Pair-production and three-body decay of the lighter stop at the ILC in one-loop order in the MSSM

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GRACE-SUSY collaboration

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Outline

1. Motivation
2. Three-body decay of stop1
3. Pair-production of stop1
4. Summary

1. Motivation

- **Low MET events**
  can be hidden at the LHC

- **Usually, MET(3-body decay) < MET(2-body decay)**

- **Large Yukawa coupling of top quark** ⇨ $M_{\tilde{t}_1} < M_{\tilde{q}(\neq \tilde{t}_1)}$

2. Three-body decay of stop1

- **Two scenarios:**

Scenario 1. Large slepton masses

$$\tilde{t}_1 \rightarrow b W^+ \tilde{\chi}_1^0$$ ⇨ **major decay mode (BR ~ 100%)**

1-loop correction: Ref. Iizuka, K. et al., PoS(RADCOR2009)068, (2010).

Scenario 2. Small slepton masses

'Semi-Leptonic' decay modes dominate ⇦ We focus on

$$\tilde{t}_1 \rightarrow b l^+ \tilde{\nu}_l \qquad \tilde{t}_1 \rightarrow b \tilde{l}^+ \nu_l$$

Parameters

Scenario 1			
$\tan\beta$	10	$m_{\tilde{b}_1}$	330GeV
μ	-750GeV	$\theta_{\tilde{b}}$	0.6π
M_2	400GeV	m_A	525GeV
$m_{\tilde{\ell}_1^+}$	325GeV	$m_{\tilde{g}}$	1389GeV
$m_{\tilde{\ell}_2^+}$	370GeV	$m_{\tilde{\chi}_1^0}$	194GeV
$\theta_{e,\mu}$	0.05π	$m_{\tilde{\chi}_1^+}$	396GeV
θ_τ	0.2π		
$m_{\tilde{\nu}_{e,\mu}}$	316GeV		
$m_{\tilde{\nu}_\tau}$	328GeV		
$m_{\tilde{t}_2}$	480GeV		
$\theta_{\tilde{t}}$	0.8π		

Scenario 2			
$\tan\beta$	7	$m_{\tilde{b}_1}$	330GeV
μ	-500GeV	$\theta_{\tilde{b}}$	0.6π
M_2	300GeV	m_A	300GeV
$m_{\tilde{\ell}_1^+}$	170GeV	$m_{\tilde{g}}$	1042GeV
$m_{\tilde{\ell}_2^+}$	175GeV	$m_{\tilde{\chi}_1^0}$	146GeV
$\theta_{e,\mu}$	0.01π	$m_{\tilde{\chi}_1^+}$	294GeV
θ_τ	0.2π		
$m_{\tilde{\nu}_{e,\mu}}$	151GeV		
$m_{\tilde{\nu}_\tau}$	152GeV		
$m_{\tilde{t}_2}$	600GeV		
$\theta_{\tilde{t}}$	0.8π		

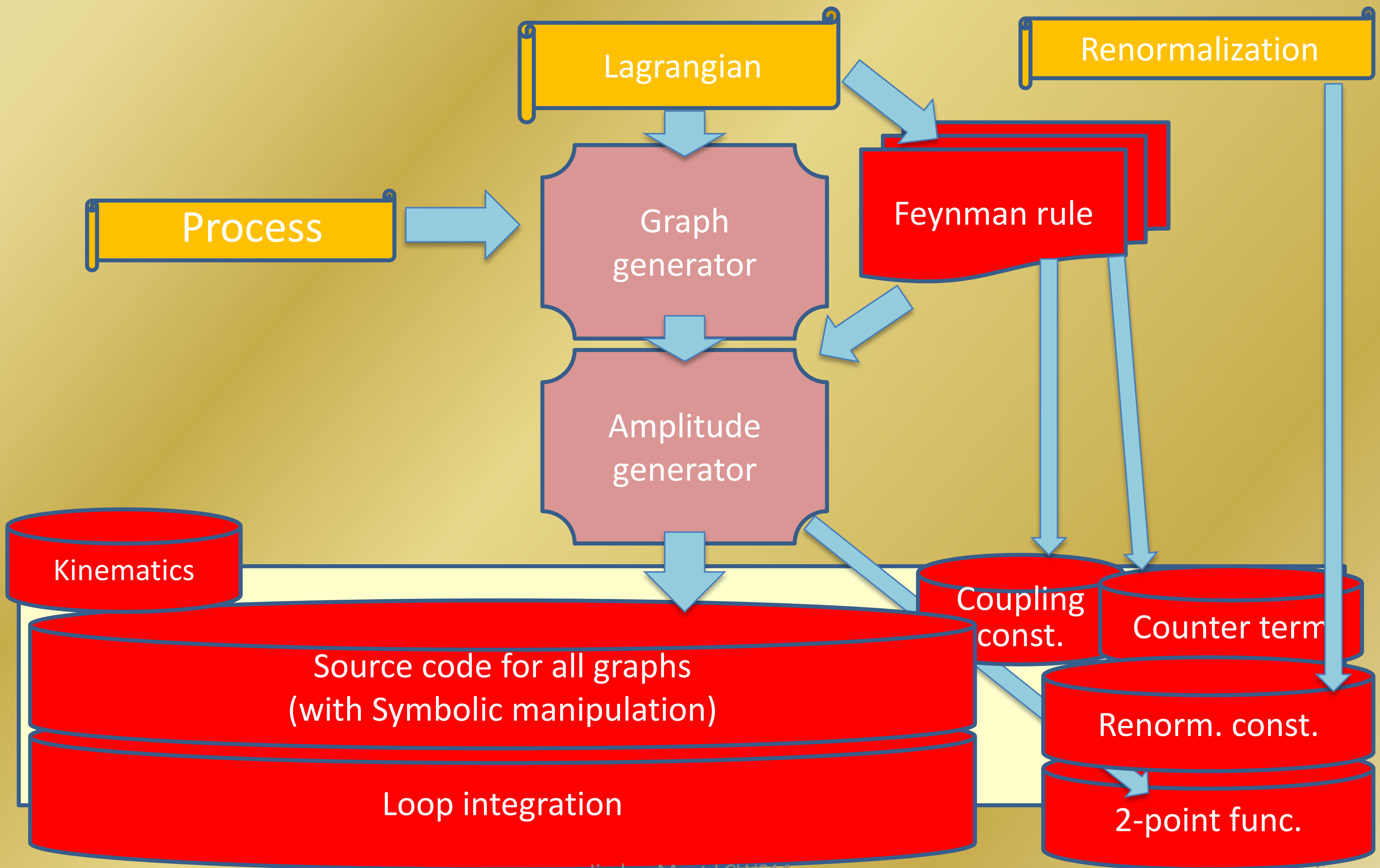
Calculation tool

GRACE/SUSY-loop

- **Generates all Feynman diagrams automatically**
- **Generates physical amplitudes automatically**
- **Incorporates libraries (2-point functions, Loop integral, Kinematics, etc.)**
- **Integrates the matrix element by the adaptive Monte Carlo method (**BASES**)**
- **Does Monte Carlo event generation (**SPRING**)**
- **Enables various self-check for the results (UV cancellation, IR cancellation, NLG invariance, etc.)**

Other automatic SUSY 1-loop systems
SloopS (Boudjema, F., et al., 2005), FeynArt/Calc (Hahn, T., 2001, 2006)

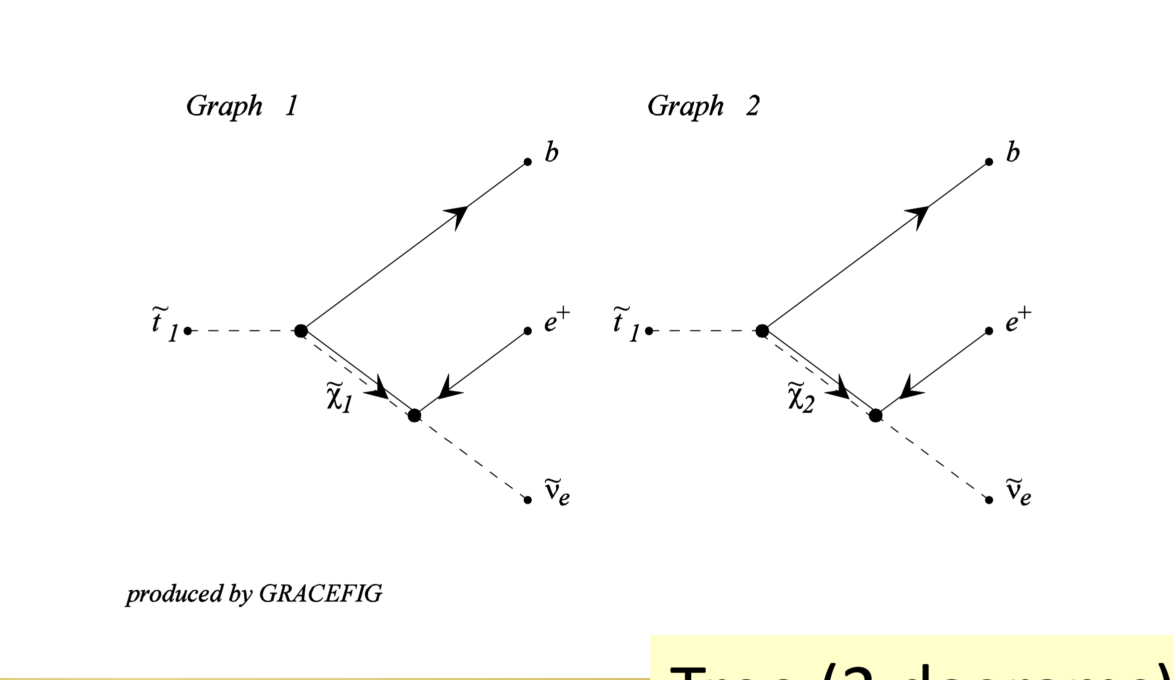
Structure of automatic systems for loop calculation



