



New Physics from Oscillations at the DUNE Near Detector

In collaboration with P. Coloma, J. López-Pavón & S. Urrea, based on JHEP 08 (2021) 065

Salvador Rosauro-Alcaraz 16/11/2021



Introduction

Standard neutrino oscillations

What we know (at 1σ)

I. Esteban et al. 2007.14792 www.nu-fit.org

Solar sector $\begin{cases} \sin^2 \theta_{12} = 0.304^{+0.012}_{-0.012} \\ \Delta m_{21}^2 = 7.42^{+0.21}_{-0.20} \cdot 10^{-5} eV^2 \end{cases}$

Atm. sector $\begin{cases} \sin^2 \theta_{23} = 0.573^{+0.016}_{-0.020} \\ |\Delta m_{31}^2| = 2.517^{+0.026}_{-0.028} \cdot 10^{-3} eV^2 \end{cases}$

$$\sin^2 \theta_{13} = 0.02219^{+0.00062}_{-0.00063}$$

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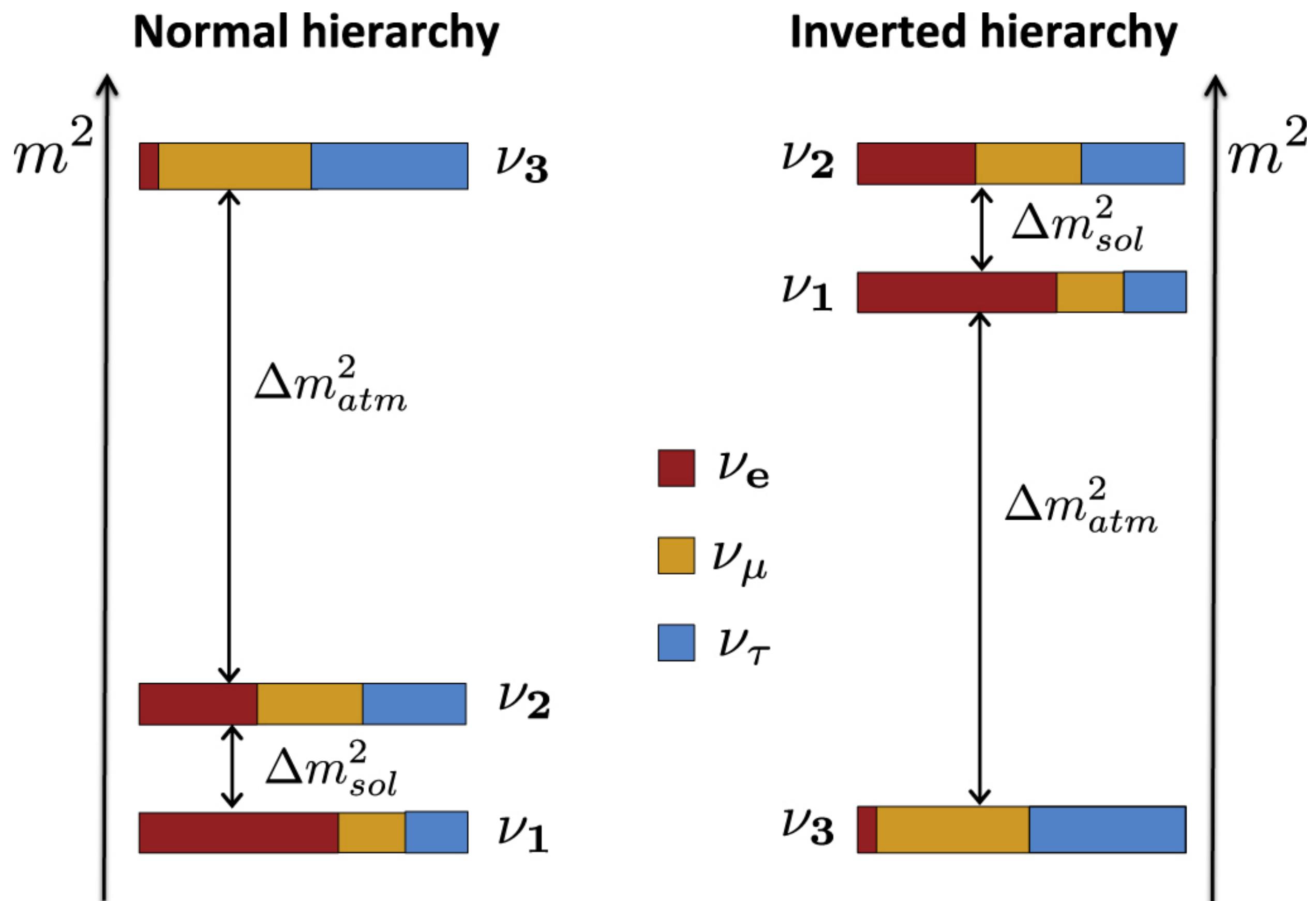
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What we do not know (yet)

Is there leptonic
CP violation, i.e., $\delta \neq 0, \pi$?

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Mass ordering: $sign(\Delta m_{31}^2)$

