Lepton Flavour Violation in scenarios with stau next-to-LSP

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Koichi Hamaguchi, JHEP02(2005) 027

Sourov Roy, in preparation

Flavour in the era of the LHC
CERN, Nov 2005

INTRODUCTION

In a supersymmetric theory the most general lagrangian is:

$$\mathcal{L} = \mathcal{L}_{SUSY} + \mathcal{L}_{\not{SUSY}}$$

$$-\mathcal{L} = \sum_\alpha \left|\frac{\partial W}{\partial \phi_\alpha}\right|^2 + \frac{1}{2}\sum_a g_a^2 \left(\sum_\alpha \phi_\alpha^\dagger T^a \phi_\alpha\right)^2 + \sum_\alpha m_{\phi_\alpha}^2 |\phi_\alpha|^2 + \text{trilinear} + B\mu H_1 H_2 + + \frac{1}{2} M\lambda\lambda$$

Already "known" from measurements of the fermionic masses and mixing angles, and the gauge interactions.

???

The challenge is to determine the soft breaking terms.
In particular, in the leptonic sector: $(m^2_{e_L})_{ij}$, $(m^2_{e_R})_{ij}$, $(A_e)_{ij}$

How??

⋆ Non-accelerator physics:

- rare decays ($\mu \to e\gamma$, $\tau \to \mu\gamma$...). Lepton Flavour Violating.
- electric dipole moments. Lepton flavour conserving, but $\not{CP}$.

INDIRECT PROBES

⋆ Accelerator physics:

- mass splittings between sleptons.
- **LFV production and decay of SUSY particles**
- $\not{CP}$ in the production and decay of SUSY particles.

DIRECT PROBES

⋆ Diferent signatures depending on which is the LSP,

- neutralino — interaction $\sim \frac{1}{M_W^2} \longrightarrow$ WIMP
  $\longrightarrow$ See Rückl's talk.
- axino — interaction $\sim \frac{1}{f_{PQ}^2} \longrightarrow$ Super-WIMP
- gravitino — interaction $\sim \frac{1}{F} \longrightarrow$ Super-WIMP
  Not so thoroughly studied...

⋆ When the gravitino is the LSP, different arguments point to the possibility that the NLSP has to be a RH stau.

⋆ There are two strategies to study LFV:

– LFV decay of (stopped) staus

– LFV production of staus

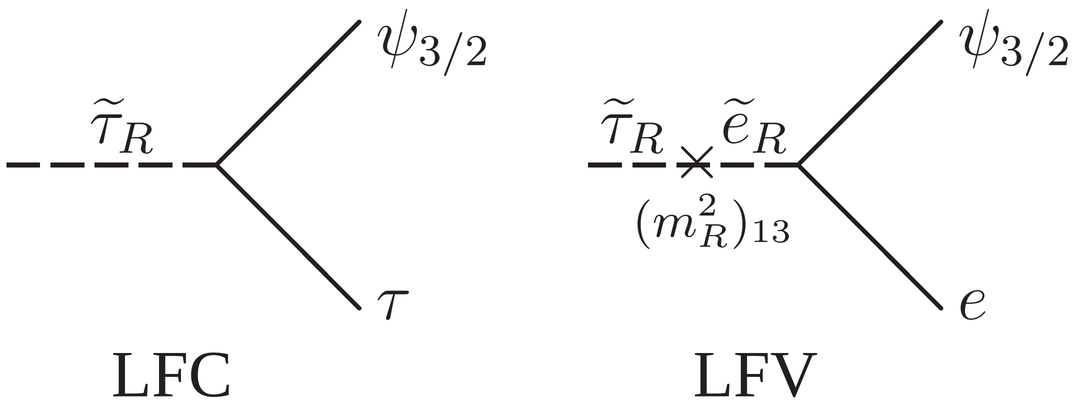
LFV decay of stopped staus

⋆ If the gravitino is the LSP, the NLSP can only decay gravitionally into gravitinos ⇒ very long lifetimes

⋆ NLSPs could be collected and studied in detail:

- LHC: $\mathcal{O}(10^4)$ charged sleptons
- $e^- e^-$ LC: $\mathcal{O}(10^5 - 10^6)$ charged sleptons

⋆ In particular, one could study lepton flavour violating decays

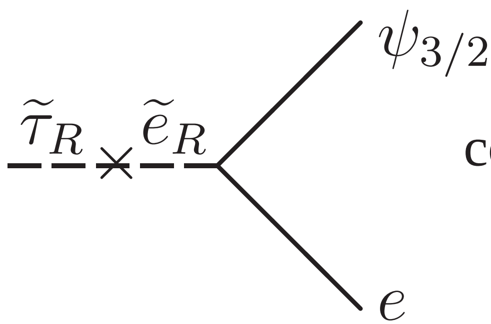


However...

