NSI at Neutrino Factories

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IPPP
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8th IDS-NF Plenary Meeting

University of Glasgow, April 18-20, 2012

Mainly based on a collaboration with:

P. Coloma, A. Donini
(IFT UAM/CSIC)
and
H. Minakata (TMU)

JHEP 1108:036,2011
arXiv:1105.5936

Very Brief Motivation

- Neutrino masses and mixing → evidence of Physics Beyond the SM

- NSI: a model independent way of parameterizing the whole possible New Physics effects in neutrino oscillations.

- We will focus on *NSI effects in neutrino propagation*. Paying special attention to:

  - Correlations among the oscillation parameters.
  - CP violation effects.
  - Impact of *large* θ_{13} on NSI sensitivities

NSI: what is that?

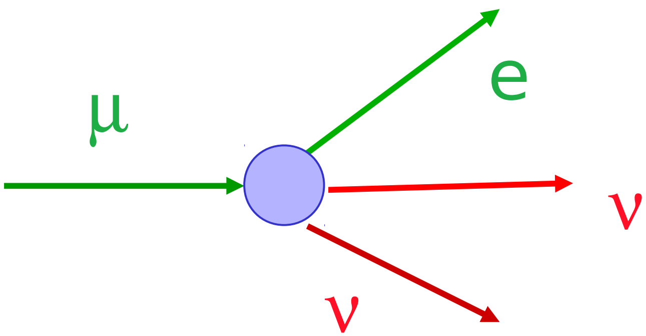
$$\mathcal{L}_{eff} = \mathcal{L}^{SM} + \mathcal{L}_{\nu}^{mass} + \sum \delta\mathcal{L}_i^{p,d,m}$$

NSI: what is that?

$$\mathcal{L}_{eff} = \mathcal{L}^{SM} + \mathcal{L}_{\nu}^{mass} + \sum \delta\mathcal{L}_i^{p,d,m}$$

NSI@production

$$\mu^- \to e^- \nu_\mu \bar{\nu}_\alpha$$



$$\delta\mathcal{L}^p : \epsilon^p_{e\alpha} (\bar{\mu}\gamma^\mu_L \nu_\mu)(\bar{\nu}_\alpha \gamma_{\mu L} e)$$

ν

NSI: what is that?

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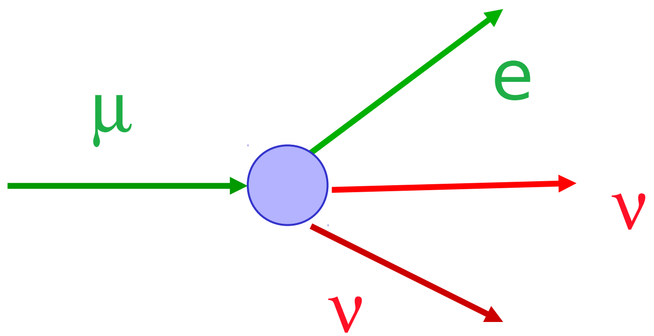
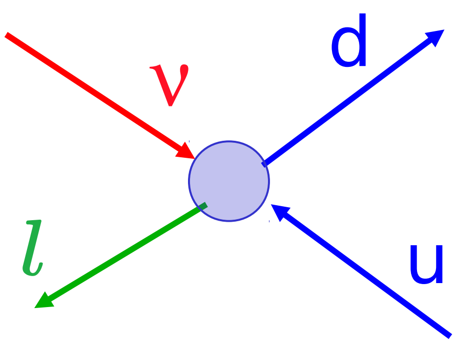


$$\delta\mathcal{L}^p : \epsilon^p_{e\alpha}(\bar{\mu}\gamma^\mu_L \nu_\mu)(\bar{\nu}_\alpha \gamma_{\mu L} e)$$

NSI@detection

$\nu_\alpha N \rightarrow l^-_\alpha N'$



$$\delta\mathcal{L}^d : \epsilon^d_{\mu\alpha}(\bar{\nu}_\alpha \gamma^\mu_L \mu)(\bar{d}\gamma_{\mu L} u)$$

NSI: what is that?

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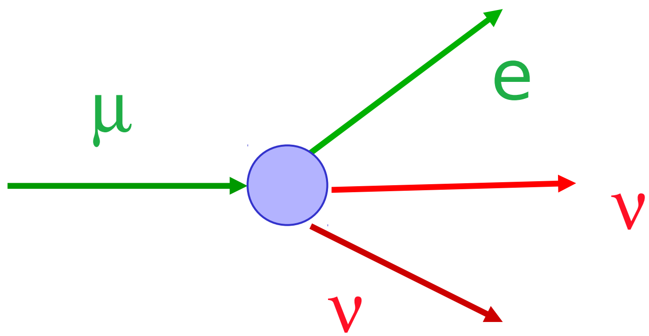

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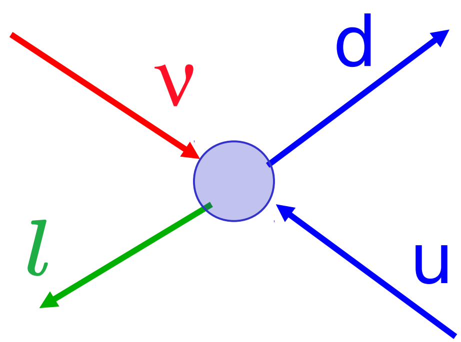
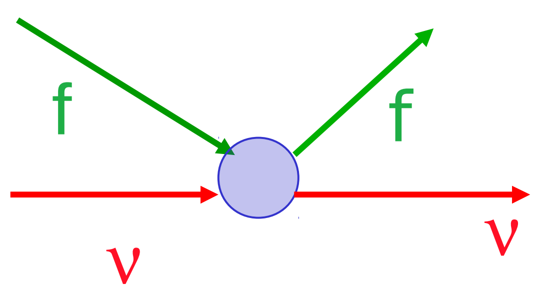


$\delta\mathcal{L}^d : \epsilon^d_{\mu\alpha}(\bar{\nu}_\alpha \gamma^\mu_L \mu)(\bar{d}\gamma_{\mu L} u)$

NSI@propagation

$\nu_\alpha f \to \nu_\beta f$



$\delta\mathcal{L}^m : \epsilon^m_{\alpha\beta}(\bar{\nu}_\alpha \gamma^\mu_L \nu_\beta)(\bar{f}\gamma_\mu f)$

NSI: what is that?

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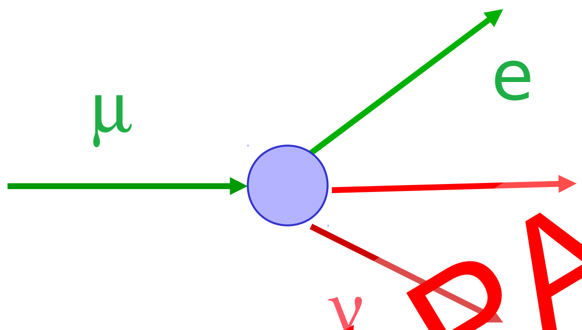
NSI@production

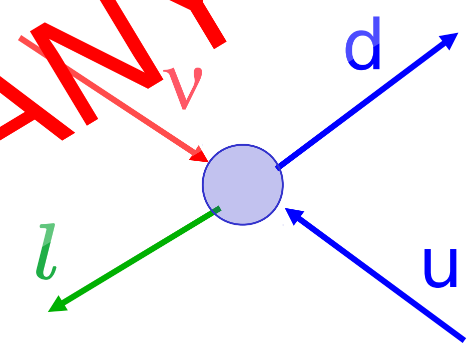
$$\mu^- \to e^- \nu_\mu \bar{\nu}_\alpha$$



$$\delta\mathcal{L}^p : \epsilon^p_{e\alpha} (\bar{\mu}\gamma^\mu_L \nu_\mu)(\bar{\nu}_\alpha \gamma_{\mu L} e)$$

NSI@detection

$$\nu_\alpha N \to l_\alpha^- N'$$



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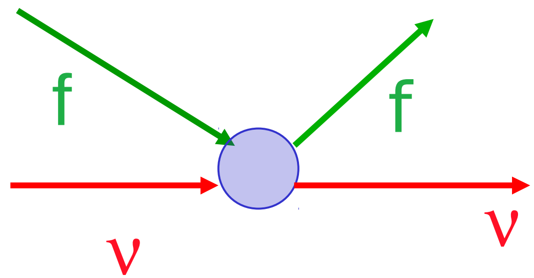

$$\delta\mathcal{L}^m : \epsilon^m_{\alpha\beta} (\bar{\nu}_\alpha \gamma^\mu_L \nu_\beta)(\bar{f}\gamma_\mu f)$$

TOO MANY PARAMETERS!

NSI: what is that?

$$\mathcal{L}_{eff} = \mathcal{L}^{SM} + \mathcal{L}_{\nu}^{mass} + \sum \delta\mathcal{L}_i^{p,d,m}$$

NSI@production

$$\boxed{\mu^- \to e^- \nu_\mu \bar{\nu}_\alpha}$$

Near Detectors

See Near Detector session:
R. Matev, S. Mishra
MINSIS workshop report,
arXiv:1009.0476 [hep-ph]
etc

NSI@detection

$$\boxed{\nu_\alpha N \to l_\alpha^- N'}$$

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NSI @ production/detection

- Zero distance effect @ L=0. Can be tested with Near Detectors

$$P_{\alpha\beta}(L=0) \propto |\epsilon^{s}_{\alpha\beta} + \epsilon^{d*}_{\beta\alpha}|^2$$

Analysis in the context of IDS-NF when only New Physics in production is considered: Tang, Winter 09; arXiv:0903.3039 [hep-ph]

Study in the context of IDS-NF when New Physics comes from dimension 6 effective operators (non-unitary lepton mixing matrix): Antusch, Blennow, Fernandez-Martinez, JLP 09; arXiv:0903.3986 [hep-ph]

⇓

Tau Near Detectors very useful to constrain this kind of New Physics

NSI @ production/detection

- Interference with standard neutrino oscillations at longer L gives interesting sensitivity to new CP-violation effects

$$P_{\mu\tau} = \sin^2 2\theta_{23} \sin^2 \frac{\Delta_{31} L}{2} - 2|\epsilon_{\mu\tau}| \sin\delta_{\mu\tau} \sin 2\theta_{23} \sin\Delta_{31} L + 4|\epsilon_{\mu\tau}|^2$$

If New Physics comes from dimension 6 effective operators. 50 GeV NuFact with Opera-like tau detector at L=130 km:
Gavela, Fernandez-Martinez, JLP, Yasuda 07; hep-ph:0703098

Similar new CP-violation effects with sterile neutrinos
Donini, Fuki, JLP, Meloni, Yasuda 08; arXiv: 0812.3703

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$$\boxed{\mu^- \to e^- \nu_\mu \bar{\nu}_\alpha}$$

NSI@detection

$$\boxed{\nu_\alpha N \to l_\alpha^- N'}$$

Effective matter
Potential:
Far Detectors

NSI@propagation

$$\boxed{\nu_\alpha f \to \nu_\beta f}$$

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Effective matter
Potential:
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$$\nu_\alpha f \to \nu_\beta f$$

NSI in propagation

$$\delta\mathcal{L}^m = -2\sqrt{2}G_F \sum_{f,P} \epsilon^{fP}_{\alpha\beta}(\bar{\nu}_\alpha \gamma^\mu_L \nu_\beta)(\bar{f}\gamma_\mu P f)$$

$$\Downarrow$$

$$A^{NSI} = A \begin{pmatrix} 1+\epsilon_{ee} & \epsilon_{e\mu} & \epsilon_{e\tau} \\ \epsilon^*_{e\mu} & \epsilon_{\mu\mu} & \epsilon_{\mu\tau} \\ \epsilon^*_{e\tau} & \epsilon^*_{\mu\tau} & \epsilon_{\tau\tau} \end{pmatrix}$$

$$H = \frac{1}{2} U^\dagger diagonal\{m_1^2, m_2^2, m_3^2\} U + A^{NSI}$$

In the SM flavour basis

NSI in propagation

- Model independent approach. Mild experimental constraints:

$$|\varepsilon^{\oplus}_{\alpha\beta}| < \begin{pmatrix} 4.2 & 0.33 & 3.0 \\ 0.33 & 0.068 & 0.33 \\ 3.0 & 0.33 & 21 \end{pmatrix} \qquad |\varepsilon^{\odot}_{\alpha\beta}| < \begin{pmatrix} 2.5 & 0.21 & 1.7 \\ 0.21 & 0.046 & 0.21 \\ 1.7 & 0.21 & 9.0 \end{pmatrix}$$

neutral Earth-like matter *neutral Solar-like matter*

C. Biggio, M. Blennow and E.Fernandez-Martinez; ArXiv: 0907.0097

- However, from a theoretical point of view, NSI parameters are not expected to be so huge at all!

Gavela, Hernandez, Ota, Winter 2008; ArXiv: 0809.3451

Antusch, Baumann, Fernandez-Martinez 2008; ArXiv: 0807.1003

NSI in propagation

- NSI effects in propagation have been widely studied in the literature, even in Neutrino Factories.

  Blennow, Fernandez-Martinez, Gavela, Huber, Kopp, Lindner, Meloni, Minakata, Nunokawa, Ohlsson, Ota, Ribeiro, Schwetz,Tang, Uchinami, Valle, Winter, Zukanovich-Funchal, etc, etc

- However, correlations have not been studied before.

- We want to study correlations ⇒ Many parameters at the same time in the simulations!

  Huber, Lidner, Winter 04

- MonteCUBES allows to introduce all parameters at once

  M.Blennow, E. Fernández-Martínez; arXiv:0903.3985

Why a Neutrino Factory?

- Long baseline
- High energies
- Multi-channel facility

Large matter effects!

Why a Neutrino Factory?

- Long baseline
- High energies
- Multi-channel facility

Large matter effects!

- Nice sensitivities to standard oscillation parameters
- Finally it seems that $\theta_{13} \neq 0$!!

T2K, Minos,
Daya Bay, Reno

Optimization of NF to
search for New Physics?

Set ups

1. IDS25:
   - 25 GeV muons;
   - Two 50 kton MIND detectors
     - @4000 km
     - @7500 km
   - 5×10^{20} useful muon decays/year/baseline/polarity
   - Running time = 5+5

Set ups

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2. IDS50: 50 GeV upgrade of the IDS25

Set ups

3. 1B50:

- 50 GeV muons:
- A composite detector @ 4000 km:
  - 50 kton MIND to detect muons;
  - 4 kton MECC to detect taus
- Double flux: 10^{21} useful muon decays/year/polarity
- Running time: 5+5

Set ups

4. LENF:

- 4.5 GeV muons;
- One 20 kton magnetized TASD @1300 km
- $1.4 \cdot 10^{21}$ useful muon decays/year/polarity
- Running time: 10+10

Fernandez-Martinez, Li, and Pascoli (work in preparation)

Information from oscillation probalilities

Brief review of the analytical dependences:

- $\epsilon_{\alpha\alpha}$ appear always in the same combination:

$$\epsilon_{ee} - \epsilon_{\tau\tau} \Longleftrightarrow \mathcal{O}\left(\epsilon^3\right)$$

$\epsilon_{\mu\mu} - \epsilon_{\tau\tau} \Longleftrightarrow \mathcal{O}\left(\epsilon^2\right)$ only in $P_{\mu\mu}, P_{\mu\tau}$

T. Kikuchi, H. Minakata, S. Uchinami; arXiv:0809.3312v2 [hep-ph]

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- Linear dependence on $\epsilon_{\mu\tau}$:

$$P_{\mu\mu}^{NSI} = -P_{\mu\tau}^{NSI} = -\mathrm{Re}\left(\epsilon_{\mu\tau}\right)\left(AL\right) sin\left(\Delta_{31} L\right) + \mathcal{O}\left(\epsilon^2\right)$$

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→ cuadratic dependence

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$\longrightarrow$ cuadratic dependence

