LHC SUSY Searches (II)
with Leptons, Photons, Long-Lifetime, or No Large MET

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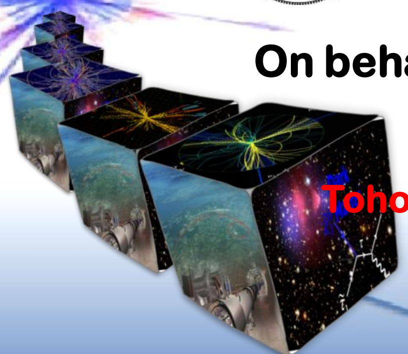
On behalf of the ATLAS and CMS Collaborations



Tohoku Workshop on  Higgs and Beyond

June 6, 2013

OUTLINE

Where is ?
How to probe ?

© my daughter

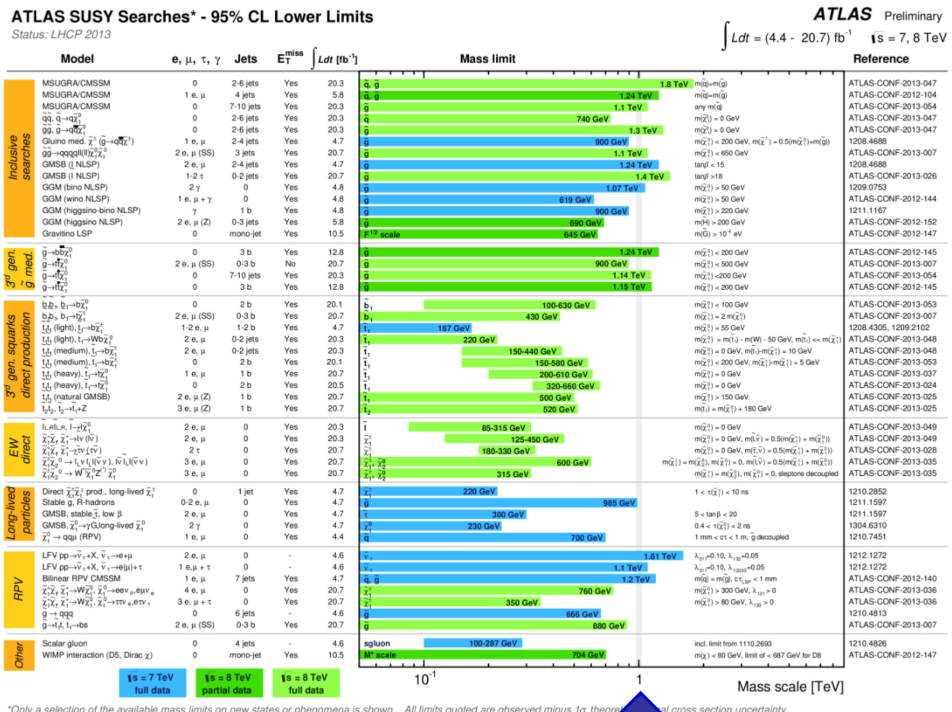
Part II: Charginos, Neutralinos, Sleptons, RPV, Long-lived (LL) Particles

I review several selected topics to compare ATLAS and CMS results. We see amazingly (but expectedly) both detectors are providing almost same physics performance.

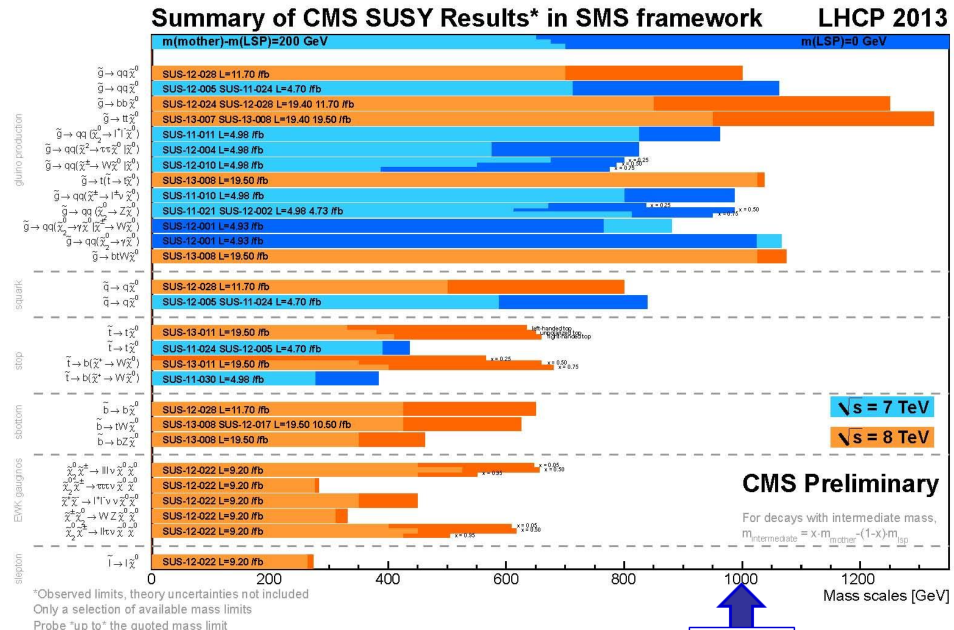
/// ATLAS ///
https://twiki.cern.ch/twiki/bin/view/AtlasPublic
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

/// CMS ///
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

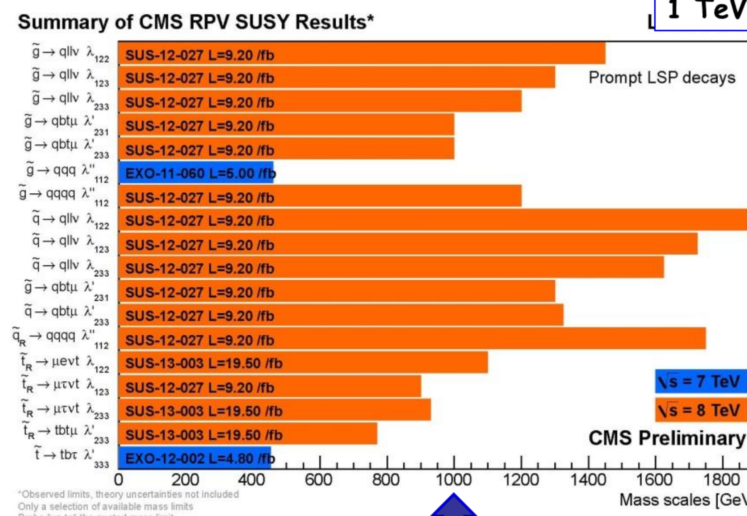
LHC SUSY Searches At A Glance



1 TeV



1 TeV



RPV

1 TeV

- Probing a TeV scale at LHC8 ☺
- No hints of SUSY (yet) in very diverse SUSY search programs ☹

[Note] –1 sigma exclusion limits rather than the nominal value are also available in ATLAS and CMS papers.

Closer Look at ATLAS

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: LHCP 2013

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int Ldt$ [fb^{-1}]
Inclusive searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3
	MSUGRA/CMSSM	1 e, μ	4 jets	Yes	5.8
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3
	Gluino med. $\tilde{\chi}^\pm$ ($\tilde{g}\to q\bar{q}\tilde{\chi}^\pm$)	1 e, μ	2-4 jets	Yes	4.7
	$\tilde{g}\tilde{g}\to qqqql\ell(\ell\ell)\tilde{\chi}_1^0\tilde{\chi}_1^0$	2 e, μ (SS)	3 jets	Yes	20.7
	GMSB ($\tilde{\ell}$ NLSP)	2 e, μ	2-4 jets	Yes	4.7
	GMSB ($\tilde{\tau}$ NLSP)	1-2 τ	0-2 jets	Yes	20.7
	GGM (bino NLSP)	2 γ	0	Yes	4.8
	GGM (wino NLSP)	1 e, μ + γ	0	Yes	4.8
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	4.8
	GGM (higgsino NLSP)	2 e, μ (Z)	0-3 jets	Yes	5.8
	Gravitino LSP	0	mono-jet	Yes	10.5
3rd gen. $\tilde{g}$ med.	$\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	12.8
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	2 e, μ (SS)	0-3 b	No	20.7
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0	3 b	Yes	12.8
3rd 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
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to t\tilde{\chi}_1^\pm$	2 e, μ (SS)	0-3 b	Yes	20.7
	$\tilde{t}_1\tilde{t}_1$ (light), $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	1-2 e, μ	1-2 b	Yes	4.7
	$\tilde{t}_1\tilde{t}_1$ (light), $\tilde{t}_1\to Wb\tilde{\chi}_1^0$	2 e, μ	0-2 jets	Yes	20.3
	$\tilde{t}_1\tilde{t}_1$ (medium), $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	2 e, μ	0-2 jets	Yes	20.3
	$\tilde{t}_1\tilde{t}_1$ (medium), $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	0	2 b	Yes	20.1
	$\tilde{t}_1\tilde{t}_1$ (heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	1 e, μ	1 b	Yes	20.7
	$\tilde{t}_1\tilde{t}_1$ (heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	0	2 b	Yes	20.5
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e, μ (Z)	1 b	Yes	20.7
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+Z$	3 e, μ (Z)	1 b	Yes	20.7

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int Ldt$ [fb^{-1}]
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
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e, μ	0	Yes	20.3
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	0	Yes	20.7
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e, μ	0	Yes	20.7
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W^{(*)}\tilde{\chi}_1^0 Z^{(*)}\tilde{\chi}_1^0$	3 e, μ	0	Yes	20.7
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	0	1 jet	Yes	4.7
	Stable $\tilde{g}$, R-hadrons	0-2 e, μ	0	Yes	4.7
	GMSB, stable $\tilde{\tau}$, low β	2 e, μ	0	Yes	4.7
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	0	Yes	4.7
	$\tilde{\chi}_1^0\to qq\mu$ (RPV)	1 e, μ	0	Yes	4.4
RPV	LFV $pp\to\tilde{\nu}_\tau+X$, $\tilde{\nu}_\tau\to e+\mu$	2 e, μ	0	-	4.6
	LFV $pp\to\tilde{\nu}_\tau+X$, $\tilde{\nu}_\tau\to e(\mu)+\tau$	1 e, μ + τ	0	-	4.6
	Bilinear RPV CMSSM	1 e, μ	7 jets	Yes	4.7
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e, μ	0	Yes	20.7
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 e, μ + τ	0	Yes	20.7
	$\tilde{g}\to qqq$	0	6 jets	-	4.6
	$\tilde{g}\to\tilde{t}_1 t$, $\tilde{t}_1\to bs$	2 e, μ (SS)	0-3 b	Yes	20.7
Other	Scalar gluon	0	4 jets	-	4.6
	WIMP interaction (D5, Dirac χ)	0	mono-jet	Yes	10.5

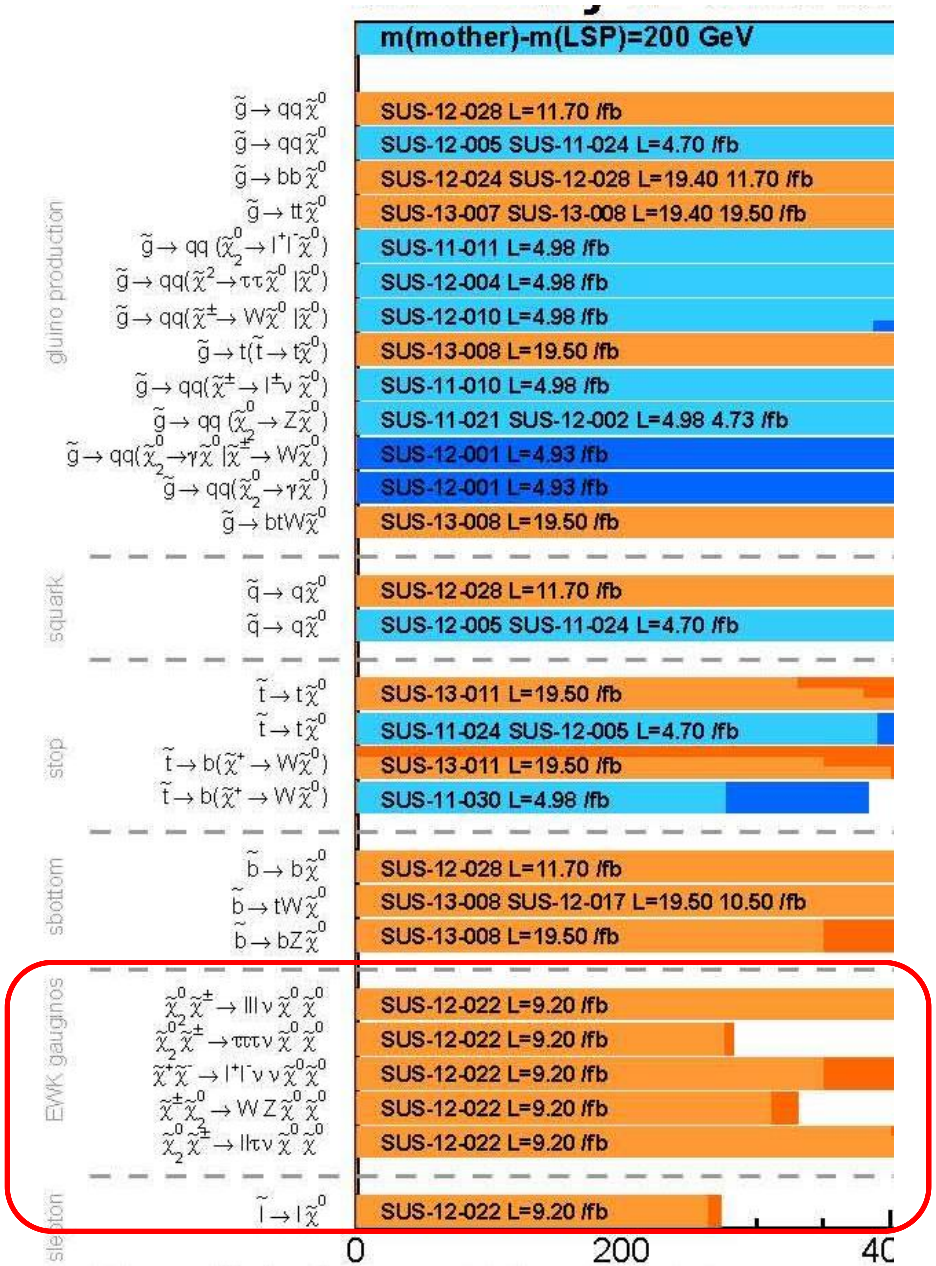
LL

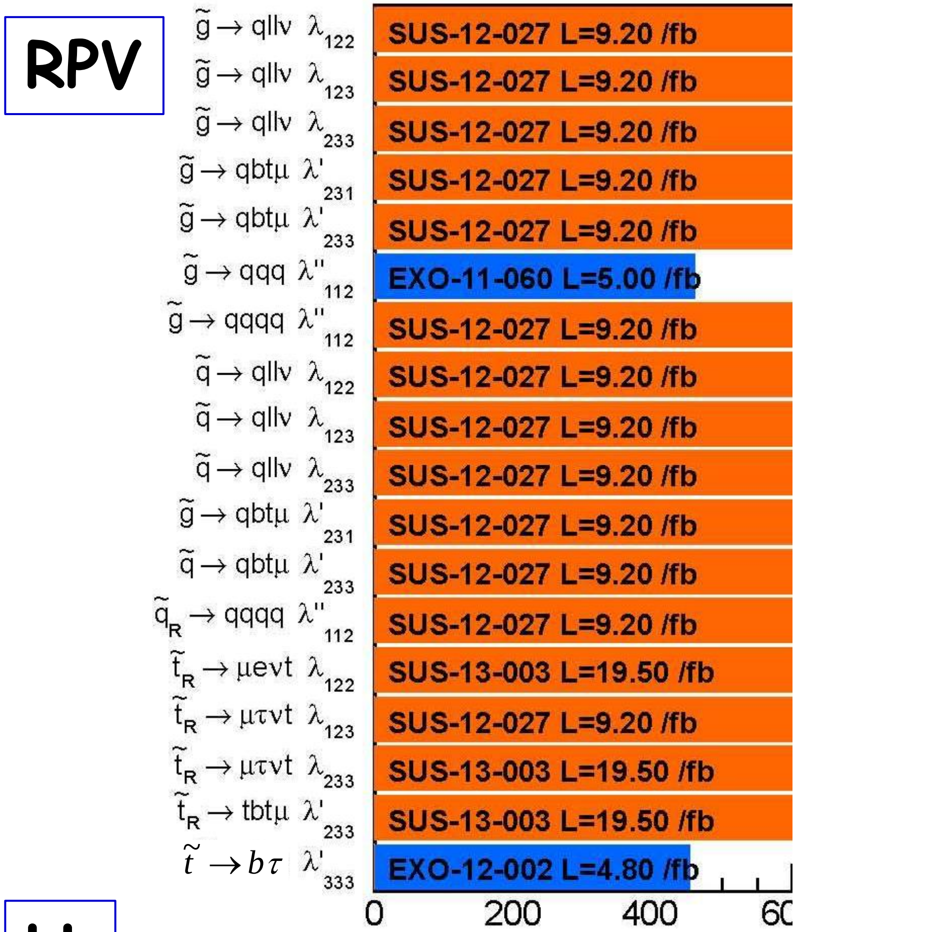
RPV

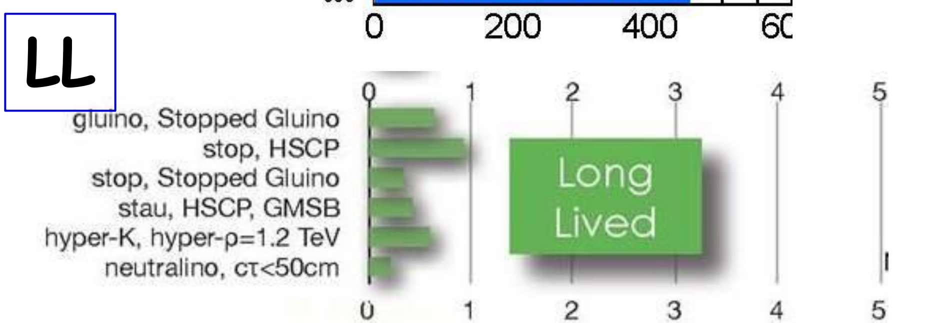
$\sqrt{s}$ = 7 TeV full data | $\sqrt{s}$ = 8 TeV partial data | $\sqrt{s}$ = 8 TeV full data

*Only a selection of the available mass limits on new states or phenomena is s

Closer Look at CMS







A Few Words in My Mind

/// Scenarios and Models in Market///

- Simplified Model Spectra (SMS) Scenarios
- Minimal and non-minimal scenarios in Supersymmetric SM
- Minimal and non-minimal scenarios in AMSB, GMSB, SUGRA/CMSSM, …
- Natural SUSY, Split SUSY, …
- RPV

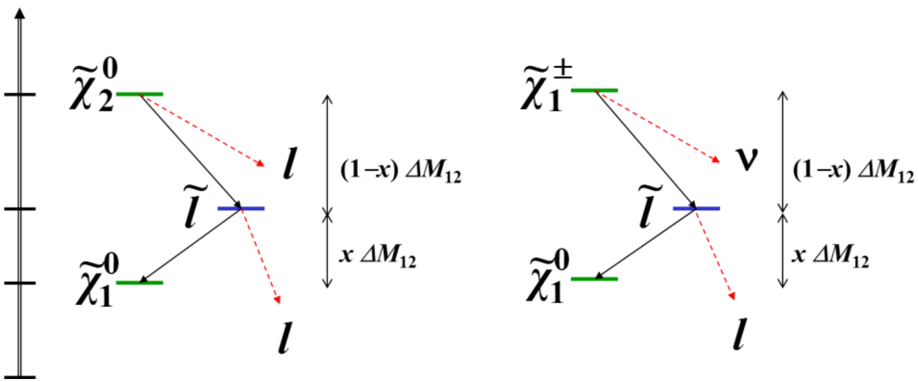
/// Questions ///

- What do we do with (i) heavy $1^{st}/2^{nd}$ generation squarks and gluino, and (ii) small ΔM (mass difference between NLSP and LSP)?
- How can we probe **colorless SUSY sector**?
    1) Tagging energetic jets (+ MET) from cascade decays
    2) Tagging leptons
    3) Tagging photons
    4) Tagging with timing
    5) Any other means?
- What if the nature is SUSY without a stable LSP?

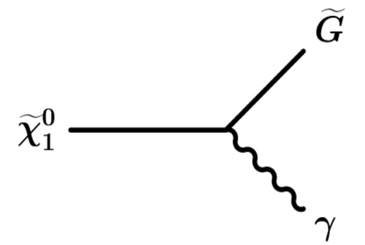
SUSY Probe Metric at LHC

Charginos, Neutralinos, Sleptons

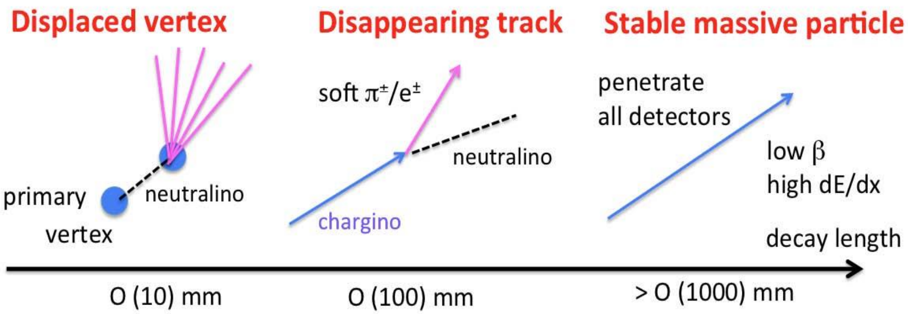
Multiple Leptons + MET



Photons + MET

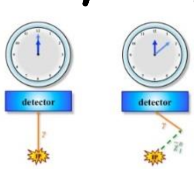


Outside a box …



"non-pointing" γ

"delayed" γ

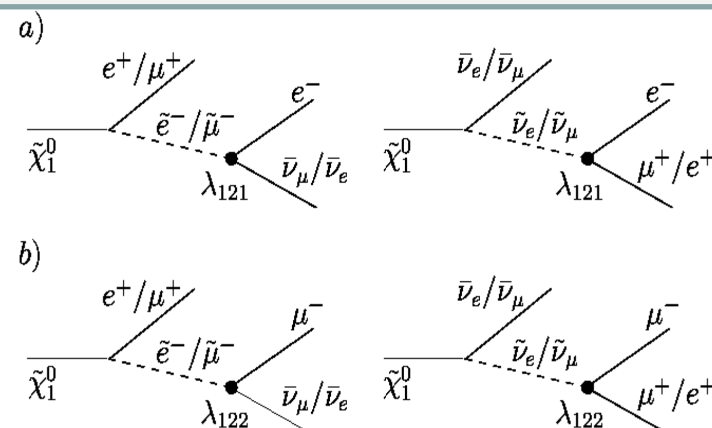


Multiple Leptons + no "MET"

$$W_{RPV} = \lambda_{ijk} L_i L_j \overline{E}_k + \lambda'_{ijk} L_i Q_j \overline{D}_k + k_i L_i H_u + \lambda''_{ijk} \overline{U}_i \overline{D}_j \overline{D}_k$$

Lepton Number Violation

Baryon Number Violation



Electroweak Sector

- Charginos (C1, C2), Neutralinos (N1, N2, N3, N4)

- LSP?
  - Lightest Neutralino (N1): Bino-like, Wino-like, Higgsino-like, Bino-Higgsino-like ..

