General Neutrino-Electron Interactions at the DUNE Near Detector

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Outline

1. General neutrino interactions

2. Neutrino-electron scattering at the DUNE near detector

1. General neutrino interactions

Standard, Non-Standard, Even-Less-Standard?

Standard neutrino interactions

Reactor and accelerator neutrinos

Among our favourite sources of neutrinos:

- Reactors and accelerators controllable & rather well understood
- Still neutrino flux determination theoretical and experimental challenge
- Interesting approaches:
  - Compare two observables which have a similar relative flux dependence, such that the flux cancels (why we are here...)
  - Choose observables which are not too sensitive to the flux normalisation (why I am here...)

Standard neutrino interactions

Reactor and accelerator neutrinos

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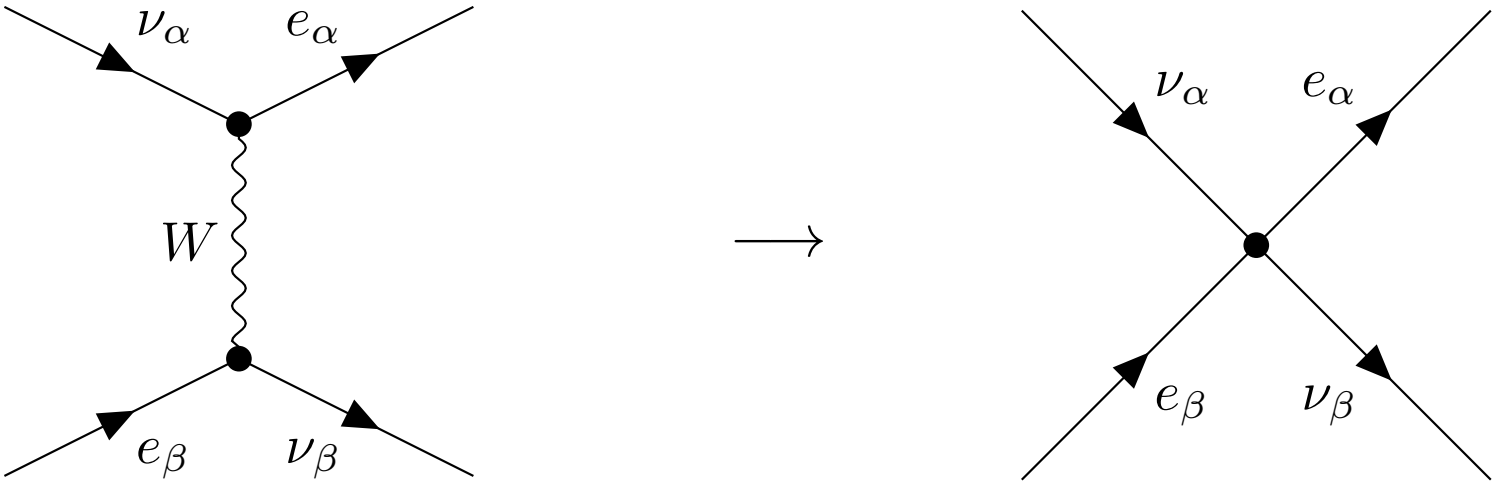


$$2\sqrt{2}G_F = \frac{g^2}{2m_W^2}$$

Standard neutrino interactions

Reactor and accelerator neutrinos

- Both sources typically below the weak scale ⇒ well-described by Fermi theory of effective interactions between four fermions

Fermi Lagrangians (in flavor basis)

$$\mathcal{L}_{NC} = -2\sqrt{2}G_F \sum_{X=L,R} g_L^{\nu} \left(\overline{\nu}^{\alpha}\gamma^{\mu}P_L\nu^{\alpha}\right) g_X^{\psi} \left(\overline{\psi}\gamma_{\mu}P_X\psi\right)$$

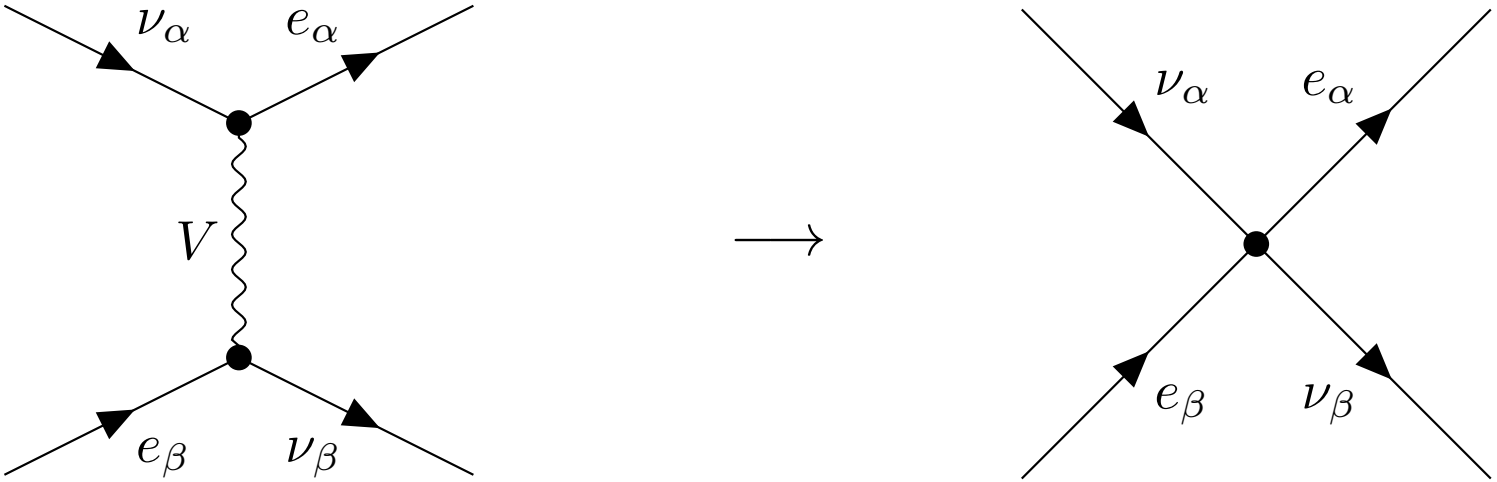
$$\mathcal{L}_{CC}^{\ell} = -2\sqrt{2}G_F \left(\overline{e}^{\alpha}\gamma^{\mu}P_L\nu^{\alpha}\right) \left(\overline{e}^{\beta}\gamma_{\mu}P_L\nu^{\beta}\right)$$

$$\mathcal{L}_{CC}^{q} = -2\sqrt{2}G_F \left(\overline{e}^{\alpha}\gamma^{\mu}P_L\nu^{\alpha}\right) \left(\overline{u}^{\beta}\gamma_{\mu}P_L d^{\beta}\right)$$

$$\psi = e, u, d, \ldots$$

Non-Standard neutrino interactions

- Idea: New high-energy physics may leave a similar trace like the "integrated out" W and Z bosons in the low-energy regime $\Rightarrow$ Non-Standard modifications with respect to Fermi theory



