BSM searches at neutrino experiments

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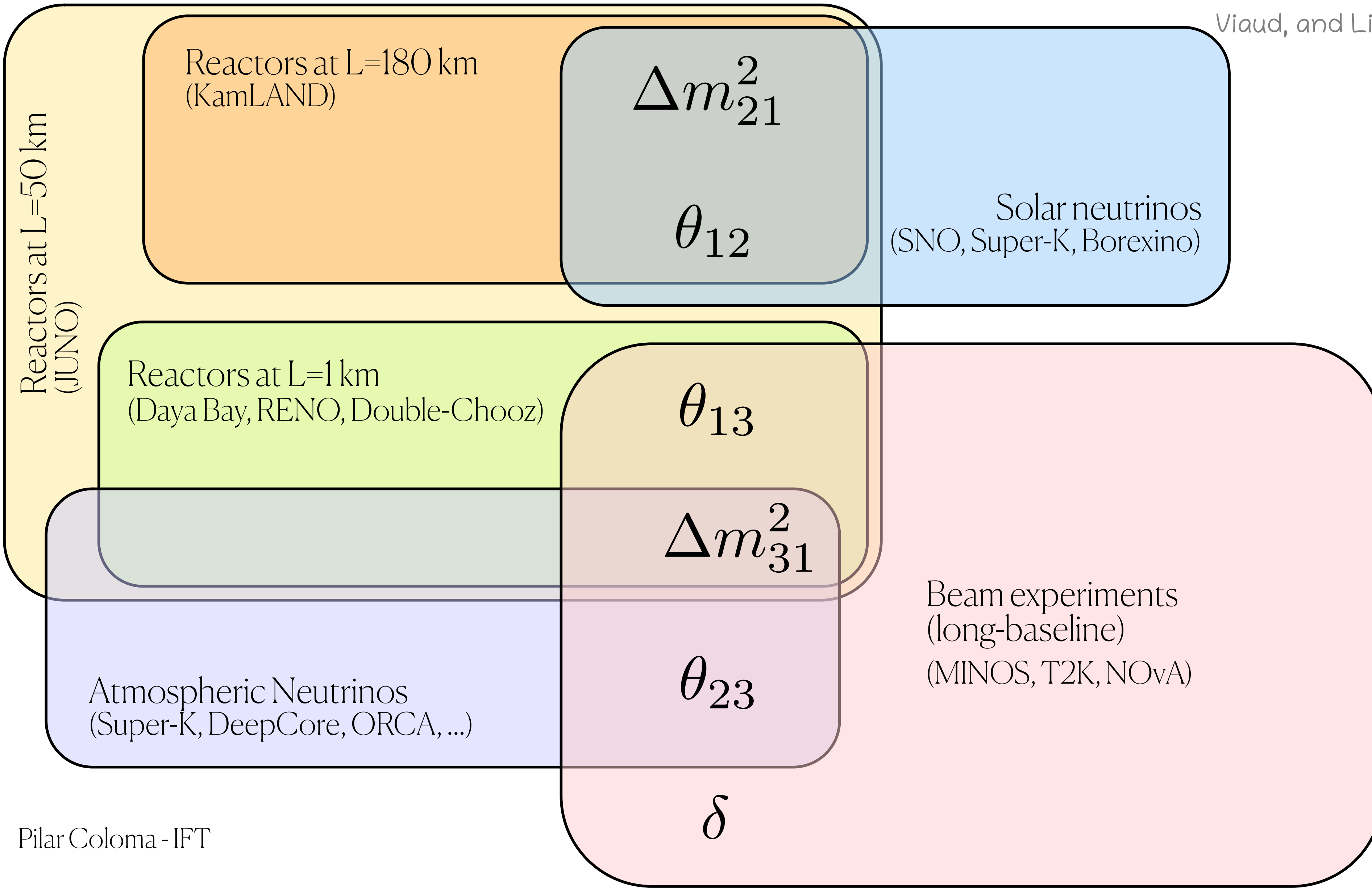
IRN Neutrino Meeting
IJCLab, Orsay - June 1st, 2026

Instituto de Física Teórica UAM-CSIC

Neutrino oscillation picture

See talks by Carretero Cuenca, Viaud, and Lisi



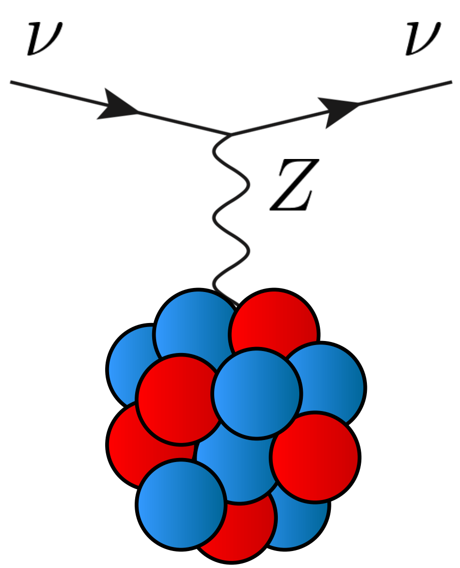
Recent experimental developments

Coherent Elastic Neutrino-Nucleus Scattering (CEvNS)

$$\frac{d\sigma}{dE_r} = \frac{G_F^2}{2\pi}\frac{\mathcal{Q}^2}{4}F^2(2ME_r)M\left(2 - \frac{ME_r}{E_\nu^2}\right)$$

Freedman, PRD 9 (1974)

$$\mathcal{Q}^2 = (Zg_p^V + Ng_n^V)^2$$



→ Coherence condition: |q| < 1/R
→ This imposes an upper bound on the allowed recoil ~O (1-10) keV

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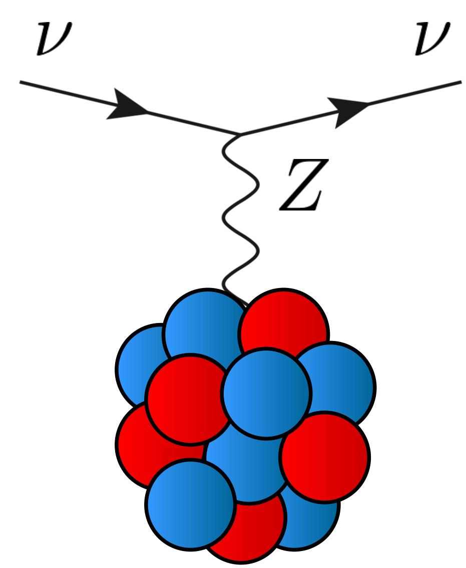


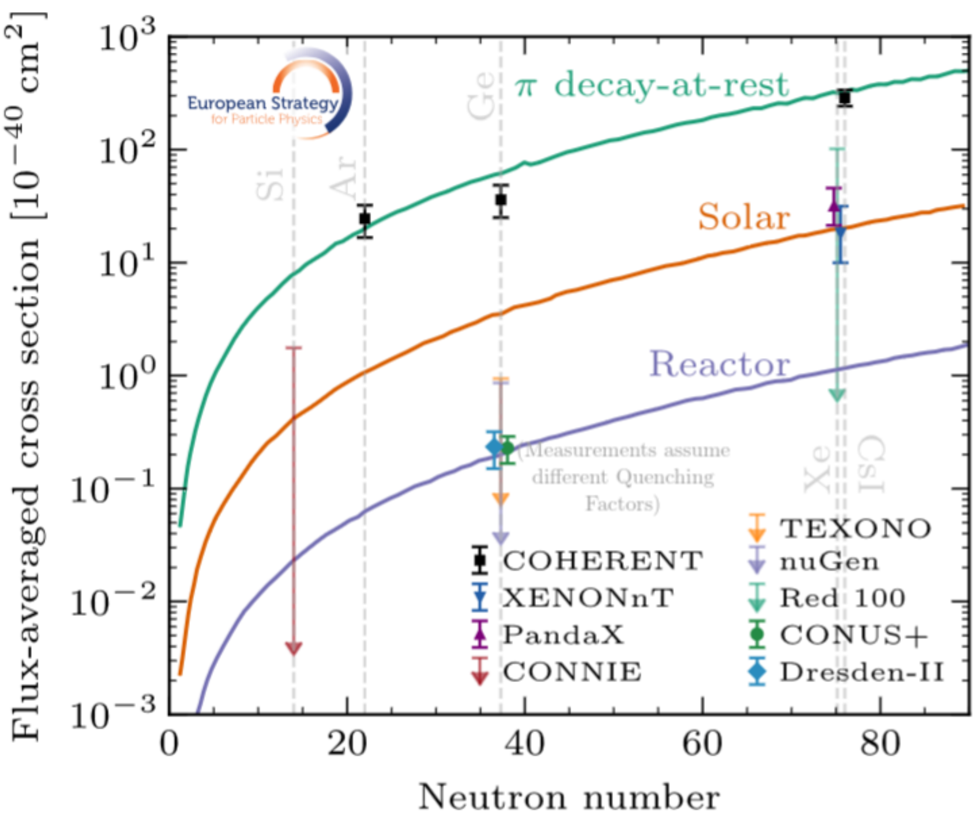


Figure from ESS Physics Briefing Book, 2511.03883

→ Coherence condition: |q| < 1/R
→ This imposes an upper bound on the allowed recoil ~O (1-10) keV

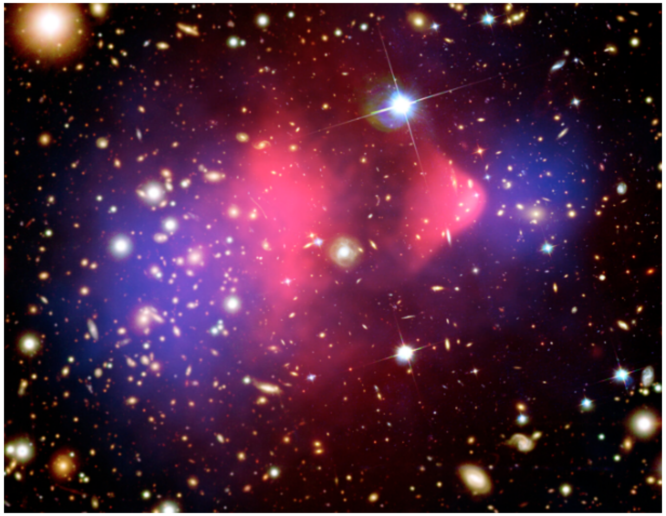
Open questions in the SM

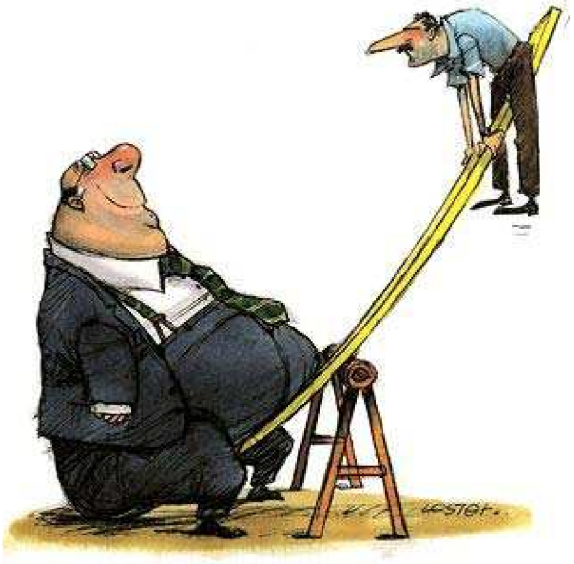
Experimental evidence:

Dark matter
Neutrino masses
Matter-antimatter asymmetry
...

Theoretical indications:

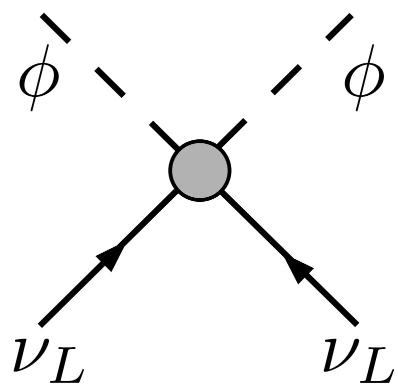
Strong-CP problem
Hierarchy problem
Flavor puzzle
Cosmological constant

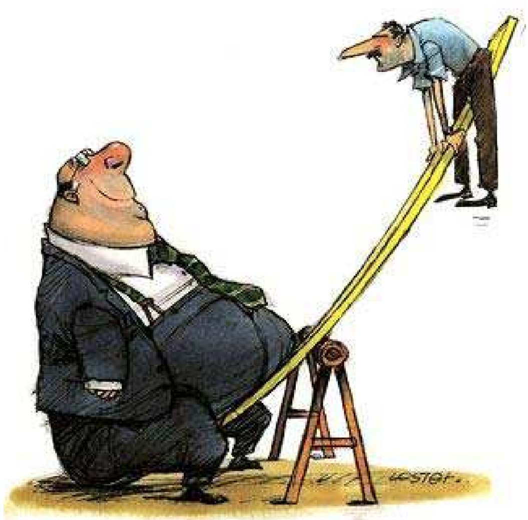




New physics in the neutrino sector

$$\mathcal{L}_{\rm eff} \supset \mathcal{O}^{d=4} + \frac{1}{\Lambda}\mathcal{O}^{d=5} + \frac{1}{\Lambda^2}\mathcal{O}^{d=6} + \ \dots$$





$$\propto \frac{1}{\Lambda}(\overline{L}_L\widetilde{\phi})(\widetilde{\phi}^t L_L^c) \to m_\nu \bar{\nu}_L \nu_L^c$$

Weinberg, 1979

Outline

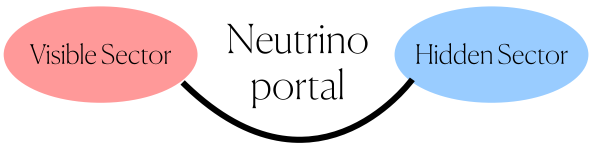
- Effects from additional operators: new neutrino states and new effective interactions at low energies
- Searches for Non-Standard Interactions in the neutrino sector: current status
  - synergies between oscillation + scattering data
- NSI in a wider context:
  - light mediators and SMEFT

$$\mathcal{L}_{\rm eff} \supset \mathcal{O}^{d=4} + \frac{1}{\Lambda}\,\mathcal{O}^{d=5} + \frac{1}{\Lambda^2}\,\mathcal{O}^{d=6} + \ldots$$

