Global Fit to Modified Neutrino Couplings and the V_{us}/V_{ud} Problem

Antonio Coutinho[1], Andreas Crivellin[1,2], Claudio Andrea Manzari[1,2]

[1]Paul Sherrer Institute, [2]University of Zurich

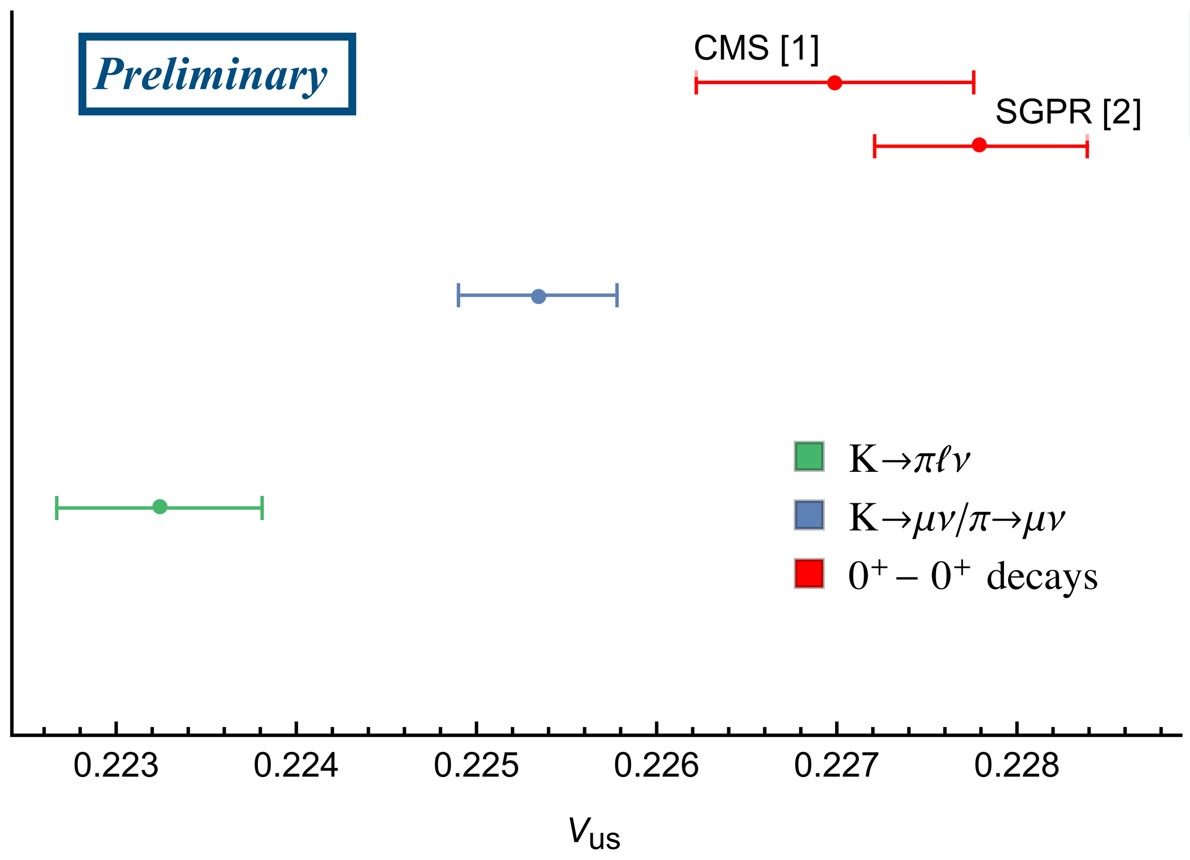

Figure I. Tension in the V_{us} measurements from 3 different processes: $K \to \pi\mu\nu$, $\frac{K\to\mu\nu}{\pi\to\mu\nu}$ and super-allowed β transitions

1. Abstract

Modified couplings of neutrinos to SM gauge bosons can be generated via higher dimensional operators. The modified couplings enter directly in $Z \to \nu\nu$ and $W \to \ell\nu$ and indirectly in $Z \to \ell^+\ell^-$. In addition they enter in all low energy observables involving neutrinos, like τ, μ and meson decays. Here, K and π decays are the most relevant due to their exquisite experimental and theoretical precision, while the uncertainties in B are still too large to give relevant bounds. There are, not only, stringent bounds from $K \to \mu\nu / K \to e\nu$ and $\pi \to \mu\nu/\pi \to e\nu$ but also interesting discrepancies between different determinations of V_{us} and V_{ud} from K decays and super-allowed β decays. In particular there is a tension between the following measurements:

- V_{us} from $K \to \pi\ell\nu$,
- V_{us}/V_{ud} from $K \to \ell\nu/\pi \to \ell\nu$,
- V_{us} from $0^+ - 0^+$ transitions,

as shown in Figure I. From this discussion it is clear that a global fit to all these data, reported in Table I, is required to asses consistently the impact of modified neutrino couplings.

Observable	Measurement
M_W [GeV]	80.379 ± 0.012
$N_\nu^{\rm exp} = (1+\varepsilon_{ee})^2 + (1+\varepsilon_{\mu\mu})^2 + (1+\varepsilon_{\tau\tau})^2$	2.9840 ± 0.0082
Γ_Z [GeV]	2.4952 ± 0.0023
σ_h^0 [nb]	41.541 ± 0.037
g_V^ℓ	-0.03783 ± 0.00041
g_A^ℓ	-0.50123 ± 0.00026
$\frac{K\to\mu\nu}{K\to e\nu} \simeq \lvert 1+\frac{1}{2}\varepsilon_{\mu\mu} - \frac{1}{2}\varepsilon_{ee}\rvert$	0.9978 ± 0.0020
$\frac{\pi\to\mu\nu}{\pi\to e\nu} \simeq \lvert 1+\frac{1}{2}\varepsilon_{\mu\mu} - \frac{1}{2}\varepsilon_{ee}\rvert$	1.0021 ± 0.0016
$\frac{\tau\to\mu\nu\bar\nu}{\tau\to e\nu\bar\nu} \simeq \lvert 1+\frac{1}{2}\varepsilon_{\mu\mu} - \frac{1}{2}\varepsilon_{ee}\rvert$	1.0018 ± 0.0014
$\frac{K\to\pi\mu\bar\nu}{K\to\pi e\bar\nu} \simeq \lvert 1+\frac{1}{2}\varepsilon_{\mu\mu} - \frac{1}{2}\varepsilon_{ee}\rvert$	1.0010 ± 0.0025
$\frac{W\to\mu\bar\nu}{W\to e\bar\nu} \simeq \lvert 1+\frac{1}{2}\varepsilon_{\mu\mu} - \frac{1}{2}\varepsilon_{ee}\rvert$	0.996 ± 0.010
$\frac{\tau\to e\nu\bar\nu}{\mu\to e\bar\nu\nu} \simeq \lvert 1+\frac{1}{2}\varepsilon_{\tau\tau} - \frac{1}{2}\varepsilon_{\mu\mu}\rvert$	1.0011 ± 0.0015
$\frac{\tau\to\pi\nu}{\pi\to\mu\bar\nu} \simeq \lvert 1+\frac{1}{2}\varepsilon_{\tau\tau} - \frac{1}{2}\varepsilon_{\mu\mu}\rvert$	0.9962 ± 0.0027
$\frac{\tau\to K\nu}{K\to\mu\bar\nu} \simeq \lvert 1+\frac{1}{2}\varepsilon_{\tau\tau} - \frac{1}{2}\varepsilon_{\mu\mu}\rvert$	0.9858 ± 0.0070
$\frac{W\to\tau\bar\nu}{W\to\mu\bar\nu} \simeq \lvert 1+\frac{1}{2}\varepsilon_{\tau\tau} - \frac{1}{2}\varepsilon_{\mu\mu}\rvert$	1.034 ± 0.0013
$\frac{\tau\to\mu\nu\bar\nu}{\mu\to e\nu\bar\nu} \simeq \lvert 1+\frac{1}{2}\varepsilon_{\tau\tau} - \frac{1}{2}\varepsilon_{ee}\rvert$	1.0030 ± 0.0015
$\frac{W\to\tau\bar\nu}{W\to e\bar\nu} \simeq \lvert 1+\frac{1}{2}\varepsilon_{\tau\tau} - \frac{1}{2}\varepsilon_{ee}\rvert$	1.031 ± 0.0013
$\lvert V_{us}^{K\to\mu\nu}\rvert \simeq \lvert V_{us}^{\mathcal{L}}(1-\frac{1}{2}\varepsilon_{ee})\rvert$	0.2255 ± 0.0007
$\lvert V_{us}^{K_L\to\pi\mu\nu}\rvert \simeq \lvert V_{us}^{\mathcal{L}}(1-\frac{1}{2}\varepsilon_{ee})\rvert$	0.2233 ± 0.0007
$\lvert V_{us}^{K^\pm\to\pi\mu\nu}\rvert \simeq \lvert V_{us}^{\mathcal{L}}(1-\frac{1}{2}\varepsilon_{ee})\rvert$	0.2238 ± 0.0012
$\lvert V_{us}/V_{ud}\rvert^{K/\pi\to\mu\nu}$	0.2313 ± 0.0005
$\lvert V_{ud}^\beta\rvert_{\rm CMS} \simeq \sqrt{1-\lvert V_{us}^{\mathcal{L}}\rvert^2}\lvert 1-\frac{1}{2}\varepsilon_{\mu\mu}\rvert$	0.97389 ± 0.00018
$\lvert V_{ud}^\beta\rvert_{\rm SGPR} \simeq \sqrt{1-\lvert V_{us}^{\mathcal{L}}\rvert^2}\lvert 1-\frac{1}{2}\varepsilon_{\mu\mu}\rvert$	0.97370 ± 0.00014

