Way to crosscheck μ-e conversion in the case of no signals of $\mu \to e\gamma$ and $\mu \to 3e$

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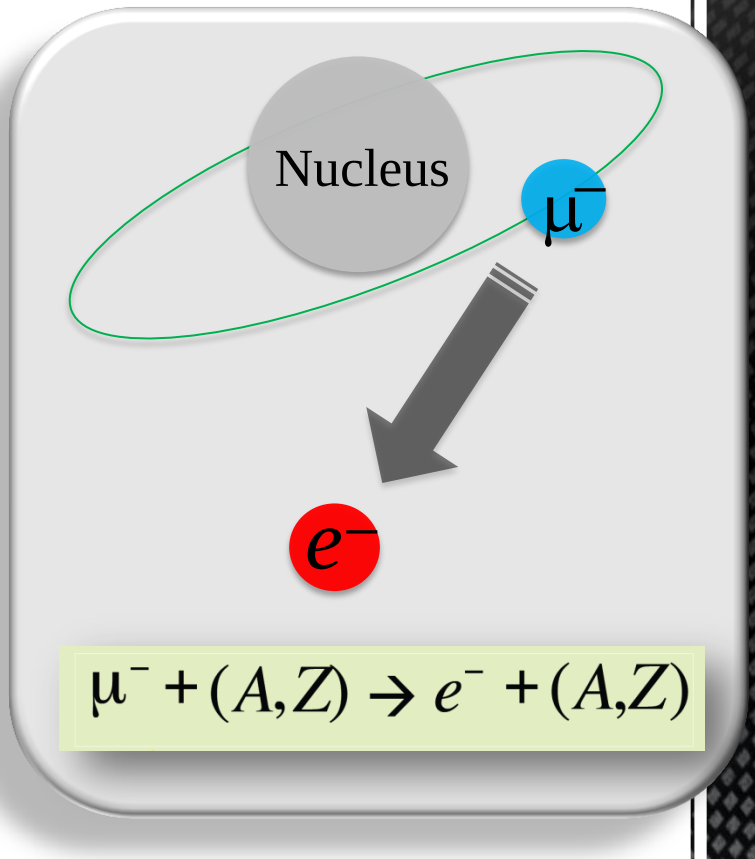
Key ingredient:
Interplay between measurement of exotic dijet@LHC and observations of μ-e conv.@near future experiments

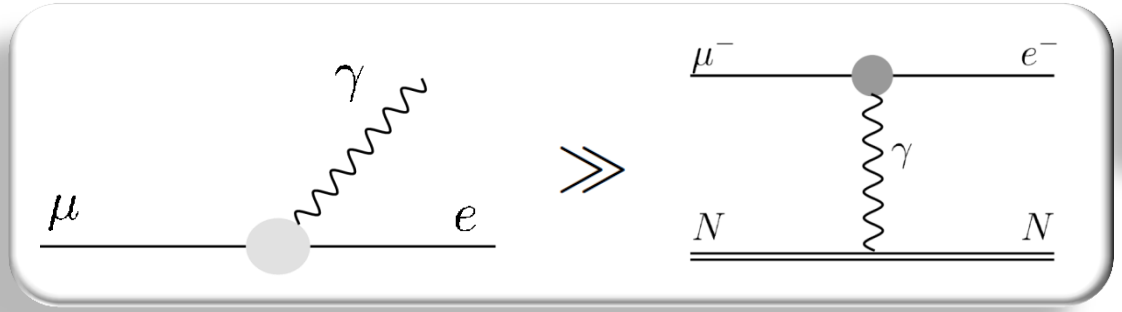
Waiting for μ-e conversion

- ☑ COMET, DeeMe, and Mu2e launch soon!
- ☑ Discovery of the μ-e conv. = clear evidence of new physics
- ☑ With observations of $\mu \rightarrow e\gamma$ and/or $\mu \rightarrow 3e$
  - Identification of type of LFV interaction
  - Determination of relevant parameters



Waiting for μ-e conversion

- ☑ If $\mu \rightarrow e\gamma$ will never be observed after the discovery of μ-e conv.
  - Dipole LFV interaction and relevant models are ruled out



SUSY models, etc.

- ☑ $\mu \rightarrow 3e$ will never be also observed
  - How to confirm the discovery of μ-e conversion???
  - No LFV interaction and no new physics???

