Systematics vs Searches for New Physics in Long Baseline Experiments

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Where systematics enter

Precision measurement of neutrino observables limited by:

See talk by Hadley, NuPhys2017

- Statistics
- Neutrino energy reconstruction
- Knowledge of unoscillated spectrum, cross section and background contamination

Ankowski&Mariani, J.Phys.G44 (2017) no.5, 054001

$$R(\chi) = \int dE_\nu \phi(E_\nu) \frac{d\sigma(E_\nu)}{d\chi} \epsilon(\chi) P(E_\nu, \vec{\theta})$$

- $R(\chi)$: set of observables
- $\phi(E_\nu)$: ν flux
- $\frac{d\sigma(E_\nu)}{d\chi}$: describes likelihood for a ν to produce an event of kinematics χ
- $\epsilon(\chi)$: detector efficiency

systematics enter in almost every factor (flux normalization, energy calibration, nuclear effects...)

Near to far extrapolation at reactors

- Correlated systematics reduced by using the unoscillated event distribution at Near Detector to predict the distribution at the Far Detector

- Used with great success in reactor experiments to measure θ_{13}

Ankowski&Mariani, J.Phys.G44 (2017) no.5, 054001

$$\frac{R_{far}(E_\nu)}{R_{near}(E_\nu)} \approx \frac{\phi_{far}(E_\nu) P_{\alpha\to\alpha}}{\phi_{near}(E_\nu)} = \left(\frac{L_{near}}{L_{far}}\right)^2 P_{\alpha\to\alpha}$$

Understood: small uncertainties on the cross sections, well-known relations between χ and $E\nu$

Near to far extrapolation at long baselines

Relation not valid for long-baseline experiments:

1. Absolute cross section known with an accuracy of 10-20%
2. Kinematics more difficult to treat because of several interaction mechanisms
3. In appearance measurements initial and final states are different

↓

appearance: near-to-far event distribution depends on the σ_e/σ_μ ratio

- could be different from 1 if nuclear models are tuned to reproduce μ data at ND
- since conventional beams designed to minimize the ν_e contamination, the ν_e statistics at FD is lower by 2-3 orders of magnitude compared to ν_μ

Near to far extrapolation at long baselines

Importance of a ND

• To provide detailed information on event kinematics

To reduce uncertainties related to:

- fluxes
- interaction models
- backgrounds

example: systematics in flux and xs in T2K:

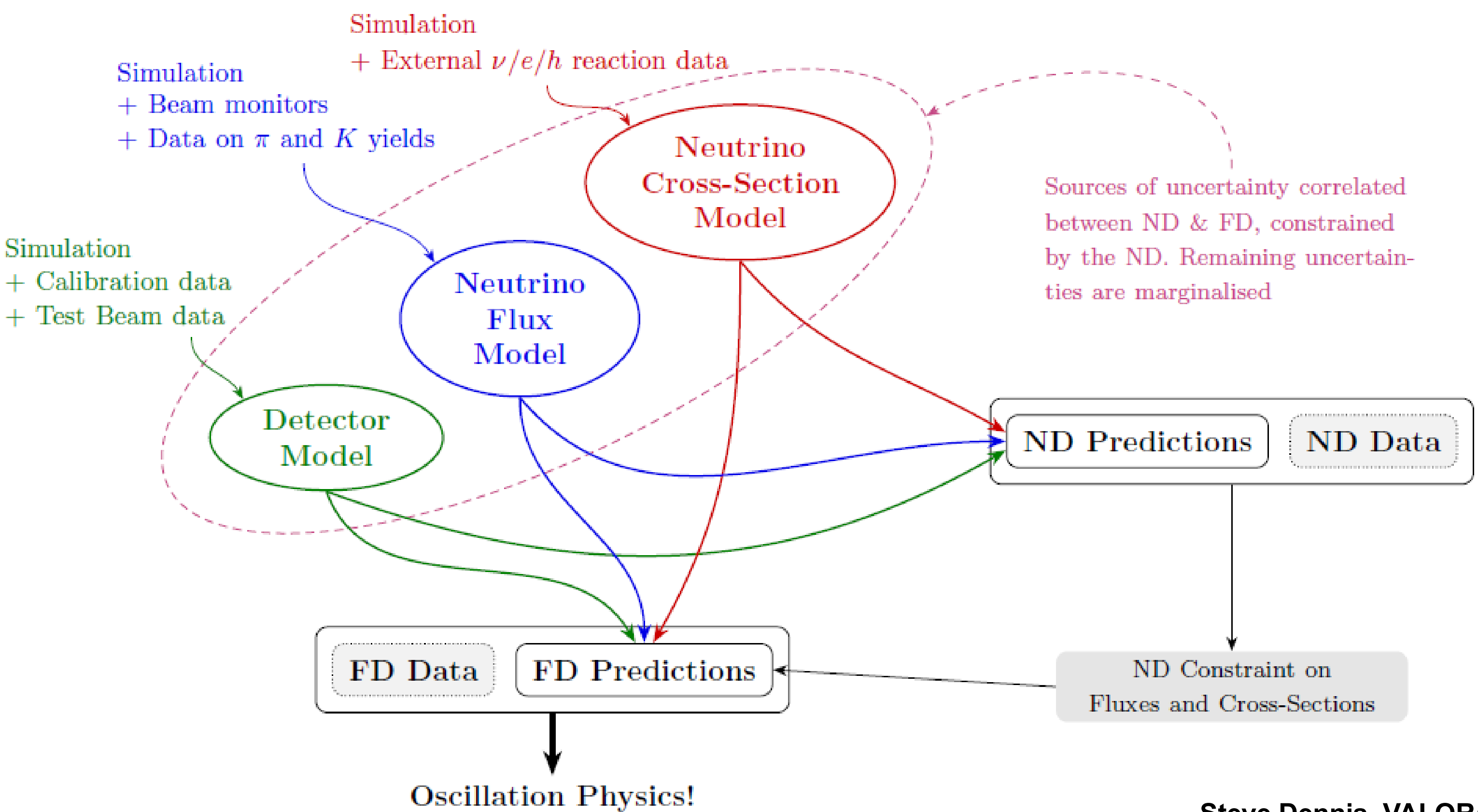
disappearance channel: from 21.7% to 2.7%

appearance channel: from 26.0% to 3.2%

+ an effort to reduce the σ_e/σ_μ ratio at a 3% level
(new near detector employing water scintillator)