Additional neutrino eigenstates

$$\mathcal{L}_{\text{eff}} \supset \mathcal{O}^{d=4} + \frac{1}{\Lambda}\mathcal{O}^{d=5} + \frac{1}{\Lambda^2}\mathcal{O}^{d=6} + \ldots$$

$$\phi \bar{\nu}_L \nu_R + \ldots$$



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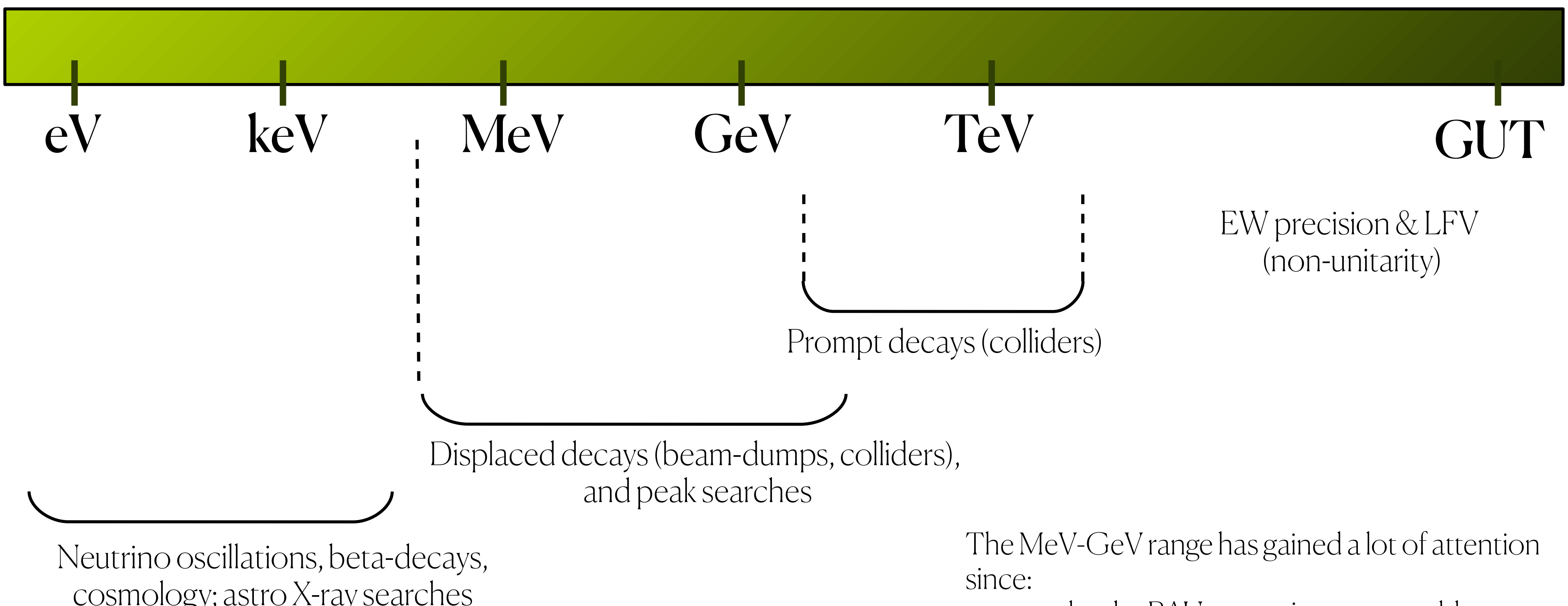
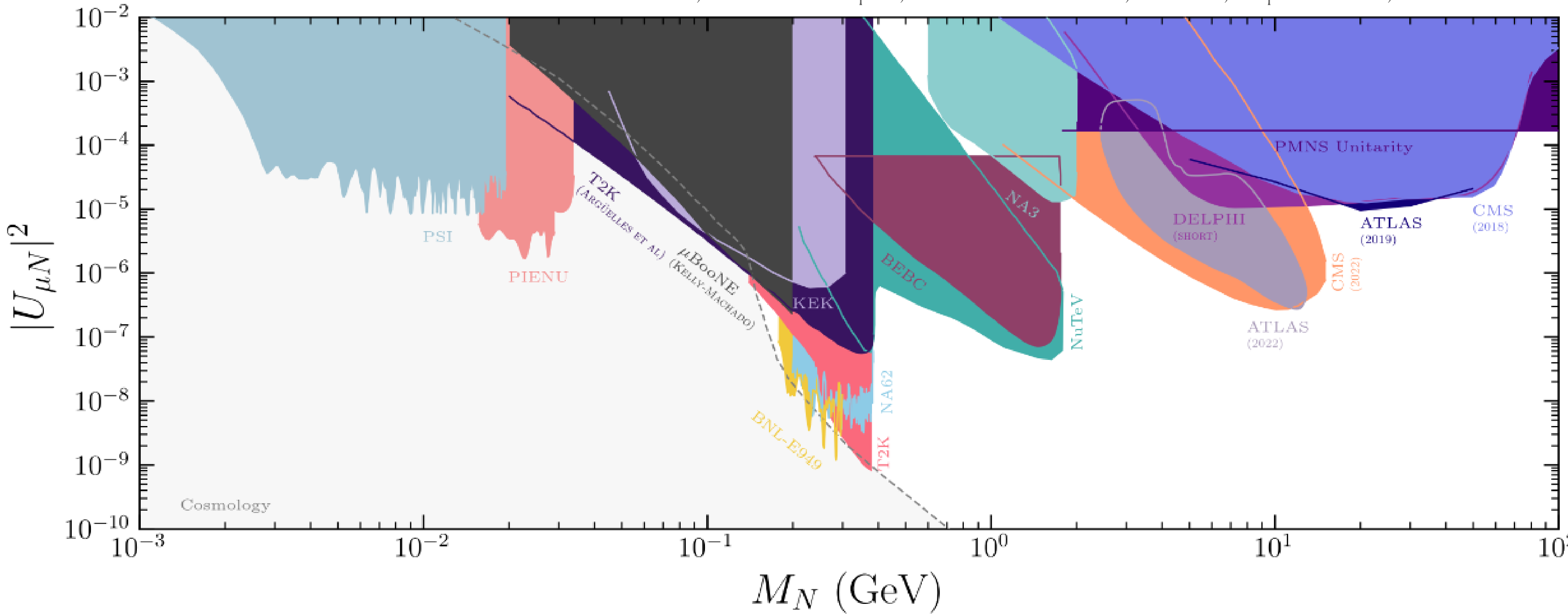


The MeV-GeV range has gained a lot of attention since:
- may solve the BAU + neutrino mass problems
- phenomenologically testable
- does not worsen Higgs hierarchy problem

Additional neutrino eigenstates

$$\mathcal{L}_{\rm eff} \supset \mathcal{O}^{d=4} + \frac{1}{\Lambda}\mathcal{O}^{d=5} + \frac{1}{\Lambda^2}\mathcal{O}^{d=6} + \dots$$

Fernandez-Martinez, Gonzalez-Lopez, Hernandez-Garcia, Hostert, Lopez-Pavon, 2304.06772



$$\mathcal{L}_{\text{eff}} \supset \mathcal{O}^{d=4} + \frac{1}{\Lambda}\mathcal{O}^{d=5} + \frac{1}{\Lambda^2}\mathcal{O}^{d=6} + \ldots$$

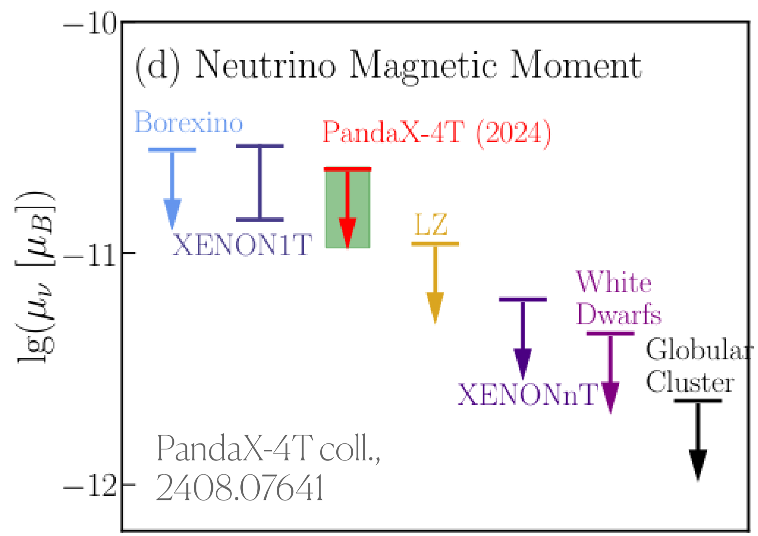
Higher-dimensional operators

$$\mathcal{L}_{\text{eff}} \supset \mathcal{O}^{d=4} + \frac{1}{\Lambda}\mathcal{O}^{d=5} + \frac{1}{\Lambda^2}\mathcal{O}^{d=6} + \ldots$$

$$\bar{\nu}_L \sigma^{\mu\nu} \nu_R F_{\mu\nu}$$

e.g. neutrino magnetic moments

$$\frac{d\sigma_\beta^{\mu_\nu}}{dT_e} = \frac{d\sigma_\beta^{\text{SM}}}{dT_e} + \left(\frac{\mu_{\nu_\beta}}{\mu_B}\right)^2 \frac{\alpha^2 \pi}{m_e^2}\left[\frac{1}{T_e} - \frac{1}{E_\nu}\right]$$



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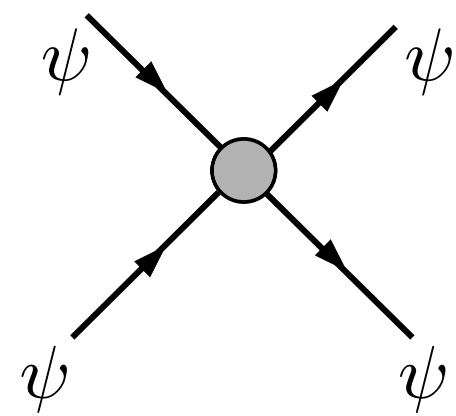


$$G_x \sim \frac{g_x^2}{\Lambda^2}$$

Wolfenstein '78; Mikheev & Smirnov '85; Valle '87; Roulet '91; Guzzo, Masiero, Petcov '91; ...

Charged-current NSI

$$\mathcal{L}_{\text{eff}} \supset \mathcal{O}^{d=4} + \frac{1}{\Lambda}\mathcal{O}^{d=5} + \frac{1}{\Lambda^2}\mathcal{O}^{d=6} + \ldots$$

In the WEFT, for interactions with quarks:

$$(\bar{u}^j \gamma^\mu P_L d^k)(\bar{\ell}_\alpha \gamma_\mu P_L \nu_\beta)$$

$$(\bar{u}^j \gamma^\mu P_R d^k)(\bar{\ell}_\alpha \gamma_\mu P_L \nu_\beta)$$

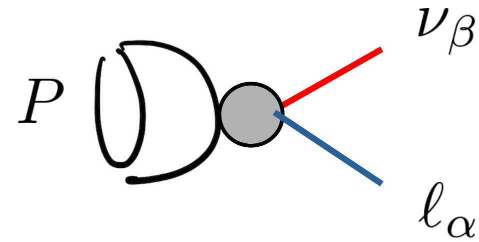
Not present in the SM:

$$(\bar{u}^j d^k)(\bar{\ell}_\alpha P_L \nu_\beta)$$

$$(\bar{u}^j \gamma_5 d^k)(\bar{\ell}_\alpha P_L \nu_\beta)$$

$$(\bar{u}^j \sigma^{\mu\nu} P_L d^k)(\bar{\ell}_\alpha \sigma_{\mu\nu} P_L \nu_\beta)$$

May affect neutrino production & detection

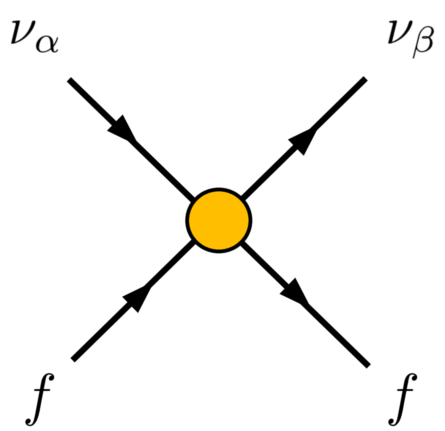


Recent works in this direction include:
Falkowski, Gonzalez-Alonso, Tabrizi, 1901.04553 & 1910.02971; Kopp, Tabrizi, Urrea, 2509.21537; Kopp, Rocco, Tabrizi, 2401.07902; Falkowski, Gonzalez-Alonso, Kopp, Soreq, Tabrizi, 2105.12136; Cherchiglia & Santiago, 2309.15924;

Neutral-current NSI

$$\mathcal{L}_{\text{eff}} \supset \mathcal{O}^{d=4} + \frac{1}{\Lambda}\mathcal{O}^{d=5} + \frac{1}{\Lambda^2}\mathcal{O}^{d=6} + \ldots$$

In the WEFT:



Vector
$(\bar{f}\gamma^\mu f)(\bar{\nu}_\alpha \gamma_\mu P_L \nu_\beta)$

May affect:

Neutrino propagation in matter

Neutrino detection

Axial-vector
$(\bar{f}\gamma^\mu \gamma^5 f)(\bar{\nu}_\alpha \gamma_\mu P_L \nu_\beta)$

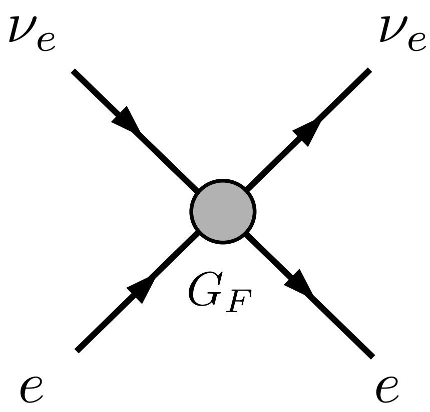
May affect:

~~Neutrino propagation in matter~~

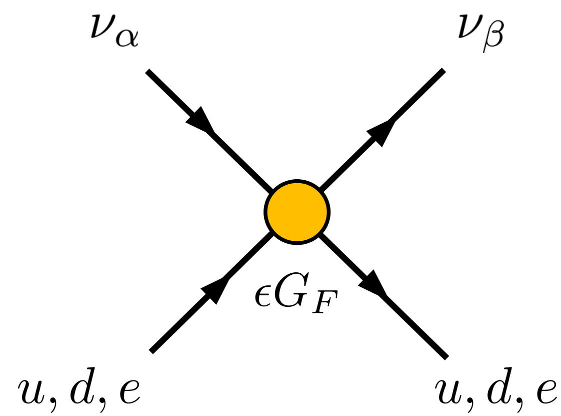
Neutrino detection

NSI in oscillations

$$H = U\mathcal{H}_0 U^\dagger +$$



$$+$$



NSI in oscillations

$$H = U\mathcal{H}_0U^\dagger + \sqrt{2}G_F N_e(x)\begin{pmatrix} 1+\tilde{\mathcal{E}}_{ee}(x) & \mathcal{E}_{e\mu}(x) & \mathcal{E}_{e\tau}(x) \\ \mathcal{E}^*_{e\mu}(x) & 0 & \mathcal{E}_{\mu\tau}(x) \\ \mathcal{E}^*_{e\tau}(x) & \mathcal{E}^*_{\mu\tau}(x) & \tilde{\mathcal{E}}_{\tau\tau}(x) \end{pmatrix}$$

$$\mathcal{E}_{\alpha\beta} = \varepsilon^{e,V}_{\alpha\beta} + \varepsilon^{p,V}_{\alpha\beta} + Y_n(x)\varepsilon^{n,V}_{\alpha\beta}\,; Y_n(x) \equiv \frac{N_n(x)}{N_e(x)}$$

$$\tilde{\mathcal{E}}_{\alpha\alpha} \equiv \mathcal{E}_{\alpha\alpha} - \mathcal{E}_{\mu\mu}$$

NSI in oscillations

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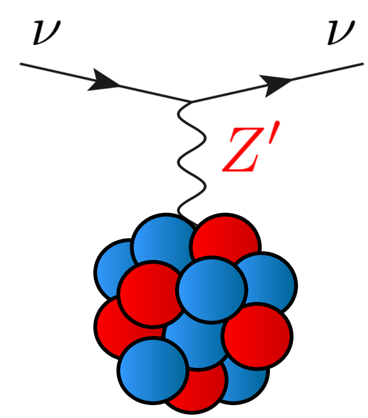
- Three important limitations:
  - Only vector NSI
  - Cannot determine the three flavor-diagonal entries independently
  - Multiple degenerate solutions
- Scattering data is needed!
  - nu-e elastic scattering (solar exps, DM direct detection exps)
  - Scattering with nuclei:
    - Coherent regime: CEvNS Barranco, Miranda, Rashba, JHEP 12 (2005) 021
    - Incoherent: SNO, CHARM, NuTeV, MINOS+, NOvA, ...



$$\varepsilon G_F \propto \frac{g_f g_\nu}{M^2_{Z'}}$$

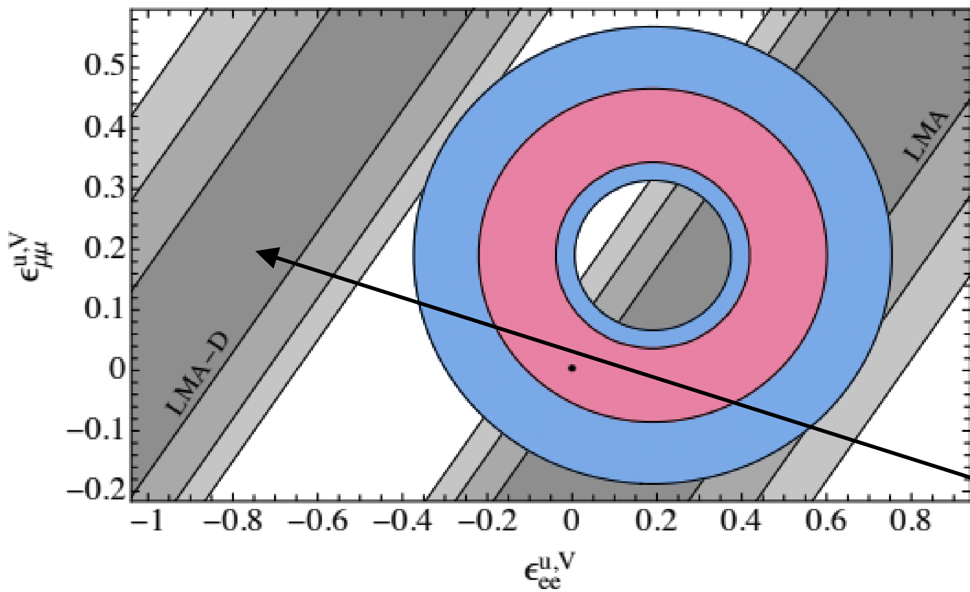
See e.g. Davidson, Peña-Garay, Rius, Santamaria, hep-ph/0302093;
Abbaslu, Dehpour, Farzan, Safari, 2312.12420; Ilma, Rafi Alam, Alvarez-Ruso, et al, 2412.04818; Abbaslu & Farzan, 2509.02711;
Gehrlein, Hoefken Zink, Machado, Pinheiro, 2604.16176

Synergies: oscillations vs scattering

Coloma, Gonzalez-Garcia, Maltoni and Schwetz, 1708.02899

LMA-D Miranda,Tortola, Valle, hep-ph/0406280

See also Gonzalez-Garcia, Maltoni, Salvado, 1103.4265; Coloma & Schwetz, 1604.05772



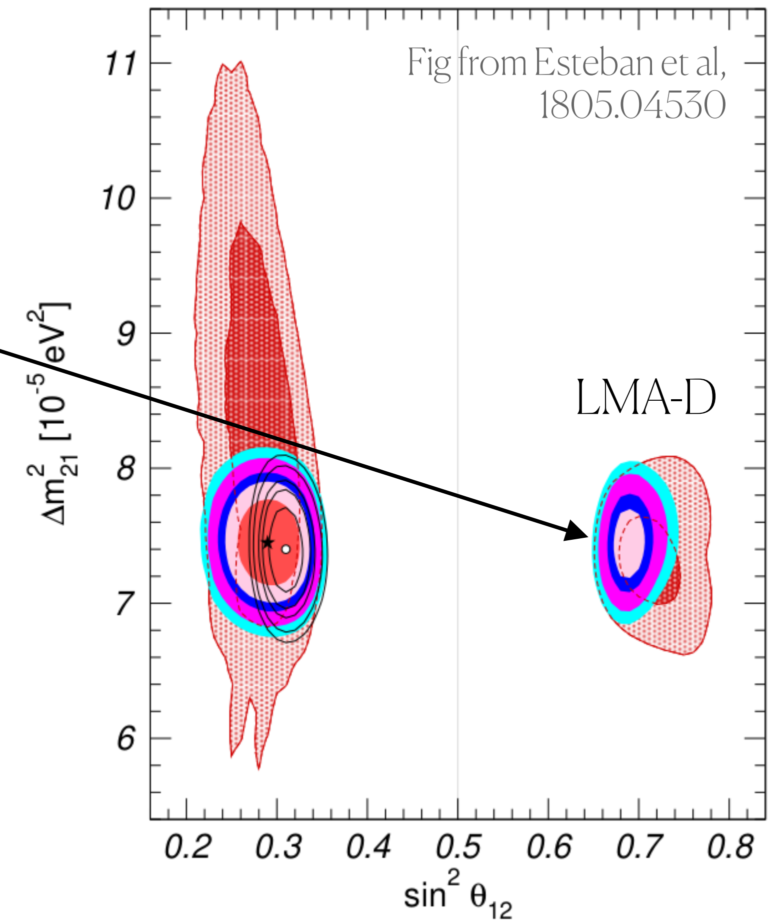


Fig from Esteban et al, 1805.04530

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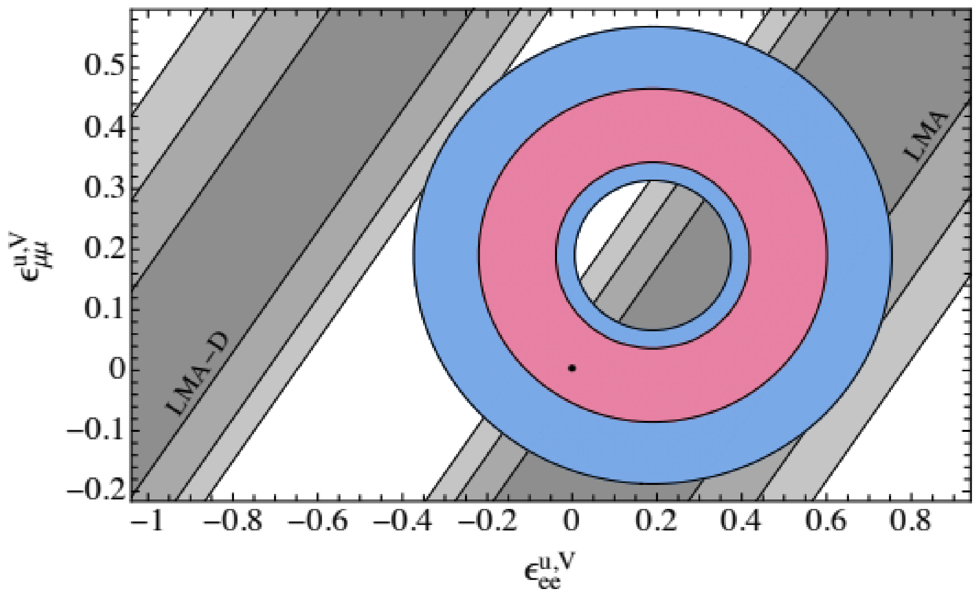
Coloma, Gonzalez-Garcia, Maltoni and Schwetz, 1708.02899



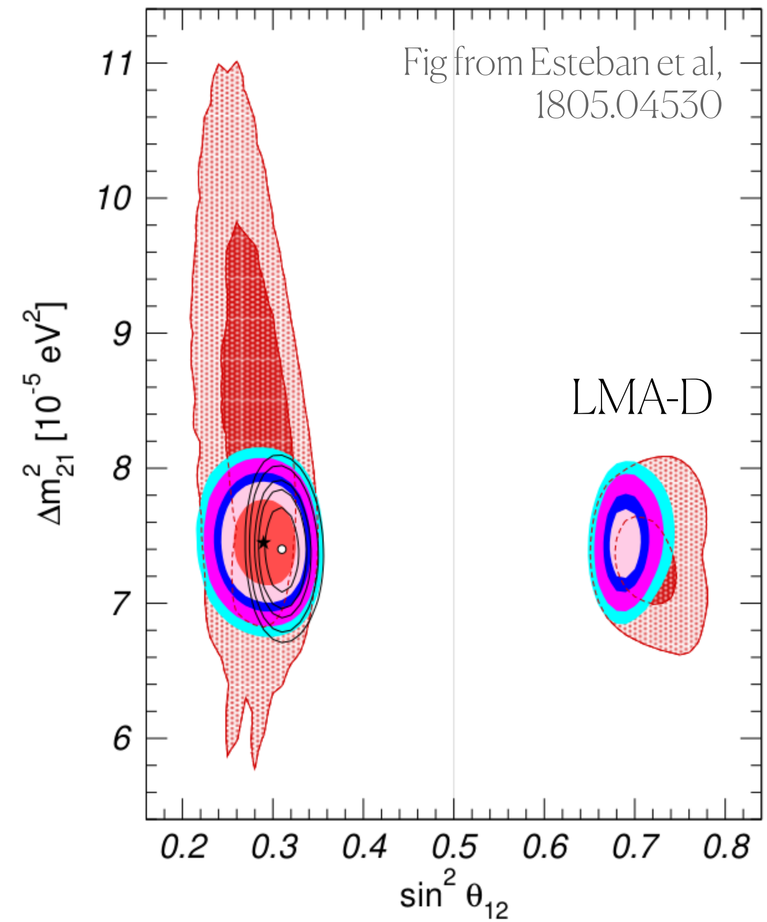
$$\sigma_{\alpha}^{\mathrm{CE}\nu\mathrm{NS}} \propto (\mathcal{Q}_{\alpha\alpha})^2 + \sum_{\beta\neq\alpha} |\mathcal{Q}_{\alpha\beta}|^2$$

$$\mathcal{Q}_{\alpha\beta}(\vec{\varepsilon}) = Z(g_p^V \delta_{\alpha\beta} + \varepsilon_{\alpha\beta}^{p,V}) + N(g_n^V \delta_{\alpha\beta} + \varepsilon_{\alpha\beta}^{n,V})$$

→ **Blind spot**: NSI with protons and neutrons can always cancel for a given nucleus → data on several nuclei needed!

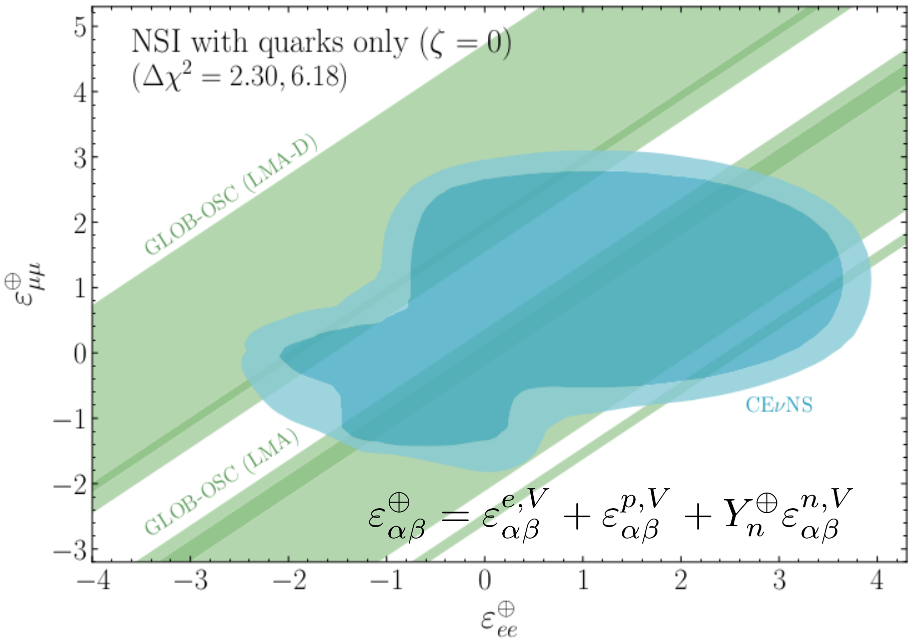
LMA-D Miranda, Tortola, Valle, hep-ph/0406280

