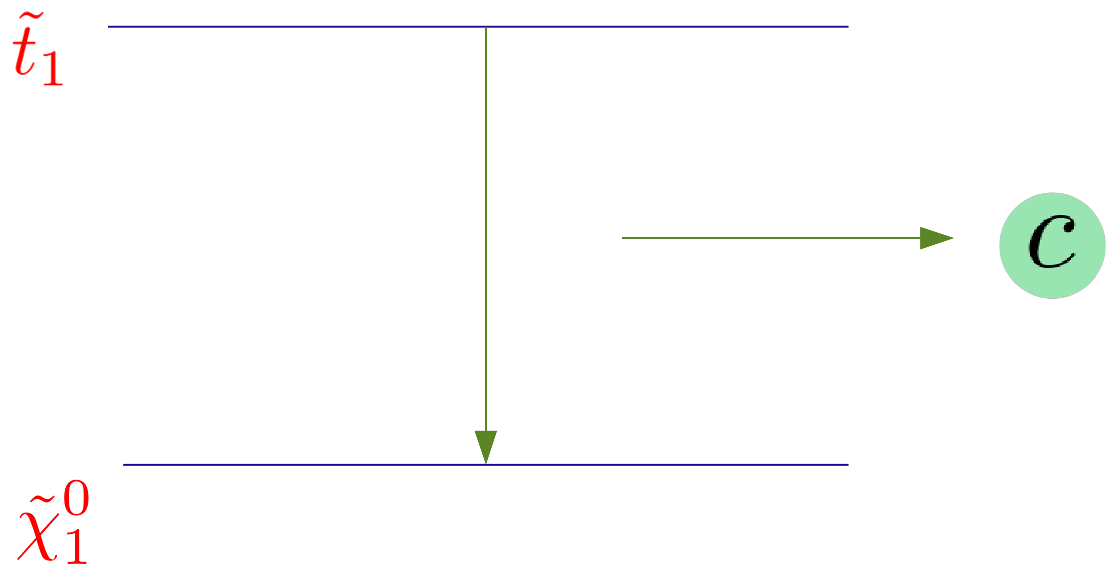
Boosted di-boson from mixed heavy top squarks

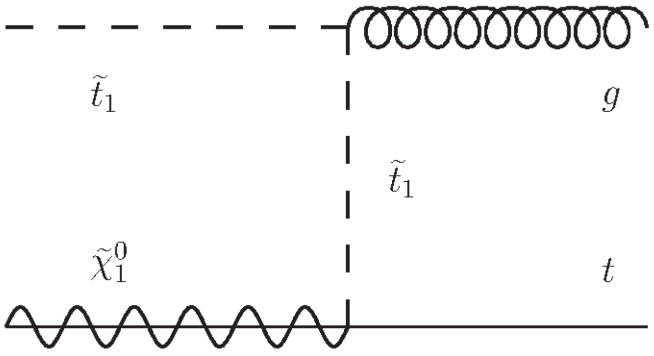
Diptimoy Ghosh

Rome

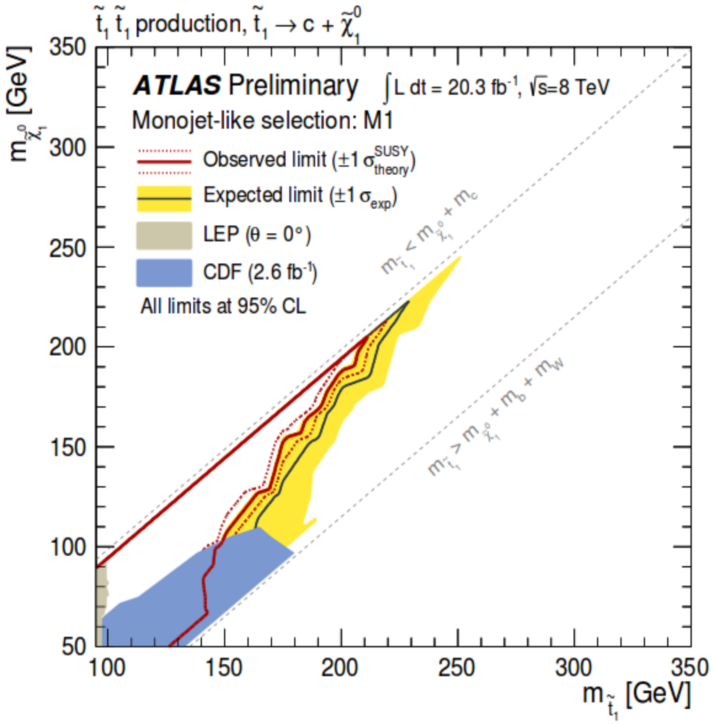
Degenerate $\tilde{t}_1$ and $\tilde{\chi}_1^0$



