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pMSSM combination SUSY searches at LHC

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on Behalf of ATLAS and CMS

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pMSSM in a nutshell

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MSSM is an extension of the SM with a minimal set of 124 (105+19) parameters. A phenomenological approach would be daunting with such a large number of free parameters coming from the theory

By making few assumptions it is possible to reduce the number of parameters to 19 parameters coming from SUSY sector. We assume

- ➡No new source of CP violation
- ➡No FCNC
- ➡First and second Generation universality

The free input parameters are:

- ➡$\tan\beta$: ratio of vev of Higgs doublets
- ➡M_A: mass of pseudoscalar Higgs
- ➡μ: Higgs-Higgsino mass parameter
- ➡M_1, M_2, M_3: wino, bino, gluino masses
- ➡5 1^{st}, 2^{nd} generation sfermion masses
- ➡5 3^{rd} generation sfermion masses
- ➡A_t, A_b, A_T: trilinear couplings in 3^{rd} generation
- ➡(gravitino LSP)

The higgs doublet and Bino parameters are determined through EWK symmetry breaking.

The reduced number of parameters makes the pMSSM a theory with a greater predictability than MSSM.
Only a reduced set of parameters become interesting when looking at a single sector of the model

Combination Strategies

ATLAS analysis overview

ATLAS interpreted many results in pMSSM scenarios, multiple final states were sought after considering both EWK productions and Strongly produced SUSY particles. Results are obtained in 2-d slices of pMSSM space, with all the other parameters fixed or decoupled

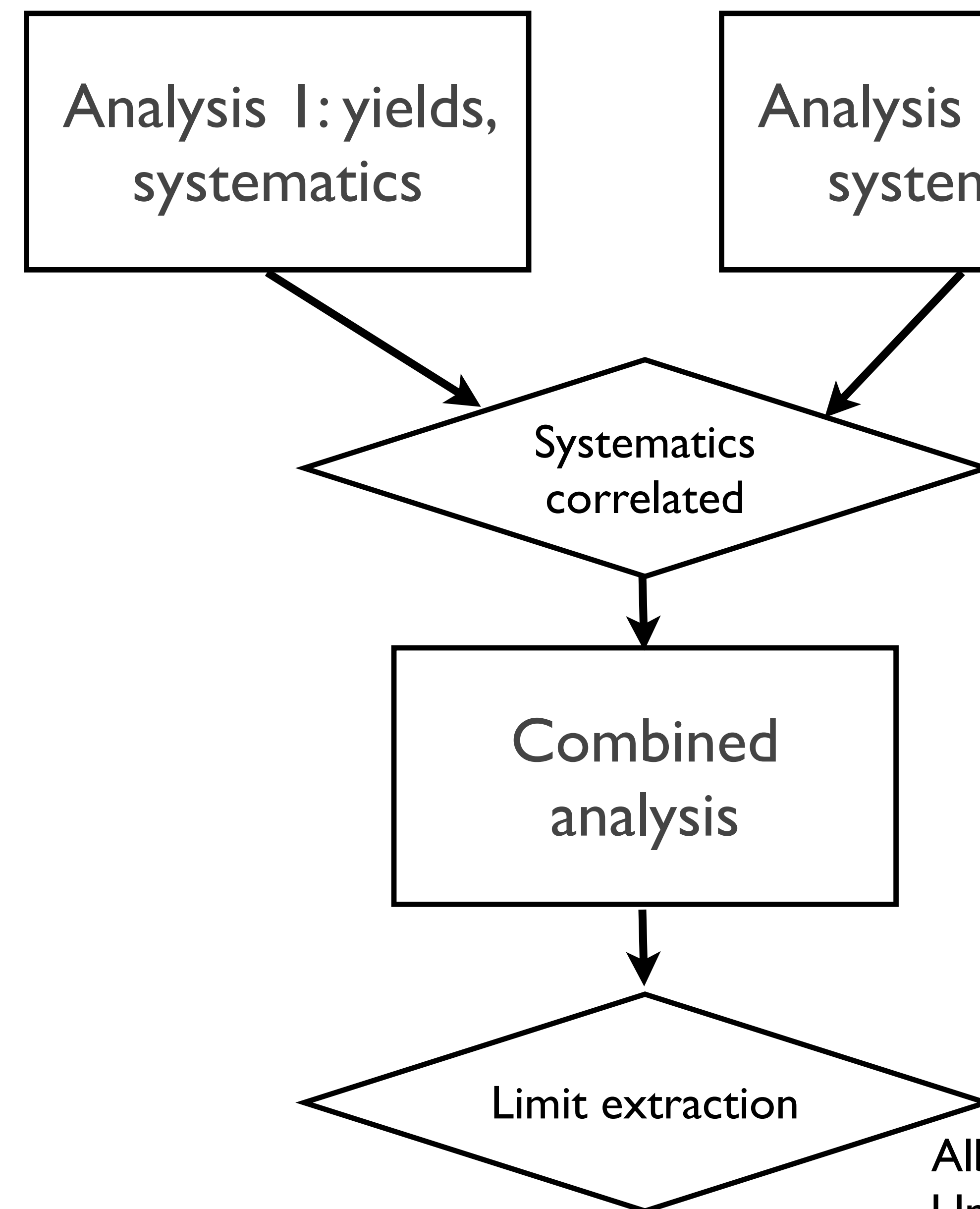
Exclusion limits are obtained through a frequentist approach: CL_s interpretation

Similar analyses have been combined to extend sensitivities in some sectors

Results from 5 searches will be presented in this talk

- EWK production :2+3 lepton final state combination
- EWK production :2τ final states
- 3^{rd} generation: stop, sbottom searches
- 3^{3d} generation: 1 lepton + stop
- inclusive squark gluino searches

Combination schema



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CMS Overview

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CMS made a global fit of its searches for SUSY with a pMSSM reinterpretation.
Not a reinterpretation of all single analyses.
Data from 7TeV and 8TeV samples combined

Bayesian approach: priors are taken from existing results

i	Observable $\mu_j(\theta)$	Constraint $D_j^{\text{non-DCS}}$	Likelihood function $L(D_j^{\text{non-DCS}}\|\mu_j(\theta))$	MCMC / post-MCMC
1a	$BR(b \to s\gamma)$ [43, 44]	$(3.55 \pm 0.23^{\text{stat}} \pm 0.24^{\text{th}} \pm 0.09^{\text{sys}}) \times 10^{-4}$	Gaussian	MCMC
1b	$BR(b \to s\gamma)$ [45]	$(3.43 \pm 0.21^{\text{stat}} \pm 0.24^{\text{th}} \pm 0.07^{\text{sys}}) \times 10^{-4}$	Gaussian	reweight
2a	$BR(B_s \to \mu\mu)$ [46]	observed CLs curve from [46]	$d(1-CLs)/d(BR(B_s \to \mu\mu))$	MCMC
2b	$BR(B_s \to \mu\mu)$ [47]	$(2.9 \pm 0.7 \pm 0.29^{\text{th}}) \times 10^{-9}$	Gaussian	reweight
3a	$R(B_u \to \tau\nu)$[36, 48]	1.63 ± 0.54	Gaussian	MCMC
3b	$R(B_u \to \tau\nu)$[45]	1.04 ± 0.34	Gaussian	reweight
4	Δa_μ [49]	$(26.1 \pm 6.3^{\text{exp}} \pm 4.9^{\text{SM}} \pm 10.0^{\text{SUSY}}) \times 10^{-10}$	Gaussian	MCMC
5a	m_t [50]	$173.3 \pm 0.5^{\text{stat}} \pm 1.3^{\text{sys}}$ GeV	Gaussian	MCMC
5b	m_t [51]	$173.20 \pm 0.87^{\text{stat}} \pm 1.3^{\text{sys}}$ GeV	Gaussian	reweight
6	$m_b(m_b)$ [48]	$4.19^{+0.18}_{-0.06}$ GeV	Two-sided Gaussian	MCMC
7	$\alpha_s(M_Z)$ [48]	0.1184 ± 0.0007	Gaussian	MCMC
8a	m_h	pre-LHC: $m_h^{low} = 112$	1 if $m_h \geq m_h^{low}$ 0 if $m_h < m_h^{low}$	MCMC
8b	m_h	LHC: $m_h^{low} = 120$, $m_h^{up} = 130$	1 if $m_h^{low} \leq m_h \leq m_h^{up}$ 0 if $m_h < m_h^{low}$ or $m_h > m_h^{up}$	reweight
9	sparticle masses	LEP [52] (via micrOMEGAs [37–39])	1 if allowed 0 if excluded	MCMC