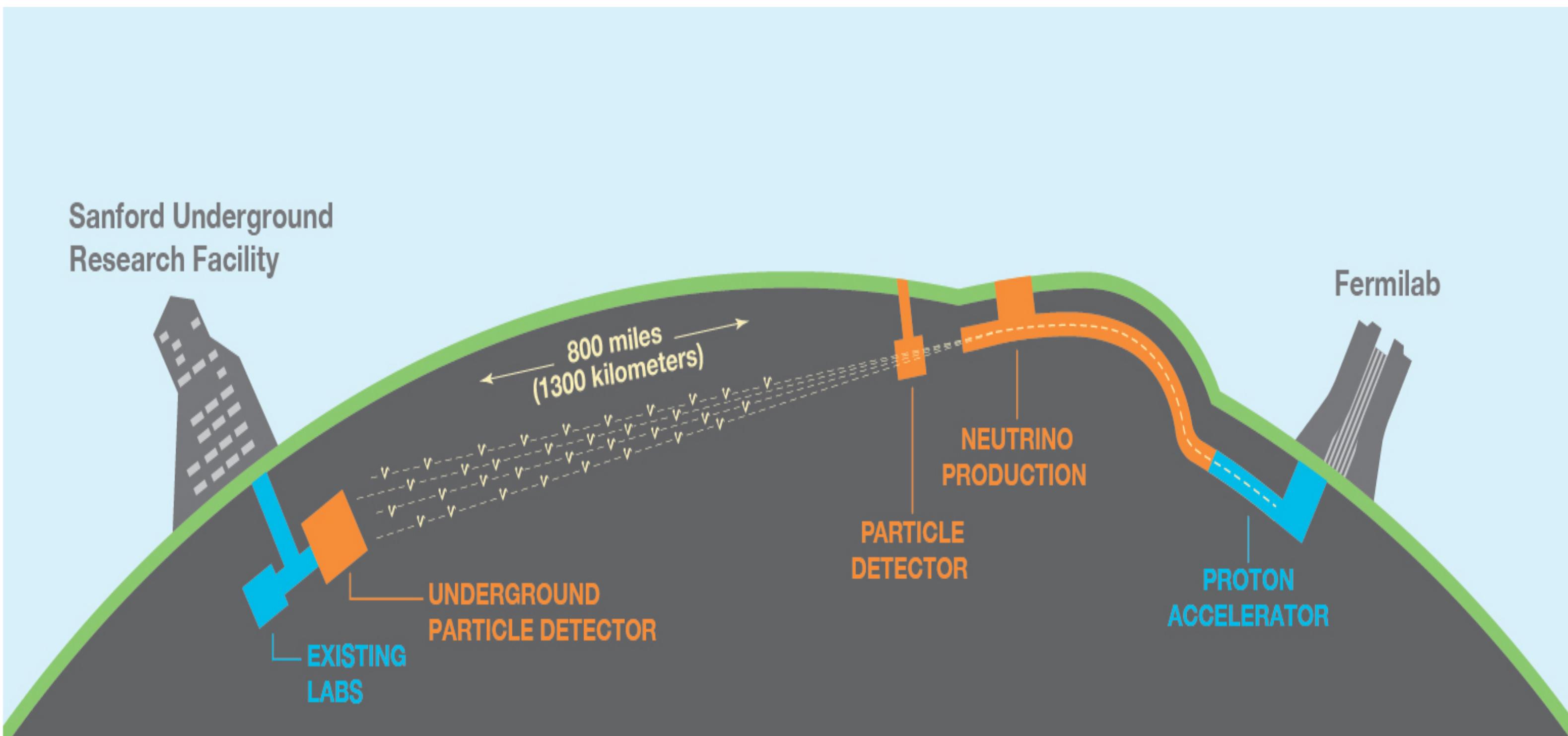
Octant of θ_{23}

Introduction

Future facilities

DUNE & T2HK

DUNE Collaboration, arXiv:2006.16043
T2HK Collaboration, arXiv:1412.4673



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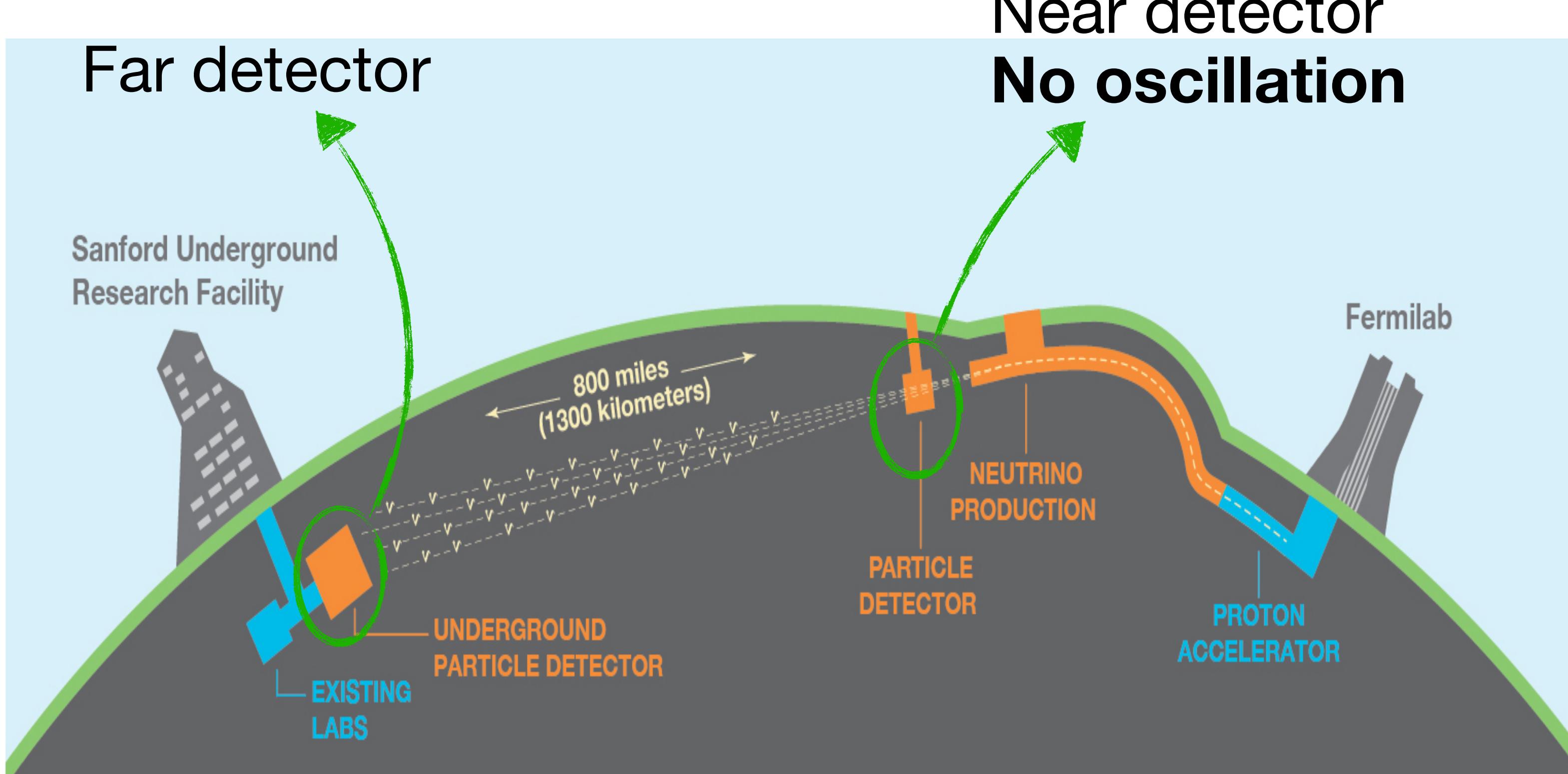
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Beyond 3ν oscillations

