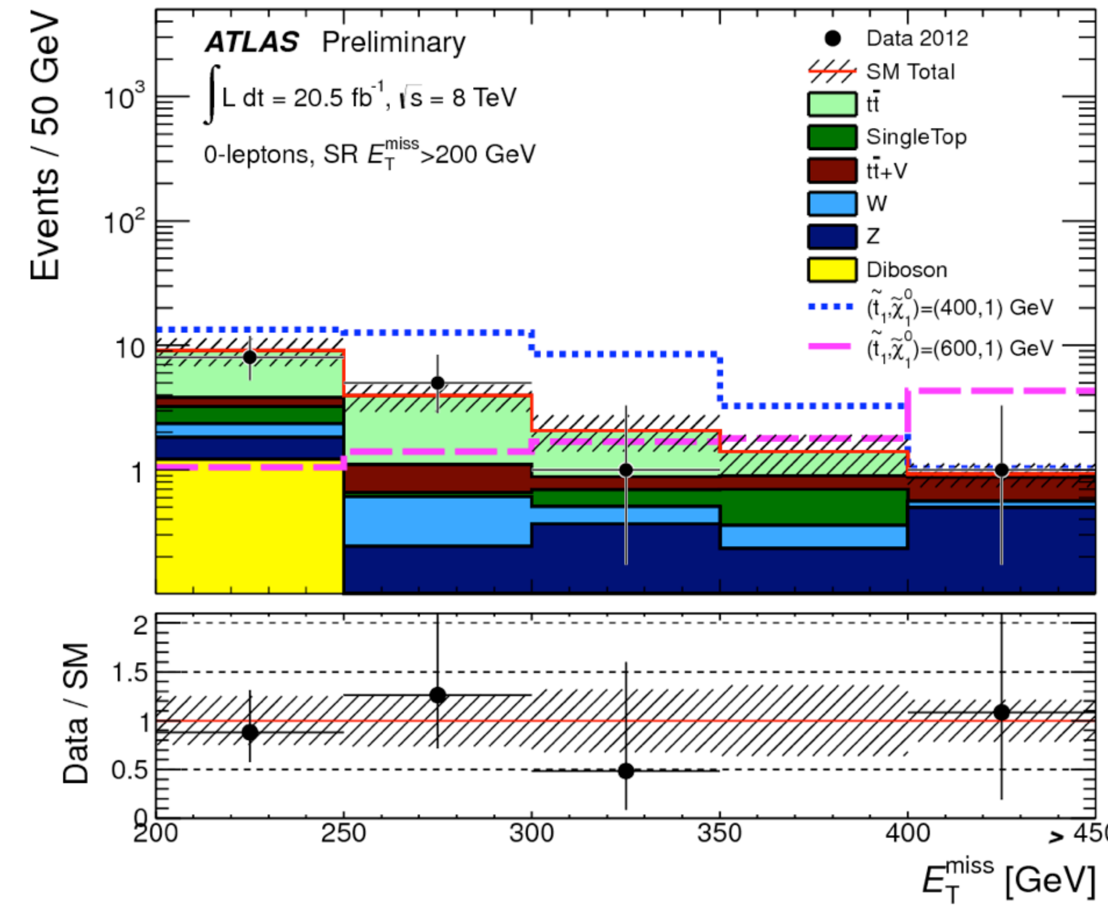
E_T^{miss} + *jets stop* search (2/2)

Control regions defined for important backgrounds:

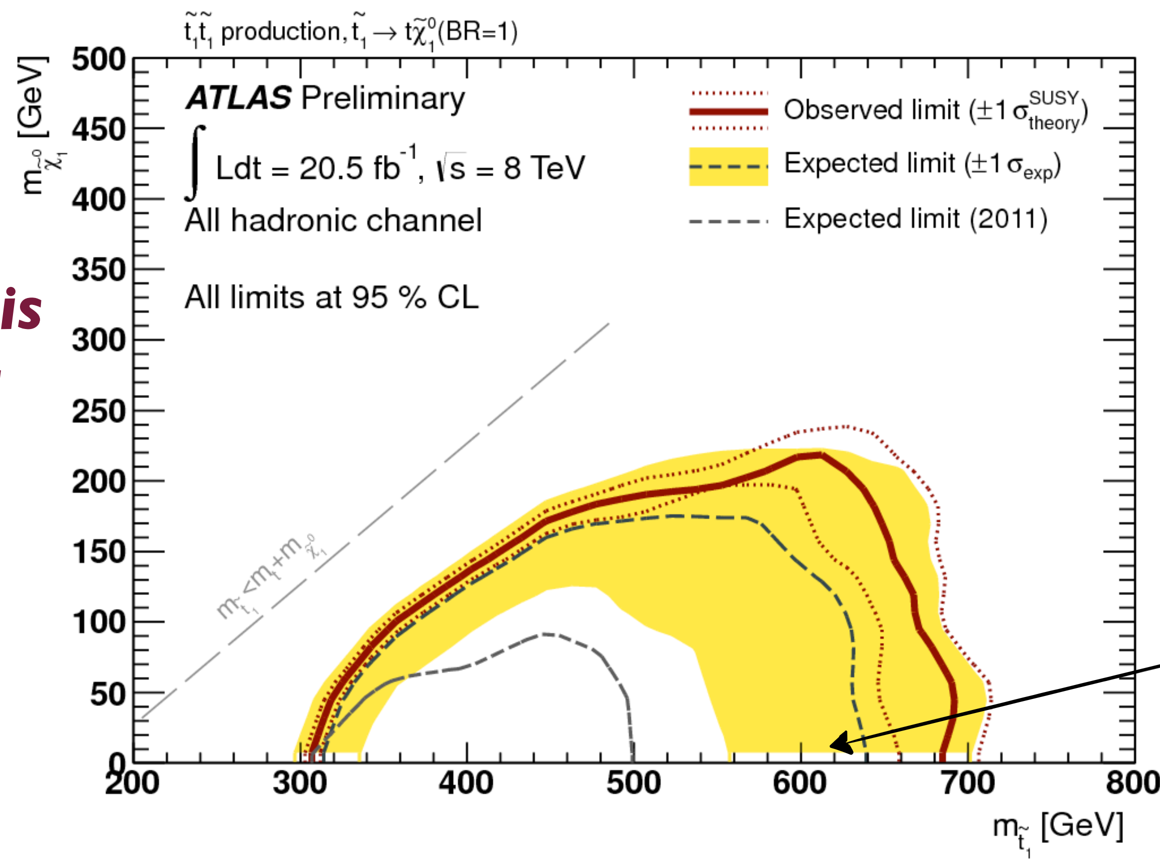
- Semileptonic $t\bar{t}$+ *jets* - hadronic τ or low p_T e/μ
- $Z \rightarrow \nu\nu$ + *jets*
- Multijets - E_T^{miss} coming from mis-measured jets

Single top, $t\bar{t}$+V and diboson estimated from MC

Simultaneous fit to each of the Signal and $t\bar{t}$ Control Regions is performed to extract the final limit.

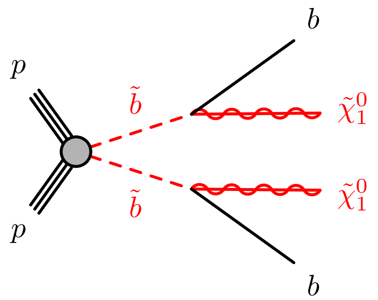


No excess is observed



$\tilde{t} \rightarrow t\,\tilde{\chi}^0_1$ excluded for masses in the range [320, 660] GeV for a massless LSP

Third generation: *sbottom*



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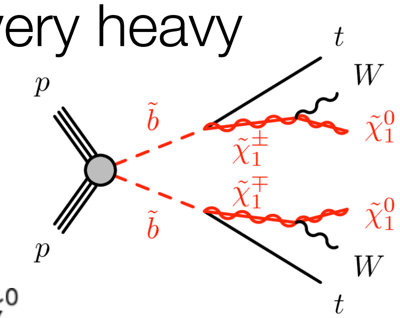