Ovsiannikova T et al 2016 J. Phys. Conf. Ser. 675 012030

A 1-stage oscillation analysis: Joint ND/FD fit



Steve Dennis, VALOR/DUNE, Near to Far Extrapolation

Talk given at the 2nd WG4 meeting of the CERN Neutrino Platform (CENF)

https://valor.pp.rl.ac.uk/

1-stage oscillation analysis: Joint ND/FD fit

Steve Dennis - Talk given at the 2nd WG4 meeting of the CERN Neutrino Platform (CENF) – Systematics in the VALOR fit

large number of systematics:

- neutrino flux systematics: 208 normalization factors (104@ND + 104@FD)

- 52 **FHC** parameters ('inspired' by MINERνA parameterisation).
  - 19 ν_μ parameters: Energy bins defined by (0, 0.5, 1., 1.5, 2., 2.5, 3., 3.5, 4., 4.5, 5., 5.5, 6., 7., 8., 12., 16., 20., 40., 100.) GeV.
  - 19 $\bar{\nu}_\mu$ parameters: as above
  - 7 ν_e parameters: Energy bins defined by (0., 2., 4., 6., 8., 10., 20., 100.) GeV.
  - 7 $\bar{\nu}_e$ parameters: as above

+ 52 for RHC

- 35 neutrino cross section systematics

- 6 Q^2-dependent systematics for ν and $\bar{\nu}$ CC QE,
- 2 systematics for ν and $\bar{\nu}$ CC MEC,
- 6 Q^2-dependent systematics for ν and $\bar{\nu}$ CC $1\pi^\pm$,
- 6 Q^2-dependent systematics for ν and $\bar{\nu}$ CC $1\pi^0$,
- 2 systematics for ν and $\bar{\nu}$ CC 2π
- 6 energy-dependent systematics for ν and $\bar{\nu}$ CC DIS ($> 2\pi$)
- 2 systematics for ν and $\bar{\nu}$ CC coherent production of pions,
- 2 overall systematics for ν and $\bar{\nu}$ NC, and
- 2 ν_e/ν_μ and ν_e/ν_μ cross-section ratio systematics.
- 1 Argon to non-Argon nucleus scaling.

- 10 FSI systematics

- 2 systematics on the overall re-interaction rate for pions and nucleons, and
- 8 systematics on the relative strength of different rescattering mechanisms (chg. exch., inelastic, absorption, pion production) for pions and nucleons.

+ ~ 300 Detector systematics

Systematic uncertainties based on the pull method

Coloma, Huber, Kopp,Winter, 2013

Coloma, Huber, Jen, Mariani, 2013

$$\chi^2 = \min_{\xi} \left\{ \sum_{D,i} \chi^2_{D,i}(\Delta m, \theta, \xi) + \sum_i \left(\frac{\xi_{\phi,i}}{\sigma_\phi}\right)^2 + \left(\frac{\xi_N}{\sigma_N}\right)^2 \right\}$$

minimization over nuisance parameters

Pull terms associated with the
signal shape ($\xi_{\phi,i}$ bin-to-bin uncorrelated)
and to overall normalizations (ξ_N fully correlated)

σ's are prior uncertainties assumed for each systematic errors

$$\chi^2_{D,i}(\Delta m, \theta, \xi) = 2\left(F_{D,i} - O_{D,i} + O_{D,i} \ln \frac{O_{D,i}}{F_{D,i}}\right)$$

true event rate: depends on the oscillation parameters

fitted event rate

↳ $$F_{i,D}(\theta, \xi) = (1 + \xi_n + \xi_{\phi,i})\, N_{i,D}(\theta)$$

Other relevant contributions to systematics: *nuclear* and *detector* effects

Number of events (true and fitted) affected by:

nuclear effects in the neutrino-nucleus interactions and *detector effects*

- QE involving a single or more nucleons in the final state (2p2h)
- Resonance excitations
- Deep-inelastic scattering

- Energy resolutions
- Efficiencies
- Thresholds

both affect energy reconstruction and thus event distributions

$$N_i^{\text{tot}} = \sum_X \sum_j \mathcal{M}_{ij}^X N_j^X$$

Migration matrices:
probability that an event of type X with a true energy in the bin j is reconstructed with an energy in the bin i

An example related to *detector* effects

Ankowski et al., Phys. Rev. D92 091301

- Events generated and fitted assuming the same nuclear target (Carbon)

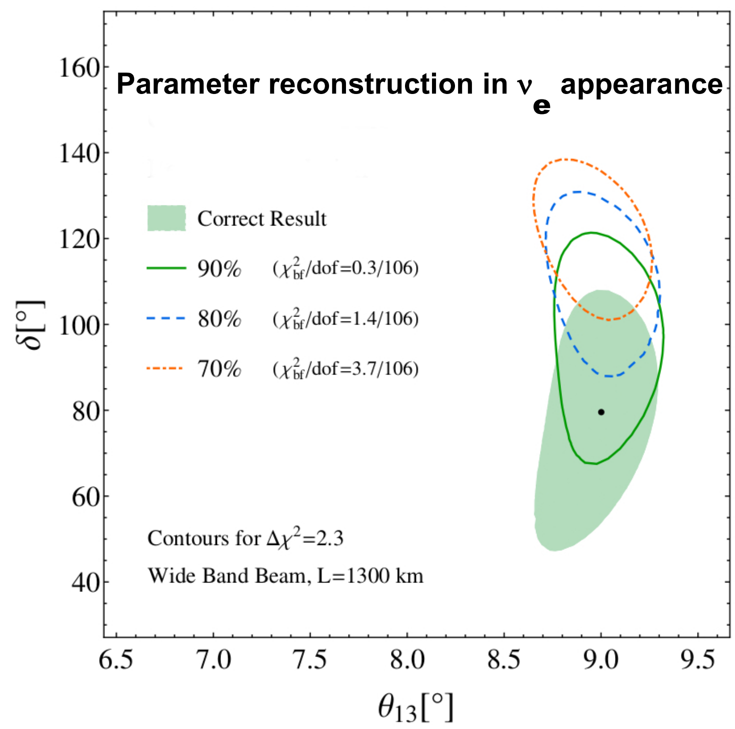
true rates take into account realistic detection capabilities

events smeared using a different function:
- Gaussian in the ideal case of no particle escaping detection

for instance: 90% is related to the fact that the distribution is fitted using the migration matrices accounting for 90% of the missing energy

