$\mathcal{L}$ight $\mathcal{S}$top $\mathcal{D}$ecay in the $\mathcal{MSSM}$ with $\mathcal{M}$inimal $\mathcal{F}$lavour $\mathcal{V}$iolation

$\mathcal{M}$. $\mathcal{M}$argarete $\mathcal{M}$ühlleitner

Institute of Theoretical Physics (Karlsruhe Institute of Technology)

In collaboration with

Eva Popenda

SUSY2011

Aug 28-Sept 2, 2011, Fermilab, USA

Outline

- ◇ **Introduction**
- ◇ **FCNC decay $\tilde{t}_1 \rightarrow c + \tilde{\chi}_1^0$**
- ◇ **One-loop calculation and renormalisation**
- ◇ **Numerical analysis**
- ◇ **Conclusions**

$\mathcal{I}$ntroduction

- **Precision measurements in flavour physics**

  ∗ in agreement with predictions of the Standard Model (SM)

  ∗ observed flavour violation can be described by SM Cabibbo-Kobayashi-Maskawa (CKM) matrix

  ⇒ New Physics (NP) contributions to Flavour Violation strongly constrained

- **Minimal Supersymmetric Extension of the SM (MSSM)**

  in principle many new flavour violating sources

  ⇒ New Physics Flavour Problem

- **Minimal Flavour Violation (MFV)** provides solution, agrees with precision measurements

  ∗ sources of flavour and CP violation given by SM structure of the Yukawa couplings ⇒

  ∗ flavour mixing in NP models governed by CKM matrix ⇒

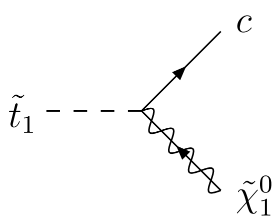
  ∗ no flavour changing neutral currents (FCNC) at tree level at $\mu = \mu_{MFV}$

$\mathcal{F}$lavour $\mathcal{C}$hanging $\mathcal{L}$ight $\mathcal{S}$top $\mathcal{D}$ecay

- **Light Stop $\tilde{t}_1$**
  - arises naturally from renormalization-group running
  - large top Yukawa coupling $\rightsquigarrow$ large mass splitting $\rightsquigarrow$ light $\tilde{t}_1$
  - light stop favoured by Baryogenesis

Carena eal; de Carlos, Espinosa; Huet, Nelson; Delepine eal; Losada; Cirigliano eal

- **FCNC decay $\tilde{t}_1 \to c + \tilde{\chi}_1^0$**



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- **FCNC decay $\tilde{t}_1 \to c + \tilde{\chi}_1^0$**
  - ∗ in MFV no tree-level coupling $\tilde{t}_1$-c-$\tilde{\chi}_1^0$ at μ_{MFV}
    $\Rightarrow$ decay mediated through charged particle loops
  - ∗ suppressed by small CKM matrix elements $|V_{cb}| = 0.04$
  - ∗ scenarios with very light $\tilde{t}_1$ NLSP and $\tilde{\chi}_1^0$ LSP
    with $m_{\tilde{t}_1} > m_c + m_{\tilde{\chi}_1^0}$ and $m_{\tilde{t}_1} < M_W + m_b + m_{\tilde{\chi}_1^0}$

$\Rightarrow \tilde{t}_1 \to c + \tilde{\chi}_1^0$ dominant decay

$\mathcal{P}$henomenology

- **Stop decay length measurements:** test minimal flavour violation Hiller eal
  - $*$ MFV and dominant decay $\tilde{t}_1 \to c + \tilde{\chi}_1^0 \rightsquigarrow$ large $\tilde{t}_1$ lifetimes
  - $*$ $\Rightarrow$ secondary vertices

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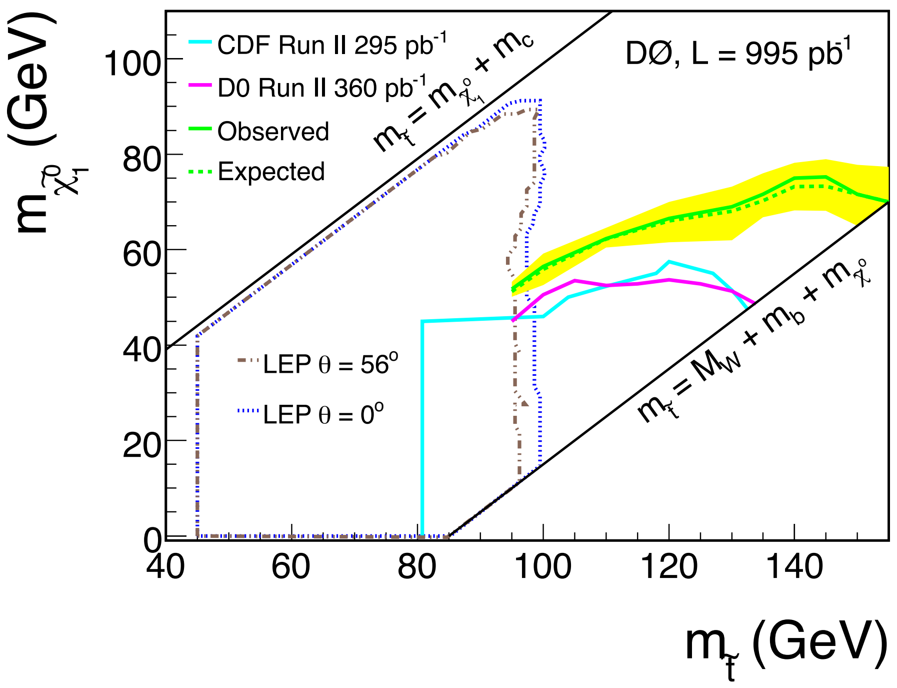
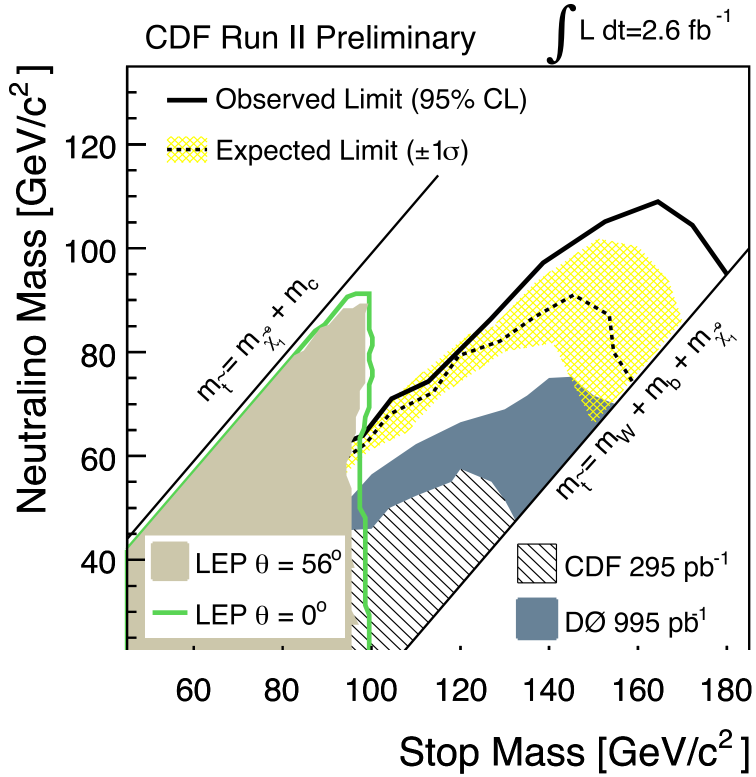
- **Exclusion limits from Tevatron** assume BR($\tilde{t}_1 \to c + \tilde{\chi}_1^0$)=1   CDF,D0
  - CDF analysis of 2 jets and MET
  - D0 search for stops plus MET

