Constraints on neutrino non-standard interactions: From neutrino oscillations to precision cosmology

Yong Du

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XIX International Workshop on Neutrino Telescopes, February 19, 2021

YD, H-L. Li, J. Tang, S. Vihonen, J-H. Yu, arXiv: 2011.14292

YD, J-H. Yu, arXiv: 2101.10475

XIX International Workshop on Neutrino Telescopes

18-26 February 2021
Online

Overview

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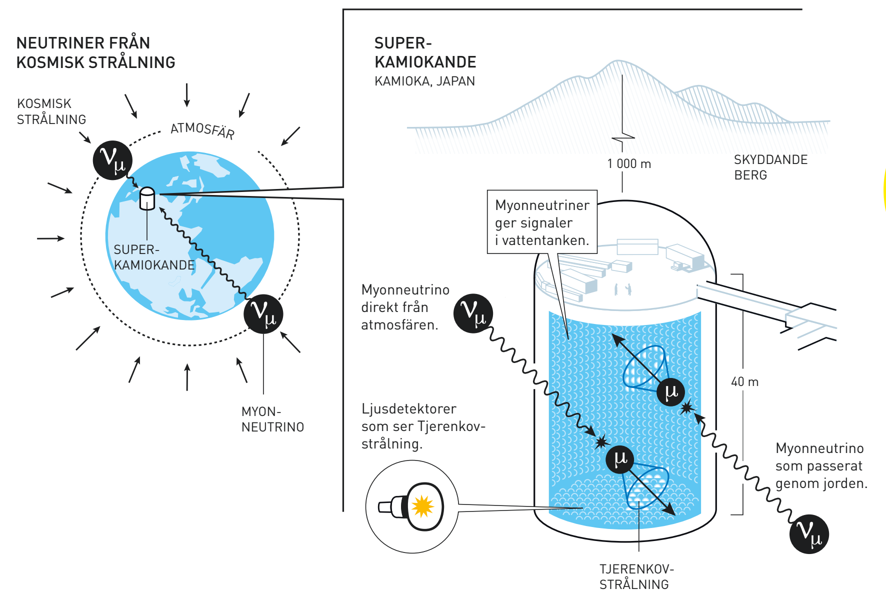

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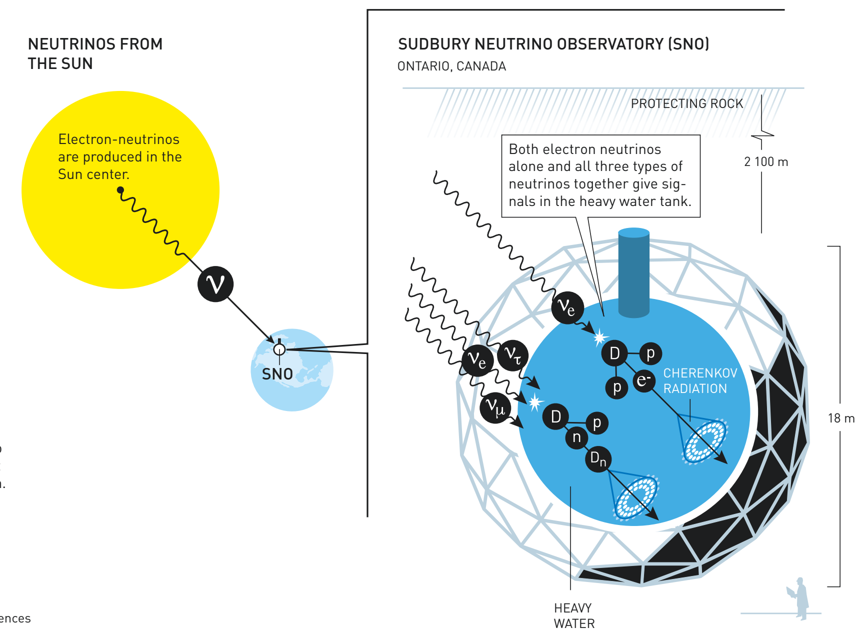

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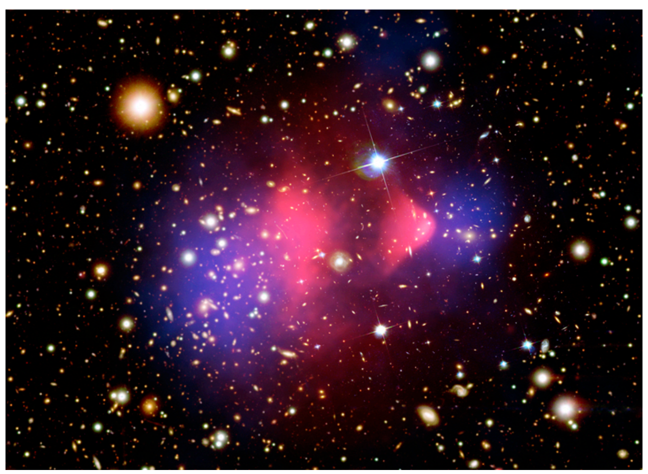

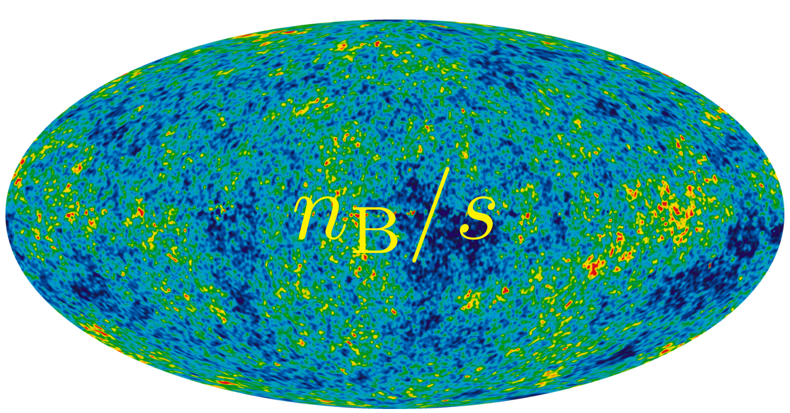

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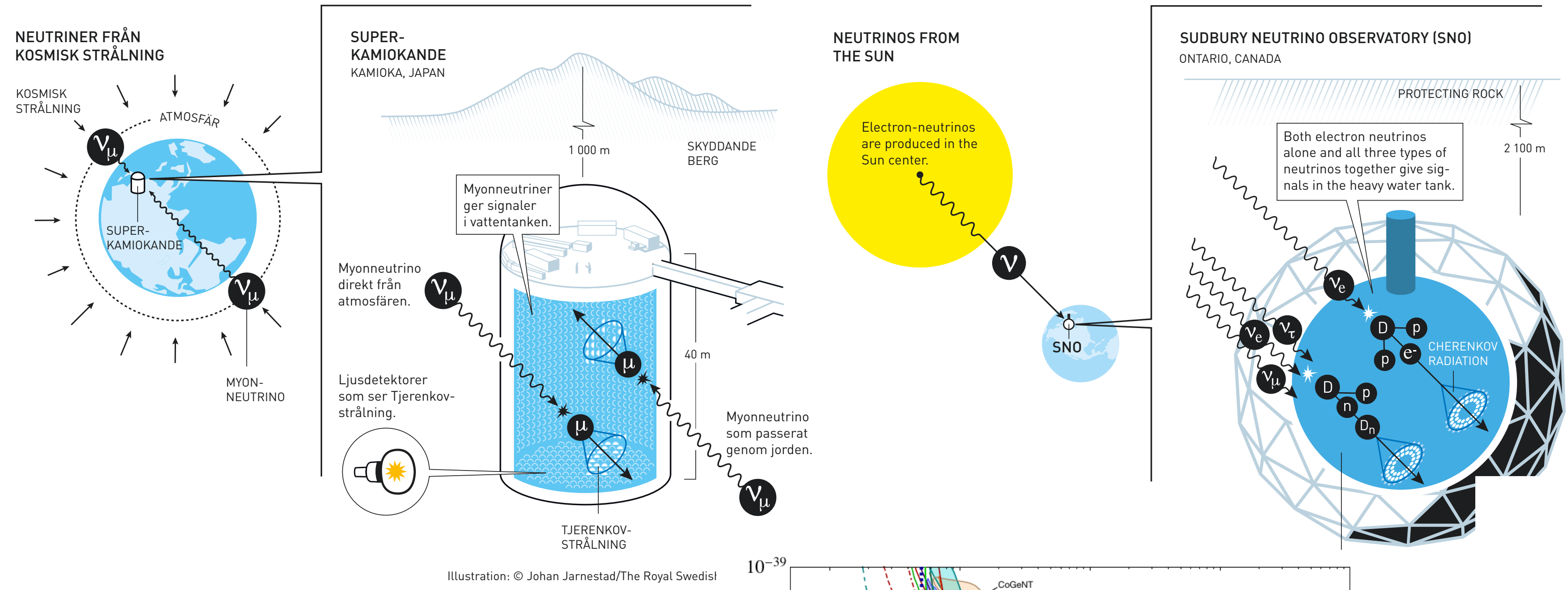

