# Effects of one-loop correction on the beta decay within R-parity violating MSSM

N. Yamanaka

(Osaka University)

In collaboration with
T. Sato (Osaka univ.), T. Kubota (Osaka univ.)

2010/08/27
Bonn,
Germany

# Introduction

## Many candidate of New Physics:

SUSY , Left-right sym. Model , Composite Model , Extra dimension , …

New physics can manifest in neutron beta decay

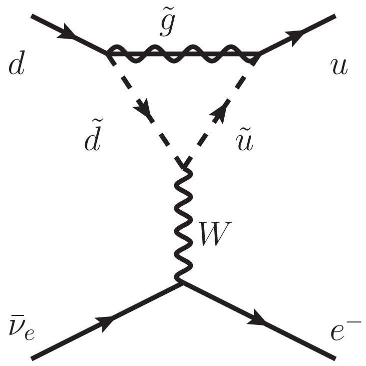
⇒ **Neutron beta decay is a good probe of New Physics**

- **General analysis of New physics in neutron beta decay**
  P. Herczeg, Prog. Part. Nucl. Phys. **29**, 413 (2001).
- **Loop level analysis of neutron beta decay within MSSM**
  M. Drees, M. Rauch, Eur. Phys. J. C**46**, 573 (2003).
  S. Profumo, M.J. Ramsey-Musolf, S. Tulin, Phys. Rev. D**75**, 075017 (2007).
- **Tree level analysis of neutron beta decay within RPVMSSM**
  P. Herczeg, J. Res. Natl. Inst. Stand. Technol. **110**, 453 (2005).
  NY, T. Sato, T. Kubota, J. Phys. G**37**, 055104 (2010).

⇒ **What about analysis of neutron beta decay within RPVMSSM at the loop level?**

# Previous works

**MSSM at loop level:**




**Contribute to D-correlation** $D\dfrac{\vec{\sigma}_n \cdot \vec{p}_e \times \vec{p}_\nu}{E_e E_\nu}$

**and Fierz interference term** $b\dfrac{m_e}{E_e}$

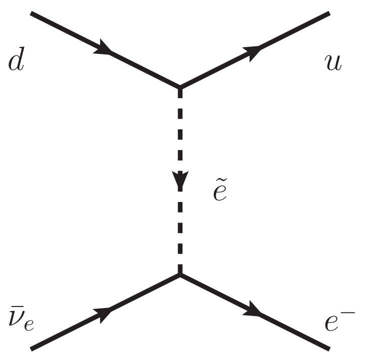
$\Rightarrow$ ***D*** **< 10**$^{-7}$

M. Drees, M. Rauch, Eur. Phys. J. C**29**, 573 (2003).

***b*** **< 10**$^{-3}$

S. Profumo *et al.*, Phys. Rev. D**75**, 075017 (2007).

**RPVMSSM at tree level:**




**Contribute to Fierz interference term** $b\dfrac{m_e}{E_e}$

**and R-correlation** $R\dfrac{\vec{\sigma}_e \cdot \vec{\sigma}_n \times \vec{p}_e}{E_e}$

$$\Rightarrow \begin{cases} |\mathrm{Re}\,\lambda_{1i1}\lambda'^{*}_{i11}| < 1.6 \times 10^{-3}[m_{\tilde{e}_L}]^2 \\ |\mathrm{Im}\,\lambda_{1i1}\lambda'^{*}_{i11}| < 3.0 \times 10^{-2}[m_{\tilde{e}_L}]^2 \end{cases}$$

P. Herczeg, J. Res. Natl. Inst. Stand. Technol. **110**, 453 (2005).

NY, T. Sato, T. Kubota, J. Phys. G**37**, 055104 (2010).