  - Gravitino

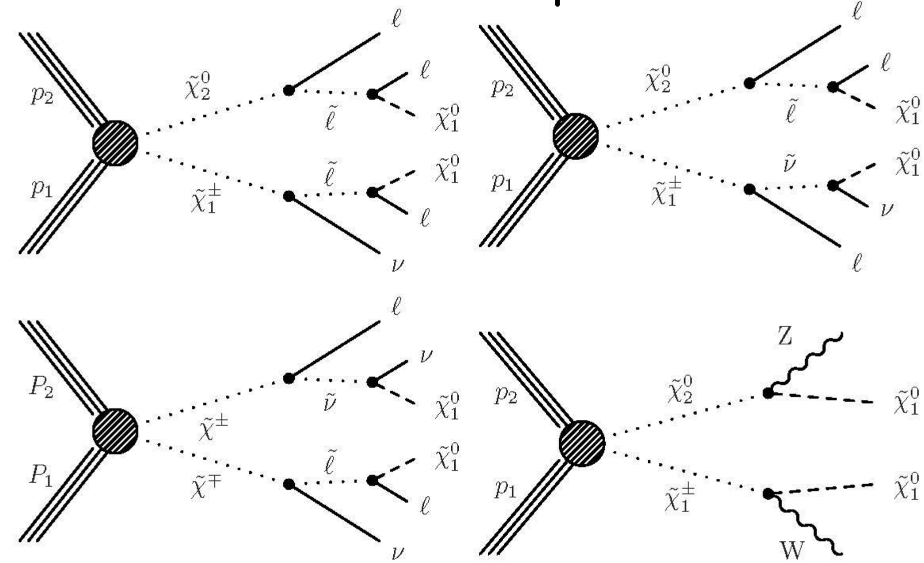
- Sleptons
  - Selectrons and smuons are mass degenerate.
  - Special case: Stau is lighter.

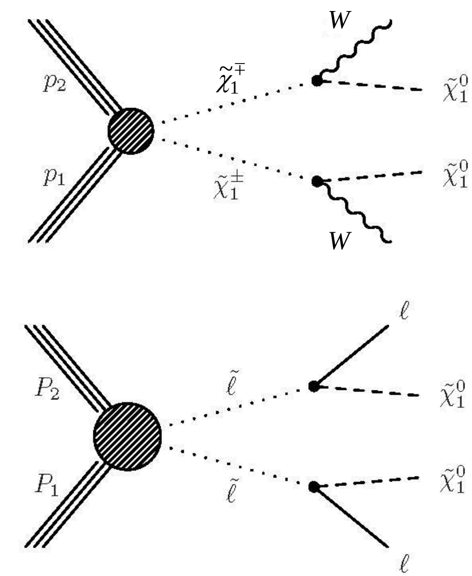
- RPV

Charginos and Neutralinos

	Analysis	Reference
ATLAS	2 leptons (e/mu)	ATLAS-2013-049 (20 /fb)
	2 leptons (tau)	ATLAS-2013-028 (20 /fb)
	3 leptons (e/mu)	ATLAS-2013-035 (20 /fb)
	4 leptons (e/mu/tau)	ATLAS-2013-036 (20 /fb)
CMS	2, 3, 4 leptons	CMS SUS-12-022 (9.2 /fb)

A few examples





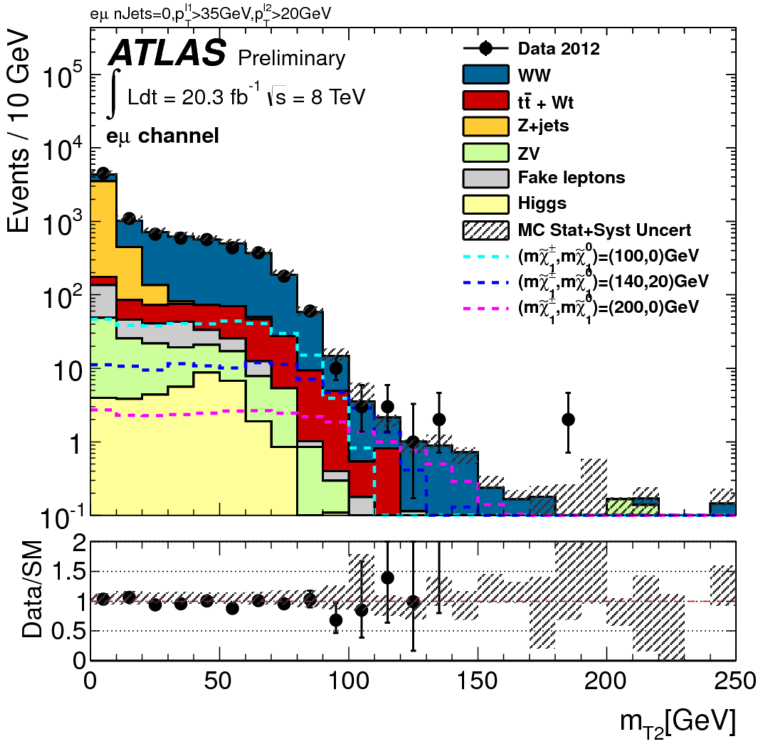
- Searches with 2, 3, 4 leptons
- Inclusive lepton (e or μ) triggers or Dilepton triggers (ee, eμ, $\mu\mu$) with 25~14/8 (ATLAS) and 17/8 (CMS)
- Other leptons with 10, 10, 20 for e, μ, τ_h
- Like-sign and opposite-sign dileptons with e, μ
- 3, 4 leptons with one τ_h
- Distinguish with and without OSSF candidates for e, μ

Controlled Regions (CRs)

- Data-driven + MC (e.g., ABCD)
- MET, m_{T2}, b-tagging, τ_h identification, Understanding fake leptons
- See, below, examples of data-MC agreements

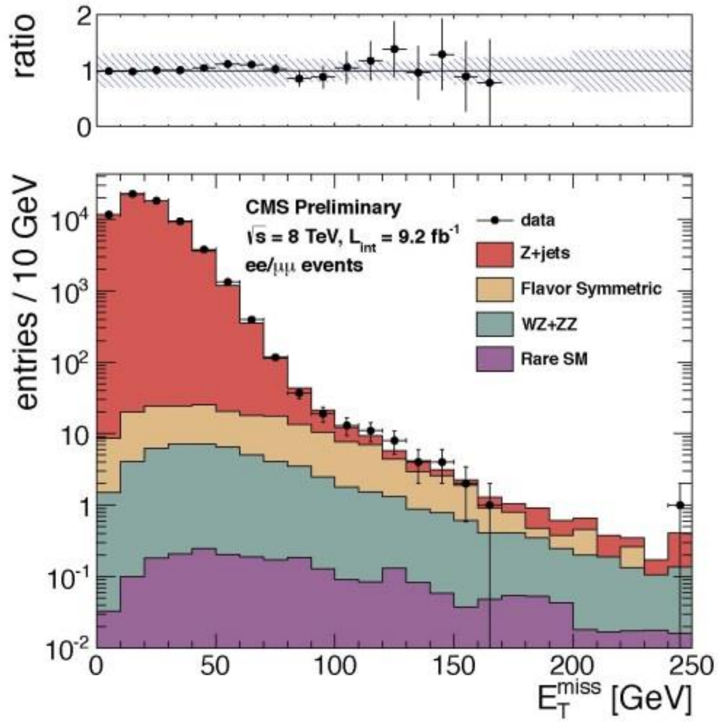
WW($\rightarrow e\nu\ \mu\nu$) CR

Distribution of m_{T2} in the OS $e\mu$ event sample with $p_T(l_1)$ > 35 GeV and $p_T(l_2)$ > 20 GeV.



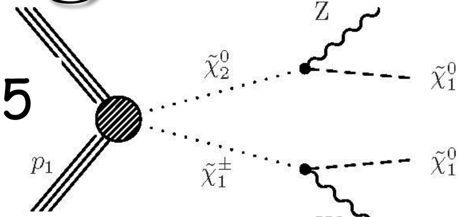
Z($\rightarrow ee/\mu\mu$)+Jets CR

B-veto & dijet mass consistent with W or Z to suppress the top events



Trilepton Signal Regions (SRs)

ATLAS-CONF-2013-035
e/μ



CMS-SUS-12-022
$e/\mu/\tau_h$

MET > 50   MET > 75   MET > 50

Table 1: The selection requirements for the signal regions. All regions are mutually exclusive and require exactly three signal leptons and a same-flavour opposite-sign (SFOS) lepton pair. Events with a b-jet or a SFOS lepton pair with mass less than 12 GeV are rejected. The mass of the SFOS lepton pair closest to the Z-boson mass is denoted by m_{SFOS}. The m_{T} is calculated from the $E_{\mathrm{T}}^{\mathrm{miss}}$ and the lepton not forming the SFOS lepton pair closest to the Z-boson mass.

Selection	SRnoZa	SRnoZb	SRnoZc	SRZa	SRZb	SRZc
m_{SFOS} [GeV]	<60	60–81.2	<81.2 or >101.2	81.2–101.2	81.2–101.2	81.2–101.2
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	>50	>75	>75	75–120	75–120	>120
m_{T} [GeV]	–	–	>110	<110	>110	>110
p_{T} 3rd ℓ [GeV]	>10	>10	>30	>10	>10	>10
SR veto	SRnoZc	SRnoZc	–	–	–	–

Table 1: SM expectations and observations for events with an ee or $\mu\mu$ OSSF pair, where the third lepton is either an electron or muon.

M_{T} (GeV)	$E_{\mathrm{T}}^{\mathrm{miss}}$ (GeV)	$M_{\ell\ell} < 75$ GeV		75 GeV $< M_{\ell\ell} <$ 105 GeV		$M_{\ell\ell} > 105$ GeV	
		total bkg	observed	total bkg	observed	total bkg	observed
> 160	50 – 100	2.1±0.5	4	3.3±0.5	3	1.2±0.7	0
	100 – 150	1.7±0.4	0	1.8±0.2	1	1.1±0.7	1
	150 – 200	0.8±0.3	1	0.63±0.16	1	0.26±0.18	0
	> 200	0.25±0.20	0	0.58±0.19	1	0.18±0.14	0
120 – 160	50 – 100	3.5±0.5	3	10.0±0.6	11	1.30±0.19	0
	100 – 150	1.1±0.3	0	1.5±0.2	0	0.17±0.05	2
	150 – 200	0.15±0.16	0	0.4±0.4	1	0.12±0.10	0
	> 200	0.11±0.05	0	0.17±0.10	1	0.08±0.09	0
0 – 120	50 – 100	53±5	63	382±15	377	19.0±1.7	22
	100 – 150	6.6±1.0	5	63±3	61	4.0±0.6	6
	150 – 200	1.4±0.3	1	16.0±0.9	13	0.9±0.3	2
	> 200	0.54±0.17	1	9.5±0.6	3	0.43±0.08	2

ATLAS SRs on CMS plot for Illustration

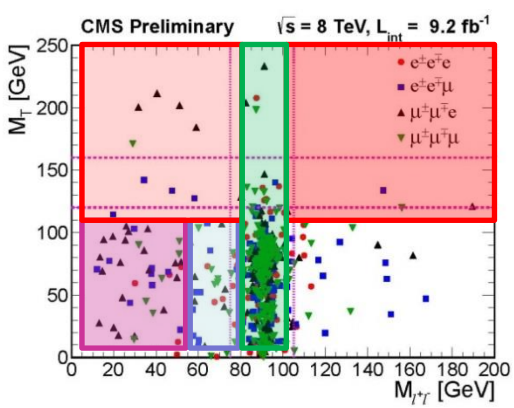


Figure 4: M_{T} versus $M_{\ell\ell}$ for three-lepton events with an ee or $\mu\mu$ OSSF dilepton pair, where the third lepton is either an electron or a muon.

SRs in m(ll), m_T, MET

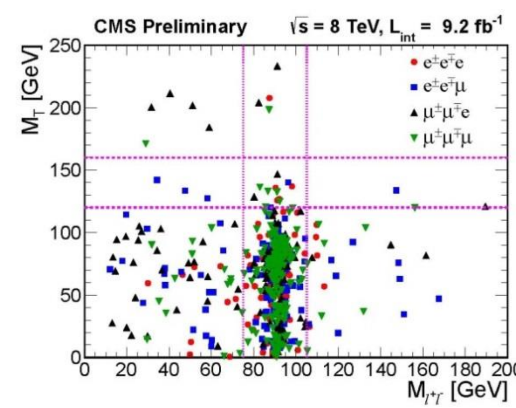
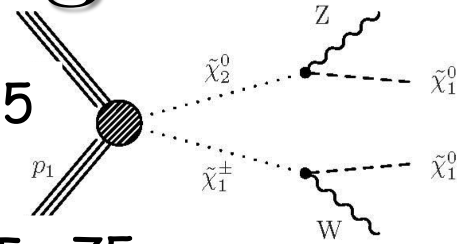


Figure 4: M_{T} versus $M_{\ell\ell}$ for three-lepton events with an ee or $\mu\mu$ OSSF dilepton pair, where the third lepton is either an electron or a muon.

Trilepton Signal Regions (SRs)

ATLAS-CONF-2013-035
e/μ



CMS-SUS-12-022
$e/\mu/\tau_h$

MET > 50 | MET > 75 | MET > 50

Table 4: Expected numbers of events from SM backgrounds and observed numbers of events in data in the signal regions, for 20.7 fb^{-1}. Both statistical and systematic uncertainties are included. The discovery p_0-value of the background only hypothesis is shown. The number of signal events N_{signal} and visible cross-section σ_{visible} that can be excluded with 95% CL are also shown.

Selection	SRnoZa	SRnoZb	SRnoZc	SRZa	SRZb	SRZc
Tri-boson	1.7 ± 1.7	0.6 ± 0.6	0.8 ± 0.8	0.5 ± 0.5	0.4 ± 0.4	0.29 ± 0.29
ZZ	14 ± 8	1.8 ± 1.0	0.25 ± 0.17	8.9 ± 1.8	1.0 ± 0.4	0.39 ± 0.28
$t\bar{t}V$	0.23 ± 0.23	0.21 ± 0.19	$0.21^{+0.30}_{-0.21}$	0.4 ± 0.4	0.22 ± 0.21	0.10 ± 0.10
WZ	50 ± 9	20 ± 4	2.1 ± 1.6	235 ± 35	19 ± 5	5.0 ± 1.4
Σ SM irreducible	65 ± 12	22 ± 4	3.4 ± 1.8	245 ± 35	20 ± 5	5.8 ± 1.4
SM reducible	31 ± 14	7 ± 5	1.0 ± 0.4	4^{+5}_{-4}	1.7 ± 0.7	0.5 ± 0.4
Σ SM	$\mathbf{96\pm19}$	$\mathbf{29\pm6}$	$\mathbf{4.4\pm1.8}$	$\mathbf{249\pm35}$	$\mathbf{22\pm5}$	$\mathbf{6.3\pm1.5}$
Data	**101**	**32**	**5**	**273**	**23**	**6**
p_0-value	0.41	0.37	0.40	0.23	0.44	0.5
N_{signal} excluded (exp)	39.3	16.3	6.2	67.9	13.2	6.7
N_{signal} excluded (obs)	41.8	18.0	6.8	83.7	13.9	6.5
σ_{visible} excluded (exp) [fb]	1.90	0.79	0.30	3.28	0.64	0.32
σ_{visible} excluded (obs) [fb]	2.02	0.87	0.33	4.04	0.67	0.31

3 bins | 3 bins

Table 1: SM expectations and observations for events with an ee or $\mu\mu$ OSSF pair, where the third lepton is either an electron or muon.

M_T (GeV)	E_T^{miss} (GeV)	$M_{\ell\ell}<75$ GeV		75 GeV $<M_{\ell\ell}<$ 105 GeV		$M_{\ell\ell}>105$ GeV	
		total bkg	observed	total bkg	observed	total bkg	observed
>160	50 – 100	2.1 ± 0.5	4	3.3 ± 0.5	3	1.2 ± 0.7	0
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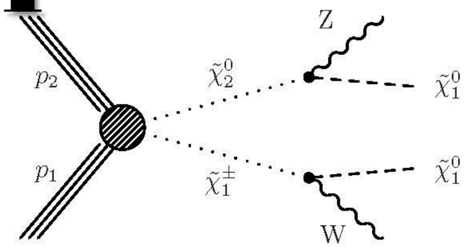
120 – 160	50 – 100	3.5 ± 0.5	3	10.0 ± 0.6	11	1.30 ± 0.19	0
	100 – 150	1.1 ± 0.3	0	1.5 ± 0.2	0	0.17 ± 0.05	2
	150 – 200	0.15 ± 0.16	0	0.4 ± 0.4	1	0.12 ± 0.10	0
	>200	0.11 ± 0.05	0	0.17 ± 0.10	1	0.08 ± 0.09	0
0 – 120	50 – 100	53 ± 5	63	382 ± 15	377	19.0 ± 1.7	22
	100 – 150	6.6 ± 1.0	5	63 ± 3	61	4.0 ± 0.6	6
	150 – 200	1.4 ± 0.3	1	16.0 ± 0.9	13	0.9 ± 0.3	2
	>200	0.54 ± 0.17	1	9.5 ± 0.6	3	0.43 ± 0.08	2

12 bins | 12 bins | 12 bins

Trilepton WZ SRs



Total Uncertainties for BG Estimates

ATLAS-CONF-2013-035

e/μ

m_T	MET		Total
<110	75 - 120	SRZa	13%
>110	75 – 120	SRZb	23%
>110	>120	SRZc	24%

CMS-SUS-12-022

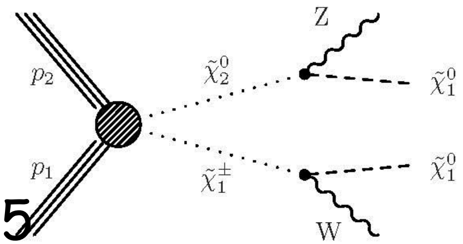
$e/\mu/\tau_h$

I mimicked "ATLAS"-like SRs.

m_T	MET	"ATLAS"	Total
<120	50 – 150	SRZa	3.9% ~ 4.8%
	>150	n/a	5.6% ~ 6.3%
>120	50 – 150	SRZb	15%, 11%, 6.0%, 13%
>120	>150	SRZc	25%, 33%, 100%, 59%

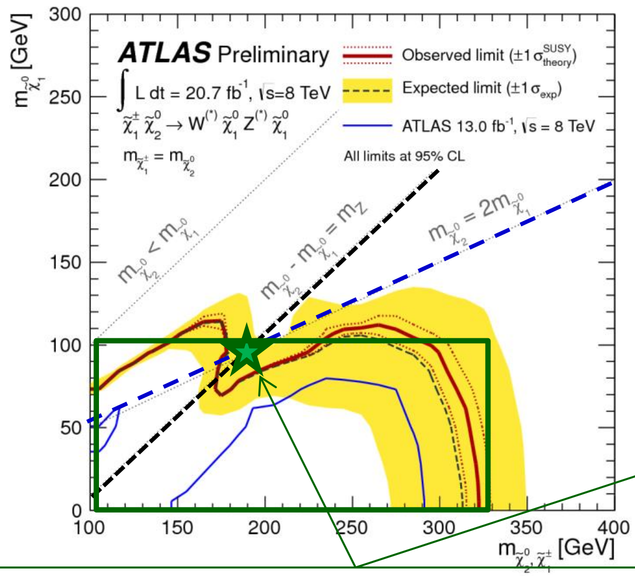
Although a dedicate cross-check by both collaborations is required, my private investigation finds that uncertainties in ATLAS and CMS analyses are similar.

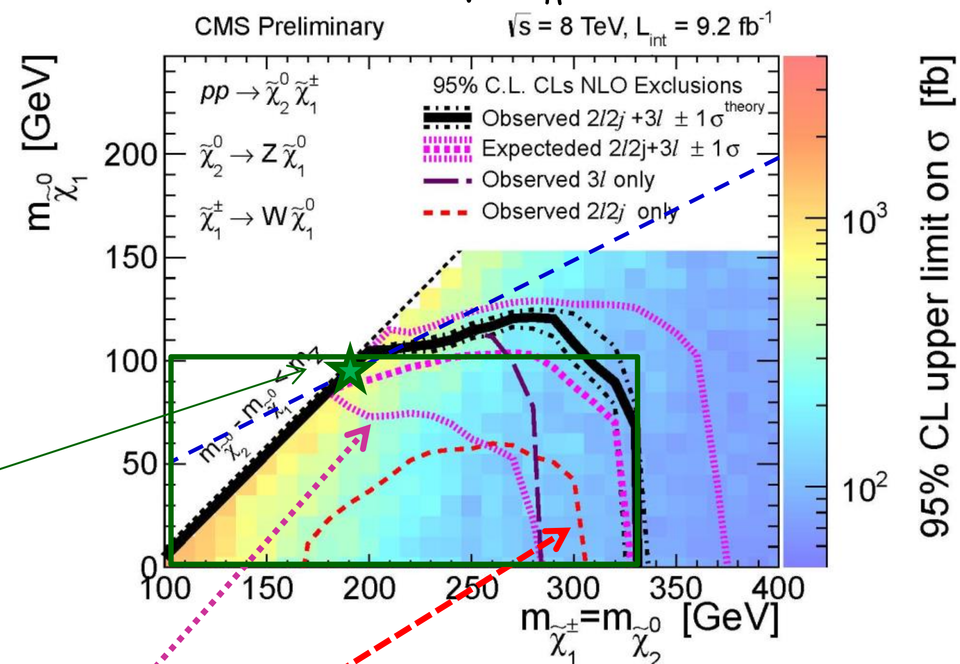
C1+N2 via W and Z



ATLAS-CONF-2013-035
e/μ

CMS-SUS-12-022
$e/\mu/\tau_h$





(90, 190) point

[Note] the "star" point is within +/-1σ uncertainty band. Also a few remarks:

- MET > 75 (ATLAS) vs MET > 50 (CMS)
- CMS has more SR grids.
- ATLAS "3L" doesn't include τ_h

3l & 2l2j … complement each other

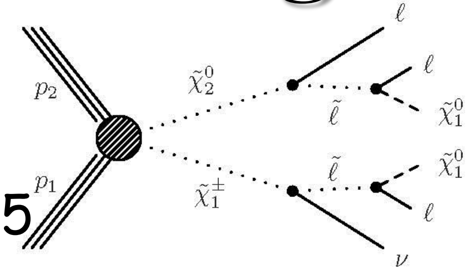
Wino-C1 and Bino-N1 up to 330 and 100 GeV

A Few Remarks

1. [Cross section] CMS values are 10% higher than the ATLAS values, as ATLAS is calculating the values with PROSPINO assuming a small Higgsino component in the C1 and N2 sector, while CMS assumes pure wino.
2. [SR bins] CMS uses more SR bins (in MET, m_{ll} and m_T) with respect to the ATLAS analysis.
3. [Tau] CMS "3L" analysis includes $N(\tau_h) \leq 1$, while ATLAS uses only e's and μ's. Although we expect a small gain in acceptance, employing τ_h still adds up something.
4. It is possible that #1, #2, and #3 could helps CMS has a competitive sensitivity with 9 fb^{-1}.
5. [Systematics] The region we are discussing is systematic-dominated. It would be good to the uncertainties used by the ATLAS and CMS analyses in detail. Looking at the tables, it seems that uncertainties fluctuate a lot depending on the SR, and I cannot track down before this conference.

