Overview of the SUSY results from the ATLAS and CMS experiments

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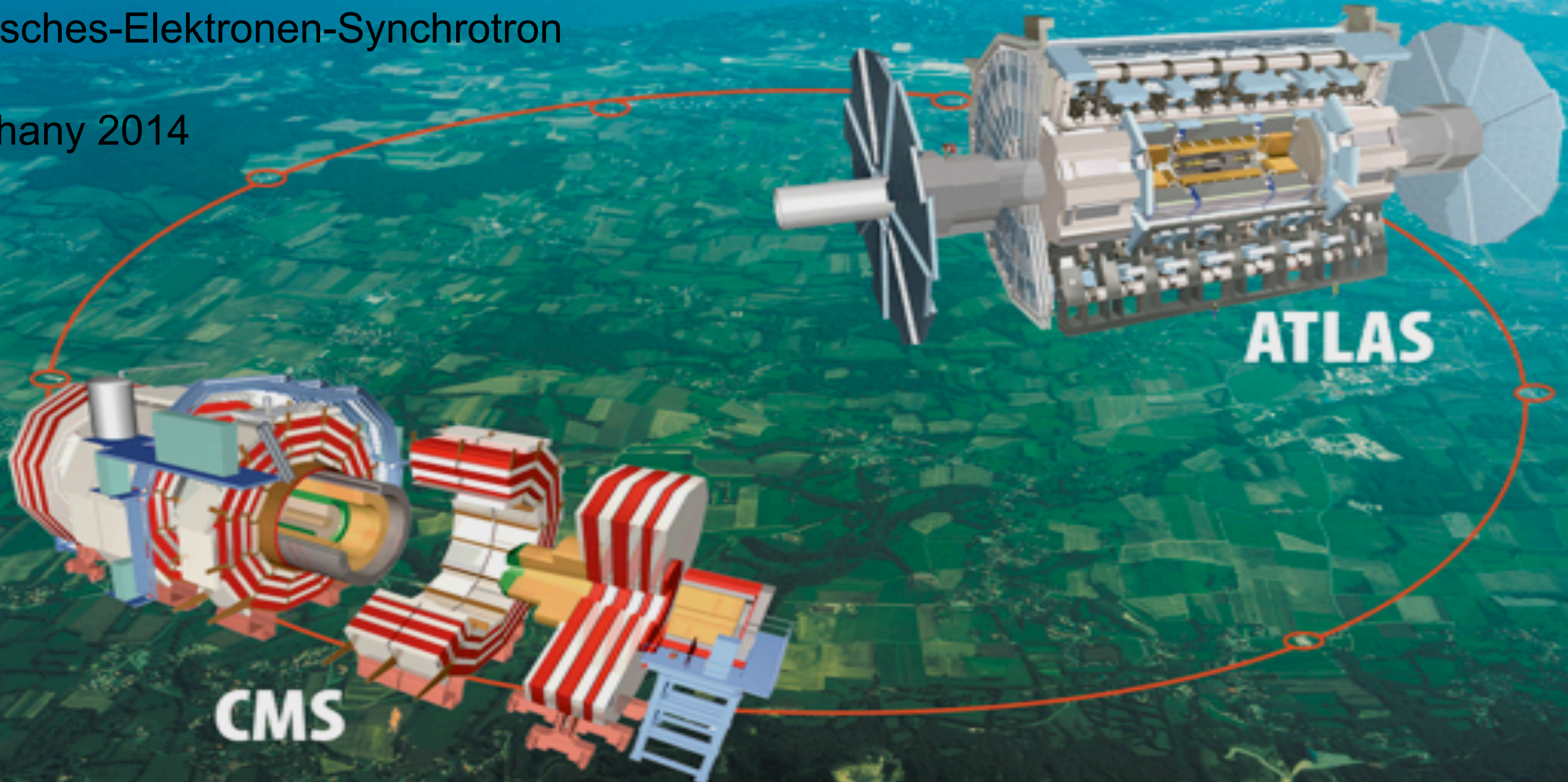
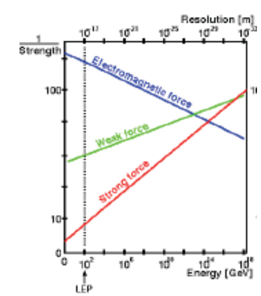
on behalf of the ATLAS & CMS collaborations
Deutsches-Elektronen-Synchrotron

Epiphany 2014



Standard Model

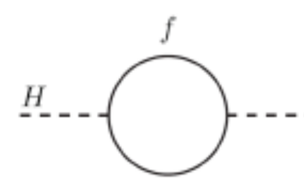
- Standard Model (SM) of elementary particles is a very successful theory
- precise predictions, verified by several experiments over many orders production rate
- discovery of the higgs boson completed the SM



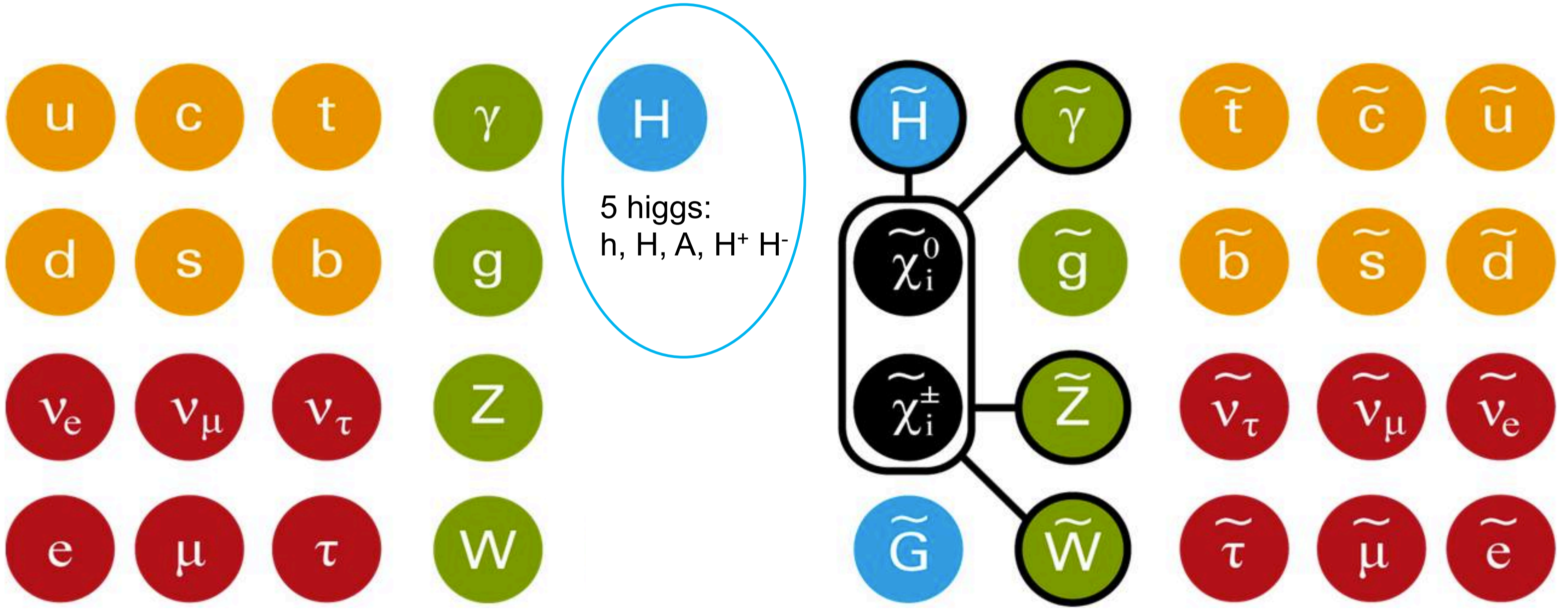
What's the problem?

- no explanations of dark matter
- no explanation of the origin of matter-anti-matter asymmetry
- no unification of the forces
- high-levels of fine tuning needed to avoid quadratic divergences

  of higgs mass corrections
- …



Supersymmetry (SUSY)

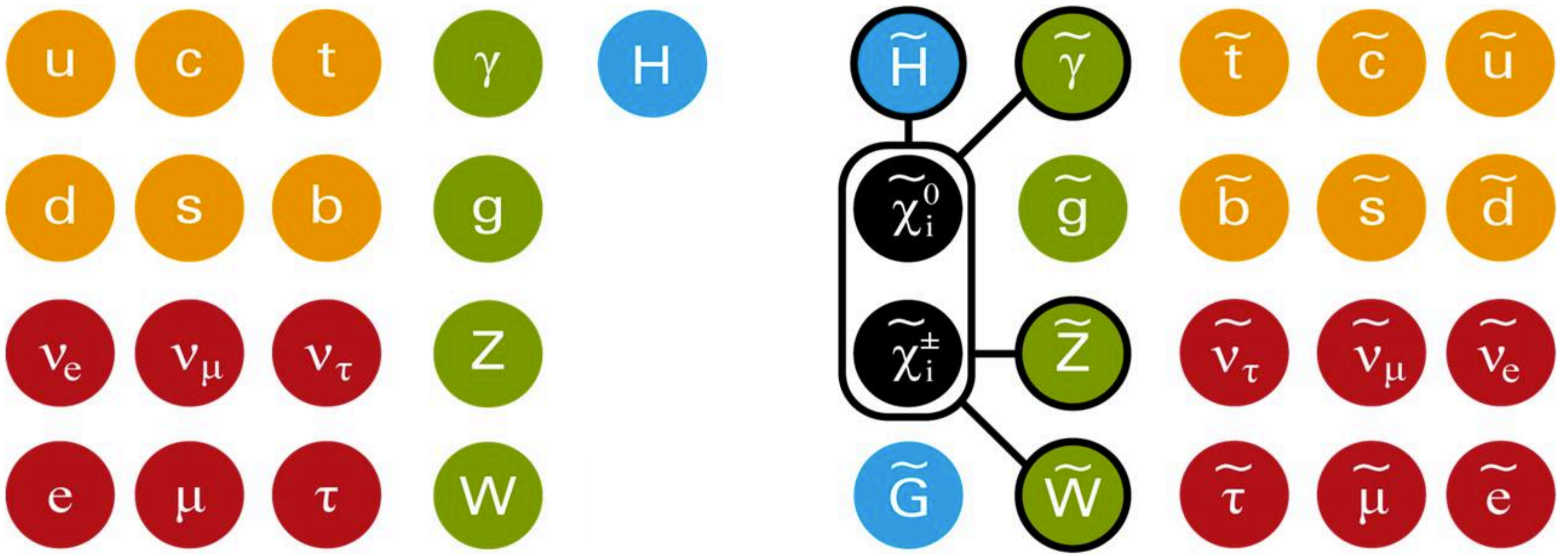


$\tilde{H}^0_u\ \tilde{H}^0_d\ \tilde{W}^0\ \tilde{B}^0 \xrightarrow{\text{mixing}} \tilde{\chi}^0_1\ \tilde{\chi}^0_2\ \tilde{\chi}^0_3\ \tilde{\chi}^0_4$ neutralinos

$\tilde{H}^+_u\ \tilde{H}^-_d\ \tilde{W}^+\ \tilde{W}^- \xrightarrow{\text{mixing}} \tilde{\chi}^\pm_1\ \tilde{\chi}^\pm_2$ charginos

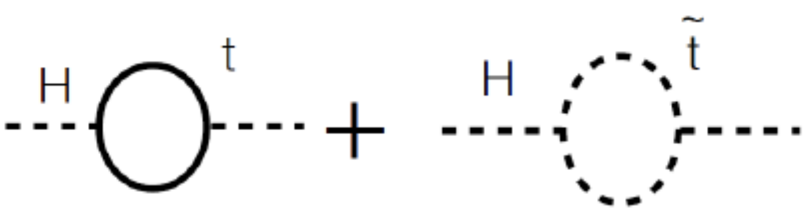
- extension of the Standard Model: introduction of a new symmetry
- relating spin ½ matter particles (fermions) ⇔ spin 1 particles (bosons)
- SUSY partners are heavier than SM partners →broken symmetry
- solves hierarchy (and other) problems of the SM

Supersymmetry (SUSY)



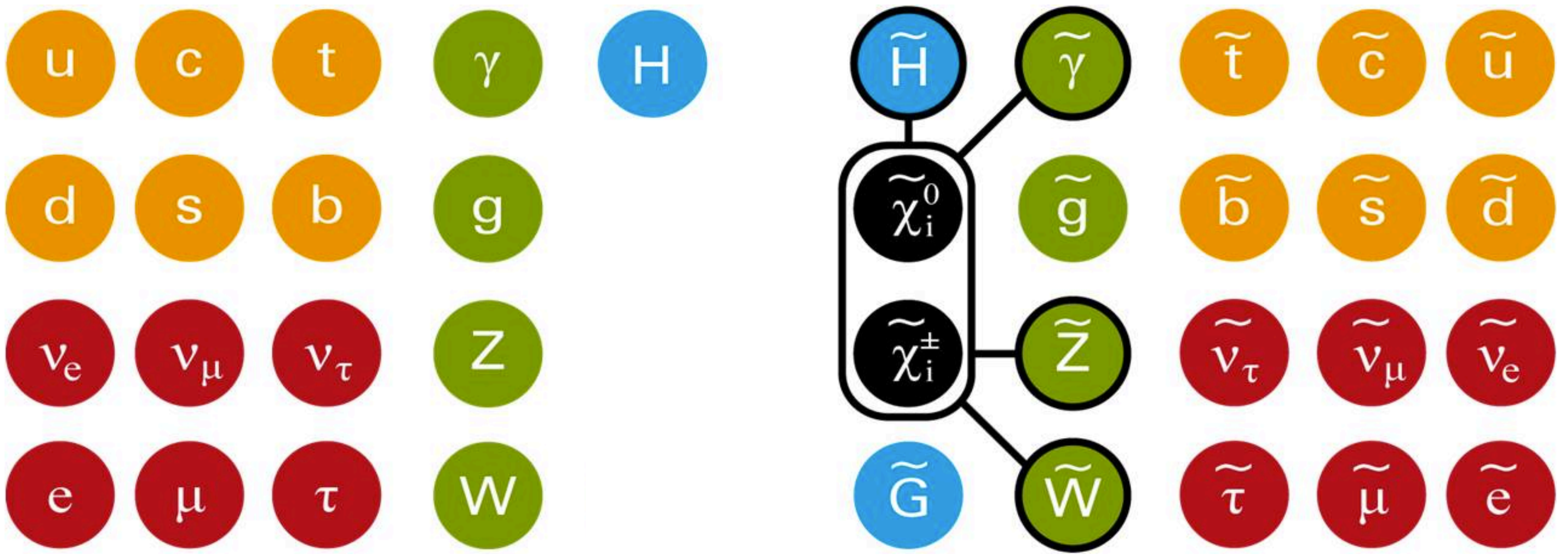
- solves hierarchy problems of the SM

  → stabilises the higgs mass from quadratically divergent loop corrections

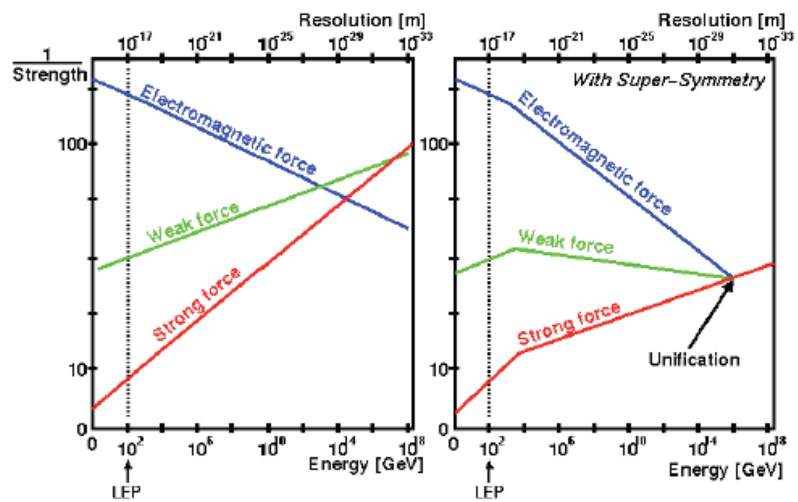


superpartner loop
cancel SM loop

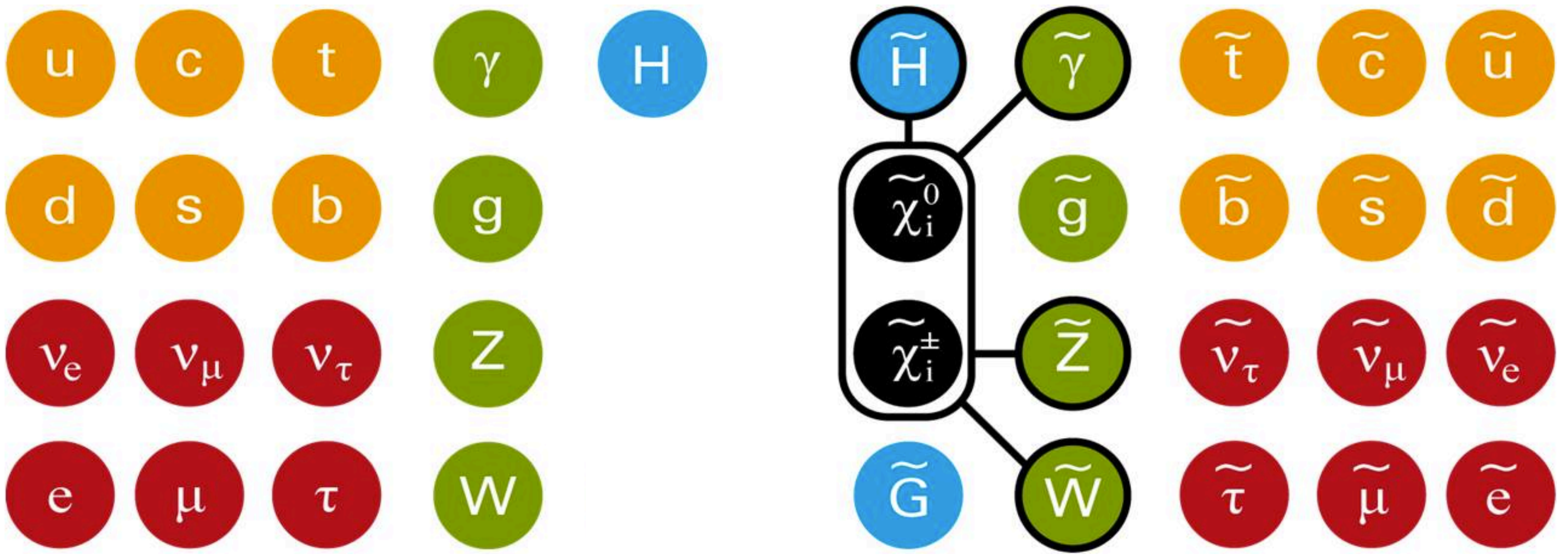
Supersymmetry (SUSY)



- provides possibility of unification of the EW and QCD coupling constants



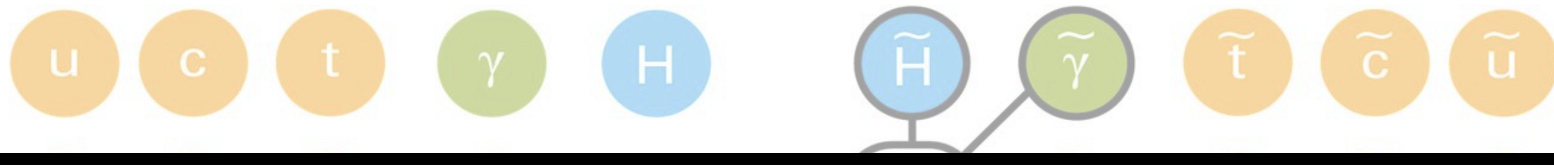
Supersymmetry (SUSY)



- new quantum number: R-parity R= $(-1)^{B+L+2S}$ = +1 (-1) SM (SUSY) particles
- if R-parity is conserved, lightest SUSY particles (LSP) is stable
- in many SUSY models, LSP is commonly lightest neutralino $\tilde{\chi}_1^0$

  → dark matter candidate

Supersymmetry (SUSY)



For the past ~30 years SUSY has been supposed to be "just around the corner", but no observation yet.

How do we search for SUSY at the LHC?

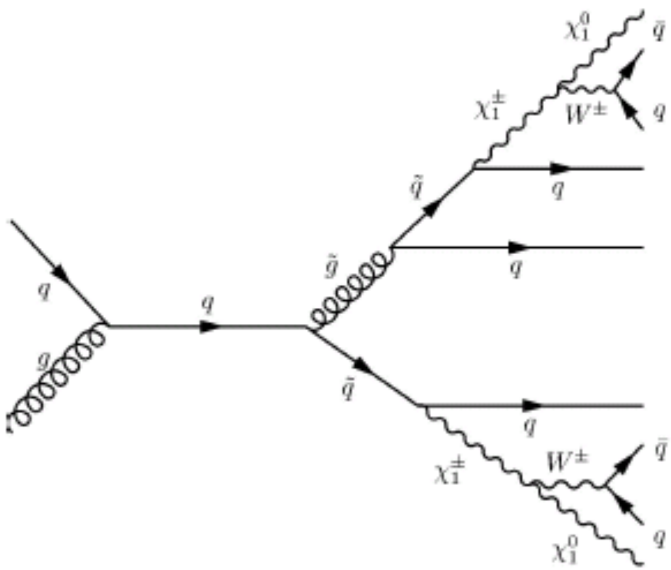
→ dark matter candidate

Searching for Supersymmetry

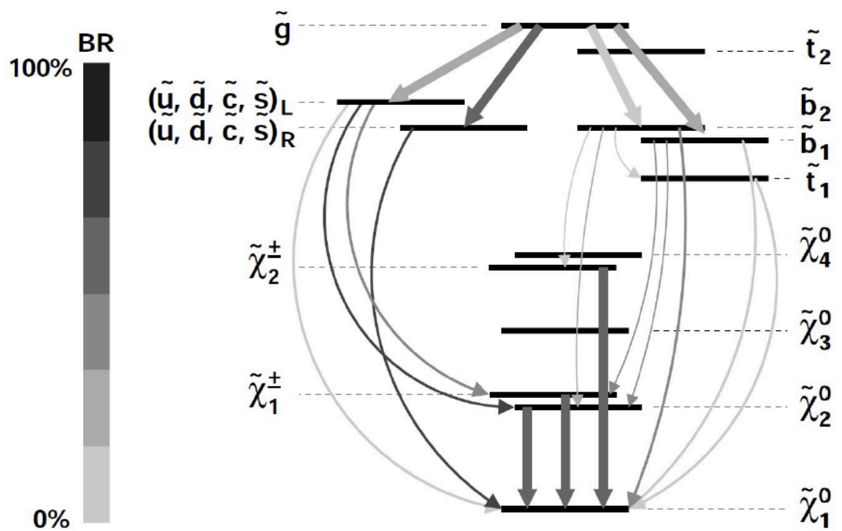
How to search for SUSY ?

A typical SUSY model involves:

- many sparticles with different masses
- different possibilities for each to decay



"typical" SUSY decay chain at the LHC

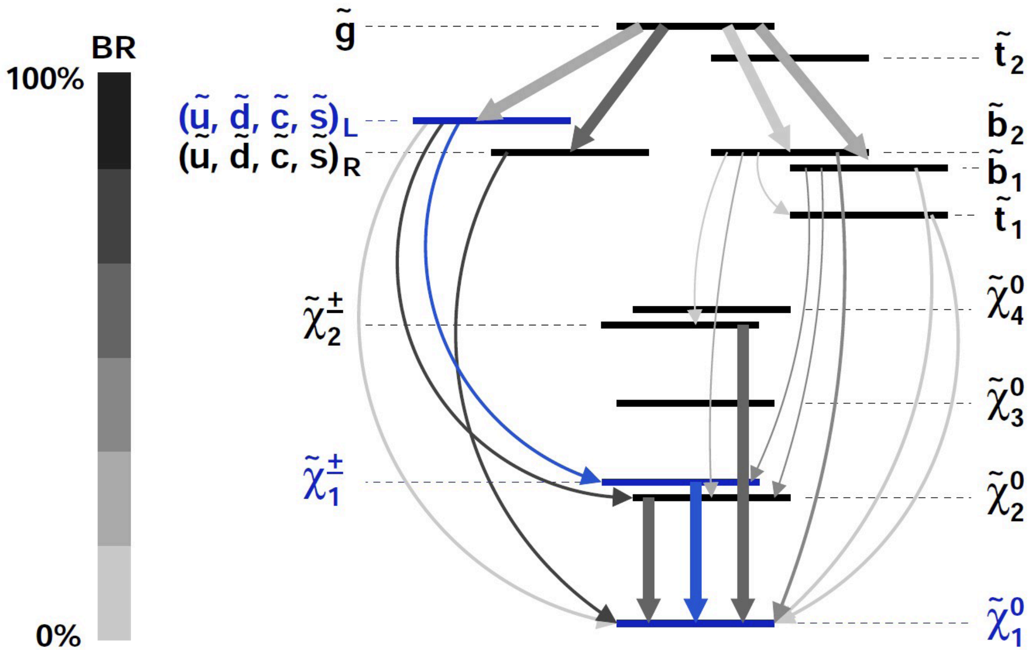


example for SUSY model e.g. CMSSM/MSUGRA

Searching for Supersymmetry

How to search for SUSY ?

✓ focus on the process of interest



squarks decay into chargino → neutralino

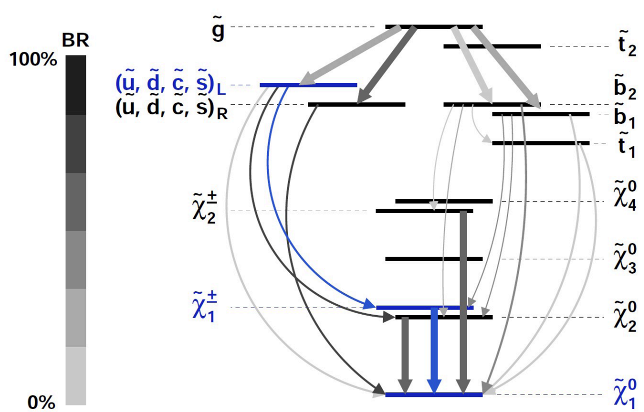
Searching for Supersymmetry

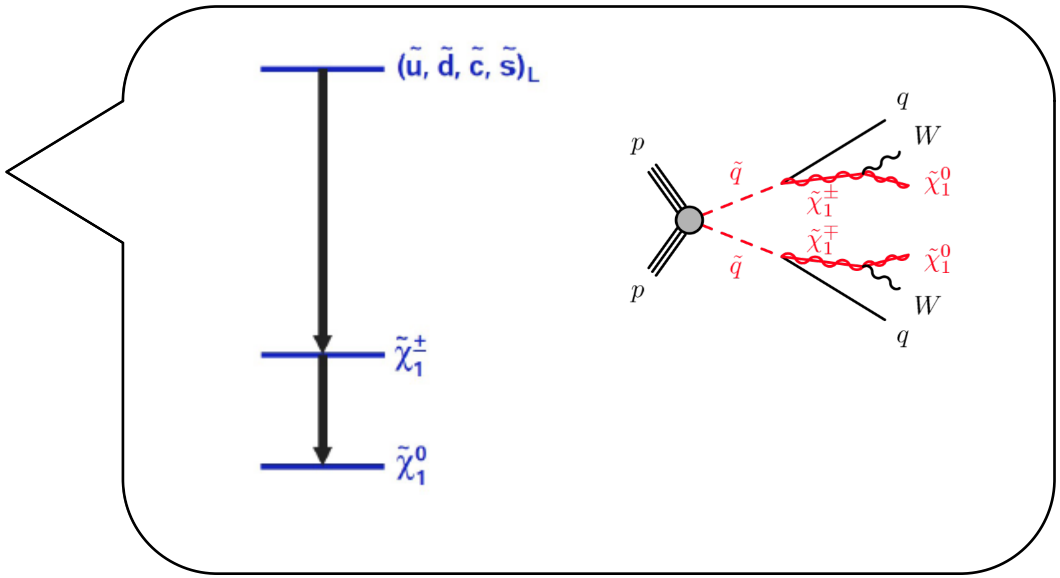
How to search for SUSY ?

