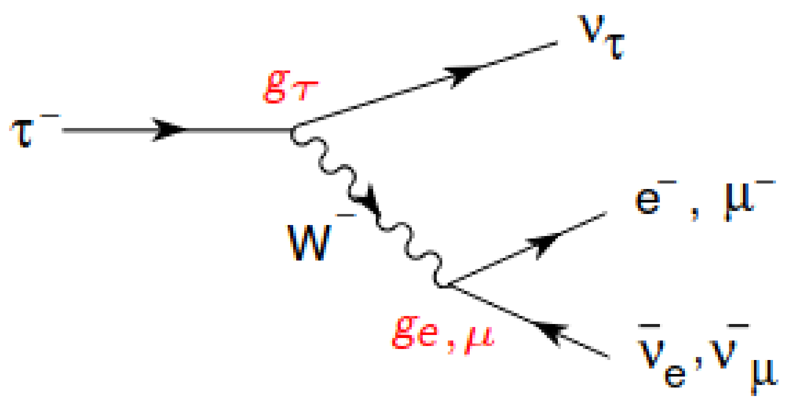
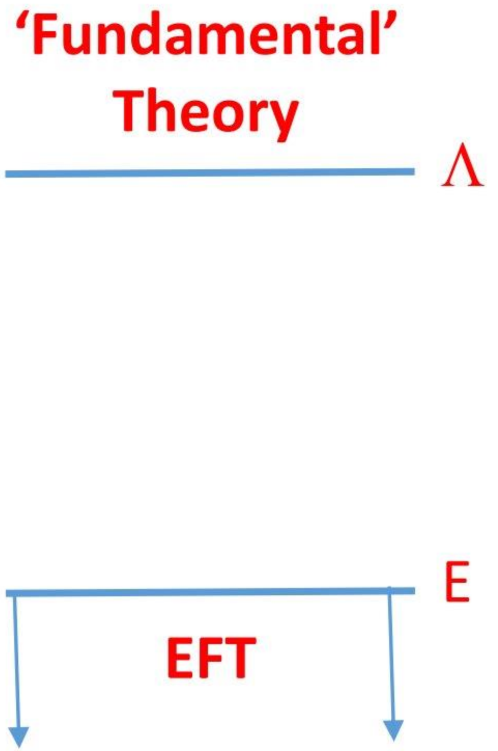
Opportunities with Tau Leptonic decays at Belle-II

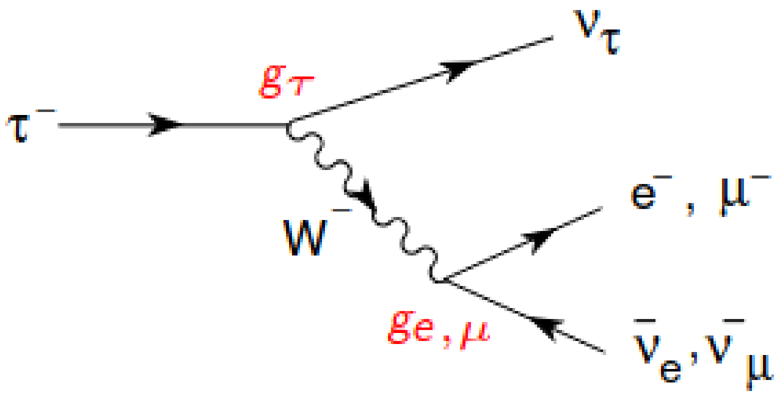


Cinvestav
Pablo Roig (Cinvestav, México)



2024 Belle-II Physics Week KEK, Oct. 14-18

Opportunities with Tau Leptonic decays at Belle-II



- Lepton Universality
- Lorentz structure of the charged current

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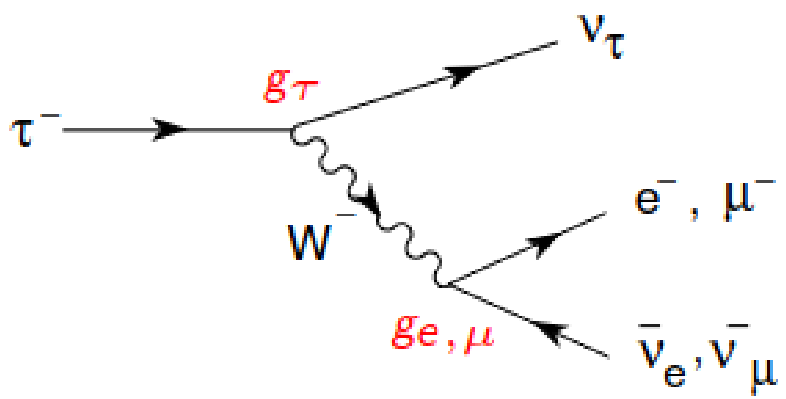
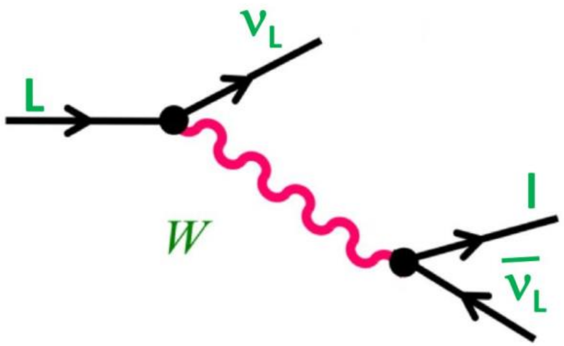


- Lepton Universality
- Lorentz structure of the charged current (including possible heavy sterile neutrinos)

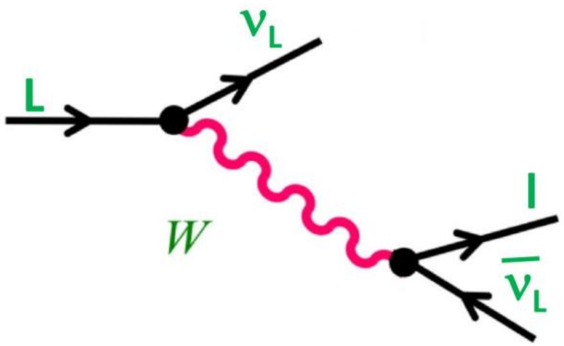
Lepton Universality



$$T(l \to \nu_l\, l' \overline{\nu}_{l'}) \sim \frac{g^2}{M_W^2 - q^2} \xrightarrow{q^2 \ll M_W^2} \frac{g^2}{M_W^2} = 4\sqrt{2}\, G_F$$

$\Gamma \sim G_F^2 m_L^5$

Lepton Universality



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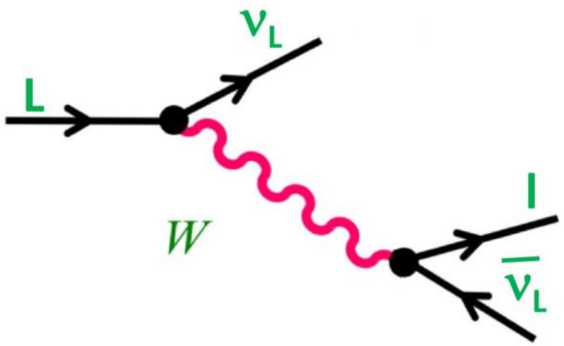
The observable: $$R_\mu = \frac{\mathcal{B}(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)}{\mathcal{B}(\tau^- \to e^- \bar{\nu}_e \nu_\tau)}$$

