# A way to crosscheck μ-e conversion in the case of no signals of μ→eγ and μ→3e

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# LFV from muon decay

Upper limit on Br

$$\mu^+ \to e^+\gamma \quad < \quad 5.7\times10^{-13}$$

$$\mu^+ \to e^+e^+e^- \quad < \quad 1.0\times10^{-12}$$

$$\mu^-\mathrm{Ti} \to e^-\mathrm{Ti} \quad < \quad 6.1\times10^{-13}$$

$$\mu^-\mathrm{Au} \to e^-\mathrm{Au} \quad < \quad 7\times10^{-13}$$

MEGII experiment updates/discovers(?)

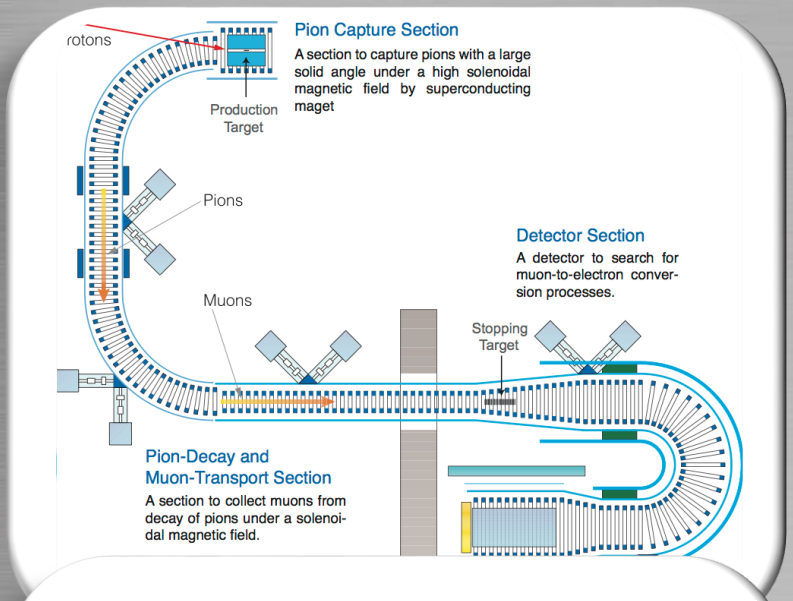
$$\mu^+ \to e^+\gamma$$

COMET/DeeMe/Mu2E discover(?)

$$\mu^- \to e^-$$

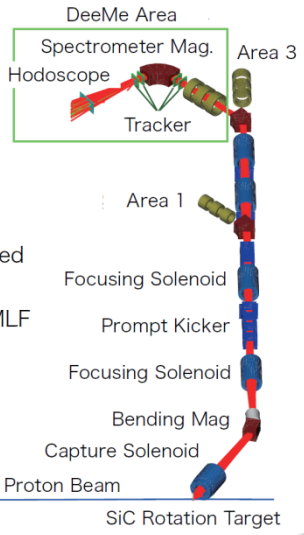
In near future

# Waiting for μ-e conversion




## DeeMe

- Search for $\mu$-e conversion in nuclear field at $10^{-14}$
- J-PARC RCS
  - High Power High Quality Pulsed Proton Beam
- H-Line, multipurpose beamline, in MLF
  - Large Acceptance
- SiC Muon Production/Stop Target
  - $\mu^- + Si \rightarrow e^- + Si$
- Electron Spectrometer
- Prompt Kicker




- ☑ COMET and DeeMe launch at J-PARC soon

Example: SUSY models

- ☑ In various models

  Discovery of μ-e conversion

  ⇕

  Discovery of other cLFV

- ☑ cLFV correlations is an evidence and probe of new physics

# Waiting for μ-e conversion

If μ-e conversion is found, while other cLFV processes will never be found

We have to discard SUSY models ?
← Biased by MSSM with RH neutrino !?