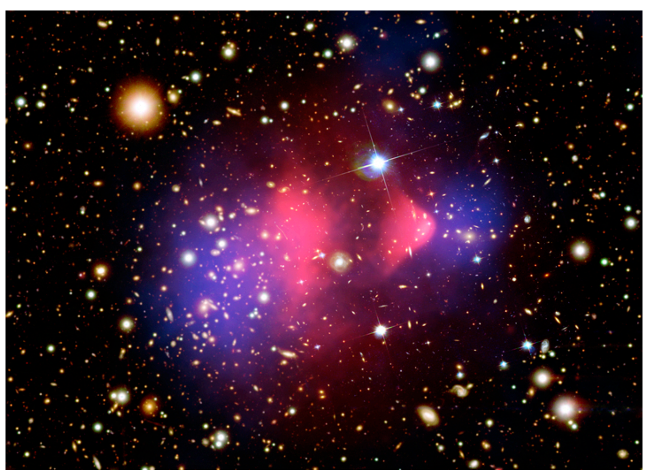

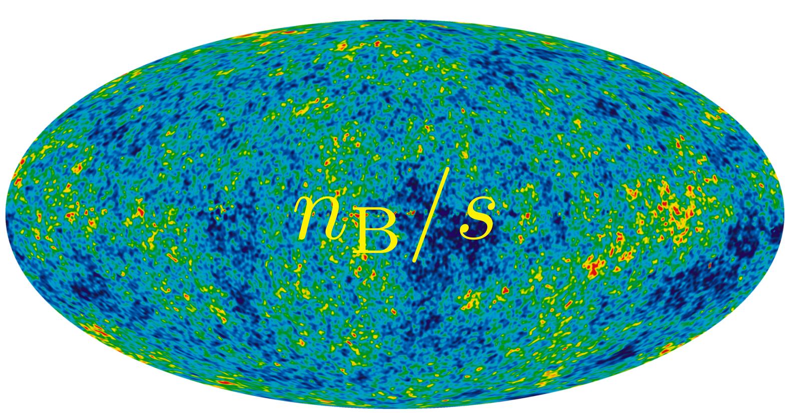

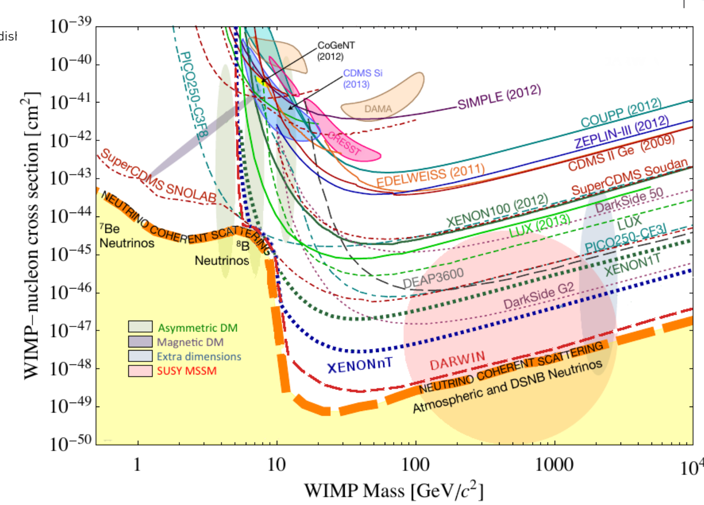

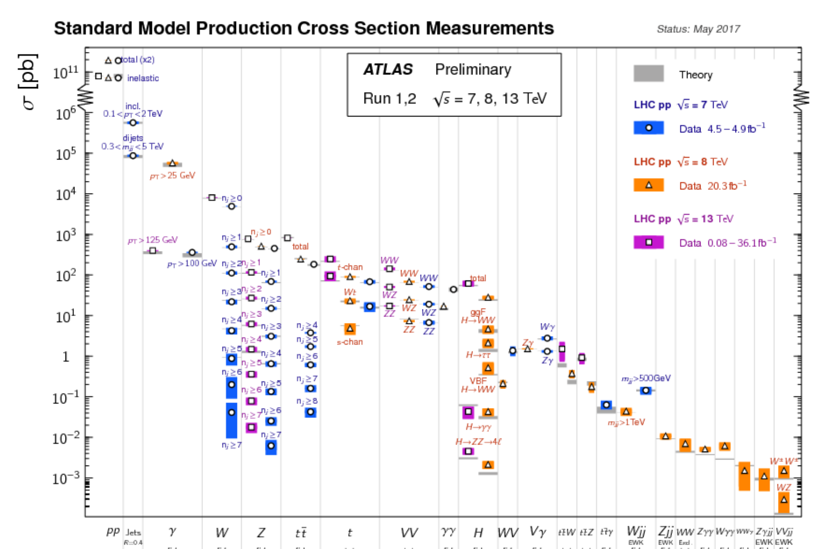

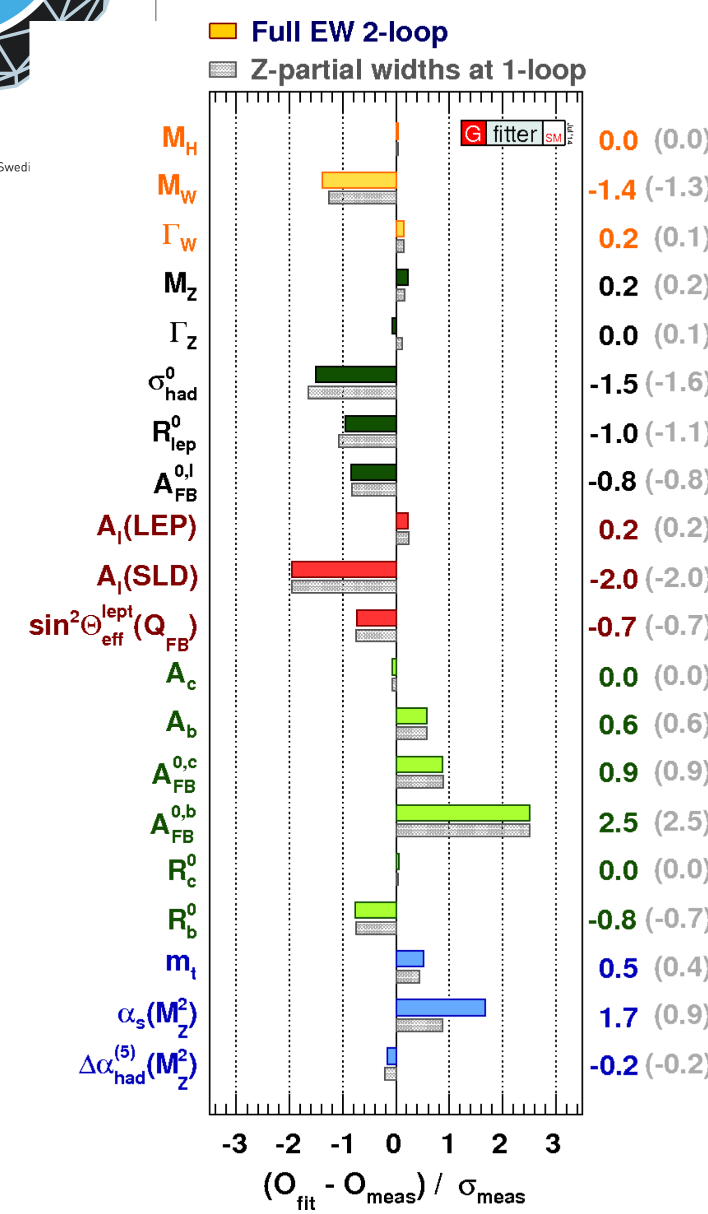

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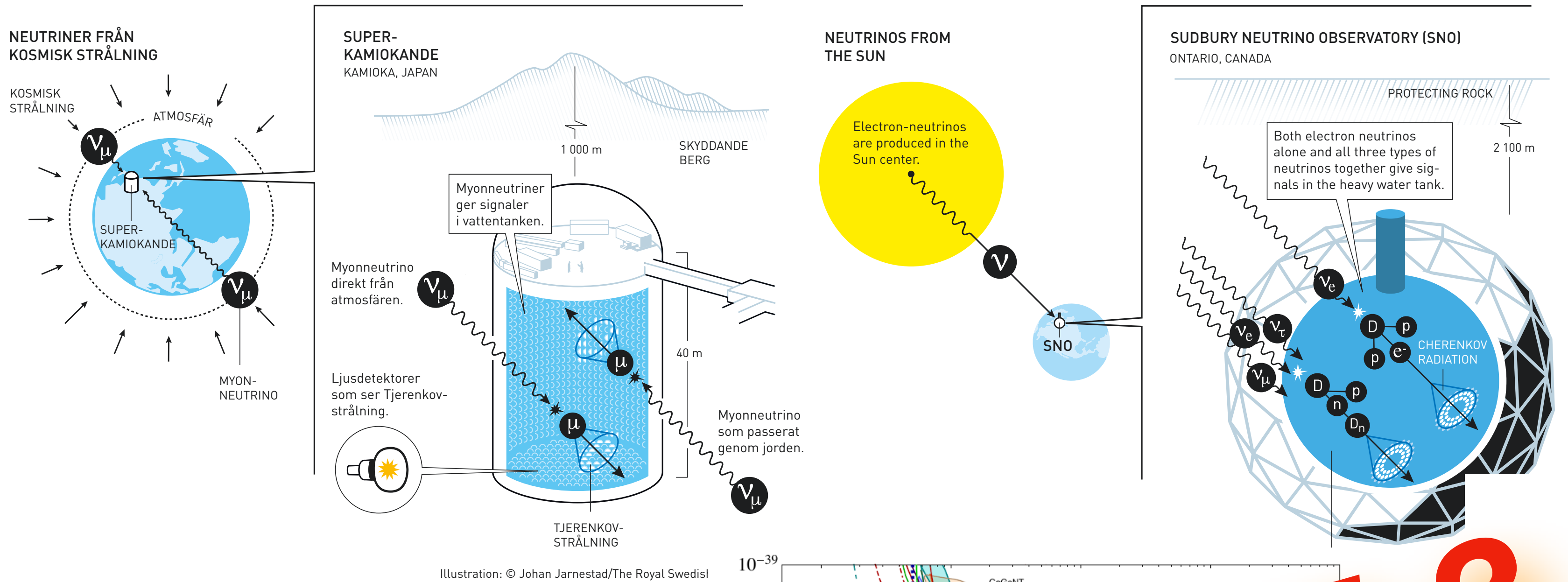
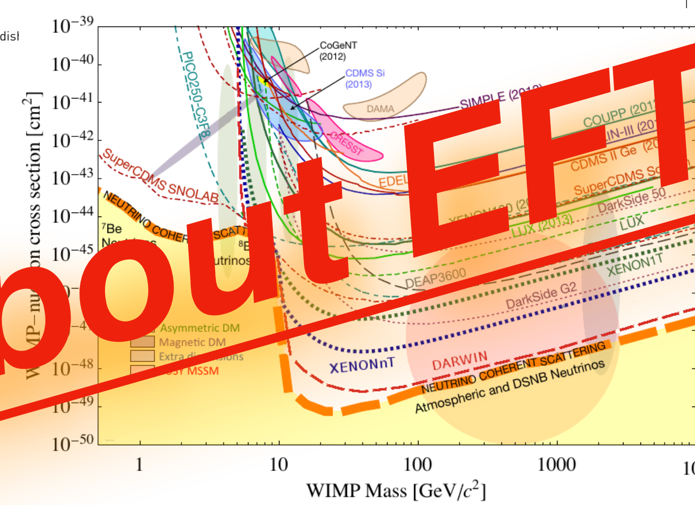
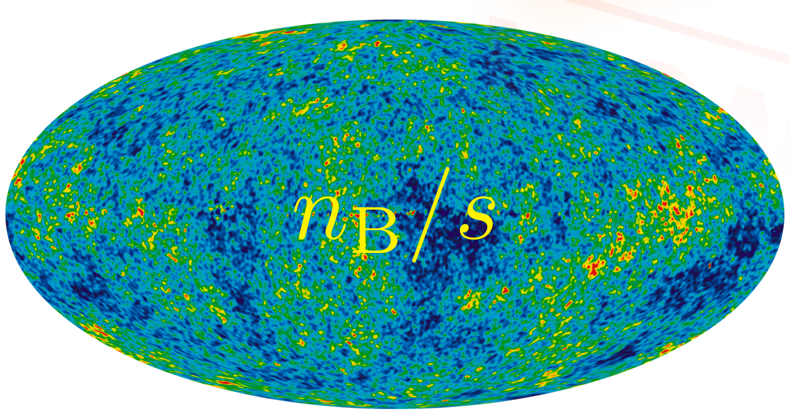
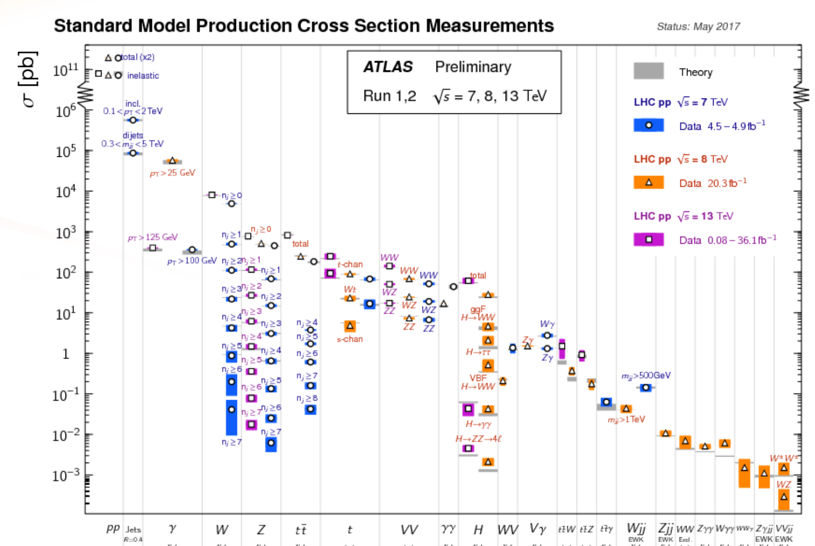
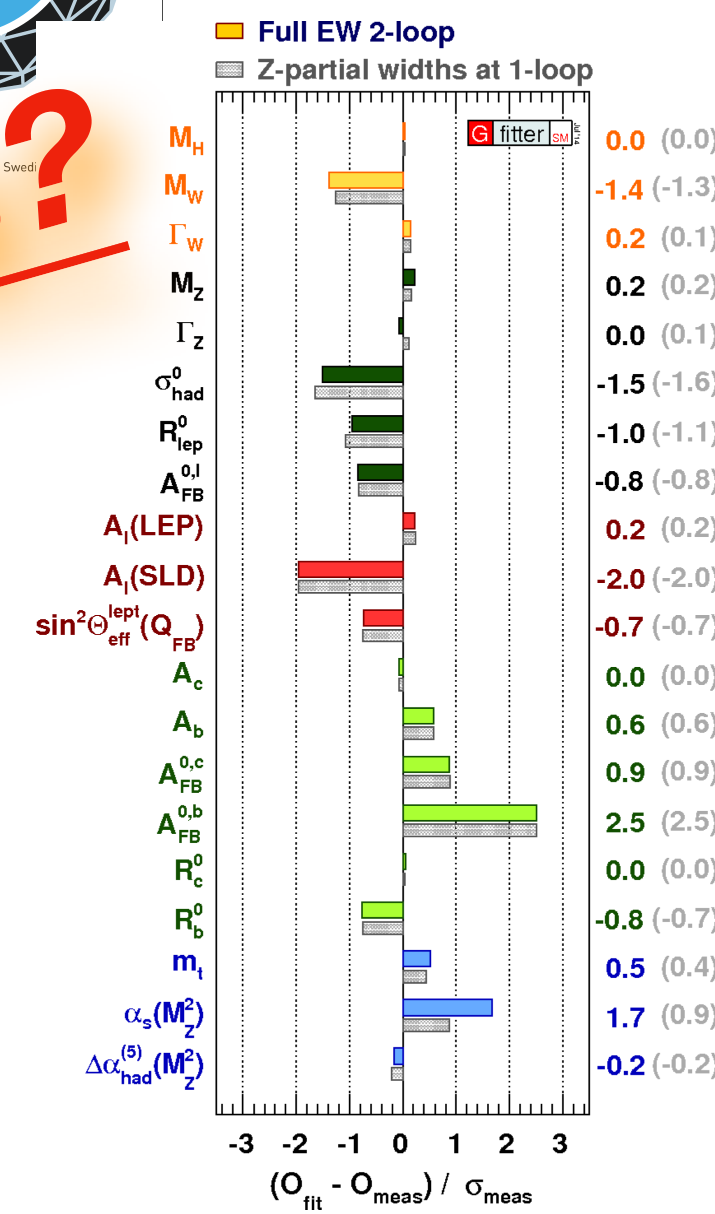




How about EFTs?