A posterior probability distribution assesses the impact of CMS searches on the pMSSM parameter space

$$p(\theta|D^{\text{CMS}}) = L(D^{\text{CMS}}|\theta)\, p^{\text{non-DCS}}(\theta).$$

HT+MHT: ≥3 jets and MET, targeting gluino and squark production with long hadronic cascades
HT+MET+b-jets: ≥3 jets ≥1 b-jets, focused on gluinos decaying to 3[3d] generation particles
EW production: targets neutralino, chargino, and slepton pair production

Analysis	$\sqrt{s}$	L
Hadronic HT + MHT search	7 TeV	4.98 fb^{-1}
Hadronic HT + MET + b-jets search	7 TeV	4.98 fb^{-1}
Leptonic search for EW prod. of $\tilde{\chi}^0, \tilde{\chi}^\pm, \tilde{l}$	7 TeV	4.98 fb^{-1}
Hadronic HT + MHT search	8 TeV	19.5 fb^{-1}
Hadronic HT + MET + b-jets search	8 TeV	19.4 fb^{-1}
Leptonic search for EW prod. of $\tilde{\chi}^0, \tilde{\chi}^\pm, \tilde{l}$ (ss, 3l, and 4l channels)	8 TeV	19.5 fb^{-1}

Statistical Method

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Need to distinguish between S+B hypothesis (H_1) and Bkg only hypothesis (H_0), two Likelihood for each hypothesis are built and a score Z is defined as

$$Z = sign(\ln B_{10}\sqrt{2|\ln B_{10}|})$$

$$B_{10}(\theta) = L(D^{CMS}|\theta, H_1)/L(D^{CMS}|\theta, H_0)$$

Z can be considered the equivalent of the frequentist sigma of exclusion Z>0 means observation significance Z<0 exclusion significance

In case of overlapping datasets, where the L can't be factorized the most significant Z from the largest non overlapping sample

HT+MET+b-jets 7TeV analysis present overlapping regions and so only the most significant region is considered for likelyhood for the combinations

Some of the regions of different analyses at different energies present overlapping dataset, like 8TeV HT+MET+b-jets and HT+MHT, in this case the combination is done by combining the Z scores of the two analyses independently

ATLAS results

EWK searches: 2L+3L final states

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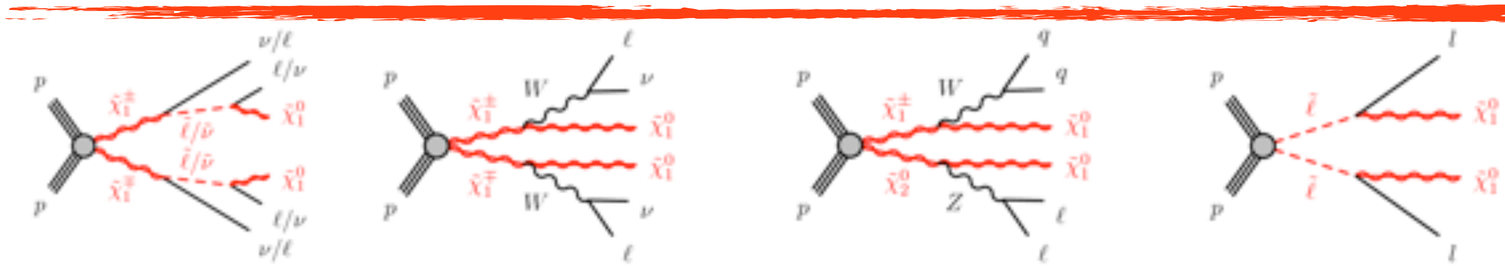
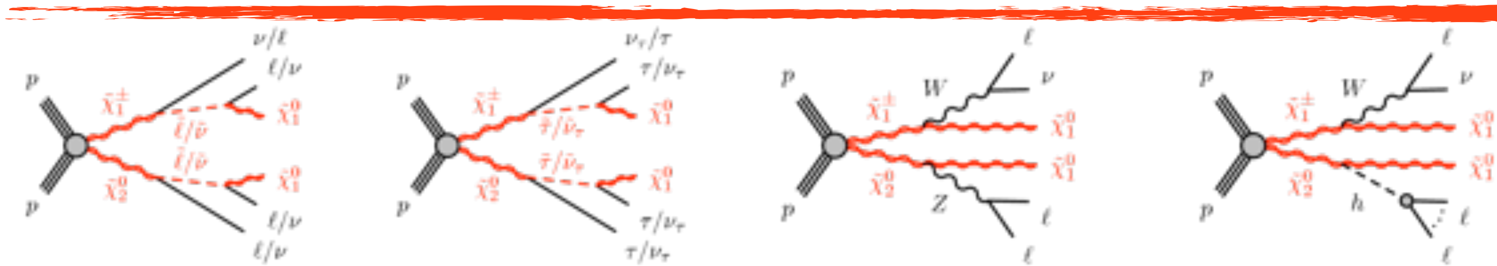
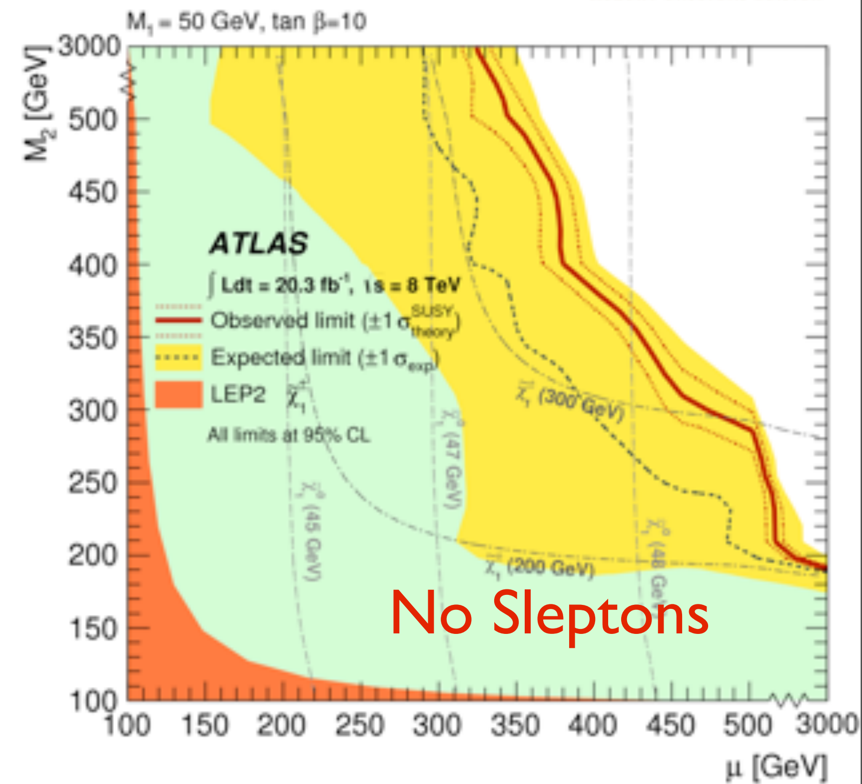