We extract $$\left| \frac{g_\mu}{g_e} \right|_\tau = \sqrt{R_\mu \frac{f(m_e^2/m_\tau^2)}{f(m_\mu^2/m_\tau^2)}}.$$

$$f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \ln x$$

It must be 1 in the SM, as a consequence of gauge symmetry

Lepton Universality



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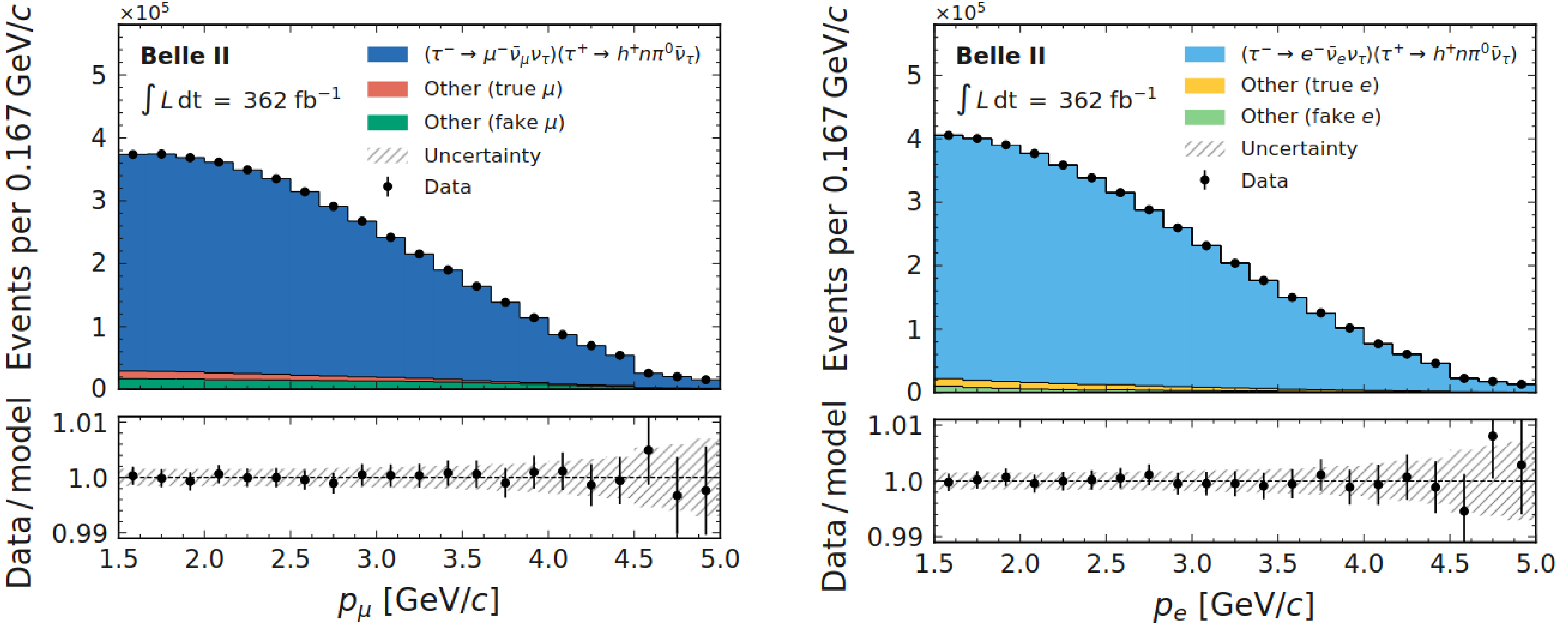
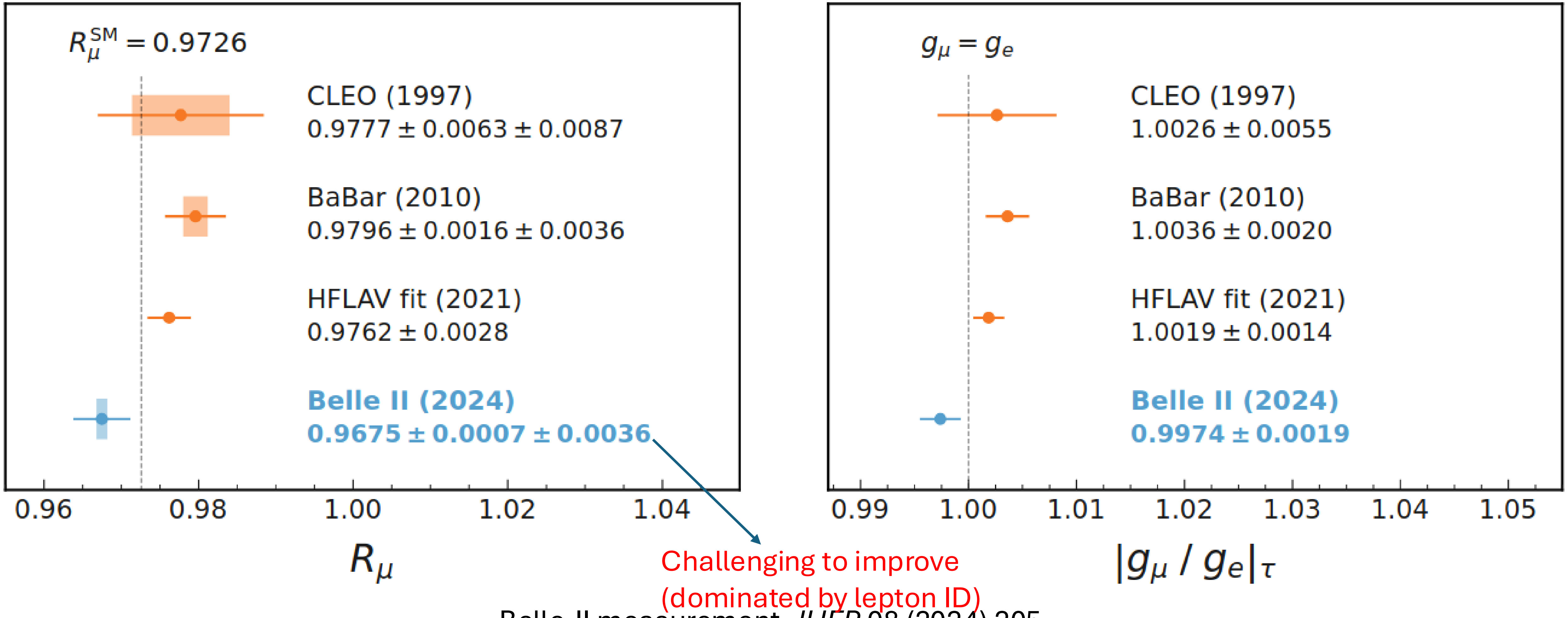
Belle-II measurement, *JHEP* 08 (2024) 205



Belle-II measurement, *JHEP* 08 (2024) 205

Figure 6. Observed momentum distribution for muon (left) and electron (right) candidates with fit results overlaid. The lower panel shows the ratio between data and fit results. The hatched area indicates the possible variation of the fitted yields due to systematic effects, with the constraints of the nuisance parameters reduced to their fit uncertainties and correlations taken into account.



Belle-II measurement, *JHEP* 08 (2024) 205

Figure 7. Determinations of R_μ (left) and $|g_\mu/g_e|_\tau$ (right) from previous individual measurements [11, 12] and the fit from the Heavy Flavor Averaging Group [15], compared with the result of this work. The shaded areas represent the statistical uncertainties, while the error bars indicate the total uncertainties. The vertical dashed line indicates the SM prediction, including mass effects.