✓ focus on the process of interest

✓ study a specific decay chain using simplified models

- simple and broad approach for SUSY searches
- small number of sparticles
- assumed BR usually 100%
- decay described by masses and cross sections

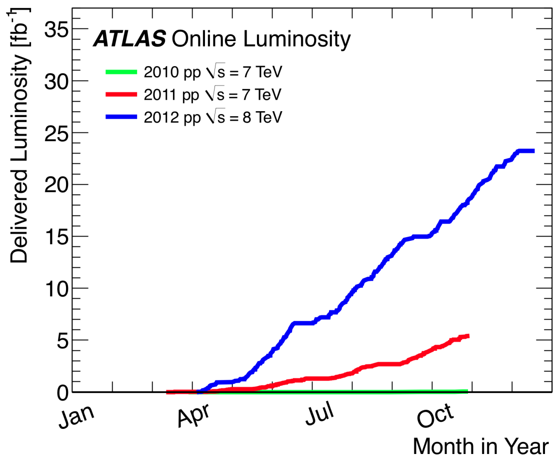


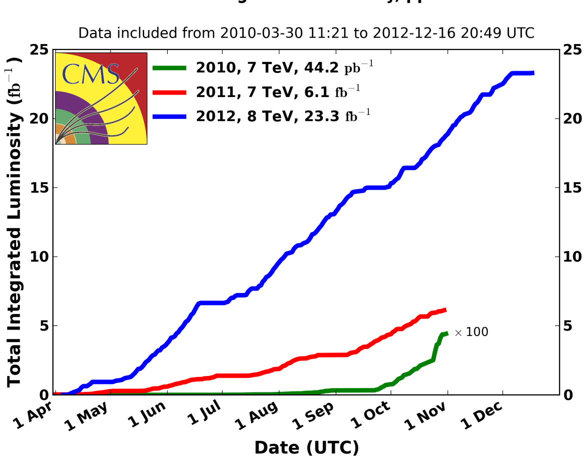


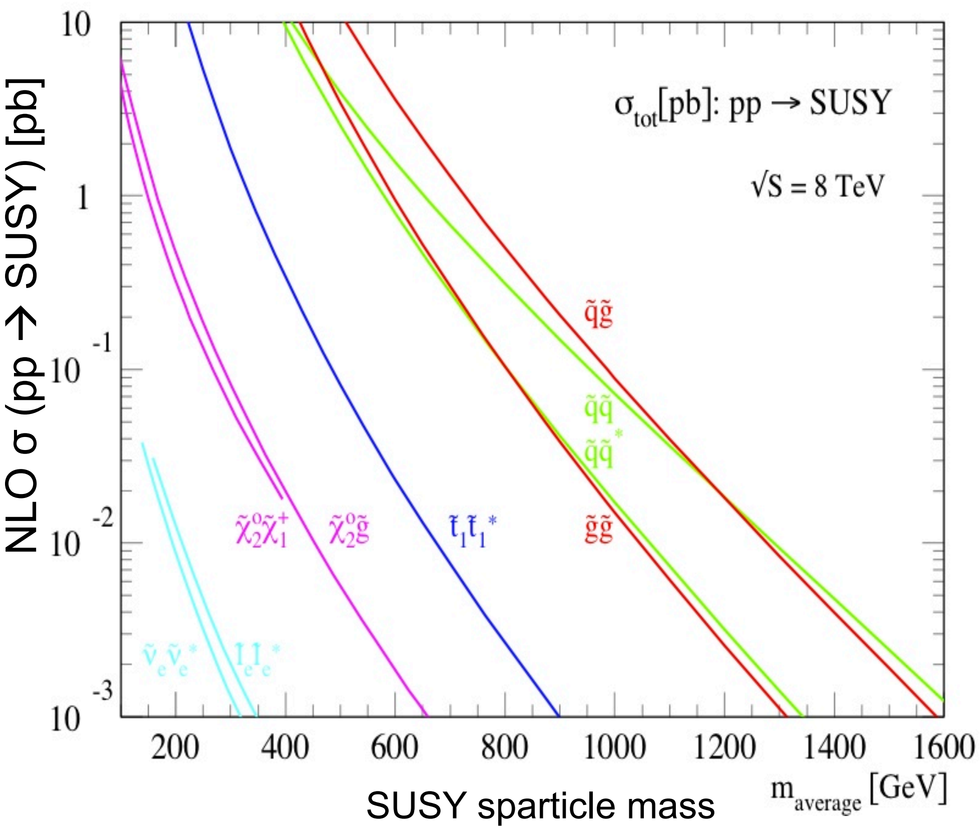
Search strategy

Where do we start?

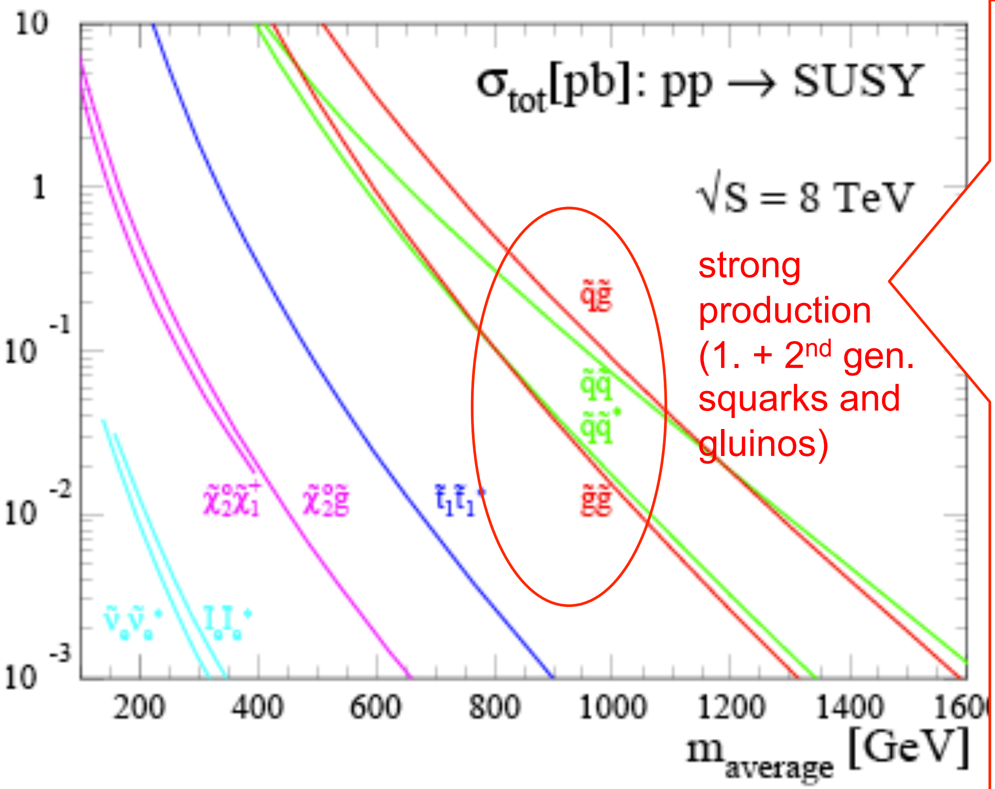
SUSY search strategy is driven by the cross-section and luminosity





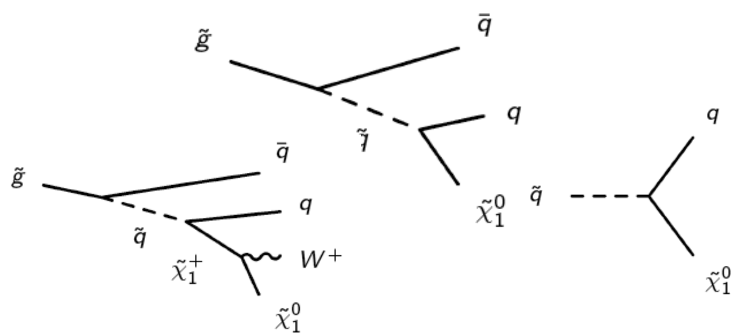


Search strategy



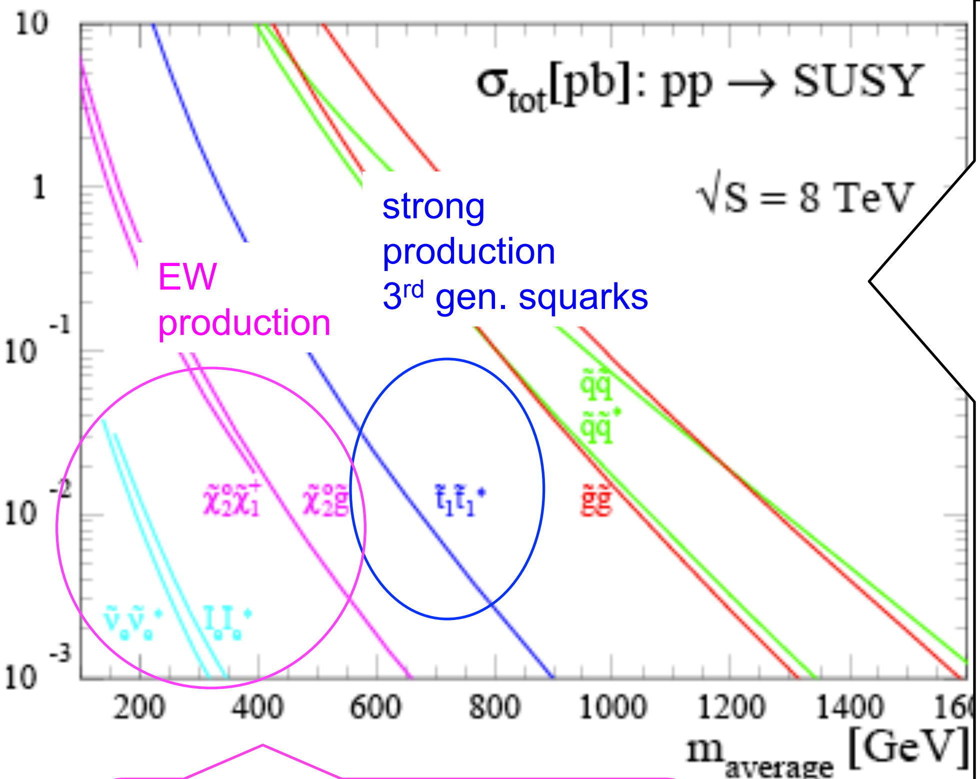
- early analyses:

  dominated by inclusive searches for strongly produced SUSY particles (gluino and squarks) due to high production cross sections
- many SUSY models e.g. MSUGRA/CMSSM dominated by strong production
- final states depend on the decays of squark/gluino: jet + E_T^{miss} + leptons

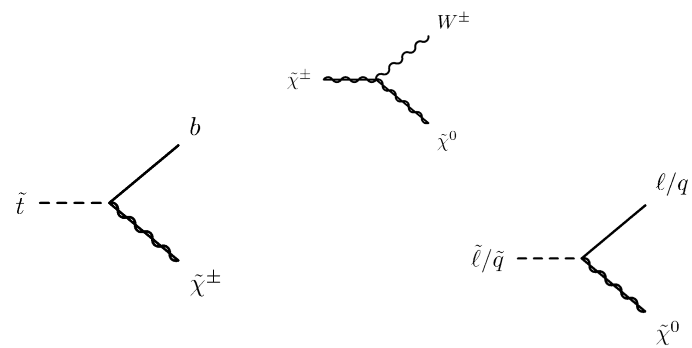


Search strategy

With increasing luminosity: access to rare production channels



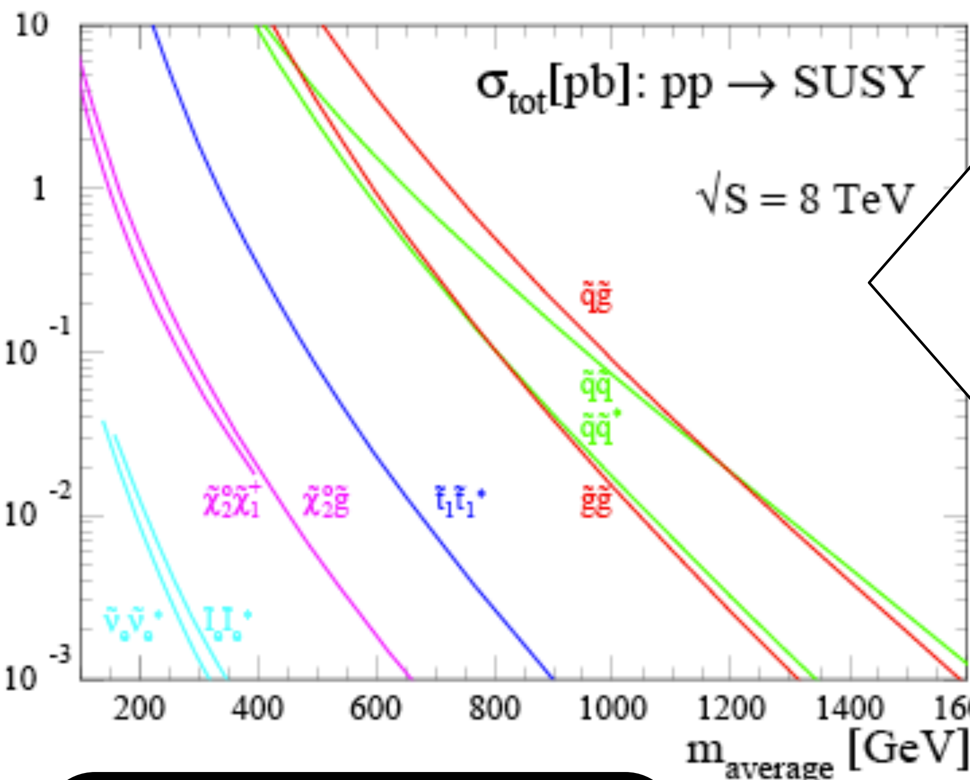
- smaller cross sections
- motivation from natural SUSY:
  - light stops (m < 1 TeV)
  - light higgsinos
  - gluinos m < 1.5-2 TeV
  - charginos, neutralinos of few hundreds GeV
- final states: (b)-jet + E_T^{miss} + leptons



if colored SUSY particles are too heavy, electroweak production can be dominant SUSY production mechanism at the LHC

Search strategy

With increasing luminosity: access to rare production channels



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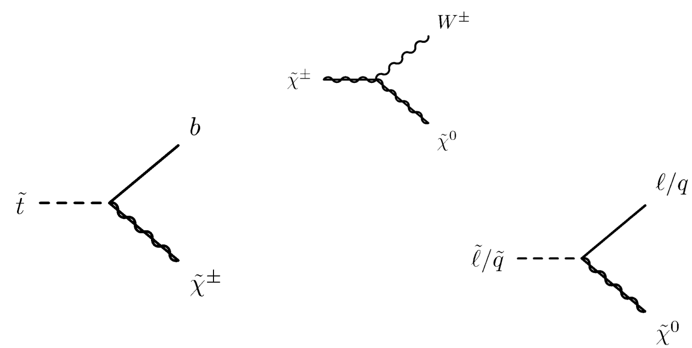


also addressed:
experimentally challenging searches such as long-lived particles and R-parity violating (RPV) scenarios

Search strategy

- search strategy designed to cover this broad spectra of different SUSY models
- for every search: signal regions are optimized individually based on the variety of the models/decay chains

prompt					Long-lived
R-parity conserved			R-parity violation		RPC or RPV various ranges of lifetime
Strong production 1st, 2nd generation squarks, gluinos	3rd generation stop, sbottom	weak production EWKinos, sleptons	RPC production RPV decays	RPV production RPV decays	

Search strategy

- search strategy designed to cover this broad spectra of different SUSY models
- for every search: signal regions are optimized individually based on the variety of the models/decay chains

I will only discuss the latest results using full 2012 data (20fb^{-1}), but unfortunately I am not able to cover all searches CMS and ATLAS have performed in the quest for SUSY!

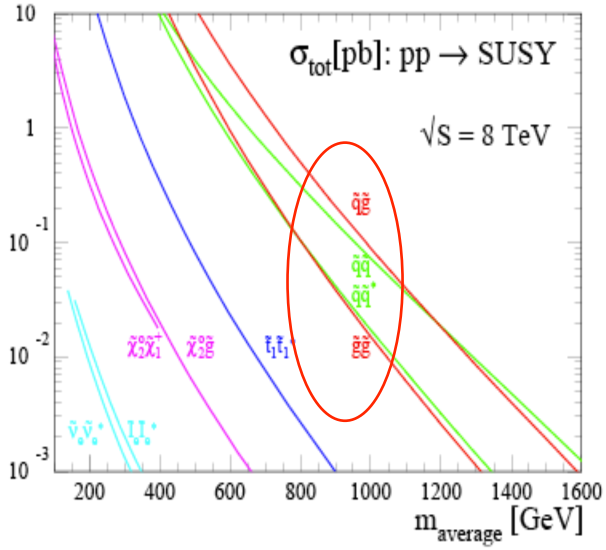
You can find a summary of all SUSY results + links to the analysis under:

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

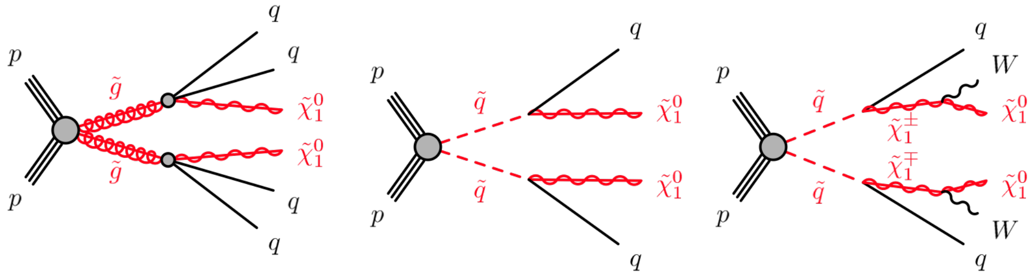
https://twiki.cern.ch/twiki/bin/view/AtlasPublicSupersymmetryPublicResults

squarks, gluinos	sbottom	sleptons	decays	decays	

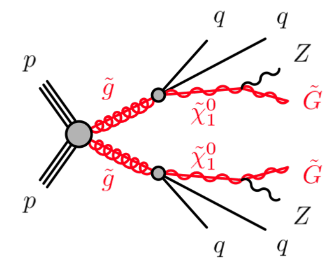
1st and 2nd generation squark and gluino production



Squark-gluino searches



squark/gluino production with neutralino LSP



squark/gluino production with gravitino LSP

- very high cross sections for strongly produced SUSY particles at the LHC

  → large yield even in small datasets

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

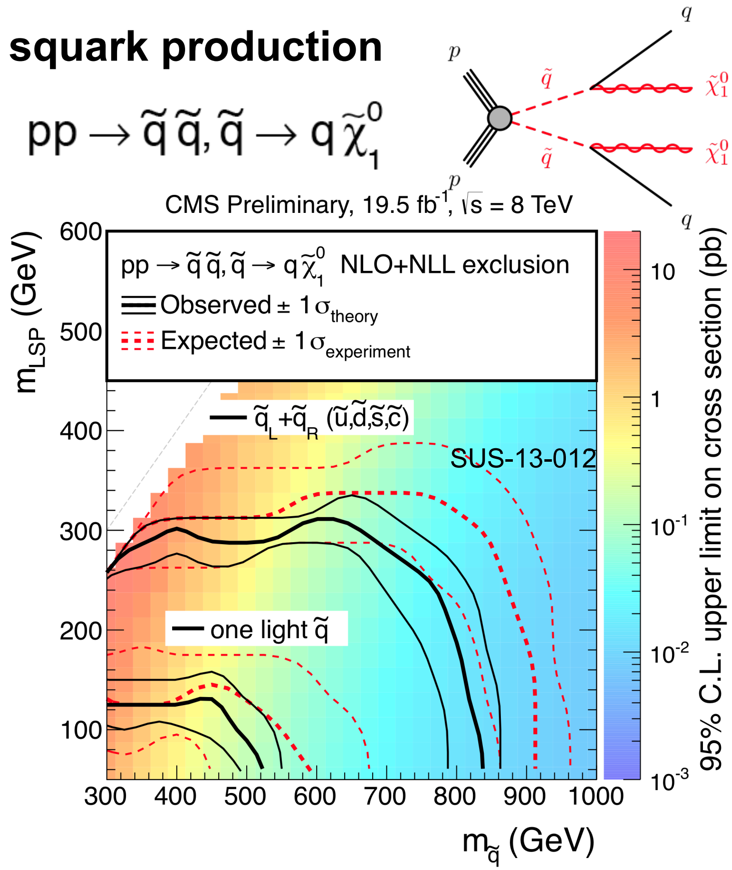
ATLAS searches

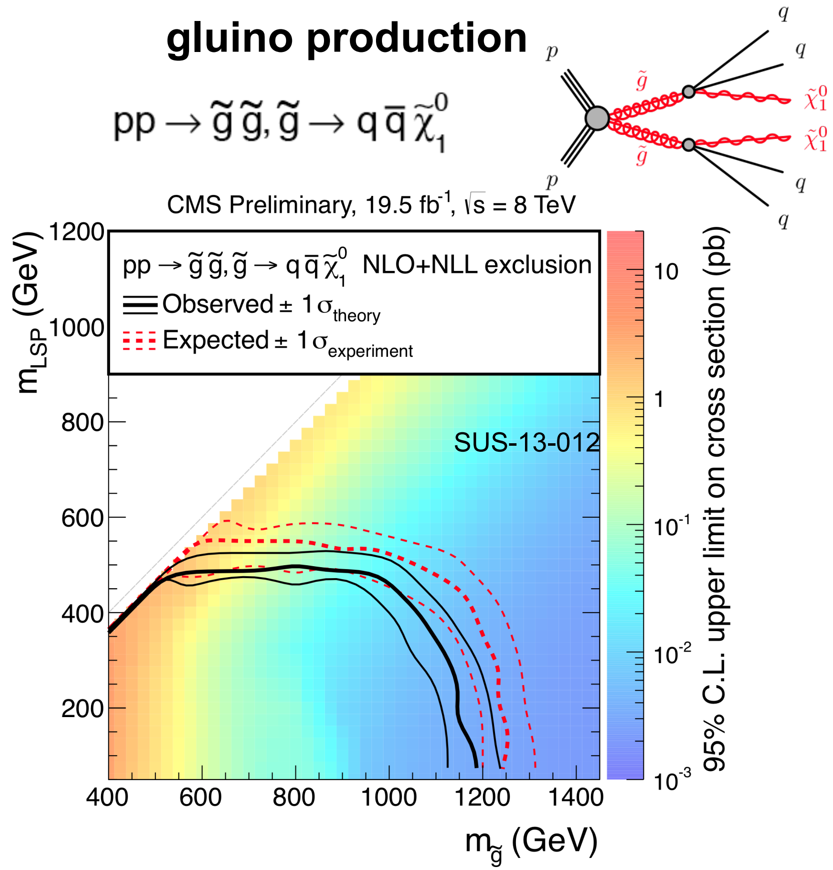
0-leptons + 2-6 jets+ E_T^{miss}	ATLAS-CONF-2013-047
0-leptons + 7-10 jets+ E_T^{miss}	arxiv 1308.1841
1-2-leptons + 3-6 jets + E_T^{miss}	ATLAS-CONF-2013-062
2-leptons + 2-6 jets + E_T^{miss} (Razor)	ATLAS-CONF-2013-089
2-leptons SS + 0-3 b-jets + E_T^{miss}	ATLAS-CONF-2013-007
1-2 taus + jets+ E_T^{miss}	ATLAS-CONF-2013-026

CMS searches

2-3, ≥ 4 jets + 0,1, 2, 3, ≥4 b-jets + E_T^{miss} (α_T)	SUS-12-028
3-5, 6-7, ≥ 8jets + E_T^{miss}	SUS-13-012

Squark-gluino searches

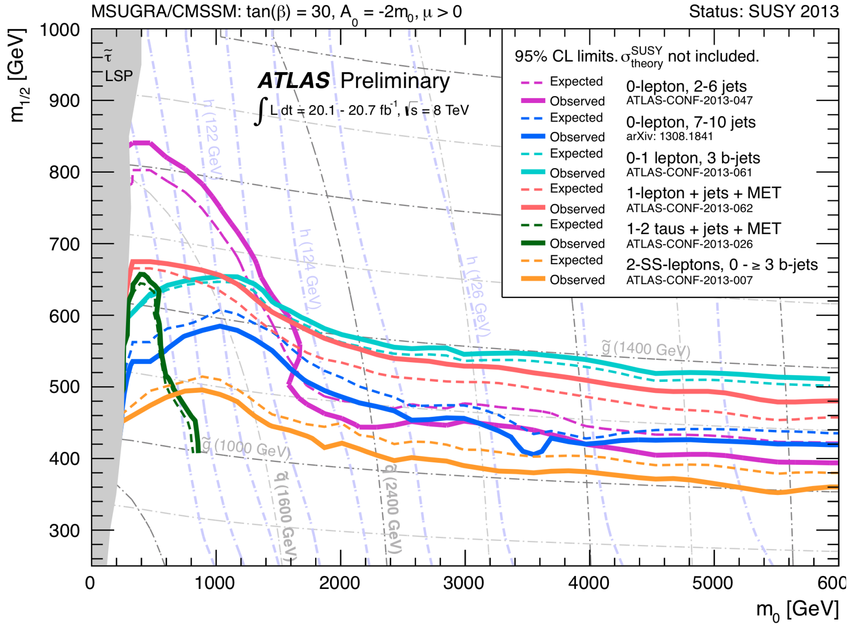




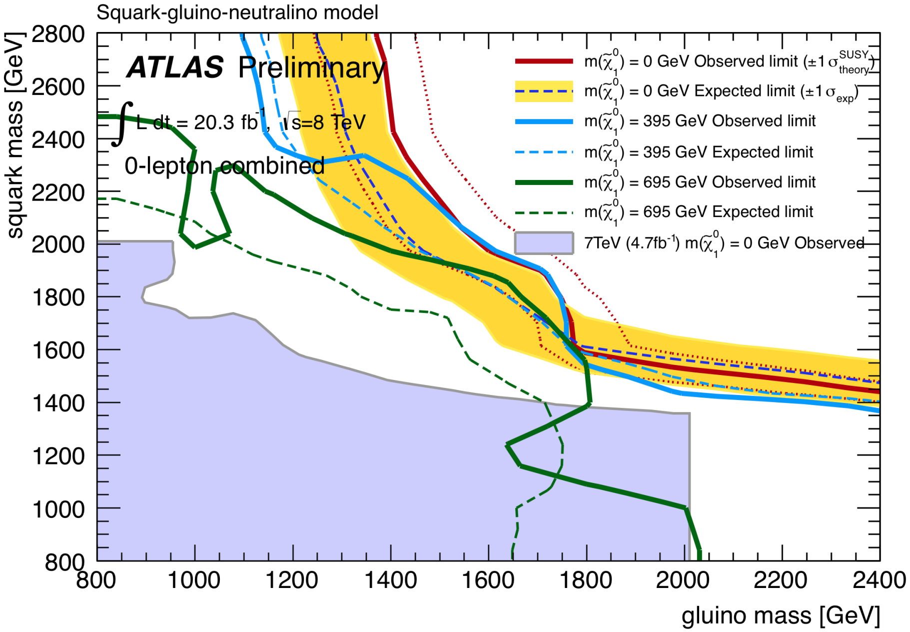
- assume 100% BR for the stated process in the simplified model grids
- weaker limits with reduced number of squarks kinematically available e.g. (u_L, u_R) : m(light squark) < 500 GeV
- limits for massless LSP: m(squark) < 850 GeV, m (gluino) < 1.2 TeV
- computed excluded cross section for each model in parameter space

Squark-gluino searches: mSUGRA – pMSSM models

mSUGRA/CMSSM grid



pMSSM grid



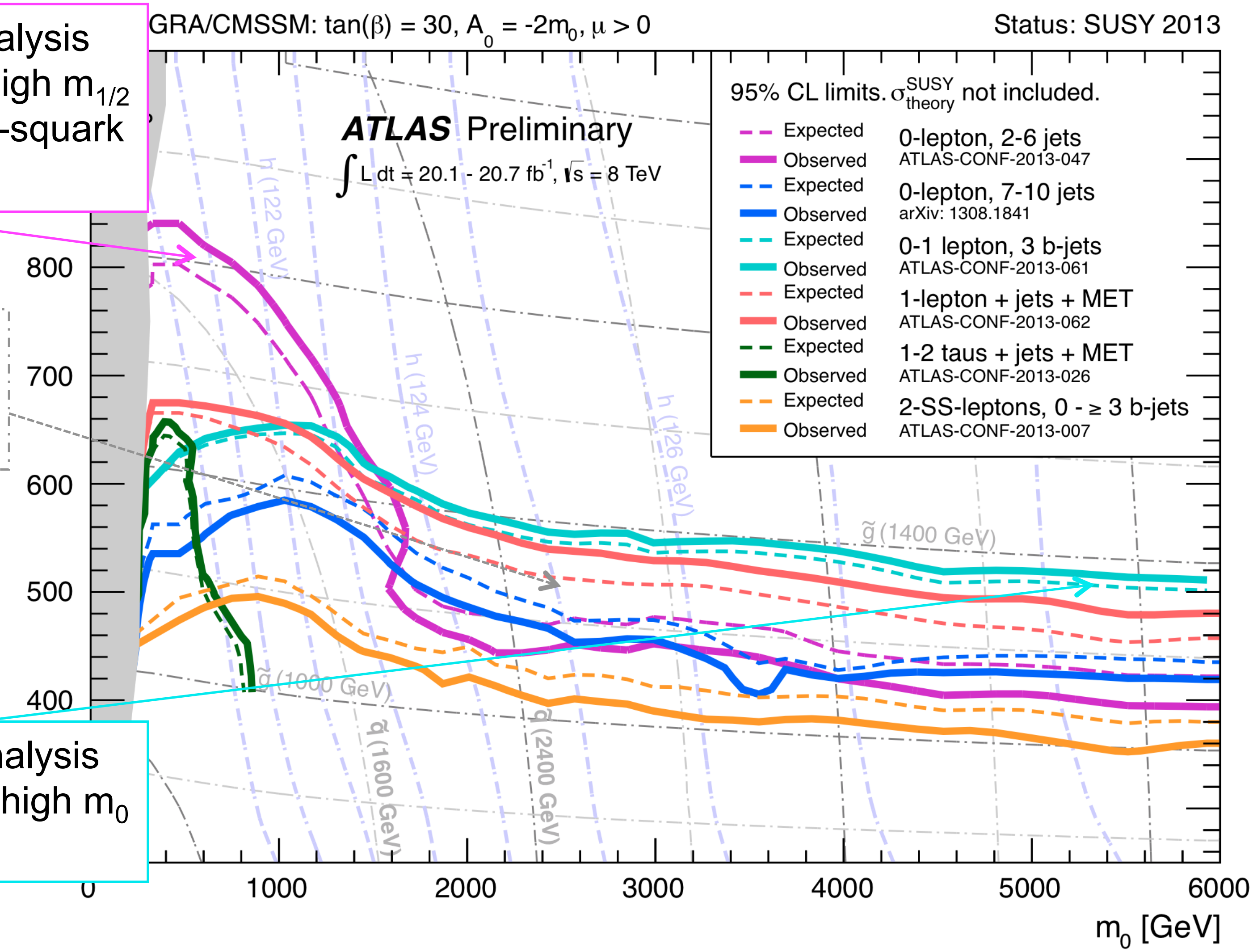
higgs-aware:
accommodates a lightest neutral scalar Higgs boson mass of 125 GeV

simplified pMSSM scenarios with only strong production of gluinos and first- and second-generation squarks (of common mass)