- ☑ COMET and DeeMe launch at J-PARC in the near future

Example: SUSY models

- ☑ In various models

  Discovery of μ-e conversion

  ⇕

  Discovery of other cLFV

- ☑ cLFV correlations is an evidence and probe of new physics

# VS other cLFV experiments

$\mu^- N \to e^- N$ Can be Tree

$\mu^+ \to e^+ \gamma$ Loop only, dipole

Gauge Symmetry forbids tree contribution

$\mu^+ \to e^+ e^- e^+$ Must be Loop

though both loop and tree are allowed

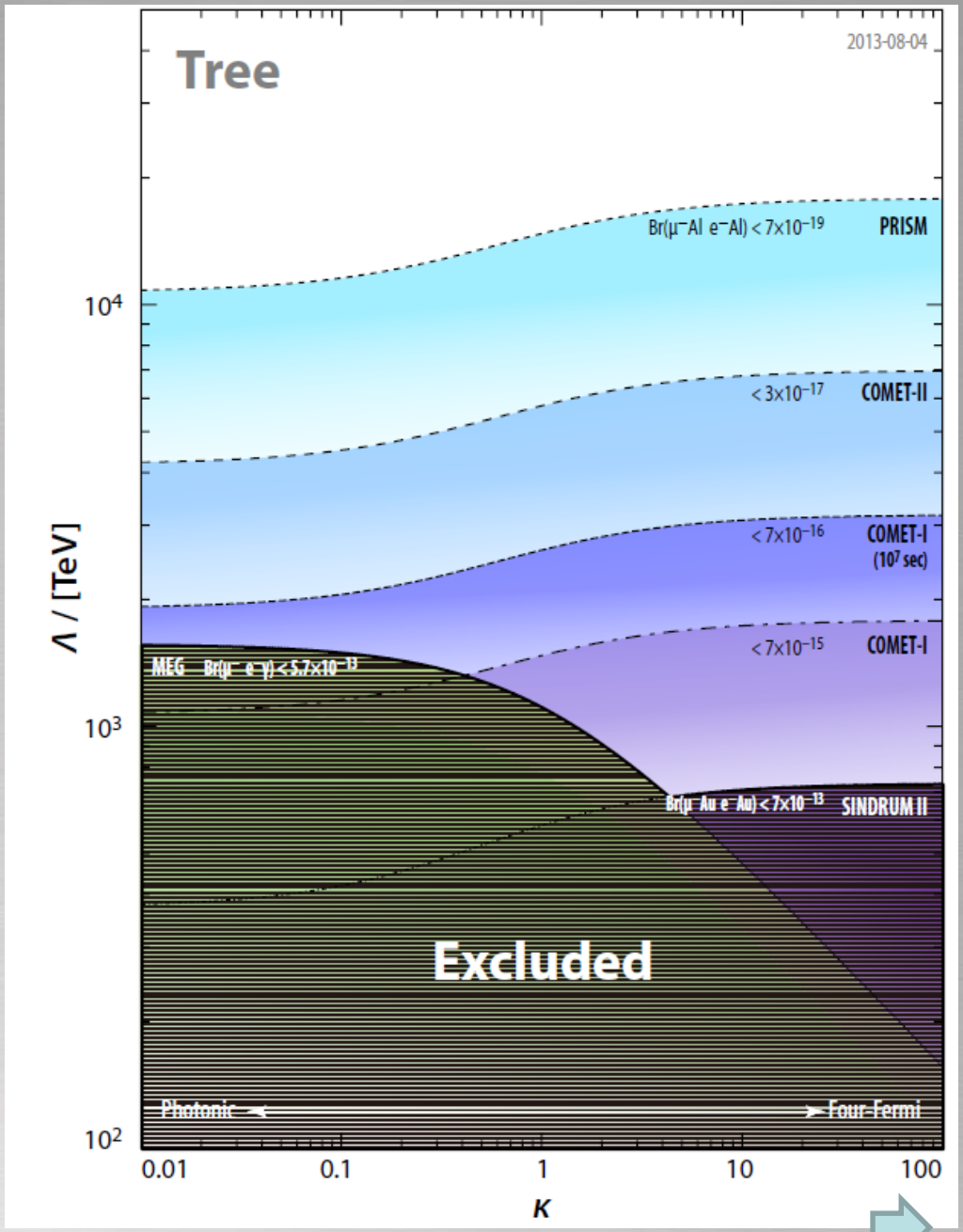
In terms of effective theory

$$\mathcal{L} = \frac{1}{1+\kappa}\frac{m_\mu}{\Lambda^2}\bar{\mu}_{\mathrm{R}}\sigma^{\mu\nu}e_{\mathrm{L}}F_{\mu\nu} + \frac{\kappa}{1+\kappa}\frac{1}{\Lambda^2}(\bar{\mu}_{\mathrm{L}}\gamma^\mu e_{\mathrm{L}})(\bar{q}_{\mathrm{L}}\gamma_\mu q_{\mathrm{L}})$$

$\kappa$ relative strength

must be very large for $\mu^- N \to e^- N$

MEG




PRISM

COMET Phase-II

COMET Phase-I

# Waiting for μ-e conversion

If μ-e conversion is found, while other cLFV processes will never be found

We have to discard SUSY models?
← Biased by MSSM with RH neutrino !?

No!

R-parity violating SUSY gives such a situation

☑ No correlations of cLFV

# Aim of this work

To find out distinctive signals to discriminate the scenario and other new physics models

To show the feasibility to determine the parameters in the RPV scenario through observing the signals

Under the assumption that μ-e conversion is found, while other cLFV processes will never be found

# R-parity violating SUSY

- Candidate of new physics: R-parity violating SUSY
- Consistent with experimental/theoretical status
  - New physics is required to cancel Higgs quadratic divergence
  - TeV scale SUSY predicts grand unification of interactions
  - So far no typical SUSY signals have been observed@LHC
- RPV terms in superpotential in SUSY

Omit the term to avoid proton decay

$$\mathcal{W}_{\not R} = \lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} L_i Q_j D^c_k + \lambda''_{ijk} U^c_i D^c_j D^c_k$$

# Framework of our scenario

Naturally realized by RG evoltion
with universal masses@GUT scale

- Slepton contribution to RPV: only 3rd generation
- Different generation of left- and right-handed leptons
  $\lambda_{ijk}$ ($i \neq k$ and $j \neq k$)

Assumption to realize
the interesting situation

- RPV terms in superpotential in SUSY

$$\mathcal{W}_{\not R} = \lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} L_i Q_j D^c_k + \lambda''_{ijk} U^c_i D^c_j D^c_k$$

# Framework of our scenario

Naturally realized unless we introduce additional sources of flavor violation

- For quarks, flavor diagonal components are much larger than off-diagonal components

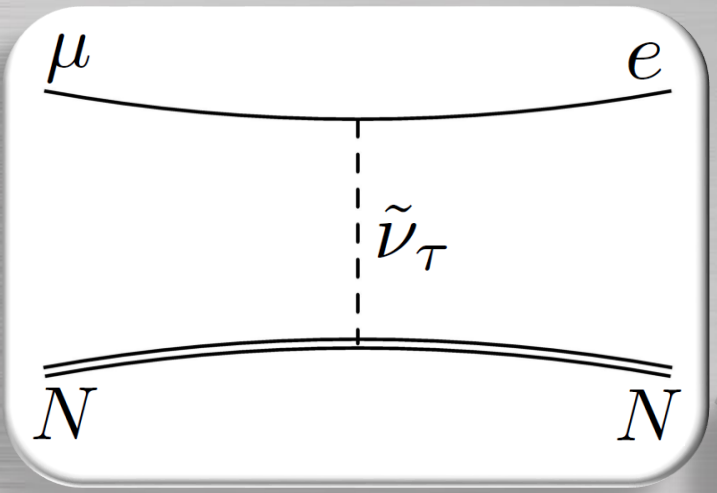
$$\lambda'_{ijj} \gg \lambda'_{ijk} \quad (j \neq k)$$

