Overview of ATLAS & CMS Supersymmetry searches

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Part of: Discovery centre for particle physics

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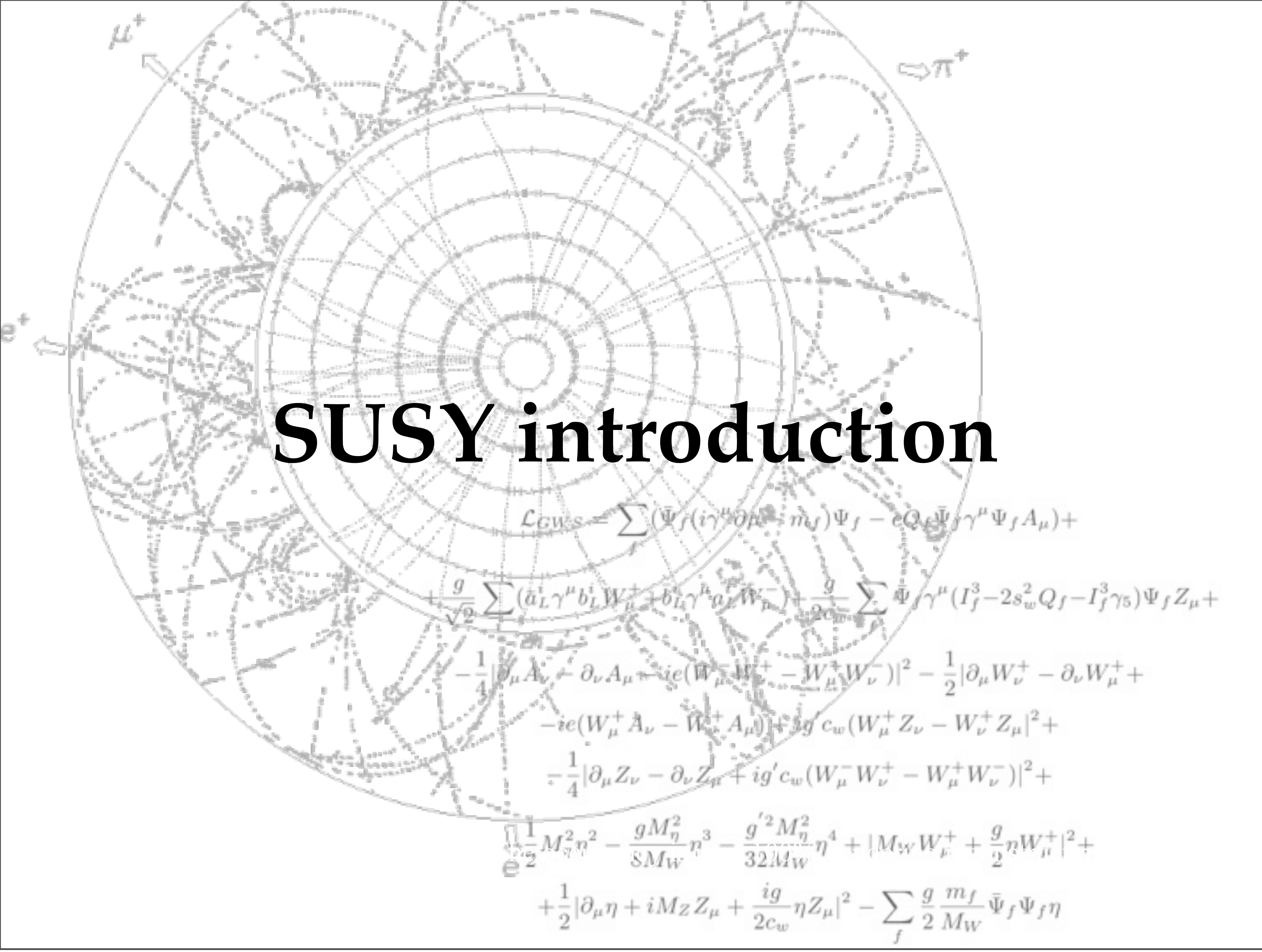
Outline of presentation

Motivations for searches:
- SUSY and naturalness
- SUSY production classes

ATLAS & CMS SUSY searches:
- Gluinos and squarks: Jets + MET
- 3rd generation squarks: b-jets + MET
- ElectroWeak production
- Generalized searches

Conclusions and outlook

<u>Notes on limited warrenty:</u>
I will assume general knowledge of LHC running and the ATLAS+CMS detectors.
Covering broadly (80+ analysis),
I will necessarily be short/undetailed.



SUSY introduction

SM vs. SUSY

The Standard Model (SM) faces problems:

- No Dark Matter (DM) candidates.
- No Matter-Antimatter asymmetry.
- Extreme fine tuning of Higgs mass.

Super Symmetry (SUSY) offers a solution:

29 sparticles, 4 Higgs' and R-parity: $R = (-1)^{2j+3B+L}$

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	$\tilde{u}_L\ \tilde{u}_R\ \tilde{d}_L\ \tilde{d}_R$	(same)
			$\tilde{s}_L\ \tilde{s}_R\ \tilde{c}_L\ \tilde{c}_R$	(same)
			$\tilde{t}_L\ \tilde{t}_R\ \tilde{b}_L\ \tilde{b}_R$	$\tilde{t}_1\ \tilde{t}_2\ \tilde{b}_1\ \tilde{b}_2$
sleptons	0	−1	$\tilde{e}_L\ \tilde{e}_R\ \tilde{\nu}_e$	(same)
			$\tilde{\mu}_L\ \tilde{\mu}_R\ \tilde{\nu}_\mu$	(same)
			$\tilde{\tau}_L\ \tilde{\tau}_R\ \tilde{\nu}_\tau$	$\tilde{\tau}_1\ \tilde{\tau}_2\ \tilde{\nu}_\tau$
neutralinos	1/2	−1	$\tilde{B}^0\ \tilde{W}^0\ \tilde{H}_u^0\ \tilde{H}_d^0$	$\tilde{N}_1\ \tilde{N}_2\ \tilde{N}_3\ \tilde{N}_4$
charginos	1/2	−1	$\tilde{W}^\pm\ \tilde{H}_u^+\ \tilde{H}_d^-$	$\tilde{C}_1^\pm\ \tilde{C}_2^\pm$
gluino	1/2	−1	$\tilde{g}$	(same)
goldstino (gravitino)	1/2 (3/2)	−1	$\tilde{G}$	(same)

If R-parity is conserved (mostly assumed):

- LSP is stable (i.e. DM candidate).
- SUSY particles are pair produced.
- Final states have MET signatures.

Extra Higgs' may solve asymmetry problem and SUSY cancels:

$$m_h^2 \approx m_{h0}^2 - \frac{\lambda_f^2}{8\pi^2} N_c^f \int^\Lambda \frac{d^4p}{p^2} \approx m_{h0}^2 + \frac{\lambda_f^2}{8\pi^2} N_c^f \Lambda^2$$

bare mass

1-loop correction

From **Quantum Diaries**

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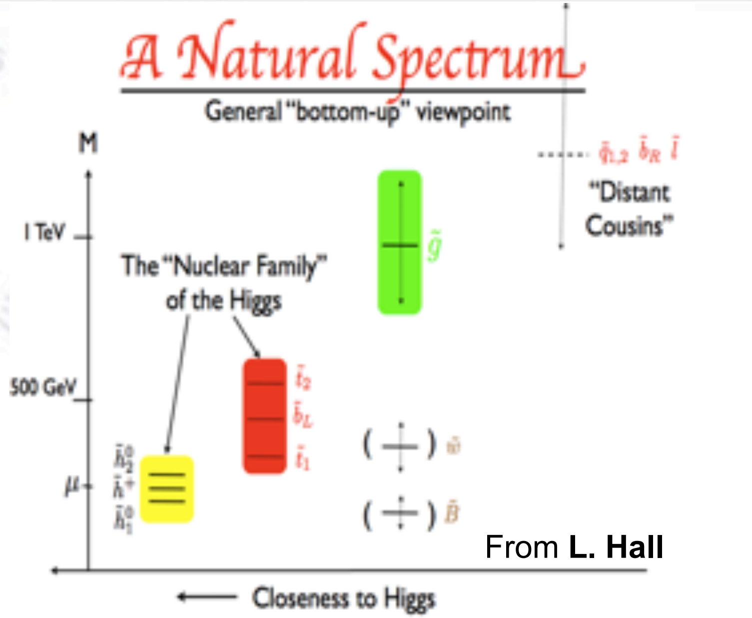

From **L. Hall**

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SM vs. SUSY naturalness

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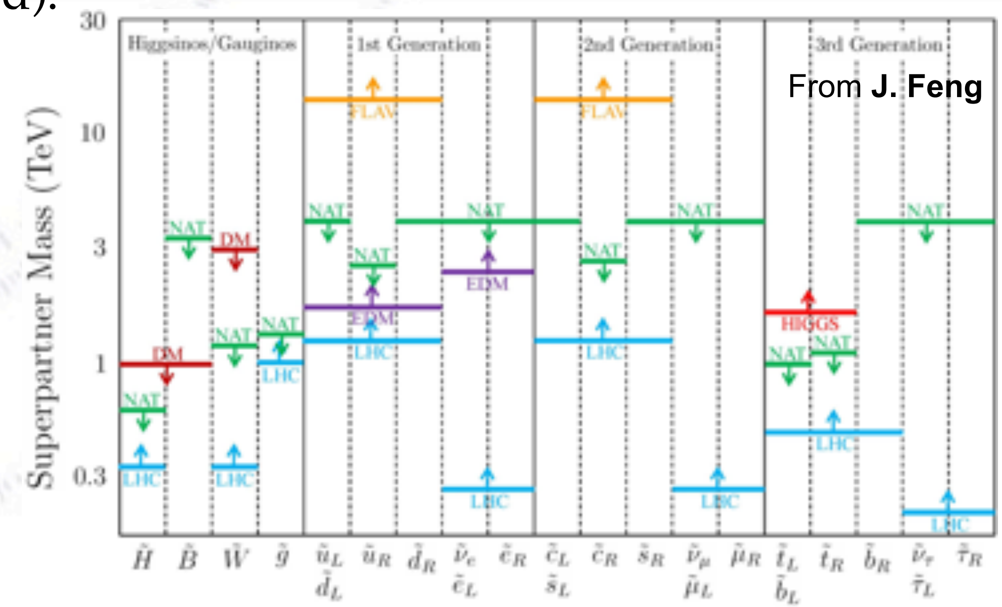

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SUSY cross section

At LHC, 1st/2nd gen. squark/ gluino production dominates (if kinematically accessible).

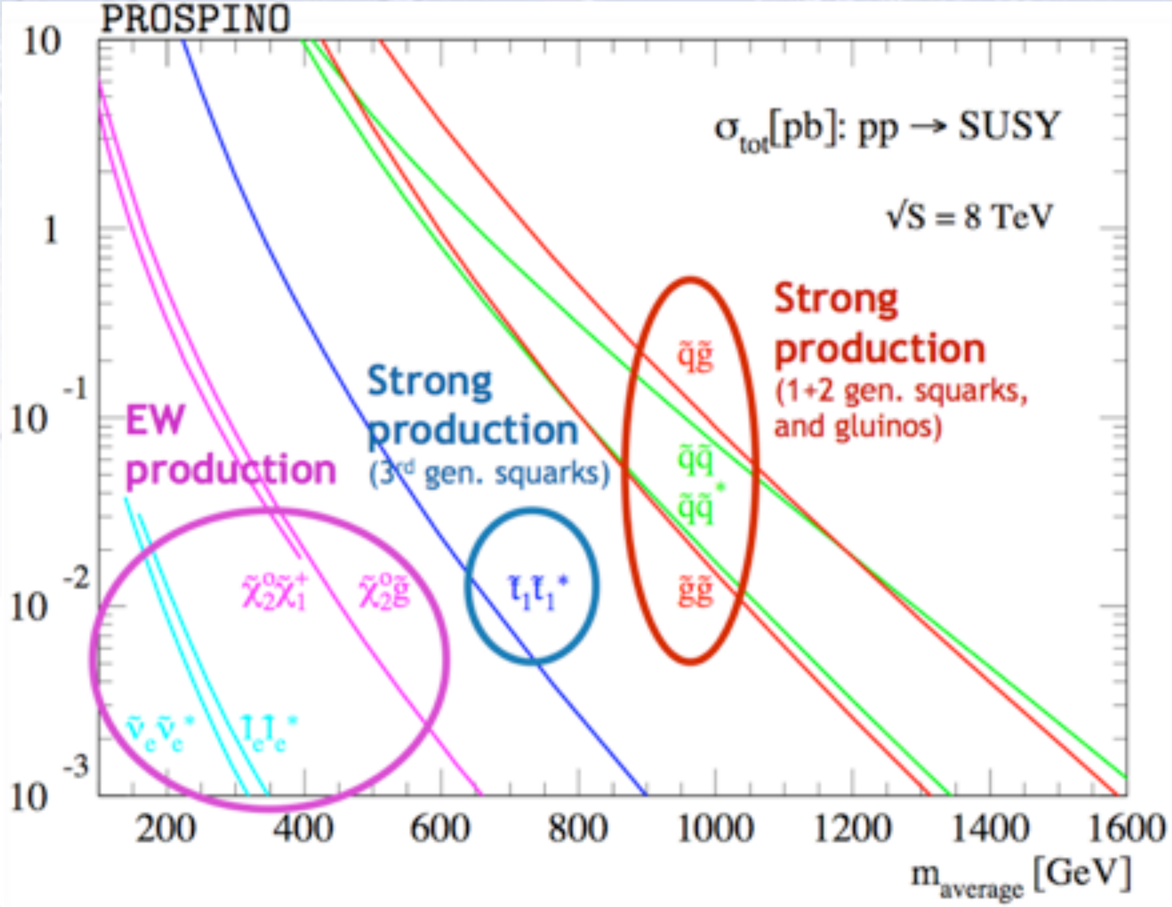
Naturalness favors light 3rd generation (e.g. stops).

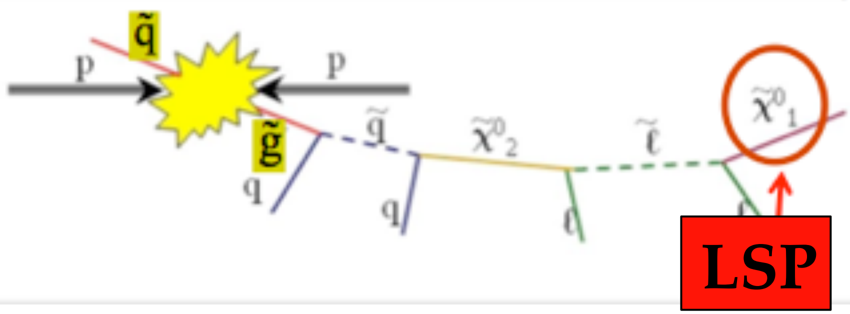
Electroweak SUSY production is suppressed at the LHC,
but of course still accessible.

Bonus: Non-SUSY New Physics often predicts SM partners to which SUSY searches are sensitive.

In addition: Large tanβ τ and b-jets, compressed spectra, long lived particles, etc.

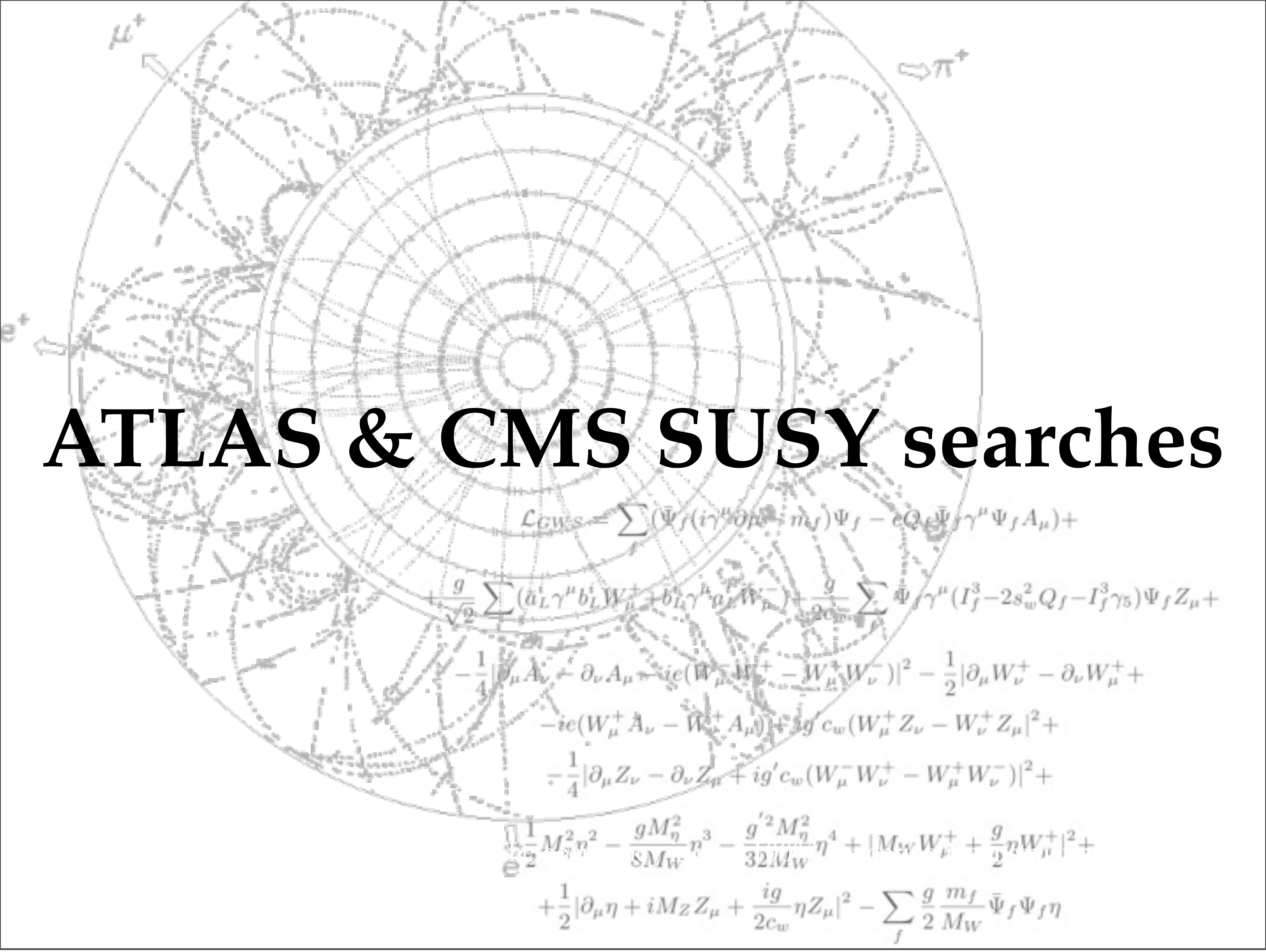
Simplified Models gives sufficient info for reinterpretations.





The LHC accelerator, the data and ATLAS & CMS detectors

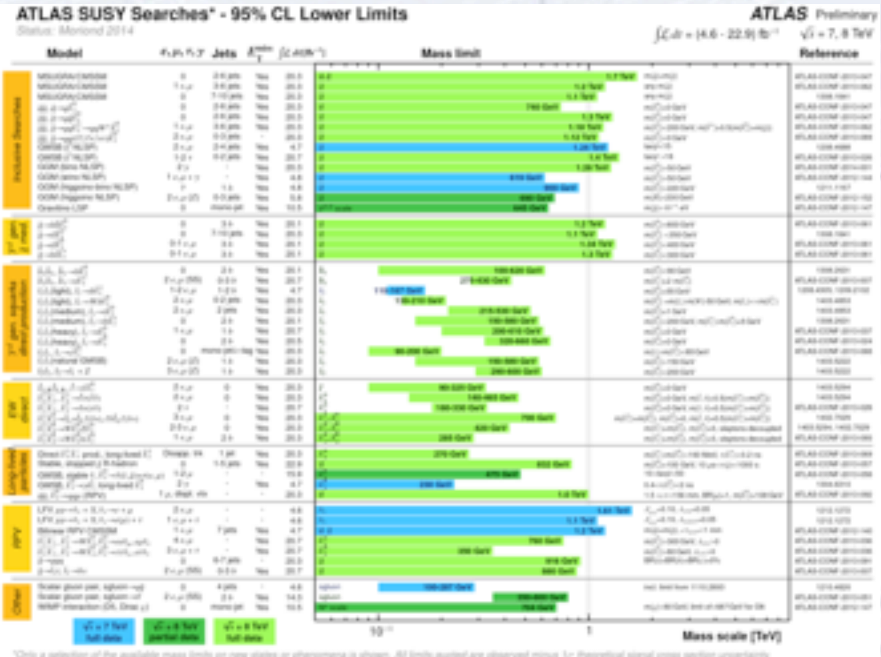
A perhaps clumpsy but certainly hearty THANKS for the hard work, excellent quality, and fantastic data.

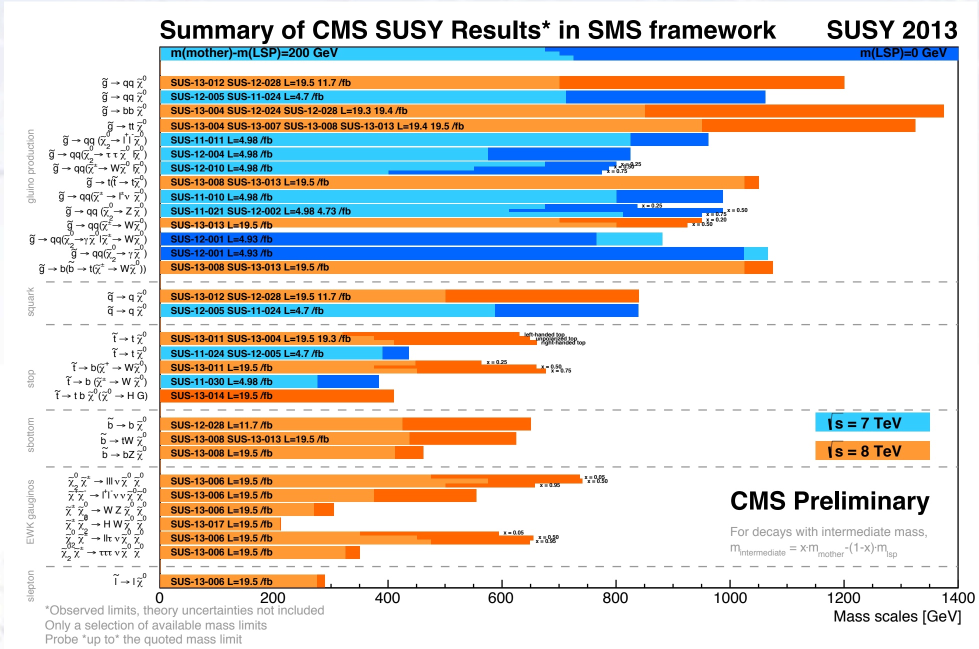


ATLAS & CMS SUSY searches

ATLAS & CMS search overview

A total of 51+31 SUSY analysis to review: Impossible!