★ In the LHC, $\widetilde{e}_R$, $\widetilde{\mu}_R$ and $\widetilde{\tau}_R$ would be produced.

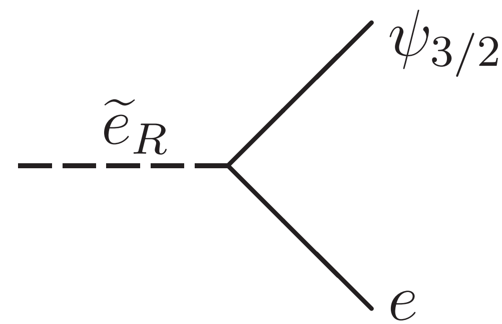
★ In a $e^- e^-$ linear collider, only $\widetilde{e}_R$ would be produced. A fraction of them would decay into $\widetilde{\tau}_R$, so both $\widetilde{e}_R$ and $\widetilde{\tau}_R$ would be present in the sample.

If selectrons were also long lived



SIGNAL

could be confused with



BACKGROUND

Could be an important source of background!!

Other backgrounds: $\widetilde{\tau}_R \rightarrow \tau \, \psi_{3/2} \rightarrow \begin{cases} \tau^- \rightarrow e^- \, \bar{\nu}_e \, \nu_\tau \quad \text{BR} \simeq 18\% \\ \tau^- \rightarrow \mu^- \, \bar{\nu}_\mu \, \nu_\tau \quad \text{BR} \simeq 17\% \\ \tau^- \rightarrow \pi^- \, \bar{\nu}_\tau \quad \text{BR} \simeq 11\% \end{cases}$

$\pi^- \hookrightarrow \mu^- \bar{\nu}_\mu \quad \text{BR} \simeq 100\%$

Analysis of backgrounds

Whether $\widetilde{e}_R$ and $\widetilde{\mu}_R$ are also long lived depends on the mass spectrum:

- If $m^2_{\widetilde{\tau}_R} - m^2_{\widetilde{\mu}_R,\widetilde{e}_R} > m_\tau$, then

$$\widetilde{\mu}_R \longrightarrow \widetilde{\tau}_R\ \tau\ \mu \text{ very fast}$$
$$\widetilde{e}_R \longrightarrow \widetilde{\tau}_R\ \tau\ e \text{ very fast}$$

The sample would consist just of $\widetilde{\tau}_R$. The backgrounds are negligible.

