Closing in on the Tip of the cMSSM Stau Coannihilation Strip

(with J. Ellis, F. Luo and J. Marrouche; **arXiv:1404.5061**)

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1

What is SUSY?
What is the cMSSM?

What is the co-annihilation strip?

2

How does one probe this theory? — accelerator experiments

What are the LHC detectors capable of?

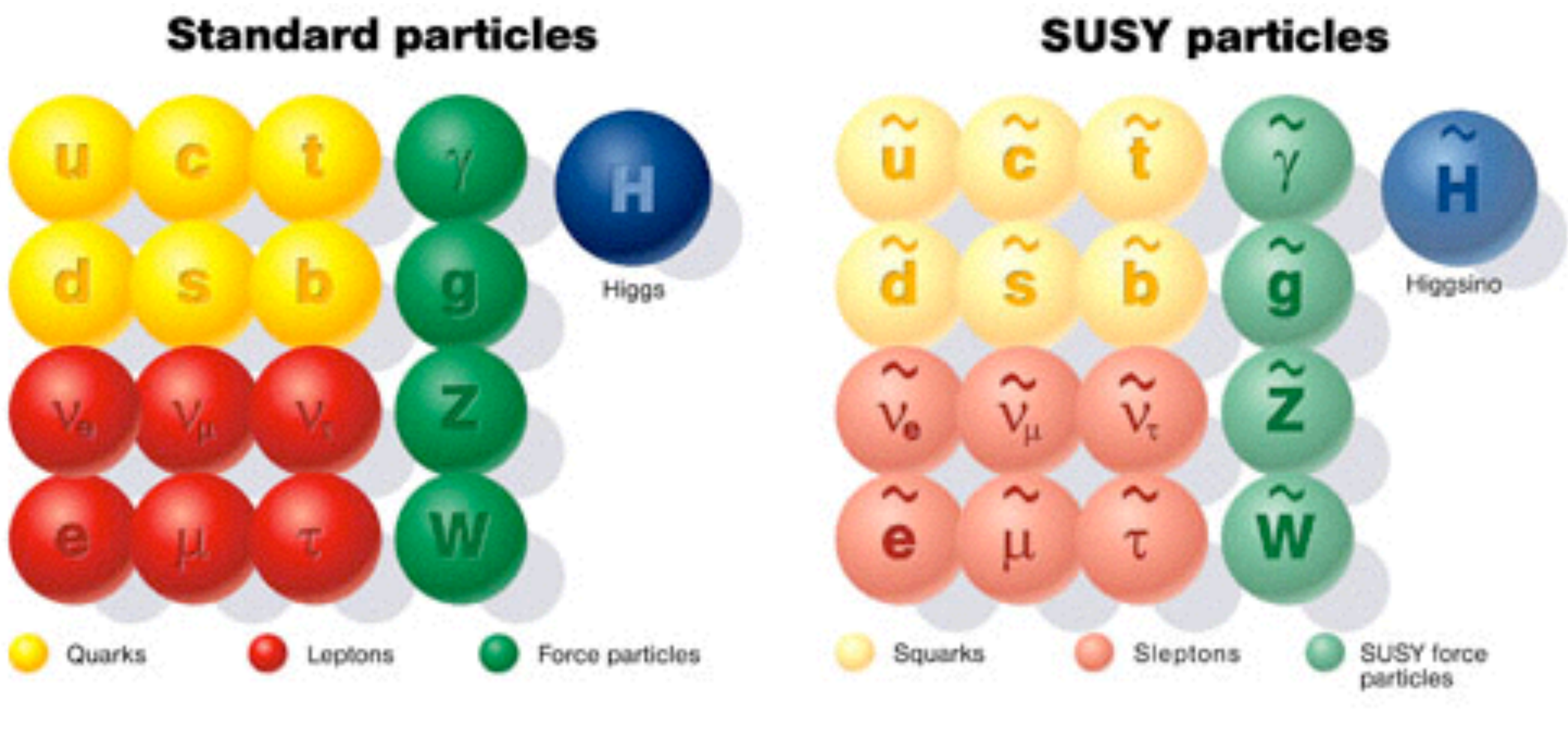
What kind of searches are relevant?

3

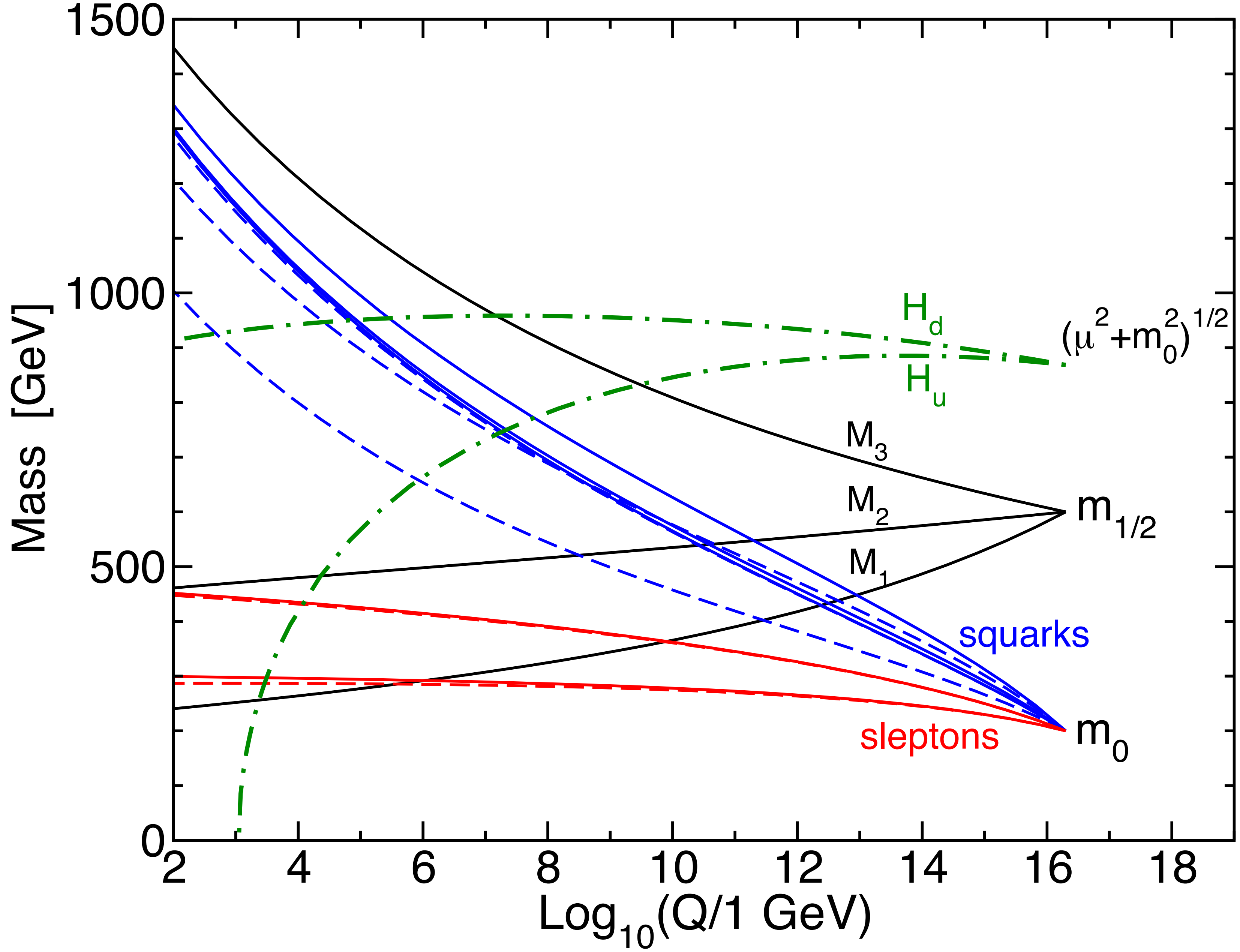
How do we use the results?

What can we do in the future?

Mandatory SUSY spectrum slide



What is the cMSSM?

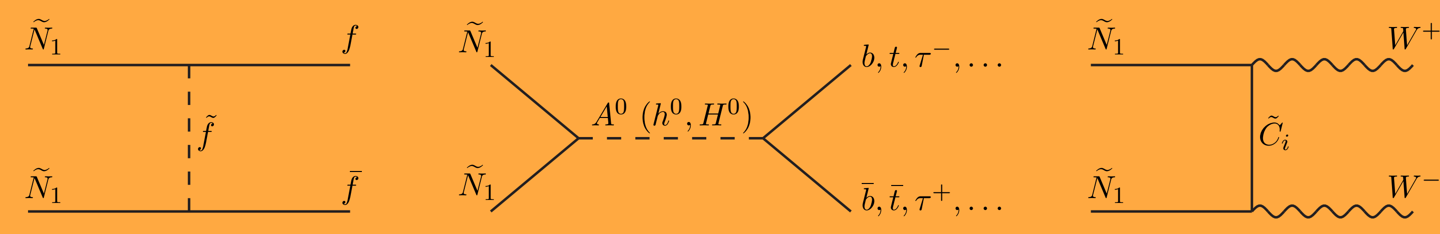


(Source: S.P. Martin; hep-ph/9709356)

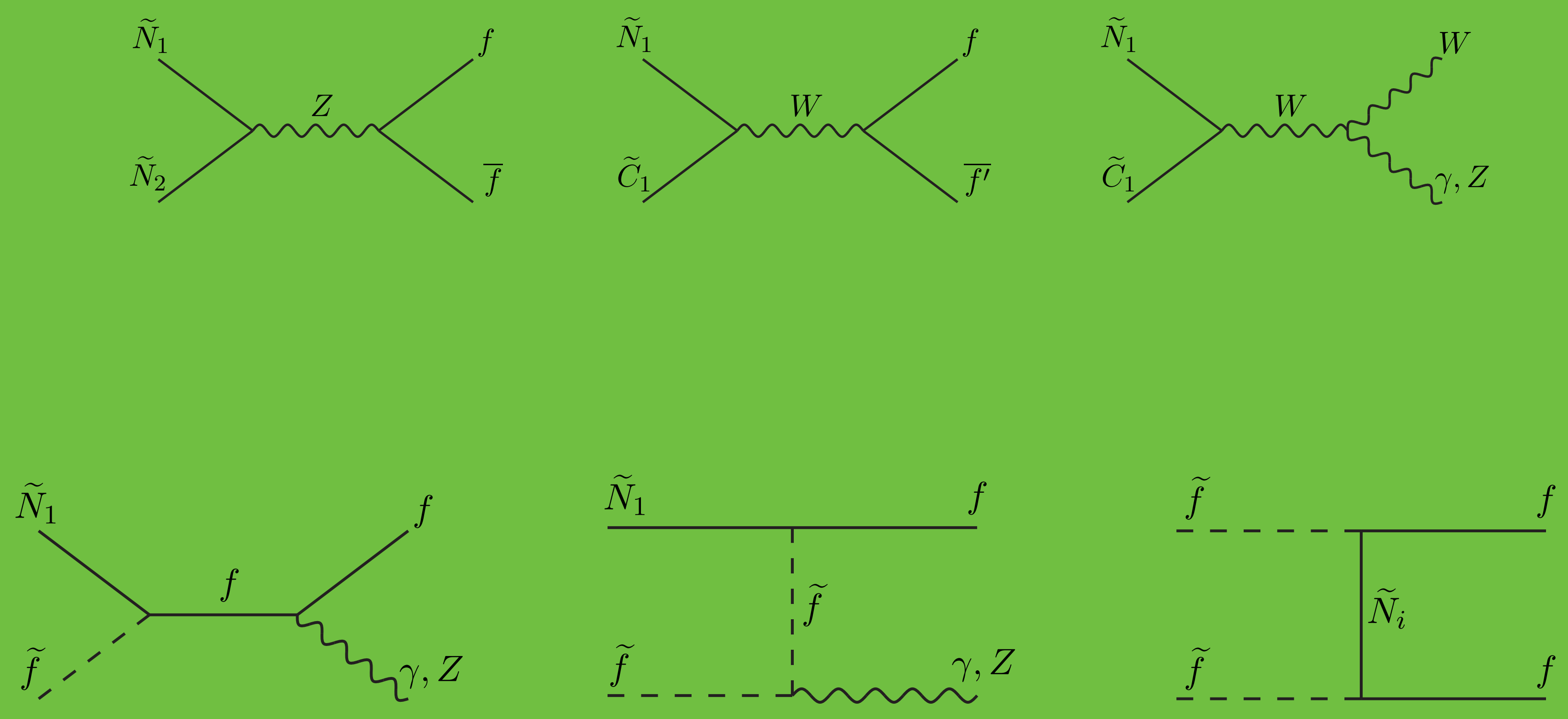
$$m_0, m_{1/2}, A_0, \tan\beta, sign(\mu)$$