$\mathcal{E}$xclusion $\mathcal{L}$imits

D0



CDF



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- **Light Stop Search at Tevatron and LHC** difficult, but feasible
  - $*$ Light Stop search at the Tevatron — Das,Datta,Guchait; Bhattacharyya,Datta,Maity; Olive,Rudaz; Demina,Lykken,Matchev,Nomerotski; Han eal; Kats,Shih; ...
  - $*$ LHC search for light stop — Bornhauser,Drees,Grab,Kim; Johansen,Edsjo,Hellman,Mistead; Han eal; Kraml,Raklev; Battacharyya,Choudhury,Datta; Carena eal; Kats,Shih; Huitu,Leinonen,Laamanen; ...

- **Approximate formula for $\tilde{t}_1 \to c + \tilde{\chi}_1^0$** — Hikasa,Kobayashi

  Calculation with no FCNC at high-scale $M_P \rightsquigarrow$ decay mediated through charged particle loops.
  Takes into account only leading log contribution $\sim \ln(M_P^2/M_W^2)$

$\mathcal{O}$ne $\mathcal{L}$oop $\mathcal{R}$esult and $\mathcal{R}$esummation

- **This work**

  MM, Popenda
  JHEP 1104 (2011) 095

  * complete one-loop calculation of $\tilde{t}_1 \to c + \tilde{\chi}_1^0$ in MFV
  * full renormalization program, including finite non-logarithmic terms

  $\Rightarrow$ study importance of neglected non-logarithmic terms

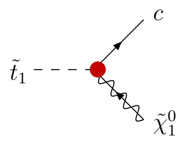
- **Resummation of large logarithm $\ln(M_P^2/M_W^2)$**
  * necessary to get reliable result
  * solution of renormalisation group equations (RGE) for soft SUSY breaking squark masses

- **Hypothesis of MFV not RGE-invariant**

  D'Ambrosio, Giudice, Isidori, Strumia

  * RG evolution $\mu_{MFV} \to \mu_{EWSB}$ including the complete flavour structure
  * $\Rightarrow$ flavour off-diagonal entries in soft SUSY breaking terms
  * weak interactions affect squark and quark mass matrices differently
  * q and $\tilde{q}$ mass matrices cannot be diagonalised simultaneously $\rightsquigarrow$ $\tilde{t}$ small admixture from $\tilde{c}$

  $\Rightarrow$ FCNC coupling $\tilde{t}_1 - c - \tilde{\chi}_1^0$ at tree level at any $\mu \neq \mu_{MFV}$



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- **Exact one-loop result: first order in expansion in powers of α**

$$\underline{\alpha(A_1 \log} + A_0) + \underline{\alpha^2(B_2 \log^2} + \underline{B_1 \log} + B_0) + \underline{\alpha^3(C_3 \log^3} + ...) * ...$$

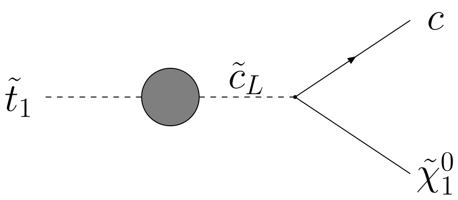
- **Comparison of exact one-loop result and tree-level FV decay**

  $\Rightarrow$ estimate importance of the resummation effects

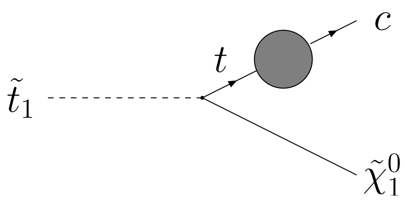
$\mathcal{C}$ontributing $\mathcal{D}$iagrams

- **$\tilde{t}_1 \to c + \tilde{\chi}_1^0$ in the framework of MFV** (we set $m_c \equiv 0$)

