Overview of Non-Standard Neutrino Interactions

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Introduction: NSI

Generic new physics affecting ν oscillations can be parameterized as 4-fermion Non-Standard Interactions:

Production or detection of a ν_β associated to a l_α

$$2\sqrt{2}G_F\varepsilon_{\alpha\beta}\left(\bar{\nu}_\beta\gamma^\mu P_L l_\alpha\right)\left(\bar{f}\gamma_\mu P_{L,R} f'\right)$$

So that $$|\nu_\alpha^s\rangle = |\nu_\alpha\rangle + \sum_{\beta=e,\mu,\tau} \varepsilon_{\alpha\beta}|\nu_\beta\rangle$$

$$\pi \rightarrow \mu + \nu_\beta \qquad n + \nu_\beta \rightarrow p + l_\alpha$$

Y. Grossman hep-ph/9507344

Direct bounds on prod/det NSI

$$2\sqrt{2}G_F\varepsilon^{ud}_{\alpha\beta}\left(\bar{l}_\beta\gamma^\mu P_L\nu_\alpha\right)\left(\bar{u}\gamma_\mu P_{L,R}d\right)$$

$$2\sqrt{2}G_F\varepsilon^{\mu e}_{\alpha\beta}\left(\bar{\mu}\gamma^\mu P_L\nu_\beta\right)\left(\bar{\nu}_\alpha\gamma_\mu P_L e\right)$$

$$\left|\varepsilon^{ud}\right| < \begin{pmatrix} 0.041 & 0.025 & 0.041 \\ 0.026 & 0.078 & 0.013 \\ 0.12 & 0.013 & 0.13 \end{pmatrix}$$

$$\left|\varepsilon^{\mu e}\right| < \begin{pmatrix} 0.025 & 0.03 & 0.03 \\ 0.025 & 0.03 & 0.03 \\ 0.025 & 0.03 & 0.03 \end{pmatrix}$$

bounds order $\sim 10^{-2}$ from comparisons of measurements of G_F:
μ, τ, π decays, CKM universality, $M_W + M_Z \ldots$

C. Biggio, M. Blennow and EFM 0907.0097

Introduction: NSI

Non-Standard ν scattering off matter can also be parameterized as 4-fermion Non-Standard Interactions:

$$2\sqrt{2}G_F\varepsilon^m_{\alpha\beta}\left(\bar{\nu}_\beta\gamma^\mu P_L\nu_\alpha\right)\left(\bar{f}\gamma_\mu P_{L,R}f\right)$$

so that $$\tilde{V}_{\mathrm{MSW}} = a_{\mathrm{CC}}\begin{pmatrix} 1+\varepsilon^m_{ee} & \varepsilon^m_{e\mu} & \varepsilon^m_{e\tau} \\ \varepsilon^{m*}_{e\mu} & \varepsilon^m_{\mu\mu} & \varepsilon^m_{\mu\tau} \\ \varepsilon^{m*}_{e\tau} & \varepsilon^{m*}_{\mu\tau} & \varepsilon^m_{\tau\tau} \end{pmatrix}$$

$\nu_\alpha \longrightarrow \nu_\beta$ in matter $f = e, u, d$

Direct bounds on matter NSI

If matter NSI are uncorrelated to production and detection direct bounds are mainly from ν scattering off e and nuclei

$$2\sqrt{2}G_F\varepsilon^m_{\alpha\beta}\left(\bar{\nu}_\beta\gamma^\mu P_L\nu_\alpha\right)\left(\bar{f}\gamma_\mu P_{L,R} f\right)$$