Modes of annihilation

direct

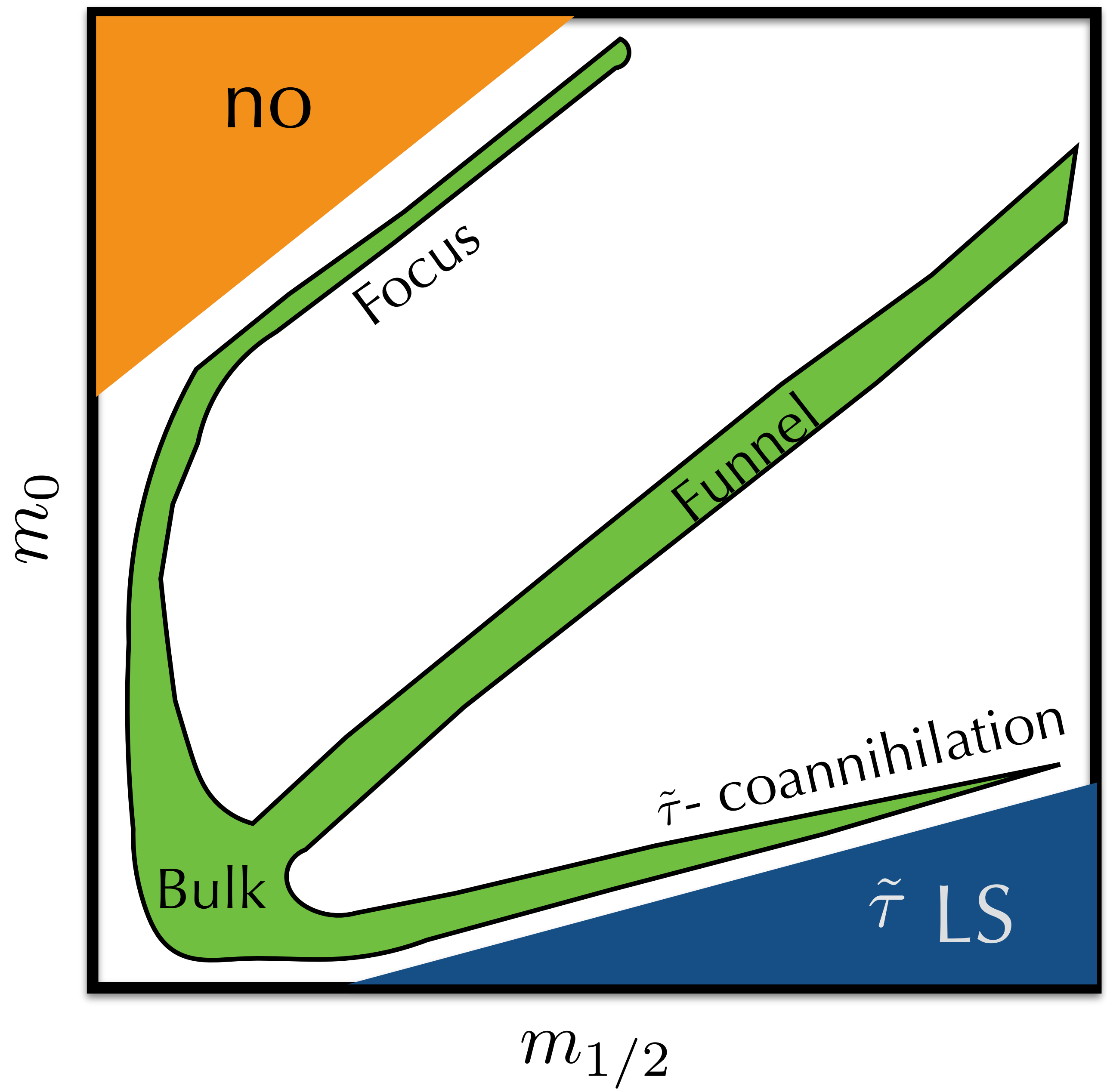


co-annihilation



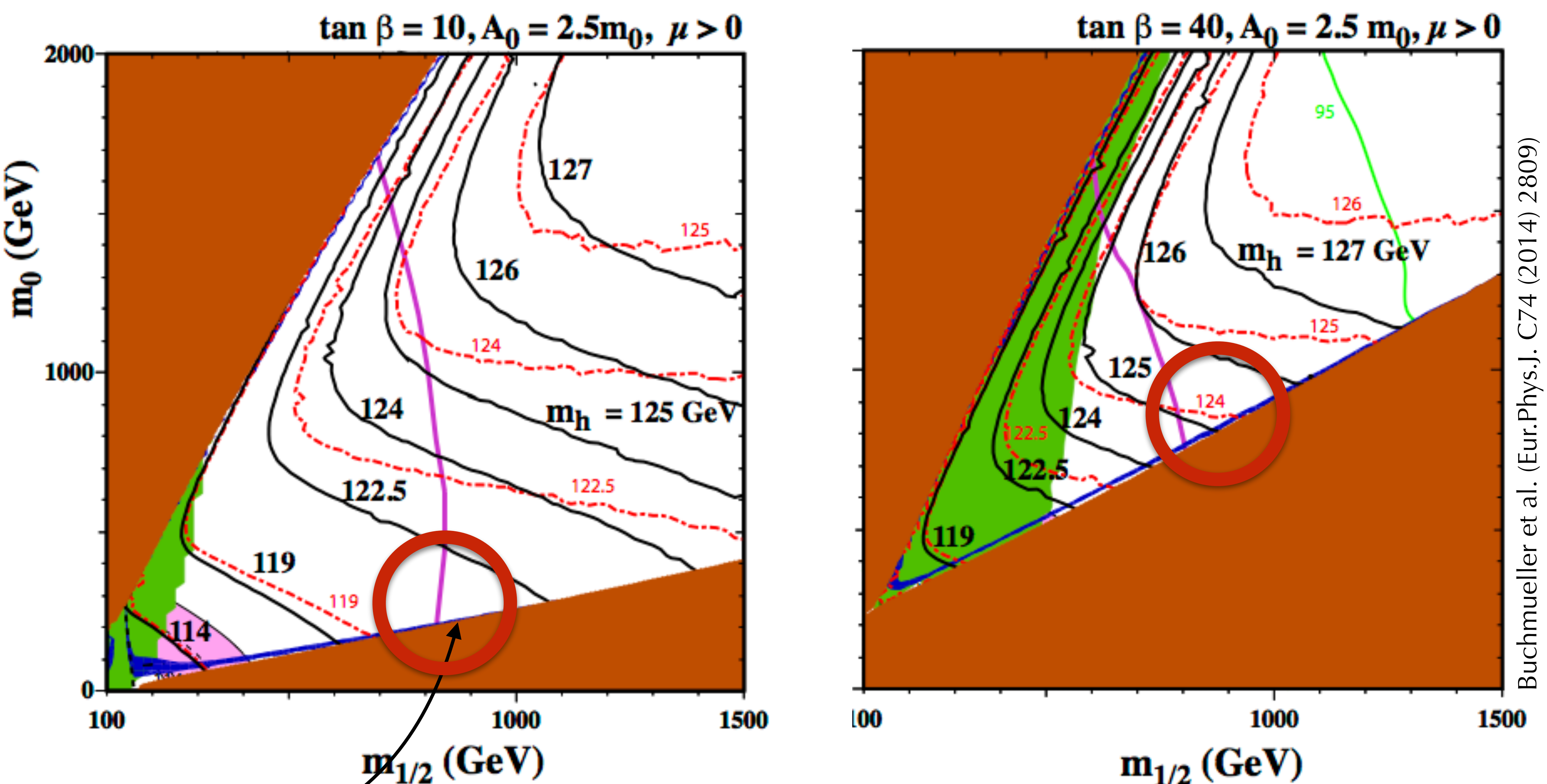
(Source: S.P. Martin; hep-ph/9709356)

What regions of CMSSM parameter space are favoured?



we use: $0.115 < \Omega_\chi h^2 < 0.125$

Higgs mass and jets+MET constraints



Buchmueller et al. (Eur.Phys.J. C74 (2014) 2809)

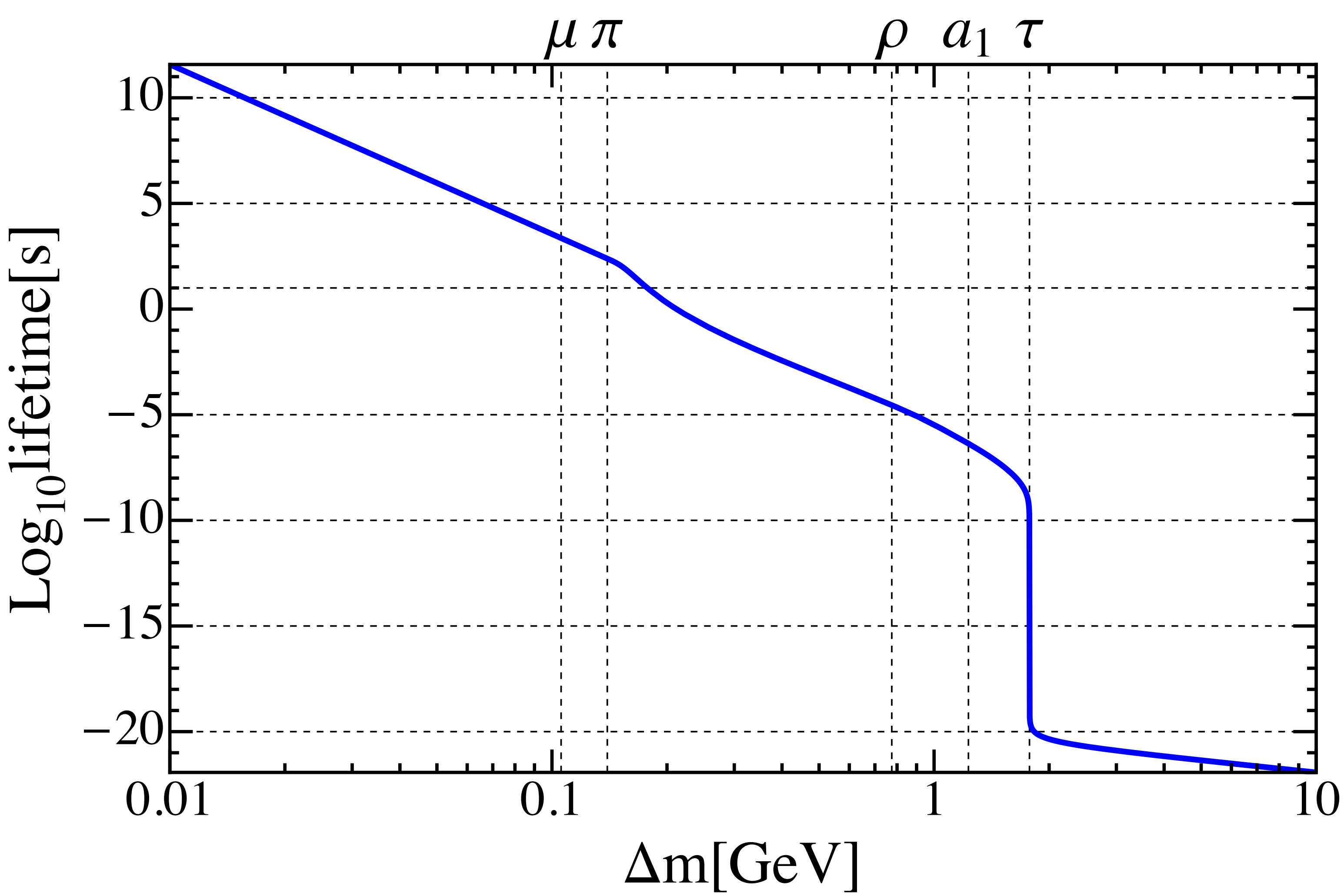
$m_\tau > \Delta m$ = Long-lived or stable staus (does MET still work?)

