# Charged Lepton Flavor Violation - Theory

Roni Harnik,
Fermilab

And now,
for something completely different:

# Hiiiiiiiiiggs!!!!

*“.....for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"*

# Outline

* CLFV in the SM
* CLFV beyond the SM - Effective Field Theories:

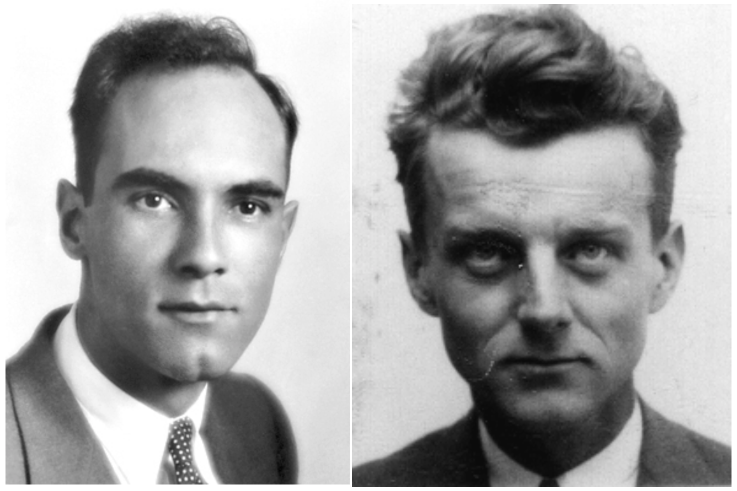
$$\mu \to e\gamma \qquad \tau \to e\gamma \qquad \tau \to \mu\gamma$$

$$\mu \to 3e \qquad \mu + N \to e + N$$

* Examples: Higgs, SUSY, ...
  what will upcoming experiments probe?

# Flavor discovered: $\mu$

- 1936: Anderson and Neddermeyer discover the muon.



- Isidor Rabi sums it up in less than 140 characters:

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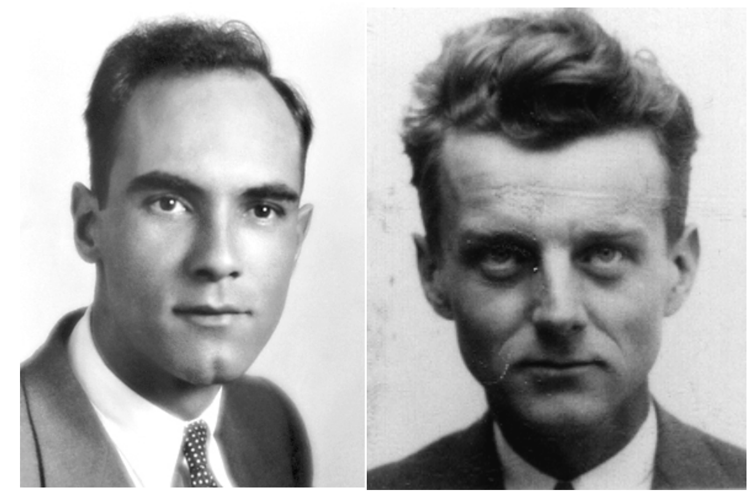

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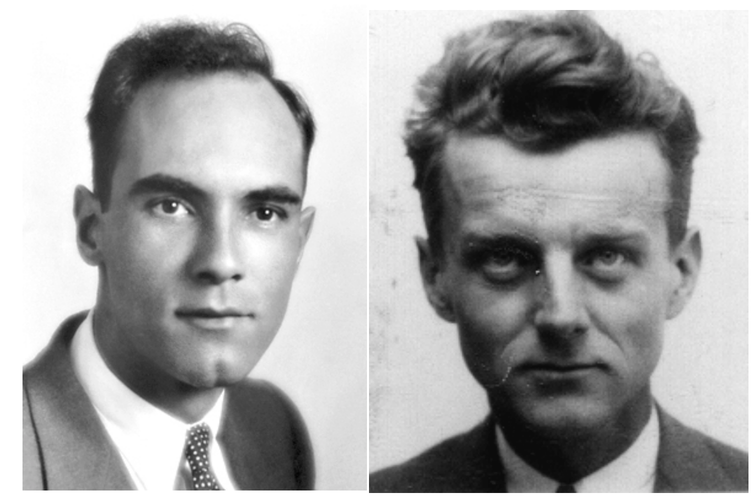

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Rabi's question was
posed over 70 years ago.
It is still unanswered!

Whats with the three flavors?
How are they related?
How do they interact with one another?

This, and the hope to discover new physics, motivate **searches for flavor violation.**

see 1303.6154 for a review.

# CLFV:

$$\mu \to e\gamma \qquad \tau \to e\gamma \qquad \tau \to \mu\gamma$$

$$\mu \to 3e \qquad \mu + N \to e + N$$

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

...

sensitive probes
of new physics.

Some reach where the LHC cannot
(either too heavy or too weakly coupled)

# Flavor in SM

* The charged lepton sector (before neutrino masses):

$$\mathcal{L} \supset y^e_{ij}\tilde{H}\, l^i_L e^j_R \xrightarrow{\text{diagonalize}} y^e_i \tilde{H}\, l^i_L e^i_R$$

* U(3)$^2$ is broken by yukawas to a U(1)$^3$ symmetry:

$$U(1)_e \times U(1)_\mu \times U(1)_\tau$$

Lepton family number

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* $U(3)^2$ is broken by yukawas to a $U(1)^3$ symmetry:

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Lepton family number

---

* Contrast this with the quark sector:

$$\mathcal{L} \supset y^u_{ij} H\, q^i u^j + y^d_{ij} \tilde{H}\, q^i u^j$$

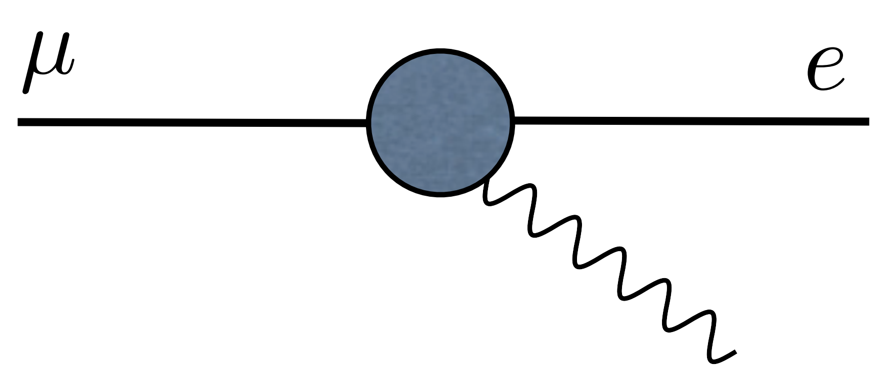
cannot diagonalize simultaneously!

$U(3)^3$ breaks to a $U(1)$.

Baryon number

# Flavor Change

- Recall: symmetry = conservation law.
- $\mu$-number and $e$-number are conserved.
- In this limit: ***no*** charged lepton flavor violation.



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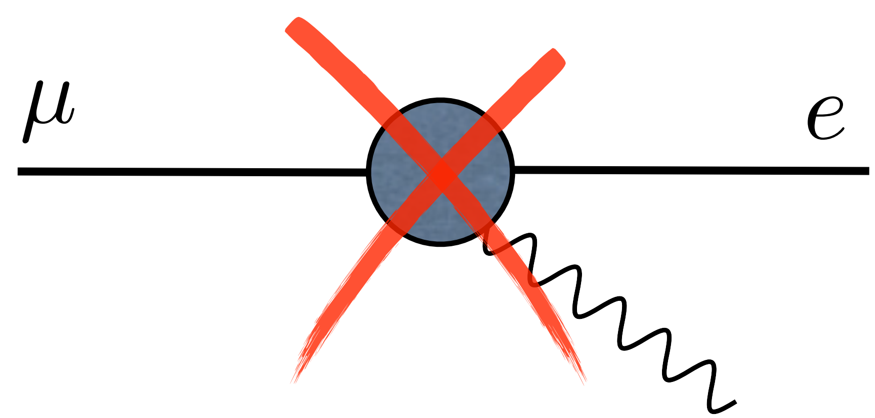

# Flavor in SM

* Now, introduce neutrino masses:

"Majorana":

$$\mathcal{L} \supset y^e_{ij}\tilde{H}\, l^i_L e^j_R + \underbrace{\frac{\lambda_{ij}}{\Lambda}(l^i_L H)(l^j_L H)}_{m^\nu_{ij}\nu^i_L\nu^j_L}$$

-or-

"Dirac":

$$\mathcal{L} \supset y^e_{ij}\tilde{H}\, l^i_L e^j_R + y^\nu_{ij} H\, l^i_L \nu^j_R$$

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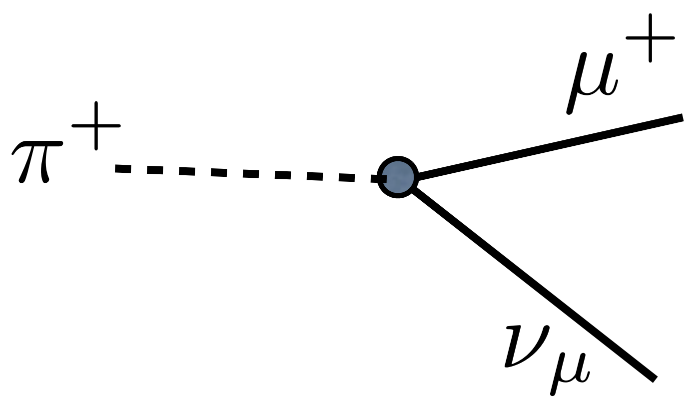
Either way:

the lepton flavor symmetry is broken

# CLFV was Observed!




Neutrino Experiments
(for more on neutrino oscillations:
upcoming lectures in winter).

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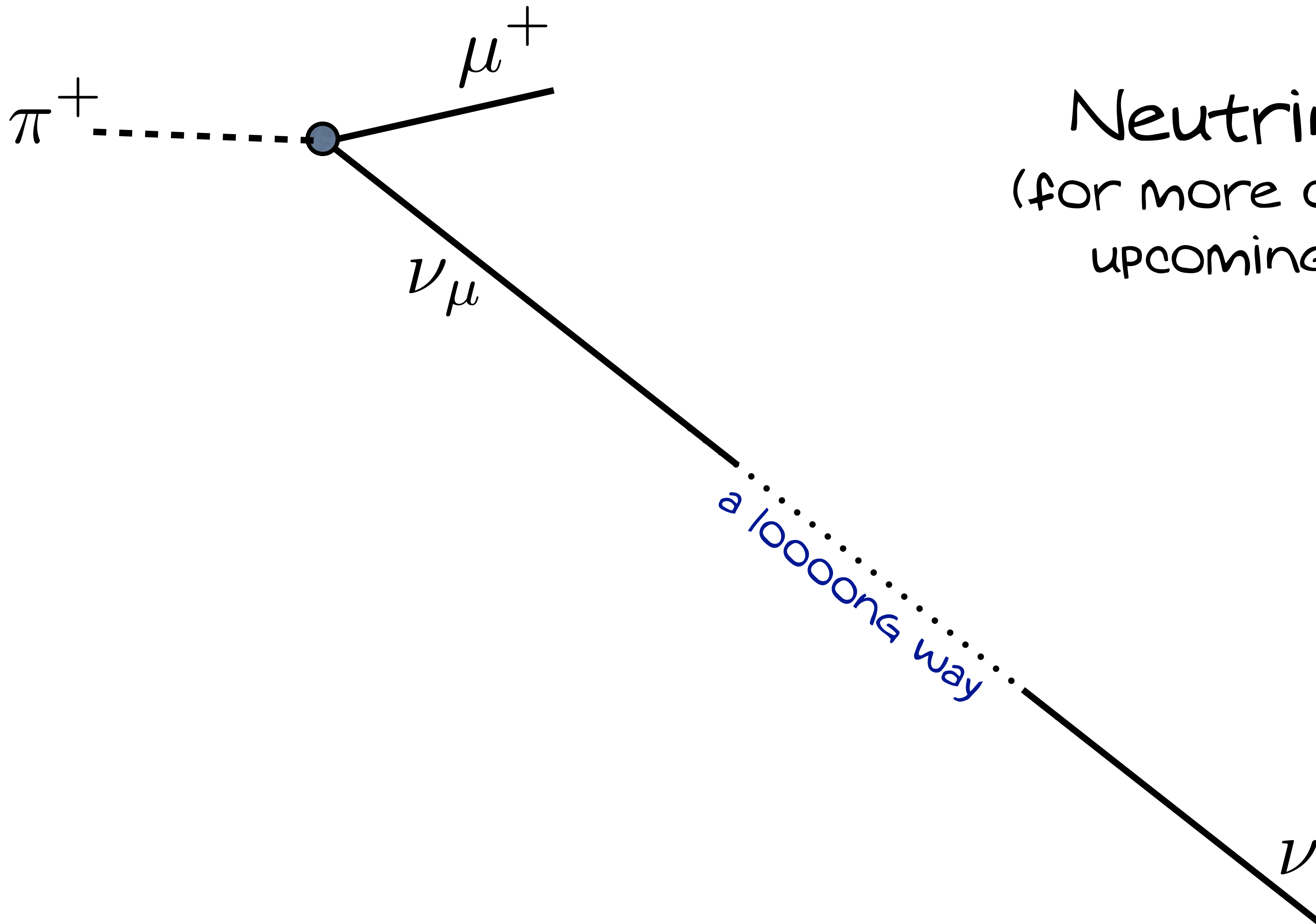


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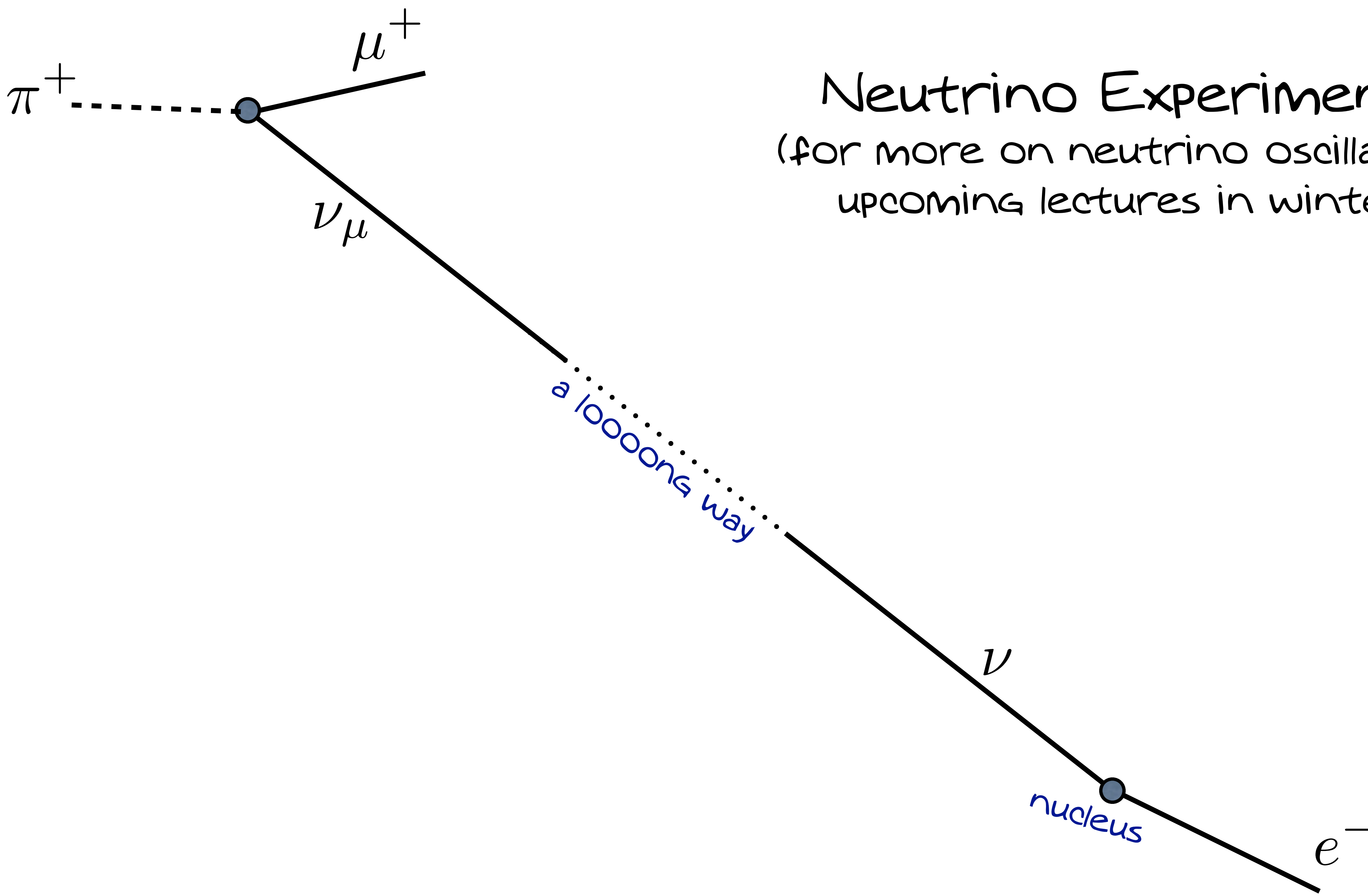


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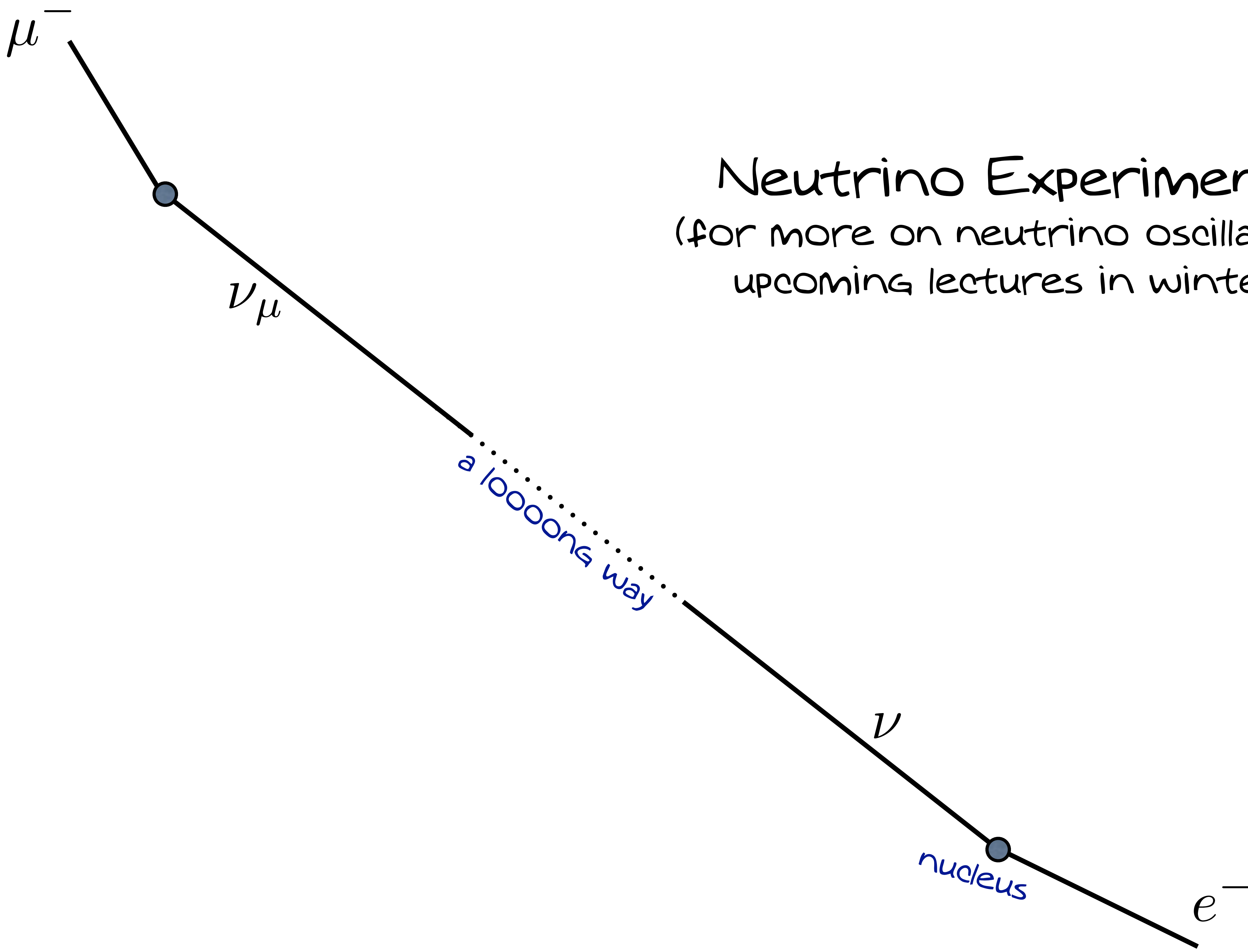


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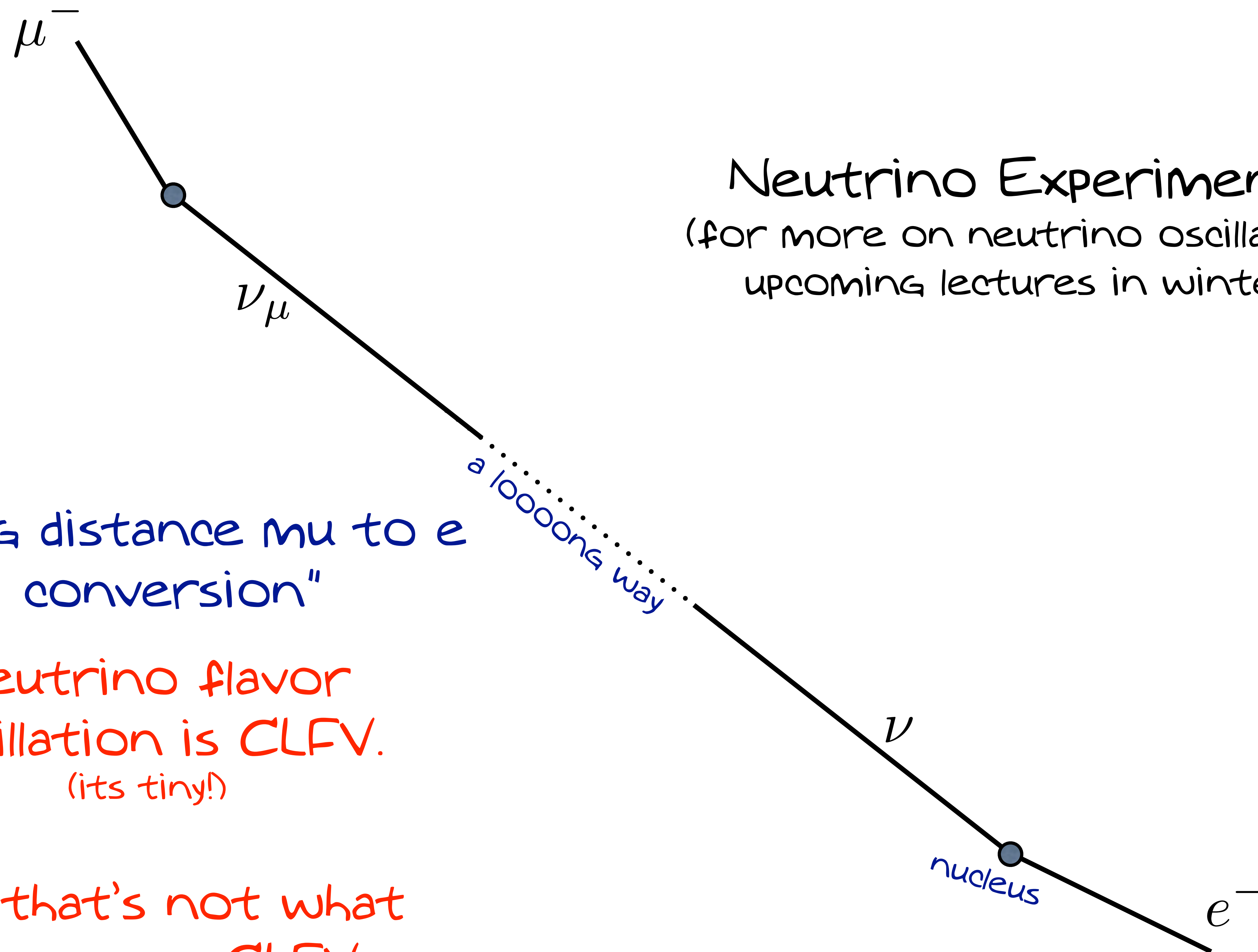



Neutrino Experiments

(for more on neutrino oscillations: upcoming lectures in winter).