2L

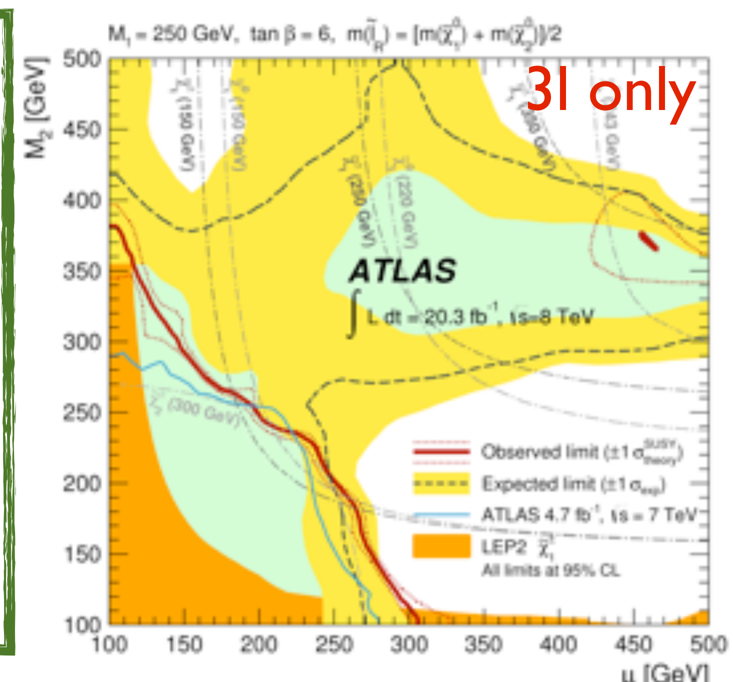


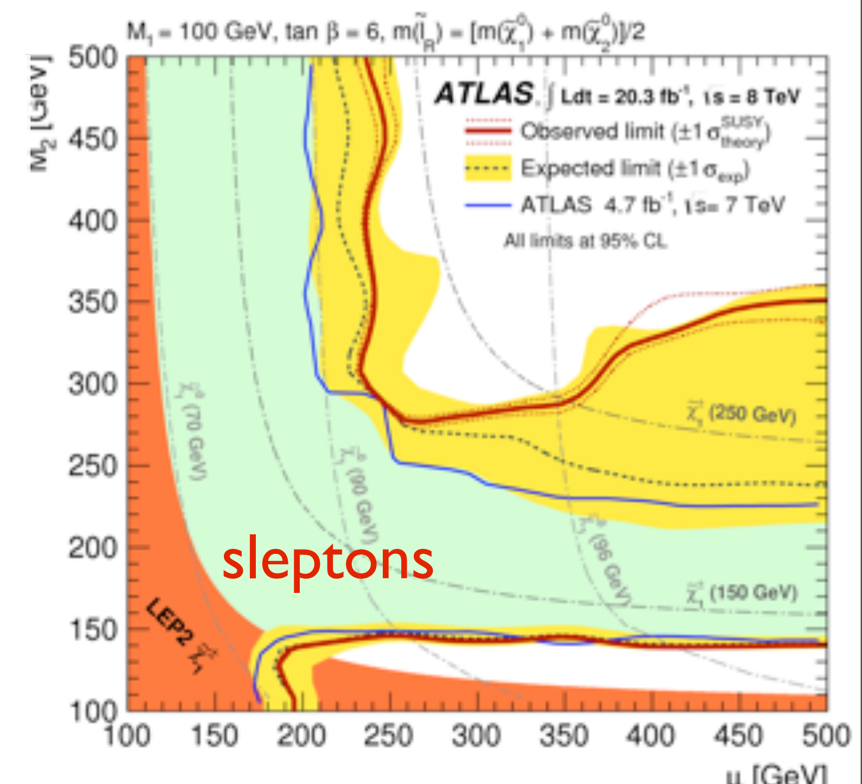
3L



The results were obtained by combining the most sensitive signal region for each analysis.

Limits were extended w.r.t. previous ATLAS results and single analysis for both decoupled slepton scenario and scenarios with right handed sleptons





EWK searches: 2τ final states

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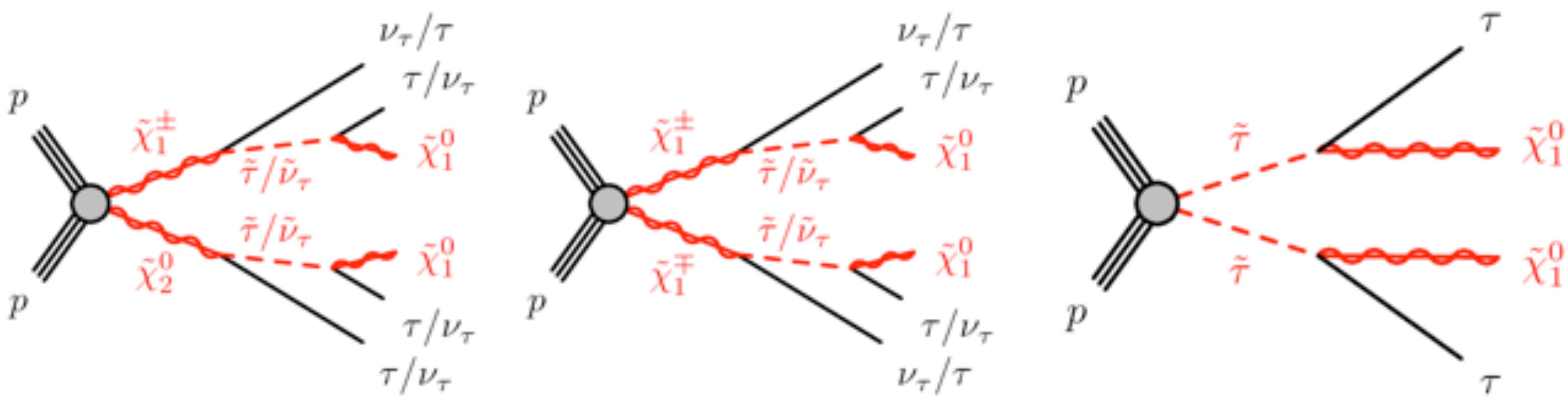
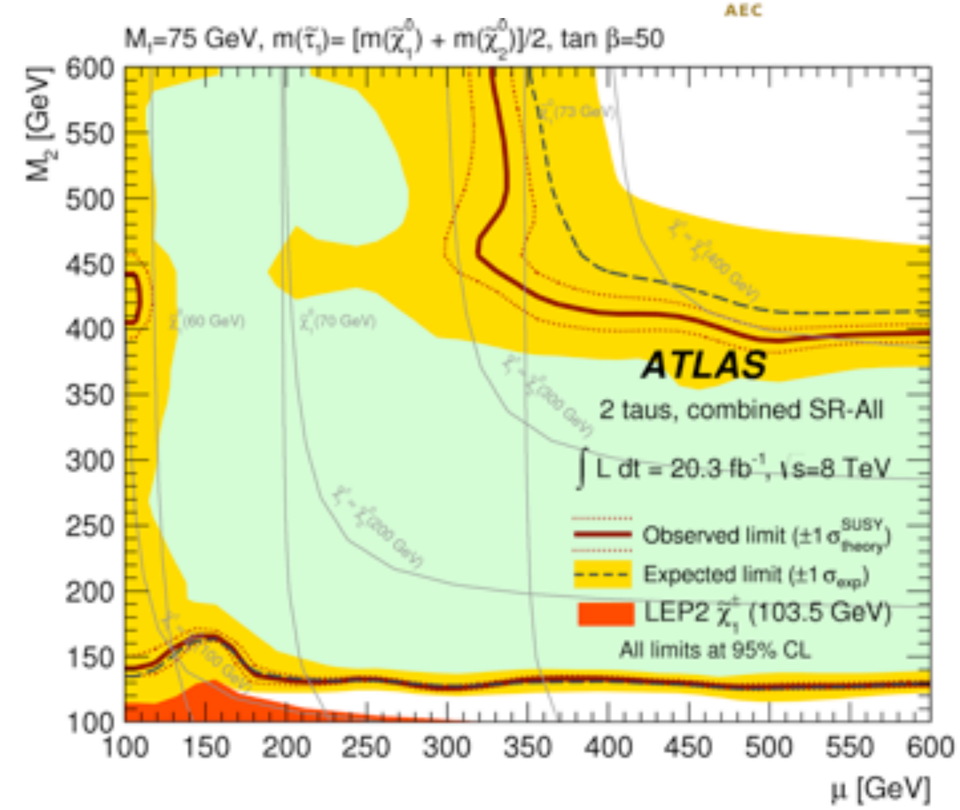
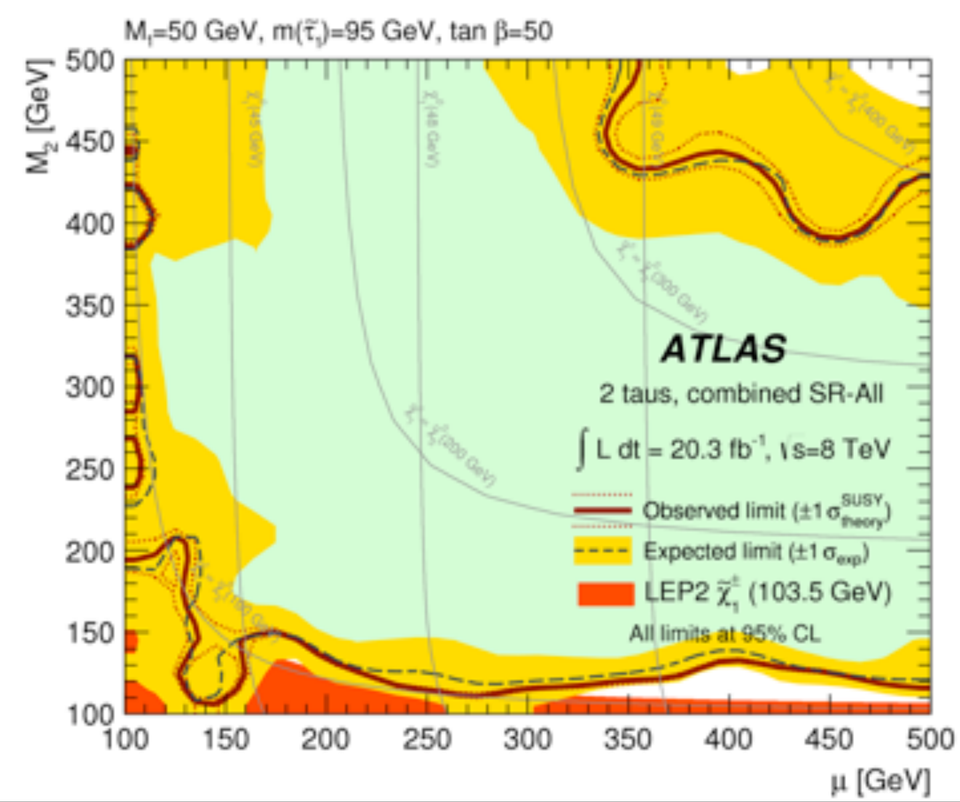