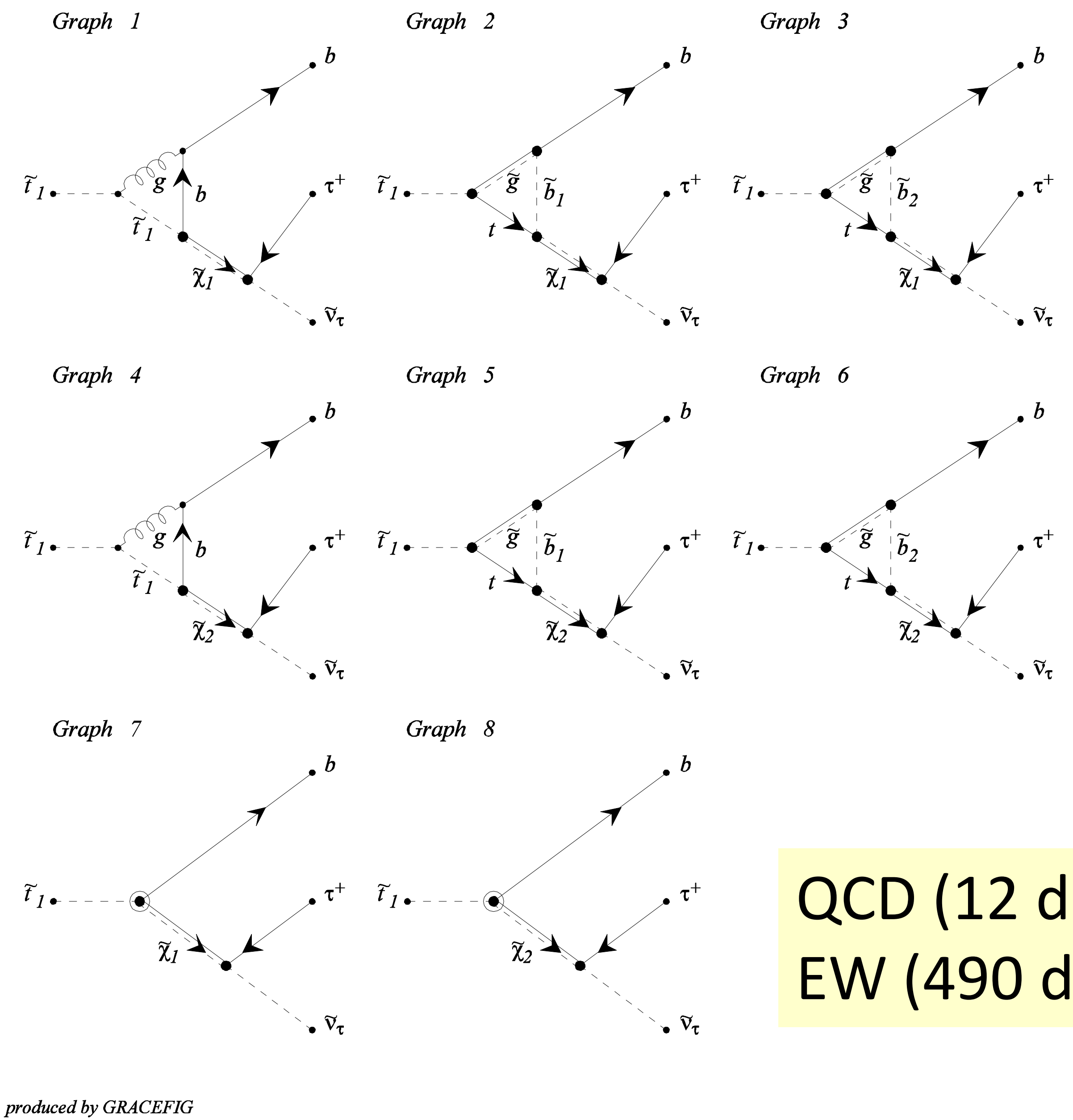
Feynman diagrams

For example,

$$\tilde{t}_1 \rightarrow b\, e^+ \tilde{\nu}_e$$

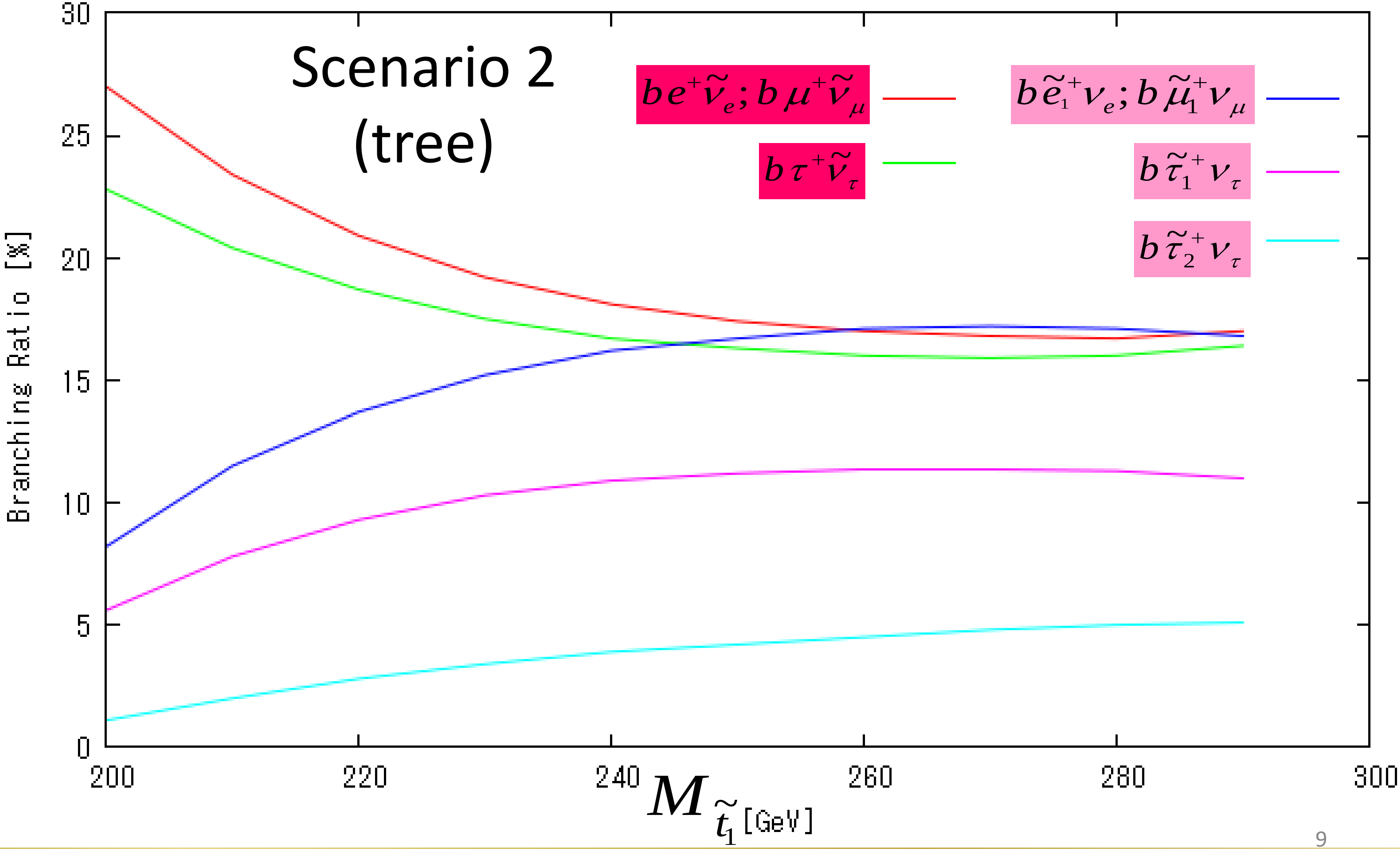


Tree (2 dagrams)

