Impact of generation mixing on the search for squarks at the LHC

Björn Herrmann

Institut für Theoretische Physik und Astrophysik
Universität Würzburg

G. Bozzi, B. Fuks, B. Herrmann, M. Klasen, Nucl. Phys. B 787: 1-54 (2007)
B. Fuks, B. Herrmann, M. Klasen, Nucl. Phys. B 810: 266-299 (2009)
A. Bartl, H. Eberl, B. Herrmann, K. Hidaka, W. Majerotto, W. Porod, *to be published*

RPP 2010
Lyon, January 25-27, 2010

Quark Flavour Violation in the MSSM

In the Standard Model, all quark flavour-violating terms are proportional to CKM-matrix

Quark Flavour Violation in the MSSM

In the Standard Model, all quark flavour-violating terms are proportional to CKM-matrix

Beyond Standard Model, e.g. Minimal Supersymmetric Standard Model (MSSM)

Minimal flavour-violation (MFV)

- no new sources of flavour violation
- in super-CKM basis squarks undergo same rotations as quarks
- all flavour-violating entries related to CKM-matrix
- Example: $\tilde{\chi}_i^{\pm} \tilde{q}_j q_k$ interaction proportional to $V_{q_j q'_k}$

Quark Flavour Violation in the MSSM

In the Standard Model, all quark flavour-violating terms are proportional to CKM-matrix

Beyond Standard Model, e.g. Minimal Supersymmetric Standard Model (MSSM)

Minimal flavour-violation (MFV)

- no new sources of flavour violation
- in super-CKM basis squarks undergo same rotations as quarks
- all flavour-violating entries related to CKM-matrix
- Example: $\tilde{\chi}_i^{\pm} \tilde{q}_j q_k$ interaction proportional to $V_{q_j q_k'}$

Non-minimal flavour-violation (NMFV)

- new sources of flavour violation can appear within SUSY-GUTs
- e.g. gravity-mediation, messenger-matter mixing, flavour symmetries, ...
- corresponding flavour-violating entries not related to CKM-matrix
- considered as free parameters

Quark Flavour Violation in the MSSM

In the Standard Model, all quark flavour-violating terms are proportional to CKM-matrix

Beyond Standard Model, e.g. Minimal Supersymmetric Standard Model (MSSM)

Minimal flavour-violation (MFV)

- no new sources of flavour violation
- in super-CKM basis squarks undergo same rotations as quarks
- all flavour-violating entries related to CKM-matrix
- Example: $\tilde{\chi}_i^{\pm}\tilde{q}_j q_k$ interaction proportional to $V_{q_j q'_k}$

Non-minimal flavour-violation (NMFV)

- new sources of flavour violation can appear within SUSY-GUTs
- e.g. gravity-mediation, messenger-matter mixing, flavour symmetries, ...
- corresponding flavour-violating entries not related to CKM-matrix
- considered as free parameters

The flavour-violating terms are incorporated in the mass matrices at the electroweak scale

$$\mathcal{M}^2_{\tilde{u}} = \begin{pmatrix} \mathcal{M}^2_{LL} & \left(\mathcal{M}^2_{RL}\right)^\dagger \\ \mathcal{M}^2_{RL} & \mathcal{M}^2_{RR} \end{pmatrix}$$

Quark Flavour Violation in the MSSM

Soft-breaking matrices can include off-diagonal, i.e. flavour-violating, entries

$$\begin{aligned}
\mathcal{M}^2_{LL,\alpha\beta} &= M^2_{Q,\alpha\beta} + \frac{1}{2}\left[m^2_{u,\alpha} + \left(\frac{1}{2} - \frac{2}{3}s^2_W\right) m^2_Z c_{2\beta}\right]\delta_{\alpha\beta} \\
\mathcal{M}^2_{RR,\alpha\beta} &= M^2_{U,\alpha\beta} + \frac{1}{2}\left[m^2_{u,\alpha} + \frac{2}{3}s^2_W m^2_Z c_{2\beta}\right]\delta_{\alpha\beta} \\
\mathcal{M}^2_{RL,\alpha\beta} &= \frac{v_2}{\sqrt{2}} A_{U,\alpha\beta} - m_{u,\alpha}\frac{\mu^*}{\tan\beta}\delta_{\alpha\beta}
\end{aligned}$$

Introduce dimensionless parametrization for flavour-violating entries

$$\begin{aligned}
\delta^{u\{LL,RR\}}_{\alpha\beta} &= M^2_{\{Q,U\},\alpha\beta}\Big/\sqrt{M^2_{\{Q,U\},\alpha\alpha}M^2_{\{Q,U\},\beta\beta}} \\
\delta^{uRL}_{\alpha\beta} &= \frac{v_2}{\sqrt{2}}A_{U,\alpha\beta}\Big/\sqrt{M^2_{U,\alpha\alpha}M^2_{Q,\beta\beta}}
\end{aligned}$$

Quark Flavour Violation in the MSSM

Soft-breaking matrices can include off-diagonal, i.e. flavour-violating, entries

$$\begin{aligned}
\mathcal{M}^2_{LL,\alpha\beta} &= M^2_{Q,\alpha\beta} + \frac{1}{2}\left[m^2_{u,\alpha} + \left(\frac{1}{2} - \frac{2}{3}s^2_W\right) m^2_Z c_{2\beta}\right] \delta_{\alpha\beta} \\
\mathcal{M}^2_{RR,\alpha\beta} &= M^2_{U,\alpha\beta} + \frac{1}{2}\left[m^2_{u,\alpha} + \frac{2}{3}s^2_W m^2_Z c_{2\beta}\right] \delta_{\alpha\beta} \\
\mathcal{M}^2_{RL,\alpha\beta} &= \frac{v_2}{\sqrt{2}} A_{U,\alpha\beta} - m_{u,\alpha} \frac{\mu^*}{\tan\beta} \delta_{\alpha\beta}
\end{aligned}$$

Introduce dimensionless parametrization for flavour-violating entries

$$\begin{aligned}
\delta^{u\{LL,RR\}}_{\alpha\beta} &= M^2_{\{Q,U\},\alpha\beta} \Big/ \sqrt{M^2_{\{Q,U\},\alpha\alpha} M^2_{\{Q,U\},\beta\beta}} \\
\delta^{uRL}_{\alpha\beta} &= \frac{v_2}{\sqrt{2}} A_{U,\alpha\beta} \Big/ \sqrt{M^2_{U,\alpha\alpha} M^2_{Q,\beta\beta}}
\end{aligned}$$

Diagonalization through 6x6 rotation matrix leads to mass eigenstates

$$\mathcal{R}_{\tilde{u}} \mathcal{M}^2_{\tilde{u}} \mathcal{R}^\dagger_{\tilde{u}} = \mathrm{diag}\left(m^2_{\tilde{u}_1}, m^2_{\tilde{u}_2}, m^2_{\tilde{u}_3}, m^2_{\tilde{u}_4}, m^2_{\tilde{u}_5}, m^2_{\tilde{u}_6}\right)$$

Constraints on the MSSM parameter space

PDG 2008-2009; HFAG 2009; WMAP 2009

Mass limits from collider searches

see e.g. Bozzi, Fuks, Herrmann, Klasen (2007); Fuks, Herrmann, Klasen (2008); Hurth, Porod (2009)

Constraints on the MSSM parameter space

PDG 2008-2009; HFAG 2009; WMAP 2009

Mass limits from collider searches

Electroweak precision and low-energy measurements

$$
\begin{aligned}
\mathrm{BR}(b \to s\gamma) &= (3.52 \pm 0.52) \cdot 10^{-4} \\
\Delta M_{B_s} &= (17.77 \pm 3.31)\ \mathrm{ps}^{-1} \\
\Delta\rho &= (1.02 \pm 1.72) \cdot 10^{-3} \\
\mathrm{BR}(b \to s\mu^+\mu^-) &= (1.60 \pm 1.00) \cdot 10^{-6} \\
\mathrm{BR}(B_s \to \mu^+\mu^-) &< 4.8 \cdot 10^{-8} \\
\mathrm{BR}(B \to \tau^+\bar{\nu}) &= (1.43 \pm 0.43) \cdot 10^{-4} \\
\Delta a_\mu = a_\mu^{\mathrm{SM}} - a_{mu}^{\mathrm{exp}} &= (29.0 \pm 8.6) \cdot 10^{-10}
\end{aligned}
$$

see e.g. Bozzi, Fuks, Herrmann, Klasen (2007); Fuks, Herrmann, Klasen (2008); Hurth, Porod (2009)

Constraints on the MSSM parameter space

PDG 2008-2009; HFAG 2009; WMAP 2009

Mass limits from collider searches

Electroweak precision and low-energy measurements

$$\begin{aligned}
\mathrm{BR}(b \to s\gamma) &= (3.52 \pm 0.52) \cdot 10^{-4} \\
\Delta M_{B_s} &= (17.77 \pm 3.31)\ \mathrm{ps}^{-1} \\
\Delta\rho &= (1.02 \pm 1.72) \cdot 10^{-3} \\
\mathrm{BR}(b \to s\mu^+\mu^-) &= (1.60 \pm 1.00) \cdot 10^{-6} \\
\mathrm{BR}(B_s \to \mu^+\mu^-) &< 4.8 \cdot 10^{-8} \\
\mathrm{BR}(B \to \tau^+\bar{\nu}) &= (1.43 \pm 0.43) \cdot 10^{-4} \\
\Delta a_\mu = a_\mu^{\mathrm{SM}} - a_{mu}^{\mathrm{exp}} &= (29.0 \pm 8.6) \cdot 10^{-10}
\end{aligned}$$

Cosmological constraints: Viable candidate for cold dark matter

$$0.1097 < \Omega_{\mathrm{CDM}} h^2 < 0.1165$$

see e.g. Bozzi, Fuks, Herrmann, Klasen (2007); Fuks, Herrmann, Klasen (2008); Hurth, Porod (2009)

Constraints on the MSSM parameter space

PDG 2008-2009; HFAG 2009; WMAP 2009

Mass limits from collider searches

Electroweak precision and low-energy measurements

$$\begin{aligned}
\mathrm{BR}(b \to s\gamma) &= (3.52 \pm 0.52) \cdot 10^{-4} \\
\Delta M_{B_s} &= (17.77 \pm 3.31)\ \mathrm{ps}^{-1} \\
\Delta\rho &= (1.02 \pm 1.72) \cdot 10^{-3} \\
\mathrm{BR}(b \to s\mu^+\mu^-) &= (1.60 \pm 1.00) \cdot 10^{-6} \\
\mathrm{BR}(B_s \to \mu^+\mu^-) &< 4.8 \cdot 10^{-8} \\
\mathrm{BR}(B \to \tau^+\bar{\nu}) &= (1.43 \pm 0.43) \cdot 10^{-4} \\
\Delta a_\mu = a_\mu^{\mathrm{SM}} - a_{mu}^{\mathrm{exp}} &= (29.0 \pm 8.6) \cdot 10^{-10}
\end{aligned}$$

Highly sensitive to QFV elements

Cosmological constraints: Viable candidate for cold dark matter

$$0.1097 < \Omega_{\mathrm{CDM}} h^2 < 0.1165$$

see e.g. Bozzi, Fuks, Herrmann, Klasen (2007); Fuks, Herrmann, Klasen (2008); Hurth, Porod (2009)

Constraints on the MSSM parameter space

PDG 2008-2009; HFAG 2009; WMAP 2009

Mass limits from collider searches

Electroweak precision and low-energy measurements

$$\begin{aligned}
\mathrm{BR}(b \to s\gamma) &= (3.52 \pm 0.52) \cdot 10^{-4} \\
\Delta M_{B_s} &= (17.77 \pm 3.31)\ \mathrm{ps}^{-1} \\
\Delta \rho &= (1.02 \pm 1.72) \cdot 10^{-3}
\end{aligned}$$

Highly sensitive to QFV elements

$$\begin{aligned}
\mathrm{BR}(b \to s\mu^+\mu^-) &= (1.60 \pm 1.00) \cdot 10^{-6} \\
\mathrm{BR}(B_s \to \mu^+\mu^-) &< 4.8 \cdot 10^{-8} \\
\mathrm{BR}(B \to \tau^+\bar{\nu}) &= (1.43 \pm 0.43) \cdot 10^{-4}
\end{aligned}$$

$$\Delta a_\mu = a_\mu^{\mathrm{SM}} - a_{mu}^{\mathrm{exp}} = (29.0 \pm 8.6) \cdot 10^{-10}$$

Rather insensitive to QFV elements

Cosmological constraints: Viable candidate for cold dark matter

$$0.1097 < \Omega_{\mathrm{CDM}} h^2 < 0.1165$$

see e.g. Bozzi, Fuks, Herrmann, Klasen (2007); Fuks, Herrmann, Klasen (2008); Hurth, Porod (2009)