Aim of this work

☑ Our target situation

μ-e conversion is discovered, while other muon LFV processes will never be found

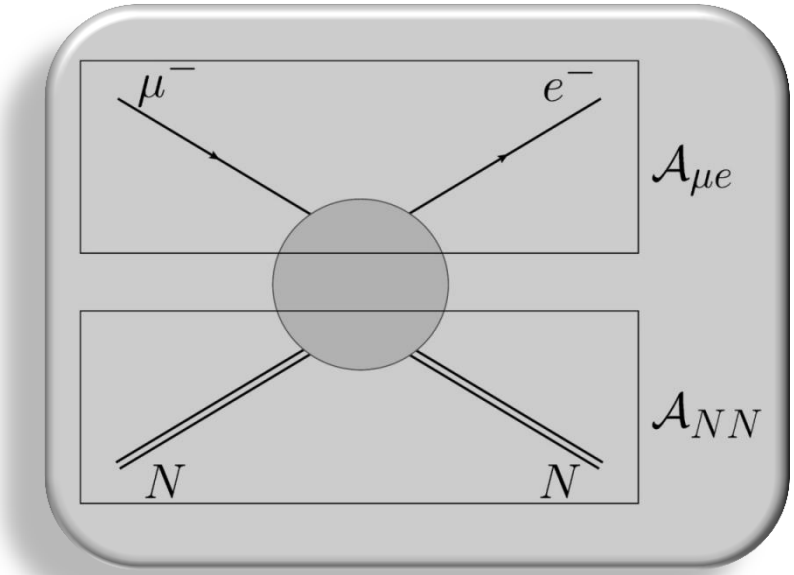
☑ Aim of this work

- Understand how to confirm the discovery of μ-e conversion
- Check the feasibility to identify underlying physics and to determine LFV parameters

Expected structure of LFV interaction

- Expected LFV interaction in our target situation

- ~~$\mu \to e\gamma$~~
  - Massive mediator
- ~~$\mu \to 3e$~~
  - Small coupling with $e^- e^+$
- μ-e conversion
  - Couple to quarks and/or gluons
  - Flavor violating coupling with μ and e



Benchmark: R-parity violating SUSY

- ☑ One of the benchmark model: R-parity violating (RPV) SUSY
- ☑ In general SUSY models contain RPV terms

$$\mathcal{W}_{\rm RPV} = \lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} L_i Q_j D^c_k + \lambda''_{ijk} U^c_i D^c_j D^c_k$$

Omit to avoid proton decay

- ☑ Setting 1

  Flavor diagonal components are larger than off-diagonal

  → $\lambda'_{ijj} \gg \lambda'_{ijk}\ (j \neq k)$

Naturally realized unless additional sources of flavor violation are introduced

Benchmark: R-parity violating SUSY

- Setting 2

  Different generation of left- and right-handed leptons

  → $\lambda_{ijk}\ (i \neq k \text{ and } j \neq k)$

- Setting 3

  SUSY particle contribution: only 3rd generation

Naturally realized by RG evolution with universal masses@GUT scale

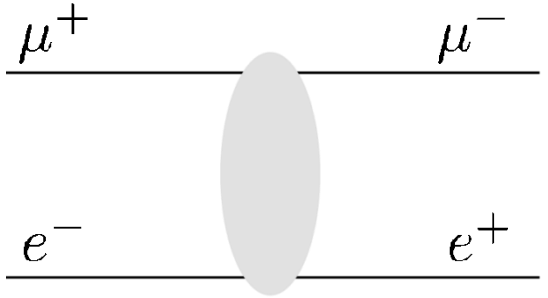
- Lagrangian

$$\mathcal{L}_{\rm RPV} = \mathcal{L}_{\lambda} + \mathcal{L}_{\lambda'},$$

$$\mathcal{L}_{\lambda} = 2\left[\lambda_{312}\tilde{\nu}_{\tau L}\overline{\mu}P_L e + \lambda_{321}\tilde{\nu}_{\tau L}\overline{e}P_L\mu + \lambda_{132}\tilde{\tau}_L\overline{\mu}P_L\nu_e + \lambda_{231}\tilde{\tau}_L\overline{e}P_L\nu_\mu\right] + \text{h.c.}$$

$$\mathcal{L}_{\lambda'} = \left[\lambda'_{311}\left(\tilde{\nu}_{\tau L}\overline{d}P_L d - \tilde{\tau}_L\overline{d}P_L u\right) + \lambda'_{322}\left(\tilde{\nu}_{\tau L}\overline{s}P_L s - \tilde{\tau}_L\overline{s}P_L c\right)\right] + \text{h.c.}.$$

Exotic processes in benchmark RPV



muonium conversion

$$\mathcal{L}_{\rm RPV} = \mathcal{L}_\lambda + \mathcal{L}_{\lambda'},$$

$$\mathcal{L}_\lambda = 2\left[\lambda_{312}\tilde{\nu}_{\tau L}\overline{\mu}P_L e + \lambda_{321}\tilde{\nu}_{\tau L}\overline{e}P_L\mu + \lambda_{132}\tilde{\tau}_L\overline{\mu}P_L\nu_e + \lambda_{231}\tilde{\tau}_L\overline{e}P_L\nu_\mu\right] + \text{h.c.}$$

