One-loop SQCD corrections to the decay $\tilde{t}_1 \to c\tilde{\chi}_1^0$

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FOR FUNDAMENTAL PHYSICS

Outline

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1. Motivation

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2. Process

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3. Results

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2. Process
3. Results
4. Conclusion

Motivation for a light stop

Motivation for a light stop

Naturalness

Cancellation of quadratic divergences

Motivation for a light stop

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Cancellation of quadratic divergences

W^+W^- Anomaly

arXiv:1406.0848v1, 1407.1043v1

Cross section 2-3σ discrepancy to SM

Motivation for a light stop

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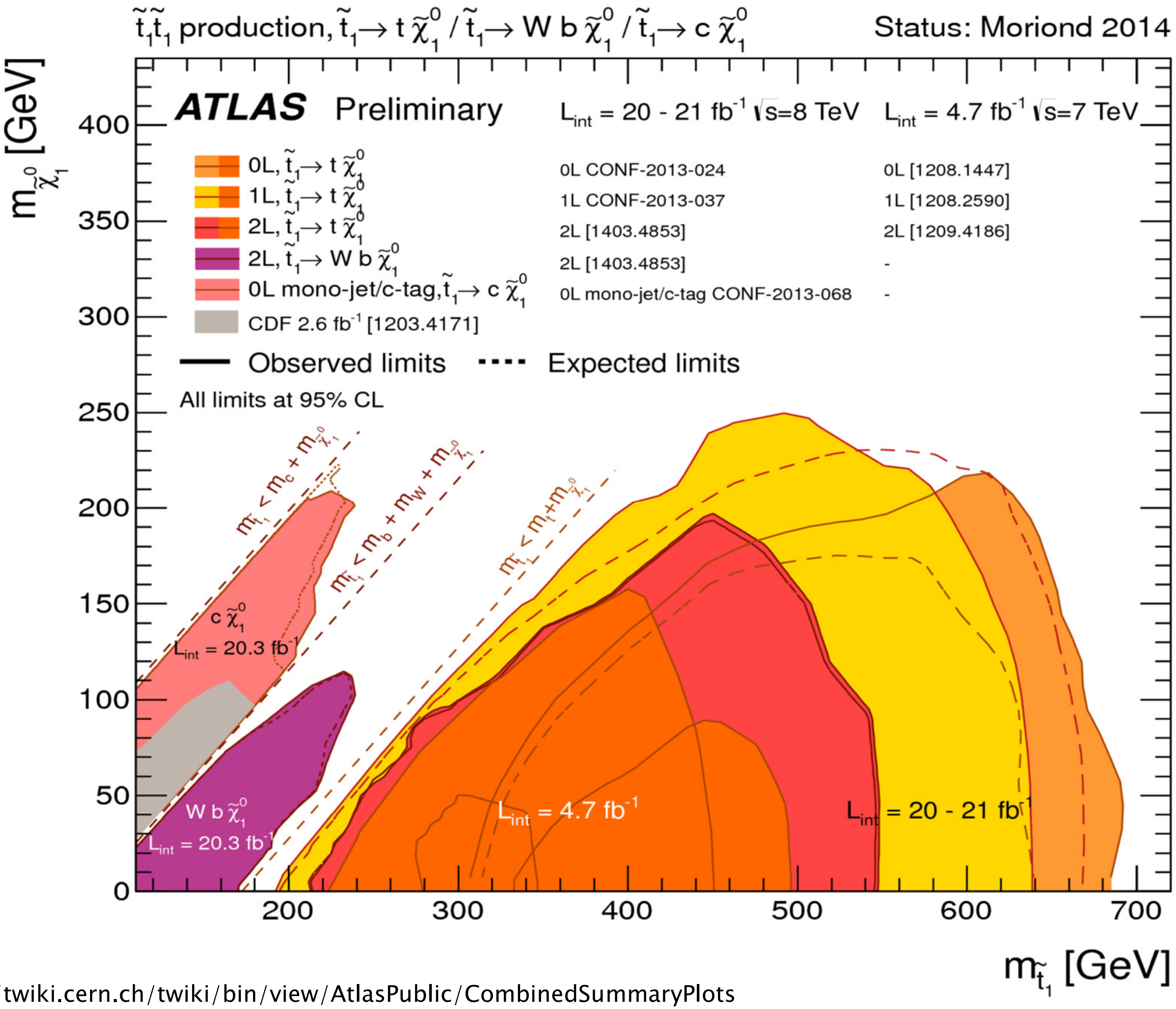
Cross section 2-3σ discrepancy to SM

RGE equations

Large Yukawa couplings of third generation

Search



Reference: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/CombinedSummaryPlots

Process

Process

Minimal Flavour Violation (MFV)

Displaced vertex

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Non-minimal Flavour Violation

Influence on other channels: $\Gamma\left(\tilde{t}_1 \rightarrow b\,\tilde{\chi}_1^0 W\right)$

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Tree level decay width

$$\Gamma\left[\tilde{t}_1 \to c\,\tilde{\chi}_1^0\right] = \frac{m_{\tilde{t}_1}}{16\pi}\frac{g_1^2}{18}\left(1-\frac{m_{\tilde{\chi}_1^0}^2}{m_{\tilde{t}_1}^2}\right)^2\left(\left|W_{21}^{\tilde{u}}\right|^2+16\left|W_{51}^{\tilde{u}}\right|^2\right), \qquad W_{s's}^{\tilde{u}*}\left(M_{\tilde{u}}^2\right)_{s't'}W_{t't}^{\tilde{u}} = m_{\tilde{u}_s}^2\delta_{st}$$

Assumptions

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$$m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} < m_t$$

$\tilde{\chi}_1^0$ is the LSP

$\tilde{t}_1$ is the NLSP

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R-parity

Dominant decays: $\tilde{t}_1 \to c\,\tilde{\chi}_1^0,\ \ \tilde{t}_1 \to b\,\tilde{\chi}_1^0 W$

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$$m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} < m_t$$

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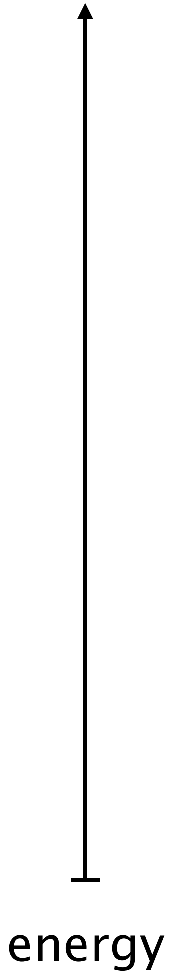
Dominant decays: $\tilde{t}_1 \to c\tilde{\chi}_1^0, \ \tilde{t}_1 \to b\tilde{\chi}_1^0 W$