"long distance mu to e conversion"

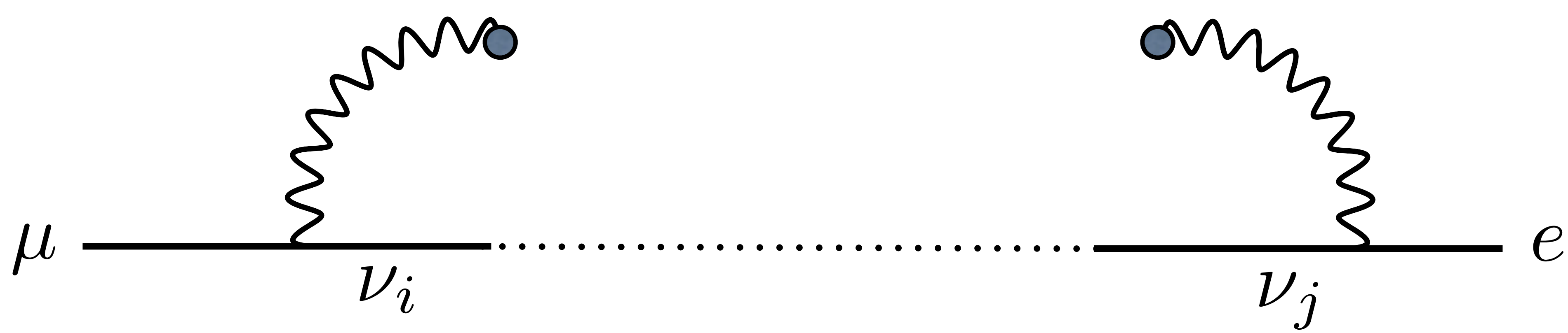
Neutrino flavor oscillation is CLFV.

(its tiny!)

But that's not what we mean by CLFV...

# CLFV in the SM

- We are searching for CLFV at *short* distances.
- Neutrino masses induce this too:



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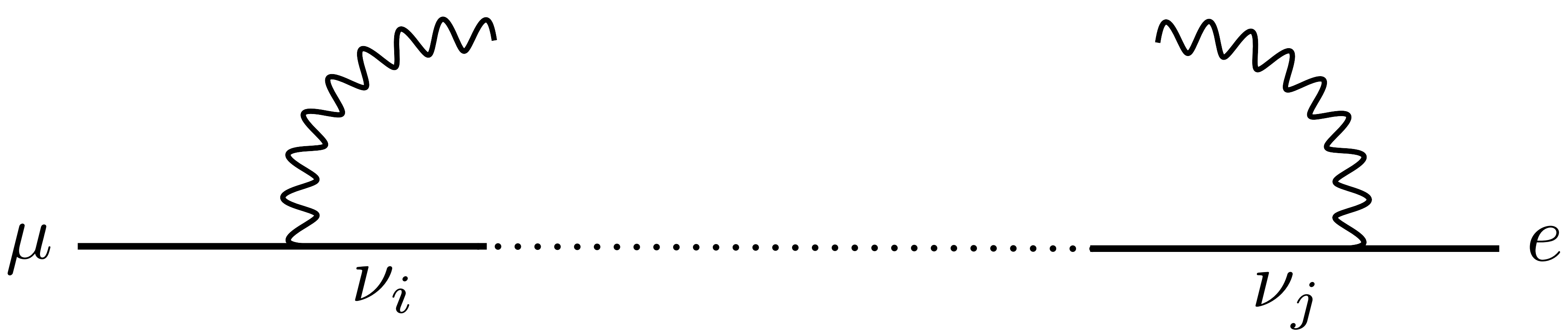

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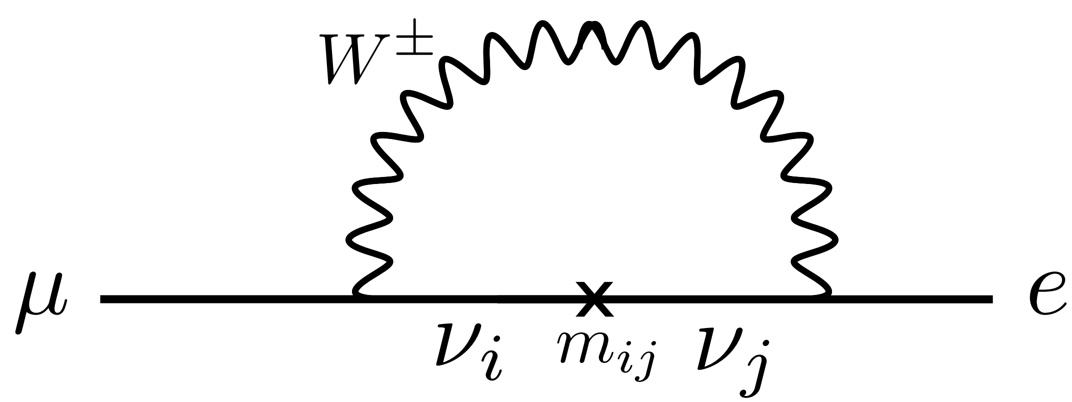

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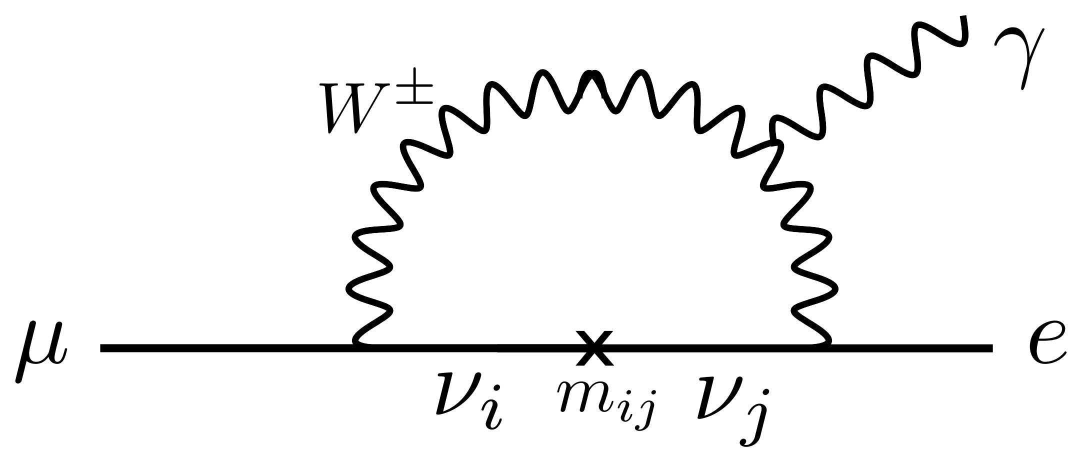
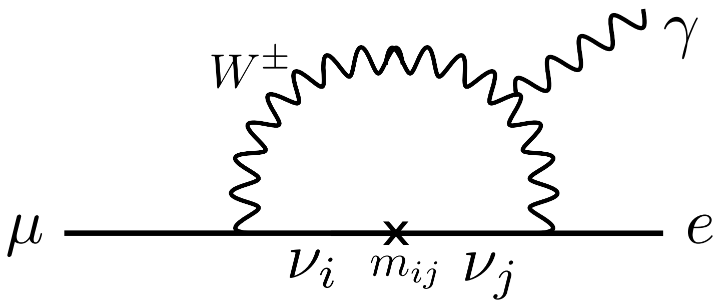


# CLFV in the SM

* Lets *estimate* this diagram, back of the envelope:
  (an aside on lazy model builders)




$\sim$

$$\sim \frac{\alpha}{(4\pi)^3} G_F^2 m_\mu^5 \left( \frac{\Delta m_\nu^2}{m_W^2} \right)^2$$

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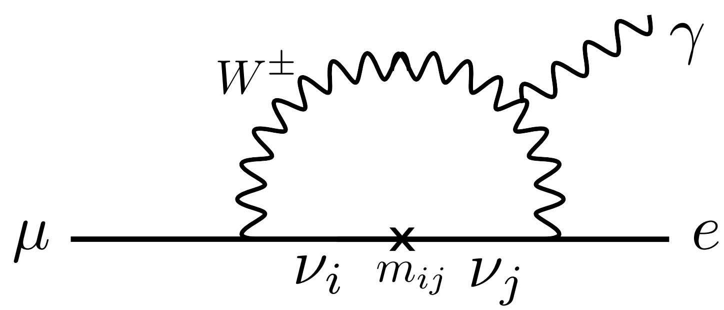


$$\sim \frac{1}{16\pi^2}$$

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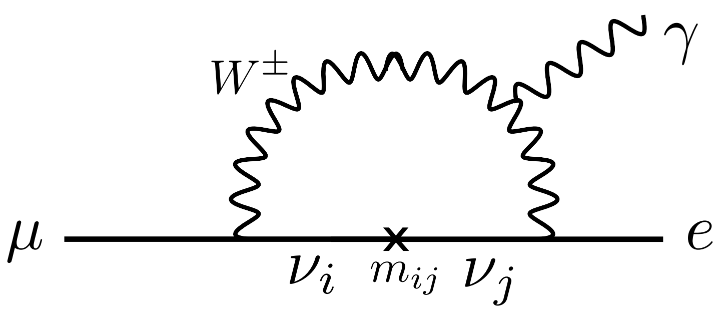


$$\sim \frac{e}{16\pi^2}$$

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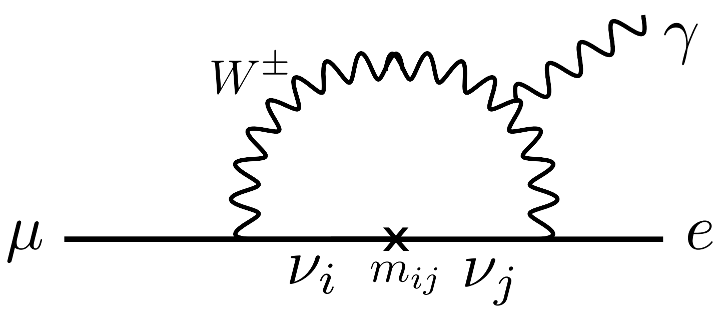


$$\sim \frac{e}{16\pi^2}\frac{g^2}{M_W^4}$$

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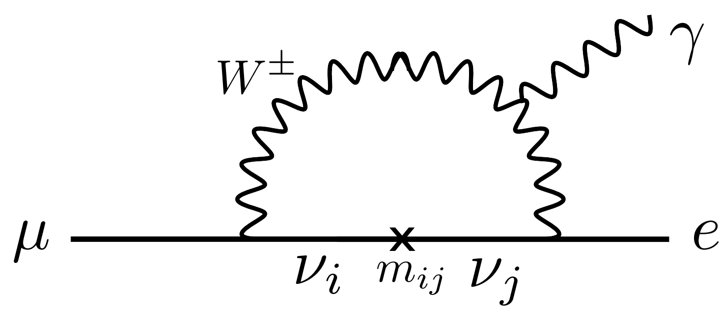


$$\sim \frac{e}{16\pi^2}\frac{g^2}{M_W^4}\sum_i U_{2i}^* U_{i1} m_{\nu i}^2$$

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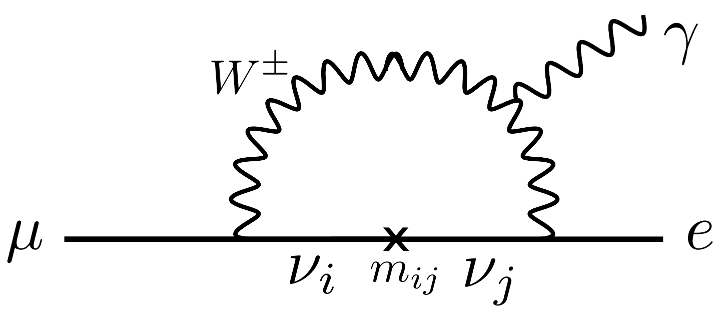


$$\sim \frac{e}{16\pi^2}\frac{g^2}{M_W^4}\underbrace{\sum_i U_{2i}^* U_{i1} m_{\nu i}^2}_{\text{GIM mechanism}}$$

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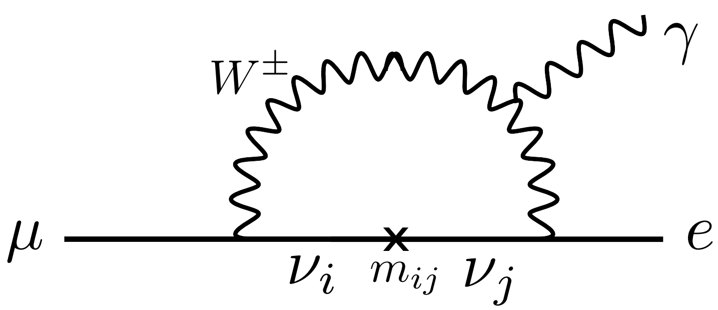


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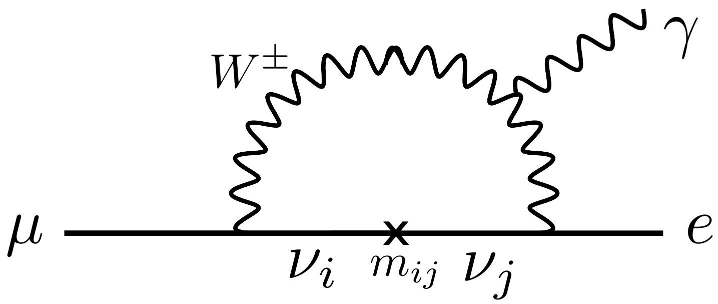


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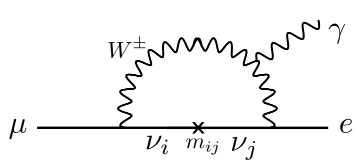
$$\Gamma \sim \Bigg|$$


$$\Bigg|^2 \sim \frac{\alpha}{(4\pi)^3} G_F^2 m_\mu^5 \left(\frac{\Delta m_\nu^2}{m_W^2}\right)^2$$

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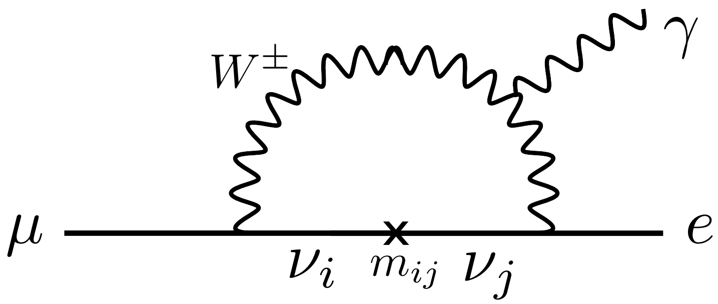


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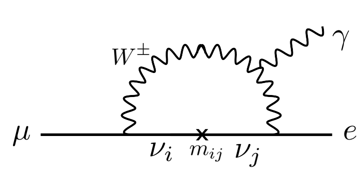
$\Gamma \sim \Big|$  $\Big|^2$



$$\sim \frac{\alpha}{(4\pi)^3} G_F^2 m_\mu^5 \left(\frac{\Delta m_\nu^2}{m_W^2}\right)^2$$ ~ Tiny

# CLFV in the SM

* For the record, the branching ration is:

$$\mathrm{BR}(\mu \to e\gamma)_{\mathrm{SM}} \sim \frac{3\alpha}{32\pi} \left( \frac{\Delta m_\nu^2}{m_W^2} \right)^2 \sim 10^{-54}$$

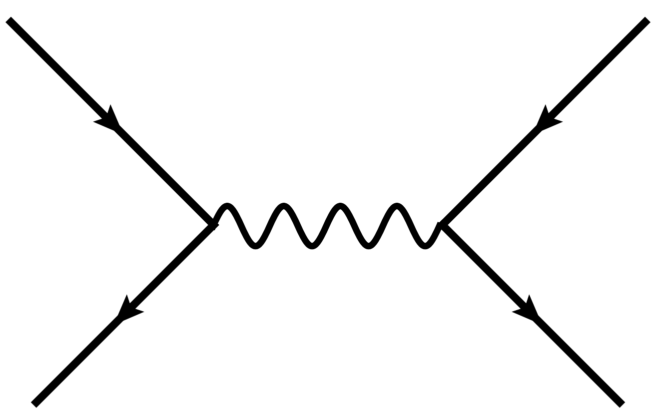
* **Bad news:** we will never observe this.
* **Good news:** we will never observe this. No backgrounds* in the search for BSM!

*Except for the difficult experimental BG's we will hear about in upcoming lectures....

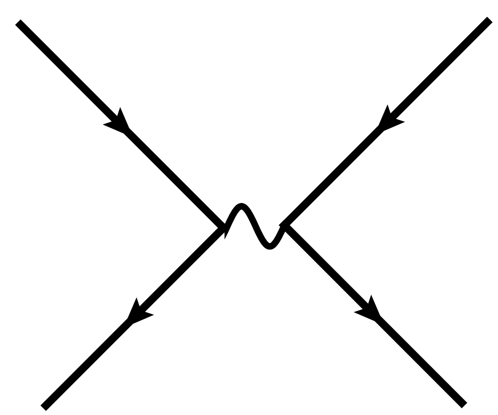
# LFV in BSM:
# Effective Field Theories

# EFT

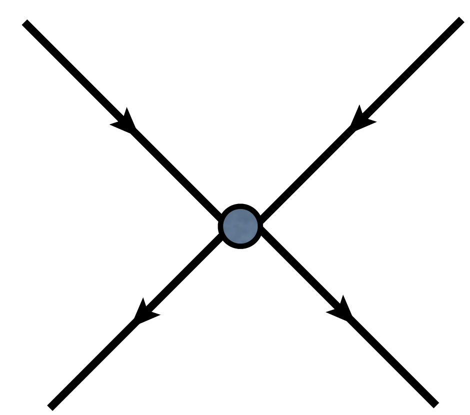
* We would like to consider **heavy new physics** that can mediate CLFV.
* Heavy state propagate for a short distance $\sim M^{-1}$ (e.g. the Yukawa potential).
* **EFT**: a theory that is valid in the IR. Describes distance scales longer than $M^{-1}$. ($M \sim$ cutoff or $\Lambda$)



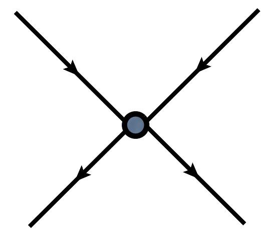
$\rightarrow$



$\simeq$



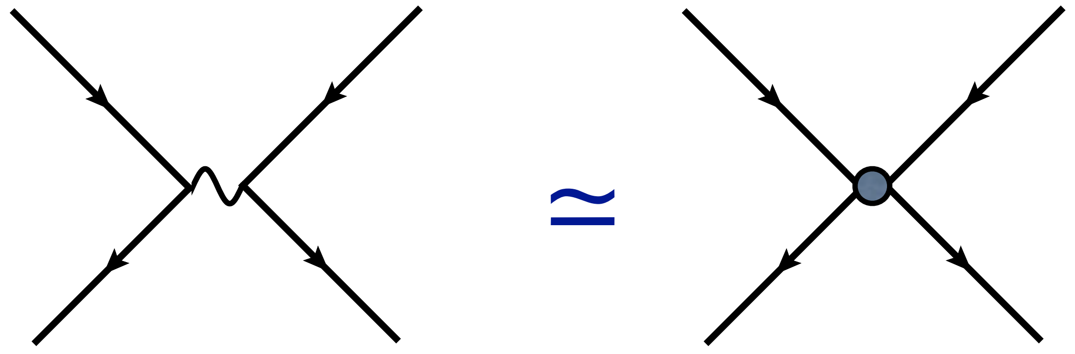
# EFT

- These interactions  are **higher-dimensional operators**.