Squark-gluino searches: mSUGRA models

0-lepton + 2-6 jets analysis strongest at low m_0, high $m_{1/2}$
→ dominated squark-squark production

≈ 1.35 TeV gluinos excluded for any squark mass

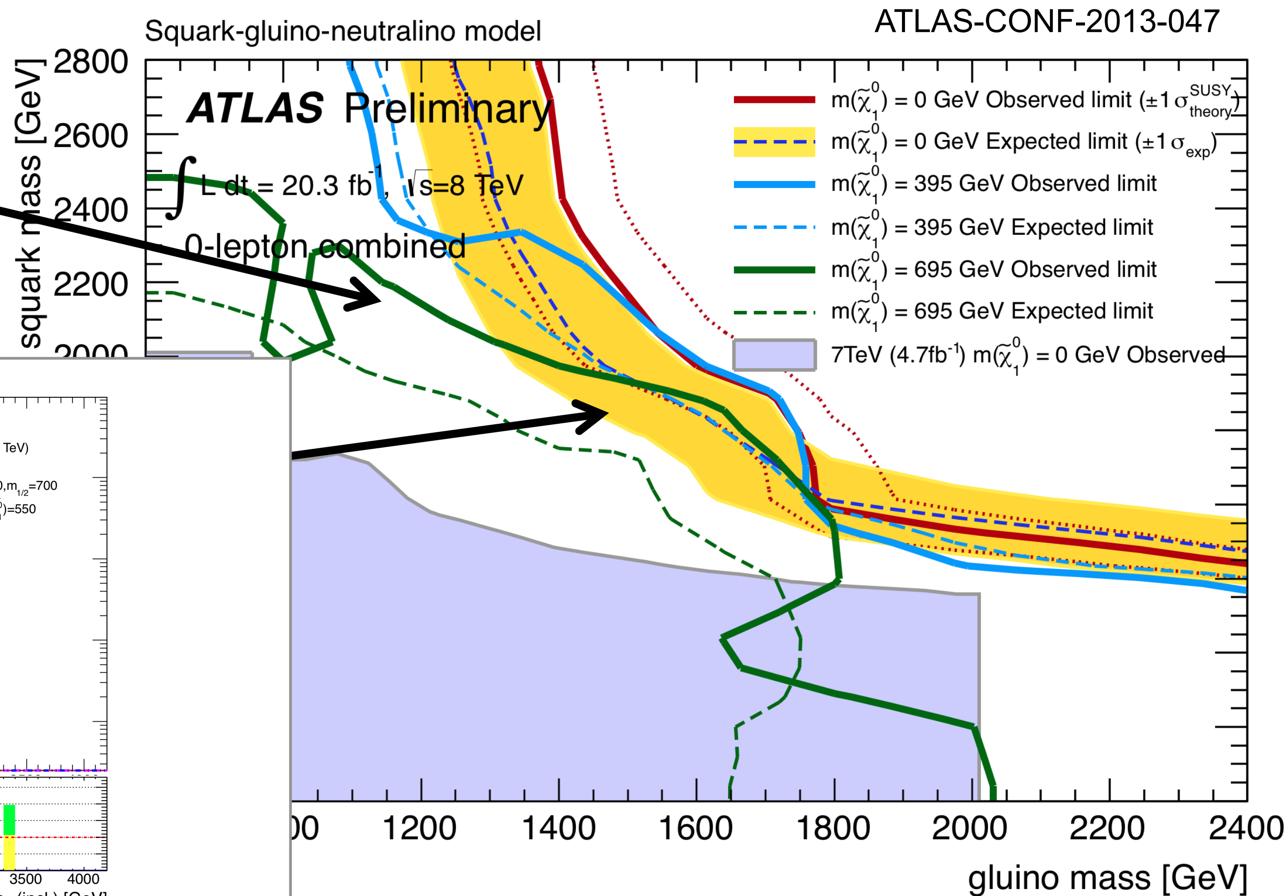


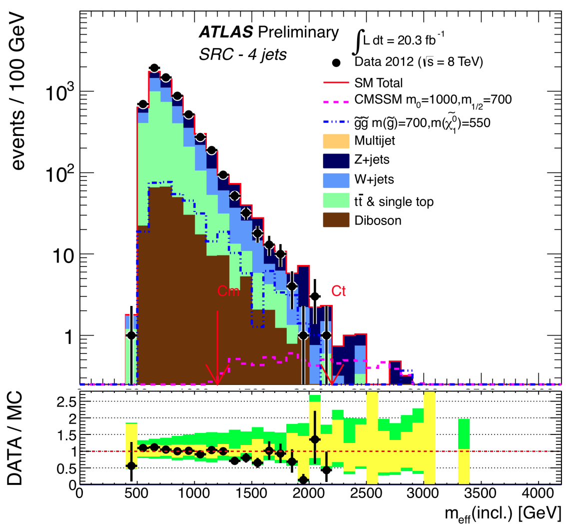
0-lepton + 3 b- jets analysis strongest at low $m_{1/2}$, high m_0
→ mostly $\tilde{g} \to \tilde{t} / \tilde{b}$

Squark-gluino searches: pMSSM models

three models with different LSP mass are considered:

- $m(\tilde{\chi}_1^0)=0$ GeV
- $m(\tilde{\chi}_1^0)=395$ GeV
- $m(\tilde{\chi}_1^0)=695$ GeV





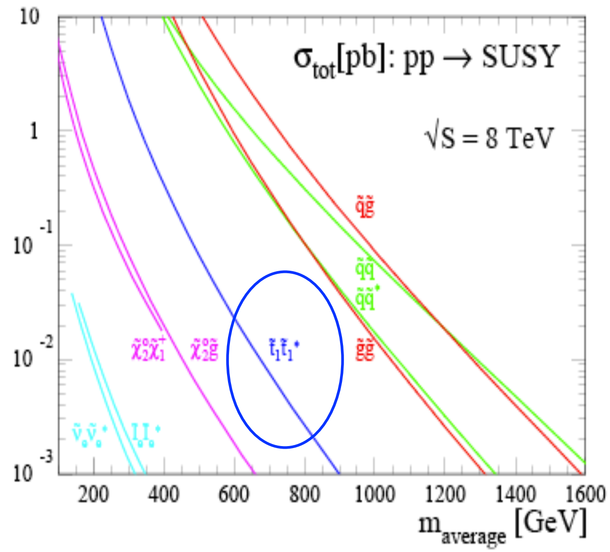
SR 4 jet

$\geq$ 4 jets, $E_T^{miss} > 160$ GeV,

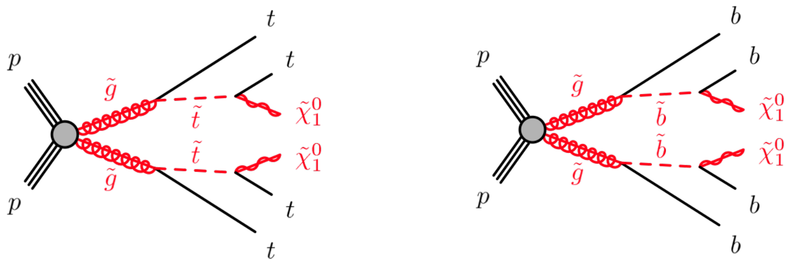
$M_{eff} = \Sigma p_T$ (jets) + $E_T^{miss} > 1.2$ (2.2) TeV

lines show best limits from the 10 SRs

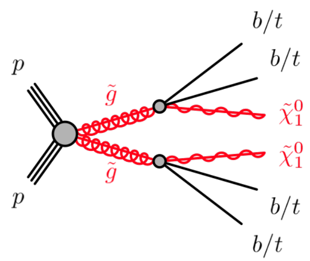
3rd generation squark production



Natural SUSY searches – gluino mediated stops/sbottoms



gluino decay via off-shell stop/sbottom



gluino decays into LSP + top/bottom quarks

- targeting natural SUSY spectra with light stops and sbottoms
- light gluino can be produced in pairs and decay through (on-shell or off-shell) stops/ sbottoms
- better controlled SM backgrounds via b-tagging and special topology signatures (e.g. many jets) provide higher sensitivity

ATLAS searches

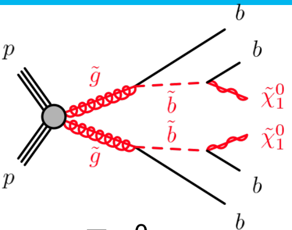
0-leptons + 7-≥ 10 jets+ E_T^{miss}	ATLAS-CONF-2013-054
0-1-lepton + ≥ 3 b-jets + E_T^{miss}	ATLAS-CONF-2013-061
2-leptons SS + 0-3 b-jets + E_T^{miss}	ATLAS-CONF-2013-007

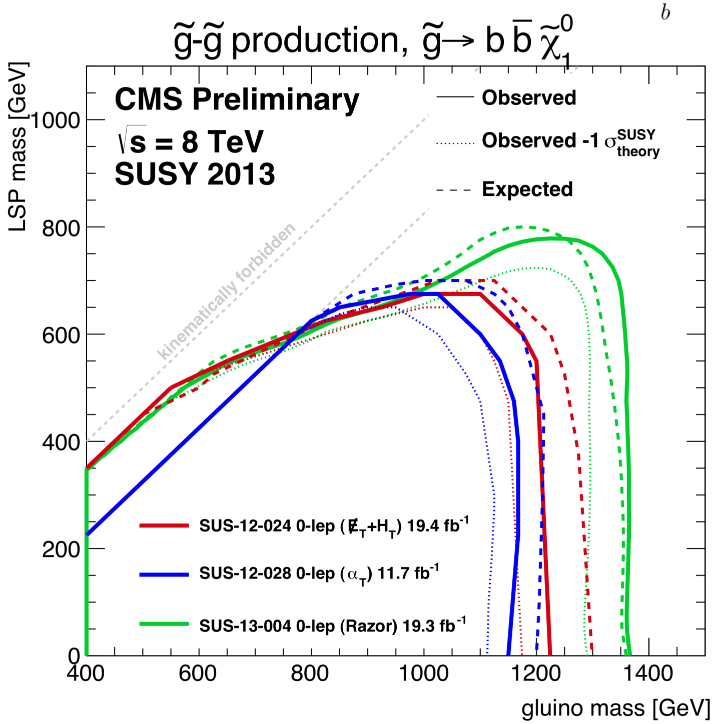
CMS searches

0 - 1 -lepton+ b-jets + E_T^{miss} (Razor)	SUS-13-004
3-5, 6-7, ≥ 8jets + E_T^{miss} (H_T)	SUS-12-024
1-lepton + b-jets + 2-3, ≥4 jets+ E_T^{miss}	SUS-13-007
3-lepton + b-jets + E_T^{miss}	SUS-13-008
2-leptons SS + b-jets + E_T^{miss}	SUS-13-013
2-leptons OS + b-jets + E_T^{miss}	SUS-13-016

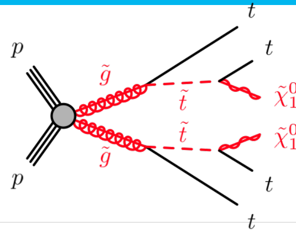
Gluino mediated sbottom-stop production

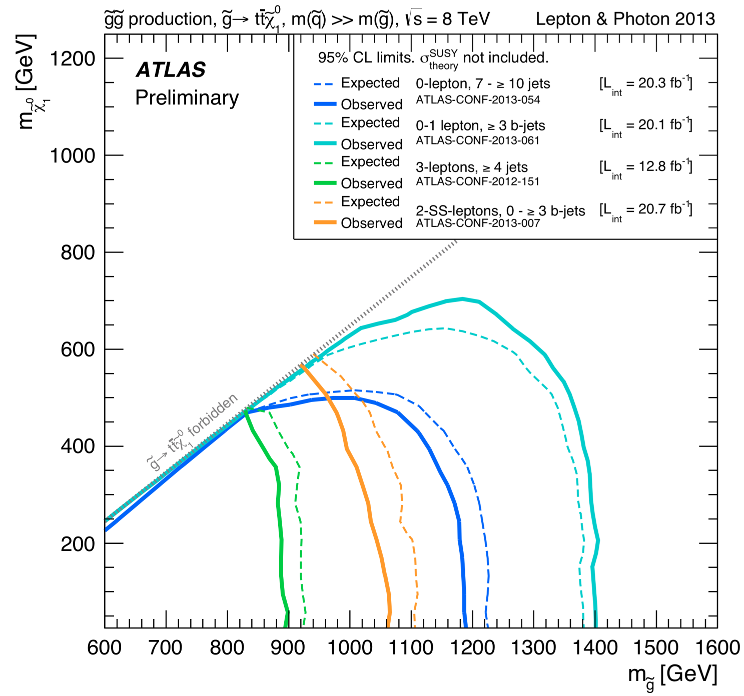
$\tilde{g} \rightarrow b\bar{b}\chi_1^0$





$\tilde{g} \rightarrow t\bar{t}\chi_1^0$

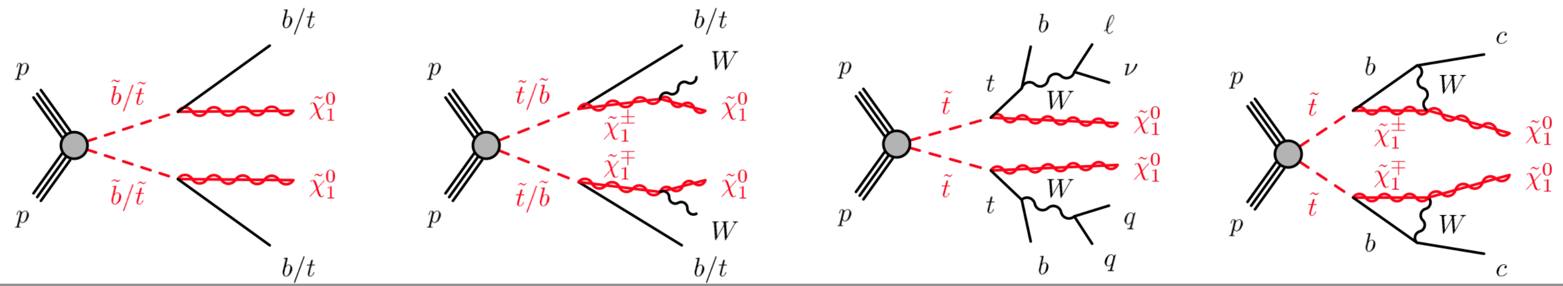




no exclusion for m(LSP) > 750 GeV
strongest limit: gluino masses < 1375 GeV for massless LSP

no exclusion for m(LSP) > 700 GeV
strongest limit: gluino masses < 1400 GeV for massless LSP

3rd generation direct production



- large spectrum of possible stops and sbottoms decays
- sensitivity is dependent on sparticle mass differences and decay channels:

  final states include (b)-jets, E_T^{miss} and (often) leptons
- effort so far: concentrated on simplified models with 100% BRs to chosen final state

ATLAS searches

sbottom searches

0-leptons + 2 b-jets+ E_T^{miss} arXiv:1308.2631
0-leptons + ≥3 b-jets+ E_T^{miss} ATLAS-CONF-2013-061
1-leptons + 4 (2 b-) jets+ E_T^{miss} ATLAS-CONF-2013-037
2-leptons (SS) + 3 (1 b-) jets+ E_T^{miss} ATLAS-CONF-2013-007

stop searches

0-lepton + 6 (2 b-) jets+ E_T^{miss} ATLAS-CONF-2013-024
0-lep. + charm/ mono-jet+ E_T^{miss} ATLAS-CONF-2013-068
2-leptons + (1, 2) b-jets+ E_T^{miss} ATLAS-CONF-2013-048/065
Z(ll) + b-jets+ jets+ E_T^{miss} ATLAS-CONF-2013-025

CMS searches

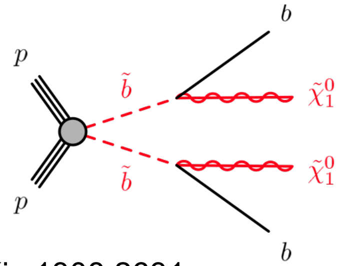
2-lepton (SS) + (b-) jets+ E_T^{miss} SUS-13-013

0 - 1 -lepton+ b-jets + E_T^{miss} (Razor) SUS-13-004
1-lepton 4 (1 b-) jets+ E_T^{miss} SUS-13-011

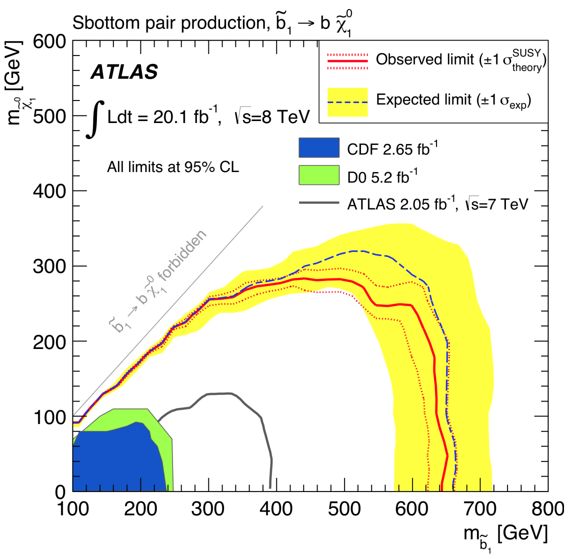
Stop 2 decays via higgs:
1-2 lepton + ≥ 4-5 (3- ≥ 4 b-) jets SUS-13-014

3^{rd} generation direct production – sbottom searches

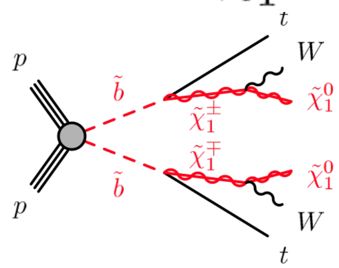
$\tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$



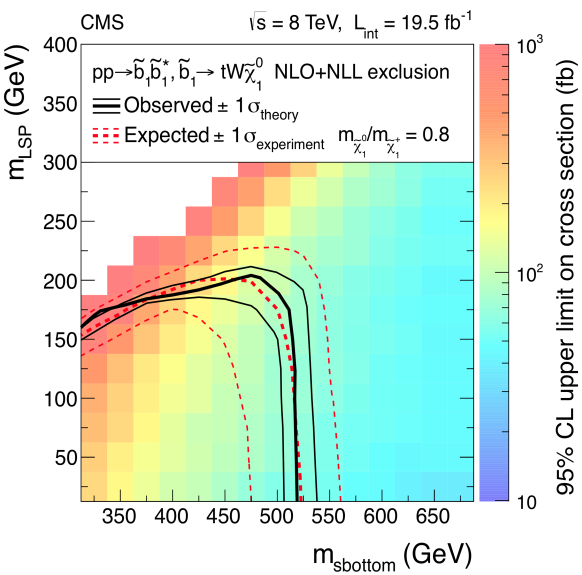
arXiv:1308.2631



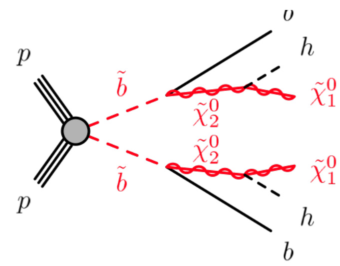
$\tilde{b}_1 \rightarrow t\tilde{\chi}_1^{\pm}$



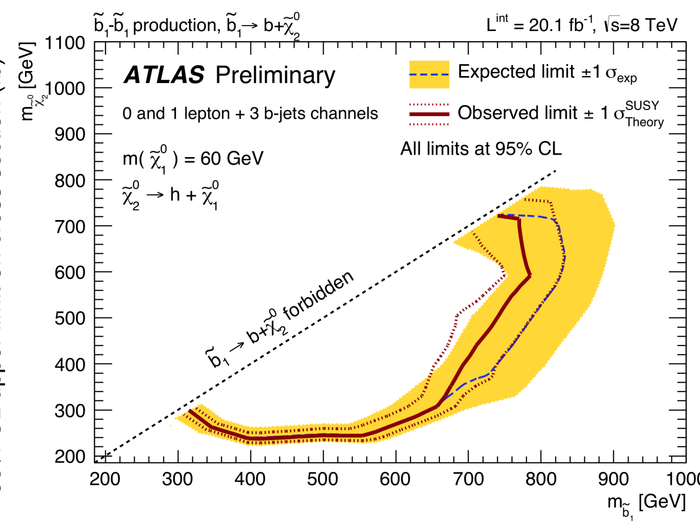
SUS-13-013



$\tilde{b}_1 \rightarrow b\tilde{\chi}_2^0 \rightarrow bh(bb)\tilde{\chi}_1^0$

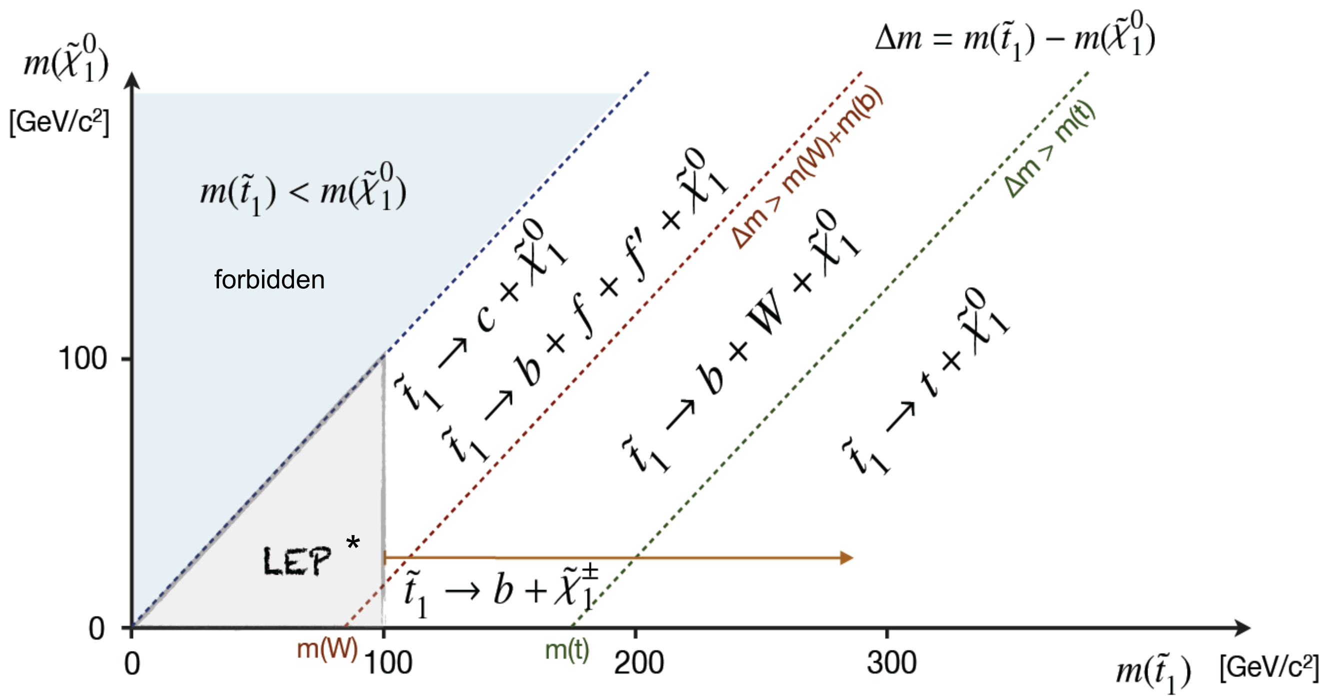


ATLAS-CONF-2013-061



- exclusion regions depend on decay chain and mass splitting e.g. between chargino – LSP
- for massless LSP: sbottoms up to 650 GeV are excluded
- best limits for LSP ~270 GeV

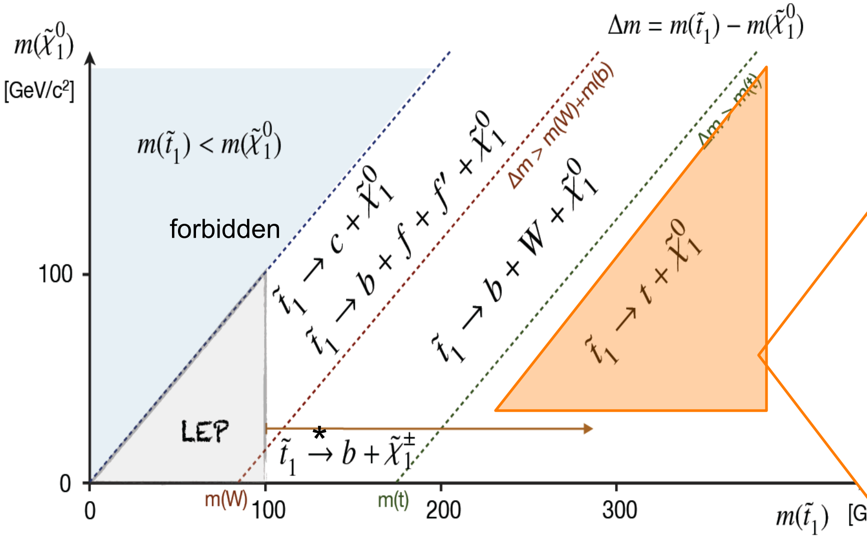
3rd generation direct production – stop searches



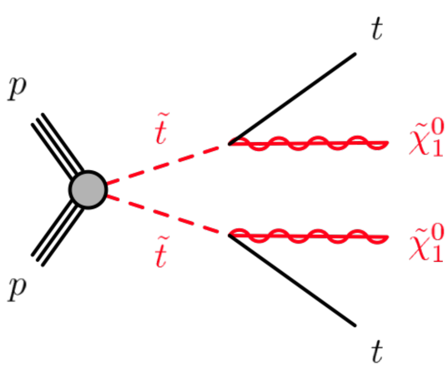
- multiple searches possible targeting different stop/chargino/neutralino mass hierarchies and decay scenarios
- decays depend on the stop mass and sparticle mass differences
- searches focus on simplified models with 100% BR on final state

* LEP: chargino mass limit at about 100 GeV

3rd generation direct production – stop searches

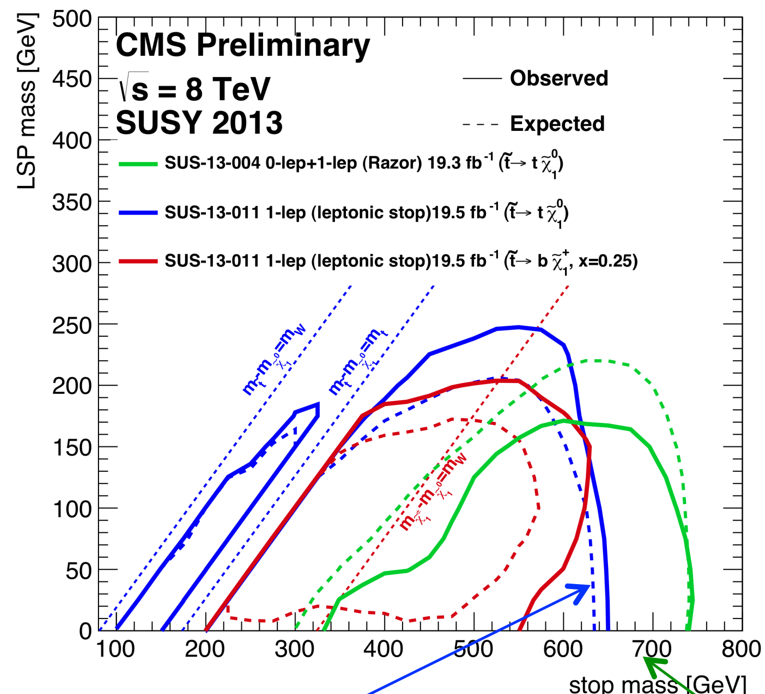


$$\tilde{t}_1 \to t\tilde{\chi}_1^0$$



stop masses up to 740 GeV for massless LSP are excluded assuming 100% BR
best limit for LSP < 250 GeV