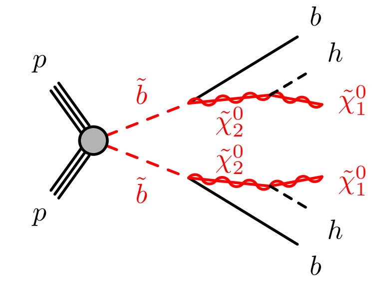

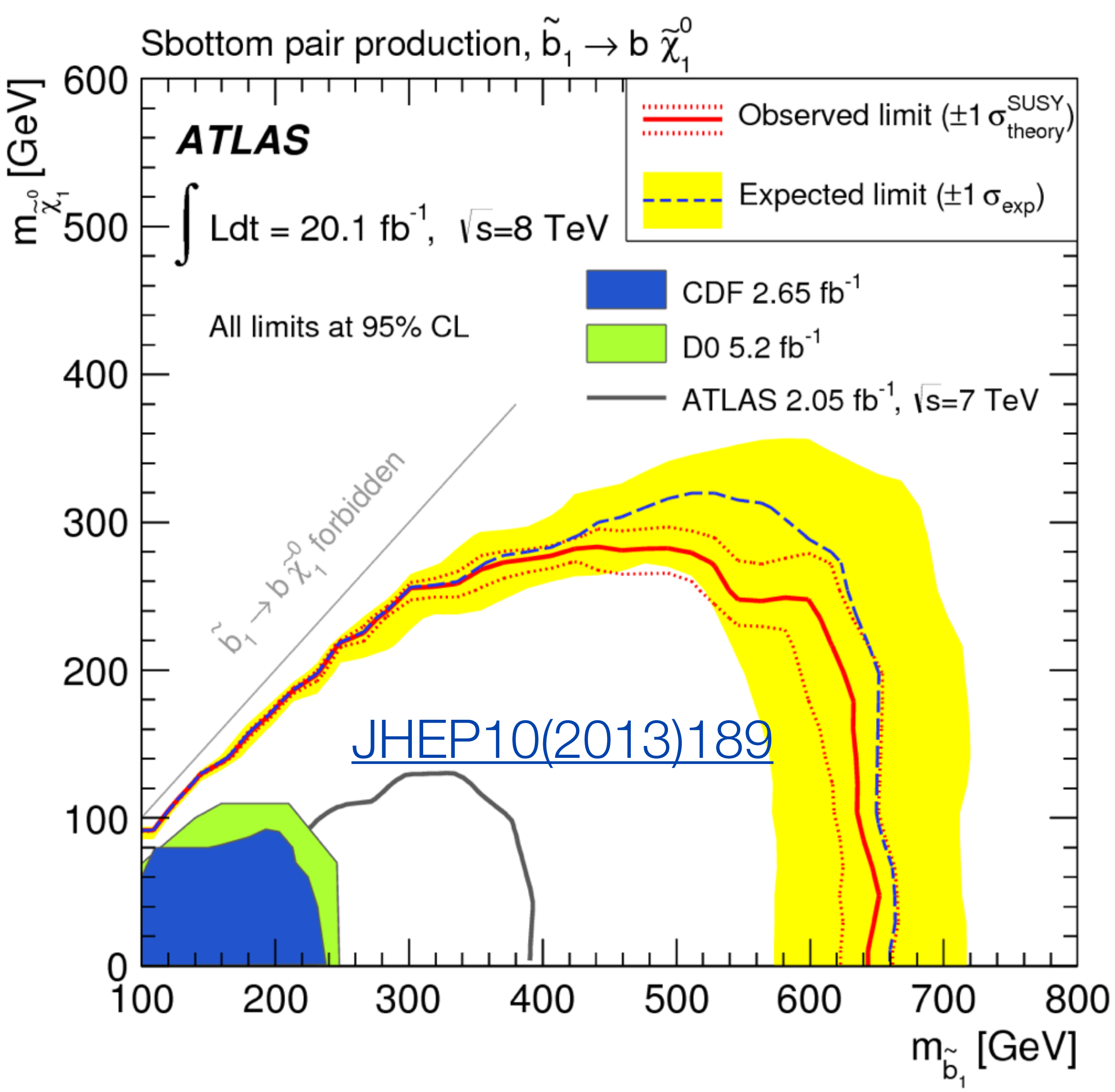

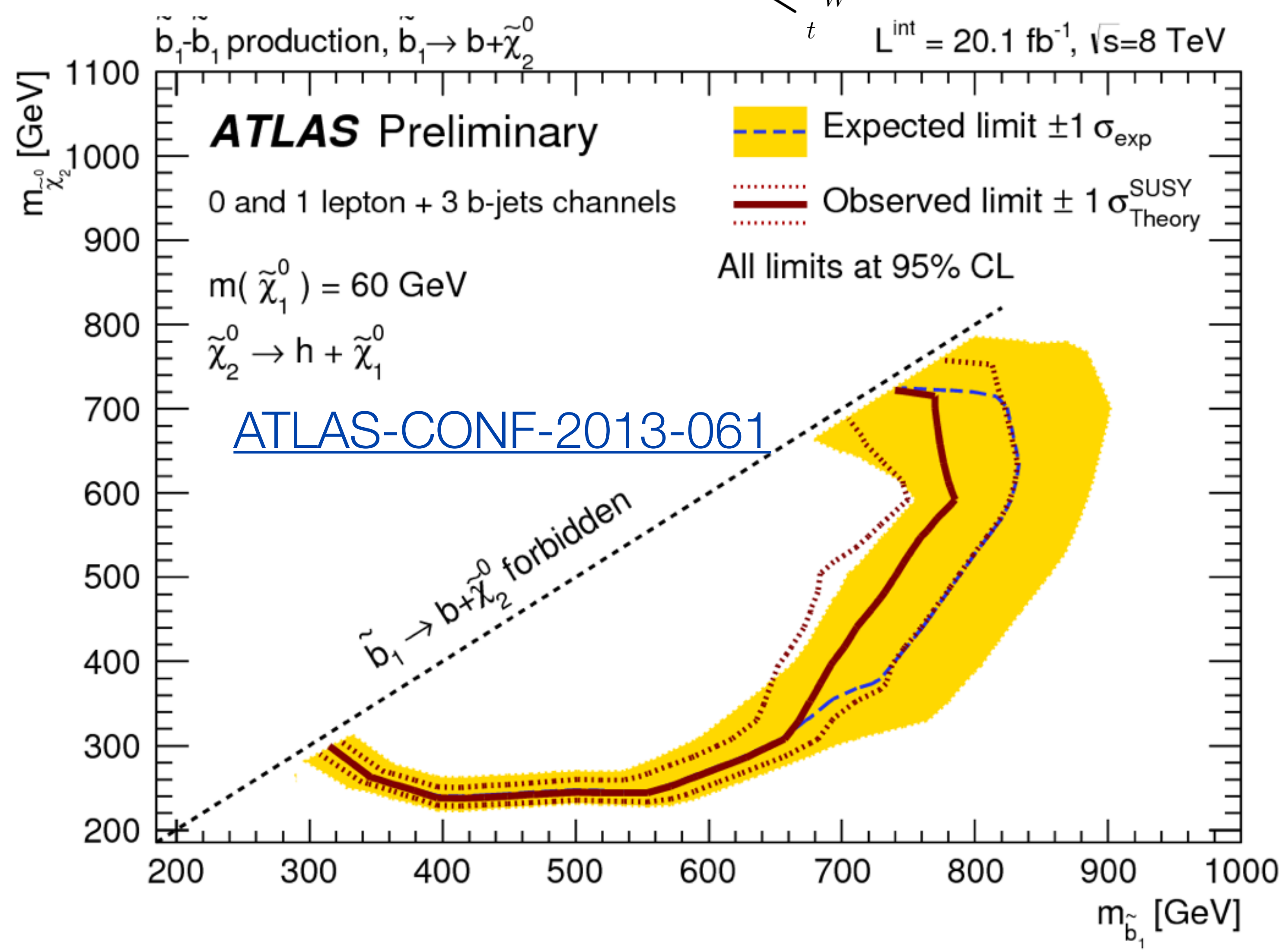

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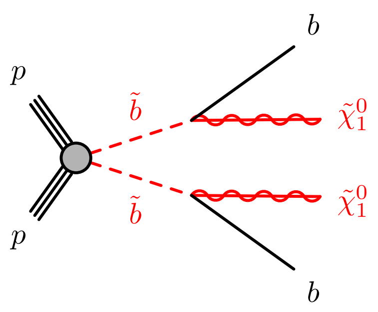

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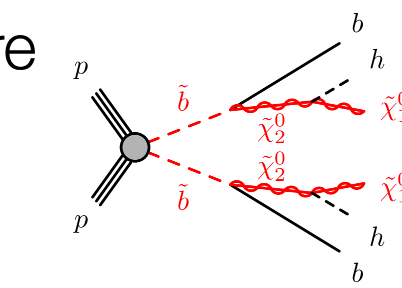
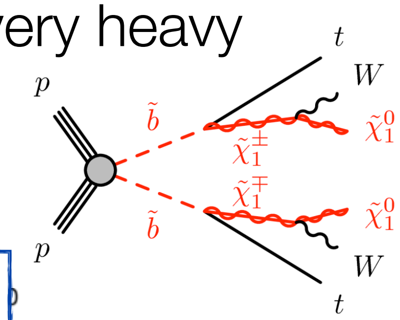
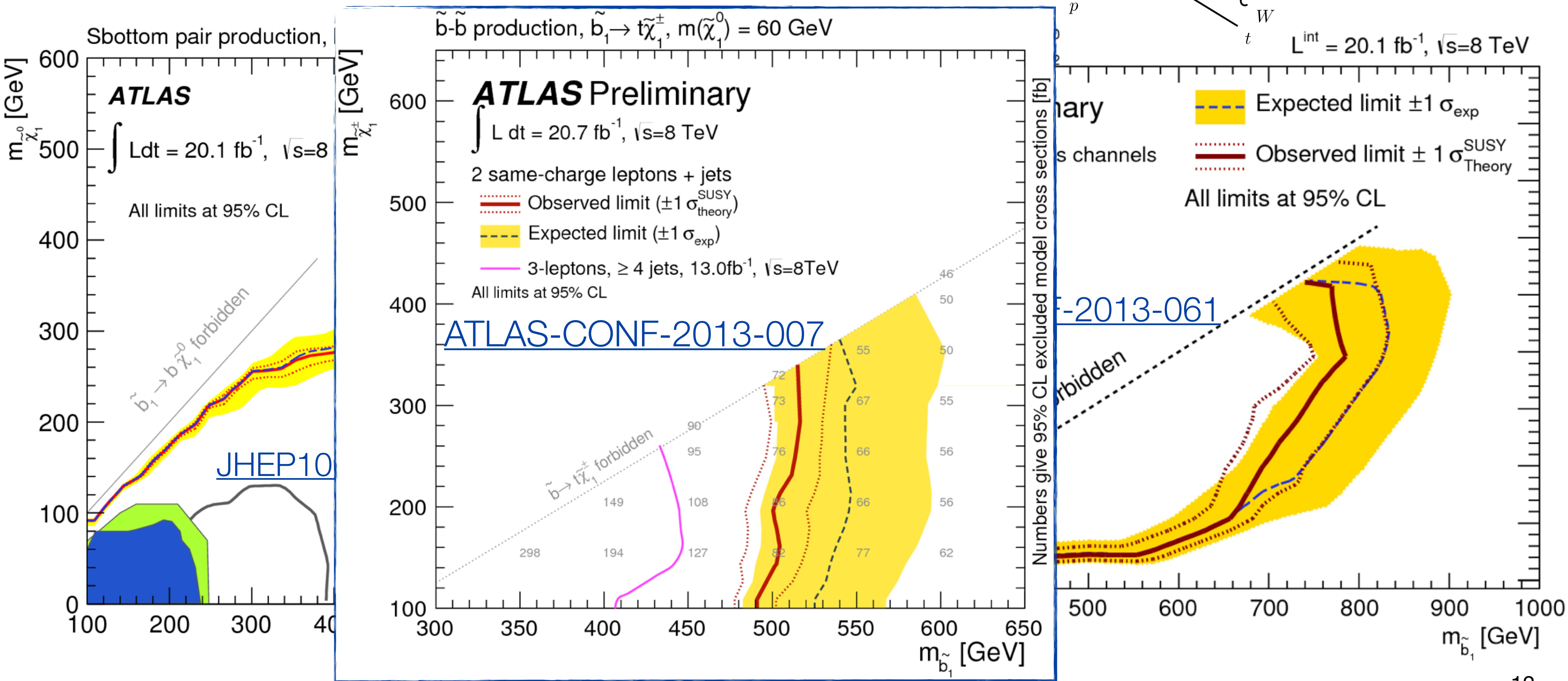




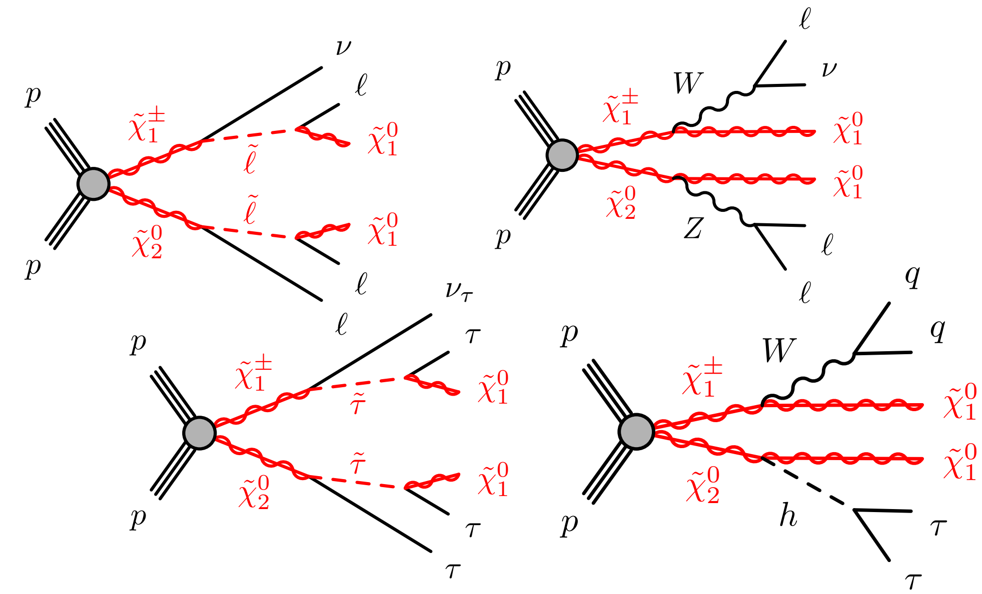


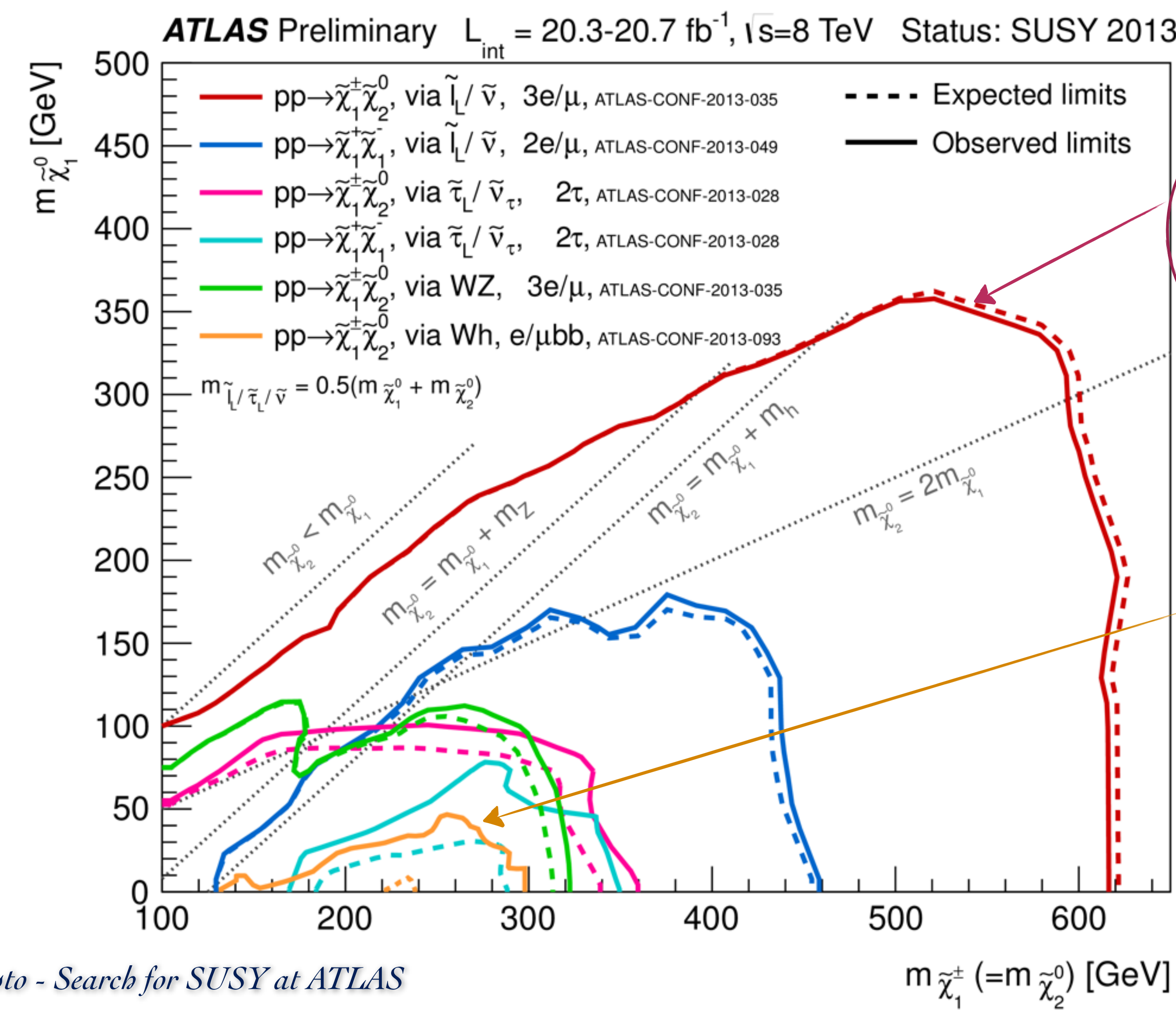
EW production

Occurs via intermediate W, Drell-Yan processes or intermediate sleptons

Search strategy depends on the slepton masses, gauge mixture and masses of charginos/ neutralinos

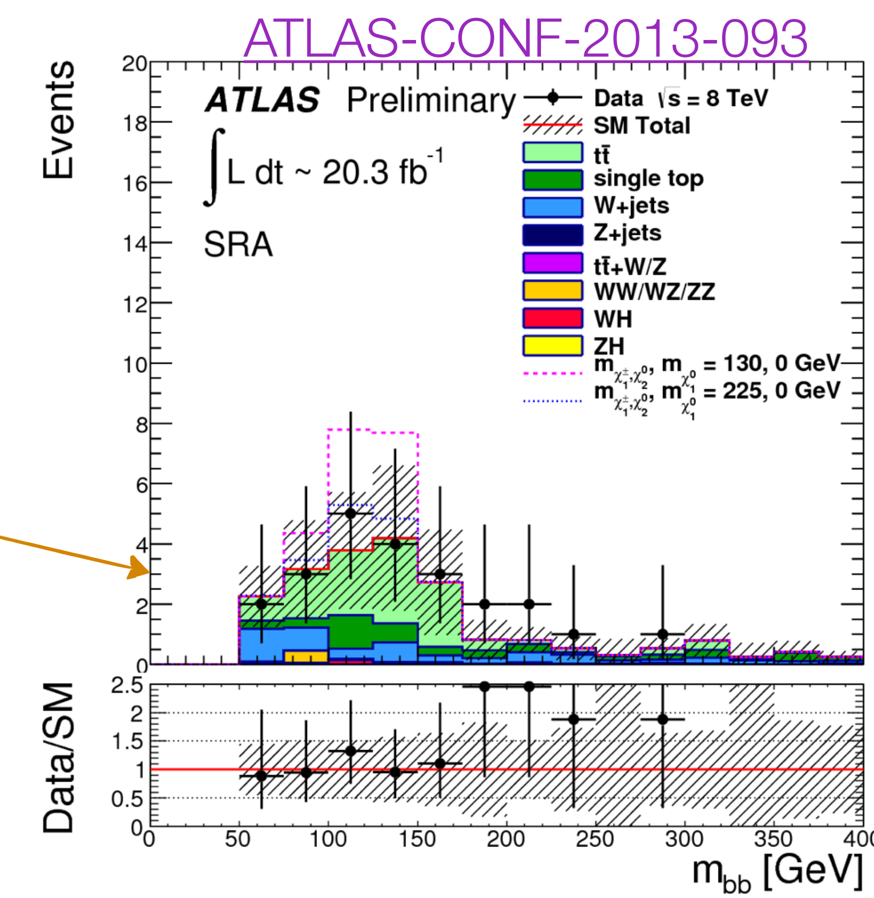
Multi-lepton signatures with low hadronic activity (low SM background)





Most sensitive channel: ≥ 3 lepton + E_T^{miss}

If sleptons too heavy decays via bosons are favored: higgs boson considered!