Pich, *Prog.Part.Nucl.Phys.* 75 (2014) 41-85; Bryman-Cirigliano-Crivellin-Inguglia *Ann.Rev.Nucl.Part.Sci.* 72 (2022) 69-91

This result in the context of other purely leptonic tests of LU

$$R^{\tau}_{\mu/e} = \frac{\mathrm{Br}[\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau]}{\mathrm{Br}[\tau^- \to \mathrm{e}^- \bar{\nu}_\mathrm{e} \nu_\tau]} \,,$$

Belle-II '24 => g_μ/g_e=0.9974(19) 1.4σ

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g_τ/g_μ=1.0010(14) 0.7σ

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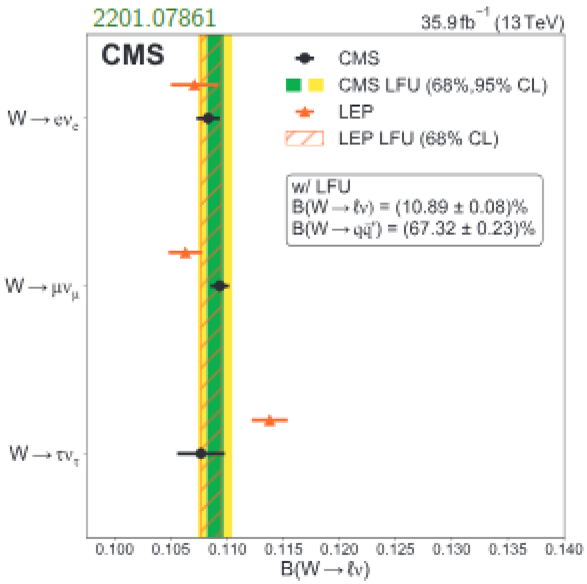
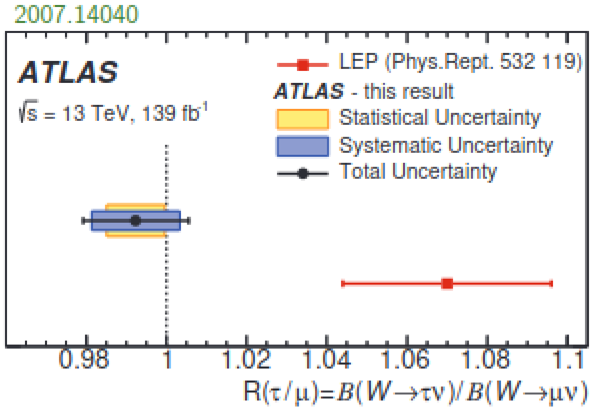
From W leptonic decays:





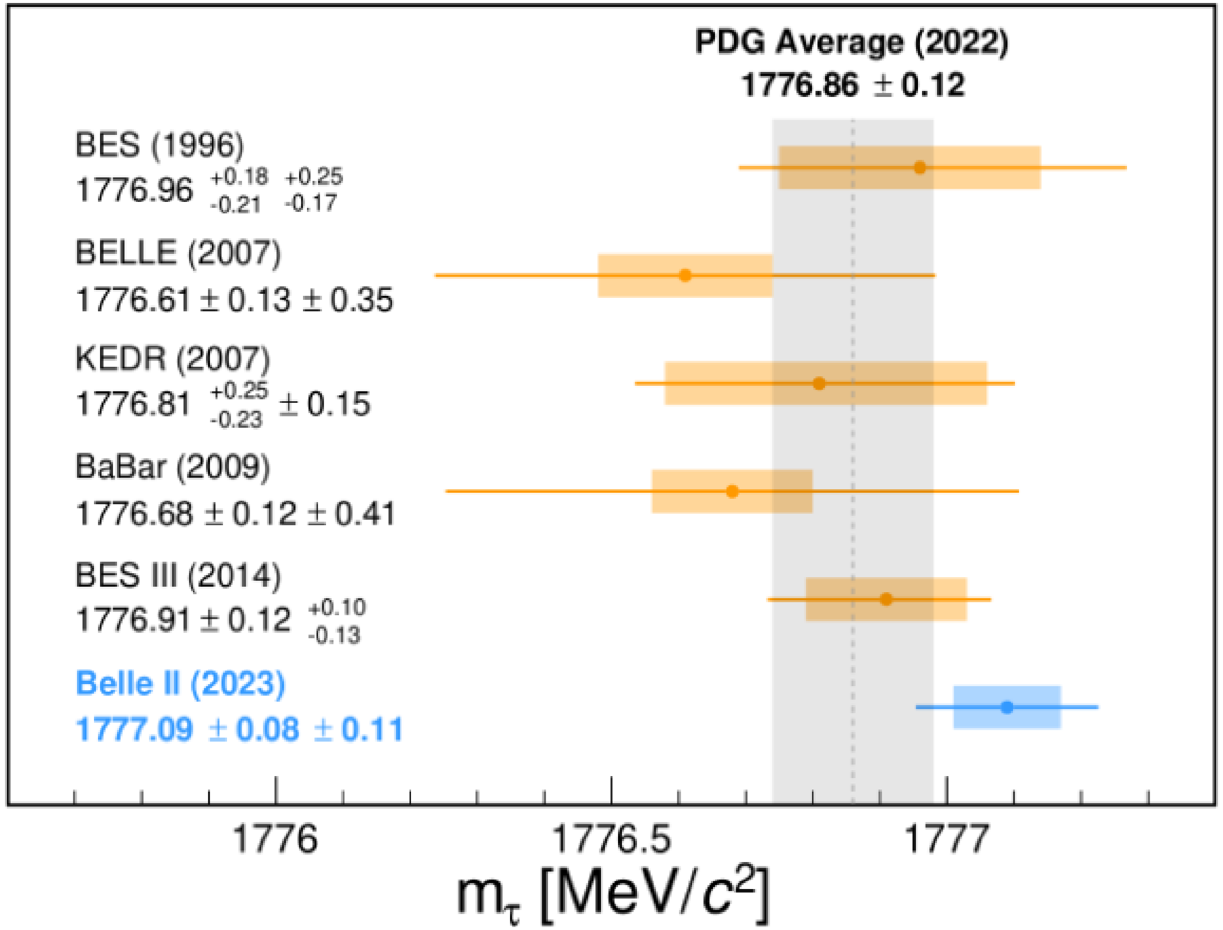
NP constrained at few TeV level

Lepton Universality

$\Gamma \sim G_F^2 m_L^5$

It can also be checked benefitting from the Belle-II τ mass measurement, using the leptonic BR determination:

Still from LEP!!