- Suppressed by powers of the cutoff, $\Lambda$.

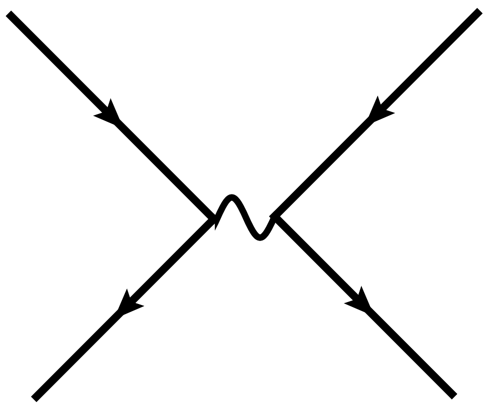
- Also known as **contact interactions**.

- The strength of the interaction is set by matching the EFT to the full theory.



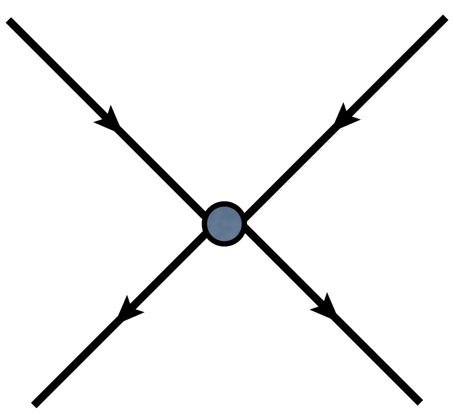
# EFT

* The classic example: weak interactions



$$\sim \quad (\bar{\mu}\gamma^{\mu} P_L \nu_{\mu}) \frac{g^2}{q^2 - m_W^2} (\bar{e}\gamma_{\mu} P_L \nu_e)$$

$$\Big\downarrow \; q^2 \ll m_W^2$$



$$\sim \quad G_F (\bar{\mu}\gamma^{\mu} P_L \nu_{\mu})(\bar{e}\gamma_{\mu} P_L \nu_e)$$

with $G_F \sim \dfrac{g^2}{m_W^2}$

# EFT for $\mu \rightarrow e\gamma$

- We need an operator with an electron, a muon, and a photon.

$$\mu \ , \ e \ , \ A_\mu$$

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$$\frac{1}{\Lambda^2} H \, \bar{\mu}_R \sigma^{\mu\nu} e_L F_{\mu\nu}$$

"dimension six"

# EFT for $\mu \to e\gamma$

* There are only two dipole operators that determine the rate for $\mu \to e\gamma$:

$$\mathcal{L}_{\mu\to e\gamma} = C_L \frac{e}{8\pi^2} m_\mu (\bar{\mu}_R \sigma^{\mu\nu} e_L) F_{\mu\nu} + C_R \frac{e}{8\pi^2} m_\mu (\bar{\mu}_L \sigma^{\mu\nu} e_R) F_{\mu\nu}$$

* The decay rate is

$$\Gamma(\mu \to e\gamma) = \frac{\alpha m_\mu^5}{64\pi^4} (|C_L|^2 + |C_R|^2)$$

<u>note</u>:
the notation is not universal across the literature.

<u>note</u>:
Similar formulea for tau to e gamma and tau to mu gamma.

# EFT for $\mu \to e$ Conversion

- Now there is no photon in the final state.
- Many more operators:

$$
\begin{aligned}
\mathcal{L}_{\rm int} \;=\; & -\frac{4G_{\rm F}}{\sqrt{2}}\left(m_\mu A_R \bar{\mu}\sigma^{\mu\nu}P_L e F_{\mu\nu} + m_\mu A_L \bar{\mu}\sigma^{\mu\nu}P_R e F_{\mu\nu} + \text{h.c.}\right) \leftarrow \text{dipoles} \\
& \underbrace{-\frac{G_{\rm F}}{\sqrt{2}}\sum_{q=u,d,s}\Big[ \left(g_{LS(q)}\bar{e}P_R\mu + g_{RS(q)}\bar{e}P_L\mu\right)\bar{q}q
+ \left(g_{LP(q)}\bar{e}P_R\mu + g_{RP(q)}\bar{e}P_L\mu\right)\bar{q}\gamma_5 q
+ \left(g_{LV(q)}\bar{e}\gamma^\mu P_L\mu + g_{RV(q)}\bar{e}\gamma^\mu P_R\mu\right)\bar{q}\gamma_\mu q
+ \left(g_{LA(q)}\bar{e}\gamma^\mu P_L\mu + g_{RA(q)}\bar{e}\gamma^\mu P_R\mu\right)\bar{q}\gamma_\mu\gamma_5 q
+ \frac{1}{2}\left(g_{LT(q)}\bar{e}\sigma^{\mu\nu}P_R\mu + g_{RT(q)}\bar{e}\sigma^{\mu\nu}P_L\mu\right)\bar{q}\sigma_{\mu\nu}q + \text{h.c.}\Big]}_{\text{Contact ops. with quarks}}
\end{aligned}
$$

see Kitano, Koike, Okada, hep-ph/0203110
for even more operators see Petrov and Zhuridov, 1308.6561

# EFT for $\mu \to e$ Conversion

* Consider a muonic atom μ-N. The muon can scatter off the nucleus and convert to e.
* The conversion rate depends on the various coefficients. For example:

$$\text{Dipole:} \quad B_{\mu N \to eN}(Z=13) = 9.9 \left(|A_L|^2 + |A_R|^2\right),$$

$$\text{Scalar:} \quad B_{\mu N \to eN}(Z=13) = 1.7 \times 10^2 \left(|g_{LS(d)}|^2 + |g_{RS(d)}|^2\right),$$

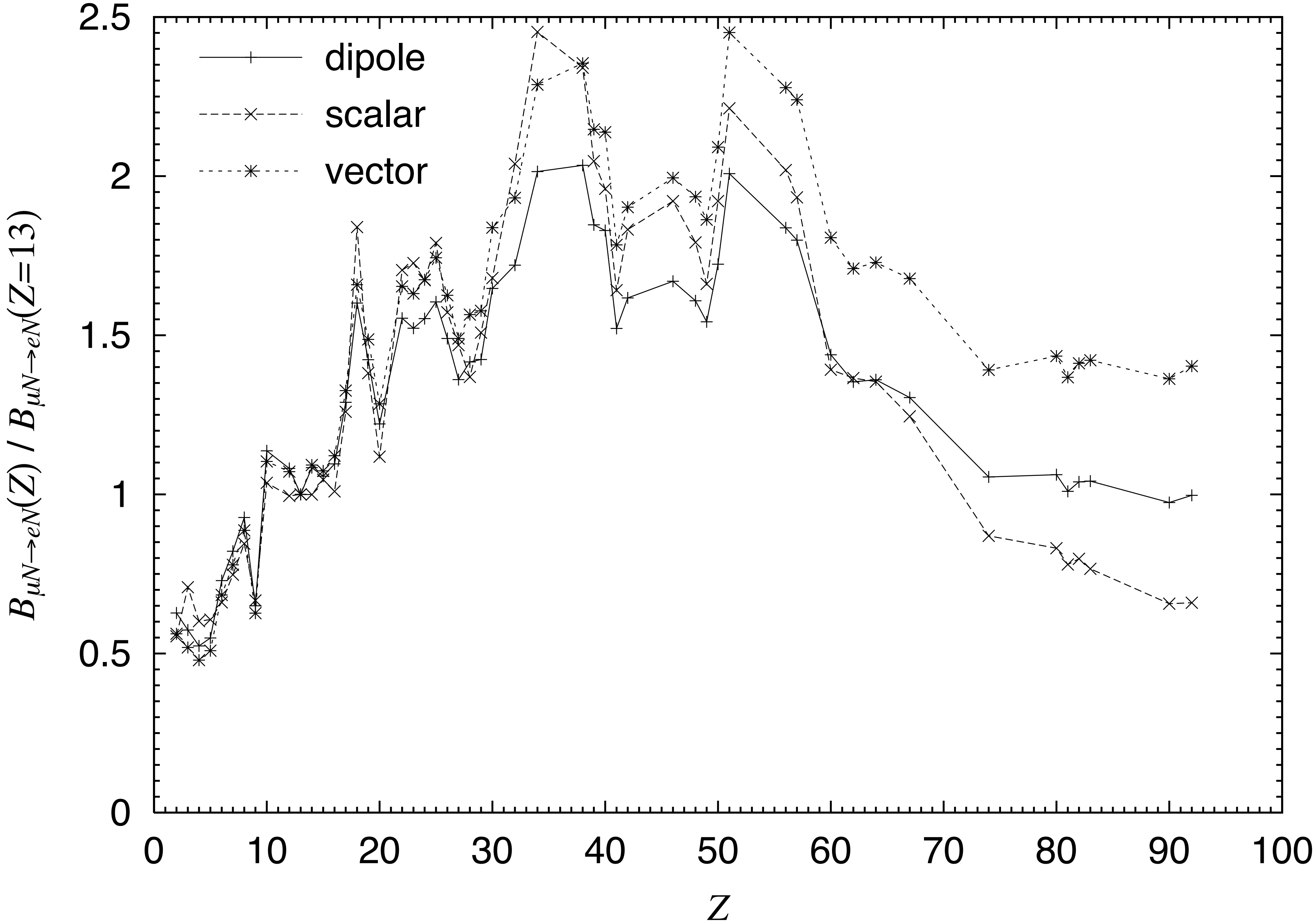
$$\text{Vector:} \quad B_{\mu N \to eN}(Z=13) = 2.0 \left(|\tilde{g}_{LV}^{(p)}|^2 + |\tilde{g}_{RV}^{(p)}|^2\right).$$

* Differences have to do with the nuclear matrix elements (and "atomic matrix element" for dipoles).

see Kitano, Koike, Okada, hep-ph/0203110

# EFT for $\mu \to e$ Conversion

- Strong dependence on atomic number and to the **operator type**:



# EFT for $\mu \to e$ Conversion

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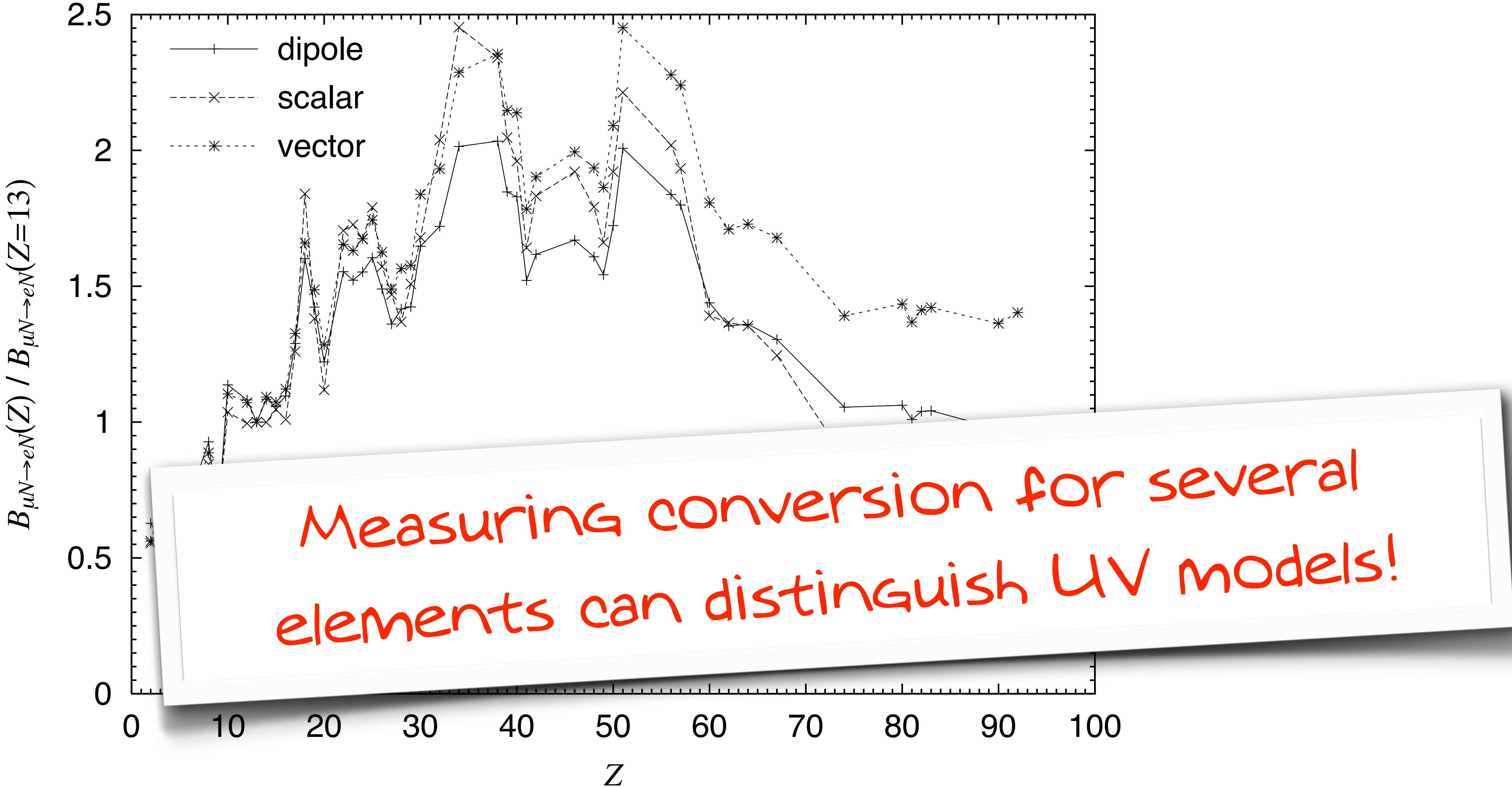


# Decay vs. Conversion

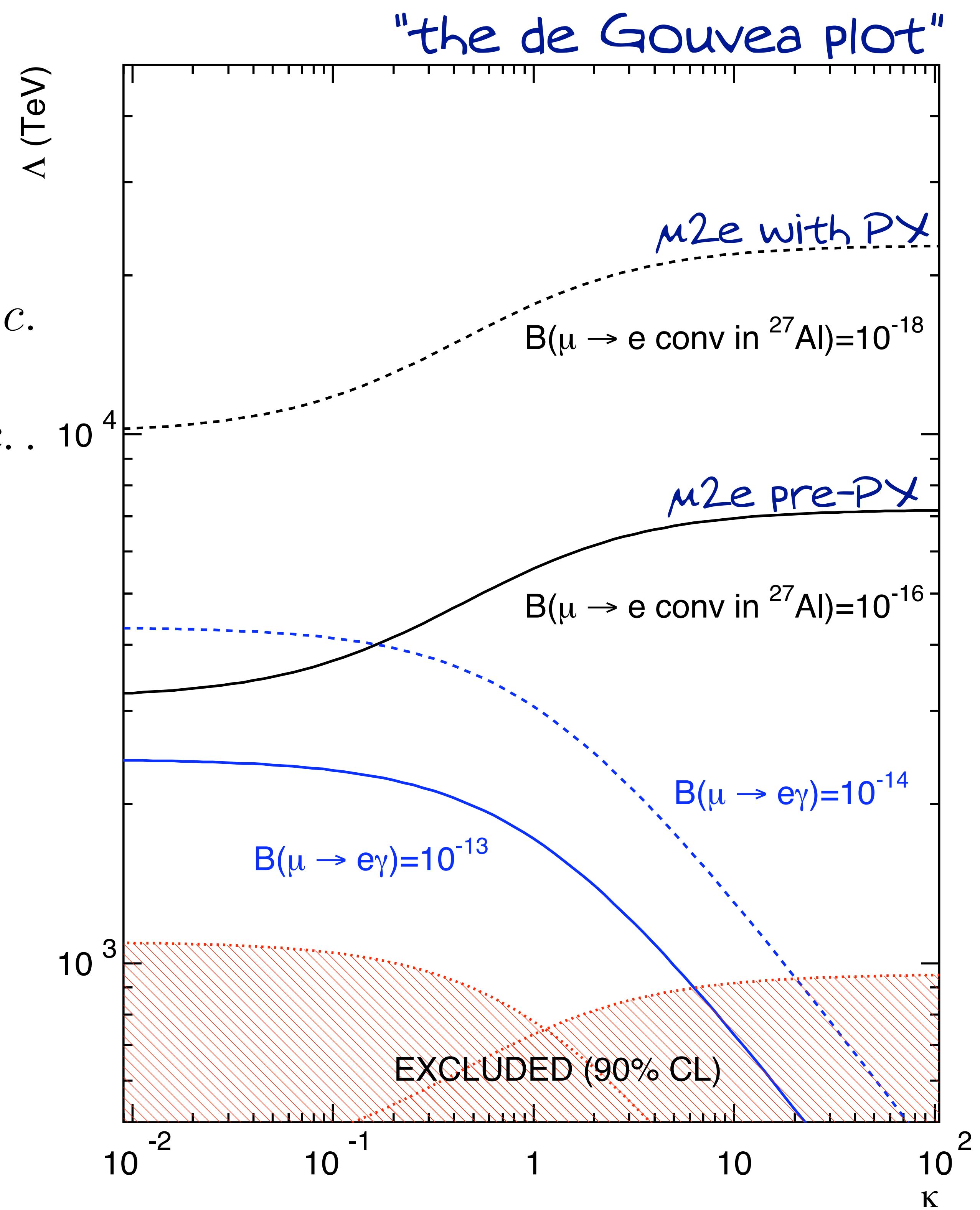
- Pick just two operators, dipole and vector:

$$\mathcal{L}_{\rm CLFV} = \frac{m_\mu}{(\kappa+1)\Lambda^2}\bar{\mu}_R\sigma_{\mu\nu}e_L F^{\mu\nu} + h.c.$$

$$\frac{\kappa}{(1+\kappa)\Lambda^2}\bar{\mu}_L\gamma_\mu e_L\left(\bar{u}_L\gamma^\mu u_L + \bar{d}_L\gamma^\mu d_L\right) + h.c..$$

**μ2e will improve the conversion limit by 4 orders of magnitude!**

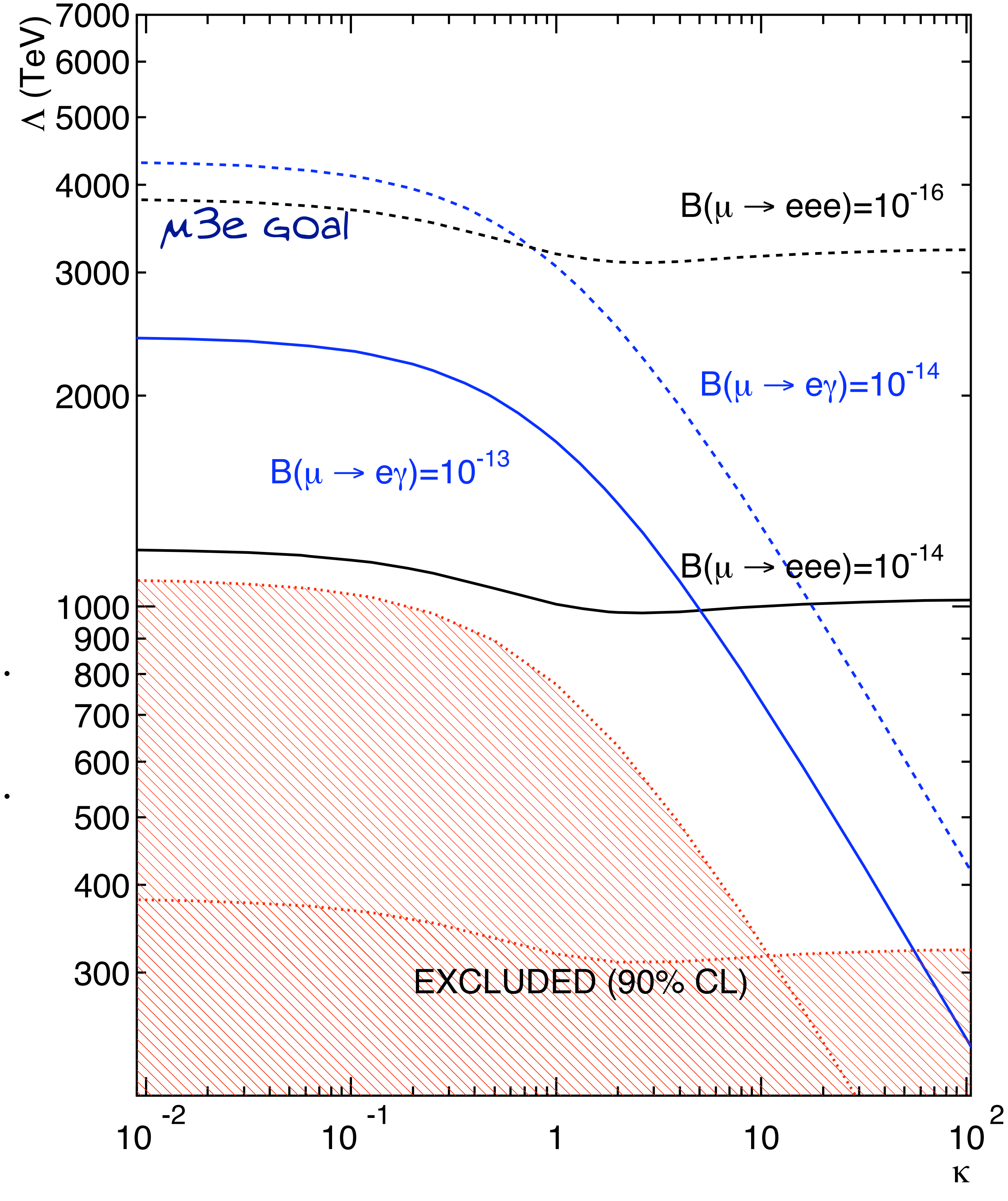
**An order of magnitude in NP scale!**



# EFT for $\mu \to 3e$

- Same interactions as for $\mu \to e$ conversion, but with the quarks replaced by electrons.
- Again, we can pick just two:

$$\mathcal{L}_{\mathrm{CLFV}} = \frac{m_\mu}{(\kappa+1)\Lambda^2}\bar{\mu}_R \sigma_{\mu\nu} e_L F^{\mu\nu} + h.c.$$
$$\frac{\kappa}{(1+\kappa)\Lambda^2}\bar{\mu}_L \gamma_\mu e_L \left(\bar{e}\gamma^\mu e\right) + h.c. .$$