# D correlation of the Neutron beta decay

**Observable: angular correlations**

$$\omega(E_e,\Omega_e,\Omega_\nu) \propto 1 + a\frac{\vec{p}_e\cdot\vec{p}_\nu}{E_eE_\nu} + b\frac{m_e}{E_e} + \langle\vec{\sigma}_n\rangle\cdot\left(A\frac{\vec{p}_e}{E_e} + B\frac{\vec{p}_\nu}{E_\nu} + D\frac{\vec{p}_e\times\vec{p}_\nu}{E_eE_\nu}\right) + \cdots$$

***D* correlation**

**Properties of *D* correlation:**
- **Sensitive to CP-odd (*V*+*A*)x(*V*-*A*)**
- **Small CKM contribution**
- **FSI: O($10^{-5}$), known to $10^{-7}$**

**⇒ Sensitive to new physics!!**

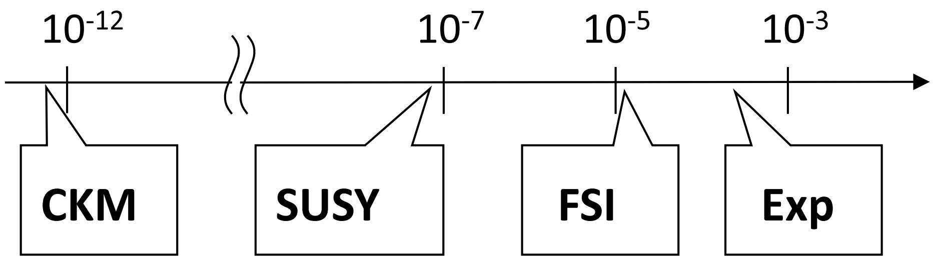
$D_{exp}$ = $(2.8 \pm 7.1) \times 10^{-4}$
Soldner *et al*., Phys. Lett. B**581** (2004) .

$D_{CKM}$ $\leqq 10^{-12}$
Herczeg, Khriplovich, PRD**56** (1997).

$D_{MSSM}$ $\leqq 10^{-7}$
Drees, Rauch, EPJ C**29** (2003).

$D_{fsi}$ $\fallingdotseq 1.31 \times 10^{-5}$
Ando, *et al.* , Phys. Lett. B**677**, 109 (2009).