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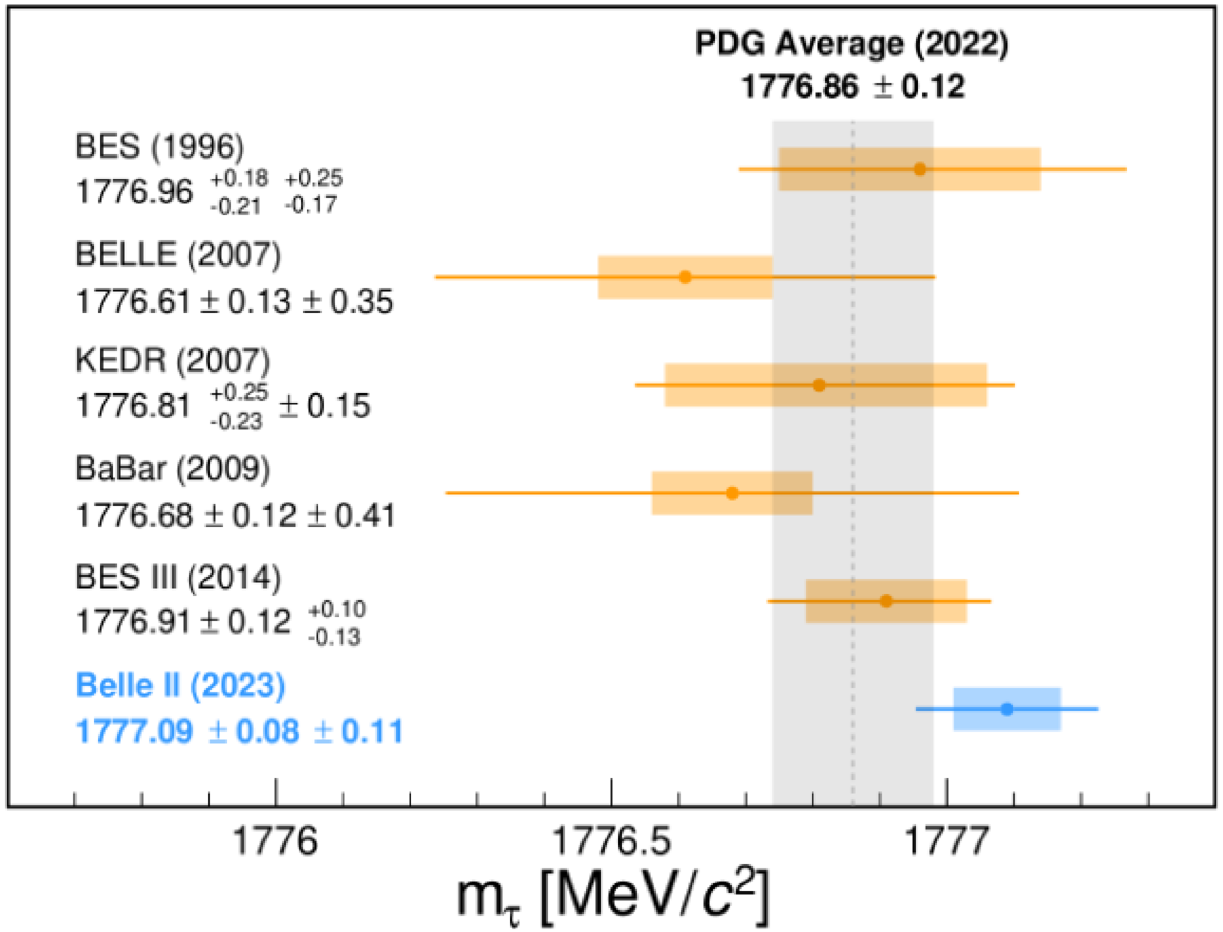
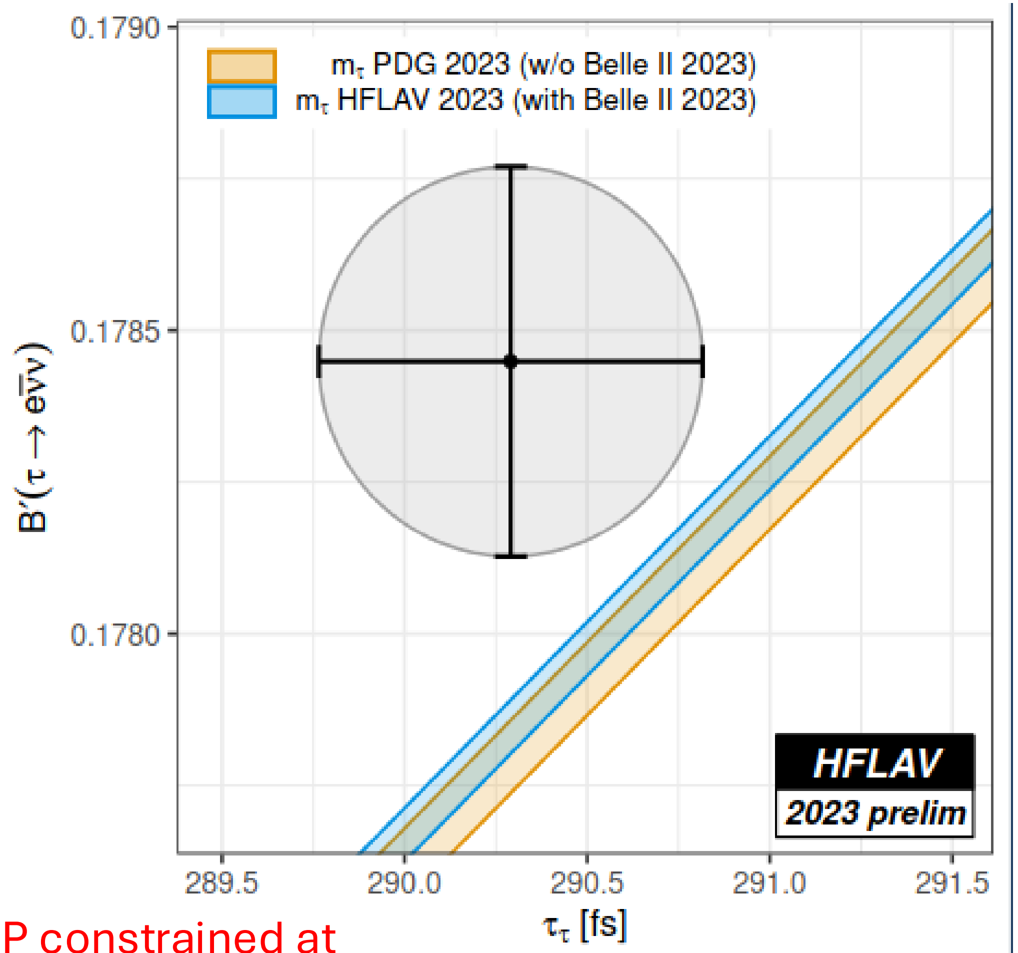


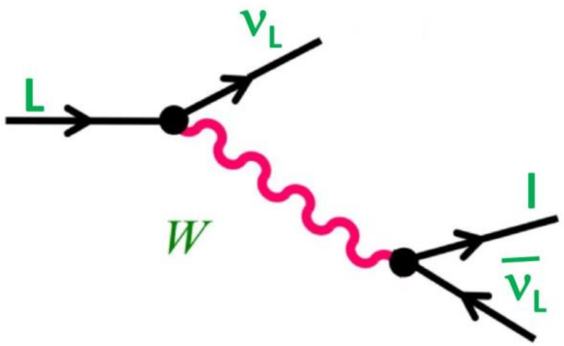


NP constrained at few TeV level

Opportunities with Tau Leptonic decays at Belle-II

Pablo Roig (Cinvestav, Mexico)

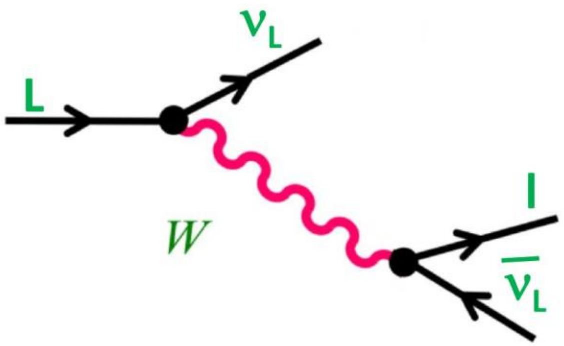
Lorentz structure of the charged current



$$\mathcal{H} = 4\frac{G_{\ell'\ell}}{\sqrt{2}} \sum_{n,\epsilon,\omega} g^n_{\epsilon\omega} \left[\overline{\ell'_\epsilon}\Gamma^n(\nu_{\ell'})_\sigma\right] \left[\overline{(\nu_\ell)_\lambda}\Gamma_n\ell_\omega\right] \,,$$

It depends on 4S, 4V & 2T complex couplings labelled also by charged lepton chiralities.