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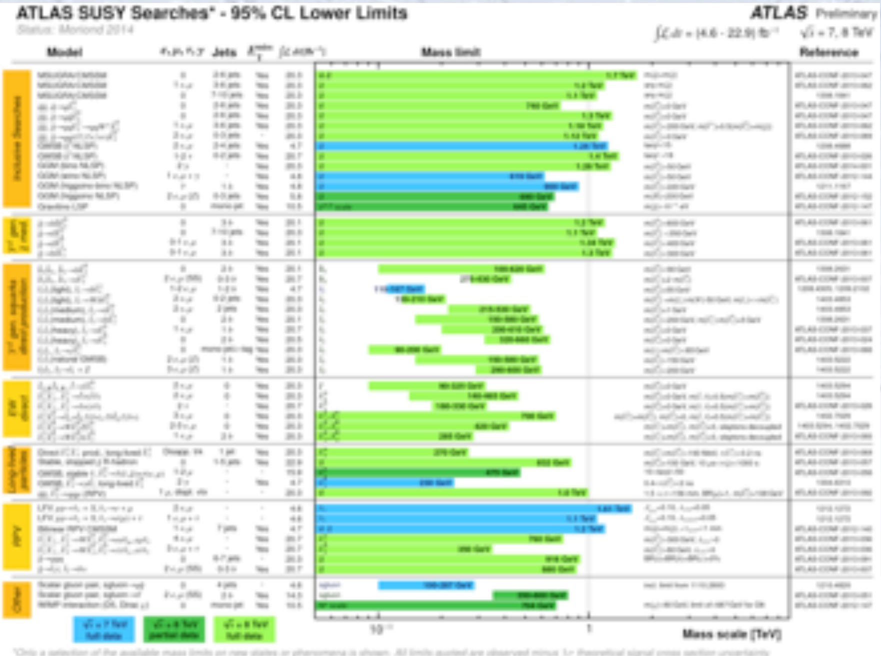
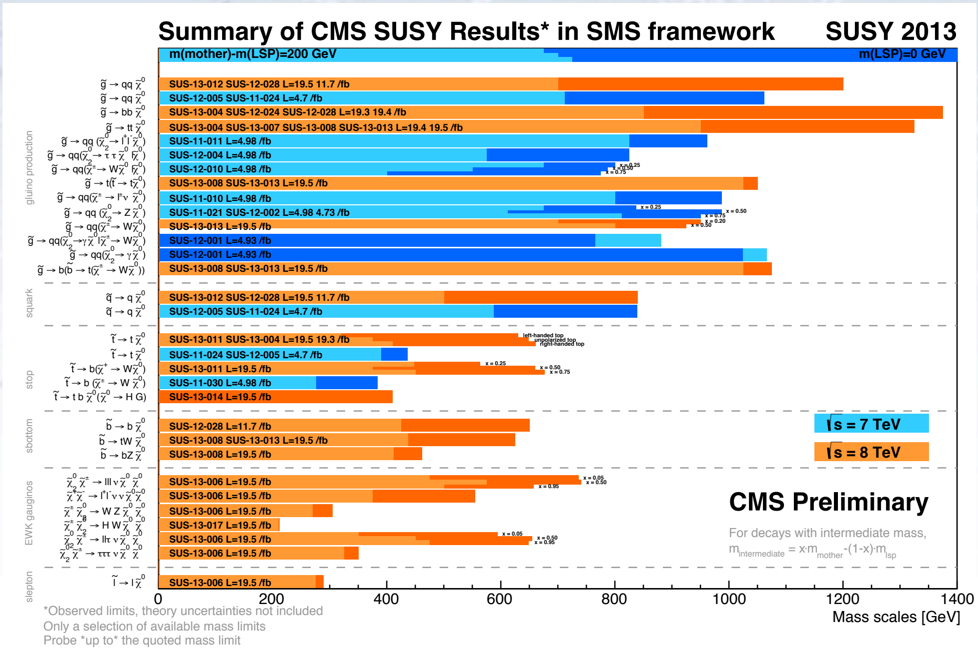
ATLAS & CMS search overview



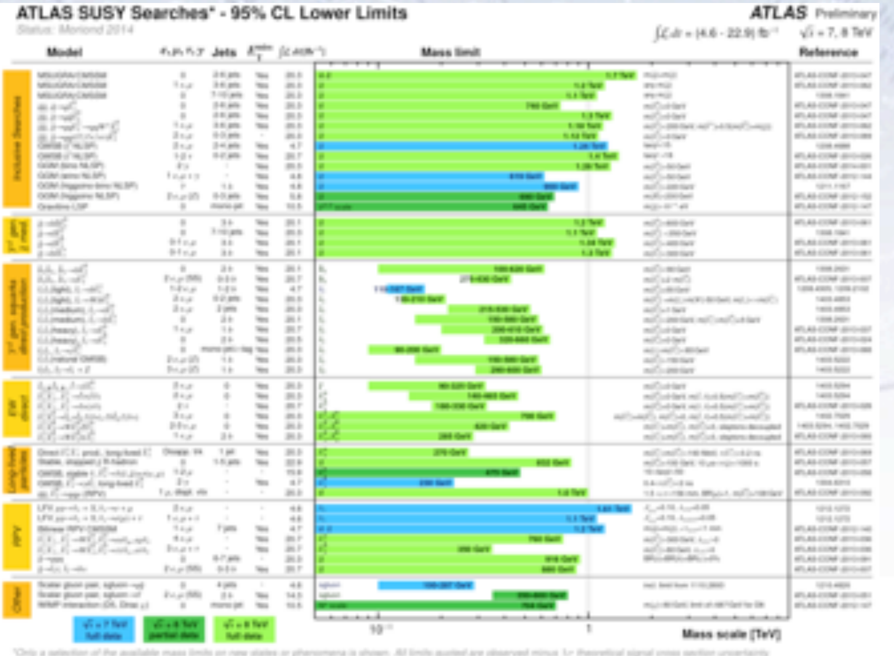


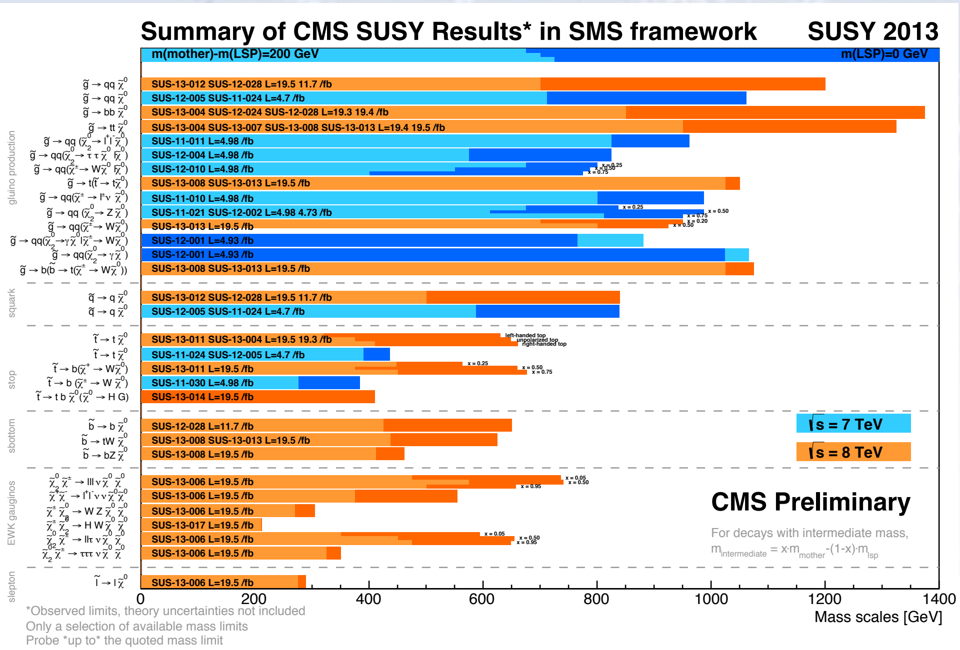
Three general subjects will be considered:

- Jets + MET searches (squarks and gluinos).
- B-jets + MET searches (stops and sbottoms).
- Leptons + MET searches (EW production of chargino/neutralino/slepton).

Furthermore, I will discuss the general coverage of SUSY phase space and one additional interesting analysis (general NP search).

ATLAS & CMS search overview





<u>Not covered:</u>

Mono- and diphoton searches (see **Toyoko Orimoto**, this afternoon).

Long-lived particle searches (see **Tristan Arnoldus du Pree**, this afternoon).

Mono jet searches (see **Valerio Rossetti**, Thursday afternoon).

Mono W/Z searches (see **Andy Nelson**, Thursday afternoon).

...and of course much more!

Gluinos and squarks: Inclusive jets + MET

Inclusive jets + MET

The 8 TeV analyses in ATLAS & CMS searching for squarks and gluinos are:

1405.7875	20.3 fb^{-1}	2-6 jets + MET
1404.2500	20.3 fb^{-1}	2 SS leptons/3 leptons + MET + b-tag
1308.1841	20.3 fb^{-1}	7-10 jets + MET
ATLAS-CONF-2013-89	20.3 fb^{-1}	2 leptons + jets + MET
ATLAS-CONF-2013-62	20.3 fb^{-1}	1-2 leptons + 3-6 jets + MET
ATLAS-CONF-2013-61	20.1 fb^{-1}	3 b-jets + MET
ATLAS-CONF-2013-26	21.0 fb^{-1}	1 tau + jets + MET
1402.4770	19.5 fb^{-1}	3-8 jets + MET
1311.6736	19.3 fb^{-1}	Lepton + jets + b-tag
PAS-SUS-12-015	19.3 fb^{-1}	Lepton + jets + b-tag
PLB 725 243, 1305.2390	19.4 fb^{-1}	3+ jets + MET + b-tag
PAS-SUS-13-019	19.5 fb^{-1}	Jets + b-tag, MT2 variable

Inclusive jets + MET

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I will consider the "classic" SUSY signature in slight detail and expand from there.
These assume the R-parity is conserved and neutralino is the LSP!

ATLAS inclusive jets + MET

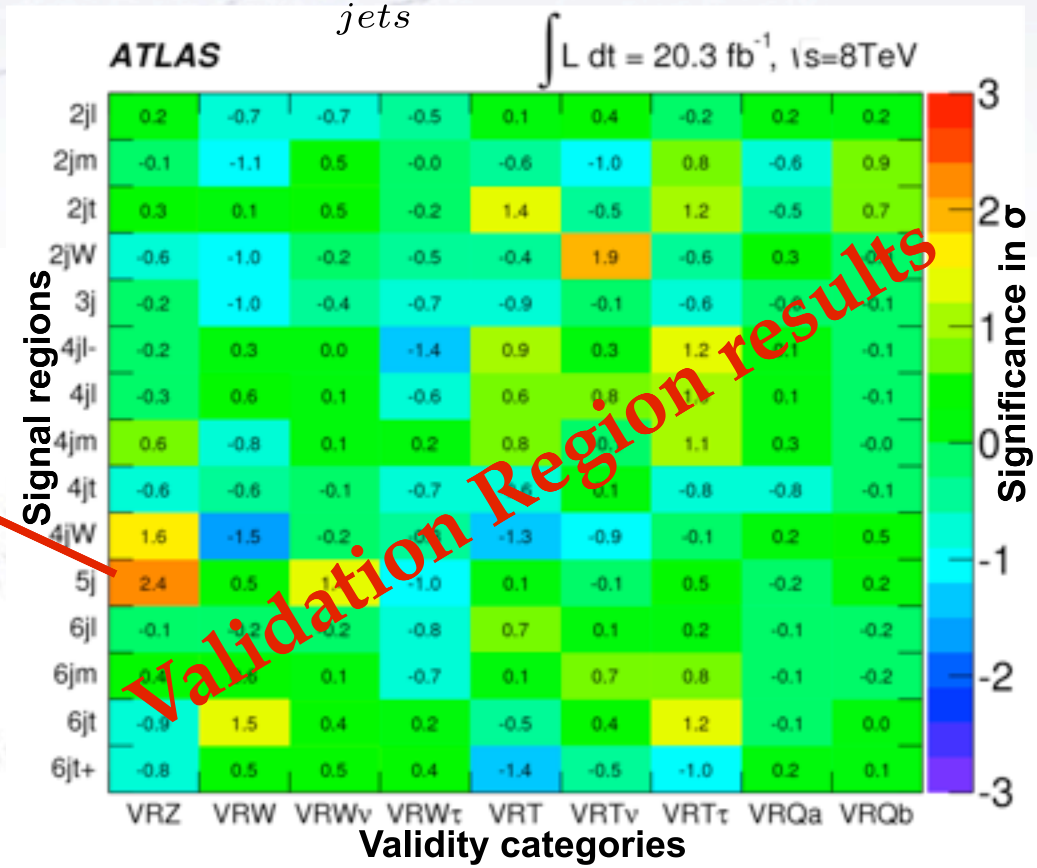
Search uses **15 inclusive signal regions** (SR) along with **60 control regions** (CR, 4 CR per SR [γ,Q,W,T]) and **135 validation regions** (VR, 9 VR per SR).

Events are selected on the basis of E_T^{miss} and $m_{\text{eff}} = \sum_{jets} p_T(jet) + E_T^{\text{miss}}$
Lepton veto is applied to all SR.

Background estimates in SR obtained from data by transfer factors:

$$N(\text{SR, scaled}) = N(\text{CR, obs}) \times \left[\frac{N(\text{SR, unscaled})}{N(\text{CR, unscaled})}\right]$$

To assure accuracy, validity is tested in VRs. Largest discrepancy is 2.4σ (13 events compared 6.1±1.3 exp.) in the Z-VR of the 5j SR.



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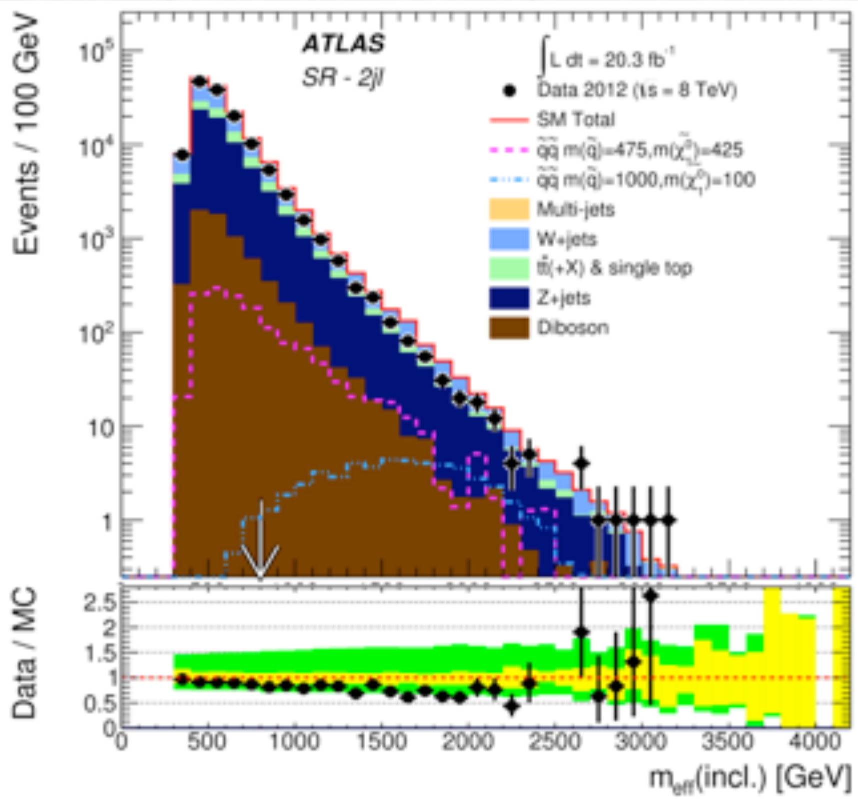
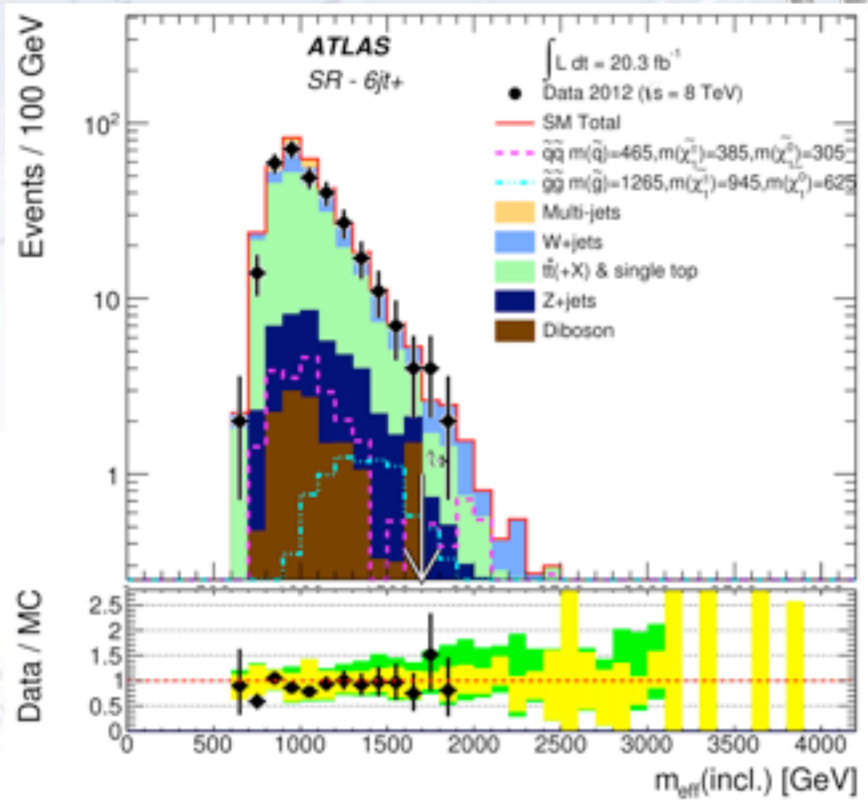
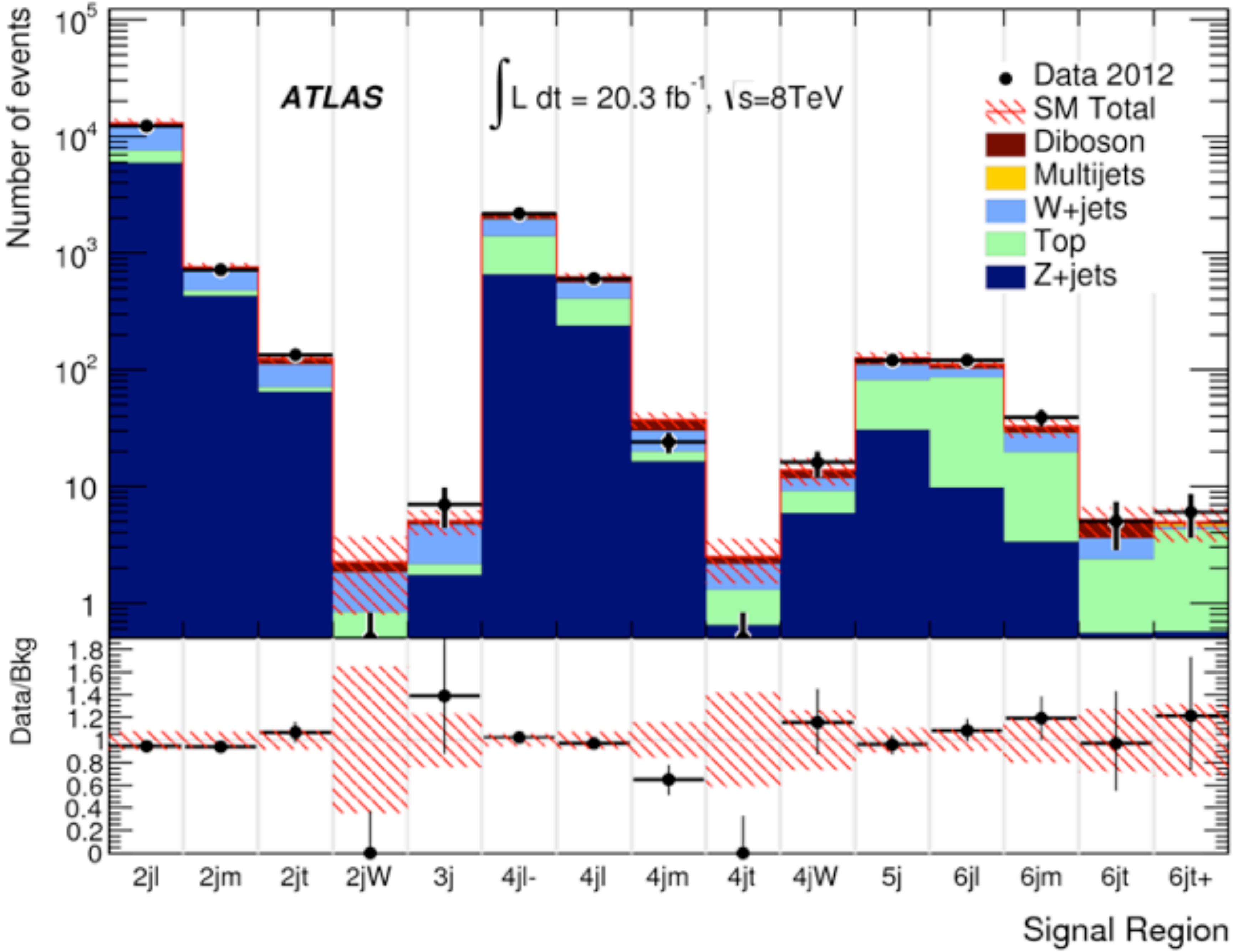
ATLAS inclusive jets + MET