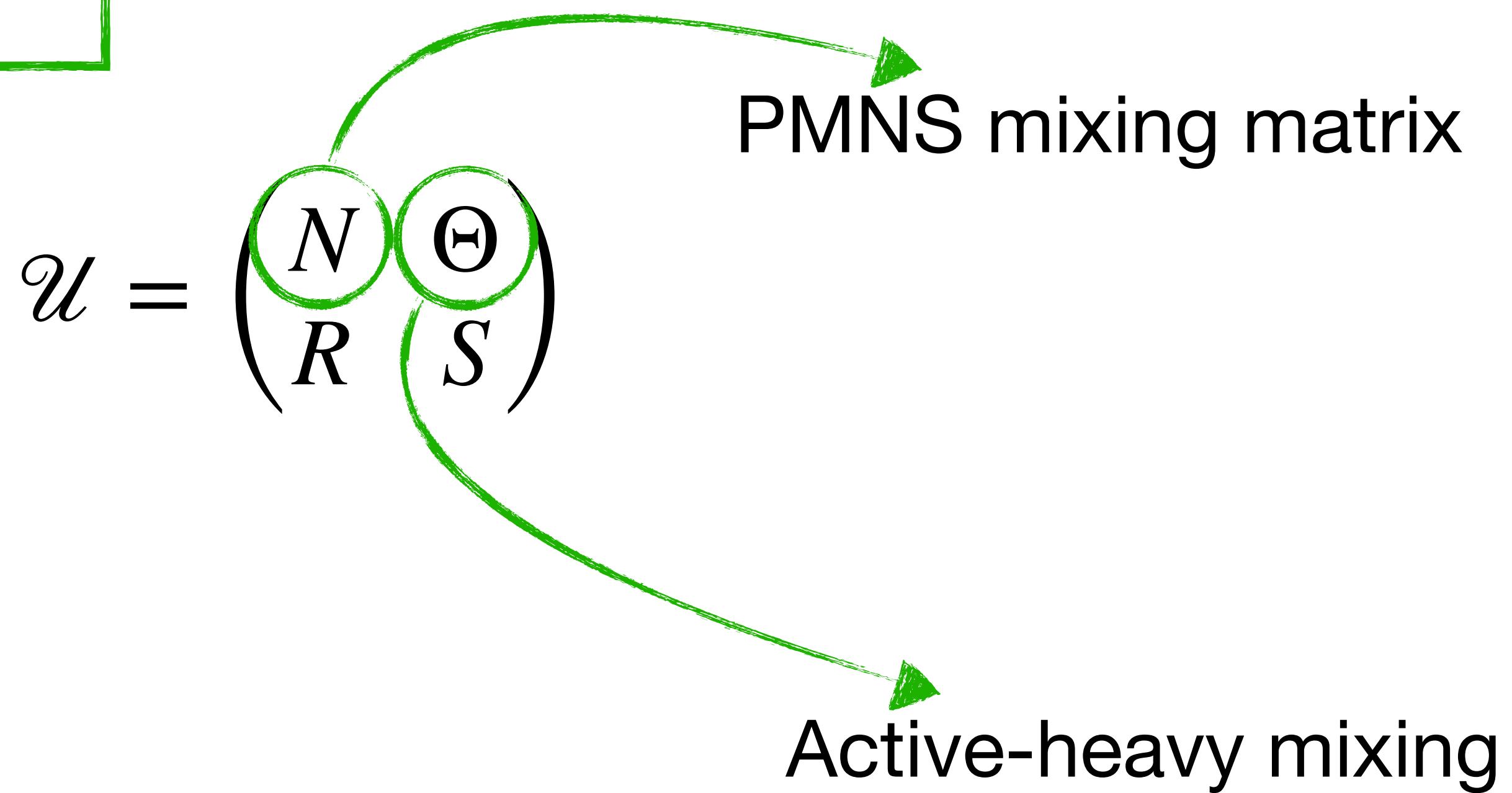
Need right-handed neutrinos to explain light neutrino masses

Introduction

Beyond 3ν oscillations

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$$\nu_\alpha = \sum_i \mathcal{U}_{\alpha i} n_i$$



Introduction

Beyond 3ν oscillations

Need right-handed neutrinos to explain light neutrino masses

$$\nu_\alpha = \sum_i \mathcal{U}_{\alpha i} n_i$$

$$\mathcal{U} = \begin{pmatrix} N & \Theta \\ R & S \end{pmatrix}$$

$$N = (I - T)U$$

$$T = \begin{pmatrix} \alpha_{ee} & 0 & 0 \\ \alpha_{\mu e} & \alpha_{\mu\mu} & 0 \\ \alpha_{\tau e} & \alpha_{\tau\mu} & \alpha_{\tau\tau} \end{pmatrix}$$

Introduction

Beyond 3ν oscillations

Need right-handed neutrinos to explain light neutrino masses

$$\nu_\alpha = \sum_{i=1}^3 N_{\alpha i} n_i + \sum_{i=4}^n \Theta_{\alpha i} n_i$$

Stronger bounds

Two regimes for non-unitarity:

- n_i not produced in neutrino oscillation experiments
- n_i participating in neutrino oscillations

Introduction

Beyond 3ν oscillations

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Two regimes for non-unitarity:

- n_i not produced in neutrino oscillation experiments
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$$\Delta m_{41}^2 \gg |\Delta m_{31}^2|$$