Squark Pair Production at Hadron Colliders

QCD factorization theorem

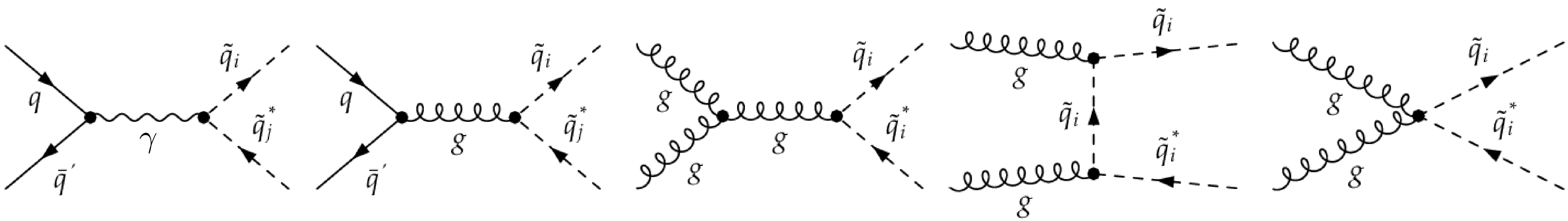
$$\boxed{\sigma = \int_{t_-}^{t_+} \mathrm{d}t \int_{4m^2/s}^{1} \mathrm{d}\tau \int_{-1/2\ln\tau}^{1/2\ln\tau} \mathrm{d}y \; f_{a/A}(x_a, M_a^2)\; f_{b/B}(x_b, M_b^2)\; \frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}t}}$$

Squark Pair Production at Hadron Colliders

QCD factorization theorem

$$\sigma = \int_{t_-}^{t_+} \mathrm{d}t \int_{4m^2/s}^{1} \mathrm{d}\tau \int_{-1/2\ln\tau}^{1/2\ln\tau} \mathrm{d}y \; f_{a/A}(x_a, M_a^2) \; f_{b/B}(x_b, M_b^2) \; \frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}t}$$

Flavour-conserving channels

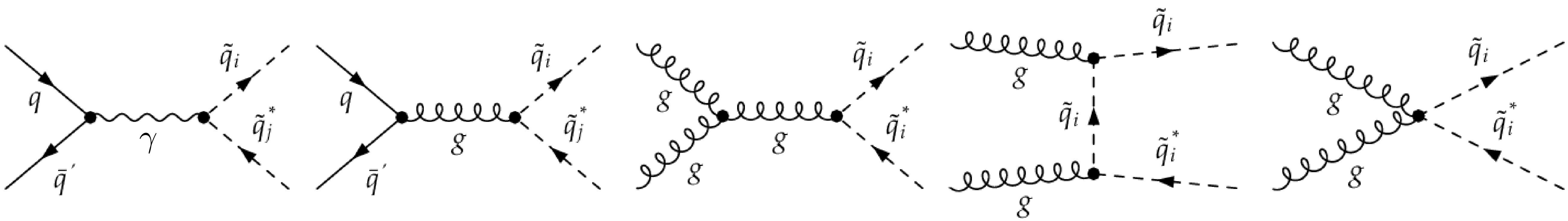


Squark Pair Production at Hadron Colliders

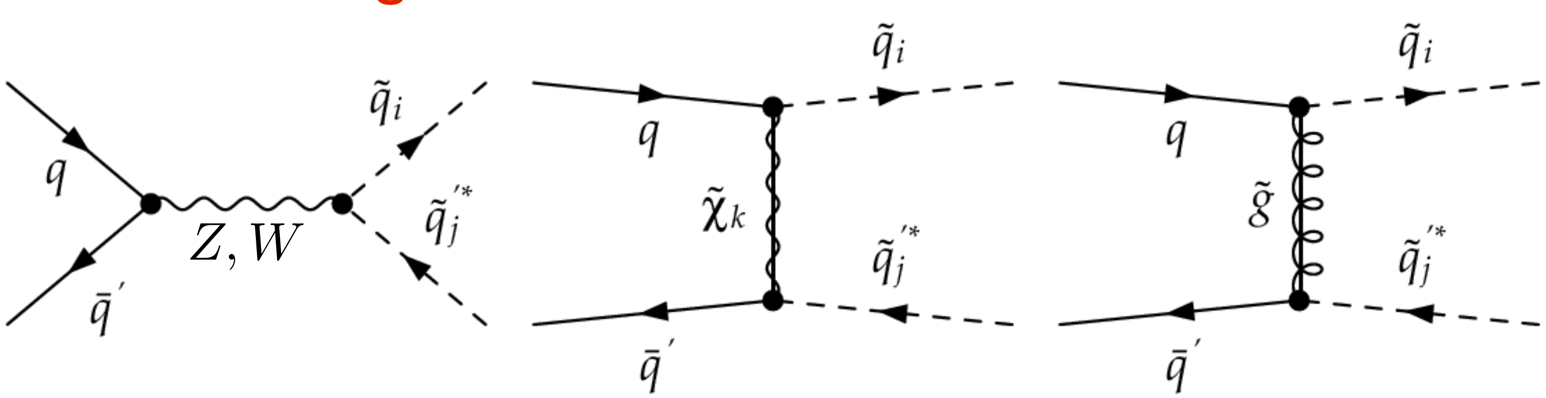
QCD factorization theorem

$$\sigma \;=\; \int_{t_-}^{t_+} \mathrm{d}t \int_{4m^2/s}^{1} \mathrm{d}\tau \int_{-1/2\ln\tau}^{1/2\ln\tau} \mathrm{d}y\; f_{a/A}(x_a, M_a^2)\; f_{b/B}(x_b, M_b^2)\; \frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}t}$$

Flavour-conserving channels



Flavour-violating channels

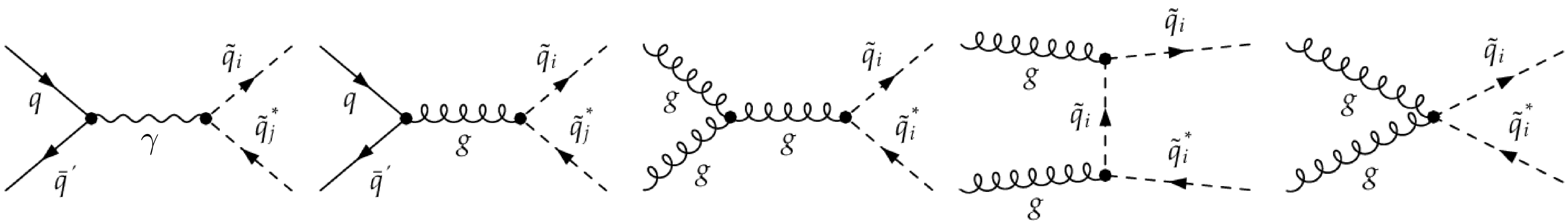


Squark Pair Production at Hadron Colliders

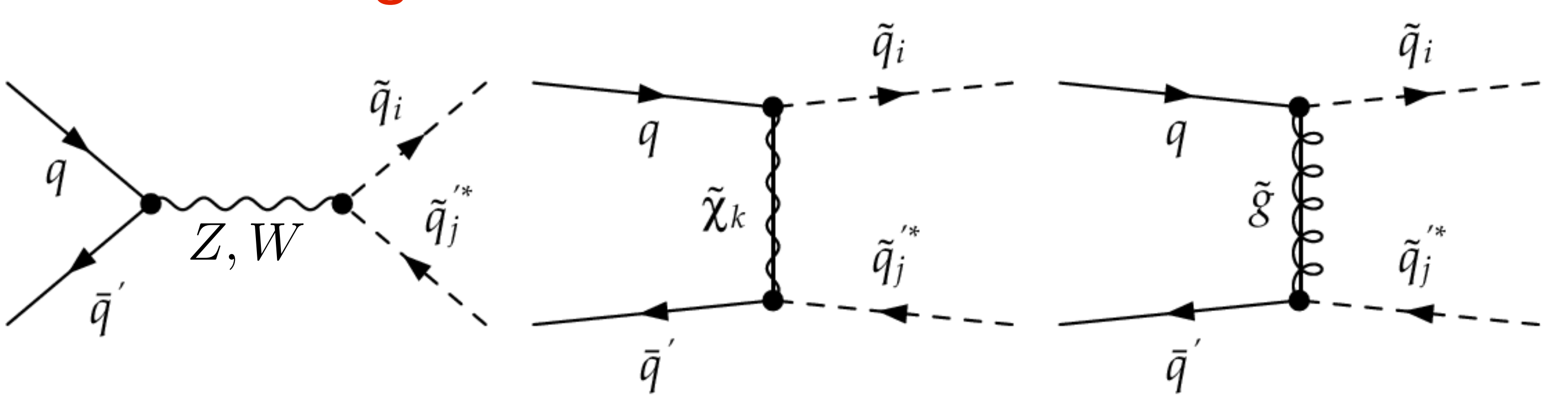
QCD factorization theorem

$$\sigma = \int_{t_-}^{t_+} \mathrm{d}t \int_{4m^2/s}^{1} \mathrm{d}\tau \int_{-1/2\ln\tau}^{1/2\ln\tau} \mathrm{d}y \; f_{a/A}(x_a, M_a^2)\; f_{b/B}(x_b, M_b^2)\; \frac{\mathrm{d}\hat\sigma}{\mathrm{d}t}$$

Flavour-conserving channels



Flavour-violating channels



Analytical expressions for squark production cross-sections and decays published in earlier works

Bozzi, Fuks, Herrmann, Klasen (2007); Fuks, Herrmann, Klasen (2008)

Reference Scenario in "phenomenological MSSM"

Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

Soft-breaking parameters defined at the electro-weak scale (in GeV)

$$M_Q^2 = \begin{pmatrix} (920)^2 & 0 & 0 \\ 0 & (880)^2 & (224)^2 \\ 0 & (224)^2 & (840)^2 \end{pmatrix} \qquad M_U^2 = \begin{pmatrix} (820)^2 & 0 & 0 \\ 0 & (600)^2 & 0 \\ 0 & 0 & (580)^2 \end{pmatrix} \qquad A_{U,\alpha\beta} = 0$$

$$M_1 = 139 \qquad M_2 = 264 \qquad M_3 = 800 \qquad \mu = 1000 \qquad \tan\beta = 10 \qquad m_A = 800$$

Reference Scenario in "phenomenological MSSM"

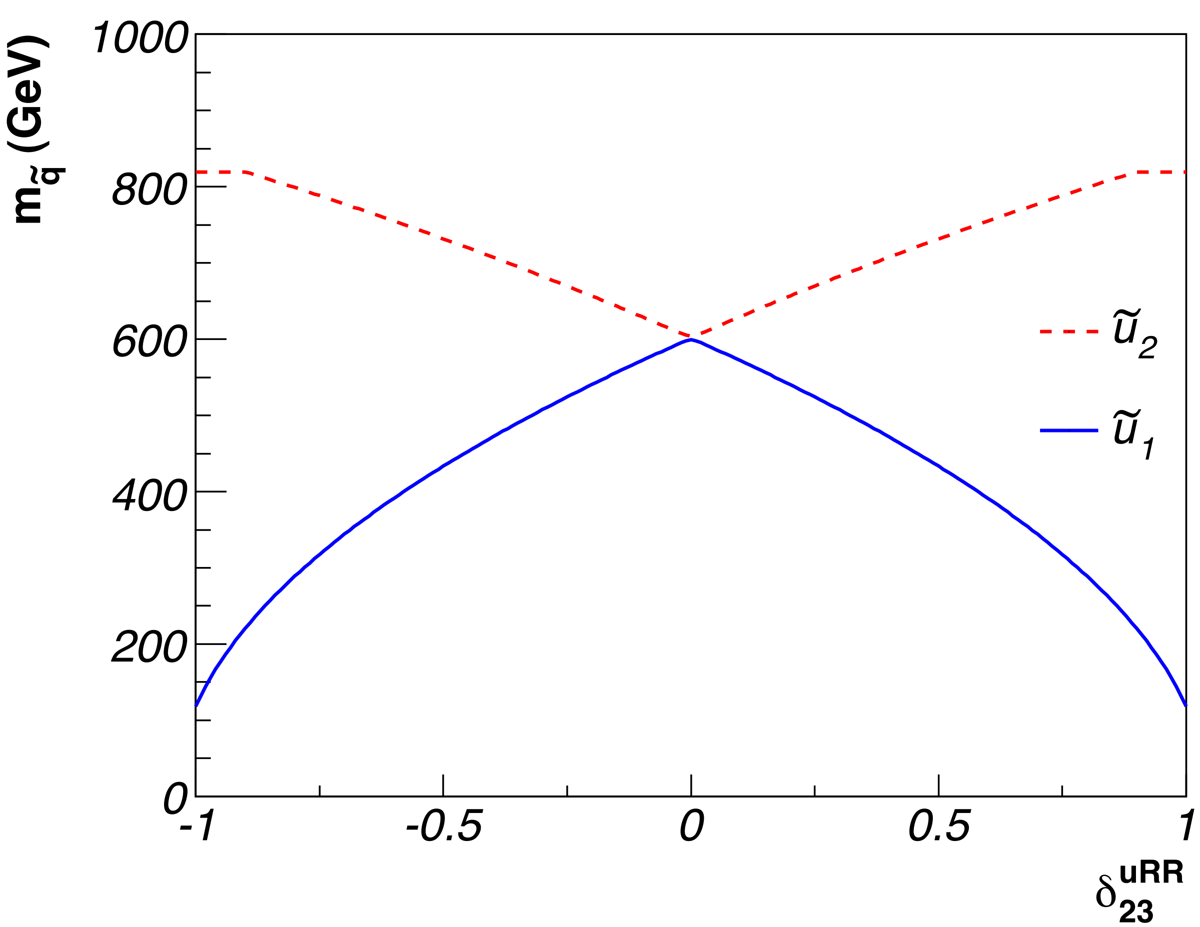
Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