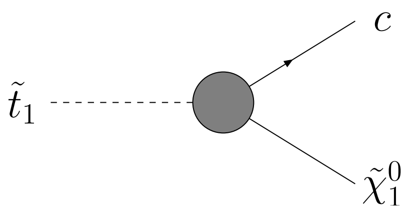
squark self-energies



quark self-energies

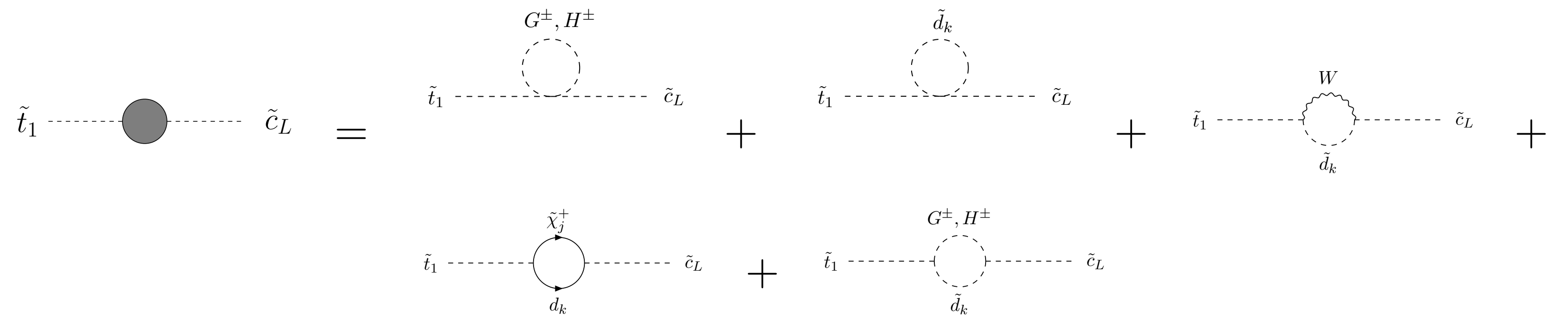


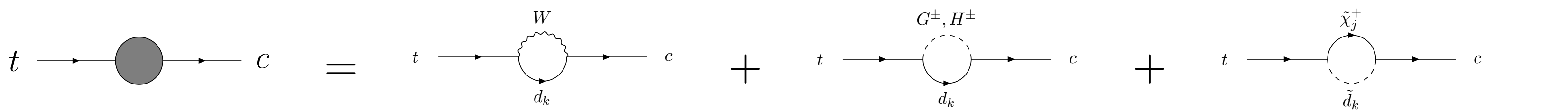
vertex corrections

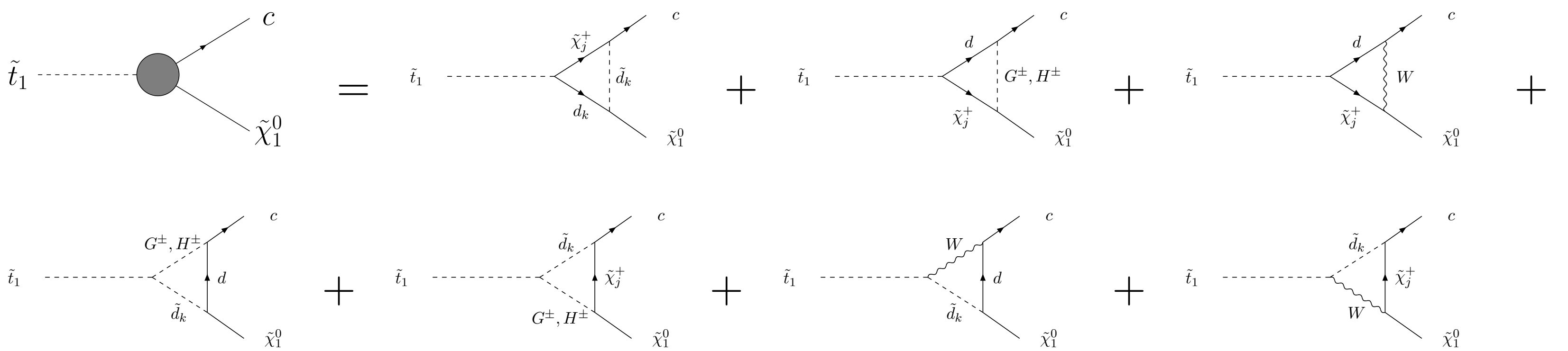


$\sum_{\text{all diagrams}}$ divergencies $\neq 0$

$\mathcal{C}$ontributing $\mathcal{D}$iagrams



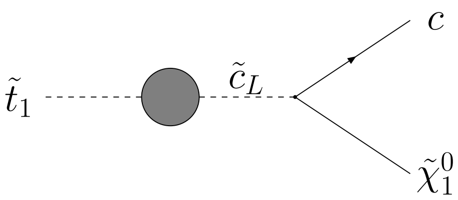




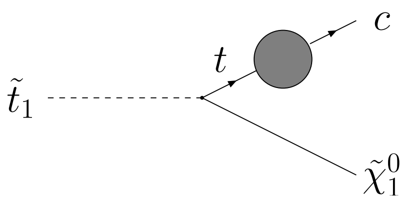
$\mathcal{R}$enormalisation

- **$\tilde{t}_1 \to c + \tilde{\chi}_1^0$ in the framework of MFV** (we set $m_c \equiv 0$)

squark self-energies



quark self-energies



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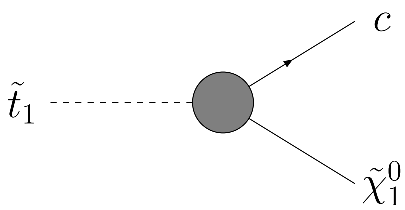
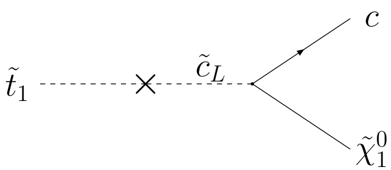


- **Field renormalisation: on-shell scheme**

squarks

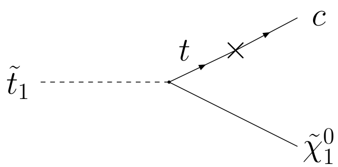
$$\tilde{q}^0_{st} = (\delta_{st} + \tfrac{1}{2}\delta\tilde{Z}_{st})\tilde{q}_t$$



$$\hat{\Sigma}_{\tilde{t}_1\tilde{c}_L}(m^2_{\tilde{t}_1}) = 0$$

quarks

$$q^0_i = (\delta_{ik} + \tfrac{1}{2}\delta Z_{ik})q_k$$



$$\bar{u}(p)\hat{\Sigma}^{tc}(p^2)\Big|_{p^2=0} = 0$$

remaining divergencies

$\mathcal{R}$enormalisation

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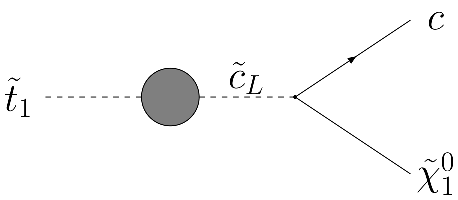
squark self-energies



