Bethe Forum on "Supersymmetry: Tools meet Models"

Status and Future of SUSY: Discussion

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Status of SUSY

- Possible indications:
    - $(g-2)_\mu$
    - Dark matter?
- No hints for supersymmetry from the LHC
- What is the perspective from the PDG point of view?
- What **are** the actual mass bounds?
- Model dependence?

Neutralino

of $\widetilde{\chi}_1^{\pm}$ and $\widetilde{\chi}_2^0$ states on the gaugino and higgsino MSSM parameters M_2 and μ. In some cases, information is used from the nonobservation of slepton decays.

Obsolete limits obtained from e^+e^- collisions up to $\sqrt{s}$=184 GeV have been removed from this compilation and can be found in the 2000 Edition (The European Physical Journal **C15** 1 (2000)) of this Review. $\Delta m = m_{\widetilde{\chi}_2^0} - m_{\widetilde{\chi}_1^0}$.

NODE=S046PHA

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>40	95	[1] ABBIENDI	04H	OPAL	all tanβ, Δm >5 GeV, m_0 >500 GeV, $A_0 = 0$
>42.4	95	[2] HEISTER	04	ALEP	all tanβ, all Δm, all m_0
>39.2	95	[3] ABDALLAH	03M	DLPH	all tanβ, $m_{\widetilde{\nu}}$ >500 GeV
>46	95	[4] ABDALLAH	03M	DLPH	all tanβ, all Δm, all m_0
>32.5	95	[5] ACCIARRI	00D	L3	tan$\beta > 0.7$, $\Delta m > 3$ GeV, all m_0
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[6] DREINER	09	THEO	
		[7] ABBOTT	98C	D0	$p\overline{p} \rightarrow \widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^0$
>41	95	[8] ABE	98J	CDF	$p\overline{p} \rightarrow \widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^0$

OCCUR=2

[1] ABBIENDI 04H search for charginos and neutralinos in events with acoplanar leptons+jets and multi-jet final states in the 192–209 GeV data, combined with the results on leptonic final states from ABBIENDI 04. The results hold for a scan over the parameter space covering the region $0 < M_2 <5000$ GeV, $-1000 < \mu <1000$ GeV and tanβ from 1 to 40. This limit supersedes ABBIENDI 00H.

NODE=S046PHA;LINKAGE=AN

[2] HEISTER 04 data collected up to 209 GeV. Updates earlier analysis of selectrons from HEISTER 02E, includes a new analysis of charginos and neutralinos decaying into stau and uses results on charginos with initial state radiation from HEISTER 02J. The limit is based on the direct search for charginos and neutralinos, the constraints from the slepton search and the Higgs mass limits from HEISTER 02 using a top mass of 175 GeV, interpreted in a framework with universal gaugino and sfermion masses. Assuming the mixing in the stau sector to be negligible, the limit improves to 43.1 GeV. Under the assumption of MSUGRA with unification of the Higgs and sfermion masses, the limit improves to 50 GeV, and reaches 53 GeV for $A_0 = 0$. These limits include and update the results of BARATE 01.

NODE=S046PHA;LINKAGE=HE

[3] ABDALLAH 03M uses data from $\sqrt{s}$ = 192–208 GeV. A limit on the mass of $\widetilde{\chi}_1^0$ is derived from direct searches for neutralinos combined with the chargino search. Neutralinos are searched in the production of $\widetilde{\chi}_1^0\widetilde{\chi}_2^0$, $\widetilde{\chi}_1^0\widetilde{\chi}_3^0$, as well as $\widetilde{\chi}_2^0\widetilde{\chi}_3^0$ and $\widetilde{\chi}_2^0\widetilde{\chi}_4^0$ giving rise to cascade decays, and $\widetilde{\chi}_1^0\widetilde{\chi}_2^0$ and $\widetilde{\chi}_1^0\widetilde{\chi}_2^0$, followed by the decay $\widetilde{\chi}_2^0 \rightarrow \widetilde{\tau}\tau$. The results hold for the parameter space defined by values of $M_2 < 1$ TeV, $|\mu| \leq 2$ TeV with the $\widetilde{\chi}_1^0$ as LSP. The limit is obtained for tan$\beta = 1$ and large m_0, where $\widetilde{\chi}_2^0\widetilde{\chi}_4^0$ and chargino pair production are important. If the constraint from Higgs searches is also imposed, the limit improves to 49.0 GeV in the $m_h^{\max}$ scenario with m_t=174.3 GeV. These limits update the results of ABREU 00J.

NODE=S046PHA;LINKAGE=AD

[4] ABDALLAH 03M uses data from $\sqrt{s}$ = 192–208 GeV. An indirect limit on the mass of $\widetilde{\chi}_1^0$ is derived by constraining the MSSM parameter space by the results from direct searches for neutralinos (including cascade decays and $\widetilde{\tau}\tau$ final states), for charginos (for all Δm_+) and for sleptons, stop and sbottom. The results hold for the full parameter space defined by values of $M_2 < 1$ TeV, $|\mu| \leq 2$ TeV with the $\widetilde{\chi}_1^0$ as LSP. Constraints from the Higgs search in the $m_h^{\max}$ scenario assuming m_t=174.3 GeV are included. The limit is obtained for tan$\beta \geq$ 5 when stau mixing leads to mass degeneracy between $\widetilde{\tau}_1$ and $\widetilde{\chi}_1^0$ and the limit is based on $\widetilde{\chi}_2^0$ production followed by its decay to $\widetilde{\tau}_1\tau$. In the pathological scenario where m_0 and $|\mu|$ are large, so that the $\widetilde{\chi}_2^0$ production cross section is negligible, and where there is mixing in the stau sector but not in stop nor sbottom, the limit is based on charginos with soft decay products and an ISR photon. The limit then degrades to 39 GeV. See Figs 40–42 for the dependence of the limit on tanβ and $m_{\widetilde{\nu}}$. These limits update the results of ABREU 00W.

NODE=S046PHA;LINKAGE=AL

[5] ACCIARRI 00D data collected at $\sqrt{s}$=189 GeV. The results hold over the full parameter space defined by $0.7 \leq$ tan$\beta \leq 60$, $0 \leq M_2 \leq 2$ TeV, $m_0 \leq 500$ GeV, $|\mu| \leq 2$ TeV The minimum mass limit is reached for tanβ=1 and large m_0. The results of slepton searches from ACCIARRI 99W are used to help set constraints in the region of small m_0. The limit improves to 48 GeV for $m_0 \gtrsim 200$ GeV and tan$\beta \gtrsim 10$. See their Figs. 6–8 for the tanβ and m_0 dependence of the limits. Updates ACCIARRI 98F.

NODE=S046PHA;LINKAGE=DL

[6] DREINER 09 show that in the general MSSM with non-universal gaugino masses there exists no model-independent laboratory bound on the mass of the lightest neutralino. An essentially massless χ_1^0 is allowed by the experimental and observational data, imposing some constraints on other MSSM parameters, including M_2, μ and the slepton and squark masses.

