THE ν KID ON THE BLOCK

Sterile Neutrinos at the eV Scale
and NuSTORM

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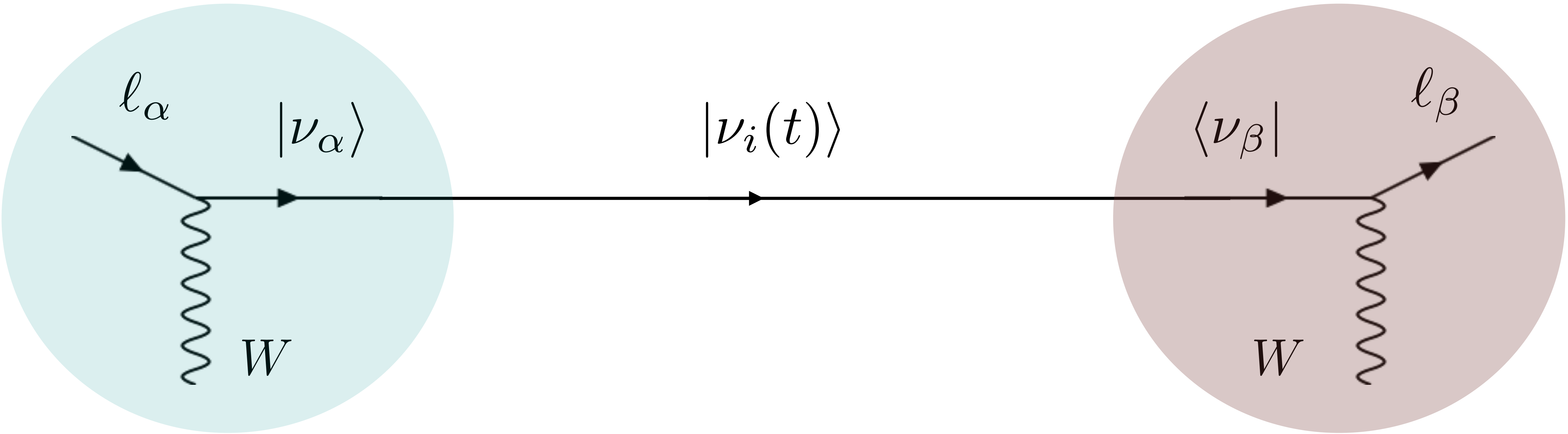
- Neutrino Oscillations
- eV Scale Sterile Neutrinos
- NuSTORM