Result of the analysis:

sizable bias in the extracted δ_{CP} value even with 20% underestimation

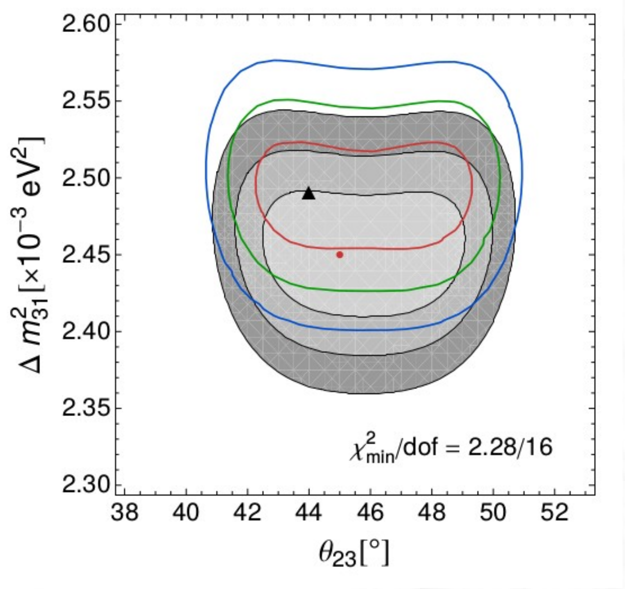


An example related to *nuclear* effects

Coloma, Huber, Jen, Mariani, 2013

Effects of the near-to-far cross section extrapolation

Parameter reconstruction in ν_μ disappearance



Shaded areas: data simulated for Oxygen and fitted using the Oxygen migration matrices

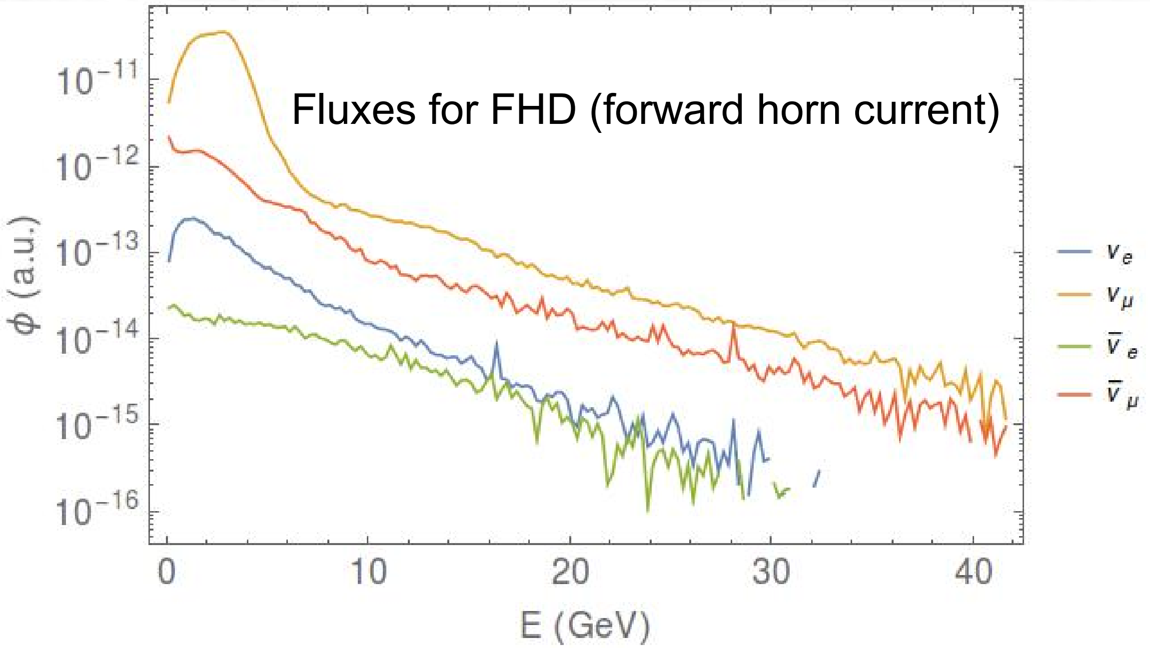
Solid lines: data simulated for Oxygen and fitted using the Carbon migration matrices

shift at the 1σ level

Relevant conclusion: better to employ the same target in ND and FD if no detailed knowledge of the Oxygen (and Argon) cross section is available

Applying some of the previous considerations to New Physics

Experimental Setup: based on 1606.09550, DUNE far detector configuration useful for GloBES (ancillary files provided by the authors)



Number of events corresponding to 150 Kt-MW-years (one mode):

ν_e appearance signal ~ 1000
ν_e appearance back ~ 320

ν_μ disappearance signal ~ 8000
ν_μ disappearance back ~ 100

NUTIME = 3.5 years
NUBARTIME = 3.5 years
LAMASS = 40 Kton (Argon)

in a 80 GeV, 1.07 MW beam

Small changes from the 50-50 ratio of neutrino to antineutrino data produce negligible changes in the sensitivities

Applying some of the previous considerations to New Physics

ν_μ disappearance analysis sample: ν_μ CC interactions with backgrounds from NC interactions (where a pion is misidentified as a muon) and ν_τ CC interactions decaying to muons

ν_e appearance analysis sample: ν_e CC interactions with backgrounds from NC, misidentified ν_μ CC interactions, intrinsic ν_e and ν_τ CC interactions decaying to electrons

Default setup for systematics:

signal normalization uncertainties

ERR_NUE_SIG = 2%
ERR_NUE_SIGBAR = 2%
ERR_NUMU_SIG = 5%
ERR_NUMU_SIGBAR = 5%

background normalization uncertainties

ERR_NUMU_BG = 5%
ERR_NUE_BG = 5%
ERR_NUTAU_BG = 20%
ERR_NUE_BGBAR = 5%
ERR_NC_BGDIS = 10%

Correlations: - in the ν_μ and $\bar{\nu}_\mu$ samples NC back is treated as correlated (ERR_NC_BGDIS);
the same is assumed for NC and ν_μ CC back. in the ν_e and $\bar{\nu}_e$ samples;
- the normalization for ν_τ CC int is 100% correlated among all samples.