Two example (2j-loose and 6j-very tight) distributions of effective mass:



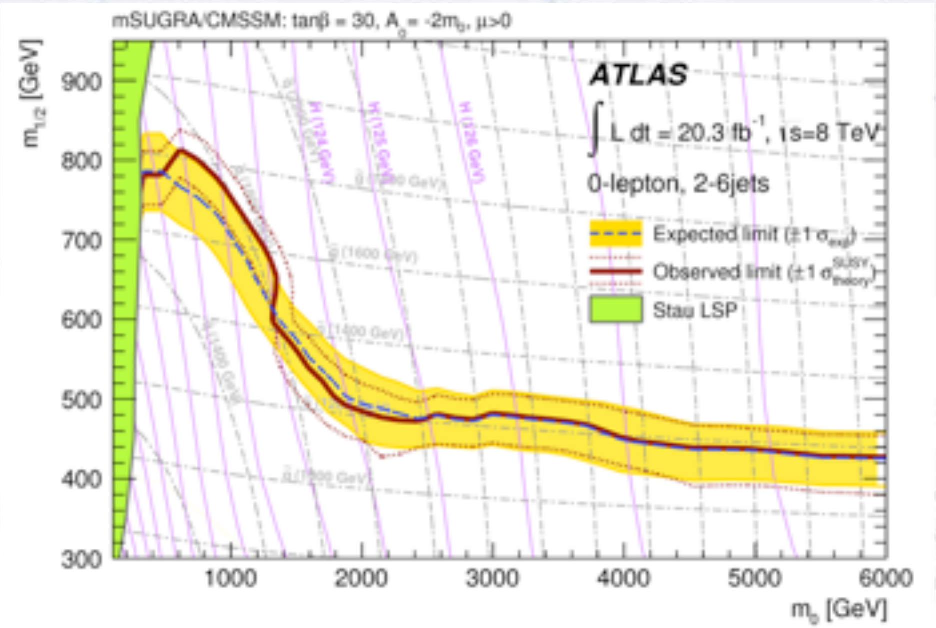


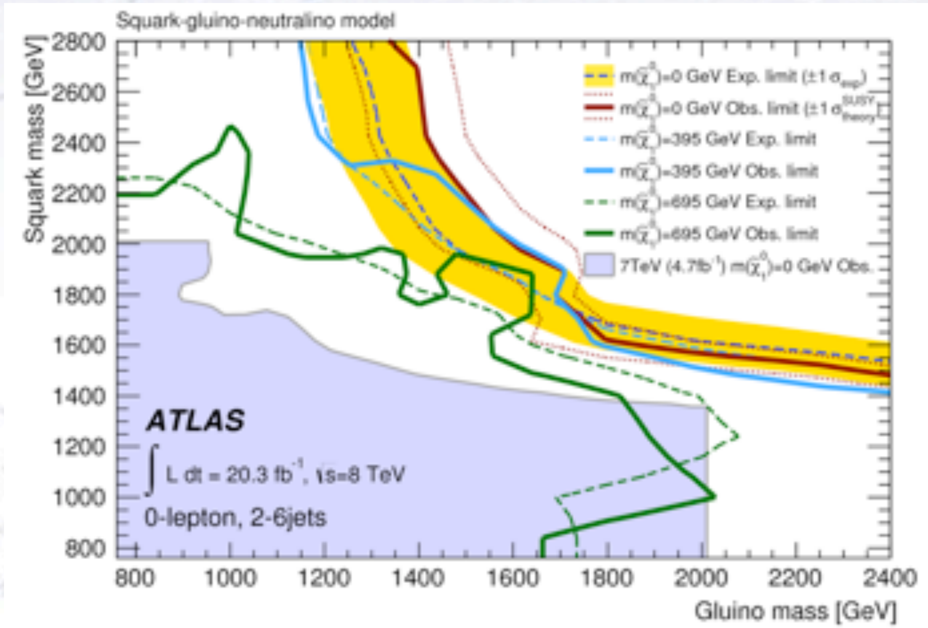
The other 13 Signal Regions also see no excesses...


ATLAS
$\int L\,dt = 20.3\ fb^{-1}$, $\sqrt{s}$=8TeV
Data 2012
SM Total
Diboson
Multijets
W+jets
Top
Z+jets
Number of events
Data/Bkg
2jl
2jm
2jt
2jW
3j
4jl-
4jl
4jm
4jt
4jW
5j
6jl
6jm
6jt
6jt+
Signal Region

ATLAS inclusive jets + MET

Two example limit plots (out of 14), using best exp. SR for each hypothesis:
Left: Exclusion limits for mSUGRA/CMSSM models.
Right: Exclusion limits for a simplified phenomenological MSSM scenario.





In simplified models we exclude gluinos with masses up to ~1.3 TeV and squarks with masses upto 850 GeV.

Note: It is interesting to note the strong dependence on the Higgs mass in the mSUGRA/CMSSM model.

CMS inclusive jets + MET

A loose baseline selection is applied:

- Minimum 3 jets with pT > 50 GeV and |η| < 2.5.
- H_T > 500 GeV.
- Missing H_T > 200 GeV.
- 3 highest pT jets do not align with missing H_T.
- Lepton veto.

$$H_T = \sum_{jets} p_T$$

$$\not{H}_T = |\vec{\not{H}}_T| = |-\sum_{jets} \vec{p}_T|$$

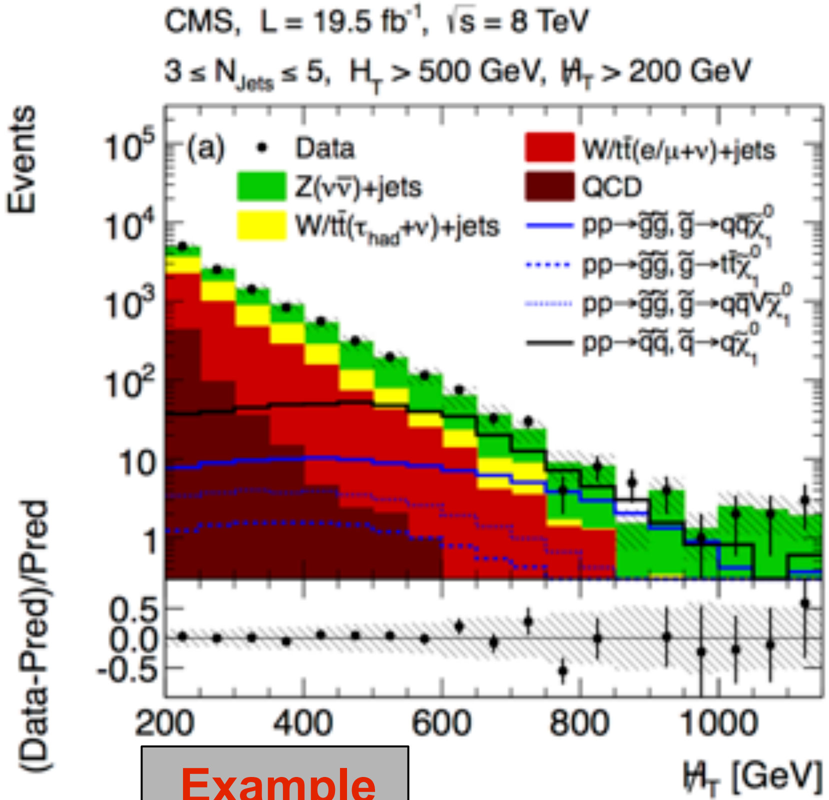
11753 events are divided into **36 exclusive SR** (Njets, H_T and missing H_T).
The background is evaluated in a similar data-driven way to ATLAS.

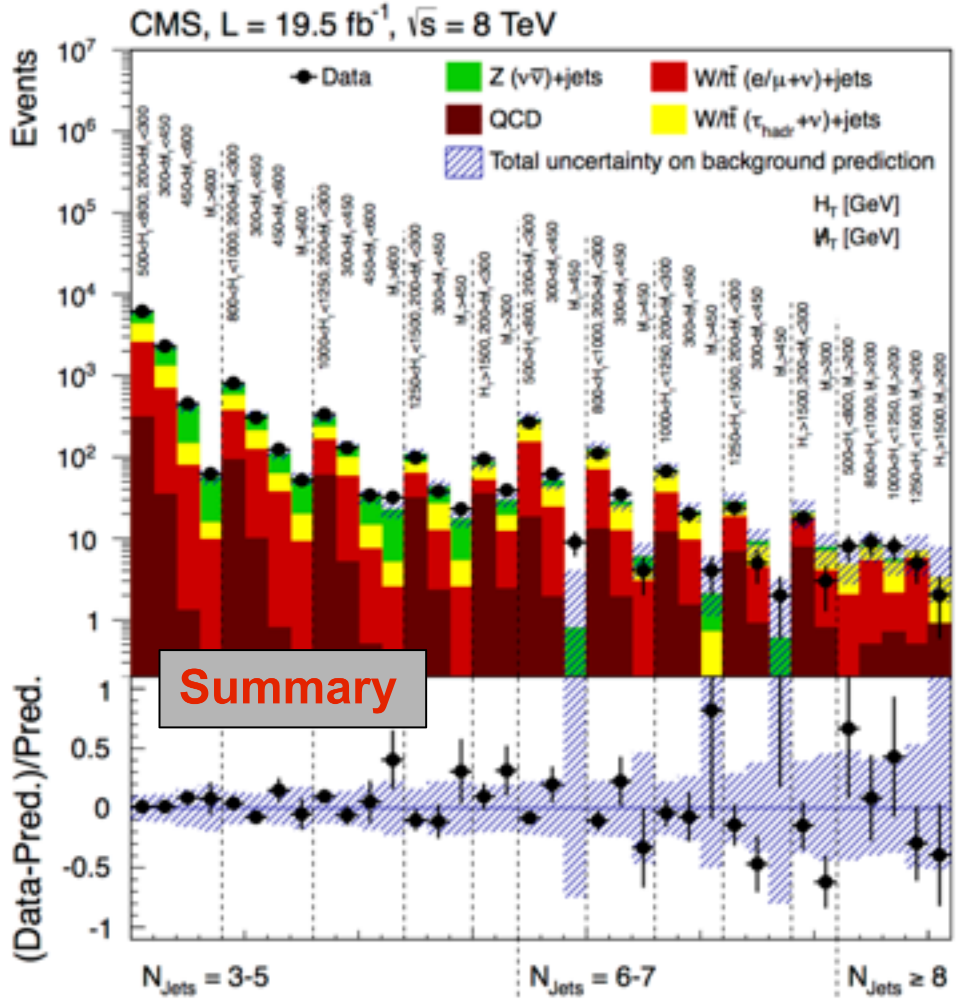
Selection N_{Jets}	Selection H_T [GeV]	Selection $\not{H}_T$ [GeV]	$Z \to \nu\bar{\nu}$	$t\bar{t}/W \to e,\mu+X$	$t\bar{t}/W \to \tau_h+X$	QCD	Total background	Data
3–5	500–800	200–300	1821 ± 387	2211 ± 448	1749 ± 210	307 ± 219	6088 ± 665	6159
3–5	500–800	300–450	994 ± 218	660 ± 133	590 ± 69	35 ± 24	2278 ± 266	2305
3–5	500–800	450–600	273 ± 63	77 ± 17	66.3 ± 9.5	$1.3^{+1.5}_{-1.3}$	418 ± 66	454
3–5	500–800	>600	42 ± 10	9.5 ± 4.0	5.7 ± 1.3	$0.1^{+0.3}_{-0.1}$	57.4 ± 11.2	62
3–5	800–1000	200–300	216 ± 46	278 ± 62	192 ± 33	92 ± 66	777 ± 107	808
3–5	800–1000	300–450	124 ± 26	113 ± 27	84 ± 12	9.9 ± 7.4	330 ± 40	305
3–5	800–1000	450–600	47 ± 11	36.1 ± 9.9	24.1 ± 3.6	$0.8^{+1.3}_{-0.8}$	108 ± 15	124
3–5	800–1000	>600	35.3 ± 8.8	9.0 ± 3.7	10.3 ± 2.0	$0.1^{+0.4}_{-0.1}$	54.8 ± 9.7	52
3–5	1000–1250	200–300	76 ± 17	104 ± 26	66.5 ± 9.9	59 ± 25	305 ± 41	335

....

CMS inclusive jets + MET

The resulting distributions are compared to estimated background:





No excesses are seen, and so limits are set.

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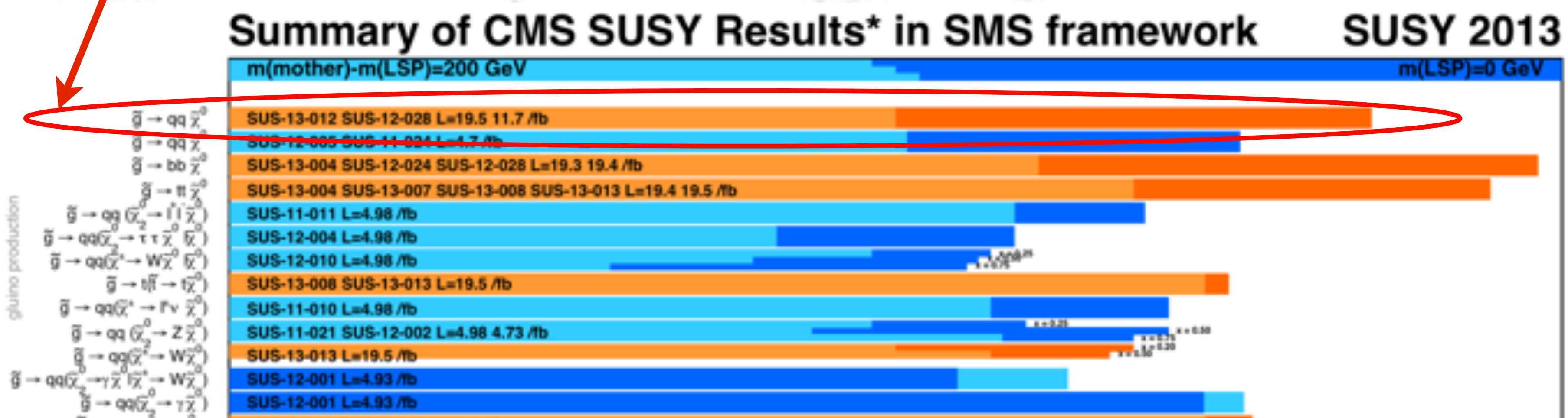
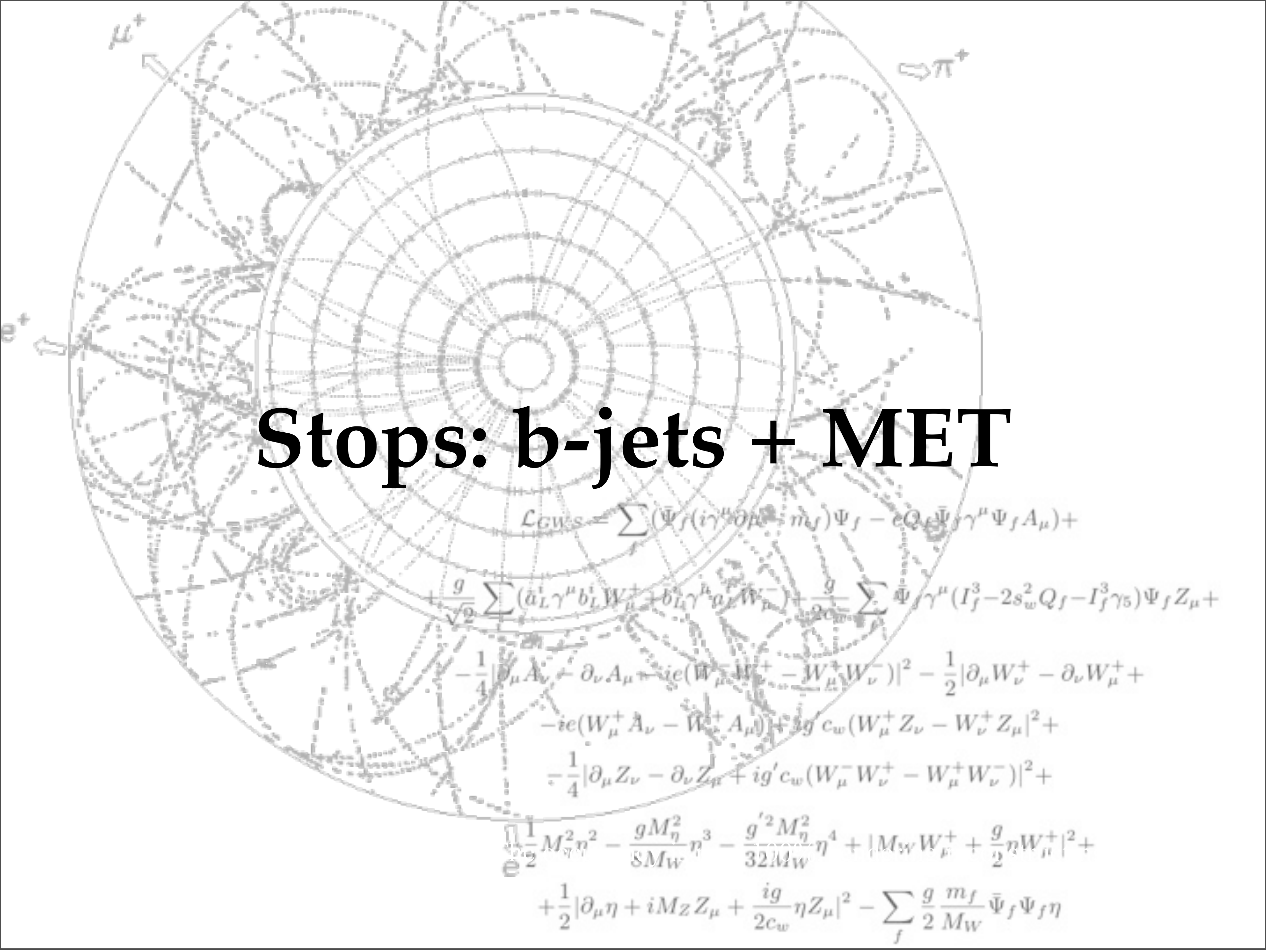
ATLAS & CMS inclusive jets + MET

The ATLAS & CMS searches covered are just one of a whole array with increasing number of leptons and b-tags.
The SUSY scenarios covered in this way are many!

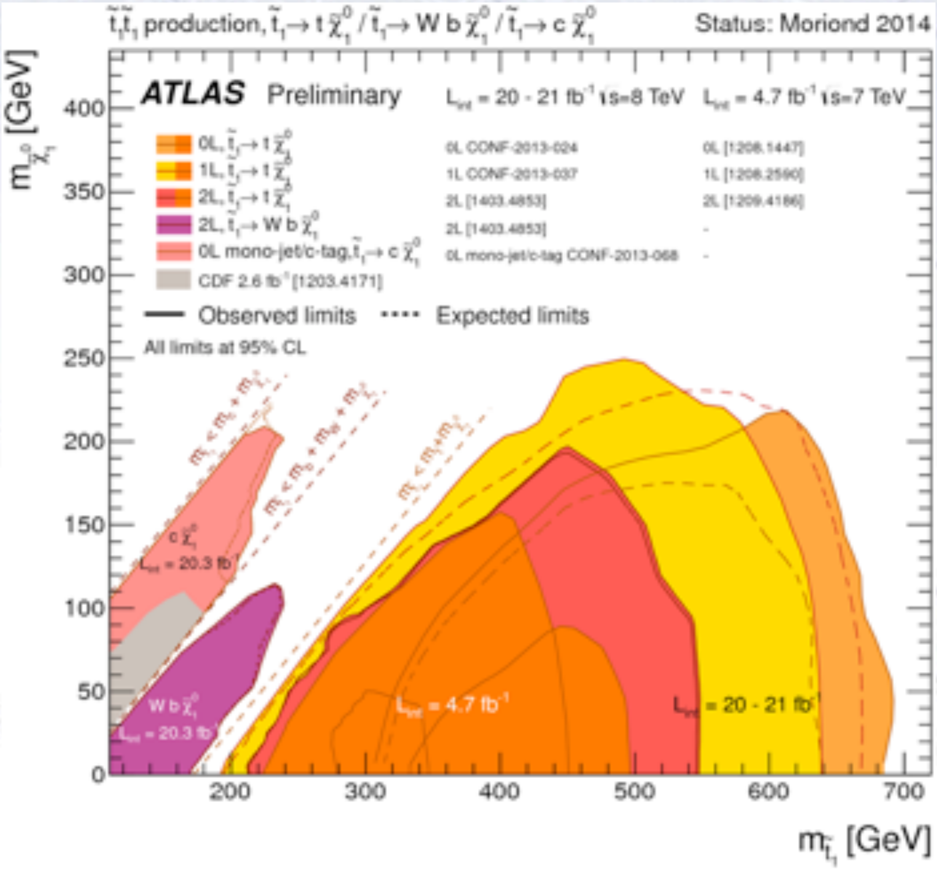


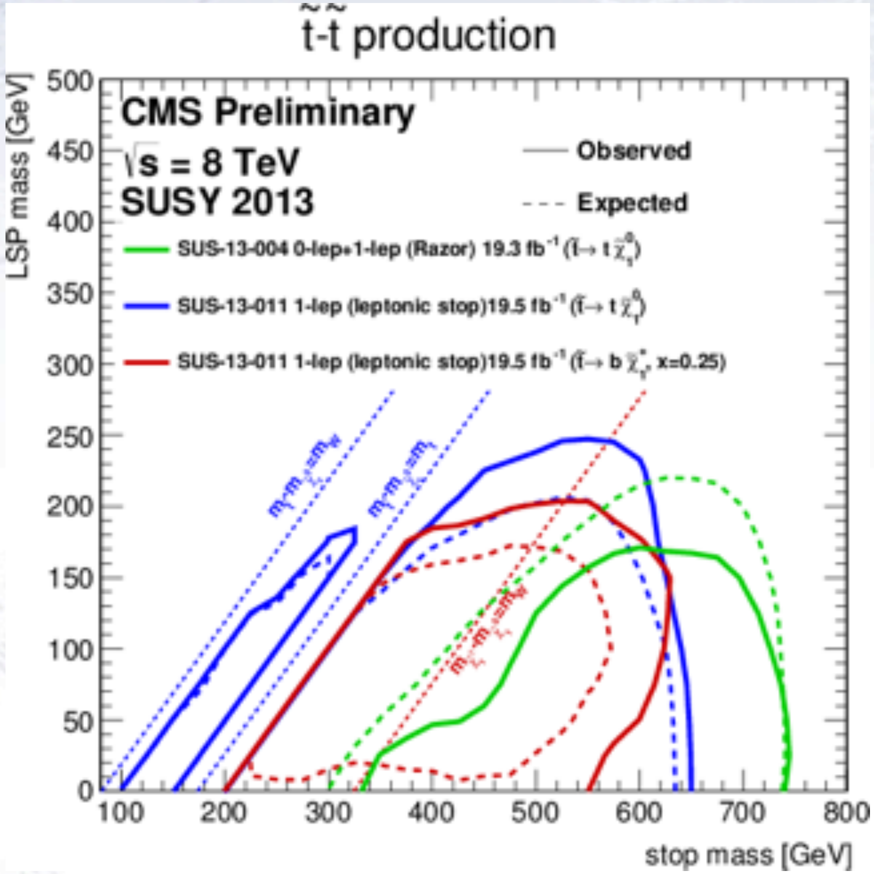


Stops: b-jets + MET

Stops in b-jets + MET

Exclusion plots for direct stop searches are shown (3 ATLAS + 3 CMS analysis).