Soft-breaking parameters defined at the electro-weak scale (in GeV)

$$M_Q^2 = \begin{pmatrix} (920)^2 & 0 & 0 \\ 0 & (880)^2 & (224)^2 \\ 0 & (224)^2 & (840)^2 \end{pmatrix} \qquad M_U^2 = \begin{pmatrix} (820)^2 & 0 & 0 \\ 0 & (600)^2 & 0 \\ 0 & 0 & (580)^2 \end{pmatrix} \qquad A_{U,\alpha\beta} = 0$$

$$M_1 = 139 \qquad M_2 = 264 \qquad M_3 = 800 \qquad \mu = 1000 \qquad \tan\beta = 10 \qquad m_A = 800$$

QFV entries in mass matrices influence on squark masses and flavour content



Reference Scenario in "phenomenological MSSM"

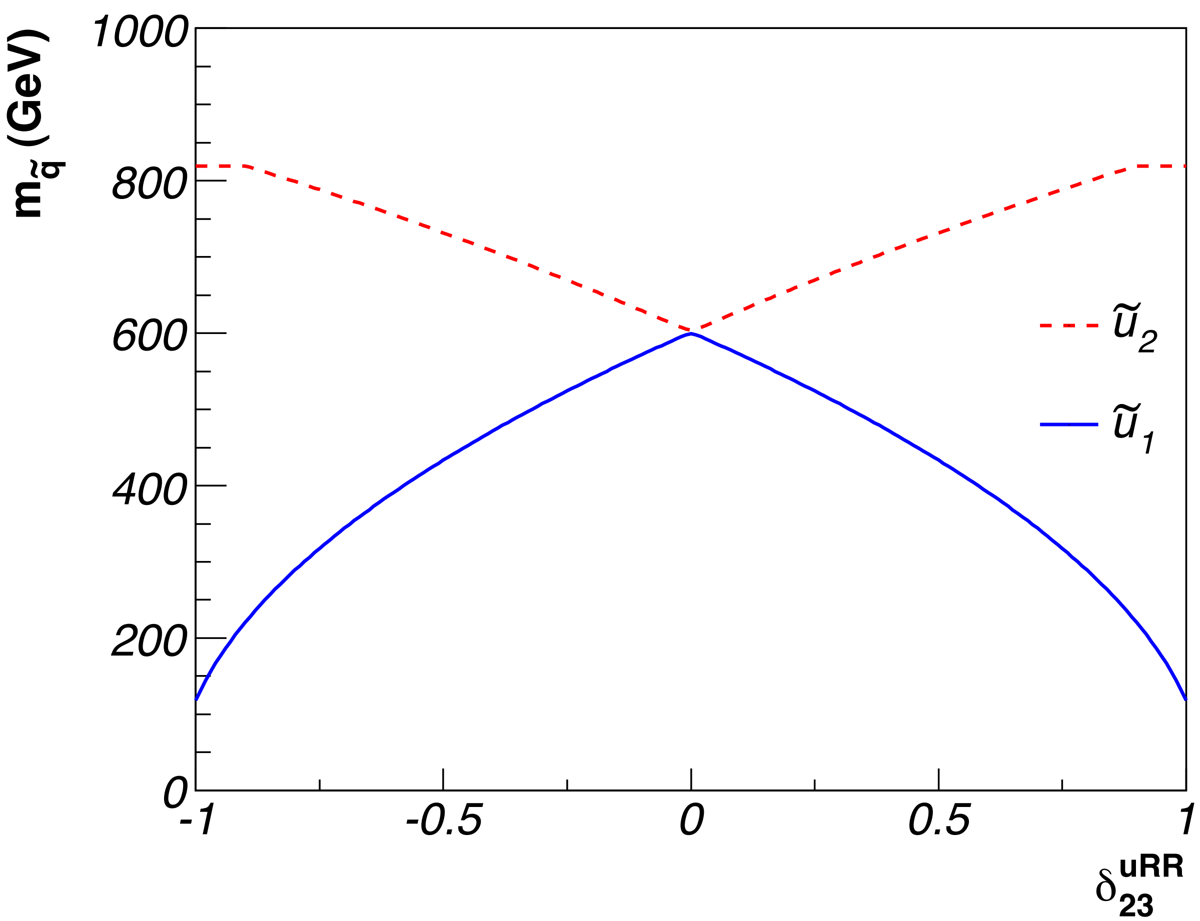
Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

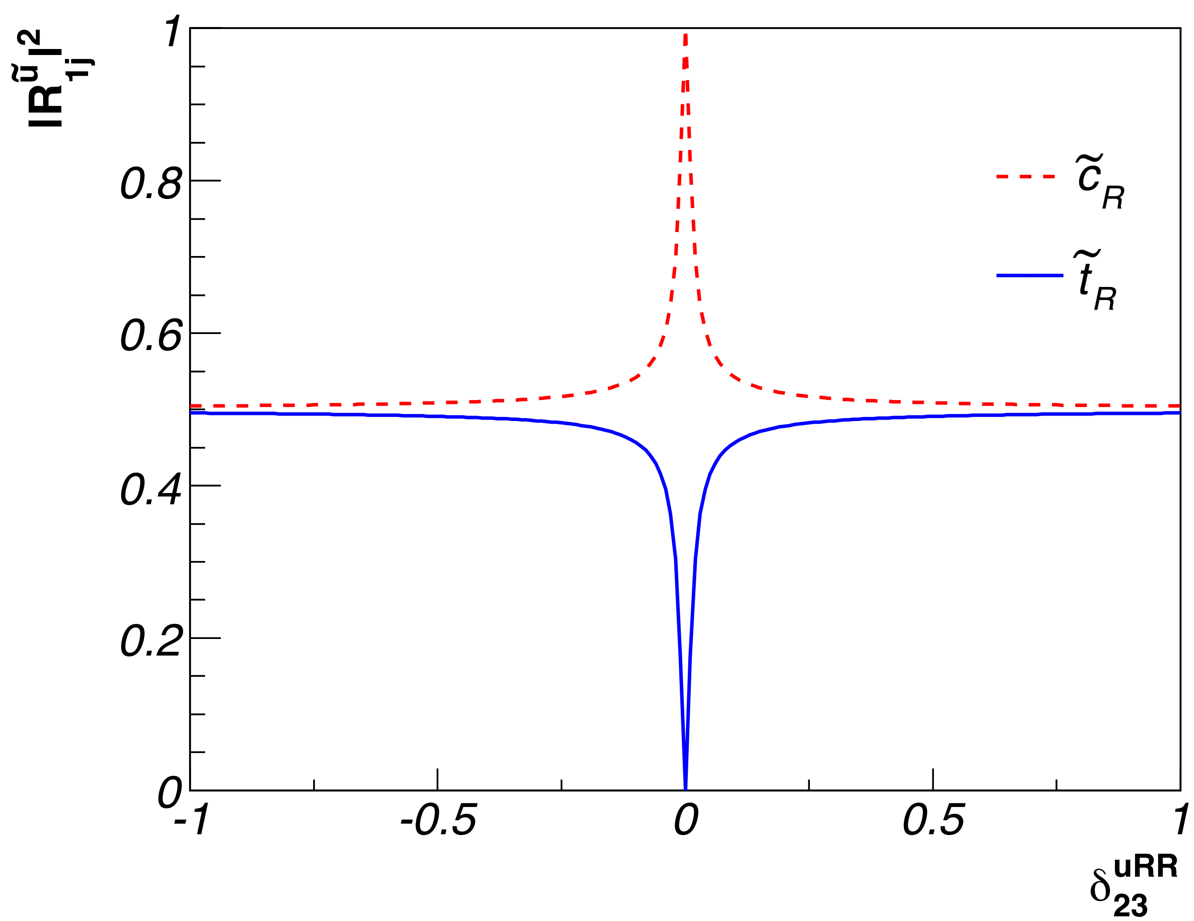
Soft-breaking parameters defined at the electro-weak scale (in GeV)

$$M_Q^2 = \begin{pmatrix} (920)^2 & 0 & 0 \\ 0 & (880)^2 & (224)^2 \\ 0 & (224)^2 & (840)^2 \end{pmatrix} \qquad M_U^2 = \begin{pmatrix} (820)^2 & 0 & 0 \\ 0 & (600)^2 & 0 \\ 0 & 0 & (580)^2 \end{pmatrix} \qquad A_{U,\alpha\beta} = 0$$

$$M_1 = 139 \qquad M_2 = 264 \qquad M_3 = 800 \qquad \mu = 1000 \qquad \tan\beta = 10 \qquad m_A = 800$$