- RPV terms in superpotential in SUSY

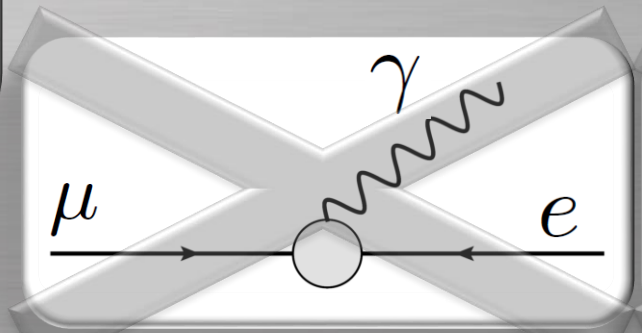
$$\mathcal{W}_{\not R} = \lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} L_i Q_j D^c_k + \lambda''_{ijk} U^c_i D^c_j D^c_k$$

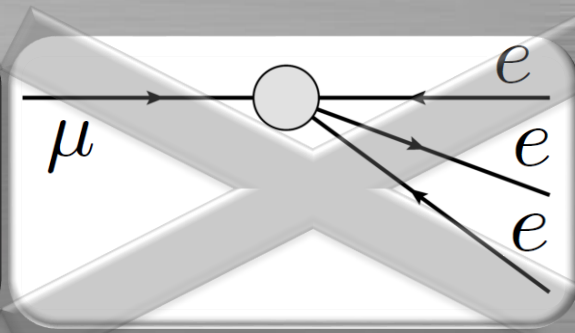
# Exotic processes in the scenario 1

$$\begin{aligned}\mathcal{L}_{\rm RPV} = 2\{ & \lambda_{312}\tilde{\nu}_\tau \bar{\mu}_R e_L + \lambda_{321}\tilde{\nu}_\tau \bar{e}_R \mu_L + \lambda_{132}\tilde{\tau}_L \bar{\mu}_R \nu_e + \lambda_{231}\tilde{\tau}_L \bar{e}_R \nu_\mu \} \\ & + \{ \lambda'_{311}(\tilde{\nu}_\tau \bar{d}_R d_L - \tilde{\tau}_L \bar{d}_R u_L) + \lambda'_{322}(\tilde{\nu}_\tau \bar{s}_R s_L - \tilde{\tau}_L \bar{s}_R c_L) \\ & + \lambda'_{333}(\tilde{\nu}_\tau \bar{b}_R b_L - \tilde{\tau}_L \bar{b}_R t_L) \} + \text{h.c.}\end{aligned}$$



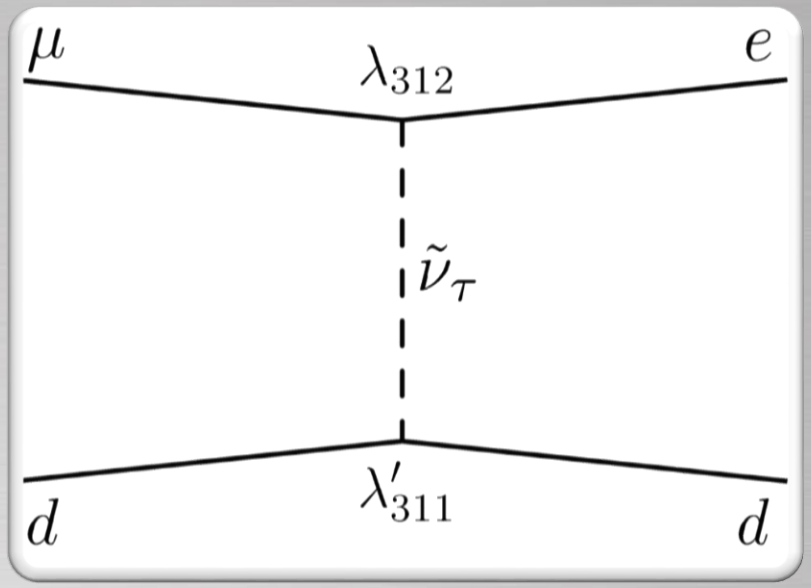

- ☑ μ-e conversion@tree level
- ☑ Negligible rates of other cLFV processes



$\mu^- N \to e^- N$ can occur at tree level

$$\mathcal{L}_{int} = -\frac{G_F}{\sqrt{2}} \sum_{q=d,s} \left\{ \left( g_{LS(q)} \bar{e} P_R \mu + g_{RS(q)} \bar{e} P_L \mu \right) \bar{q} q \right\} + \text{h.c.}$$




$$g_{LS(d)} = \frac{\sqrt{2}}{G_F} \frac{2}{m^2_{\tilde{\nu}_\tau}} \lambda'_{311} \lambda^*_{312},$$

$$g_{RS(d)} = \frac{\sqrt{2}}{G_F} \frac{2}{m^2_{\tilde{\nu}_\tau}} \lambda'^*_{311} \lambda_{321},$$

