Signature of the MSSM with ν_Rs in a long baseline experiment

Results are shown in part in the proceedings for the conference NuFACT04, [arXiv:hep-ph/0410408]

*Paper is in progress [arXiv:hep-ph/0502***]*

Toshihiko Ota

in collaboration with Joe Sato*

Osaka University Japan, *TUM, Munich, Germany

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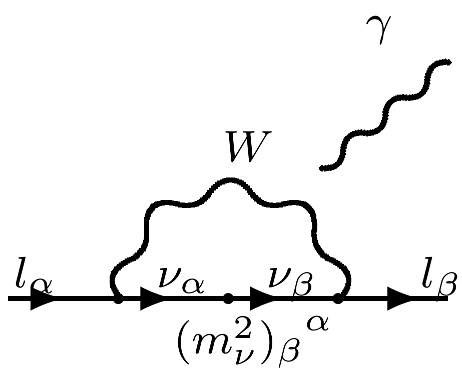
- Introduction
  - cLFV: lepton flavor violation in charged lepton sector
  - nLFV: lepton flavor violation with neutrinos
- Model independent analysis
  - Feasibility study to detect nLFV signals

    based on TO Sato Yamashita, *Phys. Rev.* **D65** (2002) 093015.
- In the MSSM with ν_Rs,
  not only cLFV but also nLFV are induced.
  - Correlation between cLFV and nLFV
  - Size of nLFV couplings. — Detectable or not?
- Summary

Introduction

Introduction: LFV

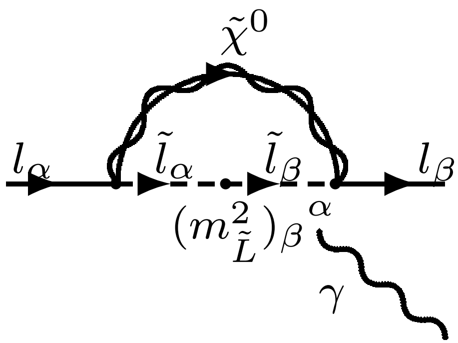
- In the SM, there is no LFV. In the SM with m_ν, it is small.



$$\mathrm{Br}(l_\alpha \to l_\beta \gamma) \simeq \frac{3\alpha}{32\pi} \left| U_{\mu i} \frac{m^2_{\nu_i}}{m^2_W} U^\dagger_{ie} \right|^2$$

Cheng Li (1977), Petcov (1977),
Marciano Sandra (1977), Shrock Lee (1977)

- In the MSSM with ν_Rs, it can be large
  - The large mixings of neutrinos may imply the large cLFV ...



$$\left(m^2_{\tilde{L}}\right)_\beta{}^\alpha \simeq -\frac{(6+a_0^2)m_0^2}{16\pi^2} \left(Y_\nu^\dagger Y_\nu\right)_\beta{}^\alpha \ln \frac{M_X}{M_R},$$

$$\mathrm{Br}(l_\alpha \to l_\beta \gamma) \simeq \frac{\alpha^3}{G_F^2} \frac{\left|\left(m^2_{\tilde{L}}\right)_\beta{}^\alpha\right|^2}{m^8_{\mathrm{SUSY}}} \tan^2\beta.$$

Borzumati Masiero (1986),
Hisano Moroi Tobe Yamaguchi (1995)

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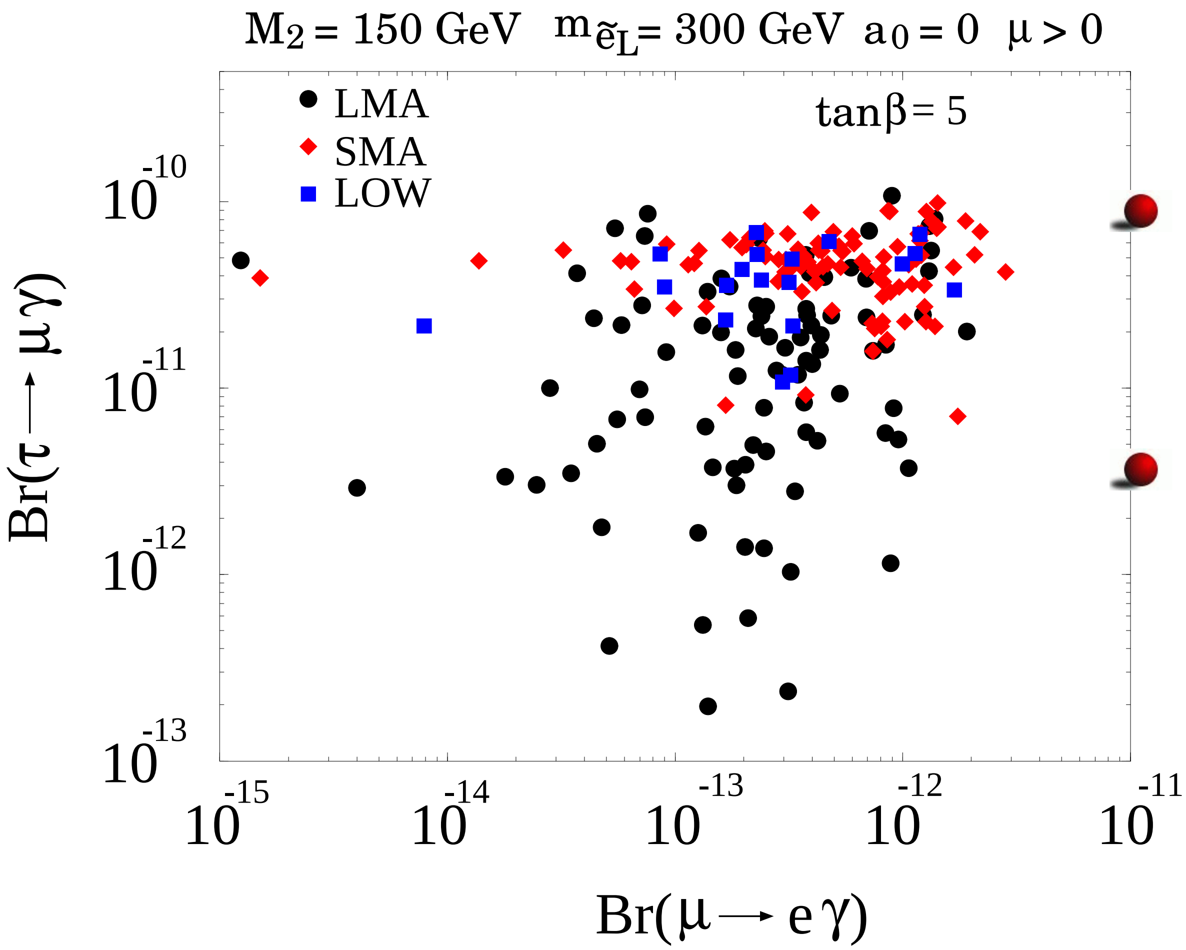
LFV in charged lepton sector (cLFV)



- One example numerical study

  Sato Tobe (2000)

- The future experiments
  $\mathrm{Br}(\mu \to e\gamma) > 10^{-14}$,
  $\mathrm{Br}(\tau \to \mu\gamma) > 10^{-8}$,
  $\mathrm{Br}(\mu \to e \text{ conv.}) > 10^{-18}$.

- The search for the cLFV is promising experiments.
  — However, we here consider an alternative process.

