SUSY SEARCHES AT LHC

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ON BEHALF OF ATLAS & CMS

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I F L P
CONICET
U N L P

IMPOSSIBLE TO COVER EVERYTHING!

Search for new physics in the multijets + missing transverse energy final state	SUS12011	CMS-SUS-12-011	4.98/fb	Accepted by PRL: arXiv:1207.1898 NEW
Search for new physics in events with opposite-sign leptons, jets and missing transverse energy	SUS11011	CMS-SUS-11-011	4.98/fb	Submitted to PLB: arXiv:1206.3949
Search for new physics with same-sign isolated dilepton events with jets and missing energy	SUS11010	CMS-SUS-11-010	4.98/fb	PRL 109, 071803 (2012), arXiv:1205.6615
Search for new physics in events with same-sign dileptons and b-tagged jets in pp collisions at √s = 7 TeV	SUS11020	CMS-SUS-11-020	4.98/fb	JHEP08(2012)110, arXiv:1205.3933
Search for Anomalous Production of Multilepton Events in pp Collisions at √s = 7 TeV	EXO11045/SUS11013	CMS-SUS-	4.98/fb	JHEP06(2012)169,
Sea… mis…				
Sea…				

All papers and public notes:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

Recent Preliminary Results with 2012 8 TeV Data

Analysis	Approved Plots	CDS Entry	Luminosity	Comment

Short Title of the CONF note	*Date*	*√s (TeV)*	*L (fb^{-1})*	*Document*	*Plots*
0 leptons + >=2-6 jets + Etmiss	08/2012	8	5.8	*ATLAS-CONF-2012-109*	*Link*
0 leptons + >=6-9 jets + Etmiss	08/2012	8	5.8	*ATLAS-CONF-2012-103*	*Link*
1 lepton + >=4 jets + Etmiss	08/2012	8	5.8	*ATLAS-CONF-2012-104*	*Link*
2 same-sign leptons + >=4 jets + Etmiss	08/2012	8	5.8	*ATLAS-CONF-2012-105*	*Link*

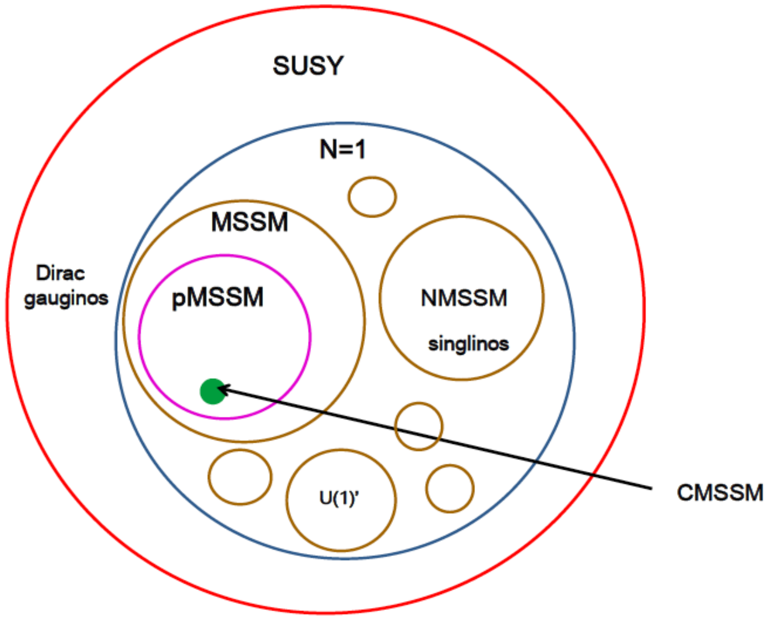
With thanks to the ATLAS and CMS SUSY convenors

2011 Data (7 TeV)

Short Title of the Paper	Date	√s (TeV)	L (fb^{-1})	Document	Plots+Aux. Material	Journal
Pair of 2-jet resonance [N=1/2 scalar gluon] NEW	10/2012	7	4.6	1210.4826	Link	Submitted to EPJC
Pair of 3-jet resonance [RPV] NEW	10/2012	7	4.6	1210.4813	Link	Submitted to JHEP
>=4 leptons + Etmiss [RPV] NEW	10/2012	7	4.7	1210.4457	Link	Submitted to JHEP
Monojet + Etmiss [WIMP] NEW	10/2012	7	4.7	1210.4491	Link	Submitted to JHEP
Disappearing track + jets + Etmiss [Direct long-lived charginos - AMSB] NEW	10/2012	7	4.7	1210.2852	Link	Submitted to JHEP
1-2 taus + 0-1 leptons + jets + Etmiss [GMSB] NEW	10/2012	7	4.7	1210.1314	Link	Submitted to EPJC
Monophoton [ADD, WIMP]	09/2012	7	4.7	1209.4625	Link	Submitted to PRL
2 leptons + jets + Etmiss [Medium stop]	09/2012	7	4.7	1209.4186	Link	Accepted by JHEP
1-2 b-jets + 1-2 leptons + jets + Etmiss [Light Stop]	09/2012	7	4.7	1209.2102	Link	Submitted to PLB
2 photons + Etmiss [GGM]	09/2012	7	4.7	1209.0753	Link	Accepted by PLB
1-2 leptons + >=2-4 jets + Etmiss	08/2012	7	4.7	1208.4688	Link	Accepted by PRD

SUSY FRAMEWORK

T. Rizzo (SLAC, 01-Aug-12)



Names	Spin	P_R	Gauge Eigenstates	Mass Eigenstates
Higgs bosons	0	+1	$H_u^0\ H_d^0\ H_u^+\ H_d^-$	$h^0\ H^0\ A^0\ H^\pm$
squarks	0	−1	$\widetilde{u}_L\ \widetilde{u}_R\ \widetilde{d}_L\ \widetilde{d}_R$	(same)
			$\widetilde{s}_L\ \widetilde{s}_R\ \widetilde{c}_L\ \widetilde{c}_R$	(same)
			$\widetilde{t}_L\ \widetilde{t}_R\ \widetilde{b}_L\ \widetilde{b}_R$	$\widetilde{t}_1\ \widetilde{t}_2\ \widetilde{b}_1\ \widetilde{b}_2$
sleptons	0	−1	$\widetilde{e}_L\ \widetilde{e}_R\ \widetilde{\nu}_e$	(same)
			$\widetilde{\mu}_L\ \widetilde{\mu}_R\ \widetilde{\nu}_\mu$	(same)
			$\widetilde{\tau}_L\ \widetilde{\tau}_R\ \widetilde{\nu}_\tau$	$\widetilde{\tau}_1\ \widetilde{\tau}_2\ \widetilde{\nu}_\tau$
neutralinos	1/2	−1	$\widetilde{B}^0\ \widetilde{W}^0\ \widetilde{H}_u^0\ \widetilde{H}_d^0$	$\widetilde{N}_1\ \widetilde{N}_2\ \widetilde{N}_3\ \widetilde{N}_4$
charginos	1/2	−1	$\widetilde{W}^\pm\ \widetilde{H}_u^+\ \widetilde{H}_d^-$	$\widetilde{C}_1^\pm\ \widetilde{C}_2^\pm$
gluino	1/2	−1	$\widetilde{g}$	(same)
goldstino (gravitino)	1/2 (3/2)	−1	$\widetilde{G}$	(same)

Why believe in SUSY?

- Light Higgs: need new physics to stabilize mass.
- Dark matter: strong evidence from astrophysics (R-parity conservation, neutral light LSP)

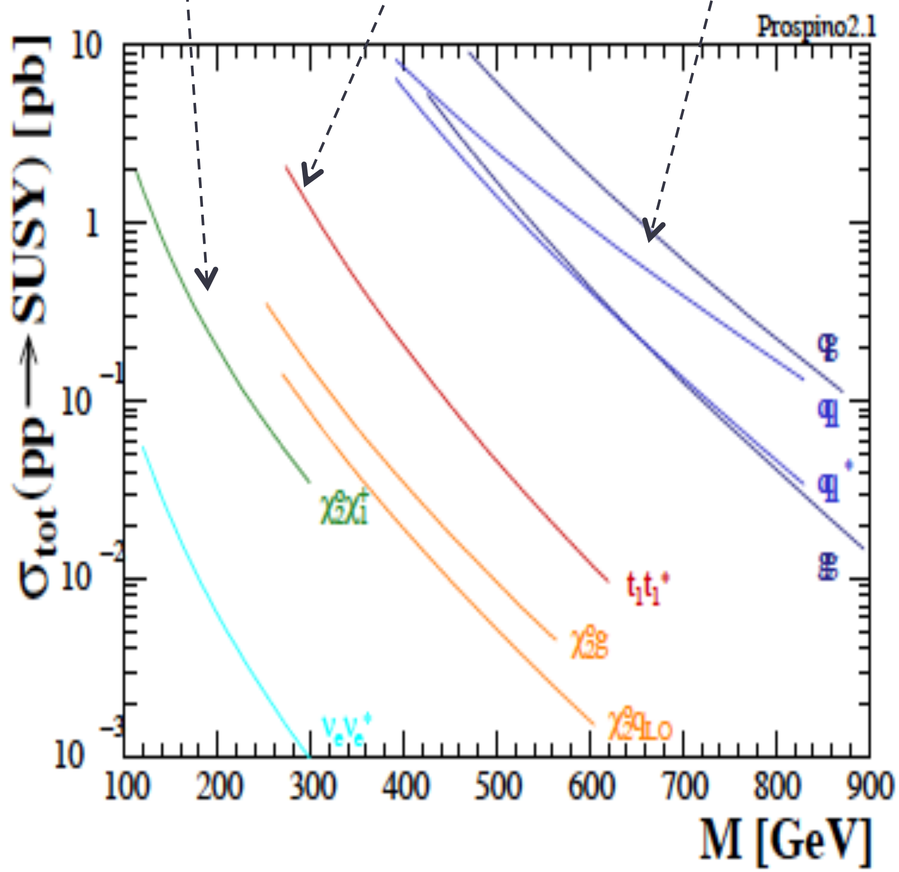
Goal: find hints of SUSY particles in 0.1–few TeV range

SUSY CROSS SECTION & MASS SPECTRUM

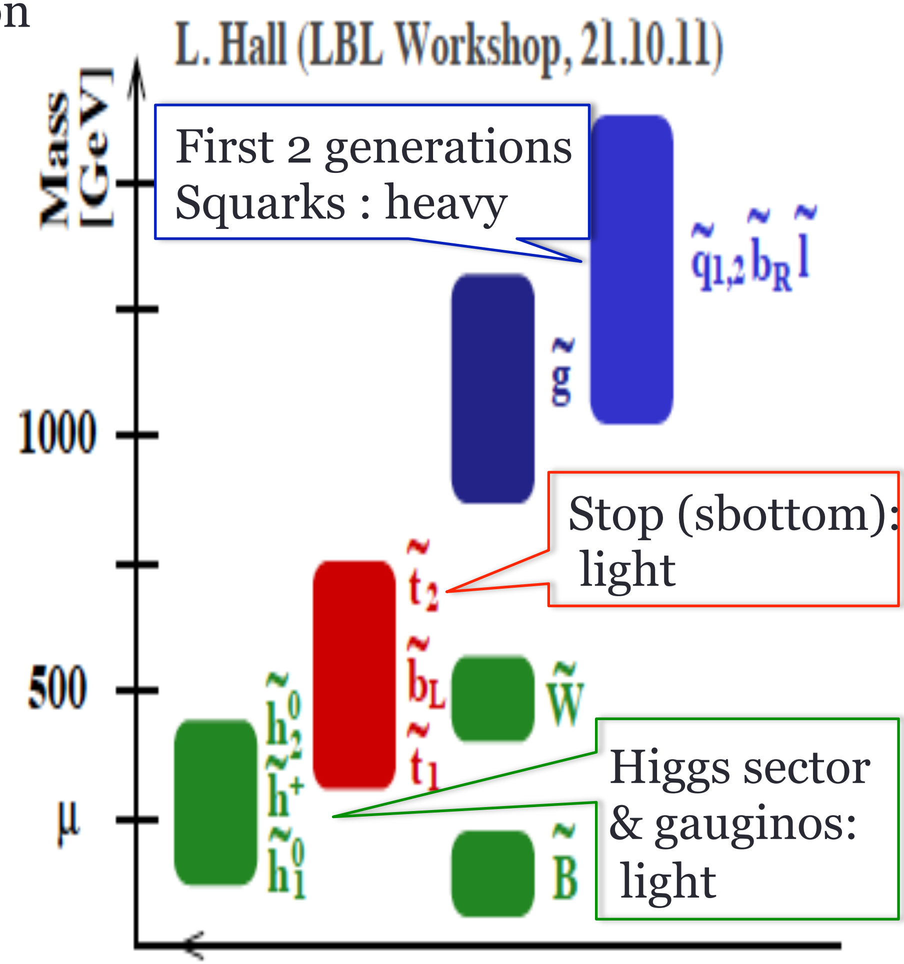
EW production of $\tilde{\chi}^{\pm}\tilde{\chi}^{0}$

Direct stop/ sbottom production

Strong production



A"natural" SUSY spectrum



SUSY ANALYSIS

1. Event selection cuts and definition of signal regions:

- Cut in a set of variables that can discriminate between signal and backgrounds.

2. Background determination:

- QCD and fake backgrounds: estimate from data
- top, W/Z+jets: estimate from data when possible or with transfer factors using background-enhaced control regions

$$N_{SR}^{est,Bkg} = \frac{N_{SR}^{MC}}{N_{CR}^{MC}}(N_{CR}^{data} - N_{CR}^{MC,others})$$

- Smaller irreducible background using MC

3. Estimate all uncertainties:

- Experimental uncertainties: jet energy scale calibration, b-tagging eff….
- Theoretical uncertainties: renormalisation and factorisation scales, PDF….

4. Look into the signal region: Excess in data?

If not, derive exclusion limits

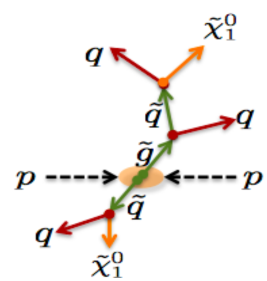
5. Interpretation

STRONG PRODUCTION IN RPC

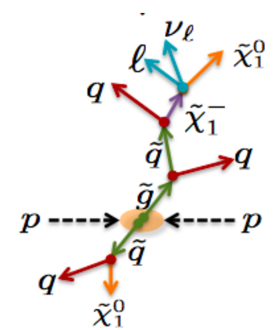
- Lightest sparticle (LSP) stable (WIMP candidate)
- Pair produced sparticles
- Cascade decay down to the LSP

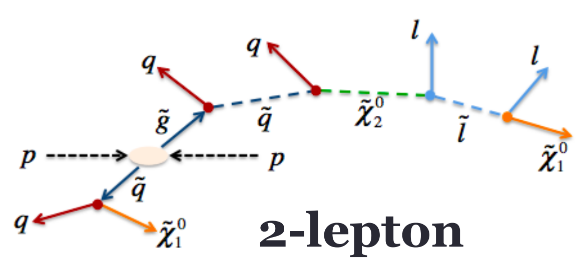
Inclusive jets + E_T^{miss} + X
X= γ, ℓ,more jets…
depending on NLSP

