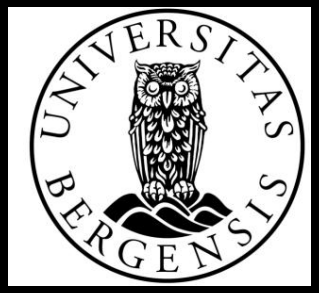
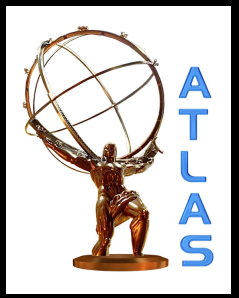
Inclusive searches for squarks and gluinos with the ATLAS detector

Bertrand MARTIN, University of Bergen

on behalf of the **ATLAS Collaboration**





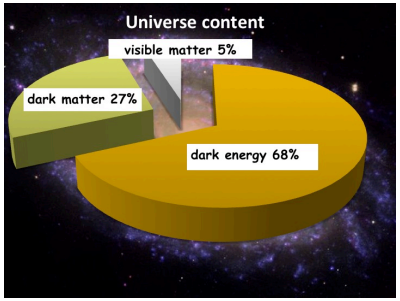
Introduction

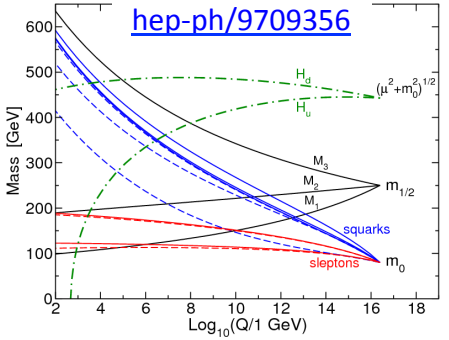
Weak scale SUSY remains one of the best motivated extensions of the Standard Model.

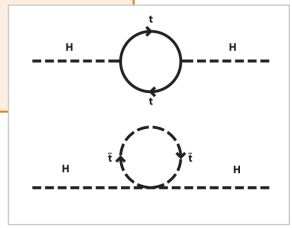
This talk presents the **latest ATLAS results** (8 TeV, 20 fb^{-1}) on searches for strongly-produced **squarks and gluinos**.

There are **many other results** I won't have time to cover. They can be found on the ATLAS public wiki.

Prospects will also be given for 14 TeV.







ATLAS SUSY Searches* - 95% CL Lower Limits

Status: ICHEP 2014

ATLAS Preliminary
$\sqrt{s}$ = 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($\tilde{g}$)	1405.7875
	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
	$\tilde{q}\tilde{q}, \tilde{q}\rightarrow q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$ 850 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m(1st gen. $\tilde{q}$)=m(2nd gen. $\tilde{q}$)	1405.7875
	$\tilde{g}\tilde{g}, \tilde{g}\rightarrow q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$ 1.33 TeV	m($\tilde{\chi}_1^0$)=0 GeV	1405.7875
	$\tilde{g}\tilde{g}, \tilde{g}\rightarrow qq\tilde{\chi}_1^{\pm}\rightarrow qqW^{\pm}\tilde{\chi}_1^0$	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
	$\tilde{g}\tilde{g}, \tilde{g}\rightarrow qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	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	tanβ<15	1208.4688
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	20.3	$\tilde{g}$ 1.6 TeV	tanβ >20	1407.0603
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde{g}$ 1.28 TeV	m($\tilde{\chi}_1^0$)>50 GeV	ATLAS-CONF-2014-001
	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(NLSP)>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
3rd gen. $\tilde{g}$ med.	$\tilde{g}\rightarrow b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$ 1.25 TeV	m($\tilde{\chi}_1^0$)<400 GeV	1407.0600
	$\tilde{g}\rightarrow t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.1 TeV	m($\tilde{\chi}_1^0$) <350 GeV	1308.1841
	$\tilde{g}\rightarrow t\bar{t}\tilde{\chi}_1^0$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$ 1.34 TeV	m($\tilde{\chi}_1^0$)<400 GeV	1407.0600
	$\tilde{g}\rightarrow b\bar{t}\tilde{\chi}_1^+$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$ 1.3 TeV	m($\tilde{\chi}_1^0$)<300 GeV	1407.0600

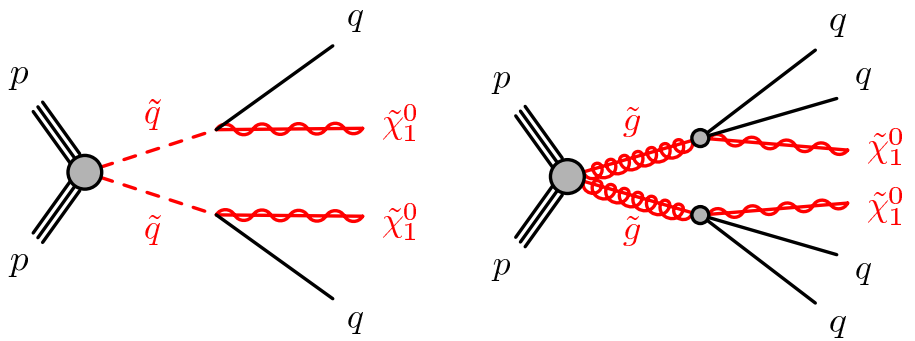
0 lepton + 2-6 jets + MET

1405.7875
sub. to JHEP

Large number of models with such signature.

- jet + MET trigger
- e/μ veto
- $\Delta\phi_{min}$(jet,MET) , MET/$\sqrt{H_T}$, MET/m_{eff} with m_{eff} = MET + Σ p_T^{jets}

15 signal regions, from 2 to 6 jets.



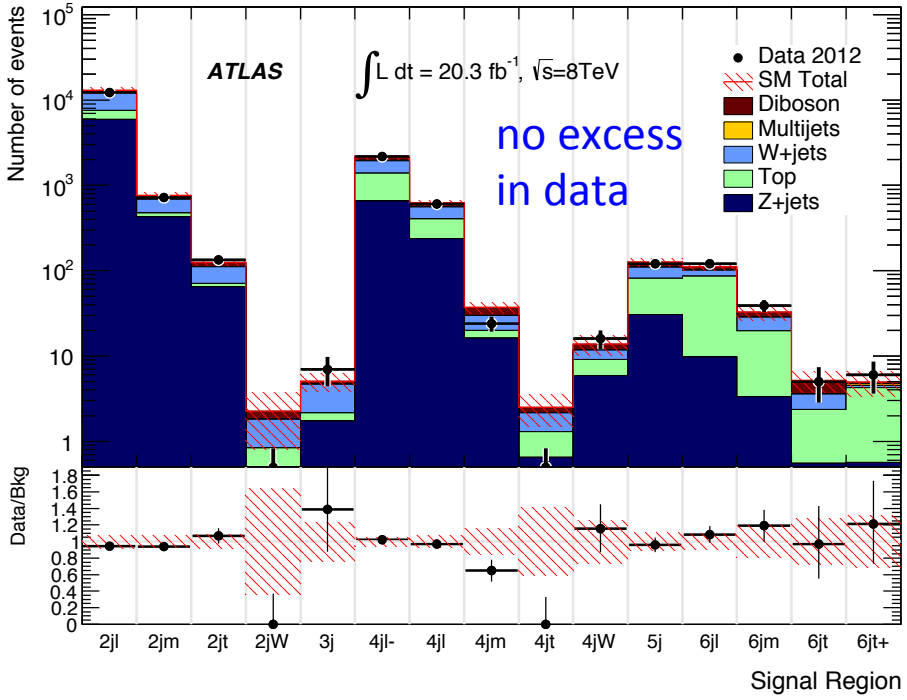
Example: direct decay

4 control regions per signal region:

- **γ+jets with "γ = MET" (Z->νν + jets)**
- **QCD: smear low-MET multi-jet data**
- **W(->lν) + jets** } ℓ+jets+MET, **b-veto**
- **$t\bar{t}$ -> $b\bar{b}qq'l\nu$** } or **b-tag**, "$\ell=\tau_{had}$"

Background normalization fitted across the 4 control regions.

Use MC-based transfer factors to predict background in signal region.

