The mu-e conversion in trilinear R-parity Violating SUSY

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In collaboration with
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Outline

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  - **Motivation**
  - **Experimental status**
- **$\mu - e$ conv. in RPV-SUSY**
  - **Introduction to RPV-SUSY**
  - **Contributions to cLFV**
  - **Numerical results**
- **Conclusions and Prospects**

@higgstan

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how about charged leptons?

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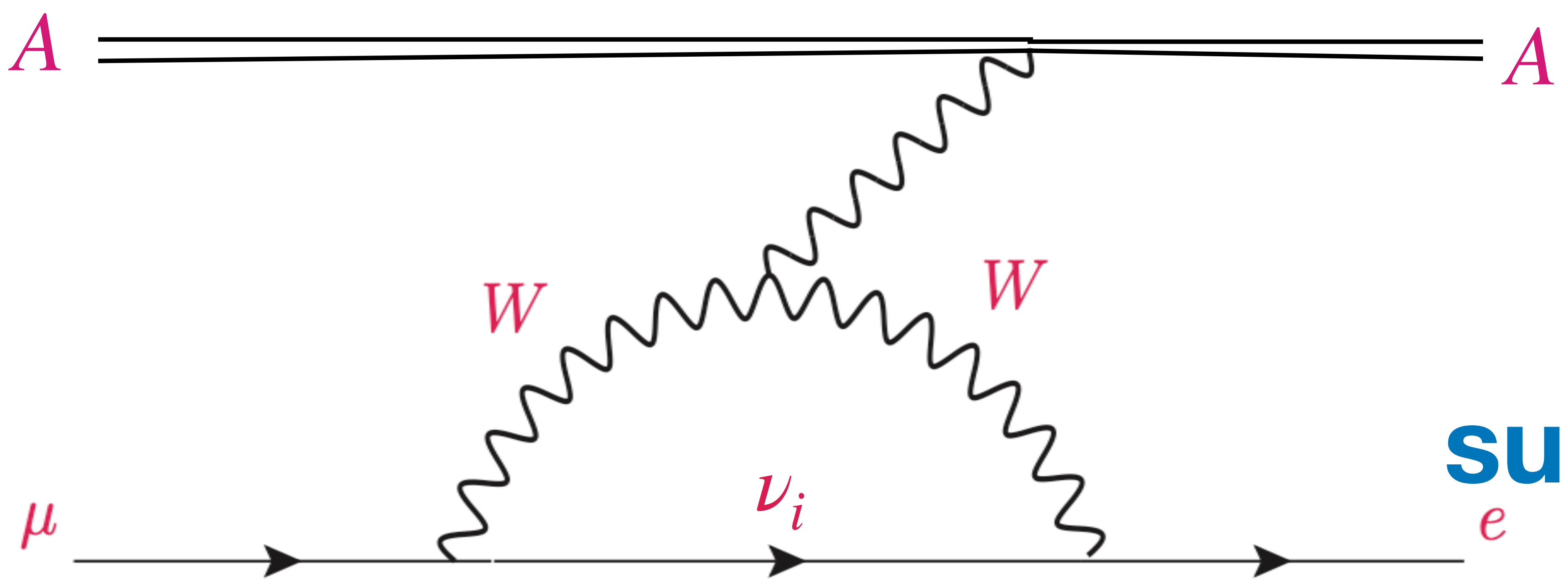

Highly suppressed

$$R(\mu N \to eN) \propto \left| \sum_l (V_{\mathrm{PMNS}})^*_{\mu i} (V_{\mathrm{PMNS}})_{ei} \boxed{\frac{m^2_{\nu_i}}{M^2_W}} \right|^2$$

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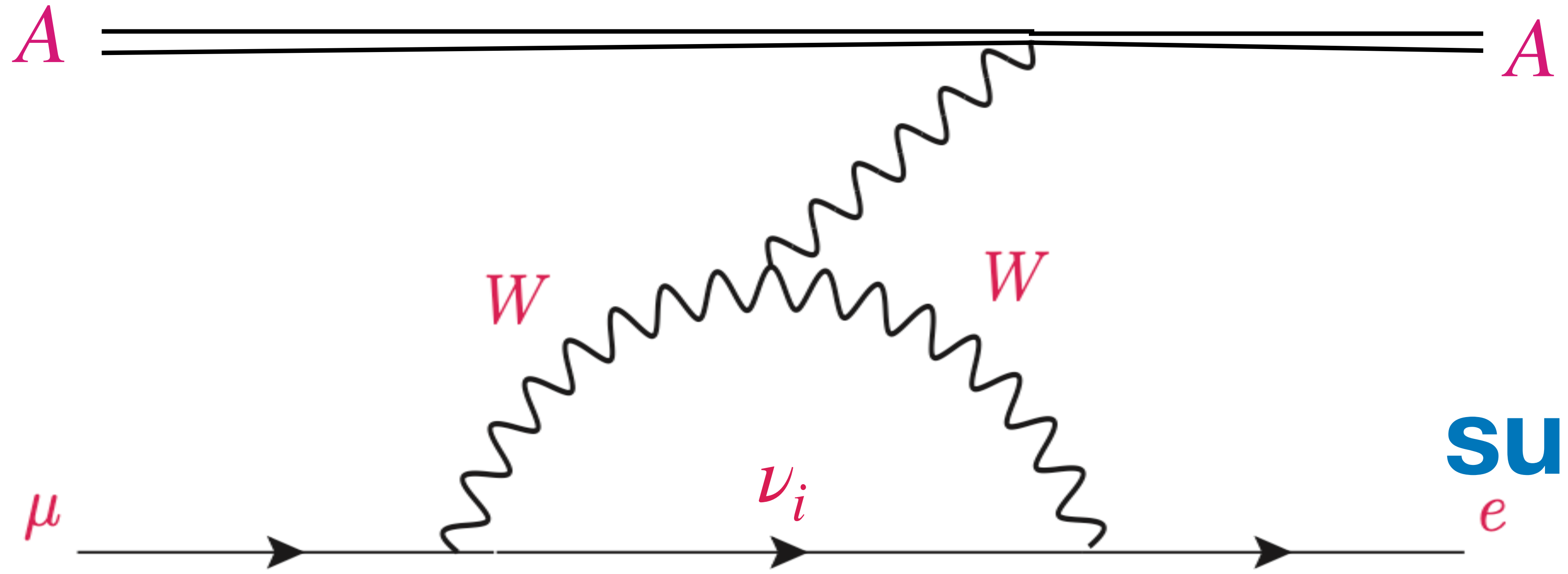

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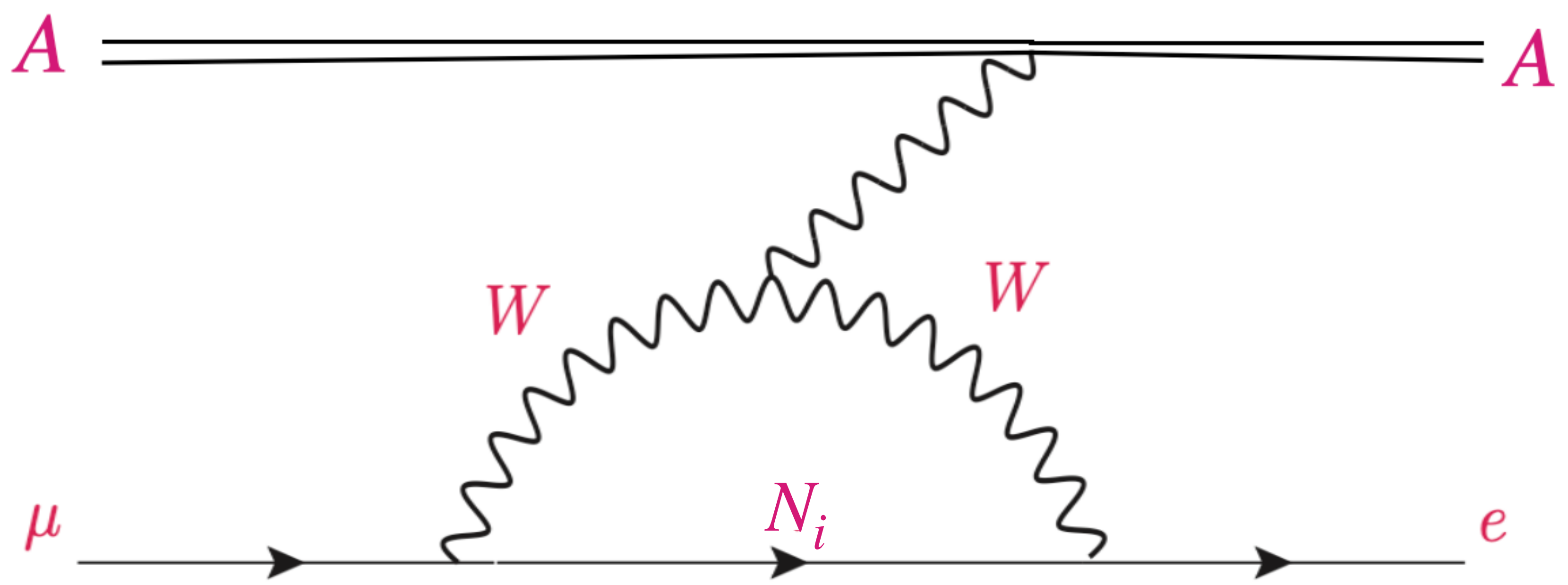
- **New Physics contribution:**

Simple example with heavy neutrino



$\sim O(0.1)$

$$R(\mu N \to eN) \propto \left(\sum_i K^*_{\mu i} K_{ei} \boxed{G(\frac{m^2_{N_k}}{m^2_W})} \right)^2$$

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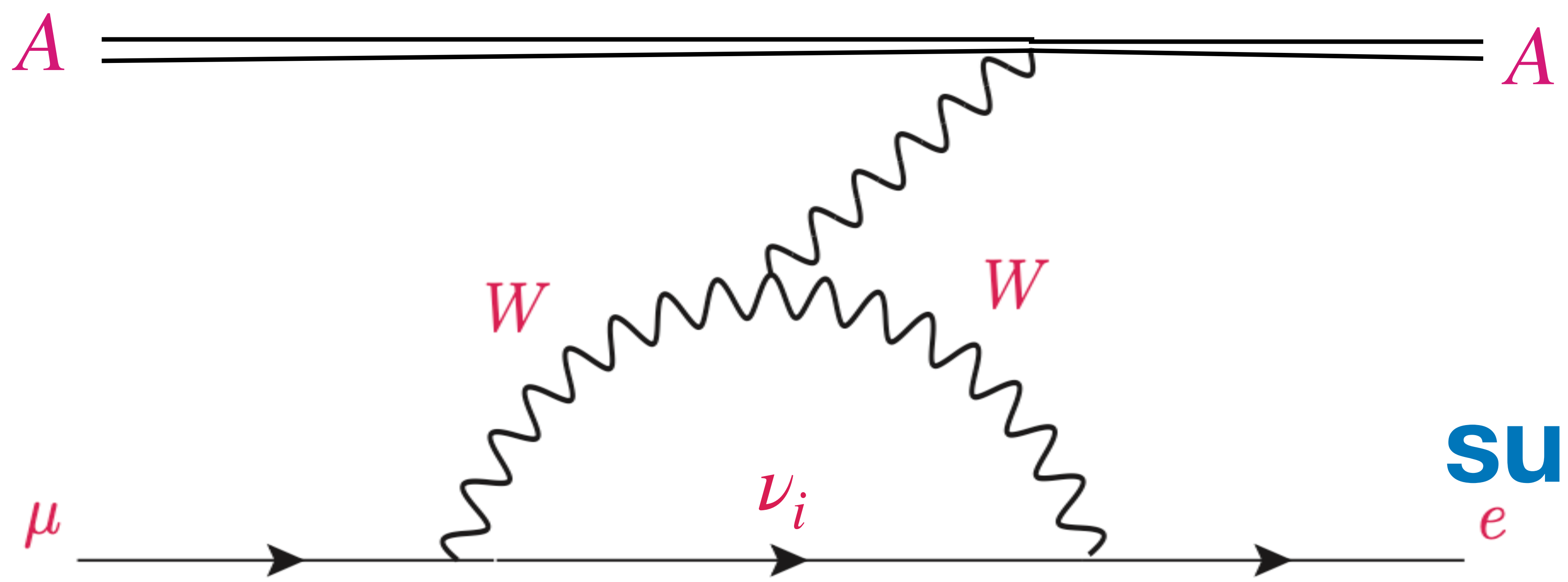

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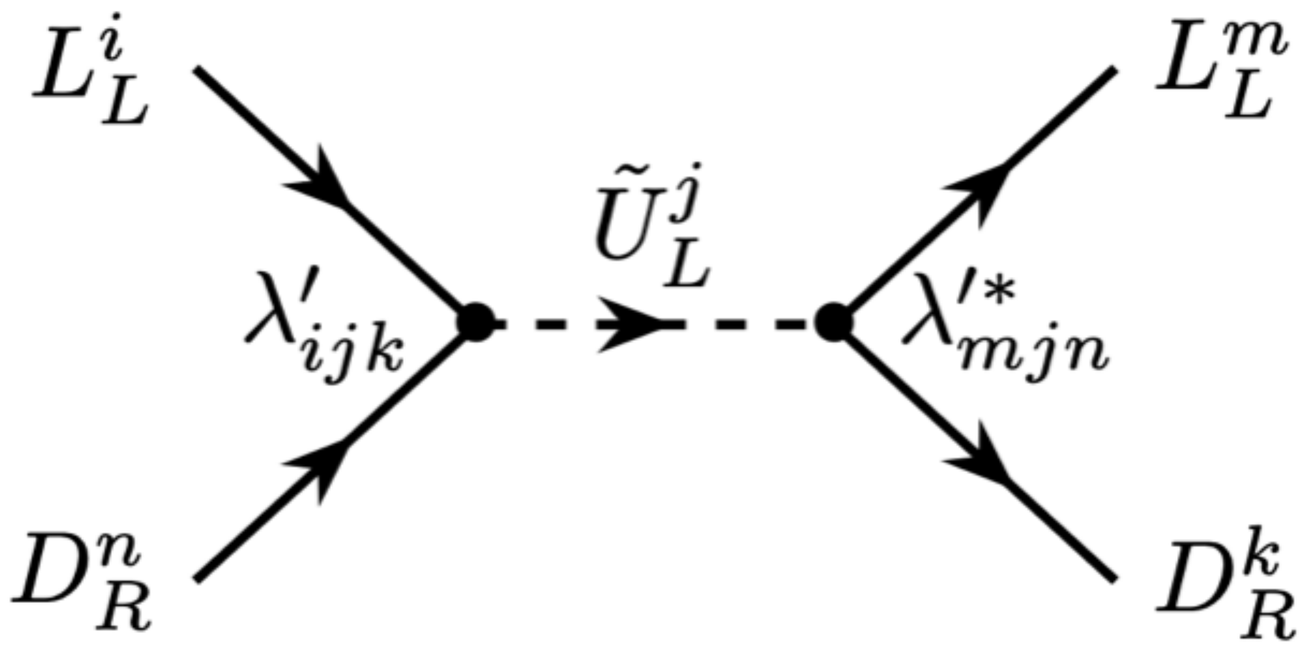