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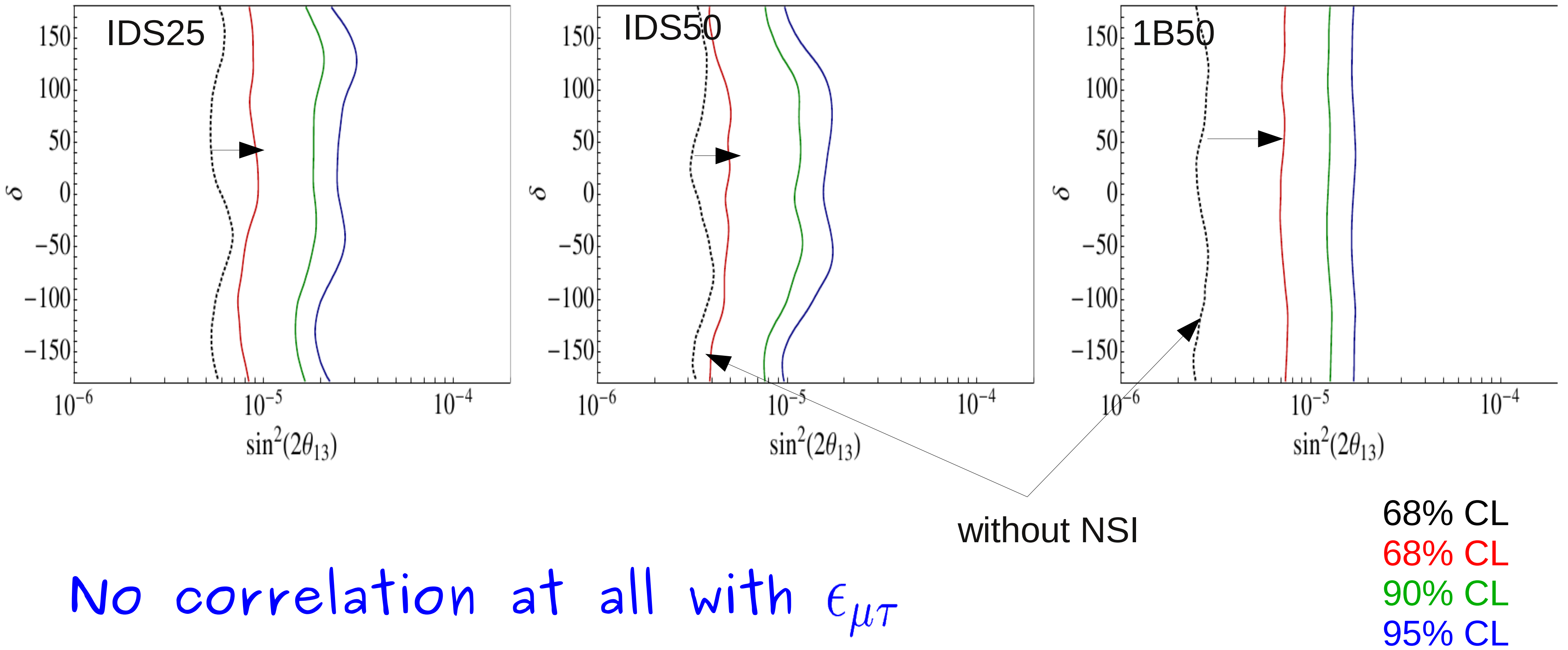
Sensitivity to θ_{13} and δ in presence of NSI

Sensitivity to θ_{13} & δ in presence of NSI



No correlation at all with $\epsilon_{\mu\tau}$

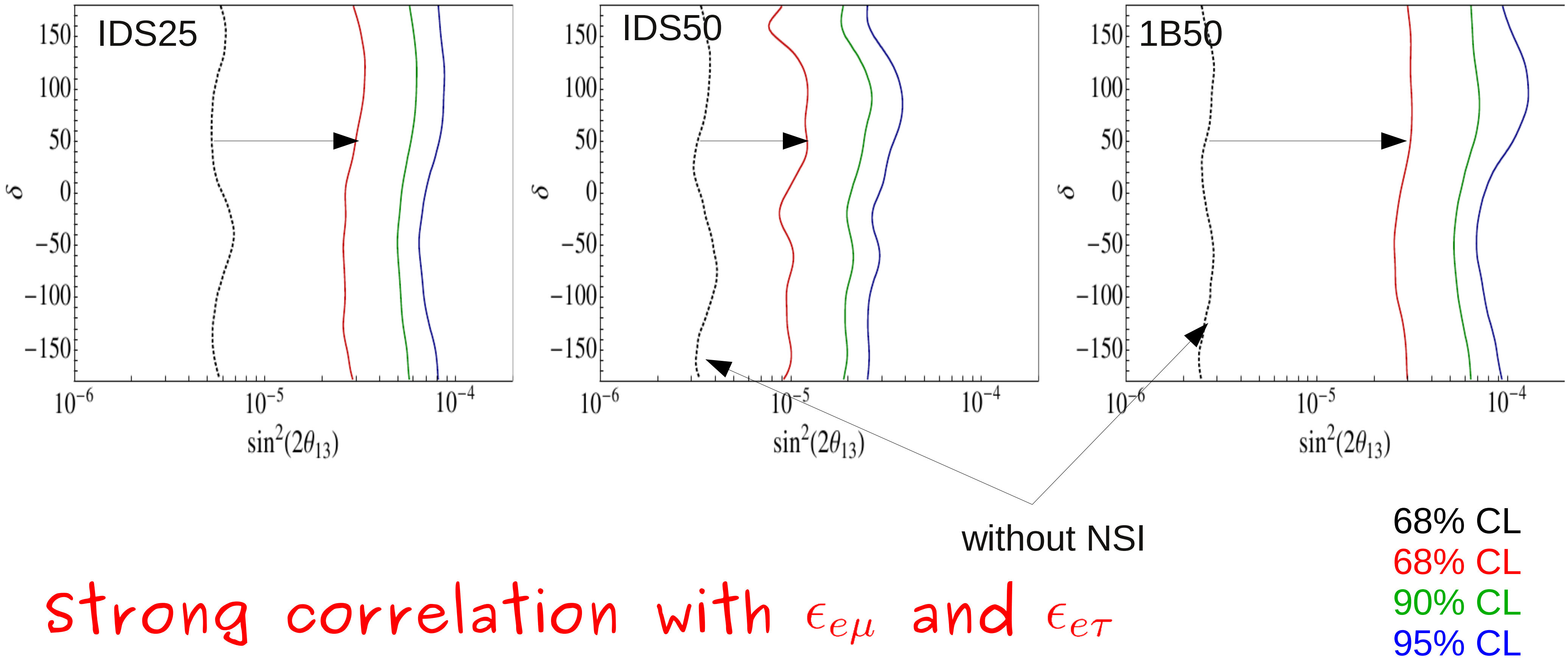
Slight worsening exclusively due to $\epsilon_{\alpha\alpha}$

Marginalization performed over all standard parameters

$$+$$

$$\epsilon_{\mu\tau},\ \epsilon_{\alpha\alpha}$$

Sensitivity to θ_{13} & δ in presence of NSI



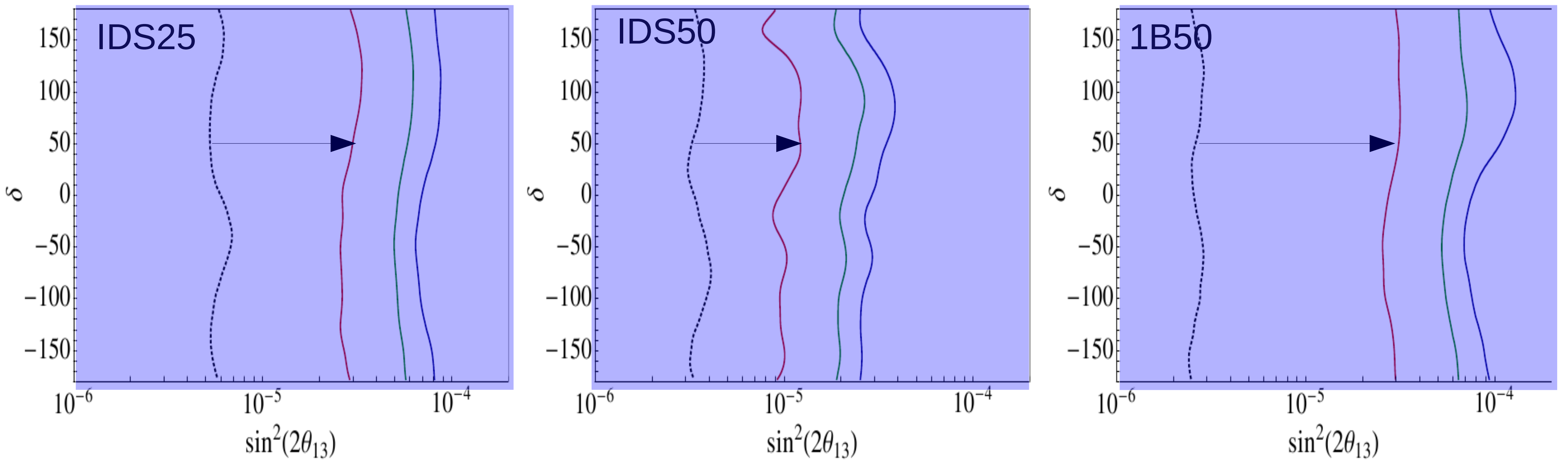
strong correlation with $\epsilon_{e\mu}$ and $\epsilon_{e\tau}$

Marginalization performed over all standard parameters

$+$

$\epsilon_{e\mu}, \epsilon_{e\tau}, \epsilon_{\alpha\alpha}$

Sensitivity to θ_{13} & δ in presence of NSI



Results from T2K, Daya Bay and Reno!!!

$$\sin^2 2\theta_{13} > 6 \cdot 10^{-2}$$ @ 95% CL

see talk by K. McDonald (Daya Bay)

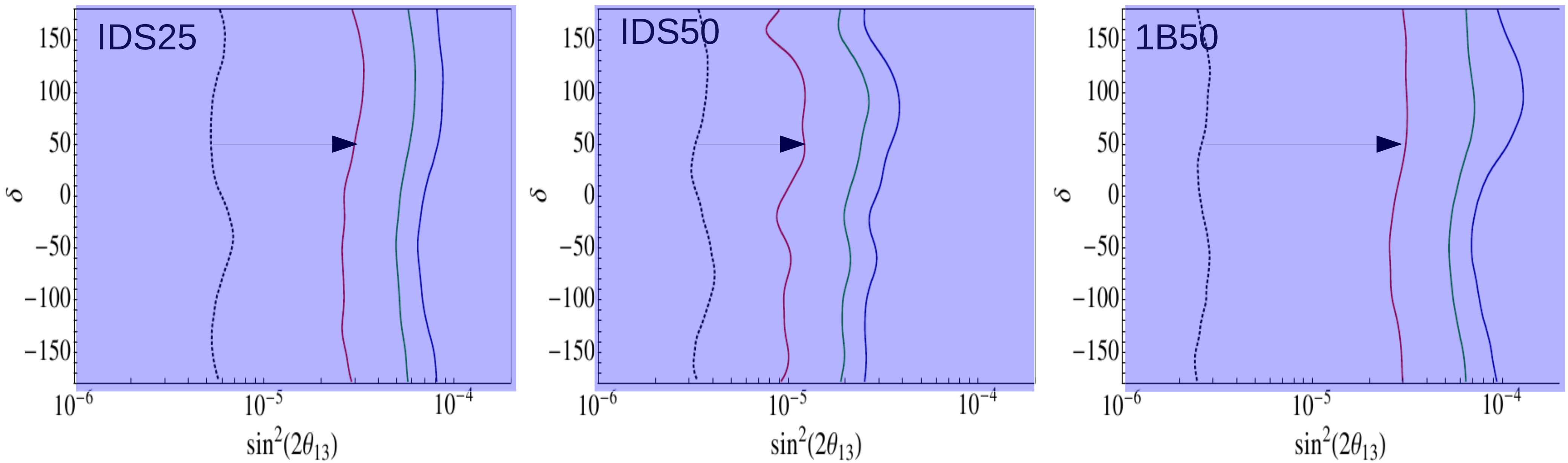
68% CL
68% CL
90% CL
95% CL

Marginalization performed over all standard parameters

$$+$$

$$\epsilon_{e\mu},\ \epsilon_{e\tau},\ \epsilon_{\alpha\alpha}$$

Sensitivity to θ_{13} & δ in presence of NSI



$\sin^2 2\theta_{13} > 6 \cdot 10^{-2}$ @ 95% CL

See talk by K. McDonald (Daya Bay)

68% CL
68% CL
90% CL
95% CL

Reasonable inputs for NSI would NOT affect the future sensitivity to θ_{13} and δ.

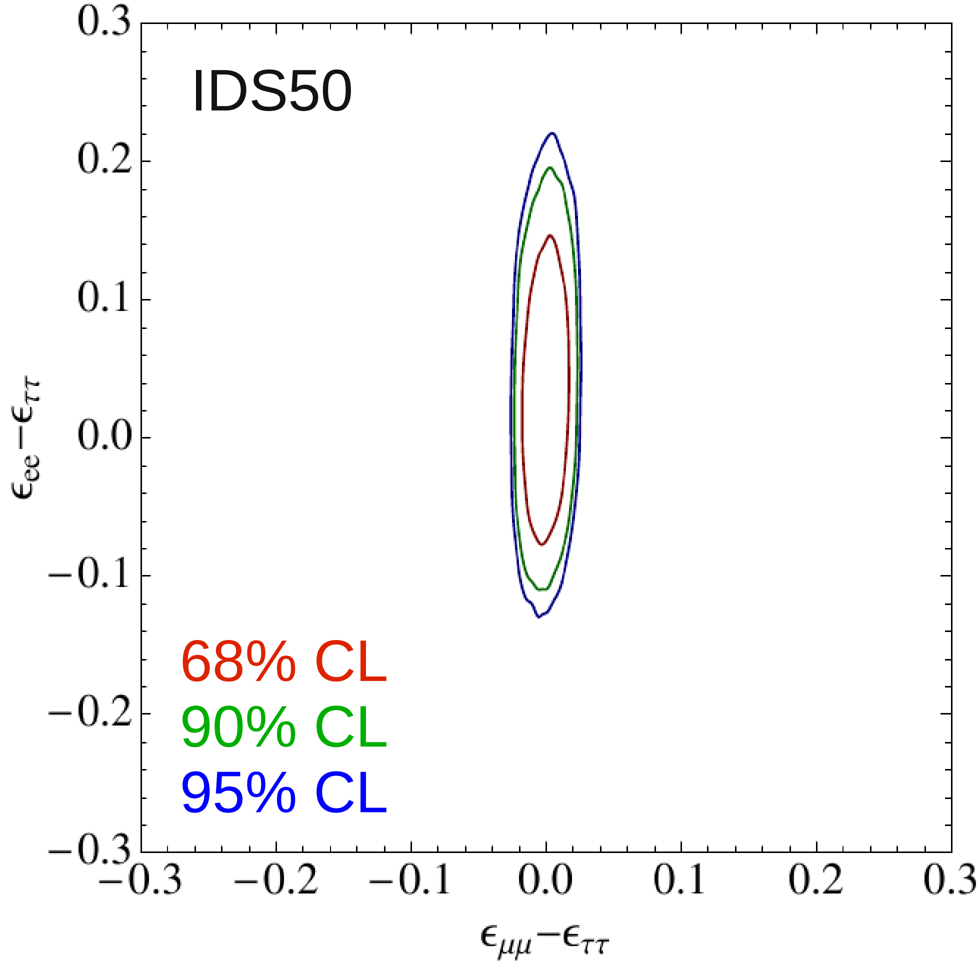
Marginalization performed over all standard parameters