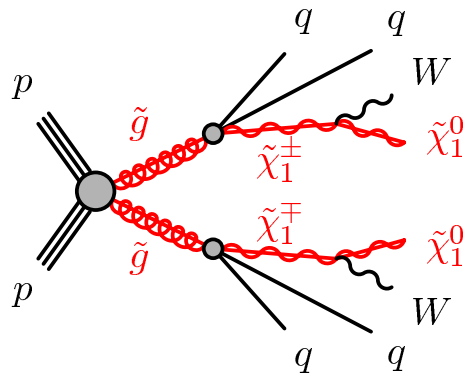


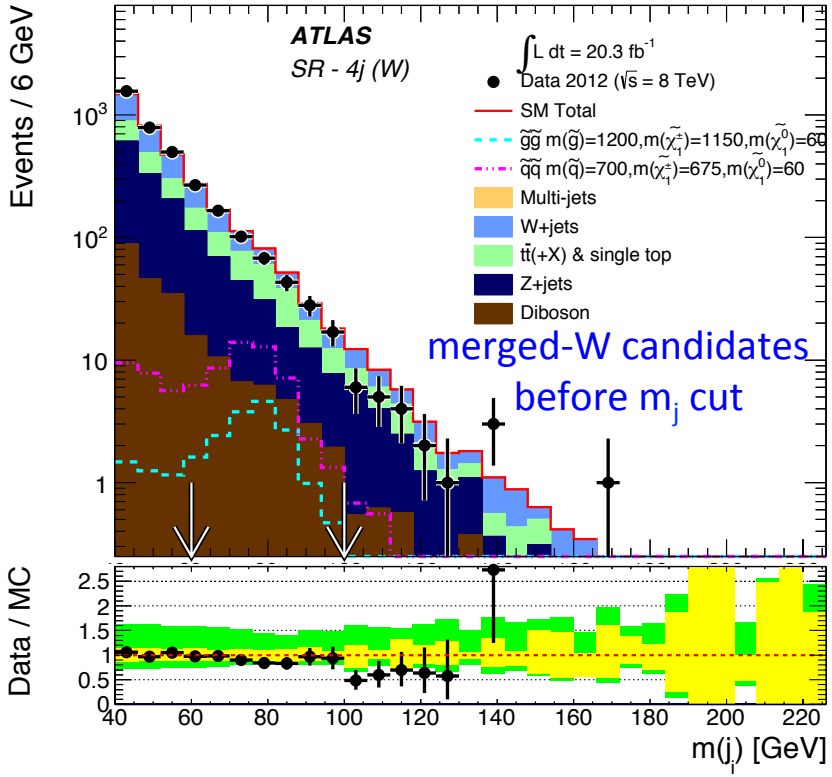
0 lepton + 2-6 jets + MET

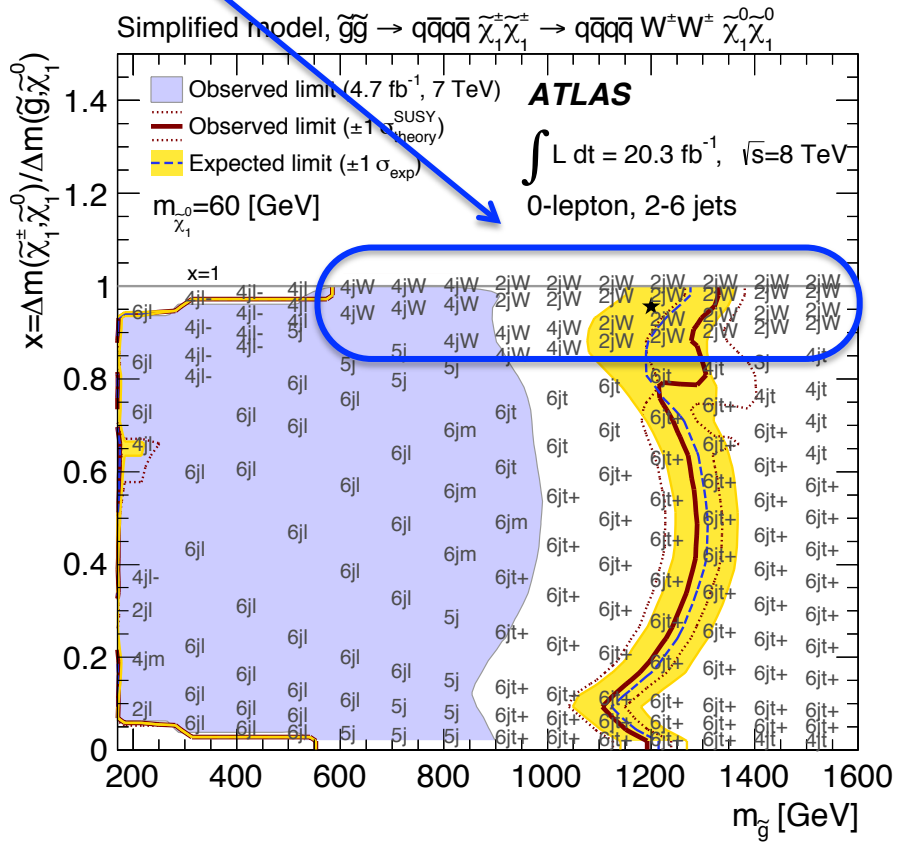
New interpretation: "1-step" decay via $\tilde{\chi}_1^{\pm}$ -> $W^{\pm}$ $\tilde{\chi}_1^0$

Expect boosted W for large Δm($\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^0$).

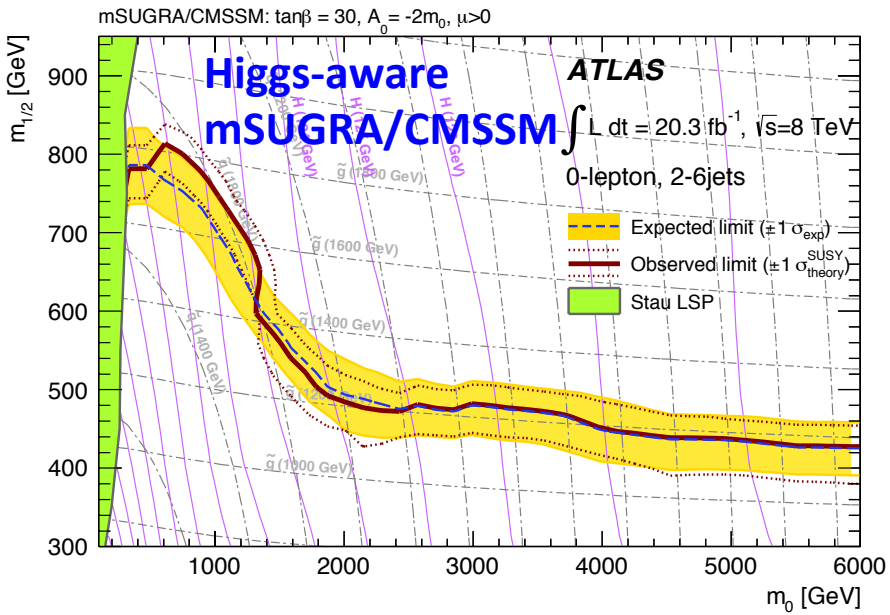
Dedicated selection with **resolved/merged W->qq' decay**, with (di)jet mass within [60,100] GeV

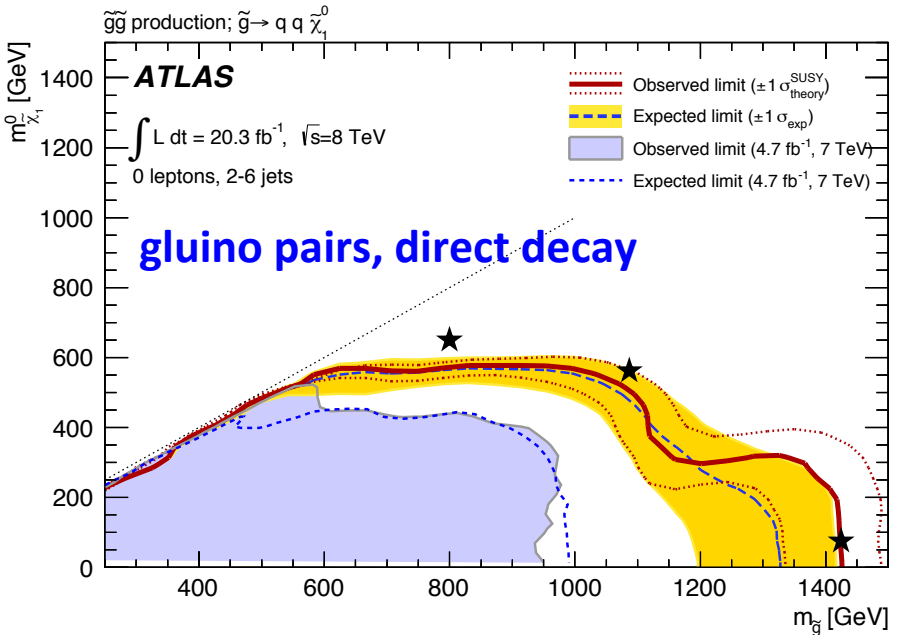


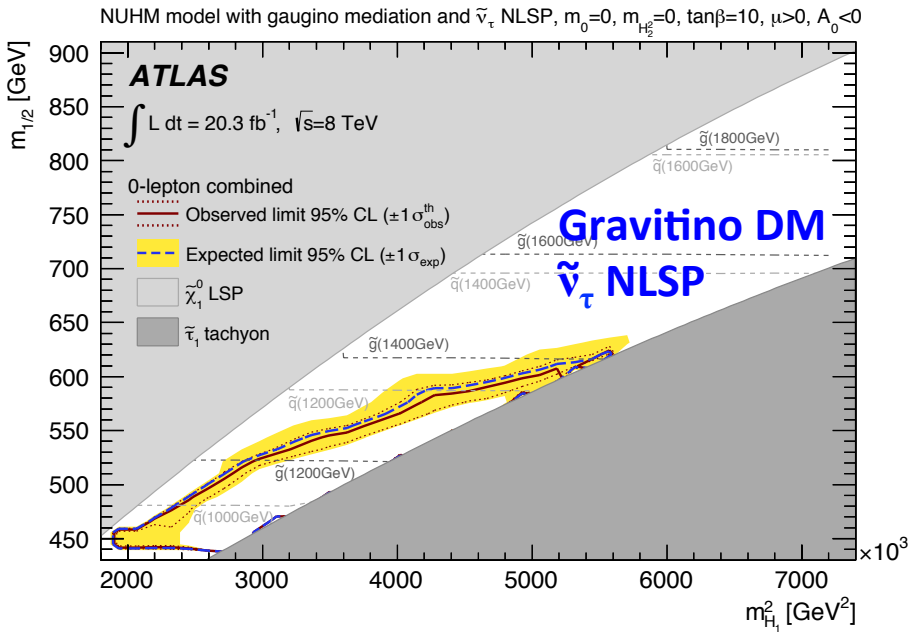


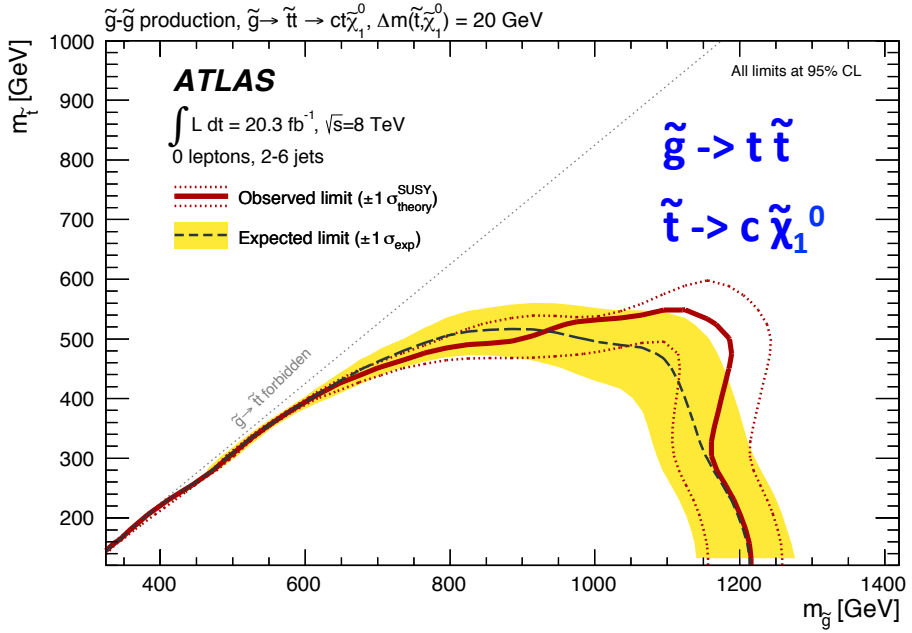


0 lepton + 2-6 jets + MET





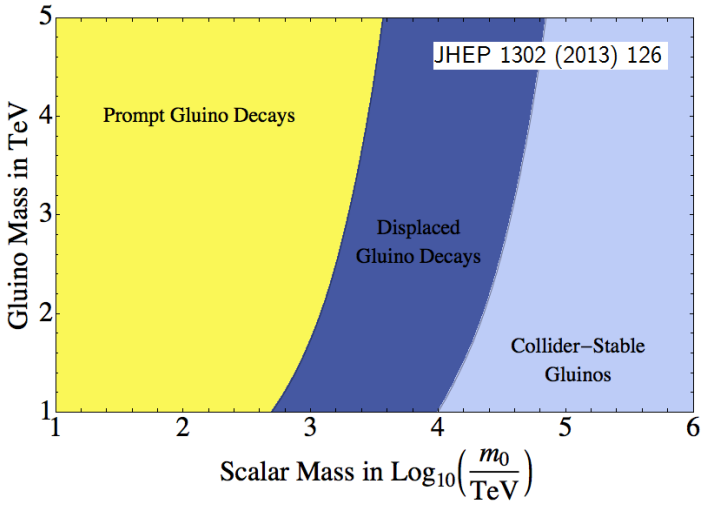




Metastable gluinos

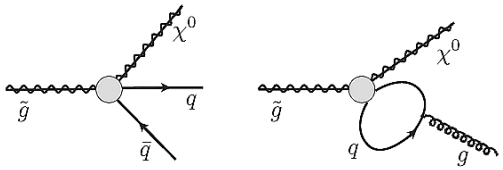
ATLAS-CONF-2014-037

Metastable $\tilde{g}$ = **decay within detector with displaced vertex**. Expected in "mini-split SUSY" for $m_{\tilde{g}} \sim$ TeV, when $m_0 \sim 10^3$-10^5 TeV (m_{Higgs} , coupling unification).