QFV entries in mass matrices influence on squark masses and flavour content

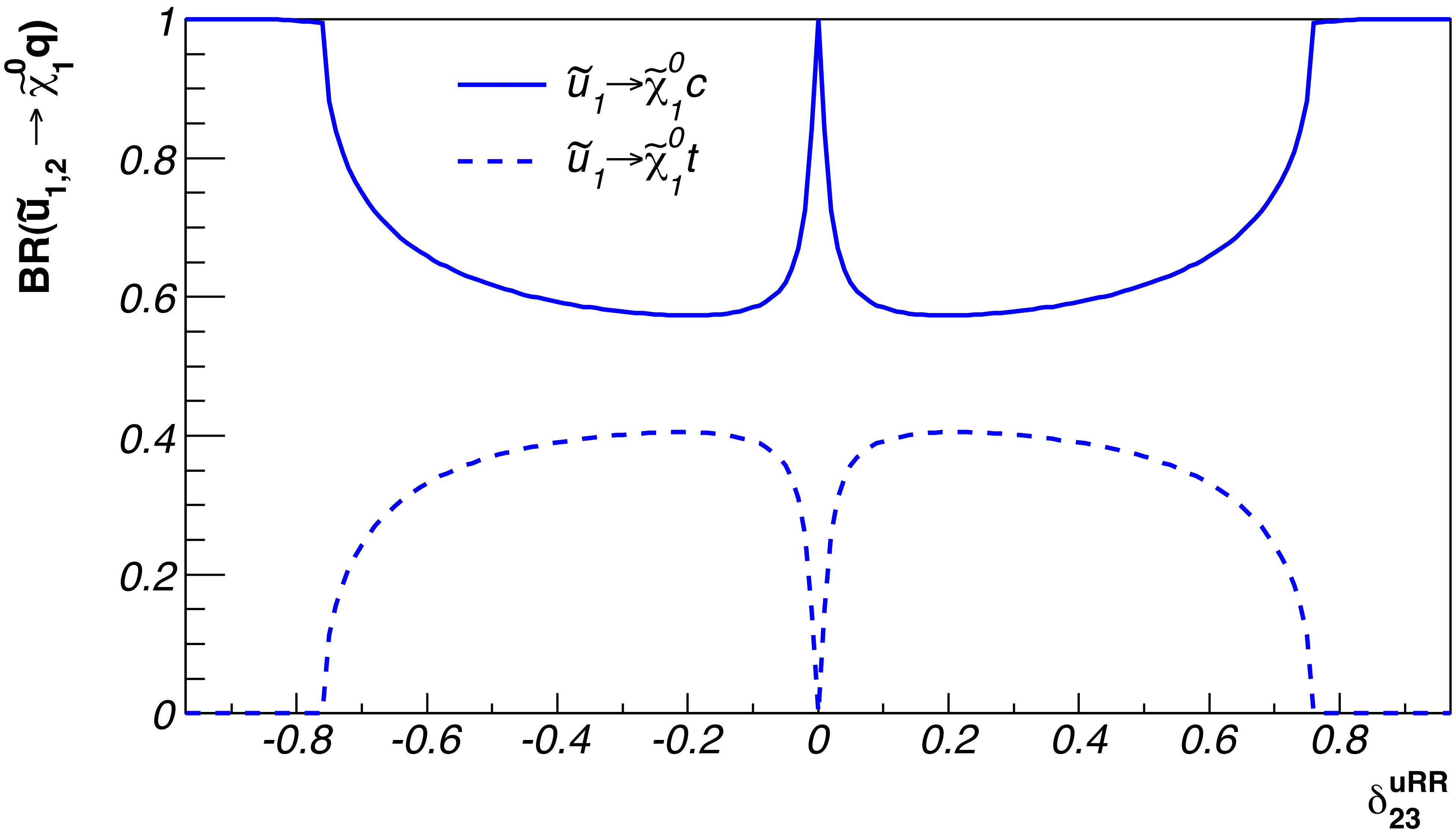




Squark Decays for QFV Reference Scenario

Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

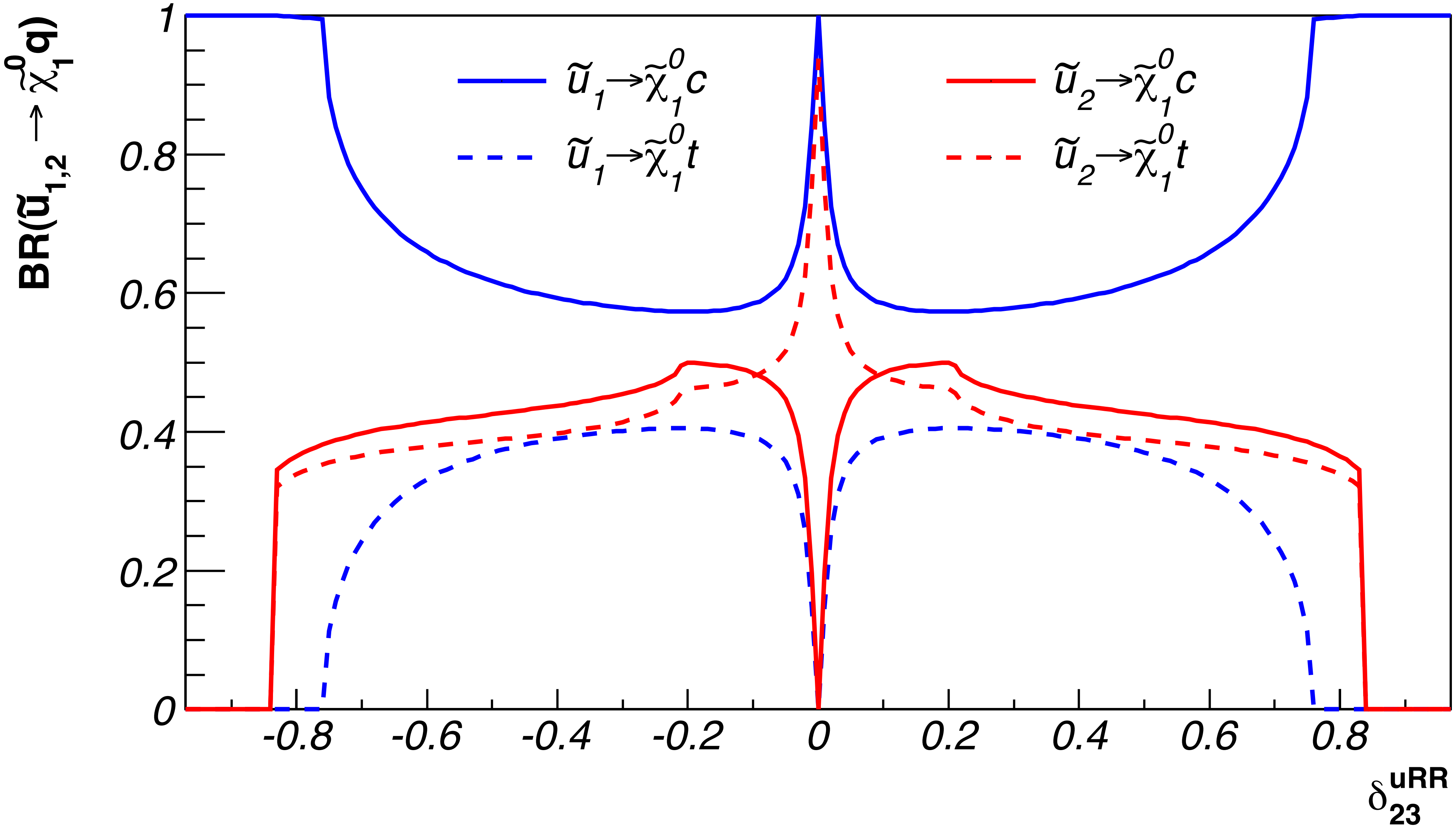
Branching ratios of squarks depend on masses and mixing matrices



Squark Decays for QFV Reference Scenario

Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

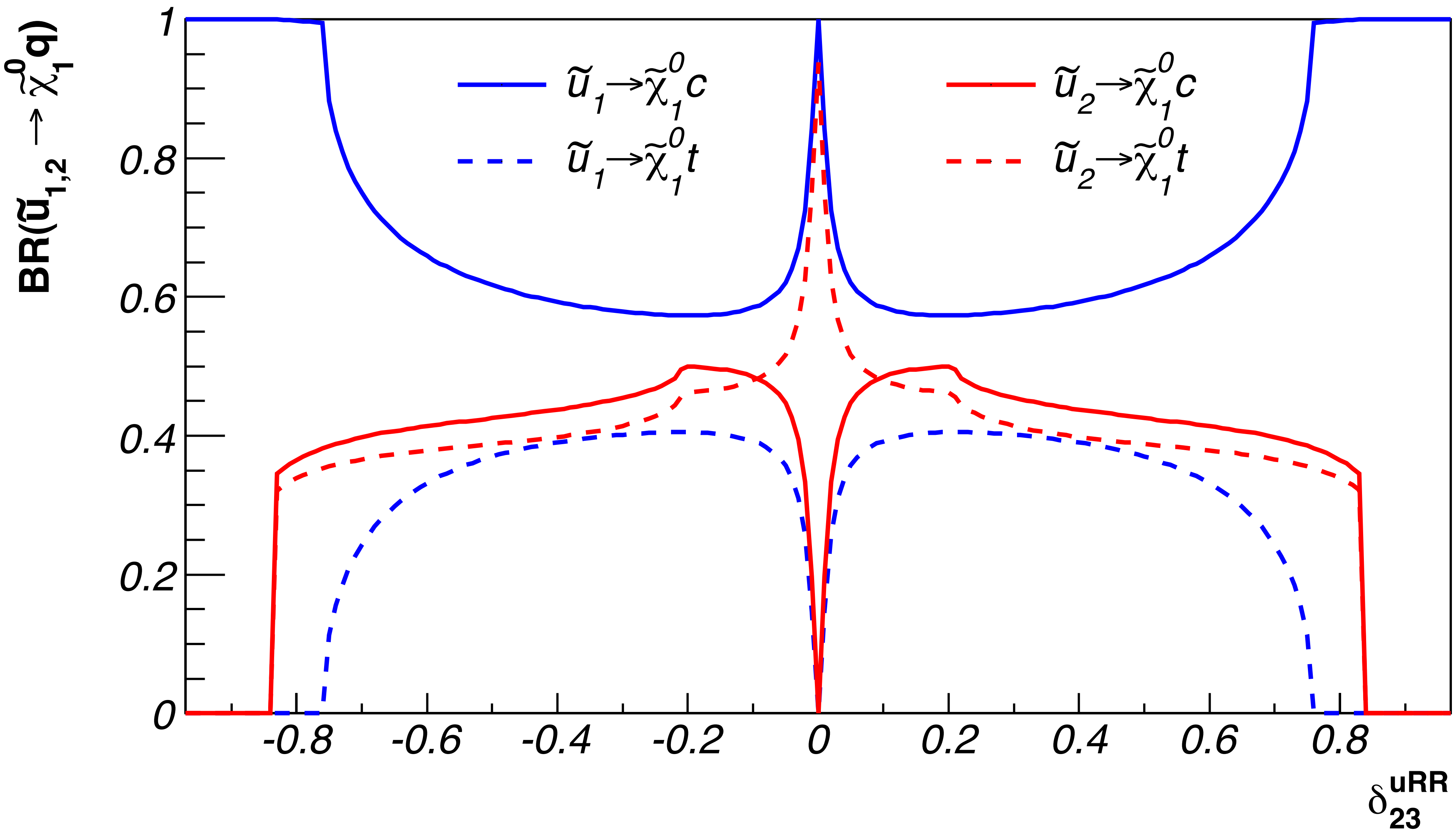
Branching ratios of squarks depend on masses and mixing matrices



Squark Decays for QFV Reference Scenario

Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

Branching ratios of squarks depend on masses and mixing matrices



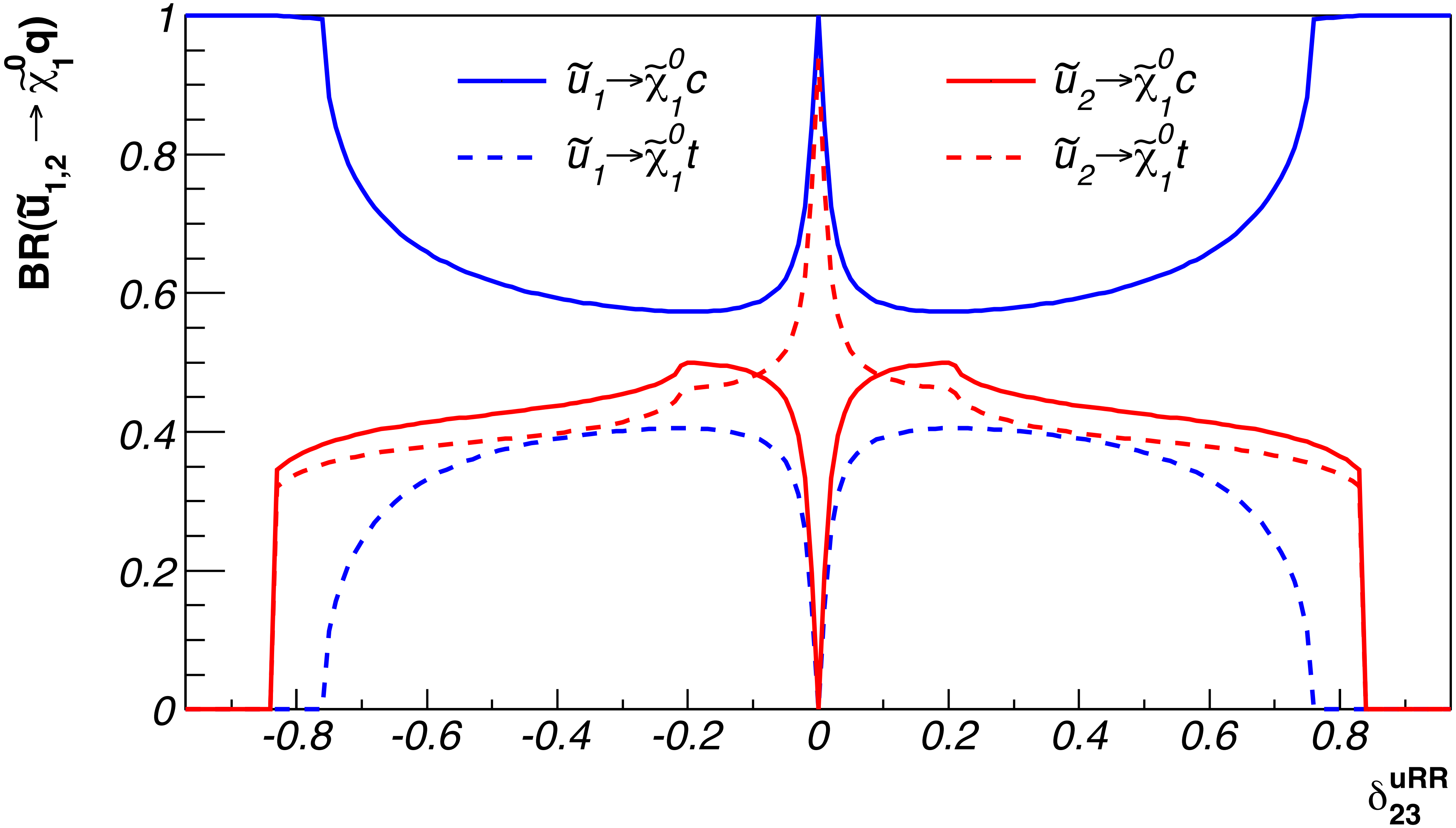
Branching ratios of lightest squarks into charm- and top-quarks can be simultaneously large

➔ large QFV effects and interesting phenomenology at colliders...