Lorentz structure of the charged current



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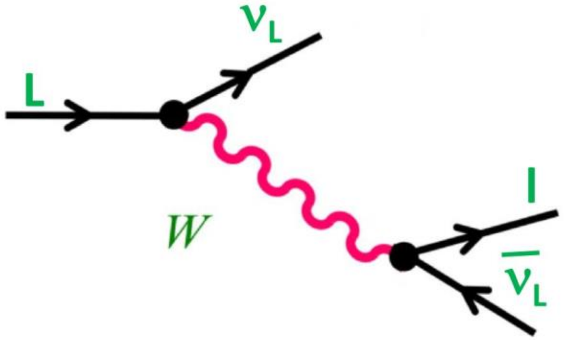
It depends on 4S, 4V & 2T complex couplings labelled also by charged lepton chiralities.

$$1 = \frac{1}{4}\left(|g^S_{RR}|^2 + |g^S_{RL}|^2 + |g^S_{LR}|^2 + |g^S_{LL}|^2\right) + 3\left(|g^T_{RL}|^2 + |g^T_{LR}|^2\right) + \left(|g^V_{RR}|^2 + |g^V_{RL}|^2 + |g^V_{LR}|^2 + |\underline{g^V_{LL}}|^2\right) .$$

Lorentz structure of the charged current



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$$1 = \frac{1}{4} \left(|g^S_{RR}|^2 + |g^S_{RL}|^2 + |g^S_{LR}|^2 + |g^S_{LL}|^2\right) + 3 \left(|g^T_{RL}|^2 + |g^T_{LR}|^2\right) + \left(|g^V_{RR}|^2 + |g^V_{RL}|^2 + |g^V_{LR}|^2 + |g^V_{LL}|^2\right) .$$

$$\frac{d^2\Gamma_{\ell\to\ell'}}{dx\, d\cos\theta} = \frac{m_\ell\, \omega^4}{2\pi^3} G^2_{\ell'\ell} \sqrt{x^2 - x_0^2} \left\{F(x) - \frac{\xi}{3} \mathcal{P}_\ell \sqrt{x^2 - x_0^2} \cos\theta\, A(x)\right\}$$

$\cos\theta = \mathbf{s}_l \cdot \mathbf{p}_{l'}$

$$\omega \equiv (m_\ell^2 + m_{\ell'}^2)/2m_\ell$$

$$x \equiv E_{\ell'}/\omega$$

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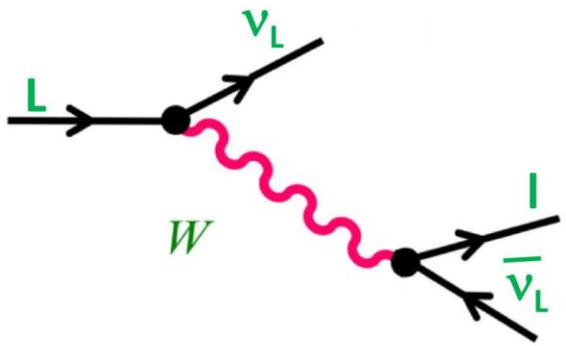
Lorentz structure of the charged current



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$$A(x) = 1 - x + \frac{2}{3}\delta\left(4x - 4 + \sqrt{1 - x_0^2}\right) .$$

Five additional parameters if the l' polarization is also measured.

Lorentz structure of the charged current

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SM		$\mu^- \to e^-\bar{\nu}_e\nu_\mu$	$\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$	$\tau^- \to e^-\bar{\nu}_e\nu_\tau$	$\tau^- \to \ell^-\bar{\nu}_\ell\nu_\tau$
3/4	ρ	0.74979 ± 0.00026	0.763 ± 0.020	0.747 ± 0.010	0.745 ± 0.008
0	η	0.057 ± 0.034	0.094 ± 0.073	—	0.013 ± 0.020
1	ξ	$1.0009 {}^{+0.0016}_{-0.0007}$	1.030 ± 0.059	0.994 ± 0.040	0.985 ± 0.030
3/4	$\xi\delta$	$0.7511 {}^{+0.0012}_{-0.0006}$	0.778 ± 0.037	0.734 ± 0.028	0.746 ± 0.021
1	ξ'	1.00 ± 0.04	—	—	—
1	ξ''	0.65 ± 0.36	—	—	—

Lorentz structure of the charged current

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Belle Phys.Rev.Lett. 131 (2023) 2, 021801
Phys.Rev.D 108 (2023) 1, 012003

Dominated by statistics. Opportunity for Belle-II

Lorentz structure of the charged current

$$\frac{d^2\Gamma_{\ell\to\ell'}}{dx\,d\cos\theta} = \frac{m_\ell\,\omega^4}{2\pi^3}\,G_{\ell'\ell}^2\,\sqrt{x^2-x_0^2}\,\left\{F(x) - \frac{\xi}{3}\mathcal{P}_\ell\,\sqrt{x^2-x_0^2}\,\cos\theta\,A(x)\right\}$$

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$$\eta = \frac{1}{2}\mathrm{Re}\left[g^V_{LL}g^{S*}_{RR} + g^V_{RR}g^{S*}_{LL} + g^V_{LR}\left(g^{S*}_{RL} + 6\,g^{T*}_{RL}\right) + g^V_{RL}\left(g^{S*}_{LR} + 6\,g^{T*}_{LR}\right)\right]$$

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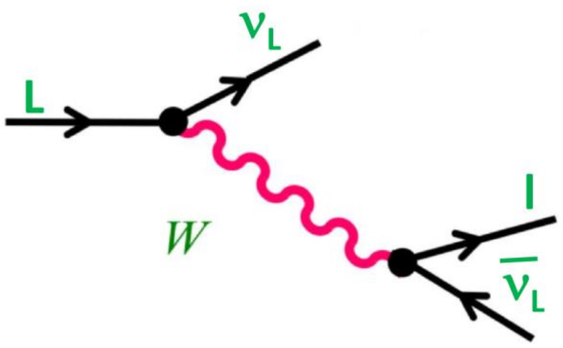
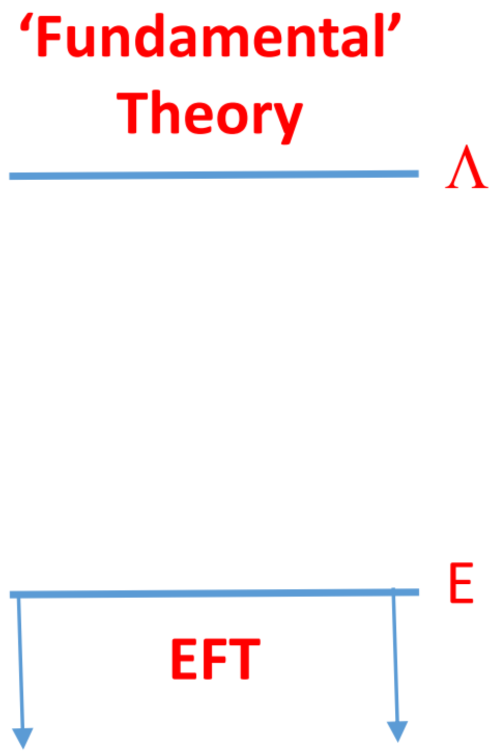


Michel parameters in presence of massive Dirac or Majorana neutrinos

(Juanma Márquez, Gabriel López Castro & P. R., JHEP11(2022)117)

$$\frac{d\Gamma}{dx\,d\cos\theta} = \frac{m_1}{4\pi^3}\omega^4 G_{ll'}^2\sqrt{x^2-x_0^2}\left(F(x) - \frac{\xi}{3}\mathcal{P}\sqrt{x^2-x_0^2}\cos\theta A(x)\right) \times \left[1+\hat{\zeta}\cdot\vec{\mathcal{P}}_{l'}(x,\theta)\right],$$

Massless case



$$\frac{d\Gamma}{dx\,d\cos\theta} = \sum_{j,k}\frac{m_1}{4\pi^3}\omega^4 G_{ll'}^2\sqrt{x^2-x_0^2} \times \Big(\big(F_{IS}(x)+F'_{IS}(x)+F''_{IS}(x)\big) - \mathcal{P}\cos\theta\big(F_{AS}(x)+F'_{AS}(x)+F''_{AS}(x)\big)\Big) \times \left[1+\hat{\zeta}\cdot\vec{\mathcal{P}}_{l'}(x,\theta)\right],$$

Linear in ν masses

Quadratic in ν masses

Massive case

Michel parameters in presence of massive Dirac or Majorana neutrinos

(Juanma Márquez, Gabriel López Castro & P. R., JHEP11(2022)117)

What is new:

- We write our expressions in the PDG parametrization form, in a way that complements all previous results, facilitating their application to model-dependent scenarios.
- We classify the Dirac and Majorana contributions with the help of a flag parameter $\epsilon = 0, 1$, making easier to distinguish between Dirac and Majorana nature of neutrinos.
- We discuss their main differences, together with some examples of its application to model-dependent theories.
- We also introduced and discussed the leading W-boson propagator correction to the differential decay rate including the final charged-lepton polarization.