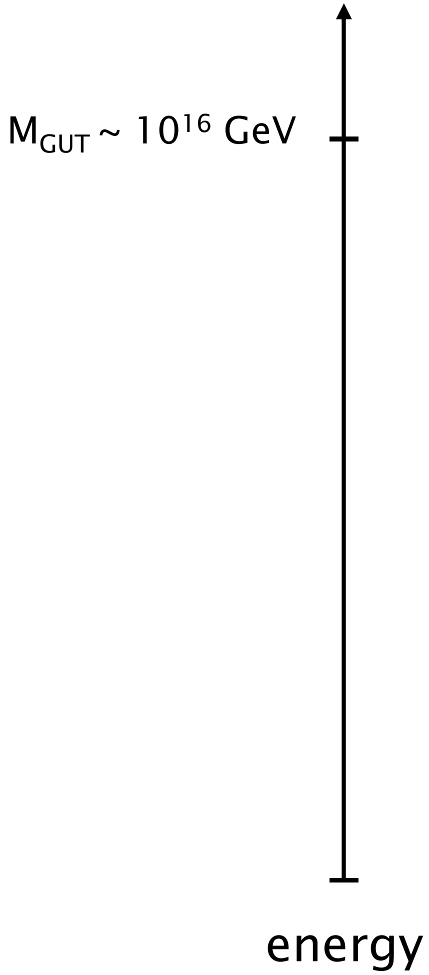
Flavour Structure

Minimal or Non-minimal flavour violation

Minimal Flavour Violation



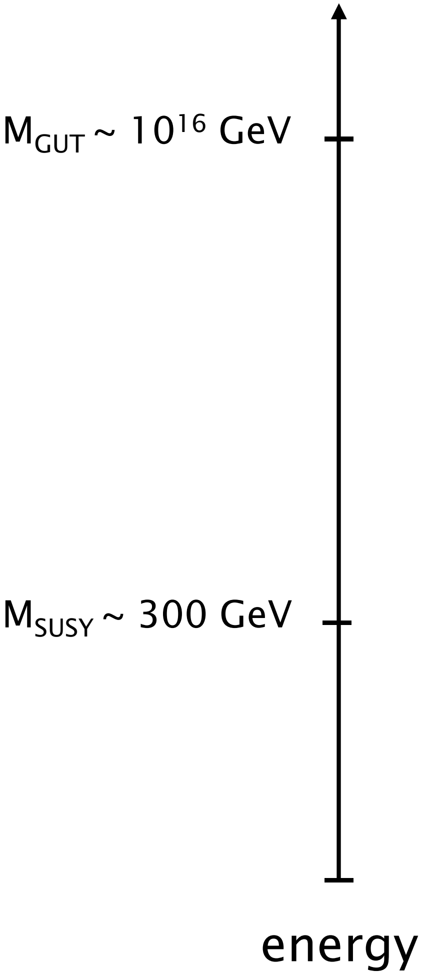
Minimal Flavour Violation



Flavour-blind SUSY breaking

$$\left(M_{\tilde{q}}^{2}\right)_{st} = m_0^2 \delta_{st} \quad \text{and} \quad A^f \sim Y^f$$

Minimal Flavour Violation



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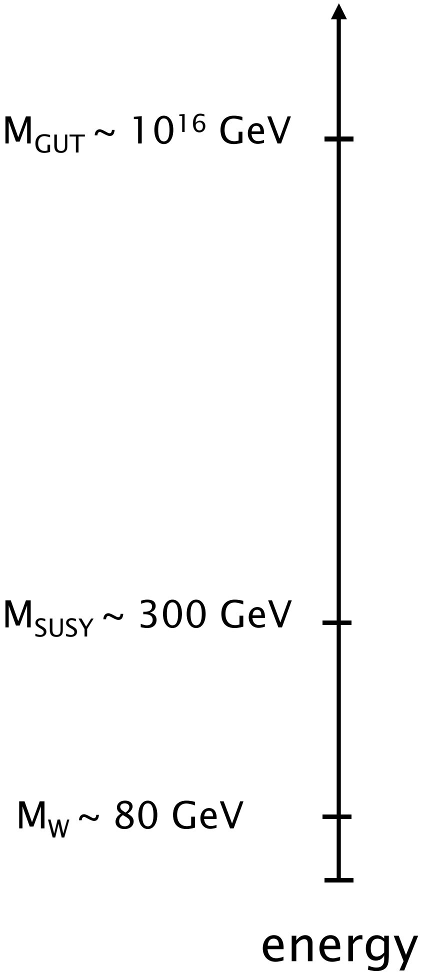
MFV spectrum

$$M_{\tilde{q}}^2 = \begin{pmatrix} m^{\tilde{q}LL} & \Delta^{\tilde{q}LR} \\ \Delta^{\tilde{q}RL} & m^{\tilde{q}RR} \end{pmatrix} \quad \text{with} \quad \Delta^{\tilde{q}LR} \sim Y^q, V_{CKM}$$

Minimal Flavour Violation



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General mass matrices

$$M_{\tilde{q}}^2 = \begin{pmatrix} m^{\tilde{q}LL} & \Delta^{\tilde{q}LR} \\ \Delta^{\tilde{q}RL} & m^{\tilde{q}RR} \end{pmatrix}$$

Non-minimal Flavour Violation

General mass matrices

$$M_{\tilde{q}}^2 = \begin{pmatrix} m^{\tilde{q}LL} & \Delta^{\tilde{q}LR} \\ \Delta^{\tilde{q}RL} & m^{\tilde{q}RR} \end{pmatrix}$$

General A-terms

$$A^u = \begin{pmatrix} A_{uu} & A_{uc} & A_{ut} \\ A_{cu} & A_{cc} & A_{ct} \\ A_{tu} & A_{tc} & A_{tt} \end{pmatrix}$$

Process

Process

$\tilde{t}_1 \rightarrow c\,\tilde{\chi}_1^0$

Tree level process: K. Hikasa, M. Kobayashi (1987) arXiv:1102.5712v1

Electroweak corrections: M. Muhlleitner, E.Popenda (2011) arXiv:1102.5712v1

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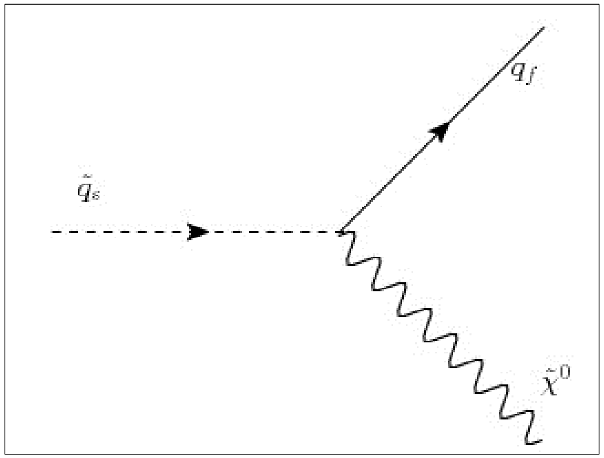

