Light top squark in Supersymmetry in the light of a heavy "higgs"

High Energy Theory Seminar

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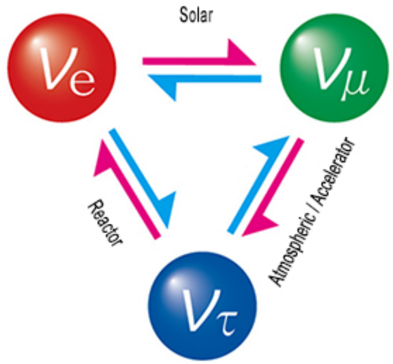
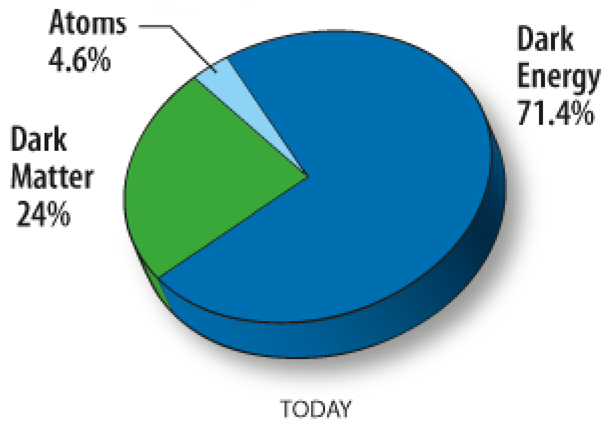
European Research Council
Funding for top researchers from anywhere in the world

Istituto Nazionale di Fisica Nucleare

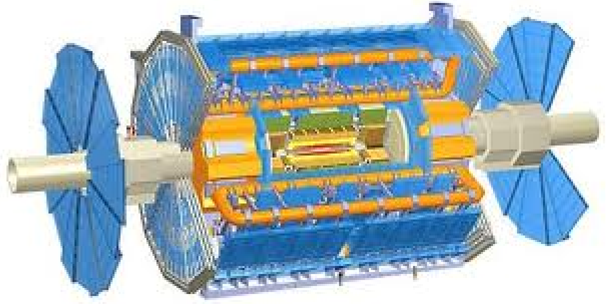
Why do we need to go beyond the Standard Model :



- Neutrino mass : Weinberg's dim-5 operator
- Dark Matter
- Dark Energy
- Cosmic baryon-antibaryon asymmetry
-
-



- Some Anomalies in particle physics:



top quark FB asymmetry, (g-2) of muon ......

but none of these -- except the last -- require new physics at TeV energies

“hierarchy” or “naturalness” problem

Three solutions known

1. Shift symmetry:

The entire Higgs multiplet are Goldstone bosons of a symmetry broken spontaneously at high energy.

2. Rotation into a gauge boson:

The Higgs fields are the 5th component of gauge fields in a model with extra space dimensions.

3. Rotation into a fermion:

The symmetry is supersymmetry.

Higgs sector in the MSSM

Need (at least) two $SU(2)_L$ higgs doublets :

- Cancel the $U(1)^3_Y$ and $U(1)_Y \times SU(2)_L$ gauge anomalies due to new contribution from the higgsinos.
- Need an even number of (weyl) fermion doublets to avoid the Witten anomaly for $SU(2)_L$
- Yukawa couplings for both the up and down type fermions in a SUSY(holomorphy of the Superpotential) invariant way

$$\mathrm{H_1} = \begin{pmatrix} \mathrm{H_1^0} \\ \mathrm{H_1^-} \end{pmatrix} \quad \text{and} \quad \mathrm{H_2} = \begin{pmatrix} \mathrm{H_2^+} \\ \mathrm{H_2^0} \end{pmatrix}$$

Five physical higgs bosons after EWSB : $\mathrm{h,\ H,\ A,\ H^{\pm}}$

Only two free parameters at the tree level : $\mathrm{m_A}, \tan\beta$

$$M^2_{h,H} = \frac{1}{2}\left[M^2_A + M^2_Z \mp \sqrt{(M^2_A + M^2_Z)^2 - 4M^2_A M^2_Z \cos^2 2\beta}\right]$$

$$M^2_{H^\pm} = M^2_A + M^2_W$$

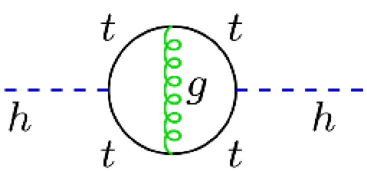
$$\tan 2\alpha = \tan 2\beta\,(M^2_A + M^2_Z)/(M^2_A - M^2_Z)$$

We have important constraint on the MSSM Higgs boson masses:

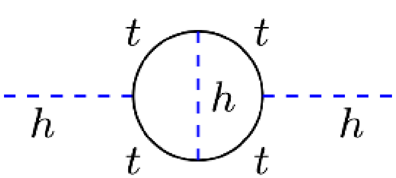
$$M_h \leq \min(M_A, M_Z)\cdot|\cos 2\beta| \leq M_Z,\ M_{H^\pm} > M_W,\ M_H > M_A \ldots$$

$$\Delta m^2_h \approx \frac{3\,m^4_t}{2\,\pi^2\,v^2}\left[\ln\left(\frac{M^2_S}{m^2_t}\right) + \frac{X^2_t}{2M^2_S}\left(1 - \frac{X^2_t}{6M^2_S}\right)\right] + \ldots$$

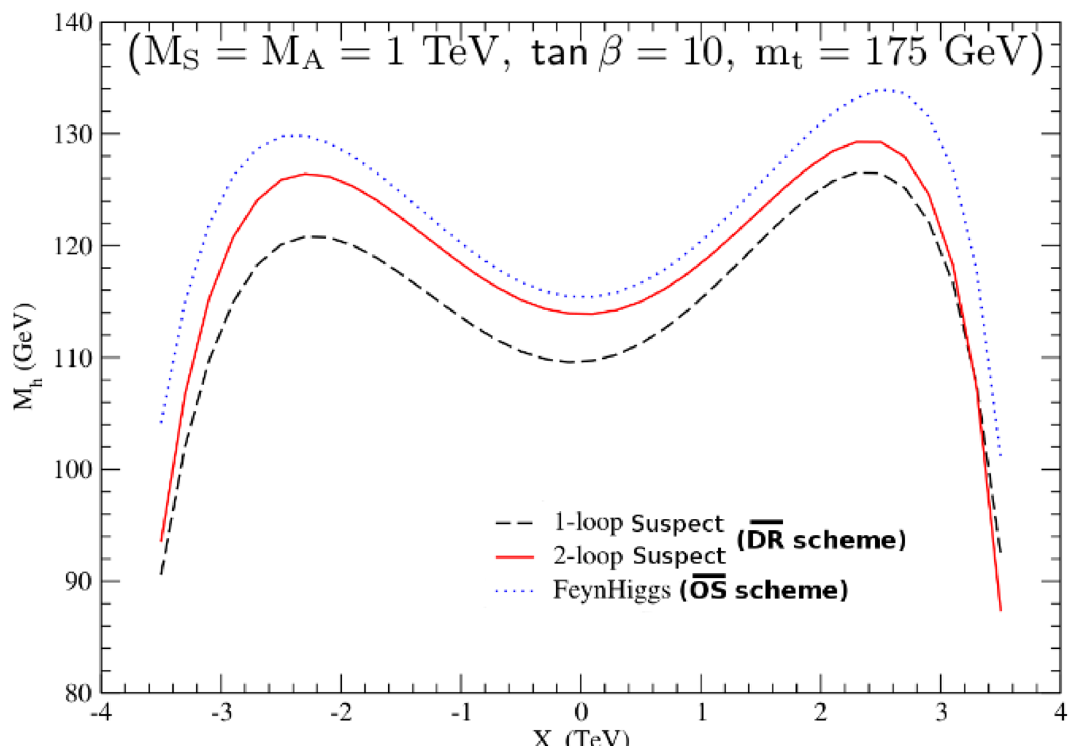
$$X_t = A_t - \frac{\mu}{\tan\beta},\quad M^2_S = M_{\tilde{t}_1} M_{\tilde{t}_2}$$

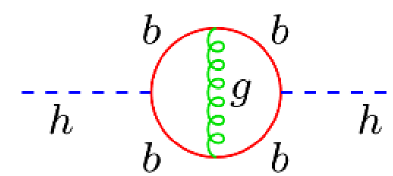


$\mathcal{O}(\alpha_t\alpha_s)$

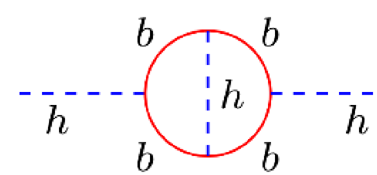


$\mathcal{O}(\alpha_t^2)$





$\mathcal{O}(\alpha_b\alpha_s)$

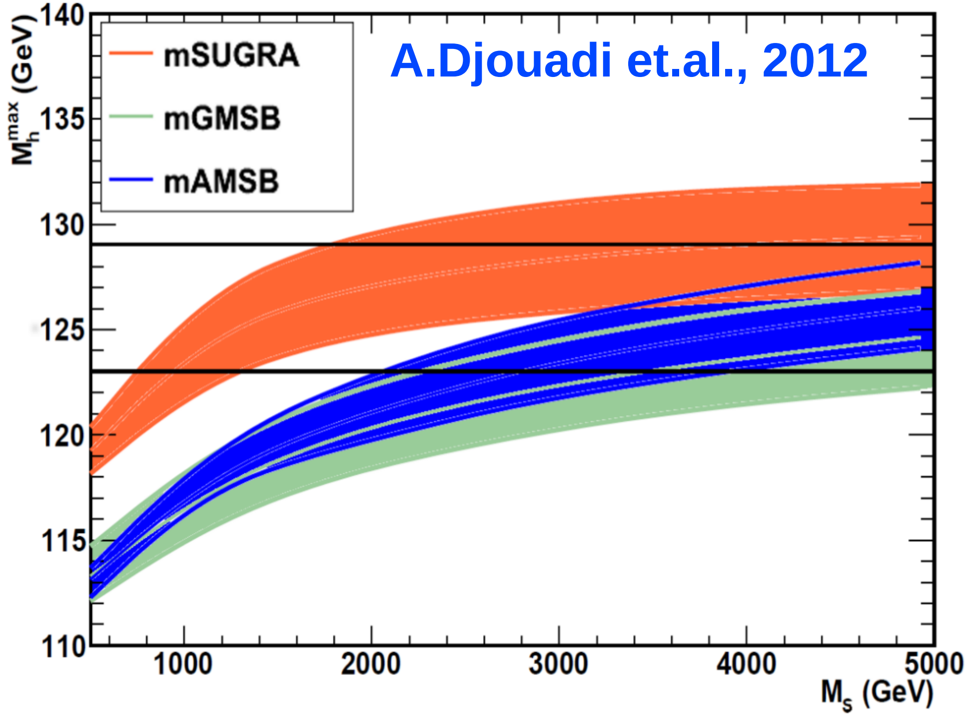


$\mathcal{O}(\alpha_b^2)$

mSUGRA:

1) Writing down microscopic models
   Which give rise to mSUGRA boundary
   conditions is an extremely difficult
   enterprise.