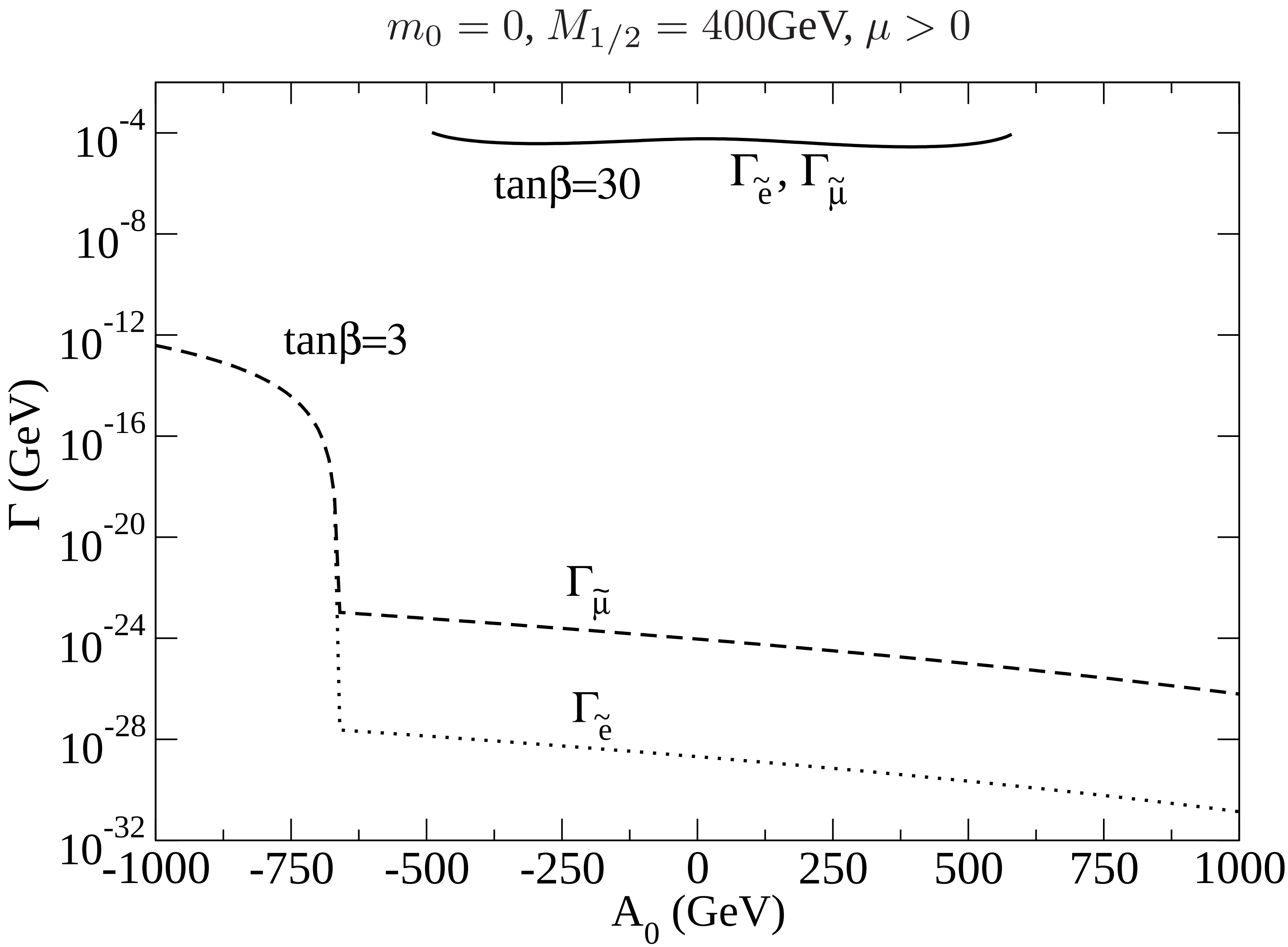
Very favourable case for the detection of flavour violation.

- If $m^2_{\widetilde{\tau}_R} - m^2_{\widetilde{\mu}_R,\widetilde{e}_R} < m_\tau$, then

$$\widetilde{\mu}_R \longrightarrow \widetilde{\tau}_R\ \bar{\nu}_\tau\ \nu_\mu \text{ rather slow}$$
$$\widetilde{e}_R \longrightarrow \widetilde{\tau}_R\ \bar{\nu}_\tau\ \nu_e \text{ very slow}$$

The sample would consist of $\widetilde{\tau}_R$ and $\widetilde{e}_R$ (perhaps also $\widetilde{\mu}_R$).

Backgrounds could be important.



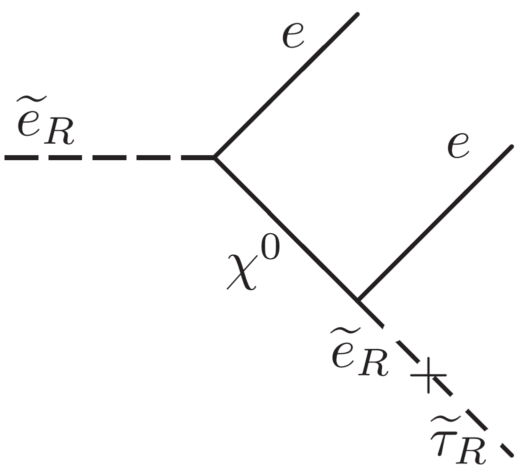
$m_0 = 0$, $M_{1/2} = 400$GeV, $\mu > 0$
10^{-4}
10^{-8}
10^{-12}
10^{-16}
10^{-20}
10^{-24}
10^{-28}
10^{-32}
Γ (GeV)
tanβ=30
$\Gamma_{\tilde{e}}$, $\Gamma_{\tilde{\mu}}$
tanβ=3
$\Gamma_{\tilde{\mu}}$
$\Gamma_{\tilde{e}}$
-1000
-750
-500
-250
0
250
500
750
1000
A_0 (GeV)

Analysis of backgrounds II: the case with LFV

LFV plays a crucial role in preparing a sample without important backgrounds.