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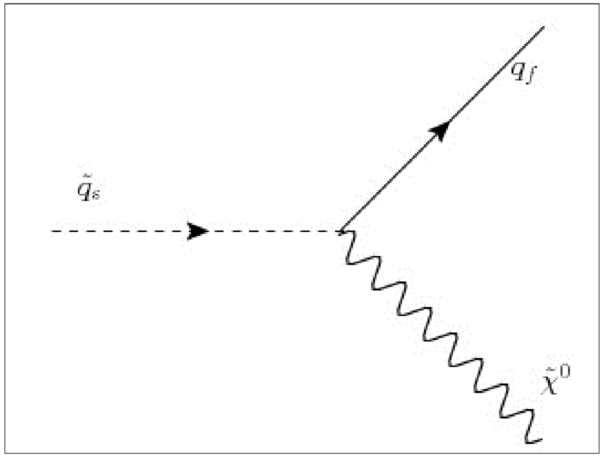

$$i\left[\Gamma^{\tilde{\chi}^0_p L}_{\tilde{u}_s u_f} P_L + \Gamma^{\tilde{\chi}^0_p R}_{\tilde{u}_s u_f} P_R\right]$$

$$\Gamma^{\tilde{\chi}^0_p L}_{\tilde{u}_s u_f} = \frac{-e}{\sqrt{2} s_W c_W} W^{\tilde{u}*}_{fs}\left(\frac{1}{3} Z^{1p}_N s_W + Z^{2p}_N c_W\right) - Y^{u_f *} W^{\tilde{u}*}_{f+3,s} Z^{4p}_N$$

$$\Gamma^{\tilde{\chi}^0_p R}_{\tilde{u}_s u_f} = \frac{2\sqrt{2}e}{3c_W} W^{\tilde{u}*}_{f+3,s} Z^{1p*}_N - Y^{u_f} W^{\tilde{u}*}_{fs} Z^{4p*}_N$$

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$\tilde{t}_1 \rightarrow c\,\tilde{\chi}_1^0$

α_s-corrections to tree level process

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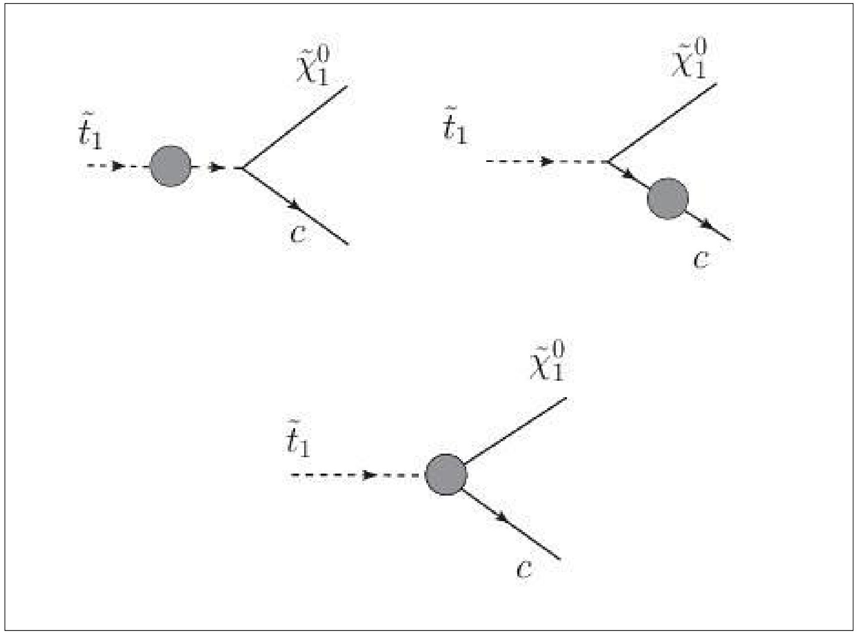

Graphs

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Squark self-energies

LSZ factors and squark masses

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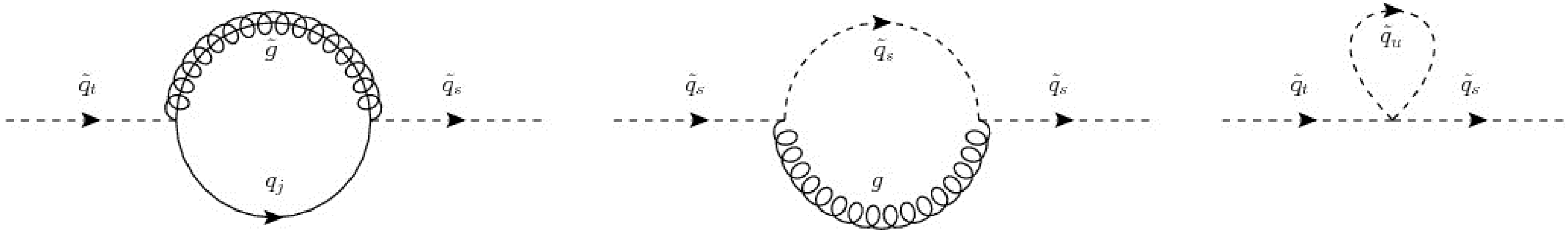
Squark self-energies

LSZ factors and squark masses



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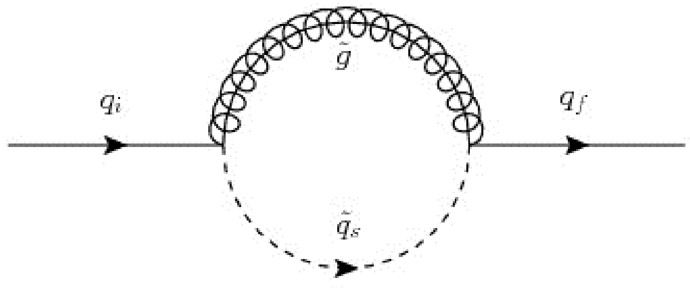