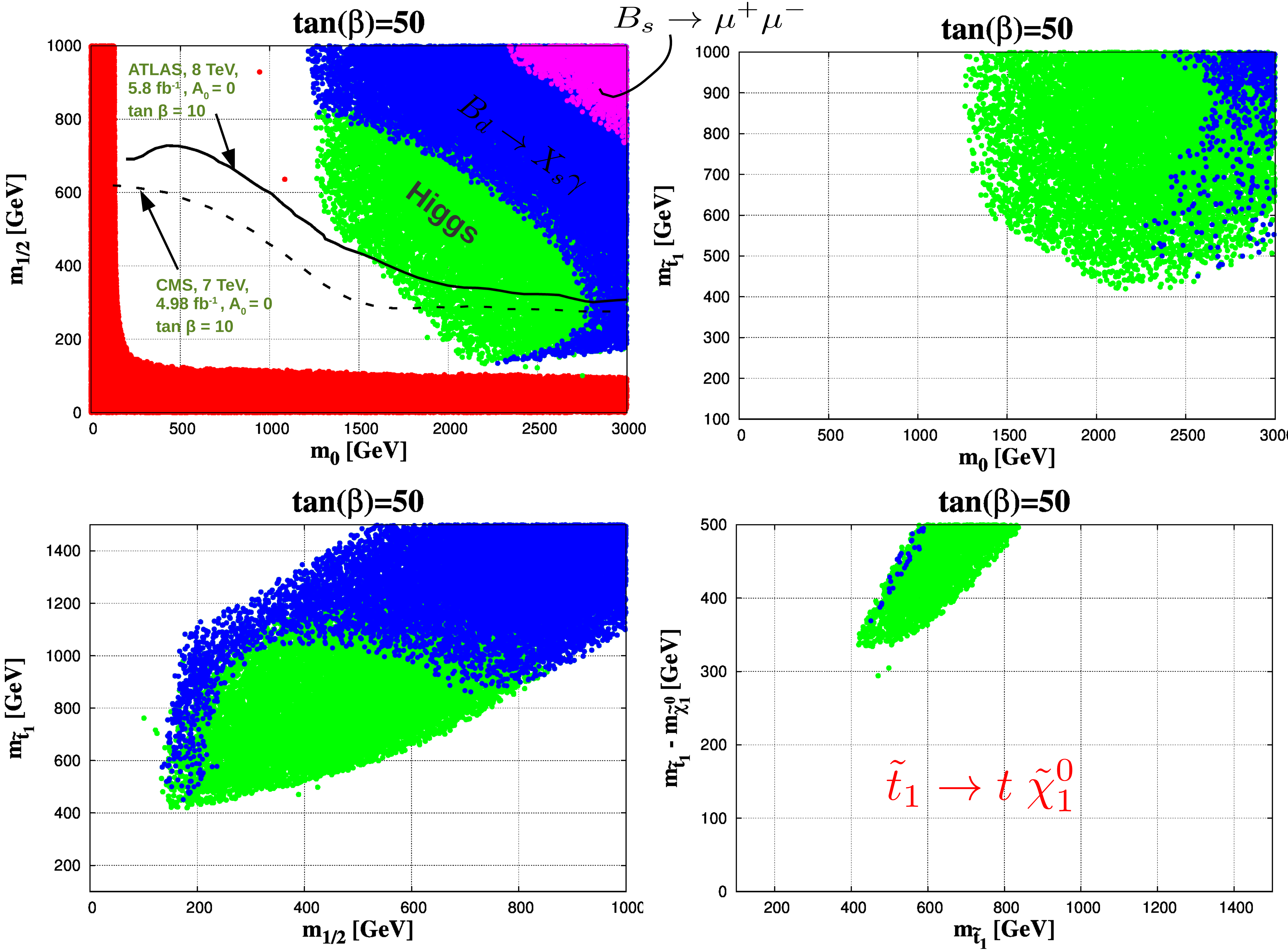
2) Phenomenologically interesting :
   Large A terms are allowed

