Could $\mu \leftrightarrow e$ observations distinguish models?

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[**LFV** = Lepton Flavour-Changing, NC contact interaction = FCNC for leptons. And NP is heavy.]

1. NP is somewhere...can look everywhere/under the lampost/chase ambulances...
   or, $[m_\nu] \Rightarrow$ LFV is an NP signature that *exists* !

2. intro $\left\{ \begin{array}{l} \text{exptal constraints + why } \mu \leftrightarrow e? \\ \text{are } \mu \to e\gamma, \mu \to e\bar{e}e, \mu A \to eA \text{ sufficient for discovery?} \end{array} \right.$

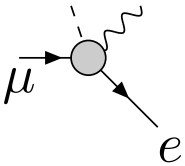
3. if we see $\mu \to e\gamma$, $\mu \to e\bar{e}e$, $\mu A \to eA$—can we distinguish models? *E.g.*:
   - type II seesaw
   - a singlet leptoquark (for R_D^*)

4. summary

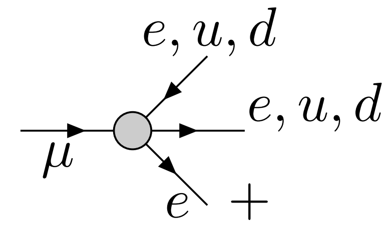
what we know about LFV : bounds/upcoming reach

$(\Delta LF = 1, \Delta QF = 0)$ $(\Delta LF = \Delta QF = 1)$, $(\Delta LF = 2)$

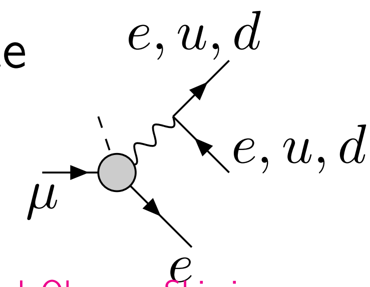
some processes	current constraints on BR	future sensitivities
$\mu \to e\gamma$	$< 4.2 \times 10^{-13}$	6×10^{-14} (MEG) $\to \ldots$
$\mu \to e\bar{e}e$	$< 1.0 \times 10^{-12}$(SINDRUM)	10^{-16} (202x, Mu3e)
$\mu A \to eA$	$< 7 \times 10^{-13}$ Au, (SINDRUMII)	$10^{-(16\to?)}$ (Mu2e,COMET)
		$10^{-(18\to?)}$ (PRISM/PRIME/ENIGMA)
$\tau \to \{e, \mu\}\gamma$	$< 3.3, 4.4 \times 10^{-8}$	few$\times 10^{-9}$ (Belle-II)
$\tau \to e\bar{e}e, \mu\bar{\mu}\mu, e\bar{\mu}\mu \ldots$	$< 1.5 - 2.7 \times 10^{-8}$	few$\times 10^{-9}$(Belle-II, LHCb?)
$\tau \to \begin{Bmatrix} e \\ \mu \end{Bmatrix} \{\pi, \rho, \phi, \ldots\}$	$\lesssim$ few $\times 10^{-8}$	few$\times 10^{-9}$ (Belle-II)
$h \to \tau^{\pm}\ell^{\mp}$	$< 1.5, 2.2 \times 10^{-3}$(ATLAS/CMS)	$< 2.4 \times 10^{-4}$ (ILC)
$h \to \mu^{\pm}e^{\mp}$	$< 6.1 \times 10^{-5}$ (ATLAS/CMS)	2.1×10^{-5} (ILC)
$Z \to e^{\pm}\mu^{\mp}$	$< 7.5 \times 10^{-7}$(ATLAS)	
$Z \to l^{\pm}\tau^{\mp}$	$< \times 10^{-7}$(ATLAS)	
$K^+ \to \pi^+\bar{\mu}e$	$< 1.3 \times 10^{-11}$ (E865)	10^{-12} (NA62)
...		
muonium		



three processes: $\mu \to e$, $\Delta F_Q = 0$



$\bullet \mu \to e\gamma$: chirality-flip, @loop in models, only dipole operators contribute



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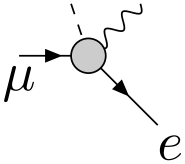
$\bullet \mu \to e\bar{e}e$: 4lepton(V+S)+dipole ops.
angular distributions$\Rightarrow$ indep constraints on 6$\to$8 coeffs.

