Boosting stop searches with boosted di-boson

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Tuning in the MSSM

$$\Delta \mathrm{m}_\mathrm{h}^2 \approx \frac{3\,\mathrm{m}_\mathrm{t}^4}{2\,\pi^2\,\mathrm{v}^2}\left[\ln\left(\frac{\mathrm{M}_\mathrm{S}^2}{\mathrm{m}_\mathrm{t}^2}\right) + \frac{\mathrm{X}_\mathrm{t}^2}{2\mathrm{M}_\mathrm{S}^2}\left(1 - \frac{\mathrm{X}_\mathrm{t}^2}{6\mathrm{M}_\mathrm{S}^2}\right)\right] + \ldots$$

$$\mathrm{X}_\mathrm{t} = \mathrm{A}_\mathrm{t} - \frac{\mu}{\tan\beta}, \quad \mathrm{M}_\mathrm{S}^2 = \mathrm{M}_{\tilde{\mathrm{t}}_1}\mathrm{M}_{\tilde{\mathrm{t}}_2}$$

$$m_h^2 = -2\left(m_{H_u}^2 + |\mu|^2\right) \text{ (large } \tan\beta\text{)}$$

$$\frac{d}{dt}m_{H_u}^2 = \frac{6|y_t|^2}{(4\pi)^2}\left(m_{\tilde{t}_L}^2 + m_{\tilde{t}_R}^2 + |A_t|^2\right) + \ldots$$

Tuning in the MSSM

$$\Delta m_h^2 \approx \frac{3\, m_t^4}{2\, \pi^2\, v^2} \left[\ln\left(\frac{M_S^2}{m_t^2}\right) + \frac{X_t^2}{2M_S^2}\left(1 - \frac{X_t^2}{6M_S^2}\right)\right] + \ldots$$

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

$$m_h^2 = -2\left(m_{H_u}^2 + |\mu|^2\right) \quad (\text{large } \tan\beta)$$

$$\frac{d}{dt} m_{H_u}^2 = \frac{6|y_t|^2}{(4\pi)^2}\left(m_{\tilde{t}_L}^2 + m_{\tilde{t}_R}^2 + |A_t|^2\right) + \ldots$$

$$\frac{d}{dt} m_{\tilde{t}}^2 = -\frac{8\alpha_s}{3\pi} M_3^2 + \ldots$$

gluino sucks effect:
the stop mass itself is attracted to the gluino mass in the IR

Strong LHC bound on gluino mass ---→ large tuning

Belanger, DG, Godbole, Kulkarni
To apper..

Light stop?

pMSSM

Parameter	Scan range (GeV)
M_1	20 – 2000
M_2	100 – 2000
$\tan(\beta)$	2 – 55
μ	100 – 3000
m_A	100 – 2000
A_t	-5000 – 5000
A_b	-5000 – 5000
$m_{\tilde{Q}_3}$	100 – 2000
$m_{\tilde{U}_3}$	100 – 2000
$m_{\tilde{D}_3}$	100 – 2000

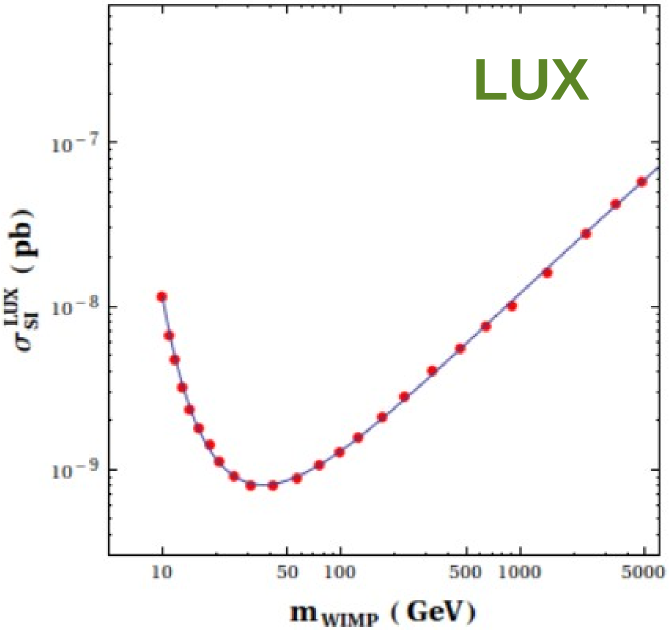
Observable	Allowed range
$\mathrm{BR}(B_d \to X_s\gamma) \times 10^4$	2.78 – 4.08
$\mathrm{BR}(B_s \to \mu^+\mu^-) \times 10^9$	1.43 – 4.37
$\mathrm{BR}(B_d \to \mu^+\mu^-) \times 10^{10}$	0.79 – 6.80
Ωh^2	≤ 0.1289

+

HiggsBounds+HiggSignals

Number of free model parameters $N_p = 10$

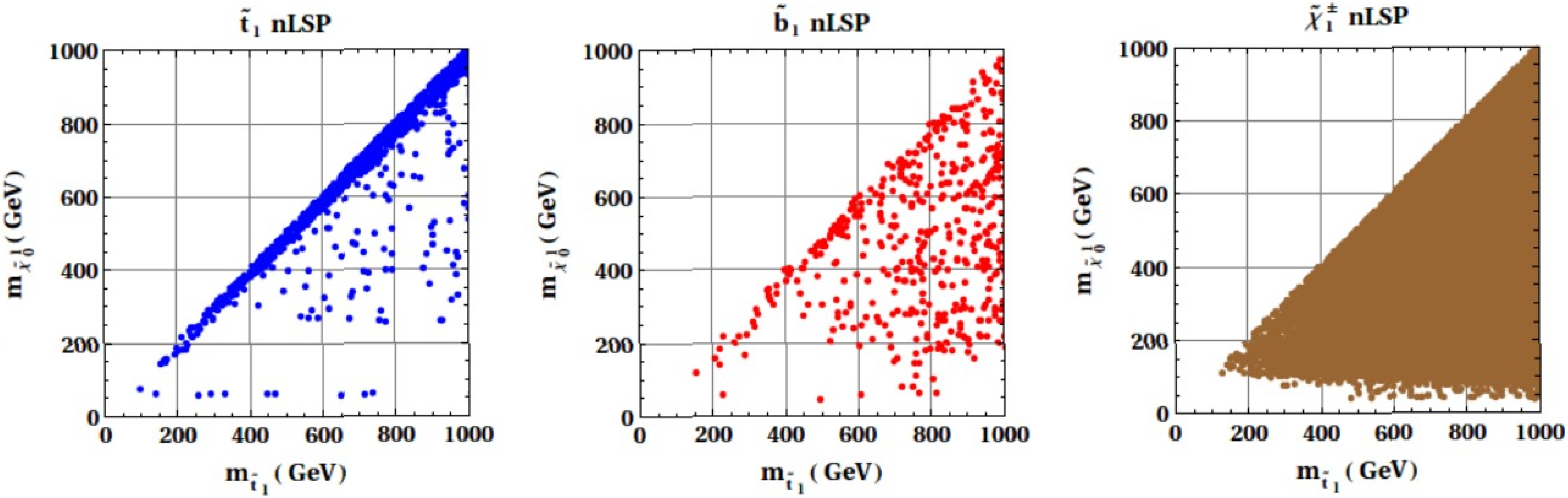
p-value ≥ 0.05



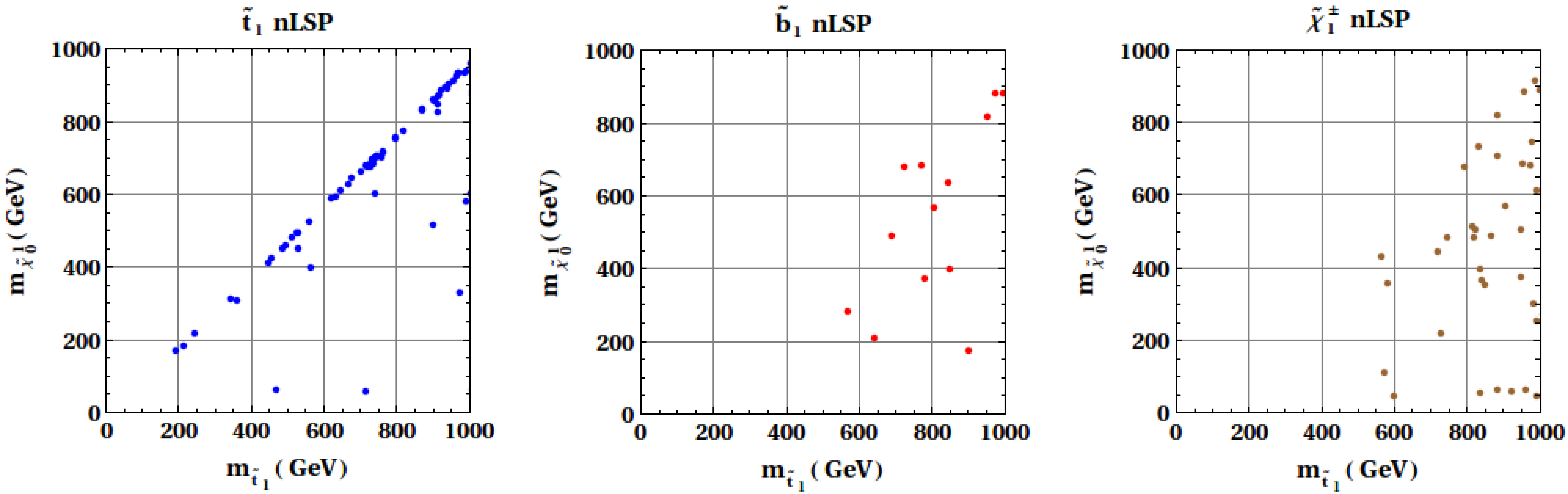
$$\log_{10}\sigma_{\mathrm{SI}}^{\mathrm{LUX}} = -8.569 + \frac{7.029}{(\log_{10} m_{\mathrm{WIMP}})^2} - \frac{7.161}{\log_{10} m_{\mathrm{WIMP}}} + 0.755\log_{10} m_{\mathrm{WIMP}} - 0.003(\log_{10} m_{\mathrm{WIMP}})^2$$

$$\sigma_{\mathrm{SI}} < \begin{cases} \sigma_{\mathrm{SI}}^{\mathrm{LUX}} & \text{for } 0.1103 < \Omega h^2 < 0.1289 \\ \frac{0.1196}{\Omega h^2}\sigma_{\mathrm{SI}}^{\mathrm{LUX}} & \text{for } \Omega h^2 < 0.1103 \end{cases}$$

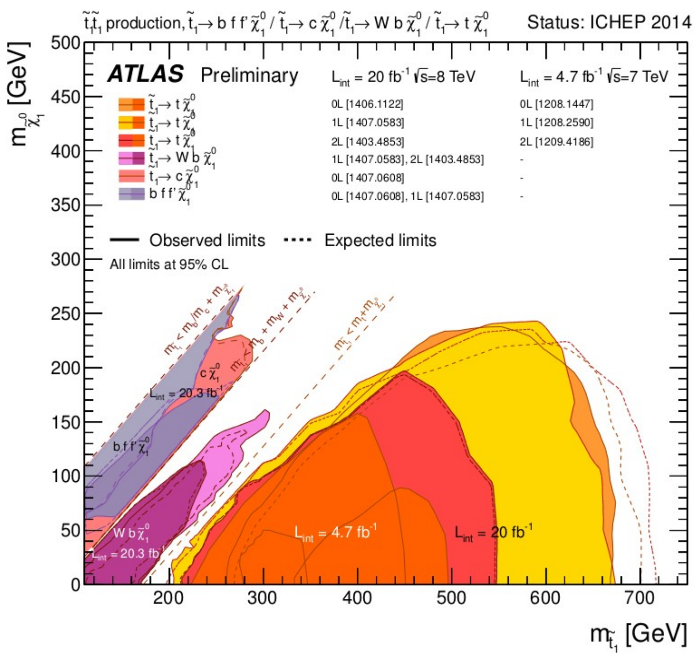
$\Omega h^2 < 0.1289$



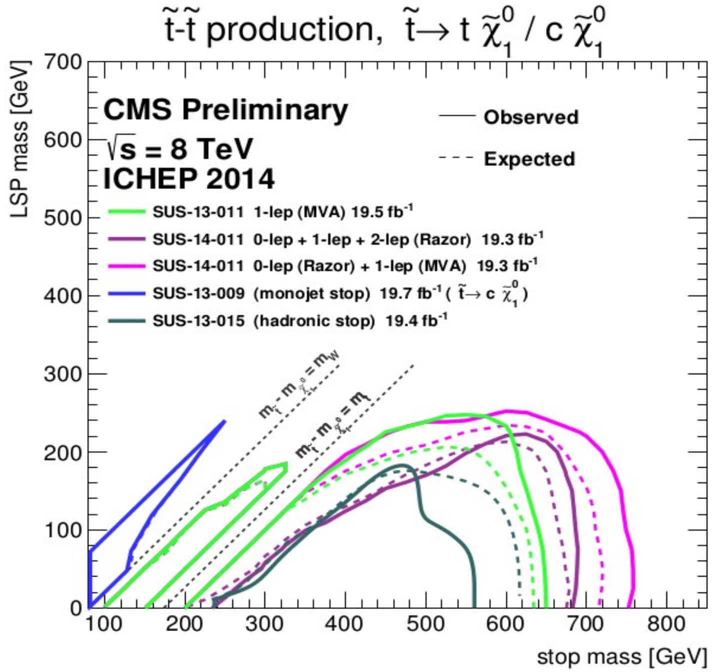
$0.1103 < \Omega h^2 < 0.1289$



LHC bounds

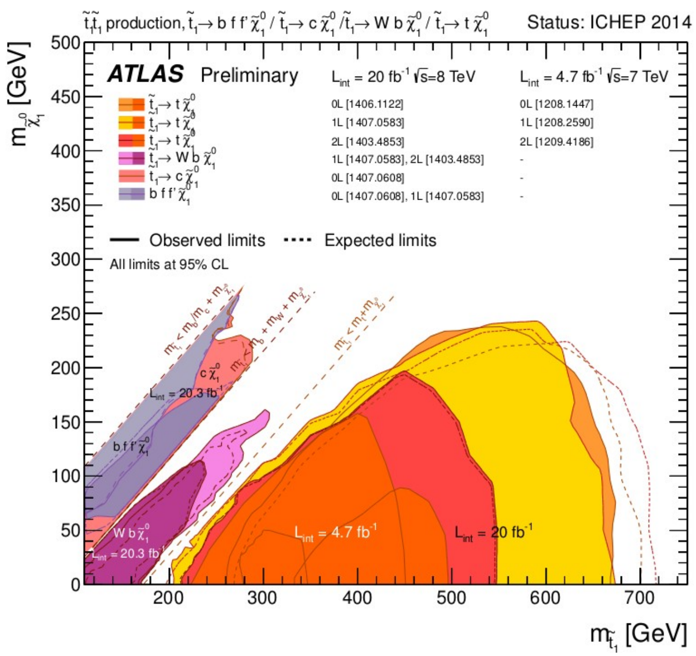


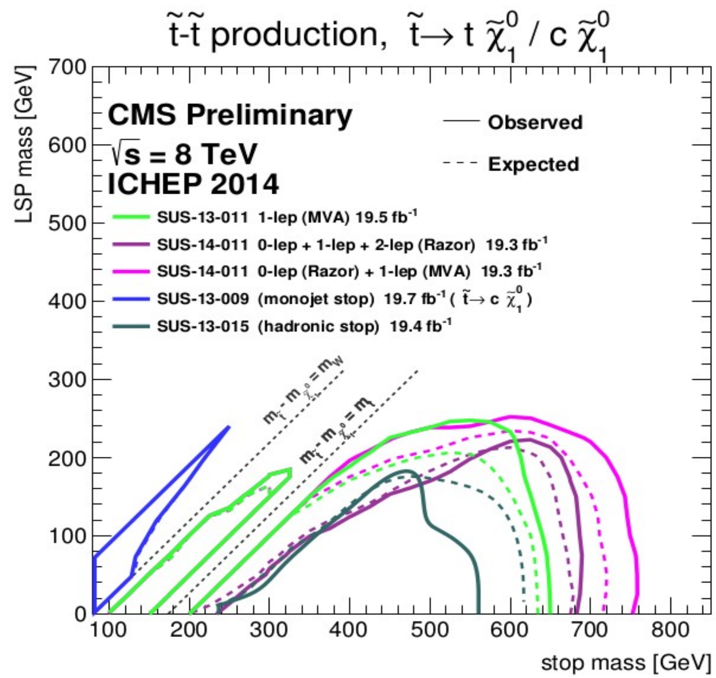
t̃₁t̃₁ production, t̃₁→ b f f' χ̃⁰₁ / t̃₁→ c χ̃⁰₁ / t̃₁→ W b χ̃⁰₁ / t̃₁→ t χ̃⁰₁
Status: ICHEP 2014
ATLAS Preliminary
L_int = 20 fb⁻¹ √s=8 TeV
L_int = 4.7 fb⁻¹ √s=7 TeV
t̃₁→ t χ̃⁰₁ 0L [1406.1122] 0L [1208.1447]
t̃₁→ t χ̃⁰₁ 1L [1407.0583] 1L [1208.2590]
t̃₁→ t χ̃⁰₁ 2L [1403.4853] 2L [1209.4186]
t̃₁→ W b χ̃⁰₁ 1L [1407.0583], 2L [1403.4853] -
t̃₁→ c χ̃⁰₁ 0L [1407.0608] -
b f f' χ̃⁰₁ 0L [1407.0608], 1L [1407.0583] -
Observed limits
Expected limits
All limits at 95% CL
c χ̃⁰₁
L_int = 20.3 fb⁻¹
b f f' χ̃⁰₁
W b χ̃⁰₁
L_int = 20.3 fb⁻¹
L_int = 4.7 fb⁻¹
L_int = 20 fb⁻¹
m_χ̃⁰₁ [GeV]
m_t̃₁ [GeV]

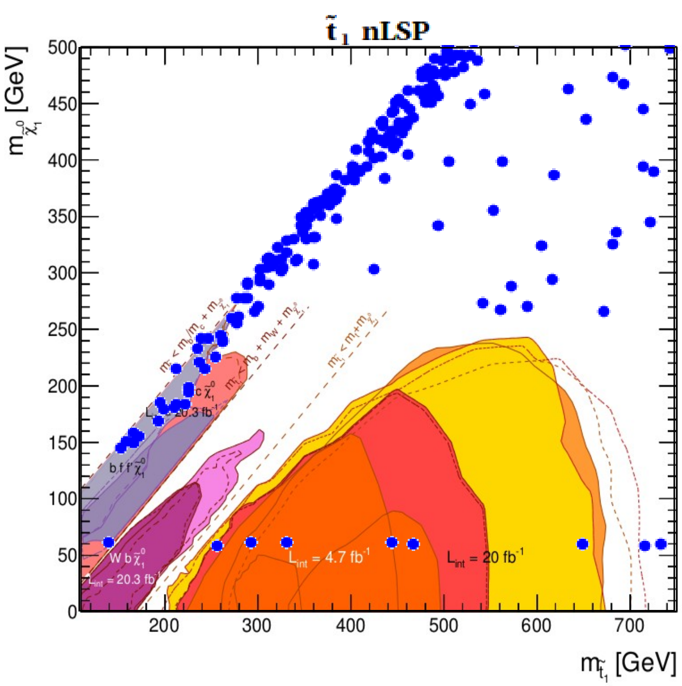


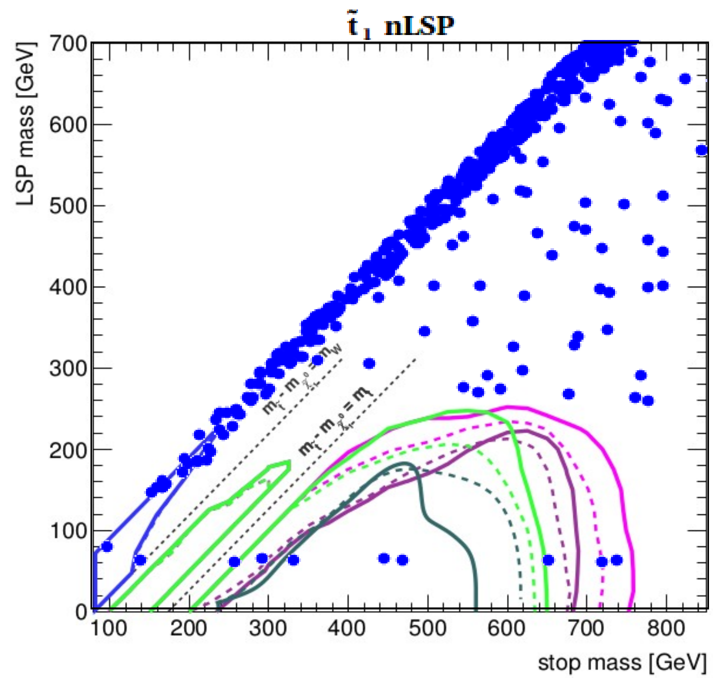
t̃-t̃ production, t̃→ t χ̃⁰₁ / c χ̃⁰₁
CMS Preliminary
√s = 8 TeV
ICHEP 2014
Observed
Expected
SUS-13-011 1-lep (MVA) 19.5 fb⁻¹
SUS-14-011 0-lep + 1-lep + 2-lep (Razor) 19.3 fb⁻¹
SUS-14-011 0-lep (Razor) + 1-lep (MVA) 19.3 fb⁻¹
SUS-13-009 (monojet stop) 19.7 fb⁻¹ (t̃→ c χ̃⁰₁)
SUS-13-015 (hadronic stop) 19.4 fb⁻¹
LSP mass [GeV]
stop mass [GeV]

