Phenomenology of Not-so-heavy Neutral Leptons

The NuTeV Anomaly, Lepton Universality, and Non-Universal Gauge-Neutrino Couplings

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- Peter Fisher (MIT)

Papers

- Phys. Rev. D67, 073012 (2003) [hep-ph/0210193]
- Phys. Rev. D68, 073001 (2003) [hep-ph/0304004]
- hep-ph/0403306

The NuTeV Anomaly

$$R_\nu = \frac{\sigma(\nu_\mu N \rightarrow \nu_\mu X)}{\sigma(\nu_\mu N \rightarrow \mu^- X)}$$

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$$R_\nu = \frac{\sigma(\nu_\mu N \to \nu_\mu X)}{\sigma(\nu_\mu N \to \mu^- X)} = g_L^2 + r g_R^2$$

$$R_{\bar\nu} = \frac{\sigma(\bar\nu_\mu N \to \bar\nu_\mu X)}{\sigma(\bar\nu_\mu N \to \mu^+ X)} = g_L^2 + \frac{g_R^2}{r}$$

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The measured value of g_L^2 was 3σ smaller than the SM prediction.

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- Neutrino mixing with gauge singlet states.
  $\rightarrow$ free from the above constraint.

Neutrino Mixing with Gauge Singlet States

ν

χ

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\begin{aligned}
\nu &= \nu_{\text{light}} \cos\theta + \nu_{\text{heavy}} \sin\theta \\
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$$W\ell\nu = W\ell\nu_{\text{light}} \cos\theta + W\ell\nu_{\text{heavy}} \sin\theta$$

General non-Universal Suppression

$\ell = e, \mu, \tau$

$Z\nu_\ell\nu_\ell$ $\qquad$ $W\ell\nu_\ell$

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$\rightarrow$ effect must be absorbed into the ρ-parameter.

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Fit to Z-pole (LEP/SLD), W mass, and NuTeV observables with S, T, U, and $\epsilon = \epsilon_e = \epsilon_\mu = \epsilon_\tau$:

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$\chi^2 = 0.6/d.o.f.$

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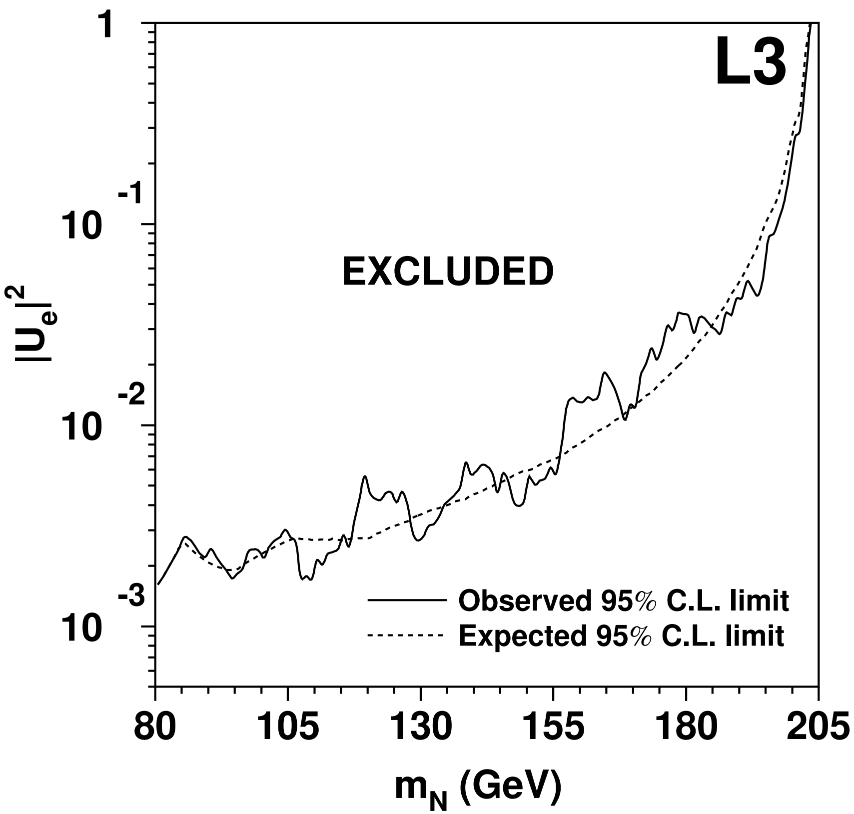
Perfect fit by adding just one parameter (ϵ)!

How heavy are the ‘heavy’ states?



Not so heavy?

Phys. Lett. B517, 67 (2001) [hep-ex/0107014]

$\mu \to e\gamma$

- MEGA Collaboration, Phys. Rev. Lett. 83, 1521 (1999) [hep-ex/9905013]

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$\to \epsilon_e\epsilon_\mu < 10^{-8}$
$\to \epsilon_e = \epsilon_\mu = 0.003$ is too large!