$\bullet \mu A \to eA$ ($= \mu^-$ in $1s$ of A, turns into e^-)
nucl. phys. $\approx$ WIMP scattering $\supset$ SpinIndep$\sim$ A^2-enhanced (+SD, neglect)
coherent, all ops interfere $\Leftrightarrow$ one op per target for $\{e_L, e_R\}$



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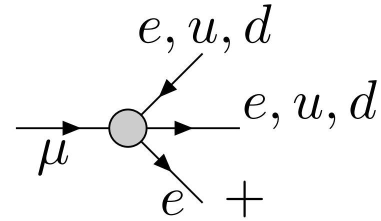
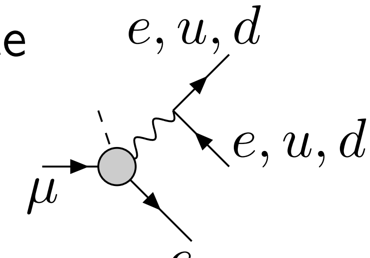


- $\mu \to e\gamma$: chirality-flip, @loop in models, only dipole operators contribute



- $\mu \to e\bar{e}e$: 4lepton(V+S)+dipole ops.
  angular distributions⇒ indep constraints on 6→8 coeffs.

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- $\mu A \to eA$ ($= \mu^-$ in $1s$ of A, turns into e^-)
  nucl. phys. ≈ WIMP scattering ⊃ SpinIndep$\sim A^2$-enhanced (+SD, neglect)
  coherent, all ops interfere ⇔ one op per target for $\{e_L, e_R\}$

- ⇒ $\mu \to e_L(e_R)$ processes, at exptal scale$\left\{\begin{array}{l}\text{described by}\\ \text{constrain}\end{array}\right\}$ **6(+6)** operators:

$$\delta\mathcal{L} \;=\; \frac{1}{v^2}\Big[C_D(m_\mu \bar{e}\sigma^{\alpha\beta}P_R\mu)F_{\alpha\beta} + C_S(\bar{e}P_R\mu)(\bar{e}P_Re) + C_{VR}(\bar{e}\gamma^\alpha P_L\mu)(\bar{e}\gamma_\alpha P_Re)$$
$$+ C_{VL}(\bar{e}\gamma^\alpha P_L\mu)(\bar{e}\gamma_\alpha P_Le) + C_{Alight}\mathcal{O}_{Alight} + C_{Aheavy\perp}\mathcal{O}_{Aheavy\perp}\Big]$$

$\{C\}$ are $\mathcal{O}(1)$ dimless numbers that can be measured (∃ more info than just rates)
O_{Alight} =combo of 4fermion operators probed by light targets (Al,Ti)
$O_{Aheavy\perp}$= indep. combo of 4fermion ops probed by heavy targets (Au)

Are $\mu \to e\gamma$, $\mu \to e\bar{e}e$, $\mu A \to eA$ sufficient for discovery?

probe few ops— if ΔF_Q=0, $\mu \to e$ occurs, will it contribute to $\mu \to e\gamma, \mu \to e\bar{e}e$ or $\mu A \to eA$?

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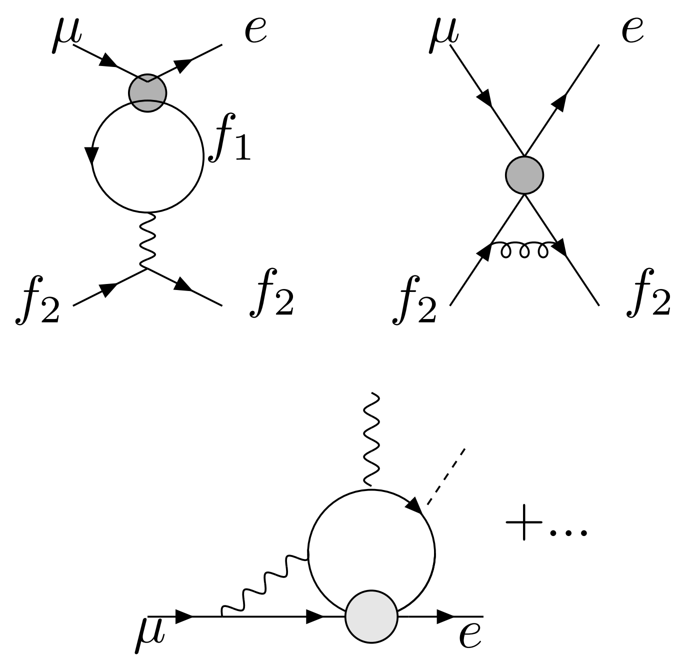
Probably yes: SM loops ensure almost every $\Delta QF = 0$, $\mu \to e$ interaction with ≤ 4 legs, contributes $\gtrsim \mathcal{O}(10^{-3})$ to amplitudes $\mu \to e\gamma$, $\mu \to e\bar{e}e$ and/or $\mu A \to eA$
(not $\bar{e}\mu G\widetilde{G}$, $\bar{e}\mu F\widetilde{F}$, $\bar{e}\gamma\mu F\partial F$...)



if see $\mu \to e\gamma$, $\mu \to e\bar{e}e$, or $\mu A \to eA$...?can distinguish models?

...studied "top-down" for decades...