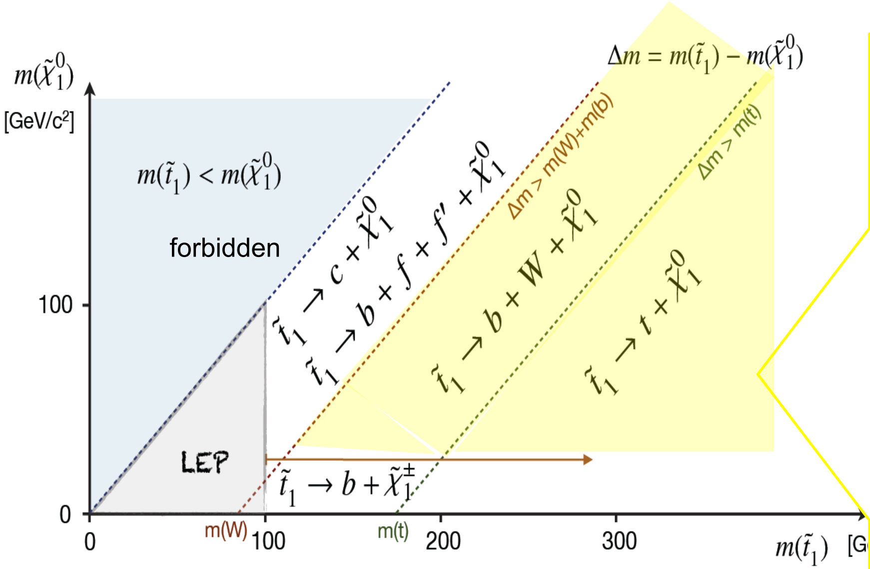
$\tilde{t}$-$\tilde{t}$ production



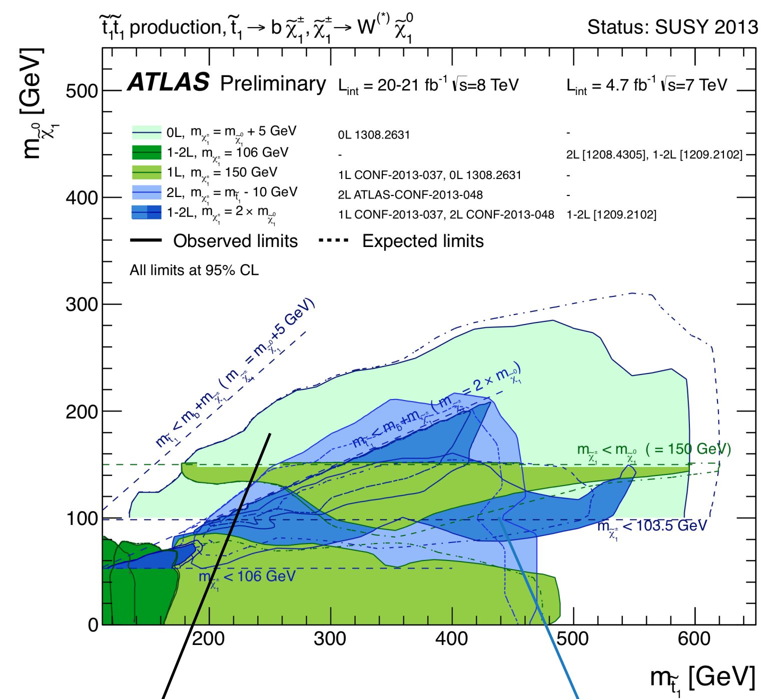
1-lepton analysis

0 + 1 lepton
Razor analysis

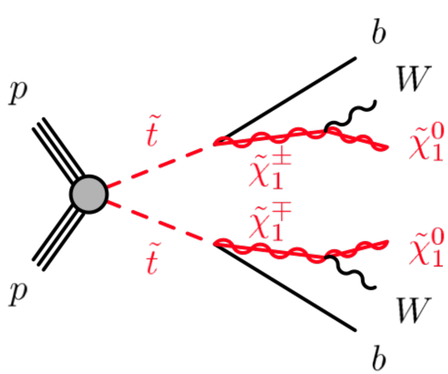
3rd generation direct production – stop searches



limits depend on chargino mass



$$\tilde{t}_1 \to b\tilde{\chi}^\pm_1$$



nearly mass-degenerated chargino, neutralino

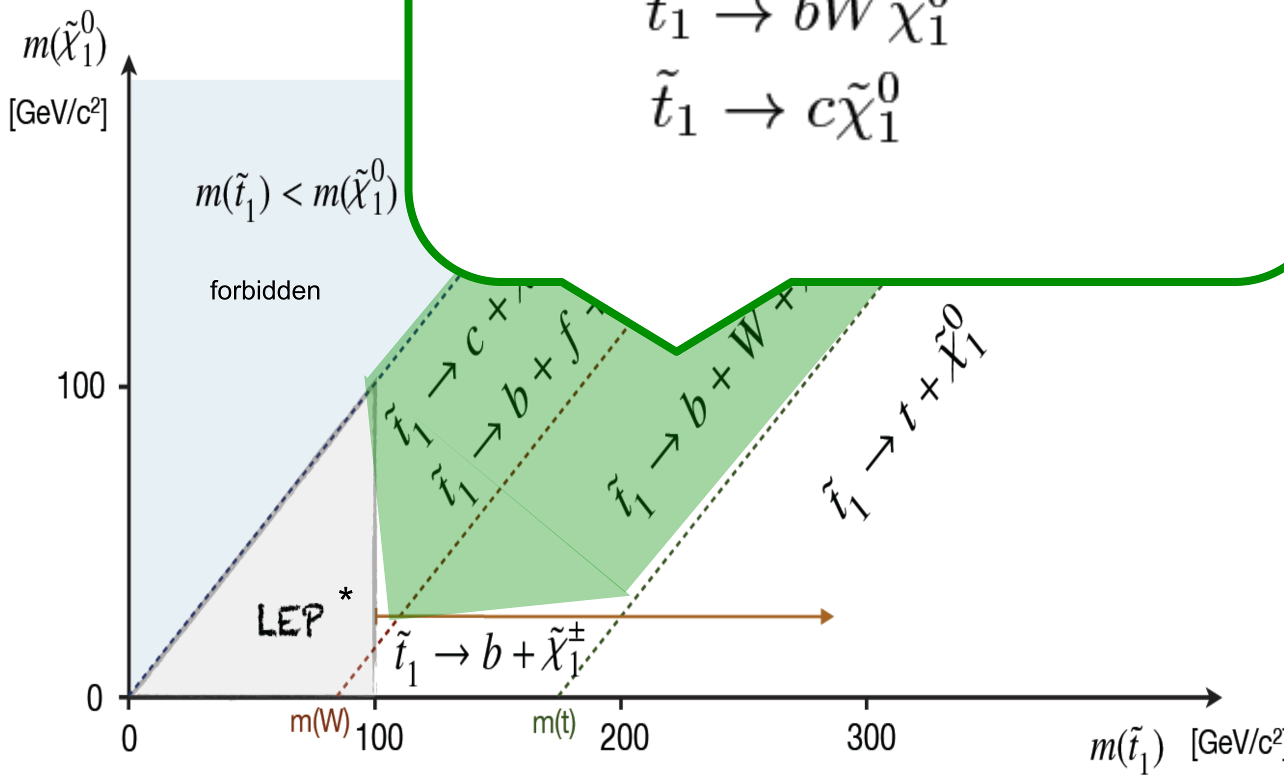
chargino mass = 2x neutralino mass

3rd generation direct production – stop searches

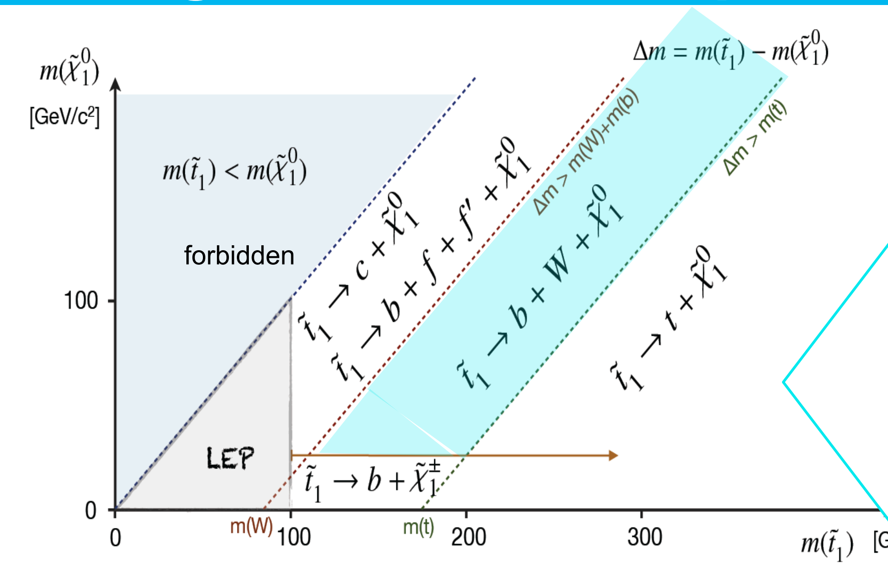
$$m_{\tilde{t}} - m_{LSP} < m_t$$

$$\tilde{t}_1 \rightarrow bW\tilde{\chi}_1^0$$

$$\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$$

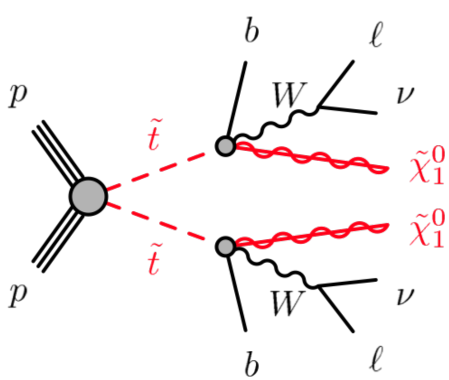


3rd generation direct production – stop searches

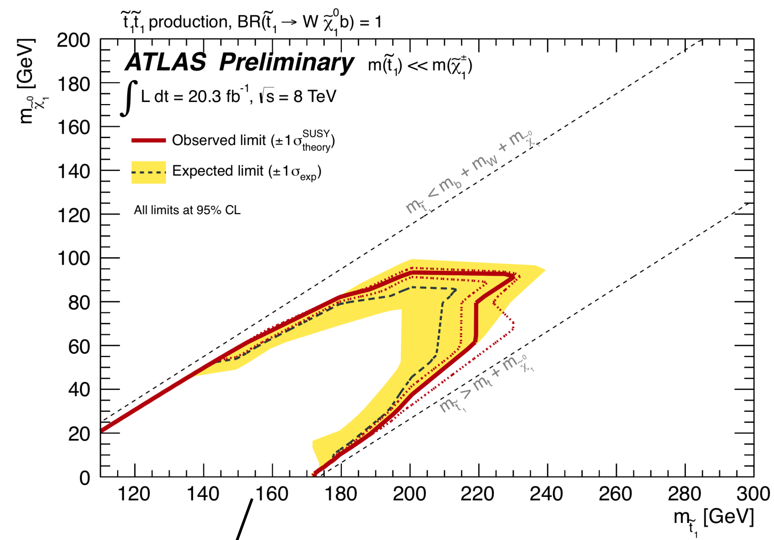


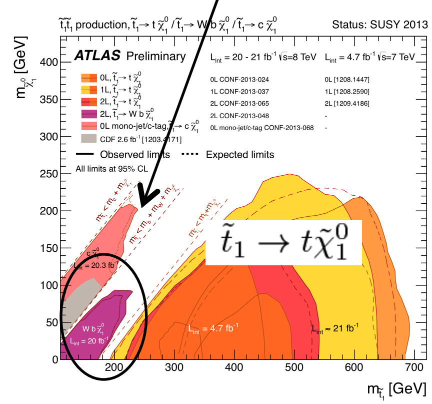
3-body decay

$$\tilde{t}_1 \to bW\tilde{\chi}^0_1$$



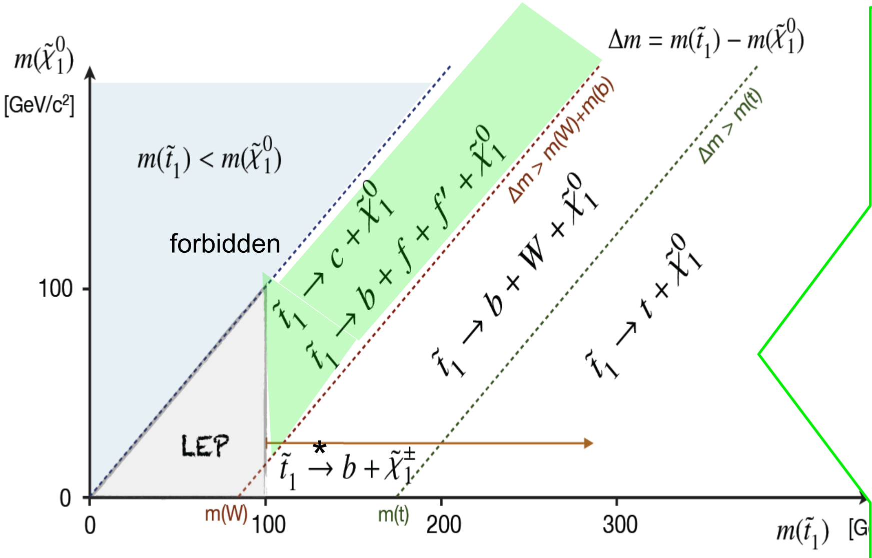
ATLAS-CONF-2013-048



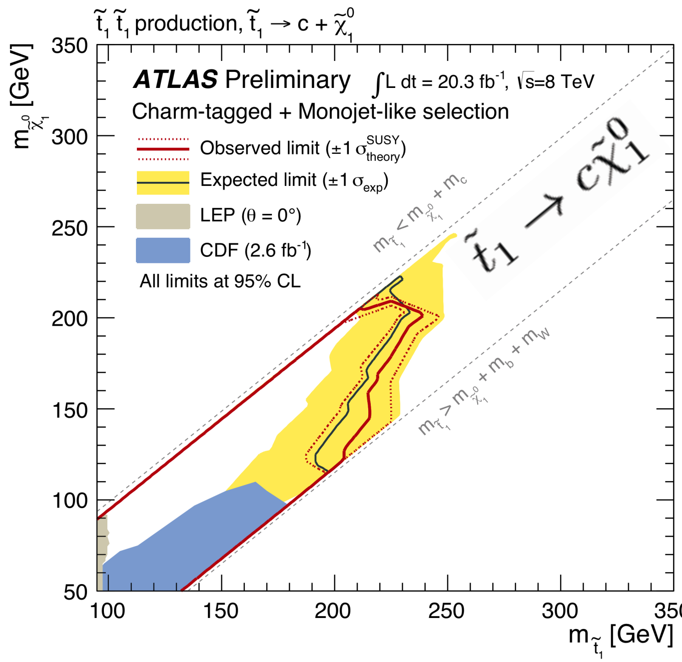


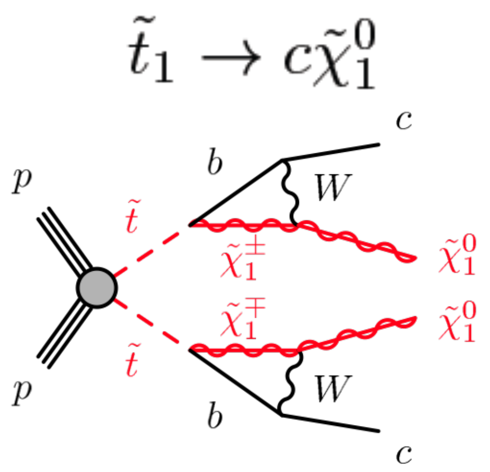
stop mass limits towards the challenging diagonal go down to about 180 GeV

3rd generation direct production – stop searches



ATLAS-CONF-2013-068

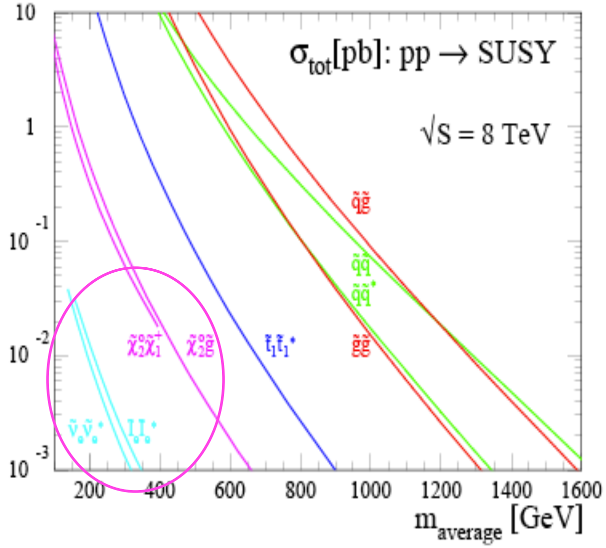




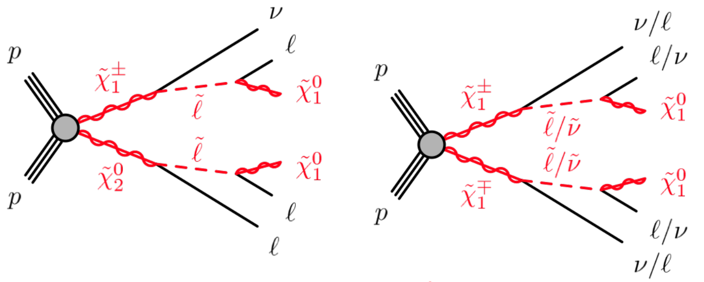
2 analyses targeting different Δm:
- mono-jet analysis (small Δm)
- charm-tagged analysis
 (with leading jet from ISR)

best limits:
m (stops) < 230 GeV
m (stops) < 200 GeV
(without limits on LSP mass)

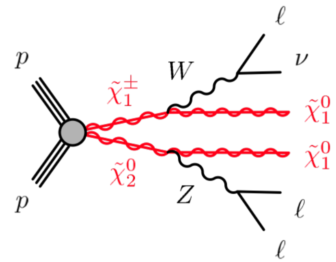
electroweak SUSY production



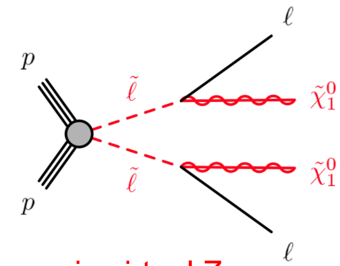
Electroweak SUSY production



via intermediate sleptons/sneutrinos



with on-shell bosons



via virtual Z

- may dominate if squarks/gluinos are heavy and neutralinos/charginos are light
- electroweak SUSY particle production ($\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ $\tilde{\chi}_1^0\tilde{\chi}_2^0$, $\tilde{\ell}\,\tilde{\ell}$....)
- occurs via intermediate W, Drell-Yan processes or intermediate sleptons
- search strategy depends on the slepton masses, gauge mixture and masses of charginos/ neutralinos
- characteristic: multi-lepton signatures with low hadronic activity → low SM background

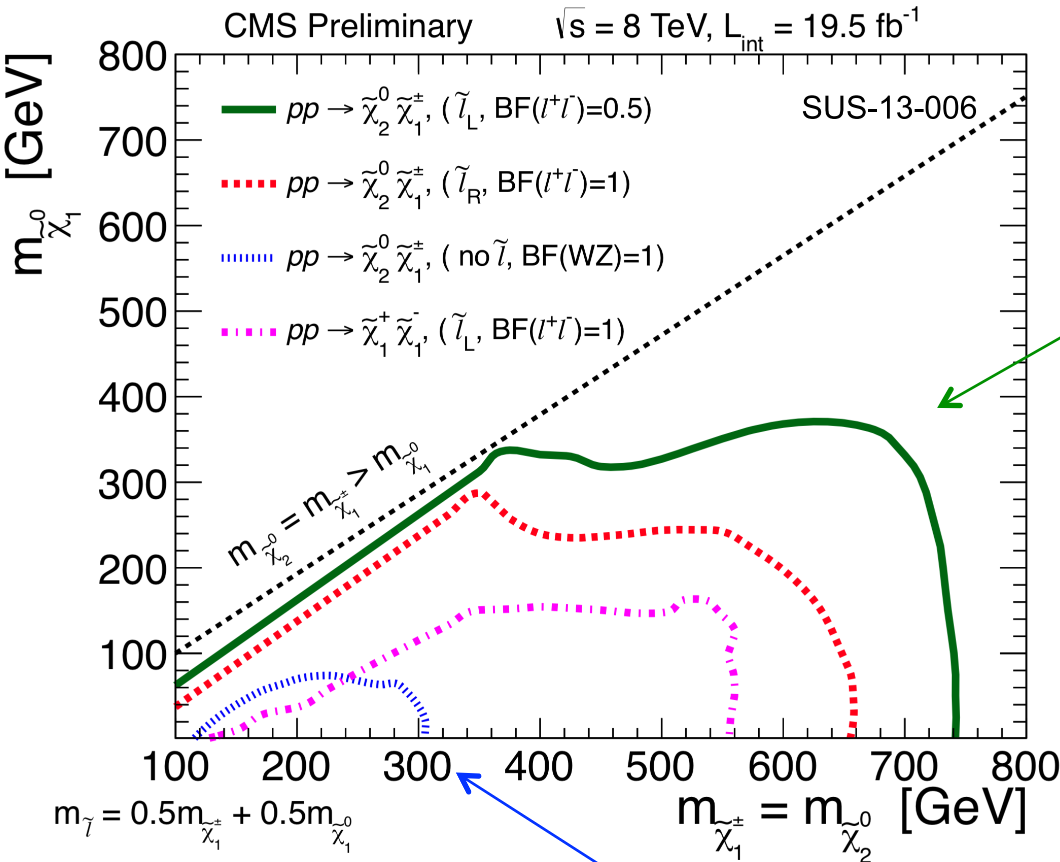
ATLAS searches

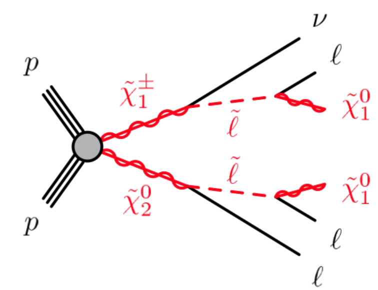
2-leptons (e, μ) + E_T^{miss}	ATLAS-CONF-2013-049
3-leptons (e, μ) + E_T^{miss}	ATLAS-CONF-2013-035
≥ 4-leptons + E_T^{miss}	ATLAS-CONF-2013-036
≥ 2-taus + E_T^{miss}	ATLAS-CONF-2013-028
WH (bb):	
1-lepton + 2 b-jets (H) + E_T^{miss}	ATLAS-CONF-2013-093

CMS searches

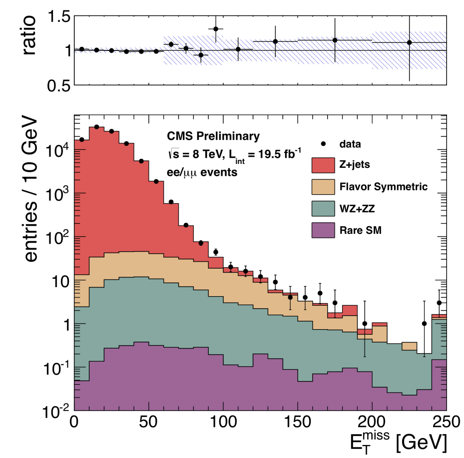
2-lepton + E_T^{miss}	SUS-13-006
3-lepton + SS di-lepton+ E_T^{miss}	SUS-13-006
3-lepton (e, μ) + E_T^{miss}	SUS-13-006
2-lepton + 2 jet + E_T^{miss}	SUS-13-006
WH(bb, WW, ZZ, ττ):	
1-lepton + 2 b-jets + E_T^{miss}	SUS-13-017
2-lepton SS + 2 -3-jets + E_T^{miss}	SUS-13-017
3-lepton + 2 b-jets + E_T^{miss}	SUS-13-017

EW SUSY production – chargino-neutralino scenario

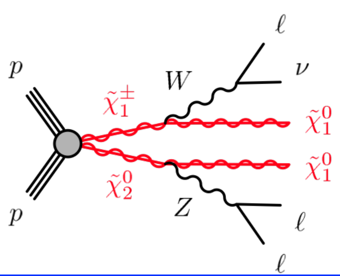




for intermediate slepton decays: $\chi_1^\pm < 740$ GeV



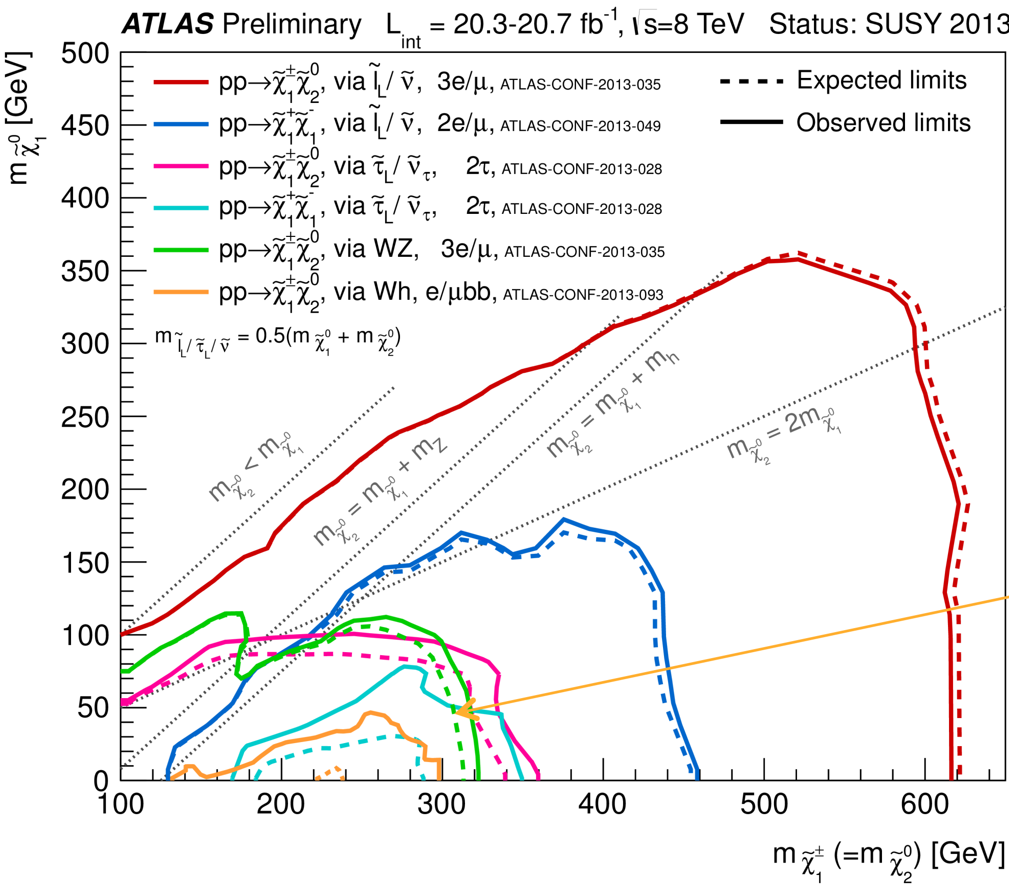
distribution after the dilepton mass requirement
81 GeV <m (ll)<101 GeV

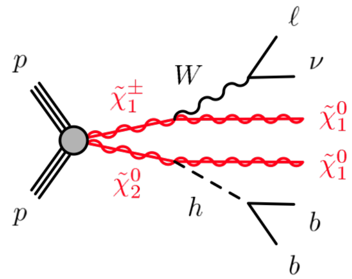


for gauge boson (W, Z) decays: $\chi_1^\pm < 315$ GeV

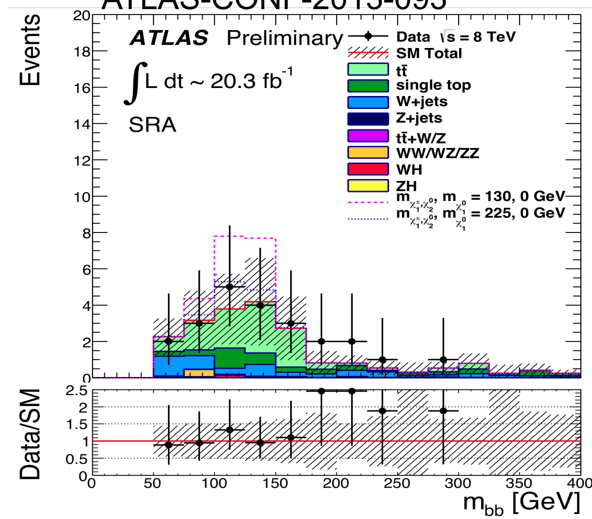
→less strong limits due to lept. BR of the W and Z-boson