LHC bounds


Status: ICHEP 2014
ATLAS Preliminary
All limits at 95% CL
Observed limits
Expected limits
m [GeV]
[GeV]


CMS Preliminary
√s = 8 TeV
ICHEP 2014
Observed
Expected
SUS-13-011 1-lep (MVA) 19.5 fb⁻¹
SUS-14-011 0-lep + 1-lep + 2-lep (Razor) 19.3 fb⁻¹
SUS-14-011 0-lep (Razor) + 1-lep (MVA) 19.3 fb⁻¹
SUS-13-009 (monojet stop) 19.7 fb⁻¹
SUS-13-015 (hadronic stop) 19.4 fb⁻¹
LSP mass [GeV]
stop mass [GeV]


nLSP
[GeV]


nLSP
LSP mass [GeV]
stop mass [GeV]

Degenerate $\tilde{t}_1$ and $\tilde{\chi}_1^0$

Degenerate $\tilde{t}_1$ and $\tilde{\chi}_1^0$

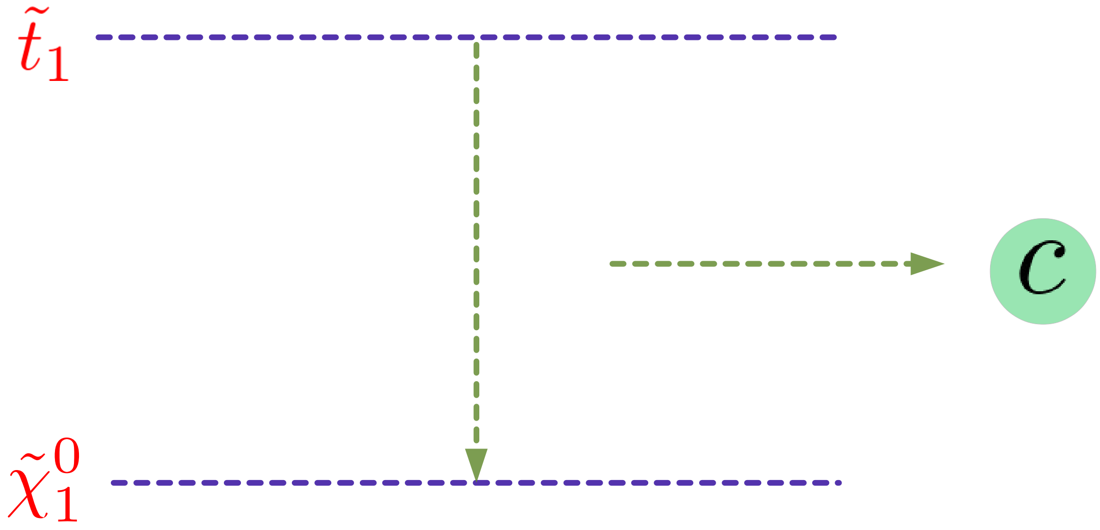
$\tilde{t}_1$

Degenerate $\tilde{t}_1$ and $\tilde{\chi}_1^0$

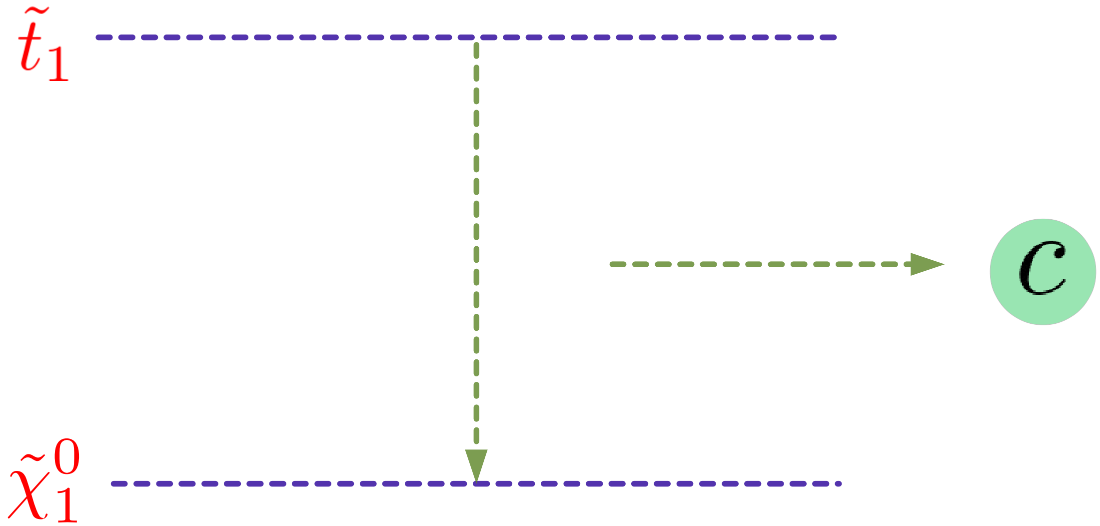
$\tilde{t}_1$

$\tilde{\chi}_1^0$

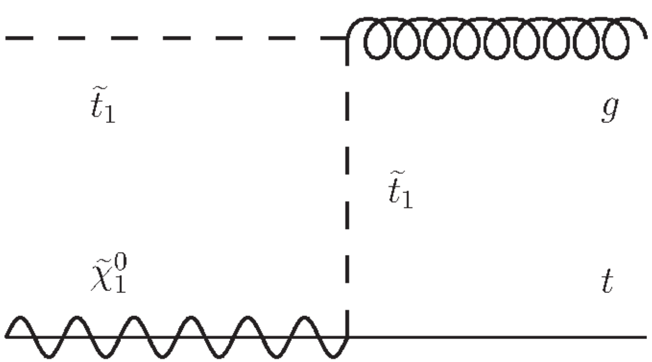
Degenerate $\tilde{t}_1$ and $\tilde{\chi}_1^0$



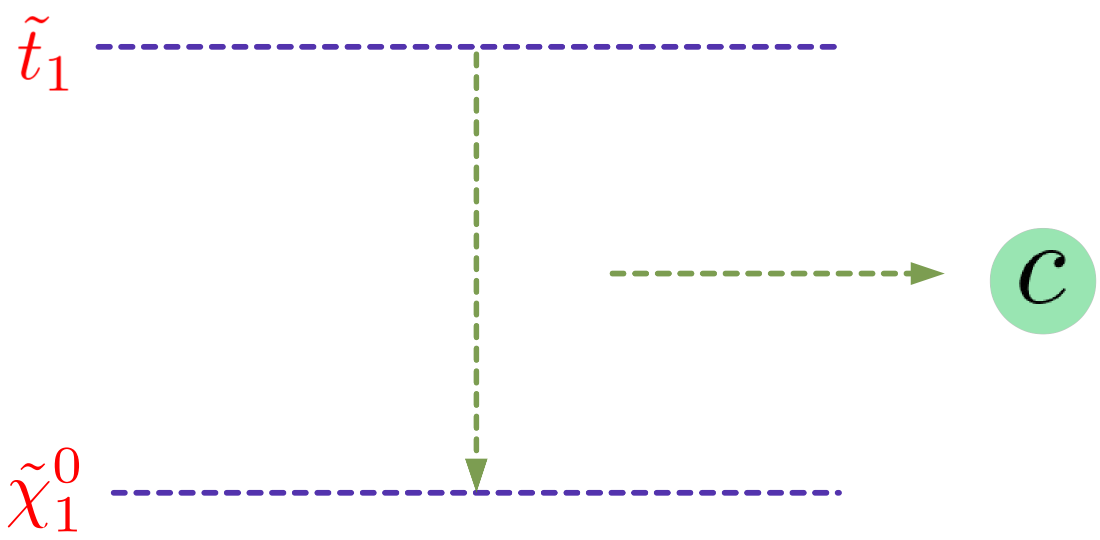
Degenerate $\tilde{t}_1$ and $\tilde{\chi}_1^0$

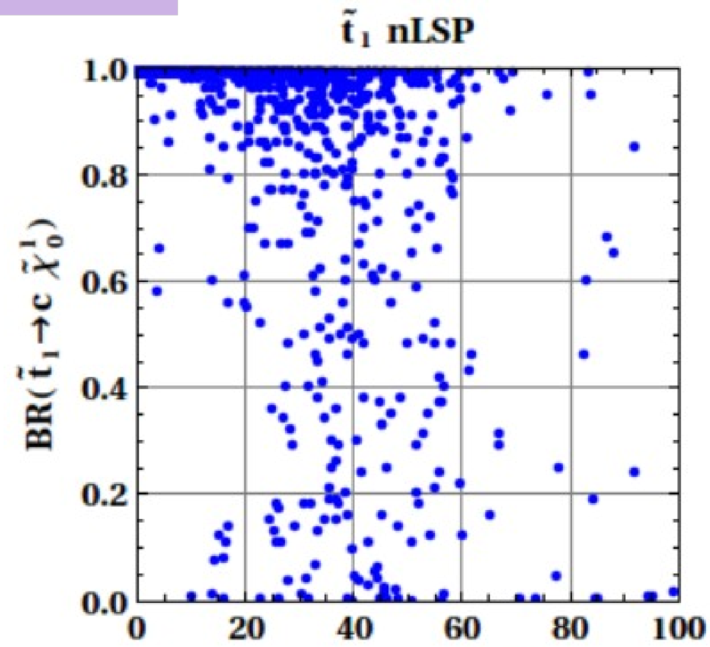


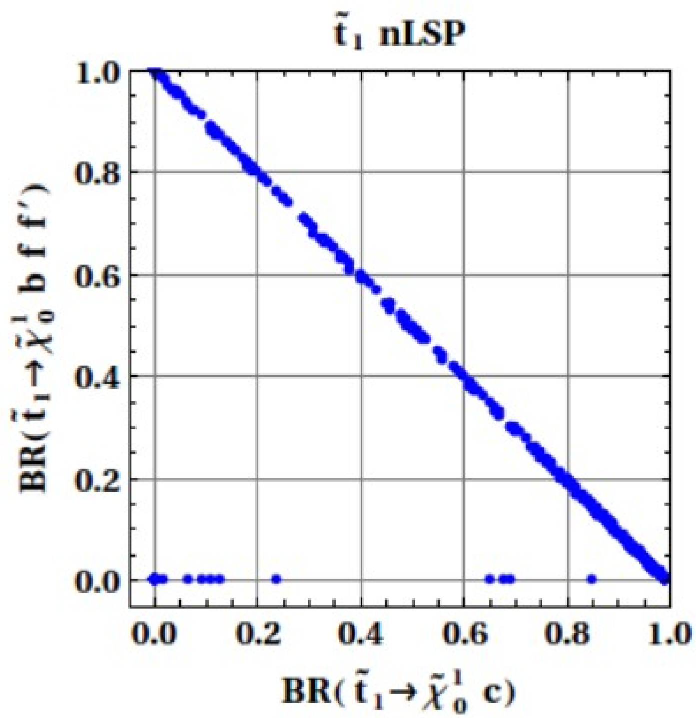
Coannihilation



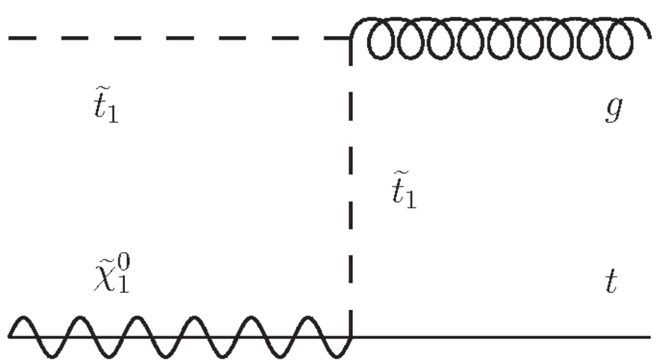
Degenerate $\tilde{t}_1$ and $\tilde{\chi}_1^0$



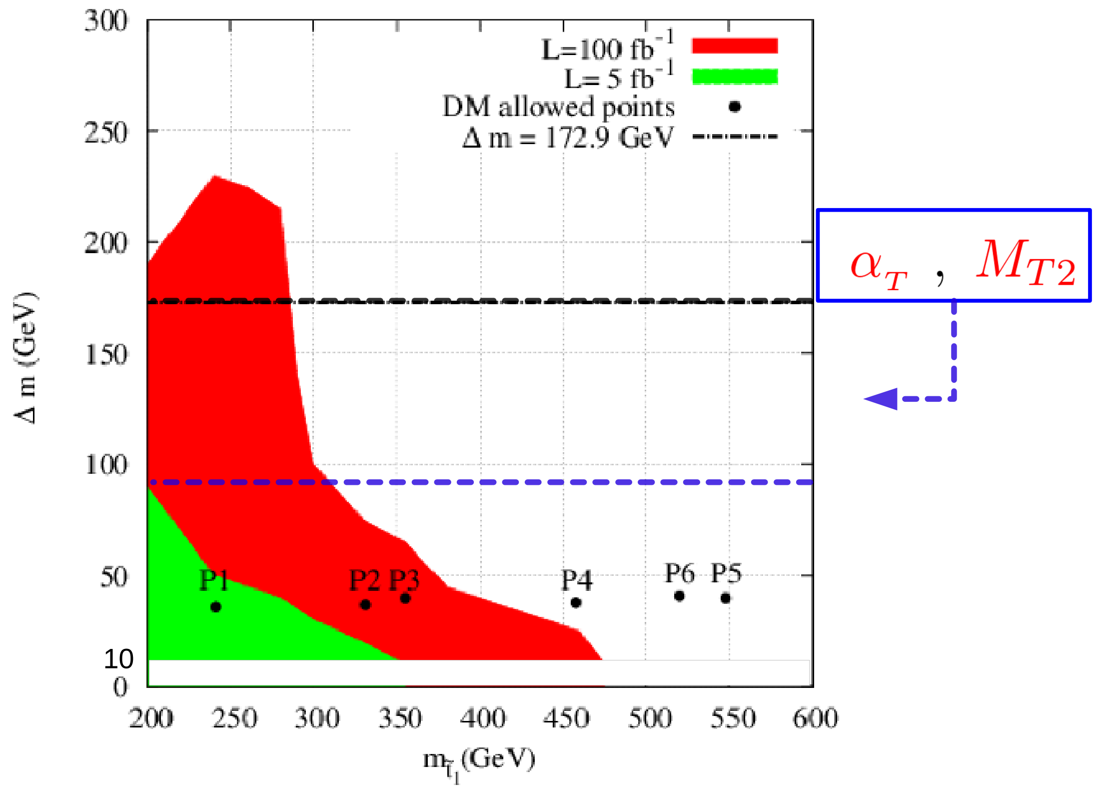


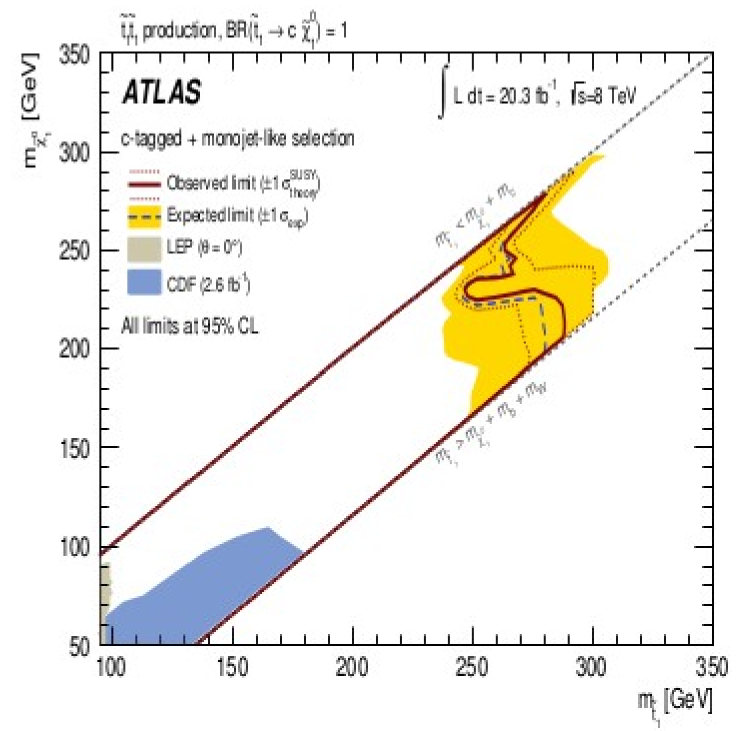


Coannihilation



LHC14 projections

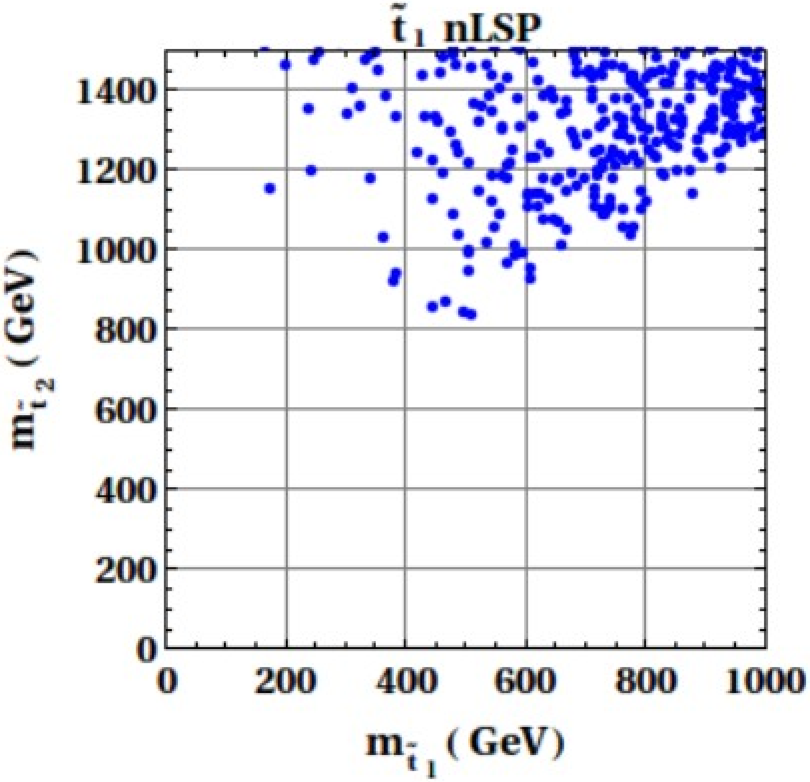


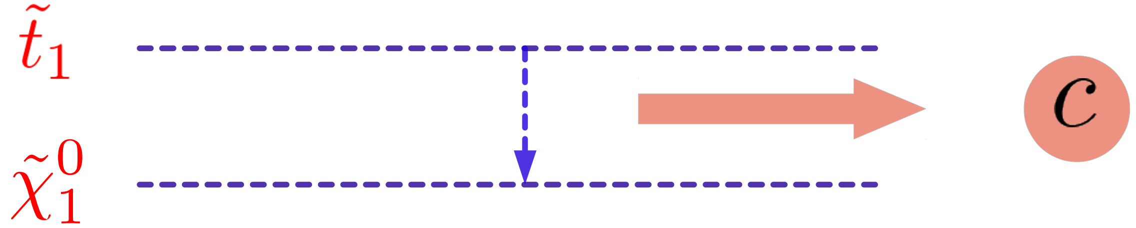


	P1	P2	P3	P4	P5	P6
$m_{\tilde{t}_1}, m_{\tilde{\chi}_1^0}$ (GeV)	241, 205	331, 294	355, 315	458, 420	548, 508	520, 479
Ωh^2	0.119	0.119	0.119	0.119	0.119	0.119
Δm (GeV)	36	37	40	38	40	41