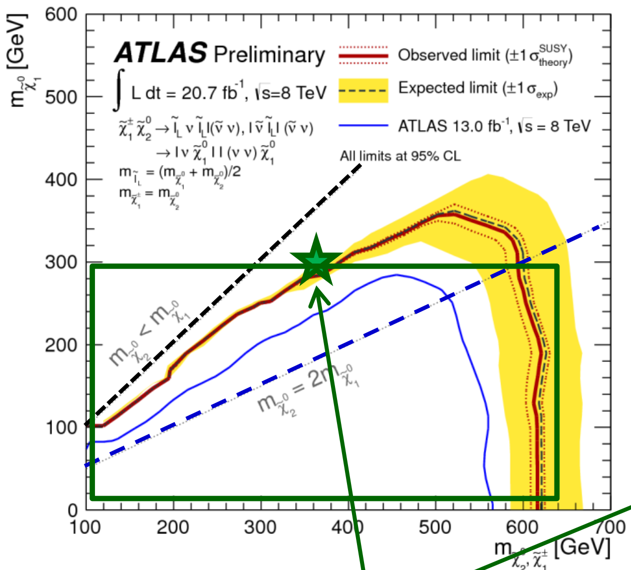
Bottom line: A 10-GeV difference (based on the expected) is inside the +/−1 sigma uncertainty band. Thus the results are in agreement within uncertainty. CMS results with 20 fb^{-1} will be released soon.

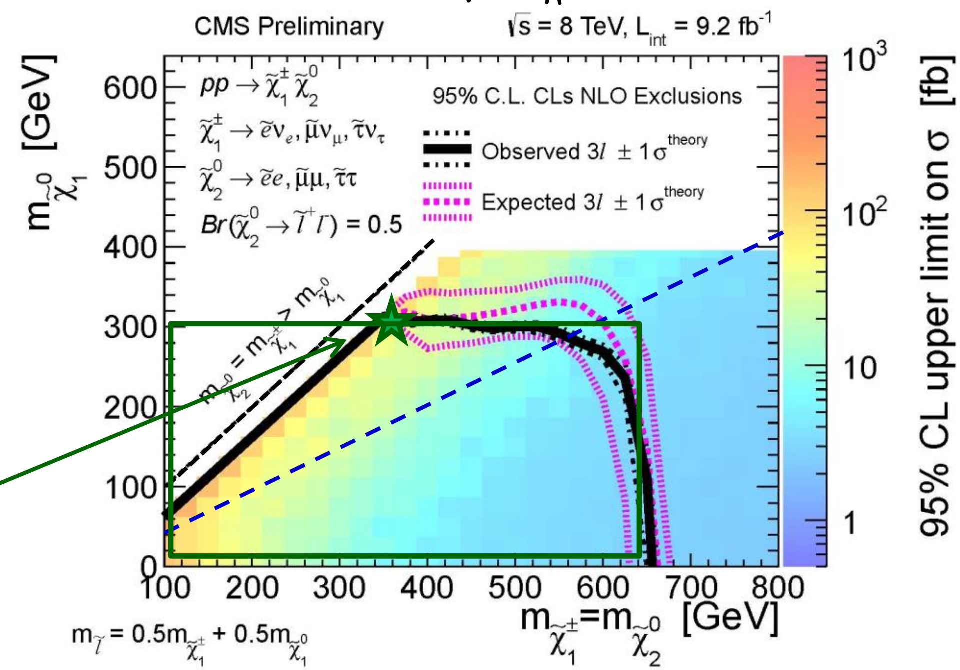
C1+N2 via Light Slepton



ATLAS-CONF-2013-035
e/μ

CMS-SUS-12-022
e/μ/τ_h



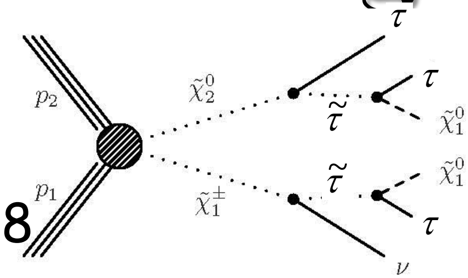


(300, 350) point
MET > 75 (ATLAS) vs MET > 50 (CMS)

Wino-C1 and Bino-N1 up to 640 and 300 GeV

C1+N2 via Light Stau

ATLAS-CONF-2013-028



CMS-SUS-12-022

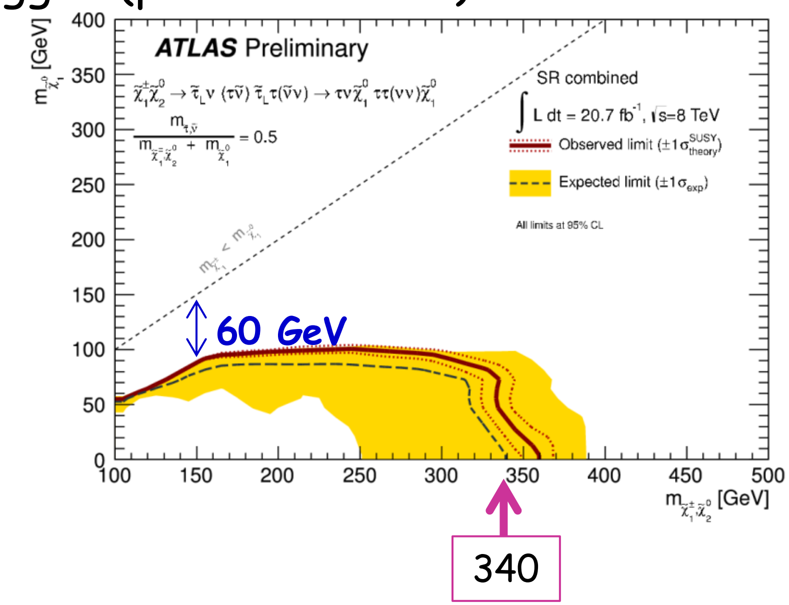
At least one OS τ_h τ_h with m_{T2}.

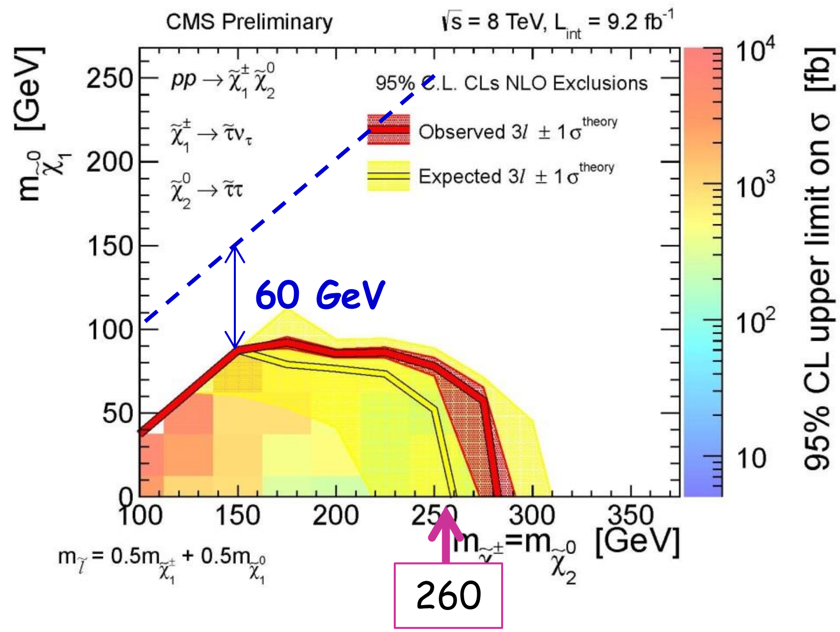
<u>3 leptons</u>

OS eμ + τ_h, LS eμ + τ_h, LS ee + τ_h, LS $\mu\mu$ + τ_h

Ditau trigger (plateau at 40, 25) or MET trigger (plateau at 150)

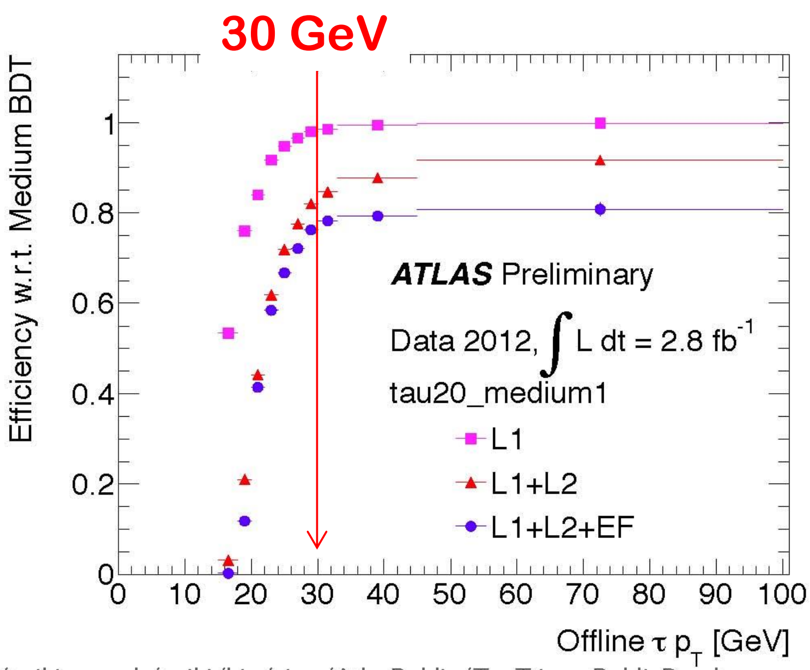
Dilepton trigger (plateau at 20, 10)



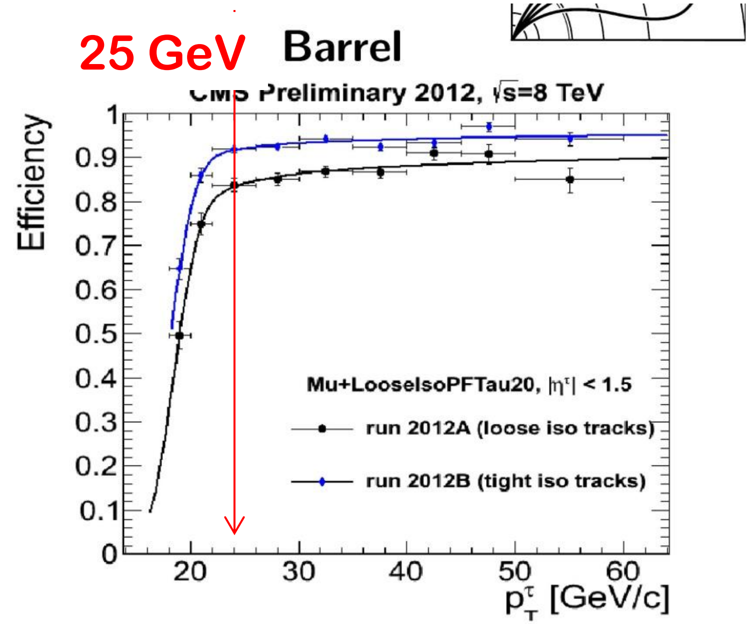


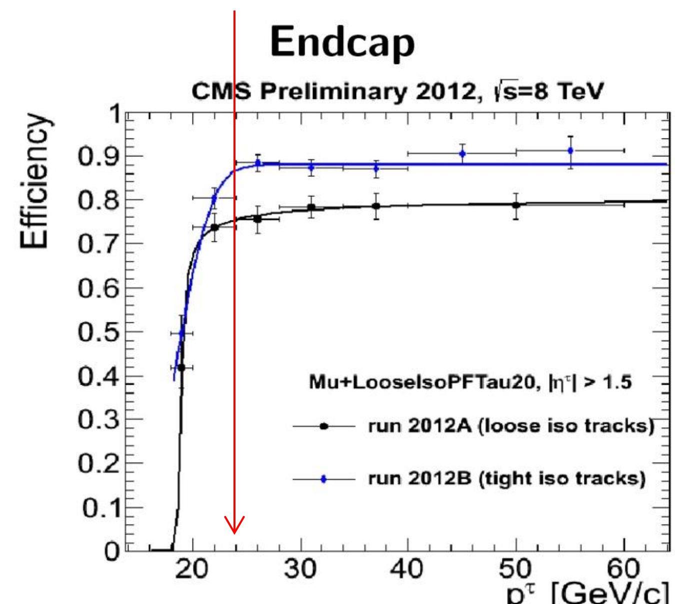
Wino-C1 and Bino-N1 up to 350 and 100 GeV