Overview

In this talk, I will only focus on neutrino NSIs from an EFT approach

- ✤ **Charge-Current (CC) NSIs: from terrestrial neutrino oscillation experiments (dim-6 SMEFT operators only)**

  YD, H-L. Li, J. Tang, S. Vihonen, J-H. Yu, arXiv: 2011.14292

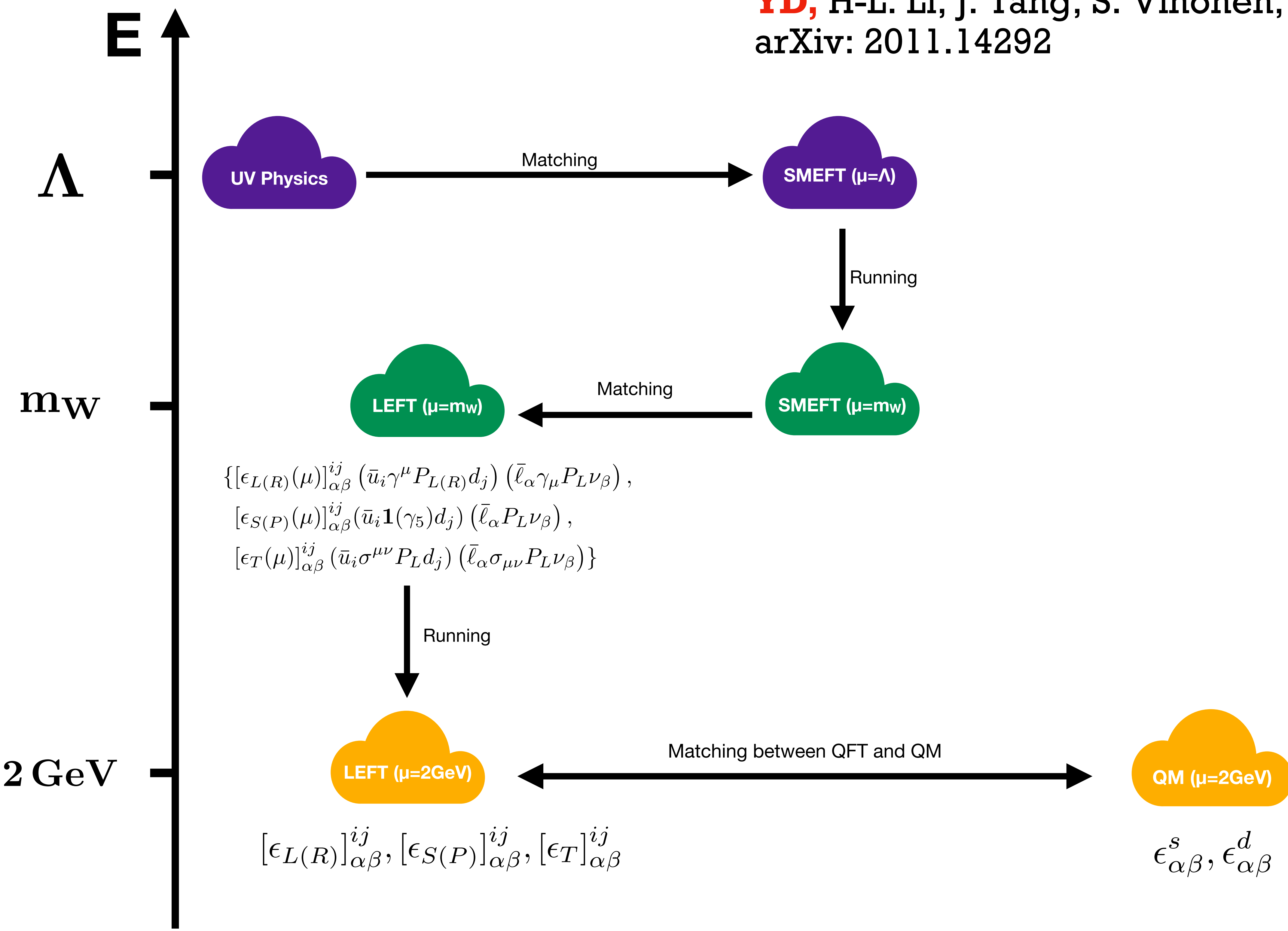
- ✤ **Neutral-Current (NC) NSIs: Neff from Planck and CMB-S4 (ν-ν, ν-e, ν-γ operators up to dim-7)**

  YD, J-H. Yu, arXiv: 2101.10475

CC NSIs

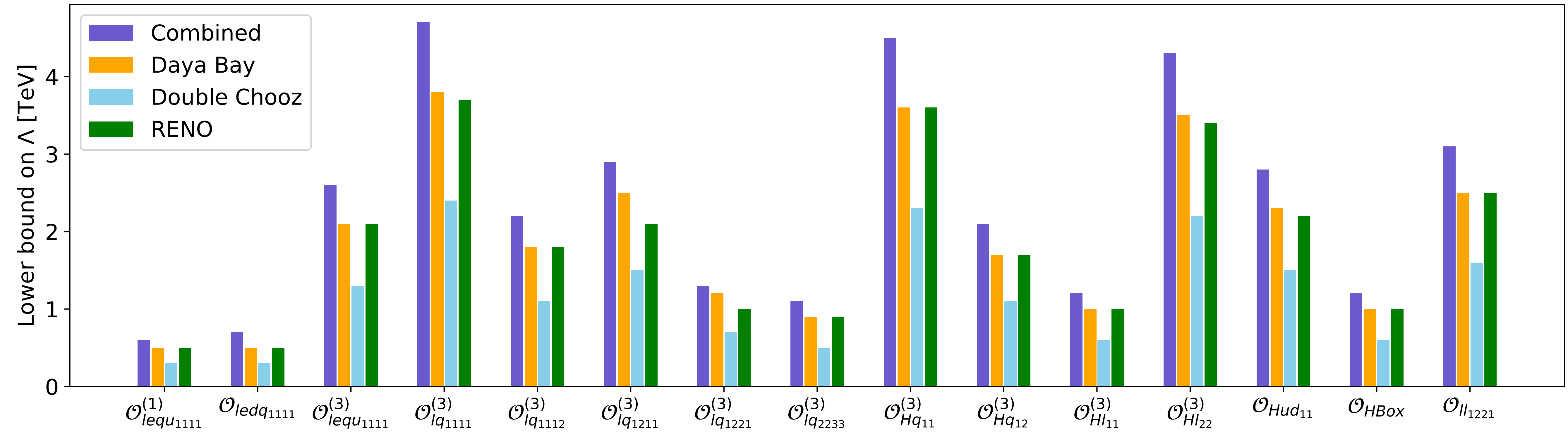
CC NSIs

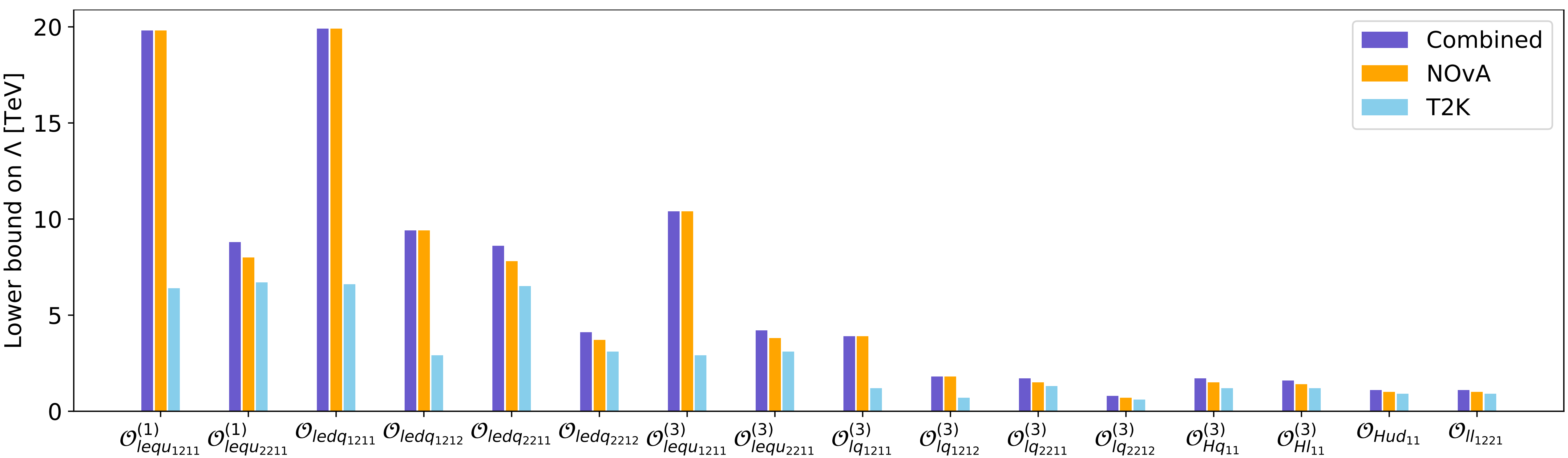
YD, H-L. Li, J. Tang, S. Vihonen, J-H. Yu, arXiv: 2011.14292



Results: CC NSIs

YD, H-L. Li, J. Tang, S. Vihonen, J-H. Yu, arXiv: 2011.14292





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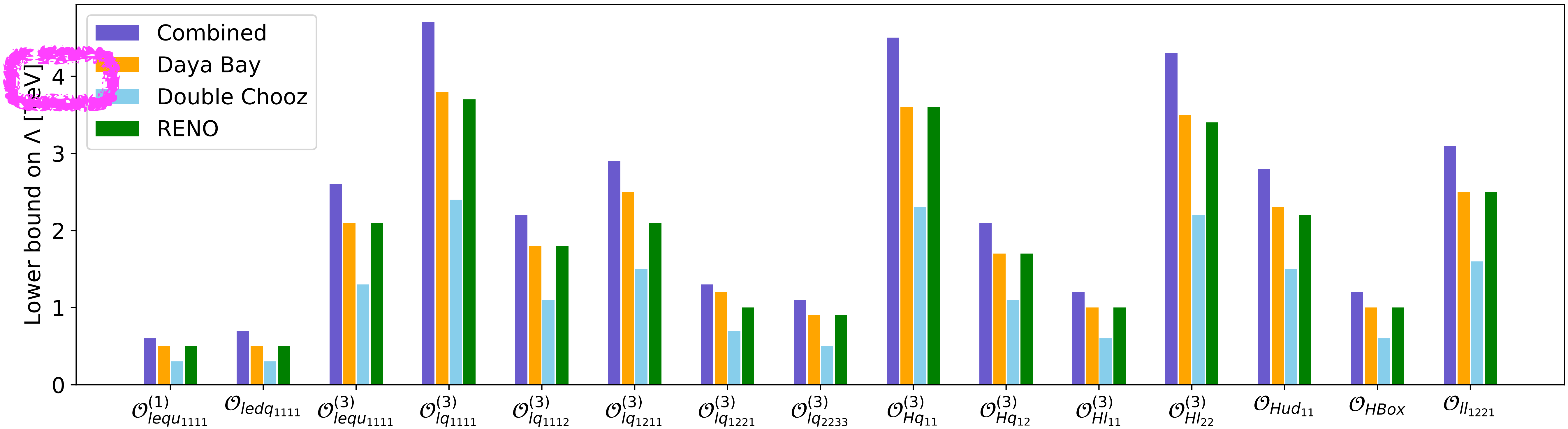