NODE=S046PHA;LINKAGE=DR

Neutralino

- PDG bound: 46 GeV, DELPHI at LEP.
    - Assumes universal gaugino masses and uses chargino lower mass bound
- Dropping assumption leads to no bound. $M_\chi = 0$ consistent with all lab data. (No assumption about DM)
- Assuming $\chi_1^0 = 100\%$ CDM, $M_\chi > 30\,\text{GeV}$ (Bottino et al, Hollik et al)

Squark

Limits from e^+e^- collisions depend on the mixing angle of the lightest mass eigenstate $\tilde{q}_1=\tilde{q}_R\sin\theta_q+\tilde{q}_L\cos\theta_q$. It is usually assumed that only the sbottom and stop squarks have non-trivial mixing angles (see the stop and sbottom sections). Here, unless otherwise noted, squarks are always taken to be either left/right degenerate, or purely of left or right type. Data from Z decays have set squark mass limits above 40 GeV, in the case of $\tilde{q} \to q\tilde{\chi}_1$ decays if $\Delta m=m_{\tilde{q}} - m_{\tilde{\chi}^0_1} \gtrsim 5$ GeV. For smaller values of Δm, current constraints on the invisible width of the Z ($\Delta\Gamma_{inv} < 2.0$ MeV, LEP 00) exclude $m_{\tilde{u}_{L,R}} <44$ GeV, $m_{\tilde{d}_R} <33$ GeV, $m_{\tilde{d}_L} <44$ GeV and, assuming all squarks degenerate, $m_{\tilde{q}} <45$ GeV.

Limits made obsolete by the most recent analyses of e^+e^-, $p\overline{p}$, and $e\,p$ collisions can be found in previous Editions of this *Review*.

NODE=S046SQK;CHECK LIMITS

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT	
> 1.110 × 10^3 (CL = 95%) [>1.100 × 10^3 GeV (CL = 95%) OUR 2012 BEST LIMIT]						
>1250	95	[1] CHATRCHYAN	13G	CMS	0,1,2, ≥ 3 b-jets + $\not{E}_T$, CMSSM, $m_{\tilde{q}} = m_{\tilde{g}}$	
> 820	95	[2] AAD	12AX	ATLS	ℓ +jets +$\not{E}_T$, CMSSM, $m_{\tilde{q}}=m_{\tilde{g}}$	
>1200	95	[3] AAD	12CJ	ATLS	$\ell^\pm$+jets+$\not{E}_T$, CMSSM, $m_{\tilde{q}}=m_{\tilde{g}}$	
>1110	95	[4] CHATRCHYAN	12AT	CMS	jets + $\not{E}_T$, CMSSM	
>1180	95	[4] CHATRCHYAN	12AT	CMS	jets + $\not{E}_T$, CMSSM, $m_{\tilde{q}}=m_{\tilde{g}}$	OCCUR=2
> 690	95	[5] AAD	11B	ATLS	$\ell^\pm\ell^\pm$+$\not{E}_T$, $m_{\tilde{g}}=m_{\tilde{q}}$+10GeV, $m_{\tilde{\chi}^0_1}$=100GeV, tanβ=4	
> 550	95	[5] AAD	11B	ATLS	$\ell^+\ell^-$+$\not{E}_T$, $m_{\tilde{g}}=m_{\tilde{q}}$+10GeV, $m_{\tilde{\chi}^0_1}$=100GeV, tanβ=4	OCCUR=2
> 558	95	[6] AAD	11C	ATLS	$\ell^+\ell^-$+jets+$\not{E}_T$, $m_{\tilde{g}}=m_{\tilde{q}}$+10GeV, $m_{\tilde{\chi}^0_1}$=100GeV, tanβ=4	
> 700	95	[7] AAD	11G	ATLS	ℓ+jets+$\not{E}_T$, tanβ=3, A_0=0, $\mu >$ 0, $m_{\tilde{g}}=m_{\tilde{q}}$	
> 870	95	[8] AAD	11N	ATLS	jets+$\not{E}_T$, degenerate $m_{\tilde{q}}$ of first two generations, $m_{\tilde{\chi}^0_1}$=0, all other supersymmetric particles heavy, $m_{\tilde{q}}=m_{\tilde{g}}$	
> 775	95	[8] AAD	11N	ATLS	jets+$\not{E}_T$, CMSSM, $m_{\tilde{q}}=m_{\tilde{g}}$	OCCUR=2
>1100	95	[9] CHATRCHYAN	11W	CMS	jets + $\not{E}_T$, CMSSM	
> 392	95	[10] AALTONEN	09S	CDF	jets+$\not{E}_T$, $m_{\tilde{q}}=m_{\tilde{g}}$	
> 379	95	[11] ABAZOV	08G	D0	jets+$\not{E}_T$, tanβ=3, μ<0, A_0=0, any $m_{\tilde{g}}$	
> 99.5		[12] ACHARD	04	L3	Δm >10 GeV, $e^+e^- \to \tilde{q}_{L,R}\overline{\tilde{q}}_{L,R}$	
> 97		[12] ACHARD	04	L3	Δm >10 GeV, $e^+e^- \to \tilde{q}_R\overline{\tilde{q}}_R$	OCCUR=2
> 138	95	[13] ABBOTT	01D	D0	$\ell\ell$+jets+$\not{E}_T$, tanβ < 10, m_0 < 300 GeV, μ < 0, A_0=0	
> 255	95	[13] ABBOTT	01D	D0	tanβ=2, $m_{\tilde{g}}=m_{\tilde{q}}$, μ <0, A_0=0, $\ell\ell$+jets+$\not{E}_T$	OCCUR=2
> 97	95	[14] BARATE	01	ALEP	$e^+e^- \to \tilde{q}\overline{\tilde{q}}$, Δm > 6 GeV	
> 224	95	[15] ABE	96D	CDF	$m_{\tilde{g}} \leq m_{\tilde{q}}$; with cascade decays, $\ell\ell$+jets+$\not{E}_T$	
• • • We do not use the following data for averages, fits, limits, etc. • • •						
>1360	95	[16] AAD	13L	ATLS	jets + $\not{E}_T$, CMSSM, $m_{\tilde{g}} = m_{\tilde{q}}$	
>1200	95	[17] AAD	13Q	ATLS	γ + b + $\not{E}_T$, higgsino-like neutralino, $m_{\tilde{\chi}^0_1}$ > 220 GeV, GMSB	
		[18] CHATRCHYAN	13	CMS	$\ell^\pm\ell^\mp$ + jets + $\not{E}_T$, CMSSM	
>1430	95	[19] CHATRCHYAN	13H	CMS	2γ + ≥ 4 jets + low $\not{E}_T$, stealth SUSY model	
> 870	95	[20] AAD	12CP	ATLS	2γ +$\not{E}_T$, GMSB, bino NLSP, $m_{\tilde{\chi}^0_1}$ > 50 GeV	
> 950	95	[21] AAD	12W	ATLS	jets + $\not{E}_T$, CMSSM, $m_{\tilde{q}} = m_{\tilde{g}}$	
		[22] CHATRCHYAN	12	CMS	e, μ, jets, razor, CMSSM	
> 760	95	[23] CHATRCHYAN	12AE	CMS	jets + $\not{E}_T$, $\tilde{q} \to q\tilde{\chi}^0_1$, $m_{\tilde{\chi}^0_1}$ < 200 GeV	
		[24] CHATRCHYAN	12AL	CMS	$\geq 3\ell^\pm$, $\not{R}$	