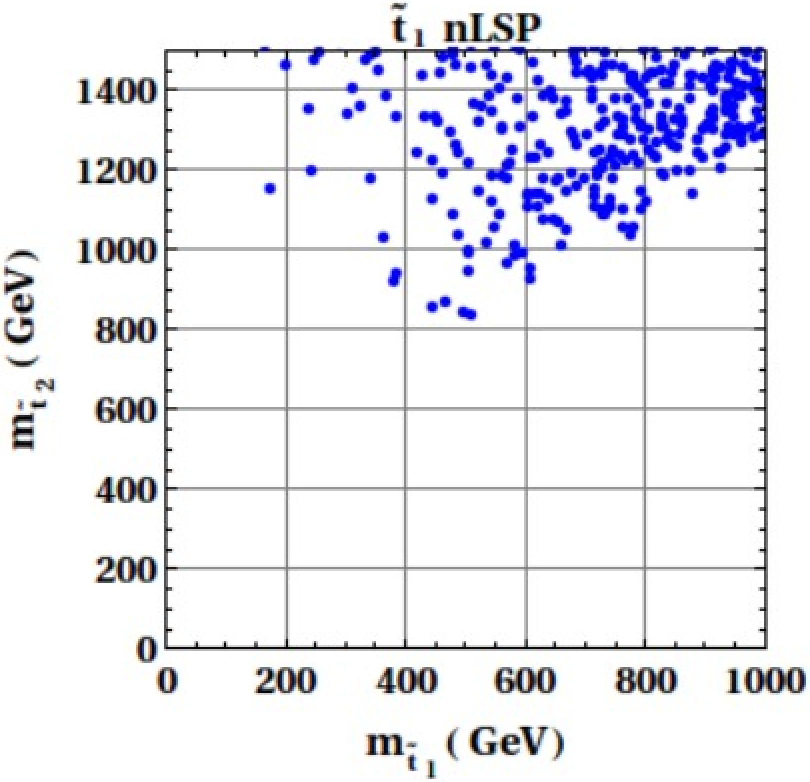
Belanger, DG, Godbole, Guchait, Sengupta
Phys.Rev. D89 (2014) 015003

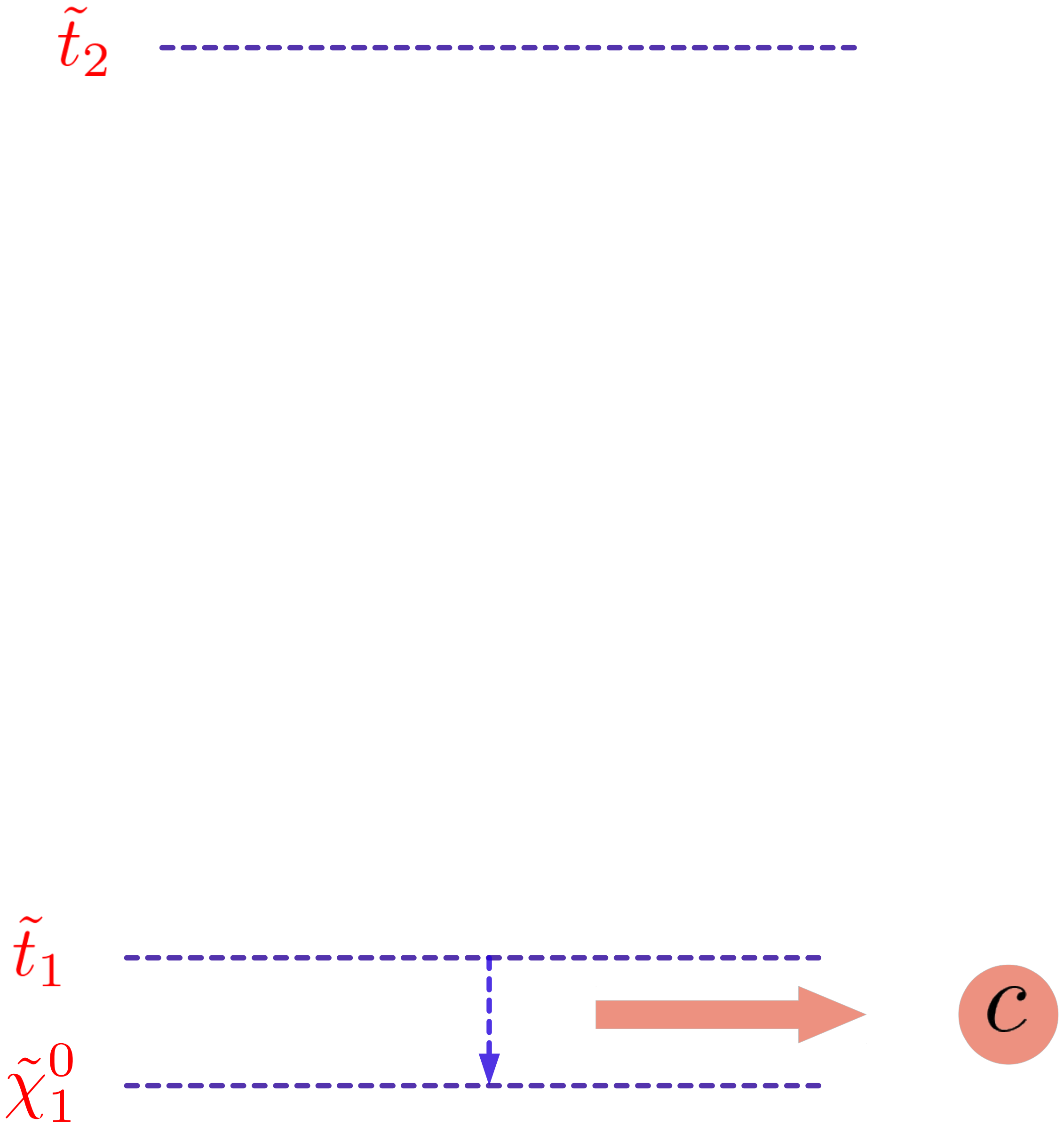
Where is $\widetilde{t}_2$



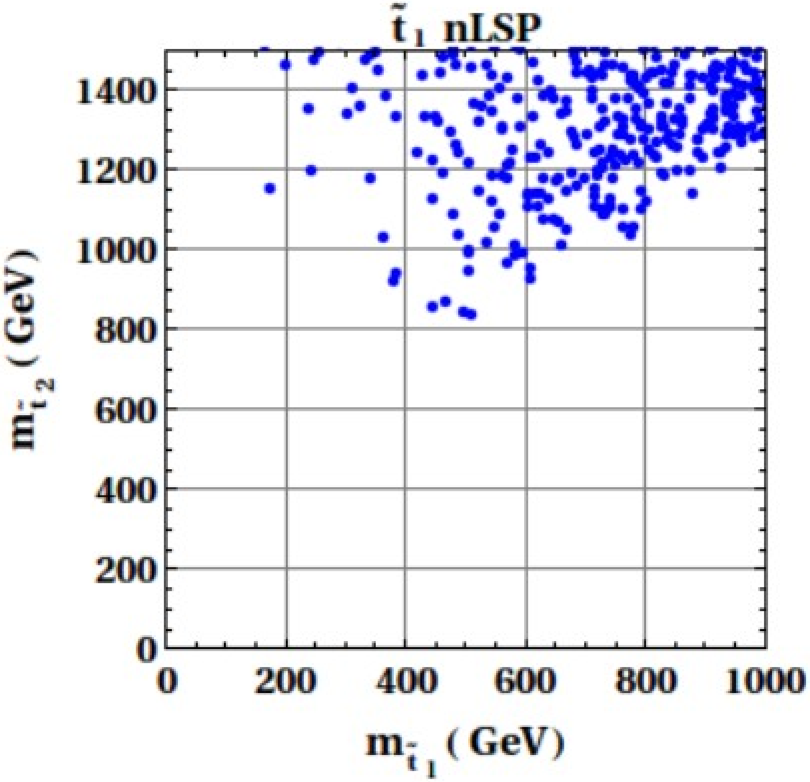


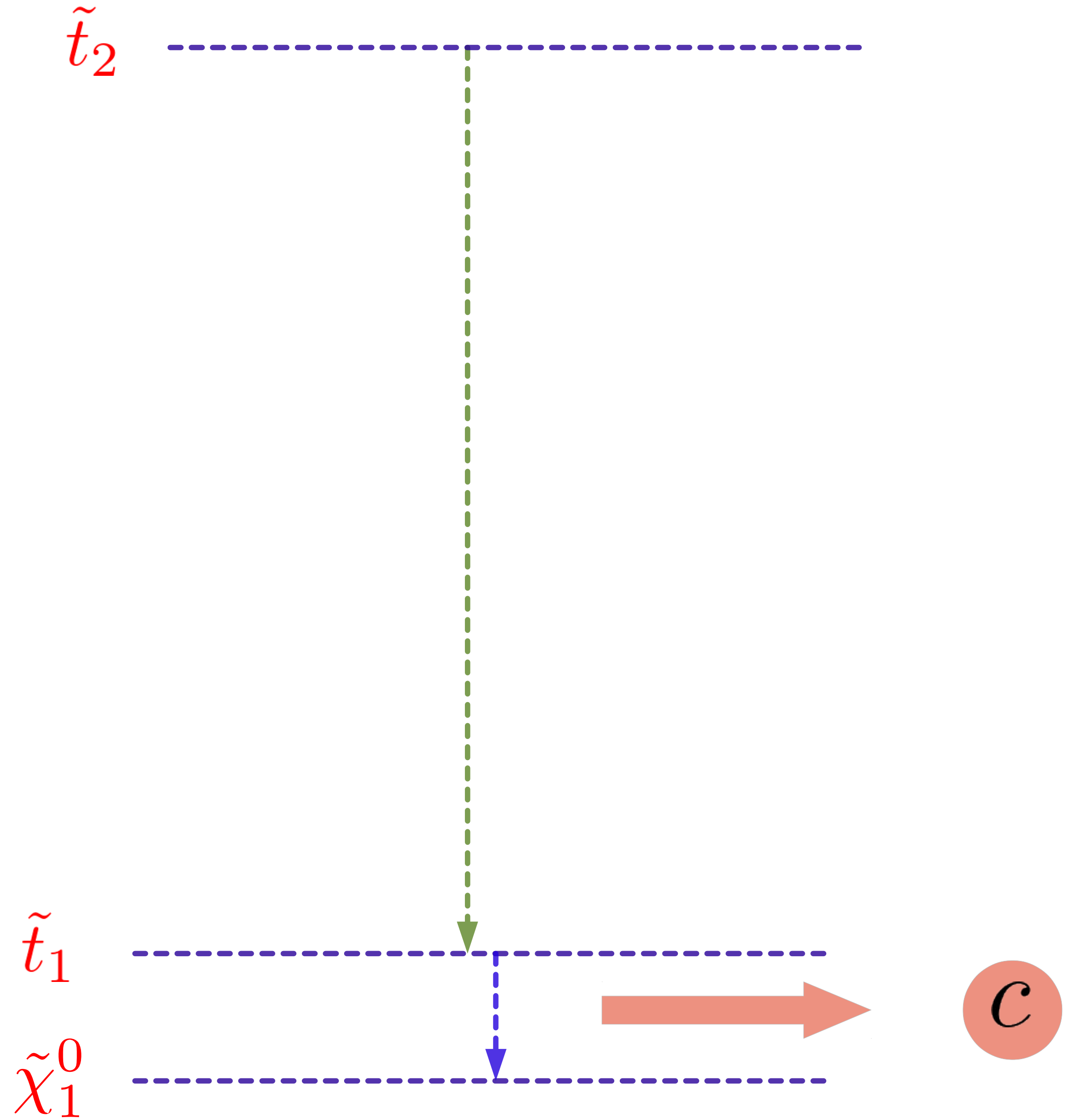
Where is $\tilde{t}_2$



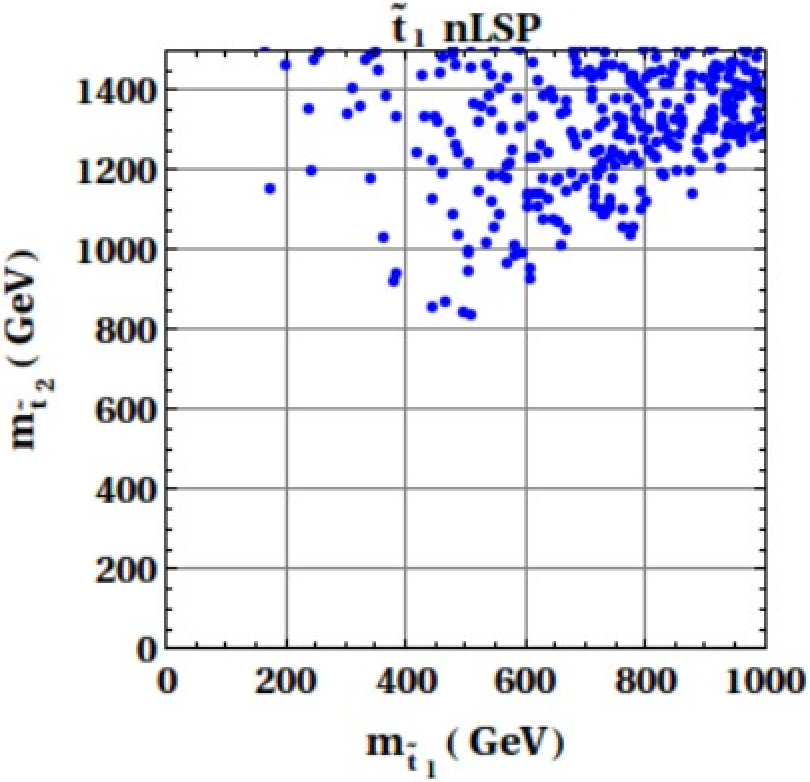


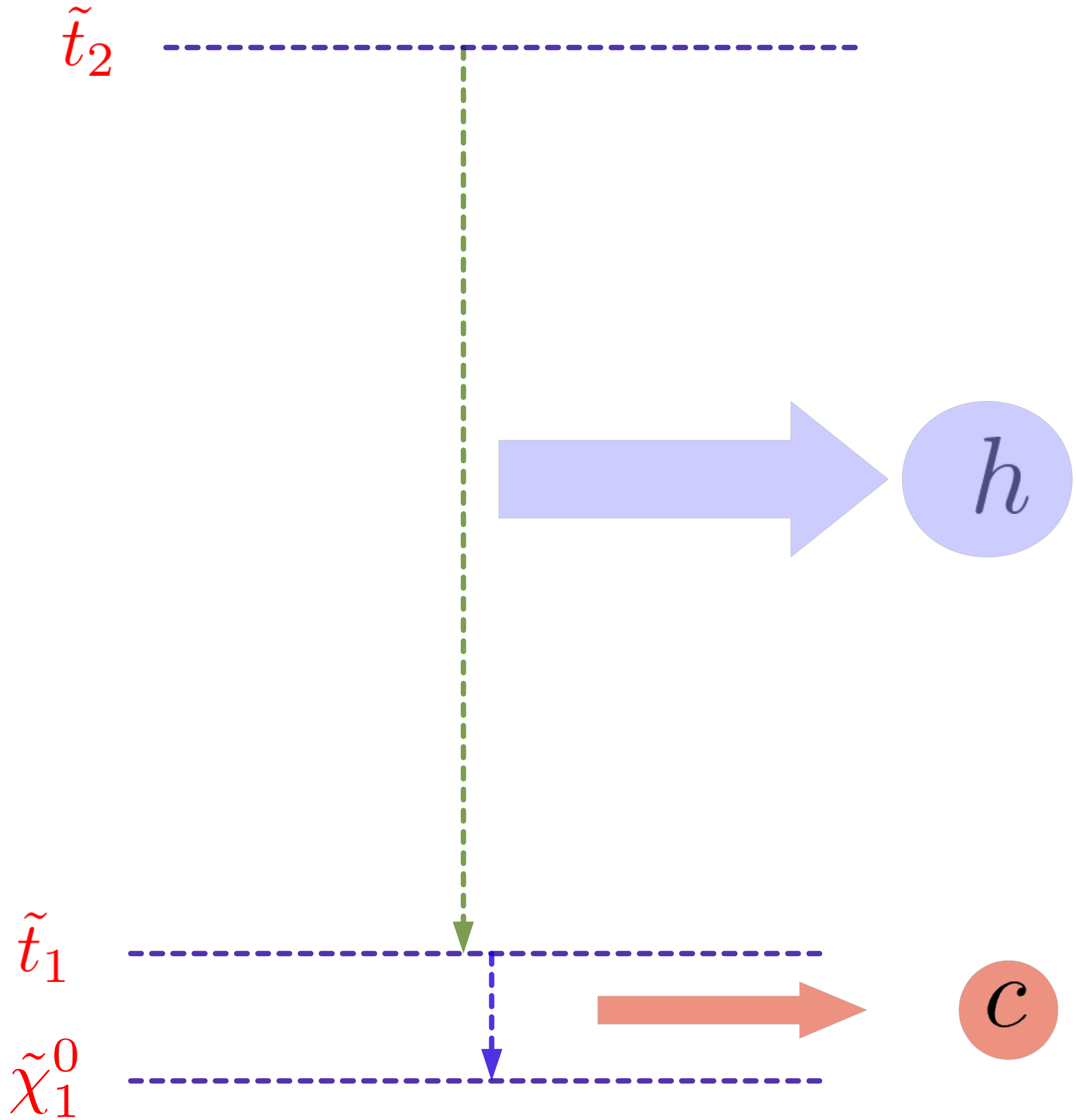
Where is $\widetilde{t}_2$



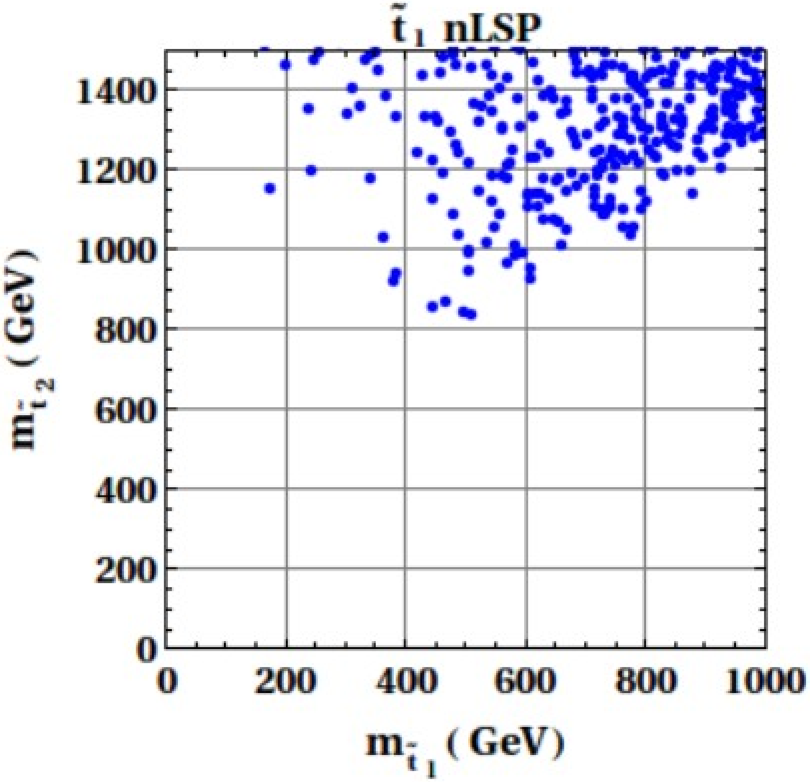


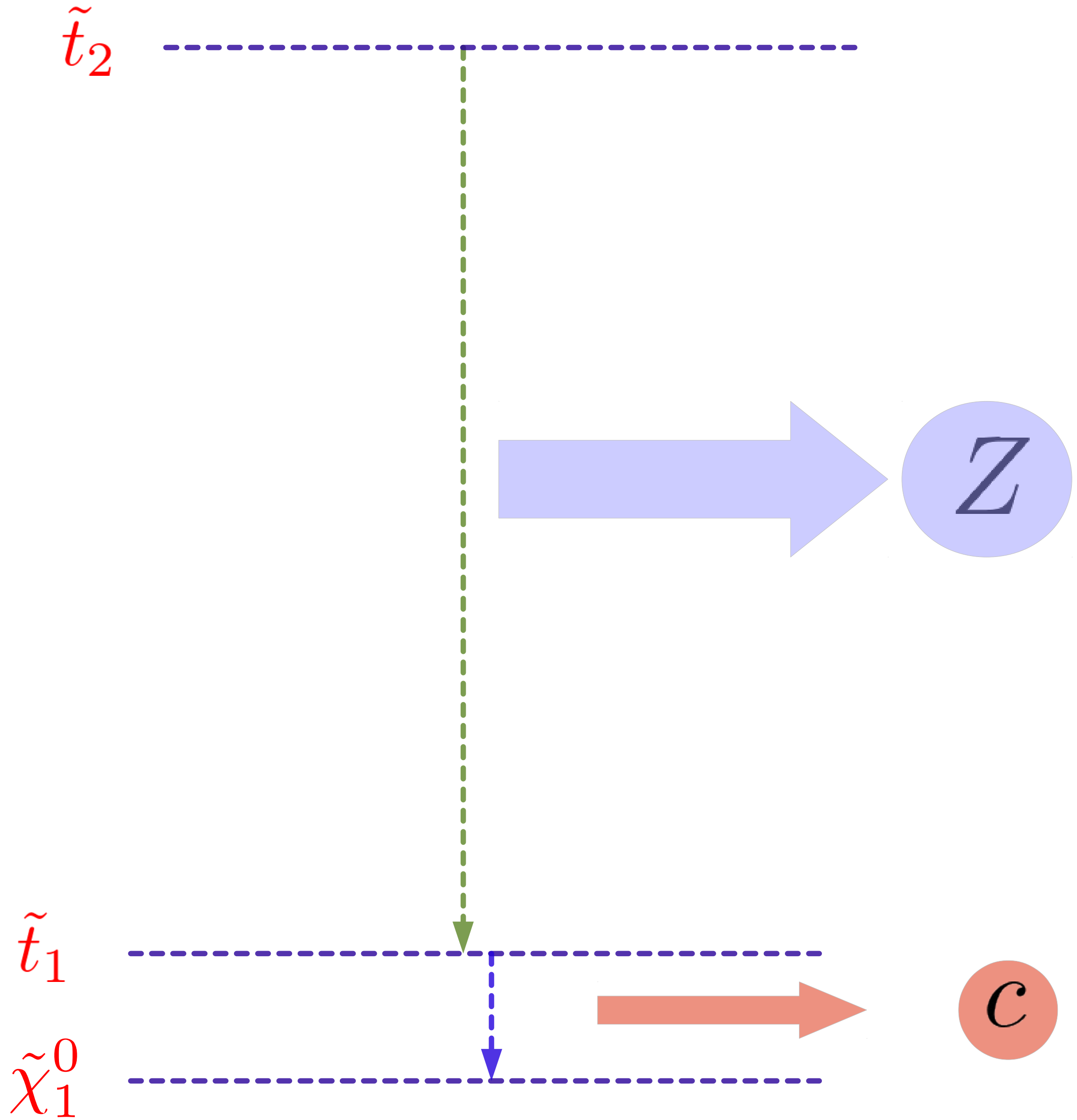
Where is $\tilde{t}_2$





Where is $\widetilde{t}_2$





Branching Ratios

DG, PRD 2013

$$\lambda_{\tilde{t}_2\tilde{t}_1 h} \quad \propto \quad 2(\sqrt{2}G_F)^{\frac{1}{2}} M_Z^2 \ \times$$