Applying some of the previous considerations to New Physics

- True-to-reconstructed smearing matrices and selection efficiencies included
- Cross sections describing charged-current and neutral-current interactions with Argon are generated using GENIE 2.8.4

Going beyond default systematics: bin-to-bin uncorrelated (signal shape)

```
/* Systematics Definitions: Vary Systematics in Energy Bins */
sys(#err_nue_sig_var)<
        @energy_list = {0.5, 1.0, 2.0, 3.0, 5.0}
        @error_list = {ERR_APP1, ERR_APP2, ERR_APP3, ERR_APP4, ERR_APP5}
```

Elizabeth Worcester
DUNE Collaboration Meeting
August 16, 2017

Preliminary results in a simplistic approach:
5 energy bins, same prior uncertainties assumed for each systematic errors for appearance and disappearance

three cases analyzed: σ = 2%, 5% and 7%

Applying some of the previous considerations to New Physics

New physics can manifest itself in two (combined) ways:

- Worsening the sensitivity to the standard physics
- Direct evidence of new phenomena

An example here on the role played by systematics in searching for NSI (much more details discussed by the two voices *Tortola* and *Fernandez-Martinez*)

Neutrino propagation in the presence of NC-like operators

$$i\frac{d}{dt}\begin{bmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{bmatrix} = \frac{1}{2E}\left\{U^\dagger\begin{bmatrix}0 & 0 & 0\\ 0 & \Delta m^2_{21} & 0\\ 0 & 0 & \Delta m^2_{31}\end{bmatrix}U + A\begin{bmatrix}1+\varepsilon^m_{ee} & \varepsilon^m_{e\mu} & \varepsilon^m_{e\tau}\\ \varepsilon^m_{\mu e} & \varepsilon^m_{\mu\mu} & \varepsilon^m_{\mu\tau}\\ \varepsilon^m_{\tau e} & \varepsilon^m_{\tau\mu} & \varepsilon^m_{\tau\tau}\end{bmatrix}\right\}\begin{bmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{bmatrix}$$

Neutrino oscillation with NSI

$(\varepsilon^m)_{\alpha\beta} = |\varepsilon^m|_{\alpha\beta}\, e^{i\phi_{\alpha\beta}}$ 6 amplitudes and 3 phases

Pilar Coloma, JHEP03 (2016) 016

	Current constraint
$\tilde{\varepsilon}_{ee}$	$(-4, -2.62) \oplus (0.33, 1.79)$
$\tilde{\varepsilon}_{\mu\mu}$	$(-0.12, 0.11)$
$\lvert\varepsilon_{\mu e}\rvert$	< 0.36
$\lvert\varepsilon_{\tau e}\rvert$	< 0.53
$\lvert\varepsilon_{\tau\mu}\rvert$	< 0.054

- appearance probabilities $P_{\mu e}$ depend on $\varepsilon_{e\mu}$, $\varepsilon_{\tau e}$ and ε_{ee}

  → 3 moduli and two more CP violating phases

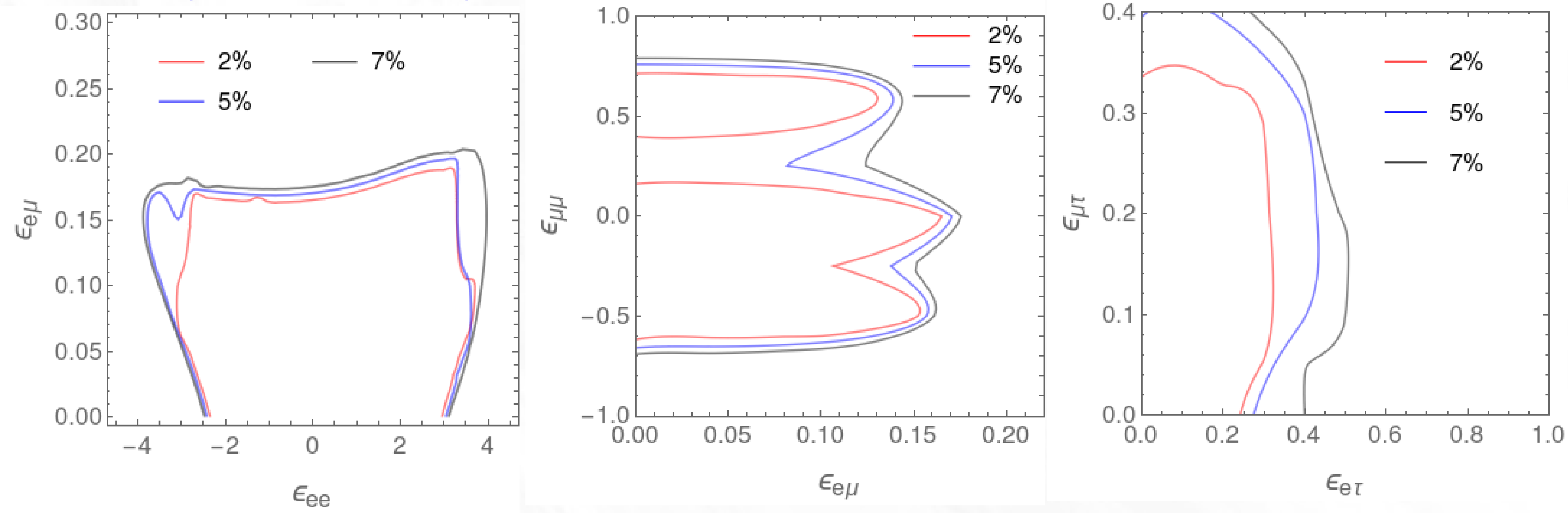
- disappearance probabilities $P_{\mu\mu}$ depend on $\varepsilon_{\mu\mu}$, $\varepsilon_{\mu\tau}$ and $\varepsilon_{\tau\tau}$

  → 2 moduli and one more CP violating phase

Neutrino oscillation with NSI

Direct bounds on the new parameters (some examples):

90% CL



	ε_{ee}	$\varepsilon_{e\mu}$	$\varepsilon_{e\tau}$	$\varepsilon_{\mu\mu}$	$\varepsilon_{\mu\tau}$
2%	(-4,3.6)	(0,0.19)	(0,0.45)	(-0.60,0.23) U (0.37,0.75)	(0,0.35)
5%	(-4,3.8)	(0,0.2)	(0,0.47)	(-0.64,0.78)	(0,0.42)
7%	(-4.5,4)	(0,0.22)	(0,0.52)	(-0.68,0.80)	(0,0.44)

