

Precision tests of unitarity in leptonic mixing

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LB, O. Fischer and J.J. van der Bij [arXiv:1310.2057] (accepted in EPL)



Outline

- 1 Introduction
- 2 Lepton unitarity violation
- 3 Data and fit
- 4 Conclusions

Introduction

LEP and several other (high and low energy) experiments delivered an impressive amount of very precise data

Assuming the SM, predictions are possible: top and Higgs masses (different degree of accuracy)

With the discovery of the Higgs boson, all parameters in the SM are fixed

⇒ No free degrees of freedom in fit to precision observables

It is universally accepted that the SM provides a satisfactory fit

However...

some anomalies: Γ_Z^{inv} , $\sin^2 \theta_{\text{eff}}^{\text{lept}}$ vs. $\sin^2 \theta_{\text{eff}}^{\text{hadr}}$, $((g - 2)_\mu)$, ...

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Introduction

Example: Γ_Z^{inv}

	Experiment	SM
$\Gamma_{\text{inv}}/\Gamma_{\text{lept}}$	5.942(16)	5.9721(2)

2σ discrepancy, deficit (similar deficit in NuTeV)

Loinaz et al. Phys.Rev. D67 (2003) 073012: postulate universal suppression $1 - \varepsilon$ in $Z\nu\nu$ coupling (also $W\ell\nu$ suppressed)

- direct reduction of $\Gamma_{\text{inv}} \propto \varepsilon$
- effect on all other observables: $G_\mu^2 = G_F^2(1 - 2\varepsilon)$, from $\mu \rightarrow e\nu_e\nu_\mu$

Result of the fit was $\varepsilon \sim \mathcal{O}(10^{-3})$, but large T parameters were also needed: perhaps a heavy SM Higgs (now excluded)

Generalisation to flavour: $G_\mu^2 = G_F^2(1 - \varepsilon_e - \varepsilon_\mu)$ [Phys.Rev. D70 (2004) 113004]

Lepton unitarity violation

What can lead to such suppression?

Mixing of active neutrinos with n sterile states Loinaz et al.

$\nu_i, i = 1, \dots, 3 + n$ mass eigenstates: PMNS matrix non-unitary

New unitary diagonalisation matrix is \mathcal{U} :

$$\begin{pmatrix} \nu_1 \\ \vdots \\ \nu_{3+n} \end{pmatrix} = \mathcal{U} \begin{pmatrix} \nu_{L_e} \\ \vdots \\ N_n \end{pmatrix}$$

such that $\mathcal{U} = U_{PMNS} \Leftrightarrow n = 0$

The amount of unitarity violation is quantified by ($\alpha, \beta = 1..3$)

$$\varepsilon_\alpha = \sum_{i>3} |\mathcal{U}_{\alpha i}|^2 = 1 - \sum_\beta |\mathcal{U}_{\alpha\beta}|^2$$

Neutrino oscillation bound: $\varepsilon \lesssim \mathcal{O}(10^{-2})$ Antusch et al., NPB 810, 369 (2009)

MEG experiment bound: off-diagonal elements of $\mathcal{U}\mathcal{U}^\dagger$ are negligible

T parameter in seesaw

Higgs boson discovered at 125 GeV, no large T parameter in SM

Large *negative* values are possible in type-I seesaw if strong cancellations in Yukawas