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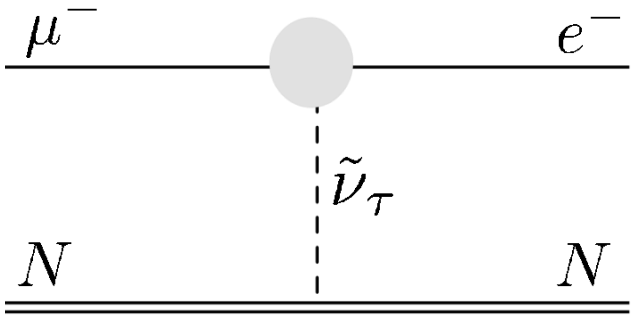
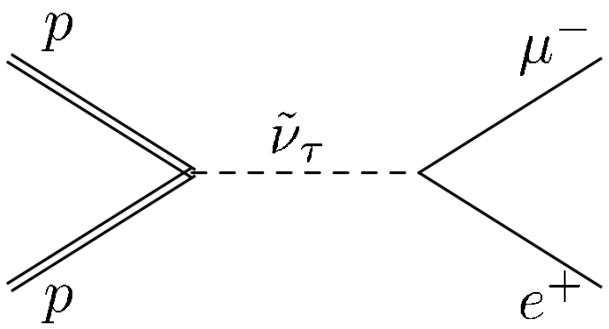
μ-e conversion



Exotic processes in benchmark RPV

pp → μ⁻e⁺



$$\mathcal{L}_{\rm RPV} = \mathcal{L}_\lambda + \mathcal{L}_{\lambda'},$$

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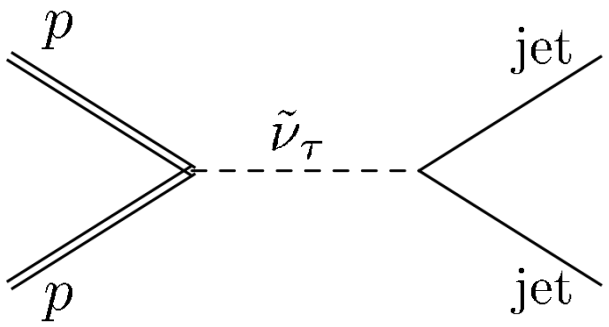
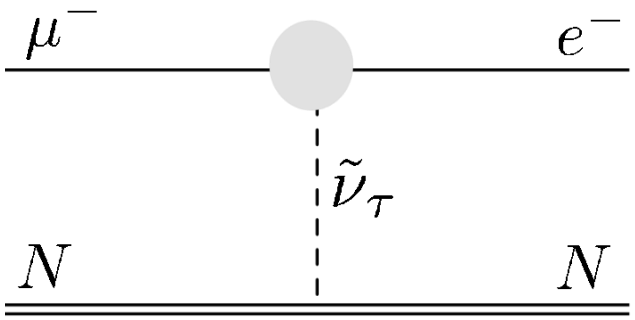
pp → dijet



μ-e conversion



- Amplitude: overlap of wave functions of μ, e, and nucleus

$$\mathcal{M} = \frac{G_F}{\sqrt{2}} \sum_{q=d,s} \int d^3\boldsymbol{x} \left(g_{LS(q)} \bar{\psi}^{(e)} P_R \psi_{1S}^{(\mu)} + g_{RS(q)} \bar{\psi}^{(e)} P_L \psi_{1S}^{(\mu)} \right) \langle N|\bar{q}q|N\rangle$$

Function of λ_{ijk}, λ'_{ijk}, and tau sneutrino mass

Matrix element determined by nucleon density for each N

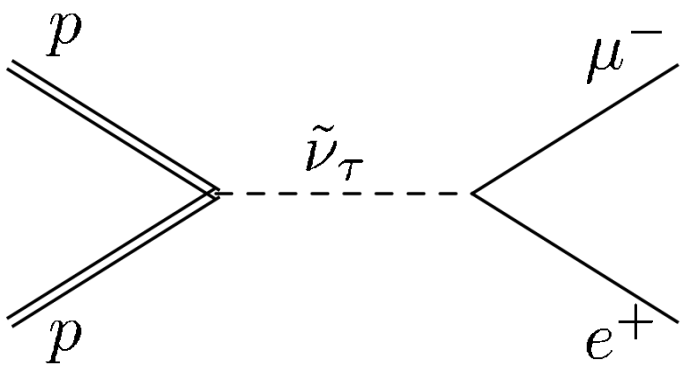
- Branching ratio

$$\mathrm{BR}(\mu^- \mathrm{Al} \to e^- \mathrm{Al}) = 2.092 \times 10^{-15} \left(\frac{1\mathrm{TeV}}{m_{\tilde{\nu}_\tau}}\right)^4 \left(\frac{\lambda'_{311}\lambda}{10^{-8}}\right)^2 \left|1 + 0.530 \left(\frac{\lambda'_{322}}{\lambda'_{311}}\right)\right|^2$$

$$= 5.881 \times 10^{-16} \left(\frac{1\mathrm{TeV}}{m_{\tilde{\nu}_\tau}}\right)^4 \left(\frac{\lambda'_{322}\lambda}{10^{-8}}\right)^2 \left|1 + 1.886 \left(\frac{\lambda'_{311}}{\lambda'_{322}}\right)\right|^2$$