Study effects at ND

Introduction

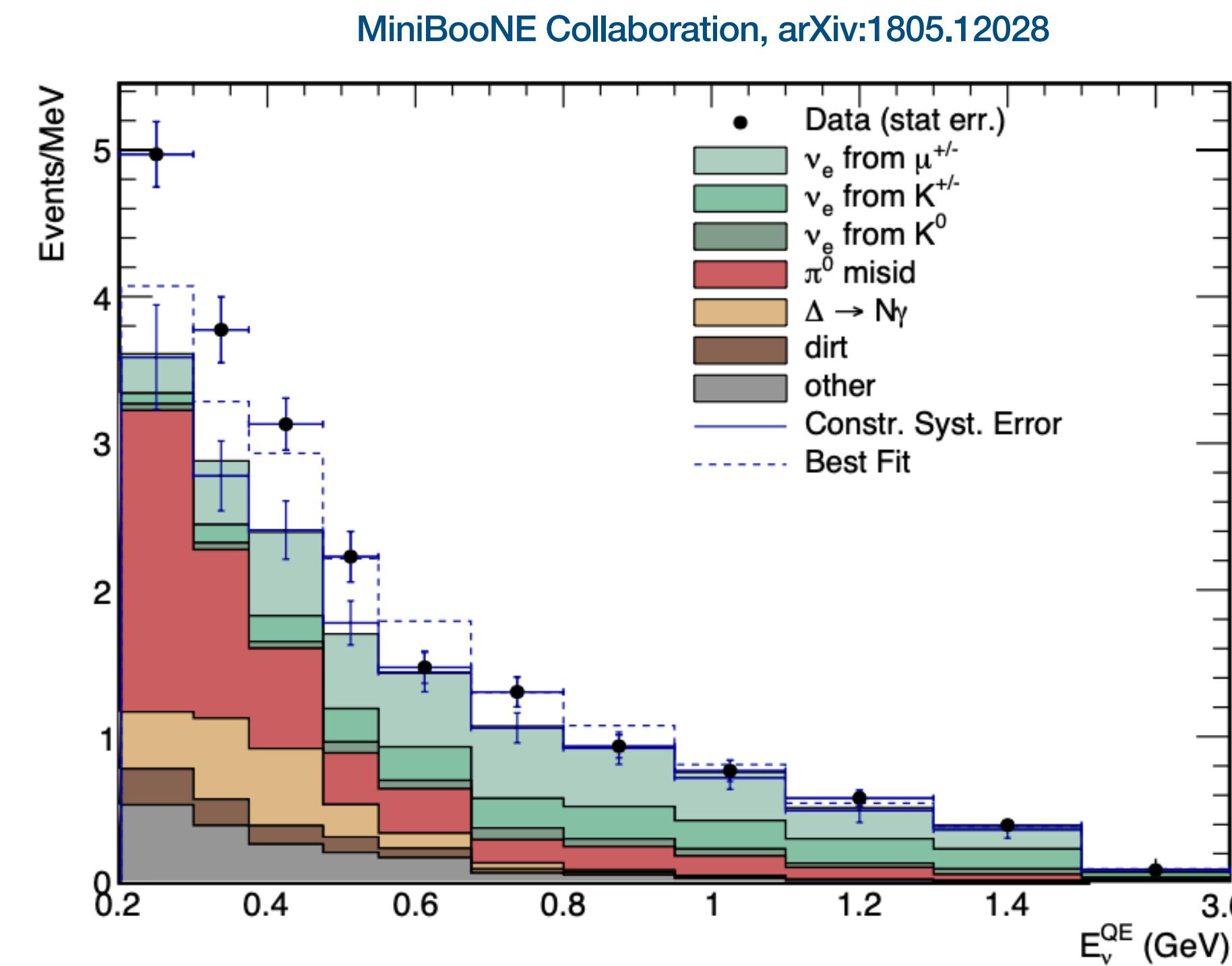
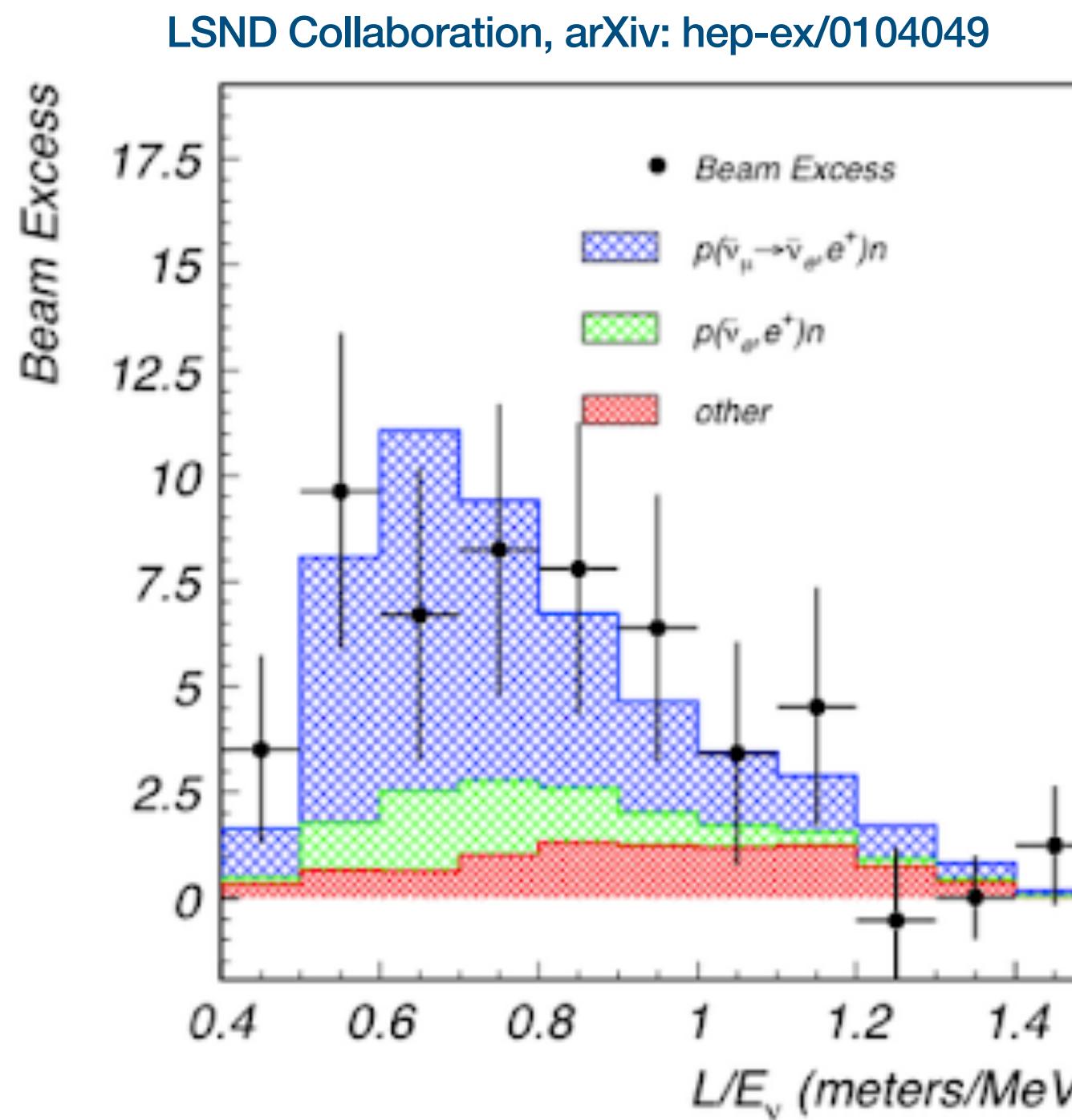
Sterile neutrino oscillations

$$P_{\gamma\beta} = \sin^2 2\theta_{\gamma\beta} \sin^2 \left(\frac{\Delta m_{41}^2 L}{4E} \right), \quad \sin^2 \theta_{\gamma\beta} \equiv 4 \left| \mathcal{U}_{\gamma 4} \right|^2 \left| \mathcal{U}_{\beta 4} \right|^2$$

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Anomalous $\nu_\mu \rightarrow \nu_e$

Introduction

Non-unitarity from low-scale physics

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Averaged-out regime $\Delta m_{41}^2 L/E \gg 1$

$$P_{\gamma\beta} = 2 \left| \alpha_{\gamma\beta} \right|^2$$

Similar to NU at high scales

Introduction

Non-standard neutrino interactions

General 4-fermion effective operator $\mathcal{L}_{NSI} = -2\sqrt{2}G_F\epsilon_{\alpha\beta}\left(\bar{\nu}_\alpha\gamma_\mu P_L\nu_\beta\right)\left(\bar{f}\gamma^\mu P_{L(R)}f\right)$

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$$P_{\gamma\beta} = \left| \epsilon_{\gamma\beta}^d \right|^2 + \left| \epsilon_{\gamma\beta}^s \right|^2 + 2 \left| \epsilon_{\gamma\beta}^d \right| \left| \epsilon_{\gamma\beta}^s \right| \cos(\Phi_{\gamma\beta}^s - \Phi_{\gamma\beta}^d)$$