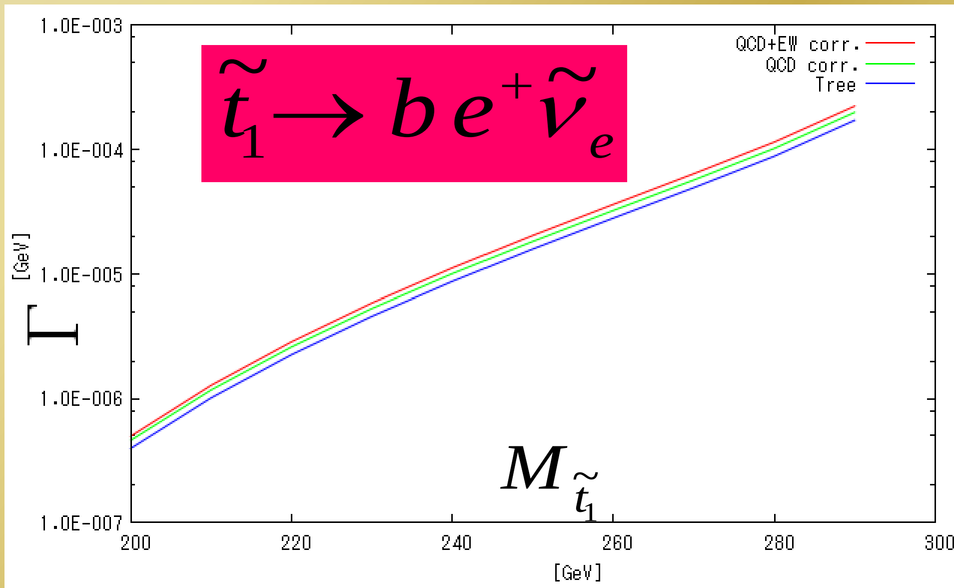


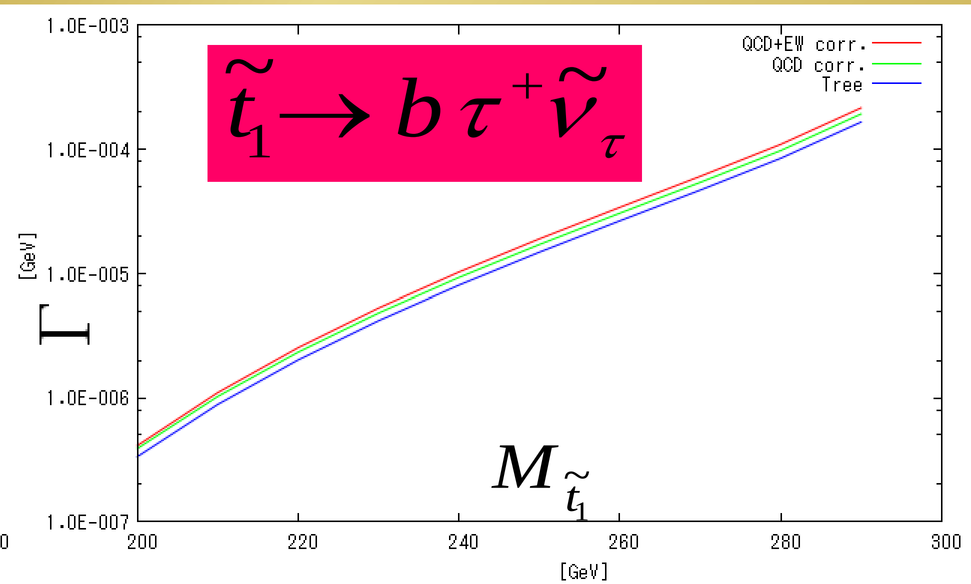
QCD (12 diagrams)
EW (490 diagrams)

