The physics case for a ν_τ detector at intermediate baseline

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History

- The use of an emulsion cloud chamber (ECC), to measure $\nu_e \longrightarrow \nu_\tau$ has been proposed by Donini, Meloni, Migliozzi in 2002 (NPB **646**:321-349,2002.) to reduce the impact of degeneracies.
- This proposal was in the context of a high threshold, non-optimized MIND
- There was no detector at the magic baseline
- A number of subsequent studies was performed to better understand the performance of an ECC in this type of beam, which found this proposal to be feasible

Standard Oscillation – I

- MIND has been re-evaluated and now a has low (few GeV) neutrino threshold, which effectively allows to fully map the 1st oscillation maximum for $L \geq 2000\,\mathrm{km}$
- The current baseline has a MIND at the magic baseline

As a result it was found that no performance is gained from having an ECC measuring $\nu_e \to \nu_\tau$ anywhere between 1000-10000km (PRD **74**:073003,2006.).

Standard Oscillation – II

This result is easy to understand:

- $\theta_{23} \simeq \pi/4$, that is, ν_τ and ν_μ are maximally mixed.
- Within a 3 flavor framework, any change of the ν_τ oscillation probability will show up with similar magnitude in the corresponding ν_μ channel
- Muons are much easier to detect than taus, hence the statistical power of a well designed muon-only experiment always outperforms tau detection

Non-standard physics

In order to perform a quantitative analysis, we need to specify a model of the unknown. Thus, we deal with "known unknowns", whereas we can not exclude the existence of "unknown unknowns", obviously the following does not apply to those.

Our model are so called contact or Fermi type interactions, which from an effective field theory approach, represent the most general class of new interactions a neutrino can have. Generally, we expect for the strength of these new interactions

$$\epsilon \sim \frac{M_{\mathrm{W}}^2}{M_{\mathrm{NSI}}^2}$$

Types of NSI

Source and Detector (charged current)