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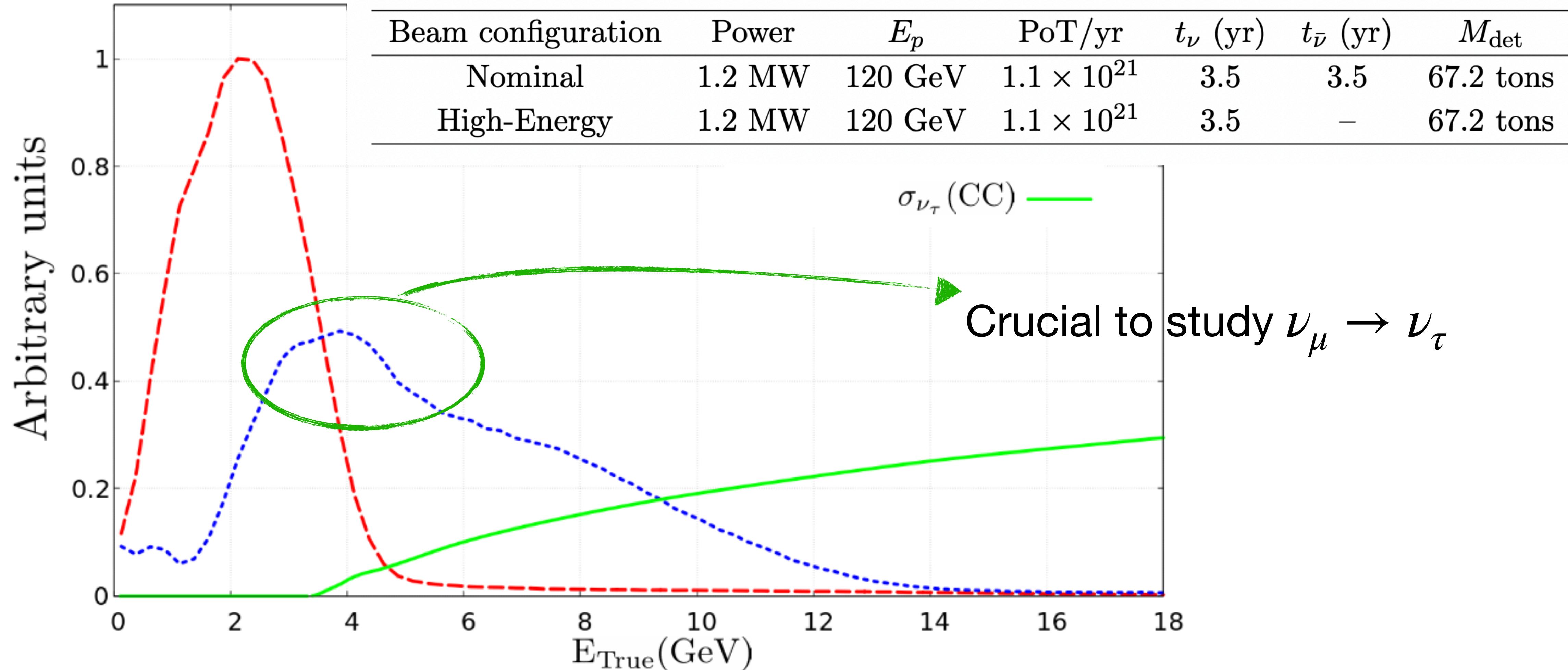
Averaged-out regime $\Delta m_{41}^2 L/E \gg 1$