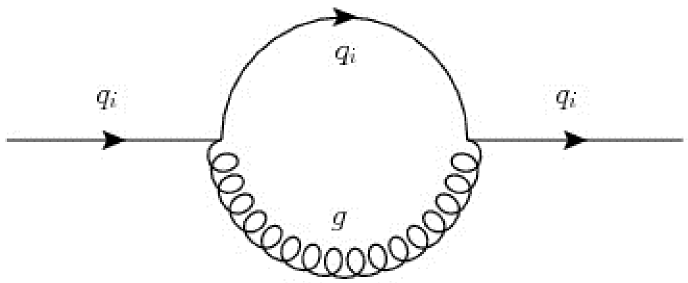

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Genuine vertex corrections

C0, B0 functions

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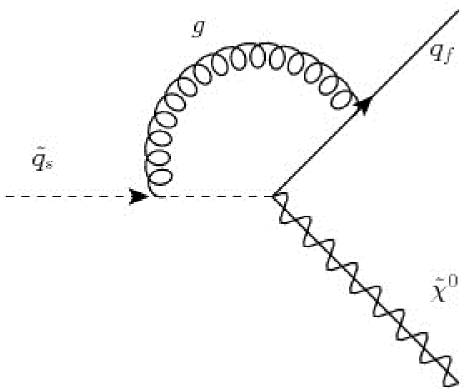
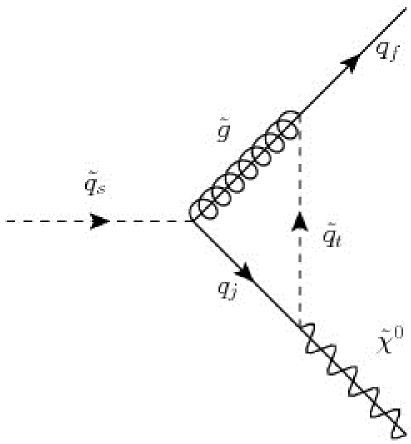
Genuine vertex corrections

C0, B0 functions





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Real emission

Collinear and IR divergences

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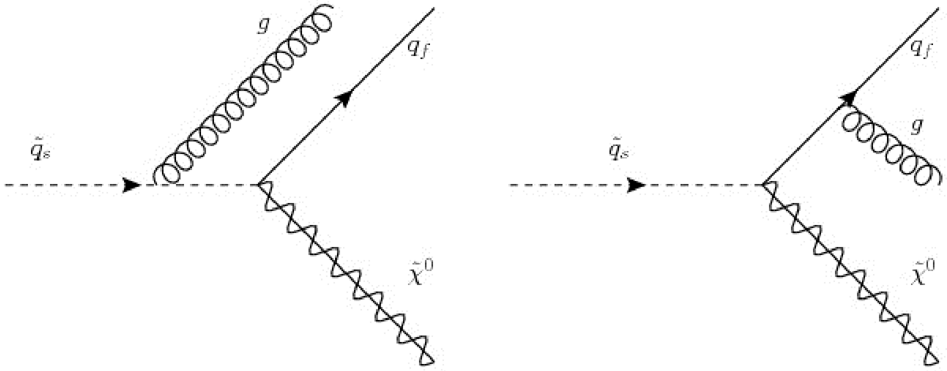
Real emission

Collinear and IR divergences



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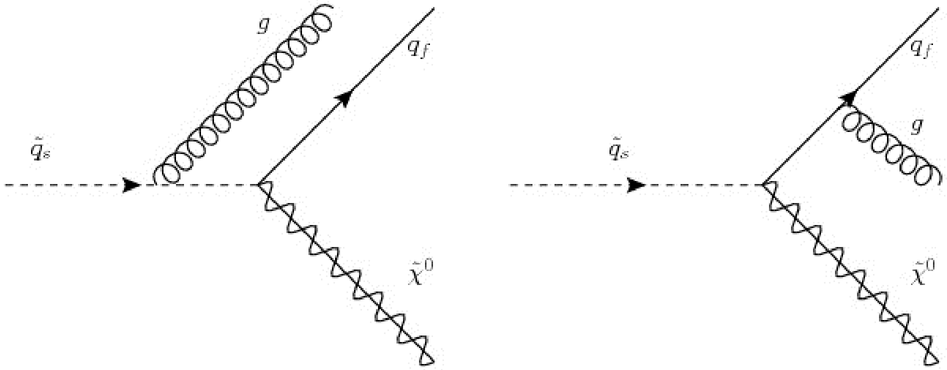


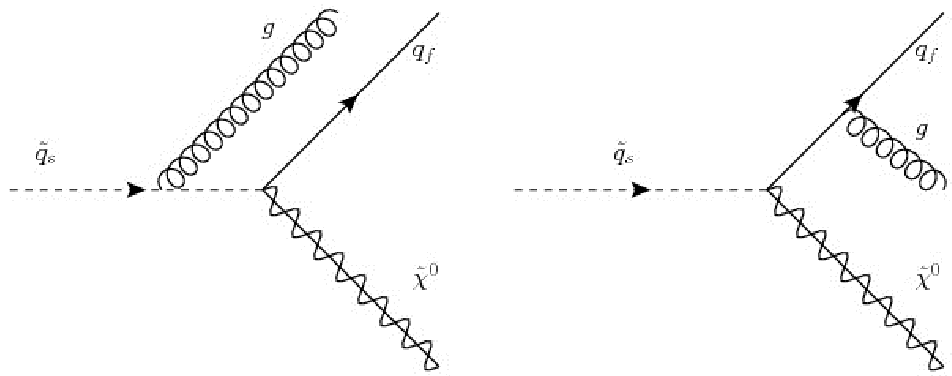
KLN theorem

$\Gamma\left(\tilde{t}_1 \to c\,\tilde{\chi}_1^0\right) + \Gamma\left(\tilde{t}_1 \to c\,\tilde{\chi}_1^0 g, E_g < \Lambda\right)$ IR finite

Graphs

Real emission

Collinear and IR divergences



KLN theorem

$\Gamma\left(\tilde{t}_1 \to c\,\tilde{\chi}_1^0\right) + \Gamma\left(\tilde{t}_1 \to c\,\tilde{\chi}_1^0 g, E_g < \Lambda\right)$ IR finite