EFT recipe to study this: (not scan model space—no measure)

• data is a "12-d" ellipse in coefficient-space (in an ideal theorist's world)

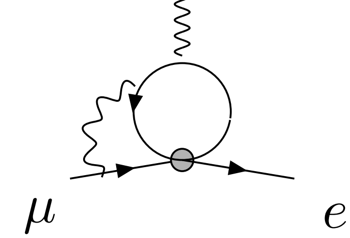
• with RGEs, can take ellipse to $\Lambda_{\rm NP}$

• are there parts of ellipse that model *cannot* fill?
If yes, model can be distinguished/ruled out by $\mu \leftrightarrow e$ data.

Apply recipe:
1) type II seewaw
2) singlet LQ for R_D^*

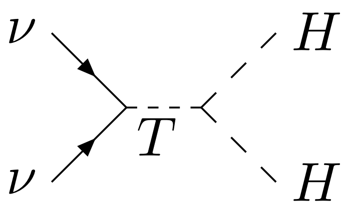
Many questions... . LFV @ loop $\leftrightarrow$ tree? LFV for singlets? NParticles interact with q? LFV not for m_ν ...?

Type II seesaw — add SU(2) triplet scalar $\vec{T}$



$$\mathcal{L} \supset \left([Y]_{\alpha\beta}\, \overline{\ell^c_\alpha} \varepsilon \vec{\tau} \cdot \vec{T} \ell_\beta + M_T \lambda_H \;\; H \varepsilon \vec{\tau} \cdot \vec{T}^* H + \text{h.c.} \right) + \ldots$$

get $[m_\nu]$ by matching:



$$[m_\nu]_{\alpha\beta} \sim \frac{[Y]_{\alpha\beta} \lambda_H M_T v^2}{M_T^2} \sim 0.03 \text{ eV} \times [Y]_{\alpha\beta} \frac{\lambda_H}{10^{-12}} \frac{\text{TeV}}{M_T}$$

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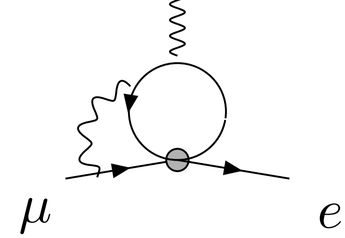

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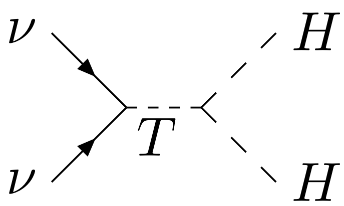

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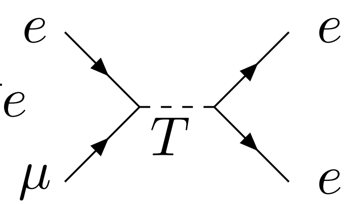
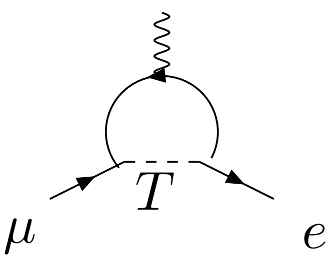
then expect:

$\mu \to e\bar{e}e$



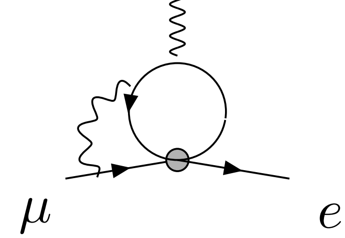
$$C^{e\mu ee}_{V,LL} \sim \frac{[Y]_{\mu e}[Y^*]_{ee} v^2}{M_T^2}, \text{matching}, \;\; f(m_{\nu 1}, \phi_i, ..) \text{ (can vanish)}$$

$\mu \to e\gamma$



$$C_{D,L} \sim \frac{y_\mu [YY^\dagger]_{\mu e} v^2}{128\pi^2 M_T^2}, \;\; \text{matching}, f(\Delta m^2, \theta_i, \delta) \geq 0, \;\; \text{known}$$

Type II seesaw — add SU(2) triplet scalar $\vec{T}$



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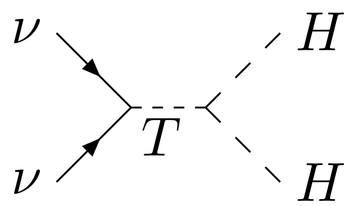

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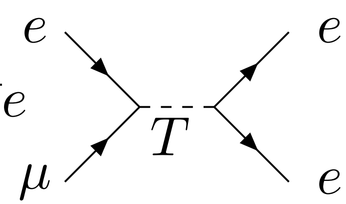

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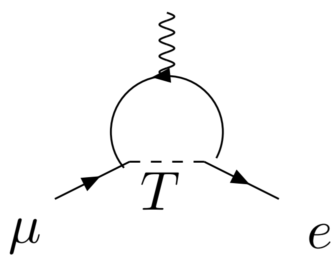