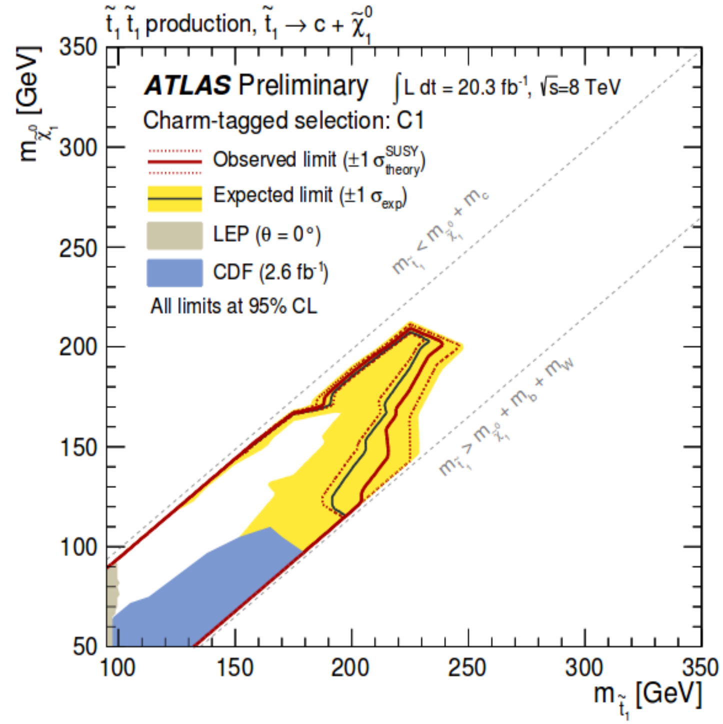
Coannihilation



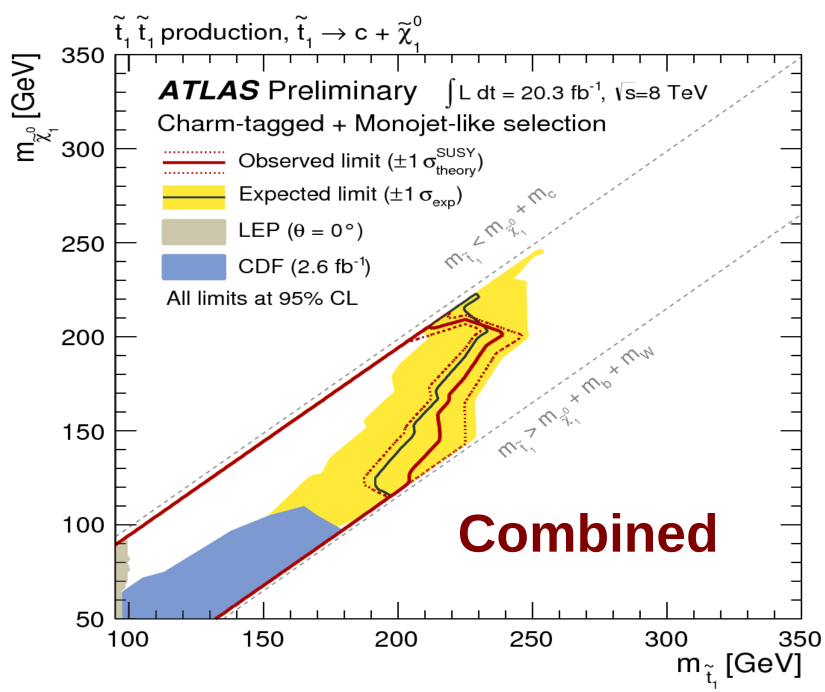
LHC8 limits



$\tilde{t}_1 \tilde{t}_1$ production, $\tilde{t}_1 \to c + \tilde{\chi}_1^0$
ATLAS Preliminary $\int L\,dt = 20.3\ fb^{-1}$, $\sqrt{s}$=8 TeV
Monojet-like selection: M1
Observed limit ($\pm 1\ \sigma^{SUSY}_{theory}$)
Expected limit ($\pm 1\ \sigma_{exp}$)
LEP ($\theta = 0°$)
CDF (2.6 fb^{-1})
All limits at 95% CL
$m_{\tilde{t}_1} < m_{\tilde{\chi}_1^0} + m_c$
$m_{\tilde{t}_1} > m_{\tilde{\chi}_1^0} + m_b + m_W$
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{t}_1}$ [GeV]

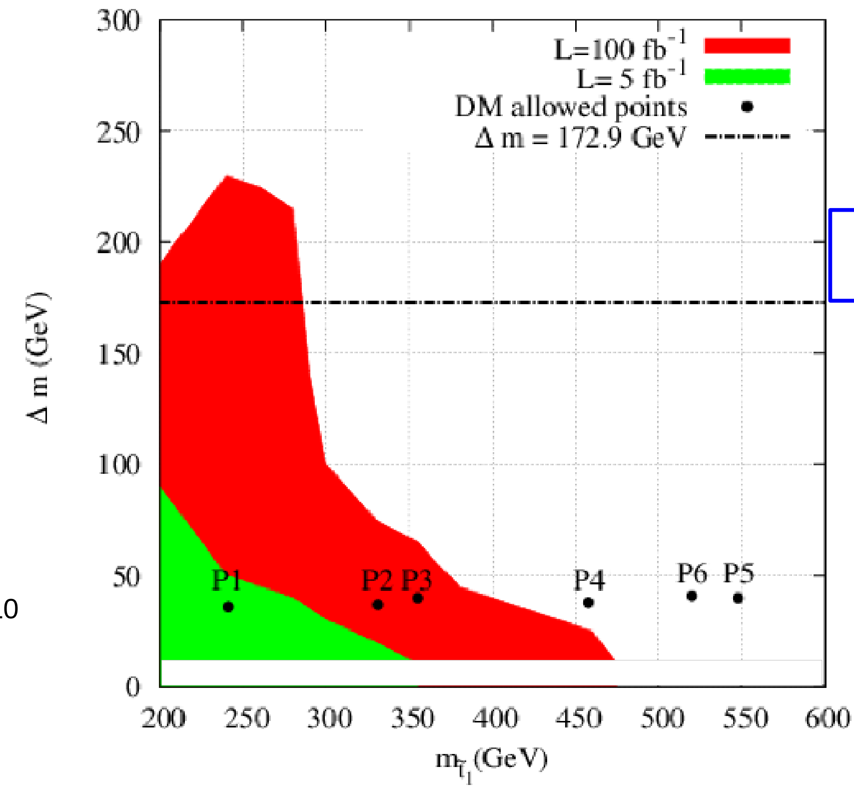


$\tilde{t}_1 \tilde{t}_1$ production, $\tilde{t}_1 \to c + \tilde{\chi}_1^0$
ATLAS Preliminary $\int L\,dt = 20.3\ fb^{-1}$, $\sqrt{s}$=8 TeV
Charm-tagged selection: C1
Observed limit ($\pm 1\ \sigma^{SUSY}_{theory}$)
Expected limit ($\pm 1\ \sigma_{exp}$)
LEP ($\theta = 0°$)
CDF (2.6 fb^{-1})
All limits at 95% CL
$m_{\tilde{t}_1} < m_{\tilde{\chi}_1^0} + m_c$
$m_{\tilde{t}_1} > m_{\tilde{\chi}_1^0} + m_b + m_W$
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{t}_1}$ [GeV]



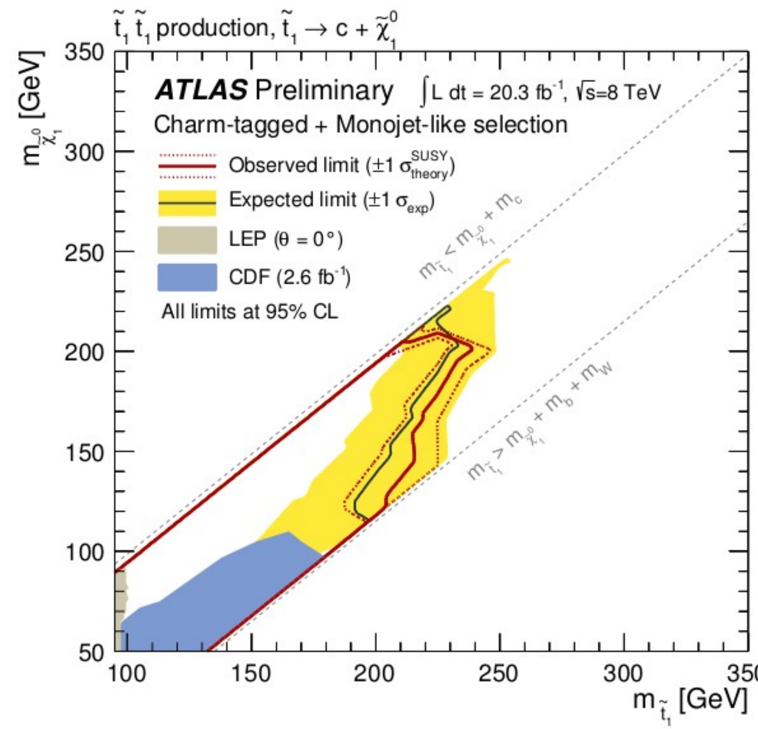
$\tilde{t}_1 \tilde{t}_1$ production, $\tilde{t}_1 \to c + \tilde{\chi}_1^0$
ATLAS Preliminary $\int L\,dt = 20.3\ fb^{-1}$, $\sqrt{s}$=8 TeV
Charm-tagged + Monojet-like selection
Observed limit ($\pm 1\ \sigma^{SUSY}_{theory}$)
Expected limit ($\pm 1\ \sigma_{exp}$)
LEP ($\theta = 0°$)
CDF (2.6 fb^{-1})
All limits at 95% CL
$m_{\tilde{t}_1} < m_{\tilde{\chi}_1^0} + m_c$
$m_{\tilde{t}_1} > m_{\tilde{\chi}_1^0} + m_b + m_W$
Combined
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{t}_1}$ [GeV]