$D_{RPV}$ **No tree contribution!**



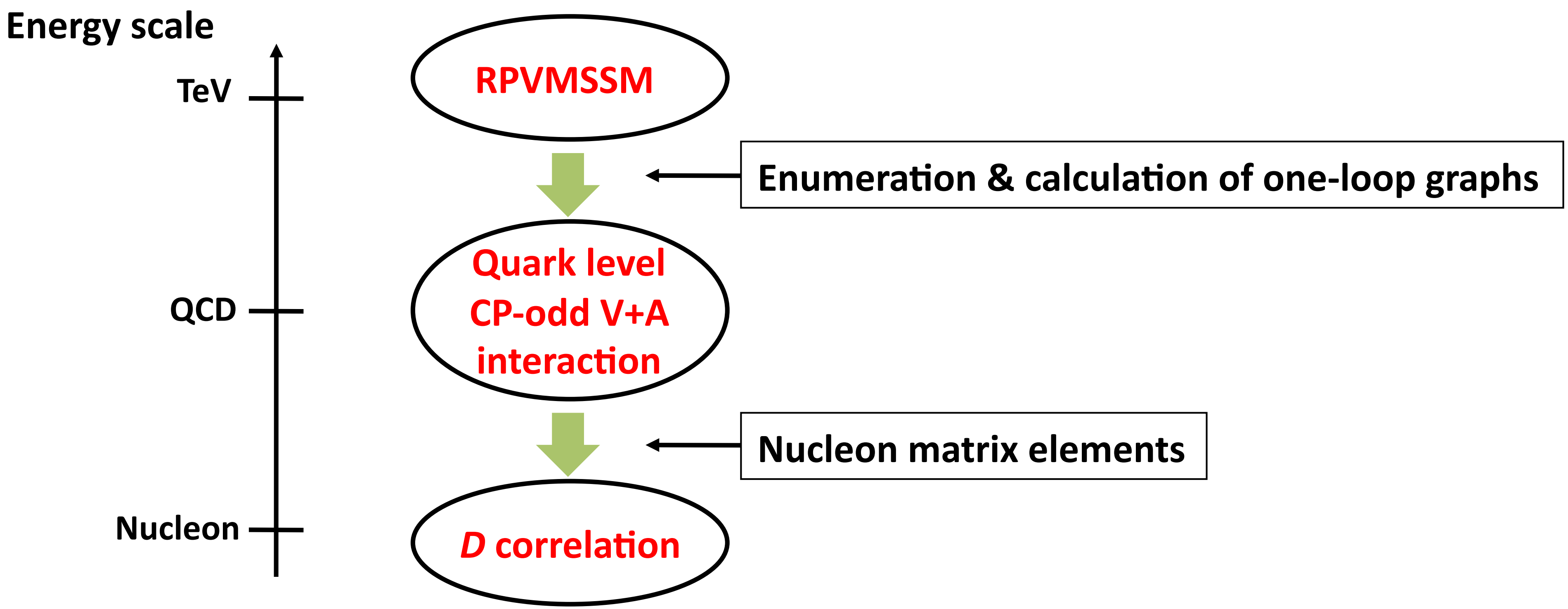

**⇒ Analysis of RPVMSSM at one-loop level is meaningful**

# *Object & outline of calculation*

## Object:

**Investigate the D correlation of the neutron beta decay within the R-parity violating minimal supersymmetric Standard Model (RPVMSSM) at one-loop level.**

## Outline of calculation:



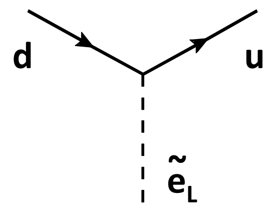
## R-parity violation

**R-parity :** $R = (-1)^{3B-L-2s}$

**R-parity violation → lepton/baryon number violation**

**RPV interactions:**

$$\begin{aligned}\mathcal{L} \;=\; & -\tfrac{1}{2}\sum_{ijk}\lambda_{ijk}\left\{\tilde{e}^{\dagger}_{Rk}\bar{\nu}^{c}_{i}P_{L}e_{j}+\tilde{e}_{Lj}\bar{e}_{k}P_{L}\nu_{i}+\tilde{\nu}_{i}\bar{e}_{k}P_{L}e_{j}+\cdots\right\}\\ & -\sum_{ijk}\lambda'_{ijk}\left\{-\tilde{e}_{Li}\bar{d}_{k}P_{L}u_{j}+\cdots\right\}\\ & -\tfrac{1}{2}\sum_{ijk}\lambda''_{ijk}\left\{\tilde{d}^{\dagger}_{Rk}\bar{u}_{i}P_{L}d^{c}_{j}+\cdots\right\}\\ & +\text{h.c.}\end{aligned}$$