EW SUSY production: Higgs final states





ATLAS-CONF-2013-093



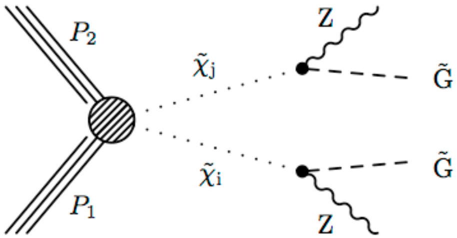
invariant mass of the 2 b-jets after 1 lepton + 2 b-jets + E_T^{miss} cut

if sleptons are heavy:
decays via bosons are favored
→ decay may include the production of Higgs

best limit for Wh decay: $\chi^\pm_1 < 300\ GeV$

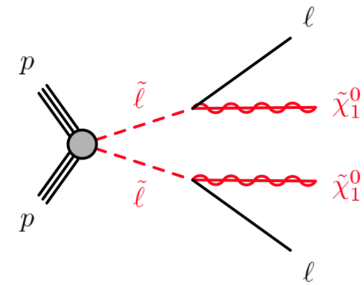
EW SUSY production GMSB and slepton scenario

GMSB Z enriched higgsino scenario



limit set using Z+dijet + 4-lept. analyses:
mass parameter μ< 370 GeV

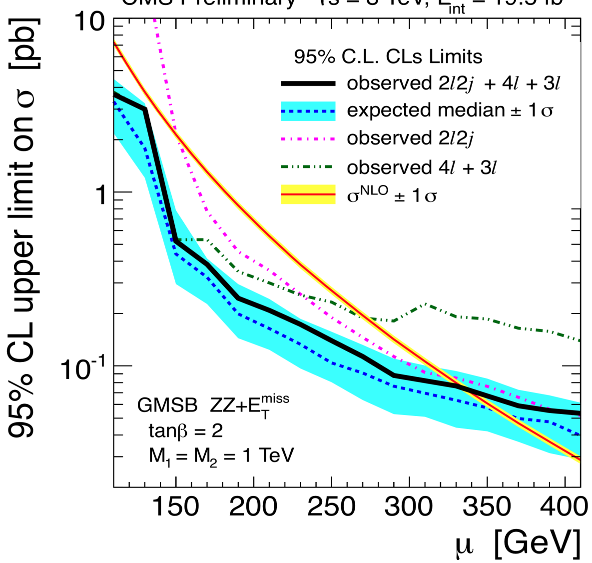
slepton production



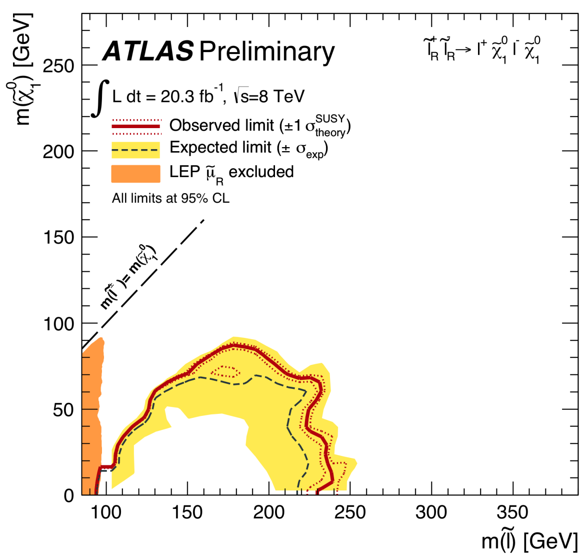
limit set using 2-lep. OS analyses:

90 GeV < $\tilde{l}_{R,L}$ < 320 GeV $\tilde{l}_R$ < 230 GeV

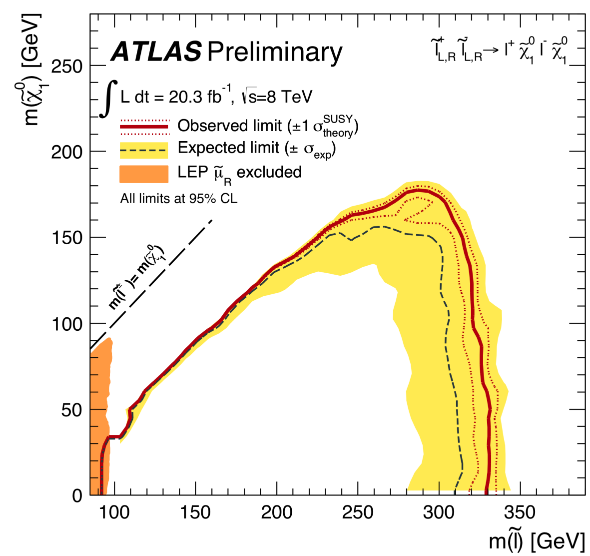
SUS-13-006



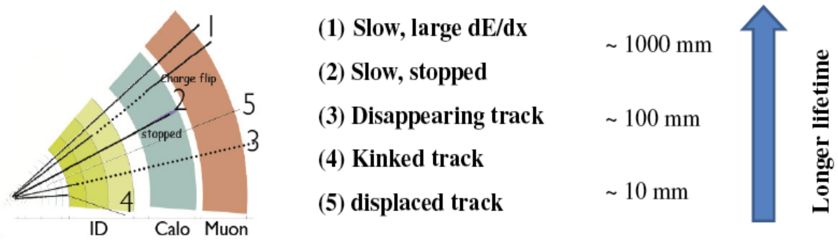
ATLAS-CONF-2013-049



ATLAS-CONF-2013-049



Long lived particles (LLP) and R-parity violation



ATLAS and CMS look at different RPV and long-lived signatures in different channels trying to cover a wide range of lifetimes e.g. disappearing tracks, R-hadrons, displaced vertex,..

- massive long-lived particles can originate from:
  - ✓ mass degeneracy e.g. small chargino-neutralino mass difference
  - ✓ heavy mediator sparticles e.g. Split SUSY (suppressed gluino decay)
  - ✓ R-parity violating terms (weak couplings)

ATLAS searches

prompt RPV

0 lep. + ≥ 7 (0-2 b-) jets + E_T^{miss}	ATLAS-CONF-2013-091
0 lep. + ≥ 6-10 (0-2 b-) jets + E_T^{miss}	arXiv 1308.1841
4 lep. + E_T^{miss}	ATLAS-CONF-2013-036
heavy resonances to eμ,μτ, eτ	PLB 723 (2013) 15

Long-lived

disappearing tracks (long-lived charginos)	arXiv: 1310.3675
stopped gluinos or squark R-hadrons (27.9 fb^{-1})	arXiv: 1310.6584
long-lived sleptons e.g. GMSB	ATLAS-CONF-2013-058
displaced vertex	ATLAS-CONF-2013-092
non-pointing photons (7 TeV)	PRD 88, 012001

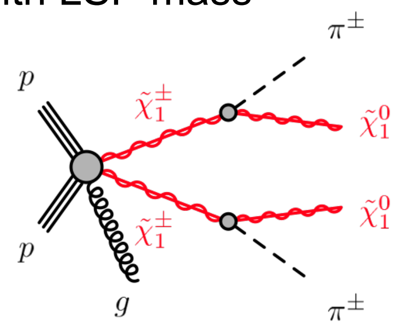
CMS searches

1 lepton + 6-8 (1-5 b-) jets + E_T^{miss}	SUS -12-015
4 lep. + E_T^{miss}	SUS -13-010
3-4 leptons + b-jet+ E_T^{miss}	arXiv: 1306.6643
2-leptons SS + b-jets + E_T^{miss}	SUS-13-013
≥3 leptons + b-jet + E_T^{miss}	SUS-12-027

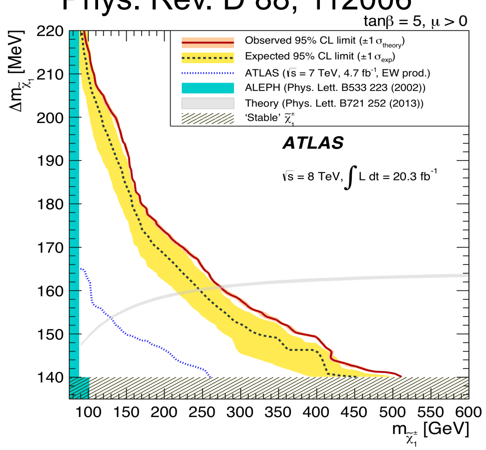
Long lived particles (LLP)

disappearing track

AMSB model where chargino mass is nearly degenerate with LSP mass



Phys. Rev. D 88, 112006

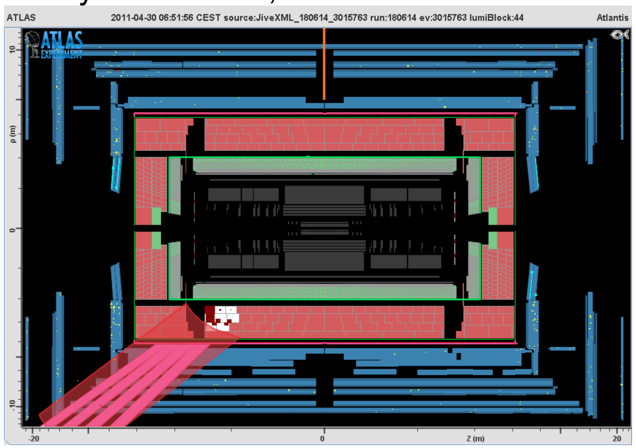


long-lived gluino R-hadrons

R-hadrons (e.g. in Split-SUSY) can stuck in the detector and decay later

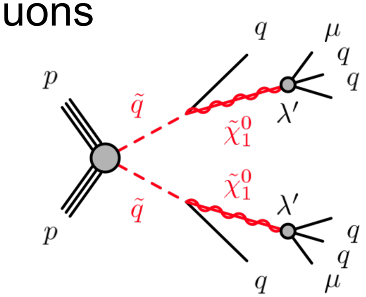
use empty LHC bunches to search for hadronic calorimeter activities

Phys. Rev. D 88, 112003

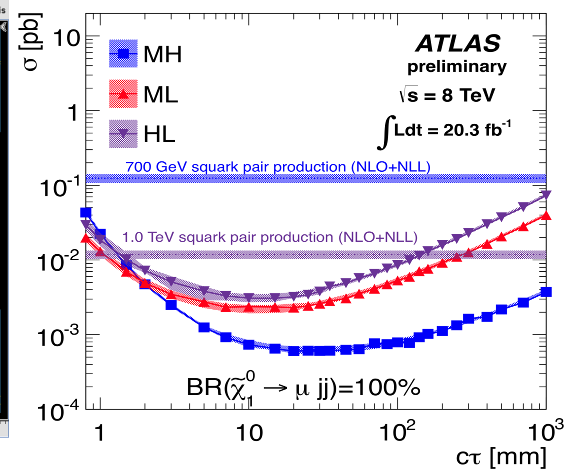


displaced vertex

search for heavy particles with multi-track, high mass vertex containing high p_T muons



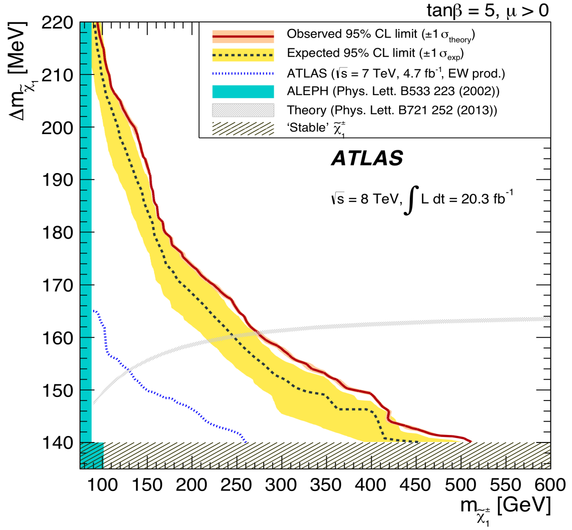
ATLAS-CONF-2013-092



Long lived particles (LLP)

disappearing track

Phys. Rev. D 88, 112006 (2013)

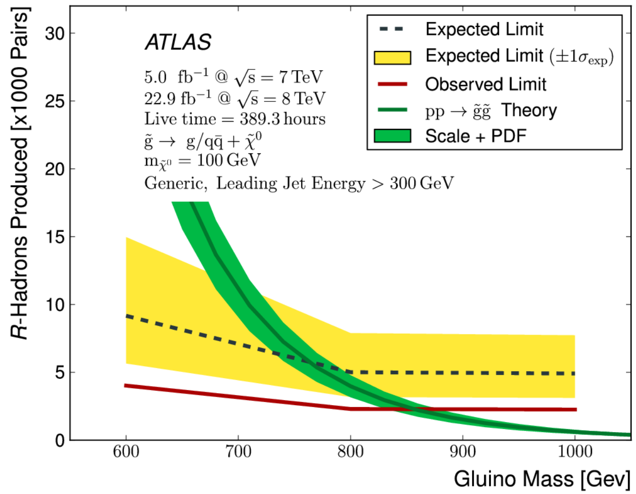


AMSB model with
Δm ~160 MeV limits:

τ~0.2 ns: $\chi_1^{\pm}$ < 270 GeV
τ ~1-10 ns: $\chi_1^{\pm}$ < 520 GeV

long-lived gluino R-hadrons

Phys. Rev. D 88, 112003 (2013)

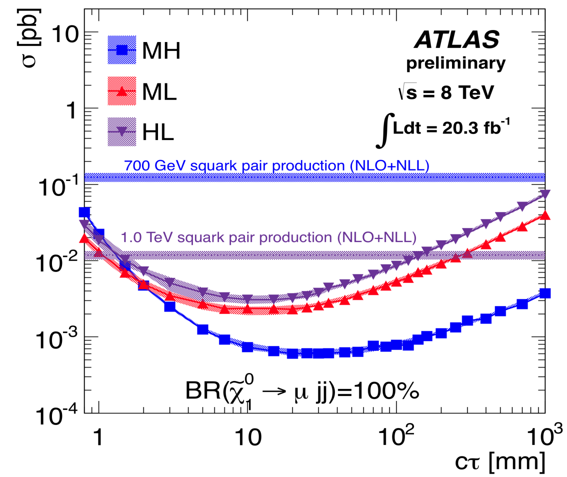


limits:
LSP = 100 GeV,
m(gluino) < 832 GeV
τ=10^{-5} s- 10^{3} s

m(stop) < 379 GeV
m(sbottom) < 344 GeV

displaced vertex

ATLAS-CONF-2013-092



limits:

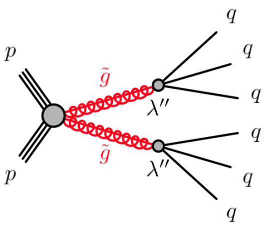
1 TeV squarks excluded for
1.5mm < cτ < 156 mm
100% BR for decays to
108 GeV LSP

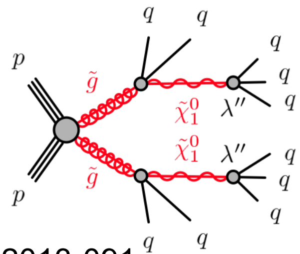
R-parity violation (RPV)

RPV can allow LSP to decay into three quarks

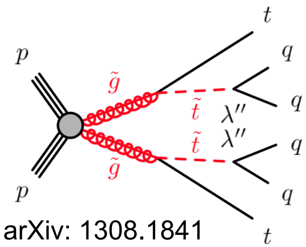
→ final states with many jets

if higgsino/gauginos are light
→ stops decay can proceed via superpartners

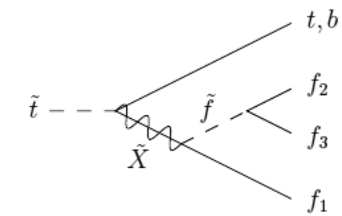




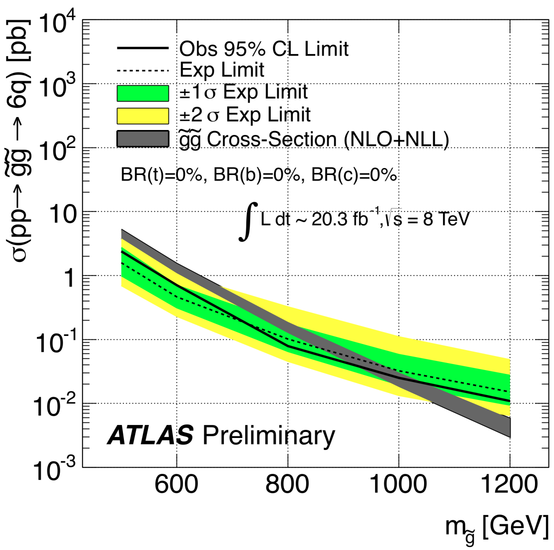
ATLAS-CONF-2013-091

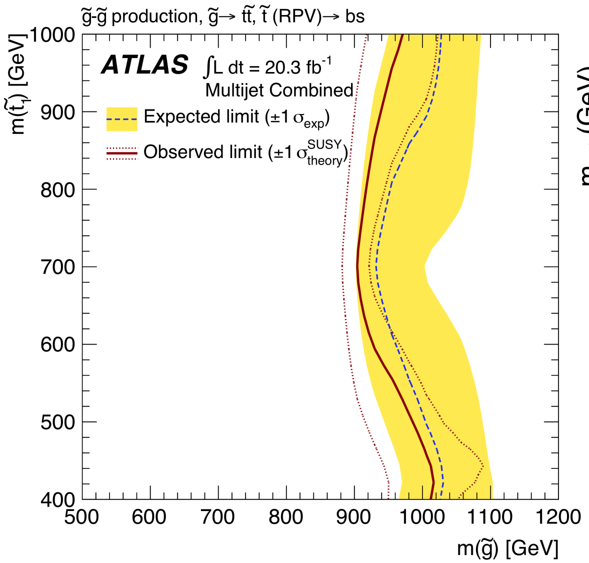


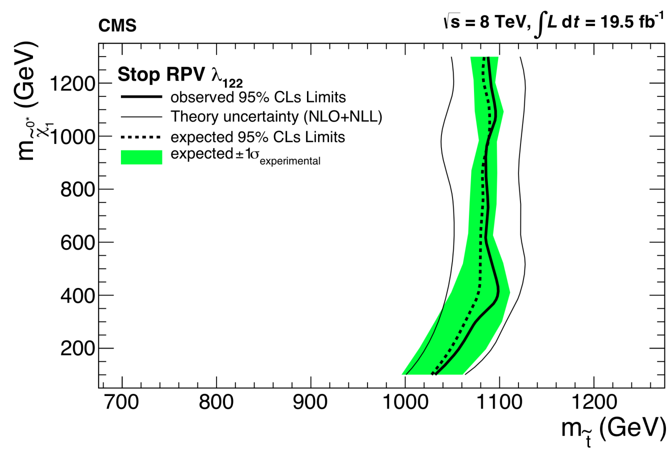
arXiv: 1308.1841
JHEP 10 (2013) 130



arXiv: 1306.6643







limits:
BR (heavy quarks) = 0%
→m(gluino) < 900 GeV
BR (top) = 100 %
→m(gluino) < 800 GeV

limits:
gluinos < 900 GeV are excluded independent of stop mass

limits:
stops are excluded up to 1 TeV

Conclusions

- ATLAS and CMS have developed a broad SUSY program
- detailed and thorough searches, covered wide ranges of signatures
- main focus on strong production, natural SUSY, RPV and long-lived SUSY searches
- effort to cover maximum area of the SUSY parameter space

  use simplified models, pheno models and full models
- no sign of SUSY found yet, but ….

  … we will start with LHC run 2 soon!
- high energy running will significantly increase our sensitivity to many SUSY scenarios

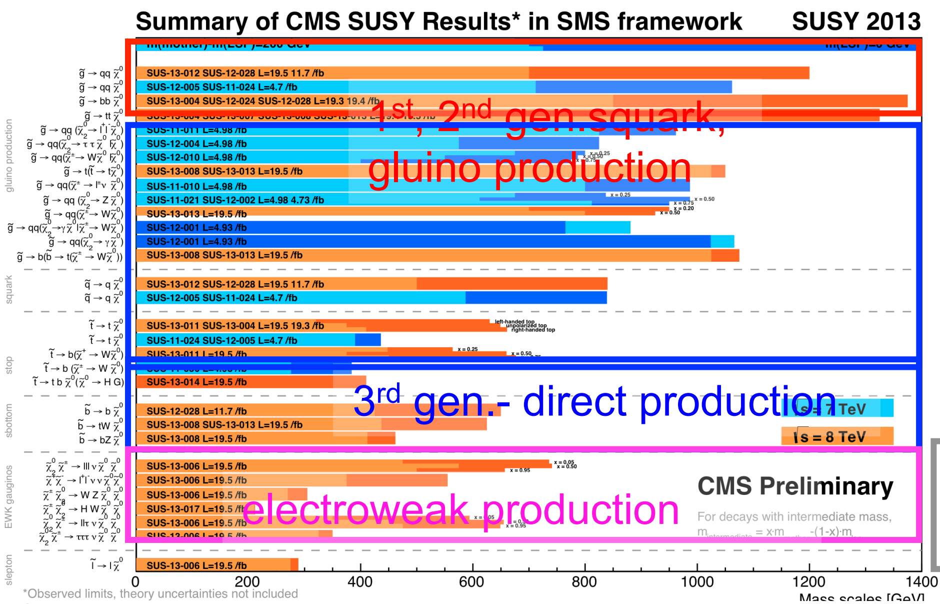
Looking forward to next exciting years!

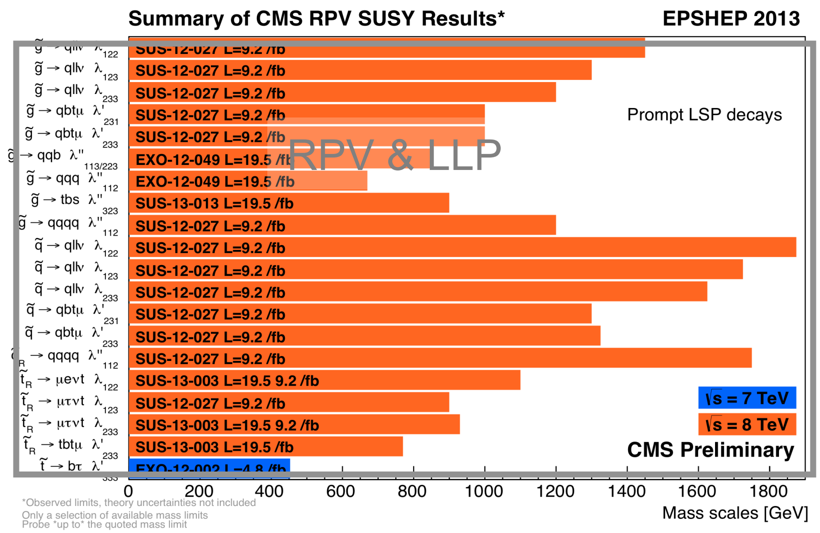
Conclusions

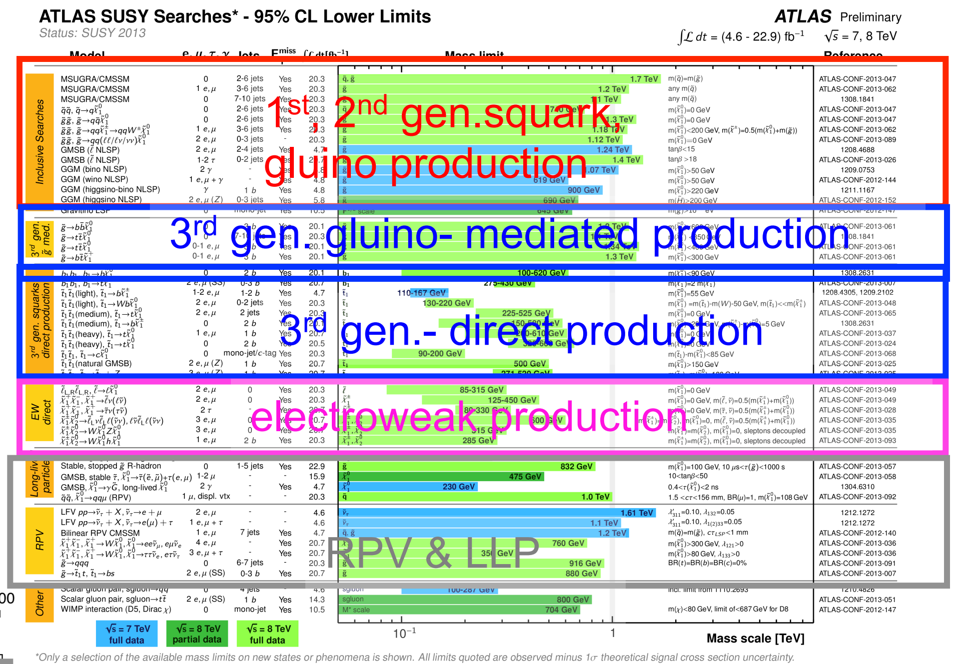
Thank you for your attention!