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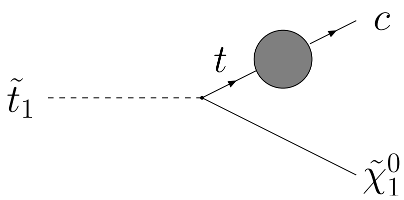

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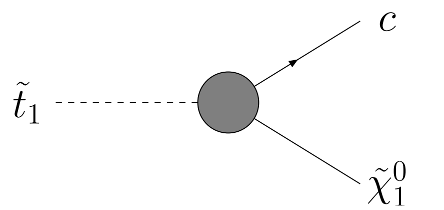

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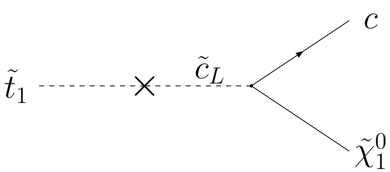

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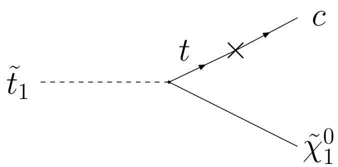
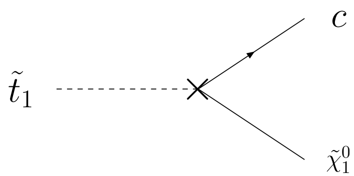


$$\bar{u}(p)\hat{\Sigma}^{tc}(p^2)\Big|_{p^2=0} = 0$$

vertex counterterm



$$(\tfrac{1}{2}\delta Z^{L\dagger}_{ct} + \delta u^{U_L}_{ct})\cos\theta_{\tilde{t}} + \tfrac{1}{2}\delta\tilde{Z}_{\tilde{c}_L\tilde{t}_1} + \delta\tilde{w}^{\dagger}_{\tilde{c}_L\tilde{t}_1}$$

$\mathcal{R}$enormalisation of the $\mathcal{M}$ixing $\mathcal{M}$atrices

- **Diagonalisation of $q, \tilde{q}$ mass matrices $\rightsquigarrow$ unitary mixing matrices $U, \tilde{W}$**

$$q^m_{L,R} = U^{q_{L,R}} q_{L,R} \quad (V^{\text{CKM}} = U^{u_L} U^{d_L \dagger}) \qquad \tilde{q}^m = \tilde{W} \tilde{q}$$

- **Renormalisation of the mixing matrices**

$$U^{(0)}_{ij} = (\delta_{ik} + \delta u_{ik}) U^R_{kj} \qquad \tilde{W}^{(0)}_{su} = (\delta_{st} + \delta \tilde{w}_{st}) \tilde{W}^R_{tu}$$

impose MFV condition on the renormalised mixing matrices: $\hat{=}\ U^R, \tilde{W}^R$ flavour-diagonal $\Rightarrow$

- **Mixing matrix counterterms $\delta u, \delta\tilde{w}$:**

flavour non-diagonal, anti-hermitian ($\leftarrow$ unitarity of $U, \tilde{W}$) Denner,Sack

$$\delta u_{ik} = \frac{1}{4}(\delta Z_{ik} - \delta Z^*_{ki}) \qquad \delta\tilde{w}_{st} = \frac{1}{4}(\delta\tilde{Z}_{st} - \delta\tilde{Z}^*_{ts})$$

- **Finite part of counterterm depends on renormalisation scheme** Gambino eal; Kniehl eal; Barroso eal

minimal subtraction: gauge independent Gross,Wilczek; Caswell eal; Kluberg-Stern, Zuber

MFV condition imposed at μ_{MFV}

$$\delta u_{ik} = \frac{1}{4}(\delta Z^{\text{div}}_{ik} - \delta Z^{*\,\text{div}}_{ki})\Big|_{p^2=0} \qquad \delta\tilde{w}_{st} = \frac{1}{4}(\delta\tilde{Z}^{\text{div}}_{st} - \delta\tilde{Z}^{*\,\text{div}}_{ts})$$

$\Rightarrow$ Result depends on MFV scale μ_{MFV}

$\mathcal{R}$esult for the $\mathcal{D}$ecay $\mathcal{F}$ormula

- **Decay amplitude**

$$\mathcal{M} = ig\bar{u}_c(k_2)(F_L\mathcal{P}_L + F_R\mathcal{P}_R)v_{\tilde{\chi}^0}(k_1)$$

$F_L \equiv 0$ for $m_c \equiv 0$

- **Result for the complete one-loop calculation**

$$F_R = \frac{g^2}{16\pi^2}\sqrt{2}\left[\frac{Z_{11}}{6}\tan\theta_W + \frac{Z_{12}}{2}\right]\frac{V_{cb}V_{tb}^* m_b^2 \cos\theta_{\tilde{t}}}{2M_W^2\cos^2\beta}\,\frac{m_{c_L}^2 + \mathcal{A}}{m_{\tilde{t}_1}^2 - m_{\tilde{c}_L}^2}\,\log\frac{\mu_{\text{MFV}}^2}{m_{\text{loop}}^2} + \text{finite terms}$$

- **Result by Hikasa/Kobayashi**

$$F_R = \frac{g^2}{16\pi^2}\sqrt{2}\left[\frac{Z_{11}}{6}\tan\theta_W + \frac{Z_{12}}{2}\right]\frac{V_{cb}V_{tb}^* m_b^2 \cos\theta_{\tilde{t}}}{2M_W^2\cos^2\beta}\,\frac{m_{c_L}^2 + \mathcal{A}}{m_{\tilde{t}_1}^2 - m_{\tilde{c}_L}^2}\,\log\frac{M_P^2}{m_W^2}$$

with $\mathcal{A} = -\mu^2 + A_b^2 + M_{\tilde{b}_R}^2 + c_\beta^2(M_W^2(t_\beta^2 - 1) + M_A^2 t_\beta^2) + m_t A_b \tan\theta_{\tilde{t}}$