LHC14 projections



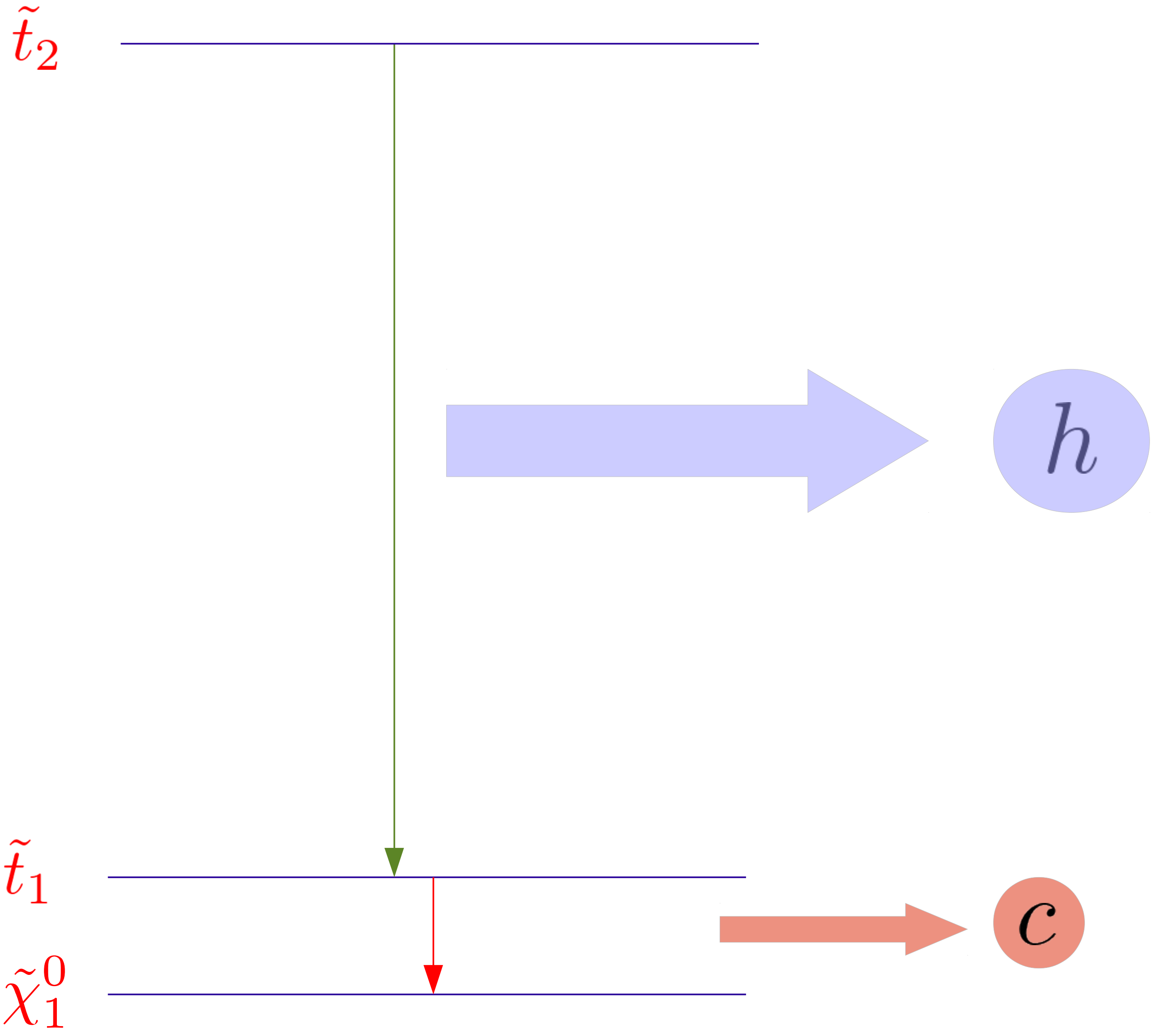
10

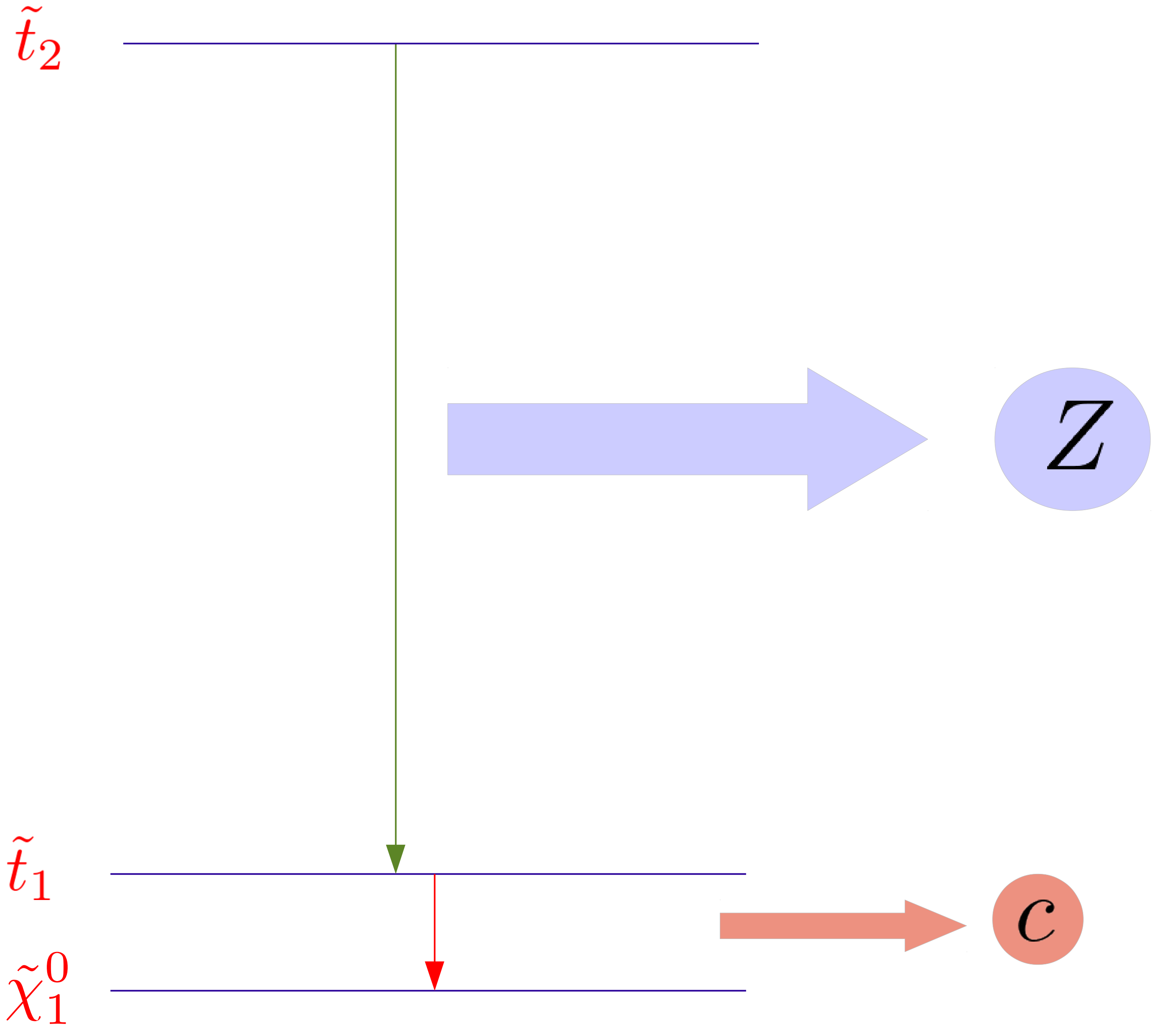
α_T , M_{T2}



	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 '13


$\tilde{t}_2$
h
$\tilde{t}_1$
c
$\tilde{\chi}_1^0$


$\tilde{t}_2$
Z
$\tilde{t}_1$
c
$\tilde{\chi}_1^0$

Branching Ratios

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

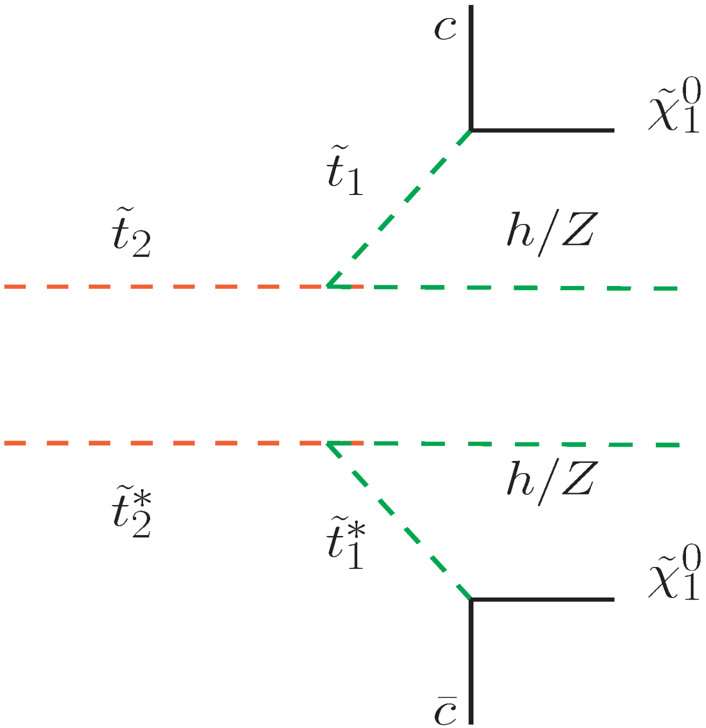