> 340	95	[25] DREINER	12A	THEO	$m_{\widetilde{q}} \sim m_{\widetilde{\chi}_1^0}$	
> 650	95	[26] DREINER	12A	THEO	$m_{\widetilde{q}} = m_{\widetilde{g}} \sim m_{\widetilde{\chi}_1^0}$	OCCUR=2
		[27] AAD	11AE	ATLS	$\ell^{\pm}\ell^{\pm}$	
		[28] AAD	11AF	ATLS	$\geq$ 6 jets + $\not{E}_T$, CMSSM	
> 290	95	[29] AARON	11	H1	$e^- p \rightarrow \widetilde{d}_R$, $\not{R}$, $LQ\overline{D}$,λ'=0.3	
> 275	95	[29] AARON	11	H1	$e^+ p \rightarrow \widetilde{u}_L$, $\not{R}$, $LQ\overline{D}$, λ'=0.3	OCCUR=2
> 330	95	[30] AARON	11C	H1	$\widetilde{u}$, $\not{R}$, $LQ\overline{D}$, λ'=0.3	
		[31] CHATRCHYAN	11AC	CMS	jets + $\not{E}_T$, CMSSM	
		[32] CHATRCHYAN	11C	CMS	$\widetilde{q} \rightarrow X\widetilde{\chi}_2^0 \rightarrow X\ell^+\ell^-\widetilde{\chi}_1^0$	
		[33] CHATRCHYAN	11G	CMS	$\widetilde{\chi}_1^0 \rightarrow \gamma\widetilde{G}$	
		[34] CHATRCHYAN	11Q	CMS	ℓ + jets + $\not{E}_T$	
> 830	95	[35] CHATRCHYAN	11V	CMS	GMSB scenario, $\widetilde{\ell}$ co-NLSP	
		[36] CHATRCHYAN	11V	CMS	$\not{R}$	OCCUR=2
		[37] KHACHATRY...	11I	CMS	jets + $\not{E}_T$	
		[38] ABAZOV	09S	D0	jets+τ+$\not{E}_T$, tanβ=15, μ <0, A_0=$-2m_0$	
> 490	95	[39] SCHAEL	07A	ALEP	$\widetilde{d}_R$, $\not{R}$, λ=0.3	
> 544	95	[39] SCHAEL	07A	ALEP	$\widetilde{s}_R$, $\not{R}$, λ=0.3	OCCUR=2
> 273	95	[40] CHEKANOV	05A	ZEUS	$\widetilde{q} \rightarrow \mu q$, $\not{R}$, $LQ\overline{D}$, λ=0.3	
> 270	95	[40] CHEKANOV	05A	ZEUS	$\widetilde{q} \rightarrow \tau q$, $\not{R}$, $LQ\overline{D}$, λ=0.3	OCCUR=2
> 275		[41] AKTAS	04D	H1	$e^{\pm} p \rightarrow \widetilde{U}_L$, $\not{R}$, $LQ\overline{D}$	
> 280		[41] AKTAS	04D	H1	$e^{\pm} p \rightarrow \widetilde{D}_R$, $\not{R}$, $LQ\overline{D}$	OCCUR=2
		[42] ADLOFF	03	H1	$e^{\pm} p \rightarrow \widetilde{q}$, $\not{R}$, $LQ\overline{D}$	
> 276	95	[43] CHEKANOV	03B	ZEUS	$\widetilde{d} \rightarrow e^- u$,$\nu d$,$\not{R}$,$LQ\overline{D}$,$\lambda$ >0.1	
> 260	95	[43] CHEKANOV	03B	ZEUS	$\widetilde{u} \rightarrow e^+ d$,$\not{R}$,$LQ\overline{D}$,$\lambda$ >0.1	OCCUR=2
> 82.5	95	[44] HEISTER	03G	ALEP	$\widetilde{u}_R$,$\not{R}$ decay	
> 77	95	[44] HEISTER	03G	ALEP	$\widetilde{d}_R$,$\not{R}$ decay	OCCUR=2
> 240	95	[45] ABAZOV	02F	D0	$\widetilde{q}$, $\not{R}$ λ'_{2jk} indirect decays, tanβ=2, any $m_{\widetilde{g}}$	
> 265	95	[45] ABAZOV	02F	D0	$\widetilde{q}$, $\not{R}$ λ'_{2jk} indirect decays, tanβ=2, $m_{\widetilde{q}}$=$m_{\widetilde{g}}$	OCCUR=2
		[46] ABAZOV	02G	D0	$p\overline{p} \rightarrow \widetilde{g}\widetilde{g}$, $\widetilde{g}\widetilde{q}$	
none 80–121	95	[47] ABBIENDI	02	OPAL	$e\gamma \rightarrow \widetilde{u}_L$, $\not{R}$ $LQ\overline{D}$, λ=0.3	
none 80–158	95	[47] ABBIENDI	02	OPAL	$e\gamma \rightarrow \widetilde{d}_R$, $\not{R}$ $LQ\overline{D}$, λ=0.3	OCCUR=2
none 80–185	95	[48] ABBIENDI	02B	OPAL	$e\gamma \rightarrow \widetilde{u}_L$, $\not{R}$ $LQ\overline{D}$, λ=0.3	
none 80–196	95	[48] ABBIENDI	02B	OPAL	$e\gamma \rightarrow \widetilde{d}_R$, $\not{R}$ $LQ\overline{D}$, λ=0.3	OCCUR=2
> 79	95	[49] ACHARD	02	L3	$\widetilde{u}_R$, $\not{R}$ decays	
> 55	95	[49] ACHARD	02	L3	$\widetilde{d}_R$, $\not{R}$ decays	OCCUR=2
> 263	95	[50] CHEKANOV	02	ZEUS	$\widetilde{u}_L \rightarrow \mu q$, $\not{R}$, $LQ\overline{D}$, λ=0.3	
> 258	95	[50] CHEKANOV	02	ZEUS	$\widetilde{u}_L \rightarrow \tau q$, $\not{R}$, $LQ\overline{D}$, λ=0.3	OCCUR=2
> 82	95	[51] BARATE	01B	ALEP	$\widetilde{u}_R$, $\not{R}$ decays	
> 68	95	[51] BARATE	01B	ALEP	$\widetilde{d}_R$, $\not{R}$ decays	OCCUR=2
none 150–204	95	[52] BREITWEG	01	ZEUS	$e^+ p \rightarrow \widetilde{d}_R$, $\not{R}$ $LQ\overline{D}$, λ=0.3	
> 200	95	[53] ABBOTT	00C	D0	$\widetilde{u}_L$, $\not{R}$, λ'_{2jk} decays	
> 180	95	[53] ABBOTT	00C	D0	$\widetilde{d}_R$, $\not{R}$, λ'_{2jk} decays	OCCUR=2
> 390	95	[54] ACCIARRI	00P	L3	$e^+e^- \rightarrow q\overline{q}$, $\not{R}$, λ=0.3	
> 148	95	[55] AFFOLDER	00K	CDF	$\widetilde{d}_L$, $\not{R}$ λ'_{ij3} decays	
> 200	95	[56] BARATE	00I	ALEP	$e^+e^- \rightarrow q\overline{q}$, $\not{R}$, λ=0.3	OCCUR=2
none 150–269	95	[57] BREITWEG	00E	ZEUS	$e^+ p \rightarrow \widetilde{u}_L$, $\not{R}$, $LQ\overline{D}$, λ=0.3	
> 240	95	[58] ABBOTT	99	D0	$\widetilde{q} \rightarrow \widetilde{\chi}_2^0 X \rightarrow \widetilde{\chi}_1^0 \gamma X$, $m_{\widetilde{\chi}_2^0} - m_{\widetilde{\chi}_1^0}$ > 20 GeV	
> 320	95	[58] ABBOTT	99	D0	$\widetilde{q} \rightarrow \widetilde{\chi}_1^0 X \rightarrow \widetilde{G}\gamma X$	OCCUR=2
> 243	95	[59] ABBOTT	99K	D0	any $m_{\widetilde{g}}$, $\not{R}$, tanβ=2, μ < 0	
> 250	95	[60] ABBOTT	99L	D0	tanβ=2, μ <0, A=0, jets+$\not{E}_T$	
> 200	95	[61] ABE	99M	CDF	$p\overline{p} \rightarrow \widetilde{q}\widetilde{q}$, $\not{R}$	
none 80–134	95	[62] ABREU	99G	DLPH	$e\gamma \rightarrow \widetilde{u}_L$, $\not{R}$ $LQ\overline{D}$, λ=0.3	
none 80–161	95	[62] ABREU	99G	DLPH	$e\gamma \rightarrow \widetilde{d}_R$, $\not{R}$ $LQ\overline{D}$, λ=0.3	OCCUR=2
> 225	95	[63] ABBOTT	98E	D0	$\widetilde{u}_L$, $\not{R}$, λ'_{1jk} decays	
> 204	95	[63] ABBOTT	98E	D0	$\widetilde{d}_R$, $\not{R}$, λ'_{1jk} decays	OCCUR=2
> 79	95	[63] ABBOTT	98E	D0	$\widetilde{d}_L$, $\not{R}$, λ'_{ijk} decays	OCCUR=3
> 202	95	[64] ABE	98S	CDF	$\widetilde{u}_L$, $\not{R}$ λ'_{2jk} decays	