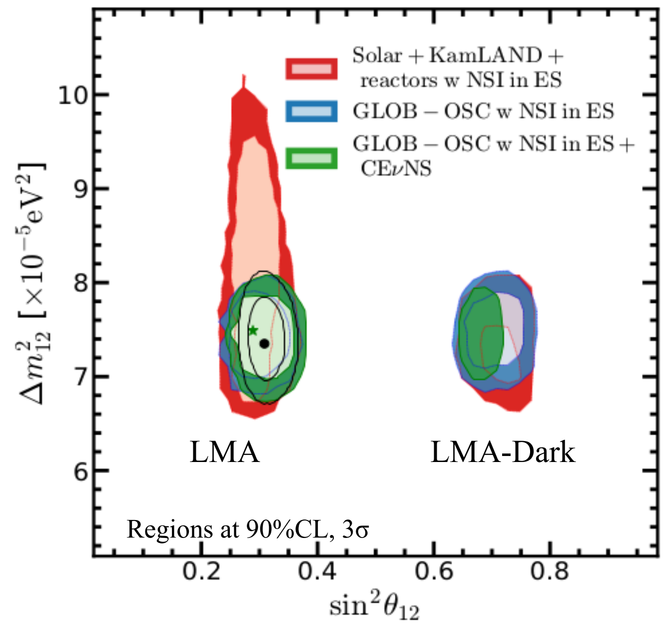
See also Gonzalez-Garcia, Maltoni, Salvado, 1103.4265; Coloma & Schwetz, 1604.05772



Synergies: oscillations vs scattering

Most general case (all operators included simultaneously):



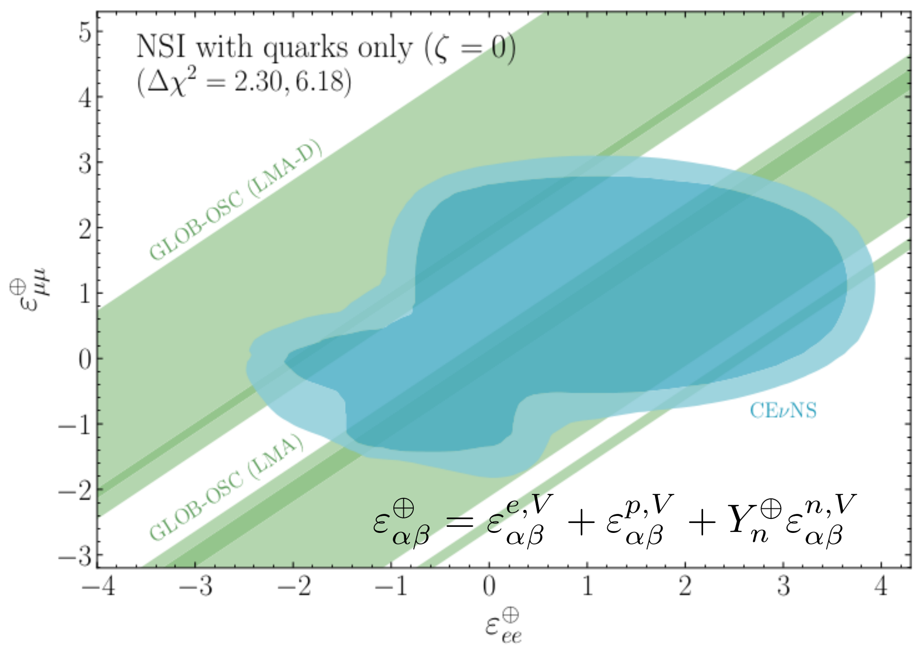


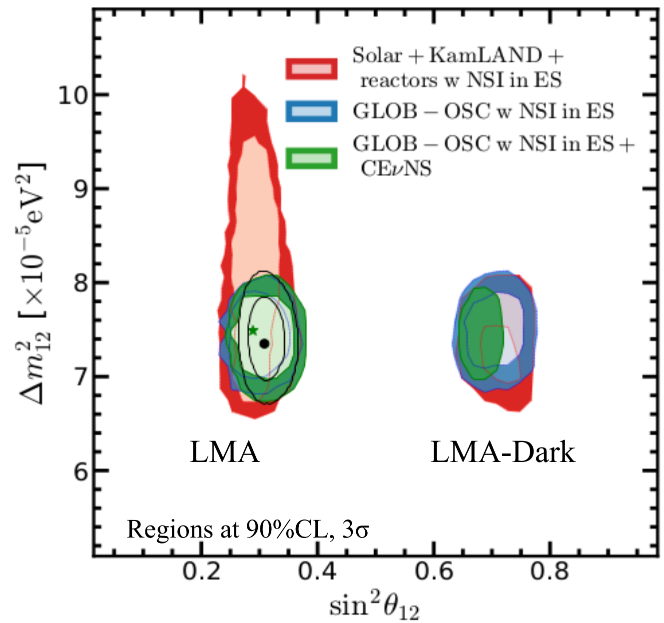
Vector NSI with quarks

Coloma, Gonzalez-Garcia, Maltoni, Pinheiro, Urrea, 2305.07698

Synergies: oscillations vs scattering

Most general case (all operators included simultaneously):





Vector NSI with quarks

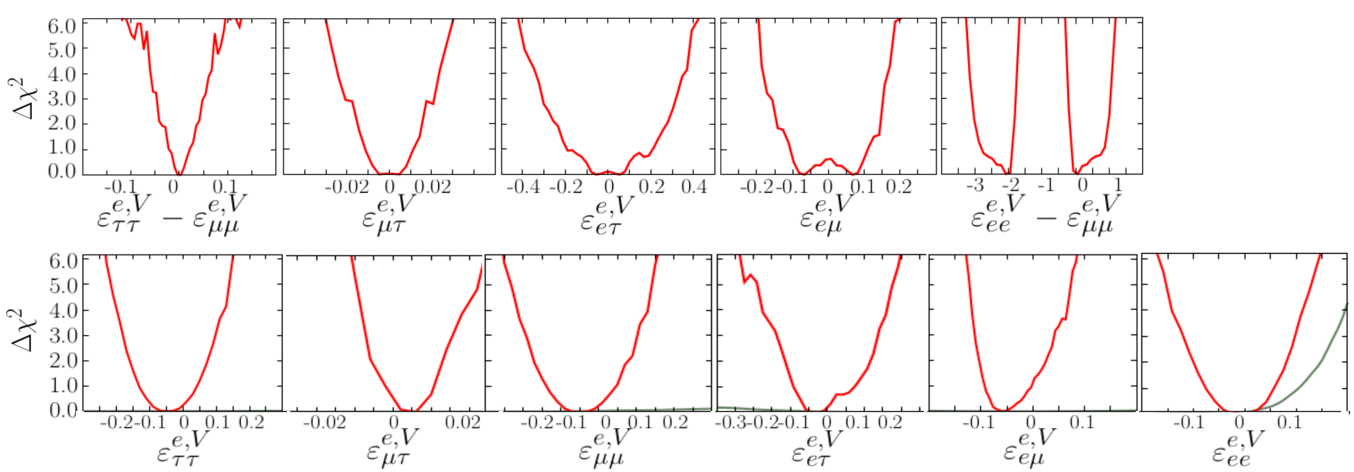
Coloma, Gonzalez-Garcia, Maltoni, Pinheiro, Urrea, 2305.07698

Vector NSI with electrons

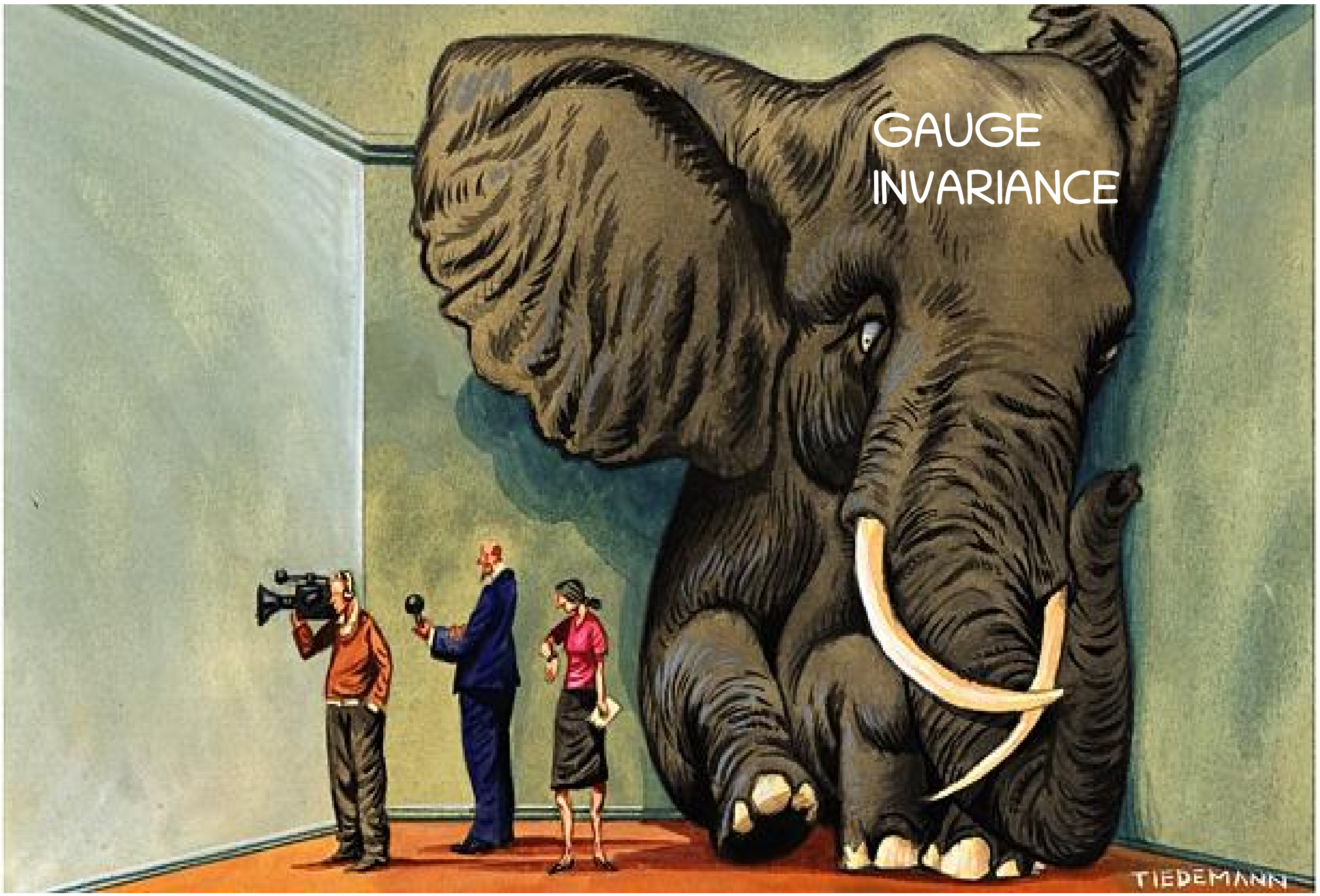
Osc. only

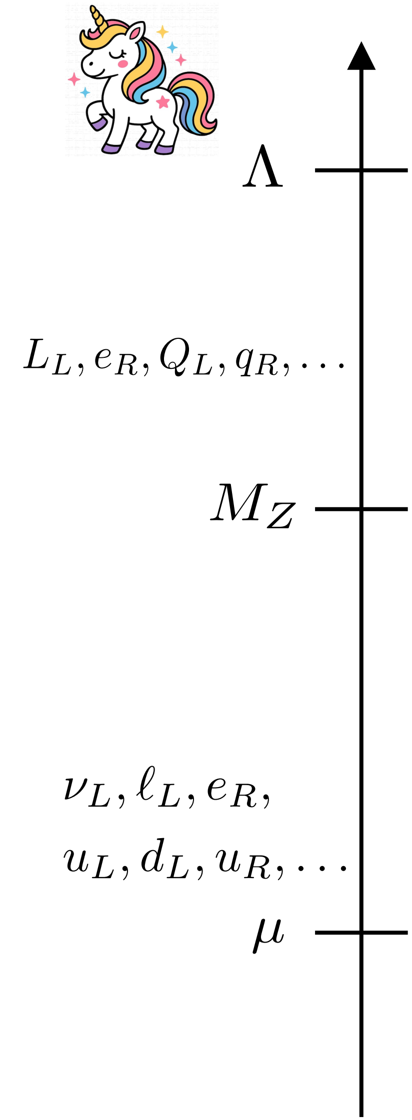
↓

Osc. + ν-e scattering



NSI in a wider context





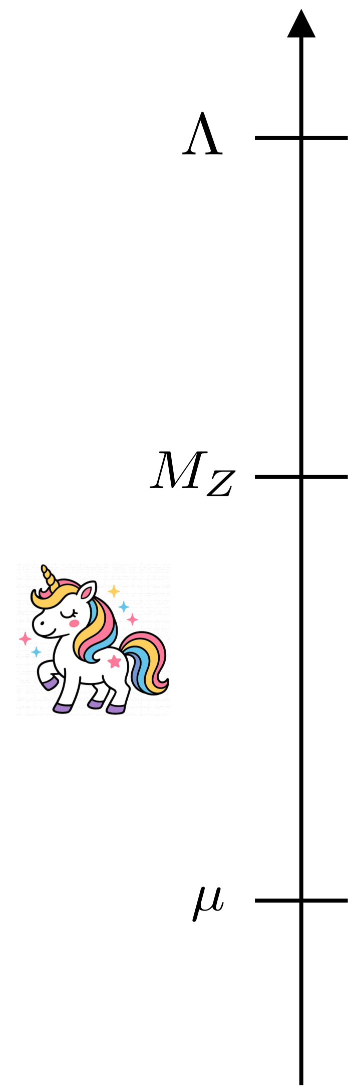
See e.g. Gavela, Hernandez, Ota, Winter, 0809.3451;
Antusch, Baumann, Fernandez-Martinez, 0807.1003

$$\mathcal{L}_{Z'} \supset \sum_f g_{Z'} Q'_f Z'_\mu \bar{f} \gamma^\mu f + \frac{1}{2} M_{Z'}^2 Z'^\mu Z'_\mu$$

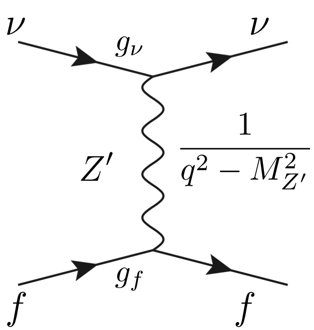
Anomaly-free (for SM + $3N_R$) and without hadronic FCNC

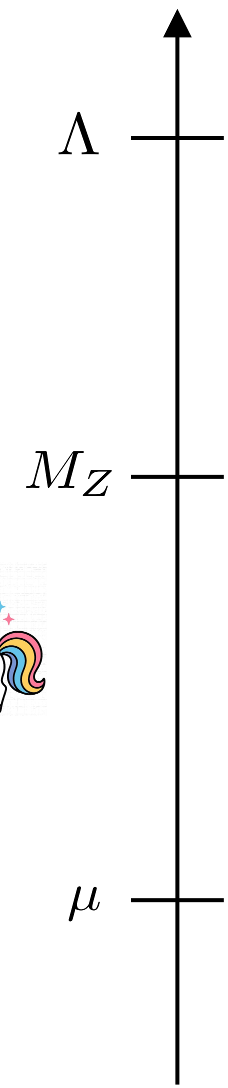
$$\mathcal{G} = G_{SM} \times U(1)_X$$
$$X = a(B-L) + b(L_\alpha - L_\beta) + c(L_\beta - L_\gamma)$$