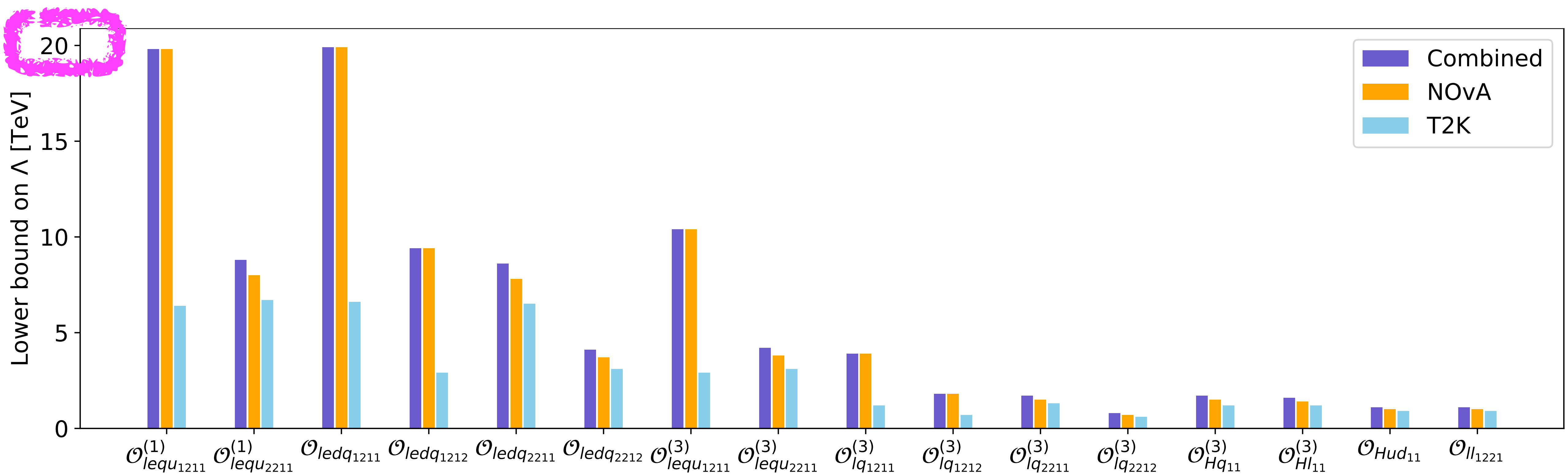

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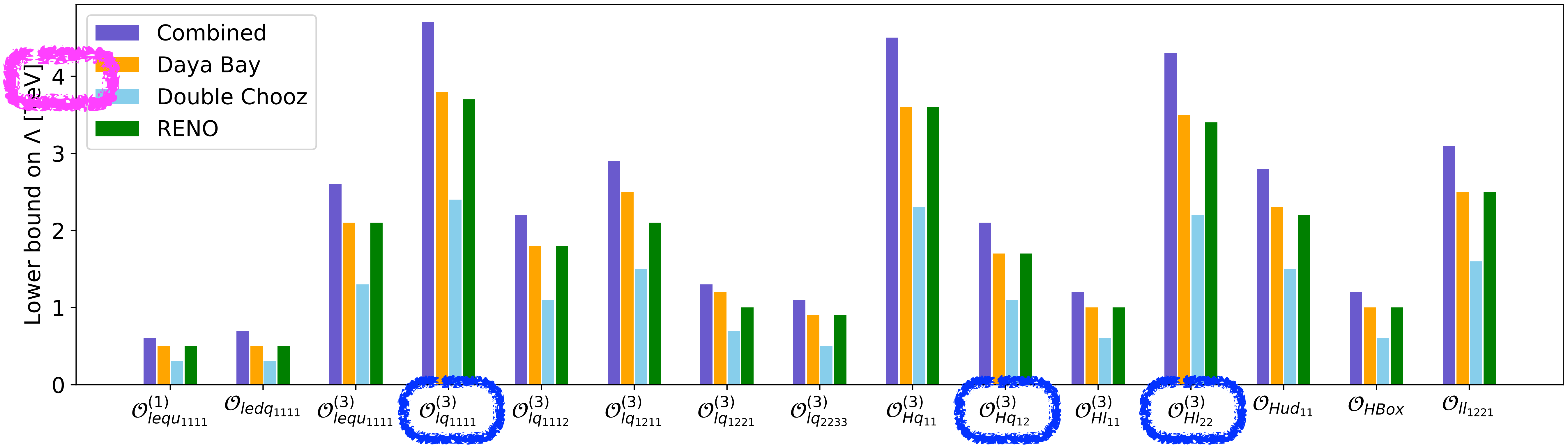

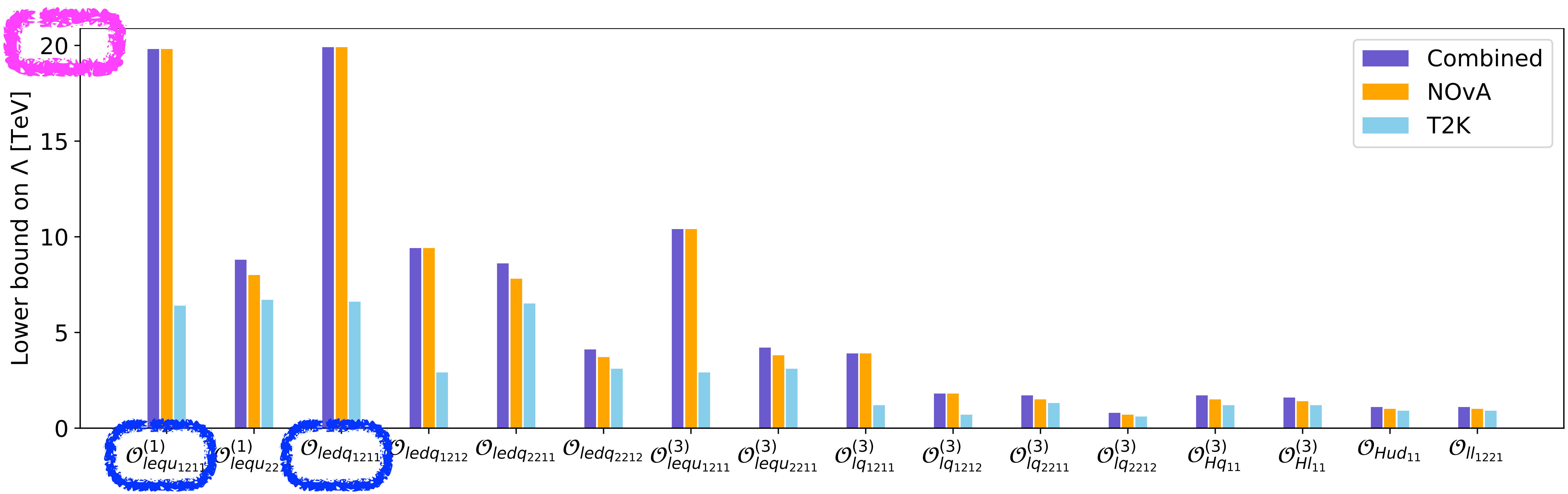

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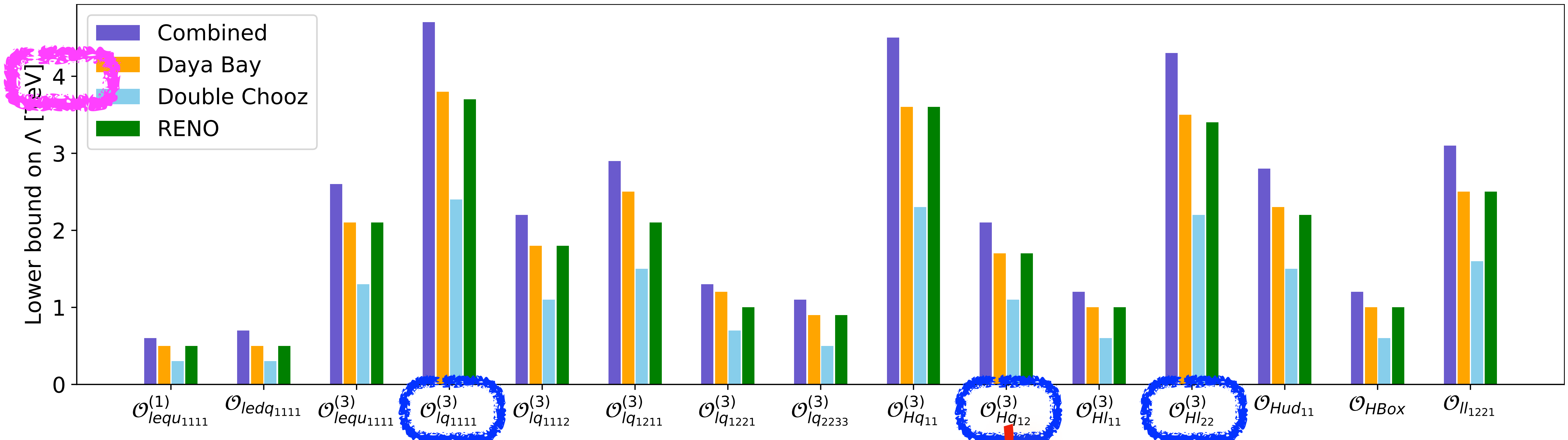
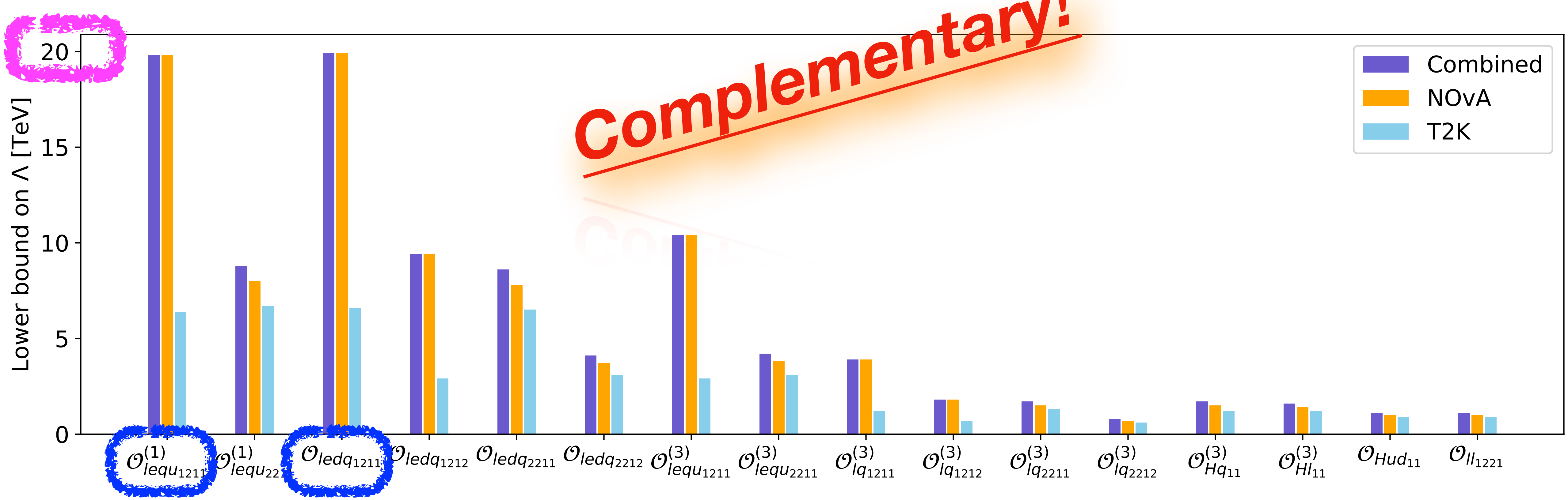
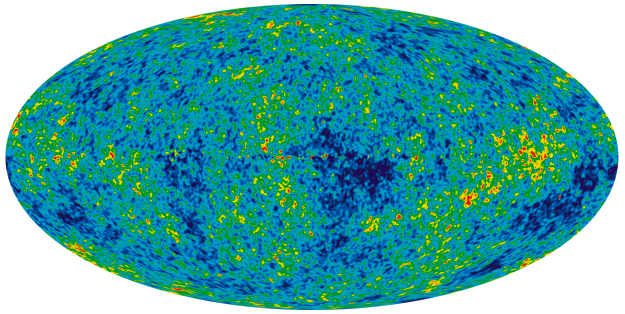