Squark Decays for QFV Reference Scenario

Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

Branching ratios of squarks depend on masses and mixing matrices



Branching ratios of lightest squarks into charm- and top-quarks can be simultaneously large

➔ large QFV effects and interesting phenomenology at colliders...

Allowed range w.r.t. experimental constraints: $\boxed{-0.8 \lesssim \delta^{uRR}_{23} \lesssim 0.8}$

Production and Decays of Squarks at LHC

Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

Interesting production signatures due to potentially large squark branching ratios

$$
\boxed{\begin{aligned}
p\,p \;&\longrightarrow\; \tilde{u}_{1,2}\,\tilde{u}^*_{1,2} \;\longrightarrow\; c\,\bar{t}\;\tilde{\chi}^0_1\,\tilde{\chi}^0_1 \\
p\,p \;&\longrightarrow\; \tilde{u}_{1,2}\,\tilde{u}_{1,2} \;\longrightarrow\; t\,t\;\tilde{\chi}^0_1\,\tilde{\chi}^0_1
\end{aligned}}
$$

Production and Decays of Squarks at LHC

Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

Interesting production signatures due to potentially large squark branching ratios

$$\boxed{\begin{array}{ccccc} p\,p & \longrightarrow & \tilde{u}_{1,2}\,\tilde{u}^*_{1,2} & \longrightarrow & c\,\bar{t}\;\tilde{\chi}^0_1\,\tilde{\chi}^0_1 \\ p\,p & \longrightarrow & \tilde{u}_{1,2}\,\tilde{u}_{1,2} & \longrightarrow & t\,t\;\tilde{\chi}^0_1\,\tilde{\chi}^0_1 \end{array}}$$

Calculation of the corresponding cross-sections

$$\begin{aligned} \sigma^{ij}_{c\bar{t}} &= \sigma(pp \to \tilde{u}_i\tilde{u}^*_j)\Big[\mathrm{BR}(\tilde{u}_i \to c\tilde{\chi}^0_1)\mathrm{BR}(\tilde{u}_j \to t\tilde{\chi}^0_1) + \mathrm{BR}(\tilde{u}_j \to c\tilde{\chi}^0_1)\mathrm{BR}(\tilde{u}_i \to t\tilde{\chi}^0_1)\Big] \\ \sigma^{ij}_{tt} &= \sigma(pp \to \tilde{u}_i\tilde{u}^*_j)\Big[\mathrm{BR}(\tilde{u}_i \to t\tilde{\chi}^0_1)\mathrm{BR}(\tilde{u}_j \to t\tilde{\chi}^0_1)\Big] \end{aligned}$$

Production and Decays of Squarks at LHC

Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

Interesting production signatures due to potentially large squark branching ratios

$$pp \;\longrightarrow\; \tilde{u}_{1,2}\,\tilde{u}^*_{1,2} \;\longrightarrow\; c\,\bar{t}\;\tilde{\chi}^0_1\,\tilde{\chi}^0_1$$

$$pp \;\longrightarrow\; \tilde{u}_{1,2}\,\tilde{u}_{1,2} \;\longrightarrow\; t\,t\;\tilde{\chi}^0_1\,\tilde{\chi}^0_1$$

Calculation of the corresponding cross-sections

$$\sigma^{ij}_{c\bar{t}} \;=\; \sigma(pp\to\tilde{u}_i\tilde{u}^*_j)\Big[\mathrm{BR}(\tilde{u}_i\to c\tilde{\chi}^0_1)\mathrm{BR}(\tilde{u}_j\to t\tilde{\chi}^0_1)+\mathrm{BR}(\tilde{u}_j\to c\tilde{\chi}^0_1)\mathrm{BR}(\tilde{u}_i\to t\tilde{\chi}^0_1)\Big]$$

$$\sigma^{ij}_{tt} \;=\; \sigma(pp\to\tilde{u}_i\tilde{u}^*_j)\Big[\mathrm{BR}(\tilde{u}_i\to t\tilde{\chi}^0_1)\mathrm{BR}(\tilde{u}_j\to t\tilde{\chi}^0_1)\Big]$$

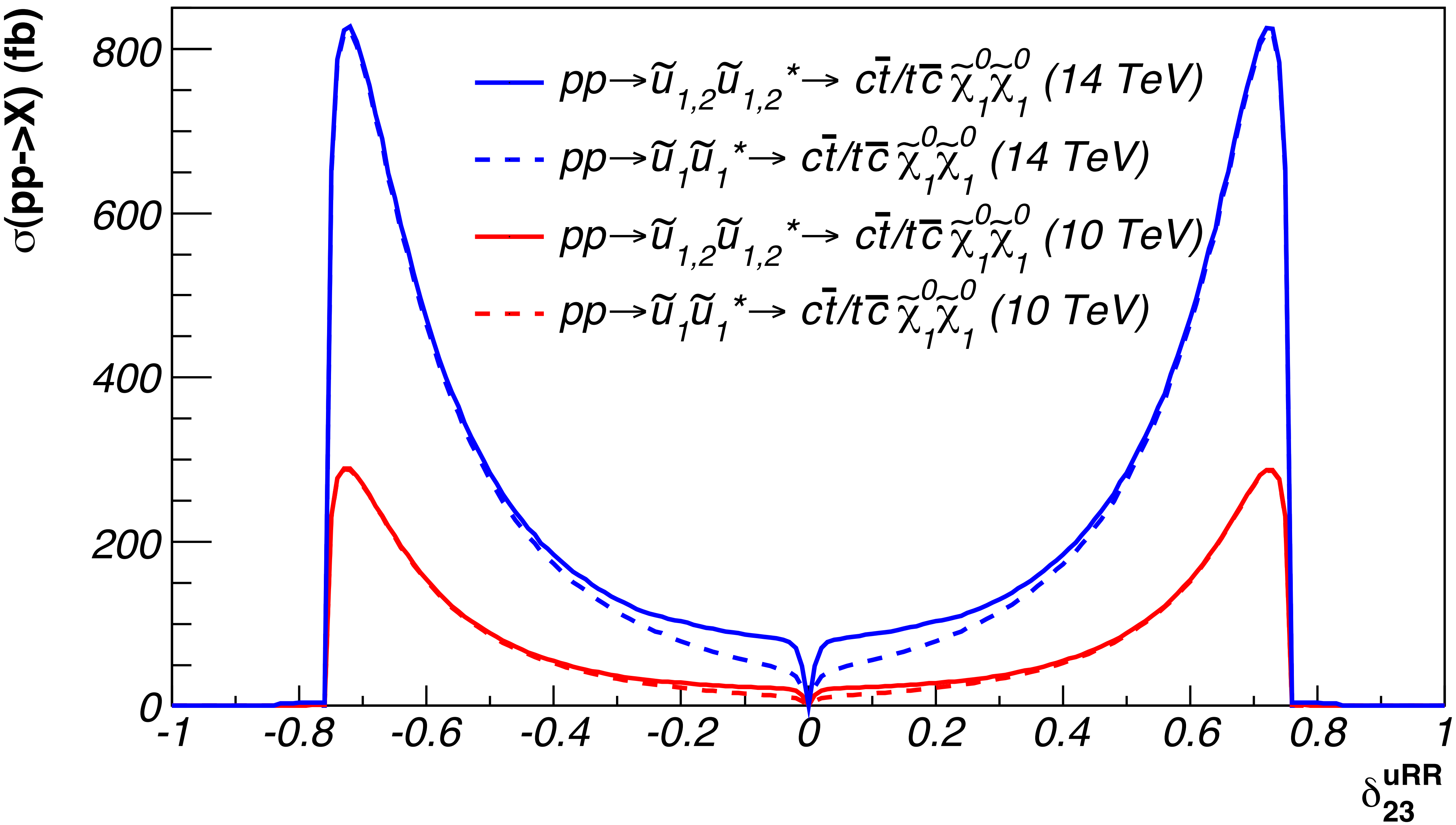
Numerical calculation

- SPheno3 for mass spectrum, constraints, and branching ratios [Porod 2003-2010]
- Whizard/O'Mega for production cross-sections [Kilian, Ohl, Reuter 2001-2010] (MSSM with QFV implemented!) [Herrmann 2009]
- Verification using FeynArts/FormCalc [Hahn 2001-2010] and XSUSY [Fuks, Herrmann *to be published*]
- CTEQ6L parton distribution functions [Pumplin *et al.* (CTEQ)]

Signatures at LHC for QFV Reference Scenario

Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

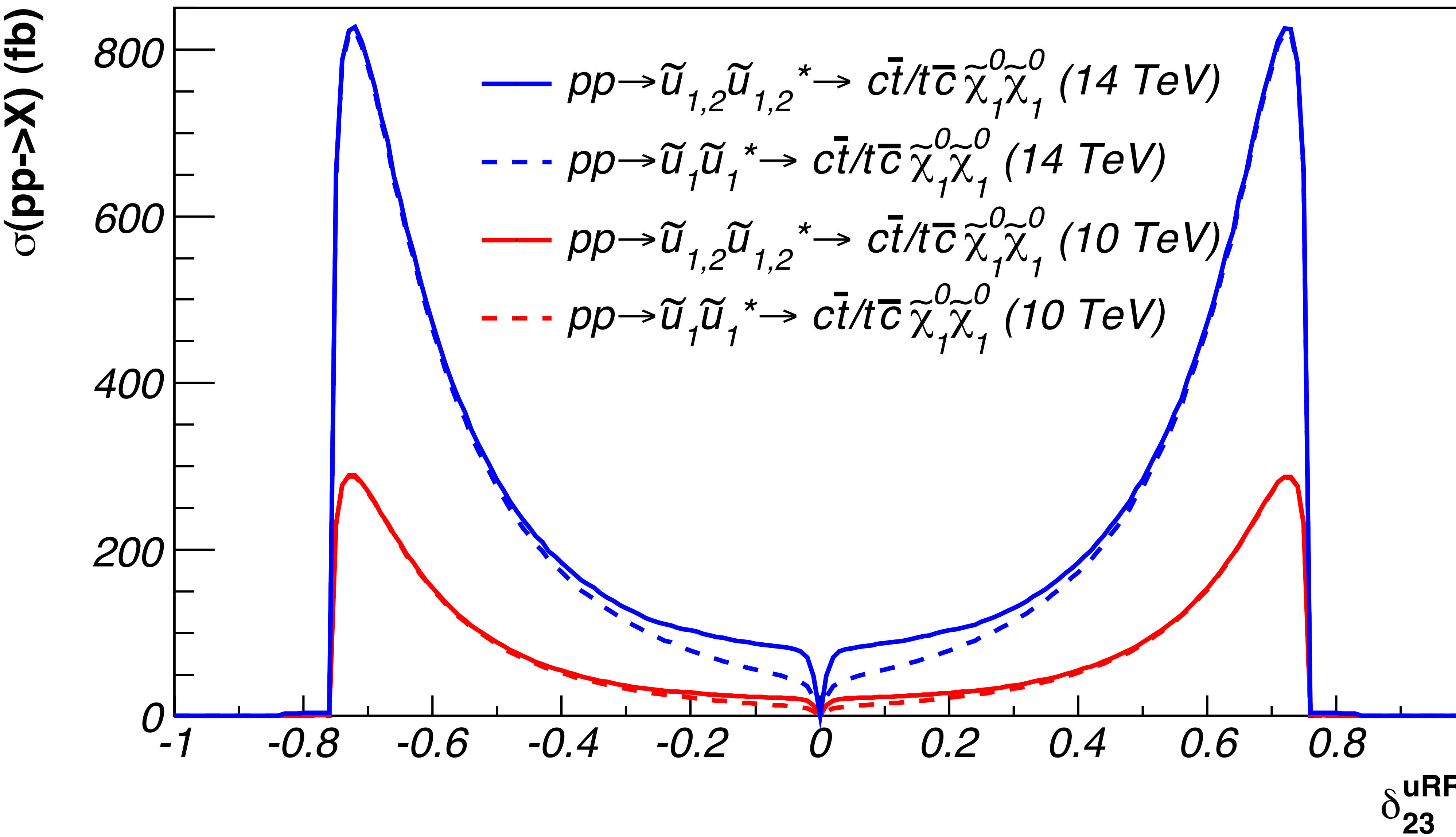
Charm-top associated production provides interesting signature