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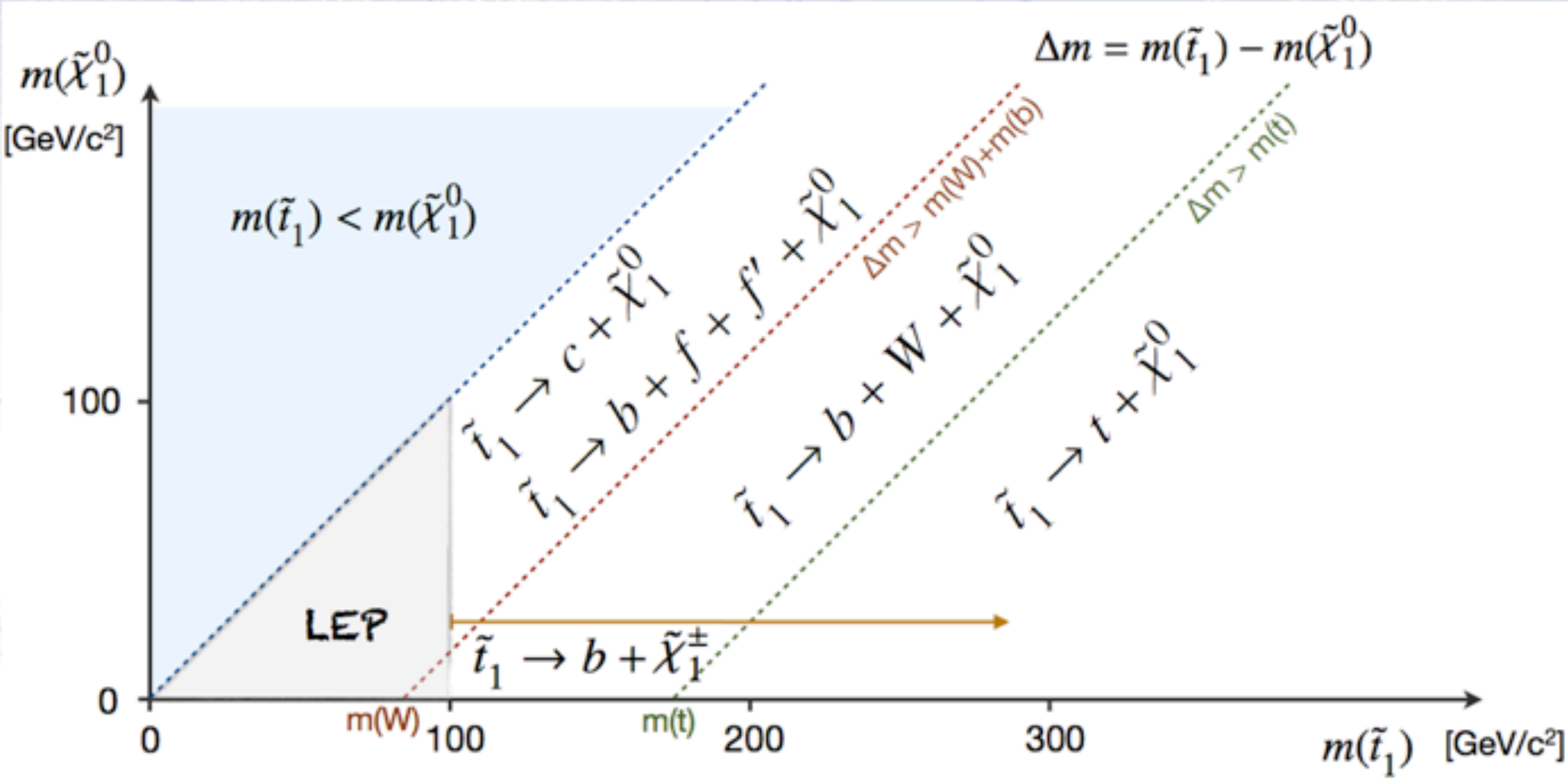

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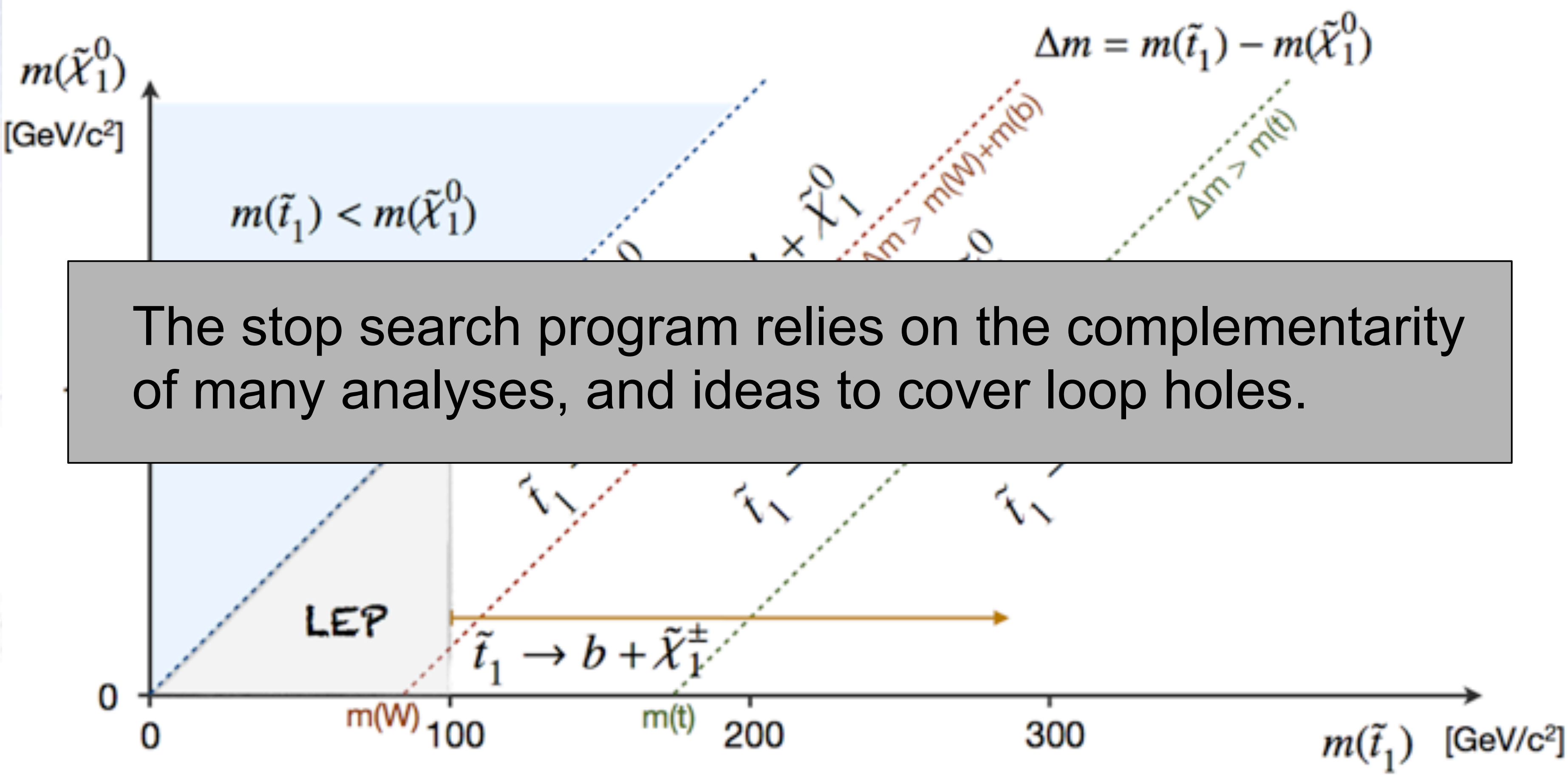

The stop search program relies on the complementarity of many analyses, and ideas to cover loop holes.

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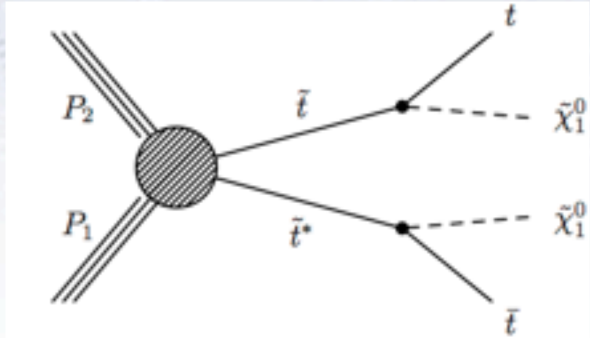
Stops in b-jets + MET

The razor variables M_R and R are defined studying the dijet topology resulting from the production of two squarks, each decaying to a quark and a stable neutralino [CMS SUS-13-004].

$$M_R \equiv \sqrt{(p_{j_1} + p_{j_2})^2 - (p_z^{j_1} + p_z^{j_2})^2}$$

$$M_T^R \equiv \sqrt{\frac{E_T^{miss}(p_T^{j1} + p_T^{j2}) - \vec{E}_T^{miss}\cdot(\vec{p}_T^{\,j1} + \vec{p}_T^{\,j2})}{2}}$$

$$R \equiv \frac{M_T^R}{M_R}$$



Defining **9 signal regions**, the baseline selection is:

- With leptons: $M_R > 300$ GeV, $R^2 > 0.15$
- Without leptons: $M_R > 400$ GeV, $R^2 > 0.25$

M_R and R tends to be a peaking function for signal and a smooth falling function for background.

	Requirements			
Box	lepton	b-tag	kinematic	jet
Dilepton Boxes				
MuEle	≥ 1 tight electron and ≥ 1 loose muon	≥ 1 b-tag	($M_R > 300$ GeV and $R^2 > 0.15$) and ($M_R > 450$ GeV or $R^2 > 0.2$)	≥ 2 jets
MuMu	≥ 1 tight muon and ≥ 1 loose muon	≥ 1 b-tag	($M_R > 300$ GeV and $R^2 > 0.15$) and ($M_R > 450$ GeV or $R^2 > 0.2$)	≥ 2 jets
EleEle	≥ 1 tight electron and ≥ 1 loose electron	≥ 1 b-tag	($M_R > 300$ GeV and $R^2 > 0.15$) and ($M_R > 450$ GeV or $R^2 > 0.2$)	≥ 2 jets
Single Lepton Boxes				
MuMultiJet	≥ 1 tight muon	≥ 1 b-tag	($M_R > 300$ GeV and $R^2 > 0.15$) and ($M_R > 450$ GeV or $R^2 > 0.2$)	≥ 4 jets
MuJet	≥ 1 tight muon	≥ 1 b-tag	($M_R > 300$ GeV and $R^2 > 0.15$) and ($M_R > 450$ GeV or $R^2 > 0.2$)	2 or 3 jets
EleMultiJet	≥ 1 tight electron	≥ 1 b-tag	($M_R > 300$ GeV and $R^2 > 0.15$) and ($M_R > 450$ GeV or $R^2 > 0.2$)	≥ 4 jets
EleJet	≥ 1 tight electron	≥ 1 b-tag	($M_R > 300$ GeV and $R^2 > 0.15$) and ($M_R > 450$ GeV or $R^2 > 0.2$)	2 or 3 jets
Hadronic Boxes				
MultiJet	none	≥ 1 b-tag	($M_R > 400$ GeV and $R^2 > 0.25$) and ($M_R > 550$ GeV or $R^2 > 0.3$)	≥ 4 jets
2b-Jet	none	≥ 2 b-tag	($M_R > 400$ GeV and $R^2 > 0.25$) and ($M_R > 550$ GeV or $R^2 > 0.3$)	2 or 3 jets

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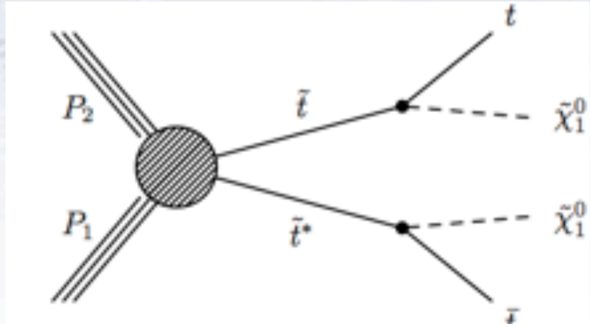
Stops in b-jets + MET

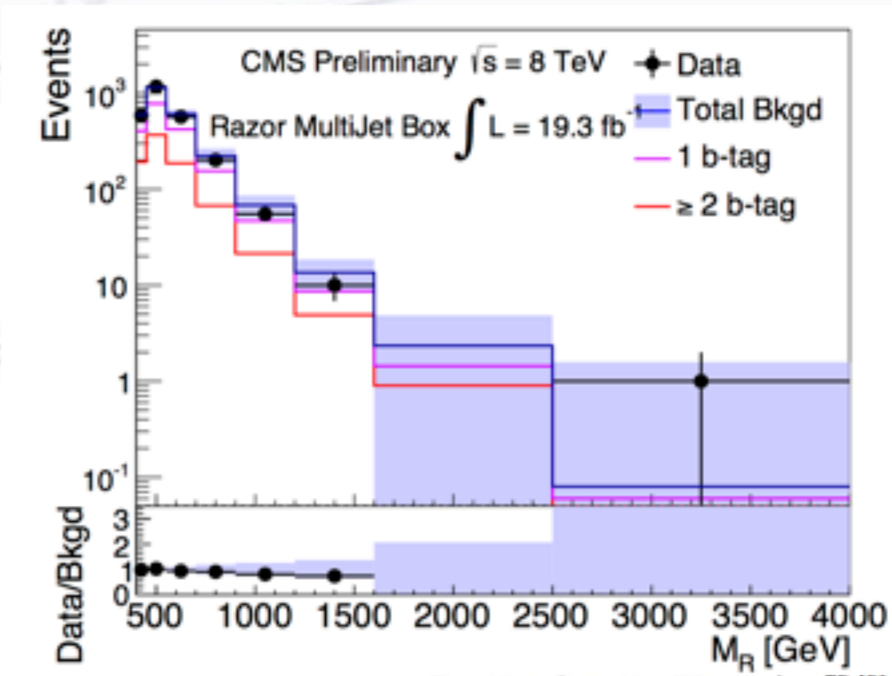
The razor variables M_R and R are defined studying the dijet topology resulting from the production of two squarks, each decaying to a quark and a stable neutralino [CMS SUS-13-004].

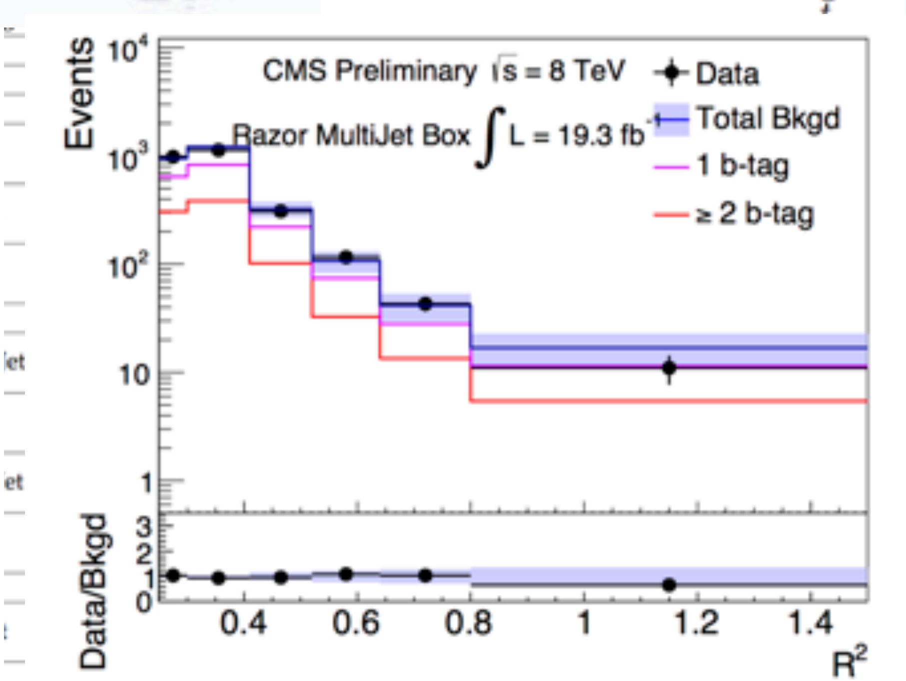
$$M_R \equiv \sqrt{(p_{j_1} + p_{j_2})^2 - (p_z^{j_1} + p_z^{j_2})^2}$$

$$M_T^R \equiv \sqrt{\frac{E_T^{miss}(p_T^{j1} + p_T^{j2}) - \vec{E}_T^{miss} \cdot (\vec{p}_T^{j1} + \vec{p}_T^{j2})}{2}}$$

$$R \equiv \frac{M_T^R}{M_R}$$







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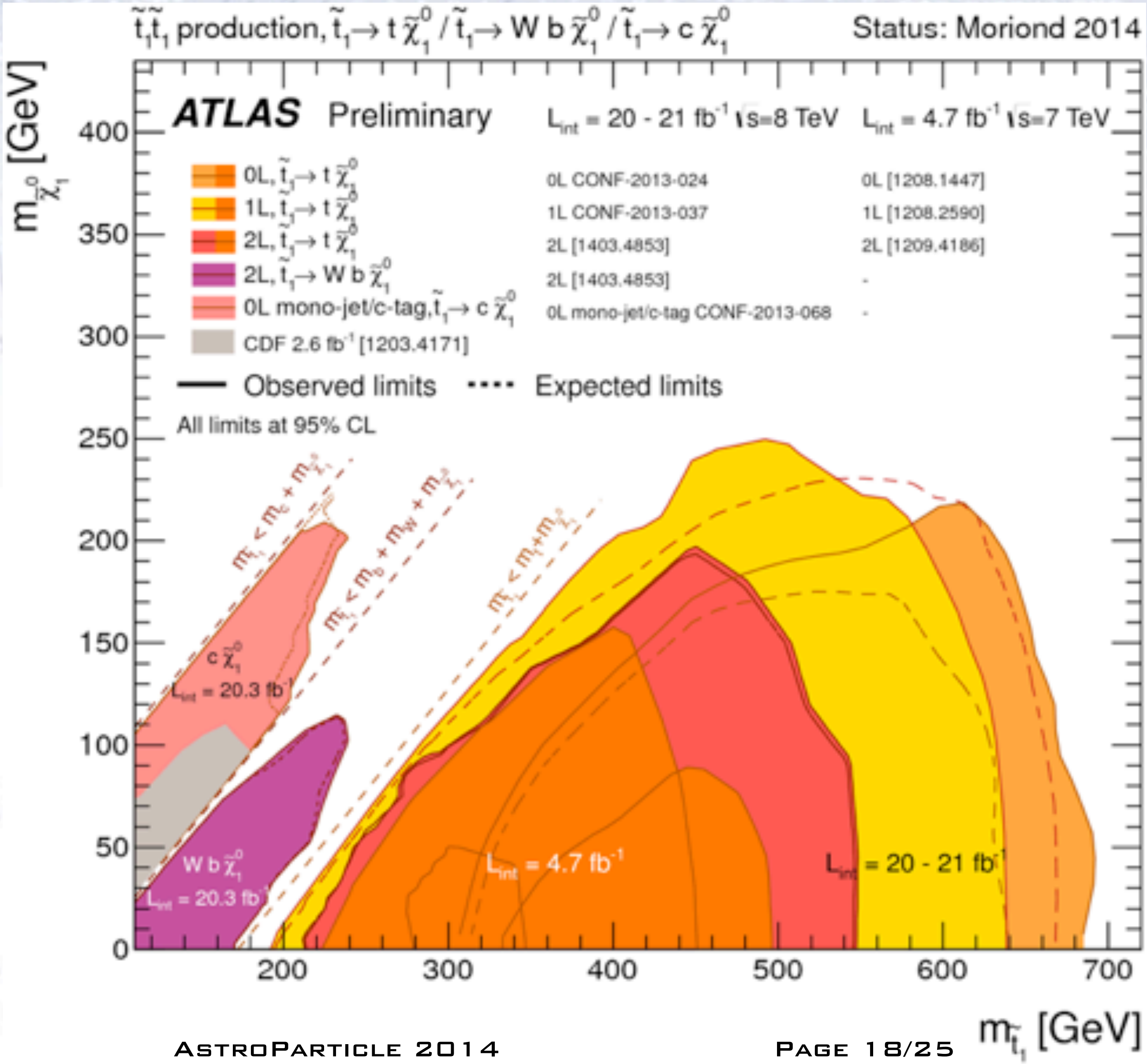
Loopholes in stop searches...