NC NSIs

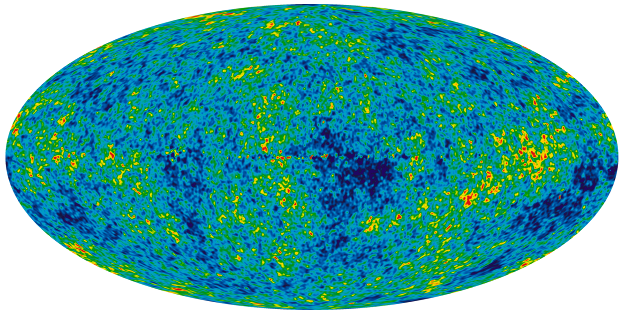


$$\rho_R = \left[1 + \frac{7}{8}\left(\frac{4}{11}\right)^{\frac{4}{3}} N_{\rm eff}\right]\rho_\gamma$$

NC NSIs

YD, J-H. Yu, arXiv: 2101.10475

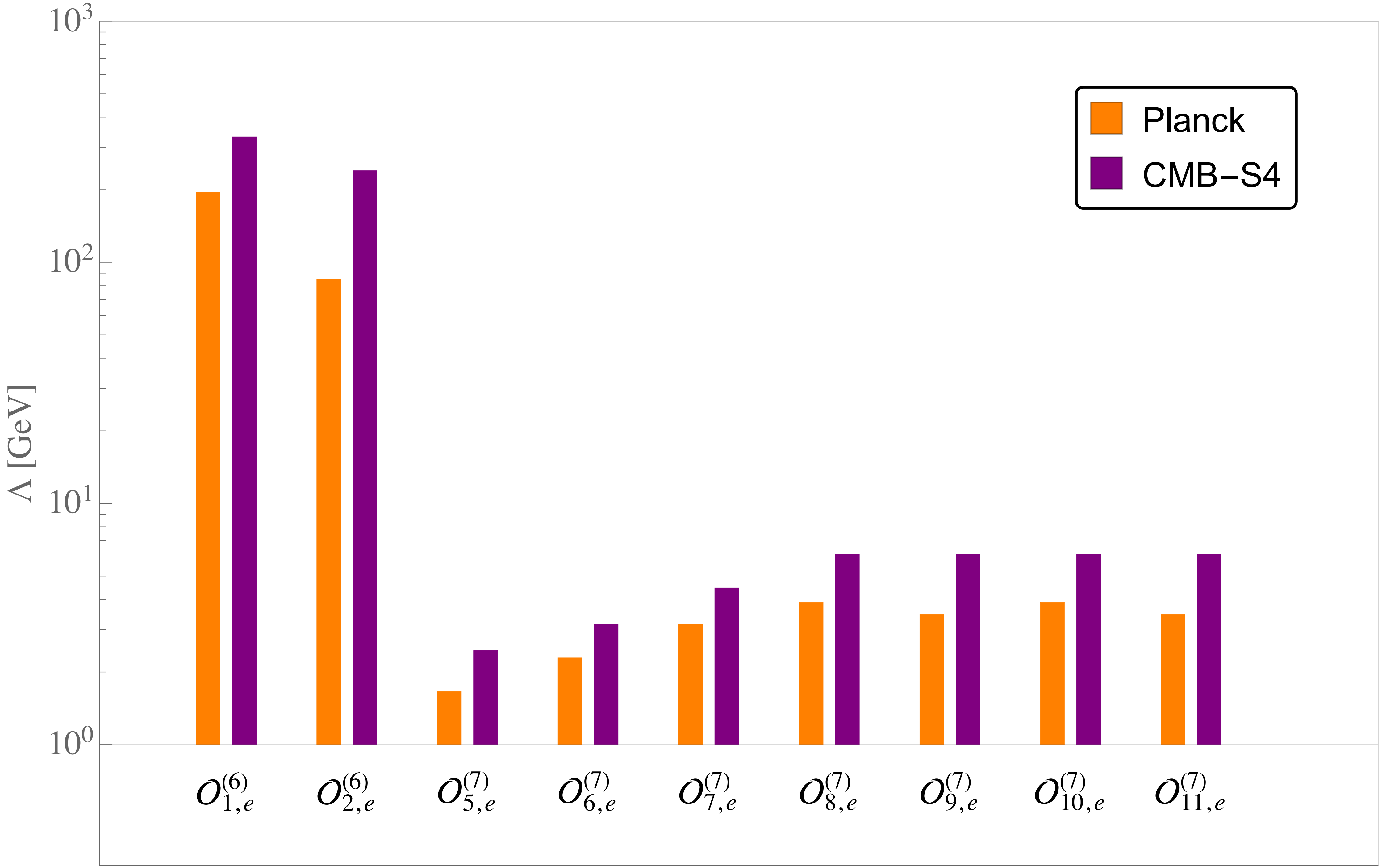
Dimensions	Operators	Wilson coefficients
dimension-5	$\mathcal{O}_1^{(5)} = \frac{e}{8\pi^2}\left(\bar{\nu}_\beta \sigma^{\mu\nu} P_L \nu_\alpha\right) F_{\mu\nu}$	$C_1^{(5)}$
dimension-6	$\mathcal{O}_{1,f}^{(6)} = \left(\bar{\nu}_\beta \gamma_\mu P_L \nu_\alpha\right)\left(\bar{f}\gamma^\mu f\right)$	$C_{1,f}^{(6)}$
	$\mathcal{O}_{2,f}^{(6)} = \left(\bar{\nu}_\beta \gamma_\mu P_L \nu_\alpha\right)\left(\bar{f}\gamma^\mu \gamma_5 f\right)$	$C_{2,f}^{(6)}$
	$\mathcal{O}_3^{(6)} = \left(\bar{\nu}_\beta P_L \nu_\alpha\right)\left(\bar{\nu}_{\beta'} P_L \nu_{\alpha'}\right)^\clubsuit$	$C_3^{(6)}$
	$\mathcal{O}_4^{(6)} = \left(\bar{\nu}_\beta \gamma_\mu P_L \nu_\alpha\right)\left(\bar{\nu}_{\beta'} \gamma_\mu P_L \nu_{\alpha'}\right)^\clubsuit$	$C_4^{(6)}$
	$\mathcal{O}_5^{(6)} = \left(\bar{\nu}_\beta \sigma^{\mu\nu} P_L \nu_\alpha\right)\left(\bar{\nu}_{\beta'} \sigma^{\mu\nu} P_L \nu_{\alpha'}\right)^\clubsuit$	$C_5^{(6)}$
dimension-7	$\mathcal{O}_1^{(7)} = \frac{\alpha}{12\pi}\left(\bar{\nu}_\beta P_L \nu_\alpha\right) F^{\mu\nu} F_{\mu\nu}$	$C_1^{(7)}$
	$\mathcal{O}_2^{(7)} = \frac{\alpha}{8\pi}\left(\bar{\nu}_\beta P_L \nu_\alpha\right) F^{\mu\nu} \widetilde{F}_{\mu\nu}$	$C_2^{(7)}$
	$\mathcal{O}_{5,f}^{(7)} = m_f\left(\bar{\nu}_\beta P_L \nu_\alpha\right)\left(\bar{f} f\right)$	$C_{5,f}^{(7)}$
	$\mathcal{O}_{6,f}^{(7)} = m_f\left(\bar{\nu}_\beta P_L \nu_\alpha\right)\left(\bar{f} i\gamma_5 f\right)$	$C_{6,f}^{(7)}$
	$\mathcal{O}_{7,f}^{(7)} = m_f\left(\bar{\nu}_\beta \sigma^{\mu\nu} P_L \nu_\alpha\right)\left(\bar{f}\sigma_{\mu\nu} f\right)$	$C_{7,f}^{(7)}$
	$\mathcal{O}_{8,f}^{(7)} = \left(\bar{\nu}_\beta i \overleftrightarrow{\partial}_\mu P_L \nu_\alpha\right)\left(\bar{f}\gamma^\mu f\right)$	$C_{8,f}^{(7)}$
	$\mathcal{O}_{9,f}^{(7)} = \left(\bar{\nu}_\beta i \overleftrightarrow{\partial}_\mu P_L \nu_\alpha\right)\left(\bar{f}\gamma^\mu \gamma_5 f\right)$	$C_{9,f}^{(7)}$
	$\mathcal{O}_{10,f}^{(7)} = \partial_\mu\left(\bar{\nu}_\beta \sigma^{\mu\nu} P_L \nu_\alpha\right)\left(\bar{f}\gamma_\nu f\right)$	$C_{10,f}^{(7)}$
	$\mathcal{O}_{11,f}^{(7)} = \partial_\mu\left(\bar{\nu}_\beta \sigma^{\mu\nu} P_L \nu_\alpha\right)\left(\bar{f}\gamma_\nu \gamma_5 f\right)$	$C_{11,f}^{(7)}$



$$\rho_R = \left[1 + \frac{7}{8}\left(\frac{4}{11}\right)^{\frac{4}{3}} N_{\rm eff}\right]\rho_\gamma$$

Results: NC NSIs

YD, J-H. Yu, arXiv: 2101.10475



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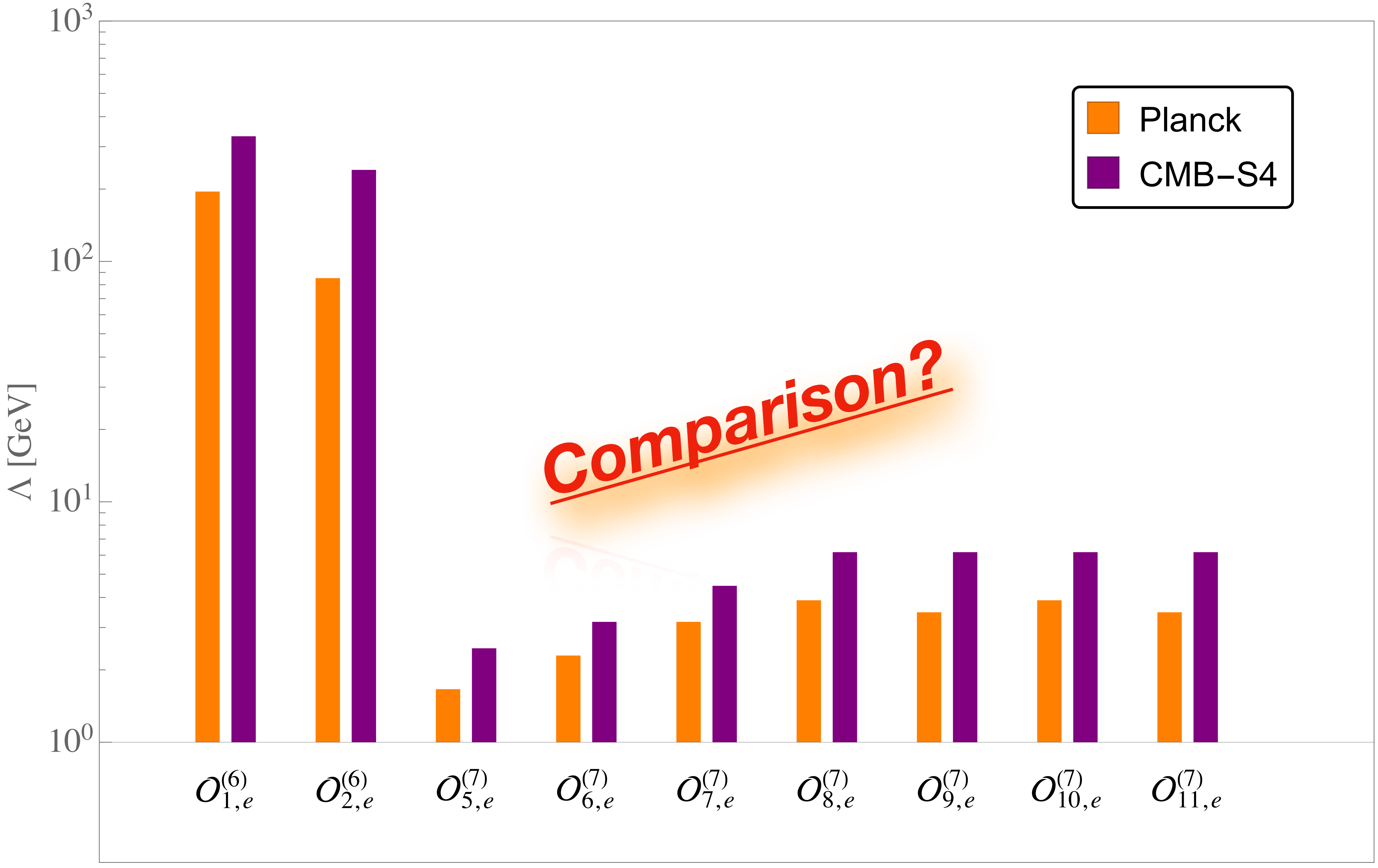