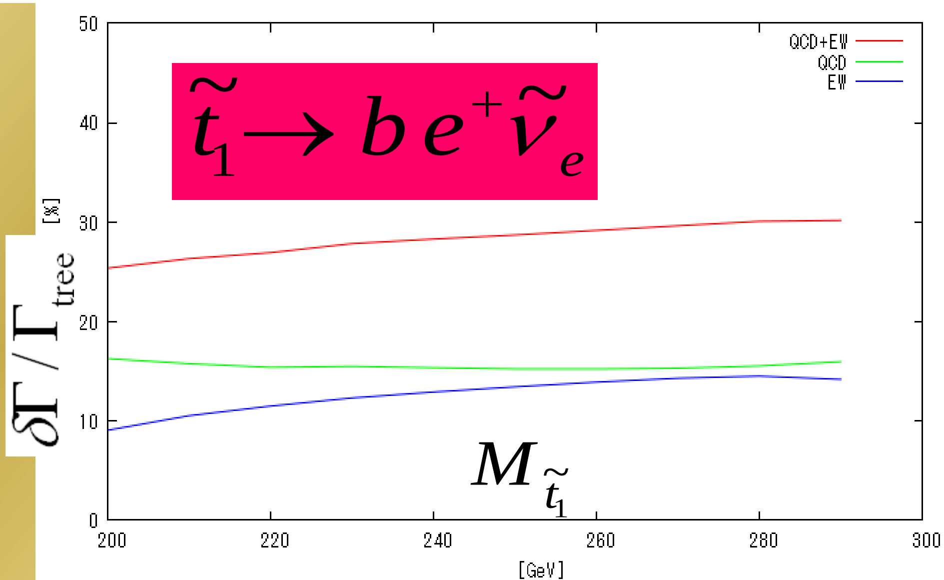
Branching ratios of $\tilde{t}_1$ decay

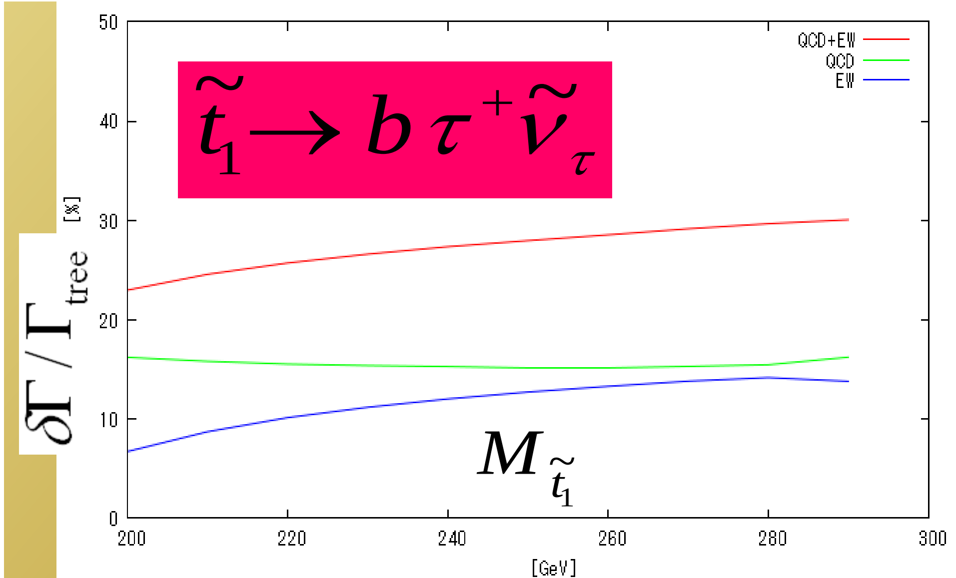


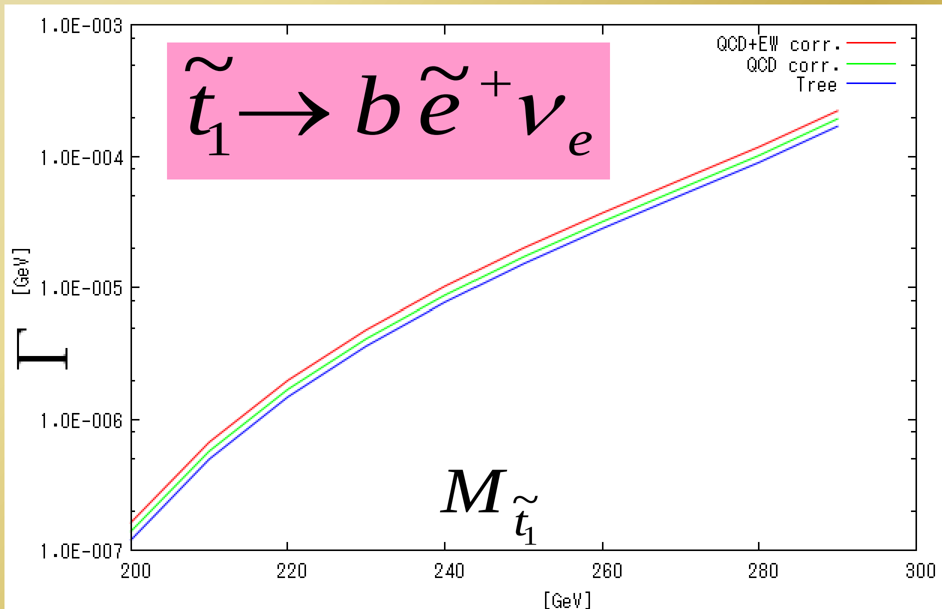
RC of decay widths

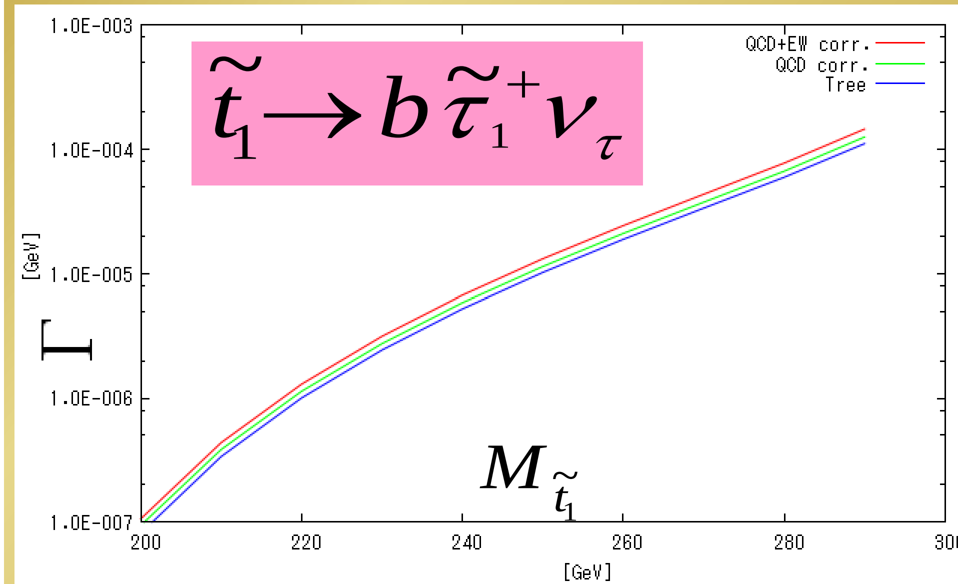


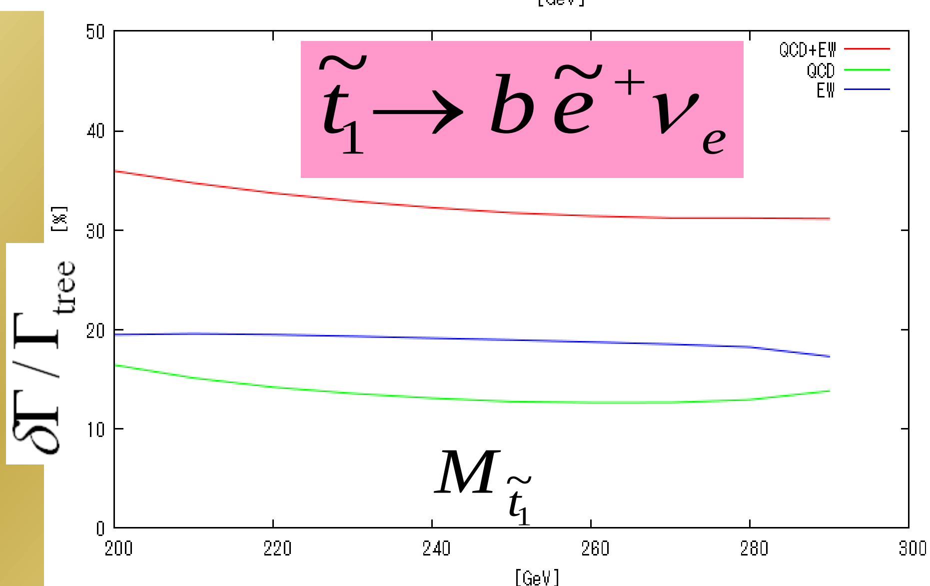


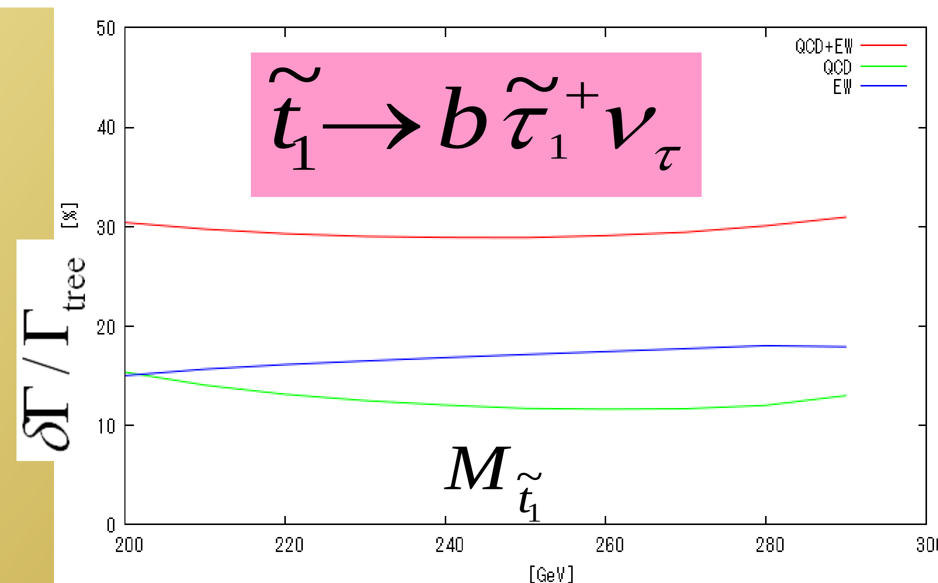


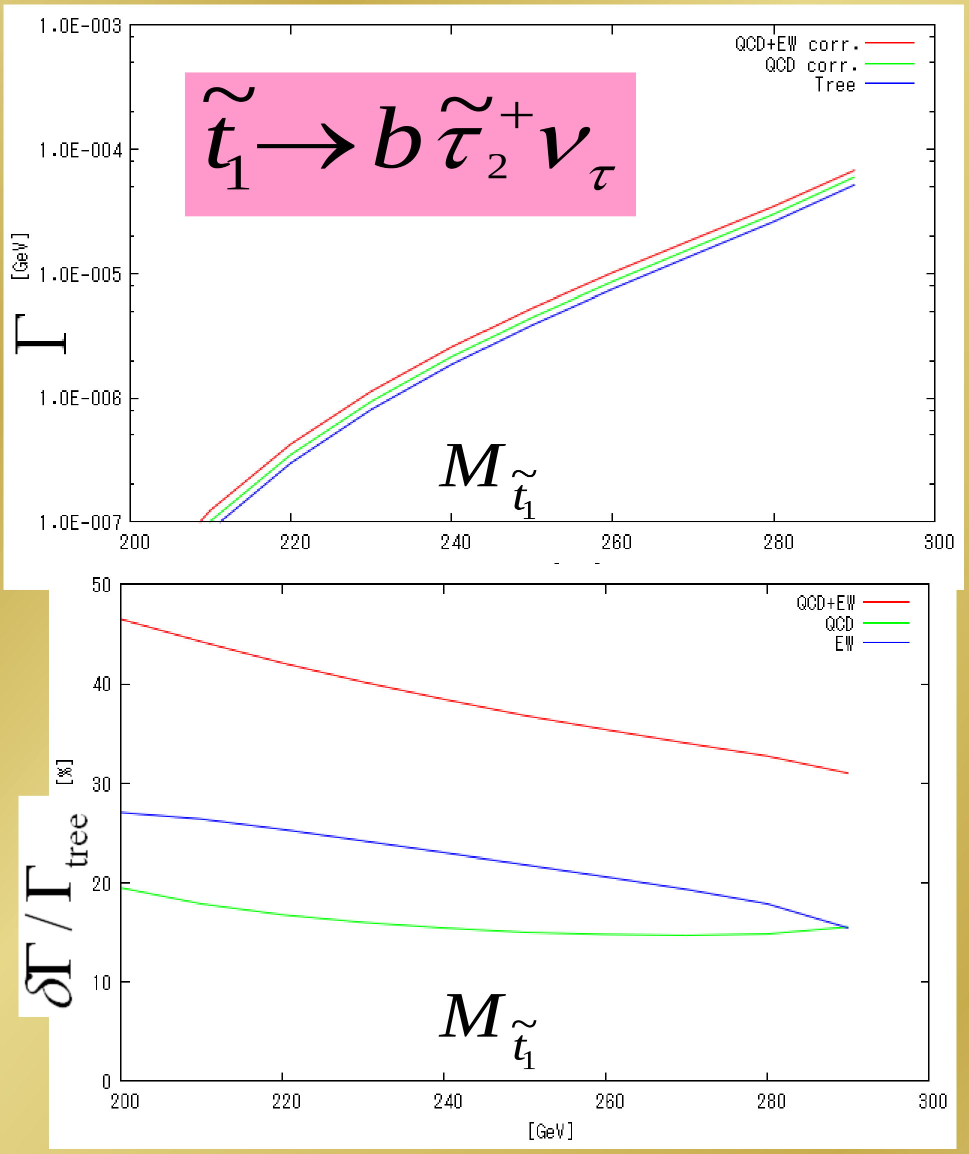



$\tilde{t}_1 \to b\,\tilde{e}^+\nu_e$
QCD+EW corr.
QCD corr.
Tree
Γ [GeV]
1.0E-003
1.0E-004
1.0E-005
1.0E-006
1.0E-007
$M_{\tilde{t}_1}$
200
220
240
260
280
300
[GeV]


$\tilde{t}_1 \to b\,\tilde{\tau}_1^+\nu_\tau$
QCD+EW corr.
QCD corr.
Tree
Γ [GeV]
1.0E-003
1.0E-004
1.0E-005
1.0E-006
1.0E-007
$M_{\tilde{t}_1}$
200
220
240
260
280
300
[GeV]