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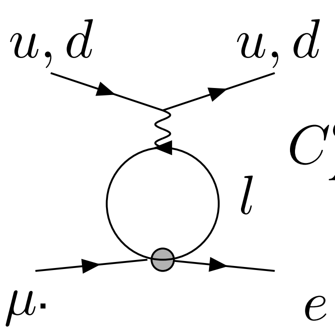
$\mu A \to eA$



$$C^{e\mu qq}_{Al,L} \sim \frac{\alpha_e}{3\pi} \frac{[YY^\dagger]_{\mu e} v^2}{M_T^2} \log\frac{m_l}{m_T} \;,\;\; \text{RG} \;,\; f(m_{\nu 1}, \phi_i, ..), \;\text{can vanish}$$

but RG-loop for $\mu \to e\gamma$ too,+its m_l-cutoff$\to f(\sum m_{\nu_i},\, \phi_i)$

Type II seesaw: predictions

(recall 12 (complex) operator coefficients $\left\{ \begin{array}{l} C_{DR},\ C^{e\mu ee}_{VLL},\ C^{e\mu ee}_{VLR},\ C^{e\mu ee}_{SRR},\ C_{AlightL},\ C_{AheavyR} \\ C_{DL},\ C^{e\mu ee}_{VRL},\ C^{e\mu ee}_{VRR},\ C^{e\mu ee}_{SLL},\ C_{AlightL},\ C_{AheavyR} \end{array} \right.$

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- seven coefficients for LFV-involving-singlet-leptons are negligeable

(predicted by all m_ν models where NP interacts with doublets)

Test by polarising μ. Kuno Okada

- any of C_{DR}, $C^{e\mu ee}_{VLL}$ or $C_{Al,L}$ $(\propto C^{e\mu ee}_{VLR})$ can vanish, sometimes both 4f.

($\Rightarrow$ $\mu \to e\gamma$ or $\mu A \to eA$ can vanish , but not $\mu \to e\bar{e}e$ ($\propto$ |dipole|^2+|4l|^2)

...umm. How to represent?

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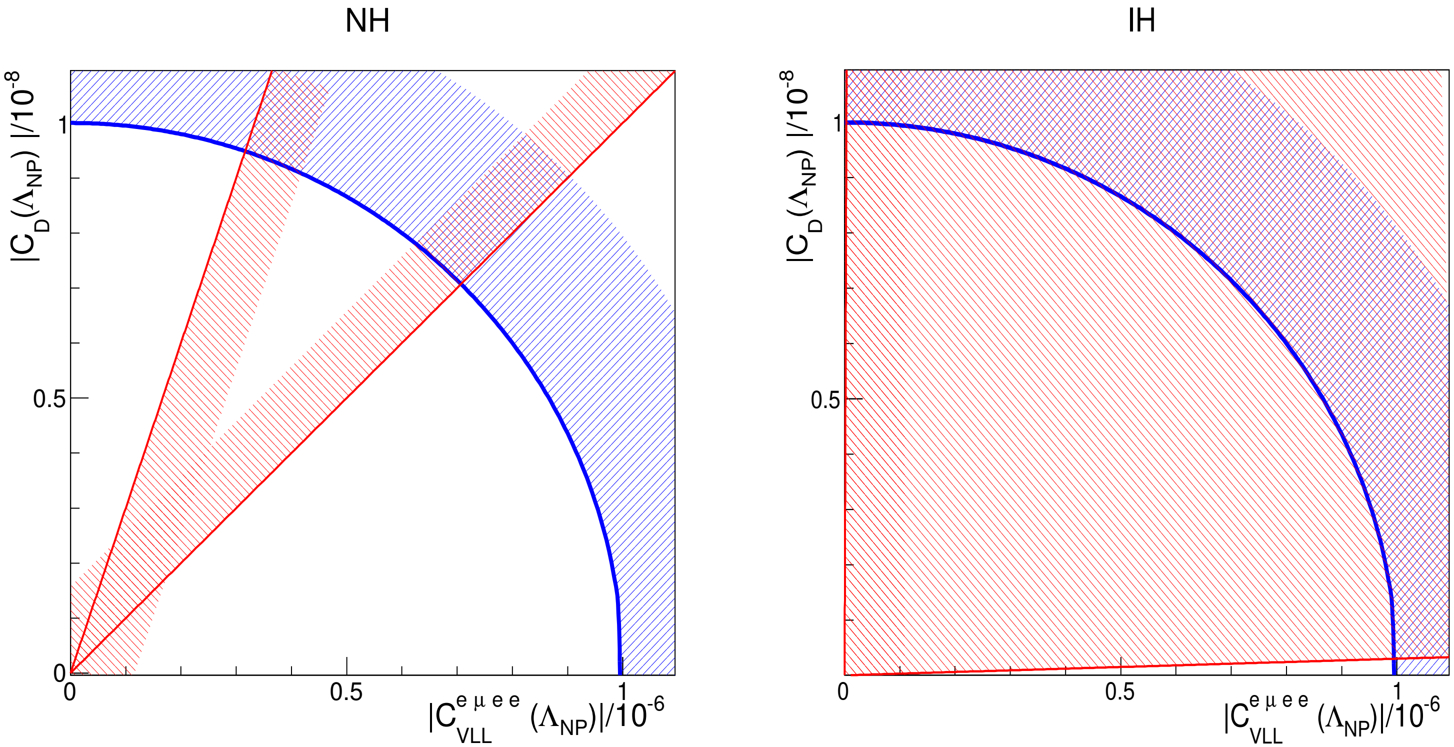