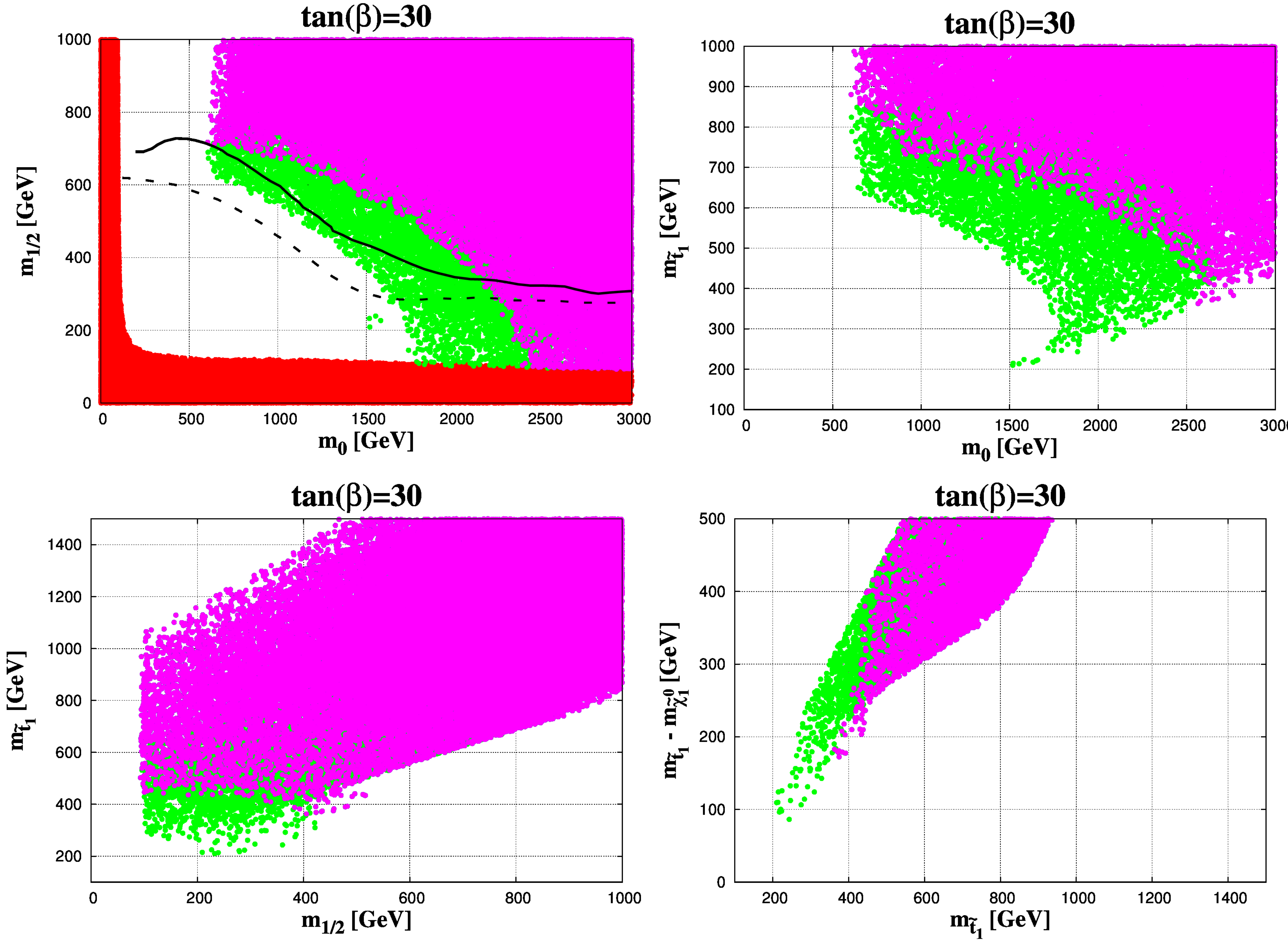


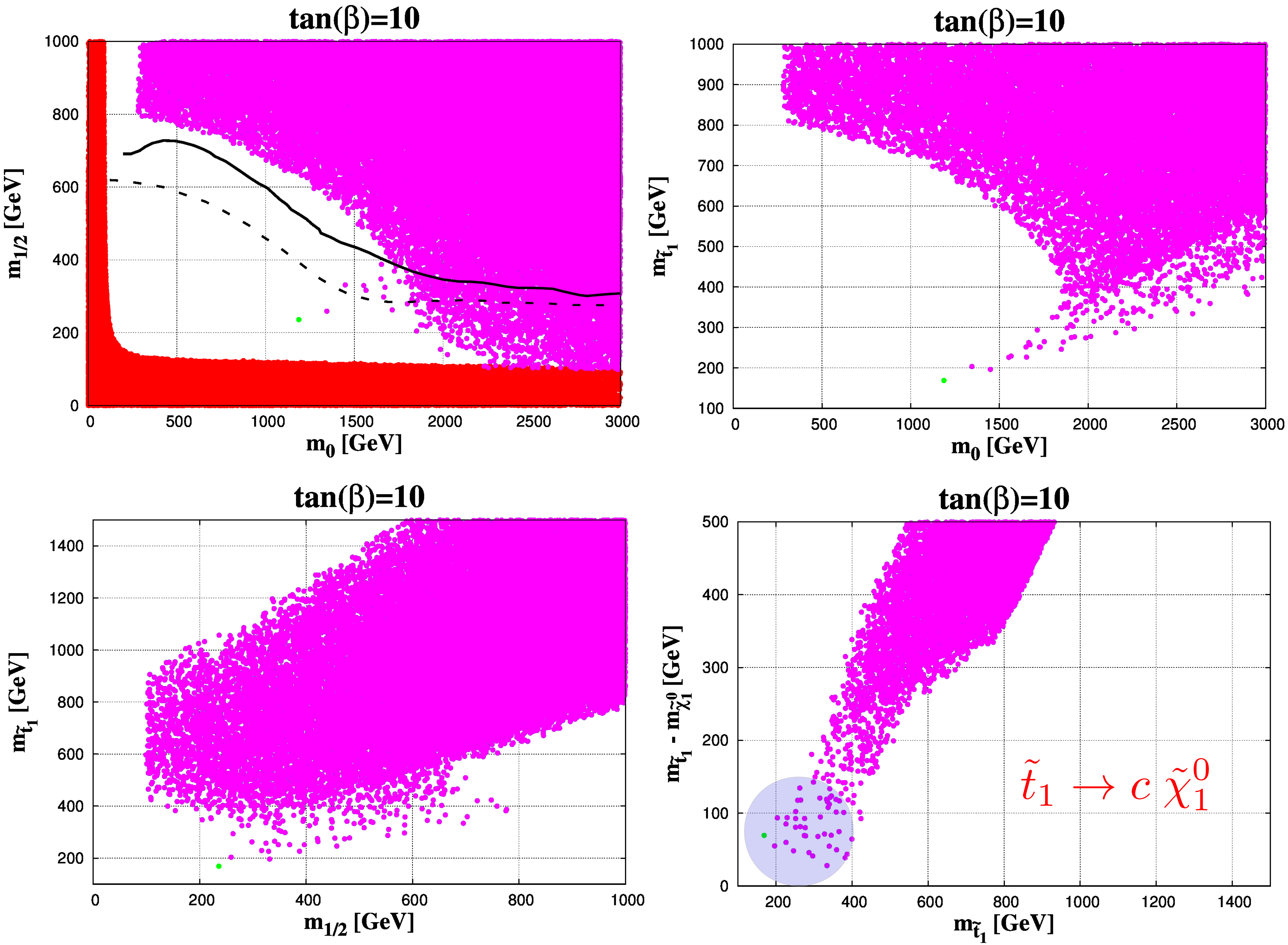
GMSB :

MSSM + mGMSB + 125 GeV higgs :

1) Modify GMSB to achieve large
   A-terms at the messenger scale
2) Modify the MSSM

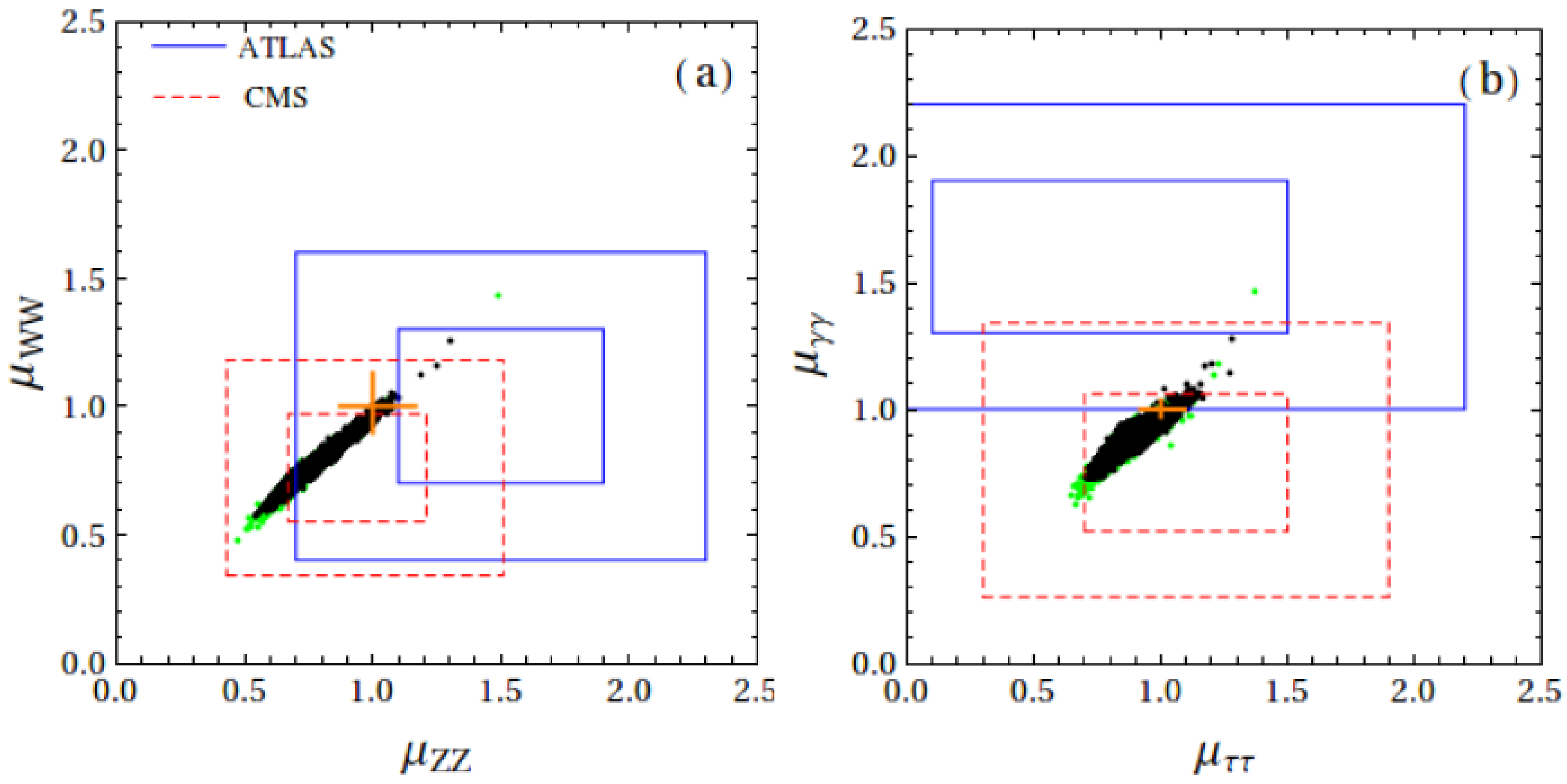

tan(β)=50
$B_s \to \mu^+\mu^-$
ATLAS, 8 TeV,
5.8 fb^{-1}, A_0 = 0
tan β = 10
$B_d \to X_s\gamma$
Higgs
CMS, 7 TeV,
4.98 fb^{-1}, A_0 = 0
tan β = 10
$m_{1/2}$ [GeV]
m_0 [GeV]
tan(β)=50
$m_{\tilde{t}_1}$ [GeV]
m_0 [GeV]
tan(β)=50
$m_{\tilde{t}_1}$ [GeV]
$m_{1/2}$ [GeV]
tan(β)=50
$m_{\tilde{t}_1}$ - $m_{\tilde{\chi}_1^0}$ [GeV]
$\tilde{t}_1 \to t\,\tilde{\chi}_1^0$
$m_{\tilde{t}_1}$ [GeV]


tan(β)=30
m_{1/2} [GeV]
m_0 [GeV]
tan(β)=30
m_{t̃_1} [GeV]
m_0 [GeV]
tan(β)=30
m_{t̃_1} [GeV]
m_{1/2} [GeV]
tan(β)=30
m_{t̃_1} - m_{χ̃_1^0} [GeV]
m_{t̃_1} [GeV]



tan(β)=10
m_{1/2} [GeV]
m_0 [GeV]
tan(β)=10
m_{t̃1} [GeV]
m_0 [GeV]
tan(β)=10
m_{t̃1} [GeV]
m_{1/2} [GeV]
tan(β)=10
m_{t̃1} - m_{χ̃1^0} [GeV]
m_{t̃1} [GeV]
$\tilde{t}_1 \to c\,\tilde{\chi}_1^0$

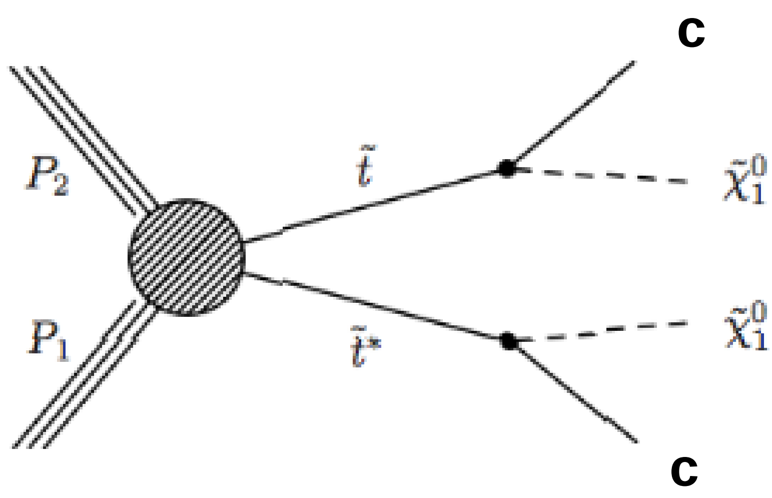
$$\mu_{X\bar{X}} \equiv \frac{N_{X\bar{X}}}{N^{\rm SM}_{X\bar{X}}} = \frac{\sigma(pp \to h^0)}{\sigma_{\rm SM}(pp \to h^0)} \times \frac{\mathcal{B}(h^0 \to X\bar{X})}{\mathcal{B}_{\rm SM}(h^0 \to X\bar{X})}$$