$$P_{\gamma\beta} = 2 |\alpha_{\gamma\beta}|^2$$

Translate bounds from $\alpha_{\gamma\beta}$ to $\epsilon_{\gamma\beta}$

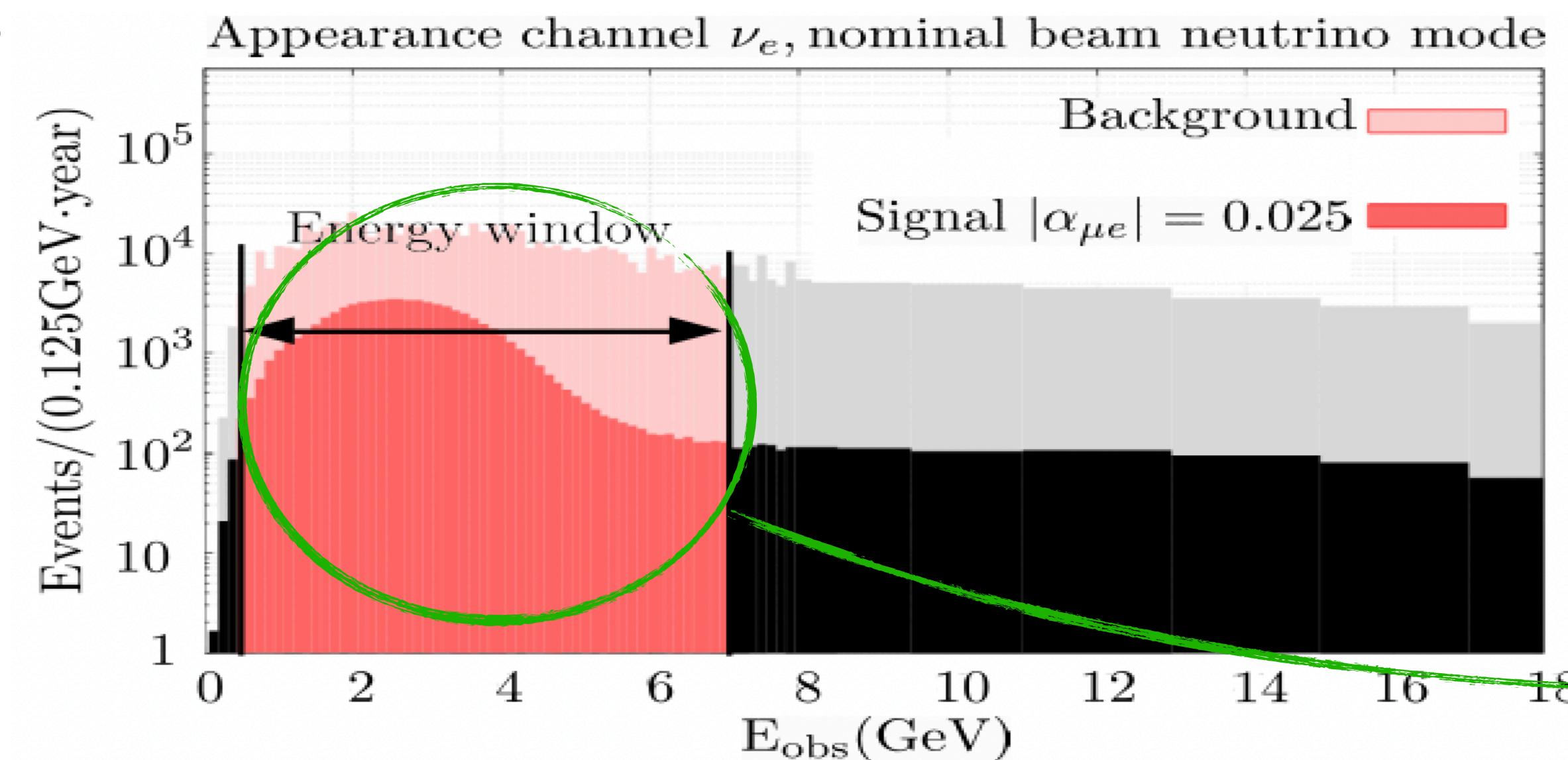
Simulation details

DUNE flux & detector simulation

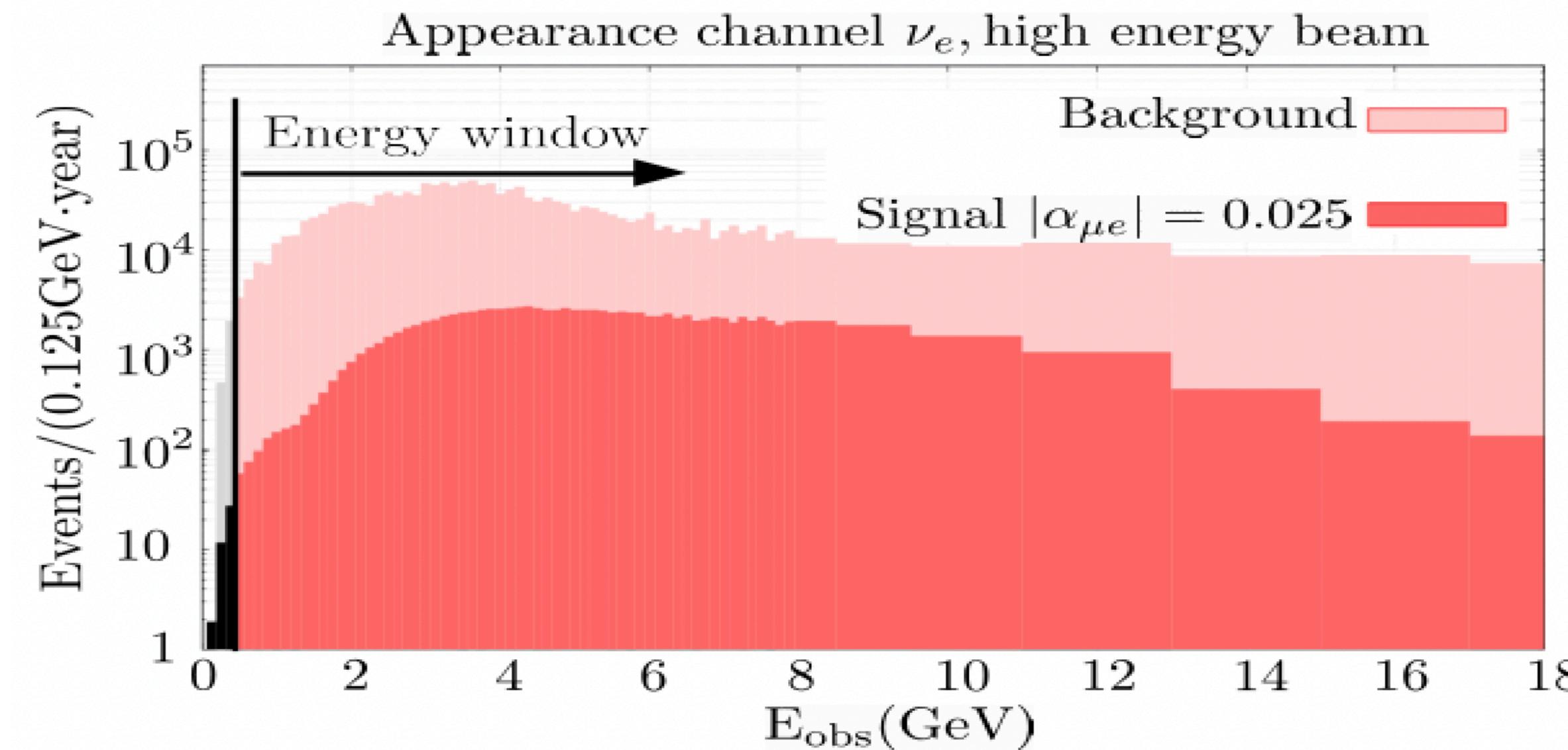


Simulation details

Event rates



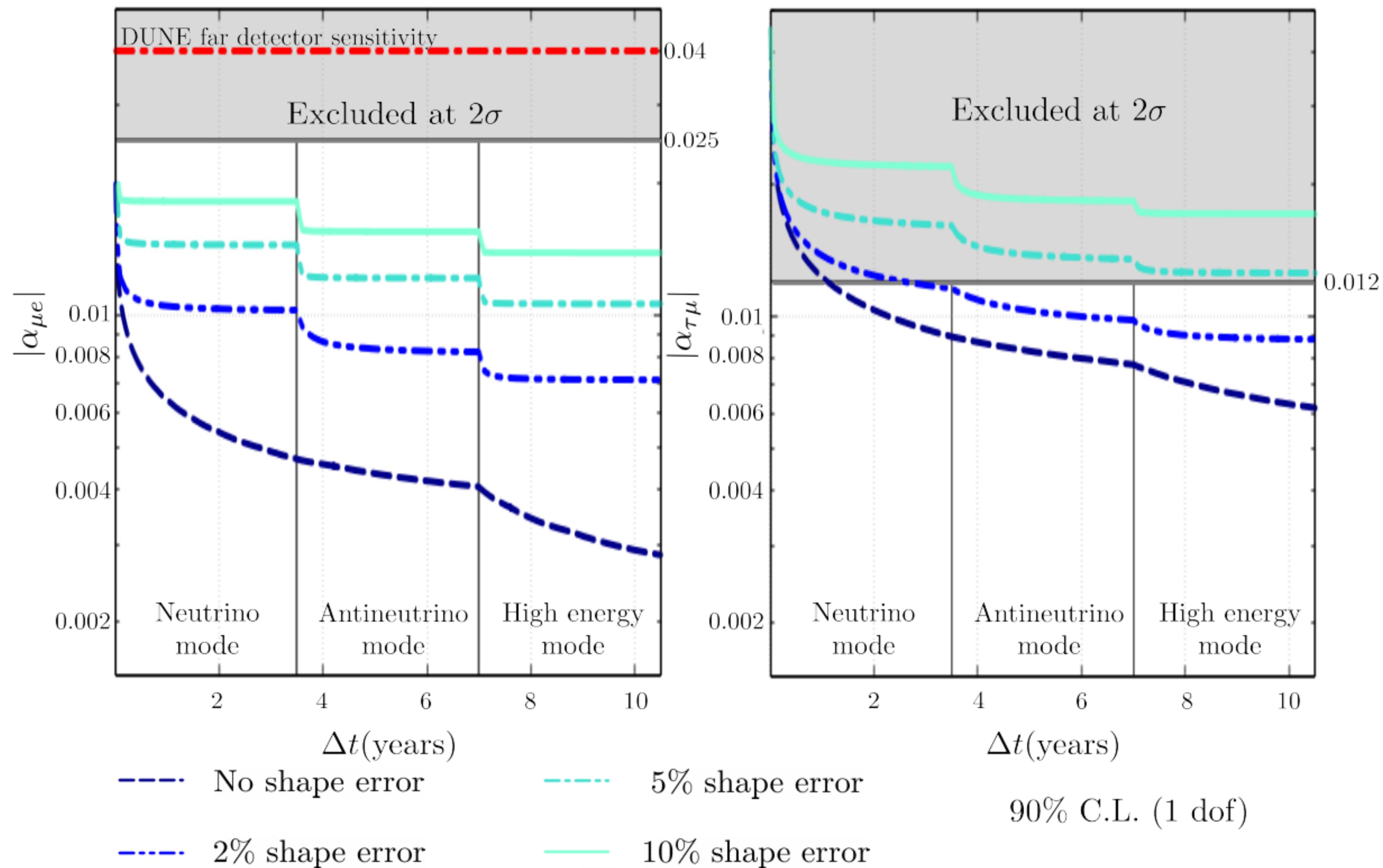
Events included
in the analysis



Results

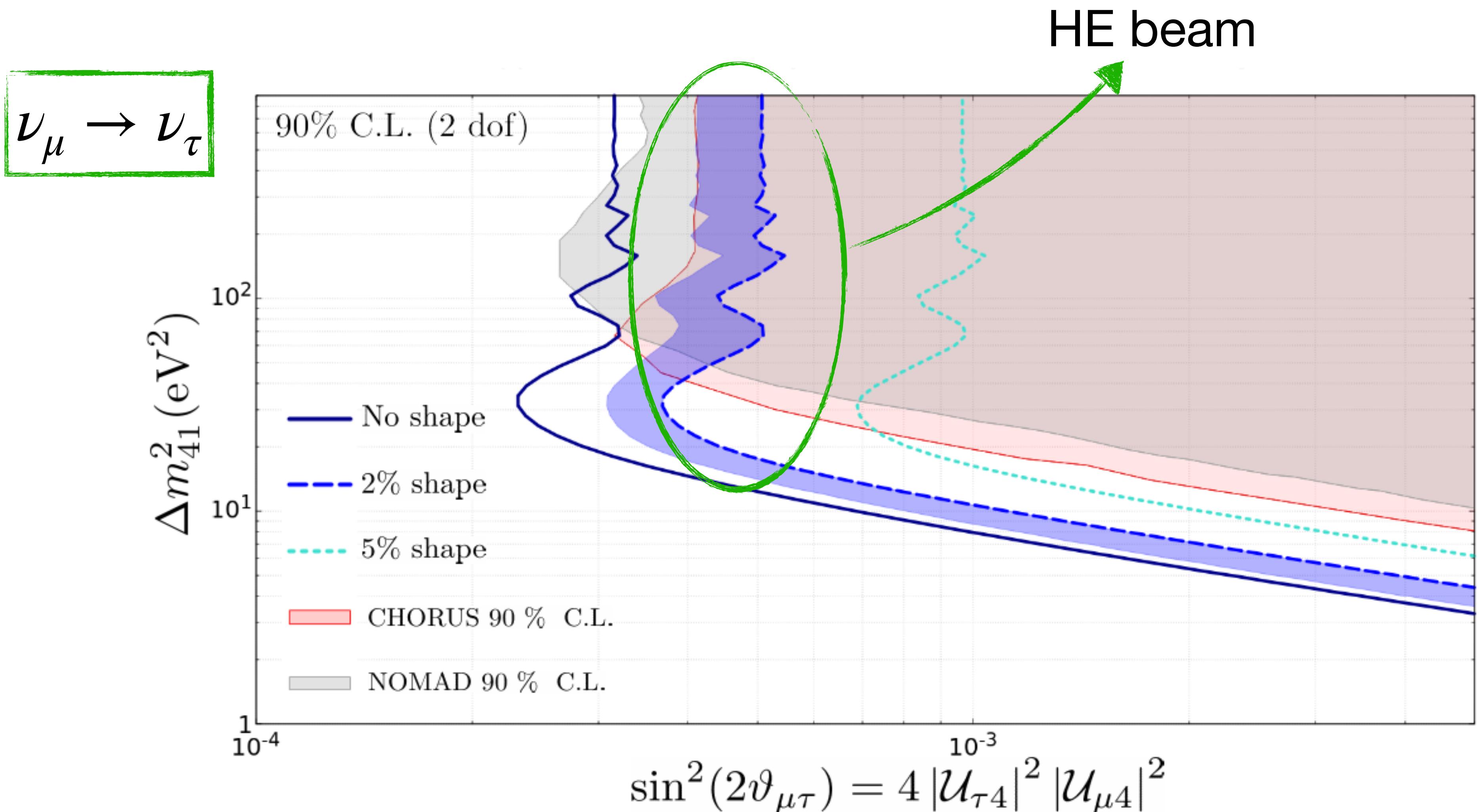
Non-unitarity

$$\Delta m_{41}^2 L/E \gg 1$$



Results

Sterile oscillations

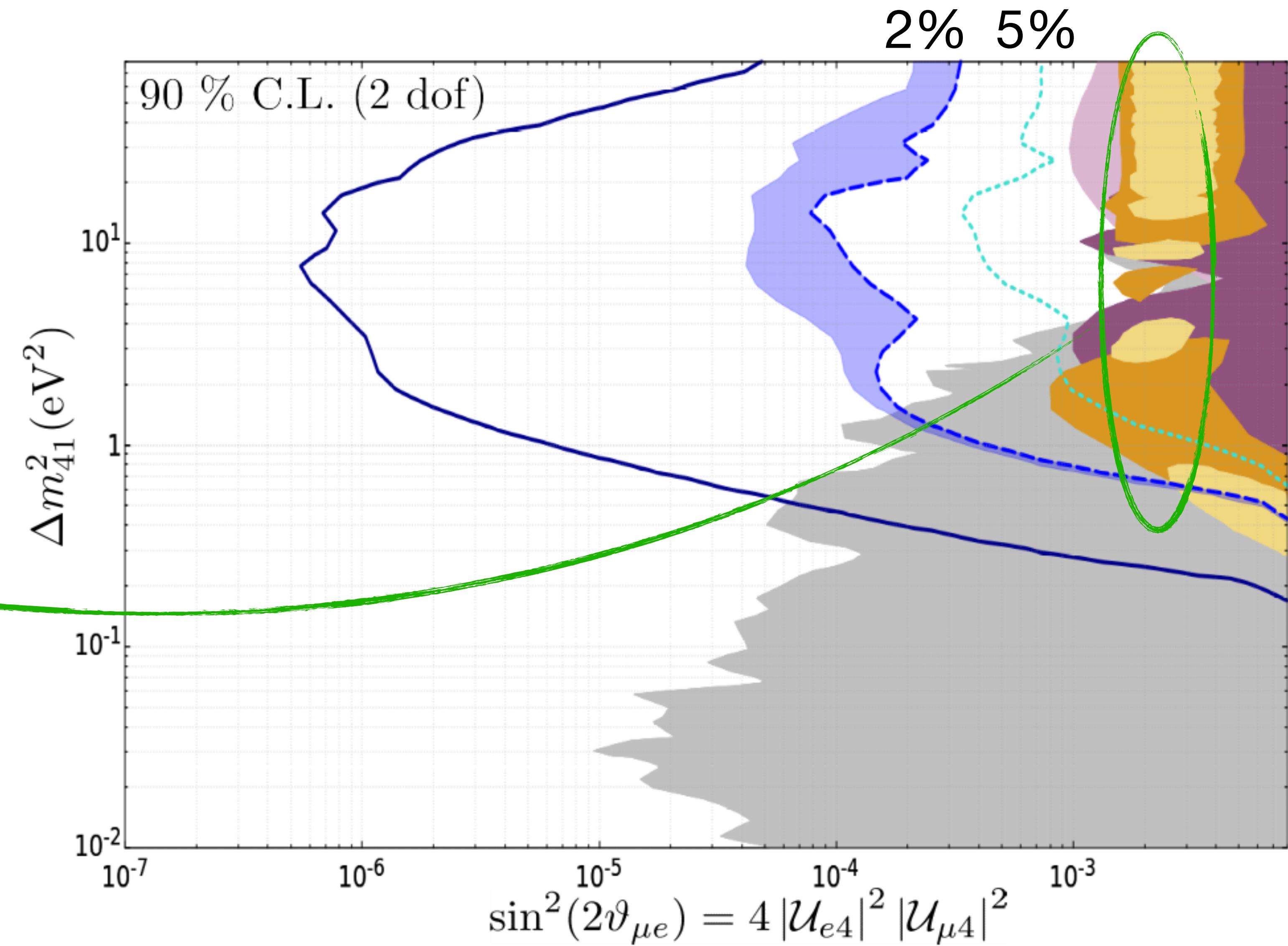


Results

Sterile oscillations

$$\nu_\mu \rightarrow \nu_e$$

LSND & MiniBooNE



Results

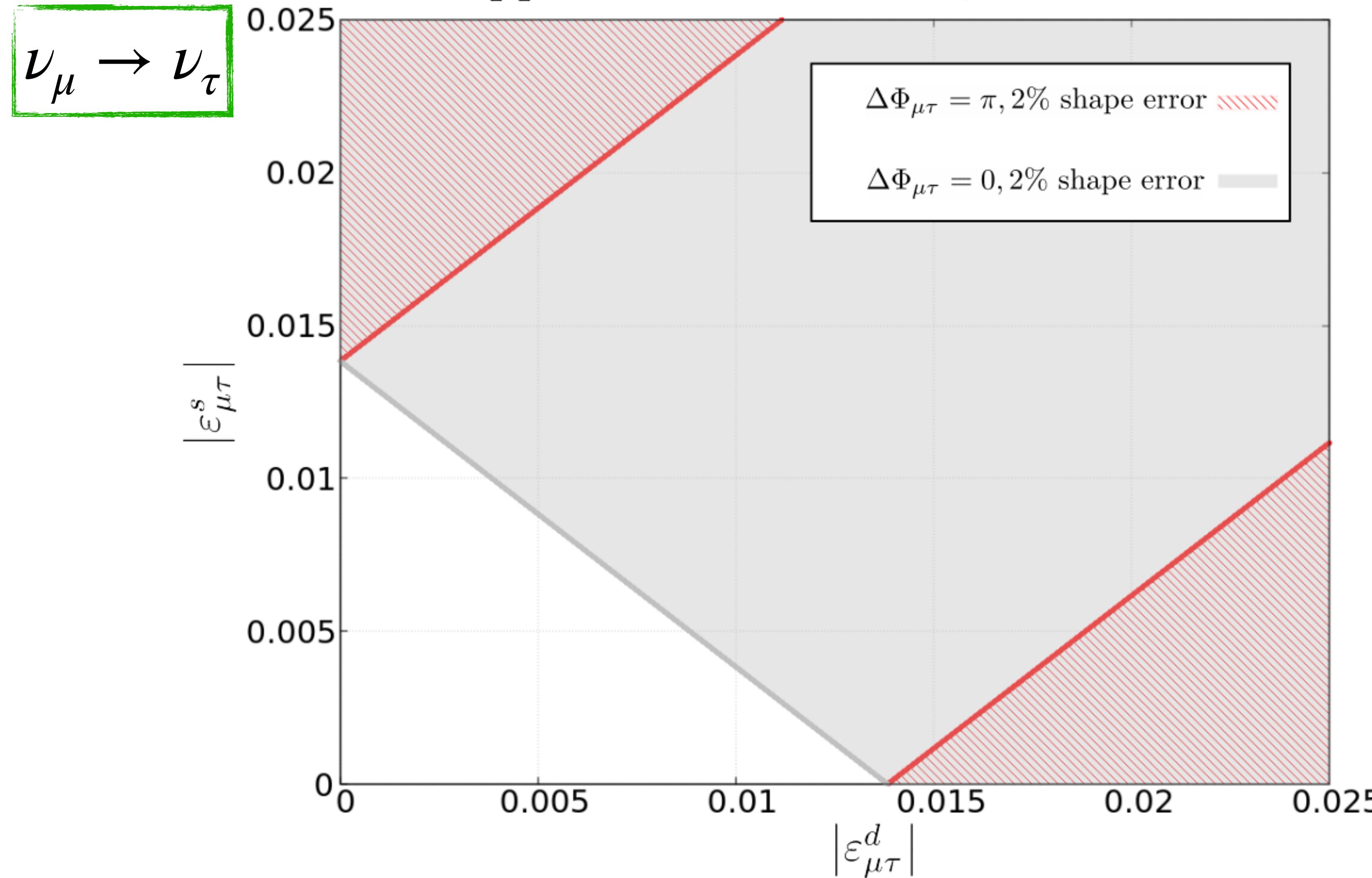
Non-standard neutrino interactions