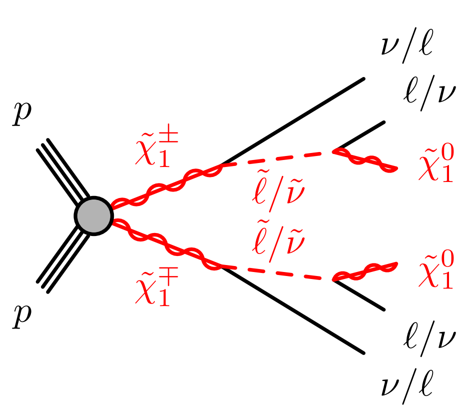
3 leptons + E_T^{miss} (1/3)

SUSY-2013-12 (arXiv:1402.7029)

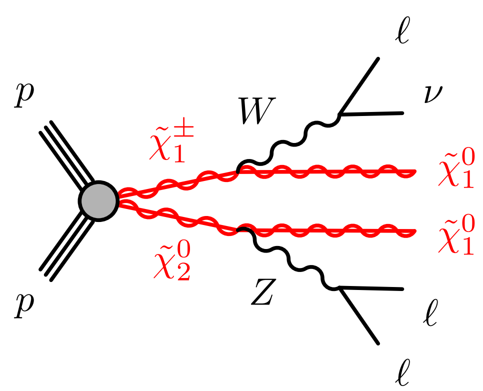
Search for direct production of $\tilde{\chi}^{\pm}_1$ and $\tilde{\chi}^0_2$ in 3 final state leptons

4 Simplified Models considered

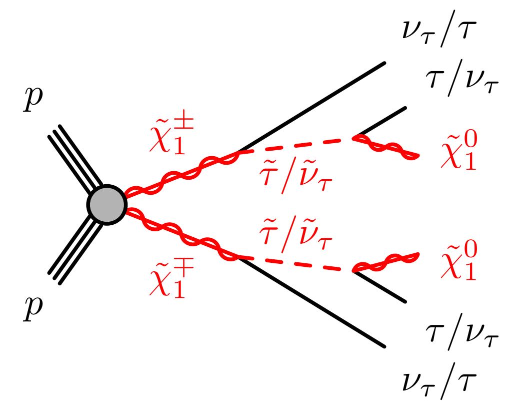
$\tilde{\chi}^0_1$ 100% bino , $\tilde{\chi}^{\pm}_1$ & $\tilde{\chi}^0_2$ 100% wino, $m(\tilde{\chi}^{\pm}_1) \simeq m(\tilde{\chi}^0_2)$



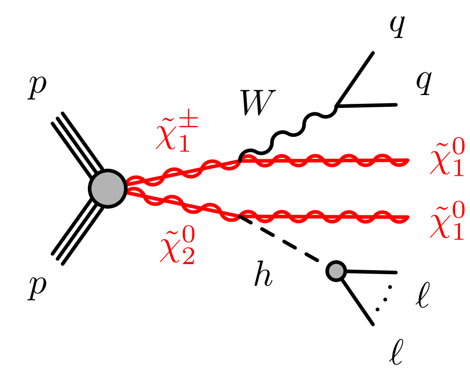
BF(3l)=50%



BF(WZ)=100%



BF(3τ)=50%



BF(Wh)=100%

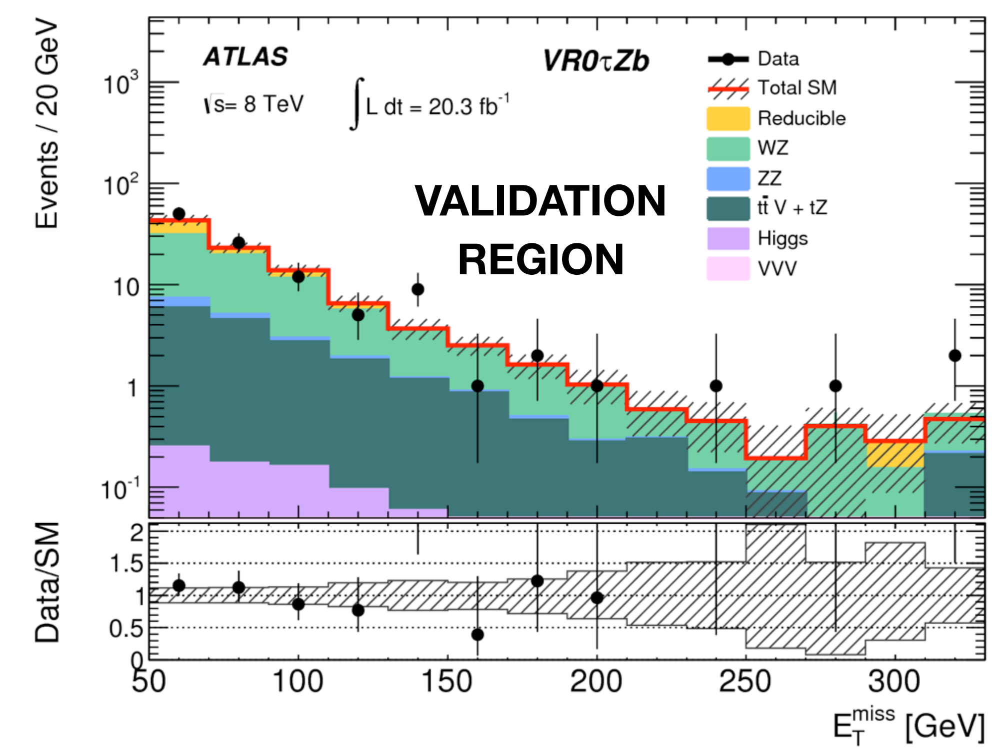
5 Signal Regions (4 disjoint) depending on the final states and the decays mediators

SR	SRτa	SRτb	SR1τ	SR2τa	SR2τb
flavor/sign	$l^+l^-l^{\pm}$, $l^+l^-l'^{\pm}$	$l^{\pm} l^{\pm} l'^{\mp}$	$\tau\, l^{\mp} l^{\pm}$, $\tau\, l^{\mp} l'^{\pm}$	$\tau\, ll$	$\tau^{\pm} l^{\mp} l$
target model	$\tilde{l}$,W Z-mediated	W h-mediated	W h-mediated	$\tilde{\tau}_L$-mediated	W h-mediated
dominant background	WZ, tt	tt, VVV	WZ, tt	WZ, tt	WZ, tt

3 leptons + E_T^{miss} (2/3)

Background composition:

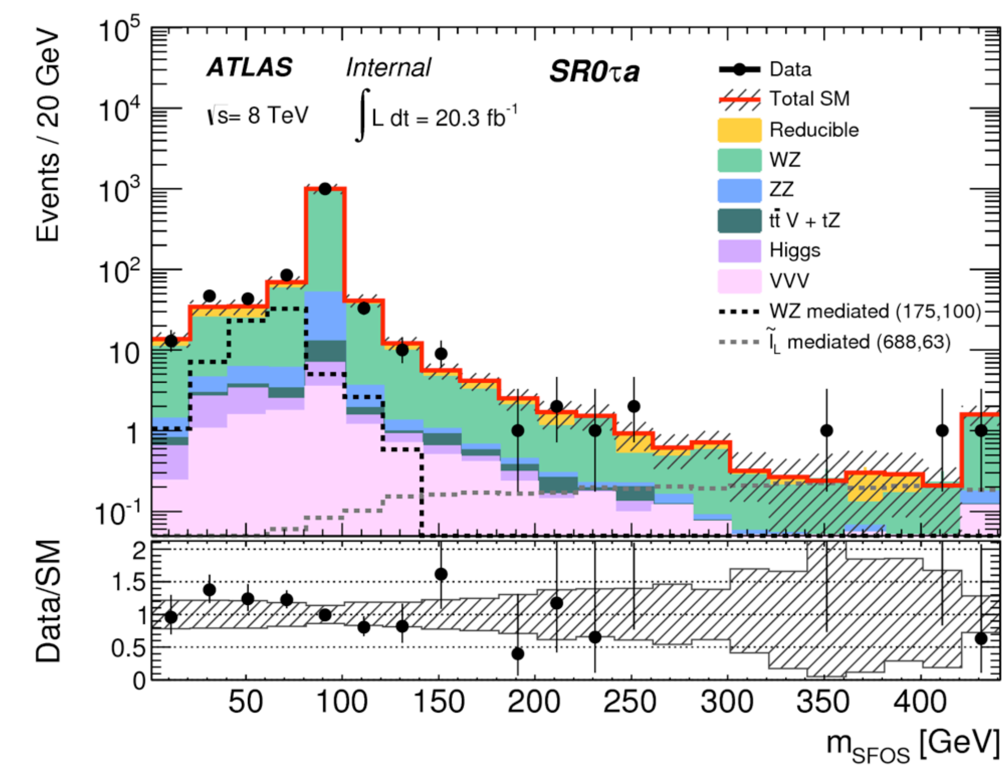
- **Irreducible:**
  - 3 real leptons (*WZ, ZZ, WWW, WWZ, $t\bar{t}$+V, tZ, Higgs*)
  - Estimated from MC, correction factors from data
- **Reducible: fake leptons (*non-prompt leptons,jets* and ɣ conversion)**
  - From single and pair *top* production, *V+jets, WW, W+jets*
  - Modeled by matrix method
    - Leading lepton assumed real (2x2 matrix)
    - Set of linear equations relating the kinematic properties of the other two leptons to the real and fake lepton composition of the data sample
    - Real and fake probabilities found from MC and corrected to data
    - Real and fake probabilities split into process and type (LightFlavor/HeavyFlavor/Conversion)



Background validation

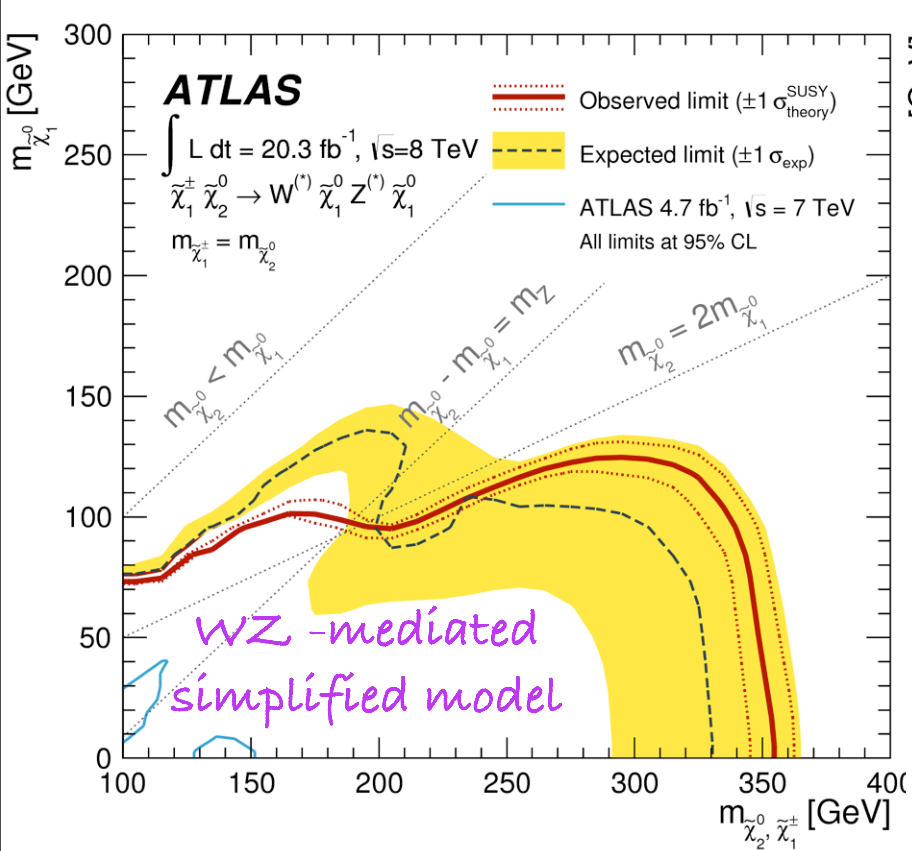
Background predictions tested in Validation regions (VR)