$$\left[(\frac{2}{3}\sin^2\theta_W - \frac{1}{4})\cos(2\beta)\ \sin(2\theta_t) + \frac{1}{2}\frac{m_t}{M_Z^2}\cos(2\theta_t)\ X_t \right]$$

$$\lambda_{\tilde{t}_2\tilde{t}_1 Z} \approx \frac{g}{2M_W} m_t X_t$$

$$m^2_{\tilde{t}_{1,2}} = m_t^2 + \frac{1}{2}\left[m^2_{LL} + m^2_{RR} \mp \sqrt{(m^2_{LL} - m^2_{RR})^2 + 4m_t^2 X_t^2} \right]$$

$$\sin 2\theta_t = \frac{2m_t X_t}{m^2_{\tilde{t}_1} - m^2_{\tilde{t}_2}} \quad , \quad \cos 2\theta_t = \frac{m^2_{LL} - m^2_{RR}}{m^2_{\tilde{t}_1} - m^2_{\tilde{t}_2}}$$

$$M^2_{\tilde{t}} = \begin{pmatrix} m^2_{LL} & m_t X_t \\ m_t X_t & m^2_{RR} \end{pmatrix}$$

Branching Ratios

DG, PRD 2013

$$\lambda_{\tilde{t}_2\tilde{t}_1 h} \quad \propto \quad 2(\sqrt{2}G_F)^{\frac{1}{2}} M_Z^2 \ \times$$

$$\left[(\frac{2}{3}\sin^2\theta_W - \frac{1}{4}) \cos(2\beta)\ \sin(2\theta_t) + \frac{1}{2}\frac{m_t}{M_Z^2} \cos(2\theta_t)\ X_t \right]$$

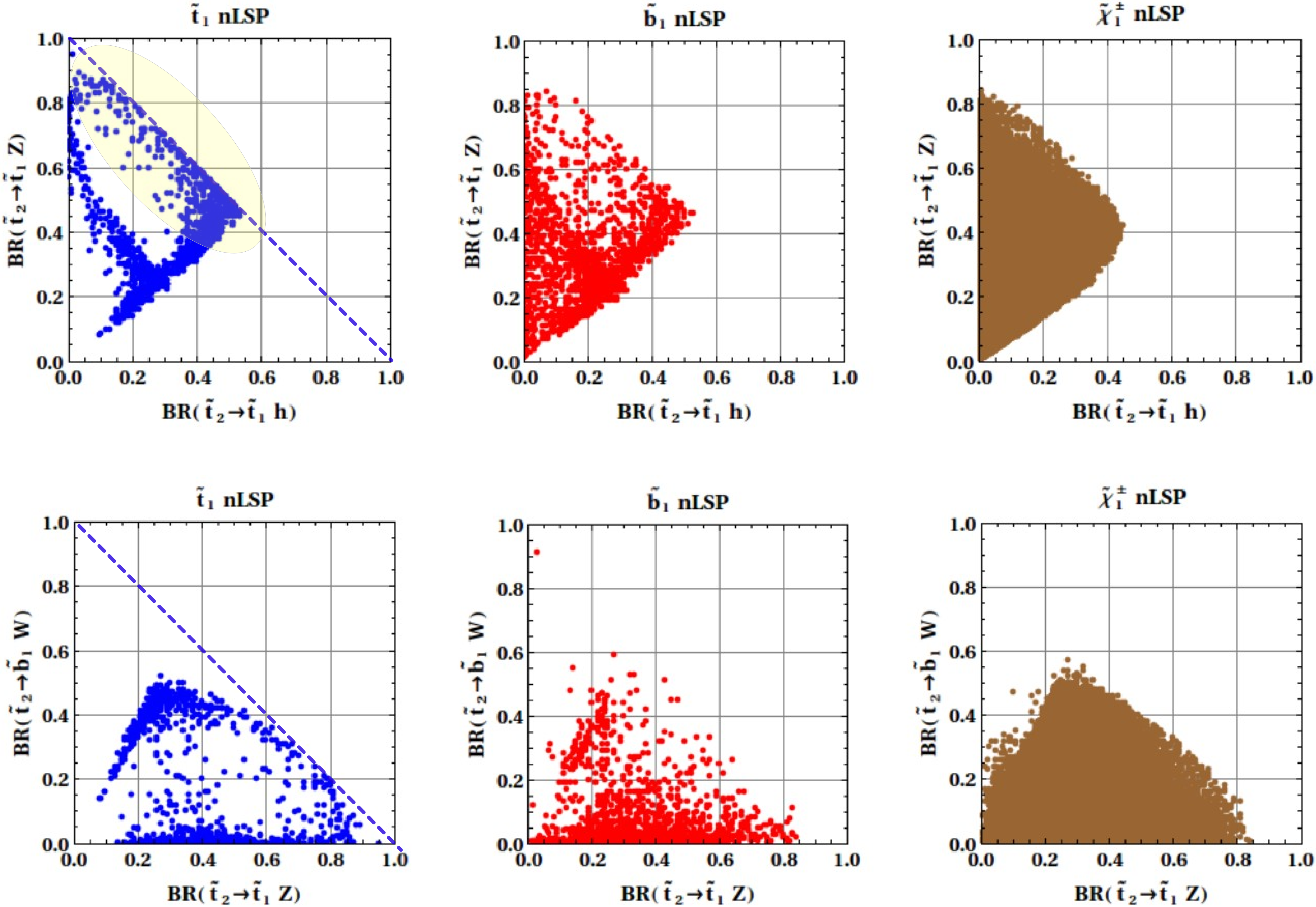
$$\lambda_{\tilde{t}_2\tilde{t}_1 Z} \approx \frac{g}{2M_W} m_t X_t$$

Higgs mass → Large $\mathrm{Br}(\tilde{t}_2 \to \tilde{t}_1 Z/h)$

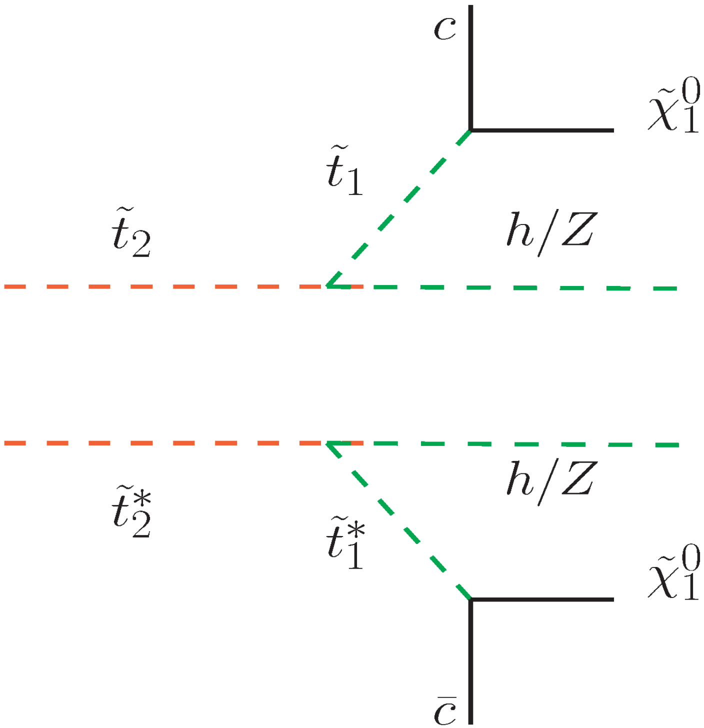
$$m^2_{\tilde{t}_{1,2}} = m_t^2 + \frac{1}{2}\left[m^2_{LL} + m^2_{RR} \mp \sqrt{(m^2_{LL} - m^2_{RR})^2 + 4m_t^2 X_t^2} \right]$$

$$\sin 2\theta_t = \frac{2m_t X_t}{m^2_{\tilde{t}_1} - m^2_{\tilde{t}_2}} \quad , \quad \cos 2\theta_t = \frac{m^2_{LL} - m^2_{RR}}{m^2_{\tilde{t}_1} - m^2_{\tilde{t}_2}}$$

$$M^2_{\tilde{t}} = \begin{pmatrix} m^2_{LL} & m_t X_t \\ m_t X_t & m^2_{RR} \end{pmatrix}$$



$\tilde{t}_1$ nLSP
$\tilde{b}_1$ nLSP
$\tilde{\chi}_1^\pm$ nLSP
BR($\tilde{t}_2 \to \tilde{t}_1$ Z)
BR($\tilde{t}_2 \to \tilde{t}_1$ h)
$\tilde{t}_1$ nLSP
$\tilde{b}_1$ nLSP
$\tilde{\chi}_1^\pm$ nLSP
BR($\tilde{t}_2 \to \tilde{b}_1$ W)
BR($\tilde{t}_2 \to \tilde{t}_1$ Z)



DG, PRD 2013

Model:1		Model:2	
pMSSM inputs	Masses	pMSSM inputs	Masses
$M_1 = 300$	$m_{\tilde{t}_2} = 1005$	$M_1 = 410$	$m_{\tilde{t}_2} = 1003$
$M_2 = 650$	$m_{\tilde{t}_1} = 334$	$M_2 = 850$	$m_{\tilde{t}_1} = 434$
$M_3 = 2100$	$m_{\tilde{\chi}_1^0} = 300$	$M_3 = 2600$	$m_{\tilde{\chi}_1^0} = 411$
$\mu = 2000$	$m_{\tilde{\chi}_2^0} = 676$	$\mu = 2000$	$m_{\tilde{\chi}_2^0} = 884$
$m_A = 1500$	$m_{\tilde{\chi}_1^\pm} = 676$	$m_A = 1500$	$m_{\tilde{\chi}_1^\pm} = 884$
$\tan\beta = 10$	$m_h = 125$	$\tan\beta = 7.5$	$m_h = 125$
$m_{Q3} = 1010$		$m_{Q3} = 1050$	
$m_{t_R} = 630$		$m_{t_R} = 770$	
$m_{b_R} = 3000$		$m_{b_R} = 3000$	
$A_t = -1700$		$A_t = -1600$	
$\mathcal{B}(\tilde{t}_2 \to \tilde{t}_1\, Z) = 52\%$ $\mathcal{B}(\tilde{t}_2 \to \tilde{t}_1\, h) = 39\%$ $\mathcal{B}(\tilde{t}_1 \to c\, \tilde{\chi}_1^0) = 82\%$		$\mathcal{B}(\tilde{t}_2 \to \tilde{t}_1\, Z) = 56\%$ $\mathcal{B}(\tilde{t}_2 \to \tilde{t}_1\, h) = 41\%$ $\mathcal{B}(\tilde{t}_1 \to c\, \tilde{\chi}_1^0) = 90\%$	

Final State

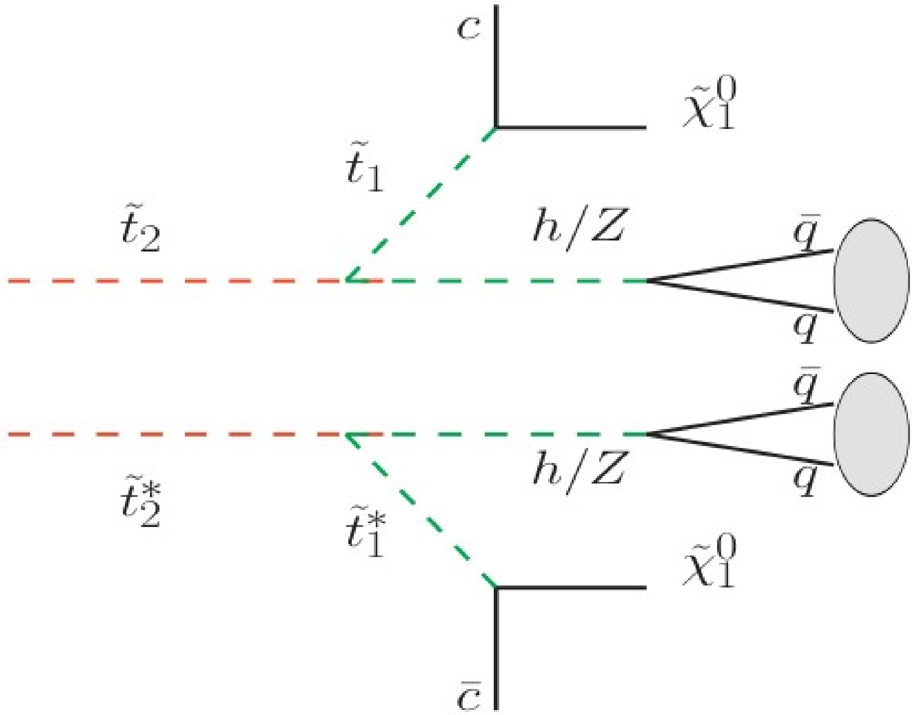
$$\mathrm{pp} \rightarrow \widetilde{\mathrm{t}}_2\, \widetilde{\mathrm{t}}_2^* \rightarrow \widetilde{\mathrm{t}}_1\, \widetilde{\mathrm{t}}_1^*\, \mathrm{Z}\, \mathrm{Z} \rightarrow Z\, Z\, \widetilde{\chi}_1^0\, \widetilde{\chi}_1^0\, c\, \bar{c}$$
$$\hookrightarrow Z\, Z\; + \not{p}_T + \text{soft jets}$$

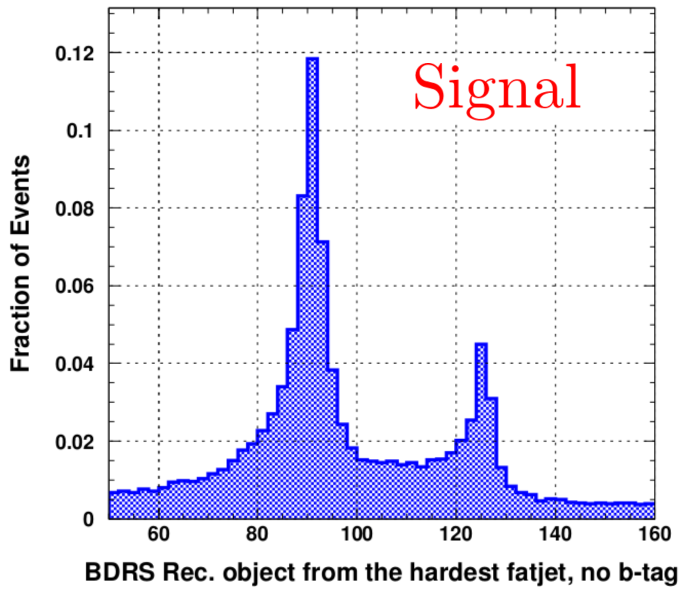
$$\mathrm{pp} \rightarrow \widetilde{\mathrm{t}}_2\, \widetilde{\mathrm{t}}_2^* \rightarrow \widetilde{\mathrm{t}}_1\, \widetilde{\mathrm{t}}_1^*\, \mathrm{Z}\, \mathrm{h} \rightarrow Z\, h\, \widetilde{\chi}_1^0\, \widetilde{\chi}_1^0\, c\, \bar{c}$$
$$\hookrightarrow Z\, h\; + \not{p}_T + \text{soft jets}$$

$$\mathrm{pp} \rightarrow \widetilde{\mathrm{t}}_2\, \widetilde{\mathrm{t}}_2^* \rightarrow \widetilde{\mathrm{t}}_1\, \widetilde{\mathrm{t}}_1^*\, \mathrm{h}\, \mathrm{h} \rightarrow h\, h\, \widetilde{\chi}_1^0\, \widetilde{\chi}_1^0\, c\, \bar{c}$$
$$\hookrightarrow h\, h\; + \not{p}_T + \text{soft jets}$$

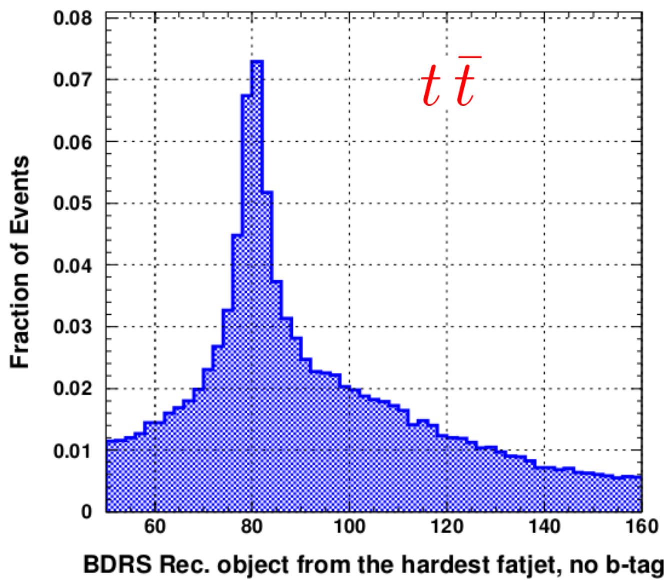
Final State

$$
\begin{aligned}
\mathrm{pp} &\rightarrow \widetilde{\mathrm{t}}_2\,\widetilde{\mathrm{t}}_2^* \rightarrow \widetilde{\mathrm{t}}_1\,\widetilde{\mathrm{t}}_1^*\,\mathrm{Z}\,\mathrm{Z} \rightarrow Z\,Z\,\widetilde{\chi}_1^0\,\widetilde{\chi}_1^0\,c\,\bar{c} \\
&\hookrightarrow Z\,Z + \not{p}_T + \text{soft jets} \\
\mathrm{pp} &\rightarrow \widetilde{\mathrm{t}}_2\,\widetilde{\mathrm{t}}_2^* \rightarrow \widetilde{\mathrm{t}}_1\,\widetilde{\mathrm{t}}_1^*\,\mathrm{Z}\,\mathrm{h} \rightarrow Z\,h\,\widetilde{\chi}_1^0\,\widetilde{\chi}_1^0\,c\,\bar{c} \\
&\hookrightarrow Z\,h + \not{p}_T + \text{soft jets} \\
\mathrm{pp} &\rightarrow \widetilde{\mathrm{t}}_2\,\widetilde{\mathrm{t}}_2^* \rightarrow \widetilde{\mathrm{t}}_1\,\widetilde{\mathrm{t}}_1^*\,\mathrm{h}\,\mathrm{h} \rightarrow h\,h\,\widetilde{\chi}_1^0\,\widetilde{\chi}_1^0\,c\,\bar{c} \\
&\hookrightarrow h\,h + \not{p}_T + \text{soft jets}
\end{aligned}
$$