veery prelim

model lives in red pie slice expt excludes blue region outside pie plate

vert. axis $\sim C_{DL}(m_\mu) \leftrightarrow \mu \to e\gamma$; horiz. axis $C^{e\mu ee}_{VLL}(m_\mu)$; C_{Al} vanishes.

A leptoquark (for R_{D^*})

SU(2) singlet scalar LQ, mass m_{LQ}, interactions to all flavours of l and q:

$$(-\lambda_L^{lr}\overline{\ell}_l \varepsilon q_r^c + \lambda_R^{lr}\overline{e}_l u_r^c)S + h.c.$$

⋆ generates scalar (+ vector) $\mu A \to eA$ operators at tree
  ($\mu A \to eA$ specially sensitive to scalar ops)
⋆ generates LFV operators for singlet leptons as well as doublets

⇒ it can fill the whole ellipse? Consistent with any $\mu \leftrightarrow e$ observation?
Not quite: not generate $(\bar{e}P_{R,L}\mu)(\bar{e}P_{R,L}e)$ (dim8 in SMEFT), detectable to $\mu \to e\bar{e}e$.

Summary

upcoming searches for $\mu \to e\gamma, \mu \to e\bar{e}e$ and $\mu A \to eA$ will have excellent sensitivity ($\Lambda_{\rm NP} \gtrsim 10^4 v$) to $\sim$ a dozen operator coefficients.

Loop effects described by (leading order) RGEs ensure that almost every $\mu \to e$ operator (chiral basis) with ≤ 4 legs (in broken EW), contributes to amplitudes for $\mu \to e\gamma$, $\mu \to e\bar{e}e$ and/or $\mu A \to eA$, suppressed by $\gtrsim \mathcal{O}(10^{-3})$. Can even have interesting sensitivity to products of some $(\mu \to \tau) \times (\tau \to e)$ interactions!

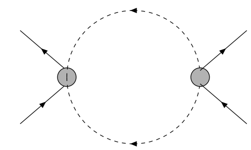
Prospects for distinguishing between models using $\mu \to e$ observations can be explored in EFT (using operator basis motivated by observables...). More later on what we learn :)

Backup

theoretical expectations for LFV rates

1. put m_ν in loops with EW bosons (SM for Dirac m_ν, in EFT for Majorana):

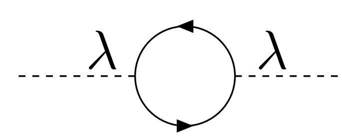
$$BR_{LFV} \gtrsim \left| \frac{m_\nu^2}{16\pi^2 v^2} \log \frac{\Lambda_{\rm NP}}{v} \right|^2 \gtrsim 10^{-55}$$



ugh....but m_ν, LFV different dependance on NP scale Λ_{NP}(and cplgs λ?):

$$m_\nu \sim \frac{\lambda^2 v^2}{\Lambda_{\rm NP}} \quad , \quad \sqrt{BR_{LFV}} \sim \frac{\lambda^2 v^2}{\Lambda_{\rm NP}^2}$$

2. input other relation for λ and Λ_{NP} : $\Delta m_H^2 \Big|_{NP} \sim \frac{\lambda^2 \Lambda_{\rm NP}^2}{16\pi^2} < v^2$



$$\Rightarrow \quad BR_{LFV} \gtrsim \left| \frac{1}{16\pi^2} \left[\frac{m_\nu}{\pi v} \right]^{4/3} \right|^2 \sim 10^{-38}$$

still too small... but used same coupling λ for LNV and LFV...

3. many models separate LFV from LNV (SUSY seesaw, type II and inverse seesaws, NP for flavour anomalies...) and predict $BR_{LFV} \lesssim$ expt. Study such models here.