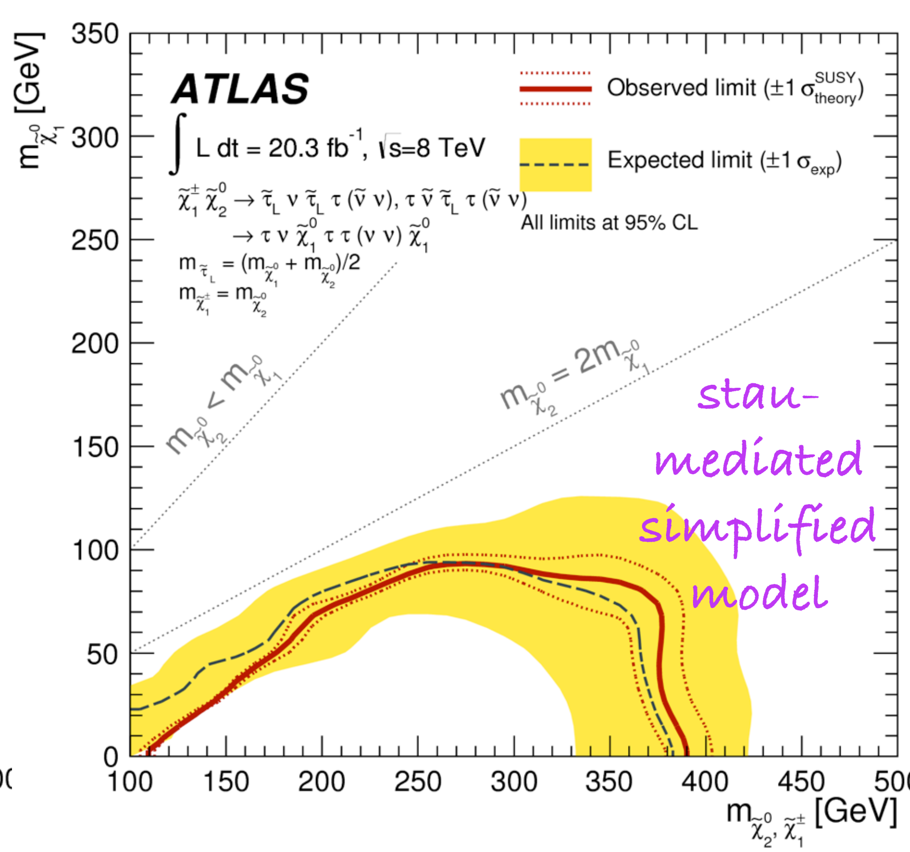
- Only to assess potential signal contamination (negligible).
- Two main definitions depending on the *b-jets* multiplicity:
  - low-E_T^{miss} ("a" regions) and high-E_T^{miss} + *b-tagged jet* ("b" regions)

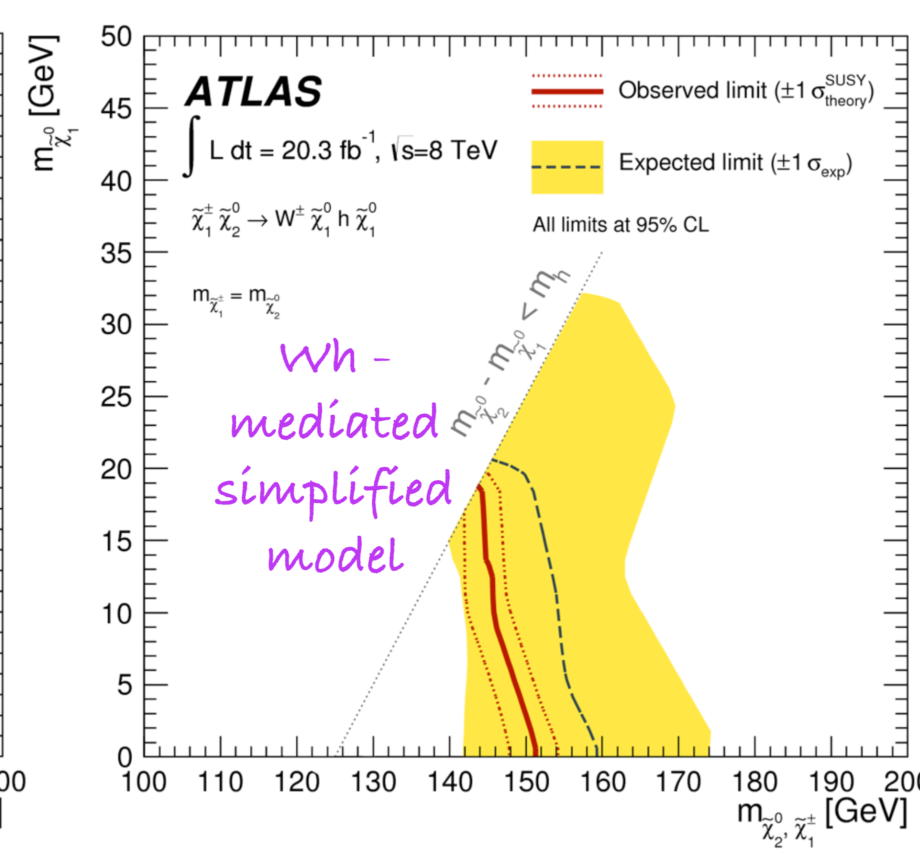


3 leptons + E_T^{miss} (3/3)

In all SR Results are consistent with SM expectations
Exclusion limits are calculated by statistically combining results from a number of disjoint signal regions.







Other Simplified SUSY result:
- slepton decays: exclusion up to 730 GeV

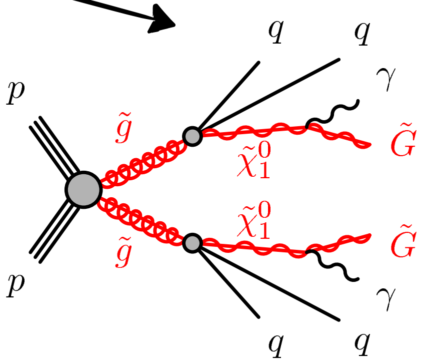
Results also interpreted in the pMSSM scenario (in back-up slides)

Diphoton+E_T^{miss} (1/2)

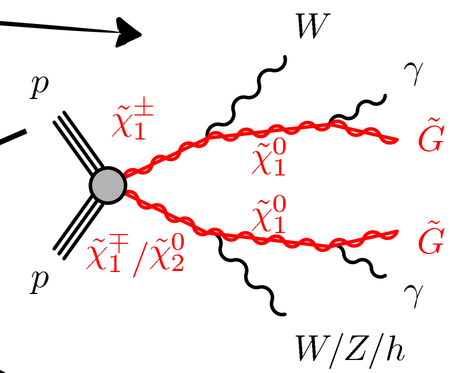
ATLAS-CONF-2014-001

Two General Gauge Mediated (GGM) scenarios where LSP is $\tilde{G}$ and NLSP is $\tilde{\chi}^0_1$, bino like

NNLSP: octet of $\tilde{g}$



5 signal regions



NNLSP: degenerated winos $\tilde{\chi}^0_2$ $\tilde{\chi}^{\pm}_1$

Strong Production
- high mass bino → SP1
- low mass bino → SP2

Model Independent Search
not optimized for any specific model

Weak Production
- high mass bino → WP1
- low mass bino → WP2

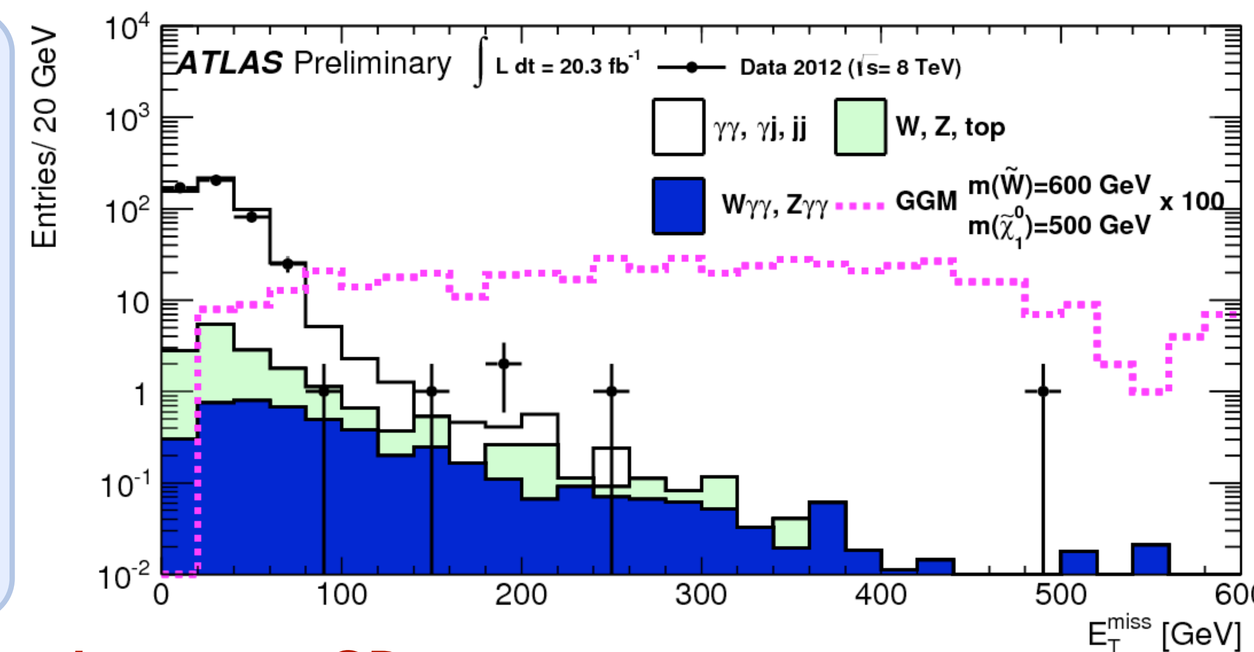
BACKGROUND SOURCES:

- QCD-initiated backgrounds (e.g. $pp \to \gamma\gamma$, $pp \to \gamma+jet$, $pp \to dijets$): *jet* mis-identified as γ + E_T^{miss}
- Electroweak-initiated backgrounds (e.g. $pp \to W\gamma \to e+\gamma$): *e* mis-identified as γ, neutrino leads to E_T^{miss}
- Tri-boson production (irreducible) (e.g. $pp \to Z\gamma\gamma \to \nu\bar{\nu}\gamma\gamma$, $pp \to W^{\pm}\gamma\gamma \to l^{\pm}\nu\gamma\gamma$): real E_T^{miss} + real γ γ

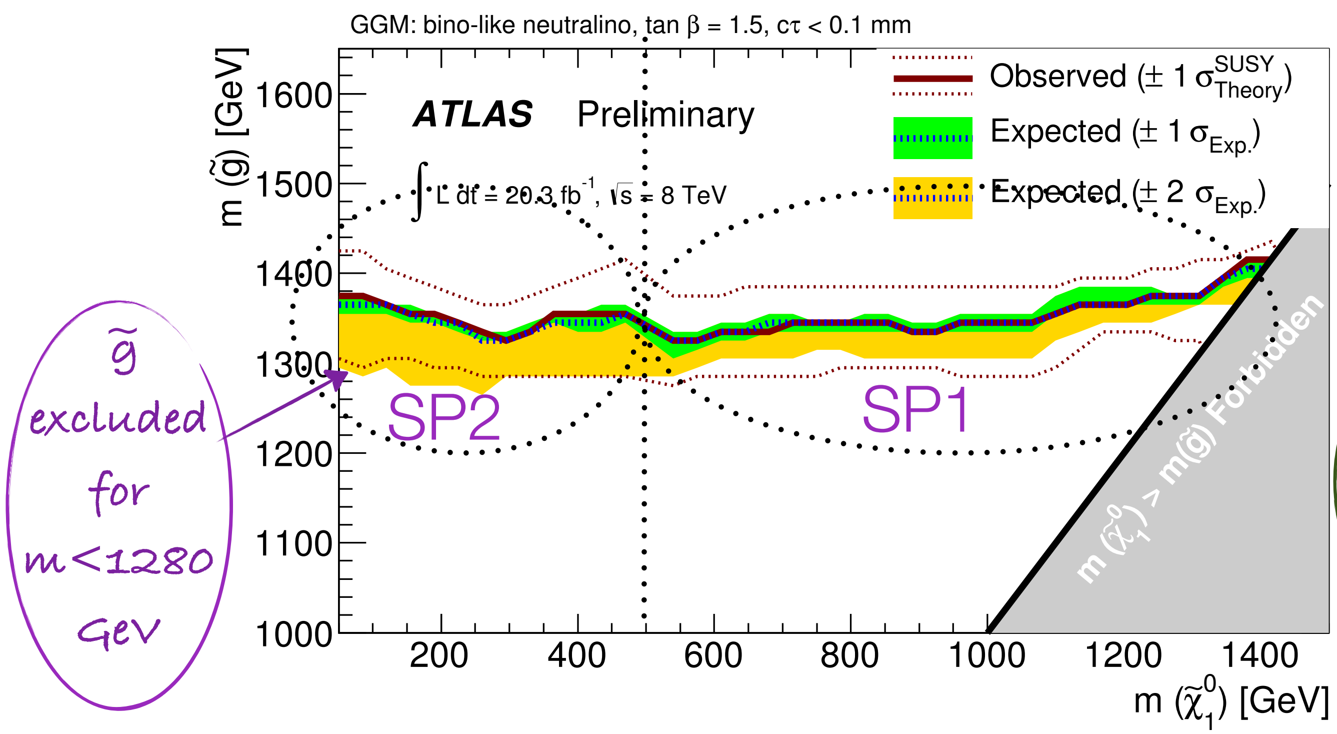
Diphoton+E_T^{miss} (2/2)