[Ref] Tau Trigger

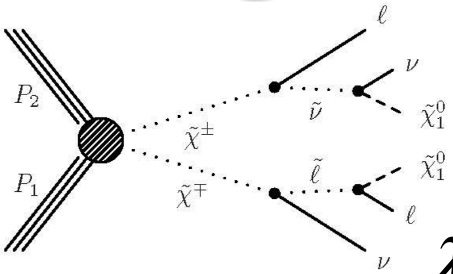


//twiki.cern.ch/twiki/bin/view/AtlasPublic/TauTriggerPublicResults





C1+C1 via Light Sleptons

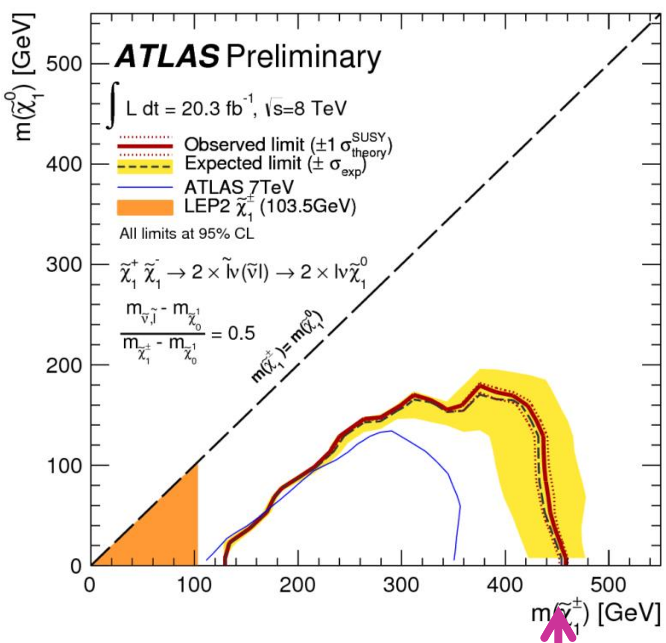


$\chi_1^{\pm} \rightarrow \tilde{\ell}\,\nu(\ell\,\tilde{\nu})$

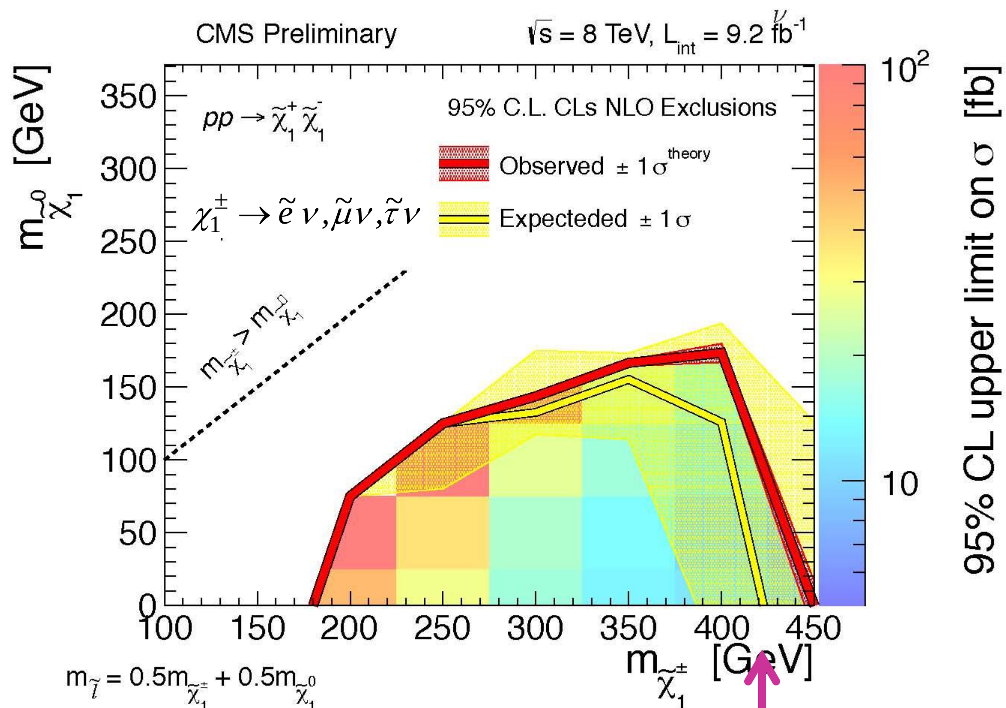
e/μ

$\chi_1^{\pm} \rightarrow \tilde{e}\,\nu, \tilde{\mu}\nu, \tilde{\tau}\,\nu$

e/μ/τ_h

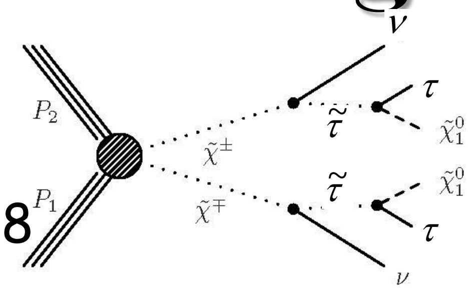


450



420

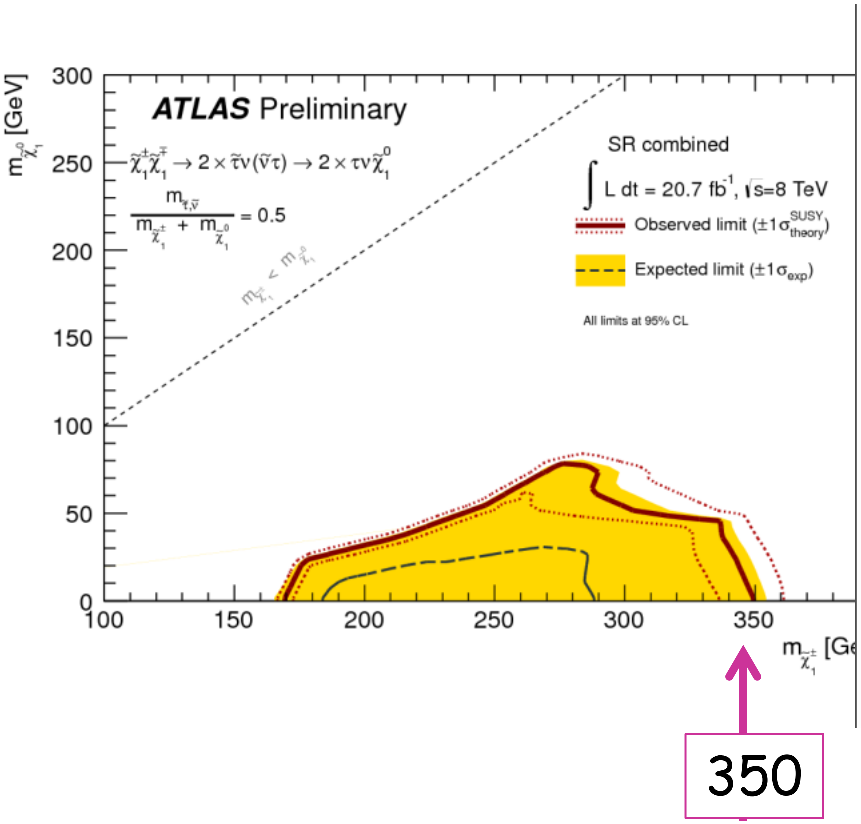
C1+C1 via Light Stau



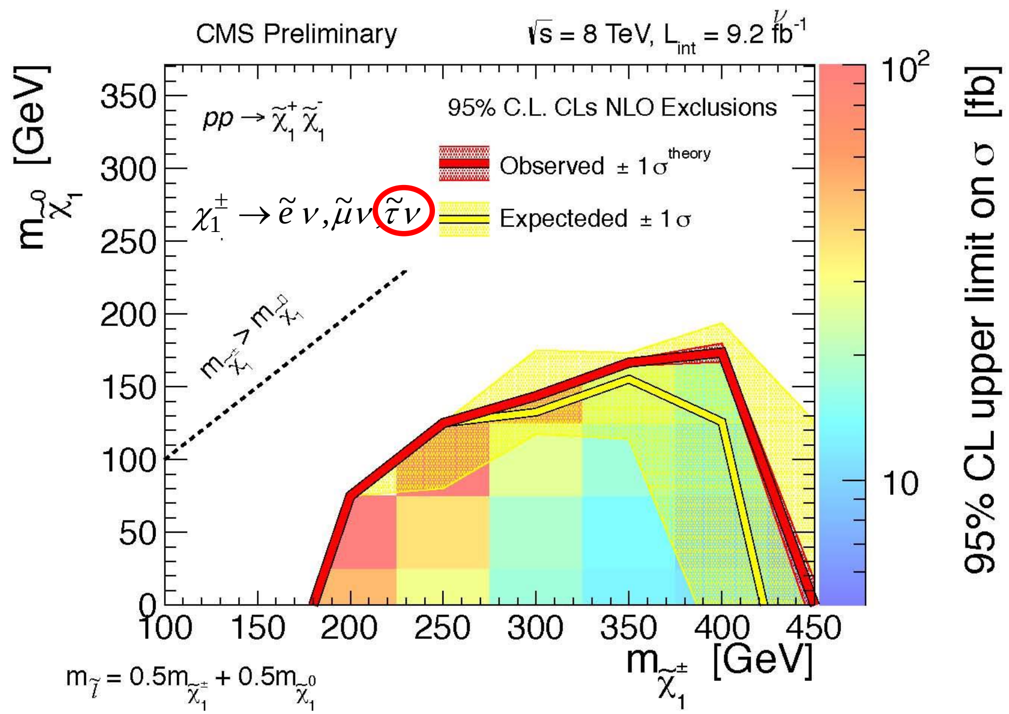
ATLAS-CONF-2013-028

CMS-SUS-12-022

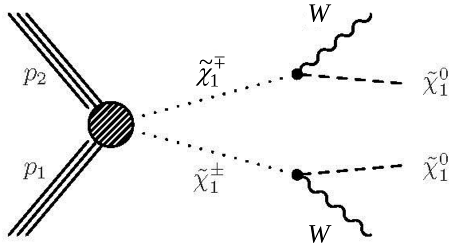
OS ττ



e/μ/τ_h

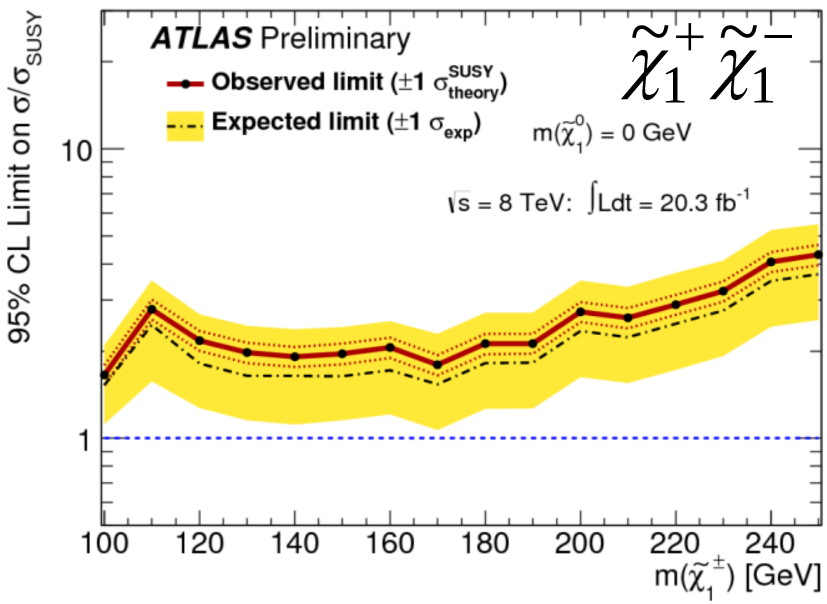


C1+C1 via WW   Summary Plot



ATLAS-CONF-2013-049

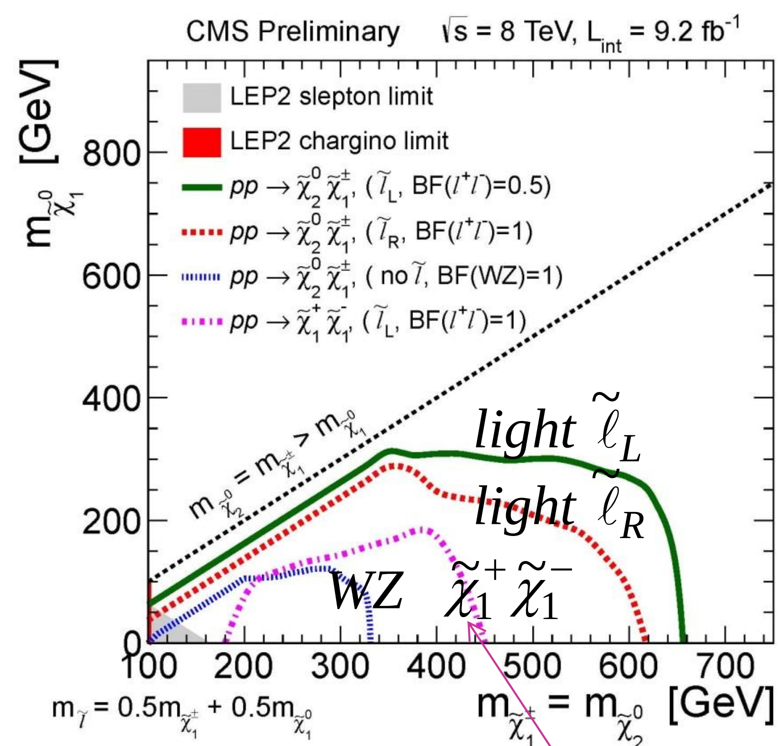
OS ee/eμ/μμ via WW



$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0, \tilde{\chi}_1^{+}\tilde{\chi}_1^{-}$

CMS-SUS-12-022

OS ee/eμ/μμ



via light slepton (p.19)

EWKino Summary

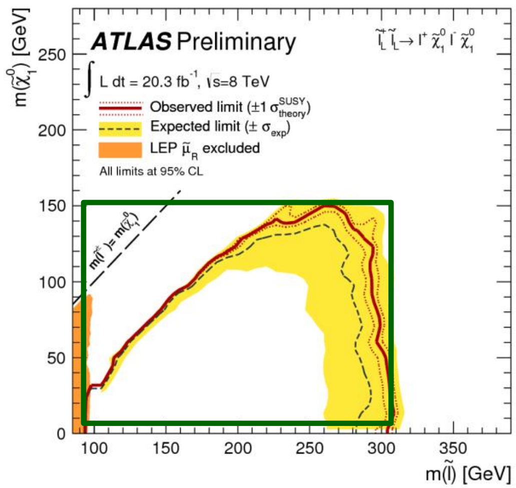
- ALTAS and CMS are producing very similar physics results.
- Wino-Chargino and Bino-LSP
  - ✓ Up to 640 and 300 GeV for light slepton case
  - ✓ Up to 340 and 100 GeV for W and Z cases
- Weaker limits for
  - ✓ heavy slepton
  - ✓ being Higgsinos
  - ✓ small mass difference (compressed spectra)

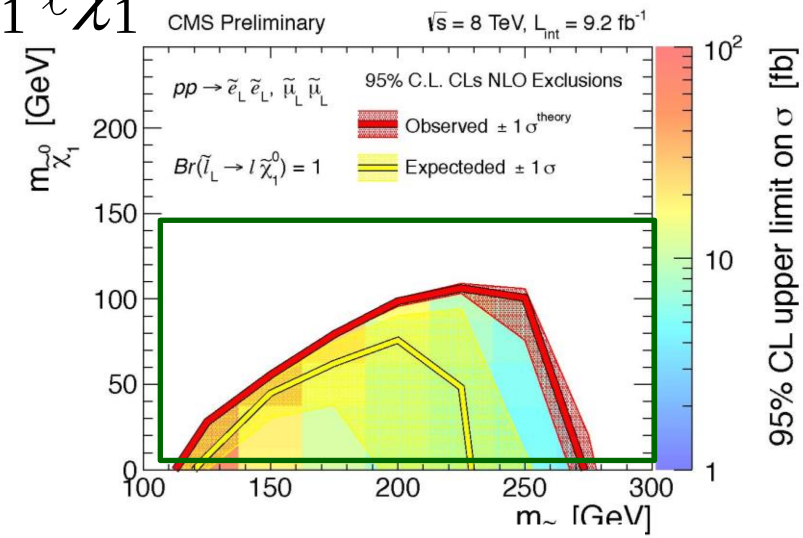
Sleptons

ATLAS-CONF-2013-049
OS ee, μμ
m_{T2}

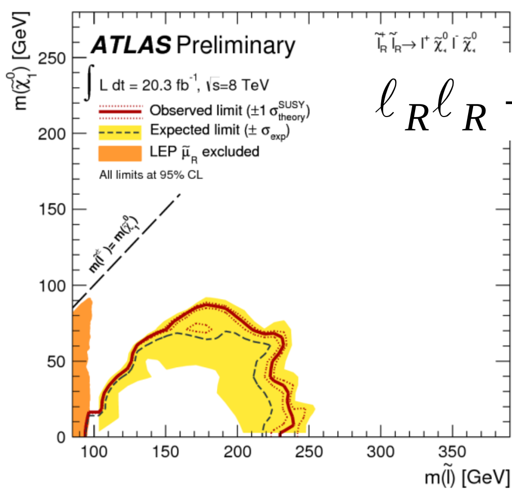
CMS-SUS-12-022
2 leptons

$$\tilde{\ell}_L\tilde{\ell}_L \rightarrow \ell\tilde{\chi}_1^0\ell\tilde{\chi}_1^0$$

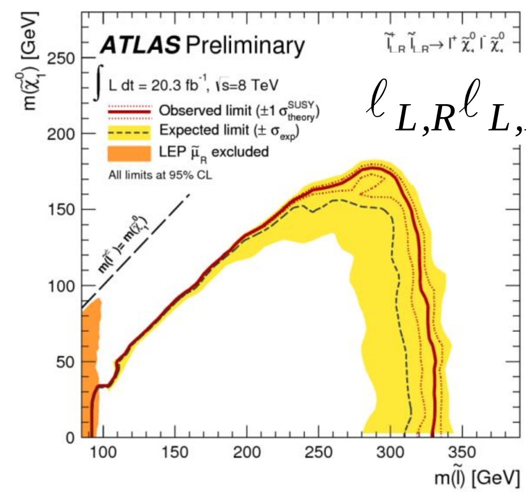




$$\tilde{\ell}_R\tilde{\ell}_R \rightarrow \ell\tilde{\chi}_1^0\ell\tilde{\chi}_1^0$$



$$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R} \rightarrow \ell\tilde{\chi}_1^0\ell\tilde{\chi}_1^0$$

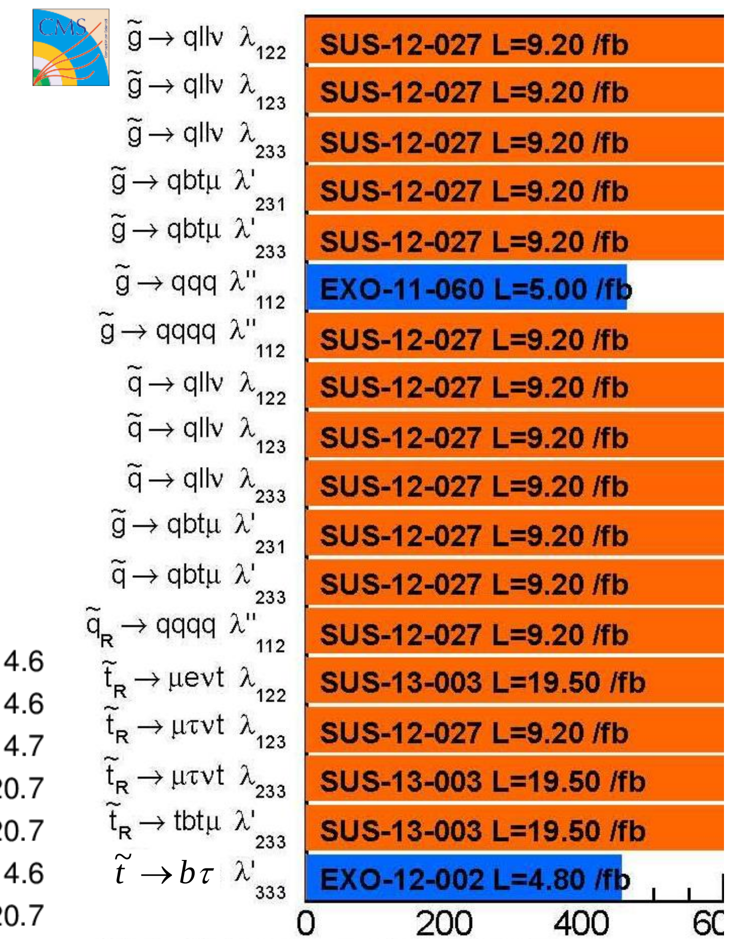


RPV

$$W_{RPV} = \lambda_{ijk} L_i L_j \overline{E}_k + \lambda'_{ijk} L_i Q_j \overline{D}_k + k_i L_i H_u + \lambda''_{ijk} \overline{U}_i \overline{D}_j \overline{D}_k$$

Lepton Number Violation — Baryon Number Violation

- RPV → no DM candidate. But the nature might have non-SUSY DM.
- Multi-leptons or multi-jets with no intrinsic MET:
  - ✓ Resonant PRV production and RPV decay
  - ✓ RPC production and RPV N1 decay
- Selected topics here and assuming one dominant coupling

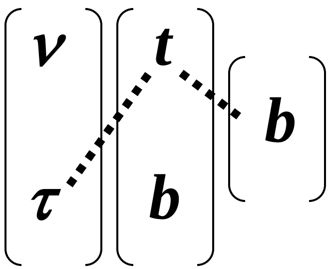


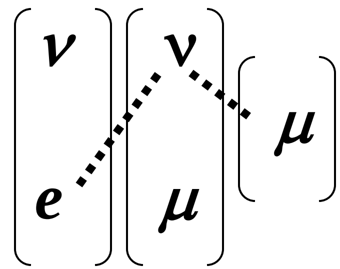
LFV $pp \to \tilde{\nu}_\tau + X, \tilde{\nu}_\tau \to e+\mu$	2 e, μ	0	-	4.6
LFV $pp \to \tilde{\nu}_\tau + X, \tilde{\nu}_\tau \to e(\mu)+\tau$	1 e,μ + τ	0	-	4.6
Bilinear RPV CMSSM	1 e, μ	7 jets	Yes	4.7
$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+ \to W\tilde{\chi}_1^0, \tilde{\chi}_1^0 \to ee\nu_\mu, e\mu\nu_e$	4 e, μ	0	Yes	20.7
$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+ \to W\tilde{\chi}_1^0, \tilde{\chi}_1^0 \to \tau\tau\nu_e, e\tau\nu_\tau$	3 e, μ + τ	0	Yes	20.7
$\tilde{g} \to qqq$	0	6 jets	-	4.6
$\tilde{g} \to \tilde{t}_1 t, \tilde{t}_1 \to bs$	2 e, μ (SS)	0-3 b	Yes	20.7

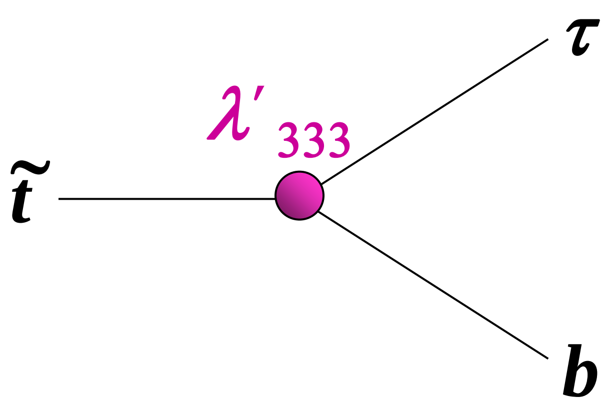
RPV Decays

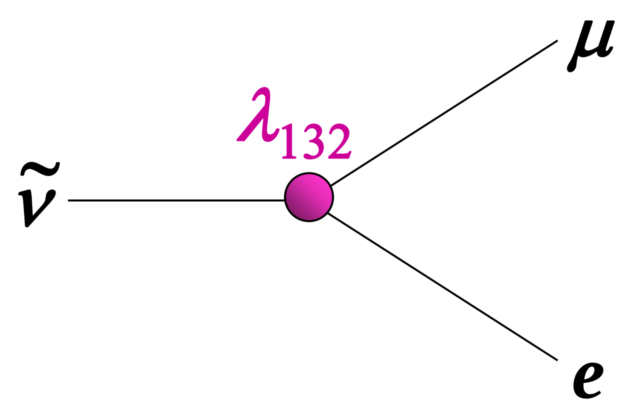
e.g., $\lambda'_{333} L_3 Q_3 D_3$

e.g., $\lambda_{132} L_1 L_3 E_2$







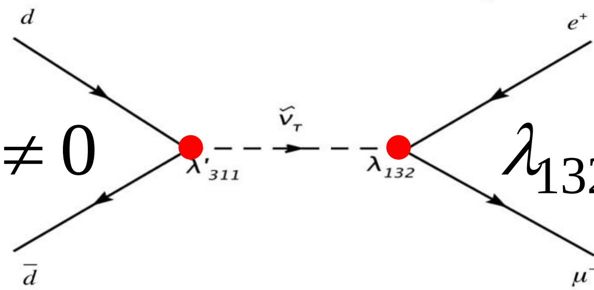


Resonant Snutrino

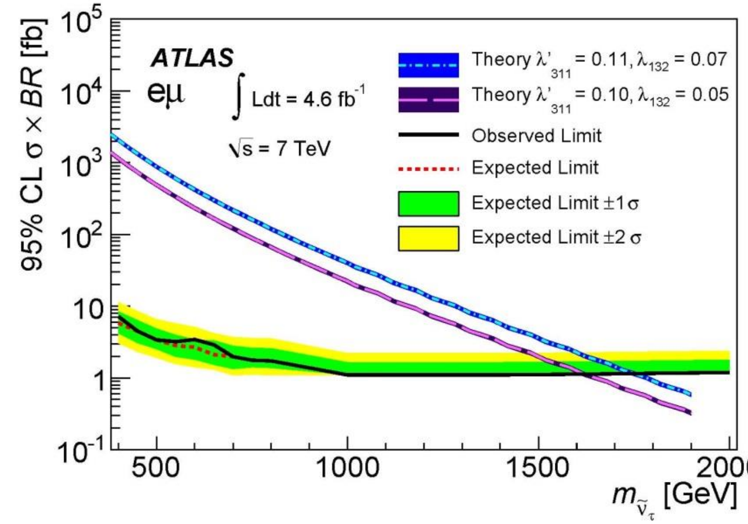
(PLB) http://arxiv.org/abs/1212.1272, CERN-PH-EP-2012-326

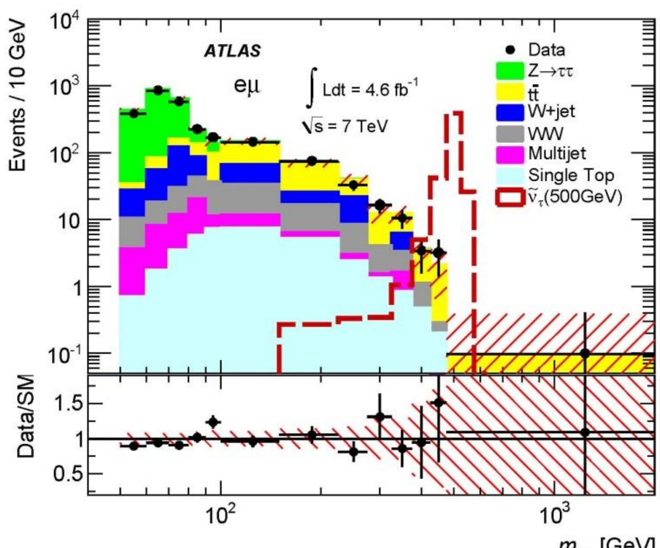
$$L_{(LVF)} = \frac{1}{2}\lambda_{ijk} L_i L_j e_k + \lambda'_{ijk} L_i Q_j d_k$$

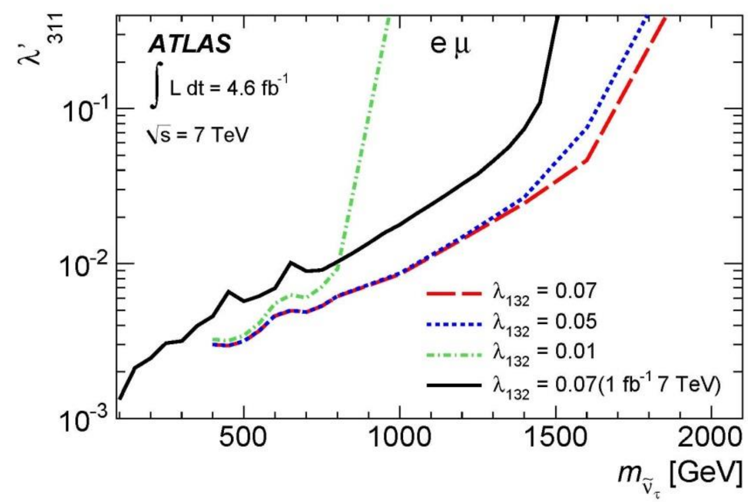
$\lambda'_{311} \neq 0$ $\lambda_{132} \neq 0$



- Single-lepton trigger
- $p_T(e, \mu) > 25$, OS e μ, $\Delta\phi > 2.7$
- Scan in M(e μ)