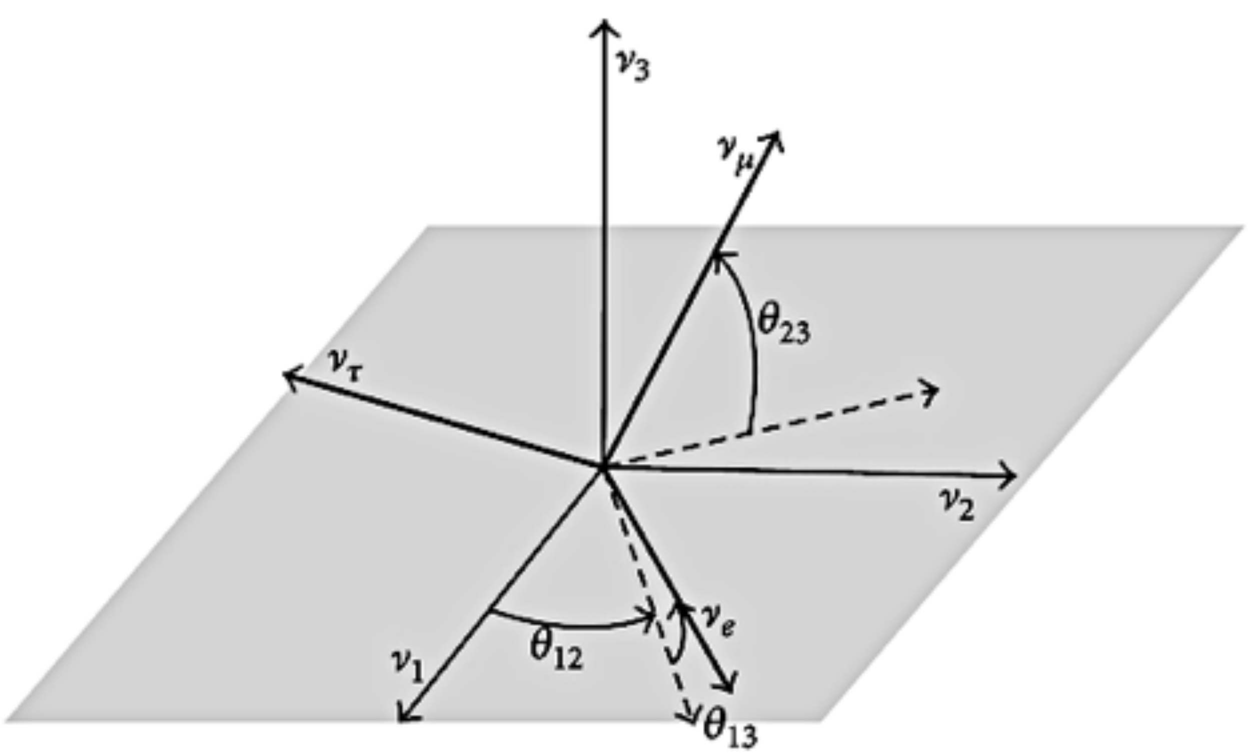
NEUTRINO OSCILLATIONS

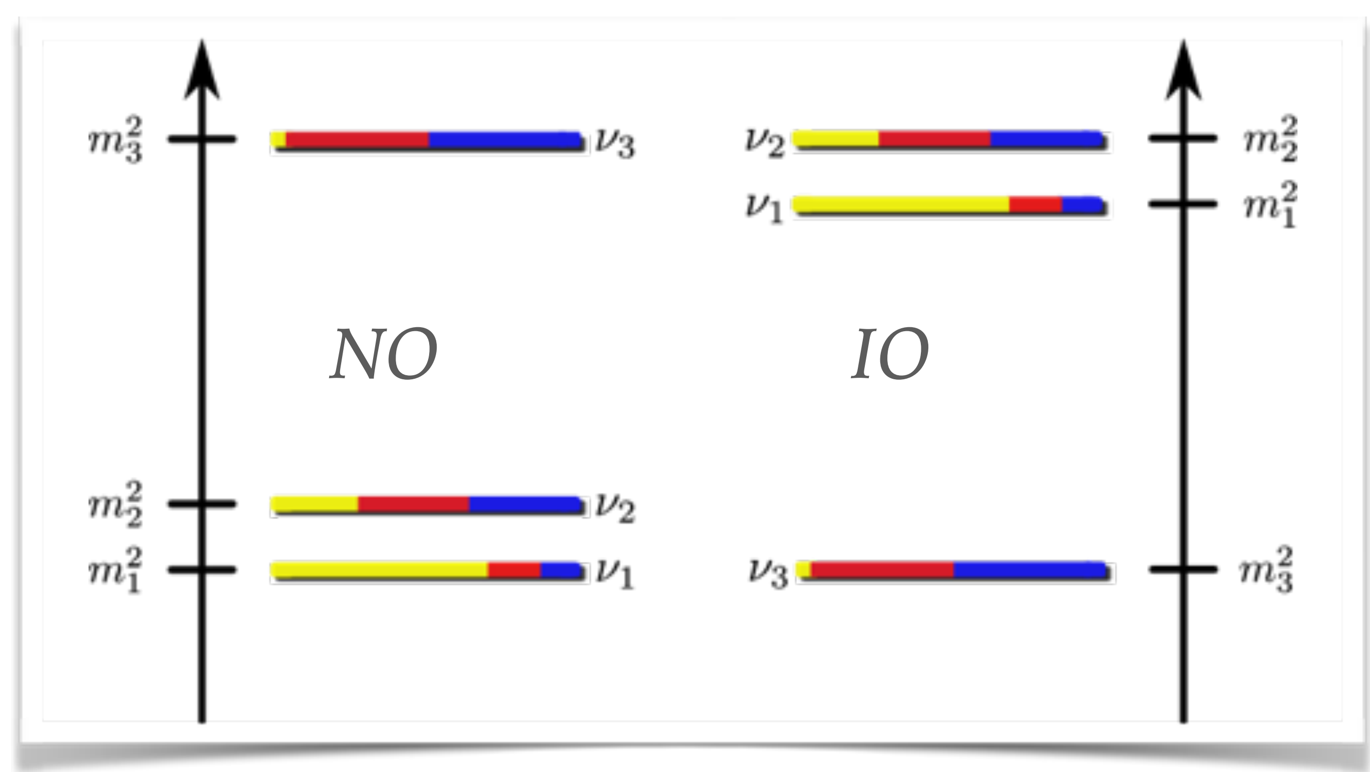
$$\begin{aligned} P_{\nu_\alpha \to \nu_\beta} &= \left| \langle \nu_\beta | \nu_\alpha(t) \rangle \right|^2 \\ &= \sum_{k,j} U^*_{\alpha k} U_{\beta k} U_{\alpha j} U^*_{\beta j} e^{-i(E_k - E_j)t} \end{aligned}$$



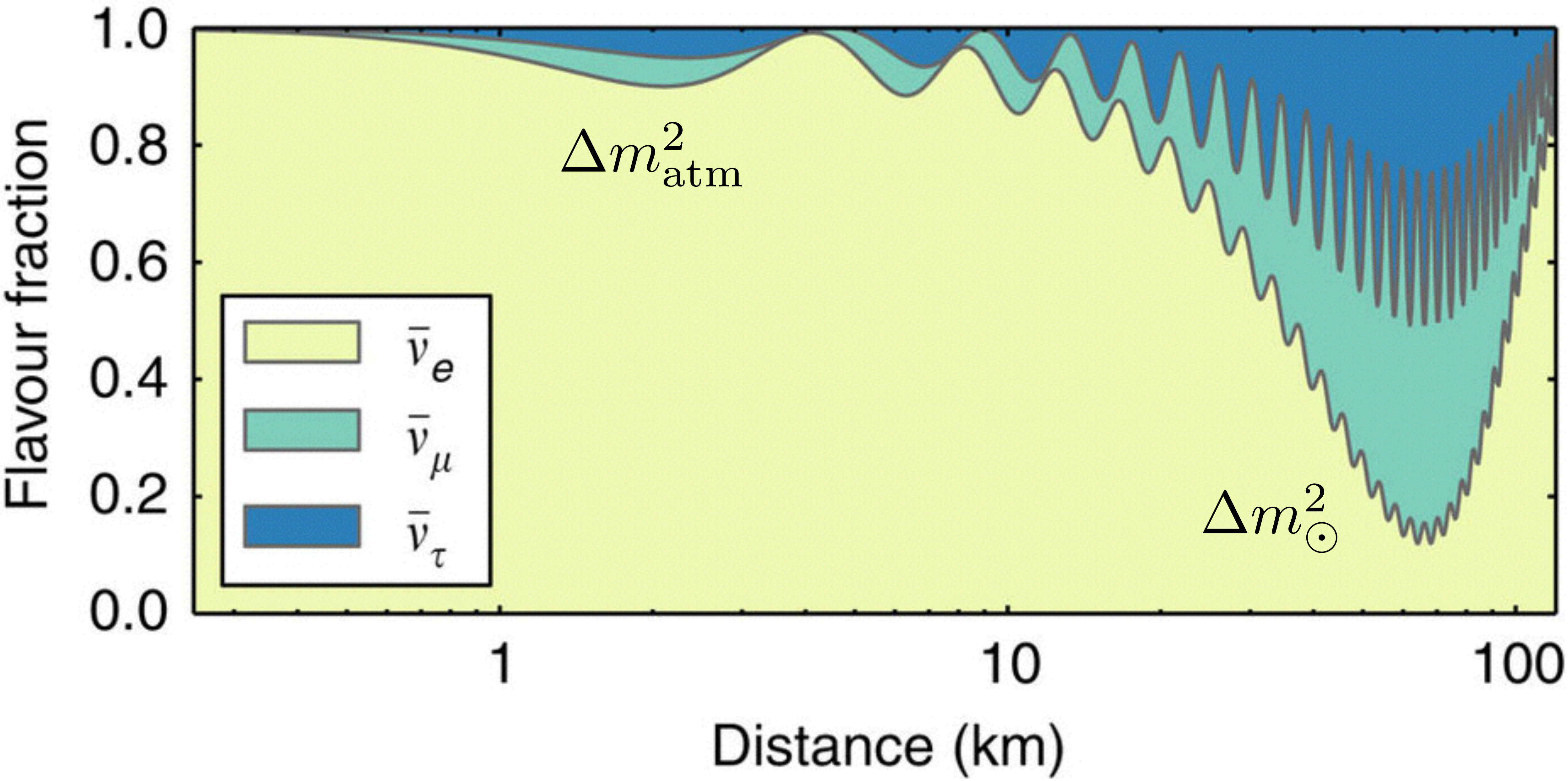
3 NEUTRINO SCENARIO — $\theta_{12}, \theta_{13}, \theta_{23}, \delta, \Delta m^2_{21}, \Delta m^2_{31}$