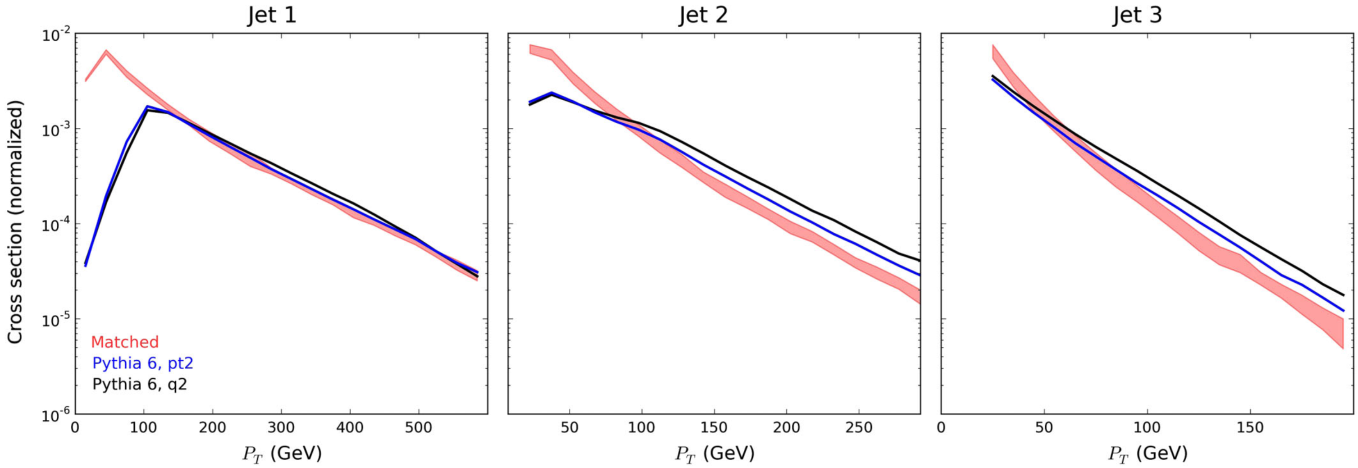

FIG. 6 (color online). Comparison between two jet MLM matching and adding the parton shower to a matrix element that already contains a hard jet (double counting).

As stated above, in the limit of degeneracy, the exact decay mode of the top squark does not change the phenomenology. However, as we increase the mass splitting, the precise decay mode can become important. An example is that if the final state decay products are $b\ell\nu$ or bjj, the process can look very similar to normal top production. In this case, the bounds may be weakened from the ones presented here.

We would also like to state that although we have labeled the scenario Top squark, it can in fact apply to any scenario where only a single squark eigenstate is light. This is because if the gluino is decoupled, there are no t-channel production processes. Thus the cross section is identical for all squark states and there is no parton density functions (PDF) flavor dependence. In fact in this case, the limit is more likely to hold as the mass splitting is increased between the squark and the LSP because the decay,

$$\tilde{q}_i \to q_i \tilde{\chi}_1^0, \tag{5}$$

can be expected to dominate.

The second model that we consider, "Squark," can almost be considered a subcategory of the above. Here, instead of a single eigenstate, we now place the first two generations of squarks, quasidegenerate with the LSP. Thus, the only difference in phenomenology from the first model mentioned is that the cross section is increased by a factor of 8. Hence, we can expect the limit to be significantly more stringent. The model can easily accommodate a different number of squarks by a simple rescaling of the cross section. After considering the quasidegeneracy case ($\Delta M = 1$ GeV), we then study the phenomenology as the mass splitting is increased, until we reach the limit of a massless LSP. These models can be in particular motivated if the gluino is given a Dirac mass term, that can produce a

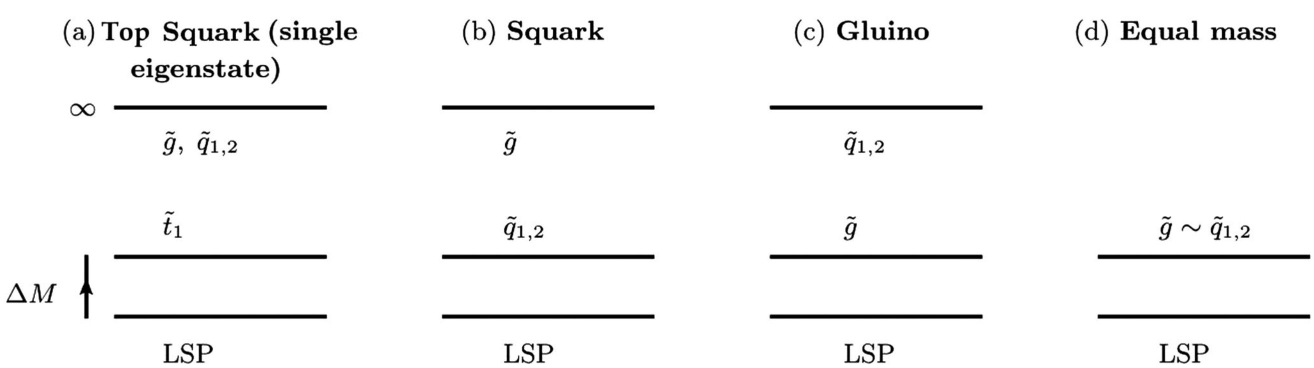

FIG. 7. The spectra for the simplified models studied in this paper. For the top squark scenario we place the top squark (or a single eigenstate squark) quasidegenerate with the LSP and remove all other particles from the spectrum. In the squark scenario we place the first and second generation squarks quasidegenerate with the LSP while removing all other particles. The gluino scenario has the gluino placed quasidegenerate with the LSP and all other particles removed. In the equal mass scenario, the first two generations of squarks and the gluino are placed degenerate with the LSP and all other particles are removed. In all models quasidegenerate refers to 1 GeV mass splitting. Larger mass splittings are investigated all the way up to a massless LSP.