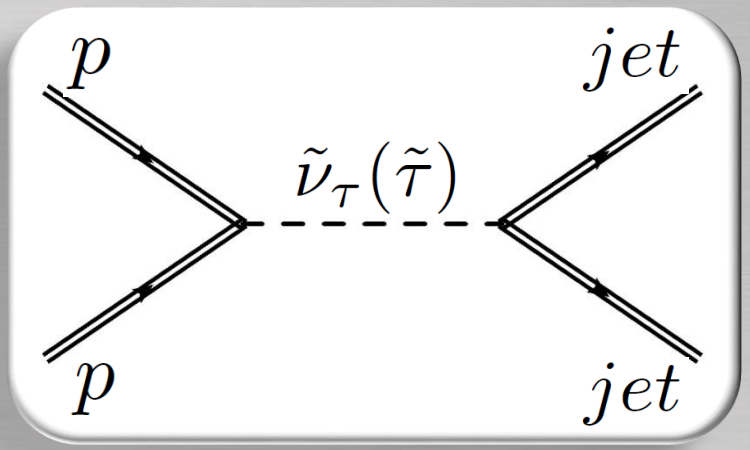
$$g_{LS(s)} = \frac{\sqrt{2}}{G_F} \frac{2}{m^2_{\tilde{\nu}_\tau}} \lambda'_{322} \lambda^*_{312},$$

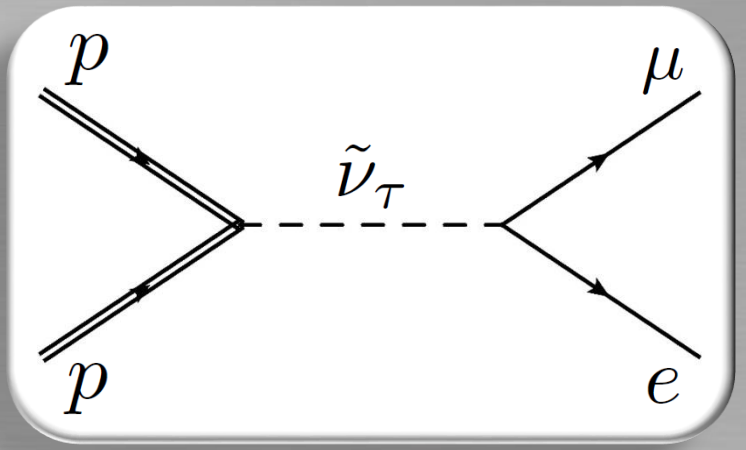
$$g_{RS(s)} = \frac{\sqrt{2}}{G_F} \frac{2}{m^2_{\tilde{\nu}_\tau}} \lambda'^*_{322} \lambda_{321}.$$

# Exotic processes in the scenario 2

$$\begin{aligned}\mathcal{L}_{\rm RPV} = 2\{ & \lambda_{312}\tilde{\nu}_\tau \bar{\mu}_R e_L + \lambda_{321}\tilde{\nu}_\tau \bar{e}_R \mu_L + \lambda_{132}\tilde{\tau}_L \bar{\mu}_R \nu_e + \lambda_{231}\tilde{\tau}_L \bar{e}_R \nu_\mu \} \\ & + \{ \lambda'_{311}(\tilde{\nu}_\tau \bar{d}_R d_L - \tilde{\tau}_L \bar{d}_R u_L) + \lambda'_{322}(\tilde{\nu}_\tau \bar{s}_R s_L - \tilde{\tau}_L \bar{s}_R c_L) \\ & + \lambda'_{333}(\tilde{\nu}_\tau \bar{b}_R b_L - \tilde{\tau}_L \bar{b}_R t_L) \} + \text{h.c.}\end{aligned}$$

- High energy dijet and $\mu\bar{e}$ resonances@LHC

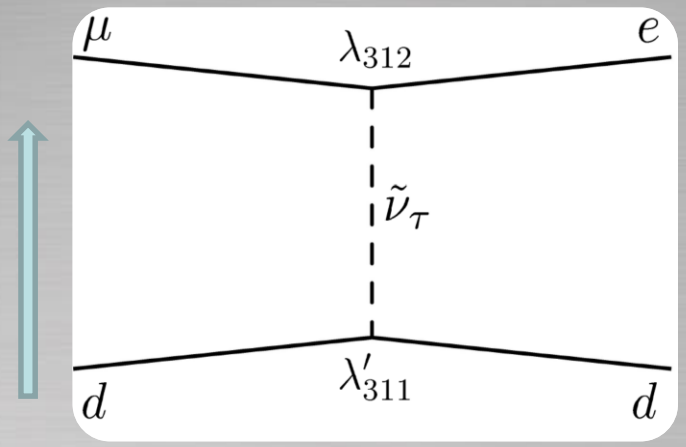


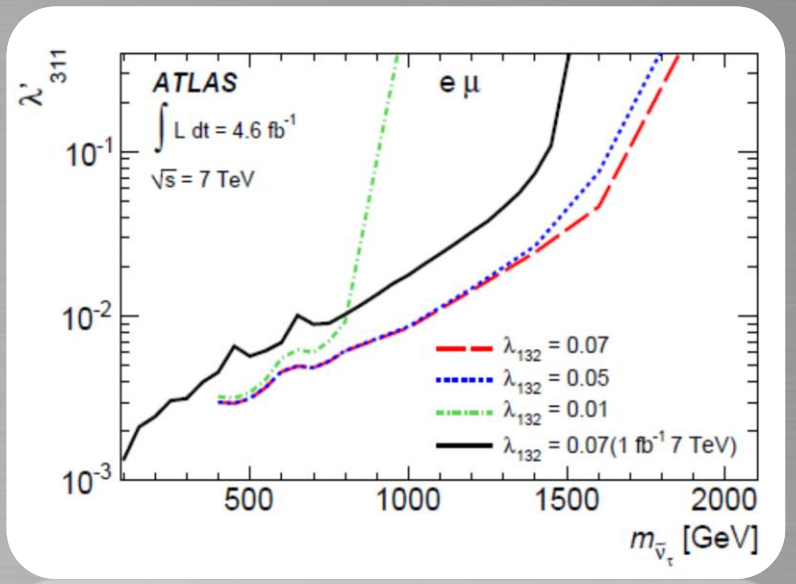



# Sneutrino Production 1

$$pp \to \mu^{-(+)} + e^{+(-)}$$

CERN-PH-EP-2012-326




**Search for a heavy narrow resonance decaying to $e\mu$, $e\tau$, or $\mu\tau$ with the ATLAS detector in $\sqrt{s} = 7$ TeV $pp$ collisions at the LHC**

