AD4HEP WORKSHOP
ANOMALY DETECTION FOR HIGH ENERGY PHYSICS

GEFAN
Grupo de Estudos em Física e Astrofísica de Neutrinos

UNICAMP

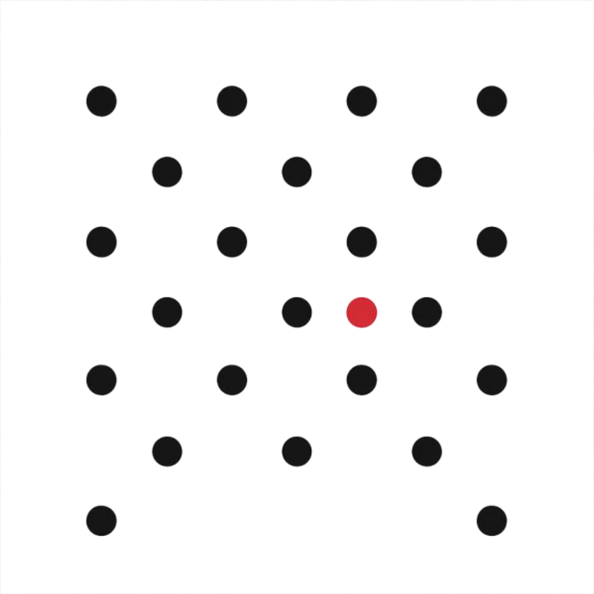
Unveiling New Physics Models through meson decays and their impact on neutrino experiments

Adriano Cherchiglia

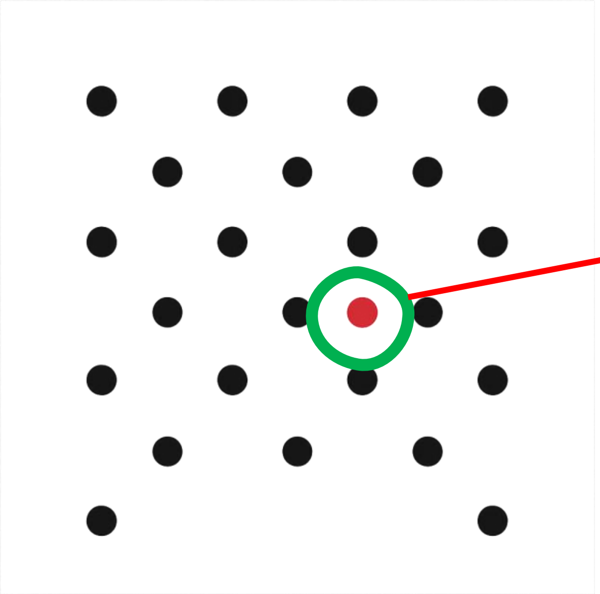
[JHEP 03 (2024) 018]

CNPq

Motivation

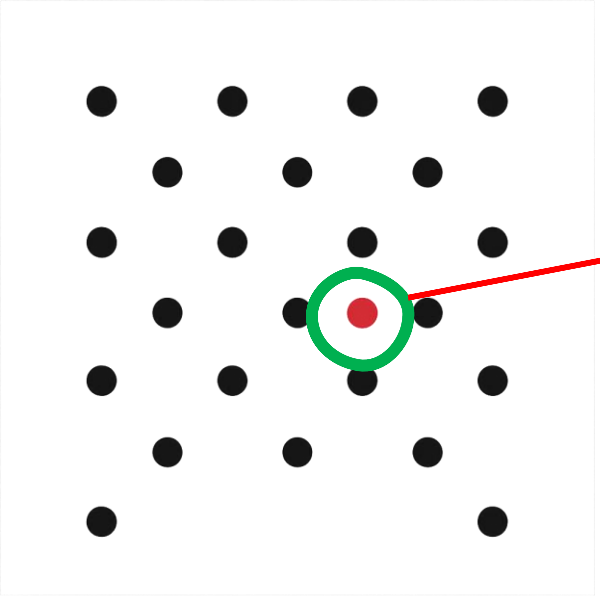


Motivation



Anomaly detected!

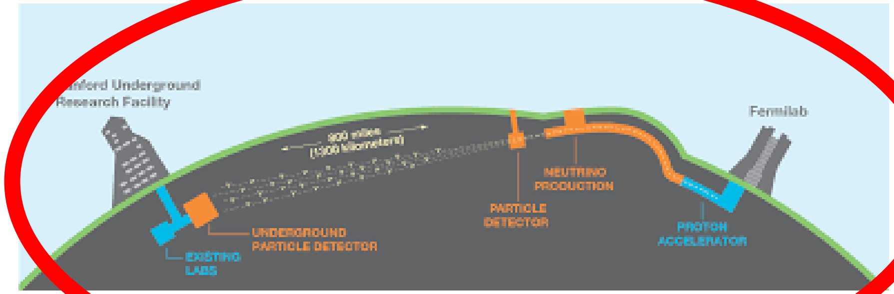
Motivation



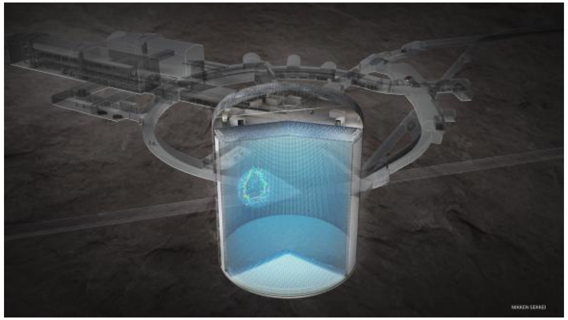
Anomaly detected!

And now?

Motivation

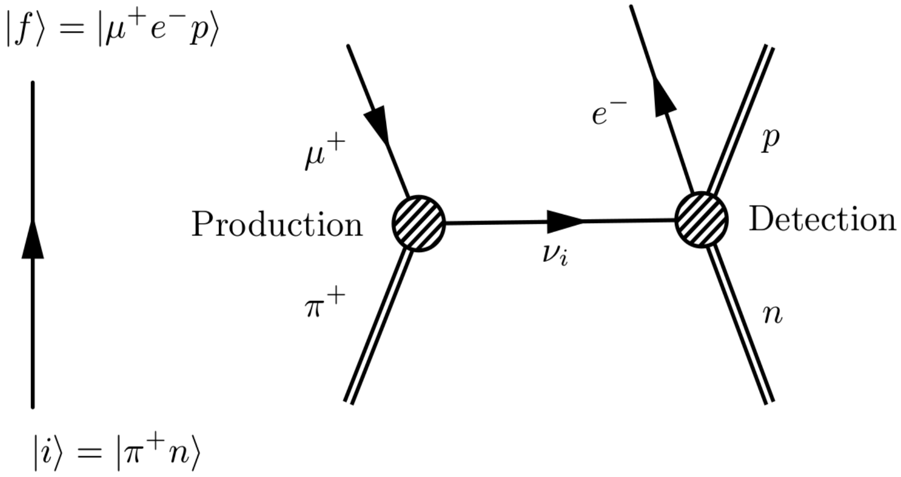


[DUNE]