$pp \to \mu^- e^+$ and $pp \to$ dijet@LHC

- ☑ Dominant: s-channel resonance



- ☑ Cross sections are approximated by the Breit-Wigner formula

$$\sigma(pp \to f_1 f_2) = F(\sqrt{s}, m_{\tilde{\nu}_\tau}, q_1, q_2) \times \Gamma_{\tilde{\nu}_\tau} \mathrm{BR}(\tilde{\nu}_\tau \to q_1 q_2) \mathrm{BR}(\tilde{\nu}_\tau \to f_1 f_2)$$
$$= F(\sqrt{s}, m_{\tilde{\nu}_\tau}, q_1, q_2) m_{\tilde{\nu}_\tau} \times \gamma_{\tilde{\nu}_\tau} \mathrm{BR}(\tilde{\nu}_\tau \to q_1 q_2) \mathrm{BR}(\tilde{\nu}_\tau \to f_1 f_2)$$

Determined by initial quarks and mediator mass

Depends only on couplings

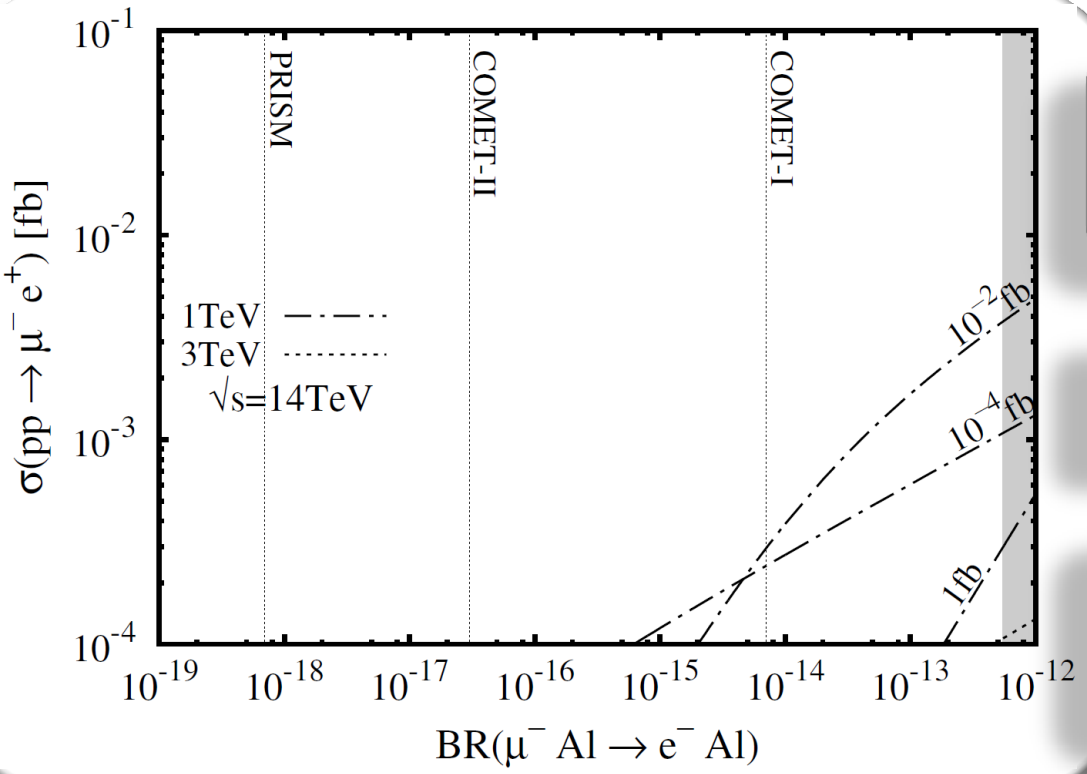
$$\gamma_{\tilde{\nu}_\tau} = \Gamma_{\tilde{\nu}_\tau} / m_{\tilde{\nu}_\tau}$$

Correlation of μ-e conv. and LHC signals

- ☑ How to confirm μ-e conversion event
- ☑ How to discriminate the benchmark scenario and other models

- ☑ Check the correlations of
  - $\mathrm{BR}(\mu^- + N \to e^- + N)$
  - $\sigma(pp \to \mu\bar{e})$
  - $\sigma(pp \to jj)$