0-lepton



1-lepton





2-lepton

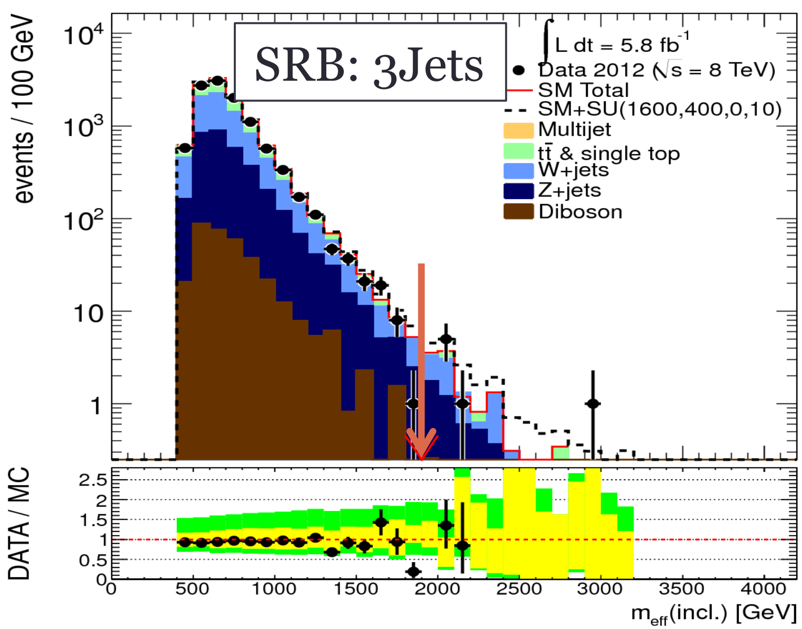
ATLAS 0-LEPTON + JETS + E_T^{miss}

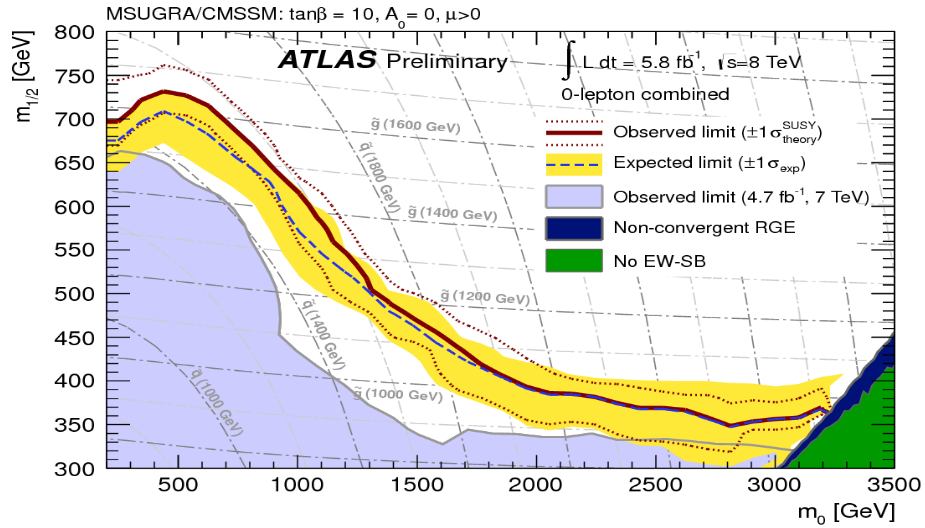
8 TeV

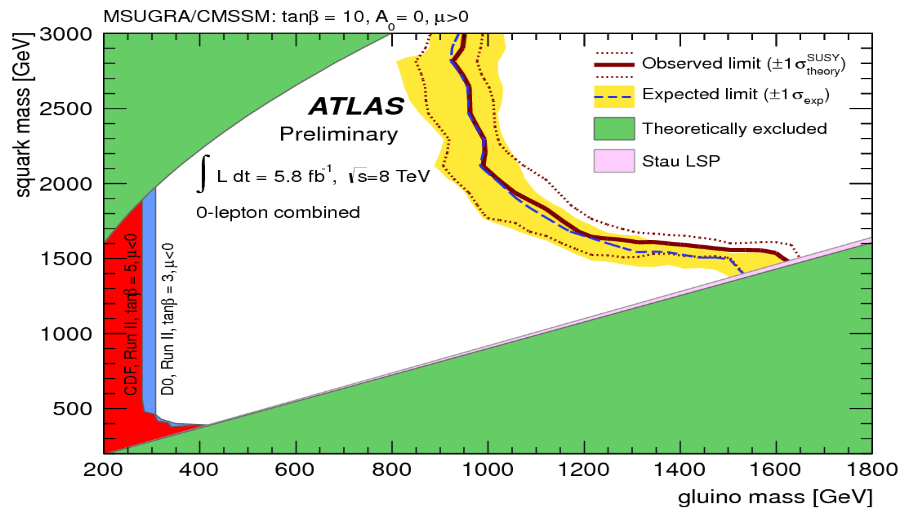
- 0-l , 6-9 Jets
- 0-l , 2-6 Jets

Reported here

Effective mass, $m_{\rm eff} = H_T + E_T^{miss}$



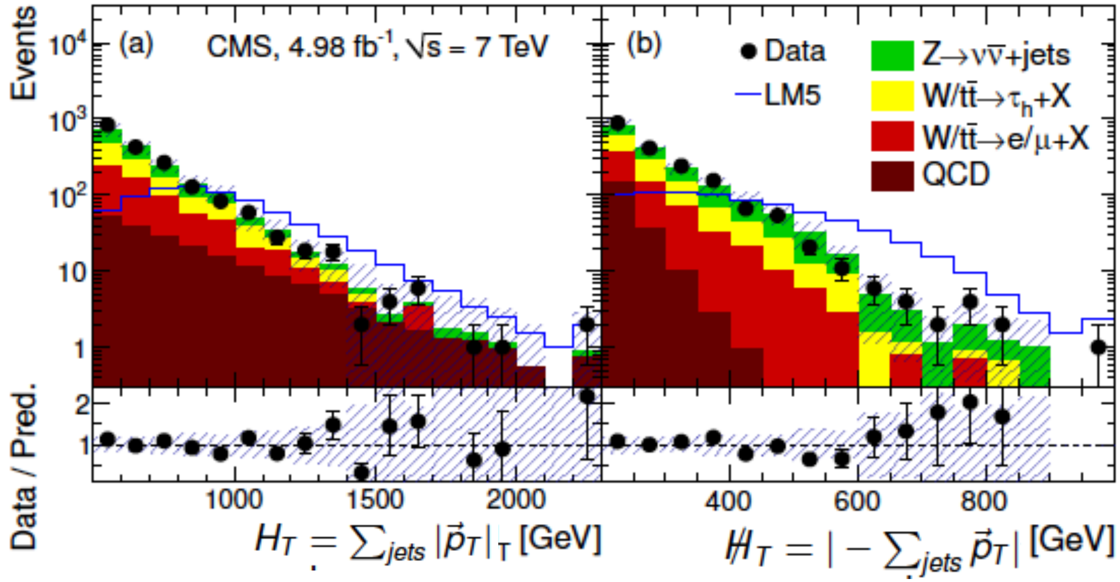




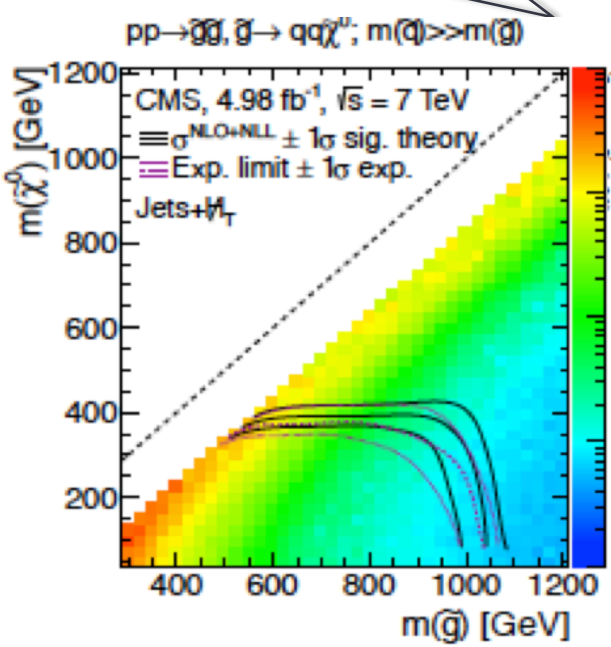
- $m_{1/2}$<350 GeV excluded for all values of m_0; $m_{1/2}$<740 GeV for low values of m_0
- Squark and Gluino masses below 1.5 TeV

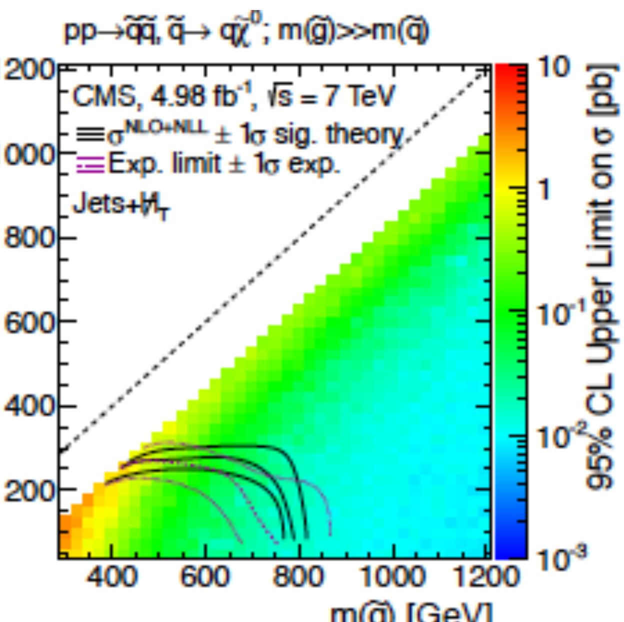
CMS JET + H_T^{miss} ANALYSIS

0-lepton, ≥3 jets generic SUSY search.



Interpretation in simplified models with only gluinos or squarks production





$m(\tilde{g}) < 1$ TeV

$m(\tilde{q}) < 0.76$ TeV

for $m(\tilde{\chi}_1^0)$ <200 GeV

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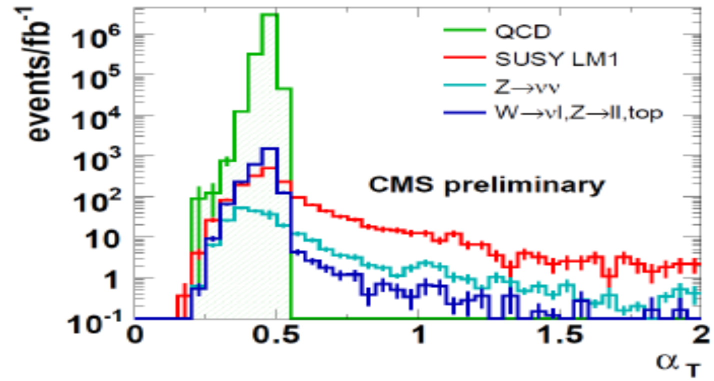
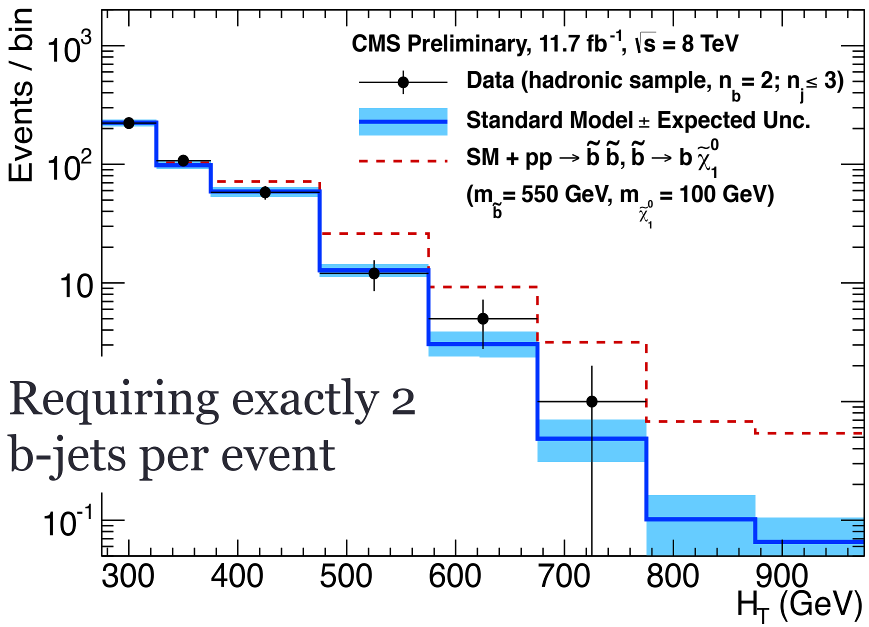
CMS α_T ANALYSIS

8 TeV

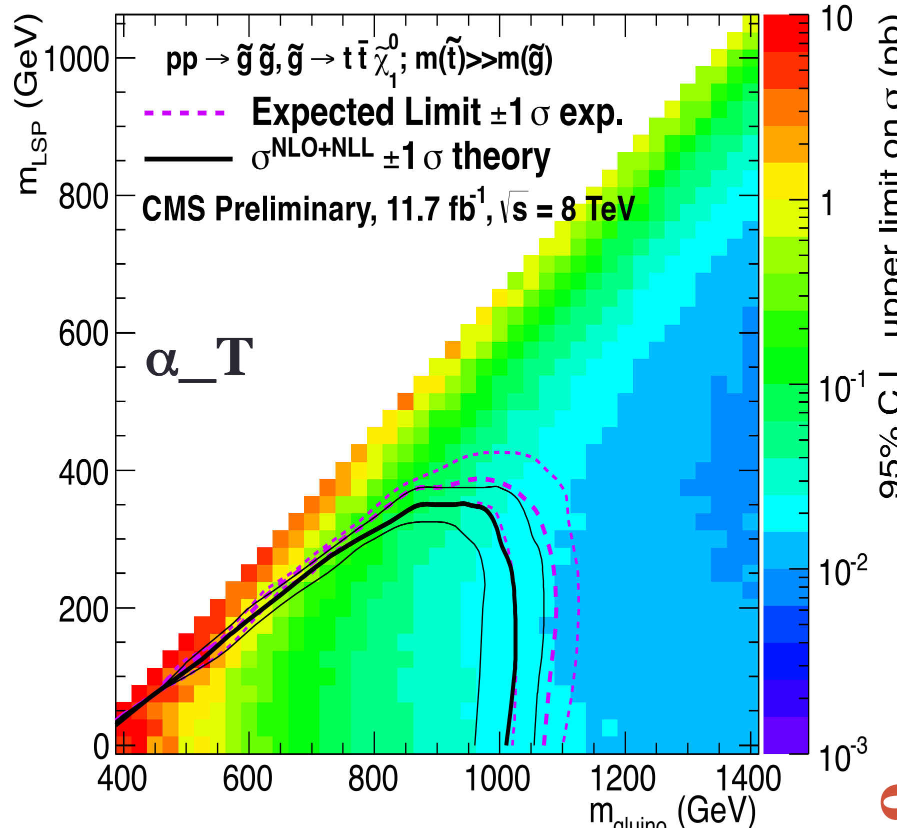
≥2 jets with b-jets

$$\alpha_T = \frac{E_T^{j_2}}{M_T} \quad , \quad M_T = \sqrt{\left(\sum_{i=1}^{2} E_T^{j_i}\right)^2 - \left(\sum_{i=1}^{2} p_x^{j_i}\right)^2 - \left(\sum_{i=1}^{2} p_y^{j_i}\right)^2}\,.$$

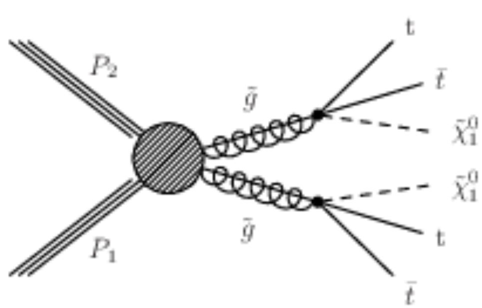




Requiring exactly 2 b-jets per event



Interpretation in SMS

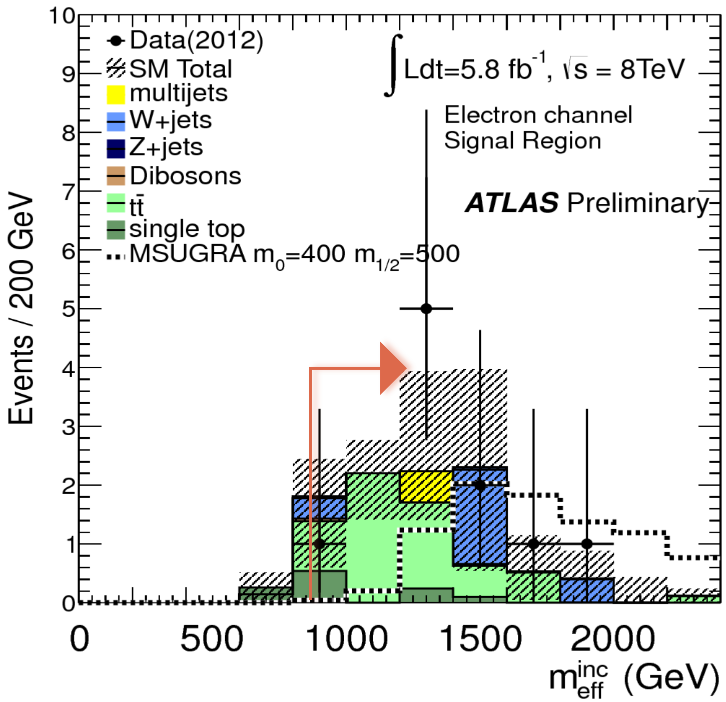


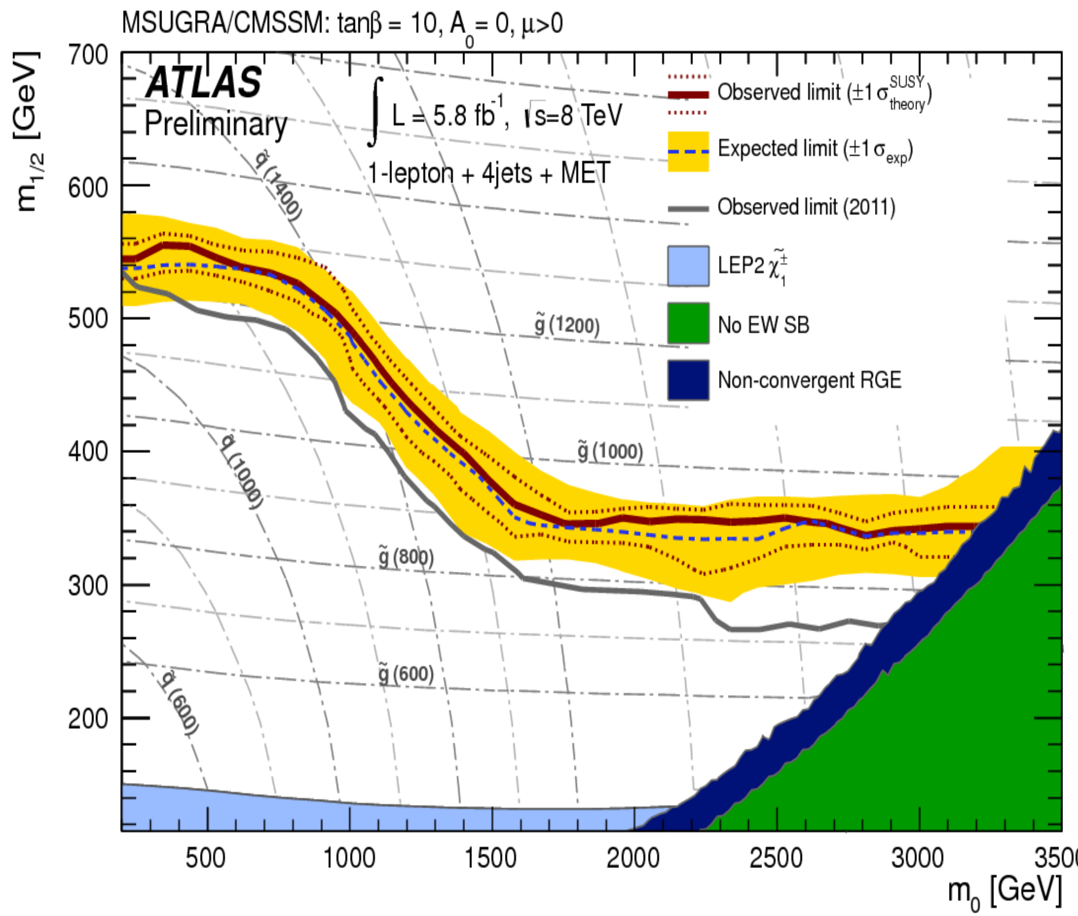
ATLAS 1-LEPTON ANALYSIS 8 TeV

Signal region with exactly one lepton (e or μ), ≥4 jets and E_T^{miss}

$$m_T = \sqrt{2 p_T^{\ell} E_T^{miss} (1 - \cos(\Delta\phi(\vec{\ell}, p_T^{miss})))}$$

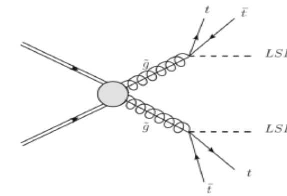
$$m_{eff}^{inc} = p_T^{\ell} + \sum_{i=1} p_{T,i} + E_T^{miss}$$