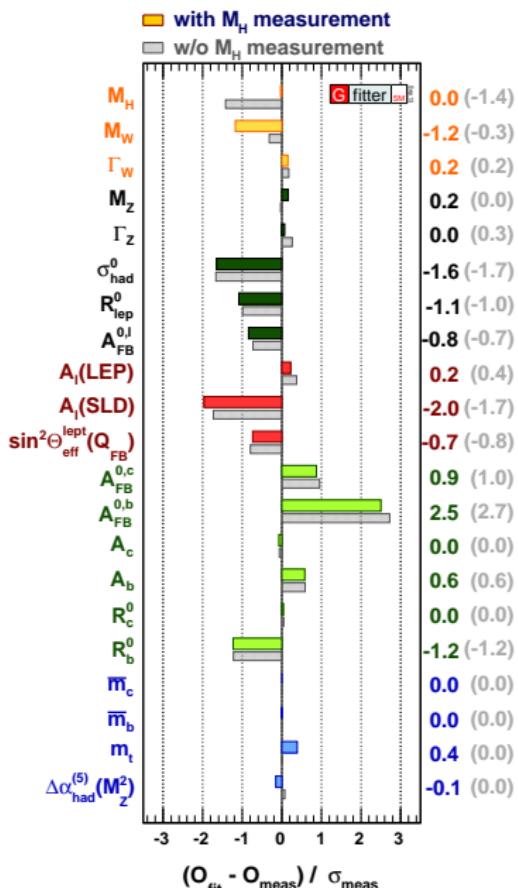
Akhmedov et al., JHEP 1305 (2013) 081

Problems:

- Lepton universality data treated only as constraints ...
- ✗ ... best fit point in contradiction with them
- Strong fine tuning to achieve cancellation ...
- ✗ ... not needed, because best fit point is for negligible T parameter

In this talk: fit to data with highest precision, EWPT and universality
T parameter included to parametrize unknown contributions

GFitter [Eur. Phys. J. C 72, 2205 (2012)]



- little impact from Higgs (M_W gets worse)
- most of measures do not matter in the fit
→ dilution of $\chi^2/d.o.f.$
- only positive pull from $A_{FB}^{0,b} \sim \sin^2 \theta_{\text{eff}}^{\text{hadr}}$

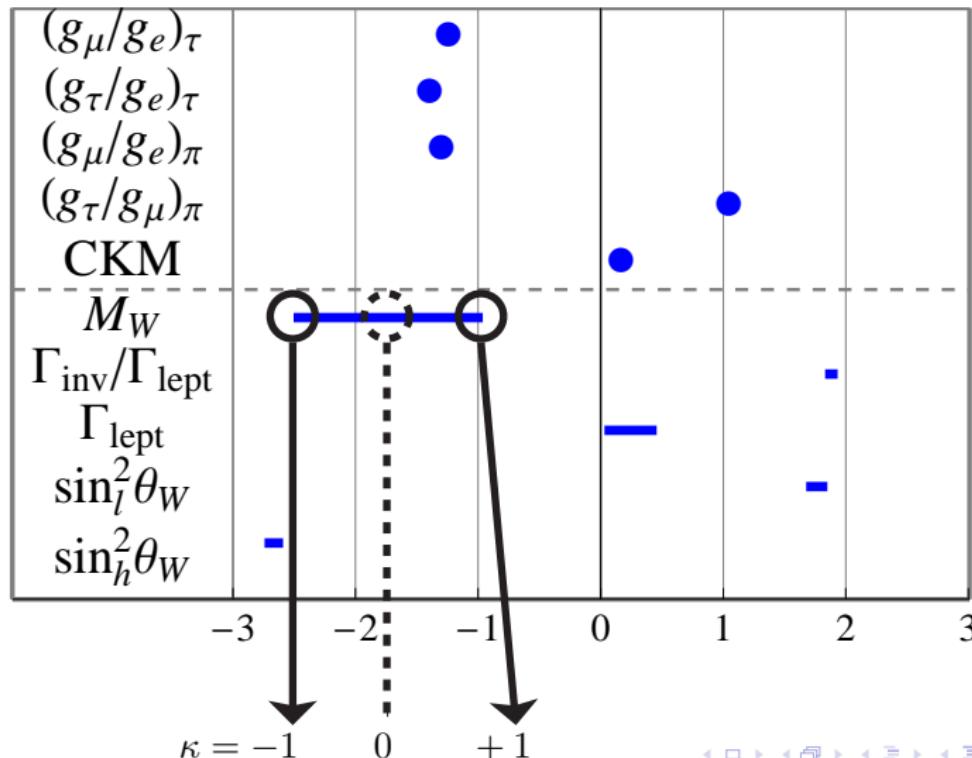
Data

We are after $\mathcal{O}(10^{-3})$ effect, we need measures with comparable accuracy