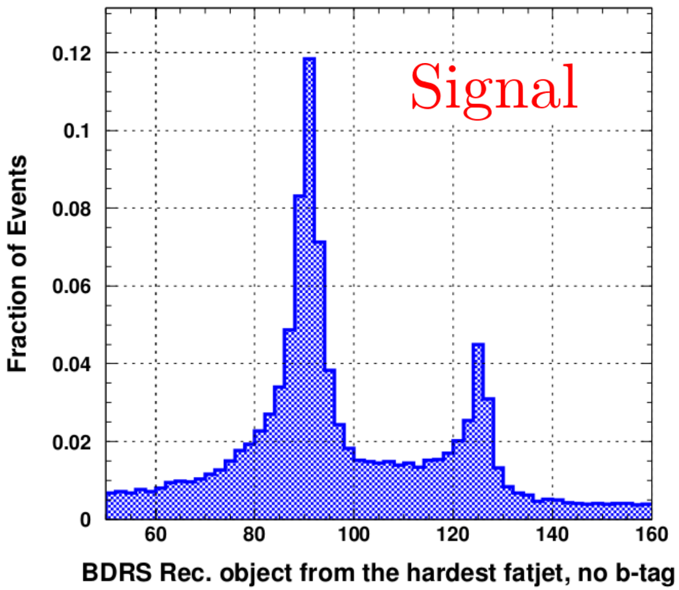



Signal
Fraction of Events
0.12
0.1
0.08
0.06
0.04
0.02
0
60
80
100
120
140
160
BDRS Rec. object from the hardest fatjet, no b-tag

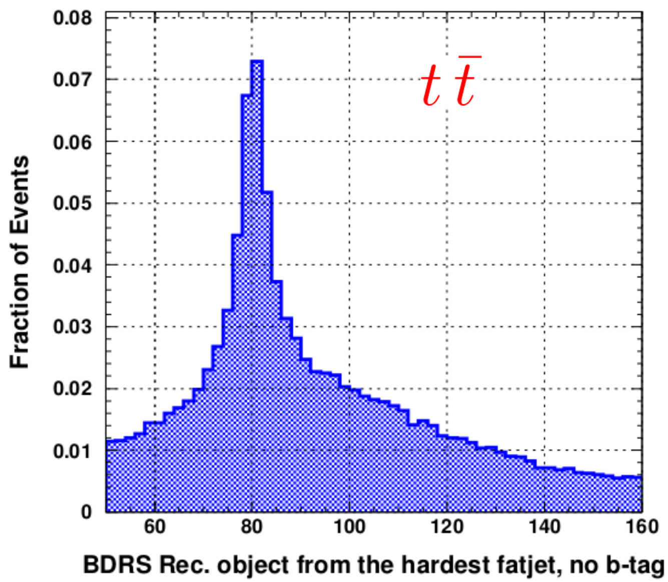
BDRS, R=1.0

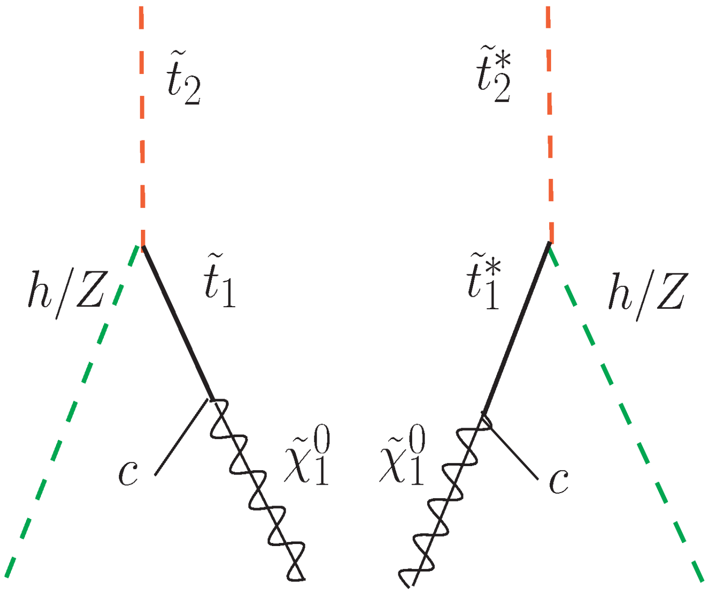

$t\,\bar{t}$
Fraction of Events
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
60
80
100
120
140
160
BDRS Rec. object from the hardest fatjet, no b-tag

DG, PRD 2013

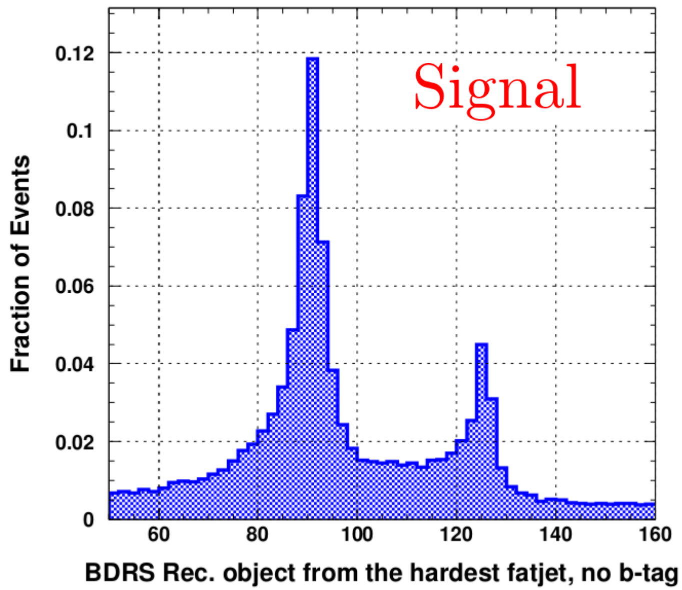


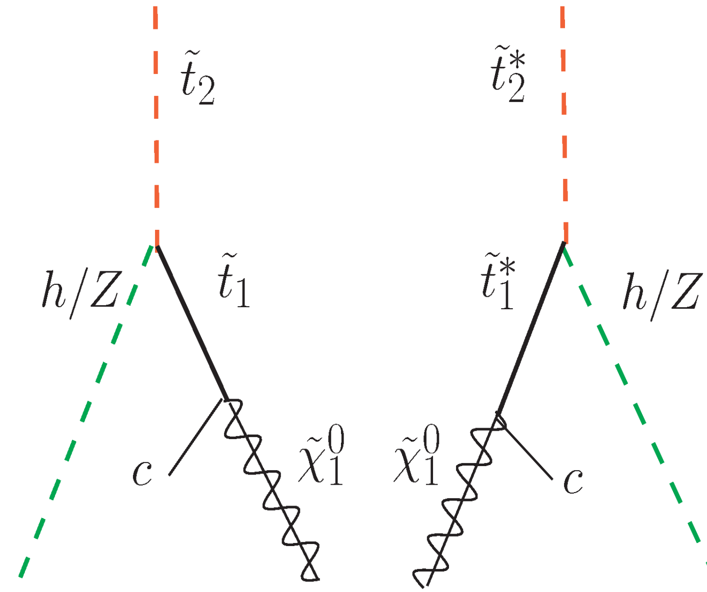
BDRS, R=1.0



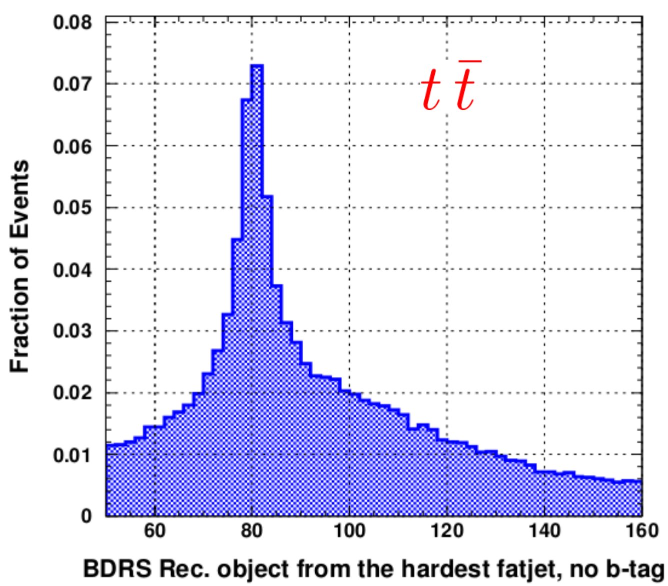


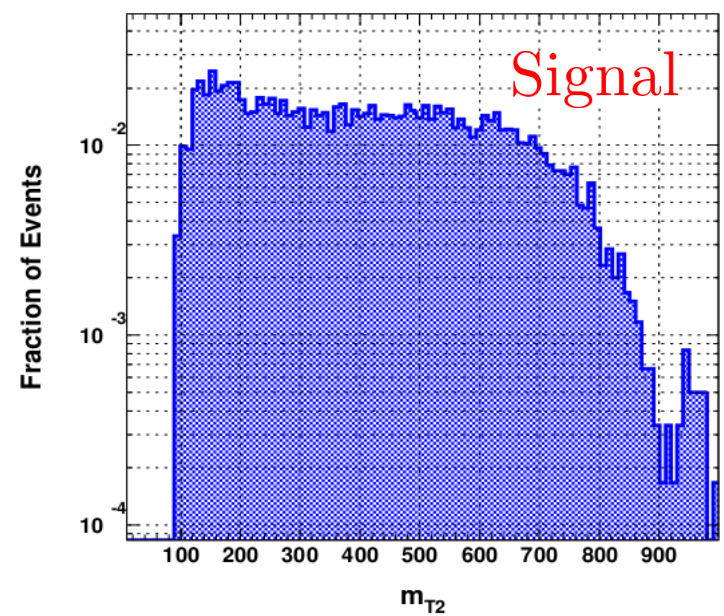
DG, PRD 2013





BDRS, R=1.0





Results

			No. of events after							
Process	Production cross-section	Simulated events	S1	S2	S3	S4	S5	S6	Final cross-section (fb)	$\mathcal{S}$ (100 fb^{-1})
Signal										
Model:1	10 fb	10^5	6012	4902	2736	2359	2143	1718	17.2×10^{-2}	4.3
Model:2	10 fb	10^5	6170	5319	2813	2421	2081	1853	18.5×10^{-2}	4.6
Backgrounds										
$t\bar{t}$	833 pb	10^8	221747	148580	142	41	26	11	9.1×10^{-2}	
$t\bar{t}Z\,(1j)$	1.12 pb	226110	2484	1444	8	7	1	1	0.5×10^{-2}	
$t\bar{t}W^{\pm}\,(1j)$	770 fb	276807	1365	787	5	3	3	2	0.5×10^{-2}	
$t\bar{t}h\,(1j)$	700 fb	231064	1893	1027	2	2	2	2	0.6×10^{-2}	
$t/\bar{t}\,W^{\pm}\,(1j)$	64 pb	6518431	7596	5801	13	9	3	3	2.9×10^{-2}	
$P_1\,P_2\,P_3(1j)$ $(P_i \in W\,Z\,h)$	500 fb	313350	1475	1093	10	5	4	2	0.3×10^{-2}	
$P_1\,P_2 + 1j/2j$ $(P_i \in Z\,h)$	5.5 pb	738779	2927	2646	3	3	3	3	2.2×10^{-2}	
Total Background									16.1×10^{-2}	

$\not{p}_T$ M_{T2}

$h\,h/h\,Z/Z\,Z$

DG, PRD 2013

PHYSICAL REVIEW D **88,** 115013 (2013)

Boosted dibosons from mixed heavy top squarks

Diptimoy Ghosh*

INFN, Sezione di Roma, Piazzale A. Moro 2, I-00185 Roma, Italy and Fermilab, P.O. Box 500, Batavia, Illinois 60510, USA

(Received 14 August 2013; published 19 December 2013)

The lighter mass eigenstate ($\tilde{t}_1$) of the two top squarks, the scalar superpartners of the top quark, is extremely difficult to discover if it is almost degenerate with the lightest neutralino ($\tilde{\chi}_1^0$), the lightest stable supersymmetric particle in the R-parity conserving supersymmetry. The current experimental bound on $\tilde{t}_1$ mass in this scenario stands only around 200 GeV. For such a light $\tilde{t}_1$, the heavier top squark ($\tilde{t}_2$) can also be around the TeV scale. Moreover, the high value of the Higgs (h) mass prefers the left- and right-handed top squarks to be highly mixed, allowing the possibility of a considerable branching ratio for $\tilde{t}_2 \longrightarrow \tilde{t}_1 h$ and $\tilde{t}_2 \longrightarrow \tilde{t}_1 Z$. In this paper, we explore the above possibility together with the pair production of $\tilde{t}_2\, \tilde{t}_2^*$, giving rise to the spectacular diboson + missing transverse energy final state. For an approximately 1 TeV $\tilde{t}_2$ and a few hundred GeV $\tilde{t}_1$ the final state particles can be moderately boosted, which encourages us to propose a novel search strategy employing the jet substructure technique to tag the boosted h and Z. The reconstruction of the h and Z momenta also allows us to construct the stransverse mass M_{T2}, providing an additional efficient handle to fight the backgrounds. We show that a 4–5σ signal can be observed at the 14 TeV LHC for $\sim$1 TeV $\tilde{t}_2$ with 100 fb^{-1} integrated luminosity.

Thank you very much!

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Phys.Rev. D88 (2013) 115013, arXiv:1308.0320

Thank you very much!

Additional Material

M_{T2}

Let us define m_T first : Consider the decay $A \to B\,\tilde{\chi}$

$$m_A^2 = m_B^2 + m_{\tilde{\chi}}^2 + 2(E_{TA}E_{T\tilde{\chi}}\cosh(\Delta\eta) - \mathbf{p}_{TB}\cdot\mathbf{p}_{T\tilde{\chi}})$$

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

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

$\cosh(\Delta\eta) \geq 1$

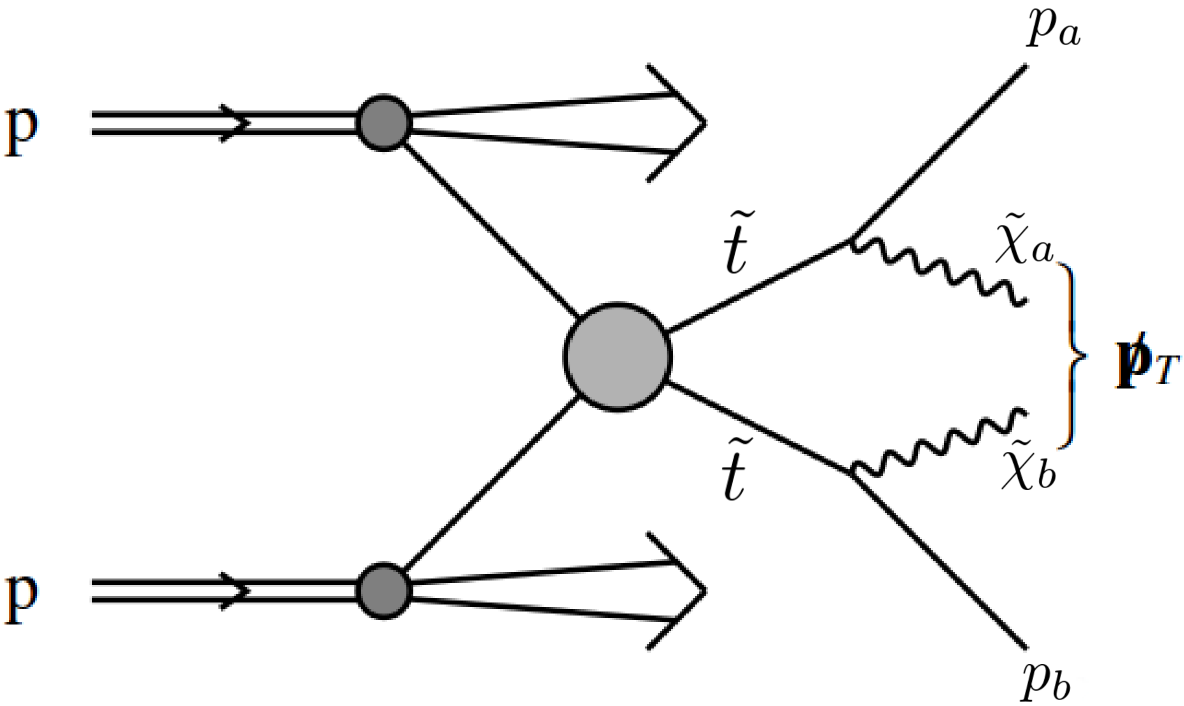
$$m_A^2 \geq m_B^2 + m_{\tilde{\chi}}^2 + 2(E_{TA}E_{T\tilde{\chi}} - \mathbf{p}_{TB}\cdot\mathbf{p}_{T\tilde{\chi}})$$

$$m_A \geq \sqrt{m_B^2 + m_{\tilde{\chi}}^2 + 2(E_{TA}E_{T\tilde{\chi}} - \mathbf{p}_{TB}\cdot\mathbf{p}_{T\tilde{\chi}})}$$

$$m_T(\mathbf{p}_{TB}, \mathbf{p}_{T\tilde{\chi}})$$ for given m_B, $m_{\tilde{\chi}}$

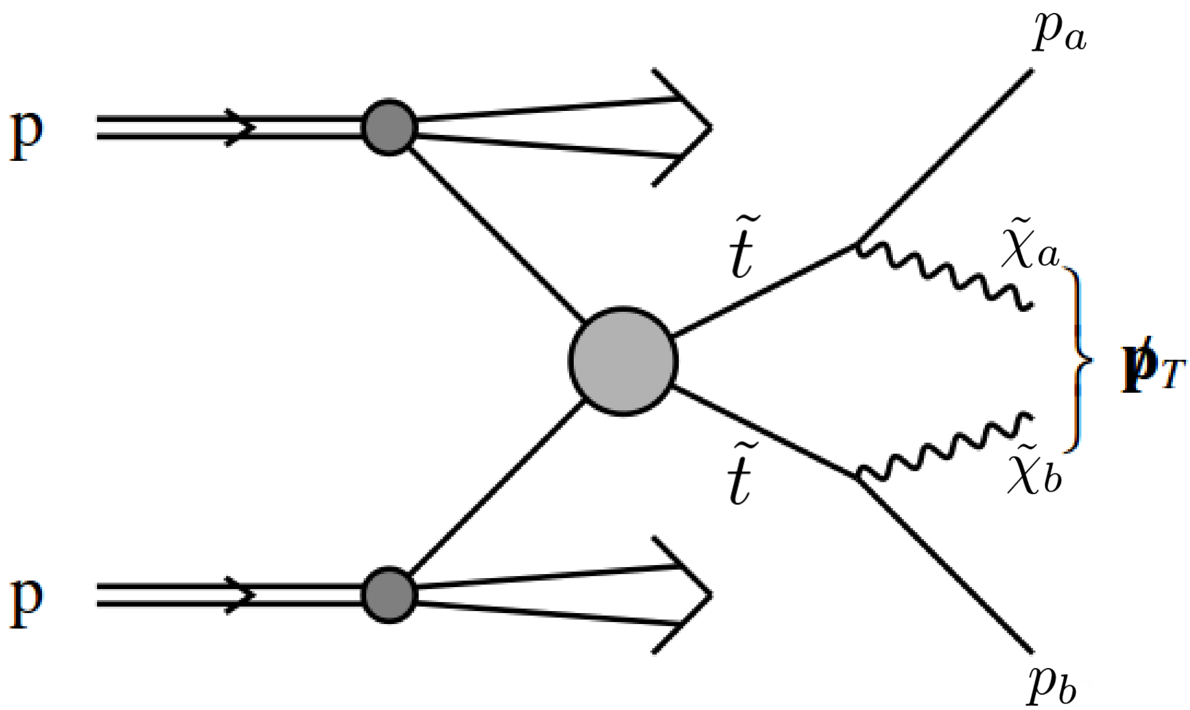
Now consider a decay with two sources of missing energy :

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



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

Now consider a decay with two sources of missing energy :