Decays of the stau

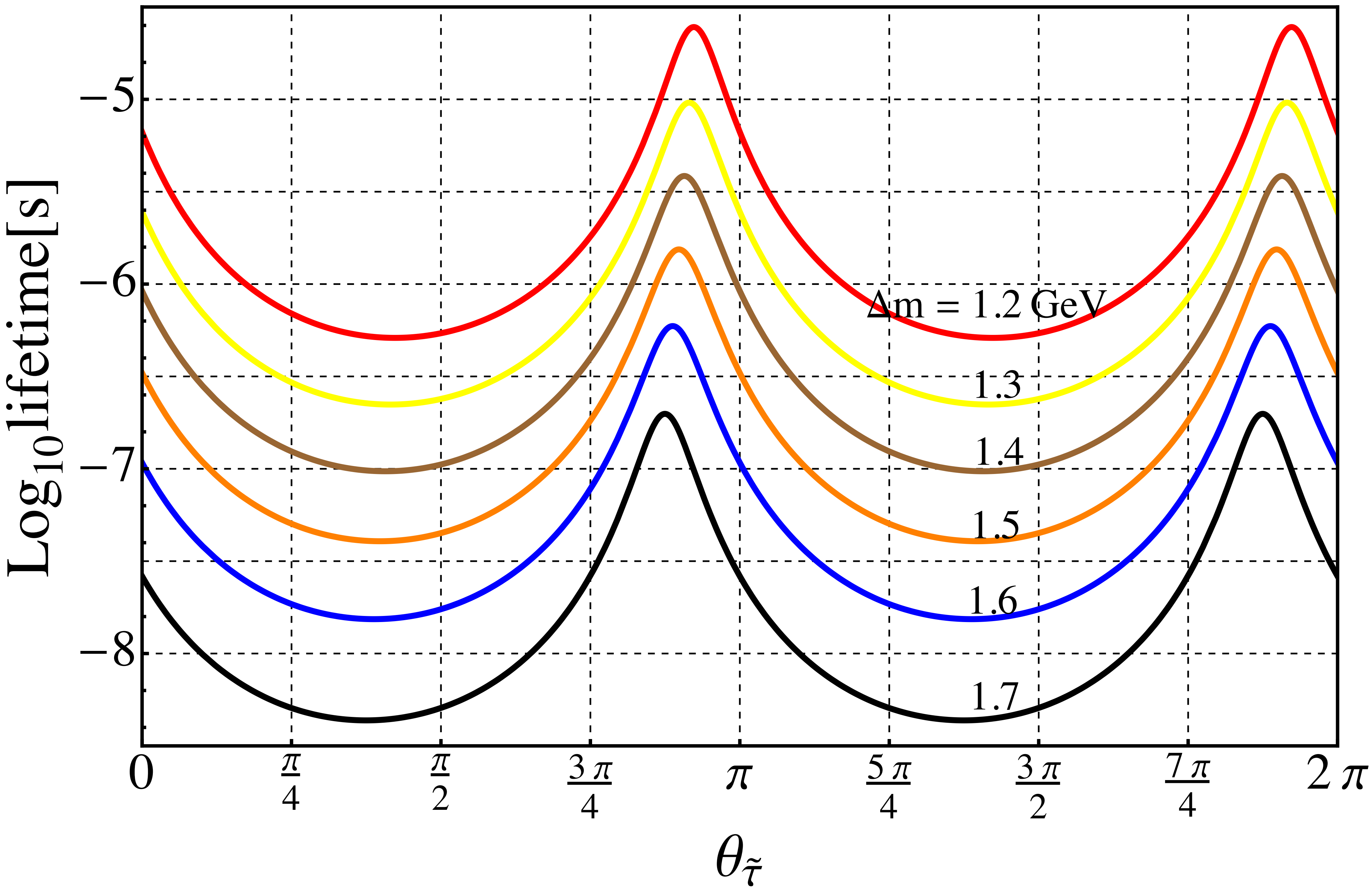
Dependence of lifetime on stau-neutralino mass difference

$$\tilde{\tau}_1^- \to \tau^- \chi.$$

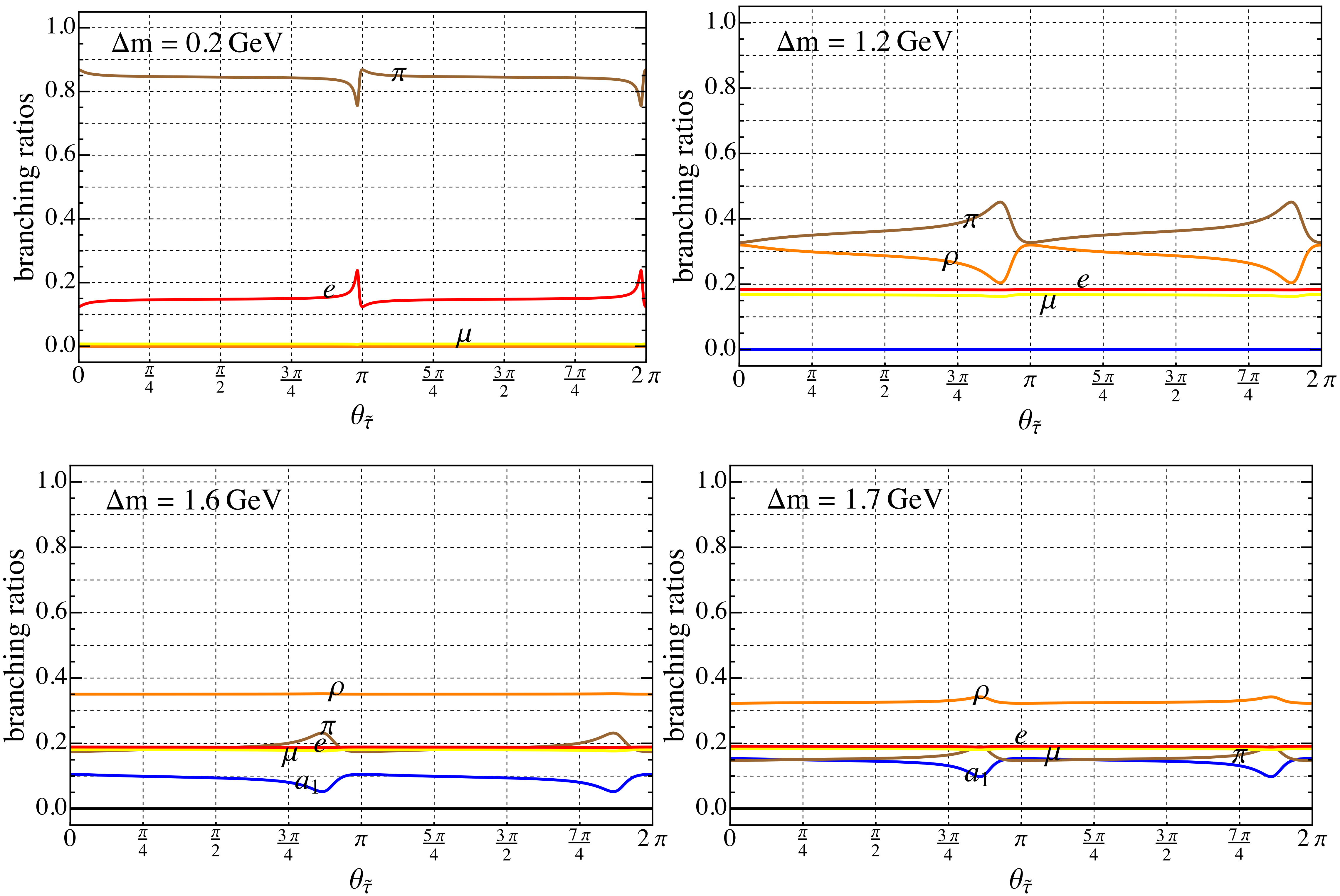
$$\tilde{\tau}_1^- \to \pi^- \nu_\tau \chi$$
$$\tilde{\tau}_1^- \to \rho^- \nu_\tau \chi$$
$$\tilde{\tau}_1^- \to a_1^- \nu_\tau \chi$$
$$\tilde{\tau}_1^- \to e^- \bar{\nu}_e \nu_\tau \chi$$
$$\tilde{\tau}_1^- \to \mu^- \bar{\nu}_\mu \nu_\tau \chi.$$