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$



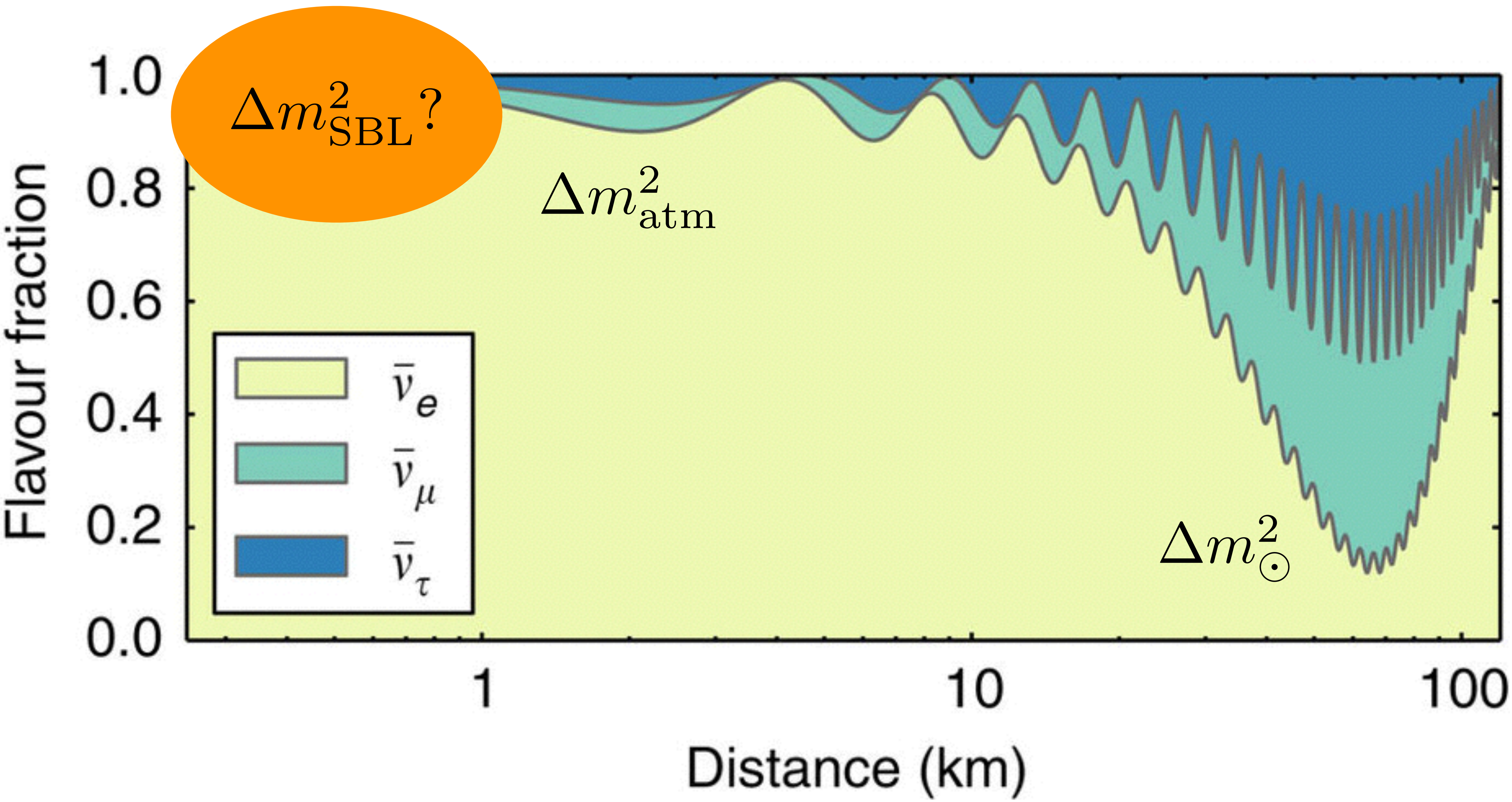


FLAVOUR FRACTION OF A NEUTRINO BEAM



$E = 4$ MeV

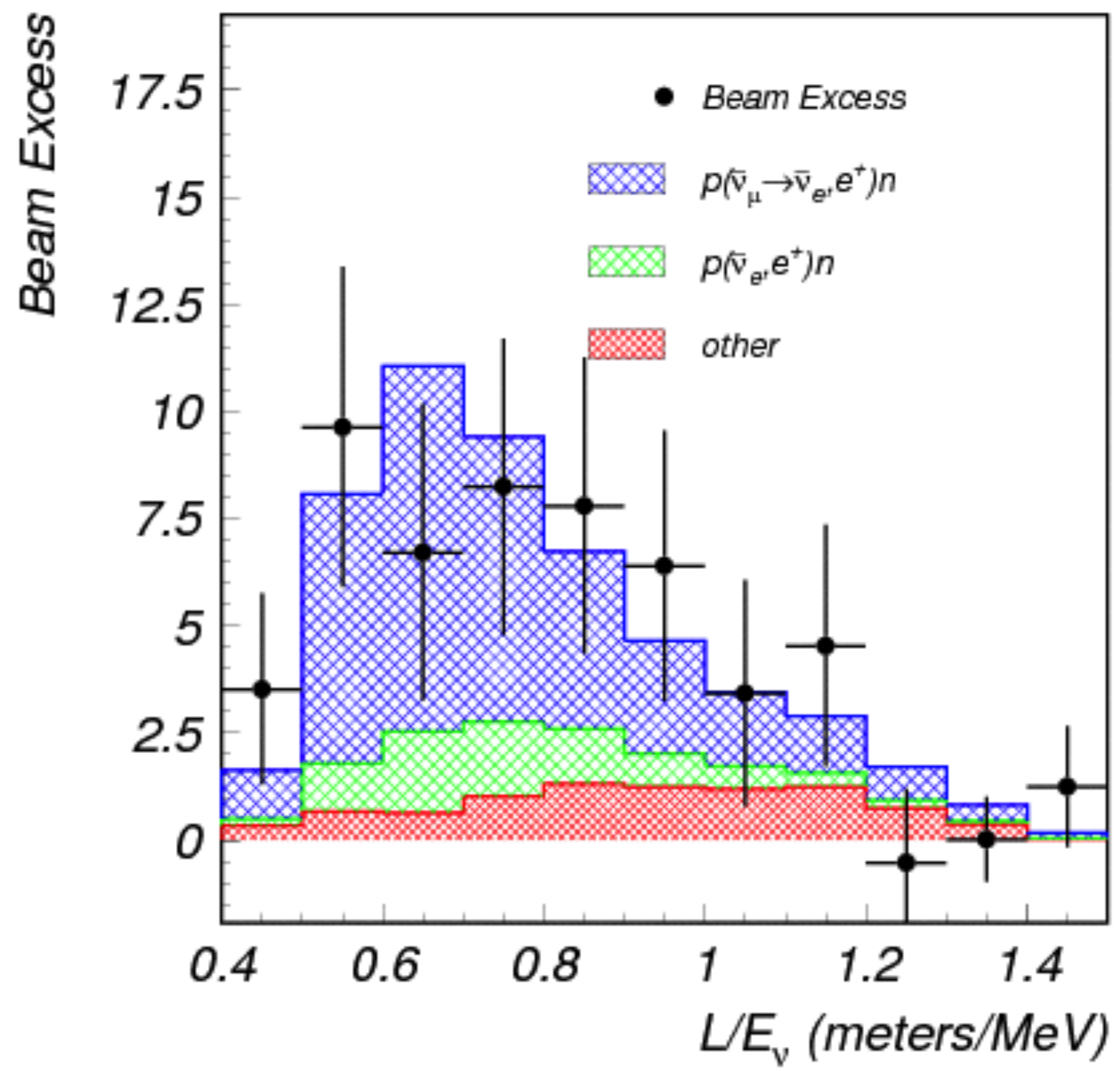
FLAVOUR FRACTION OF A NEUTRINO BEAM



$E = 4$ MeV

SHORT BASELINE ANOMALIES

- Gallium Deficit
- Reactor Deficit
- LSND Excess

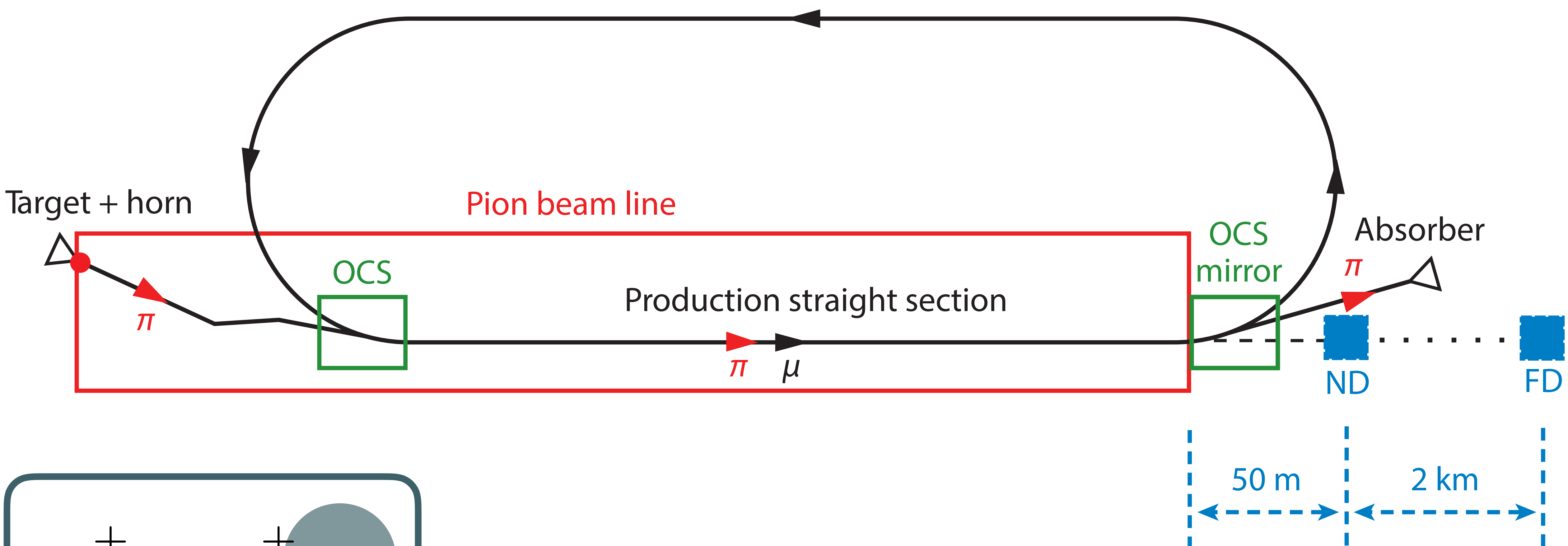


- MiniBoone Low Energy Excess

νSTORM

The Ultimate Test

A ν BEAM



$$\pi^+ \to \mu^+ \nu_\mu$$

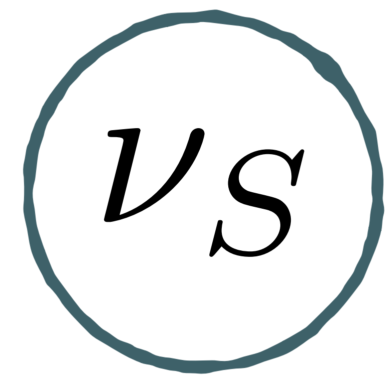
$$\mu^+ \to e^+ \nu_e \overline{\nu}_\mu$$