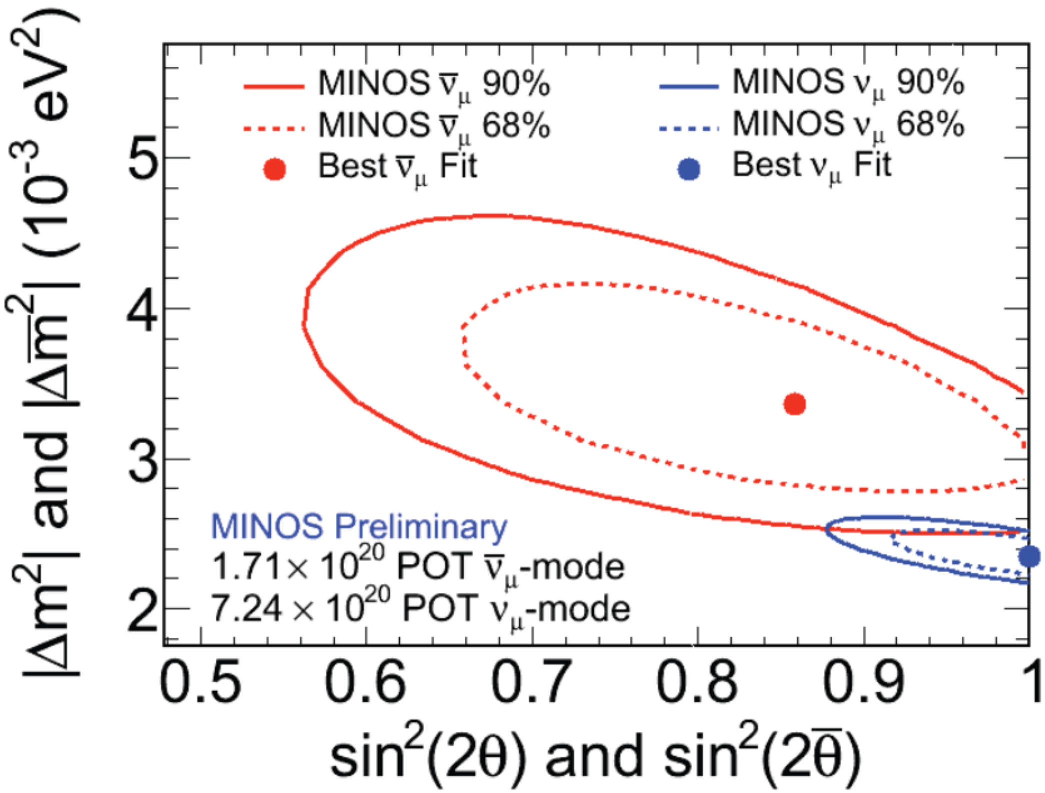
$$\left|\varepsilon^e_m\right| < \begin{pmatrix} 0.14 & 0.1 & 0.44 \\ 0.1 & 0.03 & 0.1 \\ 0.44 & 0.1 & 0.5 \end{pmatrix} \quad \left|\varepsilon^u_m\right| < \begin{pmatrix} 1 & 0.05 & 0.5 \\ 0.05 & 0.008 & 0.05 \\ 0.5 & 0.05 & 3 \end{pmatrix} \quad \left|\varepsilon^d_m\right| < \begin{pmatrix} 0.6 & 0.05 & 0.5 \\ 0.05 & 0.015 & 0.05 \\ 0.5 & 0.05 & 6 \end{pmatrix}$$

Rather weak bounds…

…can they be saturated avoiding additional constraints?

S. Davidson, C. Peña garay, N. Rius and A. Santamaria hep-ph/0302093
J. Barranco, O. G. Miranda, C. A. Moura and J. W. F. Valle hep-ph/0512195
J. Barranco, O. G. Miranda, C. A. Moura and J. W. F. Valle 0711.0698