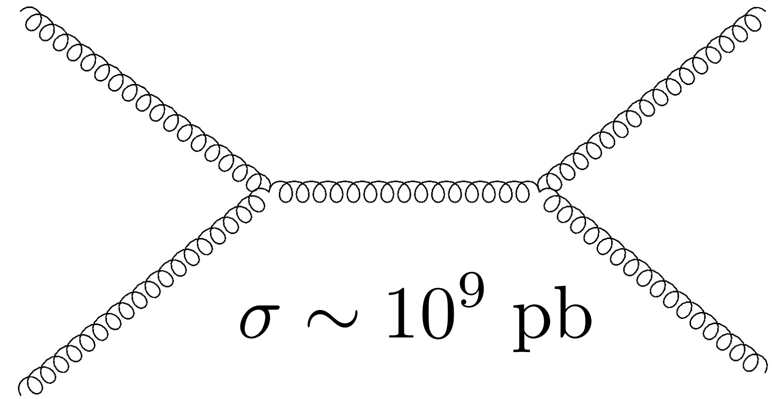


$B_d \to X_s\gamma$
$B_s \to \mu^+\mu^-$
$B_d \to \mu^+\mu^-$
$B^+ \to \tau^+\nu$
$K^+ \to \mu^+\nu$

Present data does not resolve between SM and mSUGRA

A Dighe, DG, K Patel, S Raychaudhuri, 1303.0721





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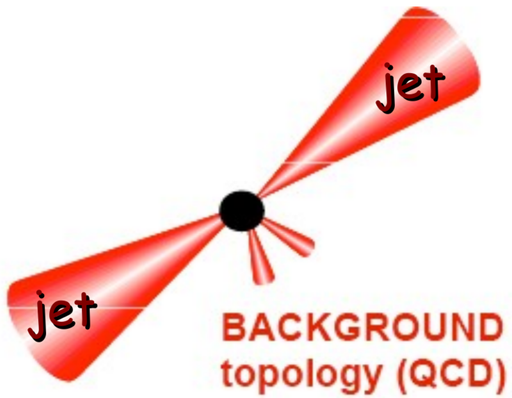
$$\alpha_T = \frac{p_T^{j2}}{\sqrt{H_T^2 - \not{H}_T^2}} \qquad H_T = \sum_j |\vec{p_T}| \qquad \not{H}_T = |\sum_j \vec{p_T}|$$



Jets are back-to-back in ϕ

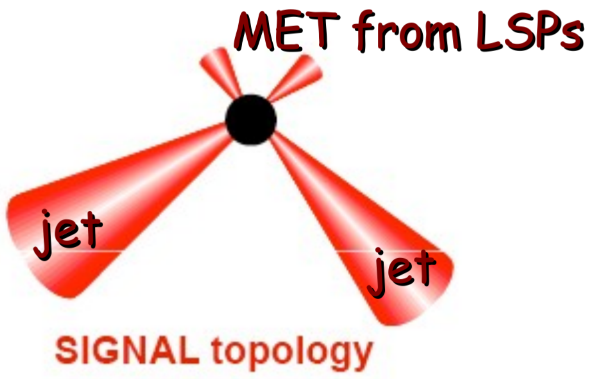
$$\alpha_T = 0.5$$

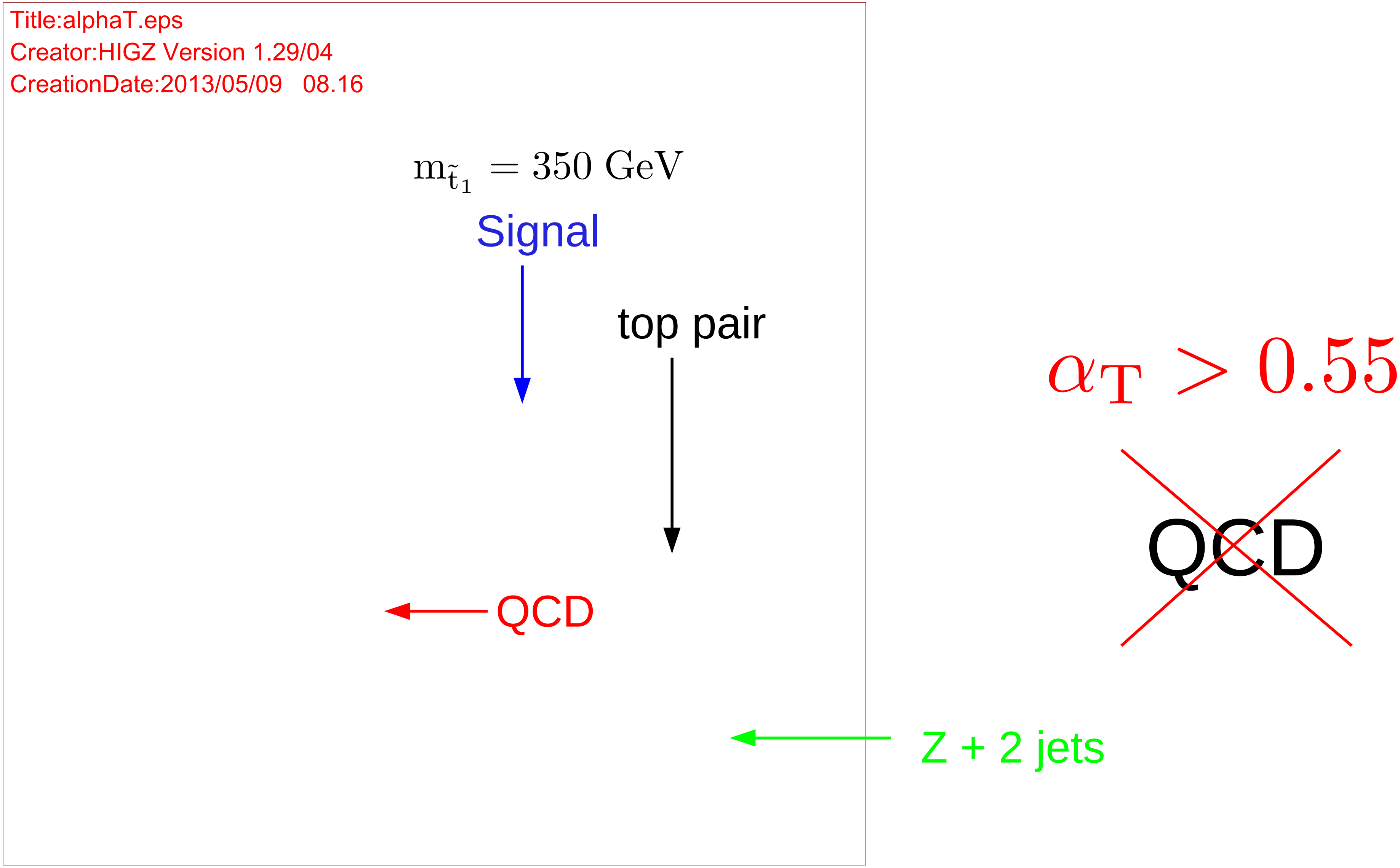
in the case of an imbalance in the measured p_Ts of back-to-back jets

$$\alpha_T < 0.5$$

when the two jets are not back-to-back and balancing genuine MET

$$\alpha_T > 0.5$$





DG, R Godbole, M Guchait, D Sengupta, in preparation

$$\tilde{l} \to l\tilde{\chi}$$

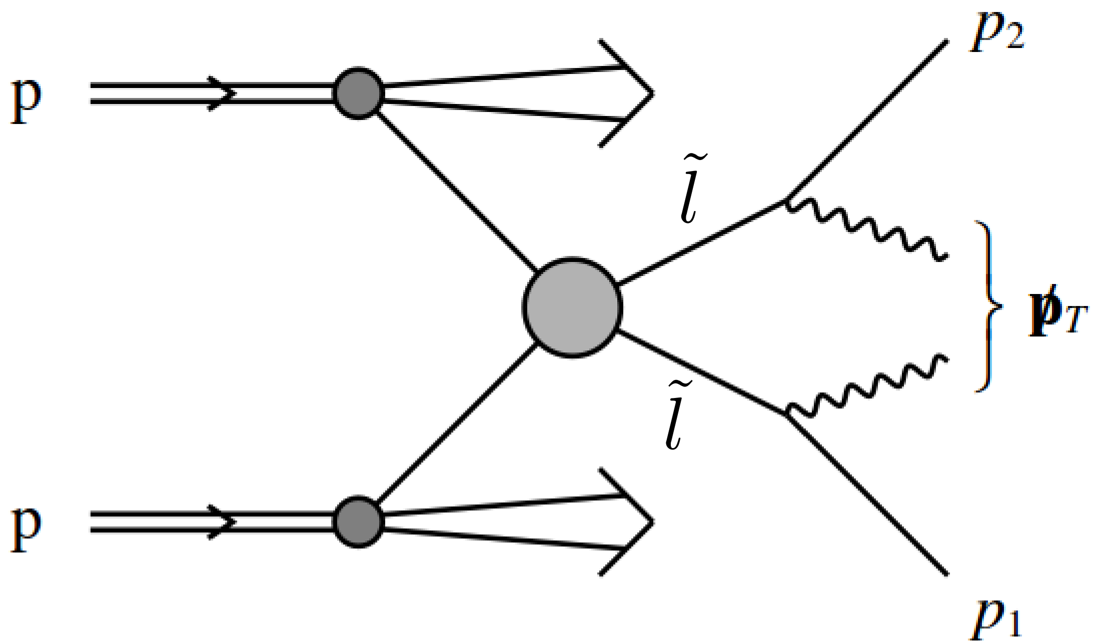
$$m_{\tilde{l}}^2 = m_l^2 + m_{\tilde{\chi}}^2 + 2(E_{Tl}E_{T\tilde{\chi}}\cosh(\Delta\eta) - \mathbf{p}_{Tl}\cdot\mathbf{p}_{T\tilde{\chi}})$$

$$\eta = \frac{1}{2}\ln[(E+p_z)/(E-p_z)]$$

$$E_T = \sqrt{\mathbf{p}_T^2 + m^2}$$

$$m_{\tilde{l}}^2 \geq m_T^2(\mathbf{p}_{Tl}, \mathbf{p}_{T\tilde{\chi}}) \equiv m_l^2 + m_{\tilde{\chi}}^2 + 2(E_{Tl}E_{T\tilde{\chi}} - \mathbf{p}_{Tl}\cdot\mathbf{p}_{T\tilde{\chi}})$$