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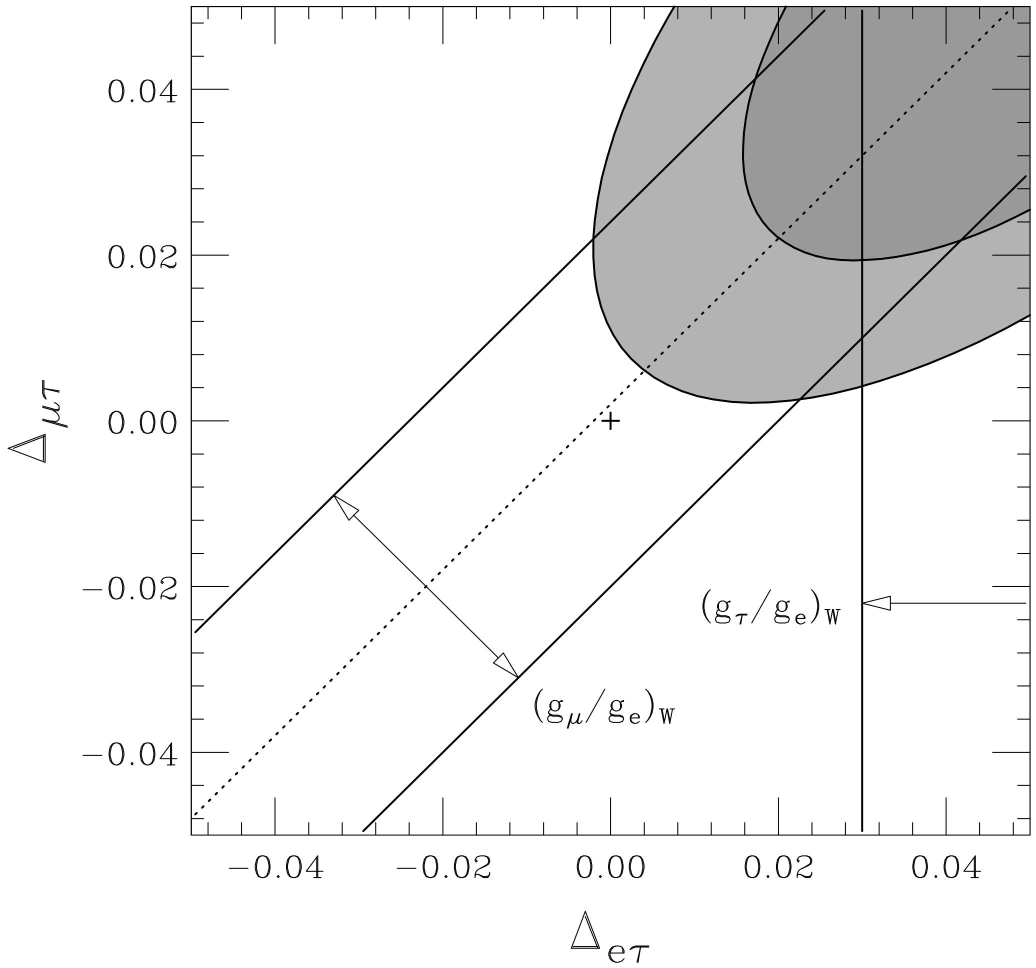
- Constraints on the ratios of effective couplings from W, τ, μ, π, and K decay.
  $\longrightarrow$ constraints on:

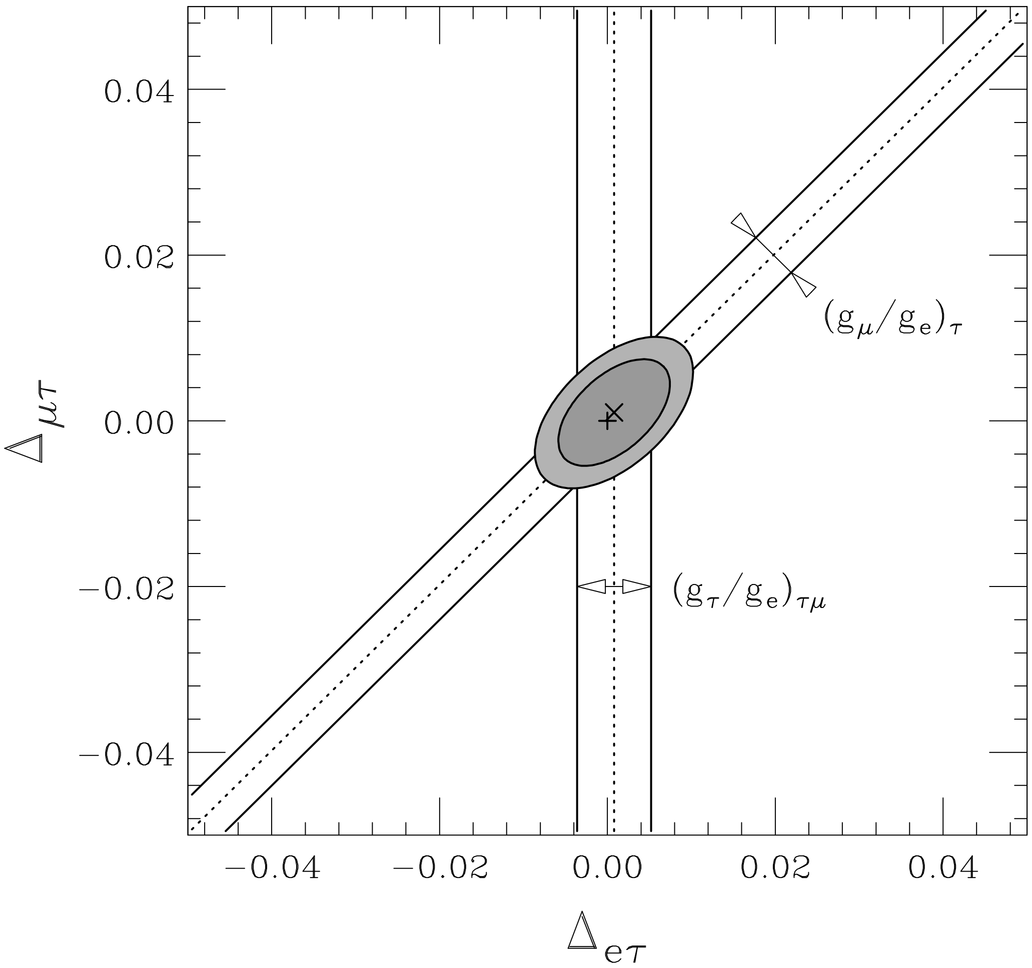
$$
\begin{aligned}
\epsilon_e - \epsilon_\tau &\equiv \Delta_{e\tau} \\
\epsilon_\mu - \epsilon_\tau &\equiv \Delta_{\mu\tau}
\end{aligned}
$$