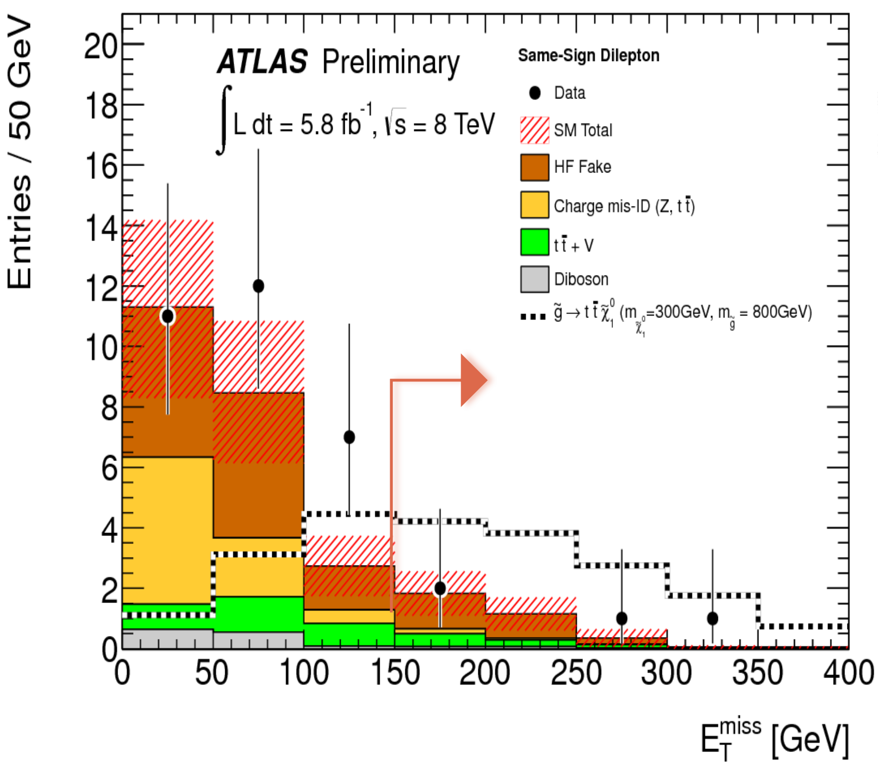


In mSUGRA limit on squark and gluino masses (<1.24 TeV) improved by about 100 GeV with respect to 7 TeV analysis

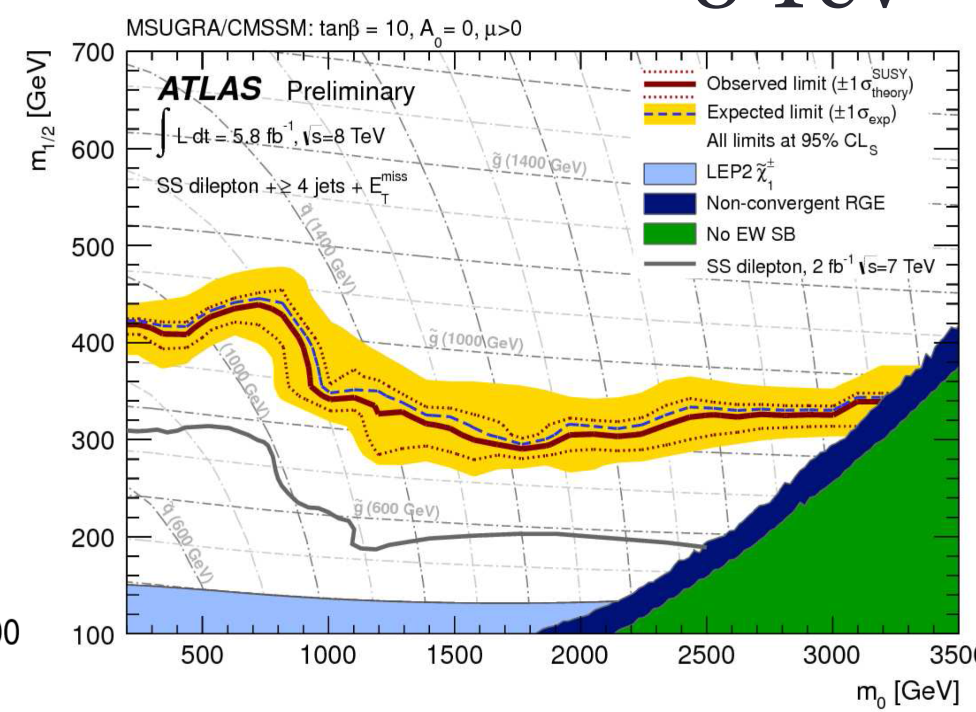
ATLAS 2-LEPTON SS ANALYSIS



- MSSM-gluinos are strongly interacting Majorana fermions.
- Same sign leptons from the two legs in 50% of the cases + jets + E_T^{miss}
- The requirement of SS leptons suppresses the contribution from SM processes and thus enhances the potential SUSY signal significance.



8 TeV



Competitive at high m_0 where gluino production dominates

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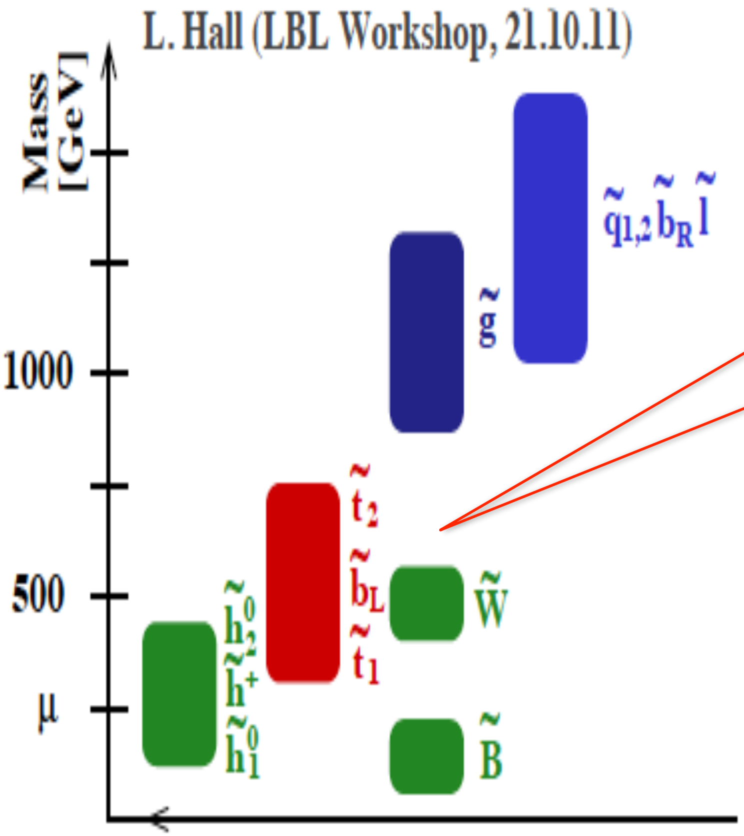
THIRD-GENERATION SQUARKS



Naturalness requires :

- stop and sbottoms up to 600 GeV.
- Gluinos up to 1.5 TeV.

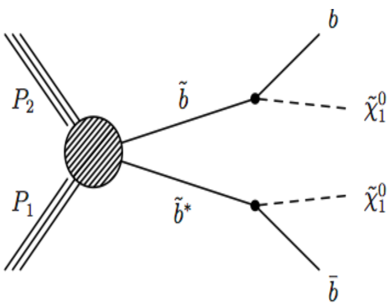
✓ Direct production: bs, Ws, ts, E_T^{miss}

✓ Gluino mediated: : bs, Ws, ts, E_t^{miss}, jets

CMS DIRECT SBOTTOM

8 TeV

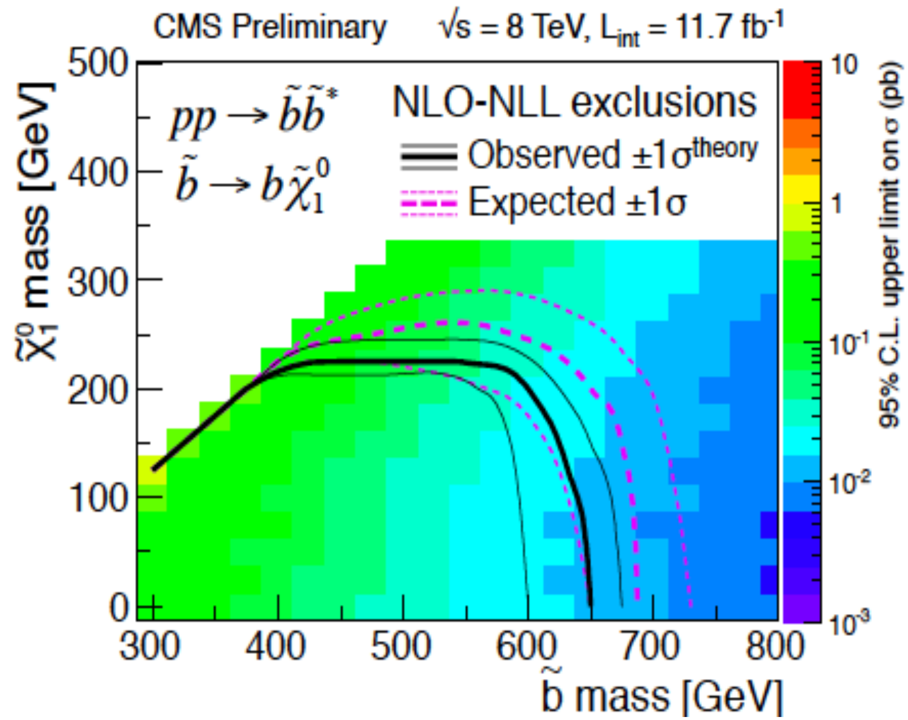
Direct production : short cascade



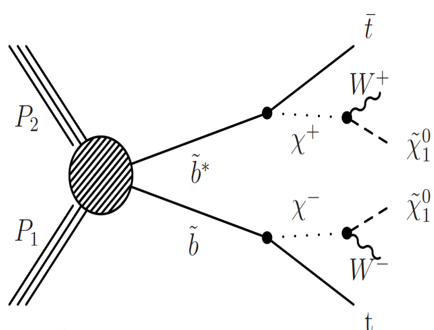
Large E_T^{miss}

≥2 jets, b-tagged jets

SR: H_T, Nj(2-3), Nb-jets(1-2)

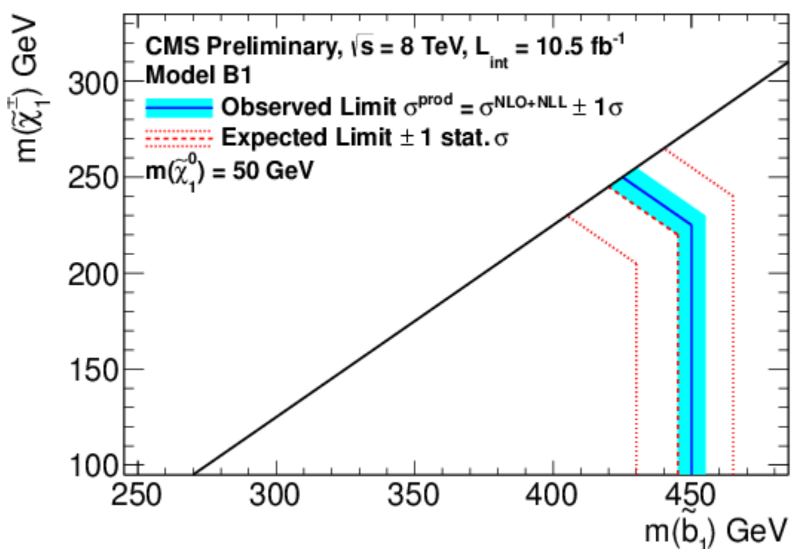


Direct production : long cascade



Same sign dilepton with at least 2 b-tagged jets.

SR: lepton charges, E_T^{miss}, H_T, Nb-jets



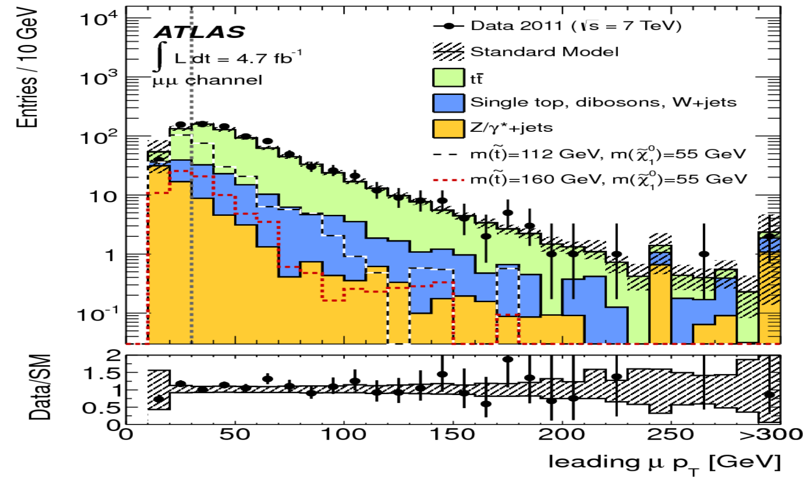
ATLAS DIRECT SCALAR TOP

Very light stop

$m(\tilde{\chi}_1^\pm) < m(\tilde{t}_1) < m(t) \quad \tilde{t}_1 \to b\tilde{\chi}_1^\pm \to bW^{(*)}\tilde{\chi}_1^0$

106 GeV

→soft dilepton + jets + E_T^{miss}

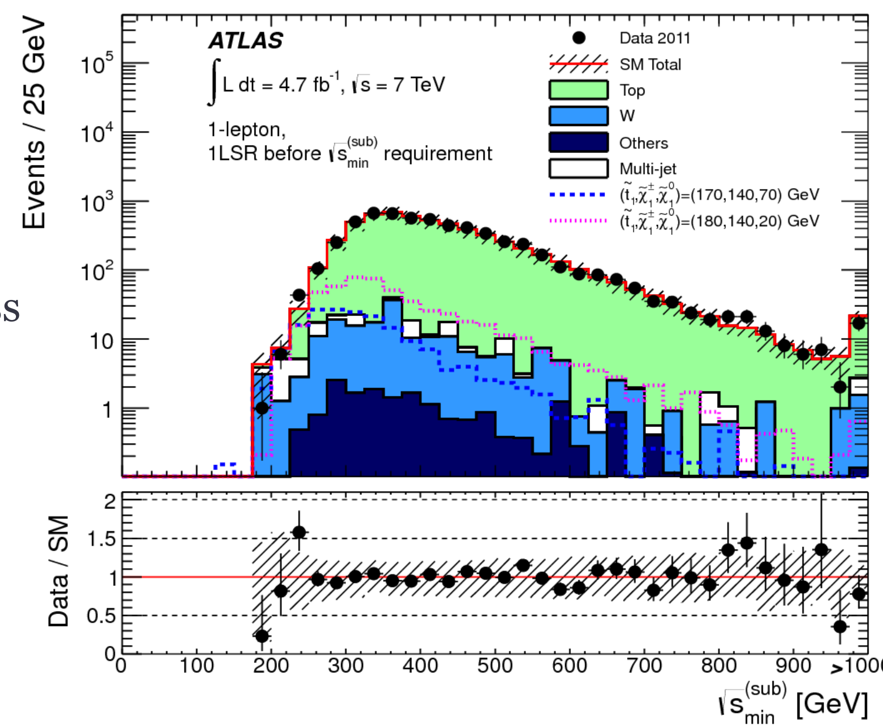


Light stop

Scalar top mass below or around top quark mass

→1(2) leptons, b-jets, jets, E_T^{miss}

$$\sqrt{s}_{\min}^{(sub)} = \left\{ \left(\sqrt{m_{(sub)}^2 + p_{T(sub)}^2} + \sqrt{\left(m^{miss}\right)^2 + \left(E_T^{miss}\right)^2} \right)^2 - \left(\vec{p}_{T(sub)} + \vec{p}_T^{miss} \right)^2 \right\}^{1/2}$$



ATLAS DIRECT SCALAR TOP

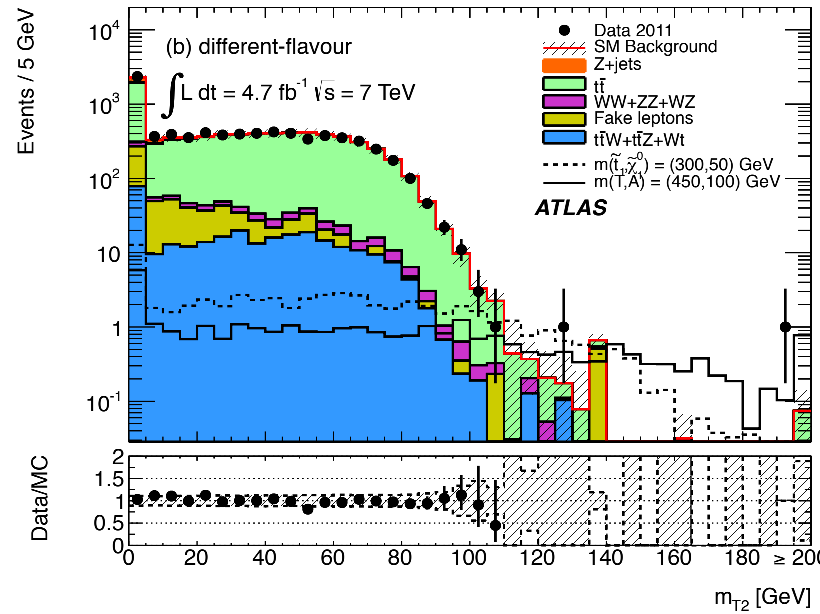
Medium stop

$$\tilde{t}\tilde{t} \rightarrow \tilde{\chi}^0_1 t \;\; \tilde{\chi}^0_1 \bar{t} \rightarrow \tilde{\chi}^0_1 b l^+ \nu \;\; \tilde{\chi}^0_1 \bar{b} l^- \nu$$

→2 leptons (ee, eμ, μμ), E_T^{miss}

Discriminating variable m_{T2}

$$m_{T2}(\mathbf{p}_T^{\ell_1}, \mathbf{p}_T^{\ell_2}, \mathbf{p}_T^{miss}) = \min_{\mathbf{q}_T + \mathbf{r}_T = \mathbf{p}_T^{miss}} \left\{ \max[\, m_T(\mathbf{p}_T^{\ell_1}, \mathbf{q}_T), m_T(\mathbf{p}_T^{\ell_2}, \mathbf{r}_T) \,] \right\}$$