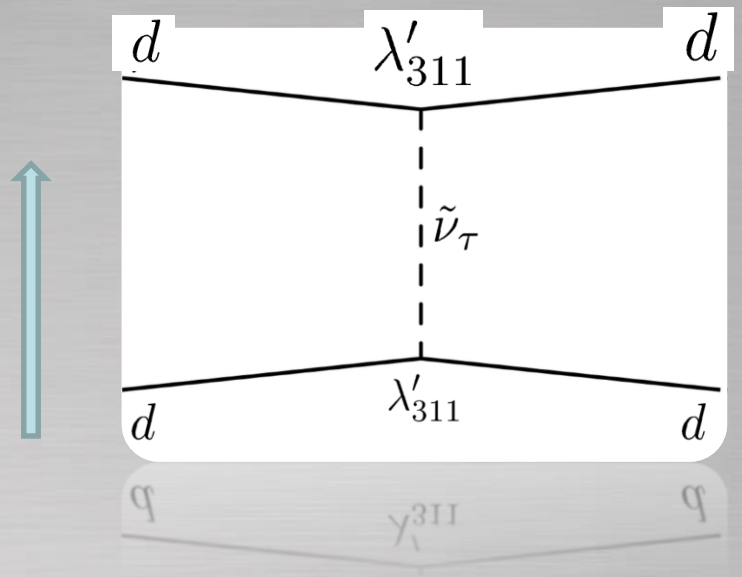
$$\sigma(pp \to \mu^{-(+)} + e^{+(-)}) \propto \lambda'^2_{3ii} \frac{\lambda^2_{312(321)}}{\lambda'^2 + \lambda^2}$$

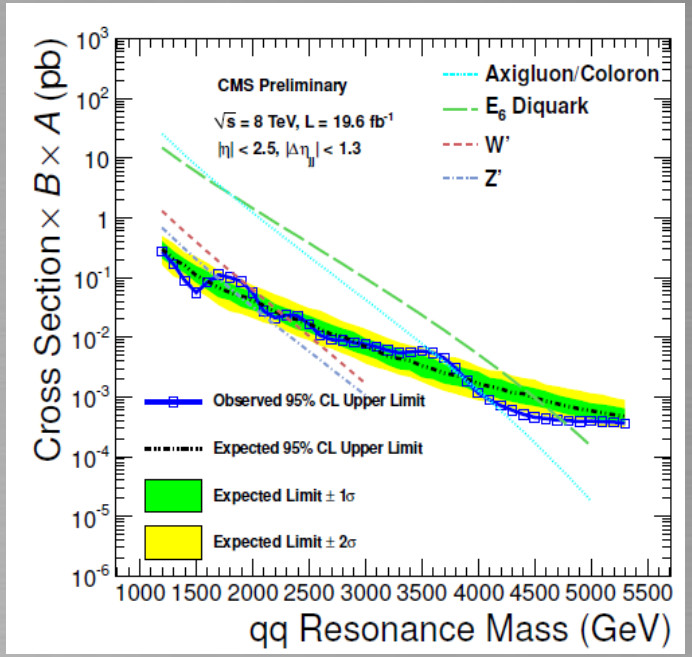
Creation * BR

# Sneutrino Production 2

$$pp \to jj$$

CMS PAS EXO-12-059




Search for Narrow Resonances using the Dijet Mass Spectrum with 19.6 fb$^{-1}$ of pp Collisions at $\sqrt{s} = 8$ TeV

It is not a search for LFV. A Kind of Z' search

$$\sigma(pp \to jj) \propto \lambda'^2_{3ii} \frac{\lambda'^2_{3jj}}{\lambda'^2 + \lambda^2}$$