$$\nu_\mu \to \nu_\mu$$

$$\overline{\nu}_\mu \to \overline{\nu}_\mu$$

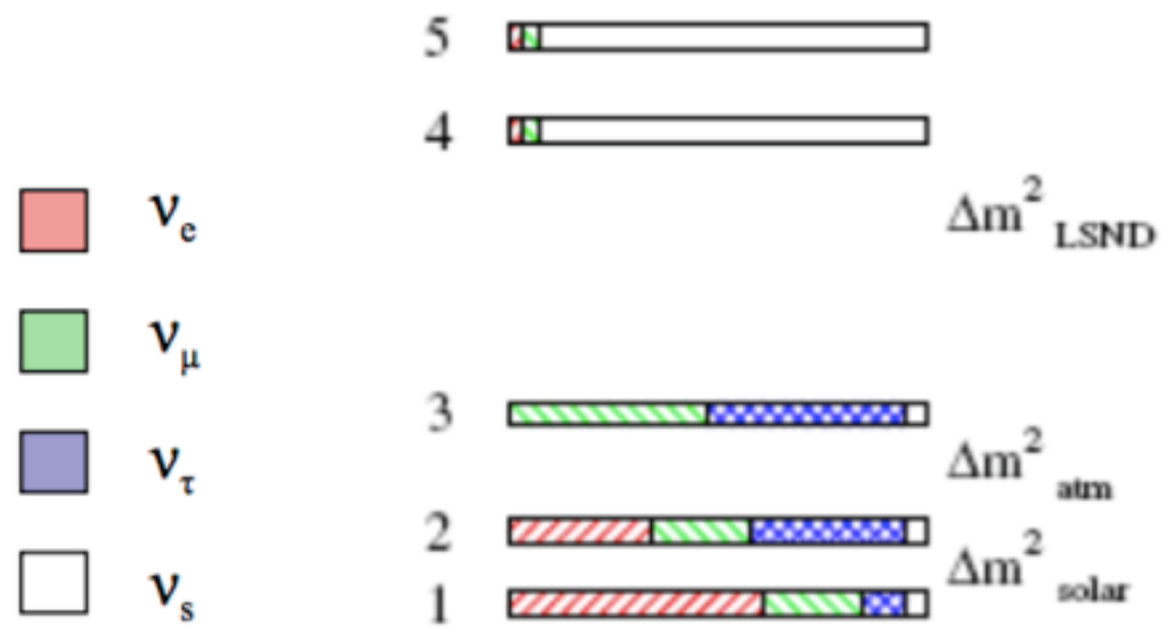
$$\nu_e \to \nu_\mu$$

3 + N MODELS



Standard Model Singlet

New mass eigenstates are mostly sterile.



PRODUCTION DECOHERENCE EFFECTS

For oscillations to happen: $$\frac{\delta x}{L} \ll 1$$

$$\delta x \delta p > 1 \qquad \Longrightarrow \qquad \frac{\delta p}{P} > \frac{1}{P\delta x} \gg \frac{1}{LP} = \frac{\Delta m^2}{4\pi E}$$

$$|\nu_\alpha(\vec{x}, t)\rangle = \sum_i U^*_{\alpha i} \Psi_i(\vec{x}, t) \, |\nu_i\rangle$$