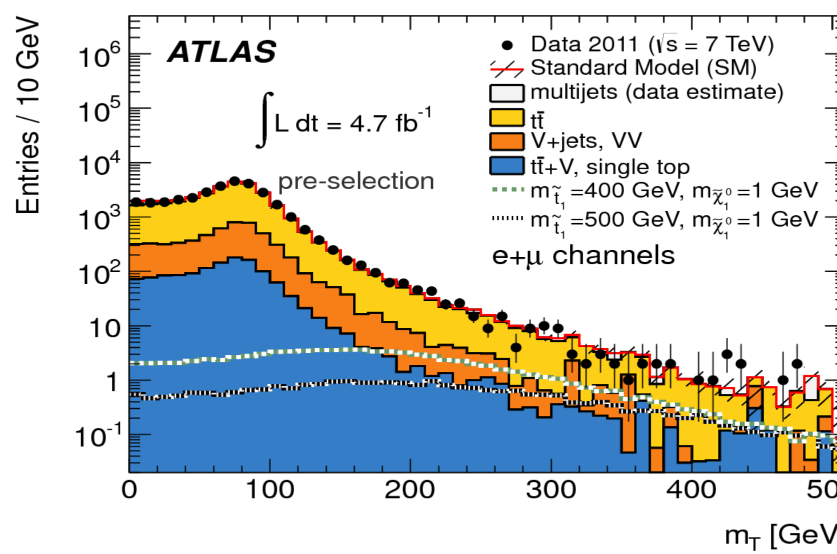


Heavy stop

Look for hadronic or leptonic top decays with extra E_T^{miss}

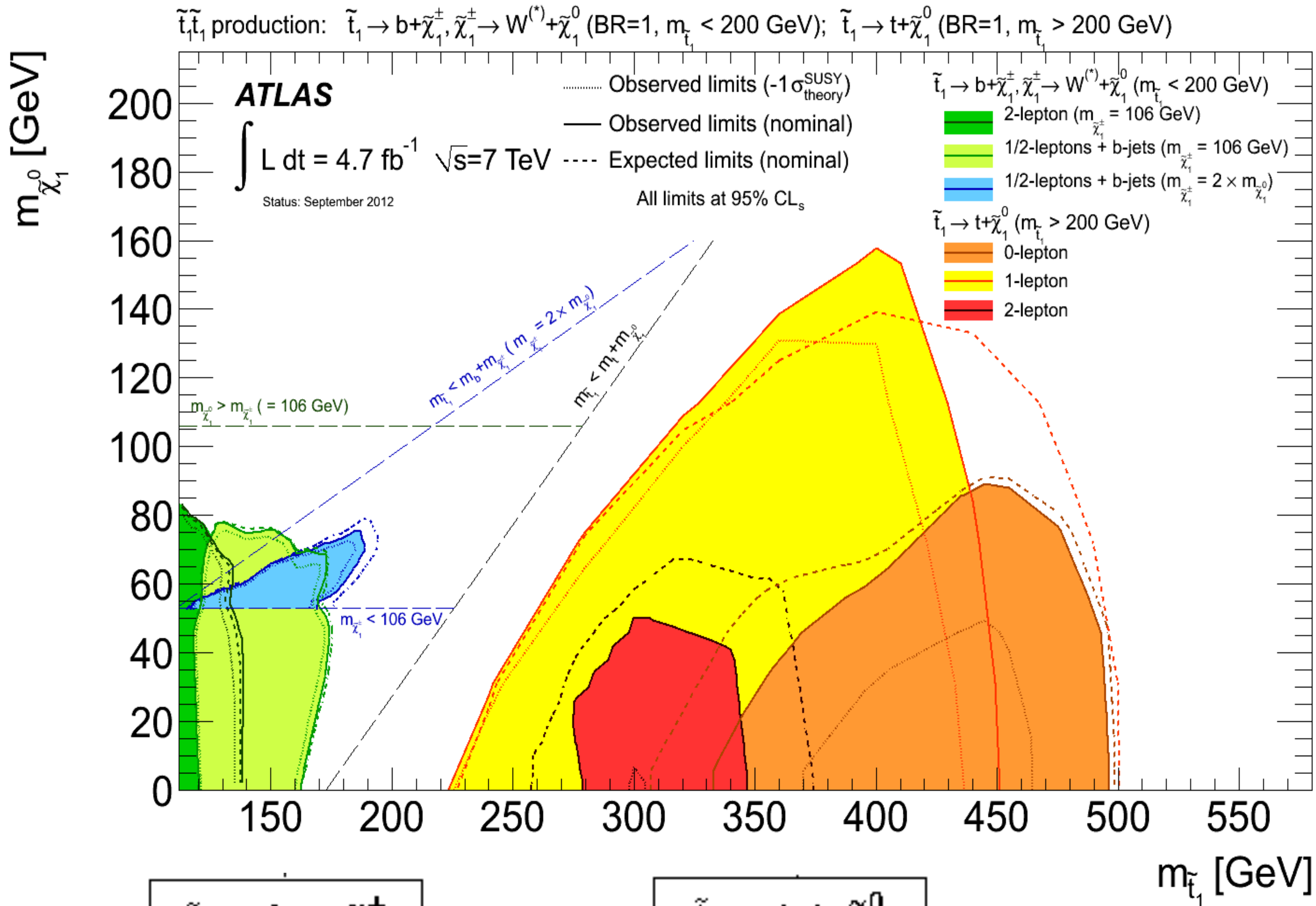
→1 lepton, ≥ 4 jets (1b-jet)

Requirement	SR A	SR B	SR C	SR D	SR E
E_T^{miss} [GeV] >	150	150	150	225	275
$E_T^{miss} / \sqrt{H_T}$ [GeV$^{1/2}$] >	7	9	11	11	11
m_T [GeV] >	120	120	120	130	140



$E_T^{miss} > 40$ GeV

FINAL RESULTS FOR STOP PAIR PRODUCTION SEARCHES AT 7 TeV (4.7 fb^{-1})



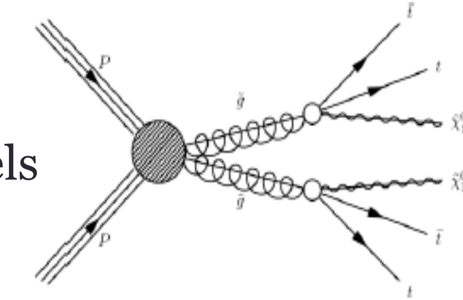
$\tilde{t} \to b + \tilde{\chi}_1^\pm$

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

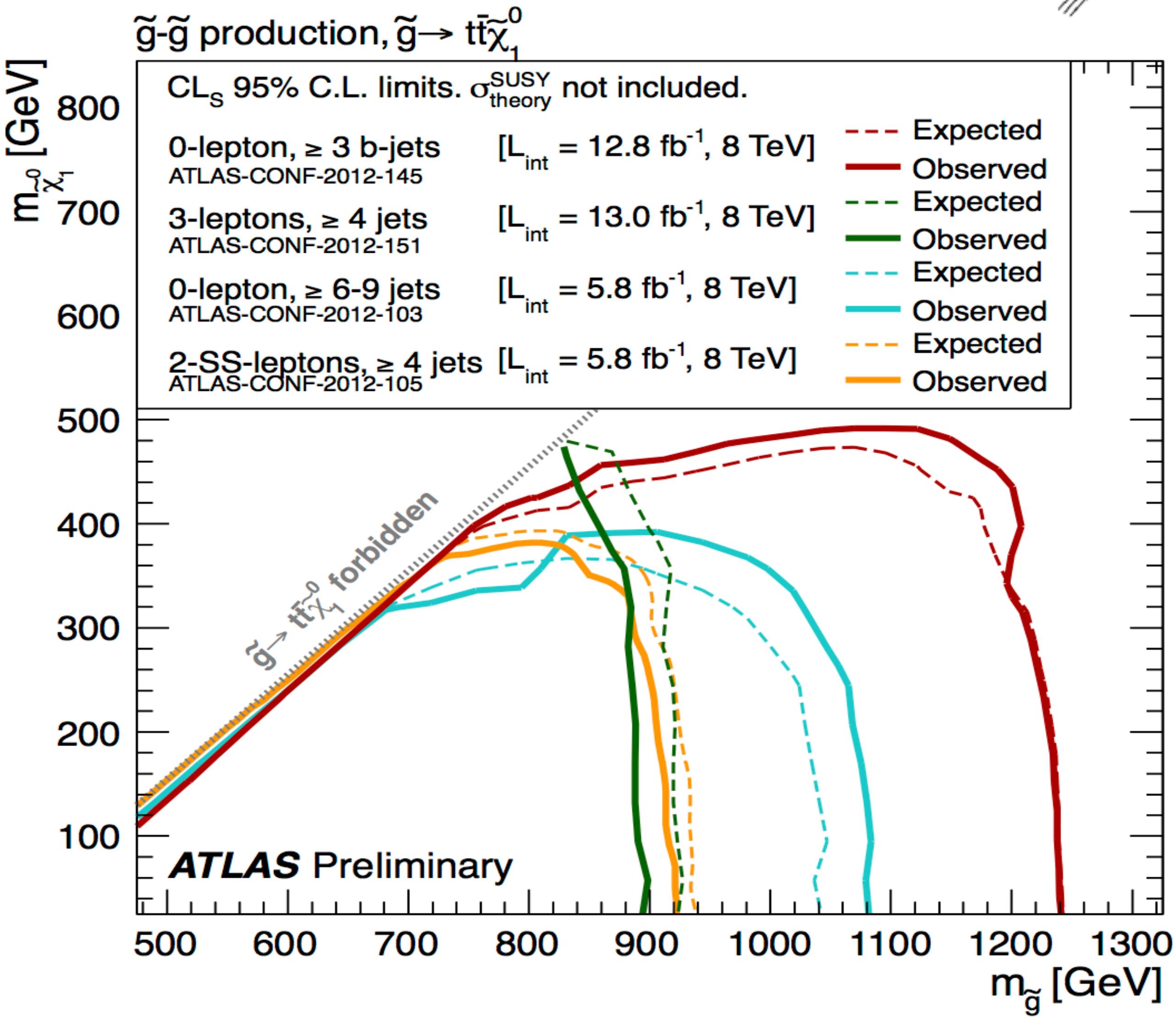
ATLAS GLUINO MEDIATED

8 TeV

Gtt simplified models



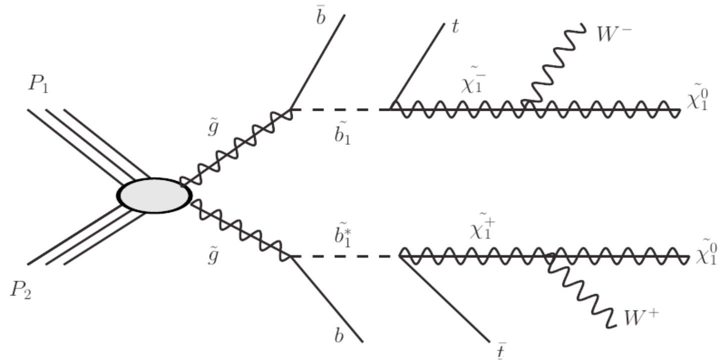
Large jet multiplicities



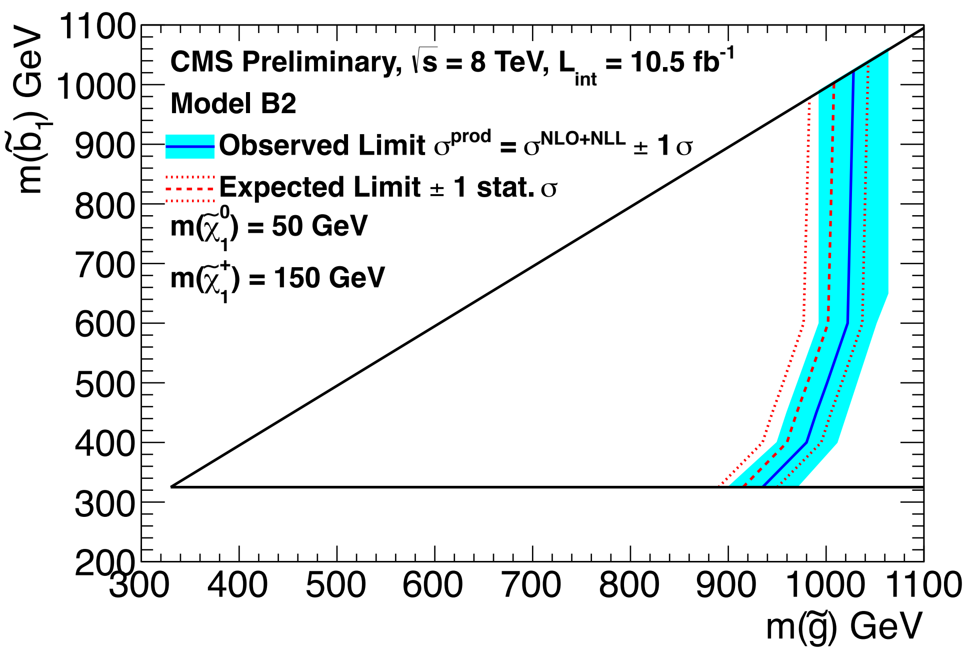
CMS SBOTTOM FROM GLUINOS 8 TeV

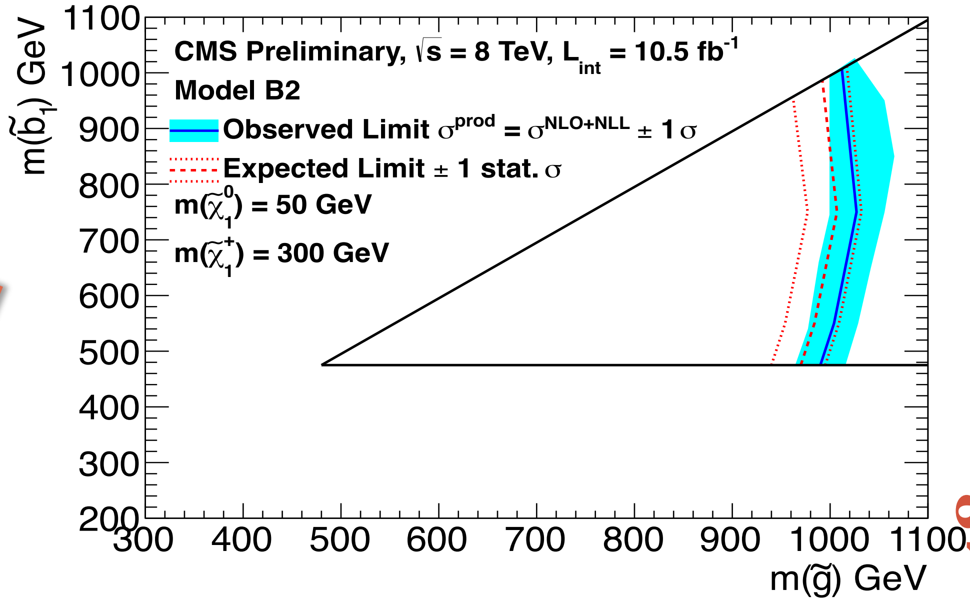
2 SS leptons and ≥2 b-jets

Interpretation in several SMS



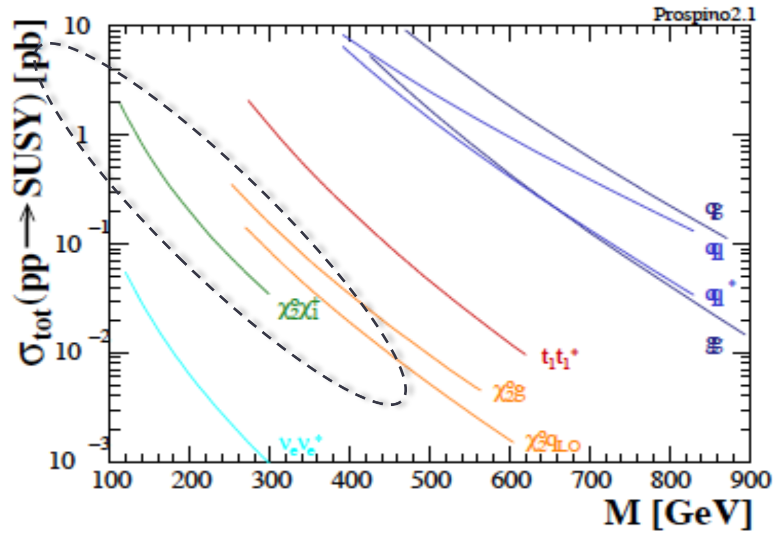
Exclusion (95% C.L.) for different choices of the chargino mass.

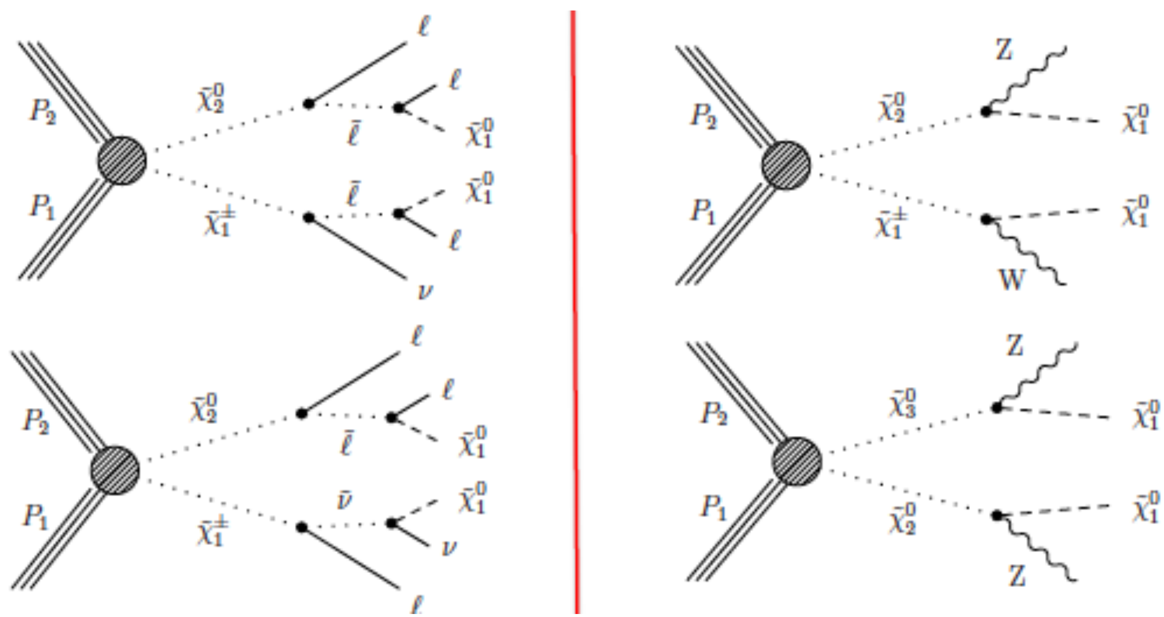




ELECTROWEAK PRODUCTION OF SUSY PARTICLES

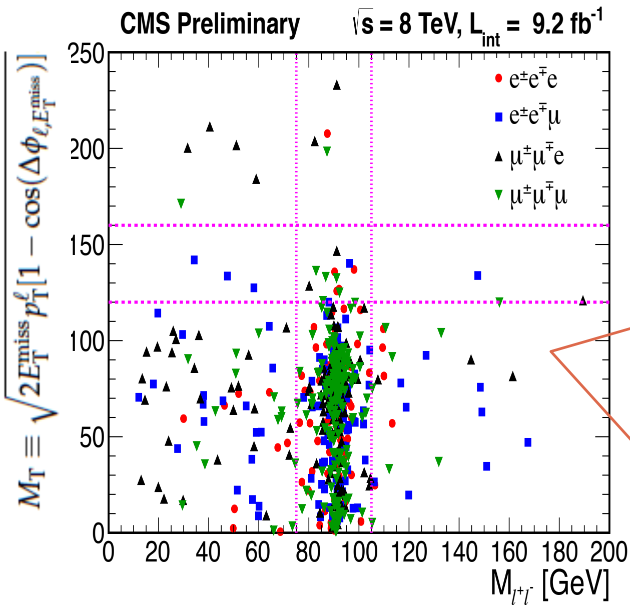
- ✓ Weak production could be the dominant production at this stage.
- ✓ Models with decays into sleptons/W, Z.
- ✓ Signatures with multiple charged leptons.