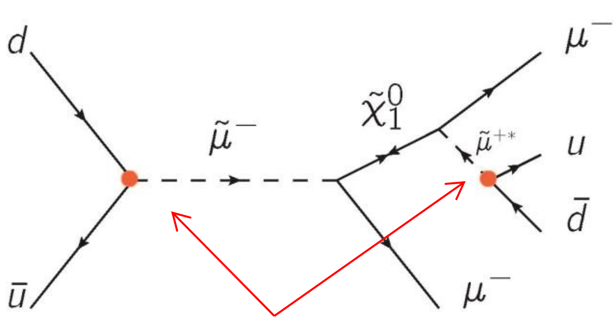




Also: Single-lepton trigger → $\mu\tau$. $e\tau$

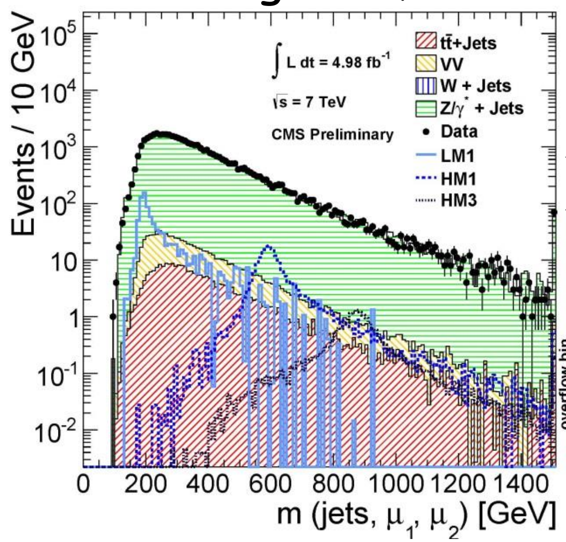
Resonant Smuon

CMS-SUS-13-005

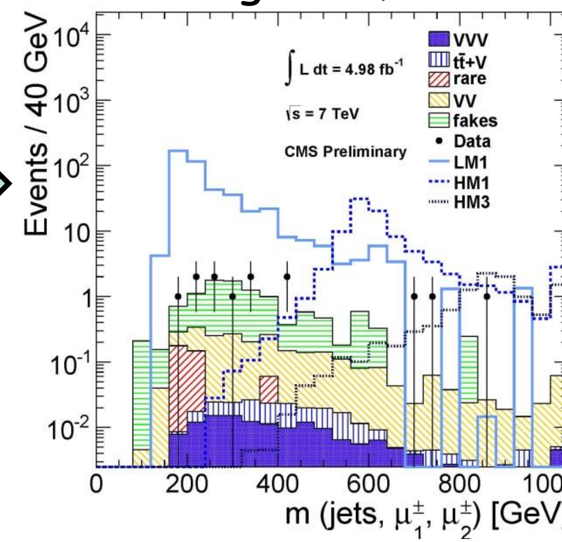


$$\lambda'_{211} \neq 0$$

No B-tag veto, no LS

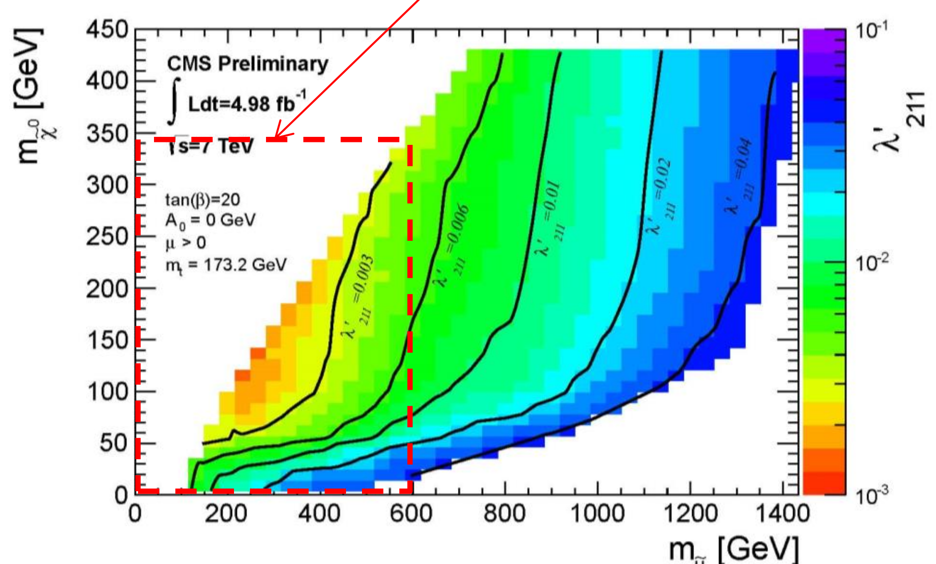


B-tag veto, LS

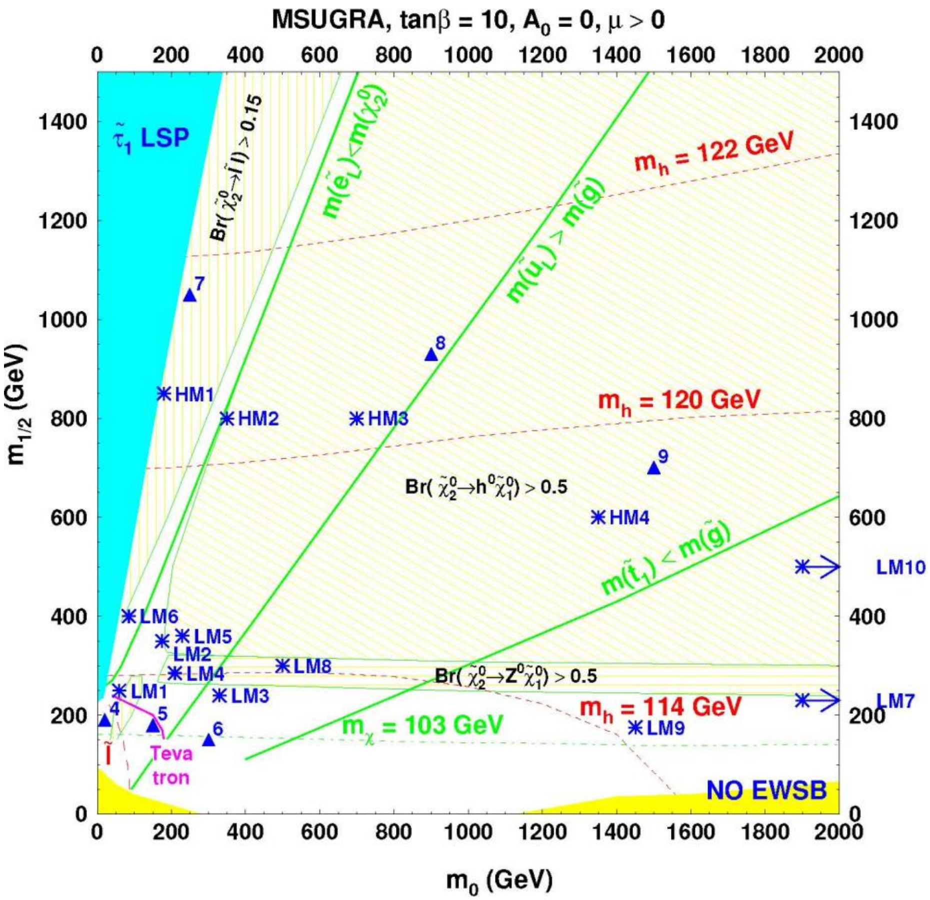


- Like-sign μμ with 20/15 GeV, 2+ jets with 30 GeV
- Z veto, B-tag veto, MET < 50 GeV
- Fake muons from heavy flavor is a primary background.
- M(μμ j) and M(μ j)
- Data is consistent with the SM expectation.
- Interpretation of resonant smuon

D0, PRL 97(2006)111801



[Ref] CMS SUSY Mass Points



LM1: m(smuon) = 185 GeV, m(N1) = 97 GeV

- Same as post-WMAP benchmark point B' and near DAQ TDR point 4.
- M(gluino) > M(squark), hence gluino -> squark+quark is dominant
- B(X^0_2 -> slep_R lept) = 11.2%, B(X^0_2 -> stau_1 tau) = 46%, B(X^+_1 -> sneut_L lept) = 36%
- ISASUGRA7.69 output

HM1: m(smuon) = 593 GeV, m(N1) = 356 GeV

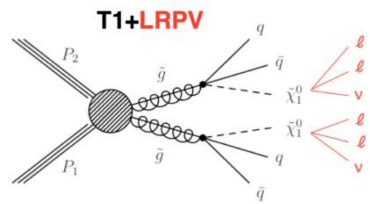
- M(gluino) > M(squark), hence gluino -> squark+quark is dominant
- B(gluino -> $stop_1$+t) = 25%, B($squark_L$ -> q+X^0_2) = 32%,
  but B($stop_1$ -> t+X^0_2) = 6%, B($stop_1$ -> t+X^0_3) = 18%, B($stop_1$ -> t+X^0_4) = 9%.
- B(X^0_2 -> $slep_L$ lept) = 27%, B(X^0_2 -> $stau_1$ tau) = 14%, B(X^+_1 -> snu_L lept) = 37%
- Tree level total cross-section is 54 fb.
- ISASUGRA7.69 output

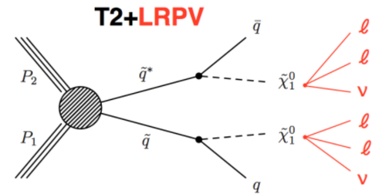
HM3: m(smuon) = 876 GeV, m(N1) = 339 GeV, m(N2) = 638

- M(gluino) > M(squark), hence gluino -> squark+quark is dominant
- B(gluino -> $stop_1$+t) = 52%, B($squark_L$ -> q+X^0_2) = 32%,
  but B($stop_1$ -> t+X^0_2) = 5%, B($stop_1$ -> t+X^0_3) = 20%, B($stop_1$ -> t+X^0_4) = 11%.
- B(X^0_2 -> h^0 X^0_1) = 94%, B(X^+_1 -> W^+ X^0_1) = 100%
- Tree level total cross-section is 48 fb.
- ISASUGRA7.69 output

RPV in 4 Leptons (e/mu)

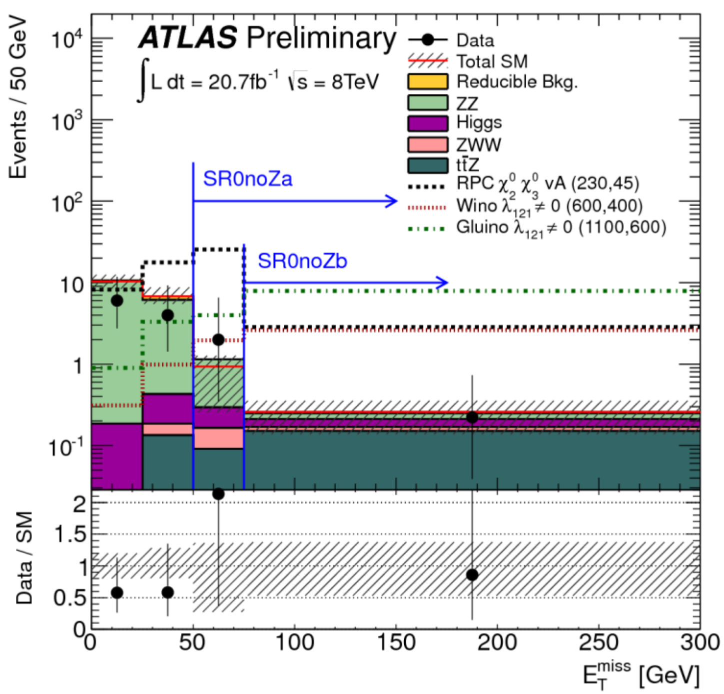
$$\lambda_{121} \neq 0$$





ATLAS-CONF-2013-036

SR	$N(\ell = e,\mu)$	$N(\tau)$	Z Candidate	E_T^{miss}[GeV]		m_{eff}[GeV]	Scenario
SR0noZa	≥4	≥0	extended veto	>50			RPC
SR0noZb	≥4	≥0	extended veto	>75	or	>600	RPV
SR1noZ	=3	≥1	extended veto	>100	or	>400	RPV
SR0Z	≥4	≥0	request	>75			GGM
SR1Z	=3	≥1	request	>100			GGM

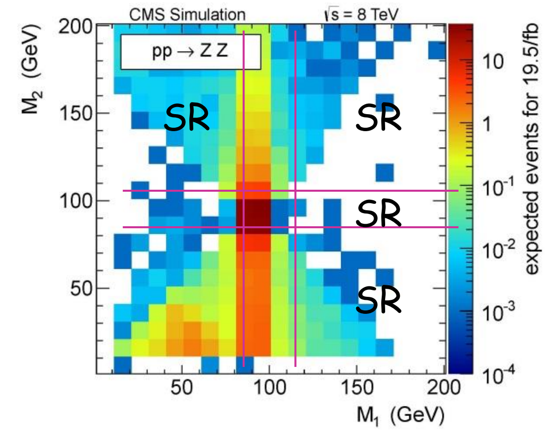


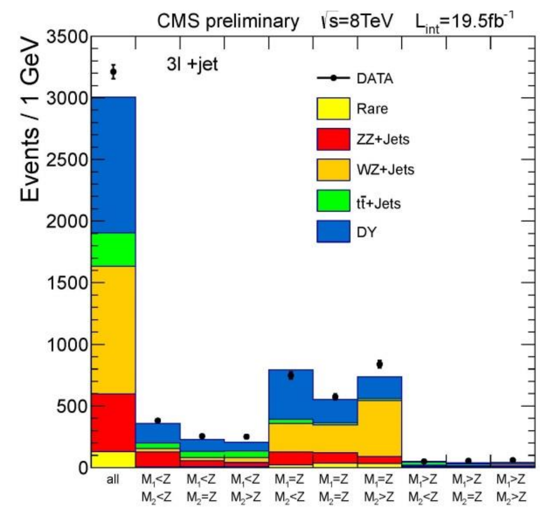
CMS-SUS-13-010

$N(\ell) = 4$

$N(\tau_h) = 0$

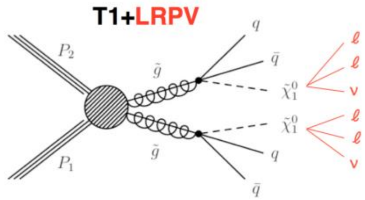
$N(\mathrm{OSSF}\ \ell\ell) \geq 1$

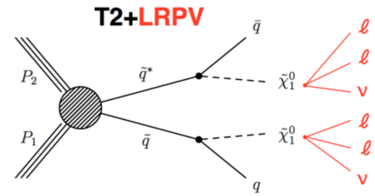




RPV in 4 Leptons (e/mu)

$\lambda_{121} \neq 0$

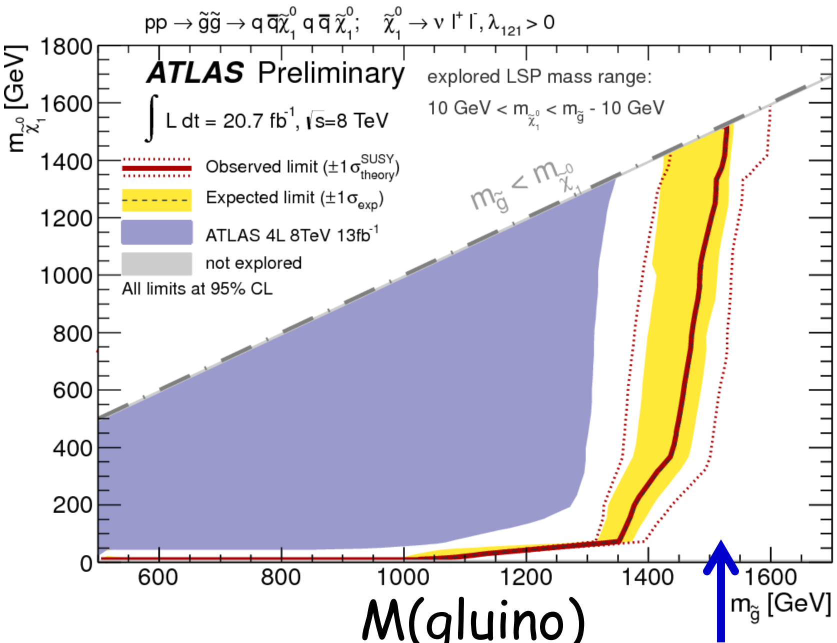


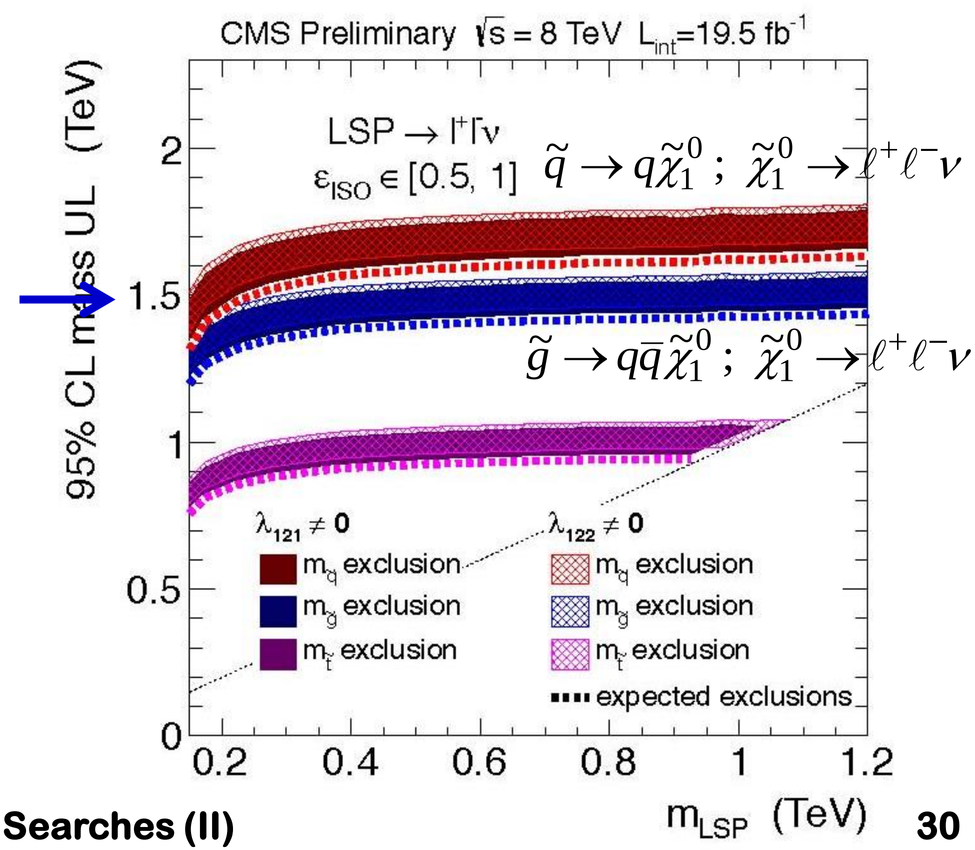


ATLAS-CONF-2013-036

CMS-SUS-13-010

$$\tilde{g} \to q\bar{q}\tilde{\chi}_1^0\ ;\ \tilde{\chi}_1^0 \to \ell^+\ell^-\nu$$





RPV in 4 Leptons (e/mu/tau)

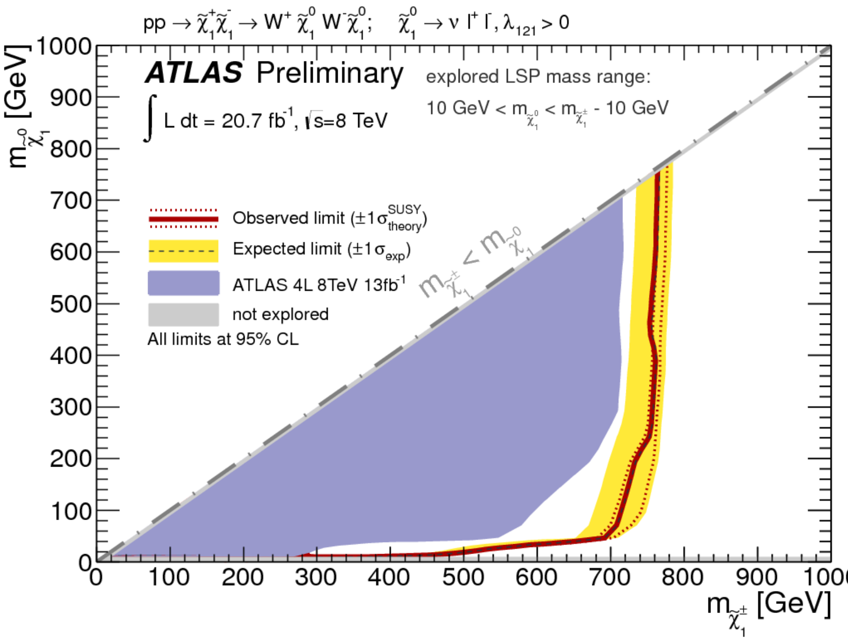
≥ 4 leptons

$$pp \to \tilde{\chi}_1^+ \tilde{\chi}_1^- \to W^+ \tilde{\chi}_1^0 W^- \tilde{\chi}_1^0;\ \tilde{\chi}_1^0 \to \ell^+ \ell^- \nu$$

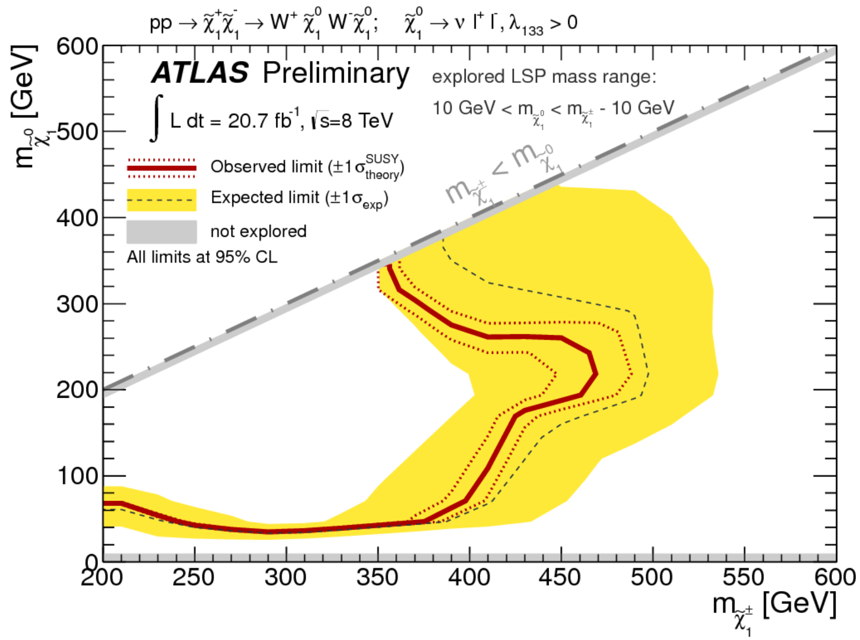
ATLAS-CONF-2013-036

SR	$N(\ell = e, \mu)$	$N(\tau)$	Z Candidate	E_T^{miss}[GeV]		m_{eff}[GeV]	Scenario
SR0noZa	≥4	≥0	extended veto	>50			RPC
SR0noZb	≥4	≥0	extended veto	>75	or	>600	RPV
SR1noZ	=3	≥1	extended veto	>100	or	>400	RPV
SR0Z	≥4	≥0	request	>75			GGM
SR1Z	=3	≥1	request	>100			GGM

$\lambda_{121} \neq 0$



$\lambda_{133} \neq 0$



Very Rich RPV MSSM Program

1209.0764
J.A. Evans
Y. Kats

final state	collaboration	$\mathcal{L}$ (fb^{-1})	ref.
pairs of dijets	ATLAS	0.034, 4.6	[41, 42]
	CMS	2.2	[43]
leptoquark pairs	CMS	5.0	[44]
	CMS	4.8	[45]
$t\bar{t}$	ATLAS	0.70	[46]
	CMS	2.0-2.3	[47, 48]
$t\bar{t}$ + jet	CMS	5.0	[49]
$t\bar{t} + m_T$	ATLAS	1.04	[50]
leptonic m_{T2}	ATLAS	4.7	[51]
ℓ + jets + MET	CMS	4.7	[52]
	ATLAS	4.7	[53, 54]
OS $\ell\ell$ + MET	CMS	4.98	[55]
	ATLAS	1.04, 4.7	[56, 57]
SS $\ell\ell$ + MET	ATLAS	1.04, 2.05	[56, 58]
SS $\ell\ell$	ATLAS	1.6, 4.7	[59, 60]
SS $\ell\ell$ (+ MET)	CMS	4.98	[61, 62]
SS $\ell\ell + b$ (+ MET)	CMS	4.98	[63]
b' (SS $\ell\ell$ or $3\ell + b$)	CMS	4.9	[64]
b' (SS $\ell\ell$)	ATLAS	4.7	[65]
3 or 4 ℓ	ATLAS	1.02	[66, 67]
3 ℓ + MET	ATLAS	2.06, 4.7	[68, 69]
4 ℓ + MET	ATLAS	2.06	[70]
3 or 4 ℓ (+ MET)	CMS	4.98	[7]
1 or 2 τ + jets + MET	ATLAS	2.05, 4.7	[71–73]
$\tau + \ell$ + jets + MET	ATLAS	4.7	[73]
	CMS	5.0	[55]
b + jets + MET	ATLAS	2.05, 4.7	[74, 75]
	CMS	1.1, 4.98	[76, 77]
$b + \ell$ + jets + MET	ATLAS	2.05	[74]
	CMS	4.96-4.98	[78, 79]
Z + jets + MET	CMS	4.98	[80]
	ATLAS	2.05	[81]
jets + MET	ATLAS	4.7	[82, 83]
	CMS	1.1, 4.98	[84, 85]
(b)-jets with α_T	CMS	1.14, 4.98	[86, 87]

Table 5: 7 TeV LHC searches used for inferring limits.