# UV Models

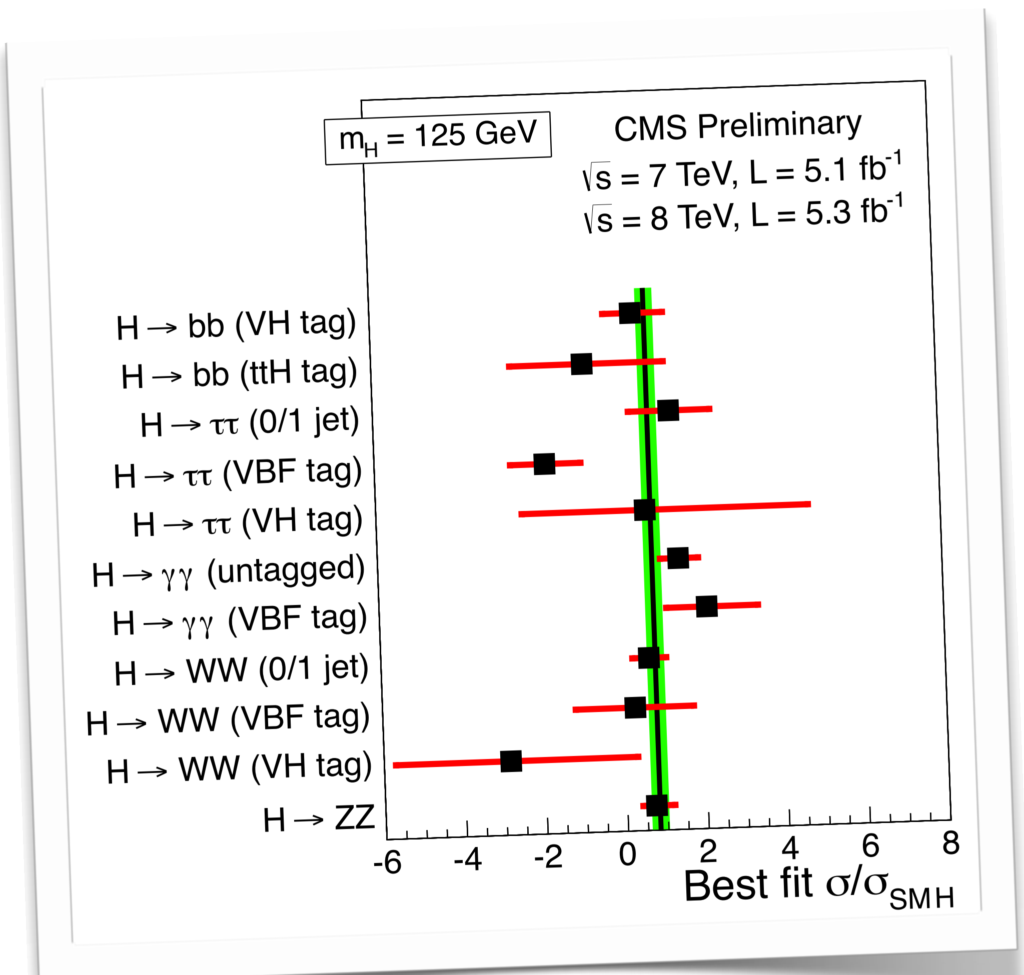
There are many examples.

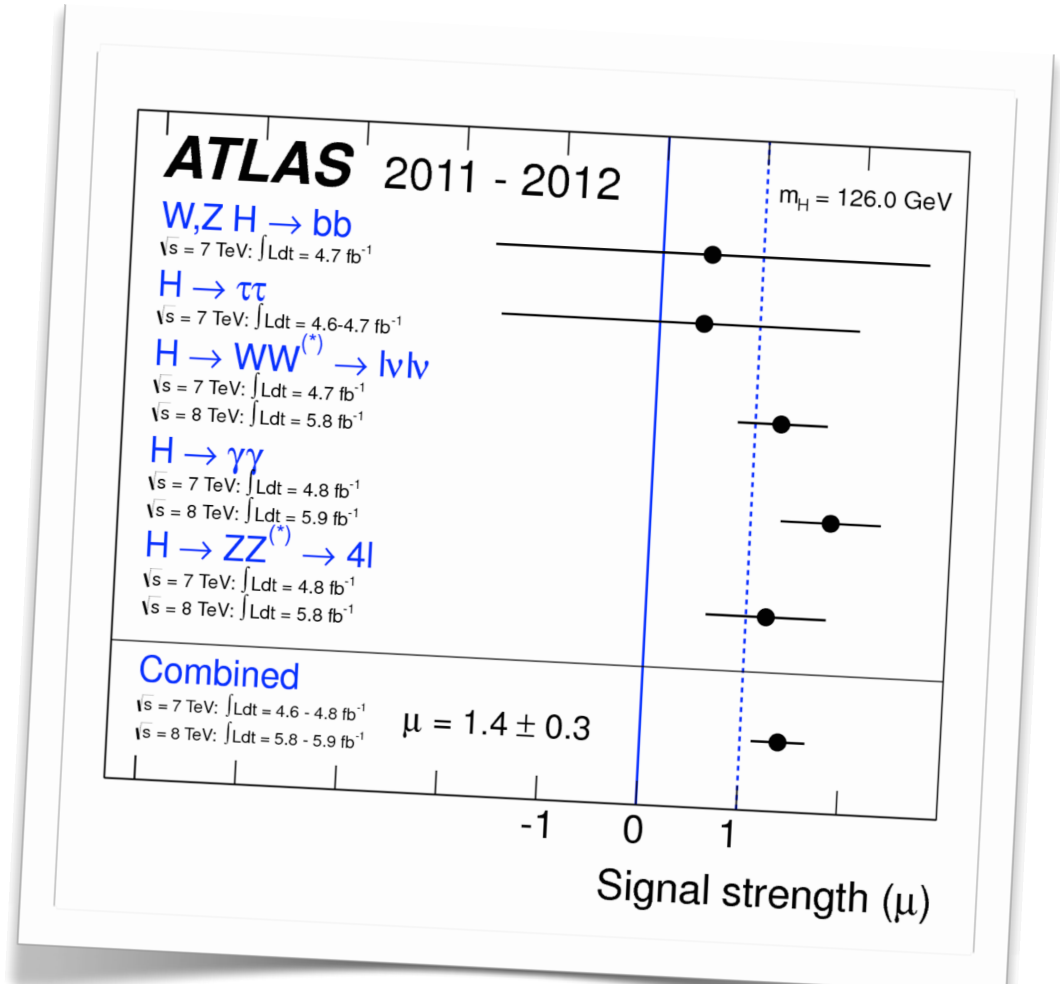
For my personal convenience I will show those that I worked on.

# 1. Higgs
# 2. High Scale SUSY

# Higgs Couplings

- We found the Higgs. Where's the New Physics?



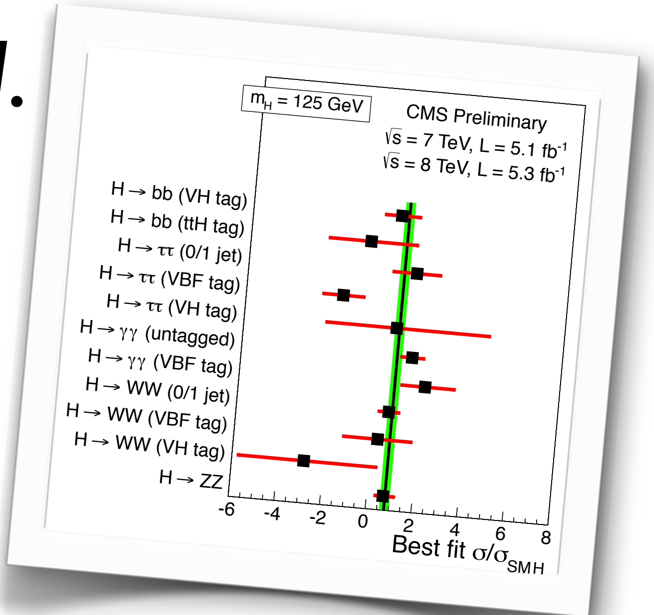




*Many BSM frameworks can lead to modified Higgs couplings.*

A remarkable new opportunity to find NP!

# Higgs Couplings: SM

* The Higgs couplings in the SM are *determined.*
  *Thats why they are so important to measure!*




* Yukawa couplings:

$$\mathcal{L} \supset y_i h f_L^i f_R^i + \text{h.c.} \qquad \text{with} \qquad y_i = \frac{m_i}{v}$$

In the SM Yukawa couplings are:

* Flavor diagonal.
* Real (CP is conserved).

# Can We violate this?

## Can we have FV Higgs couplings?

In the mass basis, could we have

$$\mathcal{L}_Y = -m_i \bar{f}_L^i f_R^i - Y_{ij}(\bar{f}_L^i f_R^j)h + h.c. + \cdots$$

?

# Flavor Violating Higgs

* UV Recipe for FV Higgs:

**1**. Rip a page from a paper that modifies Higgs couplings.

**2**. Sprinkle flavor indices all over the place.

**3**. Re-diagonalize mass matrix.

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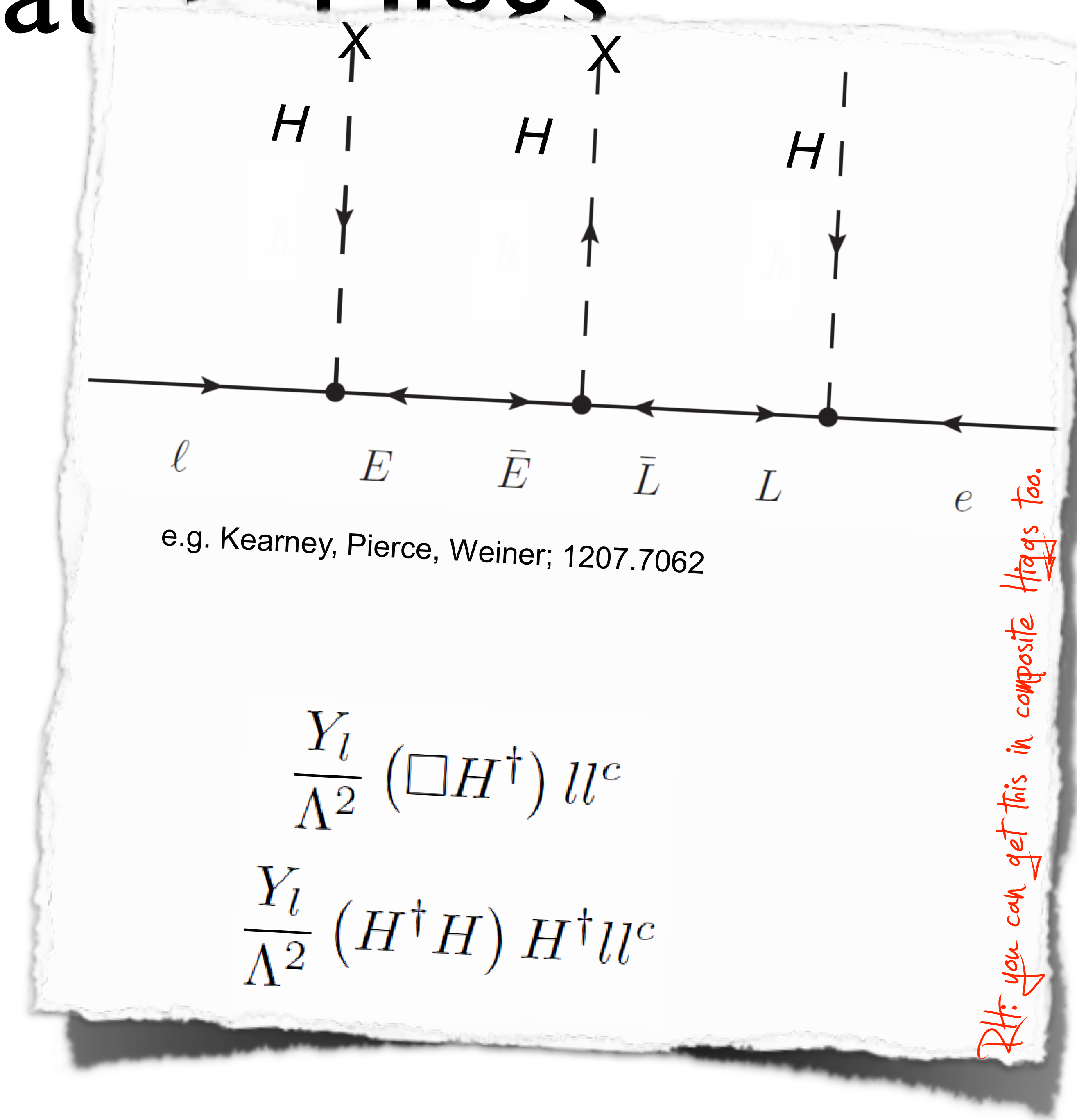

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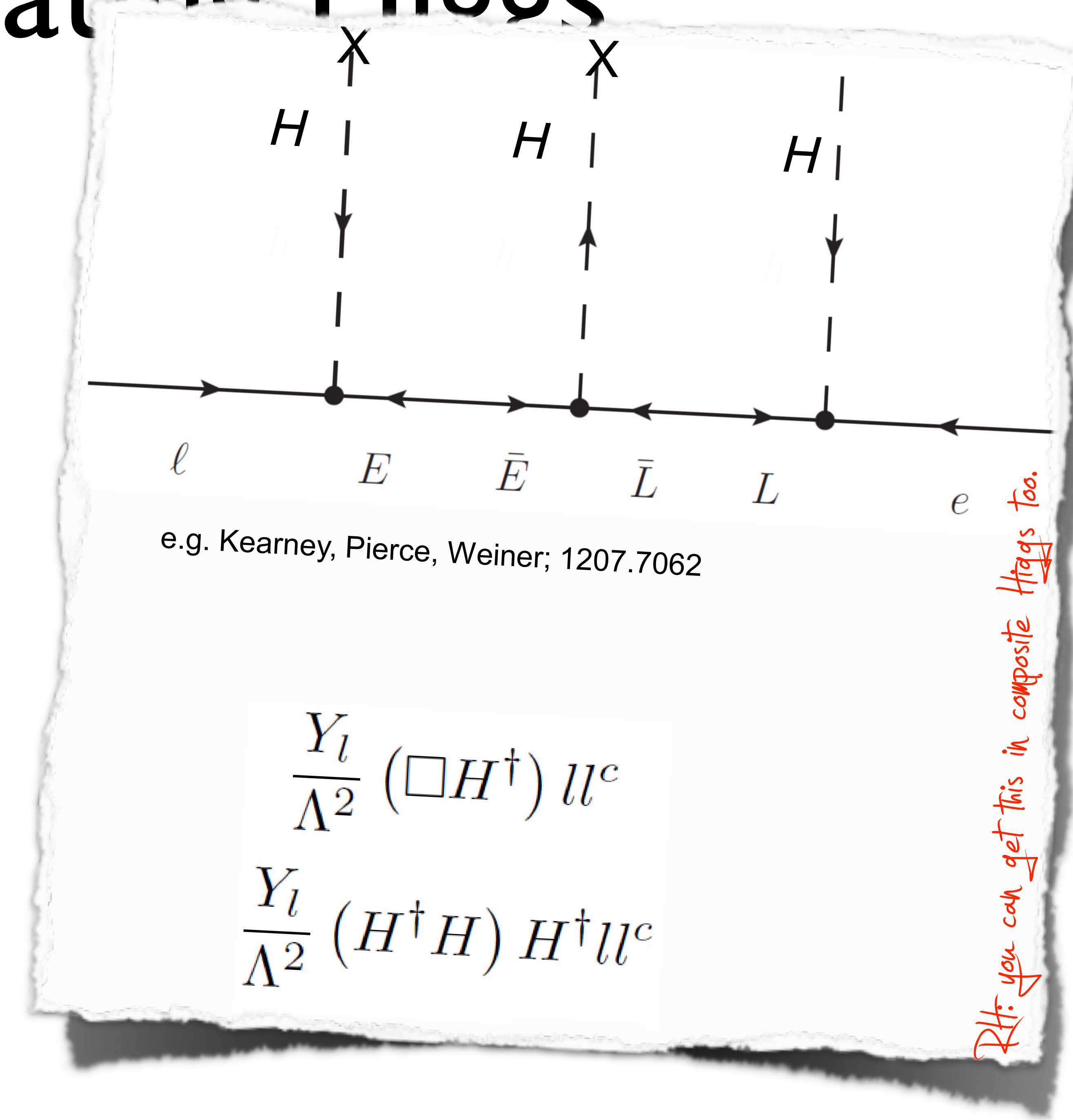


$$\mathcal{L} = \lambda_f H \bar{f} f + \frac{(H^\dagger H) H \bar{f} f}{\Lambda^2}$$