Results: NC NSIs comparison

YD, J-H. Yu, arXiv: 2101.10475

$$\mathcal{L}_{\rm NSI}^{\rm NC} = -2\sqrt{2}G_F \sum_{\alpha\beta,f,P} \epsilon_{\alpha\beta}^{f,P} \left(\bar{\nu}_\alpha \gamma_\mu P_L \nu_\beta\right)\left(\bar{f}\gamma^\mu P f\right)$$

ϵ's	[103]	[97]	[82]	[83]	[84]	[85]	[90]	[98]	[35]	This work	
										Planck	CMB-S4
$\epsilon_{ee}^{e,L}$	[-0.010, 2.039]	[-1.53, 0.38]	[-0.07, 0.1]	[-0.05, 0.12]	[-0.03, 0.08]	[-0.036, 0.063]	[-0.017, 0.027] [-0.003, 0.003]	[-0.08, 0.08]	[-0.185, 0.380] [-0.130, 0.185]	[-1.6, 1.44]	[-0.61, 0.46]
$\epsilon_{e\mu}^{e,L}$	[-0.179, 0.146]	[-0.84, 0.84]	-	-	[-0.13, 0.13]	-	[-0.152, 0.152] [-0.055,0.055]	[-0.33, 0.35]	[-0.025, 0.052] [-0.017, 0.040]	[-1.6, 1.44]	[-0.61, 0.46]
$\epsilon_{e\tau}^{e,L}$	[-0.860, 0.350]	[-0.84, 0.84]	[-0.4, 0.4]	[-0.44, 0.44]	[-0.33, 0.33]	-	[-0.152, 0.152] [-0.055,0.055]	[-0.33, 0.35]	[-0.055, 0.023] [-0.042, 0.012]	[-1.6, 1.44]	[-0.61, 0.46]
$\epsilon_{\mu\mu}^{e,L}$	[-0.364, 1.387]	-	[-0.03,0.03]	-	[-0.03, 0.03]	-	[-0.040, 0.04] [-0.010,0.010]	-	[-0.290, 0.390] [-0.192, 0.240]	[-1.6, 1.44]	[-0.61, 0.46]
$\epsilon_{\mu\tau}^{e,L}$	[-0.035, 0.028]	-	[-0.1,0.1]	-	[-0.1, 0.1]	-	-	-	[-0.015, 0.013] [-0.010, 0.010]	[-1.6, 1.44]	[-0.61, 0.46]
$\epsilon_{\tau\tau}^{e,L}$	[-0.350, 1.400]	-	[-0.5,0.5]	-	[-0.46, 0.24]	[-0.16 , 0.110] [0.41, 0.66]	[-0.040, 0.04] [-0.010,0.010]	-	[-0.360, 0.145] [-0.120, 0.095]	[-1.6, 1.44]	[-0.61, 0.46]
$\epsilon_{ee}^{e,R}$	[-0.010, 2.039]	[-0.07, 0.08]	[-1, 0.5]	[-0.04, 0.14]	[0.004, 0.151]	[-0.27, 0.59]	[-0.33 , 0.25] [-0.07, 0.07]	[-0.04, 0.06]	[-0.185, 0.380] [-0.130, 0.185]	[-1.6, 1.44]	[-0.39, 0.31]
$\epsilon_{e\mu}^{e,R}$	[-0.179, 0.146]	[-0.19, 0.19]	-	-	[-0.13, 0.13]	-	[-0.236, 0.236] [-0.08, 0.08]	[-0.15, 0.16]	[-0.025, 0.052] [-0.017, 0.040]	[-1.6, 1.44]	[-0.39, 0.31]
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$\epsilon_{\mu\mu}^{e,R}$	[-0.364, 1.387]	-	[-0.03,0.03]	-	[-0.03, 0.03]	-	[-0.10 , 0.12] [-0.006, 0.006]	-	[-0.290, 0.390] [-0.192, 0.240]	[-1.6, 1.44]	[-0.39, 0.31]
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Results: NC NSIs comparison

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ϵ's	[103]	[97]	[82]	[83]	[84]	[85]	[90]	[98]	[35]	This work	
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$\epsilon_{e\tau}^{e,R}$	[-0.860, 0.350]	[-0.19, 0.19]	[-0.7, 0.7]	[-0.27, 0.27]	[-0.05 , 0.05] [-0.28, 0.28]	-	[-0.236, 0.236] [-0.08, 0.08]	[-0.15, 0.16]	[-0.055, 0.023] [-0.042, 0.012]	[-1.6, 1.44]	[-0.39, 0.31]
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Complementary!

Summary

We investigate charge- and neutral-current neutrino NSIs in the EFT framework.

- For CC NSIs, we find reactor (Daya Bay, Double Chooze, RENO) and long baseline (T2K, NOvA) neutrino experiments are complementary, the latter are sensitive to new physics already at the ~20TeV scale.

- For NC NSIs up to dim-7, constraints from precision measurements of Neff (Planck, CMB-S4) are complementary to other type of neutrino experiments (COHERENT, collider, solar and reactor neutrino experiments, DUNE etc).

Back up

Reactor vs LBL neutrino experiments

Reactor

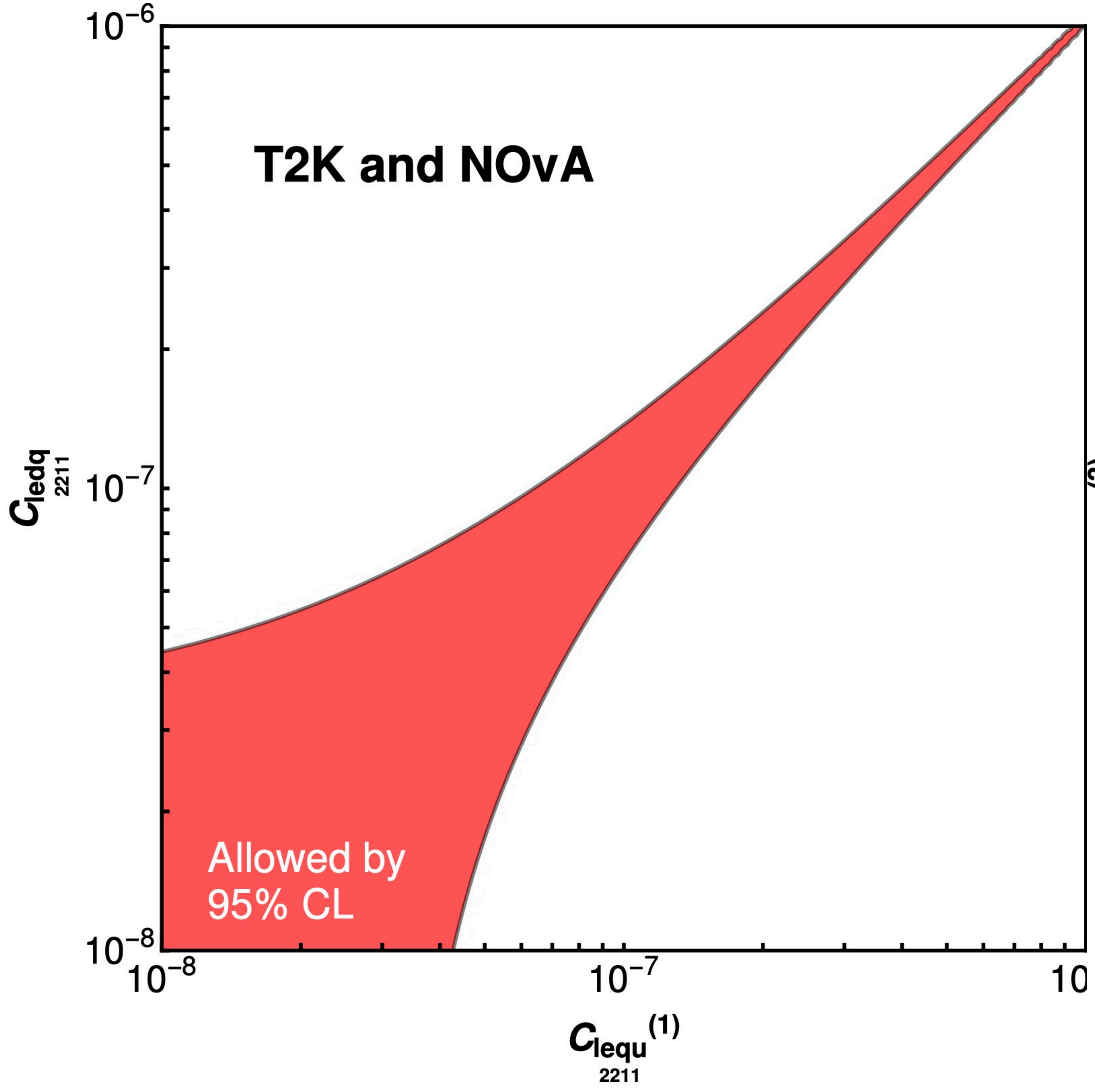
$$\epsilon^s_{e\beta} = \left[\epsilon_L - \epsilon_R - \frac{g_T}{g_A}\frac{m_e}{f_T\left(E_\nu\right)}\epsilon_T\right]^*_{e\beta}, \qquad (\beta \text{ decay}) \tag{2.4}$$