Final state	b-jets	Scenario(s)
$(\tau^+ j)(\tau^- j)$	0	LQD332
$(jj)(jj)$	0, 2	UDD312/323
$8j$	4, 6	UDD312/323 with $\tilde{H}$ decaying via $\tilde{t}$; UDD213 with $\tilde{H}^\pm \to \tilde{H}^0$
$\ell^+\ell^- + 6j$	2, 4, 6	LQD232/233 with $\tilde{H}/\tilde{W}$ (unless decays via $\tilde{b}_L$ or $\tilde{b}_R$) LQD221/123 with $\tilde{W}$
$\tau^+\tau^- + 6j$	2, 4, 6	LQD332/333 with $\tilde{H}/\tilde{W}$ (unless decays via $\tilde{b}_L$ or $\tilde{b}_R$) LQD321/323 with $\tilde{H}$-$\tilde{\nu}_\tau/\tilde{\tau}_L$ or $\tilde{W}$ (with or without $\tilde{\chi}^\pm \to \tilde{\chi}^0$)
$\tau^\pm\tau^\pm + 6j$	2, 4	LQD321/323 with $\tilde{H}$-$\tilde{\nu}_\tau/\tilde{\tau}_L$ or $\tilde{W}$, with $\tilde{\chi}^\pm \to \tilde{\chi}^0$
$t\bar{t} + 6j$	2, 4	UDD212/213 with $\tilde{g}/\tilde{B}$; UDD213 with $\tilde{H}$
$t\bar{t} + 4j + \mathrm{MET}$	2, 4, 6	LQD321/323 with $\tilde{g}/\tilde{B}$ LQD323/233/333 with $\tilde{H}$ decaying via $\tilde{b}_R$ LQD232/233/332/333 with $\tilde{H}/\tilde{W}$ decaying via $\tilde{b}_L$ LQD232/233/332/333 with $\tilde{B}$ (unless decays via $\tilde{t}$)
(tt or $\bar{t}\bar{t}$) + $6j$	4, 6	UDD312/323 with $\tilde{H}^\pm \to \tilde{H}^0$
$t\bar{t} + 2\tau + 4j$ $t\bar{t} + \tau + 4j + \mathrm{MET}$	2, 4	LQD321/323 with $\tilde{g}/\tilde{B}$; LQD323 with $\tilde{H}$-$\tilde{b}_R$
$\tau^+\tau^- W^+W^- + 2j$ $\tau + W^+W^- + 2j + \mathrm{MET}$ $W^+W^- + 2j + \mathrm{MET}$	0	LQD323 with $\tilde{b}_R$
4 tops + $4j$	4, 6	UDD312/323 with $\tilde{B}$
$6j + \mathrm{MET}$	2, 4	LQD221/123/321/323 with $\tilde{W}$ LQD321/323 with $\tilde{W}^\pm \to \tilde{W}^0$ LQD232/332 with $\tilde{W}^\pm \to \tilde{W}^0$ (unless decays via $\tilde{t}$) LQD323 with $\tilde{H}^\pm \to \tilde{H}^0 \to \tilde{b}_R$
$\ell + 6j + \mathrm{MET}$	2, 4	LQD221/123 with $\tilde{W}$
$\tau + 6j + \mathrm{MET}$	2, 4	LQD321/323 with $\tilde{W}$ (with or without $\tilde{W}^\pm \to \tilde{W}^0$) LQD323 with $\tilde{H}^\pm \to \tilde{H}^0 \to \tilde{b}_R$
$\tau^+\tau^- + 2b + \mathrm{MET}$	2	LLE123/233 with heavy $\tilde{W}$
$W^+W^- + 4j$	0	UDD213 with $\tilde{b}_R$

Table 6: Dominant final states in scenarios for which the coverage is insufficient (for $m_{\mathrm{stop}} \lesssim 500$ GeV). See tables 1–4 for more detailed descriptions of the scenarios mentioned. The chargino is assumed to decay directly via a sfermion and its RPV coupling (rather than transition to a neutralino first), except where explicitly noted otherwise. As before, couplings related by interchanging electrons and muons, or first and second generation quarks, are listed just once. The second column indicates the possible number of b-jets in each scenario (including those coming from top decays, where relevant).

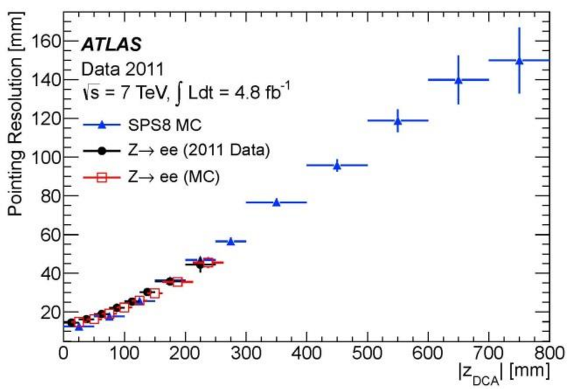
GMSB

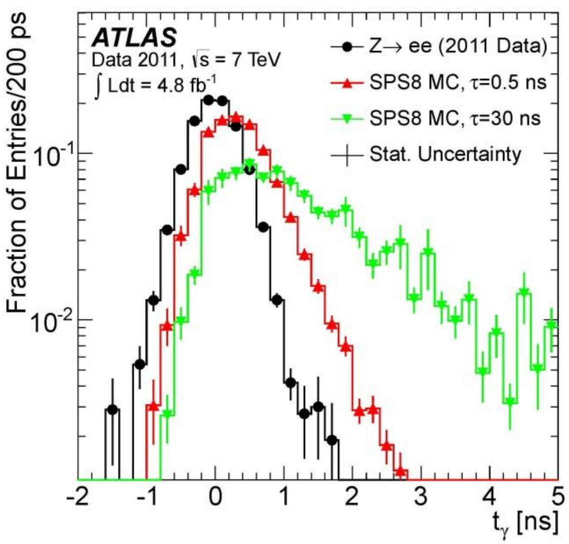
- GMSB with lightest neutralio (NLSP) → gravitino (LSP) + photon
  - ✓ Electroweak pair production of gauginos or cascade decay of gluinos
  - ✓ Two photons + MET or Photon(s) + jets + MET
  - ✓ "Non-pointing" (ATLAS) or "Delayed" (CMS) photons
  - ✓ Stable Massive Particles or SMPs" (ATLAS) or "Heavy Stable Charged Particles or HSCPs" (CMS)

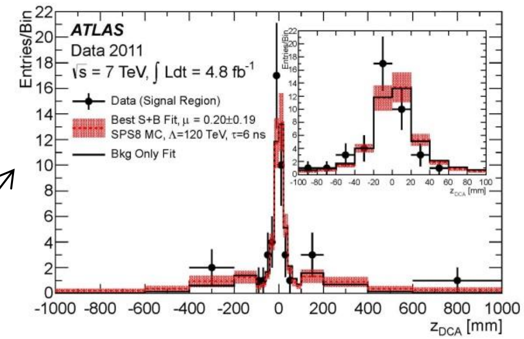
“Non-pointing” Photons

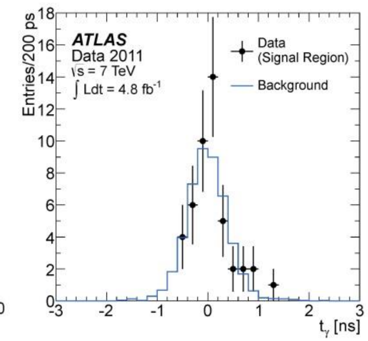
arXiv:1304.6310 (5/fb), CERN-PH-EP-2013-049 (PRD)

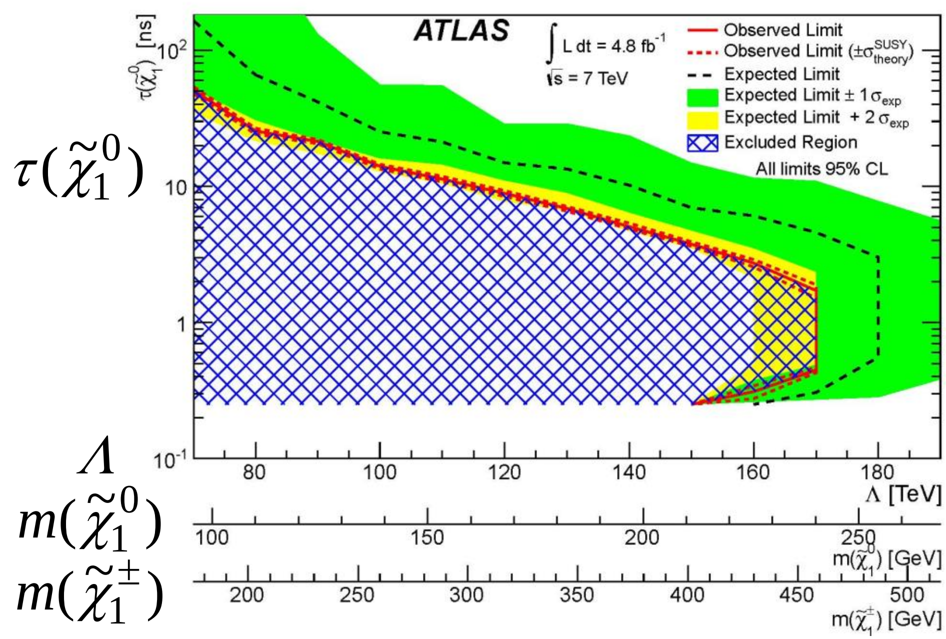
- N(γ) >= 2, $p_T(\gamma)$ > 50 → MET > 75 and photon vertex & timing







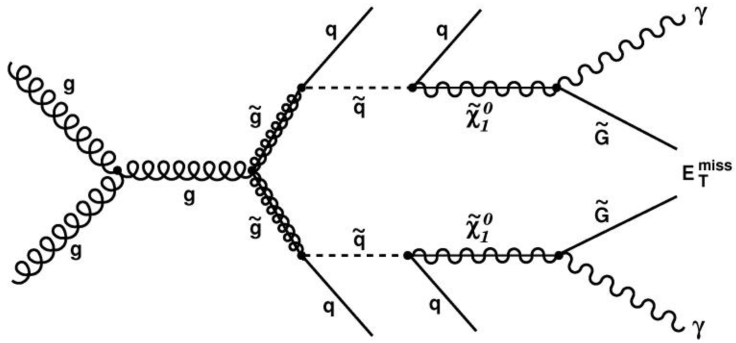


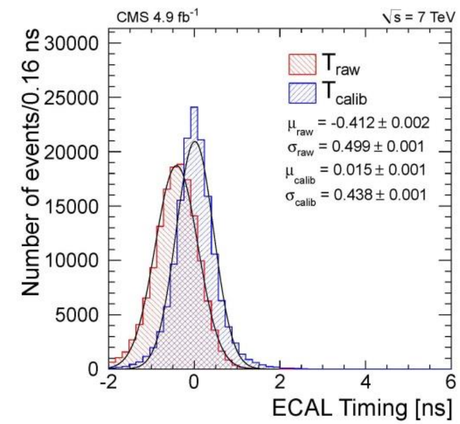


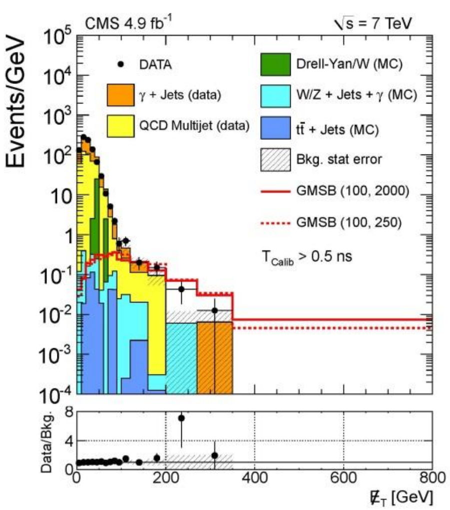
"Displayed" Photon

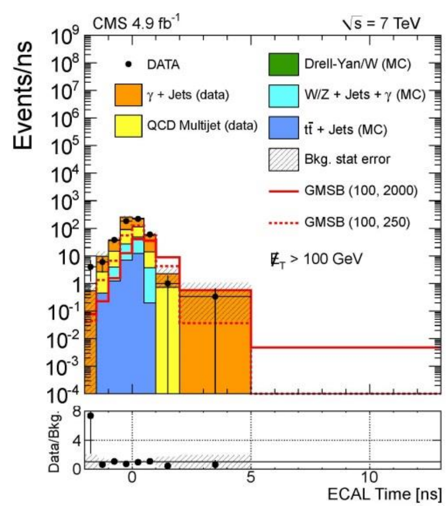
arXiv:1212.1838 (5/fb), CMS-EXO-11-035 (PLB)

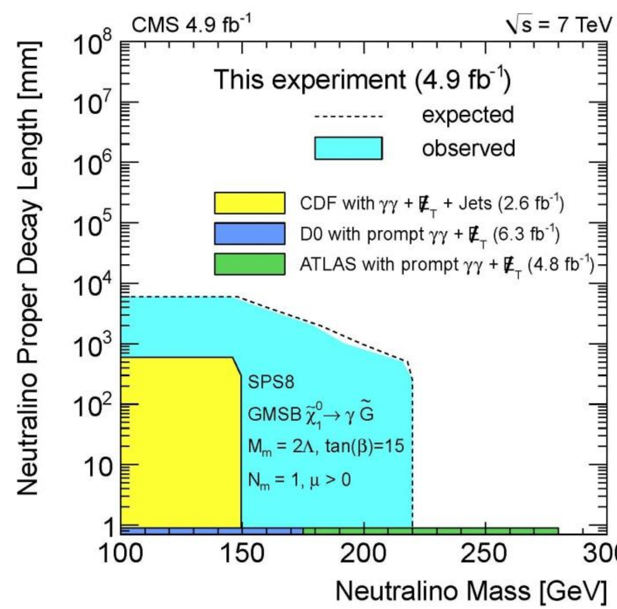
- N(j) > 3, $p_T(\gamma) > 100$ → MET and photon timing









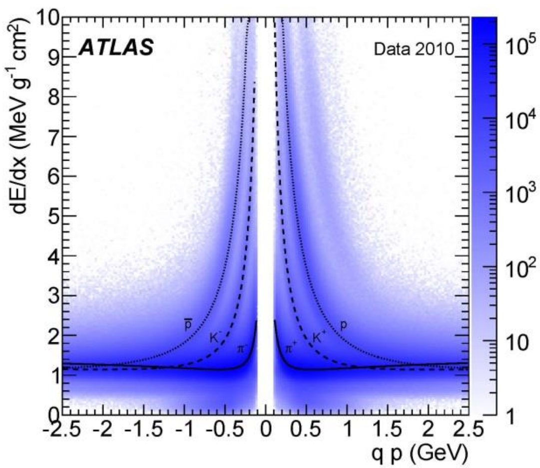


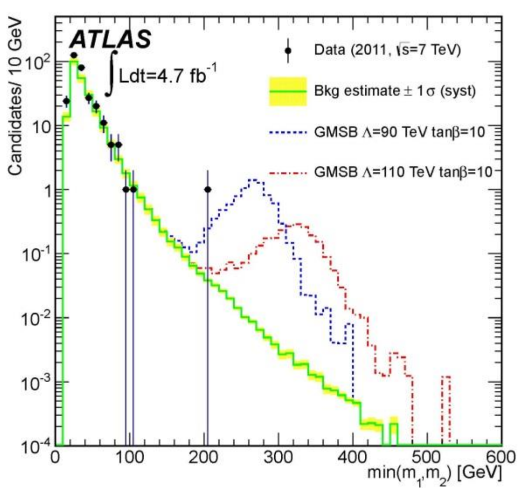
Stable Massive Particle

PLB 720 (2013) 277, arXiv:1211.1597

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/SUSY-2012-01/

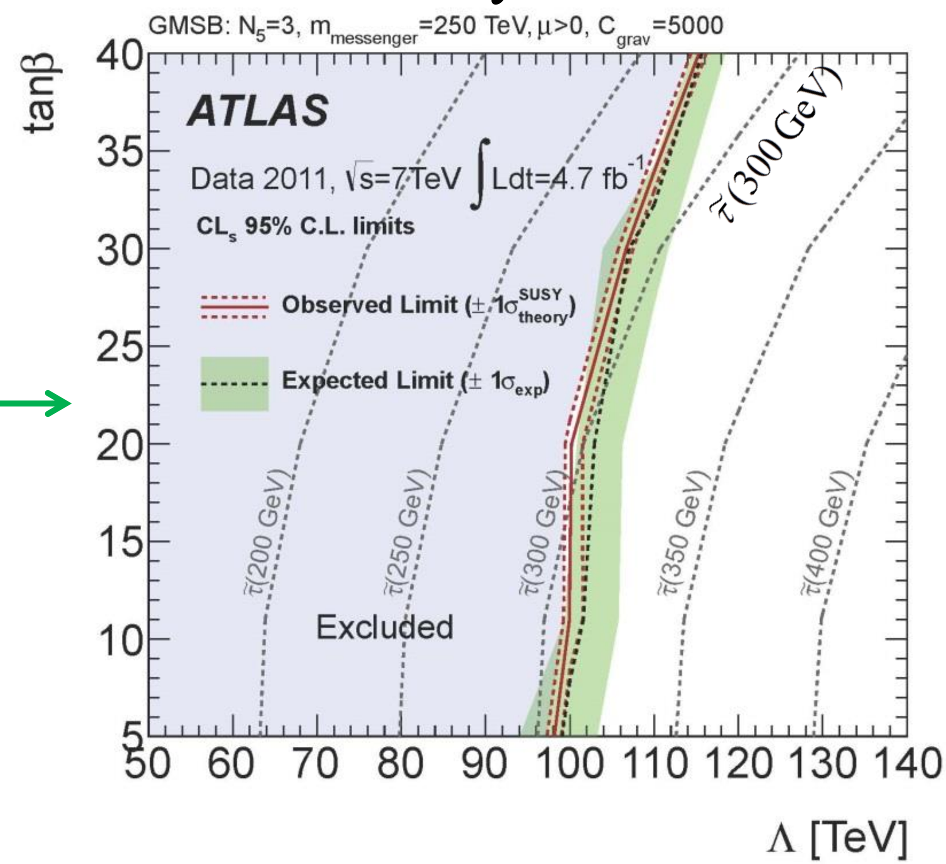
- ❖ Long-lived sleptons, squarks and gluinos
  - ✓ High pT track + Heavy (m > 100) + Slow (large dE/dX, long TOF)





$m = p / \beta\gamma c$

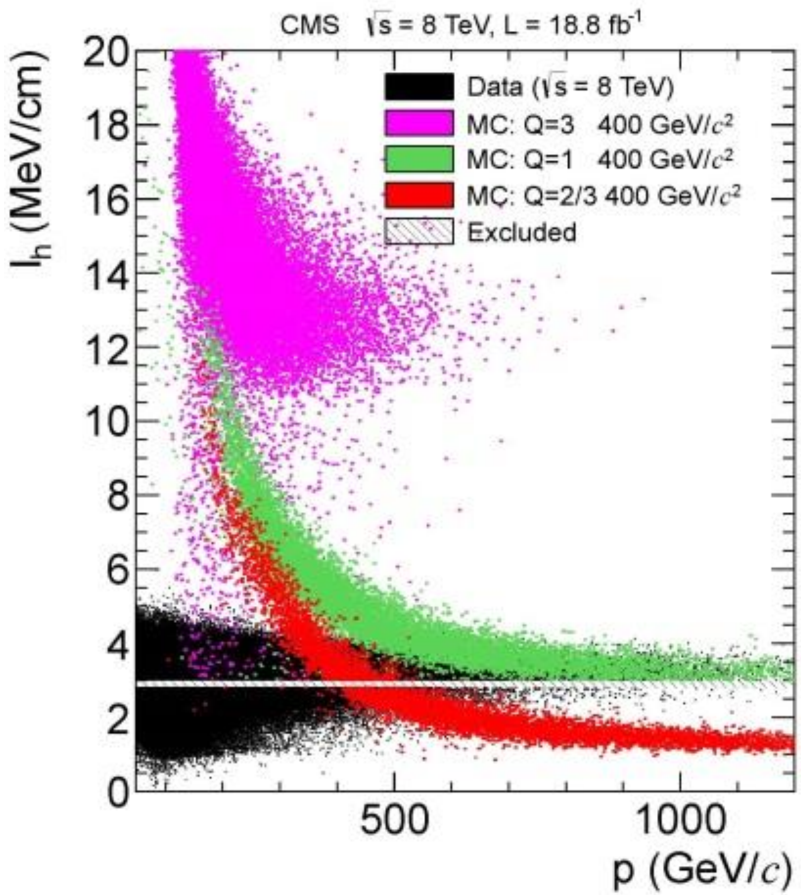
$\tilde{\tau}$

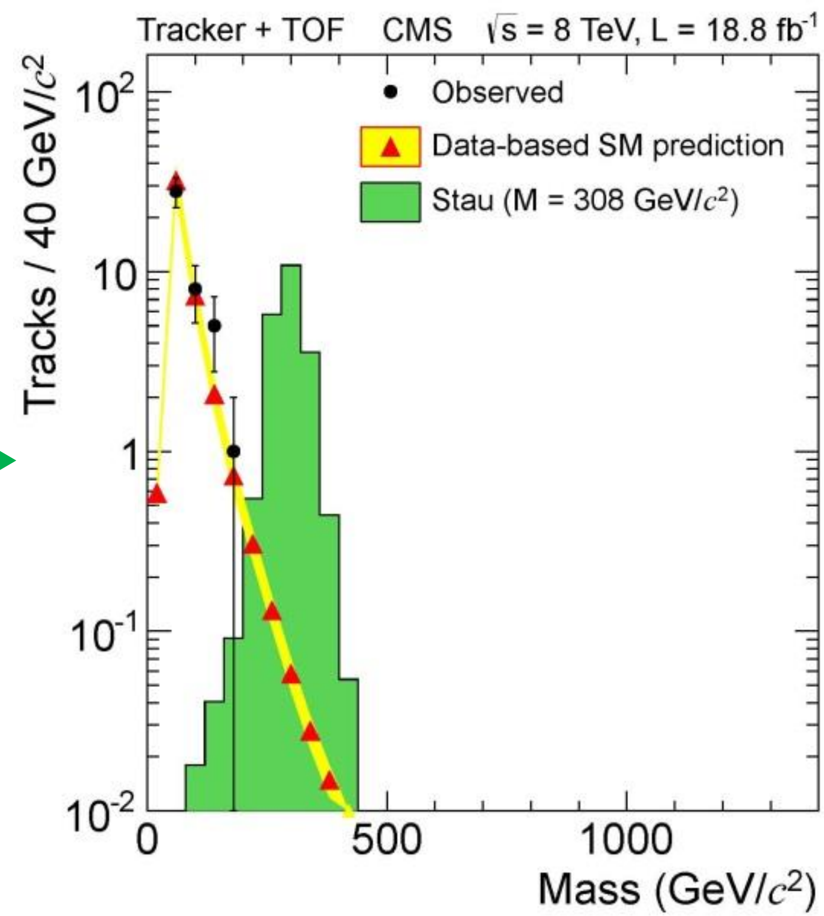


Heavy Stable Charged Particle

arXiv:1305.0491 (20/fb), CMS-EXO-12-026 (JHEP)