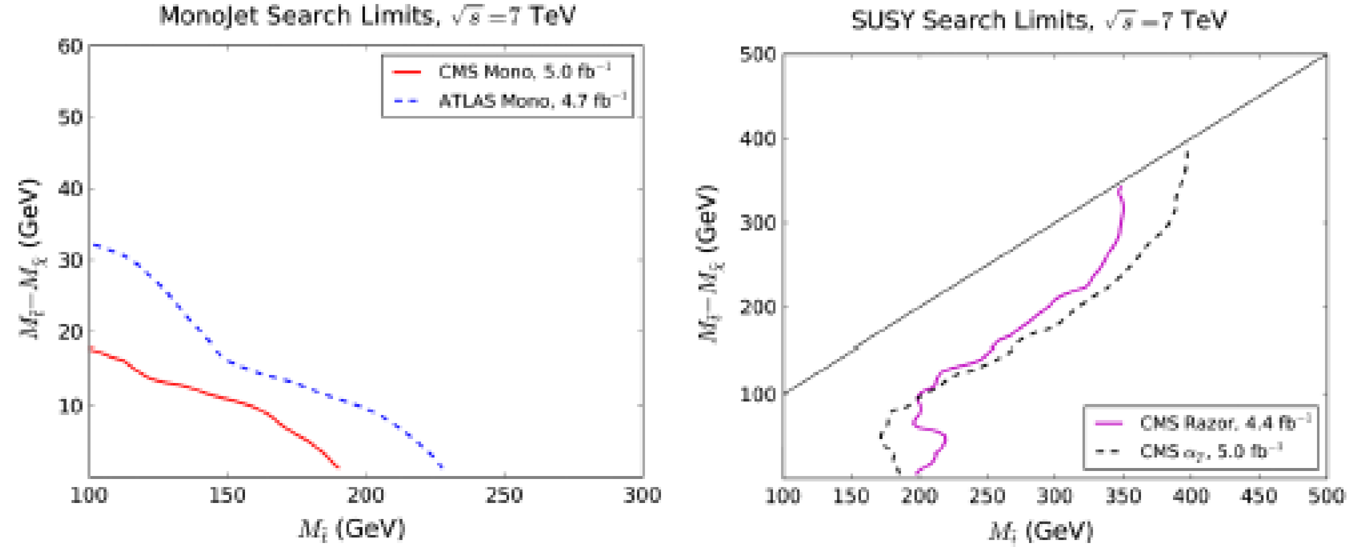

FIG. 9 (color online). Limits from the monojet and SUSY searches for top squarks (or a single eigenstate squark) as the mass splitting to the LSP is increased.

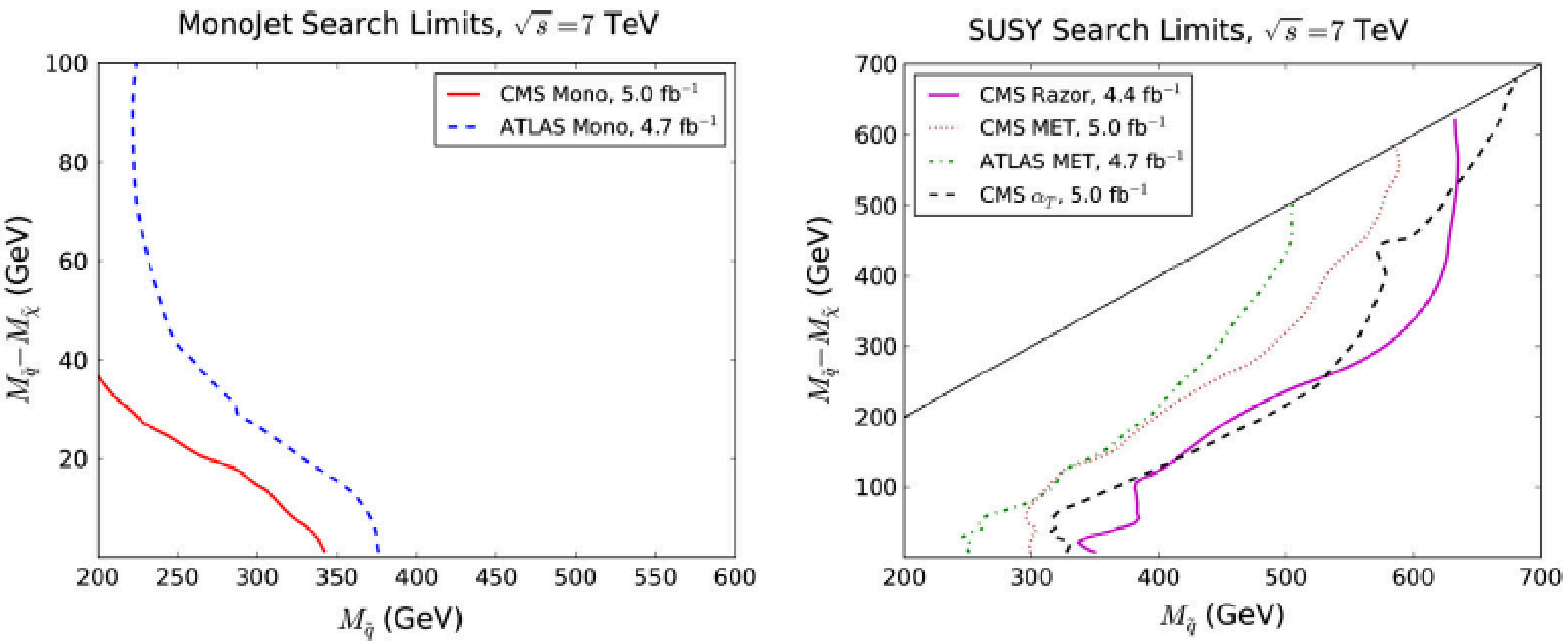

FIG. 11 (color online). Limits from the monojet and SUSY searches for first and second generation squarks as the mass splitting to the LSP is increased.