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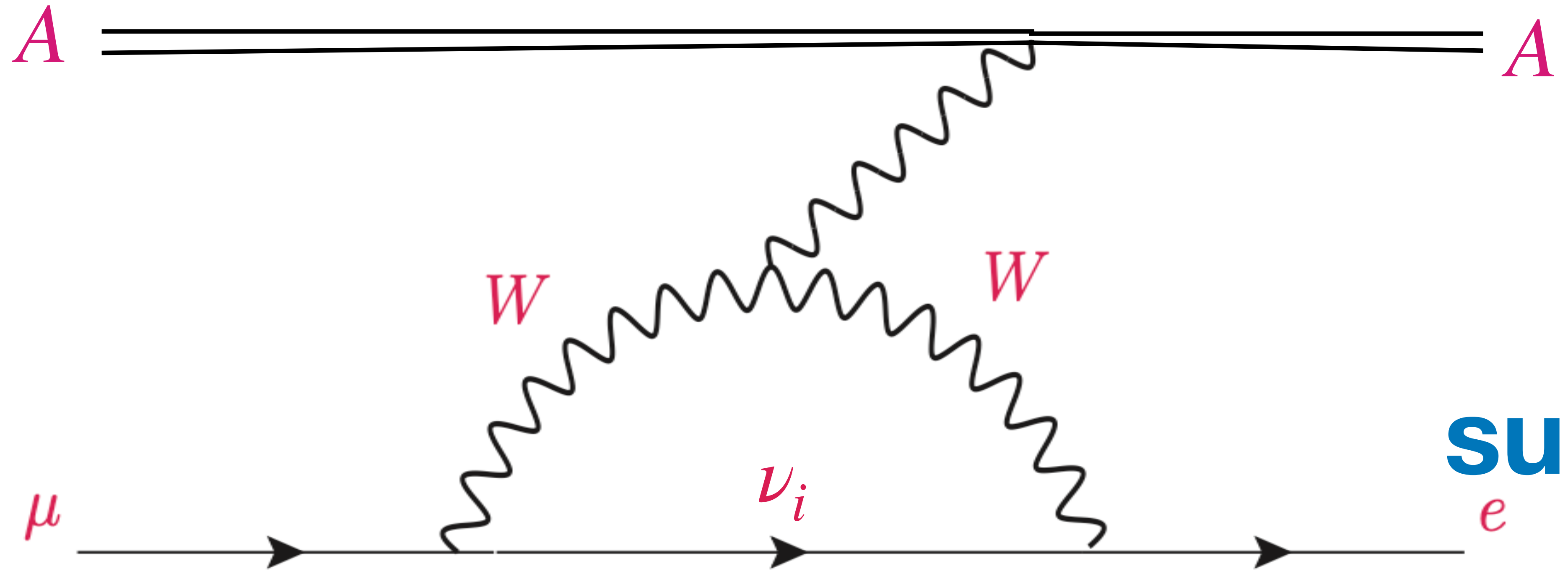

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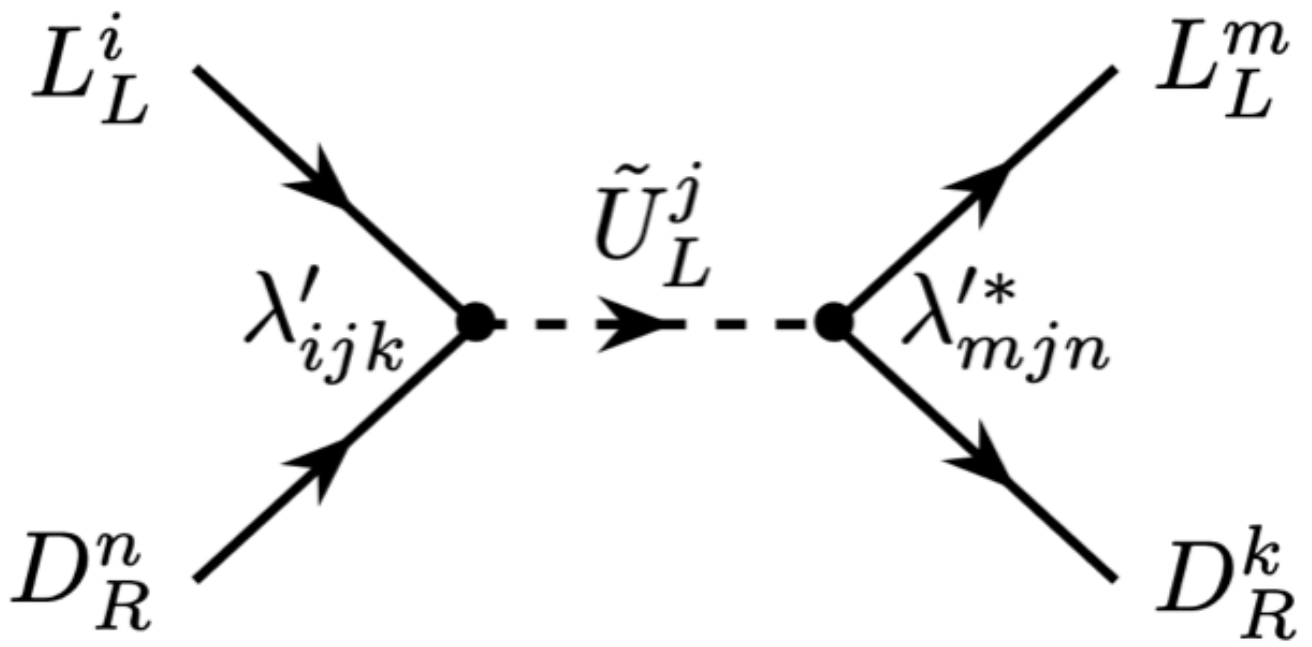

Tree-level contributions

Any extension of SM with NP mass at TeV scale can generate large cLFV

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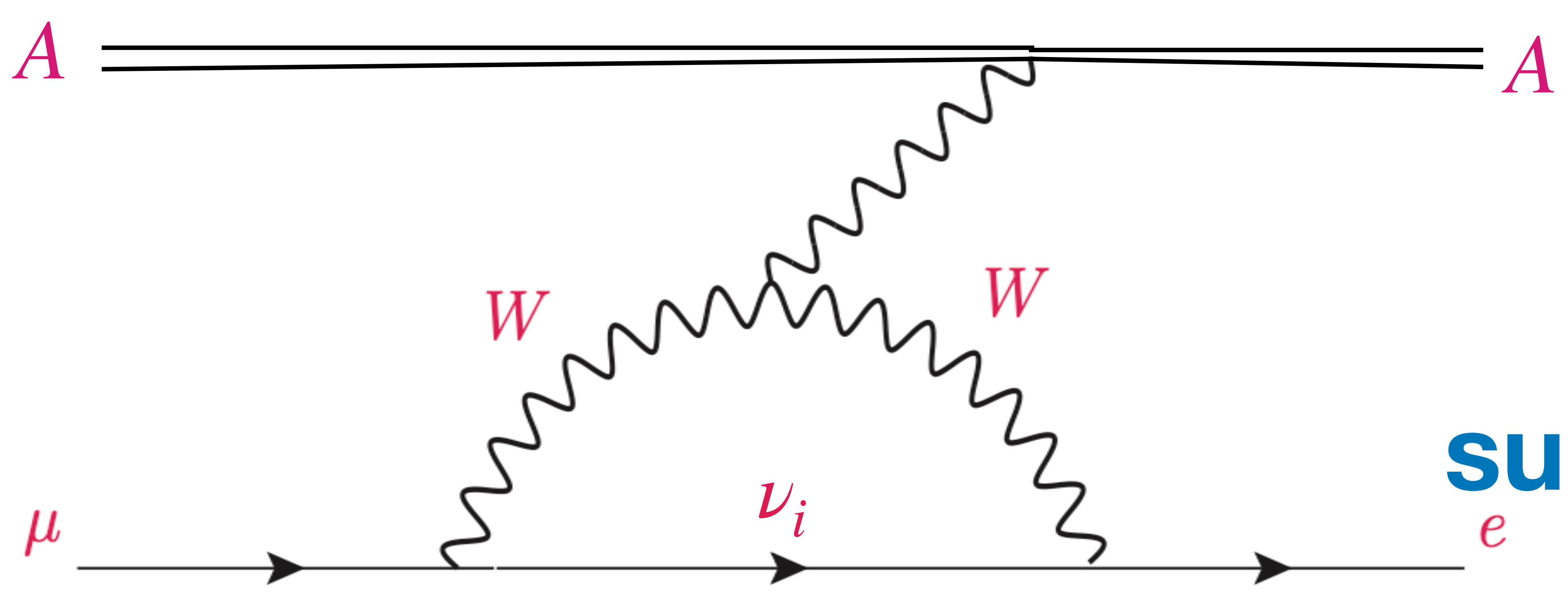

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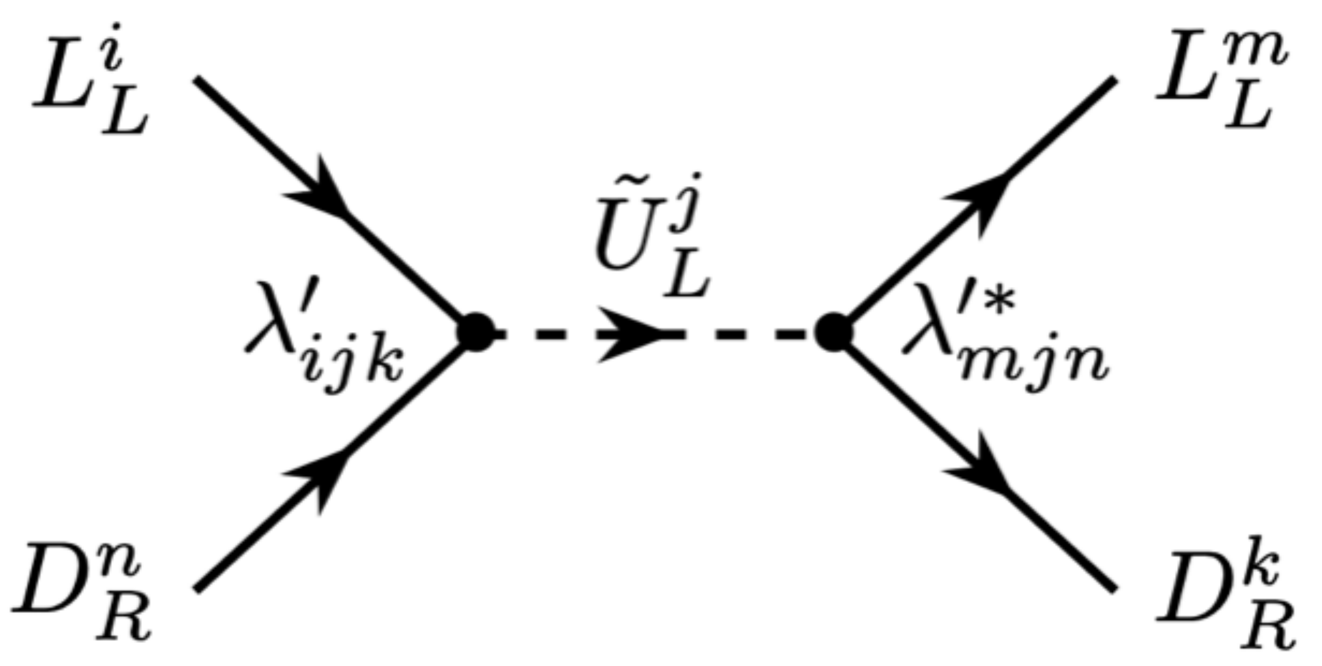

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Any extension of SM with NP mass at TeV scale can generate large cLFV

Observation of cLFV would indicate a clear signal of New physics

Introduction: Experiment Status

μLFV offers **better experimental reach**, cleaner observables, and **stronger sensitivity** to new physics than τLFV.

- **New progress on $\mu \to e\gamma$ in 2025**
- **Best limits from Exp. Searches on $\mu N \to eN$ and $\mu \to 3e$ are given by 20~40 years ago**
- **Near future plans for $\mu N \to eN$ and $\mu \to 3e$**

Decay modes	Limits on Br.		Exp.
$\mu + \mathrm{Ti} \to e + \mathrm{Ti}$	$< 6.1 \times 10^{-13}$	1998	SINDRUM II
$\mu + \mathrm{Au} \to e + \mathrm{Au}$	$< 7 \times 10^{-13}$	2006	SINDRUM II
$\mu^+ \to e^+\gamma$	$< 1.5 \times 10^{-13}$	2025	MEG-II
$\mu^+ \to e^+e^+e^-$	$< 1.0 \times 10^{-12}$	1987	SINDRUM
$\mu + \mathrm{Al} \to e + \mathrm{Al}$	$\sim 3 \times 10^{-15}$	2027	COMET (Phase I)
$\mu + \mathrm{Al} \to e + \mathrm{Al}$	$\sim 3 \times 10^{-17}$		COMET (Phase II)
$\mu + \mathrm{Al} \to e + \mathrm{Al}$	$\sim 6.2 \times 10^{-16}$	2027	Mu2e (Run I)
$\mu + \mathrm{Al} \to e + \mathrm{Al}$	$\sim 3 \times 10^{-17}$	2030	Mu2e (Run II)
$\mu^+ \to e^+\gamma$	$\sim 6.0 \times 10^{-14}$	2026	MEG-II
$\mu^+ \to e^+e^+e^-$	$\sim 2.0 \times 10^{-15}$	2026	Mu3e (Phase I)
$\mu^+ \to e^+e^+e^-$	$\sim 10^{-16}$	2030	Mu3e (Phase II)

Detail plan, Weihao's talk

RPV-SUSY: Model

Name		spin-0	spin-1/2	$SU(3)_C \times SU(2)_L \times U(1)_Y$
sqaurk, quark	Q	$(\tilde{U}_L, \tilde{D}_L)$	(U_L, D_L)	$(3, 2, 1/6)$
	U	$\tilde{U}_R$	U_R	$(3, 1, 2/3)$
	D	$\tilde{D}_R$	D_R	$(3, 1, -1/3)$
slepton, lepton	L	$(\tilde{\nu}, \tilde{E}_L)$	(ν, E_L)	$(1, 2, -1/2)$
	E	$\tilde{E}_R$	E_R	$(1, 1, -1)$
Higgs, higgsino	H_u	(H_u^+, H_u^0)	$(\tilde{H}_u^+, \tilde{H}_u^0)$	$(1, 2, 1/2)$
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gluon, gluino	g	$\tilde{g}$	$(8, 1, 0)$
W bosons, winos	$W^\pm, W^0$	$\tilde{W}^\pm, \tilde{W}^0$	$(1, 3, 0)$
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Each particle has a SUSY partner

Same QNs but different spin

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

A discrete symmetry, introduced to distinguish SM particles from their superpartners.

$$R_p = (-1)^R = \begin{cases} +1 & \text{for ordinary particles,} \\ -1 & \text{for their superpartners.} \end{cases}$$

If imposed:

- forbids B/L violating superpotential terms
- leads to the RPC-MSSM phenomenology

$$W_{\text{MSSM}} = y_u \bar{u} Q H_u - y_d \bar{d} Q H_d - y_e \bar{e} L H_d + \mu H_u H_d$$

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- **SUSY is constrained, but not excluded:**

  strongest bounds apply to minimal RPC scenarios.

- **RPV changes collider signatures:**

  reduced missing-energy signals can weaken standard SUSY limits.

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$$W \supset \frac{1}{2}\lambda_{ijk}L_iL_jE^c_k + \lambda'_{ijk}L_iQ_jD^c_k + \frac{1}{2}\lambda''_{ijk}U^c_iD^c_jD^c_k$$

contribute to $\mu N \to eN$ and $\mu \to 3e$ at tree level

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$$\mathcal{L}_{\lambda'} = -\lambda'_{ijk}\Big(\overline{\nu^c_{Li}}D_{Lj}\tilde{D}^*_{Rk} + \overline{\nu^c_{Li}}\tilde{D}_{Lj}D^c_{Rk} + \tilde{\nu}_{Li}\overline{D^c_{Lj}}D^c_{Rk} - \overline{E^c_{Li}}U_{Lj}\tilde{D}^*_{Rk} - \overline{E^c_{Li}}\tilde{U}_{Lj}D^c_{Rk} - \tilde{E}_{Li}\overline{U^c_{Lj}}D^c_{Rk}\Big) + \text{h.c.}$$

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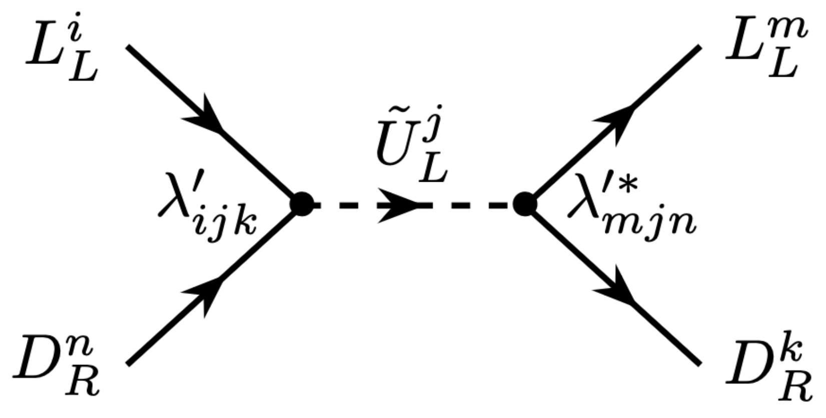
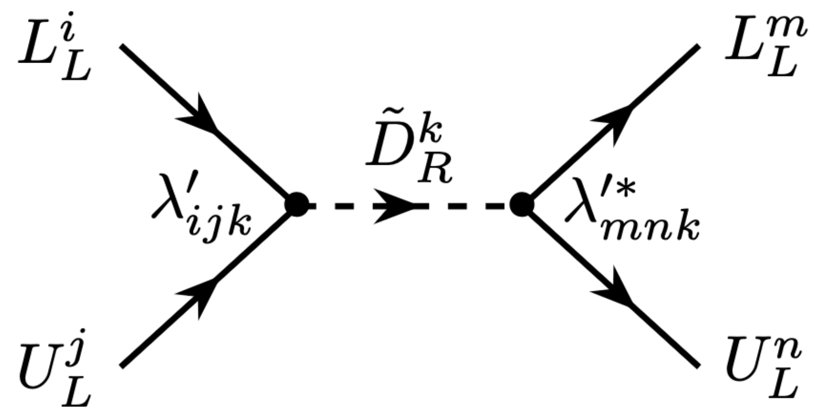


$$-\frac{\lambda'_{ijk}\lambda'^*_{mjn}}{2m^2_{\tilde{U}_{Rj}}}[\overline{D_{Rk}}\gamma_\mu D_{Rn}][\overline{E_{Lm}}\gamma^\mu E_{Li}]$$

$$+\frac{\lambda'_{ijk}\lambda'^*_{mnk}}{2m^2_{\tilde{D}_{Rk}}}[\overline{U_{Ln}}\gamma_\mu U_{Lj}][\overline{E_{Lm}}\gamma^\mu E_{Li}]$$