- GMSB (stable stau), split SUSY (R-hadron), …
  - ✓ High p_T track + Heavy (m > 100) + Slow (large dE/dX, long TOF)

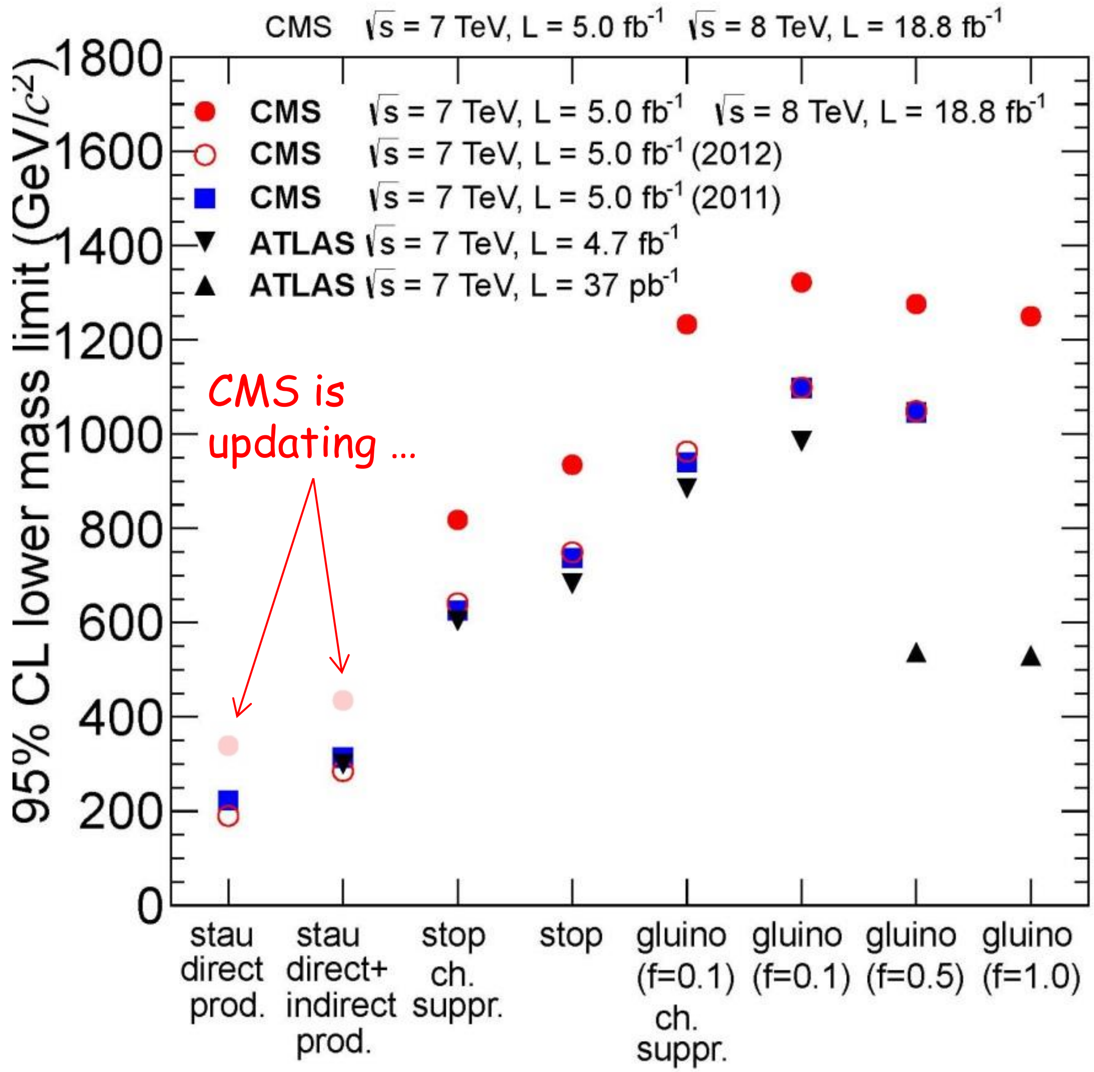




$$m = p / \beta\gamma c$$

Long-Lived Charged Particles

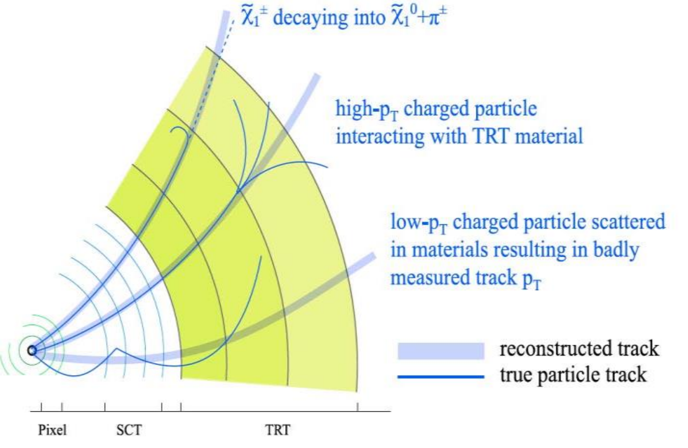
Stau, Stop, R-hadron (gluino-quark)

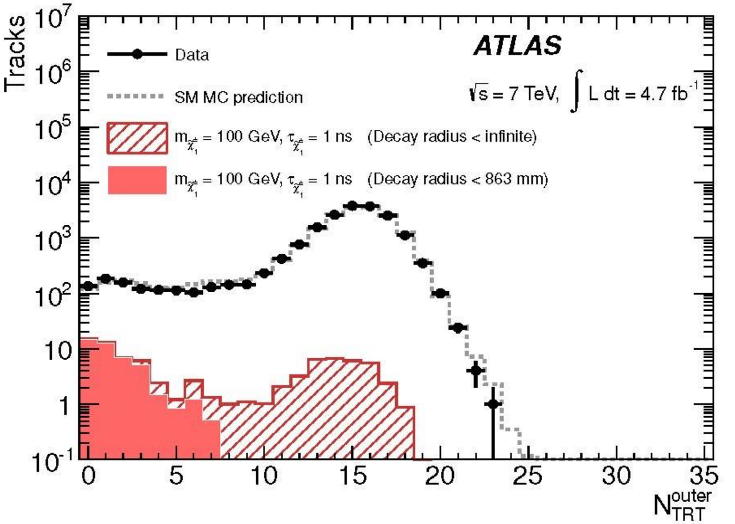


Disappearing Tracks (I)

http://link.springer.com/article/10.1007/JHEP01(2013)131

- AMSB: Wino LSP → M(C1) ~ M(N1)
- C1 could have a measureable lifetime ~O(0.1 ns)
- Signals:
  - ✓ pp→ C1N1 + jets
  - ✓ pp→ C1C1 + jets
- Look for C1 decaying in the inner TRT detector volume, leaving a small number of hits in the outer TRT modules.
- BGs:
  - High p_T charged hadrons (80%)
  - Low p_T tracks wth large bremsstrahlung radiation



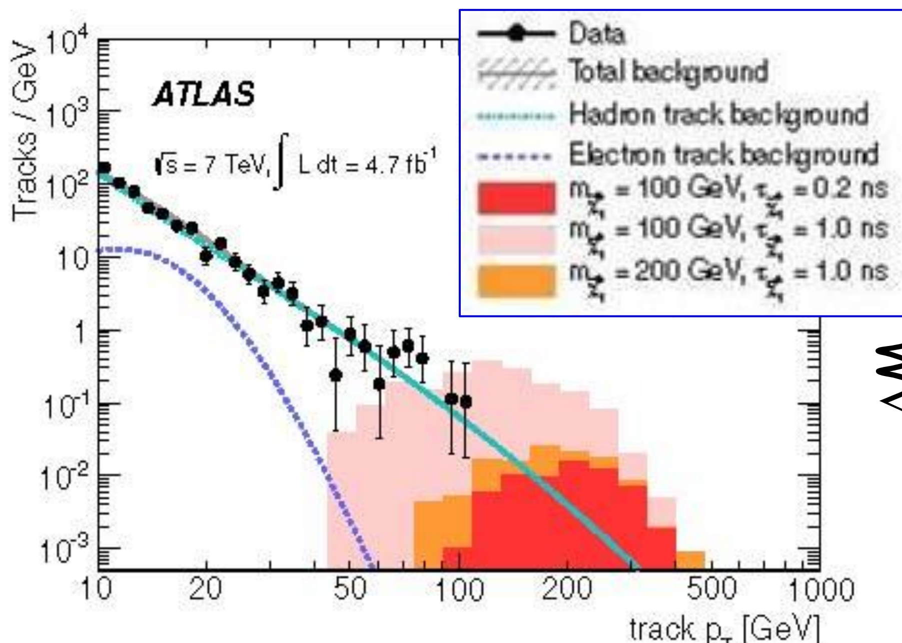


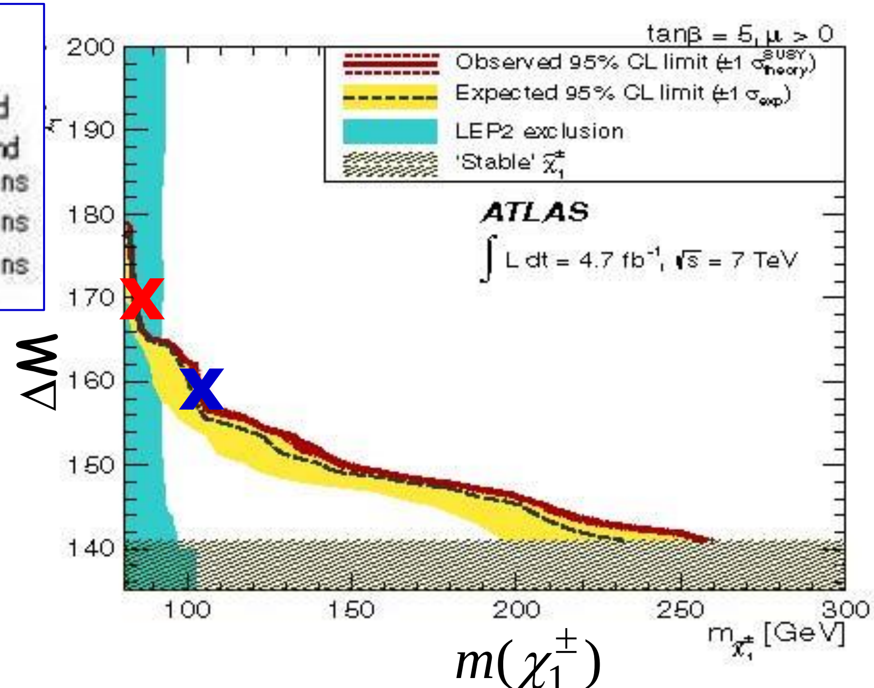
Disappearing Tracks (II)

http://link.springer.com/article/10.1007/JHEP01(2013)131

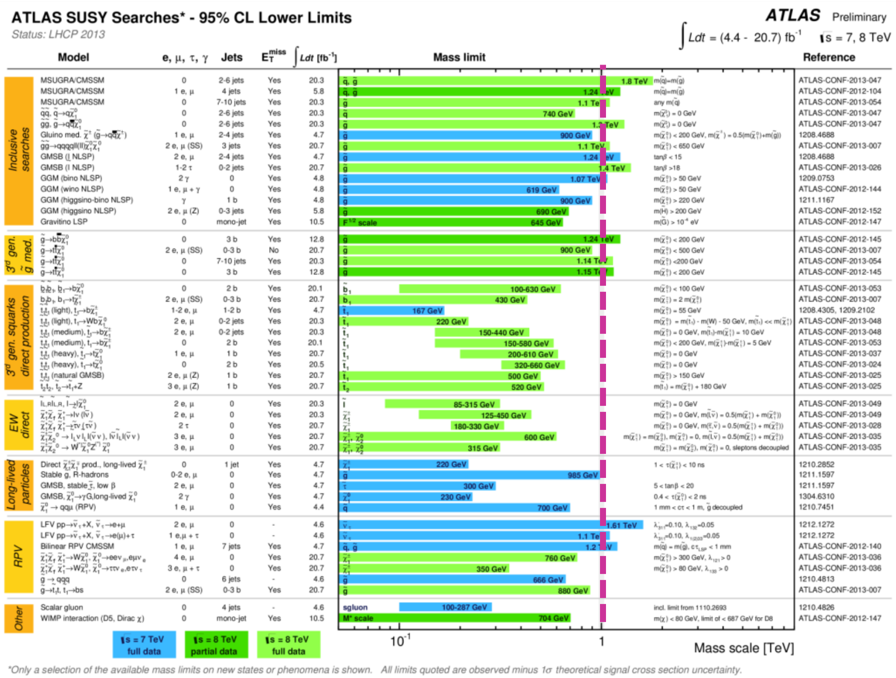
- BG Estimate
  - ✓ Derive the BG track p_T shapes from CR
  - ✓ Perform a "signal + BG" template fit to candidate tracks
- No excess over the SM expectation
- ΔM ~ 160 (170) MeV, M(C1) up to 103 (85) GeV is excluded

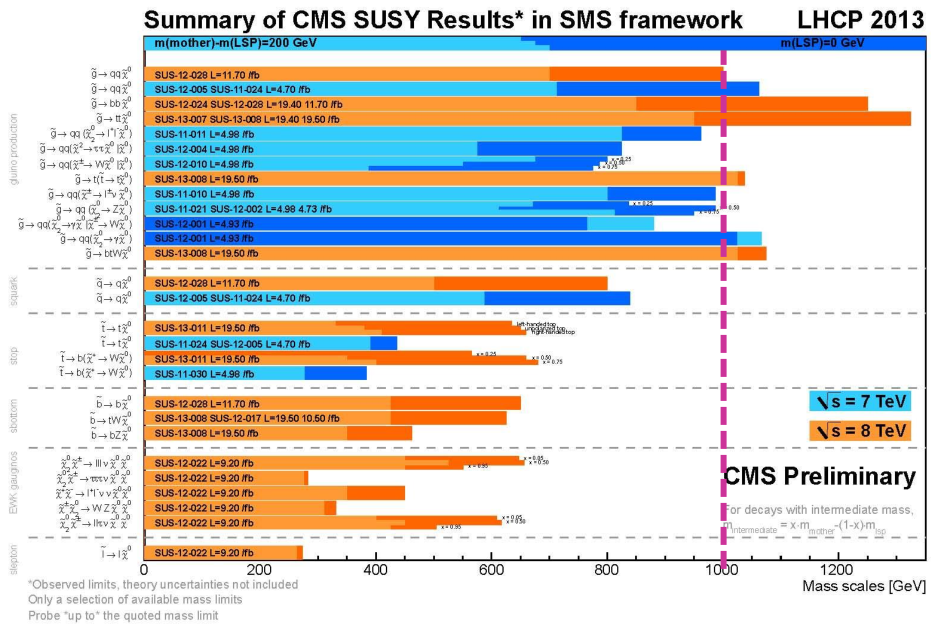
$$m(\chi_1^{\pm}) = 100, 200\,\text{GeV} \quad \tau(\chi_1^{0}) = 0.2, 1.0, 1.0\,\text{ns}$$

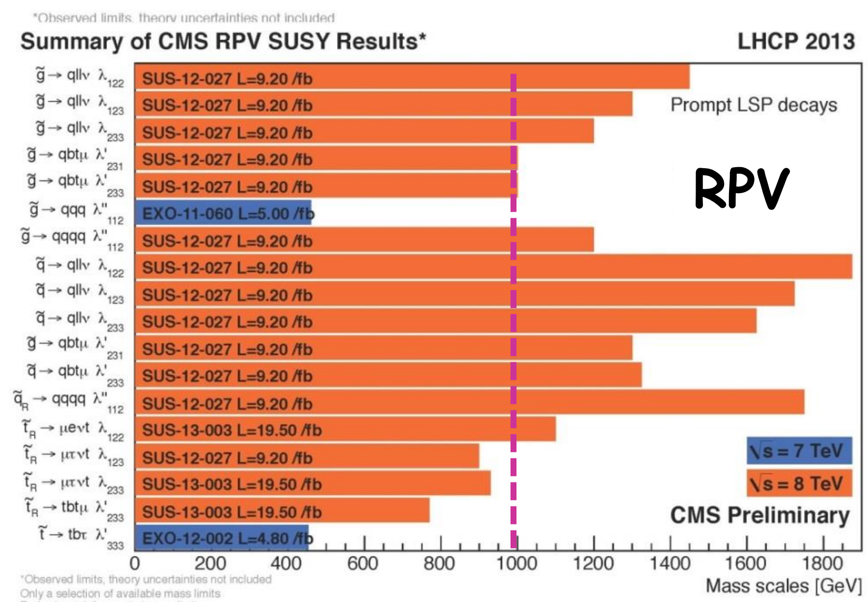




Summary



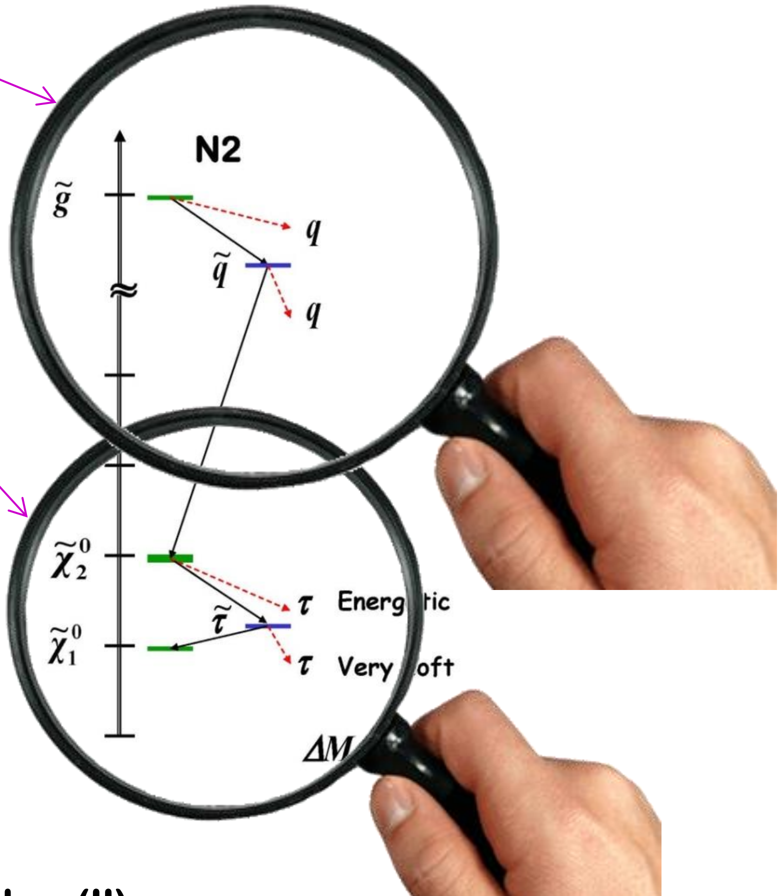




- Probing a TeV scale → No hints of SUSY (yet) in very diverse SUSY search programs, including physics beyond minimal scenarios.
- LHC13/LHC33, & ILC/TLEP along with direct/indirect DM programs
- Upgraded detectors to maintain or improve physics object reconstruction …

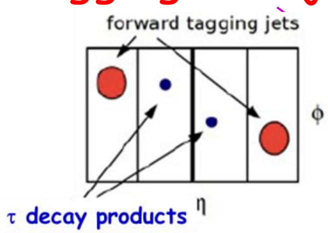
Remarks

- [Question] How can we probe colorless SUSY sector if (i) heavy 1st/2nd generation squarks and gluino, and (ii) small ΔM (mass difference between NLSP and LSP)?
- [Answer]
  1) Tagging energetic jets (+ MET) from cascade decays?
  2) Tagging leptons?
  3) Other?