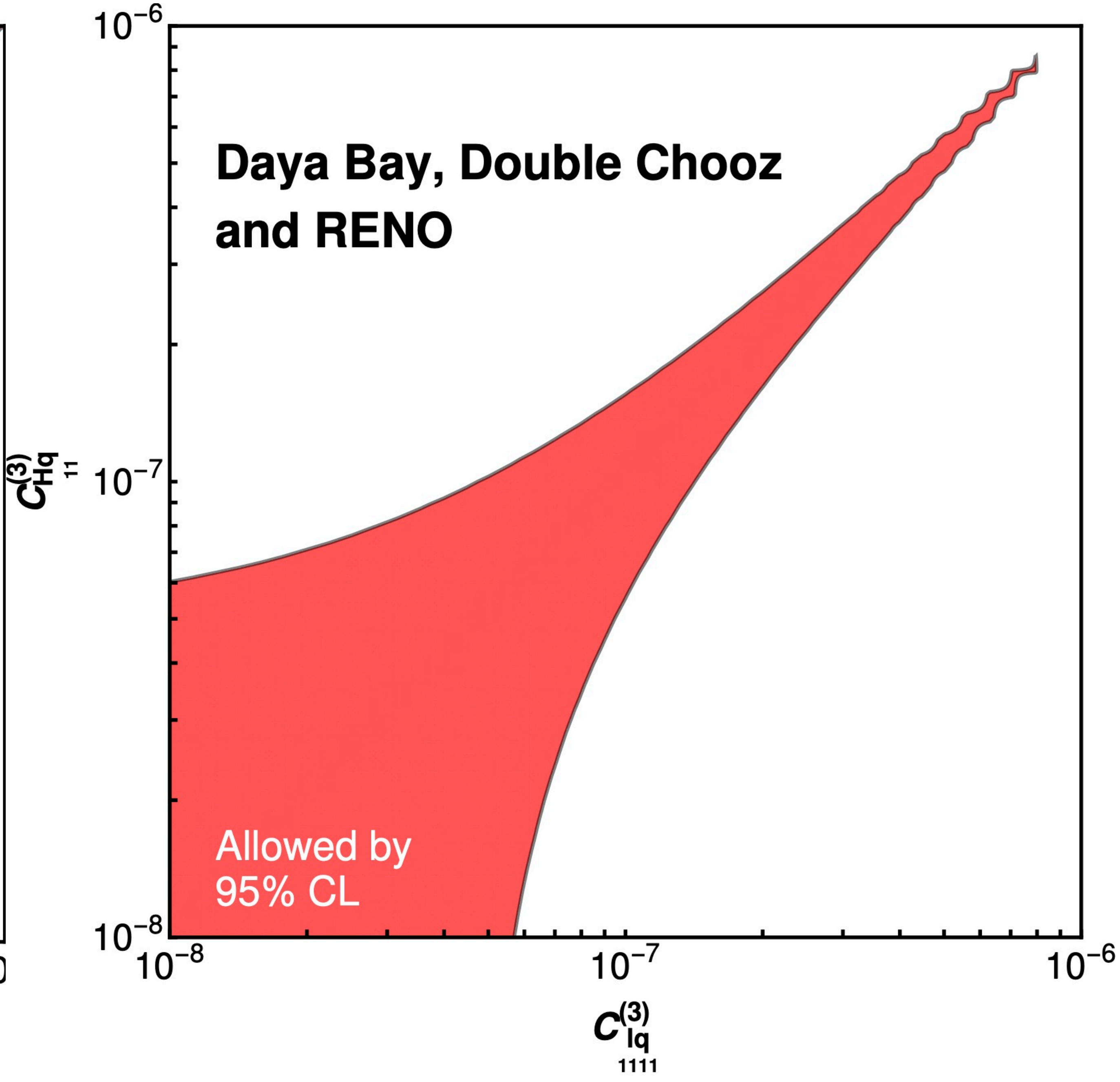
$$\epsilon^d_{\beta e} = \left[\epsilon_L + \frac{1-3g_A^2}{1+3g_A^2}\epsilon_R - \frac{m_e}{E_\nu - \Delta}\left(\frac{g_S}{1+3g_A^2}\epsilon_S - \frac{3g_A g_T}{1+3g_A^2}\epsilon_T\right)\right]_{e\beta}, \quad (\text{inverse } \beta \text{ decay}) \tag{2.5}$$

LBL

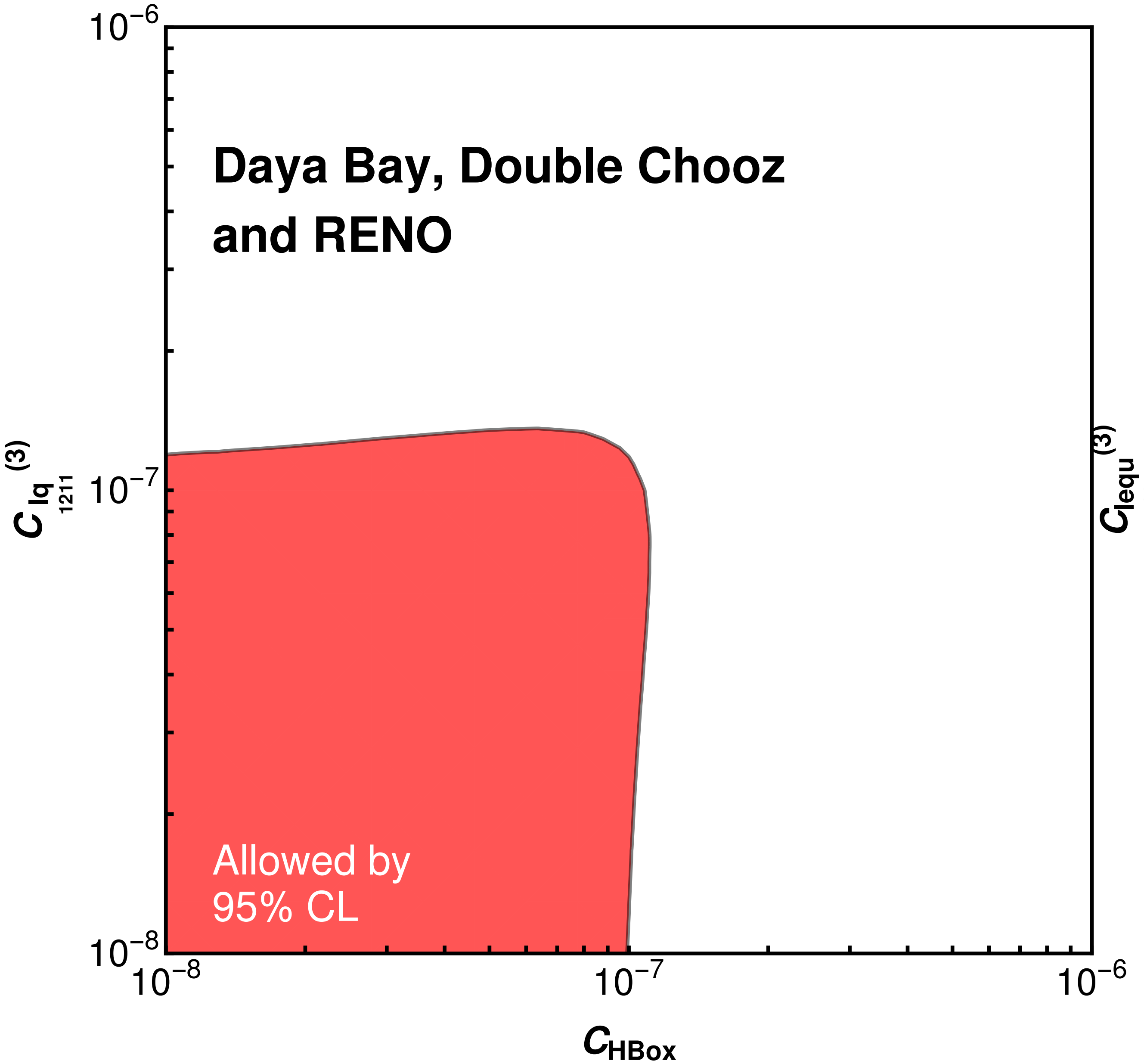
$$\epsilon^s_{\mu\beta} = \left[\epsilon_L - \epsilon_R - \boxed{\frac{m_\pi^2}{m_\mu\left(m_u + m_d\right)}\epsilon_P}\right]^*_{\mu\beta}, \qquad (\text{pion decay}) \tag{2.6}$$