Free parameters: gluino mass and lifetime, LSP mass.
Investigate 2 scenarios for gluino decay:

$$\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0 \;/\; g\tilde{\chi}_1^0$$

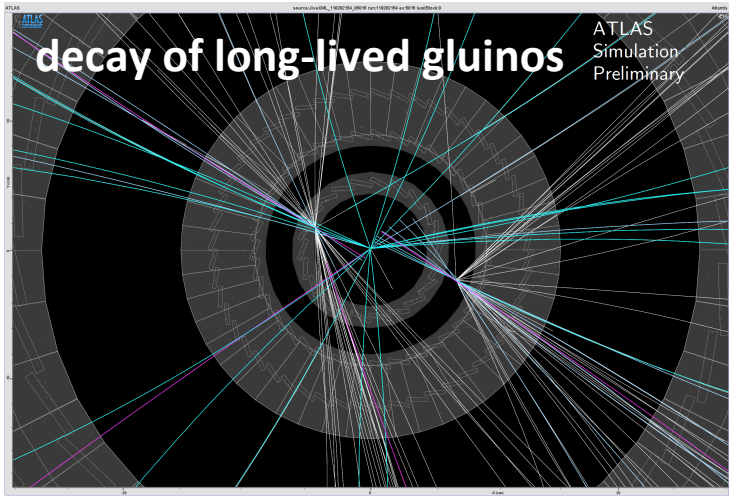


$$\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$$

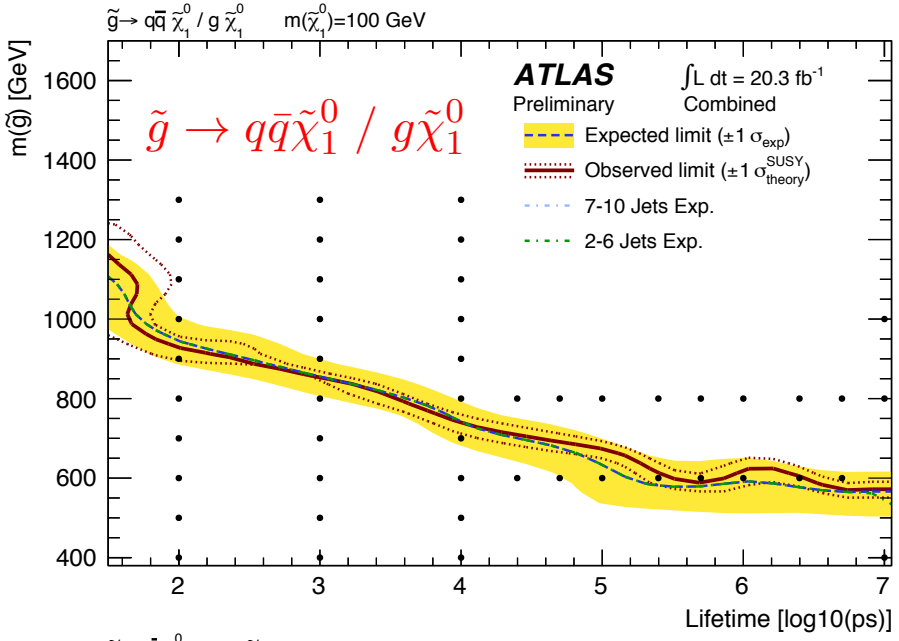
Signal MC: Pythia6 for gluino production, **hadronization and decay within R-hadron**; dedicated **Geant4 routine**.

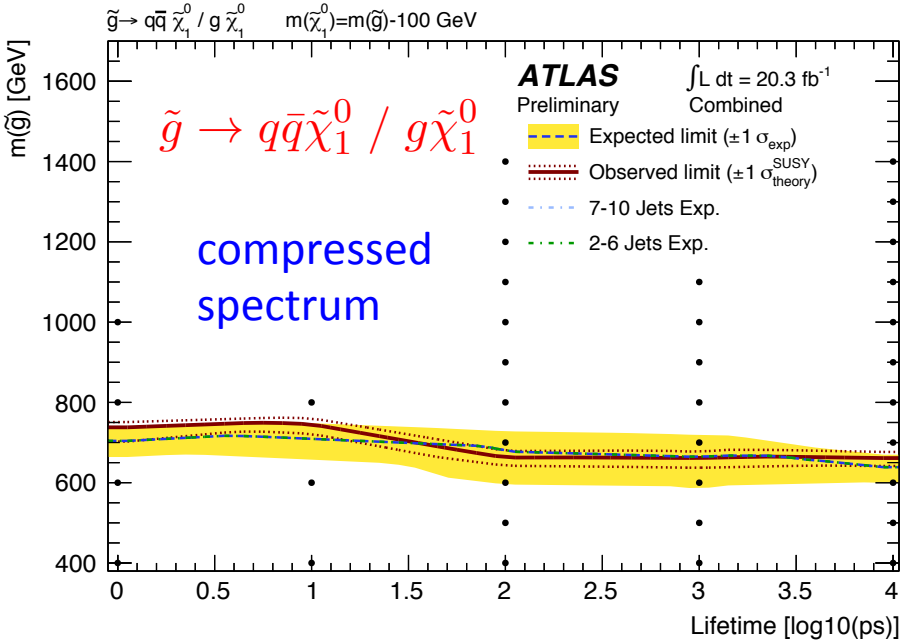
Re-interpretation of two 0-lepton searches:

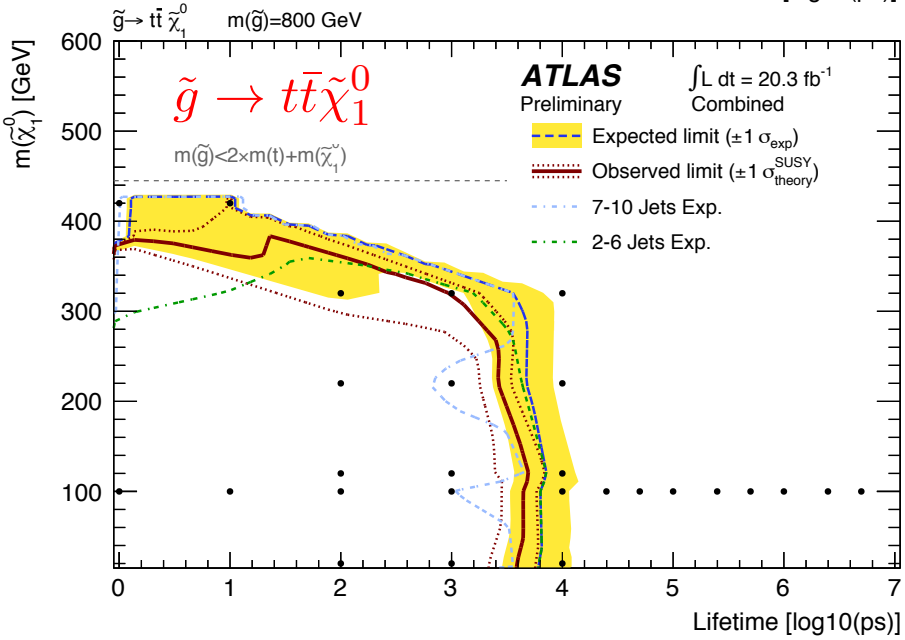
- 2-6 jets provides most sensitivity
- 7-10 jets (**0, 1, ≥2 b-jets**) important when $\tilde{g}$ decays via **tops**, since **large jet multiplicity**. For small lifetimes, gluino decay products identified as b-jets.



Metastable gluinos







3 benchmark models:

- fixed LSP mass (100 GeV)
- fixed gluino mass (800 GeV)
- compressed spectrum (Δm = 100 GeV for $\tilde{g} \to q\bar{q}\tilde{\chi}_1^0 \,/\, g\tilde{\chi}_1^0$, 480 GeV for $\tilde{g} \to t\bar{t}\tilde{\chi}_1^0$)

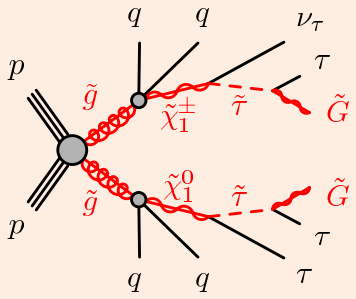
No excess observed.

Limits set as a function of gluino lifetime.