Dependence of lifetime on stau mixing angle

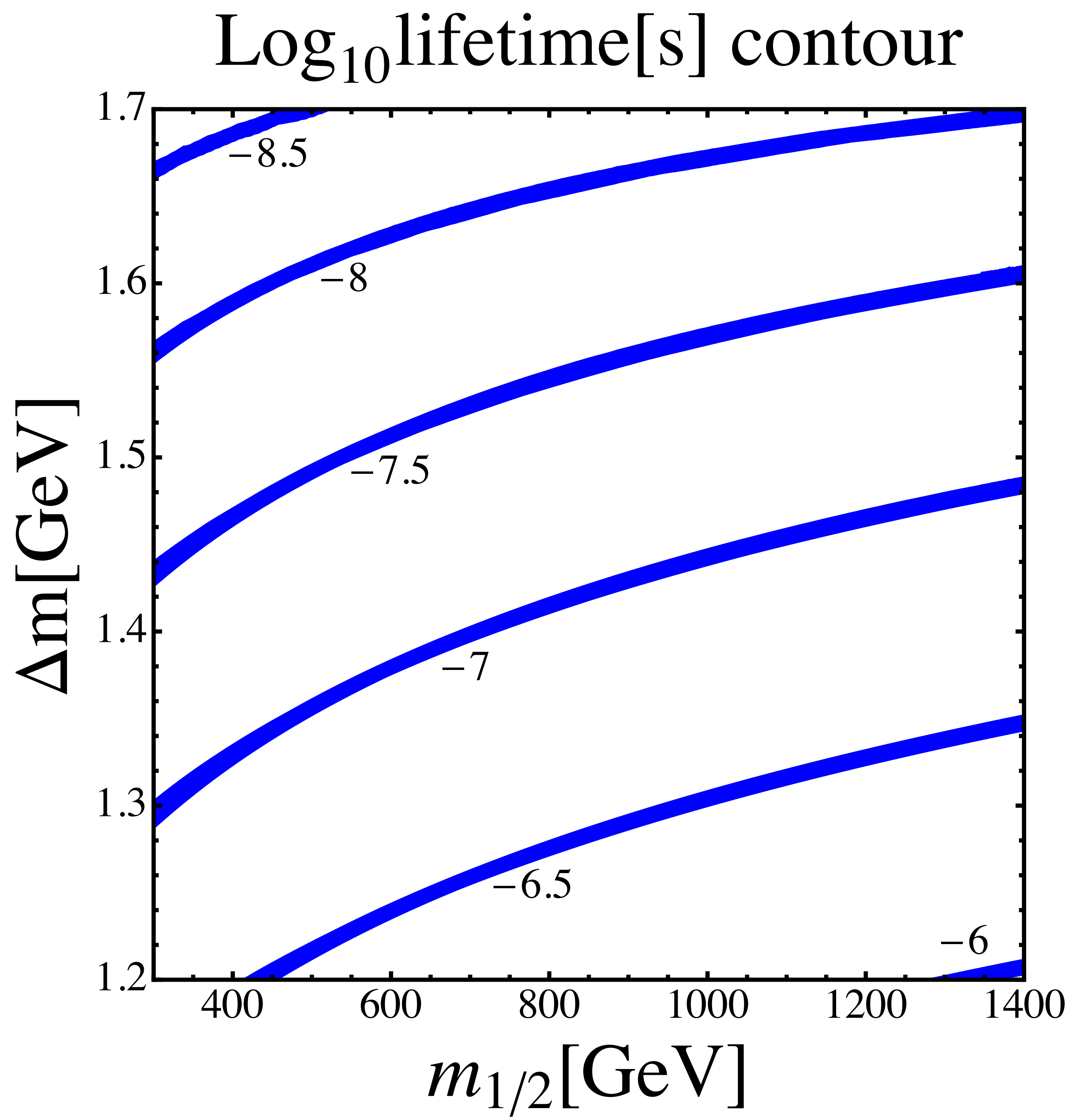


Branching fractions for different mass difference

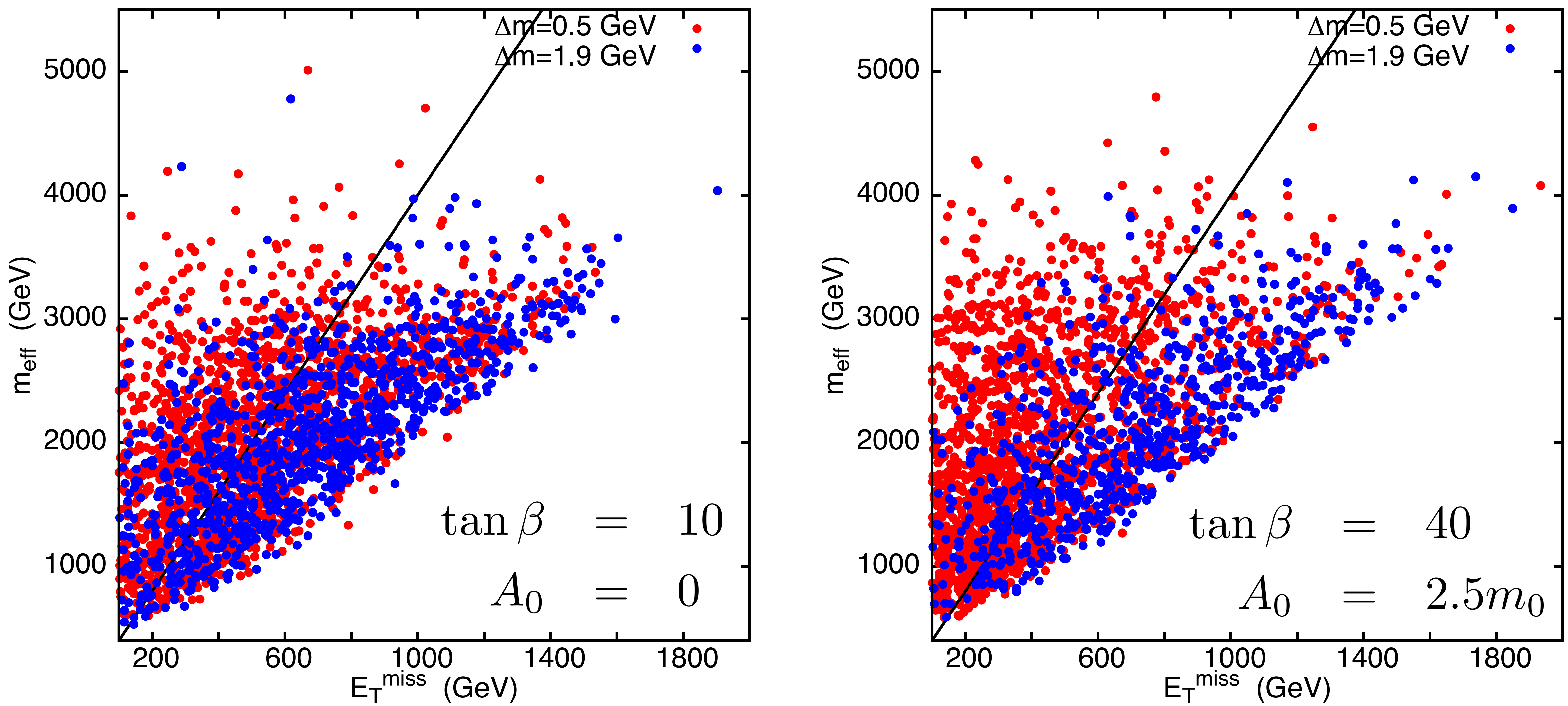


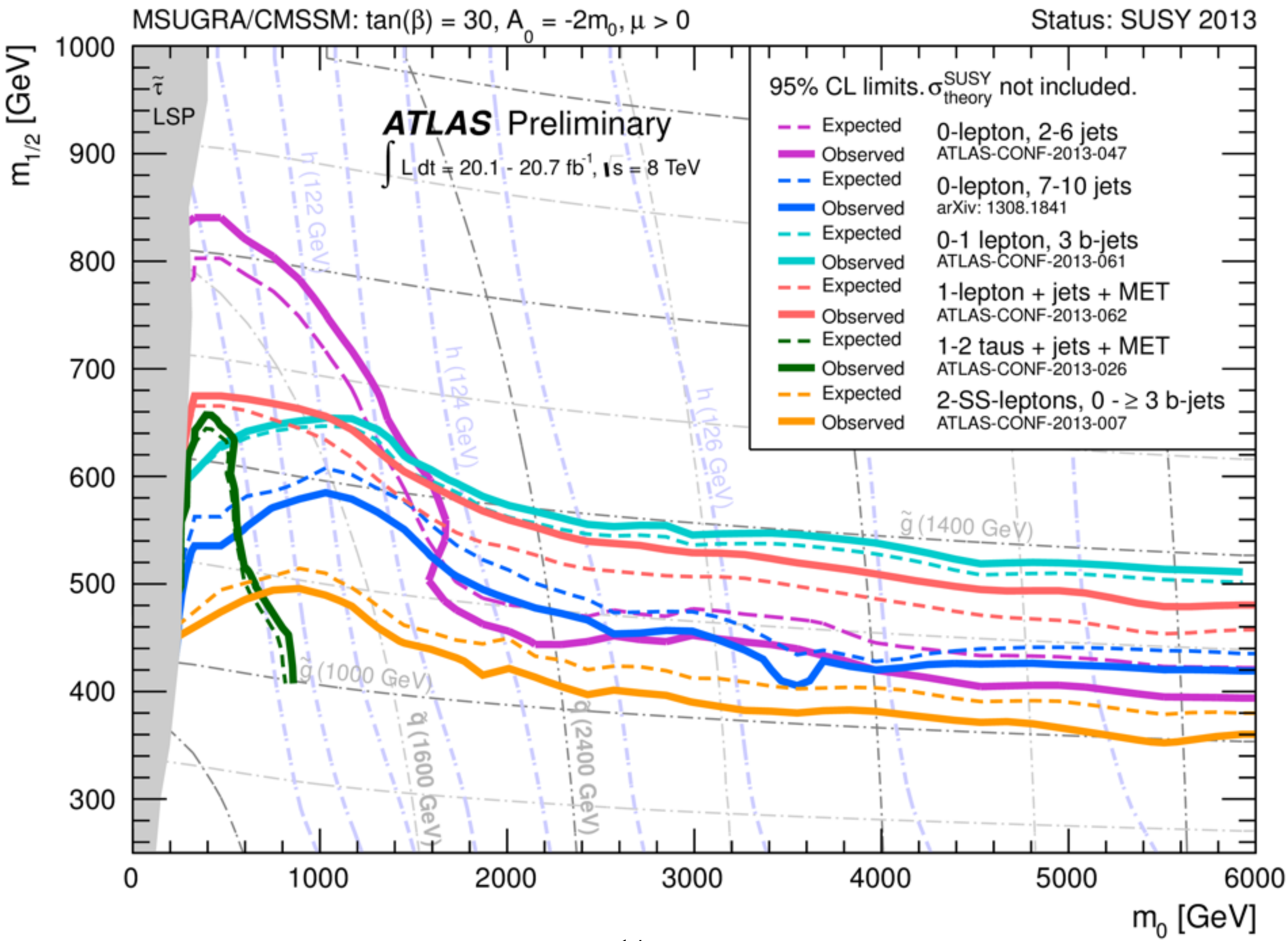
Lifetime range for our four benchmark scenarios

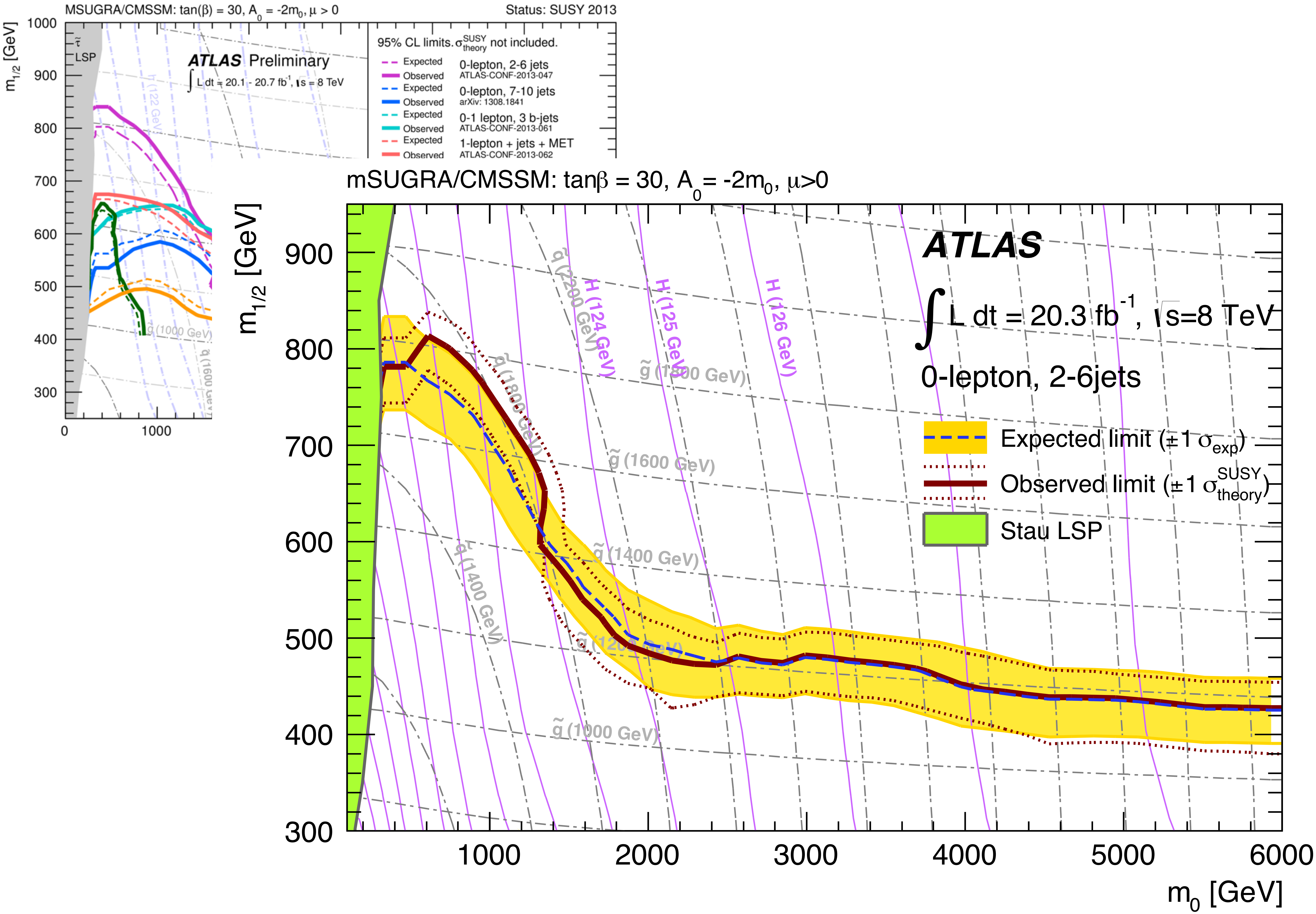
$$\tan\beta = 10, 40 \quad A_0 = 0, 2.5m_0$$



Effect of MET and M_{eff} cuts




MSUGRA/CMSSM: tan(β) = 30, A0 = -2m0, μ > 0
Status: SUSY 2013
ATLAS Preliminary
∫ L dt = 20.1 - 20.7 fb-1, √s = 8 TeV
95% CL limits. σ SUSY theory not included.
Expected
Observed
0-lepton, 2-6 jets
ATLAS-CONF-2013-047
0-lepton, 7-10 jets
arXiv: 1308.1841
0-1 lepton, 3 b-jets
ATLAS-CONF-2013-061
1-lepton + jets + MET
ATLAS-CONF-2013-062
1-2 taus + jets + MET
ATLAS-CONF-2013-026
2-SS-leptons, 0 - ≥ 3 b-jets
ATLAS-CONF-2013-007
τ̃ LSP
h (122 GeV)
h (124 GeV)
h (126 GeV)
g̃ (1000 GeV)
g̃ (1400 GeV)
q̃ (1600 GeV)
q̃ (2400 GeV)
m1/2 [GeV]
m0 [GeV]
1000
900
800
700
600
500
400
300
0
1000
2000
3000
4000
5000
6000


MSUGRA/CMSSM: tan(β) = 30, A0 = -2m0, μ > 0
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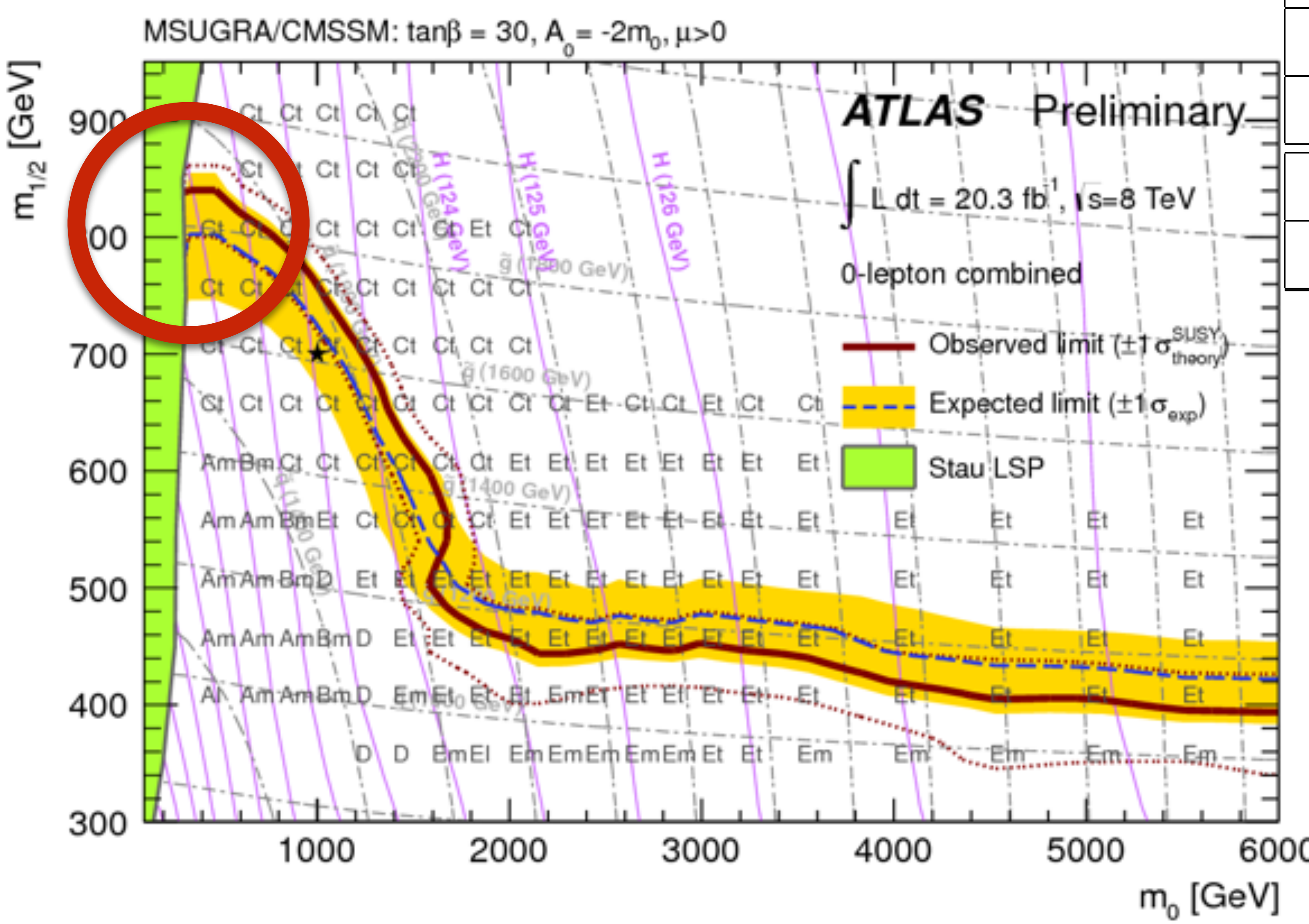
0-1 lepton, 3 b-jets
ATLAS-CONF-2013-061
1-lepton + jets + MET
ATLAS-CONF-2013-062
τ̃ LSP
m1/2 [GeV]
mSUGRA/CMSSM: tanβ = 30, A0 = -2m0, μ>0
ATLAS
∫ L dt = 20.3 fb-1, √s=8 TeV
0-lepton, 2-6jets
Expected limit (±1 σexp)
Observed limit (±1 σ theory SUSY)
Stau LSP
H (124 GeV)
H (125 GeV)
H (126 GeV)
g̃ (1800 GeV)
g̃ (1600 GeV)
g̃ (1400 GeV)
g̃ (1200 GeV)
g̃ (1000 GeV)
m0 [GeV]