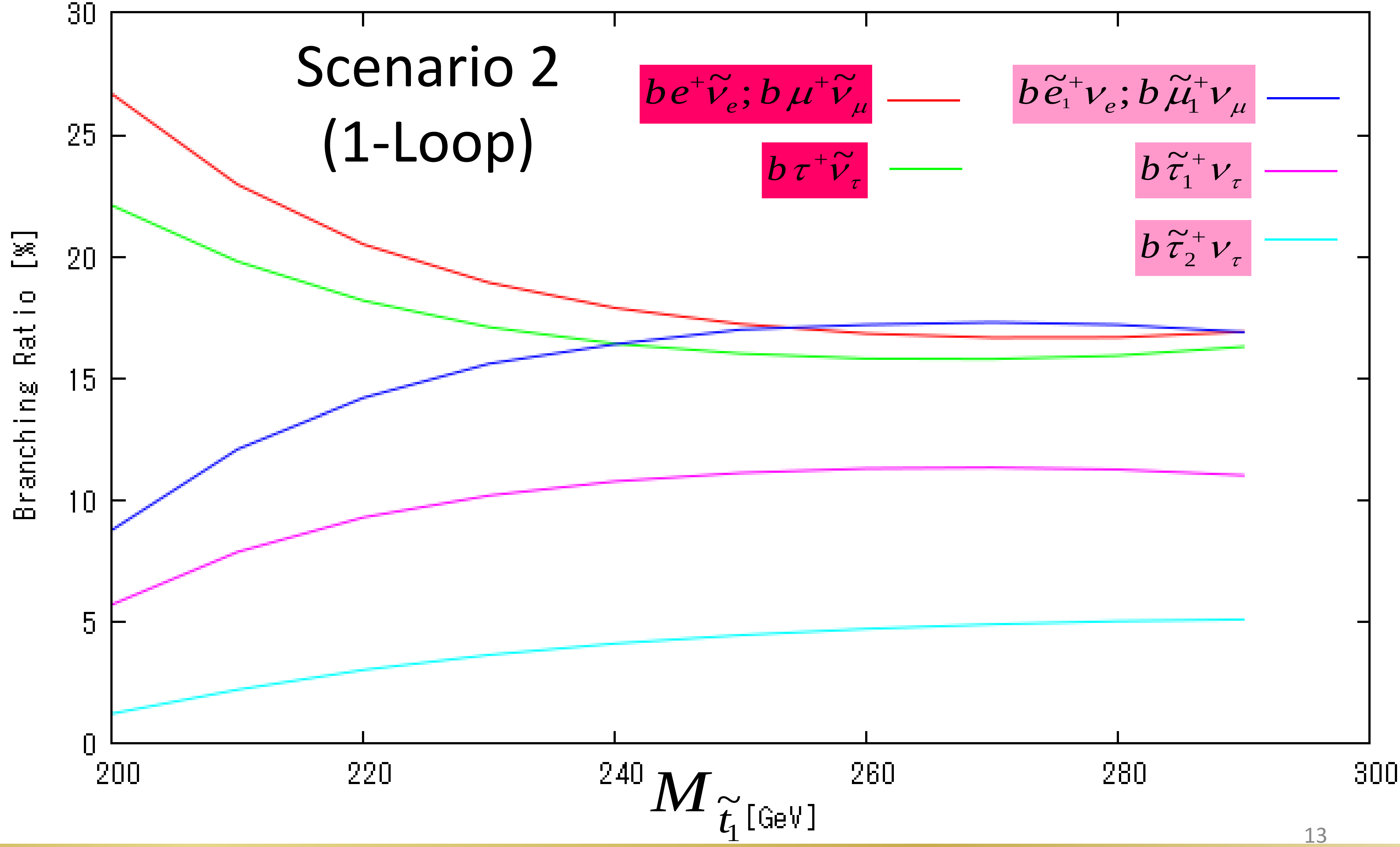

$\tilde{t}_1 \to b\,\tilde{e}^+\nu_e$
QCD+EW
QCD
EW
$\delta\Gamma / \Gamma_{tree}$ [%]
50
40
30
20
10
0
$M_{\tilde{t}_1}$
200
220
240
260
280
300
[GeV]


$\tilde{t}_1 \to b\,\tilde{\tau}_1^+\nu_\tau$
QCD+EW
QCD
EW
$\delta\Gamma / \Gamma_{tree}$ [%]
50
40
30
20
10
0
$M_{\tilde{t}_1}$
200
220
240
260
280
300
[GeV]



1.0E-003
1.0E-004
1.0E-005
1.0E-006
1.0E-007
[GeV]
Γ
QCD+EW corr.
QCD corr.
Tree
$\tilde{t}_1 \to b\,\tilde{\tau}_2^+ \nu_\tau$
$M_{\tilde{t}_1}$
200
220
240
260
280
300
50
40
30
20
10
0
[%]
$\delta\Gamma / \Gamma_{tree}$
QCD+EW
QCD
EW
$M_{\tilde{t}_1}$
200
220
240
260
280
300
[GeV]

Branching ratios of $\tilde{t}_1$ decay



Summary of $\tilde{t}_1$ decay

Decay modes	$\tilde{t}_1 \to b e^+ \tilde{\nu}_e$	$\tilde{t}_1 \to b \tau^+ \tilde{\nu}_\tau$	$\tilde{t}_1 \to b \tilde{e}^+ \nu_e$	$\tilde{t}_1 \to b \tilde{\tau}_1^+ \nu_\tau$	$\tilde{t}_1 \to b \tilde{\tau}_2^+ \nu_\tau$
QCD	15%~16%	15%~16%	13%~16%	11%~15%	15%~20%
EW	9%~14%	7%~14%	17%~20%	15%~18%	11%~27%
Max. of QCD + EW	30%	30%	36%	31%	47%

$\delta\Gamma_{\mathrm{QCD}} > \delta\Gamma_{\mathrm{EW}} > 0$ (first two modes)

$\delta\Gamma_{\mathrm{EW}} > \delta\Gamma_{\mathrm{QCD}} > 0$ (last three modes)

⇨ **Dependence of branching ratios on $M_{\tilde{t}_1}$ in the1-loop level is almost similar to that in the tree level.**

3. Pair-production of stop1

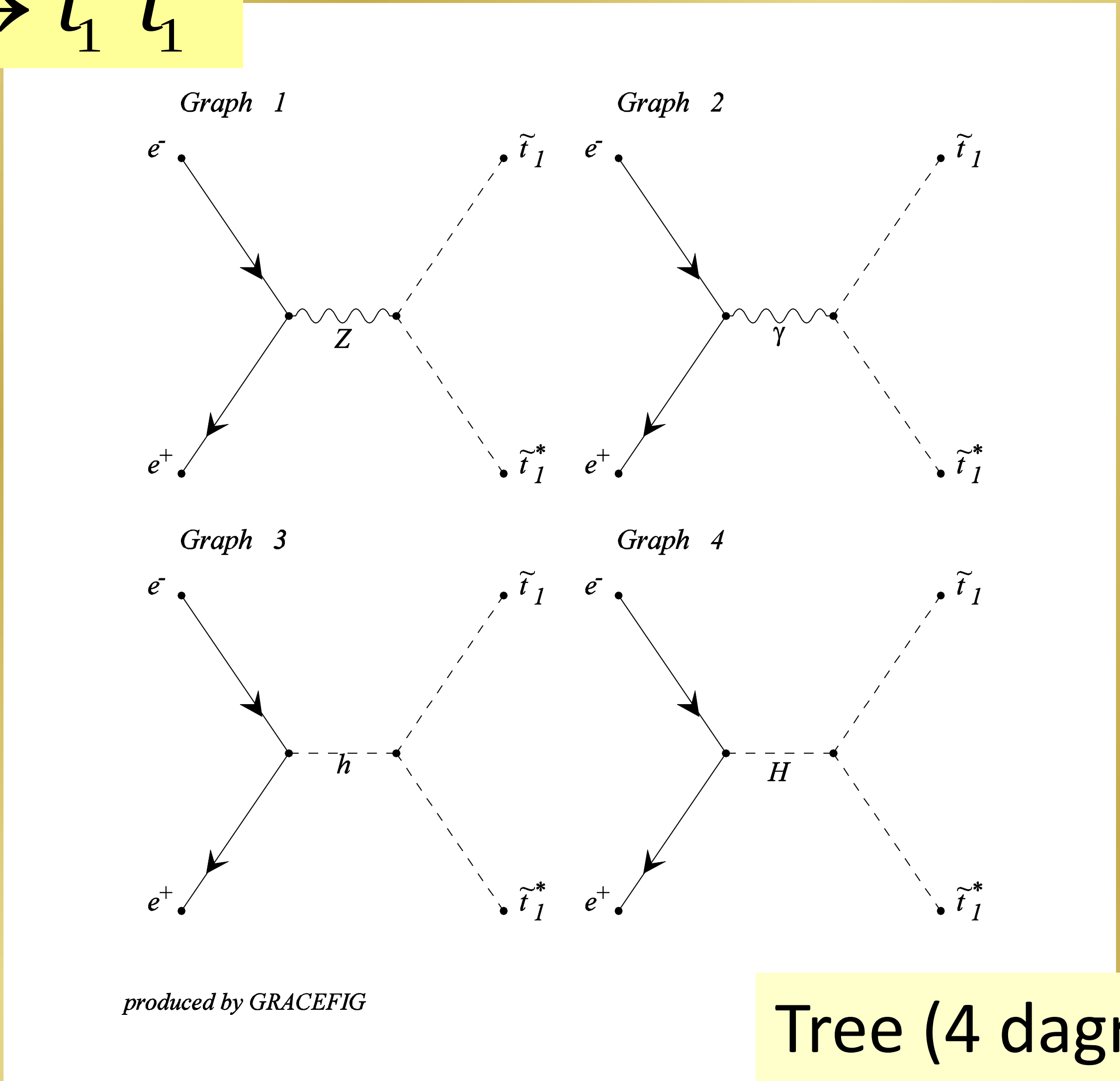
- **Calculation of cross sections is done using the parameter sets adopted in that of the decay widths.**

cf. For SPS1a' case:

Ref. Eberl, H., Fortschr. Phys. 58, No. 7–9, 712 (2010).