Signatures at LHC for QFV Reference Scenario

Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

Charm-top associated production provides interesting signature

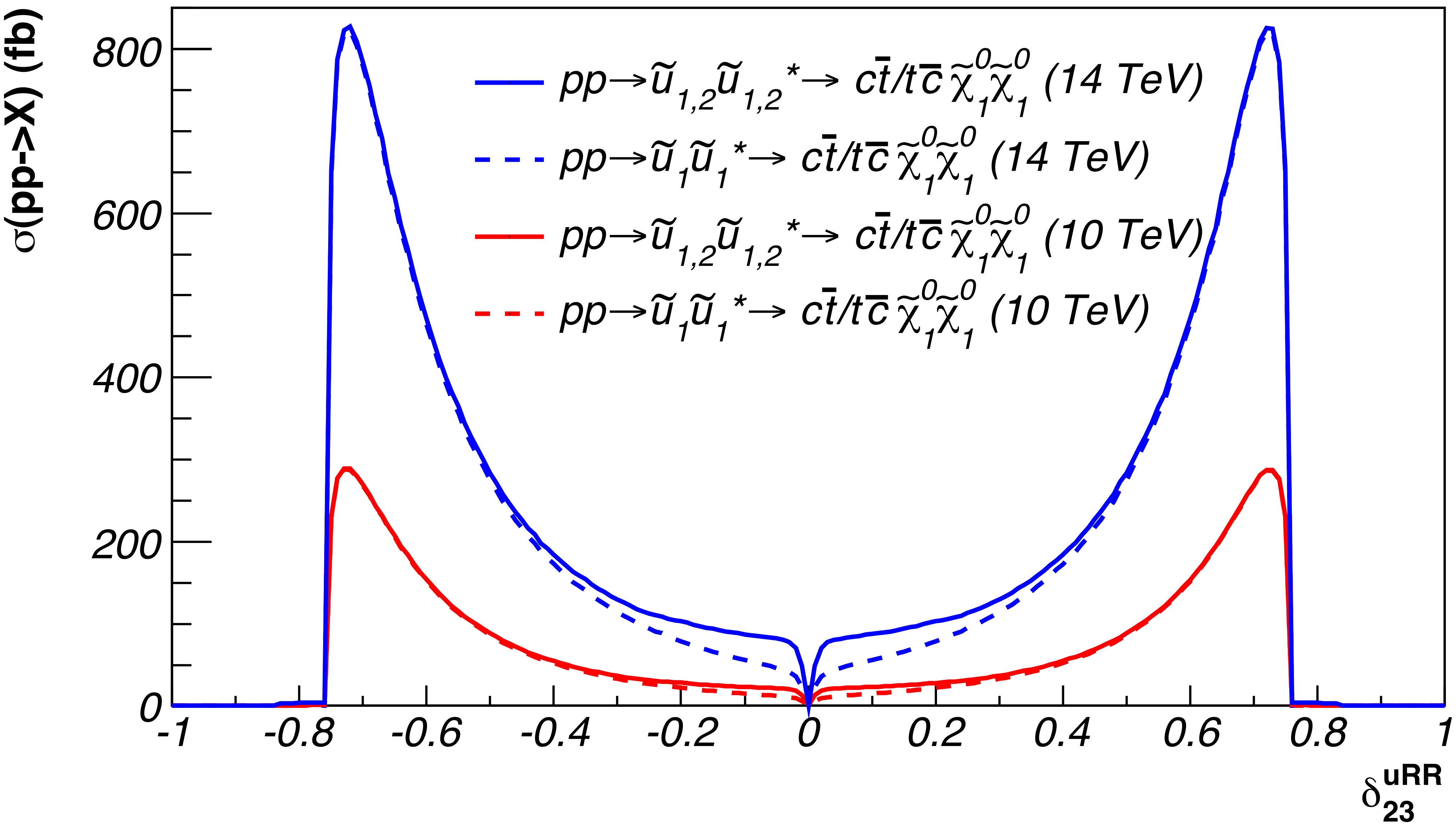


Expect ~10^4 events for "jet + top + E_T^{miss}" production at 100 fb^{-1} integrated luminosity

Signatures at LHC for QFV Reference Scenario

Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

Charm-top associated production provides interesting signature



Expect ~10^4 events for "jet + top + E_T^{miss}" production at 100 fb^{-1} integrated luminosity

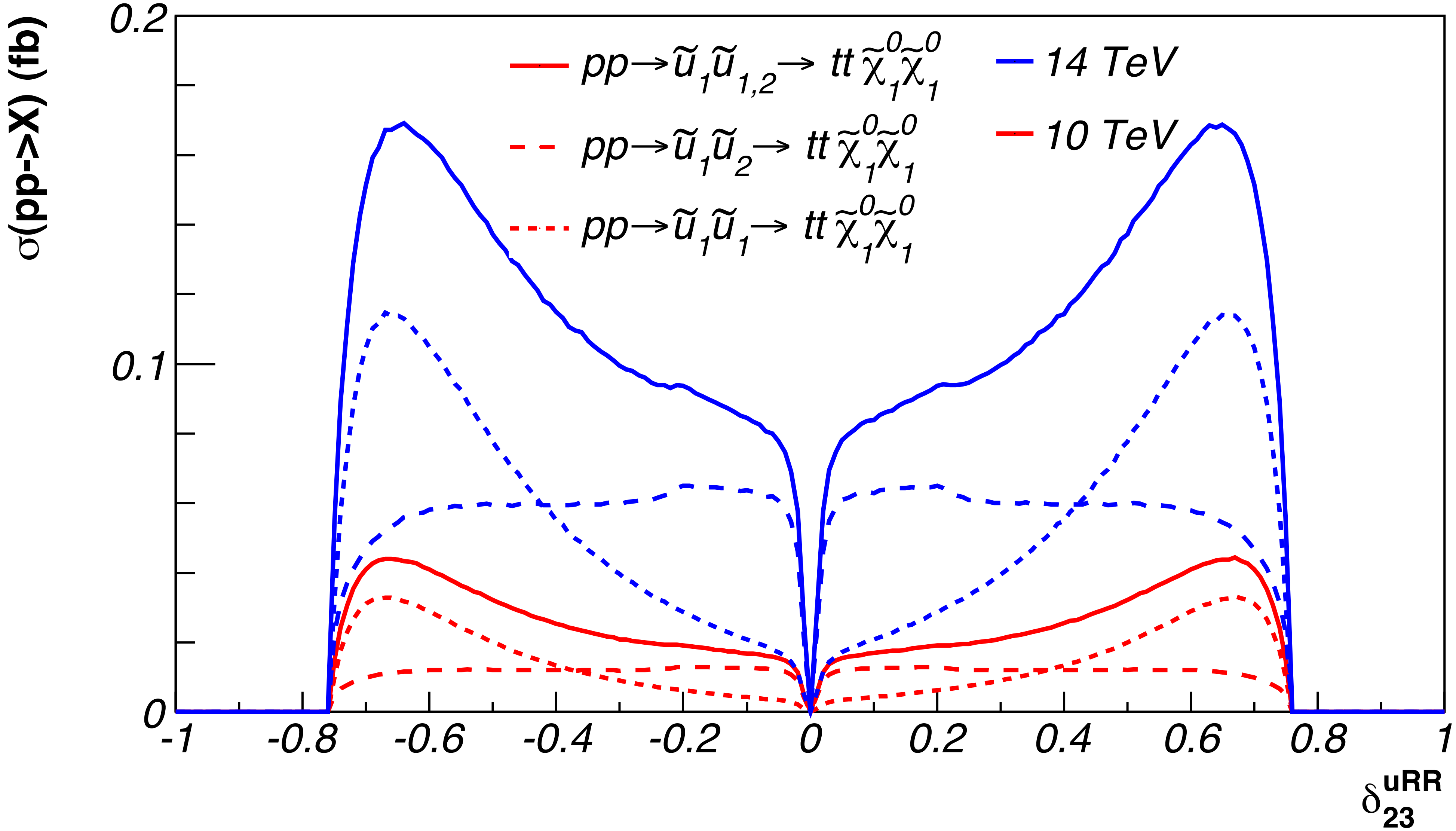
Loop corrections for dominant flavour-conserving channels enhance cross-section by about 30%

[Beenakker, Höpker, Spira, Zerwas (1997)]

Signatures at LHC for QFV Reference Scenario

Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

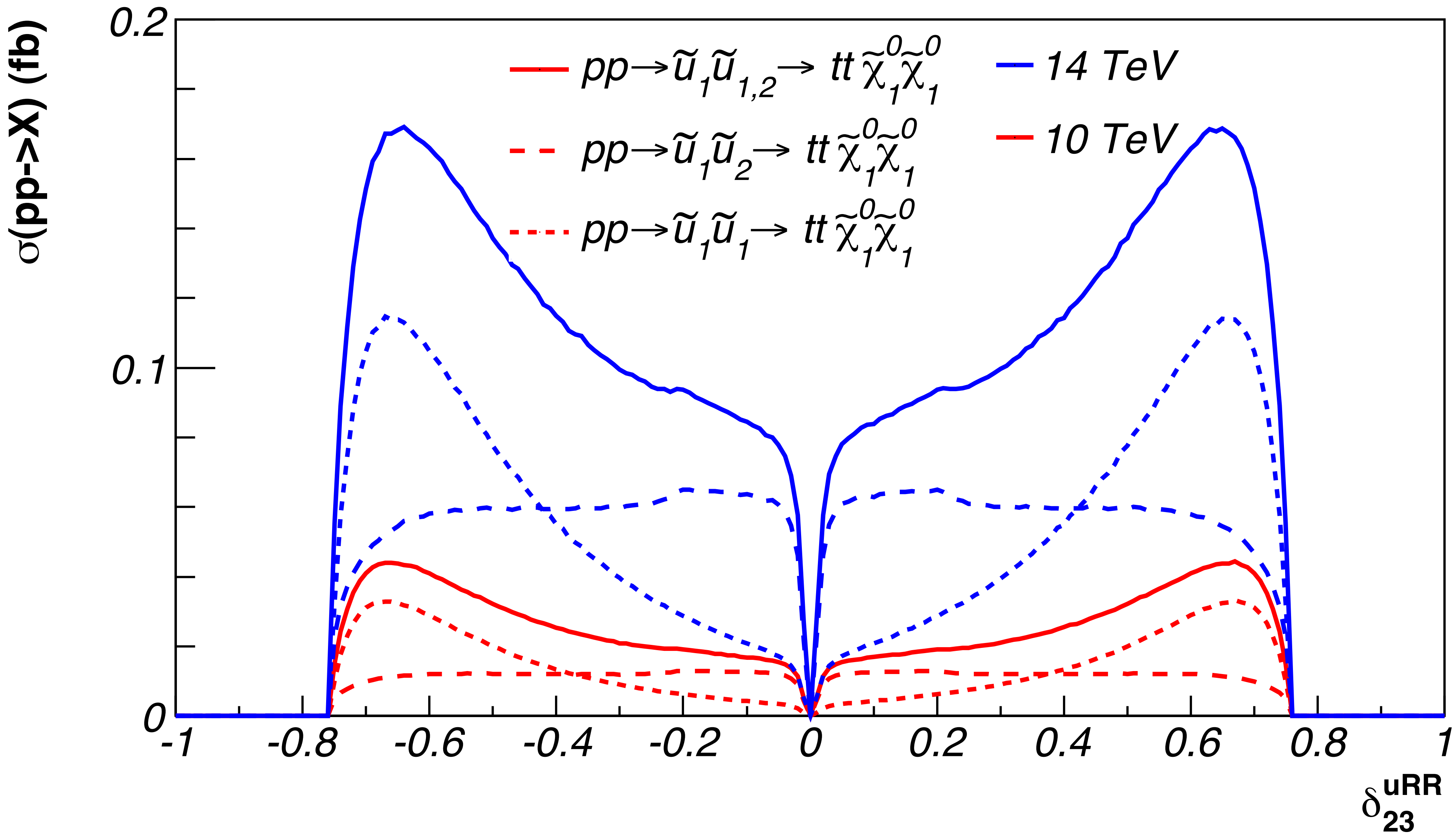
Top-quark pair production including missing energy provides another interesting signature



Signatures at LHC for QFV Reference Scenario

Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

Top-quark pair production including missing energy provides another interesting signature