[T2HK]

QFT approach

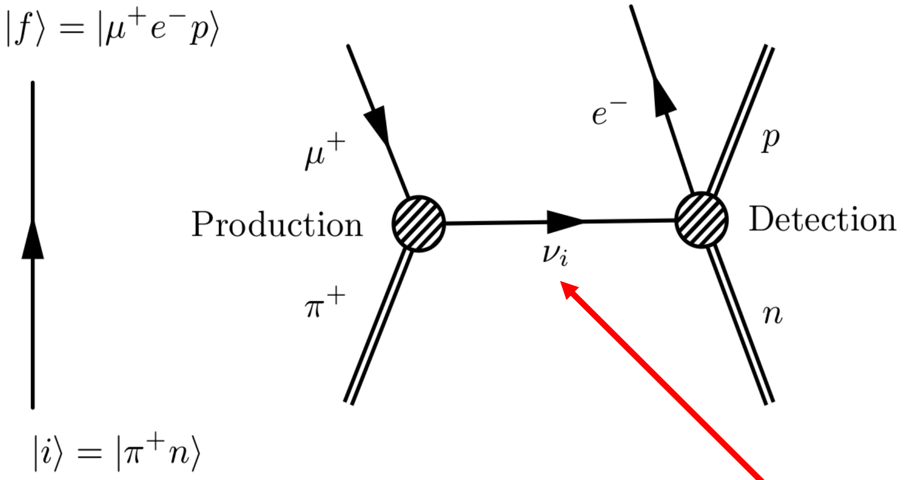


A. Falkowski, M. González-Alonso and Z. Tabrizi ([2019])

$$\upsilon_\alpha \rightarrow \upsilon_\beta$$

$$R^S_{\alpha\beta} = \frac{N_T}{32\pi L^2 m_S m_T E_\nu} \sum_{k,l} e^{-i\frac{L\Delta m^2_{kl}}{2E_\nu}} \int d\Pi_{P'} \mathcal{M}^P_{\alpha k} \overline{\mathcal{M}}^P_{\alpha l} \int d\Pi_D \mathcal{M}^D_{\beta k} \overline{\mathcal{M}}^D_{\beta l}$$

QFT approach



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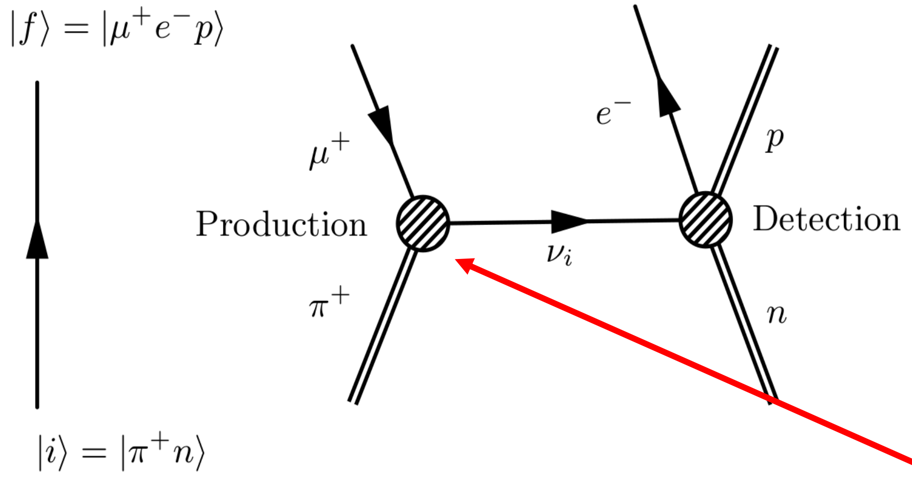
QFT approach



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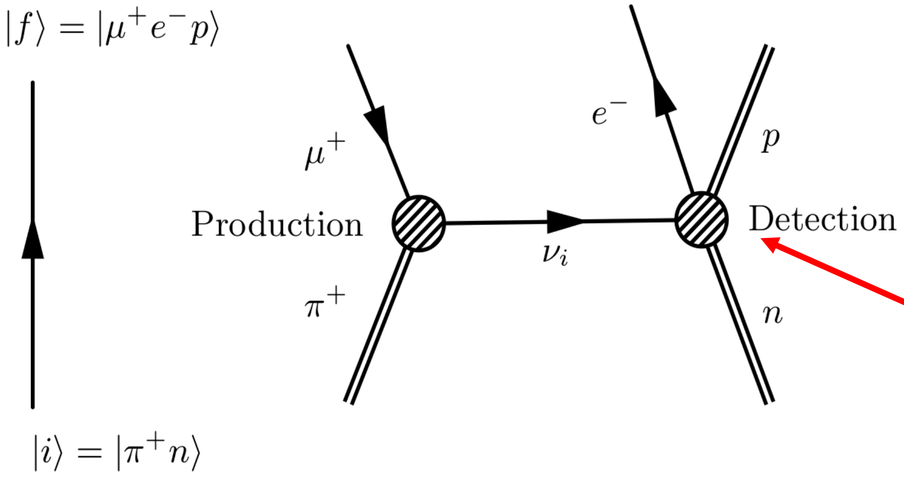

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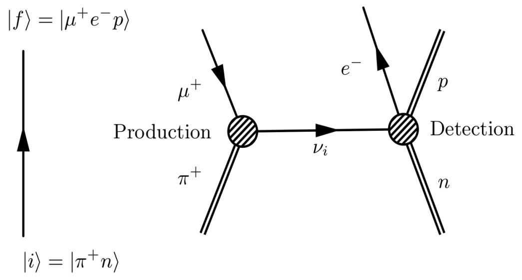
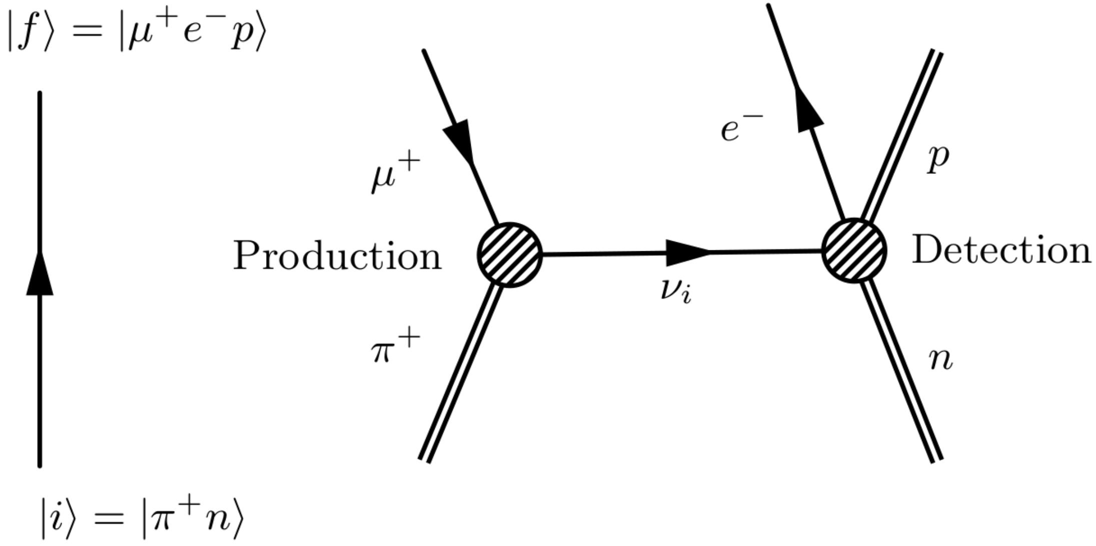