Correlation of μ-e conv. and LHC signals



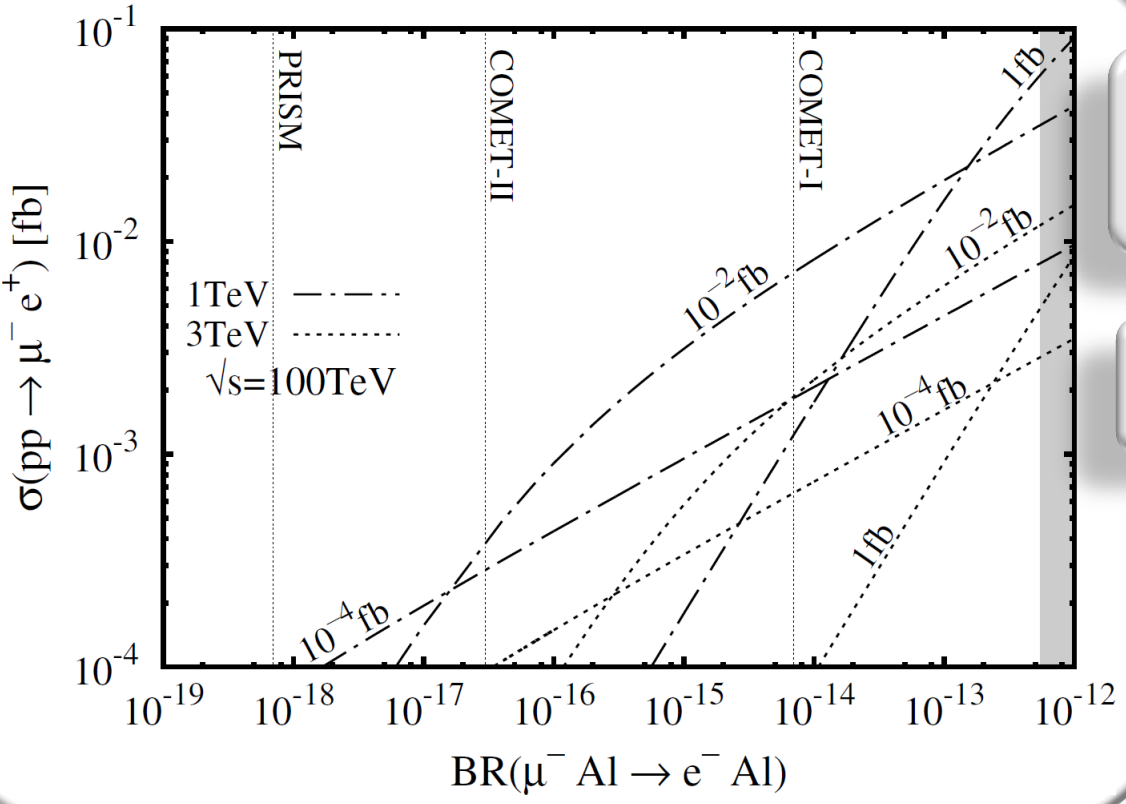
$\sigma(pp \to \mu^- e^+)$ as a function of $\mathrm{BR}(\mu^- \mathrm{Al} \to e^- \mathrm{Al})$

each line : $\sigma(pp \to jj)$

Vertical line: experimental reach of μ-e conversion search

- ☑ Unique behavior: larger $\sigma(pp \to jj)$ suggests smaller $\sigma(pp \to \mu^- e^+)$
- ☑ Check the correlations and the behavior to discriminate models

Correlation of μ-e conv. and LHC signals



$\sigma(pp \to \mu^- e^+)$ as a function of $\mathrm{BR}(\mu^- \mathrm{Al} \to e^- \mathrm{Al})$