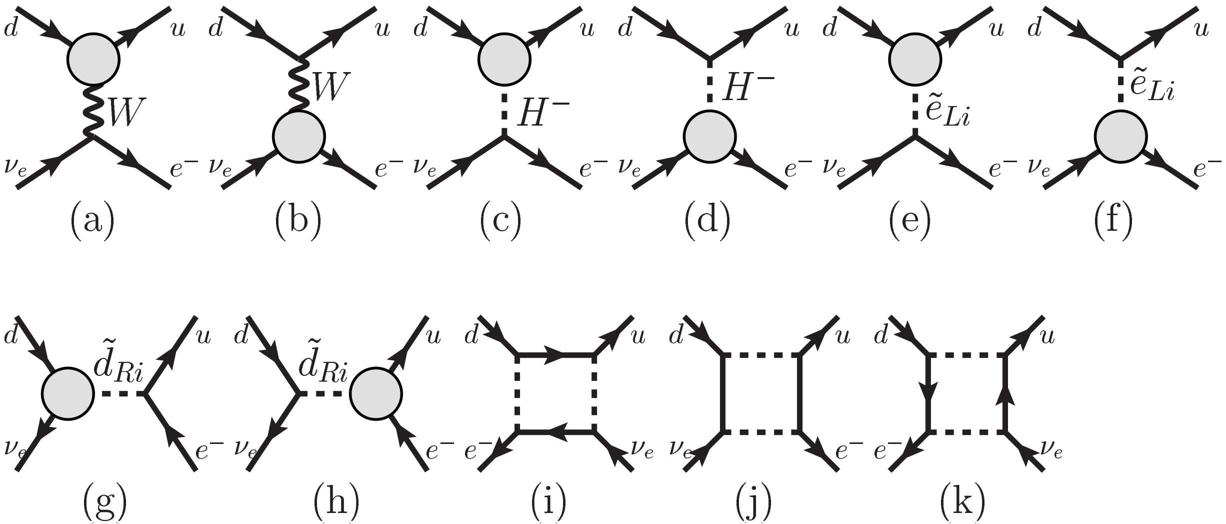



**Yukawa interaction!!**

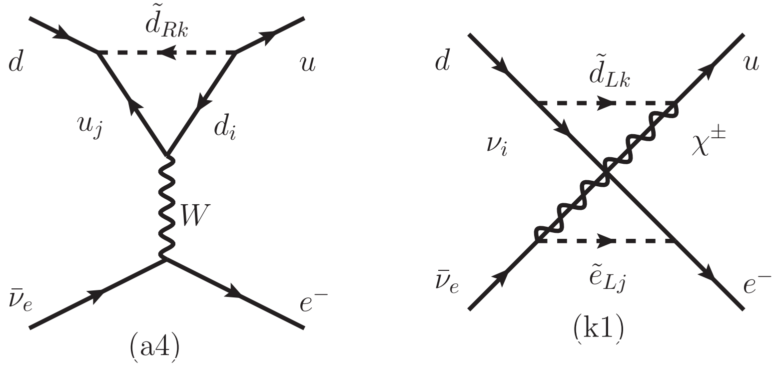
| Coupling | Current upper bounds | Sources |
|---|---|---|
| $\lvert\lambda_{121}\rvert$ | $< 0.04$ [$m_{eR}$] | CC universality |
| $\lvert\lambda_{131}\rvert$ | $< 0.05$ [$m_{eR}$] | $\tau$ decay ratio |
| $\lvert\lambda'_{211}\rvert$ | $< 0.012$ [$m_{dR}$] | K -> $\pi\nu\nu$ decay |
| $\lvert\lambda'_{311}\rvert$ | $< 0.012$ [$m_{dR}$] | K -> $\pi\nu\nu$ decay |
| $\lvert\lambda''_{312}\rvert$ | $< 2.1 \times 10^{-3}$ | $n\bar{n}$ oscillation |
| $\lvert\lambda''_{123}\rvert$ | ( $< 1.25$ ) | RG analysis |