Integration performed over all gluon energies

Renormalization

Renormalization

Dimensional Reduction (DR) and on-shell scheme

Massless charm quark

Renormalization

Dimensional Reduction (DR) and on-shell scheme

Massless charm quark

Renormalization

Introduction of counter terms

Analytic results

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Gluon contribution to decay width

$$x_1 = \frac{m^2_{\tilde{\chi}^0_1}}{m^2_{\tilde{t}_1}}$$

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Gluon contribution to decay width

$$x_1 = \frac{m^2_{\tilde{\chi}^0_1}}{m^2_{\tilde{t}_1}}$$

$$\Gamma^g = -\frac{C_F\, gs^2 m_{\tilde{t}}}{1536\pi^3}\left(\left|\Gamma^{\tilde{\chi}^0_1 L}\right|^2 + \left|\Gamma^{\tilde{\chi}^0_1 R}\right|^2\right)\left(\begin{array}{l}\left(75+8\pi^2(x_1-1)-81\,x_1\right)(x_1-1)-36(x_1-1)^2\,\mathrm{Log}\left(\dfrac{\mu}{m_{\tilde{t}}}\right)+6(4\;-\;3x_1)\,x_1\mathrm{Log}(x_1)\\ +12(x_1-1)^2\,\mathrm{Log}(x_1-1)\left(3+2\mathrm{Log}(x_1)\right)+48(x_1-1)^2\,Li_2(x_1)\end{array}\right)$$

Analytic results

Gluon contribution to decay width

$$x_1 = \frac{m_{\tilde{\chi}_1^0}^2}{m_{\tilde{t}_1}^2}$$

$$\Gamma^g = -\frac{C_F gs^2 m_{\tilde{t}}}{1536\pi^3}\left(\left|\Gamma^{\tilde{\chi}_1^0 L}\right|^2 + \left|\Gamma^{\tilde{\chi}_1^0 R}\right|^2\right)\left(\begin{array}{l}\left(75+8\pi^2(x_1-1)-81x_1\right)(x_1-1)-36(x_1-1)^2\,\mathrm{Log}\left(\frac{\mu}{m_{\tilde{t}}}\right)+6(4-3x_1)x_1\mathrm{Log}(x_1)\\ +12(x_1-1)^2\,\mathrm{Log}(x_1-1)\left(3+2\mathrm{Log}(x_1)\right)+48(x_1-1)^2\,Li_2(x_1)\end{array}\right)$$

Gluino contribution to decay width

Also completely worked out, but formulas are more complicated

Numerics

Numerics

Parameters

$$M_{\tilde{u}}^2 = \begin{pmatrix} \left(m_1^L\right)^2 & \left(\hat{\delta}^{LL}\right)_{12} & \left(\hat{\delta}^{LL}\right)_{13} & \left(\hat{\delta}^{LR}\right)_{11} & \left(\hat{\delta}^{LR}\right)_{12} & \left(\hat{\delta}^{LR}\right)_{13} \\ \left(\hat{\delta}^{LL}\right)_{21} & \left(m_2^L\right)^2 & \left(\hat{\delta}^{LL}\right)_{23} & \left(\hat{\delta}^{LR}\right)_{21} & \left(\hat{\delta}^{LR}\right)_{22} & \left(\hat{\delta}^{LR}\right)_{23} \\ \left(\hat{\delta}^{LL}\right)_{31} & \left(\hat{\delta}^{LL}\right)_{32} & \left(m_3^L\right)^2 & \left(\hat{\delta}^{LR}\right)_{31} & \left(\hat{\delta}^{LR}\right)_{32} & \left(\hat{\delta}^{LR}\right)_{33} \\ \left(\hat{\delta}^{RL}\right)_{11} & \left(\hat{\delta}^{RL}\right)_{12} & \left(\hat{\delta}^{RL}\right)_{13} & \left(m_1^R\right)^2 & \left(\hat{\delta}^{RR}\right)_{12} & \left(\hat{\delta}^{RR}\right)_{13} \\ \left(\hat{\delta}^{RL}\right)_{21} & \left(\hat{\delta}^{RL}\right)_{22} & \left(\hat{\delta}^{RL}\right)_{21} & \left(\hat{\delta}^{RR}\right)_{21} & \left(m_2^R\right)^2 & \left(\hat{\delta}^{RR}\right)_{23} \\ \left(\hat{\delta}^{RL}\right)_{31} & \left(\hat{\delta}^{RL}\right)_{32} & \left(\hat{\delta}^{RL}\right)_{33} & \left(\hat{\delta}^{RR}\right)_{31} & \left(\hat{\delta}^{RR}\right)_{32} & \left(m_3^R\right)^2 \end{pmatrix}$$

$$\left(\hat{\delta}^{LR}\right)_{ij} := \left(\delta^{LR}\right)_{ij} \left(\left(m_i^L\right)^2 + \left(m_j^R\right)^2\right)$$