Lepton Universality Constraints



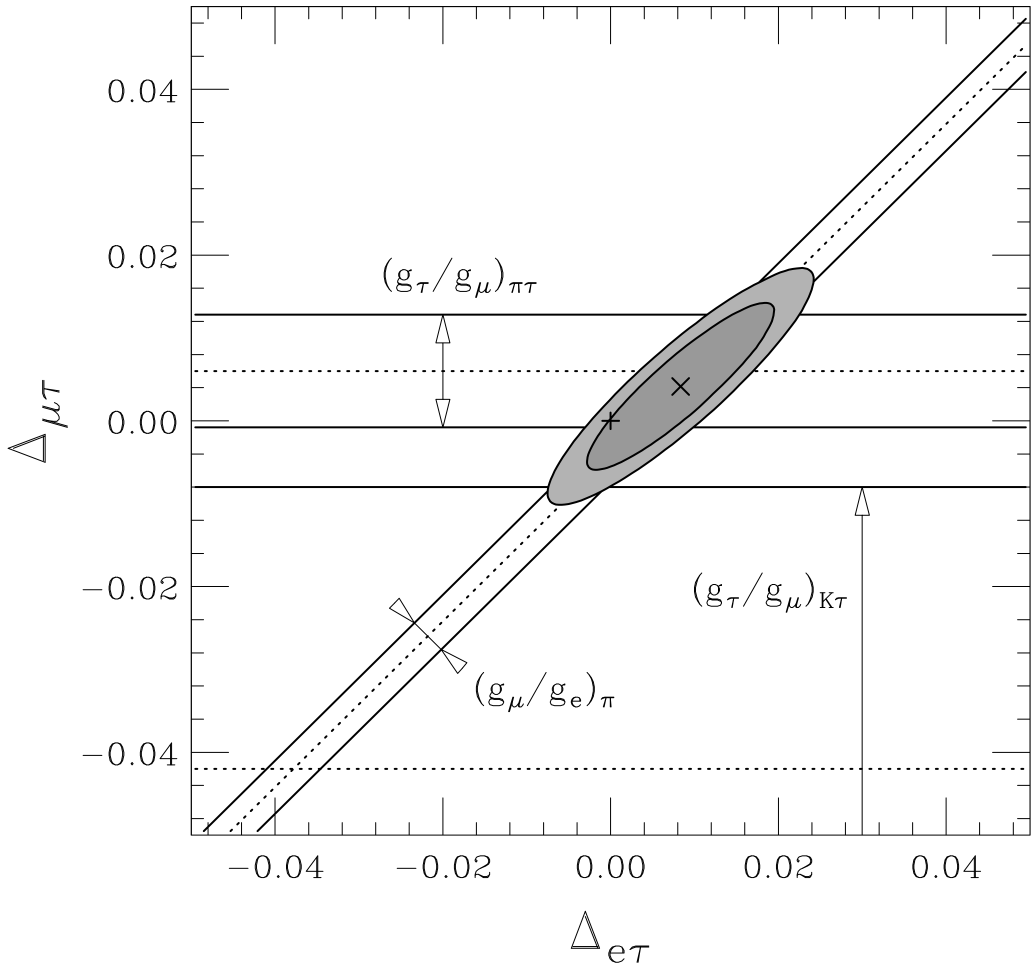
W decay

Lepton Universality Constraints



τ and μ decay

Lepton Universality Constraints



τ, π, and K decay

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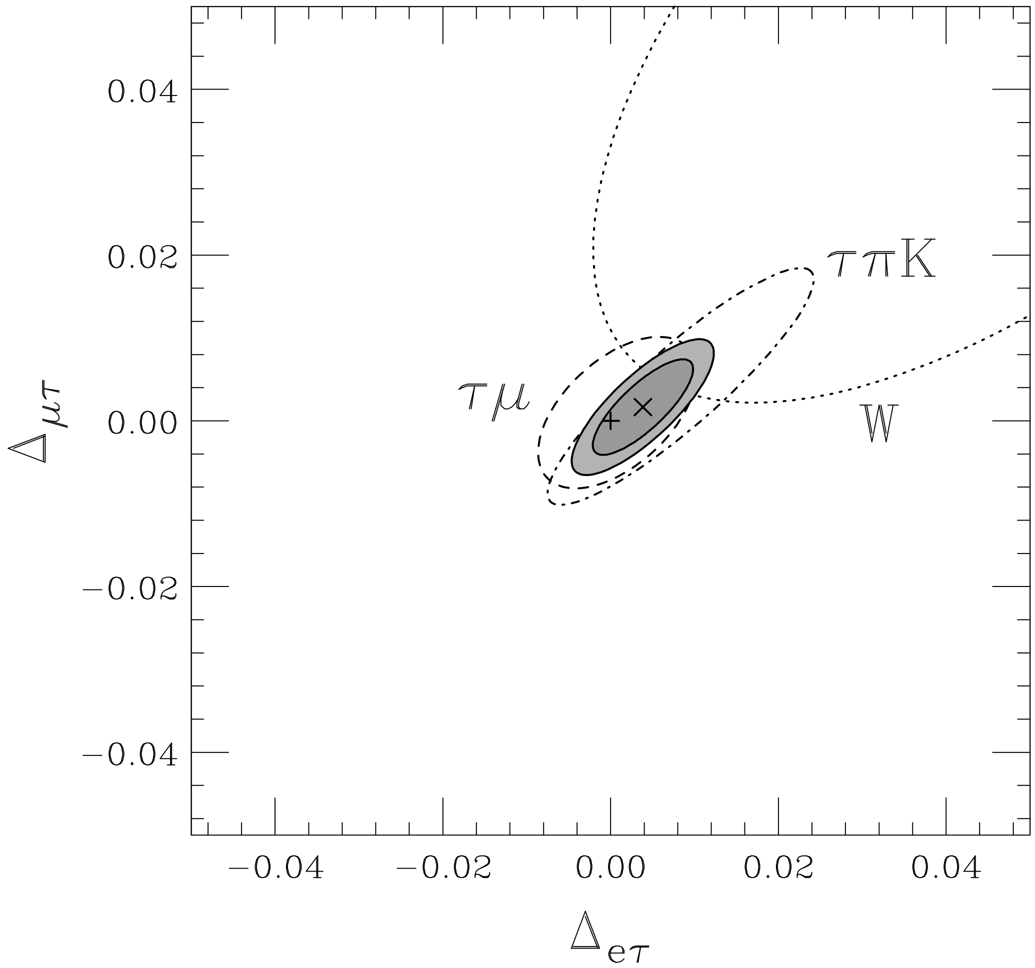