Study suggested by Denis Epifanov (generalizing earlier work by Michel, Bouchiat-Michel, Fetscher-Gerber-Johnson, Langacker-London, Shrock, Doi-Kotani-Takasugi, etc.)

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Figure 6: Neutrino mass contribution to Dirac and Majorana distributions.

Michel parameters in presence of massive Dirac or Majorana neutrinos

(Juanma Márquez, Gabriel López Castro & P. R., JHEP11(2022)117)

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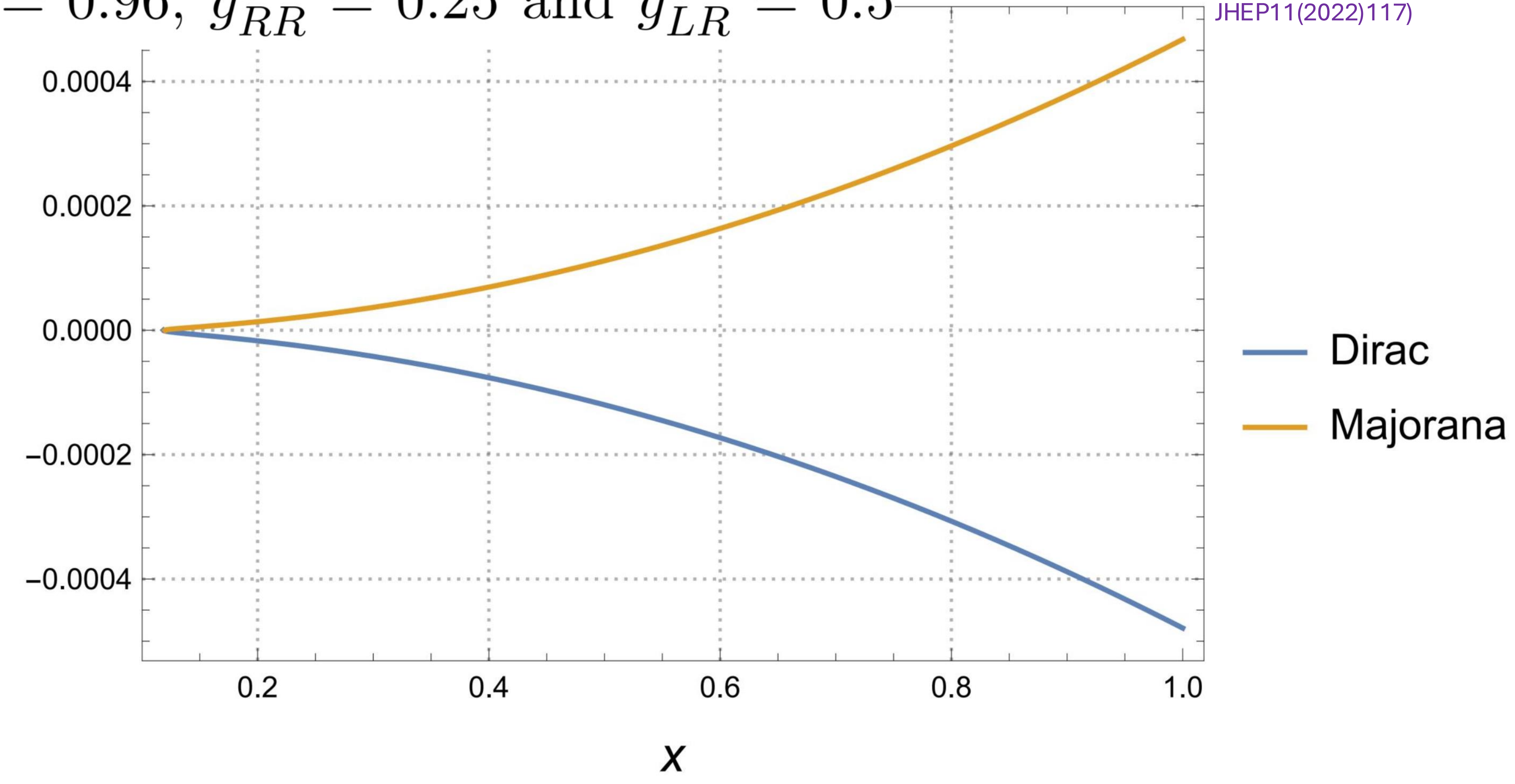

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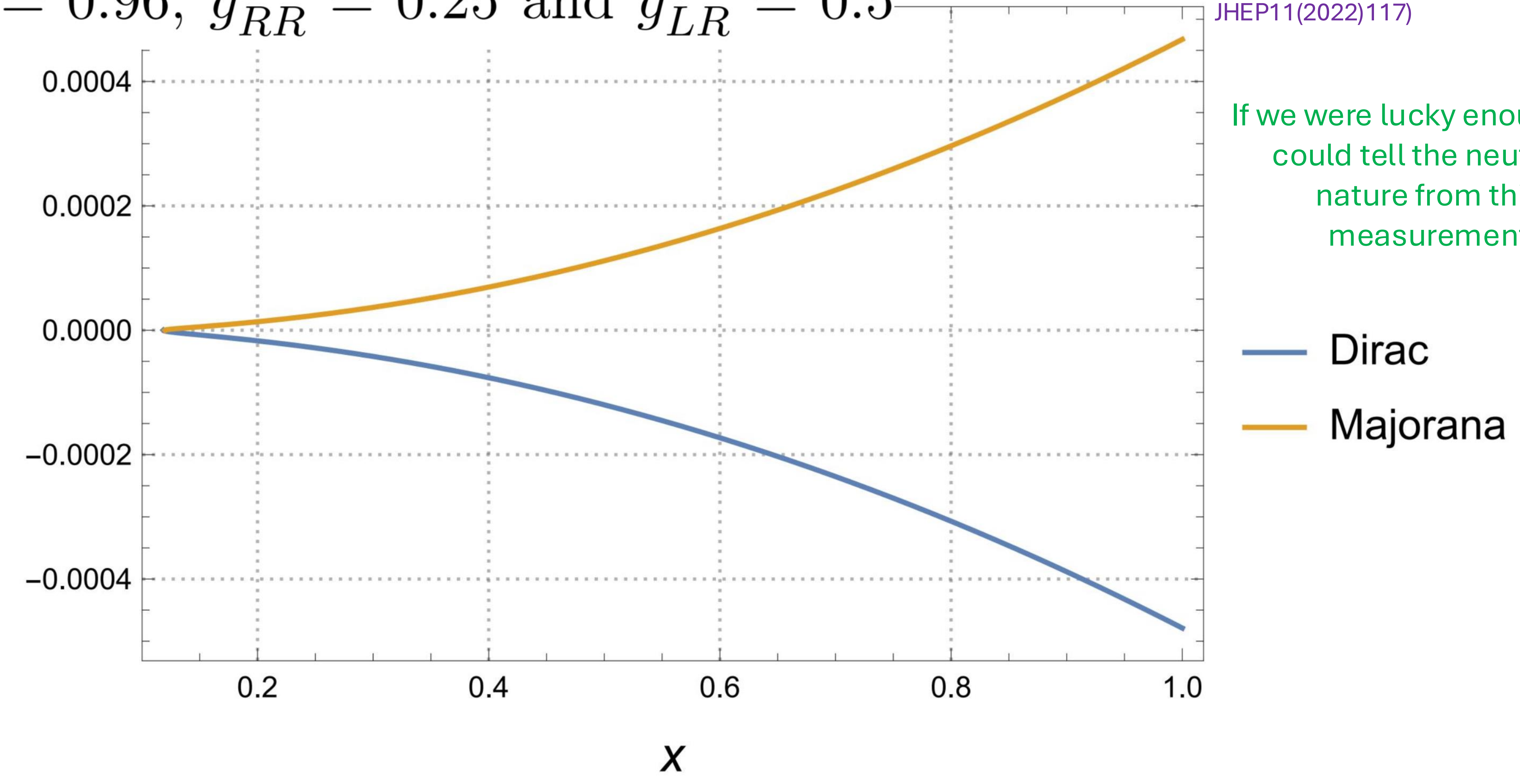