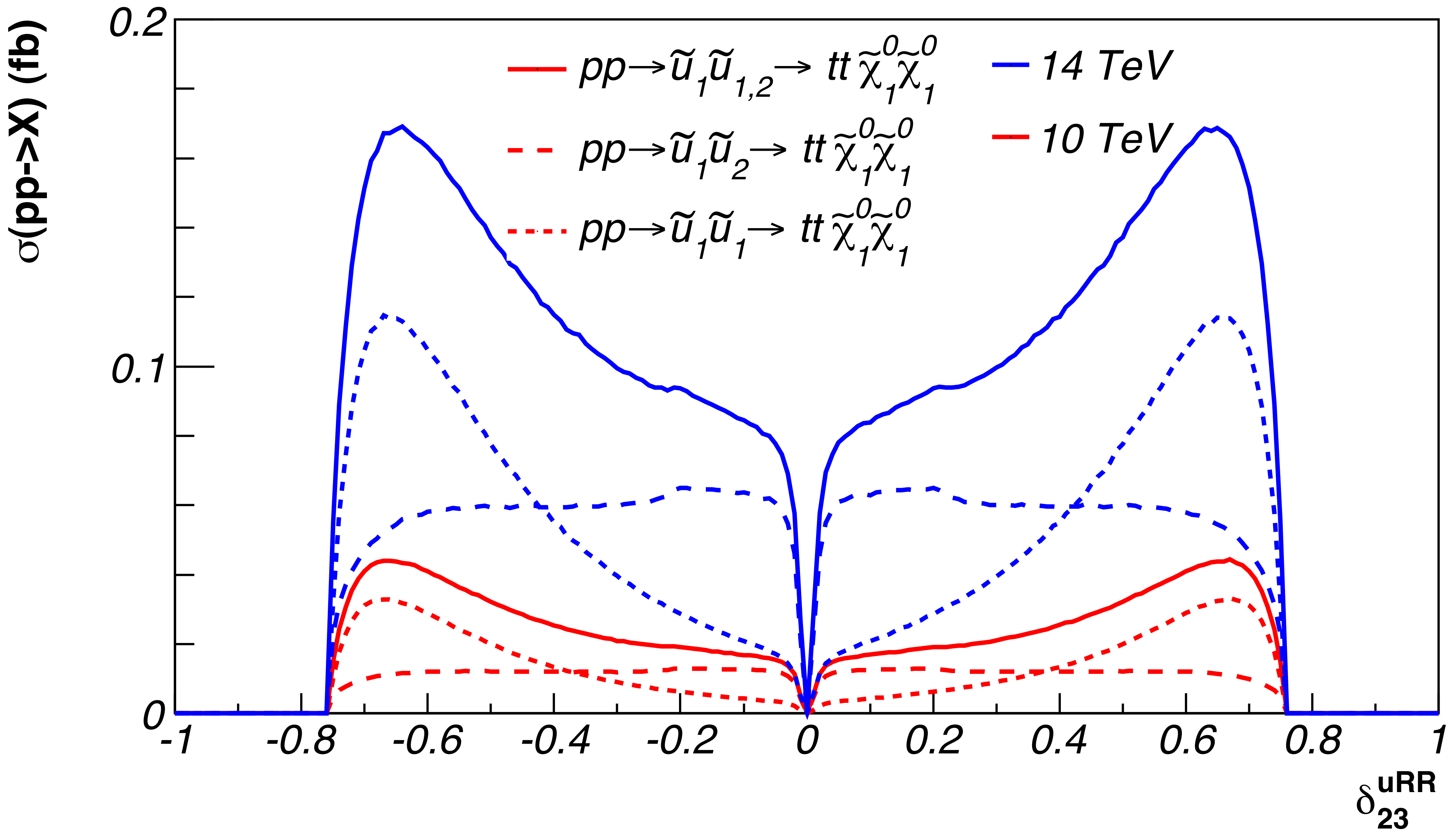


Signal "top+top+E_T^{miss}" can practically not be produced in SM or flavour-conserving MSSM

Signatures at LHC for QFV Reference Scenario

Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

Top-quark pair production including missing energy provides another interesting signature



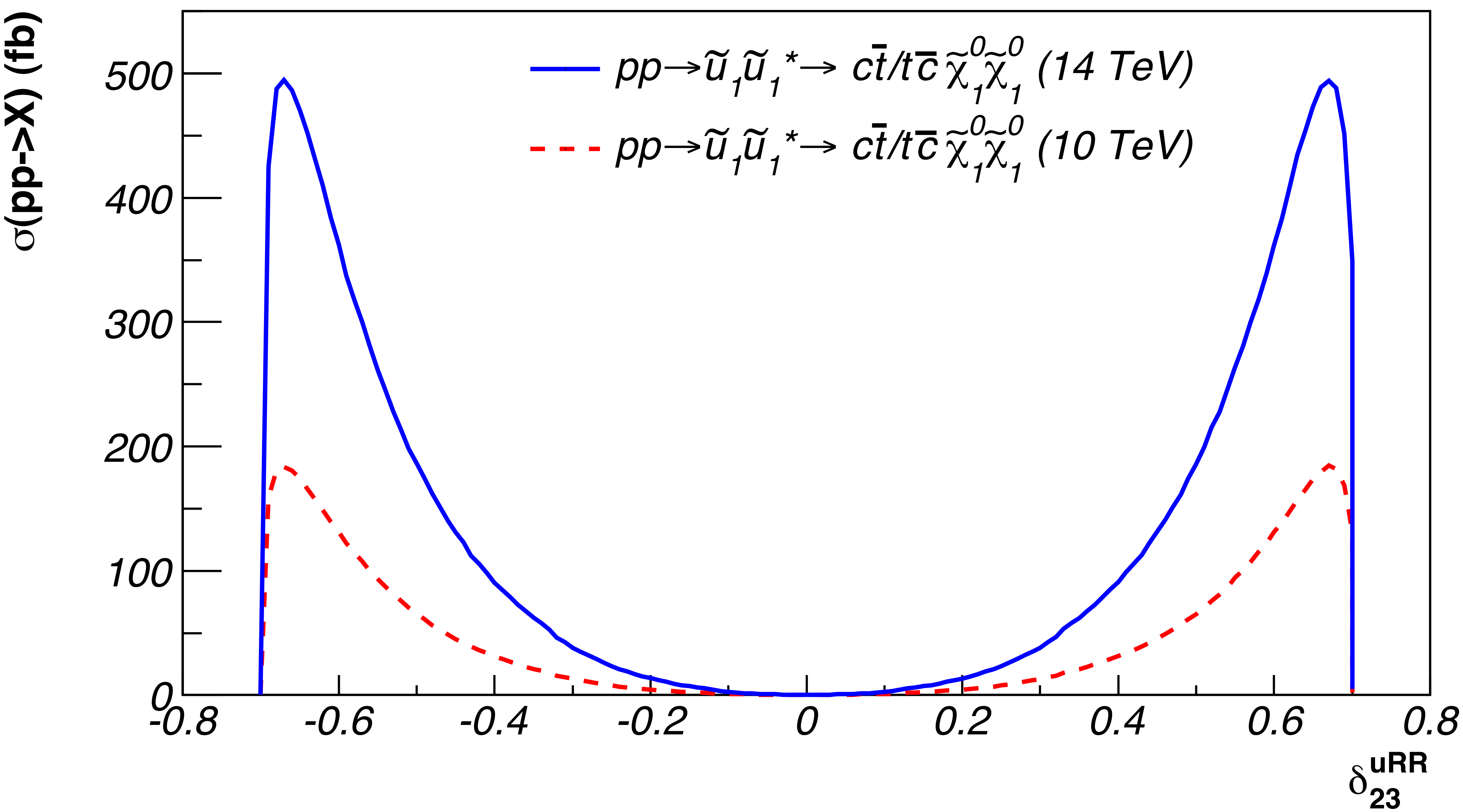
Signal "top+top+E_T^{miss}" can practically not be produced in SM or flavour-conserving MSSM

Cross-sections rather small due to absent gluon contributions,
dominant subprocess is gluino exchange from initial state charm content

Signatures at LHC for SPS1a'

Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

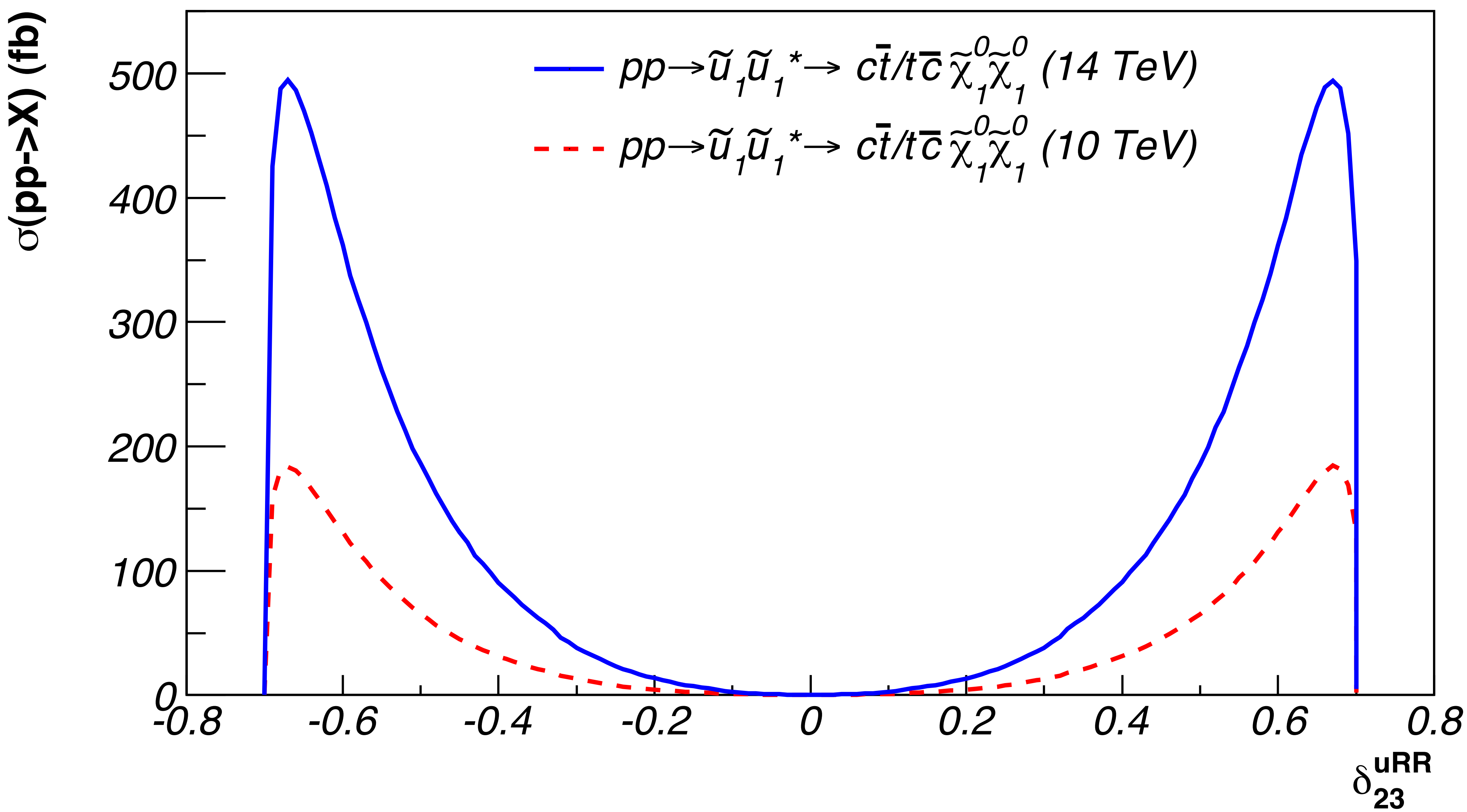
Introduce QFV entries into weak-scale soft terms of SPS1a'



Signatures at LHC for SPS1a'

Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

Introduce QFV entries into weak-scale soft terms of SPS1a'