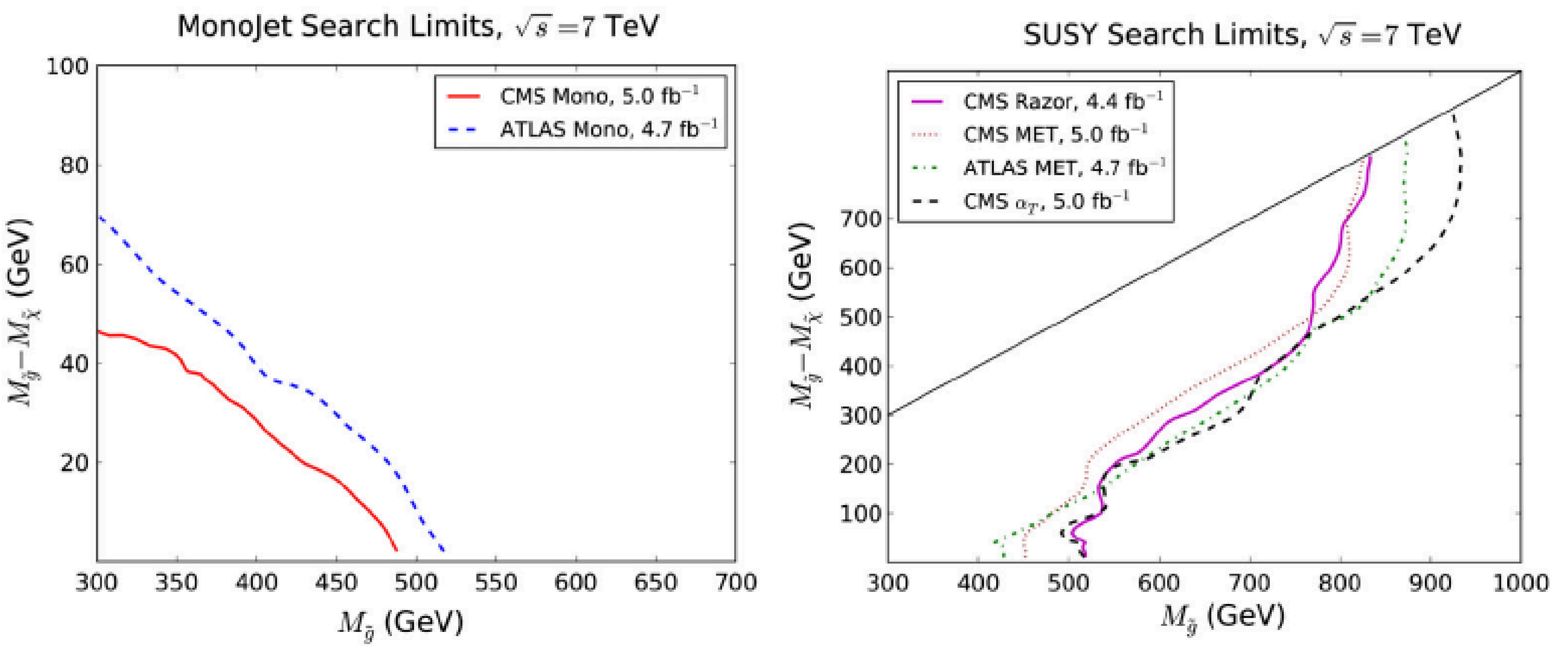

FIG. 13 (color online). Limits from the monojet and SUSY searches for gluinos as the mass splitting to the LSP is increased.

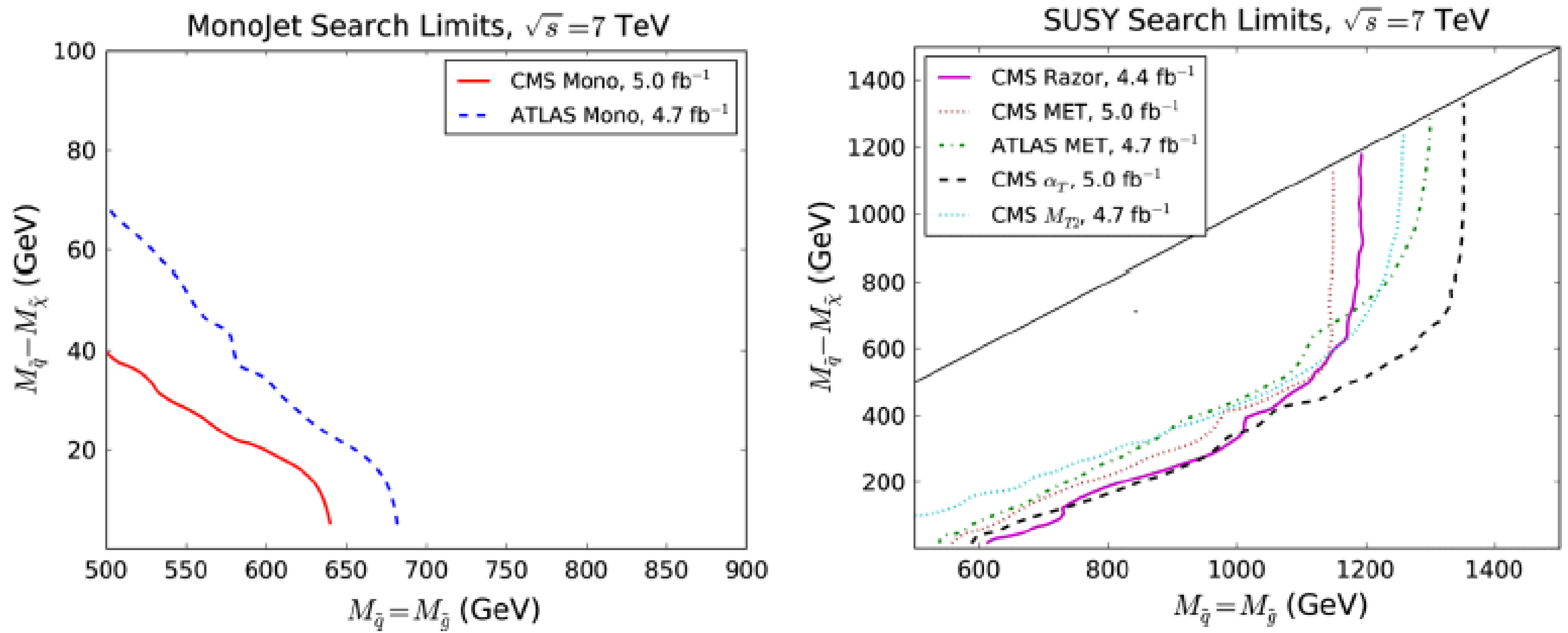

FIG. 15 (color online). Limits from the monojet and SUSY searches for the equal mass squark, gluino scenario as the mass splitting to the LSP is increased.

TABLE II. Comparison of the bounds on the mass of SUSY particles for the different searches employed at the LHC. The luminosity of the searches and the most constraining search region are also given (the search region names refer to those given in the original experimental papers).

Search	$\mathcal{L}$ (fb^{-1})	Search region (given in source)	Degeneracy bound (GeV)			
			Top squark	Squark	Gluino	Equal
Monojet						
ATLAS[a] [55]	4.7	SR3/SR4	230	370	520	680
CMS[a] [54]	5.0	$E_T^{\rm miss} > 400$	190	340	480	650
SUSY						
ATLAS MET [3]	4.7	A' med/C med	···	260	450	540
CMS α_T [5]	5.0	Optimized H_r bin	190	330	530	600
CMS MET [7]	5.0	A2	···	300	460	550
CMS M_{T2} [4]	4.7	A/B	···	···	400	500
CMS Razor [6]	4.4	bHad$(6_4 + 7_4 + 8_4 + 9_4)$	200	350	530	610

[a]The ATLAS and CMS monojet searches only give these bounds for mass differences <5 GeV. For larger mass splittings, the bounds become much weaker.