Table I. Observables of the fit

2. Coupling Modifications

At the dimension 6 level, there is just one operator which only modifies the couplings of gauge bosons to neutrinos but does not affect other couplings [3,4]:

$$\bar{L}_i\gamma_\mu\tau^I L_j H^\dagger i\tau^I H \qquad \tau^I = \left(1, -\sigma_1, -\sigma_2, -\sigma_3\right)$$

where σ's are the Pauli matrices. The Wilson coefficient of this operator leads to modifications of neutrino couplings to gauge bosons, parametrised as follows:

$$\frac{-ig_2}{\sqrt{2}}\bar\ell_i\gamma^\mu P_L\nu_j W_\mu \Rightarrow \frac{-ig_2}{\sqrt{2}}\bar\ell_i\gamma^\mu P_L\nu_j W_\mu\left(\delta_{ij}+\frac{1}{2}\varepsilon_{ij}\right)$$

$$\frac{-ig_2}{2}\bar\nu_i\gamma^\mu P_L\nu_j Z_\mu \Rightarrow \frac{-ig_2}{2}\bar\nu_i\gamma^\mu P_L\nu_j Z_\mu\left(\delta_{ij}+\varepsilon_{ij}\right)$$

Parameter	Prior
$G_F^{\rm exp}$ [GeV^{-2}]	$1.1663787(6) \times 10^{-5}$
α	$7.2973525664(17) \times 10^{-3}$
$\alpha_s(M_Z)$	$0.1181(11) \times 10^{-3}$
M_Z [GeV]	91.1876 ± 0.0021
m_H [GeV]	125.16 ± 0.13
$m_{t,\rm pole}$ [GeV]	173.08 ± 0.33
$V_{us}^{\mathcal{L}}$	0.225 ± 0.010
ε_{ee}	0.00 ± 0.05
$\varepsilon_{\mu\mu}$	0.00 ± 0.05
$\varepsilon_{\tau\tau}$	0.00 ± 0.05