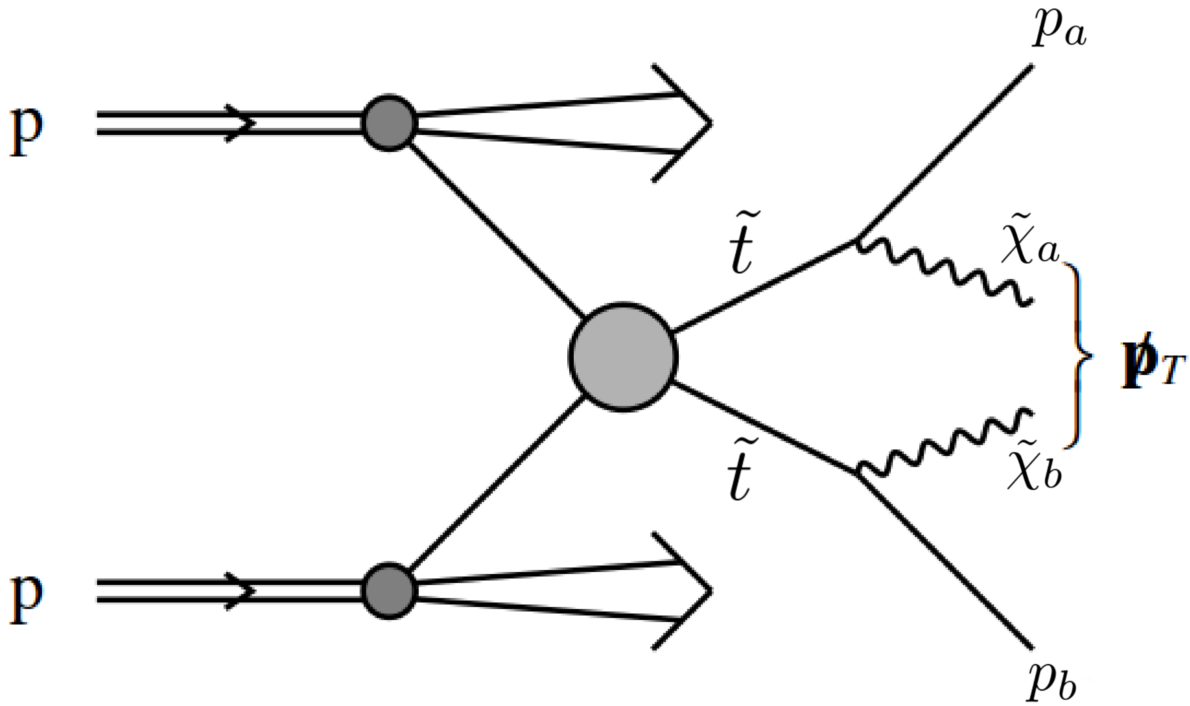


C. G. Lester and D. J. Summers, 1999

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

$$m_{\tilde{t}} \geq \qquad m_T(\mathbf{p}_{Ta}, \mathbf{p}_{T\tilde{\chi}_a})$$

Now consider a decay with two sources of missing energy :

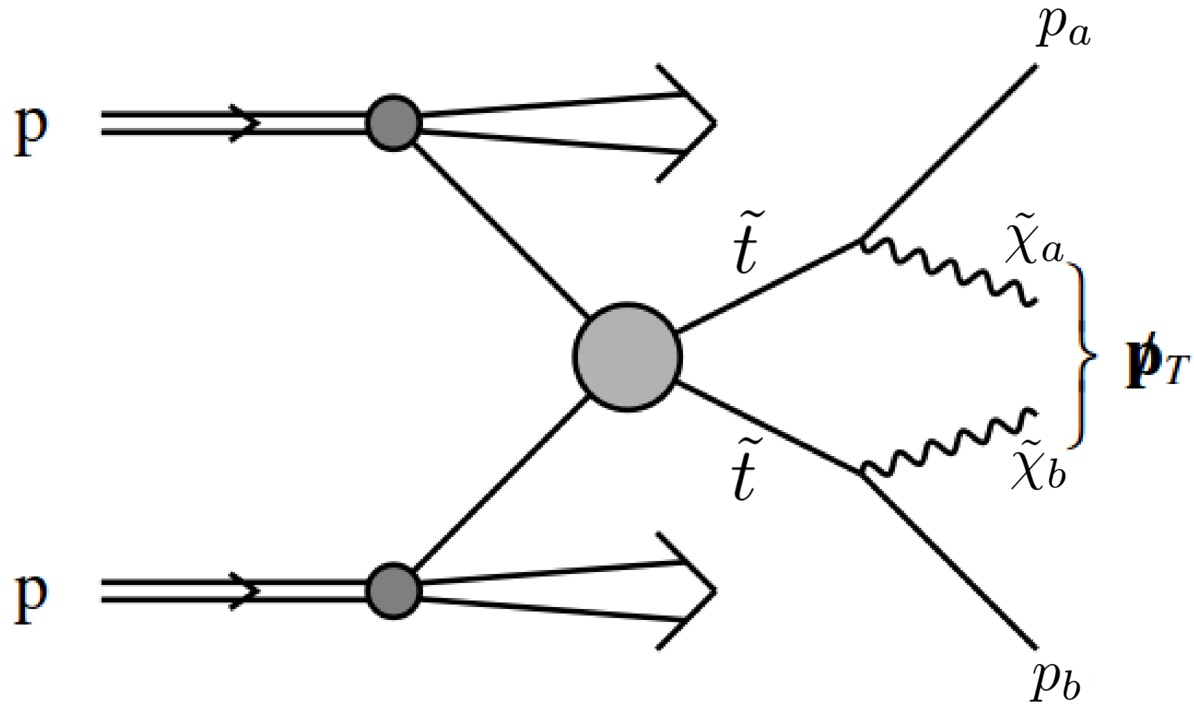


C. G. Lester and D. J. Summers, 1999

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

$$m_{\tilde{t}} \geq \qquad \{m_T(\mathbf{p}_{Ta}, \mathbf{p}_{T\tilde{\chi}_a}), m_T(\mathbf{p}_{Tb}, \mathbf{p}_{T\tilde{\chi}_b})\}$$

Now consider a decay with two sources of missing energy :



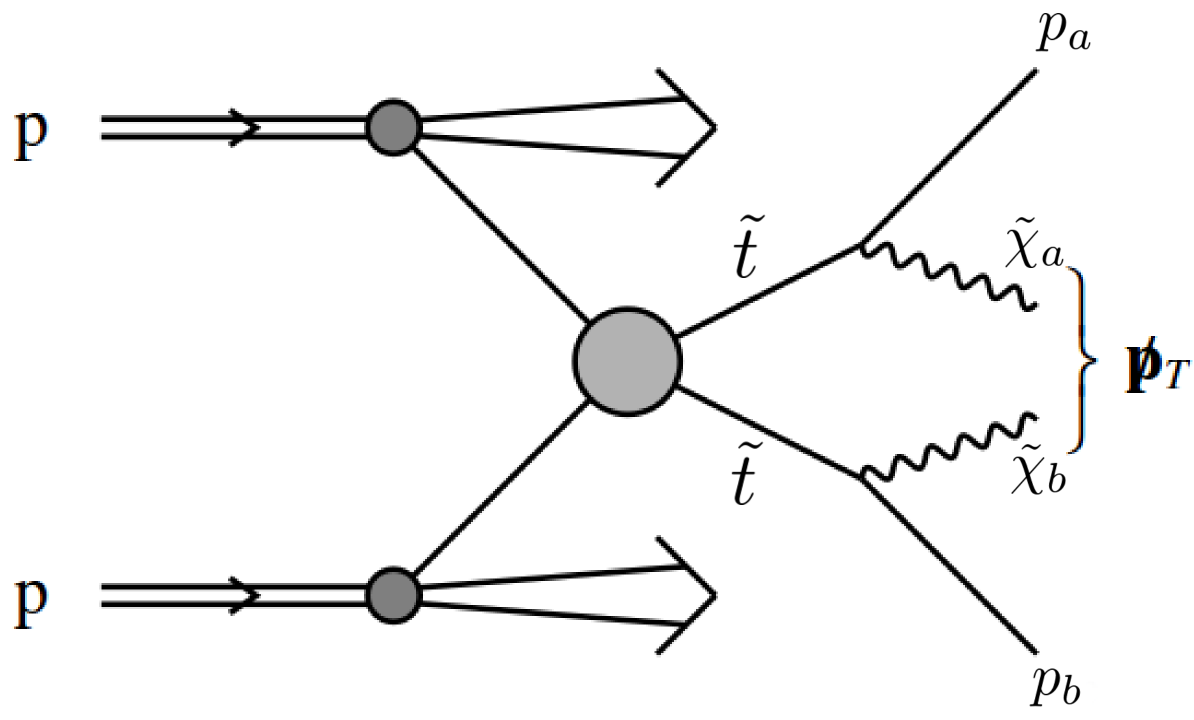
C. G. Lester and D. J. Summers, 1999

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

$$m_{\tilde{t}} \geq \max\{m_T(\mathbf{p}_{Ta}, \mathbf{p}_{T\tilde{\chi}_a}), m_T(\mathbf{p}_{Tb}, \mathbf{p}_{T\tilde{\chi}_b})\}$$

Now consider a decay with two sources of missing energy :

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

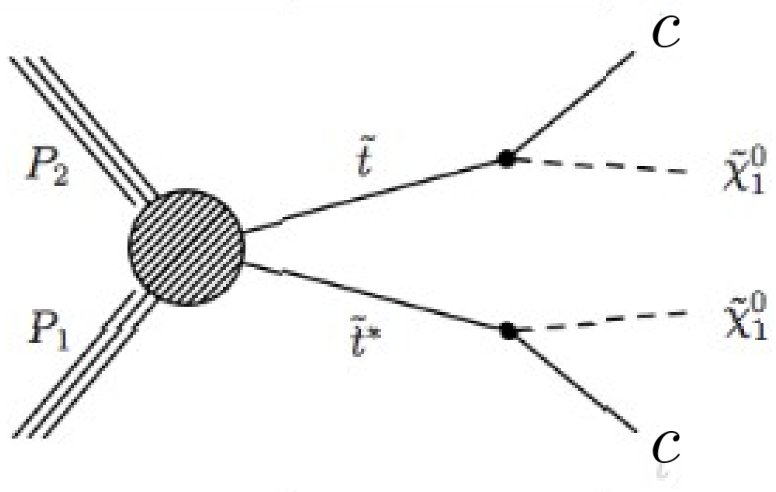


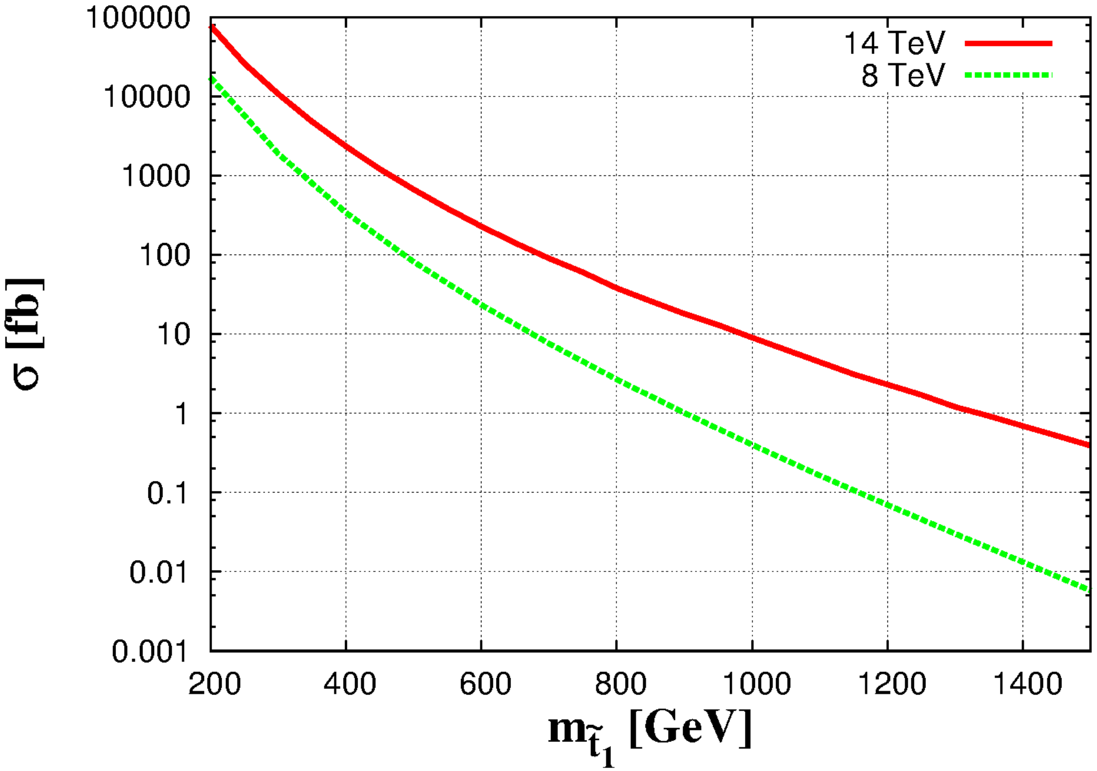
$$\not{\mathbf{p}}_T = \mathbf{p}_{T\tilde{\chi}_a} + \mathbf{p}_{T\tilde{\chi}_b}$$

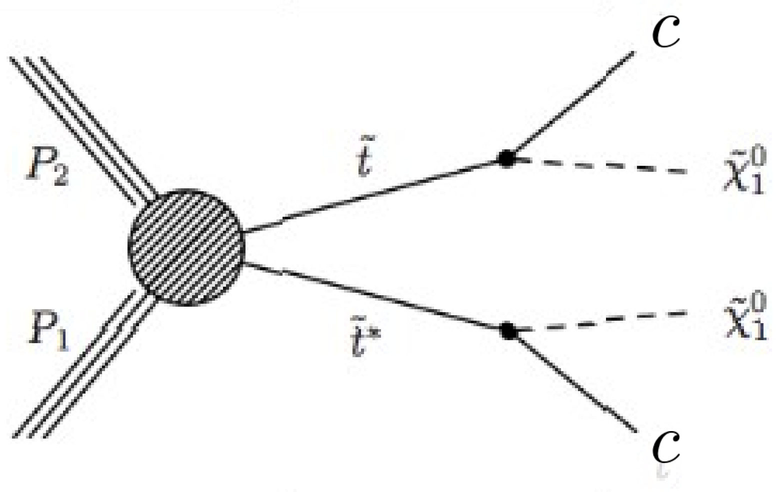
$$m_{\tilde{t}} \geq \max\{m_T(\mathbf{p}_{Ta}, \mathbf{p}_{T\tilde{\chi}_a}), m_T(\mathbf{p}_{Tb}, \mathbf{p}_{T\tilde{\chi}_b})\}$$

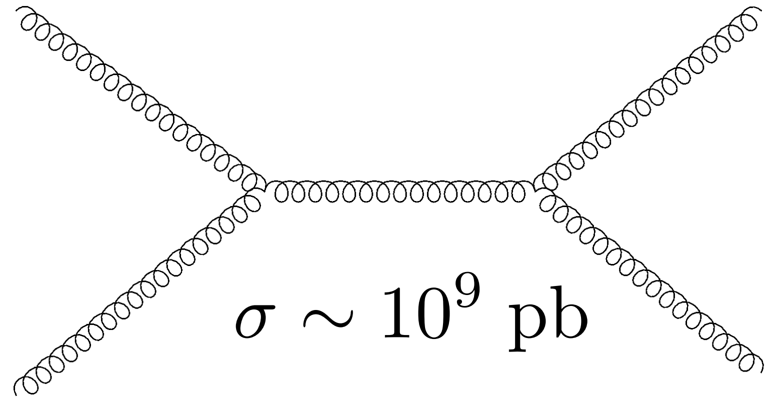
$$m_{\tilde{t}} \geq \min_{\not{\mathbf{p}}_T = \not{\mathbf{p}}_{T1} + \not{\mathbf{p}}_{T2}} \left[\max\{m_T(\mathbf{p}_{Ta}, \not{\mathbf{p}}_{T1}), m_T(\mathbf{p}_{Tb}, \not{\mathbf{p}}_{T2})\} \right]$$

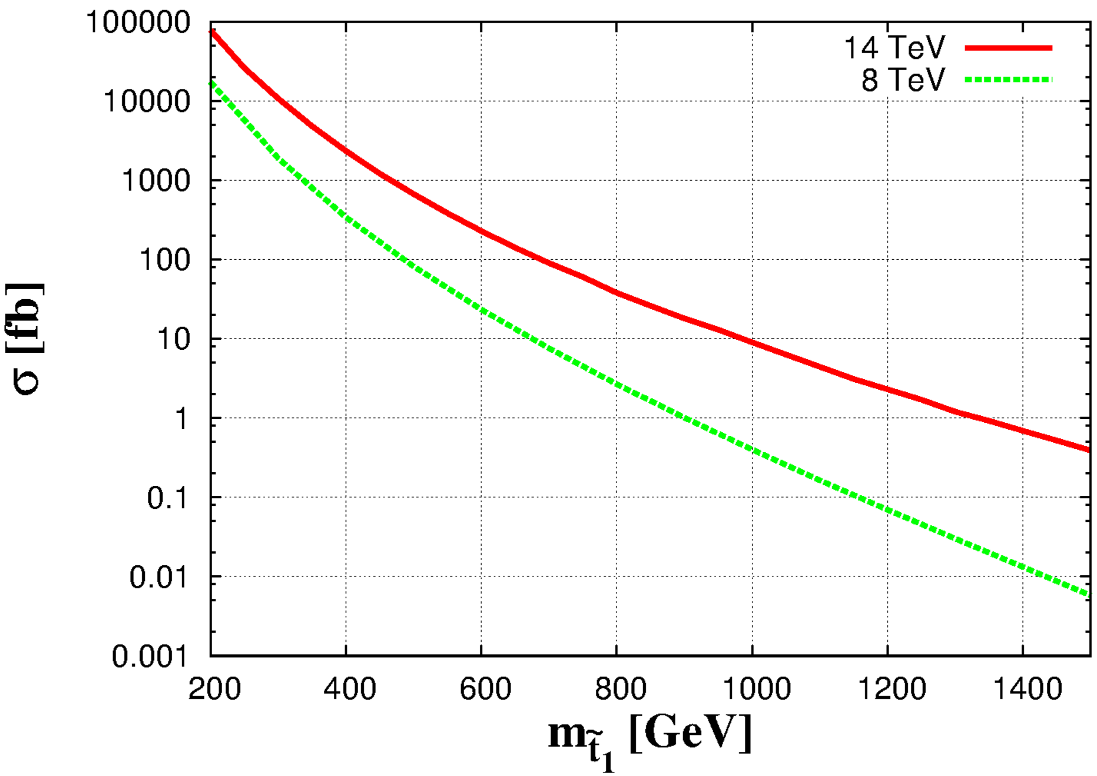
$$M_{T2}(\mathbf{p}_{Ta}, \mathbf{p}_{Tb}, \not{\mathbf{p}}_T)$$

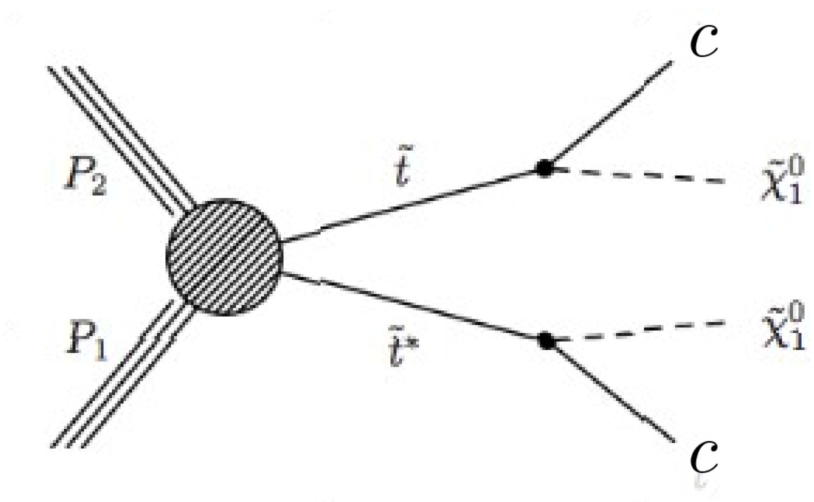

c
P_2
$\tilde{t}$
$\tilde{\chi}_1^0$
P_1
$\tilde{t}^*$
$\tilde{\chi}_1^0$
c

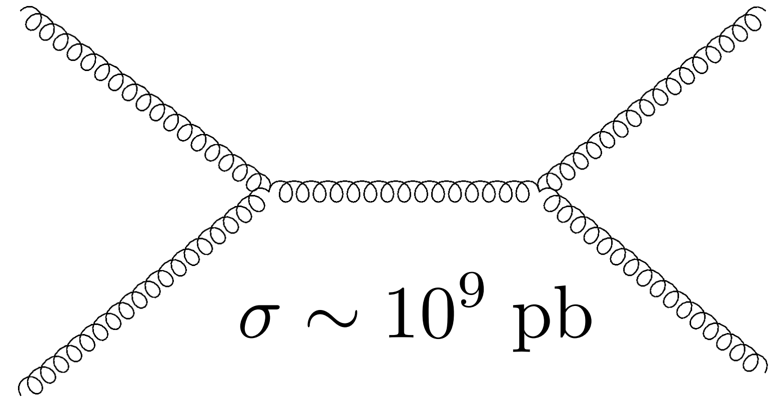

100000
10000
1000
100
10
1
0.1
0.01
0.001
200
400
600
800
1000
1200
1400
14 TeV
8 TeV
σ [fb]
$m_{\tilde{t}_1}$ [GeV]