$\tau_{(had)}$ + jets + MET

1407.0603
sub. to JHEP

Tau-rich models:
- **GMSB** at large tanβ
- **mSUGRA** at low m_0
- **bRPV**, where $\tilde{\chi}_1^0$ -> $W^*\mu(\tau)$
- **nGM** with light gluino, $\tilde{G}$ LSP



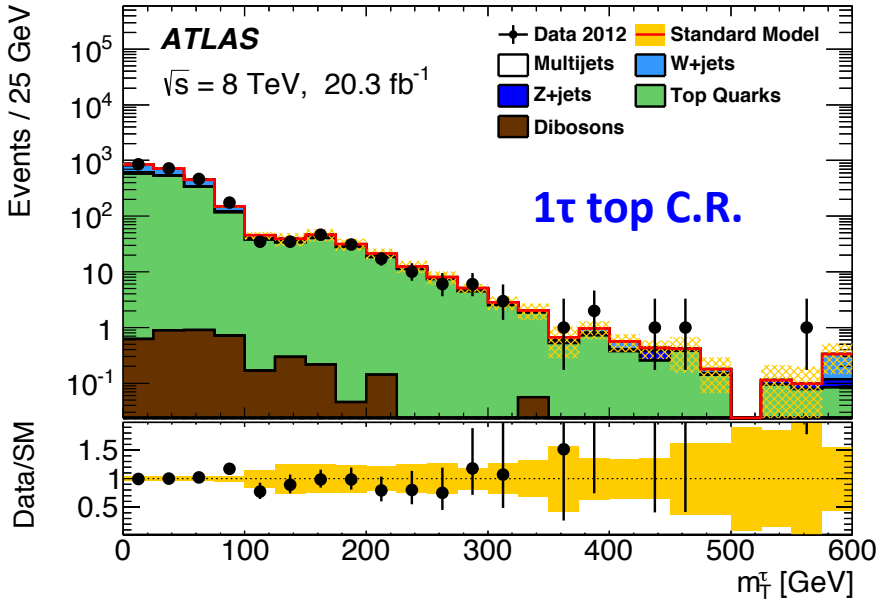
4 orthogonal channels: 1τ, 2τ, τ+e, τ+μ

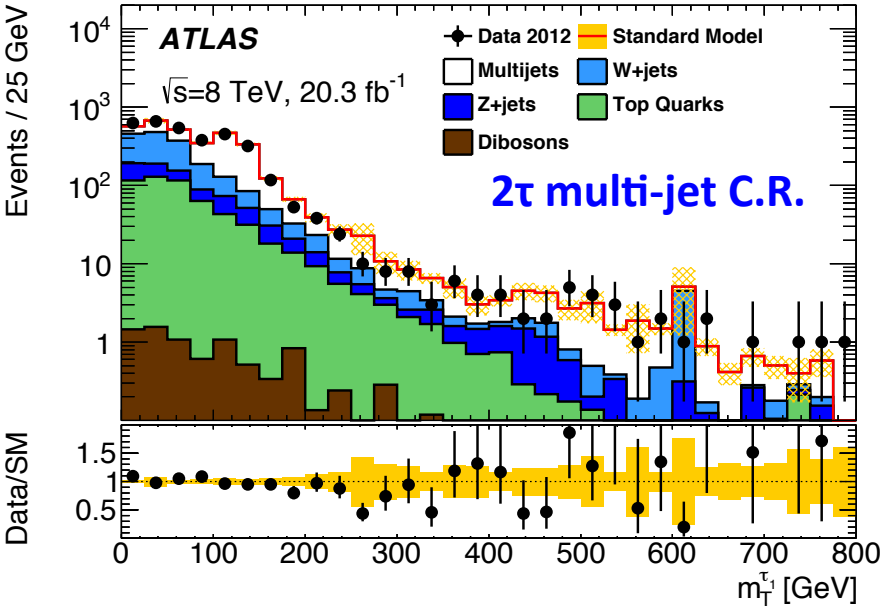
common to 1τ and 2τ
- jet+MET trigger
- e/μ veto
- 2 high p_T jets + Δφ(jet,MET)

1 medium τ, p_T > 30 GeV
m_T^τ, 2 signal regions {MET, H_T}

≥ 2 loose τ, p_T > 20 GeV
4 signal regions {$m_T^{\tau 1} + m_T^{\tau 2}$, H_T^{2j}, N_{jet}}

Control regions for W+jets, Z+jets, top, multi-jets.





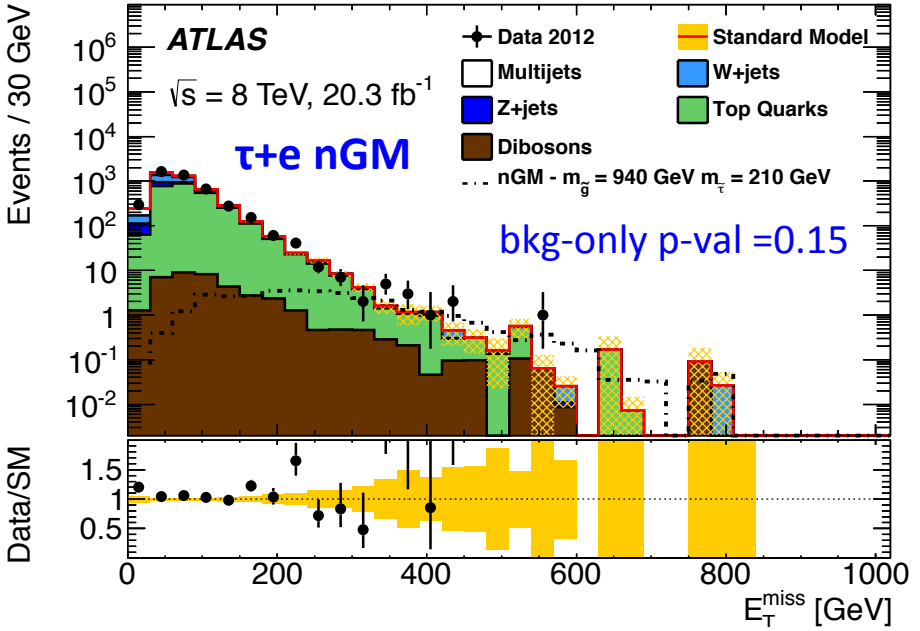
τ + jets + MET

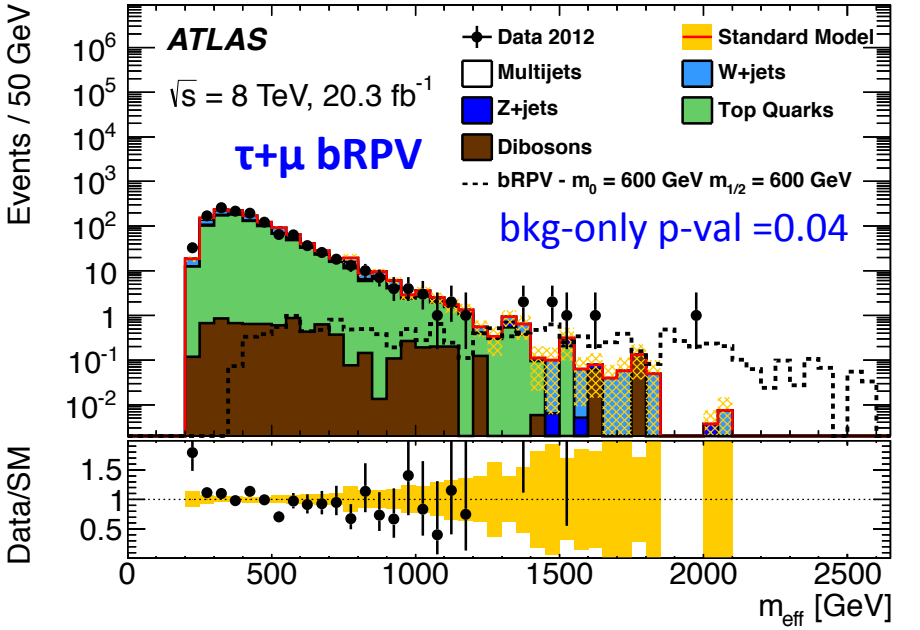
For τ+ℓ, single-lepton trigger
≥ 1 loose τ, p_T > 20 GeV
m_T^{ℓ} , 4 signal regions {m_{eff} , MET, N_{jet} }

Data-driven multi-jet background:
- ABCD method for 1τ
- jet smearing for 2τ
- matrix method for τ+ℓ

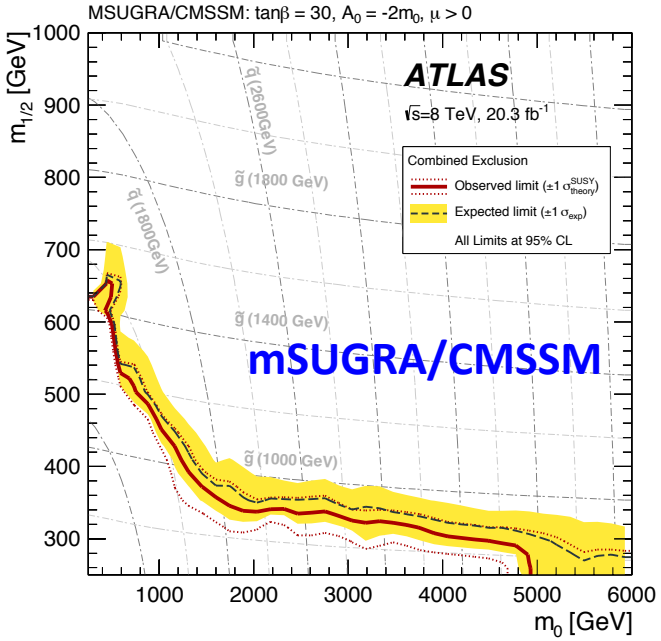
Main background uncertainty:
- differences between generators
- jet energy scale (large multiplicities)

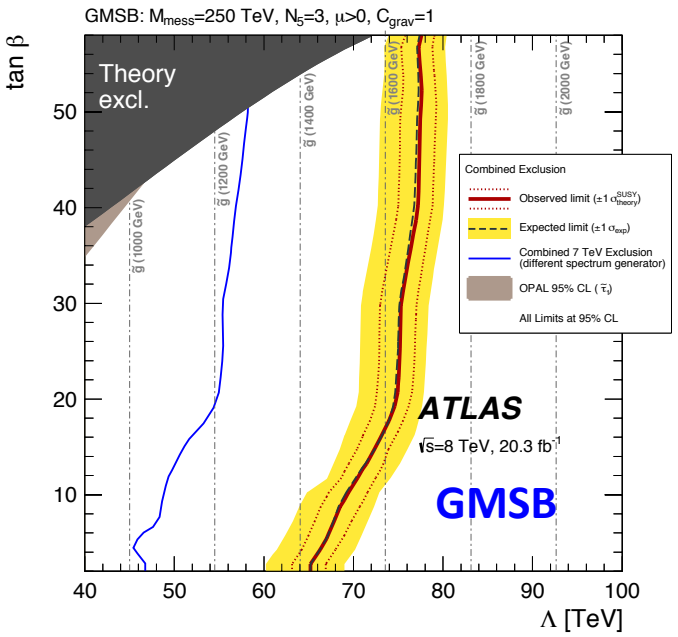
Combination: pick signal region with best expected sensitivity for each channel.