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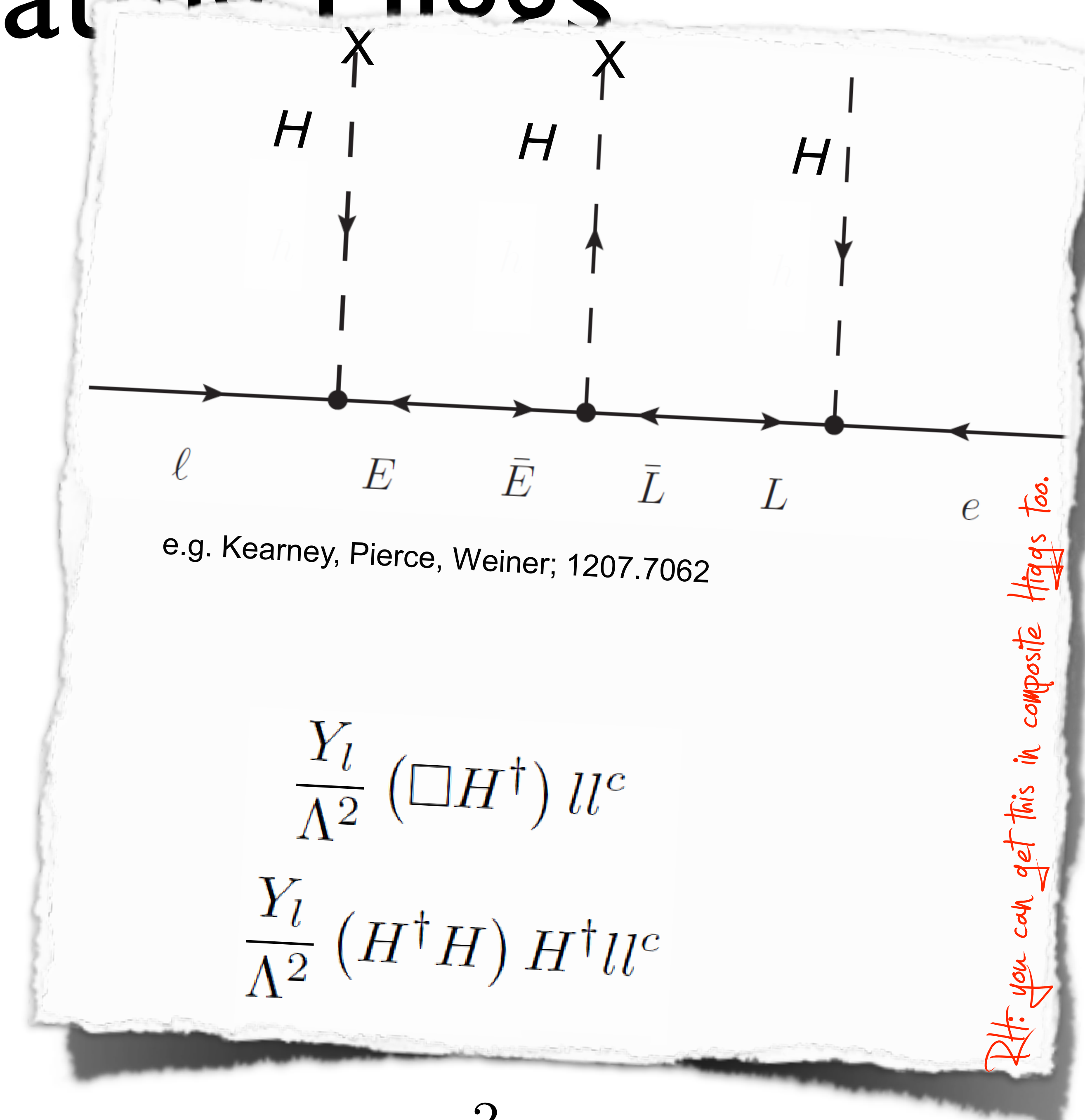


$$\mathcal{L} = \lambda_f H \bar{f} f + \frac{(H^\dagger H) H \bar{f} f}{\Lambda^2}$$

$$m_f = (\lambda_f + \frac{v^2}{\Lambda^2})v$$

$$y_f = \lambda_f + \frac{3v^2}{\Lambda^2}$$

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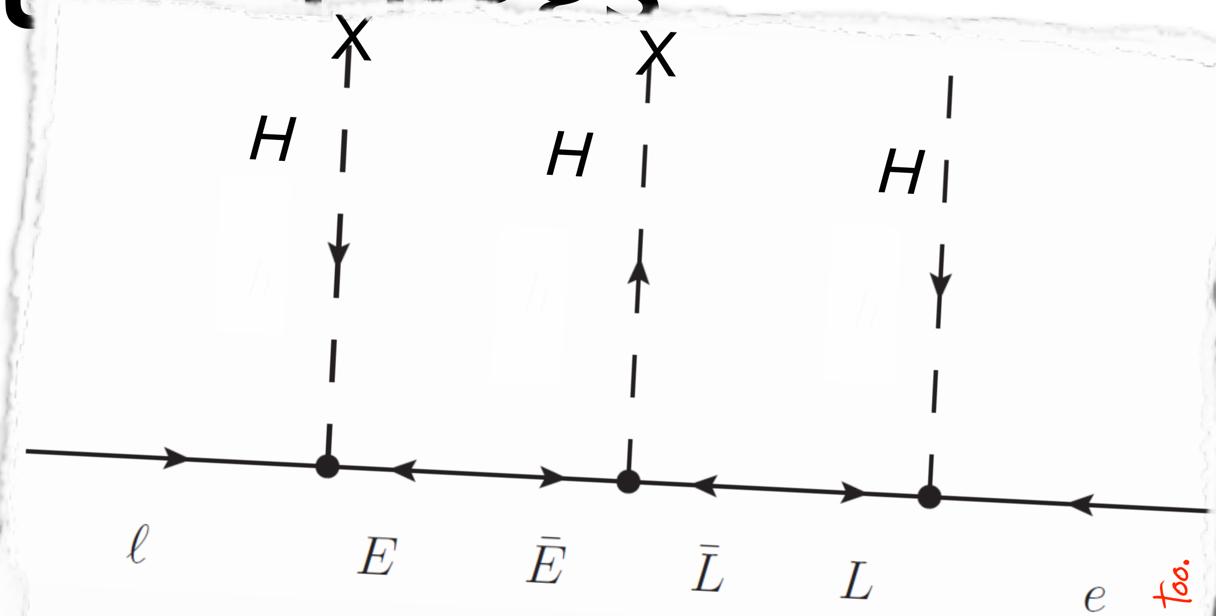


e.g. Kearney, Pierce, Weiner; 1207.7062

$$\frac{Y_l}{\Lambda^2}\left(\Box H^\dagger\right) l l^c$$

$$\frac{Y_l}{\Lambda^2}\left(H^\dagger H\right) H^\dagger l l^c$$

RH: you can get this in composite Higgs too.

$$\mathcal{L} = \lambda_f H \bar{f} f + \frac{(H^\dagger H) H \bar{f} f}{\Lambda^2}$$

$$m_f = (\lambda_f + \frac{v^2}{\Lambda^2})v$$

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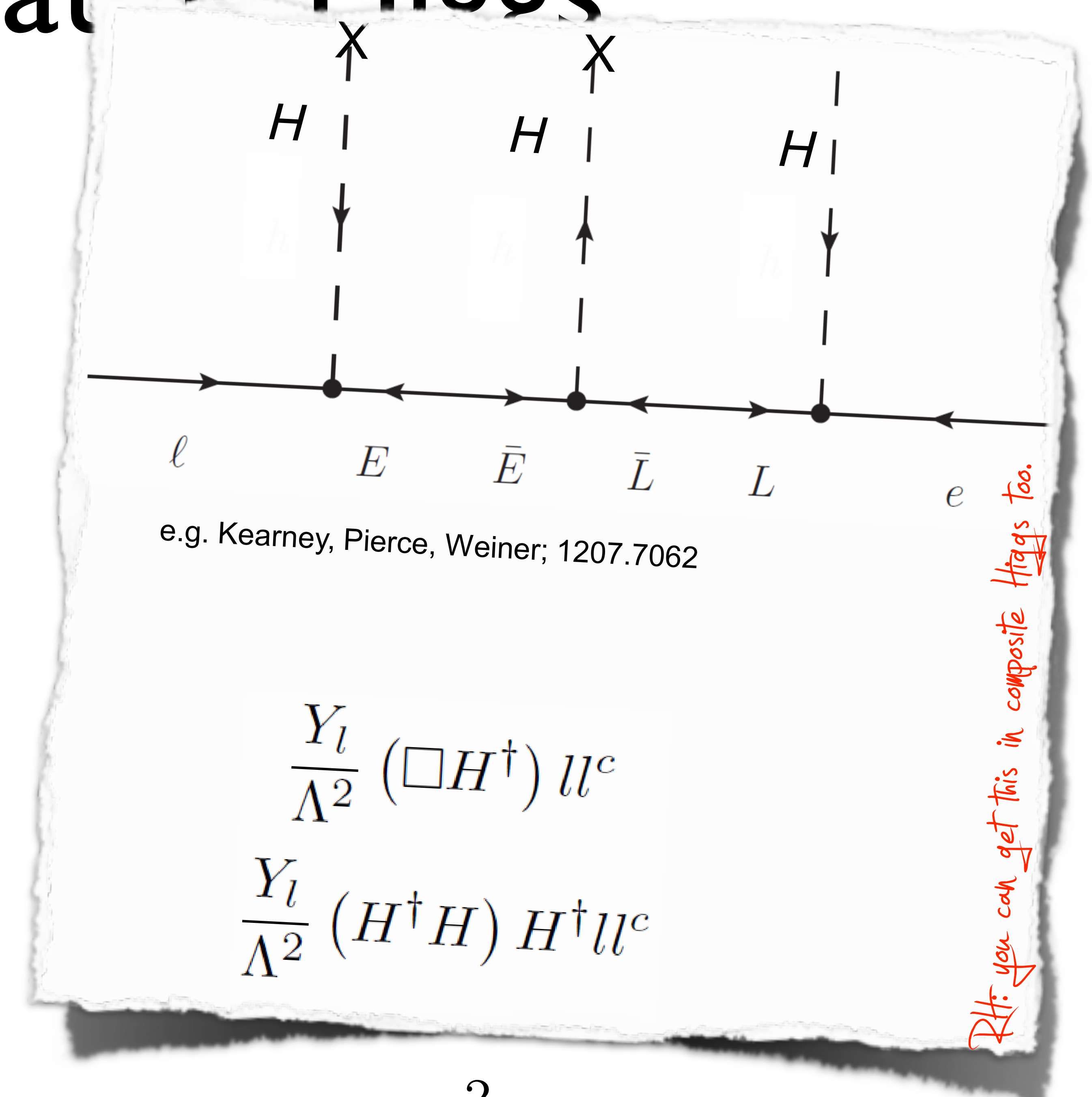


$$\mathcal{L} = \lambda_f H\bar{f}f + \frac{(H^\dagger H)H\bar{f}f}{\Lambda^2}$$

$$m_f = (\lambda_f + \frac{v^2}{\Lambda^2})v$$

$$y_f = \lambda_f + \frac{3v^2}{\Lambda^2} \longrightarrow y_f \neq \frac{m_f}{v}$$

# Flavor Violating Higgs

✱ UV Recipe for FV Higgs:

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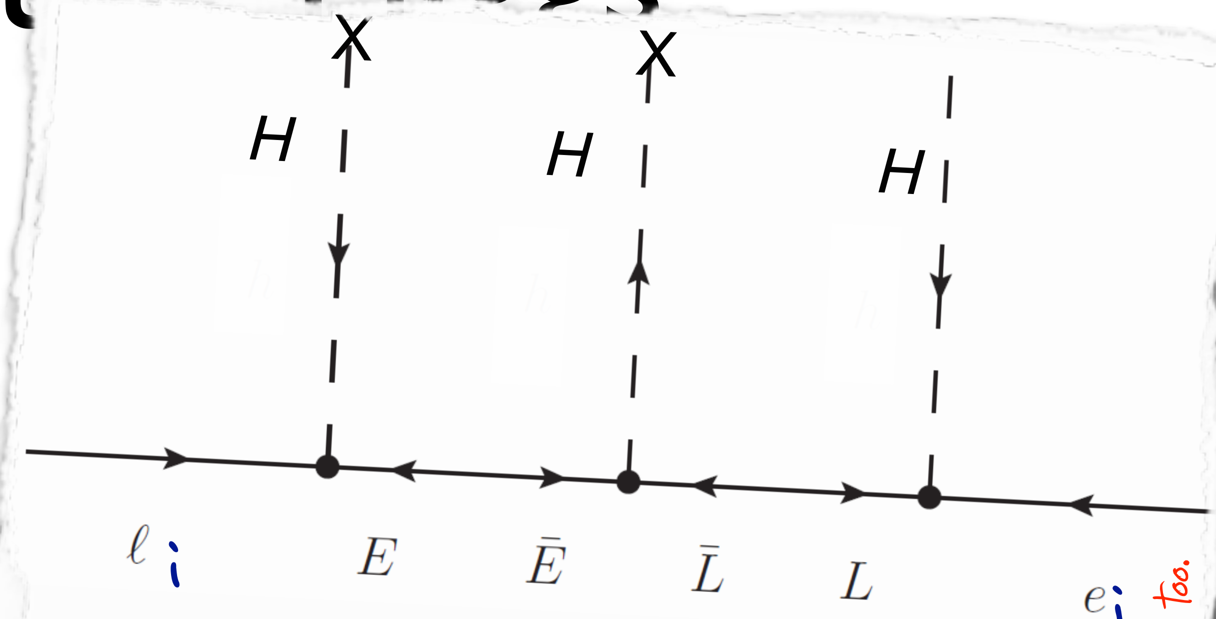



e.g. Kearney, Pierce, Weiner; 1207.7062

$$\frac{Y_{l\,ij}}{\Lambda^2}(\Box H^\dagger)\, l_i l^c_j$$

$$\frac{Y_{l\,ij}}{\Lambda^2}(H^\dagger H)\, H^\dagger l_i l^c_j$$

DH: you can get this in composite Higgs too.

$$\mathcal{L} = \lambda_f H \bar{f} f + \frac{(H^\dagger H) H \bar{f} f}{\Lambda^2}$$

$$m_f = (\lambda_f + \frac{v^2}{\Lambda^2}) v$$

$$y_f = \lambda_f + \frac{3 v^2}{\Lambda^2} \rightarrow y_f \neq \frac{m_f}{v}$$

# Flavor Violating Higgs

- Writing it a bit more neatly, we get:

$$\mathcal{L}_{SM} = \bar{f}_L^j i \not{D} f_L^j + \bar{f}_R^j i \not{D} f_R^j - \left[\lambda_{ij} (\bar{f}_L^i f_R^j) H + h.c.\right]$$
$$+ D_\mu H^\dagger D^\mu H - \lambda_H \left(H^\dagger H - \tfrac{v^2}{2}\right)^2$$

$$\Delta \mathcal{L}_Y = -\frac{\lambda'_{ij}}{\Lambda^2} (\bar{f}_L^i f_R^j) H (H^\dagger H) + h.c. + \cdots$$

# Flavor Violating Higgs

* Writing it a bit more neatly, we get:

$$\mathcal{L}_{SM} = \bar{f}^j_L i\not{D} f^j_L + \bar{f}^j_R i\not{D} f^j_R - \left[\lambda_{ij}(\bar{f}^i_L f^j_R)H + h.c.\right]$$
$$+ D_\mu H^\dagger D^\mu H - \lambda_H \left(H^\dagger H - \tfrac{v^2}{2}\right)^2$$

$$\Delta\mathcal{L}_Y = -\frac{\lambda'_{ij}}{\Lambda^2}(\bar{f}^i_L f^j_R)H(H^\dagger H) + h.c. + \cdots$$

$$\sqrt{2}m = V_L\left[\lambda + \frac{v^2}{2\Lambda^2}\lambda'\right]V_R^\dagger v \qquad \sqrt{2}Y = V_L\left[\lambda + 3\frac{v^2}{2\Lambda^2}\lambda'\right]V_R^\dagger$$

or $$Y_{ij} = \frac{m_i}{v}\delta_{ij} + \frac{v^2}{\sqrt{2}\Lambda^2}\hat{\lambda}_{ij}$$

An arbitrary matrix!
(sort of)

# “Natural” FV

* FV that’s too large comes at a tuning price:

$$\sqrt{2}m = V_L\left[\lambda + \frac{v^2}{2\Lambda^2}\lambda'\right]V_R^\dagger v \qquad \sqrt{2}Y = V_L\left[\lambda + 3\frac{v^2}{2\Lambda^2}\lambda'\right]V_R^\dagger$$

* Requiring no cancelation in the determinant

$$|Y_{\tau\mu}Y_{\mu\tau}| \lesssim \frac{m_\mu m_\tau}{v^2}$$

(same for any pair of fermions)

In an era of data, considerations of fine tuning are not of huge importance...
But we’ll keep it in the back of our mind.

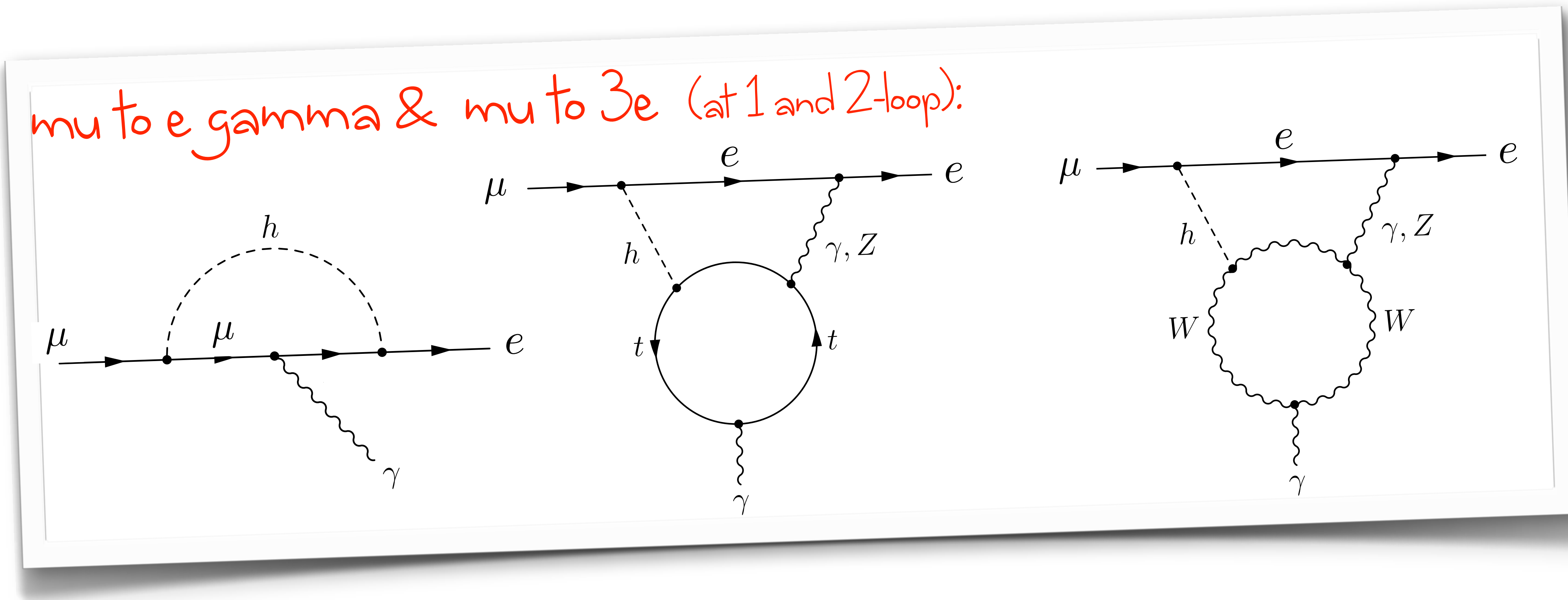
# Leptonic Flavor Violation

$$\mathcal{L}_Y \supset -Y_{e\mu}\bar{e}_L\mu_R h - Y_{\mu e}\bar{\mu}_L e_R h - Y_{e\tau}\bar{e}_L\tau_R h - Y_{\tau e}\bar{\tau}_L e_R h - Y_{\mu\tau}\bar{\mu}_L\tau_R h - Y_{\tau\mu}\bar{\tau}_L\mu_R h + h.c..$$

Which experiments constrain the $Y_{ij}$'s?

# Higgs couplings to $\mu e$

* Higgs coupling to $\mu e$ is constrained, e.g. by:



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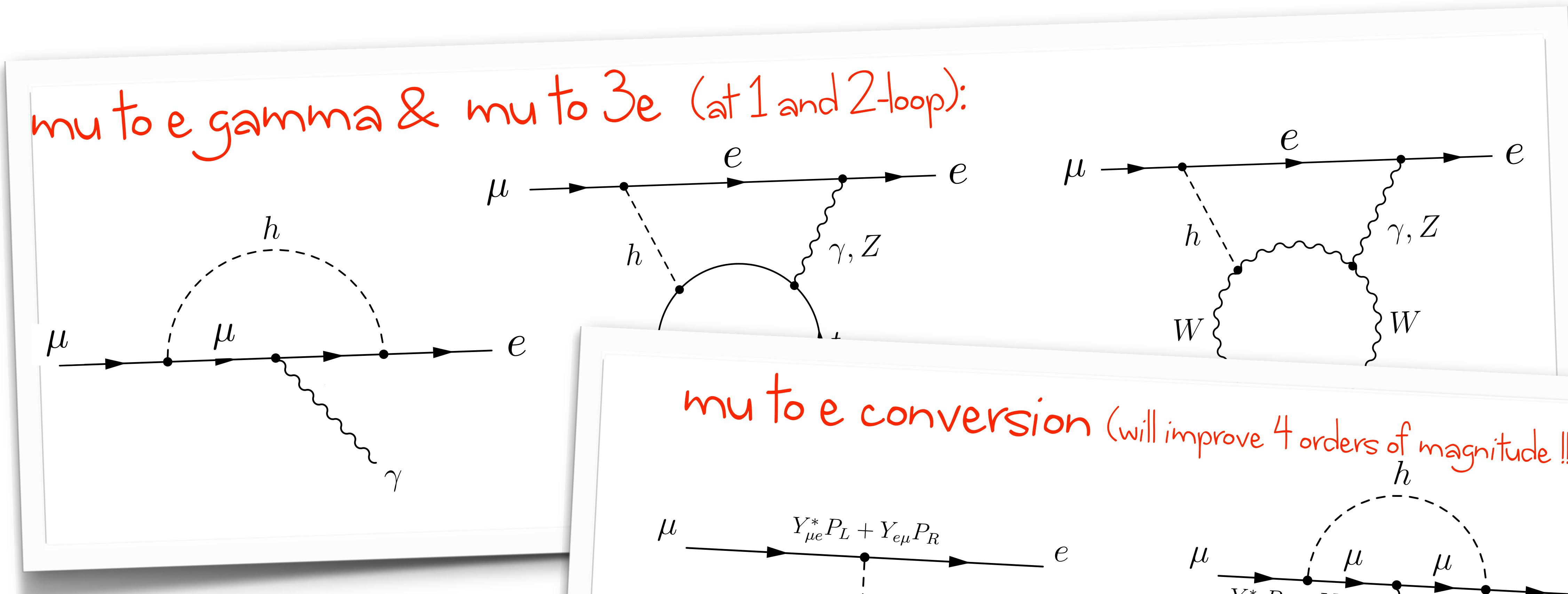