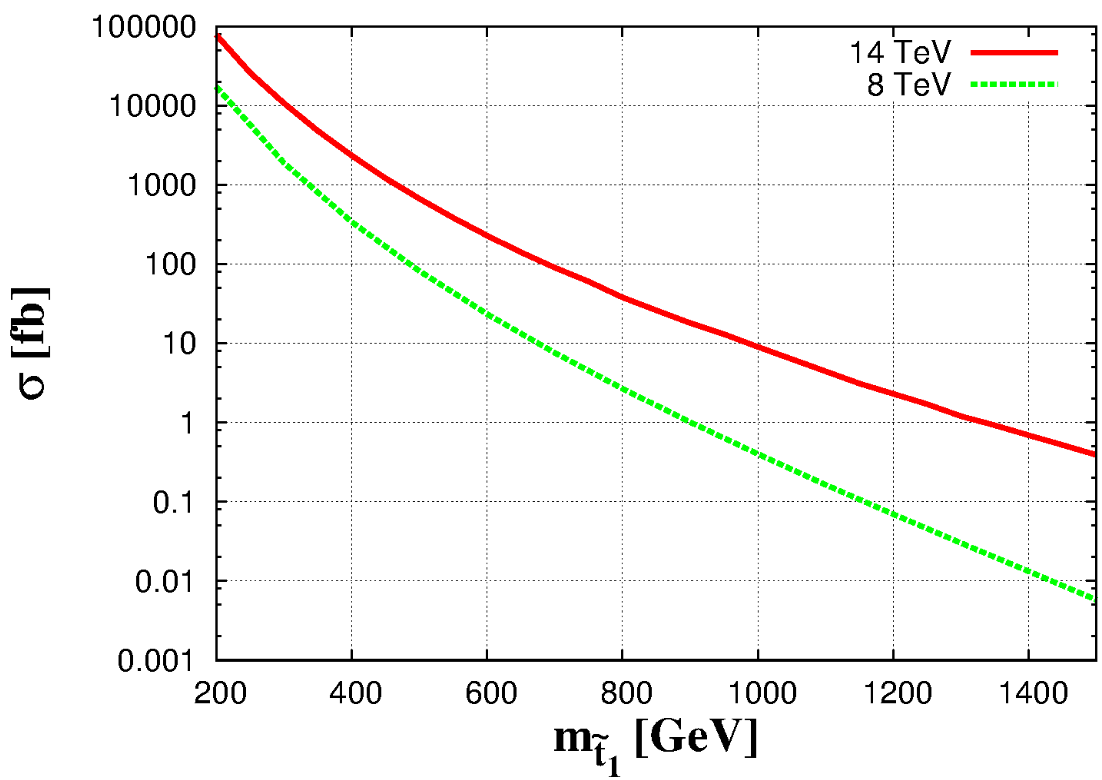

c
P_2
$\tilde{t}$
$\tilde{\chi}_1^0$
P_1
$\tilde{t}^*$
$\tilde{\chi}_1^0$
c


$\sigma \sim 10^9$ pb

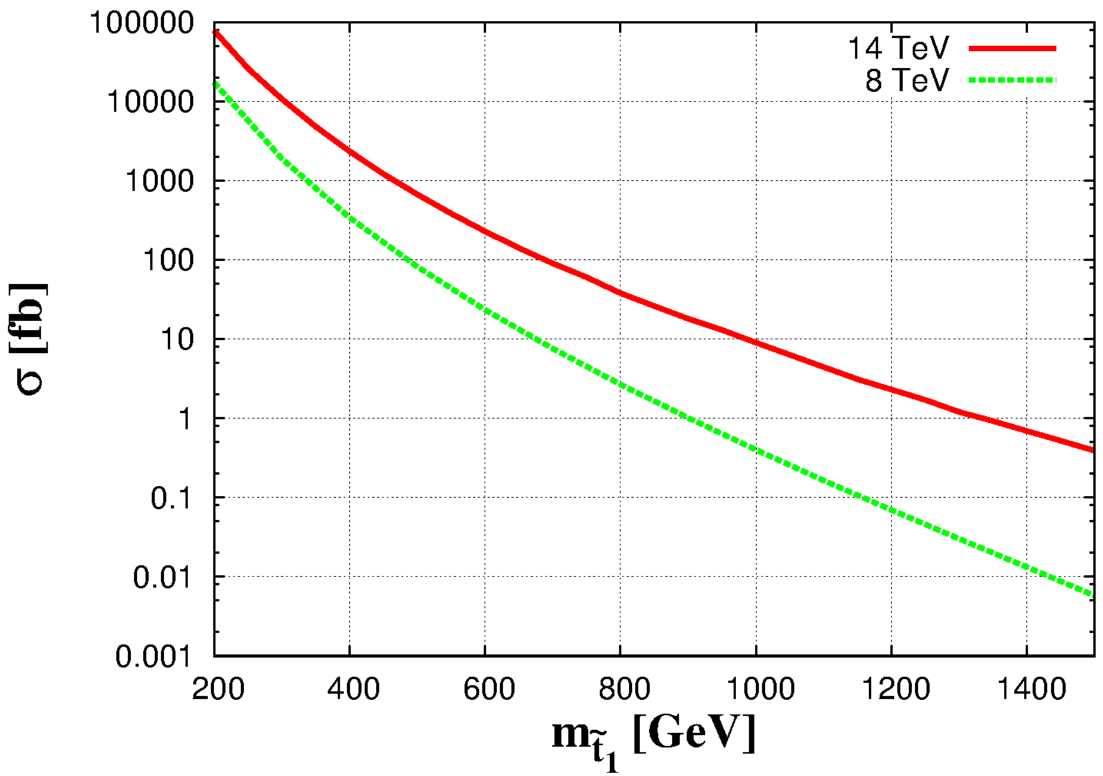

100000
10000
1000
100
10
1
0.1
0.01
0.001
200
400
600
800
1000
1200
1400
14 TeV
8 TeV
σ [fb]
$m_{\tilde{t}_1}$ [GeV]


c
P_2
$\tilde{t}$
$\tilde{\chi}_1^0$
P_1
$\tilde{t}^*$
$\tilde{\chi}_1^0$
c

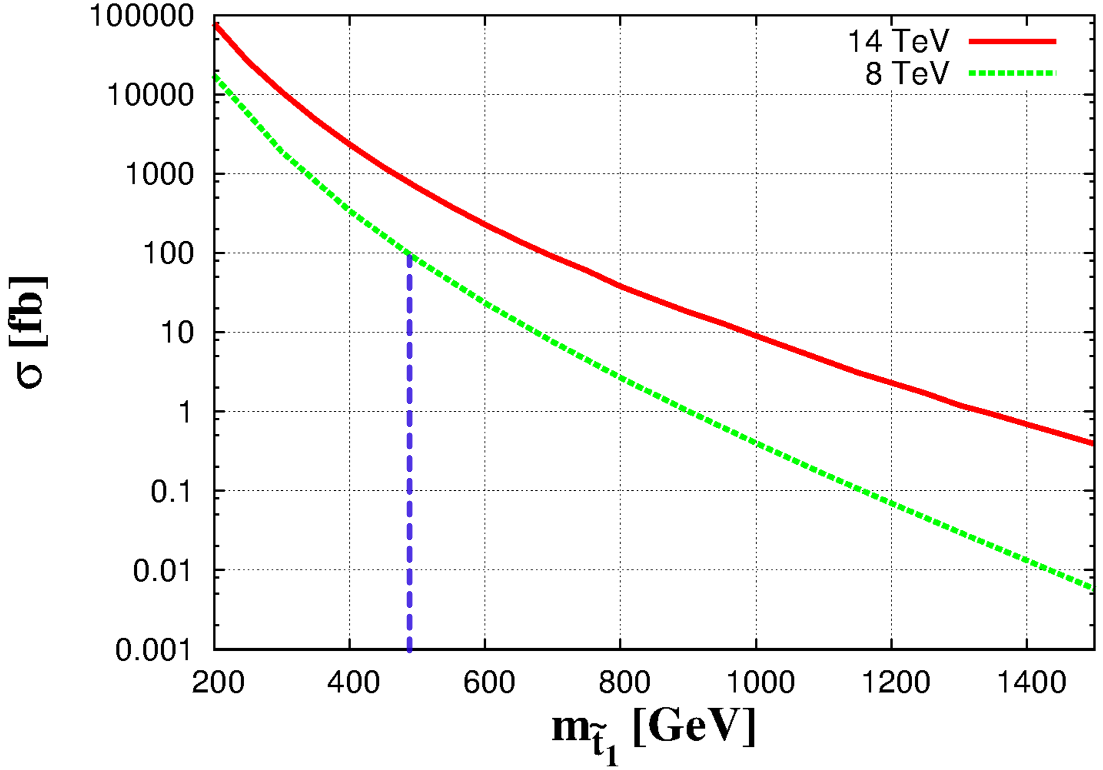

$\sigma \sim 10^9$ pb


14 TeV
8 TeV
100000
10000
1000
100
10
1
0.1
0.01
0.001
200
400
600
800
1000
1200
1400
σ [fb]
$m_{\tilde{t}_1}$ [GeV]

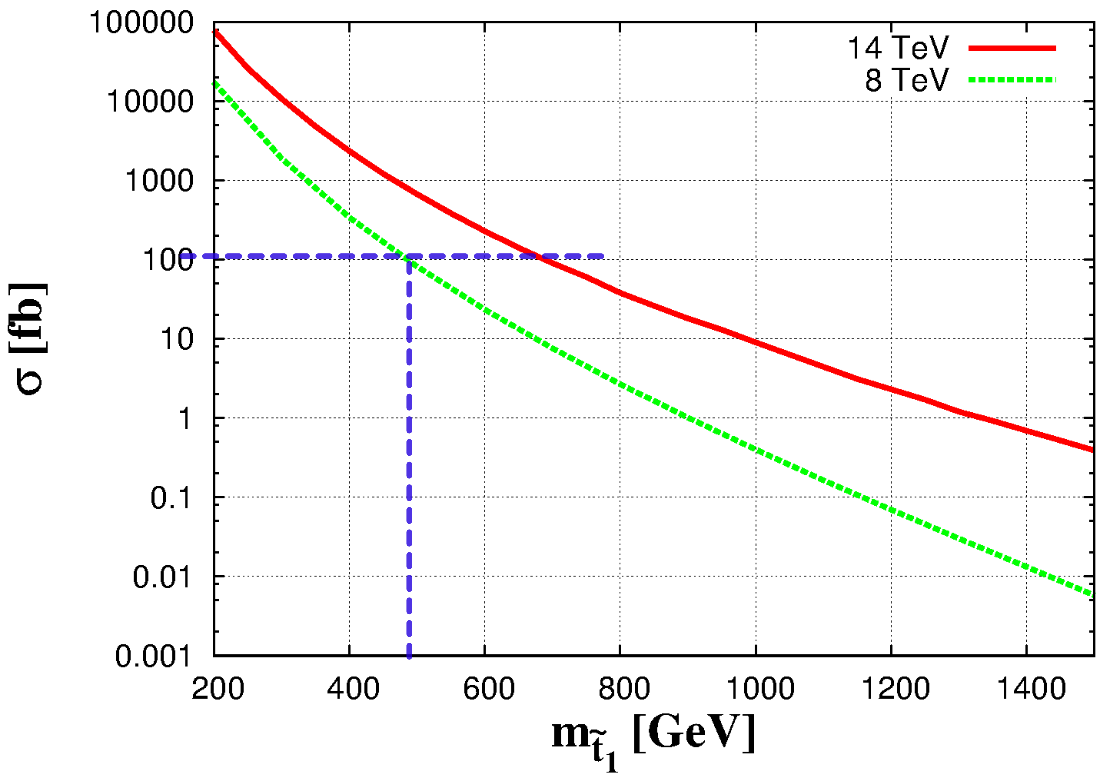
$8\text{TeV},\ 25\text{fb}^{-1},\ m_{\tilde{t}_1} = 500\text{GeV}$ **vs.** $14\text{TeV},\ 100\text{fb}^{-1},\ m_{\tilde{t}_1} = 1000\text{GeV}$



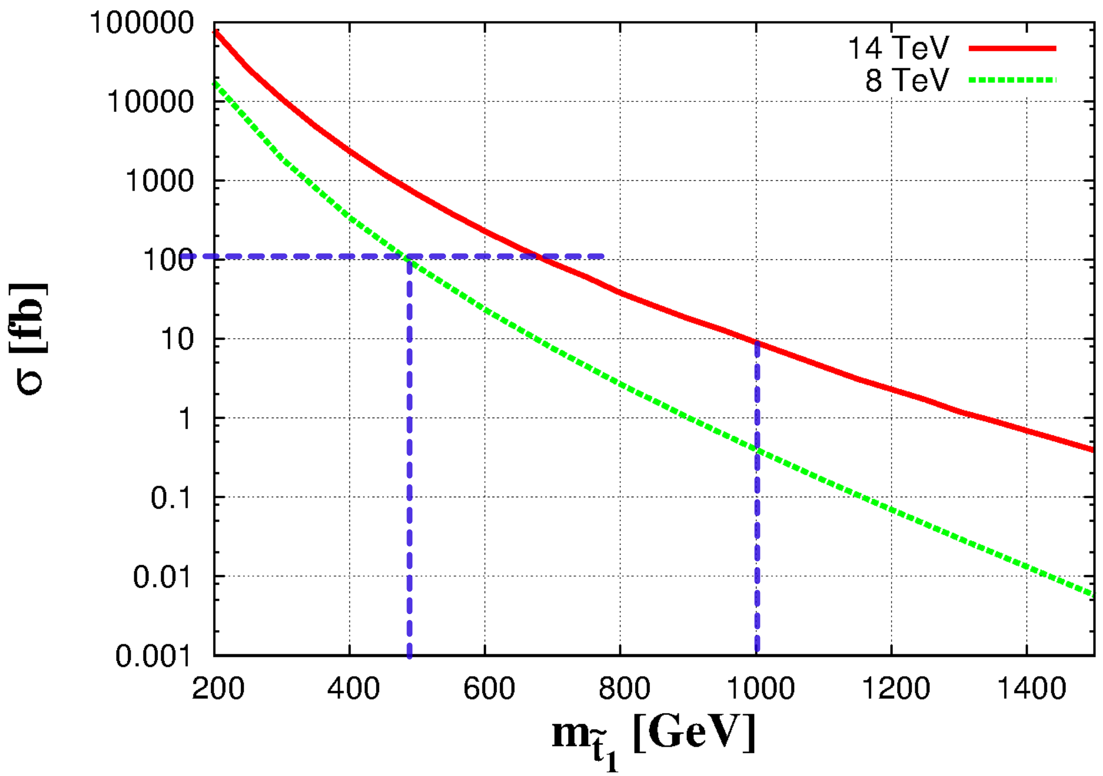
$8\text{TeV},\ 25\text{fb}^{-1},\ m_{\tilde{t}_1} = 500\text{GeV}$ vs. $14\text{TeV},\ 100\text{fb}^{-1},\ m_{\tilde{t}_1} = 1000\text{GeV}$



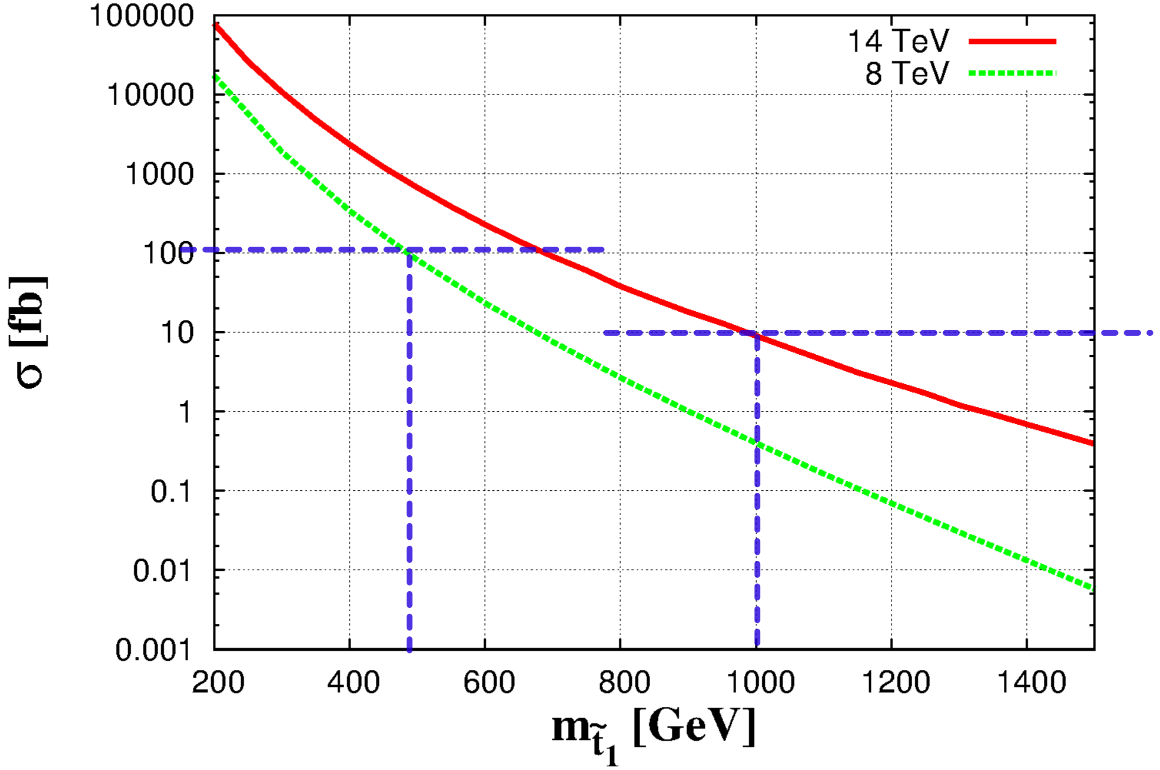
$8\mathrm{TeV},\ 25\mathrm{fb}^{-1},\ m_{\tilde{t}_1} = 500\mathrm{GeV}$ vs. $14\mathrm{TeV},\ 100\mathrm{fb}^{-1},\ m_{\tilde{t}_1} = 1000\mathrm{GeV}$