$+$

$\epsilon_{e\mu},\ \epsilon_{e\tau},\ \epsilon_{\alpha\alpha}$

Sensitivity to NSI parameters

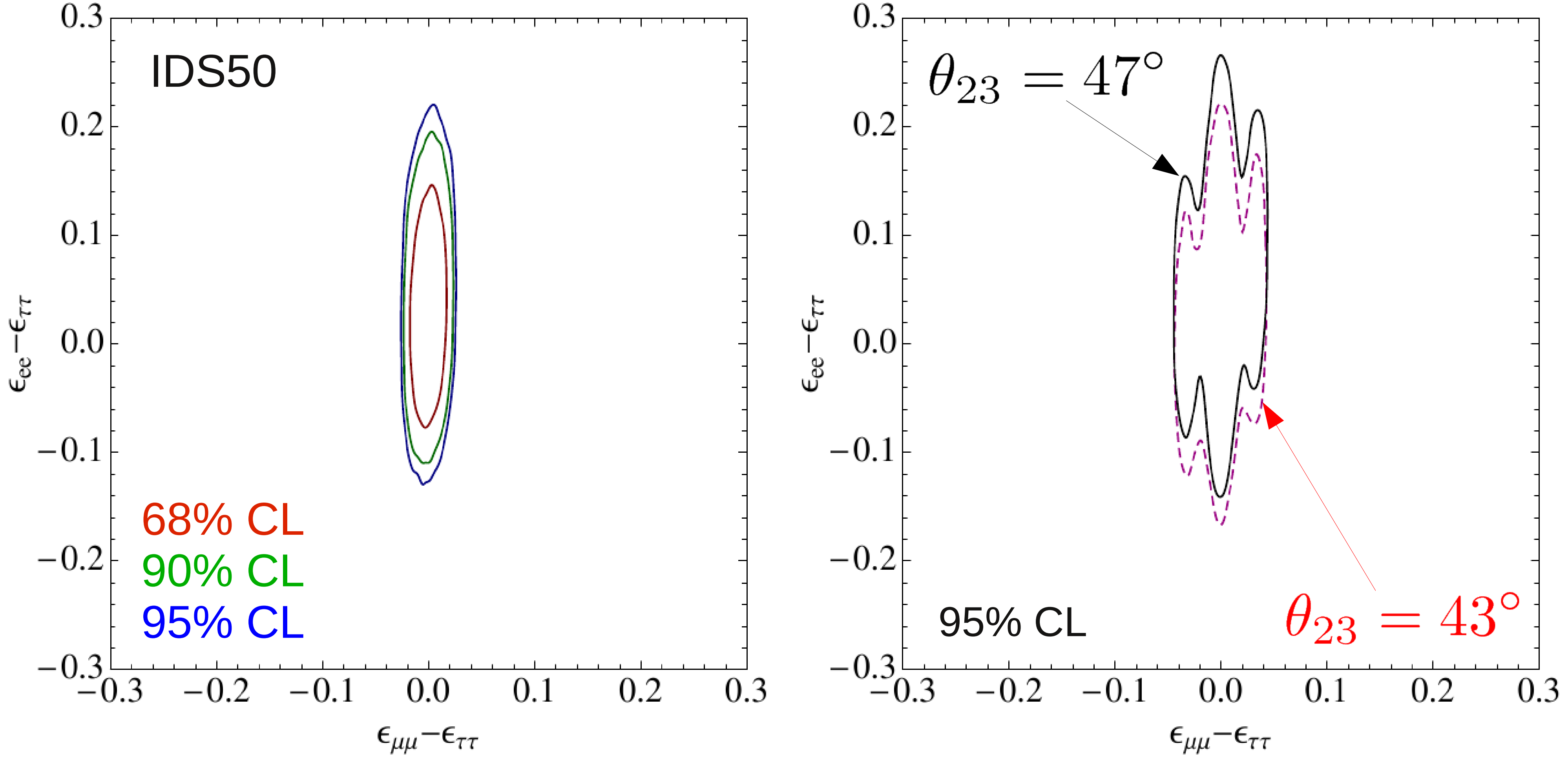
Sensitivity to $\epsilon_{\alpha\alpha}$



$$\theta_{13} = 0$$
$$\theta_{23} = 45^\circ$$

(Marginalization performed over all parameters)

Sensitivity to $\epsilon_{\alpha\alpha}$

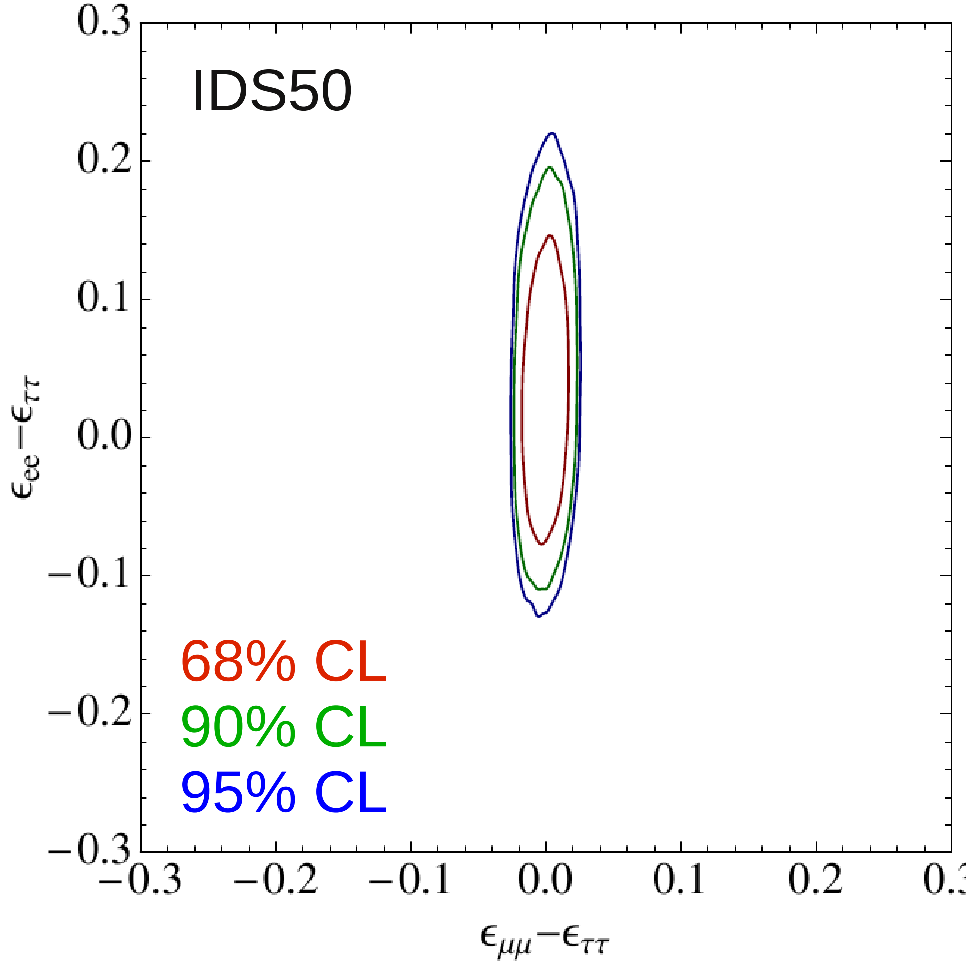


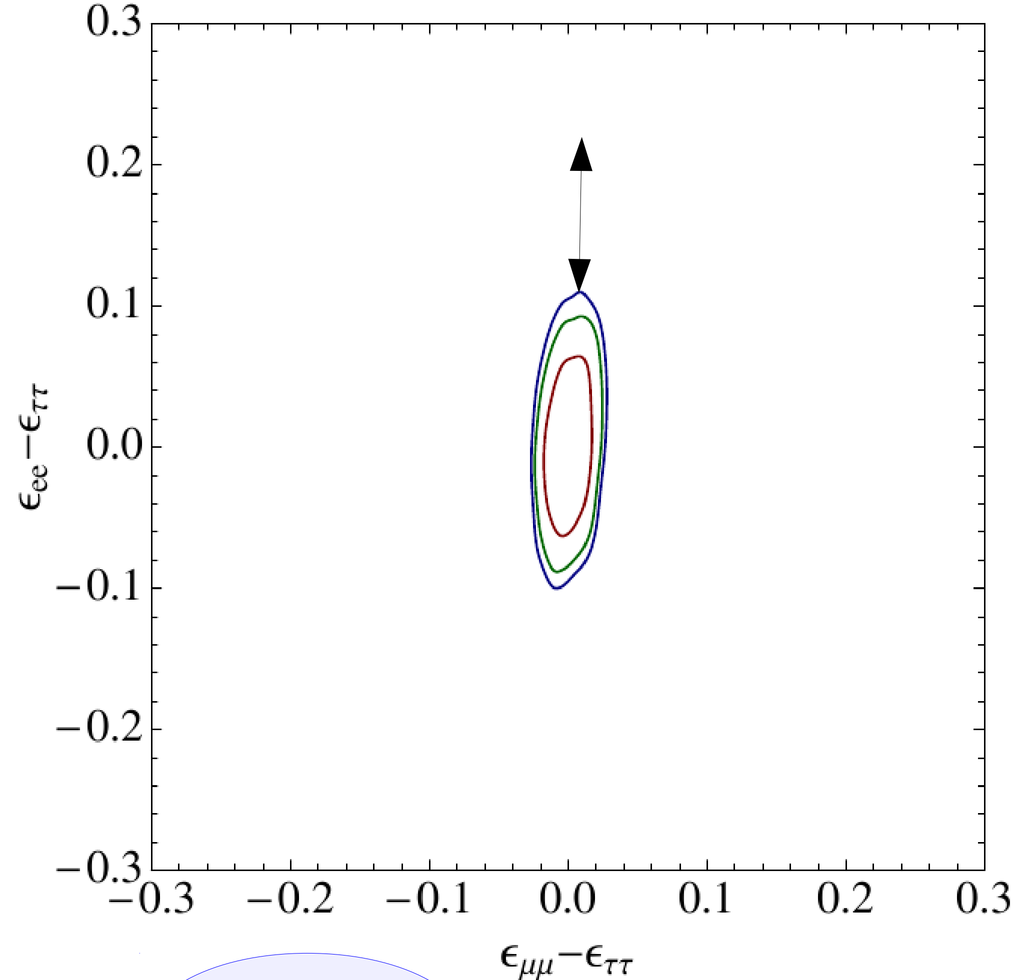
$\theta_{13} = 0$
$\theta_{23} = 45^\circ$

$\theta_{13} = 0$
$\delta\theta_{23} \neq 0$

(Marginalization performed over all parameters)

Sensitivity to $\epsilon_{\alpha\alpha}$



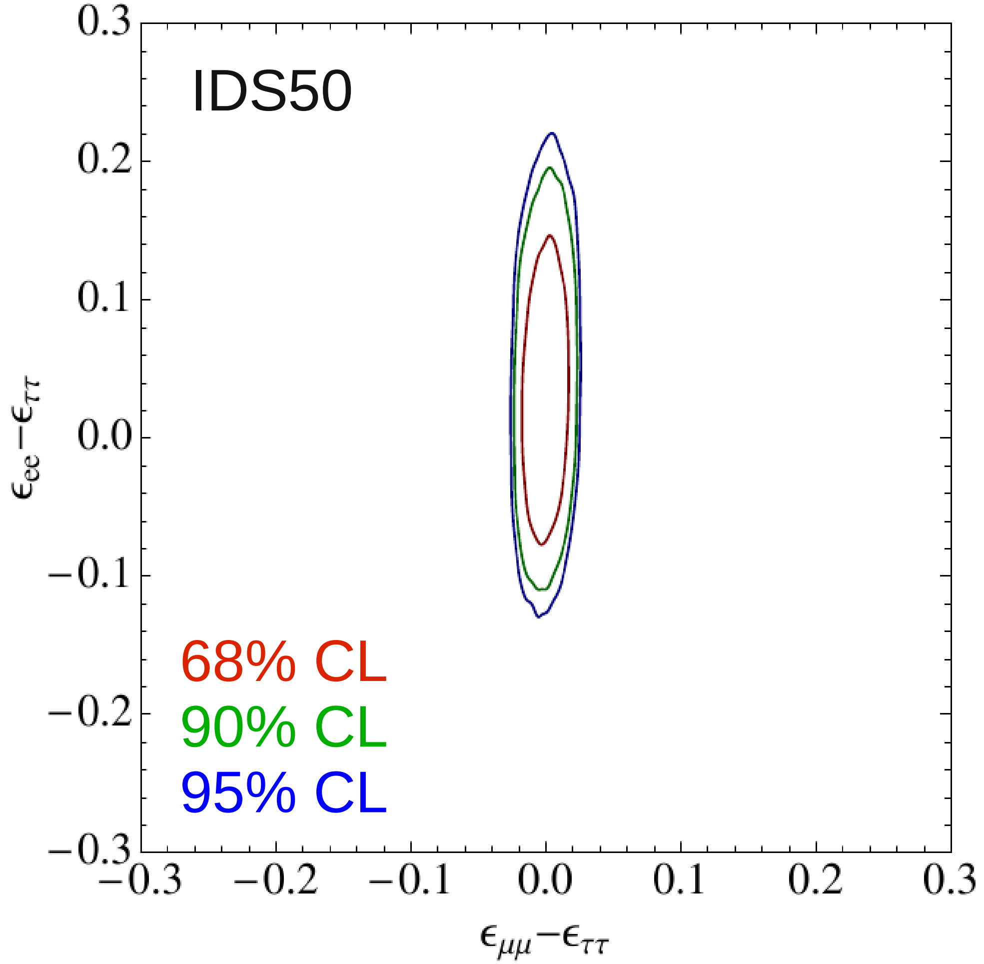


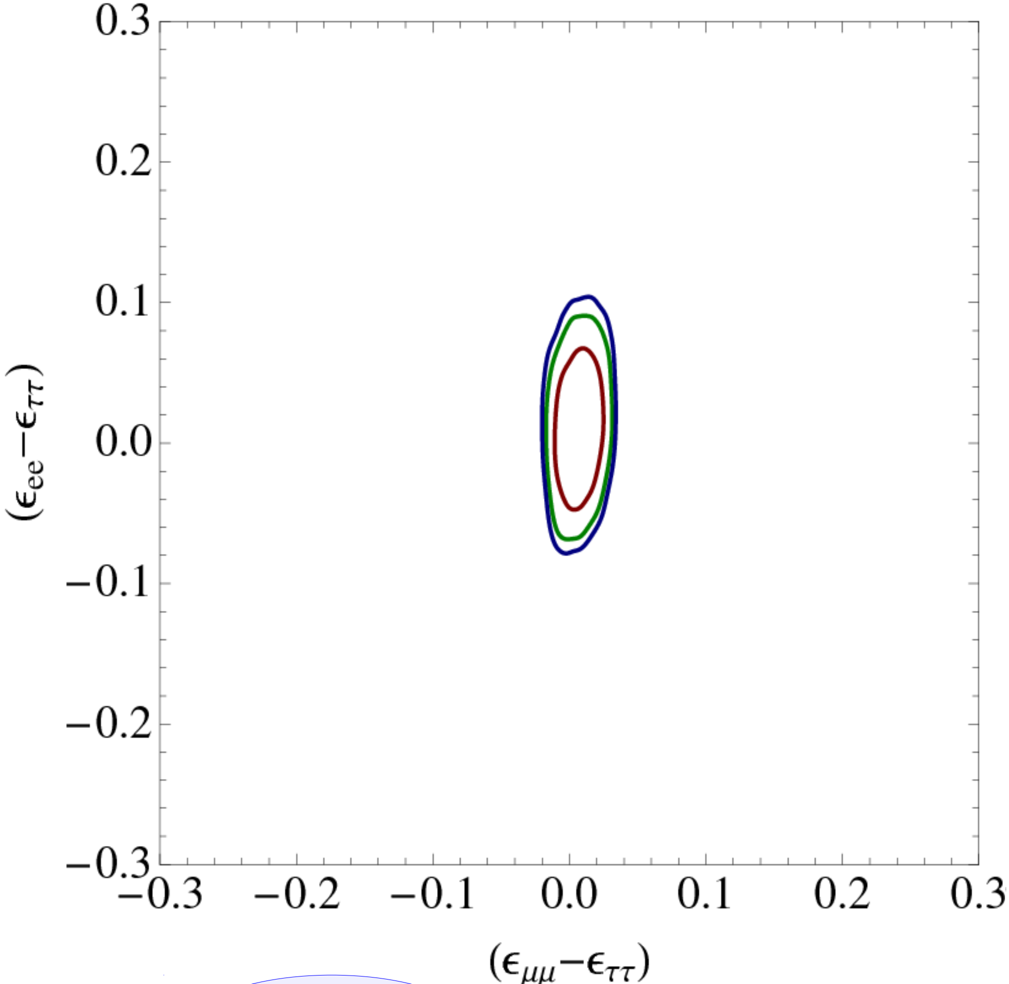
$\theta_{13} = 0$
$\theta_{23} = 45^\circ$

$\theta_{13} = 3^o$
$\theta_{23} = 45^\circ$

(Marginalization performed over all parameters)