See e.g. Araki, Heeck, Kubo, JHEP 07 (2012) 083
Greljo, Soreq, Stangl, Thomsen, Zupan, JHEP 04 (2022) 151
Greljo, Stangl, Thomsen, Zupan, 2203.13731

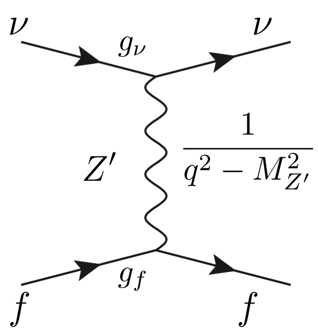


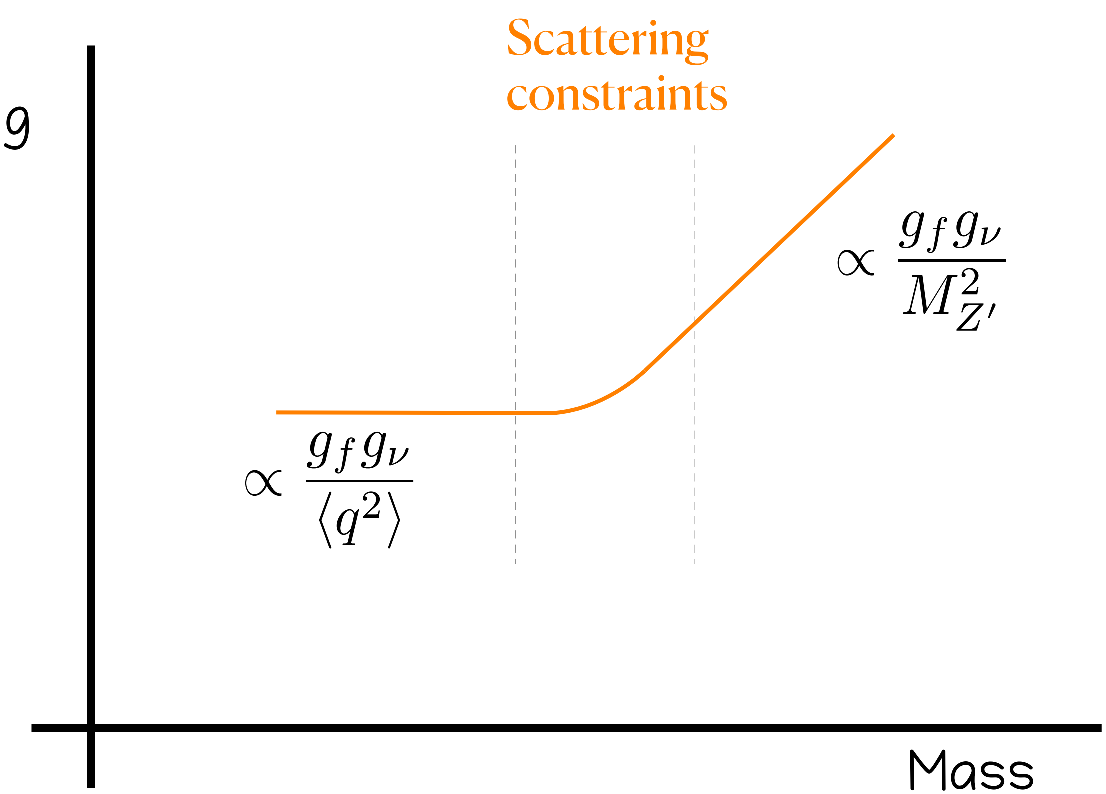
Light mediators

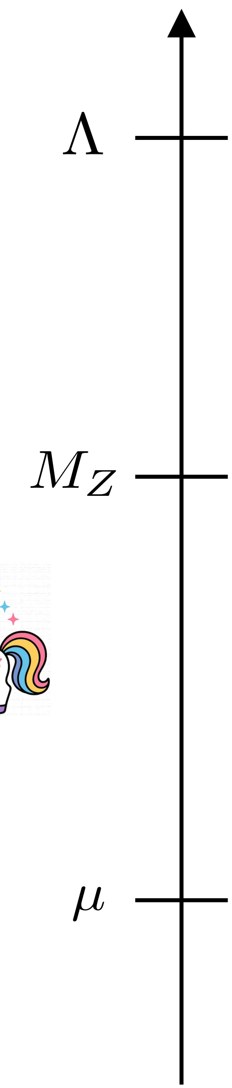




Light mediators: scattering exps







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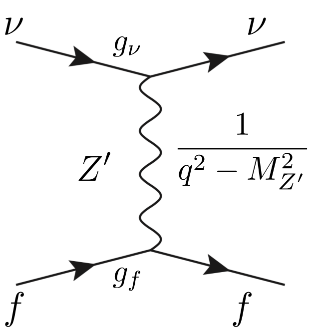
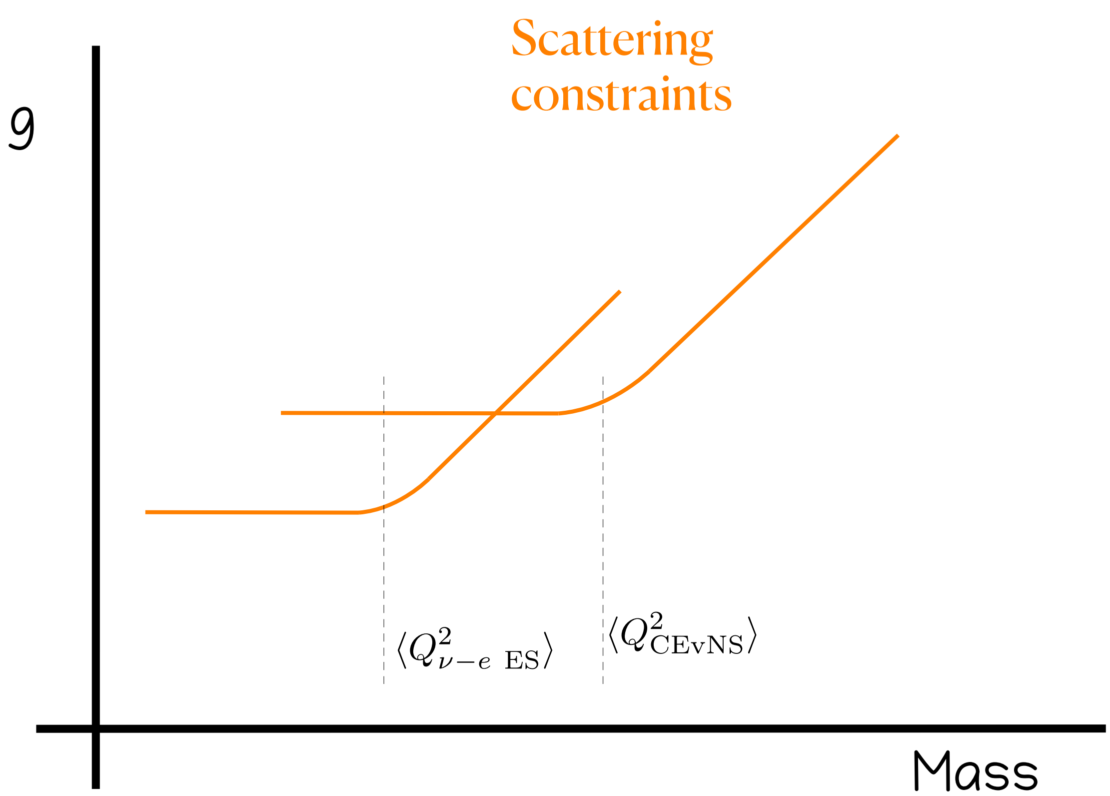
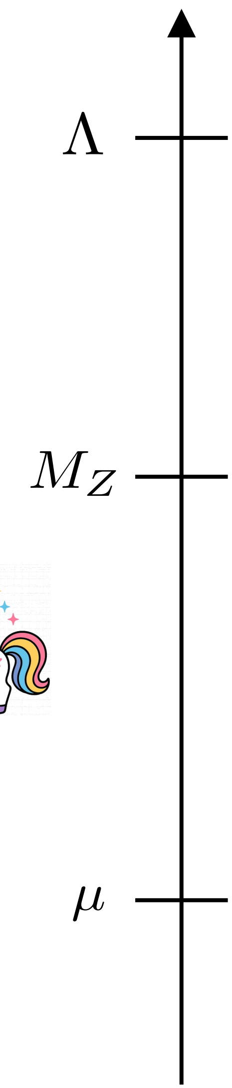
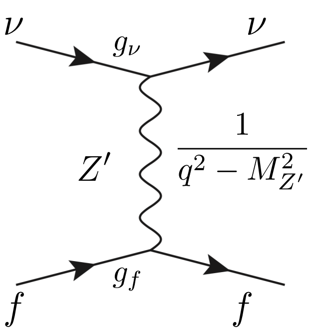


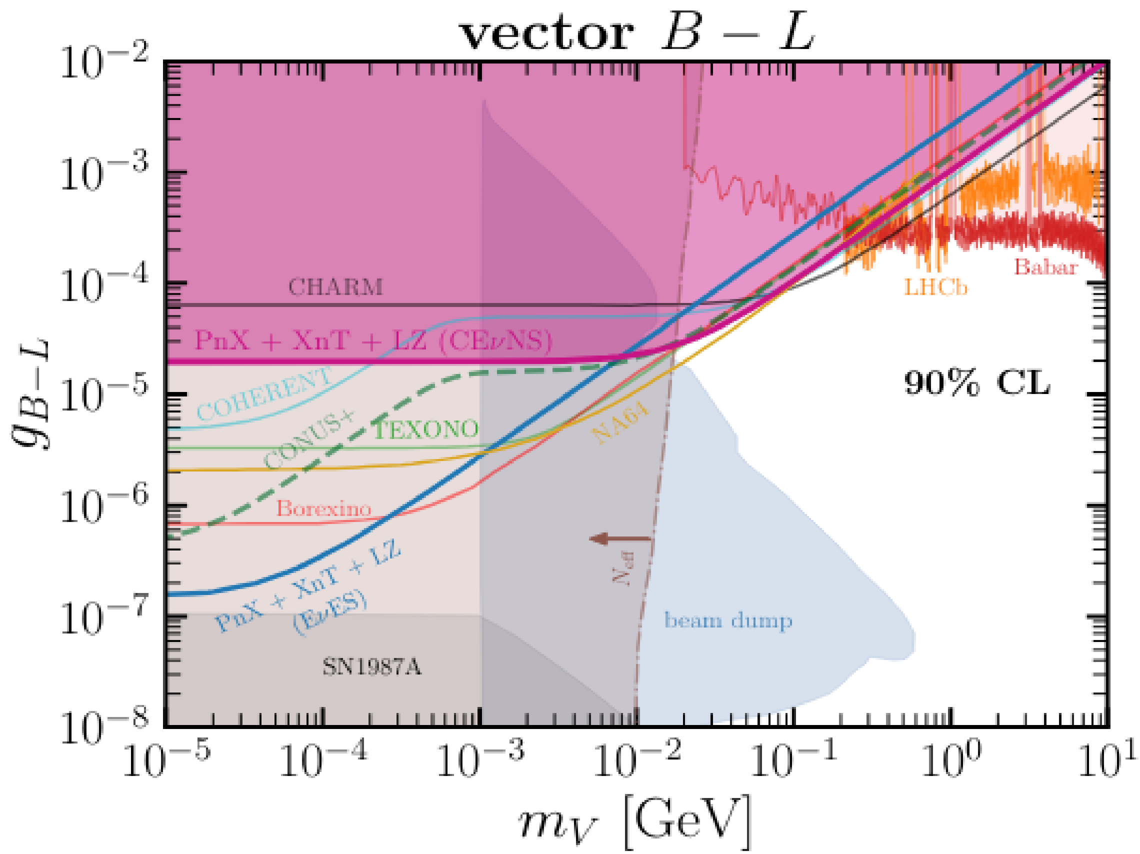


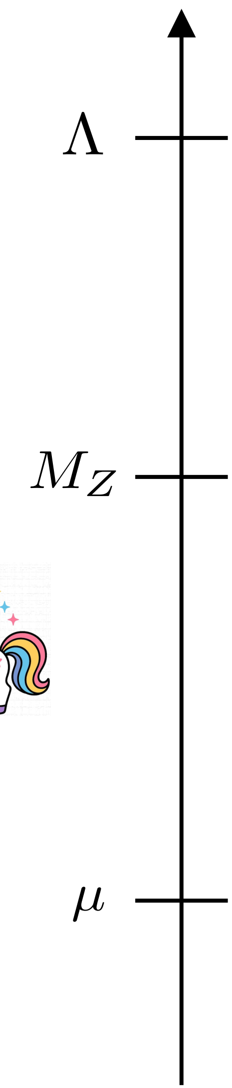


Harnik, Kopp, Machado, 1202.6073;
Bilmis et al, 1502.07763;
Cerdeno, Fairbairn, Jubb, Machado, Vincent, 1604.01025;
Coloma, Esteban, Gonzalez-Garcia et al, 2202.10829;
...