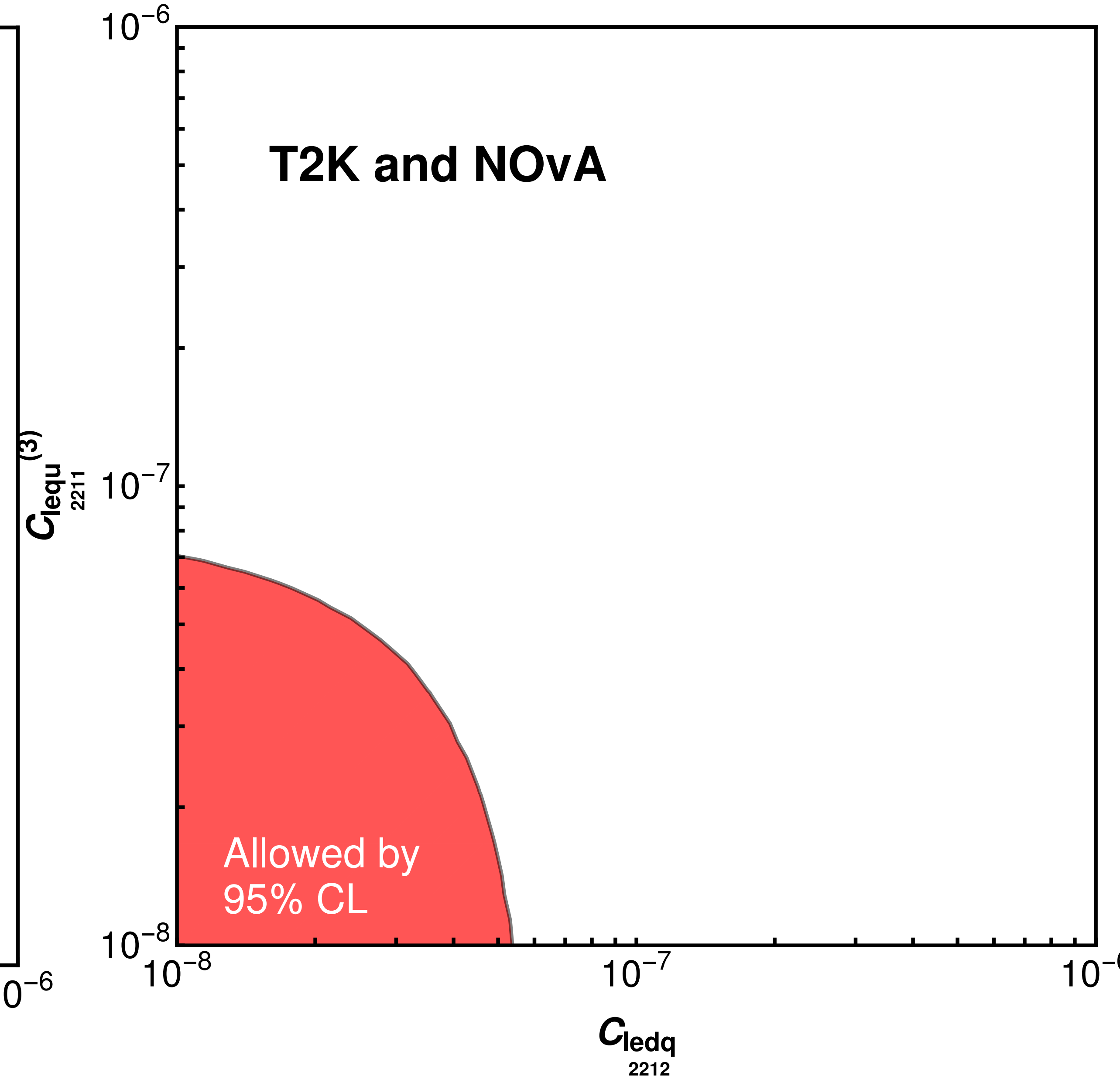
Multiple operators





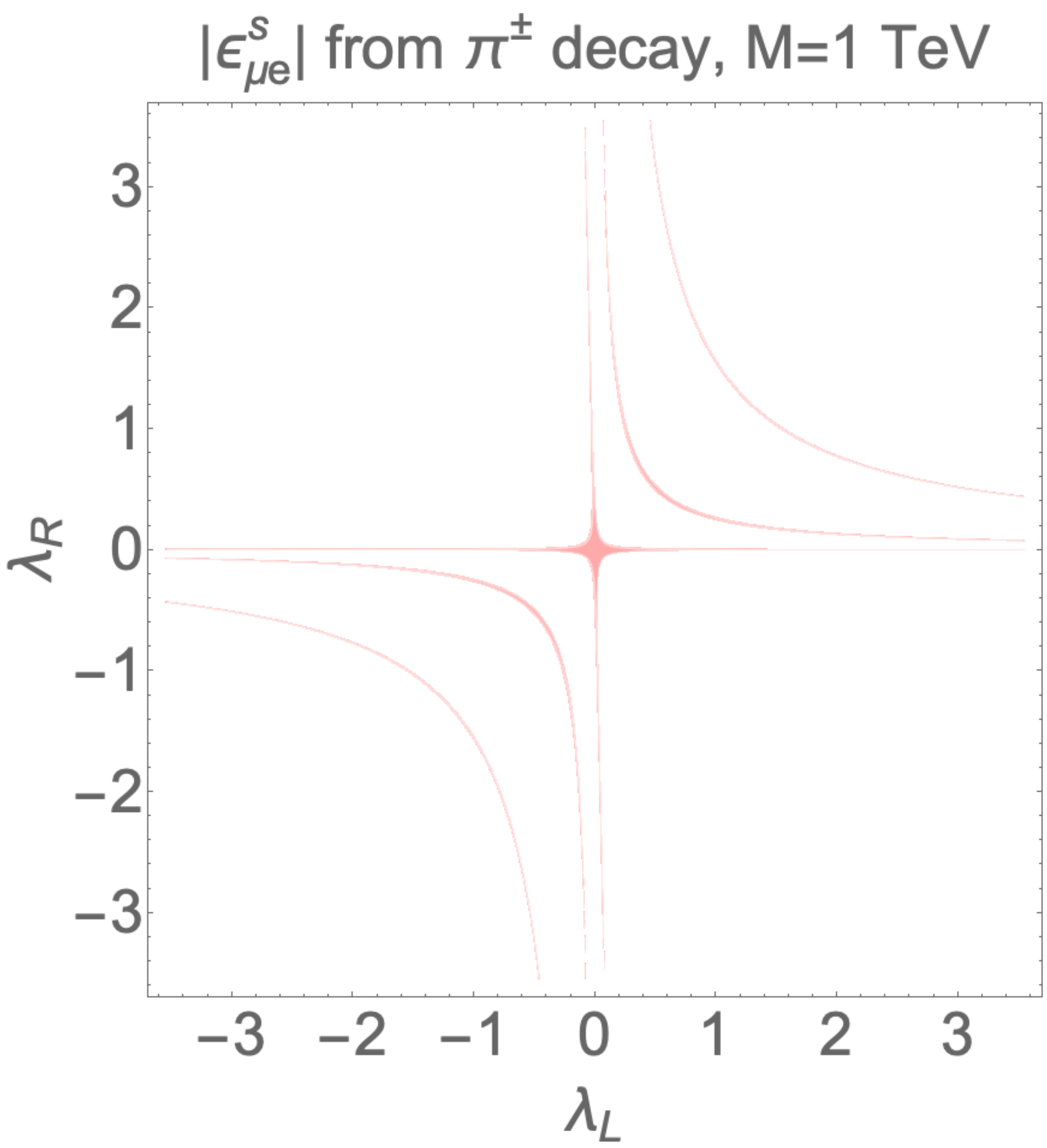
Multiple operators

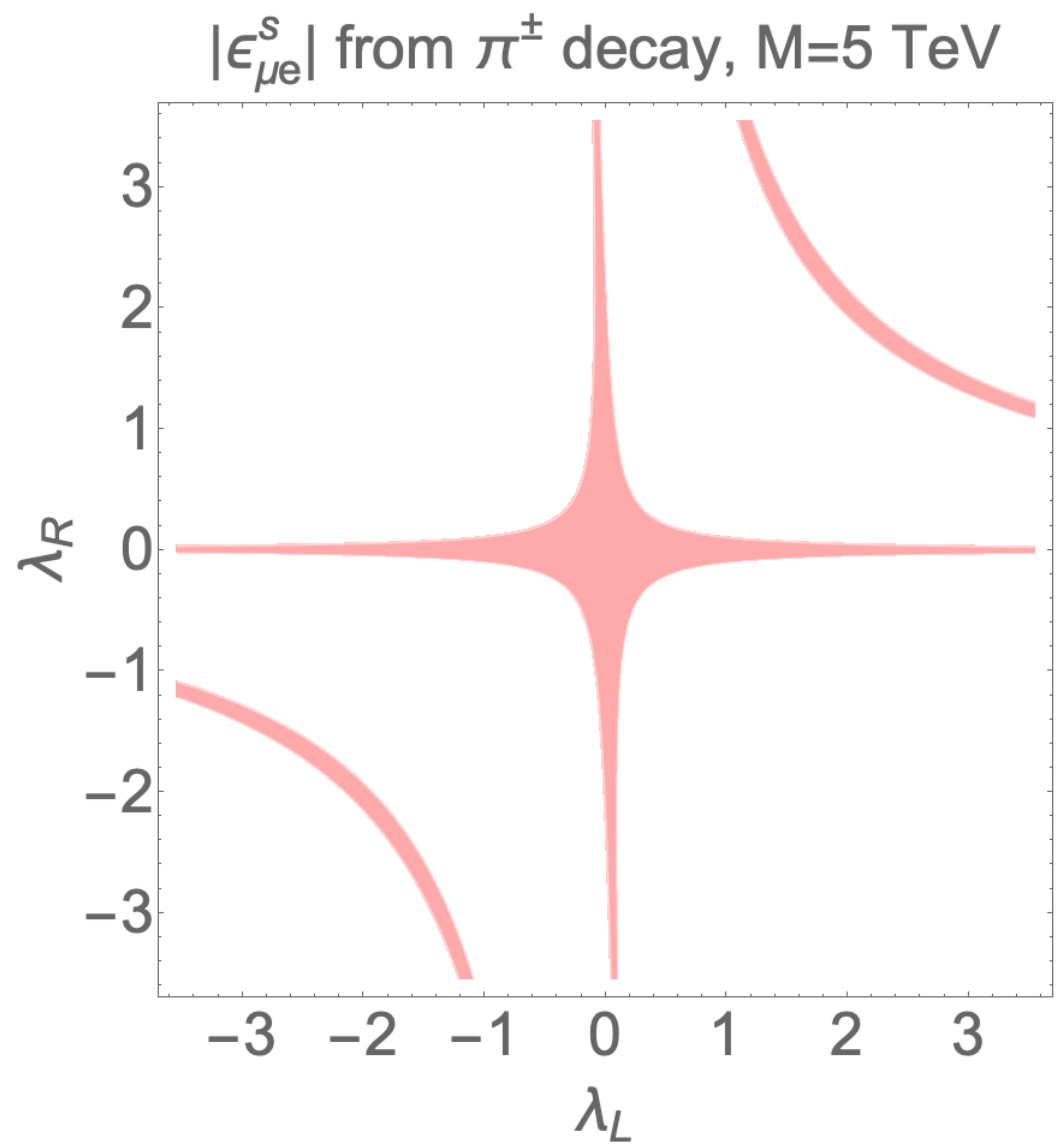




Simplified leptoquark model

$$\mathcal{L}_{\rm LQ} = |D_\mu S|^2 - M_1^2|S|^2 - \lambda_{H1}|H|^2|S|^2 - \frac{c}{2}|S|^4$$
$$+ \left((\lambda^L)_{i\alpha}\bar{q}_i^c \epsilon \ell_\alpha + (\lambda^R)_{i\alpha}\bar{u}_i^c e_\alpha\right) S_1 + \text{h.c.}$$





NC NSIs: Comparison

ϵ's	[103]	[97]	[82]	[83]	[84]	[85]	[90]	[98]	[35]	This work	
										Planck	CMB-S4
$\epsilon_{ee}^{e,L}$	[-0.010, 2.039]	[-1.53, 0.38]	[-0.07, 0.1]	[-0.05, 0.12]	[-0.03, 0.08]	[-0.036, 0.063]	[-0.017, 0.027] [-0.003, 0.003]	[-0.08, 0.08]	[-0.185, 0.380] [-0.130, 0.185]	[-1.6, 1.44]	[-0.61, 0.46]
$\epsilon_{e\mu}^{e,L}$	[-0.179, 0.146]	[-0.84, 0.84]	-	-	[-0.13, 0.13]	-	[-0.152, 0.152] [-0.055,0.055]	[-0.33, 0.35]	[-0.025, 0.052] [-0.017, 0.040]	[-1.6, 1.44]	[-0.61, 0.46]
$\epsilon_{e\tau}^{e,L}$	[-0.860, 0.350]	[-0.84, 0.84]	[-0.4, 0.4]	[-0.44, 0.44]	[-0.33, 0.33]	-	[-0.152, 0.152] [-0.055,0.055]	[-0.33, 0.35]	[-0.055, 0.023] [-0.042, 0.012]	[-1.6, 1.44]	[-0.61, 0.46]
$\epsilon_{\mu\mu}^{e,L}$	[-0.364, 1.387]	-	[-0.03,0.03]	-	[-0.03, 0.03]	-	[-0.040, 0.04] [-0.010,0.010]	-	[-0.290, 0.390] [-0.192, 0.240]	[-1.6, 1.44]	[-0.61, 0.46]
$\epsilon_{\mu\tau}^{e,L}$	[-0.035, 0.028]	-	[-0.1,0.1]	-	[-0.1, 0.1]	-	-	-	[-0.015, 0.013] [-0.010, 0.010]	[-1.6, 1.44]	[-0.61, 0.46]
$\epsilon_{\tau\tau}^{e,L}$	[-0.350, 1.400]	-	[-0.5,0.5]	-	[-0.46, 0.24]	[-0.16 , 0.110] [0.41, 0.66]	[-0.040, 0.04] [-0.010,0.010]	-	[-0.360, 0.145] [-0.120, 0.095]	[-1.6, 1.44]	[-0.61, 0.46]
$\epsilon_{ee}^{e,R}$	[-0.010, 2.039]	[-0.07, 0.08]	[-1, 0.5]	[-0.04, 0.14]	[0.004, 0.151]	[-0.27, 0.59]	[-0.33 , 0.25] [-0.07, 0.07]	[-0.04, 0.06]	[-0.185, 0.380] [-0.130, 0.185]	[-1.6, 1.44]	[-0.39, 0.31]
$\epsilon_{e\mu}^{e,R}$	[-0.179, 0.146]	[-0.19, 0.19]	-	-	[-0.13, 0.13]	-	[-0.236, 0.236] [-0.08, 0.08]	[-0.15, 0.16]	[-0.025, 0.052] [-0.017, 0.040]	[-1.6, 1.44]	[-0.39, 0.31]
$\epsilon_{e\tau}^{e,R}$	[-0.860, 0.350]	[-0.19, 0.19]	[-0.7, 0.7]	[-0.27, 0.27]	[-0.05 , 0.05] [-0.28, 0.28]	-	[-0.236, 0.236] [-0.08, 0.08]	[-0.15, 0.16]	[-0.055, 0.023] [-0.042, 0.012]	[-1.6, 1.44]	[-0.39, 0.31]
$\epsilon_{\mu\mu}^{e,R}$	[-0.364, 1.387]	-	[-0.03,0.03]	-	[-0.03, 0.03]	-	[-0.10 , 0.12] [-0.006, 0.006]	-	[-0.290, 0.390] [-0.192, 0.240]	[-1.6, 1.44]	[-0.39, 0.31]
$\epsilon_{\mu\tau}^{e,R}$	[-0.035, 0.028]	-	[-0.1,0.1]	-	[-0.1, 0.1]	-	-	-	[-0.015, 0.013] [-0.010, 0.010]	[-1.6, 1.44]	[-0.39, 0.31]
$\epsilon_{\tau\tau}^{e,R}$	[-0.350, 1.400]	-	[-0.5,0.5]	-	[-0.25, 0.43]	[-1.05, 0.31]	[-0.10 , 0.12] [-0.006, 0.006]	-	[-0.360, 0.145] [-0.120, 0.095]	[-1.6, 1.44]	[-0.39, 0.31]

Table 4. Summary of constraints on dimension-6 neutrino-electron NC NSIs from previous studies and this work. Constraints from a global fitting of all kinds of neutrino oscillation data plus the COHERENT result are obtained in Ref. [103], the TEXONO collaboration in Ref. [97], the LEP, LSND and CHARM-II experiments in Ref. [82], a global analysis of $\nu_e e$ and $\bar{\nu}_e e$ scattering data from LSND, Irvine, Rovno and MUNU experiments in Ref. [83], OPAL, ALEPH, L3, DELPHI, LSND, CHARM-II, Irvine, Rovno and MUNU experiments in Ref. [84], solar and reactor neutrino experiments in Ref. [85], low-energy solar neutrinos at source and detector from the Borexino experiment in Ref. [90], a global analysis of short baseline νe and $\bar{\nu} e$ data from LSND, LAMPF, Irvine, Rovno, MUNU, TEXONO and KRANOYARSK in Ref. [98], and DUNE in Ref. [35].