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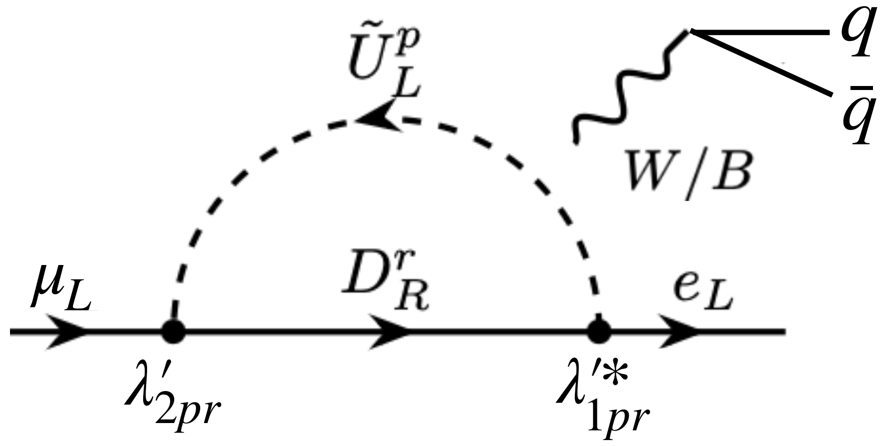

$$\supset \frac{g_1^2}{192\pi^2 m^2_{\tilde{u}}}\lambda'_{2pr}\lambda'^*_{1pr} \times \text{LF}$$

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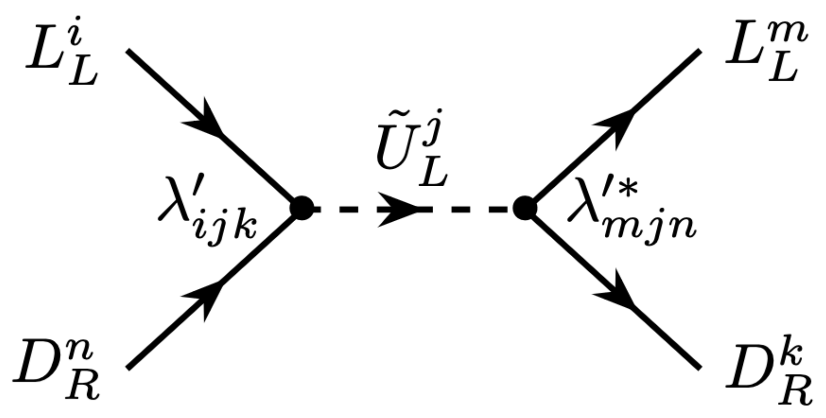

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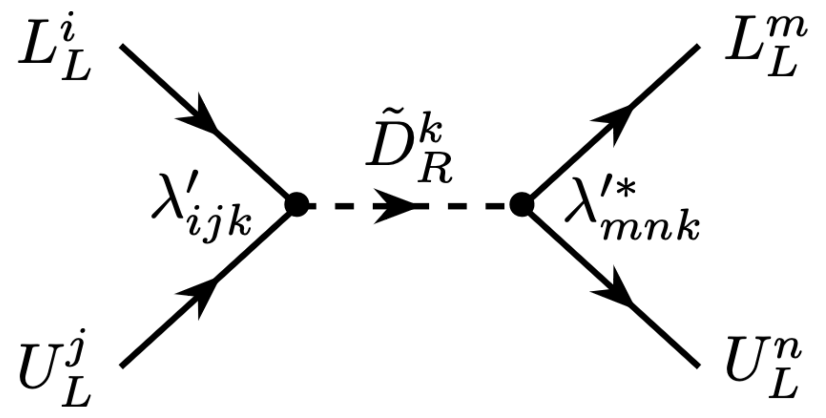

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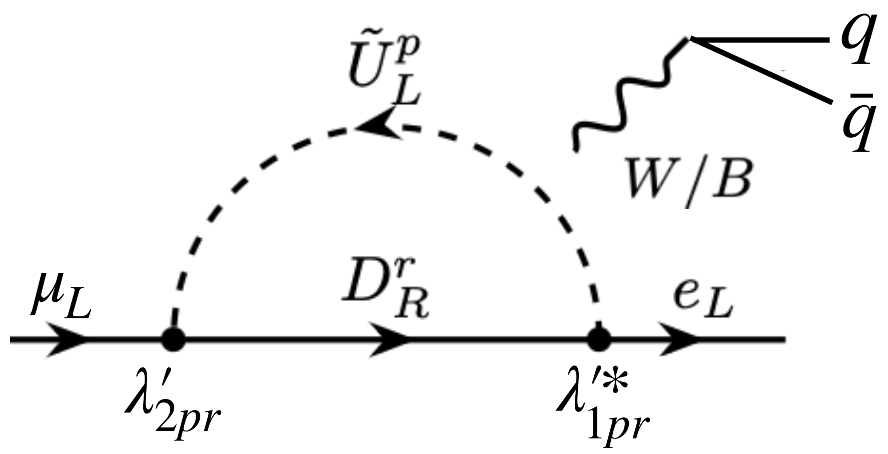

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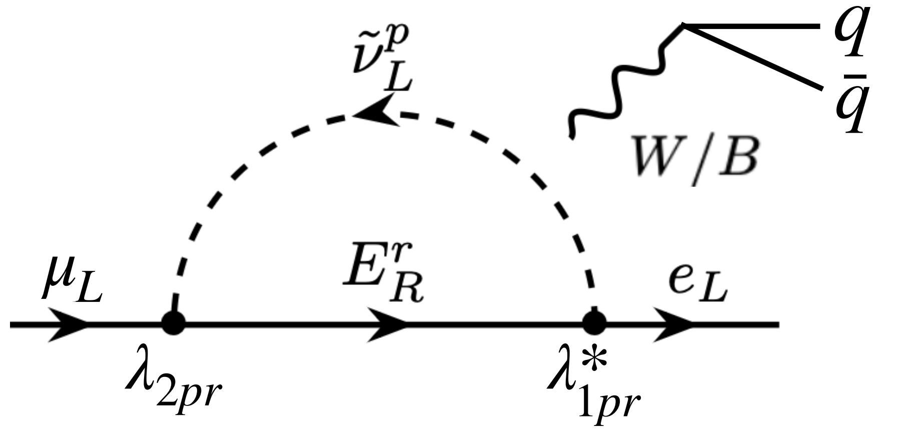

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One can get the complete tree and one-loop matching conditions from the model to SMEFT

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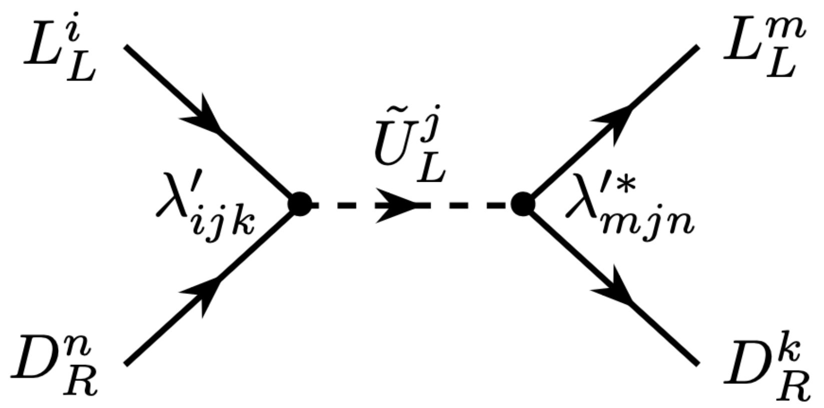

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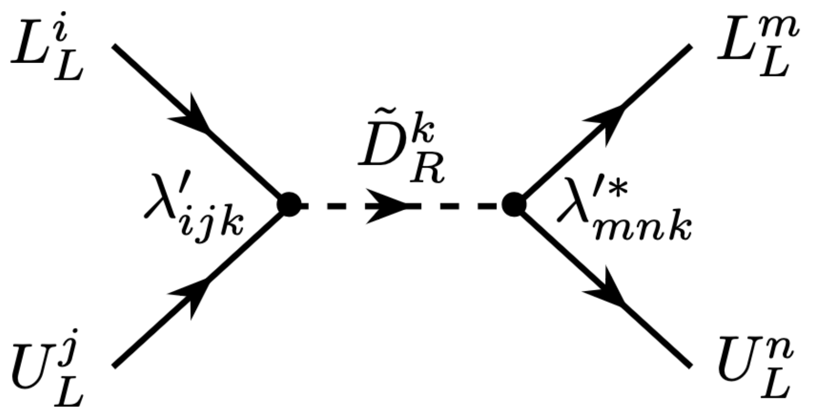

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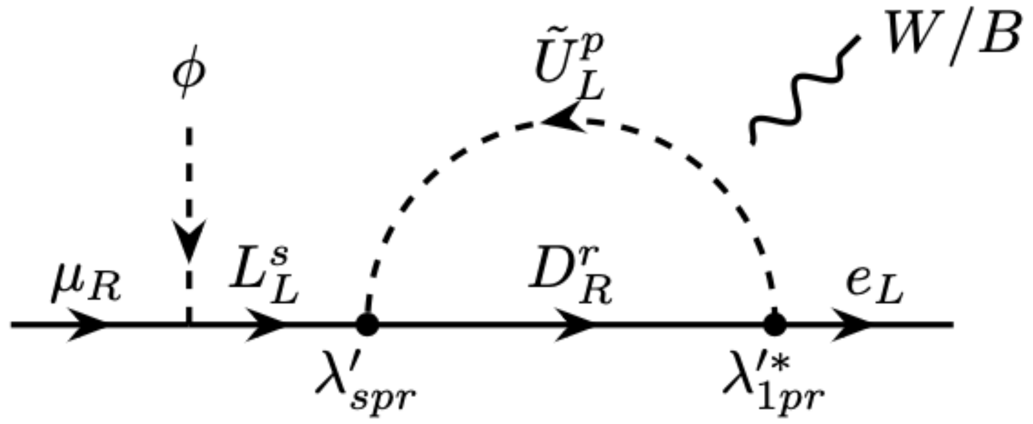
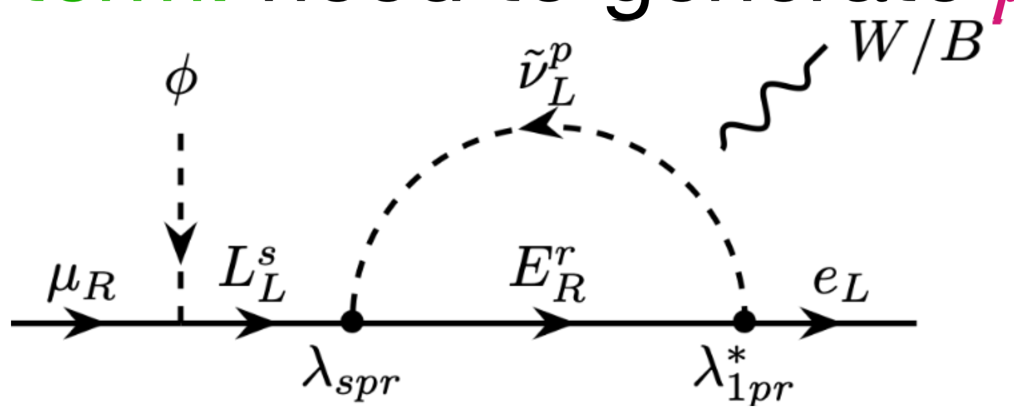


$$\mathcal{C}^{12}_{eW} = \frac{-3g_2Y_e^{s2}}{128\pi^2m^2_{\tilde{q}}}\lambda'_{spr}\lambda'^*_{1pr} \times \text{LF}$$

λ term: need to generate $\mu N \to eN$ at loop level

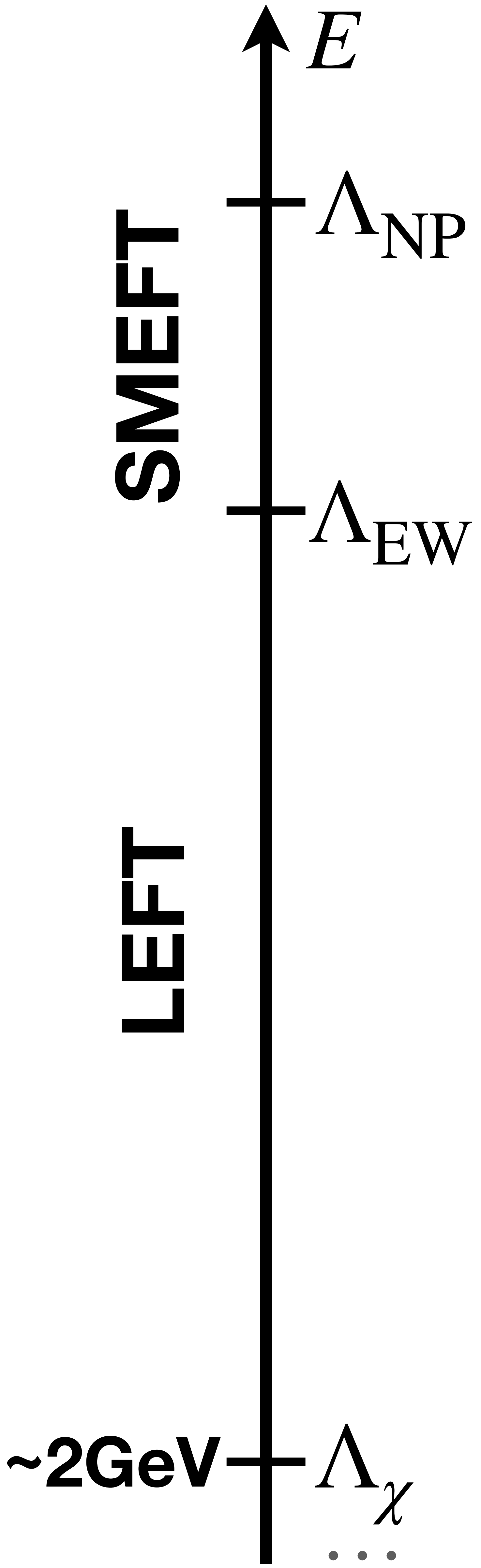


$$\mathcal{C}^{12}_{eW} = \frac{g_2Y_e^{s2}}{128\pi^2m^2_{\tilde{\nu}}}\lambda_{spr}\lambda^*_{1pr} \times \text{LF}$$

……

One can get the complete tree and one-loop matching conditions from the model to SMEFT

RPV-SUSY: EFT Framework



RPV-SUSY: EFT Framework

RPV-SUSY: EFT Framework

RPV-SUSY: EFT Framework

RPV-SUSY: EFT Framework

RPV-SUSY: EFT Framework

RPV-SUSY: Pheno.