Light mediators: scattering exps

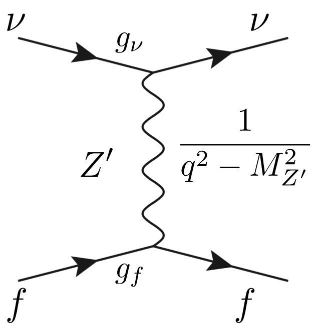


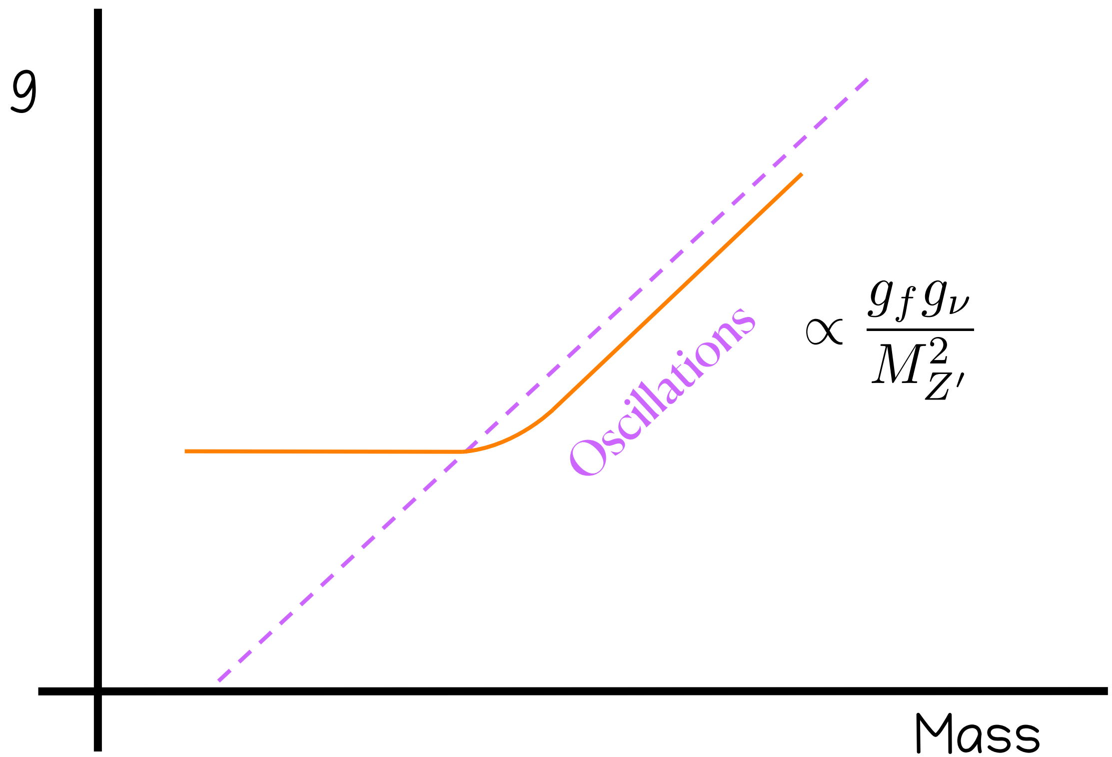


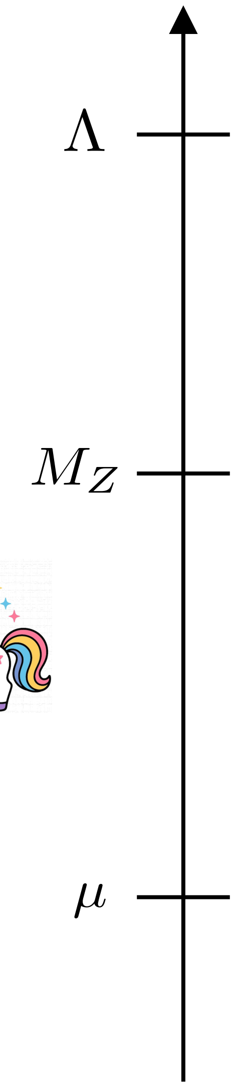


de Romeri, Papoulias, Pompa, Sanchez-Garcia, Ternes, 2603.00554
(similar results in Atzori Corona, Cadeddu, Cargioli et al, 2509.22178)

Light mediators: oscillations

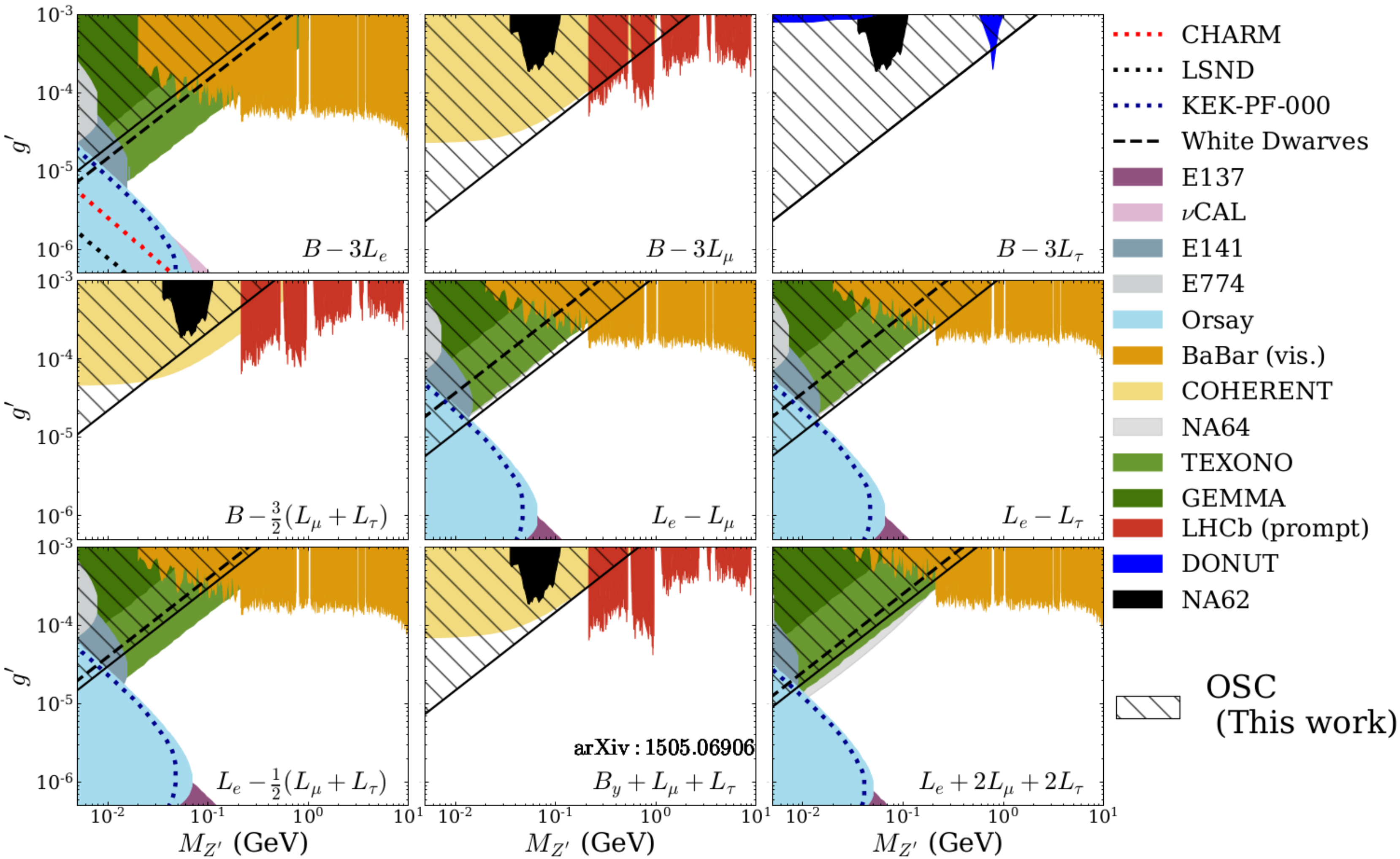






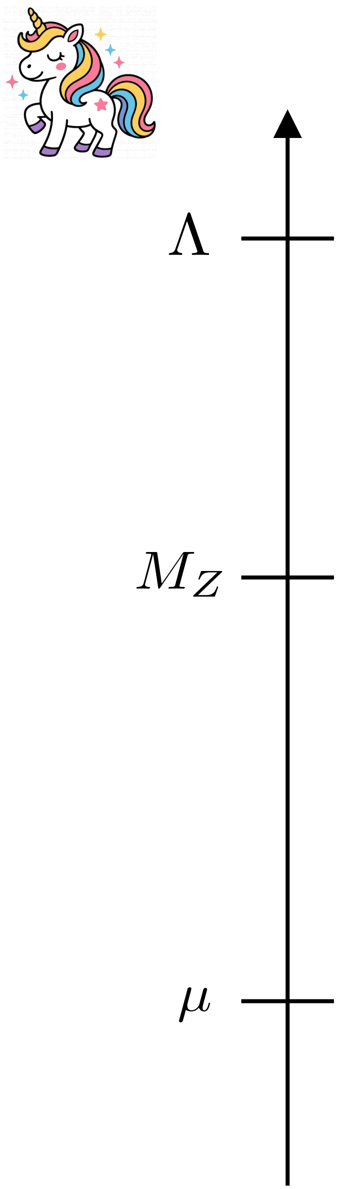
Harnik, Kopp, Machado, 1202.6073; Farzan 1505.06906, Farzan & Shoemaker, 1512.09147, Farzan & Heeck, 1607.07616, Babu, Friedland, Machado, Mocioiu, 1705.01822, ...

Light mediators: oscillations



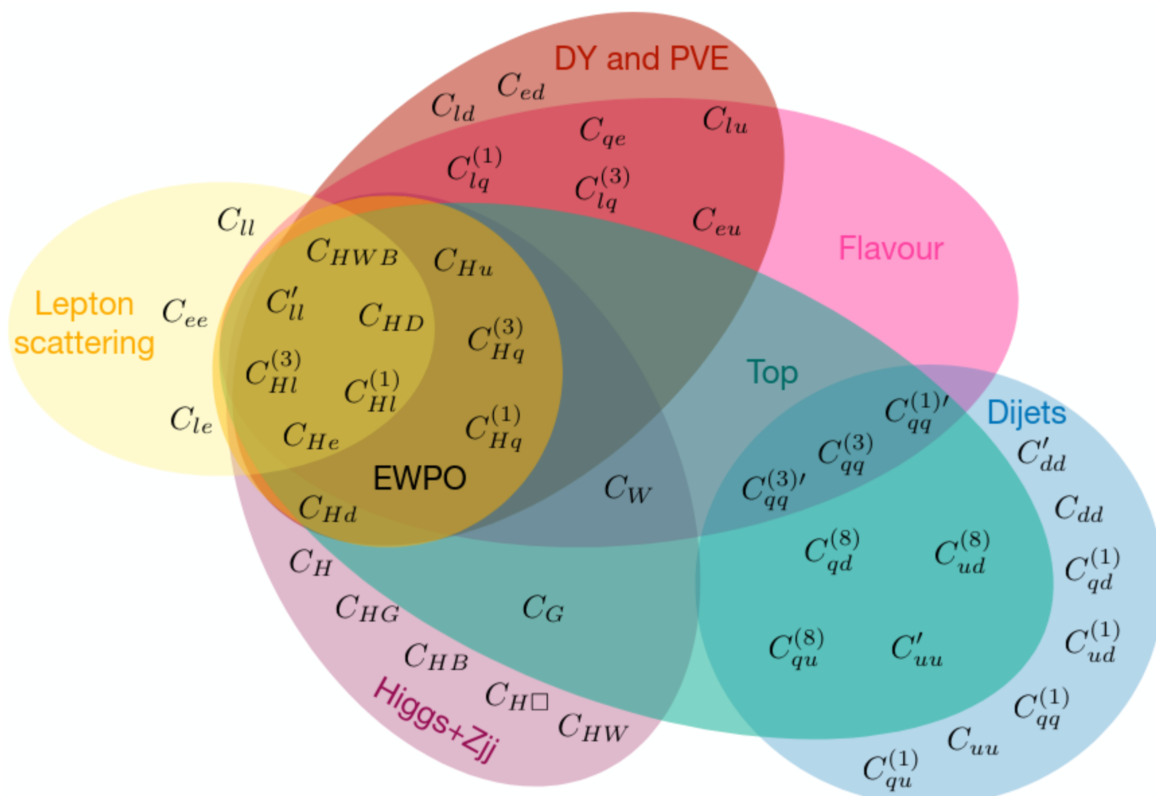
Coloma, Gonzalez-Garcia and Maltoni, 2009.14220

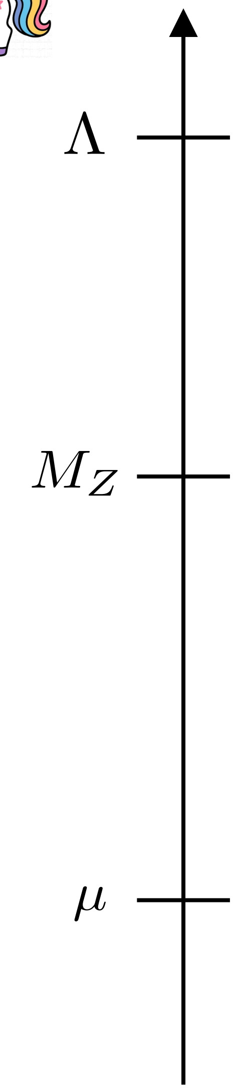
$$\varepsilon^{f}_{\alpha\alpha} = q_{\nu_\alpha} q_f \frac{1}{\sqrt{G_F}} \frac{g'^2}{M^2_{Z'}}$$