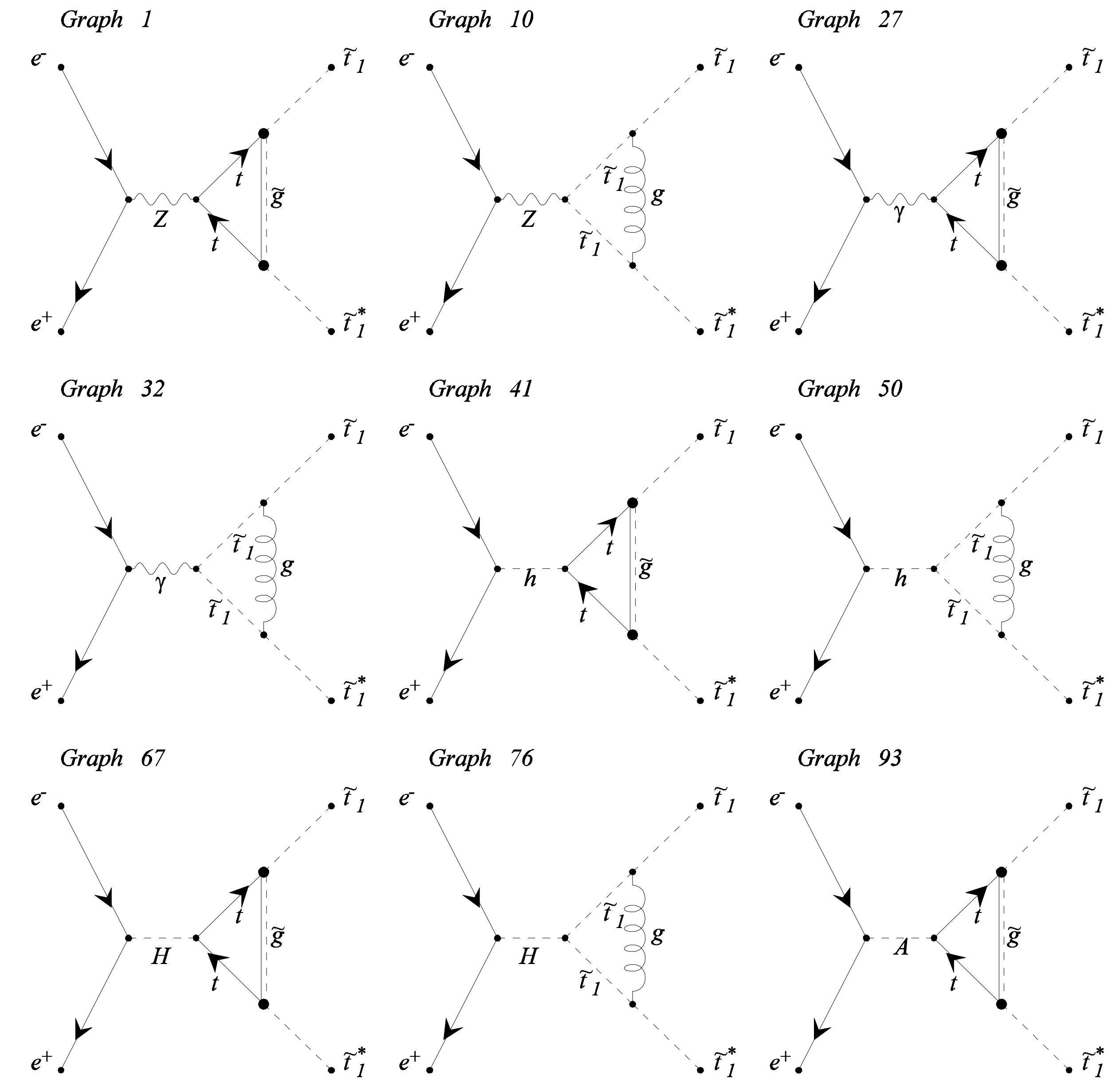
Feynman diagrams

$$e^- e^+ \to \tilde{t}_1 \tilde{t}_1^*$$



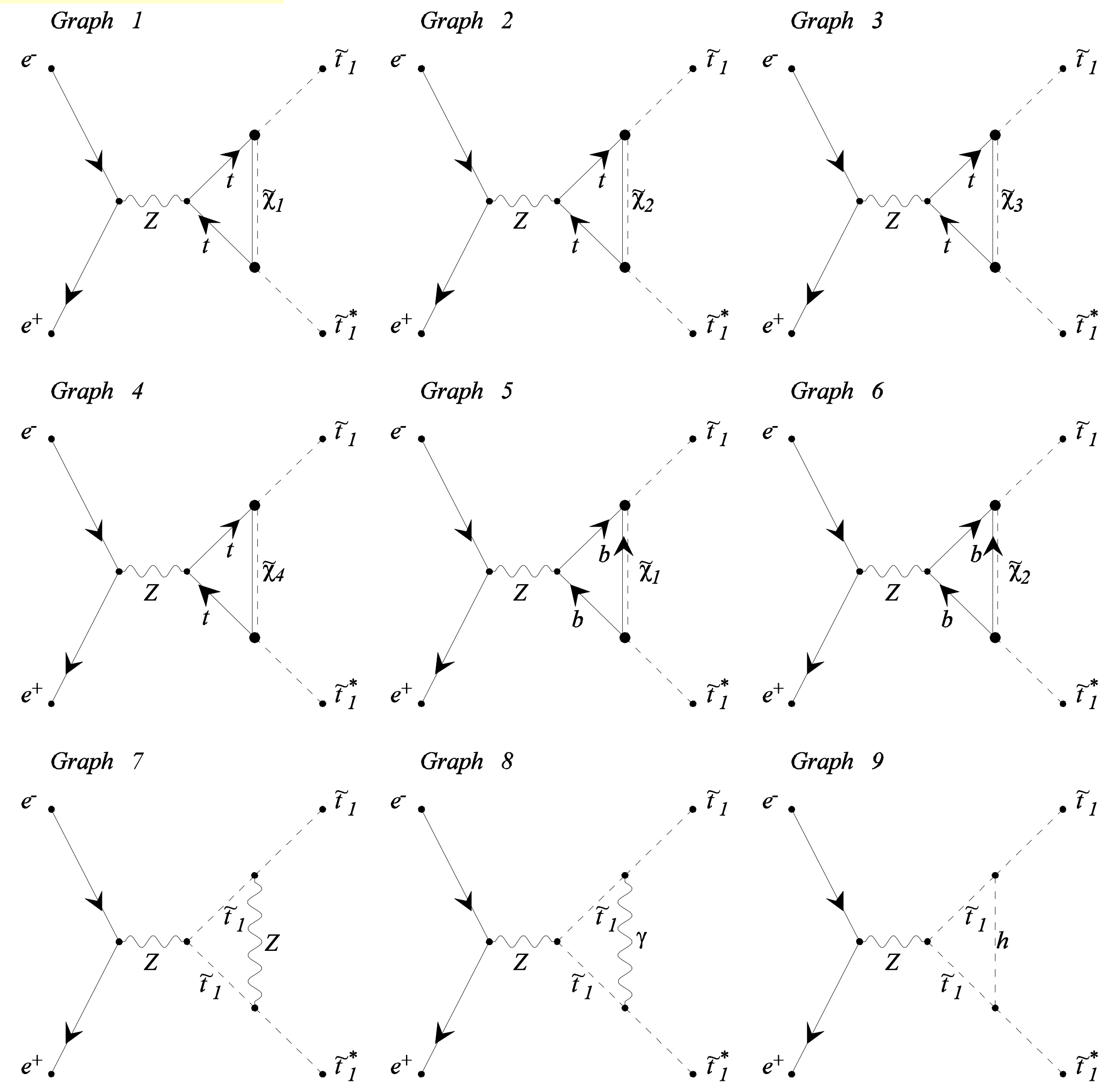
Tree (4 dagrams)

QCD (252 diagrams)



produced by GRACEFIG

EW (1251 diagrams)