Observable	Experiment	SM
$(g_\mu/g_e)_\tau$	1.0020(16)	1.0
$(g_\tau/g_e)_\tau$	1.0029(21)	1.0
$(g_\mu/g_e)_\pi$	1.0021(16)	1.0
$(g_\tau/g_\mu)_\pi$	0.9965(33)	1.0
CKM	0.9999(6)	1.0
M_W (GeV)	80.385(15)	80.359(11)
$\Gamma_{\text{inv}}/\Gamma_{\text{lept}}$	5.942(16)	5.9721(2)
Γ_{lept} (MeV)	83.984(86)	84.005(15)
$s_{\text{eff}}^{2,\text{lept}}$	0.23113(21)	0.23150(1)
$s_{\text{eff}}^{2,\text{hadr}}$	0.23222(27)	0.23150(1)

Also: MEG ($\mu \rightarrow e\gamma$) and $\beta\beta0\nu$ bounds accounted for

$$(\sigma_{th} - \sigma_{exp} + \kappa \delta_{th})/\delta_{exp}$$



Fit of SM with T parameter

Observable	χ^2_{SM}	χ^2_T
Total χ^2	21.34	20.32
$(g_\mu/g_e)_\tau$	19.80	18.78
$(g_\tau/g_e)_\tau$	20.28	19.26
$(g_\mu/g_e)_\pi$	19.65	18.63
$(g_\tau/g_\mu)_\pi$	19.99	18.97
CKM	21.31	20.29
M_W (GeV)	19.39	19.35
$\Gamma_{\text{inv}}/\Gamma_{\text{lept}}$	17.80	16.85
Γ_{lept} (MeV)	21.36	20.19
$S_{\text{eff}}^{2,\text{lept}}$	18.25	18.14
$S_{\text{eff}}^{2,\text{hadr}}$	14.24	10.46

Table: The χ^2 for the standard model (χ^2_{SM}) and the minimum with the T parameter, evaluated *excluding* the entry on each line. The total χ^2 (considering all entries) is given for reference.

Impact of unitarity violation

$$\frac{g_\alpha}{g_\beta} = 1 - \frac{\epsilon_\alpha - \epsilon_\beta}{2}$$

$$CKM = 1 + \epsilon_\mu$$

$$\frac{M_W}{[M_W]_{\text{SM}}} = 1 + 0.11(\epsilon_e + \epsilon_\mu) + 0.0056T$$

$$\frac{\Gamma_{\text{inv}}/\Gamma_{\text{lept}}}{[\Gamma_{\text{inv}}/\Gamma_{\text{lept}}]_{\text{SM}}} = 1 - 0.76(\epsilon_e + \epsilon_\mu) - 0.67\epsilon_\tau - 0.0015T$$

$$\frac{\Gamma_{\text{lept}}}{[\Gamma_{\text{lept}}]_{\text{SM}}} = 1 + 0.60(\epsilon_e + \epsilon_\mu) + 0.0093T$$

$$\frac{\sin^2 \theta_{\text{eff}}}{[\sin^2 \theta_{\text{eff}}]_{\text{SM}}} = 1 - 0.72(\epsilon_e + \epsilon_\mu) - 0.011T$$