ATLAS-CONF-2013-047

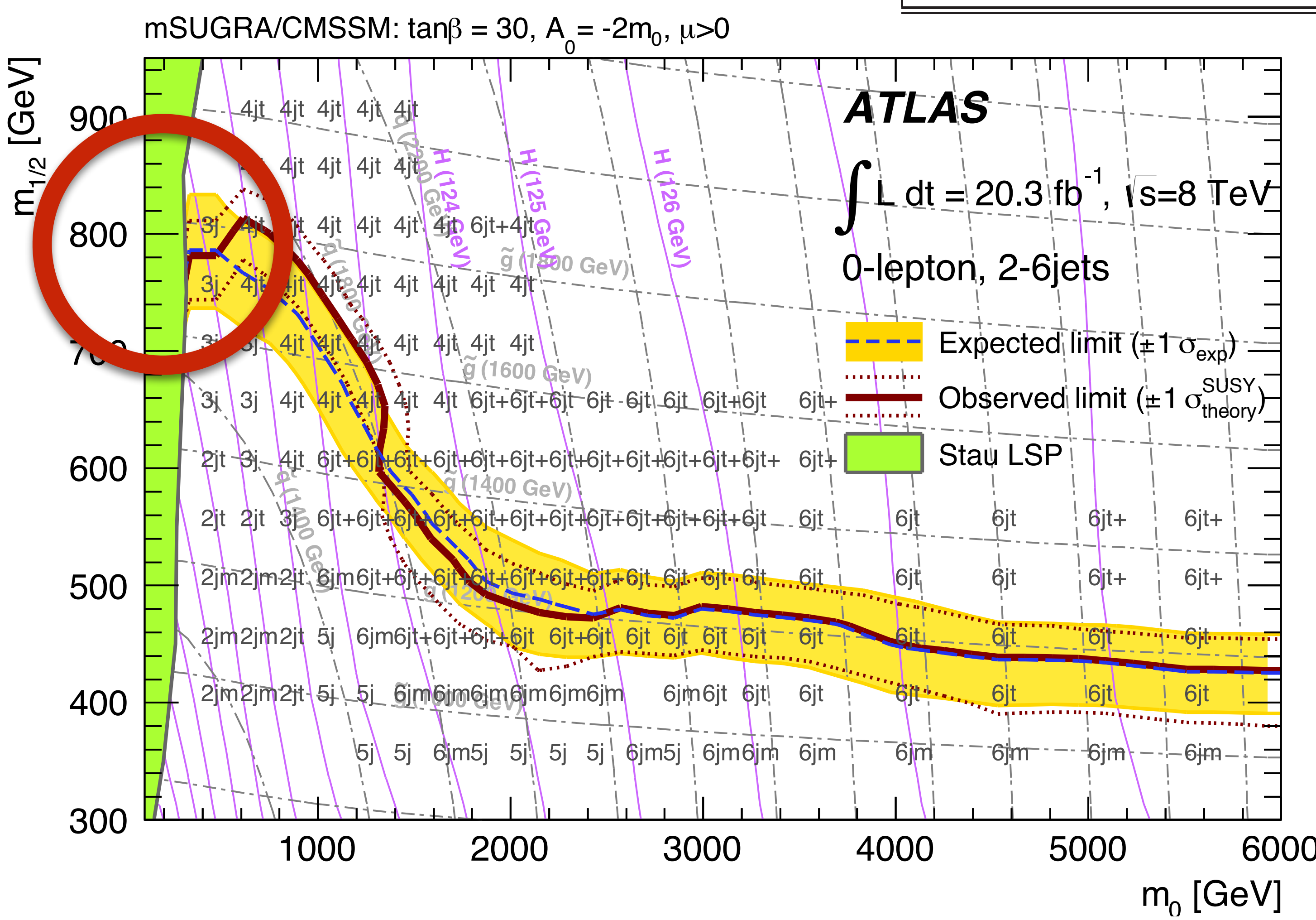


Requirement	Channel		
	(3-jets)	C (4-jets)	
	T	M	T
E_T^{miss}[GeV] >	160		
$p_T(j_1)$ [GeV] >	130		
$p_T(j_2)$ [GeV] >	60		
$p_T(j_3)$ [GeV] >	60	60	
$p_T(j_4)$ [GeV] >	–	60	
$p_T(j_5)$ [GeV] >	–	–	
$p_T(j_6)$ [GeV] >	–	–	
$\Delta\phi(\text{jet}_i, \mathbf{E}_T^{miss})_{min}$ >	) > 40 GeV)})	0.4 (i = {	
$E_T^{miss}/m_{eff}(Nj)$ >	0.4	0.25	0.25
m_{eff}(incl.) [GeV] >	2200	1200	2200

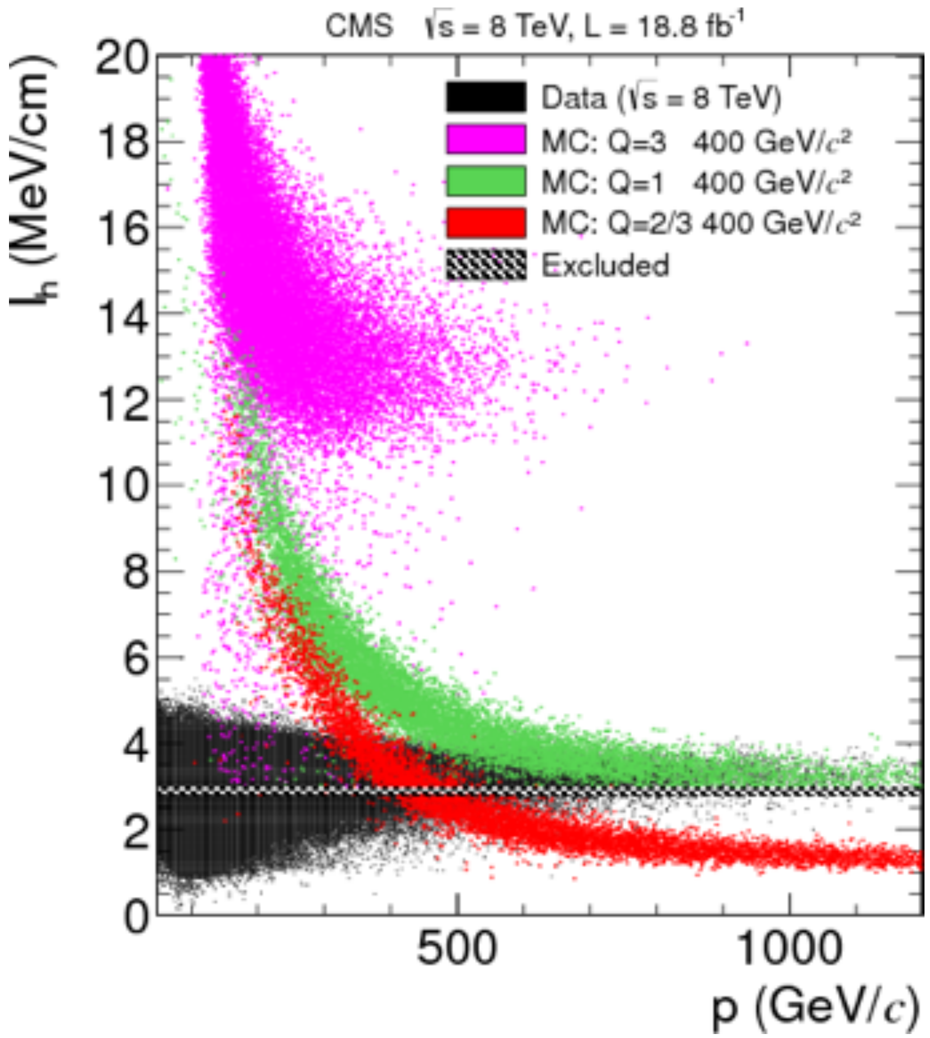
arXiv:1405.7875

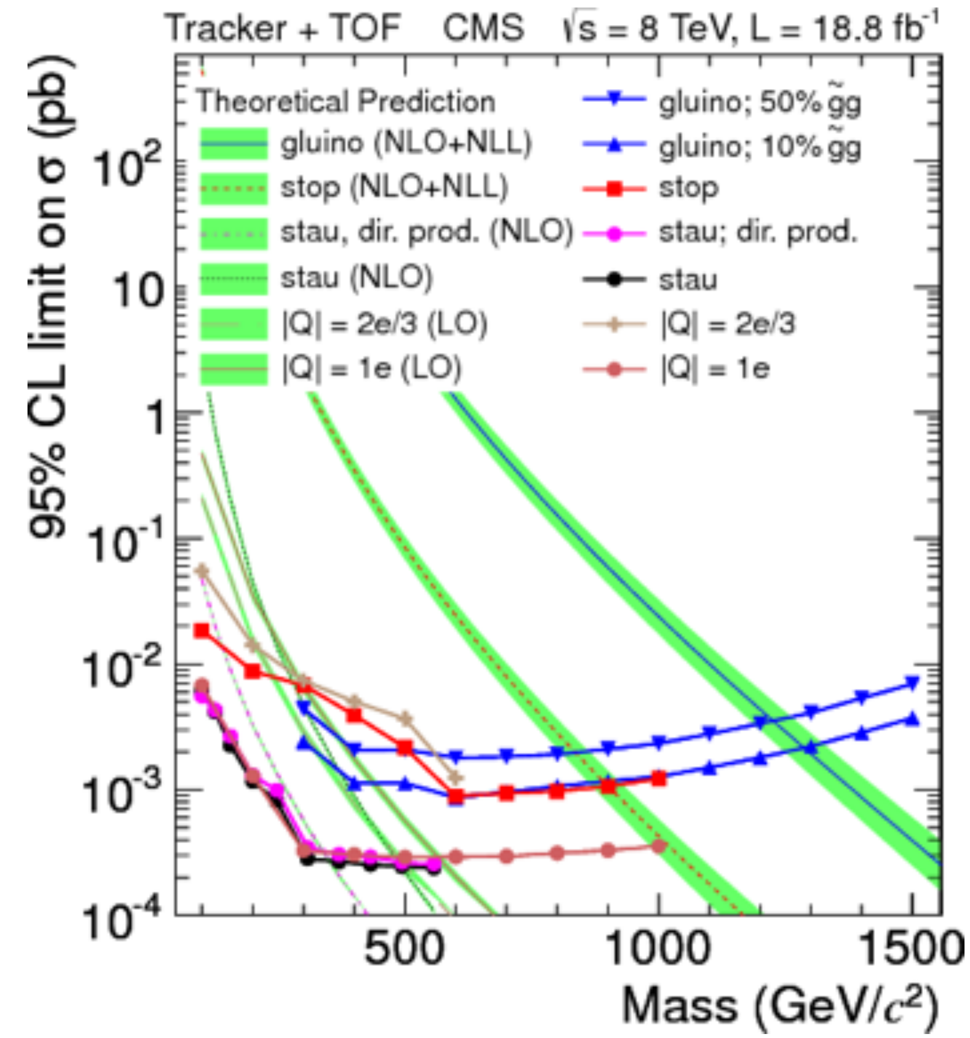
Requirement	Signal Region					
	2jl	**2jm**	**2jt**	**2jW**	**3j**	**4jW**
E_T^{miss}[GeV] $>$	160					
$p_T(j_1)$ [GeV] $>$	130					
$p_T(j_2)$ [GeV] $>$	60					
$p_T(j_3)$ [GeV] $>$	–				60	40
$p_T(j_4)$ [GeV] $>$	–					40
$\Delta\phi(\text{jet}_{1,2,(3)}, \mathbf{E}_T^{miss})_{min} >$	0.4					
$\Delta\phi(\text{jet}_{i>3}, \mathbf{E}_T^{miss})_{min} >$	–					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

Signal Region								
4jl-	**4jl**	**4jm**	**4jt**	**5j**	**6jl**	**6jm**	**6jt**	**6jt+**
160								
130								
60								
60								
60								
–				60				
–					60			
0.4								
0.2								
10		–						
–		0.4	0.25	0.2			0.25	0.15
700	1000	1300	2200	1200	900	1200	1500	1700