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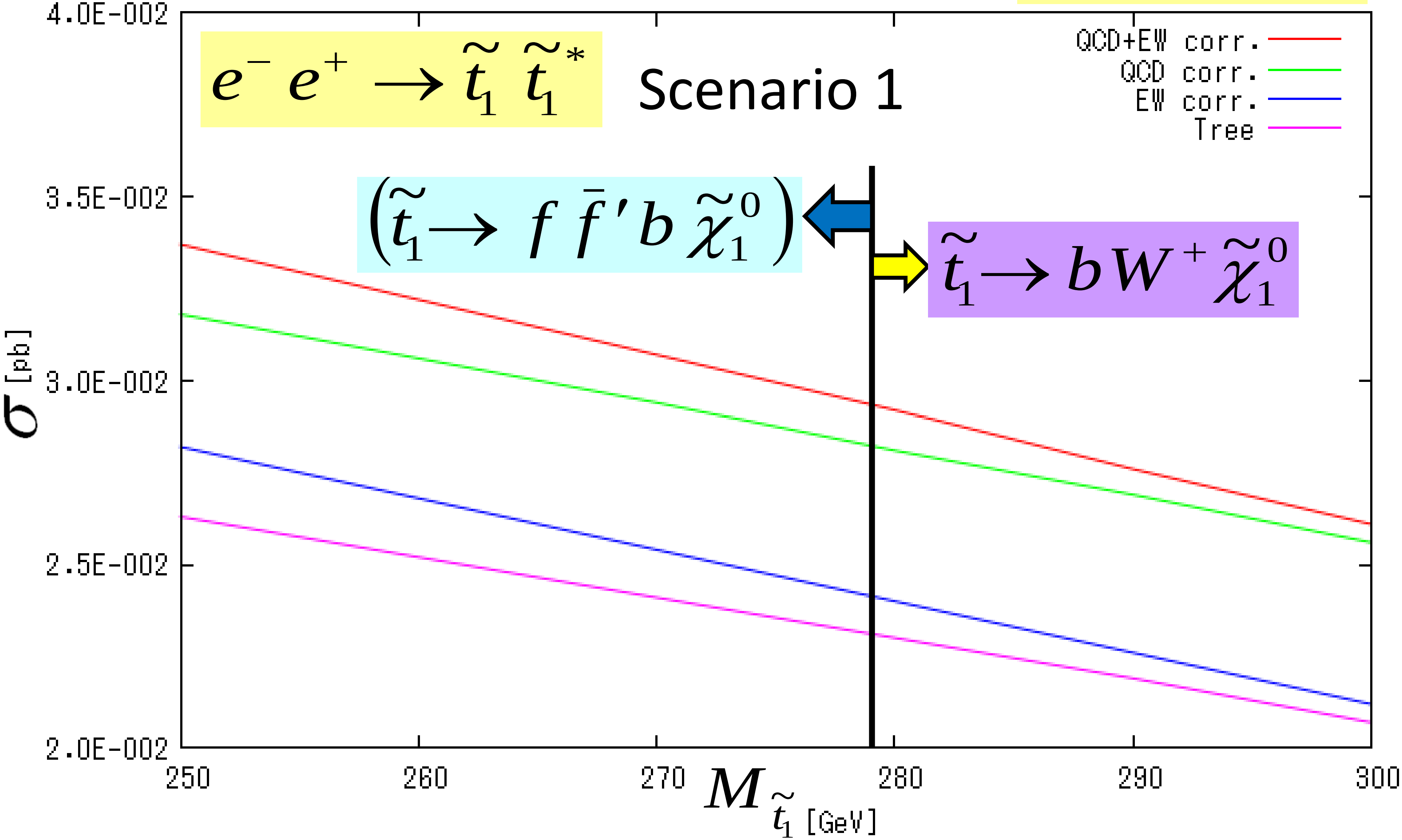
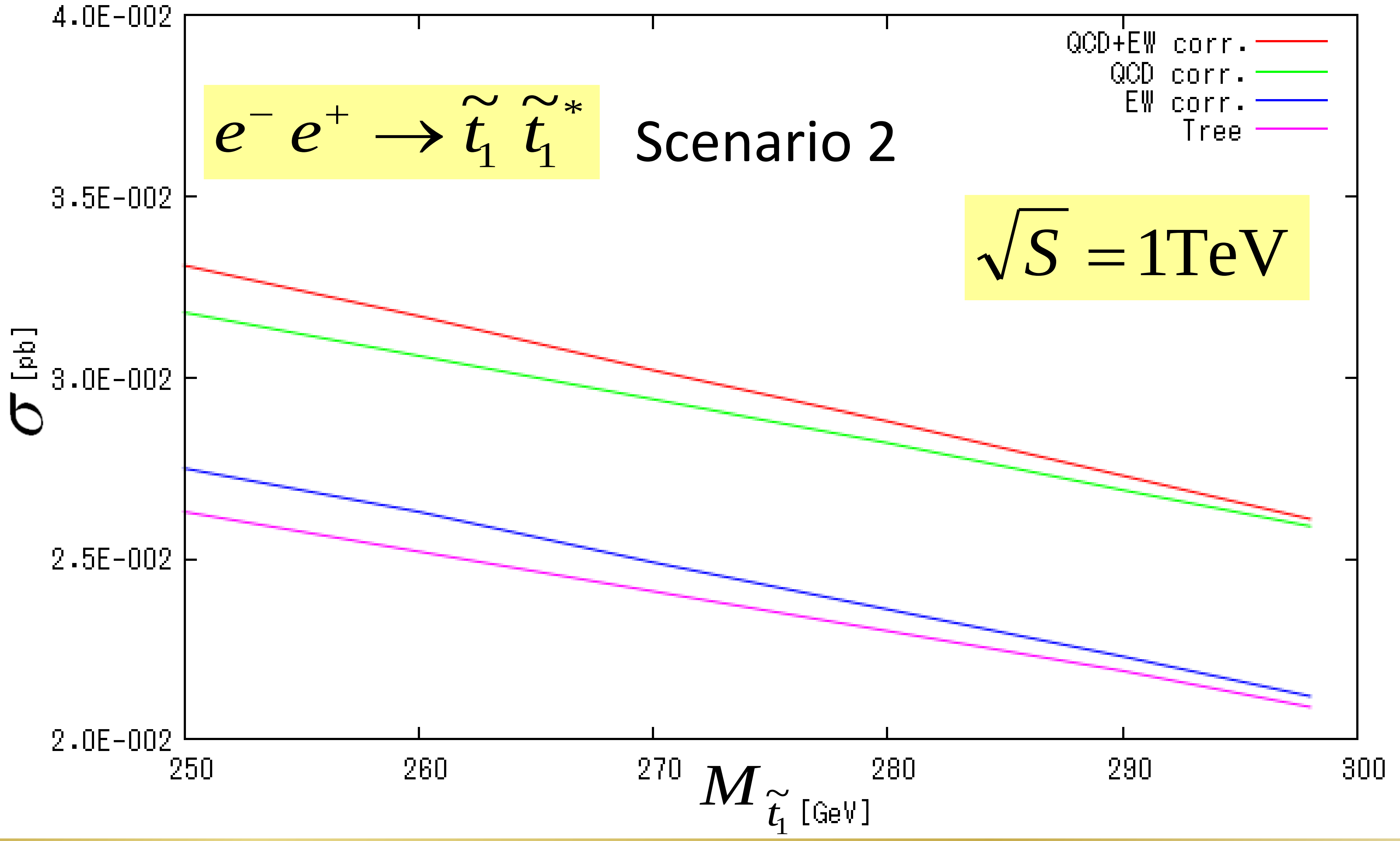
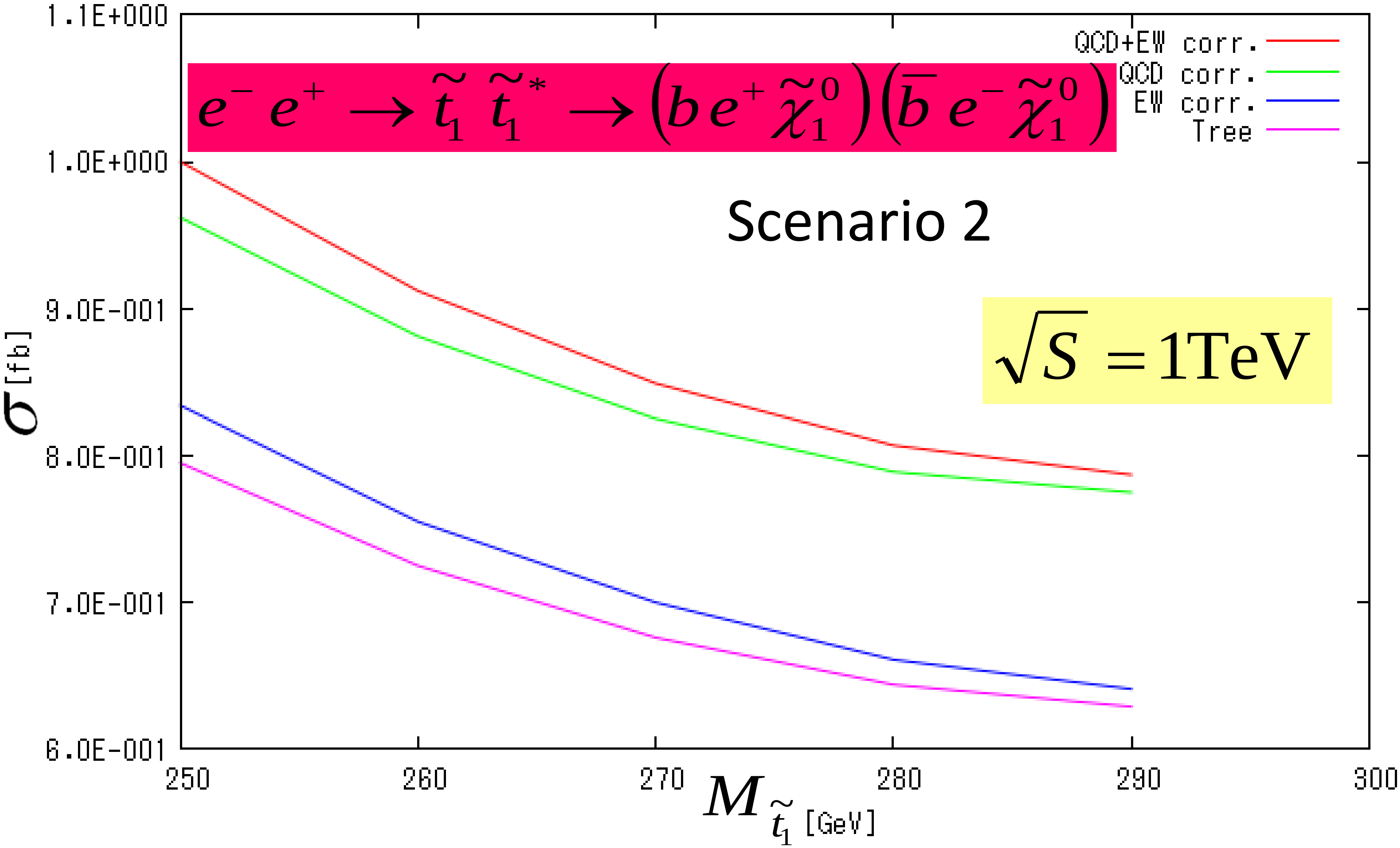
Cross sections