All decays combined

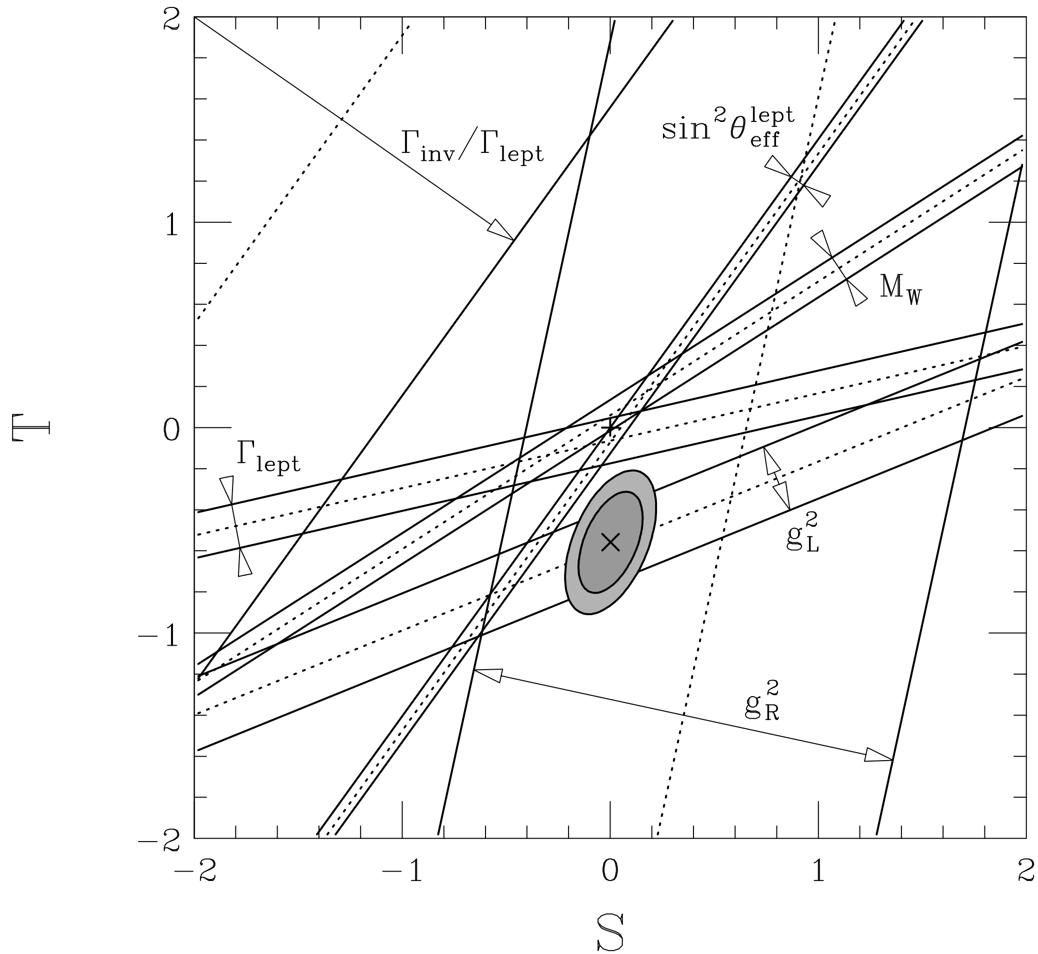
Fit with non-Universal ϵ's

Fit to Z-pole (LEP/SLD), W mass, NuTeV, and lepton universality constraints with S, T, U, ϵ_e, and ϵ_μ. (Including ϵ_τ does not improve the quality of the fit):

$$
\begin{aligned}
S &= 0.00 \pm 0.10 \\
T &= -0.56 \pm 0.16 \\
U &= 0.62 \pm 0.17 \\
\epsilon_e &= 0.0049 \pm 0.0018 \\
\epsilon_\mu &= 0.0027 \pm 0.0014
\end{aligned}
$$

$\chi^2 = 0.3/d.o.f.$

Five Parameter Fit ($S, T, U, \epsilon_e, \epsilon_\mu$)



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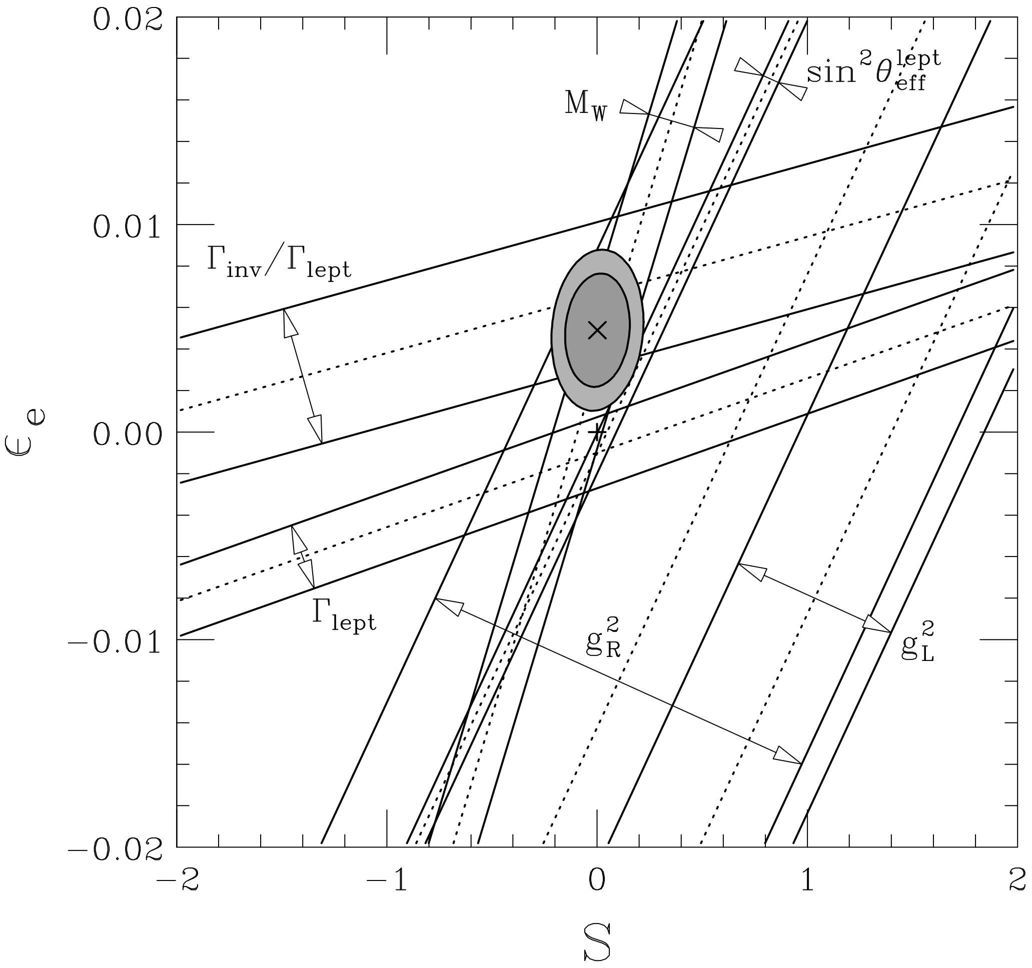