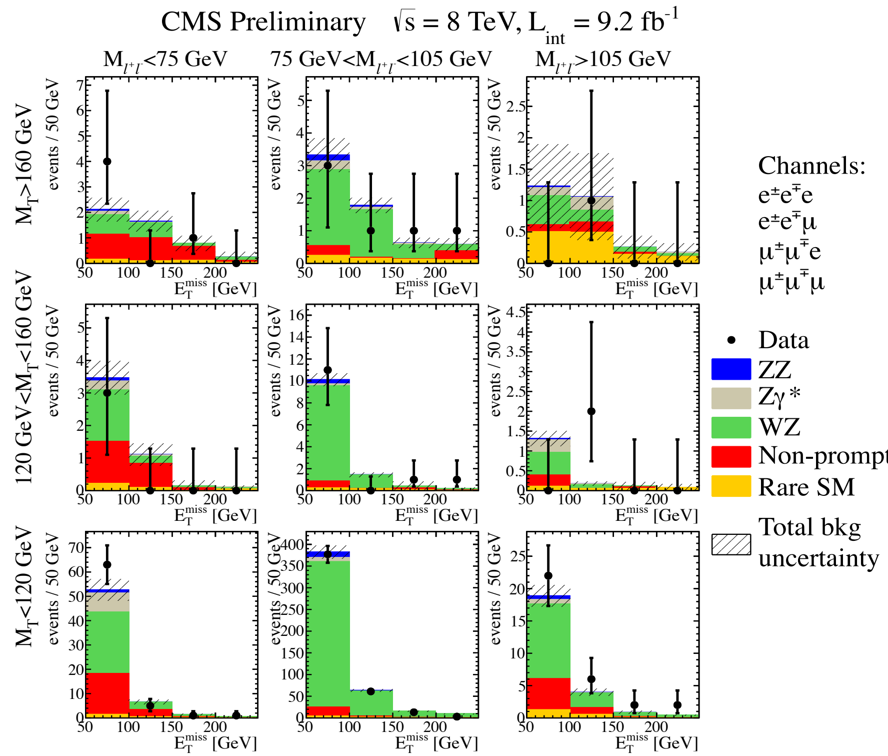


CMS EWK PRODUCTION: $\tilde{\chi}^{\pm}\tilde{\chi}^{0}$

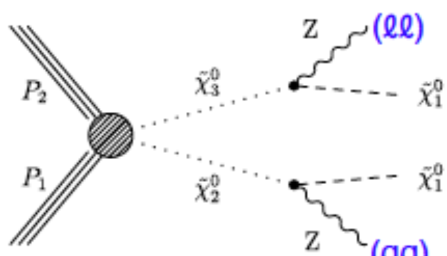
3 leptons + E_T^{miss}: M_T & M(ll)

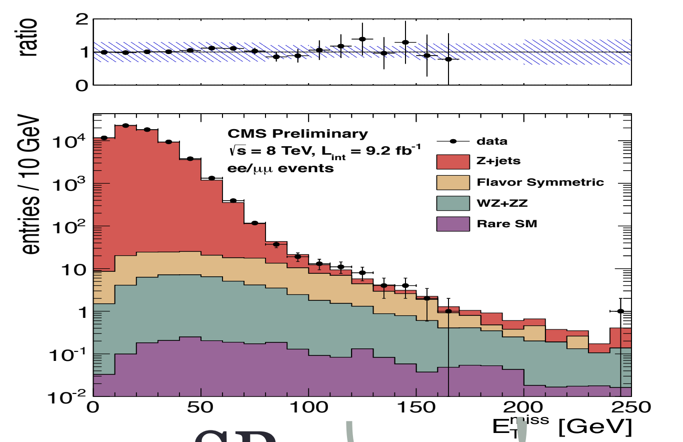


Depending on the mass sppliting, signal may show up in one of the search regions.



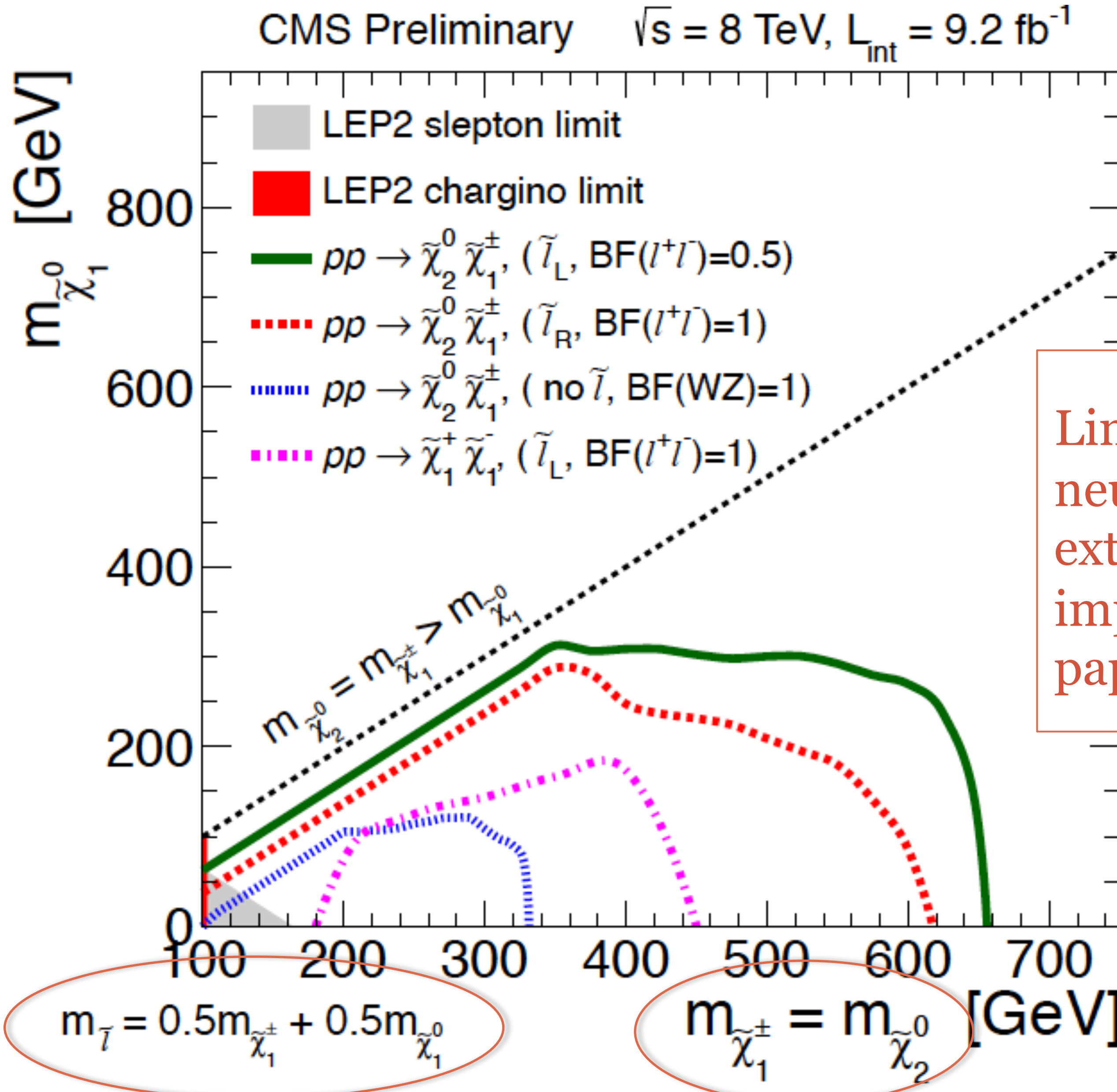
2leptons + dijet + E_T^{miss}





SRs

CMS WEAKLY PRODUCED SUSY

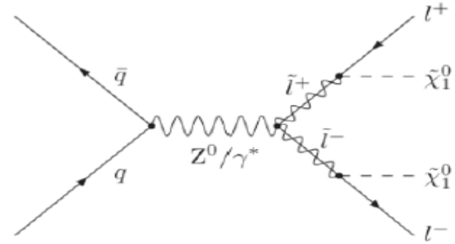


8 TeV

Limits on chargino-neutralino in SMS, extended and improved from 2011 paper

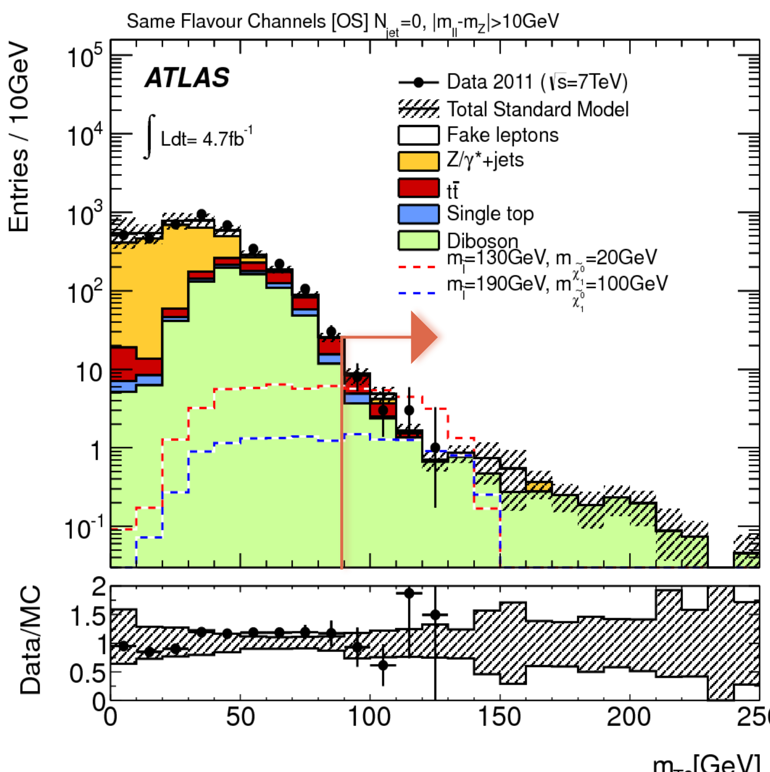
ATLAS EWK PRODUCTION: SLEPTONS

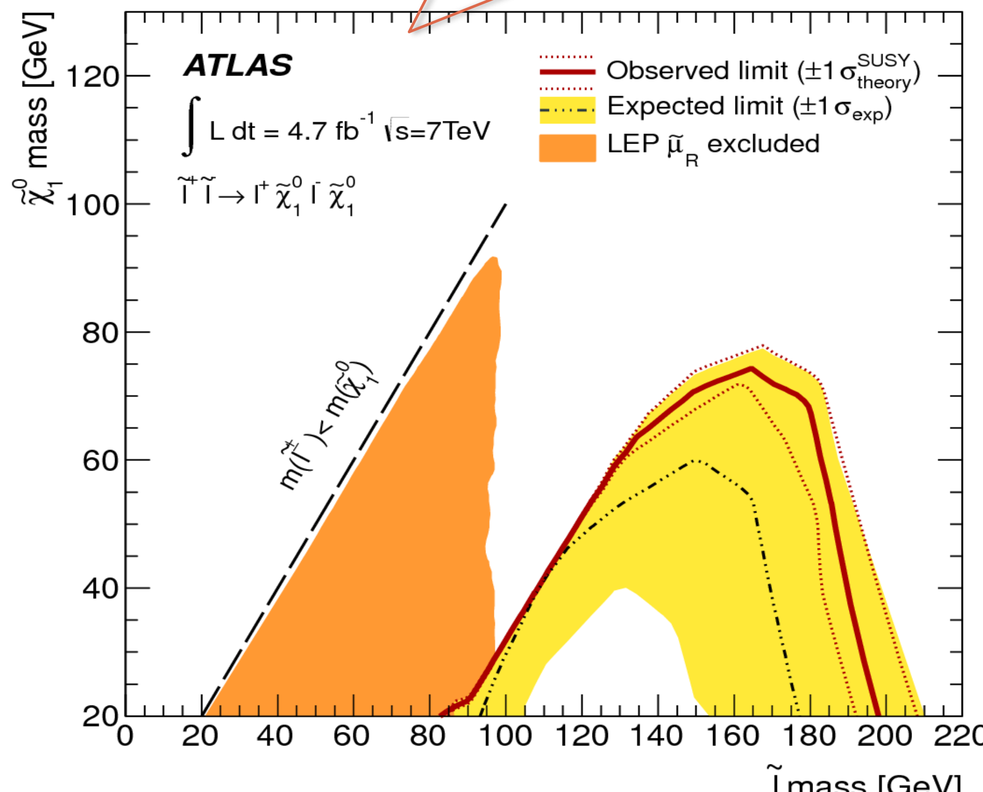
2 leptons + E_T^{miss}



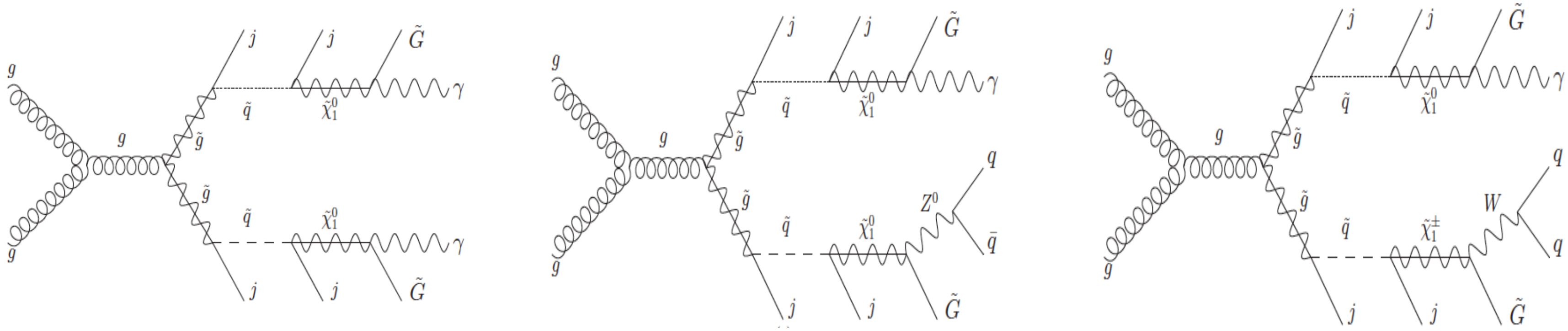
Reduce the WW background by using its endpoint in tranverse mass: m_{T2} (at ~90 GeV)

Limits on sleptons- pMSSM



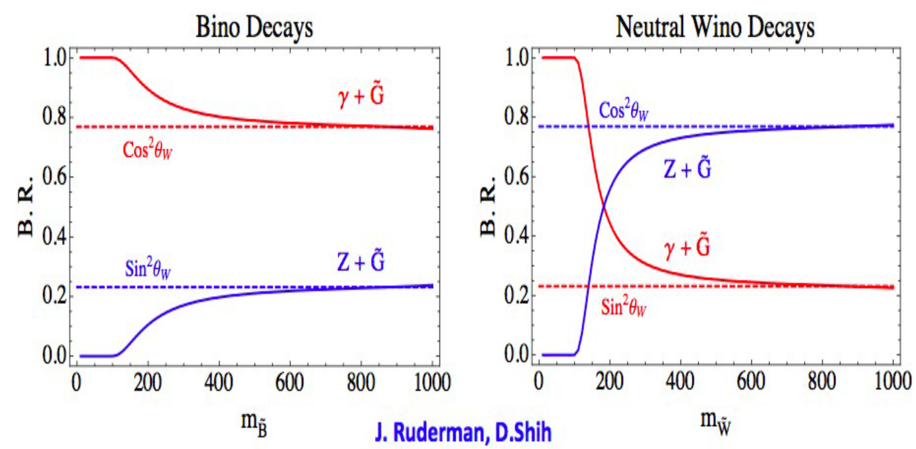


PHOTONS + E_T^{miss} → GMSB SCENARIOS



GGM (General Gauge Mediation)

Depending on the nature of NLSP, different experimental signatures.

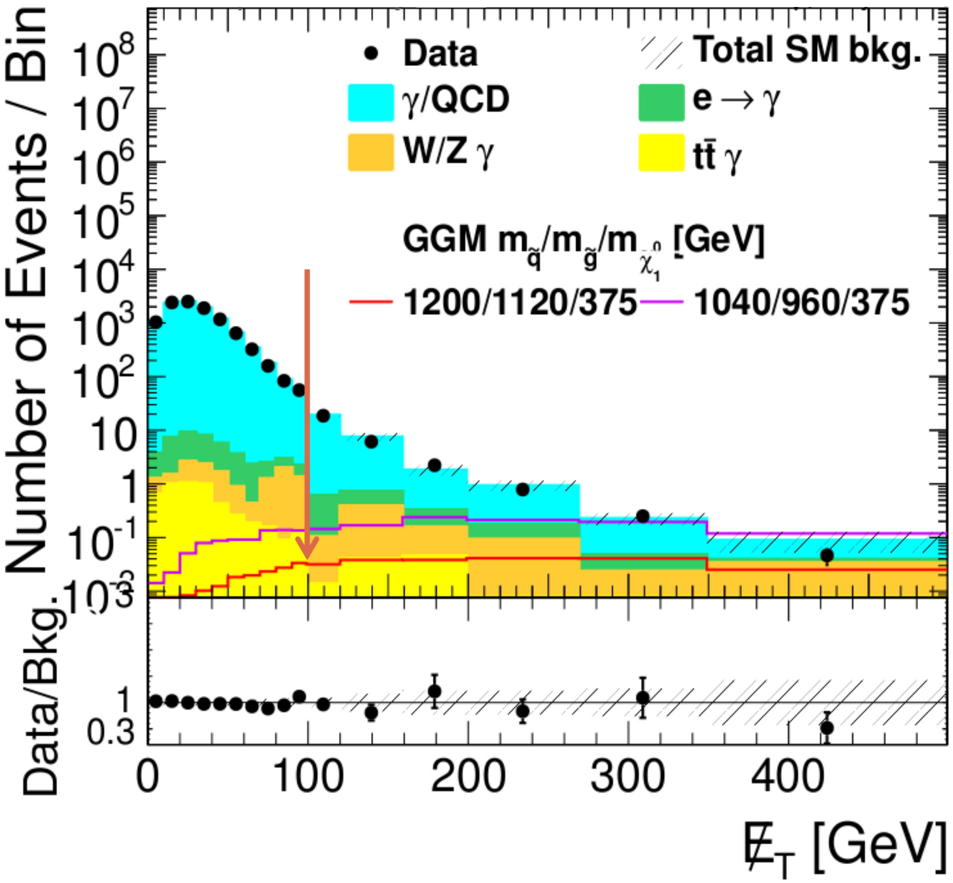


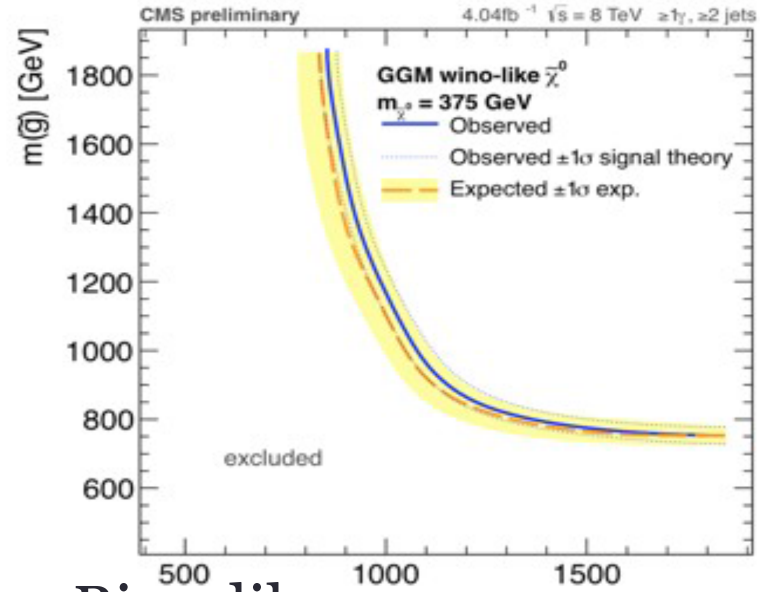
Photons provide a clean experimental signature, reconstructed with high purity and efficiency.