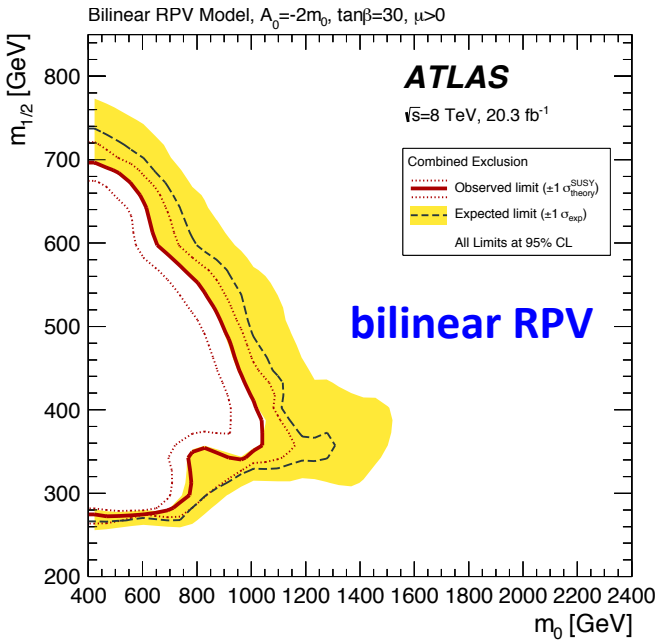




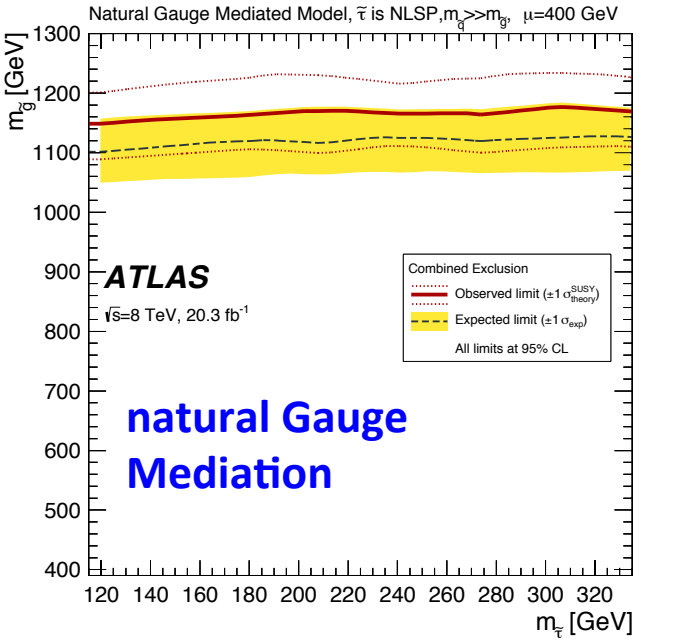
τ + jets + MET





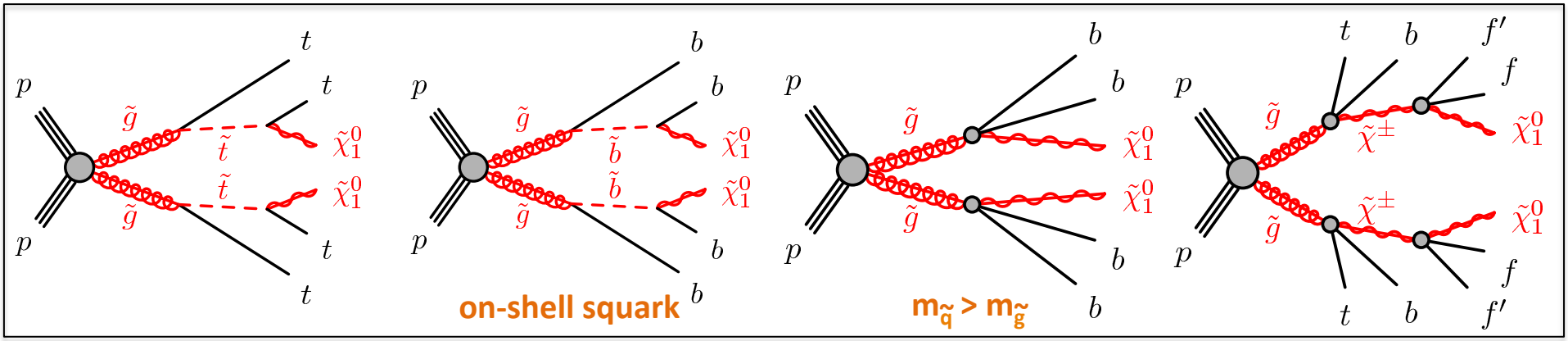


No excess in data



0-1 lepton, ≥ 3 b-jets + MET

1407.0600
sub. to JHEP



2 channels, with ≥ 3 b-jets:

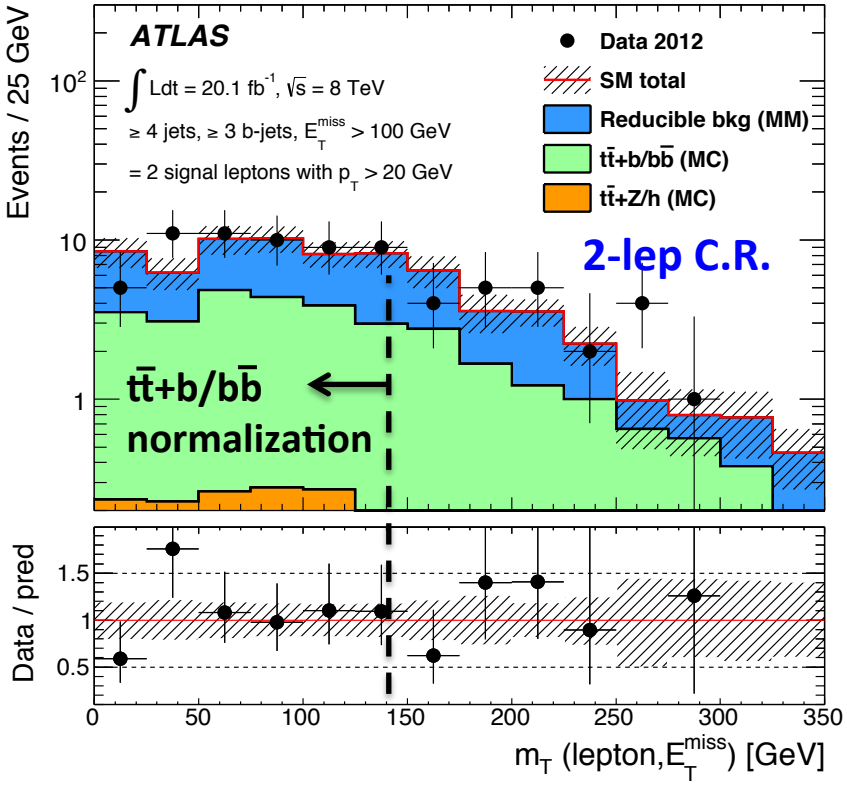
- **0 lepton, ≥ 4 or 7 jets**
- **≥ 1 lepton, ≥ 6 jets**

Search for **sbottom** or **stop/top** in gluino decay.

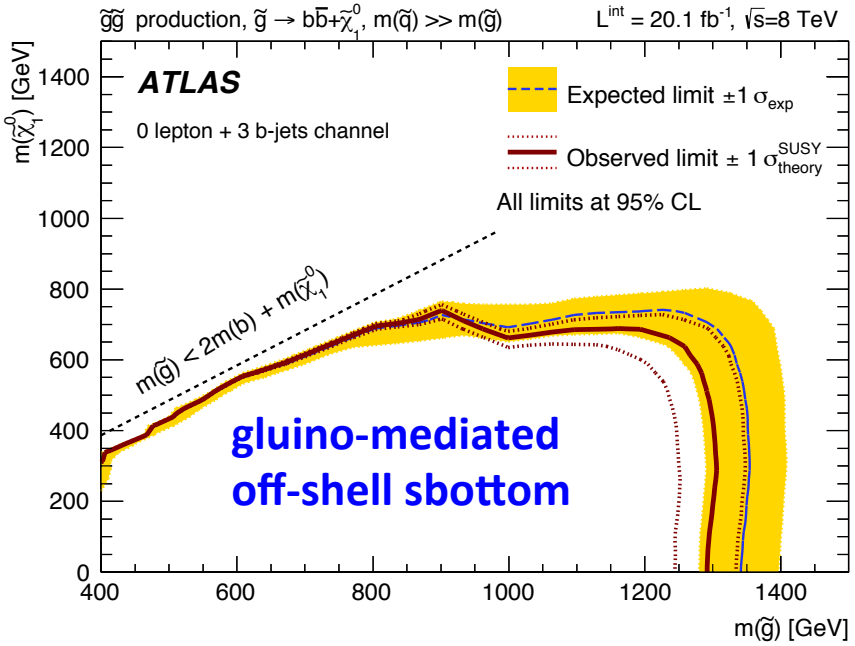
Background with 3 real b-jets: $t\bar{t}$ +b/b$\bar{b}$, normalized to data in 2-lepton control region

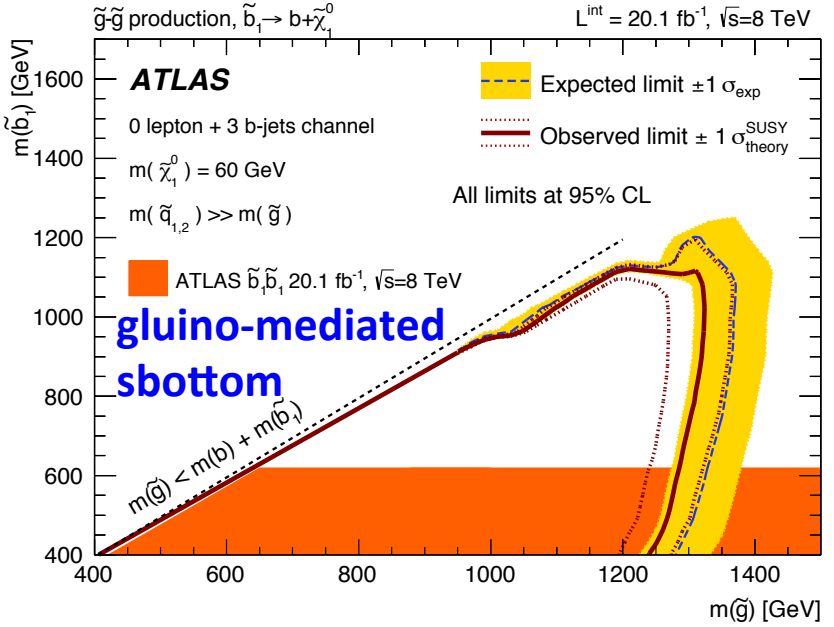
For fake b-jets,
0-lepton: semi-leptonic $t\bar{t}$
1-lepton: di-lepton $t\bar{t}$ with τ_{had} (high m_T cut)

