Non-Standard Interactions in MINOS

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Outline

- Neutrino oscillations with non-standard interactions

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- The MINOS experiment

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- Outcome of simulations

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- Comments on GLoBES

Neutrino oscillations

- Effective Hamiltonian in matter

$$H_{\mathrm{fl}} = \frac{1}{2E} U \begin{pmatrix} 0 & 0 & 0 \\ 0 & \Delta m^2_{21} & 0 \\ 0 & 0 & \Delta m^2_{31} \end{pmatrix} U^\dagger + \begin{pmatrix} V_{CC} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

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- $V_{CC} = \sqrt{2}\, G_F N_e$ is the effective matter potential

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- Effective Hamiltonian in matter including NSI

$$H_{\text{fl}} = \frac{1}{2E} U \begin{pmatrix} 0 & 0 & 0 \\ 0 & \Delta m^2_{21} & 0 \\ 0 & 0 & \Delta m^2_{31} \end{pmatrix} U^\dagger$$

$$+ V_{CC} \begin{pmatrix} 1+\epsilon_{ee} & \epsilon_{e\mu} & \epsilon_{e\tau} \\ \epsilon^*_{e\mu} & \epsilon_{\mu\mu} & \epsilon_{\mu\tau} \\ \epsilon^*_{e\tau} & \epsilon^*_{\mu\tau} & \epsilon_{\tau\tau} \end{pmatrix}$$

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$\lvert\epsilon_{\mu\mu}\rvert < 0.017$	$\lvert\epsilon_{\mu\tau}\rvert < 0.013$	$\lvert\epsilon_{\tau\tau}\rvert \sim \mathrm{O}(1)$

S. Davidson *et al.*, JHEP **03**, 011 (2003), hep-ph/0302093

M. C. Gonzalez-Garcia and M. Maltoni, Phys. Rev. **D70**, 033010 (2004), hep-ph/0404085

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- $\Rightarrow \epsilon_{e\mu}$, $\epsilon_{\mu\mu}$ and $\epsilon_{\mu\tau}$ can be neglected
- What constraints could be put on ϵ_{ee}, $\epsilon_{e\tau}$ and $\epsilon_{\tau\tau}$ by future experiments?

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- Far Detector at Soudan mine, northern Minnesota
- Takes data since 2005, preliminary results in summer 2006 after approximately one year of running

MINOS collaboration, Phys. Rev. Lett. **97**, 191801 (2006), hep-ex/0607088

The MINOS experiment

- Geographical layout

MINOS experiment simulation

- Simulated with the General Long Baseline Experiment Simulator (GLoBES)

  P. Huber, M. Lindner and W. Winter, Comput. Phys. Commun. **167**, 195 (2005), `hep-ph/0407333`

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- Simulation of five years running time
- Neutrino oscillation and NSI parameters used for the simulations

$\sin^2(2\theta_{12}) = 0.8$	$\epsilon_{ee} = 0$
$\sin^2(2\theta_{13}) = 0.07$ or 0	$\epsilon_{e\mu} = 0$
$\sin^2(2\theta_{23}) = 1$	$\epsilon_{e\tau} = 0$
$\Delta m^2_{21} = (7 \cdot 10^{-5})$ eV^2	$\epsilon_{\mu\mu} = 0$
$\Delta m^2_{32} = (2.74 \cdot 10^{-3})$ eV^2	$\epsilon_{\mu\tau} = 0$
$\delta = \frac{\pi}{2}$	$\epsilon_{\tau\tau} = 0$