$\mathcal{N}$umerical $\mathcal{A}$nalysis

- **Numerical analysis:** mSUGRA framework
  - $*$ flavour-independent parameters at M_{GUT}: $M_0, M_{1/2}, A_0, \tan\beta$, sign$\mu$
  - $*$ common $M_{\tilde{q}_L} \rightsquigarrow \tilde{u}, \tilde{d}$ mass matrices can be simultaneously flavour-diagonal
  - $*$ scenarios with very light stop: $\tilde{t}_1$ NLSP, $\tilde{\chi}_1^0$ LSP
  - $*$ mass spectra and mixing angles at EWSB with

SPheno, Porod
SoftSUSY, Allanach

- **Possible decay modes:**

$\tilde{t}_1 \to c + \tilde{\chi}_1^0$	dominating$V_{cb} \approx 0.04$
$\tilde{t}_1 \to u + \tilde{\chi}_1^0$	suppressed by $V_{ub} \approx 0.003$
$\tilde{t}_1 \to \tilde{\chi}_1^0 b f \bar{f}$	suppressed due to phase space

$\mathcal{C}$omparison with $\mathcal{A}$pproximate $\mathcal{R}$esult

- **Comparison of decay widths: exact one-loop and approximate formula**

$$m_{\tilde{t}_1} = 130 \text{ GeV} , \quad m_{\tilde{\chi}_1^0} = 92 \text{ GeV} , \quad m_{\tilde{\chi}_1^+} = 175 \text{ GeV}$$

SUSY-HIT
Djouadi,MM,Spira

$\lvert F_R^{\text{1-loop}} \rvert$	$\lvert F_R^{\text{H/K}} \rvert$	$\Gamma^{\text{1-loop}}$[GeV]	$\Gamma^{\text{H/K}}$[GeV]
$1.460 \cdot 10^{-4}$	$1.531 \cdot 10^{-4}$	$5.862 \cdot 10^{-9}$	$6.446 \cdot 10^{-9}$

∗ difference in exact and approximate decay width: $\mathcal{O}(10\%)$

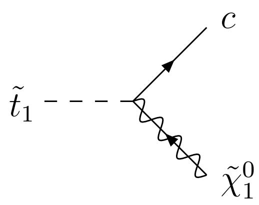
∗ finite terms in exact result contribute to F_R with $3 - 5\%$

∗ difference in finite terms $\Rightarrow$ 10% effect on Γ

∗ difference in branching ratios: negligible

$\mathcal{R}$esummation $\mathcal{E}$ffects

- **Renormalisation group approach** includes resummation of large logarithms

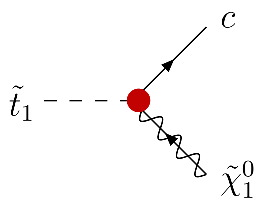


$\sim \tilde{W}_{\tilde{t}_1 \tilde{c}_1} = 0$ at $\mu_{MFV} = 10^{16}$ GeV

MFV assumption is not RGE invariant and only holds at $\mu = \mu_{MFV} = 10^{16}$ GeV

Flavour off-diagonal matrix element as a result of RG evolution down to μ_{EWSB}

$\Rightarrow$ tree level FCNC decay at EWSB scale



$\sim \tilde{W}_{\tilde{u}_1 \tilde{c}_1} \neq 0$ at μ_{EWSB}

$$F_R^{\text{FV}} = -\sqrt{2}\left[\frac{Z_{11}}{6}\tan\theta_W + \frac{Z_{12}}{2}\right]\tilde{W}_{\tilde{u}_1 \tilde{c}_L}$$

- **Comparison of one-loop MFV and FV tree-level result:** $m_{\tilde{u}_1} \approx m_{\tilde{t}_1}$

$\lvert F_R^{\text{1-loop}}\rvert$	$\lvert F_R^{\text{FV}}\rvert$	$\Gamma^{\text{1-loop}}$[GeV]	Γ^{FV}[GeV]
$1.460 \cdot 10^{-4}$	$3.306 \cdot 10^{-5}$	$5.862 \cdot 10^{-9}$	$3.006 \cdot 10^{-10}$

$\mathcal{B}$ranching $\mathcal{R}$atios

- **With resummation effects**

$\tilde{t}_1 \to \tilde{\chi}_1^0 u$ resummed flavour off-diagonal matrix element $\tilde{W}_{\tilde{u}_1 \tilde{u}_L}$

$\tilde{t}_1 \to \tilde{\chi}_1^0 b f \bar{f}'$ calculation including tree-level FV couplings not available
additional contributions expected to be small due to CKM suppression

branching ratio	BR($\tilde{t}_1 \to \tilde{\chi}_1^0 c$)	BR($\tilde{t}_1 \to \tilde{\chi}_1^0 u$)	BR($\tilde{t}_1 \to \tilde{\chi}_1^0 b f \bar{f}'$)
Exact one-loop	0.9443	0.0053	0.0504
Resummed TL	0.4884	0.0032	0.5084

- 4-body decay width unchanged in both cases
- Branching ratio $\tilde{t}_1 \to \tilde{\chi}_1^0 u$ in both cases suppressed by 2 orders of magnitude
- Resummation effects reduce $\Gamma(\tilde{t}_1 \to \tilde{\chi}_1^0 c)$ by a factor ~ 20