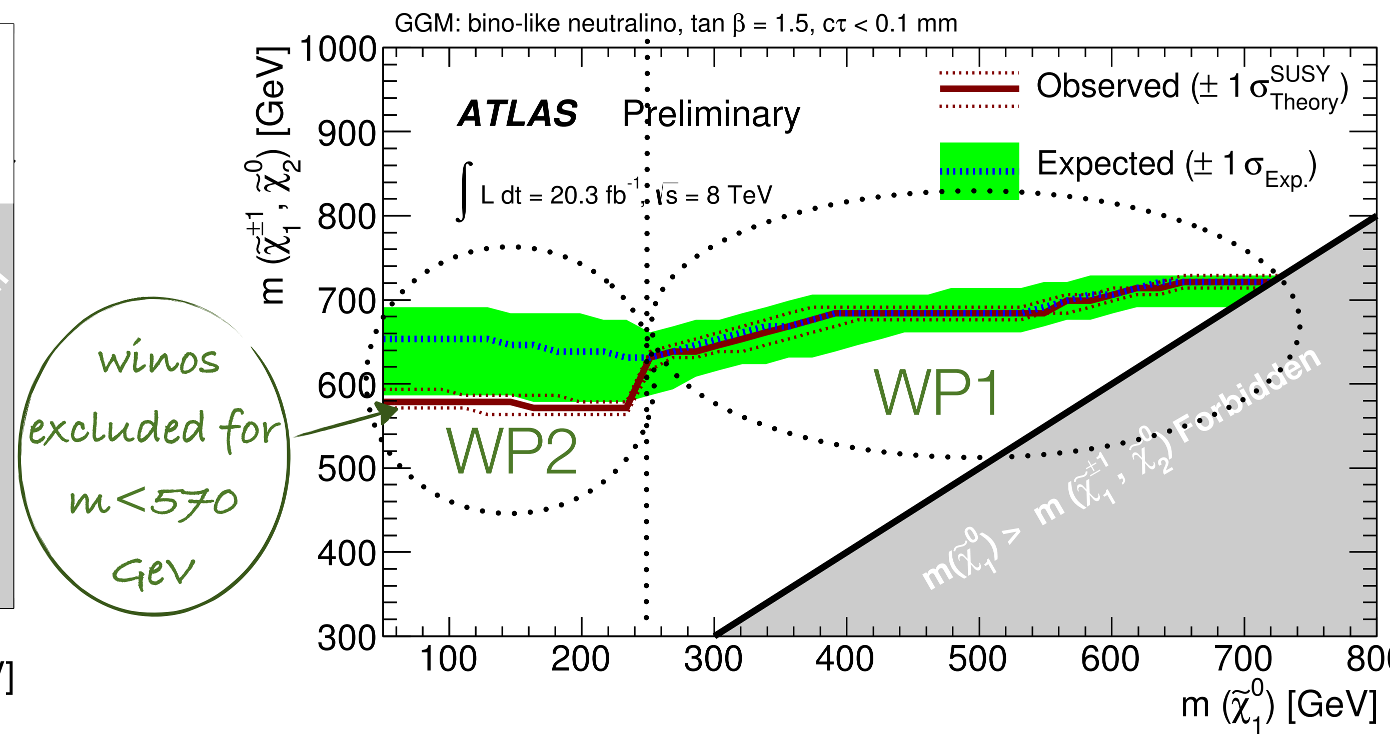
Selection variables:

- H_T : sum of p_T of ɣ, *jets*, μ and electrons
- M_{eff} : sum of E_T^{miss} and H_T (higher in SP searches, **not** for **MIS**)
- Δφ E_T^{miss} - *jet* (ɣ) (**only** for **SP1,WP2**):
  - Min Δφ between E_T^{miss} and reconstructed *jet* (ɣ), E_T >75 GeV
  - Up to two *jets*, or two ɣ
- Use M_{eff} in the SP signal regions, H_T in the WP ones



No excess observed in any SR

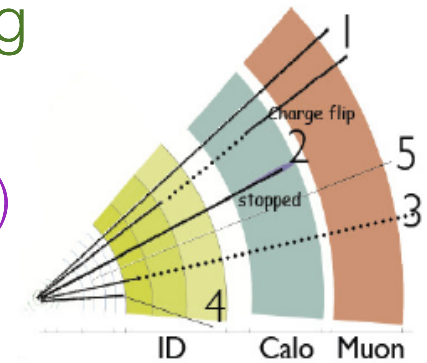




Long Lived particle search

Possible in both R-parity violating and conserving scenarios :

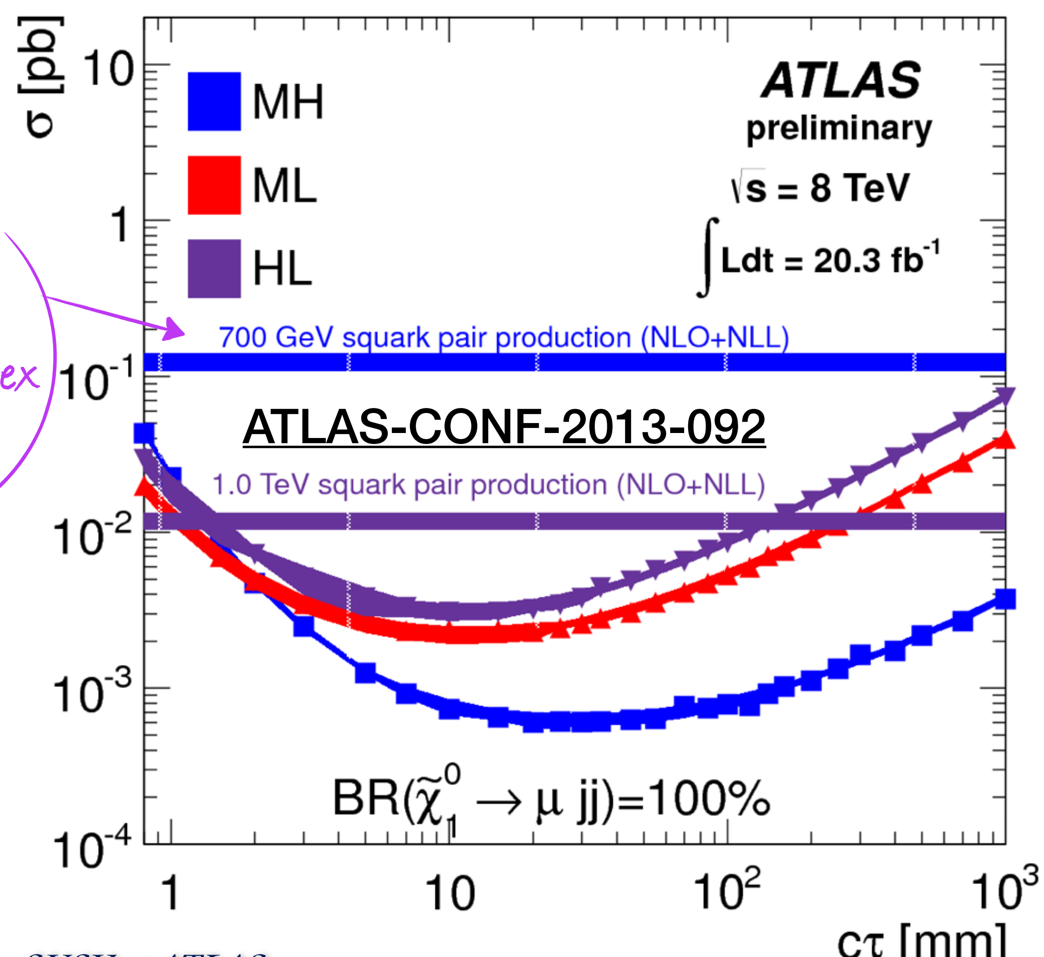
- LSP can have a long lifetime due to small coupling (λ)
- slow NLSP decay to LSP due to mass degeneracy, weak coupling or virtual heavy mediator particles (AMSB *chargino/neutralino*, Split Susy *R-hadrons*, GMSB *stau*)

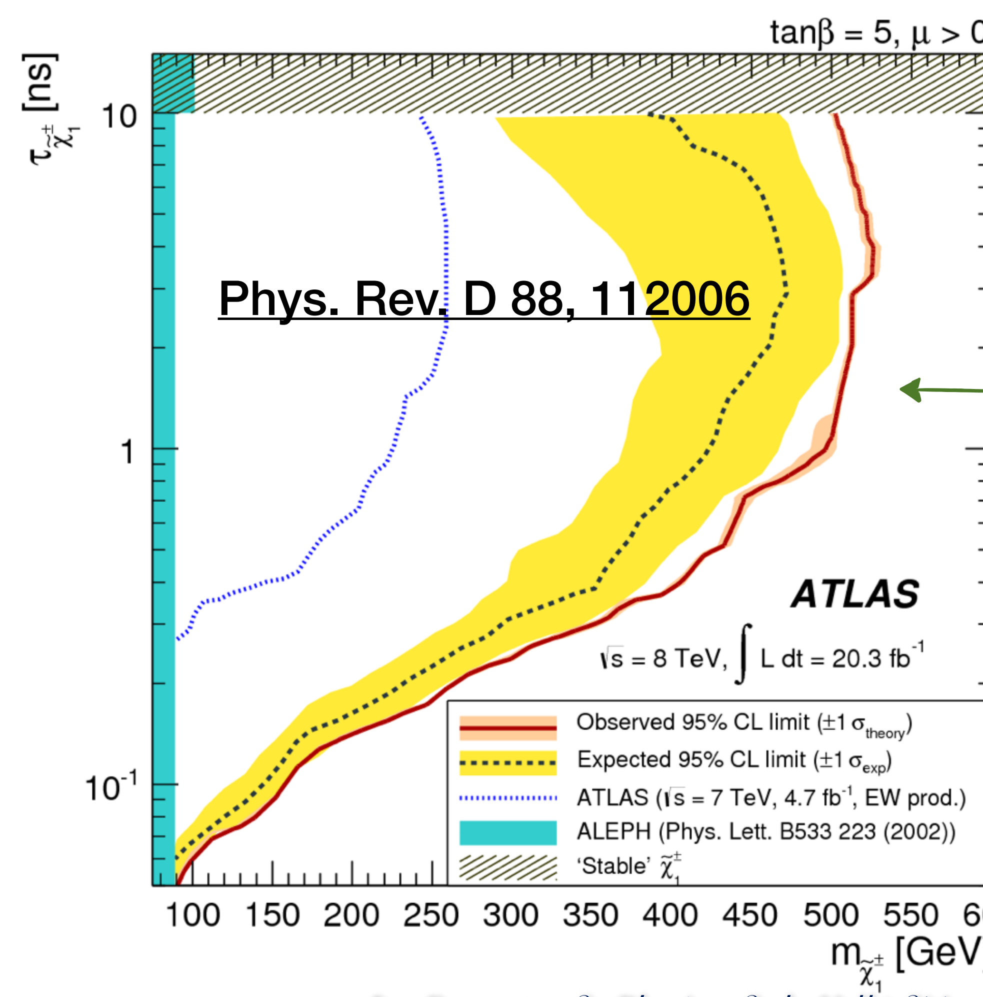


(1) Slow, large dE/dx ~ 1000 mm
(2) Slow, stopped
(3) Disappearing track ~ 100 mm
(4) Kinked track
(5) displaced track ~ 10 mm

Longer lifetime

Muons and multitrack displaced vertex final states





chargino decays expected to be observed as "disappearing tracks" inside the tracking

Stopped gluino search

Phys. Rev. D 88, 11

Long lived gluinos can bind to SM quarks from vacuum, forming the so-called 'R-hadrons'

R-hadrons loose energy (dE/dX, nuclear scattering) in the detector and may stop inside the detector material

Selection based on:

- Empty bunch crossings triggers with calorimeter activity
- High energetic jet in the central pseudorapidity region
- Muon activity veto

Strong model dependence in the signal stopping fraction

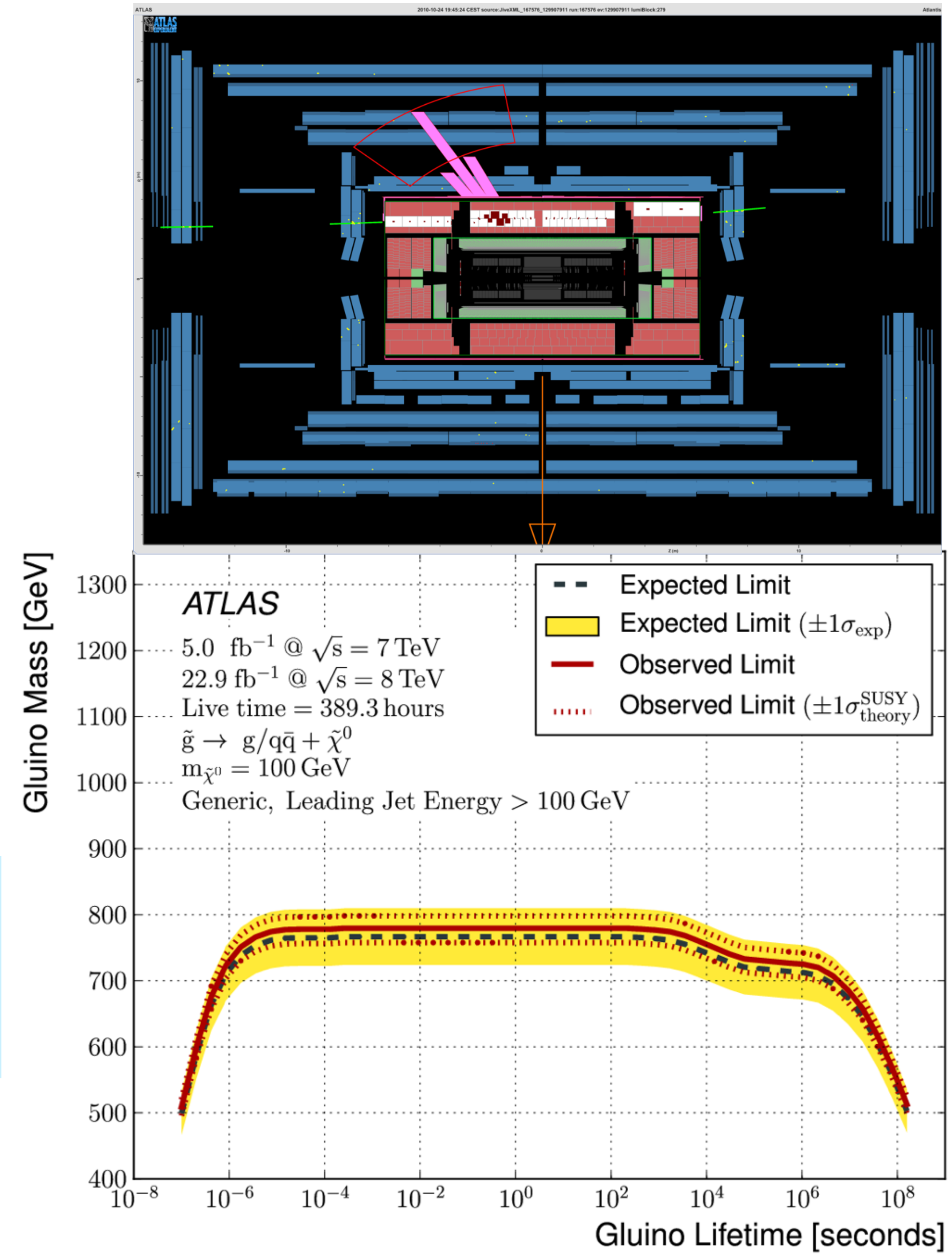
Main backgrounds:

- Cosmics (measured in low-lumi runs)
- Beam-halo (measured in unpaired bunches)

No excess is observed

Limits on gluinos masses:

- $m_{\tilde{g}} < 832$ GeV excluded, for $1\ \mu s < \tau_{\tilde{g}} < 1000$ s
- $m_{\tilde{g}} > 600$GeV excluded, for lifetimes of up to 2 years!



Mass limits summary (1/2)

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: SUSY 2013

ATLAS Preliminary

$\int \mathcal{L}\, dt = (4.6 - 22.9)\ \mathrm{fb}^{-1}$ $\sqrt{s}$ = 7, 8 TeV

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt [fb^{-1}]$	Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.7 TeV	$m(\tilde{q})=m(\tilde{g})$	ATLAS-CONF-2013-047
	MSUGRA/CMSSM	1 e, μ	3-6 jets	Yes	20.3	$\tilde{g}$ 1.2 TeV	any $m(\tilde{q})$	ATLAS-CONF-2013-062
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.1 TeV	any $m(\tilde{q})$	1308.1841
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$ 740 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$ 1.3 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}_1^{\pm}\to qqW^{\pm}\tilde{\chi}_1^0$	1 e, μ	3-6 jets	Yes	20.3	$\tilde{g}$ 1.18 TeV	$m(\tilde{\chi}_1^0)$<200 GeV, $m(\tilde{\chi}^{\pm})=0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$	ATLAS-CONF-2013-062
	$\tilde{g}\tilde{g}, \tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e, μ	0-3 jets	-	20.3	$\tilde{g}$ 1.12 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-089
	GMSB ($\tilde{\ell}$ NLSP)	2 e, μ	2-4 jets	Yes	4.7	$\tilde{g}$ 1.24 TeV	$\tan\beta$<15	1208.4688
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ	0-2 jets	Yes	20.7	$\tilde{g}$ 1.4 TeV	$\tan\beta$ >18	ATLAS-CONF-2013-026
	GGM (bino NLSP)	2 γ	-	Yes	4.8	$\tilde{g}$ 1.07 TeV	$m(\tilde{\chi}_1^0)$>50 GeV	1209.0753
	GGM (wino NLSP)	1 $e, \mu + \gamma$	-	Yes	4.8	$\tilde{g}$ 619 GeV	$m(\tilde{\chi}_1^0)$>50 GeV	ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	4.8	$\tilde{g}$ 900 GeV	$m(\tilde{\chi}_1^0)$>220 GeV	1211.1167
	GGM (higgsino NLSP)	2 e, μ (Z)	0-3 jets	Yes	5.8	$\tilde{g}$ 690 GeV	$m(\tilde{H})$>200 GeV	ATLAS-CONF-2012-152
	Gravitino LSP	0	mono-jet	Yes	10.5	$F^{1/2}$ scale 645 GeV	$m(\tilde{g})>10^{-4}$ eV	ATLAS-CONF-2012-147
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$ 1.2 TeV	$m(\tilde{\chi}_1^0)$<600 GeV	ATLAS-CONF-2013-061
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.1 TeV	$m(\tilde{\chi}_1^0)$ <350 GeV	1308.1841
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$ 1.34 TeV	$m(\tilde{\chi}_1^0)$<400 GeV	ATLAS-CONF-2013-061
	$\tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$ 1.3 TeV	$m(\tilde{\chi}_1^0)$<300 GeV	ATLAS-CONF-2013-061
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{b}_1$ 100-620 GeV	$m(\tilde{\chi}_1^0)$<90 GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to t\tilde{\chi}_1^{\pm}$	2 e, μ (SS)	0-3 b	Yes	20.7	$\tilde{b}_1$ 275-430 GeV	$m(\tilde{\chi}_1^{\pm})=2\,m(\tilde{\chi}_1^0)$	ATLAS-CONF-2013-007
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\to b\tilde{\chi}_1^{\pm}$	1-2 e, μ	1-2 b	Yes	4.7	$\tilde{t}_1$ 110-167 GeV	$m(\tilde{\chi}_1^0)$=55 GeV	1208.4305, 1209.2102
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\to Wb\tilde{\chi}_1^0$	2 e, μ	0-2 jets	Yes	20.3	$\tilde{t}_1$ 130-220 GeV	$m(\tilde{\chi}_1^0)=m(\tilde{t}_1)-m(W)$-50 GeV, $m(\tilde{t}_1)<<m(\tilde{\chi}_1^{\pm})$	ATLAS-CONF-2013-048
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\to t\tilde{\chi}_1^0$	2 e, μ	2 jets	Yes	20.3	$\tilde{t}_1$ 225-525 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-065
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\to b\tilde{\chi}_1^{\pm}$	0	2 b	Yes	20.1	$\tilde{t}_1$ 150-580 GeV	$m(\tilde{\chi}_1^0)$<200 GeV, $m(\tilde{\chi}_1^{\pm})-m(\tilde{\chi}_1^0)$=5 GeV	1308.2631
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	1 e, μ	1 b	Yes	20.7	$\tilde{t}_1$ 200-610 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-037
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	0	2 b	Yes	20.5	$\tilde{t}_1$ 320-660 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-024
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$ 90-200 GeV	$m(\tilde{t}_1)-m(\tilde{\chi}_1^0)$<85 GeV	ATLAS-CONF-2013-068
	$\tilde{t}_1\tilde{t}_1$(natural GMSB)	2 e, μ (Z)	1 b	Yes	20.7	$\tilde{t}_1$ 500 GeV	$m(\tilde{\chi}_1^0)$>150 GeV	ATLAS-CONF-2013-025
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+Z$	3 e, μ (Z)	1 b	Yes	20.7	$\tilde{t}_2$ 271-520 GeV	$m(\tilde{t}_1)=m(\tilde{\chi}_1^0)$+180 GeV	ATLAS-CONF-2013-025

10^{-1} 1 Mass scale [TeV]

$\sqrt{s}$ = 7 TeV full data | $\sqrt{s}$ = 8 TeV partial data | $\sqrt{s}$ = 8 TeV full data

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

Mass limits summary (2/2)

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: SUSY 2013

ATLAS Preliminary

$\int \mathcal{L}\, dt = (4.6 - 22.9)\ \mathrm{fb}^{-1}$ $\sqrt{s} = 7,\ 8$ TeV

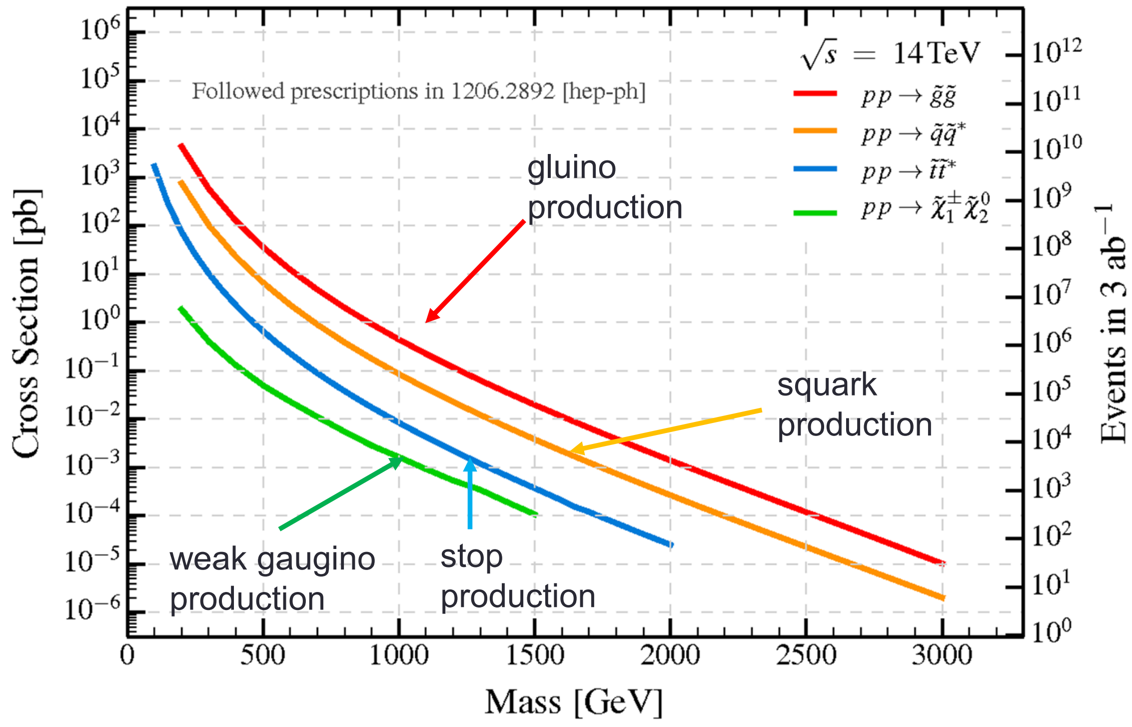
	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt[\mathrm{fb}^{-1}]$	Mass limit		Reference
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e,μ	0	Yes	20.3	$\tilde{\ell}$ 85-315 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-049
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	20.3	$\tilde{\chi}_1^\pm$ 125-450 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\ell},\tilde{\nu})$=0.5($m(\tilde{\chi}_1^\pm)$+$m(\tilde{\chi}_1^0)$)	ATLAS-CONF-2013-049
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.7	$\tilde{\chi}_1^\pm$ 180-330 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\tau},\tilde{\nu})$=0.5($m(\tilde{\chi}_1^\pm)$+$m(\tilde{\chi}_1^0)$)	ATLAS-CONF-2013-028
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	20.7	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ 600 GeV	$m(\tilde{\chi}_1^\pm)$=$m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})$=0.5($m(\tilde{\chi}_1^\pm)$+$m(\tilde{\chi}_1^0)$)	ATLAS-CONF-2013-035
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	3 e,μ	0	Yes	20.7	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ 315 GeV	$m(\tilde{\chi}_1^\pm)$=$m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled	ATLAS-CONF-2013-035
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 h\tilde{\chi}_1^0$	1 e,μ	2 b	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ 285 GeV	$m(\tilde{\chi}_1^\pm)$=$m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled	ATLAS-CONF-2013-093
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^\pm$ 270 GeV	$m(\tilde{\chi}_1^\pm)$-$m(\tilde{\chi}_1^0)$=160 MeV, $\tau(\tilde{\chi}_1^\pm)$=0.2 ns	ATLAS-CONF-2013-069
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	22.9	$\tilde{g}$ 832 GeV	$m(\tilde{\chi}_1^0)$=100 GeV, 10 μs<$\tau(\tilde{g})$<1000 s	ATLAS-CONF-2013-057
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	15.9	$\tilde{\chi}_1^0$ 475 GeV	10<tanβ<50	ATLAS-CONF-2013-058
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	4.7	$\tilde{\chi}_1^0$ 230 GeV	0.4<$\tau(\tilde{\chi}_1^0)$<2 ns	1304.6310
	$\tilde{q}\tilde{q}$, $\tilde{\chi}_1^0\to qq\mu$ (RPV)	1 μ, displ. vtx	-	-	20.3	$\tilde{q}$ 1.0 TeV	1.5 <$c\tau$<156 mm, BR(μ)=1, $m(\tilde{\chi}_1^0)$=108 GeV	ATLAS-CONF-2013-092
RPV	LFV $pp\to\tilde{\nu}_\tau+X$, $\tilde{\nu}_\tau\to e+\mu$	2 e,μ	-	-	4.6	$\tilde{\nu}_\tau$ 1.61 TeV	λ'_{311}=0.10, λ_{132}=0.05	1212.1272
	LFV $pp\to\tilde{\nu}_\tau+X$, $\tilde{\nu}_\tau\to e(\mu)+\tau$	1 $e,\mu+\tau$	-	-	4.6	$\tilde{\nu}_\tau$ 1.1 TeV	λ'_{311}=0.10, $\lambda_{1(2)33}$=0.05	1212.1272
	Bilinear RPV CMSSM	1 e,μ	7 jets	Yes	4.7	$\tilde{q}, \tilde{g}$ 1.2 TeV	$m(\tilde{q})$=$m(\tilde{g})$, $c\tau_{LSP}$<1 mm	ATLAS-CONF-2012-140
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e,μ	-	Yes	20.7	$\tilde{\chi}_1^\pm$ 760 GeV	$m(\tilde{\chi}_1^0)$>300 GeV, λ_{121}>0	ATLAS-CONF-2013-036
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 $e,\mu+\tau$	-	Yes	20.7	$\tilde{\chi}_1^\pm$ 350 GeV	$m(\tilde{\chi}_1^0)$>80 GeV, λ_{133}>0	ATLAS-CONF-2013-036
	$\tilde{g}\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$ 916 GeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2013-091
	$\tilde{g}\to\tilde{t}_1 t$, $\tilde{t}_1\to bs$	2 e,μ (SS)	0-3 b	Yes	20.7	$\tilde{g}$ 880 GeV		ATLAS-CONF-2013-007
Other	Scalar gluon pair, sgluon$\to q\bar{q}$	0	4 jets	-	4.6	sgluon 100-287 GeV	incl. limit from 1110.2693	1210.4826
	Scalar gluon pair, sgluon$\to t\bar{t}$	2 e,μ (SS)	1 b	Yes	14.3	sgluon 800 GeV		ATLAS-CONF-2013-051
	WIMP interaction (D5, Dirac χ)	0	mono-jet	Yes	10.5	M* scale 704 GeV	$m(\chi)$<80 GeV, limit of<687 GeV for D8	ATLAS-CONF-2012-147