LFV interaction with neutrinos (nLFV)

- We here discuss a process with the neutrino flavor violation, such as

$$\mu^- \to \nu_\tau e^- \bar{\nu}_e, \quad \nu_\alpha e^- \to \nu_\beta e^-, \quad \nu_\alpha d \to \ell_\beta u.$$

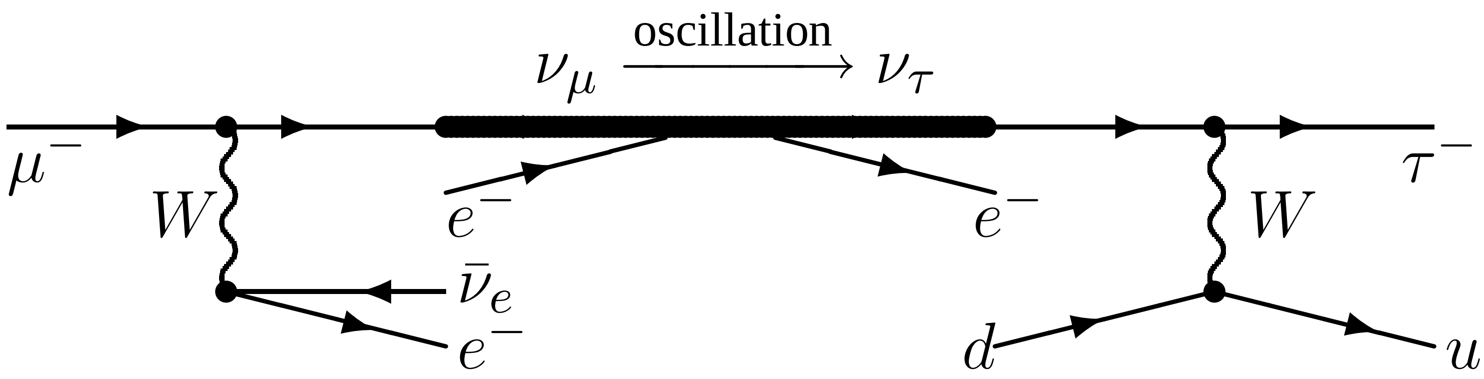
These processes affect the neutrino oscillation experiments.

Gonzalez-Garcia Grossman Gusso Nir (2001)
Gago Guzzo Nunokawa Teves Zukanovich Funchal (2001)
Huber Schwetz Valle (2002)
Fogli Lisi Mirizzi Montanino (2002)

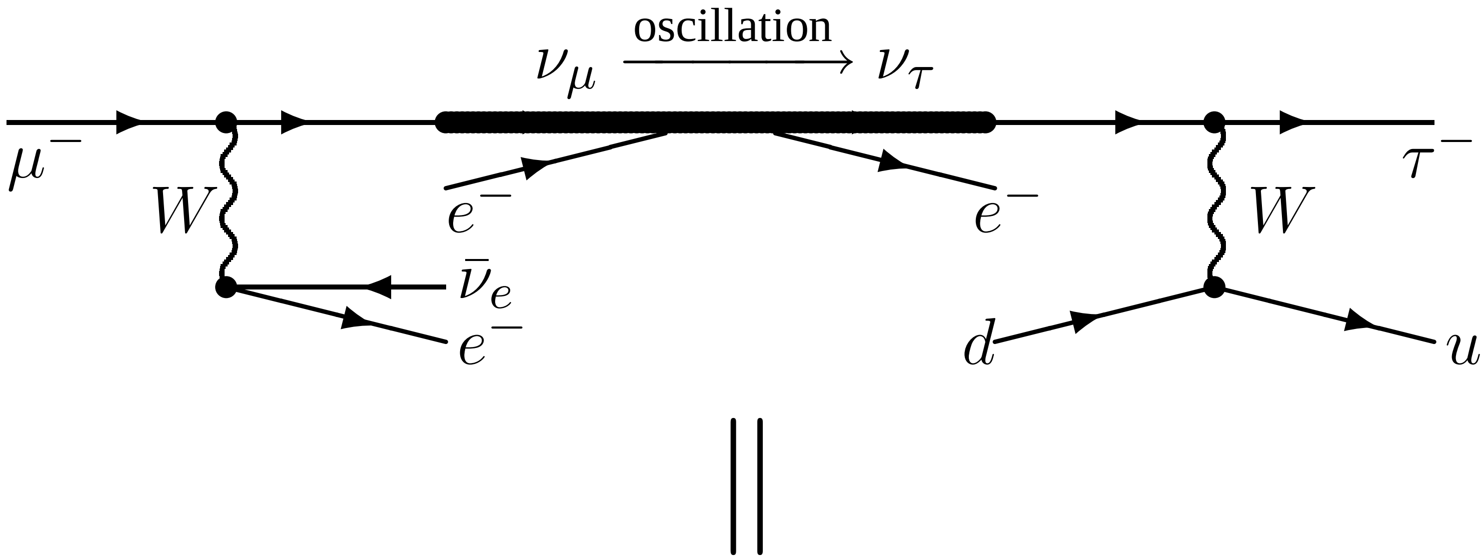
- Can we detect these effects in oscillation experiments?
— Yes, we can, but it depends on the type and size of nLFV interaction. TO Sato Yamashita (2001)
- In the MSSM+ν_R, what is the typical size of nLFV couplings?
— We show the correlation between nLFV and cLFV.

Model independent approach

Standard Oscillation $\nu_\mu \to \nu_\tau$

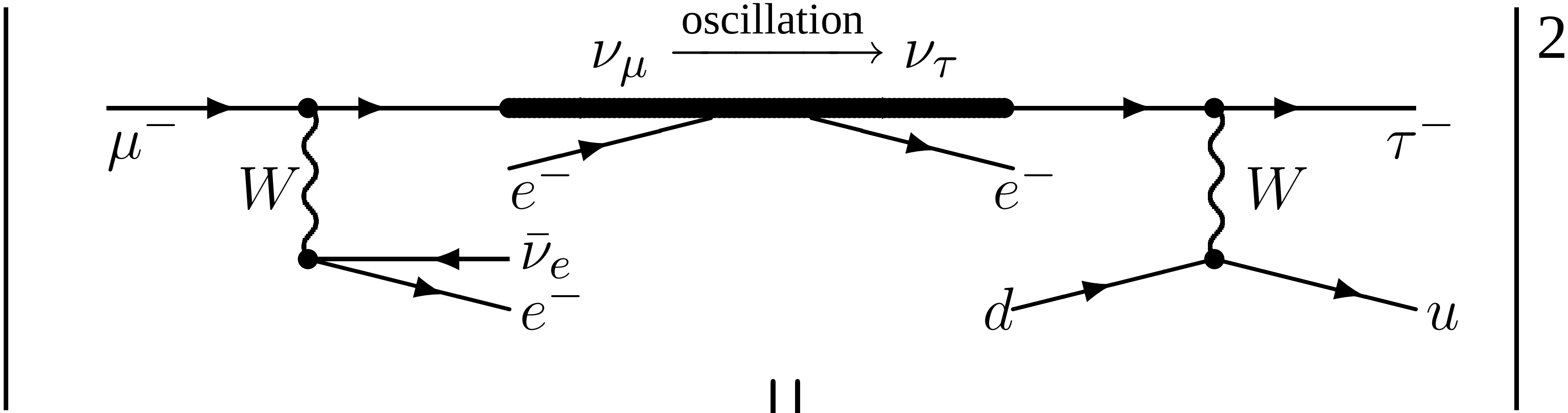


Standard Oscillation $\nu_\mu \to \nu_\tau$



$$\mathcal{A}(\mu \to \nu_\mu \bar{\nu}_e e) \times \mathcal{A}(\nu_\mu \xrightarrow{\text{osc}} \nu_\tau) \times \mathcal{A}(\nu_\tau d \to \tau u)$$