$\Rightarrow$ decrease in branching ratio by a factor 1/2

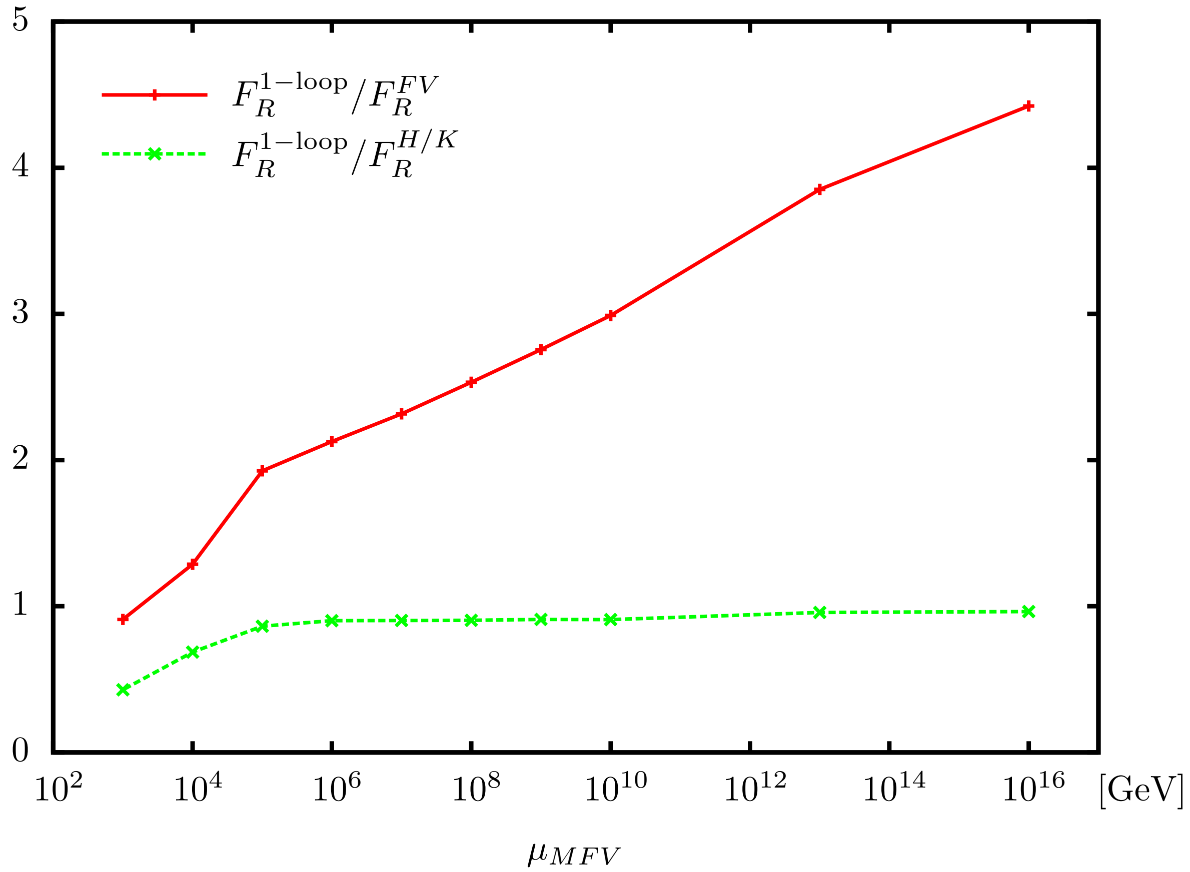
$\Rightarrow$ Resummation effects are important for large scale $\mu_{MFV} = M_{GUT}$

$\mathcal{A}$nalyis for different μ_{MFV}

- **Different μ_{MFV}:** study importance of resummation effects, study quality of approximated result
- **Decreasing μ_{MFV}:**

∗ one-loop MFV result approaches resummed FV tree-level result
∗ one-loop MFV result better than approximate formula by Hikasa/Kobayashi

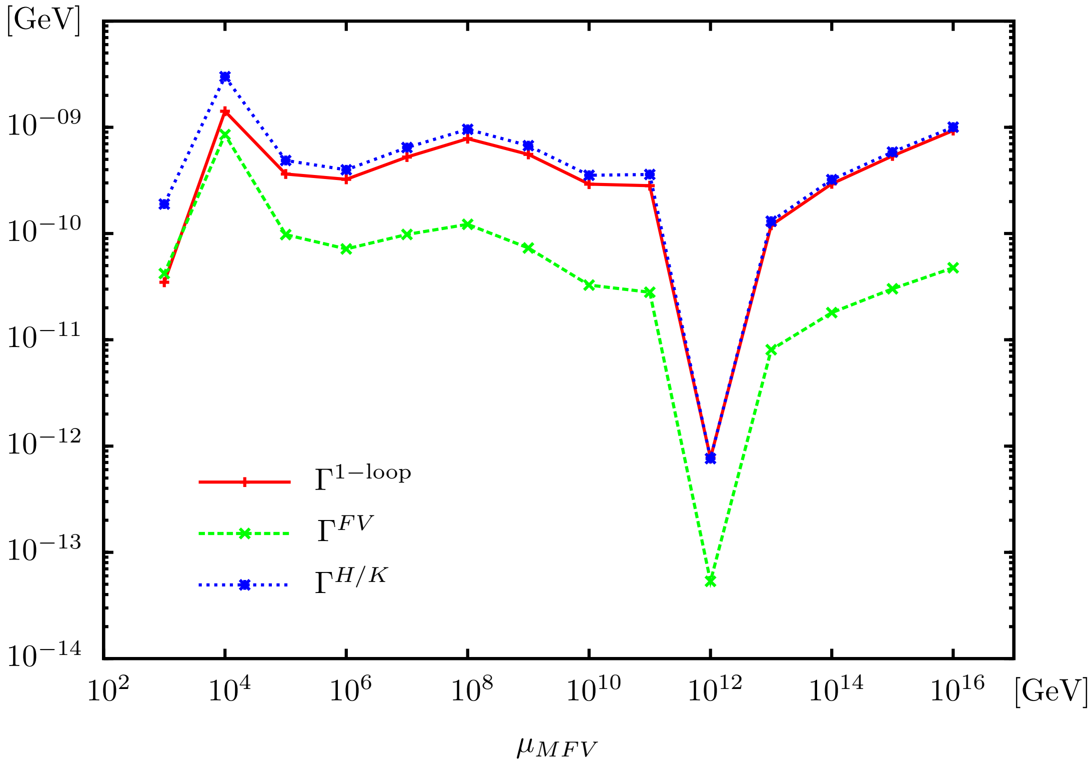
- **Numerical analysis:** scenarios with different μ_{MFV} but the same mass spectrum



$\mathcal{A}$nalyis for different μ_{MFV}

- **Size of decay width:** does not only depend on size of log
- **Coefficient of the logarithmic term:**

$$\mathcal{A} = -\mu^2 + A_b^2 + M_{\tilde{b}_R}^2 + c_\beta^2(M_W^2(t_\beta^2 - 1) + M_A^2 t_\beta^2) + m_t A_b \tan\theta_{\tilde{t}}$$



Small stop decay widths ⇒ long lifetimes ⇒ secondary vertex

- observation of secondary vertex: strong support for MFV principle
- lifetime measurement: infomation on size of flavour-changing coupling