Sensitivity to $\epsilon_{\alpha\alpha}$





$$\theta_{13} = 0$$
$$\theta_{23} = 45^\circ$$

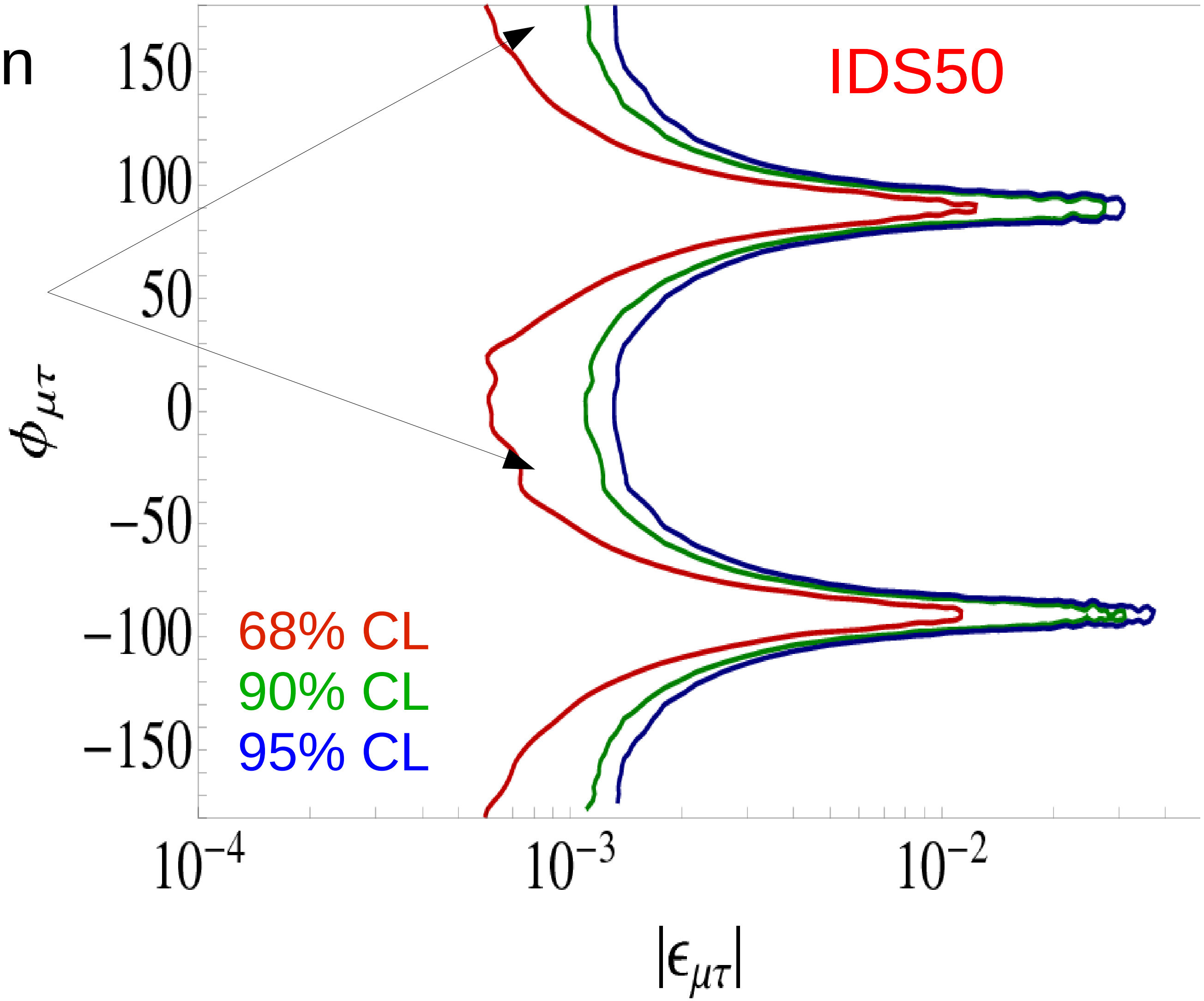
$$\theta_{13} = 10^o$$
$$\theta_{23} = 45^\circ$$

(Marginalization performed over all parameters)

Sensitivity to $\epsilon_{\mu\tau}$

- Linear dependence on the real part:

$$P_{\mu\mu}^{NSI}(\varepsilon) \propto \mathrm{Re}(\epsilon_{\mu\tau})$$



(Marginalization performed over all parameters)

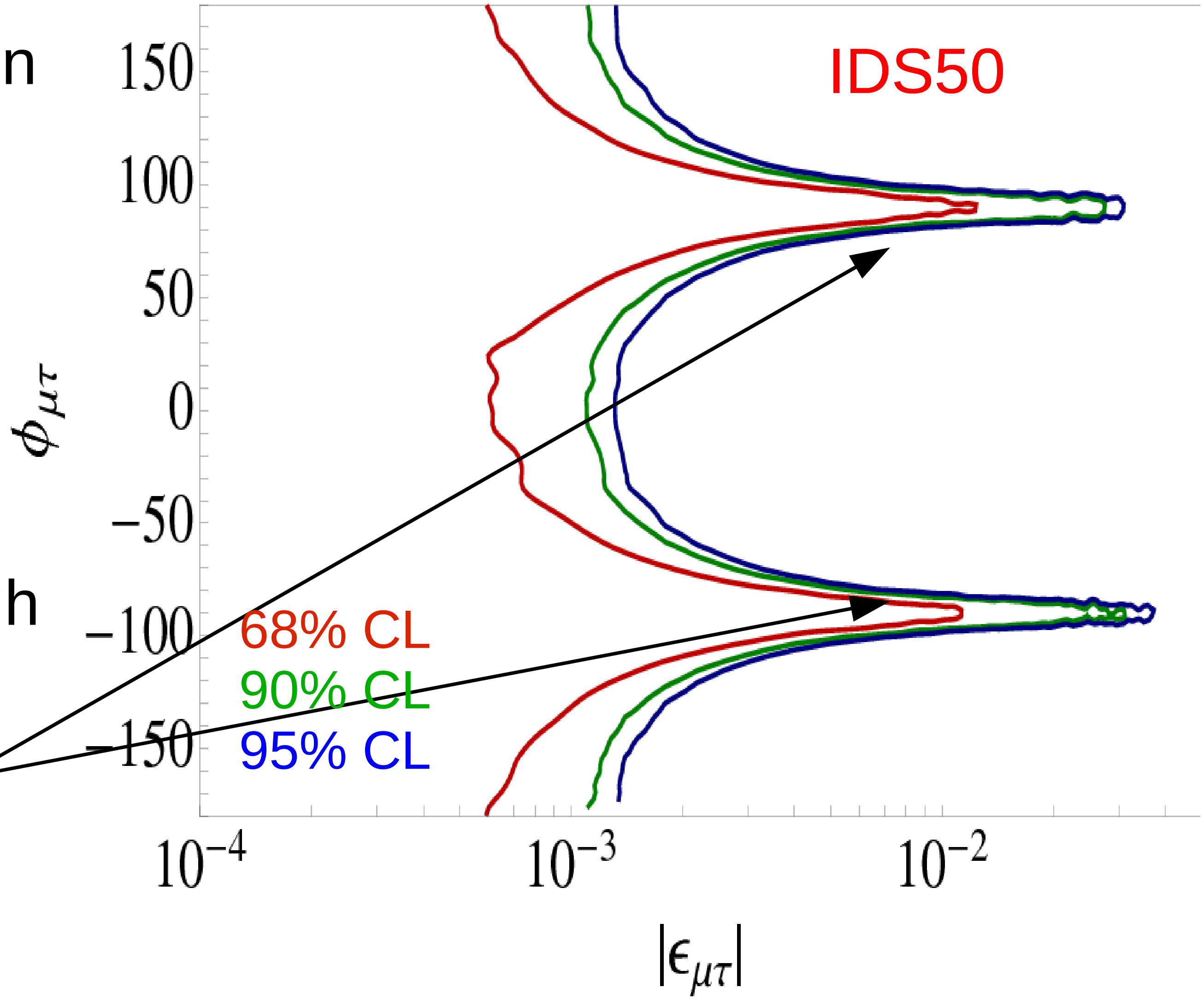
Sensitivity to $\epsilon_{\mu\tau}$

- Linear dependence on the real part:

$$P_{\mu\mu}^{NSI}(\varepsilon) \propto \mathrm{Re}(\epsilon_{\mu\tau})$$

- Dependence on the imaginary part through 2nd order terms:

$$P_{\mu\mu}^{NSI} = P_{\mu\mu}^{NSI}(\varepsilon) + (\mathrm{Im}(\epsilon_{\mu\tau}))^2 + \ldots$$

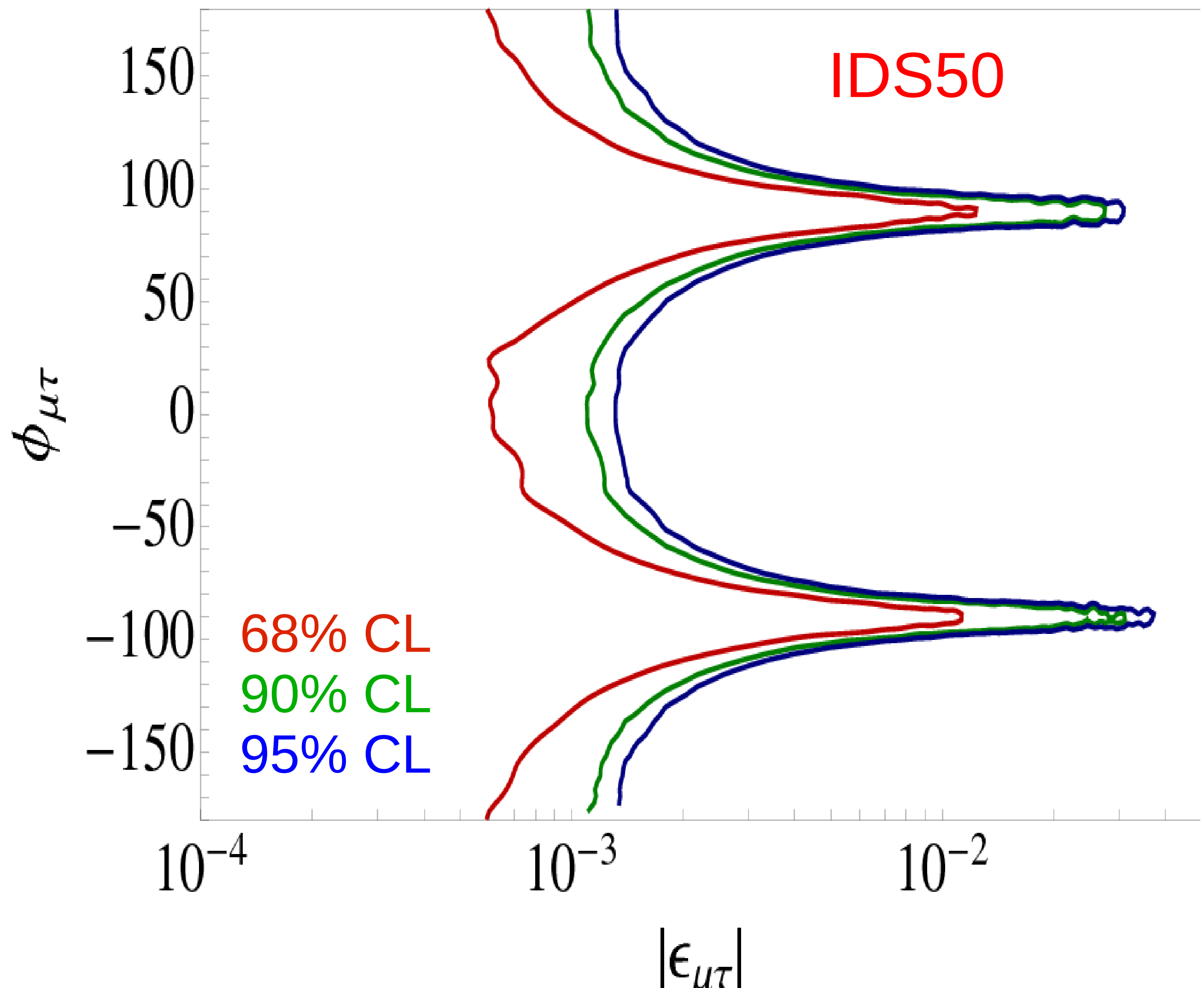


(Marginalization performed over all parameters)

Sensitivity to $\epsilon_{\mu\tau}$

- No correlation with θ_{13}, $\epsilon_{\alpha\beta}$
  Mild correlation with $\epsilon_{\alpha\alpha}$

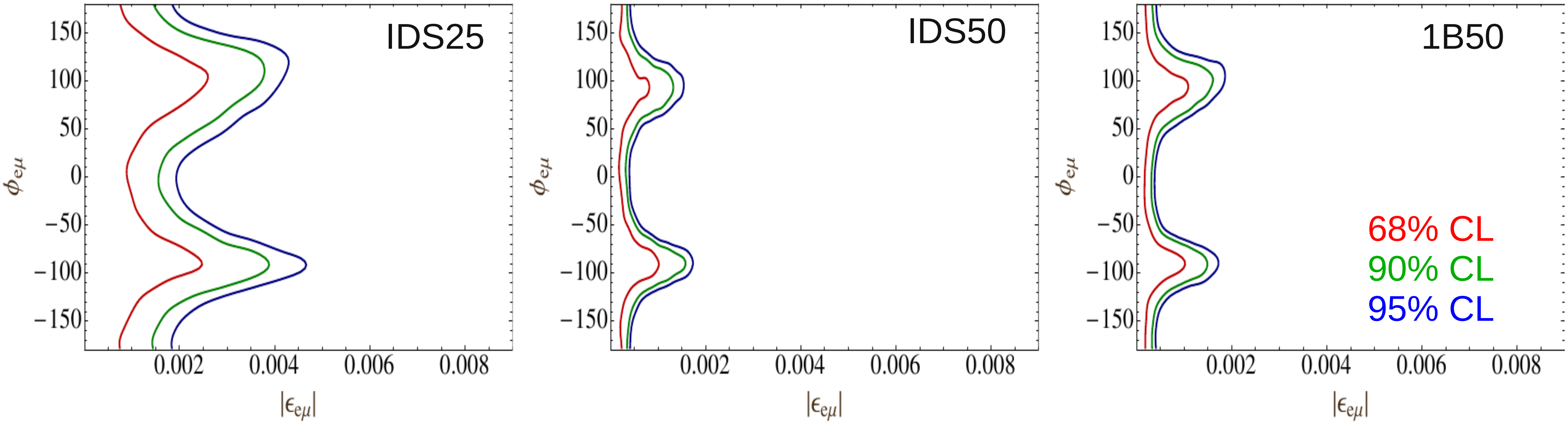
- Same result for all set-ups.



Here $\overline{\theta_{13}} = 10^o$ but no significant differences for smaller inputs.