Combination of 4 different processes.

At fixed stau mass low M_2 region is not excluded due to compressed spectra for the final state particles.
Direct stau production dominant in the High M_2 mass

Light Chargino and Neutralinos are excluded in the range of 150-350 GeV.



arXiv:1506.08616v1

3rd Generation searches: $\tilde{t}$ and $\tilde{b}$

Model name	Parameters scanned	Other parameter settings	Production channels	Typical decays
Naturalness-inspired pMSSM	350 GeV $< m_{\tilde{q}L3} <$ 900 GeV 100 GeV $< \mu < m_{\tilde{q}L3} - 150$ GeV	$M_2 = 3\mu$ $m_{\tilde{t}_R}$ such that $M_S = 800$ GeV A_t such that $X_t/M_S = \sqrt{6}$	$pp \to \tilde{t}_1\tilde{t}_1$ $pp \to \tilde{b}_1\tilde{b}_1$	For $\mu = 110$ GeV, $m_{\tilde{q}L3} = 400$ GeV $\tilde{t}_1 \to t\tilde{\chi}^0_1$(33%); $\tilde{t}_1 \to t\tilde{\chi}^0_2$(36%) $\tilde{t}_1 \to b\tilde{\chi}^{\pm}_1$(26%); $\tilde{b}_1 \to t\tilde{\chi}^{\pm}_1$ (70%) $\tilde{b}_1 \to b\tilde{\chi}^0_1$(16%); $\tilde{b}_1 \to b\tilde{\chi}^0_2$ (13%)

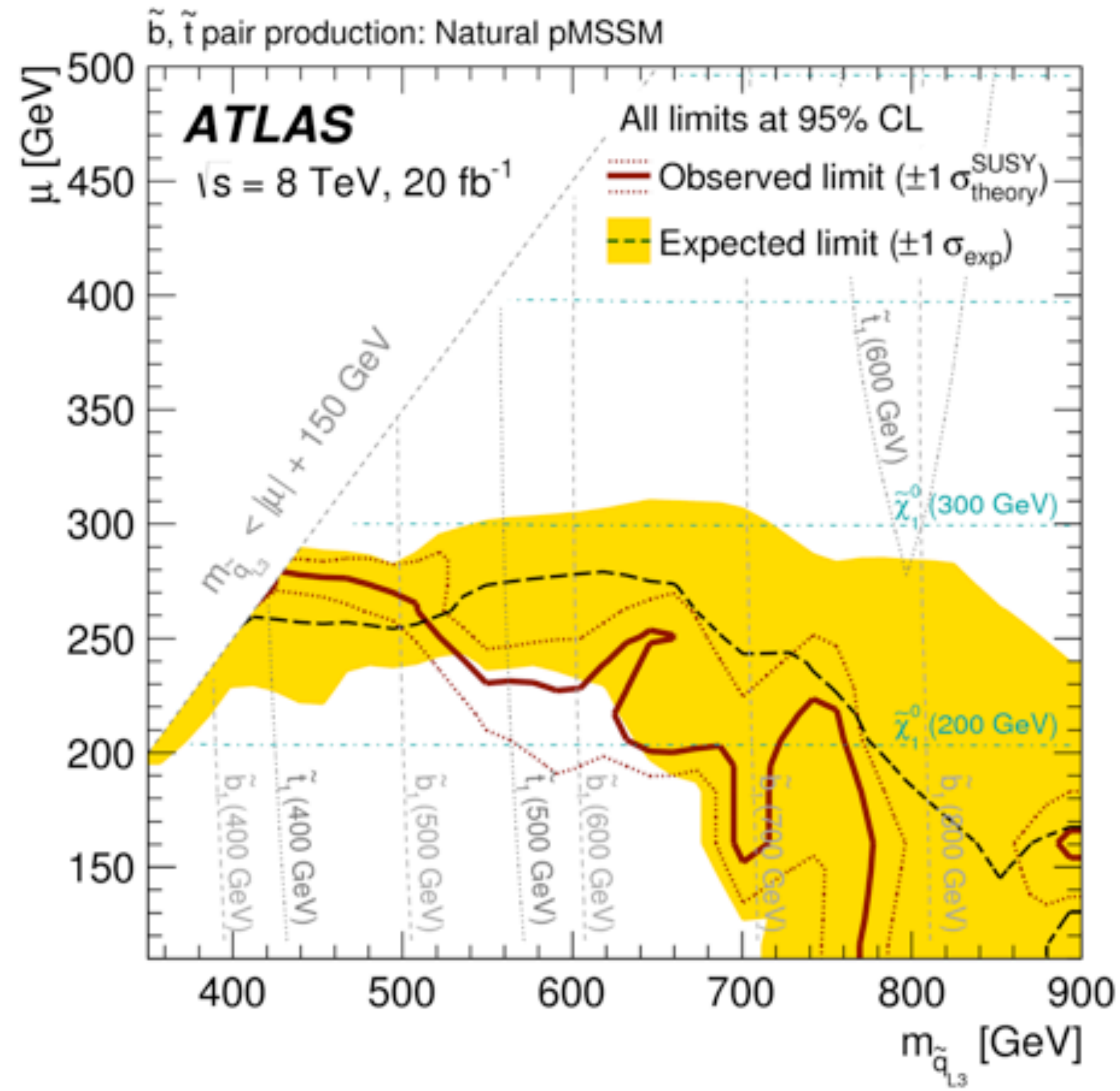
stop-sbottom-higgsino triplet model

Combination of 5 different final states: t+0lepton, t +1lepton, t+b, t+Z+2t, g+3b, t+c final states coming from stop and sbottom chain.