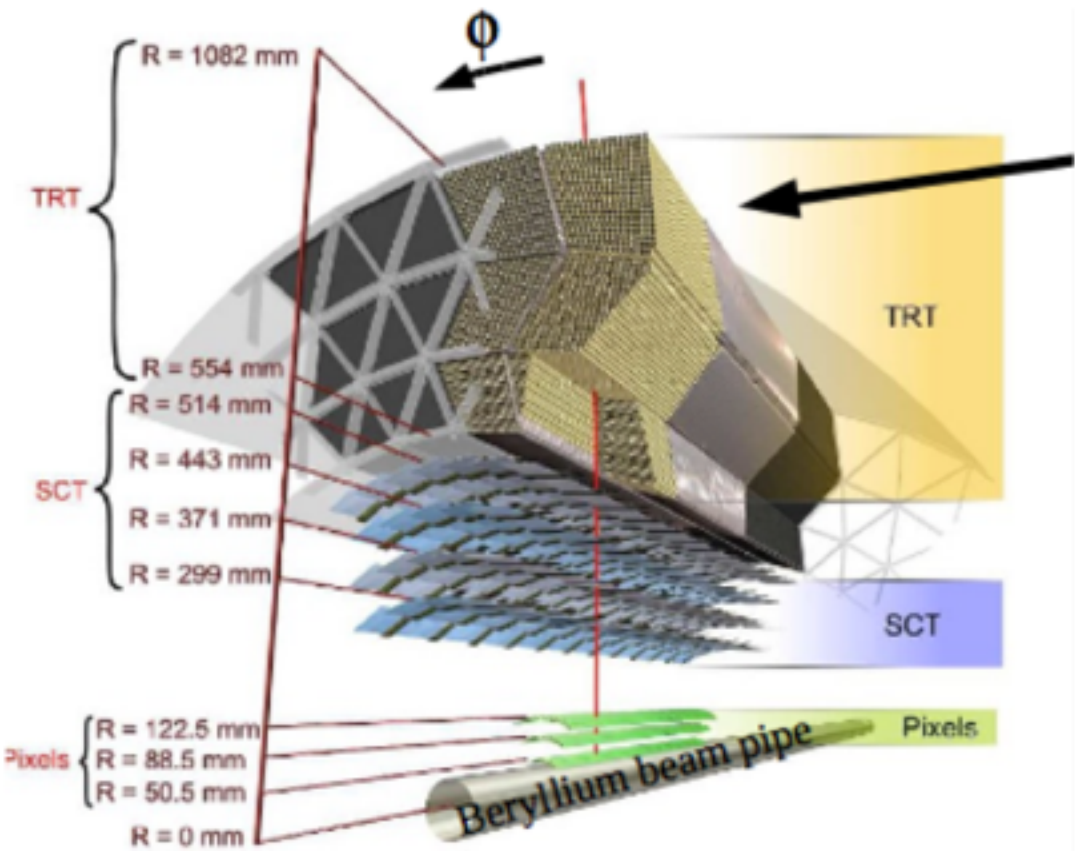
The long-lived particle search (CMS-EXO-12-026)



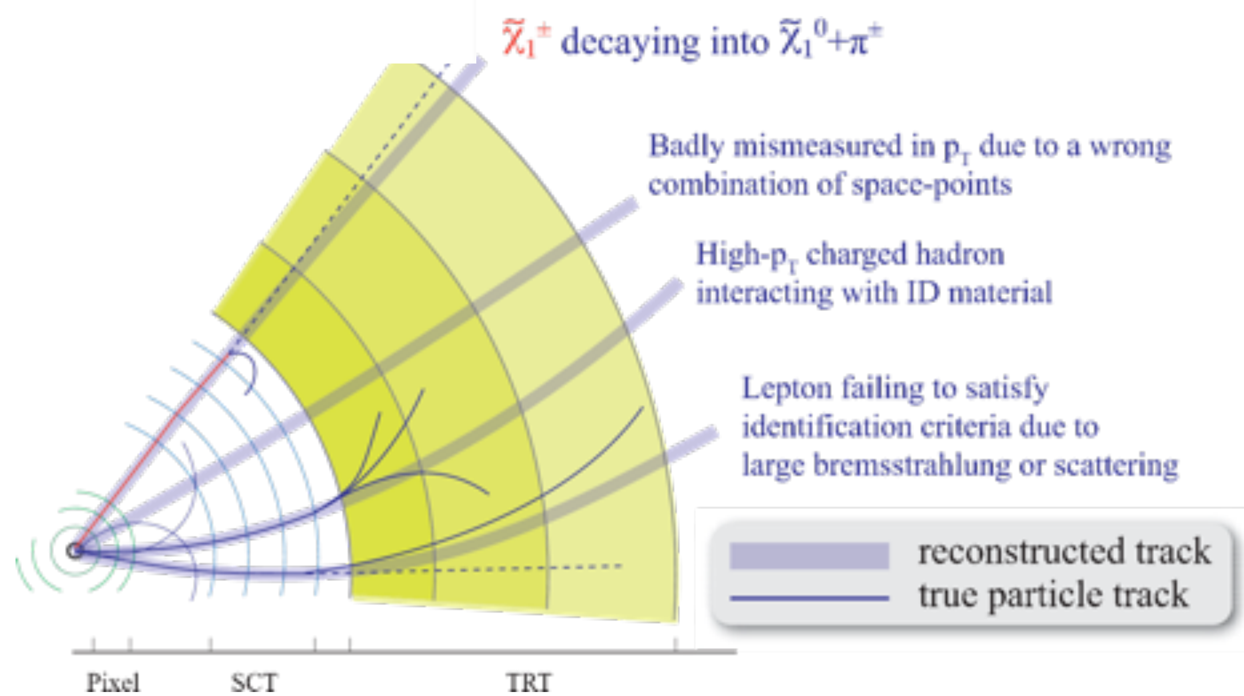


Mass (GeV/c^2)	M req. (GeV/c^2)	σ (pb) ($\sqrt{s}=7$ TeV) Exp.	Obs.	Acc.	σ (pb) ($\sqrt{s}=8$ TeV) Exp.	Obs.	Acc.	$\sigma/\sigma_{\mathrm{th}}$ (7+8 TeV) Exp.	Obs.
Direct+indirect produced stau — tracker+TOF analysis									
126	>40	0.0046	0.0035	0.29	0.0042	0.0042	0.25	0.0074	0.0065
308	>190	0.00094	0.0015	0.63	0.00029	0.00028	0.56	0.16	0.21
494	>330	0.00079	0.00084	0.74	0.00023	0.00024	0.66	1.9	1.9
Direct produced stau — tracker+TOF analysis									
126	>40	0.0056	0.0046	0.26	0.0044	0.0043	0.24	0.18	0.16
308	>190	0.0011	0.0017	0.54	0.00035	0.00035	0.46	0.62	0.66
494	>330	0.00084	0.00088	0.69	0.00025	0.00026	0.61	4.7	5.0

The disappearing track search (ATLAS-CONF-2012-034)



Requirement
Trigger selection and non-collision rejection
Lepton veto
$E_{\mathrm{T}}^{\mathrm{miss}} > 130$ GeV
Jet requirements
High-p_{T} isolated track selection
Disappearing track selection



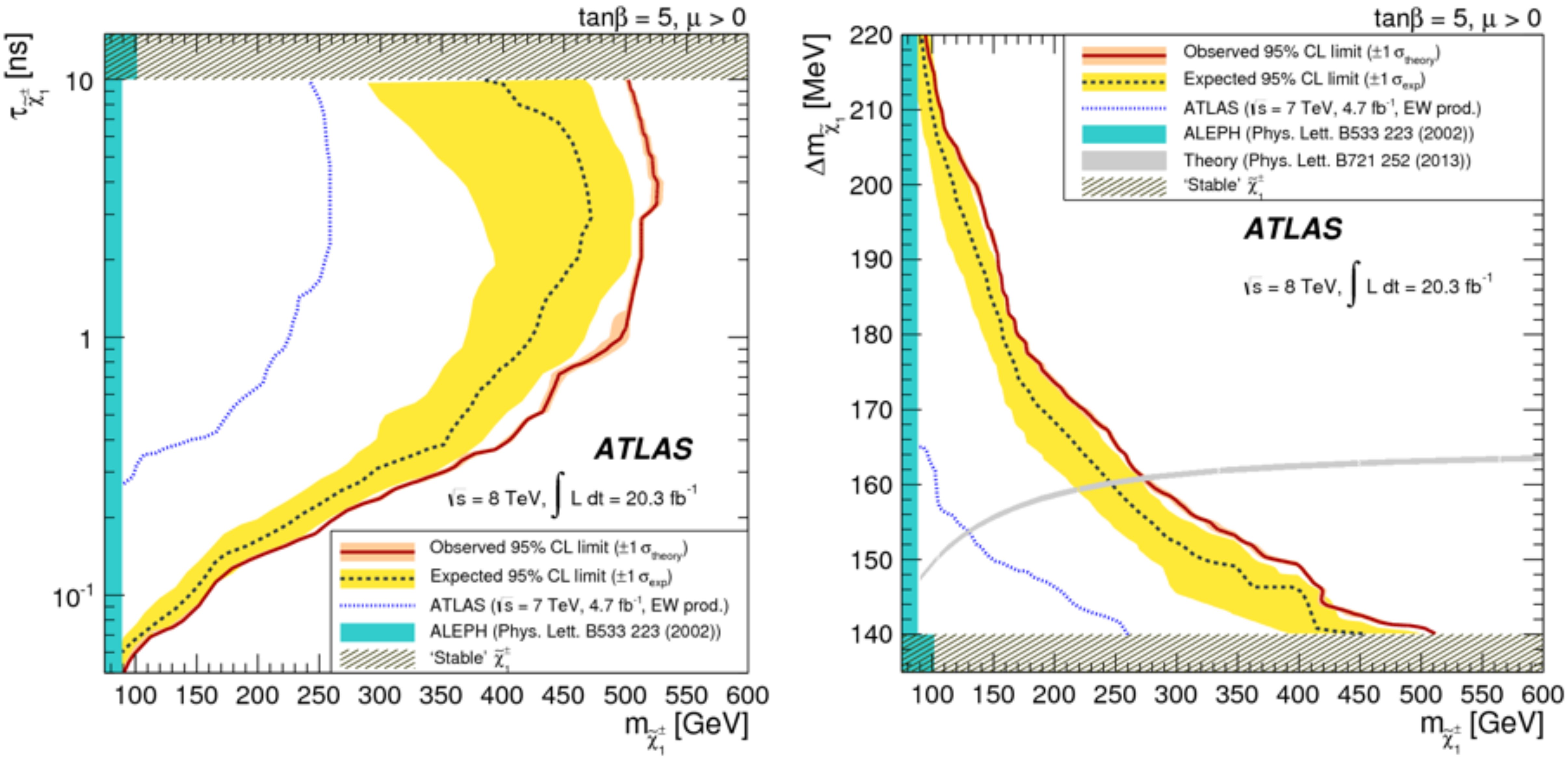
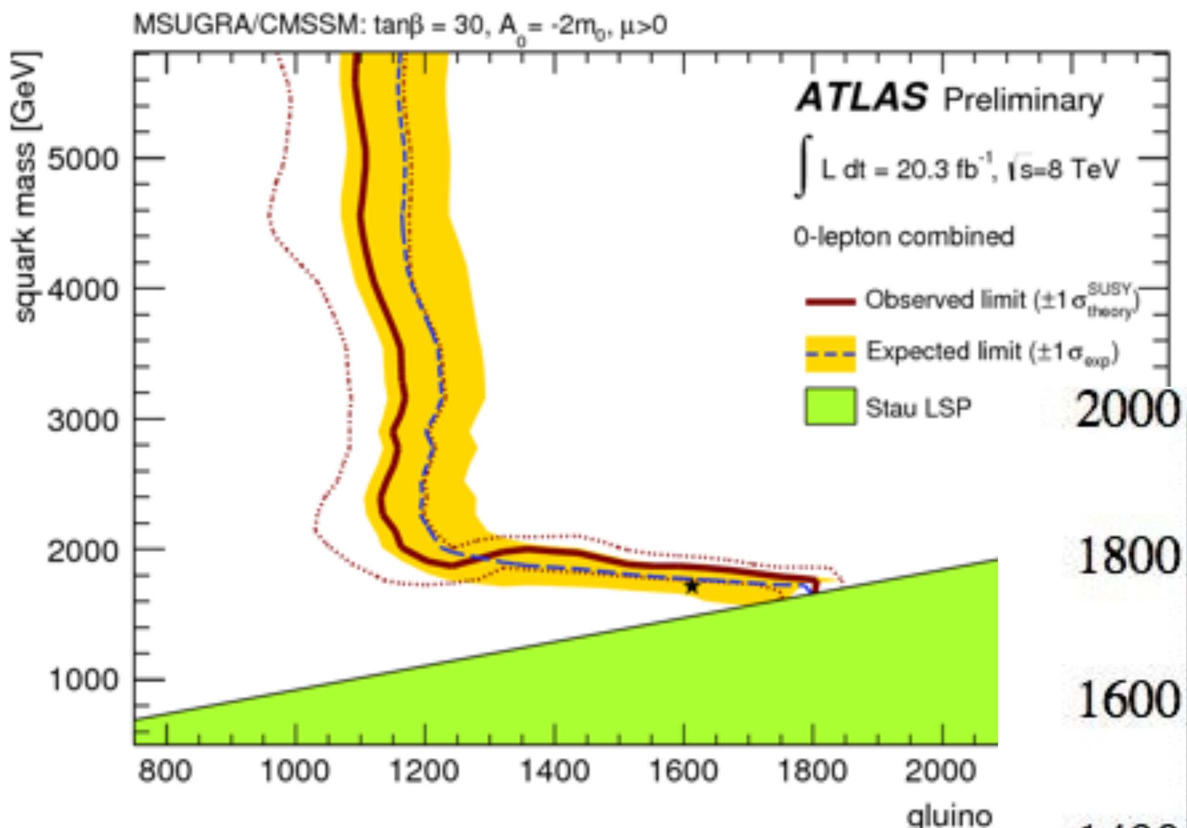