What are $\mathcal{O}_{Alight}, \mathcal{O}_{Aheavy\perp}$?

$$\mathcal{O}_{Alight,X} \sim 0.7(\overline{e}P_X\mu)\Big[(\overline{u}u) + (\overline{d}d) + ...\Big] + 0.13(\overline{e}\gamma^\alpha P_X\mu)\Big[(\overline{u}\gamma_\alpha u) + (\overline{d}\gamma_\alpha d)\Big]$$

$$\mathcal{O}_{Aheavy\perp,X} \simeq (\overline{e}\gamma^\alpha P_X\mu)\Big[0.56(\overline{u}\gamma_\alpha u) + 0.8(\overline{d}\gamma_\alpha d)\Big] + ...$$

obtained by matching nucleons to quarks, then writing

$$\mathcal{O}_{Aheavy,X} = \mathcal{O}_{Alight,X} + \epsilon\mathcal{O}_{Aheavy\perp,X}$$

where ϵ calculable misalignement $\simeq 5\%$.

problem: scalar density of u quarks in $N \in \{n,p\} \simeq$ scalar density of d quarks $\Rightarrow$ with current theory uncertainties in $\mu A \to eA$, measuring C_S^n and C_S^p only allows to determine $C_S^u + C_S^d$ (but not $C_S^u - C_S^d$).

($L \leftrightarrow R$ not identical in SMEFT, but not worry)

take observable-motivated basis to Λ_{NP}?

1. $\mu \to e\gamma$ measures $C_{D,R}(m_\mu)$

solving RGEs gives $\vec{C}(m_\mu) = \vec{C}(m_W)\boldsymbol{G}(m_\mu, m_W)$, $\Rightarrow$ define $\vec{v}_{\mu\to e\gamma}(m_\mu, \Lambda)$such that:

$$C_{DR}(m_\mu) = \vec{C}(\Lambda) \cdot \vec{v}_{\mu\to e\gamma}(m_\mu, \Lambda)$$

$$\begin{aligned}
C_{D,X}(m_\mu) \;\; = \;\; & C_{D,X}(m_W)\left(1 - 16\frac{\alpha_e}{4\pi}\ln\frac{m_W}{m_\mu}\right) \\
& -\frac{\alpha_e}{4\pi e}\ln\frac{m_W}{m_\mu}\left(-8\frac{m_\tau}{m_\mu}C^{\tau\tau}_{T,XX} + C^{\mu\mu}_{S,XX} + C_{2loop}\right) \\
& +16\frac{\alpha_e^2}{2e(4\pi)^2}\ln^2\frac{m_W}{m_\mu}\left(\frac{m_\tau}{m_\mu}C^{\tau\tau}_{S,XX}\right) \\
& -8\lambda^{a_T}\frac{\alpha_e}{4\pi e}\ln\frac{m_W}{2\text{ GeV}}\left(-\frac{m_s}{m_\mu}C^{ss}_{T,XX} + 2\frac{m_c}{m_\mu}C^{cc}_{T,XX} - \frac{m_b}{m_\mu}C^{bb}_{T,XX}\right)f_{TD} \\
& +16\frac{\alpha_e^2}{3e(4\pi)^2}\ln^2\frac{m_W}{2\text{ GeV}}\left(\sum_{u,c}4\frac{m_q}{m_\mu}C^{qq}_{S,XX} + \sum_{d,s,b}\frac{m_q}{m_\mu}C^{qq}_{S,XX}\right)
\end{aligned}$$

all coeffs on right side $C(m_W)$ (basis vectors rotate and change length with scale)

$\lambda = \alpha_s(m_W)/\alpha_s(2\text{GeV}) \simeq 0.44$, $f_{TS} \simeq 1.45$, $a_S = 12/23, a_T = -4/23$.

Counting constraints in space of $\sim$100 operators

DKunoYamanaka

Count constraints: (write $\delta\mathcal{L} = C^{flavour}_{Lorentz,XY}/v^n\ \mathcal{O}^{flav}_{Lorentz,XY}$, $X, Y \in \{L, R\}$)

$\boldsymbol{\mu \to e\gamma}$ **:** $BR(\mu \to e\gamma) = 384\pi^2(|C_{D,L}|^2 + |C_{D,R}|^2)$ $\Rightarrow$ **2 constraints**

$\boldsymbol{\mu \to e\bar{e}e}$ **:** (e relativistic $\approx$ chiral, neglect interference between e_L, e_R)

$$
\begin{aligned}
BR &= \frac{|C_{S,LL}|^2}{8} + 2|C_{V,RR} + 4eC_{D,L}|^2 + (64\ln\frac{m_\mu}{m_e} - 136)|eC_{D,L}|^2 \\
&\quad + |C_{V,RL} + 4eC_{D,L}|^2 + \{L \leftrightarrow R\}
\end{aligned}
$$