Interaction strength $\propto \frac{g_V^2}{m_V^2}$

Non-Standard neutrino interactions

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NSI Lagrangians (in flavor basis)

$$\mathcal{L}_{NC}^{\text{NSI}} = -2\sqrt{2}G_F \sum_{X=L,R} \epsilon_{\alpha\beta}^{\psi,X} \left(\overline{\nu}^{\alpha}\gamma^{\mu}P_L\nu^{\beta}\right)\left(\overline{\psi}\gamma_{\mu}P_X\psi\right)$$

$$\mathcal{L}_{CC}^{\text{NSI}} = -2\sqrt{2}G_F \sum_{X=L,R} \epsilon_{\alpha\beta}^{X} \left(\overline{e}^{\alpha}\gamma^{\mu}P_L\nu^{\beta}\right)\left(\overline{u}^{\gamma}\gamma_{\mu}P_X d^{\gamma}\right)$$

- $\epsilon \propto \frac{m_W^2}{m_{\text{NP}}^2}\frac{g_{\text{NP}}^2}{g^2}$? current bounds $\sim 10^{-3} - 10^{-1}$ dep. on flavor

General neutrino interactions

- Idea: What is the most general four-fermion interaction Lagrangian if we admit right-handed neutrinos?

General neutrino interactions

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Five Lorentz-invariant Lagrangians constructed from four Dirac spinors ψ_i

$$
\begin{aligned}
\mathcal{L}^S(\psi_1,\psi_2,\psi_3,\psi_4) &= \left(\overline{\psi}_1\psi_2\right)\left(\overline{\psi}_3\psi_4\right) , \\
\mathcal{L}^P(\psi_1,\psi_2,\psi_3,\psi_4) &= \left(\overline{\psi}_1\gamma^5\psi_2\right)\left(\overline{\psi}_3\gamma^5\psi_4\right) , \\
\mathcal{L}^V(\psi_1,\psi_2,\psi_3,\psi_4) &= \left(\overline{\psi}_1\gamma^\mu\psi_2\right)\left(\overline{\psi}_3\gamma_\mu\psi_4\right) , \\
\mathcal{L}^A(\psi_1,\psi_2,\psi_3,\psi_4) &= \left(\overline{\psi}_1\gamma^\mu\gamma^5\psi_2\right)\left(\overline{\psi}_3\gamma_\mu\gamma^5\psi_4\right) , \\
\mathcal{L}^T(\psi_1,\psi_2,\psi_3,\psi_4) &= \left(\overline{\psi}_1\sigma^{\mu\nu}\psi_2\right)\left(\overline{\psi}_3\sigma_{\mu\nu}\psi_4\right) , \\
\sigma^{\mu\nu} &= \frac{i}{2}[\gamma^\mu,\gamma^\nu]
\end{aligned}
$$

General neutrino interactions

- Reformulate in terms of definite chiralities:

Five Lorentz-invariant Lagrangians constructed from four Dirac spinors ψ_i

$$\mathcal{L}^S_{XY}(\psi_1,\psi_2,\psi_3,\psi_4) = \left(\overline{\psi}_1 P_X \psi_2\right)\left(\overline{\psi}_3 P_Y \psi_4\right)$$
$$\mathcal{L}^V_{XY}(\psi_1,\psi_2,\psi_3,\psi_4) = \left(\overline{\psi}_1 \gamma^\mu P_X \psi_2\right)\left(\overline{\psi}_3 \gamma_\mu P_Y \psi_4\right)$$
$$\mathcal{L}^T_{X}(\psi_1,\psi_2,\psi_3,\psi_4) = \left(\overline{\psi}_1 \sigma^{\mu\nu} P_X \psi_2\right)\left(\overline{\psi}_3 \sigma_{\mu\nu} P_X \psi_4\right)$$
$$X, Y = L, R$$

$\Rightarrow$ in principle 10 indep. interaction terms for chiral fermions

General neutrino interactions

- Reformulate in terms of definite chiralities:

Five Lorentz-invariant Lagrangians constructed from four Dirac spinors ψ_i

$$\mathcal{L}^S_{LY}(\psi_1, \nu_L, \psi_3, \psi_4) = \left(\overline{\psi}_1 P_L \nu_L\right)\left(\overline{\psi}_3 P_Y \psi_4\right)$$

$$\text{NSI: } \mathcal{L}^V_{LY}(\psi_1, \nu_L, \psi_3, \psi_4) = \left(\overline{\psi}_1 \gamma^\mu P_L \nu_L\right)\left(\overline{\psi}_3 \gamma_\mu P_Y \psi_4\right)$$

$$\mathcal{L}^T_{L}(\psi_1, \psi_2, \psi_3, \psi_4) = \left(\overline{\psi}_1 \sigma^{\mu\nu} P_L \nu_L\right)\left(\overline{\psi}_3 \sigma_{\mu\nu} P_L \psi_4\right)$$

$$X, Y = L, R$$

$\Rightarrow$ in principle 10 indep. interaction terms for chiral fermions

General neutrino interactions

- Reformulate in terms of definite chiralities:

Five Lorentz-invariant Lagrangians constructed from four Dirac spinors ψ_i

$$\mathcal{L}_{LY}^{S}\left(\nu_L, \nu_L, \psi_3, \psi_4\right) = \left(\overline{\nu}_L P_L \nu_L\right)\left(\overline{\psi}_3 P_Y \psi_4\right) = 0$$

$$\text{NSI: } \mathcal{L}_{LY}^{V}\left(\nu_L, \nu_L, \psi_3, \psi_4\right) = \left(\overline{\nu}_L \gamma^\mu P_L \nu_L\right)\left(\overline{\psi}_3 \gamma_\mu P_Y \psi_4\right)$$

$$\mathcal{L}_{L}^{T}\left(\nu_L, \nu_L, \psi_3, \psi_4\right) = \left(\overline{\nu}_L \sigma^{\mu\nu} P_L \nu_L\right)\left(\overline{\psi}_3 \sigma_{\mu\nu} P_L \psi_4\right) = 0$$

$$Y = L, R$$

$\Rightarrow$ in principle 10 indep. interaction terms for chiral fermions

General neutrino interactions

- Considering left-handed and right-handed neutrinos, the general four-fermion interaction Lagrangians can be parametrised as

GNI Lagrangians (in flavor basis)

$$\mathcal{L}_{NC}^{\text{GNI}} = -\frac{G_F}{\sqrt{2}} \sum_{\alpha,\beta} \sum_{j=1}^{10} \left(\epsilon^{j,\psi}\right)_{\alpha\beta} \left(\overline{\nu}^{\alpha} \mathcal{O}_j \nu^{\beta}\right) \left(\overline{\psi} \mathcal{O}'_j \psi\right)$$

$$\mathcal{L}_{CC}^{\text{GNI}} = -\frac{G_F}{\sqrt{2}} \sum_{\alpha,\beta} \sum_{j=1}^{10} \left(\epsilon^{j,\psi}\right)_{\alpha\beta} \left(\overline{e}^{\alpha} \mathcal{O}_j \nu^{\beta}\right) \left(\overline{u} \mathcal{O}'_j d\right)$$