Interpreted in naturalness inspired pMSSM, low μ, stop mass <1TeV, spectrum defined by 2 neutralinos and 1 chargino of mass of O(μ)

The abundance of light SUSY particles allow for a large number of possible decay chains

The combination is obtained by selecting the best CL_s for each scanned point among the different analyses



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3rd Generation searches: $\tilde{t}$ + 1lepton

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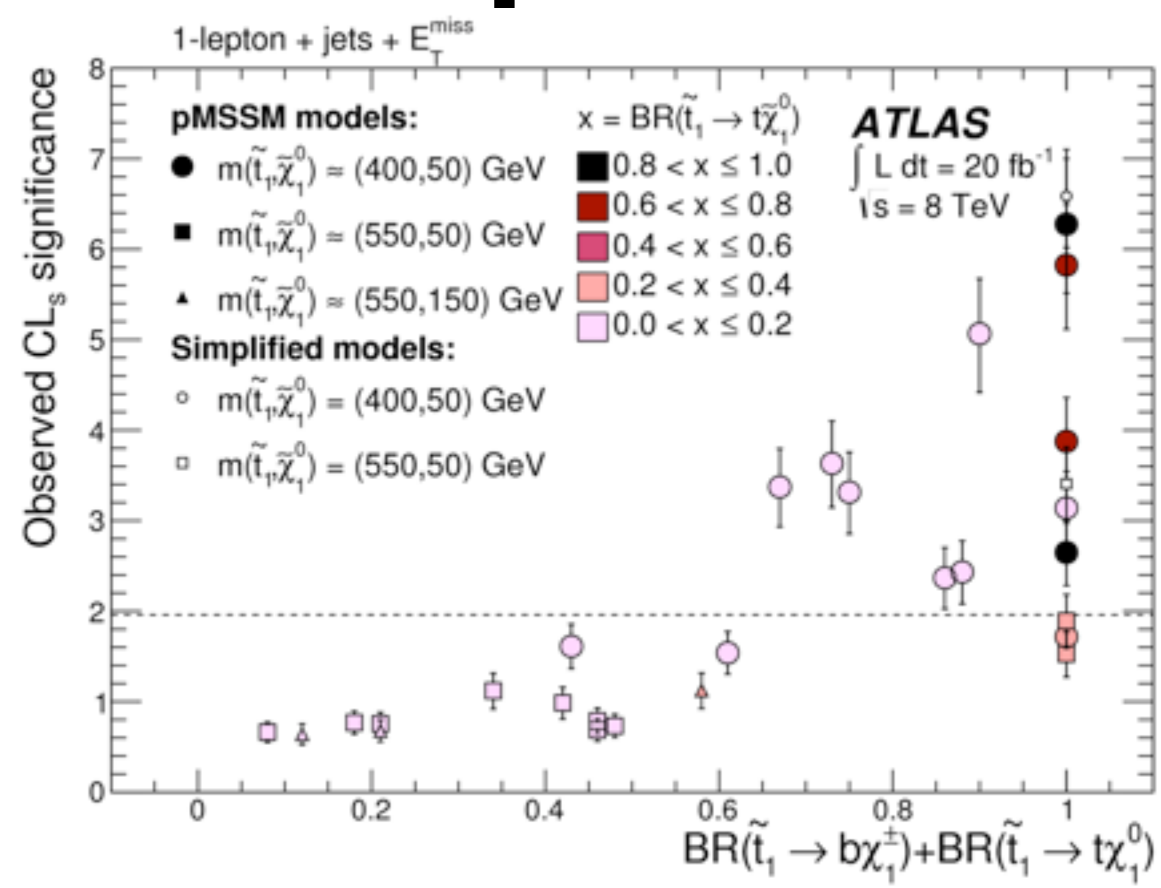
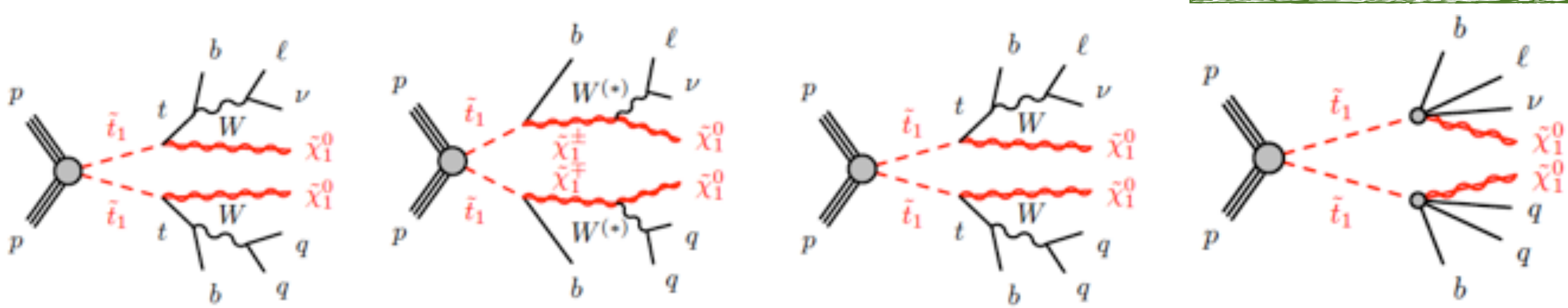
Mass [GeV]						Branching ratio $\tilde{t}_1 \to$						
$\tilde{t}_1$	$\tilde{\chi}_1^0$	$\tilde{\chi}_2^0$	$\tilde{\chi}_3^0$	$\tilde{\chi}_1^\pm$	$\tilde{\chi}_2^\pm$	$t\tilde{\chi}_1^0$	$t\tilde{\chi}_2^0$	$t\tilde{\chi}_3^0$	$b\tilde{\chi}_1^\pm$	$b\tilde{\chi}_2^\pm$	$[T_{11}]^2$	$[N_{11}]^2$
404	40	221	230	220	1073	0.09	0.01	0.09	0.81	0.00	0.53	0.96
404	44	324	445	325	471	0.16	0.00	0.00	0.84	0.00	0.98	0.99
407	46	368	372	367	1515	0.74	0.00	0.00	0.26	0.00	0.02	0.98
408	49	187	207	188	376	0.02	0.31	0.23	0.41	0.04	0.97	0.95
409	39	211	212	206	1768	0.05	0.24	0.02	0.68	0.00	0.56	0.95
409	49	180	190	179	795	0.02	0.22	0.17	0.59	0.00	0.99	0.94
410	40	232	253	234	427	0.11	0.25	0.00	0.64	0.00	0.96	0.97
410	43	387	396	386	889	0.88	0.00	0.00	0.12	0.00	0.01	0.99
413	42	197	367	197	385	0.03	0.10	0.00	0.85	0.02	0.95	0.98
413	45	373	406	374	508	0.32	0.00	0.00	0.68	0.00	0.99	0.99
414	45	194	440	195	453	0.03	0.14	0.00	0.83	0.00	0.96	0.99
416	45	394	397	393	1975	0.90	0.00	0.00	0.10	0.00	0.99	0.99
417	46	333	350	335	573	0.65	0.00	0.00	0.35	0.00	0.96	0.98
418	39	206	209	202	1779	0.09	0.05	0.28	0.59	0.00	0.47	0.95
546	46	292	310	292	520	0.02	0.28	0.24	0.44	0.01	0.98	0.98
547	46	346	374	346	500	0.12	0.49	0.00	0.22	0.16	0.93	0.98
550	40	225	235	225	760	0.02	0.28	0.24	0.46	0.00	0.98	0.96
551	43	351	366	351	621	0.07	0.38	0.21	0.35	0.00	0.98	0.99
552	41	249	275	252	420	0.02	0.20	0.21	0.44	0.13	0.98	0.97
552	42	332	337	331	1496	0.05	0.47	0.35	0.13	0.00	0.99	0.98
552	43	346	350	344	1501	0.08	0.27	0.52	0.13	0.00	0.97	0.98
552	43	385	397	385	731	0.36	0.00	0.00	0.64	0.00	0.97	0.99
554	44	439	445	439	1007	0.21	0.00	0.00	0.79	0.00	0.99	0.99
555	47	279	287	280	933	0.04	0.54	0.38	0.04	0.00	0.97	0.97
553	147	169	444	168	455	0.31	0.12	0.00	0.27	0.30	0.07	0.93
554	151	195	207	191	1969	0.09	0.35	0.43	0.12	0.00	0.88	0.68
546	154	210	213	200	434	0.07	0.40	0.34	0.05	0.14	0.86	0.70



27 pMSSM models were considered varying stop and neutralino masses and stop BR. Final states with 1 lepton and multiple jets were considered