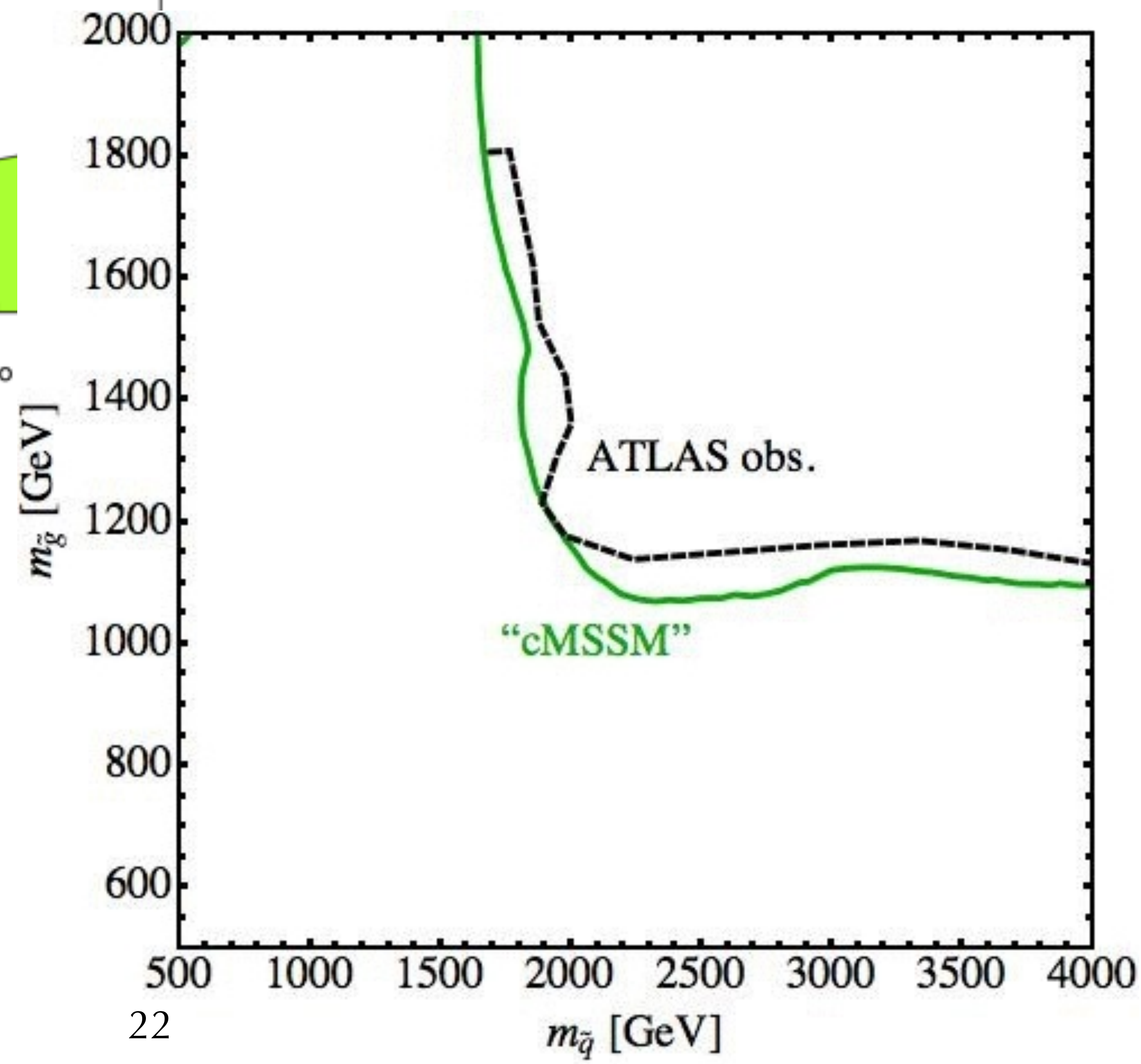
TABLE III. Numbers of observed and expected background events as well as the probability that a background-only experiment is more signal-like than observed (p_0) and the model-independent upper limit on the visible cross-section ($\sigma_{\rm vis}^{95\%}$) at 95% CL.

	$p_{\rm T}^{\rm track} > 75$ GeV	$p_{\rm T}^{\rm track} > 100$ GeV	$p_{\rm T}^{\rm track} > 150$ GeV	$p_{\rm T}^{\rm track} > 200$ GeV
Observed events	59	36	19	13
Expected events	48.5 ± 12.3	37.1 ± 9.4	24.6 ± 6.3	18.0 ± 4.6
p_0 value	0.17	0.41	0.46	0.44
Observed $\sigma_{\rm vis}^{95\%}$ [fb]	1.76	1.02	0.62	0.44
Expected $\sigma_{\rm vis}^{95\%}$ [fb]	$1.42^{+0.50}_{-0.39}$	$1.05^{+0.37}_{-0.28}$	$0.67^{+0.27}_{-0.19}$	$0.56^{+0.23}_{-0.16}$