- Ten ϵ-parameters instead of two!
- Remark: Parametrisation not unique, but convenient

General neutrino interactions

j	$\overset{(\sim)}{\epsilon}_j$	$\mathcal{O}_j$	$\mathcal{O}'_j$
1	ϵ_L	$\gamma_\mu(\mathbb{1}-\gamma^5)$	$\gamma^\mu(\mathbb{1}-\gamma^5)$
2	$\tilde{\epsilon}_L$	$\gamma_\mu(\mathbb{1}+\gamma^5)$	$\gamma^\mu(\mathbb{1}-\gamma^5)$
3	ϵ_R	$\gamma_\mu(\mathbb{1}-\gamma^5)$	$\gamma^\mu(\mathbb{1}+\gamma^5)$
4	$\tilde{\epsilon}_R$	$\gamma_\mu(\mathbb{1}+\gamma^5)$	$\gamma^\mu(\mathbb{1}+\gamma^5)$
5	ϵ_S	$(\mathbb{1}-\gamma^5)$	$\mathbb{1}$
6	$\tilde{\epsilon}_S$	$(\mathbb{1}+\gamma^5)$	$\mathbb{1}$
7	$-\epsilon_P$	$(\mathbb{1}-\gamma^5)$	γ^5
8	$-\tilde{\epsilon}_P$	$(\mathbb{1}+\gamma^5)$	γ^5
9	ϵ_T	$\sigma_{\mu\nu}(\mathbb{1}-\gamma^5)$	$\sigma^{\mu\nu}(\mathbb{1}-\gamma^5)$
10	$\tilde{\epsilon}_T$	$\sigma_{\mu\nu}(\mathbb{1}+\gamma^5)$	$\sigma^{\mu\nu}(\mathbb{1}+\gamma^5)$

General neutrino interactions

Remark on Dirac or Majorana nature

GNI NC Lagrangian (in flavor basis)

$$\mathcal{L}_{NC}^{\text{GNI}} = -\frac{G_F}{\sqrt{2}} \sum_{\alpha,\beta} \sum_{j=1}^{10} \left(\epsilon^{j,\psi}\right)_{\alpha\beta} \left(\overline{\nu}^{\alpha} \mathcal{O}_j \nu^{\beta}\right) \left(\overline{\psi} \mathcal{O}'_j \psi\right)$$

- In Dirac case (3 flavors), realness of $\mathcal{L}$ implies:

$$\epsilon^{L}_{\alpha\beta} = \epsilon^{L*}_{\beta\alpha}\,, \qquad \tilde{\epsilon}^{L}_{\alpha\beta} = \tilde{\epsilon}^{L*}_{\beta\alpha}\,, \qquad \epsilon^{R}_{\alpha\beta} = \epsilon^{R*}_{\beta\alpha}\,, \qquad \tilde{\epsilon}^{R}_{\alpha\beta} = \tilde{\epsilon}^{R*}_{\beta\alpha}\,,$$
$$\epsilon^{S}_{\alpha\beta} = \tilde{\epsilon}^{S*}_{\beta\alpha}\,, \qquad \epsilon^{P}_{\alpha\beta} = -\tilde{\epsilon}^{P*}_{\beta\alpha}\,, \qquad \epsilon^{T}_{\alpha\beta} = \tilde{\epsilon}^{T*}_{\beta\alpha}\,,$$

  which amounts to 90 free parameters.

General neutrino interactions

Remark on Dirac or Majorana nature

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$$\epsilon^{S}_{\alpha\beta} = \tilde{\epsilon}^{S*}_{\beta\alpha}\,, \qquad \epsilon^{P}_{\alpha\beta} = -\tilde{\epsilon}^{P*}_{\beta\alpha}\,, \qquad \epsilon^{T}_{\alpha\beta} = \tilde{\epsilon}^{T*}_{\beta\alpha}\,,$$

  which amounts to 90 free parameters.

- In Majorana case one finds *additionally*:

$$\epsilon^{L/R}_{\alpha\beta} = -\tilde{\epsilon}^{L/R}_{\beta\alpha}\,, \quad \epsilon^{S/P}_{\alpha\beta} = \epsilon^{S/P}_{\beta\alpha}\,, \quad \epsilon^{T}_{\alpha\beta} = -\epsilon^{T}_{\beta\alpha}\,.$$

  which reduces the set to 48 free parameters.

General neutrino interactions

Remark on Dirac or Majorana nature

Subconclusion:

- If we discover general neutrino interactions which require Dirac nature, the case is settled!
- If we discover Majorana-compatible general interactions, the case is as open as ever.

[Rosen PRL48 1982], [Rodejohann et al. 1702.05721]

General neutrino interactions

Possible Origin

- $S/P/T$ cannot originate from dimension-6 SMEFT operators
- SM+RHν N gauge invariant EFT operators to generate $\epsilon^S, \epsilon^P, \epsilon^T$:

SM+N EFT 1

$$\mathcal{O}_{\varphi Ne} = \frac{1}{\Lambda^2} C^{\varphi Ne}_{\alpha\beta} i \left(\widetilde{\varphi}^\dagger D_\mu \varphi\right) \left(\overline{N}_\alpha \gamma^\mu e_\beta\right) + \text{h.c.}$$

$$\epsilon^{S,e_\beta}_{\alpha\beta} = -\epsilon^{P,e_\beta}_{\alpha\beta} = \widetilde{\epsilon}^{S,e_\beta *}_{\alpha\beta} = \widetilde{\epsilon}^{P,e_\beta *}_{\alpha\beta} = 2C^{\varphi N\ell}_{\alpha\beta}$$

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SM+N EFT 2

$$\mathcal{O}_{\ell N\ell e} = \frac{1}{\Lambda^2} C^{\ell N\ell e}_{\alpha\beta\gamma\delta} \left(\overline{L}^i_\alpha N_\beta\right) \epsilon_{ij} \left(\overline{L}^j_\gamma e_\delta\right) + \text{h.c.}$$

$$\epsilon^{S,e_\delta}_{\alpha\beta} = \epsilon^{P,e_\delta}_{\alpha\beta} = \widetilde{\epsilon}^{S,e_\delta *}_{\beta\alpha} = -\widetilde{\epsilon}^{P,e_\delta *}_{\beta\alpha} = \left(C^{\ell N\ell e}_{\beta\alpha\delta\delta}\right)^* + \frac{1}{2}\left(C^{\ell N\ell e}_{\delta\alpha\beta\delta}\right)^*$$

$$\epsilon^{T,e_\delta}_{\alpha\beta} = \widetilde{\epsilon}^{T,e_\delta *}_{\beta\alpha} = \frac{1}{8}\left(C^{\ell N\ell e}_{\delta\alpha\beta\delta}\right)^*$$

General neutrino interactions

Summary

Why consider GNI?