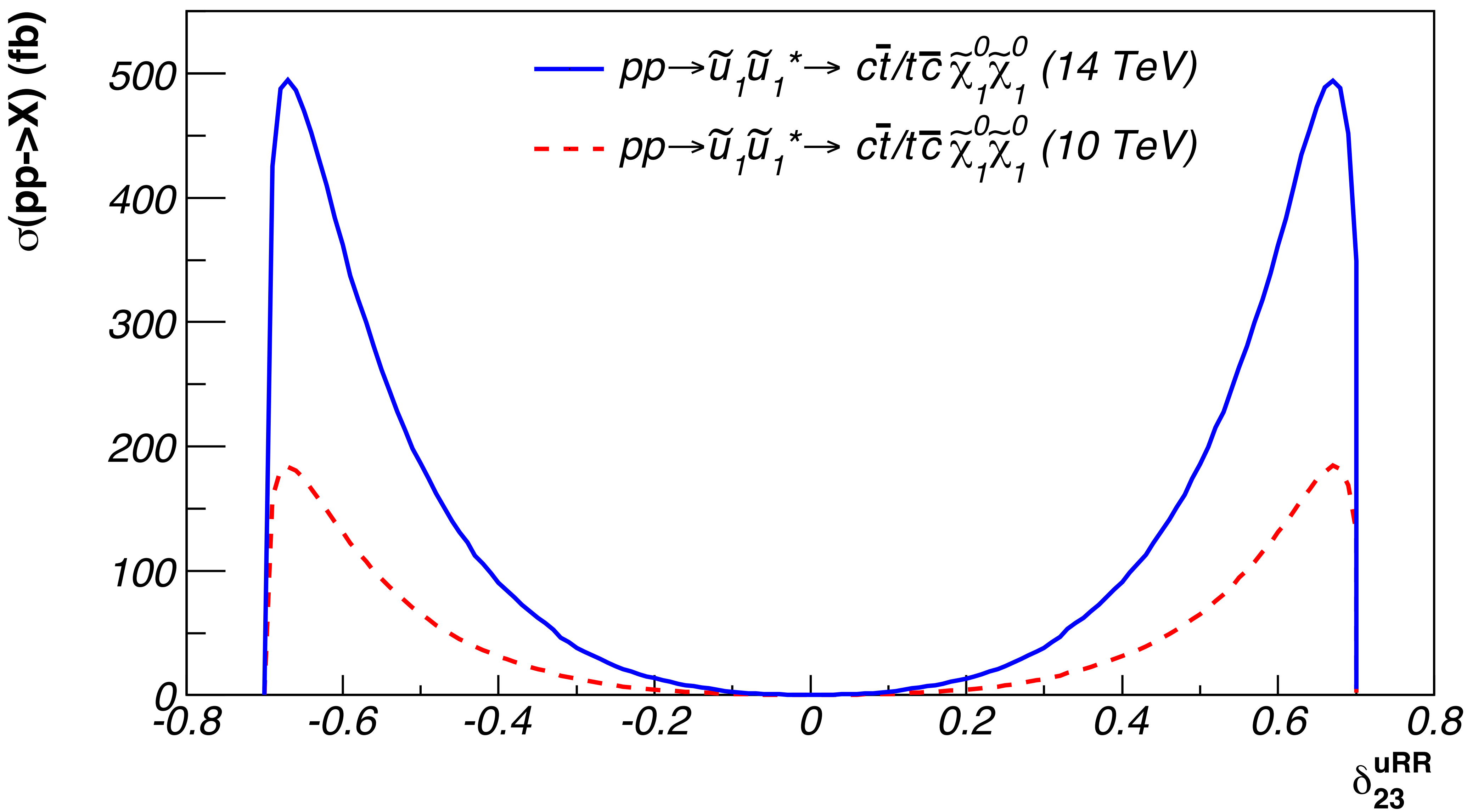


Expect up to ~10^4 events for "jet + top + E_T^{miss}" production at 100 fb^{-1} integrated luminosity

Signatures at LHC for SPS1a'

Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

Introduce QFV entries into weak-scale soft terms of SPS1a'



Expect up to ~10^4 events for "jet + top + E_T^{miss}" production at 100 fb^{-1} integrated luminosity

Allowed range w.r.t. experimental constraints: $\boxed{-0.5 \lesssim \delta_{23}^{uRR} \lesssim 0.5}$

Discrimation and Background

Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

Discrimation and Background

Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

$$p\,p \to \tilde{u}_{1,2}\,\tilde{u}^*_{1,2} \to c\,\bar{t}\ (t\,\bar{c})\ \tilde{\chi}^0_1\,\tilde{\chi}^0_1$$

???

$$p\,p \to \tilde{u}_{1,2}\,\tilde{u}^*_{1,2} \to t\,\bar{t}\ \tilde{\chi}^0_1\,\tilde{\chi}^0_1$$

Identification of top-quarks crucial: $t \to bW^+ \to b\ q\bar{q}$ [Hisano *et al.* (2002+2003)]

Efficient charm-tagging useful, otherwise search for $p\,p \to \tilde{u}_{1,2}\,\tilde{u}^*_{1,2} \to q\,\bar{t}\ (t\,\bar{q})\ \tilde{\chi}^0_1\,\tilde{\chi}^0_1$

Discrimation and Background

Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

$$p\,p \to \tilde{u}_{1,2}\,\tilde{u}^*_{1,2} \to c\,\bar{t}\ (t\,\bar{c})\ \tilde{\chi}^0_1\,\tilde{\chi}^0_1$$

???

$$p\,p \to \tilde{u}_{1,2}\,\tilde{u}^*_{1,2} \to t\,\bar{t}\ \tilde{\chi}^0_1\,\tilde{\chi}^0_1$$

Identification of top-quarks crucial: $t \to bW^+ \to b\ q\bar{q}$ [Hisano *et al.* (2002+2003)]

Efficient charm-tagging useful, otherwise search for $p\,p \to \tilde{u}_{1,2}\,\tilde{u}^*_{1,2} \to q\,\bar{t}\ (t\,\bar{q})\ \tilde{\chi}^0_1\,\tilde{\chi}^0_1$

$$p\,p \to \tilde{u}_{1,2}\,\tilde{u}^*_{1,2} \to t\,t\ \tilde{\chi}^0_1\,\tilde{\chi}^0_1$$

???

$$p\,p \to \tilde{u}_{1,2}\,\tilde{u}^*_{1,2} \to t\,\bar{t}\ \tilde{\chi}^0_1\,\tilde{\chi}^0_1$$

Descrimination between top and anti-top necessary:

$$t \to bW^+ \to b\ l^+\nu$$
$$\bar{t} \to \bar{b}W^- \to \bar{b}\ l^-\nu$$

Discrimation and Background

Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

$$pp \to \tilde{u}_{1,2}\, \tilde{u}^*_{1,2} \to c\,\bar{t}\ (t\,\bar{c})\ \tilde{\chi}^0_1\, \tilde{\chi}^0_1$$??? $$pp \to \tilde{u}_{1,2}\, \tilde{u}^*_{1,2} \to t\,\bar{t}\ \tilde{\chi}^0_1\, \tilde{\chi}^0_1$$

Identification of top-quarks crucial: $t \to bW^+ \to b\ q\bar{q}$ [Hisano *et al.* (2002+2003)]

Efficient charm-tagging useful, otherwise search for $pp \to \tilde{u}_{1,2}\, \tilde{u}^*_{1,2} \to q\,\bar{t}\ (t\,\bar{q})\ \tilde{\chi}^0_1\, \tilde{\chi}^0_1$

$$pp \to \tilde{u}_{1,2}\, \tilde{u}^*_{1,2} \to t\,t\ \tilde{\chi}^0_1\, \tilde{\chi}^0_1$$??? $$pp \to \tilde{u}_{1,2}\, \tilde{u}^*_{1,2} \to t\,\bar{t}\ \tilde{\chi}^0_1\, \tilde{\chi}^0_1$$

Descrimination between top and anti-top necessary:

$$t \to bW^+ \to b\ l^+\nu$$
$$\bar{t} \to \bar{b}W^- \to \bar{b}\ l^-\nu$$

$$pp \to \tilde{u}_{1,2}\, \tilde{u}^*_{1,2} \to c\,\bar{t}\ (t\,\bar{c})\ \tilde{\chi}^0_1\, \tilde{\chi}^0_1$$??? $$pp \to \tilde{g}\, \tilde{\chi}^0_1 \to c\,\bar{t}\ (t\,\bar{c})\ \tilde{\chi}^0_1\, \tilde{\chi}^0_1$$

Gluino production channel found to be numerically small

Discrimation and Background

Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod (2010)

$$pp \to \tilde{u}_{1,2}\,\tilde{u}^*_{1,2} \to c\,\bar{t}\ (t\,\bar{c})\ \tilde{\chi}^0_1\,\tilde{\chi}^0_1$$

???

$$pp \to \tilde{u}_{1,2}\,\tilde{u}^*_{1,2} \to t\,\bar{t}\ \tilde{\chi}^0_1\,\tilde{\chi}^0_1$$

Identification of top-quarks crucial: $t \to bW^+ \to b\,q\bar{q}$ [Hisano *et al.* (2002+2003)]

Efficient charm-tagging useful, otherwise search for $pp \to \tilde{u}_{1,2}\,\tilde{u}^*_{1,2} \to q\,\bar{t}\ (t\,\bar{q})\ \tilde{\chi}^0_1\,\tilde{\chi}^0_1$

$$pp \to \tilde{u}_{1,2}\,\tilde{u}^*_{1,2} \to t\,t\ \tilde{\chi}^0_1\,\tilde{\chi}^0_1$$

???

$$pp \to \tilde{u}_{1,2}\,\tilde{u}^*_{1,2} \to t\,\bar{t}\ \tilde{\chi}^0_1\,\tilde{\chi}^0_1$$

Descrimination between top and anti-top necessary:

$$t \to bW^+ \to b\,l^+\nu$$
$$\bar{t} \to \bar{b}W^- \to \bar{b}\,l^-\nu$$

$$pp \to \tilde{u}_{1,2}\,\tilde{u}^*_{1,2} \to c\,\bar{t}\ (t\,\bar{c})\ \tilde{\chi}^0_1\,\tilde{\chi}^0_1$$

???

$$pp \to \tilde{g}\,\tilde{\chi}^0_1 \to c\,\bar{t}\ (t\,\bar{c})\ \tilde{\chi}^0_1\,\tilde{\chi}^0_1$$

Gluino production channel found to be numerically small

Standard Model top quark production can be distinguished through jets and/or missing energy

Conclusion and Outlook

Flavour-violating terms can *a priori* be present in soft-breaking terms at the electroweak scale

- Possibly not proportional to CKM-matrix (non-minimal flavour violation)
- Important impact on preferred regions of parameter space and collider signatures

Conclusion and Outlook

Flavour-violating terms can *a priori* be present in soft-breaking terms at the electroweak scale

- Possibly not proportional to CKM-matrix (non-minimal flavour violation)
- Important impact on preferred regions of parameter space and collider signatures

Certain production channels might allow to test the hypothesis of minimal flavour violation

$$\boxed{p\,p \to \tilde{u}_{1,2}\,\tilde{u}^*_{1,2} \to c\,\bar{t}\;(t\,\bar{c})\;\tilde{\chi}^0_1\,\tilde{\chi}^0_1}$$

$$\boxed{p\,p \to \tilde{u}_{1,2}\,\tilde{u}^*_{1,2} \to t\,t\;\tilde{\chi}^0_1\,\tilde{\chi}^0_1}$$

Conclusion and Outlook

Flavour-violating terms can *a priori* be present in soft-breaking terms at the electroweak scale

- Possibly not proportional to CKM-matrix (non-minimal flavour violation)
- Important impact on preferred regions of parameter space and collider signatures

Certain production channels might allow to test the hypothesis of minimal flavour violation

$$p\,p \to \tilde{u}_{1,2}\,\tilde{u}^*_{1,2} \to c\,\bar{t}\ (t\,\bar{c})\ \tilde{\chi}^0_1\,\tilde{\chi}^0_1$$

$$p\,p \to \tilde{u}_{1,2}\,\tilde{u}^*_{1,2} \to t\,t\ \tilde{\chi}^0_1\,\tilde{\chi}^0_1$$

Expect sizeable production cross-sections and rather low background

This clearly calls for detailed Monte-Carlo study (possibly including detector simulation)

[Herrmann, Porod *et al. (in preparation)*]

Conclusion and Outlook

Flavour-violating terms can *a priori* be present in soft-breaking terms at the electroweak scale

- Possibly not proportional to CKM-matrix (non-minimal flavour violation)
- Important impact on preferred regions of parameter space and collider signatures

Certain production channels might allow to test the hypothesis of minimal flavour violation

$$p\,p \to \tilde{u}_{1,2}\,\tilde{u}^*_{1,2} \to c\,\bar{t}\ (t\,\bar{c})\ \tilde{\chi}^0_1\,\tilde{\chi}^0_1$$

$$p\,p \to \tilde{u}_{1,2}\,\tilde{u}^*_{1,2} \to t\,t\ \tilde{\chi}^0_1\,\tilde{\chi}^0_1$$

Expect sizeable production cross-sections and rather low background

This clearly calls for detailed Monte-Carlo study (possibly including detector simulation)

[Herrmann, Porod *et al. (in preparation)*]

Perspectives and Outlook:

- Study further squark and gluino decays... [Bartl, Eberl, Herrmann, Hidaka, Majerotto, Porod *et al. (in preparation)*]
- Include higher-order corrections in production and decays...
- Analysis of lepton flavour-violating processes and signatures...