$$\left[(\frac{2}{3} \sin^2 \theta_W - \frac{1}{4}) \cos(2\beta) \ \sin(2\theta_t) + \frac{1}{2} \frac{m_t}{M_Z^2} \cos(2\theta_t) \ X_t \right]$$

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

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

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

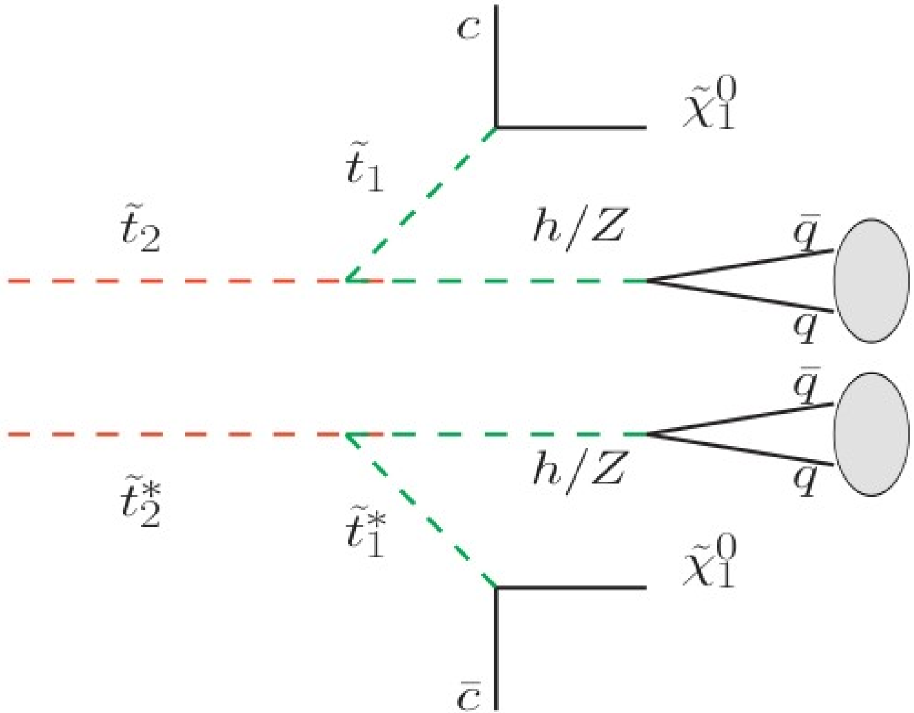
$$M^2_{\tilde{t}} = \begin{pmatrix} m^2_{LL} & m_t X_t \\ m_t X_t & m^2_{RR} \end{pmatrix}$$