$$2 \left| \alpha_{\gamma\beta} \right|^2 = \left| \epsilon_{\gamma\beta}^d \right|^2 + \left| \epsilon_{\gamma\beta}^s \right|^2 + 2 \left| \epsilon_{\gamma\beta}^d \right| \left| \epsilon_{\gamma\beta}^s \right| \cos \left(\Phi_{\gamma\beta}^s - \Phi_{\gamma\beta}^d \right)$$

Results

Non-standard neutrino interactions

Appearance channel ν_τ 90% C.L.



Conclusions

Near detectors can be useful to study physics beyond 3ν oscillations

Systematic uncertainties play a crucial role

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Study ν_τ appearance in DUNE

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Near detectors can be useful to study physics beyond 3ν oscillations

Systematic uncertainties play a crucial role

Study ν_τ appearance in DUNE

2% shape uncertainties:

- Reduce considerably the sensitivity to $\nu_\mu \rightarrow \nu_e$ around 2 orders of magnitude
- Reduce bound on NU parameters about a factor 2

Thank you!

Back-up slides

Simulation details

ν_τ detection

PDG, P. A. Zayla *et al.*, PTEP 2020
GENIE Collaboration, J. Tena-Vidal *et al.*, arXiv:2104.09179
A. de Gouvêa *et al.*, arXiv:1904.07265

Produce τ through CC interactions

Consider only τ hadronic decay ($BR(\tau \rightarrow had) \sim 65\%$)

Main background due to NC

Simulation details

Systematic uncertainties

Event sample	Contribution	Benchmark 1		Benchmark 2		Benchmark 3	
		σ_{norm}	σ_{shape}	σ_{norm}	σ_{shape}	σ_{norm}	σ_{shape}
ν_e -like	Signal	5%	–	5%	–	5%	–
	Intrinsic cont.	10%	–	10%	2%	10%	5%
	Flavor mis-ID	5%	–	5%	2%	5%	5%
	NC	10%	–	10%	2%	10%	5%
ν_μ -like	$\nu_\mu, \bar{\nu}_\mu$ CC (signal)	10%	–	10%	2%	10%	5%
	NC	10%	–	10%	2%	10%	5%
ν_τ -like	Signal	20%	–	20%	–	20%	–
	NC	10%	–	10%	2%	10%	5%

Allows every bin to vary independently