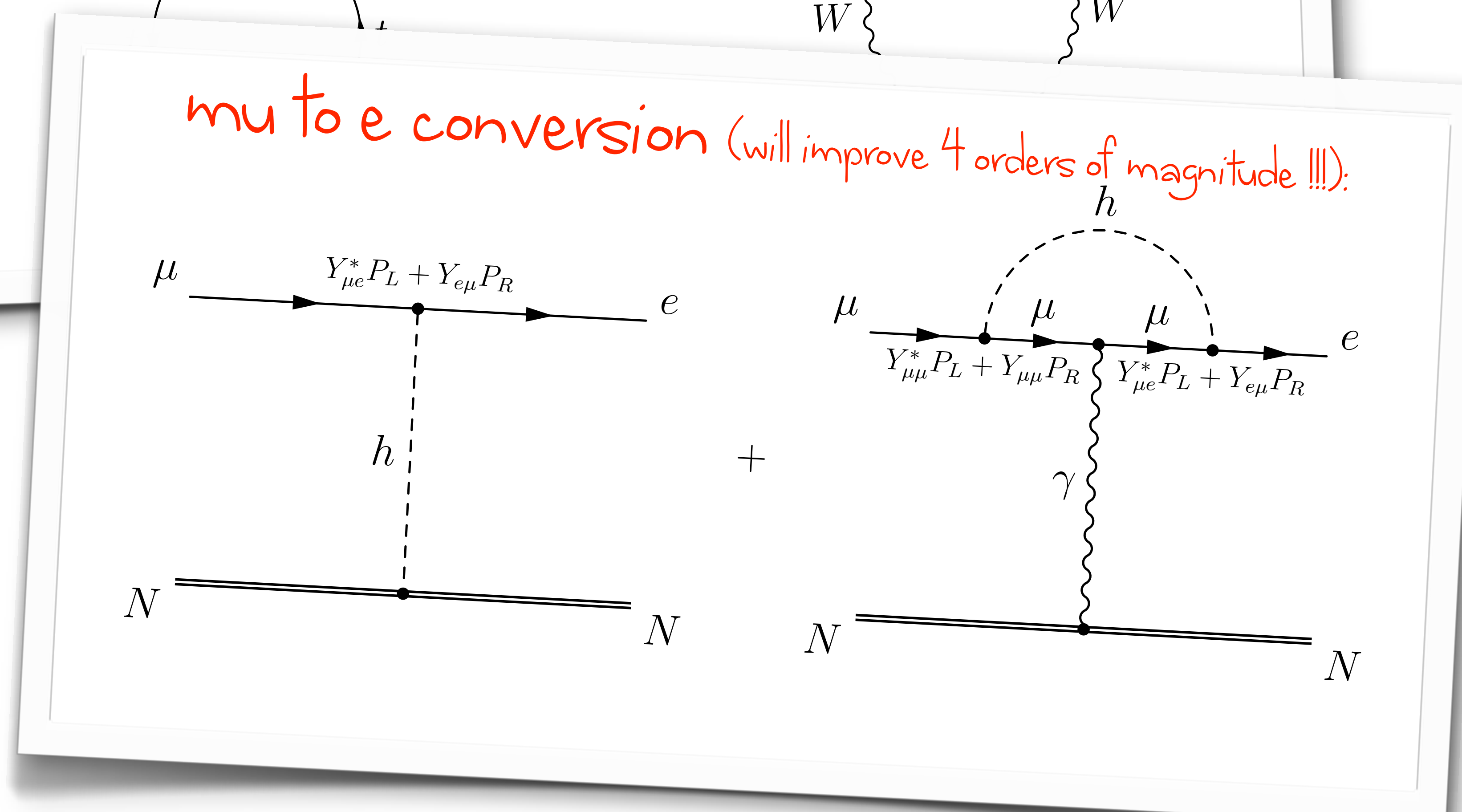

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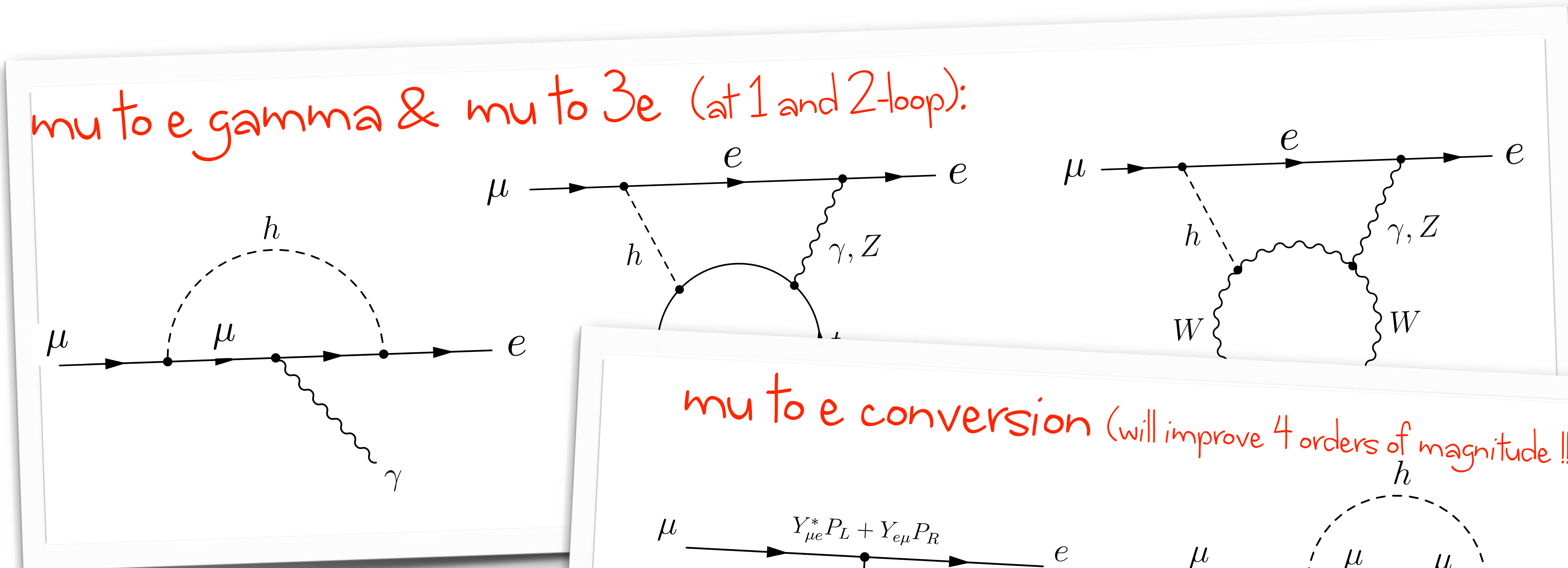
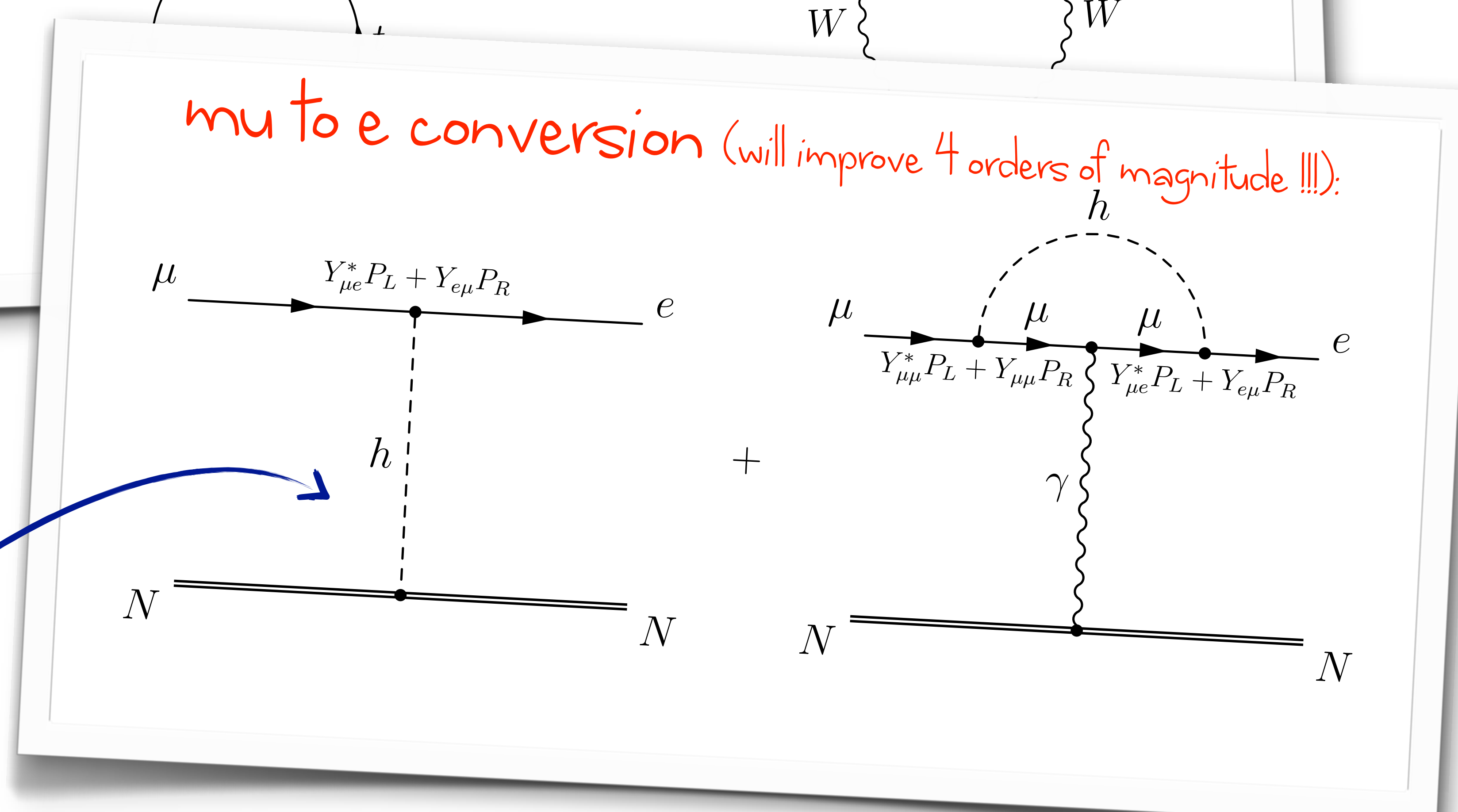


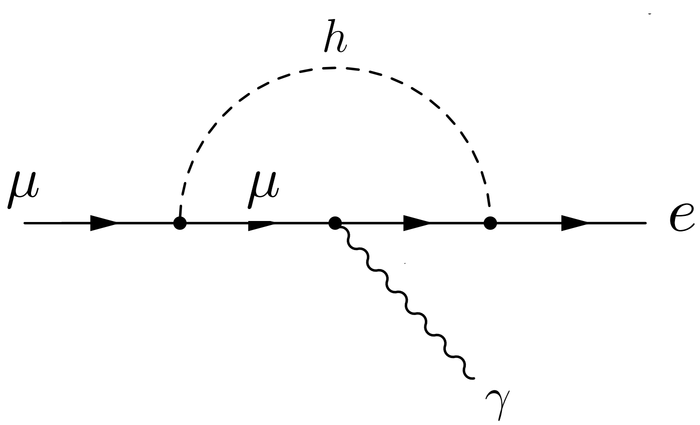




Which operator?

# Higgs couplings to $\mu e$

* Lets practice more. we are aiming for:

$$H ; (\bar{\mu}_R \sigma^{\mu\nu} e_L) F_{\mu\nu}$$




$\sim$

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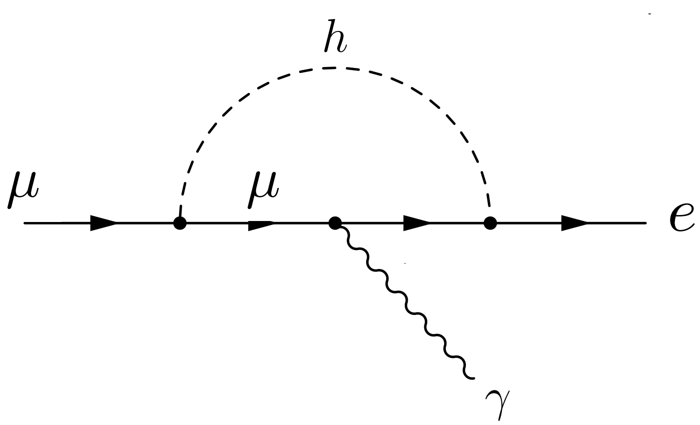


$$\sim \frac{1}{16\pi^2}$$

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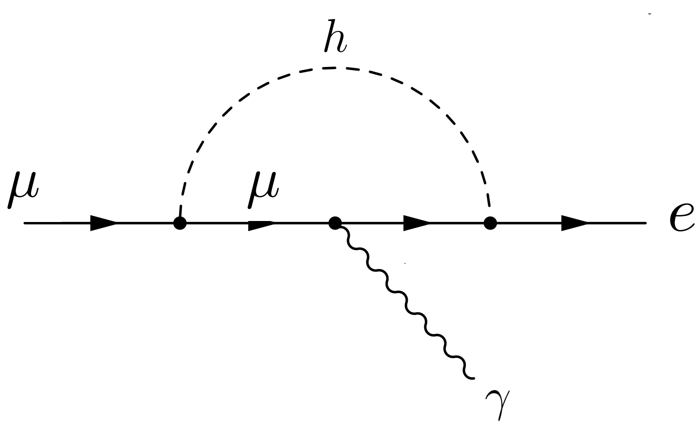


$$\sim \frac{e}{16\pi^2}$$

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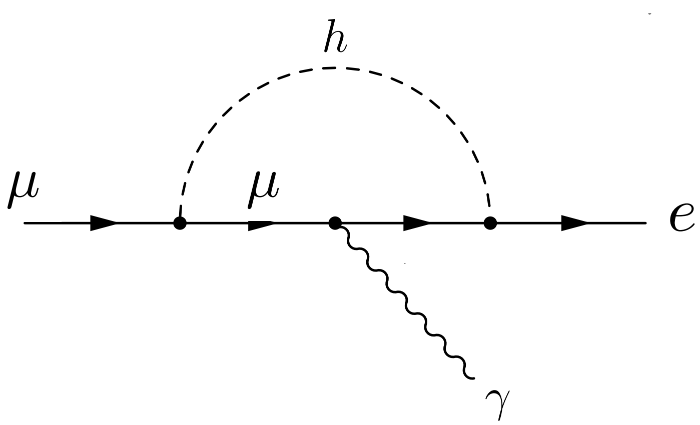


$$\sim \frac{e}{16\pi^2} m_\mu$$

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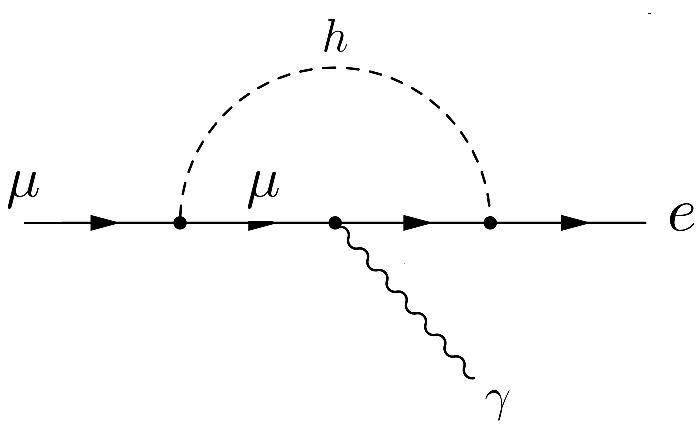


$Y_\mu \langle H \rangle$

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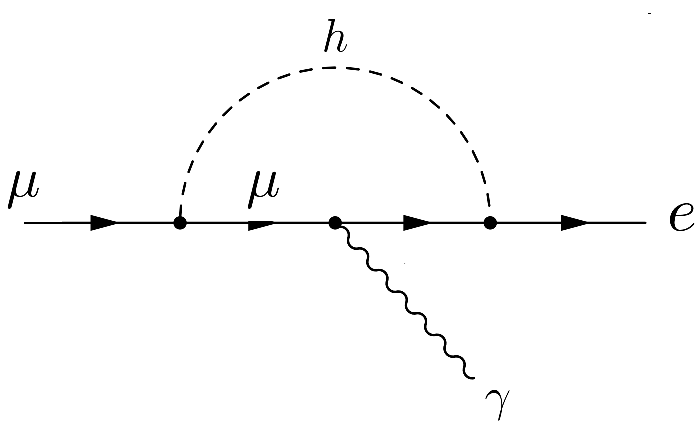


$Y_\mu \langle H \rangle$

$$\sim \frac{e}{16\pi^2} m_\mu \frac{1}{m_h^2}$$

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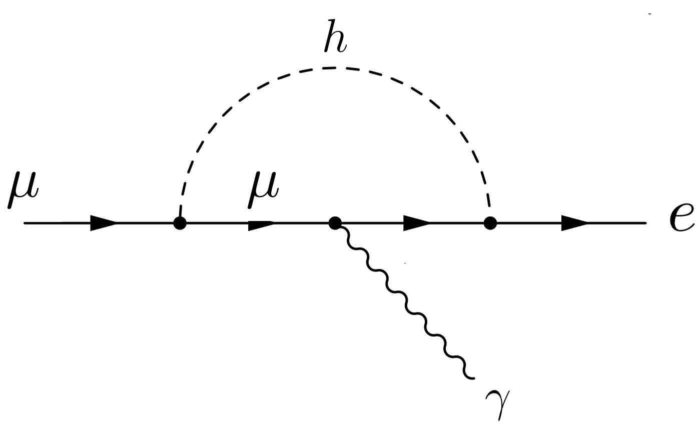


$Y_\mu \langle H \rangle$

$$\sim \frac{e}{16\pi^2} m_\mu \frac{1}{m_h^2} Y^*_{\mu\mu} Y_{\mu e}$$

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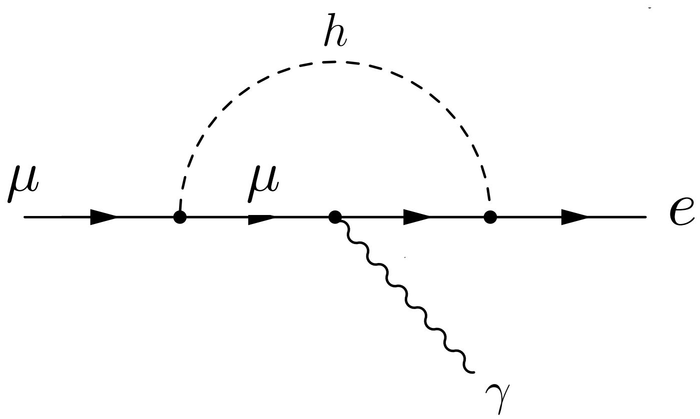


$Y_\mu \langle H \rangle$

$$\sim \frac{e}{16\pi^2} m_\mu \frac{1}{m_h^2} Y^*_{\mu\mu} Y_{\mu e} \log \ldots$$

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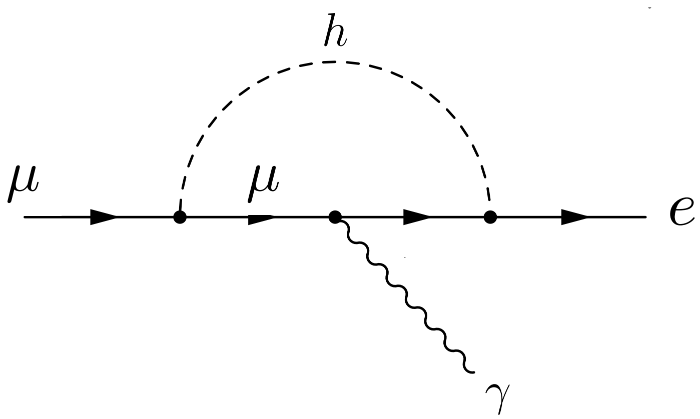
$Y_\mu \langle H \rangle$




$$\sim \frac{e}{16\pi^2} m_\mu \frac{1}{m_h^2} Y^*_{\mu\mu} Y_{\mu e} \log \ldots$$

- The notation is $$\mathcal{L}_{\mu \to e\gamma} = C_L \frac{e}{8\pi^2} m_\mu (\bar{\mu}_R \sigma^{\mu\nu} e_L) F_{\mu\nu}$$

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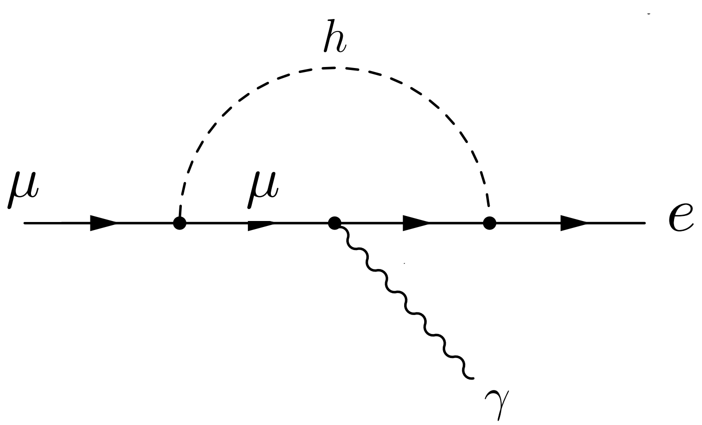



$Y_\mu \langle H \rangle$

$$\sim \frac{e}{16\pi^2} m_\mu \frac{1}{m_h^2} Y^*_{\mu\mu} Y_{\mu e} \log \ldots$$

- The notation is $\mathcal{L}_{\mu\to e\gamma} = C_L \frac{e}{8\pi^2} m_\mu (\bar{\mu}_R \sigma^{\mu\nu} e_L) F_{\mu\nu}$

- The real answer is (pages of algebra)-

$$c_L^{1\mathrm{loop}} \simeq \frac{1}{12 m_h^2} Y_{\tau\tau} Y^*_{\tau\mu} \left( -4 + 3 \log \frac{m_h^2}{m_\tau^2} \right)$$

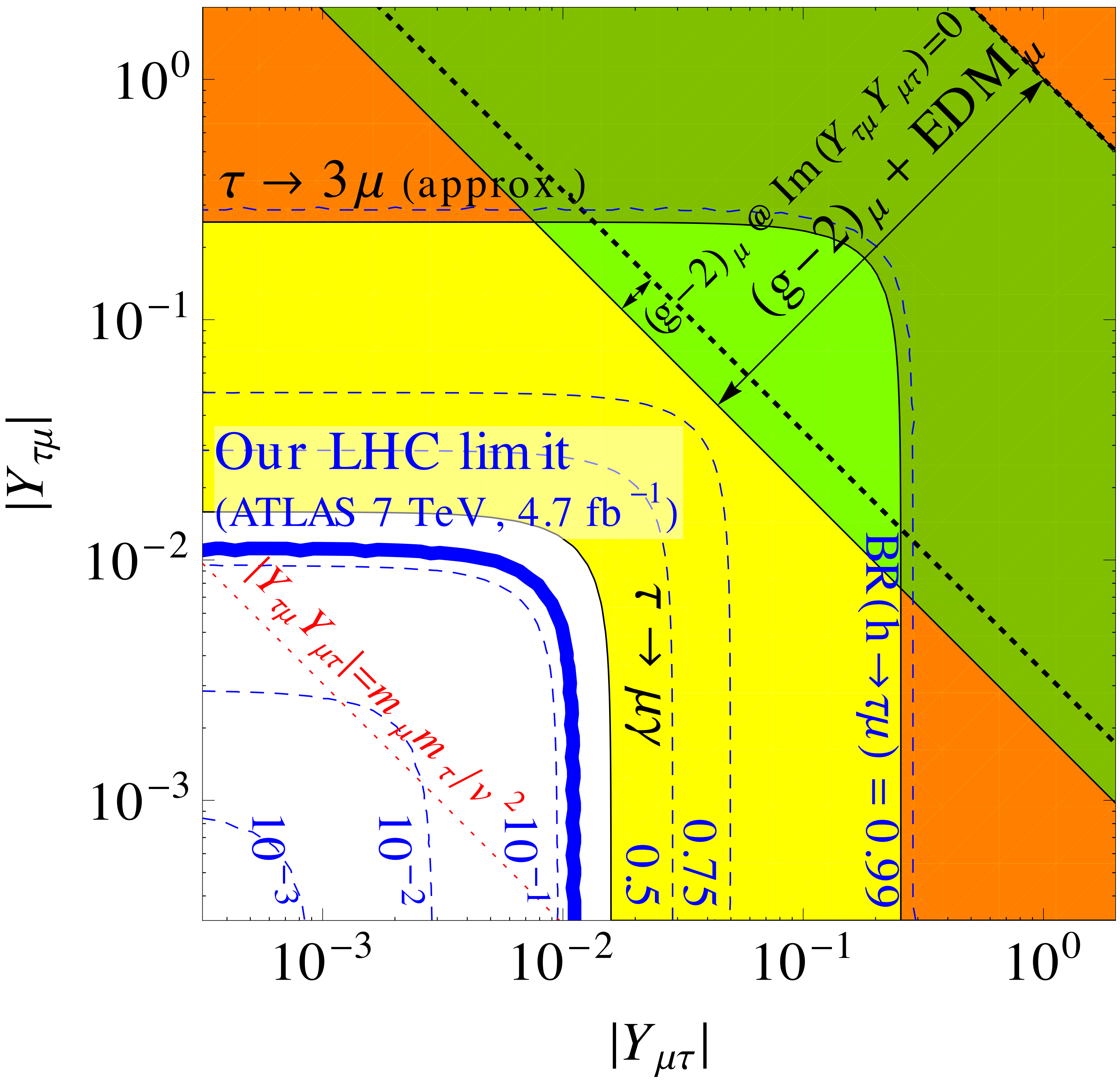
(swap tau with mu and mu with e)

# Higgs couplings to $\mu e$

Outside of
LHC reach.