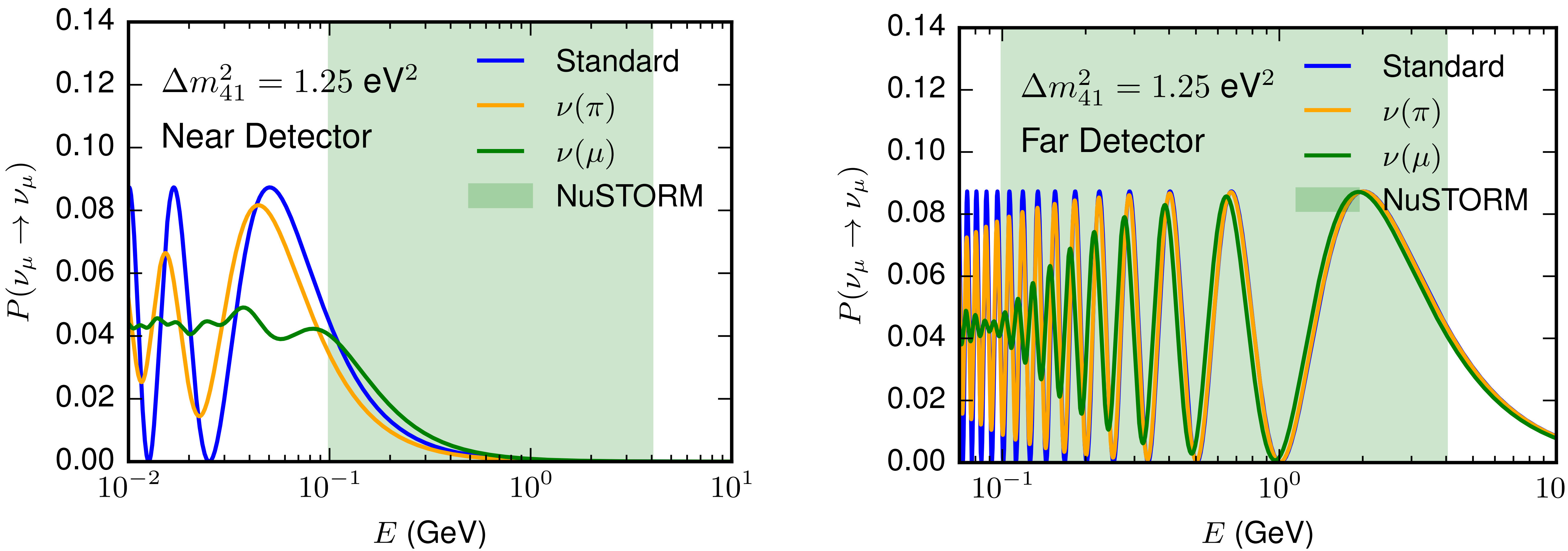
Can use a wavepacket approach!

$$\Psi_i(\vec{x}, t) = \int \frac{d^3 p}{(2\pi)^{3/2}} f_i^S(\vec{p} - \vec{p_i}) e^{i\vec{p}.\vec{x} - iE_i(p)t}$$

DECOHERENCE EFFECTS – PRODUCTION

$$P_{\nu_\mu\to\nu_\mu} = \overline{P} + \frac{\sin^2 2\theta_{\mu\mu}}{2(1+\xi^2)}\left[\cos\Delta + \xi\sin\Delta\right]$$

$$\frac{\ell_p}{\ell_{\rm decay}} \gg 1 \qquad \Delta = \frac{\Delta m^2_{41} L}{2E} \qquad \xi = \frac{v_i\,\Delta}{L\,\Gamma_i}$$