$$\cosh\eta \geq 1$$



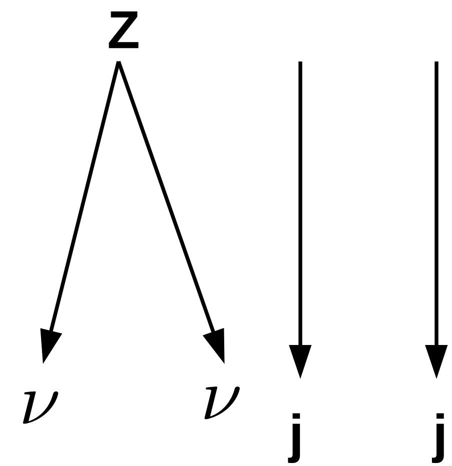
C. G. Lester and D. J. Summers, 1999

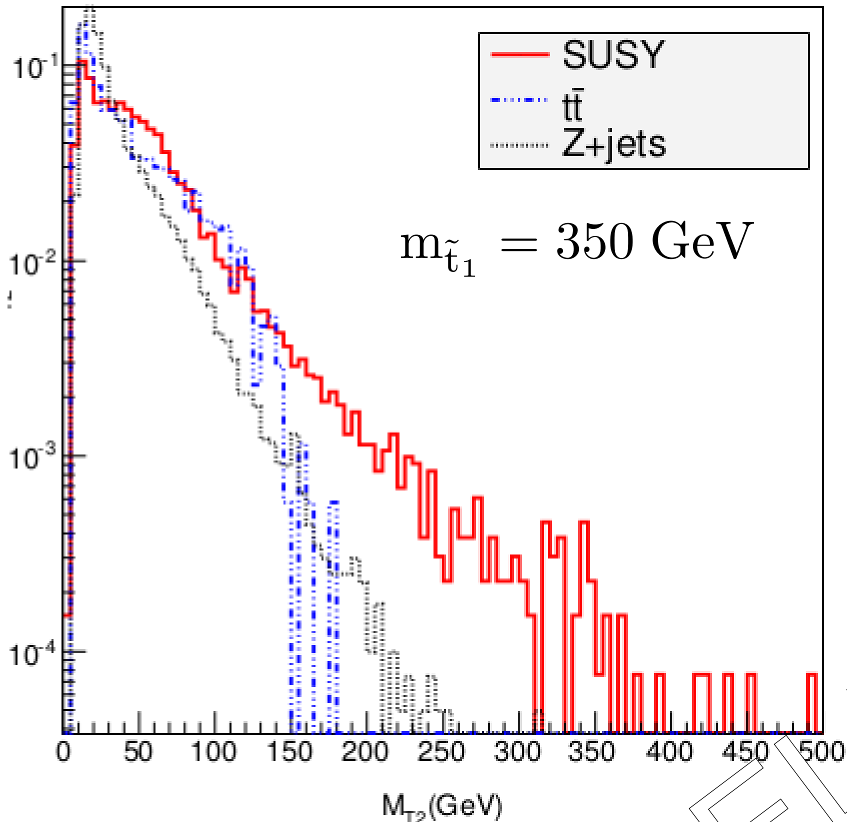
$$\not{\mathbf{p}}_T = \mathbf{p}_{T\tilde{\chi}_a} + \mathbf{p}_{T\tilde{\chi}_b}$$

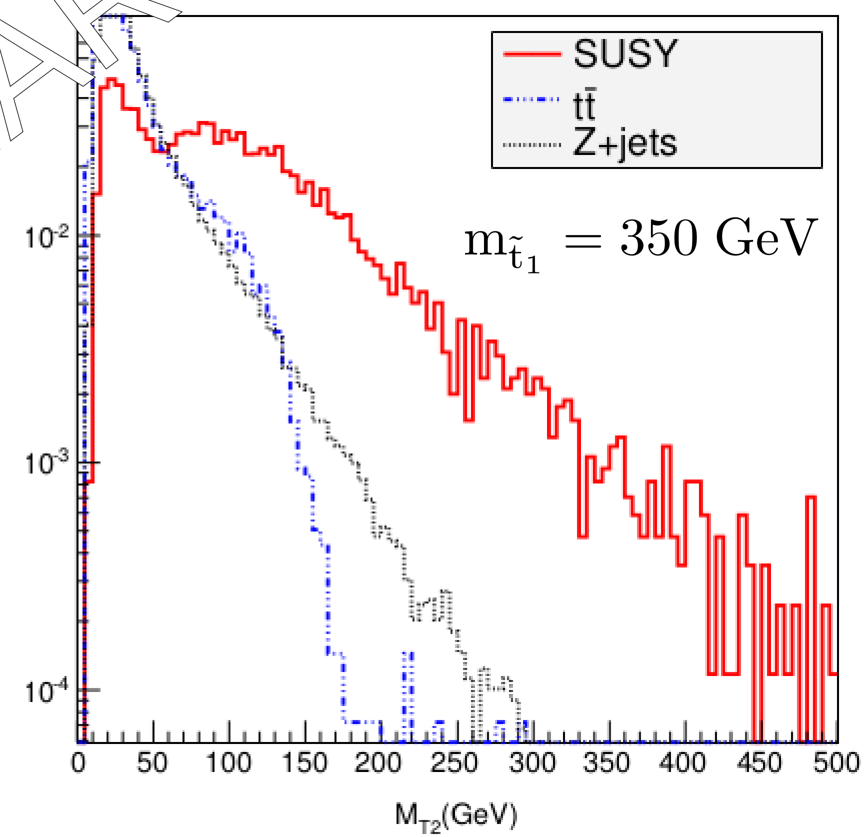
$$m_{\tilde{l}}^2 \geq \max\{m_T^2(\mathbf{p}_{Tl^-}, \mathbf{p}_{T\tilde{\chi}_a}), m_T^2(\mathbf{p}_{Tl^+}, \mathbf{p}_{T\tilde{\chi}_b})\}$$

$$m_{\tilde{l}}^2 \geq M_{T2}^2 \equiv \min_{\not{\mathbf{p}}_1 + \not{\mathbf{p}}_2 = \not{\mathbf{p}}_T} \left[\max\left\{m_T^2(\mathbf{p}_{Tl^-}, \not{\mathbf{p}}_1), m_T^2(\mathbf{p}_{Tl^+}, \not{\mathbf{p}}_2)\right\}\right]$$

$$M_{T2}(\vec{p}_T^{\,j1}, \vec{p}_T^{\,j2}, \vec{\not{p}}_T) = \min_{\vec{\not{p}}_T = \vec{\not{p}}_T^{\,1} + \vec{\not{p}}_T^{\,2}} \left[\max\{ M_T(\vec{p}_T^{\,j1}, \vec{\not{p}}_T^{\,1}), M_T(\vec{p}_T^{\,j2}, \vec{\not{p}}_T^{\,2}) \} \right]$$