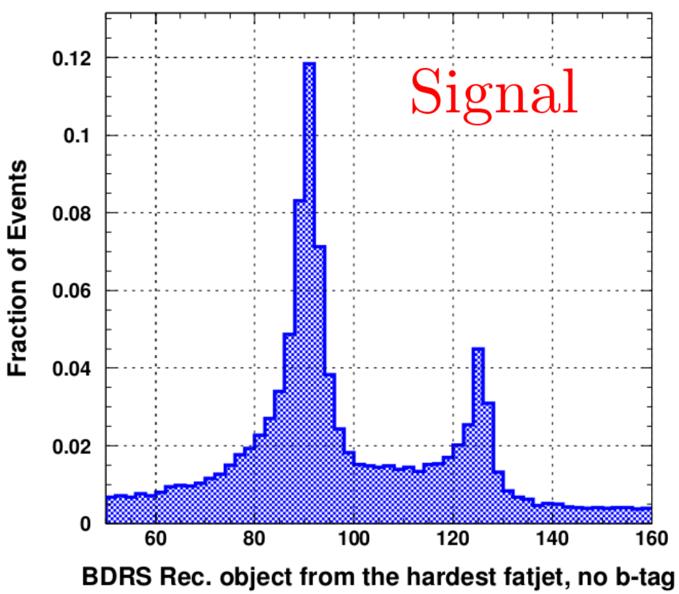


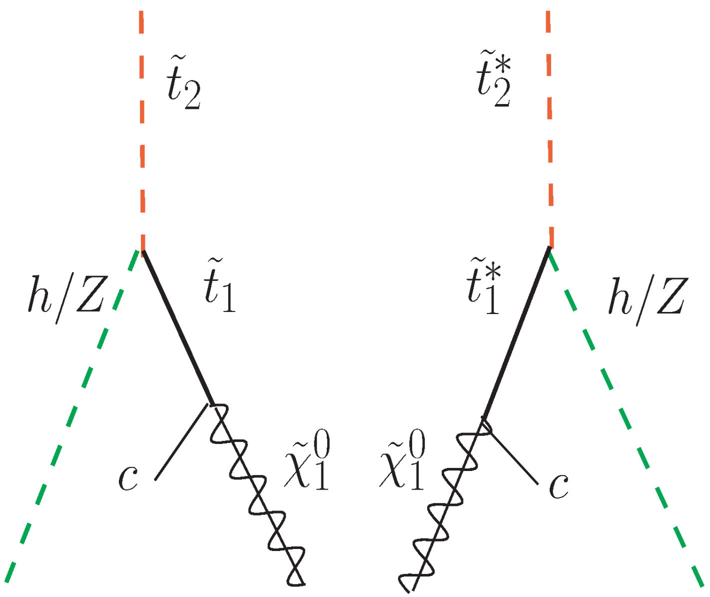
Model:1						Model:2					
pMSSM inputs			Masses			pMSSM inputs			Masses		
M_1	=	300	$m_{\tilde{t}_2}$	=	1005	M_1	=	410	$m_{\tilde{t}_2}$	=	1003
M_2	=	650	$m_{\tilde{t}_1}$	=	334	M_2	=	850	$m_{\tilde{t}_1}$	=	434
M_3	=	2100	$m_{\tilde{\chi}_1^0}$	=	300	M_3	=	2600	$m_{\tilde{\chi}_1^0}$	=	411
μ	=	2000	$m_{\tilde{\chi}_2^0}$	=	676	μ	=	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			
$\mathcal{B}(\widetilde{t}_2 \to \widetilde{t}_1\, Z) = 52\%$ $\mathcal{B}(\widetilde{t}_2 \to \widetilde{t}_1\, h) = 39\%$ $\mathcal{B}(\widetilde{t}_1 \to c\, \widetilde{\chi}_1^0) = 82\%$						$\mathcal{B}(\widetilde{t}_2 \to \widetilde{t}_1\, Z) = 56\%$ $\mathcal{B}(\widetilde{t}_2 \to \widetilde{t}_1\, h) = 41\%$ $\mathcal{B}(\widetilde{t}_1 \to c\, \widetilde{\chi}_1^0) = 90\%$					

Final State

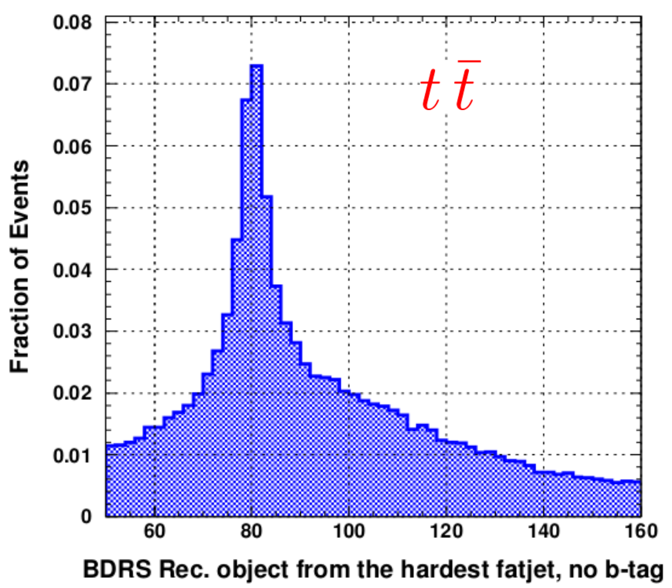
$$\mathrm{pp} \;\to\; \widetilde{\mathrm{t}}_2\,\widetilde{\mathrm{t}}_2^* \;\to\; \widetilde{\mathrm{t}}_1\,\widetilde{\mathrm{t}}_1^*\,\mathrm{Z}\,\mathrm{Z} \;\to\; Z\,Z\,\widetilde{\chi}_1^0\,\widetilde{\chi}_1^0\,c\,\bar{c}$$
$$\hookrightarrow\; Z\,Z\; + \not{p}_T + \text{soft jets}$$
$$\mathrm{pp}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

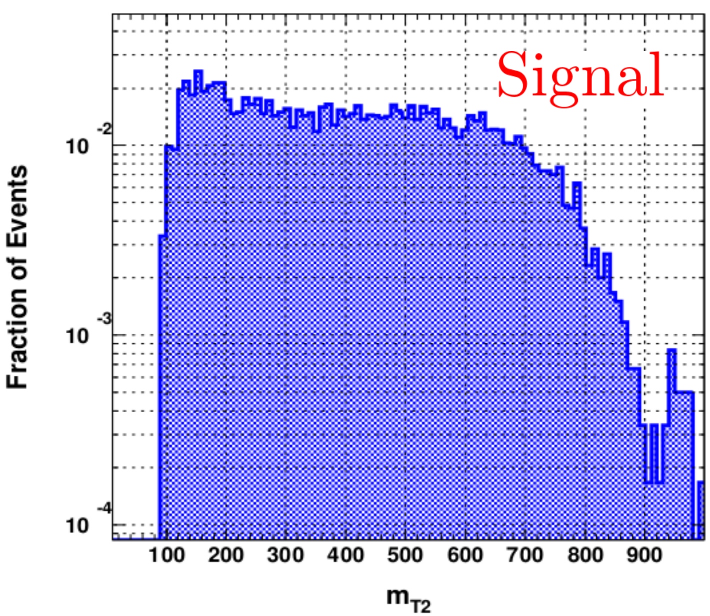



Signal
Fraction of Events
BDRS Rec. object from the hardest fatjet, no b-tag


$\tilde{t}_2$
$\tilde{t}_2^*$
h/Z
$\tilde{t}_1$
$\tilde{t}_1^*$
h/Z
c
$\tilde{\chi}_1^0$
$\tilde{\chi}_1^0$
c

BDRS, R=1.0


$t\,\bar{t}$
Fraction of Events
BDRS Rec. object from the hardest fatjet, no b-tag


Signal
Fraction of Events
m_{T2}

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}	

$h\,h/h\,Z/Z\,Z$ (S1)

$\not{p}_T$ (S3)

M_{T2} (S4)

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

Boosted dibosons from mixed heavy top squarks

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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 $\tilde{t}_2 \to \tilde{t}_1 h$ and $\tilde{t}_2 \to \tilde{t}_1 Z$. 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 ~1 TeV $\tilde{t}_2$ with 100 fb^{-1} integrated luminosity.