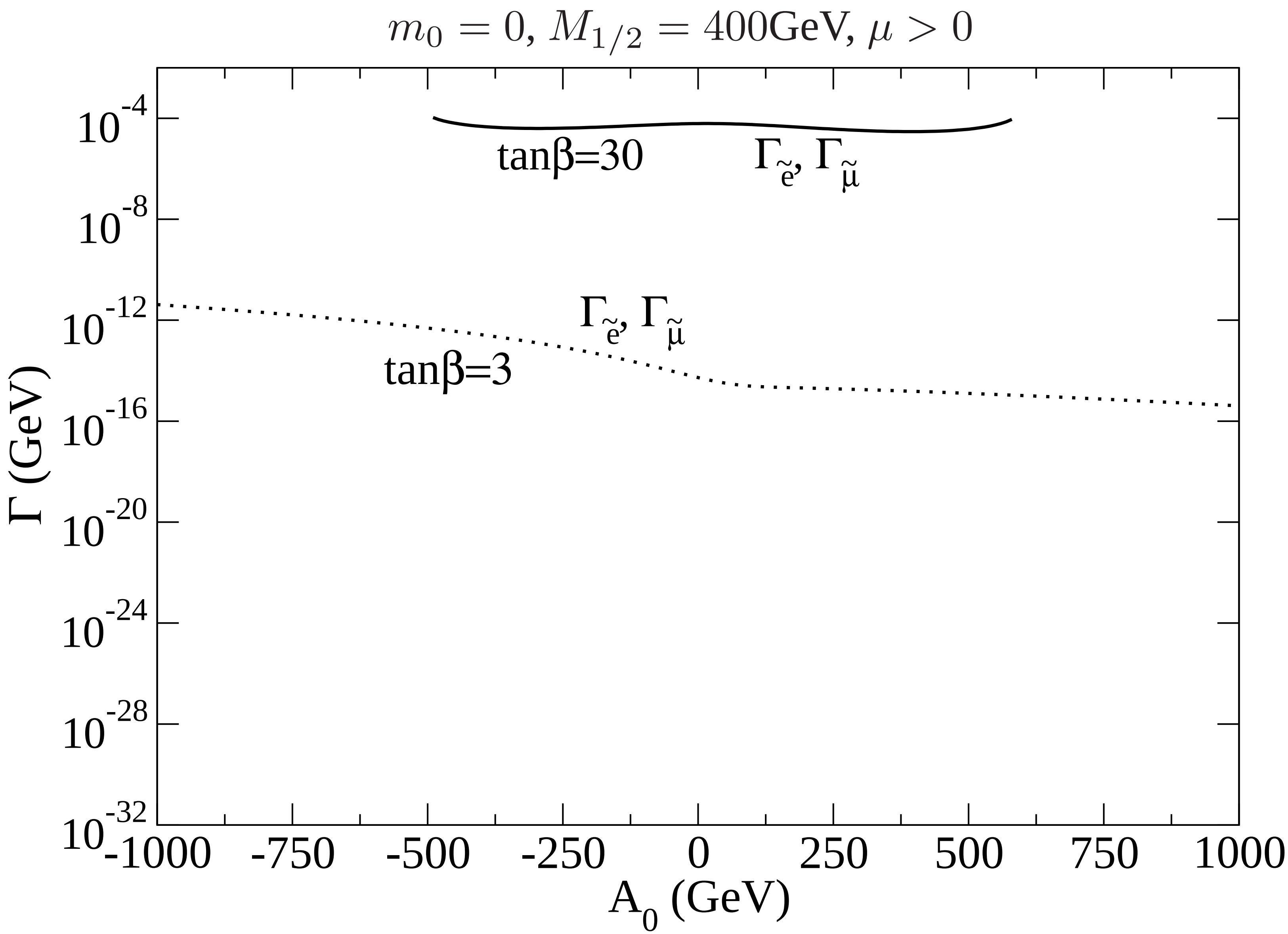
• LFV induces a contribution to the mass splitting. When $(m^2_{\tilde{l}_R})_{23}/m_1 \gtrsim m_\tau$, the decay $\tilde{e}_R \to \tilde{\tau}_R\, \tau\, e$ becomes kinematically accessible.