$$\text{BR}(\mu \rightarrow e\gamma) \propto \epsilon_e \epsilon_\mu$$

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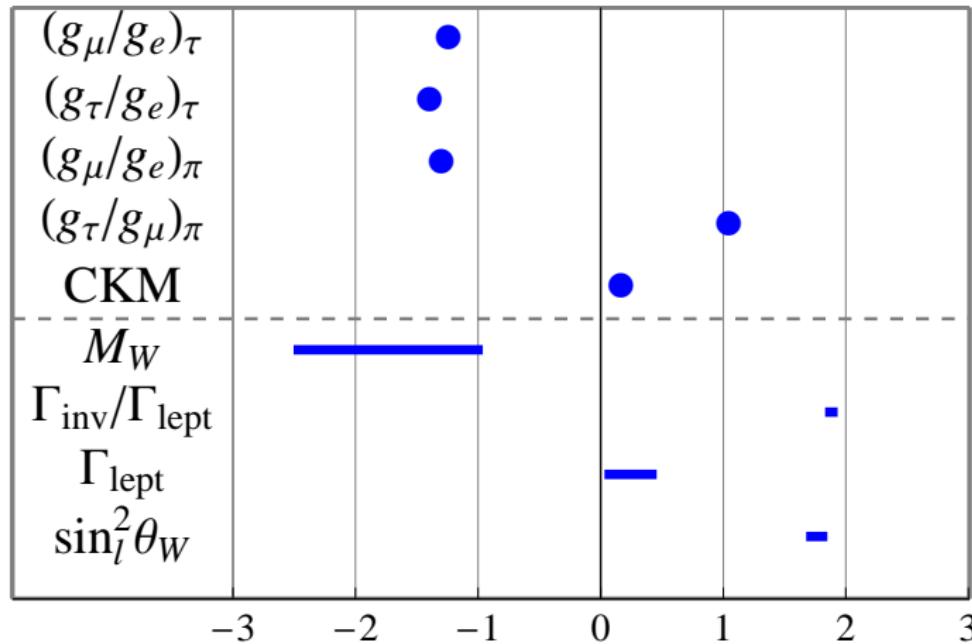
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Result of the fit

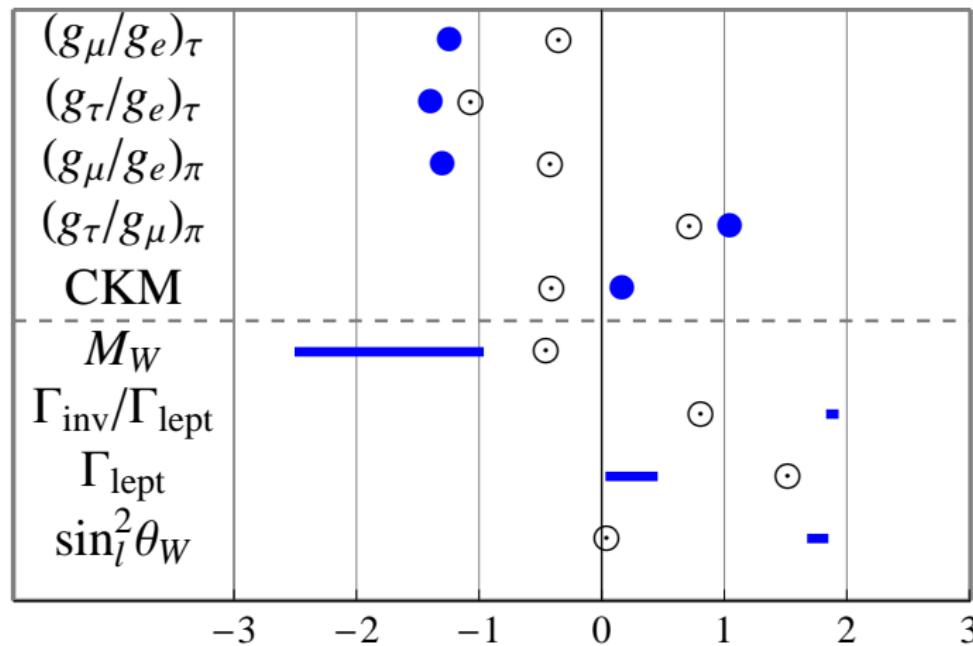
Observable	χ^2_{SM}	χ^2_T	χ^2_ϵ	$\chi^2_{\epsilon+T}$
Total χ^2	21.34	20.32	18.03	18.00
$(g_\mu/g_e)_\tau$	19.80	18.78	17.49	17.36
$(g_\tau/g_e)_\tau$	20.28	19.26	14.00	13.46
$(g_\mu/g_e)_\pi$	19.65	18.63	17.39	17.24
$(g_\tau/g_\mu)_\pi$	19.99	18.97	17.29	17.27
CKM	21.31	20.29	15.87	15.20
M_W (GeV)	19.39	19.35	16.87	11.65
$\Gamma_{\text{inv}}/\Gamma_{\text{lept}}$	17.80	16.85	15.76	15.41
Γ_{lept} (MeV)	21.36	20.19	17.55	17.54
$s_{\text{eff}}^{2,\text{lept}}$	18.25	18.14	16.15	16.03
$s_{\text{eff}}^{2,\text{hadr}}$	14.24	10.46	5.34	5.31