A. Falkowski, M. González-Alonso and Z. Tabrizi (2019)

$$\mathcal{M}^{P,\pi}_{\alpha k} \equiv \mathcal{M}(\pi^+ \to \ell^+_\alpha \nu_k) = -i\, m_\mu f_{\pi^\pm} \frac{V_{ud}}{v^2} [\mathcal{P}U]^*_{\alpha k} (\bar{u}_{\nu_k} P_L v_{\ell_\alpha})$$

$$[\mathcal{P}]_{\alpha\sigma} \equiv \delta_{\alpha\sigma} + \bar{\epsilon}_{\alpha\sigma}$$

QFT approach



BSM effects at production

$$\bar{\epsilon}_{\alpha\beta}$$

QFT approach

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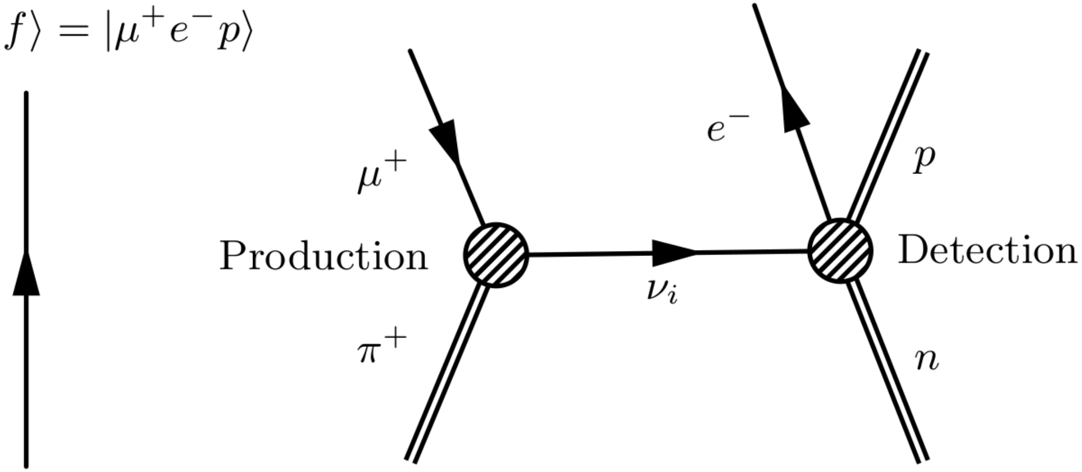
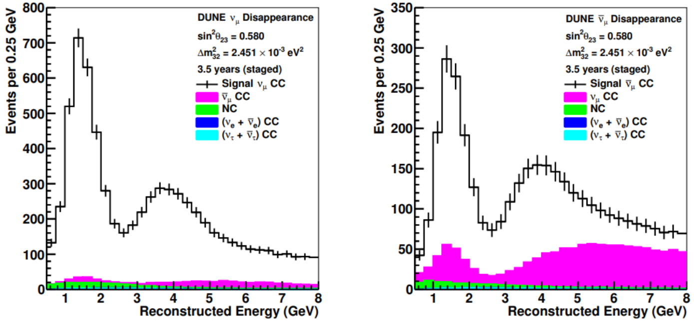
$$|f\rangle = |\mu^+ e^- p\rangle$$



$$|i\rangle = |\pi^+ n\rangle$$



2006.16043

BSM effects at production

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QFT approach

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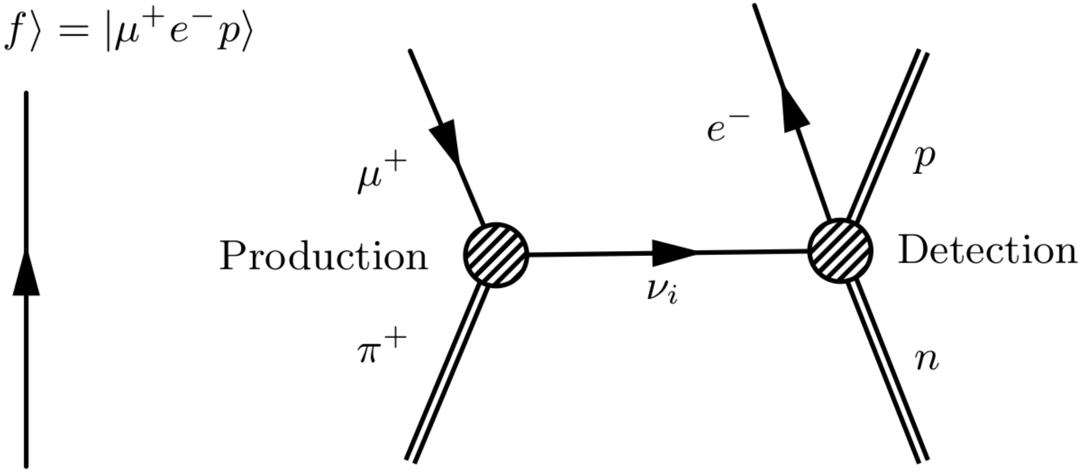

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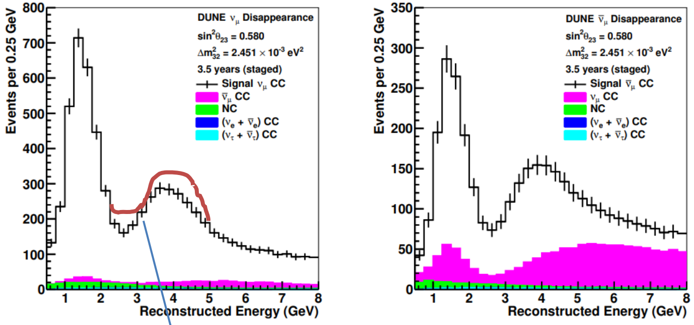
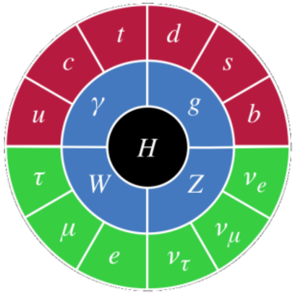