(Marginalization performed over all parameters)

Sensitivity to $\epsilon_{e\mu}$ $\qquad \overline{\theta_{13}} = 0$

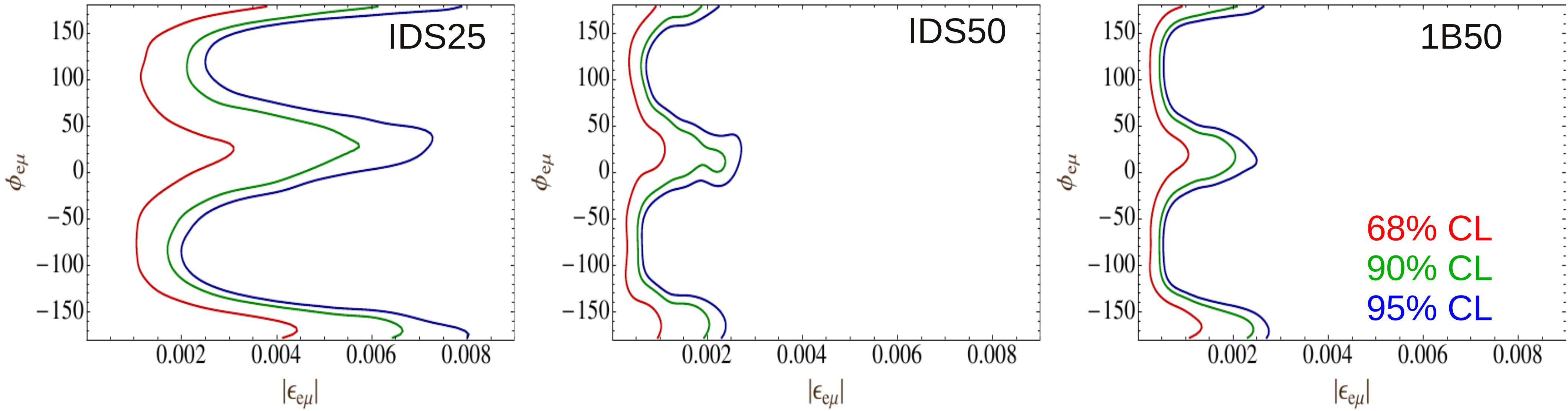


Key factor: **ENERGY** (either with 1 or 2 baselines)

(Marginalization performed over all parameters)

Sensitivity to $\epsilon_{e\mu}$

$\overline{\theta_{13}} = 3^o$; $\overline{\delta} = -\pi/2$



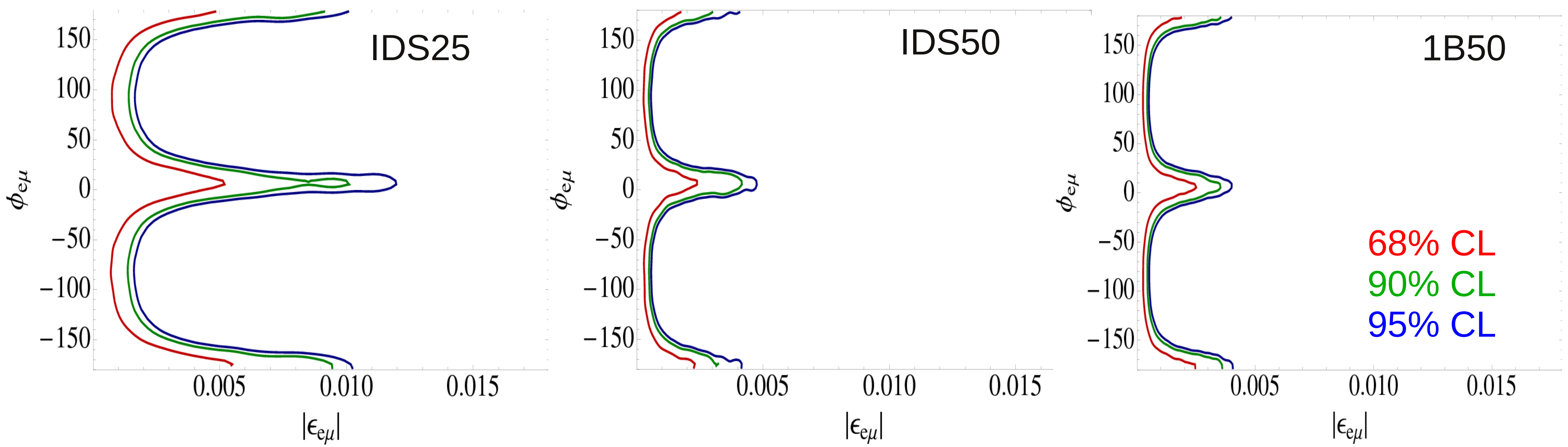
$\theta_{13} \neq 0$

worse sensitivity to $\epsilon_{e\mu}$
(more standard oscillation "background")

Key factor: **ENERGY** (either with 1 or 2 baselines)

(Marginalization performed over all parameters)

Sensitivity to $\epsilon_{e\mu}$ $\quad \overline{\theta_{13}} = 10^o; \ \overline{\delta} = -\pi/2$



$\theta_{13} \neq 0$ ⇒ *worse sensitivity* to $\epsilon_{e\mu}$
(more standard oscillation "background")

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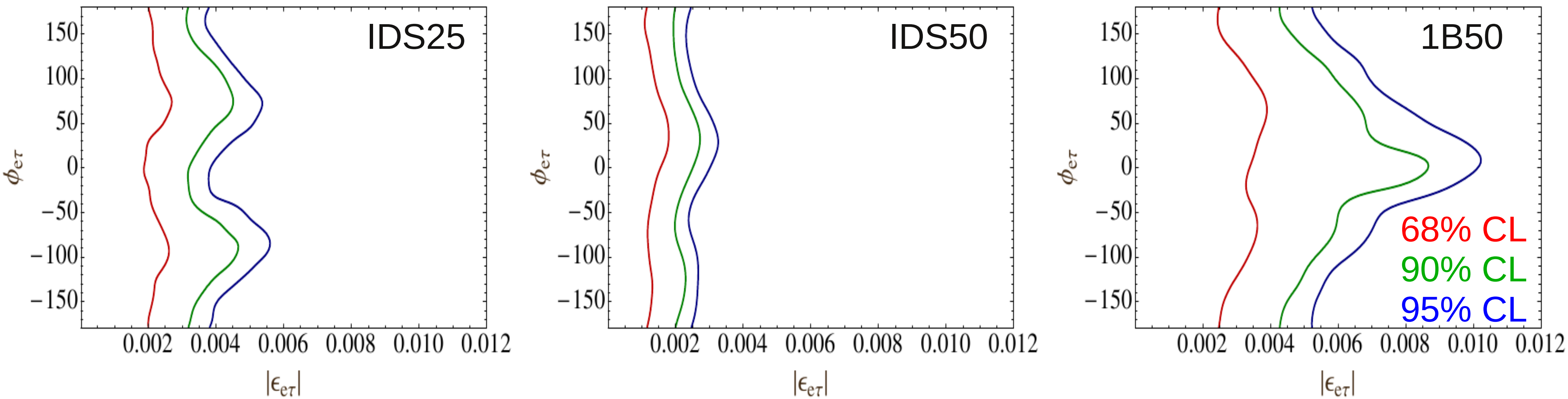
Sensitivity to $\epsilon_{e\tau}$ $\quad \overline{\theta_{13}} = 0$

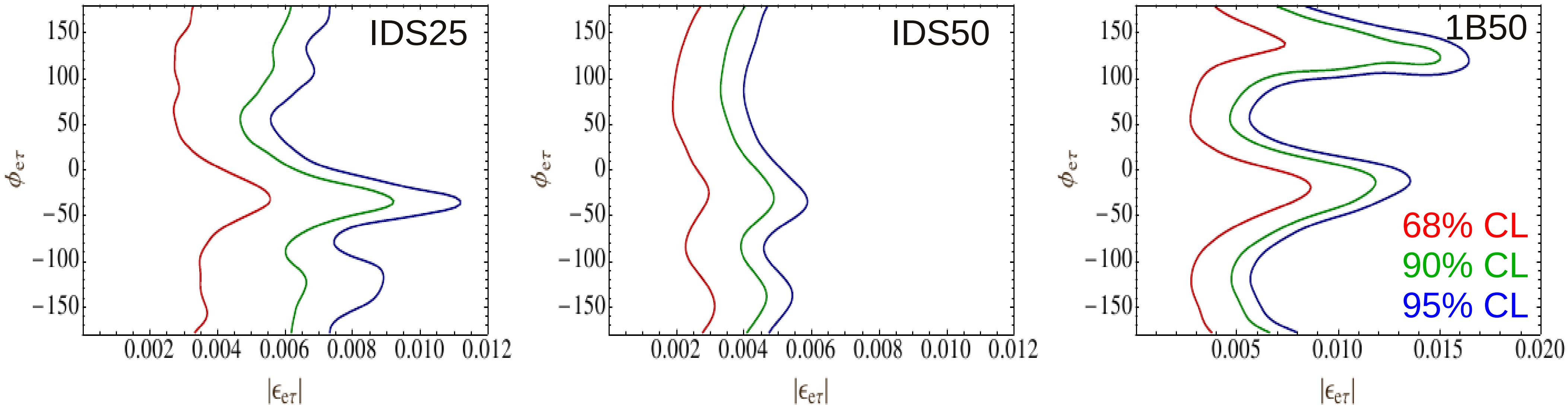


Key factor: Combination of Baselines

(Marginalization performed over all parameters)

Sensitivity to $\epsilon_{e\tau}$

$\overline{\theta_{13}} = 3^o; \overline{\delta} = -\pi/2$



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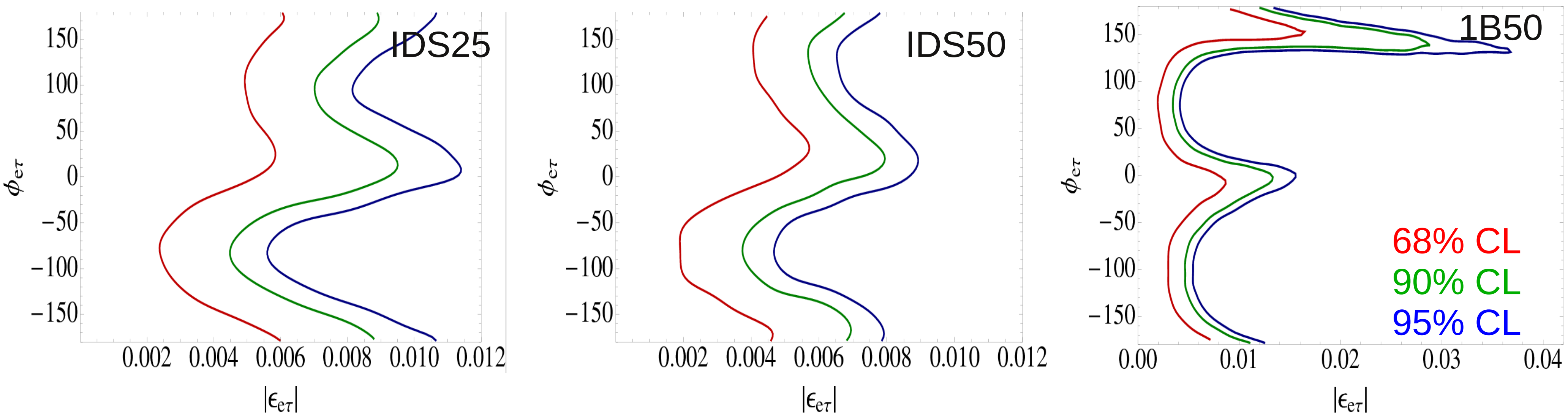

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Sensitivity to NSI at LENF

Fernandez-Martinez, Li and Pascoli (work in preparation)

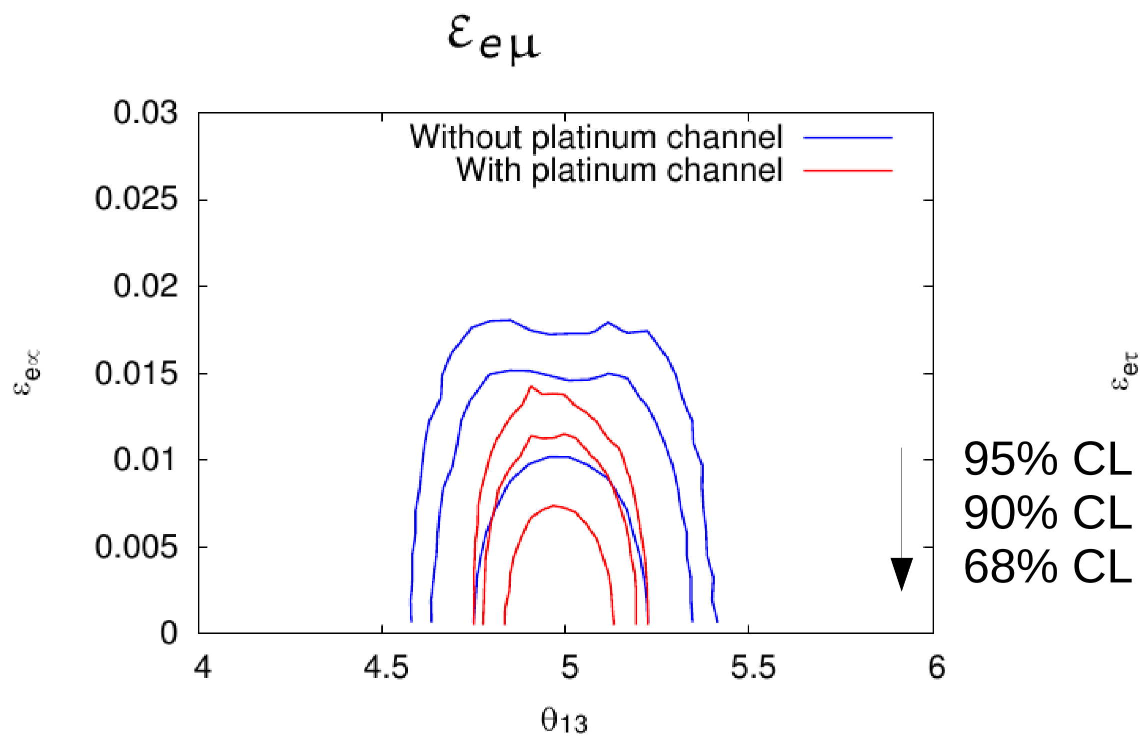
- Sensitive to Golden $(\nu_e \to \nu_\mu, \overline{\nu}_e \to \overline{\nu}_\mu)$, disappearance $(\nu_\mu \to \nu_\mu, \overline{\nu}_\mu \to \overline{\nu}_\mu)$ and *maybe* Platinum $(\nu_\mu \to \nu_e, \overline{\nu}_\mu \to \overline{\nu}_e)$ channels

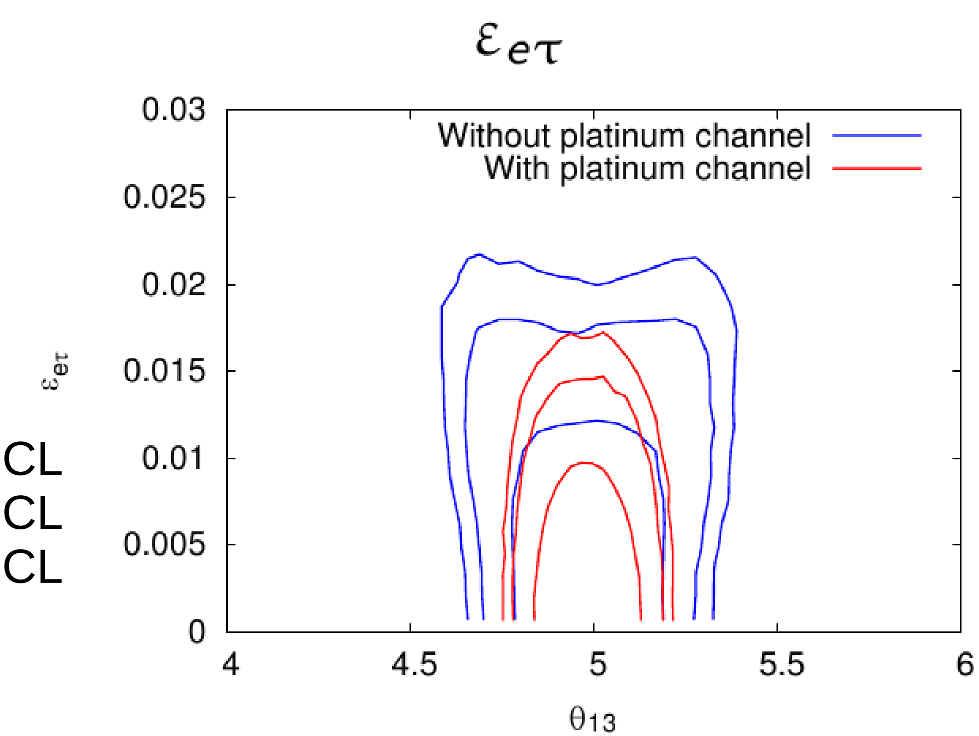
↓

In principle, sensitive to all NSI parameters

Sensitivity to NSI at LENF

Fernandez-Martinez, Li and Pascoli (work in preparation)





- Sensitivities down to $\mathcal{O}(10^{-2})$

$$\overline{\theta_{13}} = 5^o;\ \overline{\delta} = 0$$

- Non negligible impact of the platinum channel
- Update in preparation

New CP violation effects

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We have studied the region of the $(\delta, \phi_{e\mu}, \phi_{e\tau})$ parameter space for which a CP-violating signal can be distinguised from a CP-conserving one.