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Additional Material

$$A \rightarrow B\,\tilde{\chi}$$

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

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

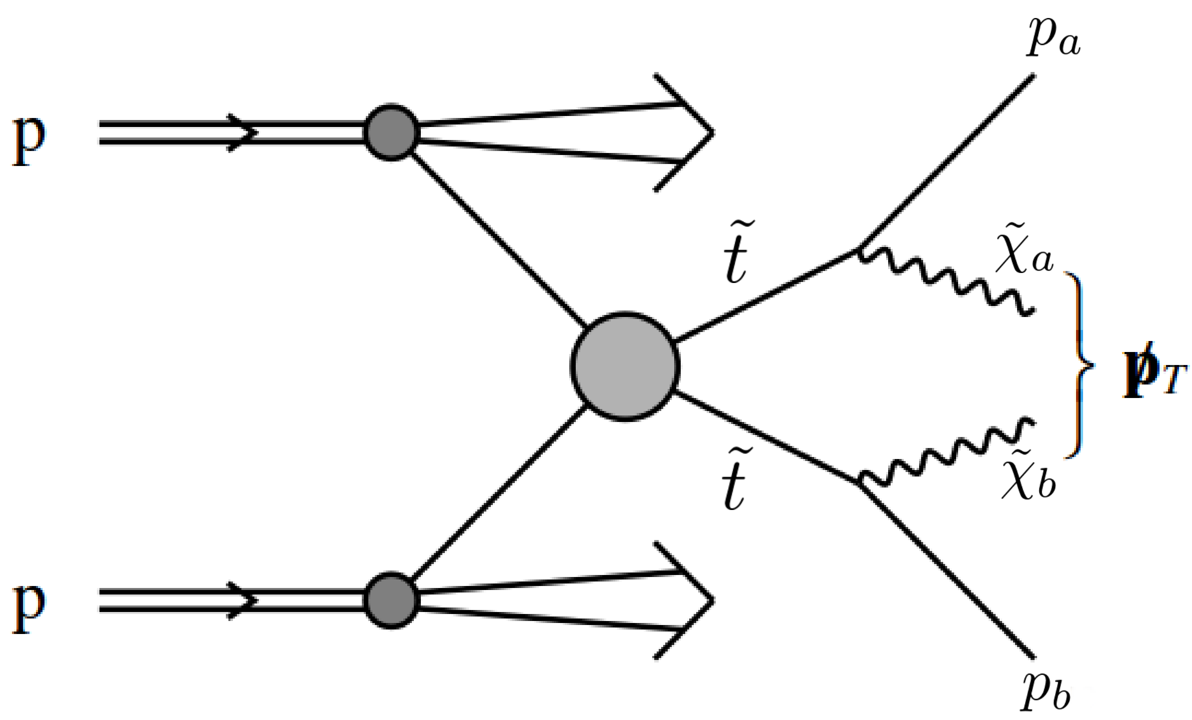
$$E_T = \sqrt{\mathbf{p}_T^2 + m^2}$$

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

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

$$\Downarrow$$

$$m_T^2(\mathbf{p}_{TB}, \mathbf{p}_{T\tilde{\chi}})$$

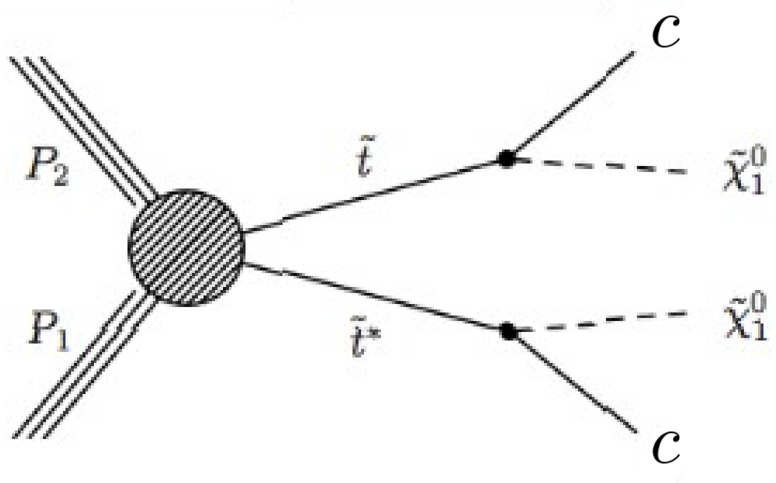


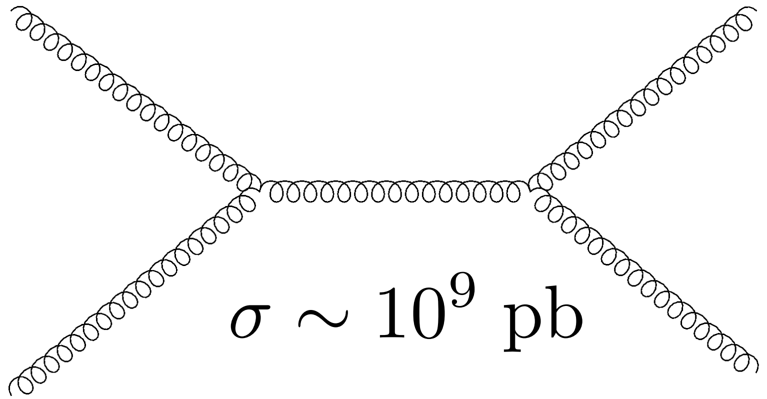
C. G. Lester and D. J. Summers, 1999

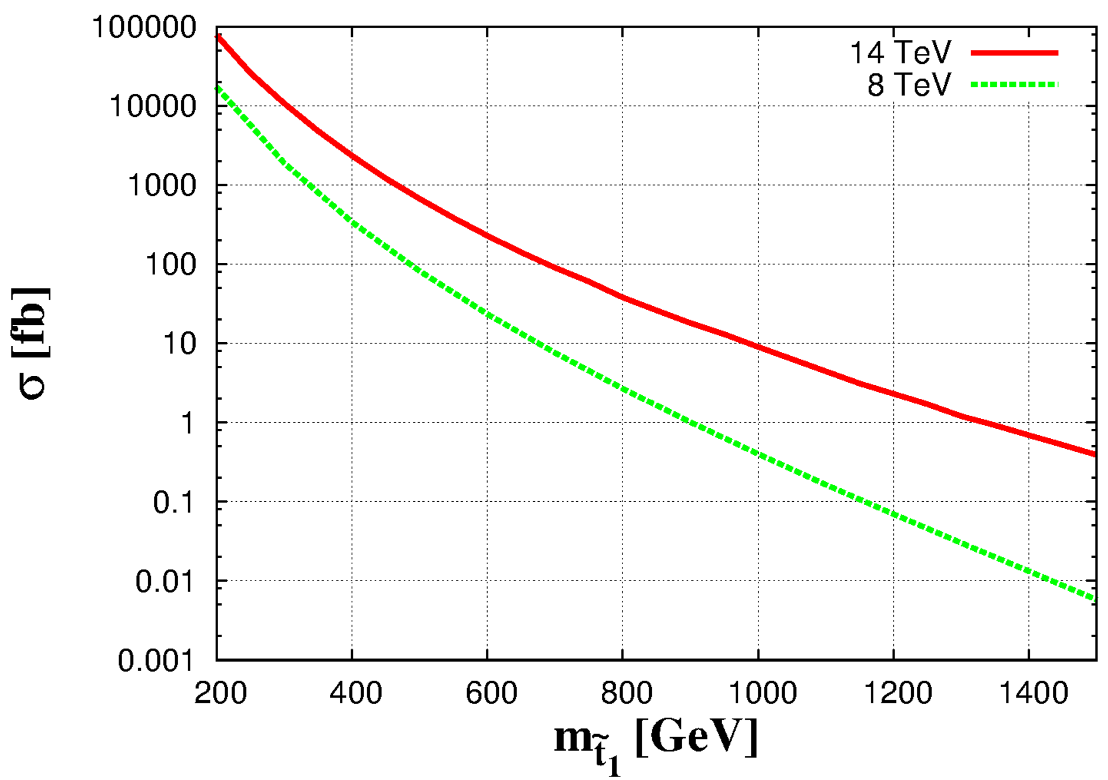
$$\not{p}_T = \mathbf{p}_{T\tilde{\chi}_a} + \mathbf{p}_{T\tilde{\chi}_b}$$

$$m_{\tilde{t}}^2 \geq \qquad m_T^2(\mathbf{p}_{Ta}, \mathbf{p}_{T\tilde{\chi}_a})$$