CMS γ + JET + E_T^{miss}

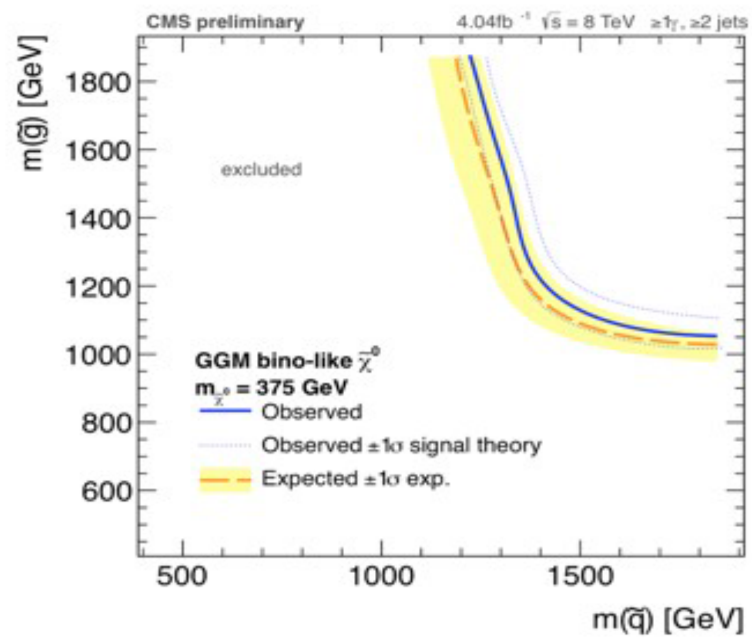
Wino-like 8 TeV

NLSP type	$\gamma + 2\,\text{jets} + E_T^{miss}$
Bino	$\text{jets} + \tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \text{jets} + \gamma + Z + \tilde{G}\tilde{G}$
Wino	$\text{jets} + \tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \text{jets} + \gamma + Z + \tilde{G}\tilde{G}$ $\text{jets} + \tilde{\chi}_1^0\tilde{\chi}_1^\pm \rightarrow \text{jets} + \gamma + W^\pm + \tilde{G}\tilde{G}$





Bino-like



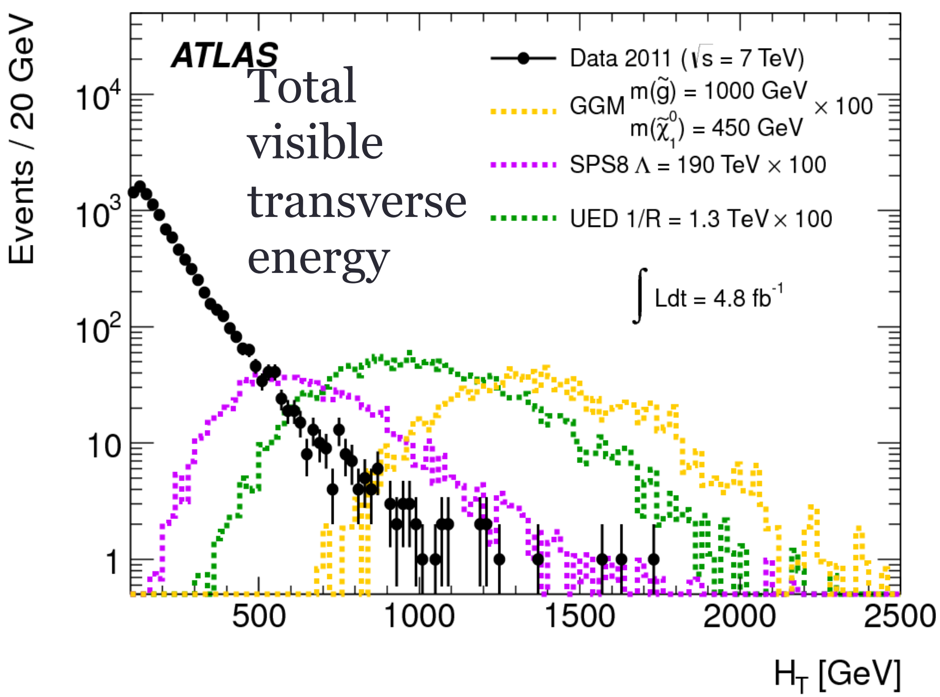
ATLAS $\gamma\gamma + E_T^{miss}$

General Gauge Mediation (GGM)

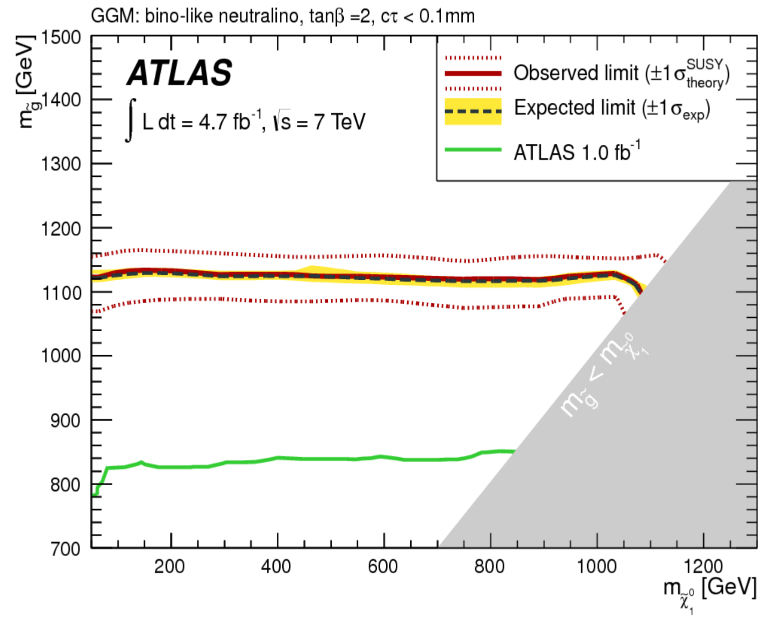
Simplified models:

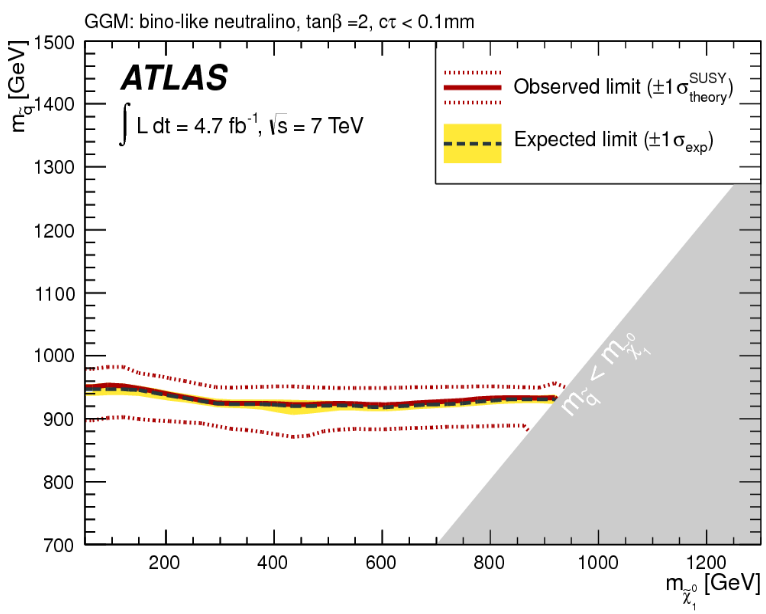
- Gluino/squarks for production
- Bino-like neutralino as NLSP
- Gravitino

3 SR: E_T^{miss}, H_T, $\Delta\phi(\gamma, E_T^{miss})$



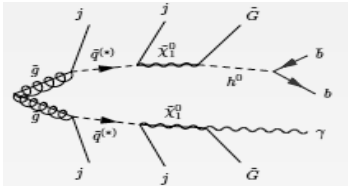
Total visible transverse energy



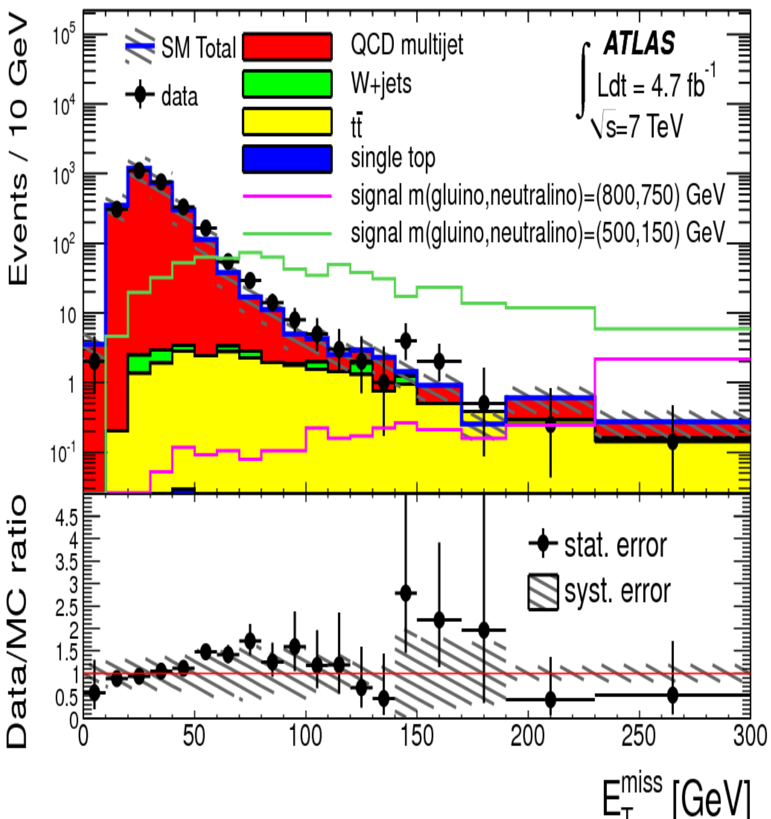


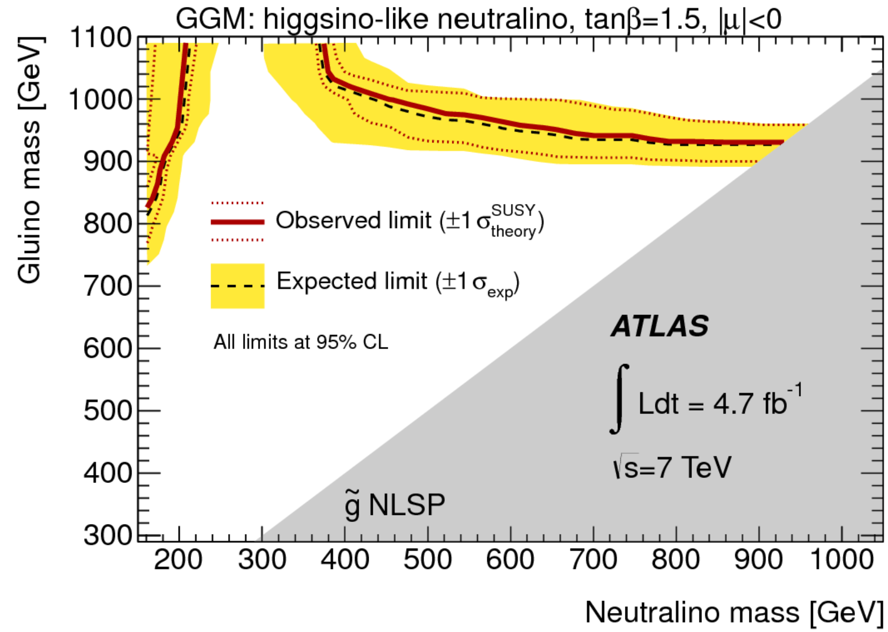
ATLAS $\gamma + b + E_T^{miss}$

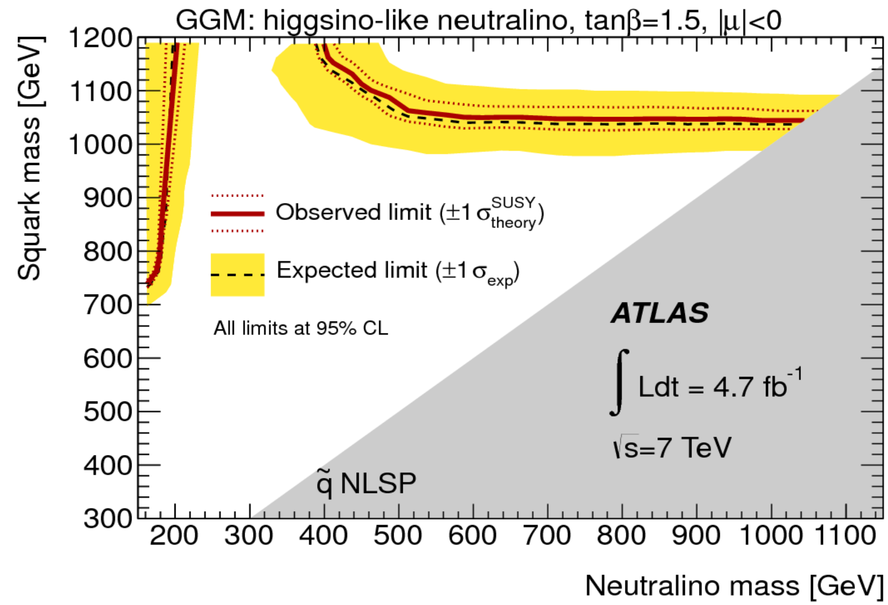
Selection



1 photon ($p_T > 125$ GeV)	$m_T(\gamma, E_T^{miss}) > 100$ GeV
≥ 2 jets ($p_T > 20$ GeV)	$\Delta\phi\ (E_T^{miss}, \text{jet}) > 0.4$
≥ 1 b-tagged jet	veto e/μ
$E_T^{miss} > 150$ GeV	veto second photon





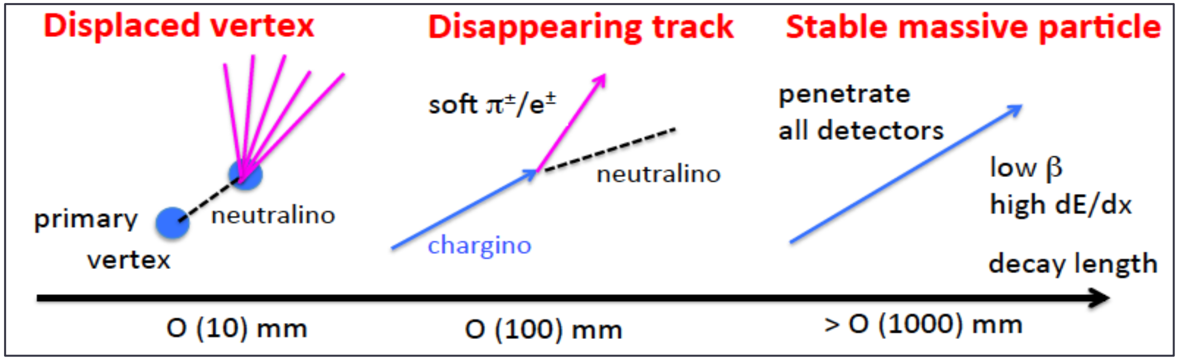


RPV & LONG-LIVED SPARTICLES

- R-parity Violation: Lifetime proportional *to* $\lambda^2, \lambda'^2, \lambda''^2$

$$W_{\not R_p} = \mu_i H_u L_i + \frac{1}{2}\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \frac{1}{2}\lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

Displaced vertex if $\lambda, \lambda', \lambda'' < 10^{-7}$



- A long-lived (LL) can also be produced in RPC

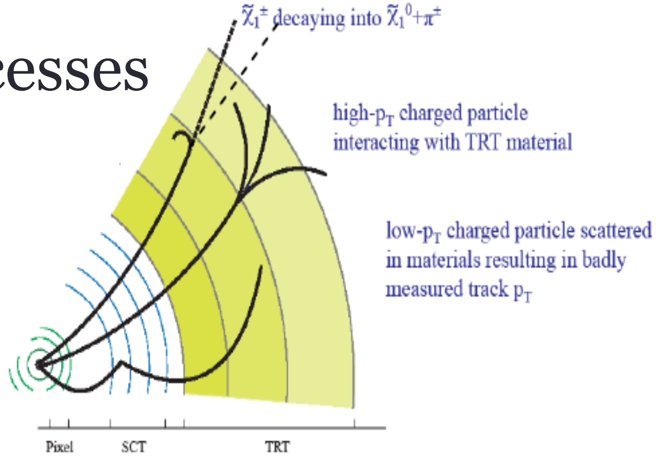
- $\Delta M(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0)$ ~100 MeV (e.g, AMSB) → disappearing track
- Heavy LLP: sleptons, squarks, gluinos (R-hadrons)