$\mathcal{S}$ummary and $\mathcal{O}$utlook

- Complete one-loop calculation of $\tilde{t}_1 \to c + \tilde{\chi}_1^0$ in MFV including finite terms not dependent on $\log \mu_{MFV}$

- Full renormalisation program including gauge-independent renormalisation of the mixing matrices

- Comparison with existing approximate formula by Hikasa/Kobayashi: difference in partial width $\mathcal{O}(10\%)$ due to finite terms

- Comparison to tree-level decay with RG evolution induced FV coupling
  * resummation effects important for large μ_{MFV}
  * big impact on branching ratio

- **Next step:** one-loop correction to FV tree-level decay
  $\Rightarrow$ improve predictions for light stop decay widths and branching ratios

Backup Slides

$\mathcal{B}$ranching $\mathcal{R}$atios with $\mathcal{E}$xact $\mathcal{F}$ormula

(1)	$m_{\tilde{t}_1} = 104$ GeV	$m_{\tilde{\chi}_1^0} = 92$ GeV	$m_{\tilde{\chi}_1^+} = 175$ GeV	
$M_0 = 200$ GeV	$M_{1/2} = 230$ GeV	$A_0 = -920$ GeV	$\tan\beta = 10$	sign$(\mu) = +$
(2)	$m_{\tilde{t}_1} = 130$ GeV	$m_{\tilde{\chi}_1^0} = 92$ GeV	$m_{\tilde{\chi}_1^+} = 175$ GeV	
$M_0 = 200$ GeV	$M_{1/2} = 230$ GeV	$A_0 = -895$ GeV	$\tan\beta = 10$	sign$(\mu) = +$

branching ratio	BR$(\tilde{t}_1 \to \tilde{\chi}_1^0 c)$	BR$(\tilde{t}_1 \to \tilde{\chi}_1^0 u)$	BR$(\tilde{t}_1 \to \tilde{\chi}_1^0 bf\bar{f}')$
Scenario (1)	0.9944	0.0056	$4.587 \cdot 10^{-5}$
Scenario (2)	0.9443	0.0053	0.0504

- FCNC decay dominates in both scenarios
- Branching ratio $\tilde{t}_1 \to \tilde{\chi}_1^0 u$ in both cases suppressed by 2 orders of magnitude
- 4-body decay less important in (1) due to reduced phase space
- Effect on BR of interest only at the percent level

$\mathcal{B}$ranching $\mathcal{R}$atios - $\mathcal{C}$omparison $\mathcal{E}$xact $\mathcal{F}$ormula and H/K

(1) $m_{\tilde{t}_1} = 104$ GeV $m_{\tilde{\chi}_1^0} = 92$ GeV $m_{\tilde{\chi}_1^+} = 175$ GeV

(2) $m_{\tilde{t}_1} = 130$ GeV $m_{\tilde{\chi}_1^0} = 92$ GeV $m_{\tilde{\chi}_1^+} = 175$ GeV

- **Exact 1-loop result:**

branching ratio	BR($\tilde{t}_1 \to \tilde{\chi}_1^0 c$)	BR($\tilde{t}_1 \to \tilde{\chi}_1^0 u$)	BR($\tilde{t}_1 \to \tilde{\chi}_1^0 b f \bar{f}'$)
Scenario (1)	0.9944	0.0056	$4.587 \cdot 10^{-5}$
Scenario (2)	0.9443	0.0053	0.0504

- **Approximate result by H/K:**

branching ratio	BR($\tilde{t}_1 \to \tilde{\chi}_1^0 c$)	BR($\tilde{t}_1 \to \tilde{\chi}_1^0 u$)	BR($\tilde{t}_1 \to \tilde{\chi}_1^0 b f \bar{f}'$)
Scenario (1)	0.9944	0.0056	$4. \cdot 10^{-5}$
Scenario (2)	0.9486	0.0053	0.0460

$\mathcal{B}$ranching $\mathcal{R}$atios - $\mathcal{C}$omparison $\mathcal{E}$xact and resummed FV TL result

(1) $m_{\tilde{t}_1} = 104$ GeV $m_{\tilde{\chi}_1^0} = 92$ GeV $m_{\tilde{\chi}_1^+} = 175$ GeV

(2) $m_{\tilde{t}_1} = 130$ GeV $m_{\tilde{\chi}_1^0} = 92$ GeV $m_{\tilde{\chi}_1^+} = 175$ GeV

- **Exact 1-loop result:**

branching ratio	BR($\tilde{t}_1 \to \tilde{\chi}_1^0 c$)	BR($\tilde{t}_1 \to \tilde{\chi}_1^0 u$)	BR($\tilde{t}_1 \to \tilde{\chi}_1^0 b f \bar{f}'$)
Scenario (1)	0.9944	0.0056	$4.587 \cdot 10^{-5}$
Scenario (2)	0.9443	0.0053	0.0504

- **Resummed FV tree-level result:**

branching ratio	BR($\tilde{t}_1 \to \tilde{\chi}_1^0 c$)	BR($\tilde{t}_1 \to \tilde{\chi}_1^0 u$)	BR($\tilde{t}_1 \to \tilde{\chi}_1^0 b f \bar{f}'$)
Scenario (1)	0.9925	0.0066	$8.956 \cdot 10^{-4}$
Scenario (2)	0.4884	0.0032	0.5084