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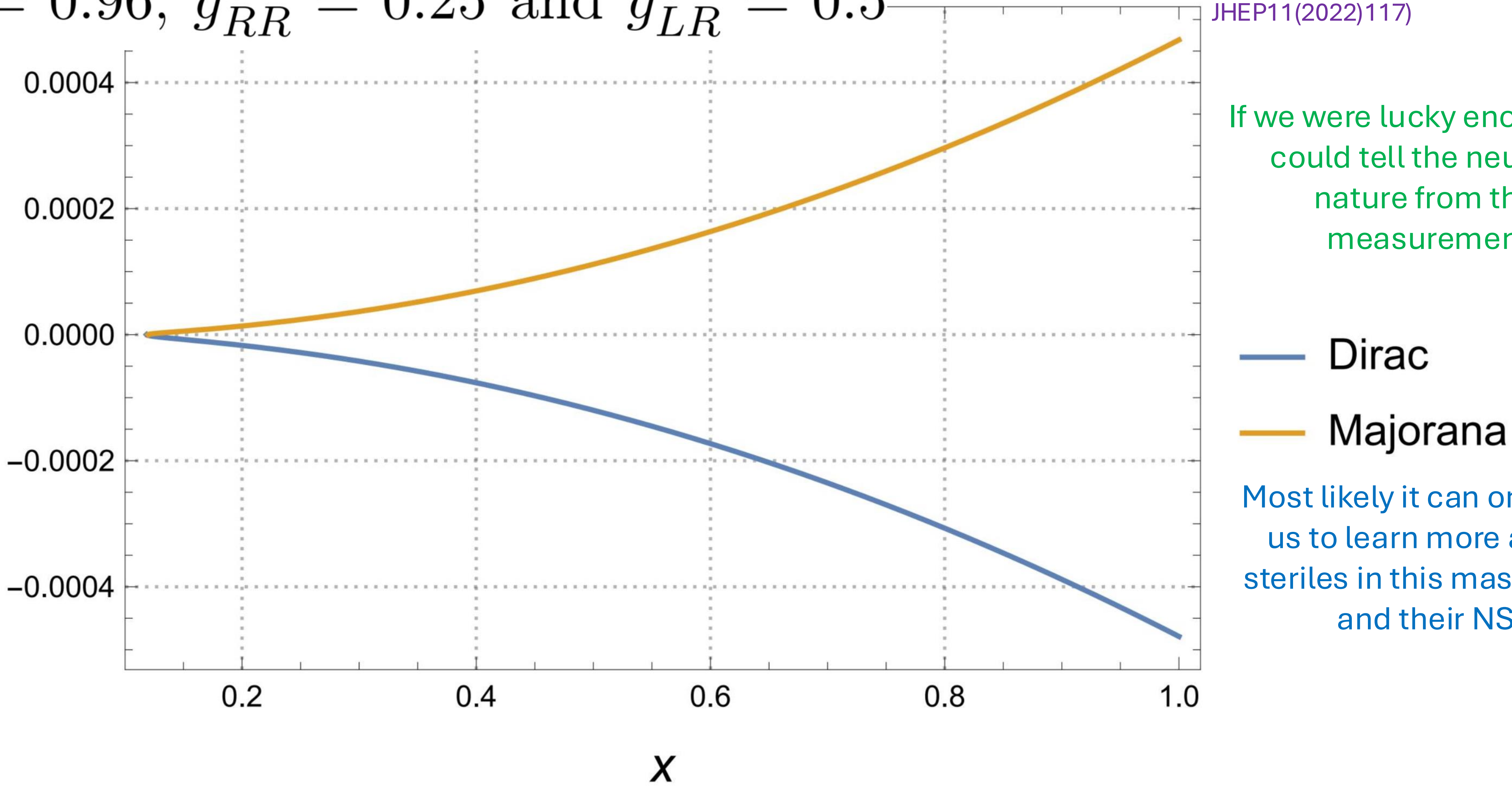

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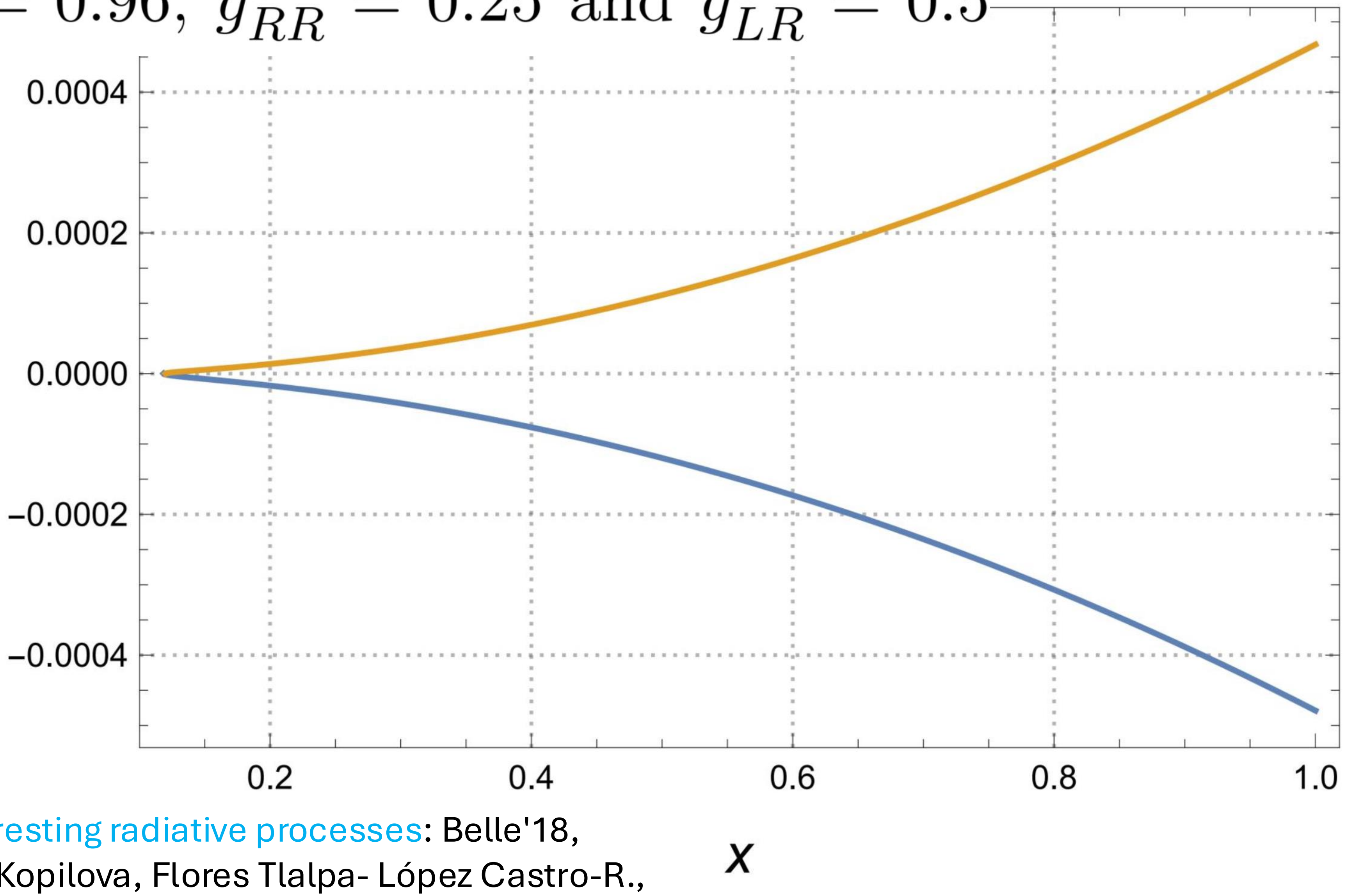