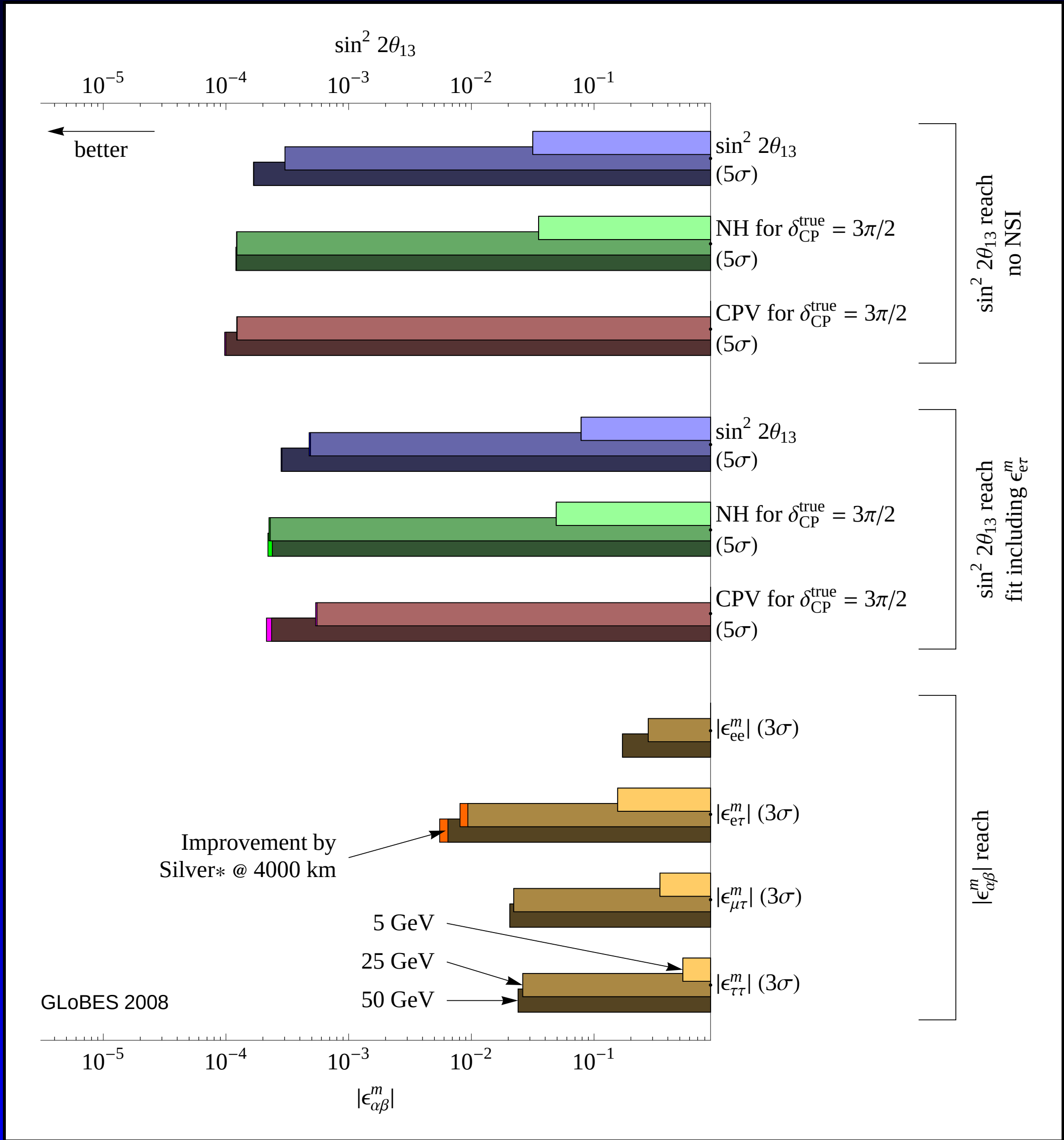
$$|\nu_\alpha^s\rangle = |\nu_\alpha\rangle + \sum_{\beta=e,\mu,\tau} \epsilon^s_{\alpha\beta} |\nu_\beta\rangle, \qquad \text{e.g. } \pi^+ \xrightarrow{\epsilon^s_{\mu e}} \mu^+ \nu_e$$

$$\langle\nu_\alpha^d| = \langle\nu_\alpha| + \sum_{\beta=e,\mu,\tau} \epsilon^d_{\beta\alpha} \langle\nu_\beta| \qquad \text{e.g. } \nu_\tau N \xrightarrow{\epsilon^d_{\tau e}} e^- X\,.$$

Propagation (neutral current)

$$\tilde{V}_{\mathrm{MSW}} = \sqrt{2} G_F N_e \begin{pmatrix} 1+\epsilon^m_{ee} & \epsilon^m_{e\mu} & \epsilon^m_{e\tau} \\ \epsilon^{m*}_{e\mu} & \epsilon^m_{\mu\mu} & \epsilon^m_{\mu\tau} \\ \epsilon^{m*}_{e\tau} & \epsilon^{m*}_{\mu\tau} & \epsilon^m_{\tau\tau} \end{pmatrix}$$