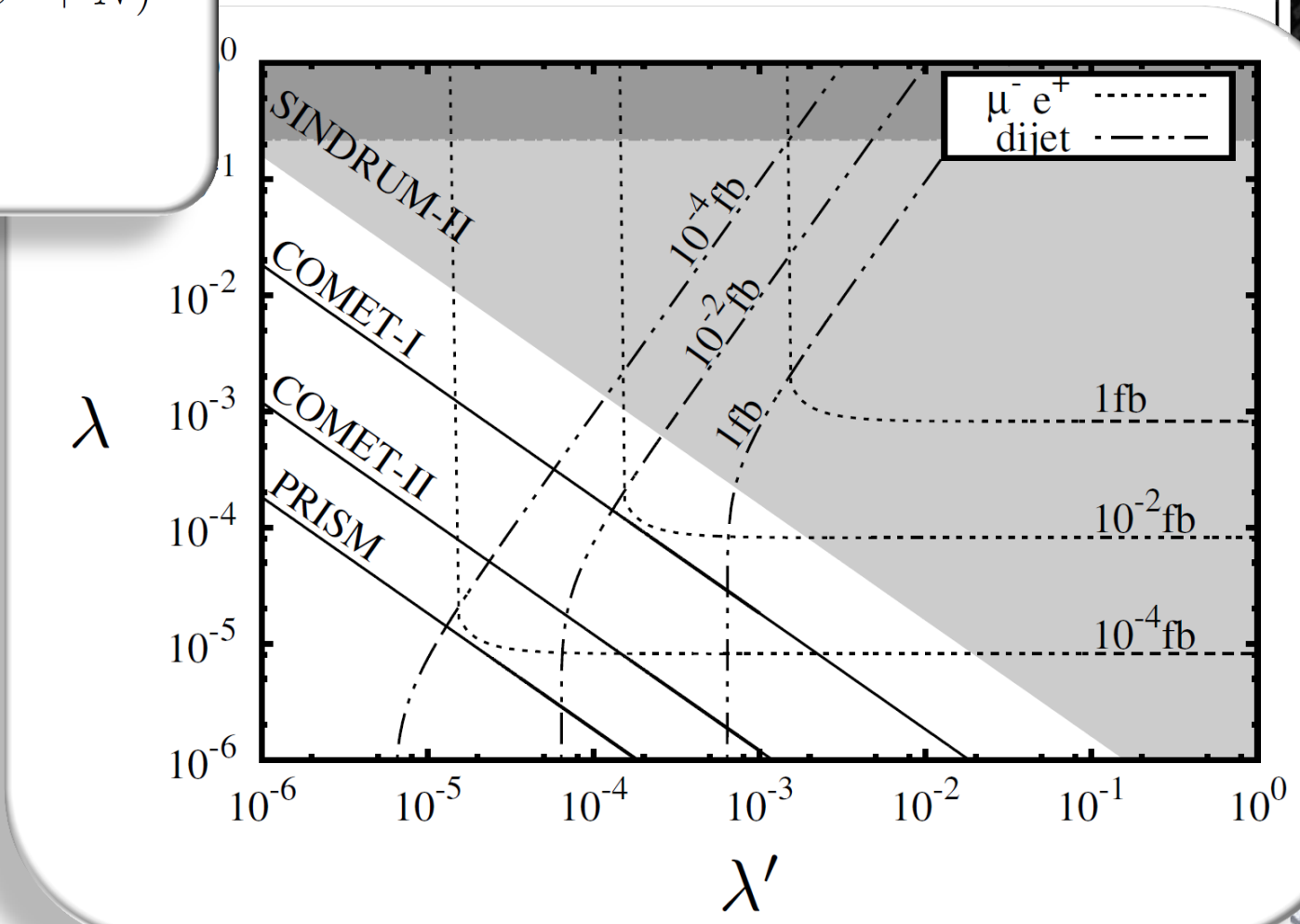
each line : $\sigma(pp \to jj)$

- ☑ Accessible up to ~3TeV slepton
- ☑ Exhibit the correlation to check LFV in our target situation

Determination of model parameters

Contour plot of

- $\mathrm{BR}(\mu^- + N \to e^- + N)$
- $\sigma(pp \to \mu\bar{e})$
- $\sigma(pp \to jj)$



Determination of model parameters

- sneutrino mass $m_{\tilde{\nu}_\tau} = 1\mathrm{TeV}$
- collision energy $\sqrt{s} = 100\mathrm{TeV}$

- Shaded region: excluded by SINDRUM-II
- Solid line: experimental reach of μ-e conversion search

- ☑ μ-e conversion searches will cover parameter space wherein LHC can survey
- ☑ μ-e conv. searches and LHC precisely determine RPV parameters!