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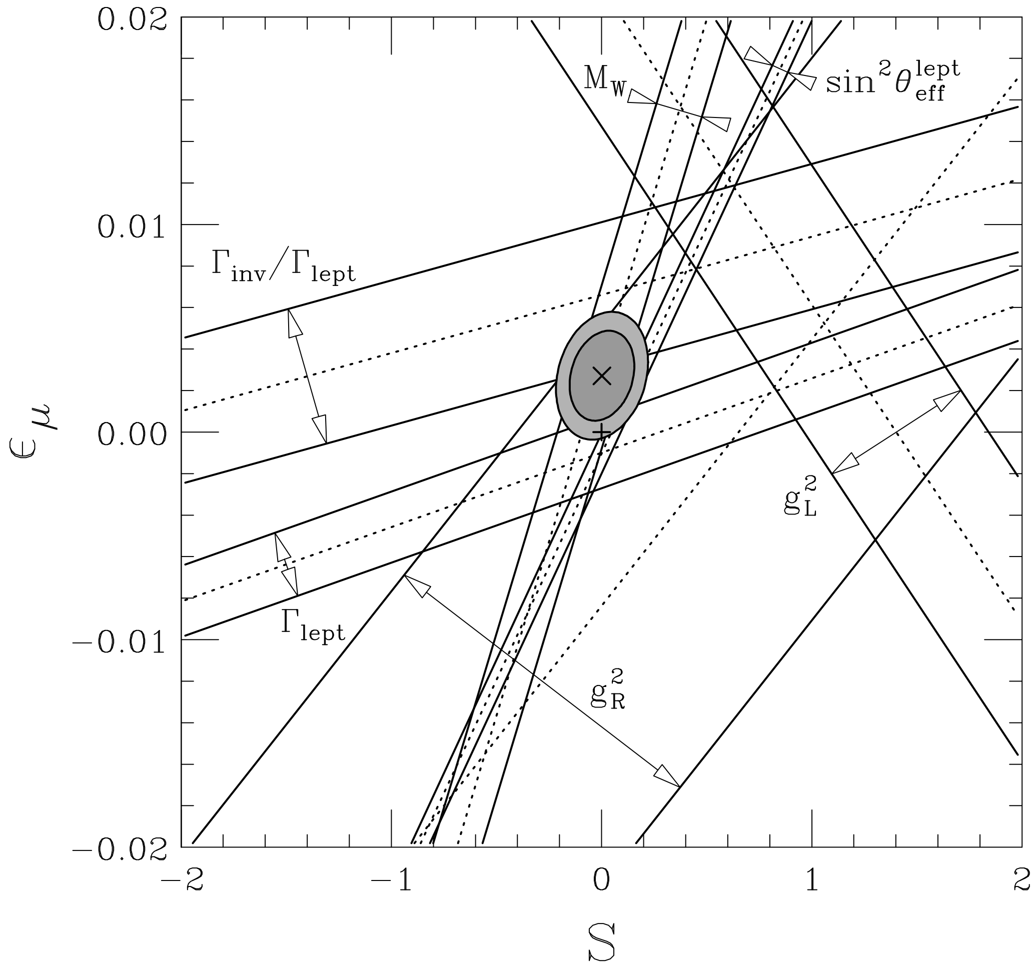

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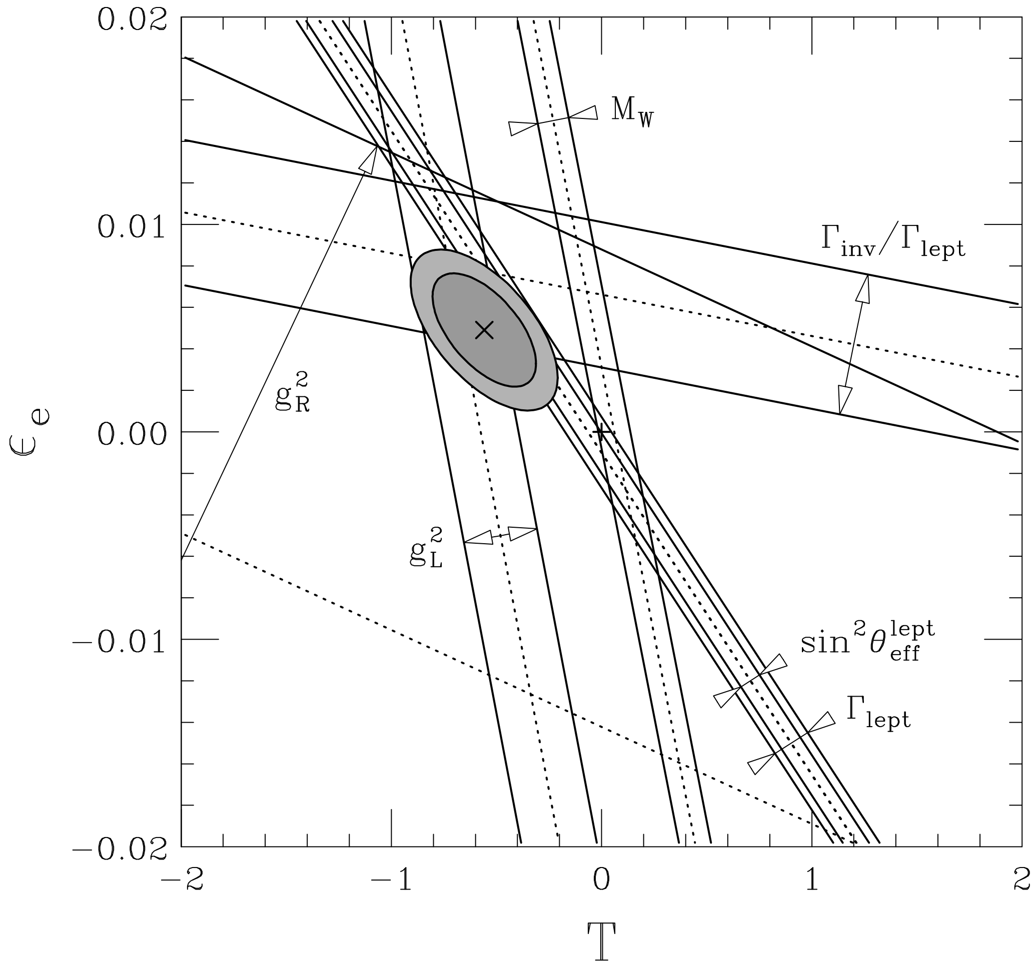