BACKUP

Summary of exclusion limits







Summary of exclusion limits of ATLAS SUSY searches

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

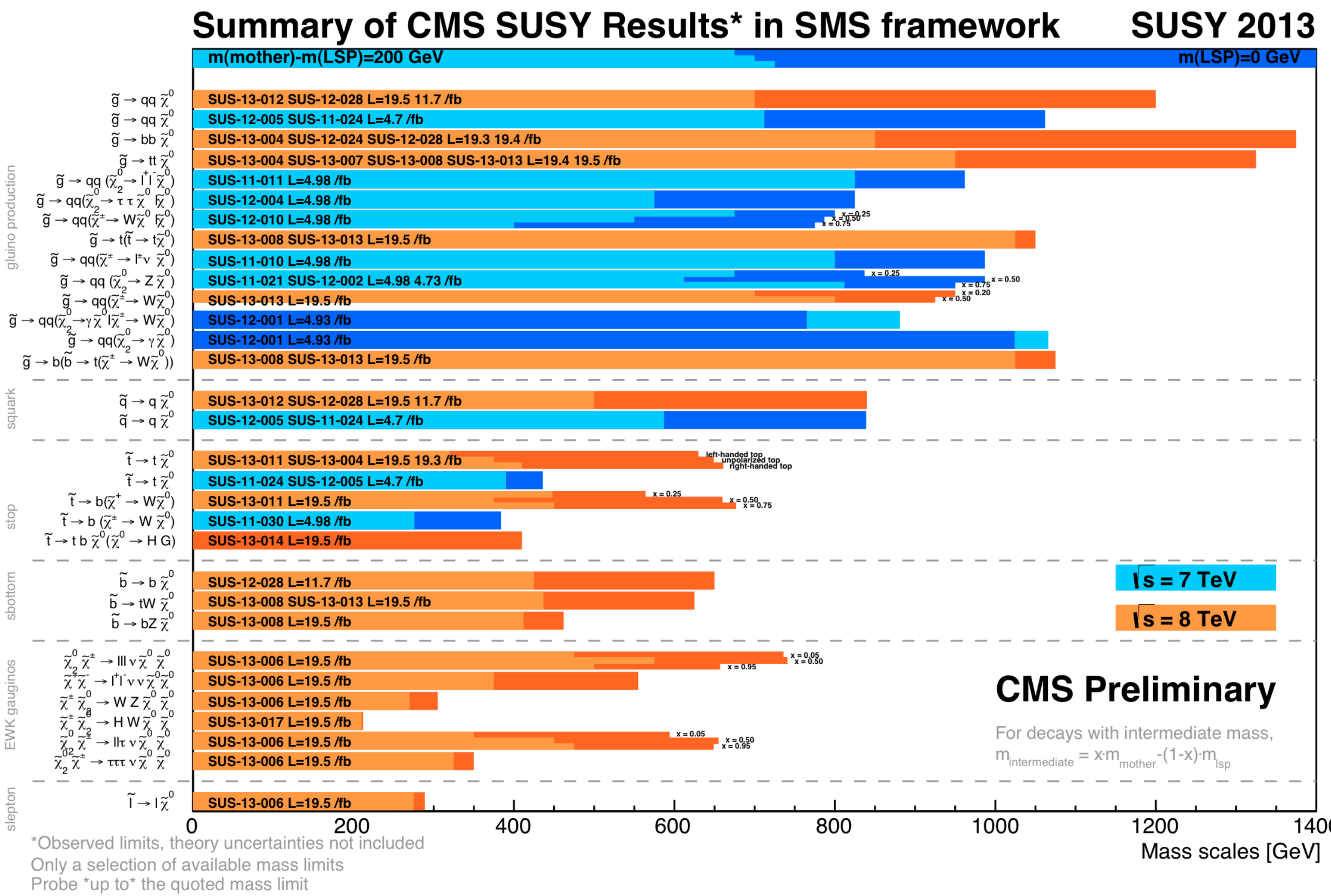
	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt [fb^{-1}]$	Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde q, \tilde g$ 1.7 TeV	$m(\tilde q)=m(\tilde g)$	ATLAS-CONF-2013-047
	MSUGRA/CMSSM	1 e,μ	3-6 jets	Yes	20.3	$\tilde g$ 1.2 TeV	any $m(\tilde q)$	ATLAS-CONF-2013-062
	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
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<$\tan\beta$<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

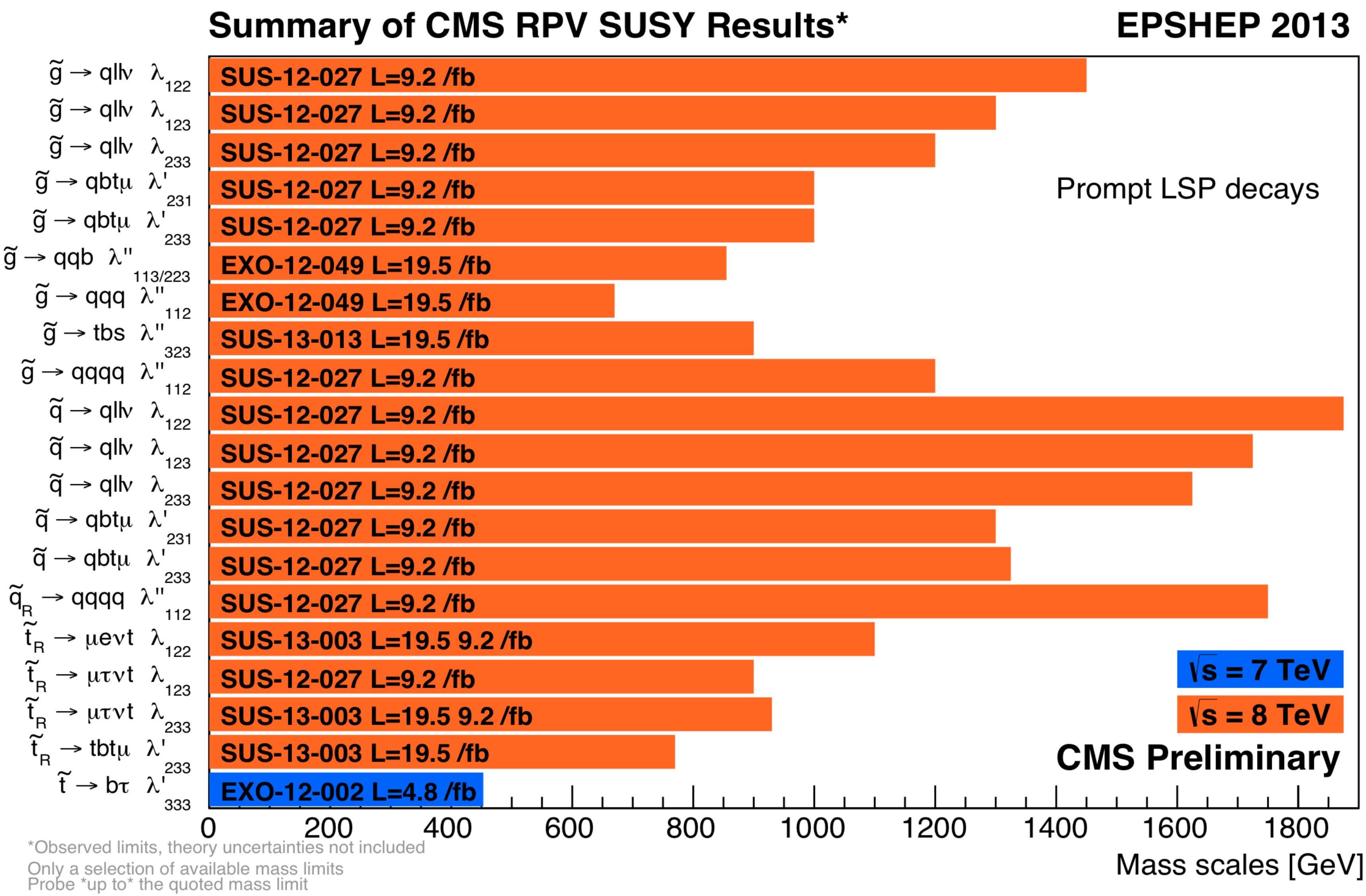
10^{-1} 1 Mass scale [TeV]

*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.

Summary of exclusion limits of CMS SUSY searches



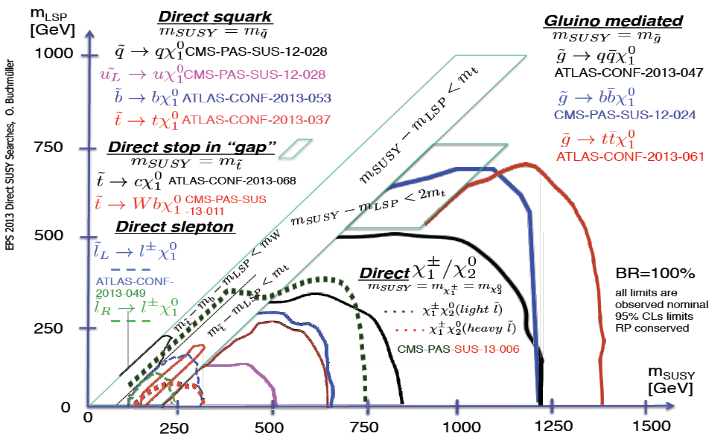
Summary of exclusion limits of CMS SUSY searches



Conclusions

- 95% CL exclusion limits are set on various models:

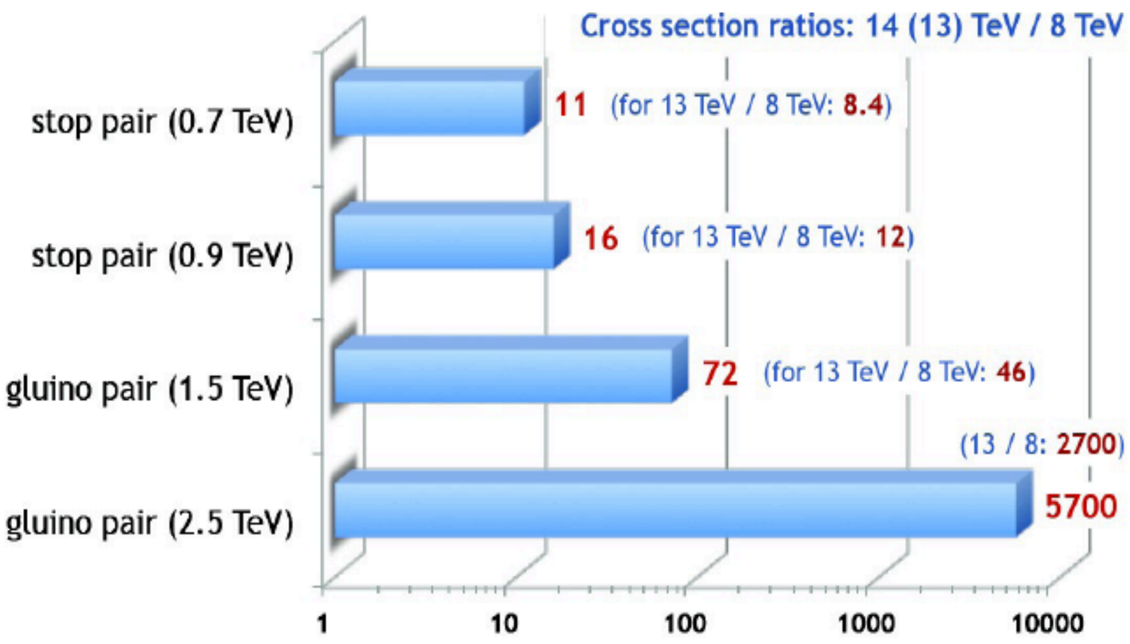
$\tilde{q} \rightarrow q\chi_1^0$	850 GeV (500 GeV)
$\tilde{g} \rightarrow q\bar{q}\chi_1^0$	1200 GeV
$\tilde{g} \rightarrow b\bar{b}\chi_1^0$	1375 GeV
$\tilde{g} \rightarrow t\bar{t}\chi_1^0$	1400 GeV
$\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$	750 GeV
$\tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$	650 GeV
$\tilde{l} \rightarrow l^{\pm}\chi_1^0$	320 GeV



Outlook

What is next?

- increase sensitivity to difficult SUSY scenarios
- explore new channels, probe more parameter space
- prepare for √s = 13 TeV, LHC run-2 in 2016/2017



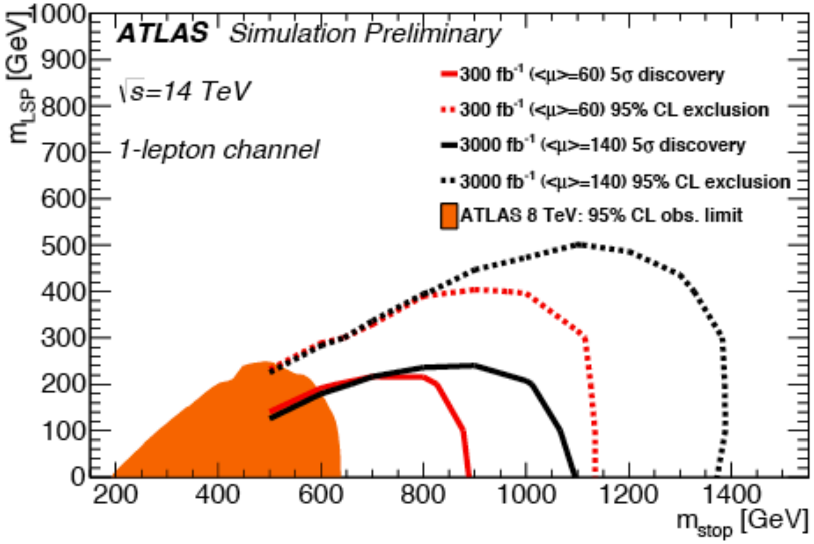
C. Potter, LHC Seminar,
October 2013

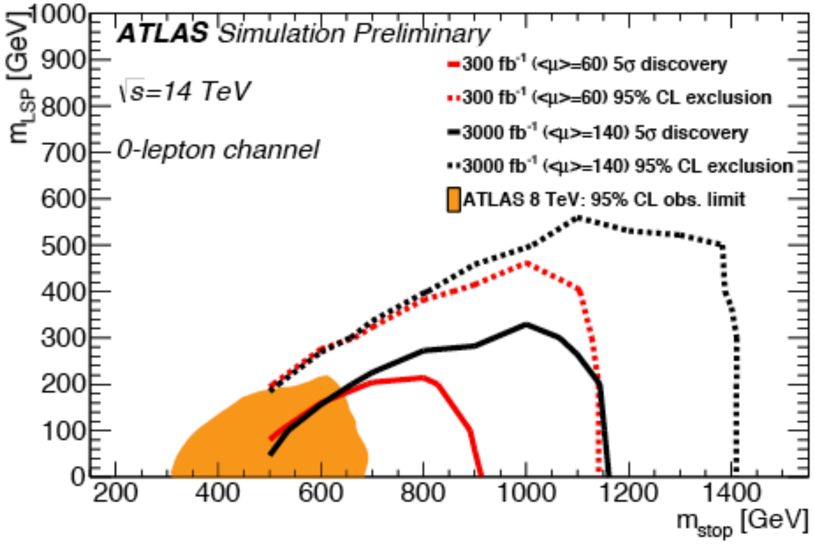
Outlook

ATL-PHYS-2013-011

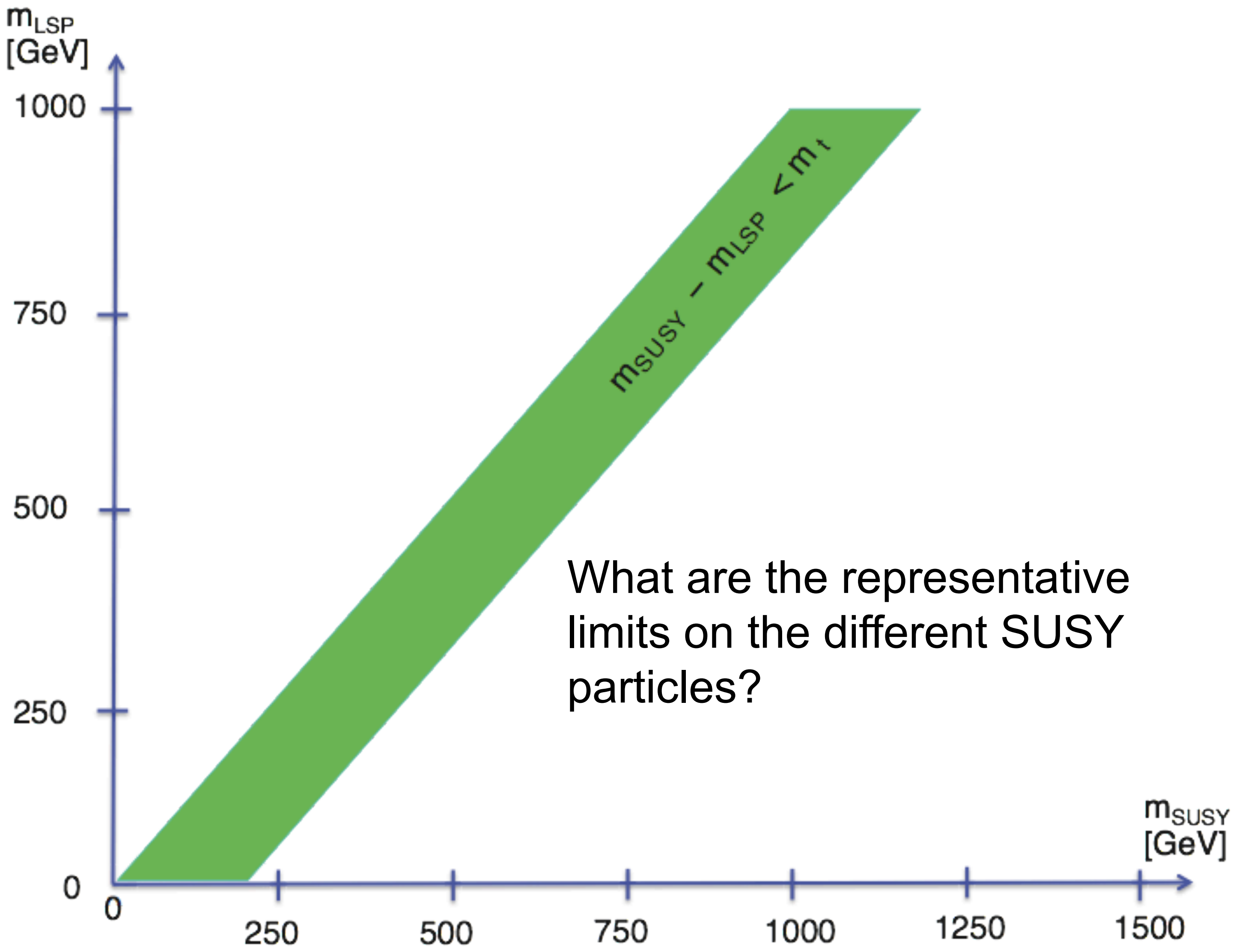
- high-energy LHC run will significantly increase the sensitivity to many SUSY scenarios e.g. expect factor ~10 for 600 GeV stops and factor ~2 for 2 TeV gluinos

  → improvement for 300 fb^{-1} and 3000 fb^{-1} at $\sqrt{s}$ = 14 TeV



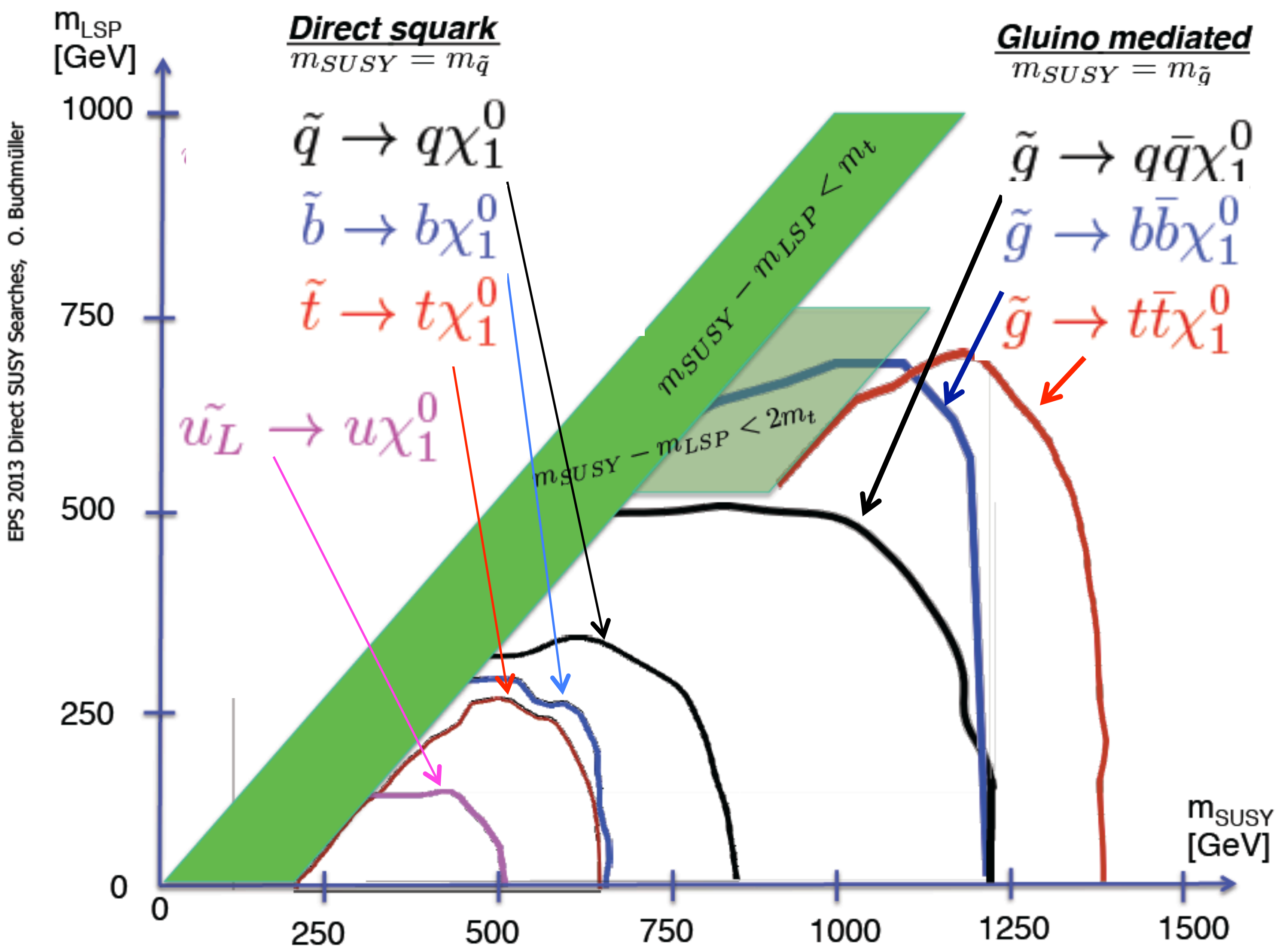


SUSY limits

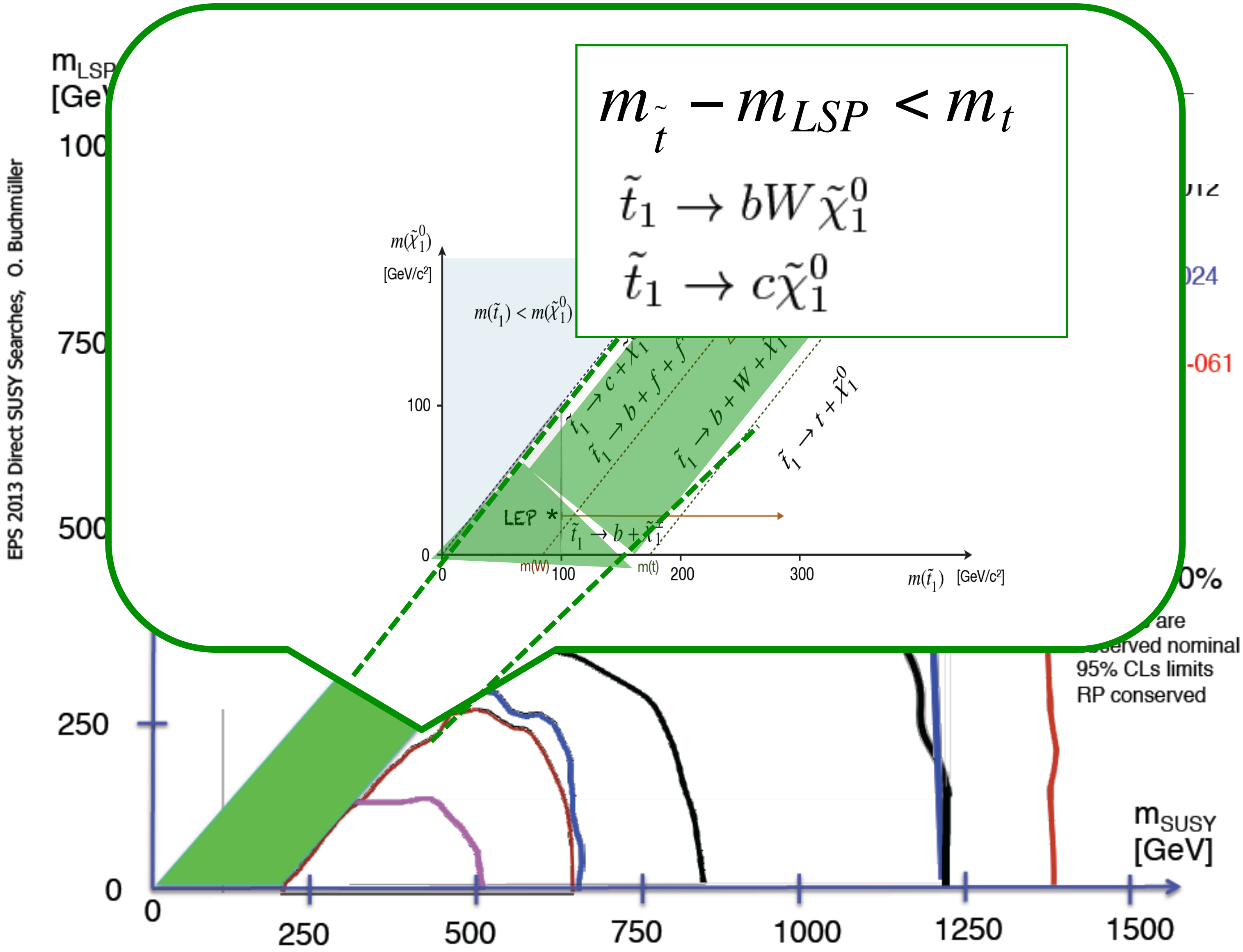


What are the representative limits on the different SUSY particles?

3rd generation direct production

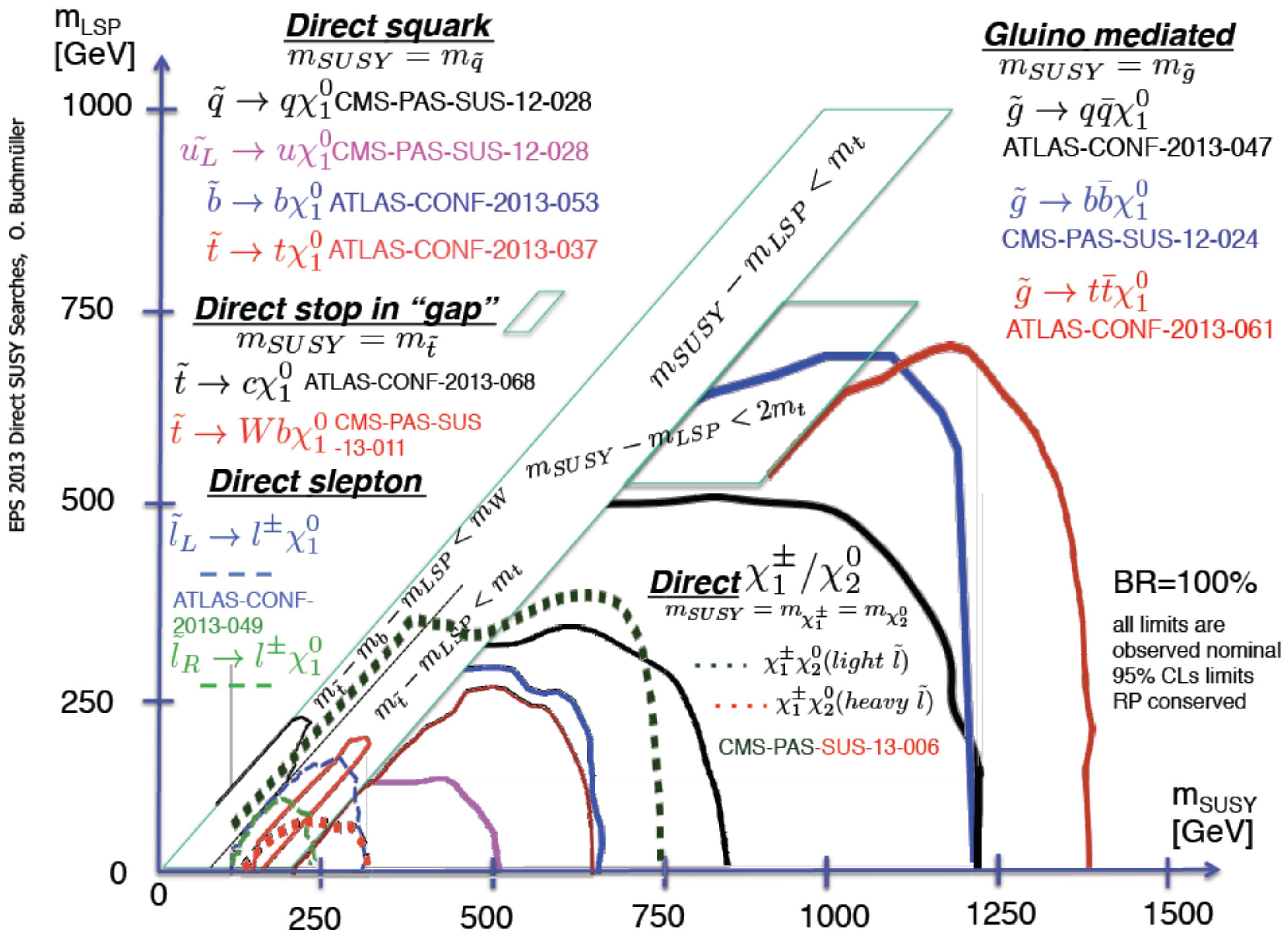


3rd generation direct production



Conclusions

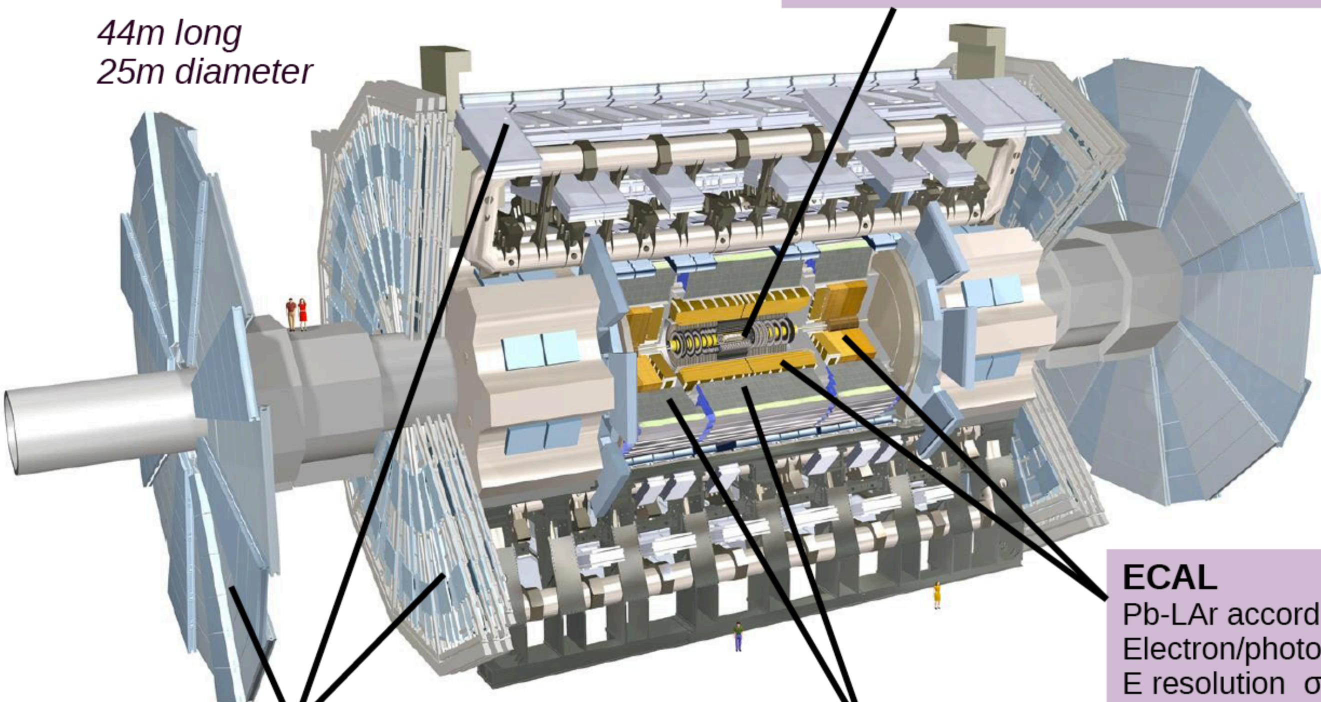
Thank you for your attention!