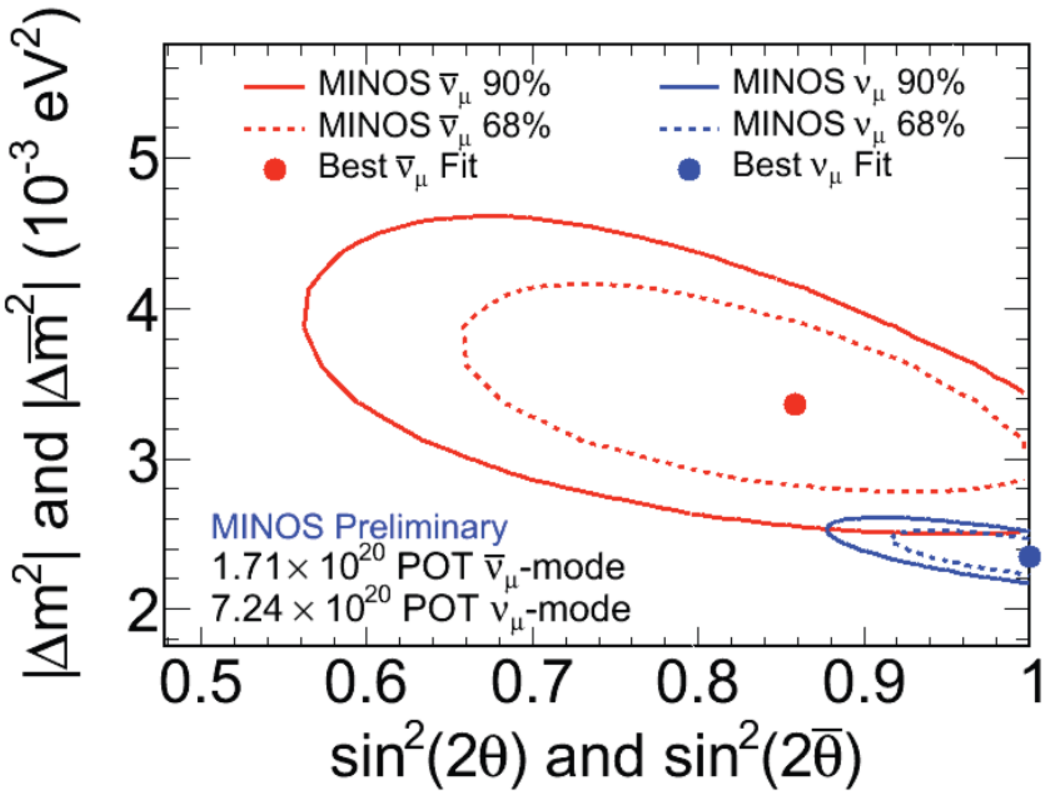
MINOS and LSND/MiniBooNE via NSI



Tension between MINOS nu and antinu data

P. Adamson et al, MINOS collaboration 1104.0344

MINOS and LSND/MiniBooNE via NSI



Can be accommodated with matter NSI

$\varepsilon_{\mu\tau} \sim 0.4$

or detection NSI

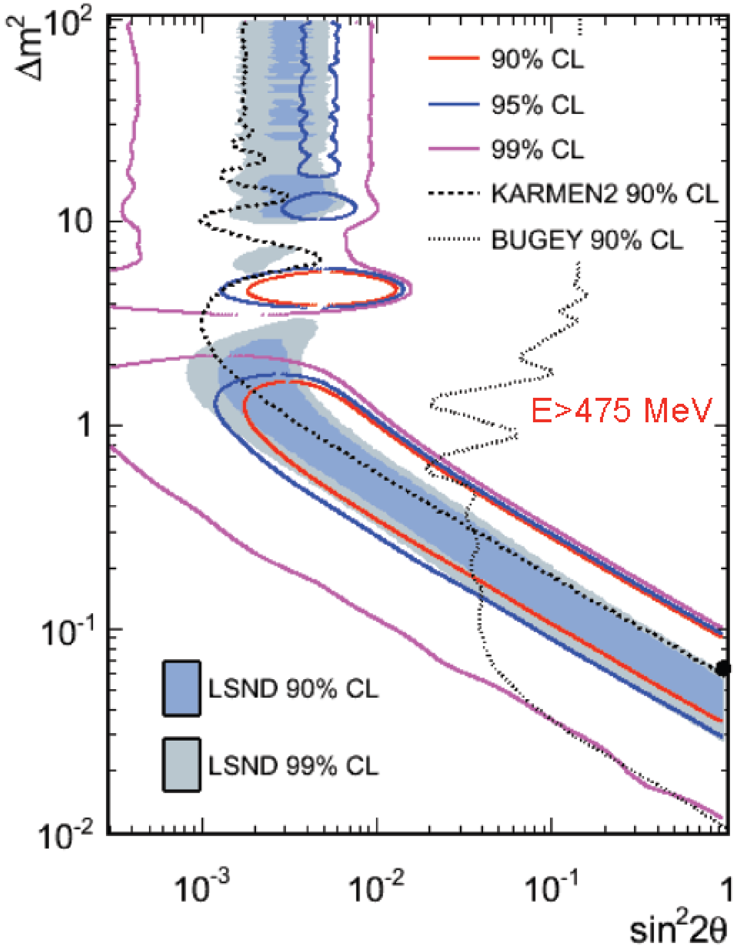
$\varepsilon_{\mu\tau} \sim 0.1$

W. A. Mann et al 1006.5720
J. Kopp et al 1009.0014

Tension between MINOS nu and antinu data

P. Adamson et al, MINOS collaboration 1104.0344

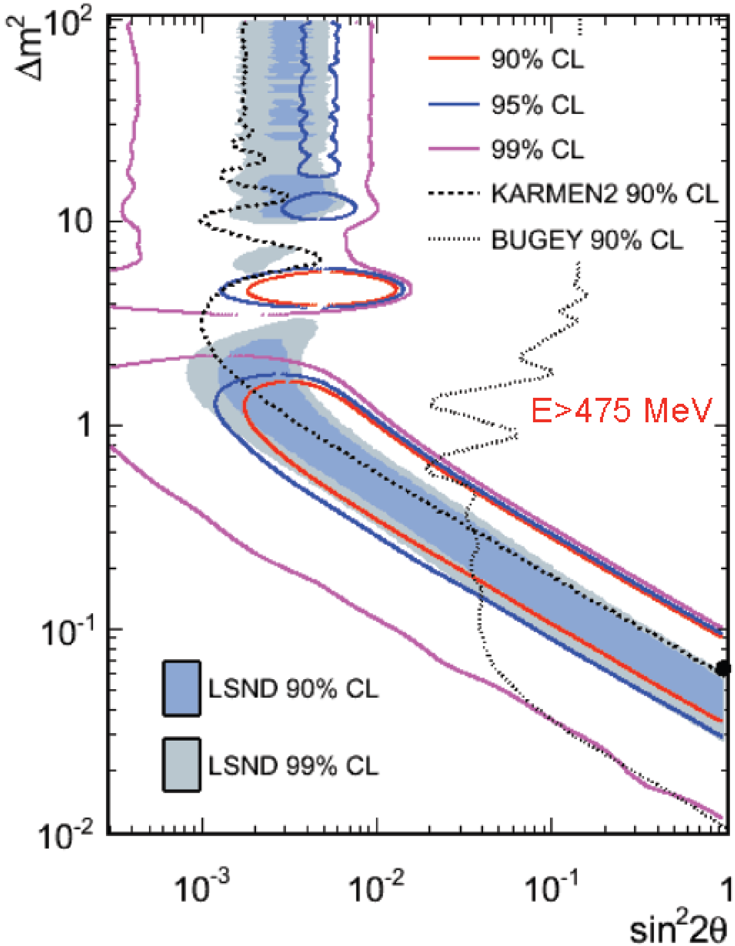
MINOS and LSND/MiniBooNE via NSI



Agreement between MiniBooNE and LSND antinu data

A. A. Aguilar-Arevalo et al, MiniBooNE collaboration, 1007.1150

MINOS and LSND/MiniBooNE via NSI



Can be accommodated with production/detection NSI + sterile neutrinos

$\varepsilon_{e\mu} \sim 0.01$

E. Akhmedov and T. Schwetz 1007.4171

Agreement between MiniBooNE and LSND antinu data

A. A. Aguilar-Arevalo et al, MiniBooNE collaboration, 1007.1150

Gauge invariance

However $2\sqrt{2}G_F\varepsilon^m_{\alpha\beta}\left(\bar{\nu}_\beta\gamma^\mu P_L\nu_\alpha\right)\left(\bar{f}\gamma_\mu P_{L,R}f\right)$