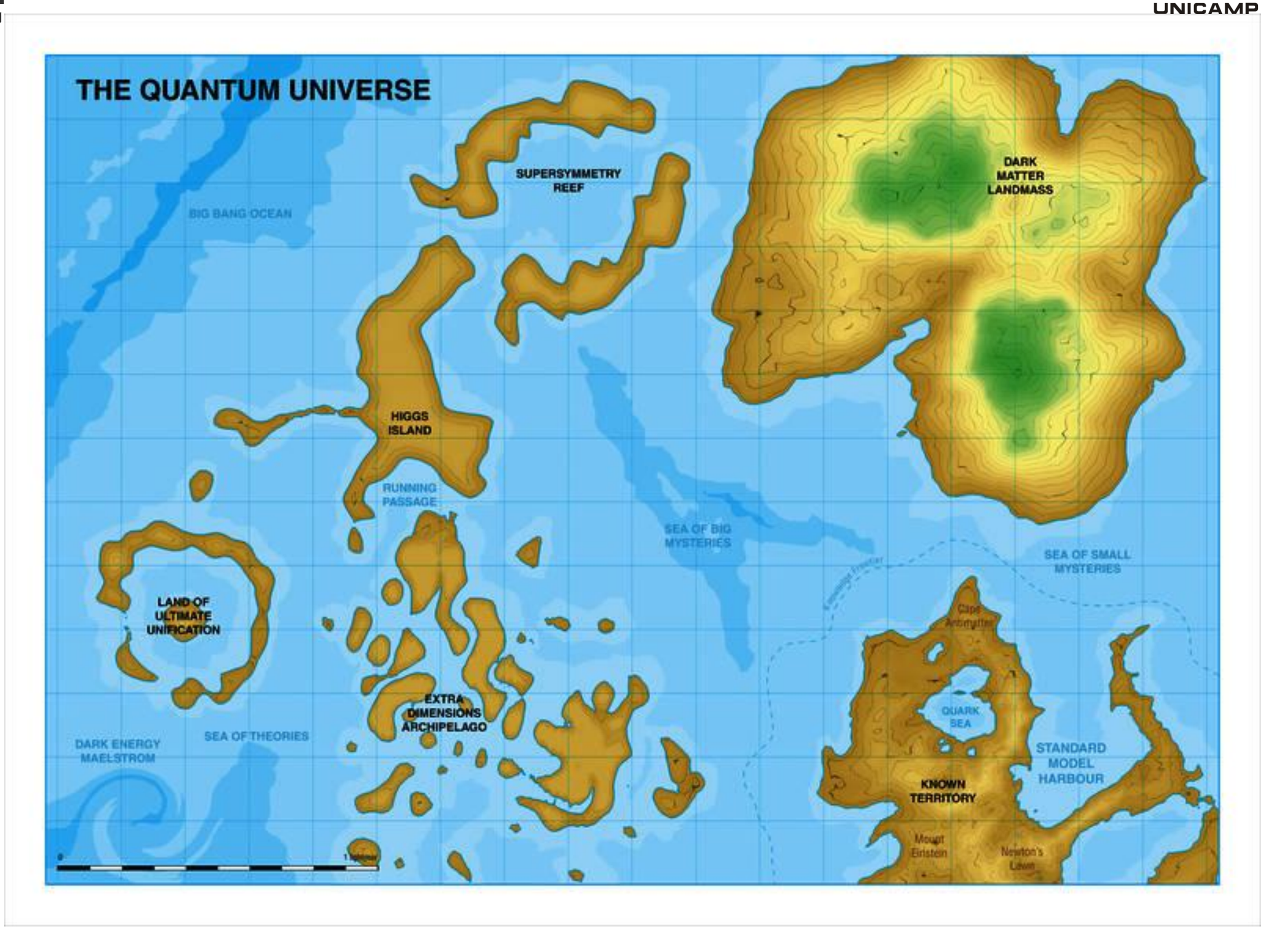
[2006.16043](2006.16043)

$$\bar{\epsilon}_{23}$$

General picture



?



- Neutrino masses?
- Dark matter?
- Matter-antimatter asymmetry?
- .....

Illustration by WWW.FORM-ONE.DE

General picture

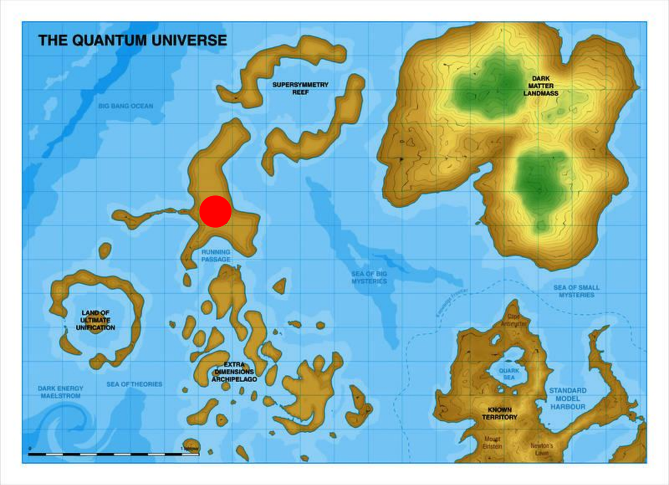
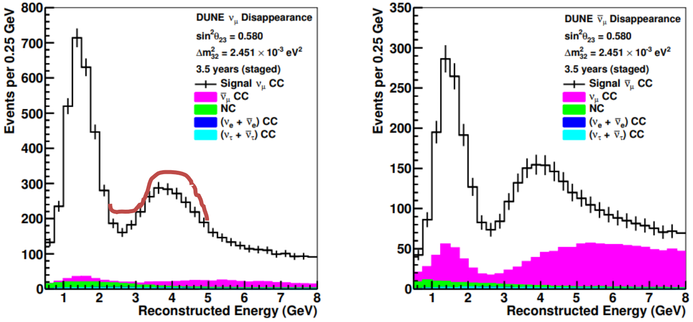


Illustration by WWW.FORM-ONE.DE



2006.16043

Effective Field Theory

General picture

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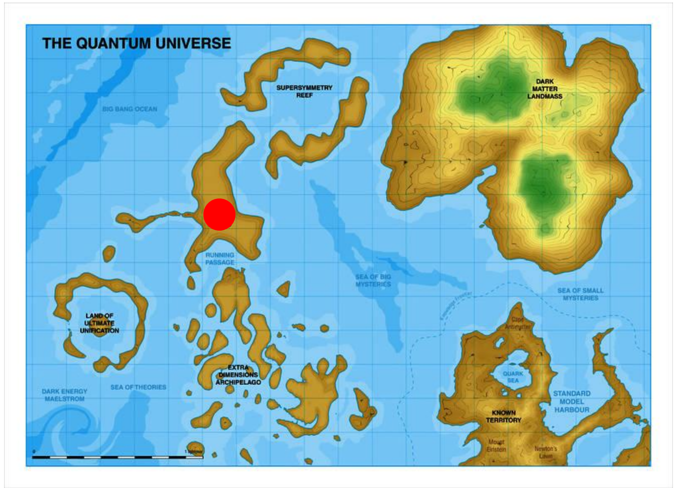