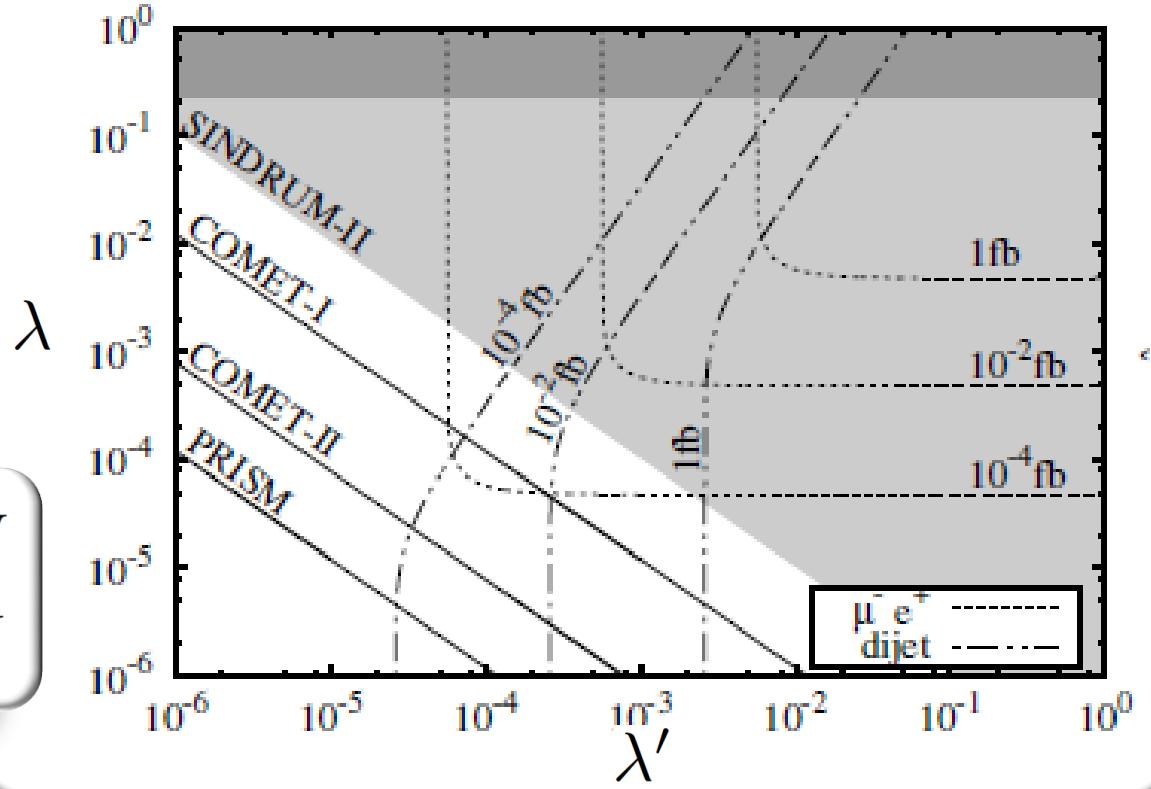
Creation * BR

# Correlations of distinctive signals

Contour plot of

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

- sneutrino mass $m_{\tilde{\nu}_\tau} = 1\mathrm{TeV}$
- collision energy $\sqrt{s} = 14\mathrm{TeV}$




- ☑ μ-e conversion search is a strong tool for exploring RPV
- ☑ PRISM explores all parameter space wherein LHC can survey

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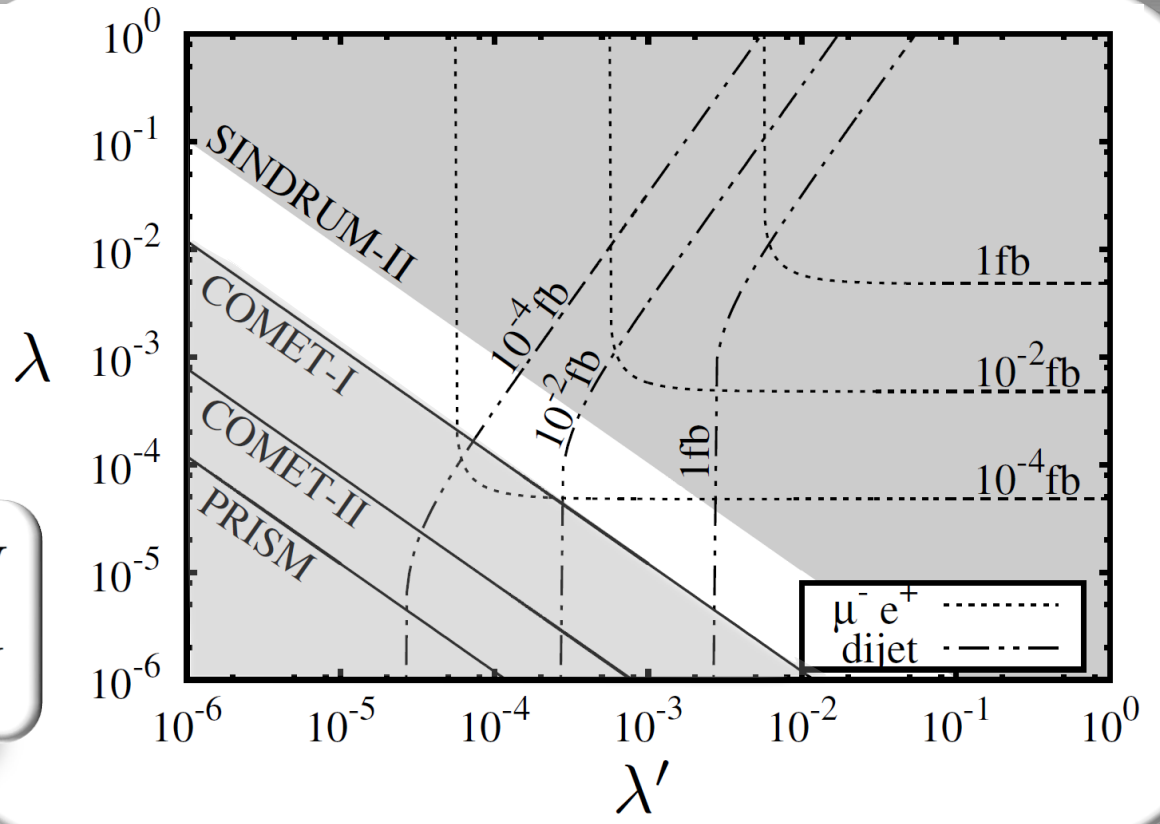