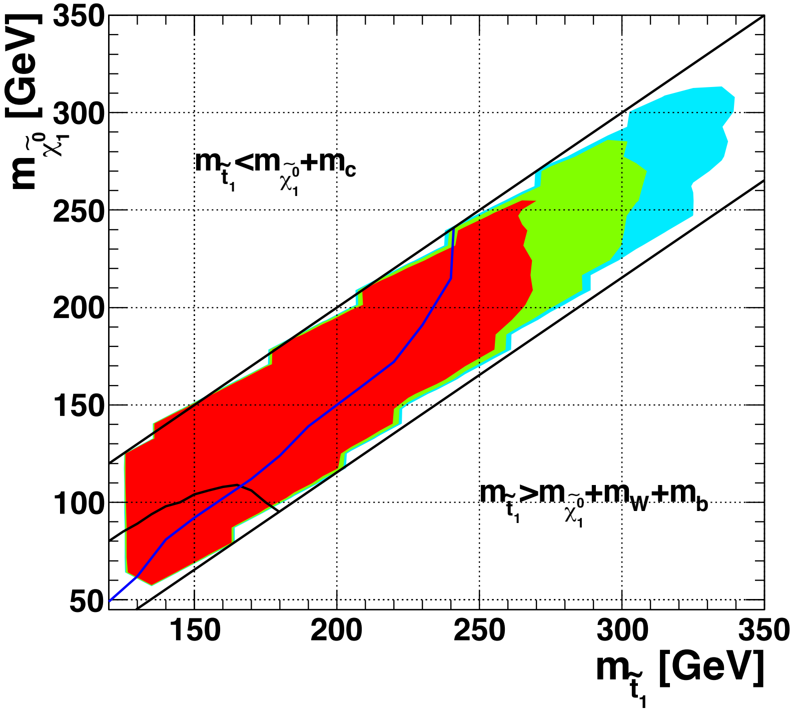
• **In events with two b-jets and missing energy** Bornhauser, Drees, Grab, Kim '10

▷ production of $\tilde{t}_1\tilde{t}_1^*b\bar{b}$ including pure QCD and mixed EW-QCD contributions

▷ production: $pp \to \tilde{t}_1\tilde{t}_1^*b\bar{b}$, decay: $\tilde{t}_1 \to c + \tilde{\chi}_1^0$

▷ small $\tilde{t}_1 - \tilde{\chi}_1^0$ mass splitting $\Rightarrow$ c-jets too soft to be exploited

▷ signature: large missing energy + 2 b-jets



$\mathcal{M}$easurement of $\mathcal{F}$lavour $\mathcal{M}$ixing with MFV at the LHC

- **Establish MFV experimentally:** challenging, possible if $e.g.$ Hiller, Nir, 2008

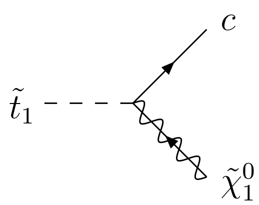
▷ $\tilde{t}_1$ is NLSP and $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} \lesssim b \Rightarrow \tilde{t}_1 \to c + \tilde{\chi}_1^0$ dominates

▷ CKM suppression $\rightsquigarrow$ $\tilde{t}_1$ lifetime is usually long $\Rightarrow$ secondary vertex

1) Flavour suppression needed for secondary vertex $\leftarrow$ unique to MFV models
   observation of secondary vertex $\Rightarrow$ strong support for MFV

2) Lifetime measurement $\rightarrow$ information on size of flavour changing coupling
   (after higgsino/gaugino decomposition of neutralino & left/right decomposition of stop is known)

- **MVF no tree-level decay $\tilde{t}_1 \to c + \tilde{\chi}_1^0$**



$= 0$

How do the mixing matrices look like?

Flavour mixing in the SM

$\bar{q}_{Li} m_{ij} q_{Rj}$ with $q^m_{L,R} = U^{q_{L,R}} q_{L,R}$ and $q = u, d$

◇ $U^q_{L,R}$ are unitary, $U^{q\dagger}_{L,R} U^q_{L,R} = 1$

◇ $U^q_{L,R}$ diagonalise the mass matrix m_{ij}: $U^q_{Lki} m_{ij} U^{q\dagger}_{Rjm} = m_k \delta_{km}$

◇ CKM matrix $V^{\text{CKM}} = U^{u_L} U^{d_L \dagger}$

◇ no further flavour transitions

$\mathcal{T}$ree-$\mathcal{L}$evel $\mathcal{C}$alculation - cont'd

• Flavour and LR mixing in the MSSM

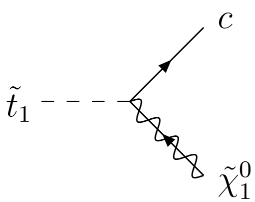
$$\begin{pmatrix} \tilde{u}_1 \\ \tilde{c}_1 \\ \tilde{t}_1 \\ \tilde{u}_2 \\ \tilde{c}_2 \\ \tilde{t}_2 \end{pmatrix} = \begin{pmatrix} \text{squark} \\ \text{mixing} \\ \text{matrix: } \tilde{W} \\ (6 \times 6) \end{pmatrix} \begin{pmatrix} \tilde{u}_L \\ \tilde{c}_L \\ \tilde{t}_L \\ \tilde{u}_R \\ \tilde{c}_R \\ \tilde{t}_R \end{pmatrix}$$

- ◇ $\tilde{W}$ is unitary, $\tilde{W}^\dagger \tilde{W} = 1$
- ◇ $\tilde{W}$ diagonalises mass matrix $\tilde{W} M^{\tilde{q}} \tilde{W}^\dagger = M^{\tilde{q}}_{\text{diag}}$
- ◇ in general many new sources of flavour violation

• Mixing matrix factorises in MFV

$$\tilde{W} = \begin{pmatrix} \cos\tilde{\theta}_{\tilde{q}_i} & -\sin\tilde{\theta}_{\tilde{q}_i} \\ \sin\tilde{\theta}_{\tilde{q}_i} & \cos\tilde{\theta}_{\tilde{q}_i} \end{pmatrix} \begin{pmatrix} U_L^q & 0 \\ 0 & U_R^q = \end{pmatrix} = \underbrace{W}_{\text{flavour diagonal}} \cdot \; U$$

$\Rightarrow$ process vanishes at tree-level:



$\sim W_{ct} = 0$

$\mathcal{R}$enormalisation of the $\mathcal{S}$quark and $\mathcal{Q}$uark $\mathcal{F}$ields

- **Squark wave function renormalisation constant (OS renormalisation)**

$$\delta\tilde{Z}_{\tilde{t}_1\tilde{c}_L} = \frac{2}{m^2_{\tilde{c}_L} - m^2_{\tilde{t}_1}} \Sigma_{\tilde{t}_1\tilde{c}_L}(m^2_{\tilde{t}_1})$$

- **Quark wave function renormalisation constant (OS renormalisation)**

$$\delta Z^{L*}_{tc} = \frac{2}{m_t} \Sigma^{ct*}_S(0) \qquad \delta Z^{R*}_{tc} = \frac{2}{m_t} \Sigma^{tc}_S(0)$$