ATLAS CHARGINO DISAPPEARING TRACK

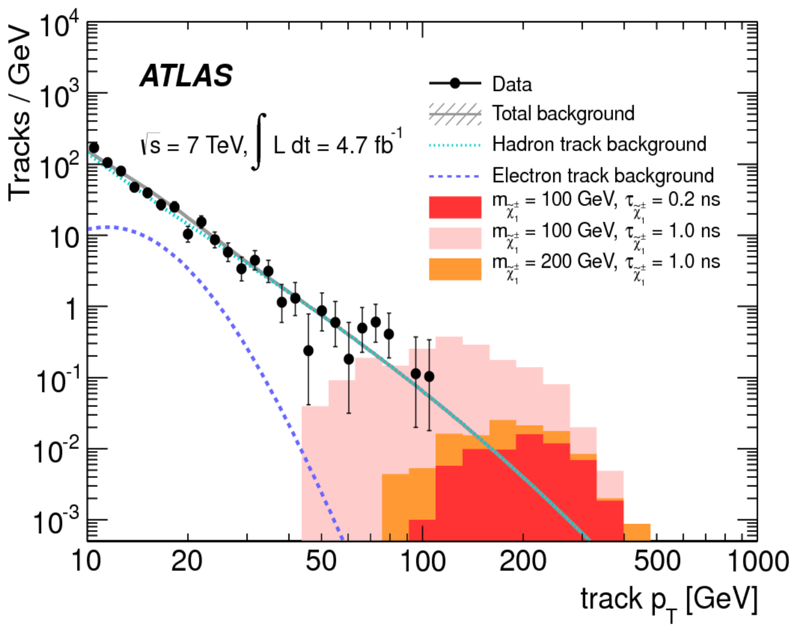
Long-lived AMSB charginos via EW processes

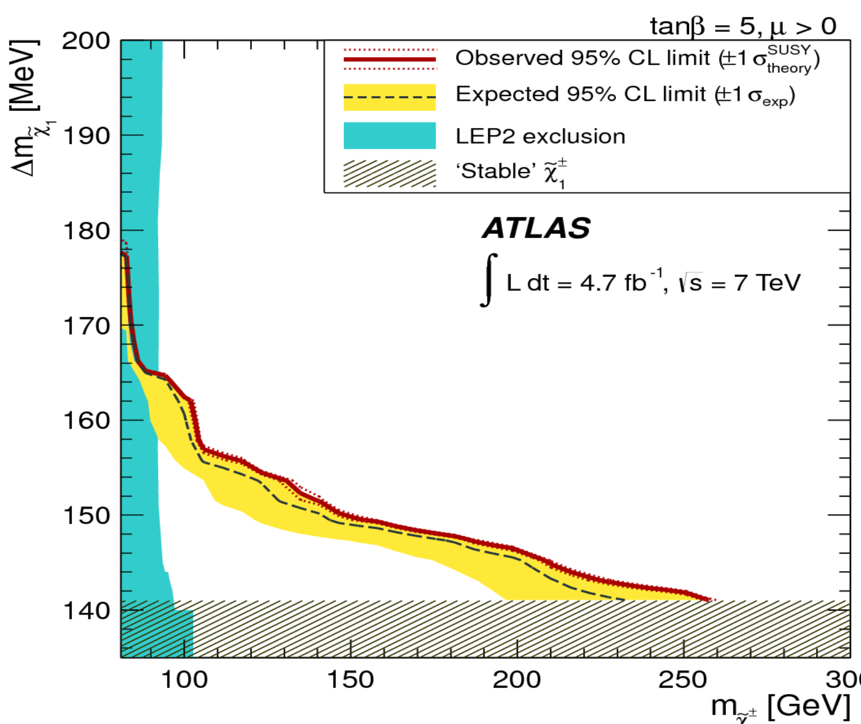
$$pp \to \tilde{\chi}_1^{\pm}\tilde{\chi}_1^0 j, \quad pp \to \tilde{\chi}_1^{+}\tilde{\chi}_1^{-} j$$

$\tilde{\chi}_1^{\pm} \to \tilde{\chi}_1^0 \pi^{\pm}$ →BR set to 100%



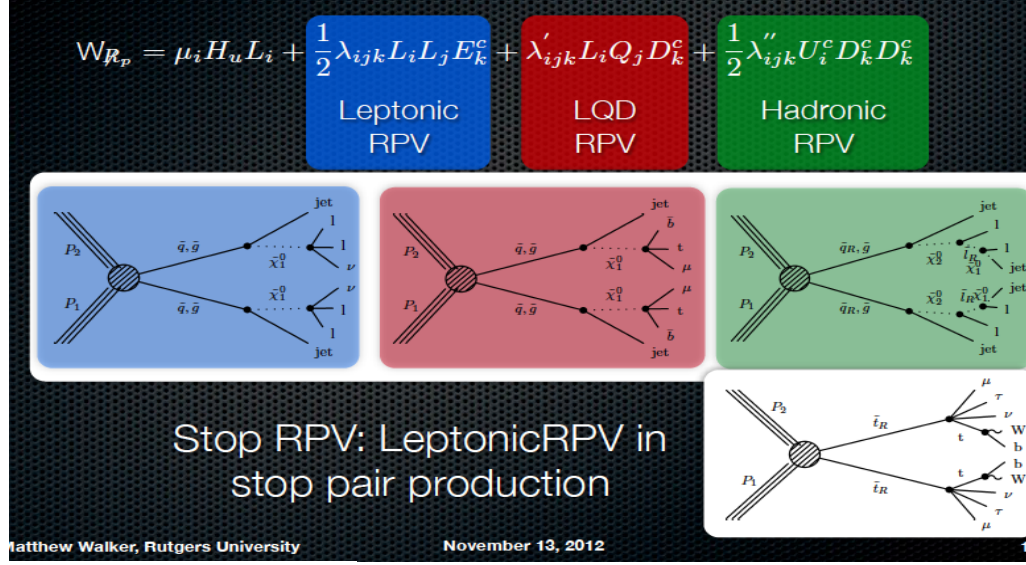
- ✓ Jet (from ISR) + E_T^{miss}
- ✓ earch for high-pT isolated tracks that stop in outer TRT.
- ✓ Model independent results.



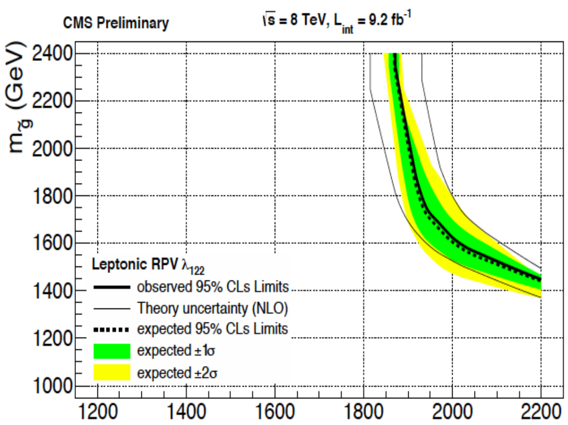


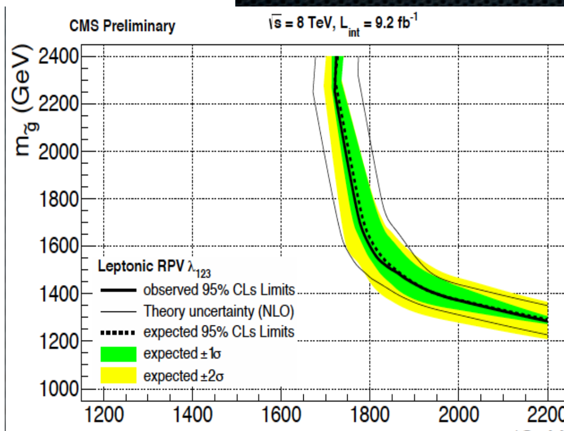
CMS RPV SEARCH

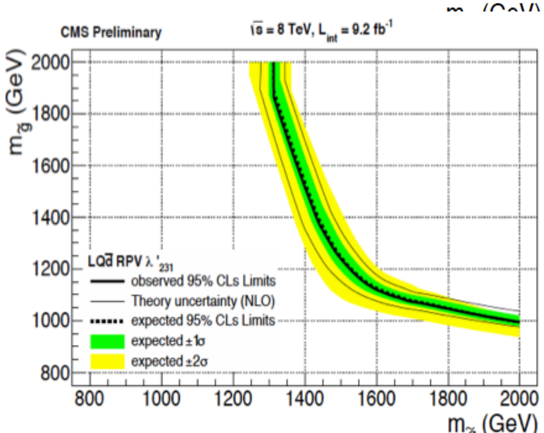
Multileptons provide sensitivity to several new physics models