- Model-independent parametrisation of new physics (more general than NSI)
- Indirect access to high energy scales $m/g = (\sqrt{2}/\epsilon\, G_F)^{1/2}$
- Experimentally accessible by cross section measurements
- Can potentially discriminate Dirac from Majorana nature of neutrinos
- Can be generated at the level of gauge-invariant dimension-six operators

Open:

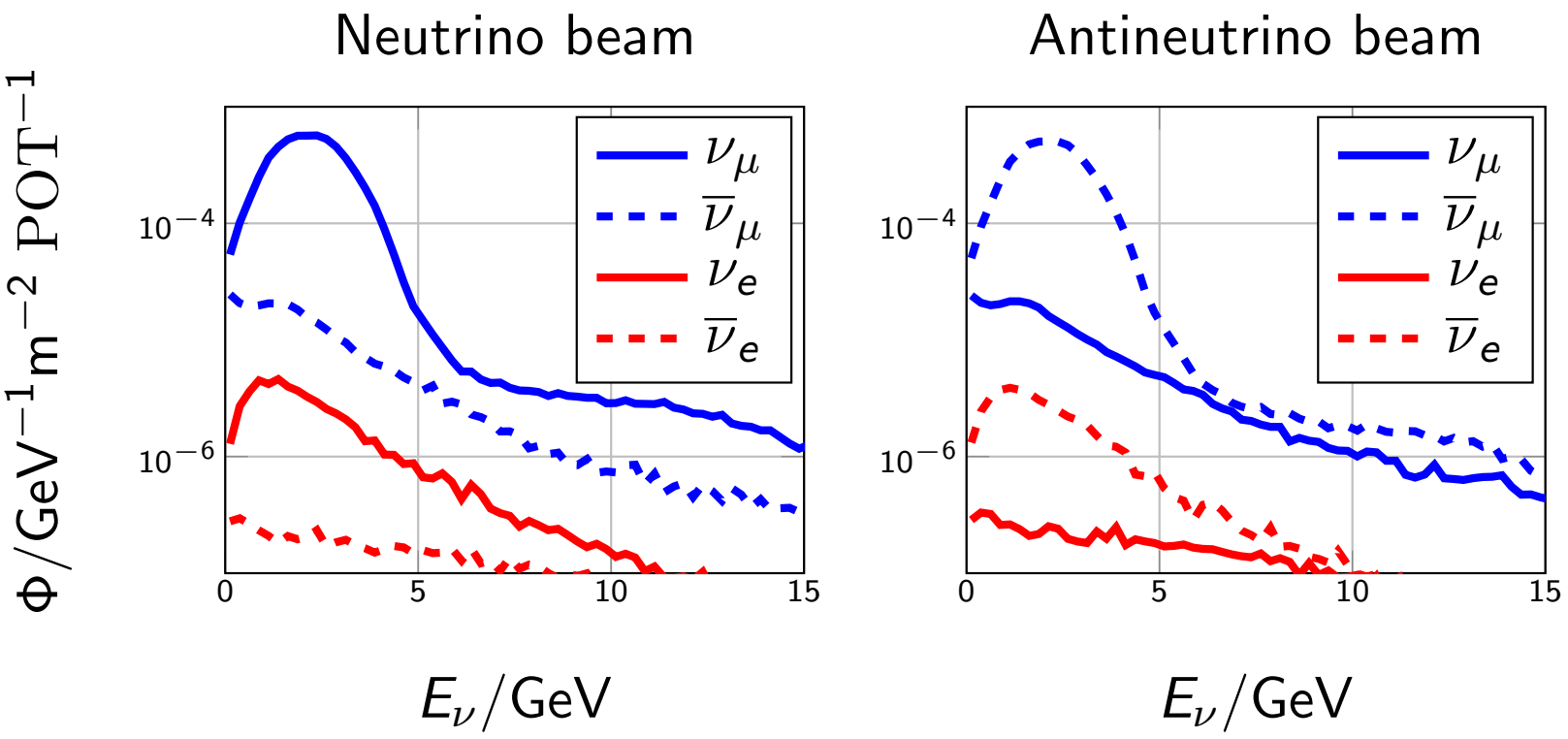
- Complete models generating them?

2. Neutrino-electron scattering at DUNE ND

Based on
[I.B., W. Rodejohann 1810.02220]

Neutrino-electron scattering at the DUNE near detector

Neutrino fluxes



[DUNE; T. Alion et al. 1606.09550], Plot: [I.B., W. Rodejohann 1810.02220]

Neutrino-electron scattering at the DUNE near detector

Ideas:

1. Most abundand leptonic scattering $\nu_\mu + e \to \nu_\beta + e$
What is the sensitivity of DUNE ND to new physics from this process? [Falkowski et al. 1802.08296]
2. Matter NSI are known to affect the measurement of δ_{CP}. Can we constrain them independently to support the measurement?

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The general interaction Lagrangian

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Neutrino-electron scattering at the DUNE near detector

Differential cross sections

$$\frac{\mathrm{d}\sigma_{\nu_\mu \to \nu_\beta}}{\mathrm{d}T} = \frac{G_F^2 m_e}{\pi}\left[A + 2B\left(1 - \frac{T}{E_\nu}\right) + C\left(1 - \frac{T}{E_\nu}\right)^2 + D\frac{m_e T}{E_\nu^2}\right]$$

$$\frac{\mathrm{d}\sigma_{\overline{\nu}_\mu \to \overline{\nu}_\beta}}{\mathrm{d}T} = \frac{G_F^2 m_e}{\pi}\left[C + 2B\left(1 - \frac{T}{E_\nu}\right) + A\left(1 - \frac{T}{E_\nu}\right)^2 + D\frac{m_e T}{E_\nu^2}\right]$$

$E_\nu \gg m_e$: energy of the incoming (anti)neutrino
T: kinetic energy of the recoiled electron

$$A_{\mathrm{SM}} = 2g_L^2\delta_{\mu\beta}\,, \quad B_{\mathrm{SM}} = 0\,, \quad C_{\mathrm{SM}} = 2g_R^2\delta_{\mu\beta}\,, \quad D_{\mathrm{SM}} = -2g_L g_R\delta_{\mu\beta}$$

Neutrino-electron scattering at the DUNE near detector

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$$A = 2|\epsilon^L_{\mu\beta}|^2 + \frac{1}{4}(|\epsilon^S_{\mu\beta}|^2 + |\epsilon^P_{\mu\beta}|^2) + 8|\epsilon^T_{\mu\beta}|^2 - 2\mathrm{Re}\left((\epsilon^S+\epsilon^P)_{\mu\beta}\epsilon^{T*}_{\mu\beta}\right)\,,$$

$$B = -\frac{1}{4}(|\epsilon^S_{\mu\beta}|^2 + |\epsilon^P_{\mu\beta}|^2) + 8|\epsilon^T_{\mu\beta}|^2\,,$$

$$C = 2|\epsilon^R_{\mu\beta}|^2 + \frac{1}{4}(|\epsilon^S_{\mu\beta}|^2 + |\epsilon^P_{\mu\beta}|^2) + 8|\epsilon^T_{\mu\beta}|^2 + 2\mathrm{Re}\left((\epsilon^S+\epsilon^P)_{\mu\beta}\epsilon^{T*}_{\mu\beta}\right)\,,$$

$$D = -2\mathrm{Re}\left(\epsilon^L_{\mu\beta}\epsilon^{R*}_{\mu\beta}\right) + \frac{1}{2}|\epsilon^S_{\mu\beta}|^2 - 8|\epsilon^T_{\mu\beta}|^2\,.$$