For $\mu N \to eN$:

$$\begin{aligned}\Gamma_{\text{conv}} = \Big| & \left(\mathcal{C}^{S,RR}_{eu,1211} + \mathcal{C}^{S,RL}_{eu,1211}\right)\left(G^{p,u}_S S^{(p)} + G^{n,u}_S S^{(n)}\right) \\ & + \left(\mathcal{C}^{S,RR}_{ed,1211} + \mathcal{C}^{S,RL}_{ed,1211}\right)\left(G^{p,d}_S S^{(p)} + G^{n,d}_S S^{(n)}\right) \\ & + \left(\mathcal{C}^{S,RR}_{ed,1222} + \mathcal{C}^{S,RL}_{ed,1222}\right)\left(G^{p,s}_S S^{(p)} + G^{n,s}_S S^{(n)}\right) \\ & + \left(\mathcal{C}^{V,LL}_{eu,1211} + \mathcal{C}^{V,LR}_{eu,1211}\right)\left(G^{p,u}_V V^{(p)} + G^{n,u}_V V^{(n)}\right) \\ & + \left(\mathcal{C}^{V,LL}_{ed,1211} + \mathcal{C}^{V,LR}_{ed,1211}\right)\left(G^{p,d}_V V^{(p)} + G^{n,d}_V V^{(n)}\right) \\ & + \left(\mathcal{C}^{V,LL}_{ed,1222} + \mathcal{C}^{V,LR}_{ed,1222}\right)\left(G^{p,s}_V V^{(p)} + G^{n,s}_V V^{(n)}\right) \\ & + D\mathcal{C}^{*}_{e\gamma,12}/\left(2m_\mu\right)\Big|^2 + \ldots\end{aligned}$$

$D, S^{(p,n)}, V^{(p,n)}$: overlap integrals

Heeck, et.al, NPB, 2203.00702

Different values in Ti, Au, Al

The integral uncertainties: 2%~5% for Al, Ti

8%~10% for Au

For $\mu \to e\gamma$:

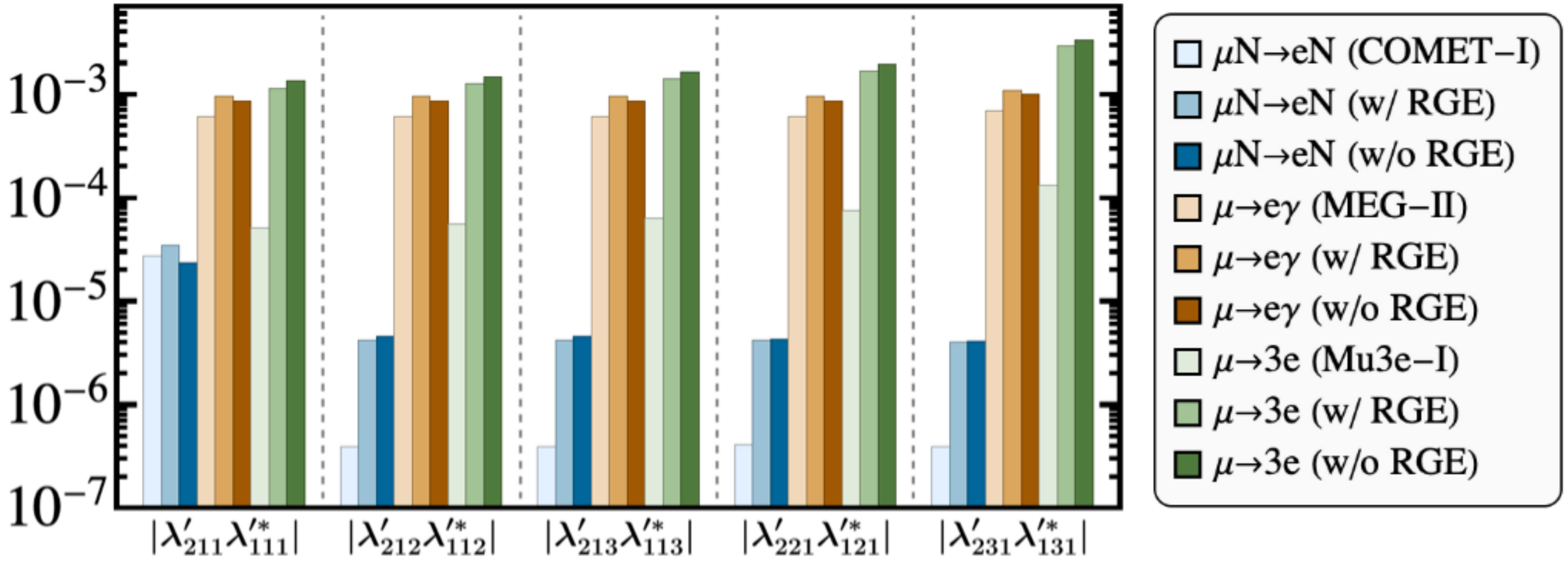
$$\text{Br}(\mu \to e\gamma) = \tau_\mu \times \frac{(m_\mu^2 - m_e^2)^3}{4\pi m_\mu^3}\left(|\mathcal{C}_{e\gamma,12}|^2 + |\mathcal{C}_{e\gamma,21}|^2\right)\,,$$

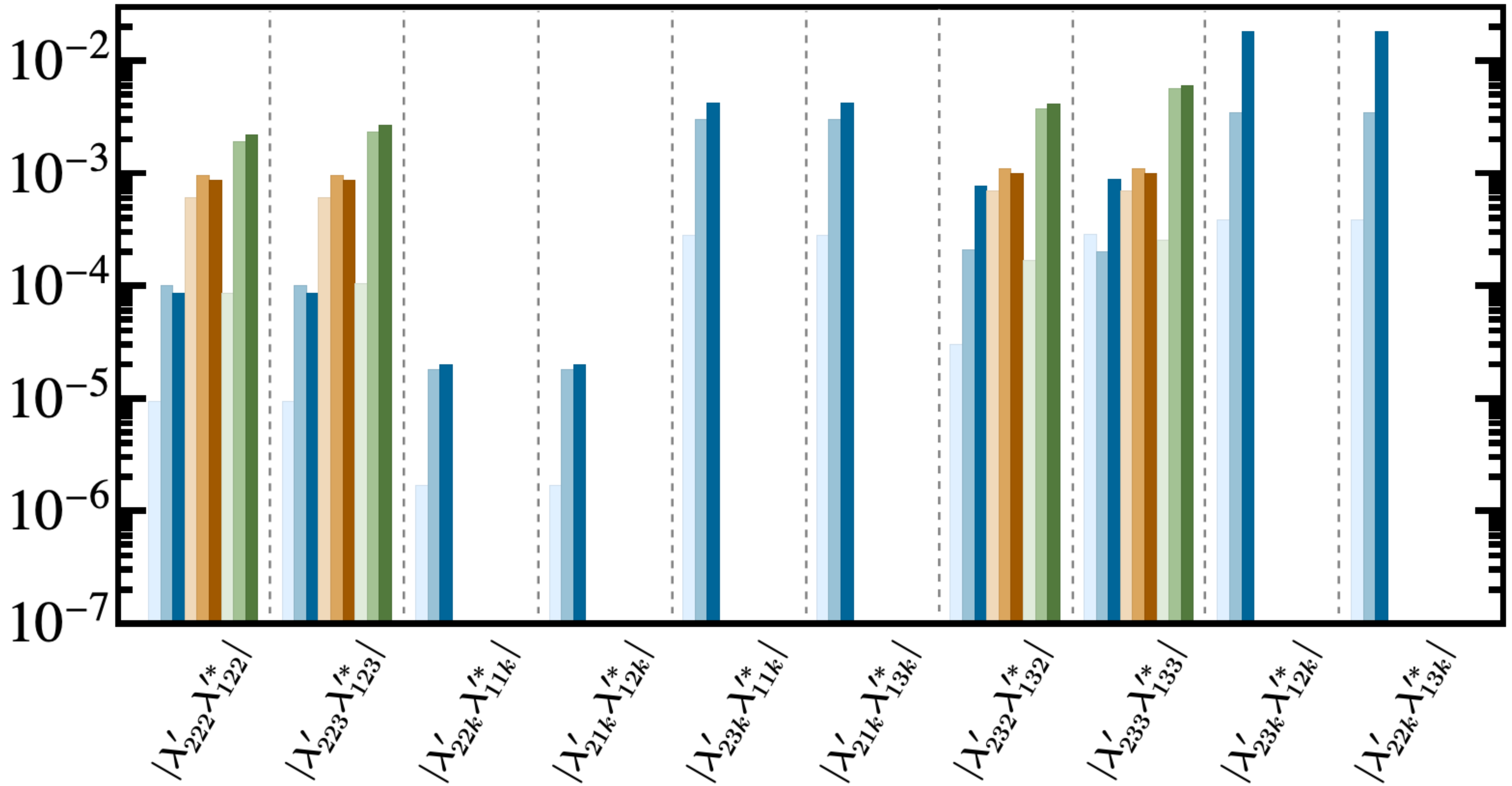
For $\mu \to eee$:

$$\begin{aligned}\text{Br}(\mu \to 3e) = & \frac{1}{64G_F^2}\left(\left|\mathcal{C}^{S,RR}_{ee,1121}\right|^2 + \left|\mathcal{C}^{S,RR}_{ee,1112}\right|^2\right) \\ & + \frac{\alpha_{\text{em}}}{\pi G_F^2 m_\mu^2}\left(\ln\frac{m_\mu^2}{m_e^2} - \frac{17}{4}\right)\left(|\mathcal{C}_{e\gamma,12}|^2 + |\mathcal{C}_{e\gamma,21}|^2\right) \\ & + \frac{1}{8G_F^2}\left(2\left|\mathcal{C}^{V,RR}_{ee,1112} + \frac{4e}{m_\mu}\mathcal{C}^{*}_{e\gamma,12}\right|^2 + 2\left|\mathcal{C}^{V,LL}_{ee,1112} + \frac{4e}{m_\mu}\mathcal{C}_{e\gamma,21}\right|^2\right. \\ & \left. + \left|\mathcal{C}^{V,LR}_{ee,1112} + \frac{4e}{m_\mu}\mathcal{C}^{*}_{e\gamma,12}\right|^2 + \left|\mathcal{C}^{V,LR}_{ee,1211} + \frac{4e}{m_\mu}\mathcal{C}_{e\gamma,21}\right|^2\right)\end{aligned}$$

Numerical Results

Keep one combination nonzero at a time





- For $\mu N \to eN$ in most of cases, tree level contributions dominate.
- For $\mu \to e\gamma$ and $\mu \to 3e$, only loop-level can contribute
- future $\mu N \to eN$ exp. can give the stronger limits.

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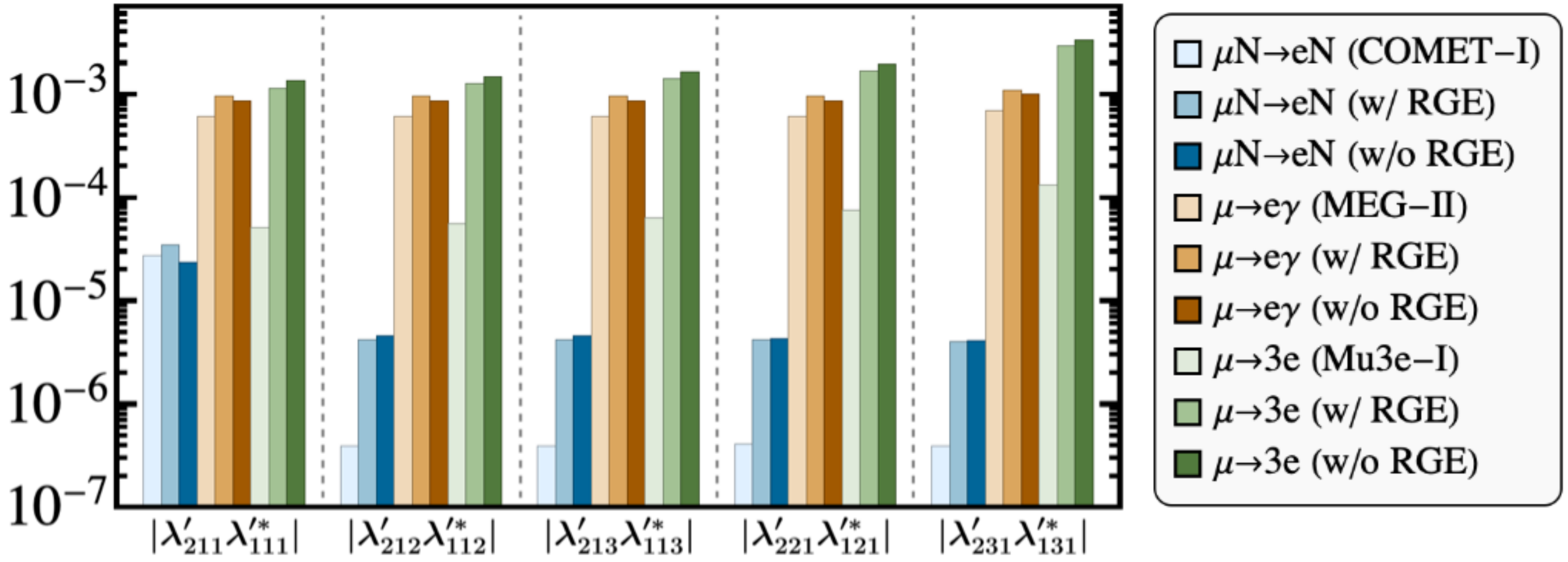

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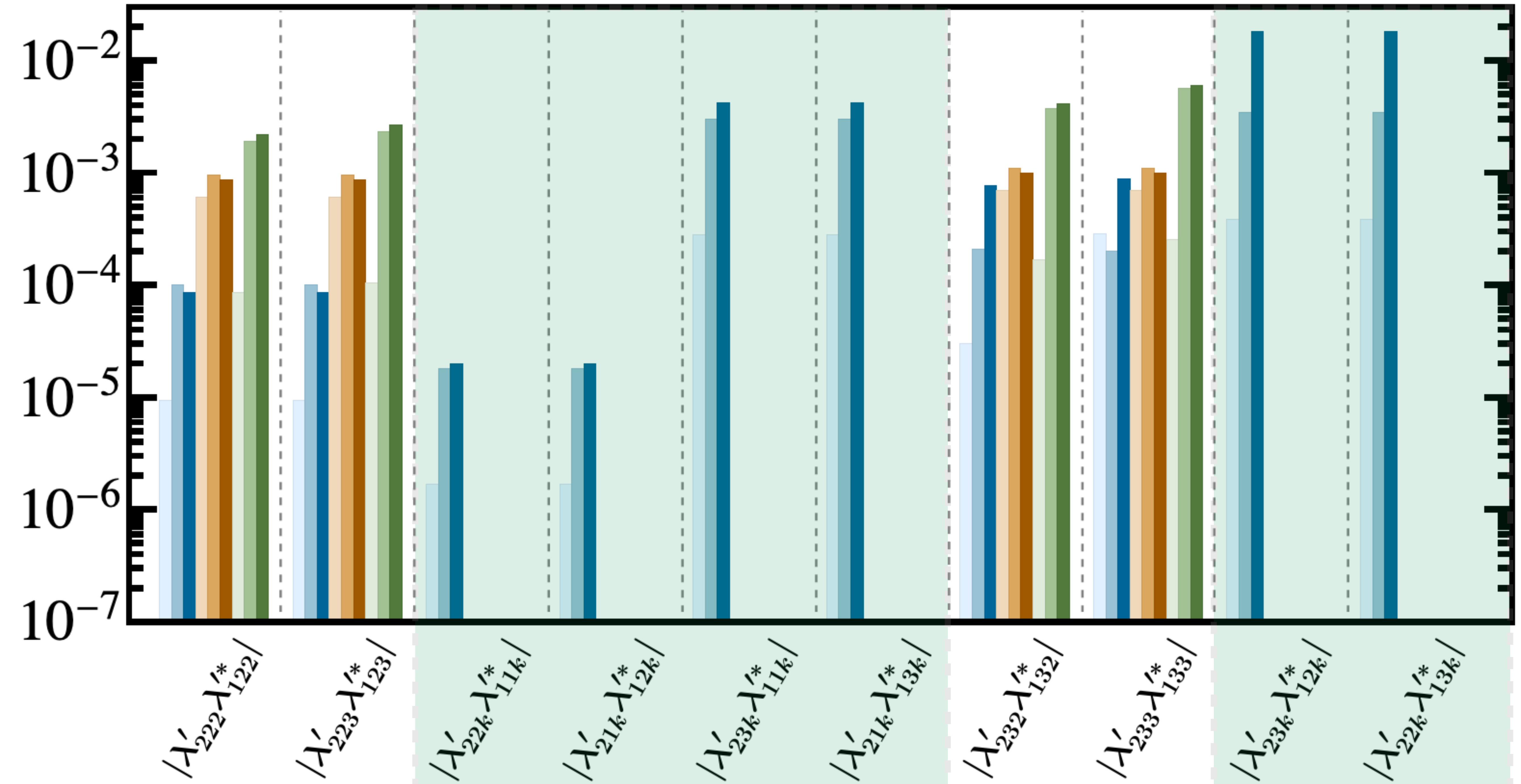
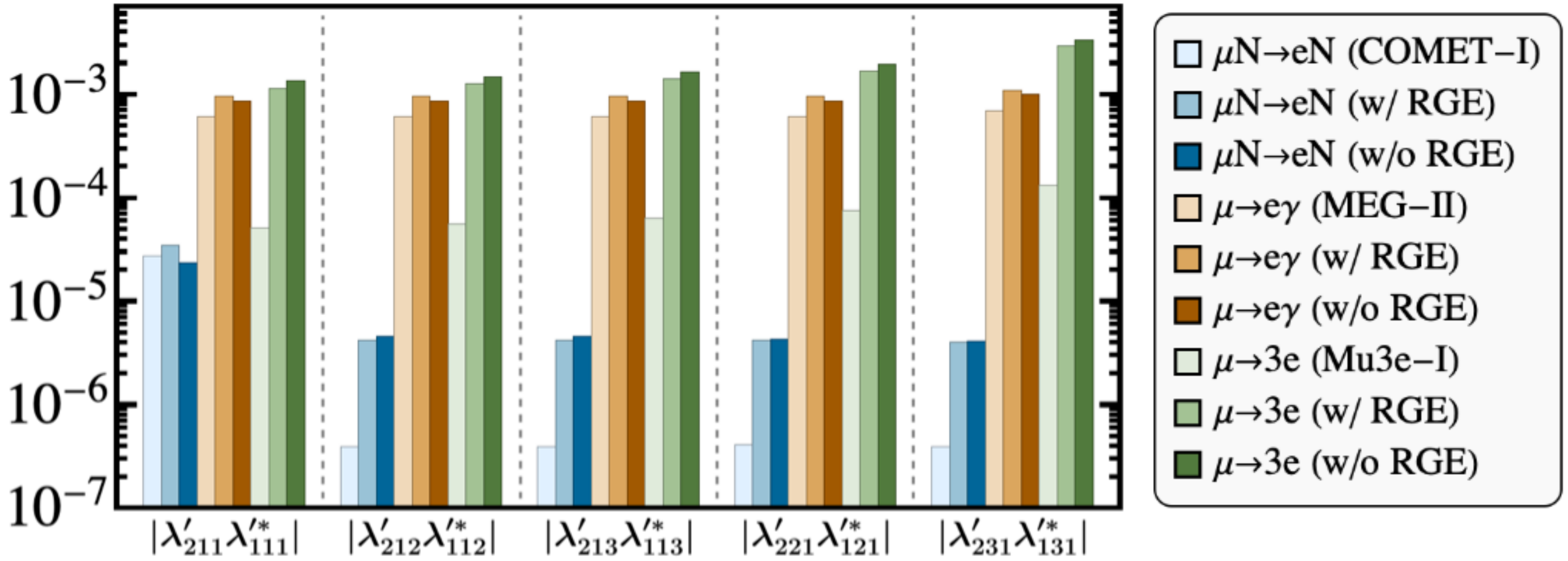