is related to $2\sqrt{2}G_F\varepsilon^m_{\alpha\beta}\left(\bar{l}_\beta\gamma^\mu P_L l_\alpha\right)\left(\bar{f}\gamma_\mu P_{L,R}f\right)$

by gauge invariance and very strong bounds exist

$\varepsilon^m_{e\mu} < \sim 10^{-6}$

$\varepsilon^m_{e\tau} < \sim 10^{-4}$

$\varepsilon^m_{\mu\tau} < \sim 10^{-4}$

$\mu \to e\,\gamma$
$\mu \to e$ in nuclei
τ decays

S. Bergmann et al. hep-ph/0004049
Z. Berezhiani and A. Rossi hep-ph/0111147
S. Antusch, M. Blennow, EFM and T. Ota, 1005.0756

Large NSI?

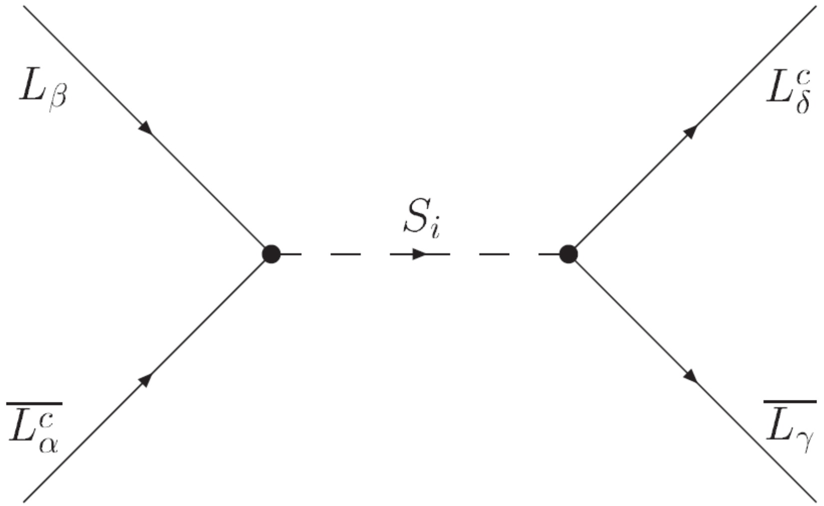
Search for gauge invariant SM extensions parametrized by d=6 or higher effective operators satisfying:

- The Higgs Mechanism is responsible for EWSB
- NSI are generated at tree level
- 4-charged fermion ops not generated at the same level or cancelled among different contributions

S. Antusch, J. Baumann and EFM 0807.1003
B. Gavela, D. Hernández, T. Ota and W. Winter 0809.3451
S. Antusch, M. Blennow, EFM and T. Ota, 1005.0756

Large NSI?

At d=6 only one direct possibility: charged scalar singlet



Present in Zee model or R-parity violating SUSY

$$\mathcal{L}^S_{int} = -\lambda^i_{\alpha\beta}\overline{L^c_\alpha} i\sigma_2 L_\beta S_i + \text{H.c.} = \lambda^i_{\alpha\beta} S_i (\overline{\ell^c_\alpha} P_L \nu_\beta - \overline{\ell^c_\beta} P_L \nu_\alpha) + \text{H.c.}$$

$$\mathcal{L}^{d=6,as}_{NSI} = c^{d=6,as}_{\alpha\beta\gamma\delta}\left(\overline{L^c_\alpha} i\sigma_2 L_\beta\right)\left(\overline{L_\gamma} i\sigma_2 L^c_\delta\right) \qquad \varepsilon^{m,e_L}_{\alpha\beta} = \sum_i \frac{\lambda^i_{e\beta}\lambda^{i*}_{e\alpha}}{\sqrt{2} G_F m^2_{S_i}}$$

M. Bilenky and A. Santamaria hep-ph/9310302

Large NSI?