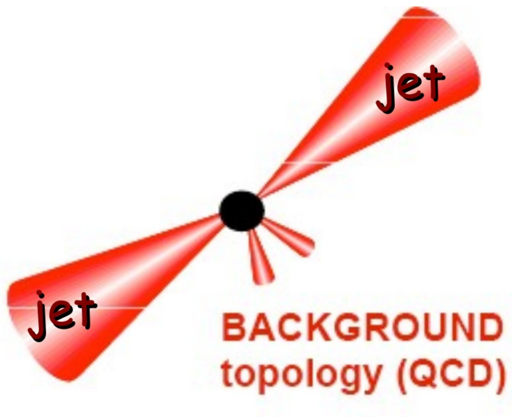
$$m_{\tilde{t}}^2 \geq \underbrace{\min_{\not{p}_T = \not{p}_{T1} + \not{p}_{T2}} \left[\max\{ m_T^2(\mathbf{p}_{Ta}, \not{p}_{T1}), m_T^2(\mathbf{p}_{Tb}, \not{p}_{T2}) \} \right]}_{M_{T2}^2(\mathbf{p}_{Ta}, \mathbf{p}_{Tb}, \not{p}_T)}$$


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


$\sigma \sim 10^9$ pb


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]
14 TeV
8 TeV

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



Jets are back-to-back in ϕ

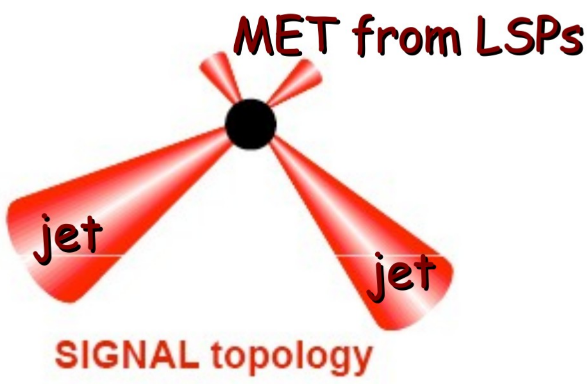
$$\alpha_T = 0.5$$

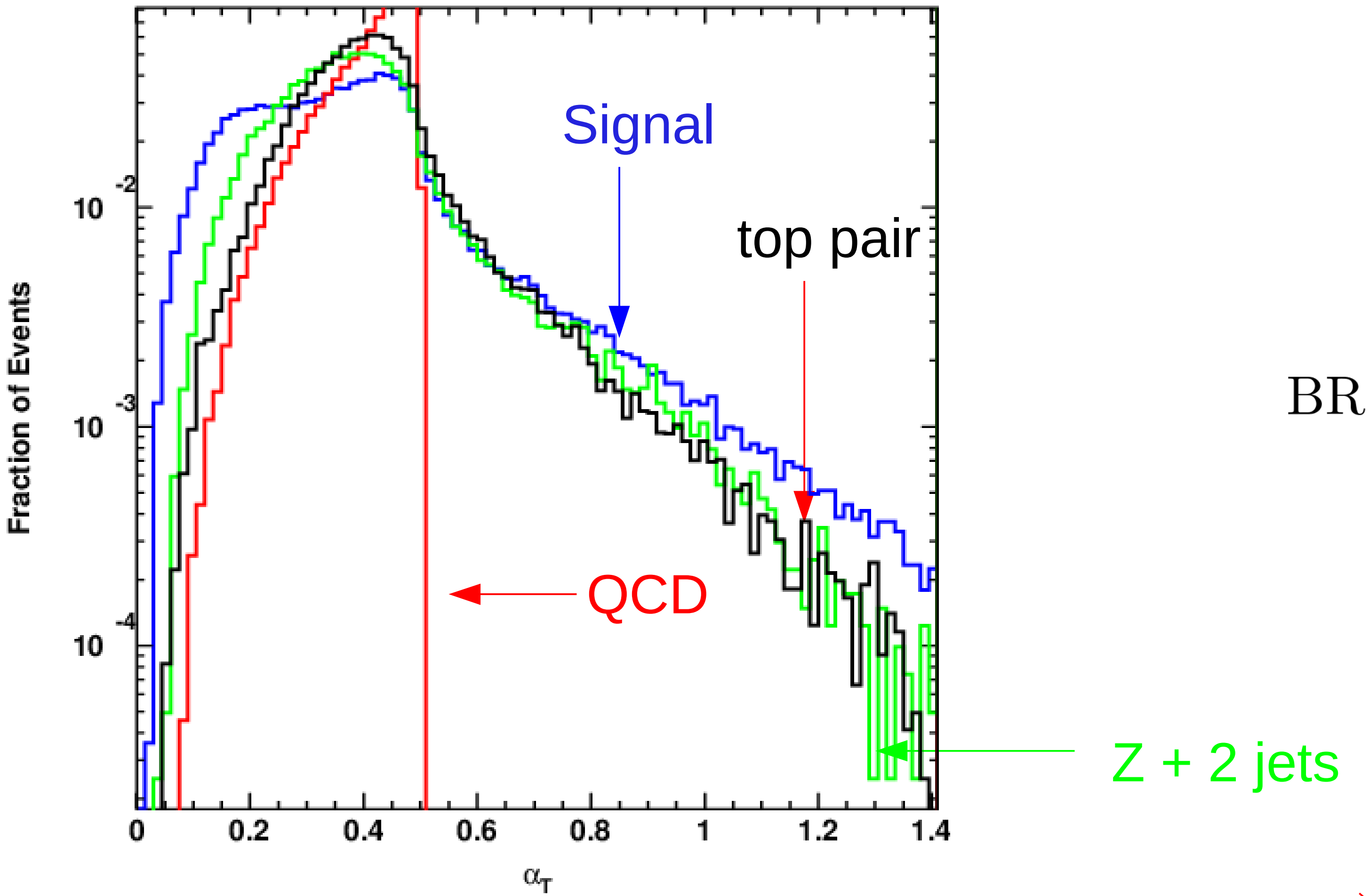
in the case of an imbalance in the measured p_Ts of back-to-back jets

$$\alpha_T < 0.5$$

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

$$\alpha_T > 0.5$$





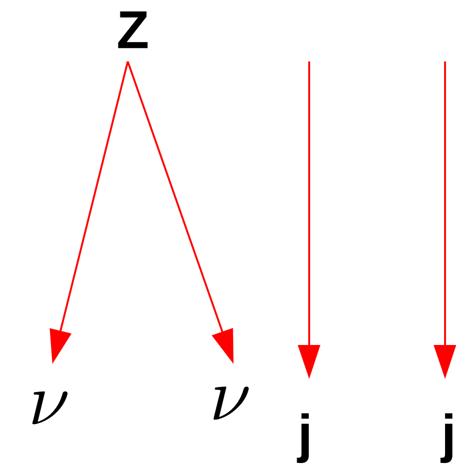
$$\begin{aligned} m_0 &= 2589 \\ m_{1/2} &= 695 \\ A_0 &= -5849 \\ \tan\beta &= 10 \\ m_{\tilde{t}_1} &= 331 \\ m_{\tilde{\chi}_1^0} &= 306 \\ \mathrm{BR}(\tilde{t}_1 \to c\,\tilde{\chi}_1^0) &= 97\% \end{aligned}$$