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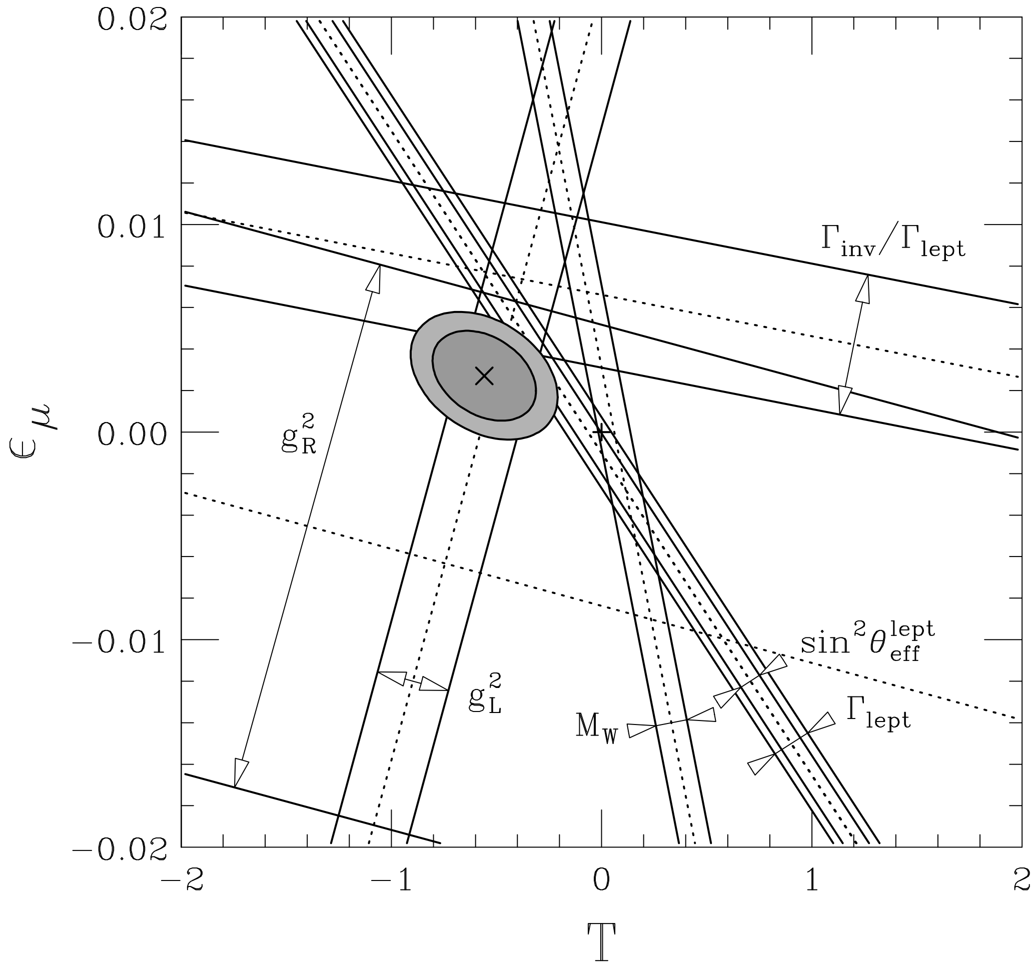