$\sqrt{S} = 1\text{TeV}$



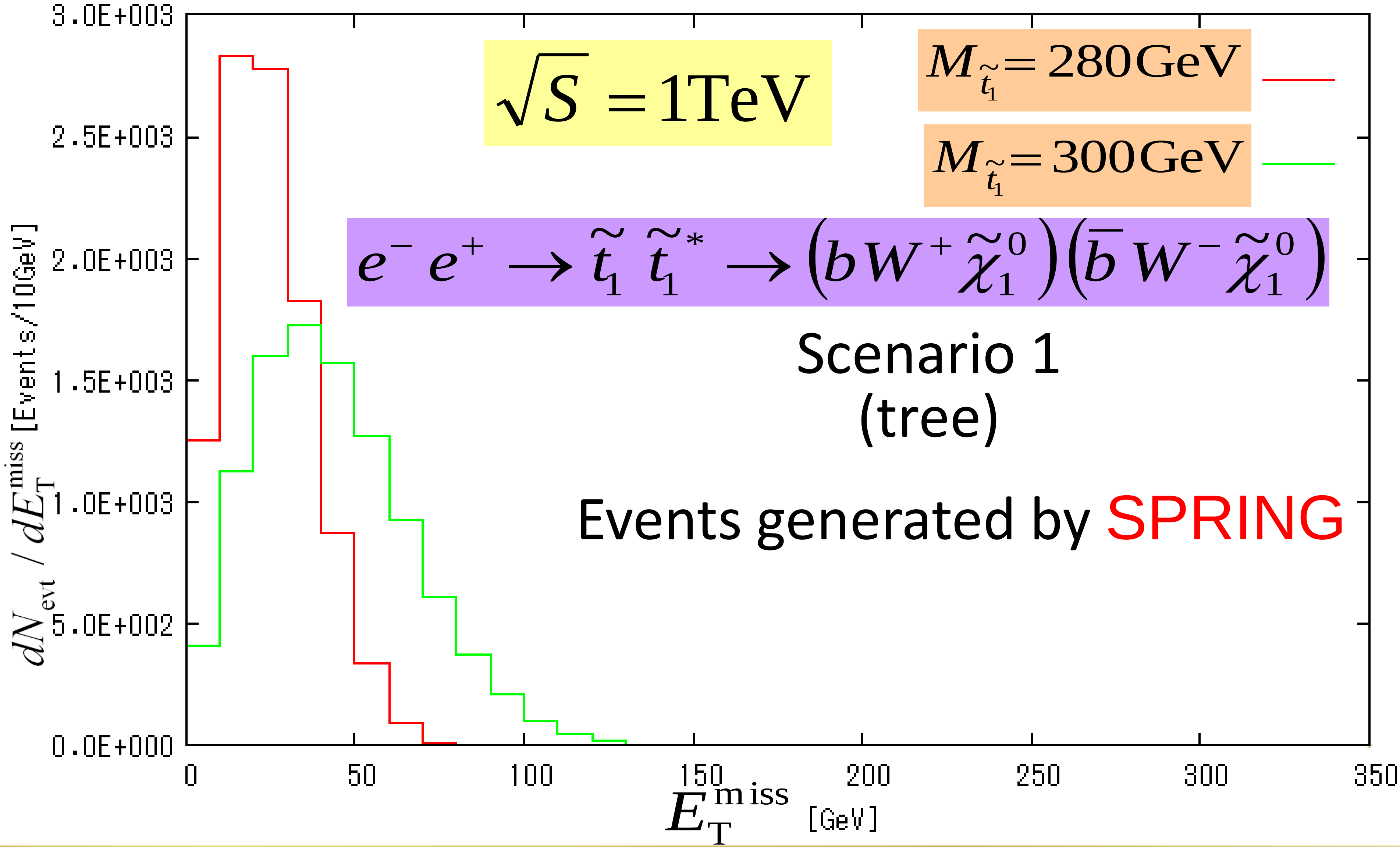


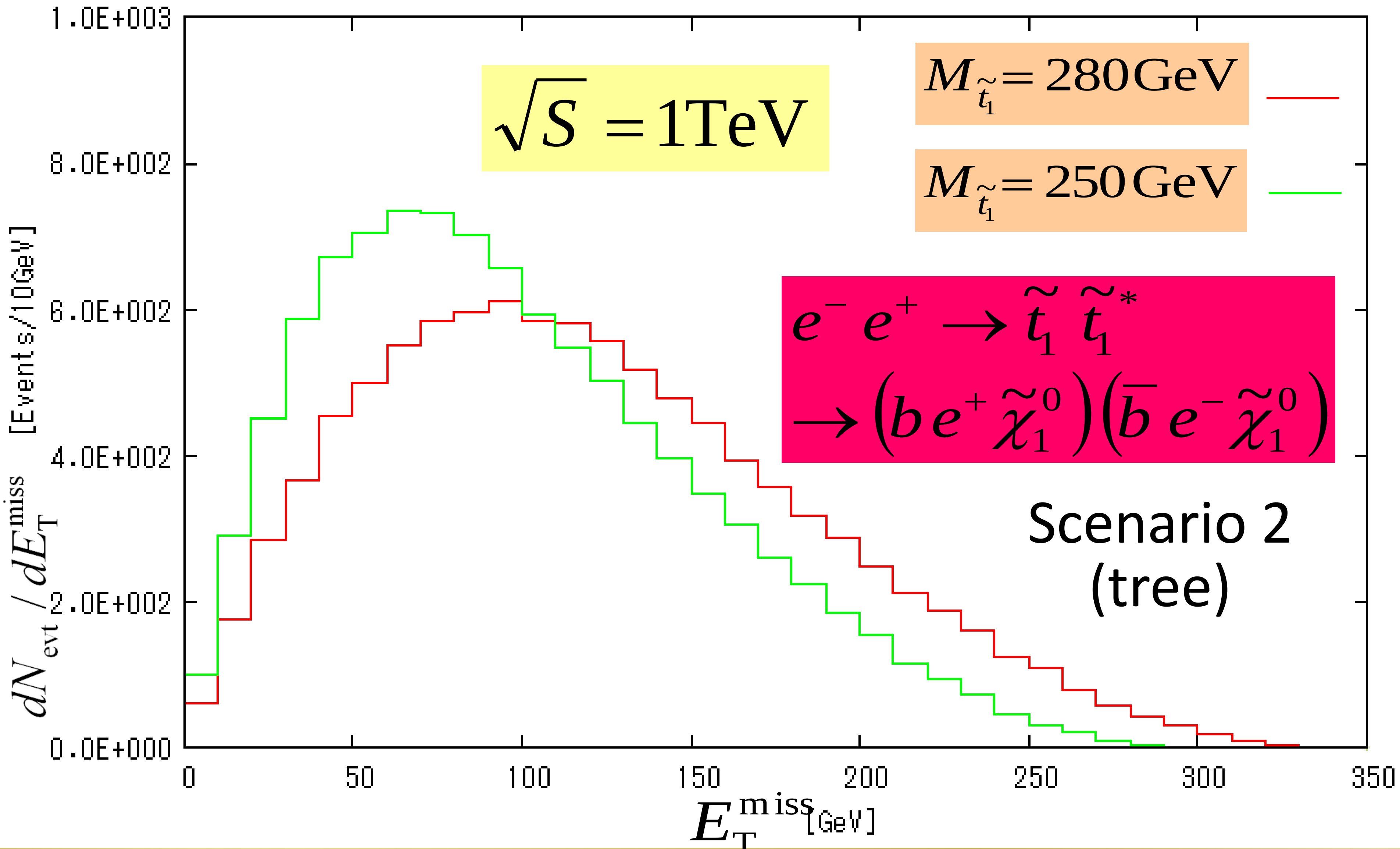
QCD+EW corr.
QCD corr.
EW corr.
Tree
$e^- e^+ \to \tilde{t}_1 \tilde{t}_1^*$
Scenario 2
$\sqrt{S} = 1\text{TeV}$
4.0E-002
3.5E-002
3.0E-002
2.5E-002
2.0E-002
σ [pb]
250
260
270
280
290
300
$M_{\tilde{t}_1}$ [GeV]



1.1E+000
1.0E+000
9.0E-001
8.0E-001
7.0E-001
6.0E-001
250
260
270
280
290
300
QCD+EW corr.
QCD corr.
EW corr.
Tree
$e^- e^+ \to \tilde{t}_1 \tilde{t}_1^* \to \left(b e^+ \tilde{\chi}_1^0\right)\left(\bar{b} e^- \tilde{\chi}_1^0\right)$
Scenario 2
$\sqrt{S} = 1\mathrm{TeV}$
σ [fb]
$M_{\tilde{t}_1}$ [GeV]

MET distribution





$\sqrt{S} = 1\text{TeV}$
$M_{\tilde{t}_1} = 280\text{GeV}$
$M_{\tilde{t}_1} = 250\text{GeV}$
$e^- e^+ \rightarrow \tilde{t}_1 \tilde{t}_1^*$
$\rightarrow (b e^+ \tilde{\chi}_1^0)(\bar{b} e^- \tilde{\chi}_1^0)$
Scenario 2
(tree)
dN_{evt} / dE_T^{miss} [Events/10GeV]
1.0E+003
8.0E+002
6.0E+002
4.0E+002
2.0E+002
0.0E+000
0
50
100
150
200
250
300
350
E_T^{miss} [GeV]

4. Summary

- **Both QCD and EW corrections have positive sign for decay widths and cross sections in the range of the mass of stop1 for which 3-body decay of stop1 is dominant.**
- **Events for MET < 100GeV should be analyzed in detail for ILC study.**