Table: The χ^2 for the standard model (χ^2_{SM}), the minimum with T parameter only (χ^2_T), with unitarity violation only (χ^2_ϵ), with unitarity violation and the T parameter ($\chi^2_{\epsilon+T}$), are evaluated *excluding* the entry on each line. The total χ^2 (considering all entries) is given for reference.

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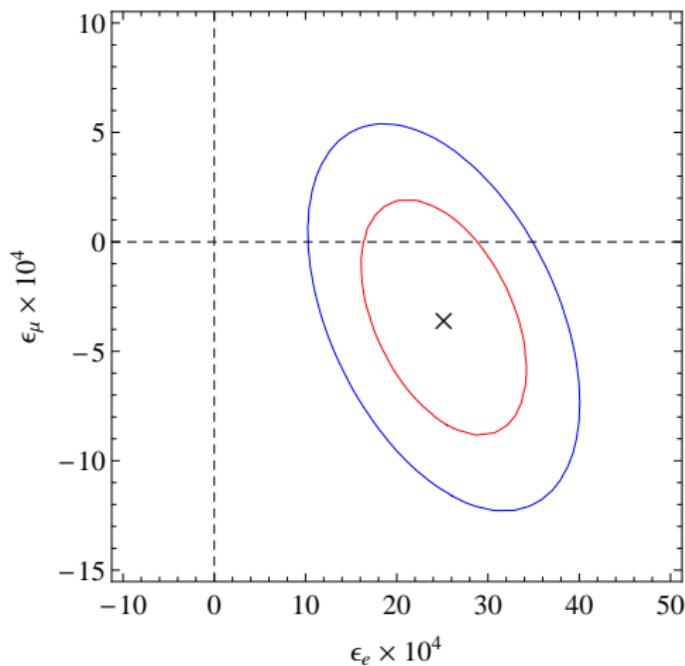
Best fit point excluding $\sin^2\theta_{\text{eff}}^{\text{hadr}}$

$$\chi^2_{\varepsilon} = 5.34$$

$$\begin{aligned}\varepsilon_e &= (25.2 \pm 8.1) \times 10^{-4} \\ \varepsilon_\mu &= (-3.4 \pm 4.8) \times 10^{-4} \\ \varepsilon_\tau &= (18.4 \pm 27.6) \times 10^{-4}\end{aligned}$$

with a correlation matrix of

$$\rho = \begin{pmatrix} 1 & -0.32 & -0.12 \\ -0.32 & 1 & -0.04 \\ -0.12 & -0.04 & 1 \end{pmatrix}$$



Conclusions

Standard model fit to data is *not* satisfactory

Hint of existence of sterile neutrinos from Γ_{inv}^Z

Slight improvement by neglecting $\sin^2\theta_{\text{eff}}^{\text{hadr}}$

Slight improvement by considering unitarity violation

Major improvement with both: $\varepsilon_e \sim \mathcal{O}(10^{-3})$ at 3σ , $\chi^2 \sim 5$
(no need for extra T parameter)

Outlook: LHC and MESA, improving by a factor two M_W and $\sin^2\theta_{\text{eff}}$
assuming the same central values $\rightarrow 5.3\sigma$ effect