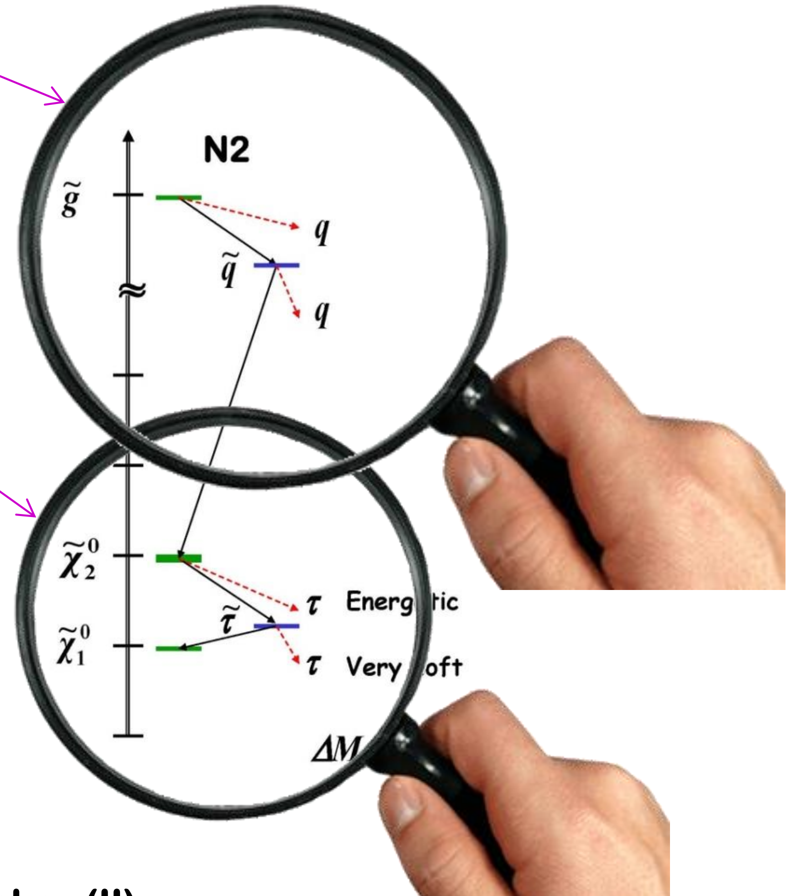


Remarks

- [Question] How can we probe colorless SUSY sector if (i) heavy 1st/2nd generation squarks and gluino, and (ii) small ΔM (mass difference between NLSP and LSP)?
- [Answer]
  1) Tagging energetic jets (+ MET) from cascade decays?
  2) Tagging leptons?
  3) Tagging VBF jets → WW Collider

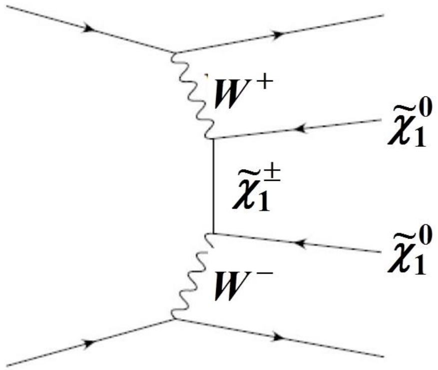


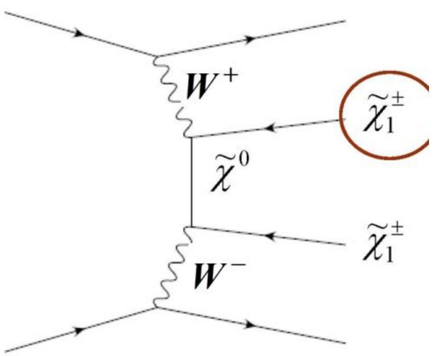
1) A. Datta, P. Konar, and B. Mukhopadhyaya, "Invisible Charginos and Neutralinos from Gauge Boson Fusion: A Way to Explore Anomaly Mediation", PRL 88 (2002) 181802.
2) G. Giudice, T. Han, K. Wang, and L.T. Wang, "Nearly Degenerate Gauginos and Dark Matter at the LHC", PRD 81 (2010) 115011
3) B. Dutta, A. Gurrola, W. Johns, T. Kamon, P. Sheldon, K. Sinha, "Vector Boson Fusion Processes as a Probe of Supersymmetric Electroweak Sectors at the LHC", PRD 87 (2013) 035029
4) A.G. Delannoy, B. Dutta, A. Gurrola, W. Johns, T. Kamon, E. Luiggi, A. Melo, P. Sheldon, K. Sinha, K. Wang, S. Wu, "Probing Dark Matter at the LHC using Vector Boson Fusion Processes", arXiv:1304.7779 [hep-ph]



DM Production via VBF

A.G. Delannoy, B. Dutta, A. Gurrola, W. Johns, T. Kamon, E. Luiggi, A. Melo, P. Sheldon, K. Sinha, K. Wang, S. Wu, "Probing Dark Matter at the LHC using Vector Boson Fusion Processes", arXiv:1304.7779 [hep-ph]





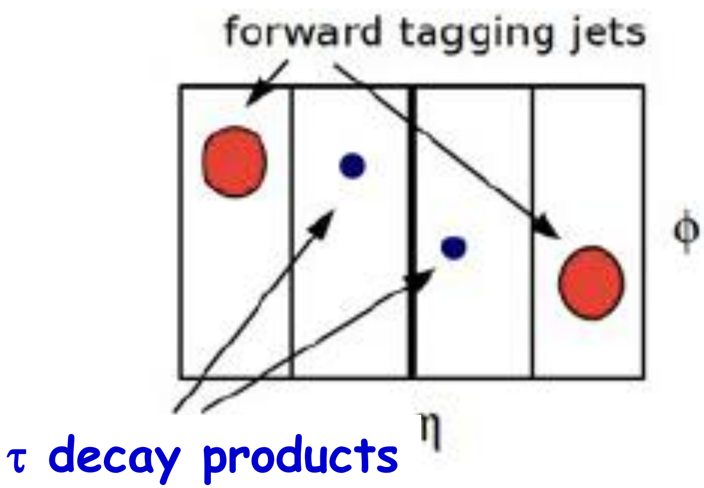
$jj + MET + X$

- The final state is same as invisible Higgs signal.
- But, Larger p_T jets
- Cross section?
  - ✓ Wino-like DM
  - ✓ Bino-Higgsino DM
- Feasibility?
  - ✓ ~50 GeV Wino-DM at 8 TeV
  - ✓ ~1000 GeV Wino-DM at 14 TeV
  - ✓ Bino-Higgsino DM at 14 TeV
- More?
  - ✓ Example, disappearing tracks?

$$\Delta M = M(\tilde{\chi}_1^{\pm}) - M(\tilde{\chi}_1^0) \sim 100\ MeV$$
$$\Rightarrow Br(\tilde{\chi}_1^{\pm} \to \tilde{\chi}_1^0 \pi^{\pm}) \sim 100\%$$
$$P_T(\pi^{\pm}) \sim \Delta M \sim 100\ MeV$$

“Dark Side” of SUSY?

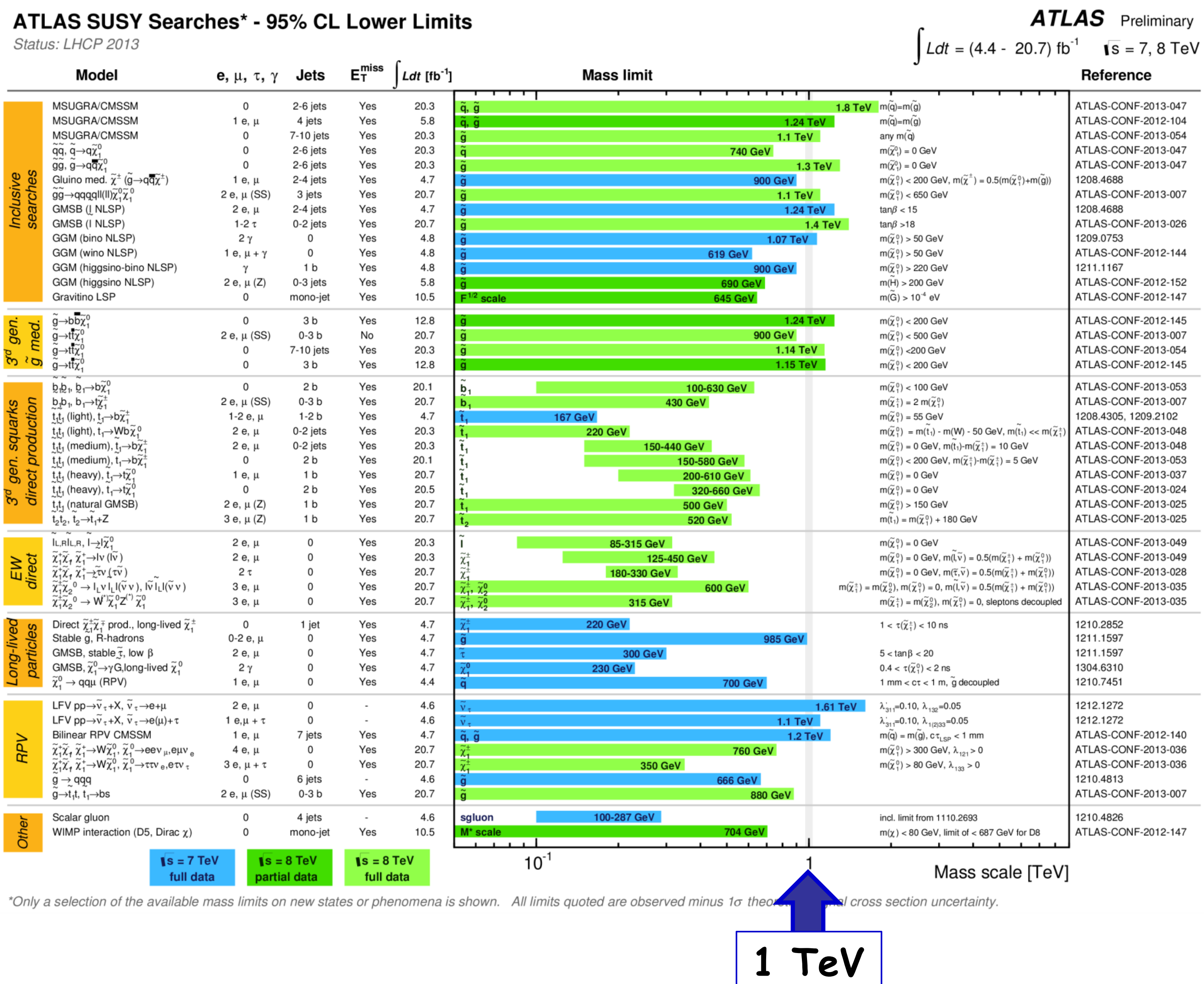
Backup



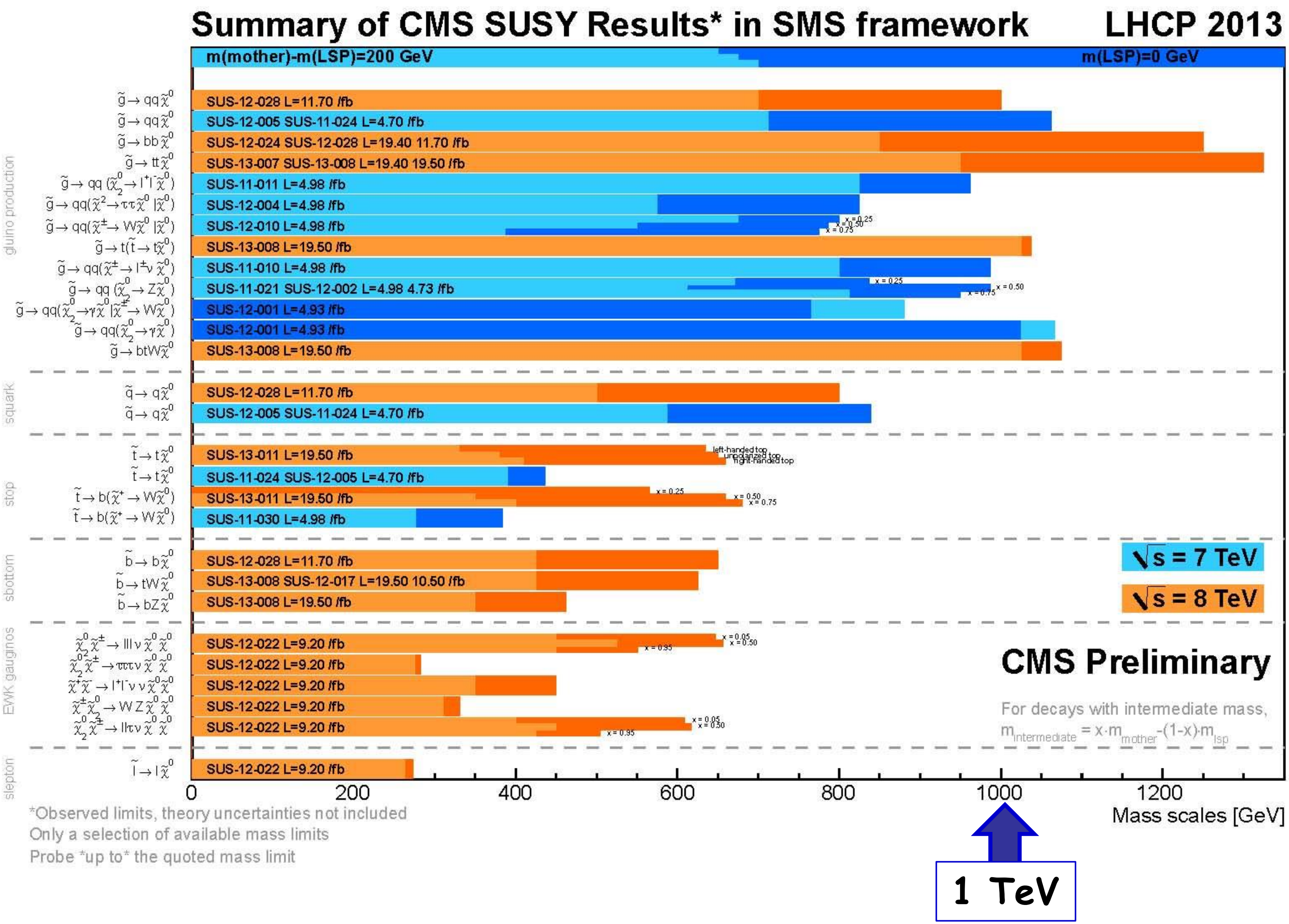
$$\beta^{-1} = 1 + \frac{c\delta_t}{L}$$

$$\mathcal{M}_{\tilde{\chi}^0} = \begin{pmatrix} M_1 & 0 & -M_Z s_W c_\beta & M_Z s_W s_\beta \\ 0 & M_2 & M_Z c_W c_\beta & -M_Z c_W s_\beta \\ -M_Z s_W c_\beta & M_Z c_W c_\beta & 0 & -\mu \\ M_Z s_W s_\beta & -M_Z c_W s_\beta & -\mu & 0 \end{pmatrix}$$

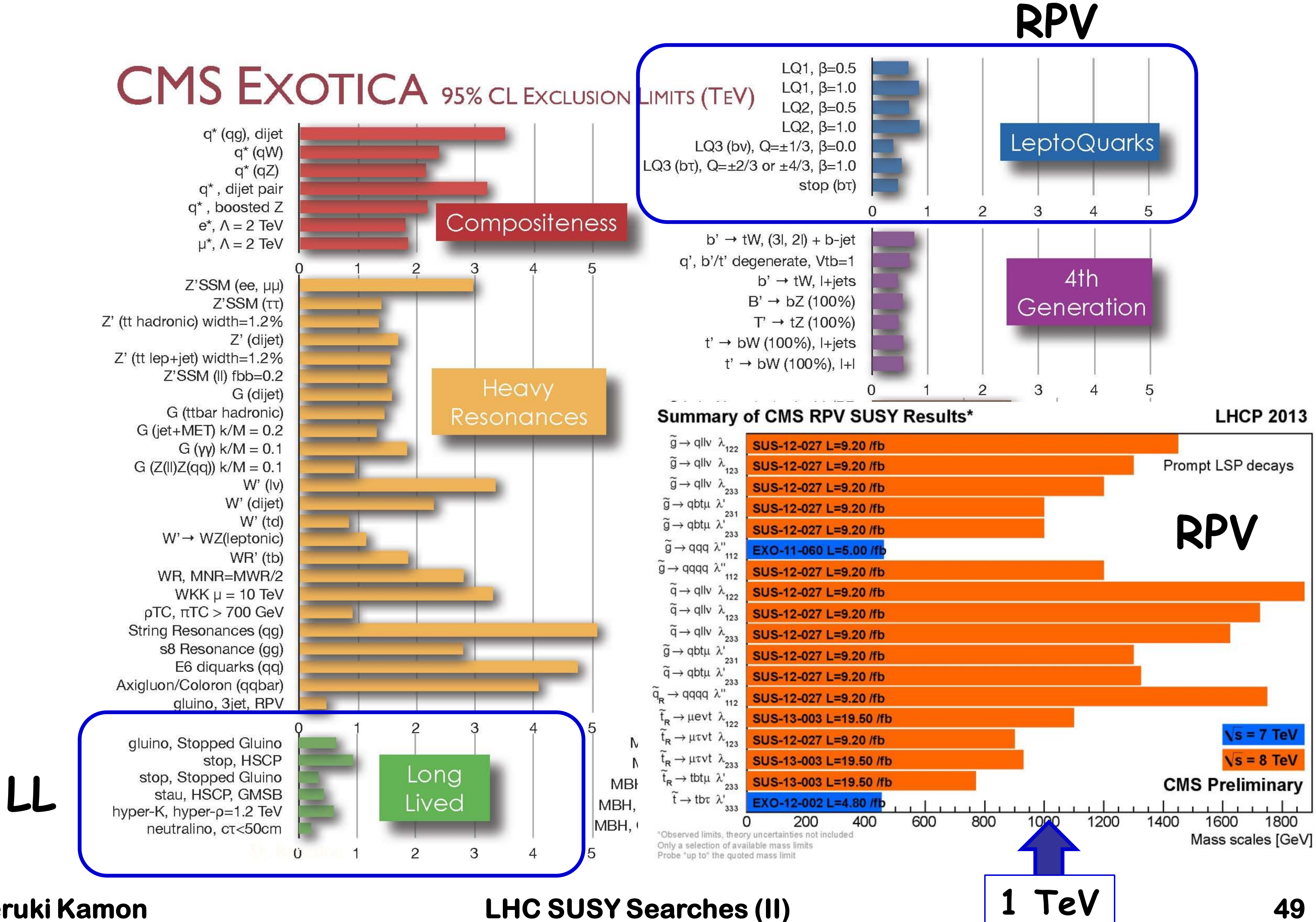
ATLAS At A Glance



CMS At A Glance

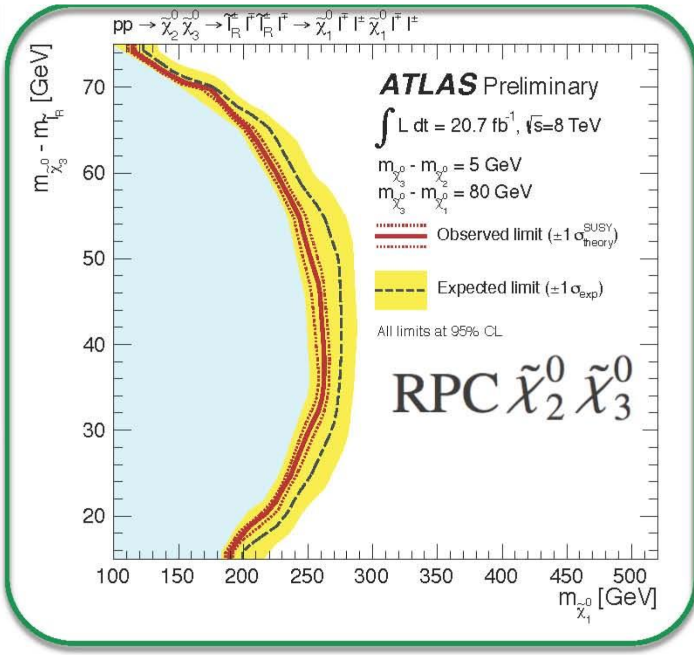


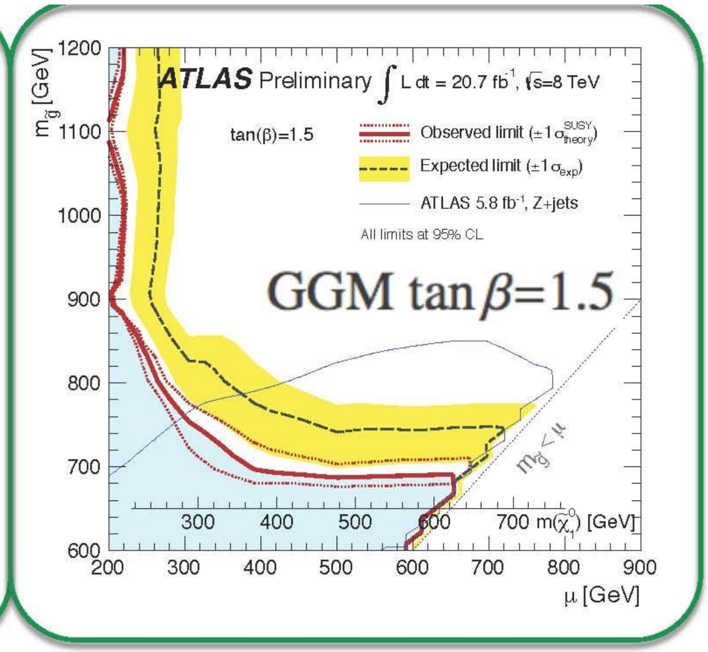
CMS' At A Glance

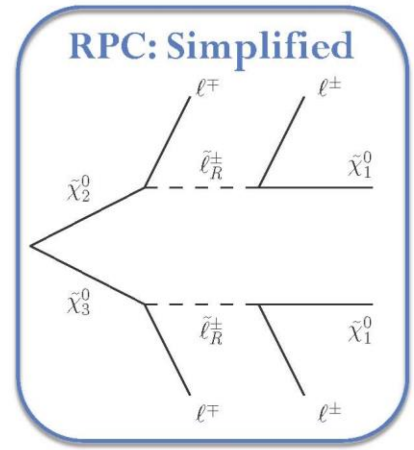


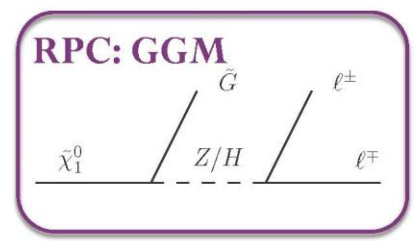
4 Leptons (e/mu/tau)

≥ 4 leptons









Can we probe DM Properties?

$$M_{\tilde{\chi}^0} = \begin{pmatrix} M_1 & 0 & -M_Z s_W c_\beta & M_Z s_W s_\beta \\ 0 & M_2 & M_Z c_W c_\beta & -M_Z c_W s_\beta \\ -M_Z s_W c_\beta & M_Z c_W c_\beta & 0 & -\mu \\ M_Z s_W s_\beta & -M_Z c_W s_\beta & -\mu & 0 \end{pmatrix}$$

$s_W = \sin(\theta_W) \quad c_W = \cos(\theta_W)$

$s_\beta = \sin(\beta) \quad c_\beta = \cos(\beta)$

$M_1 << M_2,\ \mu \ \Rightarrow\ \tilde{\chi}_1^0 \approx \tilde{B}$ *pure Bino*

$M_2 << M_1,\ \mu \ \Rightarrow\ \tilde{\chi}_1^0 \approx \tilde{W}$ *pure Wino*

$\mu << M_1,\ M_2 \ \Rightarrow\ \tilde{\chi}_1^0 \approx \tilde{H}_h + \tilde{H}_d$ *pure Higgsino*

1. Bino Dark Matter … production cross section is too small. We need to study decays of C1 & N2.
   - N1 ~ Bino
   - C1 ~ Wino.
   - M(C1) ~ 2 x M(N1)
2. Wino Dark Matter
   - N1 and C1 are Wino → M(N1) ~ M(C1)
3. Higgsino Dark Matter
   - N1 ~ C1 ~ Higgsino → M(N1) ~ M(C1)
4. Bino-Higgsino Dark Matter