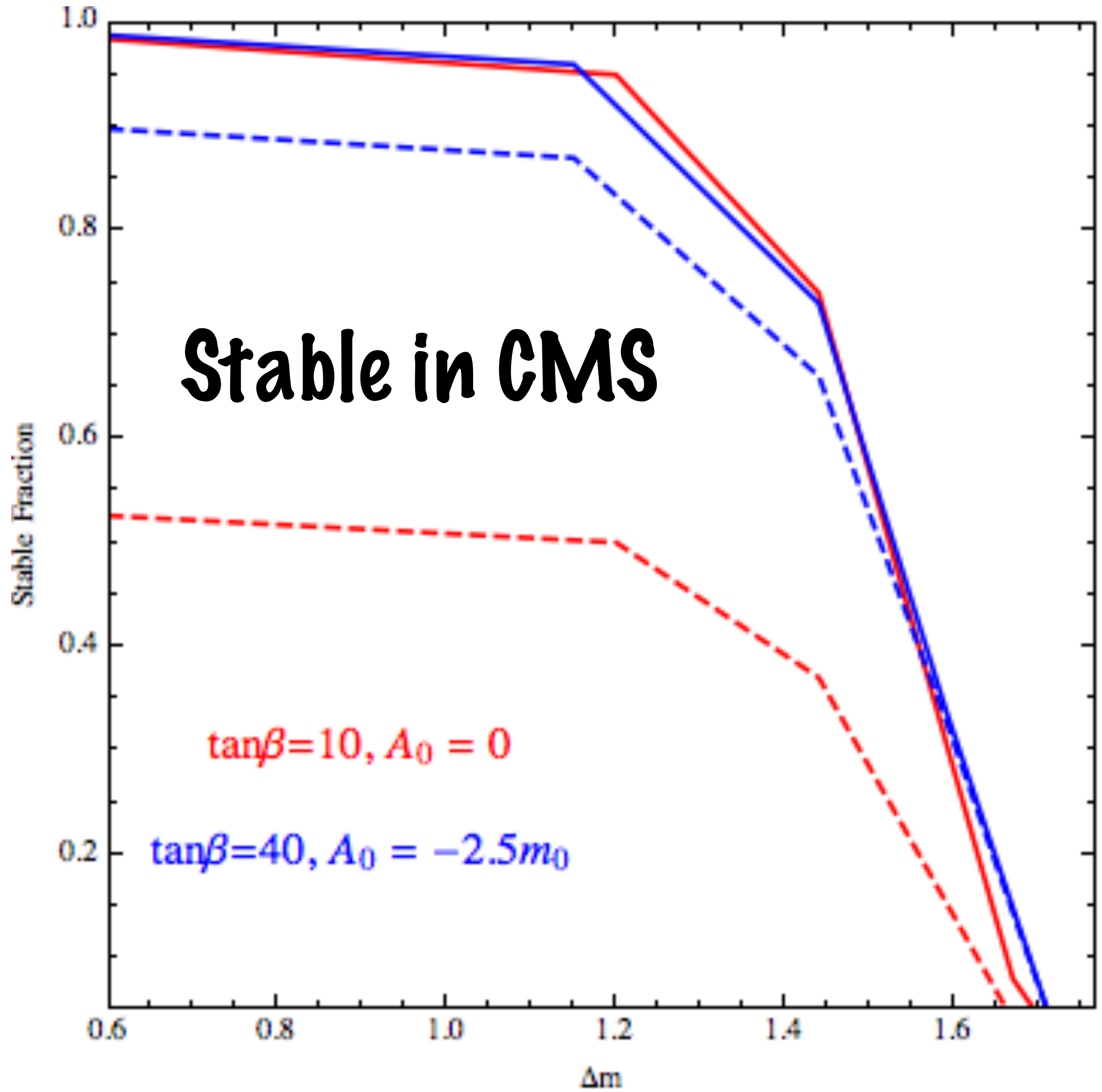
Interpreting the ATLAS and CMS results

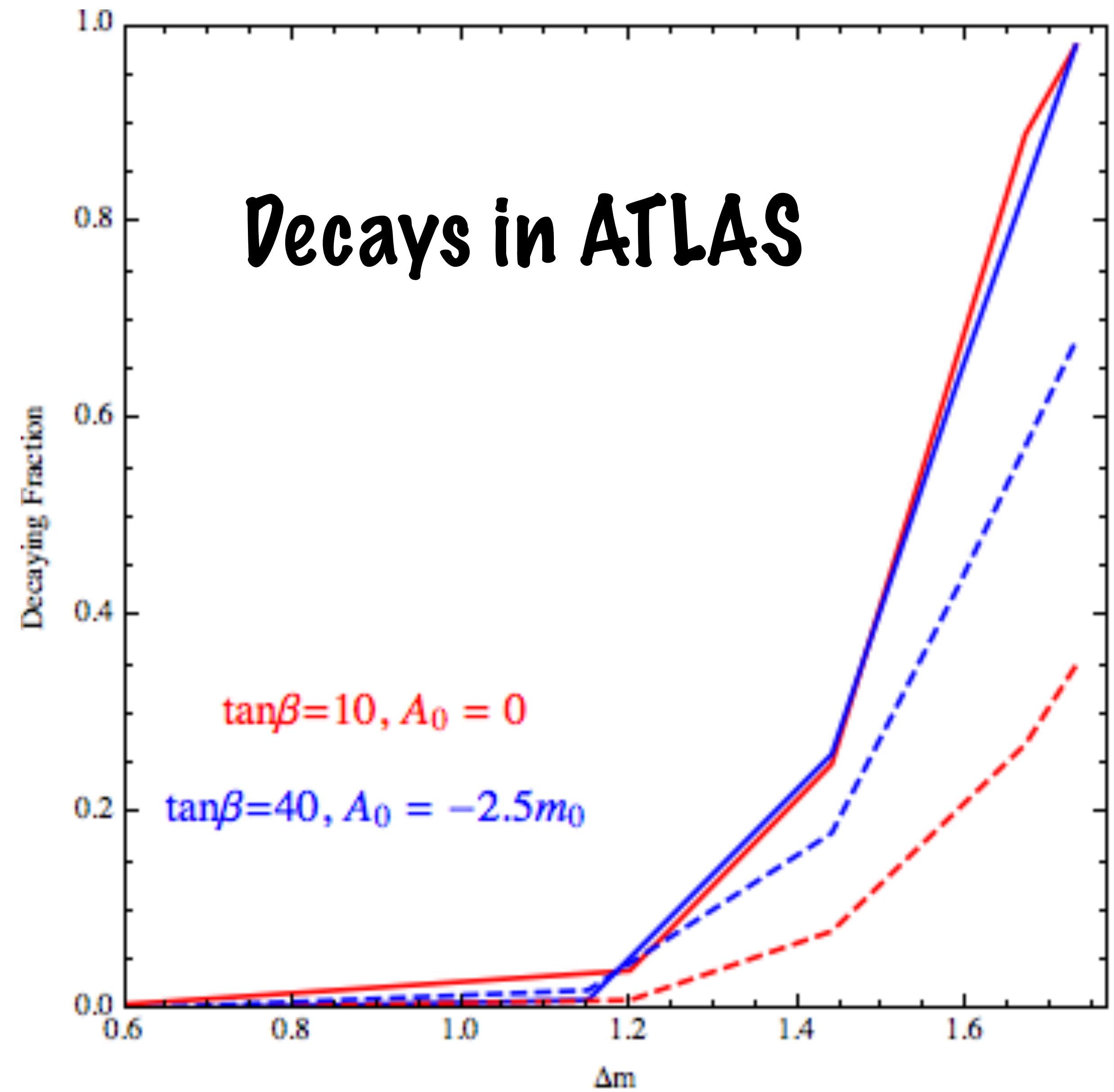
Validation of jets+MET simulation



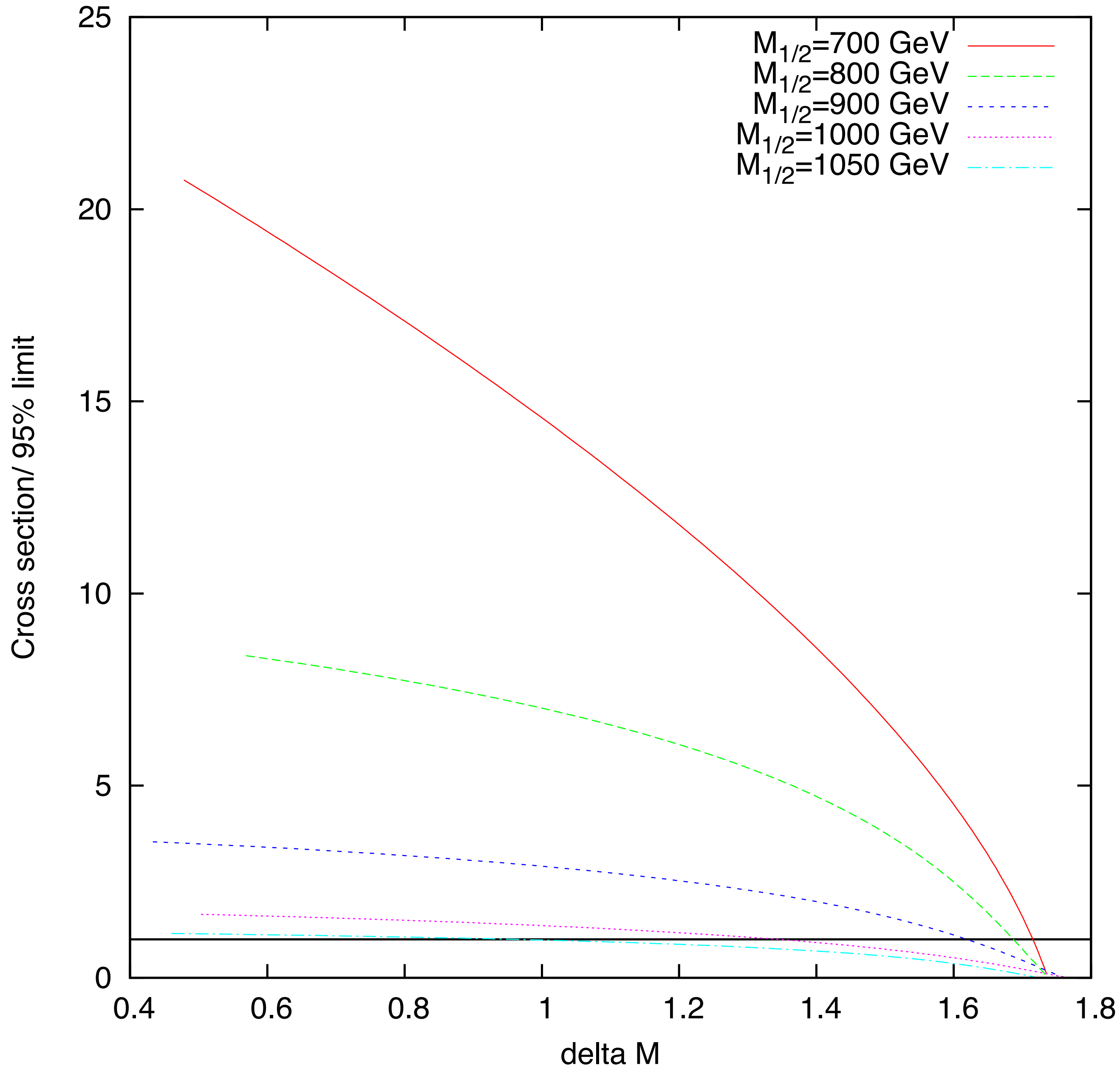


Stau fractions for the search criteria

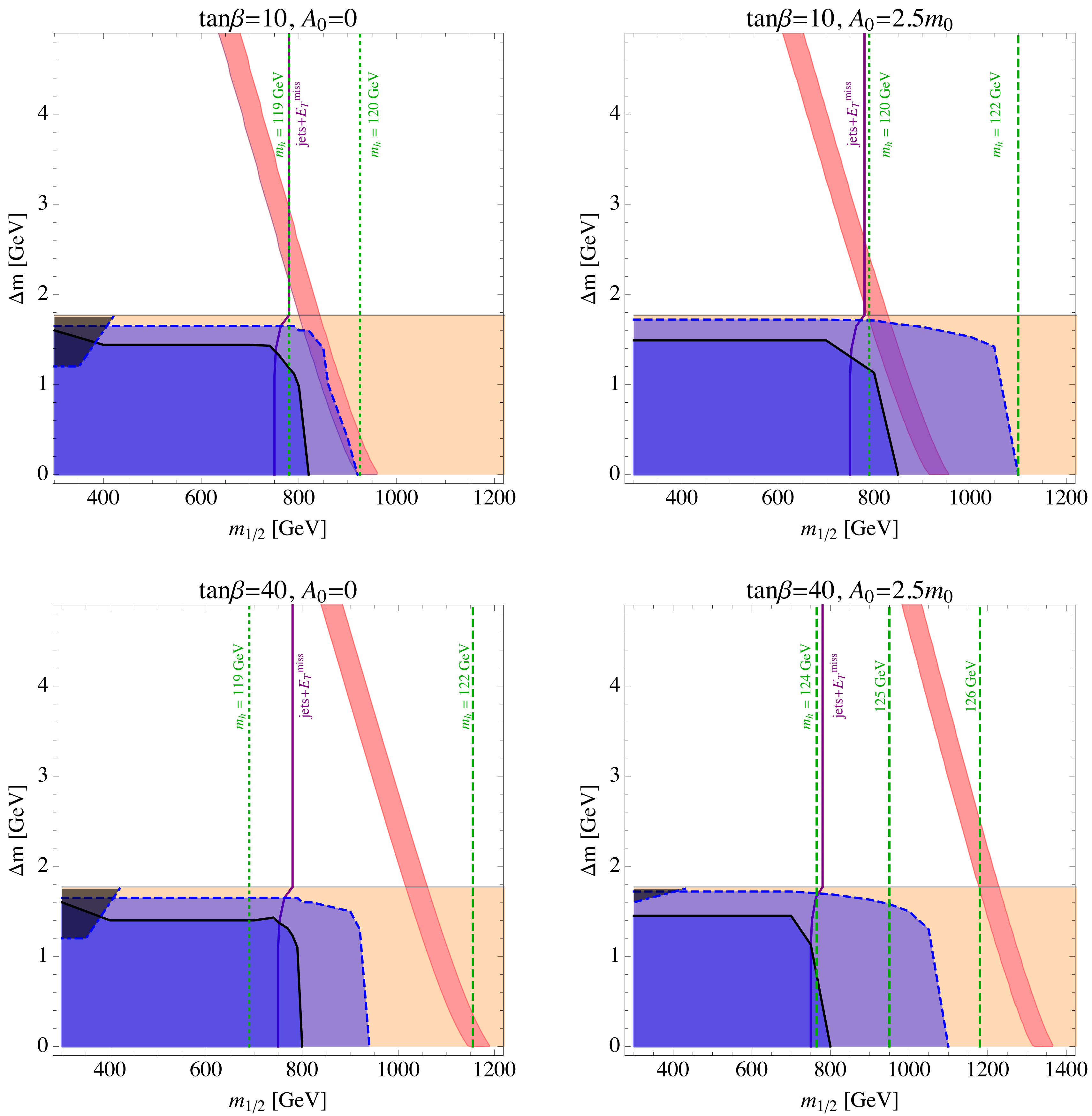




Exclusions for $\tan\beta = 40; A_0 = 2.5m_0$



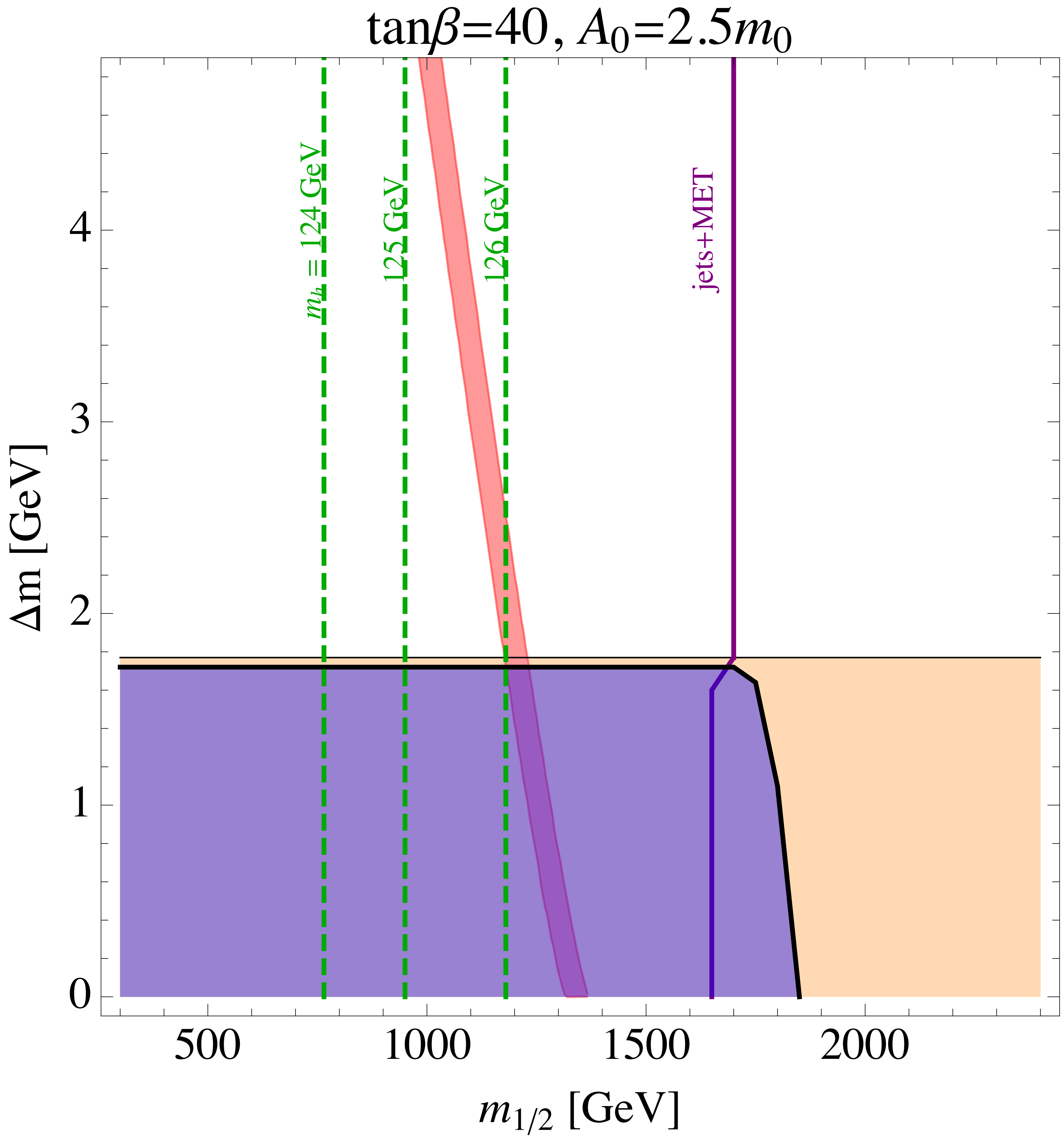
Results



tanβ=10, A_0=0
tanβ=10, A_0=2.5m_0
tanβ=40, A_0=0
tanβ=40, A_0=2.5m_0
m_h = 119 GeV
m_h = 120 GeV
m_h = 122 GeV
m_h = 124 GeV
125 GeV
126 GeV
jets+E_T^{miss}
Δm [GeV]
$m_{1/2}$ [GeV]

What next?

Predictions for 14 TeV LHC run



Conclusions

- LHC jets+MET search slightly weakened in region where staus are long-lived. The limit is close to probing the tip of the co-annihilation strip for tanß = 10.
- The stable track search for direct stau production (model ind.) rules out stau masses up to 336 - 345 GeV for $m_{1/2}$ values of 800-850 GeV (**stronger than the MET search!**)
- This is improved to $m_{1/2}$ values of 930-1100 GeV when all stau production modes are taken into account.
- The model independent track search will be able to rule out the full strip for tanß = 40 with 75 fb^{-1} at 14 TeV.
- The disappearing track closes the gap between these two, but is not very sensitive, gives $m_{1/2}$ limit of about 400 GeV.