• **The LFV selectron decay $\tilde{e}_R \to \tilde{\tau}_R\, e\, e$ can be very efficient** (this channel is usually kinematical open)



$$\Gamma(\tilde{e}_R \to \tilde{\tau}_R\, e\, e) \approx \left(\frac{(m^2_{\tilde{l}_R})_{13}}{m_1^2}\right) \Gamma(\tilde{e}_R \to \tilde{\tau}_R\, \tau\, e)$$

LFV plays a double role: it is not only the object of our investigation, but also a crucial ingredient for the success of it!!



with LFV

$(m^2_{\tilde{l}_R})_{23}/m_1^2 = (m^2_{\tilde{l}_R})_{13}/m_1^2 = 0.01$

Prospects to observe LFV with stopped staus

$\star$ If LFV exists in nature, backgrounds in this experiment would be negligible $\Rightarrow$ all the electrons have to come from LFV $\tilde{\tau}_R$ decays.

$\star$ If no electron is observed

- LHC: $N_{\tilde{\tau}}(\text{init.}) = N_{\tilde{\mu}}(\text{init.}) = N_{\tilde{e}}(\text{init.}) = 1000$

$$(m^2_{\tilde{l}_R})_{13}/m^2_1 \lesssim 3 \times 10^{-2} \text{ @ } 90\%\text{c.l.}$$

- e^-e^- LC: $N_{\tilde{\tau}}(\text{init.}) = 0,\ N_{\tilde{\mu}}(\text{init.}) = 0,\ N_{\tilde{e}}(\text{init.}) = 10000$

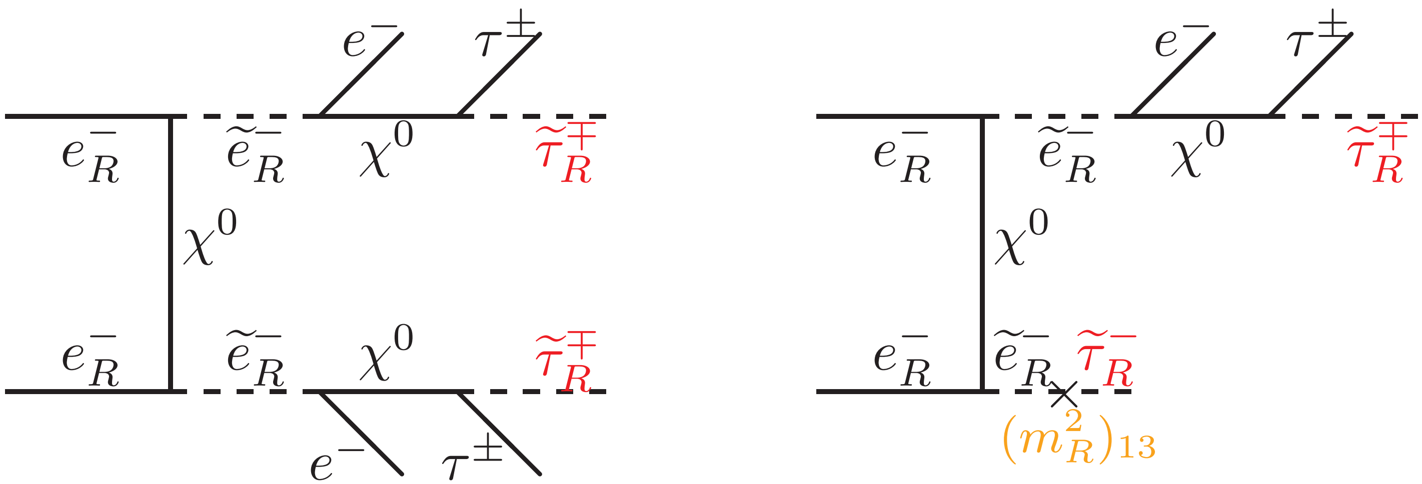
$$(m^2_{\tilde{l}_R})_{13}/m^2_1 \lesssim 2 \times 10^{-2} \text{ @ } 90\%\text{c.l.}$$

LFV production of staus

Future directions: abandon the requirement of stopped staus (in progress)

Example: At the $e^- e^-$ Linear Collider, if $m_{\tilde{\tau}_R} < m_{\tilde{e}_R} < m_{\tilde{\chi}^0}$

LFC **LFV**



- four charged fermions in the final state
- $\tilde{\tau}_R$'s positive or negative