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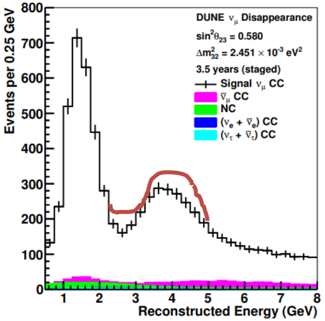

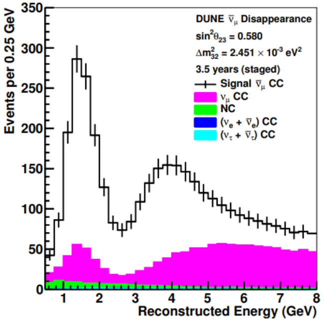

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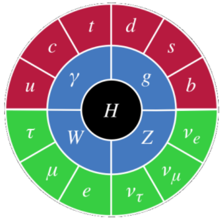

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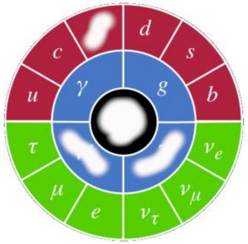

General picture

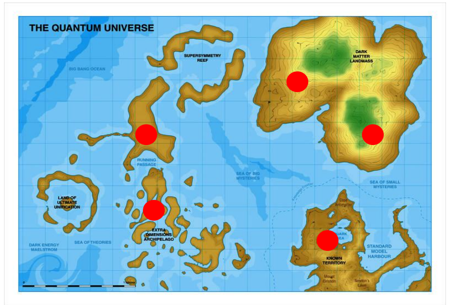

Illustration by WWW.FORM-ONE.DE

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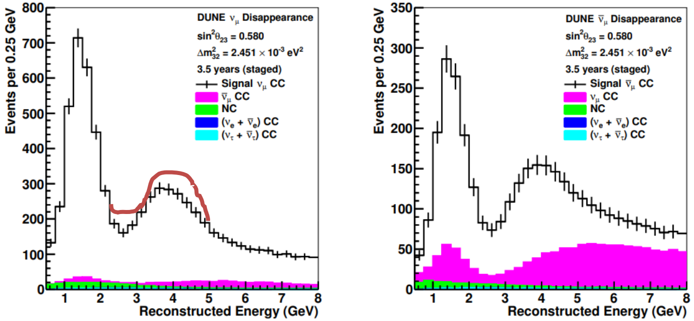
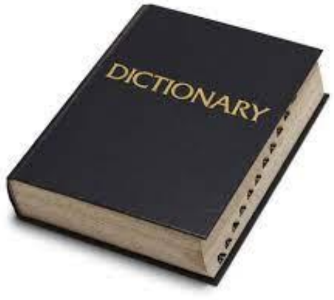


2006.16043



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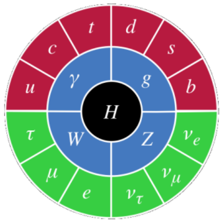
SMEFT



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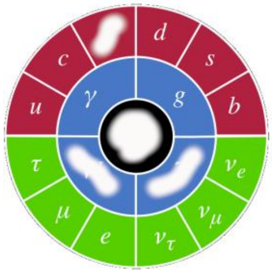

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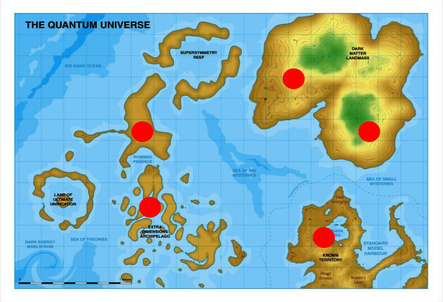

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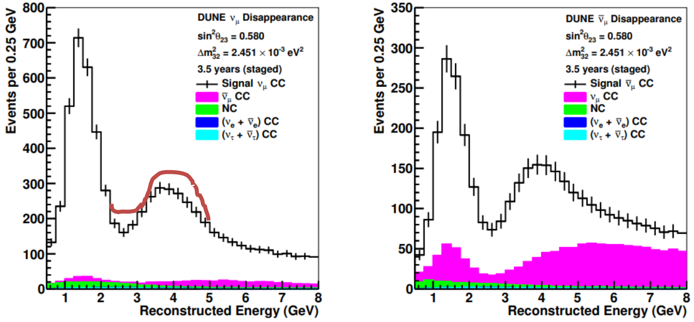

[2006.16043]

[eft-neutrinos]

[JHEP 03 (2024) 018]

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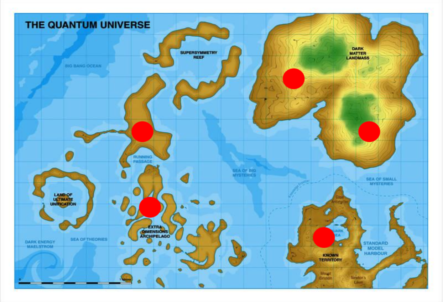

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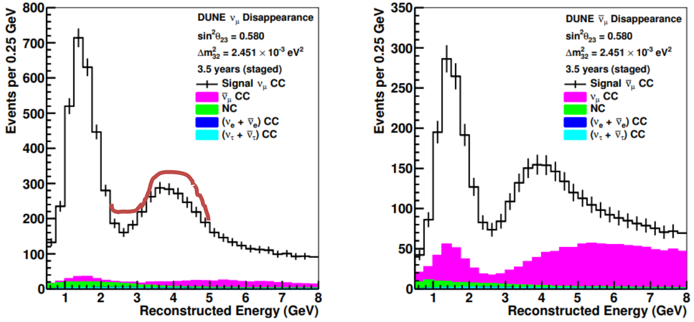

Tree-level matching

[2006.16043]

[eft-neutrinos]

[JHEP 03 (2024) 018]

General picture

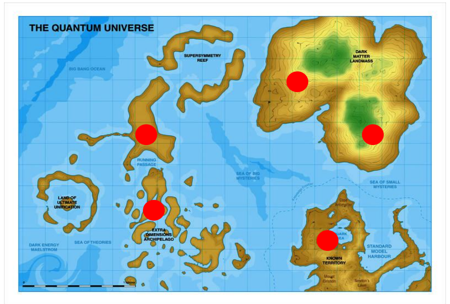

Illustration by WWW.FORM-ONE.DE

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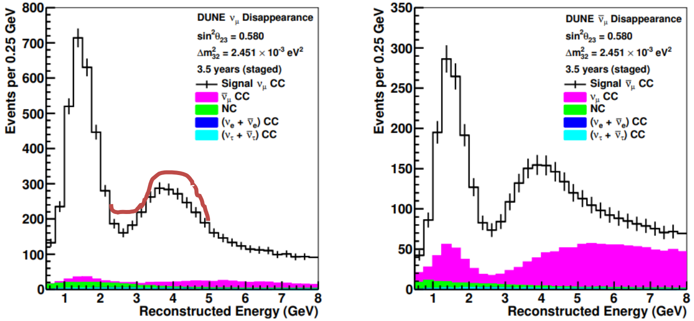

One-loop matching!