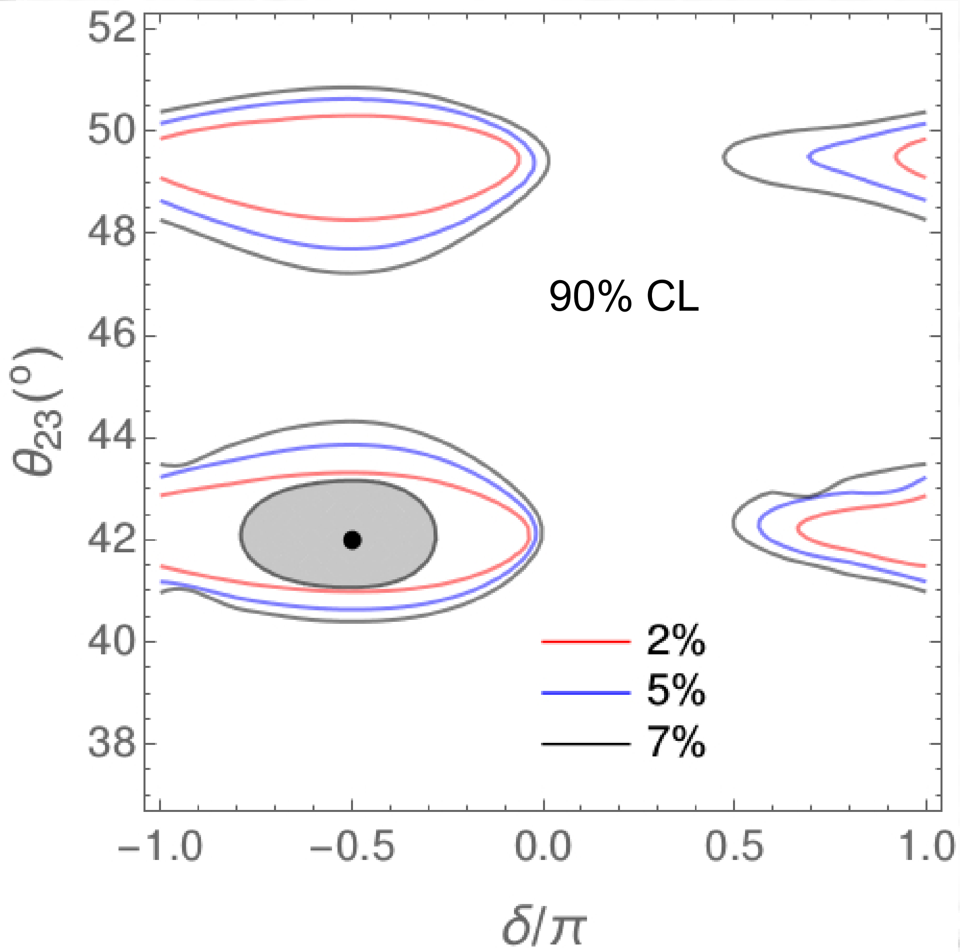
→ in agreement with Liao,Marfatia,Whisnant, JHEP 1701 (2017) 071

a ~10% variation on the bounds

Effects of New Physics on Standard Oscillation

the (θ_{23},δ) plane

Filled region: Standard Model results



Bad news:

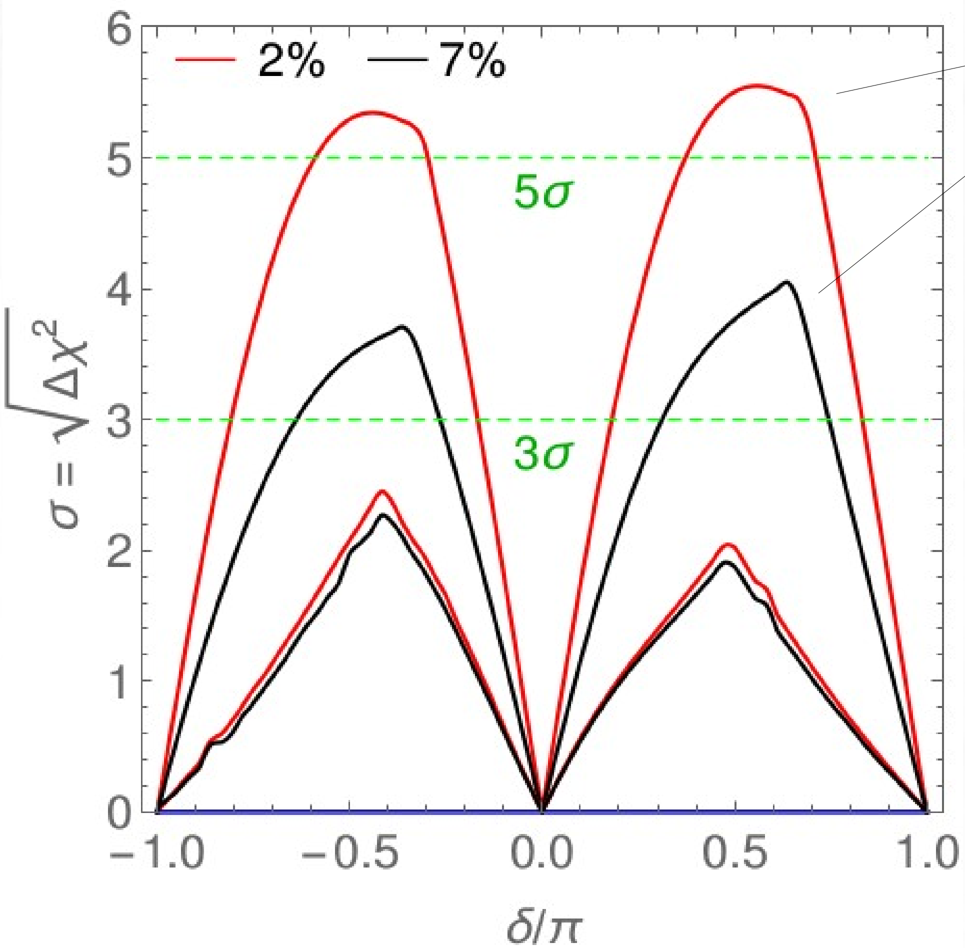
- appearance of octant degeneracy already with 2% sys
- impossible to check maximal CP violation

see also

Pilar Coloma, JHEP03 (2016) 016

Effects of New Physics on CP discovery

significance with which the CP violation can be determined as a function of δ



Standard Model results

Main features:

- strong reduction in the sensitivity

- soft dependence on sys for the NSI case: 8% loss in sensitivity (at the pick)