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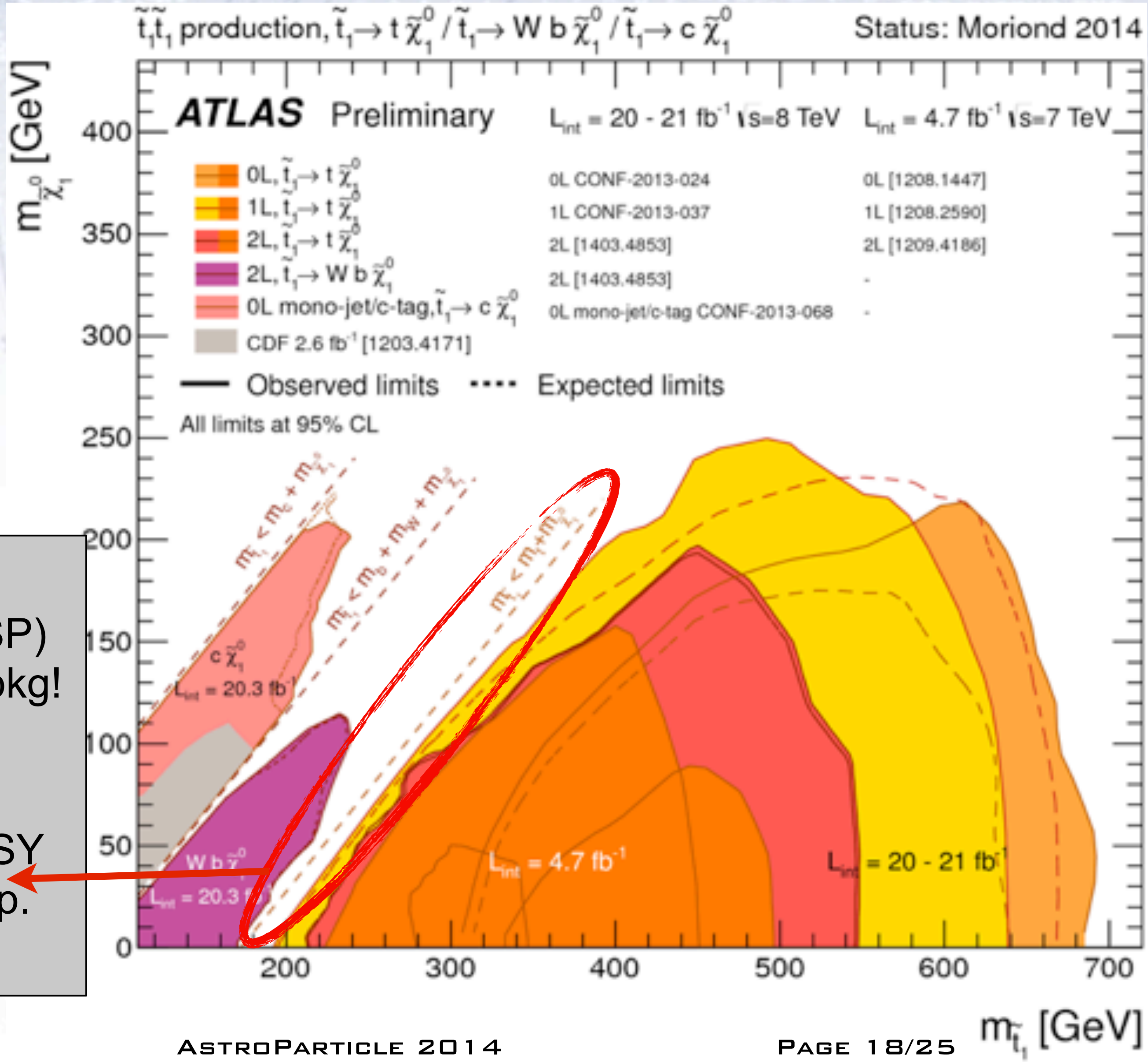


<u>"Stealth stop"</u>
m(stop) ~ m(top) + m(LSP)
⇒ Kinematics like ttbar bkg!

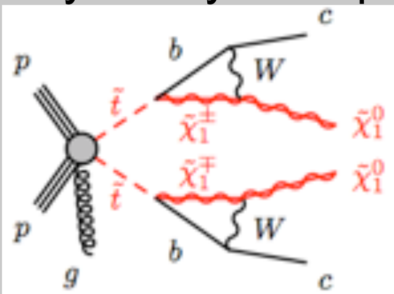
- Shape fits
- BDT analysis
- Search for heavier SUSY particles decaying to stop.
- Other ideas...

Loopholes in stop searches...

Very light stop

m(stop) < m_b + m_W + m(LSP)

⇒ 4-body decay w. c-quarks!



- Monojet + MET
- c-tag + MET

"Stealth stop"

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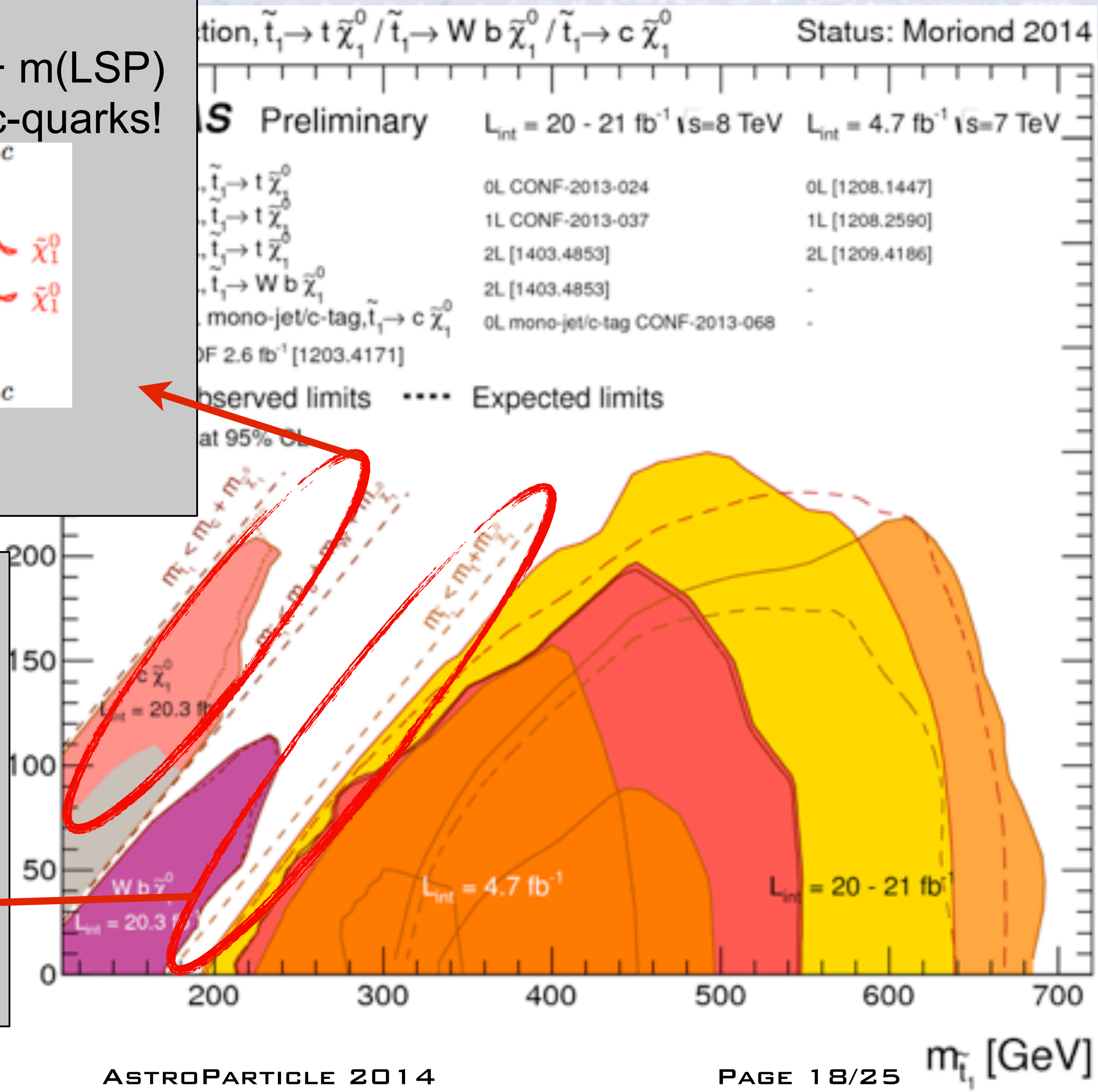

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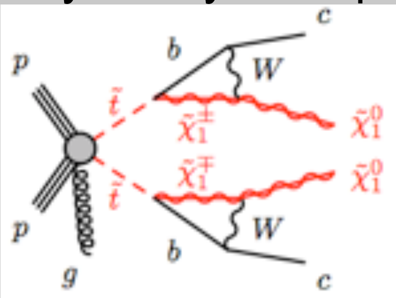
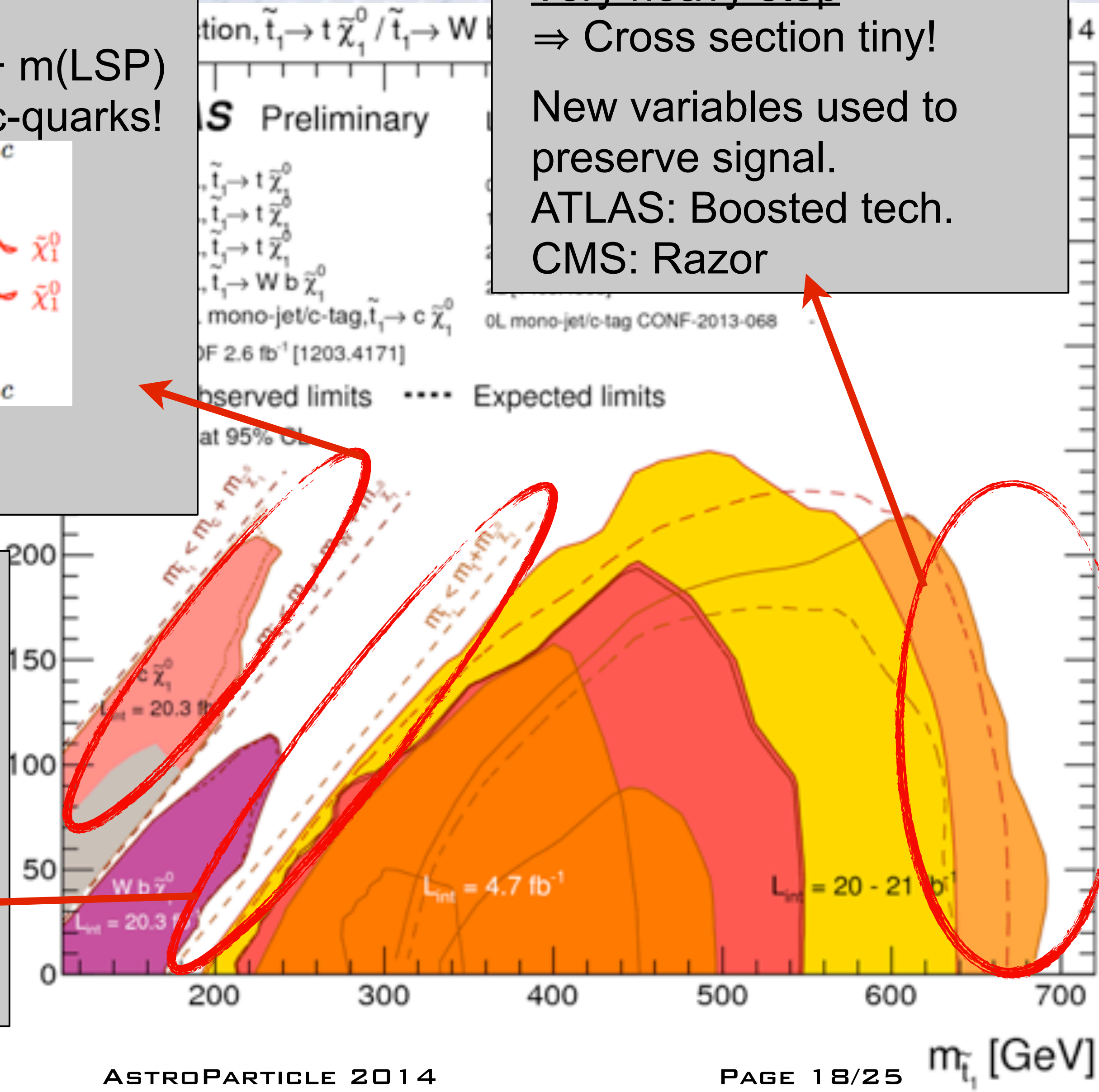


- Monojet + MET
- c-tag + MET

Very heavy stop
⇒ Cross section tiny!

New variables used to preserve signal.
ATLAS: Boosted tech.
CMS: Razor



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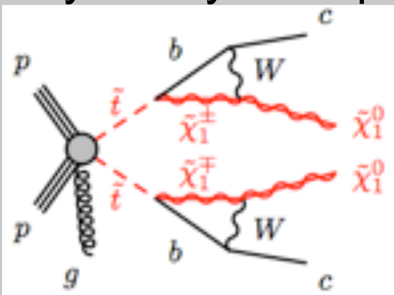

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Very heavy stop

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"Stealth stop"

m(stop) ~ m(top) + m(LSP)

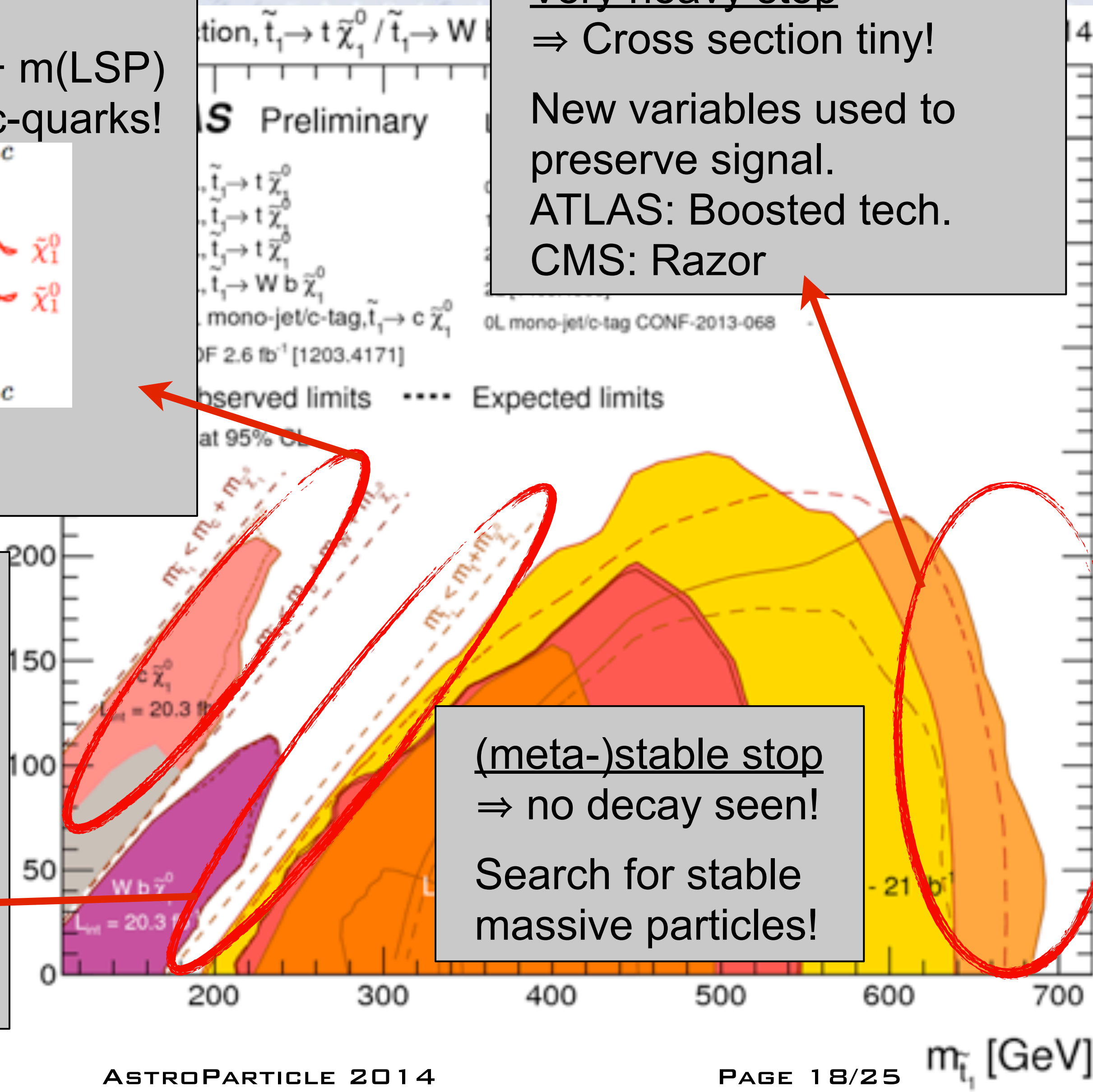
⇒ Kinematics like ttbar bkg!

- Shape fits
- BDT analysis
- Search for heavier SUSY particles decaying to stop.
- Other ideas...

(meta-)stable stop

⇒ no decay seen!

Search for stable massive particles!



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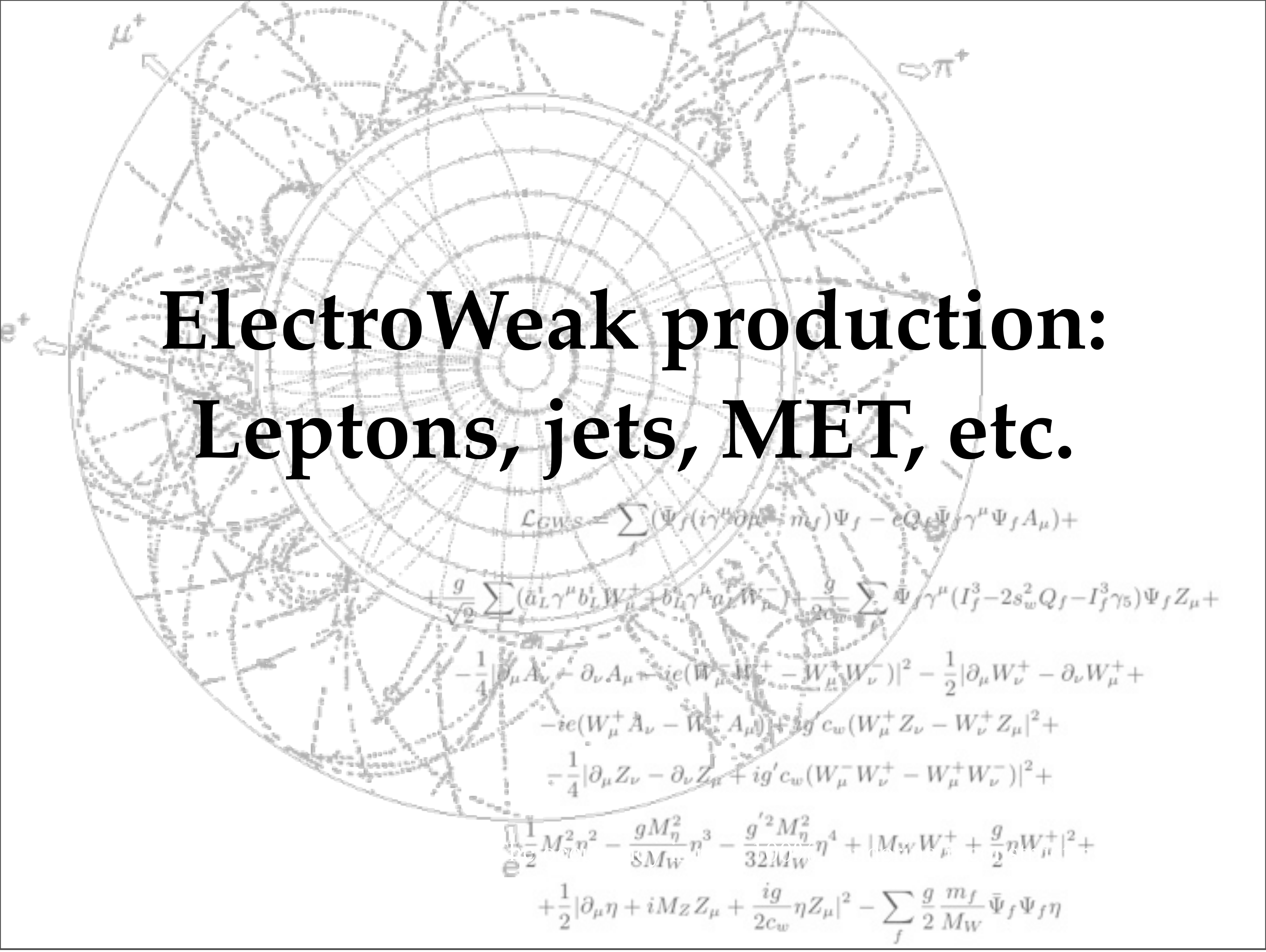


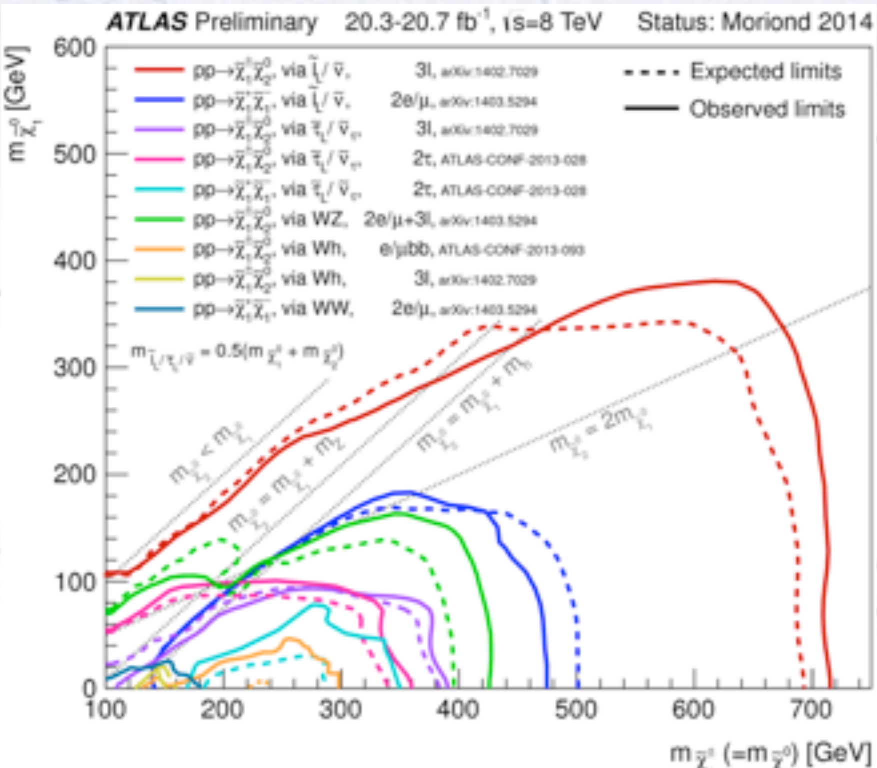
ElectroWeak production: Leptons, jets, MET, etc.