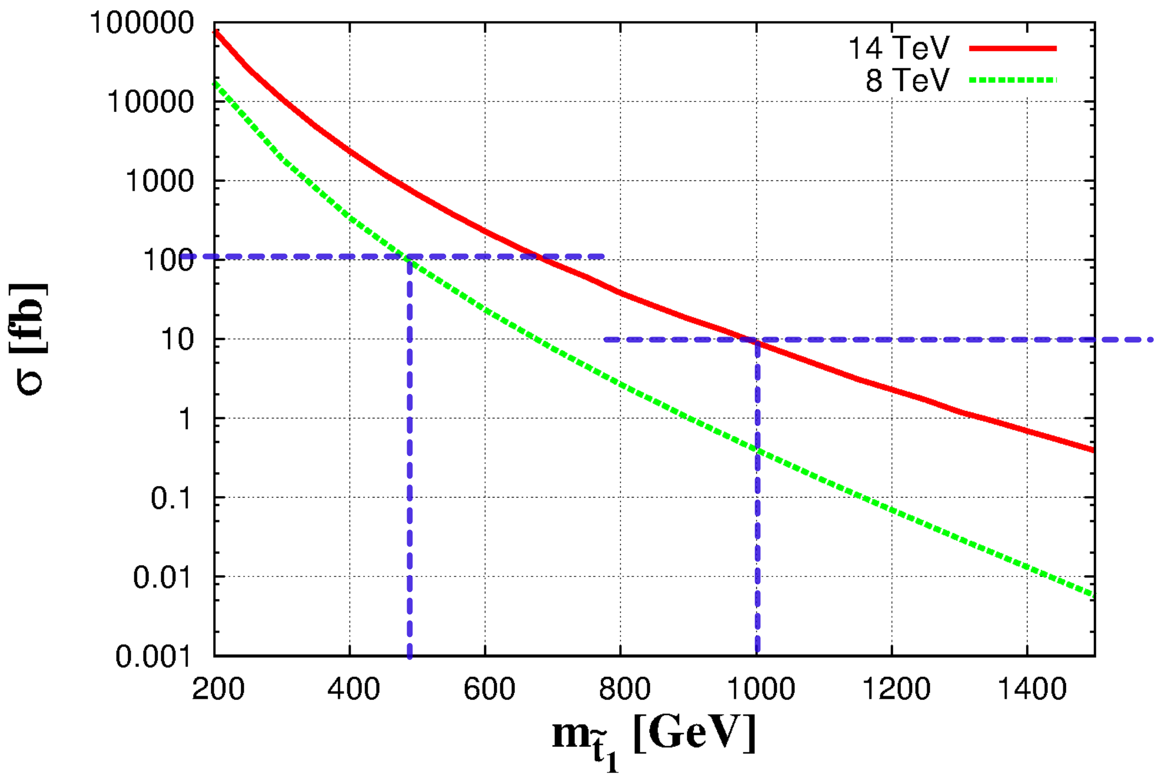
$8\mathrm{TeV},\ 25\mathrm{fb}^{-1},\ m_{\tilde{t}_1} = 500\mathrm{GeV}$ vs. $14\mathrm{TeV},\ 100\mathrm{fb}^{-1},\ m_{\tilde{t}_1} = 1000\mathrm{GeV}$



$8\mathrm{TeV},\ 25\mathrm{fb}^{-1},\ m_{\tilde{t}_1} = 500\mathrm{GeV}$ **vs.** $14\mathrm{TeV},\ 100\mathrm{fb}^{-1},\ m_{\tilde{t}_1} = 1000\mathrm{GeV}$



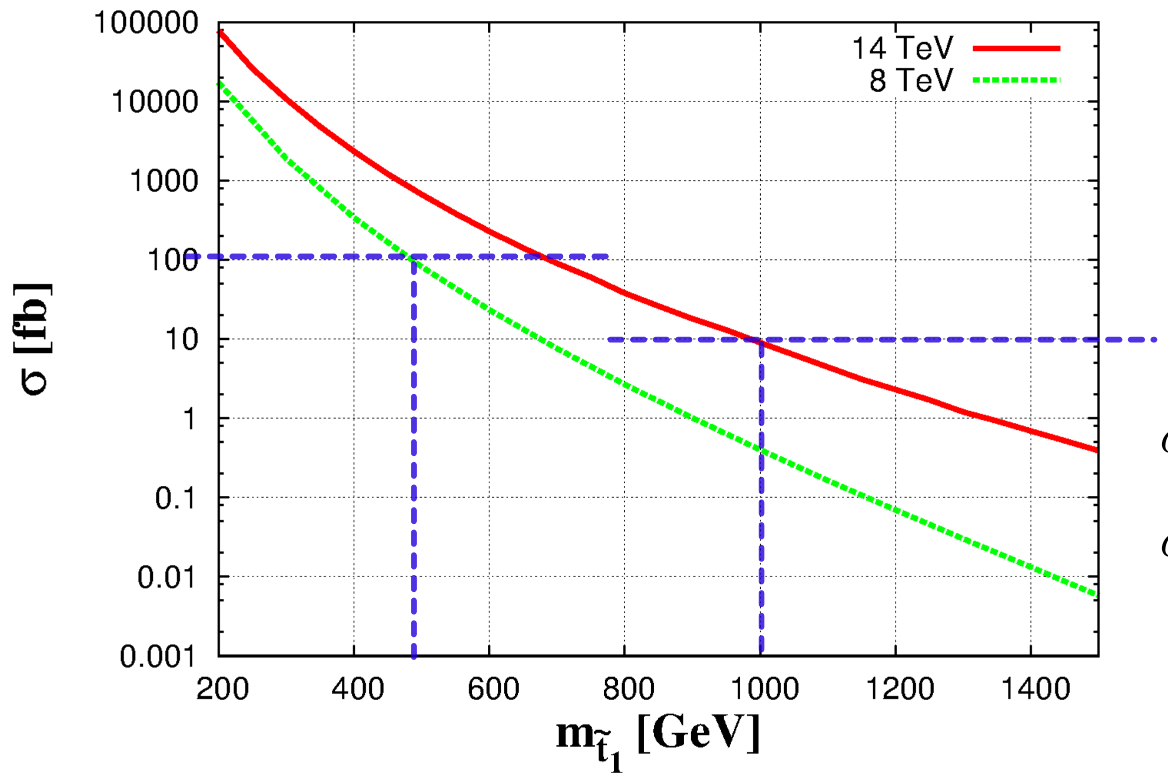
$8\text{TeV},\ 25\text{fb}^{-1},\ m_{\tilde{t}_1} = 500\text{GeV}$ vs. $14\text{TeV},\ 100\text{fb}^{-1},\ m_{\tilde{t}_1} = 1000\text{GeV}$



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

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

$8\text{TeV},\ 25\text{fb}^{-1},\ m_{\tilde{t}_1} = 500\text{GeV}$ **vs.** $14\text{TeV},\ 100\text{fb}^{-1},\ m_{\tilde{t}_1} = 1000\text{GeV}$

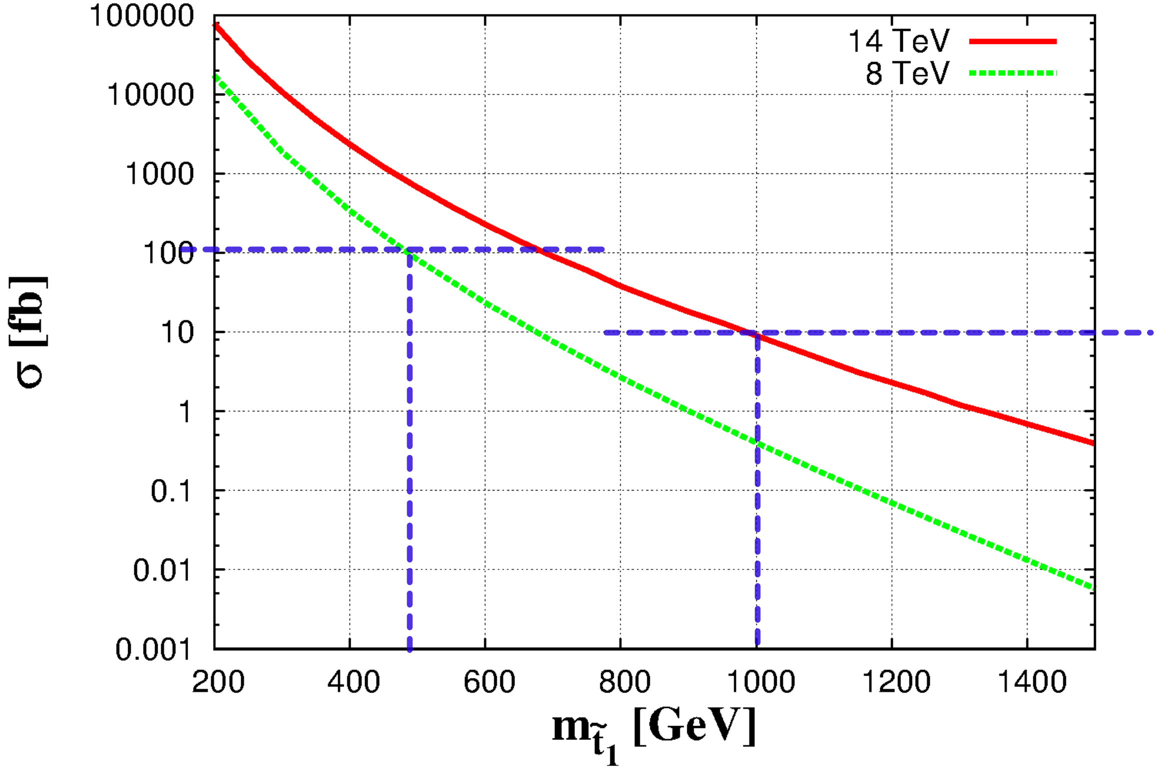


$\sigma_{t\bar{t}} \sim 225$ pb 8TeV

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

$$S \dashrightarrow \frac{S}{10}$$

$8\mathrm{TeV},\ 25\mathrm{fb}^{-1},\ m_{\tilde{t}_1} = 500\mathrm{GeV}$ **vs.** $14\mathrm{TeV},\ 100\mathrm{fb}^{-1},\ m_{\tilde{t}_1} = 1000\mathrm{GeV}$



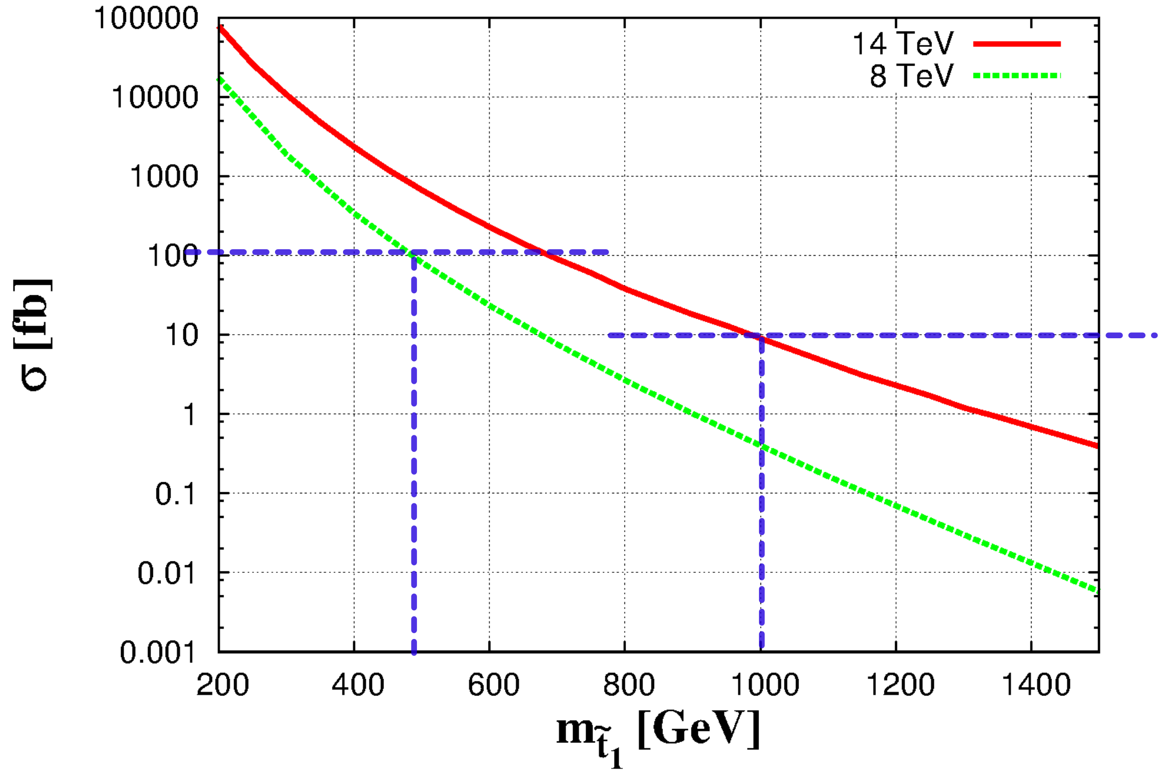
$\sigma_{t\bar{t}} \sim 225$ pb 8TeV

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

$S \dashrightarrow \frac{S}{10}$

$B \dashrightarrow B \times 4$

$8\mathrm{TeV},\ 25\mathrm{fb}^{-1},\ m_{\tilde{t}_1} = 500\mathrm{GeV}$ **vs.** $14\mathrm{TeV},\ 100\mathrm{fb}^{-1},\ m_{\tilde{t}_1} = 1000\mathrm{GeV}$



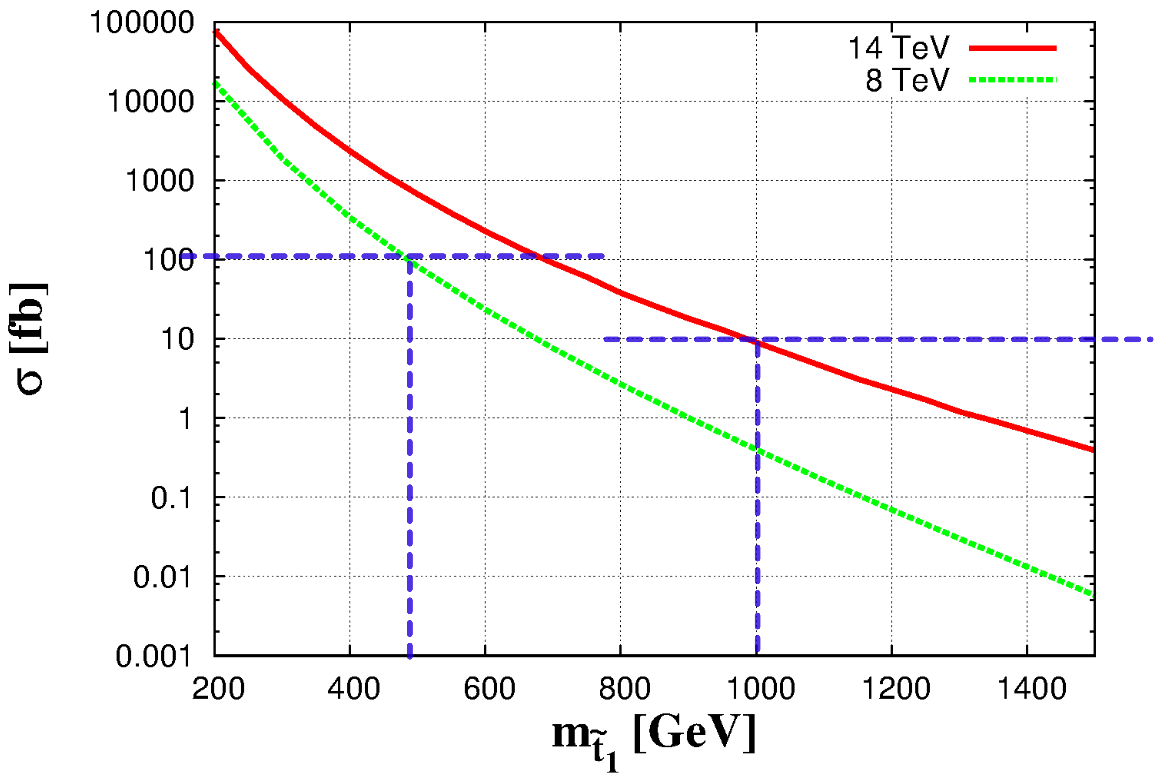
$\sigma_{t\bar{t}} \sim 225$ pb 8TeV

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

$$S \dashrightarrow \frac{S}{10} \times 4$$

$$B \dashrightarrow B \times 4$$

$8\text{TeV},\ 25\text{fb}^{-1},\ m_{\tilde{t}_1} = 500\text{GeV}$ **vs.** $14\text{TeV},\ 100\text{fb}^{-1},\ m_{\tilde{t}_1} = 1000\text{GeV}$



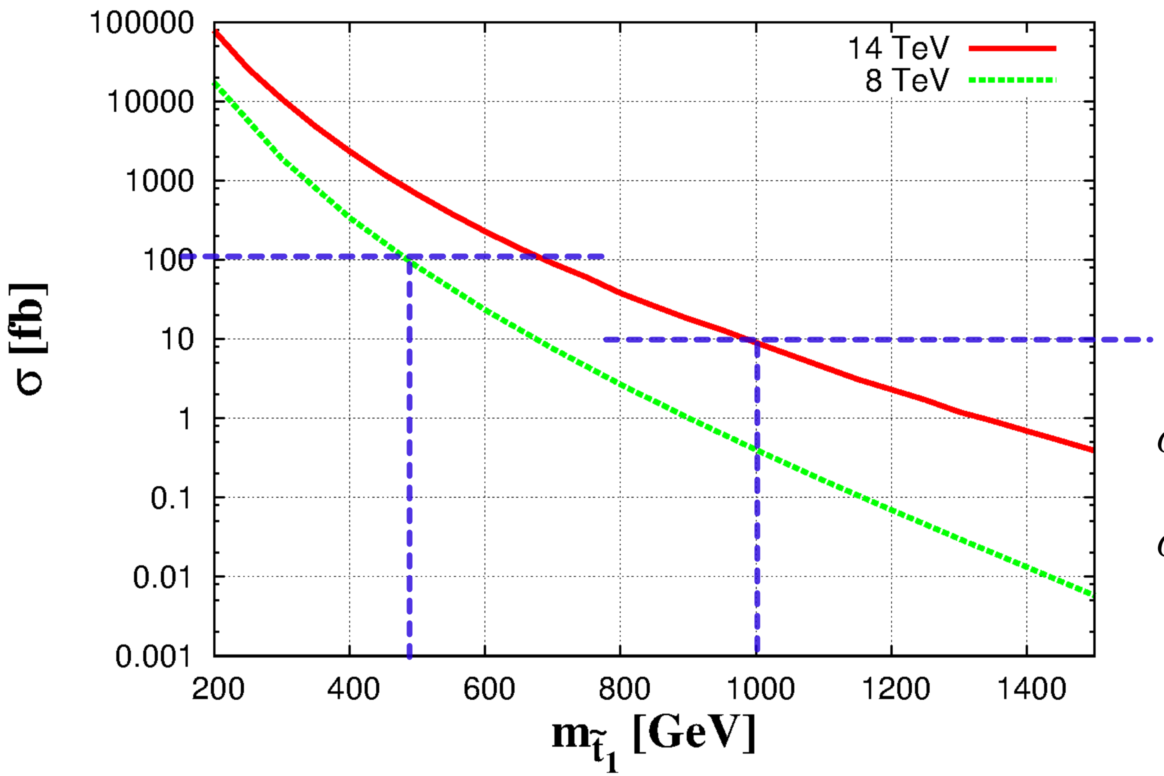
$\sigma_{t\bar{t}} \sim 225$ pb 8TeV

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

$S \dashrightarrow \frac{S}{10} \times 4$

$B \dashrightarrow B \times 4 \times 4$

$8\mathrm{TeV},\ 25\mathrm{fb}^{-1},\ m_{\tilde{t}_1} = 500\mathrm{GeV}$ **vs.** $14\mathrm{TeV},\ 100\mathrm{fb}^{-1},\ m_{\tilde{t}_1} = 1000\mathrm{GeV}$



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

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

$$S \dashrightarrow \frac{S}{10} \times 4$$

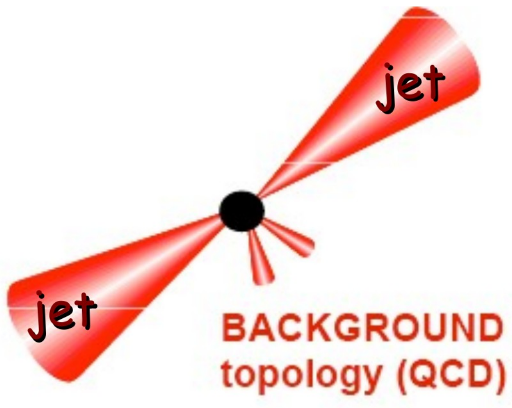
$$B \dashrightarrow B \times 4 \times 4$$

$$\frac{S}{\sqrt{B}} \dashrightarrow \frac{1}{10} \times \frac{S}{\sqrt{B}}$$

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

$$H_T = \sum_j |\vec{p_T}|$$

$$\not{H}_T = |\sum_j \vec{p_T}|$$



Jets are back-to-back in ϕ

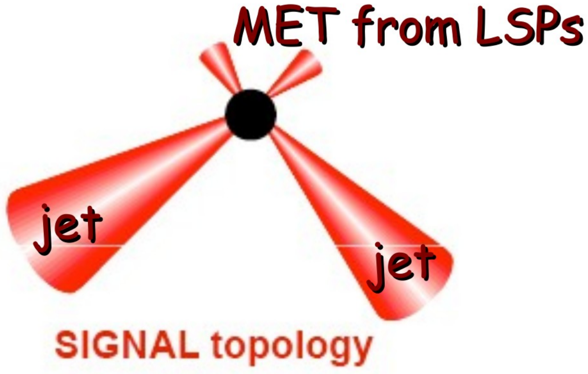
$$\alpha_T = 0.5$$

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

$$\alpha_T > 0.5$$



Dark matter relic density