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The result depends strongly on the input values of θ_{13}, $\epsilon_{e\mu}$ and $\epsilon_{e\tau}$. In arXiv: 1105.5936 we distinguished 2 cases:

- $\theta_{13} > 3°$, such that it has been tested at T2K, Daya Bay and Reno $\longrightarrow$ We fix θ_{13}

- $\theta_{13} < 3°$, such that it could not have been tested. $\longrightarrow$ We marginalize over θ_{13}

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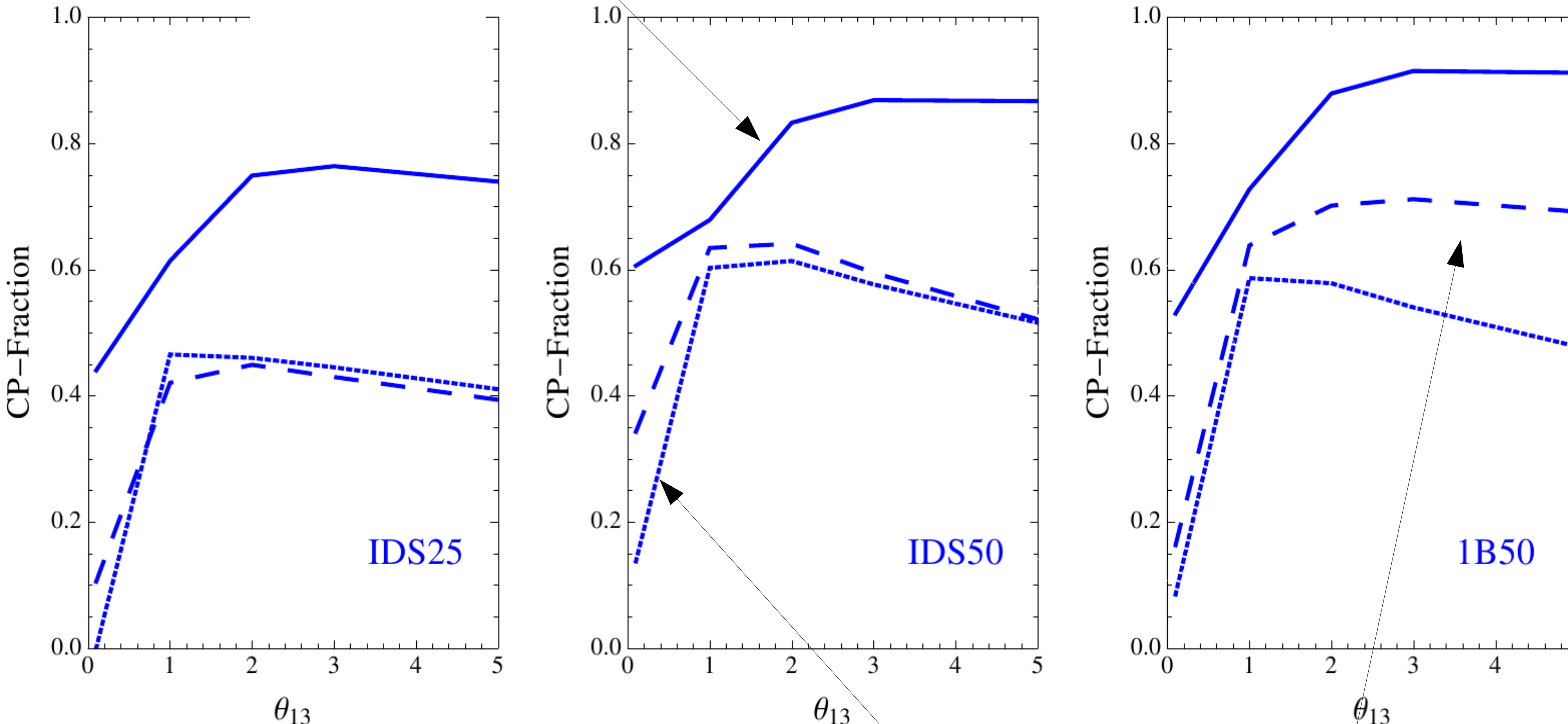
Generalized CP-fraction (CP-volume)

$(|\epsilon_{e\mu}|, |\epsilon_{e\tau}|) = (10^{-2}, 10^{-2})$



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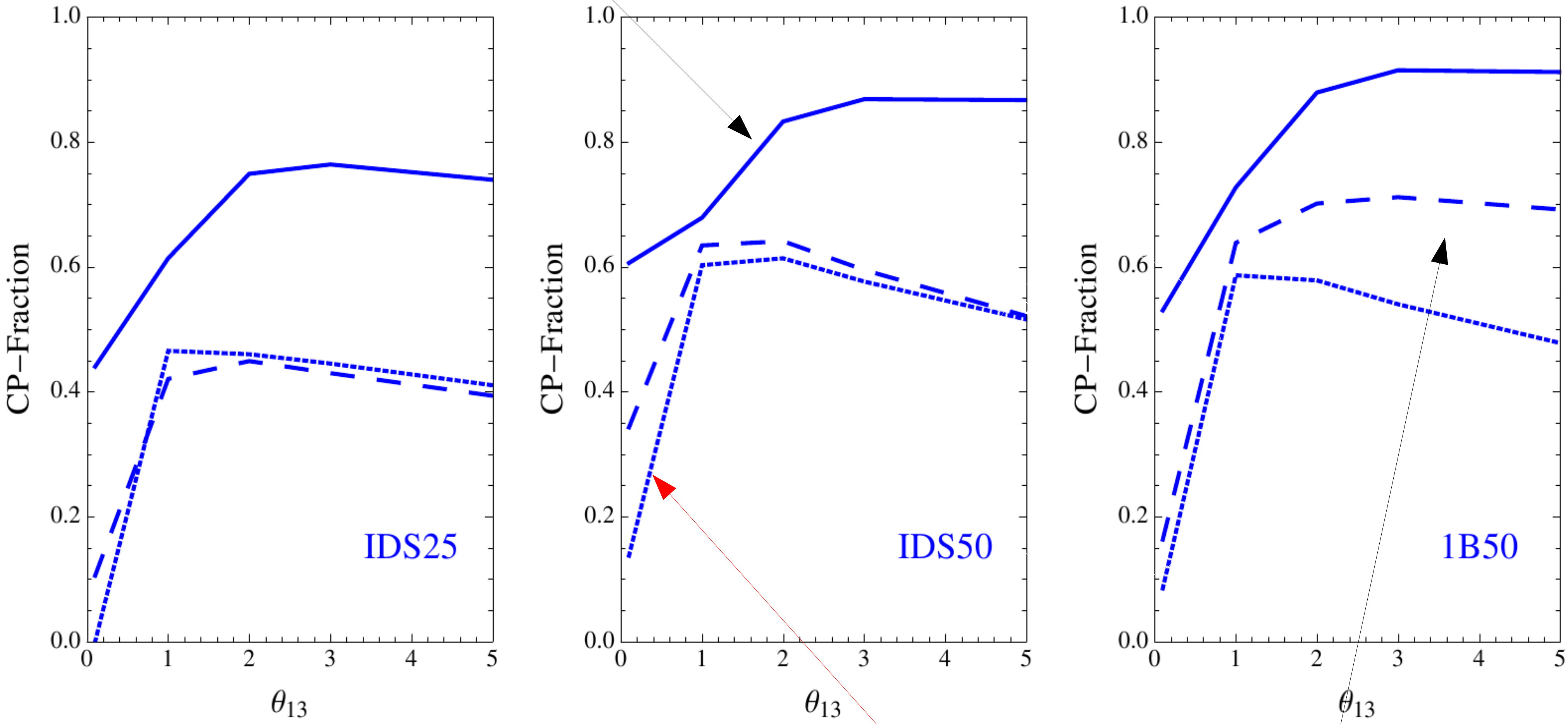

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Dominated by standard CP-violation

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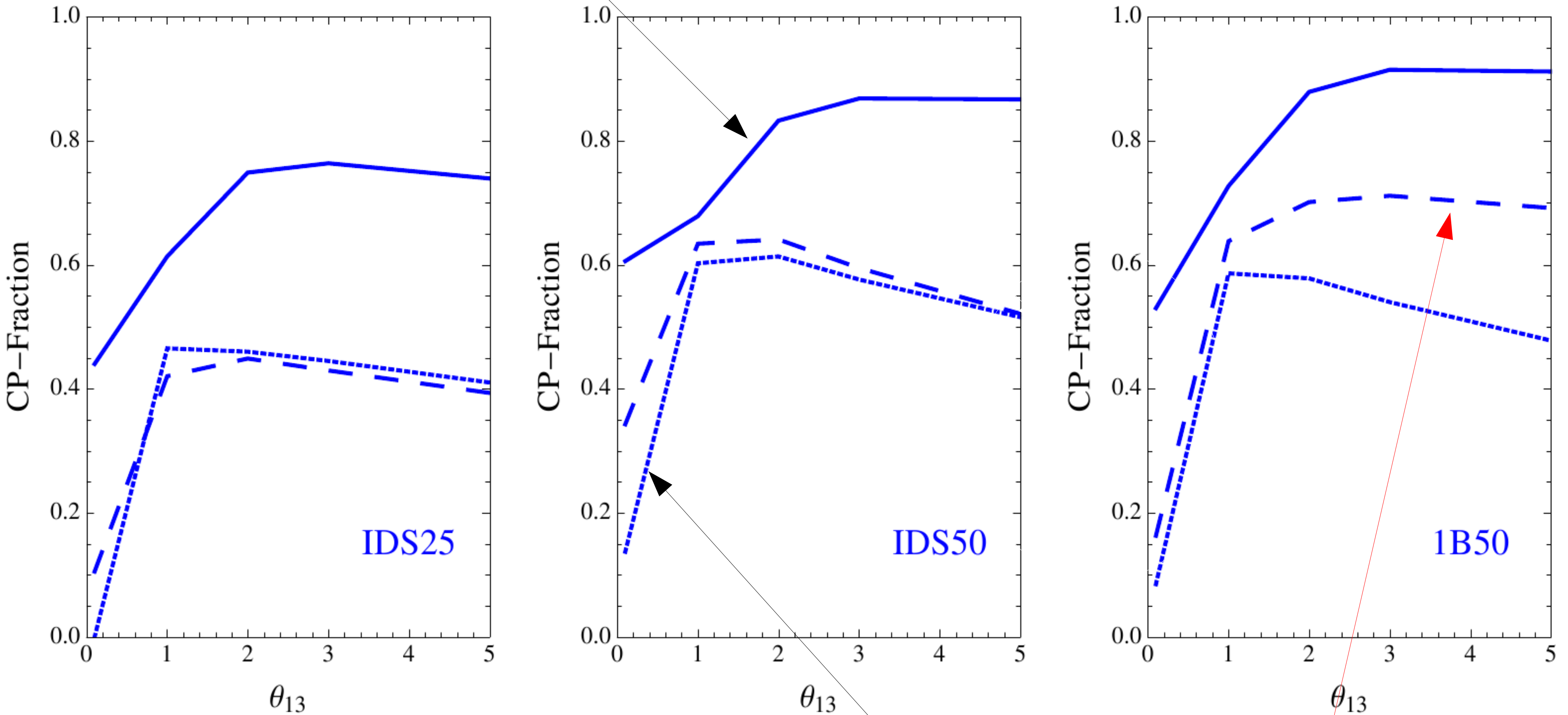

Mainly dominated by standard CP-violation

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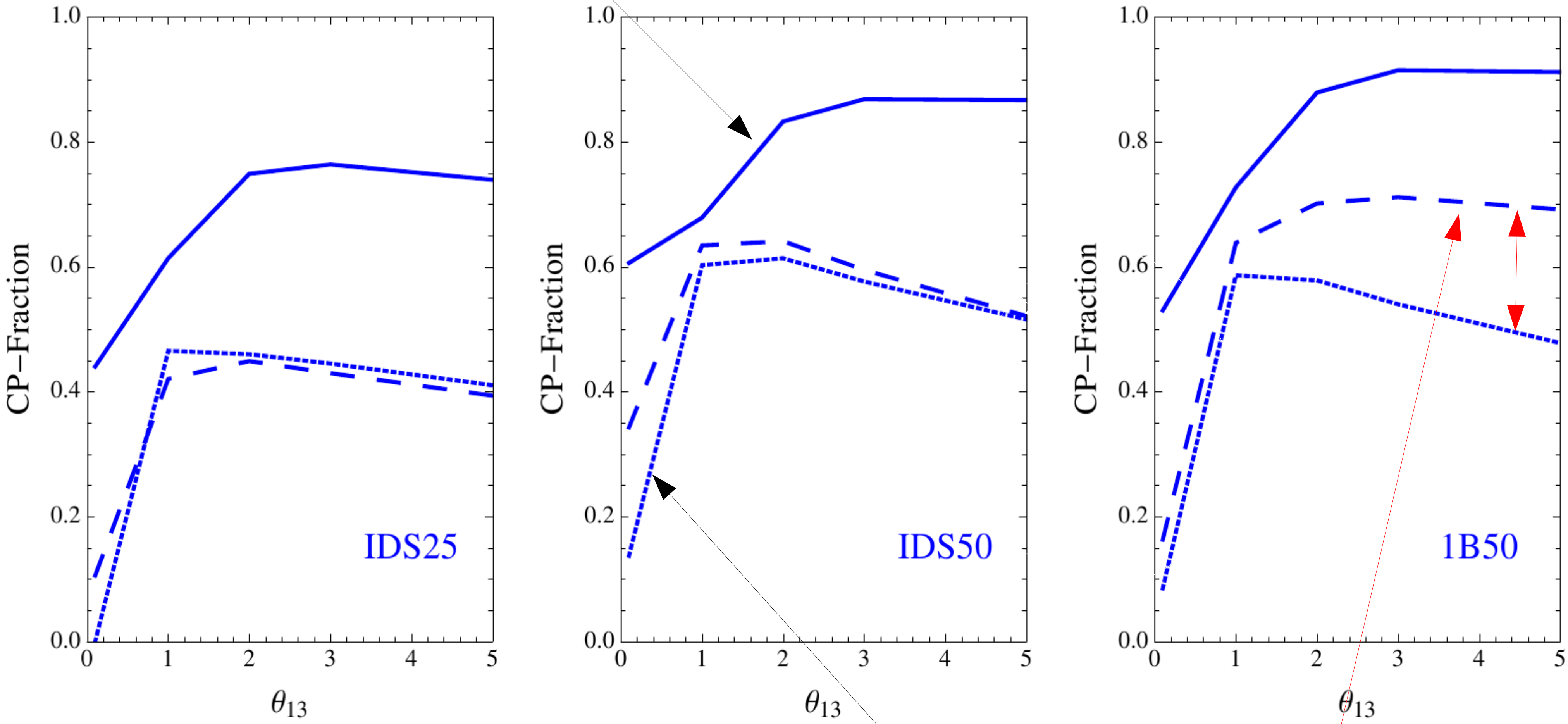


Mainly dominated by standard CP-violation

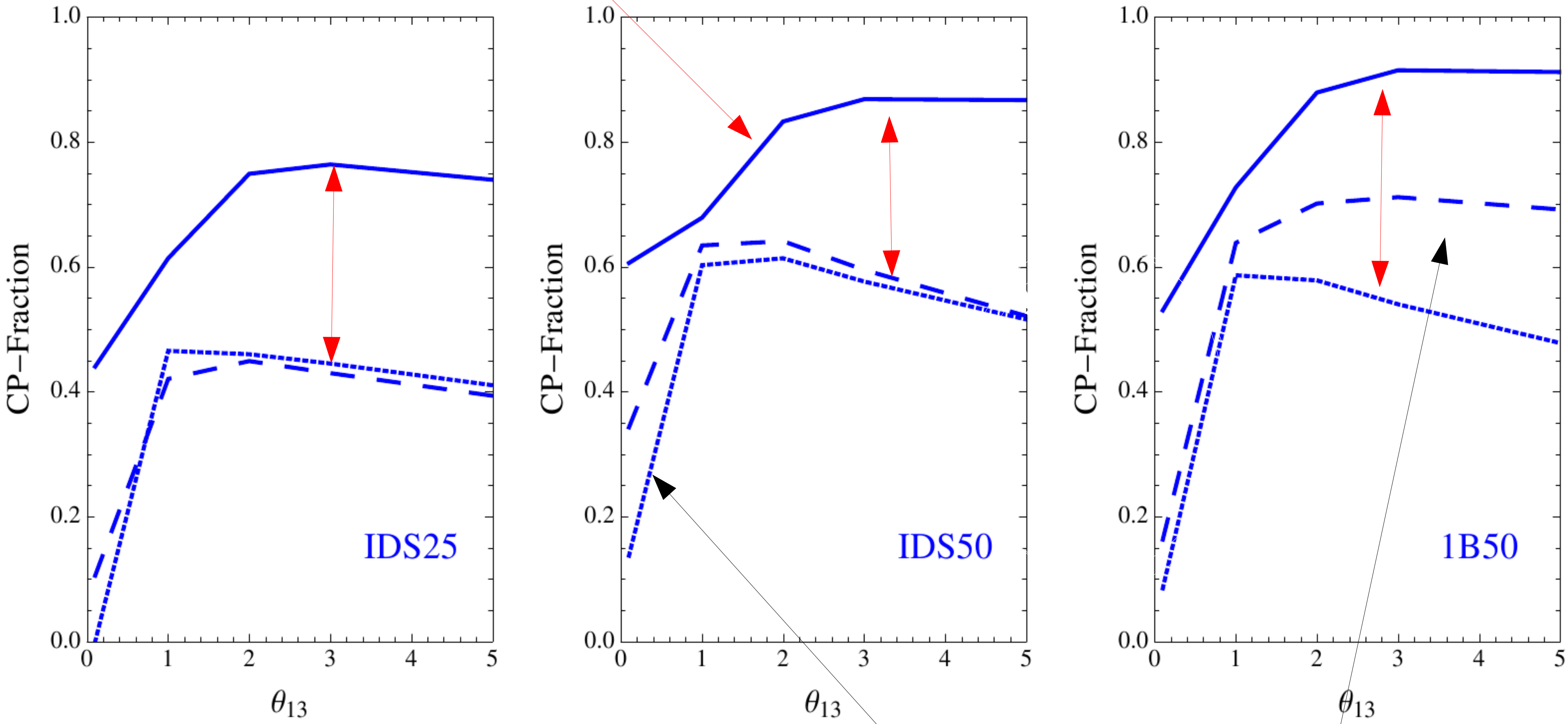
$(|\epsilon_{e\mu}|, |\epsilon_{e\tau}|) = (10^{-3}, 10^{-2})$

Relevant NSI CP-violation contribution in 1B50 for *large* θ_{13}

$(|\epsilon_{e\mu}|, |\epsilon_{e\tau}|) = (10^{-3}, 10^{-3})$

Generalized CP-fraction (CP-volume)

$(|\epsilon_{e\mu}|, |\epsilon_{e\tau}|) = (10^{-2}, 10^{-2})$



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Important New CP-violation effects
sofltly dependent on θ_{13}

Conclusions: HENF

- NSI in propagation do NOT affect sensitivity to θ_{13} and δ

- Sensitivity to diagonal NSI parameters: independent of the set up

  - Sizeable effects due to $\delta\theta_{23} \neq 0,\ \theta_{13} \neq 0;$

  - No correlation with non diagonal parameters

  - $(\epsilon_{ee} - \epsilon_{\tau\tau}) < 10^{-1}$ (limited by matter uncertainty)

  - $(\epsilon_{\mu\mu} - \epsilon_{\tau\tau}) < \mathcal{O}(10^{-2})$ IDS25 & 1B50 worse by factor 3 for $\theta_{13} = 10^{o}$

- Sensitivity to off-diagonal NSI parameters:

  - $\epsilon_{e\mu}$: higher Energies are the key
  - $\epsilon_{e\tau}$: the MB is the key
  - worse $\epsilon_{e\mu}/\epsilon_{e\tau}$ sensitivity for large θ_{13}
  - $\epsilon_{\mu\tau}$: independent of the set up.