ATLAS detector

3-level trigger
Rate 40 MHz → ~400 Hz

Inner Detector
Silicon pixels & strips + TRT straws
Precise tracking and vertexing, electron/pion separation
p resolution σ/p_T ~3.8×10^{-4} p_T (GeV) ⊕ 0.015



ECAL
Pb-LAr accordion
Electron/photon id & measurement
E resolution σ/E ~10%/√E

Muon Spectrometer
Air-core toroids with gas-based muon chambers
Muon measurement
p resolution σ/p < 10% up to p ~ 1 TeV

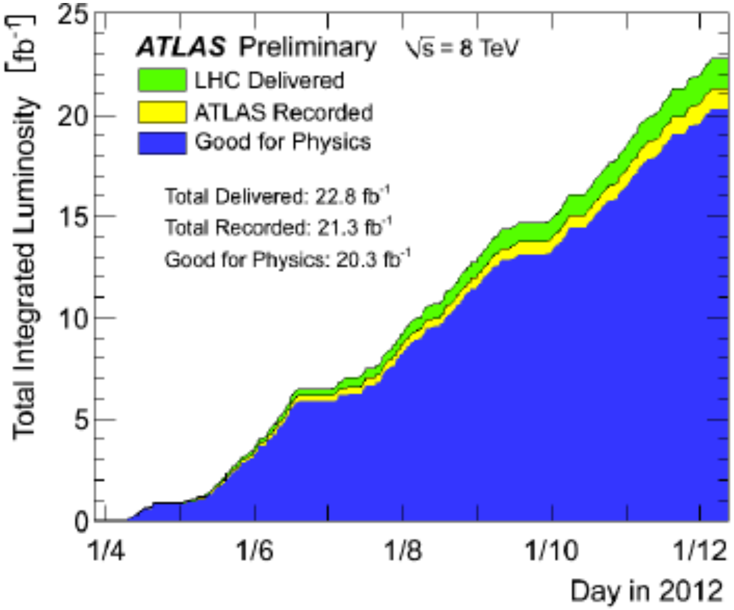
HCAL
Fe/scintillator tiles (central), Cu/Q-LAr (fwd)
Measurement of jets & missing E_T
E resolution σ/E ~50%/√E ⊕ 0.03

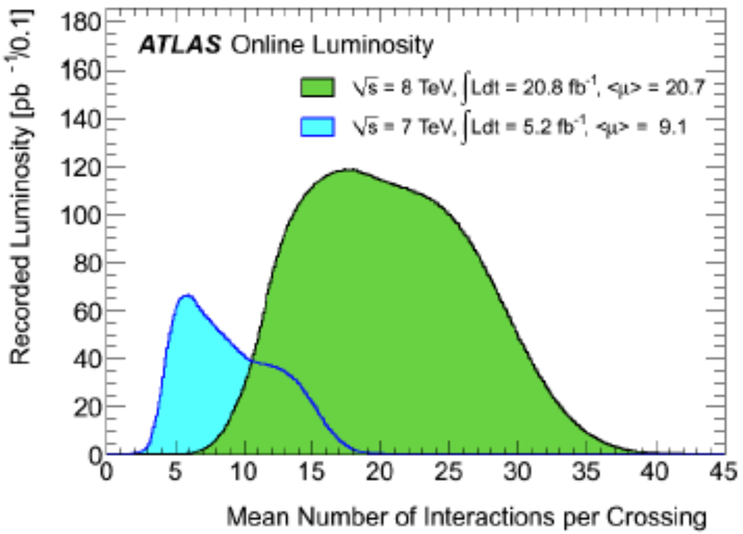
Experimental setup: Luminosity and pileup

~ 22 fb^{-1} collected at $\sqrt{s}$ = 8 TeV
~ 5 fb^{-1} collected at $\sqrt{s}$ = 7 TeV

with ~ 90% of the delivered data being good for physics

Most results presented here use the full 8 TeV dataset

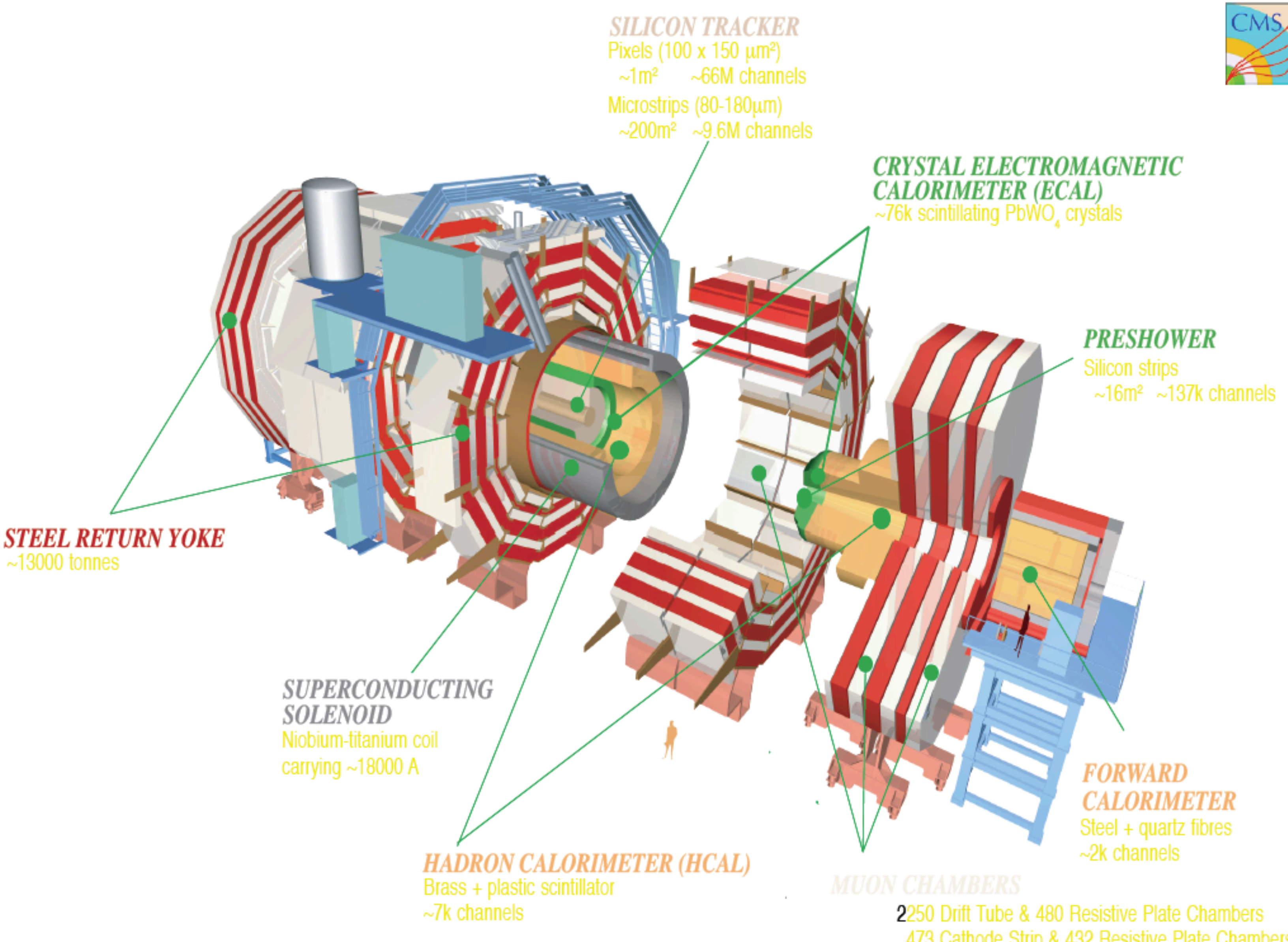




Large luminosity results in large pileup (number of interactions per bunch crossing)

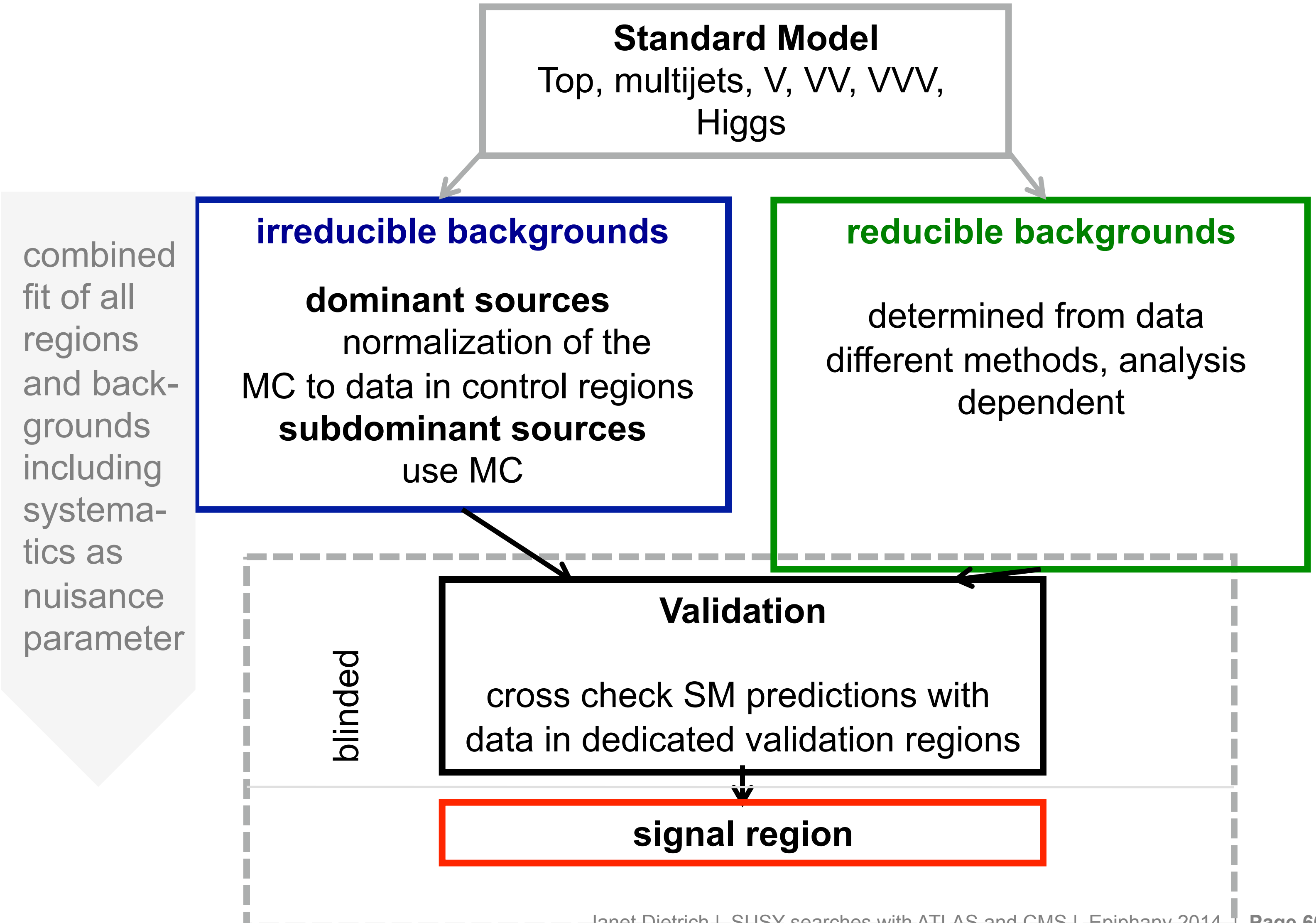
Pileup suppression strategies have been carefully developed

CMS detector



Background

- understanding and modeling of the SM background is important for every SUSY search



Systematic uncertainties

- *MC statistics:* statistical uncertainties from the limited number of simulated events in the SRs and CRs
- *JET:* propagation of the jet energy scale calibration (JES) and resolution (JER) uncertainties; JES uncertainties do propagate to E_T^{miss}
- *LEPTON:* lepton reconstruction, identification and trigger efficiencies, energy and momentum measurements; lepton energy scale uncertainties propagate to E_T^{miss}
- *B-tagging:* uncertainties on the b-jet identification efficiency and charm and light-flavor jet rejection factors
- *Luminosity:* 2.8 % derived from a preliminary calibration of the luminosity scale from beam-separation scans
- *Soft term:* additional uncertainties on E_T^{miss} associated with the energy deposits not assigned to any object
- *Theory:* generator modeling uncertainties obtained by comparing results from different MC generators, parton shower modeling (PS), initial and final state radiation (ISR/FSR)
- Signal: taken from an envelope of cross-section predictions using different PDF sets and factorization and normalization scales

Flavor tagging

- b-tagging

Advanced algorithm based on multivariate technique.

- **MV1**: a Neural Network based tagger that combines information from transverse and longitudinal impact parameter (IP) significance, secondary vertex, geometry of decay chain.

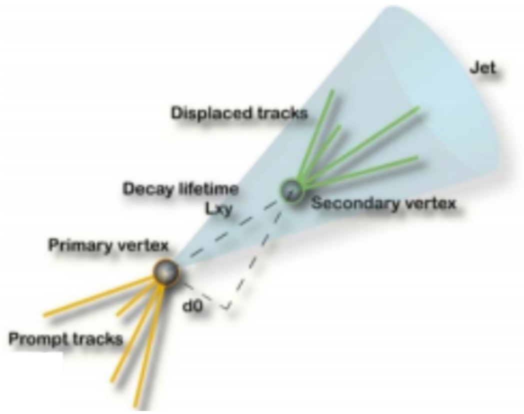
➢ efficiency: 70% with 0.7% light flavour and 20% charm jets.

- c-tagging

Using multivariate techniques to combine information from impact parameters of displaced vertices within the jet.

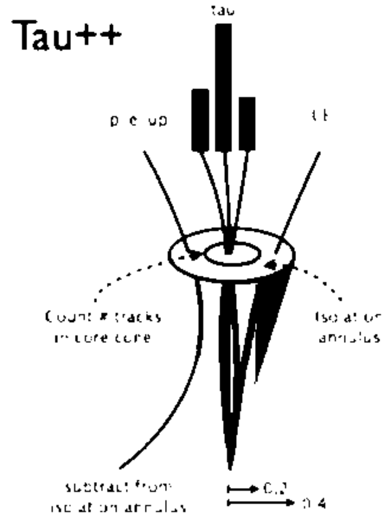
Operating points:

- **Medium**
  - 20% c-tagging efficiency
  - Rejection factors: 5 b-jets, 140 light-jets, 10 tau-jets
- **Loose**
  - 95% c-tagging efficiency
  - Rejection factors: 2 b-jets



- Hadronically decaying tau reconstruction

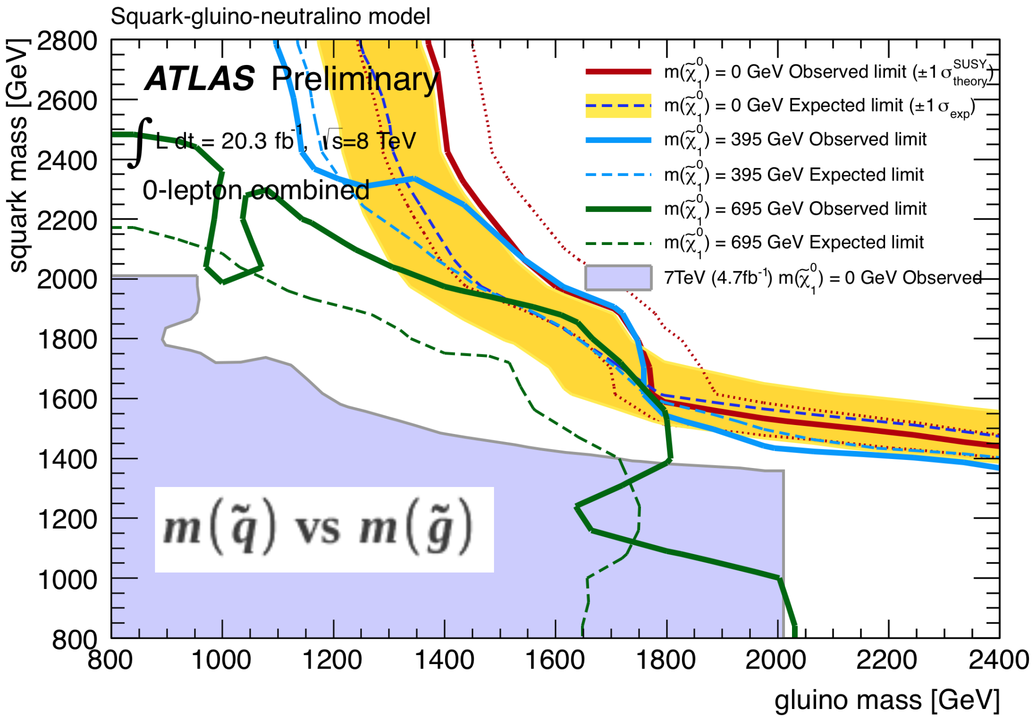
- **Reconstruction**: seeded by baseline jets
- **Track associated**: core and isolation tracks
- Information from tracking and calorimeters combined to derive **identification variables**
- **Four-momentum** from clusters in core cone + TES correction



Squark-gluino production pMSSM grid

— — Expected limit
Yellow band ±1σ experimental uncertainties

—— Red line: Observed limit
— — Dashed lines ±1σ signal theory uncertainties



Signal uncertainties considered

In yellow band
- Experimental uncertainties
- ISR uncertainty on signal MC
  Up to 30% in some regions with small Δm

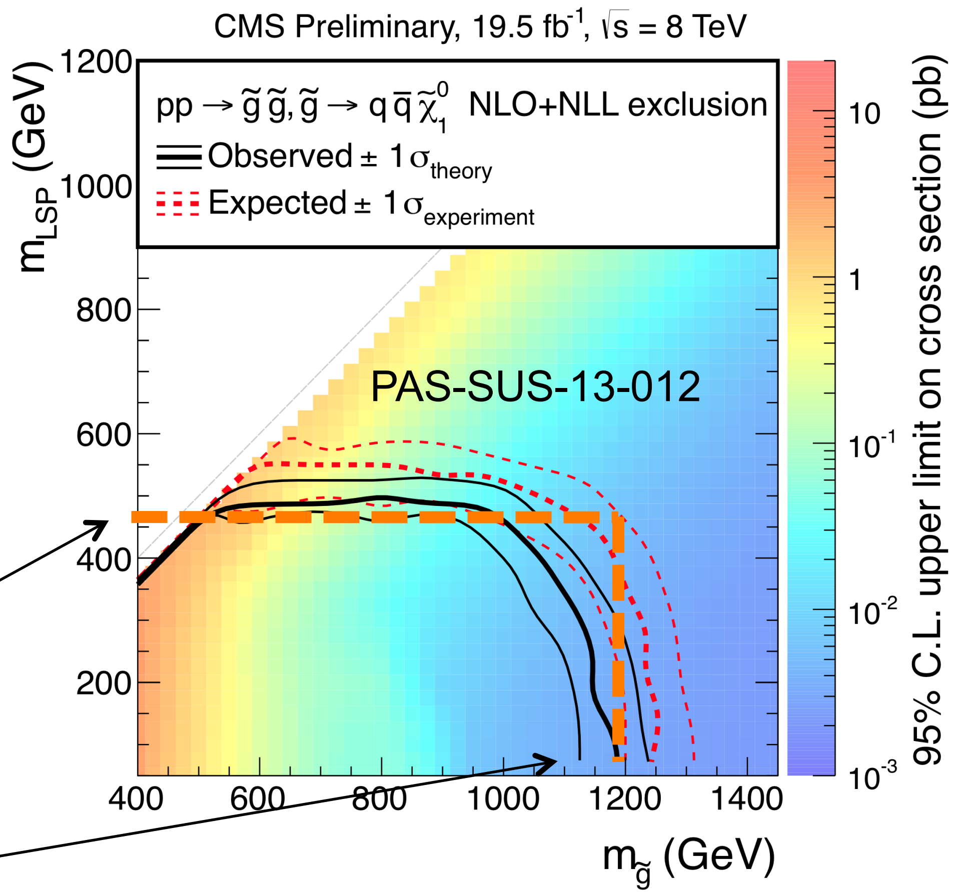
In red dashed lines
- Cross-section uncertainties
  (PDF, renormalisation/factorization scales)

SUSY limits

- compute the 95% CL model independent limits on $\sigma_{vis} = \sigma \times A \times \varepsilon$
- compute 95% CL model dependent exclusion curves on σ_{SUSY} and sparticle masses

------ expected limits
------ ± 1 σ experimental uncertainties + ISR uncertainties on signal MC

—— observed limits
----- ± 1σ signal theory uncertainties (xsection uncertainties, PDF, renormalisation/factorisation scales)



best limits:

LSP mass ≈ 450 GeV
gluino mass ≈ 1200 GeV

How to search for SUSY?

SUSY variables

scalar sum of all jets p_T + scalar some of all leptons p_T

$$H_T = \sum p_{T,\mathrm{jets}} + \sum p_{T,\mathrm{leptons}}$$

effective mass

$$M_{\mathrm{eff}} = H_T + E_T^{\mathrm{miss}}$$

transverse mass of lepton and E_T^{miss}

$$m_{CT}(\mathrm{lep1}, \mathrm{lep2}) = [E_T(\mathrm{lep1}) + E_T(\mathrm{lep2})]^2 - [p_T(\mathrm{lep1}) + p_T(\mathrm{lep2})]^2$$

cotransverse mass of two leptons

$$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}}^{\mathrm{lep}} E_{\mathrm{T}}^{\mathrm{miss}} - 2 \mathbf{p}_{\mathrm{T}}^{\mathrm{lep}} \cdot \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}}$$

cotransverse mass of 2b -jets

$$m_{\mathrm{CT}}^2 = \left(E_{\mathrm{T}}^{b_1} + E_{\mathrm{T}}^{b_2}\right)^2 - \left|\mathbf{p}_{\mathrm{T}}^{b_1} - \mathbf{p}_{\mathrm{T}}^{b_2}\right|^2$$
$$\approx 2 p_{\mathrm{T}}^{b_1} p_{\mathrm{T}}^{b_2} (1 + \cos \Delta\phi_{bb})$$

$$m_{\mathrm{CT}}^{\max} \approx \frac{m_{\mathrm{heavy}}^2 - m_{\mathrm{invisible}}^2}{m_{\mathrm{heavy}}}$$

How to search for SUSY?

SUSY variables

stransverse mass of two leptons and E_T^{miss}

$$m_{T2} = \min_{\mathbf{q}_T}\left[\max\left(m_T(\mathbf{p}_T^{\ell 1}, \mathbf{q}_T), m_T(\mathbf{p}_T^{\ell 2}, \mathbf{p}_T^{miss} - \mathbf{q}_T)\right)\right]$$

relative $E_T^{miss, rel}$

$$E_T^{miss,rel.} = \begin{cases} E_T^{miss} & \text{if } \Delta\phi_{\ell,j} \geq \pi/2 \\ E_T^{miss} \times \sin\Delta\phi_{\ell,j} & \text{if } \Delta\phi_{\ell,j} < \pi/2 \end{cases}$$

α_T

= variable to reject multi-jet events efficiently without significant E_t^{miss} or with transverse energy mismeasurements; for a di-jet event with the less energetic jet: $E_T j^2$ and the transverse mass of the di-jet system:

$$\alpha_T = \frac{E_T^{j_2}}{M_T},$$

$$M_T = \sqrt{\left(\sum_{i=1}^{2} E_T^{j_i}\right)^2 - \left(\sum_{i=1}^{2} p_x^{j_i}\right)^2 - \left(\sum_{i=1}^{2} p_y^{j_i}\right)^2}$$

for back-to-back jets with $E_T j^2 = E_T j^1$ $\alpha_T = 0.5$

How to search for SUSY?

Razor variables

• looks at the rest frame of the heavy SUSY particles (R-frame)

→ exploit the symmetry in the visible portion of pair-produced sparticles decays

• decay products of a single sparticle decay are grouped in a mega-jet
= symmetric chains in the rest frame of the sparticles

• in the R-frame each sparticle has about the same mass m_{heavy}

• energy of the mega jets E_1, E_2

$$E_1 = E_2 = \frac{m^2_{\mathrm{Heavy}} - m^2_{\mathrm{LSP}}}{2 \times m_{\mathrm{Heavy}}}$$

• characteristic mass $M_R = 2 \times E_1 = 2 \times E_2$

• in the lab frame: $M'_R = \sqrt{(j_{1,E} + j_{2,E})^2 - (j_{1,z} + j_{2,z})^2}$

with: $j_{i,E}$ = energy mom. of mega-jet, $j_{i,z}$ = longitud. momentum

• transverse information of the system

$$M_T^R = \left[\frac{1}{2} \times |\mathbf{E}_\mathbf{T}^\mathbf{miss}| \times (|\mathbf{j}_{1,\mathbf{T}}| + |\mathbf{j}_{2,\mathbf{T}}|) - \frac{1}{2} \times \mathbf{E}_\mathbf{T}^\mathbf{miss} \cdot (\mathbf{j}_{1,\mathbf{T}} + \mathbf{j}_{2,\mathbf{T}})\right]^{1/2}$$

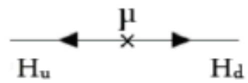
• Razor variable: $R = M^R_T / M'_R$

SM → small values, SUSY between 0-1

Natural SUSY

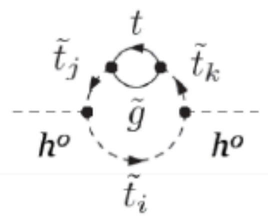
Expect light stop, sbottom, not-too heavy gluino, and light higgsinos (gauginos)