"The Physics Program for DUNE at LBNF"
1512.06148

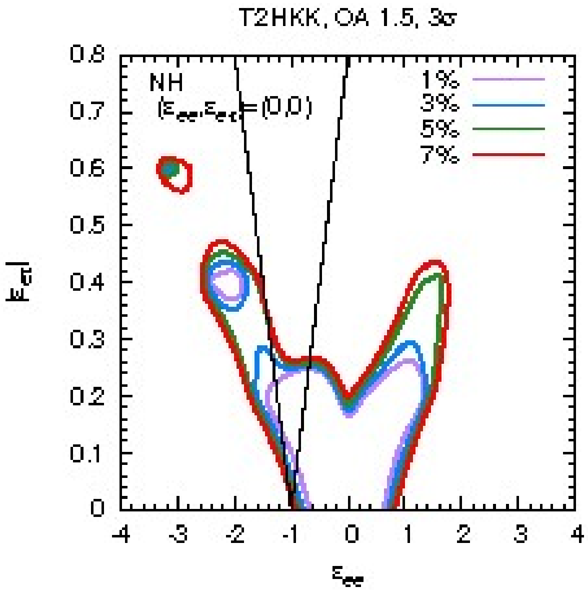
$$\Delta\chi^2_{CPV} = Min[\Delta\chi^2_{CP}(\delta^{test}_{CP} = 0), \Delta\chi^2_{CP}(\delta^{test}_{CP} = \pi)], \text{ where}$$
$$\Delta\chi^2_{CP} = \chi^2_{\delta^{test}_{CP}} - \chi^2_{\delta^{true}_{CP}}.$$

Other Long Baseline Experiments

Based on: Ghosh&Yasuda, PRD 96,013001 (2017)

T2HKK: two Cerenkov detectors tanks of 187 Kt each, one of them in Korea; off-axis angles 1.5°, 2°, 2.5°; L~1100 Km
1.3 MW, total exposure: 27 x 10^{21} pot

uncertainty of x% → signal and background normalization errors of x% for both app and dis



$| \varepsilon_{e\tau} |$

ε_{ee}

Impact of systematics from 7% to 1%:

- range of ε_{ee} reduced by ~35%
- range of $\varepsilon_{e\tau}$ reduced by ~10%

Compared to DUNE (at fixed systematics):

- T2HKK performs slightly better for ε_{ee}
- DUNE performs slightly better for $\varepsilon_{e\tau}$

Conclusions

- capabilities of all setups are largely sensitive to systematic errors

- constraints on the NSI parameters improves in DUNE by ~8% if the flux shape uncertainty passes from 7% to 2%

- unavoidable octant degeneracy with NSI in DUNE for the set of systematics analyzed here

TO DO’s

- analyze more observables (CP phases - Other New Physics scenarios)

- check the impact of different systematic hypotheses

- take into account the effects of a Near Detector (too many sys?)

- ....

Backup slides

An example of migration matrices

Ankowski et al., Phys. Rev. D92 073014

$$N_i^{\rm tot} = \sum_X \sum_j \mathcal{M}_{ij}^X N_j^X$$

- Neutrino-nucleus charged-current interactions simulated with GENIE in QE, RES, DIS and two-nucleons knockout channels
- Energy resolutions: gaussian smearing with different σ for different particles
- Efficiencies (energy independent): 60% for π, 80% for other mesons, 50% for protons, 100% for charged particles
- Thresholds: measured kinetic energy of 20 MeV for mesons and 40 MeV for protons

Title::
Creator:ROOT Version 5.34/17
CreationDate:Tue Mar 31 11:08:13 2015
CreationDate:Tue Mar 31 11:08:13 2015

Title::
Creator:ROOT Version 5.34/17
CreationDate:Tue Apr 7 11:36:04 2015
CreationDate:Tue Apr 7 11:36:04 2015

Neutrino oscillation with NSI

Theoretical considerations: Standard framework

$|\nu_\alpha^s\rangle = |\nu_\alpha\rangle$ → neutrino produced at a source "s" in association with a charged lepton

$\langle\nu_\beta^d| = \langle\nu_\beta|$ → neutrino that produces a charged lepton at a detector "d"

Propagation of neutrinos between source and detector

$$\mathrm{i}\frac{\mathrm{d}}{\mathrm{d}t}\begin{bmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{bmatrix} = \frac{1}{2E}\left\{U^\dagger\begin{bmatrix}0 & 0 & 0\\ 0 & \Delta m_{21}^2 & 0\\ 0 & 0 & \Delta m_{31}^2\end{bmatrix}U + \begin{bmatrix}A & 0 & 0\\ 0 & 0 & 0\\ 0 & 0 & 0\end{bmatrix}\right\}\begin{bmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{bmatrix}$$

Neutrino oscillation with NSI

Theoretical considerations: Non-Standard framework

1- non-flavor diagonal CC-like operators that affect the nu interactions with charged leptons at source and detectors (contributions from several Lorentz structures of D=6 operators)

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

$$\langle\nu_\beta^d| = \langle\nu_\beta| + \sum_{\gamma=e,\mu,\tau} \varepsilon_{\gamma\beta}^d \langle\nu_\gamma|$$

2- propagation in the presence of NC-like operators

contributions from V+-A currents

$$\mathrm{i}\frac{\mathrm{d}}{\mathrm{d}t}\begin{bmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{bmatrix} = \frac{1}{2E}\left\{U^\dagger\begin{bmatrix}0 & 0 & 0\\ 0 & \Delta m_{21}^2 & 0\\ 0 & 0 & \Delta m_{31}^2\end{bmatrix}U + A\begin{bmatrix}1+\varepsilon_{ee}^m & \varepsilon_{e\mu}^m & \varepsilon_{e\tau}^m\\ \varepsilon_{\mu e}^m & \varepsilon_{\mu\mu}^m & \varepsilon_{\mu\tau}^m\\ \varepsilon_{\tau e}^m & \varepsilon_{\tau\mu}^m & \varepsilon_{\tau\tau}^m\end{bmatrix}\right\}\begin{bmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{bmatrix}$$

Neutrino oscillation with NSI

Three different sources on new physics parameters

$(\varepsilon^{s,d})_{\alpha\beta}$ two independent 3x3 complex matrices → 36 parameters

$(\varepsilon^{m})_{\alpha\beta}$ 6 amplitudes and 3 phases

Current bounds

$$|\varepsilon^{s/d}_{\alpha\beta}| < \begin{bmatrix} 0.041 & 0.025 & 0.041 \\ 0.026 & 0.078 & 0.013 \\ 0.12 & 0.018 & 0.13 \end{bmatrix}$$

$$|\varepsilon^{m}_{\alpha\beta}| < \begin{bmatrix} 4.2 & 0.3 & 3.0 \\ 0.3 & - & 0.04 \\ 3.0 & 0.04 & 0.15 \end{bmatrix}$$

Biggio,Blennow,Fernandez-Martinez
JHEP 0908, 090 (2009)

ofter parametrized subtracting (identity * $\varepsilon_{\tau\tau}$) → $\tilde{\varepsilon}_{ee}$, $\tilde{\varepsilon}_{\mu\mu}$