  $\mathcal{O}(10^{-2} - 10^{-3})$

Conclusions: HENF

- CP violation:

  - CP violation exclusively due to NSI could be measured for *reasonable* input values of the NSI parameters.

  - $\epsilon_{e\mu} \approx \epsilon_{e\tau}$: $\epsilon_{e\mu}$ dominates, correlations only between $\delta, \phi_{e\mu}$

  - $\epsilon_{e\mu} \ll \epsilon_{e\tau}$: more complex behaviour, involved correlations among 3 CP phases: $\delta, \phi_{e\mu}, \phi_{e\tau}$

  - $\epsilon_{e\mu}, \epsilon_{e\tau} < 10^{-3}$. Hard to see any NSI CP-violation signal

- In general, higher Energies set ups perform better as expected

LENF

- Sensitive to $\epsilon_{e\mu}$ and $\epsilon_{e\tau}$ down to $\mathcal{O}(10^{-2})$
- An updated study is coming (work in progress)

  Fernandez-Martinez, Li, and Pascoli

Thank you!

Back-up

New CP violation effects

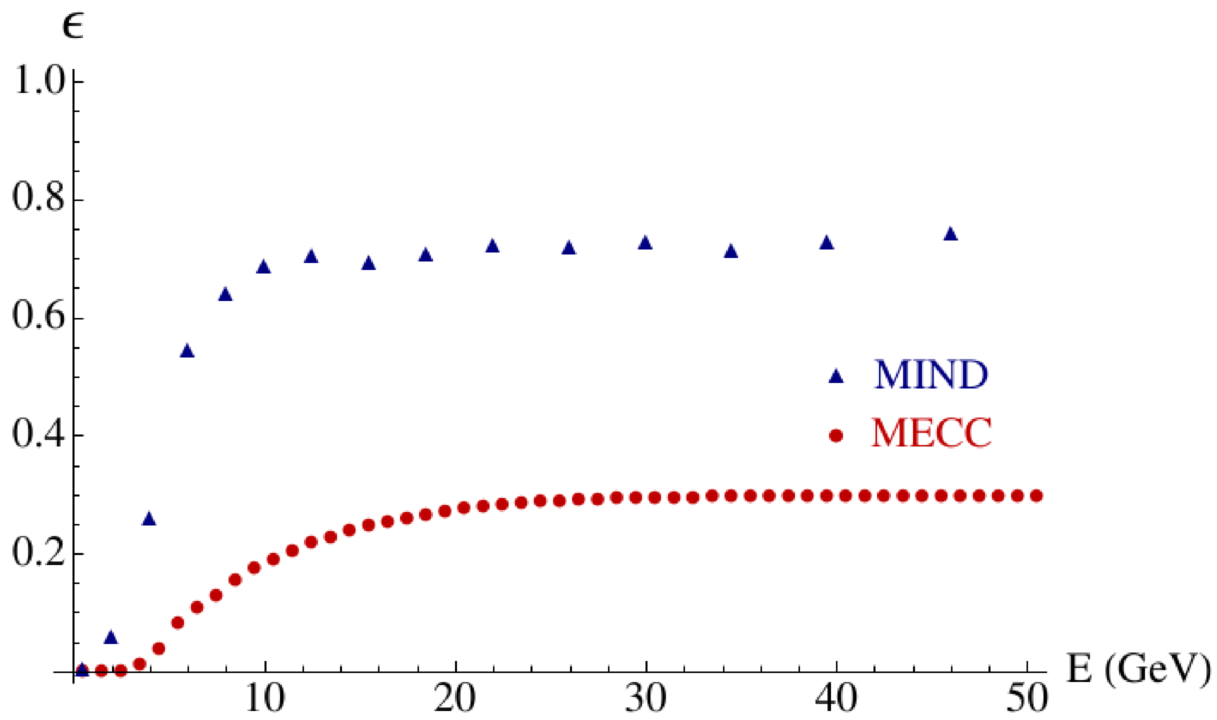
- We have measured the 3D CP discovery potential: the region of the $(\delta,\varphi_{e\mu},\varphi_{e\tau})$ parameter space for which a CP-violating signal can be distinguished from a CP-conserving one

- This corresponds to check if, given the input triple $(\delta,\varphi_{e\mu},\varphi_{e\tau})$, the χ^2 at the CP-conserving points $\{(0,0,0), (0,0,\pi), (0,\pi,0), (\pi,0,0), (0,\pi,\pi), (\pi,0,\pi), (\pi,\pi,0), (\pi,\pi,\pi)\}$ is larger than a given (3dof's) CL

$$\chi^2_{CPC}(\theta_{13},\bar{\theta}_{13};\{\bar{\phi}\}) = \min_{\{\phi\}_{CPC}} \left(\chi^2(\theta_{13},\bar{\theta}_{13};\{\phi\}_{CPC},\{\bar{\phi}\})\right)$$

W.Winter, Phys. Lett. B671 (2009) 77, arXiv:0808.3583

MIND & MECC



	$\sigma(E)$	f_S	f_B
MIND	$0.55\sqrt{E}$	2.5%	20%
MECC	$0.2E$	15%	20%

TASD

	TASD
Energy threshold	0.5 GeV
Efficiency of ν_μ ($\bar{\nu}_\mu$) detection	73% for E $<$ 1 GeV, 90% for E $>$ 1 GeV
Efficiency of ν_e ($\bar{\nu}_e$) detection	37% for E $<$ 1 GeV, 47% for E $>$ 1 GeV
Systematics	2%
Energy resolution - QE (non-QE) events	10% (10%)
Background for ν_μ ($\bar{\nu}_\mu$) detection	1×10^{-3}
Background for ν_e ($\bar{\nu}_e$) detection	1×10^{-2}

New CP violation effects: $\epsilon_{e\mu} \approx \epsilon_{e\tau}$

$|\epsilon_{e\mu}| = |\epsilon_{e\tau}| = 10^{-2}$

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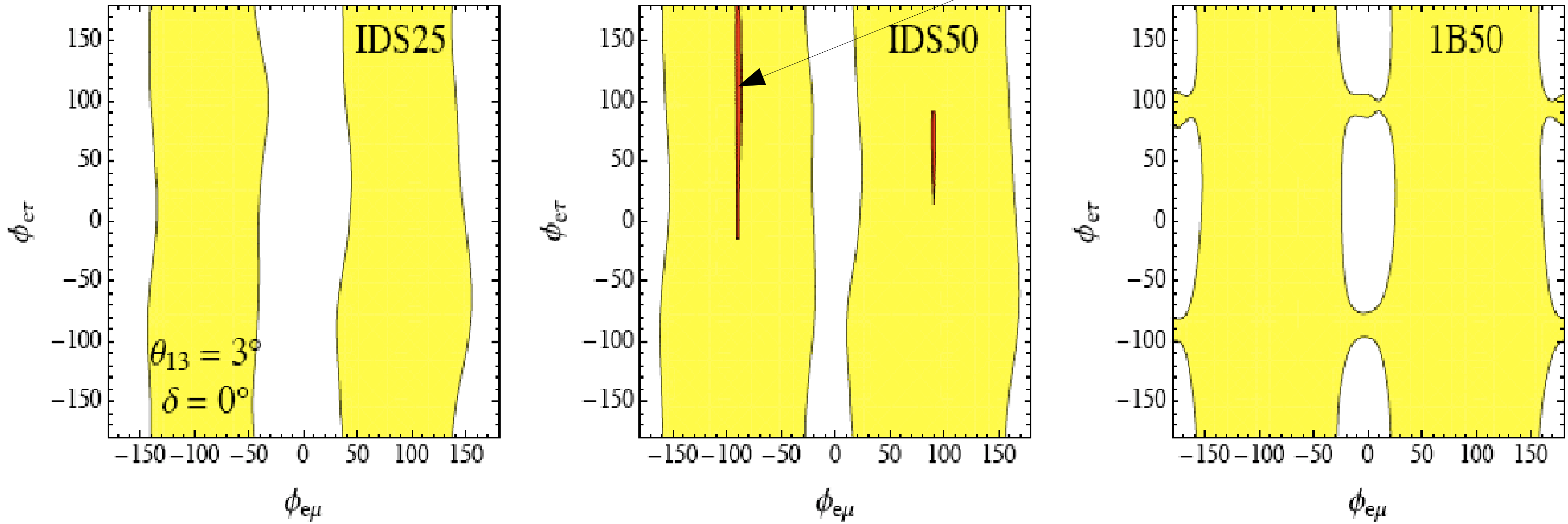

$\theta_{13} = 3^o \quad \delta = 0$

99 % CL .

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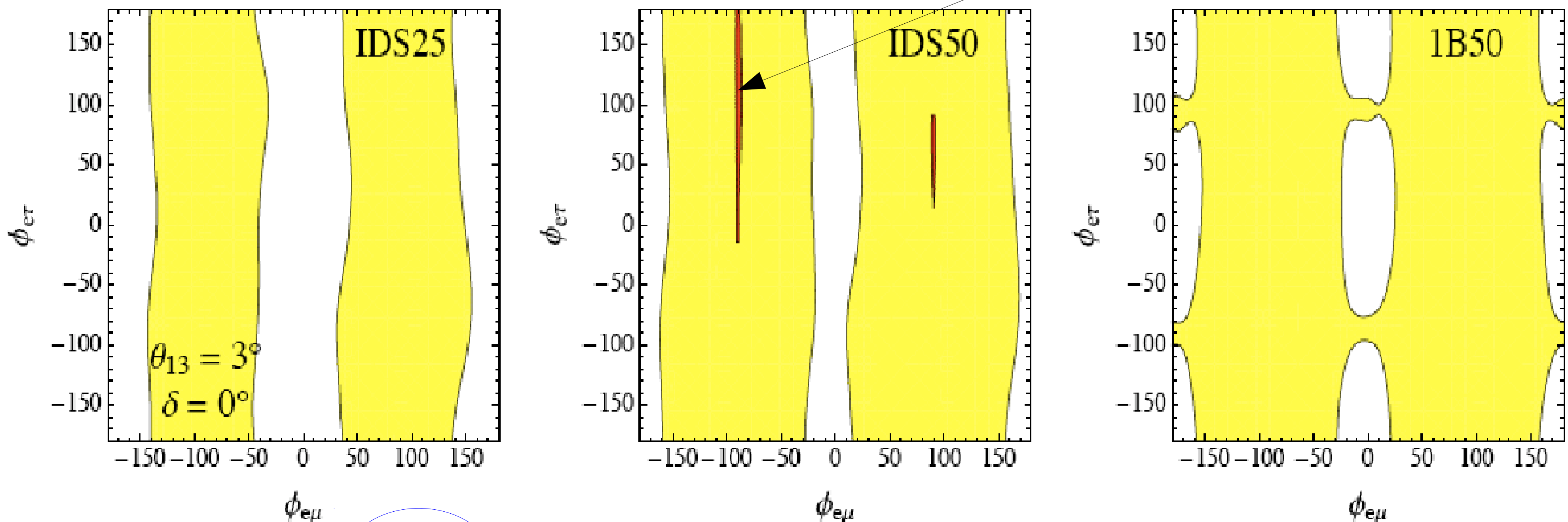


$\theta_{13} = 3^o$ $\delta = 0$

99 % CL .

Pure NSI CP violation effect !

$\epsilon_{e\mu}$ dominates over the rest $\epsilon_{\alpha\beta}$ ⟺ vertical bands

New CP violation effects

Easy to understand from oscillation probability:

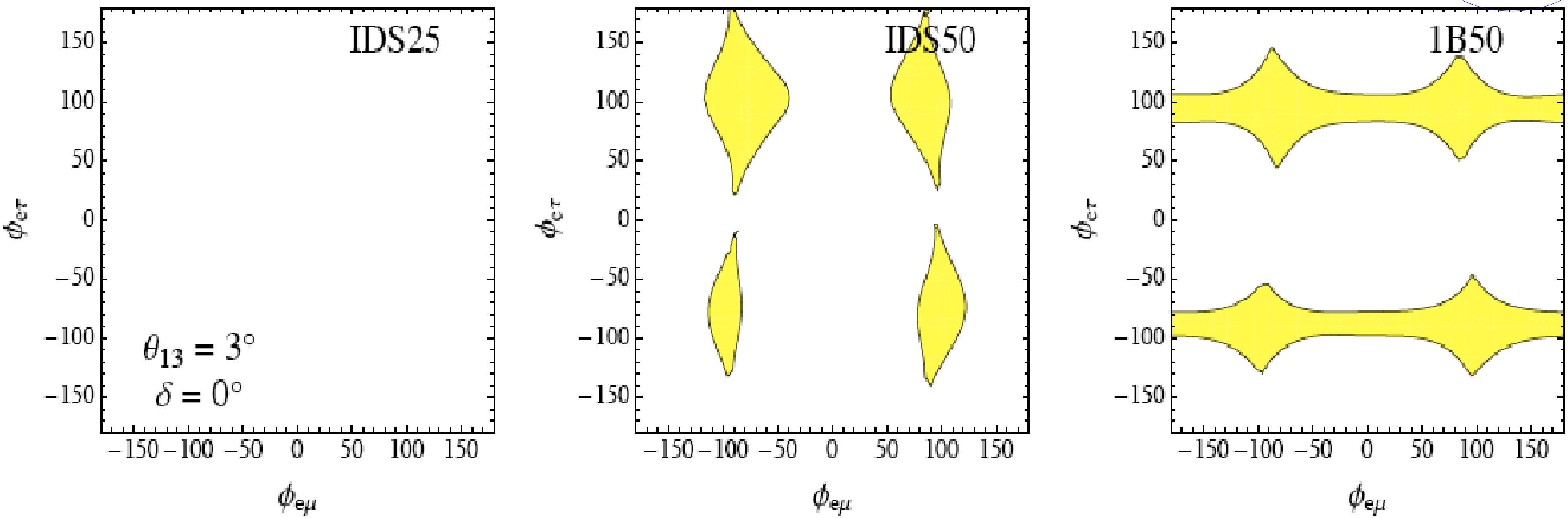
$$P_{e\mu} = \Bigg| A_{e\mu}^{SM} + \\ +\epsilon_{e\mu}\left[\sin\left(\frac{AL}{2}\right) e^{-i\frac{\Delta_{31}L}{2}} + \left(\frac{A}{\Delta_{31}-A}\right)\sin\left(\frac{\Delta_{31}-A}{2}L\right)\right] \\ -\epsilon_{e\tau}\left[\sin\left(\frac{AL}{2}\right) e^{-i\frac{\Delta_{31}L}{2}} - \left(\frac{A}{\Delta_{31}-A}\right)\sin\left(\frac{\Delta_{31}-A}{2}L\right)\right]\Bigg|^2$$

partial cancelation

New CP violation effects: $\epsilon_{e\mu} \ll \epsilon_{e\tau}$

99 % CL .