Tree-level: Higgsino < ~350 GeV

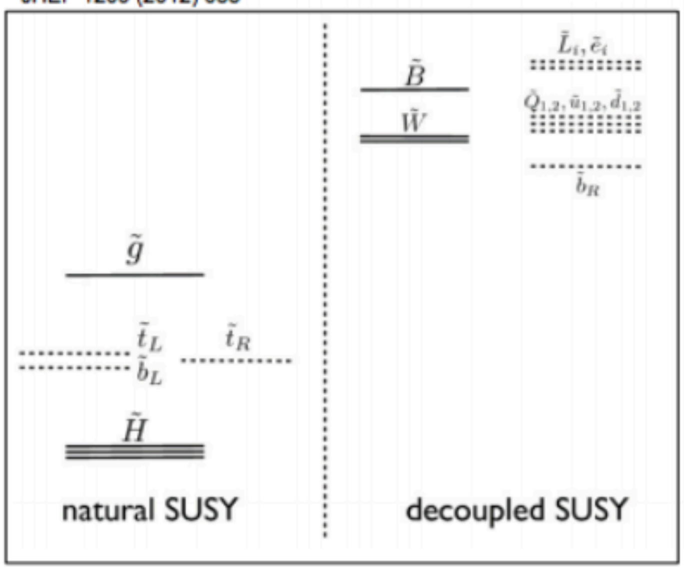


One loop: stop < ~1 TeV

Two loops: gluino < ~2 TeV

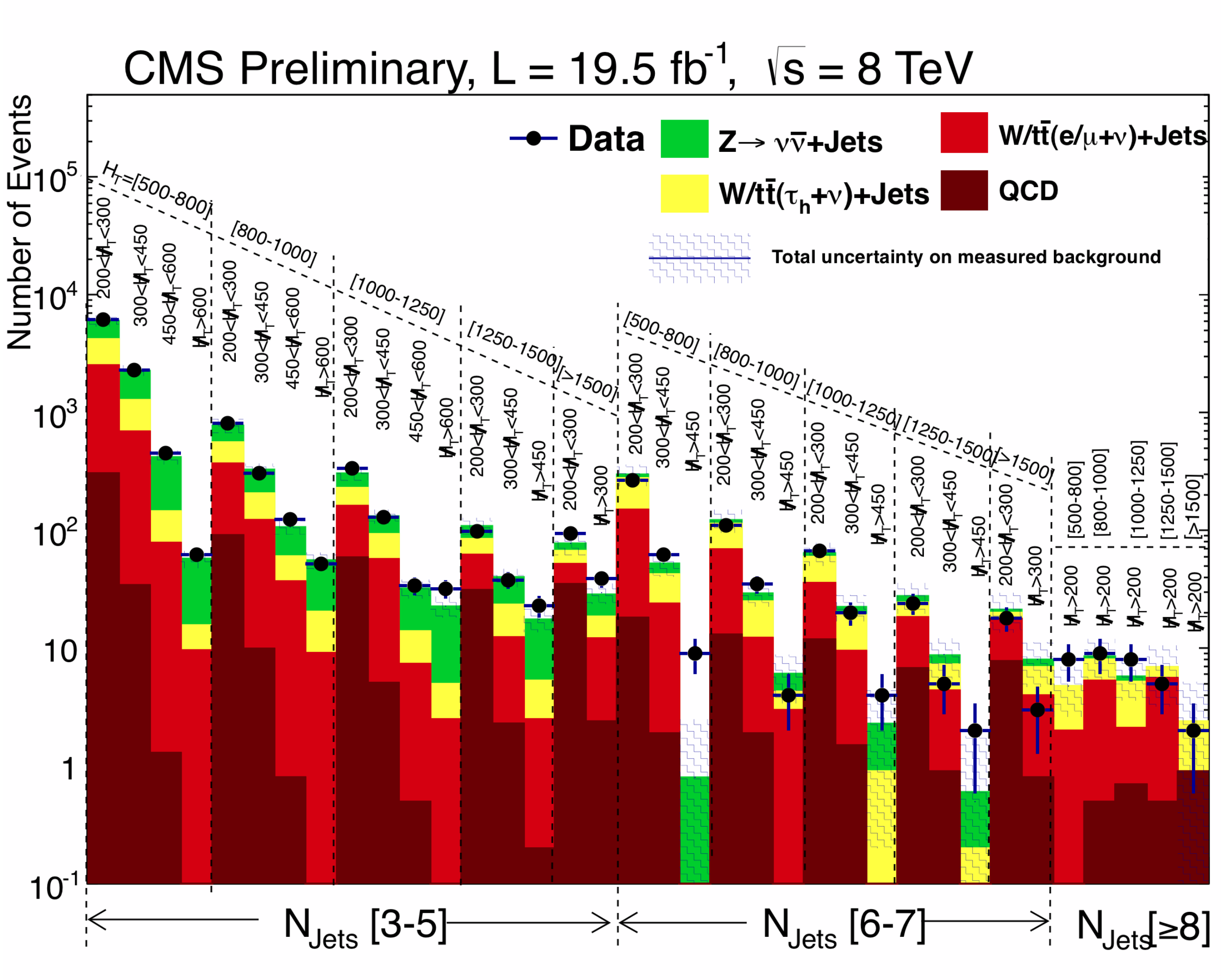


JHEP 1209 (2012) 035



Squark-gluino production

SUS-13-012



RPV searches

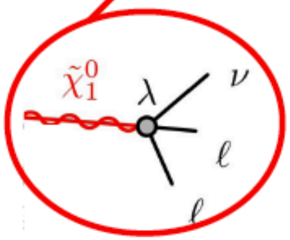
The MSSM potential

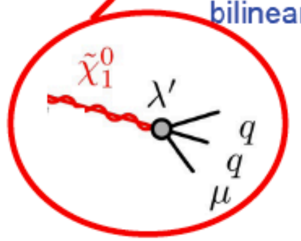
$$W_{\not{R}_p} = \lambda_{ijk}\hat{L}_i\hat{L}_j\hat{E}^C_k + \lambda'_{ijk}\hat{L}_i\hat{Q}_j\hat{D}^C_k + \epsilon_i\hat{L}_i\hat{H}_u + \lambda''_{ijk}\hat{U}^C_i\hat{D}^C_j\hat{D}^C_k$$

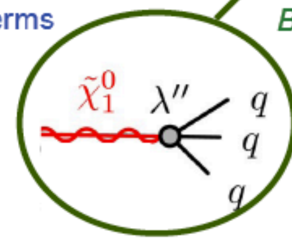
bilinear terms

B-number violating terms

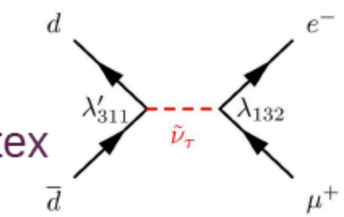
RPV couplings $\lambda, \lambda', \lambda''$







RPV can be at the production vertex and/or at decay vertices



Extra RPV term

$\Lambda''_{ijk}\hat{U}^c_i\hat{D}^c_j\hat{D}^c_k$

- $\tilde{g} \rightarrow qqq$
- $\tilde{\chi}^0_1 \rightarrow qqq$

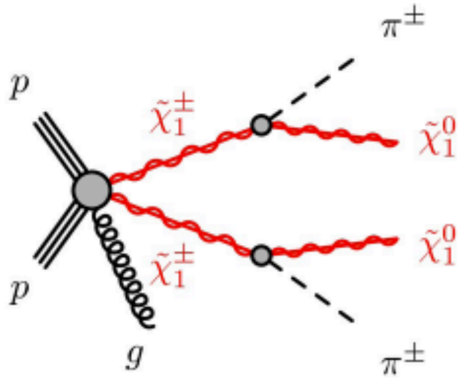
Λ''_{112} — only light quarks
SR: $\geq$ 6 jets high p_T

Λ''_{113}, Λ''_{123} — 2 b-jet produced
SR: $\geq$ 6 jets + 2 b-jets high p_T

RPV search channels

» Multijets (2x3 jets)
Heavy resonance to eμ, eτ, μτ PLB 723 (2013) 15
4-leptons ATLAS-CONF-2013-036

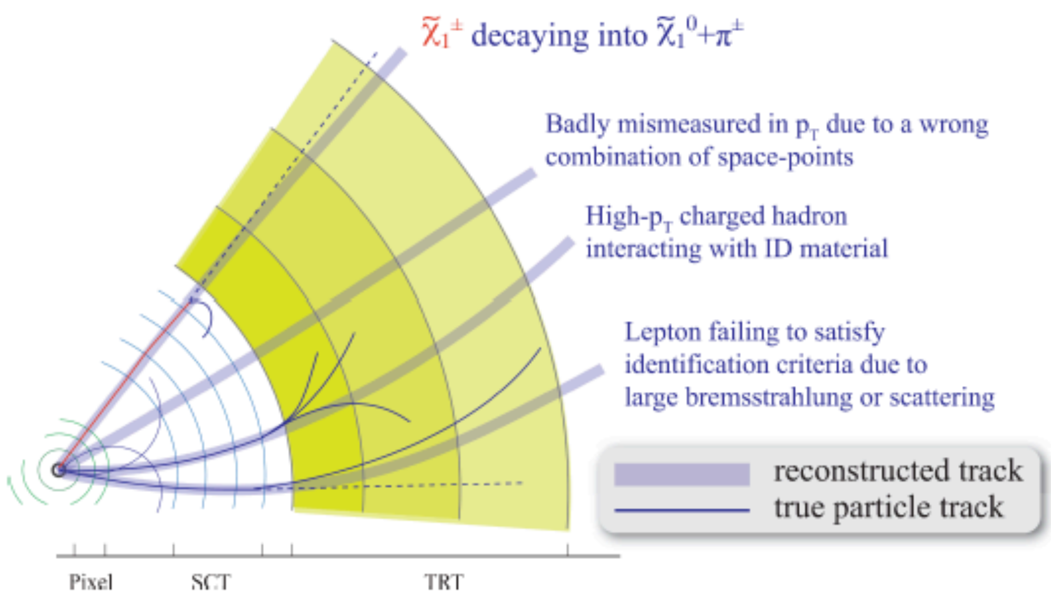
LLP – disappearing track

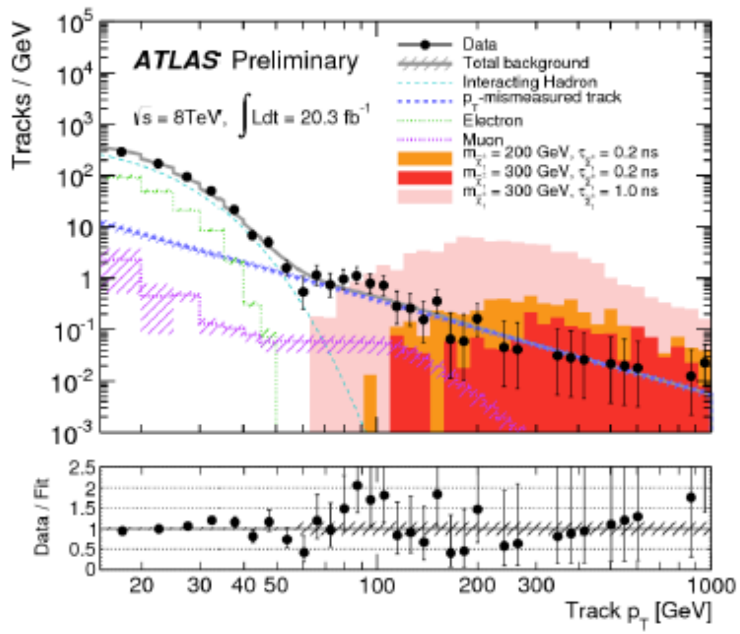


Many SUSY model e.g. AMSB have almost mass degenerate chargino and LSP → long-lived chargino

Chargino travels into detector before decaying to soft pion + LSP → disappearing track

Trigger on ISR jet
Look for isolated, high p_T tracks with < 5 TRT hits

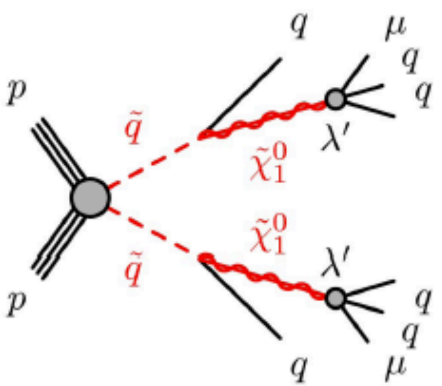




Background track p_T shape taken from data
Signal + background template fit for candidate tracks

No significant excess observed

μ + displaced vertrex ATLAS-CONF-2013-092

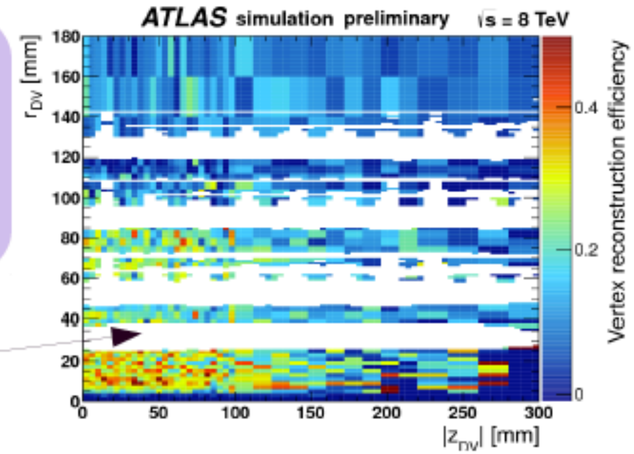


Consider the LSP to be long-lived, decaying to a muon and jets
Dedicated reconstruction of tracks and vertices

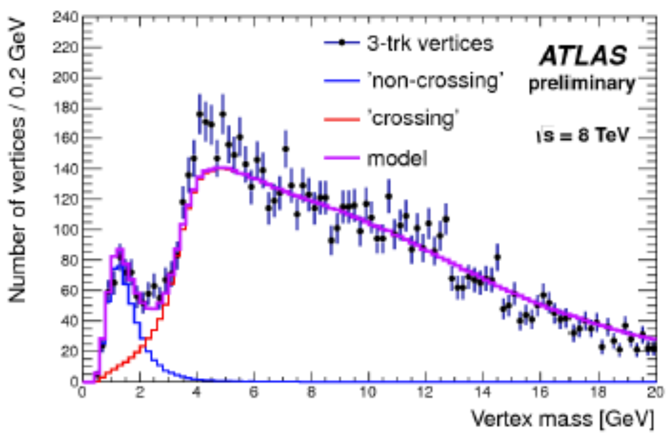
Trigger with one high-p_T muon

Search for a displaced vertex (DV)
within r < 180 mm and |z| < 300 mm
m_{DV} > 10 GeV and > 4 tracks

To suppress hadronic interactions, veto vertices from regions of high density



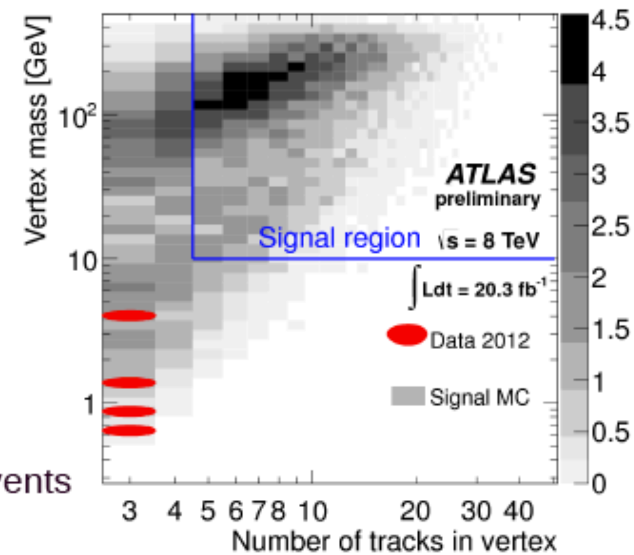
Dominating background from hadronic interactions with gas molecules (outside beampipe)
Usually low mass, but random track crossing can give high mass



Model m_{DV} with jet-triggered events

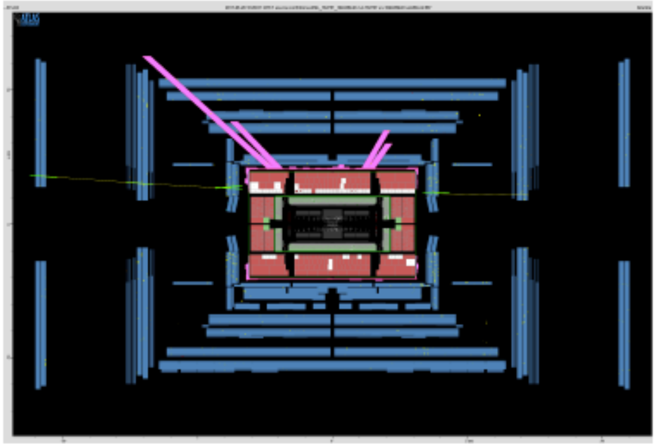
Random track combination background negligible

Expected 0.02 ± 0.02 events
Observed 0

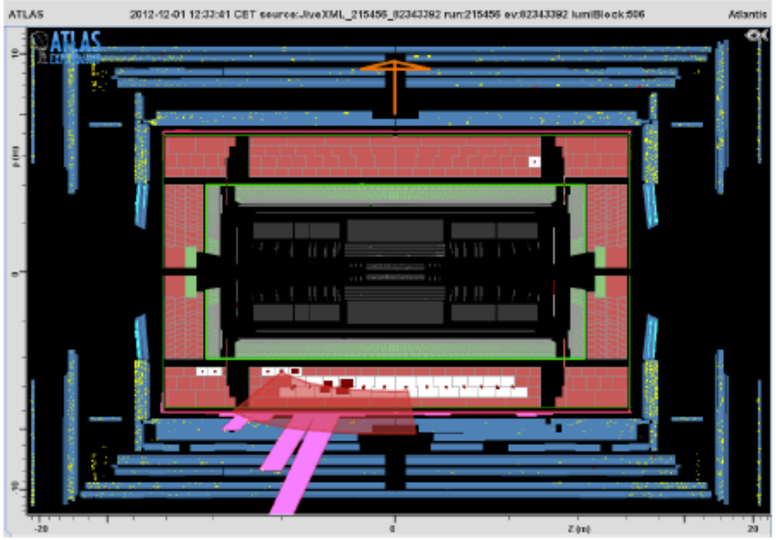


Long-lived gluino R-hadrons

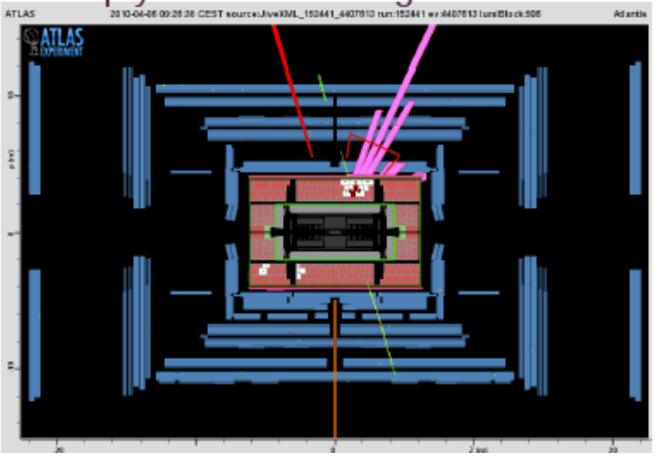
A beam-halo candidate event during an unpaired bunch crossing in data.

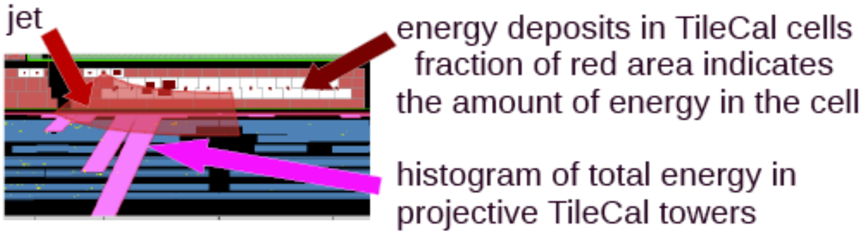


A candidate event display from 2011 data passing all selections



A cosmic ray muon candidate event during an empty bunch crossing in data

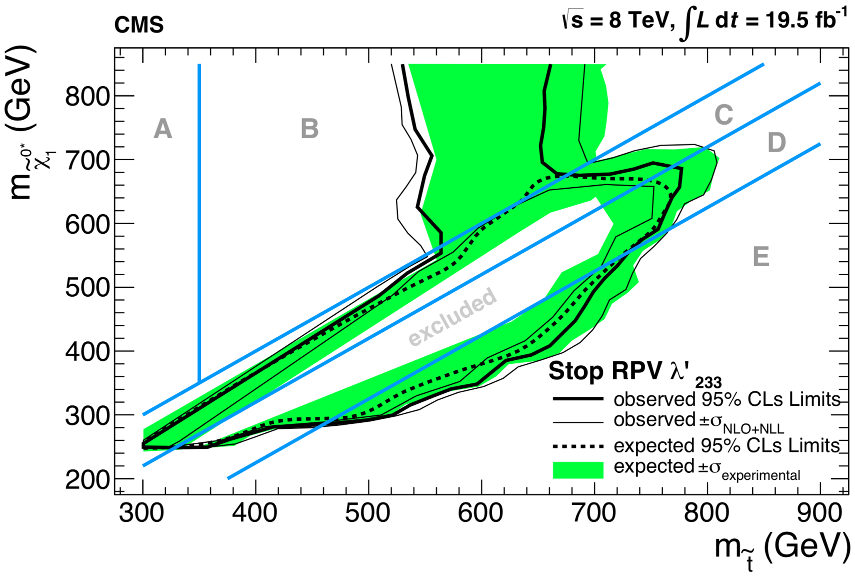




Muon segments are drawn but not reconstructed

R-parity violation (RPV)

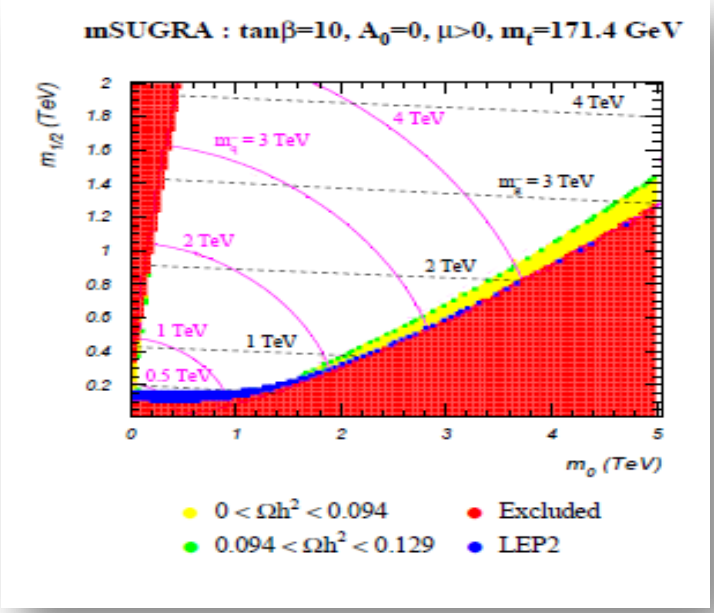
RPV stop searches (arXiv: 1306.6643)



MSUGRA = Gravity-Mediated Supersymmetry Breaking

= most studied scenario is the 5 parameter mSUGRA model

M_0:	**common boson mass at GUT scale**
$M_{1/2}$:	**common fermion mass at GUT scale**
tan β:	ratio of higgs vacuum expectation values
A_0:	common GUT trilinear coupling
μ :	sign of Higgs potential parameter

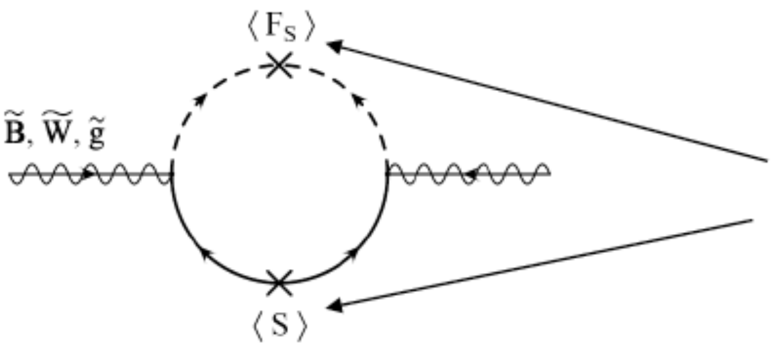


GMSB = Gauge Mediated Supersymmetry Breaking

- Gauge Mediated Supersymmetry Breaking is method of communicating supersymmetry breaking to the supersymmetric Standard Model through the Standard Model's gauge interactions. Typically a hidden sector breaks supersymmetry and communicates it to massive messenger fields that are charged under the Standard Model. These messenger fields induce a gaugino mass at one loop and then this is transmitted on to the scalar superpartners at two loops.
- the maximum Higg's boson mass predicted is just 121.5GeV → with the Higgs being discovered at 125GeV - this has likely been disproved

GMSB

Gauge mediated SUSY breaking can be understood in terms of loop effects in a renormalizable framework (in contrast to mSUGRA).



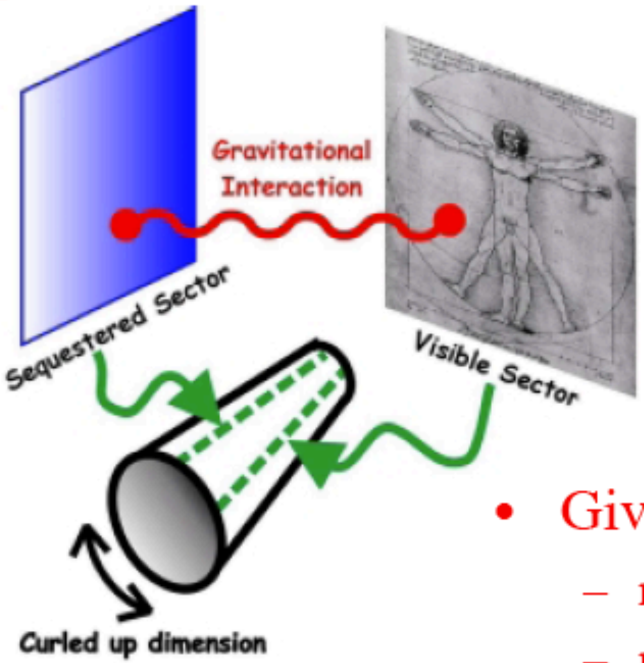
Masses of the gauginos are produced via couplings to a massive messenger sector

Parameters (general model has 124):

→ Λ: Breaking scale
→ M: Mass scale of the messengers
→ tanβ: Ratio of Higgs vacuum expectation values
→ N: Number of messenger chiral supermultiplets
→ sign(μ): Sign of the Higgs mass parameter
→ C_{grav}: Scale factor of the Gravitino mass → lifetime of NLSP

AMSB = Anomaly Mediated Supersymmetry Breaking

- Characteristic near-degeneracy of χ_1^0 (LSP) and χ_1^+ masses
- $\Delta m < m(\pi)$
  - Long lived χ_1^+
  - 'cannonball'
- $\Delta m > 1$ GeV
  - multi-hadron decay

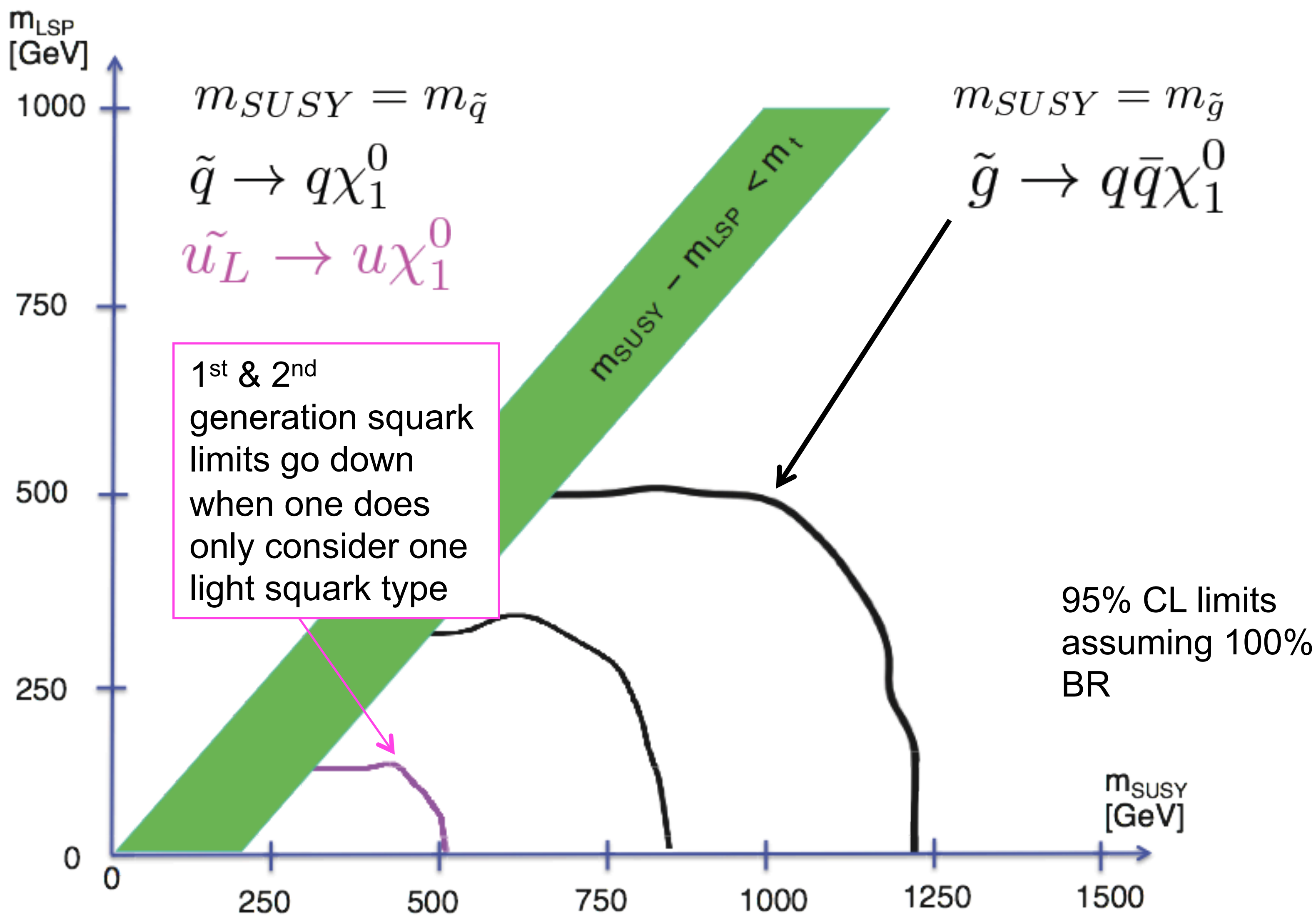


- Our Model:
  - RPC
  - $\tan\beta = 10$
  - $m_{3/2} = 36$ TeV
  - $m_0 = 500$ GeV
  - μ +ve

- Giving:
  - $m(\chi^+) = 99.0$ GeV
  - $m(\chi^0) = 98.4$ GeV
  - $\Delta m = 631$ MeV
  - $c\tau = 360$ µm

Examine model with $c\tau \Rightarrow$ vertexing

SUSY limits



m_{LSP} [GeV]
1000
750
500
250
0
0
250
500
750
1000
1250
1500
m_{SUSY} [GeV]
$m_{SUSY} = m_{\tilde{q}}$
$\tilde{q} \rightarrow q\chi_1^0$
$\tilde{u_L} \rightarrow u\chi_1^0$
$m_{SUSY} = m_{\tilde{g}}$
$\tilde{g} \rightarrow q\bar{q}\chi_1^0$
$m_{SUSY} - m_{LSP} < m_t$
1st & 2nd generation squark limits go down when one does only consider one light squark type
95% CL limits assuming 100% BR