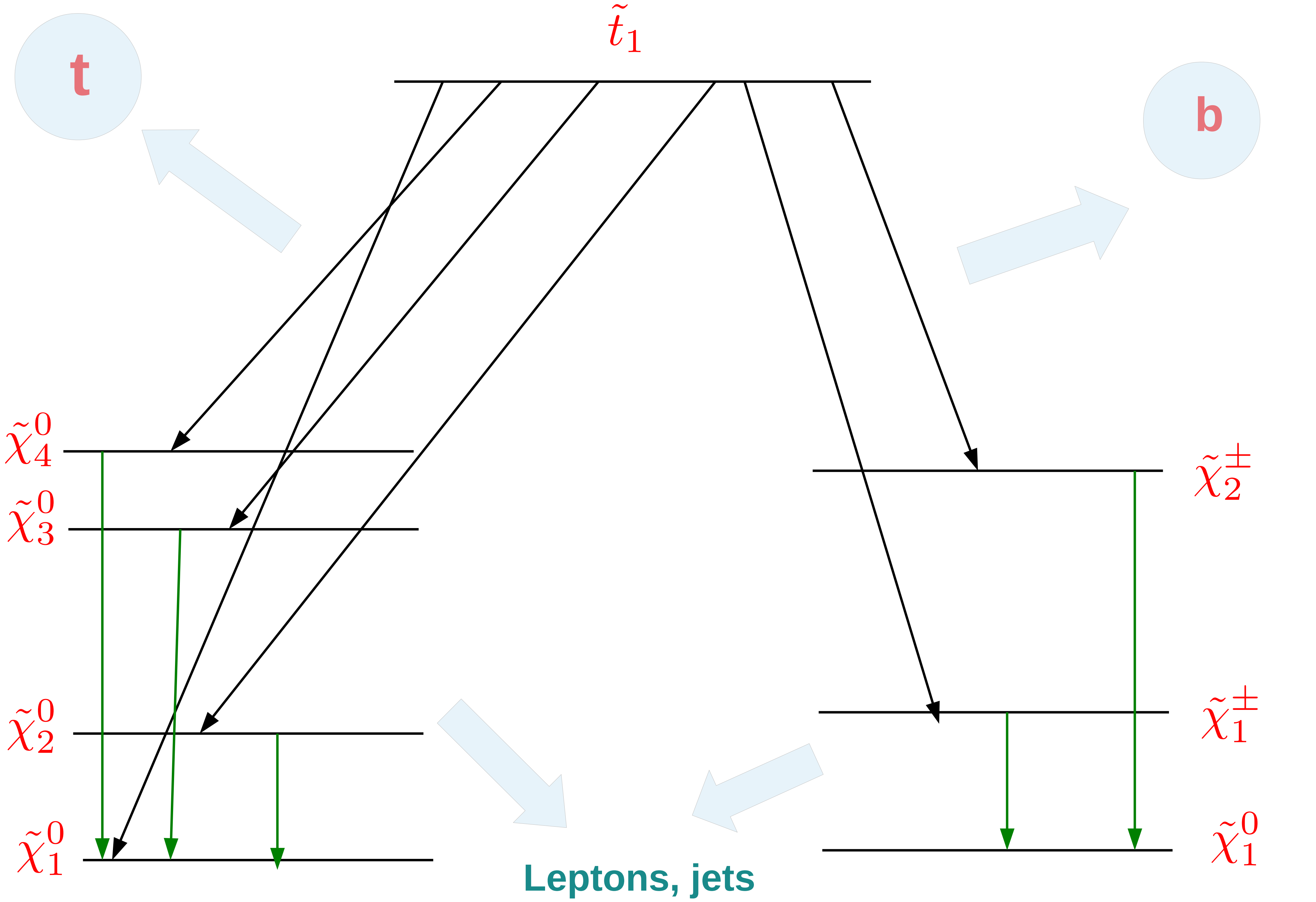


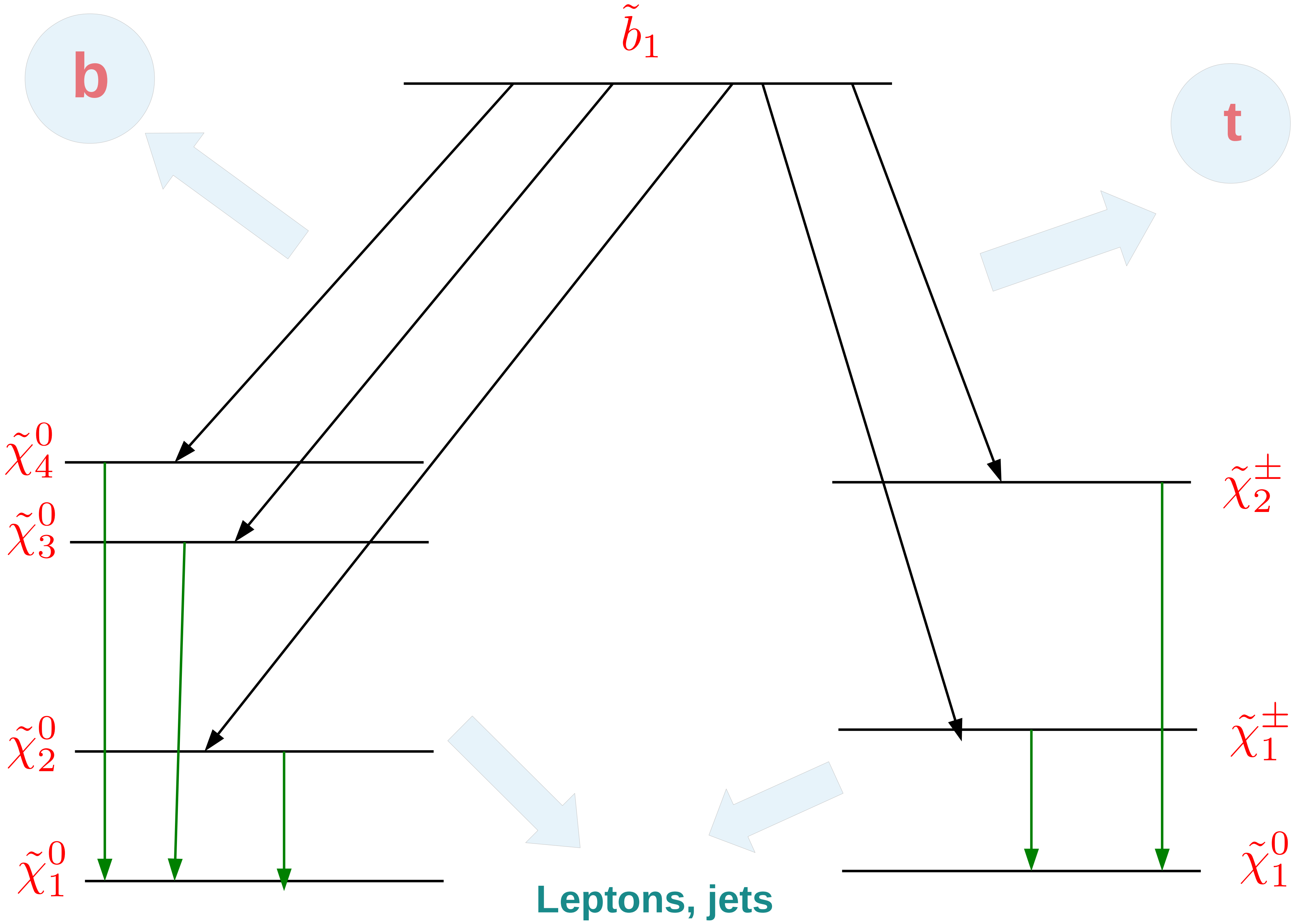
Some attempts :

1201.5714
1211.2997
1212.4856
1304.3068

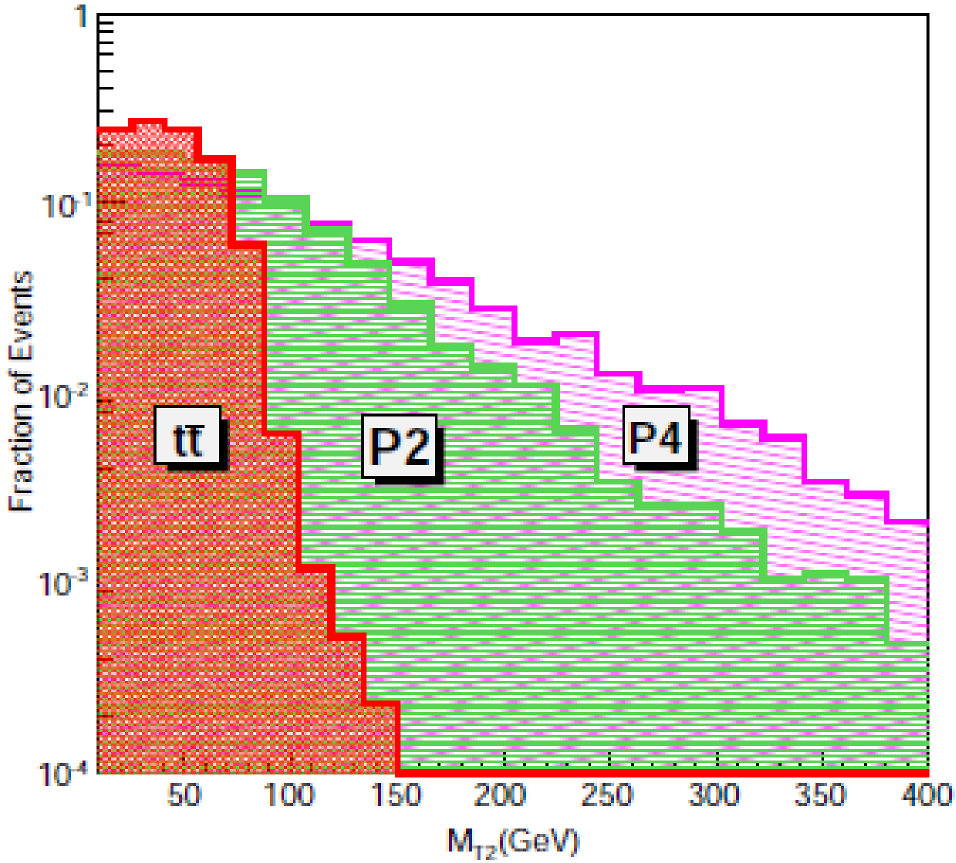
Not sensitive to the mass range beyond 250 GeV

DG, R Godbole, M Guchait, D Sengupta, in preparation


$\tilde{t}_1$
t
b
$\tilde{\chi}_4^0$
$\tilde{\chi}_3^0$
$\tilde{\chi}_2^0$
$\tilde{\chi}_1^0$
$\tilde{\chi}_2^\pm$
$\tilde{\chi}_1^\pm$
$\tilde{\chi}_1^0$
Leptons, jets


$\tilde{b}_1$
b
t
$\tilde{\chi}_4^0$
$\tilde{\chi}_3^0$
$\tilde{\chi}_2^0$
$\tilde{\chi}_1^0$
$\tilde{\chi}_2^\pm$
$\tilde{\chi}_1^\pm$
$\tilde{\chi}_1^0$
Leptons, jets

$$\mathrm{M_{T2}}(\overrightarrow{\mathrm{p}}_{\mathrm{T}}^{\ell 1}, \overrightarrow{\mathrm{p}}_{\mathrm{T}}^{\ell 2}, \overrightarrow{\not p}_{\mathrm{T}}) = \min_{\overrightarrow{\not p}_{\mathrm{T}} = \overrightarrow{\not p}_{\mathrm{T}}^{1} + \overrightarrow{\not p}_{\mathrm{T}}^{2}} \left[\max\{\mathrm{M_T}(\overrightarrow{\mathrm{p}}_{\mathrm{T}}^{\ell 1}, \overrightarrow{\not p}_{\mathrm{T}}^{1}), \mathrm{M_T}(\overrightarrow{\mathrm{p}}_{\mathrm{T}}^{\ell 2}, \overrightarrow{\not p}_{\mathrm{T}}^{2})\} \right]$$