Squark: other issues

- Squark degeneracy (single squark)
- R-parity violation: talk last week by Riccardo Torre
  - Considered stop production, followed by UDD decay, ie 4 jets
  - No bound at 100 GeV, chance of detection for $m_{\tilde{t}} = 200\,\mathrm{Gev}$
- Simplified models? See gluinos

Gluino

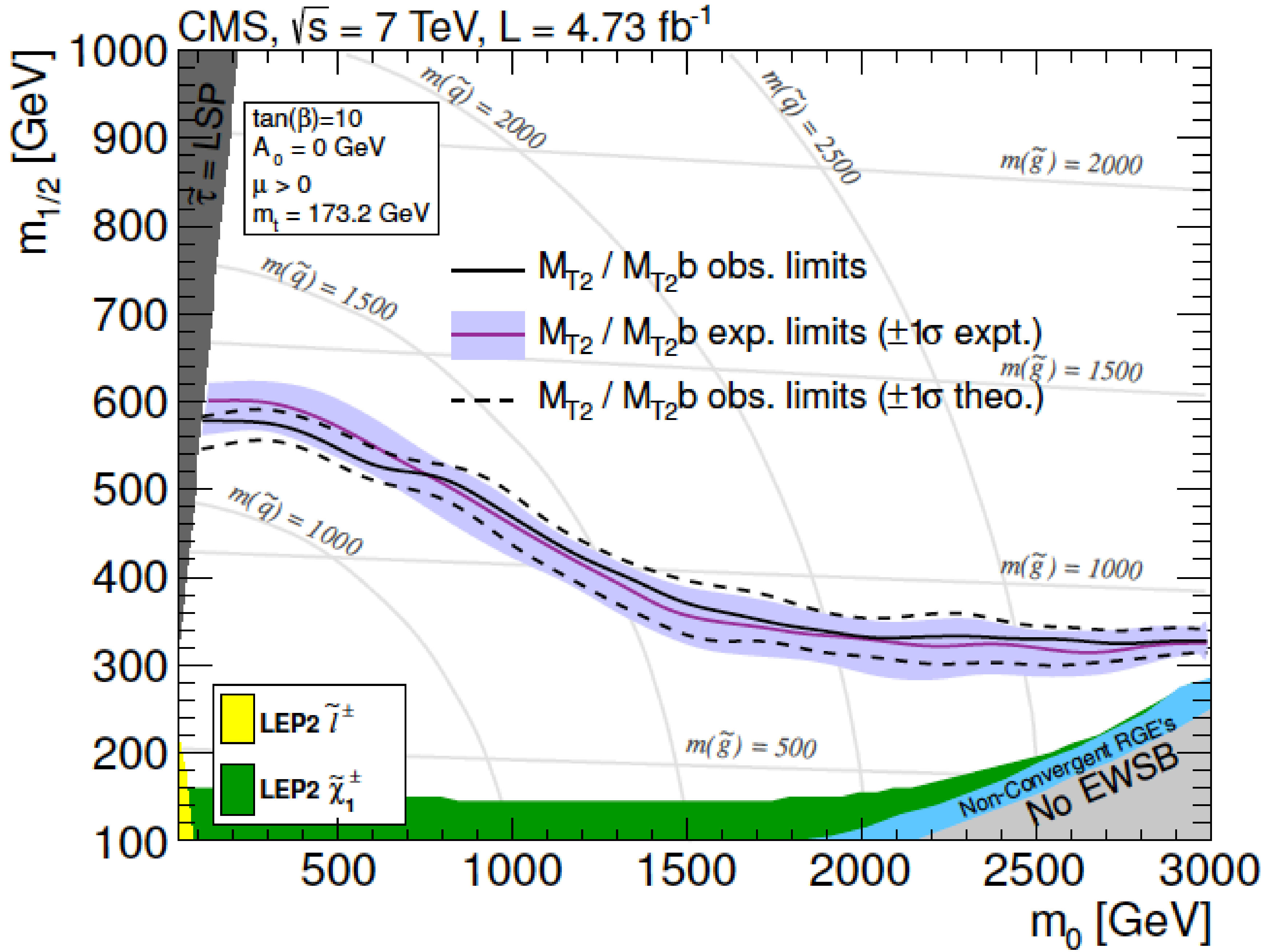

Figure 5. Top: exclusion limit in the CMSSM $(m_0, m_{1/2})$ plane for the M_{T2} and $M_{\mathrm{T2}}b$ analyses with $\tan\beta = 10$. Bottom: Combined limit based on the best expected limit at each point.

fundamental models, not necessarily in a supersymmetric framework. We studied the following topologies:

- gluino pair production, with $\widetilde{g} \rightarrow q\overline{q}\widetilde{\chi}^0$;
- gluino pair production, with $\widetilde{g} \rightarrow b\overline{b}\widetilde{\chi}^0$;
- gluino pair production, with $\widetilde{g} \rightarrow t\overline{t}\widetilde{\chi}^0$;
- gluino pair production, with $\widetilde{g} \rightarrow q\overline{q}Z\widetilde{\chi}^0$.

The last of these models is used to demonstrate the sensitivity of the analysis in a high jet multiplicity topology, since the hadronic decay of the Z boson can lead to (maximally) 8 jets in the final state. In figure 6 the 95% CL excluded cross sections are reported as