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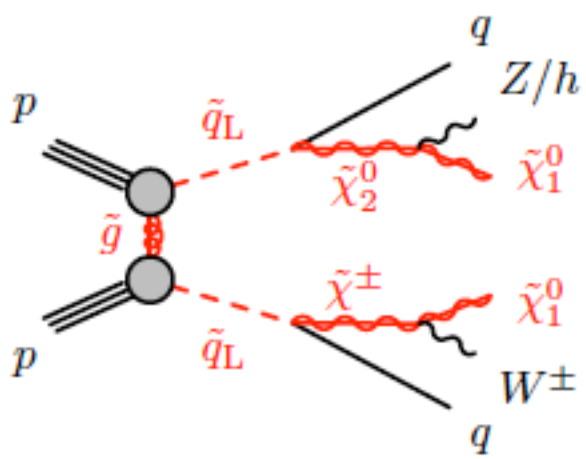
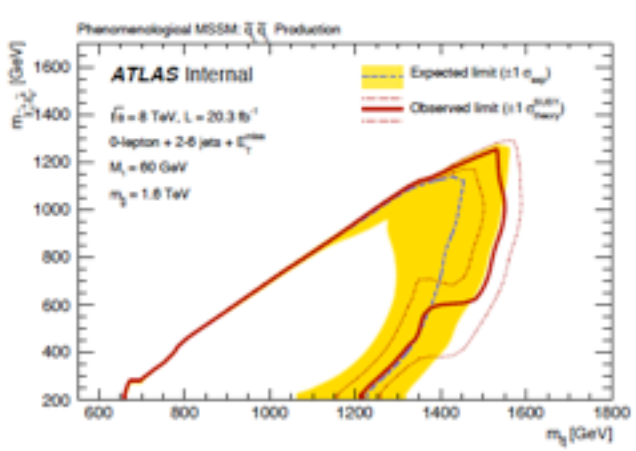
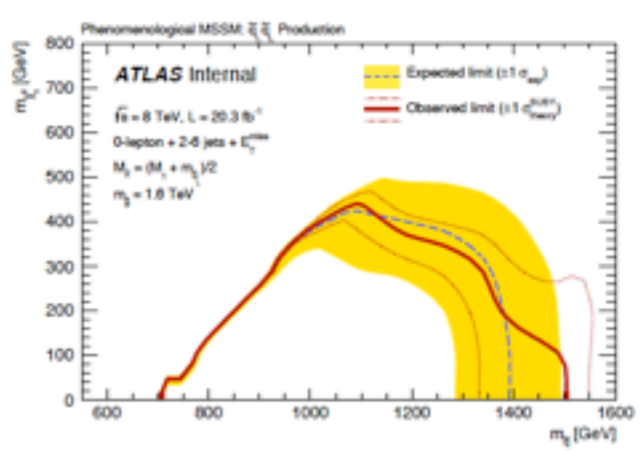
Inclusive q̃, g̃

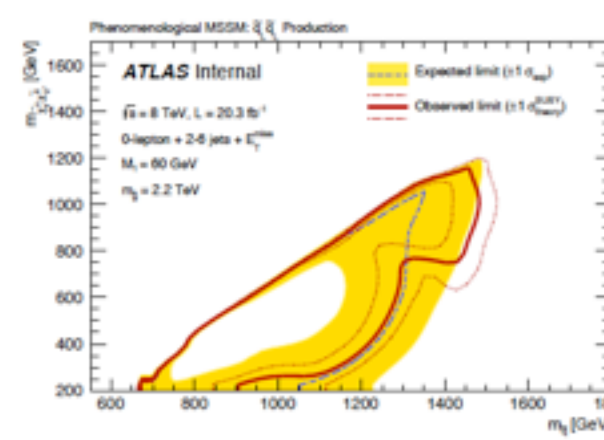


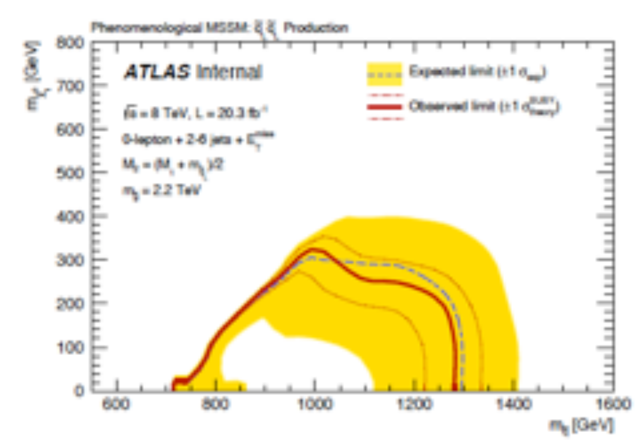
Only left handed first and second generation squarks, lightest two neutralinos, and chargino, considered kinematically accessible.
gluino masses between 1.6TeV and 3.0 TeV
All other particle decoupled at 5TeV
h is set to be SM and have SM decays

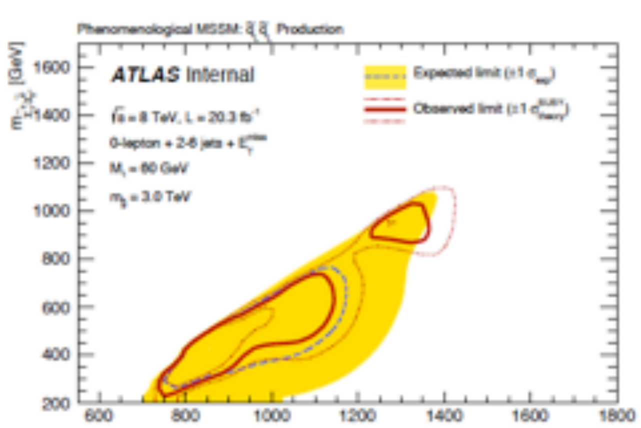
Analysis look for high P_T jets with no leptons in the final states

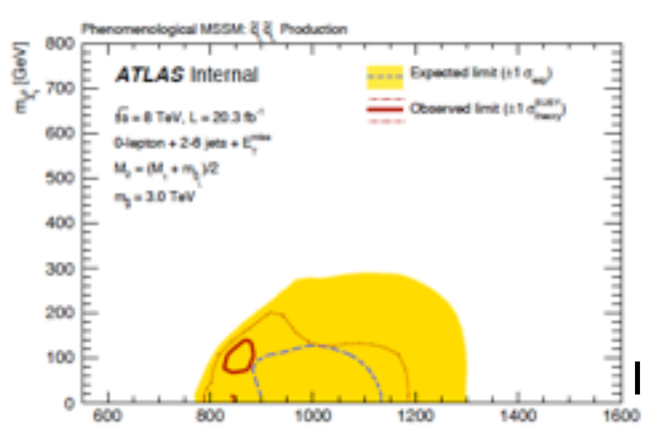












For each M_1 M_2 choice of parameters a combination of all the considered gluino masses (1.6, 2.2 3.0 TeV) is considered, and results are combined for 0L+4j and 0L+5j final states