For $\mu \to e\gamma$, $\mu \to 3e$, contributions are **GIM suppressed**

Numerical Results

Keep one combination nonzero at a time



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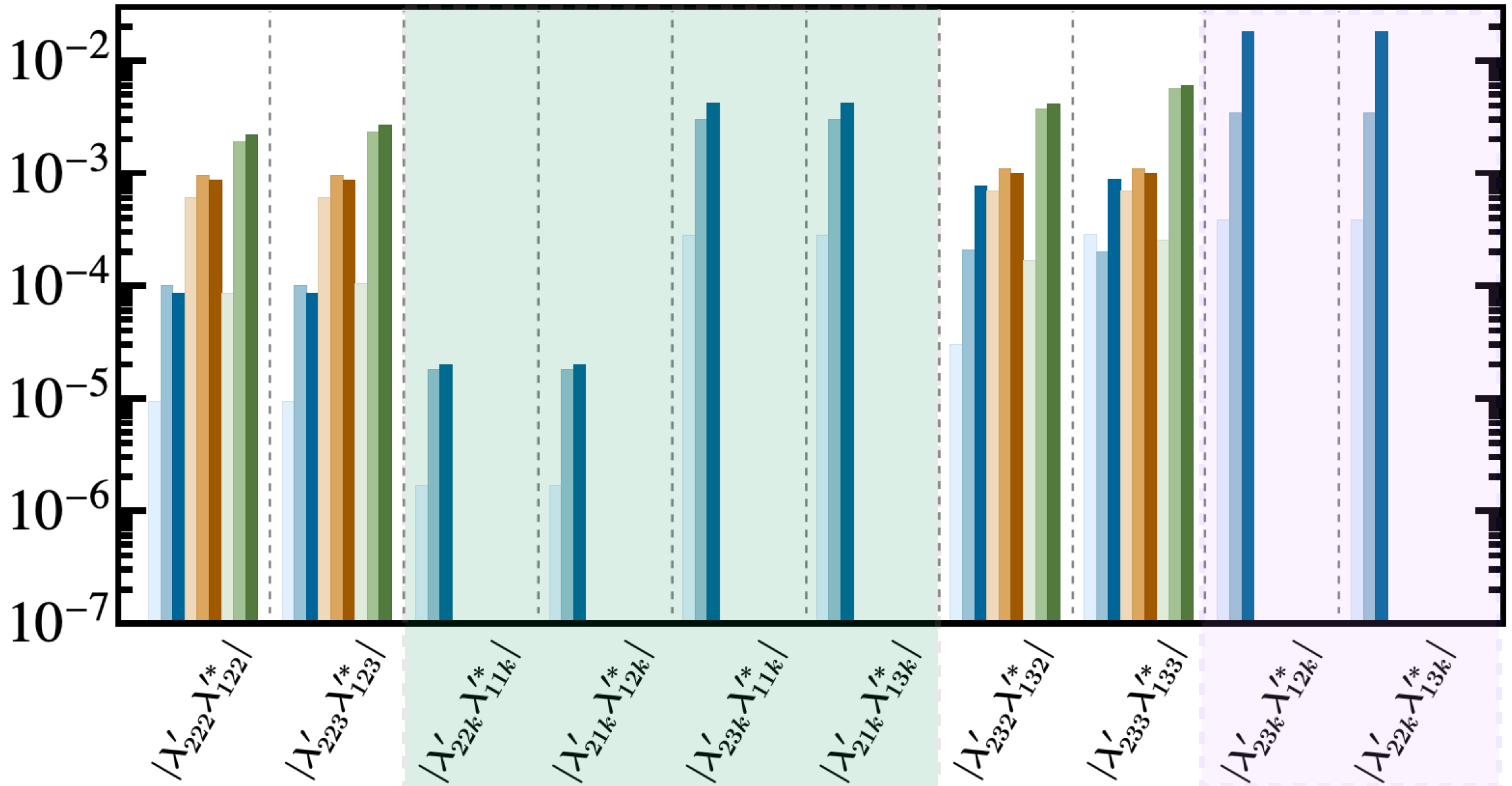

For $\mu \to e\gamma$, $\mu \to 3e$, contributions are **GIM suppressed**

For $\mu N \to eN$, the **RG running** can **give ~80% improvement** of the limit.

Numerical Results

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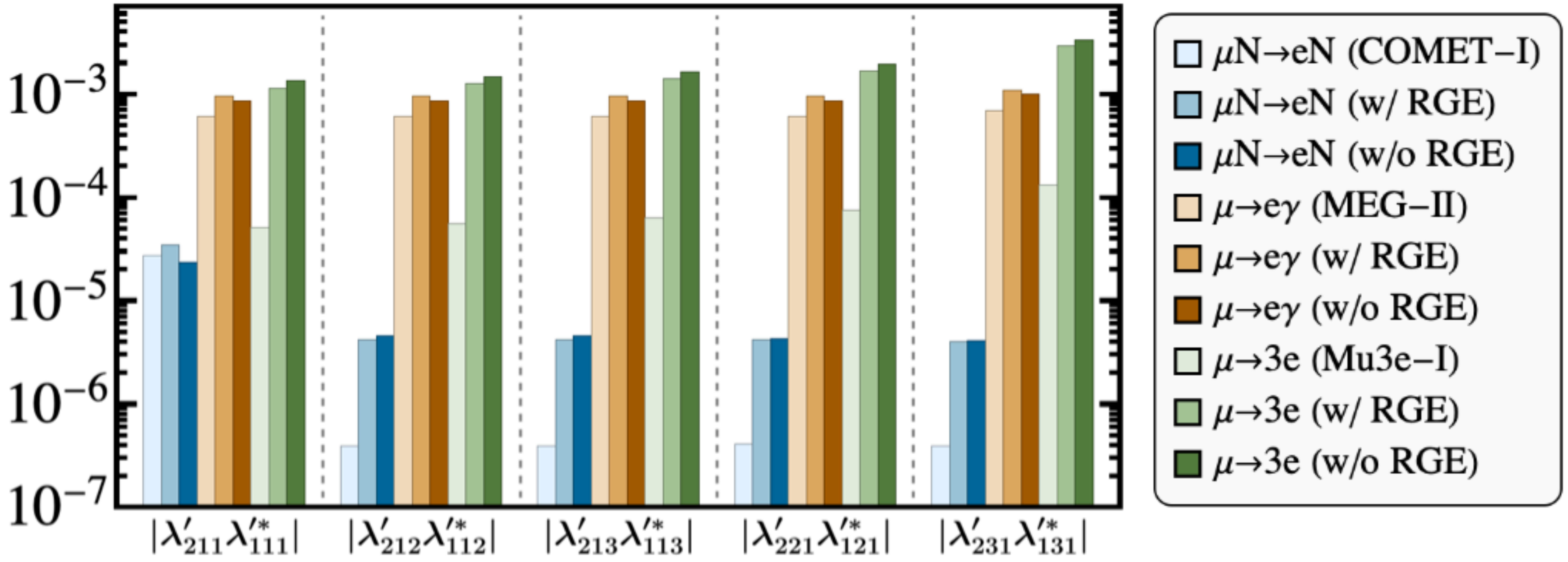

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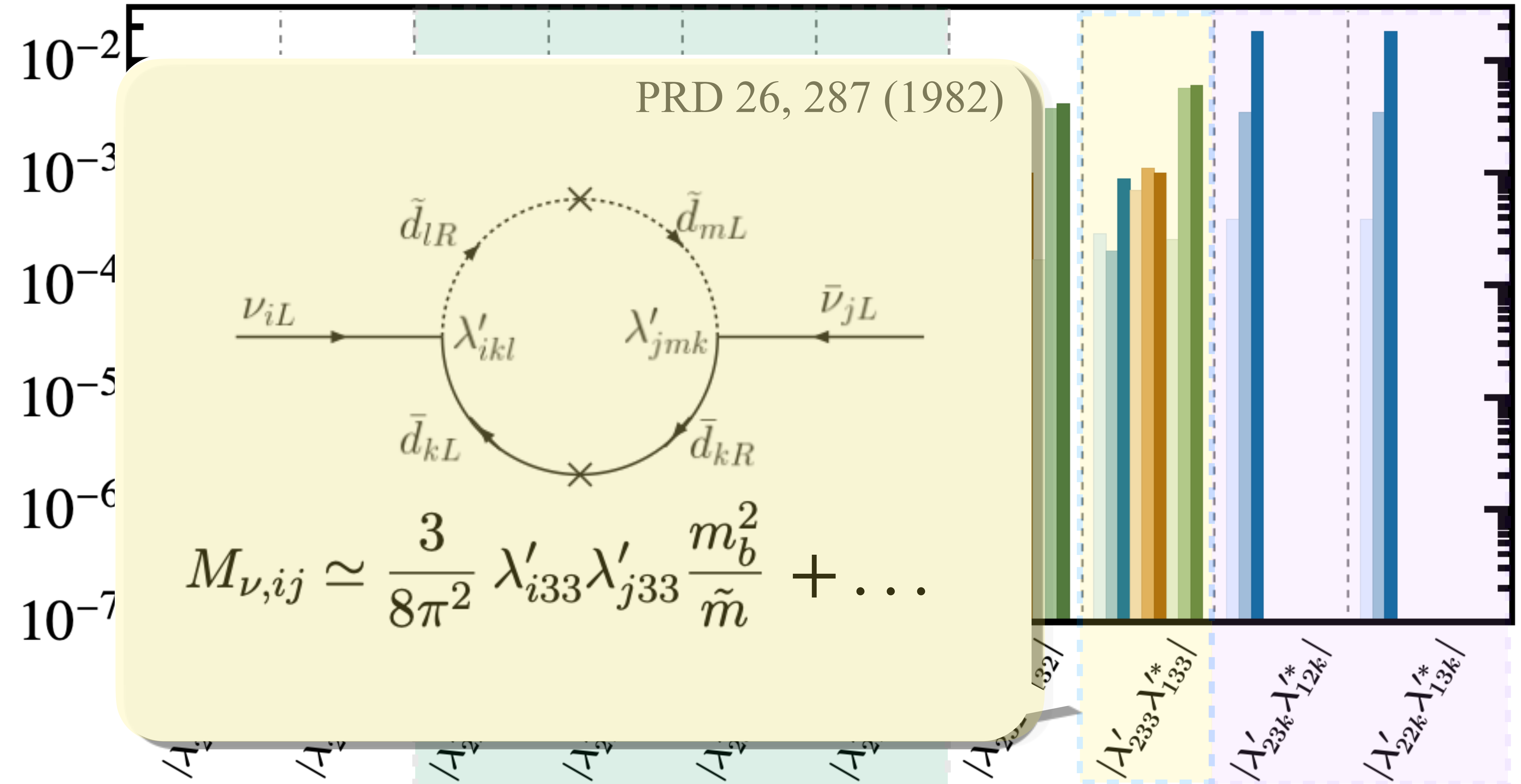

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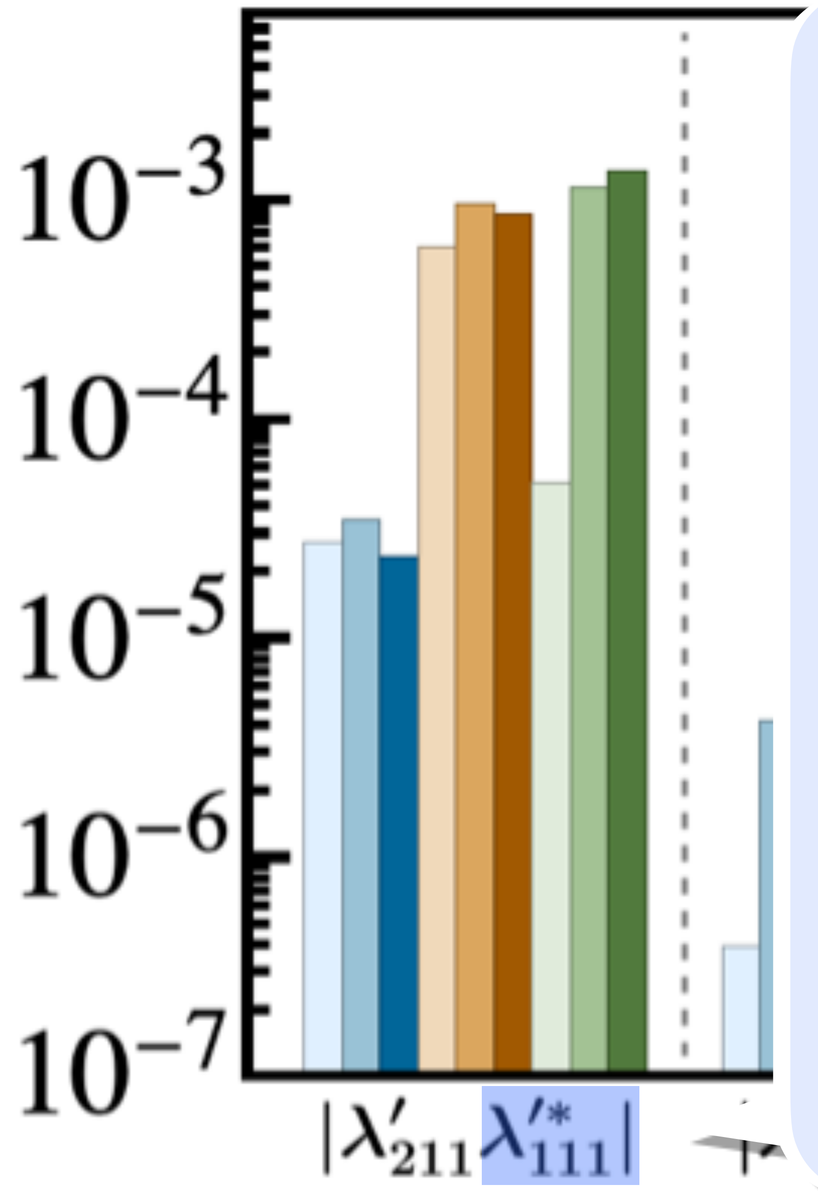
Neutrino mass will give much stronger limits than cLFV NPB 231 (1984) 194