Neutrino-electron scattering at the DUNE near detector

Observable parameters

Exotic S, P, T interactions:

- Unless S/P *and* T non-vanishing depend only on $|\epsilon^j_{\mu\beta}|^2$
- Sum over final neutrino flavors:

$$\text{Observables} = |\epsilon^j_\mu|^2 \equiv \sum_{\beta=e,\mu,\tau} |\epsilon^j_{\mu\beta}|^2 \,, \quad j = S, P, T$$

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Non-Standard L, R interactions:

- Seperate SM and NSI contributions:

$$\sum_\beta \left| g_j \delta_{\mu\beta} + \epsilon^{j,\mathrm{NSI}}_{\mu\beta} \right|^2 = \left(g_j + \epsilon^{j,\mathrm{NSI}}_{\mu\mu} \right)^2 + \sum_{\beta=e,\tau} |\epsilon^j_{\mu\beta}|^2 \,, \quad j = L, R$$

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- Flavor diagonal and non-diagonal parts contribute seperately:

$$\text{Observables} = \epsilon^{j,\mathrm{NSI}}_{\mu\mu},\ |\epsilon^{j,\mathrm{NSI}}_\mu|^2 \equiv \sum_{\beta=e,\tau} |\epsilon^j_{\mu\beta}|^2 \,, \quad j = L, R$$

Neutrino-electron scattering at the DUNE near detector

Observable parameters

In conclusion: 7 Observables

Obs.	$\epsilon_{\mu\mu}^{L/R,\mathrm{NSI}}$	$\lvert\epsilon_{\mu}^{L/R,\mathrm{NSI}}\rvert$	$\lvert\epsilon_{\mu}^{S/P/T}\rvert$
GNI	$\epsilon_{\mu\mu}^{L/R,\mathrm{NSI}}$	$\lvert\epsilon_{\mu e}^{L/R,\mathrm{NSI}}\rvert$, $\lvert\epsilon_{\mu\tau}^{L/R,\mathrm{NSI}}\rvert$	$\lvert\epsilon_{\mu e}^{S/P/T}\rvert$, $\lvert\epsilon_{\mu\mu}^{S/P/T}\rvert$, $\lvert\epsilon_{\mu\tau}^{S/P/T}\rvert$

- 4 NSI and 3 exotic
- Reduces to 6 if we consider that S and P are indistinguishable

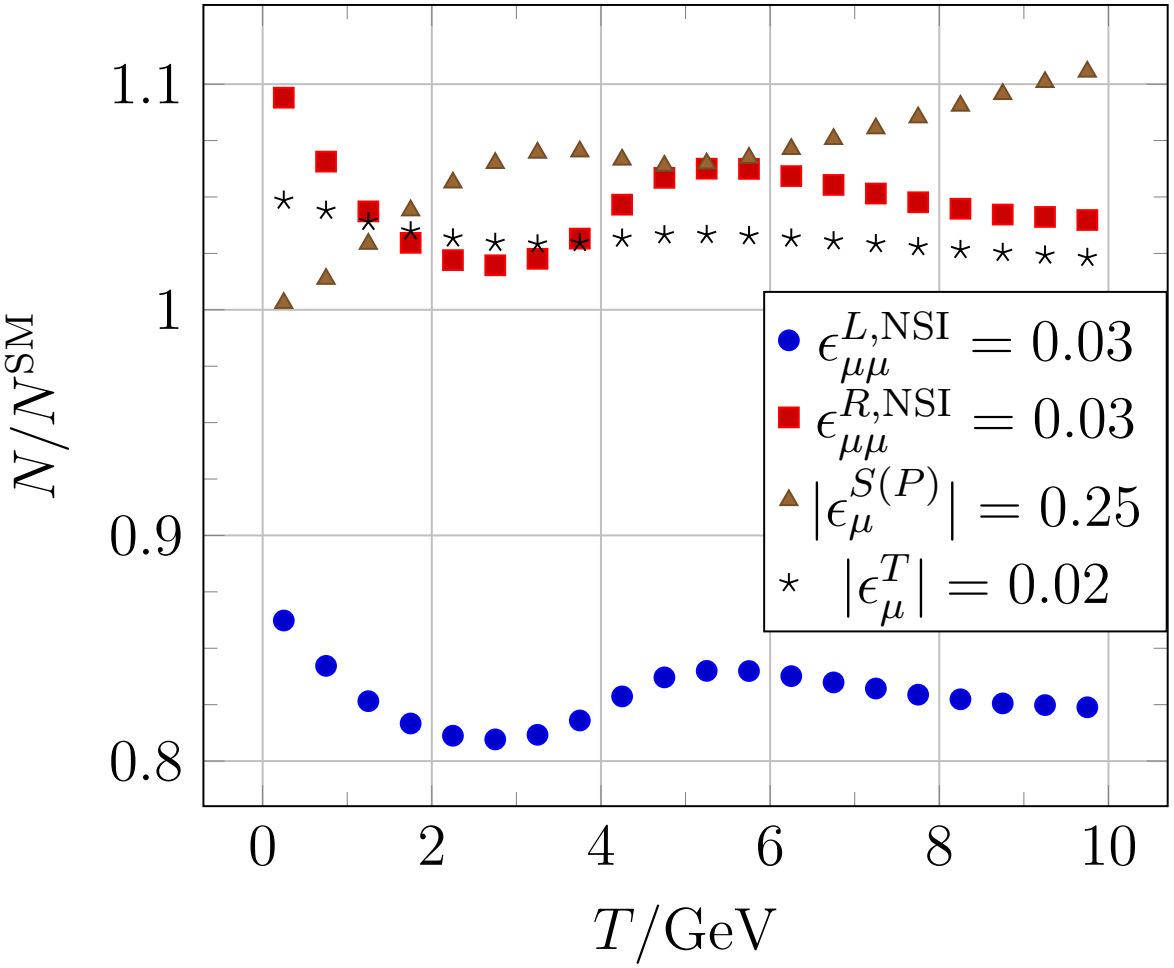
Neutrino-electron scattering at the DUNE near detector

Experimental Setup

- Assume 84t argon
- Measure kinetic energy of recoiled electrons ($E_{\text{th}} = 0$, update in prep.)
- Assume $0.06/\sqrt{E_e}$(GeV) resolution
- 2.5+2.5 years of operation (total $2.809 \cdot 10^{21}$ POT per channel)
- 1% flux normalisation uncertainty (5% update in prep.)