Table II. Parameters of the fit

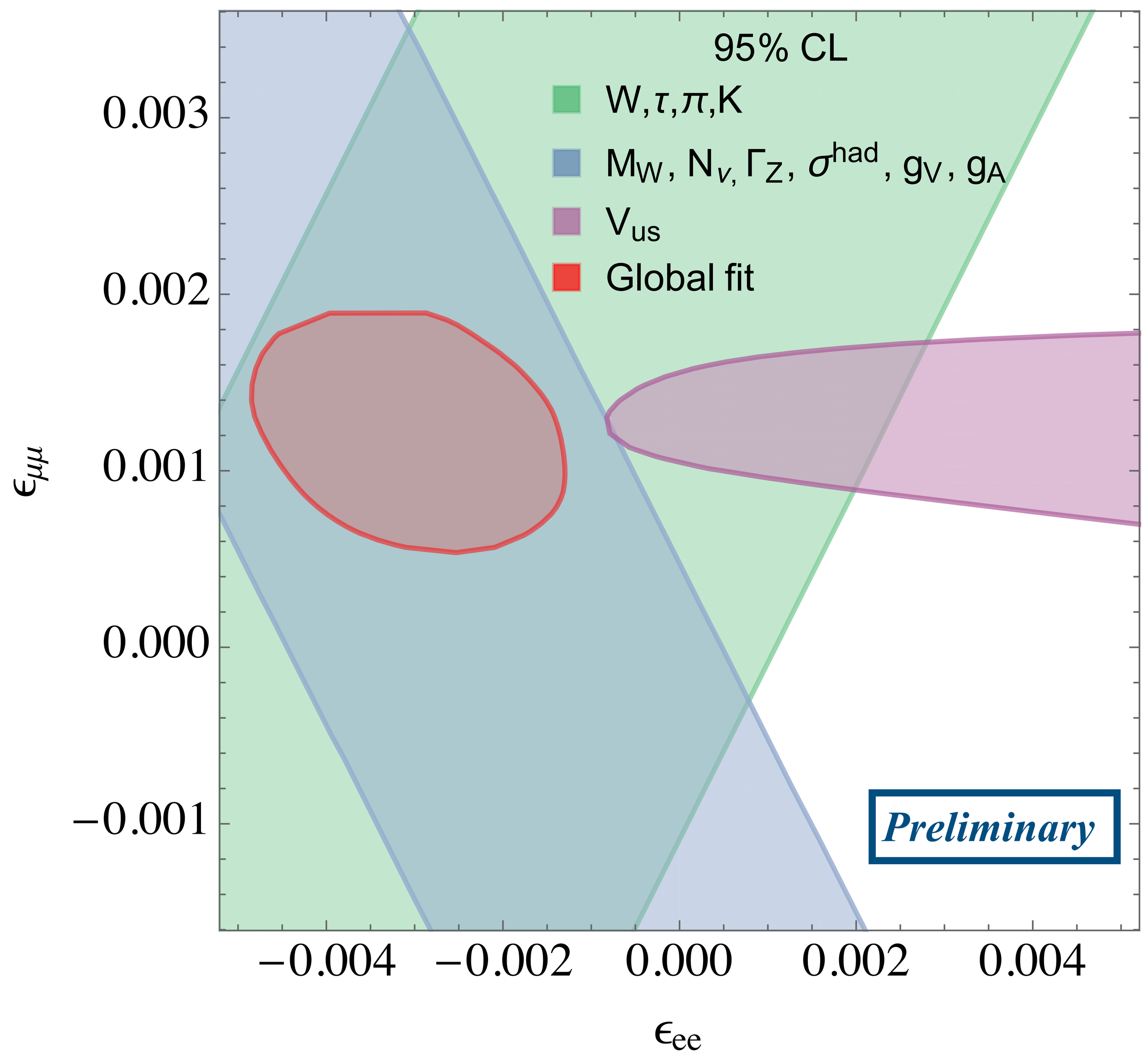

Figure II. ε_{ee} vs $\varepsilon_{\mu\mu}$ Fit

3. Analysis & Results

We perform the analysis in the Bayesian framework.To accomplish such endeavour, we have adopted the publicly available HEPfit package [5], whose Markov Chain Monte Carlo determination of posteriors is powered by the Bayesian Analysis Toolkit (BAT). Employing The Metropolis-Hastings algorithm implemented in BAT to sample from the desired distribution, our MCMC runs involved 6 chains with a total of 2 million events per chain. **We find more than 4 sigma preference for NP in neutrino couplings to SM gauge bosons.** This, can be seen in Figure II and Figure III, and strongly motivates the investigation of NP models which could give rise to such modified couplings.