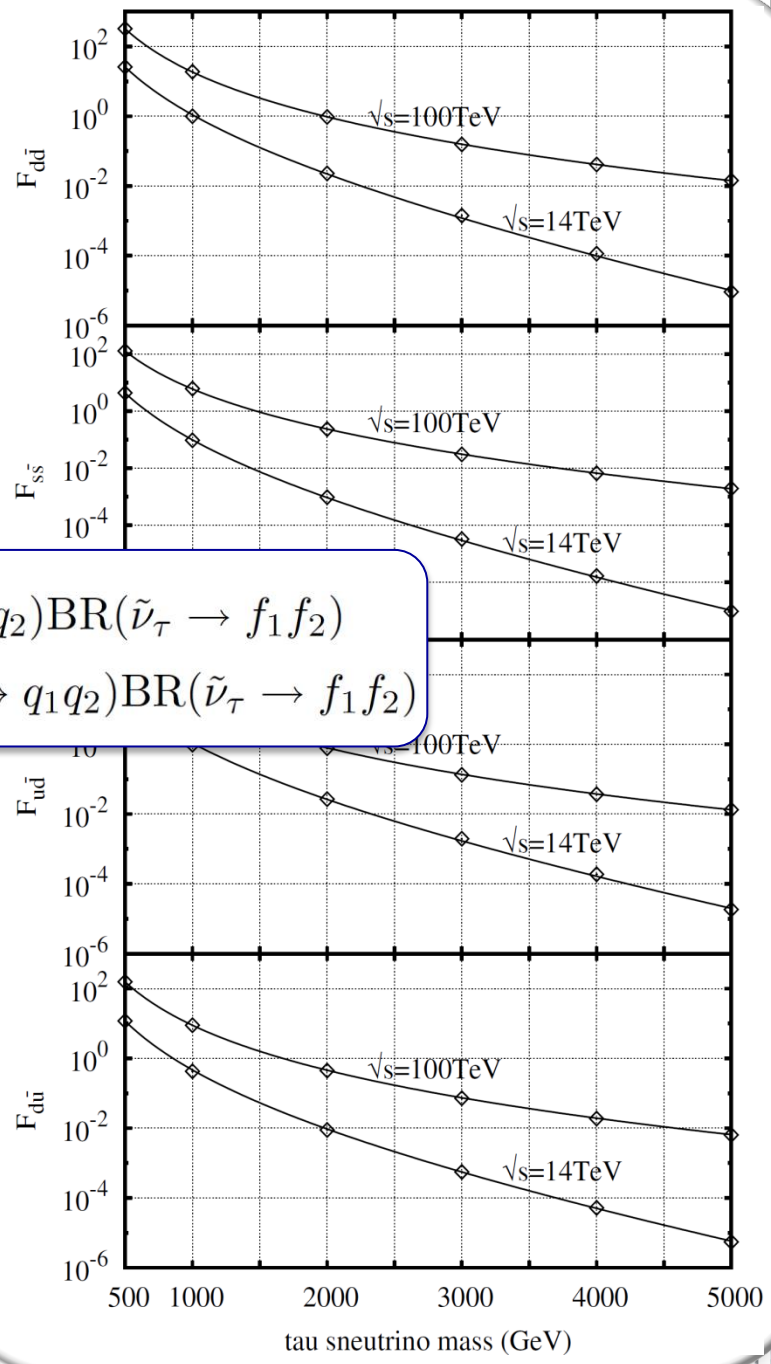
Summary

- We studied the situation that μ-e conversion is discovered while other muon LFV processes will never be observed
- Important issues in such a situation are
  - How to confirm the discovery of μ-e conversion
  - How to determine LFV parameters and its underlying physics
- We expected LFV interaction in such a situation, and studied R-parity violating SUSY as a benchmark
- Key ingredients are pp $\rightarrow \mu^- e^+$ and pp $\rightarrow$ dijet
- We can discriminate models and determine parameters from the correlation of $\mathrm{BR}(\mu^- N \to e^- N)$, $\sigma(pp \to jj)$, and $\sigma(pp \to \mu^- e^+)$