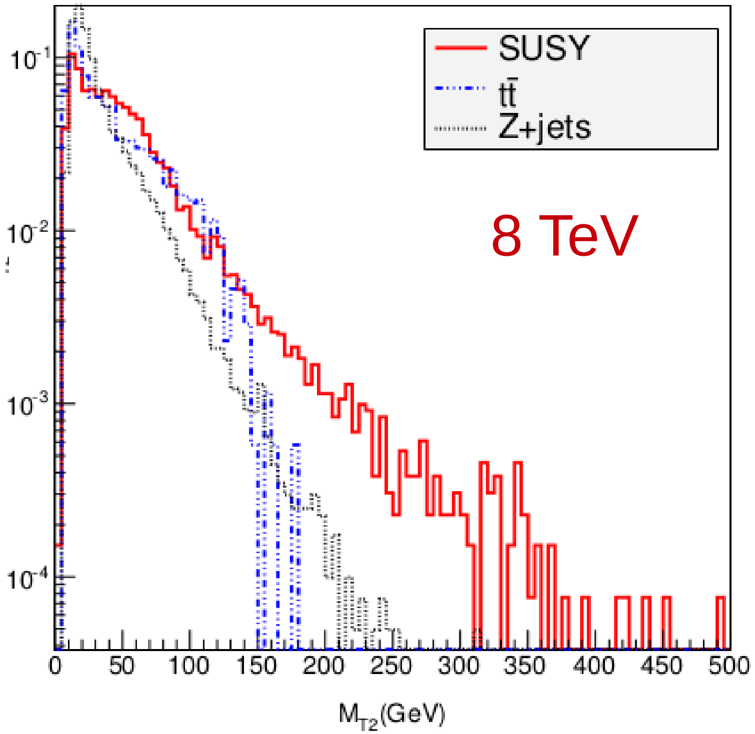
$$\alpha_{\mathrm{T}} > 0.55$$

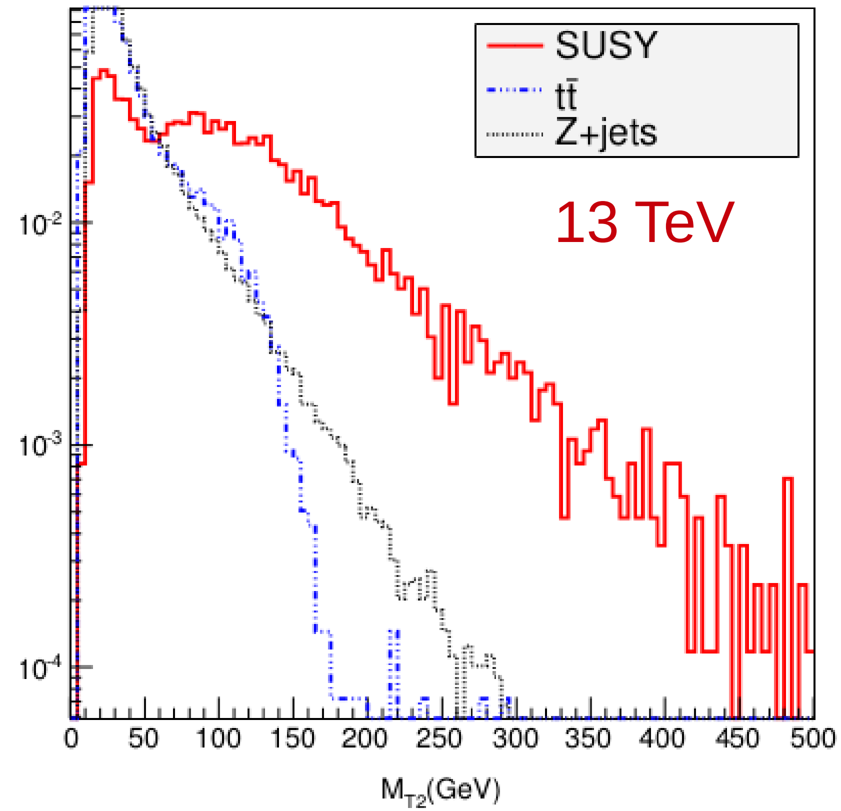
~~QCD~~

Belanger, DG, Godbole, Guchait, Sengupta, PRD 2013

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

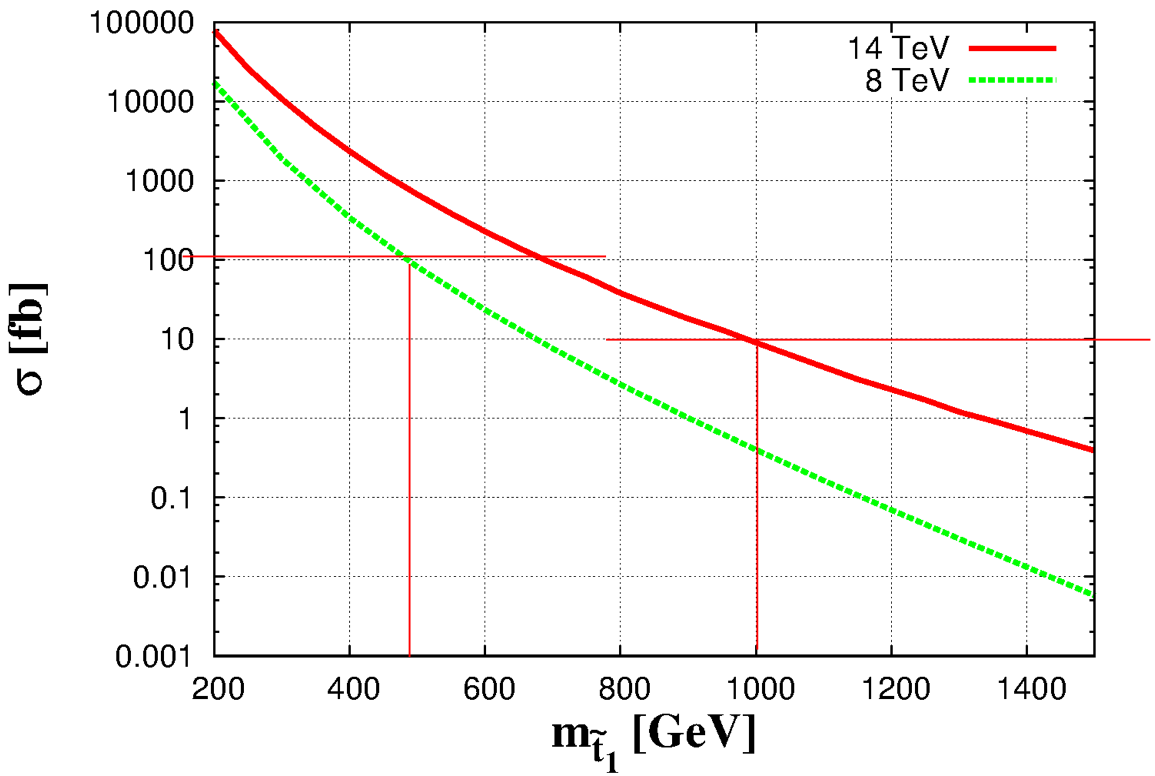






Belanger, DG, Godbole, Guchait, Sengupta, PRD 2013

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

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

$$B \rightarrow B \times 4 \times 4$$

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