Expected sensitivities

- Parameter space: $\tilde{\varepsilon}_{ee}$, $\tilde{\varepsilon}_{\mu\mu}$, $|\varepsilon_{\mu e}|$, $|\varepsilon_{\tau e}|$, and $|\varepsilon_{\tau\mu}|$ + $\phi_{\mu e}$, $\phi_{\tau e}$, and $\phi_{\tau\mu}$

- + six standard oscillation parameters

- Parameter estimation based on Bayesian inference

- Efficient sample of parameters done with a MonteCarlo Markov Chain
  (MonteCUBES + GLoBES)

probability of observing the data set *d* given a certain set of values for the parameters Θ

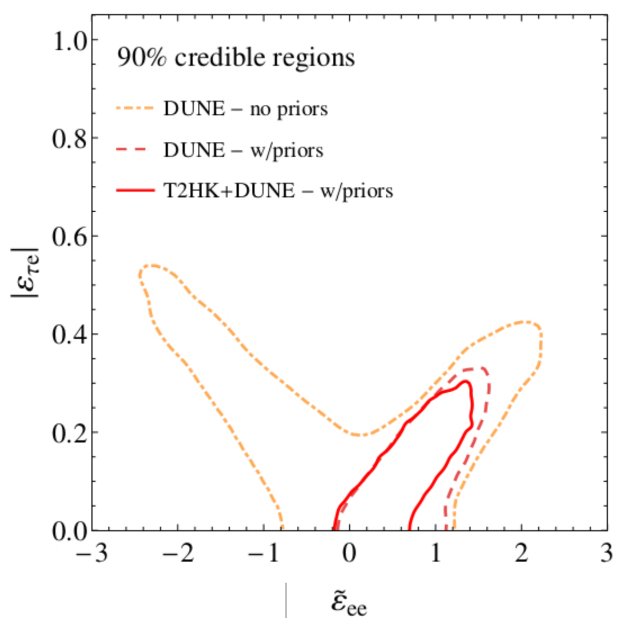
$$\mathcal{P} = P(\Theta \mid d) = \frac{\mathcal{L}(d \mid \Theta) P(\Theta)}{P(d)}$$

posterior probability

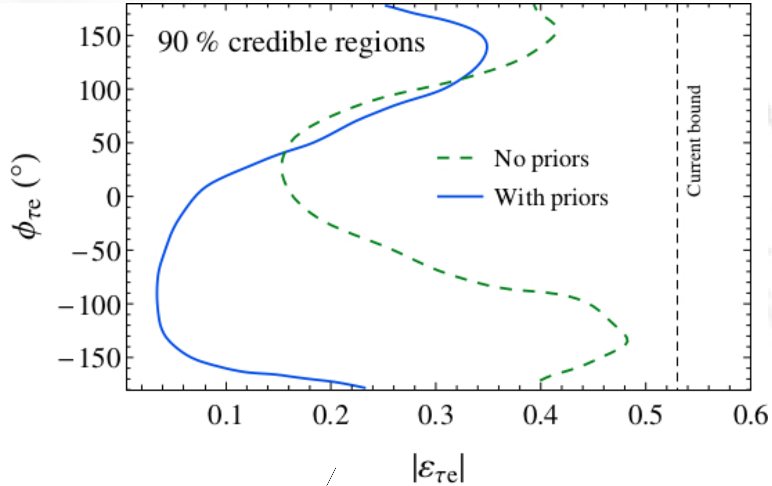
total probability of measuring the data set *d*

Expected sensitivities: some examples

Pilar Coloma, JHEP03 (2016) 016



gaussian priors on standard parameters for NSI profiles priors taken from Gonzalez-Garcia&Maltoni,JHEP 1309, 152 (2013)



improvement by a factor of 2 (no prior case)

modulation due to the CP phase

Expected sensitivities: summary of results

Pilar Coloma, JHEP03 (2016) 016

	DUNE with no priors on NSI	DUNE with priors	Current constraint
$\tilde{\varepsilon}_{ee}$	$(-1.89, 1.65)$	$(0.15, 1.49)$	$(-4, -2.62)$ $\oplus(0.33, 1.79)$
$\tilde{\varepsilon}_{\mu\mu}$	$(-0.17, 0.19)$ $\oplus(-0.6, -0.33) \oplus (0.53, 0.63)$	$(-0.18, 0.10)$	$(-0.12, 0.11)$
$\lvert\varepsilon_{\mu e}\rvert$	< 0.076	< 0.073	< 0.36
$\lvert\varepsilon_{\tau e}\rvert$	< 0.37	< 0.25	< 0.53
$\lvert\varepsilon_{\tau\mu}\rvert$	< 0.11	< 0.035	< 0.054

not a huge improvement ($\tilde{\varepsilon}_{\mu\mu}$)

factor of 5 better ($\lvert\varepsilon_{\mu e}\rvert$)

20% better ($\lvert\varepsilon_{\tau e}\rvert$)

strong dependence on the CP phase ($\lvert\varepsilon_{\tau\mu}\rvert$)

The problem of the degeneracies: spoiling the sensitivity to the standard oscillation parameters

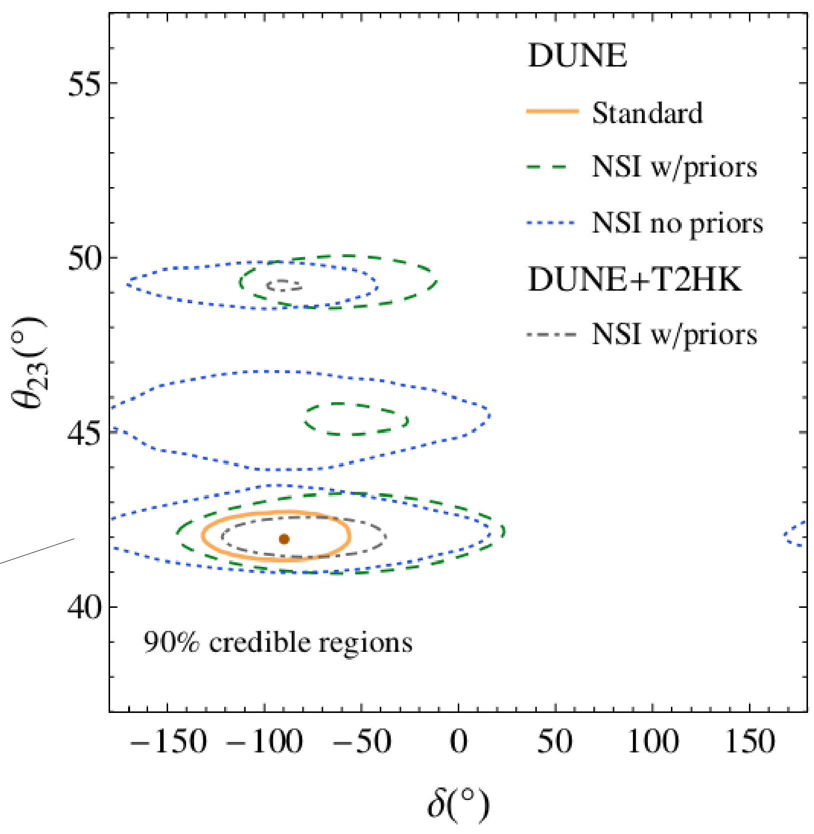
$$P_{\mu\mu} \sim P^{std}_{\mu\mu} + O(\delta\theta_{23} \widetilde{\epsilon_{\mu\mu}})$$