Λ
M_Z
μ

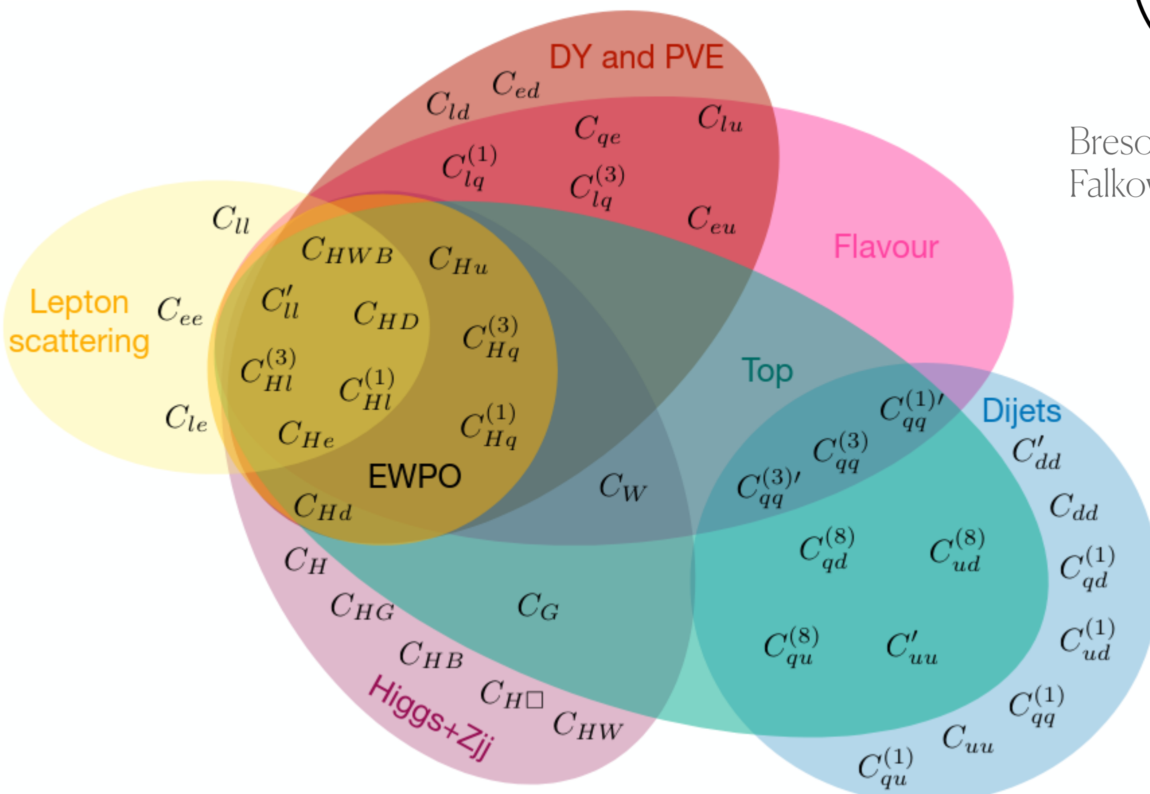
From SMEFT to NSI



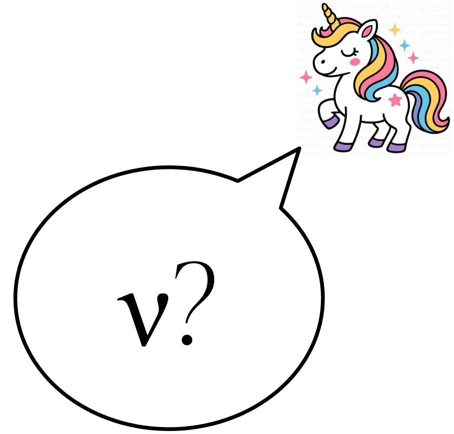


Bartocci, Biekötter, Hurth, 2311.04963

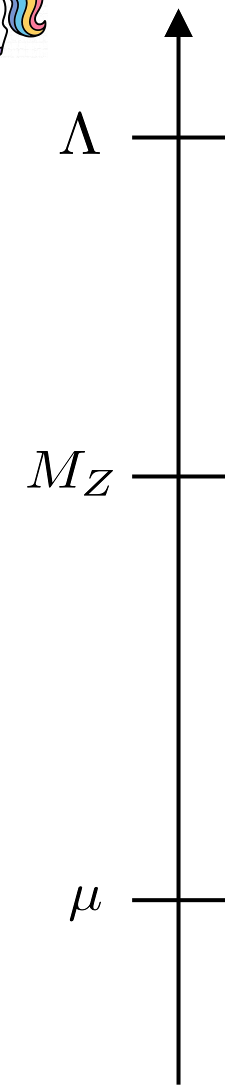
From SMEFT to NSI



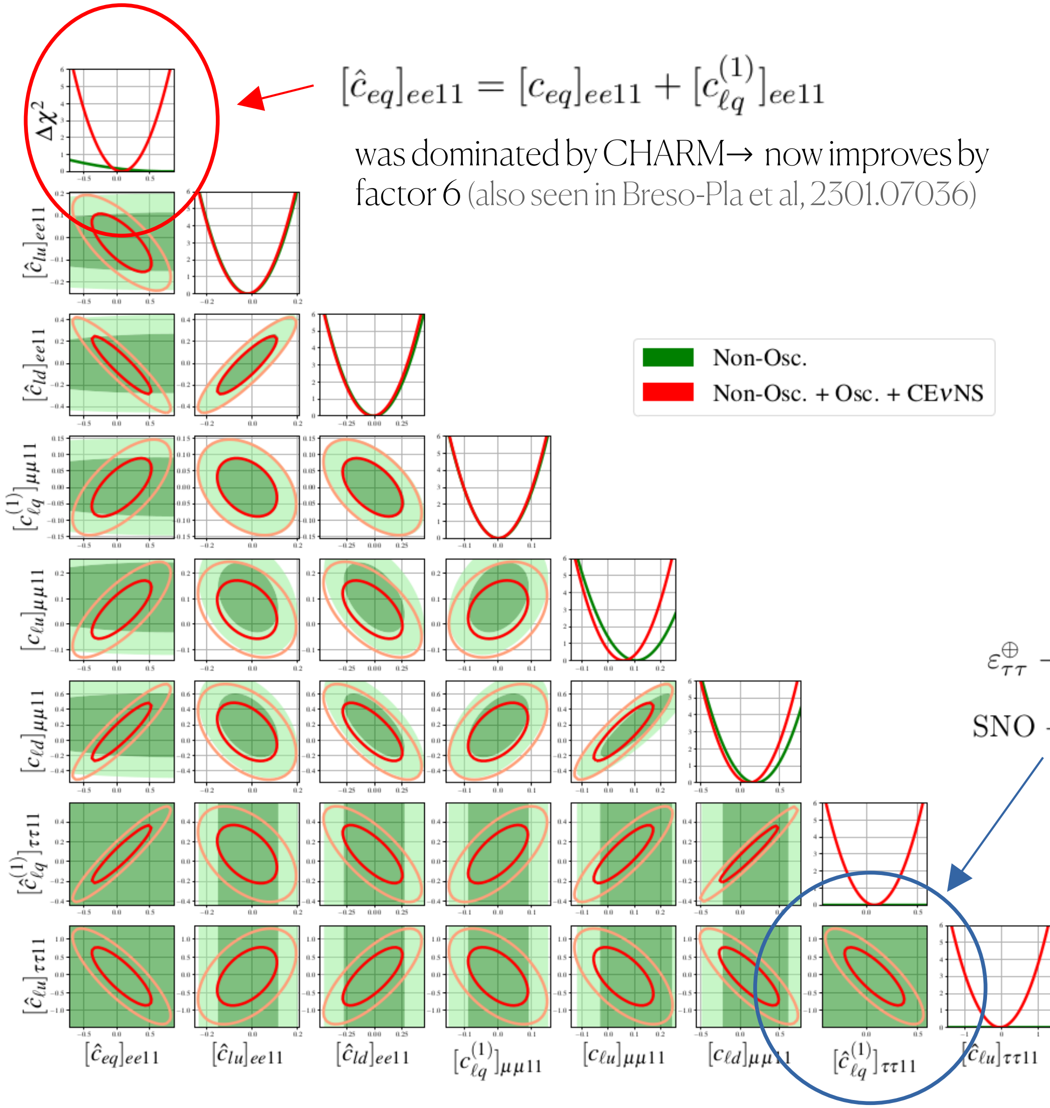
Bartocci, Biekötter, Hurth, 2311.04963



Breso-Pla et al, 2301.07036;
Falkowski et al, 1706.03783, ...



From NSI to SMEFT



$$[\hat{c}_{eq}]_{ee11} = [c_{eq}]_{ee11} + [c^{(1)}_{\ell q}]_{ee11}$$

was dominated by CHARM→ now improves by factor 6 (also seen in Breso-Pla et al, 2301.07036)

Coloma, Fernandez-Martinez, Lopez-Pavon, Marcano, Naredo-Tuero, Urrea, 2411.00090

Operators	1σ interval	
	Non-Osc.	Non-Osc. + Osc. + CEνNS
$[\hat{c}_{eq}]_{ee11}$	0.76 ± 1.80	0.07 ± 0.30
$[c_{\ell u}]_{\mu\mu 11}$	0.110 ± 0.091	0.058 ± 0.076
$[c_{\ell d}]_{\mu\mu 11}$	0.19 ± 0.27	0.11 ± 0.25
$[\hat{c}^{(1)}_{\ell q}]_{\tau\tau 11}$	Unconstrained	0.07 ± 0.19
$[\hat{c}_{\ell u}]_{\tau\tau 11}$	Unconstrained	-0.04 ± 0.54

$$\varepsilon^{\oplus}_{\tau\tau} \longrightarrow [\hat{c}^{(1)}_{\ell q}]_{\tau\tau 11} = [c^{(1)}_{\ell q}]_{\tau\tau 11} + \frac{2+Y_n^{\oplus}}{3(1+Y_n^{\oplus})}[c_{\ell u}]_{\tau\tau 11} + \frac{1+2Y_n^{\oplus}}{3(1+Y_n^{\oplus})}[c_{\ell d}]_{\tau\tau 11}\,,$$

$$\text{SNO} \longrightarrow [\hat{c}_{\ell u}]_{\tau\tau 11} = [c_{\ell u}]_{\tau\tau 11} - [c_{\ell d}]_{\tau\tau 11}\,.$$

(similar efforts in this direction: Breso-Pla et al , 2301.07036; Terol-Calvo et al, 1912.09131; Altmannshofer, M. Tammaro, Zupan, 1812.02778)

Summary & Outlook

- The three-neutrino picture seems robust
  - hints emerging for CPV and mass ordering – but more data is needed
  - JUNO - great results with only 60 days of data taking
- Recent developments (th, exp) have renewed the interest of the community in searches for new neutrino interactions
  - Very competitive bounds on neutrino magnetic moments from direct detection exps
  - New neutrino interactions bounded at the percent level for some operators
- When NSI are put in a broader context:
  - Highly competitive bounds on light mediators from oscillations, CEvNS, and nu-e scattering data
  - Global analyses of neutrino data (oscillations + scattering) provide significant contributions to the SMEFT program

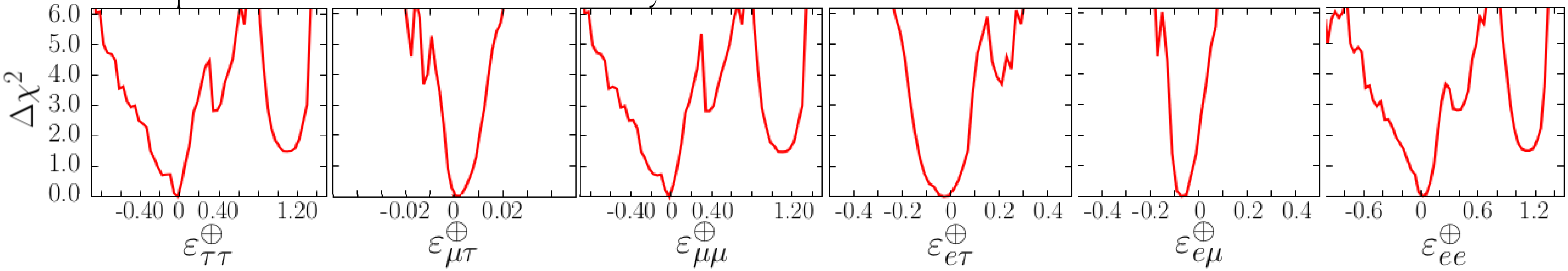
Thanks!

Work partially supported by Grants CEX2020-001007-S, PID2022-142545NB-C21, CNS2023-145338, H2020-101086085-ASYMMETRY

Backup

Global fit: OSC + CEvNS + ES

All operators included simultaneously



Overall, for the effective NSI in the Earth: $\varepsilon^{\oplus}_{\alpha\beta} = \varepsilon^{e,V}_{\alpha\beta} + \varepsilon^{p,V}_{\alpha\beta} + Y^{\oplus}_n \varepsilon^{n,V}_{\alpha\beta}$

→ Off-diagonal operators < O(0.1), O(0.05)

→ Diagonal operators < O(0.2), O(0.4)

(plus small regions at higher CL, around ε~1.2)

For axial NSI:

→ with quarks (SNO): multiple solutions appear, even for one operator at a time

→ with electrons (solar exps): O(0.1-0.4) for nue, O(0.8-1.0) for other flavors

Coloma, Gonzalez-Garcia, Maltoni, Pinheiro, Urrea, 2305.07698

Room for improvement

Recent proposals to use NC scattering **at long-baseline experiments** (MINOS/MINOS+, NovA)

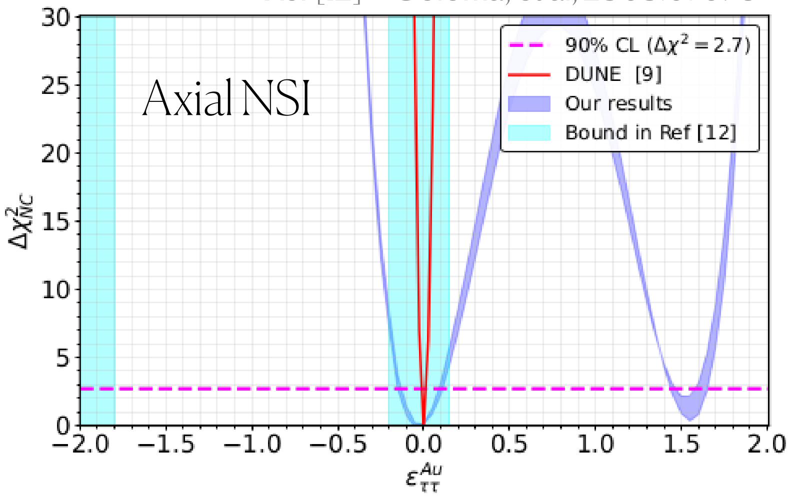
→ large nutau flux available

→ complementary constraints to SNO (and CHARM)

1. Axial NSI (oscillations are blind to these)

Abbaslu, Dehpour, Farzan, Safari, 2312.12420
Ilma, Rafi Alam, Alvarez-Ruso, et al, 2412.04818
Abbaslu & Farzan, 2509.02711