Standard Oscillation $\nu_\mu \to \nu_\tau$



$$\left| \mathcal{A}(\mu \to \nu_\mu \bar{\nu}_e e) \times \mathcal{A}(\nu_\mu \xrightarrow{\text{osc}} \nu_\tau) \times \mathcal{A}(\nu_\tau d \to \tau u) \right|^2$$

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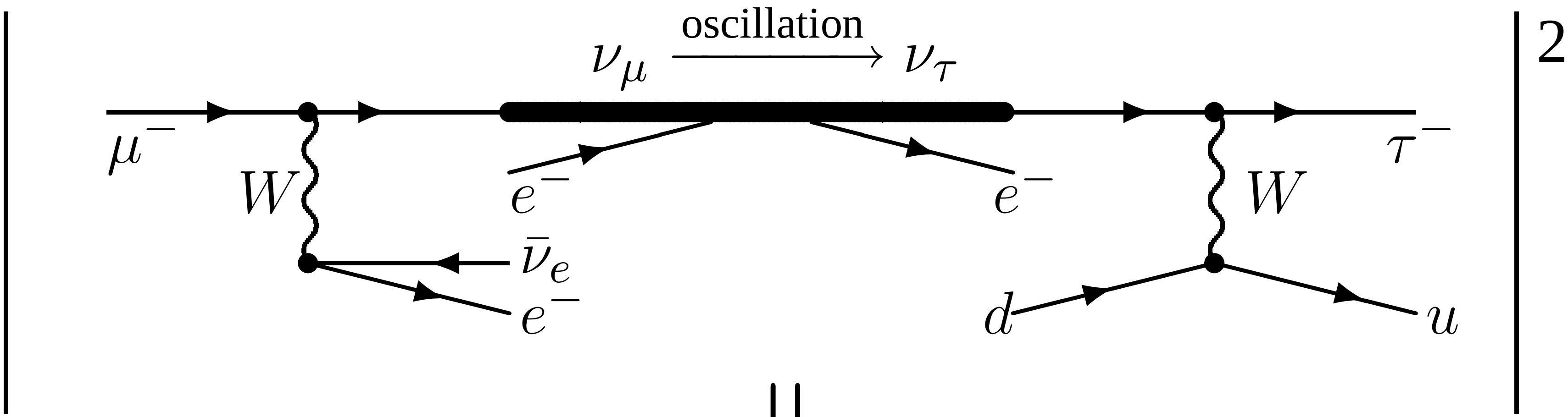

$$\Vert$$

$$\left| \mathcal{A}(\mu \to \nu_\mu \bar{\nu}_e e) \times \mathcal{A}(\nu_\mu \xrightarrow{\text{osc}} \nu_\tau) \times \mathcal{A}(\nu_\tau d \to \tau u) \right|^2$$

$$\Vert$$

$$\Gamma_{\text{SM}}(\mu \to \nu_\mu \bar{\nu}_e e) \times P_{\nu_\mu \to \nu_\tau} \times \sigma_{\text{SM}}(\nu_\tau d \to \tau u)$$

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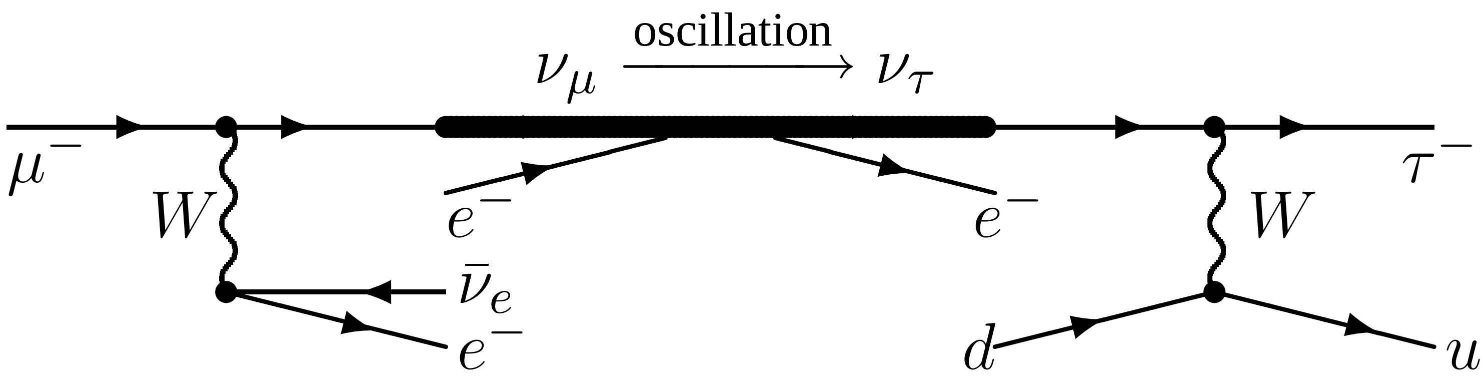
Oscillation with nLFV interactions



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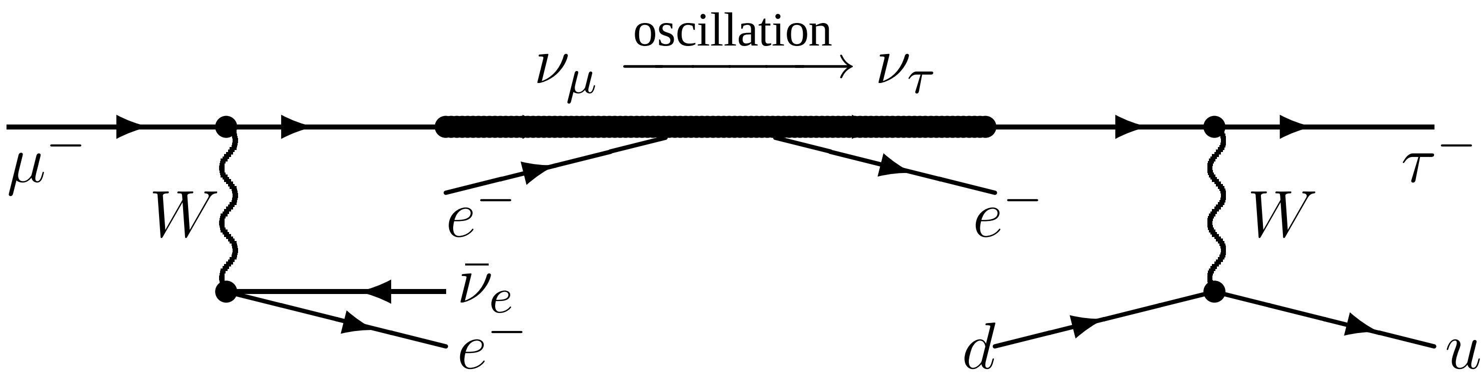