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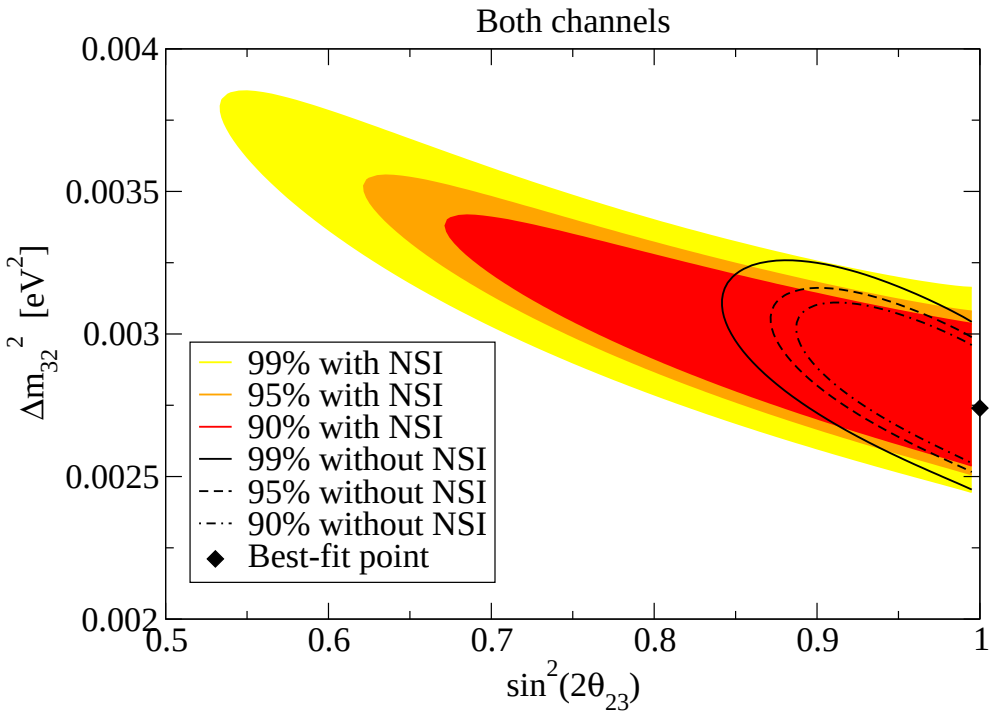
- NSI parameters are assumed to be real

Simulation results

- $\sin^2(2\theta_{23})$–Δm^2_{32} plane



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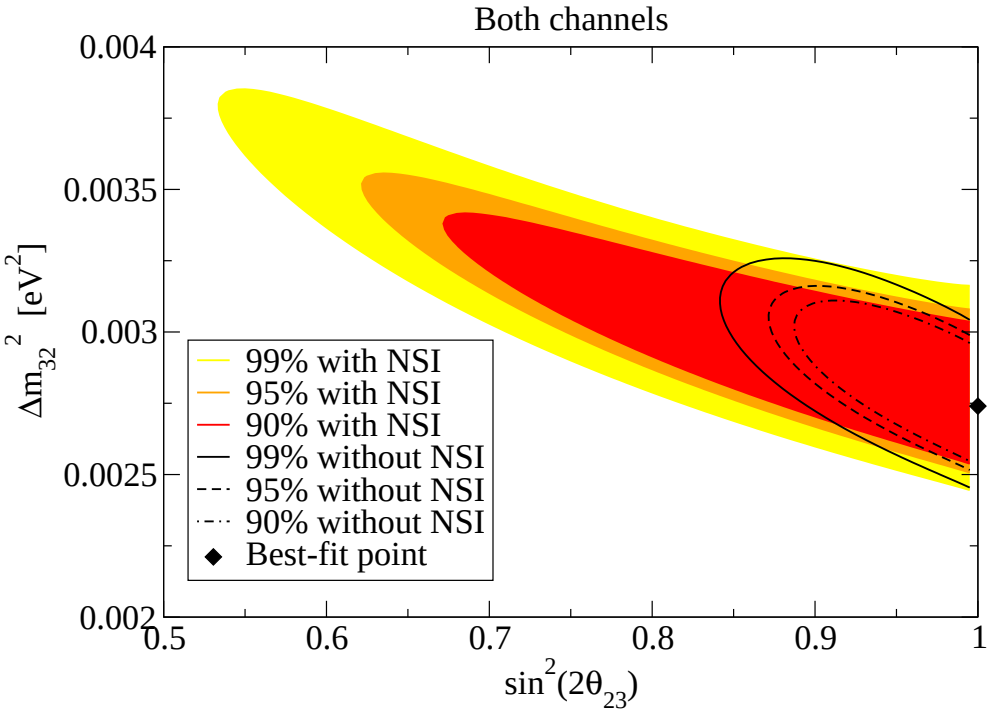
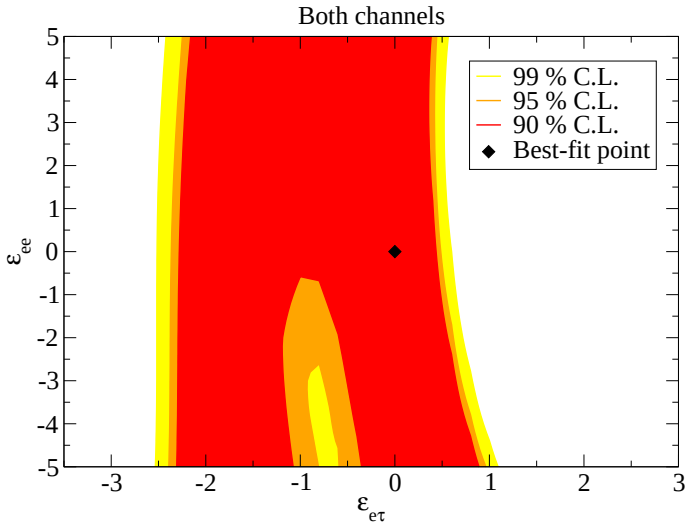