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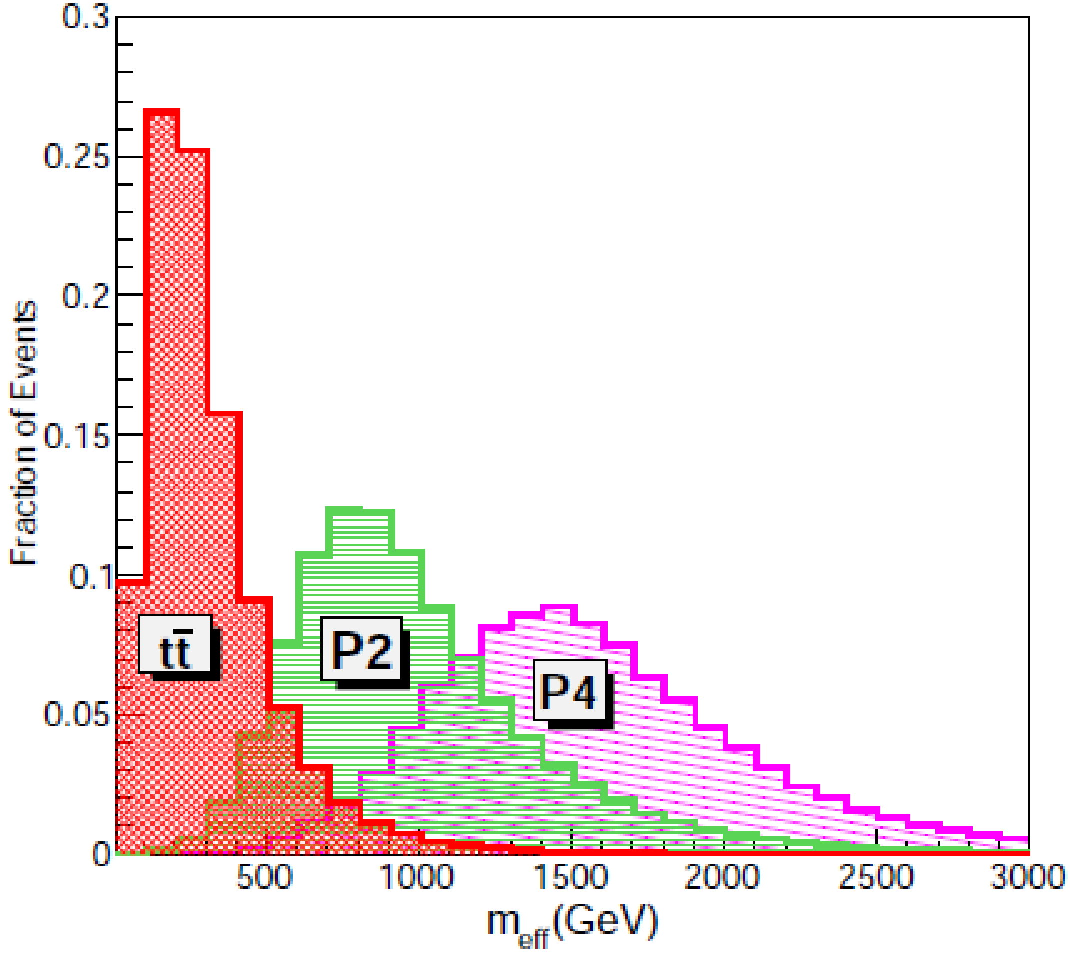
CreationDate:Mon May 13 08:11:20 2013

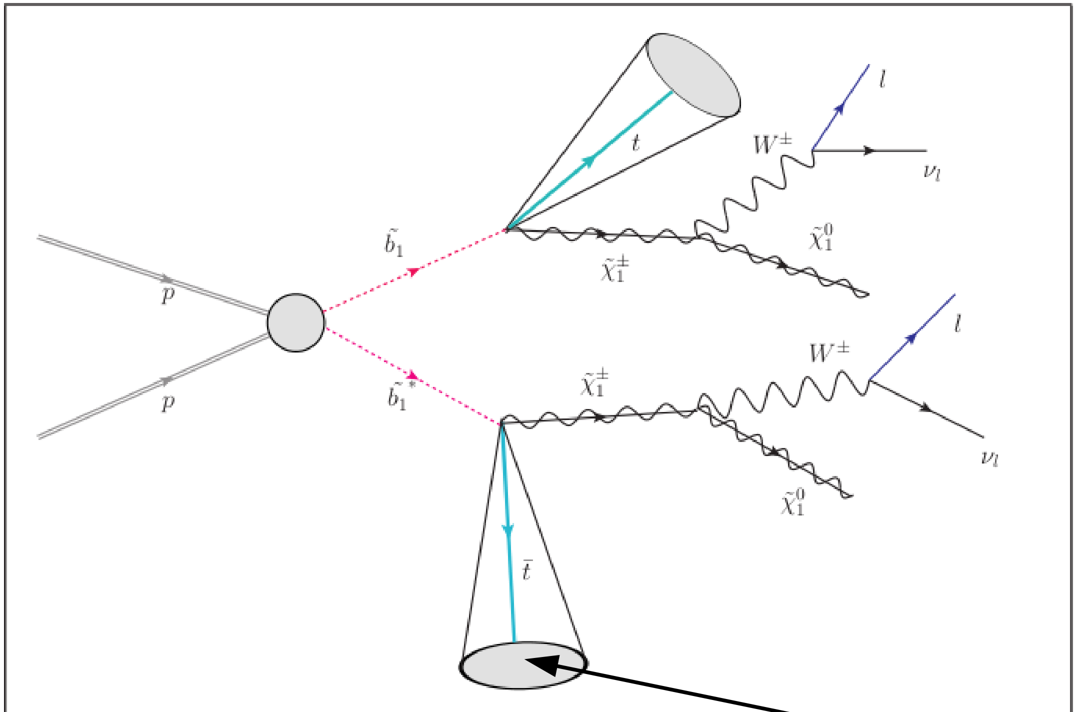
$$\mathrm{P2} : \tilde{t}_1 = 600\,\mathrm{GeV}$$

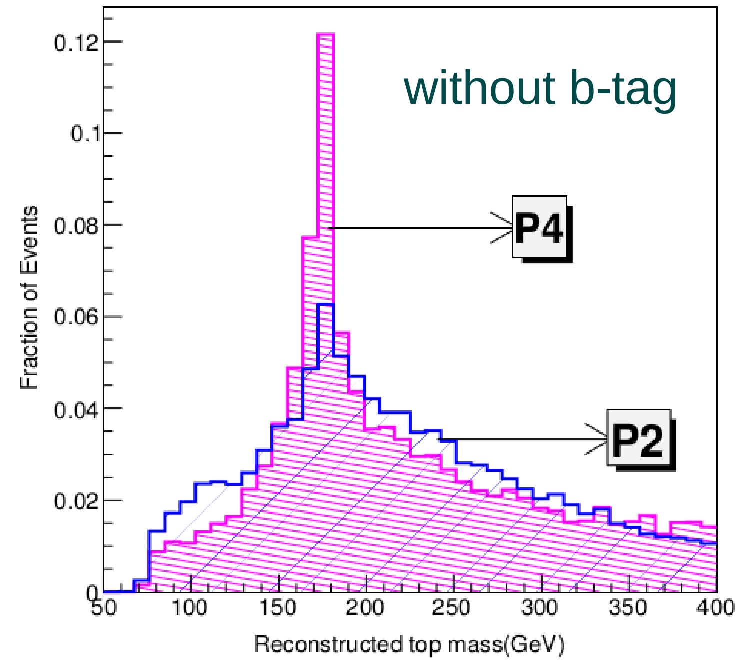
$$\mathrm{P4} : \tilde{t}_1 = 1\,\mathrm{TeV}$$



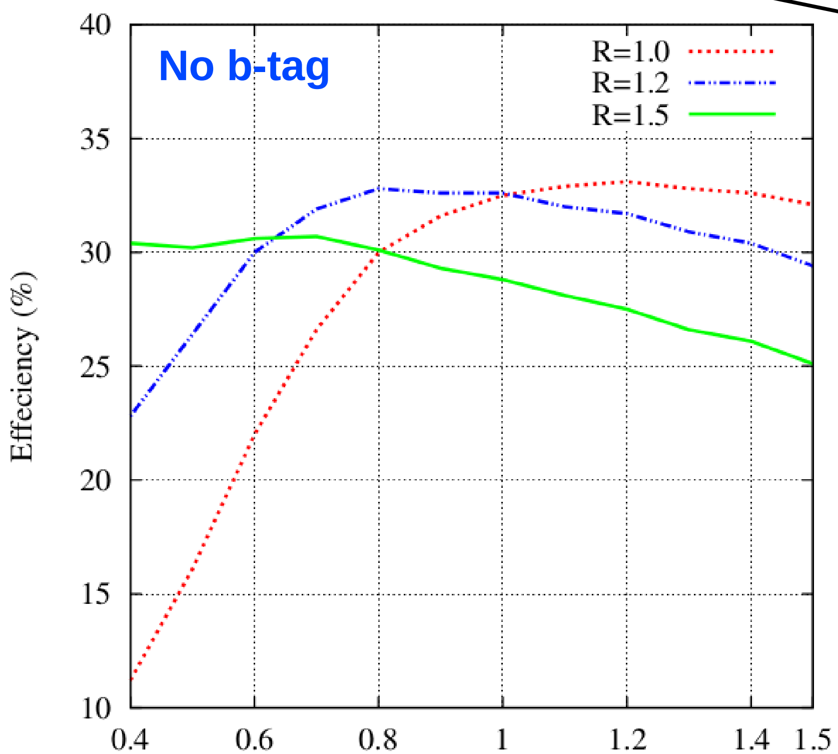
$$m_{\mathrm{eff}} = \sum_{j} |\overrightarrow{p_T}| + \sum_{\ell} |\overrightarrow{p_T}|$$

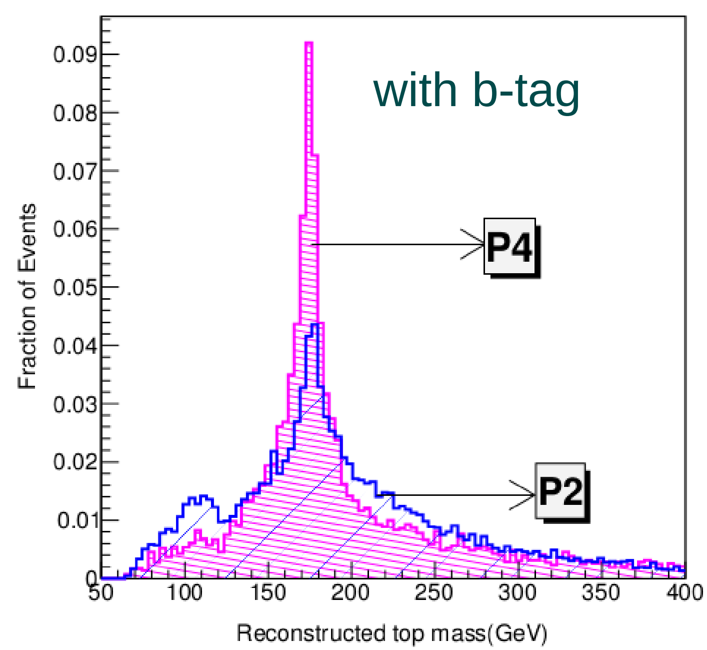
Correlated with the stop mass





JHToptagger





A Chakraborty, D K Ghosh, DG, D Sengupta, 1303.5776

C1 : 2 hard isolated leptons C2 : $M_{T2} > 125$ GeV C3 : $m_{\rm eff} > 800$ GeV