$\Rightarrow$ **6 more constraints**

$\boldsymbol{\mu A \to eA}$ **:**(S^N_A,V^N_A=integral over nucleus A of N distribution$\times$lepton wavefns, **different** for diff. A)

$$BR_{SI} \sim Z^2|V^p_A\tilde{C}^p_{V,L} + S^p_A\tilde{C}^p_{S,R} + V^n_A\tilde{C}^n_{V,L} + S^b_A\tilde{C}^n_{S,R} + D_AC_{D,R}|^2 + |L \leftrightarrow R|^2$$

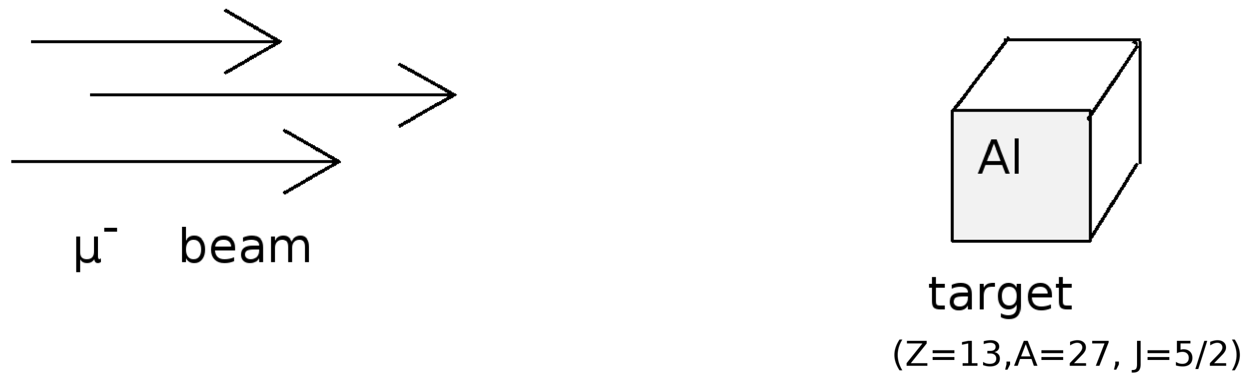
$$BR_{SD} \sim |\tilde{C}^N_A + 2\tilde{C}^N_T|^2$$

SI bds on Au, Ti, (+ SD on ?Ti, Au?) $\Rightarrow$ **$4+2$ more constraints**

future: improved theory, 3SI+2SD targets $\Rightarrow$ **6+4** constraints

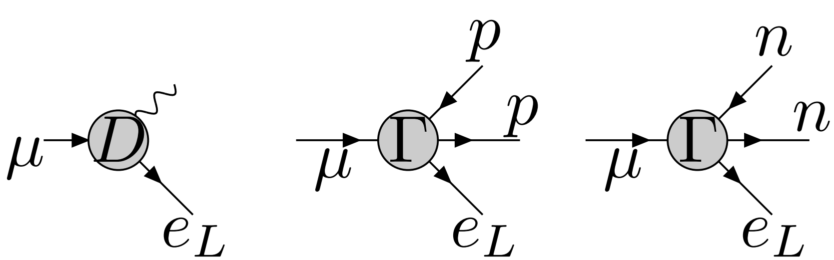
is 12-20 constraints on ~ 100 operators a problem?

$\mu A \to eA$: most sensitive process, expt + th



- μ^- captured by Al nucleus, tumbles down to $1s$. $(r \sim Z\alpha/m_\mu \gtrsim r_{Al})$
- in SM: muon "capture" $\mu + p \to \nu + n$, or decay-in-orbit
- LFV:μ interacts with $\vec{E}$, nucleons (via $\widetilde{C}^N_{\Gamma,X}(\bar{e}\Gamma P_X N)(\bar{N}\Gamma N)$), converts to e

$(E_e \approx m_\mu$ so $e_L/e_R)$



$$\Gamma = \{I, \gamma_5, \gamma^\alpha, \gamma^\alpha\gamma_5, \sigma\}$$
$$\Gamma = \{S, P, V\ ,\ A\ ,\ T\}$$

$\approx$ WIMP scattering on nuclei

1) "Spin Independent" rate $\propto A^2$ (amplitude $\propto \sum_N \propto A$)

KitanoKoikeOkada

$$BR_{SI} \sim \quad Z^2|\sum ...\tilde{C}_{SI}|^2 \quad , \qquad \tilde{C}_{SI} \in \{\tilde{C}^p_V, \tilde{C}^p_S, \tilde{C}^n_V, \tilde{C}^n_S, C_D\}$$

2) "Spin Dependent" rate $\sim \Gamma_{SI}/A^2$ (sum over $N \propto$ spin of only unpaired nucleon)

$$BR_{SD} \sim ...|\tilde{C}^N_A + 2\tilde{C}^N_T|^2$$

CiriglianoDavidsonKuno
HoferichterEtal

Can't we do without RGEs, etc?

in discovery mode for LFV+electroweak loops are small...include later?