$$\delta\theta_{23} \to \theta_{23} - \pi/4$$

main consequence: many allowed values of θ_{23}

no priors on NSI spoils knowledge in δ and θ_{23}

values chosen by Nature



Going beyond the matter NSI

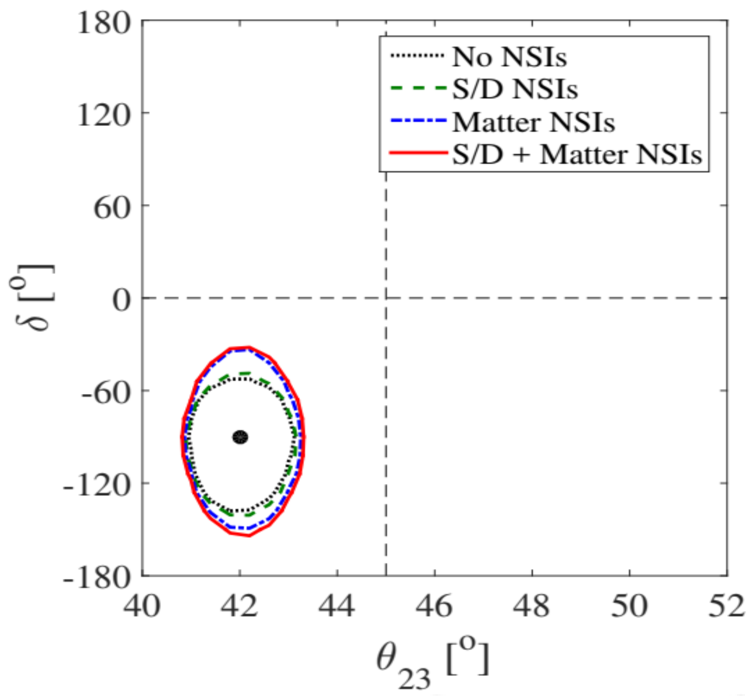
$$|\nu_\alpha^s\rangle = |\nu_\alpha\rangle + \sum_{\gamma=e,\mu,\tau} \varepsilon^s_{\alpha\gamma}|\nu_\gamma\rangle$$

$$\langle\nu_\beta^d| = \langle\nu_\beta| + \sum_{\gamma=e,\mu,\tau} \varepsilon^d_{\gamma\beta}\langle\nu_\gamma|$$

- many parameters acting simultaneously
- relevant set of source/detector parameters:

  $\varepsilon^s_{\mu e}$, $\varepsilon^s_{\mu\mu}$, $\varepsilon^s_{\mu\tau}$, $\varepsilon^d_{\mu e}$, $\varepsilon^d_{\tau e}$

Blennow et al., JHEP03 (2016) 016



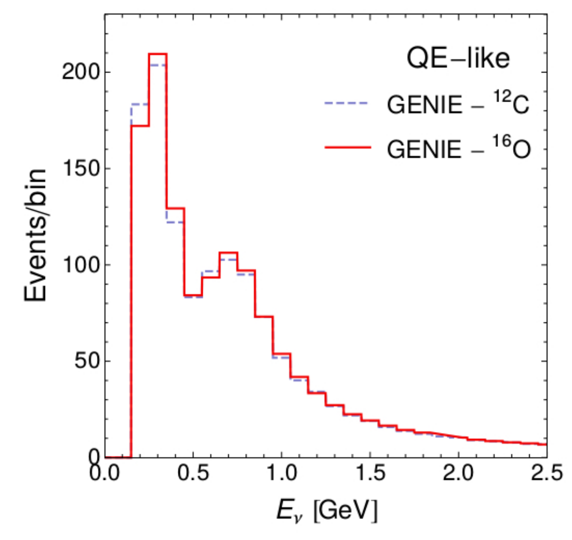
- 5 + 5 run
- vanishing NSI central values
- atmospheric angle not significantly affected

An example related to *nuclear* effects

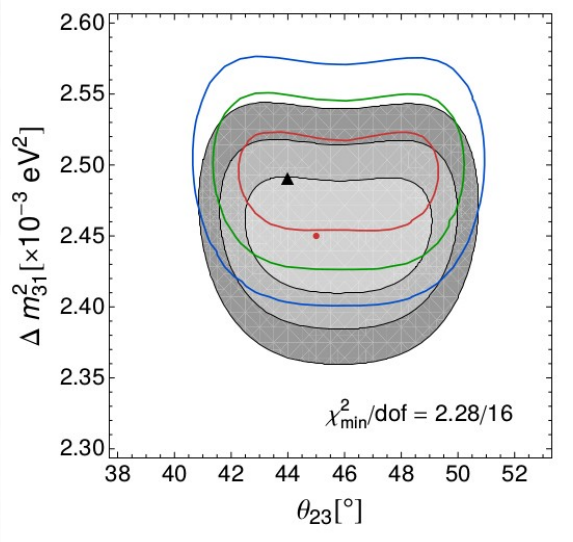
Coloma, Huber, Jen, Mariani, 2013

Effects of the near-to-far cross section extrapolation

event distribution for a T2K-like experiment



Parameter reconstruction in ν_μ disappearance



Solid lines: data simulated for Oxygen and fitted using the Carbon migration matrices

Shaded areas: data simulated for Oxygen and fitted using the Oxygen migration matrices

shift at the 1σ level

Relevant conclusion: better to employ the same target in ND and FD if no detailed knowledge of the Oxygen (and Argon) cross section is available