C4 : $\not{p}_T > 150$ GeV C5 : 1 hadronic top tag

			No. of events after the cut					
Signal	$m_{\tilde{t}_1}$ (GeV)	Simulated events (in units of 10^4)	C1	C2	C3	C4	C5	Final Cross-section (in units of 10^{-2} fb)
P1	423	50	42319	1802	615	461	71	51.2
P2	632	10	16429	1569	1000	800	205	67.6
P3	834	5	9423	1325	1134	982	226	23.5
P4	1031	5	10114	1782	1690	1517	363	10.2

			No. of events after the cut					
SM backgrounds	Production Cross-section (fb)	Simulated events (in units of 10^4)	C1	C2	C3	C4	C5	Final Cross-section (in units of 10^{-2} fb)
$t\bar{t}$+ jets	918000	4320	1587596	601	39	29	4	8.5
tbW	61000	600	215807	80	4	2	1	1.0
$t\bar{t}Z$	1121	7	6255	253	52	20	2	3.2
$t\bar{t}W$	769	5	4471	31	3	2	1	1.5
$t\bar{t}W^+W^-$	10	1	1588	33	14	13	6	0.6
$t\bar{t}t\bar{t}$	10	1	1781	31	14	10	4	0.4
Total Background								15.2

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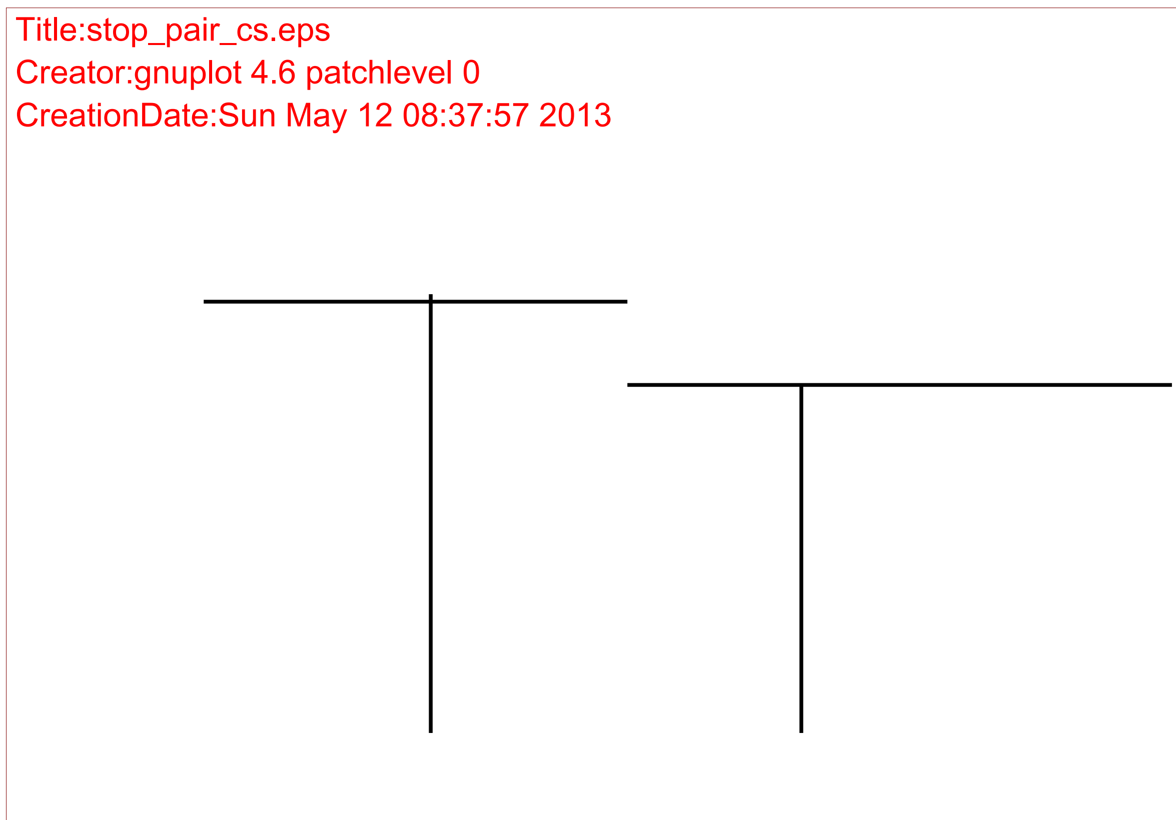
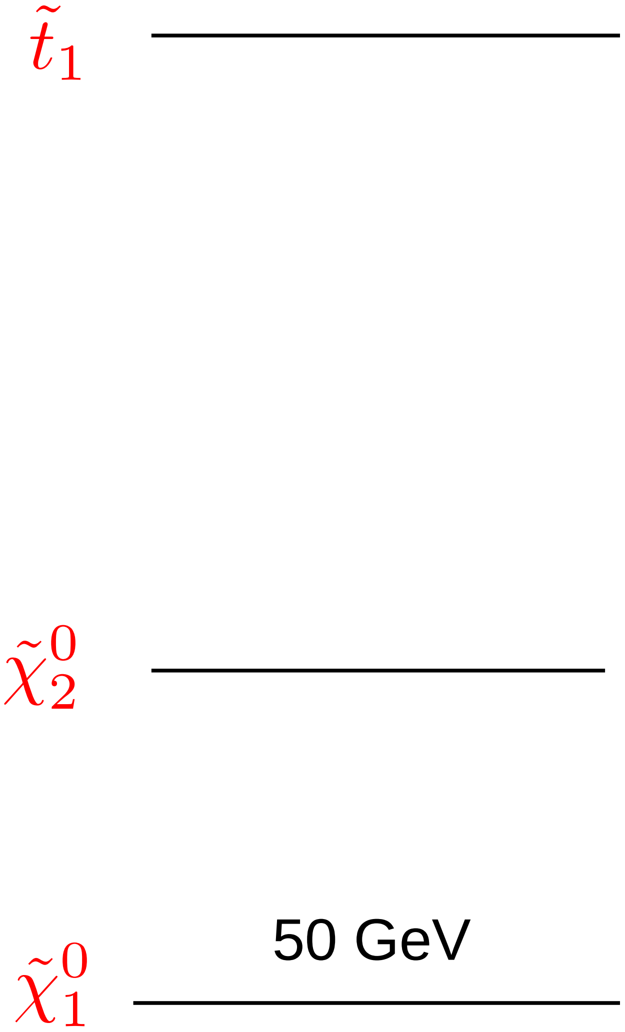
		Signal (N_S)			Backgrounds (N_B)			$\mathcal{S} = \frac{N_S}{\sqrt{N_B + (0.1 N_B)^2}}$		
	$m_{\tilde{t}_1}$ (GeV)	10 fb^{-1}	50 fb^{-1}	100 fb^{-1}	10 fb^{-1}	50 fb^{-1}	100 fb^{-1}	10 fb^{-1}	50 fb^{-1}	100 fb^{-1}
P1	423	5.2	26.0	52.0	1.6	8.0	16.0	4.1	8.8	12.1
P2	632	6.8	34.0	68.0	1.6	8.0	16.0	5.3	11.6	15.8
P3	834	2.4	12.0	24.0	1.6	8.0	16.0	1.9	4.1	5.6
P4	1031	1.0	5.0	10.0	1.6	8.0	16.0	0.8	1.7	2.3



$\sigma_{t\bar{t}} \sim 225$ pb 8TeV

$\sigma_{t\bar{t}} \sim 925$ pb 14TeV



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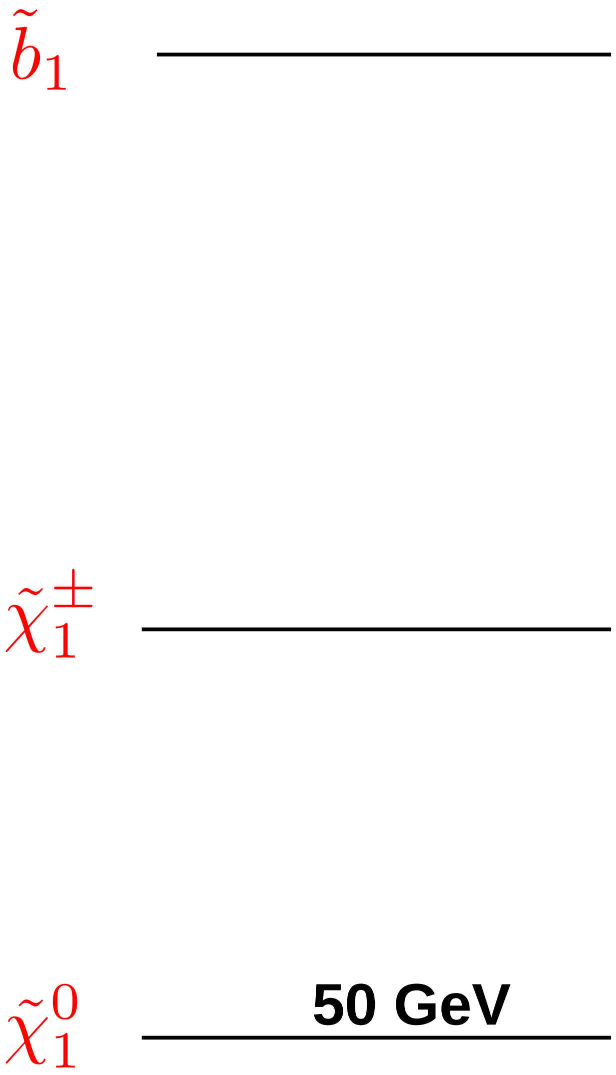
A Chakraborty, D K Ghosh, DG, D Sengupta, 1303.5776



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Summary

ATLAS and CMS took a good bite out of the
SUSY parameter space

Higgs mass has made it even worse

Light third generation squarks could be the culprit behind the
relatively heavy higgs mass

A very light NLSP stop squark is allowed even in some of the
minimal models

The stop NLSP region is very poorly constrained by ATLAS
and CMS and dedicated searches are necessary to probe this region

The use of MT2 and effective mass seem to be extremely effective
To suppress SM background, for heavier stops the use of jet
Substructure techniques to reconstruct the hadronically decaying
tops might be an additional handle

Heavier stops will allow quite a large number of decay topologies,
hence dedicated searches for various final states should be carried out


Thank You
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