- Similar results by Friedland and Lunardini

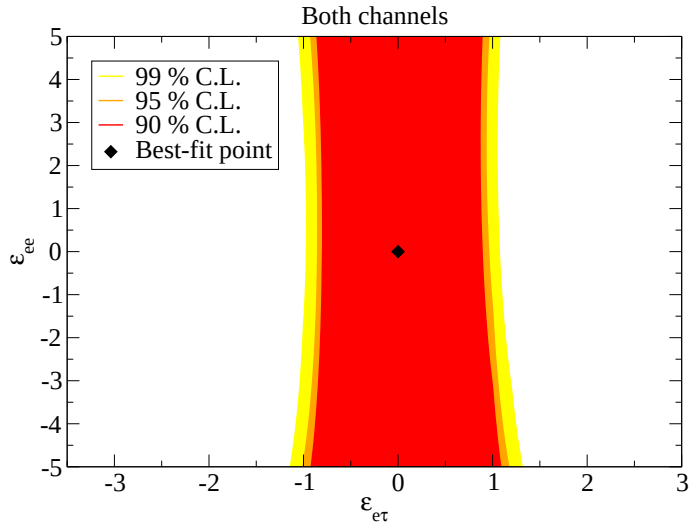
A. Friedland and C. Lunardini, Phys. Rev. **D74**, 033012 (2006), `hep-ph/0606101`

Simulation results

- Constraints on NSI parameters



$\sin^2(2\theta_{13}) = 0.07$



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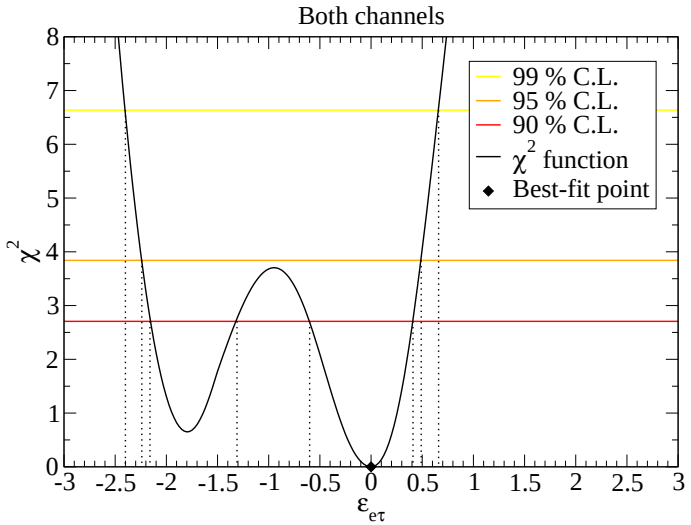
- Full three-flavor treatment

Simulation results

- Constraints on NSI parameters



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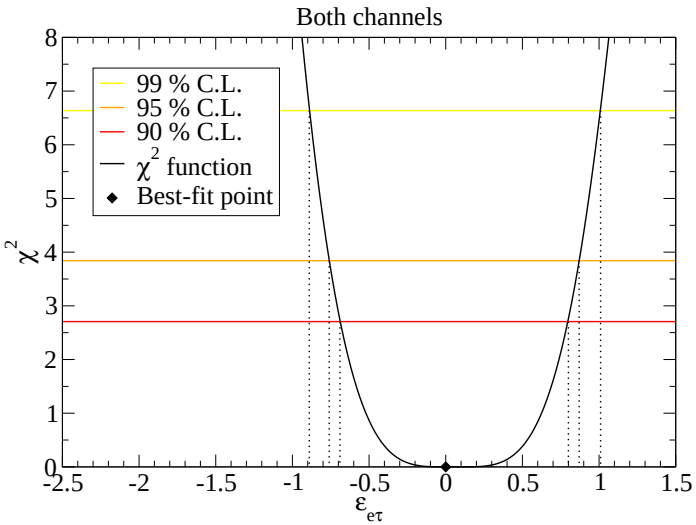

$$\sin^2(2\theta_{13}) = 0$$

Simulation results

- Constraints on NSI parameters

$\sin^2(2\theta_{13}) = 0.07$	$-2.16 < \epsilon_{e\tau} < -1.31$ $-0.60 < \epsilon_{e\tau} < 0.41$
$\sin^2(2\theta_{13}) = 0$	$-0.69 < \epsilon_{e\tau} < 0.8$
Confidence level	90 %