Numerics

Parameters

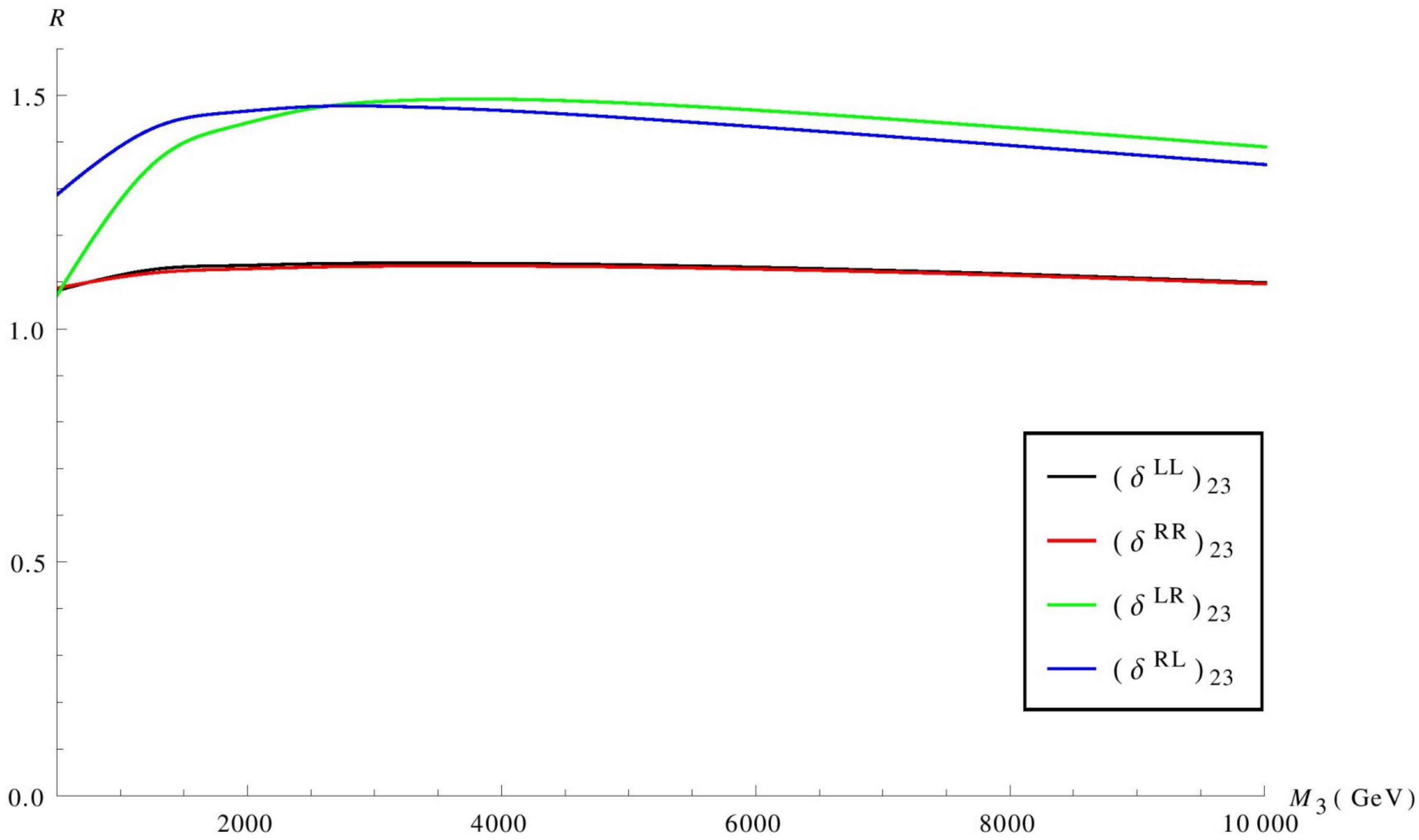
$$M_{\tilde{u}}^2 = \begin{pmatrix} (m_1^L)^2 & (\hat{\delta}^{LL})_{12} & (\hat{\delta}^{LL})_{13} & (\hat{\delta}^{LR})_{11} & (\hat{\delta}^{LR})_{12} & (\hat{\delta}^{LR})_{13} \\ (\hat{\delta}^{LL})_{21} & (m_2^L)^2 & (\hat{\delta}^{LL})_{23} & (\hat{\delta}^{LR})_{21} & (\hat{\delta}^{LR})_{22} & (\hat{\delta}^{LR})_{23} \\ (\hat{\delta}^{LL})_{31} & (\hat{\delta}^{LL})_{32} & (m_3^L)^2 & (\hat{\delta}^{LR})_{31} & (\hat{\delta}^{LR})_{32} & (\hat{\delta}^{LR})_{33} \\ (\hat{\delta}^{RL})_{11} & (\hat{\delta}^{RL})_{12} & (\hat{\delta}^{RL})_{13} & (m_1^R)^2 & (\hat{\delta}^{RR})_{12} & (\hat{\delta}^{RR})_{13} \\ (\hat{\delta}^{RL})_{21} & (\hat{\delta}^{RL})_{22} & (\hat{\delta}^{RL})_{21} & (\hat{\delta}^{RR})_{21} & (m_2^R)^2 & (\hat{\delta}^{RR})_{23} \\ (\hat{\delta}^{RL})_{31} & (\hat{\delta}^{RL})_{32} & (\hat{\delta}^{RL})_{33} & (\hat{\delta}^{RR})_{31} & (\hat{\delta}^{RR})_{32} & (m_3^R)^2 \end{pmatrix}$$

$$(\hat{\delta}^{LR})_{ij} := (\delta^{LR})_{ij} \left((m_i^L)^2 + (m_j^R)^2 \right)$$