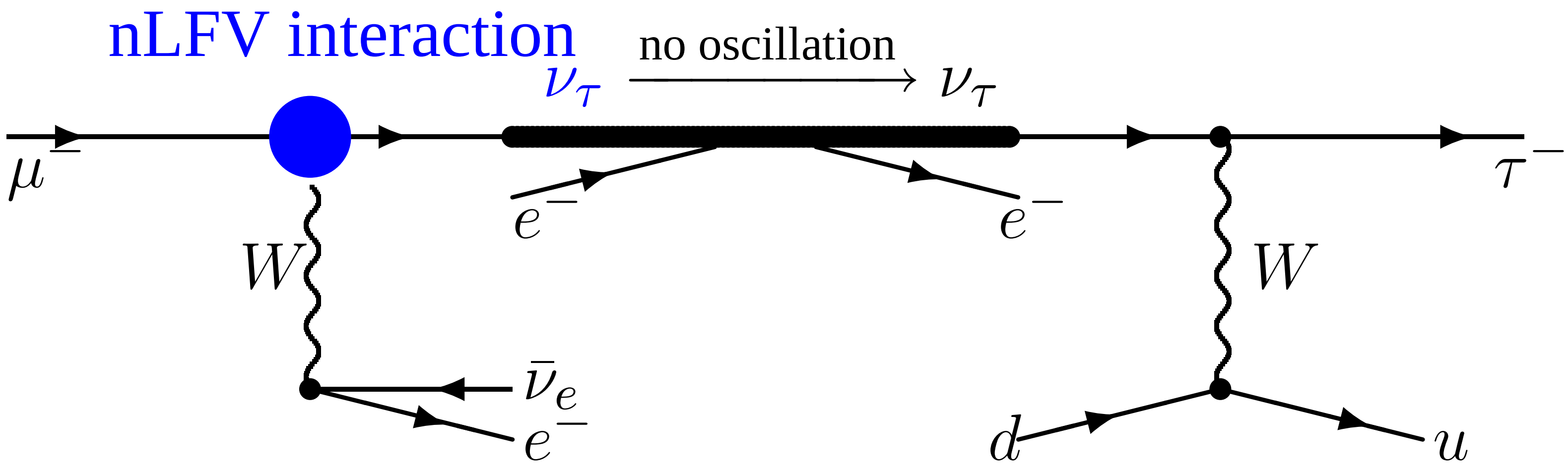

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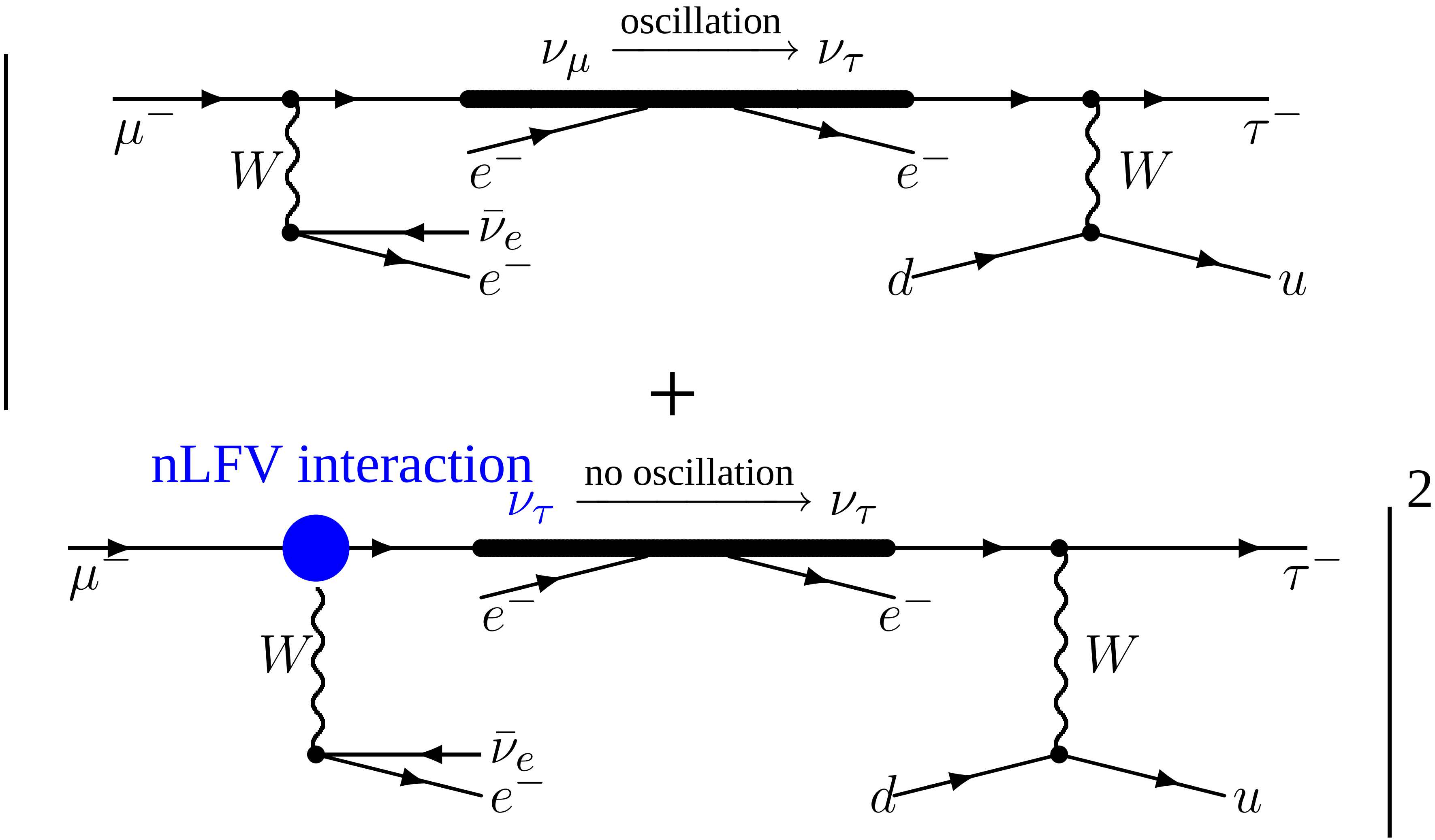
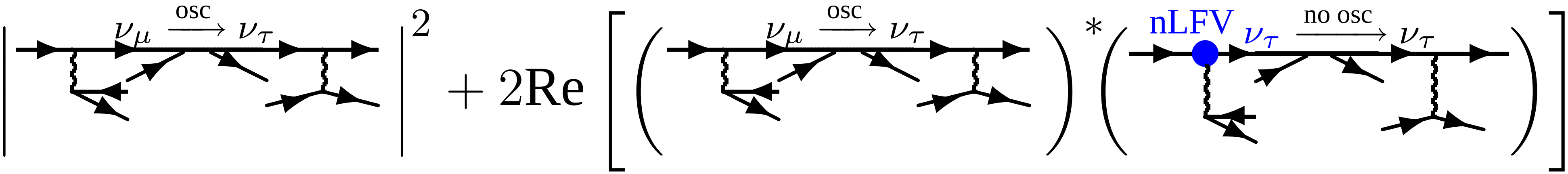