Probing
"natural" models.

# Higgs couplings to $\tau\mu$




LHC $h \to \tau\mu$ gives dominant bound.

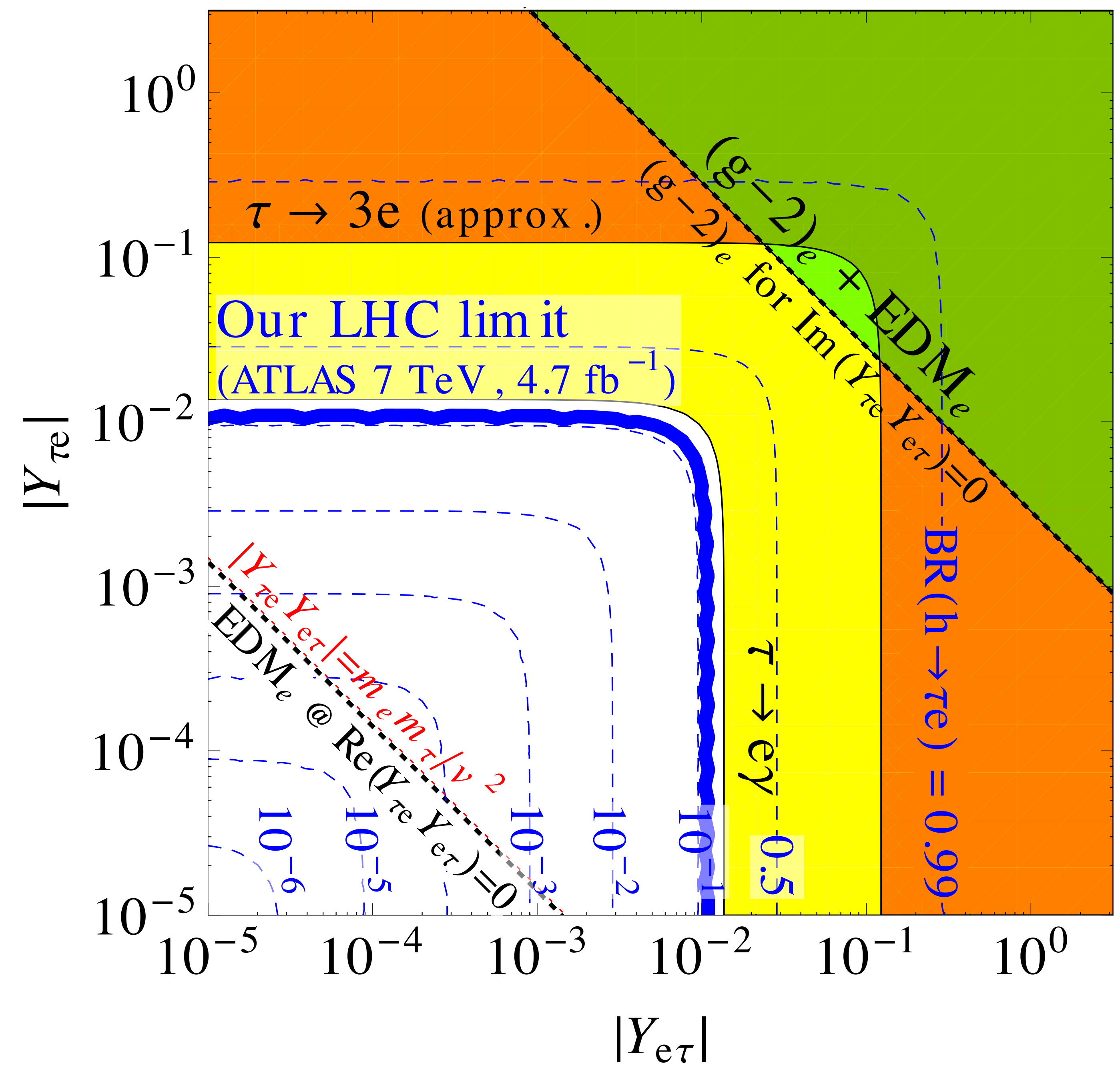
(currently just a theorist's re-interpretation)

"natural models" are within reach.

RH, Kopp, Zupan 1209.1397

# Higgs couplings to $\tau e$

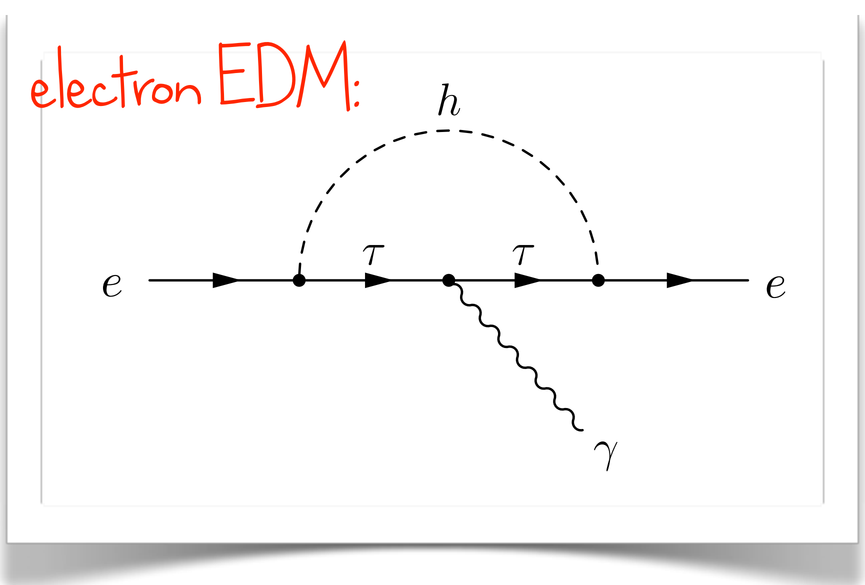
* $\tau e$ is similar to $\tau\mu$.... but:

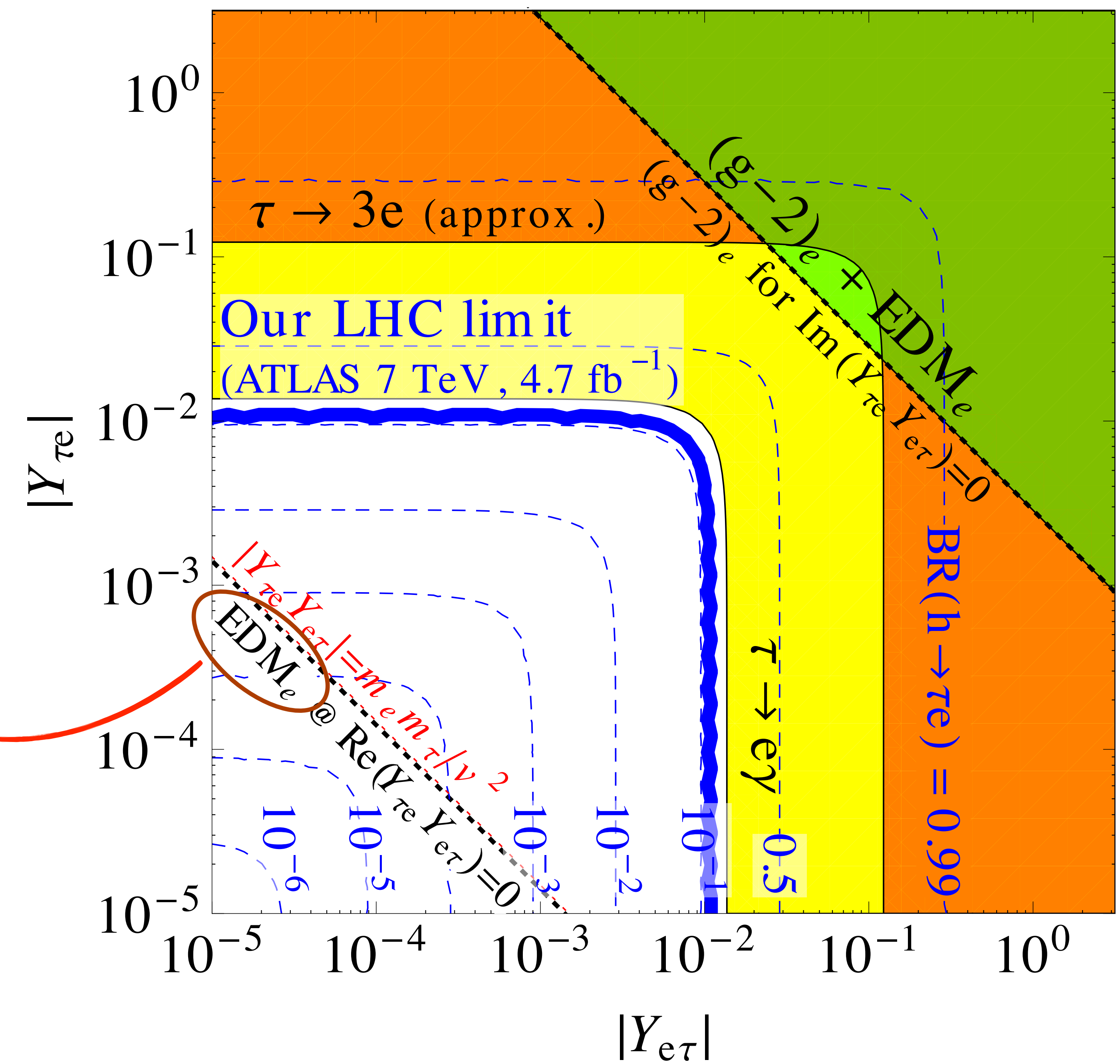


# Higgs couplings to $\tau e$

* $\tau e$ is similar to $\tau\mu$.... but:

Electron EDM is interesting here!



# Higgs Summary:

## Flavor violation:

✓ =sensitive at the level of $Y_{ij} \lesssim \frac{\sqrt{m_i m_j}}{v}$.

| Leptons | Probe |
|---|---|
| $\mu$-$e$ | muons ✓ |
| $\tau$-$e$ | eEDM* ✓ |
| $\tau$-$\mu$ | LHC ✓ |

| d-quarks | Probe |
|---|---|
| $s$-$d$ | K-K ✓ |
| $b$-$d$ | B-B ✓ |
| $b$-$s$ | $B_s$-$B_s$ ✓ |

| d-quarks | Probe |
|---|---|
| $c$-$u$ | D-D ✓ |
| $t$-$u$ | nEDM* ✓ |
| $t$-$c$ | LHC / D-D ✓? |

*LHC, if CP is conserved.

## CP violation:

| Phase | Probe |
|---|---|
| $e$ | e-EDM |
| $u,d$ | nEDM |
| $\gamma$ | eEDM |

| Phase | Probe |
|---|---|
| $t$ | EDMs |
| $\tau$ | LHC / Higgs factory |
| $Z$ | LHC |

Multiple probes across frontiers!

Almost all channels are sensitive at well motivated levels!

# Split SUSY

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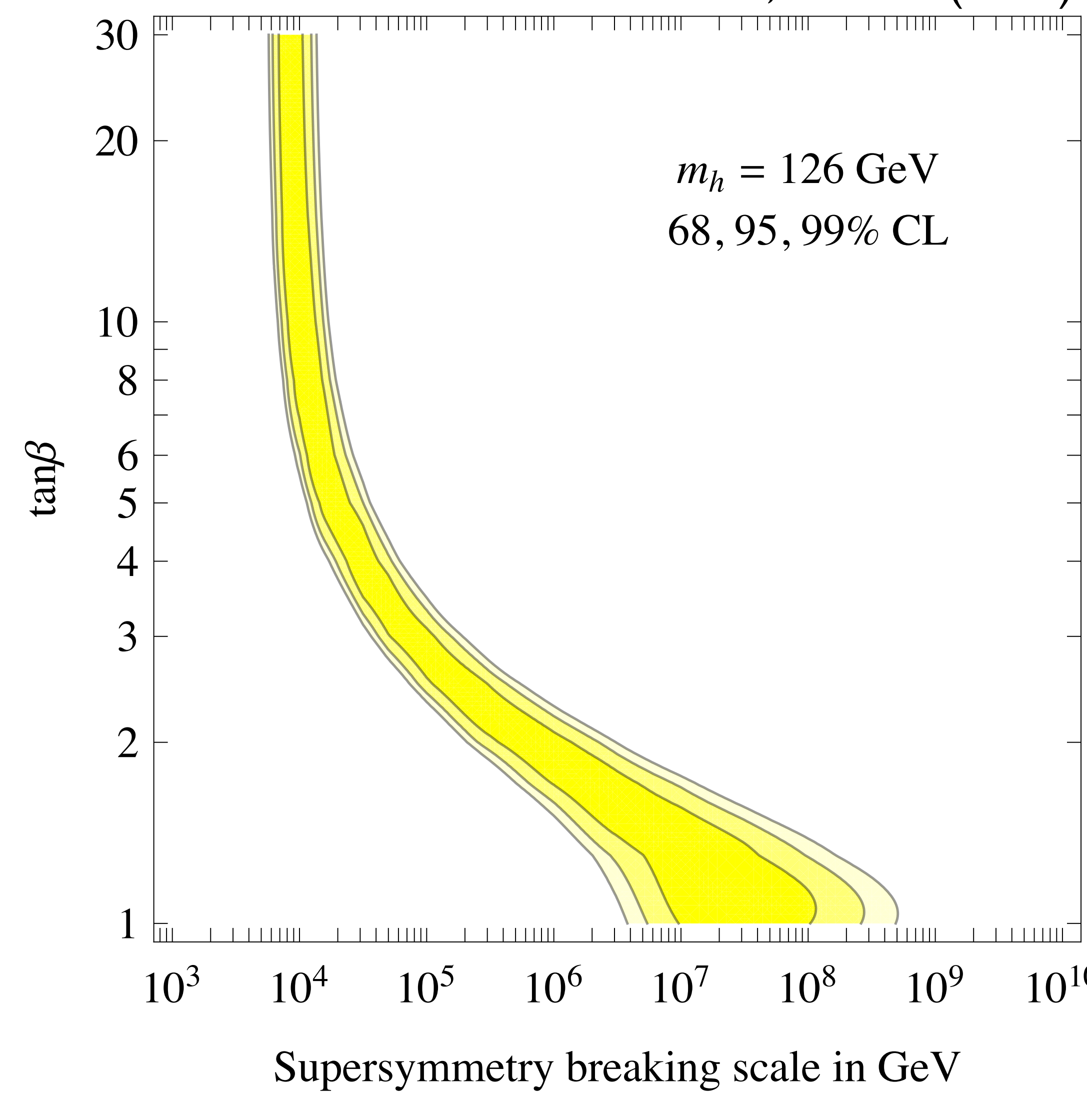
- SUSY has a “missing superpartner problem”.
- Maybe SUSY addresses most, *but not all* of the tuning.
- The Higgs mass provides a hint:

Giudice, Strumia (2012)



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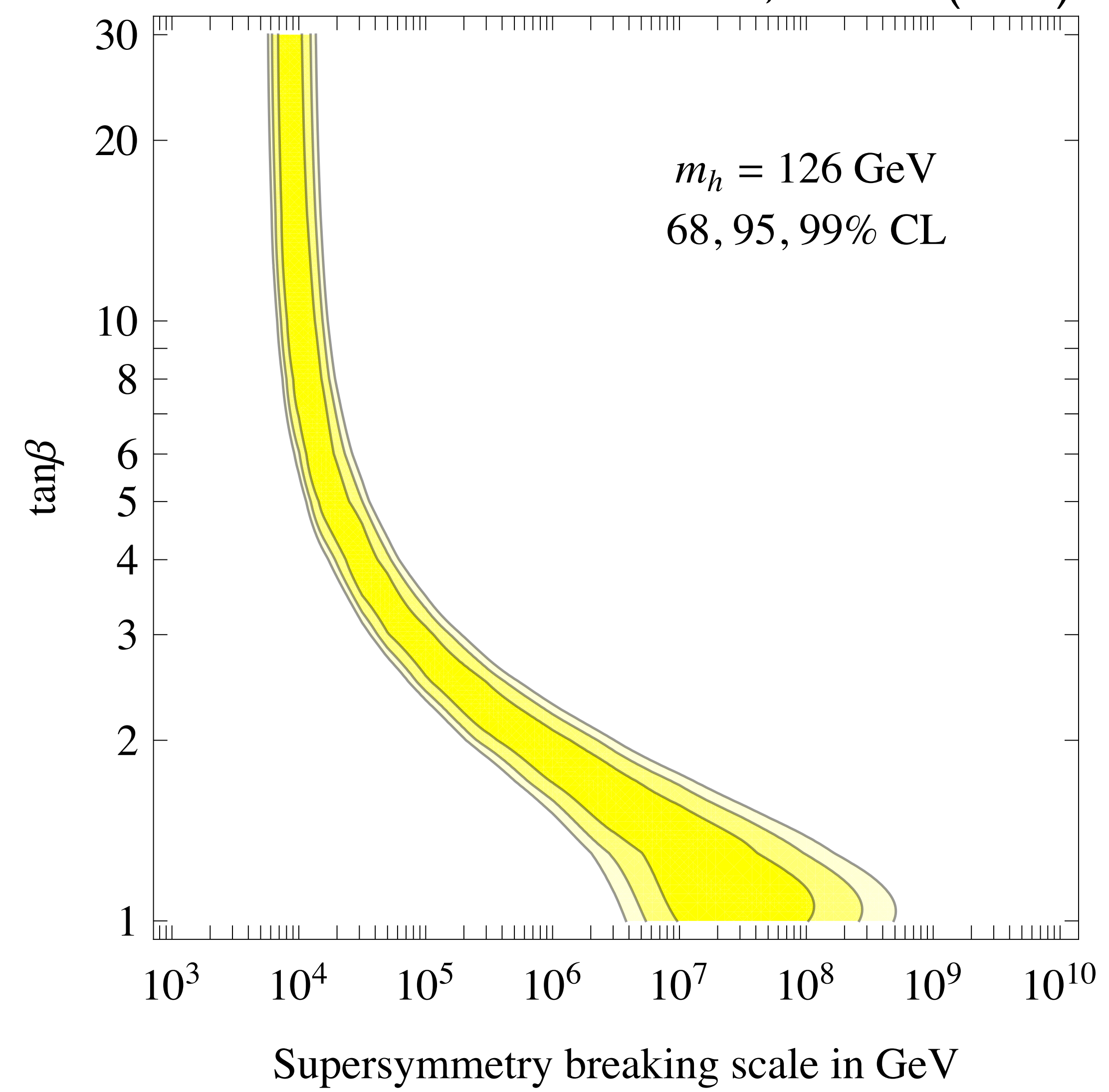