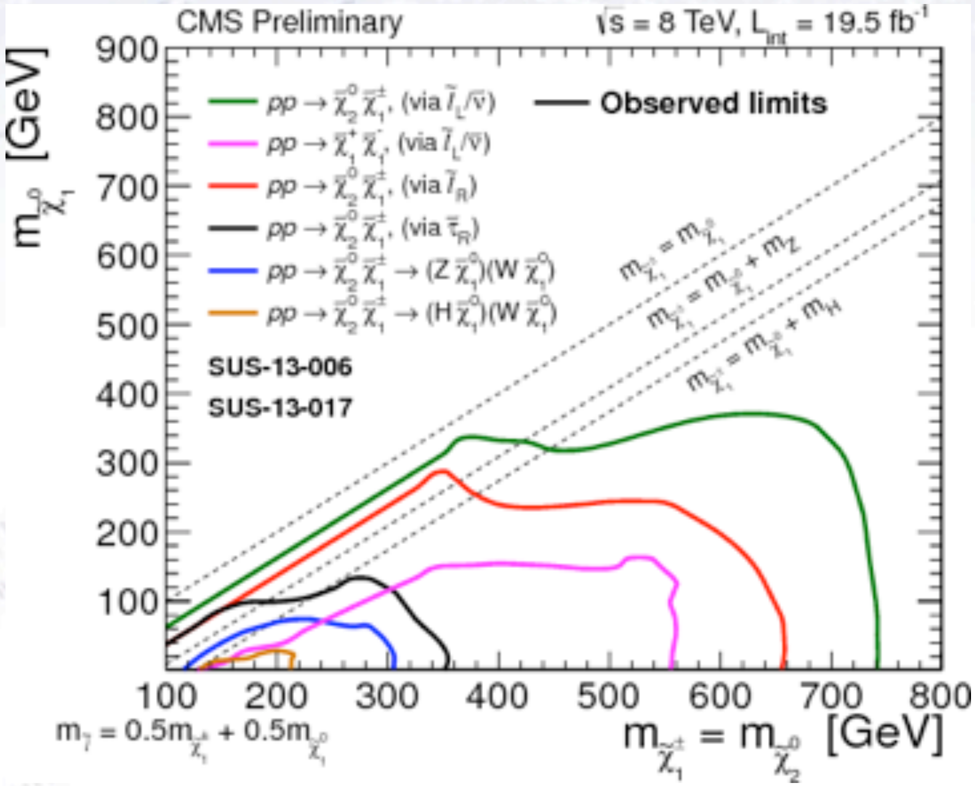
ElectroWeak SUSY production

Searching for charginos, neutralinos, and sleptons

EW SUSY provides "toughest" but perhaps also most interesting SUSY window.

With assumptions, there are 9 parameters: $M_1, M_2, \mu, \tan\beta, m^2_{\tilde{e}_L}, m^2_{\tilde{e}_R}, m^2_{\tilde{\tau}_L}, m^2_{\tilde{\tau}_R}, \theta_{\tilde{\tau}}$



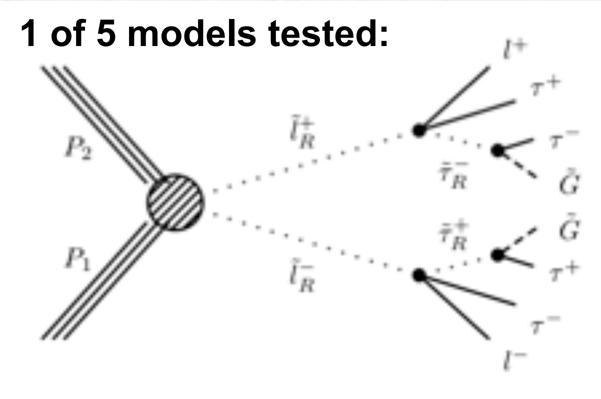


Cascade decays to LSP yields many interesting SM particles: Leptons, W/Z, Higgs

Maximal reach so far is ~700 GeV, dominated by multilepton channels.

Multi-lepton + MET

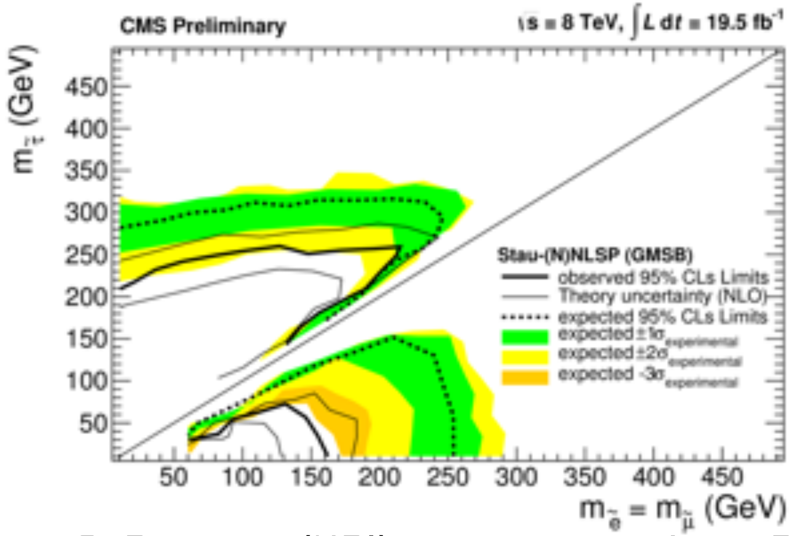
1 of 5 models tested:



3 leptons (e,μ,τ) are required to have $p_T > 20, 10, 20$ GeV (1st, 2nd, and τ_h).

Candidates are then classified according to: Nlepton, Ntau, b-tag, N OSSF, on/off Z, H_T, E_T^{miss}

Largest discrepancy is in 4 lepton, OSSF1, off-Z, one τ_h, no b-tag and $H_T < 200$ GeV: **3** (0.60 ± 0.24), **4** (2.1 ± 0.5) and **15** (7.5 ± 2.0) events observed (expected).



4 lepton final states. Similar table for 3 lepton final states

≥4 leptons $H_T > 200$ GeV	$m_{\ell^+\ell^-}$	E_T^{miss} (GeV)	$N_{\tau_h}=0, N_b=0$ Obs.	Exp.	$N_{\tau_h}=1, N_b=0$ Obs.	Exp.	$N_{\tau_h}=0, N_b\geq1$ Obs.	Exp.	$N_{\tau_h}=1, N_b\geq1$ Obs.	Exp.
OSSF0	—	(100, ∞)	0	$0.01^{+0.03}_{-0.01}$	0	$0.01^{+0.06}_{-0.01}$	0	$0.02^{+0.04}_{-0.02}$	0	0.11 ± 0.08
OSSF0	—	(50, 100)	0	$0.00^{+0.02}_{-0.00}$	0	$0.01^{+0.06}_{-0.01}$	0	$0.00^{+0.03}_{-0.00}$	0	0.12 ± 0.07
OSSF0	—	(0, 50)	0	$0.00^{+0.02}_{-0.00}$	0	$0.07^{+0.10}_{-0.07}$	0	$0.00^{+0.02}_{-0.00}$	0	0.02 ± 0.02
OSSF1	Off-Z	(100, ∞)	0	$0.01^{+0.02}_{-0.01}$	1	0.25 ± 0.11	0	0.13 ± 0.08	0	0.12 ± 0.12
OSSF1	On-Z	(100, ∞)	1	0.10 ± 0.06	0	0.50 ± 0.27	0	0.42 ± 0.22	0	0.42 ± 0.19
OSSF1	Off-Z	(50, 100)	0	0.07 ± 0.06	1	0.29 ± 0.13	0	0.04 ± 0.04	0	0.23 ± 0.13
OSSF1	On-Z	(50, 100)	0	0.23 ± 0.11	1	0.70 ± 0.31	0	0.23 ± 0.13	1	0.34 ± 0.16
OSSF1	Off-Z	(0, 50)	0	$0.02^{+0.03}_{-0.02}$	0	0.27 ± 0.12	0	$0.03^{+0.04}_{-0.03}$	0	0.31 ± 0.15
OSSF1	On-Z	(0, 50)	0	0.20 ± 0.08	0	1.3 ± 0.5	0	0.06 ± 0.04	1	0.49 ± 0.19
OSSF2	Off-Z	(100, ∞)	0	$0.01^{+0.02}_{-0.01}$	—	—	0	$0.01^{+0.06}_{-0.01}$	—	—
OSSF2	On-Z	(100, ∞)	1	$0.15^{+0.16}_{-0.15}$	—	—	0	0.34 ± 0.18	—	—
OSSF2	Off-Z	(50, 100)	0	0.03 ± 0.02	—	—	0	0.13 ± 0.09	—	—
OSSF2	On-Z	(50, 100)	0	0.80 ± 0.40	—	—	0	0.36 ± 0.19	—	—
OSSF2	Off-Z	(0, 50)	1	0.27 ± 0.13	—	—	0	0.08 ± 0.05	—	—
OSSF2	On-Z	(0, 50)	5	7.4 ± 3.5	—	—	2	0.80 ± 0.40	—	—

≥4 leptons $H_T < 200$ GeV	$m_{\ell^+\ell^-}$	E_T^{miss} (GeV)	$N_{\tau_h}=0, N_b=0$ Obs.	Exp.	$N_{\tau_h}=1, N_b=0$ Obs.	Exp.	$N_{\tau_h}=0, N_b\geq1$ Obs.	Exp.	$N_{\tau_h}=1, N_b\geq1$ Obs.	Exp.
OSSF0	—	(100, ∞)	0	0.11 ± 0.08	0	0.17 ± 0.10	0	$0.03^{+0.04}_{-0.03}$	0	0.04 ± 0.04
OSSF0	—	(50, 100)	0	$0.01^{+0.03}_{-0.01}$	2	0.70 ± 0.33	0	$0.00^{+0.02}_{-0.00}$	0	0.28 ± 0.16
OSSF0	—	(0, 50)	0	$0.01^{+0.02}_{-0.01}$	1	0.7 ± 0.3	0	$0.00^{+0.02}_{-0.00}$	0	0.13 ± 0.08
OSSF1	Off-Z	(100, ∞)	0	0.06 ± 0.04	3	0.60 ± 0.24	0	$0.02^{+0.04}_{-0.02}$	0	0.32 ± 0.20
OSSF1	On-Z	(100, ∞)	1	[illegible]	2	2.5 ± 0.5	1	0.38 ± 0.20	0	0.21 ± 0.10
OSSF1	Off-Z	(50, 100)	0	0.18 ± 0.06	4	2.1 ± 0.5	0	0.16 ± 0.08	1	0.45 ± 0.24
OSSF1	On-Z	(50, 100)	2	1.2 ± 0.3	9	9.6 ± 1.6	2	0.42 ± 0.23	0	0.50 ± 0.16
OSSF1	Off-Z	(0, 50)	2	0.46 ± 0.18	15	7.5 ± 2.0	0	0.09 ± 0.06	0	0.70 ± 0.31
OSSF1	On-Z	(0, 50)	4	3.0 ± 0.8	41	40 ± 10	1	0.31 ± 0.15	2	1.50 ± 0.47
OSSF2	Off-Z	(100, ∞)	0	0.04 ± 0.03	—	—	0	0.05 ± 0.04	—	—
OSSF2	On-Z	(100, ∞)	0	0.34 ± 0.15	—	—	0	0.46 ± 0.25	—	—
OSSF2	Off-Z	(50, 100)	2	0.18 ± 0.13	—	—	0	$0.02^{+0.03}_{-0.02}$	—	—
OSSF2	On-Z	(50, 100)	4	3.9 ± 2.5	—	—	0	0.50 ± 0.21	—	—
OSSF2	Off-Z	(0, 50)	7	8.9 ± 2.4	—	—	1	0.23 ± 0.09	—	—
OSSF2	On-Z	(0, 50)	*156	160 ± 34	—	—	4	2.9 ± 0.8	—	—

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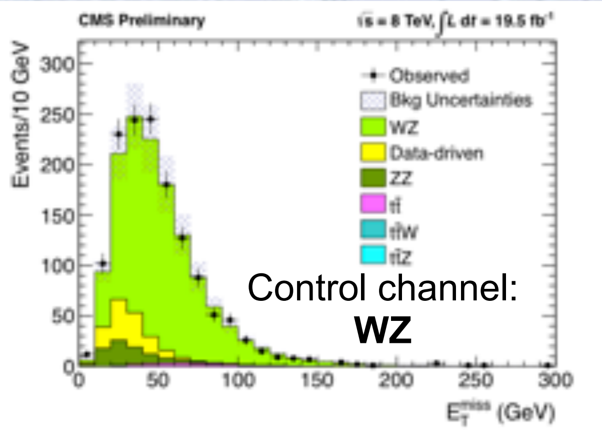
Multi-lepton + MET



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4 lepton final states. Similar table for 3 lepton final states

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OSSF0	—	(100, ∞)	0	$0.01^{+0.03}_{-0.01}$	0	$0.01^{+0.06}_{-0.01}$	0	$0.02^{+0.04}_{-0.02}$	0	0.11 ± 0.08
OSSF0	—	(50, 100)	0	$0.00^{+0.02}_{-0.00}$	0	$0.01^{+0.06}_{-0.01}$	0	$0.00^{+0.03}_{-0.00}$	0	0.12 ± 0.07
OSSF0	—	(0, 50)	0	$0.00^{+0.02}_{-0.00}$	0	$0.07^{+0.10}_{-0.07}$	0	$0.00^{+0.02}_{-0.00}$	0	0.02 ± 0.02
OSSF1	Off-Z	(100, ∞)	0	$0.01^{+0.02}_{-0.01}$	1	0.25 ± 0.11	0	0.13 ± 0.08	0	0.12 ± 0.12
OSSF1	On-Z	(100, ∞)	1	0.10 ± 0.06	0	0.50 ± 0.27	0	0.42 ± 0.22	0	0.42 ± 0.19
OSSF1	Off-Z	(50, 100)	0	0.07 ± 0.06	1	0.29 ± 0.13	0	0.04 ± 0.04	0	0.23 ± 0.13
OSSF1	On-Z	(50, 100)	0	0.23 ± 0.11	1	0.70 ± 0.31	0	0.23 ± 0.13	1	0.34 ± 0.16
OSSF1	Off-Z	(0, 50)	0	$0.02^{+0.03}_{-0.02}$	0	0.27 ± 0.12	0	$0.03^{+0.04}_{-0.03}$	0	0.31 ± 0.15
OSSF1	On-Z	(0, 50)	0	0.20 ± 0.08	0	1.3 ± 0.5	0	0.06 ± 0.04	1	0.49 ± 0.19
OSSF2	Off-Z	(100, ∞)	0	$0.01^{+0.02}_{-0.01}$	—	—	0	$0.01^{+0.06}_{-0.01}$	—	—
OSSF2	On-Z	(100, ∞)	1	$0.15^{+0.16}_{-0.15}$	—	—	0	0.34 ± 0.18	—	—
OSSF2	Off-Z	(50, 100)	0	0.03 ± 0.02	—	—	0	0.13 ± 0.09	—	—
OSSF2	On-Z	(50, 100)	0	0.80 ± 0.40	—	—	0	0.36 ± 0.19	—	—
OSSF2	Off-Z	(0, 50)	1	0.27 ± 0.13	—	—	0	0.08 ± 0.05	—	—
OSSF2	On-Z	(0, 50)	5	7.4 ± 3.5	—	—	2	0.80 ± 0.40	—	—
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OSSF0	—	(100, ∞)	0	0.11 ± 0.08	0	0.17 ± 0.10	0	$0.03^{+0.04}_{-0.03}$	0	0.04 ± 0.04
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OSSF0	—	(0, 50)	0	$0.01^{+0.02}_{-0.01}$	1	0.7 ± 0.3	0	$0.00^{+0.02}_{-0.00}$	0	0.13 ± 0.08
OSSF1	Off-Z	(100, ∞)	0	0.06 ± 0.04	3	0.60 ± 0.24	0	$0.02^{+0.04}_{-0.02}$	0	0.32 ± 0.20
OSSF1	On-Z	(100, ∞)	1	[illegible]	2	2.5 ± 0.5	1	0.38 ± 0.20	0	0.21 ± 0.10
OSSF1	Off-Z	(50, 100)	0	0.18 ± 0.06	4	2.1 ± 0.5	0	0.16 ± 0.08	1	0.45 ± 0.24
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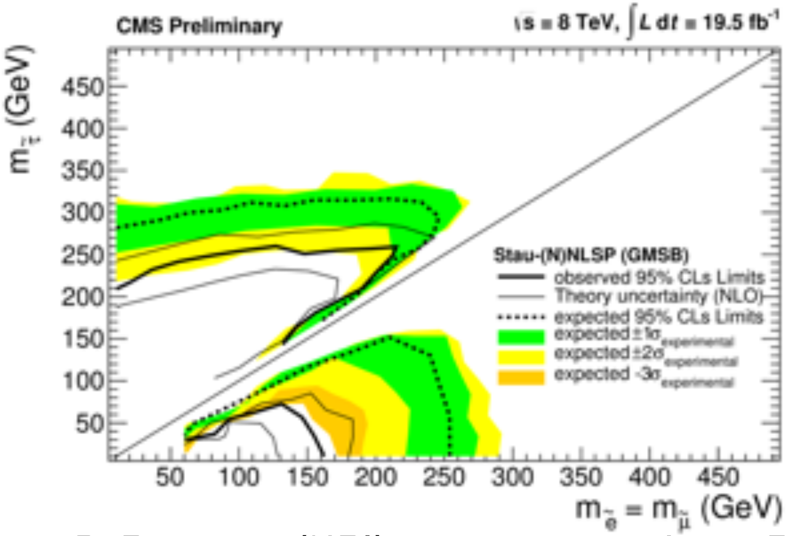
OSSF2	Off-Z	(100, ∞)	0	0.04 ± 0.03	—	—	0	0.05 ± 0.04	—	—
OSSF2	On-Z	(100, ∞)	0	0.34 ± 0.15	—	—	0	0.46 ± 0.25	—	—
OSSF2	Off-Z	(50, 100)	2	0.18 ± 0.13	—	—	0	$0.02^{+0.03}_{-0.02}$	—	—
OSSF2	On-Z	(50, 100)	4	3.9 ± 2.5	—	—	0	0.50 ± 0.21	—	—
OSSF2	Off-Z	(0, 50)	7	8.9 ± 2.4	—	—	1	0.23 ± 0.09	—	—
OSSF2	On-Z	(0, 50)	*156	160 ± 34	—	—	4	2.9 ± 0.8	—	—



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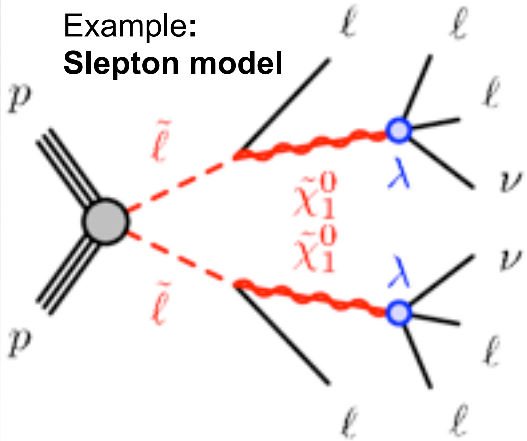
4-lepton + MET

Analysis covers 5 RPV and 3 RPC models (along with 2 GGM models).