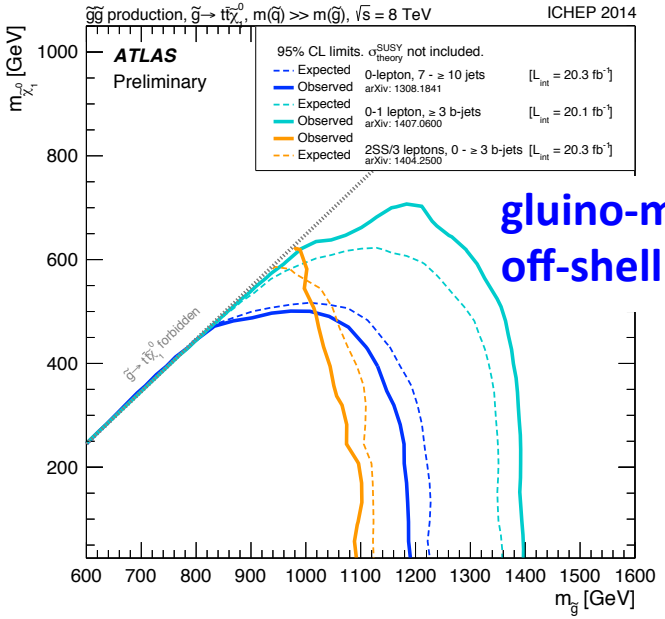
- fraction of real / fakes: matrix method
- fakes composition (τ_{had}, c- and light-jets): $t\bar{t}$ MC
- fake efficiencies from data



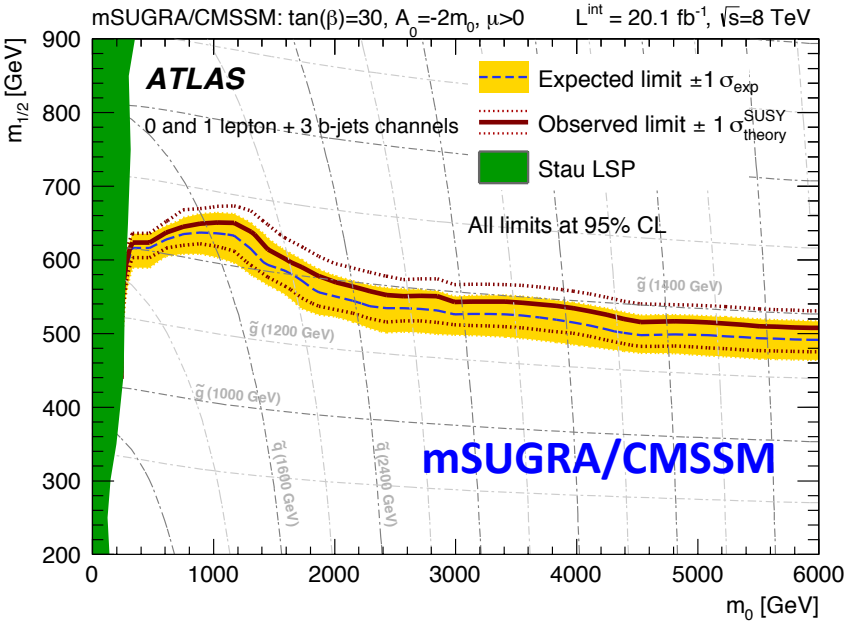
0-1 lepton, ≥ 3 b-jets + MET







No excess in data



Prospects for √s=14 TeV

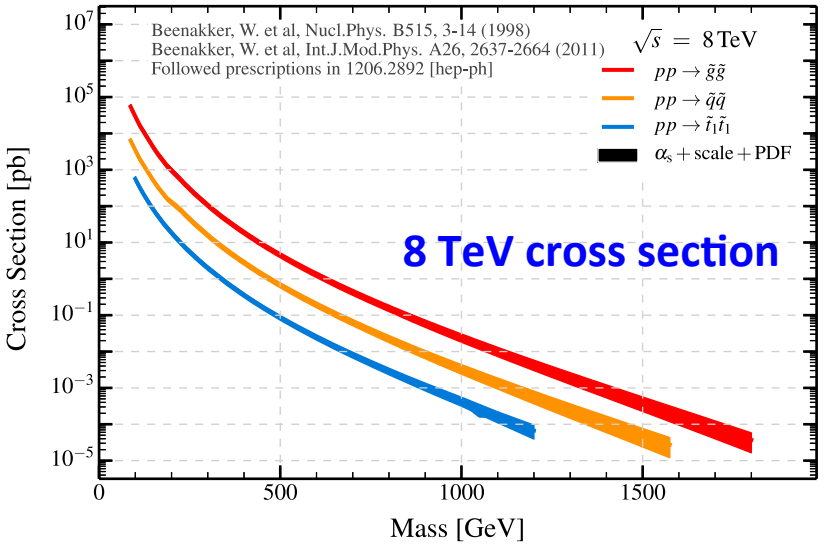
ATL-PHYS-PUB -2014-010

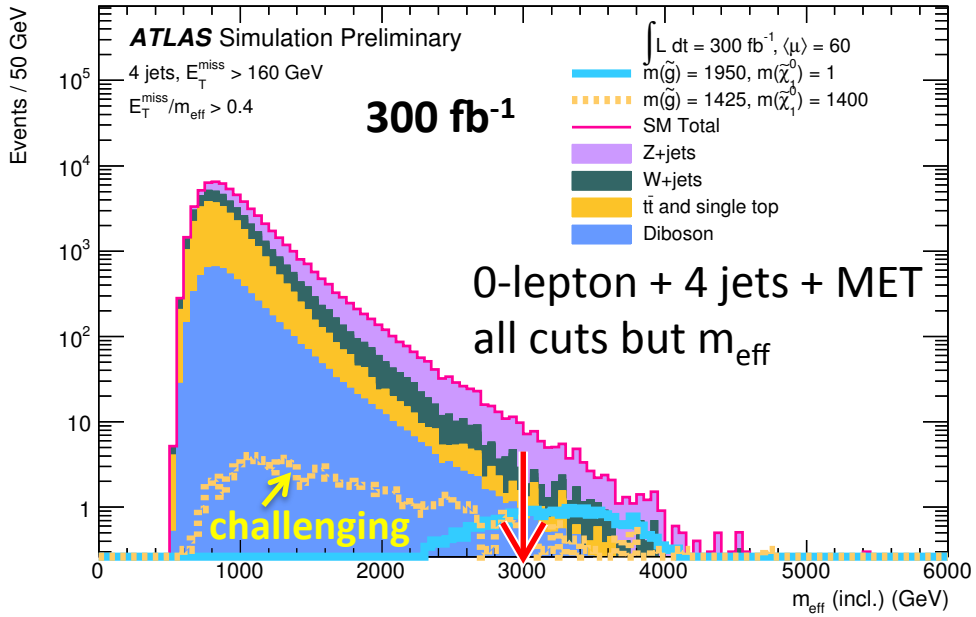
LHC 2015-2022: 300 fb^{-1} at 14 TeV, <μ> ~60
HL-LHC 2025-2032: 3000 fb^{-1} at 14 TeV, <μ> ~140

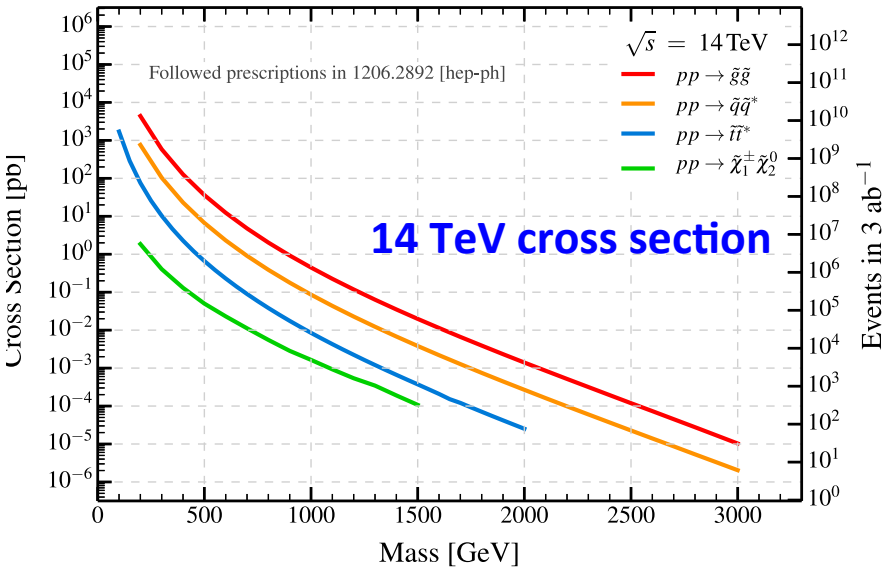
Studies at truth level, based on parameterized detector response at high pile-up.

Signal regions re-optimized.

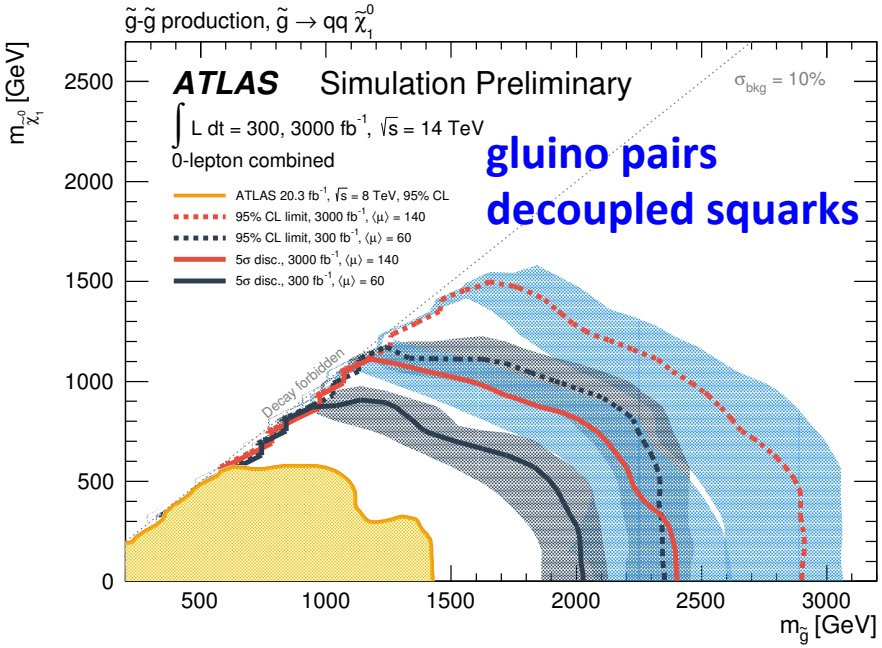
Exclusion/discovery sensitivity using significance which includes background uncertainty (10 %).