$$m_{\tilde{t}_1} = 300 GeV$$

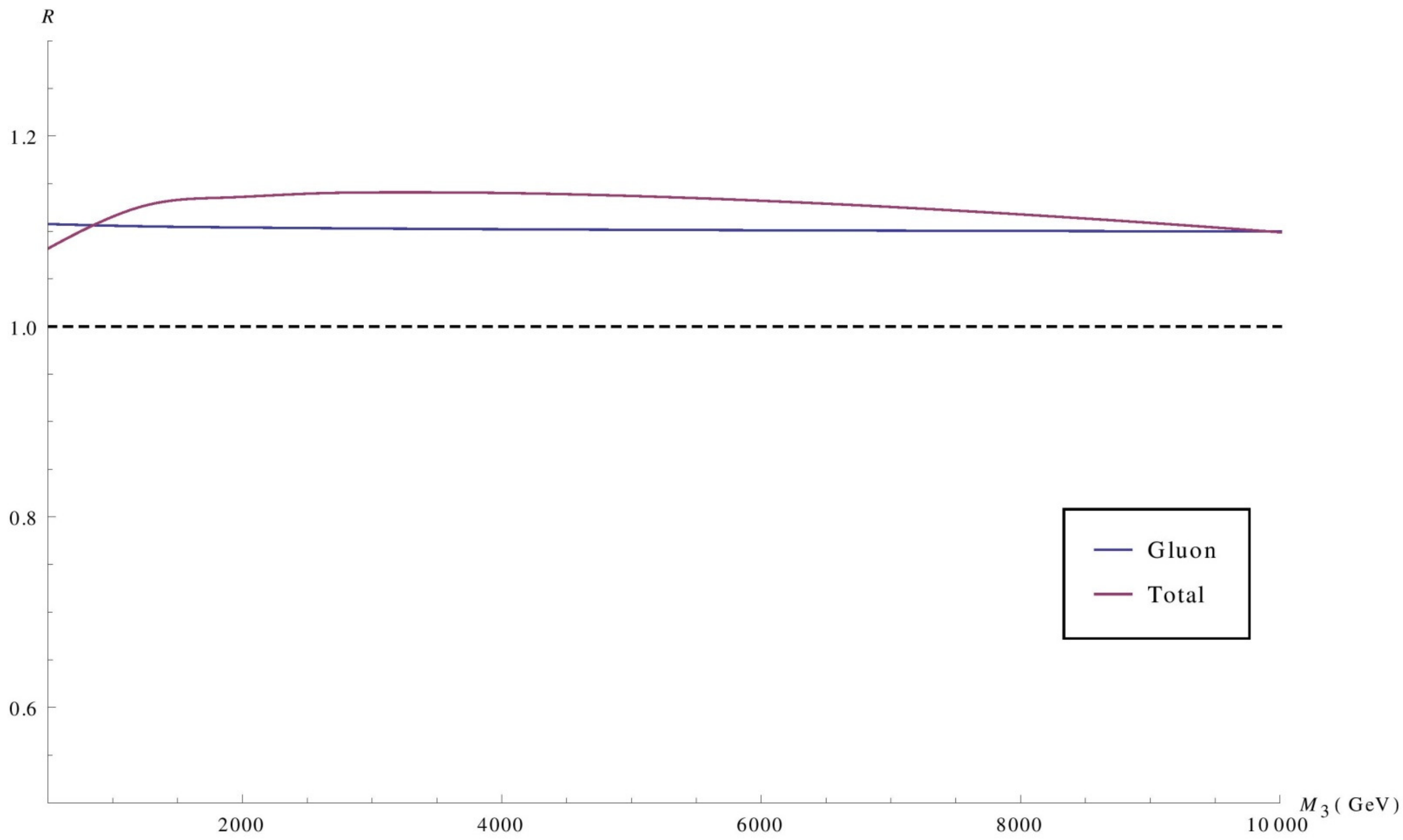
$$m_{\tilde{\chi}_1^0} = 250 GeV$$

SQCD corrections to decay width



$$R := \frac{\Gamma^{(0)} + \alpha_s \Gamma^{(1)}}{\Gamma^{(0)}}$$

Gluon vs. Gluino contribution for $(\delta^{LL})_{23}$



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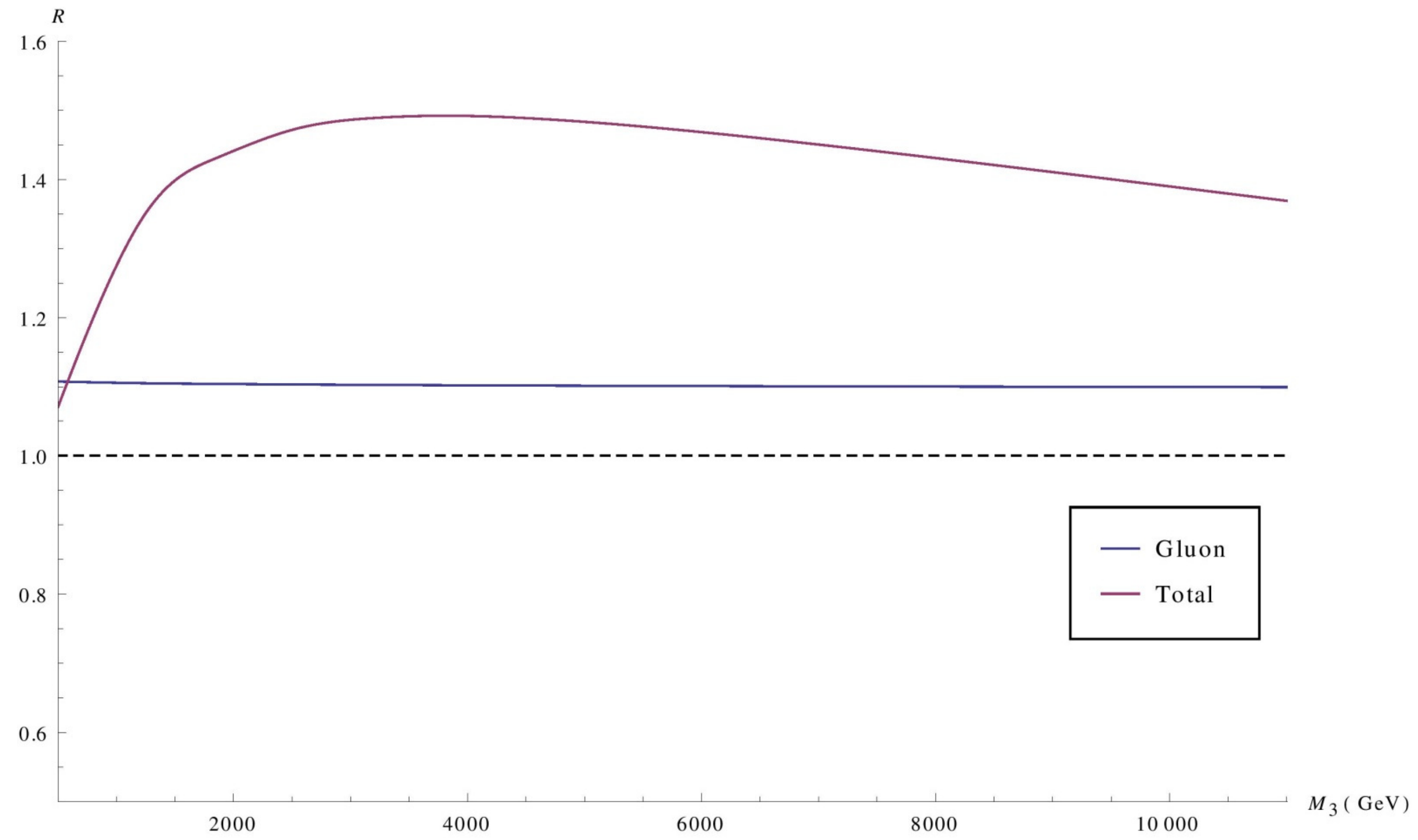
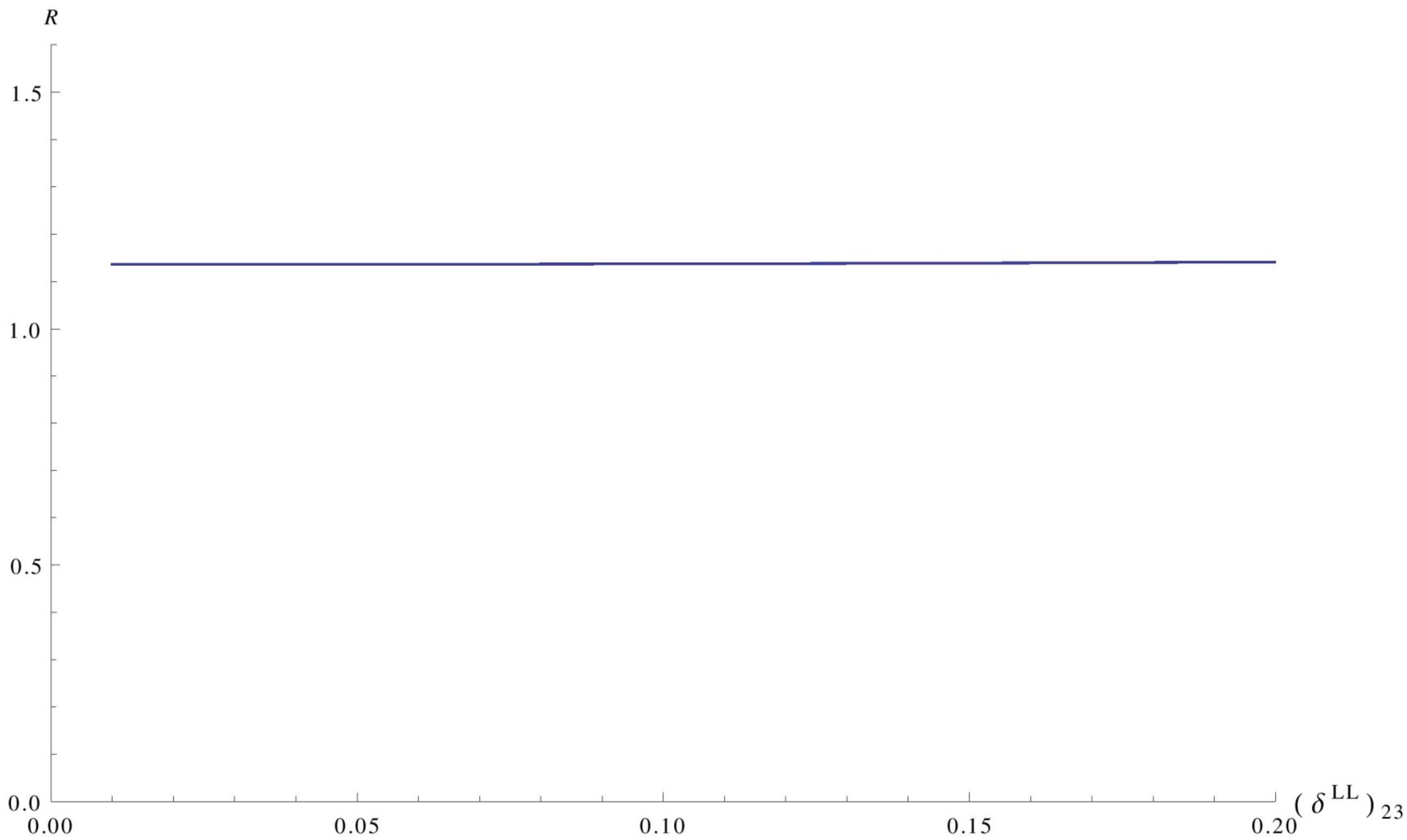
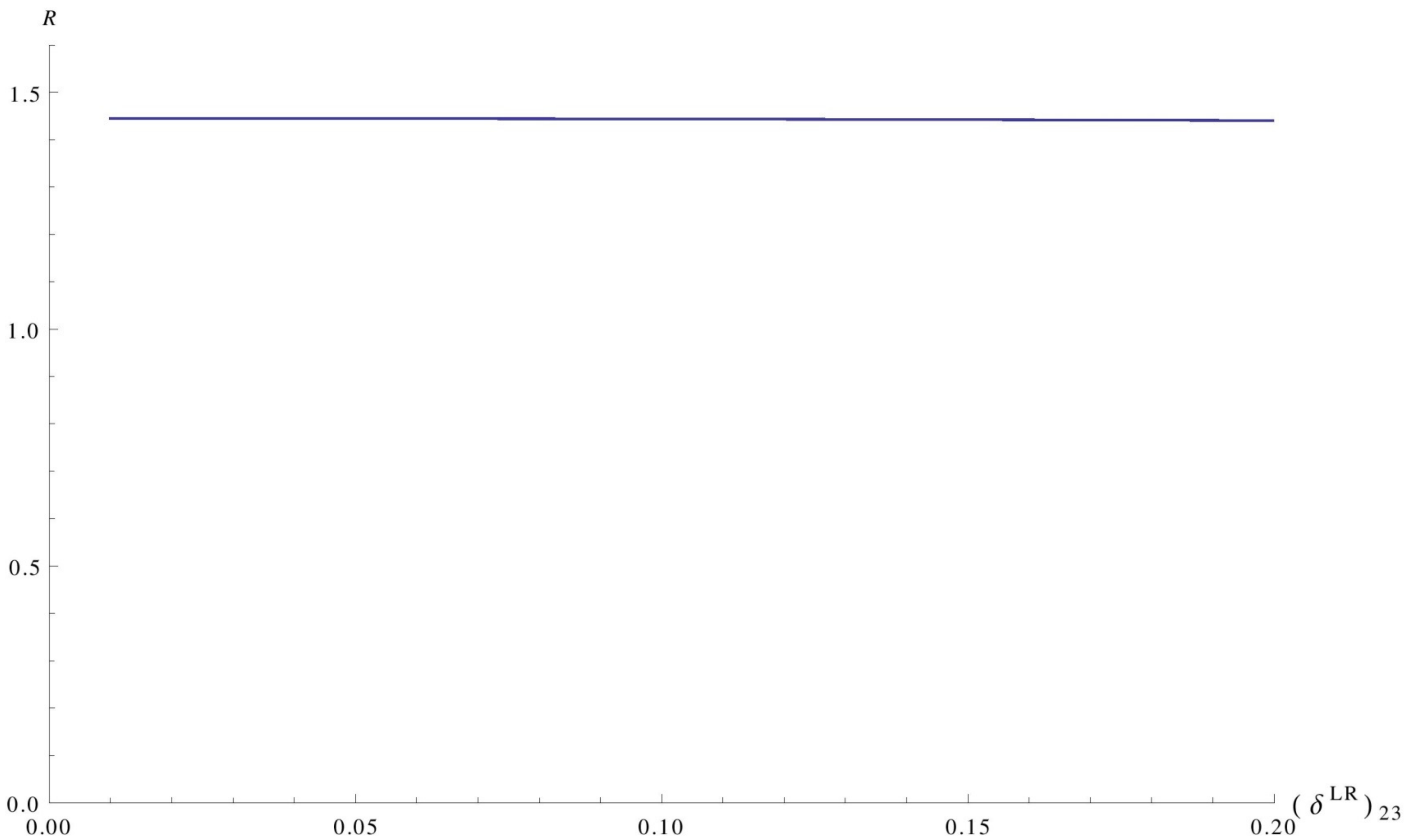


Dependence on $(\delta^{LL})_{23}$



$M_3 = 2000 GeV$

Dependence on $(\delta^{LR})_{23}$



$M_3 = 2000 GeV$

Conclusions

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QCD corrections

Up to 13% correction for LL, RR

Up to 50% correction for LR, RL

Conclusions

QCD corrections

Up to 13% correction for LL, RR

Up to 50% correction for LR, RL

Mixing

Gluon for LL

Gluino for LR

Conclusions

QCD corrections

Up to 13% correction for LL, RR

Up to 50% correction for LR, RL

Mixing

Gluon for LL

Gluino for LR

Parameters

Small dependence of $R := \frac{\Gamma^{(0)} + \alpha_s \Gamma^{(1)}}{\Gamma^{(0)}}$ on $\left(\delta^{LR}\right)_{23}, \left(\delta^{LL}\right)_{23}$

Outlook

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Effect on other channels

$$\Gamma\left(\tilde{t}_1 \to b\,\tilde{\chi}^0 W\right)$$

Thank you