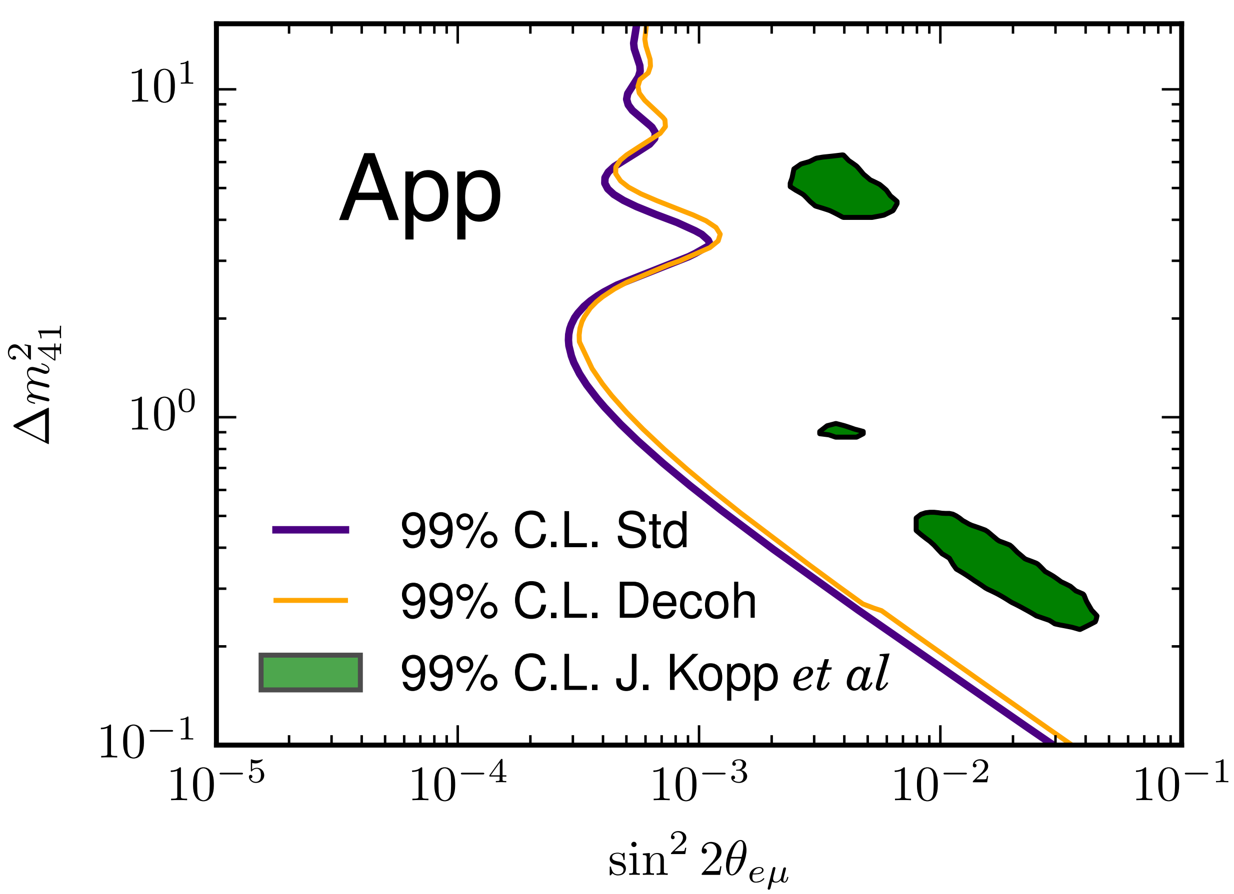
SIMPLEST 3+1 MODEL

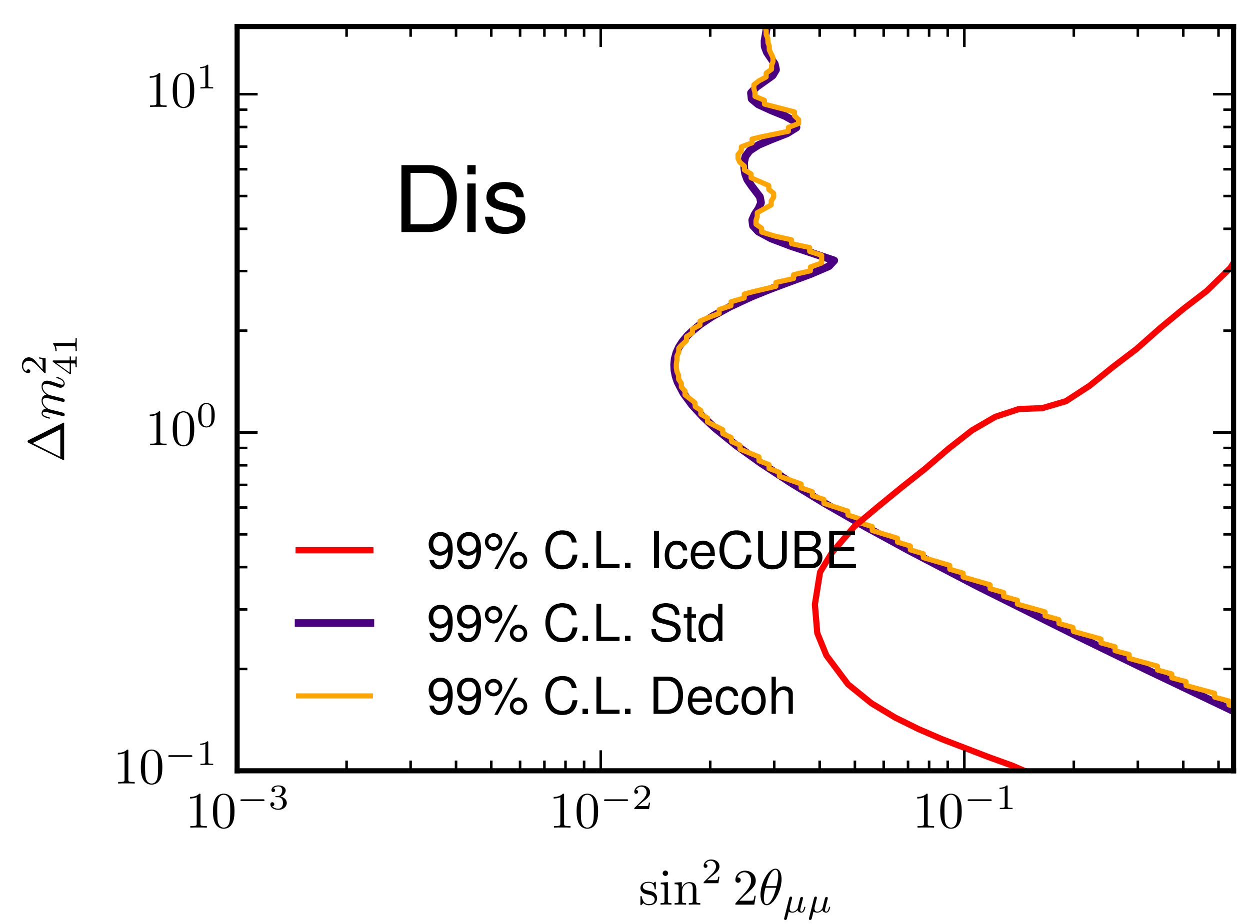
$$\Delta m^2_{41} \approx \mathcal{O}(1)\ \mathrm{eV}^2 \gg \Delta m^2_{31}, \Delta m^2_{21}$$

$$P(\nu_e \to \nu_\mu) = \sin^2 2\theta_{e\mu} \sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$

Can treat it as a 1+1 model!

$$P(\overline{\nu}_\mu \to \overline{\nu}_\mu) = 1 - \sin^2 2\theta_{\mu\mu} \sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$