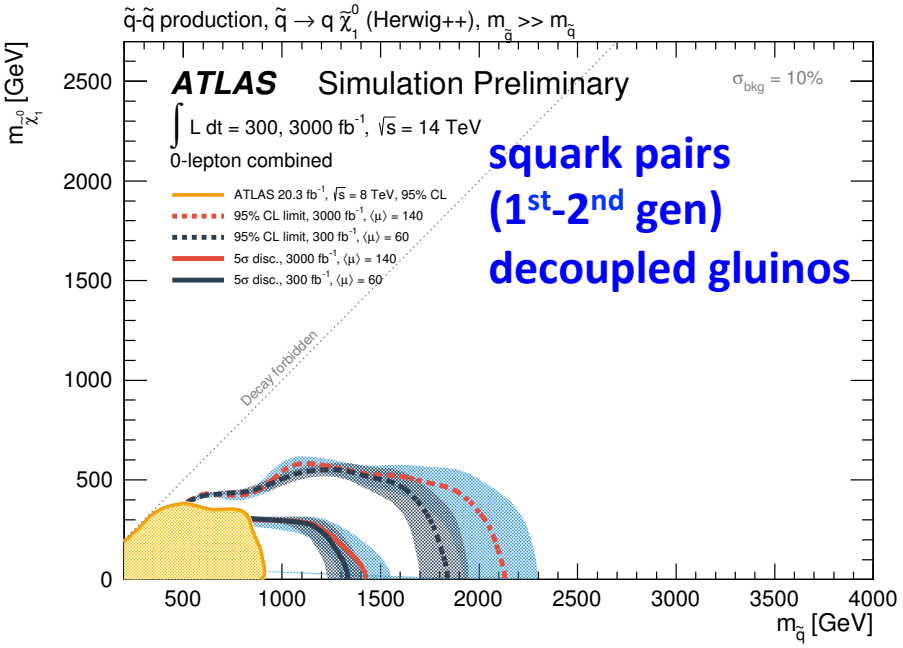


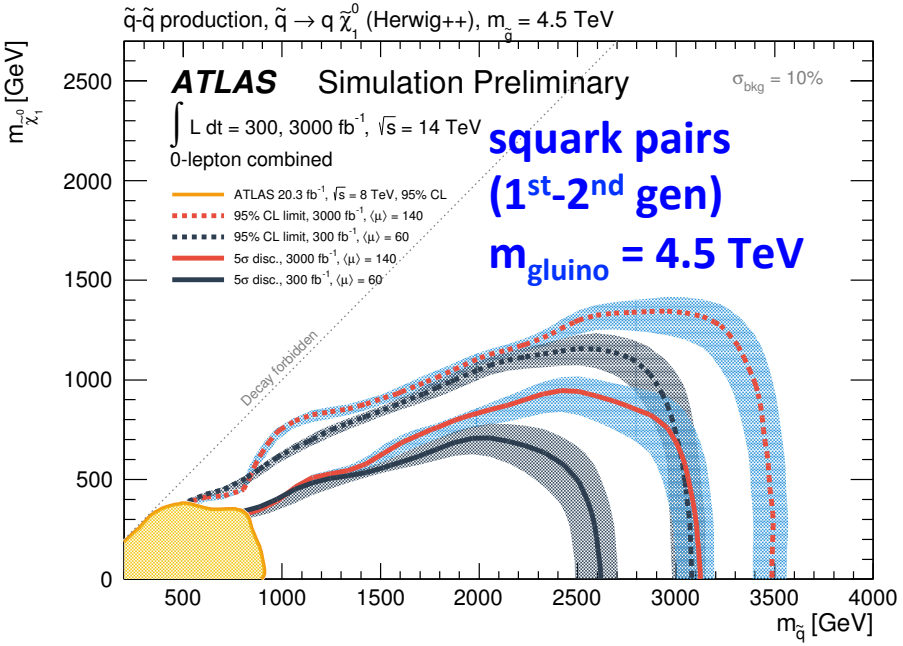




Prospects for √s=14 TeV







Discoverable regions not yet excluded ☺

Gluino limits ~not sensitive to squark mass. **Large theoretical (PDF) uncertainty at high m_{gluino} .**

Squark pair production enhanced when gluino not too heavy, via **t-channel gluino exchange**.

Summary

ATLAS has a rich program of inclusive searches for squarks and gluinos.

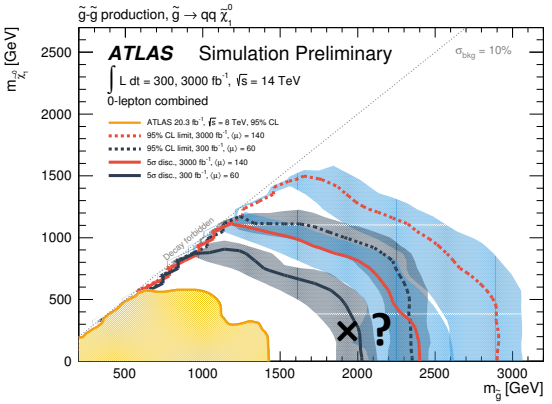
So far, no hint for a signal in data.

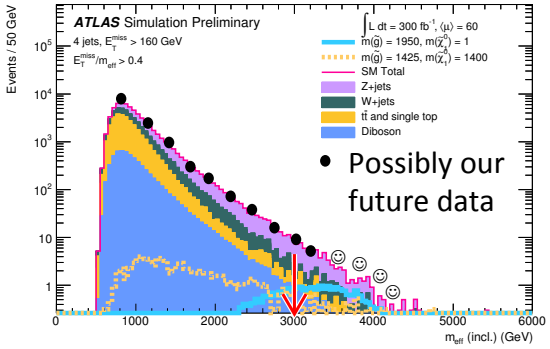
Limits have been significantly improved compared with 7 TeV analyses.

Now we have to prepare for whatever comes out of LHC Run-II data.