Simulation results

- NSI effects on $\sin^2(2\theta_{13})$

$$\tilde{U}_{e3} = U_{e3} + \epsilon_{e\tau} \frac{2EV_{CC}}{\Delta m^2_{31}} \cos(\theta_{23})$$

$$\tilde{U}_{e3} \propto \sin(\tilde{\theta}_{13}) \qquad U_{e3} \propto \sin(\theta_{13})$$

M. Blennow, T. Ohlsson and W. Winter, Eur. Phys. J. (to be published), `hep-ph/0508175`

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- If $\tilde{U}_{e3} = 0$

$$\Rightarrow \sin(\theta_{13}) \propto \epsilon_{e\tau}$$

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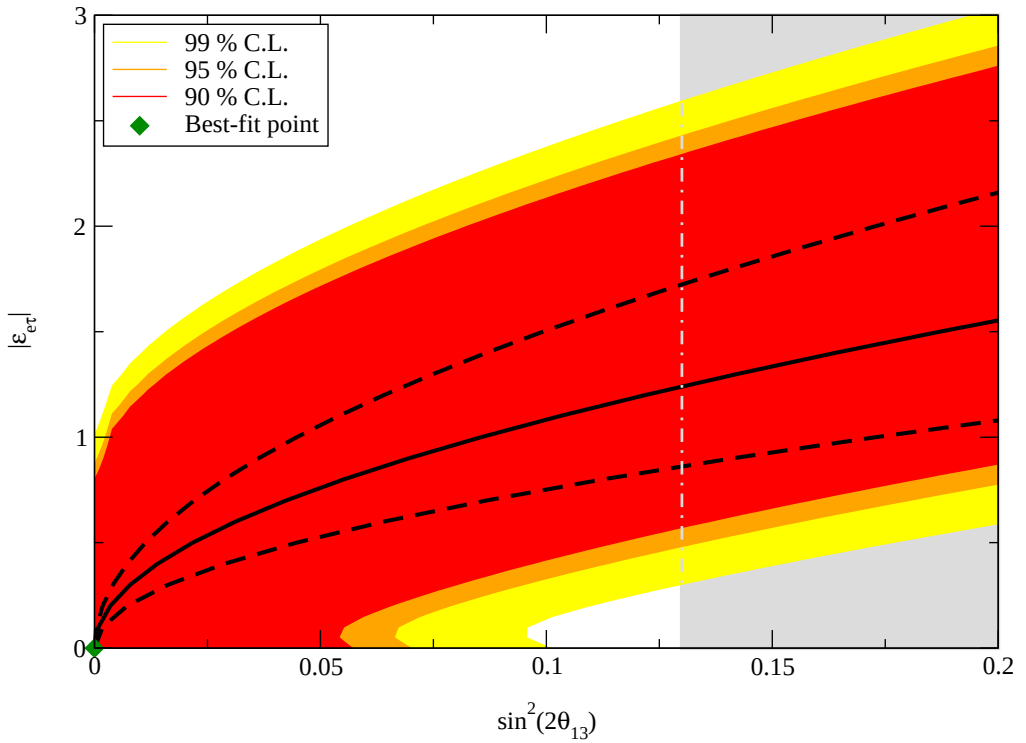

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Short summary:

- Allowed region in the $\sin^2(2\theta_{23})$–Δm^2_{32} plane is extended to lower values of $\sin^2(2\theta_{23})$ and to higher values of Δm^2_{32} if NSI effects are present

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- Possible bounds on the NSI parameter $\epsilon_{e\tau}$ depending on the value of θ_{13}

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- Possible bounds on the NSI parameter $\epsilon_{e\tau}$ depending on the value of θ_{13}
- Better upper bound on $\sin^2(2\theta_{13})$ than CHOOZ only for small $|\epsilon_{e\tau}|$

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- GUI would make the program more intuitive