$\sqrt{s}$ = 7 TeV full data | $\sqrt{s}$ = 8 TeV partial data | $\sqrt{s}$ = 8 TeV full data

10^{-1} 1 **Mass scale [TeV]**

Summary & Outlook

- The ATLAS Collaboration investigated extensively 8 TeV LHC data
- So far no hint of SUSY physics....
  - Strong *sparticles* production at TeV scale excluded
  - Use simplified models to set limits
  - Focus on smaller cross section process (limits less stringent)
- High Luminosity LHC will allow to explore more search regions



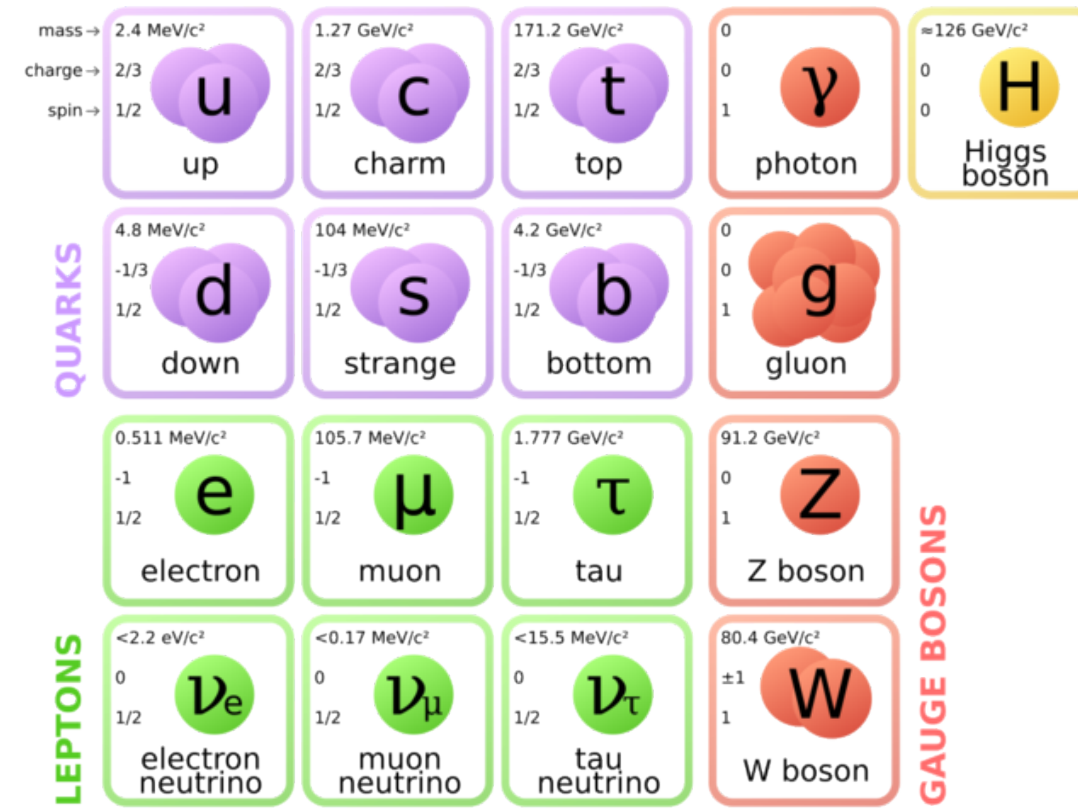
BACK-UP

Why beyond SM searches?

The Standard Model (SM) of elementary particles works pretty well!

✶ predictions verified by many experiments at high precision level

✶ the higgs boson's discovery completed the picture



... but ... still lots of questions not addressed .....

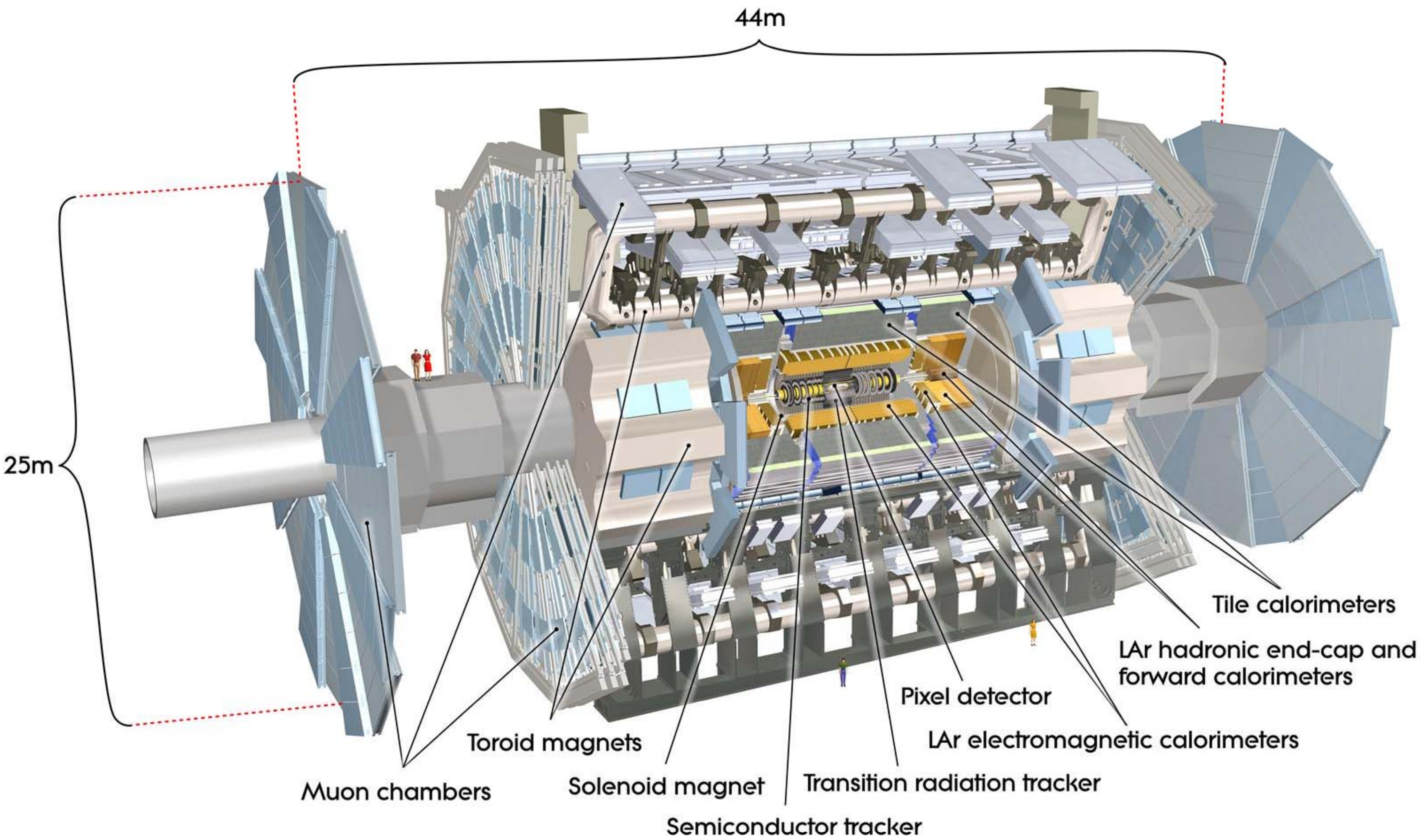
✶Dark Matter (DM) and full gravitation theory not included

✶matter-antimatter asymmetry and barion number conservation

✶naturalness

✶16 order of magnitude between electro-weak (EW) scale and Plank's mass (hierarchy problem)

A Toroidal Lhc ApparatuS



Diphoton+E_T^{miss}: background

- QCD-initiated backgrounds (e.g. $pp \to \gamma\gamma$, $pp \to \gamma$+*jet*, $pp \to$ *dijets*)
  - Jets mis-identified as γ and E_T^{miss};
  - Data-driven Model using tight γ + pseudo γ (i.e. ‘loose’, but not ‘tight’ γ)+ E_T^{miss} sample;
  - reproducibility confirmed by MC and side-bands samples, control samples normalized to di-γ data
  - in low stat region (SP1,SP2) bkg estimation confirmed by alternative method using relaxed M_{eff} cuts in control region sidebands
- Electroweak-initiated backgrounds (e.g. $pp \to W\gamma \to e+\gamma$)
  - Electrons mis-identified as photons, neutrino leads to MET
  - Data-driven model using *e*+‘tight’ γ events, normalized using rate of e mis-identified as γ in $Z \to ee$ events, fake factor as a function of pseudorapidity
- Tri-boson production (irreducible) (e.g. $pp \to Z\gamma\gamma \to \nu\bar{\nu}\gamma\gamma$, $pp \to W^{\pm}\gamma\gamma \to l^{\pm}\nu\gamma\gamma$)
  - Events are produced with real E_T^{miss} and two real γ; irreducible
  - Control region used to determine normalization of cross sections
  - $ZZ \to \nu\bar{\nu}\gamma\gamma$ contribution estimated from MC

3 leptons + E_T^{miss}: selection

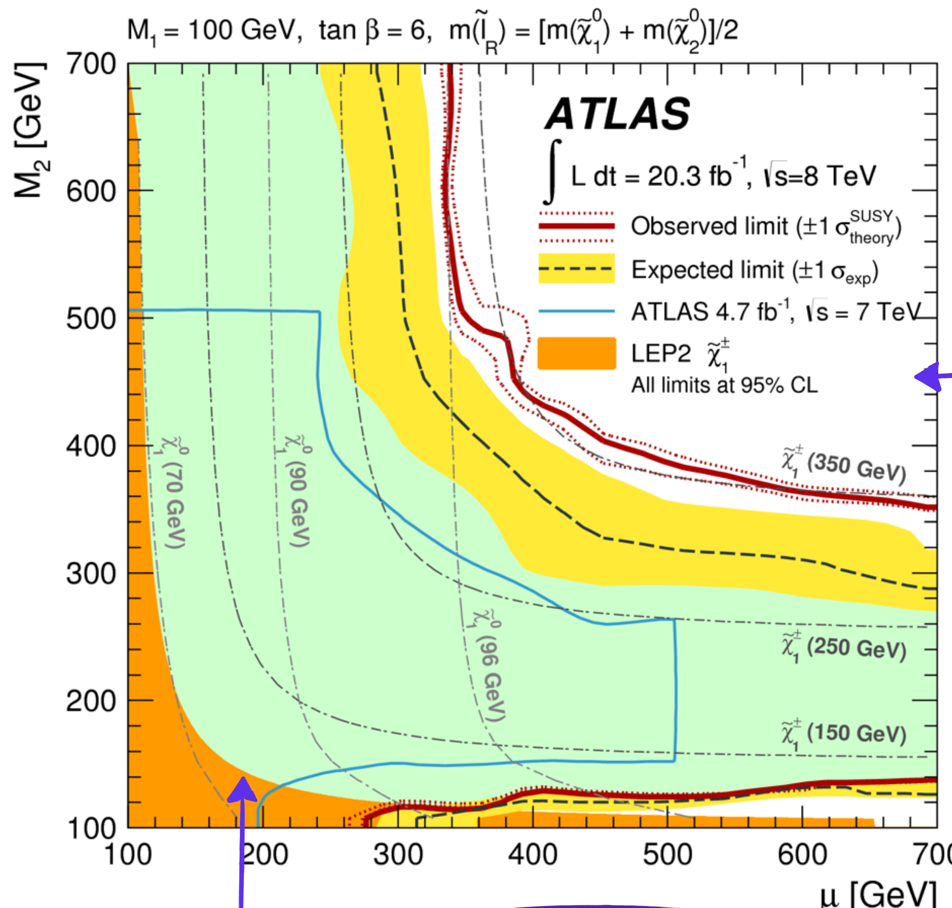
SR	SR0τa	SR0τb	SR1τ	SR2τa	SR2τb
flavour/sign	$\ell^+\ell^-\ell^\pm$, $\ell^+\ell^-\ell'^\pm$	$\ell^\pm\ell^\pm\ell'^\mp$	$\tau^\pm\ell^\mp\ell^\mp$, $\tau^\pm\ell^\mp\ell'^\mp$	$\tau\tau\ell$	$\tau^\pm\tau^\mp\ell$
b-tagged jet	veto	veto	veto	veto	veto
$E_\mathrm{T}^\mathrm{miss}$	binned	> 50	> 50	> 50	> 60
other	m_SFOS binned	$p_\mathrm{T}^{3\mathrm{rd}\,\ell} > 20$	$p_\mathrm{T}^{2\mathrm{nd}\,\ell} > 30$	max $m_\mathrm{T2} > 100$	$\sum p_\mathrm{T}^\tau > 110$
–	m_T binned	$\Delta\phi_{\ell\ell} \leq 1.0$	$\sum p_\mathrm{T}^\ell > 70$	–	$70 < m_{\tau\tau} < 120$
–	–	–	$m_{\ell\tau} < 120$	–	–
–	–	–	m_{ee} Z-veto	–	–
Target model	$\tilde{\ell}$,WZ-mediated	Wh-mediated	Wh-mediated	$\tilde{\tau}_L$-mediated	Wh-mediated
Dominant background	*WZ, tt*	*tt, VVV*	*WZ, tt*	*WZ, tt*	*WZ, tt*