Since $\lambda_{\alpha\beta} = -\lambda_{\beta\alpha}$ only $\varepsilon_{\mu\mu}$, $\varepsilon_{\mu\tau}$ and $\varepsilon_{\tau\tau} \neq 0$

Very constrained:

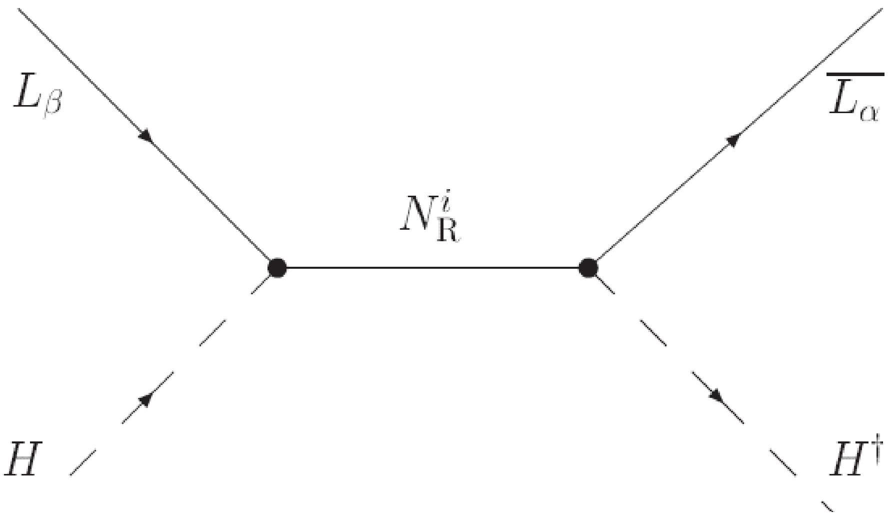
$$
\begin{aligned}
|\varepsilon^{m,e_L}_{\mu\mu}| &< 8.2 \cdot 10^{-4} \\
|\varepsilon^{m,e_L}_{\tau\tau}| &< 8.4 \cdot 10^{-3} \\
|\varepsilon^{m,e_L}_{\mu\tau}| &< 1.9 \cdot 10^{-3}
\end{aligned}
$$

$\mu \to e\,\gamma$
μ decays
τ decays
CKM unitarity

F. Cuypers and S. Davidson hep-ph/9310302
S. Antusch, J. Baumann and EFM 0807.1003

Large NSI?

At d=6 indirect way: fermion singlets



Effective Lagrangian

$$L = i\,\bar{\nu}_\alpha \partial K_{\alpha\beta} \nu_\beta + \bar{\nu}_\alpha M_{\alpha\beta} \nu_\beta - \frac{g}{\sqrt{2}}\left(W_\mu^+ \bar{l}_\alpha \gamma^\mu P_L \nu_\alpha + h.c.\right) - \frac{g}{\cos\theta_W}\left(Z_\mu \bar{\nu}_\alpha \gamma^\mu P_L \nu_\alpha + h.c.\right) + \ldots$$

Effective Lagrangian

$$L = i\bar{\nu}_\alpha \partial K_{\alpha\beta}\nu_\beta + \bar{\nu}_\alpha M_{\alpha\beta}\nu_\beta - \frac{g}{\sqrt{2}}\left(W_\mu^+ \bar{l}_\alpha \gamma^\mu P_L \nu_\alpha + h.c.\right) - \frac{g}{\cos\theta_W}\left(Z_\mu \bar{\nu}_\alpha \gamma^\mu P_L \nu_\alpha + h.c.\right) + \ldots$$

Diagonal mass and canonical kinetic terms

$$L = i\bar{\nu}_i \partial \nu_i + \bar{\nu}_i m_{ii} \nu_i - \frac{g}{\sqrt{2}}\left(W_\mu^+ \bar{l}_\alpha \gamma^\mu P_L N_{\alpha i} \nu_i + h.c.\right) - \frac{g}{\cos\theta_W}\left(Z_\mu \bar{\nu}_i \gamma^\mu P_L (N^\dagger N)_{ij} \nu_j + h.c.\right) + \ldots$$