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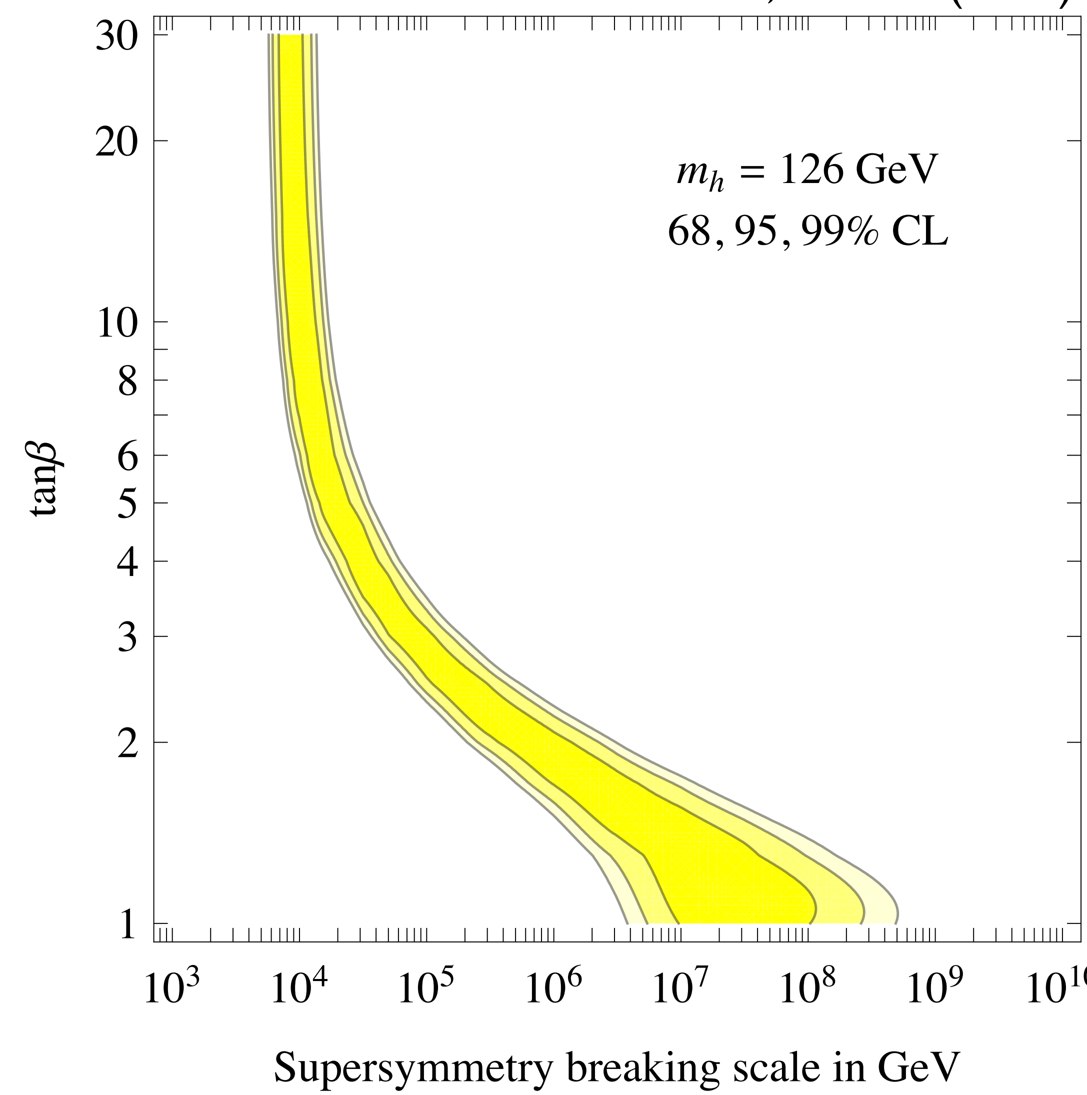
Goal: try to reach O(PeV) with as many probes as possible.

Giudice, Strumia (2012)



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* Lepton superpatners at 100-1000 TeV.

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Assume large FV at the high scale.
Can we probe it?

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Higgsinos can be either here or here.

* Gauginos at a few TeV

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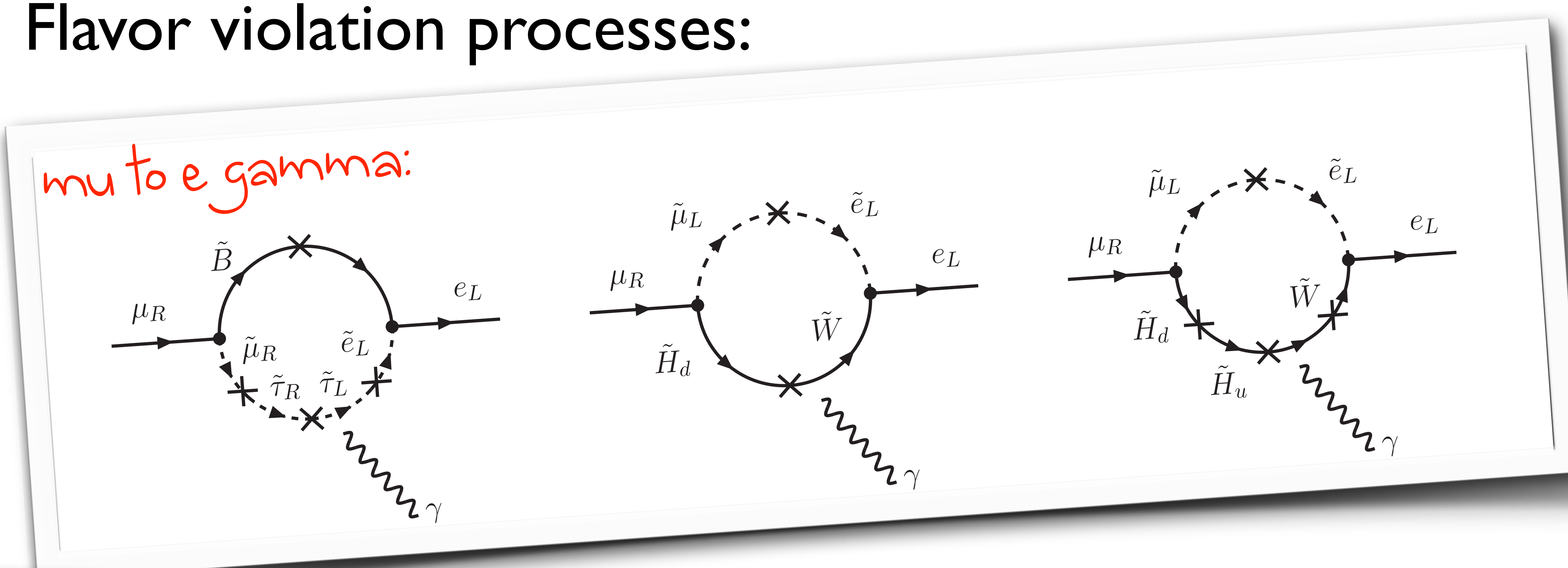
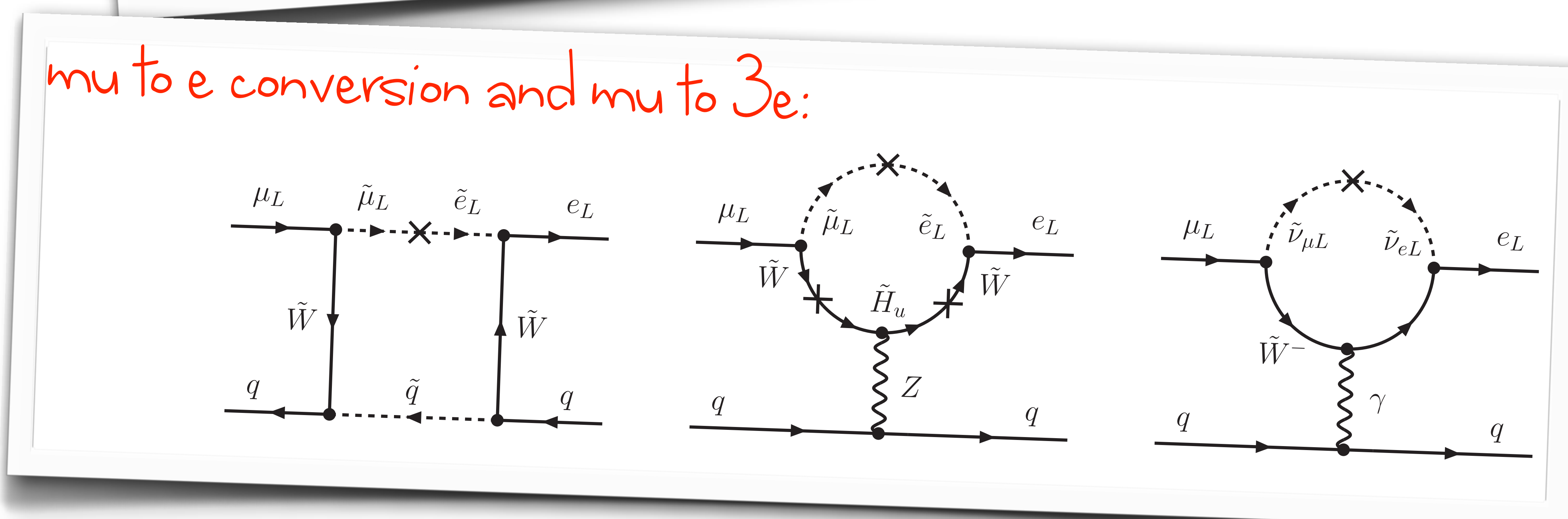
# LFV form PeV Sleptons

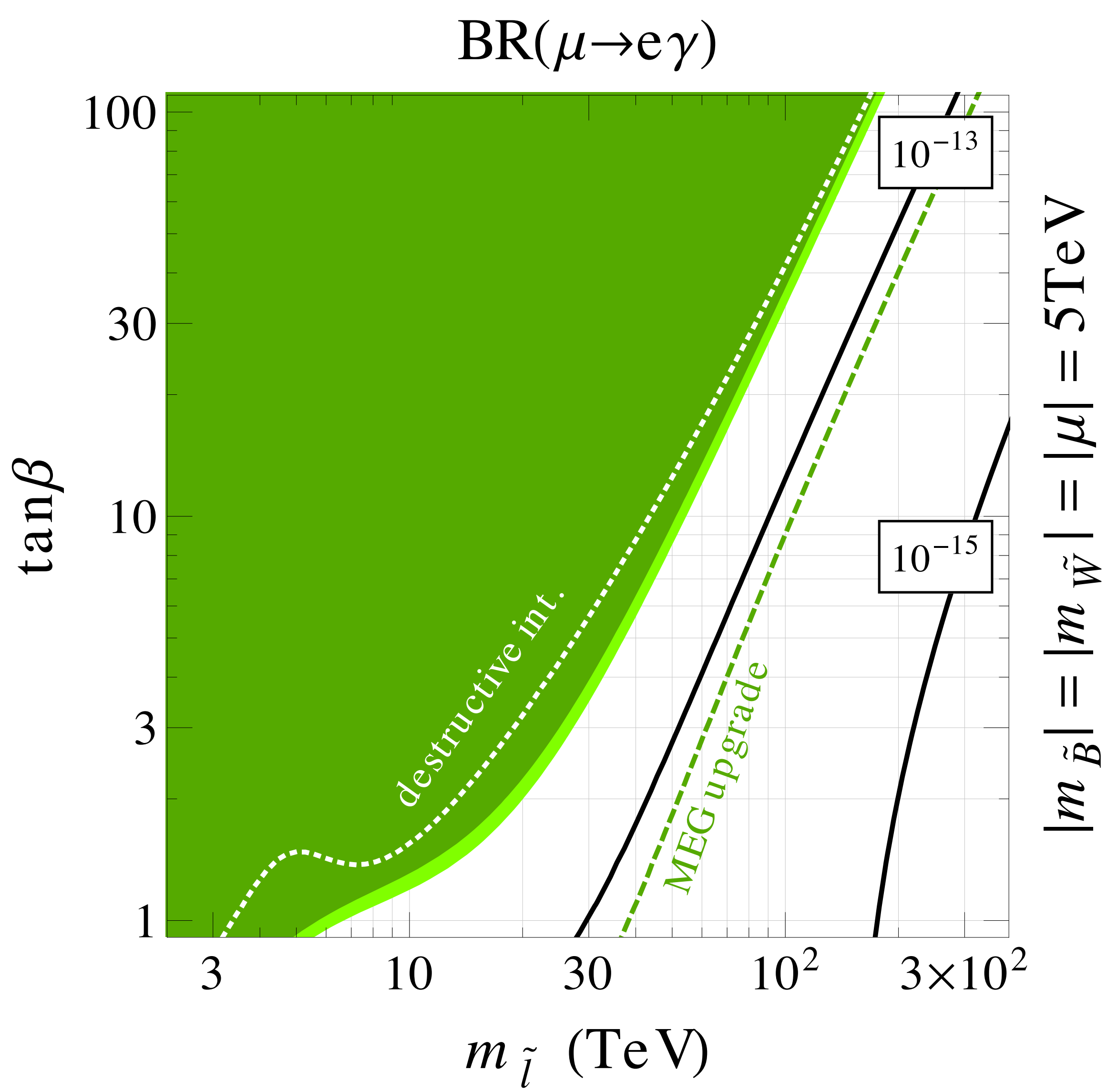
* Flavor violation processes:

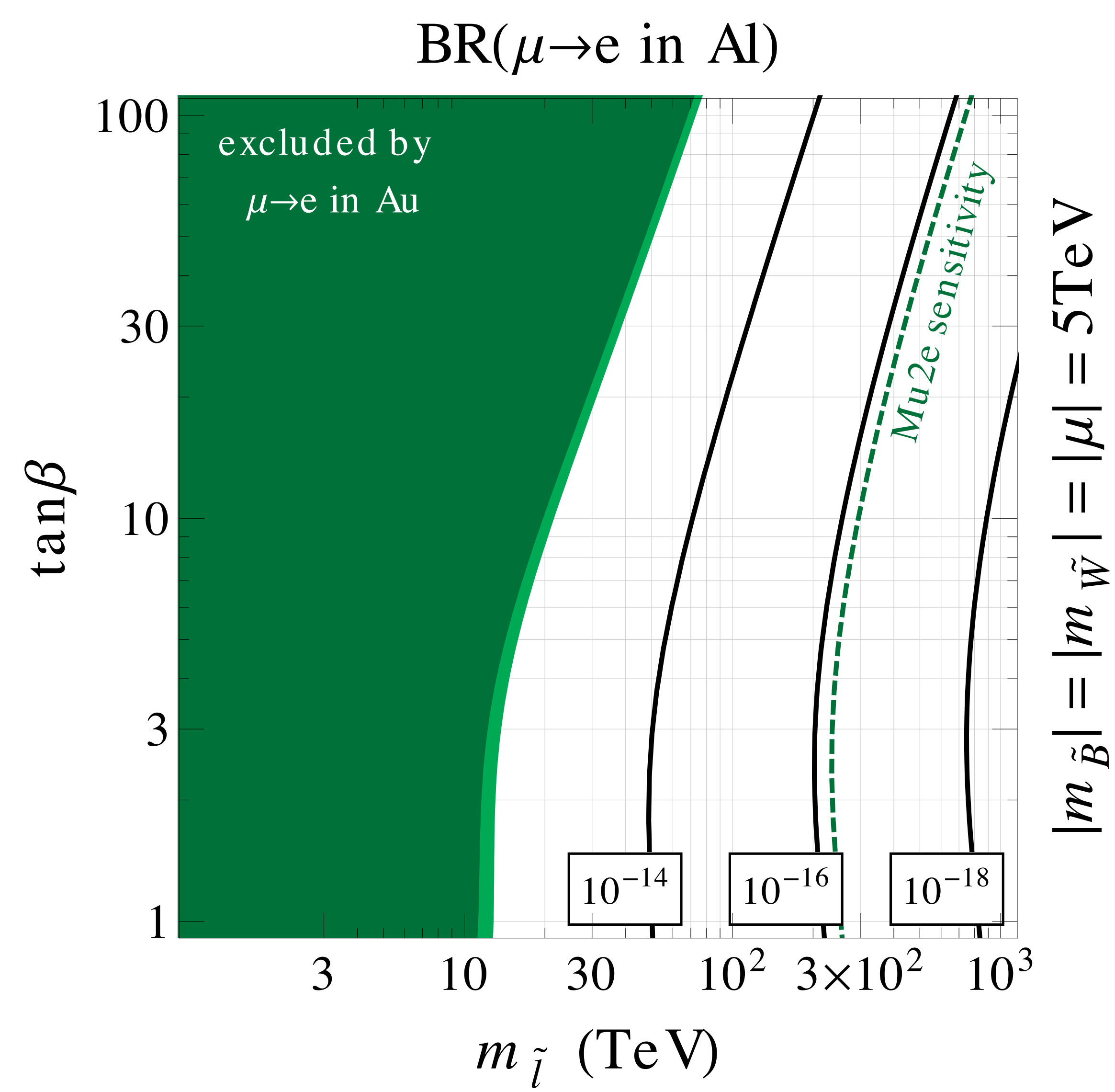


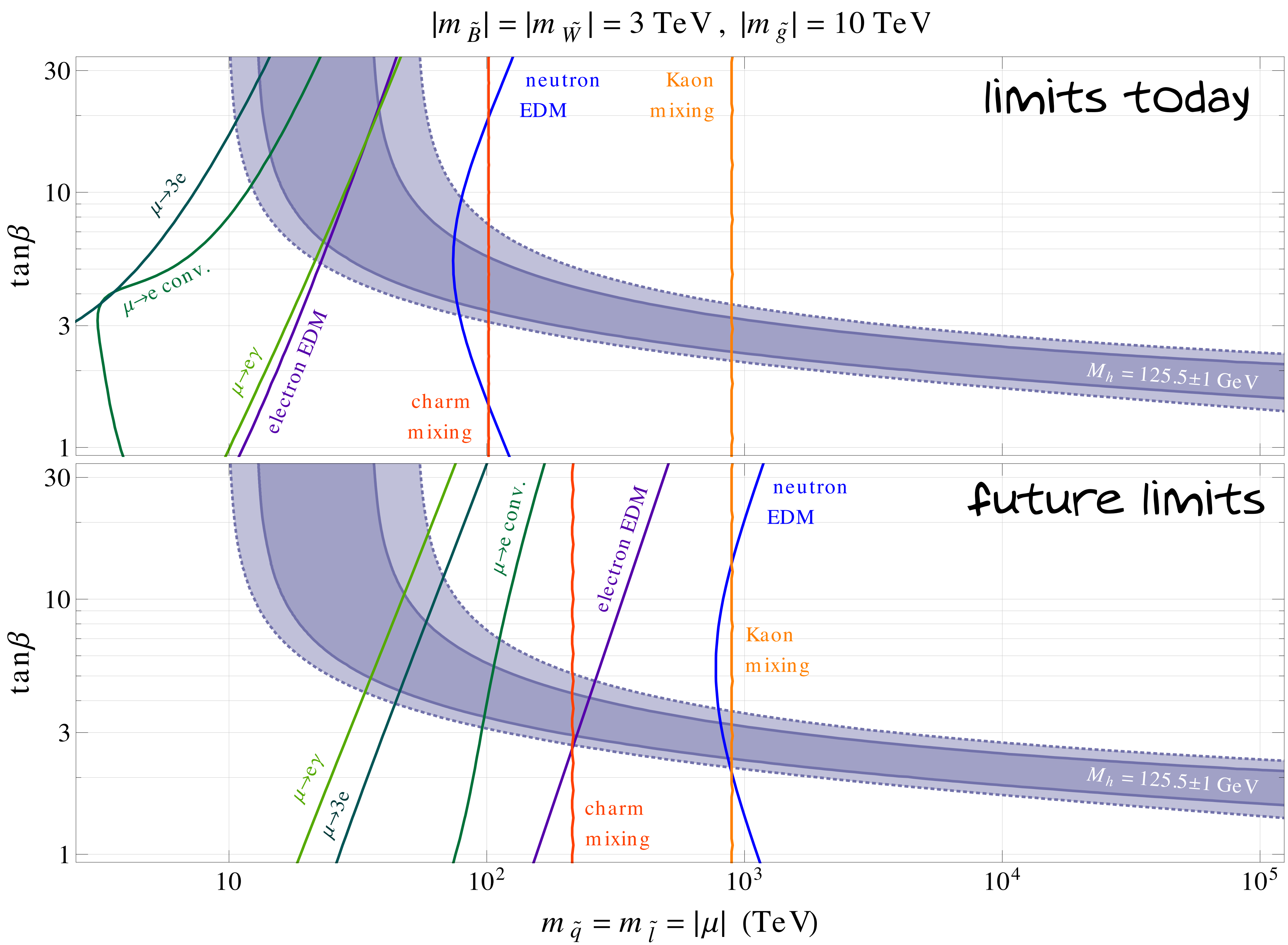
# LFV form PeV Sleptons

- LFV is sensitive to sleptons 100's of TeV!



# Other Probes




LFV is not alone!

# Conclusions

* What's the deal with flavor? we still don't know!
* CLFV is a sensitive probe of many NP scenarios. (EFT's are a simple way to parametrize them).
* For the LHC, new physics probed by LFV is often:
  - either too heavy (as in Split SUSY).
  - or too weakly couples (as for the Higgs).
* The mu2e experiment will move the limit by four orders of magnitude! A decade in NP scale!

**Isidor I. Rabi**
@RabiNMR

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The muon: who ordered that !?

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