Neutrino-electron scattering at the DUNE near detector

Expected recoil spectra in the SM and in presence of GNI



Spectral distortions good way to distinguish new interactions (less flux normalisation sensitivity)

Neutrino-electron scattering at the DUNE near detector

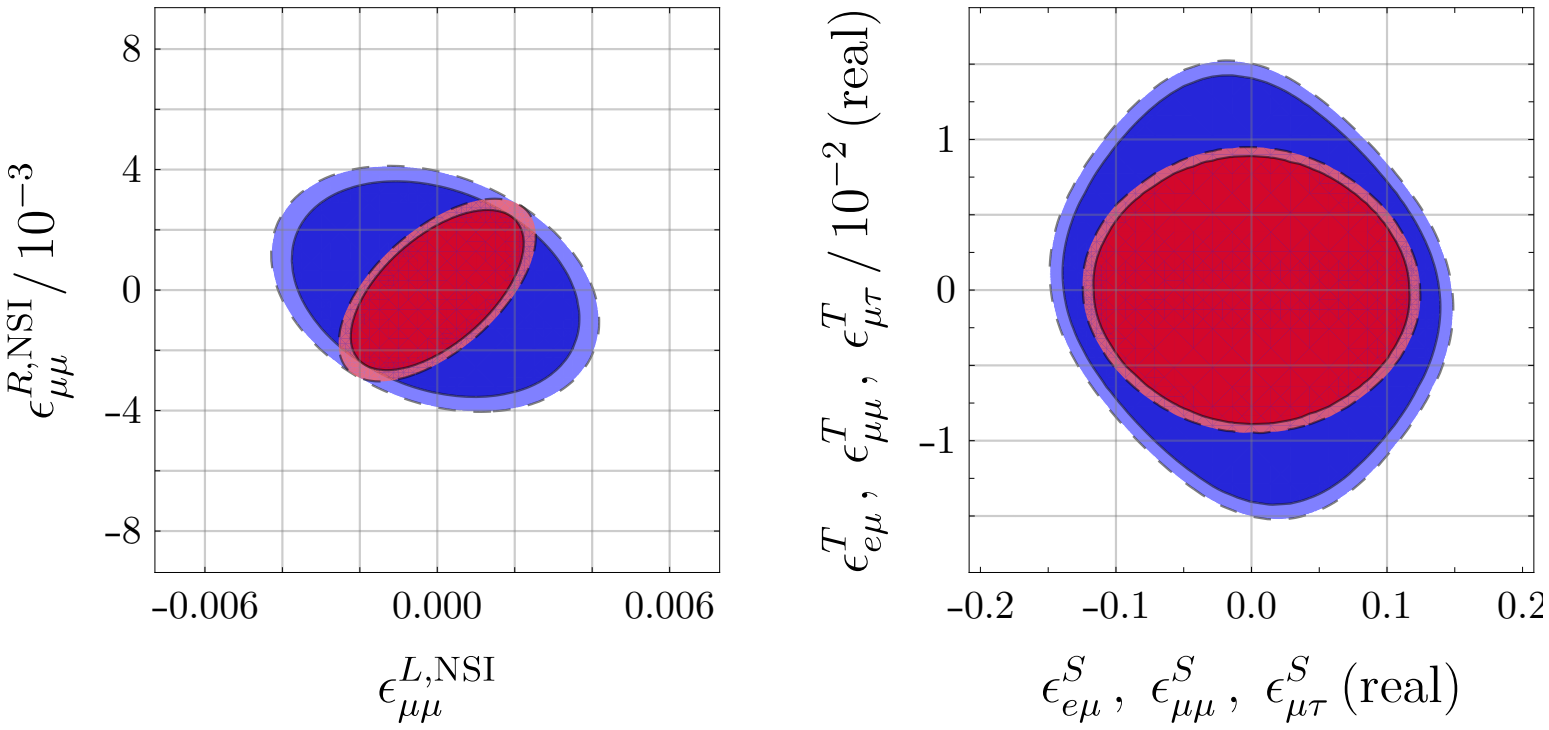
Expected bounds (90%CL) at 1% flux normalisation uncertainty, 2.5+2.5 years

Observ.	NP Param.	Proj. DUNE	CHARM-II	$\frac{M}{g'}$[TeV]
$\epsilon_{\mu\mu}^{L,\mathrm{NSI}}$	$\epsilon_{\mu\mu}^{L,\mathrm{NSI}}$	± 0.0028	$[-0.06, 0.02]$	6.7
$\epsilon_{\mu}^{L,\mathrm{NSI}}$	$\lvert\epsilon_{e\mu}^{L,\mathrm{NSI}}\rvert$, $\lvert\epsilon_{\mu\tau}^{L,\mathrm{NSI}}\rvert$	0.039		1.8
$\epsilon_{\mu\mu}^{R,\mathrm{NSI}}$	$\epsilon_{\mu\mu}^{R,\mathrm{NSI}}$	± 0.0027	$[-0.06, 0.02]$	6.8
$\epsilon_{\mu}^{R,\mathrm{NSI}}$	$\lvert\epsilon_{e\mu}^{R,\mathrm{NSI}}\rvert$, $\lvert\epsilon_{\mu\tau}^{R,\mathrm{NSI}}\rvert$	0.035		1.9
ϵ_{μ}^{S}	$\lvert\epsilon_{e\mu}^{S}\rvert$, $\lvert\epsilon_{\mu\mu}^{S}\rvert$, $\lvert\epsilon_{\mu\tau}^{S}\rvert$	0.12	0.4	1.0
ϵ_{μ}^{P}	$\lvert\epsilon_{e\mu}^{P}\rvert$, $\lvert\epsilon_{\mu\mu}^{P}\rvert$, $\lvert\epsilon_{\mu\tau}^{P}\rvert$	0.12	0.4	1.0
ϵ_{μ}^{T}	$\lvert\epsilon_{e\mu}^{T}\rvert$, $\lvert\epsilon_{\mu\mu}^{T}\rvert$, $\lvert\epsilon_{\mu\tau}^{T}\rvert$	0.012	0.04	3.1

Preliminary update: More conservative configuration of 5% flux normalisation uncertainty and $E_{\mathrm{th}} = 1\,\mathrm{GeV}$ weakens bounds by roughly 30% $\Rightarrow$ still clear improvement