CMS results

Combination Results

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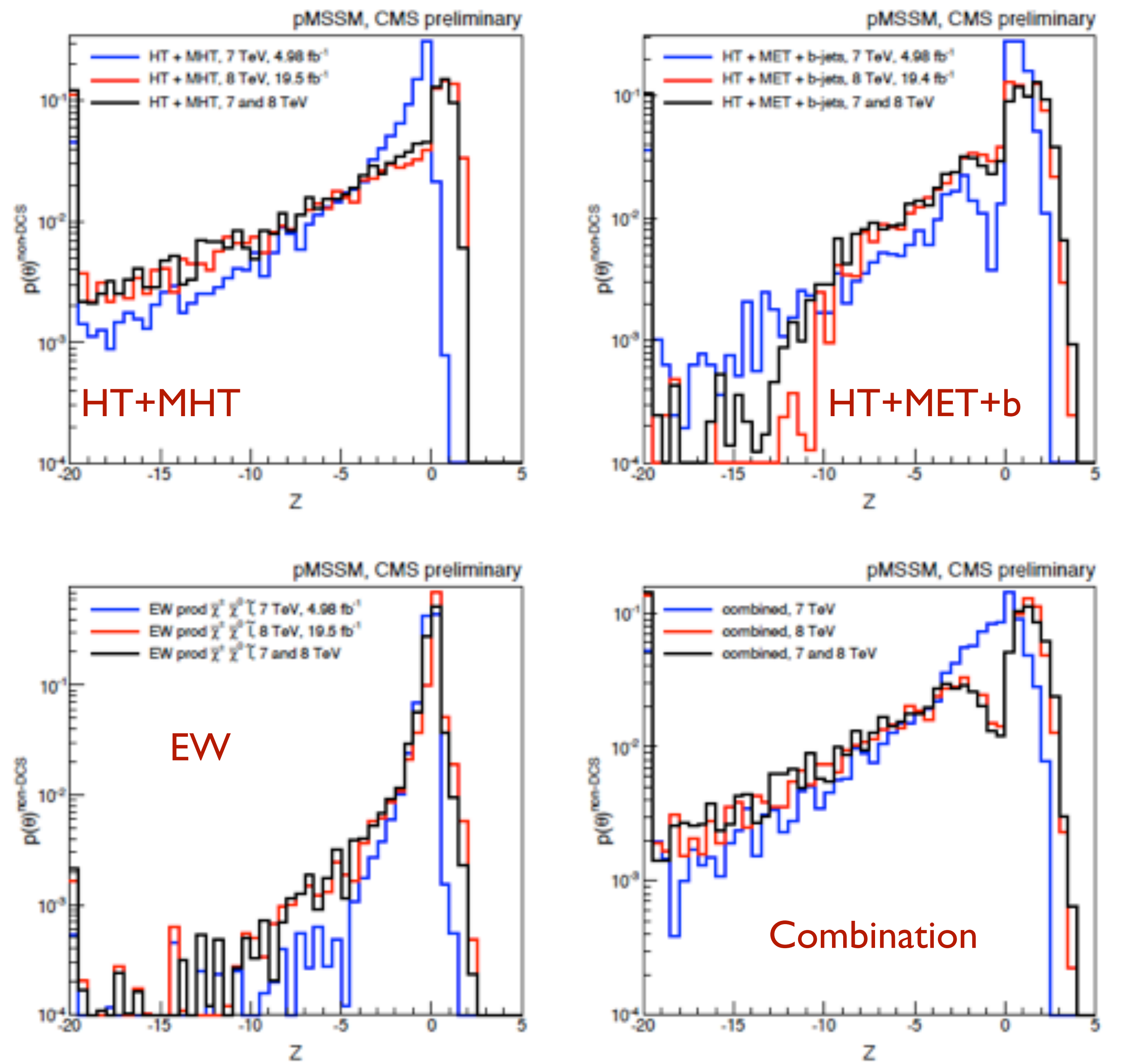
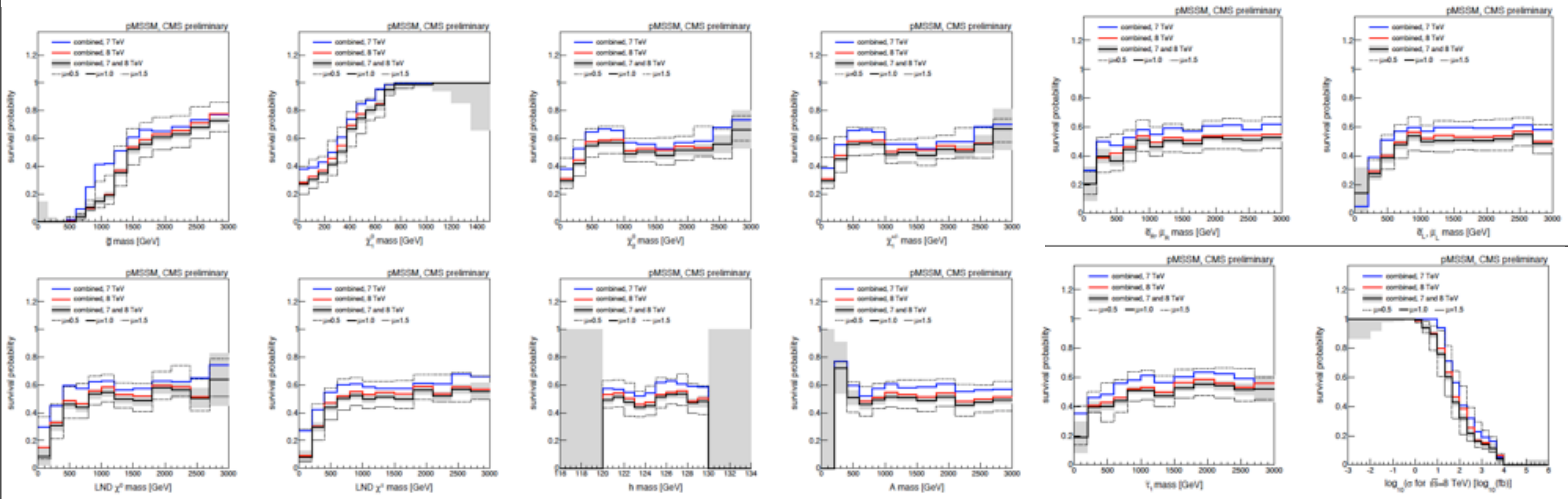
	$p(Z < -1.64)$		$p(Z < -3)$		$p(Z < -5)$	
	7 TeV					
HT + MHT	0.40	(0.23)	0.26	(0.15)	0.17	(0.09)
HT + MET + b-jets	0.19	(0.02)	0.14	(0.02)	0.098	(0.02)
EW prod. $\tilde{\chi}^{\pm}, \tilde{\chi}^{0}, \tilde{l}$	0.026	(0.008)	0.011	(0.005)	0.005	(0.002)
combination	0.42		0.29		0.19	
	8 TeV					
HT + MHT	0.45	(0.16)	0.37	(0.16)	0.30	(0.14)
HT + MET + b-jets	0.31	(0.03)	0.23	(0.02)	0.17	(0.02)
EW prod. $\tilde{\chi}^{\pm}, \tilde{\chi}^{0}, \tilde{l}$	0.050	(0.019)	0.029	(0.013)	0.016	(0.008)
combination	0.47		0.41		0.32	
	7 and 8 TeV					
HT + MHT	0.48	(0.16)	0.40	(0.16)	0.32	(0.14)
HT + MET + b-jets	0.34	(0.03)	0.26	(0.02)	0.19	(0.02)
EW prod. $\tilde{\chi}^{\pm}, \tilde{\chi}^{0}, \tilde{l}$	0.055	(0.017)	0.032	(0.012)	0.018	(0.007)
combination	0.51		0.44		0.34	