2006.16043

eft-neutrinos

SOLD

2303.16965

2412.14253

Seeking Models

UNICAMP

1810.08132

flavio

A Python package for flavour physics and other precision tests of the Standard Model

eft-neutrinos

SOLD

2303.16965

2412.14253

Seeking Models

[eft-neutrinos]

[1810.08132]

$$\bar{\epsilon}_{\beta\alpha} = \frac{v^2}{2}\left[2C^{(3)}_{\substack{Hl\\ \alpha\beta}} + 2\sum_x V^*_{x1}\left(\delta_{\alpha\beta}C^{(3)*}_{\substack{Hq\\ 1x}} - C^{(3)}_{\substack{lq\\ \alpha\beta 1x}}\right) + \delta_{\alpha\beta}C^*_{\substack{Hud\\ 11}} + p_\beta\left(C_{\substack{ledq\\ \alpha\beta 11}} - \sum_x V^*_{x1}C^{(3)}_{\substack{lequ\\ \alpha\beta x1}}\right)\right]^*$$

Seeking Models

1810.08132

eft-neutrinos

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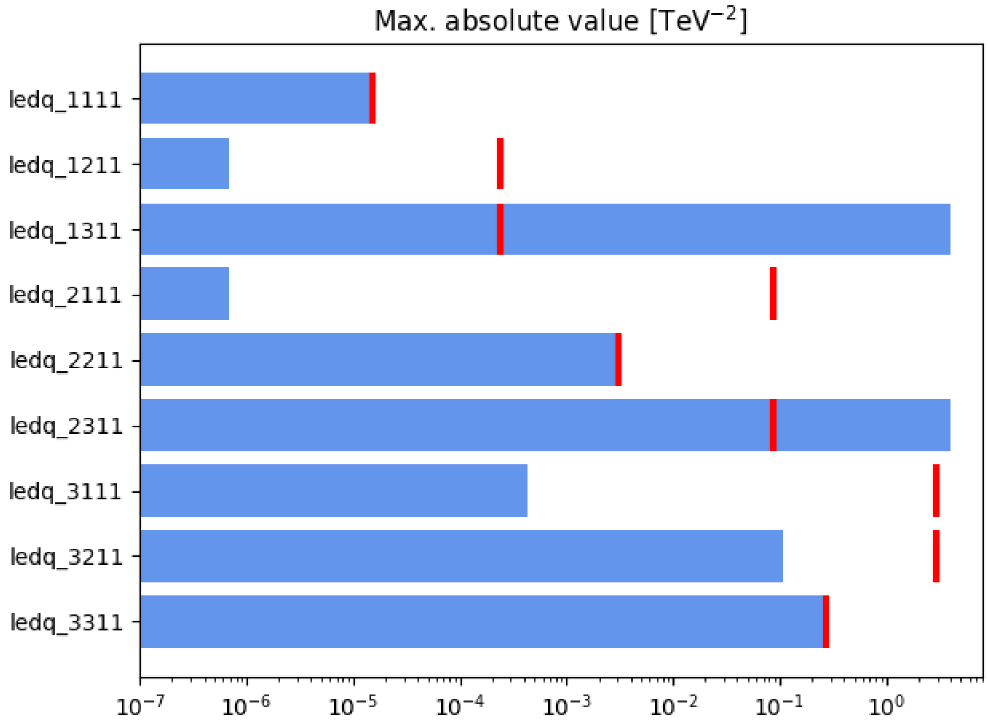
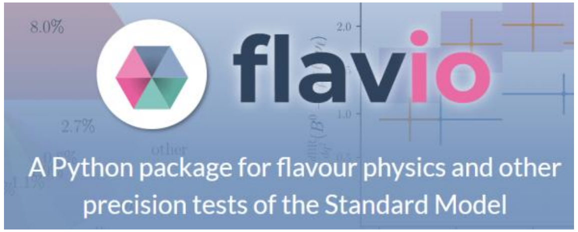
Seeking Models

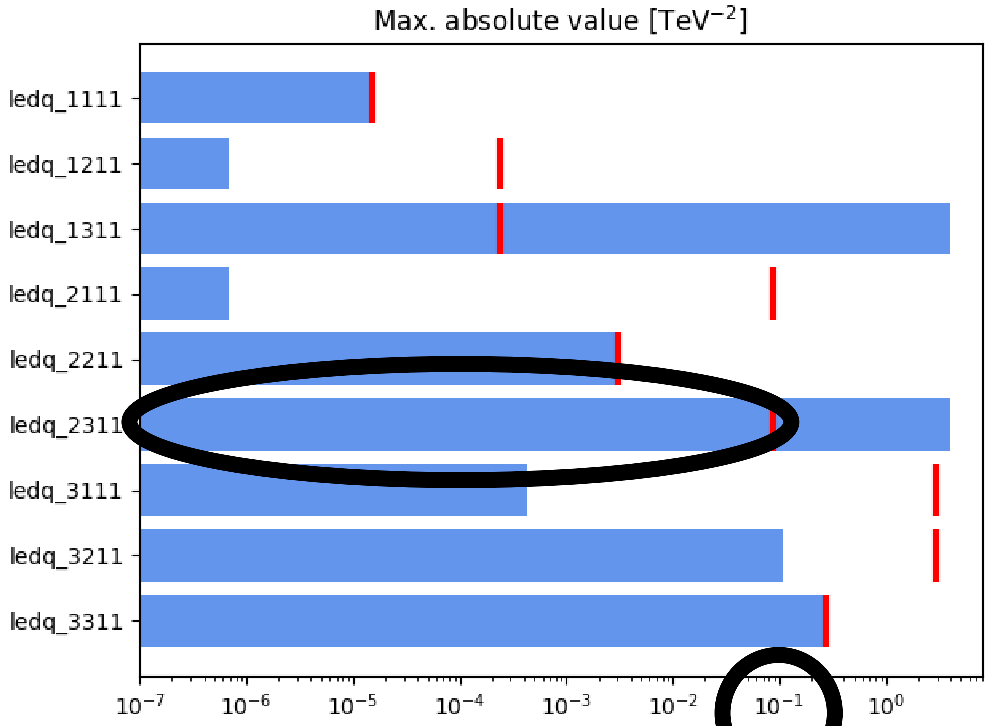


1810.08132

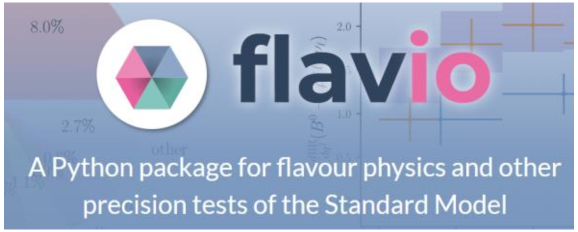


$$-\delta_{\alpha\beta}C^{*}_{\substack{Hud\\11}}+p_\beta\left(C_{\substack{ledq\\ \alpha\beta 11}}-\sum_x V^*_{x1}C^{(3)}_{\substack{lequ\\ \alpha\beta x1}}\right)\Big]^*$$