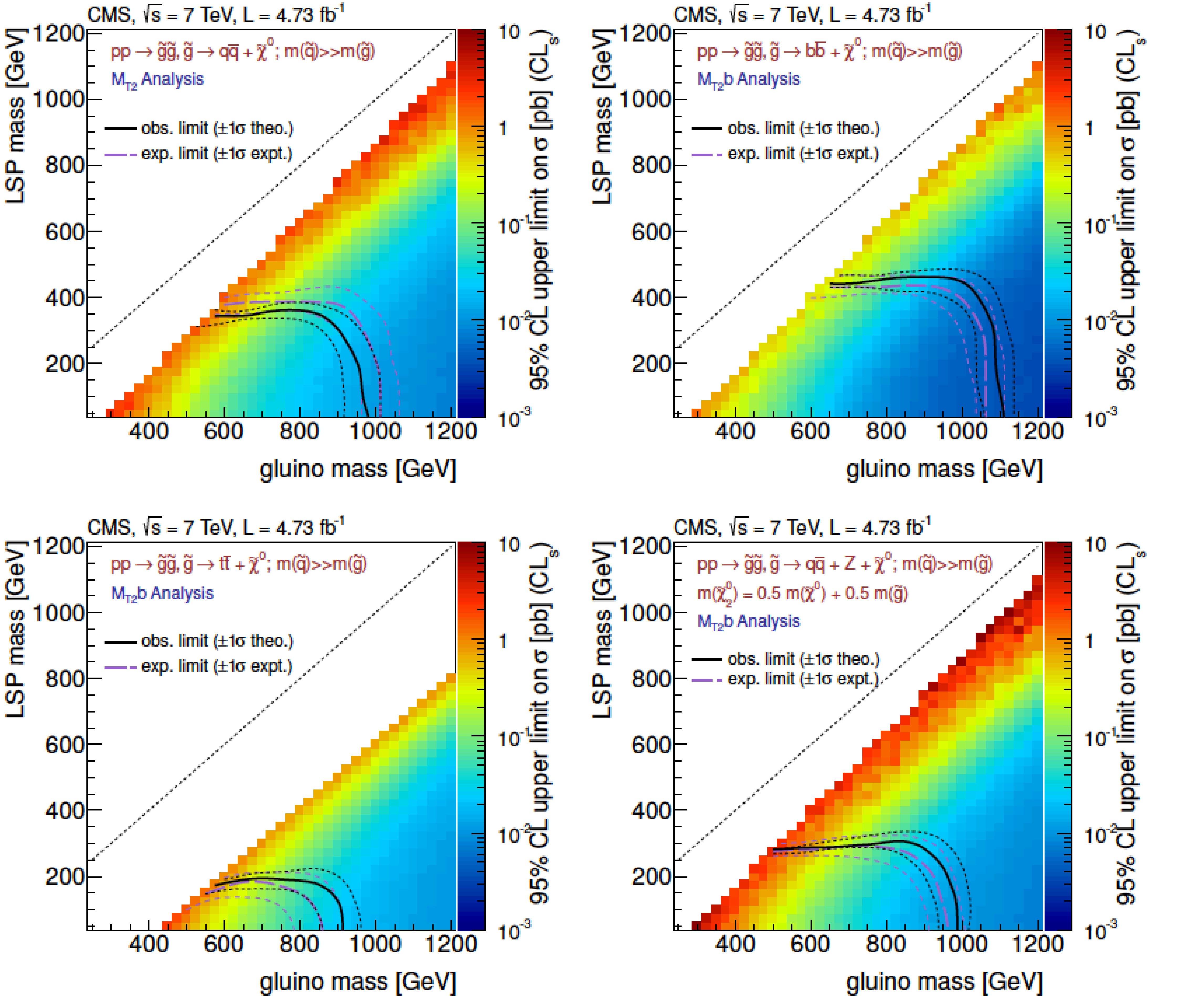

Figure 6. Exclusion limits for simplified model spectra. Upper left: gluino pair production with $\widetilde{g} \to q\overline{q}\widetilde{\chi}^0$ using the M_{T2} analysis. Upper right: gluino pair production with $\widetilde{g} \to b\overline{b}\widetilde{\chi}^0$, using the $M_{T2}b$ analysis. Lower left: gluino pair production with $\widetilde{g} \to t\overline{t}\widetilde{\chi}^0$, using the $M_{T2}b$ analysis. Lower right: gluino pair production with $\widetilde{g} \to q\overline{q}Z\widetilde{\chi}^0$, using the $M_{T2}b$ analysis. The signal production cross sections are calculated at NLO and NLL accuracy [26, 45, 46].

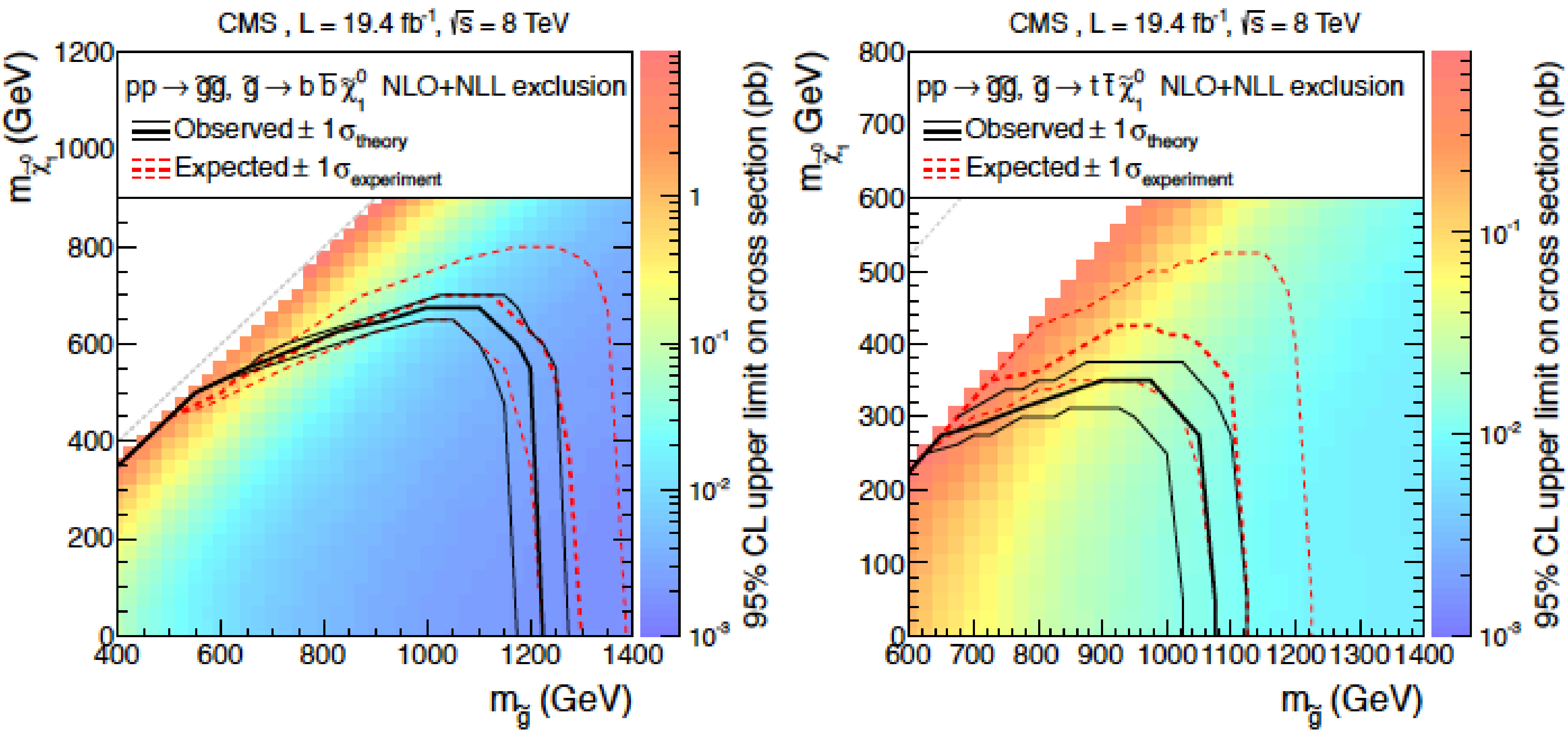

Figure 7: The 95% CL upper limits on the [left] T1bbbb and [right] T1tttt new-physics scenario cross sections (pb) derived using the CL_s method. The solid (black) contours show the observed exclusions assuming the NLO+NLL cross sections [30–34], along with the ±1 standard deviation theory uncertainties [61]. The dashed (red) contours present the corresponding expected results, along with the ±1 standard deviation experimental uncertainties.

Future of SUSY

- LHC will increase energy and luminosity
- There is no measure in parameter space (except fine-tuning?)
- Must explore every last corner of parameter space
- When should we give up?

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- When would **YOU** give up?