- ☑ COMET/DeeMe found m-e conversion ➡ white band

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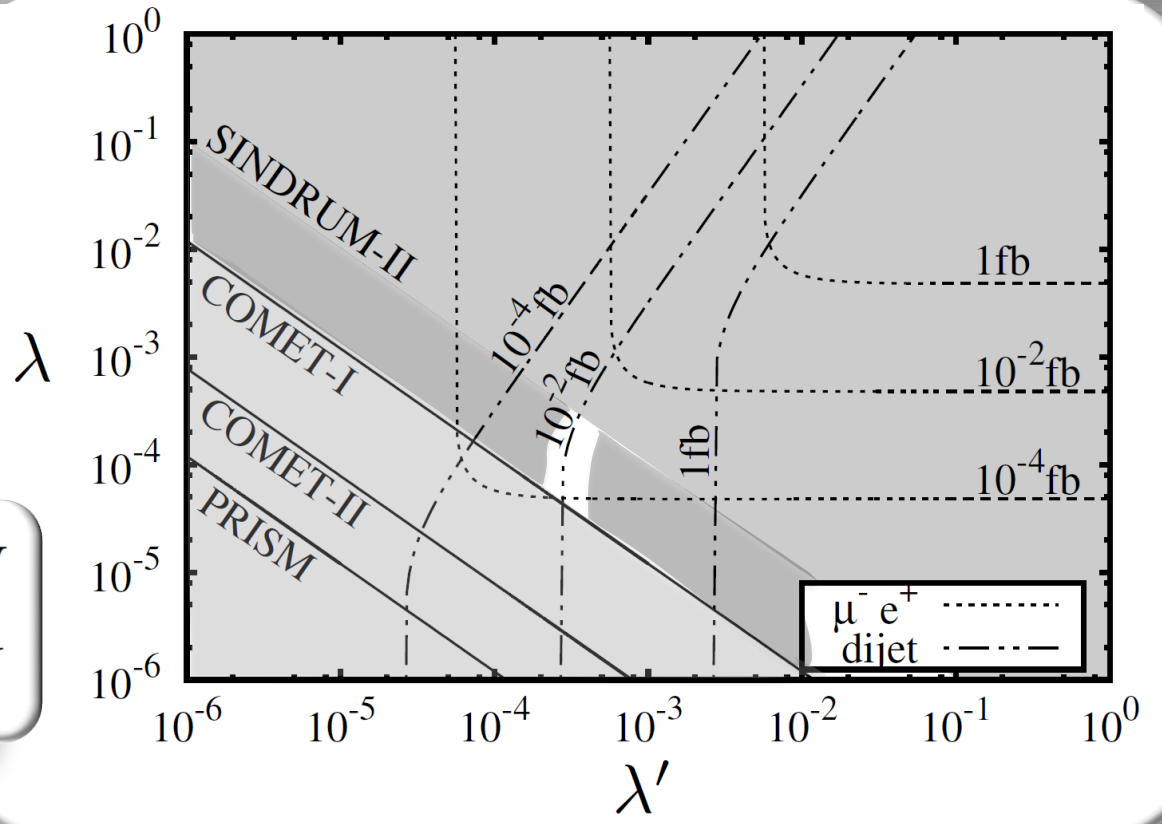


- ☑ COMET/DeeMe found m-e conversion ➡ white band
- ☑ Dijet resonance is found with $10^{-2}$fb ➡ white small region

# Correlations of distinctive signals

Contour plot of

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

- sneutrino mass $m_{\tilde{\nu}_\tau} = 1\mathrm{TeV}$
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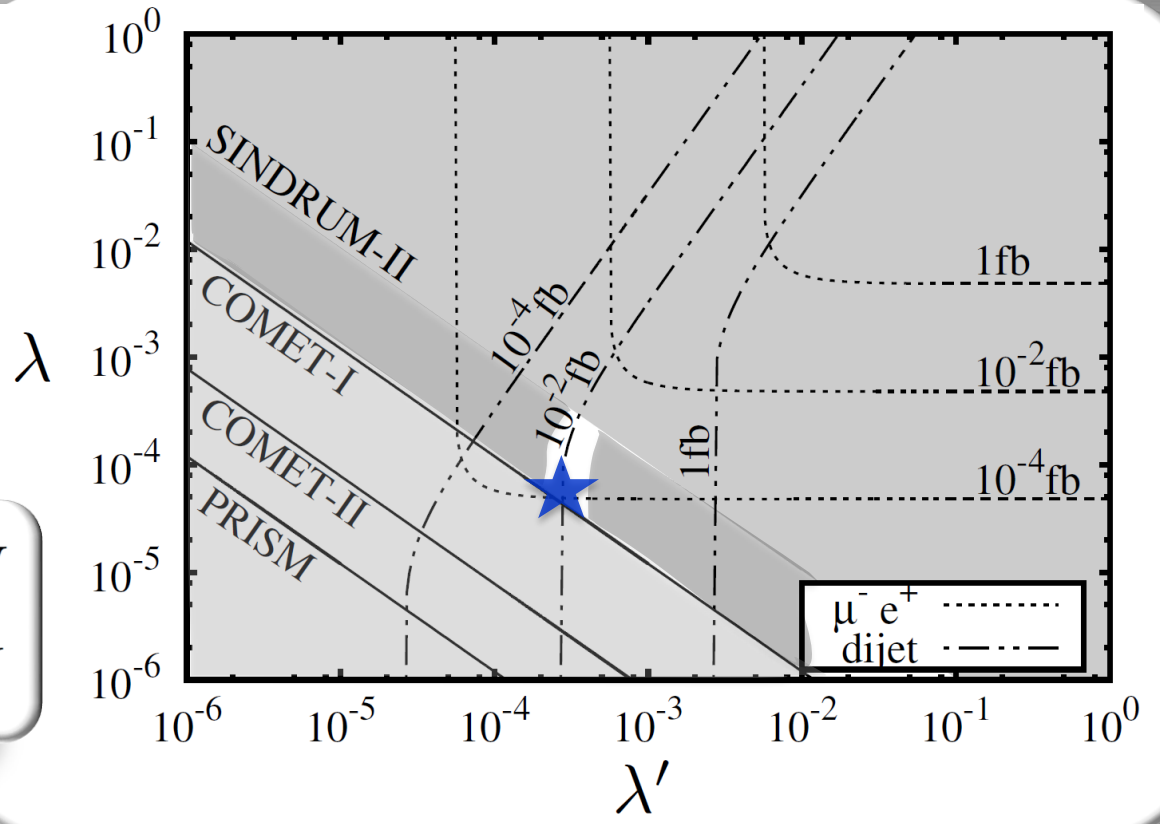
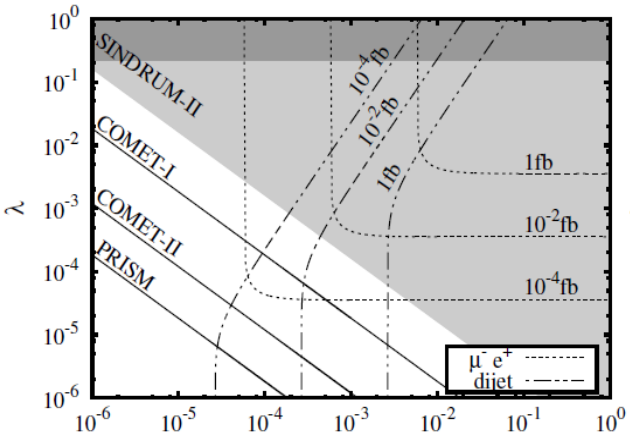