Oscillation with nLFV interactions

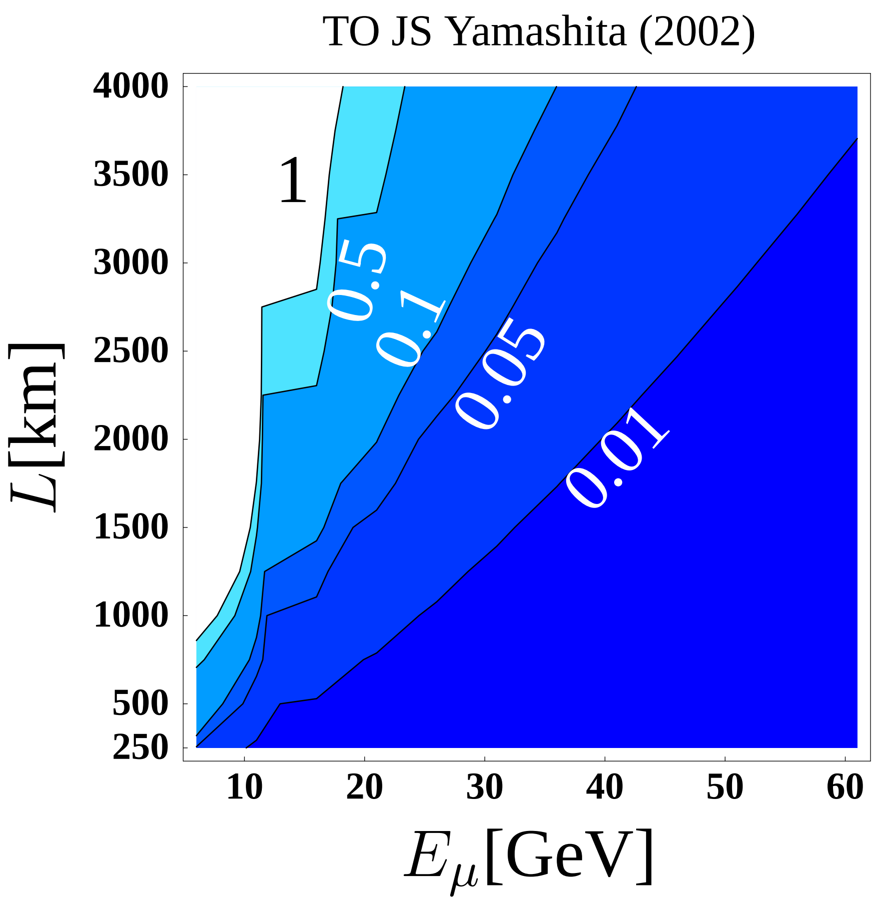


$$= \Gamma_{\text{SM}} \times \left(P_{\nu_\mu \to \nu_\tau} + 2\text{Re} \left[\epsilon^s_{\mu\tau} \mathcal{A}^*(\nu_\mu \xrightarrow{\text{osc}} \nu_\tau) \mathcal{A}(\nu_\tau \xrightarrow{\text{no osc}} \nu_\tau) \right] \right) \times \sigma_{\text{SM}},$$

where $\epsilon^s_{\mu\tau} \equiv \dfrac{\mathcal{A}(\mu \to \nu_\tau \bar{\nu}_e e)}{\mathcal{A}_{\text{SM}}}$.

- The oscillation probability is modified by the interference term due to the nLFV interaction.
- The size of the interference term is $\mathcal{O}(\epsilon^s_{\mu\tau})$, not $\mathcal{O}(|\epsilon^s_{\mu\tau}|^2)$.
  — This interference effect can occure only in the oscillaton process.

Search for the effect of $\epsilon^s_{\mu\tau}$ in $\nu_\mu \to \nu_\tau$



- Necessary (muon)×(detector size) for 90% CL detection of nLFV.

  normalized at $10^{21} \times 100$[kton]

  - $\nu_\mu \to \nu_\tau$ channel
  - $\epsilon^s_{\mu\tau} = 3 \times 10^{-3} e^{i\frac{\pi}{2}}$
  - 10% ambiguity is considered in the oscillation parameters, Δm^2s and θs, and the CP-phase δ is treated as a free parameter.

$$\mu^- \xrightarrow{G_F} \nu_\mu \xrightarrow{\text{osc.}} \nu_\tau \to \tau^-$$

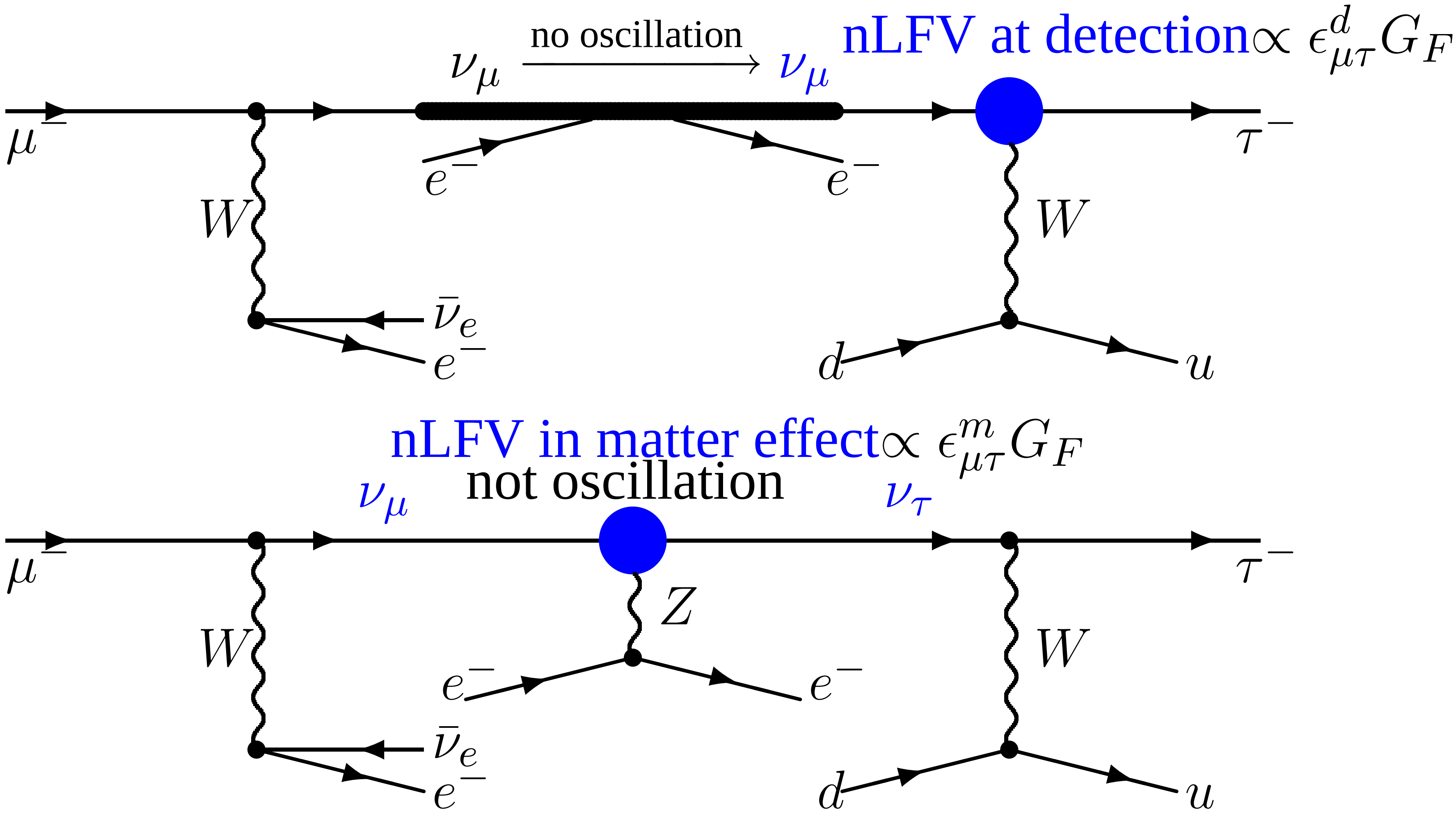
$$\mu^- \xrightarrow{\epsilon^s_{\mu\tau} G_F} \nu_\tau \xrightarrow{\text{no osc.}} \nu_\tau \to \tau^-$$

- The energy dependence of this signal is $1/E_\nu$.