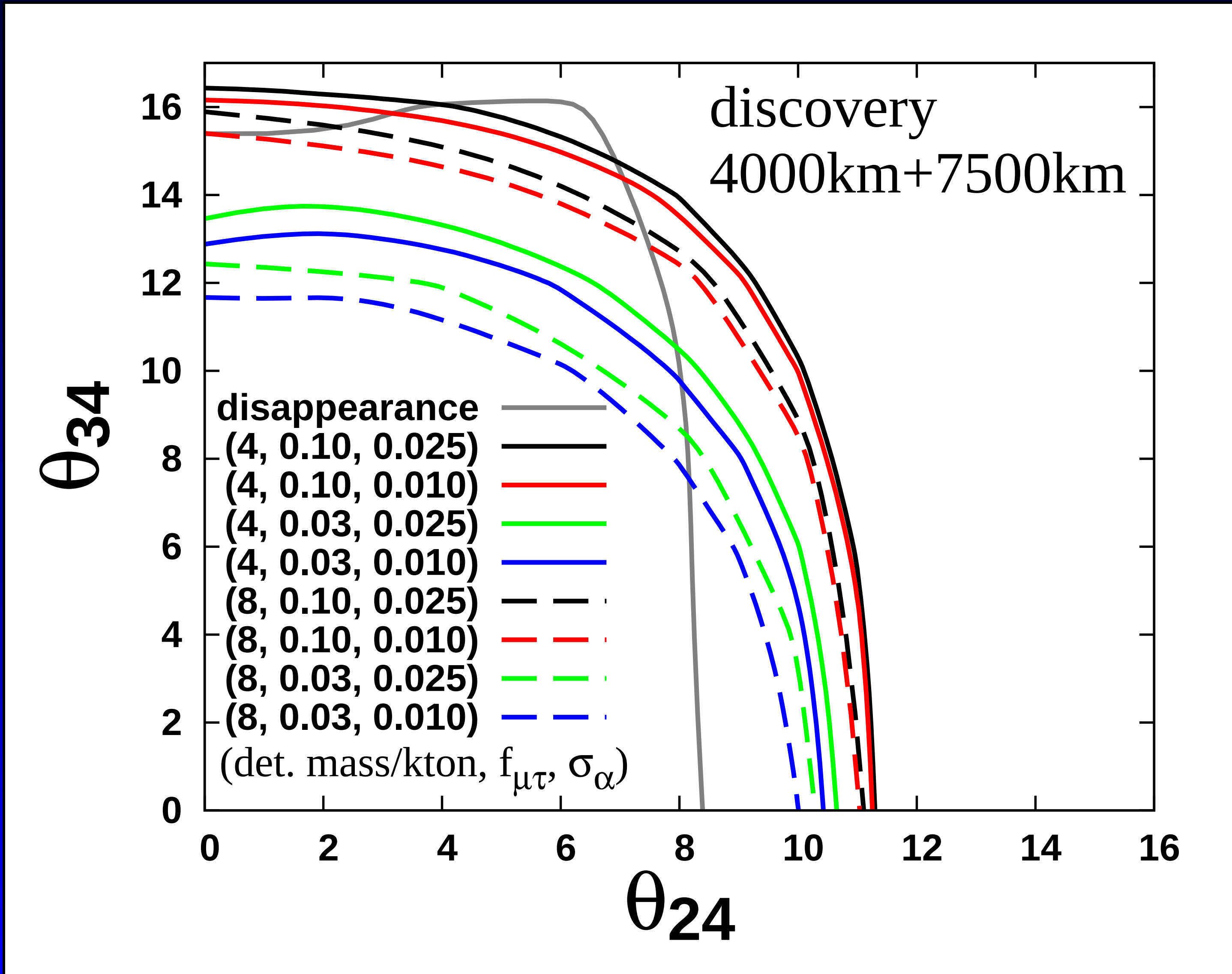
Result on NSI



from Kopp, Ota, Winter, PRD **78**:053007,2008.

$\nu_\mu \longrightarrow \nu_\tau$

Sterile neutrinos, Donini *et al.*, arXiv:0812.3703.



Summary

A fully optimized neutrino factory, with 2 low threshold MIND detectors, does not experience a significant increase in its physics reach from tau-detection capabilities at baselines exceeding a few 100km. This statement is true, both for

- Standard 3 flavor oscillation
- Non-standard interactions

In the context of additional, sterile neutrinos $\nu_\mu \longrightarrow \nu_\tau$ can provide some benefit, but it is not obvious how an optimal detector would look like.
All this information has been concisely documented in IDS-NF 008.

Baseline change request

PPEG, therefore, suggests to

- Drop the current ν_τ detector, the ECC, from the baseline configuration
- Focus attention on possible ν_τ near detection
- Have a continued effort to better understand the capabilities and limitations of alternative ν_τ detection technologies