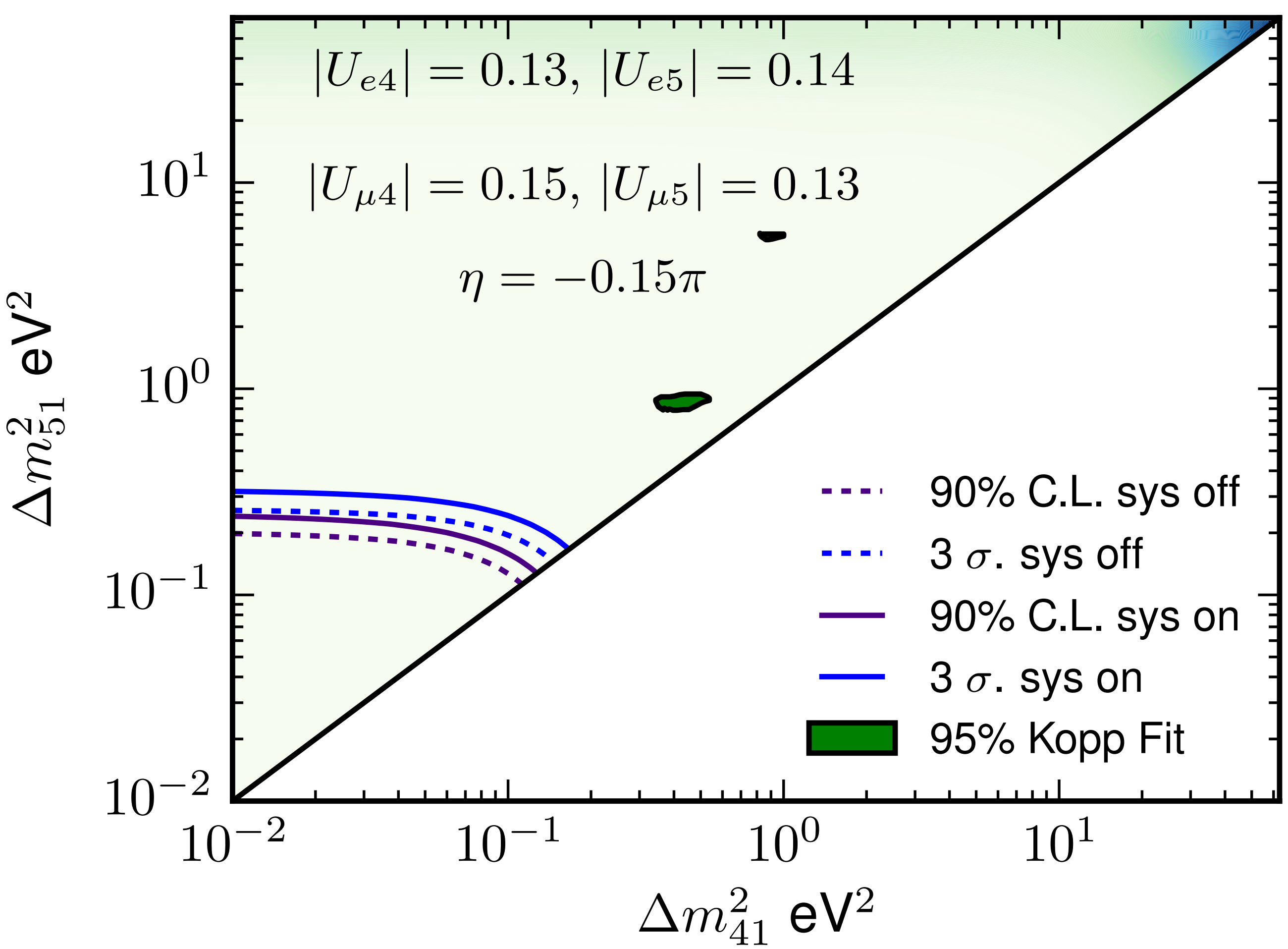


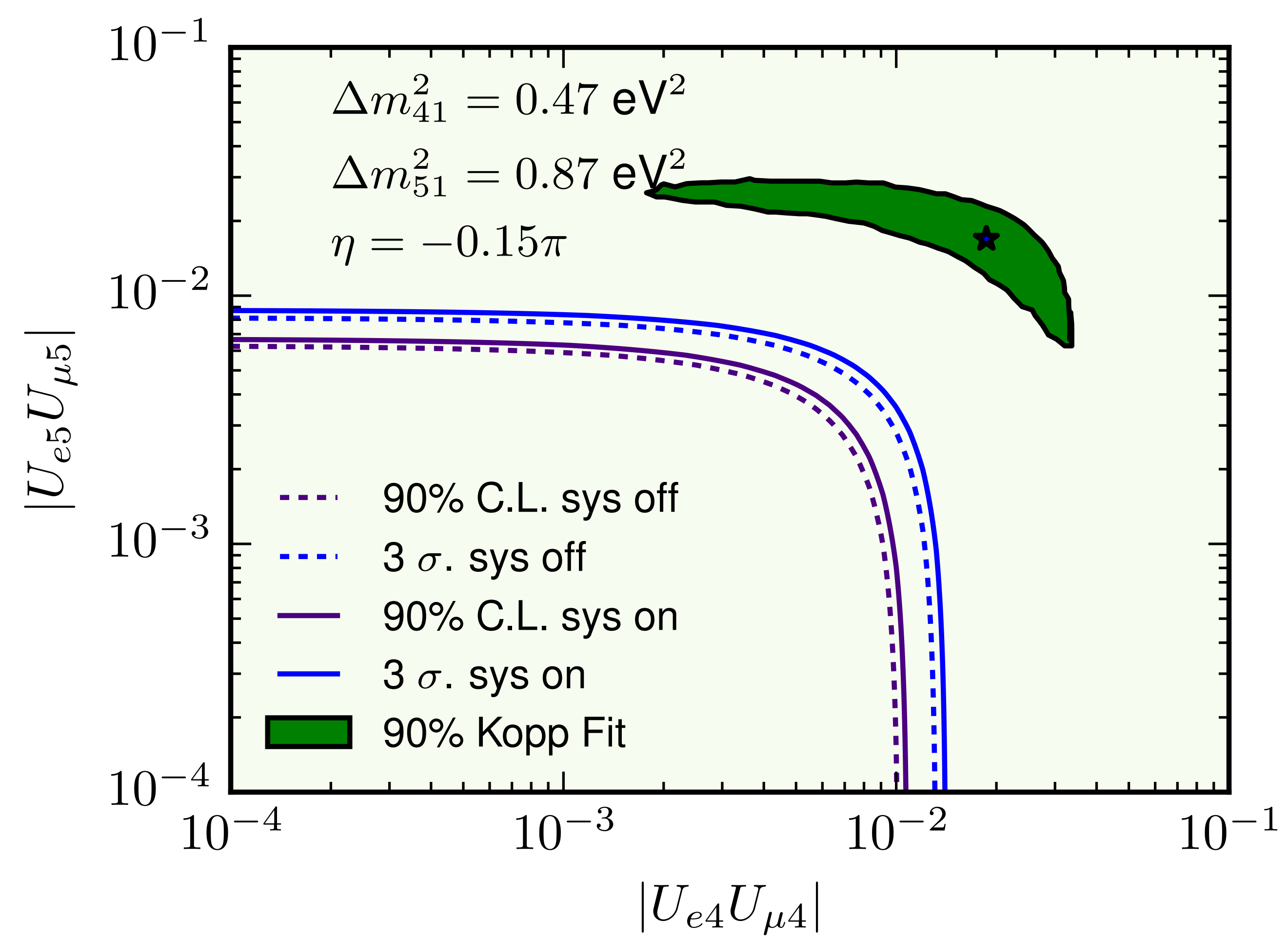


SIMPLEST 3+2 NEUTRINOS

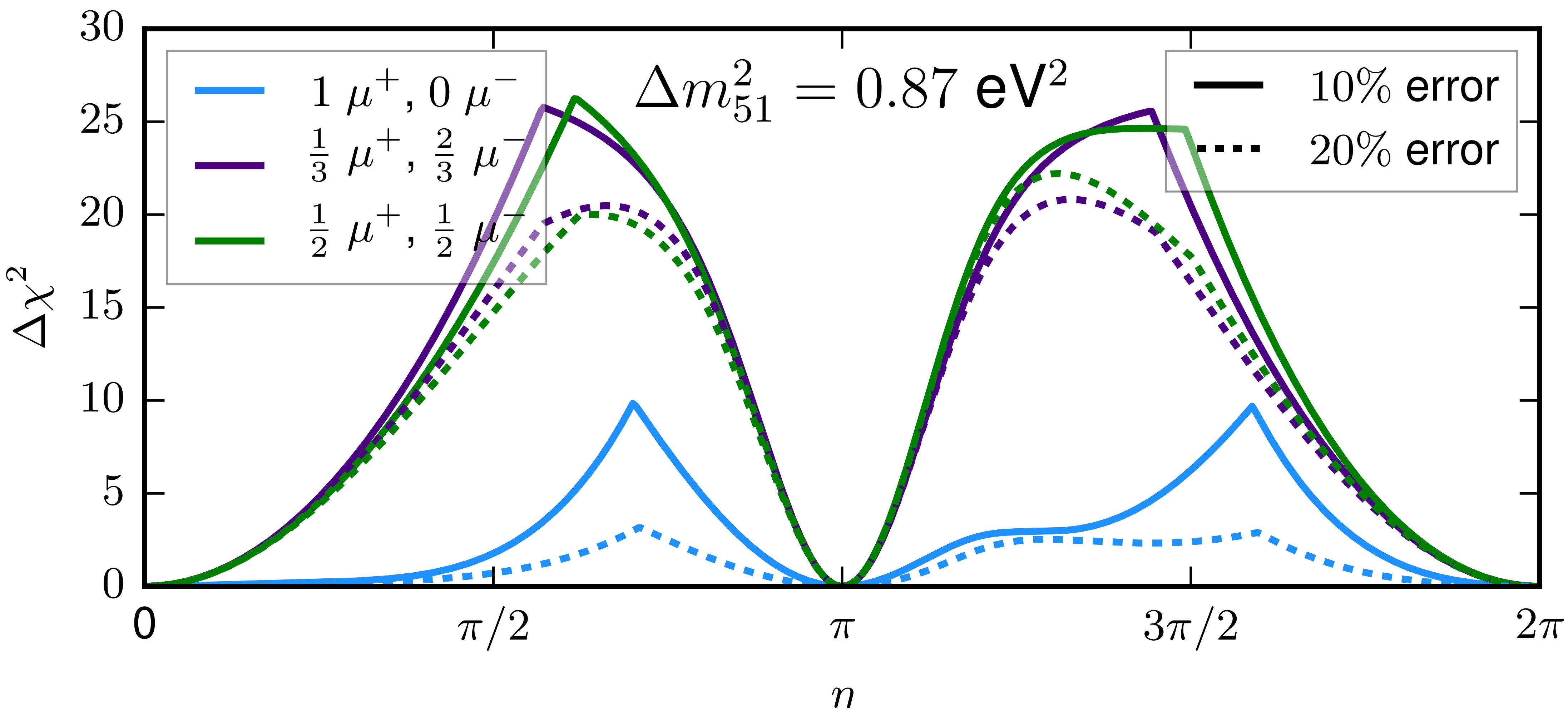
$$P^{3+2}_{\nu_e \to \nu_\mu} = 4|U_{\mu 4}|^2|U_{e4}|^2 \sin^2\Delta_{41} + 4|U_{\mu 5}|^2|U_{e5}|^2 \sin^2\Delta_{51}$$
$$+ 8|U_{\mu 4}U_{e4}U_{\mu 5}U_{e5}| \sin\Delta_{41} \sin\Delta_{51} \sin(\Delta_{41} - \eta),$$

CP phase!