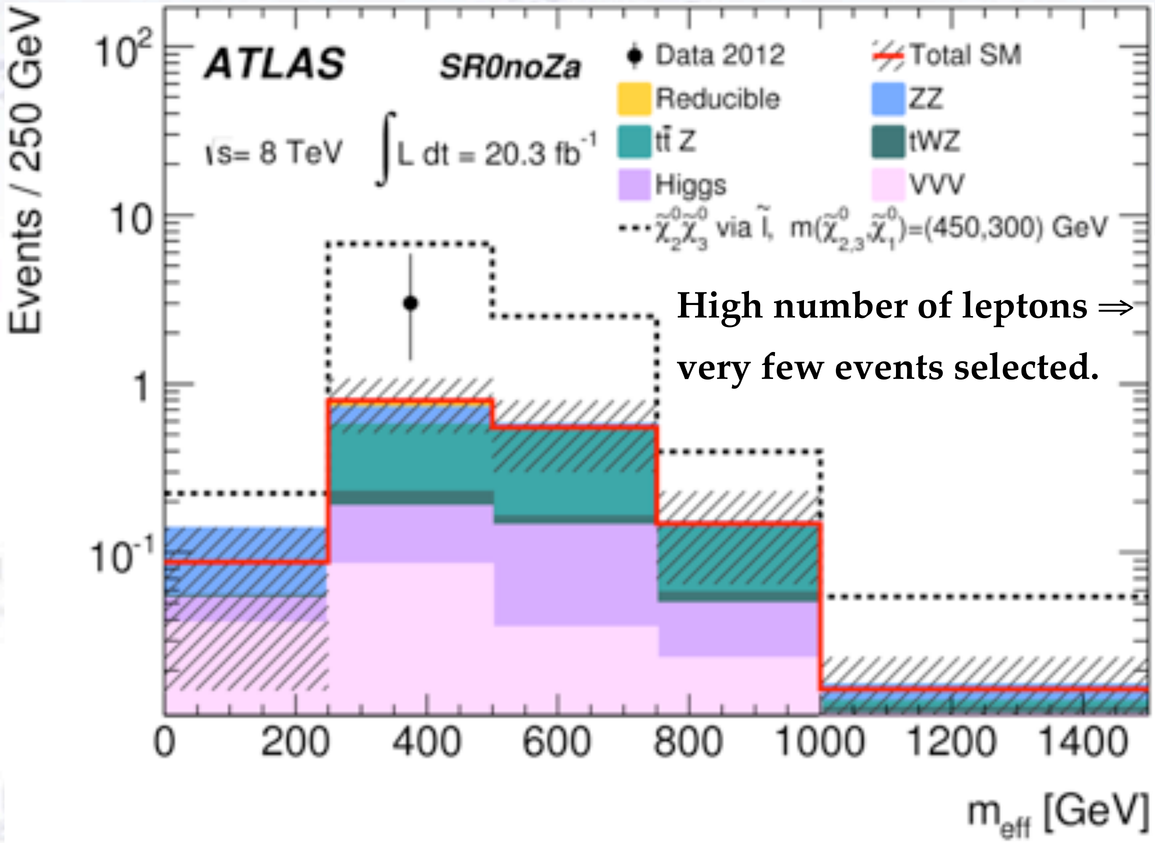


RPV Model NLSP	Decay
Chargino	$\tilde\chi_1^\pm \to W^{\pm(*)}\,\tilde\chi_1^0$
L-slepton	$\tilde\ell_L \to \ell\,\tilde\chi_1^0$
	$\tilde\tau_L \to \tau\,\tilde\chi_1^0$
R-slepton	$\tilde\ell_R \to \ell\,\tilde\chi_1^0$
	$\tilde\tau_R \to \tau\,\tilde\chi_1^0$
Sneutrino	$\tilde\nu_\ell \to \nu_\ell\,\tilde\chi_1^0$
	$\tilde\nu_\tau \to \nu_\tau\,\tilde\chi_1^0$
Gluino	$\tilde g \to q\bar q\,\tilde\chi_1^0$
	$q \in u, d, s, c$

RPC Model	Decay
R-slepton	$\tilde\chi_{2,3}^0 \to \ell^\pm \tilde\ell_R^\mp \to \ell^+\ell^-\tilde\chi_1^0$
Stau	$\tilde\chi_{2,3}^0 \to \tau^\mp \tilde\tau_1^\pm \to \tau^\mp\tau^\pm\tilde\chi_1^0$
Z	$\tilde\chi_{2,3}^0 \to Z^{(*)}\tilde\chi_1^0 \to \ell^\pm\ell^\mp\tilde\chi_1^0$

9 Signal Regions are defined according the N leptons, Z-veto and MET.

Shown is the 4^+ lepton + MET > 50 GeV Signal Region



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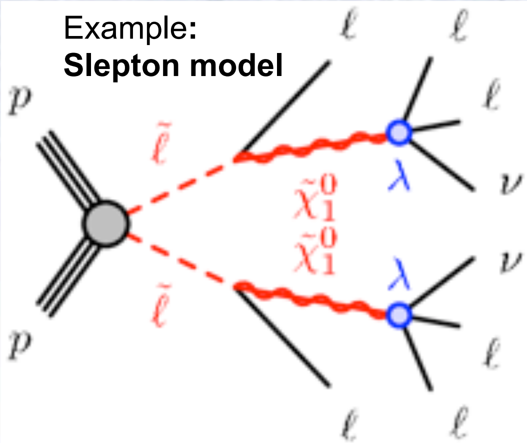
1405.5086

4-lepton + MET

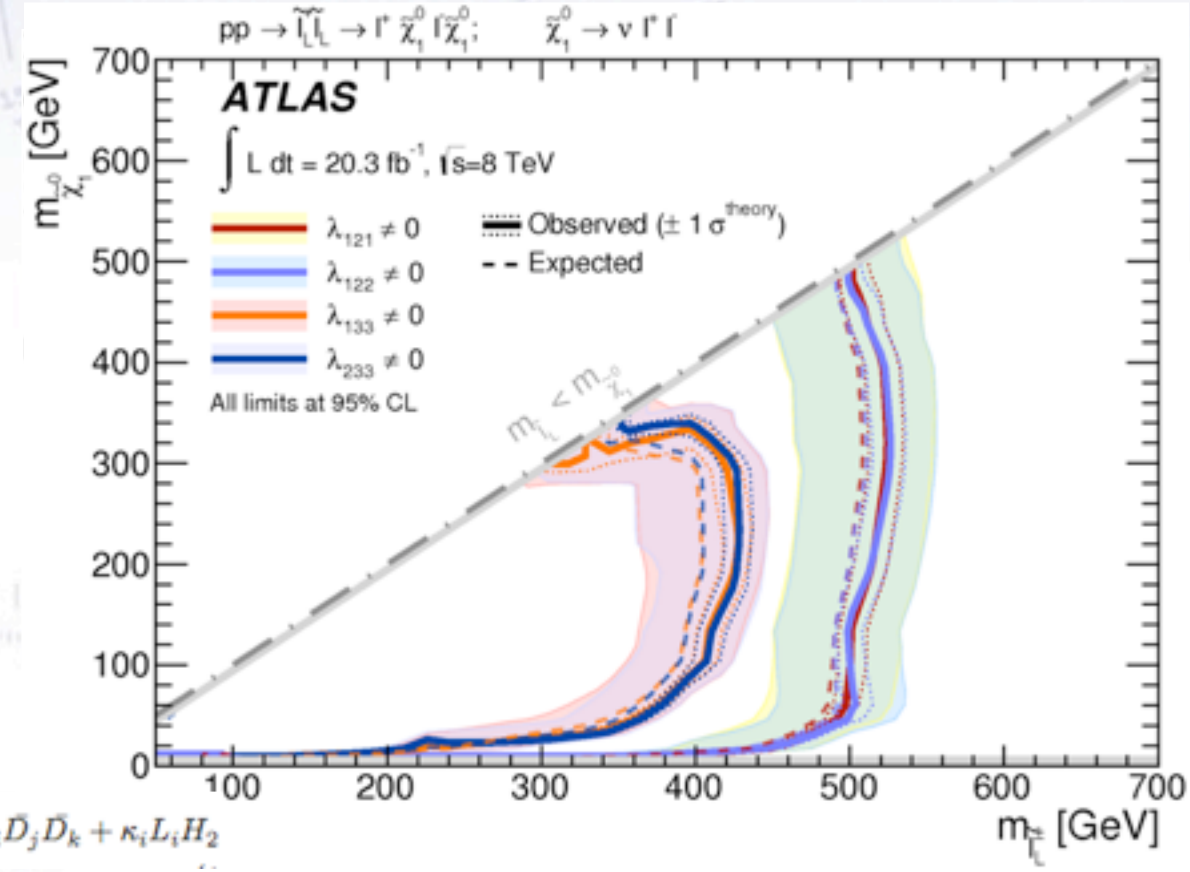
Analysis covers 5 RPV and 3 RPC models (along with 2 GGM models).

Example:
Slepton model



9 Signal Regions are defined according the N leptons, Z-veto and MET.

Shown is the 4^+ lepton + MET > 50 GeV Signal Region



RPV Model NLSP	Decay
Chargino	$\tilde{\chi}_1^\pm \to W^{\pm(*)} \tilde{\chi}_1^0$
L-slepton	$\tilde{\ell}_L \to \ell \tilde{\chi}_1^0$
	$\tilde{\tau}_L \to \tau \tilde{\chi}_1^0$
R-slepton	$\tilde{\ell}_R \to \ell \tilde{\chi}_1^0$
	$\tilde{\tau}_R \to \tau \tilde{\chi}_1^0$
Sneutrino	$\tilde{\nu}_\ell \to \nu_\ell \tilde{\chi}_1^0$
	$\tilde{\nu}_\tau \to \nu_\tau \tilde{\chi}_1^0$
Gluino	$\tilde{g} \to q\bar{q} \tilde{\chi}_1^0$
	$q \in u, d, s, c$

RPC Model	Decay
R-slepton	$\tilde{\chi}_{2,3}^0 \to \ell^\pm \tilde{\ell}_R^\mp \to \ell^+\ell^- \tilde{\chi}_1^0$
Stau	$\tilde{\chi}_{2,3}^0 \to \tau^\mp \tilde{\tau}_1^\pm \to \tau^\mp\tau^\pm \tilde{\chi}_1^0$
Z	$\tilde{\chi}_{2,3}^0 \to Z^{(*)} \tilde{\chi}_1^0 \to \ell^\pm\ell^\mp \tilde{\chi}_1^0$

$$\frac{1}{2}\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \frac{1}{2}\lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k + \kappa_i L_i H_2$$

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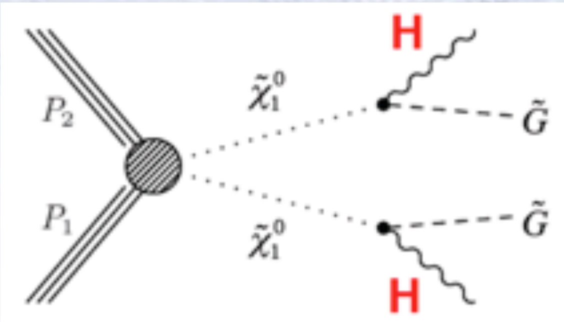
Higgsino search

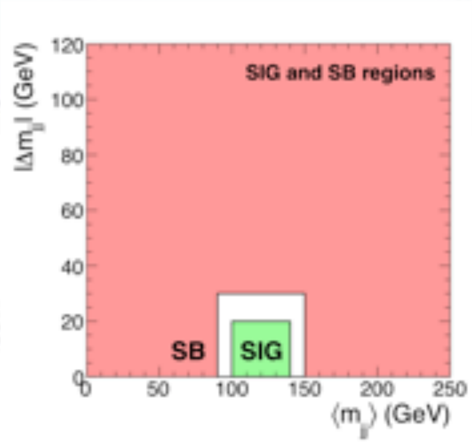
PAS-SUS-13-022

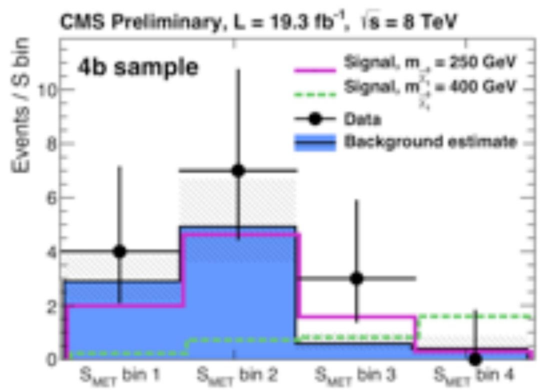


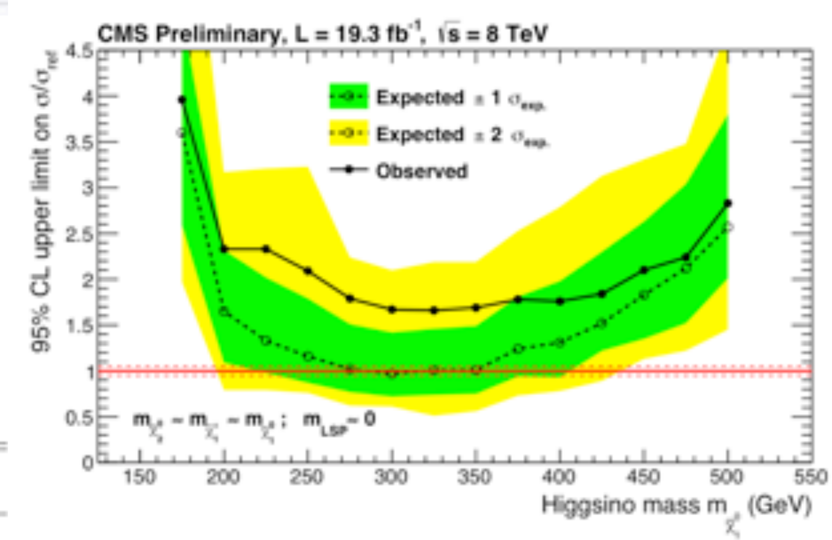
SUSY scenario: $\tilde{\chi}^0_1$ lightest higgsino and $\tilde{G}$ is LSP (each Higgs boson H decays to b-quarks).

Selection:

4-5 jets, 2+ jets $p_T > 50$ GeV and MET significance, $S_{MET} > 30$
No isolated leptons (e,μ,τ) or tracks with pT > 10 GeV!
$\Delta\phi(\text{jet, MET})_{min} > 0.3$ (0.5) for $S_{MET} > 50$ ($50 > S_{MET} > 30$)







$\mathcal{S}_{MET}$ bin	$\mathcal{S}_{MET}$ range	SM background (3b-SIG)	Data (3b-SIG)	SM background (4b-SIG)	Data (4b-SIG)
1	$30 < \mathcal{S}_{MET} < 50$	$6.7^{+1.4+1.0}_{-1.1-0.7}$	4	$2.9^{+0.8+0.5}_{-0.6-0.4}$	4
2	$50 < \mathcal{S}_{MET} < 100$	$11.6^{+1.9+0.9}_{-1.6-0.7}$	15	$4.9^{+1.1+1.4}_{-0.9-0.9}$	7
3	$100 < \mathcal{S}_{MET} < 150$	$2.44^{+0.84+0.56}_{-0.64-0.35}$	1	$0.59^{+0.39+0.09}_{-0.26-0.09}$	3
4	$\mathcal{S}_{MET} > 150$	$1.50^{+0.82+0.64}_{-0.54-0.32}$	0	$0.40^{+0.39+0.26}_{-0.22-0.10}$	0

No significant signal is seen, and limits (not unlike our "old" SM higgs ones) are set.

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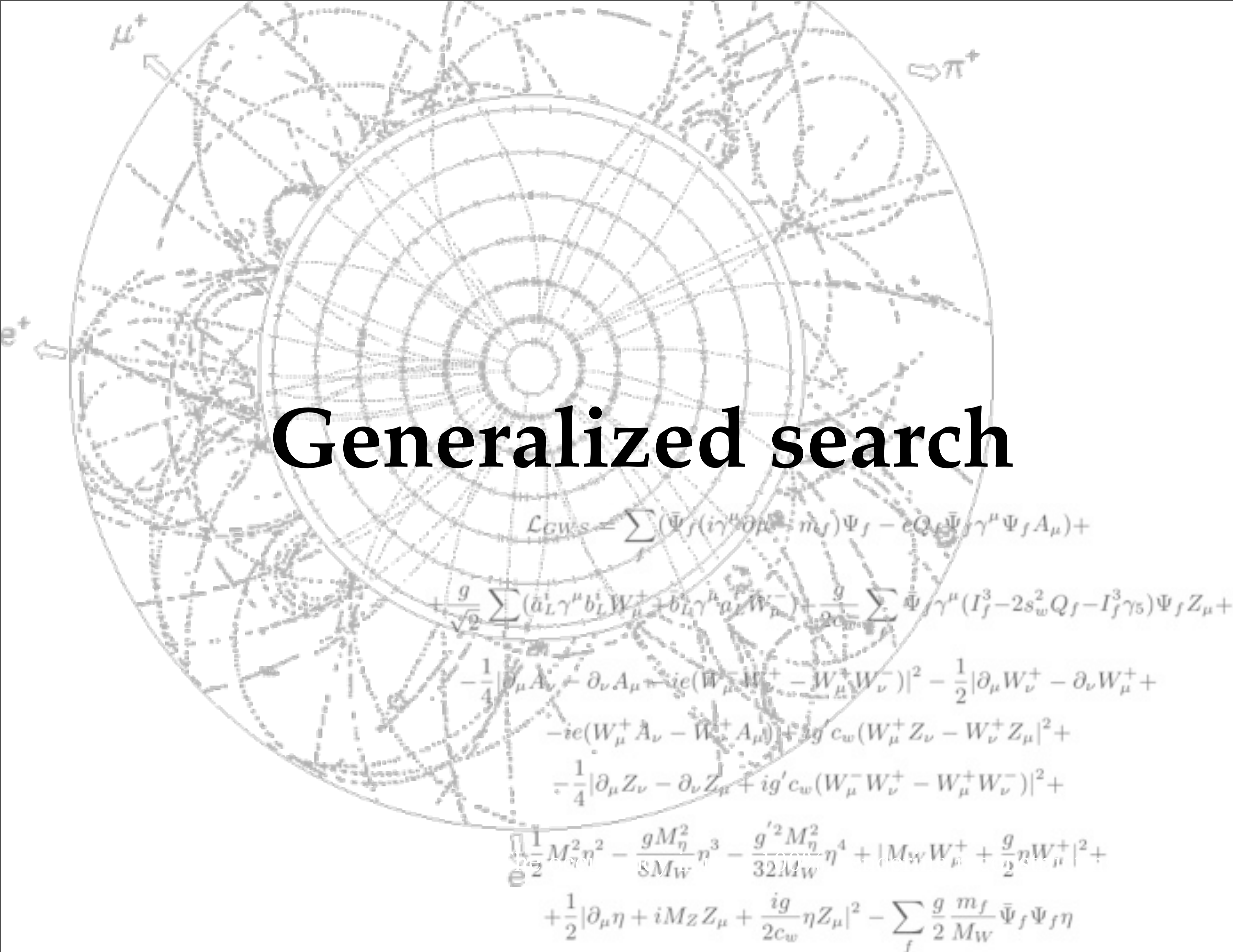
Generalized search



General new physics search

Idea: "Automate" SM background estimate for final states, and compare with data.

Objects: e, μ, γ, jets, b-jets, MET.
p_T > 25, 25, 40, 50, 50, 150.

Observables: Invariant mass, effective mass and MET.

Backgrounds: Estimated by reweighted MC, except fake lepton rate (from data).

Signal Regions (SR): 697 in total!
All regions with SM expectation > 0.1 event are considered.

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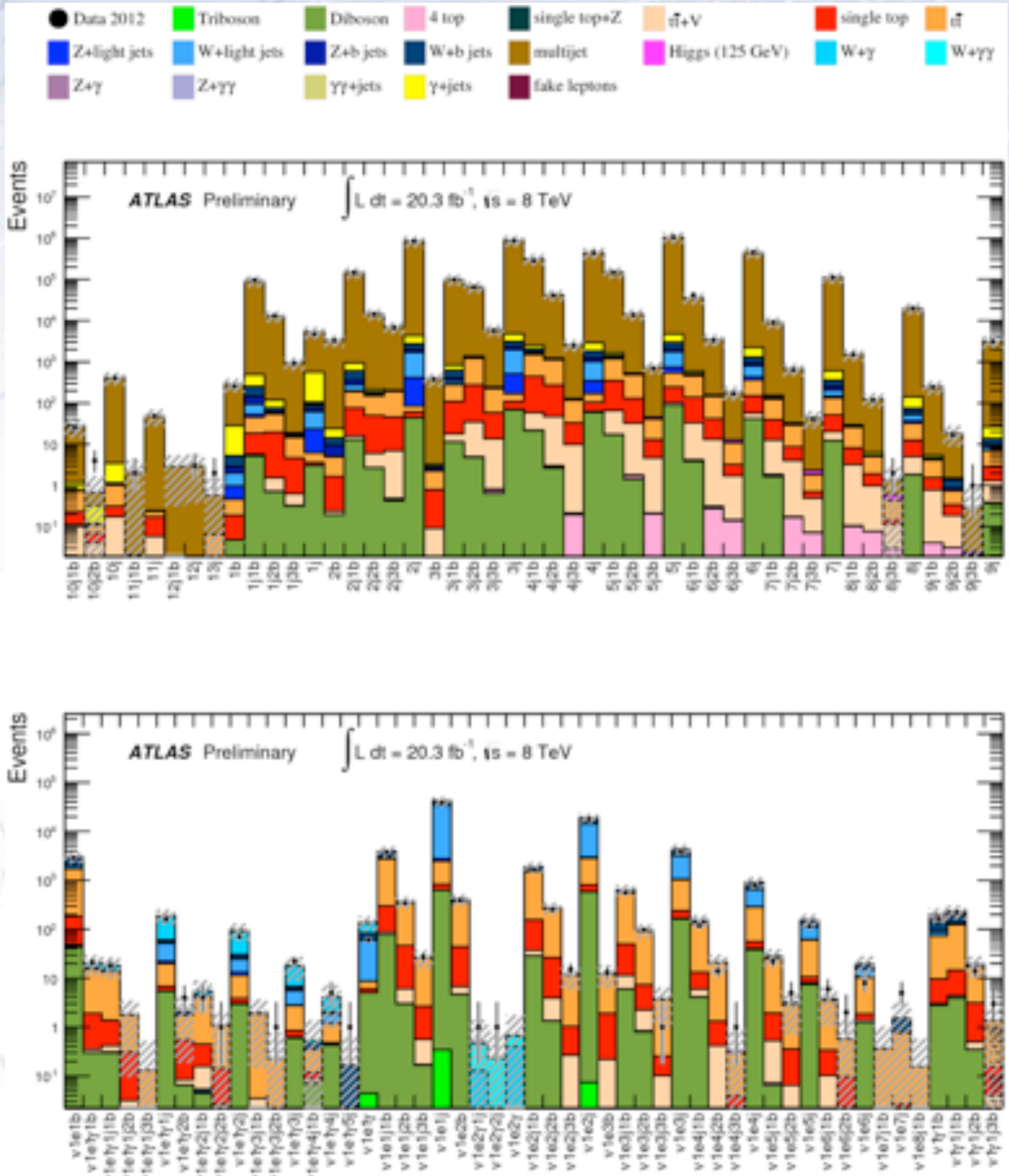
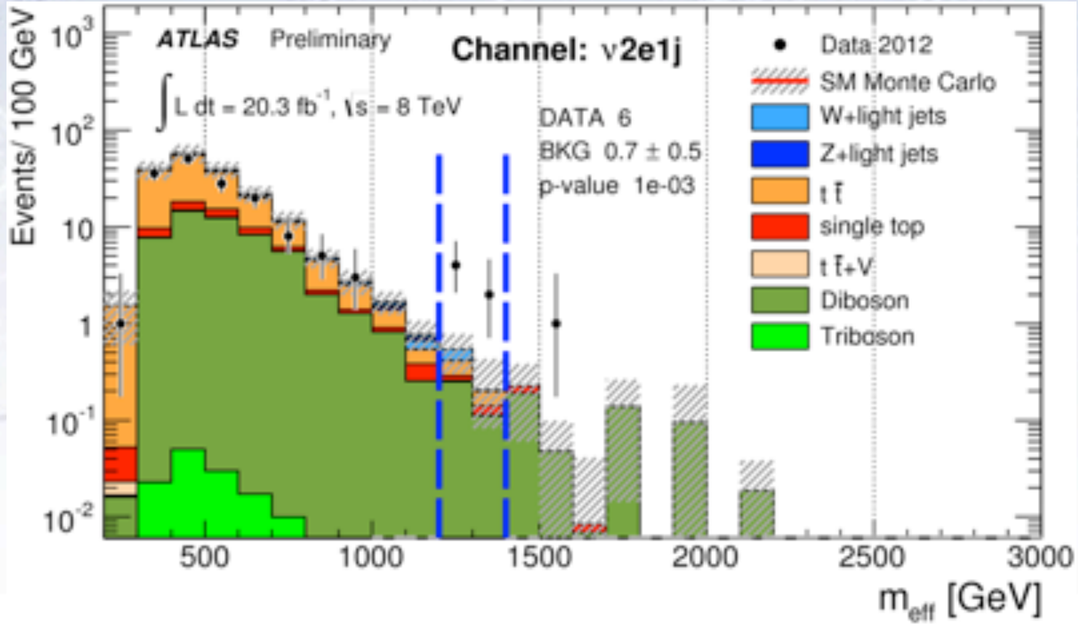