M. Chemtob, Prog. Part. Nucl. Phys. **54**, 71 (2005).

# Loop level analysis



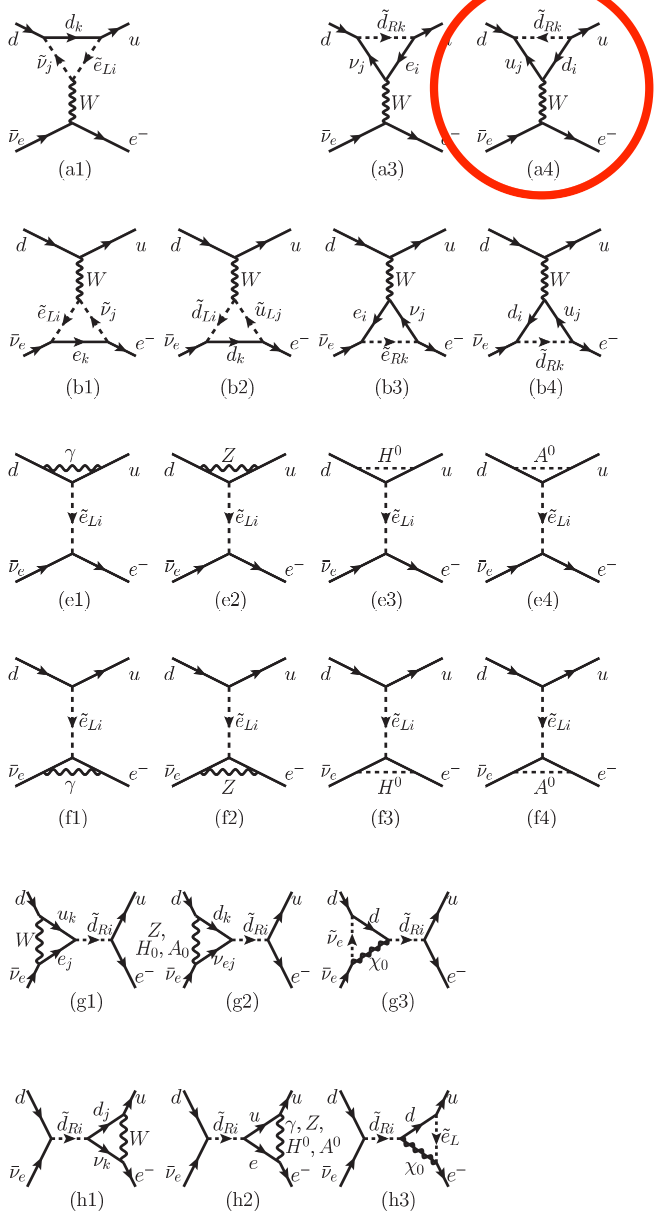

**Contributing diagrams:**

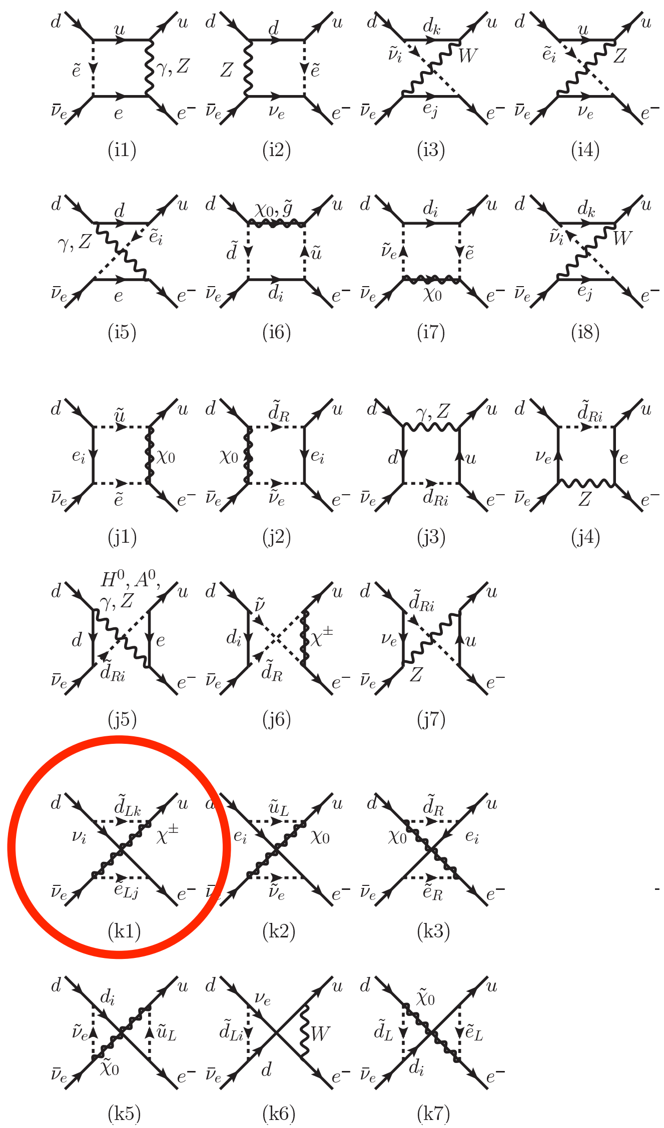



**Considerations:**

- **Only (*V*+*A*) x (*V*-*A*) contribute**
- **Diagrams with RPV couplings constrained by tree level analysis not considered**
- **Yukawa couplings with 1st & 2nd generations neglected**

# Contributing diagrams




**Charged Higgs contribution not enumerated**

# D correlation from effective interaction

## Effective interaction:

$$H_{V,A} = V_{ud}\frac{G_F}{\sqrt{2}}\,\bar{p}\gamma^\mu(g_V - g_A\gamma_5)n\,\bar{e}\gamma_\mu(1-\gamma_5)\nu_e$$

$$\boxed{+a_{LR}\,\bar{p}\gamma^\mu(g_V + g_A\gamma_5)n\,\bar{e}\gamma_\mu(1-\gamma_5)\nu_e}$$

Exotic CP-odd (*V+A*)x(*V-A*) interaction

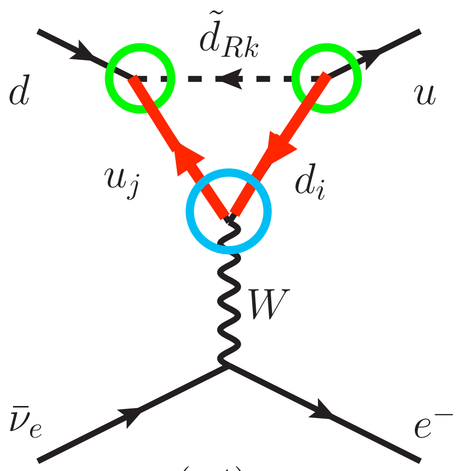
**Nucleon matrix element:**

$$\begin{cases} \langle p|\bar{u}\gamma^\mu d|n\rangle = g_V\,\bar{p}\gamma^\mu n & g_V = 1 \quad \text{(CVC)} \\ \langle p|\bar{u}\gamma^\mu\gamma_5 d|n\rangle = g_A\bar{p}\gamma^\mu\gamma_5 n & g_A = 1.27 \quad \text{(exp. data)} \end{cases}$$