Fig from Abbaslu & Farzan, 2509.02711;
Ref [12] = Coloma, et al, 2305.07698

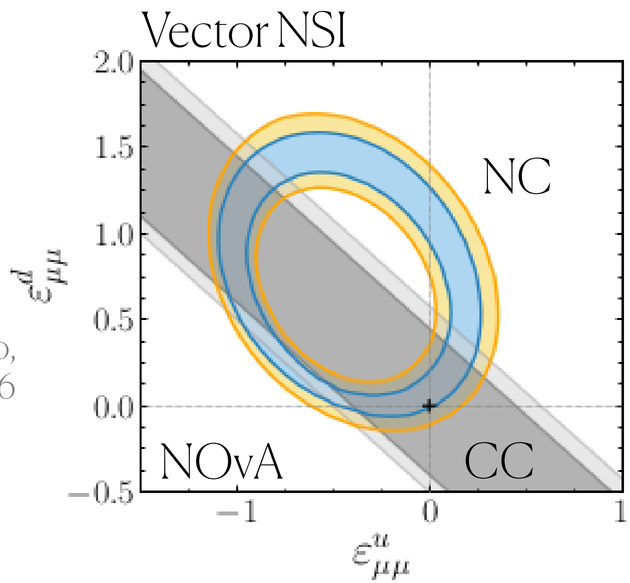


2. **Vector** NSI: can help constrain (u-d) combination

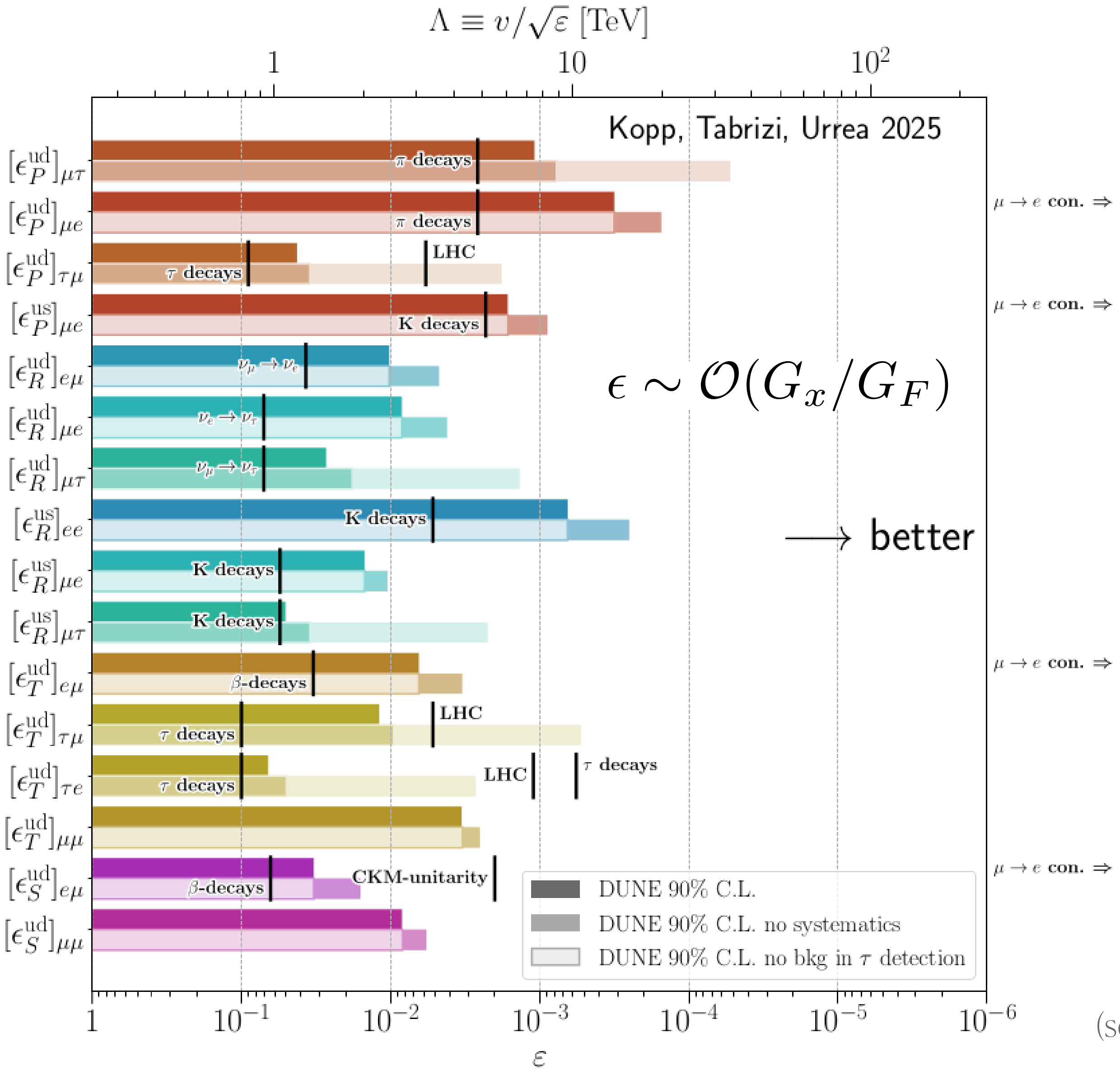
$$\varepsilon_{\alpha\beta} = \varepsilon^{eV}_{\alpha\beta} + (2+Y_n)\varepsilon^{uV}_{\alpha\beta} + (1+2Y_n)\varepsilon^{dV}_{\alpha\beta}$$
$$= \varepsilon^{eV}_{\alpha\beta} + 3\underbrace{\frac{(1+Y_n)}{2}\varepsilon^{\mathrm{iS}}_{\alpha\beta}}_{\text{isoscalar}} + \underbrace{\frac{1-Y_n}{2}\varepsilon^{\mathrm{iV}}_{\alpha\beta}}_{\text{isovector}} .$$

$$\boxed{\varepsilon^{\oplus}_{\alpha\alpha} \approx 3.08\,\varepsilon^{\mathrm{iS}}_{\alpha\alpha} - 0.025\,\varepsilon^{\mathrm{iV}}_{\alpha\alpha}}$$

Gehrlein, Hoefken Zink, Machado, Pinheiro, 2604.16176



Charged-current NSI



A systematic study of WEFT operators for DUNE includes effects in production/detection

Kopp, Tabrizi, Urrea, 2509.21537 (see also Kopp, Rocco, Tabrizi, 2401.07902)

Best results for pseudoscalar interactions, and for LFV operators

Caveats:

- only one operator included at a time
- no shape systematics
- only CCQE events

(see also Cherchiglia & Santiago, 2309.15924)

Matching NSI to SMEFT

A priori, both CC and NC operators are expected, and should be included.

However, for **lepton-flavor conserving** operators there are two <u>important caveats</u>:

1) In SMEFT, charged-current NSI are generated by:
   - vertex corrections → < 0.01 Breso-Pla et al, 2301.07036; (see also Falkowski et al, 1706.03783, ...)
   - four-fermion operators: $[c_{\ell q}^{(3)}]_{\alpha\alpha 11}, [c_{\ell edq}]_{\alpha\alpha 11}, [c_{\ell equ}^{(1)}]_{\alpha\alpha 11}, [c_{\ell equ}^{(3)}]_{\alpha\alpha 11}$

$\alpha = e$	$\alpha = \mu$	$\alpha = \tau$
Strong bounds from beta-decays and LEP	V → det., constrained (<0.01) T,S → det., chirality-suppressed A → production only (SM-like)	Only relevant for ν_τ prod. or CC det. (not included in the data) Bounds (semileptonic tau decays)

2) Neutrino oscillation experiments tune their predictions according to data (from other experiments, or from their near detector)

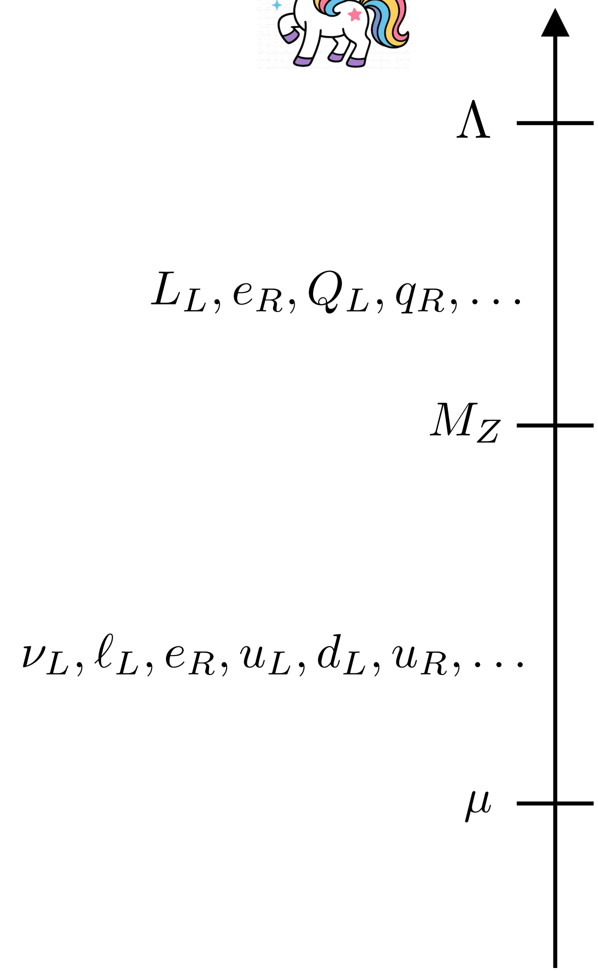
$$P_{\alpha\beta}(L) = \frac{R_\alpha^{\mathrm{CC},\beta}(L)}{N_T \Phi_\alpha^{\mathrm{est}} \frac{d\sigma_\beta^{\mathrm{est}}}{dE_\nu}}$$

→ flavor-conserving effects <u>tend to cancel</u> in the ratio (at linear order)

Matching NSI to SMEFT

$$\varepsilon^{e,V}_{\alpha\alpha} = \delta_{e\alpha}\left(\delta g_L^{We} - \delta g_L^{W\mu} + \frac{1}{2}[c_{\ell\ell}]_{e\mu\mu e}\right) - (1-4s_{\rm w}^2)\delta g_L^{Z\nu_\alpha} + \delta g_L^{Ze} + \delta g_R^{Ze}$$
$$- \frac{1}{2}\Big([c_{\ell\ell}]_{ee\alpha\alpha} + [c_{\ell e}]_{\alpha\alpha ee}\Big)\,,$$
$$\varepsilon^{u,V}_{\alpha\alpha} = \delta g_L^{Zu} + \delta g_R^{Zu} + \left(1 - \frac{8}{3}s_{\rm w}^2\right)\delta g^{Z\nu_\alpha} - \frac{1}{2}\left([c^{(1)}_{\ell q}]_{\alpha\alpha 11} + [c^{(3)}_{\ell q}]_{\alpha\alpha 11} + [c_{\ell u}]_{\alpha\alpha 11}\right)$$
$$\varepsilon^{d,V}_{\alpha\alpha} = \delta g_L^{Zd} + \delta g_R^{Zd} - \left(1 - \frac{4}{3}s_{\rm w}^2\right)\delta g^{Z\nu_\alpha} - \frac{1}{2}\left([c^{(1)}_{\ell q}]_{\alpha\alpha 11} - [c^{(3)}_{\ell q}]_{\alpha\alpha 11} + [c_{\ell d}]_{\alpha\alpha 11}\right)$$

$$\varepsilon^{u,A}_{\alpha\alpha} = \delta g_L^{Zu} - \delta g_R^{Zu} + \delta g^{Z\nu_\alpha} - \frac{1}{2}\left([c^{(1)}_{\ell q}]_{\alpha\alpha 11} + [c^{(3)}_{\ell q}]_{\alpha\alpha 11} - [c_{\ell u}]_{\alpha\alpha 11}\right)$$
$$\varepsilon^{d,A}_{\alpha\alpha} = \delta g_L^{Zd} - \delta g_R^{Zd} - \delta g^{Z\nu_\alpha} - \frac{1}{2}\left([c^{(1)}_{\ell q}]_{\alpha\alpha 11} - [c^{(3)}_{\ell q}]_{\alpha\alpha 11} - [c_{\ell d}]_{\alpha\alpha 11}\right)$$



See e.g., Falkowski, Gonzalez-Alonso, Tabrizi, 1901.04553 & 1910.02971;
Skiba & Xia, 2007.15688;
Jenkins, Manohar, Stoffer, 1709.04486;
Altmannshofer, M. Tammaro, Zupan, 1812.02778;
...

Four-fermion operators

$(\bar{L}L)(\bar{L}L)$		$(\bar{R}R)(\bar{R}R)$		$(\bar{L}L)(\bar{R}R)$	
Q_{ll}	$(\bar{l}_p\gamma_\mu l_r)(\bar{l}_s\gamma^\mu l_t)$	Q_{ee}	$(\bar{e}_p\gamma_\mu e_r)(\bar{e}_s\gamma^\mu e_t)$	Q_{le}	$(\bar{l}_p\gamma_\mu l_r)(\bar{e}_s\gamma^\mu e_t)$
$Q_{qq}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{q}_s\gamma^\mu q_t)$	Q_{uu}	$(\bar{u}_p\gamma_\mu u_r)(\bar{u}_s\gamma^\mu u_t)$	Q_{lu}	$(\bar{l}_p\gamma_\mu l_r)(\bar{u}_s\gamma^\mu u_t)$
$Q_{qq}^{(3)}$	$(\bar{q}_p\gamma_\mu\tau^I q_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$	Q_{dd}	$(\bar{d}_p\gamma_\mu d_r)(\bar{d}_s\gamma^\mu d_t)$	Q_{ld}	$(\bar{l}_p\gamma_\mu l_r)(\bar{d}_s\gamma^\mu d_t)$
$Q_{lq}^{(1)}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{q}_s\gamma^\mu q_t)$	Q_{eu}	$(\bar{e}_p\gamma_\mu e_r)(\bar{u}_s\gamma^\mu u_t)$	Q_{qe}	$(\bar{q}_p\gamma_\mu q_r)(\bar{e}_s\gamma^\mu e_t)$
$Q_{lq}^{(3)}$	$(\bar{l}_p\gamma_\mu\tau^I l_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$	Q_{ed}	$(\bar{e}_p\gamma_\mu e_r)(\bar{d}_s\gamma^\mu d_t)$	$Q_{qu}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{u}_s\gamma^\mu u_t)$
		$Q_{ud}^{(1)}$	$(\bar{u}_p\gamma_\mu u_r)(\bar{d}_s\gamma^\mu d_t)$	$Q_{qu}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{u}_s\gamma^\mu T^A u_t)$
		$Q_{ud}^{(8)}$	$(\bar{u}_p\gamma_\mu T^A u_r)(\bar{d}_s\gamma^\mu T^A d_t)$	$Q_{qd}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{d}_s\gamma^\mu d_t)$
				$Q_{qd}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{d}_s\gamma^\mu T^A d_t)$

$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		B-violating	
Q_{ledq}	$(\bar{l}_p^j e_r)(\bar{d}_s q_t^j)$	Q_{duq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(q_s^{\gamma j})^T C l_t^k\right]$
$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r)\varepsilon_{jk}(\bar{q}_s^k d_t)$	Q_{qqu}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(u_s^\gamma)^T C e_t\right]$
$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r)\varepsilon_{jk}(\bar{q}_s^k T^A d_t)$	Q_{qqq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jn}\varepsilon_{km}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(q_s^{\gamma m})^T C l_t^n\right]$
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r)\varepsilon_{jk}(\bar{q}_s^k u_t)$	Q_{duu}	$\varepsilon^{\alpha\beta\gamma}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(u_s^\gamma)^T C e_t\right]$
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j\sigma_{\mu\nu} e_r)\varepsilon_{jk}(\bar{q}_s^k\sigma^{\mu\nu} u_t)$		

Warsaw basis, 1008.4884