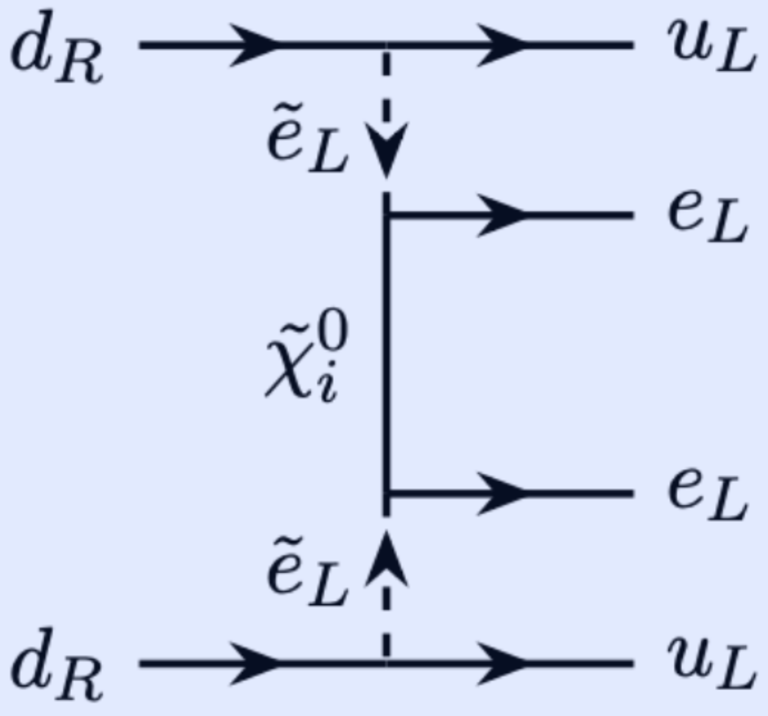
$|\lambda'_{133}\lambda'_{233}| < \mathcal{O}(10^{-7} \sim 10^{-8}) \times (\tilde{m}\ \mathrm{TeV}^{-1})$

Numerical Results

Keep one combination nonzero at a time



Cirigliano, et, al., PRL hep-ph/0406199



$0\nu\beta\beta$

KamLAND-Zen / GERDA give limit

$$\lambda'^2_{111}/m^4_{\tilde{q}}m_{\tilde{g}} < 4\times 10^{-4}\ \text{TeV}^{-5}$$

$\Rightarrow\ \lambda'_{111} < 10^{-2}$ If TeV scale $m_{\tilde{q},\tilde{g}}$

$m_{\tilde{\chi}^0}$ below the GeV scale leads to $|\lambda'_{111}| < 10^{-4}$

2112.12658 Deppisch, et al. JHEP

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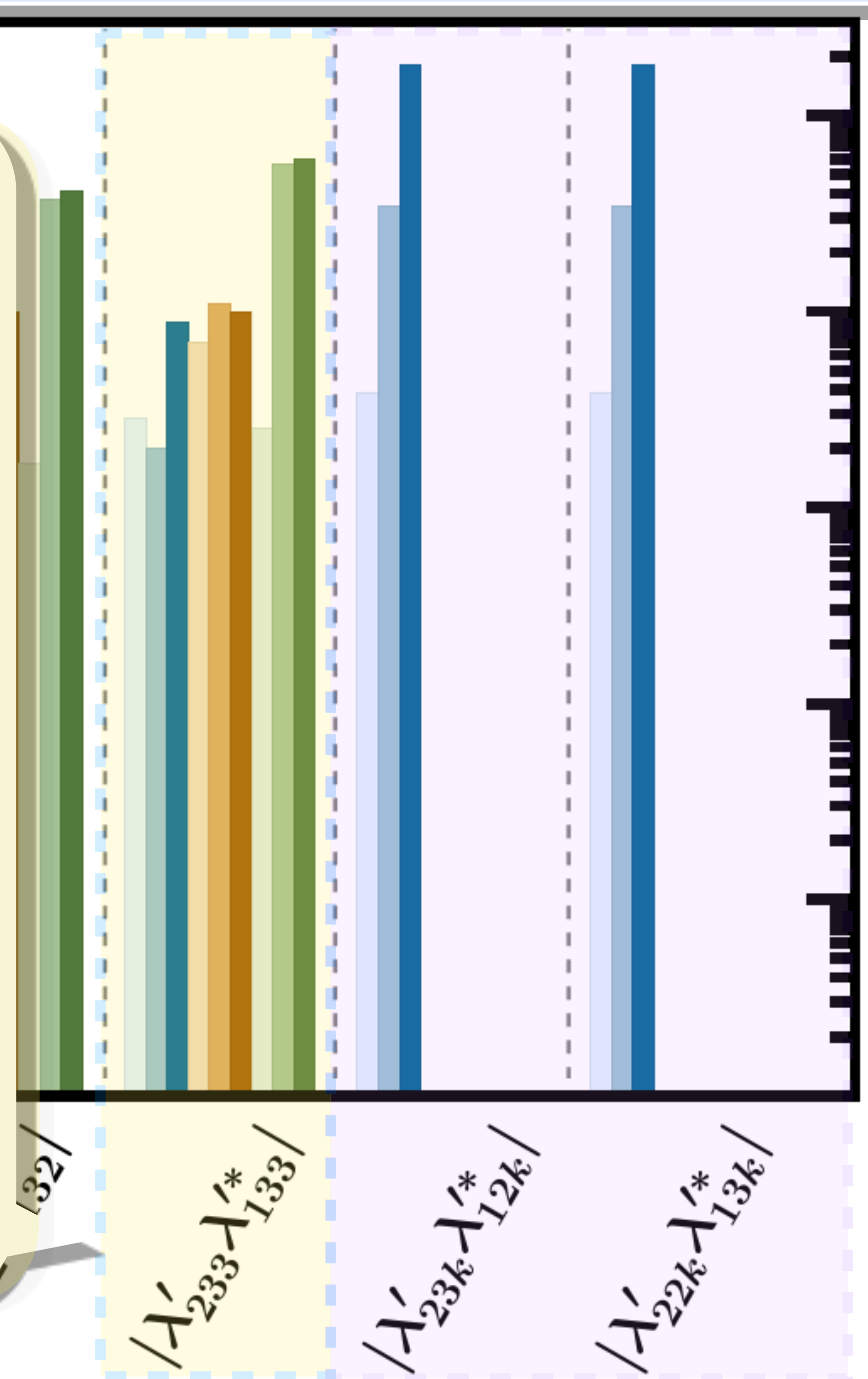
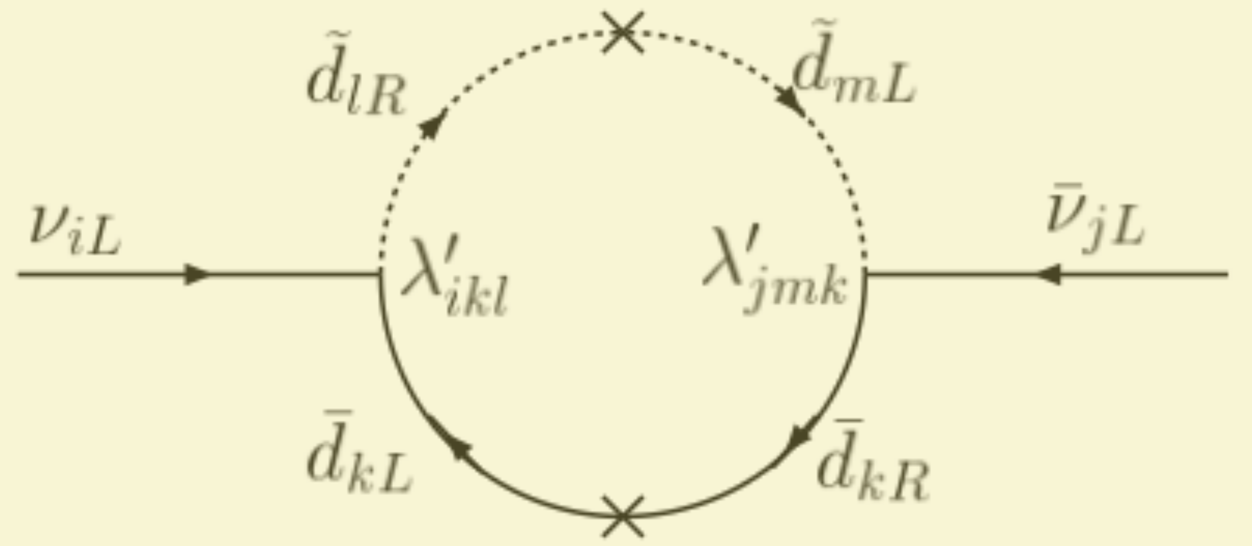


PRD 26, 287 (1982)



$$M_{\nu,ij} \simeq \frac{3}{8\pi^2}\lambda'_{i33}\lambda'_{j33}\frac{m_b^2}{\tilde{m}} + \ldots$$

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$$|\lambda'_{133}\lambda'_{233}| < \mathcal{O}(10^{-7} \sim 10^{-8})\ \times (\tilde{m}\ \text{TeV}^{-1})$$

Numerical Results

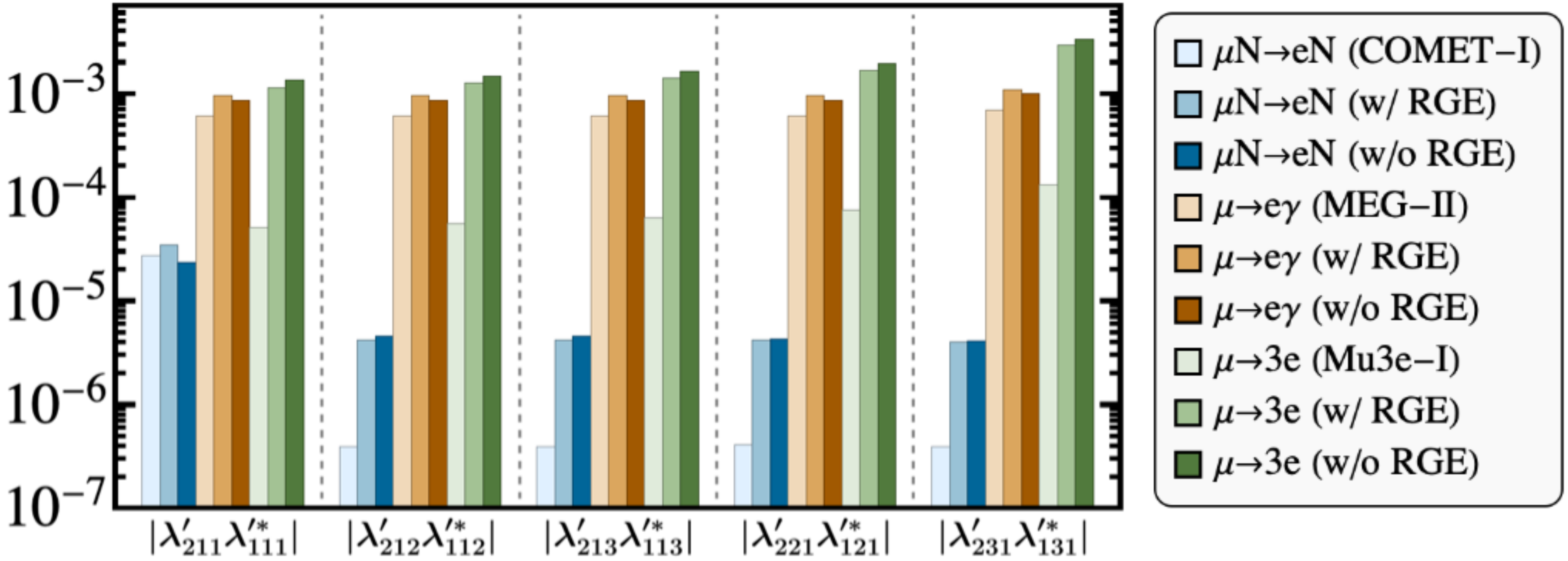
- **If no signals in these exp.:**

para. space can be constrained by the exp. limits

- **If signals have been found in $\mu \to e\gamma, \mu \to 3e$, but no signals in $\mu N \to eN$ in near future exp. with similar sensitivities:**

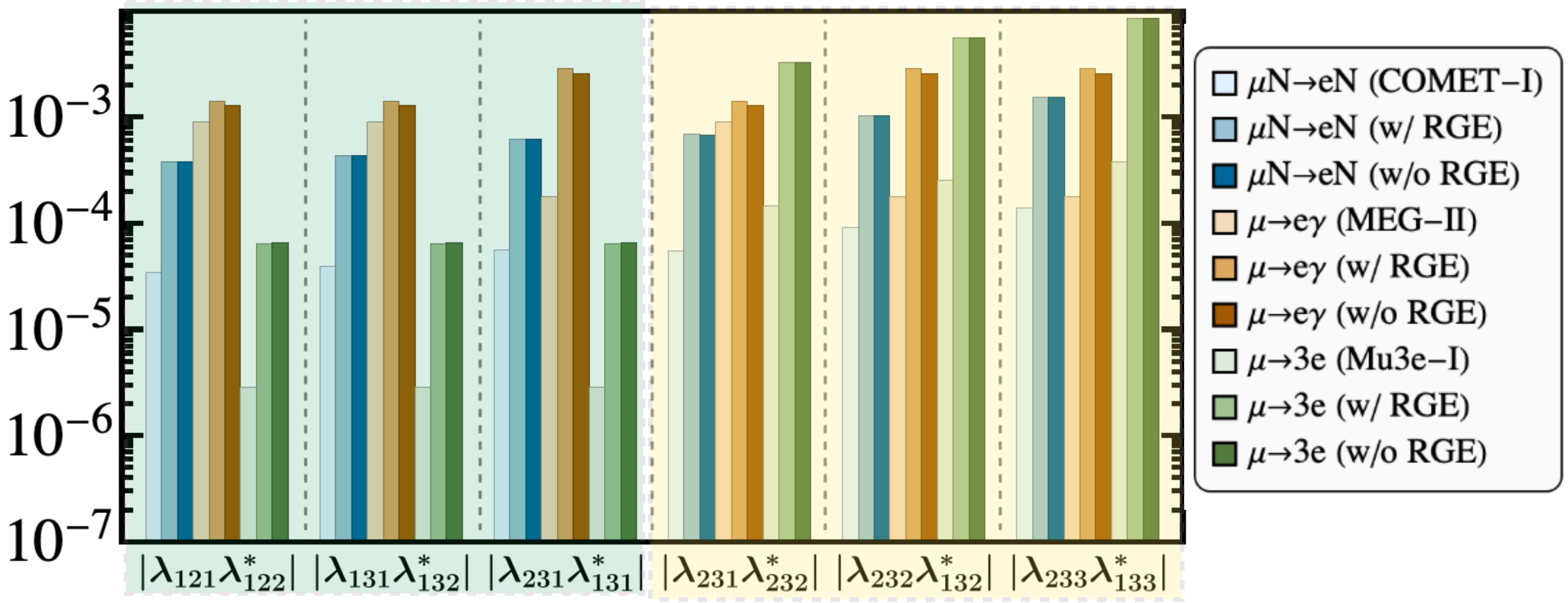
Most of these combinations can be ruled out

Things maybe different when keep more than one nonzero at a time



Numerical Results

Keep one combination nonzero at a time



For the **first three cases**:

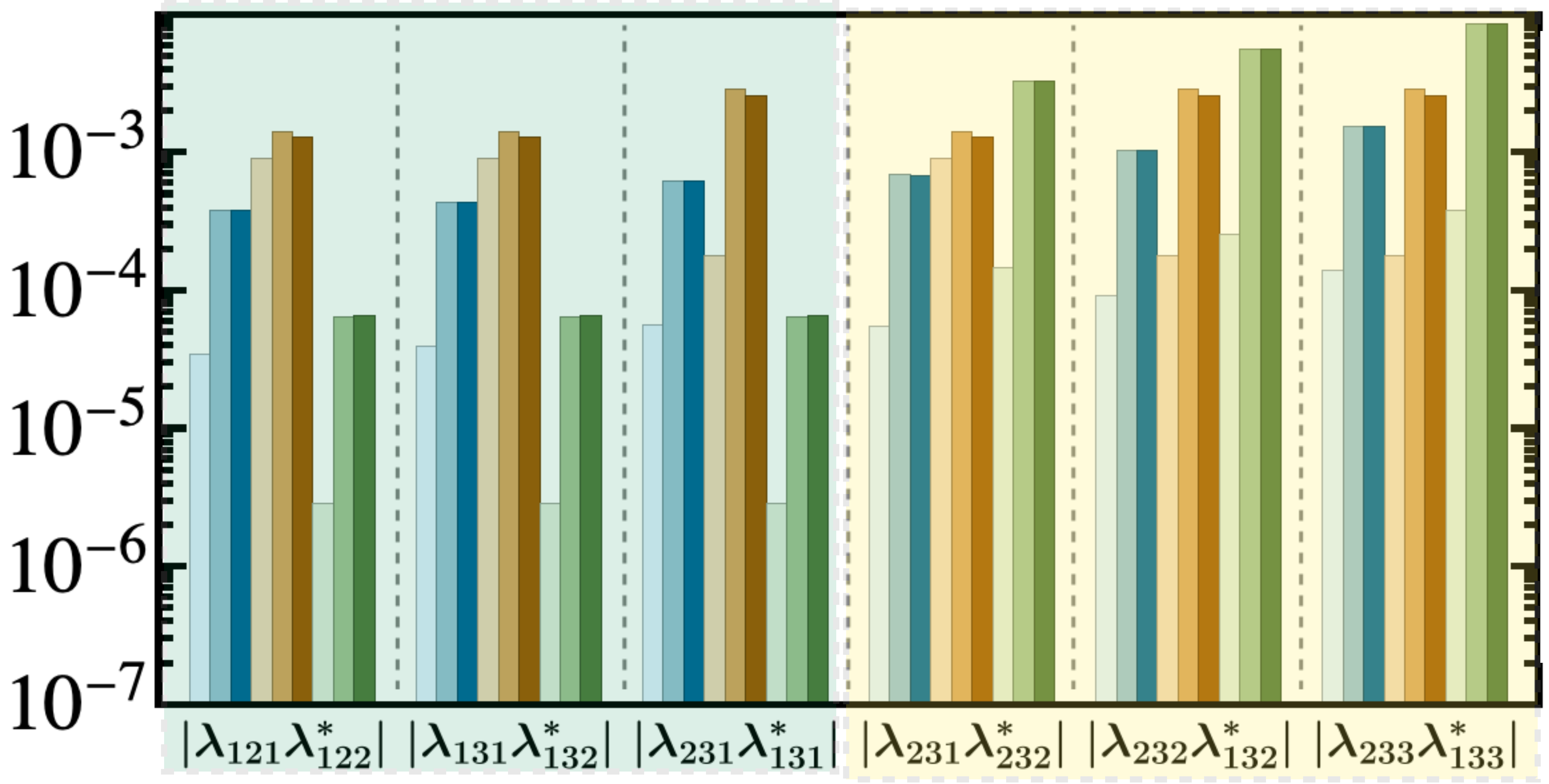
- Tree-level contribution to $\mu \to 3e$
- Future $\mu \to 3e$ exp. , e.g., Mu3e Phase-I, will **give the most stringent limits** on the para.

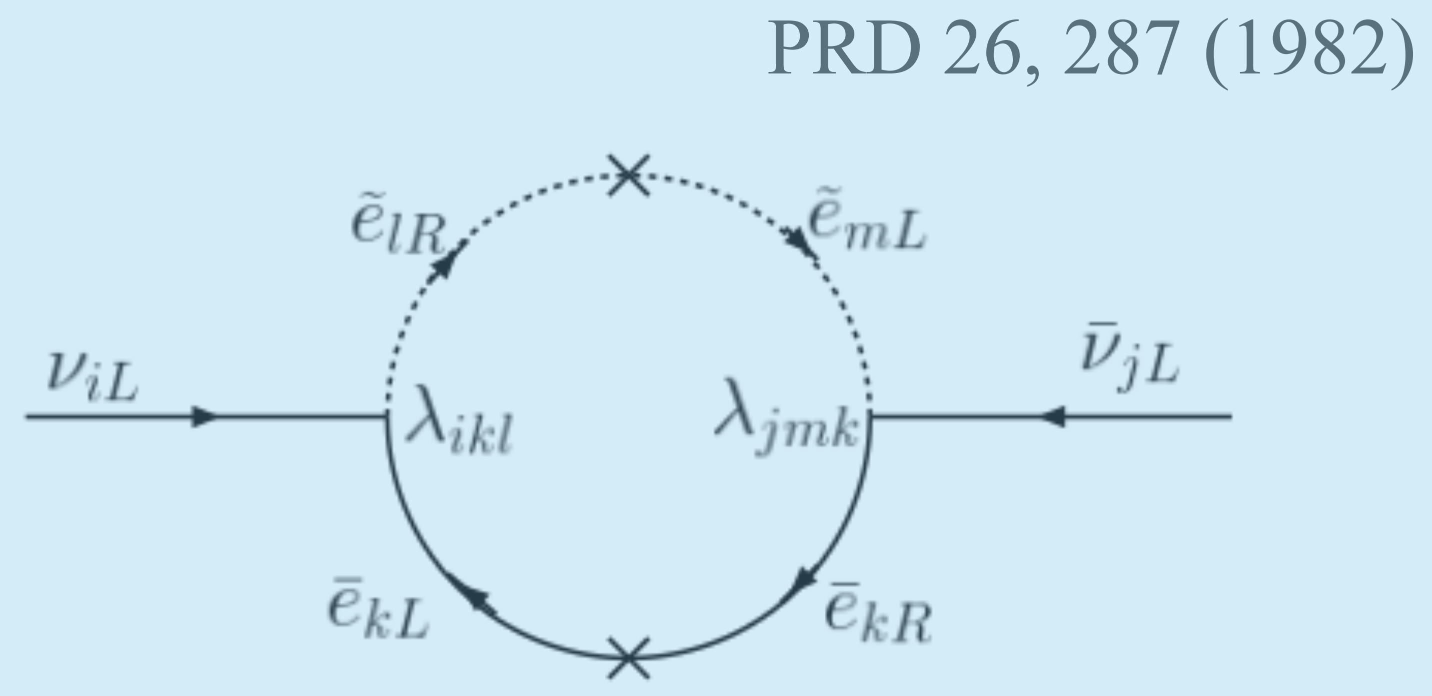
For the **last three cases**:

- **No tree-level** contribution to $\mu \to 3e$
- Future $\mu N \to eN$ exp. , e.g., COMET Phase-I, will **give the stronger limits.**

Numerical Results

Keep one combination nonzero at a time





$$M_{\nu,ij} \simeq \frac{1}{8\pi^2}\lambda_{i33}\lambda_{j33}\frac{m_\tau^2}{\tilde{m}} + \ldots$$

$$|\lambda_{233}\lambda_{133}| < 3 \times 10^{-6}$$

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Conclusion & Prospects

- As there will be **cLFV experimental improvements in the near future**, it is necessary to pay more attention to how they can play roles in NP models.
- We follow the **EFT framework**, **matching** the RPV-SUSY model to SMEFT at **tree and one-loop** level, and accounting for **RG running effects**.
- We find that **the $\mu N \to eN$ can give much stronger limits** than $\mu \to e\gamma, \mu \to 3e$ in most cases for λ' terms, also the same for specific cases of λ terms. In certain cases, $\mu N \to eN$ **conversion is the only process that can provide constraints**.
- The **RGE running effects can play an important role** and **cannot be neglected** in certain cases.
- **Combined analysis** of all the possible phenomena will lead to a **much more comprehensive examination** on the parameter space.

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- **Combined analysis** of all the possible phenomena will lead to a **much more comprehensive examination** on the parameter space.

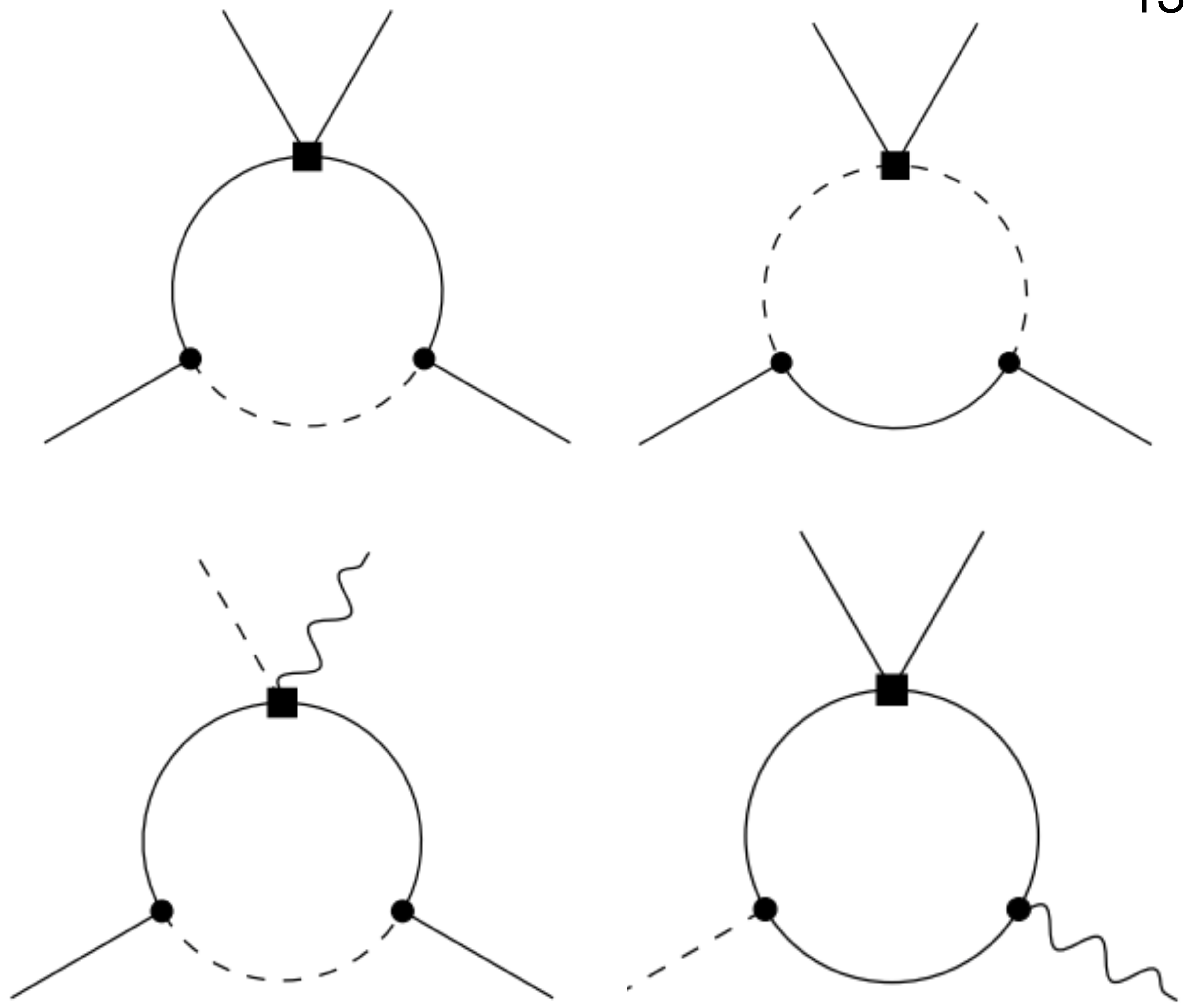
Thank you !

Backup: RG effects

RGEs in SMEFT

$$\frac{d\mathcal{C}_i}{d\ln\mu} = \frac{1}{16\pi^2}\sum_j \gamma_{ji}\mathcal{C}_i$$

1310.4838



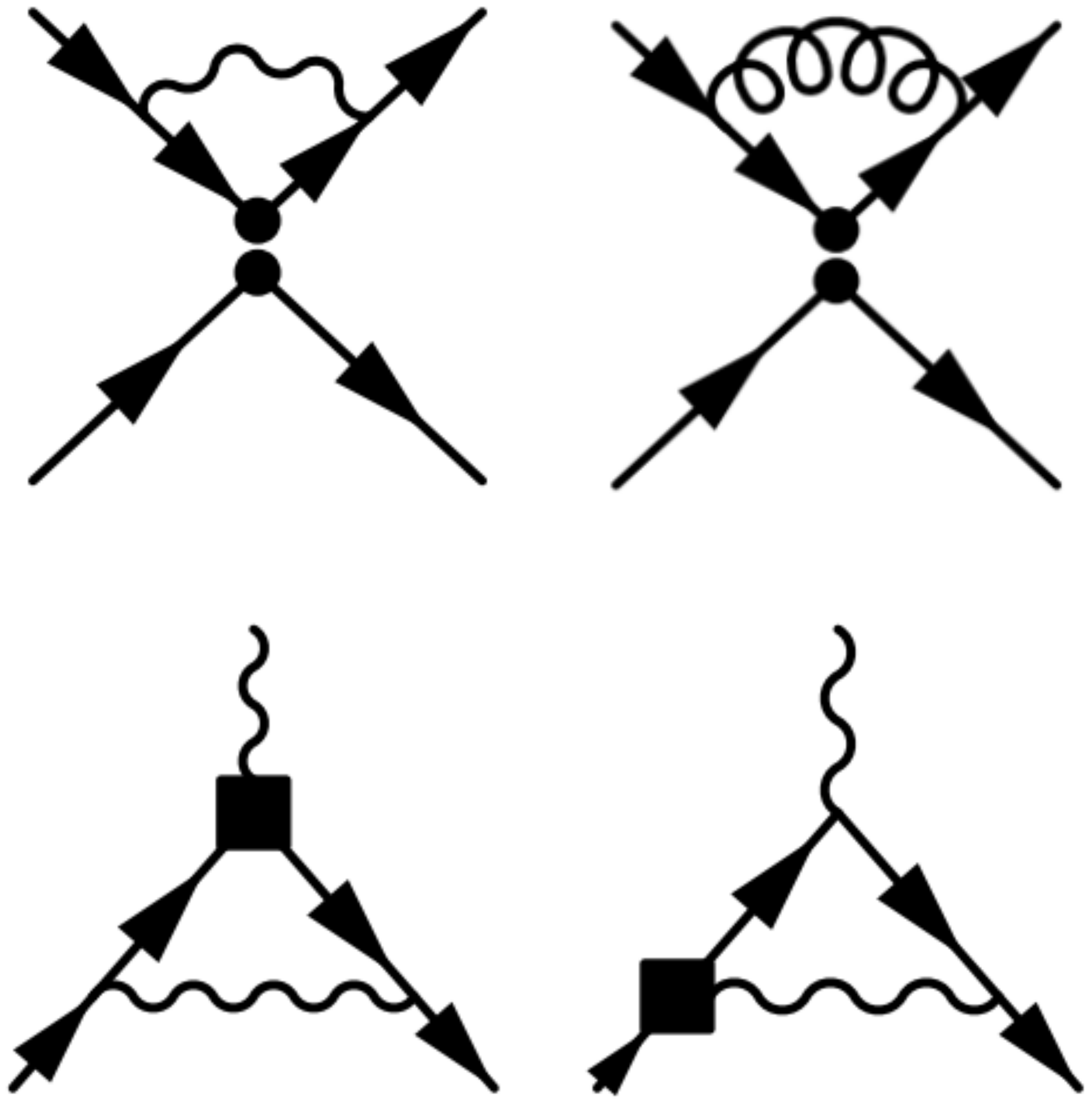
$\cdots$

$$\dot{C}_{\substack{eW\\rs}} = -2g_2N_c C^{(3)}_{\substack{lequ\\rspt}}[Y_u]_{tp} + C_{\substack{eW\\rt}}[Y_eY_e^\dagger]_{ts} + \cdots$$

RGEs in LEFT

$$\frac{d\mathcal{C}_i}{d\ln\mu} = \frac{g_s^2}{16\pi^2}\sum_j \gamma^s_{ji}\mathcal{C}_i + \frac{e^2}{16\pi^2}\sum_j \gamma^e_{ji}\mathcal{C}_i$$