Seeking Models



[1810.08132](https://arxiv.org/abs/1810.08132)



$$-\delta_{\alpha\beta} C^*_{\substack{Hud\\11}} + p_\beta \left(C_{\substack{ledq\\ \alpha\beta 11}} - \sum_x V^*_{x1} C^{(3)}_{\substack{lequ\\ \alpha\beta x1}} \right) \Big]^*$$

Seeking Models

1810.08132

"Field Content"	"SU(3)"⊗"SU(2)"	"U(1)"
{ϕ1}	{ϕ1→"$\overline{3}$"⊗"1"}	$\{Y_{\phi 1} \to \frac{1}{3}\}$
{ϕ1}	{ϕ1→"1"⊗"2"}	$\{Y_{\phi 1} \to -\frac{1}{2}\}$
{ϕ1, ϕ2}	{ϕ1→"$\overline{3}$"⊗"1", ϕ2→"3"⊗"2"}	$\{Y_{\phi 1} \to \frac{1}{3}, Y_{\phi 2} \to \frac{7}{6}\}$
{ϕ1, ϕ2}	{ϕ1→"$\overline{6}$"⊗"1", ϕ2→"3"⊗"1"}	$\{Y_{\phi 1} \to \frac{1}{3}, Y_{\phi 2} \to -\frac{1}{3}\}$
{ϕ1, ϕ2}	{ϕ1→"$\overline{6}$"⊗"1", ϕ2→"3"⊗"2"}	$\{Y_{\phi 1} \to \frac{1}{3}, Y_{\phi 2} \to \frac{7}{6}\}$

SOLD

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Seeking Models

1810.08132

"Field Content"	"SU(3)" ⊗ "SU(2)"	"U(1)"
$\{\phi 1\}$	$\{\phi 1 \to \overline{\text{"3"}} \otimes \text{"1"}\}$	$\{Y_{\phi 1} \to \frac{1}{3}\}$
$\{\phi 1\}$	$\{\phi 1 \to \text{"1"} \otimes \text{"2"}\}$	$\{Y_{\phi 1} \to -\frac{1}{2}\}$
$\{\phi 1, \phi 2\}$	$\{\phi 1 \to \overline{\text{"3"}} \otimes \text{"1"}, \phi 2 \to \text{"3"} \otimes \text{"2"}\}$	$\{Y_{\phi 1} \to \frac{1}{3}, Y_{\phi 2} \to \frac{7}{6}\}$
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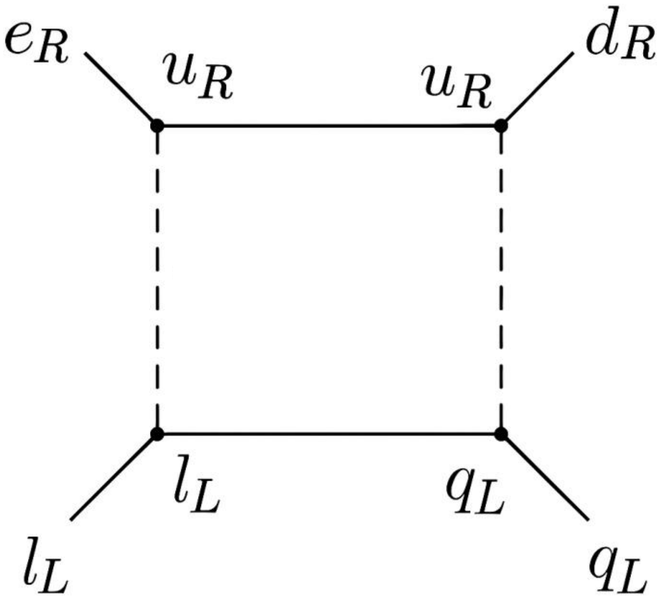
[2303.16965](2303.16965)

[2412.14253](2412.14253)

Seeking Models



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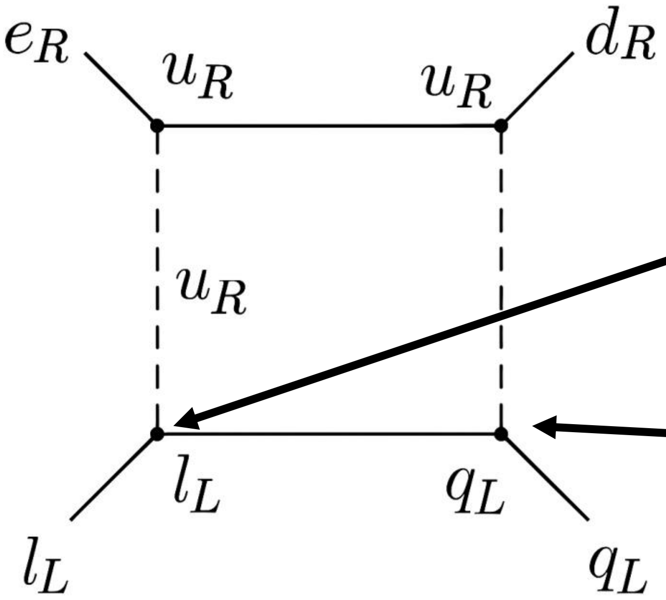

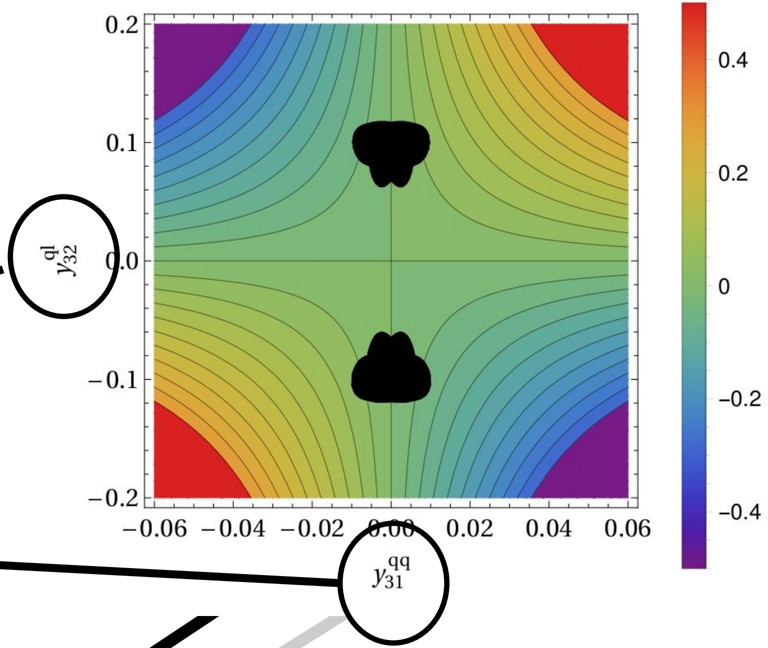

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Summary

[JHEP 03 (2024) 018]

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Exciting new results from neutrino experiments in the coming years, whose fluxes are mainly due to meson decay.