Neutrino-electron scattering at the DUNE near detector

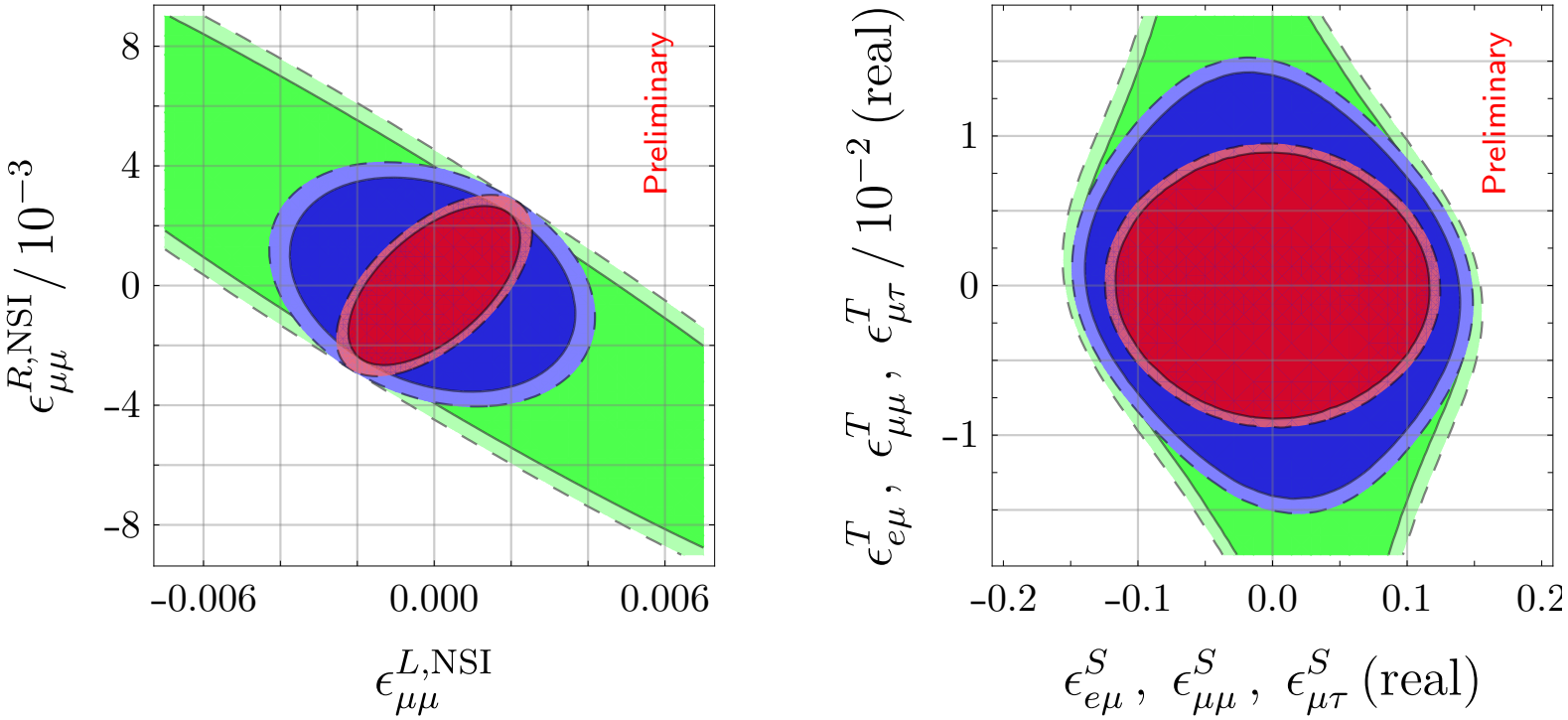
Expected two-parameter bounds



Flux normalisation uncertainty 0% 1%

Neutrino-electron scattering at the DUNE near detector

Expected two-parameter bounds



Flux normalisation uncertainty 0% 1% 5%

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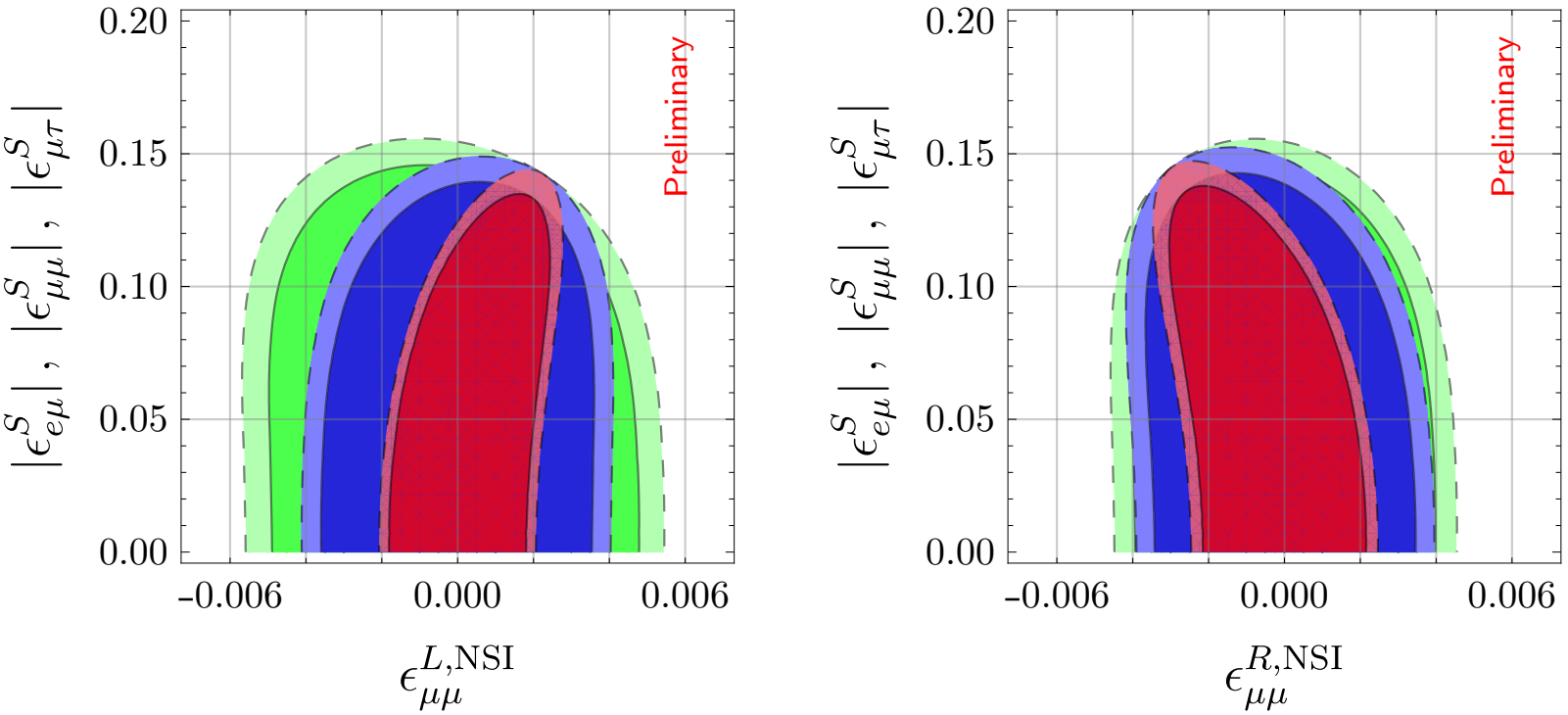