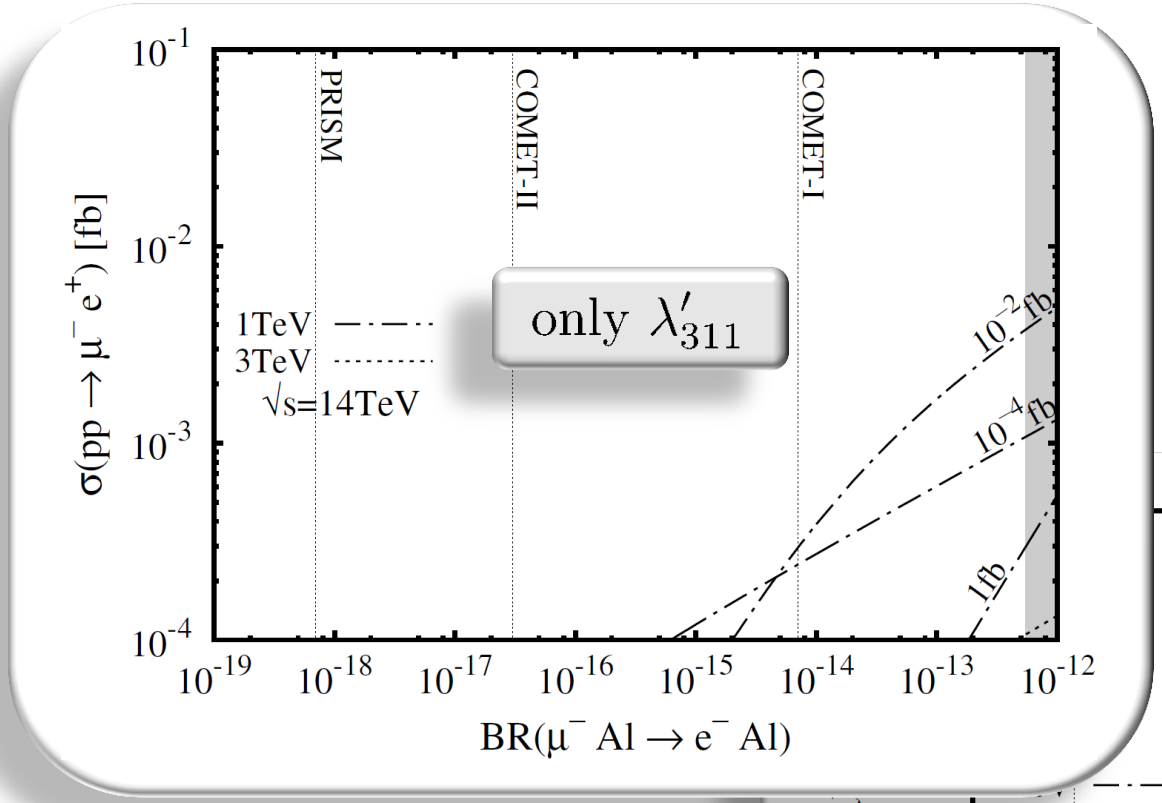
Backup slides

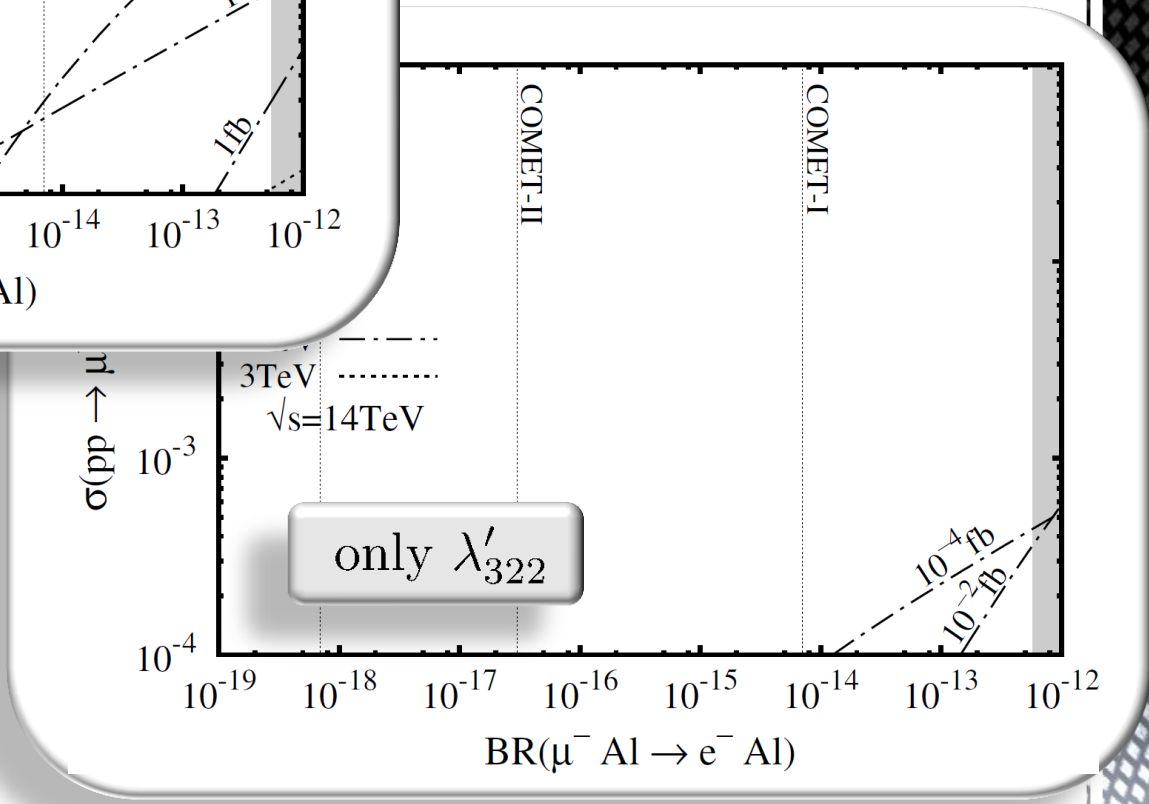
Cross section

$$\sigma(pp \to f_1 f_2) = F(\sqrt{s}, m_{\tilde{\nu}_\tau}, q_1, q_2) \times \Gamma_{\tilde{\nu}_\tau} \mathrm{BR}(\tilde{\nu}_\tau \to q_1 q_2) \mathrm{BR}(\tilde{\nu}_\tau \to f_1 f_2)$$
$$= F(\sqrt{s}, m_{\tilde{\nu}_\tau}, q_1, q_2) m_{\tilde{\nu}_\tau} \times \gamma_{\tilde{\nu}_\tau} \mathrm{BR}(\tilde{\nu}_\tau \to q_1 q_2) \mathrm{BR}(\tilde{\nu}_\tau \to f_1 f_2)$$



Correlation of μ-e conv. and LHC signals





- ☑ HogeHoge