It is quite different from the standard oscillation effect($\propto 1/E_\nu^2$).

Oscillation with nLFV interactions

- The other diagrams which contribute to $\mathcal{A}(\mu + I \to \tau + F)$



Summary of the model independent analysis

- Detectable signal ...
  - In $\nu_\alpha \to \nu_\beta$ channel, we can extract the nLFV signals only with $\epsilon^{s,m,d}_{\alpha\beta}$.
    — by using its characteristic energy dependence.
    — the nLFV amplitude *does not include neutrino oscillation* but its final states are the same as the standard one.

  - At a neutrino factory (10^{21} muons $\times 100$ kt detector), we have a chance to detect the signal of $|\epsilon^{s,m,d}_{\alpha\beta}| \sim \mathcal{O}(10^{-4})$.

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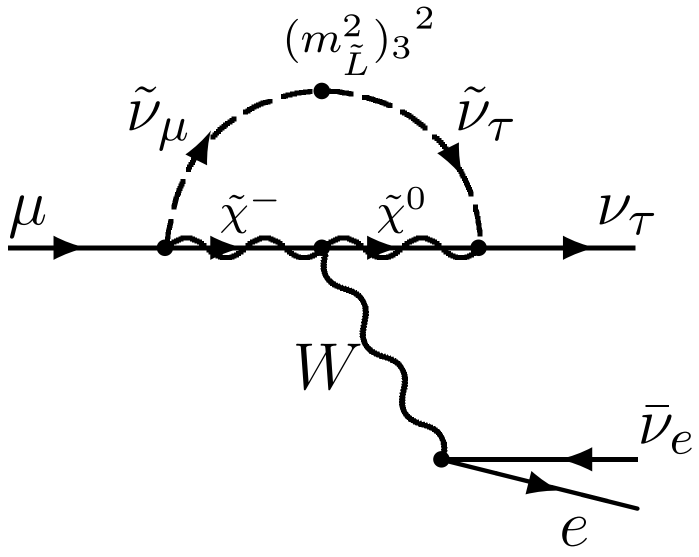
- Detectable signal ...
  - In $\nu_\alpha \to \nu_\beta$ channel, we can extract the nLFV signals only with $\epsilon_{\alpha\beta}^{s,m,d}$.
    — by using its characteristic energy dependence.
    — the nLFV amplitude *does not include neutrino oscillation* but its final states are the same as the standard one.
    - We here deal with $\epsilon_{\mu\tau}^{s,m,d}$ in the $\nu_\mu \to \nu_\tau$ channel.
  - At a neutrino factory (10^{21} muons $\times 100$ kt detector), we have a chance to detect the signal of $|\epsilon_{\alpha\beta}^{s,m,d}| \sim \mathcal{O}(10^{-4})$.
    - We make a numerical calculation for the size of nLFV couplings $\epsilon_{\mu\tau}^{s,m,d}$ in the MSSM with ν_Rs.

In the MSSM with ν_Rs

Estimation of $\epsilon^s_{\mu\tau}$ in MSSM$+\nu_R$

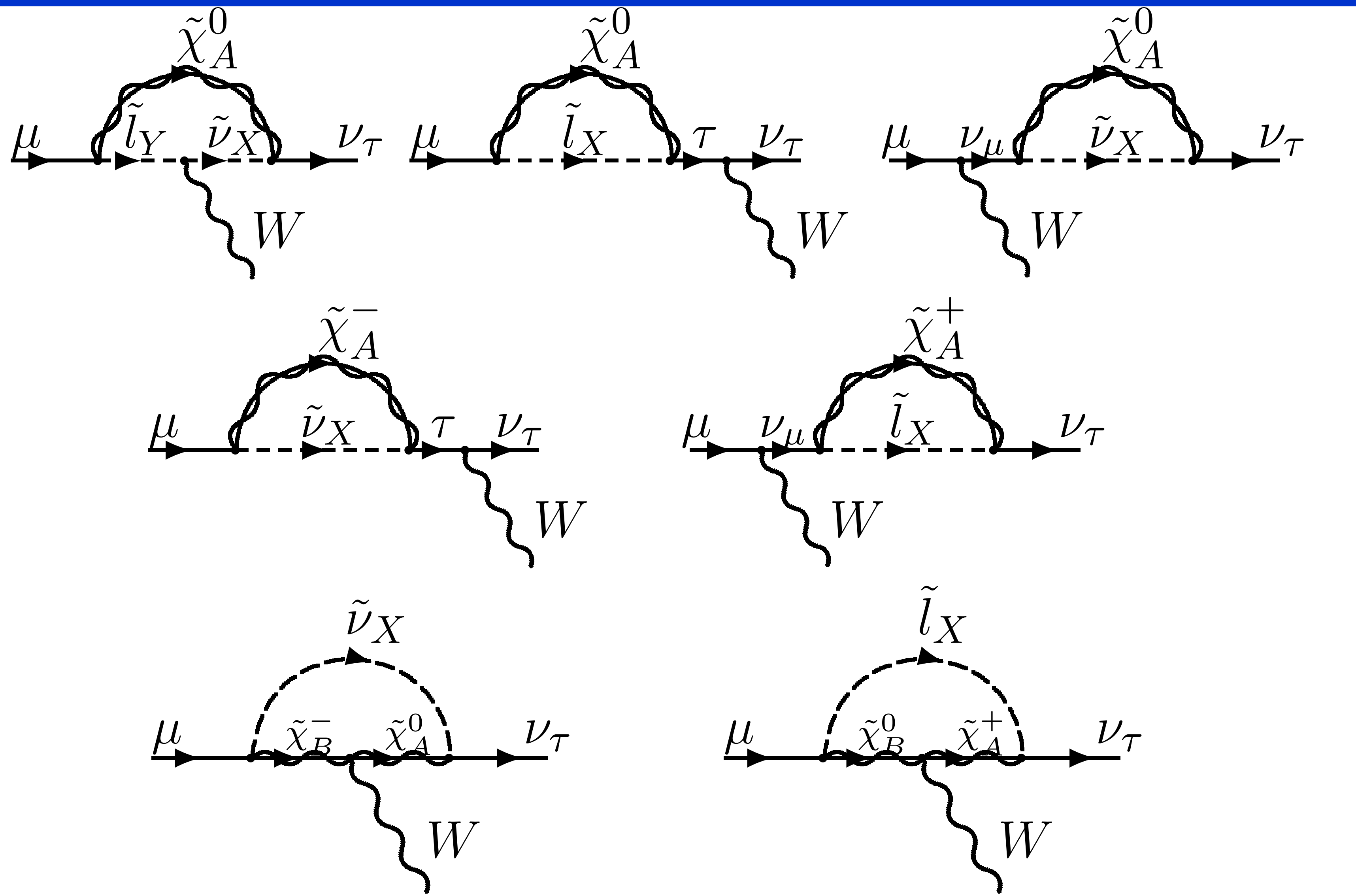


$$\sim \frac{g^2}{(4\pi)^2}\frac{(m^2_{\tilde{L}})_3{}^2}{m^2_{\text{SUSY}}}G_F \sim \epsilon^s_{\mu\tau}G_F$$

- The origin of the nLFV is the same as that of the cLFV: slepton mixing
- Naively, $\epsilon^s_{\mu\tau} \sim \mathcal{O}(10^{-4})$ in nLFV corresponds to Br$(\tau \to \mu\gamma) \sim \mathcal{O}(10^{-8})$ in cLFV.