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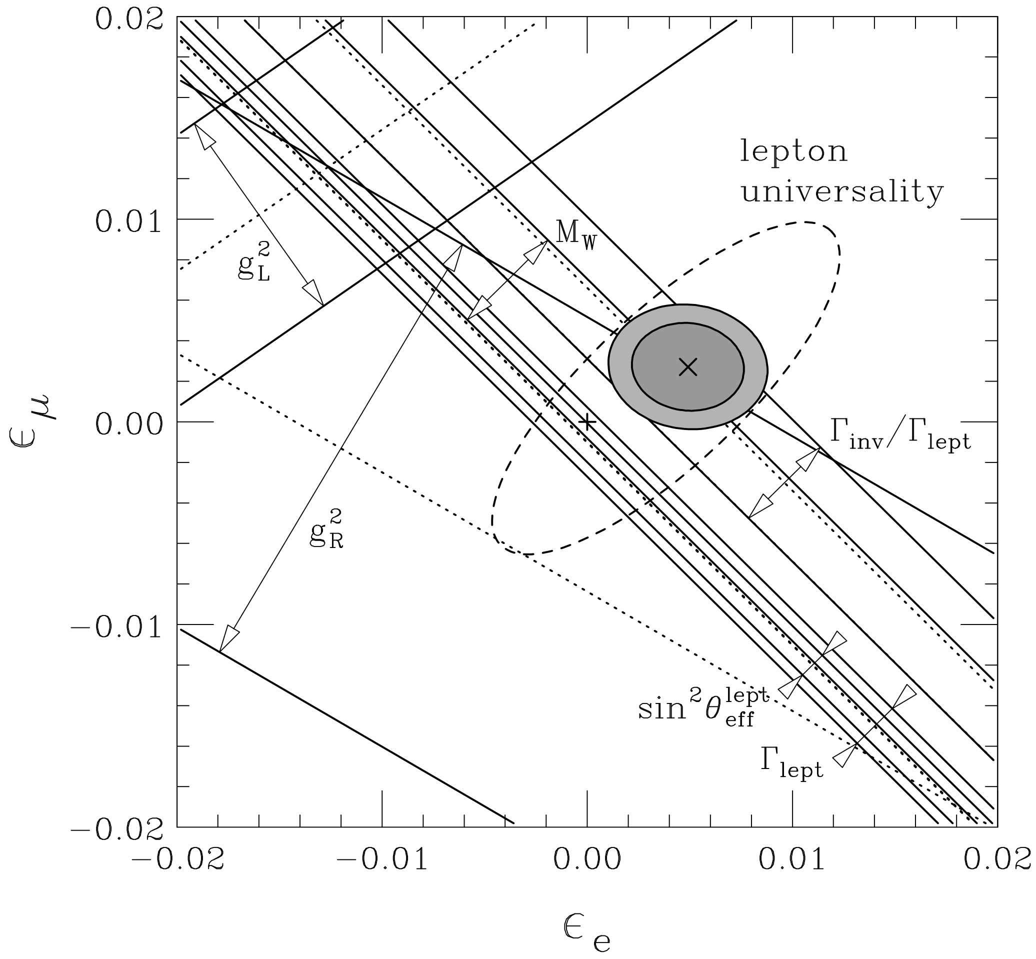

Tentative Conclusion

- It is possible to avoid the $\mu \to e\gamma$ constraint and satisfy the constraints from CC lepton universality if:

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- Subject to change with CC lepton universality data.

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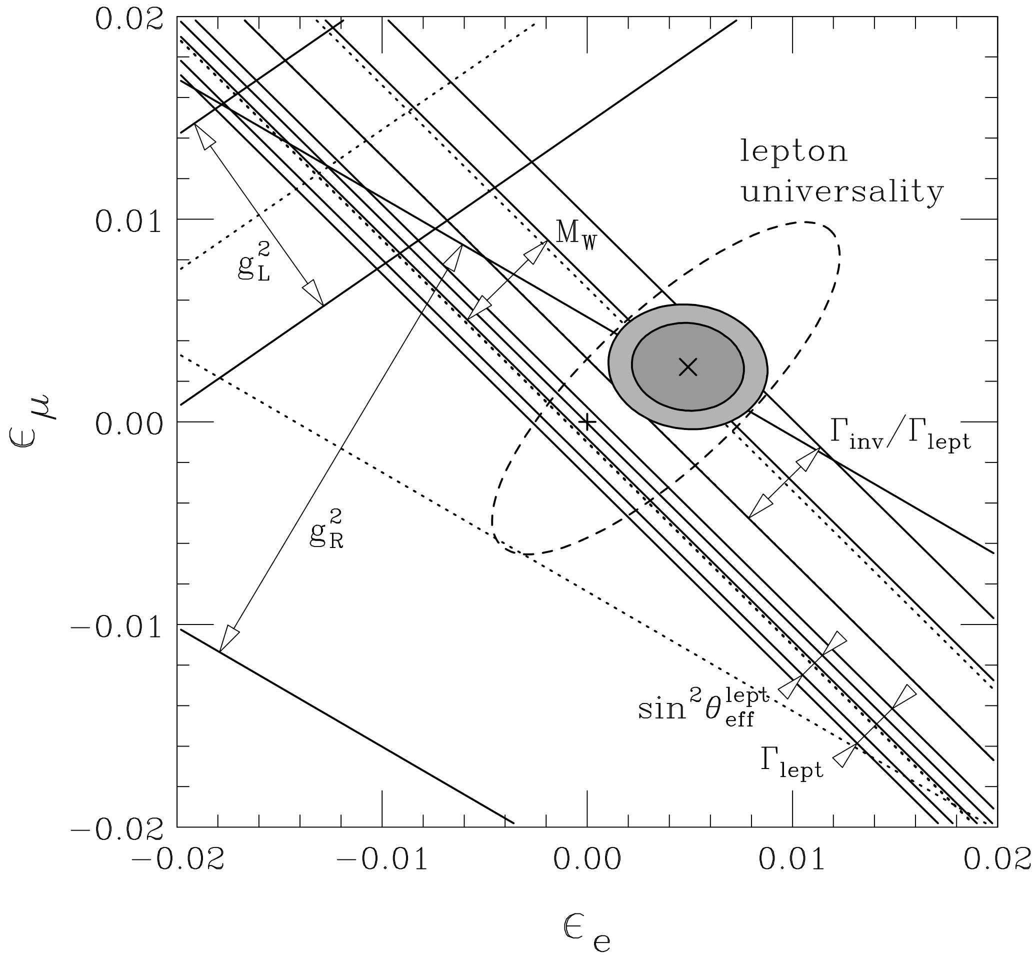
Reactor-based $\bar{\nu}e$ Scattering Experiment