- two charged fermions
- at least one $\tilde{\tau}_R$ is negative

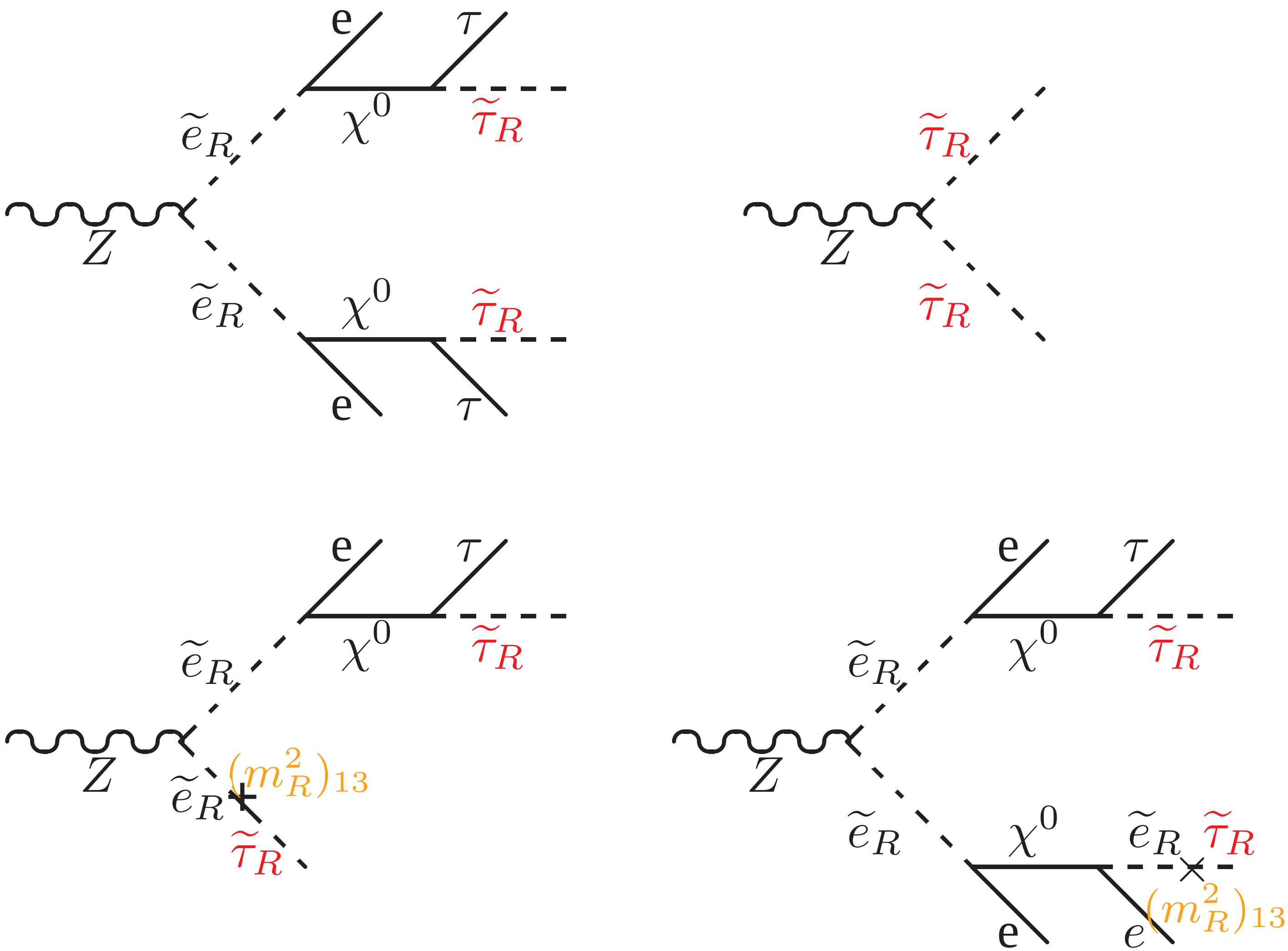
In both cases, **two heavy ionizing tracks**

BACKGROUNDS EXPECTED TO BE VERY SMALL

At the LHC or the e^+e^- linear collider, one would have

LFC

LFV



can be distinguished from the number of fermions

requires particle identification

CONCLUSIONS

⋆ In colliders it could be possible to probe **directly** lepton flavour violation, providing complementary information to the one from rare decays.

⋆ In scenarios with **stau NLSP**, lepton flavour violation could be observed cleanly in late decays, without important backgrounds.

⋆ It could be possible to probe LFV down to $(m^2_{\tilde{l}_R})_{13}/m^2_1 \lesssim 3 \times 10^{-2}$.