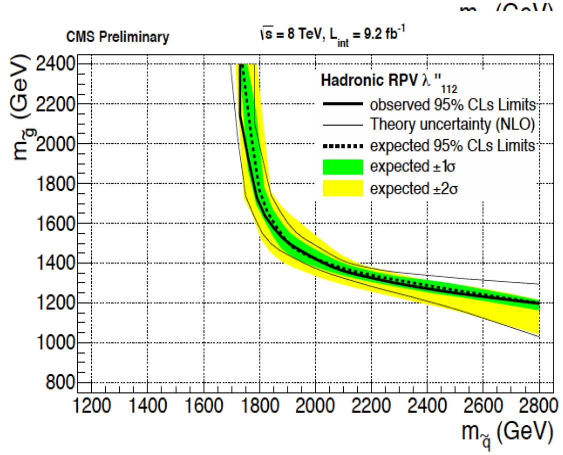


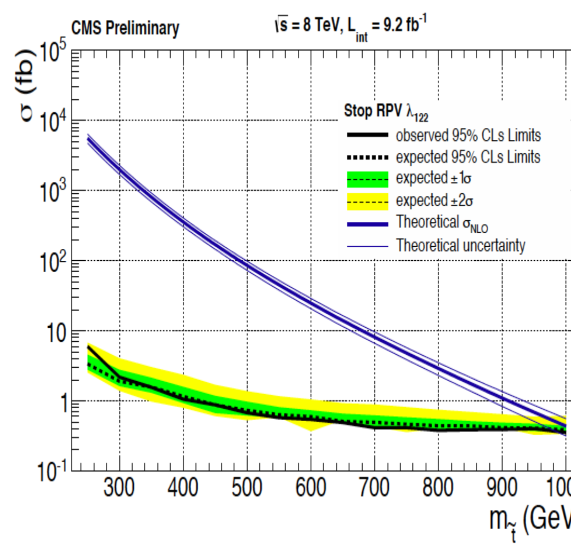
8 TeV





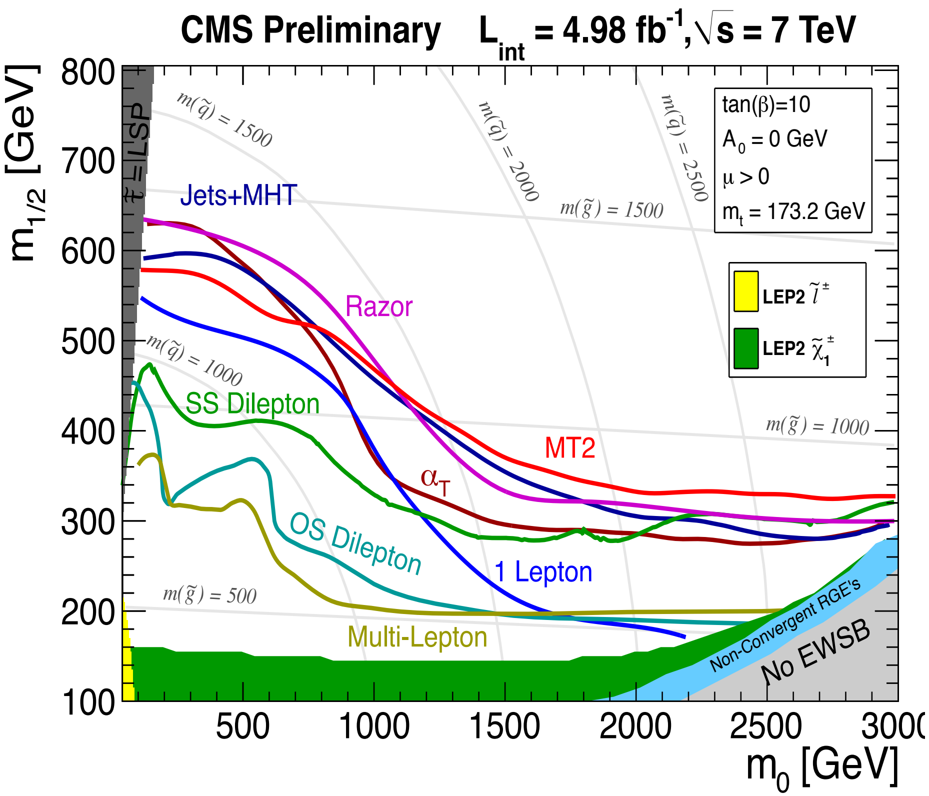




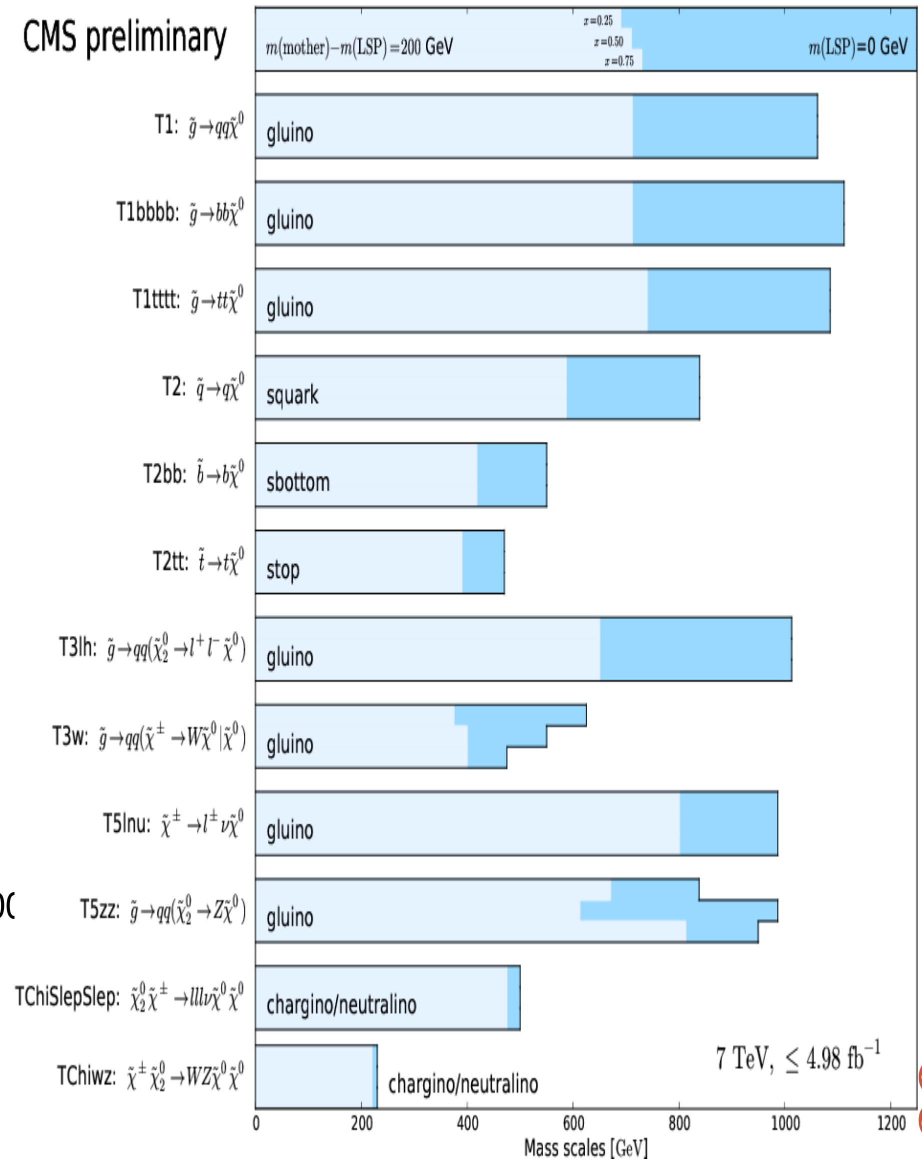


CONCLUSIONS (I): SUMMARY CMS

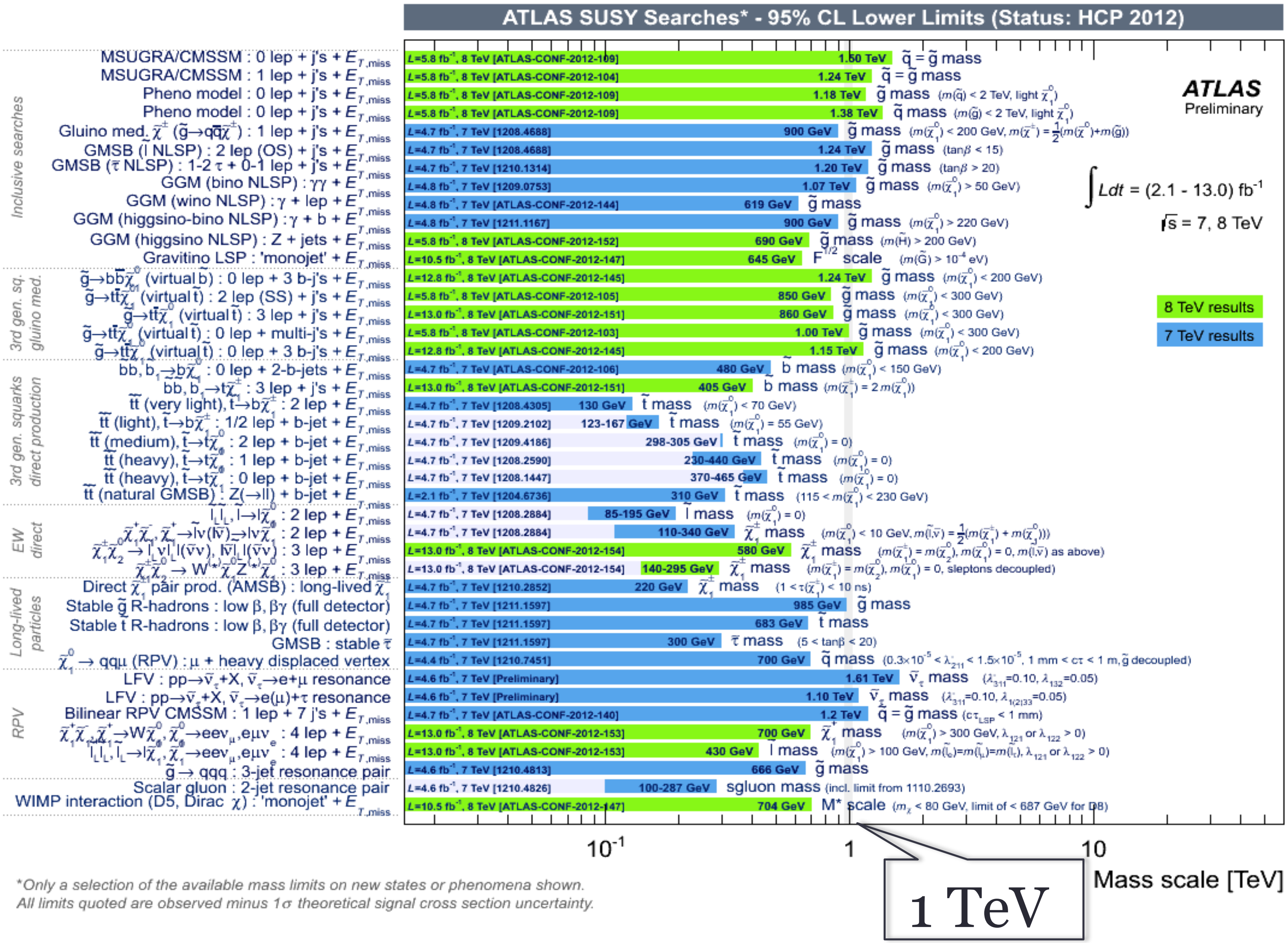
4.98 fb $^{-1}$, 7 TeV



Best analysis result per topology



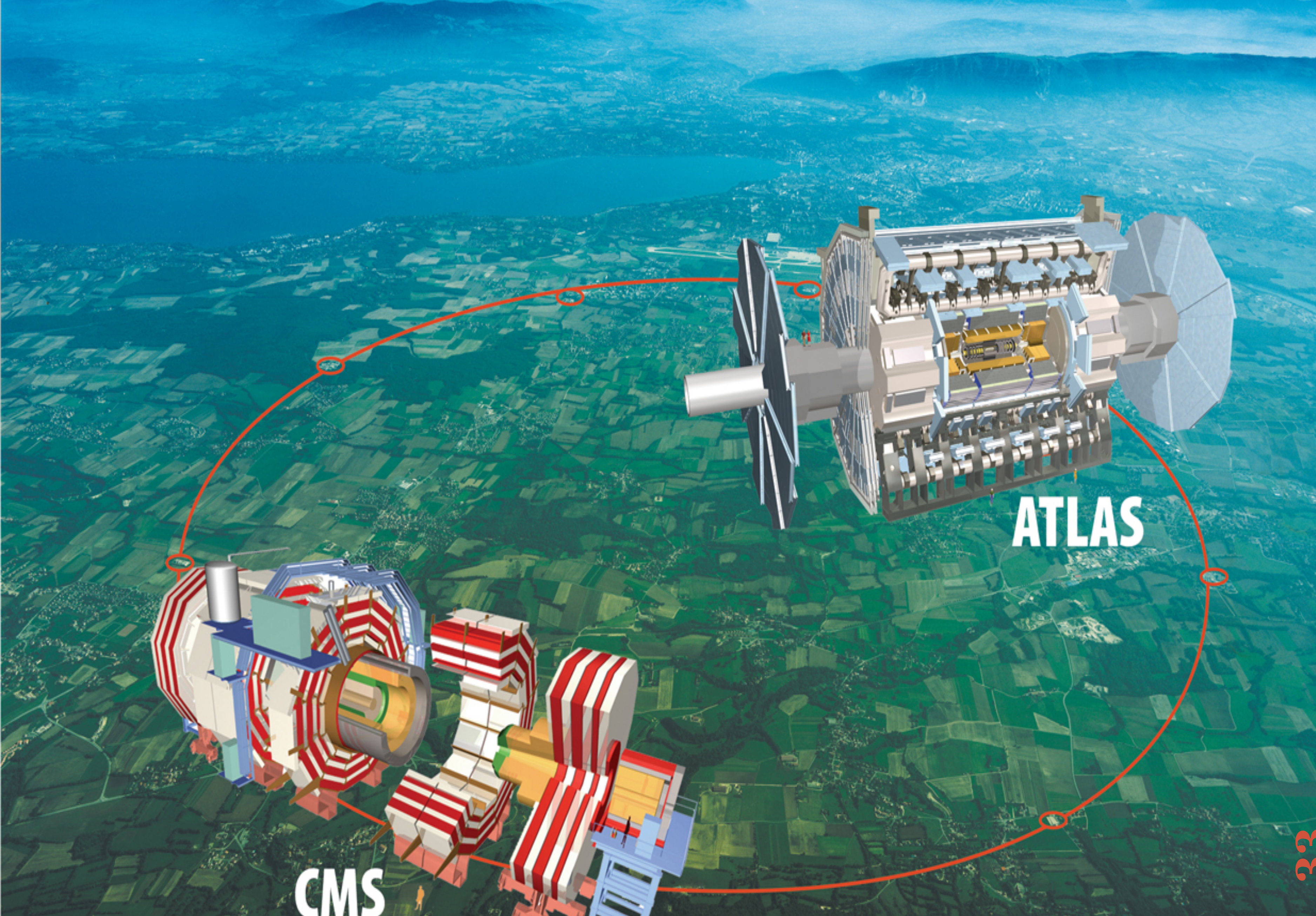
CONCLUSIONS (II): SUMMARY ATLAS



CONCLUSIONS

- ATLAS and CMS have produced an impressive number of papers and conference notes using data from 7 TeV and 8 TeV collisions.
- Probed a wide variety of SUSY motivated final states: SUSY was not "just around the corner"…
- Analysis at 8 TeV data are in progress. Expected ~20fb^{-1}. More to follow!

THANKS!

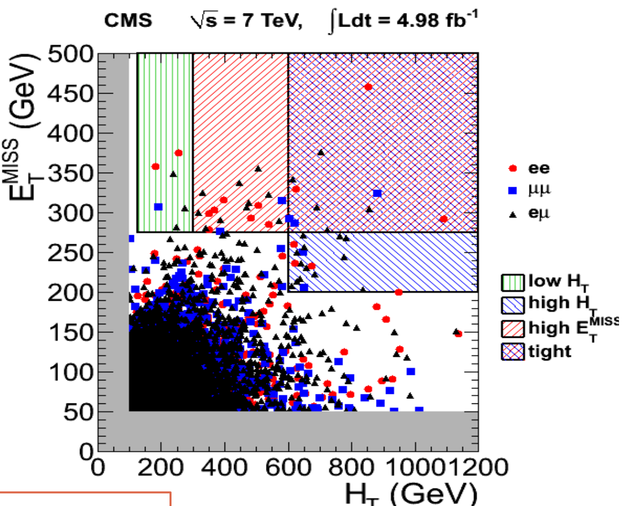


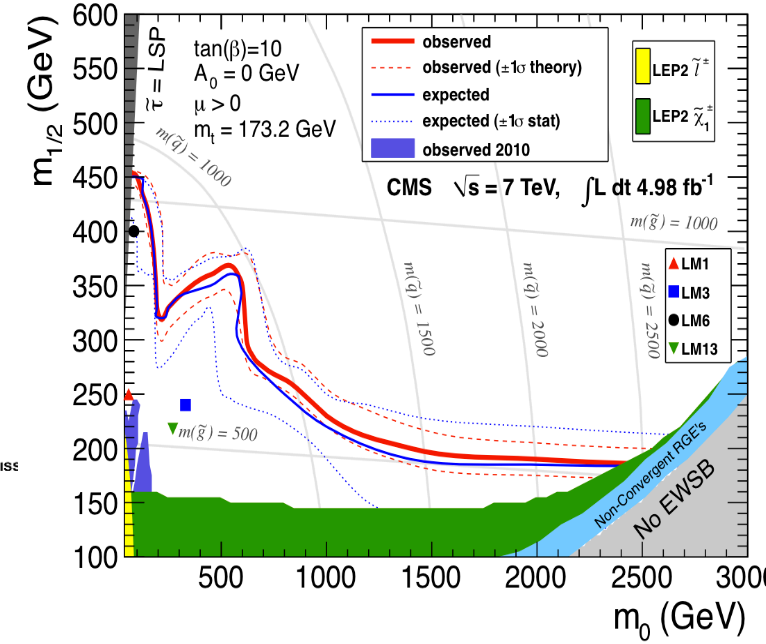
BACKUP SLIDES

CMS OS DI-LEPTON

Generic OS search

- Dileptons with large hadronic activity and MET
- Varios signal regions define in ETMiss-HT plane



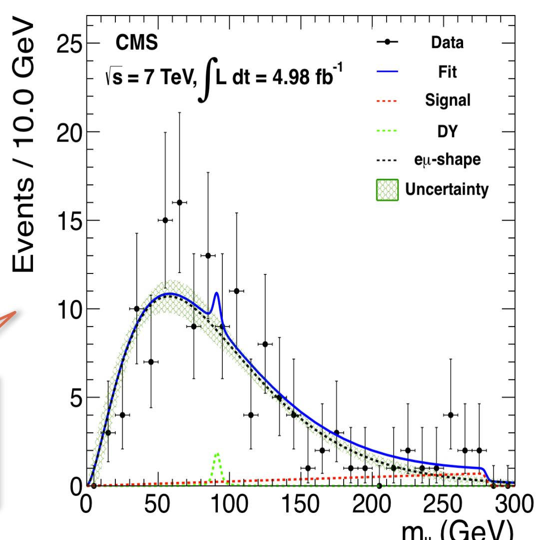


OS mass edge search

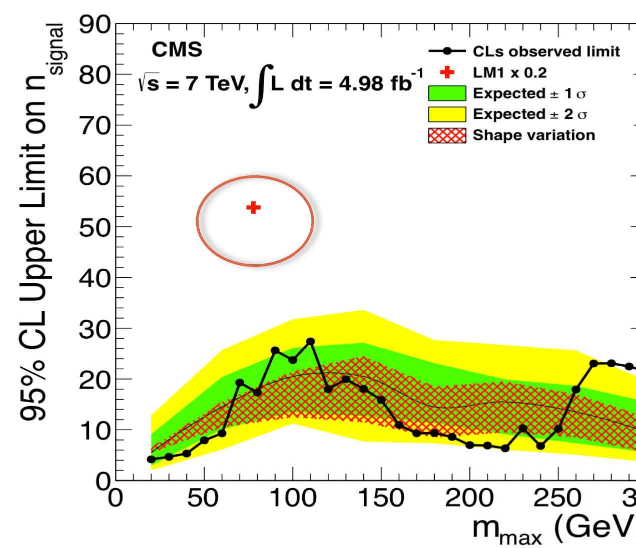
Search for kinematic edges in lepton pair inv. mass (SF)

HT>300 GeV

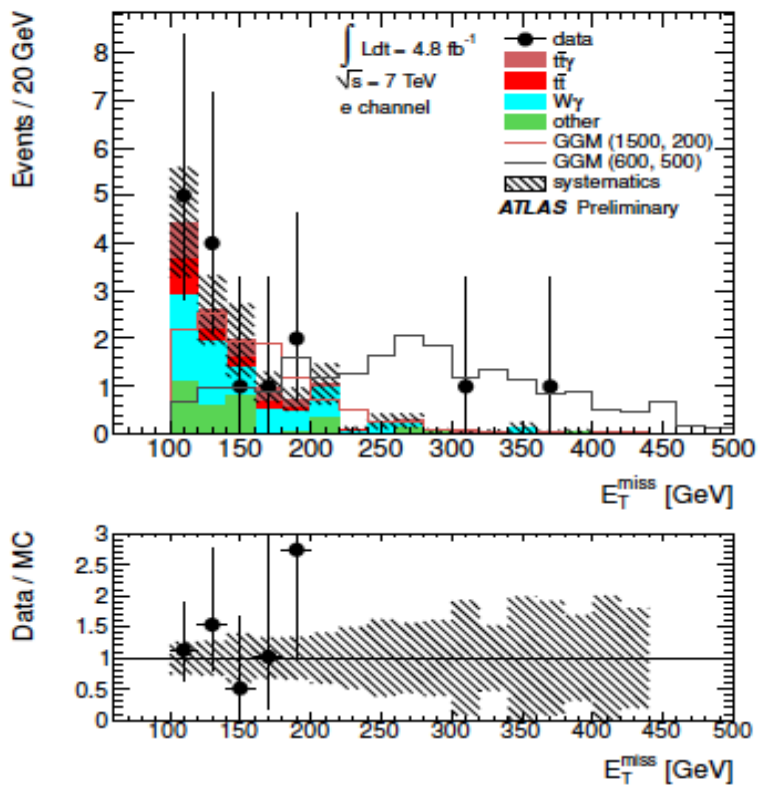
ETMiss>150 GeV

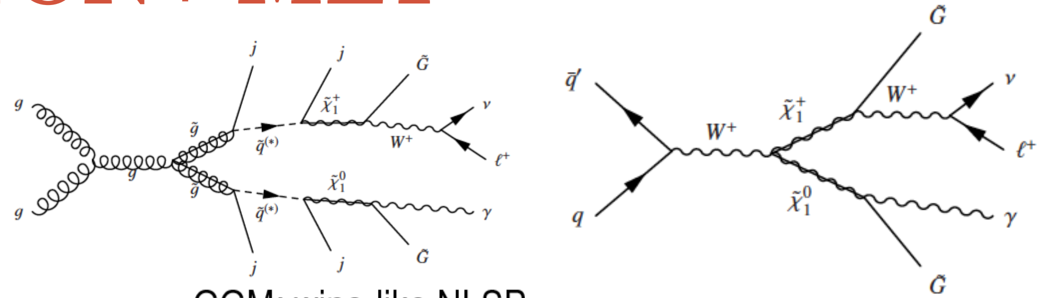


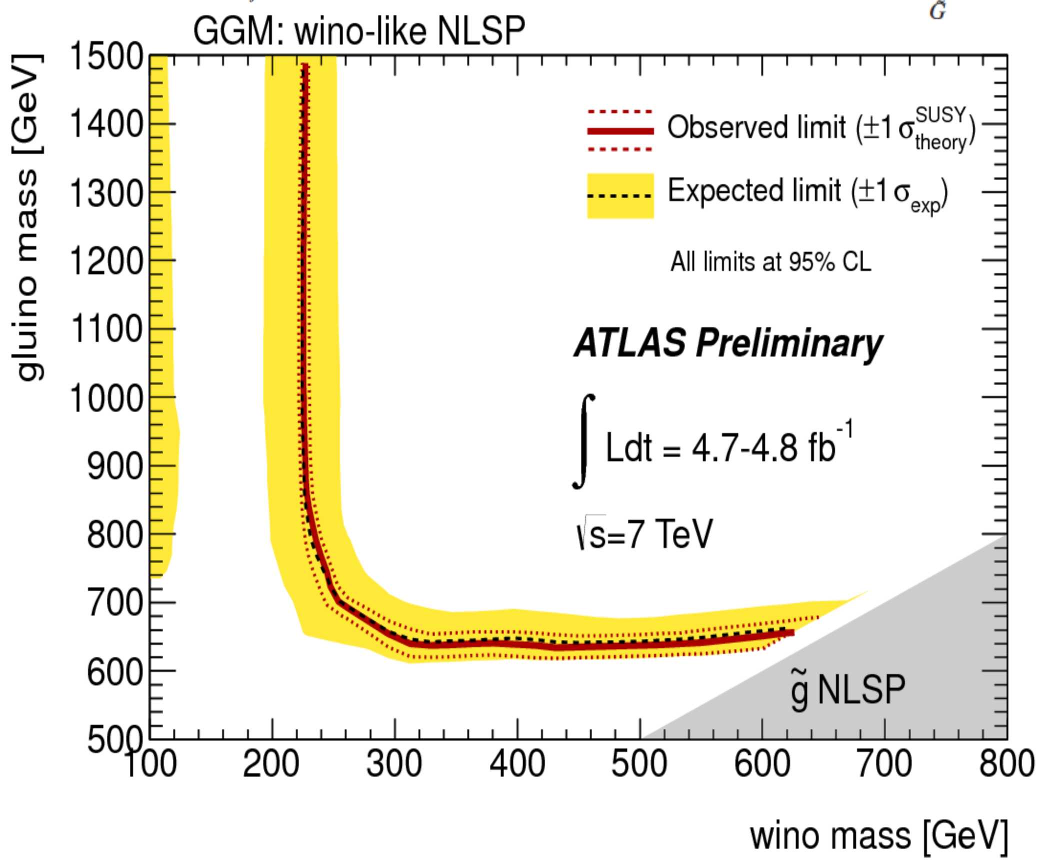
Limits depending on mass edge position (m_{max})



ATLAS γ + LEPTON+ MET







Selection	Channel	Total SM	Data
SR	e	13.0 ± 3.4	15
	μ	15.1 ± 3.6	11

- Gluinos masses < 619GeV excluded at 95% CL for any m_wino < excluded m_ gluino
- Wino masses < 221GeV excluded at 95% CL for any value of the gluino mass.

Exclusion limits

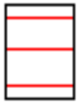
❑ Exclusion limits : a new standard ATLAS/CMS procedure (>June 2012)

- Ease the life of theorist by separating the signal theoritical and experimental systematics

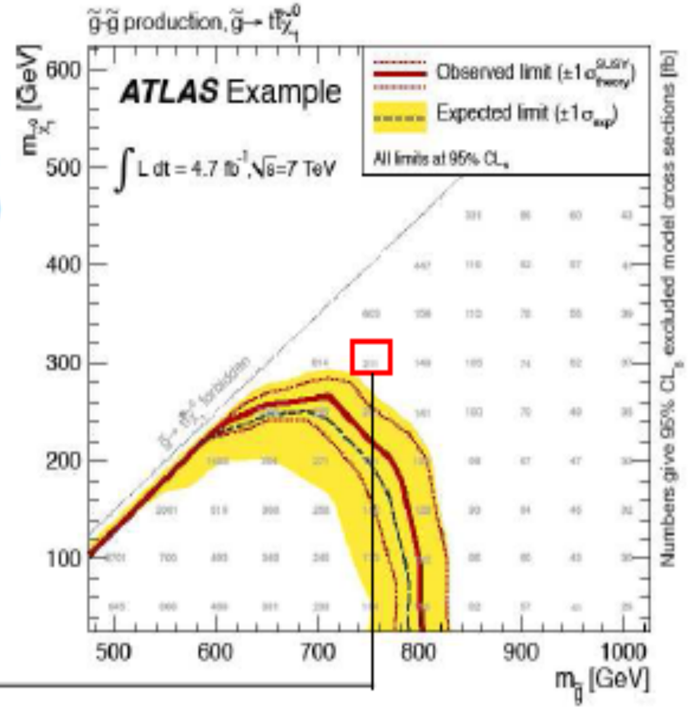
Expected limit:

- **Central value:** all uncertainties included in the fit as nuisance parameters, except theoretical signal uncertainties (PDF,scales)
- **±1σ band** : ±1σ results of the fit

Observed limit:



- **Central value**: Idem as for expected limit
- **±1σ band** : re-run and increase/decrease the signal cross section by the theoretical signal uncertainties (PDF, scales)



Excluded Model Cross section (SMS)

➔ Number quoted in paper correspond to observed -1 σ observed (conservative)