Any anomalies in upcoming years?

[eft-neutrinos]

Automatic **identification** of UV models (up to one-loop matching)

Summary

JHEP 03 (2024) 018

UNICAMP

Exciting new results from neutrino experiments in the coming years, whose fluxes are mainly due to meson decay.

Any anomalies in upcoming years?

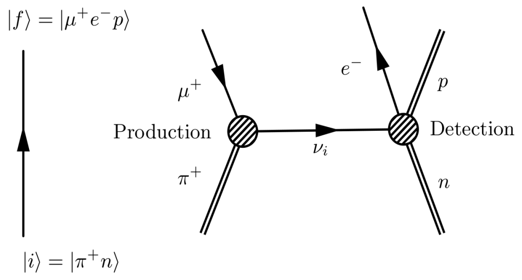
eft-neutrinos

Automatic **bound on** UV models
(up to one-loop matching)

Thank you!

Back Up

QFT approach



A. Falkowski, M. González-Alonso and Z. Tabrizi (2019)

V. Bresó-Pla, A. Falkowski, M. González-Alonso and K. Monsálvez-Pozo (2023)

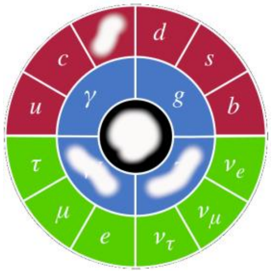
$$\int d\Pi_{P'} \mathcal{M}_{\alpha k}^{P,\pi} \bar{\mathcal{M}}_{\alpha l}^{P,\pi} = 2\, m_{\pi^\pm} \Gamma_{\pi \to \ell_\alpha \nu} \frac{[\mathcal{P}U]_{\alpha l}[U^\dagger \mathcal{P}^\dagger]_{k\alpha}}{[\mathcal{P}\mathcal{P}^\dagger]_{\alpha\alpha}}\, \delta\Big(E_\nu - E_{\nu,\pi}\Big)$$

Experimental decay rate

General picture

$$\mathcal{L}_{\rm WEFT} \supset -\frac{2V_{jk}}{v^2}\Big\{[1+\epsilon_L^{jk}]_{\alpha\beta}\left(\bar{u}^j\gamma^\mu P_L d^k\right)\left(\bar{\ell}_\alpha\gamma_\mu P_L\nu_\beta\right) + [\epsilon_R^{jk}]_{\alpha\beta}\left(\bar{u}^j\gamma^\mu P_R d^k\right)\left(\bar{\ell}_\alpha\gamma_\mu P_L\nu_\beta\right)$$
$$+\frac{1}{2}\left[\epsilon_S^{jk}\right]_{\alpha\beta}\left(\bar{u}^j d^k\right)\left(\bar{\ell}_\alpha P_L\nu_\beta\right) - \frac{1}{2}\left[\epsilon_P^{jk}\right]_{\alpha\beta}\left(\bar{u}^j\gamma^5 d^k\right)\left(\bar{\ell}_\alpha P_L\nu_\beta\right)$$
$$+\frac{1}{4}\left[\epsilon_T^{jk}\right]_{\alpha\beta}\left(\bar{u}^j\sigma^{\mu\nu}P_L d^k\right)\left(\bar{\ell}_\alpha\sigma_{\mu\nu}P_L\nu_\beta\right) + \text{h.c.}\Big\}\,.$$

LEFT



General picture

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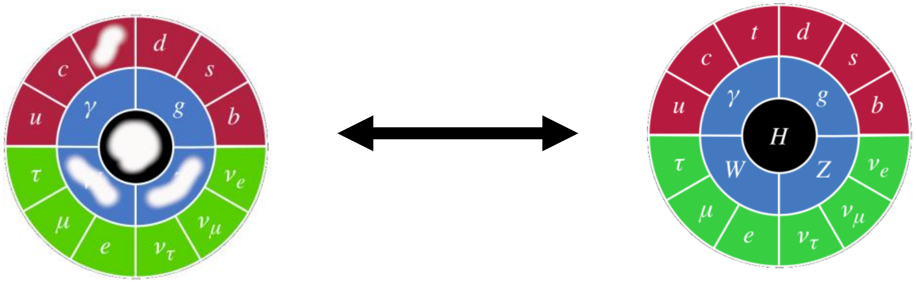
$$\mathcal{L}_{\text{WEFT}} \supset -\frac{2\,V_{jk}}{v^2}\Big\{[1+\epsilon_L^{jk}]_{\alpha\beta}\left(\bar{u}^j\gamma^\mu P_L d^k\right)\left(\bar{\ell}_\alpha\gamma_\mu P_L\nu_\beta\right)+[\epsilon_R^{jk}]_{\alpha\beta}\left(\bar{u}^j\gamma^\mu P_R d^k\right)\left(\bar{\ell}_\alpha\gamma_\mu P_L\nu_\beta\right)$$
$$+\frac{1}{2}\left[\epsilon_S^{jk}\right]_{\alpha\beta}\left(\bar{u}^j d^k\right)\left(\bar{\ell}_\alpha P_L\nu_\beta\right)-\frac{1}{2}\left[\epsilon_P^{jk}\right]_{\alpha\beta}\left(\bar{u}^j\gamma^5 d^k\right)\left(\bar{\ell}_\alpha P_L\nu_\beta\right)$$
$$+\frac{1}{4}\left[\epsilon_T^{jk}\right]_{\alpha\beta}\left(\bar{u}^j\sigma^{\mu\nu}P_L d^k\right)\left(\bar{\ell}_\alpha\sigma_{\mu\nu}P_L\nu_\beta\right)+\text{h.c.}\Big\}\,.$$

$$\bar{\epsilon}_{\alpha\sigma} = (\epsilon_L)_{\alpha\sigma} - (\epsilon_R)_{\alpha\sigma} - \frac{m_{\pi^\pm}^2}{m_{\ell_\alpha}(m_u+m_d)}(\epsilon_P)_{\alpha\sigma}$$

General picture

LEFT

SMEFT



E.E. Jenkins, A.V. Manohar and P. Stoffer (2017)

$$\bar{\epsilon}_{\beta\alpha} = \frac{v^2}{2}\left[2C^{(3)}_{\substack{Hl\\ \alpha\beta}} + 2\sum_x V^*_{x1}\left(\delta_{\alpha\beta}C^{(3)*}_{\substack{Hq\\ 1x}} - C^{(3)}_{\substack{lq\\ \alpha\beta 1x}}\right) + \delta_{\alpha\beta}C^*_{\substack{Hud\\ 11}} + p_\beta\left(C_{\substack{ledq\\ \alpha\beta 11}} - \sum_x V^*_{x1}C^{(3)}_{\substack{lequ\\ \alpha\beta x1}}\right)\right]^*$$