General new physics search

Largest discrepancies:

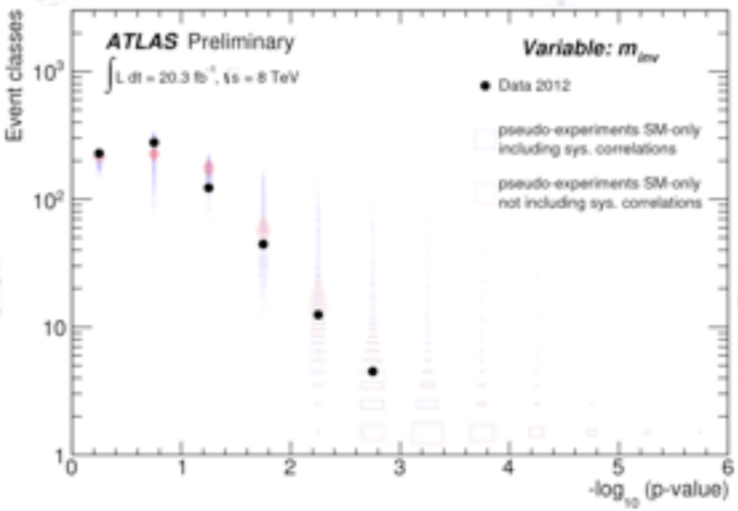
ν2e1j m_{eff}: p-value = 0.0013
  Exp = 0.7±0.5, Obs = **6**

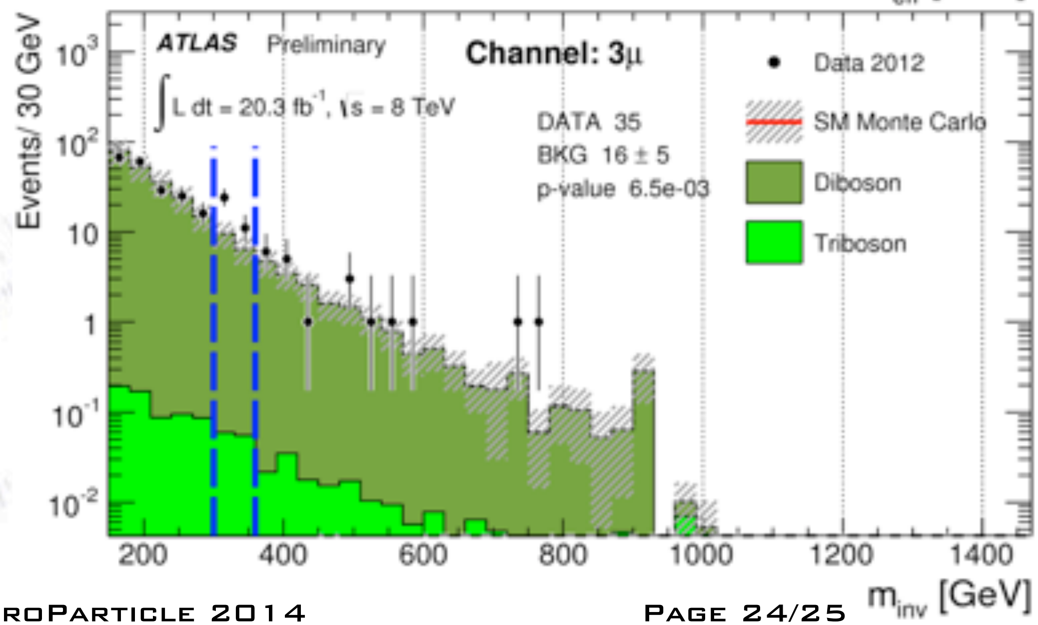
3μ m_{inv}: p-value = 0.0071
  Exp = 16 ± 5, Obs = **35**



Interpretation:

p-value distribution is compared to pseudo-experiment expectation.





"This type of search makes me sleep well at night!" [Overheard at conference]

Conclusions

Many SUSY searches performed - SUSY was **NOT** "just around the corner"!
Limits have already been pushed very far - the work impresses me much.

LHC Run2 might provide the only real chance of observing SUSY!
With Run1 experience, we're ready to maximize our reach...

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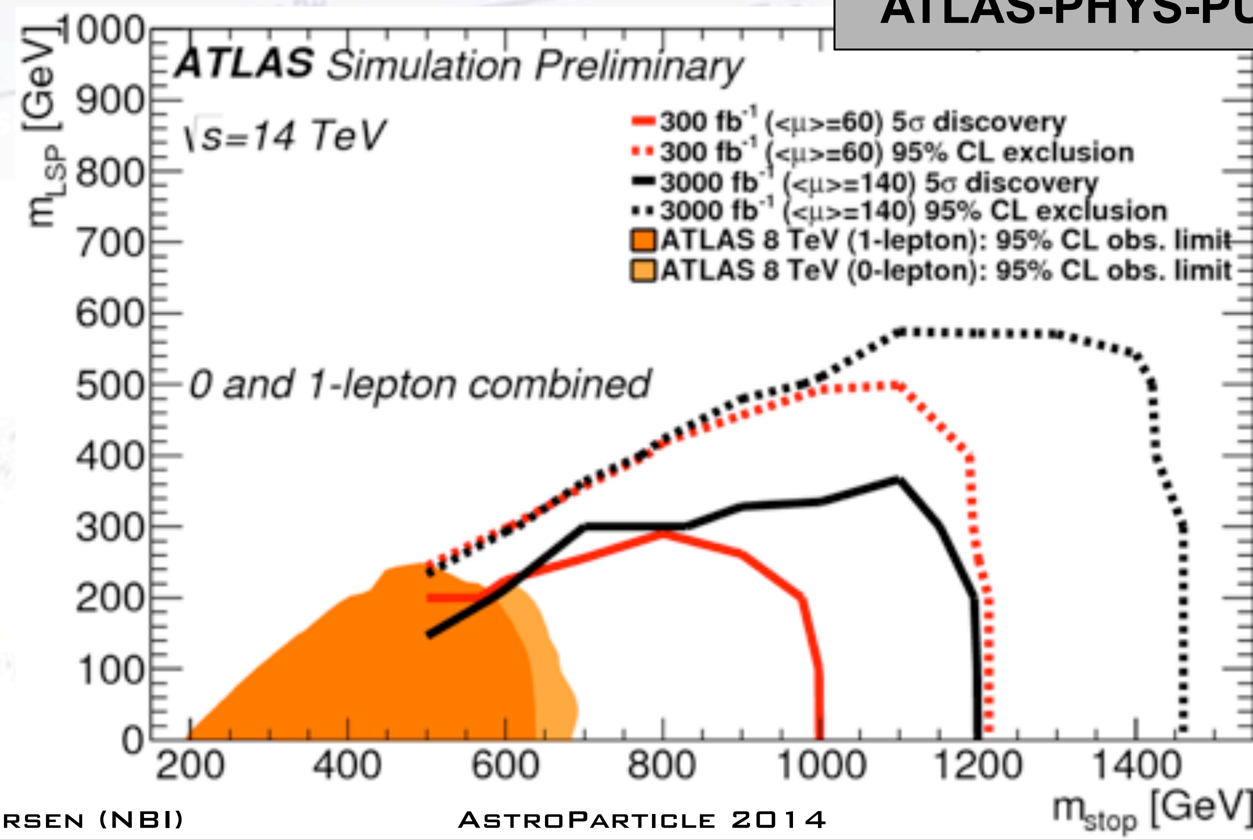

Conclusions

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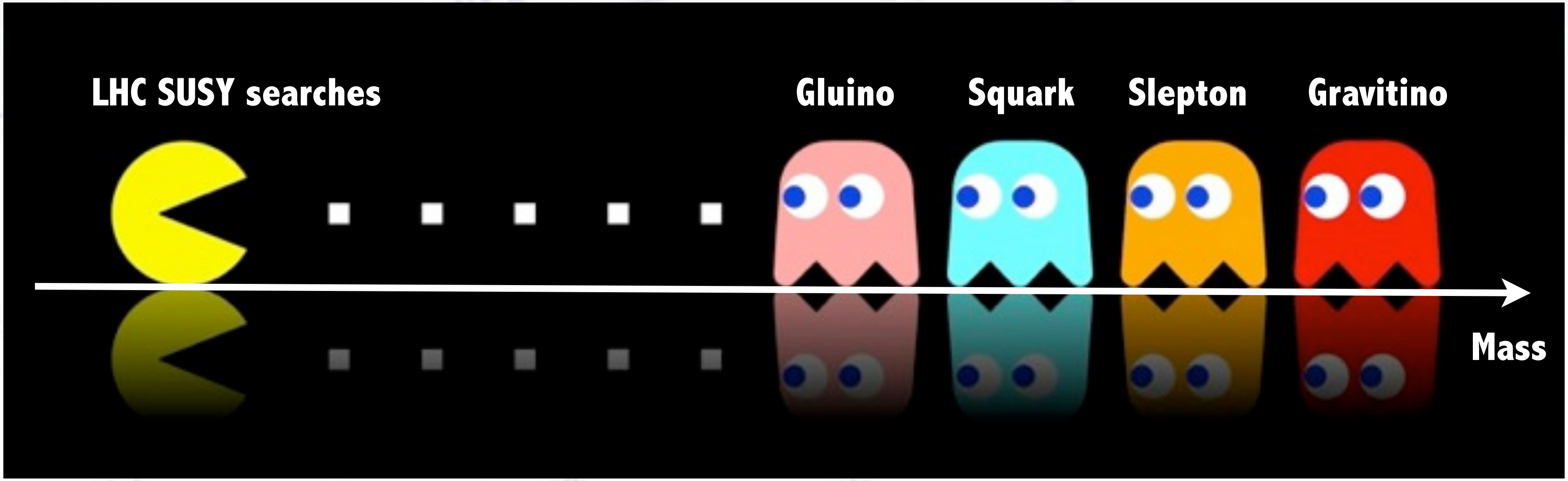
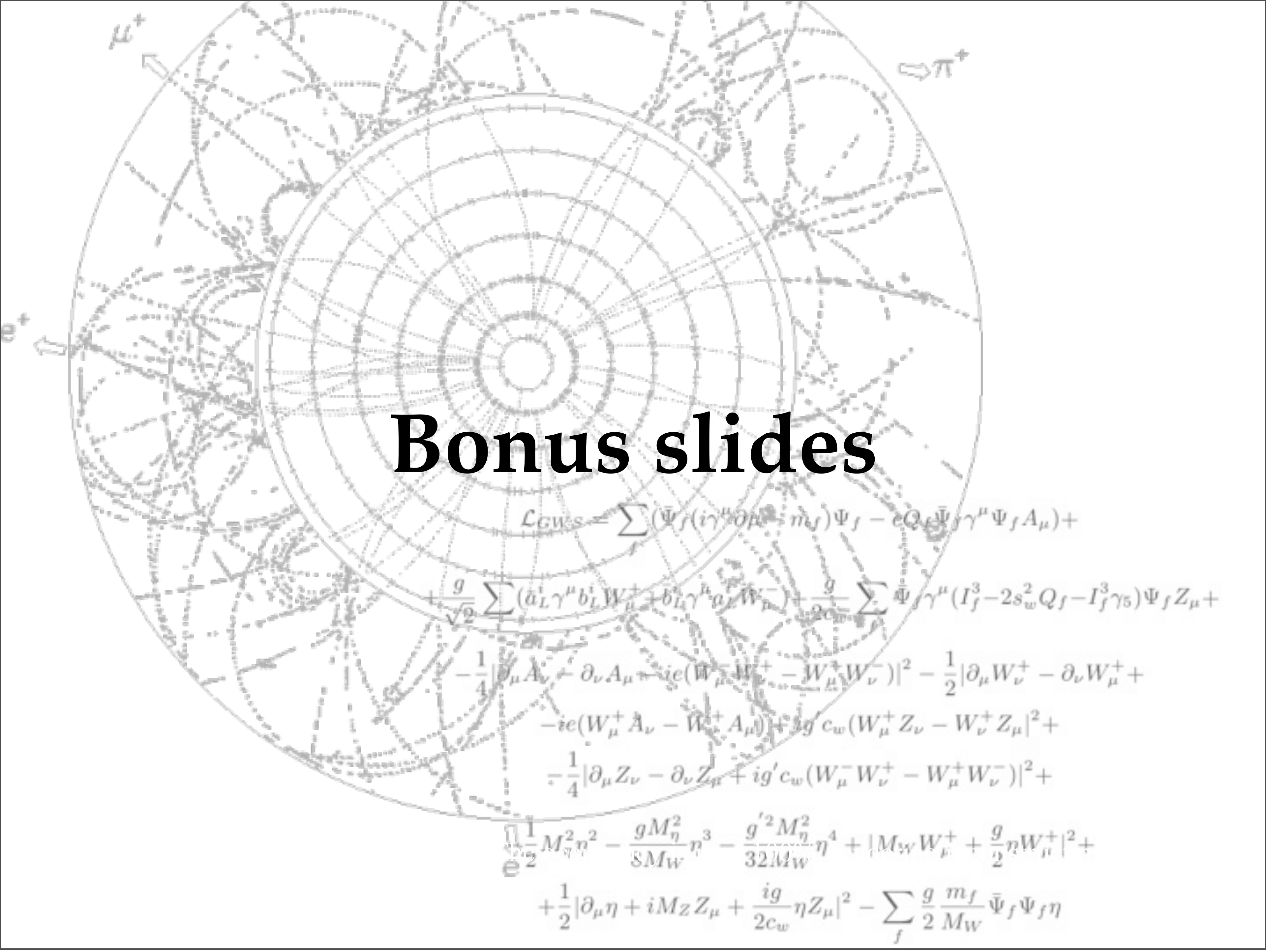


Maybe we are just chasing ghosts...

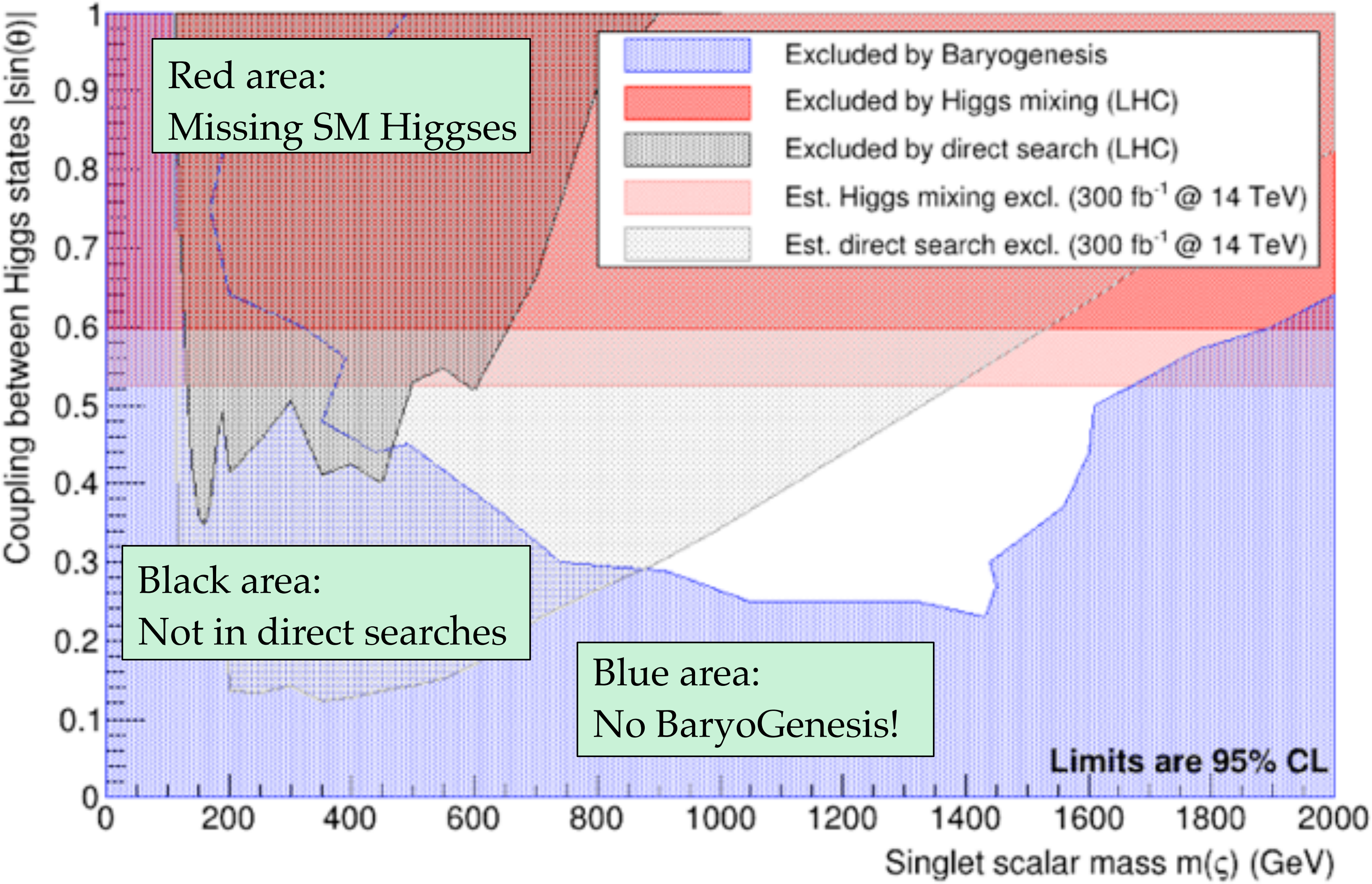
...but it's the "maybe" that keeps the chase on.



Bonus slides

Additional Higgses & BaryoGenesis

Assume the addition of one additional Higgs singlet, which mixes with the SM Higgs (sinθ). Does this allow for a first order phase transition? [PRL or 1305.4362]



ATLAS inclusive jets + MET

Requirement	Signal Region					
	2jl	2jm	2jt	2jW	3j	4jW
E_T^{miss}[GeV] >	160					
$p_T(j_1)$ [GeV] >	130					
$p_T(j_2)$ [GeV] >	60					
$p_T(j_3)$ [GeV] >	–				60	40
$p_T(j_4)$ [GeV] >	–					40
$\Delta\phi(\text{jet}_{1,2,(3)}, \mathbf{E}_T^{miss})_{min}$ >	0.4					
$\Delta\phi(\text{jet}_{i>3}, \mathbf{E}_T^{miss})_{min}$ >	–					0.2
W candidates	–			$2(W \to j)$	–	$(W \to j) + (W \to jj)$
$E_T^{miss}/\sqrt{H_T}$ [GeV$^{1/2}$] >	8	15		–		
$E_T^{miss}/m_{eff}(N_j)$ >	–			0.25	0.3	0.35
m_{eff}(incl.) [GeV] >	800	1200	1600	1800	2200	1100

Requirement	Signal Region								
	4jl-	4jl	4jm	4jt	5j	6jl	6jm	6jt	6jt+
E_T^{miss}[GeV] >	160								
$p_T(j_1)$ [GeV] >	130								
$p_T(j_2)$ [GeV] >	60								
$p_T(j_3)$ [GeV] >	60								
$p_T(j_4)$ [GeV] >	60								
$p_T(j_5)$ [GeV] >	–				60				
$p_T(j_6)$ [GeV] >	–					60			
$\Delta\phi(\text{jet}_{1,2,(3)}, \mathbf{E}_T^{miss})_{min}$ >	0.4								
$\Delta\phi(\text{jet}_{i>3}, \mathbf{E}_T^{miss})_{min}$ >	0.2								
$E_T^{miss}/\sqrt{H_T}$ [GeV$^{1/2}$] >	10		–						
$E_T^{miss}/m_{eff}(N_j)$ >	–		0.4	0.25	0.2			0.25	0.15
m_{eff}(incl.) [GeV] >	700	1000	1300	2200	1200	900	1200	1500	1700

Event selection for the 15 signal regions...

Perhaps still the best estimate of what lies beyond...