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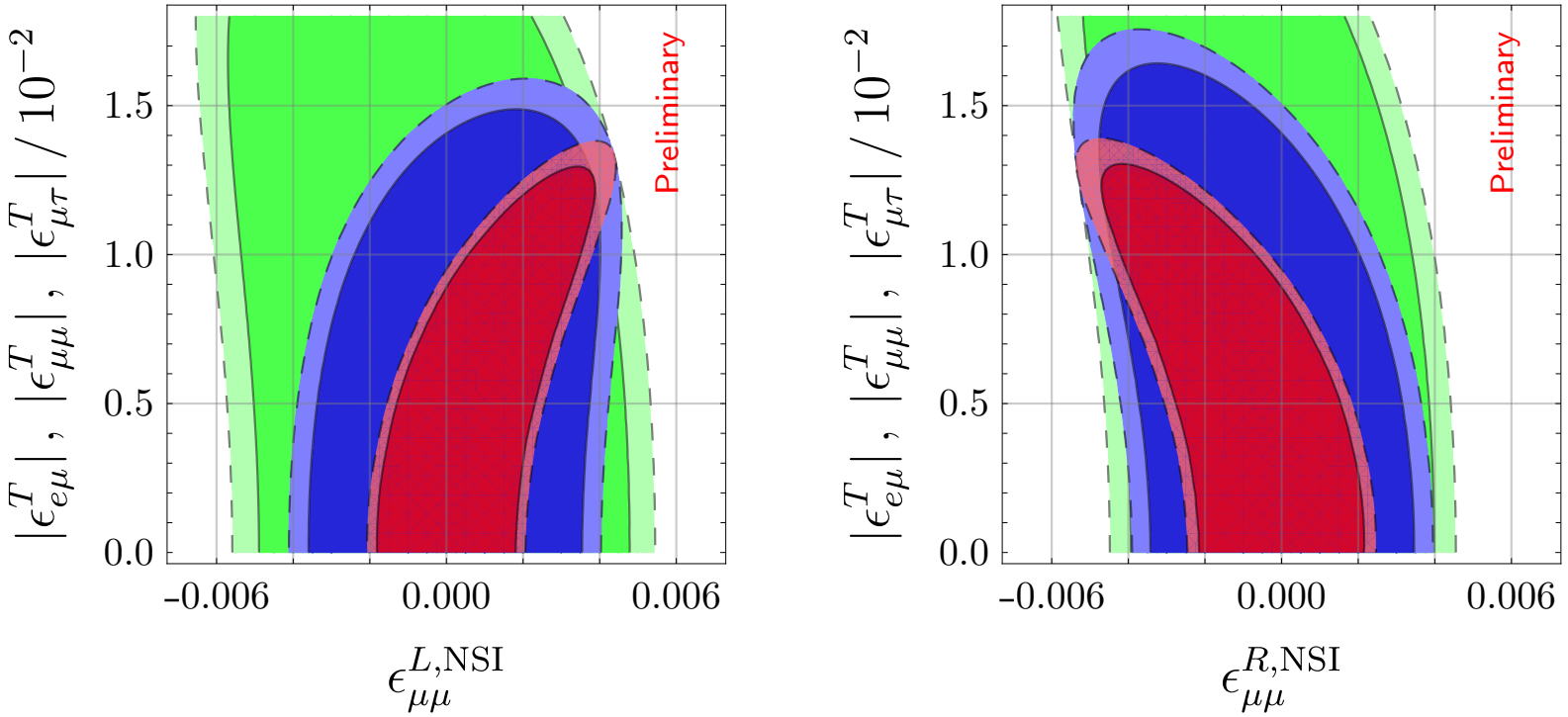

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Neutrino-electron scattering at the DUNE near detector

Degeneracies

Can we uniquely identify new physics signatures?

- $\epsilon_{\mu\mu}^{L,\mathrm{NSI}} > 0$ distinguished
- $\epsilon_{\mu\mu}^{L,\mathrm{NSI}} < 0, |\epsilon_{\mu e}^{L,\mathrm{NSI}}|, |\epsilon_{\mu\tau}^{L,\mathrm{NSI}}|$ degenerate
- $\epsilon_{\mu\mu}^{R,\mathrm{NSI}} < 0$ distinguished
- $\epsilon_{\mu\mu}^{R,\mathrm{NSI}} > 0, |\epsilon_{\mu e}^{R,\mathrm{NSI}}|, |\epsilon_{\mu\tau}^{R,\mathrm{NSI}}|$ degenerate
- $|\epsilon_{\mu}^{S}|, |\epsilon_{\mu}^{P}|$ degenerate
- $|\epsilon_{\mu}^{T}|$ distinguished

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- $|\epsilon_{\mu}^{S}|, |\epsilon_{\mu}^{P}|$ degenerate
- $|\epsilon_{\mu}^{T}|$ distinguished

Degeneracies with respect to flux normalisation:

- $\epsilon_{\mu\mu}^{L,\mathrm{NSI}} > 0$, $\epsilon_{\mu\mu}^{R,\mathrm{NSI}} < 0$ or vice versa
- $|\epsilon_{\mu}^{T}|$

Conclusion

General neutrino interactions

- leave distinct spectral signatures (NSI vs. S/P vs. T)
- are straightforward to include in fits

Sensitivity at DUNE ND (5 year run)

- Improved bounds up to one order of magnitude
- Scales up to 6 TeV indirecly accessible
- Spectral information reduces sensitivity to flux normalisation
- Complementary bounds on matter NSI to support the robustness of the determination of δ_{CP} from ν-oscillation

Thank you!

. . . and thanks to Werner Rodejohann, Xun-Jie Xu!

Backup slides

Neutrino-electron scattering at DUNE ND

Data fitting

- Employed χ^2 function:

$$\chi^2(\vec{\epsilon}) = \frac{a^2}{\sigma_a^2} + \sum_{X=\nu_\mu,\overline{\nu}_\mu} \sum_{i=1}^{n_{\mathrm{bins}}} \frac{\left((1+a)N_i^X(\vec{\epsilon}) - N_i^{X,\mathrm{SM}}\right)^2}{(\sigma_i^X)^2(\vec{\epsilon})}$$

- a: compensation for uncertainties affecting the total number of events (e.g. flux normalisation)
- Assume in each bin statistically dominated σ_i^X

General neutrino interactions

Remark

Equivalent parametrisation of GNI:

$$\mathcal{L} = -\frac{G_F}{\sqrt{2}} \sum_{a=S,P,V,A,T} (\overline{\nu}_\alpha \Gamma^a \nu_\beta) \left(\overline{\psi} \Gamma^a (C^a_{\alpha\beta} + \overline{D}^a_{\alpha\beta} i\gamma^5) \psi \right),$$

where

$$\Gamma^a \in \left\{ \mathbb{1}, i\gamma^5, \gamma^\mu, \gamma^\mu\gamma^5, \sigma^{\mu\nu} \right\},$$

used by, e.g. [Kayser et al. PRD20 (1979)], [Rosen PRL48 (1982)]