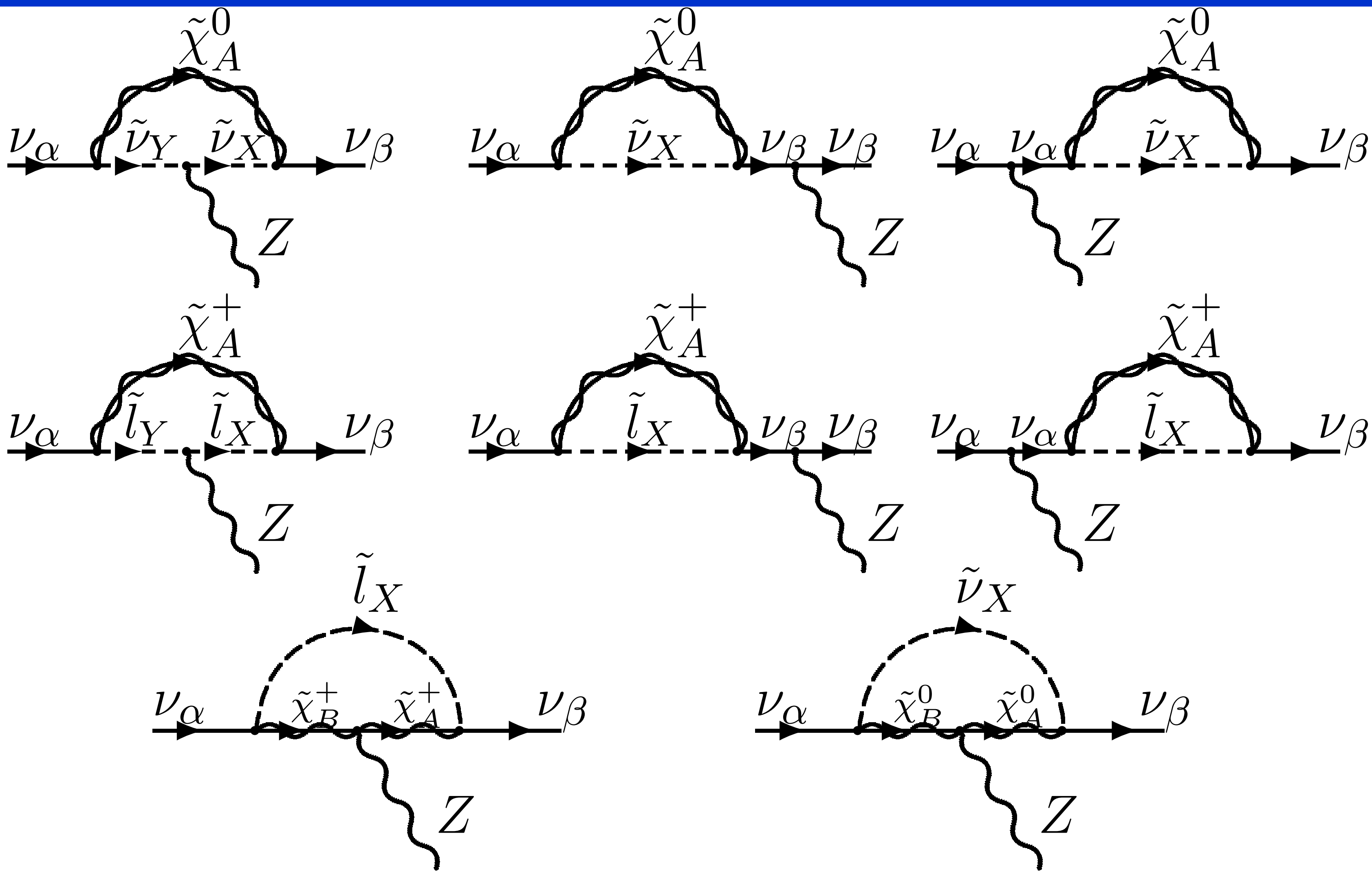
  — However, for quantitative analysis, it is necessary to make a numerical calculation ...

Numerical evaluation of $\epsilon^s_{\mu\tau}$ in MSSM+ν_R



and box diagrams ...