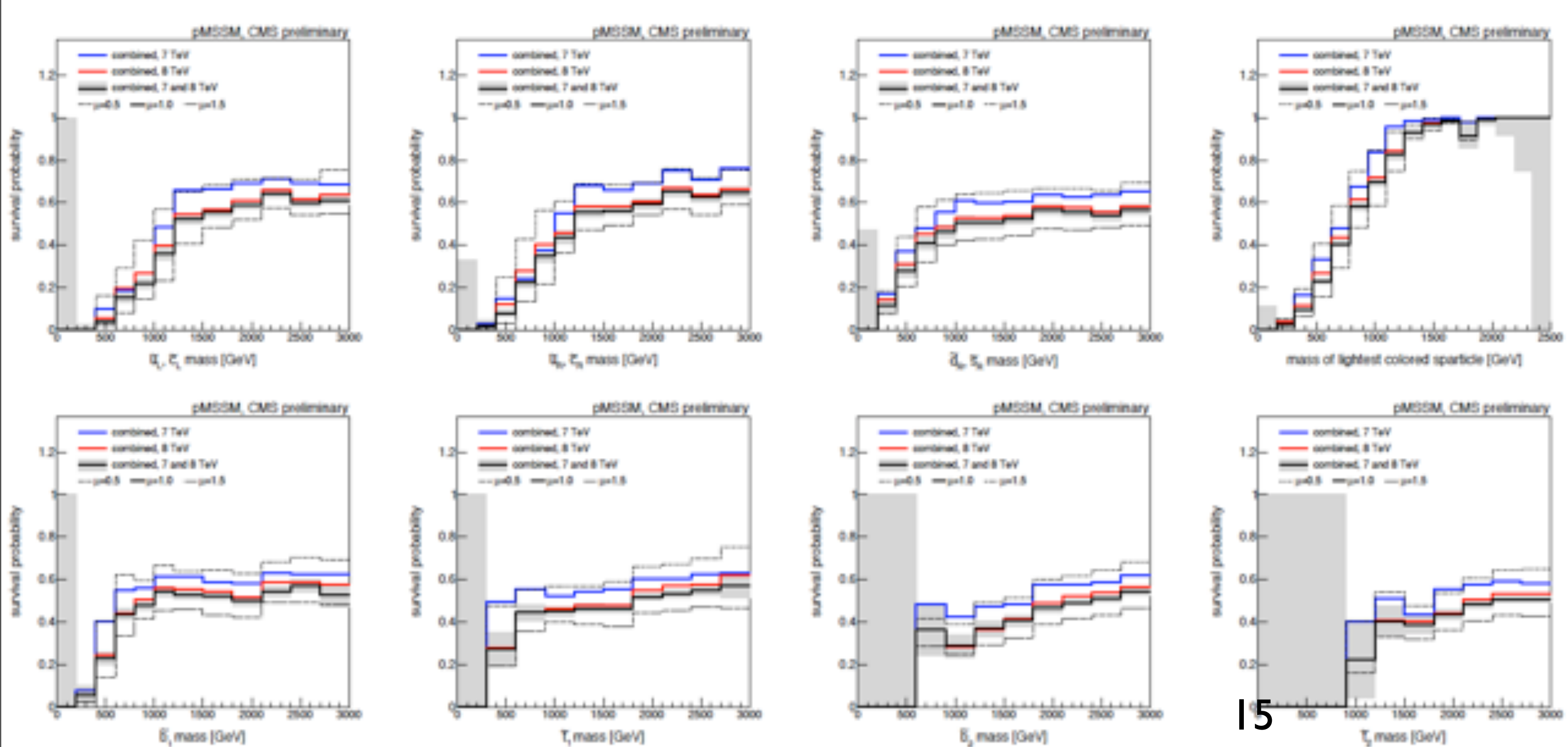


By looking at Z score for each point considered in the analysis we can calculate the fraction of pMSSM space which is excluded

Z=-1.64 correspond to 95% exclusion

Survival probabilities





In the same way the survival probability for each value of each parameter of the pMSSM space may be evaluated for the combinations

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Survival probabilities

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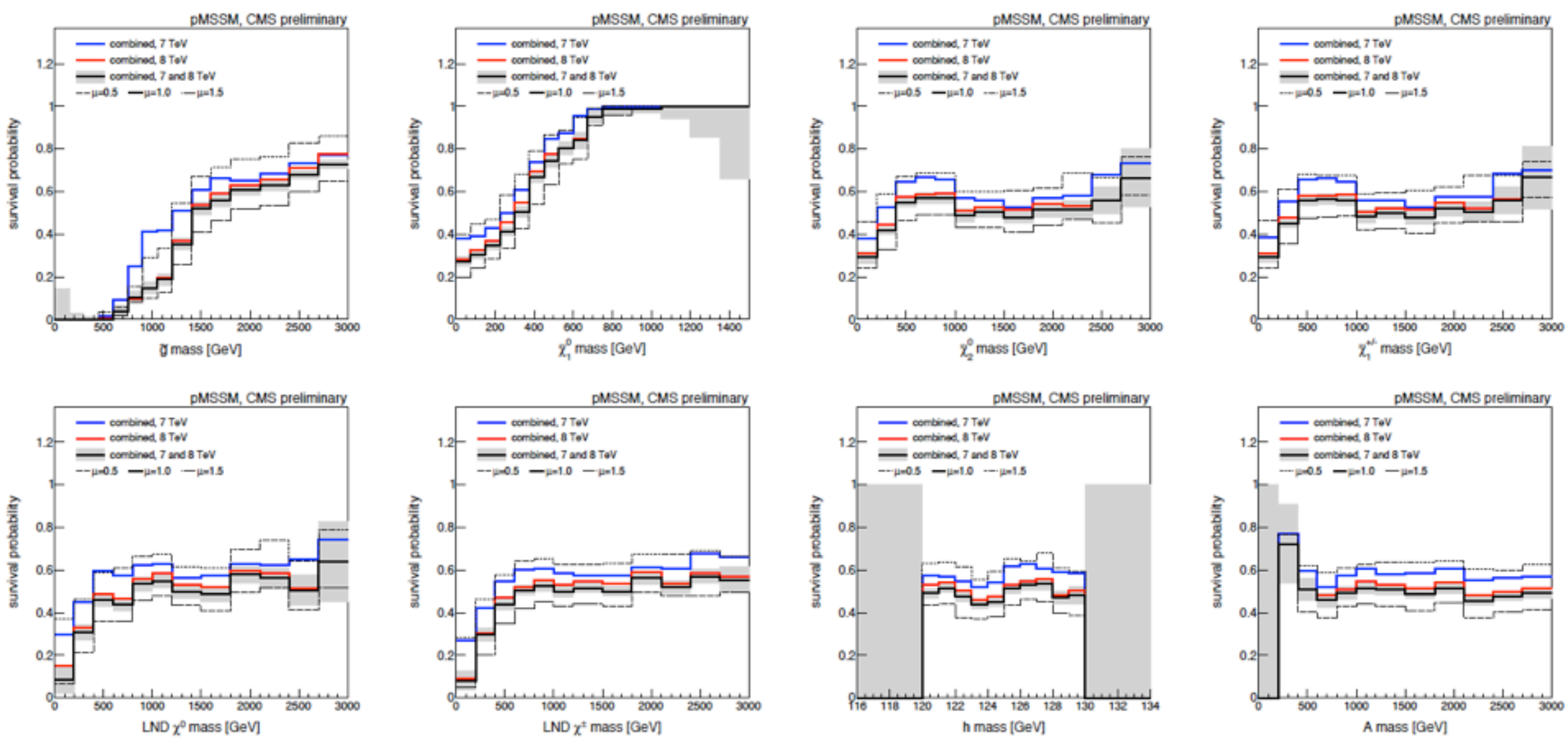

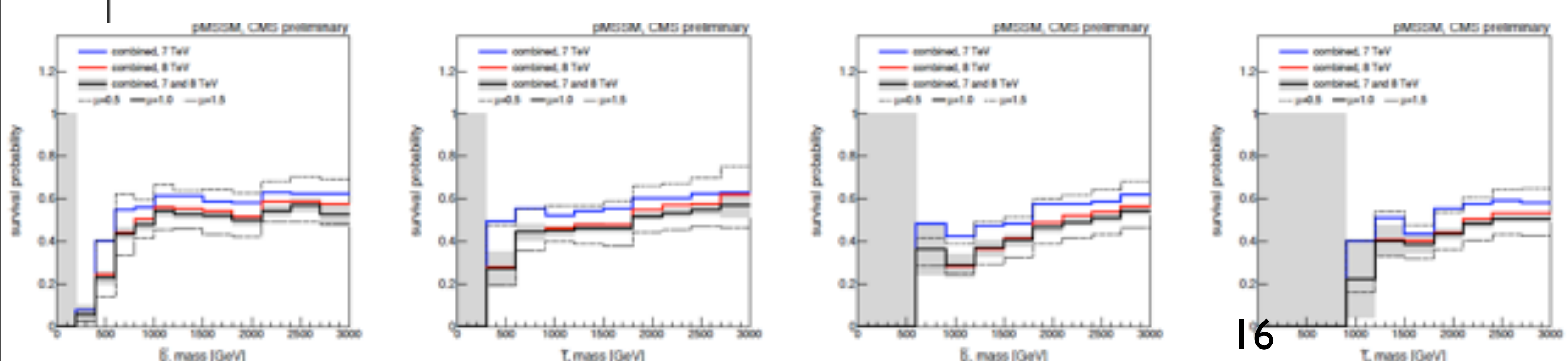

may be evaluated for the combinations

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Conclusion

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- ATLAS and CMS have pursued a large number of searches for SUSY particles interpreting their results in pMSSM scenario
- Neither ATLAS nor CMS found evidence of SUSY particles and were able to greatly reduce the available parameter space of pMSSM parameters
- ATLAS pursued a frequentist approach and interpreted every single group of final states in the pMSSM framework while CMS made a global fit of its searches to study the analysis impact on the pMSSM searches
- Combinations of different analyses at different energies enhance significantly the discovery (or rejection) reach of the LHC in SUSY searches

Backup

3rd Generation searches: t and b

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