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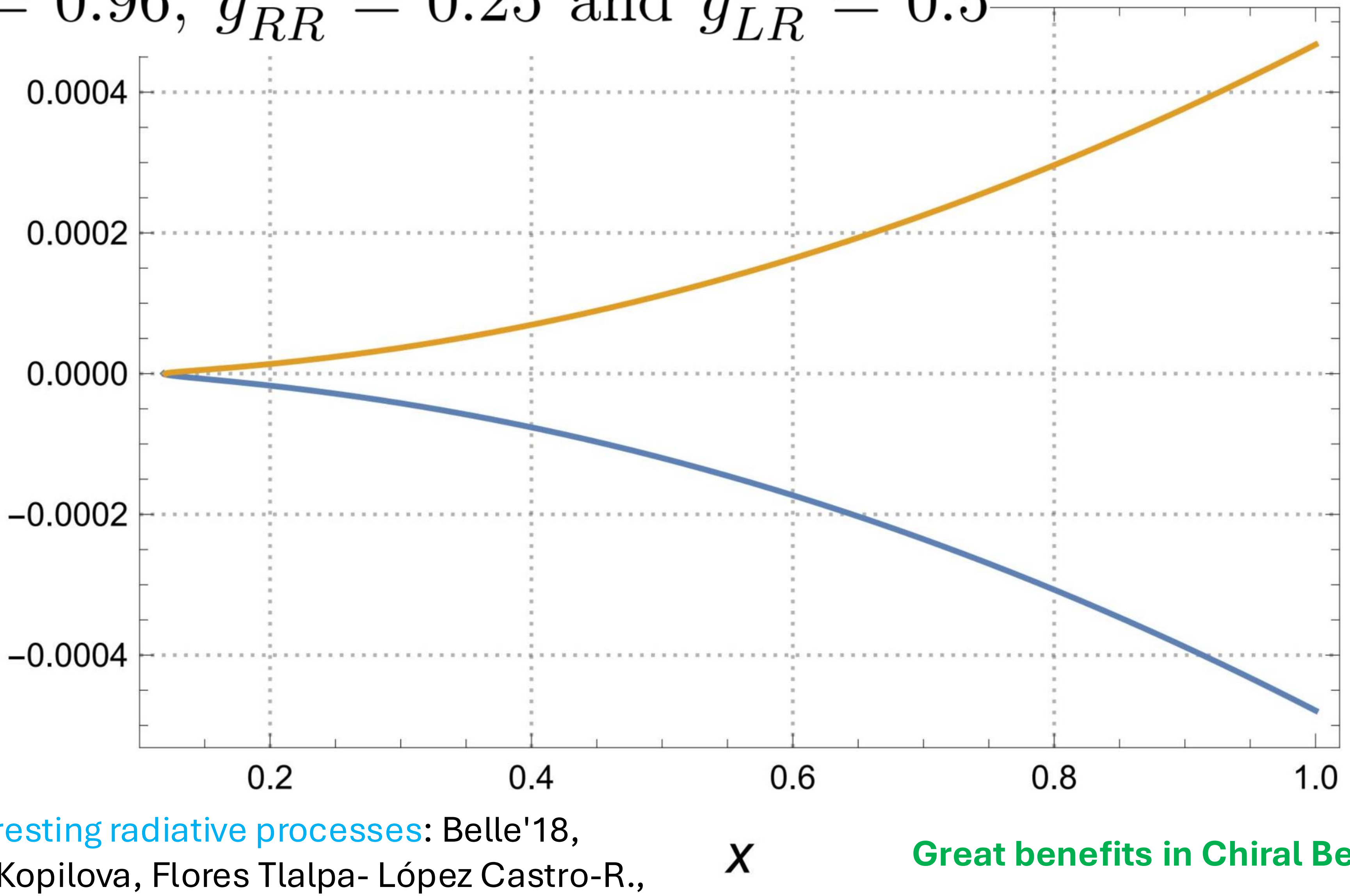

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Great benefits in Chiral Belle-II!!

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Inferring the nature of active neutrinos: Dirac or Majorana (C.S. Kim, M.V.M. Murthy & D. Sahoo, PRD105(2022)11,113006)

This paper apparently avoids the Kayser's confusion theorem 'Any property differentiating Dirac/Majorana neutrinos will be suppressed by active neutrino masses, with neutrinos coupling to the SM's $SU(2)_L$'.

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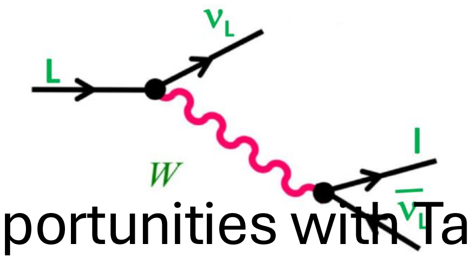

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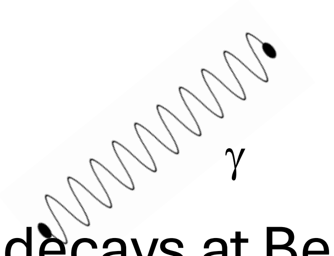

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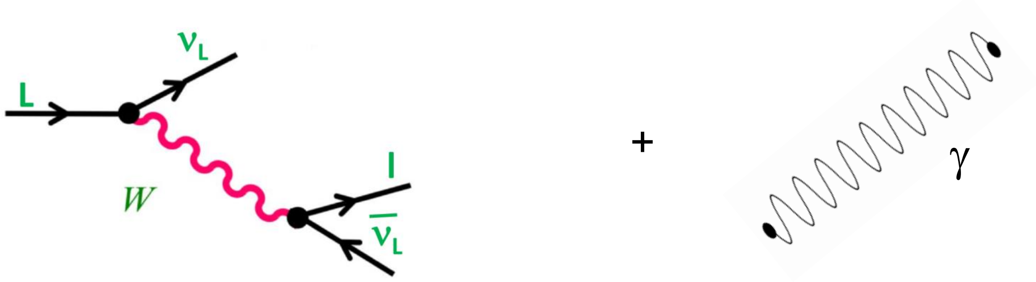
In fact, applying Kim's paper one should get BRs~10^{-4} for the b2b configuration, while we predict rates ~ 10^{-10}. Belle-II can disprove the former prediction!



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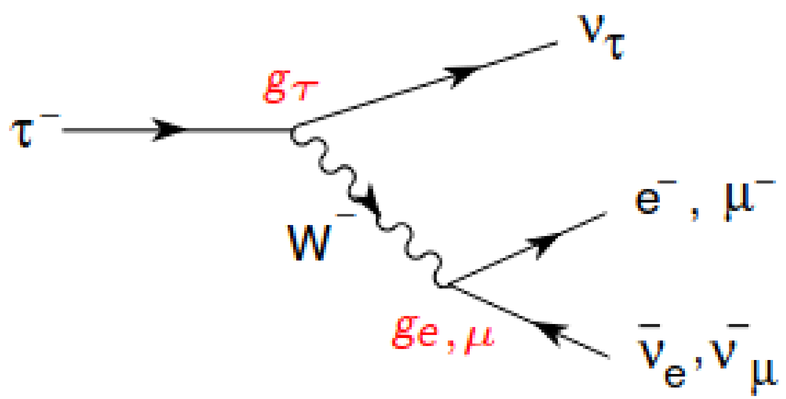
Opportunities with Tau Leptonic decays at Belle-II



- Lepton Universality
- Lorentz structure of the charged current (including possible heavy sterile neutrinos)