3 leptons + E_T^{miss} :pMSSM

Search for direct production of $\tilde{\chi}^{\pm}_1$ and $\tilde{\chi}^0_2$ in 3 final state leptons:
pMSSM interpretation

5 points considered, where

- squarks and gluino heavy (not produced)
- *m(A), m(h)*~125GeV
- Electroweakino sector parameterized with
  - M_1 (Bino); M_2 (Wino); *MU* (Higgsinos); *tan*β
- pMSSM models in μ-M_2 plane, with heavy $\tilde{l}_L$:
  - *tan*β = 6, M_1=100, 140, 250 GeV
  - *tan*β = 10, M_1=50 GeV (heavy $\tilde{e}_R$ $\tilde{\mu}_R$)
  - *tan*β = 10, M_1=75 GeV (heavy $\tilde{l}_R$)



pMSSM, M_1=100 GeV

For all the pMSSM points limited sensitivity for M1~M2< μ due to small mass difference between $\tilde{\chi}^{\pm}_1/\tilde{\chi}^0_2$ and the LSP

R-parity violation search

The proton stability forbids simultaneous lepton and baryon number violation, but no experimental evidence forbids a R-parity violating potential conserving only one of the two

$$L_{RPV} = \lambda_{ijk} L_i L_j \overline{E}_k + \lambda'_{ijk} L_i Q_j \overline{D}_k + \kappa_i L_i H_2 + \lambda''_{ijk} U_i \overline{U}_j \overline{D}_k$$

lepton number violating **baryon number violating**

LSP can decay to many quarks or leptons, opposite flavor lepton resonances...

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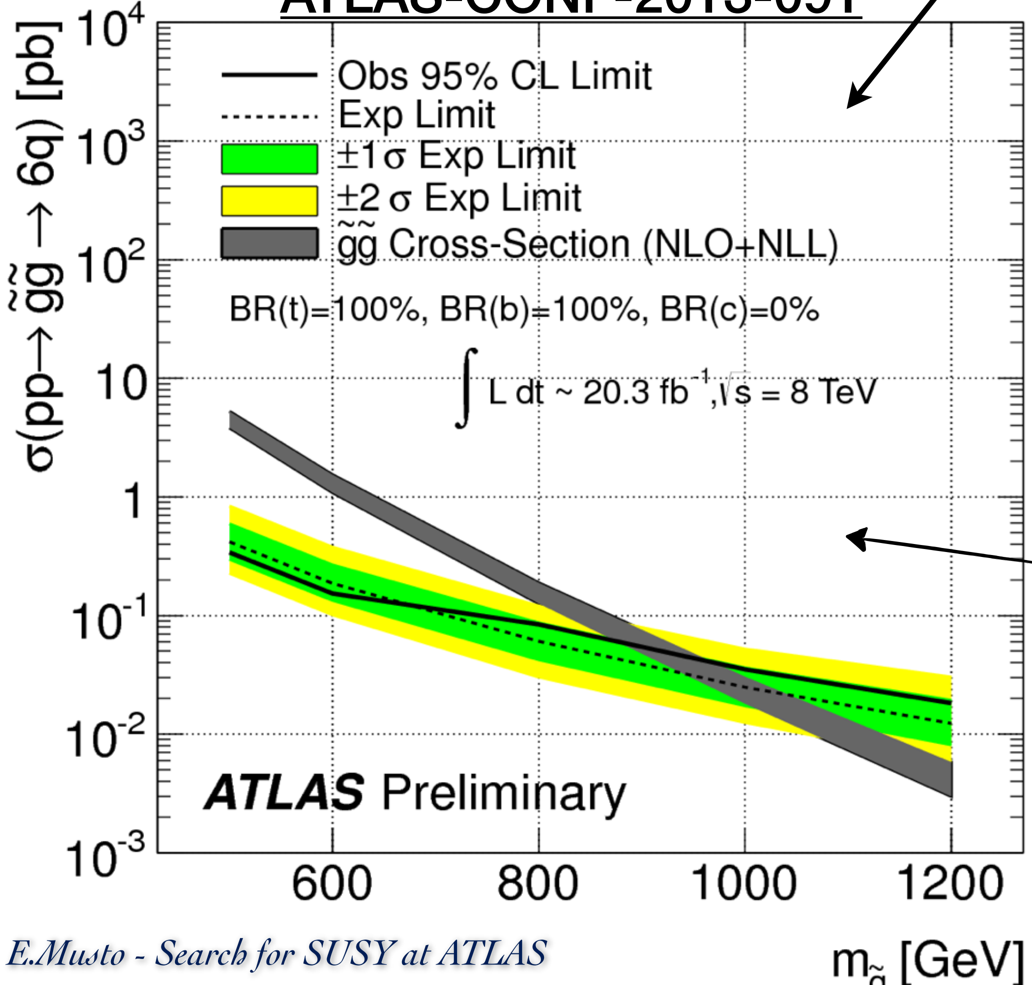
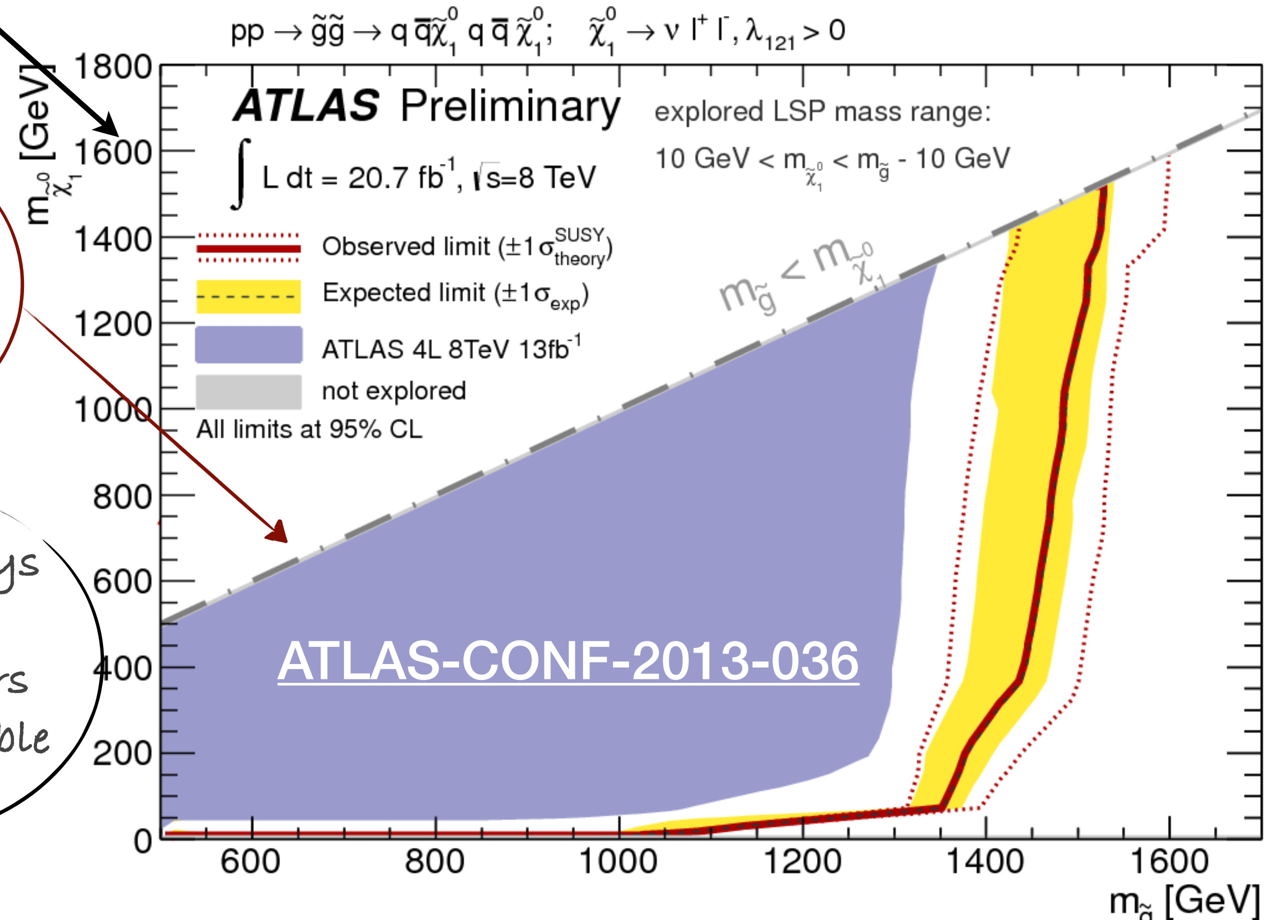


simplified SUSY models with ≥1 NLSP

gluino decays to various quark flavors with all possible BR

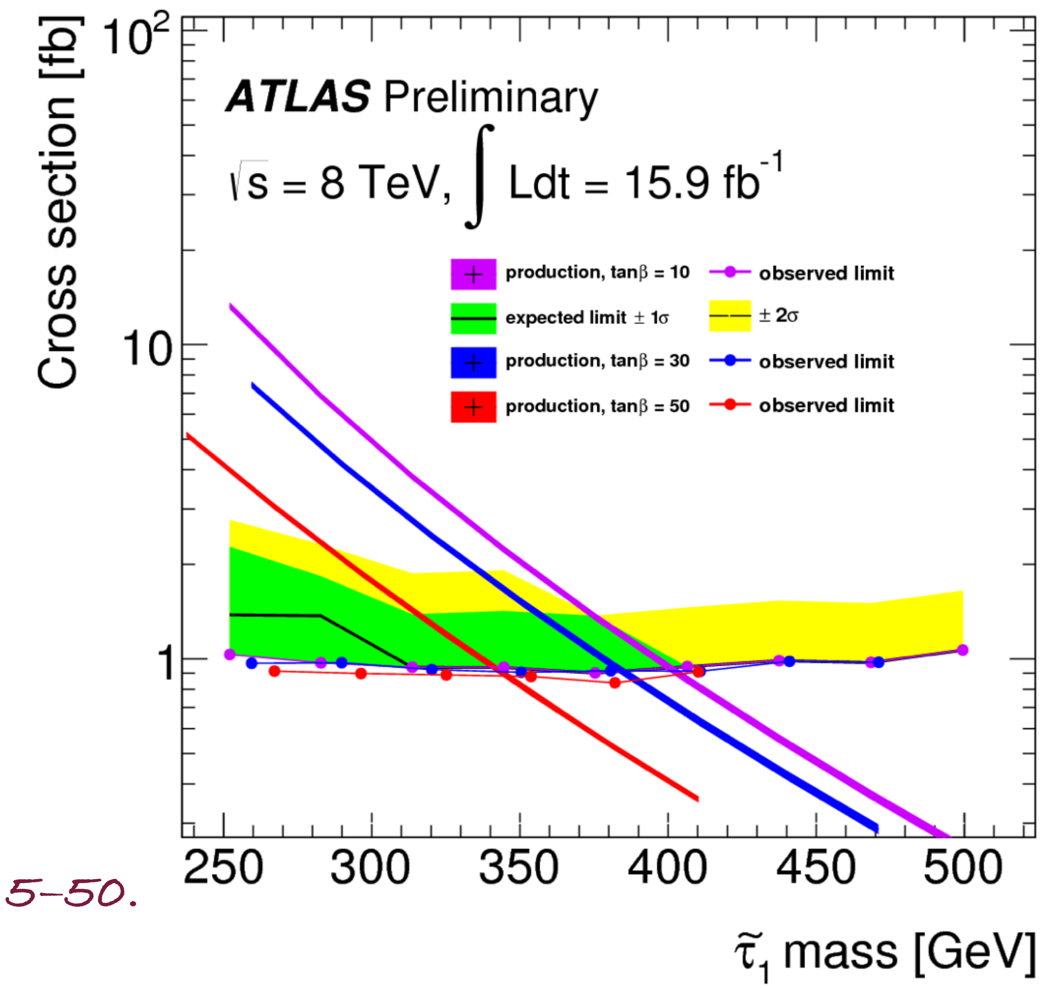


Long lived sleptons

ATLAS-CONF-2013-058

In the GMSB models the NLSP stau may be long lived and decay outside the detector
Long-lived $\tilde{\tau}_1$s appear as if they are heavy muons, charged and penetrating

- Background mainly composed of mis-measured high p_T muons, estimated from data
- Selection mainly based on quality cuts
- $\tilde{\tau}_1$ mass estimated using $m = p / (\gamma \beta)$
  - β is estimated using the time of flight (calorimeters and muon system)
  - p estimated from the particle track
- 2 candidates search matched SM expectations



Long lived staus excluded for masses below 402-347 GeV for tanβ =5-50.
Model independent limits also set for :

- directly produced long-lived sleptons (below 342 GeV for small mass difference between the light sleptons and the stau, and below 300 GeV for mass splittings of 90 GeV);
- directly produced long lived stau excluded for mass below 267 GeV.
- neutralinos decaying to long-lived staus excluded for masses below 475 GeV.