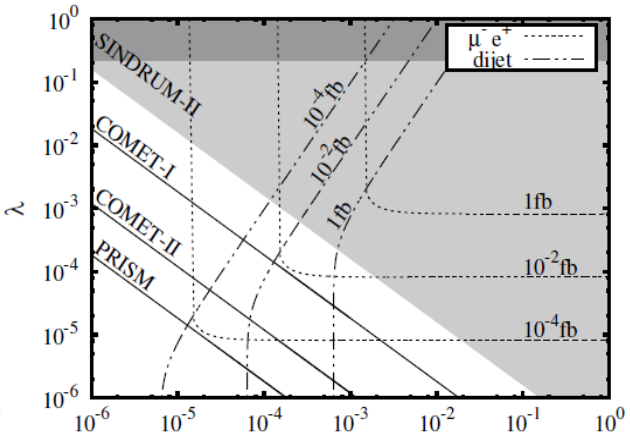

- ☑ $\mu\bar{e}$ resonance is found with $10^{-4}$fb ➡ blue star point
- ☑ J-PARC and LHC precisely determine the RPV parameters!

# Other parameters

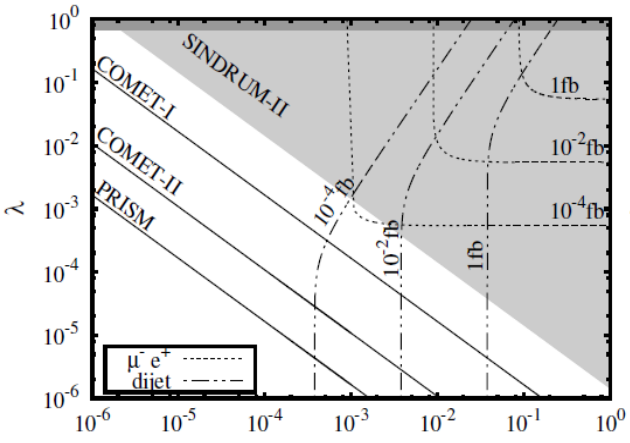
$$\lambda \equiv \lambda_{312} = \lambda_{321} = -\lambda_{132} = -\lambda_{231}$$



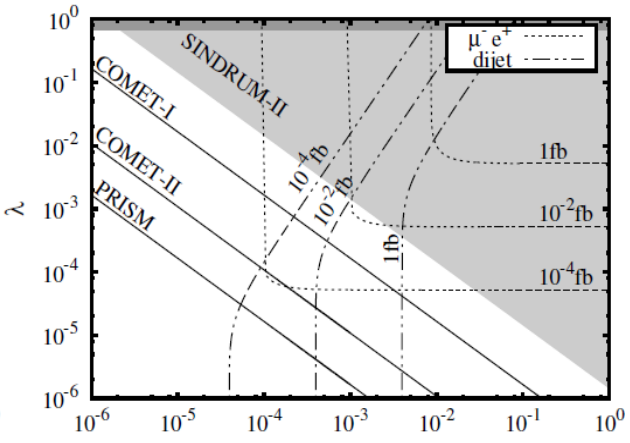

(a) $m_{\tilde{\nu}_\tau} = 1\text{TeV}$. $\sqrt{s} = 14\text{TeV}$.




(b) $m_{\tilde{\nu}_\tau} = 1\text{TeV}$. $\sqrt{s} = 100\text{TeV}$.




(c) $m_{\tilde{\nu}_\tau} = 3\text{TeV}$. $\sqrt{s} = 14\text{TeV}$.




(d) $m_{\tilde{\nu}_\tau} = 3\text{TeV}$. $\sqrt{s} = 100\text{TeV}$.

# More on coupling discrimination

- Non Standard Interaction

Pion decay in scalar channel – chiral enhancement

Exotic decay $\pi^+ \to \mu^+ \nu_e$

$$\epsilon^S_{\mu e} = \sqrt{2} \frac{m_\pi^2}{m_\mu m} \frac{\lambda^*_{312} \lambda'_{311}}{G_F m^2_{\tilde{\tau}}}$$

312 : LH electron only

- ILC with polarization

LHC signal is same for 312(LH e) and 321 (RH e)

Can you distinguish them ?

# Summary

- ☑ We studied R-parity violating SUSY model as a benchmark that μ-e conversion is observed prior to other cLFV processes

- ☑ Such a RPV scenario are simply realized by 3 settings

1. Slepton contribution to RPV: only 3rd generation
2. Different generation of left- and right-handed leptons $\lambda_{ijk}$ ($i \neq k$ and $j \neq k$)
3. For quarks, flavor diagonal components are much larger than off-diagonal components $\lambda'_{ijj} \gg \lambda'_{ijk}$ ($j \neq k$)

- ☑ Such a RPV scenario is confirmed or rejected from μ-e conversion search@J-PARC and dijet and $\mu\bar{e}$ resonances search@LHC and in future in ILC !?