counterex: $\mu A \to eA$ in model giving tensor $2\sqrt{2}G_F C_T^{uu}(\overline{e}\sigma P_R\mu)(\overline{u}\sigma u)$ at weak scale

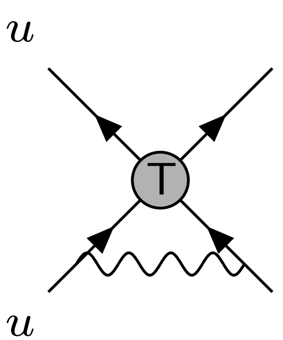
1: forget loops quark tensor matches to nucleon spin $\bar{N}\gamma\gamma_5 N$: $(N \in \{n,p\})$

$$\Rightarrow \boldsymbol{BR(\mu A \to eA) \approx BR_{SD} \approx \tfrac{1}{2}|C_T^{uu}|^2}$$

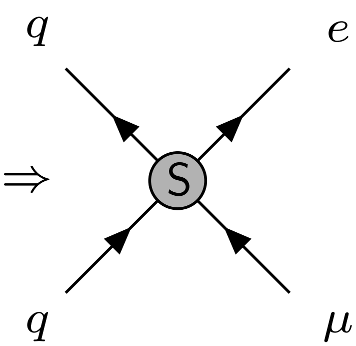
(CiriglianoDKuno)
Hoferichter etal

2: include QED loops $m_W \to 2$ GeV:

$C_T^{uu}(\overline{u}\sigma u)(\overline{e}\sigma P_Y\mu)$



$+\ldots \quad \Rightarrow$



$64\frac{\alpha_e}{4\pi}\log\frac{m_W}{m_\tau}\ C_T^{uu}\ (\overline{u}u)(\overline{e}P_Y\mu)$

$\Delta C_S^{uu}(m_\tau) \sim \frac{1}{7}C_T^{uu}(m_W)$

Then, scalar ops have enhanced nuclear matrix elements, and are SpinIndep:

$$\boldsymbol{BR(\mu A \to eA) \approx BR_{SI} \sim Z^2|2C_T^{uu}|^2 \sim 10^3 BR_{SD}}$$

loops can change Lorentz structure/external legs $\Rightarrow$ different operator whose coefficient better constrained. Important for $\mu \to e$. (?not $\tau \to l$?)

operator list:Kuno-Okada, +CiriglianoKitanoOTuzon +BowmanChengLiMatis

Operator basis $m_\tau \to m_W$: ~ 90 operators

Add QCD×QED-invar operators, representing all 3,4 point interactions of μ with e and *flavour-diagonal* combination of γ, g, u, d, s, c, b. $Y \in L, R$.

$$m_\mu(\overline{e}\sigma^{\alpha\beta}P_Y\mu)F_{\alpha\beta} \qquad dim\ 5$$

$$(\overline{e}\gamma^\alpha P_Y\mu)(\overline{e}\gamma_\alpha P_Y e) \qquad (\overline{e}\gamma^\alpha P_Y\mu)(\overline{e}\gamma_\alpha P_X e)$$

$$(\overline{e}P_Y\mu)(\overline{e}P_Y e) \qquad dim\ 6$$

$$(\overline{e}\gamma^\alpha P_Y\mu)(\overline{\mu}\gamma_\alpha P_X\mu) \qquad (\overline{e}\gamma^\alpha P_Y\mu)(\overline{\mu}\gamma_\alpha P_X\mu)$$

$$(\overline{e}P_Y\mu)(\overline{\mu}P_Y\mu)$$

$$(\overline{e}\gamma^\alpha P_Y\mu)(\overline{f}\gamma_\alpha P_Y f) \qquad (\overline{e}\gamma^\alpha P_Y\mu)(\overline{f}\gamma_\alpha P_X f)$$

$$(\overline{e}P_Y\mu)(\overline{f}P_Y f) \qquad (\overline{e}P_Y\mu)(\overline{f}P_X f) \qquad f \in \{u, d, s, c, b, \tau\}$$

$$(\overline{e}\sigma P_Y\mu)(\overline{f}\sigma P_Y f)$$

$$\frac{1}{m_t}(\overline{e}P_Y\mu)G_{\alpha\beta}G^{\alpha\beta} \qquad \frac{1}{m_t}(\overline{e}P_Y\mu)G_{\alpha\beta}\widetilde{G}^{\alpha\beta} \qquad dim\ 7$$

$$\frac{1}{m_t}(\overline{e}P_Y\mu)F_{\alpha\beta}F^{\alpha\beta} \qquad \frac{1}{m_t}(\overline{e}P_Y\mu)F_{\alpha\beta}\widetilde{F}^{\alpha\beta}$$

...zzz...but ~ 90 coeffs!

$(P_X, P_Y = (1 \pm \gamma_5)/2)$, all operators with coeff $-2\sqrt{2}G_F C$.