Effective Lagrangian

$$L = i\bar{\nu}_\alpha \partial\!\!\!/ K_{\alpha\beta}\nu_\beta + \bar{\nu}_\alpha M_{\alpha\beta}\nu_\beta - \frac{g}{\sqrt{2}}\left(W_\mu^+ \bar{l}_\alpha \gamma^\mu P_L \nu_\alpha + h.c.\right) - \frac{g}{\cos\theta_W}\left(Z_\mu \bar{\nu}_\alpha \gamma^\mu P_L \nu_\alpha + h.c.\right) + \ldots$$

Diagonal mass and canonical kinetic terms

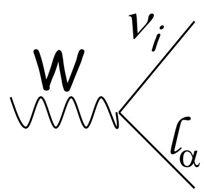
$$L = i\bar{\nu}_i \partial\!\!\!/ \nu_i + \bar{\nu}_i m_{ii}\nu_i - \frac{g}{\sqrt{2}}\left(W_\mu^+ \bar{l}_\alpha \gamma^\mu P_L N_{\alpha i}\nu_i + h.c.\right) - \frac{g}{\cos\theta_W}\left(Z_\mu \bar{\nu}_i \gamma^\mu P_L (N^\dagger N)_{ij}\nu_j + h.c.\right) + \ldots$$

$$\nu_\alpha = N_{\alpha i}\nu_i$$

N is not unitary

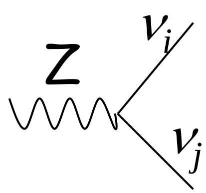
$(NN^\dagger)$ from decays

- W decays



$$\rightarrow \frac{(NN^\dagger)_{\alpha\alpha}}{\sqrt{(NN^\dagger)_{ee}}\sqrt{(NN^\dagger)_{\mu\mu}}}$$

- Invisible Z



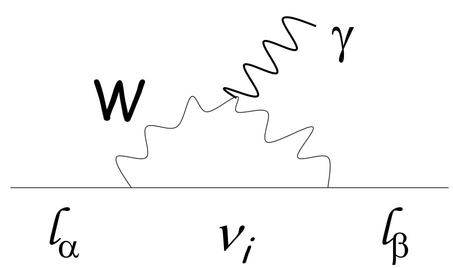
$$\rightarrow \frac{\sum_{\alpha\beta}(NN^\dagger)_{\alpha\beta}}{\sqrt{(NN^\dagger)_{ee}}\sqrt{(NN^\dagger)_{\mu\mu}}}$$

- Universality tests

$$\rightarrow \frac{(NN^\dagger)_{\alpha\alpha}}{(NN^\dagger)_{\beta\beta}}$$

Info on $(NN^\dagger)_{\alpha\alpha}$

- Rare leptons decays



Info on $(NN^\dagger)_{\alpha\beta}$

$$\rightarrow \frac{\left|(NN^\dagger)_{\alpha\beta}\right|^2}{(NN^\dagger)_{\alpha\alpha}(NN^\dagger)_{\beta\beta}}$$

After integrating out W and Z neutrino NSI induced

$(NN^\dagger)$ from decays

$$|\varepsilon| = 2\left|\delta - NN^\dagger\right| < \begin{pmatrix} 2.0\cdot 10^{-3} & 5.9\cdot 10^{-5} & 1.6\cdot 10^{-3} \\ 5.9\cdot 10^{-5} & 8.2\cdot 10^{-4} & 1.0\cdot 10^{-3} \\ 1.6\cdot 10^{-3} & 1.0\cdot 10^{-3} & 2.6\cdot 10^{-3} \end{pmatrix}$$

Experimentally

E. Nardi, E. Roulet and D. Tommasini hep-ph/9503228
D. Tommasini, G. Barenboim, J. Bernabeu and C. Jarlskog hep-ph/9503228
S. Antusch, C. Biggio, EFM, B. Gavela and J. López Pavón hep-ph/0607020
S. Antusch, J. Baumann and EFM 0807.1003

Again $\sim 10^{-3}$ bounds much more stringent than direct contraints

Ways out?

Possible loopholes of the argument to obtain large NSI:

- Interaction mediators are light and effective theory not justified: talk by Hye-Sung Lee
- NSI are generated through higher dimension operators: talk by Sacha Davidson
- NSI generated via loops
- Others?