## *D* correlation:

$$D = \frac{4g_V g_A}{g_V^2 + 3g_A^2}\,\frac{Im\,a_{LR}}{V_{ud}G_F/\sqrt{2}}$$

# Result & Analysis




(a4)

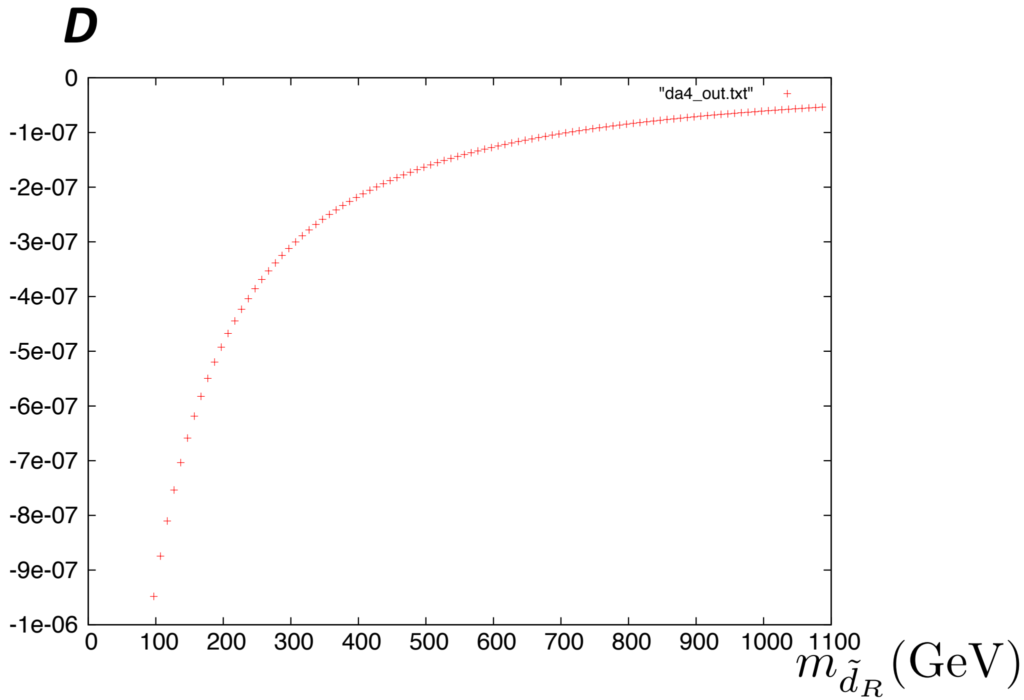
**B violating!**

**Anti-quarks!**

***V+A* current!**

**Contribute to *D* correlation!**

$$a_{LR} = -2\lambda''^{*}_{312}\lambda''_{123}\frac{G_F}{\sqrt{2}}\frac{m_t m_b}{(4\pi)^2} loop(m_b, m_t, m_{\tilde{d}_{Rk}})$$

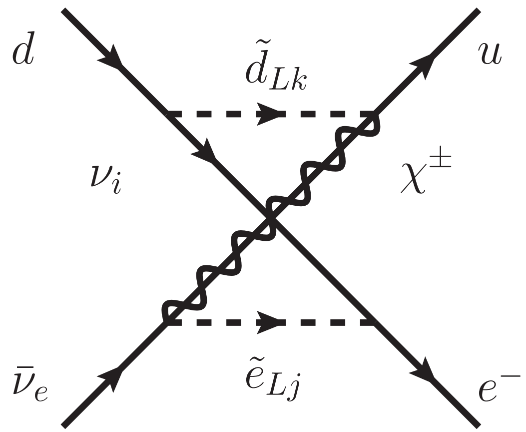



**For $m_{SUSY}$ = 100GeV, $|\lambda''_{312}|$ = $2.1\times10^{-3}$,**

***D* = O($10^{-6}$)**

**⇒ Limit to Im( $\lambda''^{*}_{312}\,\lambda''_{123}$ )**

## Result & Analysis




(k1)