Conrad, Link, Shaevitz, hep-ex/0403048

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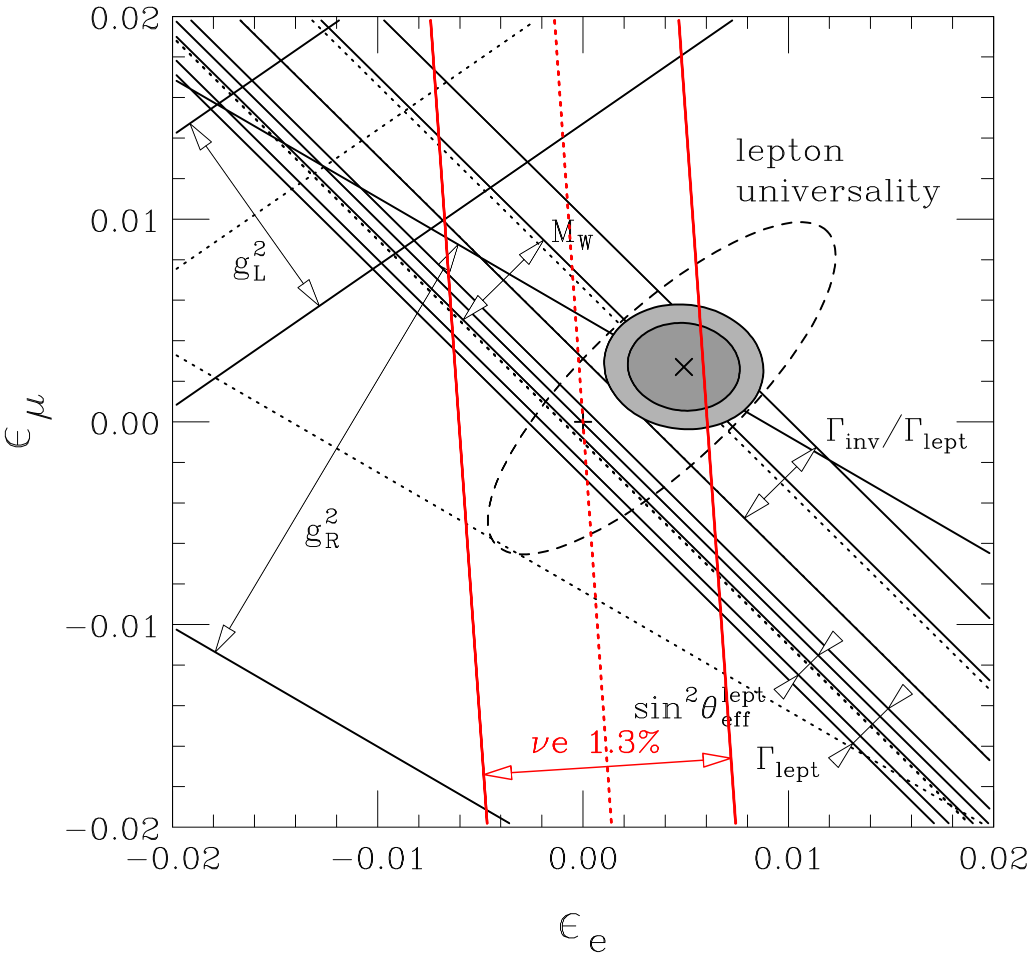

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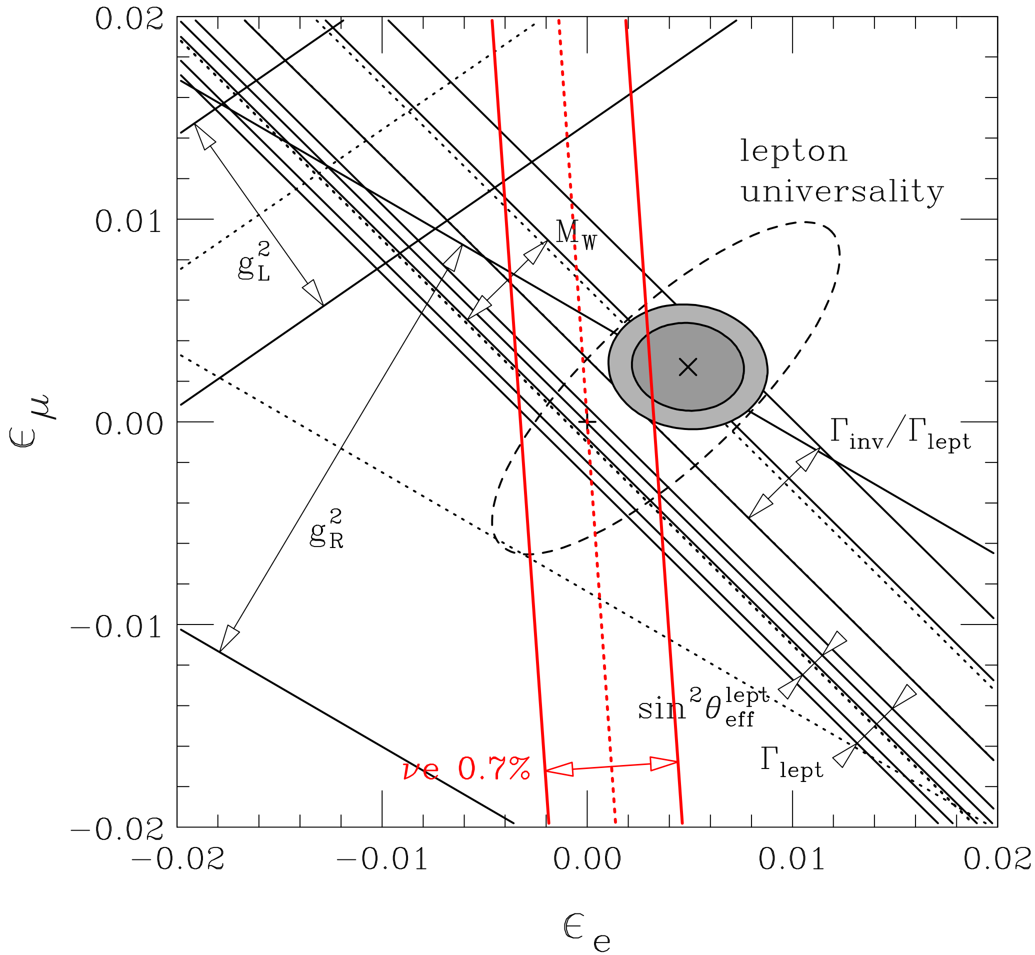

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- The CC Lepton Universality constraints from various decays are not yet consistent. Need more experiments such as accurate measurement of the $\bar{\nu}e$ scattering cross section using reactors.
- The next generation of lepton flavor violation experiments will either see a positive effect or the model is probably ruled out.