$|\epsilon_{e\mu}| = 10^{-3} \quad |\epsilon_{e\tau}| = 10^{-2}; \quad \delta = 0$



99 % CL .

$$\theta_{13} = 3^o$$

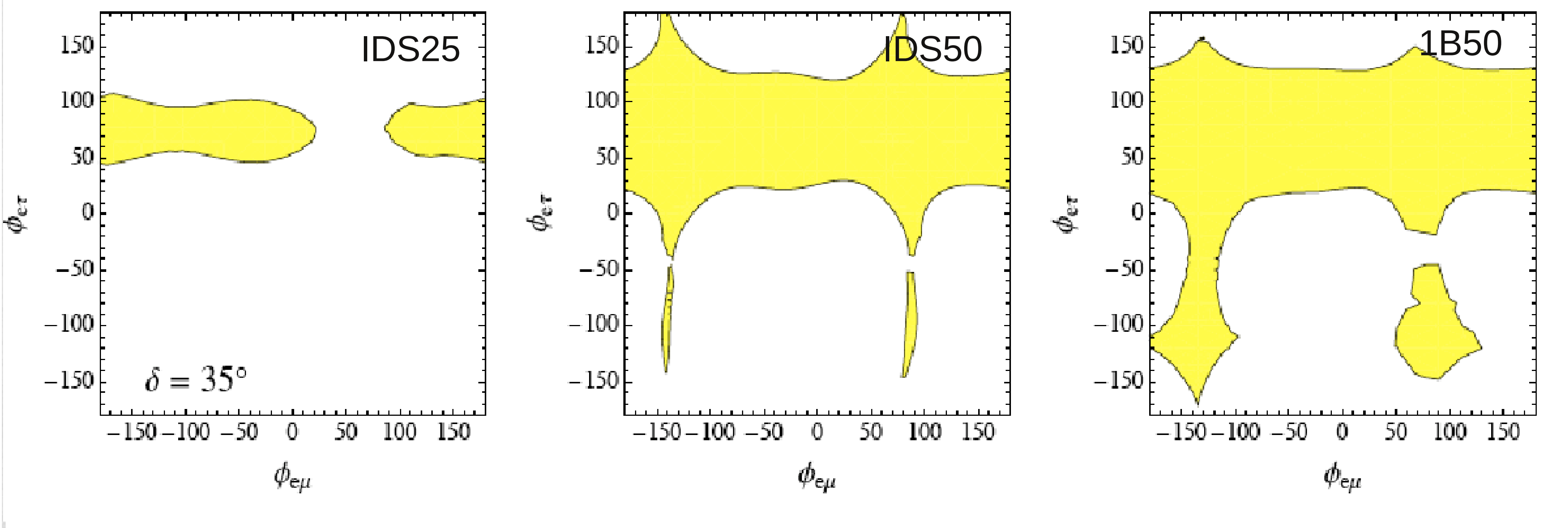
The NSI parameters are competitive

Pure NSI CP violation effect

New CP violation effects: $\epsilon_{e\mu} \ll \epsilon_{e\tau}$

99 % CL .

$|\epsilon_{e\mu}| = 10^{-3}$ $|\epsilon_{e\tau}| = 10^{-2}$; $\delta = 35$



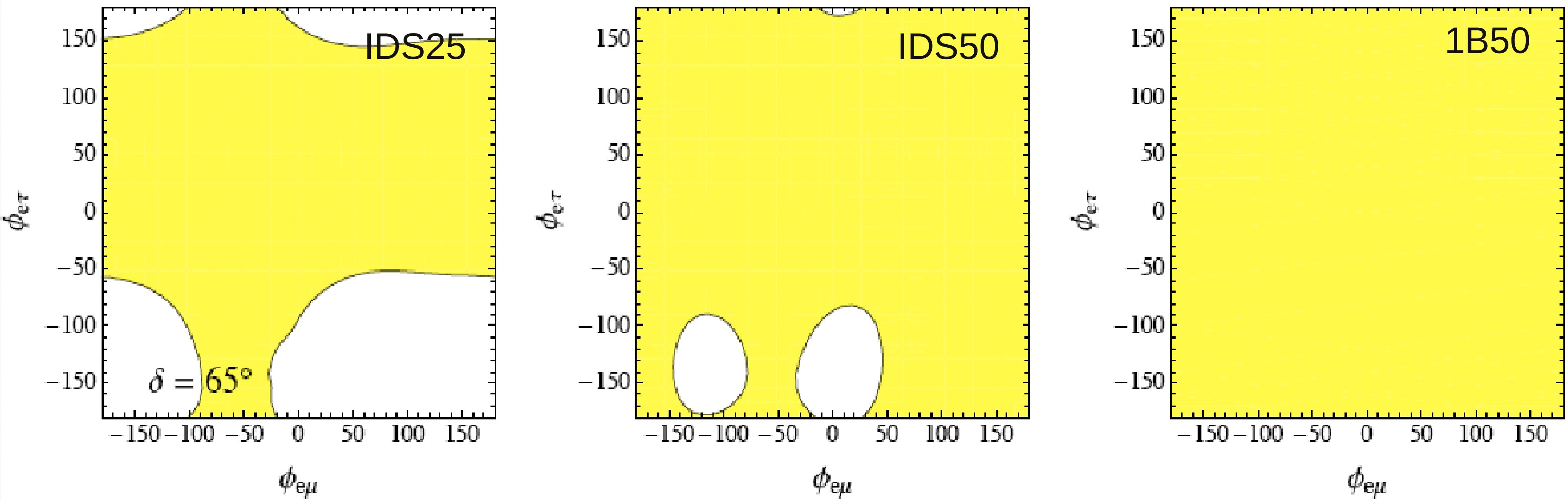
$\theta_{13} = 3^o$

3 CP-phases competing

New CP violation effects: $\epsilon_{e\mu} \ll \epsilon_{e\tau}$

99 % CL .

$|\epsilon_{e\mu}| = 10^{-3} \quad |\epsilon_{e\tau}| = 10^{-2}; \quad \delta = 65$



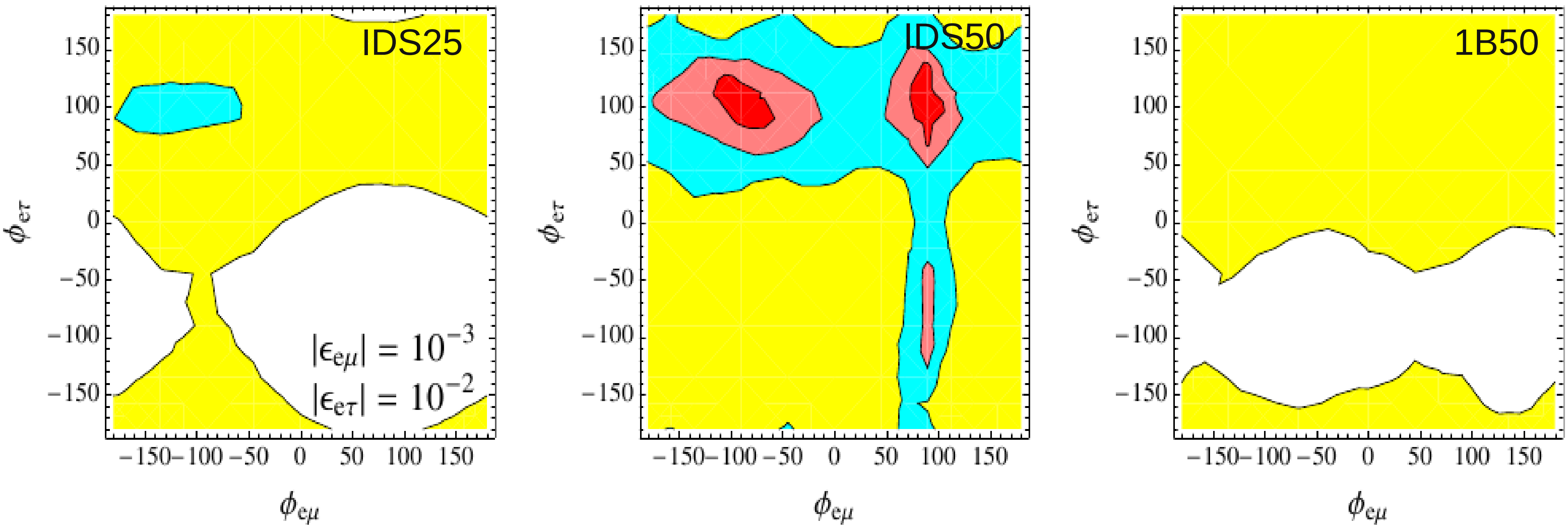
$$\theta_{13} = 3^o$$

Standard CP violation effect *dominates*

New CP violation effects: $\epsilon_{e\mu} \ll \epsilon_{e\tau}$

99 % CL .

$|\epsilon_{e\mu}| = 10^{-3} \quad |\epsilon_{e\tau}| = 10^{-2} \quad \theta_{13} = 3^o$



δ_{CP}-fraction

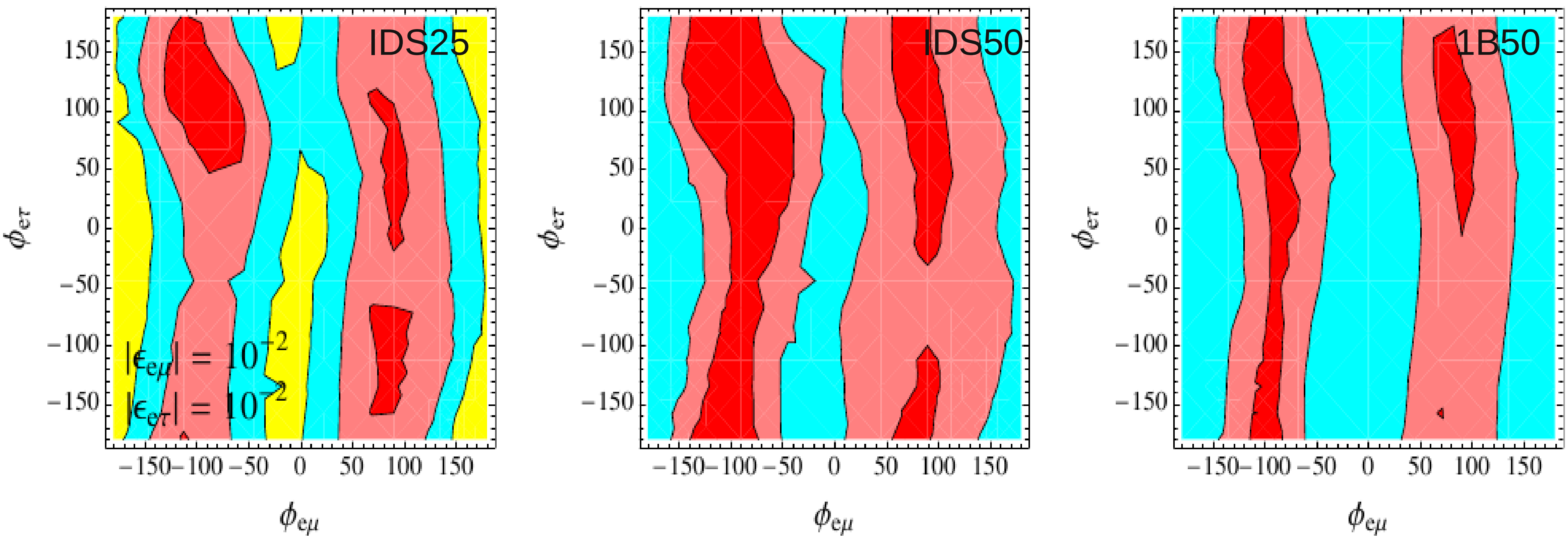
5 – 40 %
40 – 60 %
60 – 80 %
90 – 95 %

fraction of δ - axis for wich we are able to distinguish CP-violation

New CP violation effects: $\epsilon_{e\mu} \approx \epsilon_{e\tau}$

99 % CL .

$$|\epsilon_{e\mu}| = |\epsilon_{e\tau}| = 10^{-2}; \quad \theta_{13} = 3^o$$



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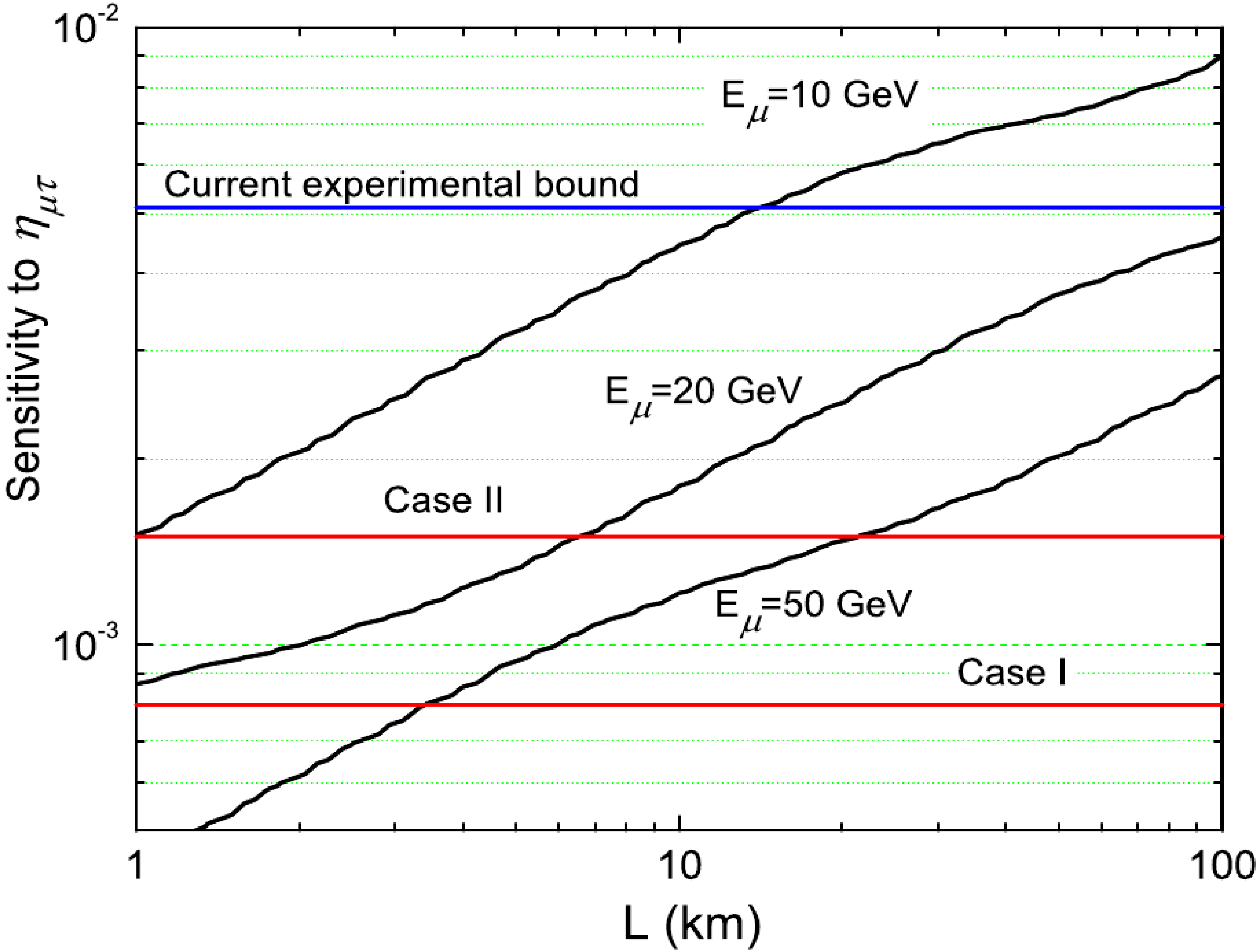

90% CL

Malinsky, Ohlsson, Zhang 09; arXiv: 0903.1961