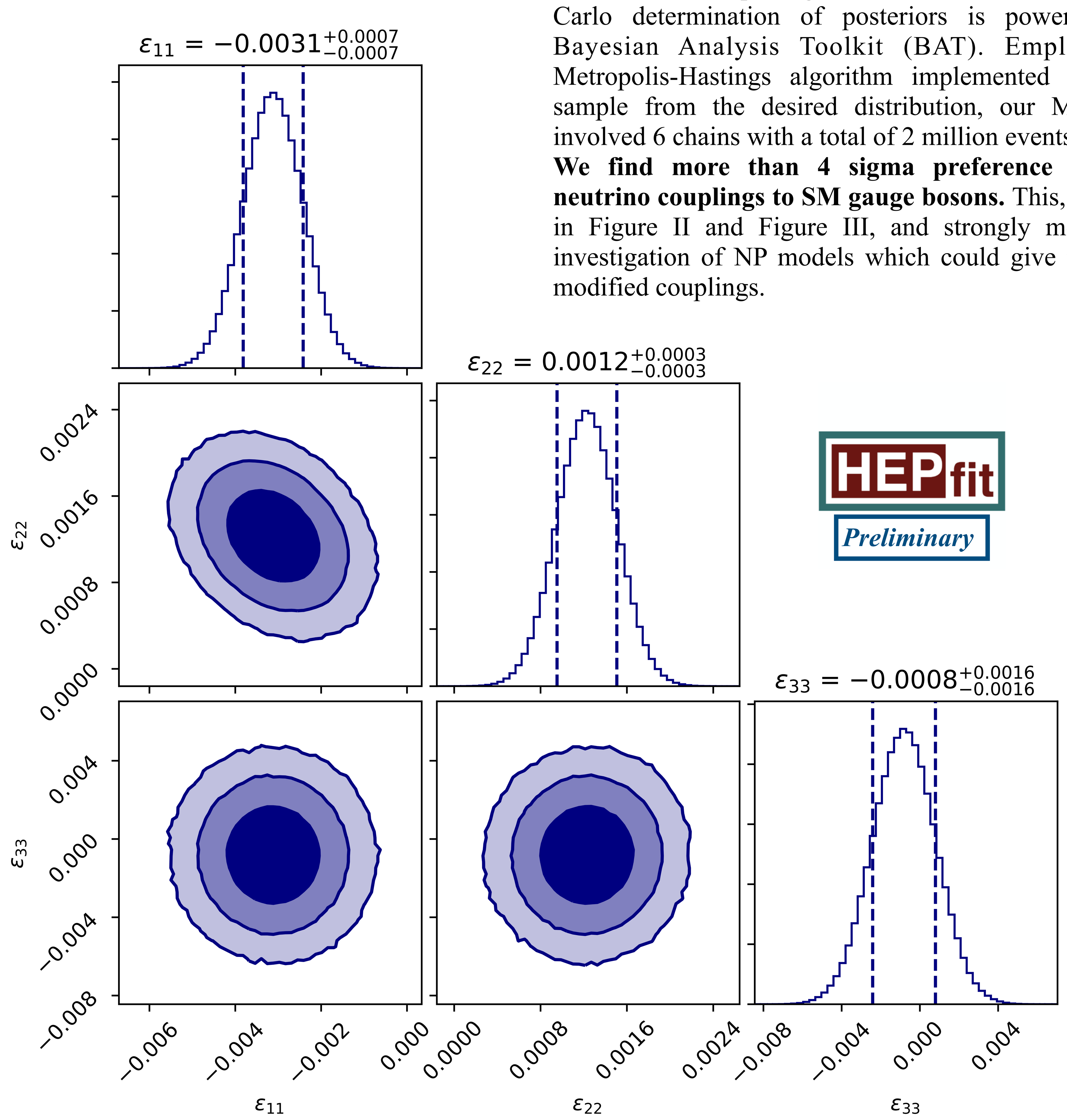

Figure III. Global Fit

Contact

Claudio Andrea Manzari
UZH & PSI
Email: claudioandrea.manzari@physik.uzh.ch
Phone: +393472693146

References

1. A. Czarnecki, W. J. Marciano, and A. Sirlin, Phys. Rev. D100, 073008 (2019), arXiv:1907.06737.
2. C. Y. Seng, M. Gorchtein, and M. J. Ramsey-Musolf,Phys. Rev. D100, 013001 (2019), arXiv:1812.03352.
3. W. Buchmuller and D. Wyler, Nucl. Phys. B268, 621(1986).
4. B. Grzadkowski, M. Iskrzynski, M. Misiak, and J.Rosiek, JHEP 10, 085 (2010), arXiv:1008.4884
5. J. de Blas et al., (2019), arXiv:1910.14012.