3+2 CP VIOLATION PHASE SENSITIVITY



WHAT CAN NUSTORM DO?

- Look for oscillations in a variety of channels.
- If it doesn't see anything, bound 3+N model parameters.
- Measure cross sections at the near detector
- R&D for muon storage rings

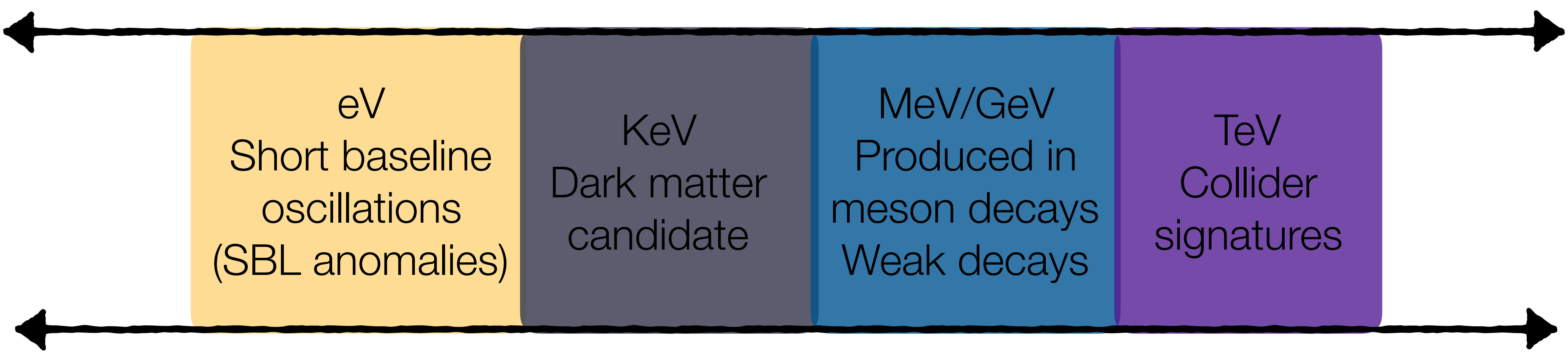
Neutrino Factories
Muon Colliders

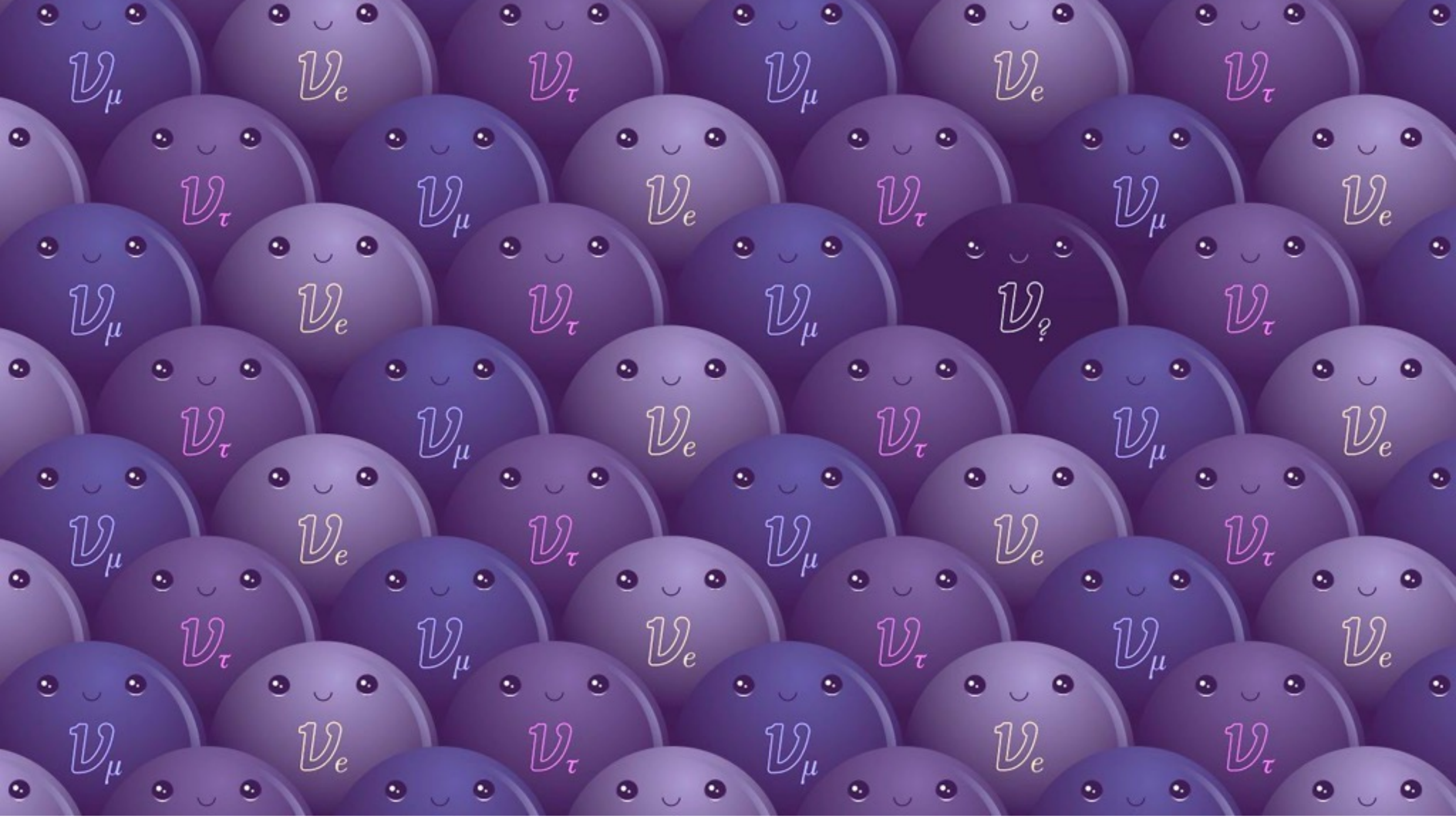
STERILE NEUTRINO SEARCHES

Standard Model Singlet

Mass not protected by any symmetry

It is possible to look for steriles at current neutrino experiments, so why not.





Thank you for listening!