1711.05270



$\cdots$

$\cdots$

Backup: RG effects

Para.	$C^{V,LL}_{eu,1211}$		$C^{V,LL}_{ed,1211}$		$C^{V,LR}_{eu,1211}$		$C^{V,LR}_{ed,1211}$	
	w/ RG effects	w/o RG effects	w/ RG effects	w/o RG effects	w/ RG effects	w/o RG effects	w/ RG effects	w/o RG effects
$\lambda'_{211}\lambda'^{*}_{111}$	0.5130	0.4748	2.768×10^{-3}	0	-5.735×10^{-3}	0	-0.5045	-0.5
$\lambda'_{212}\lambda'^{*}_{112}$	0.5130	0.4748	2.768×10^{-3}	0	-5.735×10^{-3}	0	2.908×10^{-3}	0
$\lambda'_{213}\lambda'^{*}_{113}$	0.5130	0.4748	2.758×10^{-3}	0	-5.735×10^{-3}	0	2.908×10^{-3}	0
$\lambda'_{221}\lambda'^{*}_{121}$	2.147×10^{-2}	2.515×10^{-2}	2.828×10^{-3}	0	-5.708×10^{-3}	0	-0.5045	-0.5
$\lambda'_{231}\lambda'^{*}_{131}$	-3.352×10^{-2}	0	3.743×10^{-2}	0	1.016×10^{-2}	0	-0.5128	-0.5
$\lambda'_{222}\lambda'^{*}_{122}$	2.147×10^{-2}	2.515×10^{-2}	2.828×10^{-3}	0	-5.708×10^{-3}	0	2.895×10^{-3}	0
$\lambda'_{223}\lambda'^{*}_{123}$	2.148×10^{-2}	2.515×10^{-2}	2.818×10^{-3}	0	-5.710×10^{-3}	0	2.895×10^{-3}	0
$\lambda'_{22k}\lambda'^{*}_{11k}$	0.1195	0.1093	0	0	0	0	0	0
$\lambda'_{21k}\lambda'^{*}_{12k}$	0.1195	0.1093	0	0	0	0	0	0
$\lambda'_{23k}\lambda'^{*}_{11k}$	3.448×10^{-4}	5.215×10^{-4}	2.988×10^{-4}	0	1.370×10^{-4}	0	7.028×10^{-5}	0
$\lambda'_{21k}\lambda'^{*}_{13k}$	3.448×10^{-4}	5.215×10^{-4}	2.988×10^{-4}	0	1.370×10^{-4}	0	7.028×10^{-5}	0
$\lambda'_{23k}\lambda'^{*}_{12k}$	1.301×10^{-3}	1.201×10^{-4}	-1.468×10^{-3}	0	-6.730×10^{-4}	0	3.450×10^{-4}	0
$\lambda'_{22k}\lambda'^{*}_{13k}$	1.301×10^{-3}	1.201×10^{-4}	-1.468×10^{-3}	0	-6.730×10^{-4}	0	3.450×10^{-4}	0

Table 3. The numerical expressions for the Wilson coefficients of LEFT operators with or without RG running effects that are related to μ-e conversion, which can be tree-level contributed from the λ' combinations. One can see the text for the details.

Backup: RG effects

RG plays an important role in last two cases:

$$\begin{aligned}\Gamma^{w/o}_{\text{conv.}} =& |1.201 \times 10^{-4} g[V^{(p,n)}] f(\lambda')|^2 \ ,\\ \Gamma^{w/}_{\text{conv.}} =& |(1.301 \times 10^{-3} - 6.73 \times 10^{-4}) g[V^{(p,n)}] f(\lambda')\\ & (-1.468 \times 10^{-3} + 3.45 \times 10^{-4}) g'[V^{(p,n)}] f(\lambda')|^2 \\ \simeq & |4.950 \times 10^{-4} g[V^{(p,n)}] f(\lambda')|^2\end{aligned}$$

The function of g:

$$g[V^{(p,n)}] = 2V^{(p)} + V^{(n)},$$
$$g'[V^{(p,n)}] = V^{(p)} + 2V^{(n)},$$

Isotopes	D $[m_\mu^{5/2}]$	$S^{(p)}$ $[m_\mu^{5/2}]$	$V^{(p)}$ $[m_\mu^{5/2}]$	$S^{(n)}$ $[m_\mu^{5/2}]$	$V^{(n)}$ $[m_\mu^{5/2}]$	$\Gamma_{\text{cap.}}$ $[10^6\ \text{s}^{-1}]$
^{27}Al	0.0359	0.0159	0.0165	0.0172	0.0178	0.7054
^{48}Ti	0.0859	0.0379	0.0407	0.0448	0.0481	2.590
^{197}Au	0.166	0.0523	0.0866	0.0781	0.129	13.07

The RG effects can give **10%-30% influence** on the results in **most combinations**, while can **give 80% improvement** on the upper limits for **23k,12k** and **13k,22k** combinations

Para.	Limits w/ RG effects $\mu - e$ conv.	Limits w/o RG effects $\mu - e$ conv.
$\lvert\lambda'_{23k}\lambda'^*_{12k}\rvert$	3.88×10^{-3} (Ti)	1.81×10^{-2} (Ti)
	3.43×10^{-3} (Au)	1.86×10^{-2} (Au)
	3.86×10^{-4} (Al)	1.68×10^{-3} (Al)
$\lvert\lambda'_{22k}\lambda'^*_{13k}\rvert$	3.88×10^{-3} (Ti)	1.81×10^{-2} (Ti)
	3.43×10^{-3} (Au)	1.86×10^{-2} (Au)
	3.86×10^{-4} (Al)	1.68×10^{-3} (Al)

This large RG effects can remain robust against nuclear uncertainties

Backup: overlap integral

Overlap Integral

$$D = \frac{4}{\sqrt{2}} m_\mu \int_0^\infty \mathrm{d}r\, r^2 \left[-E(r)\right] \left(g_e^- f_\mu^- + f_e^- g_\mu^-\right)$$

radial electric field

$$S^{(p)} = \frac{1}{2\sqrt{2}} \int_0^\infty \mathrm{d}r\, r^2 Z \rho^{(p)} \left(g_e^- g_\mu^- - f_e^- f_\mu^-\right),$$

$$S^{(n)} = \frac{1}{2\sqrt{2}} \int_0^\infty \mathrm{d}r\, r^2 N \rho^{(n)} \left(g_e^- g_\mu^- - f_e^- f_\mu^-\right),$$

radial parts of wavefunctions

$$V^{(p)} = \frac{1}{2\sqrt{2}} \int_0^\infty \mathrm{d}r\, r^2 Z \rho^{(p)} \left(g_e^- g_\mu^- + f_e^- f_\mu^-\right),$$

$$V^{(n)} = \frac{1}{2\sqrt{2}} \int_0^\infty \mathrm{d}r\, r^2 N \rho^{(n)} \left(g_e^- g_\mu^- + f_e^- f_\mu^-\right),$$

contain all the information about the **<u>structure of the nucleus</u>** (spherically symmetric) through the density distributions ρ of protons and neutrons.

$$\int_0^\infty \mathrm{d}r\, 4\pi r^2 \rho^{(c),(p),(n)}(r) = 1 \qquad E(r) = \frac{Ze}{r^2} \int_0^r \mathrm{d}\tilde{r}\, \tilde{r}^2 \rho^{(c)}(\tilde{r})$$

The overlap integrals can be calculated for a given isotope after specifying the **nuclear distributions**.

- Three-parameter Fermi model (3pF)

  $w = 0$ (2pF); $w = 0,\ z = 0.52$ fm (1pF)

  $$\rho^{(c)}(r) = \frac{\rho_0}{1 + \exp\left(\frac{r-c}{z}\right)} \left(1 + w\frac{r^2}{c^2}\right)$$

- Three-parameter Gaussian model (3pG)

  $$\rho^{(c)}(r) = \frac{\rho_0}{1 + \exp\left(\frac{r^2-c^2}{z^2}\right)} \left(1 + w\frac{r^2}{c^2}\right)$$

- Modified-harmonic oscillator model (MHO)

  $$\rho^{(c)}(r) = \rho_0 \left(1 + w\frac{r^2}{a^2}\right) \mathrm{e}^{-r^2/a^2}$$

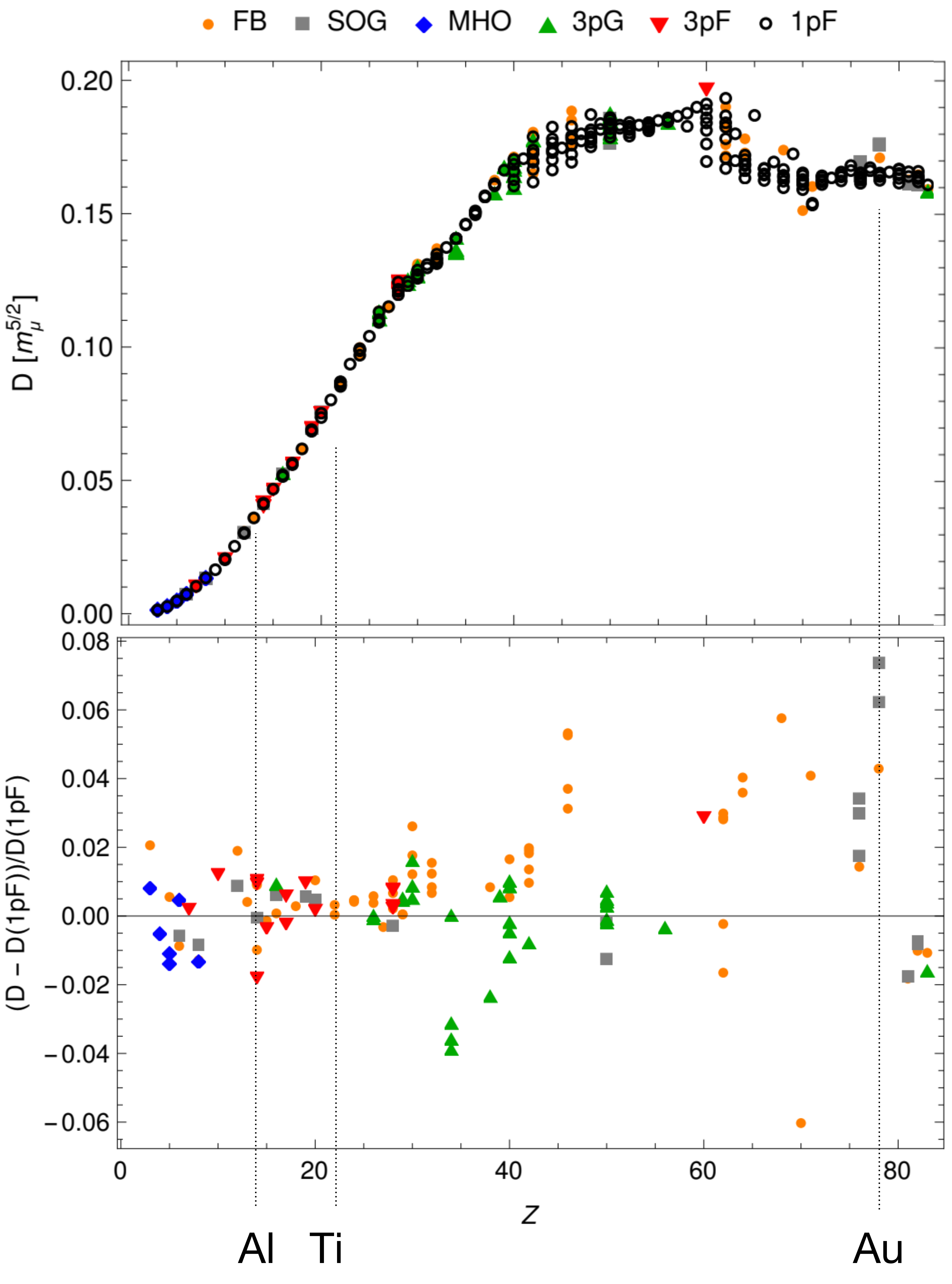
- Fourier–Bessel expansion (FB)

  $$\rho^{(c)}(r) = \begin{cases} \sum_k^n a_k j_0\left(\frac{k\pi r}{R}\right), & r \le R, \\ 0, & r > R. \end{cases}$$

- Sum of Gaussians (SOG)

  $$\rho^{(c)}(r) = \sum_k^n Q_k \frac{\mathrm{e}^{-\frac{(r-R_k)^2}{\gamma^2}} + \mathrm{e}^{-\frac{(r+R_k)^2}{\gamma^2}}}{2\pi^{3/2}\gamma^3(1 + 2R_k^2/\gamma^2)}$$

Backup: overlap integral



Isotopes	D $[m_\mu^{5/2}]$	$S^{(p)}$ $[m_\mu^{5/2}]$	$V^{(p)}$ $[m_\mu^{5/2}]$	$S^{(n)}$ $[m_\mu^{5/2}]$	$V^{(n)}$ $[m_\mu^{5/2}]$	$\Gamma_{\text{cap.}}$ $[10^6\ \text{s}^{-1}]$
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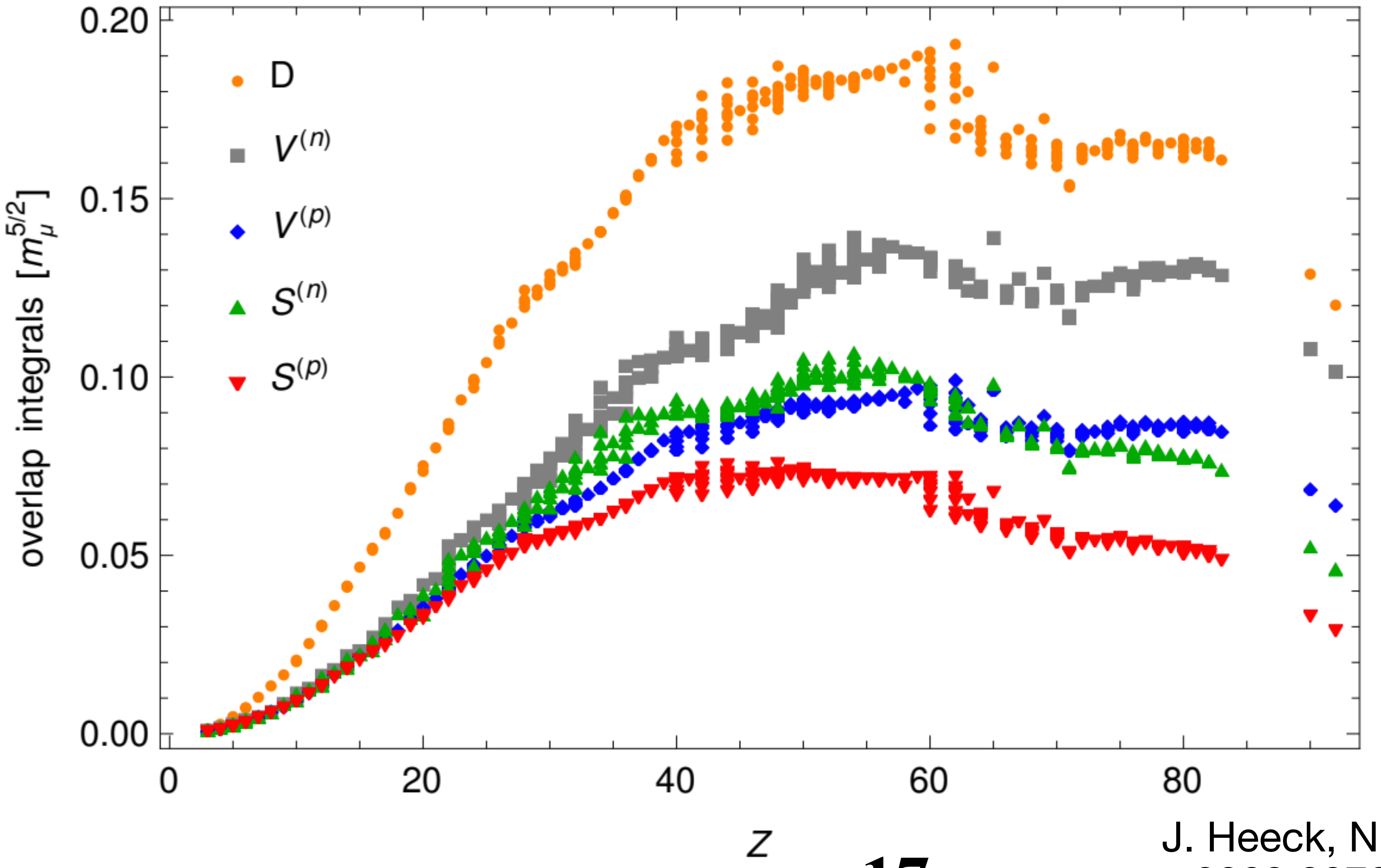
^{48}Ti	0.0859	0.0379	0.0407	0.0448	0.0481	2.590
^{197}Au	0.166	0.0523	0.0866	0.0781	0.129	13.07



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