Now

Soon, hopefully…

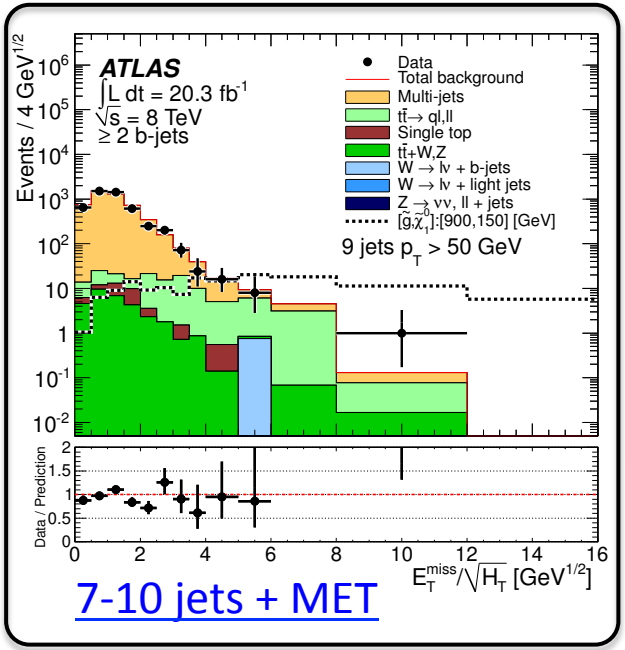




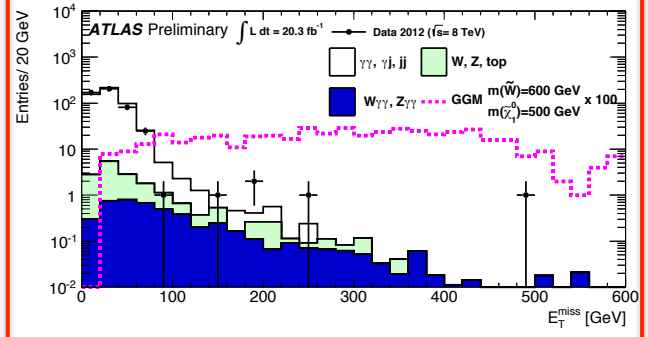
- Possibly our future data

Backup

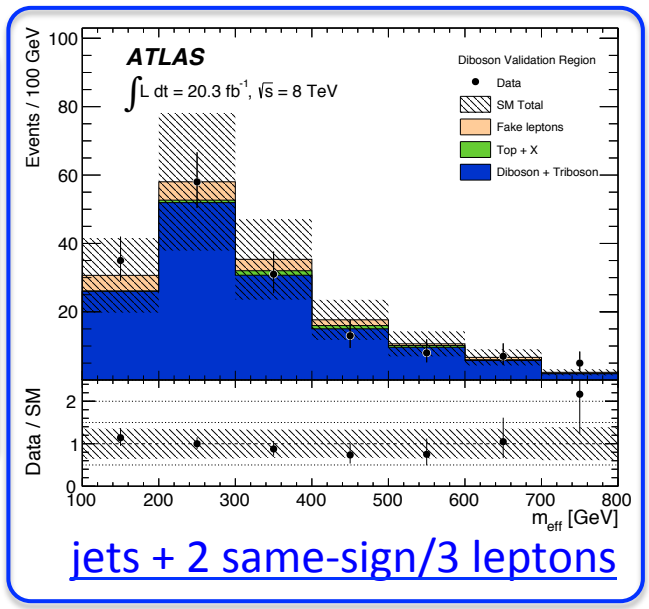
8 TeV SUSY searches not covered here



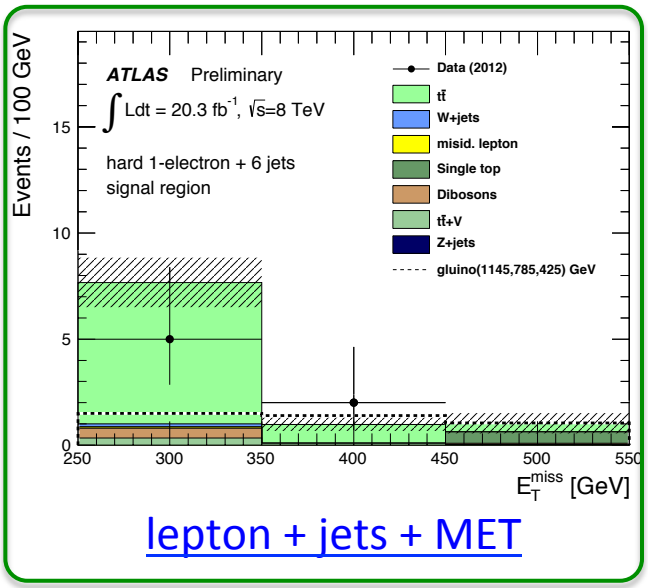
7-10 jets + MET



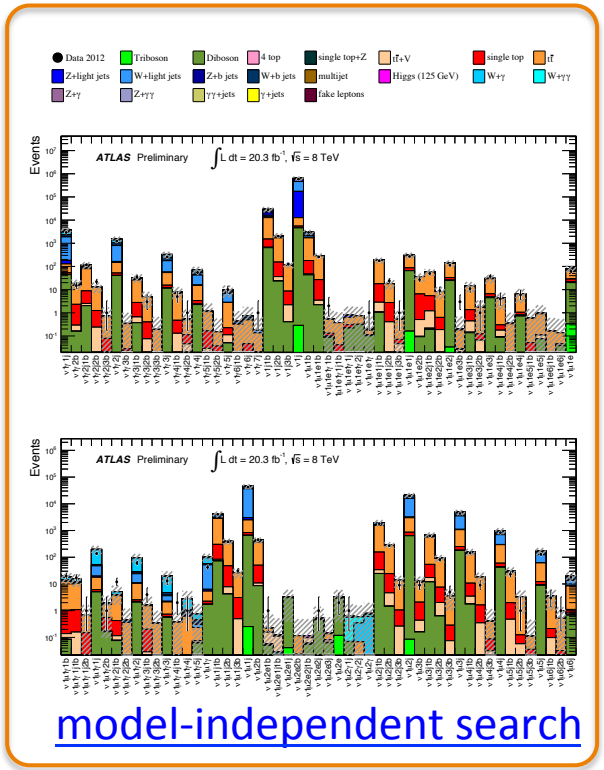
di-photon + MET



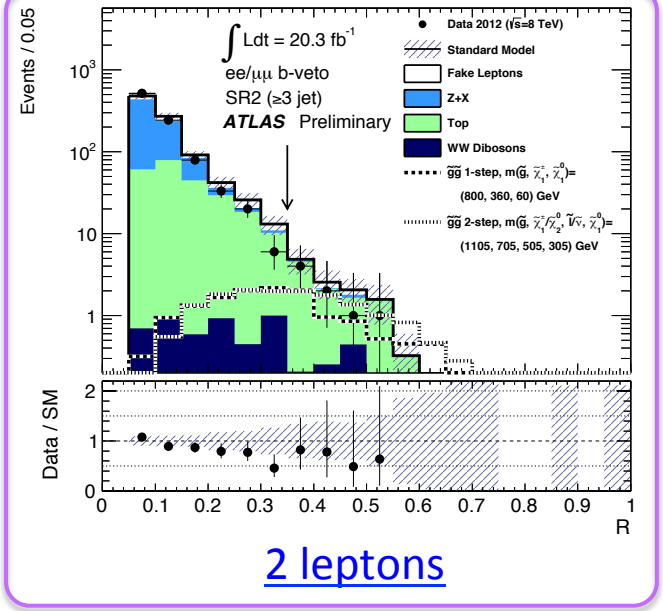
jets + 2 same-sign/3 leptons



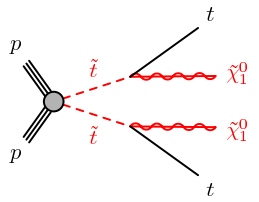
lepton + jets + MET



model-independent search



2 leptons



Light stop search via $\sigma_{t\bar{t}}$

1406.5375
sub. to EPJC

Target at scenario where a **stop quark slightly heavier than top quark**.

$$\tilde{t}_1 \to t\tilde{\chi}_1^0 \quad , \quad 1\ \mathrm{GeV} < m_{\tilde{\chi}_1^0} < m_{\tilde{t}_1} - m_t$$

Stop pairs would result in same final state as $t\bar{t}$, with slightly higher MET. Could be seen as an **excess in measured $\sigma_{t\bar{t}}$**.

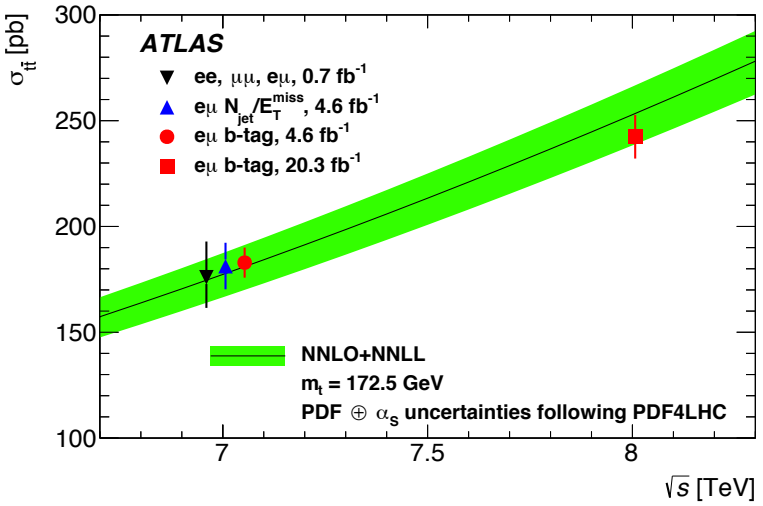
Analysis based on events with **eμ + 1/2 b-jets**, using √s=7 TeV and 8 TeV datasets.

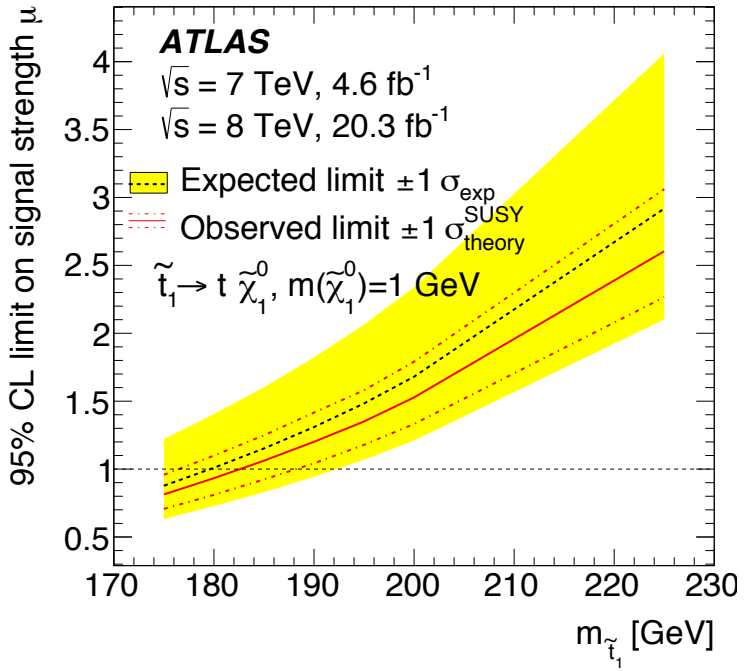
Fit signal strength parameter μ:

$$N_{\mathrm{data}} = \mathcal{L} \times \left(\varepsilon_{t\bar{t}}\, \sigma_{t\bar{t}} + \mu \times \varepsilon_{\tilde{t}_1\bar{\tilde{t}}_1}\, \sigma_{\tilde{t}_1\bar{\tilde{t}}_1} \right)$$

Exclude stop in range [$m_{\tilde{t}}$ +1 GeV, 177 GeV] assuming top from stop ~ fully right-handed.

Small dependence on LSP mass and top polarization.

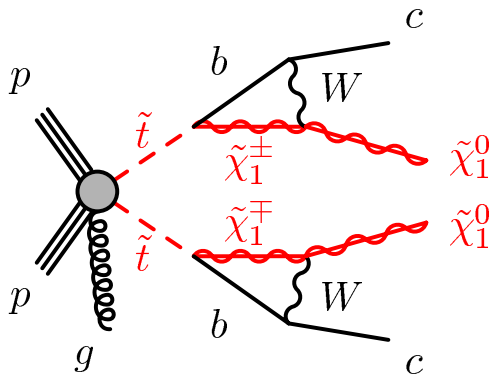




0 lepton + mono-jet/c-jets + MET

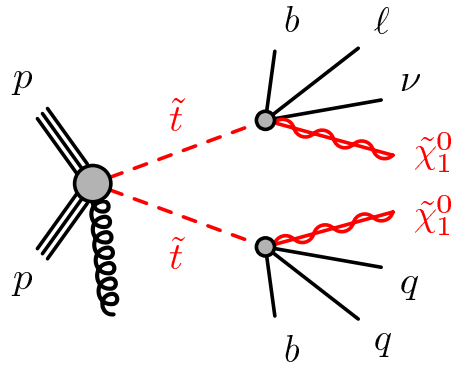
1407.0608
sub. to PRD

Light stop with small Δm($\tilde{t}_1$, $\tilde{\chi}_1^0$), favor co-annihilation.

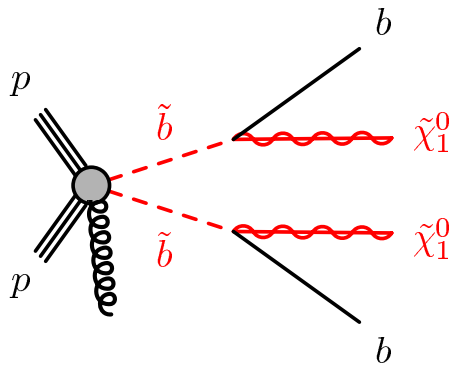


Small Δm < 20 GeV: mono-jet (ISR)
Larger Δm < m_W+m_b : c-tagged jets

$\tilde{b}$ -> b $\tilde{\chi}_1^0$ with small Δm.



mono-jet



mono-jet

- trigger: MET > 80 GeV
- MET > 150 GeV, 1 jet with p_T > 150 GeV
- veto e/μ

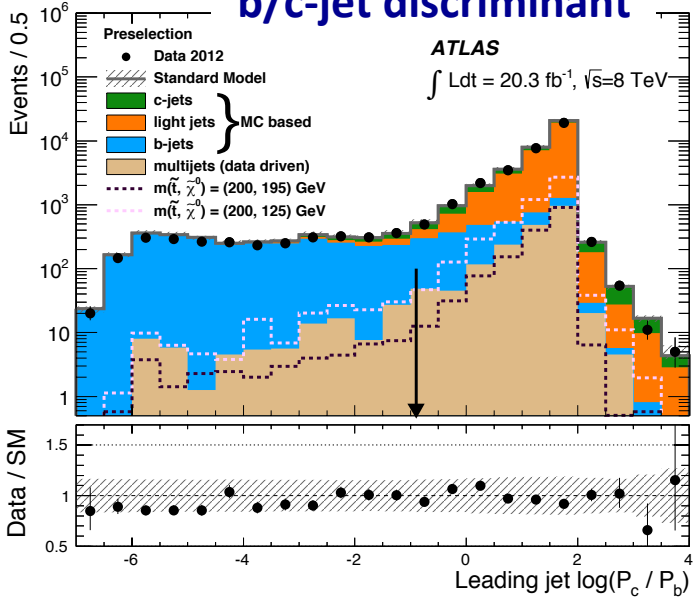
mono-jet selection:

maximum 3 jets p_T > 30 GeV, Δϕ(jet,MET) > 0.4
3 signal regions with increasing { jet p_T , MET }

c-tag selection:

≥ 4 jets with p_T > 30 GeV, Δϕ(jet,MET) > 0.4
b-jet veto, ≥1 sub-leading jet c-tagged
2 signal regions, p_T^{jet} > 290 GeV, increasing MET

b/c-jet discriminant



0 lepton + mono-jet/c-jets + MET

Control regions + transfer factors to normalize W(lν)+jets, Z(ll)+jets, tt.

Mono-jet analysis: **Z(νν)+jets normalized with W(μν)+jets control region**, similar kinematics.

Background uncertainty: 3-4.5% and 10-14% for mono-jet and c-tag analyses (syst. due to b/c-tagging ~2.8%).

No excess in data.