Numerical evaluation of $\epsilon^{m}_{\mu\tau}$ in MSSM+ν_R



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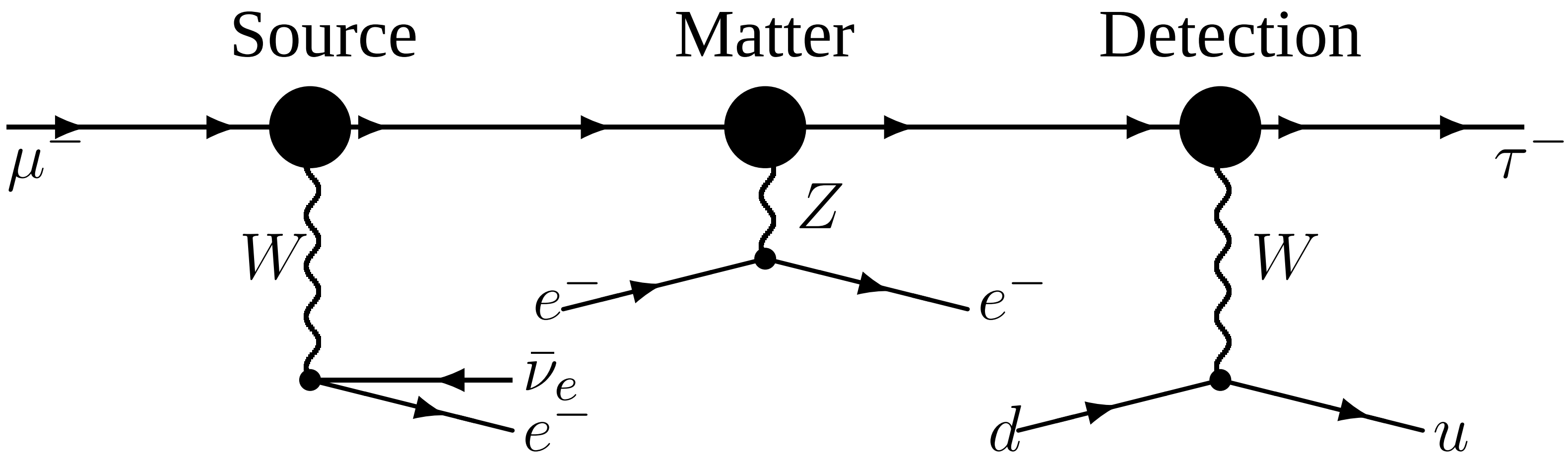
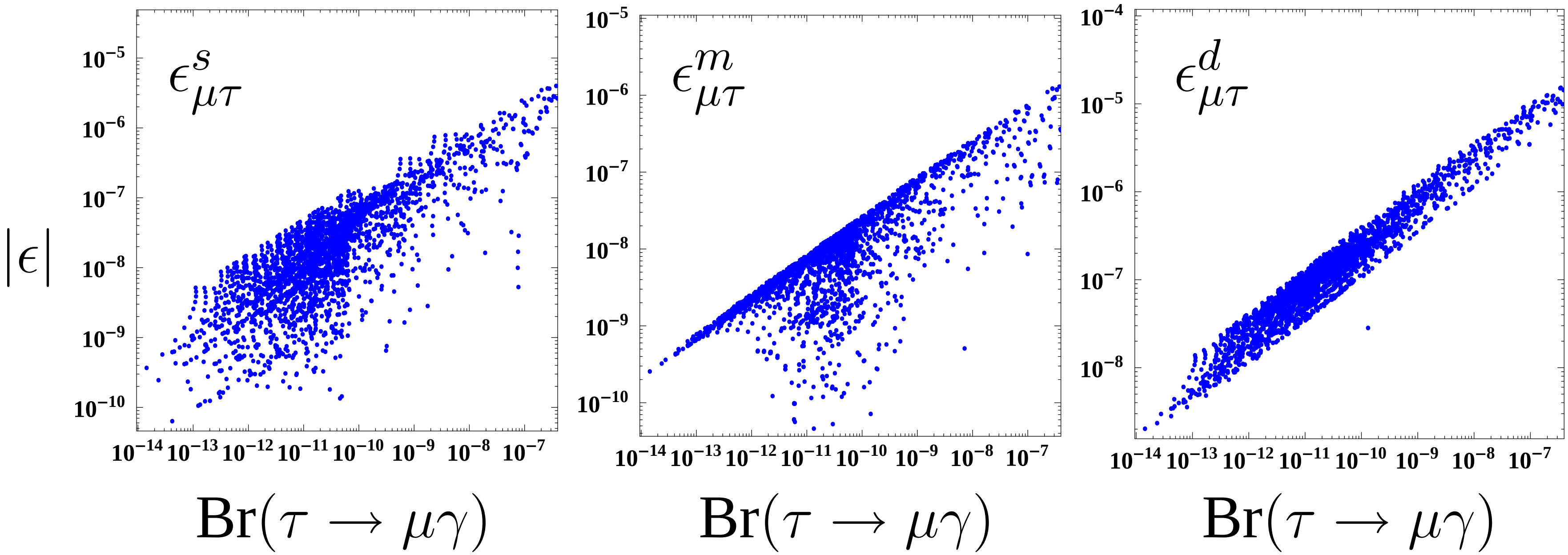
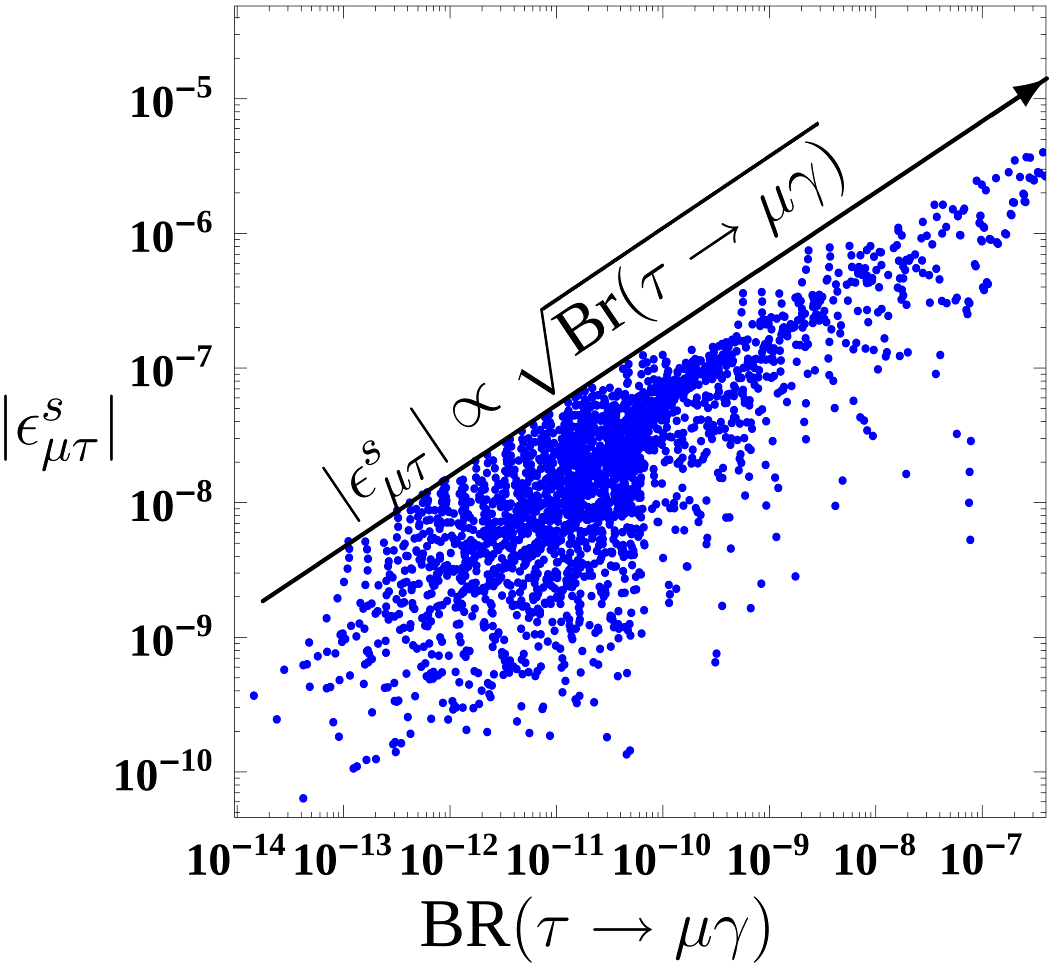
Numerical evaluation of $\epsilon^{s,m,d}_{\mu\tau}$ in MSSM+ν_R





Correlation between nLFV and cLFV



- Correlation between the nLFV coupling $\epsilon^s_{\mu\tau}$ and cLFV process $\tau \to \mu\gamma$.
  - With some different Y_νs, we scan the m_0-$M_{1/2}$ space with $a_0 = 0$, $\tan\beta = 10$, and $\mu > 0$.
- The parameter $\epsilon^s_{\mu\tau}$ is constrained at $\mathcal{O}(10^{-5})$ by the current bound of $\tau \to \mu\gamma$.
- It is smaller than the naive estimation because of cancellation among diagrams.

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- We evaluate the effective couplings of nLFV which are relevant to $\nu_\mu \to \nu_\tau$ in the MSSM with ν_Rs.
  - $\epsilon^s_{\mu\tau}$, $\epsilon^m_{\mu\tau}$, $\epsilon^d_{\mu\tau}$ where $\epsilon^{s,m,d}_{\mu\tau} \equiv \mathrm{exotic}/\mathrm{standard}$
  - Detectable size: $|\epsilon^{s,m,d}_{\mu\tau}| \gtrsim \mathcal{O}(10^{-4})$

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  - Detectable size: $|\epsilon^{s,m,d}_{\mu\tau}| \gtrsim \mathcal{O}(10^{-4})$
- In the MSSM with ν_Rs, these couplings are constrained by the process $\tau \to \mu\gamma$ as $|\epsilon^{s,m,d}_{\mu\tau}| \lesssim \mathcal{O}(10^{-5})$.
- Other model? — R-parity violation ...
  — CPV MSSM ...
  — $SU(5)$ GUT ...