**Box diagram**

↓

**Fierz transformation**

↓

**(*V+A*)x(*V-A*)** ➡ ***D* correlation!**

$$a_{LR} = \sum_{i,I} \lambda'^*_{i11}\lambda_{1i1}V_{ud}\frac{G_F}{\sqrt{2}}|Z_-^{1I}|^2\frac{m_W^2}{(4\pi)^2}loop(m_{\tilde{d}_L}, m_{\chi_I}, m_{\tilde{e}})$$

$$< \sum_{i} \lambda'^*_{i11}\lambda_{1i1}V_{ud}\frac{G_F}{\sqrt{2}}\frac{m_W^2}{(4\pi)^2}\frac{1}{2\min(\tilde{d}_L, m_{\chi_I}, m_{\tilde{e}})}$$

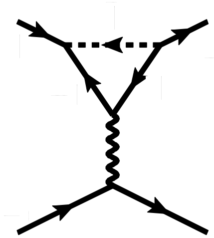
**For $m_{SUSY}$ = 100GeV (degenerate), $\lambda'^*_{i11}\,\lambda_{1i1} = 4.8\times10^{-4}$,**

➡ ***D* = O($10^{-7}$)**

**⇒ Limit to Im ($\lambda'^*_{211}\,\lambda_{121}$) , Im ($\lambda'^*_{311}\,\lambda_{131}$)**

## Summary & Future prospects

- We have investigated the *D* correlation of the neutron beta decay at one-loop level within RPVMSSM
- RPVMSSM can contribute up to $D$ = O($10^{-6}$) via baryon number violating interaction



- With further progress in experiment, possibility to obtain information on RPVMSSM from neutron beta decay

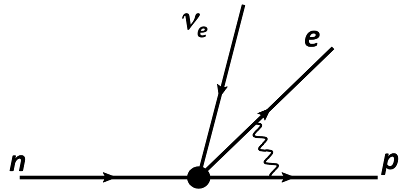
### Future prospects:

- One-loop analysis for other weak processes (EDMs, other particle decays, etc)

# Backup slides: final state interaction

**Final state interaction:**

- **Electromagnetic interaction between final state particles**
- **Contributes to the naïve T-odd observable (on-shell)**




**NLO:**

$$D_{\mathrm{FSI}} = O(10^{-5})$$

C. G. Callan, Jr., S. B. Treiman, Phys. Rev. **162**, 1494 (1967).

**NNLO: (Heavy baryon EFT)**

$$D_{\mathrm{FSI}} = (0.228(p_e^{max}/p_e)+1.083(p_e/p_e^{max})\ )\ \mathrm{x}\ 10^{-5}$$

⇒ **Accurate to 1%**

⇒ **Sensitivity of CP violating contribution to $O(10^{-7})$**

S. Ando, J. McGovern, T. Sato, Phys. Lett. B**677**, 109 (2009).

# Backup slides: loop integral

$$\begin{aligned} loop(m_1, m_2, m_3) &= \frac{1}{m_1^2 - m_2^2}\left[\frac{m_1^2}{m_3^2 - m_1^2}\log\frac{m_3^2}{m_1^2} - \frac{m_2^2}{m_3^2 - m_2^2}\log\frac{m_3^2}{m_2^2}\right] \\ &< \frac{1}{2\min(m_1, m_2, m_3)} \end{aligned}$$

## Limit from atomic EDM

$$Im \sum_{i=2,3} \lambda_{1i1}\lambda'^{*}_{i11} < 6\times10^{-6}[m_{\tilde{e}_L}]^2 \cdot \left(1 + \frac{2\pi}{\alpha}\frac{m^2_{\tilde{e}jL}}{m^2_{\tilde{\nu}jL}}\frac{\cos\theta_e \sin\phi_e}{\cos\theta_\nu \sin\phi_B}\right)$$

→ **loop level analysis**

**(Herczeg, J. Res. Natl. Ins. Sta. Tech., 110, 2005)**

# Backup slides

**Sakharov's conditions:**

- **C & CP violations**
- **Baryon/lepton number violation**
- **Departure from equilibrium**